Fysikdagarna 2023

Wednesday, 14 June 2023 - Friday, 16 June 2023

AlbaNova University Center, Stockholm

Book of Abstracts

Contents

Common Programme / 7

Welcome from SU, KTH and the Organization Commitee

Welcoming to Fysikdagarna 2023 by Jan Conrad, the Head of the Department of Physics at SU, and Mark Pearce, the Deputy Dean of the Faculty of Engineering Sciences at KTH.

The local organization committee gives a brief introduction to the meeting.

Fysikdagarna 2023 is organised by the Swedish Physical Society together with Stockholm University and KTH. It is made possible through generous support from the departments of Applied Physics and Physics, KTH, and Fysikum, Stockholm University. We gratefully acknowledge that the conference is supported by the Royal Swedish Academy of Sciences through its Nobel Institute of Physics. Marcus and Amalia Wallenberg foundation gives economical support for activities of Undervisningssektionen within the Swedish Physical Society.

We are also grateful for the interest from the participants in the exhibition:

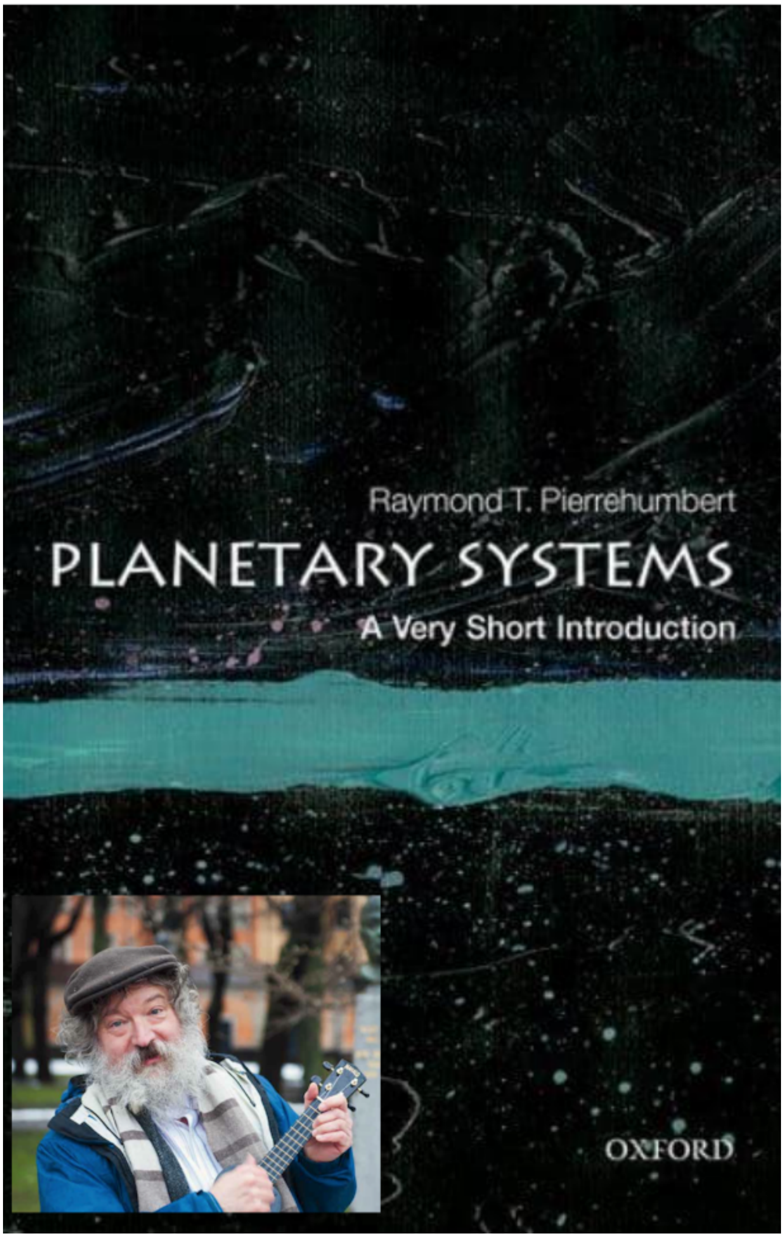
Common Programme / 35

Universal climate physics - from exoplanets to Earth's fate

Author: Raymond T. Pierrehumbert[1]

[1] *Halley Professor of Physics, University of Oxford*

The fundamental physical principles underpinning the climate crisis caused by industrial emissions of carbon dioxide were developed over the past century or more by some of the greatest minds of physics, and have withstood all challenges. I will explain these basic physical principles, and also give a survey about how the same principles account for the behaviour of the Solar System planets and are being used to explore the climates of the thousands of new planets that have been discovered orbiting stars other than our own.



Common Programme / 34

Nordita: A smörgåsbord of theoretical physics research

Author: Sofia Qvarfort[1]

[1] *Nordita*

Nordita (the Nordic Institute for Theoretical Physics) is a research institute situated at the AlbaNova campus in Stockholm. The research topics pursued at Nordita span Astrophysics and Astroparticle research, Condensed Matter and Statistical physics, High-Energy Physics and Cosmology, as well as Complex Dynamical Networks and Quantum Information. Those who pursue this research are masters students, PhD students, postdoctoral researchers, fellows, and faculty members from around the world. Key activities at Nordita include organising and taking part in scientific programmes, hosting visitors and collaborators, and, of course, having lots of fika. In my talk, I will provide an informal introduction to the research topics being pursued at Nordita and other activities that take place. I will also tell you about my own experience of joining Nordita as a postdoctoral fellow.

Common Programme / **21**

IceCube - the frozen telescope

Author: Olga Botner[1]

[1] *Uppsala University*

IceCube, located in the clear glacier ice close to the Amundsen-Scott South Pole base, has been called the world's weirdest telescope. It was completed in December 2010, after more than a decade of planning, development and extensive tests by, among others, researchers from the universities in Stockholm and Uppsala. This unique detector will give us insights into the most violent processes in the universe, taking place in the extreme environments close to black holes. IceCube encompasses one billion tons of ice, monitored by over 5000 photosensors frozen into the glacier at depths between 1450 and 2450 meters. The sensors register the faint light created when charged particles from neutrino interactions move through the ice at super-luminal speeds. Neutrinos are nearly massless subatomic particles produced in many astrophysical processes. IceCube has not only succeded in uncovering and measuring the flux of highly energetic neutrinos from outer space but for the first time also in pointing out objects producing such neutrinos.

Common Programme / 50

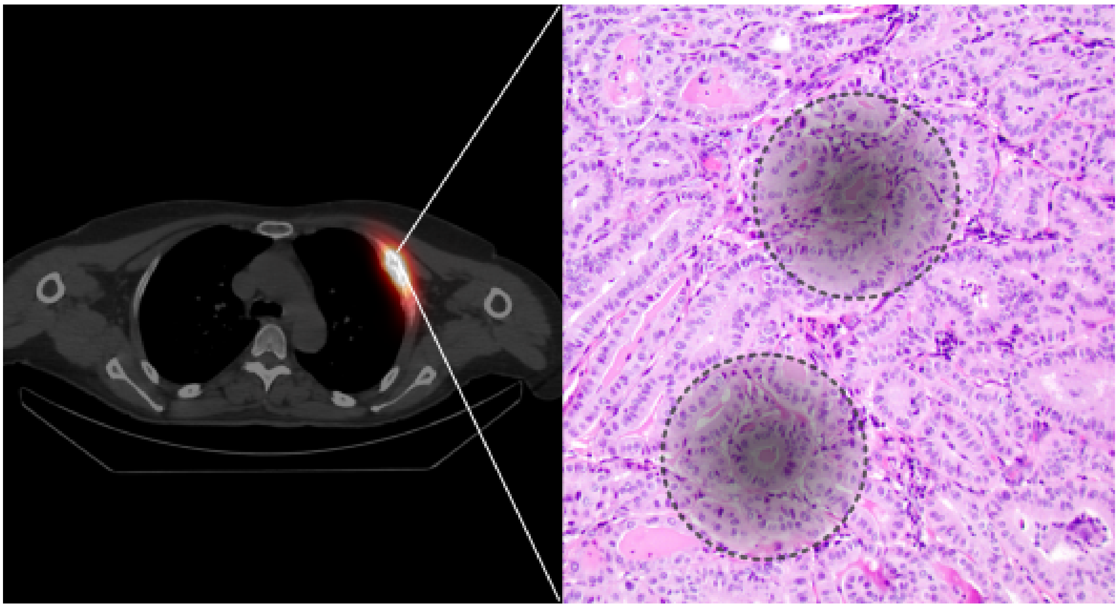
Why more patients should choose the nuclear option

Author: Joachim Nilsson[1]

[1] *Department of Molecular Medicine and Surgery, Karolinska Institutet / Department of Nuclear Medicine, Karolinska University Hospital.*

A long-serving but somewhat obscure part of radiation therapy - targeted therapy of cancer using radionuclides have advanced considerably during the last two decades. By internal irradiation through physiological accumulation of radioactivity, tumours can be treated from the inside in any and all parts of the body. With advances in design and manufacture of targeting agents labelled with therapeutic radionuclides, several new radionuclide-based drugs have been approved for clinical use and research is expanding. The treatments are associated with less side effects than most other cancer drugs, due to the highly specific accumulation in the targeted tumour cells.

This lecture will give an overview of radionuclide therapy in modern nuclear medicine. Patient cases will be presented, along with some of the physical aspects of treating patients with radionuclides. Special emphasis will be given to recent advances in tailoring individual treatments and new agents that may become part of clinical care in the near future.



A thyroid cancer metastasis in a rib (SPECT/CT image, left) can be treated effectively with radionuclide therapy (131I). The tumour tissue (light microscopy, right) accumulates iodine and is irradiatied from the inside by beta particles. The average beta particles (range shown as dashed circles) deposits its lethal energy across tens of tumour cells, inducing cell death.

Common Programme / 23

Exploring the Universe with the James Webb Space Telescope

Author: Macarena Garcia Marin[1]

[1] *European Space Agency*

The James Webb Space Telescope is the most sophisticated and powerful telescope ever flown in space. It was launched on December 25th 2021, and after 6 months of intense and successful work all its observing modes were declared ready to perform science. Since then JWST has started revolutionizing many fields of astronomy, and its images have captured the imagination of the public. In this contribution I will review the telescope design and features, discuss the key moments of the 6 months after launch, and go over the most relevant science results to date.

Common Programme / 20

Gender and physics: Perspectives on culture and identity in physics education

Author: Anna Danielsson[1]

[1] *Stockholm University*

Physics as famously been described as 'a culture of no culture', but it's also a discipline imbued with cultural associations. Physics education researchers have explored on how cultural traits of the discipline of physics, such as how it is perceived as difficult and high-status, can contribute to in/exclusions of students. In this talk I will give an introduction to how educational researchers have utilised the analytic lenses of gender, identity and culture in order to understand student experiences and promote a more inclusive physics education.

Common Programme / 22

Entanglement and the 2022 Nobel prize in physics

Author: Armin Tavakoli[1]

[1] *Lund University*

Quantum particles, even if separated by large distances, can exhibit a strangely powerful connection which allows them to instantaneously influence each other. This phenomenon is called entanglement and it gives rise to a plethora of quantum effects that have neither a counterpart nor a possible explanation in classical lines of thought. The 2022 Nobel prize in physics highlights the groundbreaking experiments that demonstrated the reality of entanglement. In this talk, I discuss the historical puzzle that entanglement posed: how it developed from being a question of metaphysics, to becoming an empirically testable hypothesis, to the present where it is paving the way for the era of quantum technology.

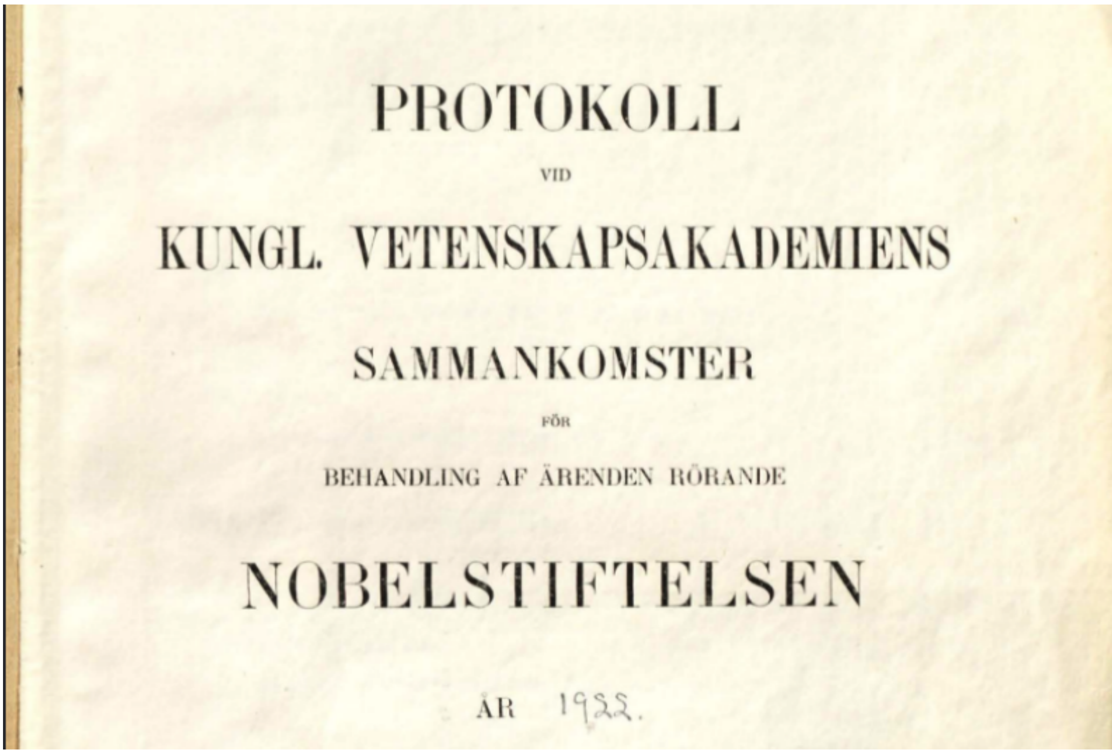
Common Programme / 19

A Glimpse inside the Nobel archives

Author: Karl Grandin[1]

[1] *Royal Swedish Academy of Sciences*

The Nobel archives of the Royal Swedish Academy of Sciences contain all valid nominations for the Nobel Prize in Physics, as well as the special reports written by the Nobel Committee members in the years open to research. It also contains the general report by the whole Committee with comments on all nominated physicists and that end up with the Committee's conclusion and their proposal for the award. Formally, also other archival material is to be found in this archive, viz. the discussion by the Physics class on the general report, as well as the minutes of the Academy in pleno, where the formal decision is made. This archive was totally secret and only to be used by the committee itself in their Prize work. But in 1974 the statutes of the Nobel Foundation were changed so that material older than 50 years could be accessed by bona fide historians of science. This talk will present the Nobel archives in physics 1901–1972 through some historical examples, but it will also ask questions like: is the now long line of Nobel Prizes in physics the same as the history of physics since 1901? What might have been missed?


PROTOKOLL

VID

KUNGL. VETENSKAPSAKADEMIENS

SAMMANKOMSTER

FÖR

BEHANDLING AF ÄRENDEN RÖRANDE

NOBELSTIFTELSEN

ÅR 1922.

Minutes of the Nobel Archives from the Royal Swedish Academy of Sciences.

Common Programme / 18

Annual meeting of Swed. Phys. Soc.

Common Programme / 130

Big Science Sweden

Author: Amelie Hallin[1]; Ernesto Gutiérrez[2]

[1] *Lund University*

[2] *Uppsala universtiet*

Corresponding Author: ernesto.gutierrez@bigsciencesweden.se

Opportunities for teachers, students and researchers to apply to big science facilities

Big science facilities offer students, teachers, researchers and engineers good opportunities for skill development through internships, summer jobs, technical projects or employment. Sweden is, in comparison to other countries, underrepresented when it comes to taking advantage of the opportunities that Swedish membership in big science facilities can provide.

The Swedish Research Council has given Big science Sweden the mission of facilitate for Swedish students, teachers, researchers and engineers to apply to CERN and other big science facilities. Big science Sweden's accomplish this through systematic information activities and events for inspiration by highlighting interesting examples and role models.

We invite researchers and teachers at Fysikdagarna to talk about the opportunities for skill that big science facilities offer. We also want to discuss how we can work together to get more Swedish students, teachers, researchers and engineers to take advantage of the opportunities that big science facilities offer.

Big Science Sweden, financed by the Swedish Research Council and Vinnova, aims to strengthen Sweden's collaboration between companies, institutes and universities and large-scale research facilities in which Sweden participates and provides funding. We work at a national level through our partner organizations: Chalmers University of Technology, Luleå University of Technology, Uppsala University, Lund University, RISE, Teknikföretagen, Region Skåne och Industrikluster IUC Syd.

Common Programme / 17

Oseen medal award and presentation

Common Programme / 150

Poster prize

The poster prize committee will present the poster contributions awarded a Fysikdagarna 2023 poster prize.

Sektionen för atom-, molekyl- och optisk fysik / 47

Sektionen för atom-, molekyl- och optisk fysik

Author: Marcus Dahlström[1]

[1] *Lunds universitet*

Welcome to the session for Atomic, Molecular and Optical (AMO) physics during the Swedish Physics Days in Stockholm 2023! The AMO section of the Swedish Physical Society will arrange a scientific program for the AMO session that highlights the breadth of ongoing AMO research in Sweden with invited speakers from Lund, Göteborg, Stockholm, Uppsala and Umeå. In addition, a number of contributed talks will be selected from submitted abstracts to the AMO session. The AMO board consists of:

- Aleksandra Foltynowicz Matyba, Umeå universitet
- Jon Grumer, Uppsala universitet
- Åsa Larsson, Stockholms universitet
- Michael Odelius, Stockholms universitet
- Vitali Zhaunerchyk, Göteborgs universitet
- Noelle Walsh, MAX IV
- Marcus Dahlström, Lunds universitet (chair)

Sektionen för atom-, molekyl- och optisk fysik / 120

Attosecond time-resolved experiments at a seeded free electron laser

Author: Praveen Kumar Maroju[1]

[1] *Lund university /University of Freiburg*

Corresponding Author: praveen_kumar.maroju@fysik.lth.se

Attosecond time-resolved experiments at a seeded free electron laser

Praveen Kumar Maroju[1,2] , Michele Di Fraia[3], Oksana Plekan[3], Matteo Bonanomi[4,5], Barbara Merzuk[1], David Busto[1,2], Ioannis Makos[1], Marvin Schmoll[1], Ronak Shah[1], Primož Rebernik Ribič[3], Luca Giannessi[3,6], Giovanni De Ninno[3,7], Carlo Spezzani[3,7], Giuseppe Penco[3], Alexander Demidovich[3], Miltcho Danailov[3], Marcello Coreno[3,6,8], Marco Zangrando[3,9], Alberto Simoncig[3], Michele Manfredda[3], Richard J. Squibb[10], Raimund Feifel[10], Samuel Bengtsson[2], Emma Rose Simpson[2], Tamás Csizmadia[11], Mathieu Dumergue[11], Sergei Kühn[11], Kiyoshi Ueda[12], Jianxiong Li[13], Kenneth J. Schafer[13], Fabio Frassetto[14], Luca Poletto[14], Kevin C. Prince[3], Johan Mauritsson[2], Carlo Callegari[3] & Giuseppe Sansone[1]

[1] *Physikalisches Institut, Albert − Ludwigs − Universitt Freiburg, Freiburg, Germany.*
[2] *Department of Physics, Lund University, Lund, Sweden.*
[3] *Elettra − Sincrotrone Trieste, Basovizza, Trieste, Italy.*
[4] *Dipartimento di Fisica Politecnico, Milan, Italy.*
[5] *Istituto di Fotonica eNanotecnologieCNR − IFN, Milan, Italy.*
[6] *INFNLaboratoriNazionalidiFrascati, Frascati, Italy.*
[7] *LaboratoryofQuantumOptics, UniversityofNovaGorica, NovaGorica, Slovenia.*
[8] *ISM − CNR, Istituto Struttura della Materia, Trieste, Italy.*
[9] *IOM − CNR, Basovizza, Trieste, Italy.*
[10] *Department of Physics, University of Gothenburg, Gothenburg, Sweden.*
[11] *ELI ALPS, ELI − HU Non − Profit Ltd., Szeged, Hungary.*
[12] *Department of Chemistry, Tohoku University , Sendai980 − 8578, Japan.*
[13] *Department of Physics and Astronomy, Louisiana State University, Baton Rouge, LA, USA.*
[14] *Istituto di Fotonica e Nanotecnologie, CNR, Padova, Italy.*

Abstract

Investigation of valence and core electron dynamics on their natural time scale requires attosecond pulses. Routinely, these dynamics are probed via pump-probe schemes using phase-locked extreme ultraviolet (XUV) attosecond pulses generated using the high harmonic generation (HHG) scheme and the infrared (IR) pulses driving the HHG process. Free electron lasers (FELs) on the other hand are an alternative source of radiation spanning the XUV to X-ray spectral regions with unprecedented intensities. However, until recently[1,2], time-resolved studies at FELs were limited to a few femtosecond timescales owing to unavailability of attosecond pulses at these FEL facilities. Here, we will present the results of experiments performed at the seeded FEL FERMI, where we demonstrate generation and characterization of attosecond pulse trains[2]. In the scheme, attosecond pulse trains were produced using the temporal beating of the multiple (three/four) phase-locked harmonics generated at FERMI and are characterized using Correlation Based Reconstruction of Attosecond pulses (CoBRA), inspired from Reconstruction of Attosecond Beating By Interference of Two-photon transitions (RABBIT) scheme. Further, we introduce a novel single-shot timing-tool to determine the relative synchronization between the attosecond pulse train and the optical oscillations of the IR field, with a temporal resolution down to a few tens of attoseconds. Using the timing-tool, for the first time, we demonstrate attosecond coherent control of photoionization in XUV-IR two-color fields by manipulating the phase of the high-order IR transitions at the seeded FEL FERMI[3].

References

1. Duris, J. *et al. Nat. Photon.* **14**, 30–36 (2020)
2. Maroju, P. K. *et al. Nature* **578**, 386–391 (2020)
3. Maroju, P.K. *et al. Nat. Photon.* 17, 200–207 (2023)

Sektionen för atom-, molekyl- och optisk fysik / 69

Laser spectroscopy of negative ions

Author: David Leimbach[1]

Co-authors: Julia Karls [1]; Ilse Kardasch [2]; Di Lu [1]; Annie Ringvall-Moberg [1]; Jose Eduardo Navarro Navarrete [3]; Miranda Nichols [1]; Yazareth Peña Rodríguez [2]; Dag Hanstorp [1]

[1] *University of Gothenburg*

[2] *University of Gothenburg, Universidad Nacional Autónoma de México*

[3] *Stockholm University*

Corresponding Author: david.leimbach@gu.se

In multi-electron systems such as atoms and molecules, the electron-electron interaction poses a major challenge for the accurate theoretical description of atomic structure and dynamics, requiring sophisticated numerical approaches. These theoretical models are then also used to provide required information for experimental analysis such as for nuclear square charge radii determinations from isotope shift measurements 1.
Negative ions can serve as excellent probes for these tests, in addition to a variety of applications in other fields [2-4]: since the Coulomb potential of the nucleus is almost entirely screened, the binding of the additional electron in a negative ion is primarily due to the many body interactions between electrons. Consequently, negative ions are sensitive probes of these effects.
However, due to the weak binding potential, the energy gained by attaching an electron to a neutral atom, referred to as electron affinity (EA), is typically only in the order of one eV. For the same reason, negative ions typically lack bound excited states with opposite parity, noticeable exceptions being lanthanum, cerium, osmium, thorium and uranium [5-9]. Consequently, the EA is the only parameter which can be probed with high precision, typically via laser photodetachment threshold spectroscopy (LPTS).
In this talk, we will present recent results of laser photodetachment experiments to determine lifetimes and binding energies of atomic negative ions, performed at the Gothenburg University Negative Ion LAboratory (GUNILLA), the electrostatic storage ring DESIREE in Stockholm and ISOLDE.

References
1 J.Z. Han et al., Phys. Rev. Research 4, 033049 (2022)
[2] G. Cerchiari et al., Phys. Rev. Lett. 120 (2018)
[3] T. J. Millar, et al., Chemical reviews 117.3 (2017)
[4] D. E. Post et al., INIS 22 (1991).
[5] R. Tang et al., American Physical Society 123, 20 (2019).
[6] C. Walter et al., Phys. Rev. A 76, (2007).
[7] R. Bilodeau and H.K. Haugen, Phys. Rev. Lett. 85, 3 (2000).
[8] C. Walter et al., Phys. Rev. Lett. 113, 6 (2014).
[9] R. Tang et al., Phys. Rev. A 103, L050801 (2021).

Sektionen för atom-, molekyl- och optisk fysik / 97

Ultrafast laser diagnostics in harsh environments

Author: Alexis Bohlin[None]

Corresponding Author: alexis.bohlin@ltu.se

New insight into mechanisms that can help to make propulsion and power systems "greener" and more sustainable cannot be simulated or known a priori, it needs to be developed through the rigorous testing and quantification. Ultrafast laser diagnostics has a tremendous potential to provide precise scalar determination at these harsh test environments, where often steep gradients in temperature and species concentration exists and these quantities evolve on a rapid time scale due to the turbulence of the flow. In this talk, I will present the development of a unique polarization-sensitive coherent Raman imaging spectrometer, with synchronized high peak-power laser pulses on a femtosecond- and picosecond timescale, and show how it is capable of quantifying spatially correlated temperature in-situ these flows with an uncertainty of less than 1%.

Sektionen för atom-, molekyl- och optisk fysik / 96

Interferometric Quantum Control (IQC) by fs/ns Rotational Coherent anti-Stokes Raman Spectroscopy (RCARS)

Authors: Meena Raveesh[1]; Joakim Bood[None]; Ali Hosseinnia[None]; Mark Linne[None]

[1] *Lund University*

Corresponding Author: meena.raveesh@forbrf.lth.se

Coherent anti-Stokes Raman Spectroscopy (CARS) being one of the important measurement techniques in reactive flows, we present a novel method to improve its diagnostic ability using quantum control. This is achieved by carefully engineering the interference of two confined quantum wavepackets, by the implementation of 2- beam hybrid fs/ns rotational CARS along with a second (control) pulse with a variable delay. Initially, the fs pulse involved in the fs/ns CARS process creates a rotational wavepacket. Then, if the control pulse arrives at an integer multiple of the molecular revival period (Trev), a wavepacket that is exactly in phase with the initial wavepacket is created, resulting in constructive interference, i.e. signal amplification. This is particularly useful in high temperature applications where species number density is lower. On the other hand, if the control pulse arrives at an integer multiple of half the molecular revival period (Trev/2), a wavepacket that is exactly in anti-phase with the initial wavepacket is created, resulting in destructive interference, i.e. signal annihilation. This can be used to improve the species-specific detection as we can annihilate specific molecular fingerprint in a mixed volume. The technique can also create spin isomer selective excitation, if the control pulse delay is quarter the molecular revival period (Trev/4). Improved species selectivity and measurement accuracy in real time environments, with spectroscopic applications in non-stationary and unpredictable reacting flows, can be obtained by selecting a delay time that is optimal for the desired purpose.

Sektionen för atom-, molekyl- och optisk fysik / 102

Scalable quantum information processing using ultralow loss silicon nitride nanophotonics

Authors: Sara Persia[1]; Victor Torres Company[1]

[1] *Chalmers University*

Corresponding Author: persias@chalmers.se

Photonics platforms provide promising advantages for many applications in the field of quantum information processing and sensing. Bulk and free-space optical systems exhibit issues in terms of scalability, cost, reproducibility, and reconfigurability. A more intriguing platform is therefore given by integrated photonics circuits, which allow the miniaturization, reproducibility, and programmability of large-scale photonics processors. Recently, a big effort has been made to develop compact and high-quality scalable devices for the generation of squeezed states of light, a fundamental ingredient for quantum computation. Among different platforms, silicon nitride microring resonators offer the best performances in terms of generation of high-level squeezing. However, current measurements of squeezing on-chip are limited by the ratio of intrinsic to extrinsic quality factors, related to excess photon losses and inefficient light coupling. At Chalmers, we work with an ultralow loss subtractive processing method for the fabrication of dispersion-engineered strong confinement silicon nitride microresonators that allow for higher Q values than possible before.

Sektionen för atom-, molekyl- och optisk fysik / 78

Double-resonance spectroscopy of methane hot-bands using a frequency comb probe

Authors: Andrea Rosina[1]; Adrian Hjältén[1]; Grzegorz Soboń[2]; Isak Silander[1]; Kevin K. Lehmann[3]; Lucile Rutkowski[4]; Vinicius Silva de Oliveira[1]; Aleksandra Foltynowicz[1]

[1] *Umeå University*

[2] *Wrocław University of Science and Technology*

[3] *University of Virginia*

[4] *Université de Rennes*

Corresponding Author: andrea.rosina@umu.se

Molecular line lists for gases at high temperatures are crucial in fields ranging from combustion to astrophysics. However, due to the lack of experimental data, some of the energy levels that constitute the lists are inaccurate or even missing, and their theoretical models need validation. Addressing these gaps is especially important for methane, a key greenhouse gas and one of the biosignatures that the James Webb Space Telescope (JWST) can readily detect on terrestrial exoplanets 1.

Analyzing absorption bands for gases at high temperatures is a major challenge due to the extreme density of lines that cannot be resolved in the spectrum of a heated sample. As temperature rises, multiple excited states (known as hot-bands) are populated, and Doppler broadening increases, so the transitions starting from these states overlap.
Optical-optical double-resonance spectroscopy (DR) overcomes this challenge by pumping room-temperature molecules to a single excited state with a monochromatic, continuous wave (CW) laser. Then, a laser probe excites transitions from this single state to the final upper states. The probe transitions are Doppler-free, because only a narrow velocity group of molecules is excited by the pump. Previous DR techniques on molecules used CW probes, with limited accessible bandwidth [2]. Instead, we use an optical frequency comb, which consist of thousands of equidistant, stable, and narrow laser lines, as a probe with large bandwidth and high resolution [3,4].

To measure and assign transitions in the $3\nu_3 \leftarrow \nu_3$ band of methane we pump with a high-power CW laser, locked to a transition in the ν_3 band of methane, at around 3.3 μm. As probe, we use a frequency comb generated by a mode-locked Er:fiber laser with 250 MHz repetition frequency, and tunable from 1.65 μm to 1.8 μm.
To calibrate the system, the comb offset and repetition frequency are stabilized and referenced to frequency standards. To enhance the interaction length and thus the absorption sensitivity, the sample of pure methane is contained in an optical cavity, which is resonant with the probe. The probe spectra are measured using a Fourier transform spectrometer with resolution limited by the comb mode width [5,6]. From these spectra, we can simultaneously retrieve center frequencies of transitions in multiple hot-bands with high selectivity, and unambiguously assign final states. The assignment allows us to validate theoretical predictions from the TheoReTS [7] database with unprecedented accuracy.

The validated theoretical models for methane will be an important tool to extract information about the conditions of hot exoplanetary atmospheres from the infrared spectra that will be measured by JWST. Furthermore, DR with frequency combs has the potential to investigate the hot-bands of other molecules in a wide range of frequencies.

References
1 M. A. Thompson et al., "The case and context for atmospheric methane as an exoplanet biosignature", Proceedings of the National Academy of Sciences 119, e2117933119 (2022).
[2] W. Demtröder, "Optical pumping and double-resonance techniques", in Laser spectroscopy 2: experimental techniques (Springer Berlin Heidelberg, Berlin, Heidelberg, 2015), pp. 225–269.
[3] A. Foltynowicz et al., "Measurement and assignment of double-resonance transitions to the 8900-9100 cm−1 levels of methane", Physical Review A 103, 022810 (2021).
[4] A. Foltynowicz et al., "Sub-doppler double-resonance spectroscopy of methane using a frequency comb probe", Physical Review Letters 126, 063001 (2021).
[5] L. Rutkowski et al., "Optical frequency comb fourier transform spectroscopy with subnominal resolution and precision beyond the Voigt profile", Journal of Quantitative Spectroscopy and Radiative
Transfer 204, 63–73 (2018).
[6] P. Maslowski et al., "Surpassing the path-limited resolution of Fourier-transform spectrometry with frequency combs", Physical Review A 93, 021802(R) (2016).
[7] M. Rey et al., "TheoReTS–an information system for theoretical spectra based on variational predictions from molecular potential energy and dipole moment surfaces", Journal of Molecular Spectroscopy 327, 138–158 (2016).

Sektionen för atom-, molekyl- och optisk fysik / 60

Mutual neutralization of hydrogen and deuterium anions with Li, O , N and C cations at DESIREE

Author: Alice Frederike Schmidt-May[1]

Co-authors: Gustav Eklund [1]; Henning Schmidt [1]; Henning Zettergren [1]; Henrik Cederquist [2]; Jon Grumer [3]; MingChao Ji [1]; Paul Barklem [3]; Stefan Rosén [4]

[1] *Stockholm University*

[2] *Physics Department, Stockholm University*

[3] *Uppsala Universitet*

[4] *Stockholms Universitet*

Corresponding Author: alice.schmidt-may@fysik.su.se

We present mutual neutralization studies of $^{1,2}H^-$ with Li^+, O^+, N^+ and C^+ at DESIREE. The systems are of astrophysical interest and the collisions take place at sub-electronvolt energies which are typical collision energies in cold stellar photospheres. The most prominent finding is a strong isotope effect on the branching fraction into Li(3s), which constitutes one of the first and only observations of its kind. We compare our results to theoretical predictions with varying degree of agreement.

Sektionen för atom-, molekyl- och optisk fysik / 118

Atomic properties of gold - a theoretical case study of atomic-structure challenges in the era of kilonovae

Author: Sema Caliskan[1]

[1] *Theoretical Astrophysics, Uppsala University, Sweden*

Corresponding Author: sema.caliskan@physics.uu.se

The cosmic origin of the neutron-capture elements beyond iron in the periodic table has long been a puzzle. In 2017, the observation of GW170817 provided the first-ever observational clue that kilonovae could be the primary source of these heavy elements. However, spectral elemental analysis of kilonovae is hindered by the lack of complete and accurate atomic data for neutron-capture elements caused by their complex electron structure. This contribution presents theoretical strategies for overcoming these challenges. Specifically, new ab-initio and semi-empirical investigations of the atomic structure and radiative properties of neutral gold are presented as a representative case for the complexity of neutron-capture elements.

Sektionen för atom-, molekyl- och optisk fysik / 98

Following photochemical bond activation reactions using ultrafast X-ray spectroscopy

Author: Raphael Jay[1]

[1] *Uppsala University*

Corresponding Author: raphael.jay@physics.uu.se

4d and 5d metal carbonyls are widely recognized for their photocatalytic C-H bond activation capabilities. UV excitation of these complexes leads to CO dissociation and the formation of a reactive metal center, which rapidly binds alkane C-H groups from solution and ultimately breaks the C-H bond. The reactivity of 3d metal carbonyls following photoinduced CO dissociation, however, is often hampered by the formation of triplet species, which instead are reactive towards Si-H bond activation. We have used ultrafast X-ray absorption spectroscopy and resonant inelastic X-ray scattering at the transition metal L-edge to access and evaluate the valence electronic structure locally at the reactive metal center all the way from the initial femtosecond excited-state and dissociation dynamics to pico- to-nanosecond bond activation. We find previously undetected species and characterize how their transient electronic structure dictates catalytic function on ultrafast timescales. We experimentally access, to the best of our knowledge for the first time, the essential charge-transfer orbital interactions, which make metal carbonyls reactive and which determine how they bind and break incoming C-H or Si-H bonds.

Sektionen för atom-, molekyl- och optisk fysik / 117

Studies of fullerene ions at DESIREE

Author: Michael Gatchell[1]

[1] *Stockholm University*

Corresponding Author: michael.gatchell@fysik.su.se

Fullerenes are the largest molecules identified thus far in the interstellar medium and have been the focus on countless studies since their discovery nearly four decades ago. 1 They do, however, still hold many secrets. At DESIREE [2], the Double ElectroStatic Ion Ring ExpEriment, a national infrastructure for ion physics research located at Stockholm University, we have recently performed a number of different studies of the properties of these molecular systems. In my talk I will give an overview of the DESIREE facility and recent results on fullerene ions. These include experiments where the stability of fullerene ions damaged by energetic collisions with atomic systems are studied on timescales ranging from microseconds to minutes; the hitherto most accurate measurements of the electron affinity of C_{60}, settling a dispute between past measurements; and the first ever studies on mutual neutralization between fullerene cations and anions at interaction energies approaching 0 eV.

References

1 H. W. Kroto *et al.*, *Nature* **318**, 162 (1985)
[2] H. T. Schmidt *et al.*, *Rev. Sci. Instrum.* **84**, 055115 (2013)

Sektionen för atom-, molekyl- och optisk fysik / 90

Manipulating photoionization on ultrashort time scale

Author: Nedjma Ouahioune[1]

[1] *Lund University*

Corresponding Author: nedjma.ouahioune@fysik.lth.se

The interaction of atoms with attosecond (10^{-18} s) light pulses has renewed interest in studying photoionization dynamics. The ionized electrons exhibit a wave-like behaviour that is commonly used to retrieve the temporal dynamics of the process using optical cross-correlation techniques between light pulses. In this work, we study the photoionization dynamics of helium in a new regime with just few-cycle pulses[1,2].

The experiment is carried out with a 200 kHz laser system that delivers carrier-to-envelope phase stabilized near-infrared (NIR) pulses of ~ 6 femtoseconds[3,4]. The laser beam is separated into a probe beam and a pump beam. The latter is used to generate two or three eXtreme UltraViolet (XUV) pulses, and is recombined and focused with the former in an experimental chamber, where helium is ionized. Cross-correlation scans between the XUV and NIR pulse are recorded using a three-dimensional momentum spectrometer. The scan exhibits complex interference patterns, which oscillate at a multiple of the NIR laser frequency, $_{IR}$. The oscillation at 2_{IR} have been the source of extensive studies and forms the basis of the so-called RABBIT technique, which stands for the reconstruction of attosecond beating by interference of two-photon transition[5].

Here, by means of spectral analysis based on Fourier transforms, an additional oscillation frequency at $_{IR}$ is found. We investigate its physical origins by modeling photoionization using the Strong Field Approximation. Finally, we quantify the influence of experimental parameters on the $_{IR}$ and 2_{IR} oscillations providing new insights into this new few-cycle regime of light-matter interaction.

References

1 Gramajo A. A. et al., Phys. Rev. A 94, 053404 (2016).
[2] Yu-Chen C. et al., PNAS 10, 10727 (2020).
[3] Mikaelsson S. et al., Nanophotonics 10, 117 (2021).
[4] Guo C. et al., J. Phys. B: At. Mol. Opt. Phys. 51, 034006 (2018)
[5] Paul P. M. et al., Science 292, 1689 (2001).

Sektionen för atom-, molekyl- och optisk fysik / 66

fs-recombination in Fe-based solar cells limits the performance

Author: Linnea Lindh[1]

Co-authors: Arkady Yartsev [2]; Kenneth Wärnmark [3]; Nils W. Rosemann [2]; Pavel Chábera [2]; Petter Persson [4]

[1] *Lund University*

[2] *Chemical Physics Lund University*

[3] *CAS Lund University*

[4] *Theoretical Chemistry Lund University*

Corresponding Author: linnea.lindh@chemphys.lu.se

It has been widely recognized in the scientific community that scarce elements such as ruthenium are not ideal for sustainable technology. During the past 10 years, progress has been made in exploring first-row transition metals as replacements for scarce metals in many solar cell and photocatalysis applications.1 Iron analogues to well-performing ruthenium-complexes were early found to not yield nearly the same solar cell performance, despite Ru and Fe being congeners.[2] Prior to our efforts, by means of ultrafast spectroscopy it was found that the relevant excited state deactivates in less than a ps, a timescale not accessible for most electron-transfer reactions.[3] Nowadays many examples of Fe-based complexes with ps-ns lifetimes have been demonstrated, mainly realized by the carbene-ligand.[4]

In the work described here, a set of push-pull Fe-carbene complexes have been characterized by means of time-resolved spectroscopy both in solution and after sensitization of titania nanoparticles.[5] In this way, parts of the dye-sensitized solar cell responsible for interfacial electron-transfer between the dye and the semiconductor are recreated, making it possible to study these processes. Creating rod-like push-pull complexes is a key strategy to facilitate the charge separation in solar cells, and to mitigate charge recombination. Our results show that indeed electron injection into titania happen within 100 fs after excitation[5] and is highly efficient.[6] However, recombination leaves only ~10 % of the initially injected electrons for the timescale accessible to contribute to solar cell performance. Moreover, the recombination was found to take place mainly with a time constant of 100 fs and return the photosensitizers to their excited state.5 The discovery of the ultrafast recombination reaction identifies the bottleneck that limits the development of the Fe-based solar cell, something that would never have been found without employing ultrafast characterisation techniques.

1 O.S. Wenger, Photoactive Complexes with Earth-Abundant Metals, J. Am. Chem. Soc. 140 (2018) 13522–13533. https://doi.org/10.1021/jacs.8b08822.
2 S. Ferrere, B.A. Gregg, Photosensitization of TiO2 by [FeII(2,2'-bipyridine-4,4'-dicarboxylic acid)2(CN)2]: Band Selective Electron Injection from Ultra-Short-Lived Excited States, J. Am. Chem. Soc. 120 (1998) 843-844. https://doi.org/10.1021/ja973504e
3 J. E. Monat, J. K. McCusker, Femtosecond Excited-State Dynamics of an Iron(II) Polypyridyl Solar Cell Sensitizer Model, J. Am. Chem. Soc. 122 (2000) 4092–4097. https://doi.org/10.1021/ja992436o
4 L. Lindh et al., Photophysics and Photochemistry of Iron Carbene Complexes for Solar Energy Conversion and Photocatalysis, Catalysts 10 (2020) 315. https://doi.org/10.3390/catal10030315
5 L. Lindh et al., Dye-Sensitized Solar Cells based on Fe N-heterocyclic Carbene Photosensitizers with Improved Rod-like Push-Pull Functionality, Chemical Science 12 (2021) 16035-16053. https://doi.org/10.1039/d1sc02963k
6 T. Harlang et al., Iron sensitizer converts light to electrons with 92% yield, Nature Chemistry 7 (2015) 883-889. https://doi.org/10.1038/nchem.2365

Sektionen för atom-, molekyl- och optisk fysik / 128

Single-photon double ionization of reactive intermediate S2

Author: Emelie Olsson[1]

Co-authors: Andreas Hult Roos [2]; John Dyke [3]; John H.D. Eland [4]; Jonas Andersson [1]; Majdi Hochlaf [5]; Måns Wallner [1]; Raimund Feifel [1]; Richard Squibb [1]; Stefano Stranges [6]; Tarek Ayari [5]; Veronica Ideböhn [1]

[1] *University of Gothenburg*

[2] *ELI Beamlines*

[3] *University of Southampton*

[4] *Oxford University*

[5] *Université Gustave Eiffel*

[6] *Universitá Sapienza*

Corresponding Author: emelie.olsson@gu.se

Disulfur, S2, is a reactive intermediate known to be important in the atmosphere of Jovian planets. Whereas the single ionization valence photoelectron spectrum of S2 is known from the early work of Dyke and coworkers, revealing its double ionization electron spectrum remained a challenge for a long time. Using time-of-flight multiple electron and ion coincidence techniques, in combination with a helium gas discharge lamp and synchrotron radiation, we investigated the double ionization electron spectrum and fragmentation dynamics of S2. The results obtained are compared with detailed calculations performed with highly correlated ab initio methods, such as CASSCF followed by MRCI for the electronic structure and potential energy curves of S2, and RCCSD(T) for total energies and dissociation limits.

Sektionen för atom-, molekyl- och optisk fysik / 71

Shining a light on disease prevention – Using Raman spectroscopy to evaluate bacterial spore viability

Author: Rasmus ÖBERG[1]

Co-authors: Dmitry Malyshev [1]; Magnus Andersson [1]

[1] *Umeå University*

Corresponding Author: rasmus.oberg@umu.se

Raman spectroscopy can be used to detect, identify, and characterize microbial organisms. In clinical settings such as hospitals, there is a need for methods to verify the sterilization of environments and equipment from pathogenic microbes such as bacteria. Of particular interest is the sterilization of so-called spore-forming bacteria since these can enter a zombie-like state when exposed to harsh environments. When in their spore form, these bacteria are highly resistant to disinfectant chemicals, high temperature (>100 ˚C), cold, radiation. Due to the hardy nature of these spores, it is especially relevant to develop ways of determining the viability of a spore population. However, current methods to verify spore viability, such as agar plate growth and PCR, are often time-consuming, or difficult to perform due to the spores' hardiness. Here, spectroscopic techniques provide a rapid alternative to existing microbiological techniques in determining the viability of a bacterial population.

In this presentation we will demonstrate a method using metabolism of heavy water (D2O) as an indicator for spore viability. By incubating a spores with D2O, a healthy spore will incorporate deuterium into its structure during metabolism, while an inactivated will not. The C-D chemical bonds formed during metabolism will then serve as an indicator for sample viability, which we can then track by a characteristic C-D Raman peak at 2200 cm-1 using a laser tweezer Raman system. We evaluated the rapidity of the method, as well as its invasiveness on a spore sample.

Sektionen för atom-, molekyl- och optisk fysik / 95

Tracking Conical Intersections with Nonlinear X-ray Raman Spectroscopy

Authors: Deependra Jadoun[1]; Markus Kowalewski[1]

[1] *Stockholm University*

Corresponding Author: deependra.singhjadoun@fysik.su.se

Conical intersections (CIs) play a vital role in processes such as the event of vision and DNA damage from sunlight. A CI appears in a molecule when electronic and nuclear motions are strongly coupled, and it acts as a funnel that guides a molecule from one electronic state to another. Substantial efforts have been made toward understanding such non-adiabatic phenomena. X-ray Raman techniques have been proposed in the past to investigate the presence of a CI in molecules. We propose a two-dimensional Raman probe scheme that uses a visible/infrared pulse and an ultra-short X-ray Raman probe pulse 1. The visible/infrared pulse interaction creates a coherent superposition of electronic states in the molecule. Probing the coherent superposition using ultra-short X-ray pulses allows visualizing the dynamic energy separation between electronic states throughout the photochemical process. The lifetime of the coherent superposition created using the infrared pulse can be read directly from two-dimensional Raman spectra. Therefore, the method aids in observing multiple indicators of a conical intersection and may allow for a more detailed study of non-adiabatic dynamics in molecules.

1 Deependra Jadoun and Markus Kowalewski. Tracking Conical Intersections with Nonlinear X-ray Raman Spectroscopy. *Ultrafast Sci.*, 2022:0003, 2022.

Sektionen för atom-, molekyl- och optisk fysik / 109

Coupling mechanisms in mutual neutralization

Author: Patrik Hedvall[1]

Co-authors: Johan Hörnquist ; Åsa Larson

[1] *Stockholm University*

Corresponding Author: patrik.hedvall@fysik.su.se

In mutual neutralisation, two oppositley charged ions collide, an electron is tranfered and the colliding pair ends up in neutral fragments. In the Born-Oppenheimer approach the electronic structure of the molecule is solved for in an initial step, and the nuclear motion is solved for in a second step giving relevant scattering information such as cross section, differential cross section and branching ratios for the reaction. The radial non-adiabatic coupling is the dominant, driving mechanism in mutual neutralization, but other couplings mechanisms may also be significant. Here, the additional couplings mechanisms of rotational coupling, spin-orbit coupling, electronic coupling and asymptotic non-adiabatic coupling are studied, and applied to the mutual neutralization in Na^{+} + I^{-} and H^{+}+H^{-} collisions.

Sektionen för atom-, molekyl- och optisk fysik / 63

Gauge-invariant absorption of light from a coherent superposition of states

Author: Axel Stenquist[1]

Co-authors: Felipe Zapata [1]; Marcus Dahlström [2]

[1] *Lund University*

[2] *Lunds universitet*

Corresponding Author: axel.stenquist@matfys.lth.se

Attosecond transient absorption spectroscopy (ATAS) is used to study electron dynamics with the aim of unravelling ultra-fast phenomena in atoms and molecules. There have been many investigations on ATAS between bound states 1, but few works has focused on the coupling of a prepared bound wave packet to both bound and continuum states [2]. A recent experimental investigation of the physical phenomena in this regime is presented in Ref. [3]. In order to disentangle the fundamental processes in this rich transient absorption regime, we establish a gauge invariant formulation of ATAS based on Yang's energy operator [4]. In the present work [5], perturbation theory is used to study the absorption of a hydrogen atom in an initial superposition state interacting with an attosecond pulse. Absorption is studied in both time and energy domain, resolved over the relative phase of the superposition. The model is validated by numerically solving the time dependent Schrödinger equation. The model allows for disentangling the absorption into fundamental processes of resonant and off-resonant nature, being symmetric and anti-symmetric over phase, respectively. The off-resonant contribution is found to be significant for states with dipole-allowed transitions to states of lower energy. This yields large regions of emission in the absorption profile of the $2p + 3p$ superpostion, not present in the $2s + 3s$ case. Additionaly, agreement with simulations of helium and neon atoms indicate the applicability of our model to more complex atoms. Using the model we have fully disentangled the ATAS spectra of two-state superpositions in atoms, with coupling to continuum and off-resonant coupling to bound states.

References

1 M Wu *et al.* J. Phys. B **49**, 062003 (2016)
[2] J M Dahlström *et al.* J. Opt. **19**, 114004 (2017)
[3] P Birk *et al.* J. Phys. B **53**, 03 (2020)
[4] K H Yang Annals of physics **101**, 62 (1976)
[5] A Stenquist *et al.* https://arxiv.org/abs/2302.05345

Sektionen för atom-, molekyl- och optisk fysik

AMO Poster Contributions

Sektionen för atom-, molekyl- och optisk fysik / 77

Relativistic Time-Dependent Configuration Interaction Singles Method

Author: Felipe Zapata[1]

Co-authors: Asimina Papoulia [2]; Rezvan Tahouri [2]; Jimmy Vinbladh [3]; Jan Marcus Dahlström [2]; Eva Lindroth [4]; Anton Ljungdahl [4]

[1] *Lund University, Universidad Autónoma de Madrid*

[2] *Lund University*

[3] *Lund University, Stockholm University*

[4] *Stockholm University*

Corresponding Author: asimina.papoulia@matfys.lth.se

Attosecond physics aims to unravel the electron motion and coherence in atoms and molecules. Major contributions to this field are the real-time observations of the motion of electrons in ions and atoms through attosecond transient absorption spectroscopy (ATAS). Despite the great success of ATAS, all studies have so far been based on non-relativistic ATAS theory. Seeking a compromise between computational cost and accuracy, the relativistic time-dependent configuration interaction singles (RTDCIS) method is proposed for studying atoms and ions. This novel method opens up the possibility to describe the electron spin dynamics by means of spin-resolved ATAS experiments far beyond the perturbative regime. Similarly, it can be applied to other strong-field processes, such as high-order harmonic generation, above-threshold ionization, laser-assisted photoionization, hole alignment, and the study of complex Rabi dynamics.

Sektionen för atom-, molekyl- och optisk fysik / 133

Ab initio molecular dynamics and quantum chemistry calculations of $Fe(CO)_5$ in ethanol solution

Author: Michael Robert Coates[1]

Co-authors: Michael Odelius [1]; Ambar Banerjee [1,2]

[1] *Stockholm University* [2] *Uppsala University*

Corresponding Author: michael.coates@fysik.su.se

Transition metal carbonyls have played a significant role in the photochemistry of organometallic complexes. The ultraviolet excitation of these complexes often results in the loss of one or more carbonyls1 that create short-lived reactive intermediates capable of interacting with the available solvent.[2] Vibrational cooling timescales and the complex free energy surface of the electronic ground state dictate the formation of transient species and photoproducts.

In this study, we employ ab initio molecular dynamics (AIMD) simulations of a benchmark system, $^1Fe(CO)_5$ solvated in ethanol and the solvated photoproducts $^1Fe(CO)_4$ and $^3Fe(CO)_4$ to assess the solvation and stability of the reactants and thermally equilibrated photoproducts. We present a characterization of the minima and transition states of the final photoproduct, $^1Fe(CO)_4$-ethanol in the singlet state and derive insights into the chemical bonding by deconstructing the molecular orbitals into atomic contributions via a partial density of states (PDOS) analysis.

1 Turner et. al. Chem. Soc. Rev., 2022, 51, 5300-5329
[2] Banerjee et. al. Nat. Comm., 2022, 13, 1337

Sektionen för atom-, molekyl- och optisk fysik / 81

Binding energy of a highly mixed excited state in Rh- and an approach to gain resolution in laser photodetachment threshold spectroscopy

Author: Yazareth Peña Rodríguez[1]

Co-authors: Annie Ringvall-Moberg [1]; Dag Hanstorp [1]; David Leimbach [1]; Di Lu [1]; Henning Schmidt [2]; Jon Grumer [3]; Jose Eduardo Navarro Navarrete [2]; Julia Karls [1]; MingChao Ji [2]; Moa Kristiansson [2]; N. D. Gibson [4]; R. Ponce [4]; S. Schiffmann [5]; S.E. Spielman [4]; T. Brage [5]; Wes Walter [4]

[1] *University of Gothenburg*

[2] *Stockholm University*

[3] *Uppsala Universitet*

[4] *Denison University*

[5] *Lund University*

Corresponding Author: guspenaya@student.gu.se

Negative ions are interesting quantum systems due to the nature of the force that binds the extra electron. Since the nucleus effectively screens the Coulomb attraction, the additional electron is bound by a dipole moment induced by electron-electron interactions. As a result, typical spectroscopic methods can not be applied and the only quantity that can be probed with high precision is the energy required to bind the extra electron, i.e. the electron affinity, defined as the energy difference between the lowest energy state of the neutral system and the negative ion. The standard method to obtain such values is through laser photodetachment threshold spectroscopy (LPTS), in which the extra electron is detached from the anion using a photon with sufficient energy [1,2].

With the applicability of infrared light sources to LPTS experiments, the determination of the binding energies and electron affinities of most transition metals were possible. These systems are of special interest due to their open d-shell, where electron correlation and relativistic effects must be taken into account. In particular, in 1998 Sheer et al. [3], obtained a higher precision measurement of the electron affinity of rhodium in comparison to the first measurement done by Feigerle et al. [4]. They also attempted to measure the binding energies of the fine-structure levels of this transition metal. Due to the small ion current, these measurements were not carried out, although the possible photon energies were available [3]. In 2019, measurements of the lifetimes of these states were performed at the Double ElectroStatic Ion Ring ExpEriment (DESIREE) facility in Stockholm, where an additional, previously unknown state was observed [5]. Subsequently, the binding energy of this state was measured at the Gothenburg University Negative Ion Laser Laboratory (GUNILLA).

It is well known that the spectral linewidth of the light source used in photodetachment experiments limits the precision of these measurements. At GUNILLA, a pulsed nanosecond laser of 90 GHz linewidth was recently purchased to perform LPT measurements. In order to reduce the linewidth to less than 10 GHz, an external air-gapped optical cavity has been designed and implemented downstream from the output of the laser [6,7]. A proof-of-principle of this cavity has been performed using photon energies between 1.77 eV and 3.04 eV.

Here, the lifetimes of the excited states of Rh- and the binding energy of the highly mixed excited state, as well as the design of an optical cavity for the reduction of the linewidth of our OPO laser system will be presented.

References:

1 D. J. Pegg, Rep. Prog. Phys. 67 85 (2004).
[2] C. Ning and Y. Lu, J. Phys. Chem. Ref. Data 51, 021502 (2022).
[3] M. Scheer, et al. Phys. Rev. A 58, 2051 (1998).
[4] C. S. Feigerle et al., J. Chem. Phys. 74, 1580–1598 (1981).
[5] J. Karls et al., Lifetimes of excited states in Rh-. In preparation.
[6] E. Hecht, Optics. Wiley-Interscience, 2002.
[7] O. Svelto and D. C. Hanna, Principles of lasers. Plenum Publishing Corporation, 1998.

Sektionen för atom-, molekyl- och optisk fysik / 104

Excited State Dynamics in the Photolysis of Phenyl azide

Author: Sambit Kumar Das[1]

Co-authors: Ambar Banerjee [1]; Michael Odelius [1]

[1] *Stockholm University*

Corresponding Author: sambit.das@fysik.su.se

The photolysis of aryl azides is widely used to produce highly reactive aryl nitrenes, an active intermediate in organic and inorganic synthesis. Phenyl azide (Ph-N_3) is considered a model system for a class of aryl azides. The photoproducts of phenyl azide have applications in various fields, e.g., photoaffinity labeling of enzymes, and preparation of electrically conducting polymers[1], while the involved mechanism is of inherent interest from the perspective of quantum chemistry. This piece of work is focused on simulating the ultrafast dynamics involved in the photo-induced N2 dissociation of phenyl azide (Ph-N_a-N_b-N_c), leading to the formation of phenyl nitrene (Ph-N) and Nitrogen molecule (N_2).

The excited states and decay dynamics are studied with Complete Active Space Self Consistent Field (CASSCF) and complementary N-Electron Valence State Perturbation Theory (NEVPT2) calculations. Initial investigations from the potential energy surface scans motivated us towards large-scale Molecular Dynamics (MD) simulations to generate a statistical overview of the excited state dynamics. Excited state MD simulations are carried out within the SHARC package from the singlet excited states S_1, S_2, S_3, S_4, and S_5, acting as initial states. The studies of the simulated trajectories reveal an average dissociation time of 20-40 fs depending on the state from which the excited state simulation initiates. The electronic structure analysis is complemented with investigations on structural dynamics, for a complete illustration of the dissociation procedure. The population analysis of the trajectories presents that irrespective of the initial state, it is the S_2 state (a π/π* state) in which the N_a-N_b bond splits followed by Nitrene formation. Analysis of the trajectories reveals a direct correlation between the splitting of the N_a-N_b bond and the N_a-N_b-N_c bond angle which takes the dynamics beyond the single degree of freedom framework.

1 Nina P. Gritsan, Zhendong Zhu, Christopher M. Hadad, and Matthew S. Platz, *J. Am. Chem. Soc.*, 3118 (2014) 1999, 121, 6, 1202-1207.

[2] Weston Thatcher Border, Nina P. Gritsan, Christopher M. Hadad, William L. Karney, Carl R. Kemnitz, and Matthew S. Platz, *Acc. Chem. Res.*, 2000, 33,11, 765-771

[3] Juan Soto, and Juan C. Otero, *J. Phys. Chem. A*, 2019, 123, 9053-9060

Sektionen för atom-, molekyl- och optisk fysik / 91

Photoelectron Signatures of Nonperturbative Dynamics in Resonant Two-photon Ionization of Helium

Author: Edvin Olofsson[1]

Co-author: Jan Marcus Dahlström [1]

[1] *Lund University*

Corresponding Author: edvin.olofsson@matfys.lth.se

When an atom is driven by a laser field with a photon energy that is nearly resonant with an atomic transition, it can undergo periodic population transfers between the ground and excited state, known as Rabi oscillations [1,2]. The aim of this work is to study photoionization from atoms for parameters

accessible to a free-electron laser (FEL) [3]. Using time dependent perturbation theory to model photoionization from a Rabi oscillating atom, we have shown that in addition to the expected pathway of ionization from the excited state, non-resonant two-photon ionization will have a comparable amplitude at intensities on the order of 10^{13} W/cm^2 [3].

The Rabi oscillations lead to an Autler-Townes-like doublet structure in the resulting photoelectron spectrum [2,3]. When the non-resonant pathway becomes important, there will be a detuning-dependent asymmetry between the two components of the doublet, which is not present when the first-order amplitude dominates [3]. Our model is able to explain observations made at FERMI for the 1s^2-1s4p resonance in He, and agrees with simulations performed using the time-dependent configuration interaction singles method [3].

As an extension of the theoretical work done in Ref. [3], we model resonant two-photon ionization of He using an effective Hamiltonian approach, that takes into account depletion and AC-Stark shifts of the resonant two-level system.

In Fig. 1 we show our prediction of different domains for photoionization from a Rabi oscillating atom at XUV wavelengths. The colored regions in Fig. 1 indicate for which combinations of intensity and pulse duration it should be possible to observe an Autler-Townes doublet in the photoelectron spectrum. The red region indicates where one-photon ionization from the excited state is dominant, and the blue region indicates where the non-resonant two-photon process is stronger. The diamond in Fig. 1 corresponds to the FEL parameters for the experiment described in Ref. [3], and shows that the experiment was performed in a region where both resonant and non-resonant processes are important.

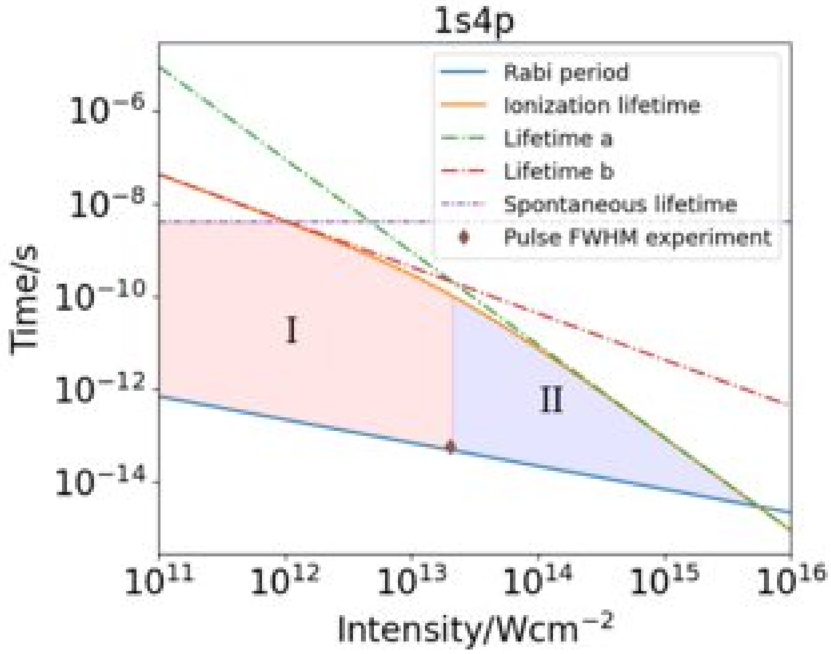


Fig.1 Relevant timescales as a function of intensity for the Rabi oscillating 1s^2-1s4p transition in He.

References
(1) I. I. Rabi, Phys. Rev. **51**, 652 (1937).

(2) S. H. Autler and C. H. Townes, Phys. Rev. **100**, 703 (1955).

(3) S. Nandi *et al.*, Nature **608**, 488 (2022).

Sektionen för atom-, molekyl- och optisk fysik / 131

DESIREE - a facility for studies of cold molecular and atomic ions

Author: Henning Schmidt[1]

[1] *Stockholm University*

Corresponding Author: schmidt@fysik.su.se

The double electrostatic ion-beam storage ring is a Swedish national research infrastructure offering beam time to users interested in studying ions of atoms, molecules and clusters. The facility is cryogenic, which results in very long ion-beam storage times and the ions are subject to interaction with a number of different laser sources and, as there are in fact two ion-storage rings in the facility, also to interactions with ions of opposite charges. A main activity is the study of mutual neutralization of interest for astrophysics. In particular studies involving the negative atomic hydrogen ion are important for proper quantitative analyses of stellar spectra to deduce the abundances of heavier elements in the atmospheres of the stars.

Sektionen för atom-, molekyl- och optisk fysik / 125

Relativistic calculations of electron–parent ion entanglement using the KRAKEN protocol

Author: Leon Petersson[1]

Co-author: Eva Lindroth [1]

[1] *Stockholm University*

Corresponding Author: leon.petersson@fysik.su.se

In most atomic systems, single ionisation- channel continua are the exception, rather than the norm. When multiple ionisation channels are open, the purity of the state density operator can provide information on the electron–Parent Ion (PI) entanglement. Although this informa- tion may not be extracted using only an XUV pump, it can be obtained with the addition of a probe pulse. This is the principle behind pump- probe methods, which allow the for extraction of time-dependent information through varying the pump-probe delay.

One recently developed interferometric pump-probe method aimed at reconstructing the one-photon density operator is known as KvanttillståndstomogRafi av AttoseKundsElektroNvågpaket (KRAKEN). KRAKEN combines an XUV pump with a two-colour IR probe, allowing for interference measurements of the population at any two intermediate energies.

From the point of view of theory, both the one- and two-photon matrix elements can be di- rectly obtained, without the need for any of the assumptions relied on in the KRAKEN protocol. Thus, both the one-photon density matrix and its KRAKEN reconstruction may be calculated — and compared — directly. The present work makes use of Relativistic Random Phase-Approximation with Exchange (RRPAE) to simulate KRAKEN in argon, where the fine-structure splitting of the ground state results in separate ionisation channels. Both the and its KRAKEN reconstruction are calculated and compared to evaluate the assumptions present in the method.

Sektionen för atom-, molekyl- och optisk fysik / 59

Survival of Interstellar Carbon Knockout Fragments

Author: Naemi Florin[1]

Co-authors: Ansgar Simonsson [1]; Henning Schmidt [1]; Henning Zettergren [1]; Henrik Cederquist [2]; Joao Ameixa ; Mark Hugo Stockett [1]; Michael Gatchell [1]; MingChao Ji [1]; Peter Reinhed [1]; Stefan Rosén [3]; Suvasthika Indrajith [1]

[1] *Stockholm University*

[2] *Physics Department, Stockholm University*

[3] *Stockholms Universitet*

Corresponding Author: naemi.florin@fysik.su.se

Synopsis

We have performed experimental and theoretical studies of knockout processes with carbonaceous molecules, and draw conclusions about the lifetimes of their decay products and their possible survival in astro- physical environments.

Abstract

The presence of polycyclic aromatic hydrocarbons (PAHs) in the interstellar medium was proposed in the 1980's 1[2] and later confirmed in 2021 [3][4][5][6]. Fullerenes, another family of carbon-based molecules, were experimentally observed [7] and later also discovered in space [8]. To gain better understanding of the formation and survival of these molecules in astrophysical environments, we have studied their collisions with single energetic atoms, leading to different knockout processes.

Spontaneous loss of a single carbon atom is an energetically unfavoured decay channel for PAHs and fullerenes. In contrast, when bombarded with atoms or ions, single atom knockout occurs at a significant rate for center of mass collision energies in the 100 eV range [9]. We have studied such knockout events on short (picosecond) timescales theoretically using the LAMMPS molecular dynamics software, and experimentally on timescales of up to minutes using an ion storage ring. The experimentally determined stability of the decay products of these carbon-based structures had previously been limited to studies on microsecond timescales [9][10][11][12]. In experiments at the DESIREE (Double Electro- Static Ion Ring ExpEriment) facility, however, we have now been able to monitor their survival on extended timescales, through colliding PAHs and fullerenes of various energies with stationary He atoms and then store the knockout fragments in a cryogenic environment mimicking interstellar conditions. We find that a portion of the knockout fragments dissociate spontaneously on timescales of tens of milliseconds, but that a significant fraction are cold enough to remain intact for the entire duration of the measurements (minute timescales). This leads us to conclude that they will survive indefinitely [13].

References

1 Leger A and Puget J L 1984 Astron. Astrophys. 137 L5
[2] Allamandola L J et al. 1895 Astrophys. J. Lett. 290 L25.
[3] Cernicharo J et al. 2021 Astron. Astrophys. 649 L15.
[4] McGuire B A, Loomis R A, Burkhardt A M et al. 2021 Science 371 1265
[5] Burkhardt A M et al. 2021 ApJL 913 L18
[6] Sita M L et al. 2022 ApJL 938 L12
[7] Kroto H W et al. 1985 Nature 318 162
[8] Cami J et al. 2010 Science 329 5996
[9] Gatchell M and Zettergren H 2016 Journal of Physics B 49 162001
[10] Stockett M H et al. 2018 Carbon 139 906
[11] Stockett M H et al. 2014 Phys. Rev. A 89 03271
[12] Stockett M H et al. 2015 J. Phys. Chem. Lett. 22 4504
[13] Gatchell M et al. 2021 Nature Communications 12 6646

Sektionen för atom-, molekyl- och optisk fysik / 85

Measuring the quantum state of a photoelectron

Author: Mattias Ammitzböll[1]

Co-authors: Hugo Laurell [1]; Sizuo Luo [1]; Robin Weissenbilder [1]; Vénus Poulain [1]; Chen Guo [1]; Shahnawaz Ahmed [2]; Anton Kockum [2]; Leon Petersson [3]; Eva Lindroth [3]; Christoph Dittel [4]; Daniel Finkelstein Shapiro [5]; Richard Squibb [6]; Raimund Feifel [6]; Mathieu Gisselbrecht [1]; Cord Arnold [1]; Andreas Buchleitner [4]; Anne L'Huillier [1]; David Busto [1]

[1] *Lund University*

[2] *Chalmers*

[3] *Stockholm University*

[4] *Freiburg University*

[5] *National Autonomous University of Mexico*

[6] *University of Gothenburg*

Corresponding Author: mattias.ammitzboll@fysik.lth.se

Abstract: We demonstrate experimentally a new quantum state tomography protocol for photoelectrons. The measured reduced density matrix, originating from different noble gases, shows that the photoelectron purity decreases due to ion–electron entanglement induced by spin–orbit interaction. Opening up the possibility for directly studying quantum properties of photoelectrons on a ultrafast timescale.

Photoelectron spectroscopy has been instrumental in the studying of the quantum nature of atoms. The discovery of the photoelectric effect 1 during the 20^{th} century was crucial for the development of quantum mechanics. The advent of attosecond science have further improved the field by measurements, not only of the modulus of the momentum, but also of its phase. Attoscience has opened up the study of dynamics on the electron timescale, but until recently mostly for pure quantum states.

Recent developments in atto-/femtosecond science can now account for mixed quantum states as well [2,3,4]. Allowing the retrieval for the full retrieval of the quantum state. We have developed a protocol called KRAKEN, where reduced density matrix elements are measured by the use of a bichromatic laser field as a probe of the created electron state. By scanning over the pump-probe delay and wavelength separation, $\delta\omega$, the sparse density matrix is retrieved. We have developed a Bayesian machine-learning algorithm based on a Hamiltonian Monte-Carlo method to extract the full density matrix based on the measured sparse density matrix. The results are then benchmarked against independent ab initio calculations. The measured (and theoretical) purities of He, Ne and Ar are 0.97 ± 0.11 (1.00), 0.83 ± 0.15 (0.79) and 0.59 ± 0.04 (0.61) respectively, showing a clear difference between the noble gases, due to spin-orbit interaction and the subsequent electron-ion entanglement.

Future developments aim at decreasing the measurement-time by using a poly-chromatic probe and pushing towards quantum process tomography, opening up towards photoelectron time-resolved studies of quantum properties.

1 A. Einstein,¨Uber einen die Erzeugung und Verwandlung des Lichtes betreffenden heuristischen Gesichtspunkt, Annalen der Physik, 322, 10.1002/andp.19053220607 (1905).

[2] C. Bourassin-Bouchet et al, Phys. Rev. X, 10, 031048 (2020).

[3] M. J.J. Vrakking, Phys. Rev. Lett., 126, 113203 (2021).

[4] H. Laurell et al, Phys. Rev. Research, 4, 033220 (2022).

Sektionen för atom-, molekyl- och optisk fysik / 75

Accelerator physics as a driver of X-ray lasers (FEL)

Author: Sverker Werin[1]

Co-authors: Francesca Curbis [1]; Johan Lundquist [1]

[1] *Lund University*

Corresponding Author: sverker.werin@maxiv.lu.se

Electron particle accelerators are the base for generation of intense X-rays. A Free Electron Laser (FEL) based on such an accelerator is able to control the process to give the X-rays laser-like properties. A FEL can provide coherent X-rays at extreme powers (GW to TW) and in very short pulses (femto-seconds to atto-seconds).
This poster will present an overview of our FEL related research. First the design of a Soft X-ray FEL (the SXL) project for the MAX IV laboratory, which is intended to use the 3 GeV MAX IV linac to generate 1-5 nm radiation in a long undulator system. We will also describe research on coherence properties of FELs operating in different modes (SASE and ECHO) at the FERMI FEL in Trieste Italy. Further, how the coherence in the SXL can be increased by a careful control of the electron bunch properties. We also touch on how AI can be used to improve the diagnostics of electron pulses for FELs.

Sektionen för elementarpartikel och astropartikelfysik

Sektionen för elementarpartikel och astropartikelfysik / 112

Studying the Higgs sector with ATLAS

Corresponding Author: christina.dimitriadi@physics.uu.se

Review of the Swedish activities exploring physics of the Higgs-sector in the ATLAS experiment.

Sektionen för elementarpartikel och astropartikelfysik / 111

Search for beyond the standard model physics with ATLAS

Corresponding Author: david.brunner@fysik.su.se

Review of the Swedish activities searching for signatures of beyond the standard model physics with the ATLAS detector.

Sektionen för elementarpartikel och astropartikelfysik / 113

ATLAS Detector Operations

Corresponding Author: ollelu@kth.se

Review of the Swedish contribution to the operations of the ATLAS detector and monitoring and optimising its performance.

Sektionen för elementarpartikel och astropartikelfysik / 114

Vector-like quarks and vacuum misalignment in composite Higgs models

Authors: Avik Banerjee[1]; Gabriele Ferretti[None]

[1] *Chalmers University of Technology*

Corresponding Author: avik@chalmers.se

Two major ingredients of a composite Higgs model are vacuum misalignment and partial compositeness. The former is essential to trigger the electroweak symmetry breaking, while the latter can explain the mass hierarchy of the quarks. The partial compositeness mechansim employes a mixing between the SM quarks and vector-like quarks, arising from a new confining sector, via four-Fermi operators. In this talk I will show the necessity of these four-Fermi interactions to misalign the vacuum of the strong sector leading to electroweak symmetry breaking and connect our observations with recent results from lattice gauge theory calculations. I will also discuss the prospect for searching vector-like quarks via non-standard decay channels at the LHC.

Sektionen för elementarpartikel och astropartikelfysik / 76

Search for dark mesons at the LHC

Author: Olga Sunneborn Gudnadottir[1]

[1] *Uppsala University*

Corresponding Author: olga.sunneborn.gudnadottir@physics.uu.se

One of the currently most widely researched questions in particle physics is "What is dark matter?". The Stealth Dark Matter theory identifies it with a stable state in a new, strongly coupled, dark sector extending the Standard Model. The constituents of the new sector, the dark quarks, form bound states in analogy with the SM QCD sector, giving rise to dark mesons, some of which can decay into SM states through Higgs interactions. In my talk I will present the first dedicated search for dark mesons at the LHC, based on gaugephobic Stealth Dark Matter. We search for pair production of dark pions, produced either resonantly via a dark rho or through Drell Yan production, that subsequently decay into top and bottom quarks. The search is done with the full Run 2 dataset with both the SU(2)R and SU(2)L models, with dark pion masses ranging from 200 GeV to 1200 GeV, and with the dark rho at least twice as heavy as the dark pion. Two final states are considered, the all-hadronic and the 1-lepton channel. The all-hadronic channel will have a result public by the time of this talk and the preliminary results will be discussed. My own work is focused on the 1 lepton channel in which the signature contains up to 8 quarks out of which 4 come from b-jets. I will describe how we faced this challenging final state, as well as the large differences in kinematics over the large signal grid, and any results we might have at the time of the talk.

Sektionen för elementarpartikel och astropartikelfysik / 110

Preparing ATLAS for the future

Author: Hannah Herde[1]

[1] *Lund University*

Corresponding Author: hannah.herde@hep.lu.se

Sektionen för elementarpartikel och astropartikelfysik / 99

ALICE activities in Lund

Author: David Silvermyr[1]

[1] *Lund University*

Corresponding Author: david.silvermyr@hep.lu.se

In the ALICE group at Lund, we analyse data from proton-proton and heavy-ion collisions to gain a better understanding of the connection between microscopic QCD processes and the properties of nuclear matter at high temperature and energy density. I will also discuss the hardware activities in our group, particularly our contributions to the ongoing and planned detector upgrades in light of the upcoming Runs 3 and 4 at the LHC, and the proposed future ALICE3 experiment.

Sektionen för elementarpartikel och astropartikelfysik / 67

The SHiP experiment at the proposed CERN SPS Beam Dump Facility

Authors: Richard Jacobsson[1]; SHiP Collaboration[None]

[1] *CERN*

Corresponding Author: richard.jacobsson@cern.ch

We present the proposal for a general-purpose intensity-frontier experimental facility BDF/SHiP, operating in beam-dump mode at the CERN SPS accelerator in the existing SPS ECN3 experimental area. This proposal is part of the ongoing decision process focused on the beyond-LS3 physics program in ECN3, which should come to conclusion by the end of 2023. The SHiP experiment aims to search for feebly interacting GeV-scale particles and perform measurements in neutrino physics. BDF/SHiP complements the worldwide program of New Physics searches by exploring a large region of parameter space that cannot be addressed by other experiments, and which reaches several orders of magnitude below existing bounds by efficiently exploiting the currently available 4x10^19 protons per year at 400 GeV for up to 10-15 years. The SHiP experiment has generic sensitivity to decay and scattering signatures of models with feebly interacting particles, such as dark-sector mediators and light dark matter. In neutrino physics, BDF/SHiP can perform unprecedented measurements with tau neutrinos and neutrino-induced charm production. This proposal benefits from the extensive studies related to the Technical Proposal submitted in 2015 and the subsequent Comprehensive Design Study (CDS) of BDF/SHiP located at a new beamline at the CERN SPS.

Sektionen för elementarpartikel och astropartikelfysik / 123

The HIBEAM/NNBAR program

Author: David Milstead[1]

[1] *Stockholm University*

Corresponding Author: milstead@fysik.su.se

The HIBEAM/NNBAR program is a multi-stage series of experiments to search for baryon number violation via neutron conversions to sterile neutrons and/or anti-neutrons. In this talk, I'll describe the theoretical motivation, the status of the project and sensitivities expected.

Sektionen för elementarpartikel och astropartikelfysik / 124

Free-Neutron Oscillation Searches at the European Spallation Source

Author: Udo Friman-Gayer[1]

[1] *European Spallation Source ERIC*

Corresponding Author: udo.friman-gayer@ess.eu

The European Spallation Source (ESS), presently under construction in Lund, Sweden, is a multidisciplinary international laboratory that aims to become the world's most powerful pulsed neutron source. At its design performance, it will also be at the "intensity frontier" of particle-physics research and provide unique opportunities to solve open questions about the fundamental building blocks of the universe.
This contribution will focus on one part of the diverse particle-physics efforts at the ESS 1, namely the search for baryon-number violating (BNV) neutron conversion into anti- or "dark" matter by the NNBAR collaboration. Such BNV processes are important assumptions of modern theories to explain experimental findings in disagreement with the standard model(s), but they have yet to be observed in the laboratory.

The first stage of the NNBAR research program, the High Intensity Baryon Extraction and Measurement (HIBEAM) experiment at the fundamental physics beamline of the ESS, is dedicated to the search for neutron oscillations into "sterile" neutrons as members of a hypothetical dark sector of matter [2]. Design criteria for the experimental setup are a low background and a precise control of the magnetic field over a large flight path on the order of 50 meters to amplify oscillations in the proposed conversion mechanism.

In the second stage, the NNBAR experiment will be operated at the large beam port (LBP) of ESS, which was specifically designed to provide an unprecedented neutron flux for neutron-antineutron oscillation searches. In combination with innovative developments in neutron moderation and -guiding technology, it is foreseen to surpass the sensitivity of a pioneering experiment at the Institut Laue Langevin in Grenoble, France [3] by three orders of magnitude. The conversion search also requires the development of a detection system to unambiguously identify the signature 1.9-GeV multi-pion final state of a neutron-antineutron annihilation event on the large detection surface.

Experiments at the scale of the NNBAR program do not only provide unique opportunities, but also pose exciting engineering and safety challenges. Both stages of the NNBAR program are in the design phase, and an extensive simulation effort is being made to optimize all aspects of the experiment operation - from the neutron source to the data analysis. This contribution will give an overview of the goals and discuss the most recent developments.

1 H. Abele *et al.*, "Particle Physics at the European Spallation Source", arXiv:2211.10396
[2] Z. Berezhiani and L. Bento, "Neutron - mirror neutron oscillations: How fast might they be?" Phys. Rev. Lett. **96** (2006) 081801, doi:10.1103/PhysRevLett.96.081801, arXiv:hep-ph/0507031
[3] M. Baldo-Ceolin, *et al.*, "A New experimental limit on neutron - anti-neutron oscillations", Z. Phys. C **63** (1994) 409–416. doi:10.1007/BF01580321

Sektionen för elementarpartikel och astropartikelfysik / 89

Status of the Light Dark Matter eXperiment (LDMX)

Author: Lene Kristian Bryngemark[1]

[1] *Lunds universitet*

Corresponding Author: lene_kristian.bryngemark@hep.lu.se

The Light Dark Matter eXperiment (LDMX) is currently being designed to search for Dark Matter (DM). It targets a window of opportunity to explore a dark sector in the MeV-GeV mass region where DM of thermal origin has not yet been excluded. This talk will outline the motivation and current status of LDMX, highlighting some of Sweden's and Lund University's recent contributions to the design and prototype tests leading up to the future construction of LDMX.

Sektionen för elementarpartikel och astropartikelfysik / 92

Background Rejection at the Light Dark Matter eXperiment with an 8 GeV Beam

Author: Erik Wallin[1]

Co-author: Ruth Pöttgen [2]

[1] *Lunds Universitet*

[2] *Lund University*

Corresponding Author: erik__jakob.wallin@hep.lu.se

The Light Dark Matter eXperiment (LDMX) is a fixed-target experiment that will be placed at the LCLS-II electron beamline at SLAC, sensitive to production of sub-GeV dark matter with missing momentum and missing energy signatures. This precision search for rare dark matter production requires strong veto capabilities to separate those events from standard model background processes. After initially running at a 4 GeV beam energy, the LCLS-II beamline will be upgraded to 8 GeV, where LDMX will take the bulk of its data. The energy increase is expected to improve both the dark matter production cross sections, as well as the background rejection capabilities.

The most challenging backgrounds for LDMX are muon conversions and photo-nuclear reactions, into complex and possibly neutral final-states, induced by an energetic bremsstrahlung photon, that can mimic the missing momentum and missing energy signature of dark matter. This simulation study shows that LDMX, with the combined veto performance of all its subsystems, can reject every standard model background event for each of 2×10^{14} electrons scattering in the target, at 8 GeV beam energy. Furthermore, the veto capabilities are shown to improve at 8 GeV beam energy compared to 4 GeV.

Sektionen för elementarpartikel och astropartikelfysik / 121

Photonuclear event generator comparisons for the Light Dark Matter eXperiment

Author: Einar Elén[1]

[1] *Lund university*

Corresponding Author: einar.elen@nuclear.lu.se

The Light Dark Matter eXperiment (LDMX) aims to perform a zero background search for light dark matter. The ability of the experiment to veto standard model backgrounds has been studied in detail based on Geant4 simulations. A critical background process for the detector design comes from photonuclear reactions of few-GeV photons with tungsten. In Geant4, these are modeled using the Bertini intranuclear cascade model. While both Geant4's hadronic models and the Bertini cascade in particular have been broadly validated, the design of LDMX is sensitive to the rates and topologies of very rare final states that have received significantly less scrutiny. This contribution will detail our efforts of comparing such final states between several alternative event generators as well as results from replacing the Bertini cascade for photonuclear reactions in Geant4 with the PEANUT model from FLUKA. The latter was made possible thanks to an interface to FLUKA's hadronic models to Geant4 that is currently being developed by the FLUKA@CERN collaboration.

Sektionen för elementarpartikel och astropartikelfysik / 73

Spin-1 Thermal Targets for Dark Matter Searches at Fixed Target Experiments

Author: Taylor Gray[1]

[1] *Chalmers University of Technology*

Corresponding Author: taylor.gray@chalmers.se

Sub-GeV dark matter (DM) has been gaining significant interest in recent years, since it can account for the thermal relic abundance while evading nuclear recoil direct detection constraints. Such light DM must carry a larger energy to be probed, either directly or through missing energy/momentum, making beam dump and fixed target experiments ideal for this mass range. Here, we extend the previous literature, which mainly focuses on the predicted experimental signals of scalar and fermionic DM, by considering simplified DM models in which the Standard Model is extended by one vector DM candidate along with one spin-1 mediator. In this analysis, we identify the parameters consistent with the observed relic abundance, calculate the relevant constraints from existing experiments and measurements, and predict the sensitivity of future experiments such as the upcoming LDMX. We find that spin-1 DM is testable by future experiments, and for certain spin-1 models, will be the first DM models probed by LDMX.

Sektionen för elementarpartikel och astropartikelfysik / 103

Three-pion scattering: From the chiral Lagrangian to the lattice

Author: Mattias Sjö[1]

Co-authors: Fernando Romero-López [2]; Johan Bijnens [1]; Jorge Baeza-Ballesteros [3]; Stephen R. Sharpe [4]; Tomáš Husek [5]

[1] *Lund University*

[2] *MIT*

[3] *U. de Valencia*

[4] *U. of Washington*

[5] *Lund U./Charles U.*

Corresponding Author: mattias.sjo@hep.lu.se

In recent years, detailed studies of three-pion systems have become possible in lattice QCD. This has in turn led to interest in 3-to-3 scattering of pions in the chiral perturbation theory framework, which complements the lattice results. In particular, it provides a valuable handle on finite-volume effects and the pion mass dependence. I present our derivation of the next-to-leading order amplitude for this process, as well as its conversion into the three-particle K-matrix, which enables direct comparison to the lattice. Our results significantly improve the agreement between theory and lattice, which was poor when only leading-order effects were taken into account.

Sektionen för elementarpartikel och astropartikelfysik / 82

The nuSTORM project in ESSnuSBplus

Author: Maja Olvegård[1]

[1] *Uppsala university*

Corresponding Author: maja.olvegard@physics.uu.se

The ESSnuSB design study is entering a new phase with a second four-year design study 2023-2026, ESSnuSBplus, funded by Horizon Europe. One of the ESSnuSBplus additions to ESSnuSB will be the design study of a low-energy nuSTORM (neutrinos from stored muons) facility based on the use of the ESS accelerator and the ESSNUSB accumulator-ring as injector complex. The nuSTORM facility consists of a dedicated target station with pion capture and transfer and a race-track storage ring in which the pions will be injected and, in the first race-track straight, decay to muons, which will be stored during many turns in the race-track ring. Each muon in the race-track ring will eventually decay producing a muon-neutrino and an electron-neutrino. In this way an intense neutrino beam containing both these species will be formed, which will be detected in a new, small near detector and in a far detector, the latter being the same as the near detector in the ESSnuSB project. nuSTORM will make possible precise measurements of both muon and electron neutrino cross sections in water as well as searches for sterile neutrinos. This talk will give and overview of the ESSnuSBplus project, with particular emphasis on the development of the nuSTORM facility.

Sektionen för elementarpartikel och astropartikelfysik / 84

Effective Field Theory descriptions of Higgs boson pair production

Author: Christina Dimitriadi[None]

Corresponding Author: christina.dimitriadi@physics.uu.se

Higgs boson pair production (HH) is traditionally considered to be of particular interest for a measurement of the trilinear Higgs self-coupling. Yet it can offer insights into other couplings as well, since - in an effective field theory (EFT) parameterisation of potential new physics - both the production cross section and kinematical properties of the Higgs boson pair depend on various other Wilson coefficients of EFT operators.
This talk presents work recently performed and documented in a LHC Higgs Working Group note, which summarises the current efforts related to the development of EFT tools for HH in gluon fusion. It also includes recommendations for EFT parameterisations and updates to benchmark scenarios. A parameterisation of the next-to-leading order QCD corrections in terms of the EFT Wilson coefficients is presented and a reweighting procedure which can be used to speed up experimental analyses is validated.

Sektionen för elementarpartikel och astropartikelfysik / 68

Anatomy of di-Higgs production with light stops

Author: Harri Waltari[1]

Co-authors: Jörgen Sjölin [2]; Luca Panizzi ; Stefano Moretti [1]

[1] *Uppsala University*

[2] *Stockholm University*

Corresponding Author: harri.waltari@physics.uu.se

We discuss the possibility of probing BSM physics via di-Higgs production, in particular light stops. We performed an amplitude-level analysis of Higgs pair production at the LHC and show what types of deviations one could expect and how they arise from different new physics contributions. The toolbox can be used also to different scenarios with additional colored scalars coupling to the Higgs and shall be extended in the future to cover more scenarios.

Sektionen för elementarpartikel och astropartikelfysik / 57

LEX EFT; The Light Exotics Effective Field Theory

Author: Linda Carpenter[None]

Corresponding Author: carpenter.690@osu.edu

I propose the creation of a Light Exotics Effective Field Theory (LEX-EFT) catalog - a generic framework to capture all interactions between the Standard Model (SM) and all (or at least a large class of) theoretically allowed exotic states beyond the Standard Model (bSM), indexed by their SM and bSM charges. . This framework. for onshell exotics, which subsumes beyond the Standard Model paradigms as generally is a complement to Standard Model Effective Field Theory (SMEFT), which can capture the off-shell effects of exotic fields. I review a general method for the construction of a complete list of gauge-invariant operators involving SM interactions with light exotics via iterative tensor product decomposition, I discuss charge flow in these operators and show how this charge flow affects the range of EFT validity and cross sections associated with an effective operator. I give an example catalog of exotic scalars coupling to SM gauge boson pairswhich demonstrates high.y non standard collider phenomenology. Finally, I further demonstrate the utility of the LEX-EFT approach with several examples of effects on kinematic distributions and cross sections that would not be captured by EFTs agnostic to the exotic degrees of freedom and may evade the main inclusive collider searches tailored to the existing preferred set of standard bSM theories

Sektionen för elementarpartikel och astropartikelfysik / 105

Tropical Feynman integration in the physical region

Authors: Michael Borinsky[1]; Henrik Munch[2]; Felix Tellander[3]

[1] *ETH*

[2] *Università degli Studi di Padova*

[3] *DESY-T*

Corresponding Author: felix.tellander@desy.de

I will present a new computer program, **feyntrop**, which uses the tropical Monte Carlo approach to evaluate Feynman integrals numerically.
In order to apply this approach for physical kinematics, we introduce a new parametric representation of Feynman integrals that implements the causal $i\varepsilon$ prescription concretely while retaining projective invariance. **feyntrop** can efficiently evaluate dimensionally regulated, quasi-finite Feynman integrals, with not too exceptional kinematics in the physical region, with a relatively large number of propagators and with arbitrarily many kinematic scales. I will provide the necessary mathematical background and discuss many explicit examples of evaluated Feynman integrals.

Sektionen för elementarpartikel och astropartikelfysik / 55

Dark Matter Searches with Cosmic-Ray Antinuclei

Author: Timothy Linden[1]

[1] *Stockholm University*

Corresponding Author: linden@fysik.su.se

Observations by AMS-02 on the International Space Station have tentatively detected approximately 10 events that are consistent with antihelium nuclei. Such a detection would be of significant theoretical interest due to the difficulty in producing any detectable antihelium flux through standard model interactions. In this talk, I will discuss the state of these observations, the state of models that are capable of producing such observations – and the possibility that dark matter may first be detected due to its exceedingly rare annihilations into heavy antinuclei states, compared to more standard processes that produce gamma rays, positrons, or antiprotons.

Sektionen för elementarpartikel och astropartikelfysik / 62

New View of Pulsar and Dark Matter Contributions to the Local Cosmic-Ray Positron Flux

Author: Isabelle John[1]

[1] *Stockholm University*

Corresponding Author: isabelle.john@fysik.su.se

High-energy cosmic-ray electrons and positrons cool rapidly as they propagate through the Galaxy, due to synchrotron interactions with magnetic fields and inverse-Compton scattering interactions with photons of the interstellar radiation field. Typically, these energy losses have been modelled as a continuous process. However, inverse-Compton scattering is a stochastic process, characterised by interactions that are rare and catastrophic. In this work, we take the stochasticity of inverse-Compton scattering into account and calculate the contributions to the local electron and positron fluxes from different sources. Compared to the continuous approximation, we find significant changes: For pulsars, that produce electron-positron pairs as they spin down, the spectrum becomes significantly smoother. For TeV-scale dark matter particles, that annihilate into electrons and positrons, the signal becomes strongly enhanced around the energy corresponding to the dark matter mass. Combined, these effects significantly improve our ability to use spectral signatures in the local electron and positron spectra to search for particle dark matter at TeV energies.

Sektionen för elementarpartikel och astropartikelfysik / 86

First Results from XENONnT and an outlook towards DARWIN

Author: Jörn Mahlstedt[1]

[1] *Stockholm University*

Corresponding Author: joern.mahlstedt@fysik.su.se

XENONnT, the latest detector of the XENON Dark Matter program, shows an unprecedentedly low background which facilitates searches for new, very rare phenomena with high sensitivity. The detector which was designed to look for elusive dark matter particles holds almost 6000 kg of ultrapure liquid xenon as a target for particle interactions. It is installed inside a water Cherenkov active muon and neutron veto, deep underground at the INFN Laboratori Nazionali del Gran Sasso in Italy.
At Stockholm university we are involved in the construction, operation and data analysis of this detector. In addition we do research and development on new photosensors in our local lab for the next generation detector, DARWIN. This talk will summarise the current status of the direct detection field with a focus on our local activities.

Sektionen för elementarpartikel och astropartikelfysik / 54

Direct searches for general dark matter-electron interactions with graphene detectors

Author: Einar Urdshals[1]

[1] *Chalmers Technical University*

Corresponding Author: urdshals@chalmers.se

We employ a non-relativistic effective theory to model dark matter (DM) induced electron ejections from graphene and carbon nanotubes (CNTs), materials currently in the R&D phase for direct detection experiments. We employ Density Functional Theory to model the material properties of graphene, and obtain observable ejection rates for arbitrary forms of scalar and spin-1/2 DM. We show how the anisotropy of graphene and CNTs cause a strong daily modulation in the rate of electron ejections, a smoking gun signal for DM. We project 3 sigma discovery potential of such a daily modulation pattern, as well as expected exclusion bounds in the case of no observed daily modulation.

Sektionen för elementarpartikel och astropartikelfysik / 116

Gamma-ray constraint on decaying axionlike particles from supernovae

Authors: Eike Christoph Müller[1]; Francesca Calore[None]; Pierluca Carenza[1]; Christopher Eckner[None]; M.C. David Marsh[None]

[1] *Stockholm University*

Corresponding Author: eike.muller@fysik.su.se

One of the strongest bounds on MeV-scale Axion-Like Particles (ALPs) interacting with photons is derived from the non-observation of a gamma-ray burst following Supernova (SN) 1987A. We strengthen this bound by including photon coalescence as an efficient production process of heavy ALPs. Furthermore, we present in some detail a new analytical method for calculating the predicted gamma-ray signal from ALP decays. With this method we can rigorously prove the validity of an approximation that has so far been used in some of the previous literature, which we show here to be valid only if all gamma rays arrive under extremely small observation angles (i.e. very close to the line of sight to the SN). However, it also shows where the approximation is not valid, and offers an efficient alternative to calculate the ALP-induced gamma-ray flux in a general setting when the observation angles are not guaranteed to be small. Finally, we show that it may be possible to reconstruct the product $g_{a\gamma}^2 m_a$ from a potential future detection of this signal by the *Fermi* Large Area Telescope.

Sektionen för elementarpartikel och astropartikelfysik / 56

The ESCAPE Dark Matter Science Project

Author: Caterina Doglioni[1]

[1] *Lund University*

Corresponding Author: caterina.doglioni@hep.lu.se

A Dark Matter Science Project is being developed in the context of the ESCAPE and EOSC-Future projects as a collaboration between scientists in European Research Infrastructures and experiments seeking to explain the nature of dark matter (such as HL-LHC, KM3NeT, CTA, DarkSide).
The goal of this ESCAPE Science Project is to highlight the synergies between different dark matter communities and experiments, by producing new scientific results as well as by making the necessary data and software tools fully available.
As part of this Science Project, we use experimental data and software algorithms from selected direct detection, indirect detection, and particle collider experiments involved in ESCAPE as prototypes for end-to-end analysis pipelines on a Virtual Research Environment that is being prepared as one of the building blocks of the European Open Science Cloud (EOSC).
This contribution focuses on the scientific results obtained over the course of this project, and on the implementation of the workflows on the Virtual Research Environment.

Sektionen för elementarpartikel och astropartikelfysik / 53

Audible Gravitational Echoes of New Physics

Authors: António Morais[1]; Roman Pasechnik[2]

[1] *Aveiro University*

[2] *Lund university*

Corresponding Author: aapmorais@ua.pt

Based on the recent article [2023.02399], we discuss the LISA potential for finding evidence of New Physics from measurements of the Stochastic GW Background (SGWB). As a benchmark scenario, we study a version of the low-scale Majoron model equipped with lepton number symmetry and an inverse seesaw mechanism for neutrino mass generation. In particular, we discuss under which circumstances the model can be probed at LISA and which implications result for collider physics observables, such as the Higgs trilinear coupling, the scalar mixing angle and the mass of a new CP-even Higgs boson. If time allows, we will also report on a scenario of symmetry restoration at zero temperature based on a model with two scalar leptoquarks.

Sektionen för elementarpartikel och astropartikelfysik / 143

Report from CERN Council

Corresponding Author: brenner@mail.cern.ch

Sektionen för elementarpartikel och astropartikelfysik / 140

ACCU

Corresponding Author: rebeca.gonzalez.suarez@physics.uu.se

Sektionen för elementarpartikel och astropartikelfysik / 139

RECFA

Corresponding Author: milstead@fysik.su.se

Sektionen för elementarpartikel och astropartikelfysik / 137

IPPOG / Outreach

Corresponding Author: jostran@kth.se

Sektionen för elementarpartikel och astropartikelfysik / 138

IUPAP

Corresponding Authors: r.catena@thphys.uni-heidelberg.de, roman.pasechnik@hep.lu.se

Sektionen för elementarpartikel och astropartikelfysik / 141

Snowmass

Corresponding Author: caterina.doglioni@hep.lu.se

Sektionen för elementarpartikel och astropartikelfysik / 142

APPEC

Corresponding Author: cfinley@fysik.su.se

Sektionen för elementarpartikel och astropartikelfysik / 52

Propagation of gauge fields in hot and dense plasmas at higher orders

Author: Andreas Ekstedt[1]

[1] *Uppsala University*

Corresponding Author: andreas.ekstedt@physics.uu.se

Thermal field theory is indispensable for describing hot and dense systems. Yet perturbative calculations are often stymied by a host of energy scales, and tend to converge slowly. This means that precise results require the apt use of effective field theories. In this talk I describe how the effective description of slowly varying gauge fields, known as hard thermal loops, can be extended to higher orders. I also discuss how to consistently define asymptotic masses at higher orders; and how to treat spectral functions close to the lightcone.

Sektionen för elementarpartikel och astropartikelfysik / 101

Hunting axions with metamaterials: the ALPHA haloscope

Author: Andrea Gallo Rosso[1]

[1] *Stockholm University*

Corresponding Author: andrea.gallo.rosso@fysik.su.se

Among the theoretical particles that could explain dark matter, axions make an ideal candidate. They can be produced in the early Universe and make up the observed abundances, permeating the universe as an invisible wave. In recent years, the efforts to build a kind of radio that would tune to this unique frequency has intensified, with conventional techniques failing to look for high frequencies. By arranging materials macroscopically in a clever fashion (so called metamaterials) to engineer a custom plasma, the Axion Longitudinal Plasma Haloscope (ALPHA) will allow for some of the best motivated and most difficult frequencies to be scanned, potentially revealing the nature of dark matter. The talk reviews the theory behind this new concept as well as providing an overview of potential search strategies.

Sektionen för elementarpartikel och astropartikelfysik / 100

Exploratory prototypes for axion detection: the ALPHA haloscope

Author: Gagandeep Kaur[1]

[1] *Stockholm University*

Corresponding Author: gagandeep.kaur@fysik.su.se

Recently, Lawson et al. (2019) proposed a plasma haloscope, based on metamaterials for the search of axions. In previous plasma haloscopes, the size of resonant cavities is limited due to the Compton wavelength of axion, making it impractical to scale detector sizes to search for higher-mass axions. However, the proposed metamaterial based detector has the potential of scanning through a range of axion masses as a tunable artificial plasma frequency can be attained by changing the wire spacing of metamaterial.
At Stockholm University, we are leading the experimental efforts for the Axion Longitudinal Plasma Haloscope (ALPHA) Consortium. Motivated by the design for resonator cavity by Rustam et al. (2022), we have designed, manufactured and studied different types of resonators that can be easily assembled and disassembled unlike the earlier designs, with plasma frequencies in the 10-20 GHz frequency range. We will share some of the promising results of the static smaller prototypes which have been optimized in terms of loss and quality factor of resonances and discuss future plans for developing a tunable prototype for axion detection.

Sektionen för elementarpartikel och astropartikelfysik / 129

DeepLearning in IceCube: challenges and prospects

Author: Thorsten Glüsenkamp[1]

[1] *Uppsala University*

Corresponding Author: thorsten.gluesenkamp@physics.uu.se

IceCube is a cubic-kilometre high-energy neutrino observatory at the South Pole. By now, it has accumulated more than 10 years of data and has started the field of high-energy neutrino astronomy with the detection of diffuse astrophysical neutrinos and evidence for a few point sources. While more data is still taken, the existing 10+ years of data is also constantly re-analyzed with better analysis techniques. However, because of data complexity and systematic uncertanties, classical statistical methods have reached their limit in extracting information. Recently, deep learning techniques have been shown outperform in various areas of reconstruction, and we highlight challenges and prospects of these new tools with some examples.

Sektionen för elementarpartikel och astropartikelfysik / 80

Refining the IceCube detector geometry using muon and LED calibration data

Author: Matti Jansson[1]

[1] *Stockholm University*

Corresponding Author: matti.jansson@fysik.su.se

The IceCube Neutrino Observatory deployed 5160 digital optical modules (DOMs) on 86 cables, called strings, in a cubic kilometer of deep glacial ice below the geographic South Pole. These record the Cherenkov light of passing charged particles, for example muons from cosmic rays or created by neutrinos. Knowledge of the DOM positions is vital for event reconstruction. While vertical positions have been calibrated, previous geometry calibration methods have been unable to measure horizontal deviations from the surface positions, largely due to degeneracies with ice model uncertainties. Thus the lateral position of the surface position of each hole is to-date used as the lateral position of all DOMs on a given string. With the recent advances in ice modeling, two new in-situ measurements have now been undertaken. Using a large sample of muon tracks, the individual positions of all DOMs on a number of strings around the center of the detector have been fitted. Verifying the results against LED calibration data shows that the string-average corrections improve detector modeling. Directly fitting string-average geometry corrections for the full array using LED data agrees with the average corrections as derived from muons where available. The per-DOM position determinations are currently systematics dominated, but work is ongoing to improve muon track reconstruction using the latest knowledge about the ice properties.

Sektionen för elementarpartikel och astropartikelfysik / 58

Responding to astrophysical alerts with the IceCube MeV neutrino data stream

Author: Nora Valtonen-Mattila[1]

[1] *Uppsala University*

Corresponding Author: nora.valtonen@physics.uu.se

The IceCube Neutrino Observatory is uniquely sensitive to MeV neutrinos emitted during a core-collapse supernova, with potential applications beyond supernova neutrino bursts. In this talk, we describe a fast response analysis that can be used to respond to external alerts, such as those from the Ligo-Virgo-Kagra detector for gravitational waves. Additionally, we will discuss the implementation of rate analysis for the search for MeV neutrinos coincident with GRB 221009A to demonstrate the versatility of this low-energy data stream.

Sektionen för elementarpartikel och astropartikelfysik / 70

The Future Circular Collider (FCC) at CERN

Author: Rebeca Gonzalez Suarez[1]

[1] *Uppsala University (SE)*

Corresponding Author: rebeca.gonzalez.suarez@physics.uu.se

With the LHC Run-3 currently underway, the global high energy physics community is actively working to define the future of collider particle physics. The European Strategy for Particle Physics has identified an e+e- Higgs factory as its top priority and the first step towards a future hadron collider with very high energy. To address these goals, a staged Future Circular Collider (FCC) is being proposed at CERN.

The FCC will consist of an electron-positron collider (FCC-ee), followed by an energy-frontier hadron collider (FCC-hh). The first stage will enable the precise study of Z, W, Higgs, and top quarks, and promises unparalleled sensitivity to detecting new physics. What's more, much of the infrastructure from the FCC-ee will be reused for the subsequent hadron collider, FCC-hh.

As the last running period before the High-Luminosity LHC, LHC Run-3 is a critical time for the high energy physics community to ramp up efforts to define the future of collider particle physics. The FCC is a promising proposal that could help unlock new insights into the fundamental nature of the universe.

Sektionen för elementarpartikel och astropartikelfysik / 83

Long-lived particles from exotic Higgs decays at FCC-ee

Author: Magdalena Vande Voorde[None]

Co-authors: Giulia Ripellino [1]; Rebeca Gonzalez Suarez [2]

[1] *KTH*

[2] *Uppsala University (SE)*

Corresponding Author: mavv@kth.se

The Future Circular Collider (FCC) is a proposed new accelerator at CERN, designed to operate in a 90 km tunnel and to run with an integrated program. The first stage, FCC-ee, will be an electron-positron collider serving as a Higgs, electroweak, and top factory at the intensity frontier. In addition to the great possibility at FCC-ee to test the Standard Model to high precision, it also has the potential to discover physics beyond the Standard Model. One such opportunity for new observations will be from direct searches for long-lived particles with decay lengths that are resolvable in the detector. These distinct experimental signatures will provide unique sensitivity to well-motivated new physics. This talk (or poster) will present a study of long-lived particles from exotic decays of the Higgs boson and its experimental signature with displaced vertices at FCC-ee.

Sektionen för elementarpartikel och astropartikelfysik

ELPA Poster Contributions

Sektionen för elementarpartikel och astropartikelfysik / 132

The ABC of RPV : Small Couplings at the LHC

Authors: Dominik Köhler[1]; Herbi Dreiner[1]; Javier Montejo Berlingen[2]; Nadja Strobbe[3]; Saurabh Nangia[1]; Víctor Martín Lozano[4]; Yong Sheng Koay[5]

[1] *University of Bonn*

[2] *Universitat Autònoma de Barcelona*

[3] *University of Minnesota*

[4] *Universitat de València*

[5] *Uppsala University*

Corresponding Author: yongsheng.koay@physics.uu.se

We investigate the phenomenology of the R-Parity Violating MSSM (RPV-MSSM) for the case of small RPV couplings. For the first time in the literature, we provide a general and model-independent treatment of its phenomenology at the LHC. We have compiled a minimal set of searches that provide complete coverage at the LHC, and we call this the “RPV Dictionary”. We also developed ABC-RPV, a program package that allows users to identify all possible LSP scenarios, RPV coupling configurations and decay chains that can give rise to an user-input collider signature and vice versa. We also provide an update on the current coverage of the RPV-MSSM at the LHC.

Sektionen för elementarpartikel och astropartikelfysik / 94

Towards a Kalman Filter-based alignment solver for ATLAS

Author: Lara Calic[1]

[1] *Lund University*

Corresponding Author: lara.calic@hep.lu.se

In high energy physics (HEP), accurately reconstructing charged particle trajectories is a challenging task. The classical Kalman filter estimates track parameters with uncertainties through prediction, filter, and smoother steps. Precisely aligning detector components increases sensitivity to new physics and improves particle identification efficiency. The ATLAS alignment solver requires input information from the Kalman Filter. This project aims to implement a Kalman Filter-based alignment strategy for the larger structures that will group individual sensors in the ATLAS tracking framework to align the Inner Tracking Detector (ITk).

Sektionen för elementarpartikel och astropartikelfysik / 64

Kaons in LDMX - Validation of Simulation

Author: Lisa Andersson Loman[1]

[1] *Lund University*

Corresponding Author: li2345lo-s@student.lu.se

Dark matter is one of our universe's greatest mysteries and very little is known about what it is. One of the dominating theories, that dark matter originates from an early universe thermal relic, indicates that it interacts with the Standard Model. If this is the case, dark matter can be produced at accelerators. The Light Dark Matter eXperiment, LDMX, is an upcoming experiment that will join the search for dark matter in the 1 to several 100 MeV mass range.

LDMX aims to detect dark matter indirectly by searching for missing momentum signals. To be able to see the signal it is important to filter out all the background. Previous studies have shown a limiting background with a very low nominal rate. It has been found that kaons, especially charged ones are the most difficult to filter out since the trace they leave in the LDMX detector resembles the signal. To study this in more detail, we would like to have more statistics. By manipulating simulations to artificially increase the rate of photo-nuclear processes producing kaons we have achieved this. However, we need to check if we also introduce other changes or unphysical behavior with this modification. Once these validations are performed, a veto strategy can be developed and optimized to reach the zero background goal of LDMX.

This contribution will present a study of the kaons produced in simulations where the kaon production is artificially enhanced.

Sektionen för elementarpartikel och astropartikelfysik / 72

Commissioning of The Cold Box, the environmental chamber designed to test the new ATLAS Inner Tracker system modules.

Author: Eduardo Torres Reoyo[1]

[1] *Student*

Corresponding Author: torresreoyo@gmail.com

The High Luminosity-Large Hadron Collider (HL-LHC) will reach an approximate pile-up of 200 collisions per bunch crossing, ten times more than the current Large Hadron Collider. Beginning operation at the end of the decade, it will accumulate 3000 fb-1, increasing the chances of observing new processes and allowing measurement of rare processes with higher precision. Moreover, the pile-up increase means more particle production, causing higher radiation damage and detector occupancy conditions. Therefore, the current tracking system in the ATLAS detector will be replaced by the new Inner Tracker system (ITk). ITk is based on silicon detectors, composed of individual sensors and readout electronics called modules. This project concerns testing the module's electrical response to repeated thermal cycling. To perform the tests, a controllable environmental chamber is under construction, The Cold Box.

Sektionen för elementarpartikel och astropartikelfysik / 88

Pulse shape fitting in LDMX hadronic calorimeter readout electronics

Author: Aksel Mihaylov[1]

[1] *Lund University*

Corresponding Author: aksel.draguanov_mihaylov.7126@student.lu.se

The universe shows signs of containing some invisible matter, known as dark matter. There are many possible constituents for dark matter, one such being light dark matter which would interact with ordinary matter through a new mediator force and have masses in the range of a few MeV to GeV. The light dark matter mass range is largely unexplored experimentally. The Light Dark Matter eXperiment, LDMX, is a proposed experiment using an electron beam incident on a tungsten target to produce dark matter. LDMX consists of trackers and calorimeters capable of fully reconstructing both the incident and recoil electrons' momentum and energy. The signature for dark matter production is a scattered electron with missing momentum. The hadronic calorimeter is responsible for detecting neutral particles, vetoing events that would otherwise mimic the signal signature in the trackers and electromagnetic calorimeter. This project focuses on characterizing the pulse shapes registered in the hadronic calorimeter's read-out electronics, using precise calibration pulses.

Sektionen för elementarpartikel och astropartikelfysik / 127

Deep Learning Based Event Reconstruction for the IceCube-Gen2 Radio Detector

Author: Nils Heyer[1]

Co-authors: Christian Glaser [1]; Thorsten Glüsenkamp [1]

[1] *Uppsala University*

Corresponding Author: nils.heyer@physics.uu.se

The planned in-ice radio array of IceCube-Gen2 at the South Pole will provide unprecedented sensitivity to ultra-high-energy (UHE) neutrinos in the EeV range. The ability of the detector to measure the neutrino's energy, direction, and flavor is of crucial importance. This contribution presents an end-to-end reconstruction of all these quantities for both detector components of the hybrid radio array ('shallow' and 'deep') using deep neural networks (DNNs). We are able to predict the neutrino direction precisely for all event topologies, including the electron neutrino charged-current ($_e$-CC) interactions, which are more complex due to the LPM effect. This highlights the advantages of DNNs for modeling the complex correlations in radio detector data, thereby enabling a measurement of the neutrino energy and direction. We discuss how we can use normalizing flows to predict the PDF for each individual event which allows modeling the complex non-Gaussian uncertainty contours of the reconstructed neutrino direction. Finally, we discuss how this work can be used to further optimize the detector layout to improve its reconstruction performance.

Sektionen för elementarpartikel och astropartikelfysik / 122

Neutron Veto Inefficiency Studies with FLUKA for the LDMX Hadronic Calorimeter

Author: Jaida Raffelsberger[1]

[1] *Lund University*

Corresponding Author: jaida_helena.raffelsberger.2355@student.lu.se

The Light Dark Matter eXperiment (LDMX) is a planned fixed-target missing-momentum experiment being designed with unique sensitivity for the largely experimentally unexplored MeV-GeV mass range for light dark matter. A key challenge for LDMX is its efficiently at vetoing rare background events such as neutral hadrons stemming from photonuclear reactions in both the target and the setup itself. To achieve this, the experiment relies on a sampling Hadronic Calorimeter (HCal) consisting of alternating layers of polystyrene scintillator bars and steel absorber plates. This configuration is based on the Mu2e experiment's cosmic ray veto.

The current design of the HCal has been optimised based on detailed Geant4 simulations to ensure that the veto performance is sufficient, in particular for the relevant photo-nuclear backgrounds. In order to ensure that the requirements obtained from simulations are accurate, a comparative study of neutron veto inefficiency between Geant4 and FLUKA has been carried out for a simplified version of the LDMX HCal which this contribution will detail.

Sektionen för elementarpartikel och astropartikelfysik / 74

Application of Boosted Decision Trees in the ATLAS search for Dark Mesons

Author: Eva Mayer[1]

[1] *Uppsala University*

Corresponding Author: eva.mayer.7038@student.uu.se

The Dark Matter question is among the most fundamental unsolved problems of modern day physics. One possible candidate for Dark Matter are Dark Mesons, a type of Stealth Dark Matter. They are predicted by extending the Standard Model with a strongly coupled dark sector. Similar to quarks they appear in confined states like baryons and mesons. Their coupling to the Higgs field allows interaction with Standard Model particles that could lead to their production at the Large Hadron Collider at CERN and their indirect detection in the ATLAS experiment. For distinguishing between the signatures of processes involving Dark Mesons and already known Standard Model processes a set of variables describing the composition and kinematics of the final states are used. The information that is extracted from these variables can be exploited even more efficiently if used in combination with machine learning. Boosted Decision Trees can be trained to make elaborate tree-shaped systems of cuts that will concatenate the discriminating power of many variables into one single final variable. The extent to which this method can improve the ATLAS search for Dark Mesons is studied in this masters project.

Sektionen för elementarpartikel och astropartikelfysik / 61

Prospects for core-collapse supernova neutrino detection in IceCube-Gen2

Author: Jakob Beise[None]

Co-author: Erin O'Sullivan

Corresponding Author: jakob.beise@physics.uu.se

The IceCube Neutrino Observatory has full sensitivity for core-collapse supernovae within the Milky Way and model-dependent sensitivity for the Large and Small Magellanic clouds. The upcoming extension of IceCube, IceCube-Gen2, offers the opportunity to implement new trigger and sensor concepts promising to improve IceCube's CCSNe sensitivity. Coincidence triggers on the one hand allow us to lower the noise rate in the measurement, pushing IceCube's sensitivity horizon further out and thereby extending its reach. Wavelength-shifting sensors on the other hand capture more signal photons due to the increased light collection and a comparably low sensor noise low. This is particularly of interest when studying the light curve nearby CCSNe with high statistics giving valuable insights into the dynamics of CCSNe. In this poster I will show what the prospects of these techniques in IceCube-Gen2 mean for the detection of CCSNe.

Sektionen för elementarpartikel och astropartikelfysik / 65

Machine learning based compression for scientific data

Authors: Alexander Ekman[1]; Axel Gallén[1]

[1] *Lund University (SE)*

Corresponding Authors: alexander.ekman@hep.lu.se, axel.gallen.6264@student.lu.se

One common issue in vastly different fields of research and industry is the ever-increasing need for more data storage. With experiments taking more complex data at higher rates, the data recorded is quickly outgrowing the storage capabilities. This issue is very prominent in LHC experiments such as ATLAS where in five years the resources needed are expected to be many times larger than the storage available (assuming a flat budget model and current technology trends) 1. Since the data formats used are already highly compressed, storage constraints could require more drastic measures such as lossy compression, where some data accuracy is lost during the compression process.

In our work, following from a number of undergraduate projects [2,3,4,5,6,7], we have developed an interdisciplinary open-source tool for machine learning-based lossy compression. The tool utilizes an autoencoder neural network, which is trained to compress and decompress data based on correlations between the different variables in the dataset. The process is lossy, meaning that the original data values and distributions cannot be reconstructed precisely. However, for certain variables and observables where the precision loss is tolerable, the high compression ratio allows for more data to be stored yielding greater statistical power.

The tool we have developed is called Baler and is available as an open source project [8][9].

1 - https://cerncourier.com/a/time-to-adapt-for-big-data/
[2] - http://lup.lub.lu.se/student-papers/record/9049610
[3] - http://lup.lub.lu.se/student-papers/record/9012882
[4] - http://lup.lub.lu.se/student-papers/record/9004751
[5] - http://lup.lub.lu.se/student-papers/record/9075881
[6] - https://zenodo.org/record/5482611#.Y3Yysy2l3Jz
[7] - https://zenodo.org/record/4012511#.Y3Yyny2l3Jz
[8] - https://zenodo.org/record/7817467#.ZED-65FBzmE
[9] - https://github.com/baler-collaboration/baler

Sektionen för elementarpartikel och astropartikelfysik / 151

ATLAS Inner Tracker Upgrade for HL-LHC: Silicon microstrip detector metrology

Author: Xiangyu Xu[1]

[1] *Lund University*

Corresponding Author: xiangyu.xu.1451@student.lu.se

The Large Hadron Collider (LHC) will be upgraded to the High-Luminosity LHC (HL-LHC) by the end of this decade, with five times larger luminosity and 200 inelastic collisions per proton-proton bunch crossing. Thus, the ATLAS detector is challenged to survive the stronger radiation and the increased particle flux. As a result, the new ATLAS Inner Tracker (ITk) will replace the current one with a new full-silicon microstrip detector. The new silicon microstrip detector required high precision during manufacturing and thus a metrology process is necessary, in which an optical zoom microscope with precise position measurement is used, and a post process program was created to handle the measuring results. Validation and tests are done in Lund, Uppsala and Copenhagen.

Sektionen för kärnfysik

Sektionen för kärnfysik / 144

artEmis - Awareness and resilience through European multi sensor system

Author: Ayse Nyberg[1]

[1] *KTH*

.

Sektionen för kärnfysik / 145

Correlated fast-neutron-gamma emission tomography for rapid localization of special nuclear materials in legacy waste drums

Author: Vivian Peters[1]

[1] *KTH*

.

Sektionen för kärnfysik / 119

Journey towards the understanding of the Hyperon-Hyperon interaction within the HADES experiment

Author: Gandharva Appagere[1]

[1] *Stockholm University*

Corresponding Author: gandharva.appagere@fysik.su.se

Hyperons are a class of baryons that contains one or more strange quark. The study of hyperons is motivated by several physics interests. One exciting example is the investigation of hyperon-hadron interactions which may provide clues to understand the strong interaction in composite quark bound states.

The
$boldsymbol\Lambda - \Lambda$ channel production and the ensuing study of interaction between both the Λ systems is expected to expand the knowledge on the role of strange particles in high-density systems like neutron stars and provide hints to unpack the 'hyperon puzzle. I. Vidaña, 2016'

The main subject of this talk is the double-Λ hyperon channel reconstruction [Eq. below] from the $p - p$ scattering data measured at HADES (High Acceptance Di-Electron Spectrometer) in march 2022 at GSI (GSI Helmholtz Centre for Heavy Ion Research (Gesellschaft für Schwerionenforschung)) HADES.
(1)

The production reaction consisted of a proton beam of kinetic energy 4.5 GeV impinging on an elongated Liquid H_2 HADES-FAIR Phase-0.

In this talk I will outline the relevant HADES detector subsystems essential for the double-Λ studies. I will also introduce the analysis steps to reconstruct the
$boldsymbol\Lambda - \Lambda$ pairs with a kinematic track fitting procedure J. Regina, 2021. I will show some preliminary results for the cross-section estimate and conclude with future work.

Sektionen för kärnfysik / 146

Machine learning algorithms for quantum mechanics

Authors: Adam Fredriksson[1]; Oskar Fallgren[1]

[1] *KTH*

.

Sektionen för kärnfysik / 147

Multilinear analysis of proton radioactivity systematics

Author: Mario Amaro[1]

[1] *KTH*

.

Sektionen för kärnfysik / 51

Underground radioactivity measurements in HADES

Author: Mikael Hult[1]

[1] *European Commission - Joint Research Centre*

Corresponding Author: mikael.ba.hult@gmail.com

The Joint Research Centre performs research and provides scientific advice to the European Commission as stipulated in the Euratom treaty. The radionuclide team at JRC-Geel (in the town Geel in Belgium) is involved in establishing international equivalence of radioactivity measurements and realising the unit Bq. To accomplish this work, there is a wide range of specially designed instruments. Some instruments are located in the 225 m deep underground laboratory HADES, which is also a laboratory open for users from the EU.
The presentation will show recent developments in HADES and describe projects linked to (i) development of radioactive reference materials, (ii) nuclear science applications of environmental radioactivity and (iii) support to fundamental physics experiments for neutrinoless double beta decay (GERDA and LEGEND)

Undervisningssektionen

Undervisningssektionen / **44**

Workshoppar om vindkraft och solenergi

Author: Vetenskapens Hus[1]

[1] *House of Science*

Vetenskapens Hus erbjudera 2 st parallella workshoppar (1 om vindkraft, 1 om solenergi) med ca 16 deltagare i varje, dvs 32 deltagare är aktiva.

För att ytterligare 32 deltagare ska kunna medverka så växlar grupper mellan föreläsning och workshoppar under förmiddagen.

Vindkraft
Vindkraft är en av de centrala pelarna i omställningen till ett hållbart samhälle. Men varifrån kommer energin och hur tar man tillvara den på bästa sätt? Den här aktiviteten ger en översikt av ett av våra viktigaste energislag. Ni får prova på delar av vårt skolprogram om vindkraft och vi diskuterar vilket lärande eleverna kan få ut ur den typen av övningar.

Solceller
Solceller kan bli en viktig del i omställningen av energisystemen i världen. Vi jämför olika typer av solceller och diskuterar hur de används och fungerar. Ni kommer att får utföra jämförande mätningar av effekten från några olika solceller. Vi diskuterar vilka övningar som är bäst för att öka elevernas förståelse för tekniken bakom solenergi.

Undervisningssektionen / **24**

Spel med höga insatser: DART och biljard i solsystemet

Author: Anders Eriksson[1]

[1] *Swedish Institute of Space Physics*

Den 26 september 2022 drämde rymdsonden DART rätt in i den lilla månen Dimorphos runt asteroiden Didymos. Denna förövning i att rädda jorden från ett hotande asteroidnedslag förlöpte till och med bättre än väntat – Dimorphos bana ändrades betydligt mer än man hoppats. Hur det kunde bli så? Och hur påverkar det våra möjligheter att puffa undan hotande asteroider? Är risken för sådana ens så stor att vi behöver bry oss?

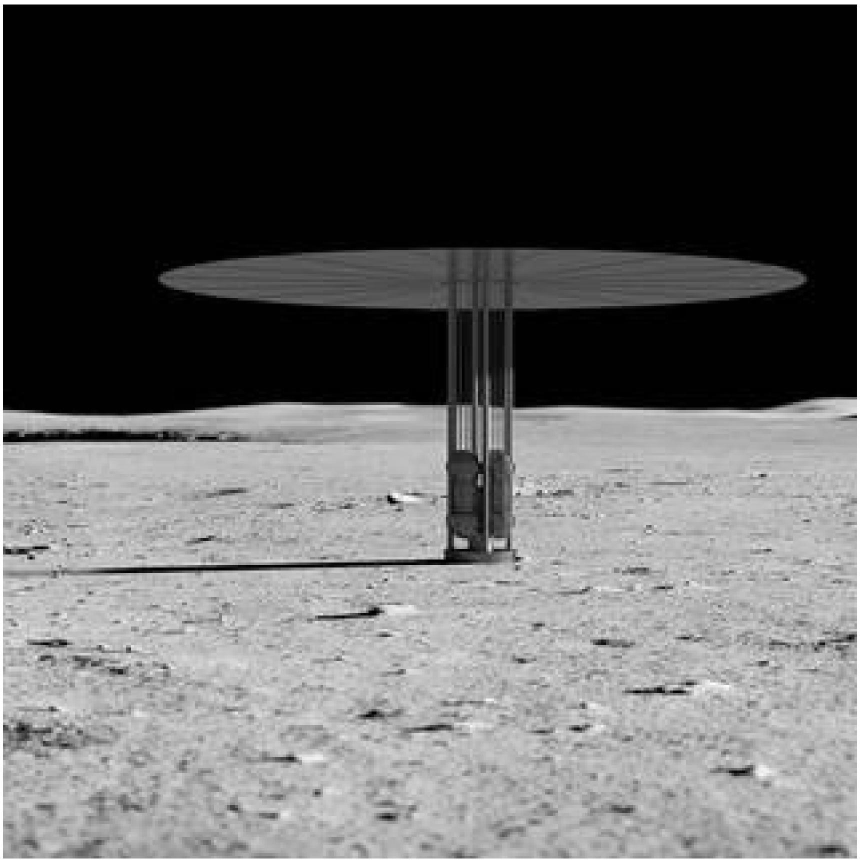
Undervisningssektionen / 136

Fjärde generationens kärnkraft – är det något att ha?

Author: Mattias Lantz[1]

[1] *Uppsala universitet*

På relativt kort tid har den svenska diskussionen om kärnkraft svängt från avveckling till behov av nya reaktorer. Begrepp som små modulära reaktorer (SMR) och fjärde generationens kärnkraft är vanligt förekommande. I den här presentationen reder vi ut vad det är för något, hur det skiljer sig från dagens kärnkraft, vad som är på gång, och några olika perspektiv på vad vi ska ha dem till.



KiloPower, en reaktor till elförsörjning på en framtida månbas. Bild: NASA

Undervisningssektionen / 49

Undervisningssektionen

Author: Hans Jakobsson[1]

[1] *Polhemskolan, Lund*

Presentation av vad undervisningssektionen gör samt mingel med mat.

Undervisningssektionen / 134

Workshop på Nobel Prize Museum – Banbrytande upptäckter

Authors: Paulina Wittung Åman[1]; Pontus Thunblad[1]; Ulf Larsson[1]

[1] *Nobel Prize Museum*

Corresponding Authors: paulina.wittung.aman@nobelprize.org, ulf.larsson@nobelprize.org

Under Nobelprisets första århundrade har en rad betydelsefulla vetenskapliga uppfinningar och upptäckter gjorts som på olika sätt förändrat vårt sätt att leva till exempel den moderna IT-tekniken, DNA-molekylens struktur och kärnklyvning. Vi tittar närmare på några av dessa inom fysikområdet och de tillämpningsområden de har idag. Vi prövar också Alfred Nobels motto om Nobelprisens ”nytta för mänskligheten” genom en duell mellan Nobelprisbelönade arbetena.

Vi samlas 8.45 den 16 juni vid Börshuset på Stortorget i Gamla stan i Stockholm. Efter besöket 9.00-11.00 går en buss 11.15 för de som ska medverka i besöket i Ytterby gruva.

Undervisningssektionen / 135

Ytterby gruva

Author: Eric Thorslund[1]

[1] *Föreningen Ytterby Gruva*

Corresponding Author: ericthorslund@telia.com

I ett stenbrott på Resarös östra udde i Vaxholms kommun påträffades för drygt 200 år sedan en tung svart sten. Detta skulle bli början till en makalös utveckling inom svensk kemisk forskning. 23 grundämnen identifierades, åtta av dessa i mineral från stenbrottet.

Under en guidad visning av gruvan, får vi en historisk exposé över gruvan användning och betydelse inom mineralogi under 1800-talet och dess militära betydelse under kalla kriget.

Notera att gummistövlar behövs för att nå de inre delarna av gruva.

Transport till och från gruvan sker med buss. Bussen går från Gamla Stan i Stockholm 11.15 den 16 juni och vi väntas vara åter i Stockholm senast 16.30.

Undervisningssektionen

UNDERV Poster Contributions

Undervisningssektionen / 79

The Sound of Physics at Ullevi Stadium

Authors: Javier Tello Marmolejo[1]; Sebastian Kilde Löfgren[1]

Co-author: Dag Hanstorp [1]

[1] *Department of Physics, University of Gothenburg*

Corresponding Authors: sebastian.kilde.lofgren@gu.se, javier.marmolejo@physics.gu.se

A common way to ground a theoretical physics concept is to learn about an experiment that showcases it. However, experiencing the concept from within is rare. This was recently done at Ullevi stadium, as part of Vetenskapsfestivalen with 400 middle school students, to illustrate the propagation of sound waves, the speed of sound, and wave interference. By reacting to sound prompts, students became data points of the sound wavefront or the interference pattern. Further, drones were used to film the experiments from above, displaying a bird's eye view of the phenomena live on a large TV screen. . This allowed the students to experience the experiments in multiple ways during the experiment and allowed their teachers to follow up using the recorded material in the classroom. Insights and learnings from this large-scale demonstration will be presented, along with reflections on similar classroom applications and the use of drones in physics education.