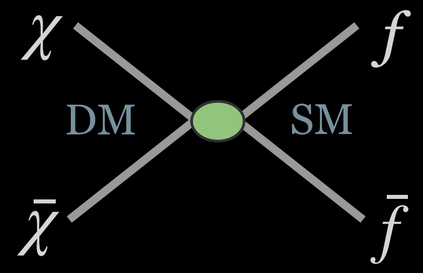
Status of the Light Dark Matter eXperiment

Lene Kristian Bryngemark, Lund University
Fysikdagarna 2023, Stockholm

LDMX

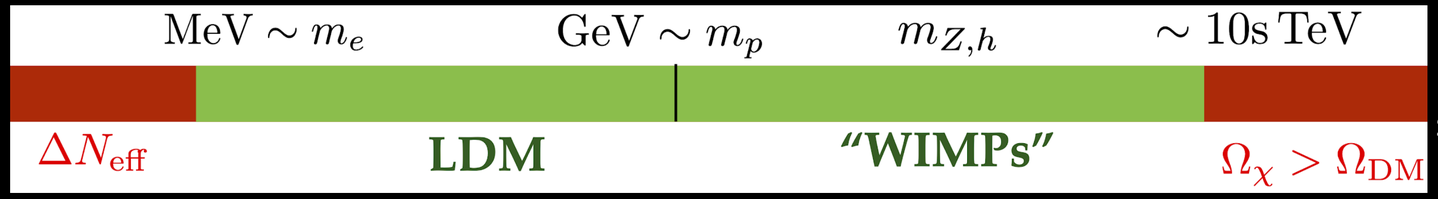
LUND UNIVERSITY

Thermal-relic dark matter: a predictive model



Is present-day dark matter a freeze-out relic from the hot early Universe?

- viable with minimal assumptions
  - observable → some minimum non-gravitational interaction
  - reaches thermal equilibrium at some point in history
- predicts a minimum interaction strength
  - experimental sensitivity target
- constrains the ~90 orders of mag. DM mass range
  - light mediator: non-SM force/dark sector



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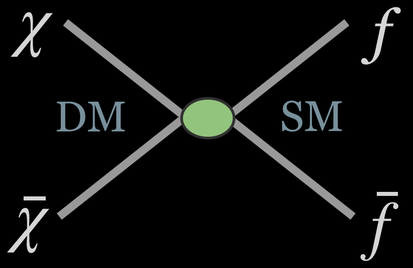

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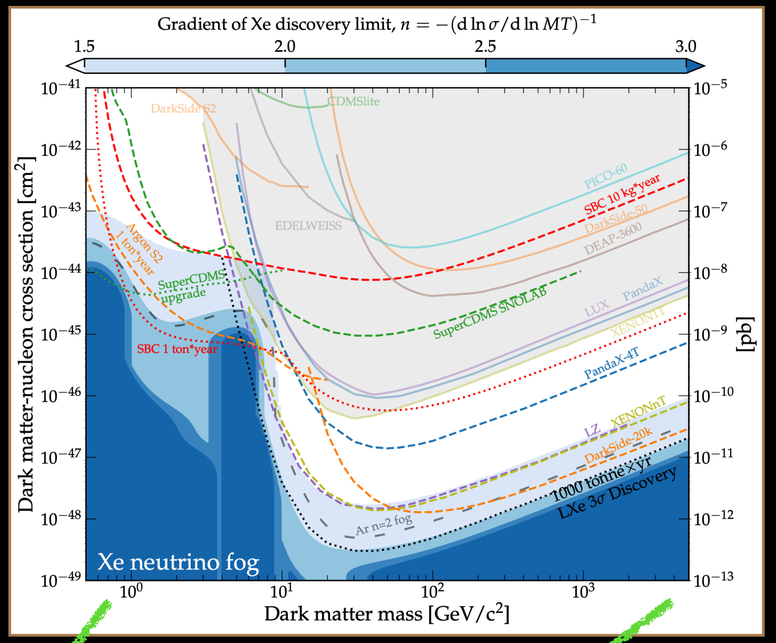

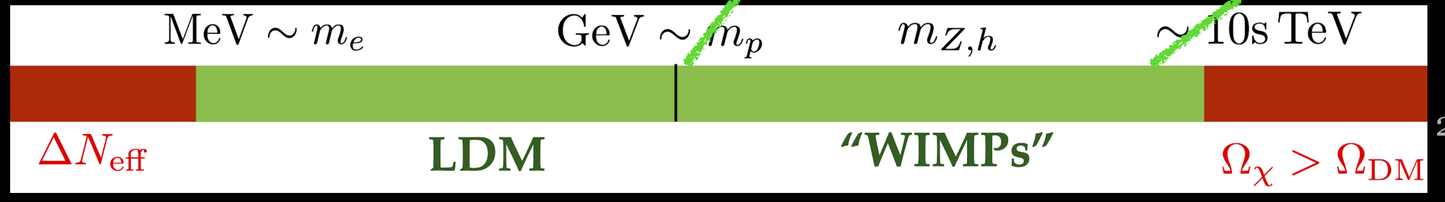

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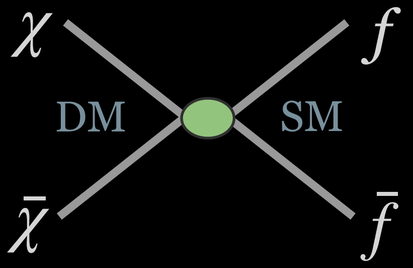

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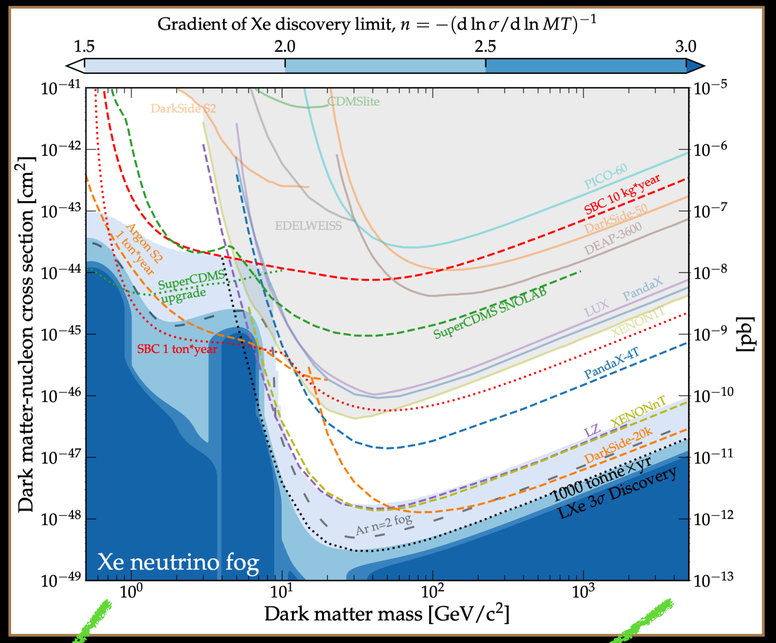
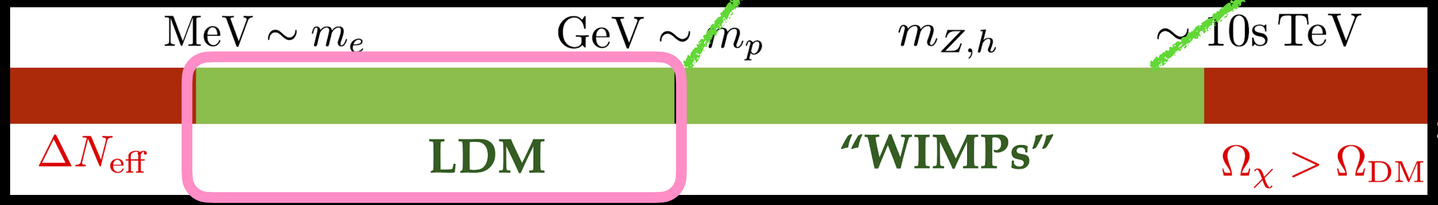
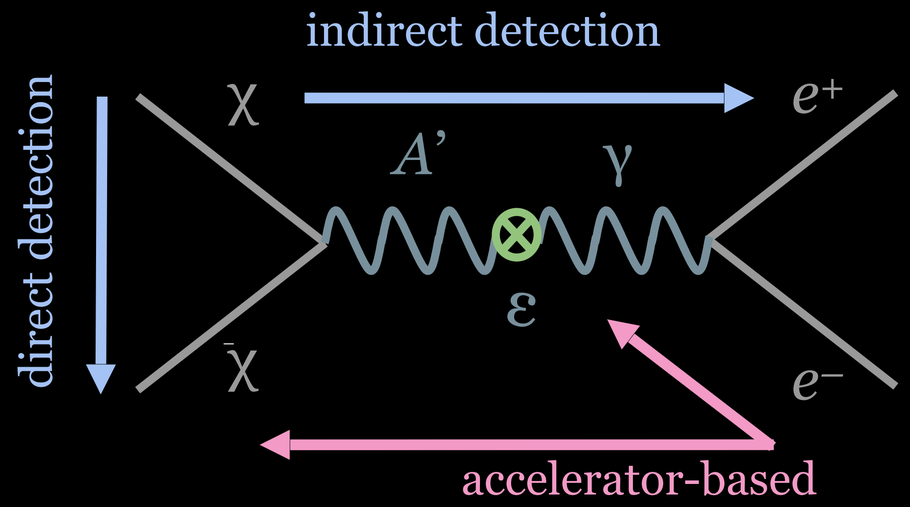


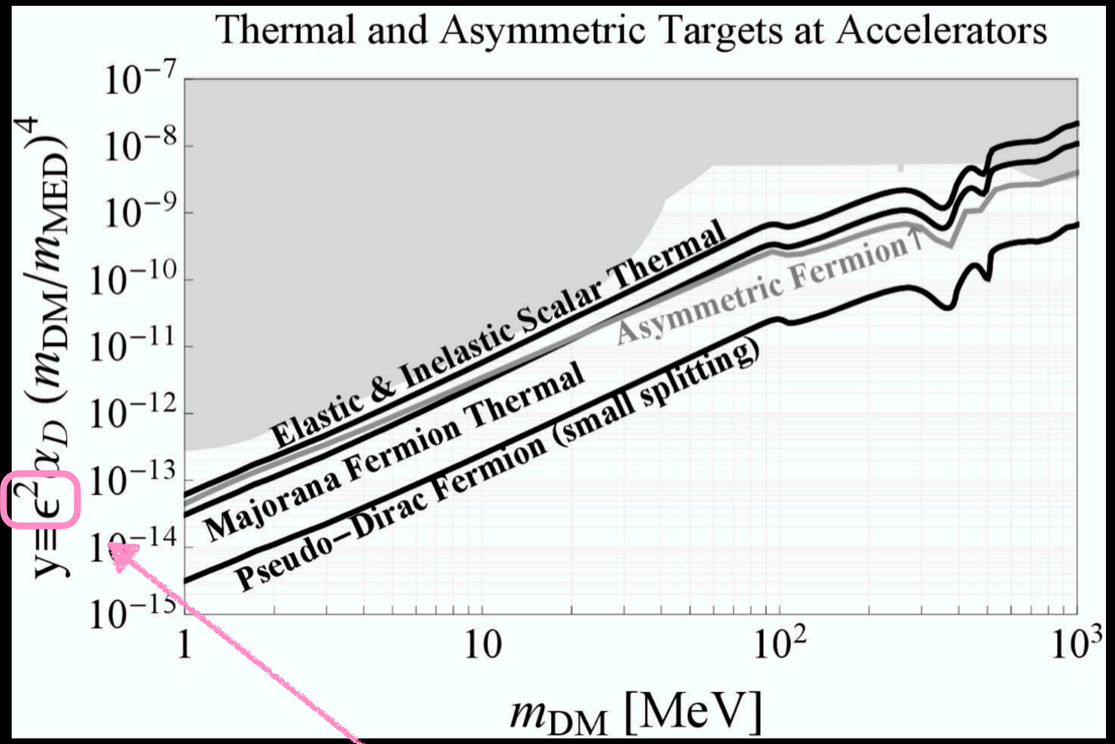


Dark sector light mediator: dark photons

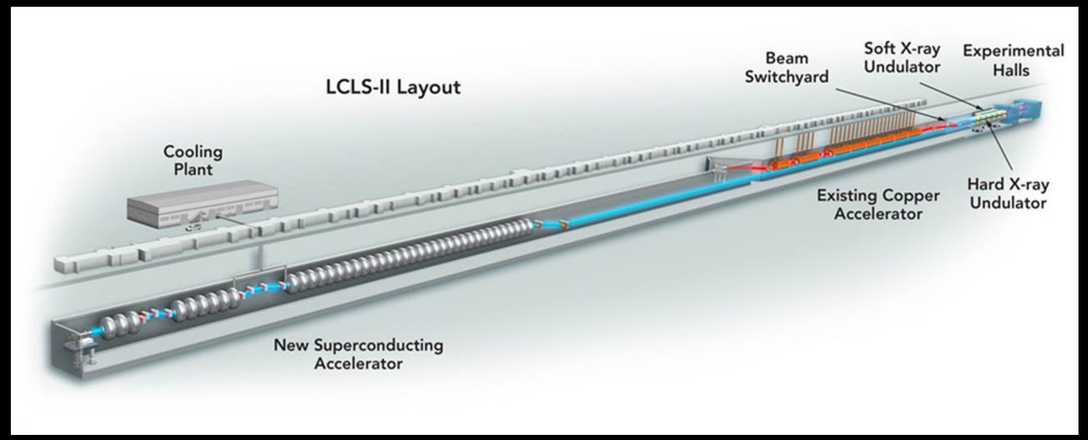
- “Simplest” possible dark sector extension
- dark QED + kinetic mixing (ε) = a feeble interaction with SM matter
- sub-GeV thermal prediction targets line up within reach at accelerators

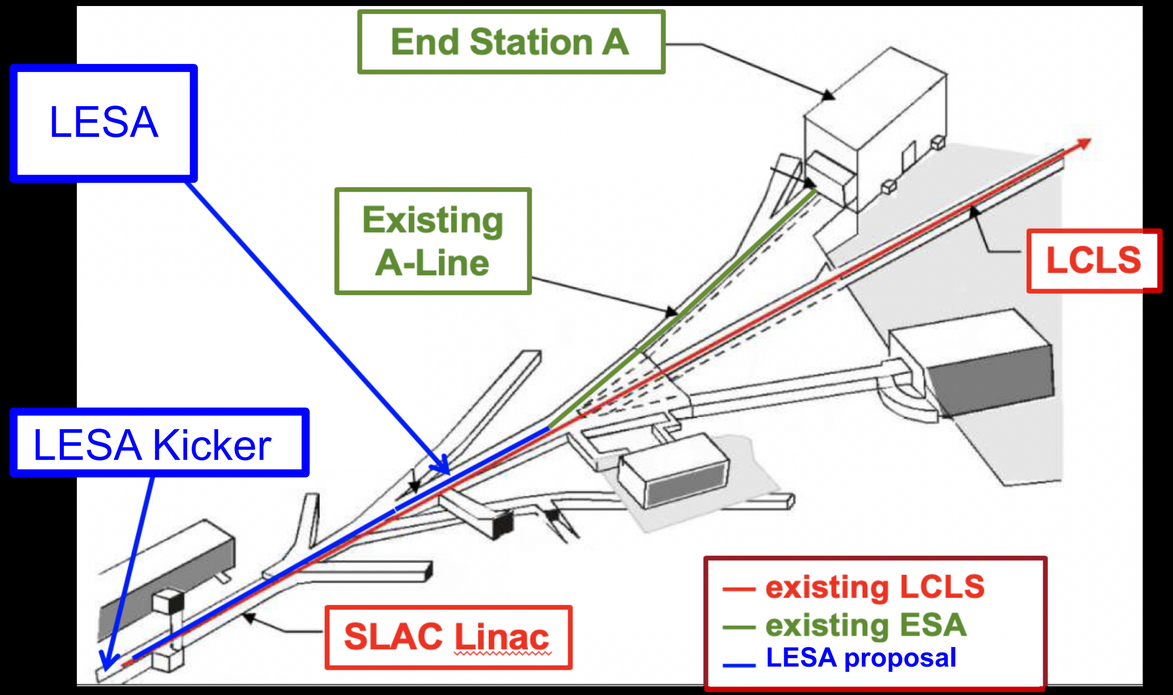


$\langle \sigma v \rangle \propto \varepsilon^2 \alpha_D$



GeV-scale electron beam at SLAC

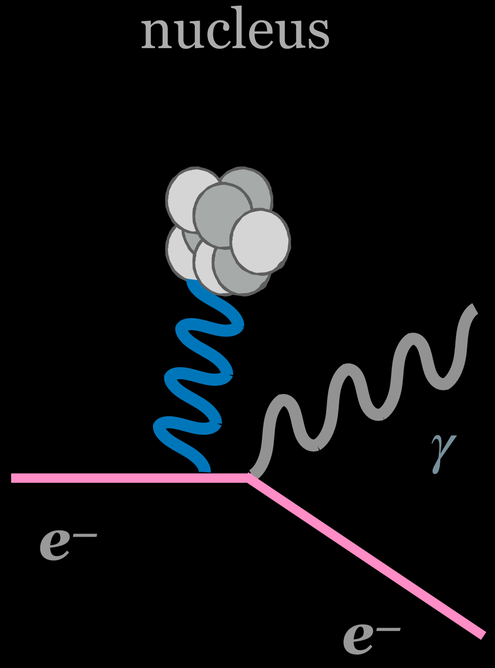




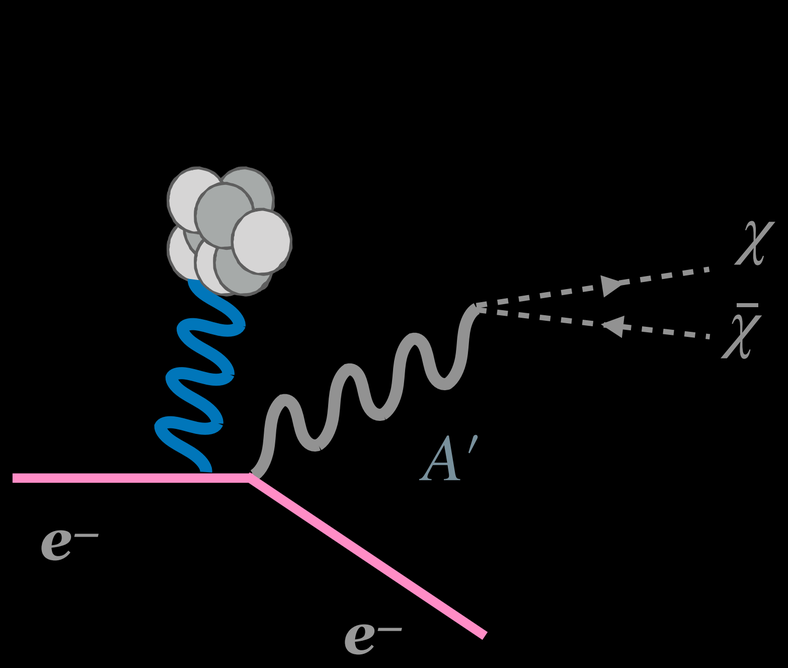
LCLS-2 beam at SLAC:

- main use: electron beam for photon science
  - steal some via Linac to End Station A (LESA)
- upgrade: 4→8 GeV beam energy
- low-current
  - measure each incoming and outgoing electron
- fast repetition rate
  - expect 37.1 MHz bucket frequency
  - and ~10^{14} electrons on target in 1-2 years

With an electron beam



SM (QED) bremsstrahlung

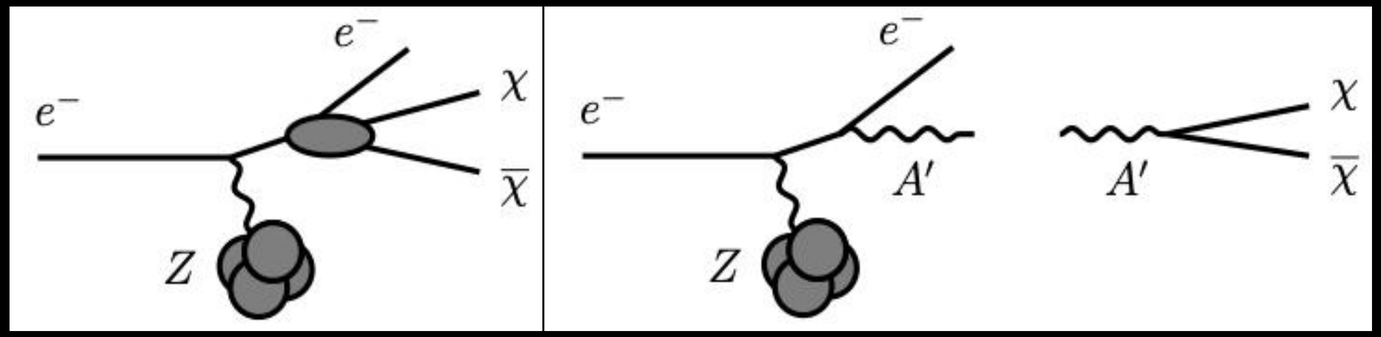


Dark photon bremsstrahlung

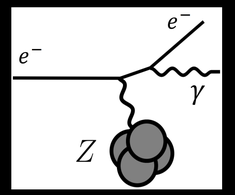
A' production $\propto \varepsilon^2$, DM subsequent decay to SM $\propto \varepsilon^4$

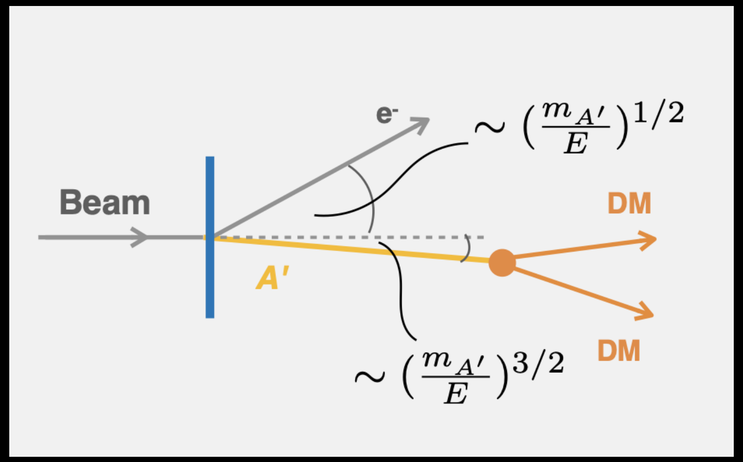
LDMX: a fixed-target missing momentum experiment

LDMX focuses on *escaping* dark matter:



c.f. SM process: photon bremsstrahlung





- massive dark photon (*A'*) bremsstrahlung in thin target
- agnostic when it comes to (invisible) fate of the *A'*
  - notice that energy goes missing
- strategy: make "all" SM backgrounds appear in detector
  - veto everything but low-activity events

Massive photon → momentum kick; missing *momentum* experiment

More detail: A high efficiency photon veto for the Light Dark Matter eXperiment, JHEP04 (2020) 003

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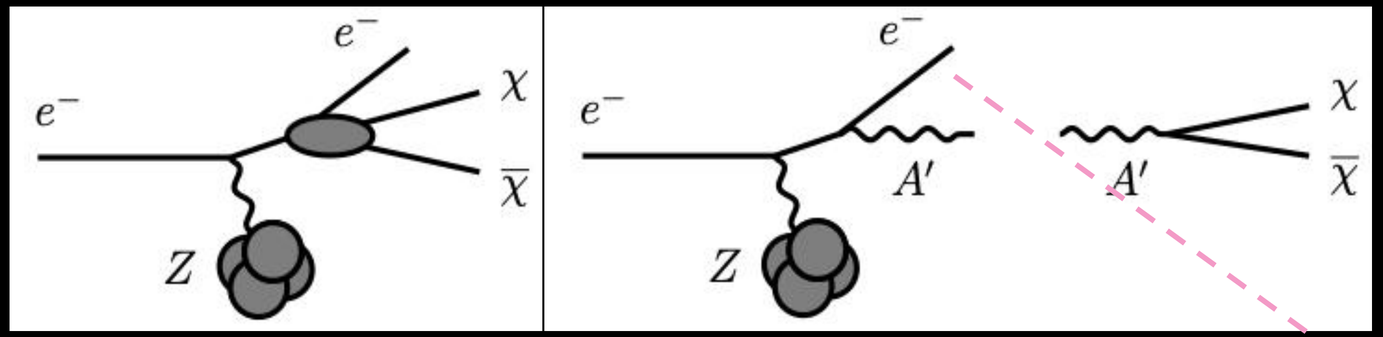

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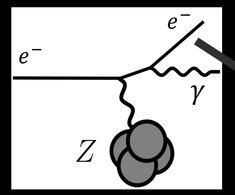

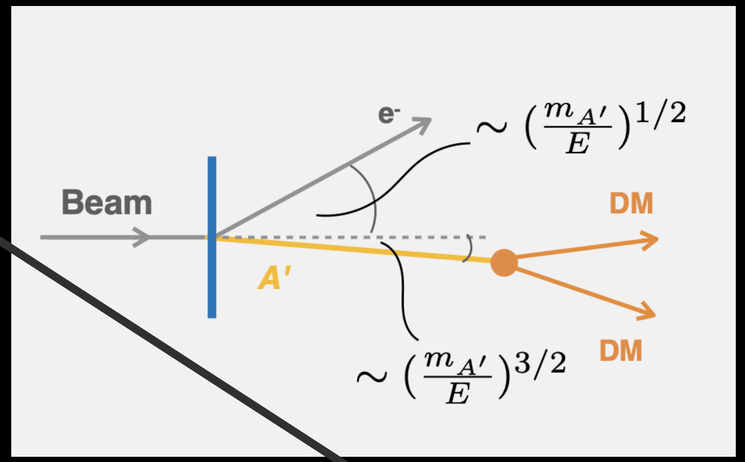

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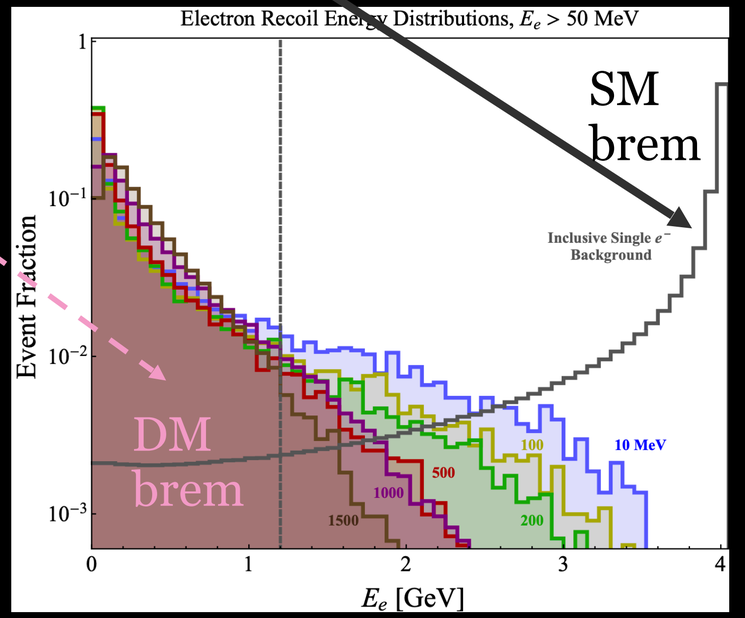

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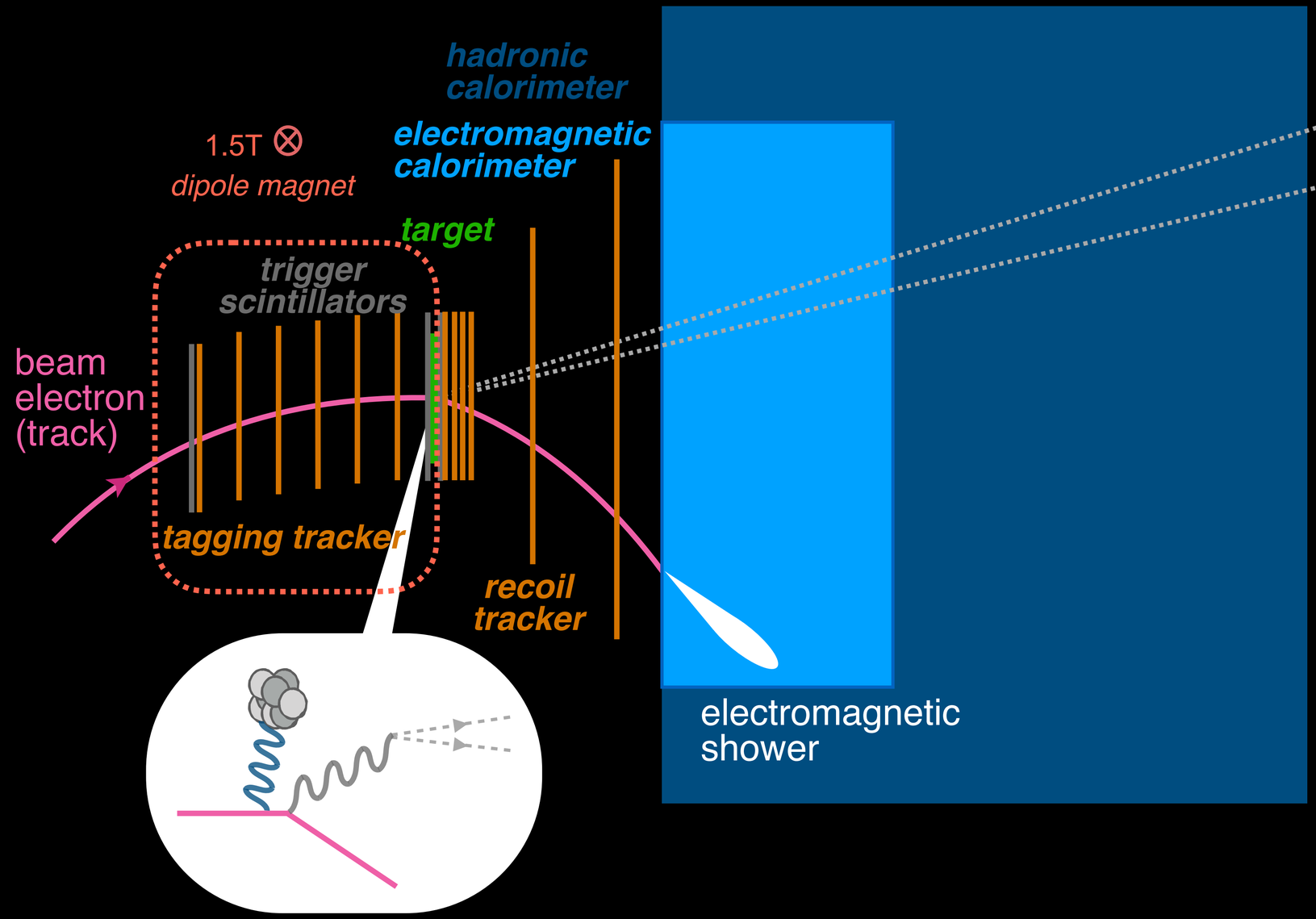
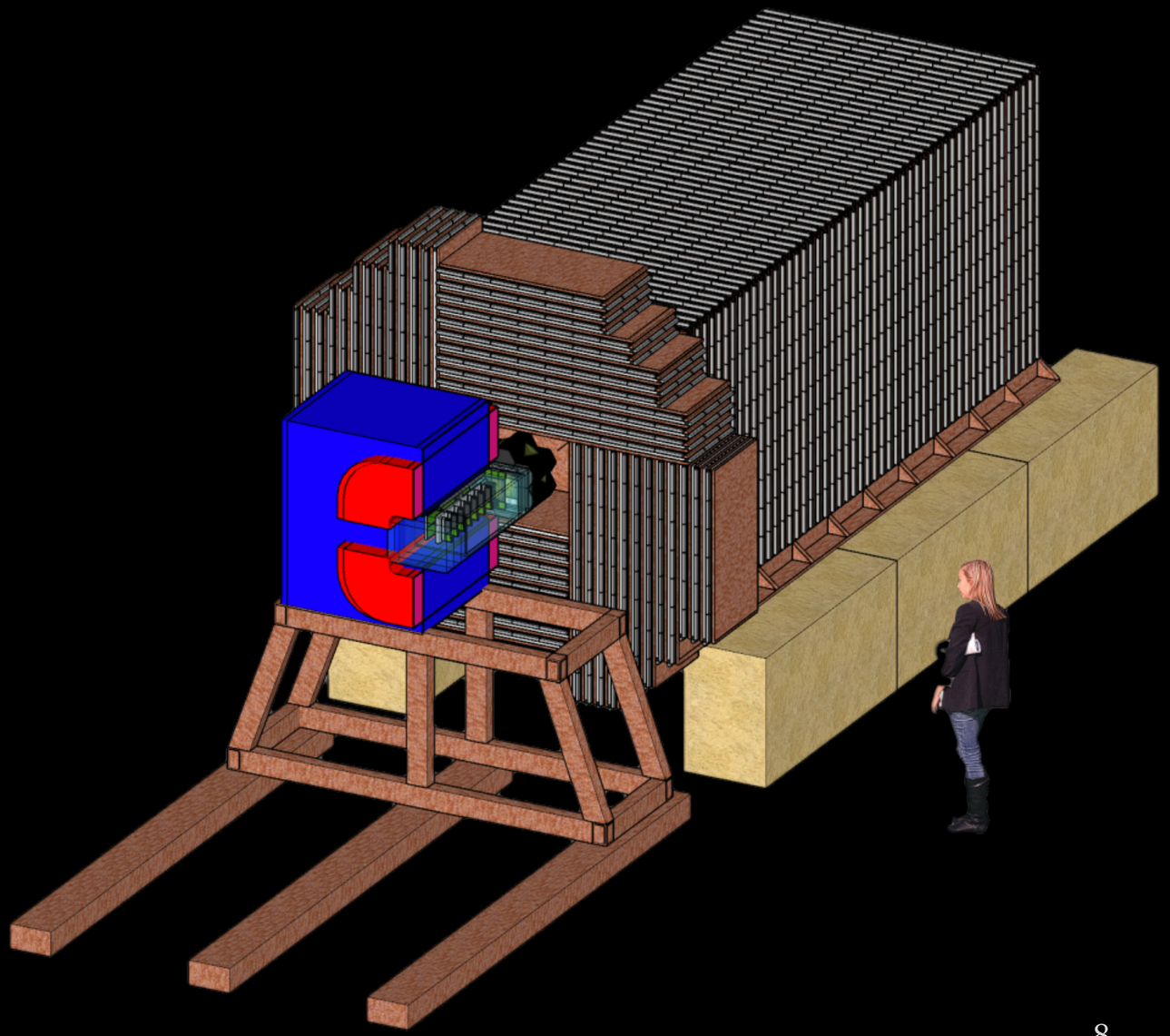
LDMX detector concept

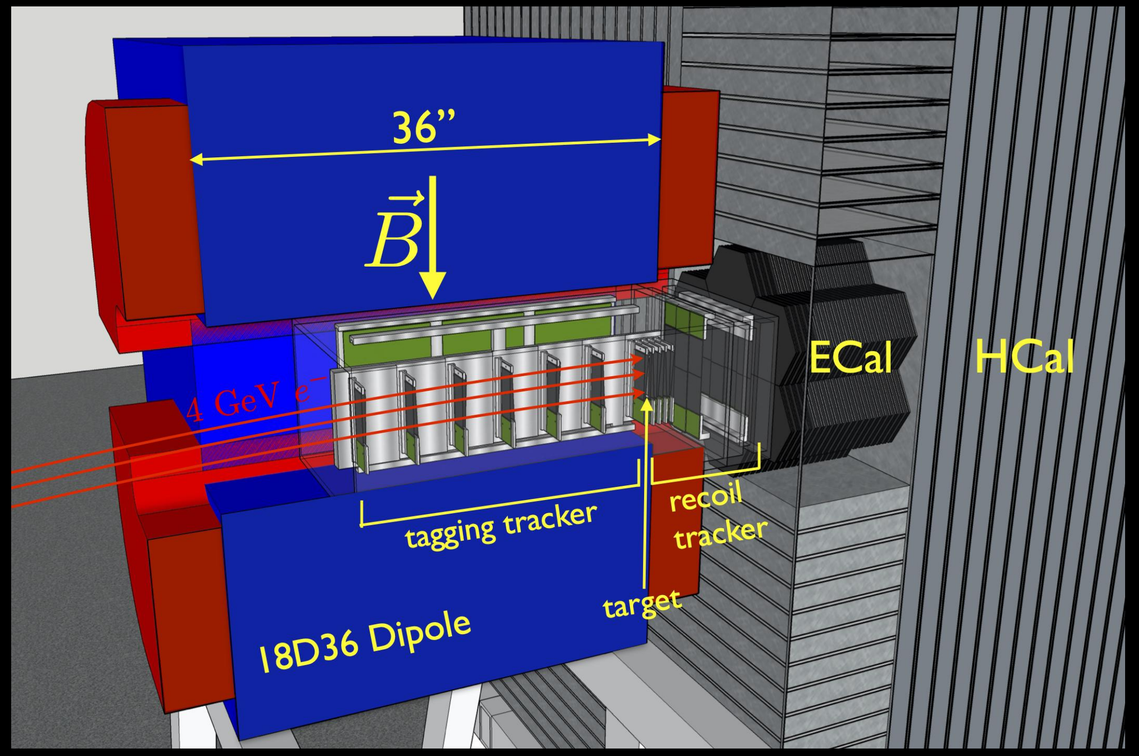
Signal cartoon



- 0.1 X_0 W target
- Measure (missing) energy in calorimeters, momentum in recoil tracker

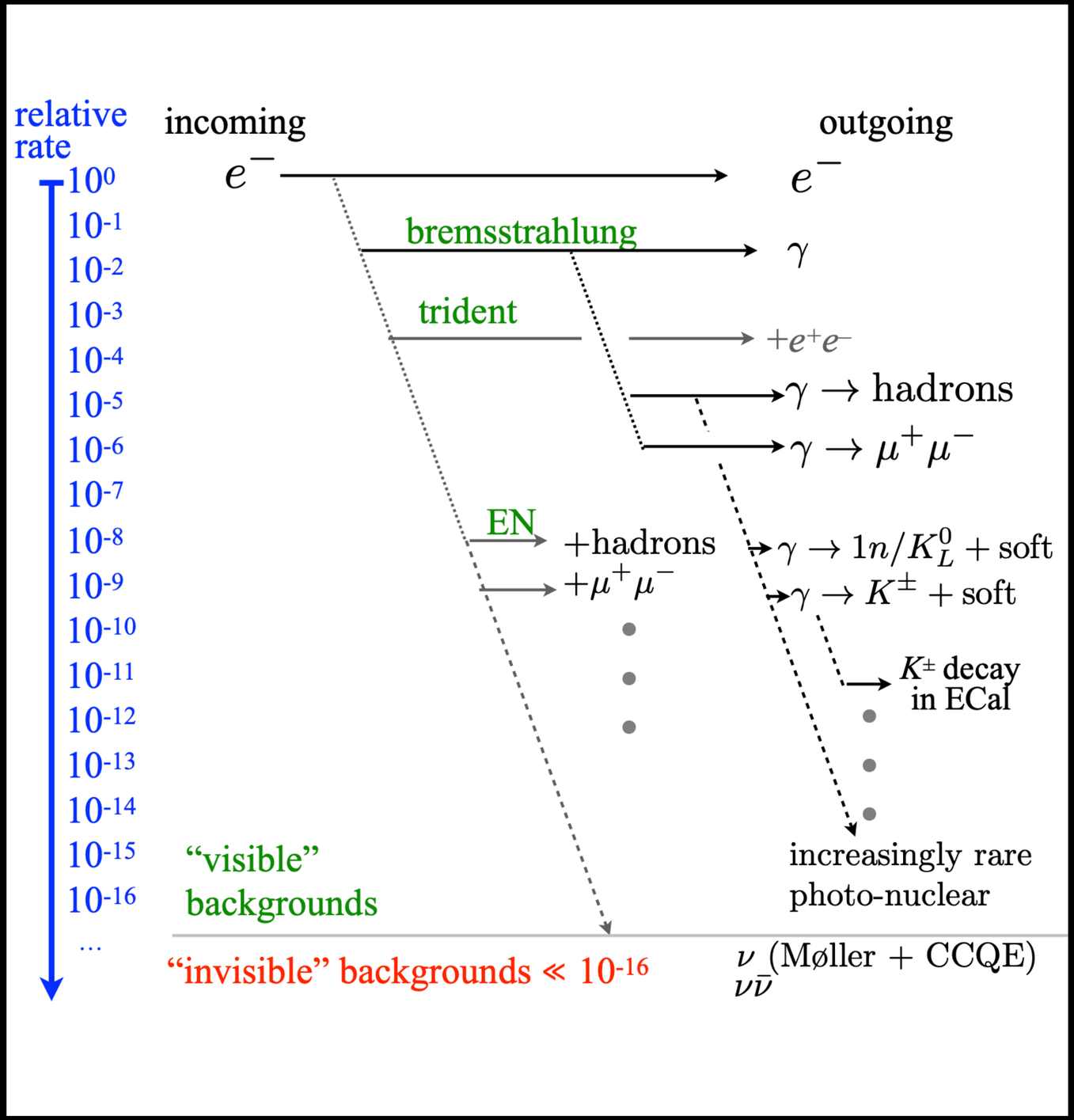
or more specifically





Backgrounds

shaping the requirements on the detector



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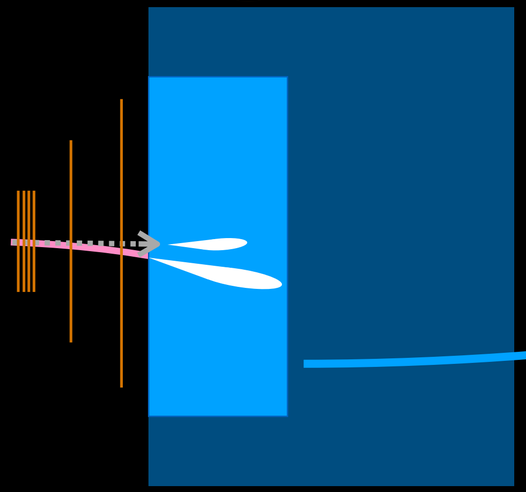

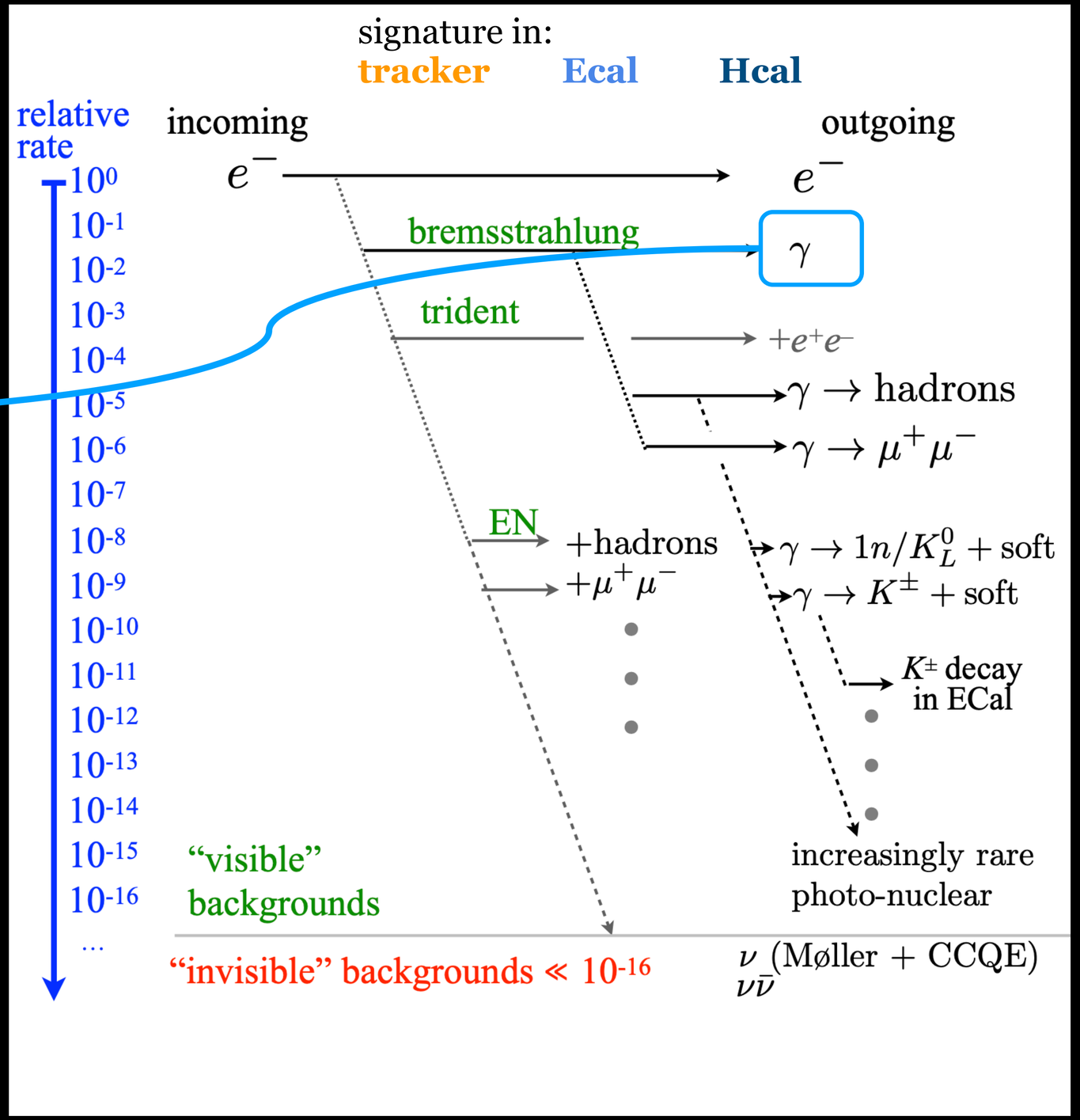

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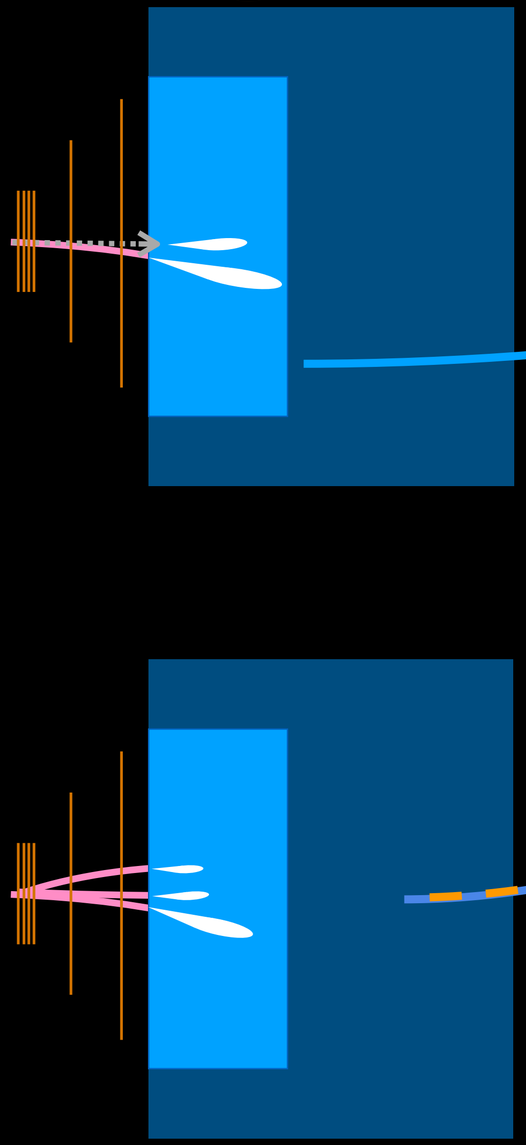


signature in:
tracker Ecal Hcal

relative rate

10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^{-11}
10^{-12}
10^{-13}
10^{-14}
10^{-15}
10^{-16}
…

incoming e^- → outgoing e^-

bremsstrahlung → γ

trident → $+e^+e^-$

$\gamma \to$ hadrons

$\gamma \to \mu^+\mu^-$

EN → +hadrons

$+\mu^+\mu^-$

$\gamma \to 1n/K_L^0 + \text{soft}$

$\gamma \to K^\pm + \text{soft}$

$K^\pm$ decay in ECal

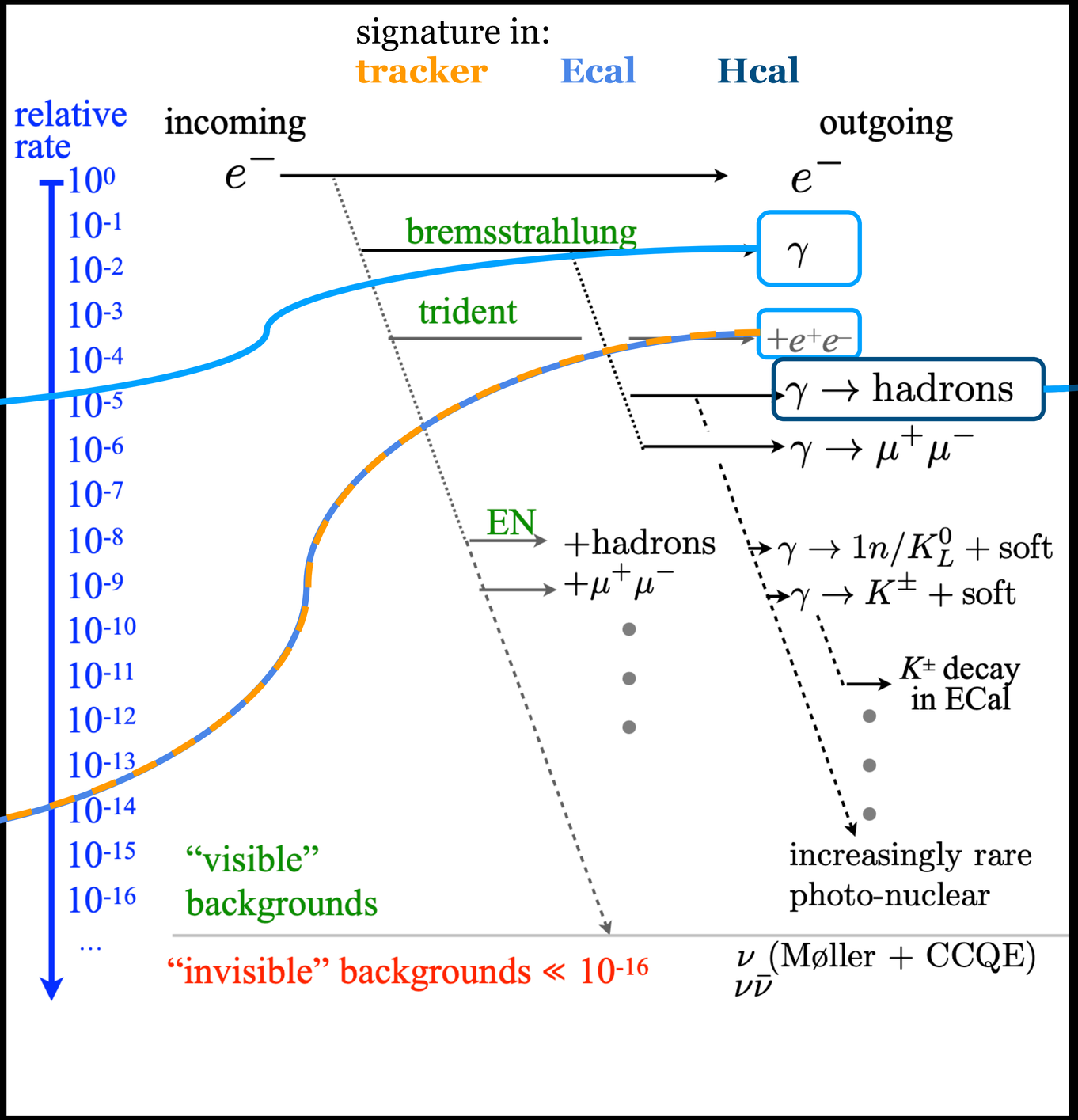
increasingly rare photo-nuclear

"visible" backgrounds

"invisible" backgrounds ≪ 10^{-16}

$\nu\bar{\nu}$ (Møller + CCQE)

Backgrounds



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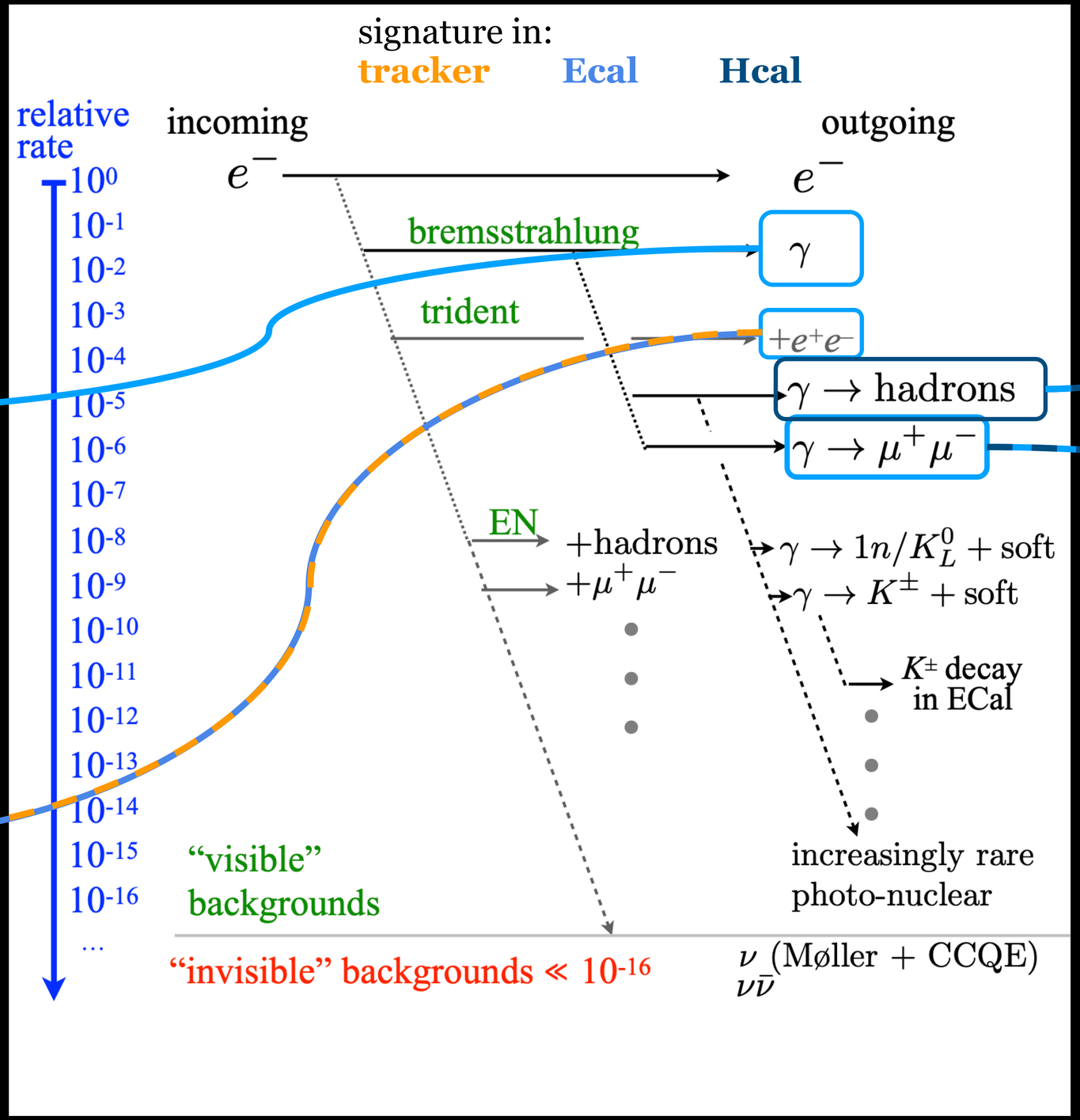

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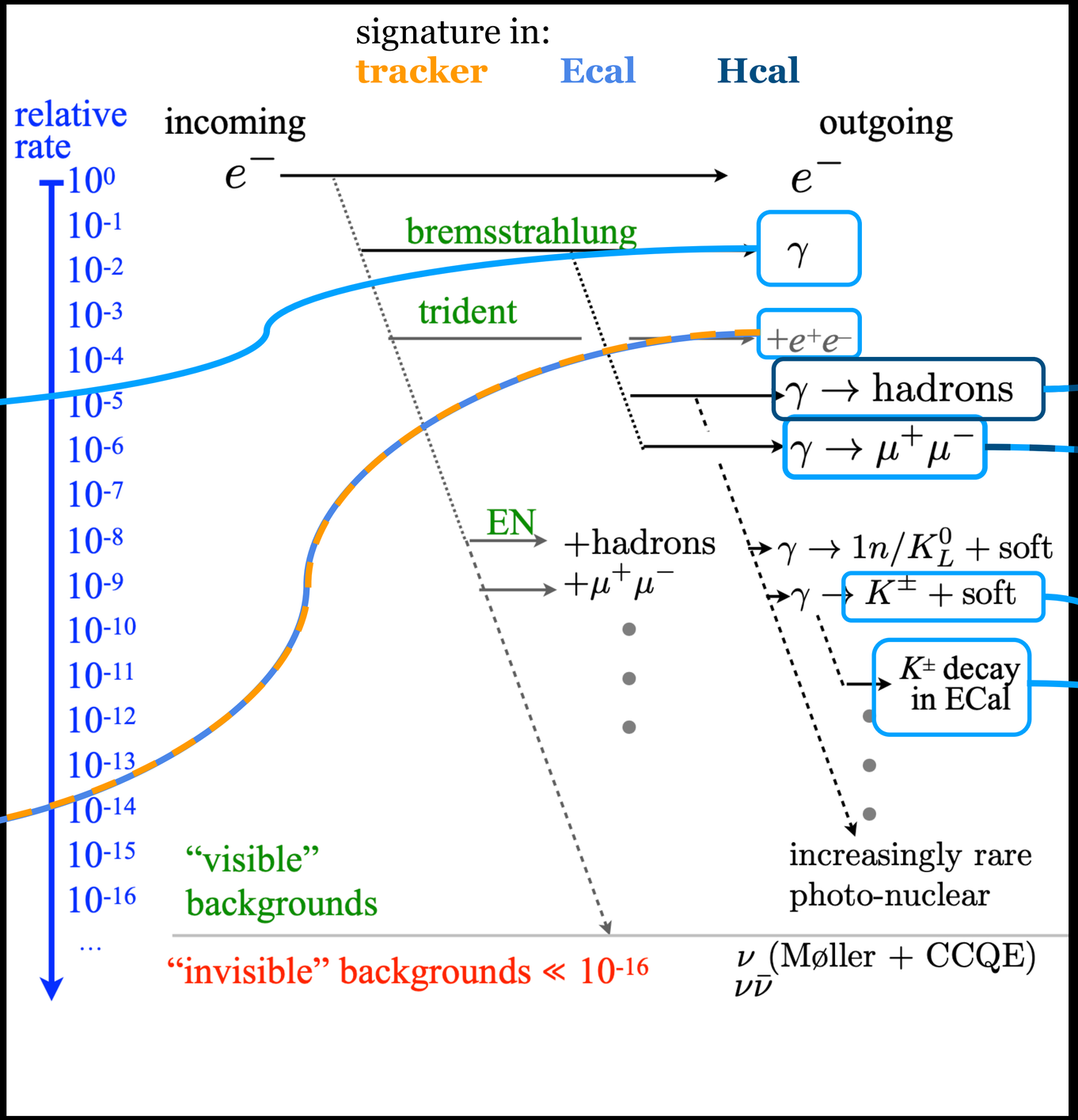

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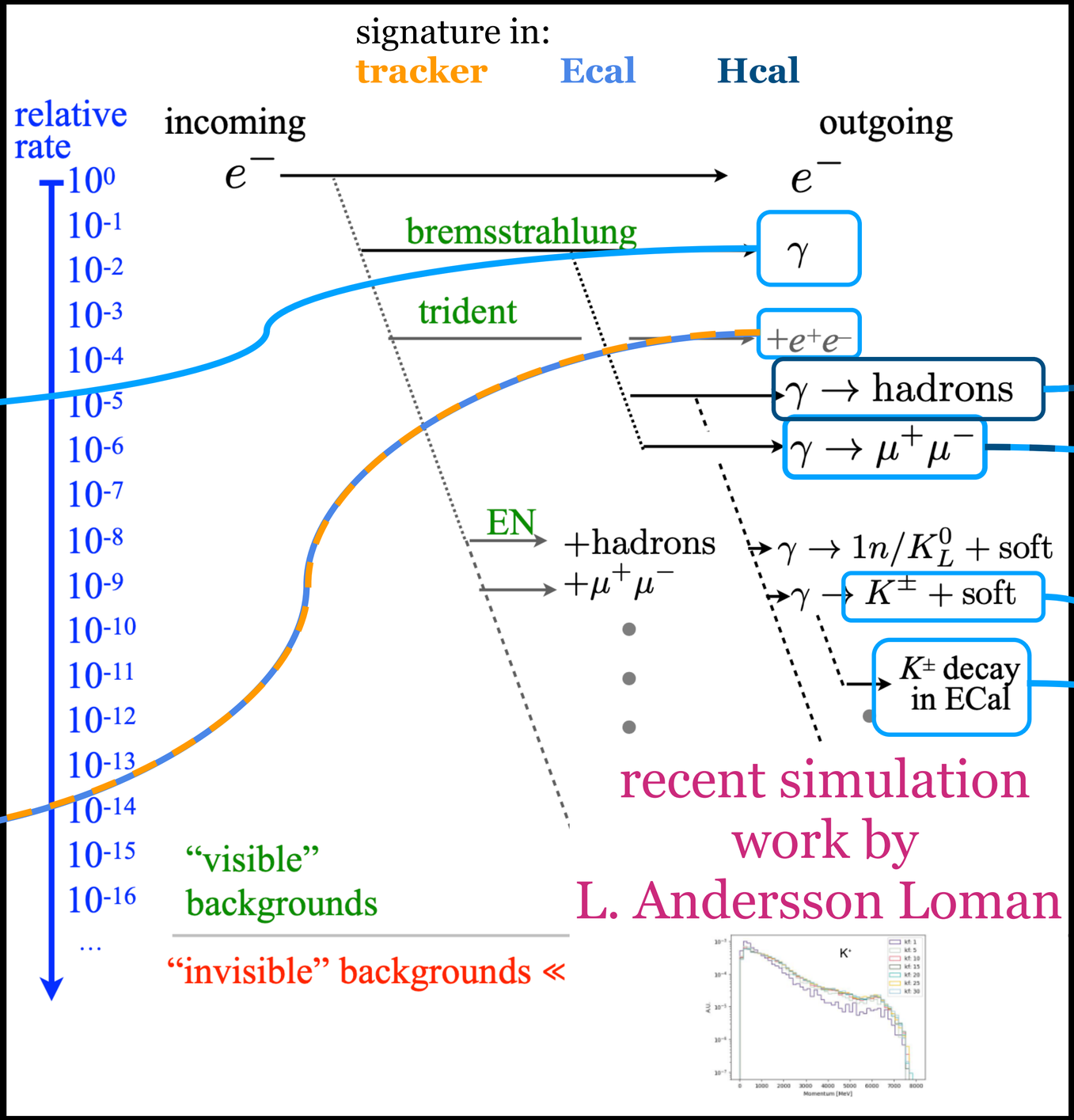

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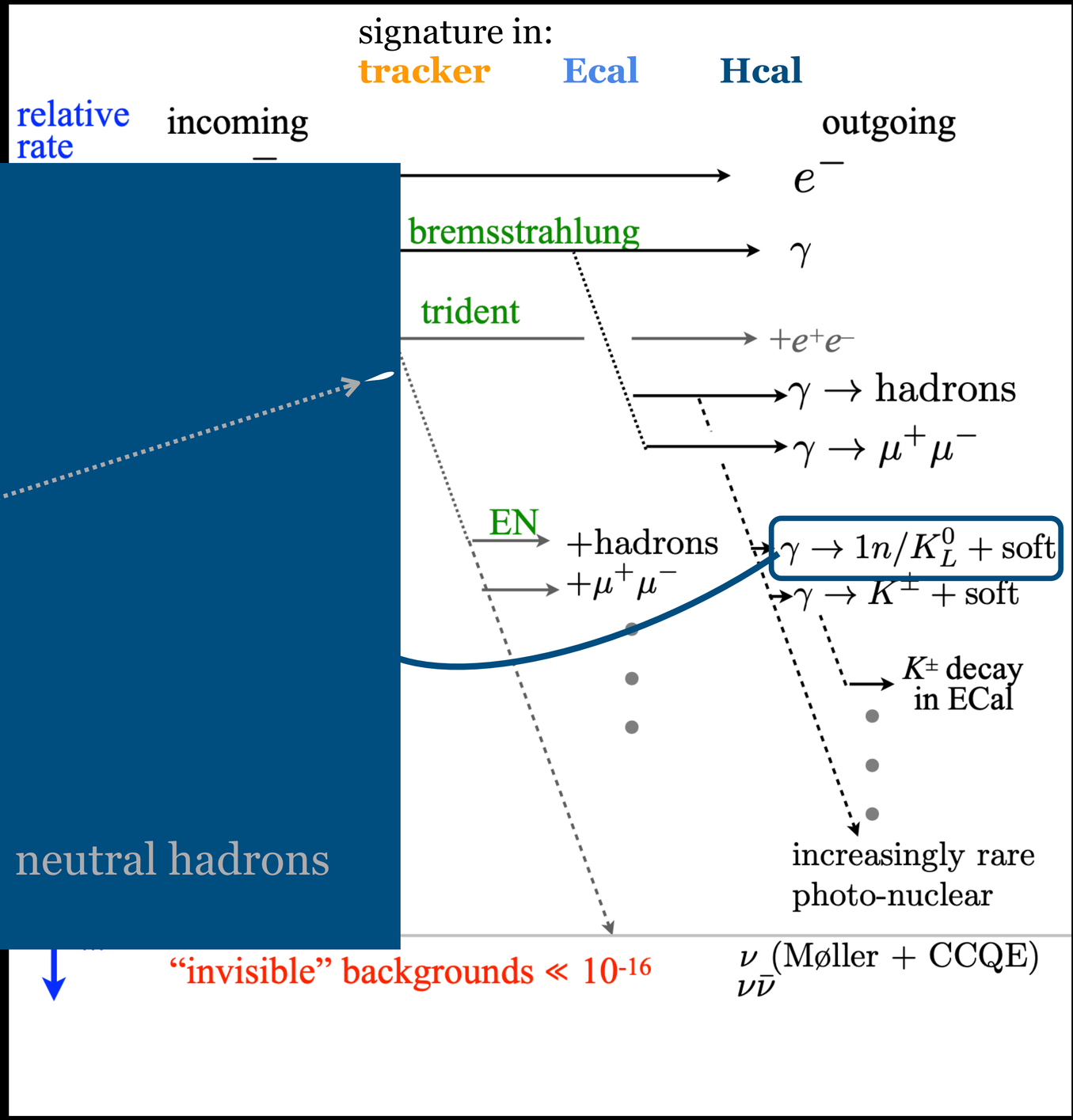

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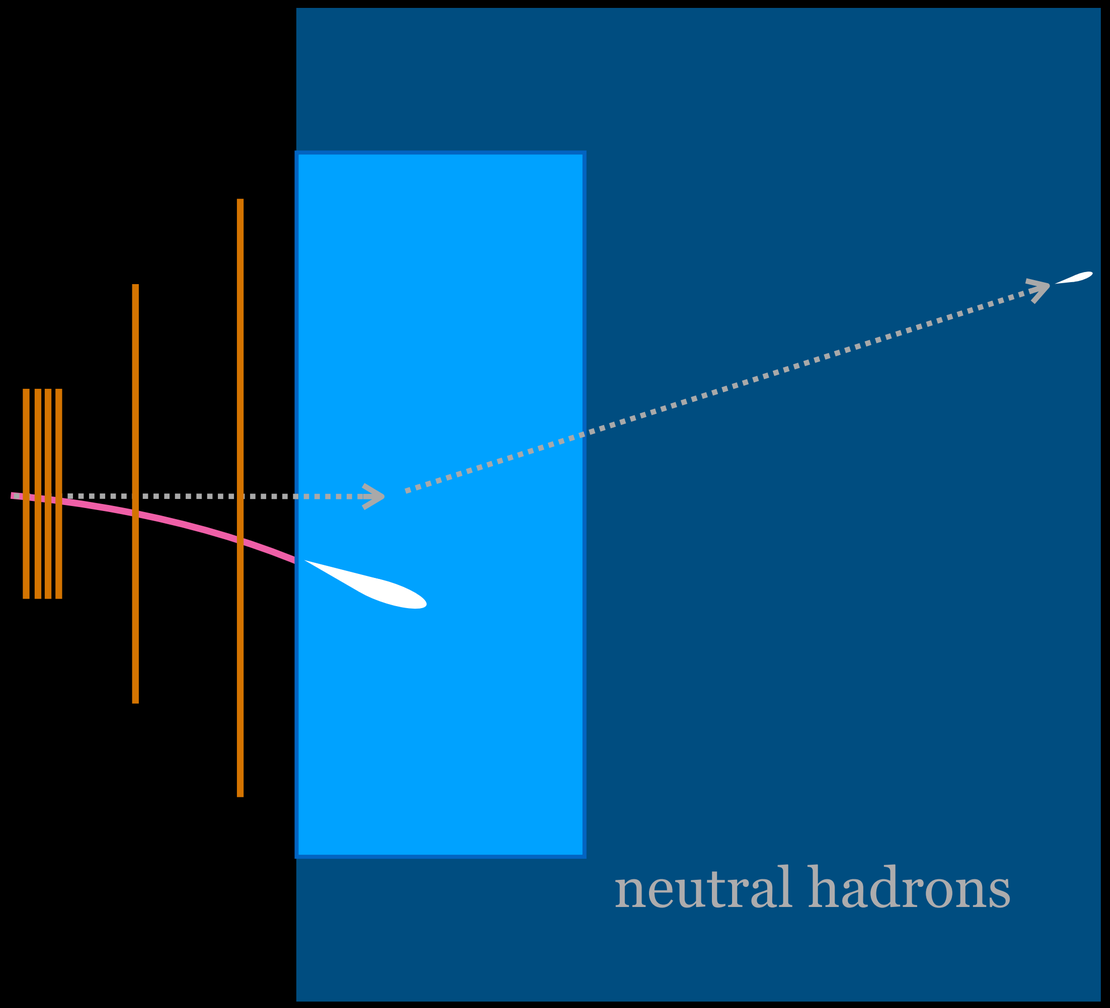

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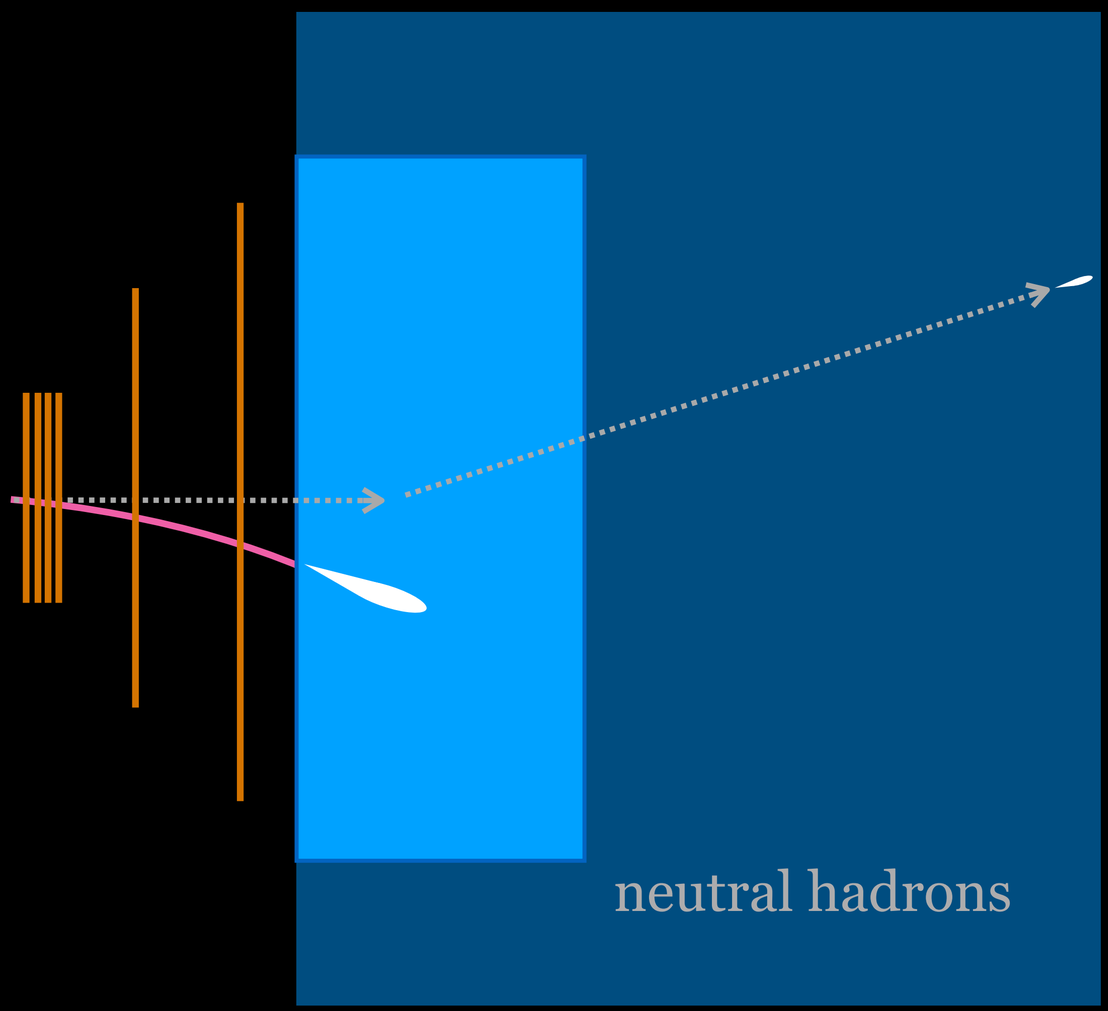
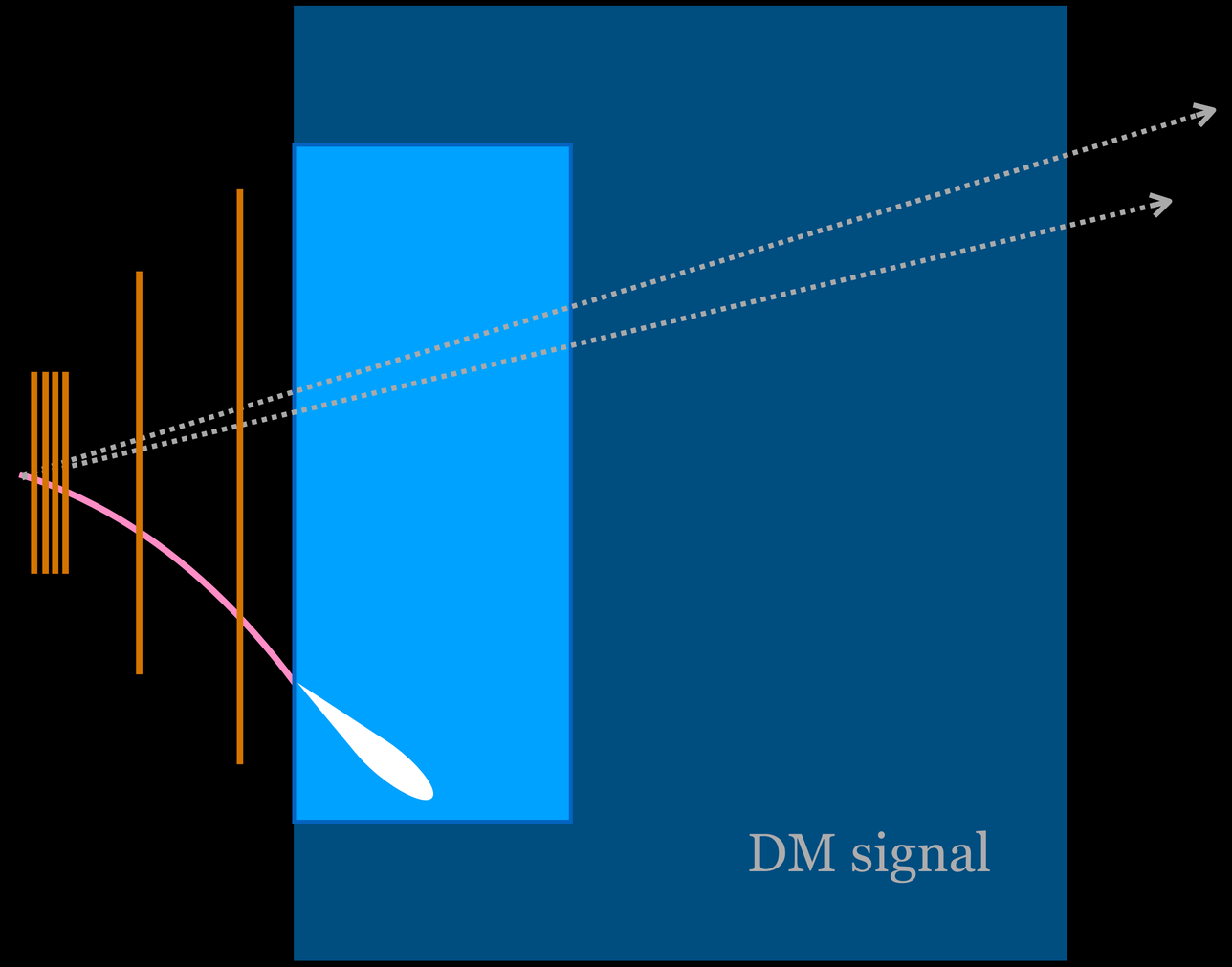


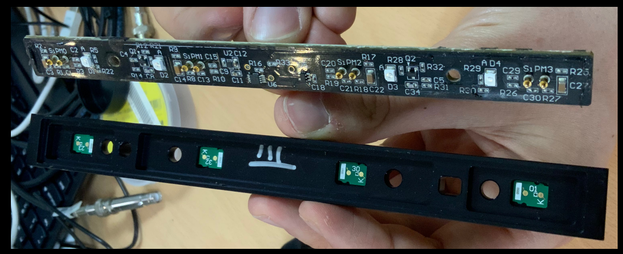
neutral hadrons



DM signal

HCal work in Lund: hardware

- Designing the HCal frontend boards
  - Scintillating fibers read out with SiPMs
  - HGCROC developed for CMS
  - used in both ECal and HCal
- Test beam at CERN last spring
  - analysis ongoing
- Test bench work to characterize signal
  - charge injection and LED flashing



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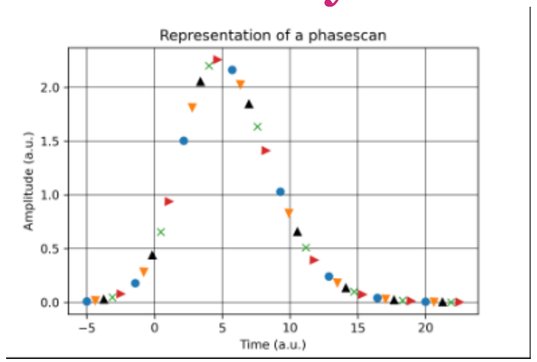
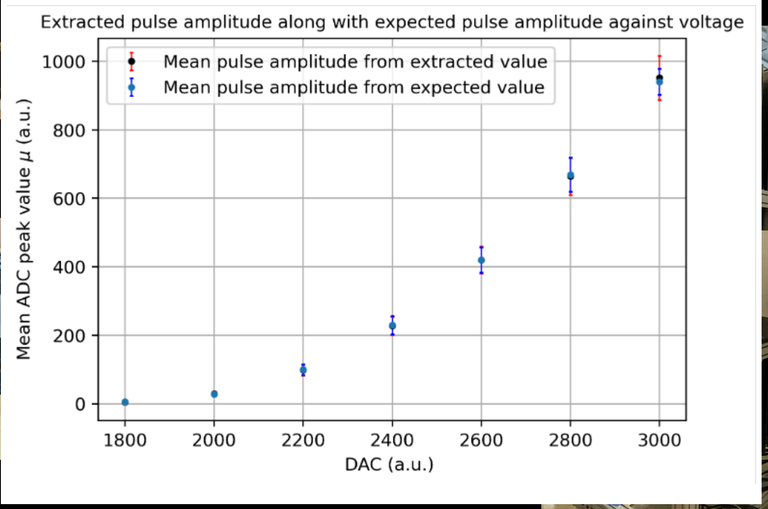
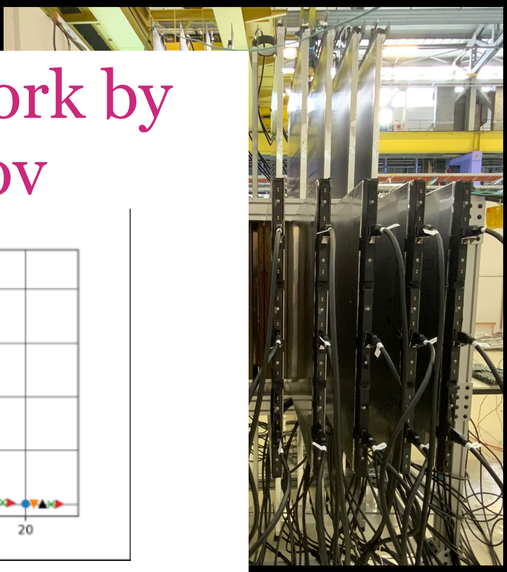
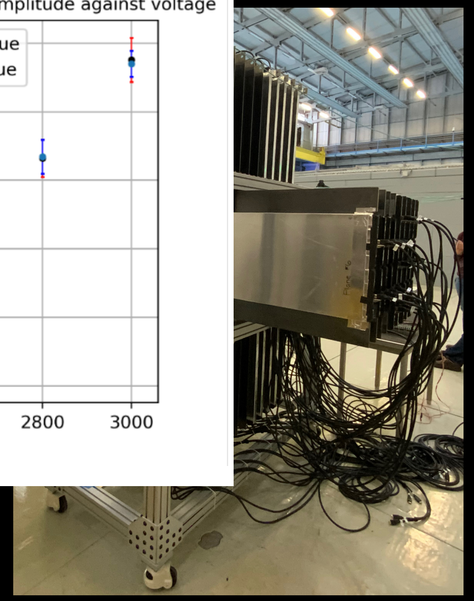
pulse fitting work by A. Mihaylov



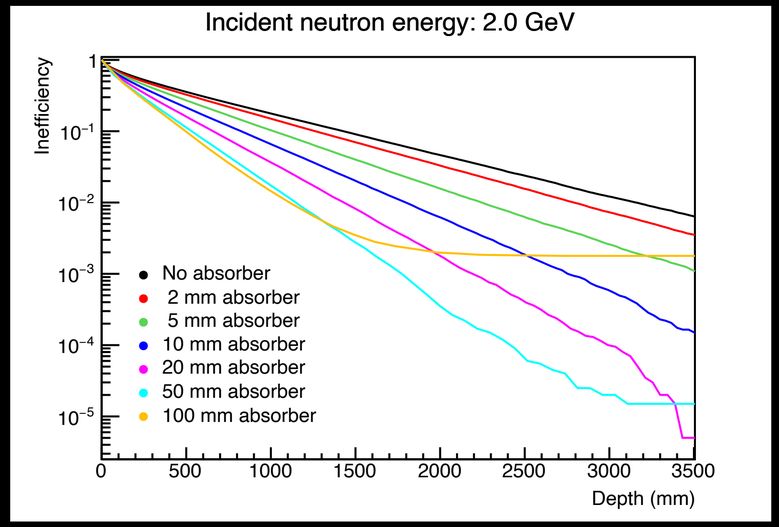






HCal work in Lund: simulation

- Design relies on simulations with Geant4+ldmx-sw
  - Zero background goal → high efficiency and much confidence needed
  - Recent development work to include other generators
  - We see good agreement with FLUKA in neutron detection efficiency
  - Comparisons of final state rates in Geant4, MCNP, FLUKA and PHITS



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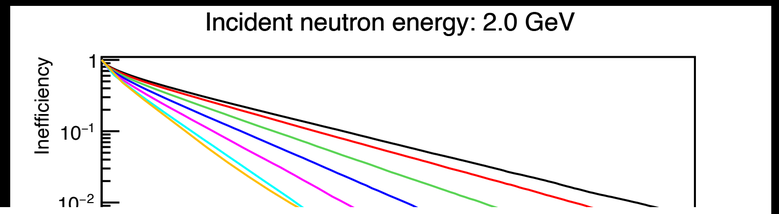
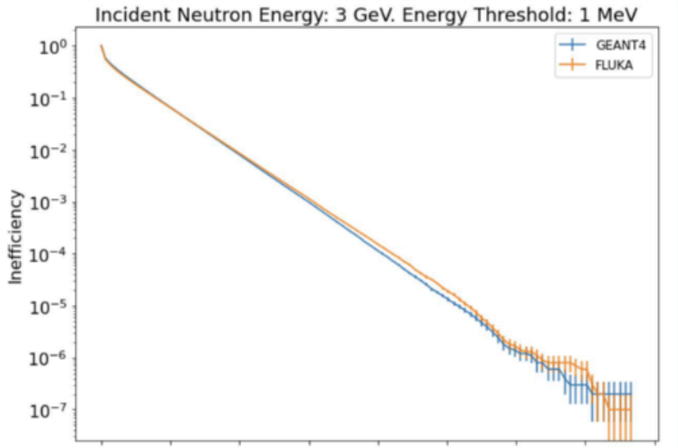


Geant4/FLUKA comparisons by J. Raffelsberger



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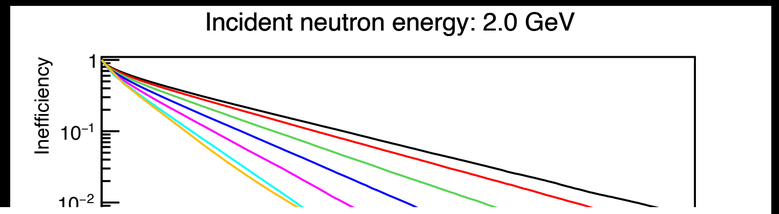

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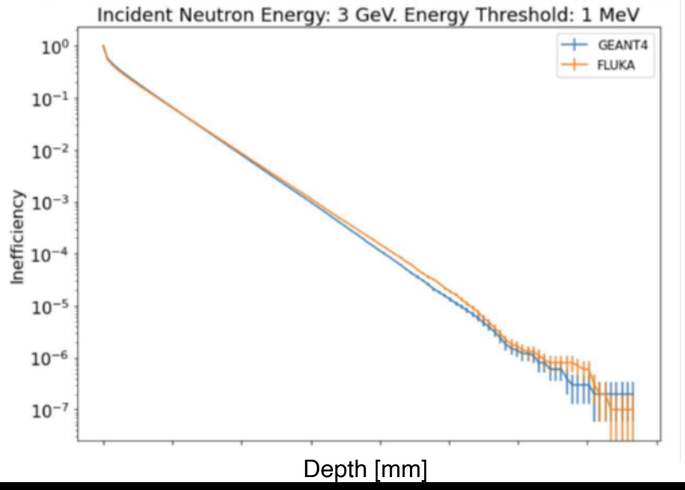

See E. Elén's talk

Further theoretical/simulation work in Sweden

Part of KAW-funded Light Dark Matter project

- Integration of Pythia in ldmx-sw
  - quite different for a fixed-target experiment: the beam sees material before the target
  - signal simulation (L. Gellersen, LU) and Geant4 integration (E. Elén, L.G. Sarmiento, LU)
- Consistent statistical treatment of data from different experiments, e.g. direct detection or accelerator-based (T. Emken, SU)
  - Enhancing statistical power by combining likelihoods in a global fit
- Extending models probed by existing and future fixed-target experiments (R. Catena and T. Gray, Chalmers)

Knut and Alice Wallenberg Foundation

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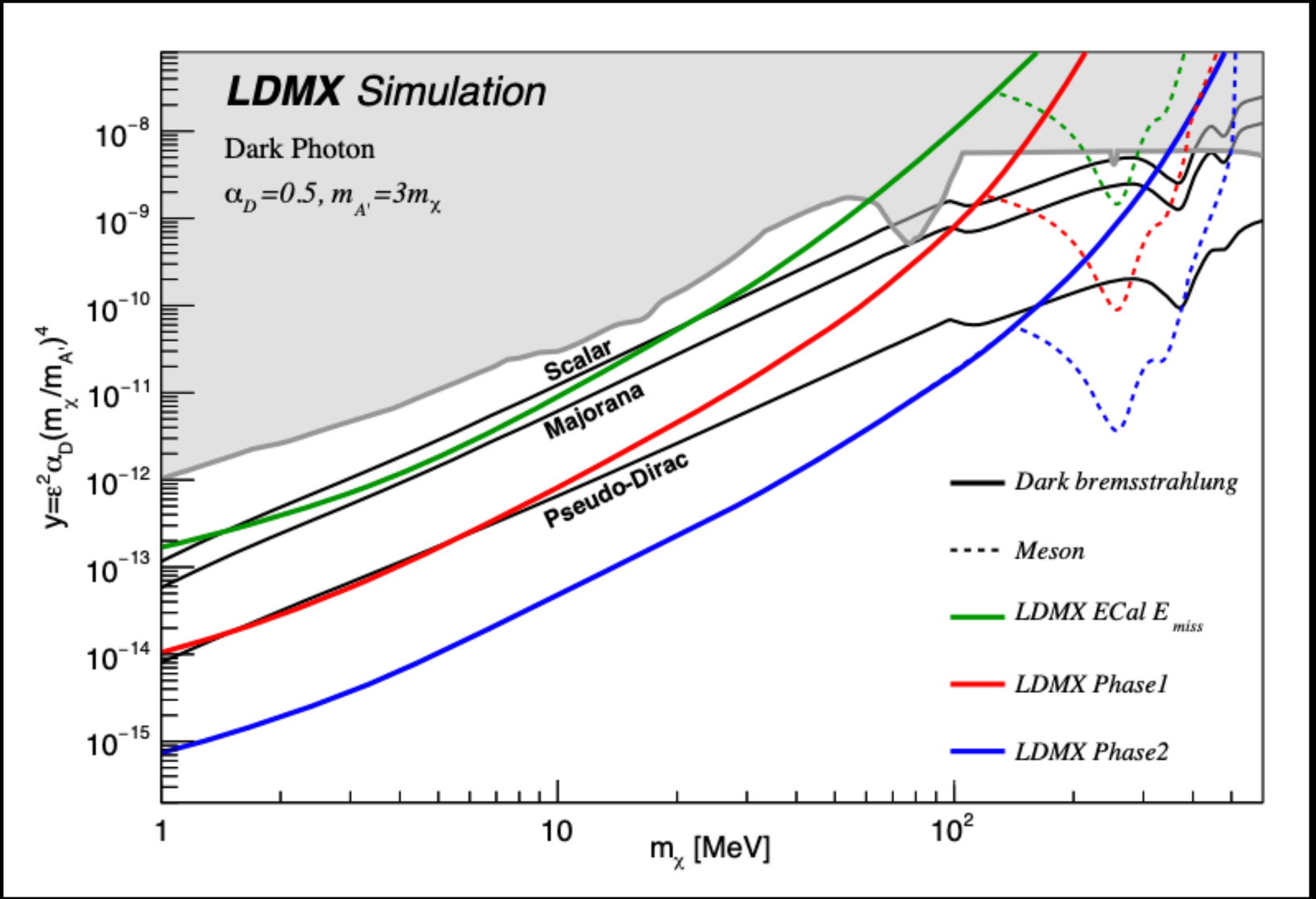
See T. Gray's talk on spin-1 DM

Knut and Alice Wallenberg Foundation

LDMX projected sensitivity

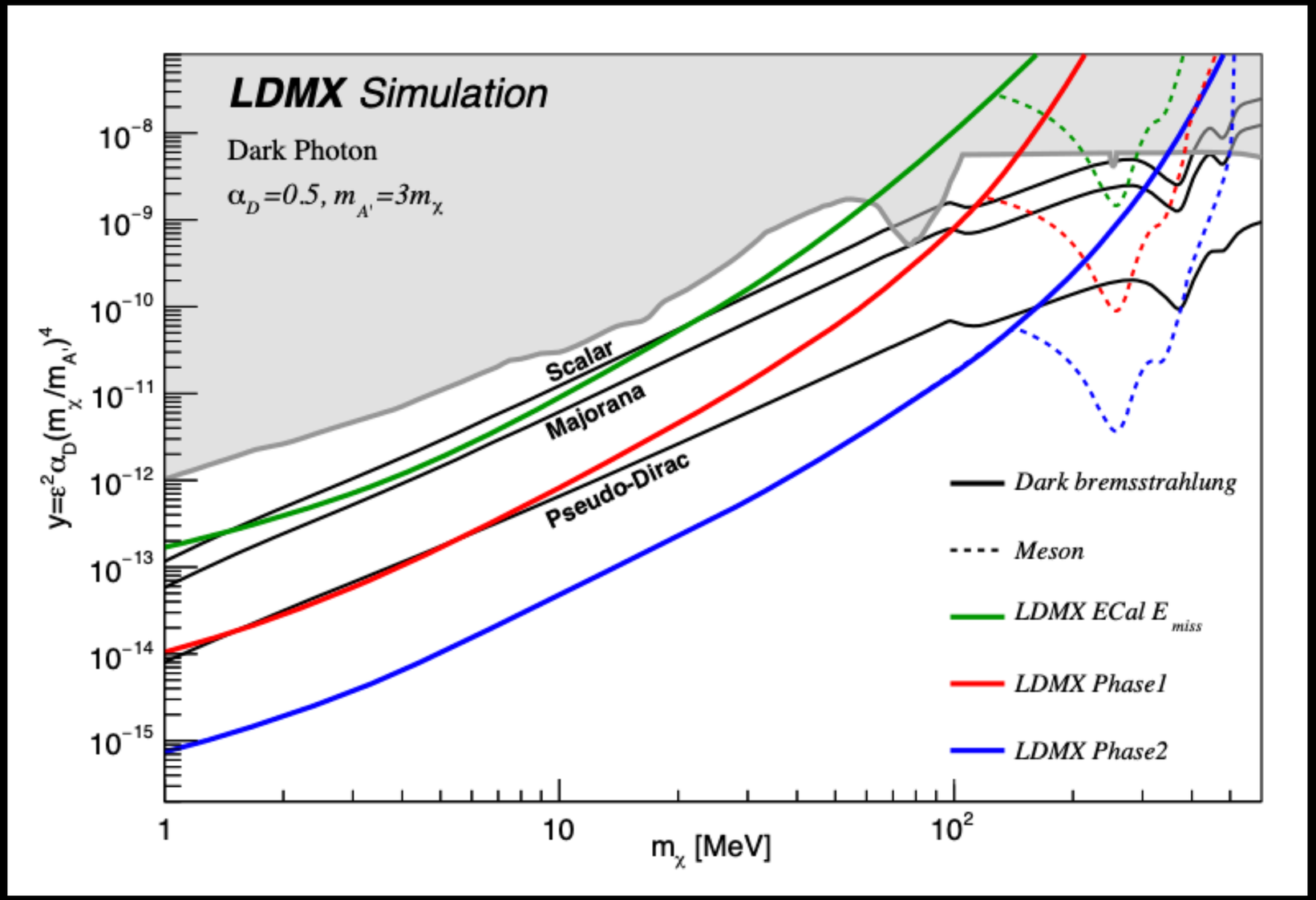


Assuming zero background

Phase 1: 4 GeV beam, $\sim 10^{14}$ electrons on target

Phase 2: 8 GeV beam, $\sim 10^{16}$ electrons on target

LDMX projected sensitivity



Assuming zero background

Phase 1: 4 GeV beam, $\sim 10^{14}$ electrons on target

Phase 2: 8 GeV beam, $\sim 10^{16}$ electrons on target

NEW result:
8 GeV veto performance by E. Wallin

Lund contributions to LDMX

- Main interests: HCal design and performance, generator integration, multi-electron triggering and analysis
- Hardware: HCal readout electronics design, HCal test stand
- Strong student involvement in software development and analysis
- Computing: Lund e-science (arc developers) designed and maintains LDMX's distributed computing system
- Leadership: co-spokesperson (T. Åkesson), physics co-coordinator (R. Pöttgen), computing and sw co-coordinator (LKB)

Summary

- LDMX is being designed to conclusively probe the stable matter mass range for DM of thermal origin
- Taking shape as simulations get more refined and prototype beam tests are available
- Lund contributes at all levels from hardware design to prototype tests, computing, data reconstruction, simulation and analysis
- KAW Light Dark Matter project integrates LDMX in a larger Swedish DM search context

LDMX

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