SHiP

Search for Hidden Particles

BDF/SHiP at the SPS ECN3 beam facility

On behalf of the SHiP Collaboration and BDF Working Group

R.J.,"Physics opportunities with the CERN SPS Beam Dump Facility", Partikeldagarna 2019, Linkoping (link)

Future physics prospects

8% of LHC+HL-LHC data recorded - still no sign of “New Physics”!

But….

<u>Experimental evidence</u>

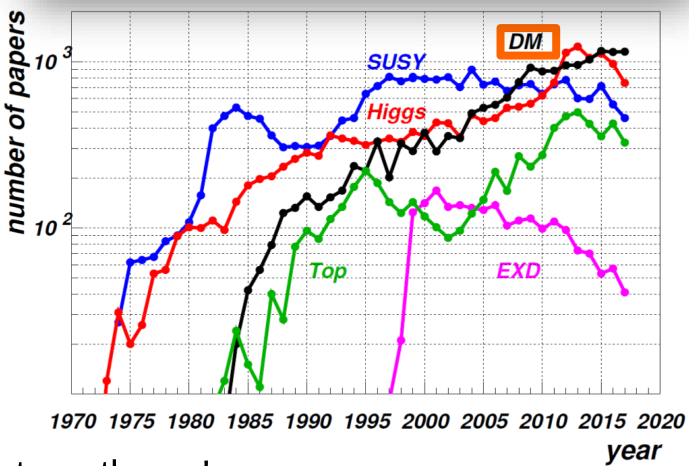
1. Mass of neutrinos (flavour oscillations)
2. Matter/antimatter asymmetry of the Universe
3. Dark Matter
4. Dark Energy

➔ *No prejudice on mass of the “new physics” required to solve these!*

<u>Theoretical “evidence” – “prejudice”</u>

1. Mass of the Higgs
2. Structure of Standard Model
3. Unification of interactions
4. Gravity
5. Inflation
6. ….

➔ *Some preference for new particles with large masses….*



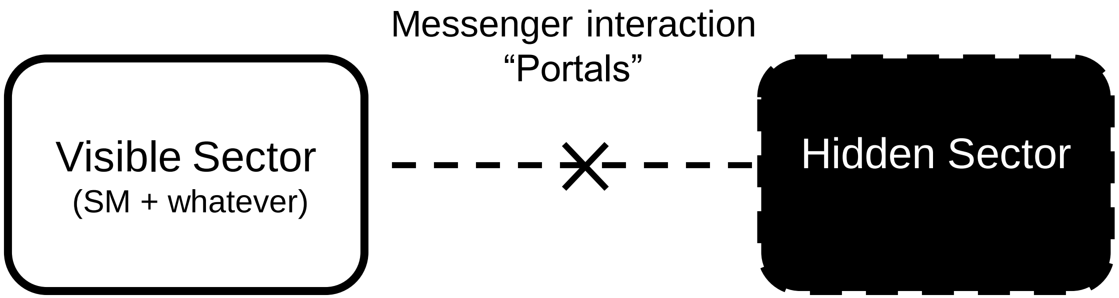
➔ For the first time, no definitive unambiguous guidance from experiments or theory!

➔ New Physics could either be very heavy OR interact very feebly!

➔ Possible guidance from cosmology and astrophysics!

Feebly interacting particles

Hidden Sector may have their own (hidden/dark) charges and interactions



Portals may "drive" dynamics observed in the Visible Sector!

- Dark Matter (trivial)
- Neutrino mass and oscillations
- Matter-Antimatter asymmetry
- Higgs mass
- Structure formation
- Inflation and Dark Energy
- ….

➔ Plethora of alternative SM extensions!

➔ Detect directly FIPs at accelerators!

Options for "portals" in SM

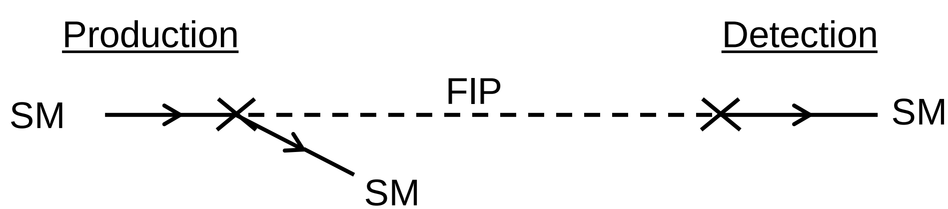
➔ Dark Photons

➔ Dark Higgses

➔ Heavy Neutrinos

➔ Axion-Like Particles

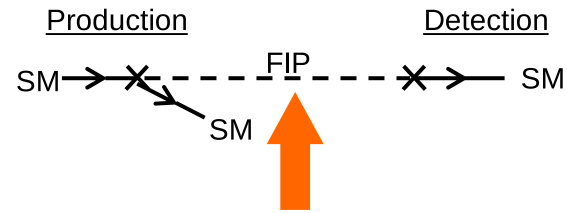
➔ *Part of a more general case of Feebly Interacting Particles - FIPs*



Caught between a rock and a hard place

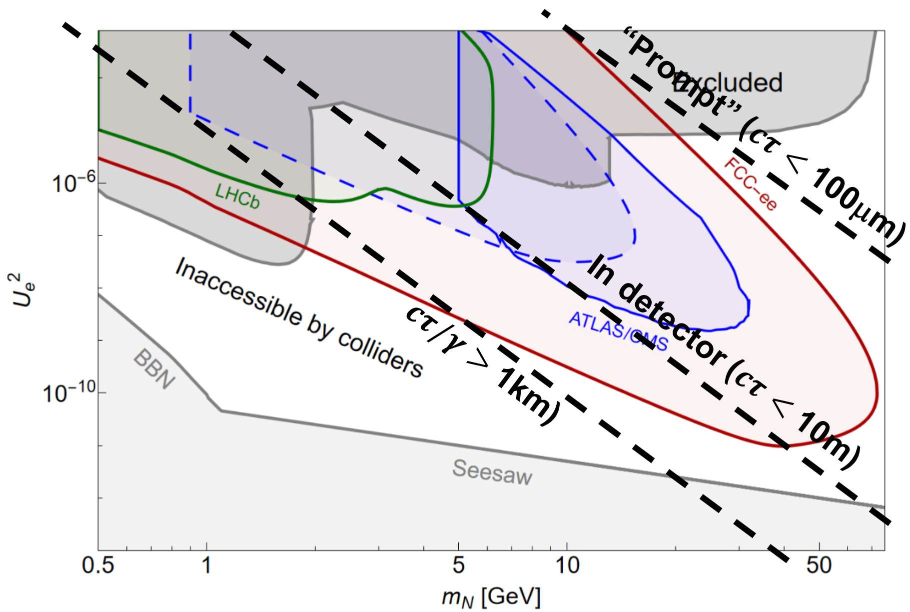
- We need massive production of $\gamma, q/g, c, b, W, Z, H$!

- New states are typically long-lived, e.g. HNL $\tau_N \sim \frac{96\pi^2 h}{|\mathcal{U}|^2 G_F^2 M_N^5}$, $|\mathcal{U}| << 1$



➔ Acceptance and background are the biggest challenges!

➔ "(Lifetime) $\otimes$ $(\epsilon \times \Omega)$ challenge"

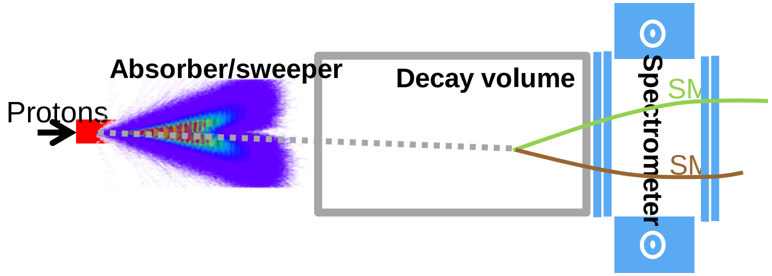


- Beam dump experiments: High luminosity and geometric acceptance, lower particle mass, long lifetimes

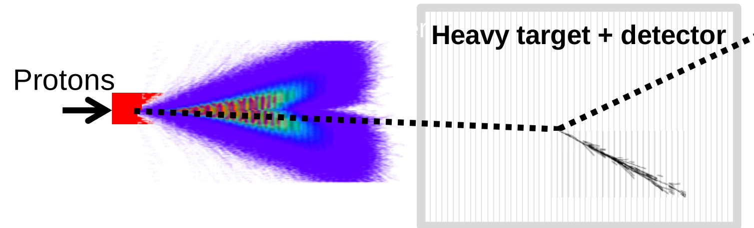
➔ Unique region that can only be explored by optimized beam-dump experiment down to "background floor"

BDF/SHiP experimental techniques

Visible decay to SM particles



Scattering off atomic electrons and nuclei



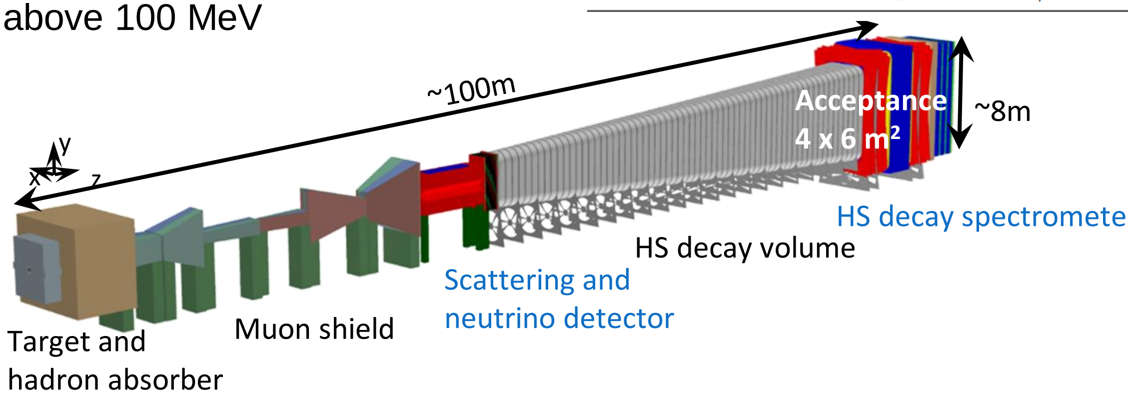
Also suitable for neutrino physics with all favours

Combined into BDF/SHiP, physics case based on 4×10^{19} protons on high-A/Z target per year for 10-15 years

- ➔ SPS $\mathcal{L}_{int}[year^{-1}]$ > 4 x 10^{45} cm^{-2}
- ➔ HL-LHC $\mathcal{L}_{int}[year^{-1}]$ = 10^{42} cm^{-2}
- ➔ *Annually* within acceptance of the detectors:
  - ~ 2×10^{17} charmed hadrons
  - ~ 2×10^{12} beauty hadrons
  - ~ 2×10^{15} tau leptons
  - $\mathcal{O}(10^{20})$ photons above 100 MeV

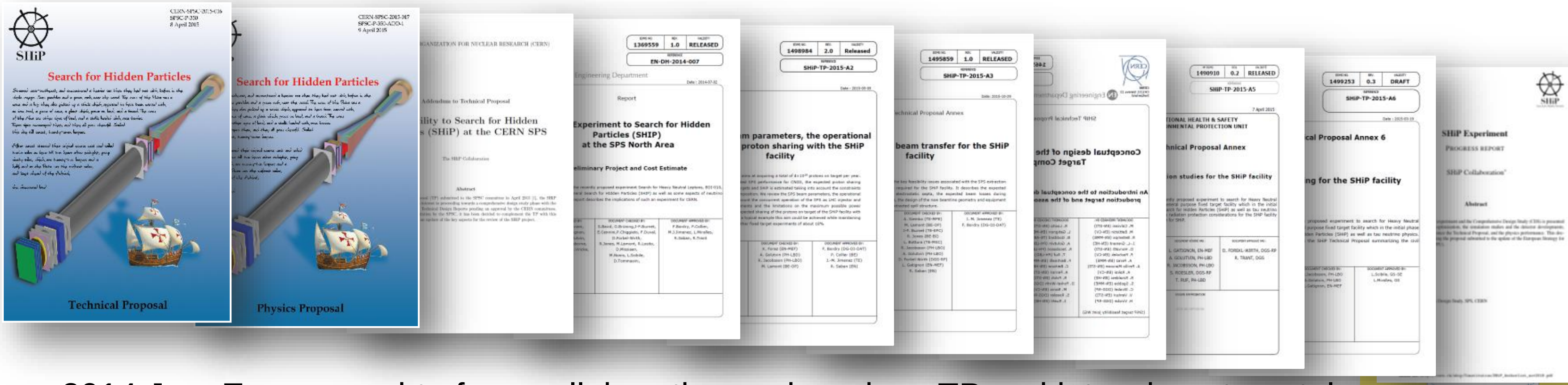
Model independent search

	Physics model	Final state
	HNL, SUSY neutralino	$\ell^\pm\pi^\mp,\ \ell^\pm K^\mp,\ \ell^\pm\rho^\mp(\rho^\mp\to\pi^\mp\pi^0)$
	DP, DS, ALP (fermion coupling), SUSY sgoldstino	$\ell^+\ell^-$
HSDS	DP, DS, ALP (gluon coupling), SUSY sgoldstino	$\pi^+\pi^-,\ K^+K^-$
	HNL, SUSY neutralino, axino	$\ell^+\ell^-\nu$
	ALP (photon coupling), SUSY sgoldstino	$\gamma\gamma$
	SUSY sgoldstino	$\pi^0\pi^0$
	LDM	Electron, proton, hadronic shower
SND	ν_τ, $\overline{\nu}_\tau$ measurements	$\tau^\pm$
	Neutrino-induced charm production (ν_e, ν_μ, ν_τ)	$D_s^\pm, D^\pm, D^0, \overline{D^0}, \Lambda_c^+, \overline{\Lambda_c}^-$

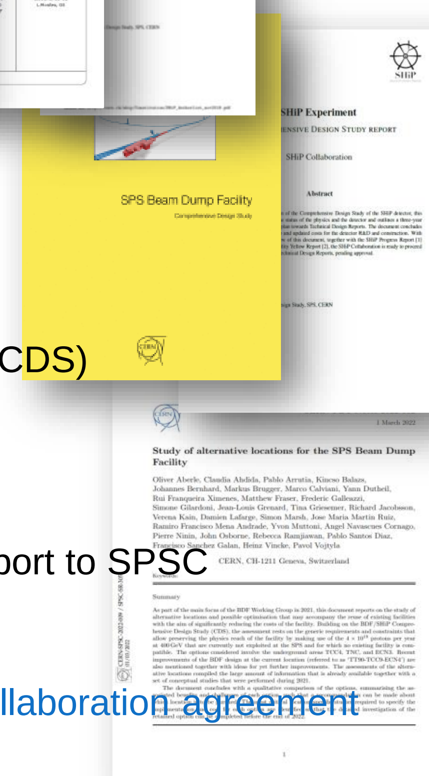


BDF/SHiP development history

- 2013 Oct: EOI with SHiP@SPS North Area as a new high intensity facility
  ...following brainstorming SHiP@IP8, SHiP@LBD, SHiP@CNGS, SHiP@WANF, SHIP@ECN3

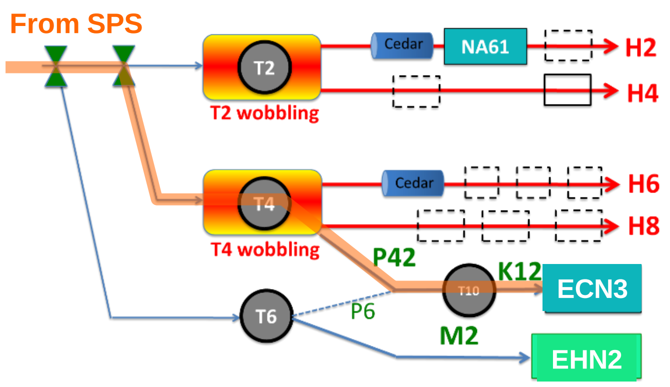


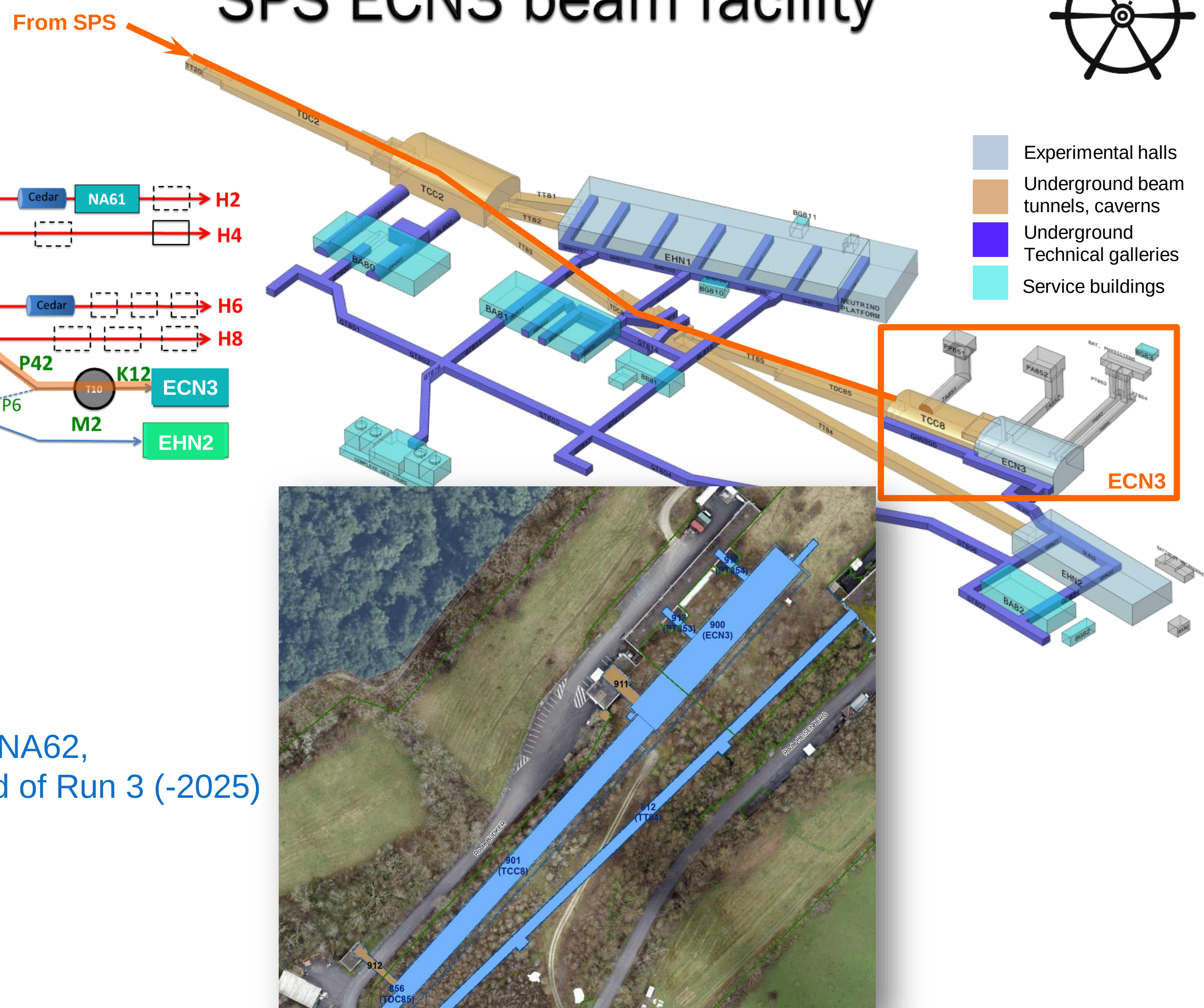
- 2014 Jan: Encouraged to form collaboration and produce TP and inter-departmental task force setup to study feasibility of facility
- 2015 Apr: TP with ~700 pages by SHiP theorists, experimentalists, and CERN accelerator, engineering, and safety departments
- 2016 Jan: Recommendation by SPSC to proceed to Comprehensive Design Study (CDS)
- 2016 Apr: CERN management launch of Beyond Collider Physics study group
  - SHiP experimental facility included under PBC as Beam Dump Facility
- 2018 Dec: EPPSU contribution submitted by SHiP and BDF, and SHiP Progress Report to SPSC
- 2019 Dec: CDS reports on BDF (Yellow Book) and SHiP submitted to SPSC
- 2020 Sep: CERN launches continued BDF R&D with SHiP MoU ontop of existing collaboration agreement
  ➔ Location and layout optimization study recommending ECN3



- 2022 Jul: CERN launches dedicated decision process over 2022-23 for future physics programme in ECN3

SPS ECN3 beam facility





Currently hosting NA62,
approved until end of Run 3 (-2025)

Status of ECN3 Decision Process

- Strong interest to return SPS to its full potential for fixed-target physics
  - Synergy with NA Consolidation in LS3 (2026 – 2028)
- ECN3 Beam Delivery Task Force has established feasibility/cost of exploiting ECN3 for higher beam intensities
- SPSC ECN3 Task Force to referee all experiment proposals and to provide the SPC with a science-based recommendation to be given to the CERN Research Board by the end of 2023

➔ ECN3 high-intensity upgrade well received by CERN Scientific Policy Committee (March 2023):
- Positive recommendation going forward to Finance Committee & CERN Council

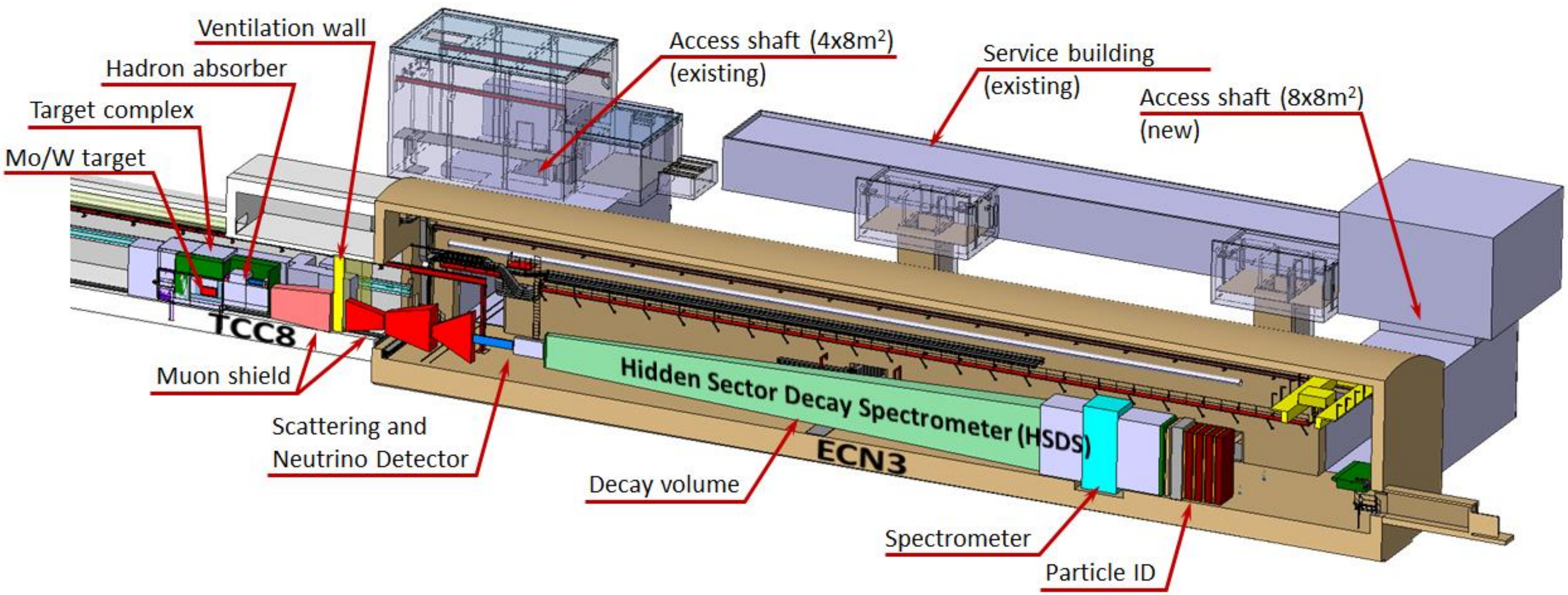
- Draft Medium Term Plan 2023 well received:
  - Immediate support (2023/24 items) for ECN3 discussed but not disputed
- Additional allocation for NA-CONS Phase 1, and allocation for Phase 2 out to 2033 accepted without noticeable reservation

➔ MTP2023, including high-intensity beam delivery, to be approved in June's Council meeting

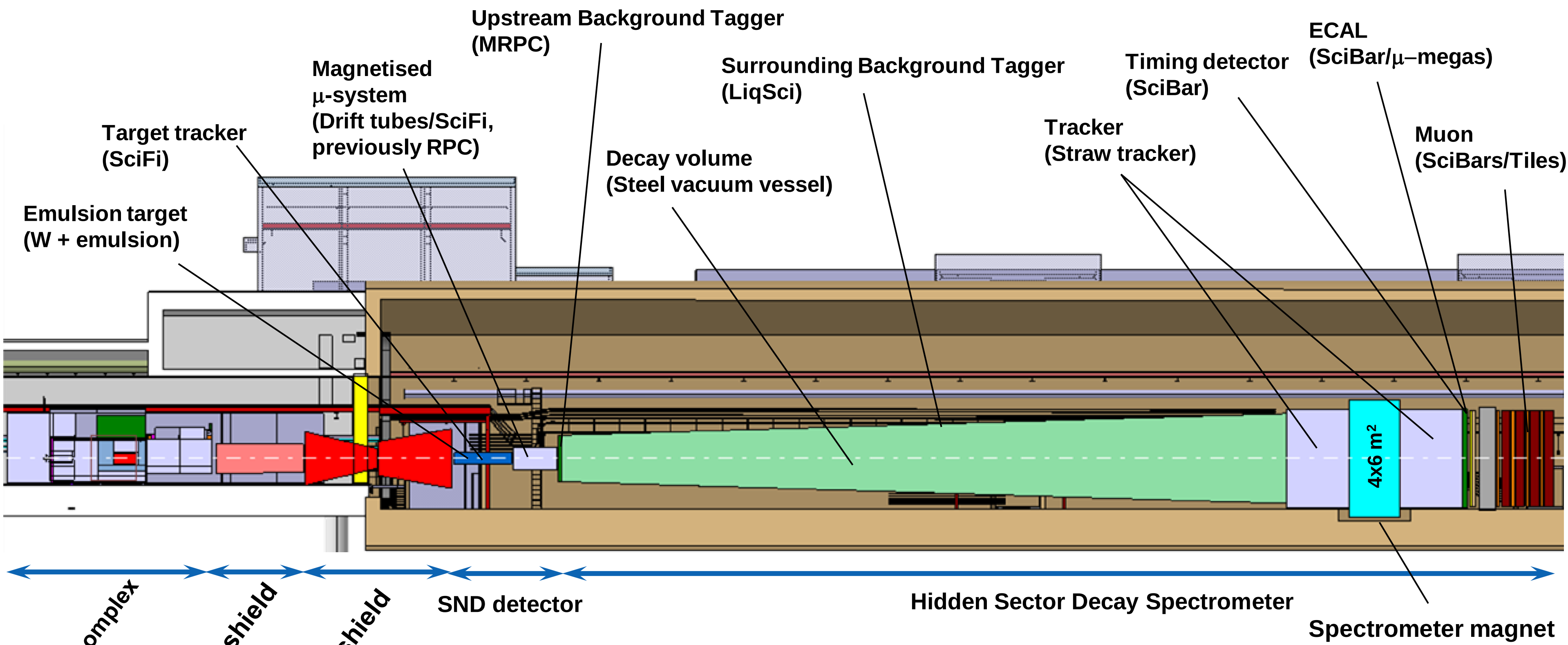
BDF/SHiP in ECN3 proposal

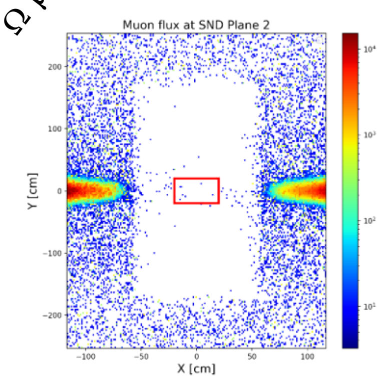
2020-2023: Facility/experiment reoptimisation for ECN3

➔ Physics programme and sensitivities same as in original proposal at new SPS beam facility



BDF/SHiP at ECN3

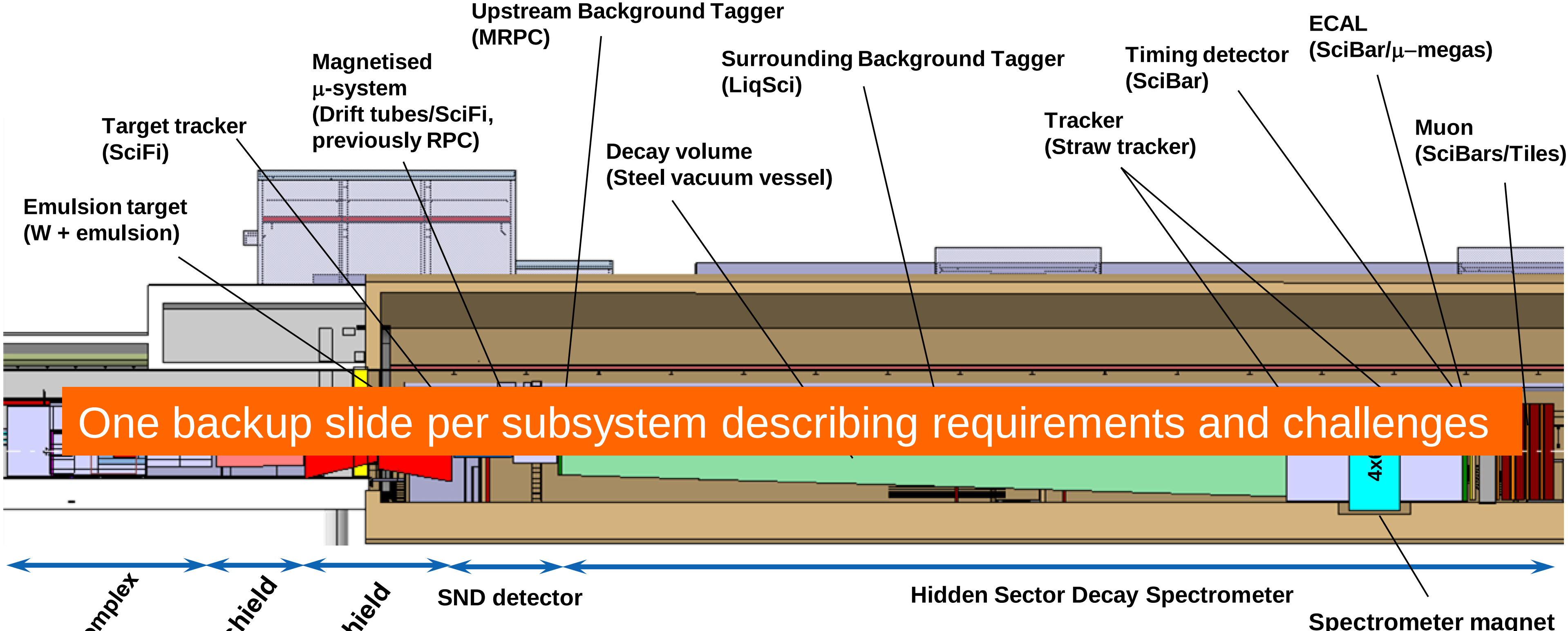




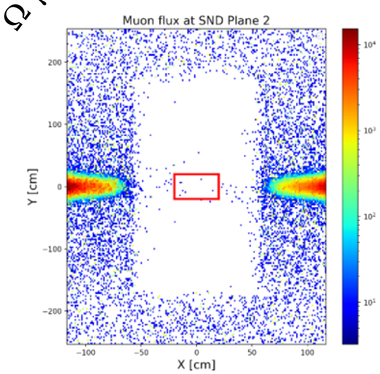
Designed for "zero background" in decay search

- Target design
- Muon shield
- Decay volume under low air pressure
- Background veto taggers
- Momentum and decay vertex information
- Invariant mass
- Impact parameter at target
- Coincidence timing
- Particle identification

BDF/SHiP at ECN3



One backup slide per subsystem describing requirements and challenges



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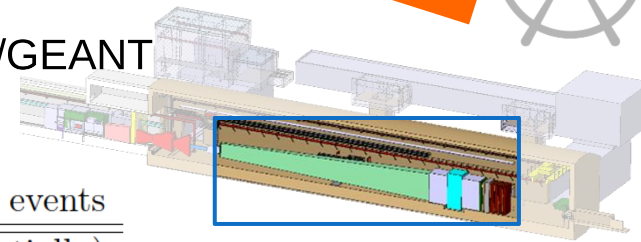
Physics sensitivity - FIPs

PRELIMINARY

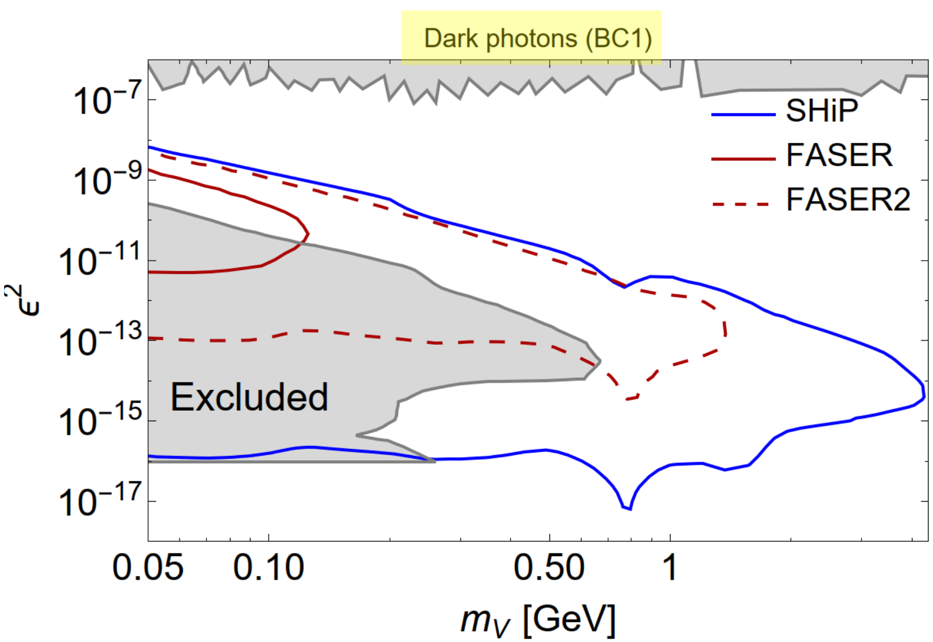
- Expected backgrounds evaluated with full simulation PYTHIA/GEANT

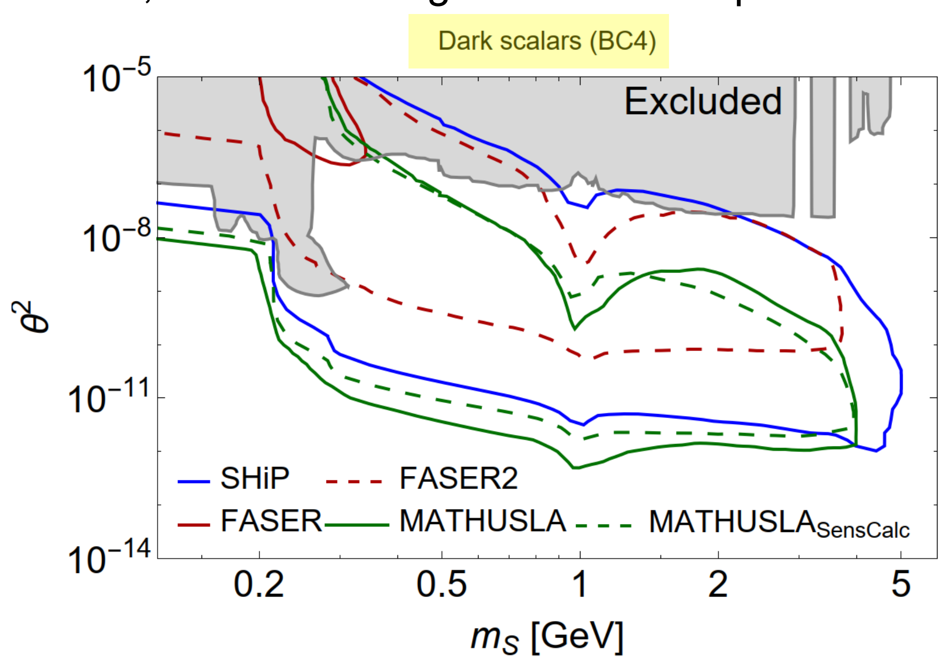


Expected background at 90% CL with 2x10[20] p.o.t.

Background source	Expected events
Neutrino DIS	< 0.1 (fully) / < 0.3 (partially)
Muon DIS (factorisation)	$< 10^{-4}$ (fully) / $< 10^{-2}$ (partially)
Muon combinatorial	2.1×10^{-3}

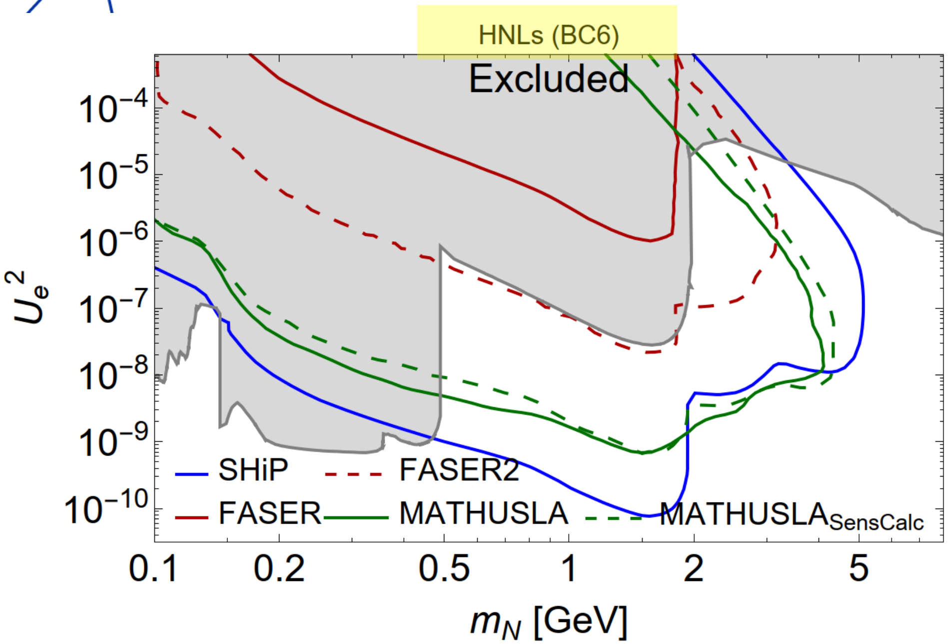
- SPSC recommend considering 10-15 years operation, within "0 background": 6x10[20] p.o.t.

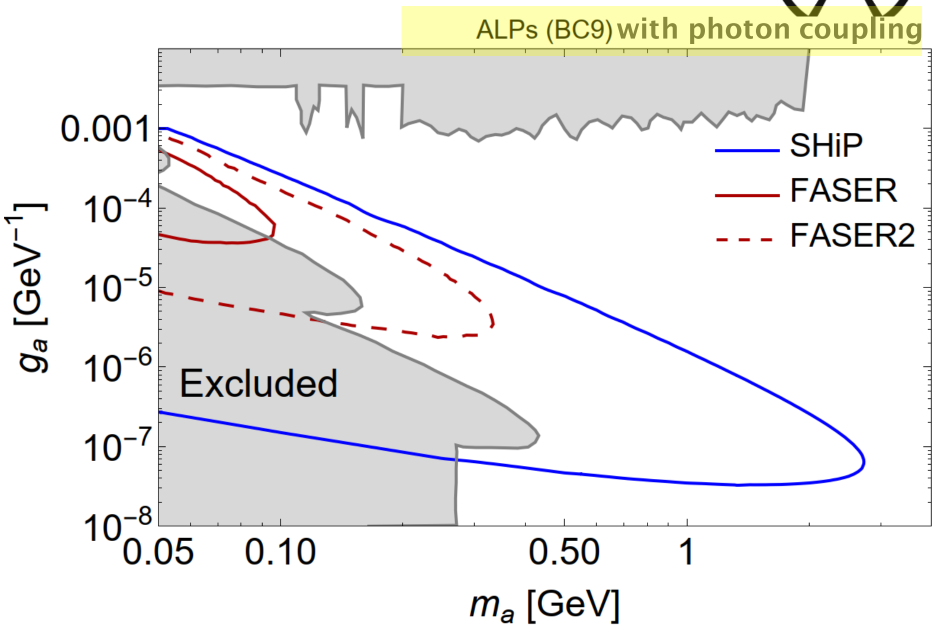




- Limits for FASER and MATHUSLA from FIPs 2022 Proceedings, arXiv:2305.01715
- Curves with SensCalc, see arXiv:2305.13383

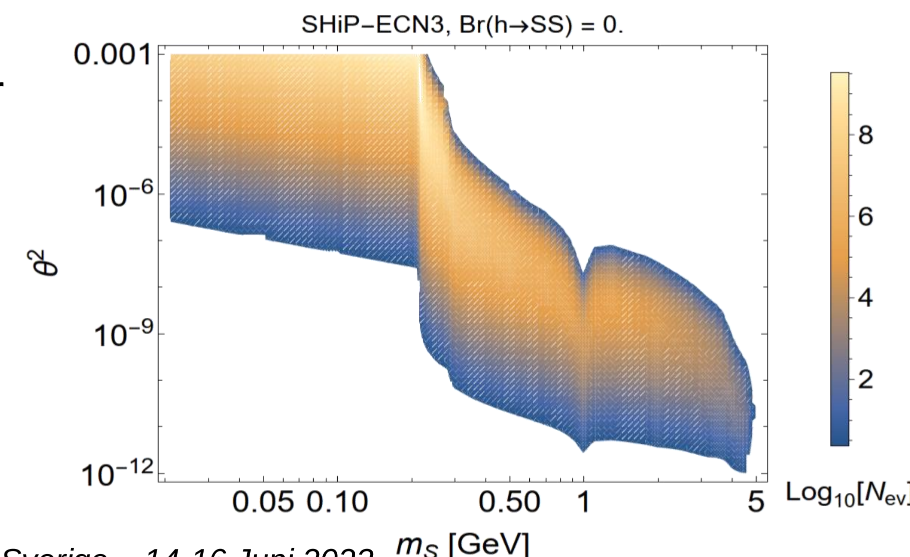
Physics sensitivities – FIPs cont'd





Experiment aimed at discovery and measurements ➔ Number of events (6×10^{20} pot) !

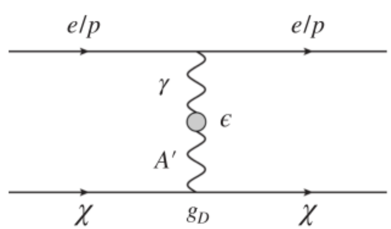
Ex. Dark scalar

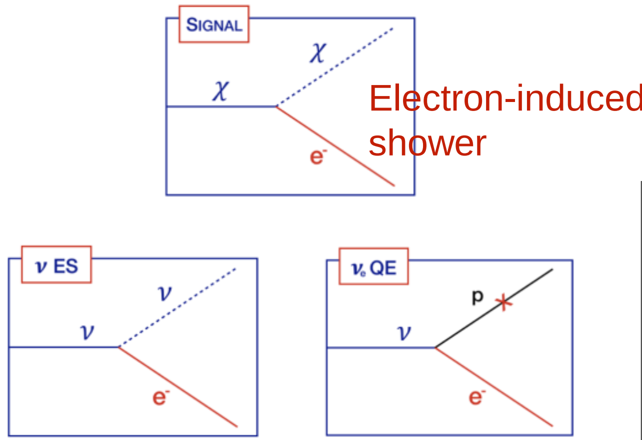


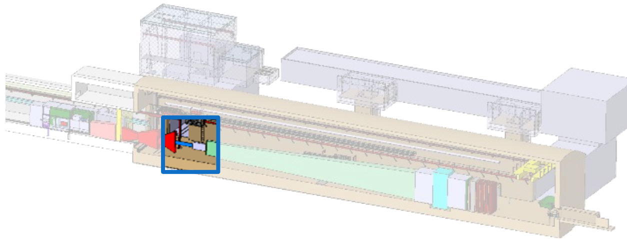
Physics sensitivity – LDM

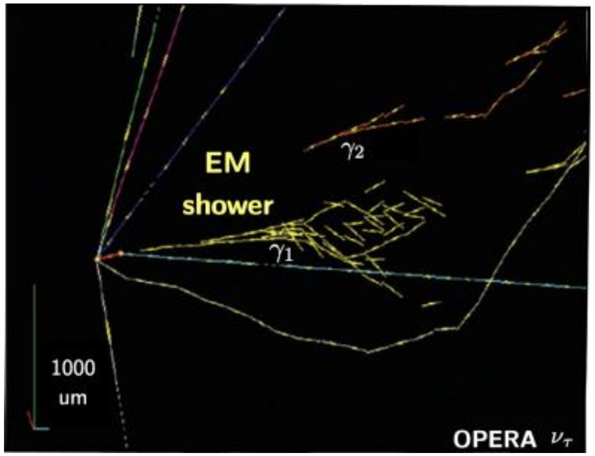
PRELIMINARY

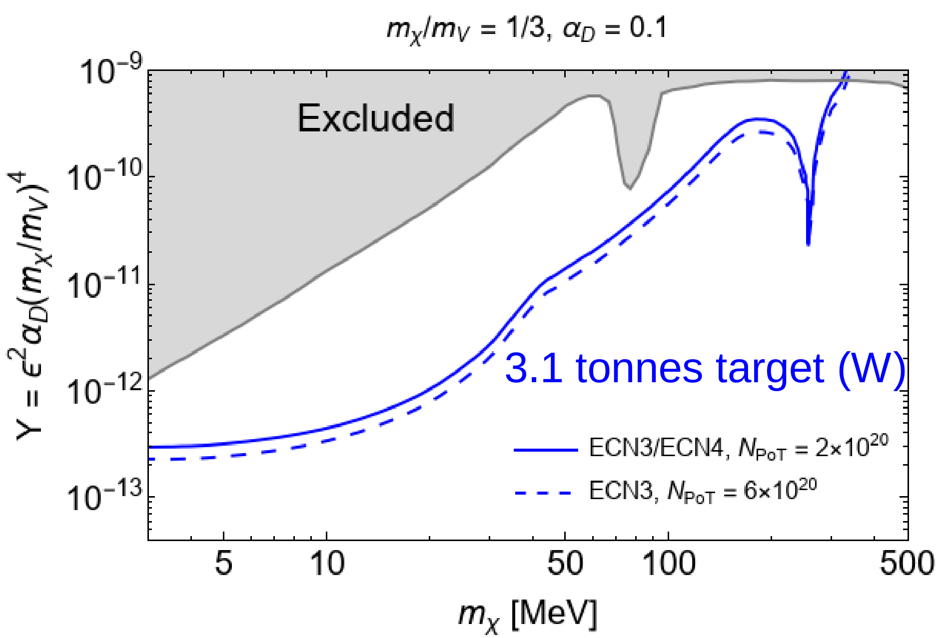
Light Dark Matter direct detection via elastic scattering off electrons ($\propto \epsilon^4 \alpha_D$)











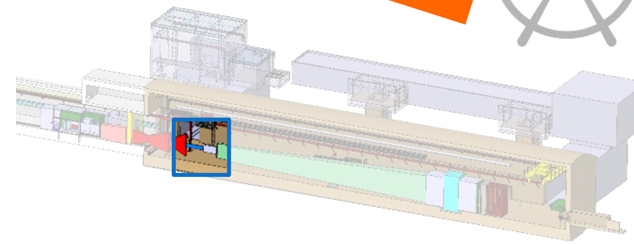
	ν_e	$\bar{\nu}_e$	ν_μ	$\bar{\nu}_\mu$	all
Elastic scattering on e^-	52	27	64	42	185
Quasi - elastic scattering	-	9			9
Resonant scattering	-	-			-
Deep inelastic scattering	-	-			-
Total	52	36	64	42	194

Physics sensitivity - Neutrino

PRELIMINARY

Neutrino programme:

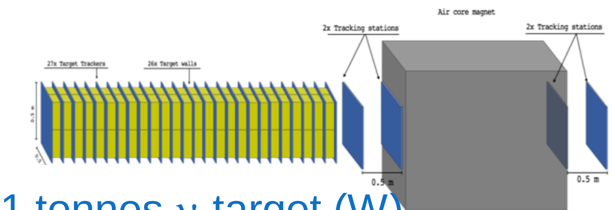
- ν_τ neutrino physics with high statistics
- First observation of anti-ν_τ
- ν_τ magnetic moment
- Charm physics
- Strange quark nucleon content
- …



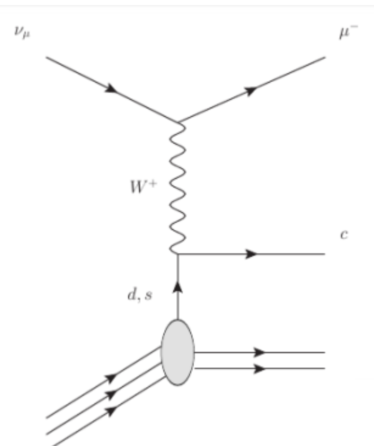
Detected number of events efficiencies included

Decay channel	ν_τ	$\overline{\nu}_\tau$
$\tau \to e$	3500	
$\tau \to \mu$	1200	900
$\tau \to h$	10 600	
$\tau \to 3h$	3700	

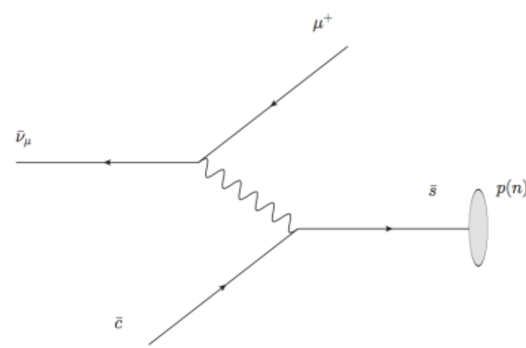
ν_τ/anti-ν_τ separation in the muonic channel of the tau



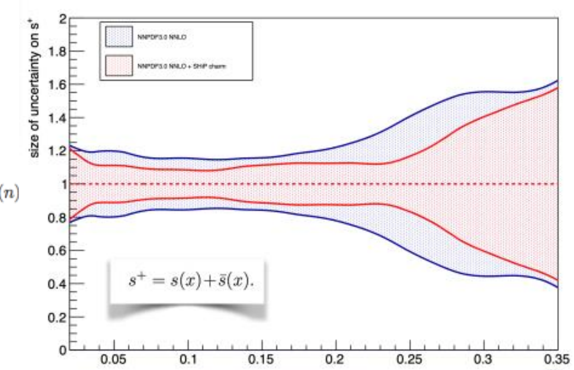
3.1 tonnes ν-target (W)



	Expected events
ν_μ	1.2×10^5
ν_e	5.4×10^4
$\bar{\nu}_\mu$	2.2×10^4
$\bar{\nu}_e$	9.3×10^3
total	2.0×10^5



No charm candidate from ν_e and ν_τ interactions ever reported

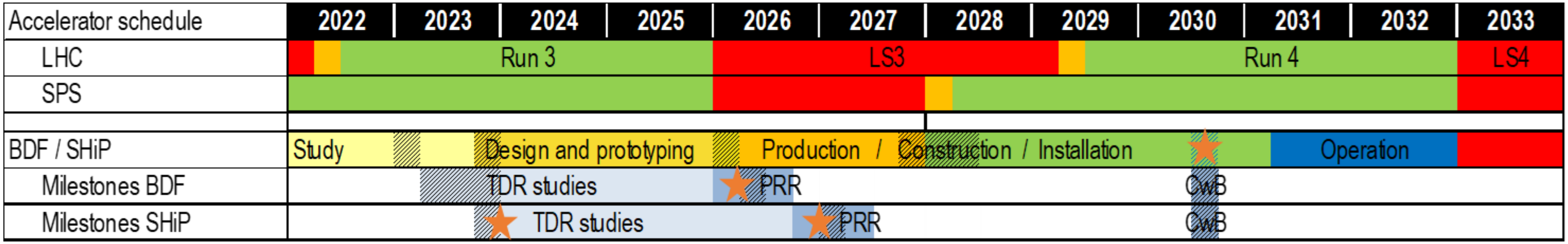


Significant improvement in s+/s- versus x

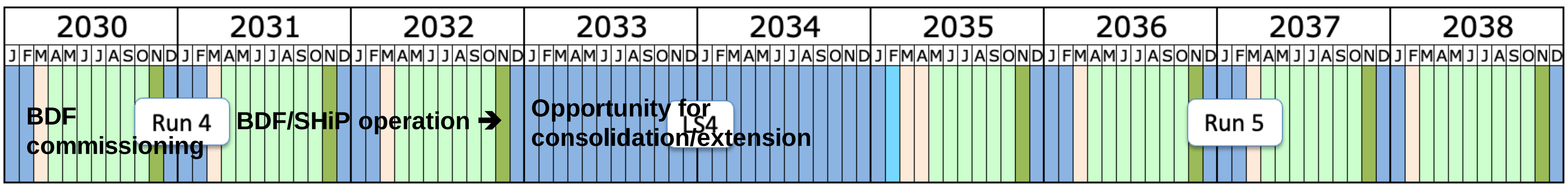
➔ Detector proof-of-concept with the SND@LHC experiment currently in operation

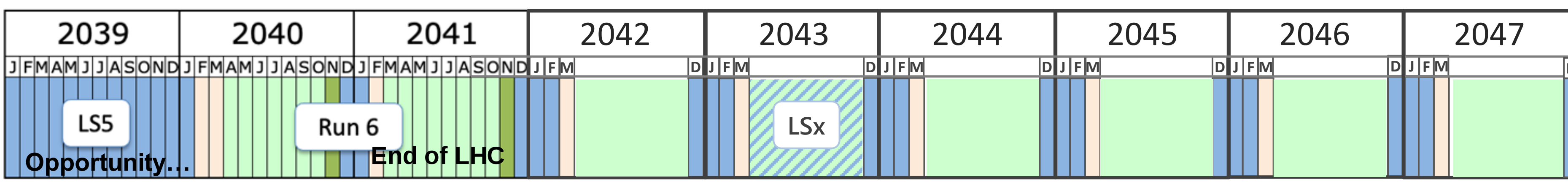
BDF/SHiP beam schedule

Preliminary timeline in ECN3 Letter of Intent (CERN-SPSC-2022-032 / SPSC-I-258)



Several upgrades/extensions of the BDF/SHiP in consideration over the operational life





Last update: April 2023

SPS decoupled from injector role in 2042
Beyond, assuming the baseline that SPS is not used as FCC-ee injector
Fully dedicated to proton/ion physics
Opportunity for BDF/SHiP extension
SPS intensity(/energy) upgrade possible (/TBD)

Conclusions

- Enormous increase in interest in feebly interacting particles over last decade
- "Coupling frontier" with synergy between accelerator-based searches and searches in astrophysics/cosmology
  - First hints might come with breadth of modern earth/space-based telescopes
- BDF/SHiP capable of covering unique region of parameter space, out of reach for collider experiments
  - Capability not only to establish existence but to measure properties such as precise mass, branching ratios, spin, etc
- ECN3 decision process should conclude by end of 2023 with TDR work starting
- Many interesting areas of developments where recent upgrade efforts or R&D for future detectors may have application on medium term

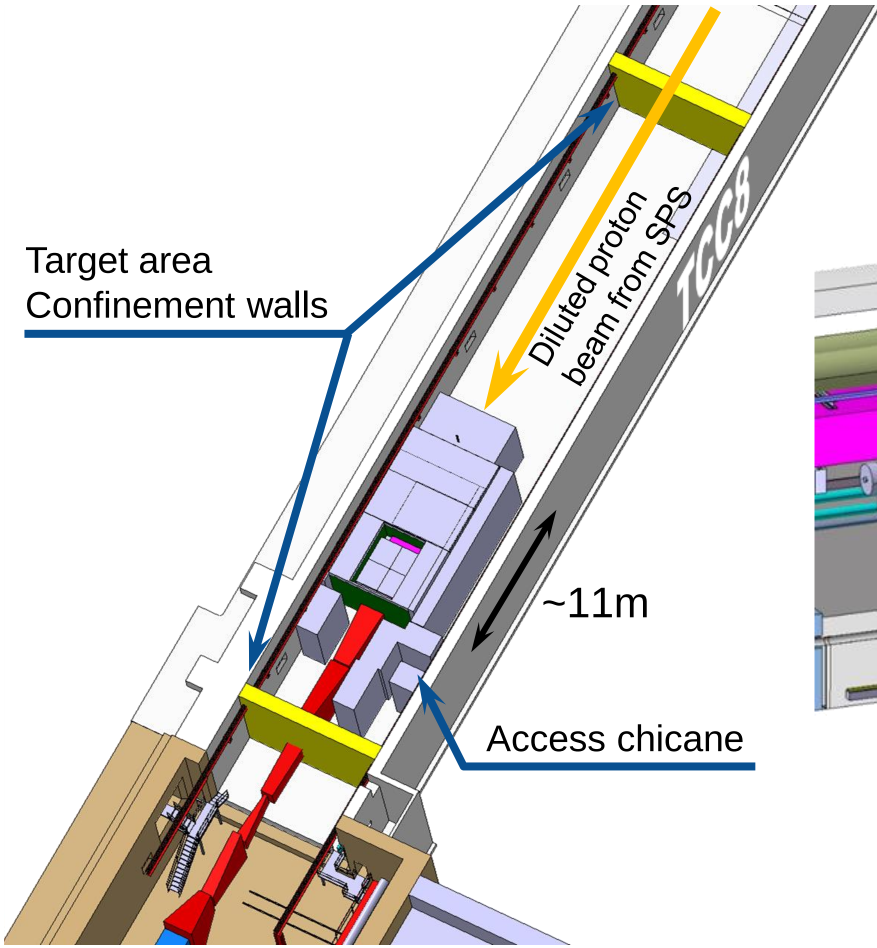
  ➔ Call for interest from groups in the community

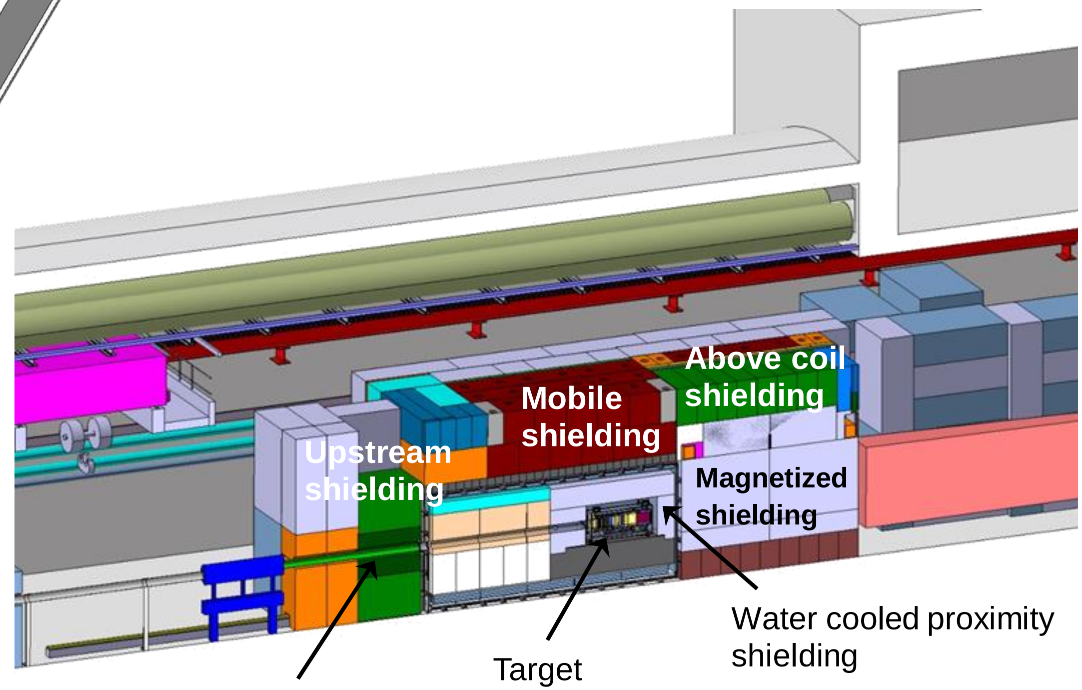
SHiP collaboration today: 40 institutes in 13 countries + CERN

SPARE SLIDES

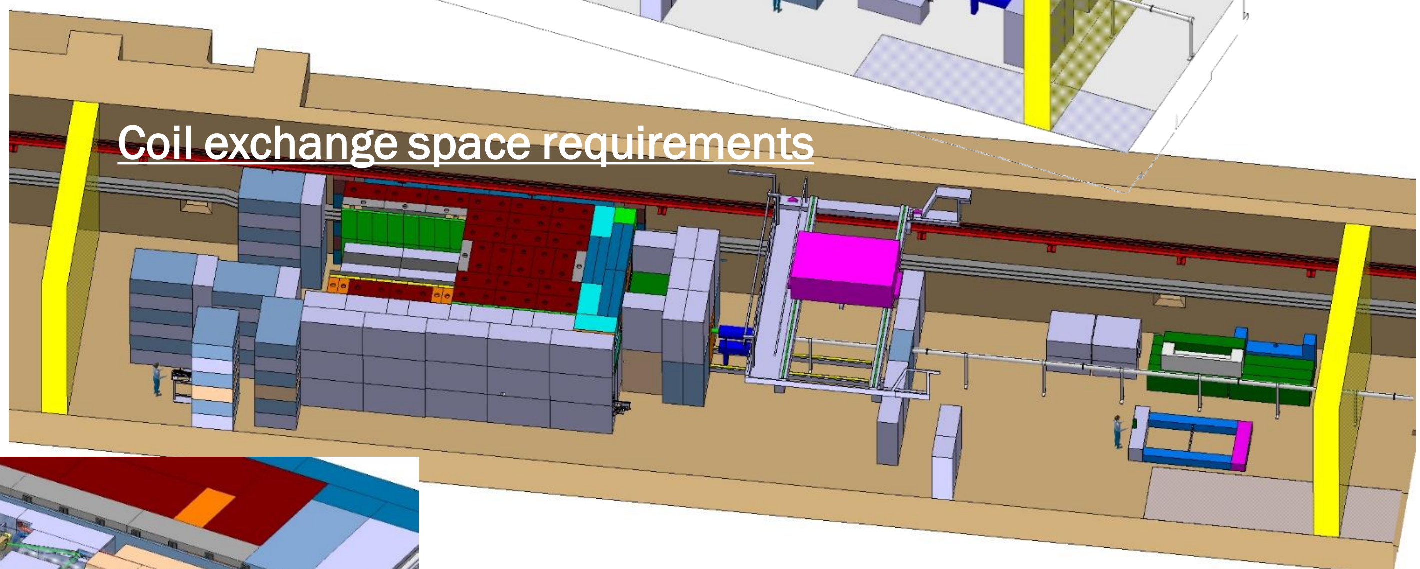
BDF/SHiP Target complex

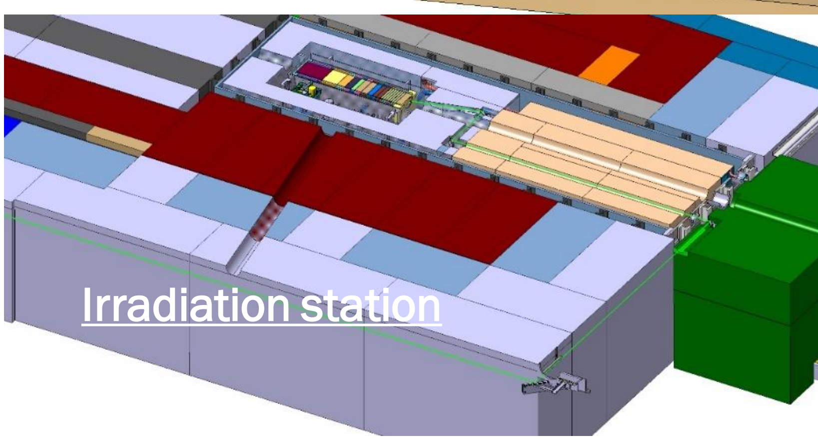
- Optimisation for implementation in target area TCC8 of ECN3
  - Optimisation of walled confinement of complex with dedicated ventilation
  - Nitrogen/vacuum as alternative to helium for inert gas embedding as for LBNF target station
  - Shielding optimization
  - Revised handling scheme with no overhead access shaft





BDF/SHiP Target complex

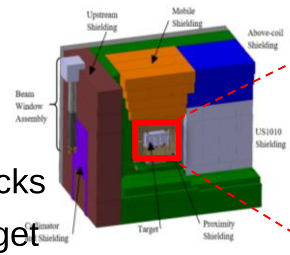


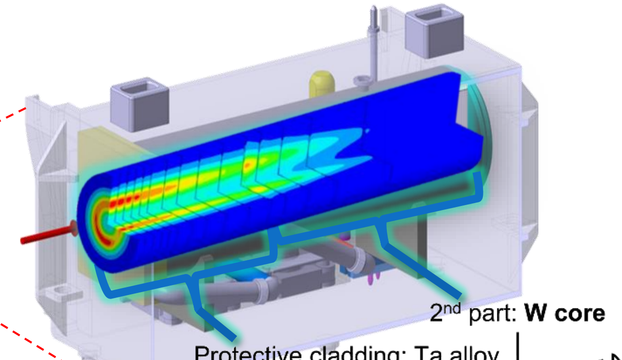


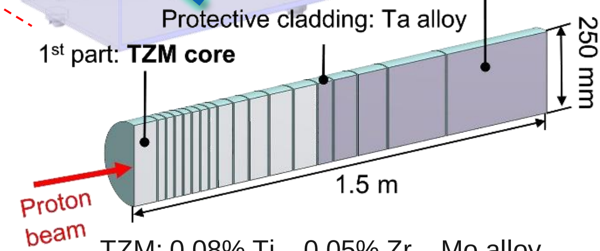
Collaboration on service cell design, service trolley, target design and annex, cladding R&D, exchange procedures, ALARA, reliable operation of target systems, etc

BDF/SHiP Target

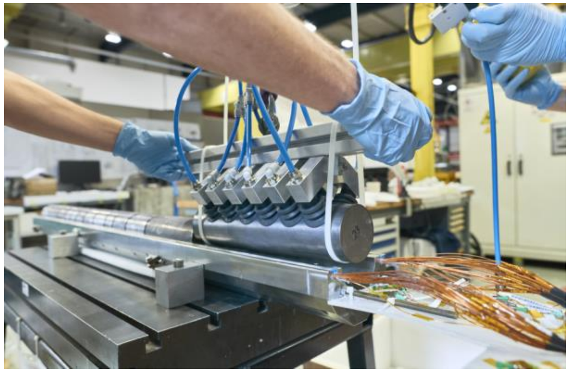
- Challenges
  - High A/Z target with high beam power of up to 2.56 MW during the 1 s spill and 320 kW on average
  - ➔ High-A/Z material resilience to high flow of cooling water
  - ➔ Target block cladding behaviour under thermo-mechanical stress
  - ➔ Integrated design of target assembly for fully remote handling

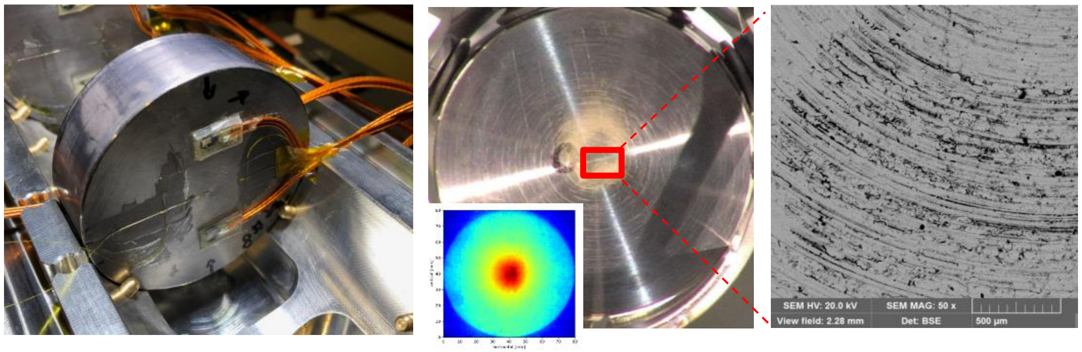






- Prototyping and beam test
  - Manufacturing validation of Ta-cladded W & TZM blocks
  - Reproduce thermo-mechanical conditions of final target
  - Cross-check FEM simulations
  - Test target online instrumentation
  - Perform detailed post-irradiation examination
  - Beam tests in 2018 with a total of 2.4 $\times 10^{16}$ protons on target
  - Good agreement with simulations



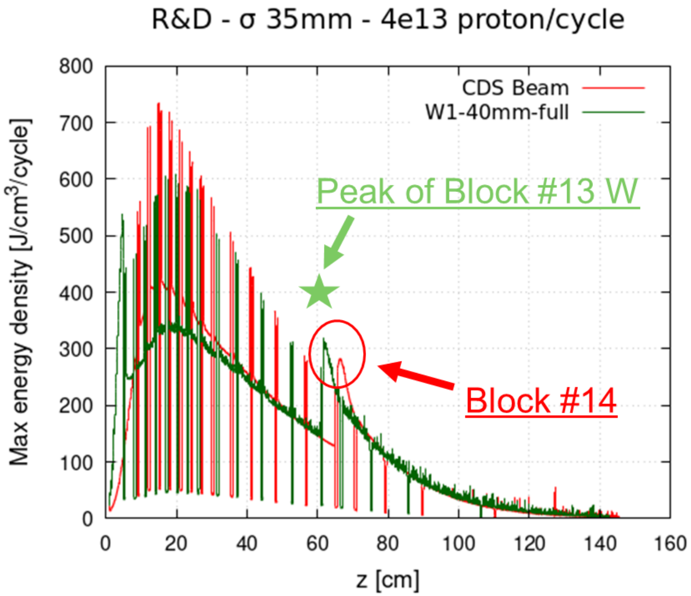


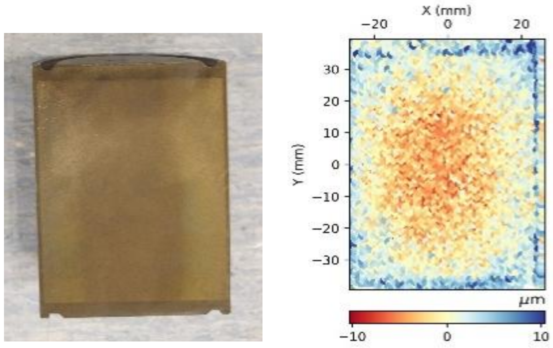
Prototype instrumentation. Visual and optical microscopy inspections during the PIE.

BDF/SHiP Target

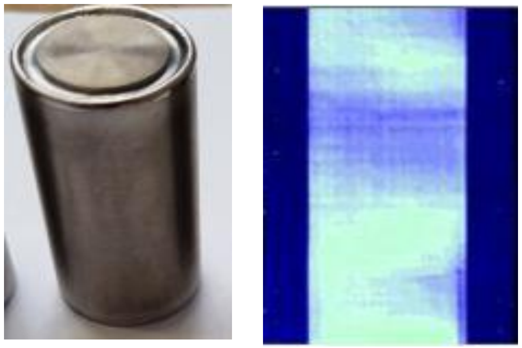
Ongoing activities

- PIE of the prototype target
  - Understand survivability of target materials & cladding-core bonding
- BDF Cladding R&D with Nb-alloys
- Loss-Of-Cooling Accident studies
- Cladding residual stress measurments
- Oxidation test campaign
- Pushing further target density





Residual stress measurements via the Counter method



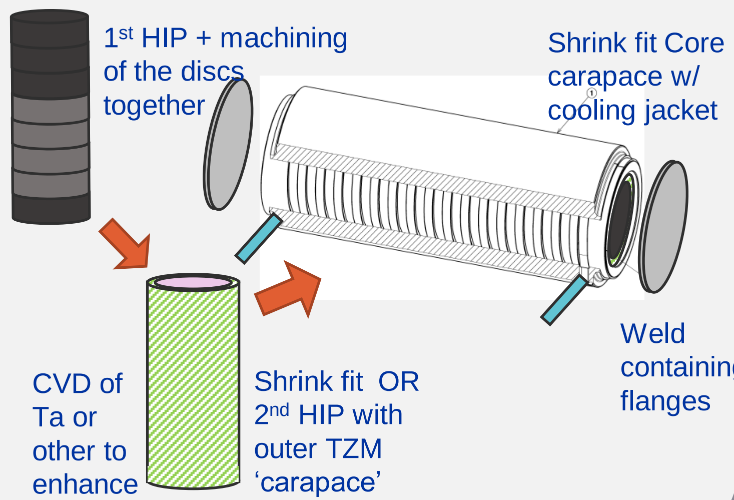
Successfully bonded Nb-alloy cladded block. UT imaging

Ta2.5W degradation at different temperatures under oxidizing atmosphere

BDF/SHiP target – new ideas

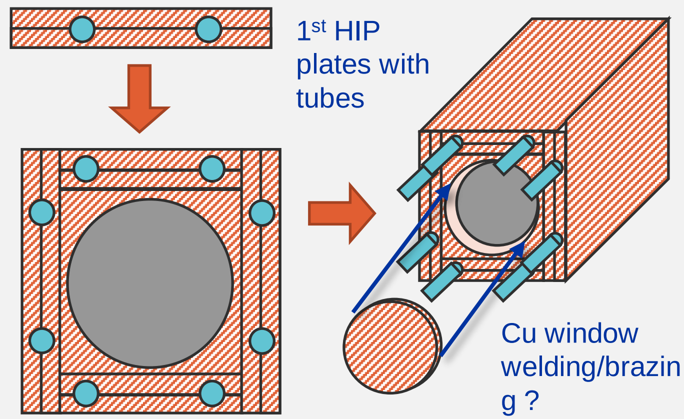
- No water gaps between TZM & W blocks → Compact target
- Highly confined core, possibly increasing thermo-mechanical robustness → more W
- Manufacturing know-how already existent → Not starting from unknown territory

The TZM Shroud Concept



L4 Dump-like cooling serpentine jackets (welded beforehand)

The HIPed Copper Concept



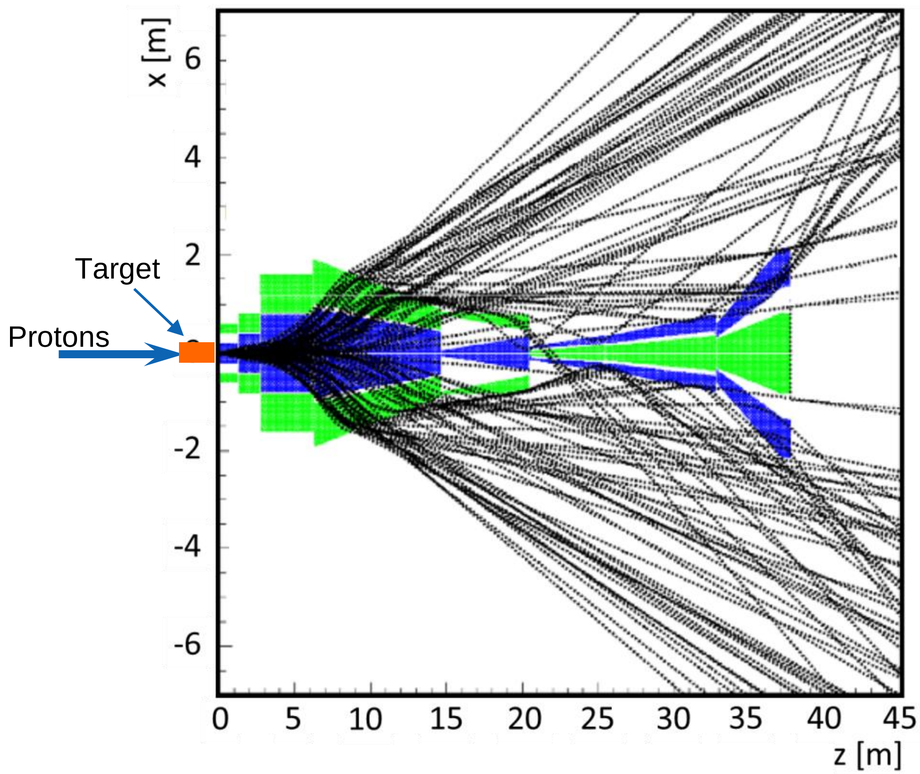
HIPed plates like SPS Main Dump TIDVG5

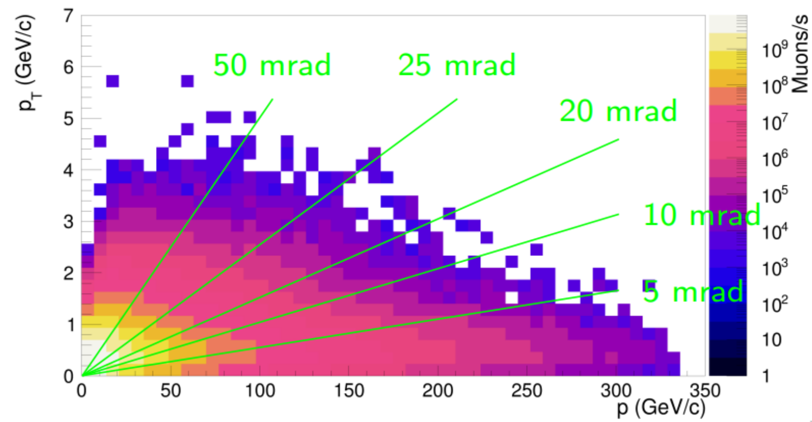
Muon shield

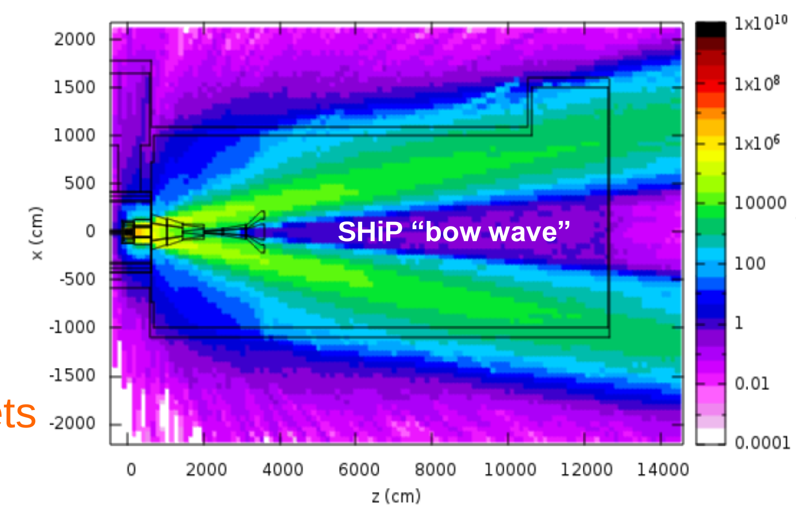
Pythia/Geant simulation (+GAN) with complete description of detector and infrastructure

Per spill of 4x10^{13} protons

- $\mathcal{O}(10^{10})$ muons (>10 GeV/c) ➔ Suppress by ~6 orders of magnitude by magnetic sweeper system



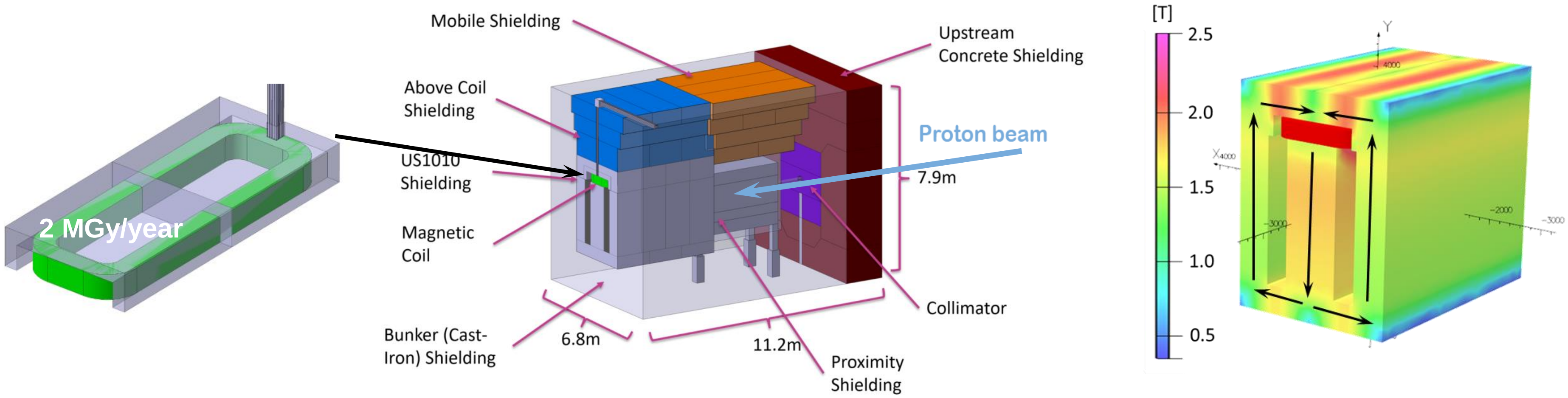




➔ Up to now “muon shield” based on resistive Ω magnets

Muon shield

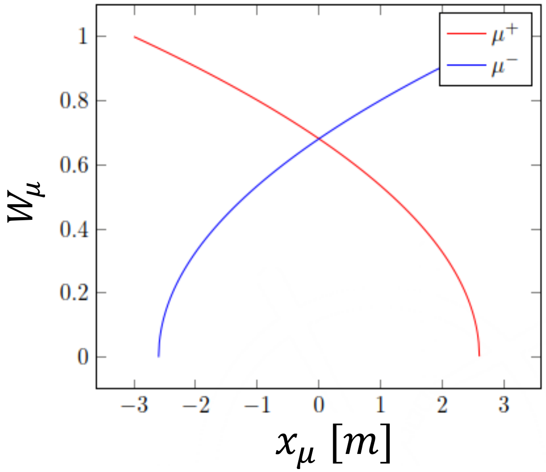
Magnetisation of hadron stopper (resistive coil)



- **Optimization of field configuration by Machine Learning** with large sample of muons simulated with PYTHIA/GEANT
  - Assumptions for resistive: 1.5 - 1.7 T field in core and 6 magnets of 5m starting length
  - Whole setup described by 43 parameters (upstream/downstream aperture height/width/length/gap)
  - Loss function

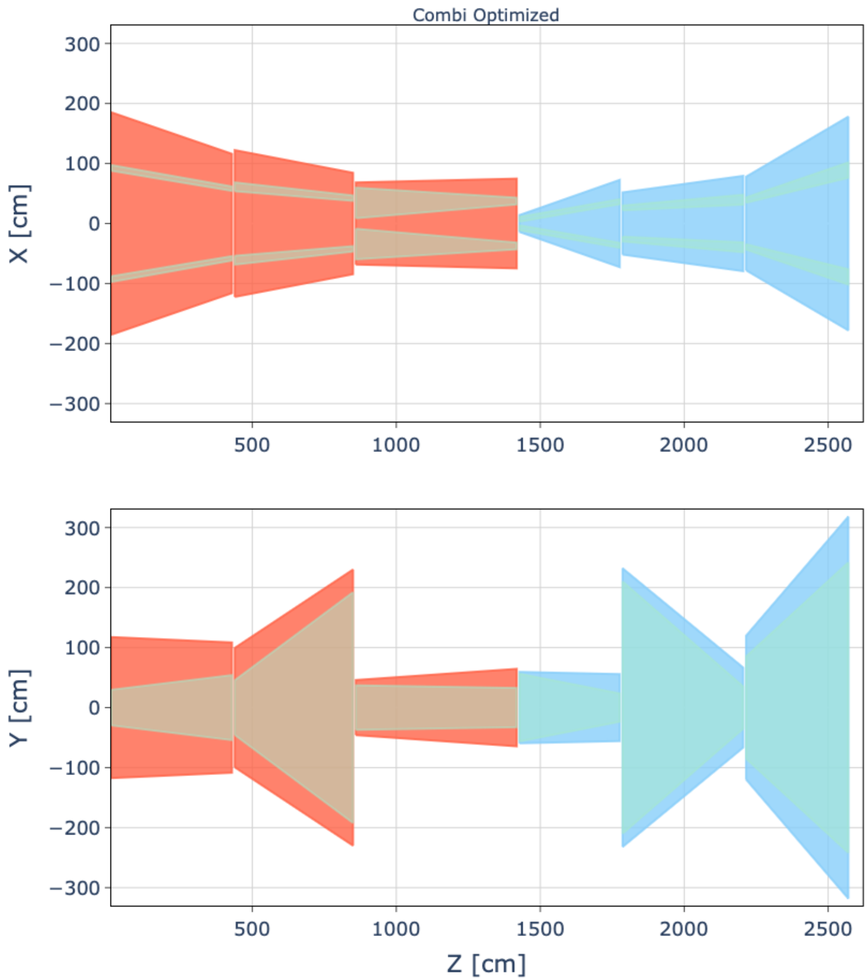
$$fcn = 1 + e^{10\times(M-M_0)/M_0} \times \left[1 + \sum_{\mu} W_\mu(x_\mu)\right]$$

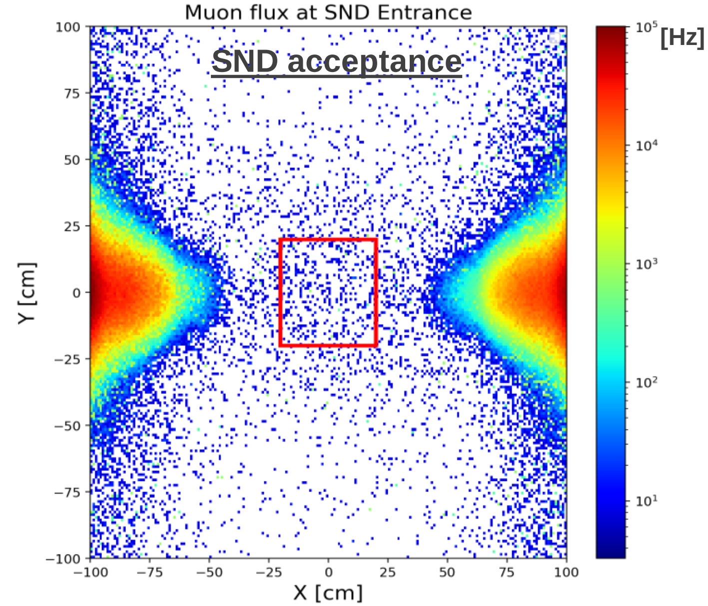
M weight of the muon shield
M_0 weight of the baseline
W_μ weighted position of muon μ at main tracker at position x_μ

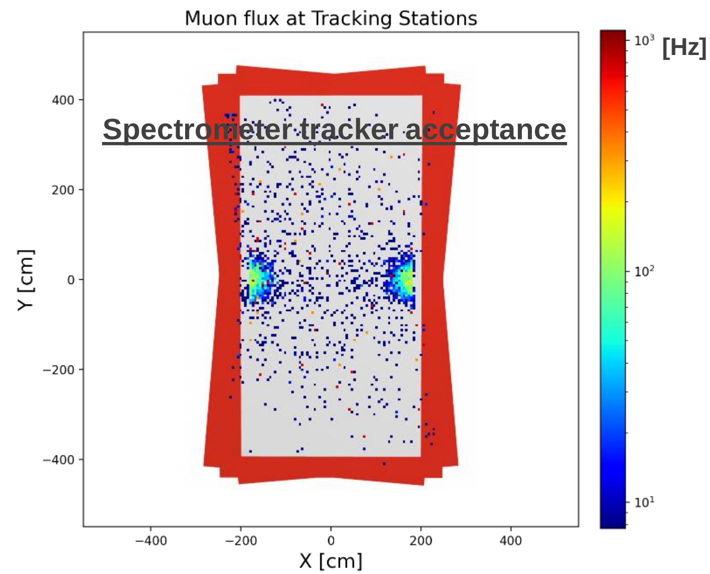


Resitive muon shield

- ECN3 Letter of Intent

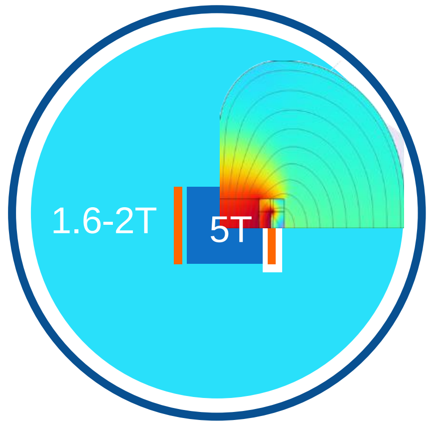




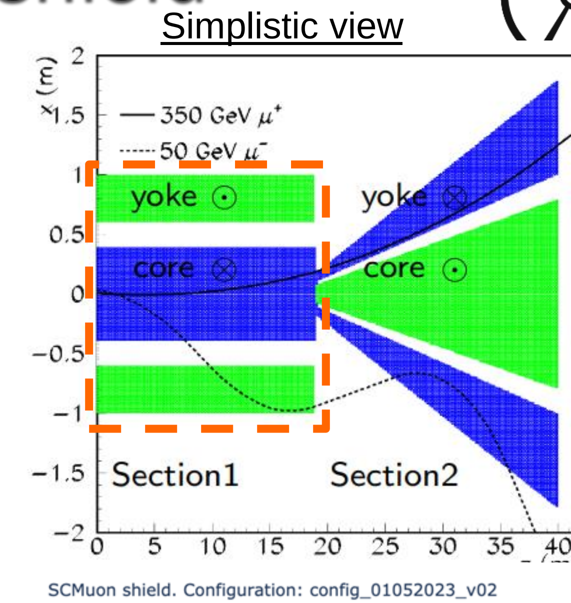


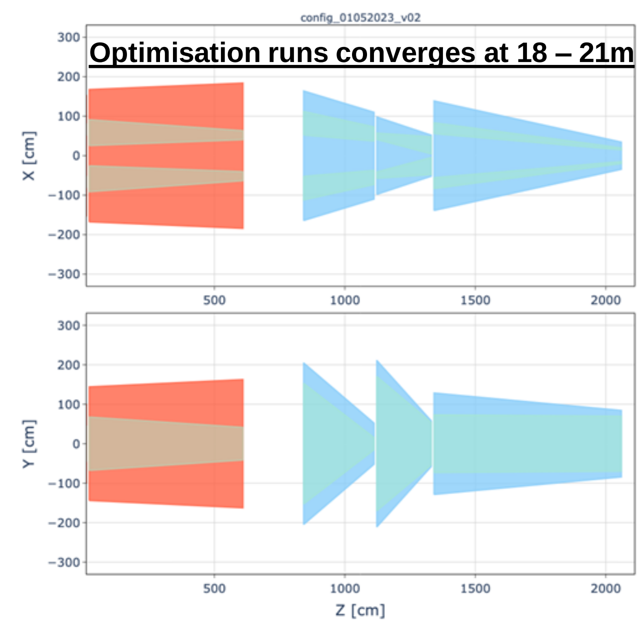
SC+Ω hybrid muon shield

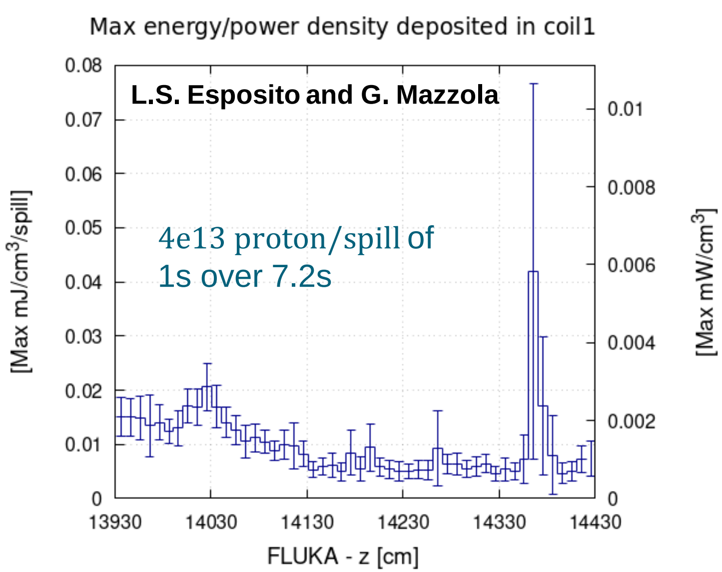
- Replace first half with SC magnet
  - Further reduction in length = closer/smaller detector
- Starting parameters:
  - Core aperture: 0.2 x 0.2 – 1.0 x 1.0 m^2 / tapered – dimensions subject to ML optimization (ongoing!)
  - **Iron core** field 5T over 4 – 8m
  - NbTi @ 4.5K
  - 50 – 100 A/mm^2
  - Virtually no beam induced heating
  - Fully contained or fringe field?
  - Cryostat around yoke or around coil?
  - 7 years to operation…
  - ➔ Challenge seems to be assembly



Simplistic view



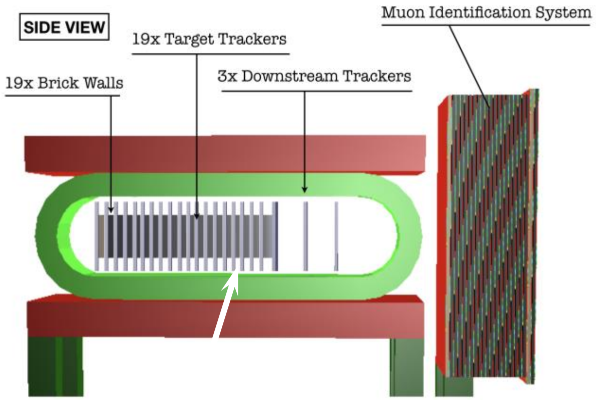


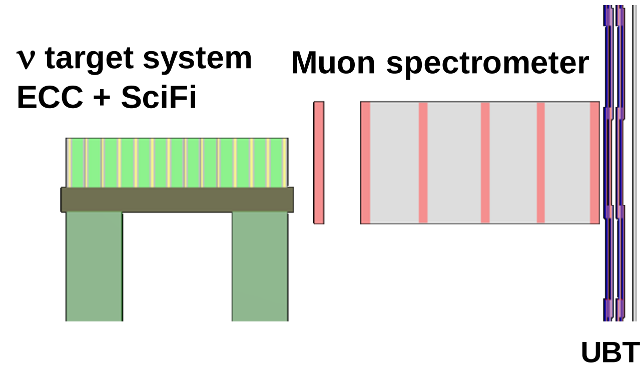


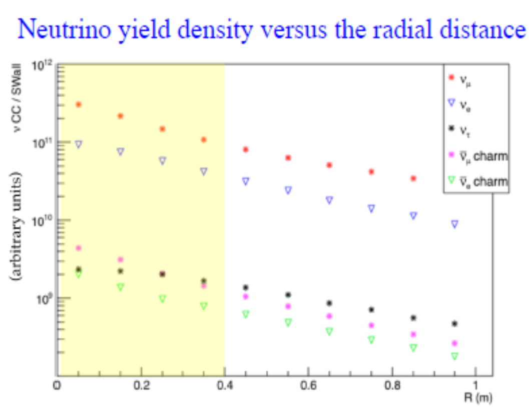
Feasibility studies ongoing in CERN EP and TE-MSC

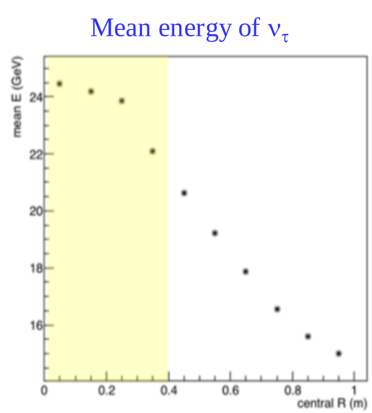
Scattering and neutrino detector

- Revised configuration
  - Magnetisation of muon system (ECN3) instead of target system (ECN4)

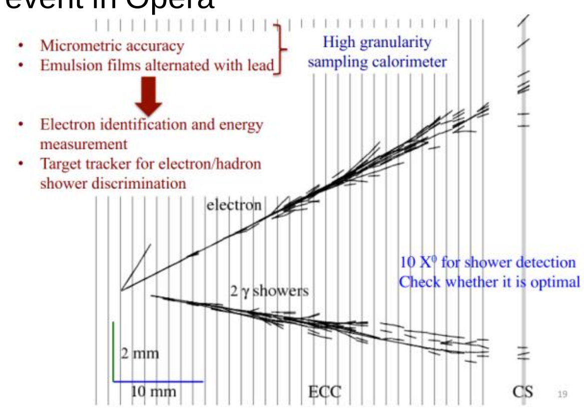








ν_e event in Opera



ECN3/ECN4 ν yield and track density of up to $6\times10^5/cm^2$ from SND@LHC experience:

- ECN4 (CDS): 8 tonnes with 2 replacements per year
- ECN3 LoI closer setup: 4.5 tonnes with 2 to 4 replacements per year → on average less emulsions

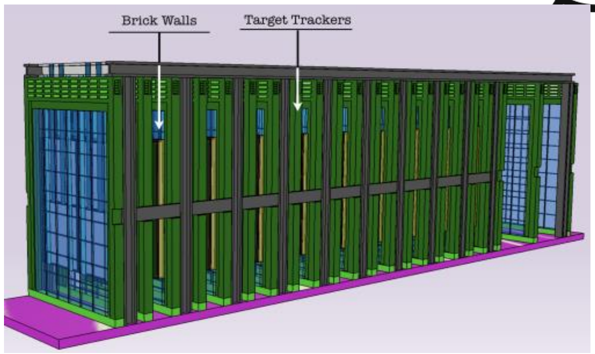
SND ECC + Target tracker

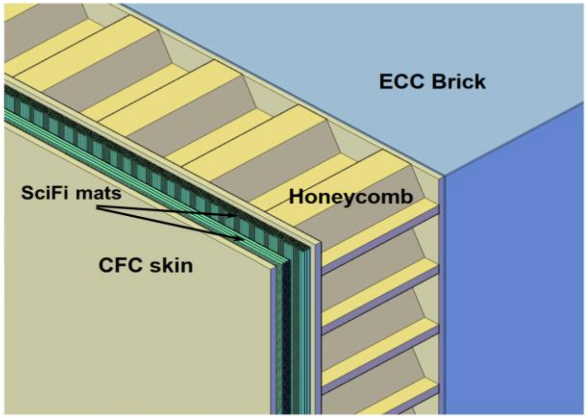
- Purpose: Neutrino/LDM vertex detector and neutrino energy with hadrons and electrons

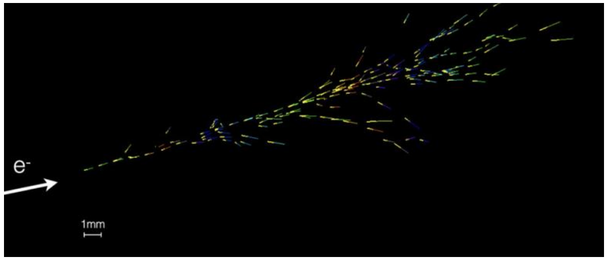
- Emulsion Cloud Chamber brick characteristics
  - Bricks of 40x40 cm^2
  - Thickness ~8 cm (57 films/lead plates → ~10 X_0)
  - Weight ~100 kg
  - Scanning speed 200 cm^2/h, 10x faster than Opera

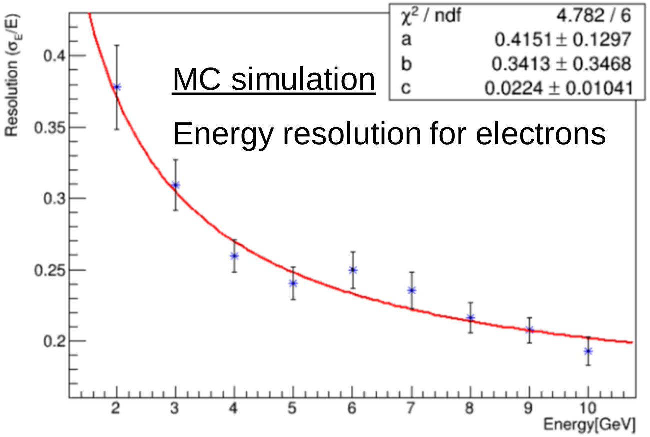
- SciFi target tracker characteristics
  - $\sigma_{x,y}$~30-50 μm resolution
  - Six scintillating fibre layers, total 3mm thickness ~ 0.05 X_0
  - Multi-channel SiPM at one end, ESR foils as mirrors on other
  - Time resolution <0.5ns
  - Extended with silicon (study in SND@HL-LHC)?

- Emulsion + TT beam test at DESY in 2019
  - Emulsion: electron identification and directionality
  - Emulsion + TT: Electron energy and time resolution



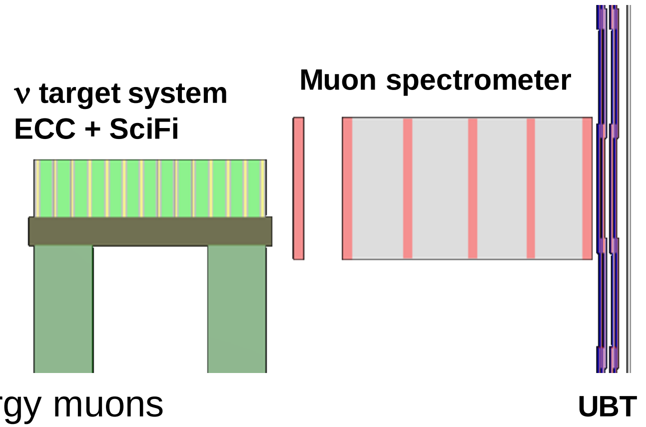


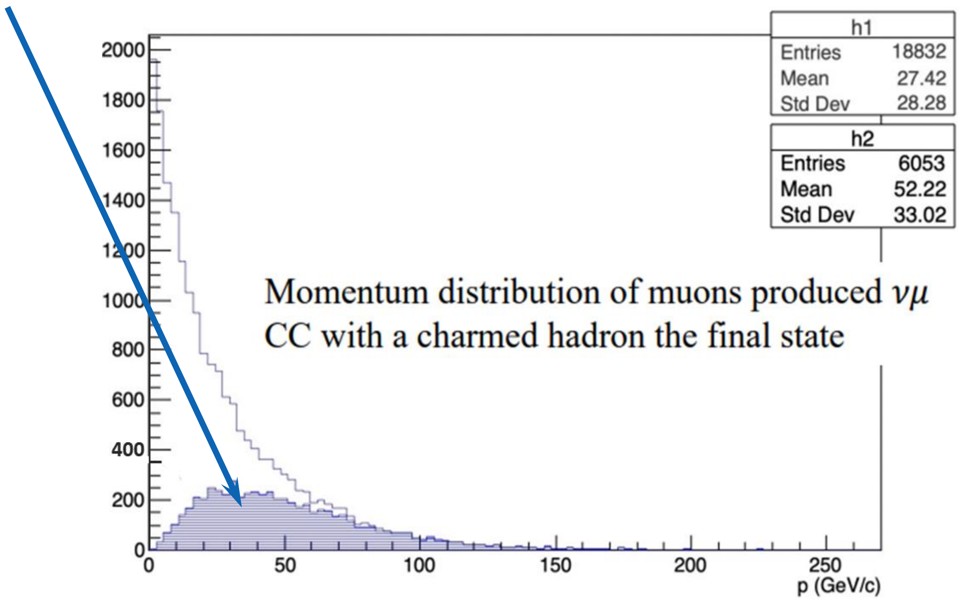




SND Muon spectrometer

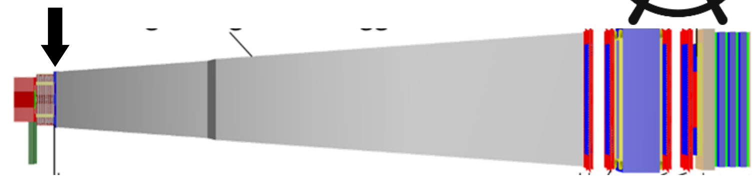
- Purpose: Track and identify muons, measure charge/momenta
- Magnetised air/iron over ~3m with ~1 T
- Momentum coverage split in two/three momentum ranges
  - Position resolution of ~100 μm
  - Hidden sector acceptance is about 1/3 and correlated with high energy muons





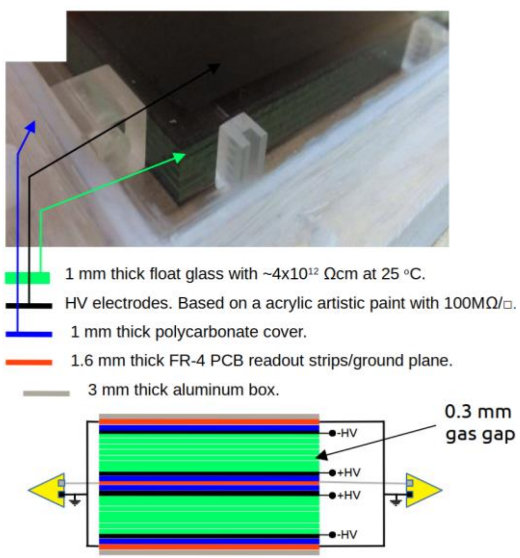
➔ Possible detector options with drift tubes or SciFi

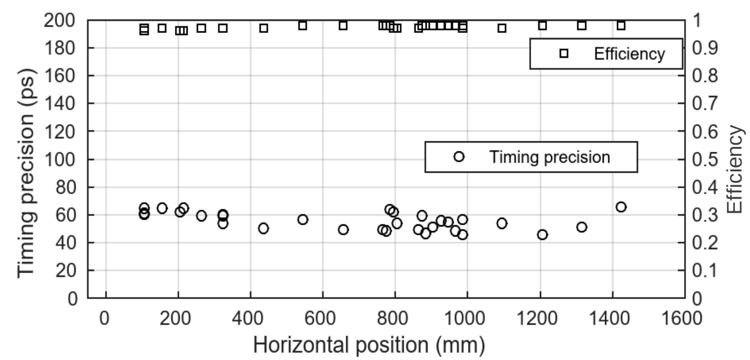
Upstream Background Tagger

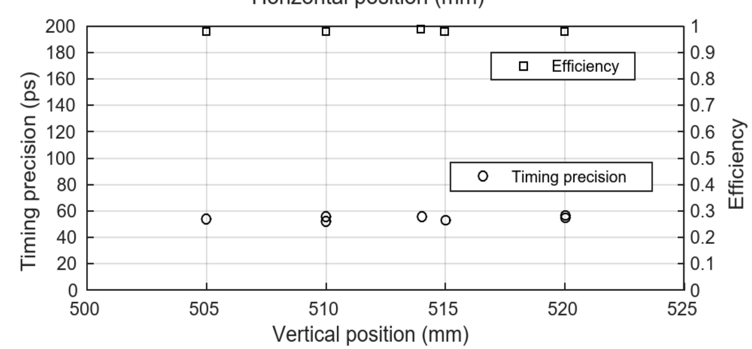


- Purpose: Veto in front of decay volume
- Characteristics with 3-layer MRPC
  - Multi-gap RPC structure: six gas gaps defined by seven 1 mm thick float glass electrodes of about 1550 × 1250 mm², separated by 0.3 mm nylon mono-filaments
  - Two identical sensitive modules sandwiched with a plane of pick-up electrodes, consisting of 1600×30 mm² Cu strips

2m² prototype in beam test at PS







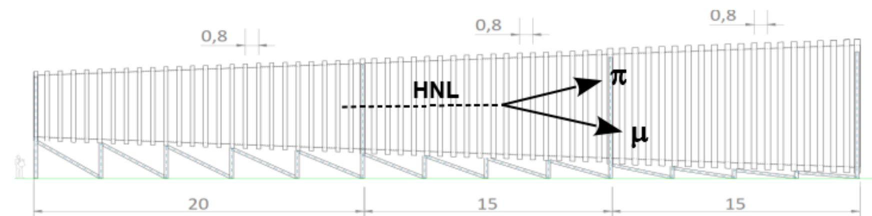
HS Decay volume

Per spill of 4x10^{13} protons

- 9 ×10^{11} neutrinos and 6x10^{11} anti-neutrinos ➔ Suppress to <10 interactions per spill with decay volume under vacuum

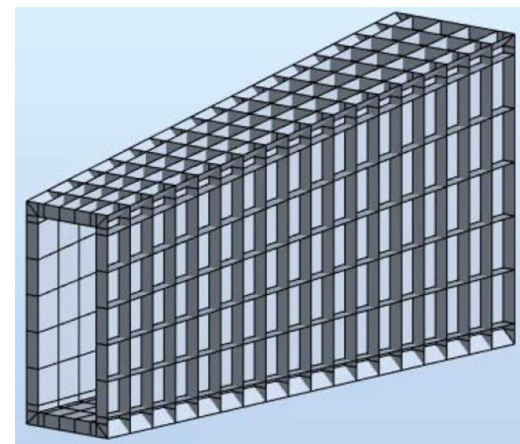
➔ Evacuated to ~mbar air – ~bar He

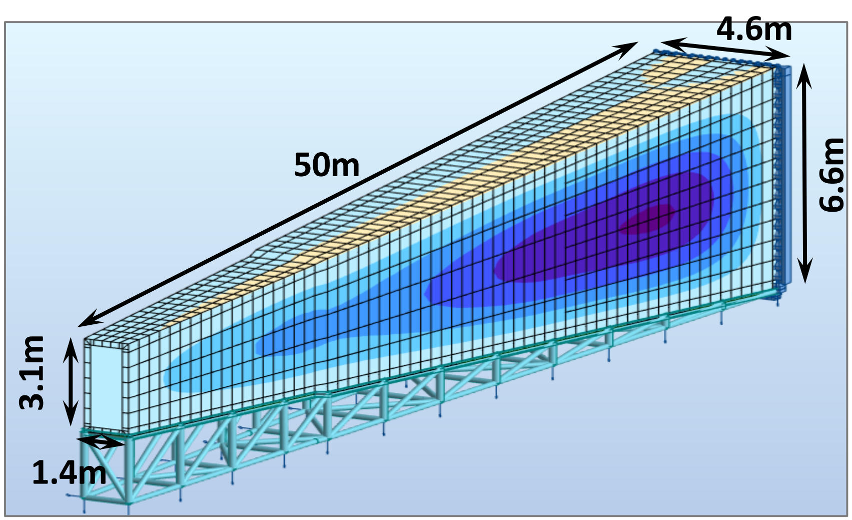
➔ Liquid scintillator veto in surrounding compartments

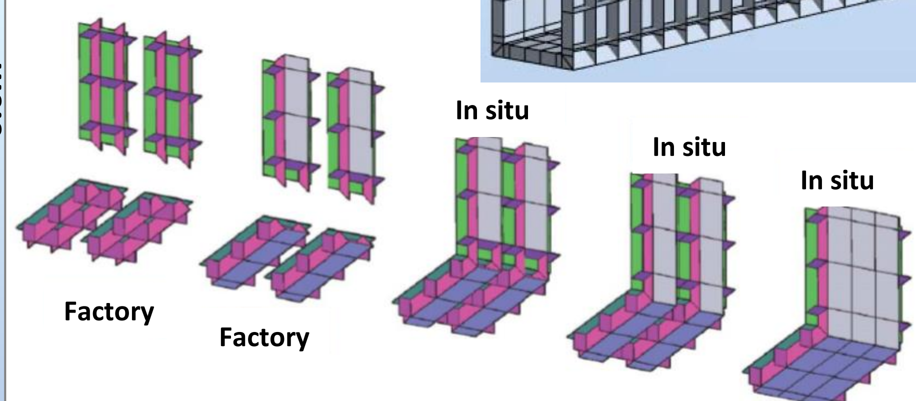


- Design constraint:
  - Thin and light wall structure

  ➔ Designed with S355JO(J2/K2)W steel according to EN 13445 Part 3-Section 8 and seismicity

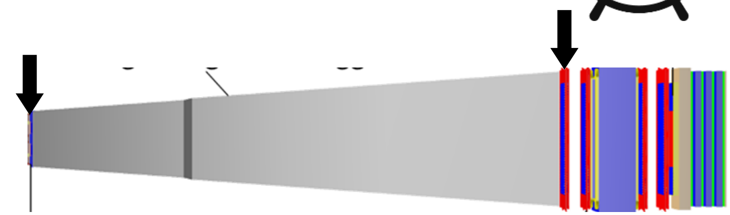


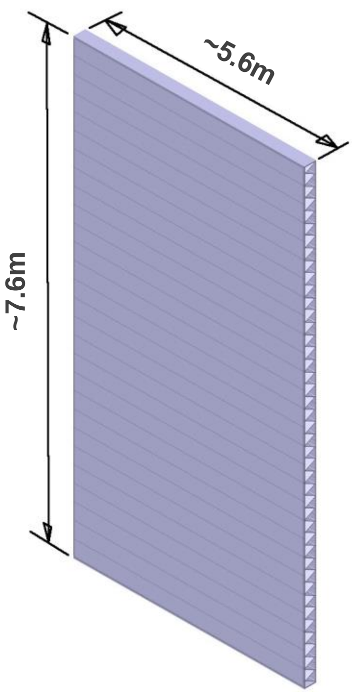


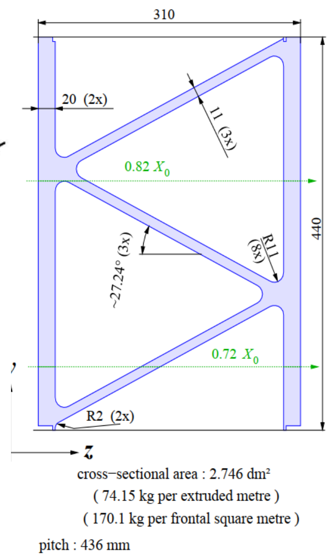


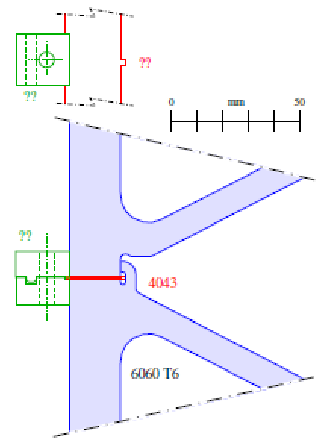
HS Vacuum vessel caps

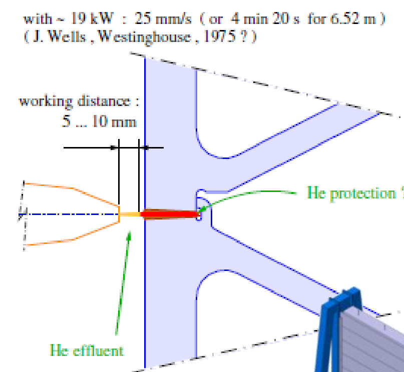
- Front- and end-cap of as low material budget as possible
  - Front: neutrino/muon interactions
  - End: performance of timing detector and calorimeter
- Current idea: 0.8 X_0 extruded Al-6060/T6 aluminium profiles

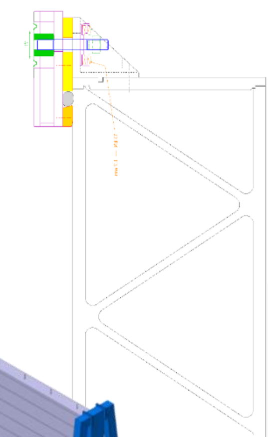


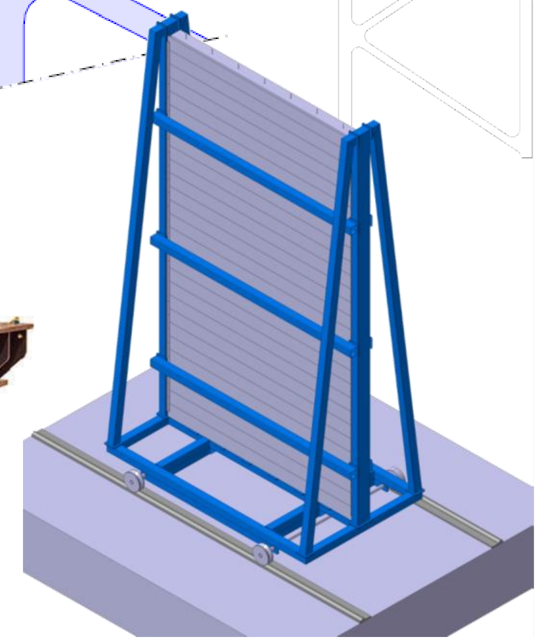










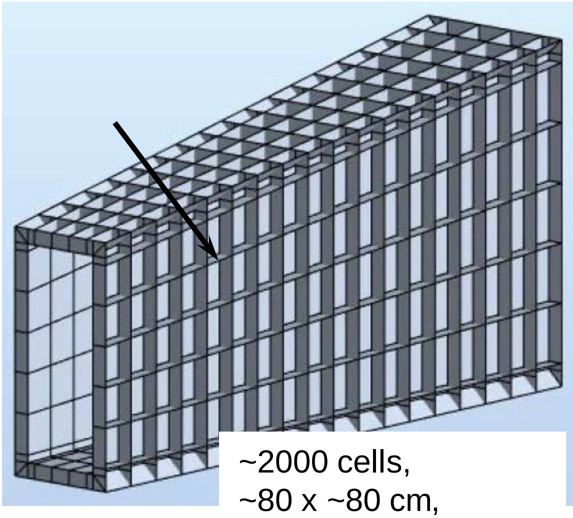


- Challenging manufacturing – in situ
  - Several techniques investigated
  - Non-vacuum electron beam welding (EBW) most obvious
  - ➔ Contact with Steigerwald Strahltechnik GmbH
  - ➔ Gun available at Hannover (contacted) and Achen universities

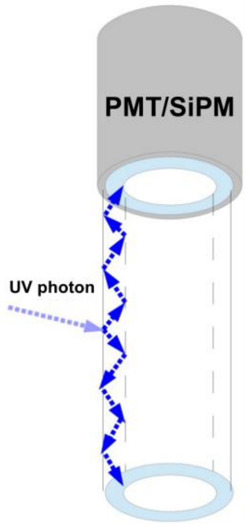
HS Surrounding Background Tagger

- Purpose: Tagging charged particles entering decay volume and tagging ν and μ interactions in the vacuum chamber walls
  - ➔ >99% efficiency and ~1ns time resolution

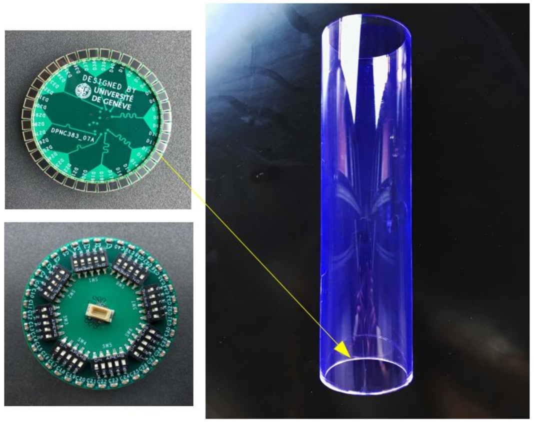
- Characteristics
  - Liquid scintillator based: linear alkylbenzene (LAB) together with 2.0 g/l diphenyl-oxazole (PPO) as the fluorescent
  - WOMs with SiPM readout Hamamatsu S14160-3050PE (40x 3x3mm²) and surrounded by PMMA vessel
  - Thickness 20cm
  - Total quantity 160 m^3 / 130 tonnes



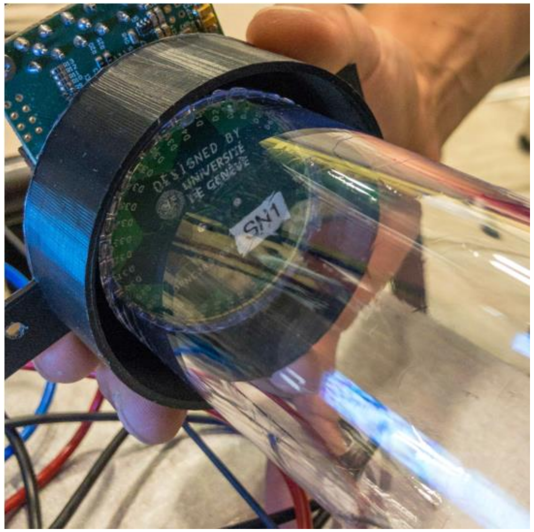
~2000 cells,
~80 x ~80 cm,
thickness ~20cm

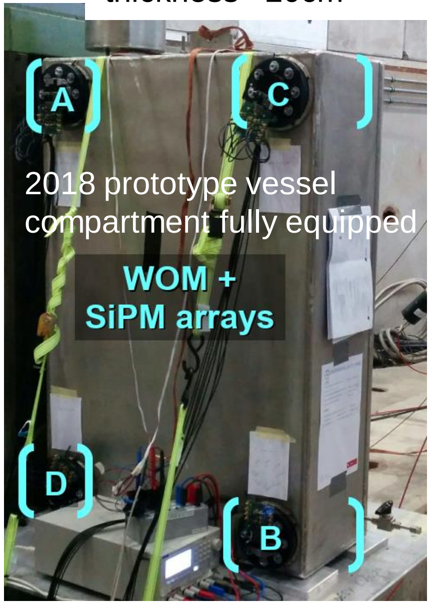


WOM w/o lightguide



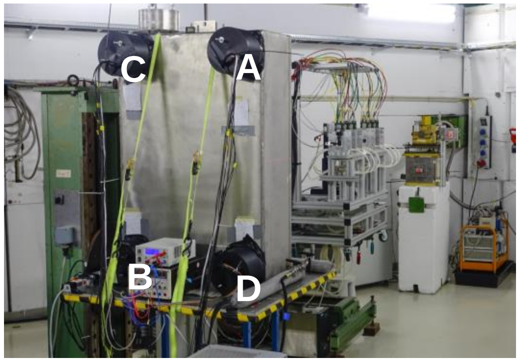
40-SiPMs array
built by Geneva

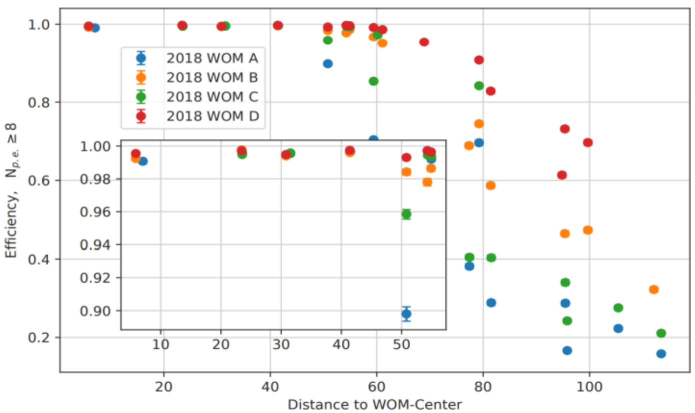


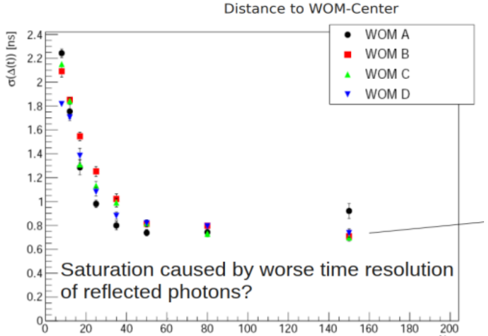


HS Surrounding Background Tagger

'Prototype 0': 2018 test beam results







'Prototype 1':

- 240 litre cell: Corten steel
- $BaSO_4$ reflective coating
- LHS prototype
- Improved mechanical & optical coupling
- 2 WOMs (SiPM readout)

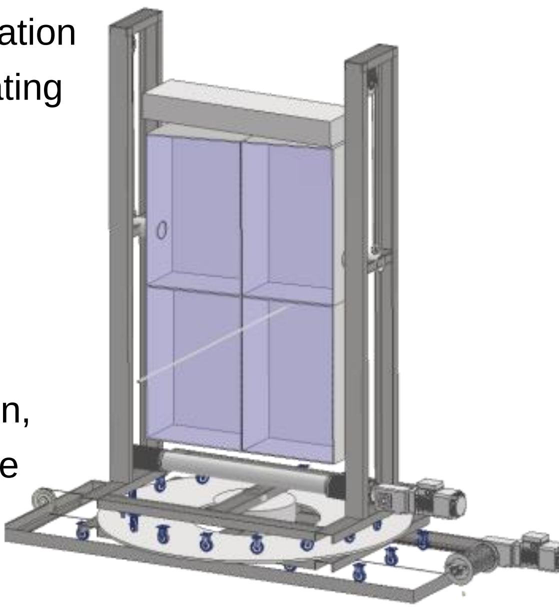
➔2022 DESY: e-

'Module 0' – 4-cell demonstrator

- LS handling system
- Improved mechanical integration
- Optimised cell reflective coating
- Updated readout & DAQ
- Multi-dimensional event reconstruction:

➔CERN test beam: 2023-Q4

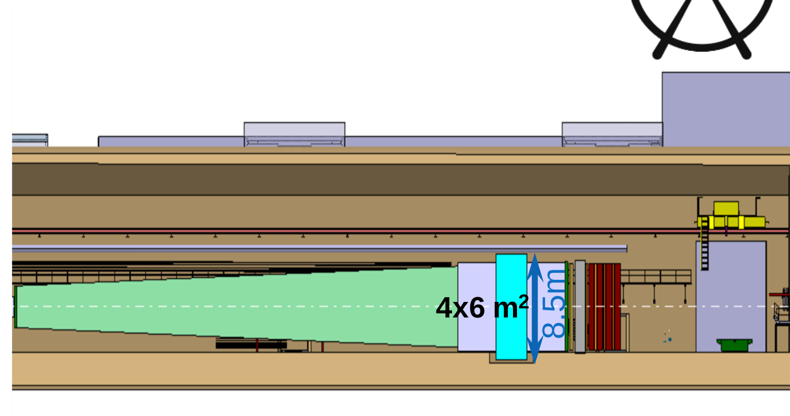
- Light yield, energy deposition,
- spatial information, incidence angle...



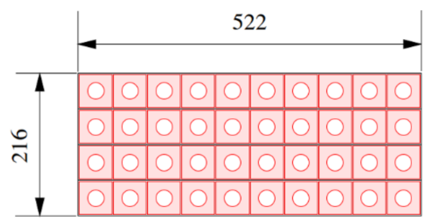
➔ >99% efficiency (>45 MeV deposited), time resolution of 1 ns

SHiP spectrometer section

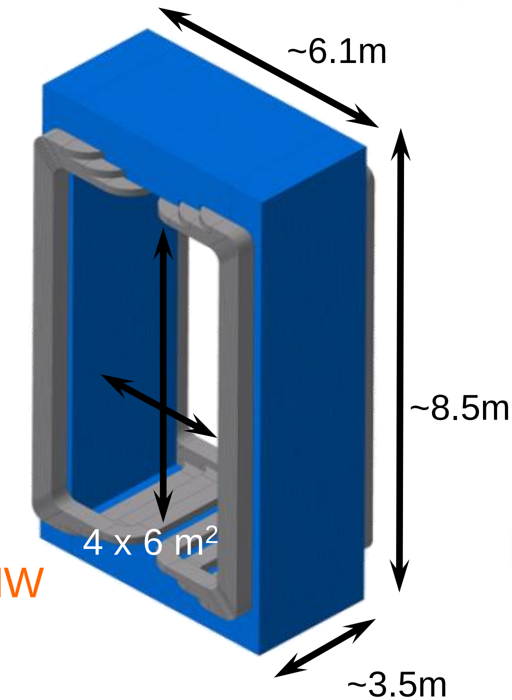
- Initial studies with aperture 5x10m^2 ➔ now 4x6m^2
  - H. Bajas, D. Tommasini, EDMS 2440157 (21 April 2020)
  - P. Wertelaers, CERN-SHiP-INT-2019-008

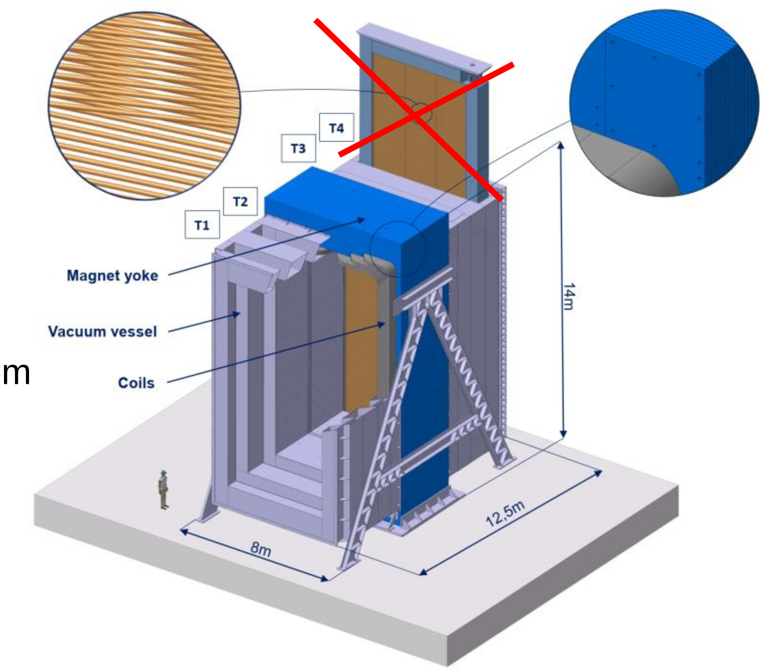


- Requirements:
  - Physics aperture 4 x 6 m^2
  - Bending field 0.6-0.7 Tm , nominal on axis ~0.15T
  - Integration of vacuum chamber



Coil's cross-section
Aluminium hollow conductor



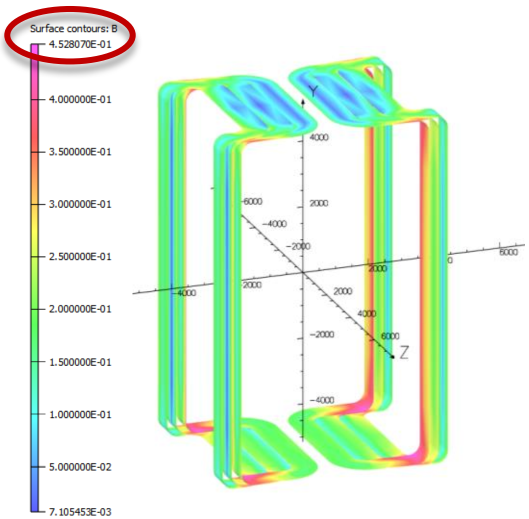


- Resistive baseline option 0.5 MW

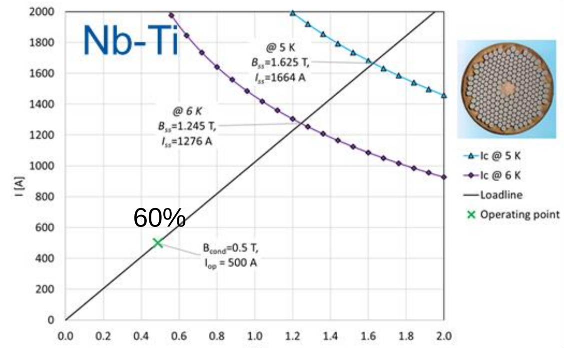
- What about superconductive with coil of same dimensions?

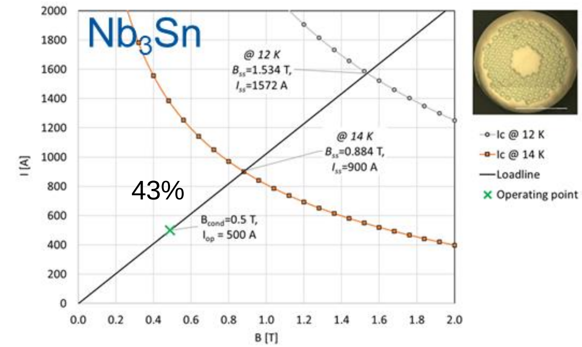
“Super-copper”

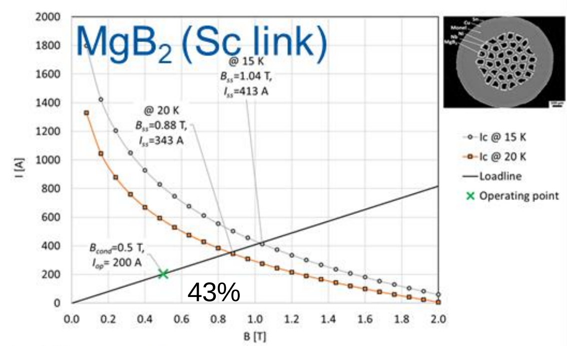
- H. Bajas, D. Tommasini, EDMS 2440157 (21 April 2020) - study of NbTi or Nb3Sn or MgB2 or ReBCO

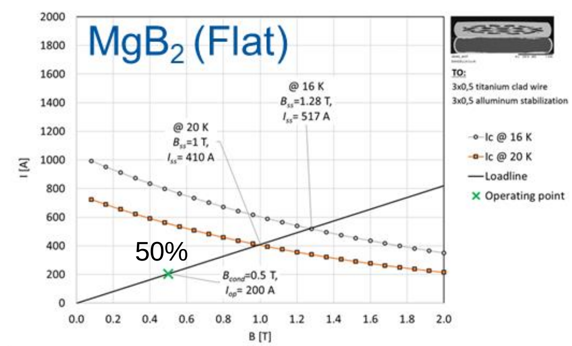


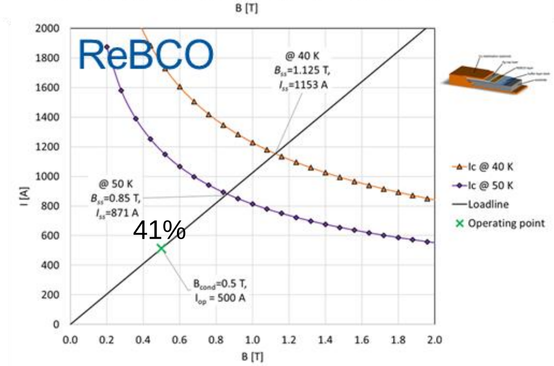
B_{peak} of 0.5 T ➔ NI_{tot} = 360 kA.turn

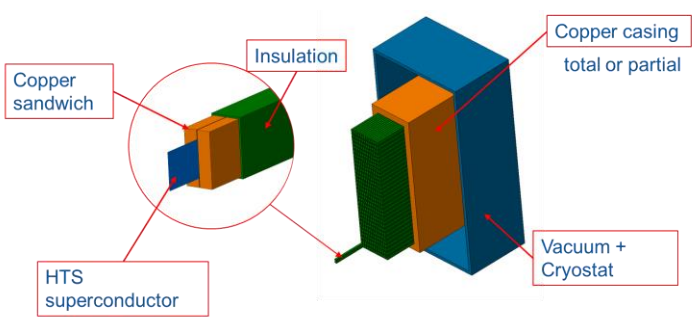








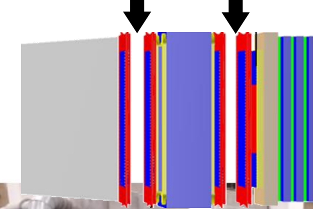




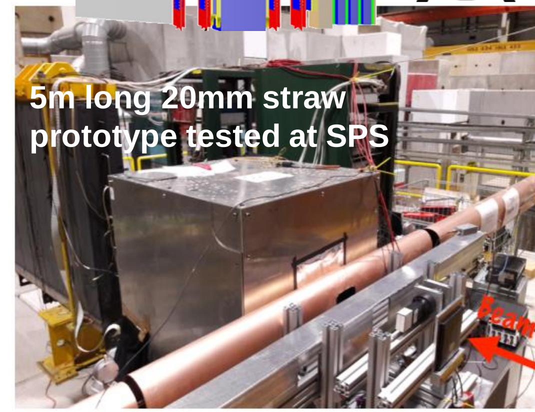
Courtesy Philip Schwarz, April 2019

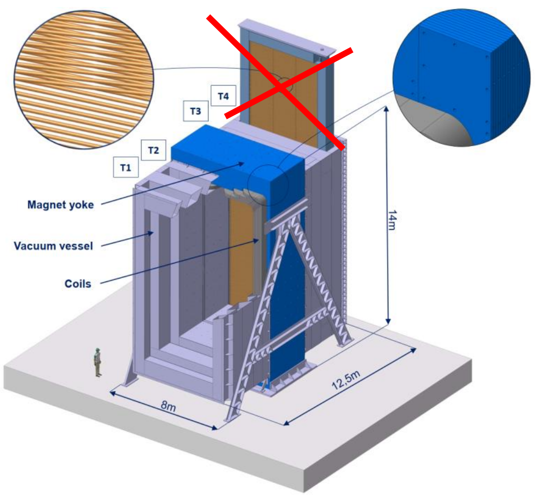
- Existing and future spectrometer magnets with large apertures will be required for many years to come!

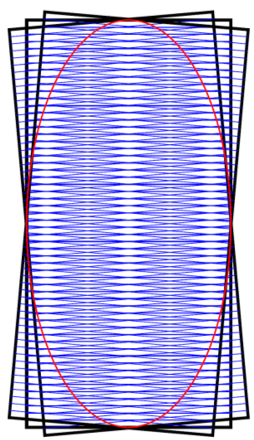
HS Straw Tracker

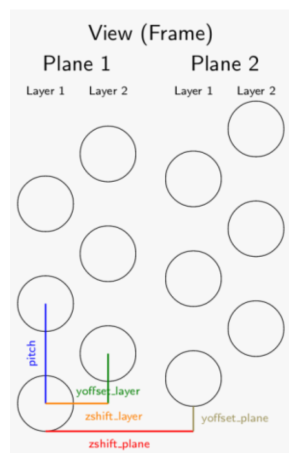


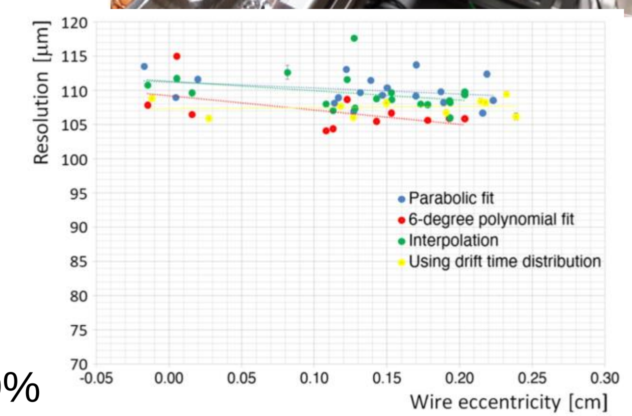
- Purpose: Track reconstruction and momentum, reconstruction of origin of neutral particle candidate. Match hits in timing detector
- Technology developed for the NA62 experiment
  - ➔ SHiP strategy: decoupling supporting frames from vacuum envelope
  - ➔ Horizontal orientation of tubes ➔ mechanical challenge
  - ➔ Lower rate allows increasing straw diameter (highest rate ~10 kHz)
- Characteristics
  - 4 x 6 m^2 sensitive area
  - 5m long 20mm diameter 36µm thick PET film coated with 50nm Cu and 20nm Au operated at 1 bar, produced and tested
  - Four stations, each with four views Y-U-V-Y, ~9600 straws





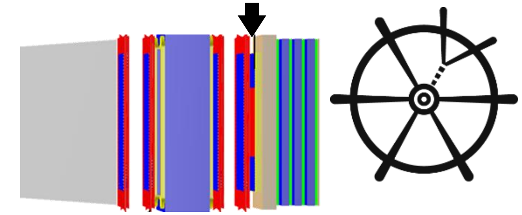






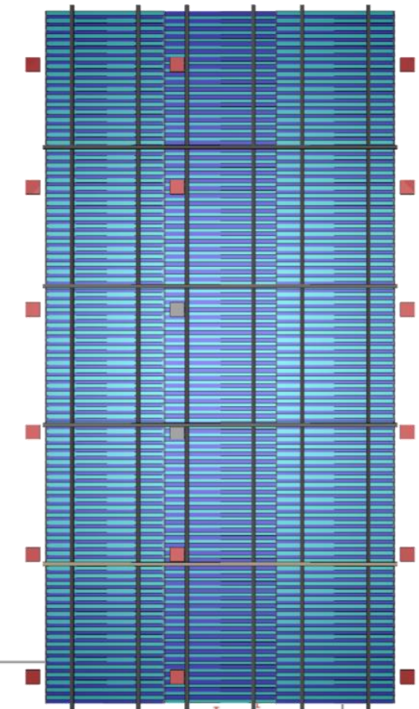
Test beams confirm 120µm hit resolution with hit efficiency >99%

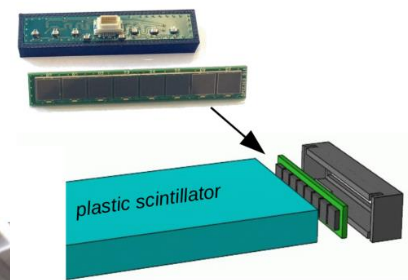
HS Timing Detector



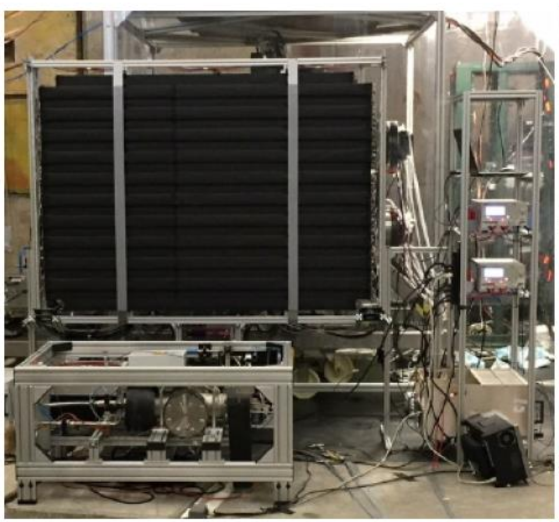
- Purpose: Provide precise timing (<100 ps) of each track to reject combinatorial background

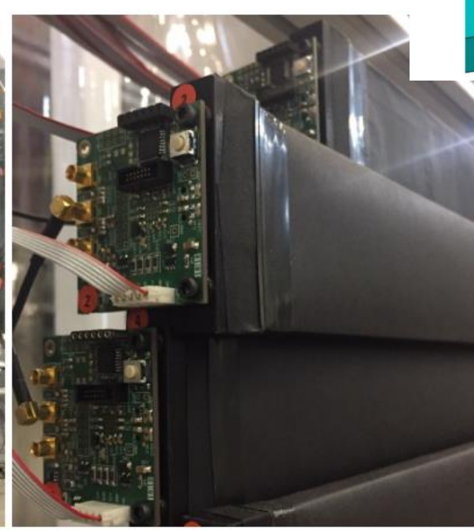
- Plastic scintillator characteristics
  - Three-column setup with EJ200 plastic bars of 135cm × 6cm × 1cm, providing 0.5cm overlap
  - Readout on both ends by array of eight 6×6 mm^2 SiPMs, 8 signals are summed
  - 330 bars and 660 channels

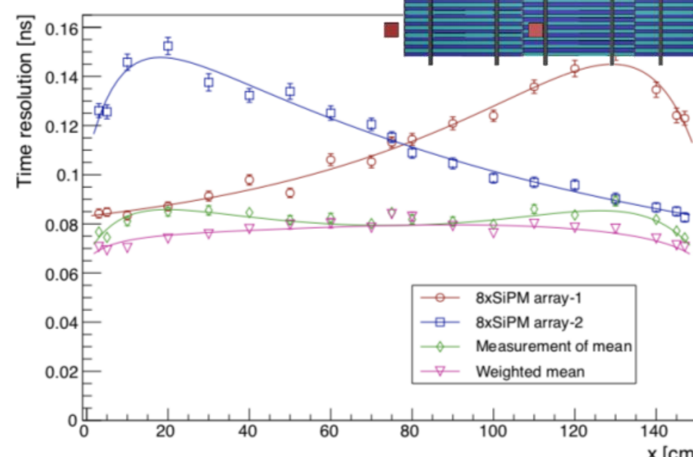




22x 168cm bar (44 channels) prototype tested at PS

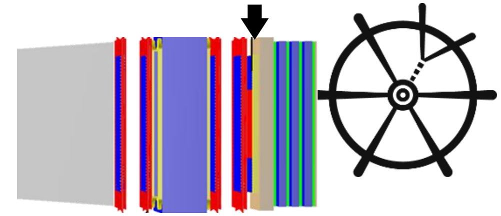






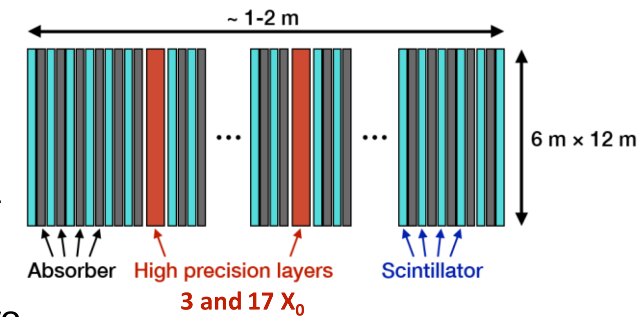
Resolution demonstrated to be ~80 ps along the whole length of the bar and over 2m^2 prototype

HS ECAL ("SplitCal")

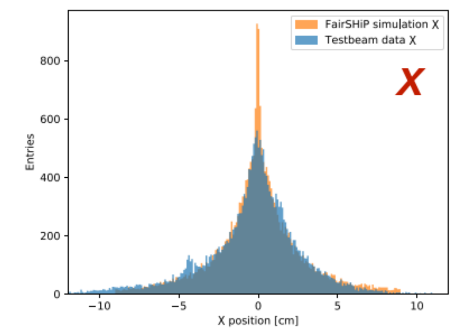


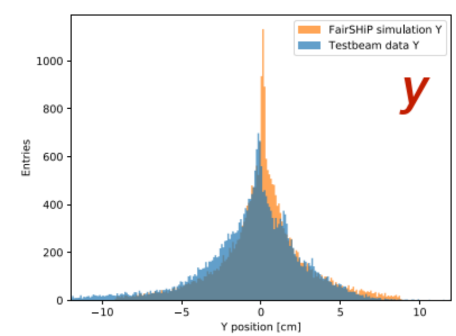
- Purpose: e/γ identification, π^0 reconstruction, photon directionality ~5mrad for ALP→ $\gamma\gamma$ (coincidence timing)
- Characteristics
  - 25 X_0 longitudinally segmented calorimeter with coarse and fine space resolution active layers
  - Coarse layers: 40-50 planes of scintillating bar readout by WLS + SiPM (0.28cm / 0.5X_0 lead + 0.56 cm plastic)
  - Fine resolution layers: 3 layers (1.12cm thick), first at 3X_0, and two layers at shower maximum to reconstruct transverse shower barycentre, with resolution of ~200μm micro-pattern or SciFi detectors, to provide photon angular resolution.

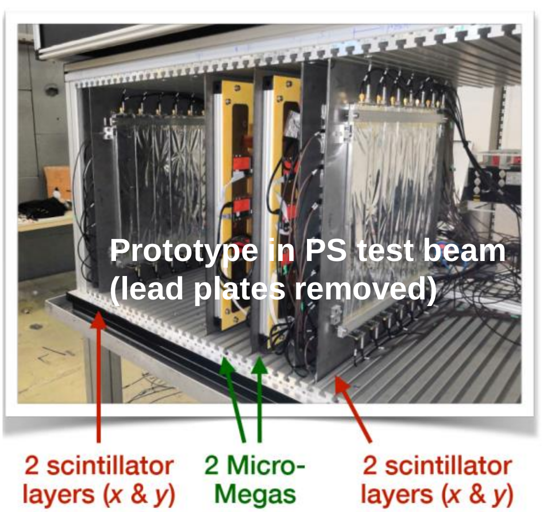
➔ 3 mrad for 20 GeV, 5 mrad for 10 GeV and 9 mrad for 6 GeV photons

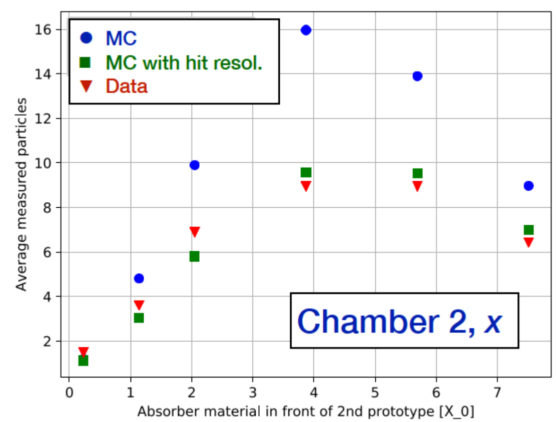


2.1 X_0







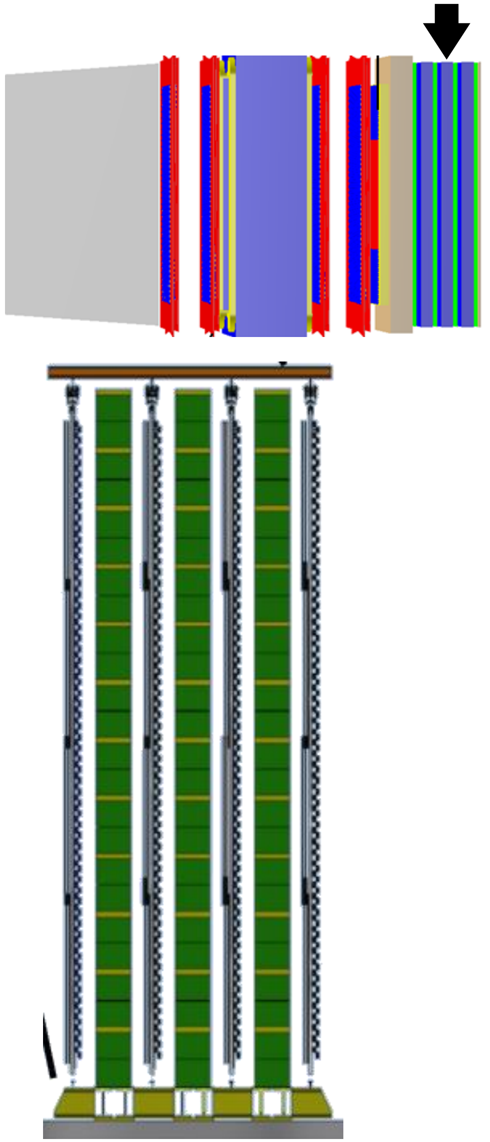


Reconstruction challenge: satellite showers in the long transverse tails

HS Muon system

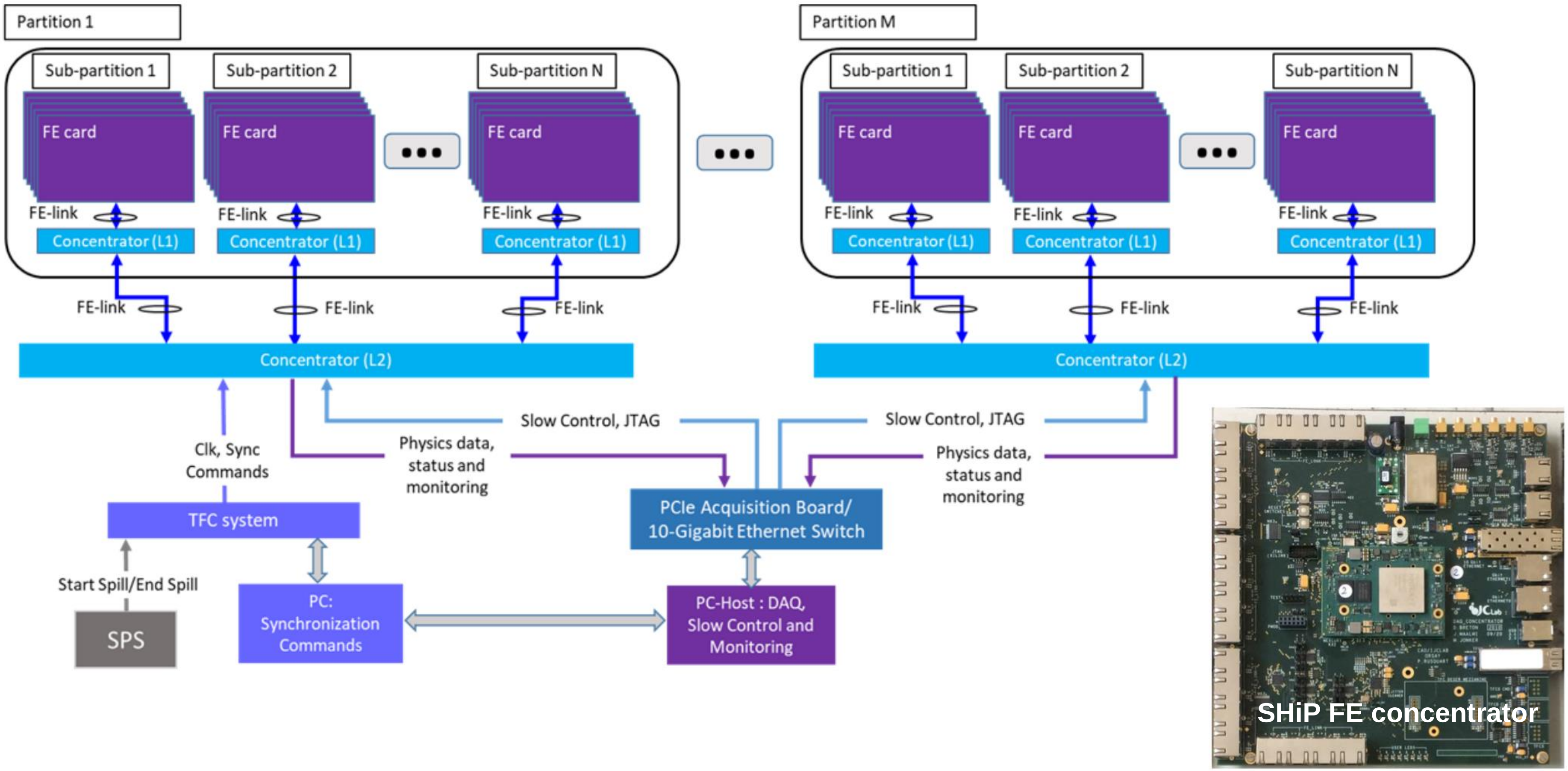
- Purpose: μ/π separation ($\varepsilon_\mu > 95\%,\ p_\mu \in 5 - 100\ GeV/c$, mis-identification <1-2%), timing to contribute to reject combinatorial background

- Characteristics
  - Three (four) stations with sensitive area of ~5x7m^2
  - Calorimeter equivalent to 6.7λ (p_μ >2.6 GeV/c)
  - Muon filters of 60cm (3.4λ each) + 10cm shielding behind last station (p_μ >5.3 GeV/c)
  - Granularity $\mathcal{O}(10x10)$ cm^2 driven by multiple scattering
  - Hit rates up to 300 kHz along vertical sides
  - ➔ Scintillating tiles / bars with SiPMs



Electronics and readout

- Subsystem architecture – aiming for common electronics
- DAQ system simulation with proper occupancy and time distribution



- ECN4 CDS detector, it is estimated that
  - About 300 concentrator boards, 25 DAQ links, 12 FEH and 42 EFF computers.