Status of the SHiP experiment

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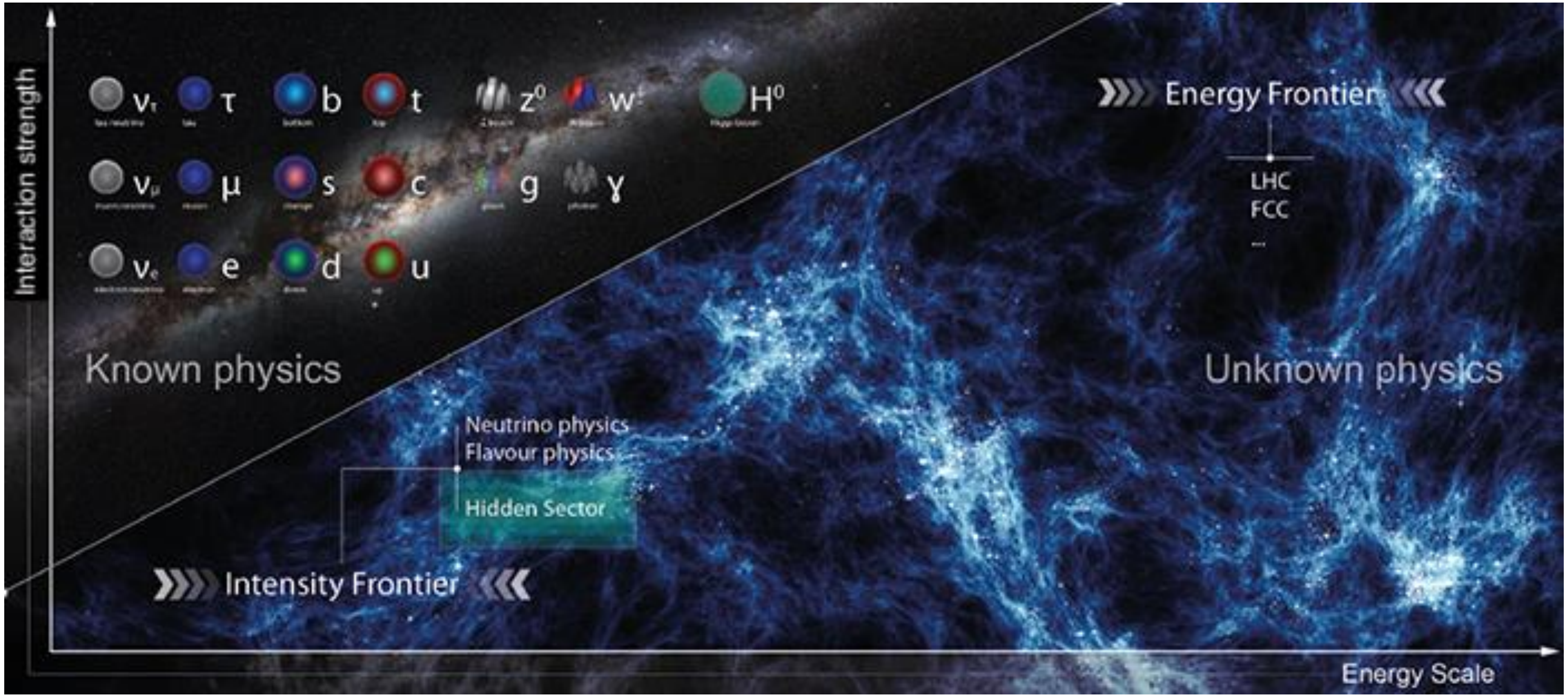
EPFL

ISOLDE Workshop and Users meeting 2025

Unexplored new particle parameters: where to look?



New particles are produced too rarely

⇒ SHiP ?

Search for Hidden Particles

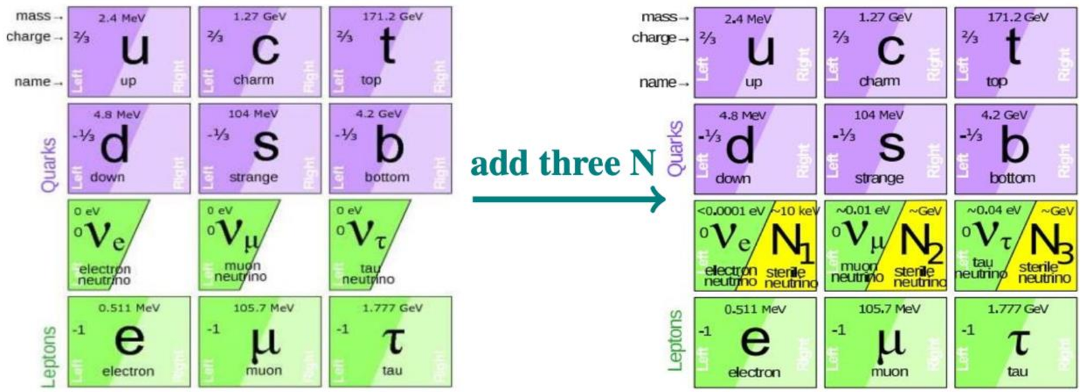
HiLumi HL-LHC PROJECT ?

New particles are too heavy to be produced ⇒ new accelerator

FCC hh ee he ?

Example: heavy neutral leptons (or neutrinos)

- right-handed neutrinos N are an example of "dark sector"



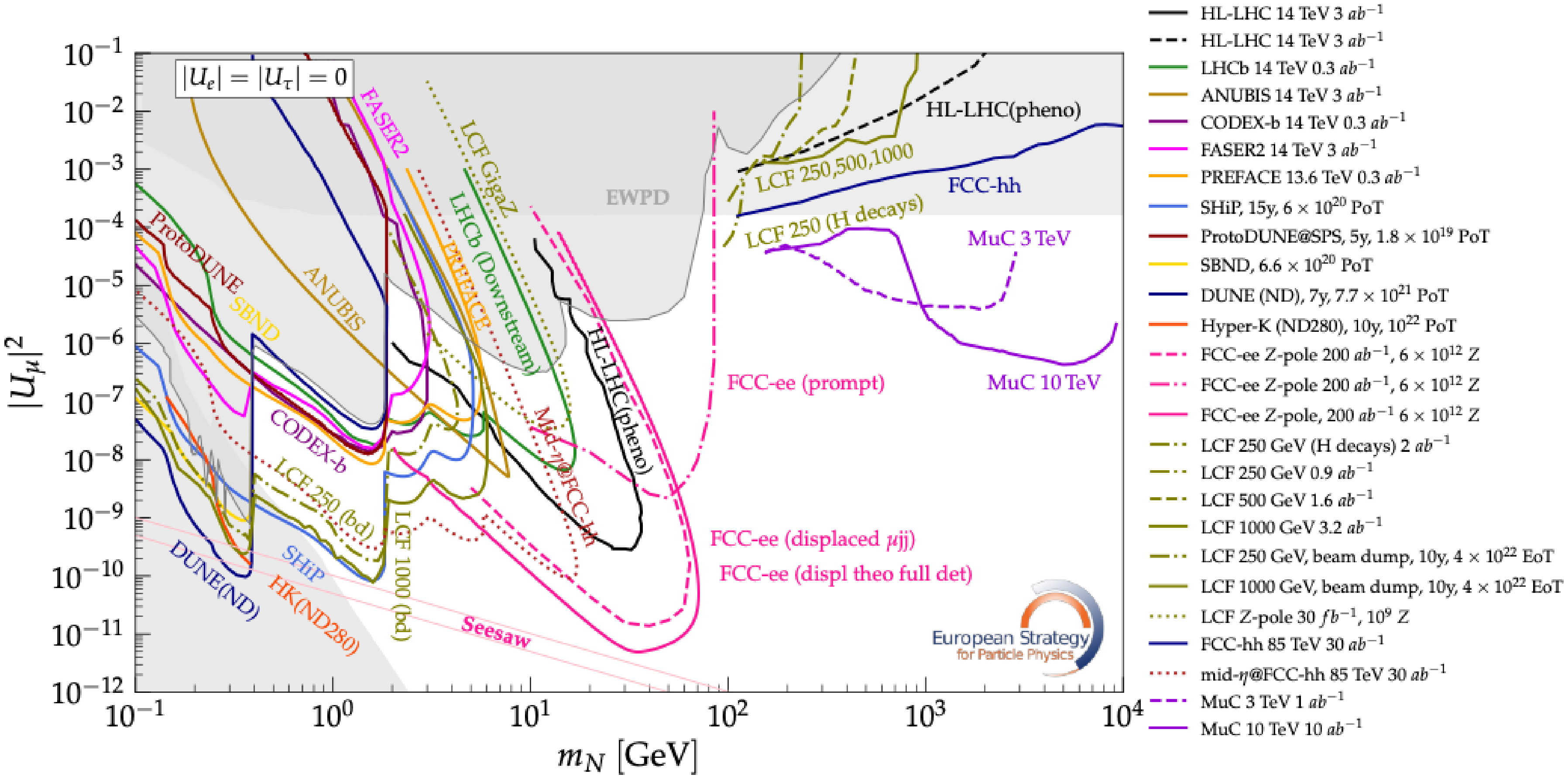
[M. Shaposhnikov et al](#)

- νMSM – a minimal extension of the SM with adding N_1, N_2, N_3
- provides a **dark matter particle N_1**:
  - very long-lived, decays as $N_1 \to \nu\gamma$
  - *debated indirect evidence from astroparticle observations exists*
- N_2 and N_3 can explain **matter dominance of the Universe**
- N_2 and N_3 can be found with conventional detectors at colliders

Intensity frontier exploration in the future

Even if there is the FCC, SHiP is the only one closing fully allowed gap below 5 GeV

interaction strength



Particle mass

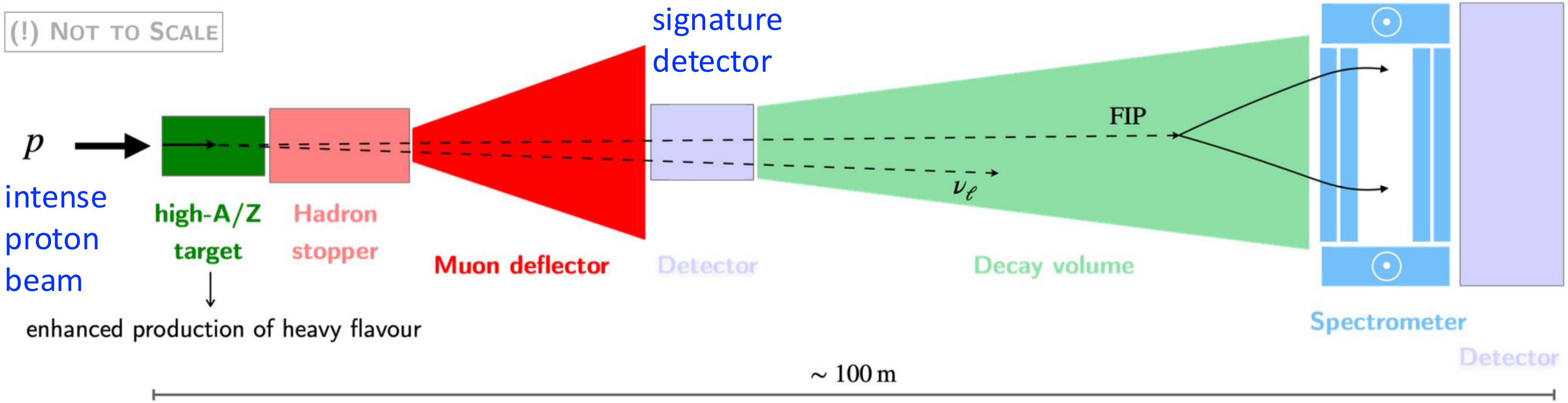
Physics Briefing Book

SHiP: unique capabilities for 1-5 GeV range

Overarching goal: 0-background operation

decay signature detector

scattering signature detector

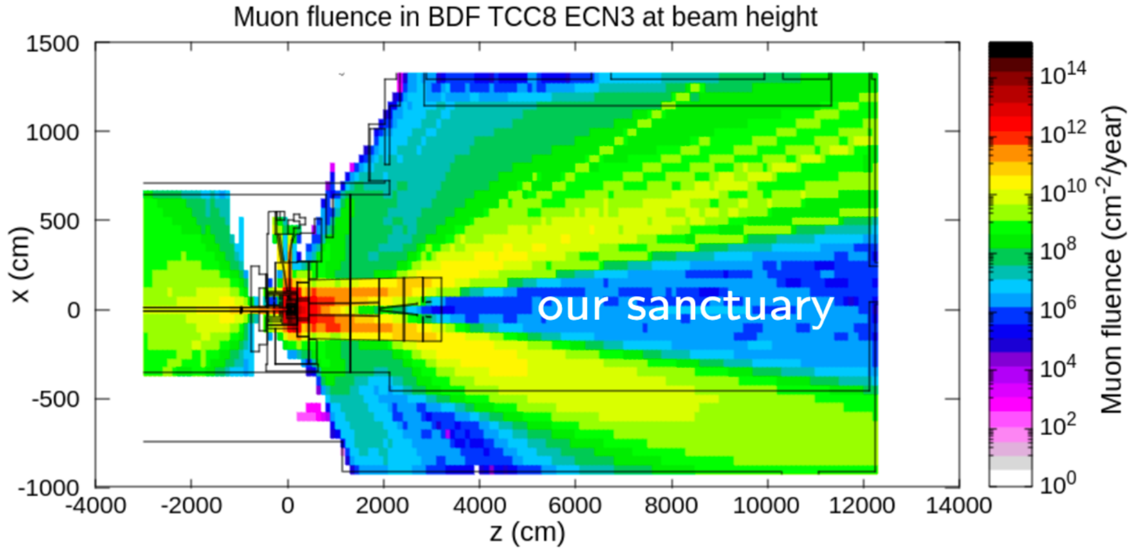


intense proton beam

Feebly interacting particles (FIPs) and neutrinos ν produced in heavy flavour hadrons decays

Main challenge: background

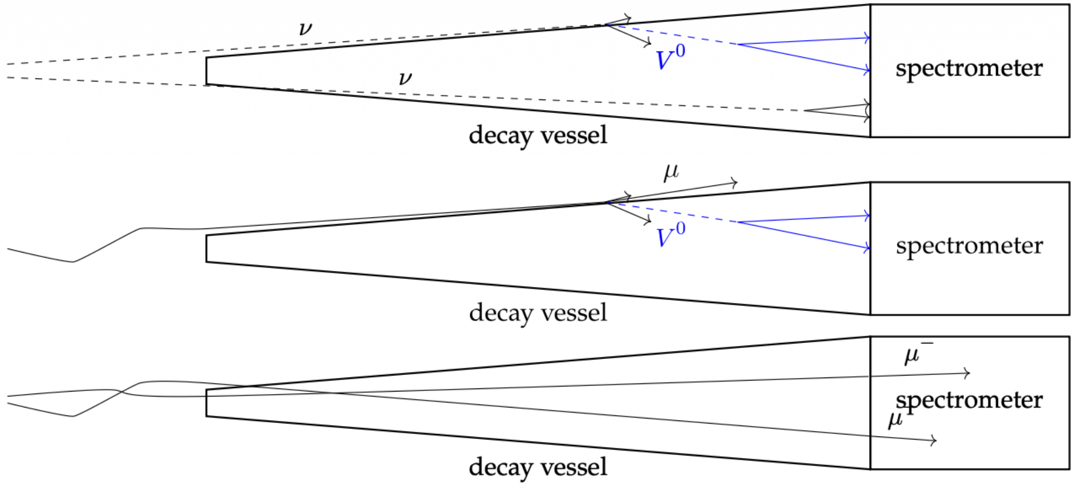
- only muons and neutrinos survive hadron stopper
- magnetic muon shield deflects muons: suppresses muon flux by 10^6



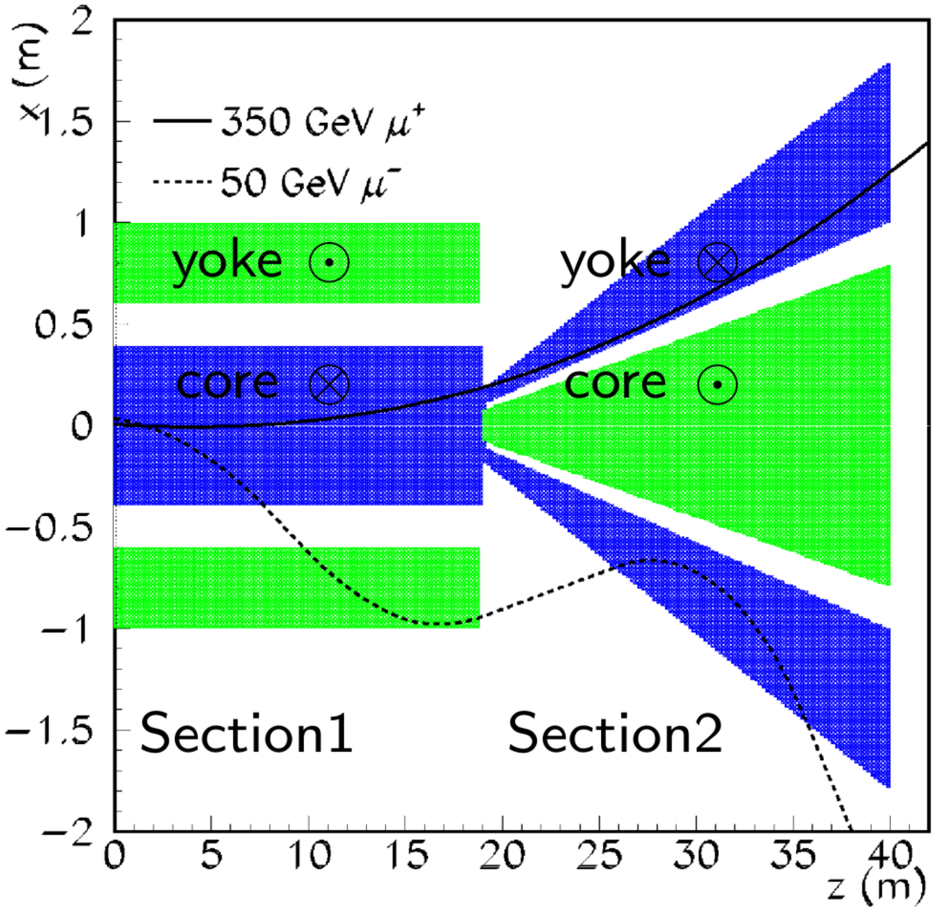
- Remaining muon flux to be precisely measured by dedicated taggers

Considered backgrounds:

1. Neutrino inelastic scattering
   - reliably estimated with simulation
   - suppressed with cuts
2. Muon inelastic scattering
3. Combinatorial muons
   - challenging for simulation



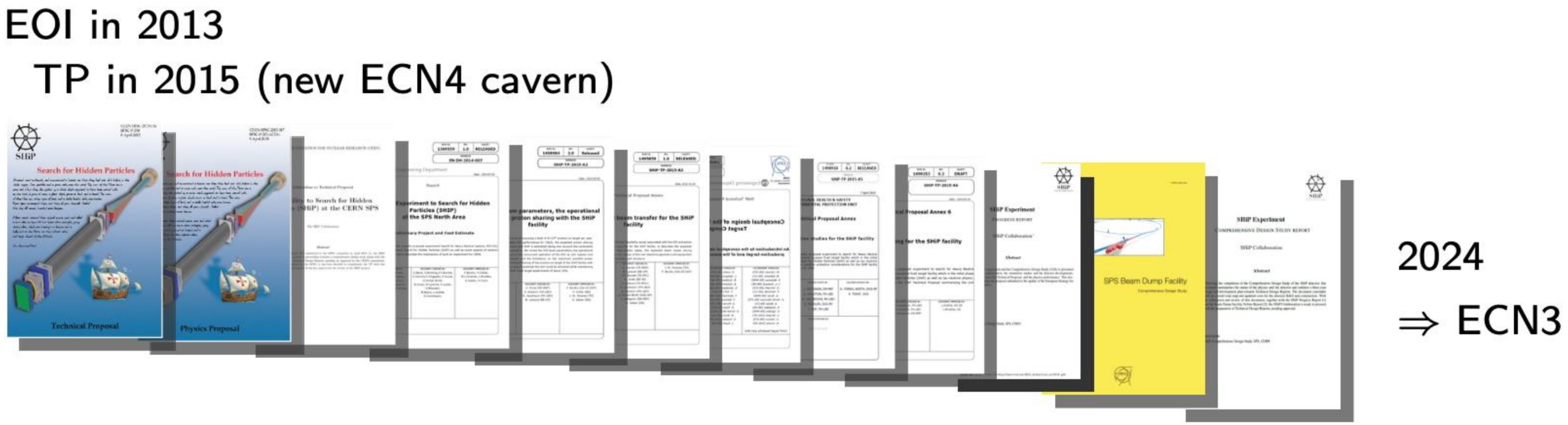
Muon shield concept: magnetized hadron stopper + 2 Sections



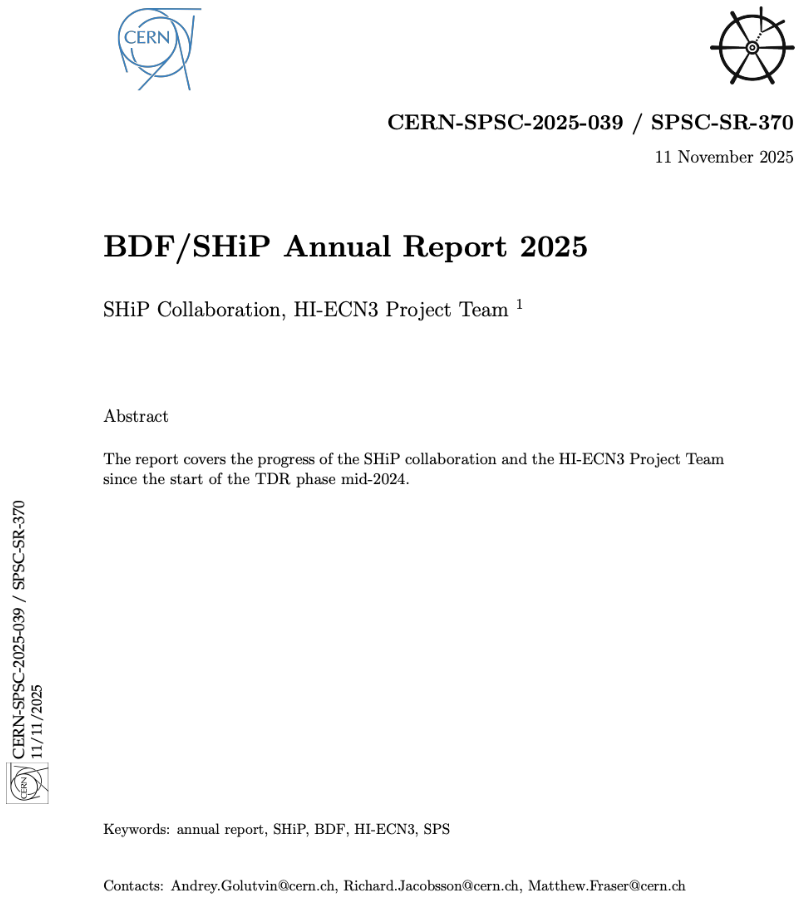
- 10^6 suppression is reached with the active shielding
- at least two magnets are necessary to deflect the continuous muon spectrum:
  - one magnet kicks out hard muons
  - second one deflects returning soft muons
- dedicated magnet optimization with ML tools is done

High-intensity project at the ECN3

- long history since EoI in 2013:



- dynamic updates since the approval in 2024
- latest status:
  - BDF/SHiP Annual Report 2025 [CERN-SPSC-2025-039]
  - last week SPSC presentation by Massimiliano Ferro-Luzzi: [indico]


CERN-SPSC-2025-039 / SPSC-SR-370

11 November 2025

BDF/SHiP Annual Report 2025

SHiP Collaboration, HI-ECN3 Project Team [1]

Abstract

The report covers the progress of the SHiP collaboration and the HI-ECN3 Project Team since the start of the TDR phase mid-2024.

Keywords: annual report, SHiP, BDF, HI-ECN3, SPS

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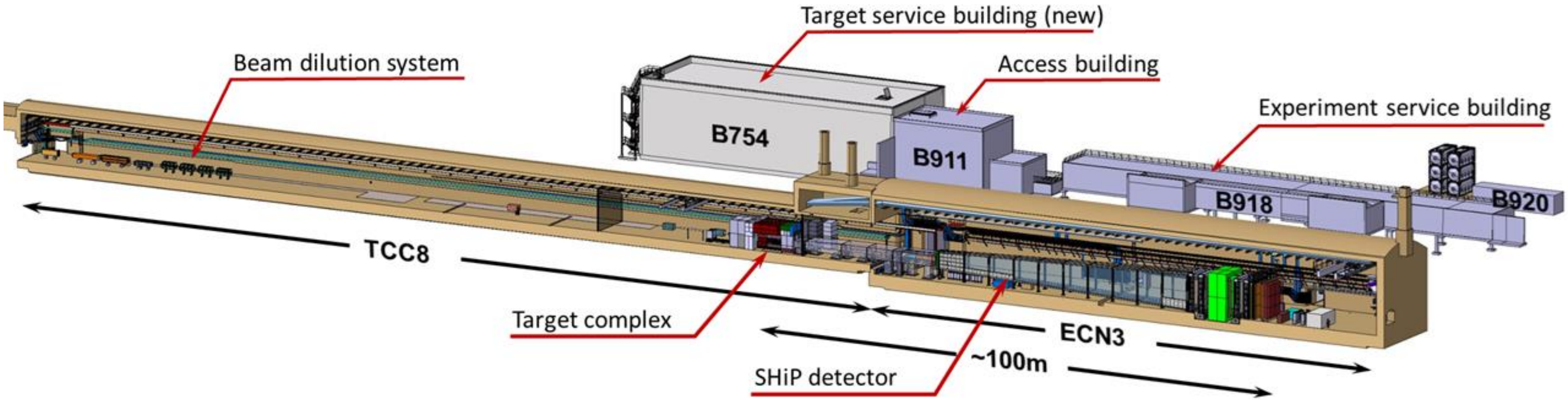
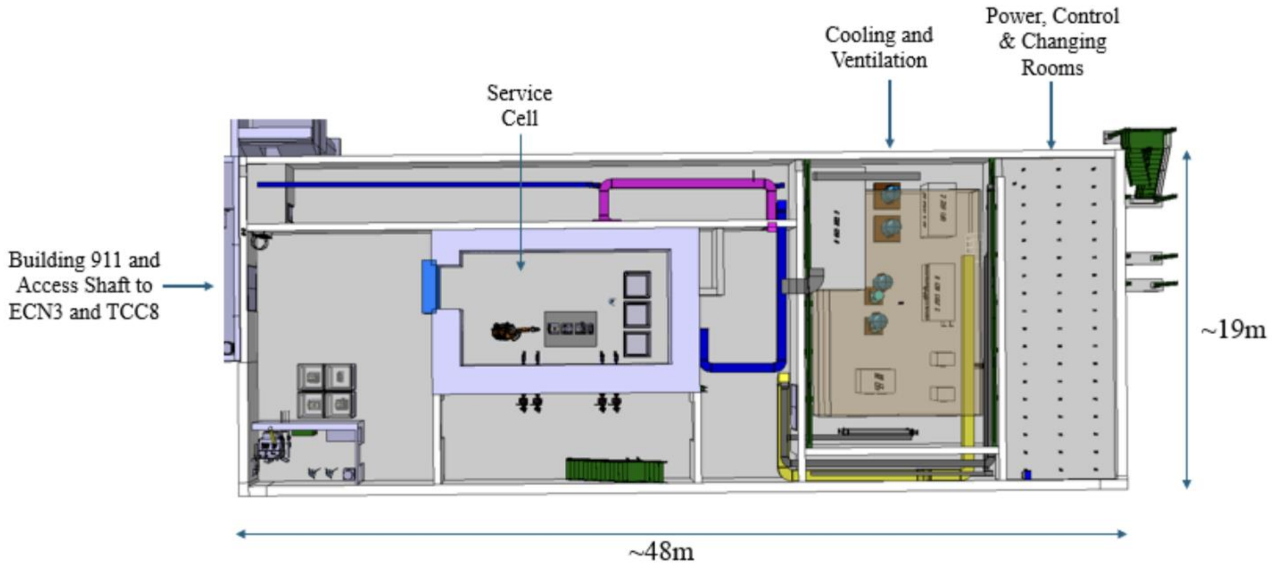
CERN-SPSC-2025-039 / SPSC-SR-370
11/11/2025

Updates in ECN3



- New target service building (B754):
  - First civil engineering has begun in May 2025
- Descoped additional access shaft in ECN3 and reusing the same access shaft and buildings

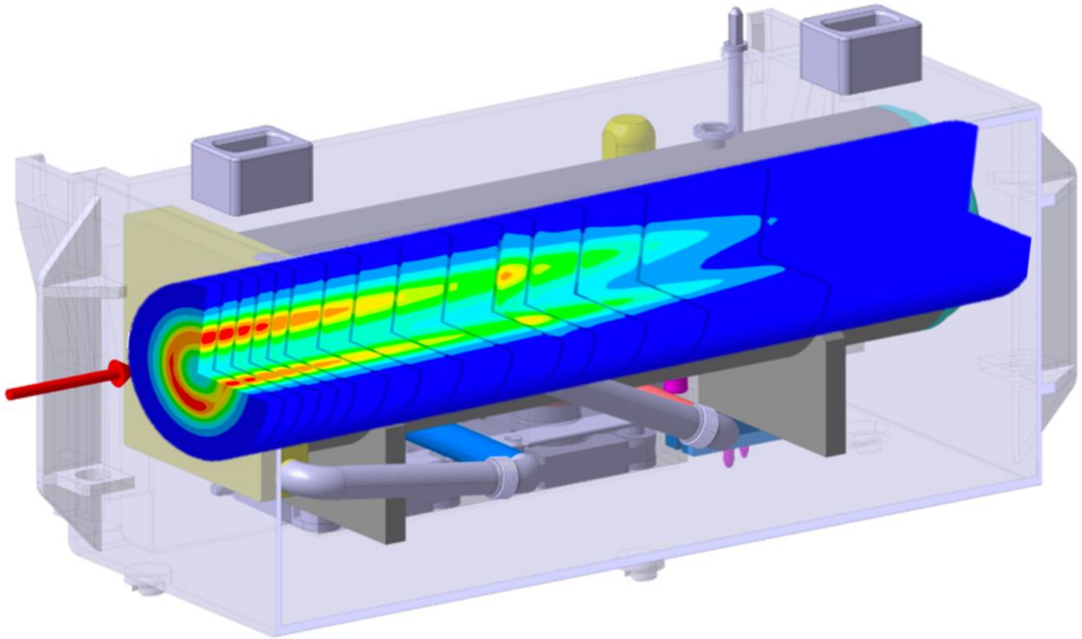
New target service building (B754)



- Supports the operation of the target station with
  - Helium cooling system
  - Proximity shielding cooling system
  - Nuclear ventilation system
  - All control systems

- Has **service cell** for handling highly radioactive target, performing post-irradiation examination of components, handling waste for final disposal

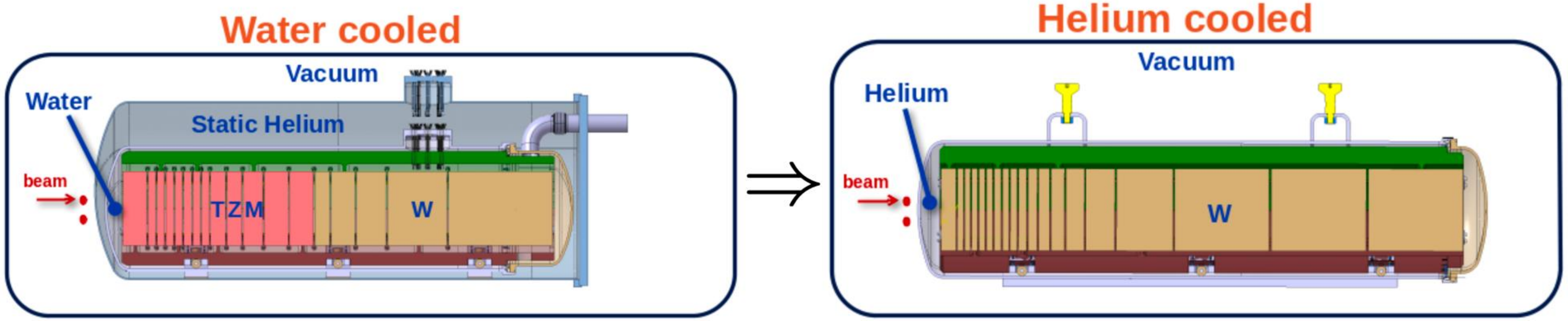
Beam dilution optimization



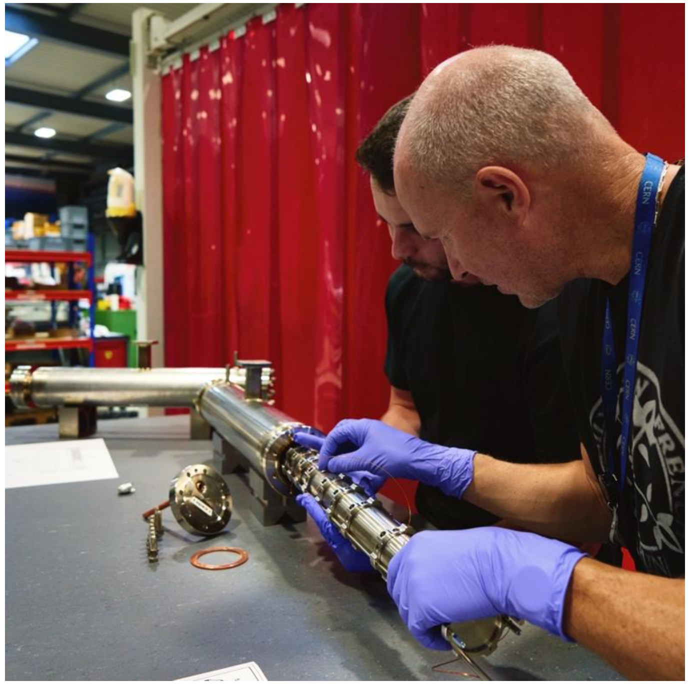
- beam circulates over target during the spill:
  - makes 4 circles with 5 cm radius
- decided to relax beam spread:
  - $\sigma_x = \sigma_y = 16$ mm (was 8 mm)
- $\Longrightarrow$ increased lifetime of the target
- Target diameter to be checked:
  - keep 25 cm or increase to 30 cm?

Target configuration update

- Target should:
  - stop and withstand 2.6 MJ per 1s spill, every 7.2s
  - be dense to absorb π/K and minimize decays to ν
- Changed design from water-cooled to He-cooled:
  - gaseous Helium design is better for operational safety
  - tungsten (W) everywhere instead of TZM Molybdenum alloy



Target prototype tested this year at T6 in TCC2



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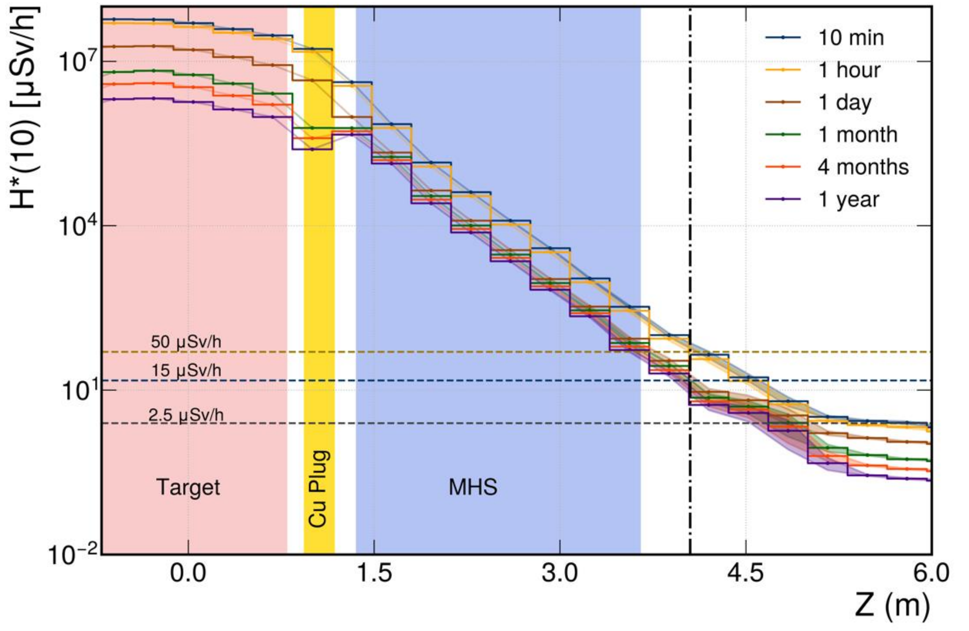
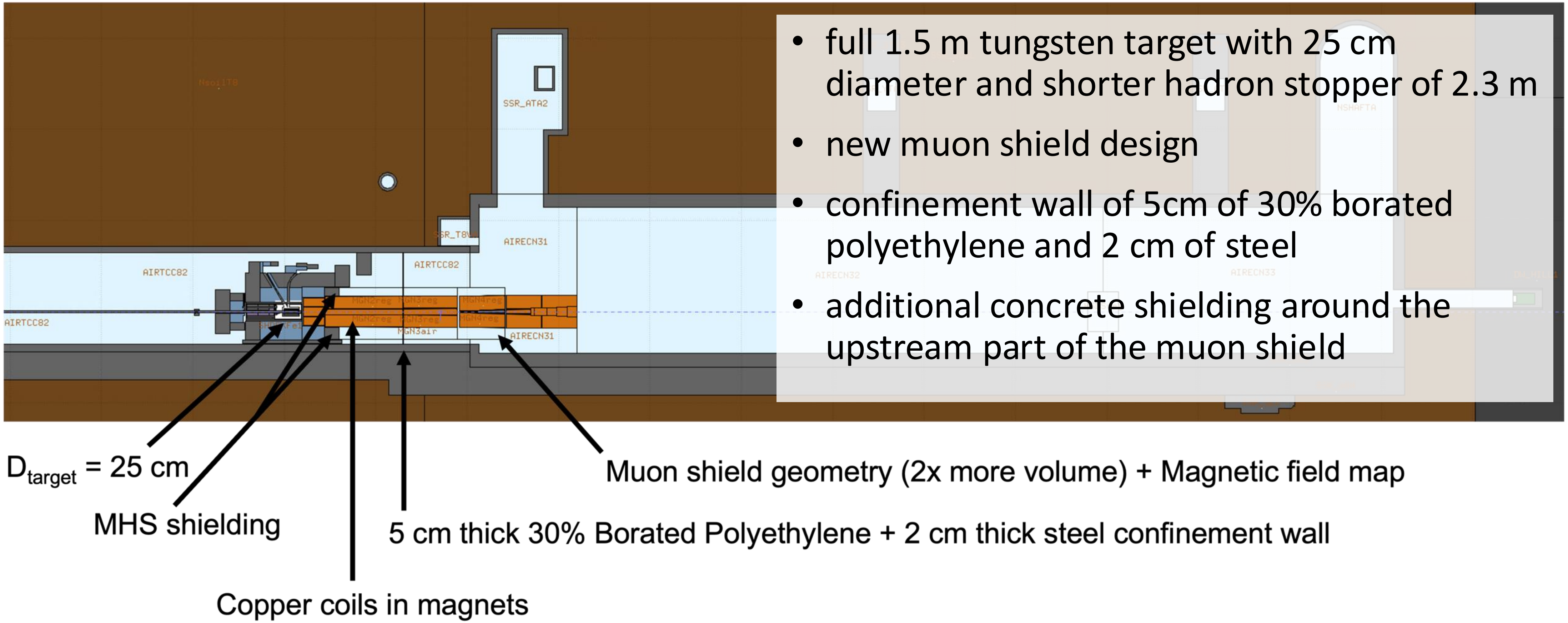
Magnetized hadron stopper



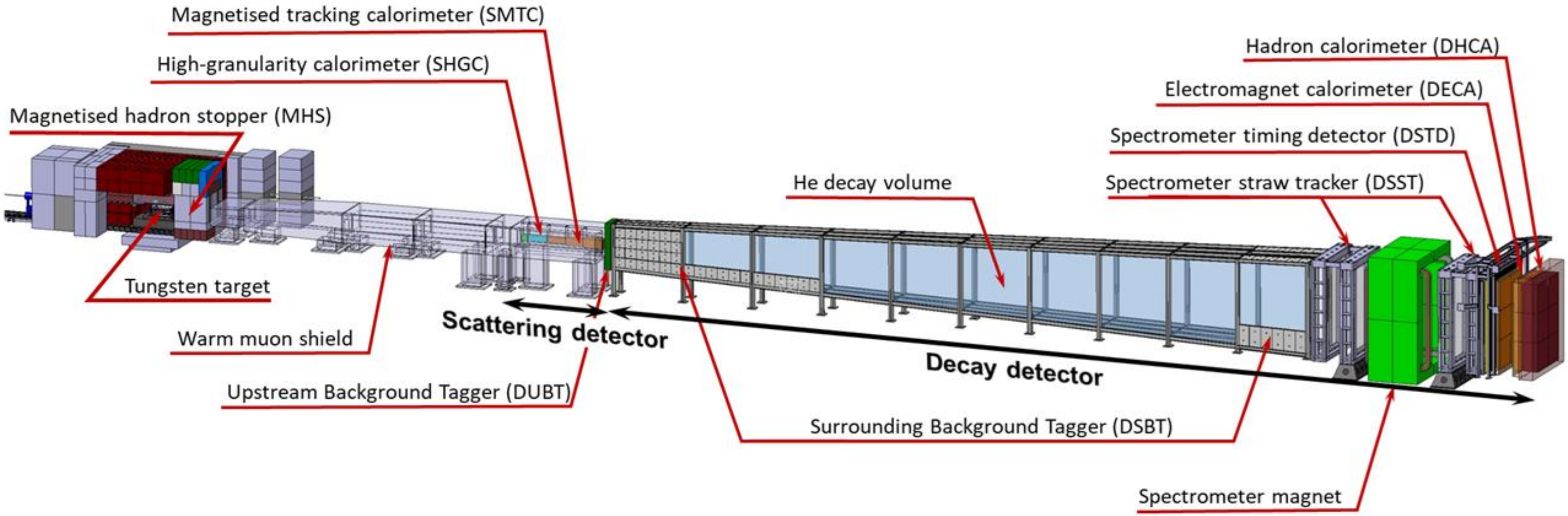
- it is part of the target complex due to radiation levels
- reduced the MHS length from 4.5 to 2.3m, based on radiation studies
  - more space for the experiment
- still optimizing the position of the confinement wall

Current target region layout

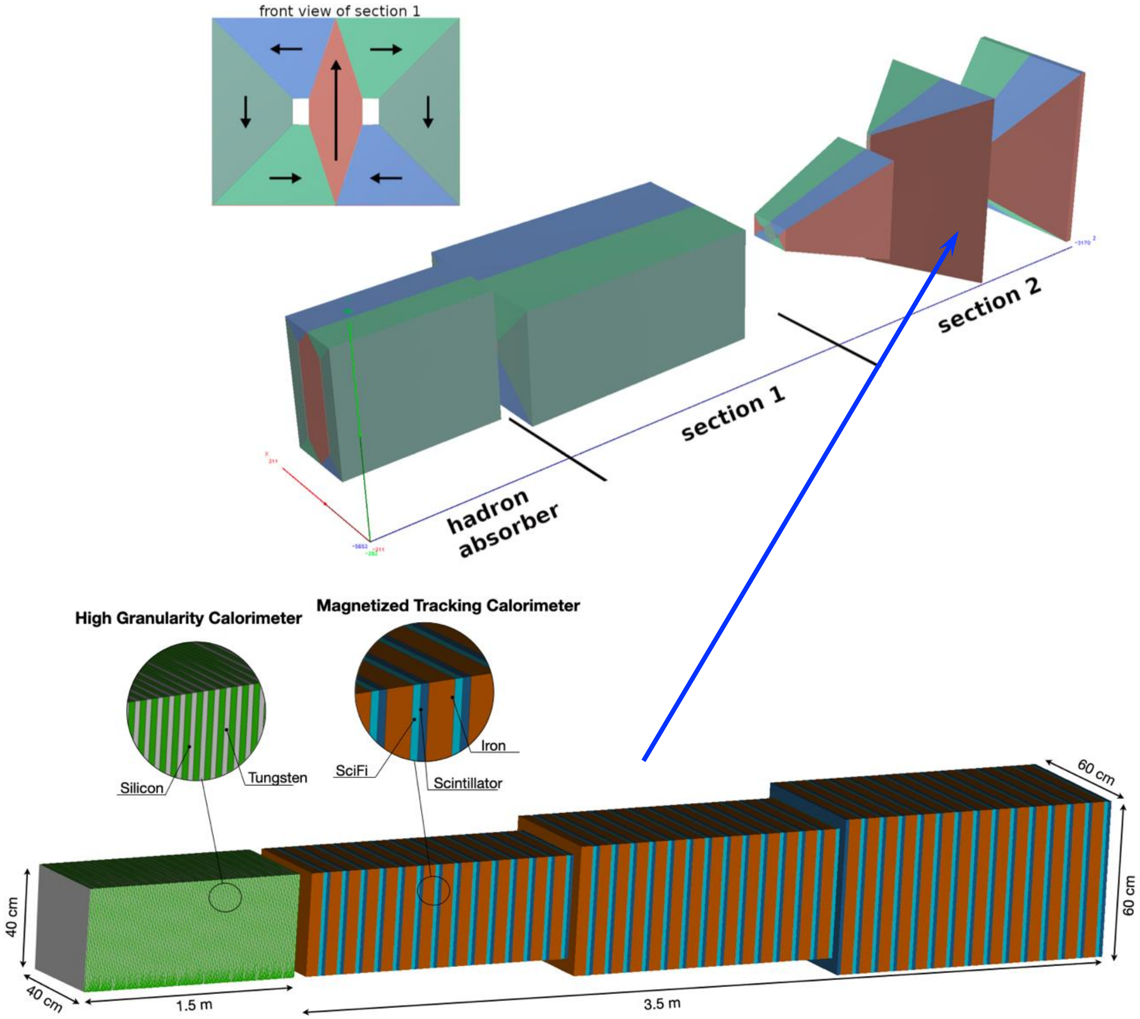
- full 1.5 m tungsten target with 25 cm diameter and shorter hadron stopper of 2.3 m
- new muon shield design
- confinement wall of 5cm of 30% borated polyethylene and 2 cm of steel
- additional concrete shielding around the upstream part of the muon shield



Experiment developments



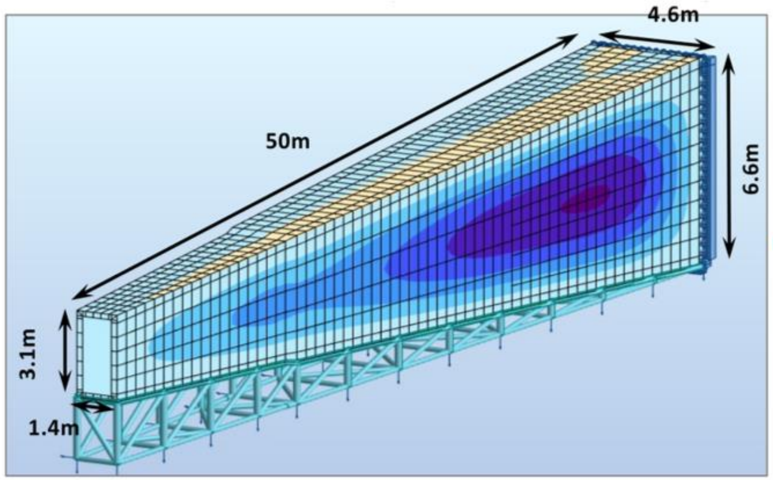
Muon shield and Scattering detector

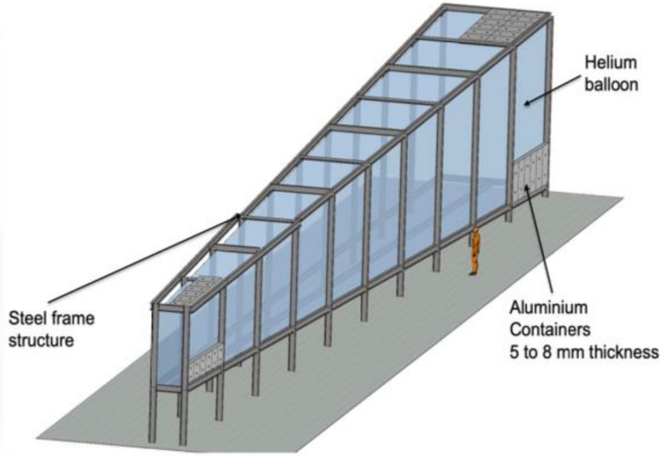


- **Muon shield** is optimized for two options:
  - full-warm (NC)
  - hybrid (SC/NC)
  - choice to be made next year, full warm is more likely
- **Scattering and Neutrino Detector (SND)** is now integrated inside the muon shield magnets:
  - high granularity calorimeter with W absorber and Si detector
  - magnetized tracking calorimeter with SciFi tracking layers and tile calorimetry

Decay volume: He balloon

- original design: decay volume is under 1mbar vacuum to suppress ν interactions
- now: 1 bar Helium reduces interactions sufficiently, so that residual background can be removed by selection and dedicated background taggers
  - surrounding material decreased from 300 tonnes to 300 kg $\Longrightarrow$ less inelastic scattering of the walls
  - straw tracker is no longer in vacuum $\Longrightarrow$ simpler design

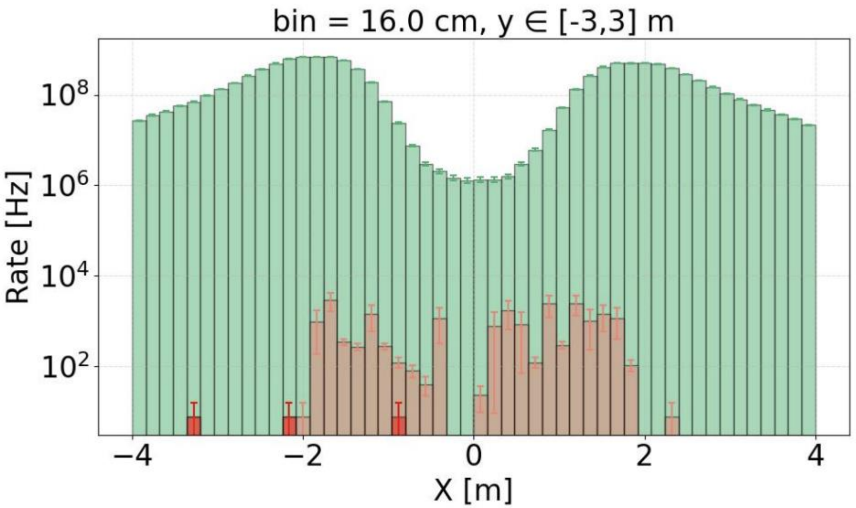




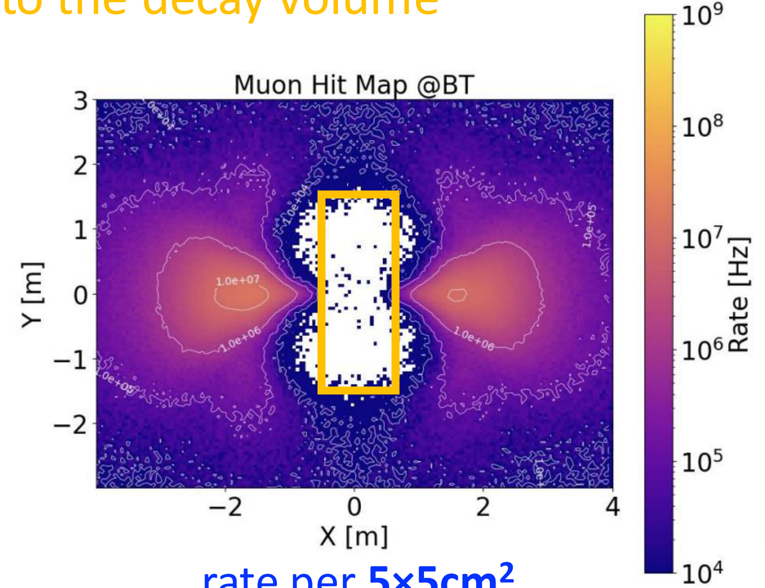
Background taggers: optimization ongoing

@ the entrance to the decay volume

Total muon rate/16 cm vs x

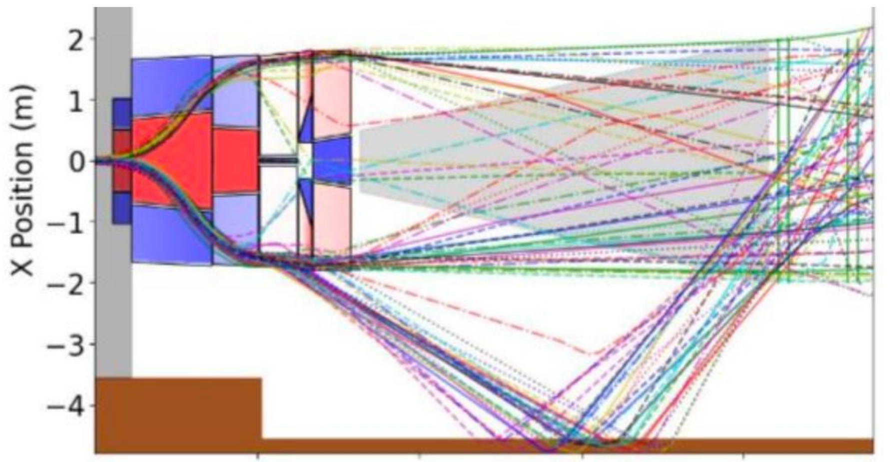


Rate of muons reaching tracker/16 cm vs x



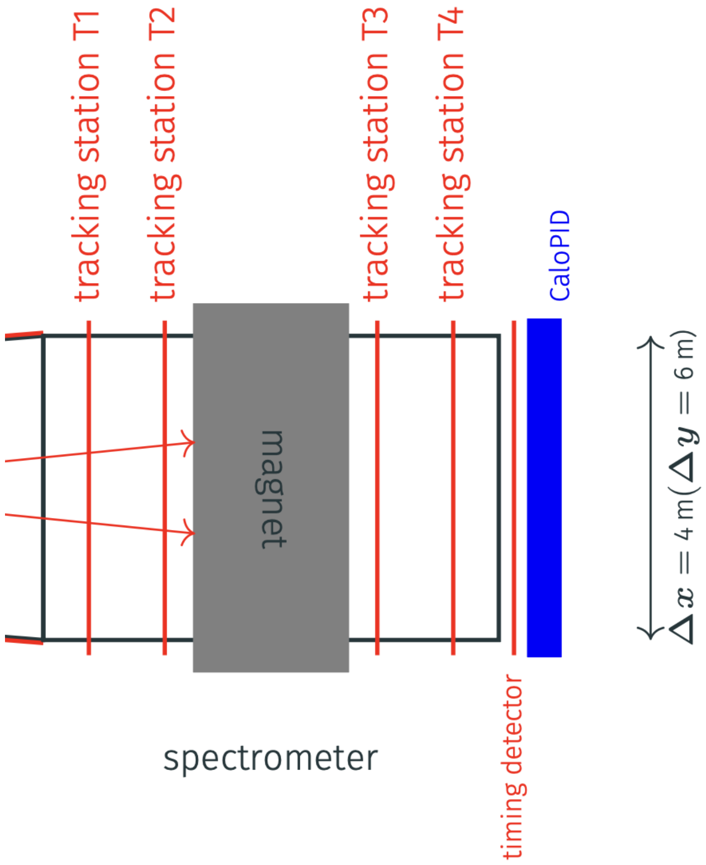
rate per **5×5cm²**

side view:



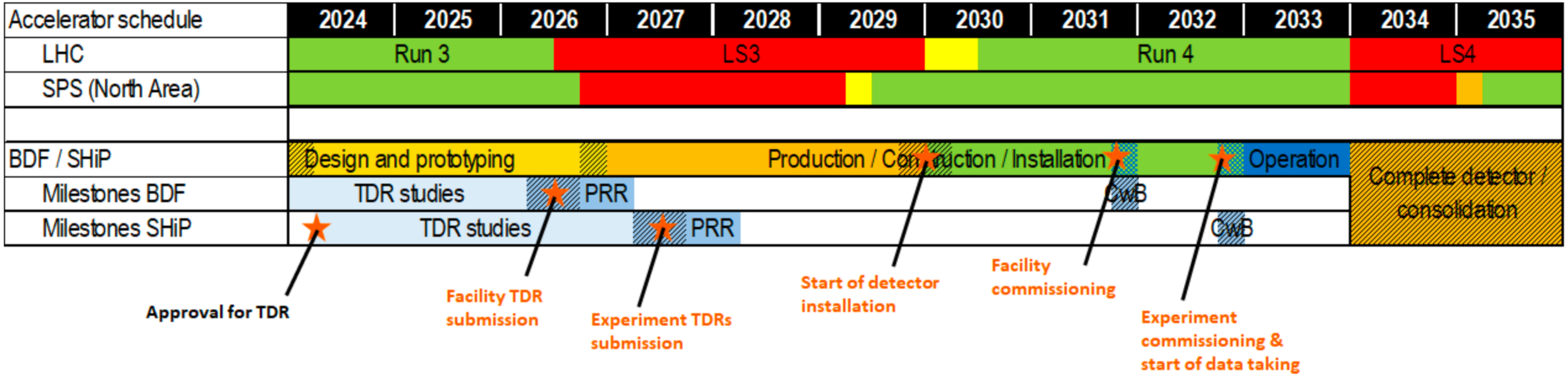
- main suppression of the muon combinatorial background is timing: 3.4×10^{-10} (with 340 ps window)
- remaining background requires "only" 99% per track tagging efficiency to be removed
- main challenges: **rate** for upstream background tagger and **coverage** for surrounding background tagger, optimizations and studies are ongoing
- Upstream background tagger: straws (coordinate) and scintillating tiles (timing)
- Surrounding background tagger: liquid scintillator cells

Decay detector



- Spectrometer should measure:
  - invariant mass, impact parameter, decay vertex of signal candidate
  - distinguish between signal models using PID of decay products
- Technologies:
  - spectrometer straw tracker (now in air): two straw types under consideration, several production sites available
  - energy-efficient superferric dipole magnet ~0.63 Tm; prototypes built and tested by CERN team
  - ECAL (splitCal: longitudinally segmented with $\sim 20X_0$ length) and HCAL prototypes tested in a beam

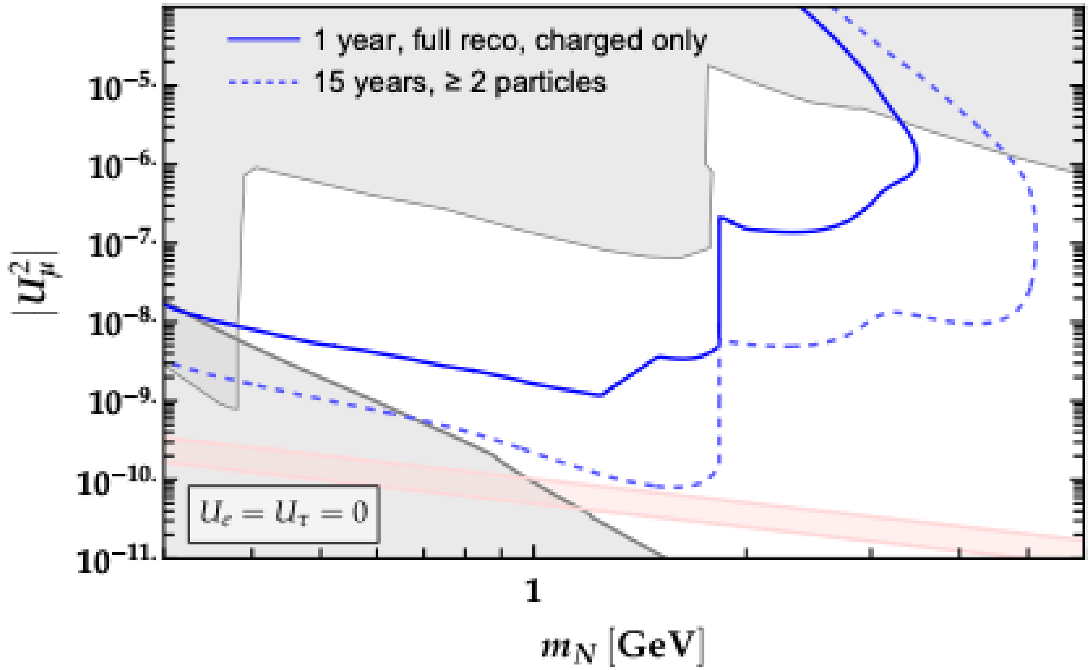
SHiP schedule



- Data-taking in Run 4 with minimal setup:
  - commissioning initial detector in 2032, physics in 2033
- Ensure charge particle reconstruction and background taggers
- Measure and study backgrounds and BDF performance in this setup
- Produce first physics results!

Sensitivities to heavy neutrinos

Heavy neutral leptons N, muon coupling $|U_\mu|^2$



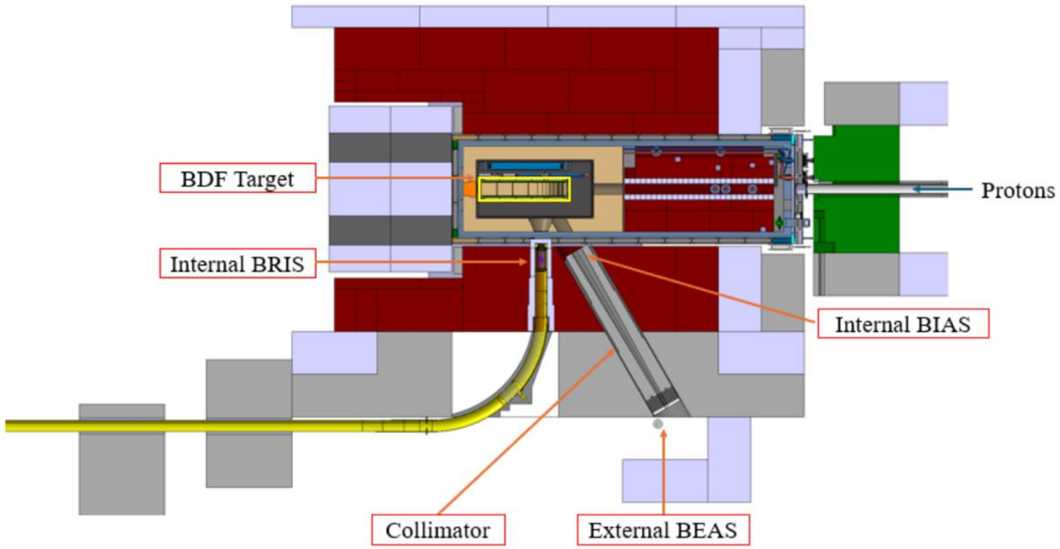
Solid pink band: seesaw limit

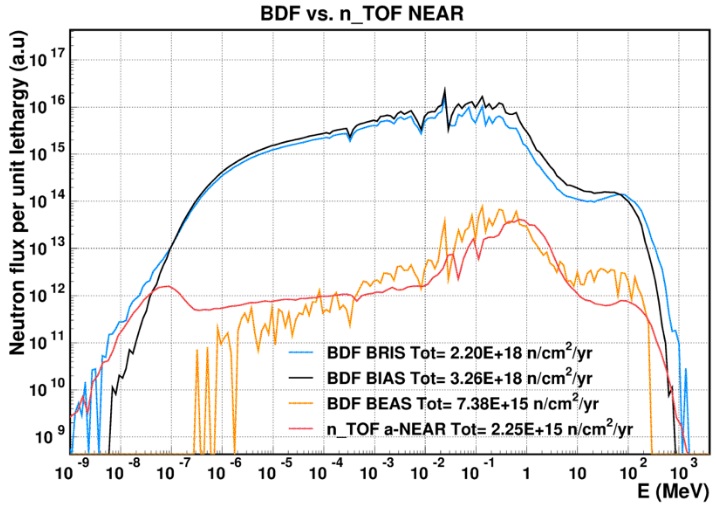
- Solid line:
  - sensitivity after one year of data-taking in 2033
  - only fully reconstructed final states with tracks
  - 4 ×10^{19} PoT
- Dashed line:
  - 15 years of running, including all final states:
  - 6 ×10^{20} PoT
- Just turning BDF/SHiP on makes a big difference!

BDF physics is much more than FIPs

- **Neutrino** physics with the Scattering and Neutrino Detector:
  - 10^4 reconstructed tau neutrinos, 10^6 – electron and muon neutrinos
  - precision and novel measurements in neutrino sector
  - performance informed by the operating SND@LHC and planned upgrade
- Proposal for **TauFV** experiment upstream the target:
  - huge number of taus can be exploited for flavour physics
  - radiation environment is challenging for a detector design
- **LAr TPC** for long-lived particles, light dark matter and neutrinos:
  - proposal in 10.1007/JHEP02(2024)196
- **n_ACT@BDF** for nuclear physics:
  - EoI CERN-SPSC-2024-027 and now Proposal CERN-SPSC-2025-038

n_ACT@BDF: A Neutron Activation Station at the SPS Beam Dump Facility (BDF)





- high-flux neutron activation station integrated into BDF target
- measure neutron-induced reaction cross section on minute and radioactive samples
- benefits nuclear astrophysics and nuclear technologies, as well as development of radiation-hard electronics (e.g., for FCC)
- complements n_TOF and is synergetic with ISOLDE for production of radioactive targets
- staged deployment aligned with SHiP is proposed:
  - BIAS/BEAS operation in 2032
  - BRIS operation in post-LS4 (2035+)

CERN-SPSC-2025-038

SHiP Collaboration

297 participants in 48 institutes in 18 countries + CERN and JINR
New groups are joining!

SHiP Collaboration

Country	Institute
Belgium	University of Ghent
Bulgaria	*University of Sofia*
Chile	*Saphir/UNAB*
Denmark	*Niels Bohr Institute*
France	IJCLab
Georgia	Georgia Technical University, Tbilisi
Germany	*Humboldt University of Berlin* Constructor University Bremen University of Freiburg University of Hamburg Forschungszentrum Jülich Karlsruhe Institute of Technology *University of Mainz* University of Siegen
Italy	*University & INFN Bari* *University & INFN Bologna* *University & INFN Cagliari* *University Federico II & INFN Napoli*
Japan	*Nagoya University* Associated: *Aichi University of Education, Kariya* *Nihon University, Tokyo* *Kobe University*

Recently joined in 2024-2025
Strengthened by addition of new group(s) in 2024-2025

Country	Institute
Kazakhstan	Insitute of Experimental Physics, Almaty
Korea	*Gyeongsang National University, Jinju* Associated: *Gwangju National University of Education* *Jeju National University* *Physics Department, Korea University, Seoul* *Sungkyunkwan University, Suwon City*
Netherlands	*Leiden University*
Portugal	*LIP, Lisbon & Coimbra*
Serbia	University of Belgrade
Switzerland	*EPFL* *University of Zurich*
Turkey	*Middle East Technical University* *Department of Physics and Engineering, Ankara University*
Ukraine	Taras Shevchenko National University of Kiev
United Kingdom	H.G. Wills Physics Laboratory, University of Bristol *Imperial College London* University of Liverpool University College London
	CERN JINR

slanted: also in SND@LHC. New groups are regularly joining SND@LHC; they will eventually join SHiP (Genova, Catania, Salerno)

Summary and outlook

- Since the approval of the BDF in SHiP in 2024, a lot of progress!
- Already introduced a new target design and He-filled decay volume
- For TDRs in 2026 (BDF) and 2027 (SHiP):
  - optimize and define the initial SHiP setup, focusing on charged particles reconstruction
  - choose muon shield variant
- Muon shield commissioning with the beam in 2031 (with BDF)
- Detector commissioning in 2032
- First physics data in 2033 (last year of Run 4)