

# **The SHiP Experiment at CERN**

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**on behalf of the SHiP Collaboration**

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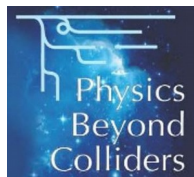


# **Search for Hidden Particles: SHiP**



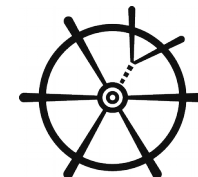


# BDF / SHiP: Introduction



**BDF: Beam Dump Facility**

**SHiP: Search for Hidden Particles**



## Part of the CERN Physics Beyond Colliders (PBC) initiative:

Exploit physics potential of the  $4 \times 10^{19}$  p.o.t./year 400 GeV SPS proton beam (ex CNGS)!

- **Expression of Interest (2013):** SPSC recommendation
- **SHiP Collaboration (2013):** CERN, member states & non-member states
- **Technical Proposal & Physics Case (2015):** Positively reviewed
- **Comprehensive Design Study (2019):** BDF & SHiP
- **European Particle Physics Strategy Update (2020):**  
BDF/SHiP recognised as a front-runner proposal (BUT costs...)
- **Strong & complementary physics case:**  
Continued R&D program (2020+): Optimisation of facility & detector design
- **Memorandum of Understanding (2022):** SHiP institutes

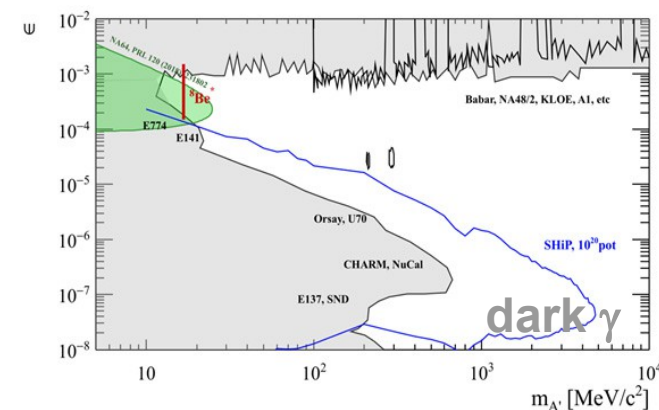
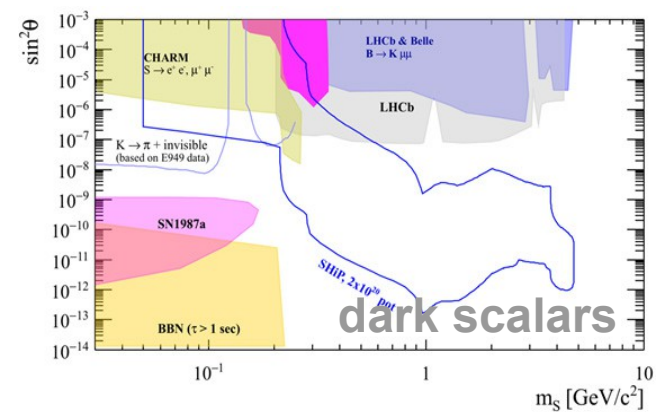
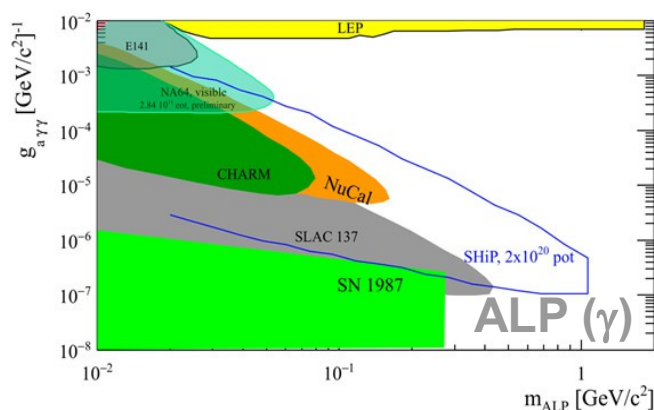
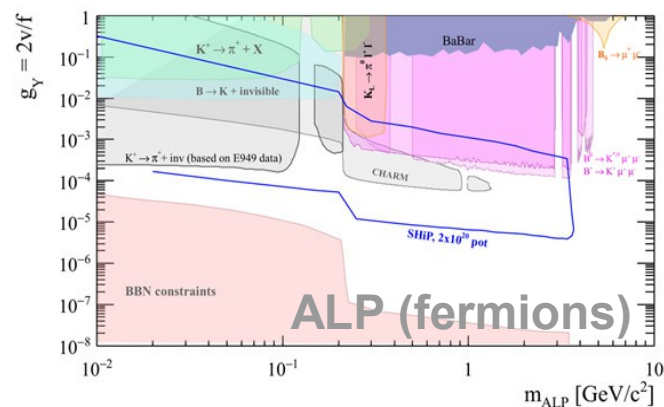




Hidden Sector (HS) portals:

Weak interaction of dark matter with visible sector?

- Possible mediators: ALP, dark  $\gamma$ , dark scalars, pseudoscalars, HNL...



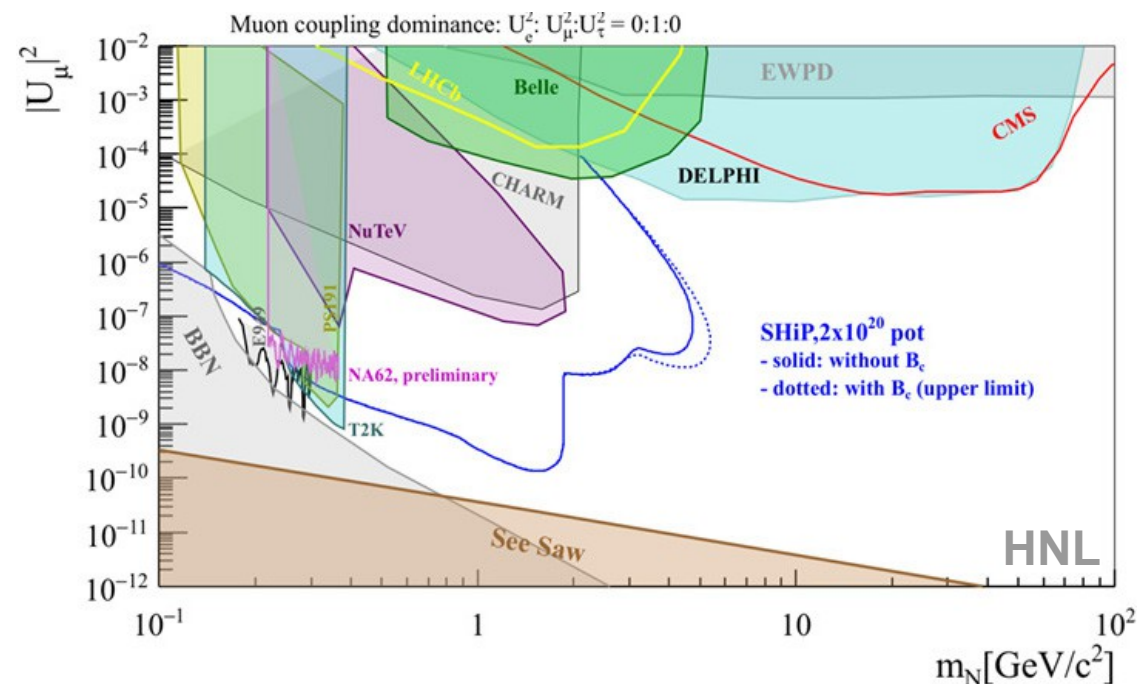


# SHiP Physics Reach

## See-saw: $\nu$ Minimal Standard Model ( $\nu$ MSM)

Extension of the SM by 3 right-handed **Heavy Neutral Leptons (HNL)**

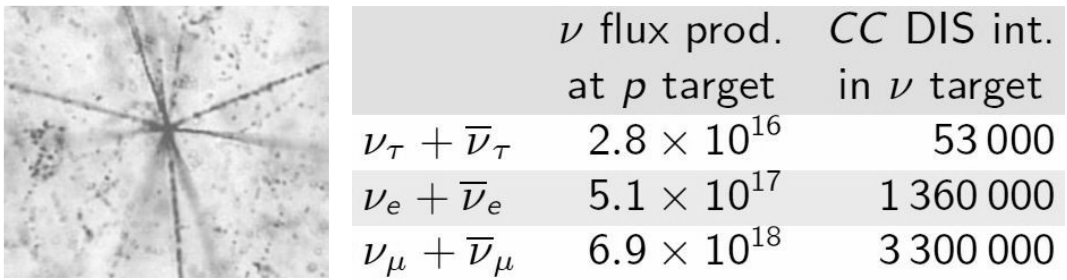
- **Light  $N_1$ :** Mass  $\mathcal{O}(10\text{keV})$ 
  - **Dark Matter** candidate
- **Heavy  $N_2, N_3$ :** Mass  $\mathcal{O}(1\text{GeV})$ 
  - Origin of  $\nu$  masses?
  - **Baryon asymmetry** of the Universe?



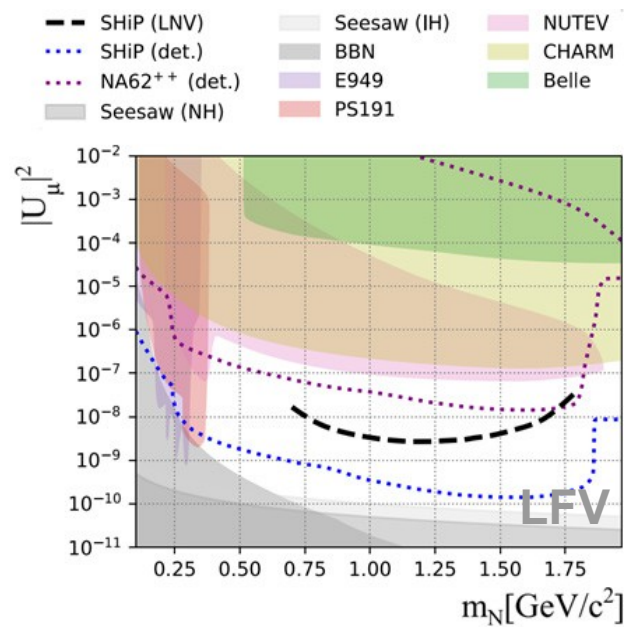
- **Production:** Decays of  $D$  &  $B$  mesons ( $c$  &  $b$  quarks),  $p$  Bremsstrahlung
- **Detection:** Visible decays into charged leptons,  $\pi$ ,  $\gamma$ ,...



ν physics:

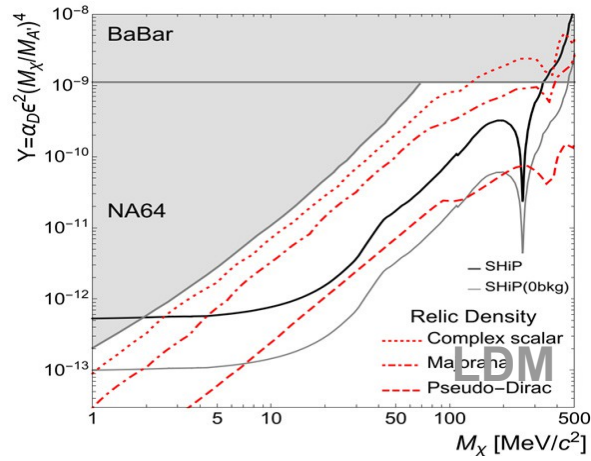



- $\nu_\tau$  &  $\bar{\nu}_\tau$  cross section measurement
- Extraction of  $F_4$  &  $F_5$  structure functions from  $\nu$  – nucleon CC DIS
- Test of Lepton Flavour Violation (LFV)



Other SM & BSM physics:

- Charm production: Measurement of the nucleon s &  $\bar{s}$  content
  - Test of the NuTeV anomaly
- Direct Light Dark Matter (LDM) search



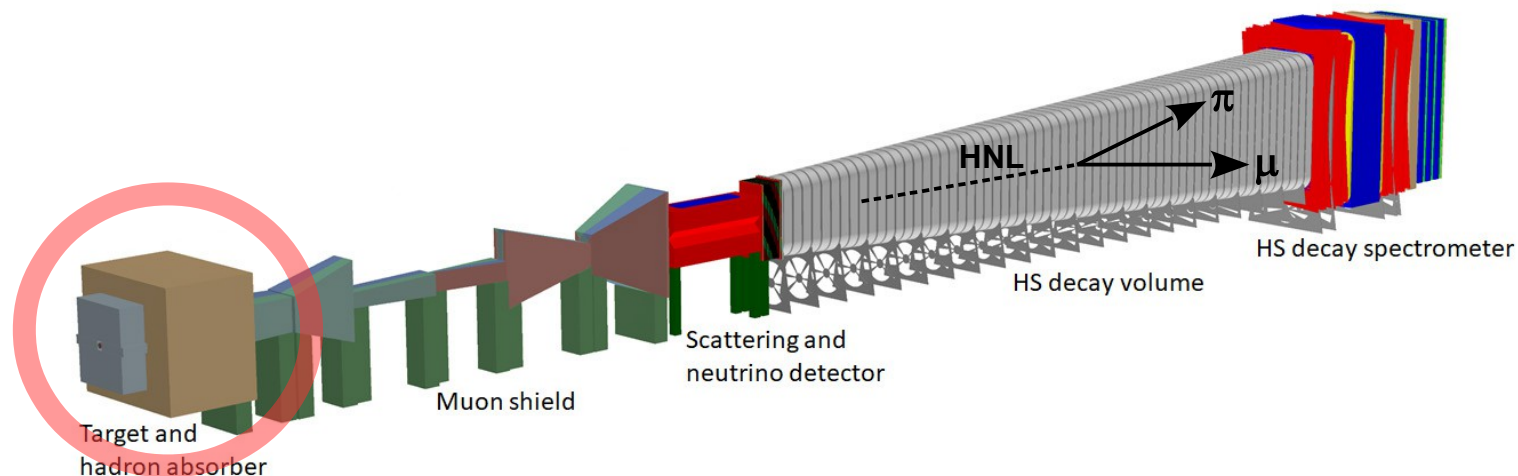


# **The SHiP Detector System**

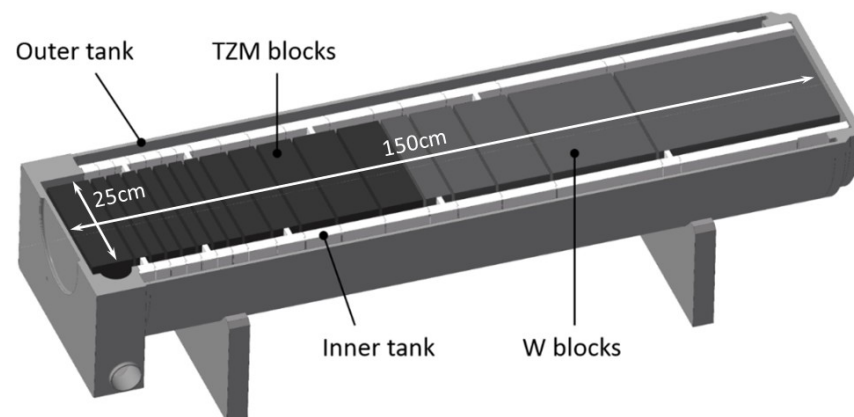




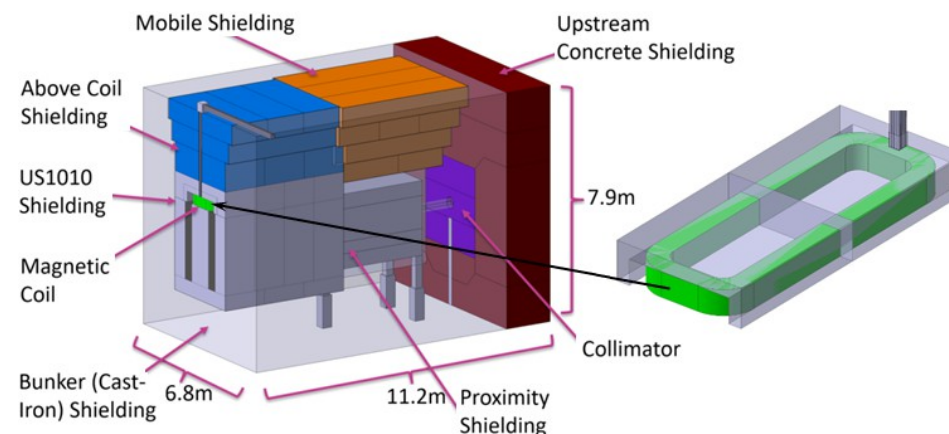
# Target & Muon Shield



**Heavy target ( $^{42}\text{Mo}$  &  $^{74}\text{W}$ ):**  
Optimised for heavy meson production

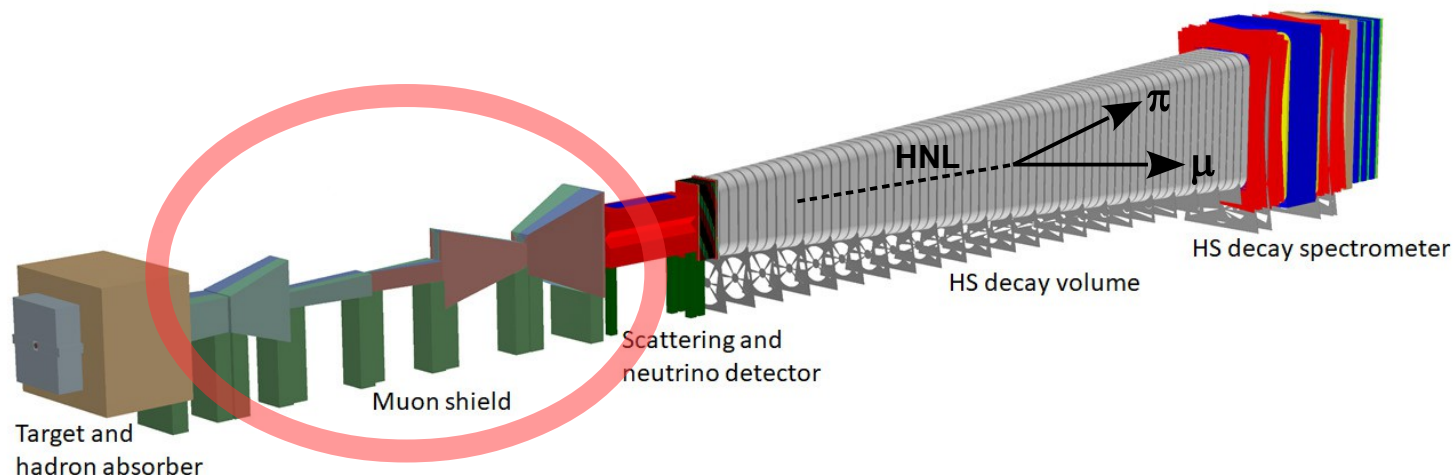


**Magnetised hadron stopper (16T):**  
Air-cooled Al coil



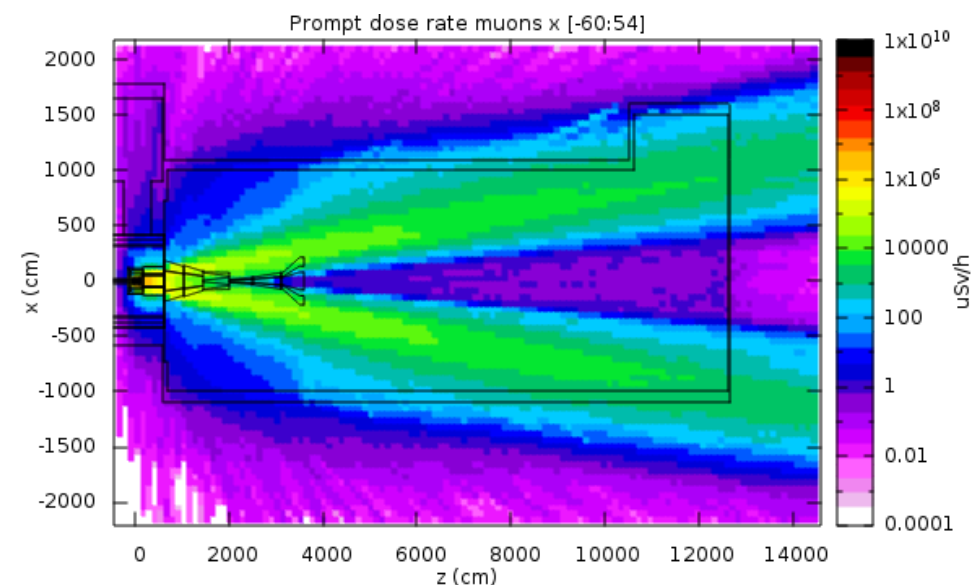


# Target & Muon Shield



**Muon shield (30m):**  $10^{11} \mu$  per 1s-spill

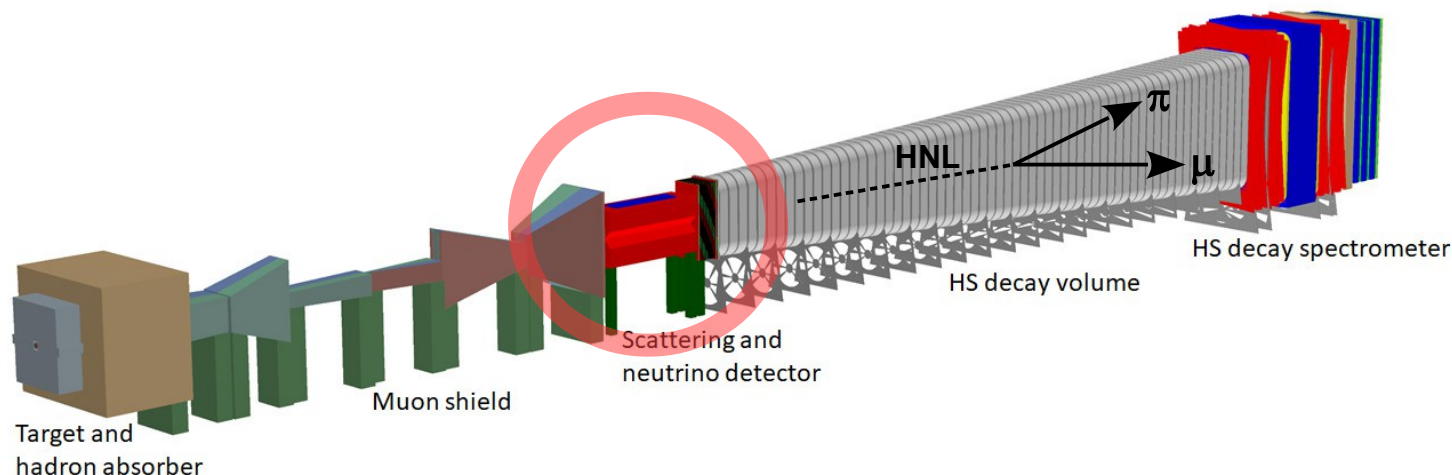
- **Passive absorber & active deflection:**
  - Grain-oriented steel sheets
  - 1.7T magnetic field
  - $< 10^5 \mu$  per 1s-spill remaining





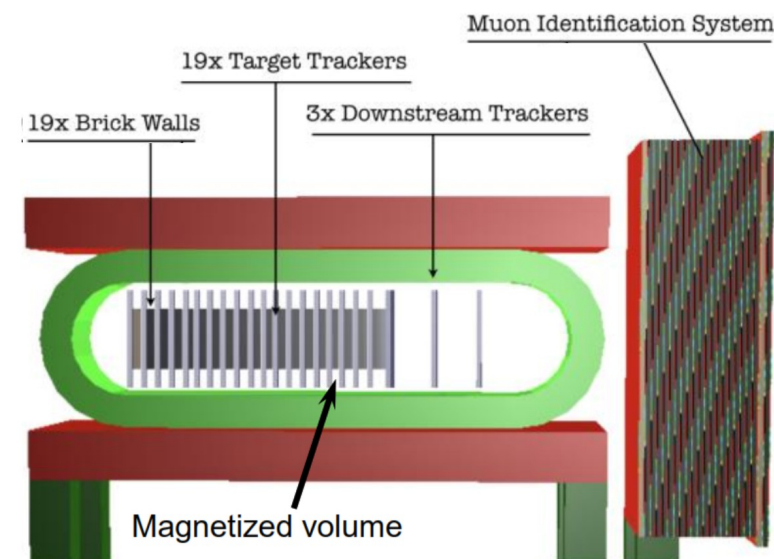


# Scattering & Neutrino Detector (SND)



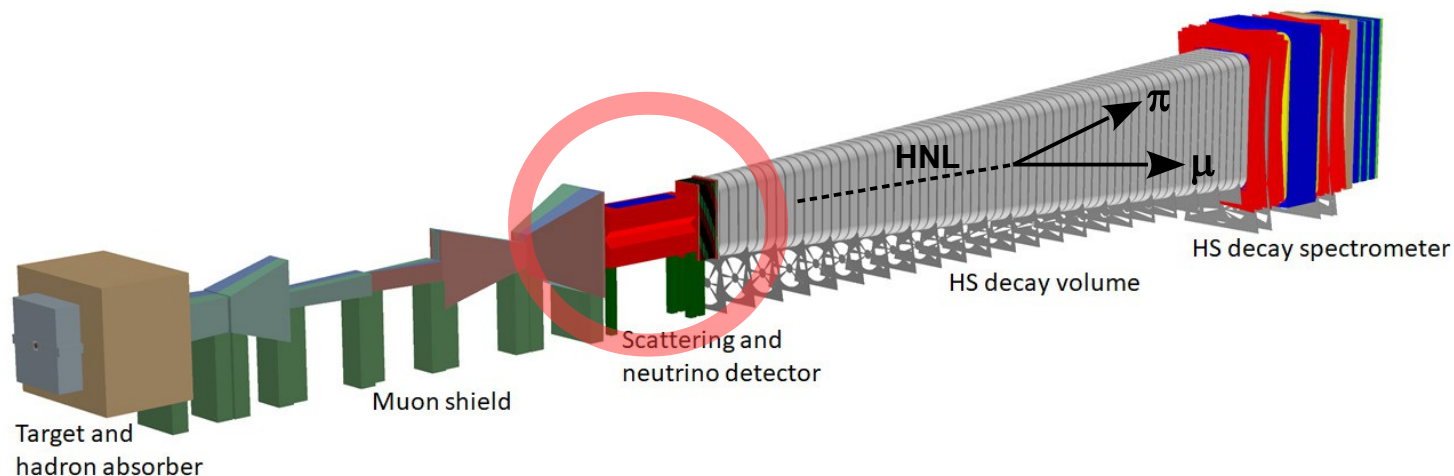
## OPERA-based concept: ED elements & ECC bricks

- High-resolution **Emulsion Cloud Chamber (ECC)** bricks
- 19 layers of **SciFi** target trackers
- **Horizontal magnetic field:**  
1.25T, active cooling
- **$\mu$  ID system:**  
12 planes of **RPCs** & **iron filters**



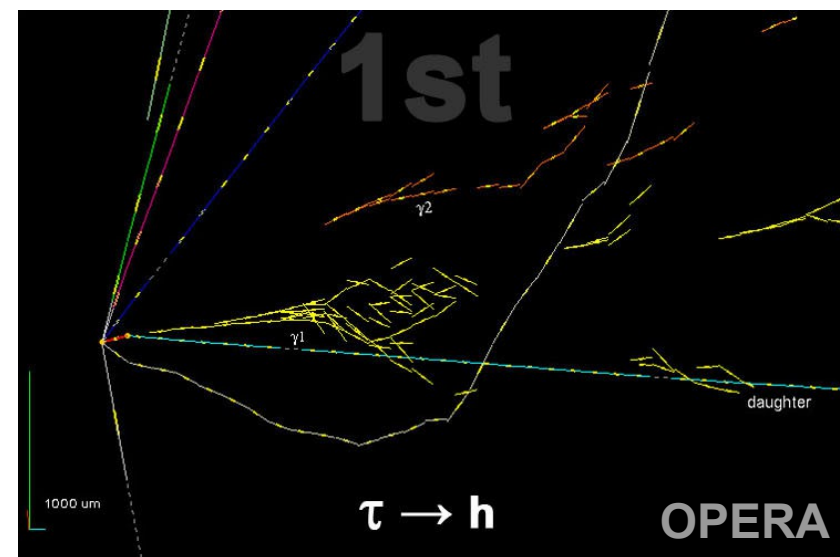


# Scattering & Neutrino Detector (SND)



## OPERA-based concept: ED elements & ECC bricks

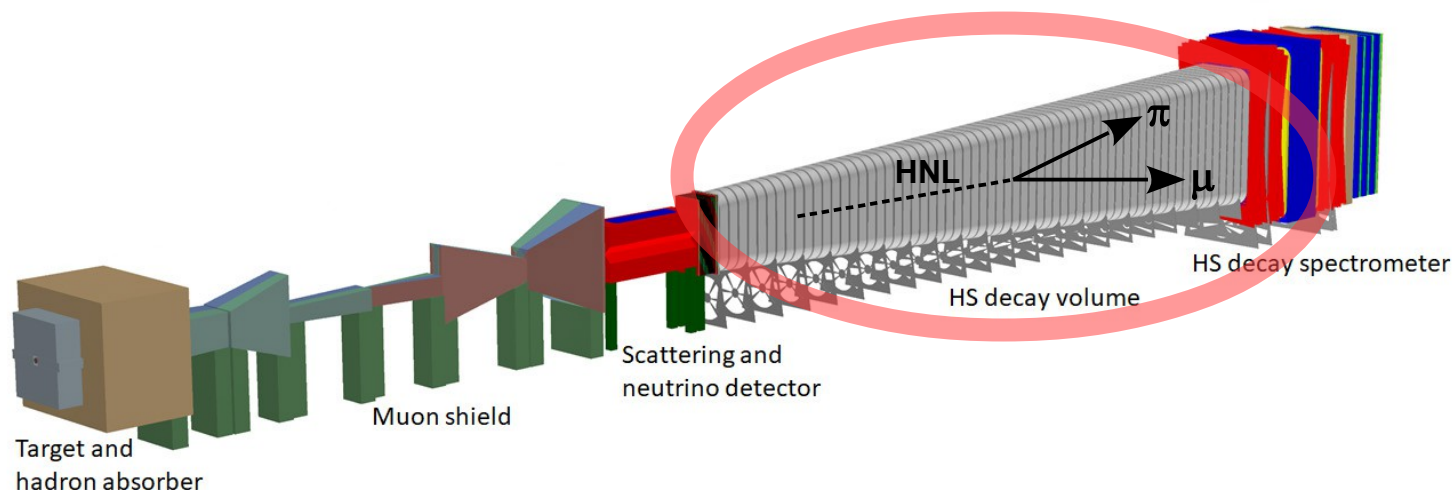
- $\nu$  physics:
  - Measurement of  $\nu_e, \nu_\mu, \nu_\tau$
  - Distinguish  $\nu$  and  $\bar{\nu}$
- Associated **charm production**
- Direct **LDM searches**







# Hidden Sector Detector (HSD)

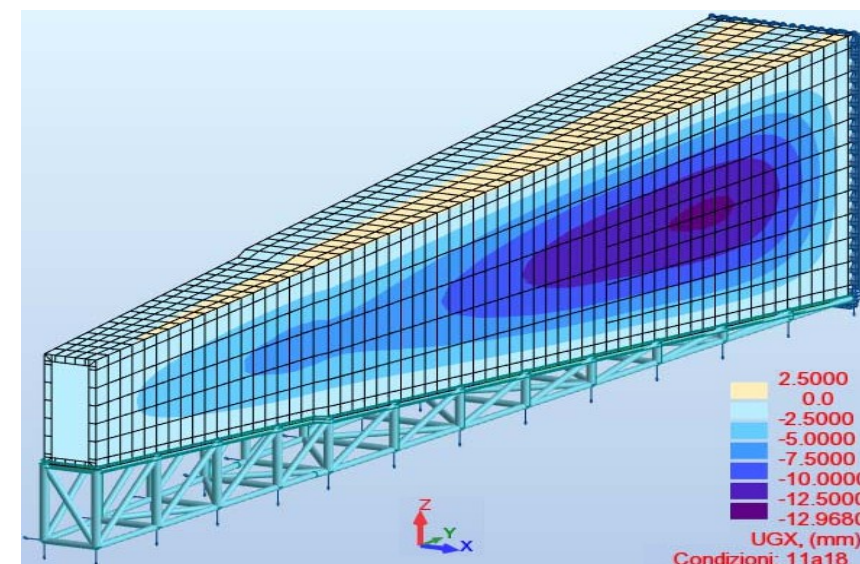


**Evacuated vessel (50m):**  $10^{-3}$  bar

- Minimal BG from  $K_L$ ,  $K_S$ ,  $\Lambda$
- **Visible decays** of HNL into charged leptons,  $\pi$ ,  $\gamma$ ,...

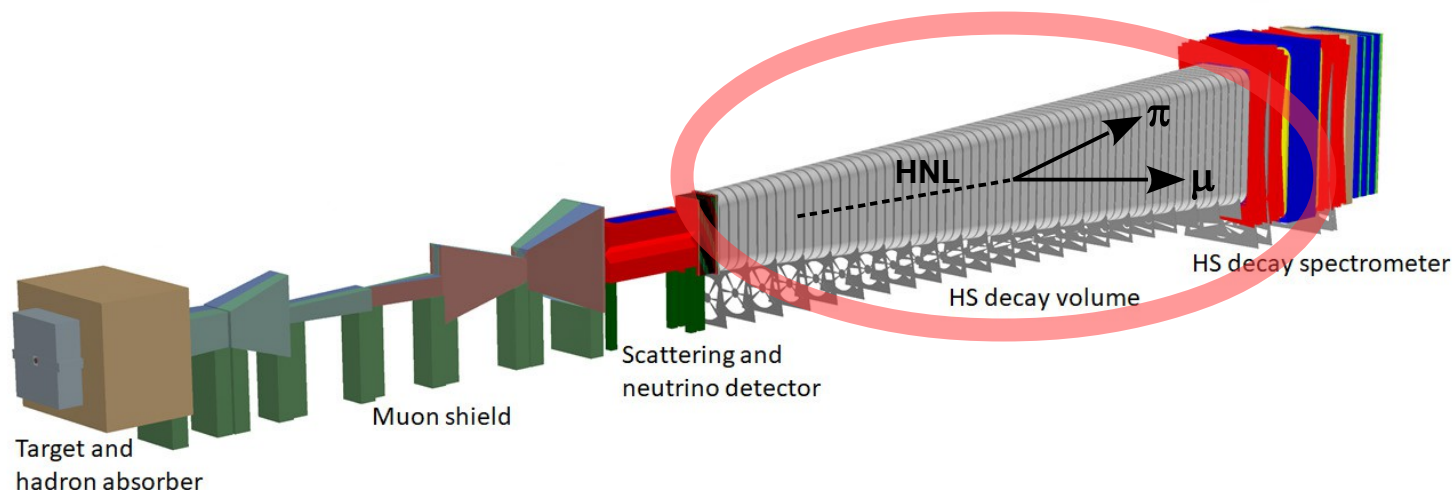
**Double-layer structure:**

- S355W black steel
- 20mm-thick sheets + strengthening ribs



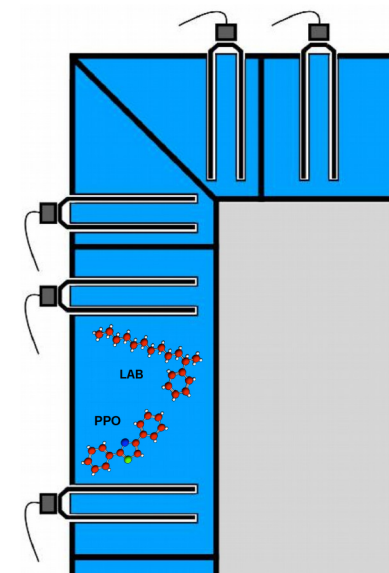


# Hidden Sector Detector (HSD)



## Liquid Scintillator-Surrounding Background Tagger (LS-SBT):

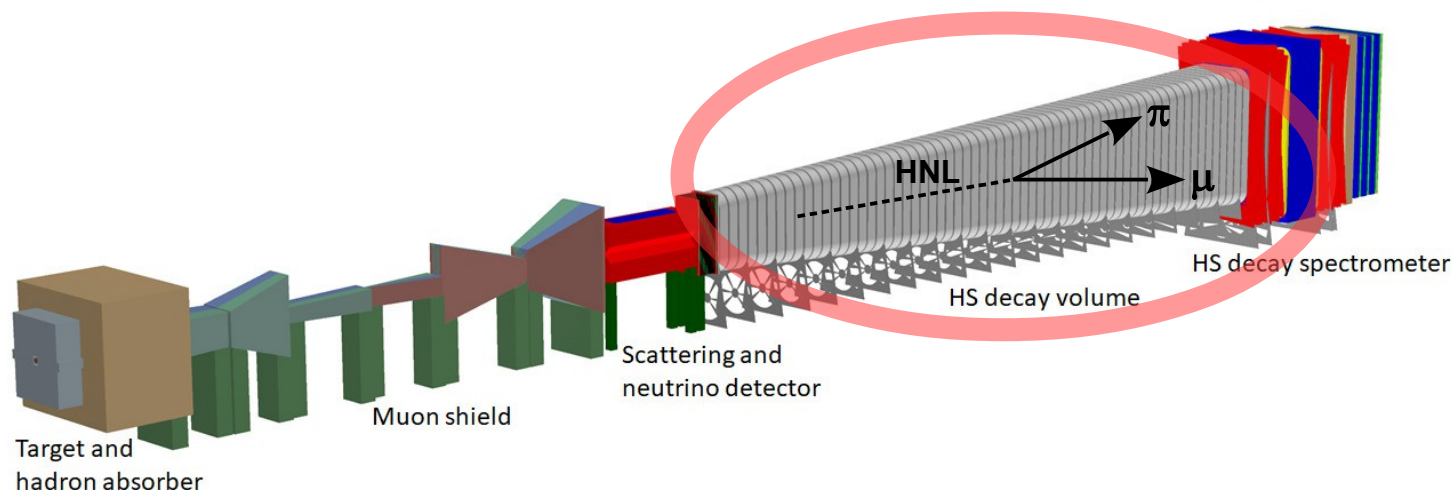
- **Discrimination against  $\mu$  and  $\nu$ -induced BG:**
  - **High efficiency** (99.9% for m.i.p.) & **good time resolution** ( $\sim$ ns)
- **Segments ( $\sim$ 2000):**  $\sim$  120cm x 80cm x 30cm
  - **Inner reflective coating:** BaSO<sub>4</sub>
  - **Filled with liquid scintillator ( $\sim$ 300m<sup>3</sup>):** LAB + PPO (2.0g/l)





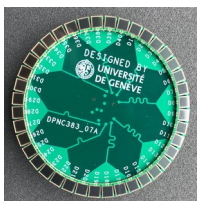


# Hidden Sector Detector (HSD)

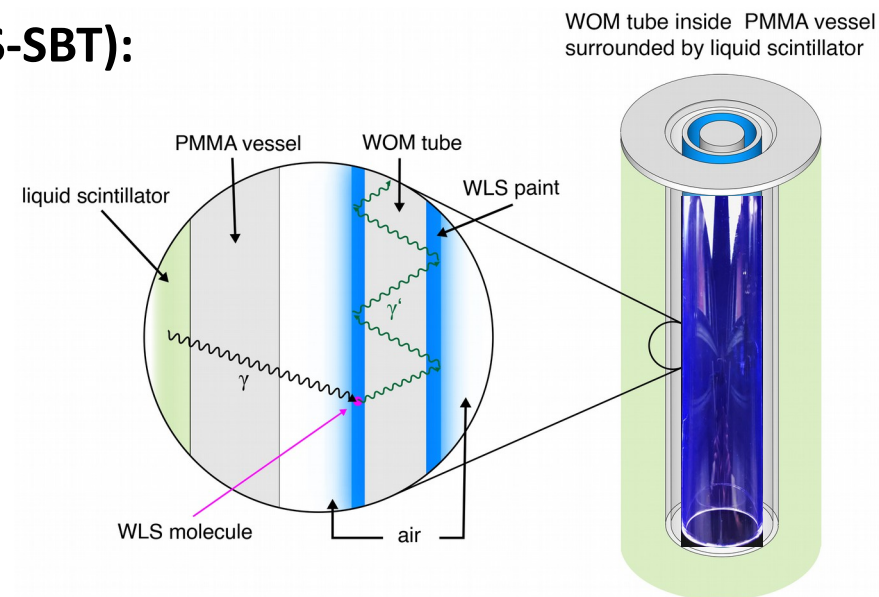


## Liquid Scintillator-Surrounding Background Tagger (LS-SBT):

- **Wavelength-Shifting Optical Modules (WOM) (~ 3500):**  
Transparent PMMA tube with **WLS coating**
- Efficient light collection by **internal total reflection**

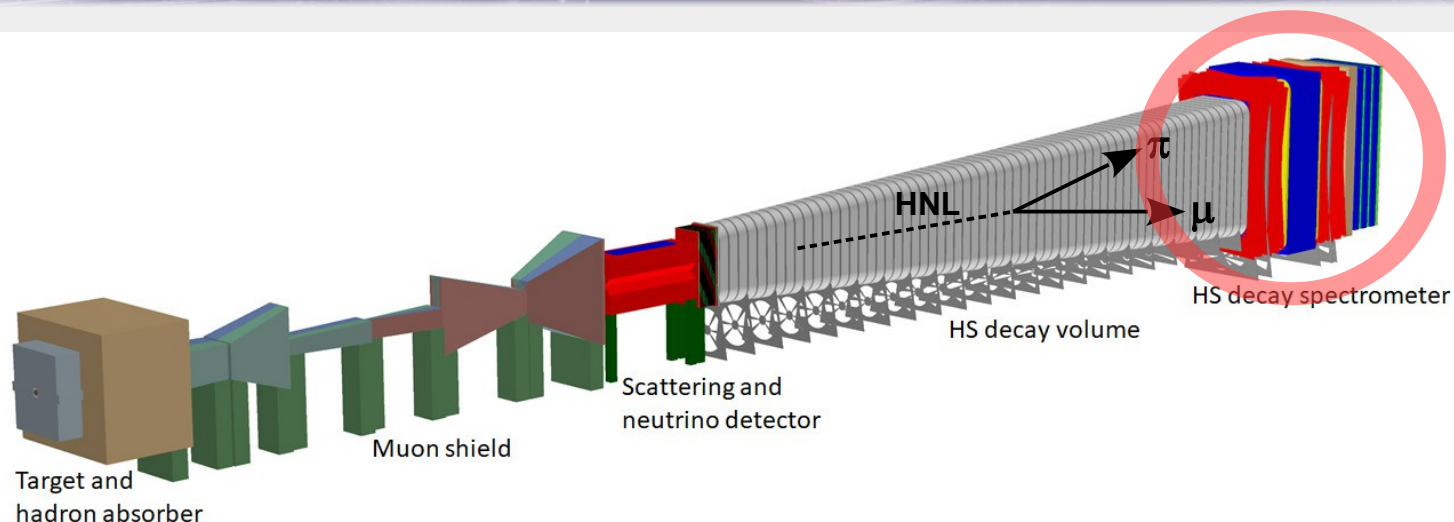


- **SiPM readout:** 40x 3x3 mm<sup>2</sup> on PCB array
- (Rough) **position resolution** by **individual (grouped) readout**



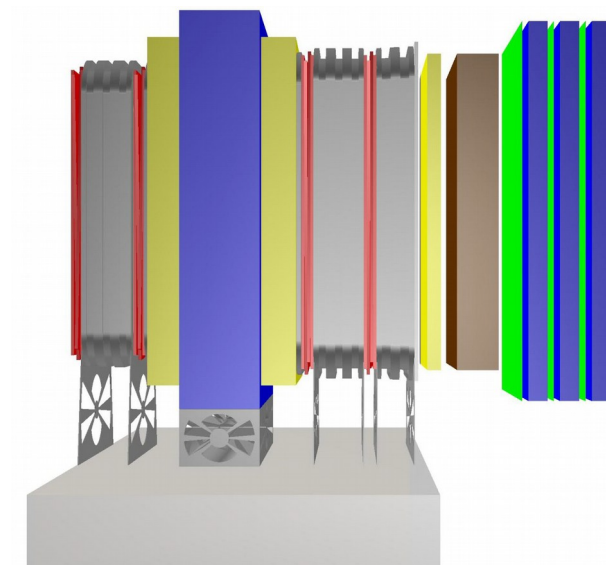


# Hidden Sector Detector (HSD)



**Spectrometer & magnet:** 5m x 10m sensitive area

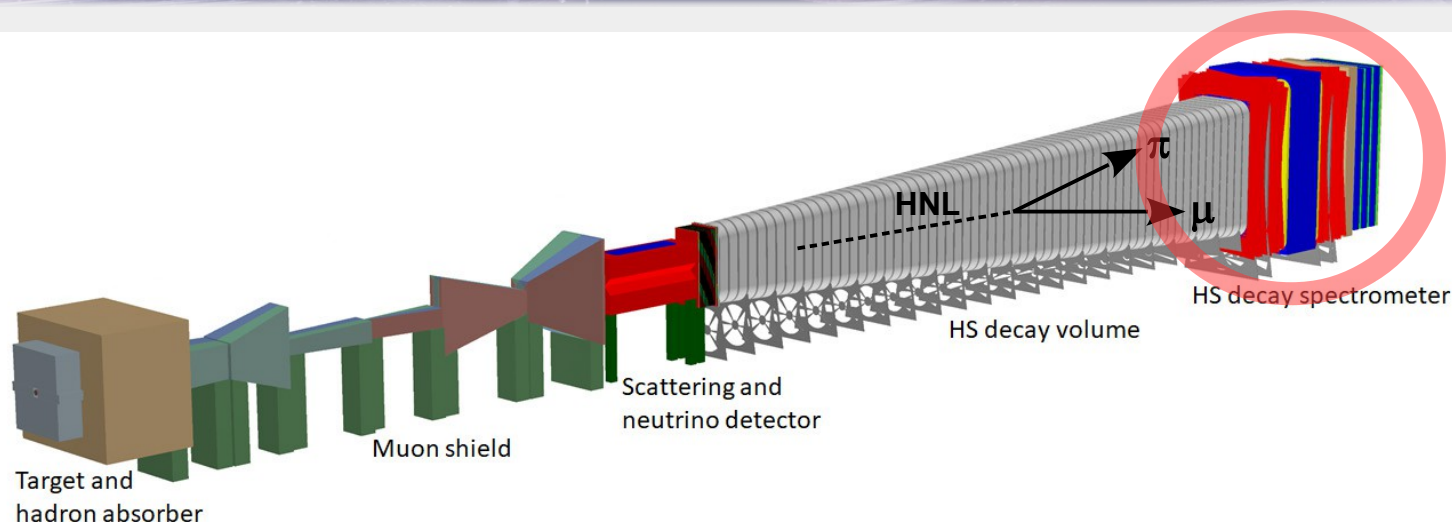
- **Horizontal magnetic field:** 0.15T
  - 1100t yoke, 55t coil mass
  - 3kA current 1.1MW dissipation
- **Superconducting option?**





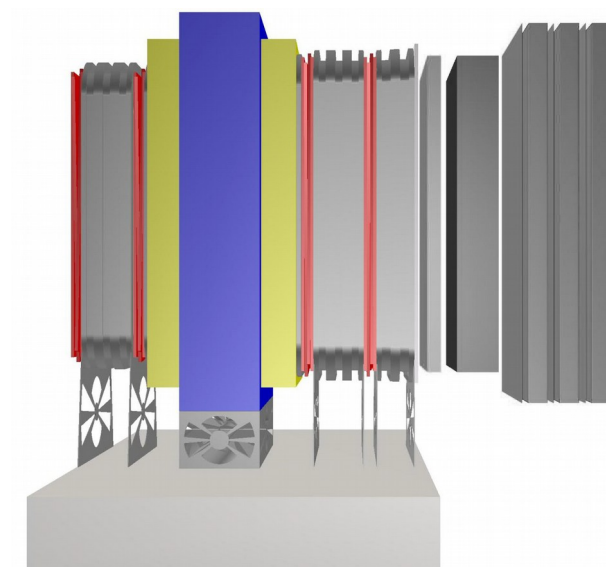


# Hidden Sector Detector (HSD)



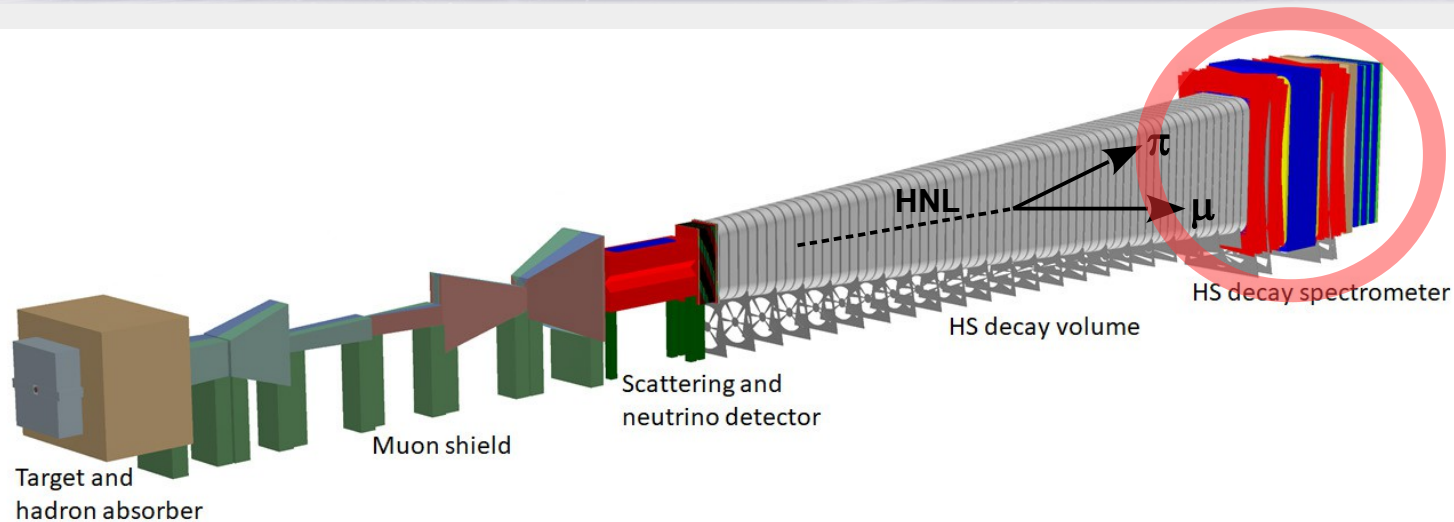
## Spectrometer Straw Tracker (SST):

- 16500 **5m-long tubes** of 2cm diameter
  - 36 $\mu$ m-thick **PET film**, coated with 50nm Cu & 20nm Au
  - 4 stations of 4 x 4 **stereo layers**
- **Spatial resolution:** 120 $\mu$ m
- **Energy resolution:**  $\leq 1\%$  for  $p < 50\text{GeV}$



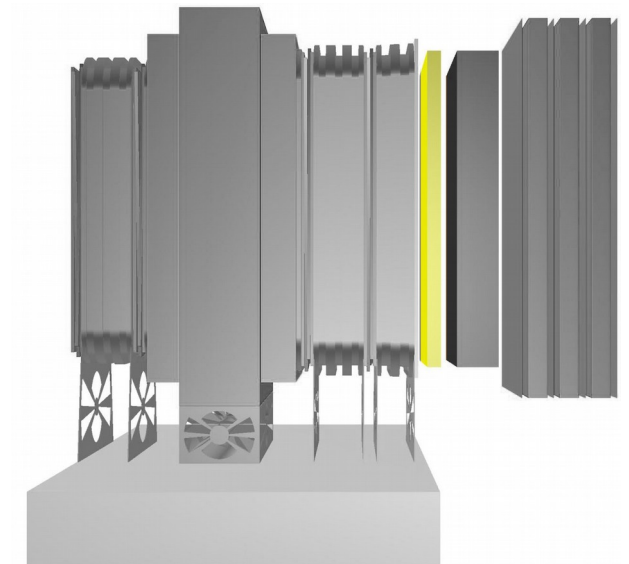


# Hidden Sector Detector (HSD)



## Timing Detector (TD): Rejection of $\mu$ combinatorial BG

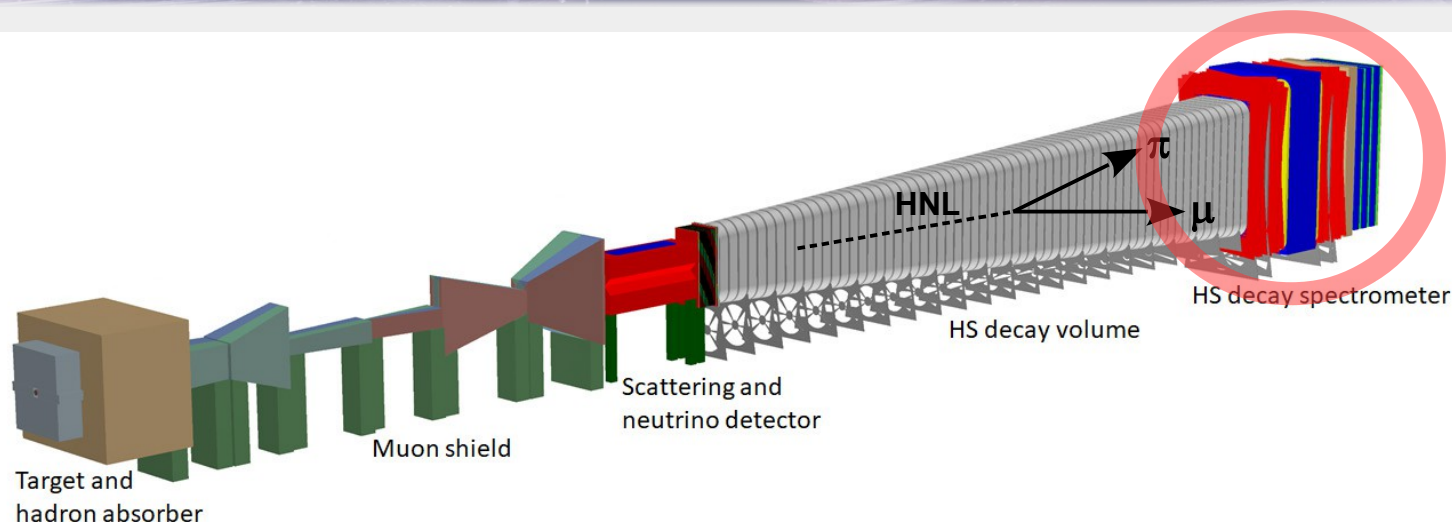
- **Plastic scintillator bars,**  
double-sided **SiPM readout**
  - **Multi-gap RPCs**  
(also considered for front-cap veto)
- **Time resolution:**  $\leq 100\text{ps}$







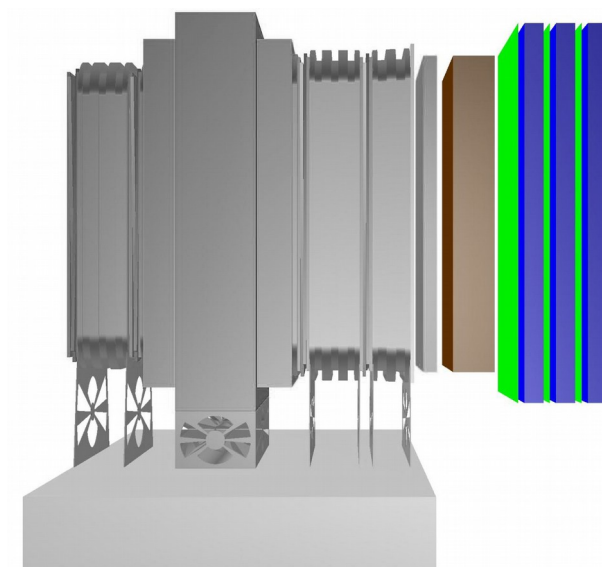
# Hidden Sector Detector (HSD)



## Electromagnetic Calorimeter (SplitCal):

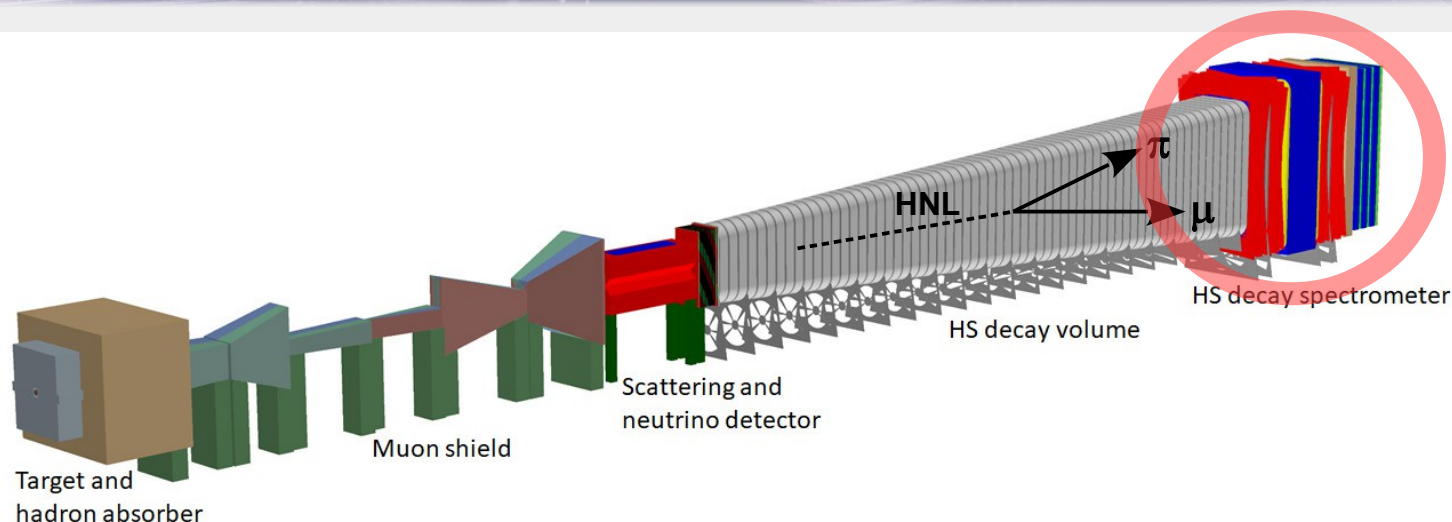
$e/\gamma$  identification,  $\pi^0$  reconstruction,  $\gamma$  directionality

- 50 layers of **plastic scintillator** with **WLS fibers** & double-sided **SiPM readout**
- 6m x 12m-wide **absorber planes**
- 3 layers of high-precision **MicroMegas**





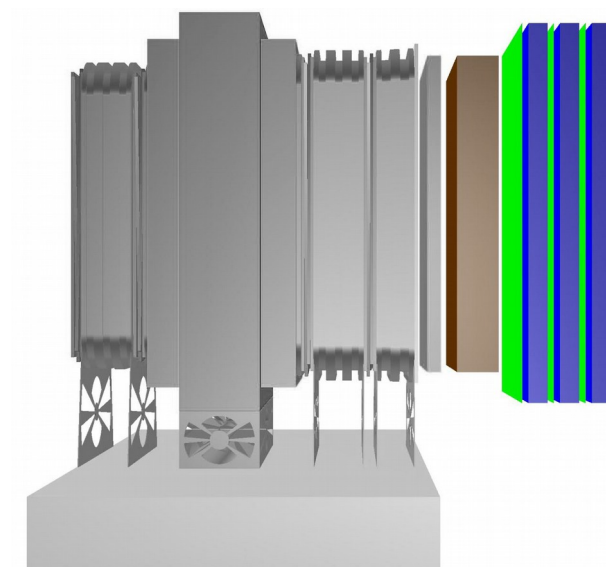
# Hidden Sector Detector (HSD)



## Muon Detector:

Rejection of  $\mu$  combinatorial BG,  $\pi/\mu$  identification

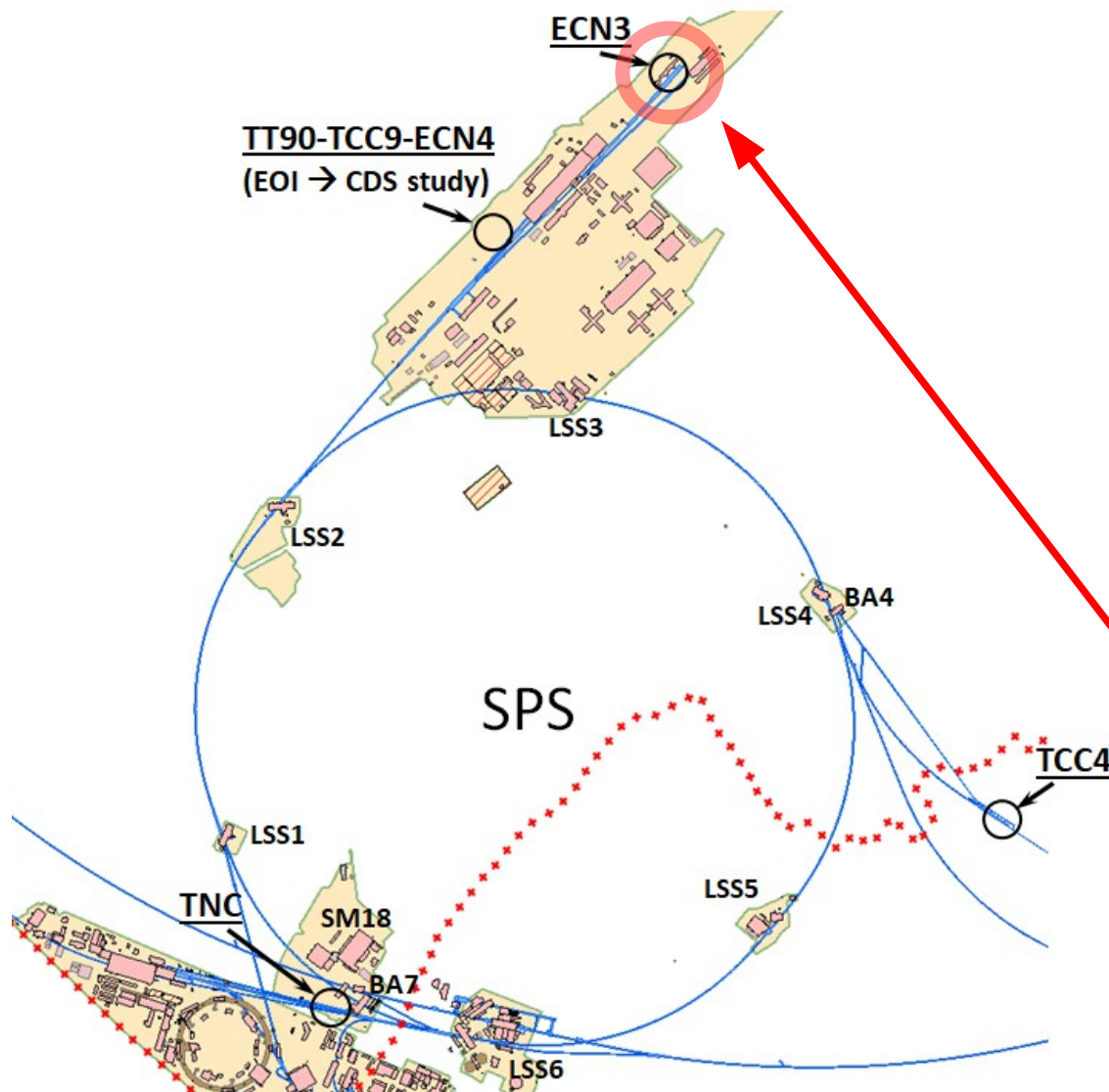
- **3 stations:** 6m x 12m sensitive area
- **Plastic scintillator** tiles (10cm x 20cm) with direct **SiPM readout**
- **Passive iron filters**







**SHIP @ ECN3**



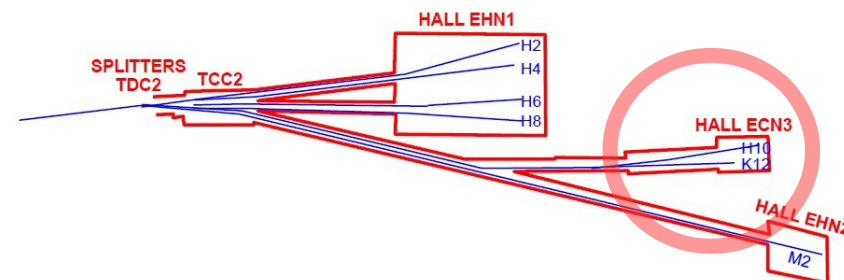
**Motivation:** Reduce cost

**Framework / motivation:**

- **Preserve original physics reach**
- **Proton delivery** as defined in CDS
- Same **basic layout & key parameters** of facility & detector

**Develop best option within 1 year!**

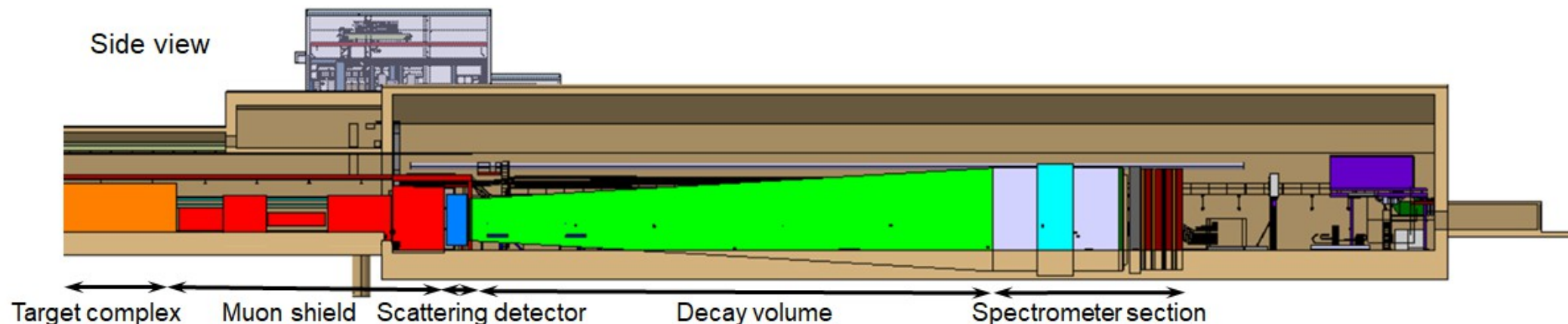
**Most promising location: ECN3**







# SHiP @ECN3

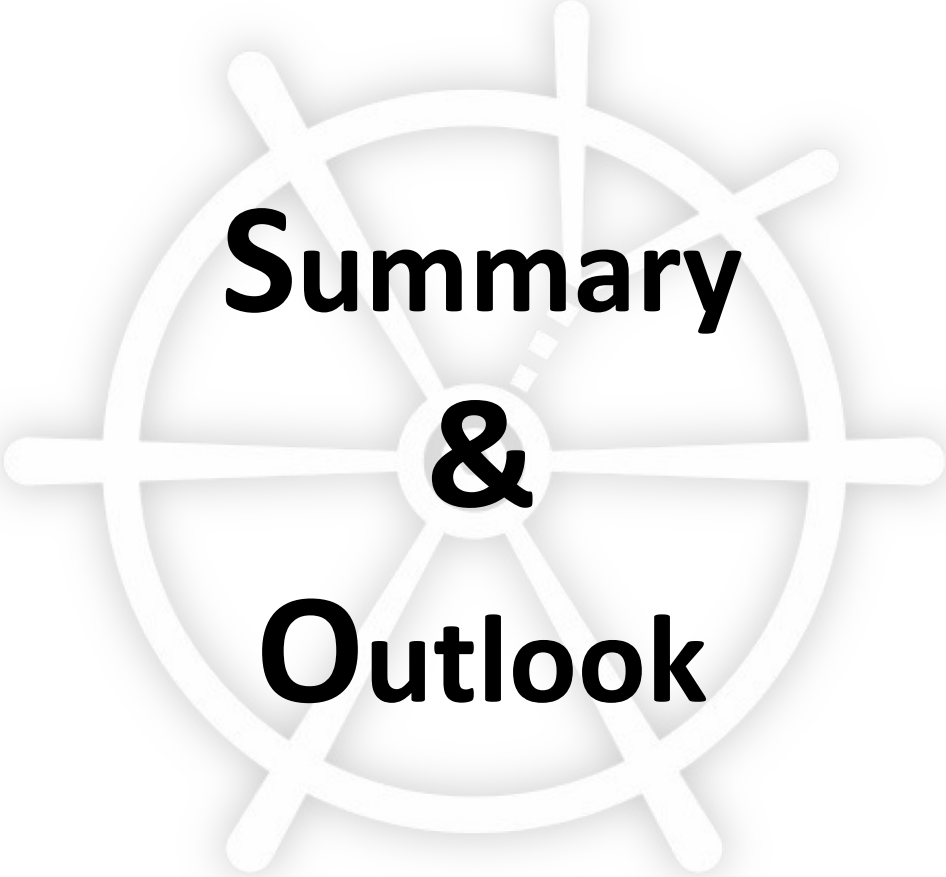


## ECN3 benefits & constraints:

- + Reuse **existing (already irradiated) infrastructure**
- + **Fully underground** experimental area
- **Spatial constraints**
- **Access shaft & ancillary buildings**

## Detector re-optimisation:

- **SND:** Emulsions → SciFi?
  - **Muon shield:** Less severe rate limit
- **Decay vessel & spectrometer:**  
Reduce transversal size by ~20%
- **Improved time & spatial resolution**
- **Adjusted BG studies...**

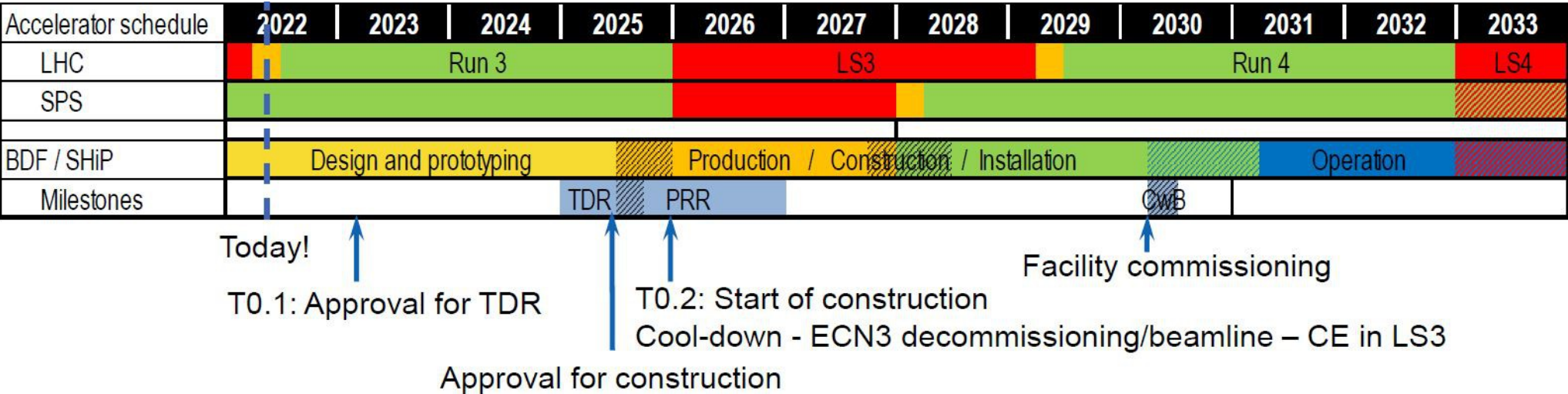


# **Summary & Outlook**

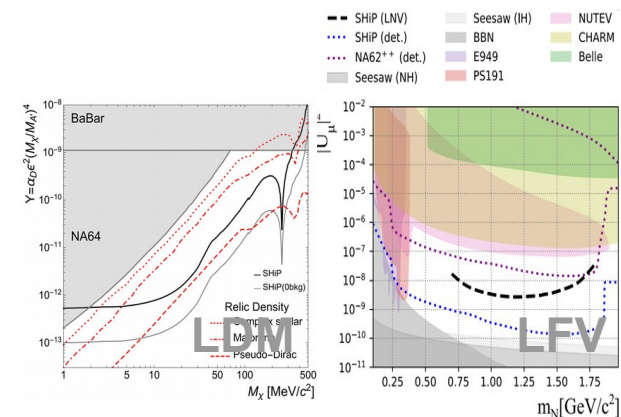
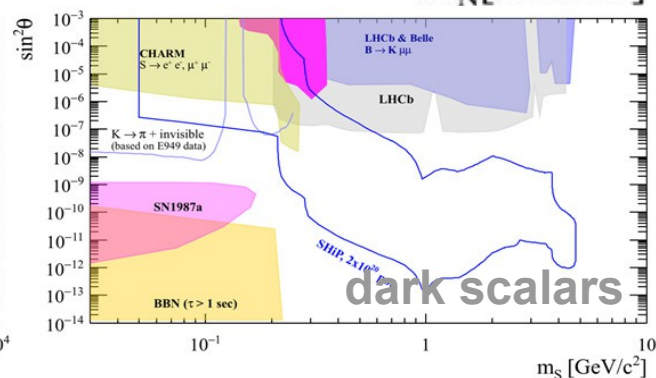
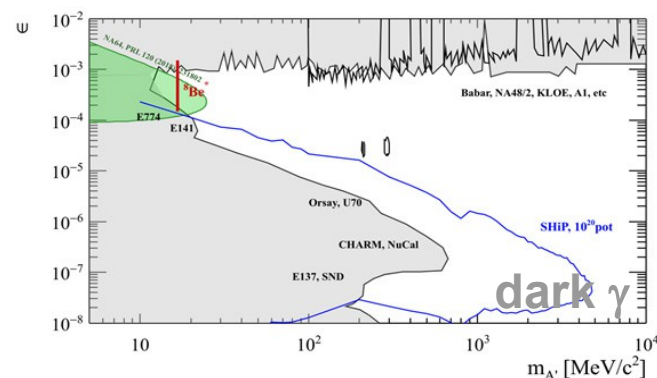
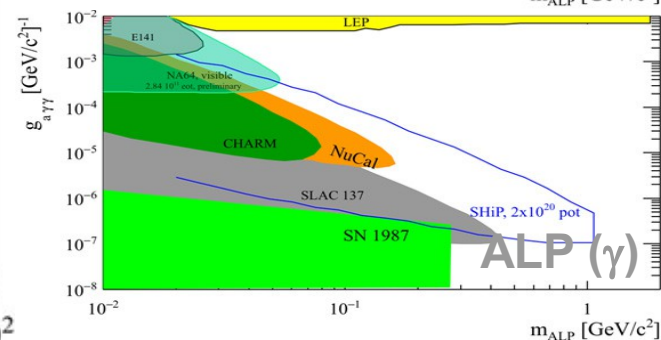
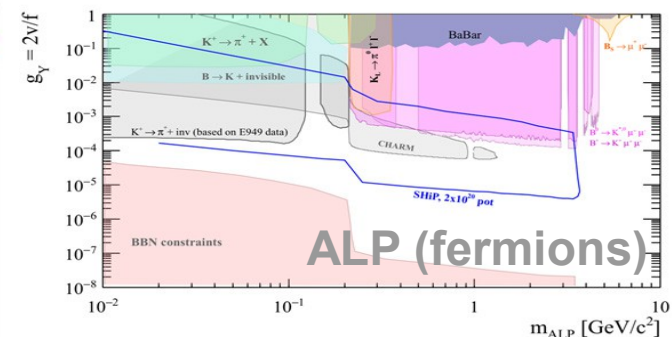


**SHiP:** Part of the **CERN Physics Beyond Colliders** initiative

- **BDF:** 400 GeV p @CERN SPS NA
- **HSD:** HNL, dark  $\gamma$ , light scalars, SUSY, ALP...
- **SND:**  $\nu_\tau$  physics, charm production, LDM scattering...
- **ECN3 beamline:** Under study as new preferred detector location
  - **Spring 2023:** Approval (for TDR)?!



# SHiP Physics Reach







# SHiP Publications of Note

## **The SHiP experiment at the proposed CERN SPS Beam Dump Facility**

Eur. Phys. J. C 82, 486 (2022) / arXiv:2112.01487

## **Study of alternative locations for the SPS Beam Dump Facility**

CERN-SPSC-2022-009 / arXiv:2204.03549

– SHiP Comprehensive Design Study –

## **SHiP Experiment – Comprehensive Design Study Report**

CERN-SPSC-2019-049

– Physics Beyond Colliders Initiative –

## **Physics Beyond Colliders at CERN – BSM Working Group Report**

CERN-PBC-REPORT-2018-007 / arXiv:1901.09966

– SHiP Physics Case –

## **A facility to Search for Hidden Particles at the CERN SPS: the SHiP physics case**

CERN-SPSC-2015-017 / arXiv:1504.04855

– SHiP Technical Proposal –

## **A facility to Search for Hidden Particles at the CERN SPS**

CERN-SPSC-2015-016 / arXiv:1504.04956