the 5th International Conference on Particle Physics and Astrophysics

Neutrino physics with the SHiP experiment at CERN

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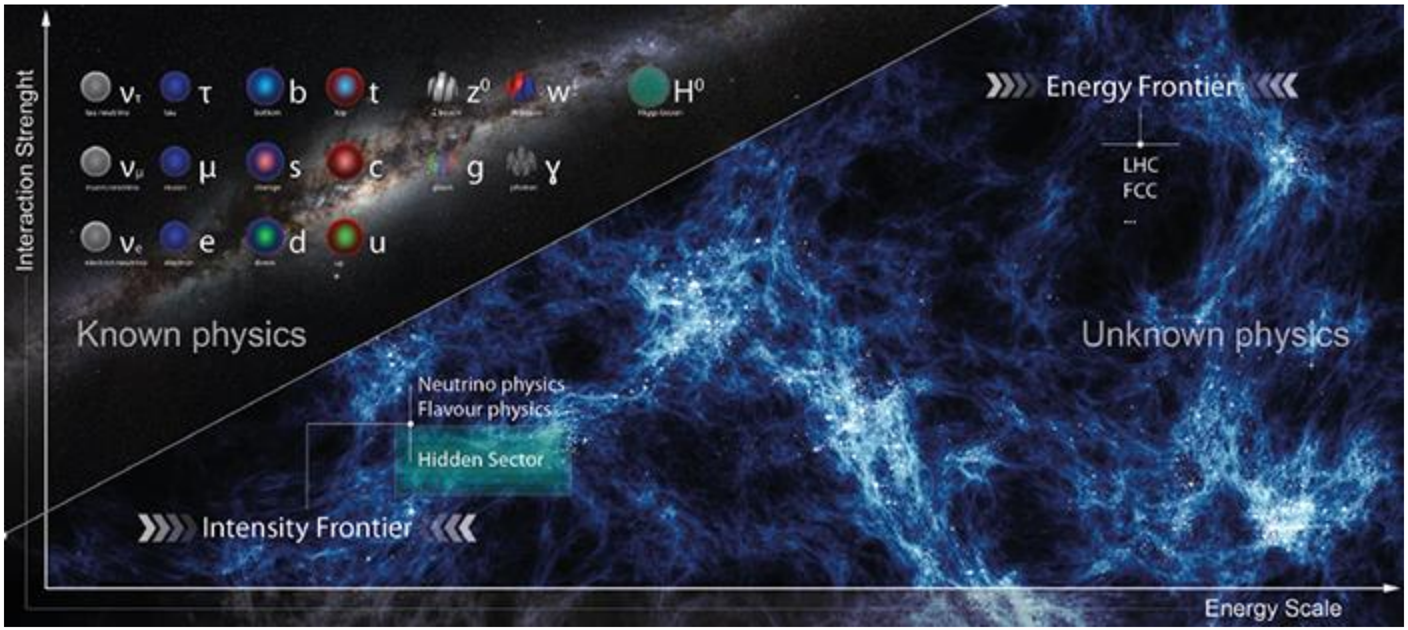
on behalf of the SHiP Collaboration

Beyond Standard Model …

Experimental hints of BSM physics

- ν masses and oscillations
- Baryon Asymmetry of the Universe
- Dark Matter



New Physics can be hidden due to

very heavy masses → *Energy Frontier, high energy collisions*

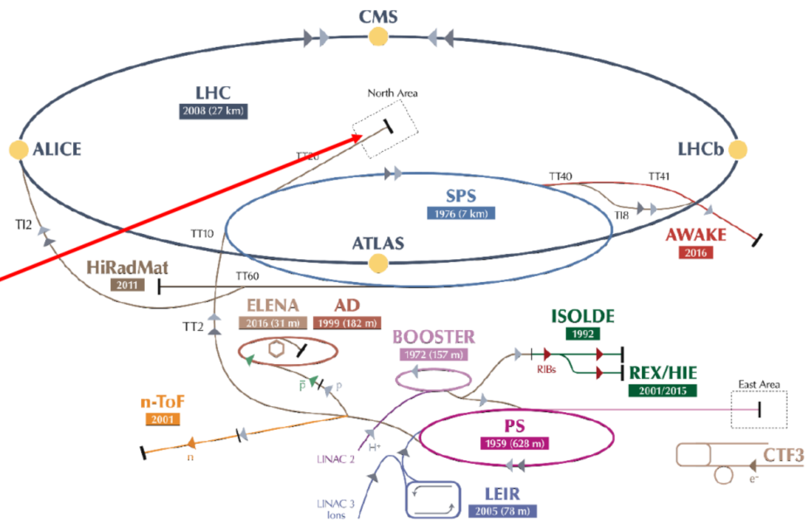
or

very weak couplings → *Intensity Frontier, beam dump*

and beyond Colliders

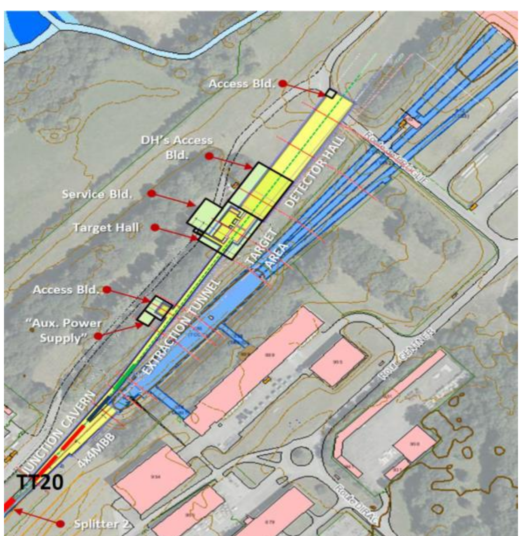
SHiP
Search for Hidden Particles

Search for Hidden Particles (SHiP) @
CERN-based Beam Dump Facility (BDF)



Proposed siting of the SPS Beam Dump Facility

- *Slow extraction (1 sec)*
- *High intensity proton beam*
  $4*10^{13}$ p/spill , $4*10^{19}$ pot/year
  $2*10^{20}$ pot/5 years
- *O(400 GeV/c) optimal beam momentum*

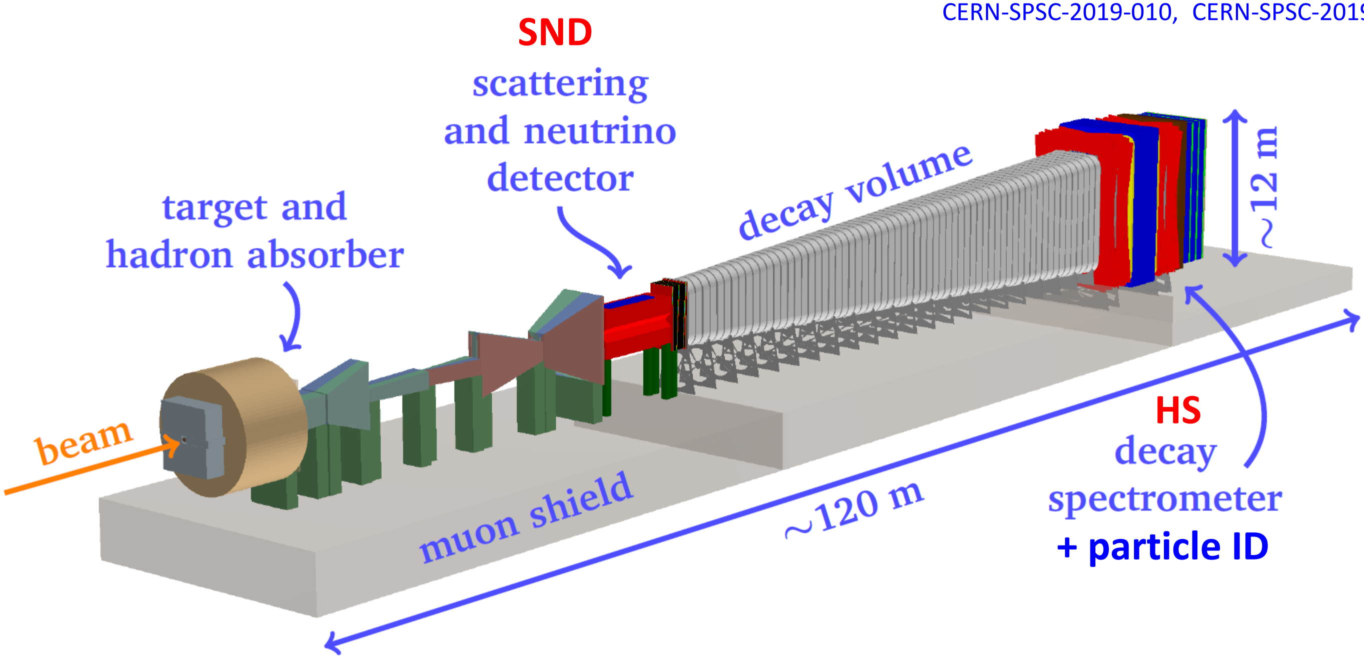


existing tunnels
existing buildings
new installations

https://doi.org/10.23731/CYRM-2020-002

The SHiP experiment

ins-det: 1504.04956, JINST 14(2019)03 P03025,
CERN-SPSC-2019-010, CERN-SPSC-2019-049 / SPSC-SR-263

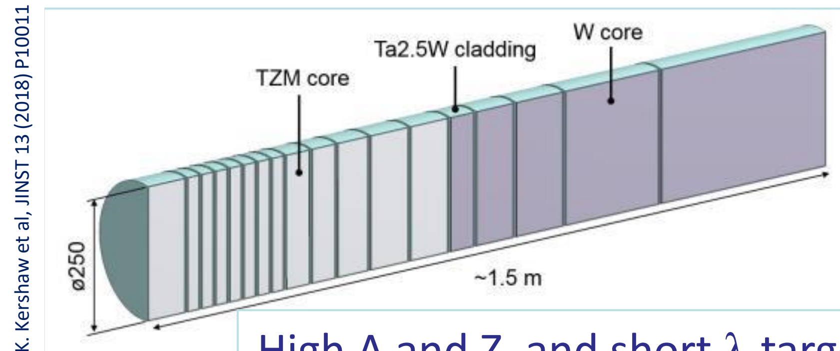


Dual detector system

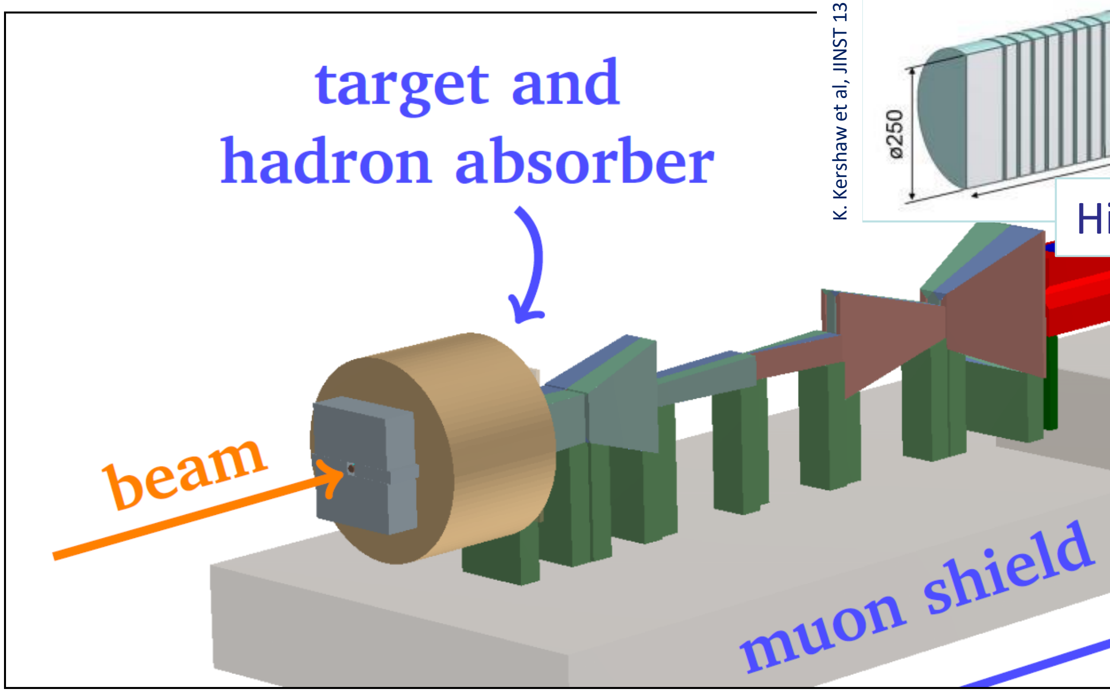
- Scattering and Neutrino Detector (SND)
  → neutrino physics and Light Dark Matter searches
- Hidden Sector detector (HS)
  → search for new, weakly coupled, long lived particles from the Hidden Sector

The SHiP experiment : general requirements

driven by Hidden Sector phenomenology



High A and Z, and short λ target

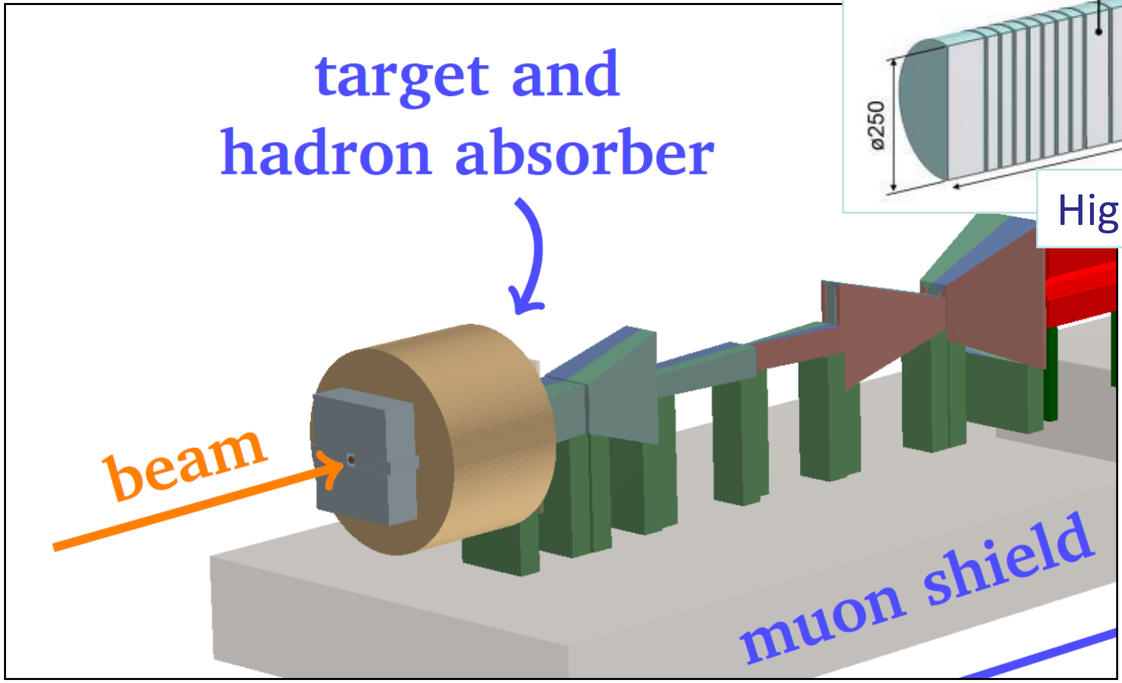


5 years of BDF@SPS ($2*10^{20}$pot):

- 10^{18} charm mesons
- 10^{14} beauty mesons
- 10^{16} tau leptons

The SHiP experiment : general requirements

driven by Hidden Sector phenomenology



High A and Z, and short λ target

Hadron absorber
Strongly reduce the huge flux of SM particles, in particular pion and kaons before decay

The SHiP experiment : general requirements

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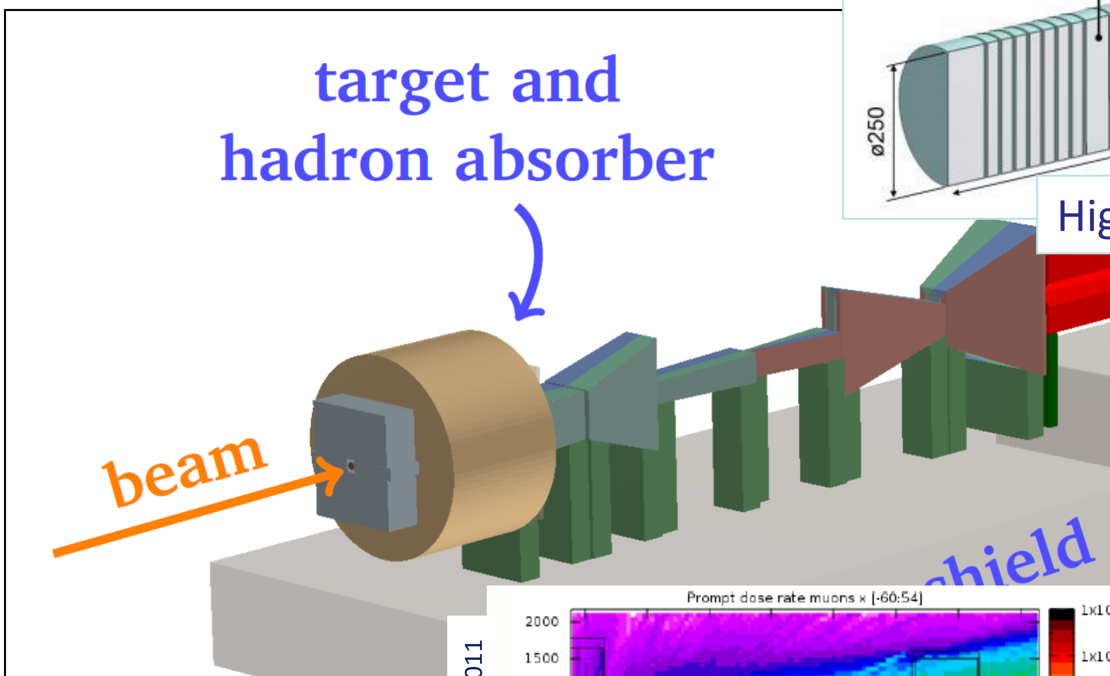
High A and Z, and short λ target



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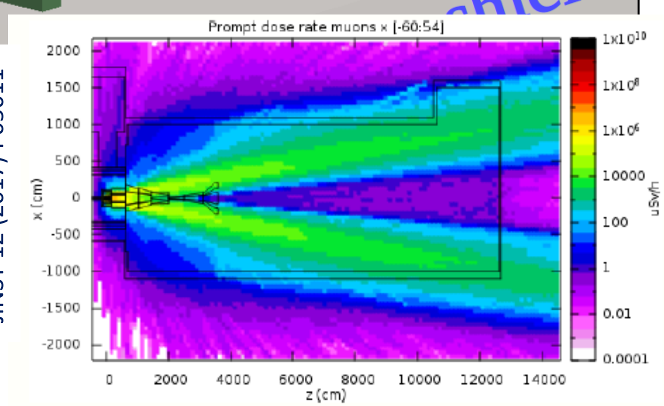


JINST 12 (2017) P05011

magnetised muon shield

$\sim 10^{11}$ μ in 1 spill reduced to < 10^5

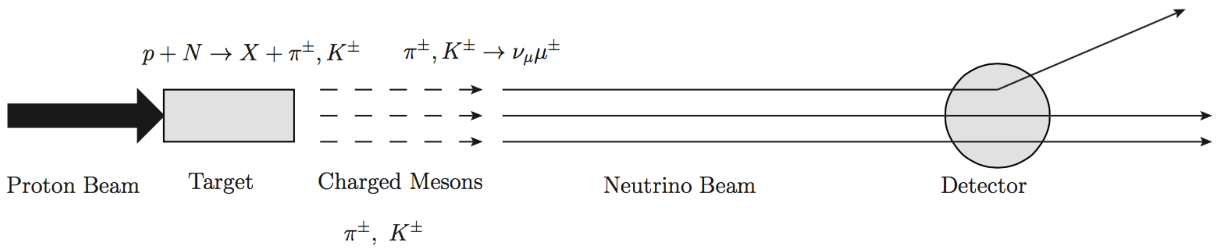
Muon spectrum validated with dedicated experiment in 2018

SHiP
Search for Hidden Particles

The Scattering and Neutrino Detector

High ν flux expected@BDF

→ Unique opportunity to perform studies on ν_τ, ν_μ, ν_e (+ cc) @SHiP SND



ν Physics potential:

- first ever observation of anti- ν_τ
- ν_τ and anti- ν_τ physics with high statistics
- ν induced charm production studies
- ν_f cross sections measurements

# of ν CC DIS int. in SND target in $2\text{x}10^{20}$ pot

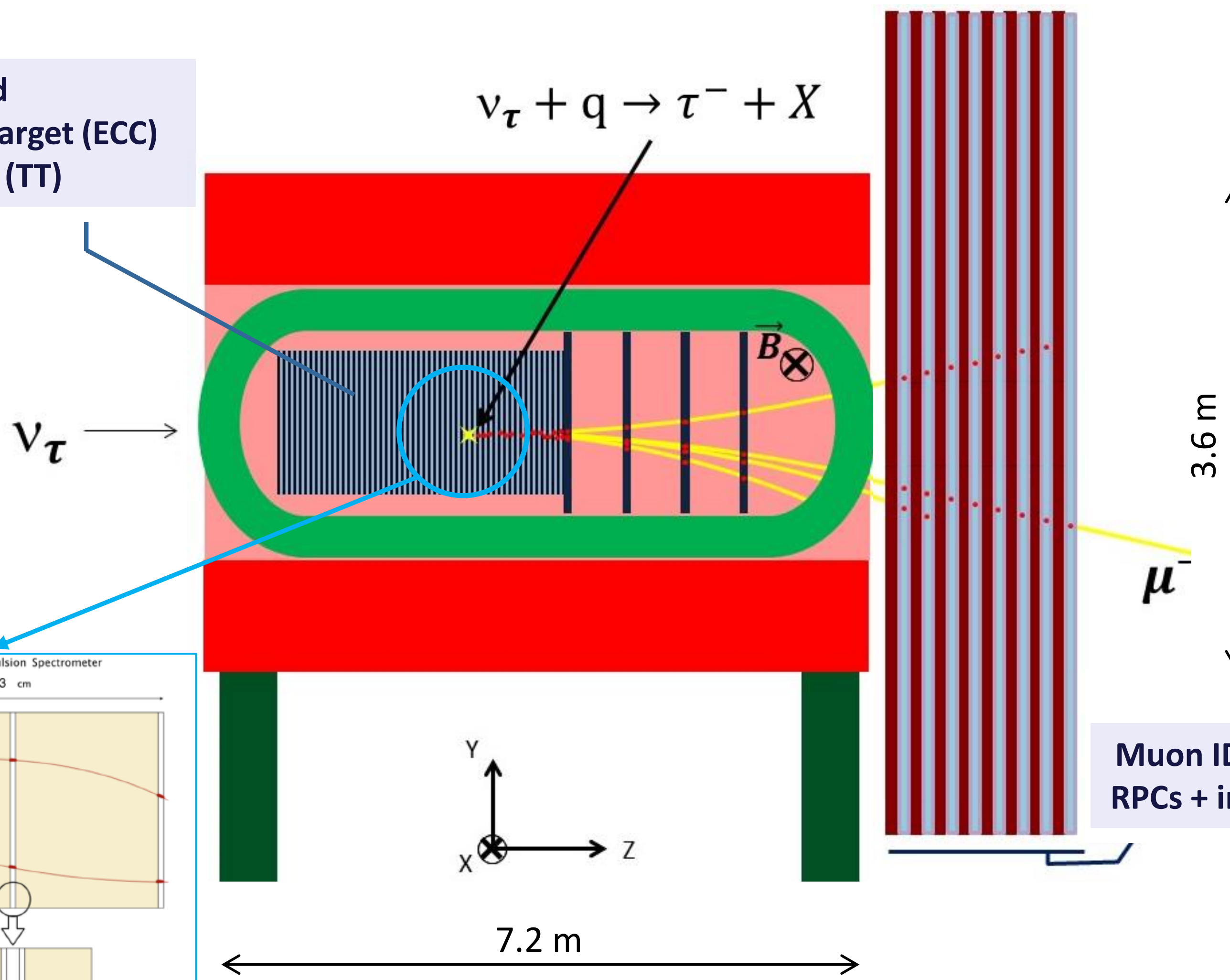
	$\bar{E}$ [GeV]	CC DIS int.
ν_e	59	1.1×10^6
ν_μ	42	2.7×10^6
ν_τ	52	3.2×10^4
$\bar{\nu}_e$	46	2.6×10^5
$\bar{\nu}_\mu$	36	6.0×10^5
$\bar{\nu}_\tau$	70	2.1×10^4

Experimental requirements:

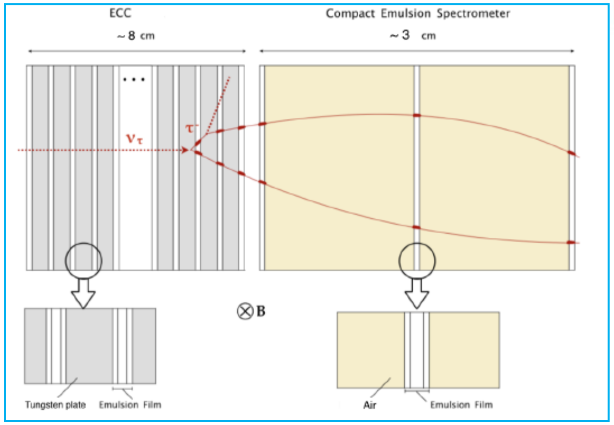
- reconstruct ν interactions → Emulsion Cloud Chamber (ECC) technique + Target Tracker (TT)
- tag ν flavour → ECC technique + μ ID system
- tag ν and anti-ν → Magnetised target

The Scattering and Neutrino Detector

Magnetized emulsion - tungsten target (ECC) + SciFi trackers (TT)



ECC bricks *à la OPERA*

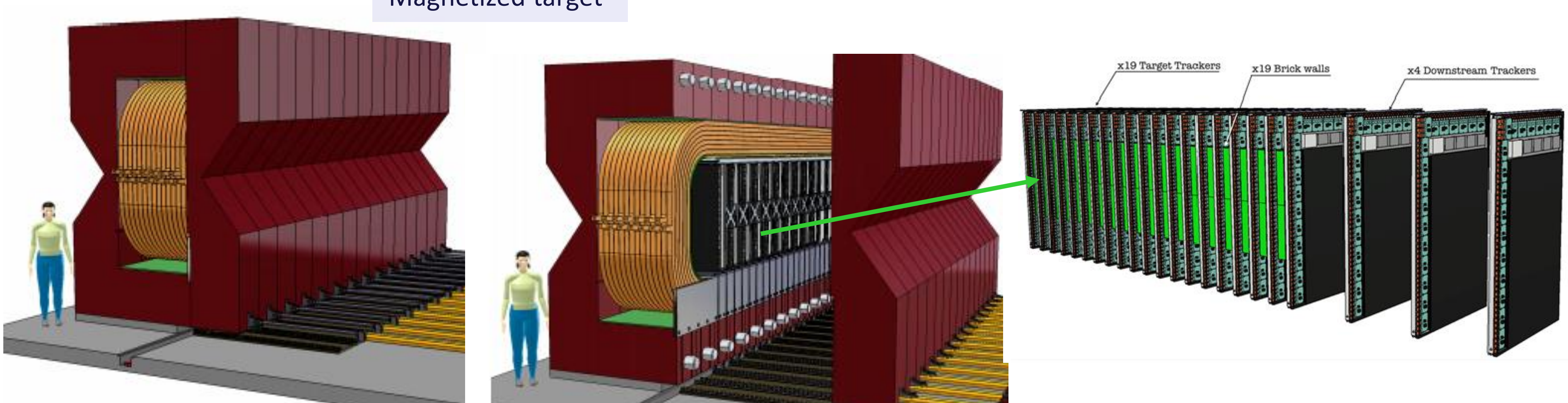


Muon ID system: RPCs + iron filters

SHiP Progress Report
CERN-SPSC-2019-010 / SPSC-SR-248

The Scattering and Neutrino Detector

Magnetized target

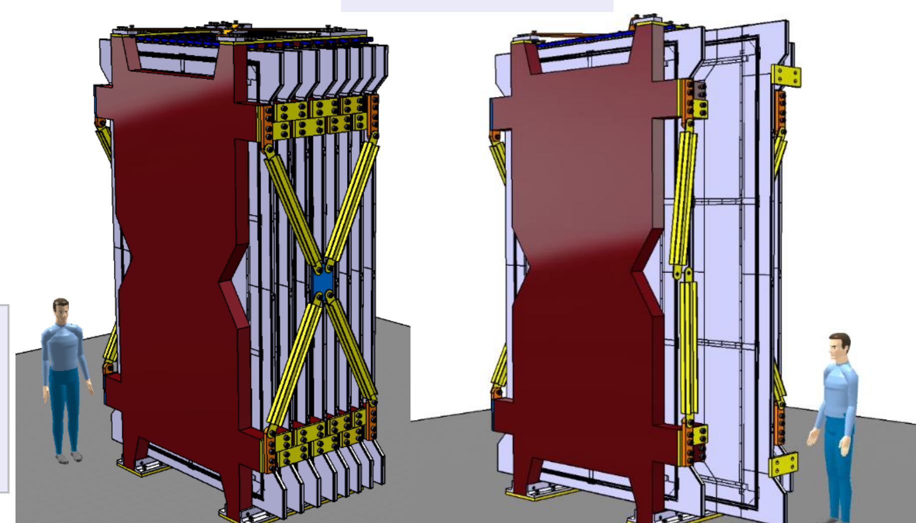


JINST 15 (2020) P01027

Magnetized volume of ~10 m^3 (B ≅ 1.2 T);

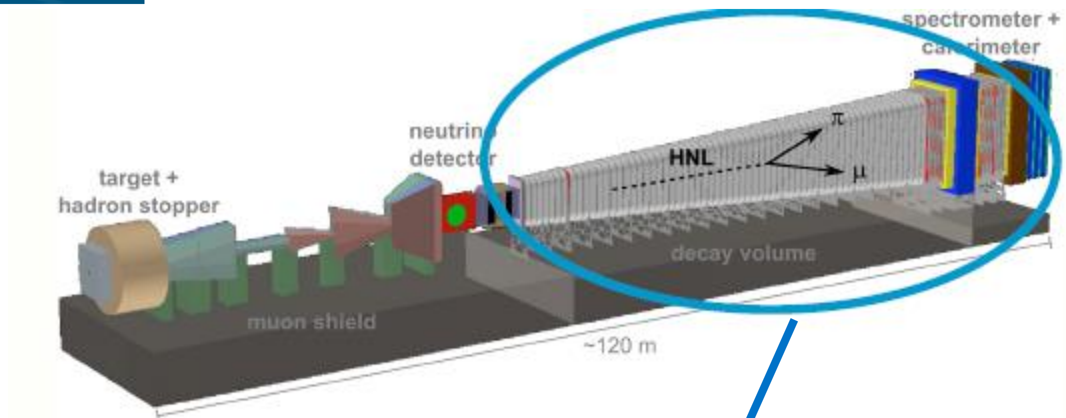
opening / closing mechanism to allow for emulsion film replacement during run

Muon ID System



RPC tracking planes hanging from top;
upper trails for insertion / extraction
sensitive area ~2×4 m^2
geometrical acceptance ~60%

The Hidden Sector Detector

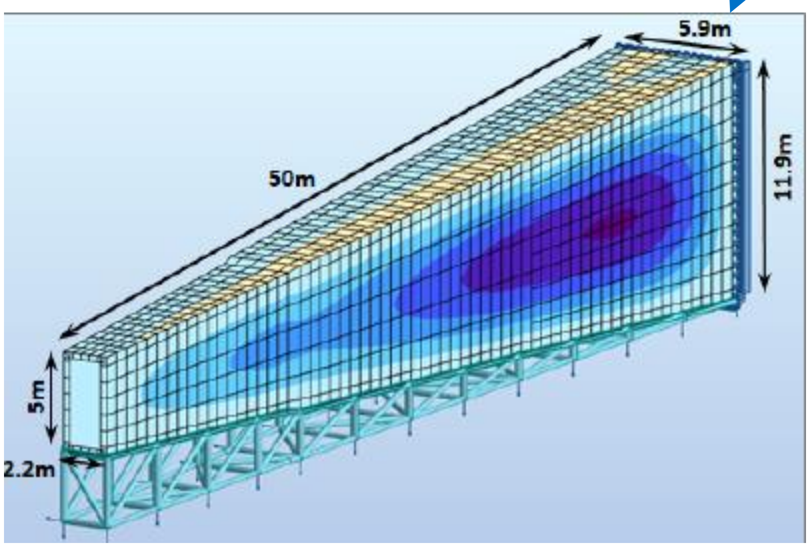


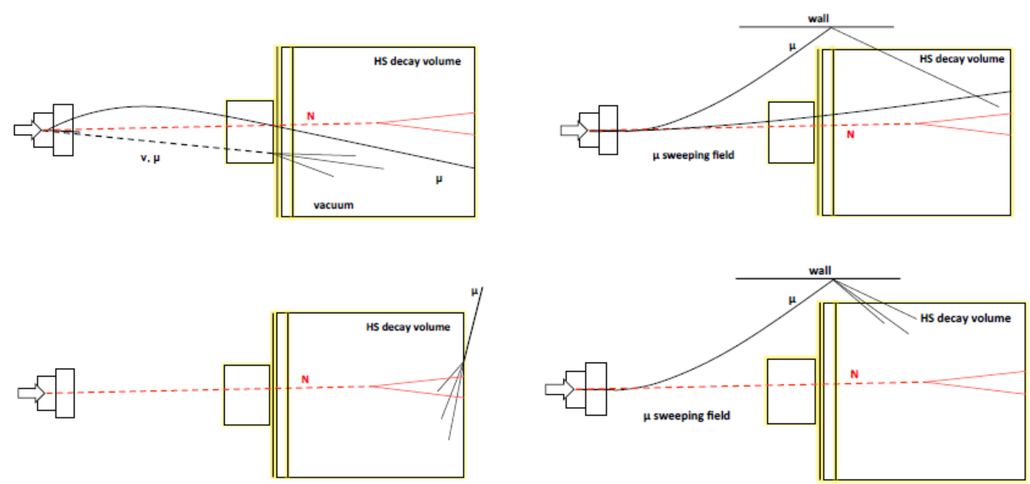
Decay Vessel

Pyramidal frustum shape, length 50 m
1 mbar, volume 2040 m^3

Double-layer steel structure
with strengthening ribs

Surrounding background tagger:
480 t of liquid scintillator





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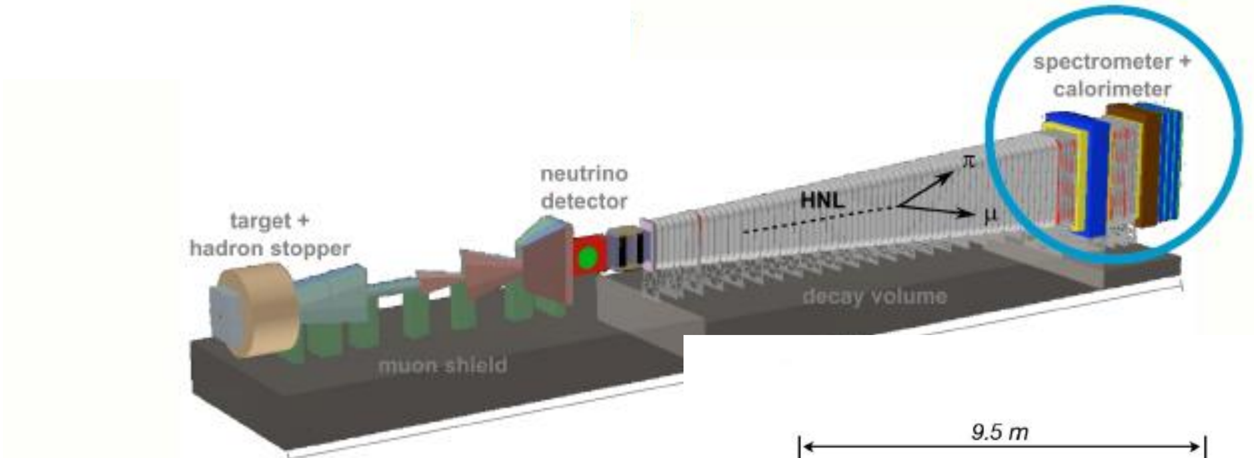
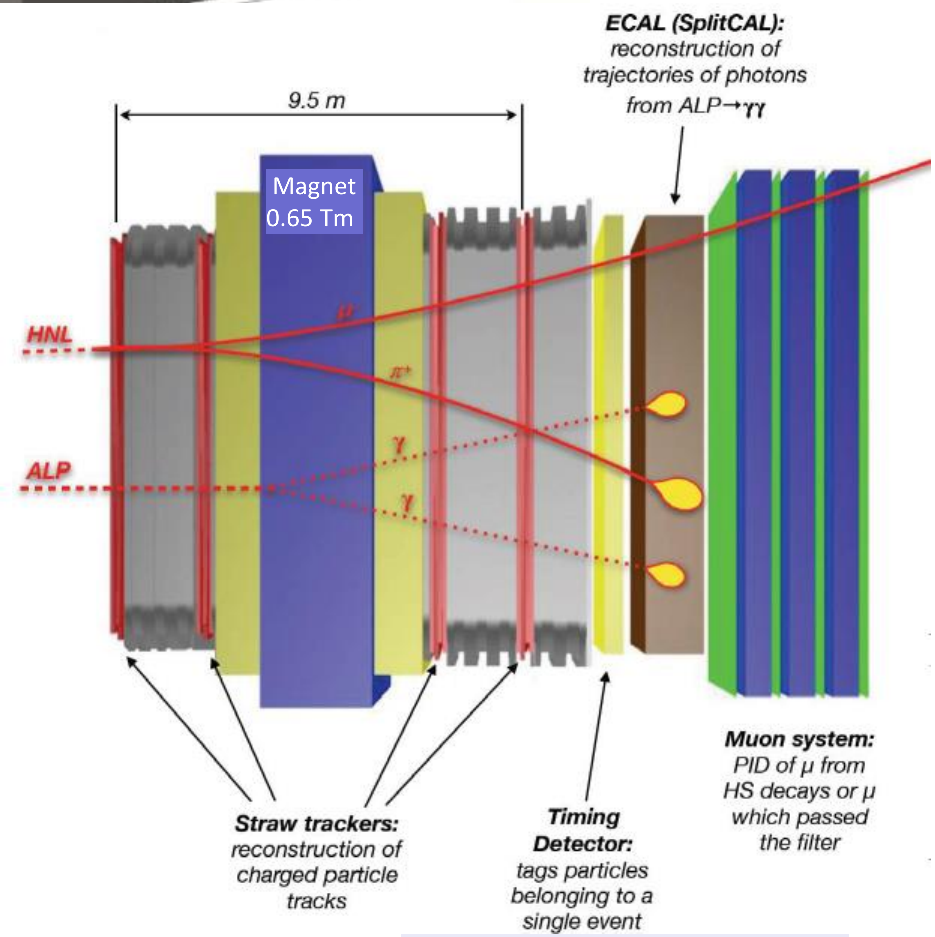


HS particle ID system



- Straw tracker (σ_x < 120 μm per straw) inside the evacuated decay volume
- Timing detector (σ_t < 100 ps) plastic scintillators + SiPM or MRPCs
- ECAL (SpiltCal) sampling lead/scintillator + SiPM high-precision layers (MicroMegas)
- Muon system four active stations equipped with scintillating tiles + SiPM + iron or concrete

Prototyping SHiP

Small-scale replica of the SHiP target

Prototype of the SND muon ID system

Prototype of a complete cell of the SBT

Prototype of MRPC (HS timing detector)

Prototype of a scintillating fibre module of the SND target tracker

Prototype of the ECAL

Neutrino physics with the SND

- First observation of anti-ν_τ

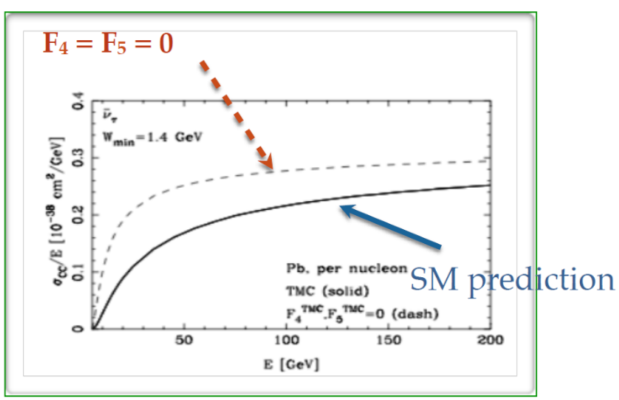
- Measurement of ν_τ and anti- ν_τ cross-sections

- First evaluation of F_4 and F_5 not accessible with other ν

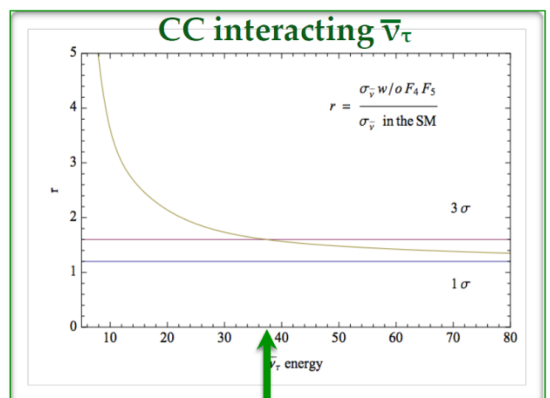
# of expected observed ν_τ int.

Decay channel	ν_τ	$\overline{\nu}_\tau$
$\tau \to \mu$	1200	1000
$\tau \to h$	4000	3000
$\tau \to 3h$	1000	700
total	6200	4700

$$\frac{d^2\sigma^{\nu(\overline{\nu})}}{dxdy} = \frac{G_F^2 M E_\nu}{\pi(1+Q^2/M_W^2)^2}\Big((y^2x + \frac{m_\tau^2 y}{2E_\nu M})F_1 + \left[(1-\frac{m_\tau^2}{4E_\nu^2}) - (1+\frac{Mx}{2E_\nu})\right]F_2 \pm \left[xy(1-\frac{y}{2}) - \frac{m_\tau^2 y}{4E_\nu M}\right]F_3 + \frac{m_\tau^2(m_\tau^2+Q^2)}{4E_\nu^2 M^2 x}F_4 - \frac{m_\tau^2}{E_\nu M}F_5\Big),$$



anti–ν_τ CC DIS cross section

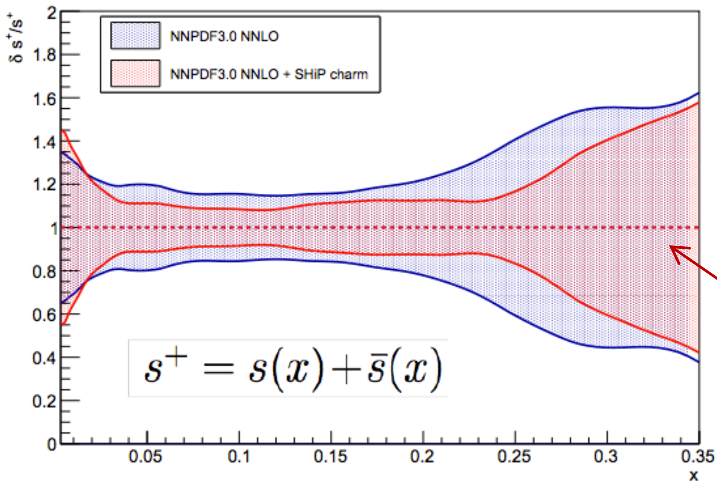


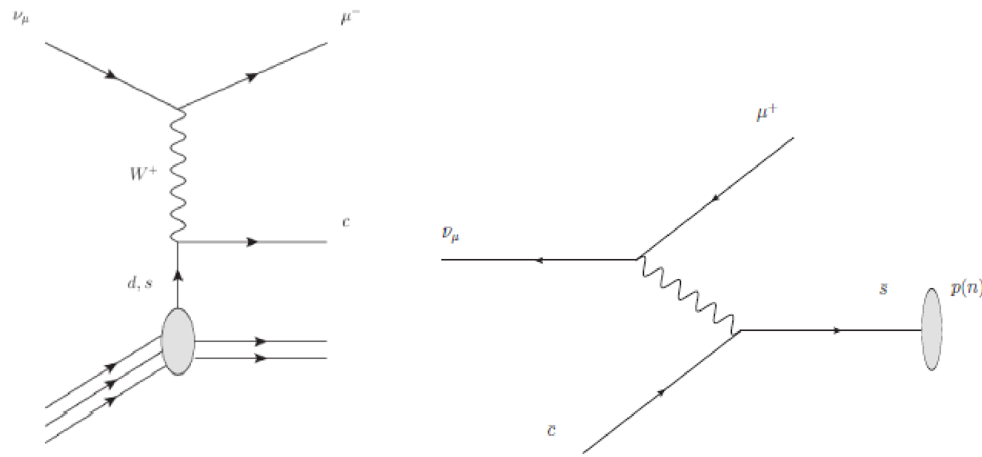
E(anti-ν_τ) < 38 GeV, ≈ 300 events exp.

Neutrino physics with the SND

- ν_e cross sections at high energies

- strange quark nucleon content through charm production





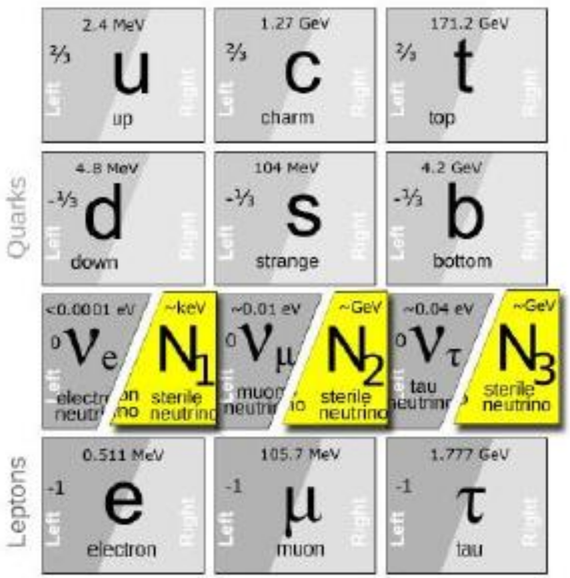
Expected anti-ν_μ induced charm yield in SHIP ~ 2.5x10^4

Observed in CHORUS ~32, in NuTeV ~1400

Significant gain in s^+/s^- vs x, with SHIP data (factor 2) obtained in the *x* range between 0.03 and 0.35

- normalization of hidden particle search

Search for Heavy Neutral Leptons



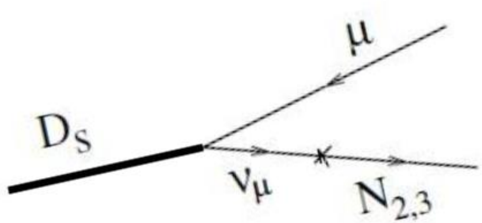
T.Asaka, M.Shaposhnikov PLB 620 (2005) 17

ν Minimal Standard Model (ν MSM):
Extension of the SM by **3 right-handed**
Heavy **N**eutral **L**eptons (**HNLs**)

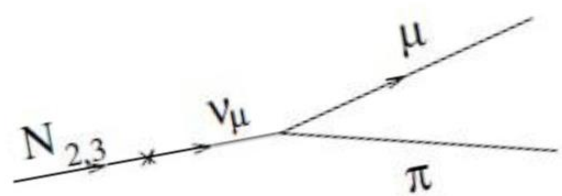
- *Light* N_1:
  Mass *O*(keV)
  Dark Matter candidate

- *Heavy* N_2,N_3:
  Mass *O*(GeV)
  Could explain ν masses (through see-saw) and baryon asymmetry

HNL production



HNL decay



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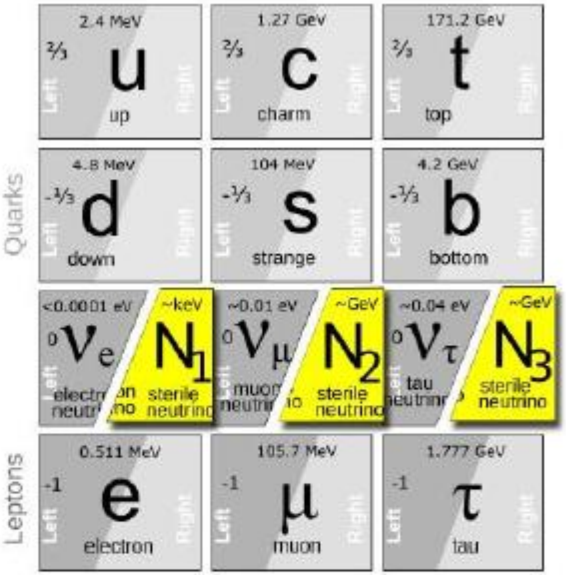

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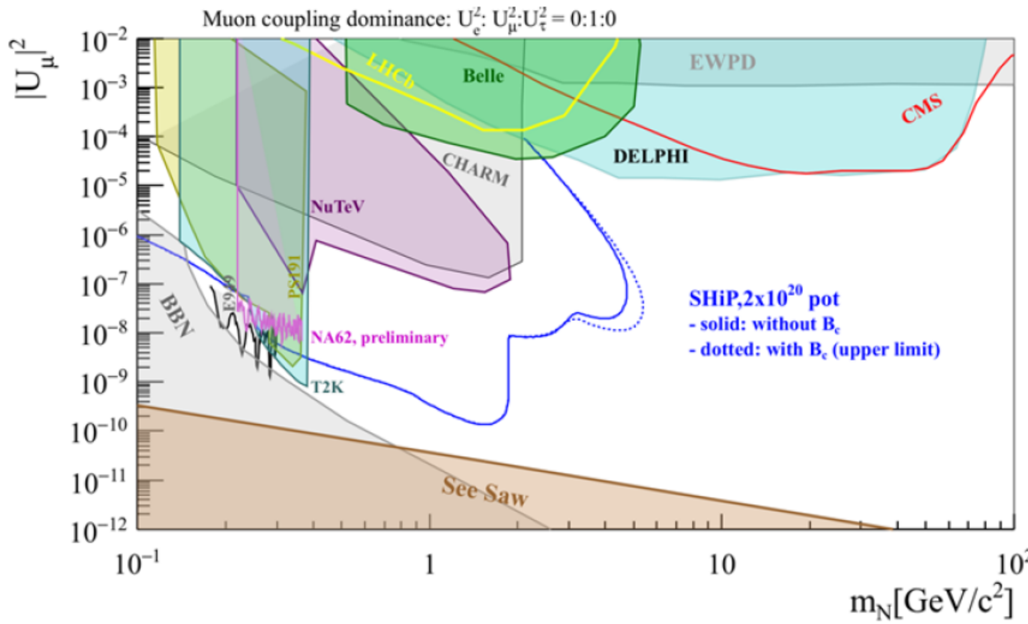
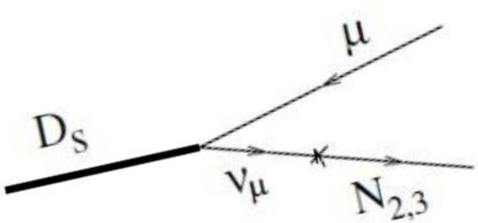
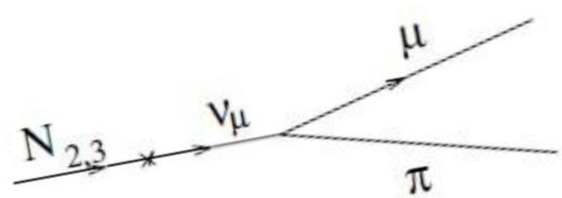


HNL production



HNL decay



Conclusion

- The SHiP experiment has been proposed at CERN to search for new Physics at the intensity frontier

- SHiP offers a unique opportunity for neutrino physics, including Heavy Neutral Leptons search and ν_τ physics with unprecedented sensitivities

- The detector R&D and prototyping activities are on-going and in a good shape

- The Beam Dump Facility and SHiP Comprehensive Design Studies were finalized in Dec. 2019, next steps towards TDR are under definition