THE SHiP EXPERIMENT AT CERN

SHiP

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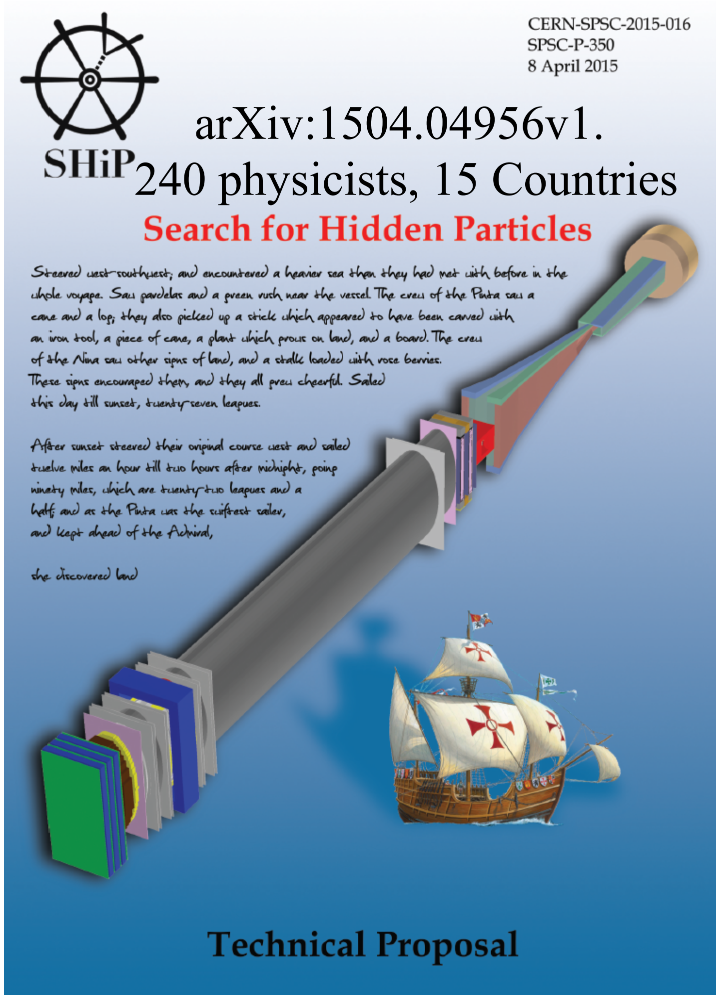
On behalf of the SHiP Collaboration



CERN-SPSC-2015-016
SPSC-P-350
8 April 2015

SHiP

arXiv:1504.04956v1.

240 physicists, 15 Countries

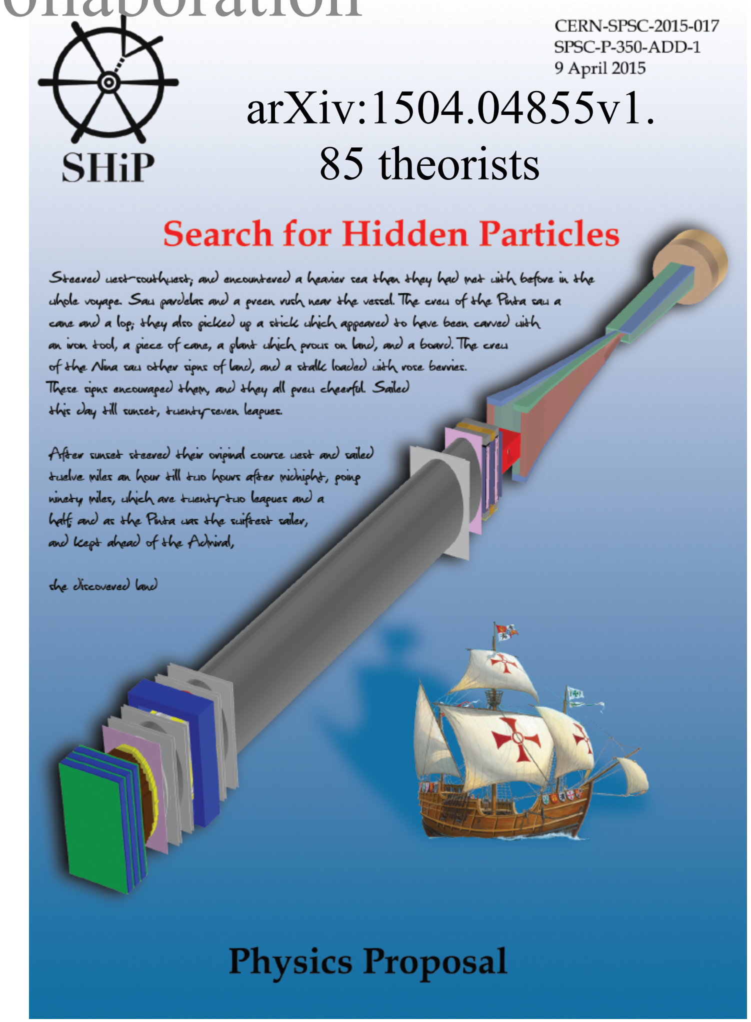
Search for Hidden Particles

Steered west-southwest; and encountered a heavier sea than they had met with before in the whole voyage. Saw pardelas and a green rush near the vessel. The crew of the Pinta saw a cane and a log; they also picked up a stick which appeared to have been carved with an iron tool, a piece of cane, a plant which grows on land, and a board. The crew of the Nina saw other signs of land, and a stalk loaded with rose berries. These signs encouraged them, and they all grew cheerful. Sailed this day till sunset, twenty-seven leagues.

After sunset steered their original course west and sailed twelve miles an hour till two hours after midnight, going ninety miles, which are twenty-two leagues and a half; and as the Pinta was the swiftest sailer, and kept ahead of the Admiral,

the discovered land

Technical Proposal



CERN-SPSC-2015-017
SPSC-P-350-ADD-1
9 April 2015

SHiP

arXiv:1504.04855v1.

85 theorists

Search for Hidden Particles

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Physics Proposal

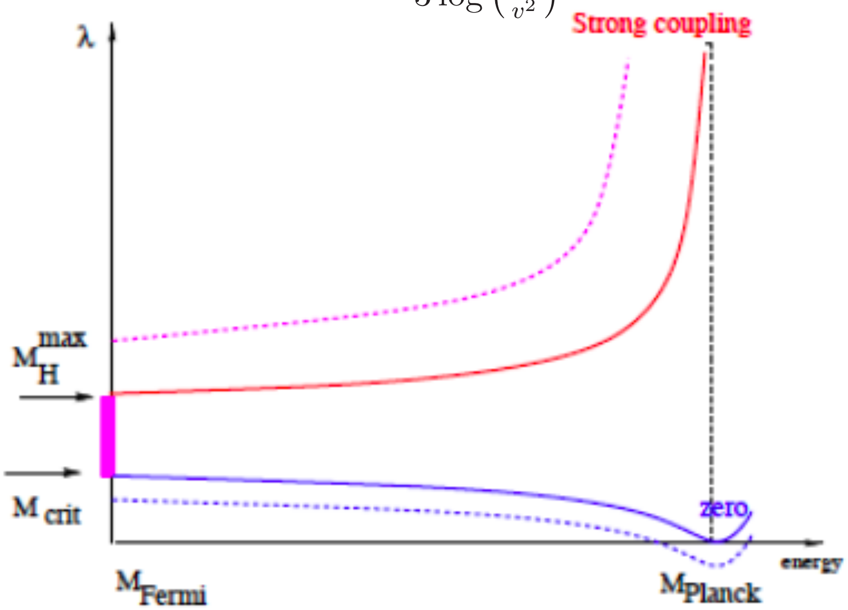
SM may well be a consistent effective theory all the way up to the Plank scale

- ✓ *M_H < 175 GeV → SM is a weakly coupled theory up to the Plank energies!*

- ✓ *M_H > 111 GeV → EW vacuum is stable or metastable with a lifetime greatly exceeding the age of our Universe (Espinosa et al)*

S. Heinemeyer, Higgs Physics, arXiv:1405.3781

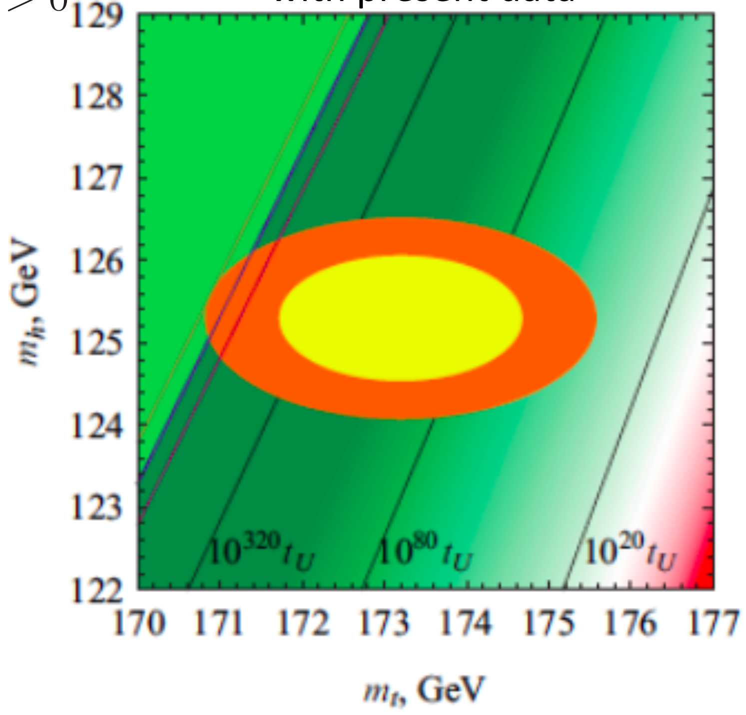
$$\lambda(\Lambda) < \infty \quad \Rightarrow \quad M_H^2 \leq \frac{8\pi^2 v^2}{3\log\left(\frac{\Lambda^2}{v^2}\right)}$$



$1{,}22 \times 10^{19}$ GeV

$\lambda(\Lambda) > 0$

Stable vacuum fully consistent with present data



G. Degrassi et al.,Higgs mass and vacuum stability in the SM at NNLO, JHEP 1208 (2012) 098

- ✓ *No sign of New Physics seen*

Nevertheless, many open questions in particle physics!

Among the most relevant ones:

Why is the Higgs boson so light (so-called "naturalness" or "hierarchy" problem) ?

What is the origin of the matter-antimatter asymmetry in the Universe ?

Why 3 fermion families ? Why do neutral leptons, charged leptons and quarks behave differently ?

What is the origin of neutrino masses and oscillations ?

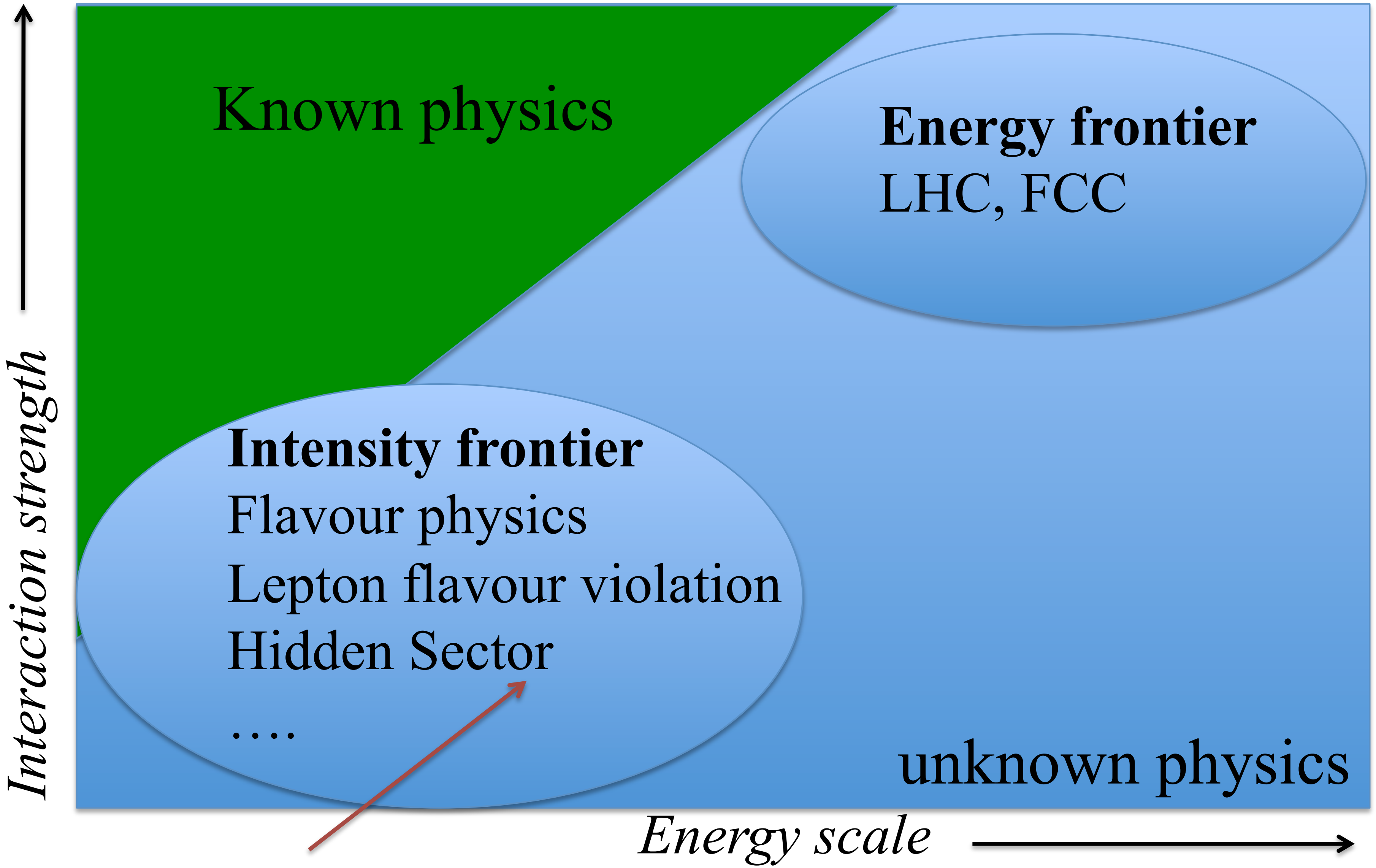
What is the composition of dark matter (~25% of the Universe) ?

However: there is NO direct evidence for new particles (yet…) from the LHC or other facilities

Where is the New Physics ?

i.e. at what E scale(s) will we find the answers to these questions ?

High Intensity Frontier

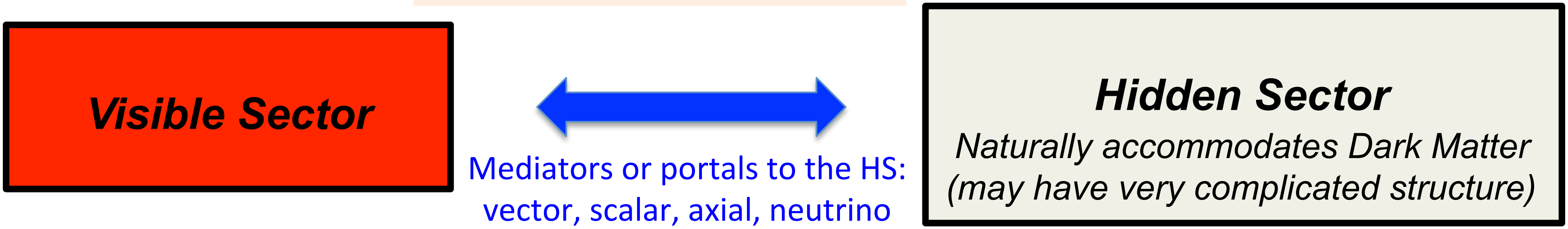


This talk

Search for Hidden Sector (HS)

or very weakly interacting NP

$$L = L_{SM} + L_{mediator} + L_{HS}$$



Visible Sector

Mediators or portals to the HS:
vector, scalar, axial, neutrino

Hidden Sector

Naturally accommodates Dark Matter
(may have very complicated structure)

- ✓ *HS production and decay rates are strongly suppressed relative to SM*
  - *Production branching ratios O(10^{-10})*
  - *Long-lived objects*
  - *Travel unperturbed through ordinary matter*

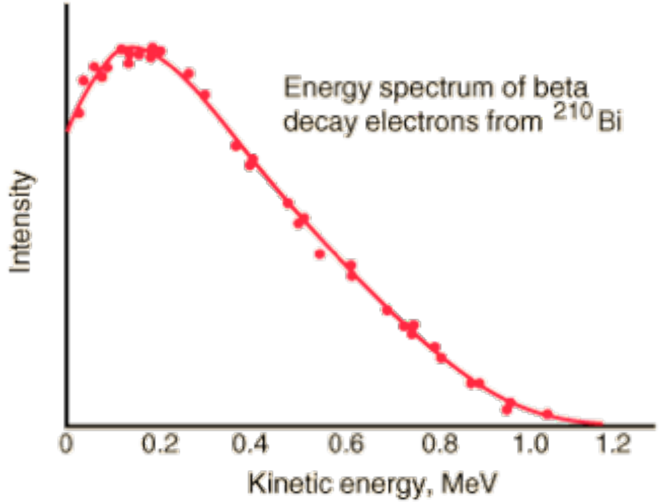
Models	*Final states*
HNL, SUSY neutralino	$l^+\pi^-$, l^+K^-, $l^+\rho^-$ $\rho^+\rightarrow\pi^+\pi^0$
Vector, scalar, axion portals, SUSY sgoldstino	l^+l^-
HNL, SUSY neutralino, axino	$l^+l^-\nu$
Axion portal, SUSY sgoldstino	$\gamma\gamma$
SUSY sgoldstino	$\pi^0\pi^0$

Full reconstruction and PID are essential to minimize model dependence

Experimental challenge is background suppression
→ requires O(0.01) carefully estimated

History lesson - 1930s:

- Back then, the "Standard Model" was photon, electron, nucleons



- Beta decay: $n \rightarrow p + e^-$

Continuous spectrum!

- Pauli proposes a radical solution - the neutrino!

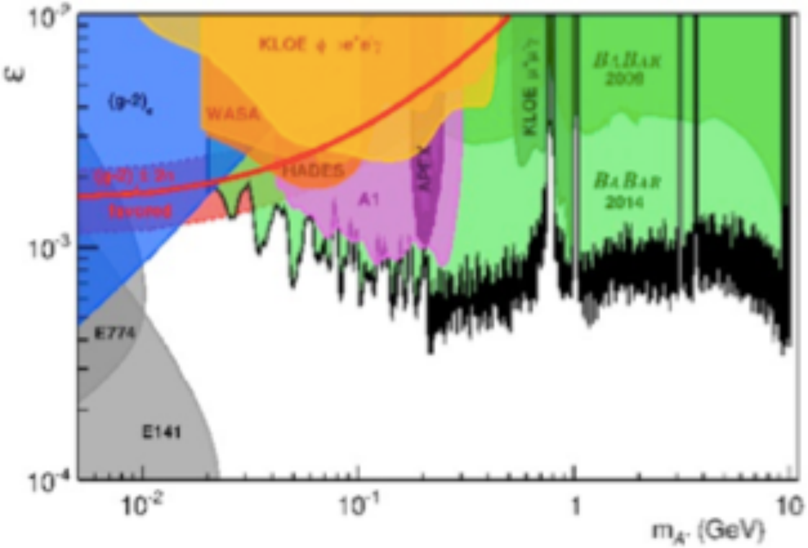
$$n \rightarrow p + e^- + \bar{\nu}$$

- Great example of a hidden sector!
  - neutrino is electrically neutral (QED gauge singlet)
  - very weakly interacting and light
  - interacts with "Standard Model" through "portal" - $\boxed{(\bar{p}\gamma^\mu n)(\bar{e}\gamma_\mu}\nu)$

Search for dark photons

- Assuming no lighter hidden particles, γ' decay into SM particles through a virtual photon:

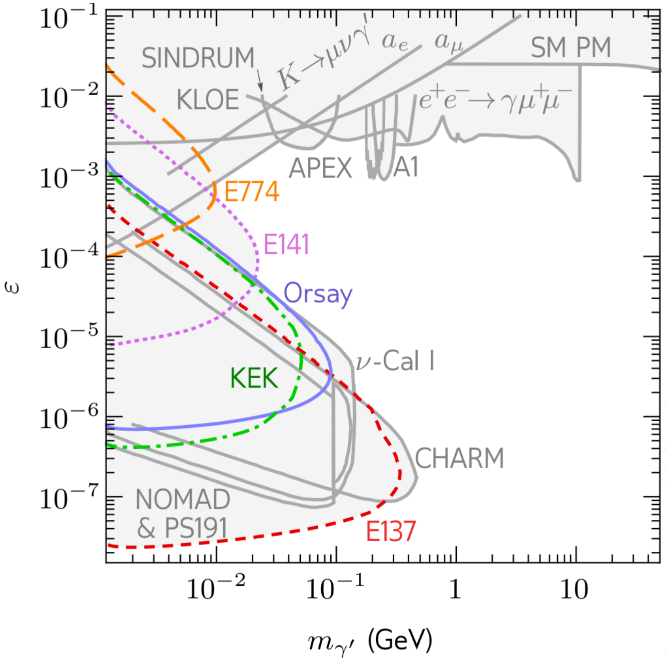
$$\gamma' \to e^+e^-, \quad \mu^+\mu^-, \quad q\bar{q}, \ldots$$



- decay length $c\tau \sim \varepsilon^{-2} m_{\gamma'}^{-1}$
- cosmological constraints (nucleo-synthesis): $\tau < 0.1$ s $\Rightarrow \varepsilon^2 m_{\gamma'} > 10^{-21}$ GeV

γ' production

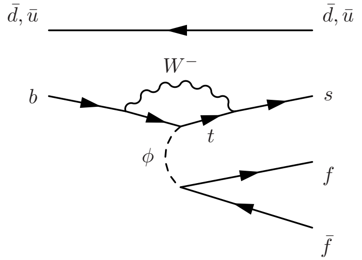
- proton bremsstrahlung:
    - initial-state radiation from the incoming proton, followed by a hard proton-nucleus interaction



- secondary particles decay:

Mass interval (GeV)	Process	$n_{\gamma'}/p.o.t$
$m_{\gamma'} < 0.135$	$\pi^0 \to \gamma\gamma'$	$\varepsilon^2 \times 5.41$
$0.135 < m_{\gamma'} < 0.548$	$\eta \to \gamma\gamma'$	$\varepsilon^2 \times 0.23$
$0.548 < m_{\gamma'} < 0.648$	$\omega \to \pi^0\gamma'$	$\varepsilon^2 \times 0.07$
$0.648 < m_{\gamma'} < 0.958$	$\eta' \to \gamma\gamma'$	$\varepsilon^2 \times 10^{-3}$

Higgs (scalar) portal: production and decay modes

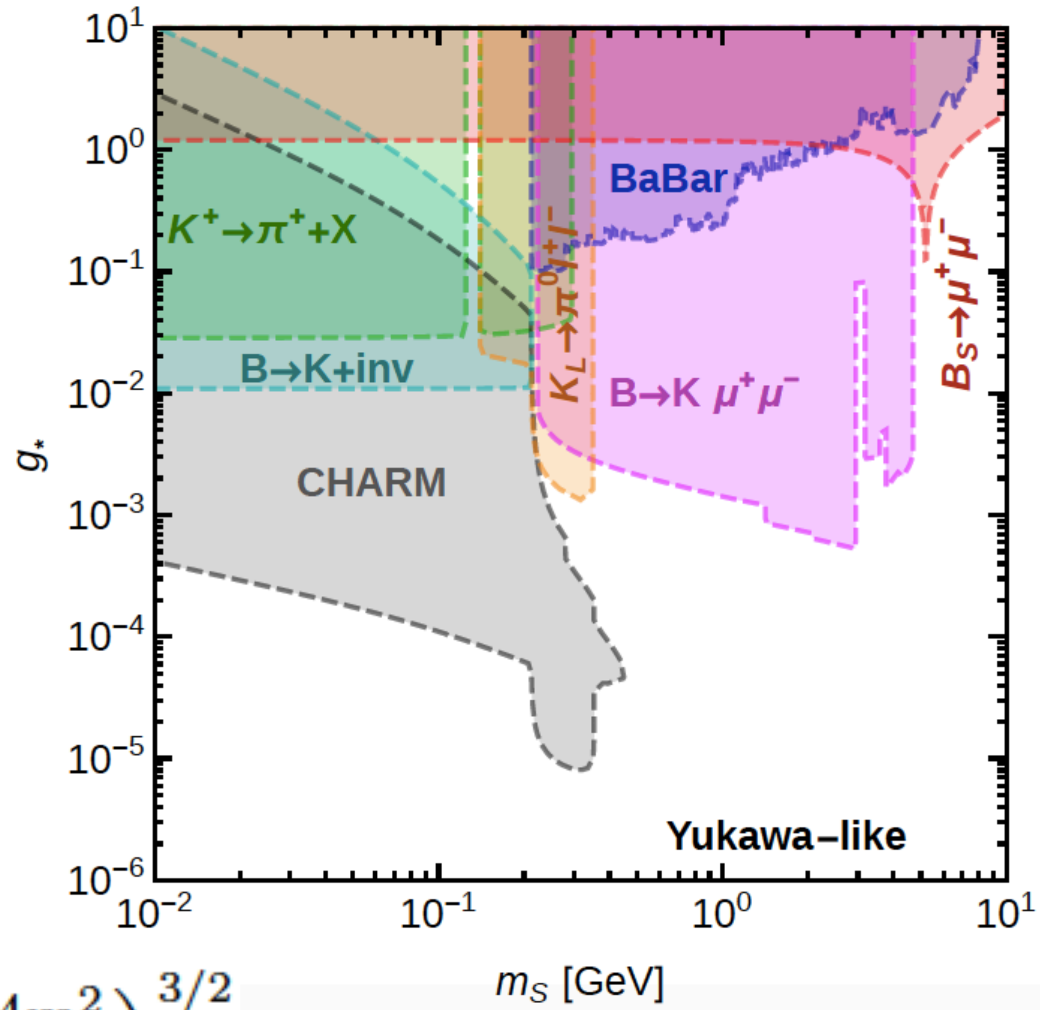


Rare B meson decays mediated by a light scalar ϕ

$$\Gamma(D \to \pi\phi) \sim (m_b^2 |V_{cb}^* V_{ub}|)^2 \propto m_b^4 \lambda^5$$

$$\Gamma(B \to K\phi) \sim (m_t^2 |V_{ts}^* V_{tb}|)^2 \propto m_t^4 \lambda^2$$

B decays favoured compared to D



$$\Gamma(S \to \ell\bar{\ell}) = \frac{g_\star^2\, m_\ell^2 m_S}{8\pi v^2}\left(1 - \frac{4m_\ell^2}{m_S^2}\right)^{3/2}$$

Motivation for Heavy Neutral Leptons

See-saw mechanism for neutrino masses

Most general renormalisable Lagrangian of SM particles (+3 singlets wrt SM gauge group):

$$L_{singlet} = i\bar{N}_I \partial_\mu \gamma^\mu N_I - Y_{I\alpha} \bar{N}_I^c \tilde{H} L_\alpha - M_I \bar{N}_I^c N_I + h.c$$

Yukawa term: mixing of N_I with active neutrinos to explain oscillations

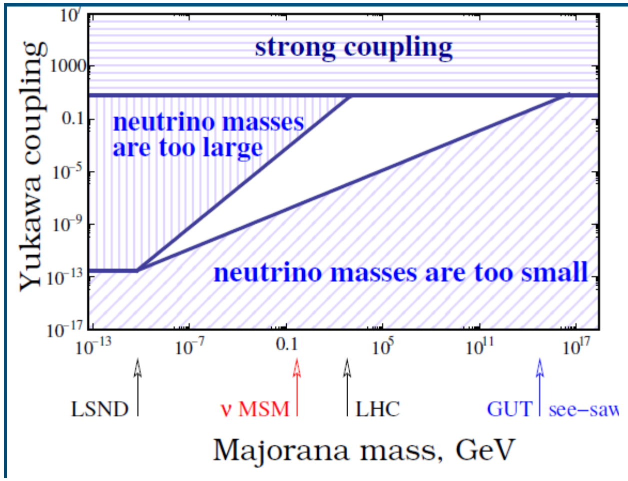
Majorana term which carries no gauge charge

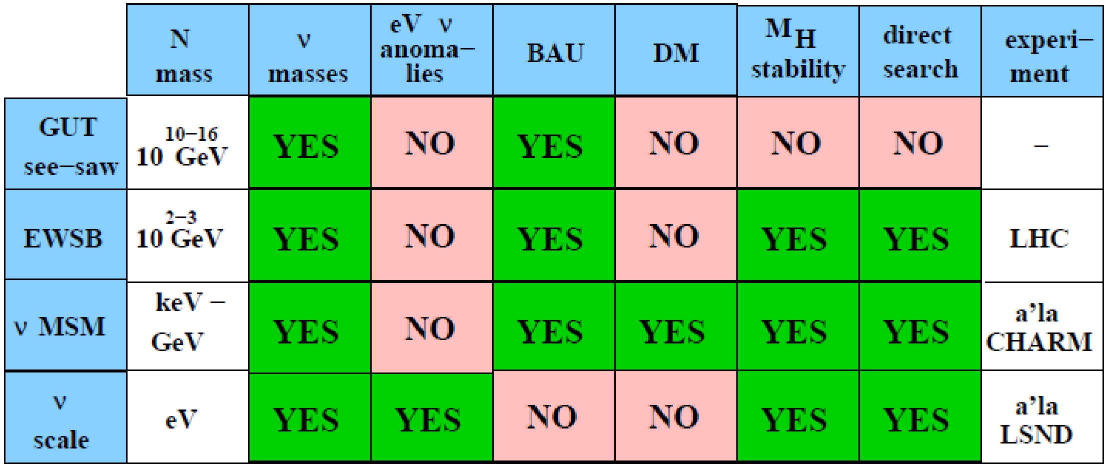
$$v \sim 246 \text{ GeV}$$

The scale of the active neutrino mass is given by the see-saw formula: $m_\nu \sim \frac{m_D^2}{M}$

where $m_D \sim Y_{I\alpha} v$ *- typical value of the Dirac mass term*

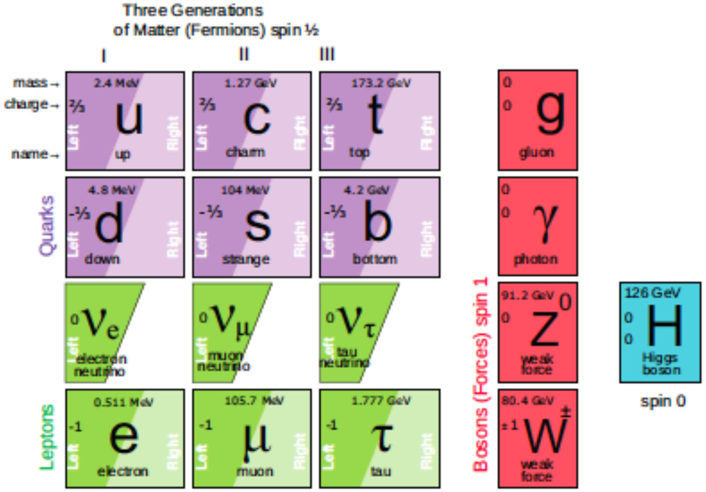
Four "popular" N mass ranges

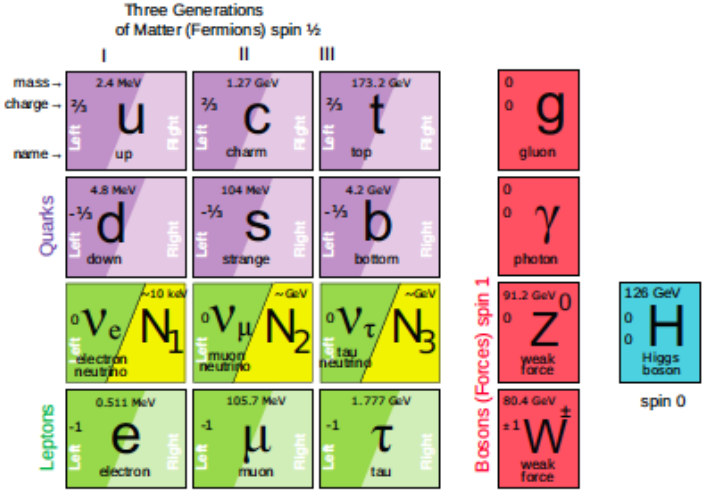




	N mass	ν masses	eV ν anoma–lies	BAU	DM	M_H stability	direct search	experi–ment
GUT see–saw	10^{10-16} GeV	YES	NO	YES	NO	NO	NO	–
EWSB	10^{2-3} GeV	YES	NO	YES	NO	YES	YES	LHC
ν MSM	keV – GeV	YES	NO	YES	YES	YES	YES	a'la CHARM
ν scale	eV	YES	YES	NO	NO	YES	YES	a'la LSND

The νMSM model: leptogenesis and dark matter





N = Heavy Neutral Lepton - HNL

Role of N_1 with mass in keV region: dark matter

Role of $N_2,\ N_3$ with mass in 100 MeV – GeV region: “give” masses to neutrinos and produce baryon asymmetry of the Universe

Role of the Higgs: give masses to quarks, leptons, Z and W and inflate the Universe.

***νMSM**: T.Asaka, M.Shaposhnikov PL **B620** (2005) 17*
M.Shaposhnikov Nucl. Phys. B763 (2007) 49

global lepton-number symmetry broken at the level of O(10^{-4}) leads to the required pattern of sterile neutrino masses consistent with neutrino oscillations data

Masses and couplings of HNLs

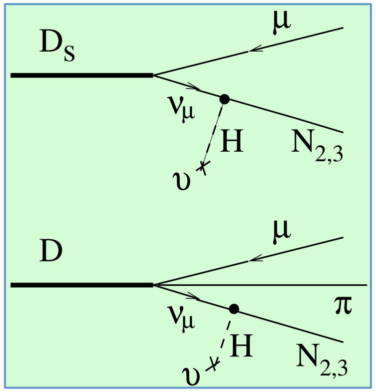
- ***$M(N_2) \approx M(N_3)$ ~ a few GeV→ CPV can be increased dramatically to explain Baryon Asymmetry of the Universe (BAU)***

Very weak $N_{2,3}$-to-ν mixing (~ U^2) → $N_{2,3}$ are much longer-lived than SM particles

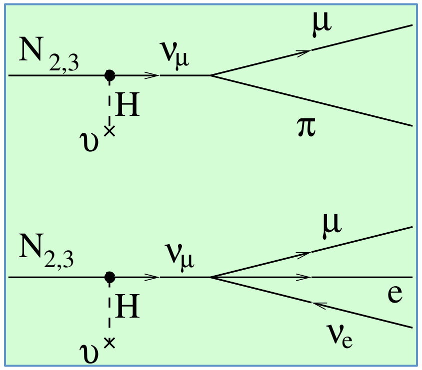
- Produced in semi-leptonic decays, $\mathrm{K} \to \mu\nu,\ \mathrm{D} \to \mu\pi\nu,\ \mathrm{B} \to \mathrm{D}\mu\nu$

- $\propto \sigma_D \times U^2$
- $U_2^2 = U_{2,\nu_e}^2 + U_{2,\nu_\mu}^2 + U_{2,\nu_\tau}^2$

Example:
$N_{2,3}$ production in charm



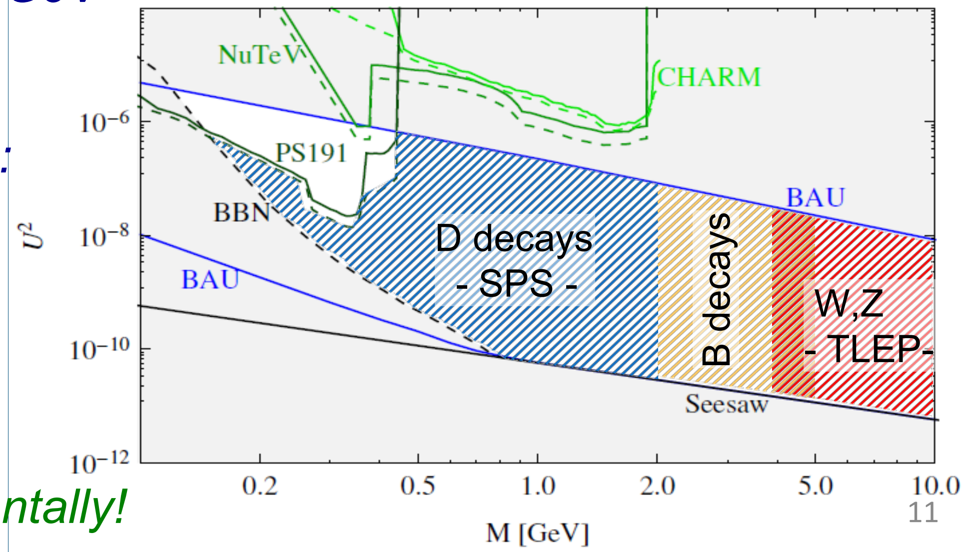
and subsequent decays



- *Typical lifetimes > 10 μs for $M(N_{2,3})$ ~ 1 GeV*
  Decay distance O(km)

- *Typical BRs (depend on flavour mixing):*

$Br(N \to \mu/e\ \pi)$ ~ 0.1 – 50%
$Br(N \to \mu^-/e^-\ \rho^+)$ ~ 0.5 – 20%
$Br(N \to \nu\mu e)$ ~ 1 – 10%

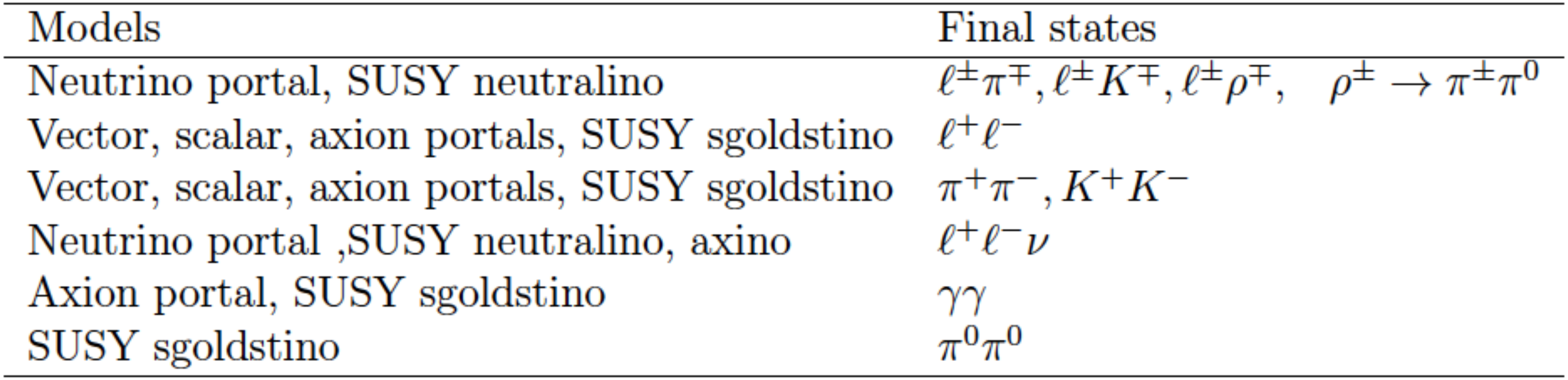


Domain only marginally explored, experimentally!

Common experimental features of Hidden Sector (HS)

- ✓ *Production through hadron decays (π, K, D, B, proton bremsstrahlung, …)*

- ✓ *Decays:*



Models	Final states
Neutrino portal, SUSY neutralino	$\ell^\pm\pi^\mp, \ell^\pm K^\mp, \ell^\pm\rho^\mp, \quad \rho^\pm \to \pi^\pm\pi^0$
Vector, scalar, axion portals, SUSY sgoldstino	$\ell^+\ell^-$
Vector, scalar, axion portals, SUSY sgoldstino	$\pi^+\pi^-, K^+K^-$
Neutrino portal ,SUSY neutralino, axino	$\ell^+\ell^-\nu$
Axion portal, SUSY sgoldstino	$\gamma\gamma$
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- ✓ *Full reconstruction and PID are essential to minimize model dependence*

- ✓ *Production and decay rates are strongly suppressed when compared to SM*
  - *Production branching ratios O(10^{-10})*
  - *Long-lived objects*
  - *Travel unperturbed through ordinary matter*

- ✓ ***Challenge is background suppression → requires O(0.01) carefully estimated***

- ✓ ***Physics with ν_τ produced in D_s decays share many of these features***

ν_τ STUDIES

- Less known particle in the Standard Model
- First observation by DONUT at Fermilab in 2001 with 4 detected candidates, *Phys. Lett. B504 (2001) 218-224*
- 9 events (with an estimated background of 1.5) reported in 2008 with looser cuts

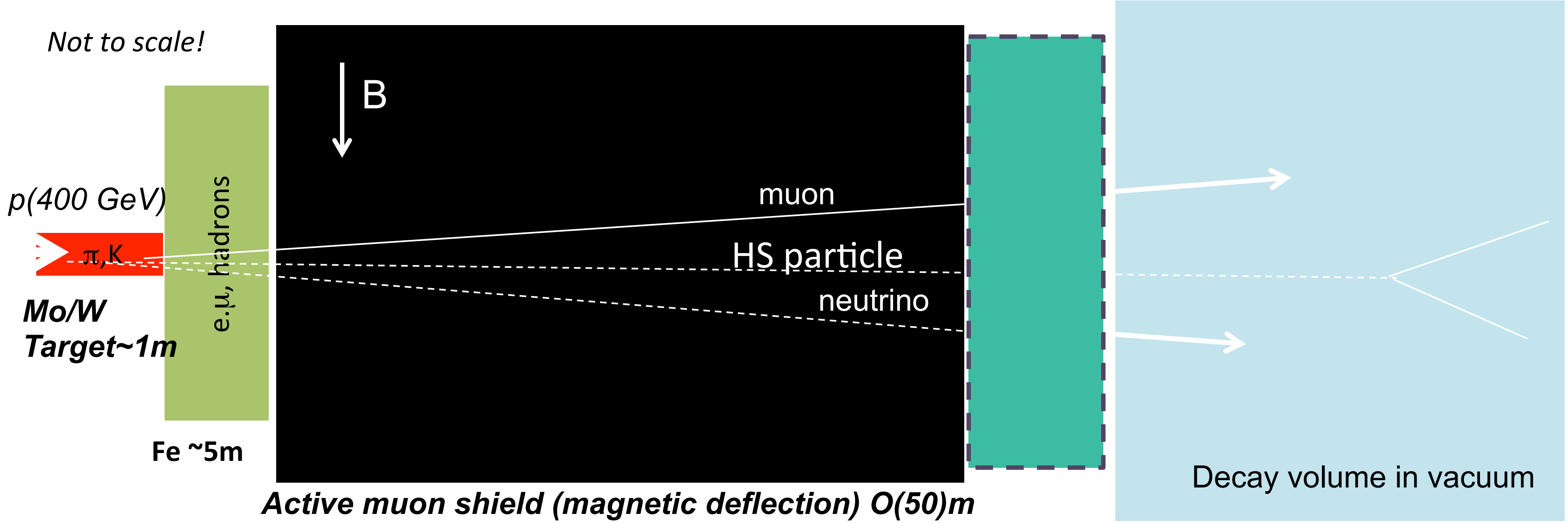
$$\sigma^{\text{const}}(\nu_\tau) = (0.39 \pm 0.13 \pm 0.13) \times 10^{-38}\ \text{cm}^2\ \text{GeV}^{-1}$$

- 5 ν_τ candidates reported by OPERA for the discovery (5.1σ result) of ν_τ appearance in the CNGS neutrino beam PRL 115 (2015) 121802
- Tau anti-neutrino never observed

General experimental requirements

Initial reduction of beam induced backgrounds

- *Heavy target to maximize Heavy Flavour production (large A) and minimize production of neutrinos in $\pi/K \rightarrow \mu\nu$ decays (short λ_{int})*
- *Hadron absorber*
- *Effective muon shield (without shield: muon rate ~10^{10} per spill of 4×10^{13} pot)*
- *Slow (and uniform) beam extraction ~1s to reduce occupancy in the detector*



Not to scale!

p(400 GeV)

Mo/W Target~1m

Fe ~5m

Active muon shield (magnetic deflection) O(50)m

Tau neutrino Detector ~10m

Length ~50m

Multidimensional optimization: *beam energy, beam intensity, background conditions and detector acceptance*

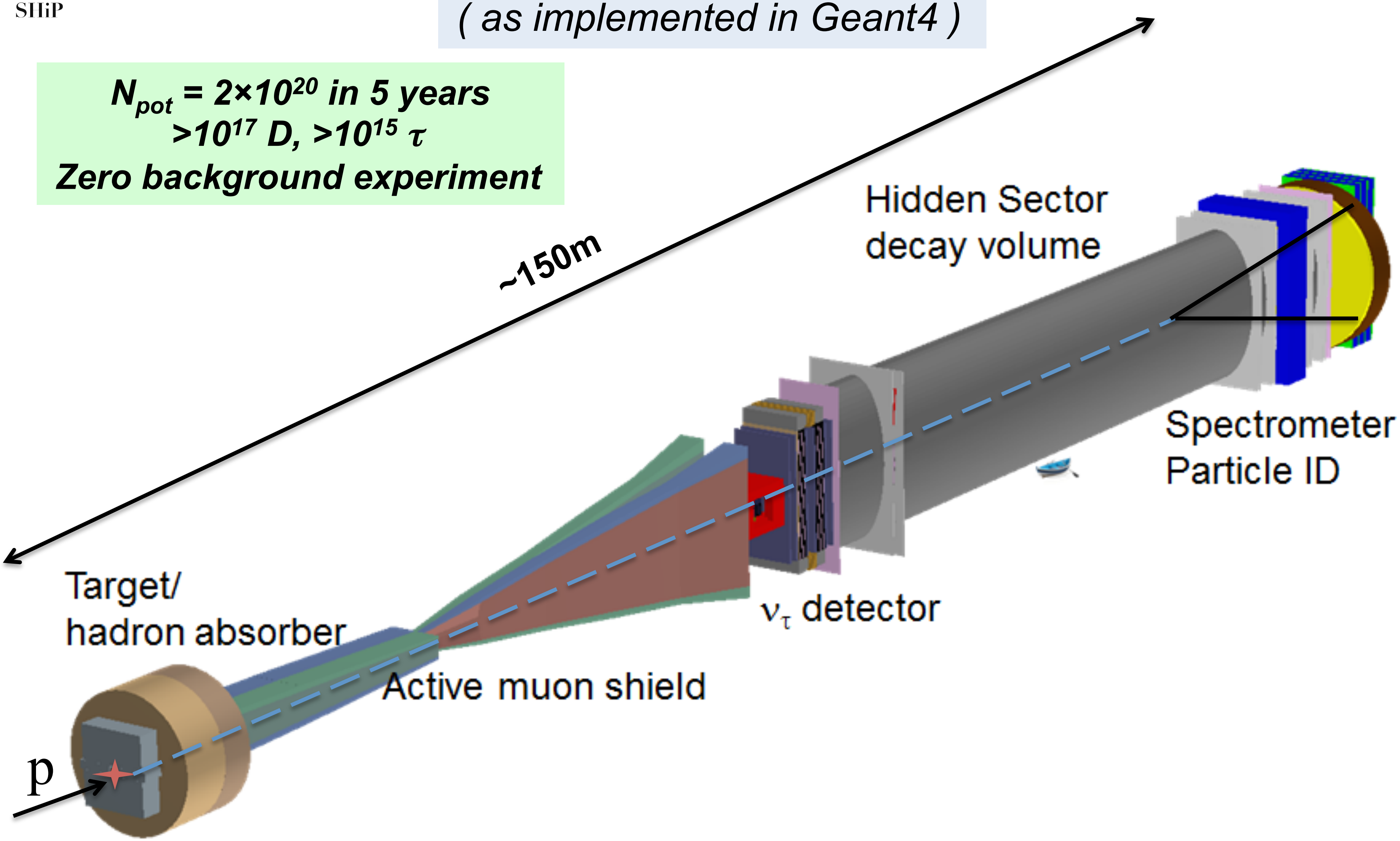
The SHiP experiment

(as implemented in Geant4)

$N_{pot} = 2\times10^{20}$ in 5 years

$>10^{17}$ D, $>10^{15}$ τ

Zero background experiment



~150m

Hidden Sector
decay volume

Spectrometer
Particle ID

ν_τ detector

Target/
hadron absorber

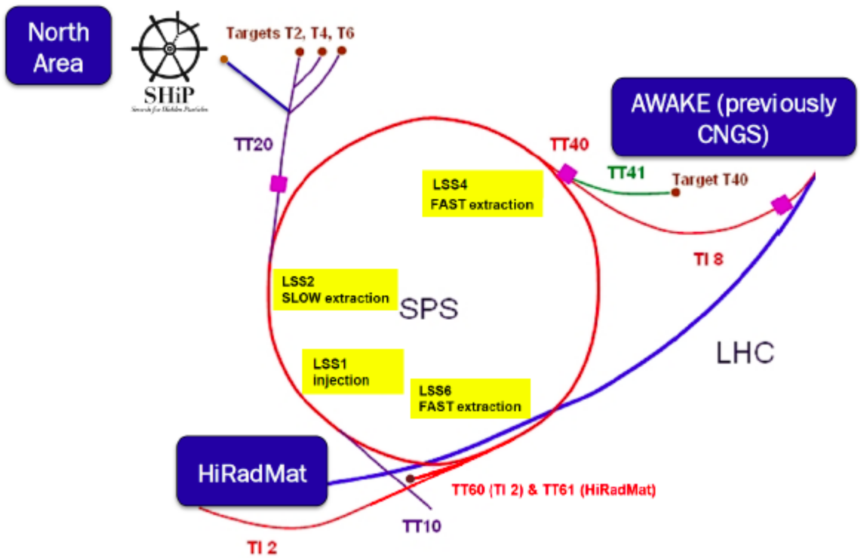
Active muon shield

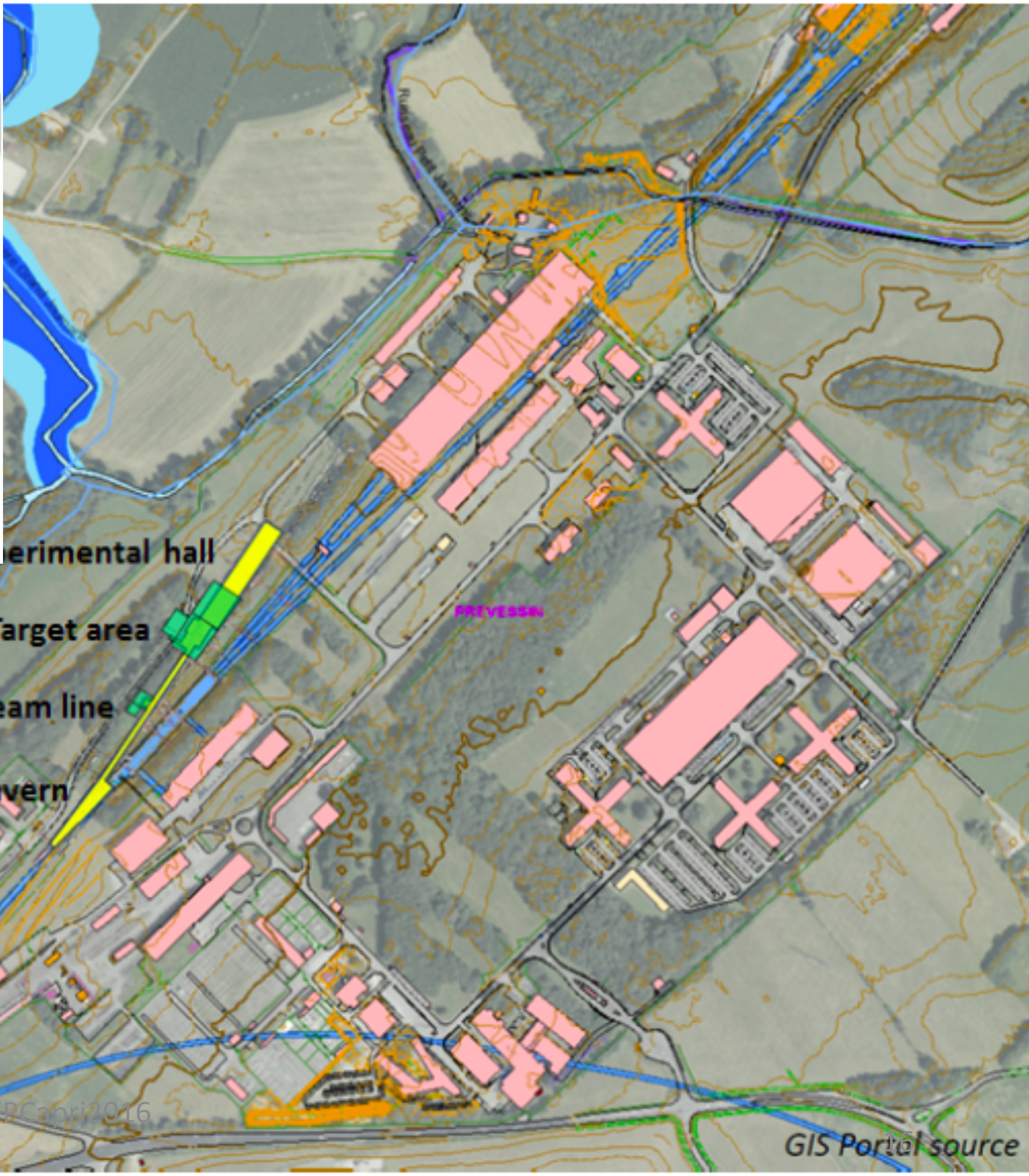
p

***The Fixed-target facility at the SPS:* Prevessin North Area site**

Proposed implementation based on minimal modification of the SPS complex

High-intensity proton beam: 4 10^{13} ppp, 4 10^{19} pot/yr, 5 years run (as for CNGS)



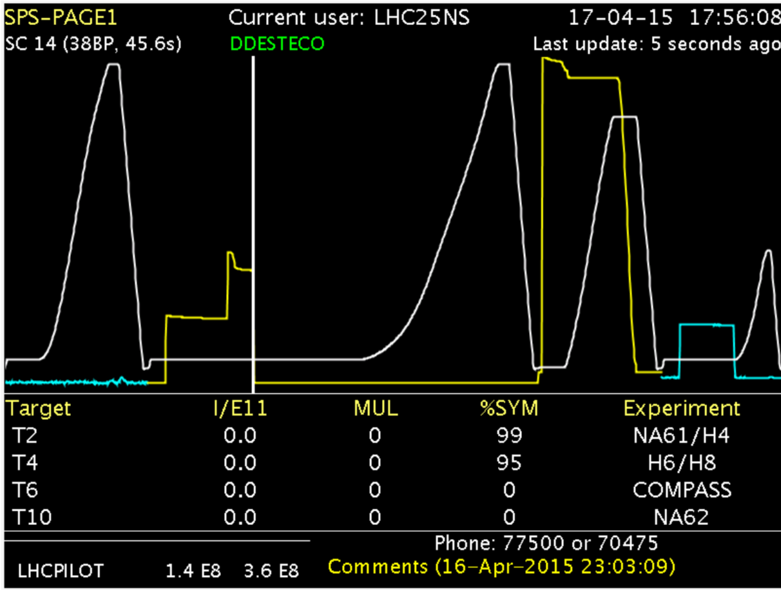


GIS Portal source

The SHiP facility is located on the North Area, and shares the TT20 transfer line and slow extraction mode with the fixed target programmes

R&D at CERN for extraction and beam lines

- Deployment of the new SHiP cycle
- Extraction loss characterisation and optimisation
  - Reduce p density on septum wires
  - Probe SPS aperture limits during slow extraction
- Development of new TT20 optics
  - Change beam at splitter on cycle-to cycle basis
- Characterisation of spill structure
- R&D and development of laminated splitter and dilution (sweep) magnets



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SC 14 (38BP, 45.6s)    DDESTECO                 Last update: 5 seconds ago

Target            I/E11       MUL       %SYM      Experiment
 T2                0.0         0         99        NA61/H4
 T4                0.0         0         95         H6/H8
 T6                0.0         0          0        COMPASS
 T10               0.0         0          0          NA62

                                 Phone: 77500 or 70475
 LHCPILOT      1.4 E8   3.6 E8   Comments (16-Apr-2015 23:03:09)
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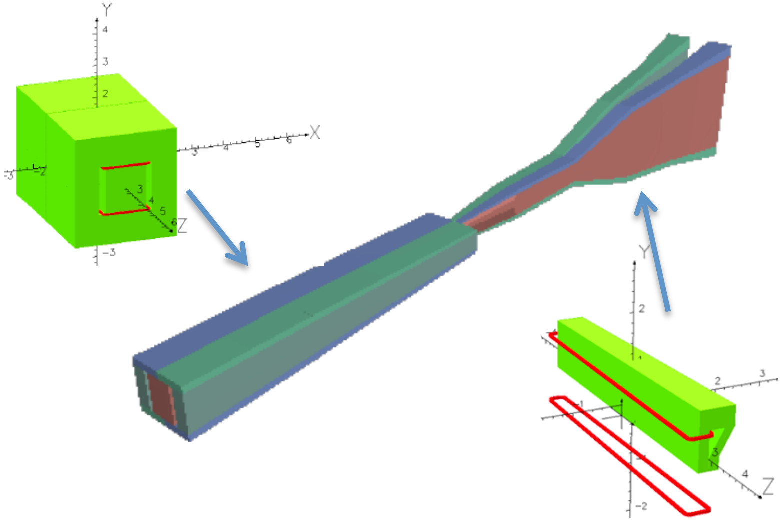
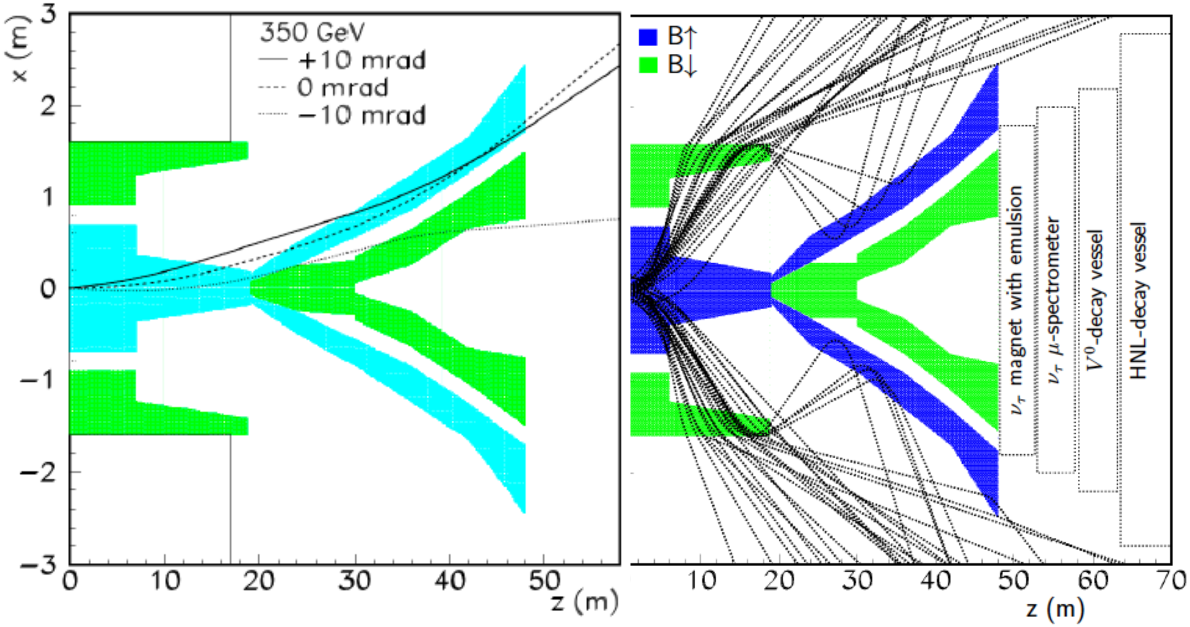
Successful test in April 2015

SHiP muon shield

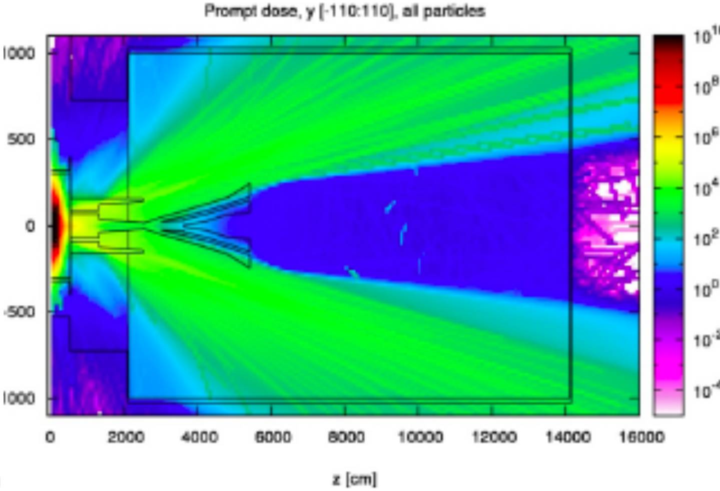
- ✓ *Muon flux limit driven by HS background and emulsion-based neutrino detector*
- ✓ *Active muon shield based entirely on magnet sweeper with a total field integral B_y = 86.4 Tm*
  - *Realistic design of sweeper magnets in progress*
  - *Challenges: flux leakage, constant field profile, modeling magnet shape*
- ✓ *< 7k muons / spill (E_μ > 3 GeV), from 10^{10}*
- ✓ *Negligible flux in terms of detector occupancy*



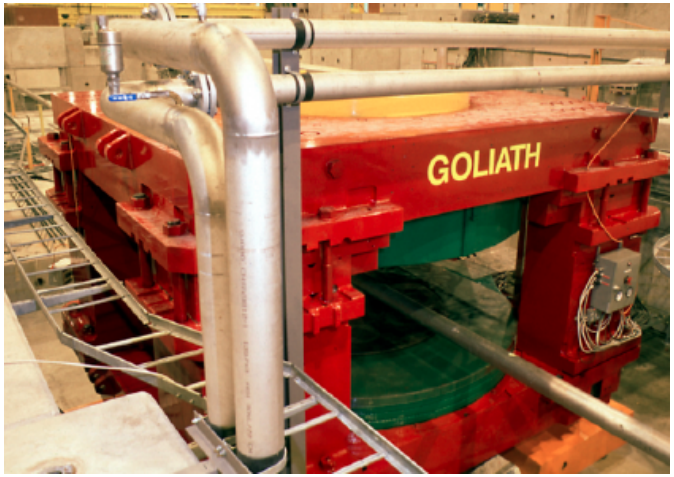
Magnetic sweeper field



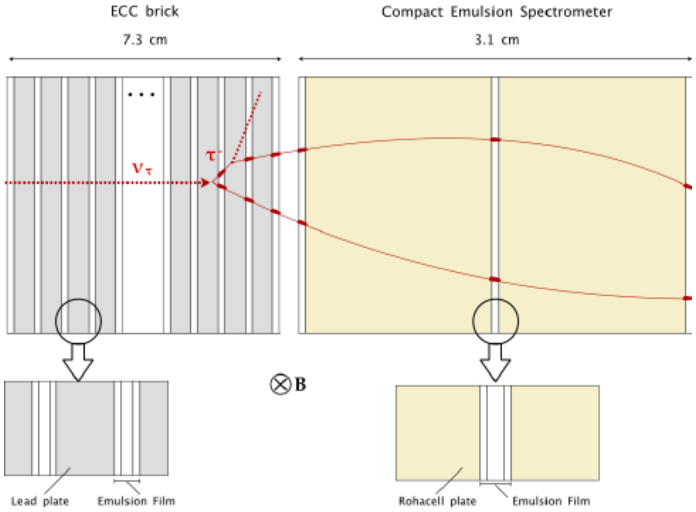
Dose rate (μSv/h) in the SHiP hall

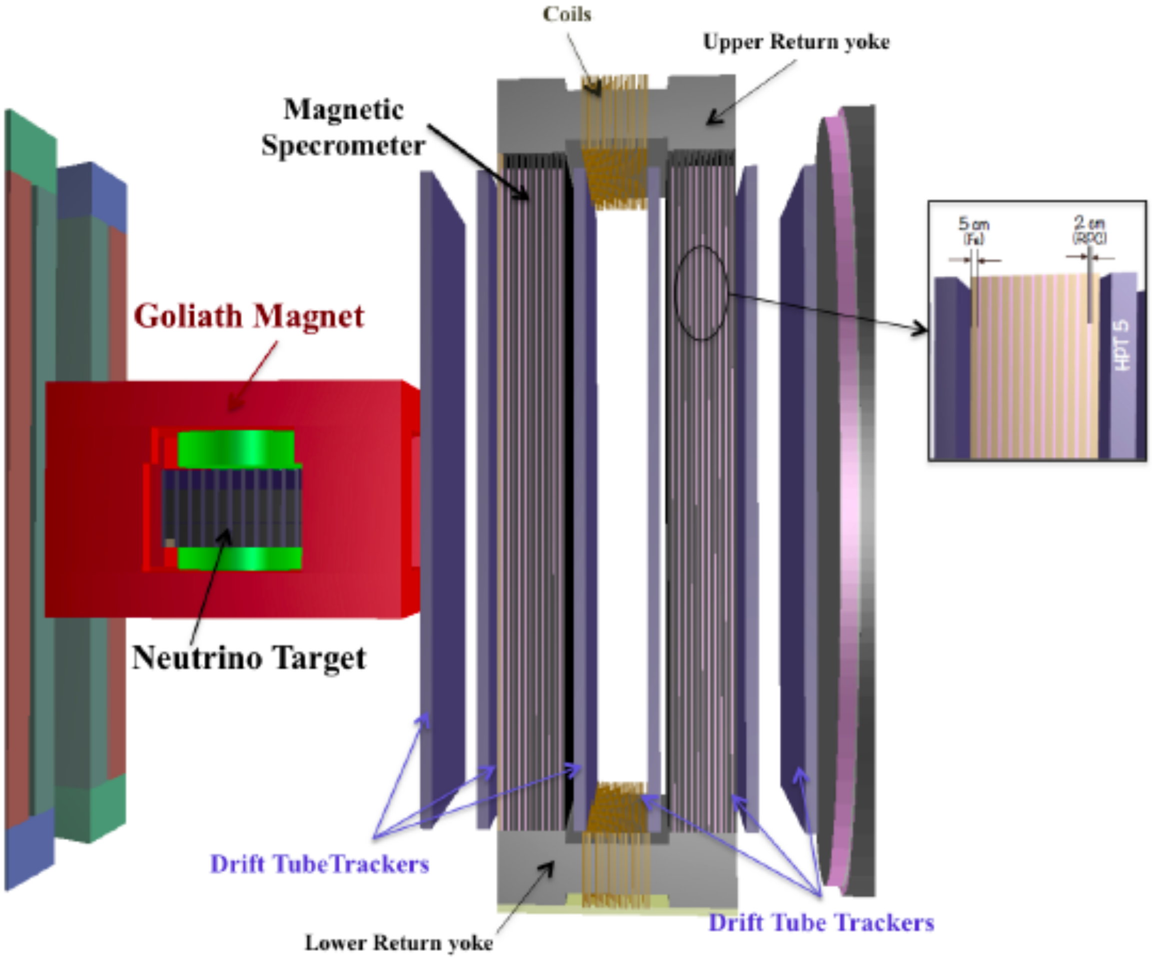


ν_τ detector follows the OPERA concept



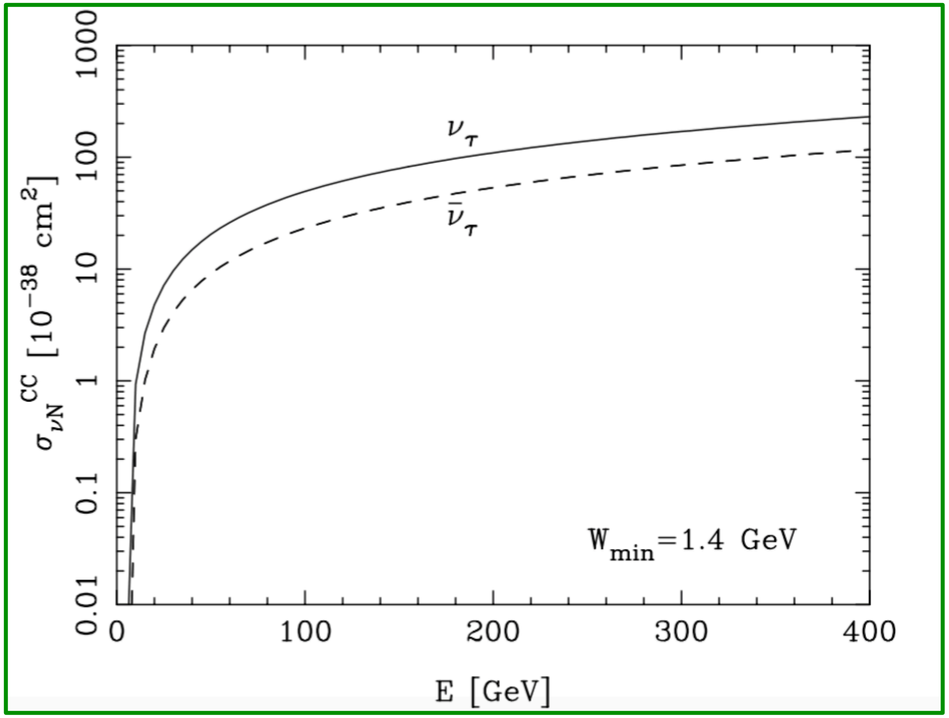
Emulsion Cloud Chamber is the key element of ν_τ detection





ν_τ INTERACTIONS IN THE TARGET

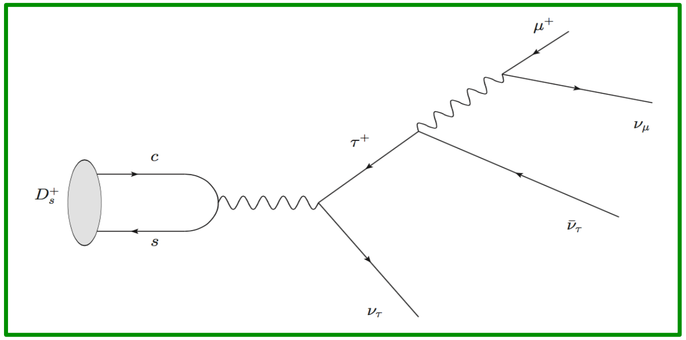
$$N_{\nu_\tau+\bar{\nu}_\tau} = 4N_p \frac{\sigma_{c\bar{c}}}{\sigma_{pN}} f_{D_s} Br(D_s \to \tau) = 2.85 \times 10^{-5} N_p = 6.6 \times 10^{15}$$



M. H. Reno, Phys. Rev. D74 (2006) 033001

Uncertainty ($\lesssim$10%) from:

- Scale choices
- Pdf
- Target mass correction



Expected number of interactions*

*in 5 years run (2x10^{20} pot)
target mass ~ 9.6 ton (Pb)

$$N_{\nu_\tau} \simeq 7.6 \times 10^3$$

$$N_{\bar{\nu}_\tau} \simeq 3.9 \times 10^3$$

20% uncertainty mainly
from scale variations in
c-cbar differential cross-section

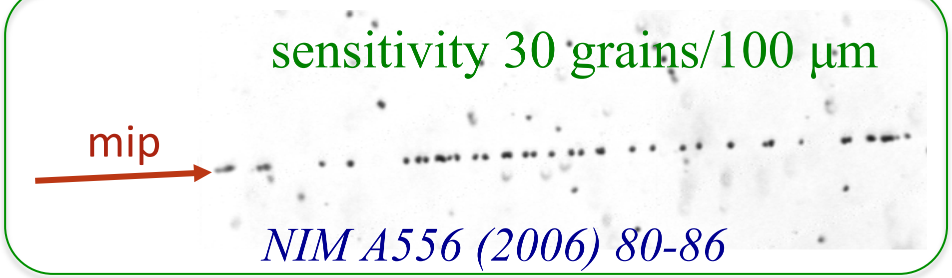
ν_τ DETECTOR

THE UNITARY CELL

<u>Emulsion Cloud Chamber (ECC)</u>

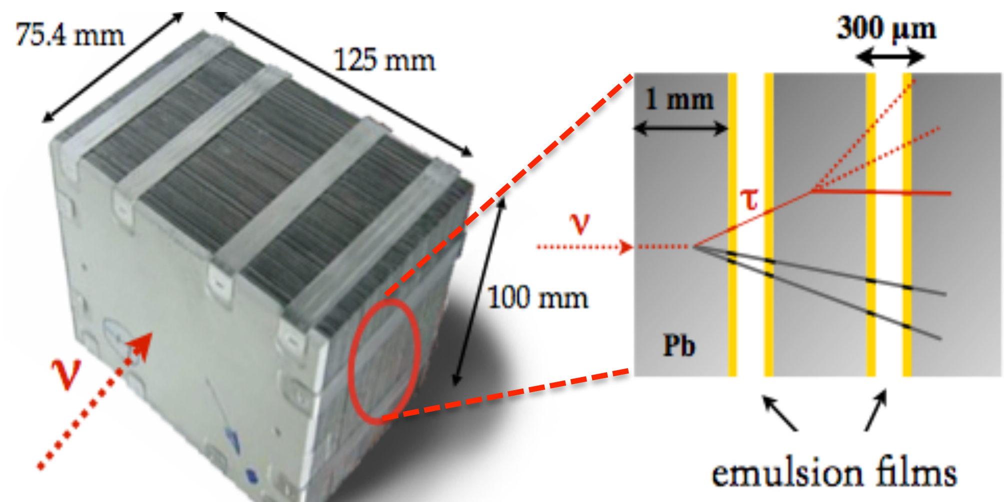
BRICK

- passive material → lead
  (massive target)
- tracking device → nuclear emulsions
  (high resolution)


sensitivity 30 grains/100 μm

NIM A556 (2006) 80-86

10 X_0



PERFORMANCES

- Primary and secondary vertex definition with μm resolution
- Momentum measurement by Multiple Coulomb Scattering
  - largely exploited in the OPERA experiment
- Electron identification: shower ID through calorimetric technique

OPERA: 1 event in 1 brick
SHIP: ~230 events/brick

ν_τ/ANTI-ν_τ SEPARATION

THE COMPACT EMULSION SPECTROMETER

Magnetised target → charge and momentum measurement for hadrons

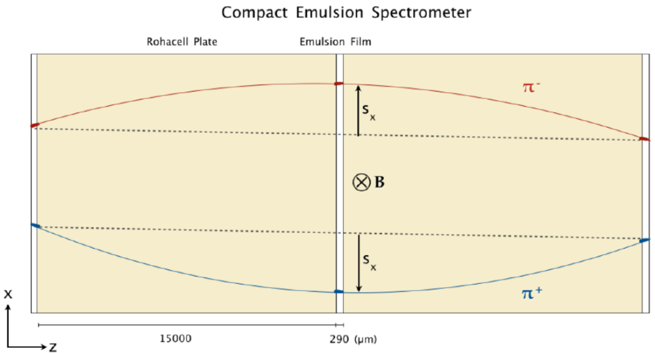
BR(τ → hadrons) ~ 65%

Use Compact Emulsion Spectrometer (CES) → R&D going on

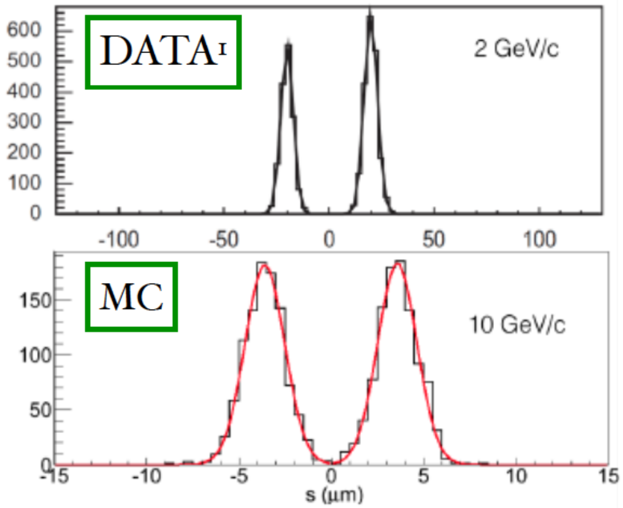
- 1T field
- 3 films interleaved with 2 Rohacell layers (15 mm)
- Thin chamber: 3cm in total
- 90% efficiency for hadronic τ daughters reaching the CES
- Sagitta to discriminate between positive and negative charge

Performances to be achieved

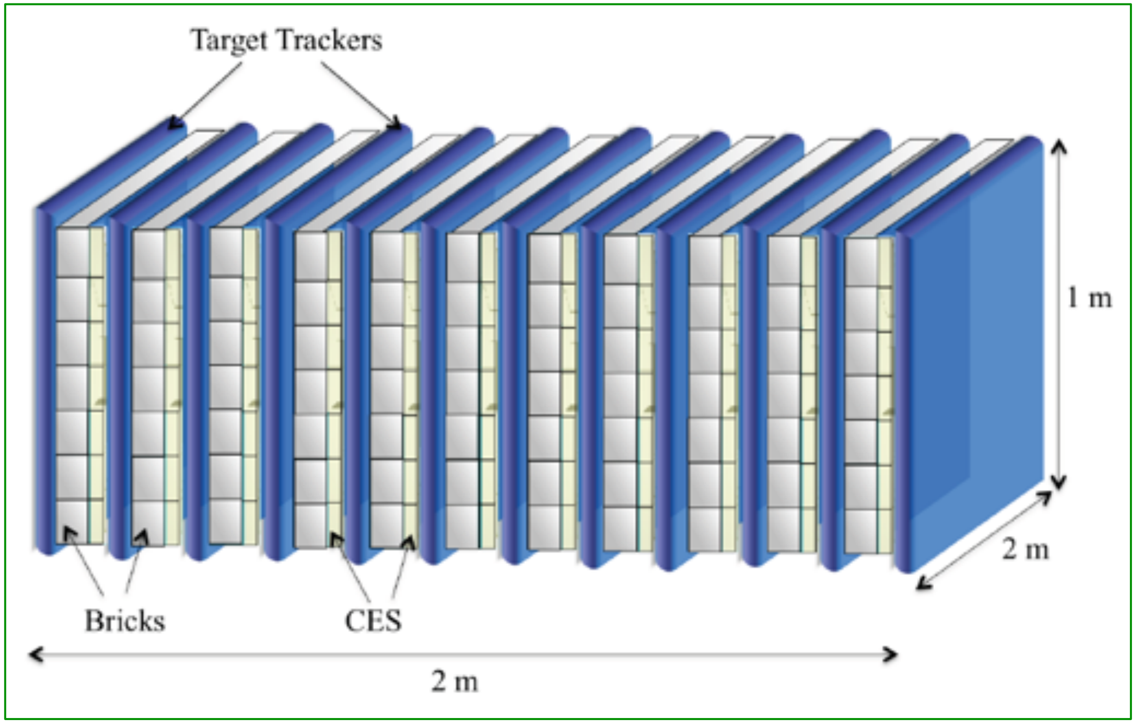
- charge measured up to 10 GeV/c (3 sigma level)
- $\Delta p/p < 20\%$ up to 12 GeV/c

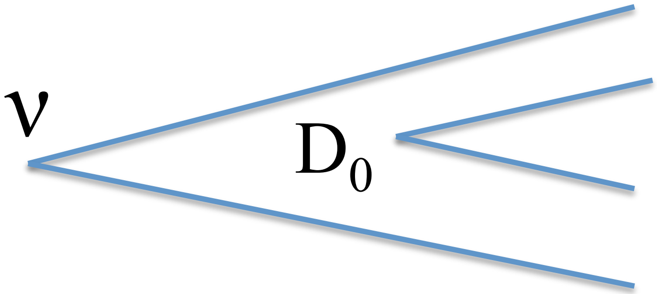


NIM A 592 (2008) 56–62



THE TARGET TRACKER





- 12 target tracker (TT) planes interleaving the 11 brick walls
- first TT plane used as veto
- Transverse size ~ 2x1 m^2

FEATURES

- Provide time stamp
- Link muon track information from the target to the magnetic spectrometer

REQUIREMENTS

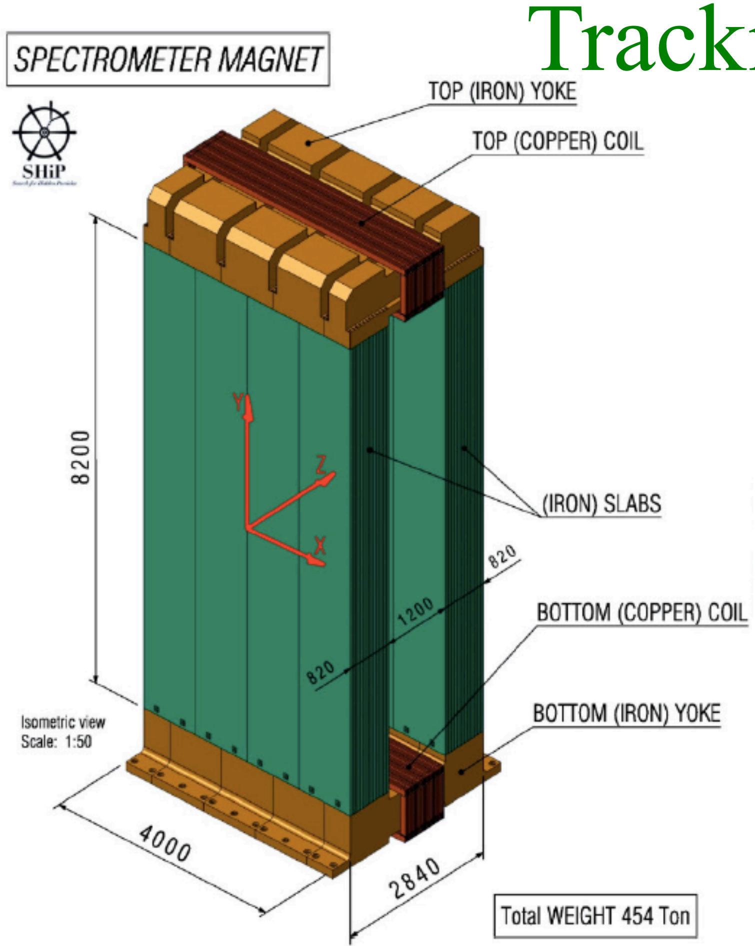
- Operate in 1T field
- X-Y position resolution < 100 μm
- high efficiency (>99%) for angles up to 1 rad

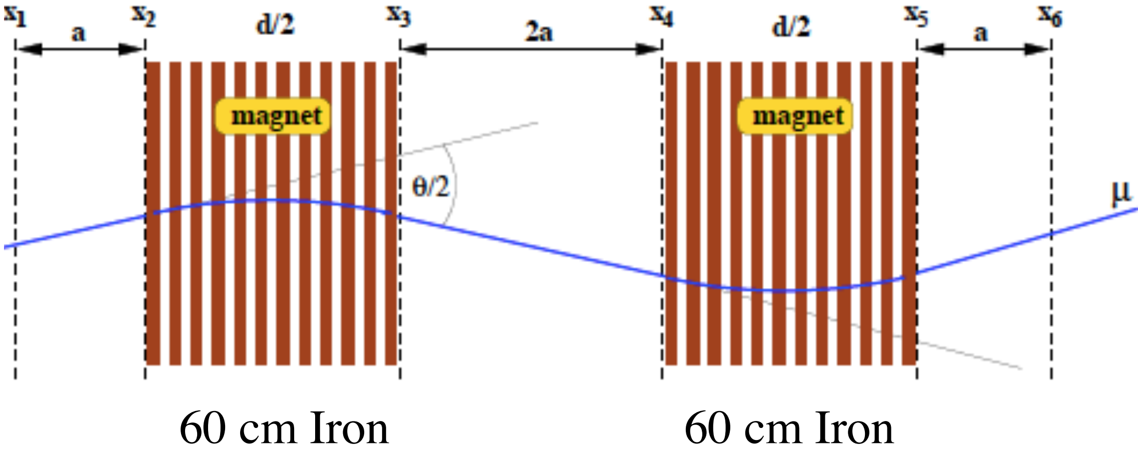
TARGET TRACKER PLANES

POSSIBLE OPTIONS

- Scintillating fibre trackers
- Micro-pattern gas detectors (GEM, Micromegas)

Tracking stations inside the magnet

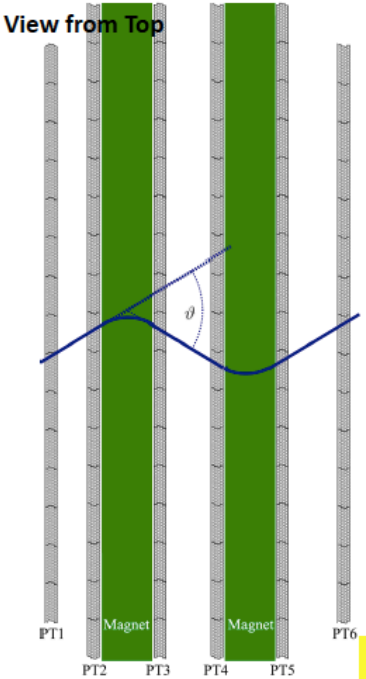


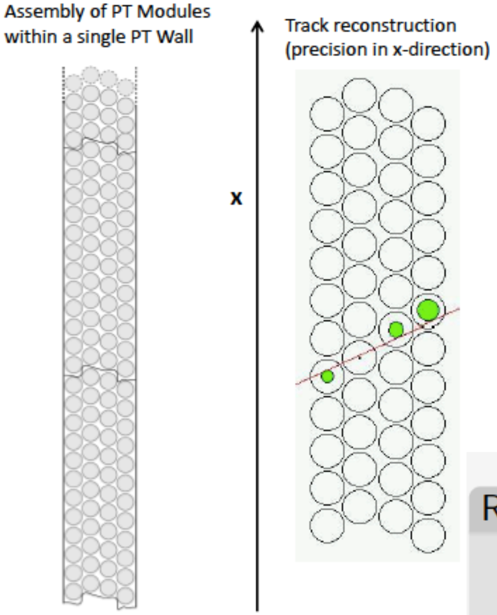


- Requirements:
  - coarse (1 cm) tracking inside the magnetised volume
  - 1ns time resolution
  - Muon rate ~5kHz/m^2 rate
  - Electron rate ~ 1 order higher
- RPC technology is one option
- Streamer versus avalanche to be studied

RPC assembly in the OPERA magnet

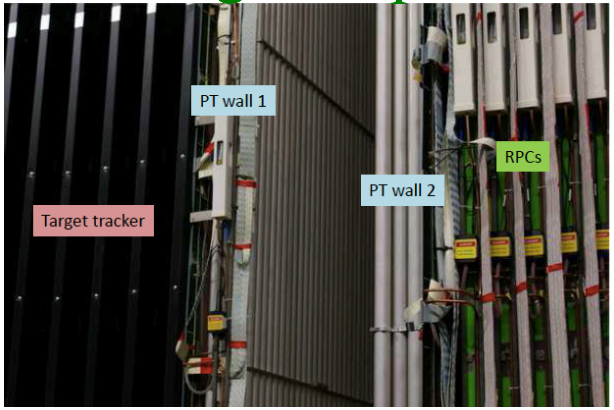
Muon momentum measurement and identification

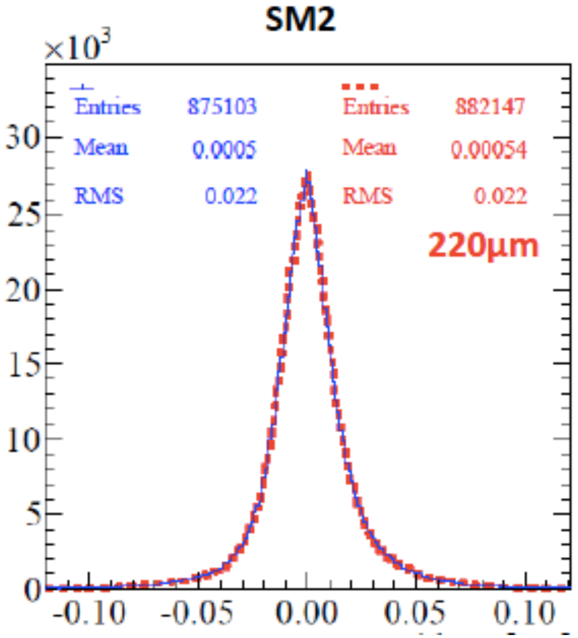




OPERA requirement: Δp/p < 25% for p < 25GeV

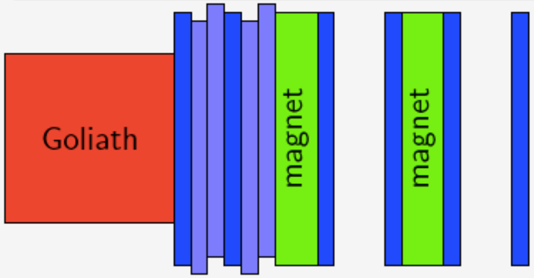
OPERA-like drift tubes are a good option



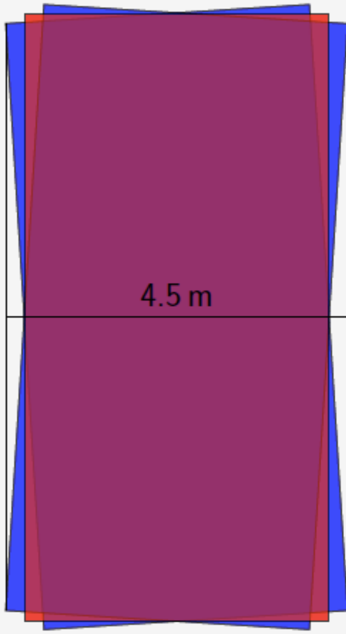


Requirements for 3d reconstruction

- Stereo angle between planes
- 3 projections to avoid ambiguities



- 2 × 3 projections
- 2 projections rotated by ±3.6°
- maximal width: 4.5 m



Hidden Sector detector concept

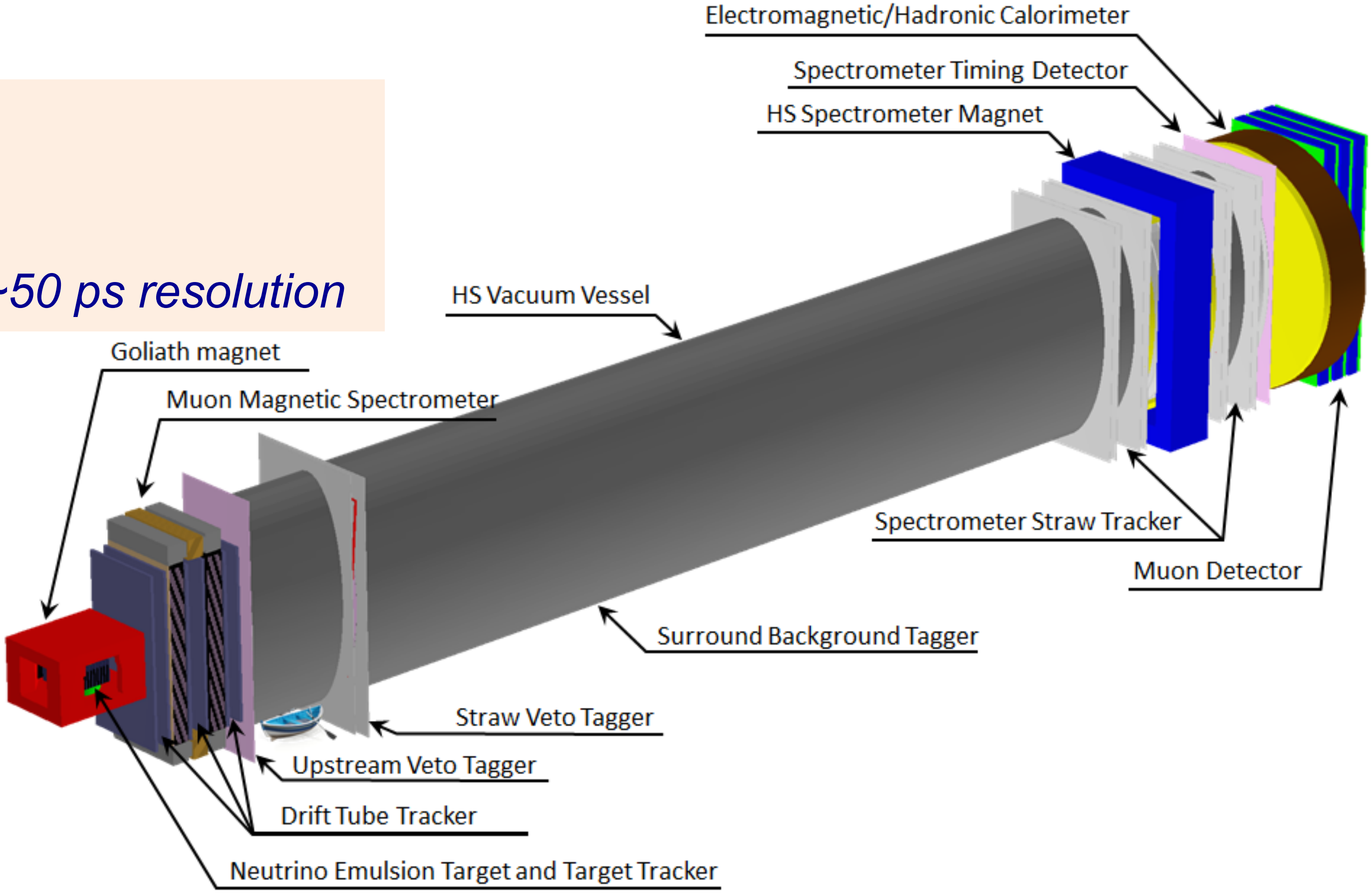
- ✓ *Reconstruction of HS decays in all possible final states*

  Long decay volume protected by various Veto Taggers, Magnetic Spectrometer followed by the Timing Detector, and Calorimeters and Muon systems.

  All heavy infrastructure is at distance to reduce neutrino / muon interactions in proximity of the detector

Challenges:

- *Large vacuum vessel*
- *5 m long straw tubes*
- *Timing detector with ~50 ps resolution*

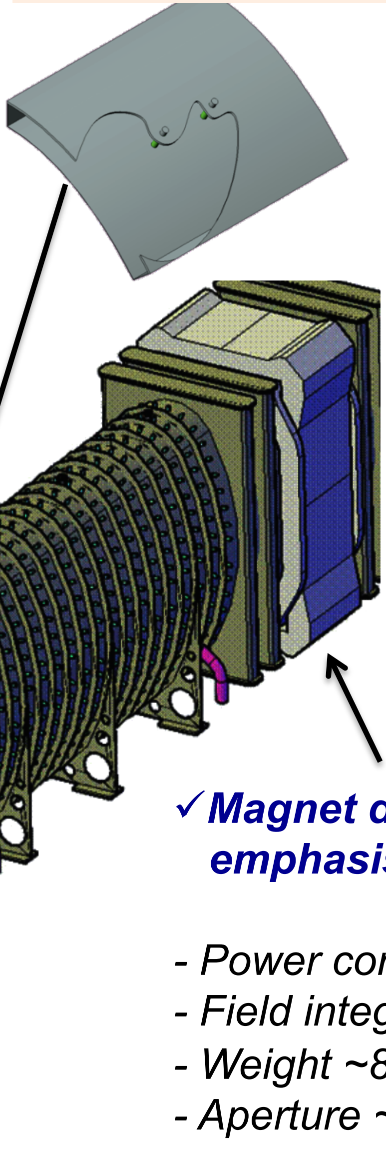


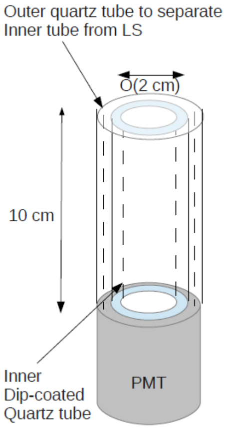
HS decay volume and spectrometer magnet

- ✓ ***Estimated need for vacuum:***
  ~ 10^{-3} mbar (<1 ν interaction)

- ✓ ***Vacuum vessel***
  - *10 m x 5 m x 60 m*
  - *Walls thickness: 8 mm (Al) / 30 mm (SS)*
  - *Walls separation: 300 mm;*
  - *Liquid scintillator (LS) volume (~360 m^3) readout by WLS optical modules (WOM) and PMTs*
  - *Vessel weight ~ 480 t*

LS cell with WOMs

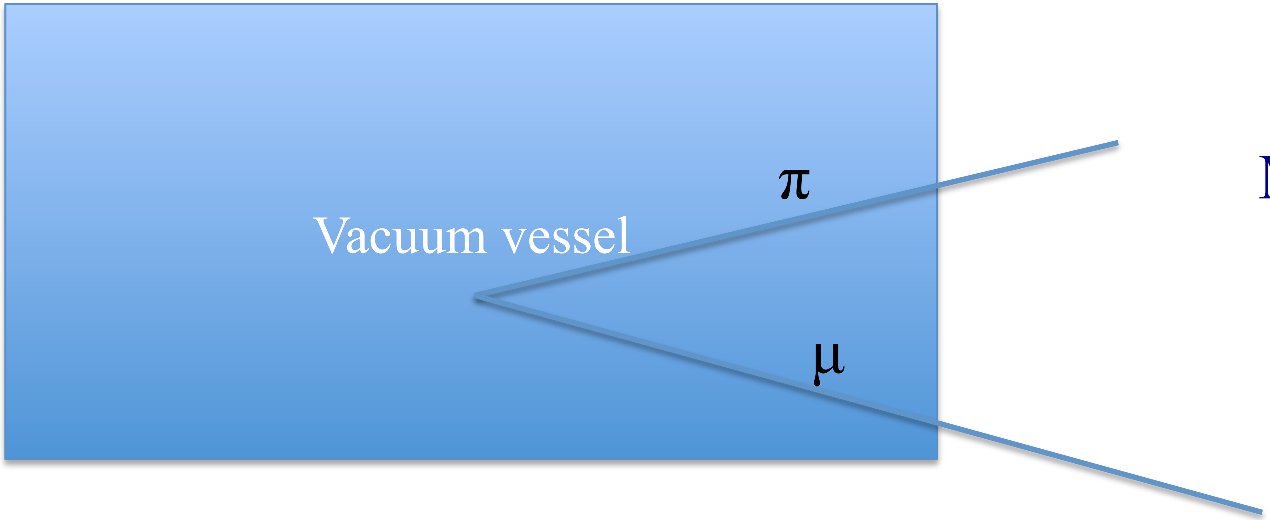




- ✓ ***Magnet designed with an emphasis on low power***

  - *Power consumption < 1 MW*
  - *Field integral: 0.65Tm over 5m*
  - *Weight ~800 t*
  - *Aperture ~50 m^2*

Signal features

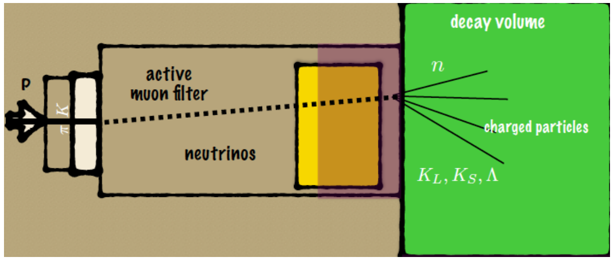


Momentum, PID

- Main background: neutrino interactions, (muon) combinatorial
- Reduce this background by:
  - IP cut
  - Invariant mass
- Important to
  - Measure precisely the momentum
  - Identify the particle
- Reduce combinatorial background by precise timing

HS Backgrounds (1)

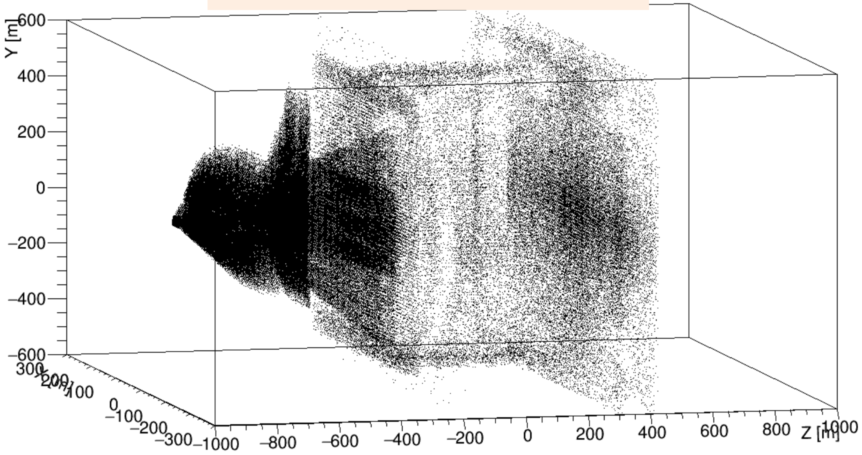
Main sources of background



✓ ***Neutrino DIS interactions with material in the vicinity of the HS decay volume***

(interactions of ν with air in the decay volume are negligible at 10^{-3} mbar)

Neutrino tomography

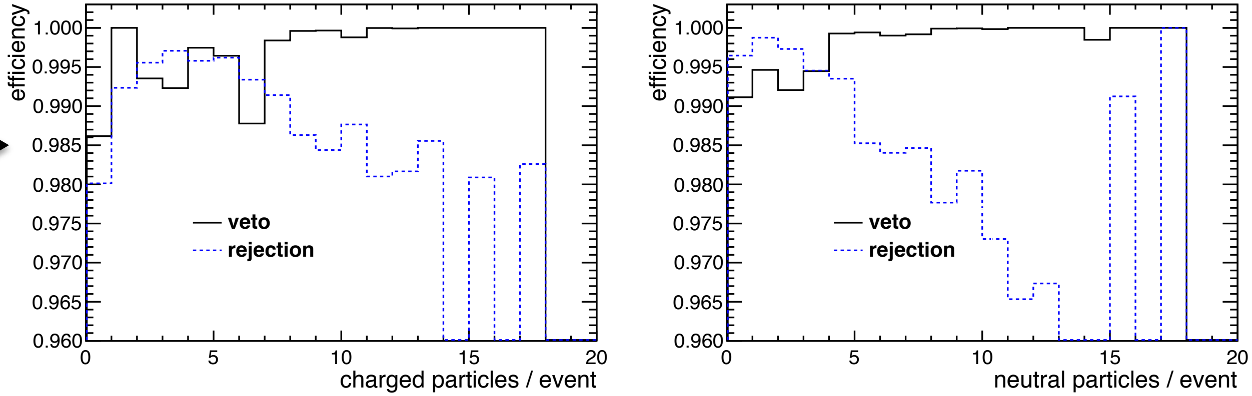


Origin of neutrino interactions

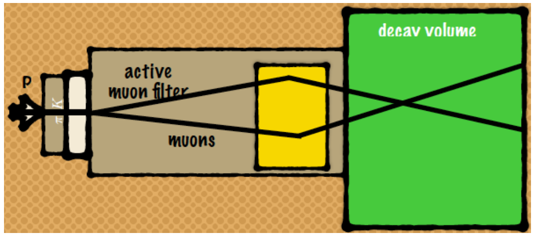
- *Walls of the decay volume (>80%)*
- *Tau neutrino detector*
- *HS tracking system*

Combination of veto and selection cuts reduces the ν-induced background to zero

Veto efficiency increases with event multiplicity →



HS Backgrounds (2)

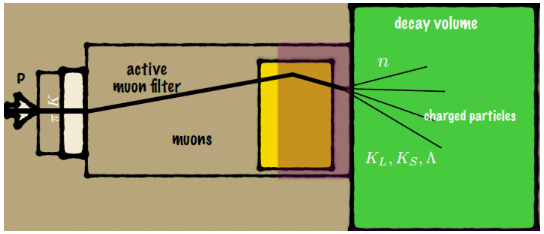


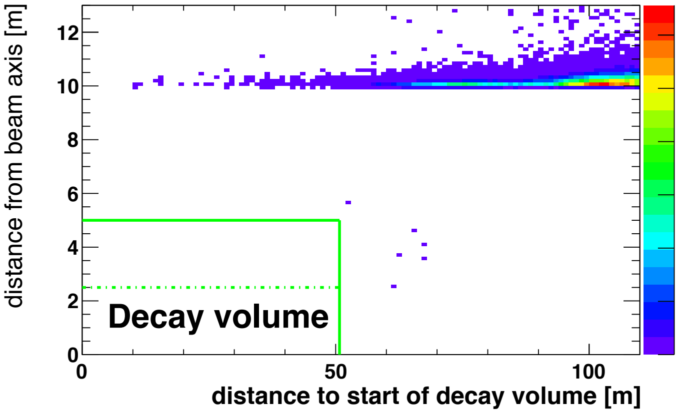
✓ Muon combinatorial background

Simulation predicts O(10^{12}) muon pairs in the decay volume in 5 years of data taking

Suppressed by:
- *Basic kinematic and topological cuts ~10^4*
- *Timing veto detectors ~10^7*
- *Upstream veto and surrounding veto taggers ~10^4*

✓ Muon DIS interactions





- *V^0s produced in the walls of the cavern*
- *DIS close to the entry of the decay volume*

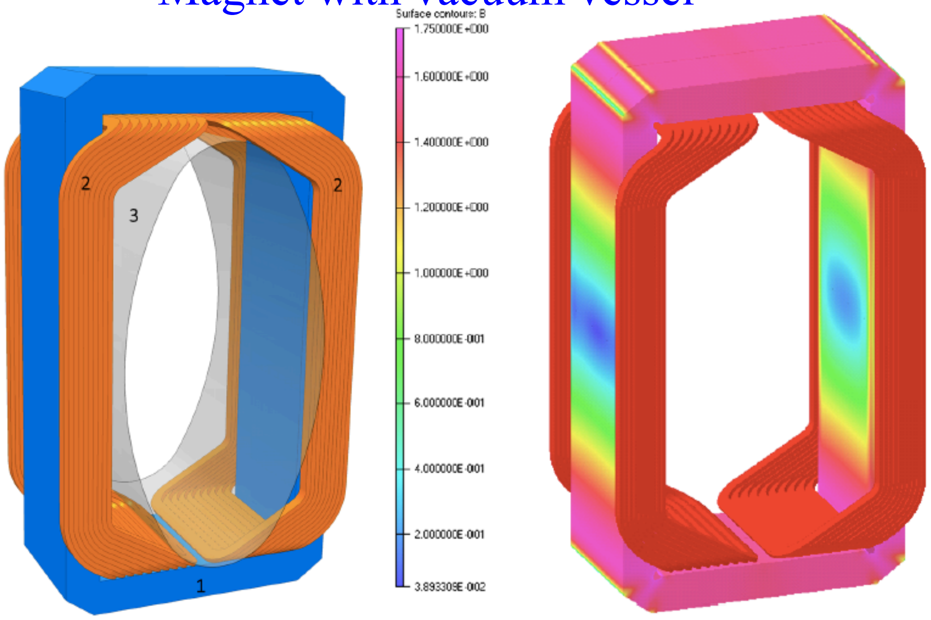
→ smaller than neutrino induced background

✓ Cosmics

Background summary: no evidence for any irreducible background

Momentum resolution of the HS (straw tubes) tracker

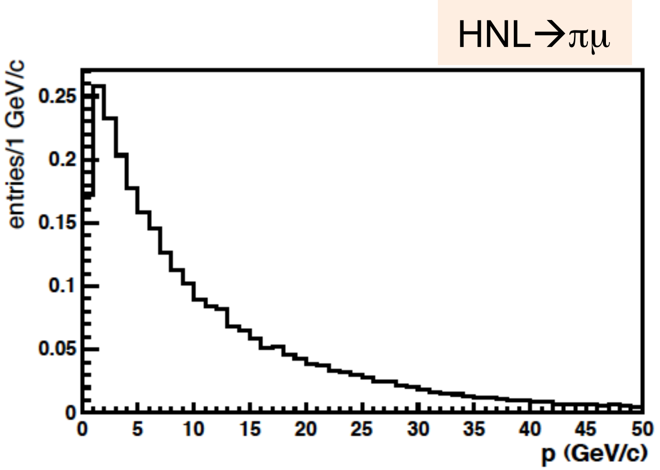
Magnet with vacuum vessel

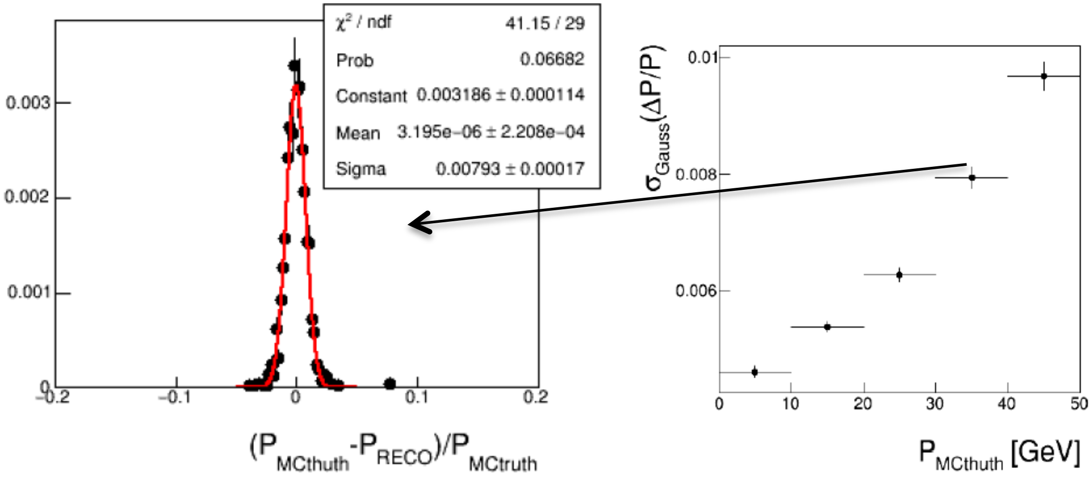


- material budget per station 0.5% X_0
- position resolution 120 μm per straw,
8 hits per station on average

$$\left(\frac{\sigma_p}{p}\right)^2 \approx [0.49\%]^2 + [0.022\%/(\mathrm{GeV}/c)]^2 \cdot p^2$$

Momentum resolution is dominated by multiple scattering below 22 GeV/c
(For HNL → $\pi\mu$, 75% of both decay products have P < 20 GeV/c)



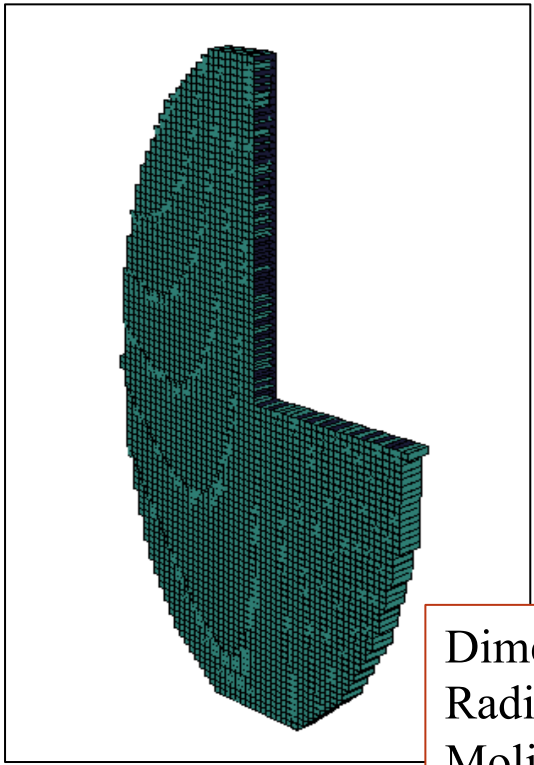


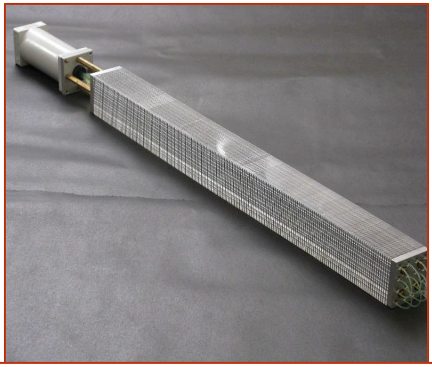
***Vertex resolution** (also driven by multiple scattering and ΔP/P):*
σ_{xy} ~ O(mm), σ_z ~ O(cm)

Calorimeters

ECAL

- Almost elliptical shape (5 m x 10 m)
- 2876 Shashlik modules
- 2x2 cells/modules, width=6 cm
- 11504 independent readout channels

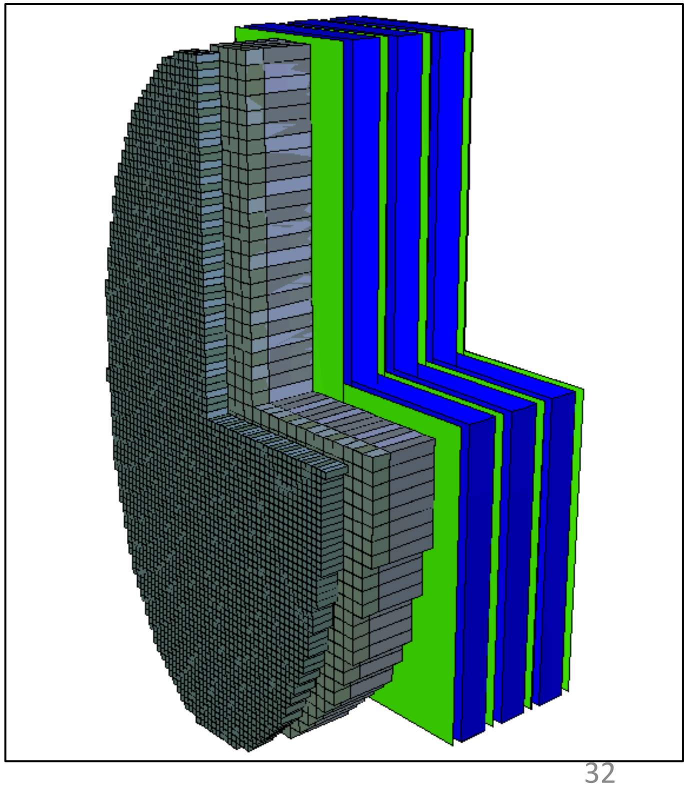




Dimensions	60x60 mm^2
Radiation length	17 mm
Moliere radius	36 mm
Radiation thickness	25 X_0
Scintillator thickness	1.5 mm
Lead thickness	0.8 mm
Energy resolution	1%

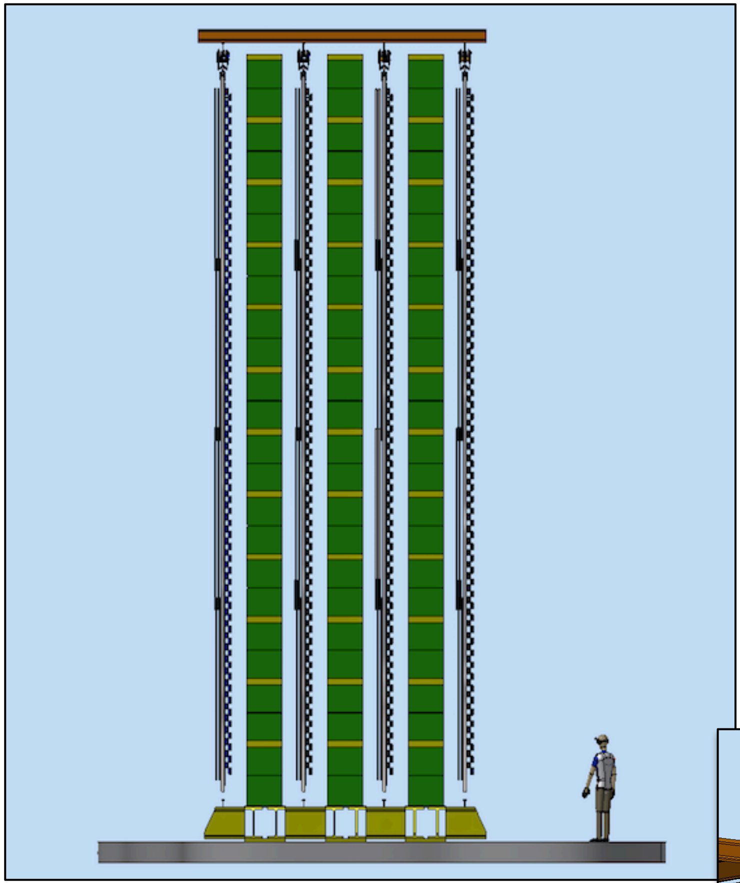
HCAL

- Matched with ECAL acceptance
- 2 stations
- 5 m x 10 m
- 1512 modules
- 24x24 cm^2 dimensions
- Stratigraphy: N x (1.5 cm steel+0.5 cm scint)
- 1512 independent readout channels



Muon System

Based on scintillating bars, with WLS fibers and SiPM readout

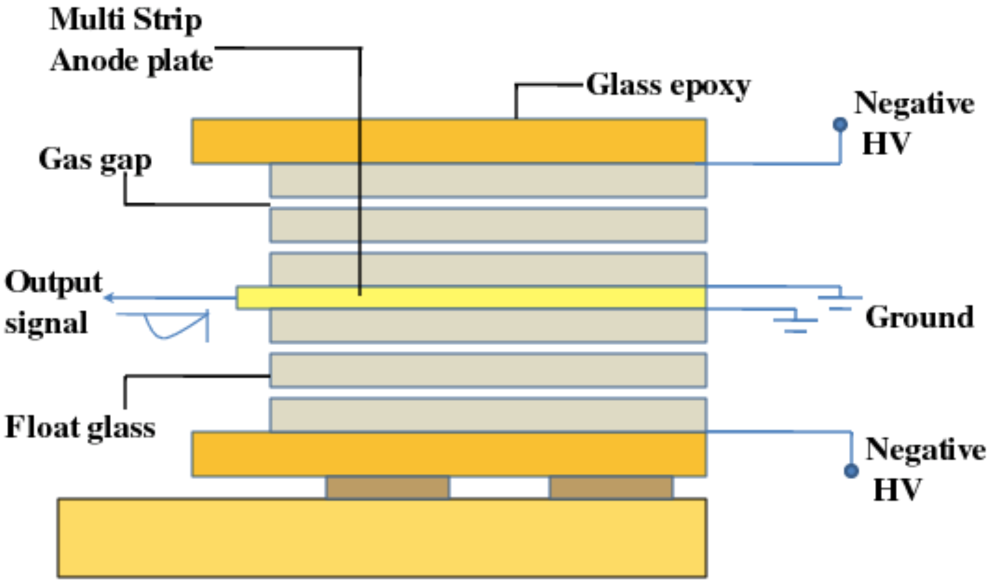


Requirements:
- High-efficiency identification of muons in the final state
- Separation between muons and hadrons/electrons
- Complement timing detector to reject combinatorial muon background

Technical Proposal (preliminary design)
- 4 active stations
- transverse dimensions: 1200x600 cm^2
- x,y view
- 3380 bars, 5x300x2 cm^3/each
- 7760 FEE channels
- 1000 tons of iron filters

Timing detector (< 100ps)

Multi-gap RPC is one option

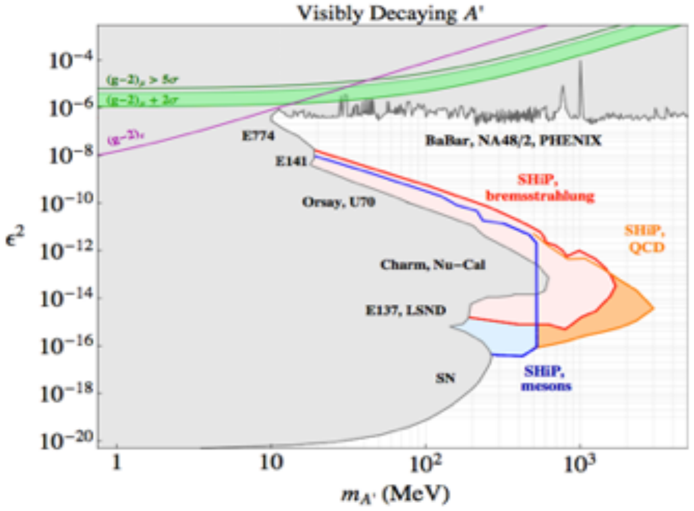


σ_{xy} ~ 1cm

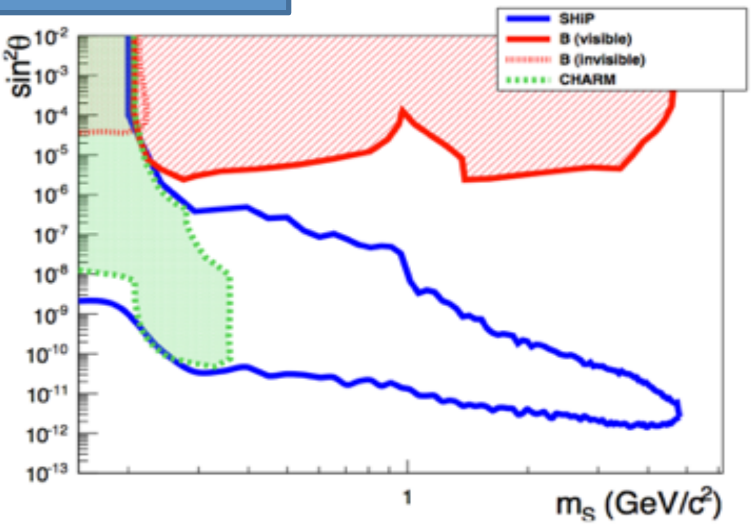
SHiP sensitivity to Hidden Sector

Based on 2x10^{20} pot
@400 GeV in 5 years

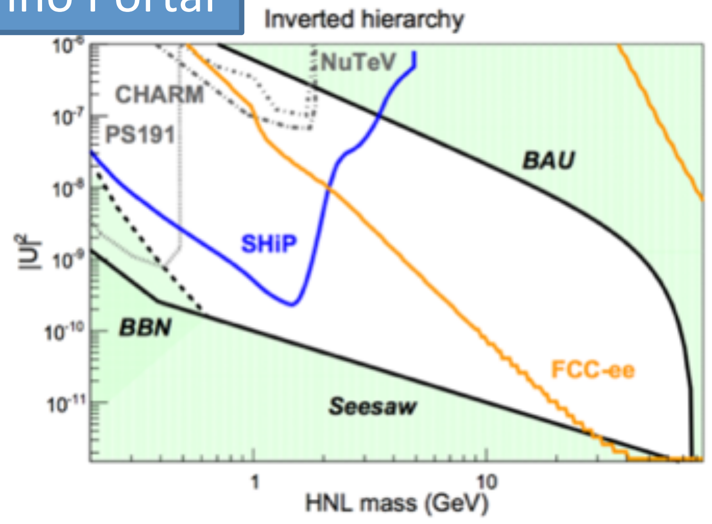
Vector Portal



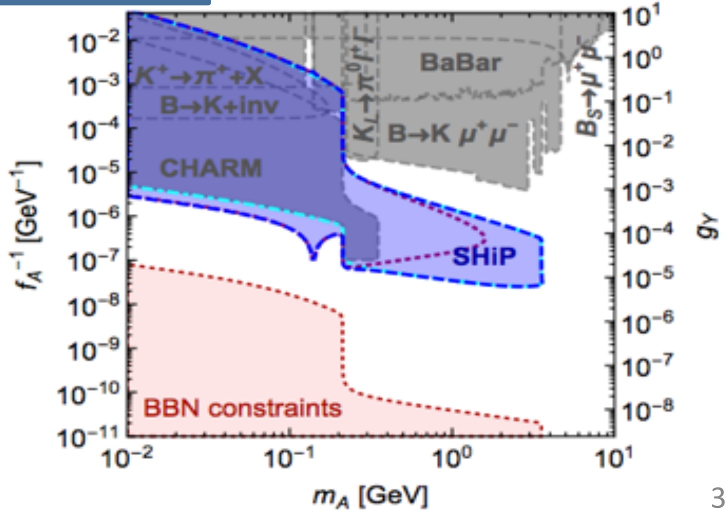
Scalar Portal



Neutrino Portal



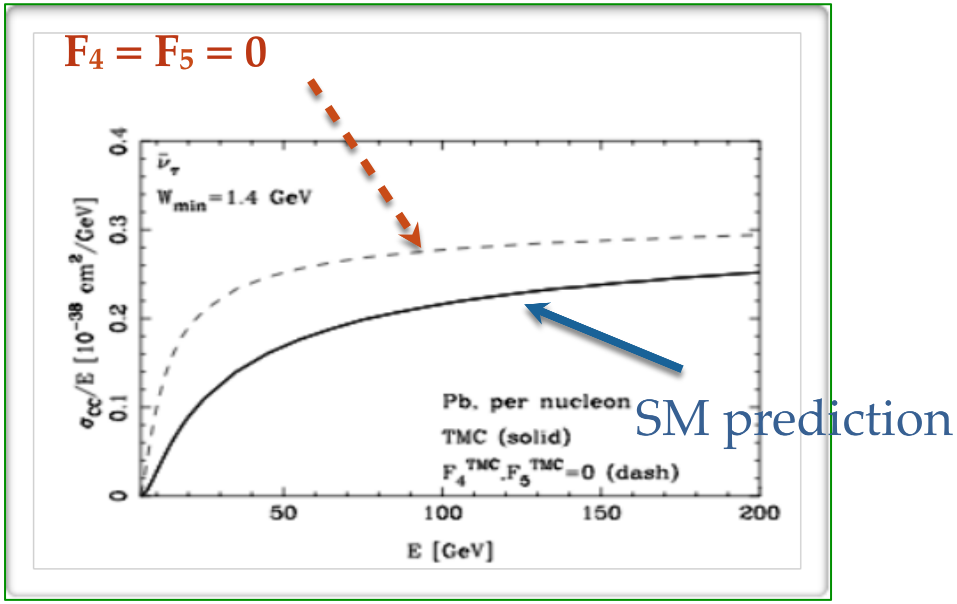
Axion Portal



F_4 AND F_5 STRUCTURE FUNCTIONS

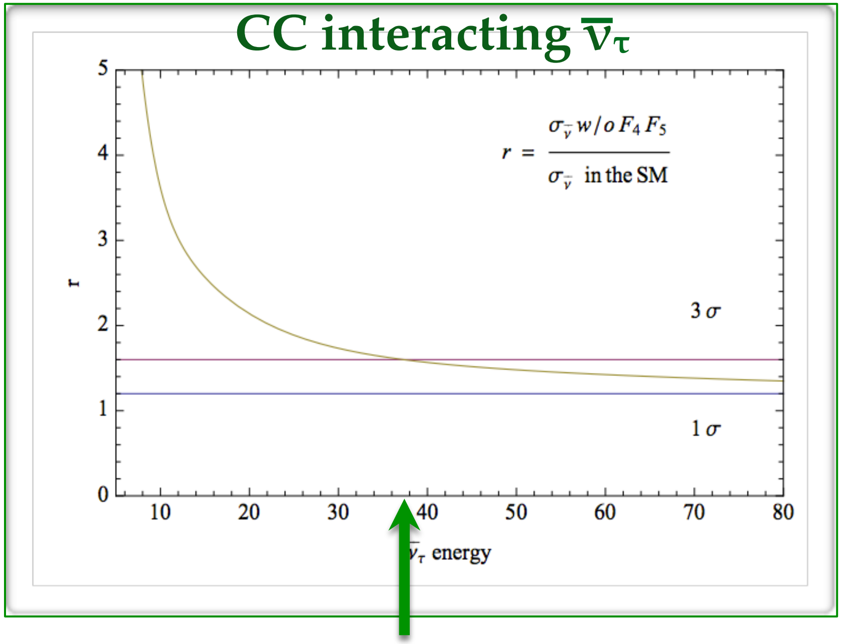
First evaluation of F_4 and F_5, not accessible with other neutrinos

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



$F_4 = F_5 = 0$

SM prediction



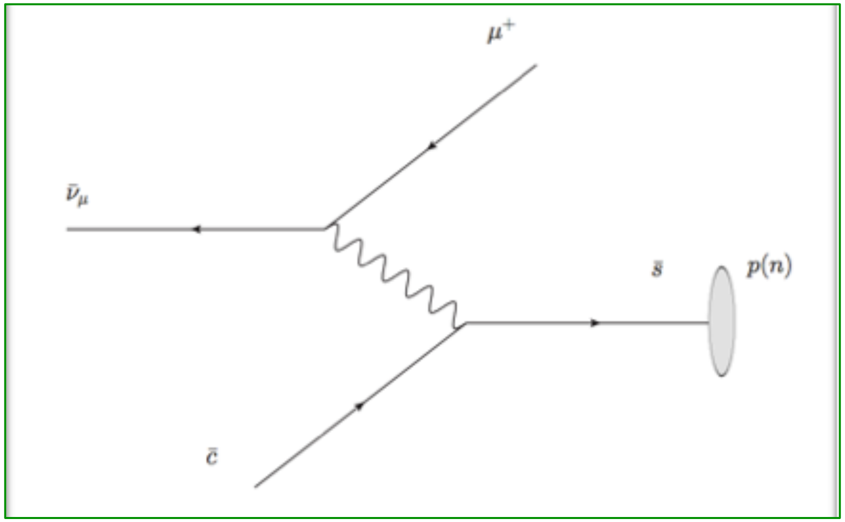
CC interacting $\bar\nu_\tau$

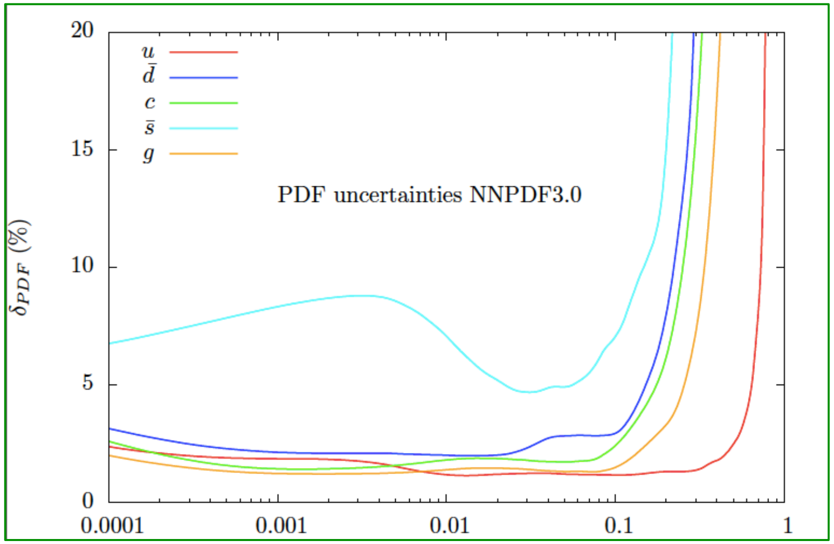
E($\bar\nu_\tau$) < 38 GeV

- At LO $F_4 = 0$, $2xF_5 = F_2$
- At NLO $F_4 \sim 1\%$ at 10 GeV

STRANGE QUARK NUCLEON CONTENT

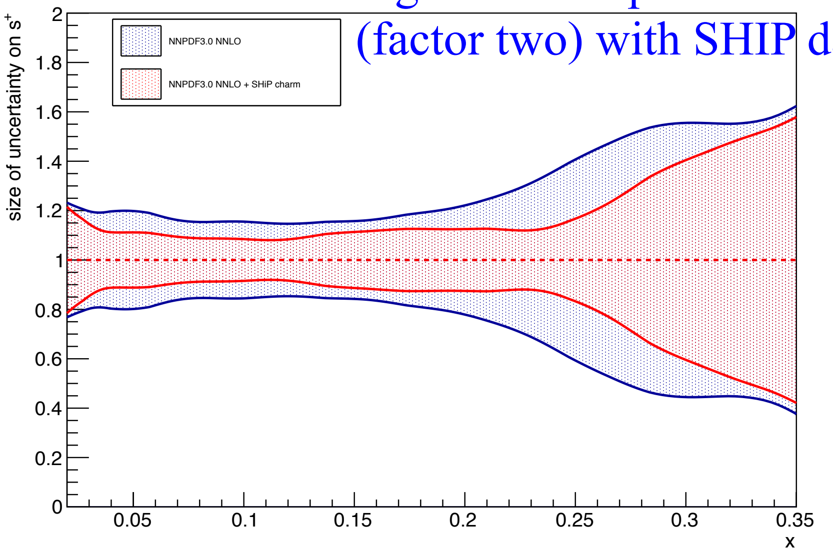
- Charmed hadron production in anti-neutrino interactions selects anti-strange quark in the nucleon
- Strangeness important for precision SM tests and for BSM searches
- W boson production at 14 TeV: 80% via $u\overline{d}$ and 20% via $c\overline{s}$





Phys. Rev. D91 (2015) 113005

Fractional uncertainty of the individual parton densities $f(x;m^2_W)$ of NNPDF3.0



- Significant improvement (factor two) with SHIP data

$$s^+ = s(x) + \overline{s}(x)$$

Added to NNPDF3.0 NNLO fit, Nucl. Phys. B849 (2011) 112–143, at $Q^2 = 2$ GeV^2

DARK MATTER SEARCH WITH THE NEUTRINO DETECTOR

χ produced by a dark photon decay

$$\chi e^- \to \chi e^-$$

P. deNiverville, D. McKeen, and A. Ritz, Phys.Rev. D86 (2012) 035022

$$\alpha' = \text{dark photon coupling with } \chi$$

SIGNAL SELECTION

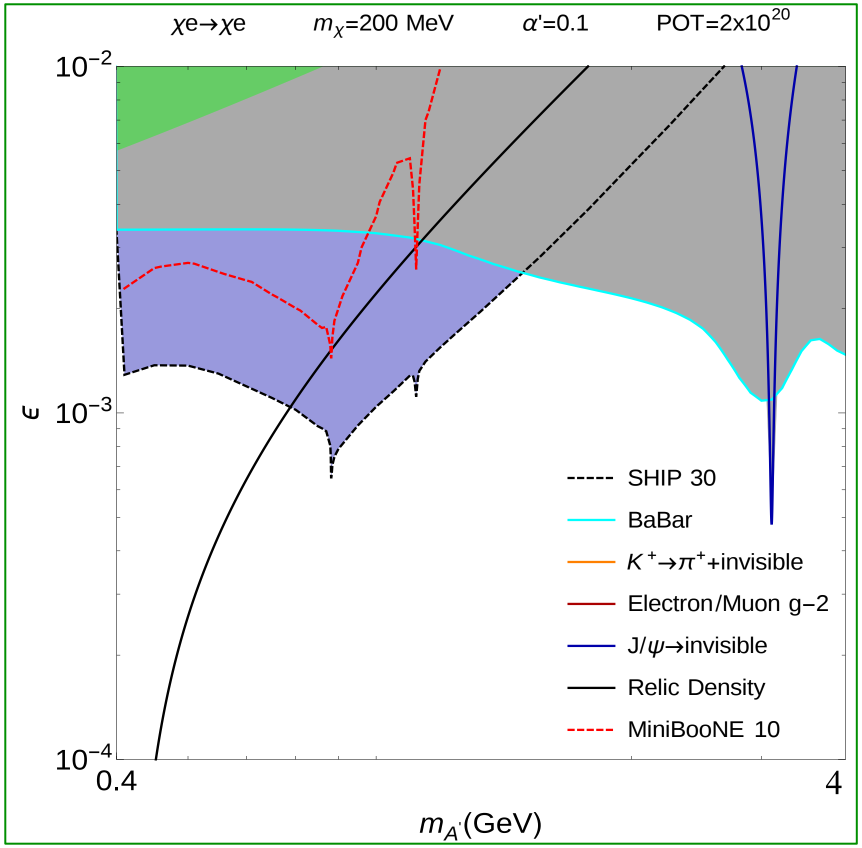
$$\begin{cases} 0.01 < \theta < 0.02 \\ E < 20 \text{ GeV} \end{cases}$$

BACKGROUND PROCESSES

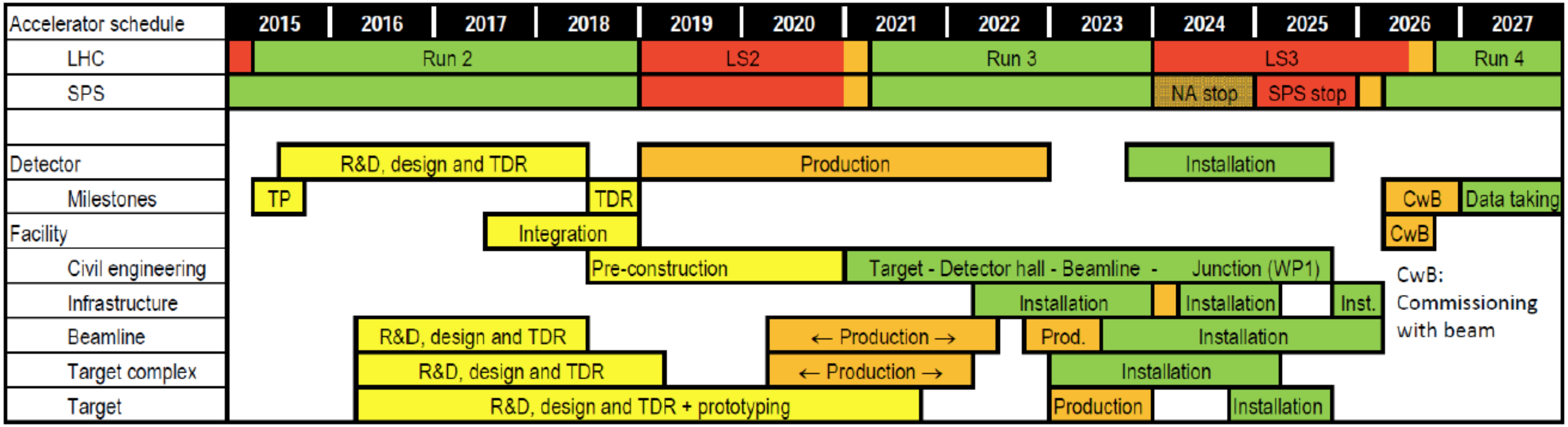
	ν_e	$\bar{\nu}_e$	ν_μ	$\bar{\nu}_\mu$	all
Elastic scattering on e^-	16	2	20	18	56
Quasi - elastic scattering	105	73			178
Resonant scattering	13	27			40
Deep inelastic scattering	3	7			10
Total	137	109	20	18	284

$$\epsilon = \text{dark photon coupling with e.m. current}$$

$$m_A = \text{dark photon mass}$$



Project schedule



- *10 years from TP to data taking*

✓ *Schedule optimized to avoid interference with operation of North Area*

  ➔ *Preparation of facility in four clear and separate work packages (junction cavern, beam line, target complex and detector hall)*

  ➔ *Use LS3 for junction cavern and first short section of SHiP beam line*

✓ *Comprehensive Design Study 2016-2018: Starting now! → Update of European HEP strategy 2018*

✓ *Construction/production 2021-*

  ➔ ***Data taking 2026***

Summary

SHIP to complement searches for New Physics at CERN in the largely unexplored domain of new, very weakly interacting particles with masses O(10) GeV

- ✓ *Unique opportunity for ν_τ physics*

- ✓ *Sensitivity improves past experiments by O(10000) for Hidden Sector and by O(~1000) for ν_τ physics*

- ✓ *Recommendations of the SPS Committee at CERN in January 2016: The SPSC supports the motivation for the search for hidden particles, which will explore a domain of interest for many open questions in particle physics and cosmology, and acknowledges the interest of the measurements foreseen in the neutrino sector. SHiP could therefore constitute a key part of the CERN Fixed Target programme in the HL-LHC era. SPSC* ***recommends*** *that the SHiP proponents proceed with the preparation of a Comprehensive Design Report (CDR), and that this preparation be made in close contact with the planned Fixed Target working group.*

- ✓ *CERN DG has launched the "Beyond Colliders Physics" Working Group. The beam dump is the first item. Kick-off meeting on September 6th-7th*

- ✓ *Design optimisation going on: your contribution is very welcome!*