SHiP
Search for Hidden Particles

Search for Hidden Particles

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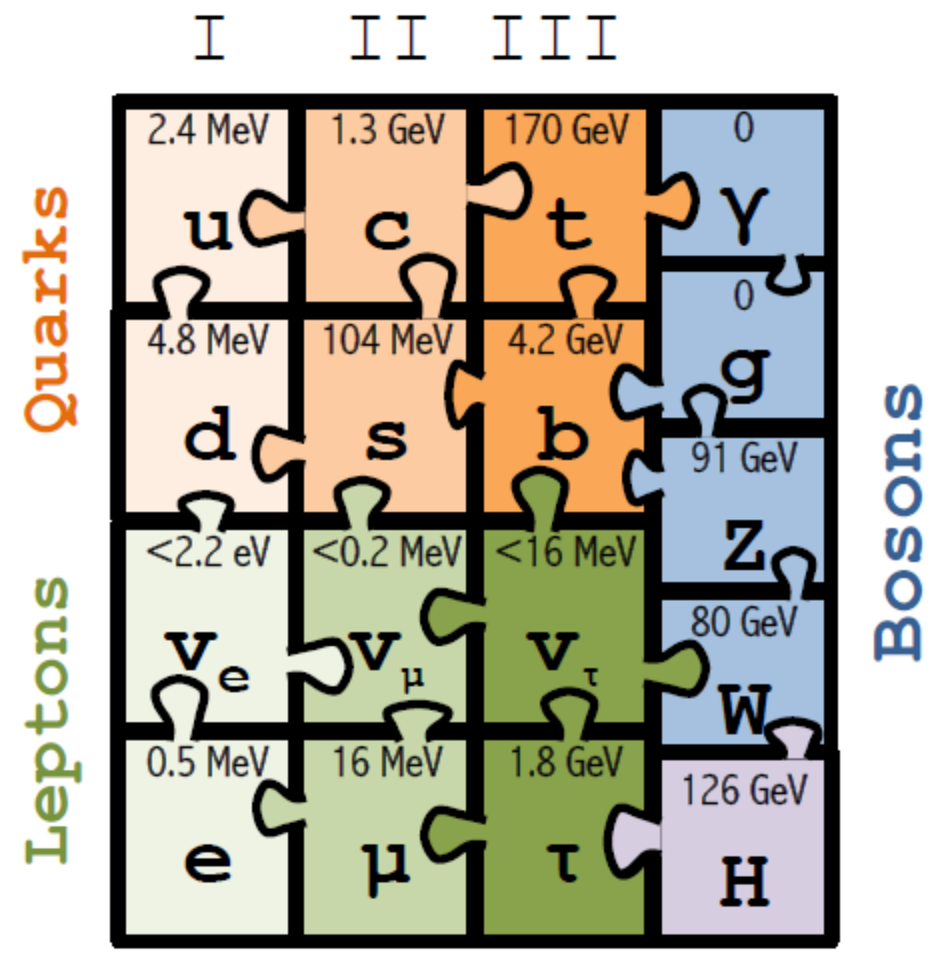
The Standard Model is complete

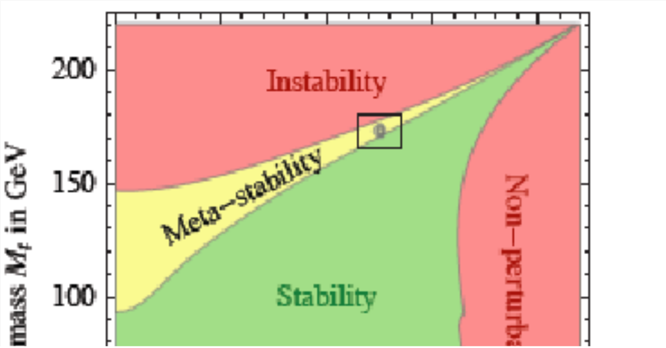
- The discovery of the Higgs boson at the LHC made the Standard Model (SM) of elementary particles complete
  - all the particles predicted by the model have been found,
  - their interactions, tested at LHC till now, are consistent with those predicted by the SM.



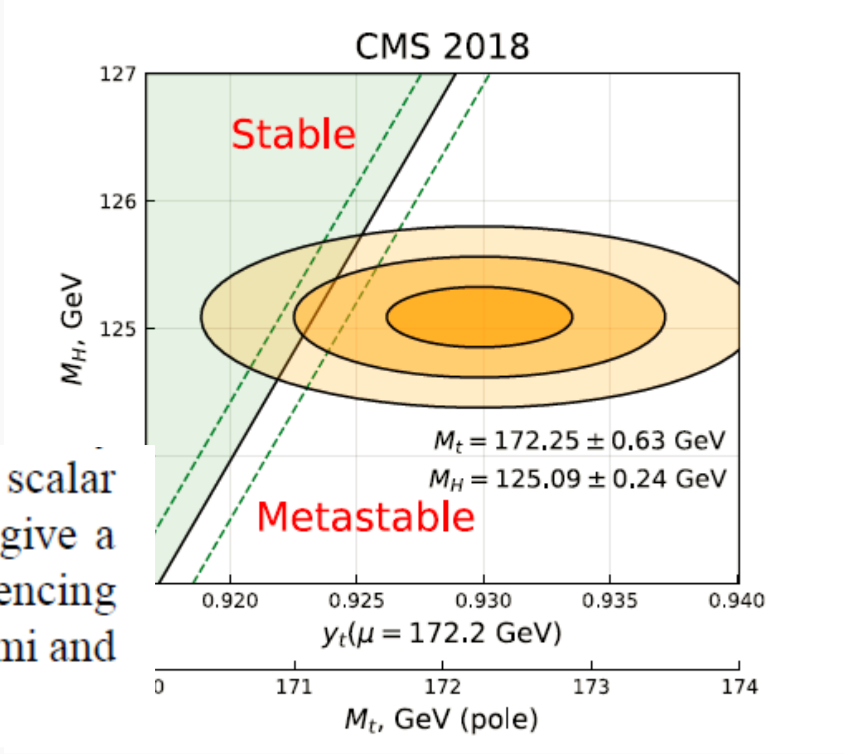
- **The Standard Model is a very consistent and complete theory.**

Beyond The Standard Model

- The Electroweak Precision Observables (EWPO) radiative corrections predicted top and Higgs masses assuming SM *and nothing else*
- We can even extrapolate the Standard Model all the way to the the Plank scale :



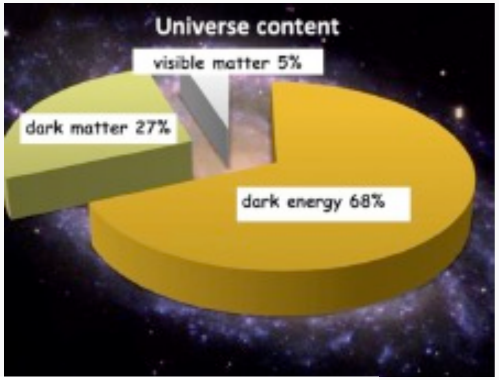
small in the transition region. Detecting the Higgs scalar with mass around 126 GeV at the LHC could give a strong hint for the absence of new physics influencing the running of the SM couplings between the Fermi and Planck/unification scales.



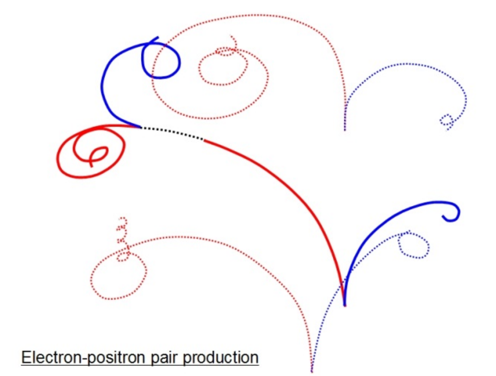
arXiv:0912.0208 M. Shaposhnikov, C, Wetterich

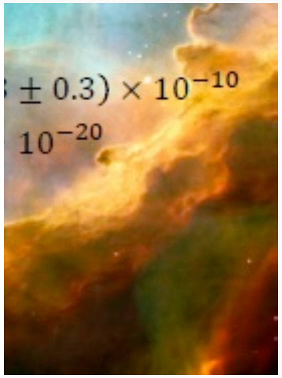
Is it the end?

No!



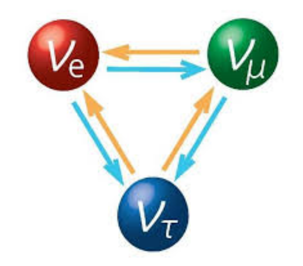
- Standard Model particles constitute only 5% of the energy in the Universe





- Matter-antimatter asymmetry

- Neutrino mass-oscillations



- **Answers beyond the Standard Model**
- **We are certain that the SM does not represent the complete picture**

Continue…but.. How?

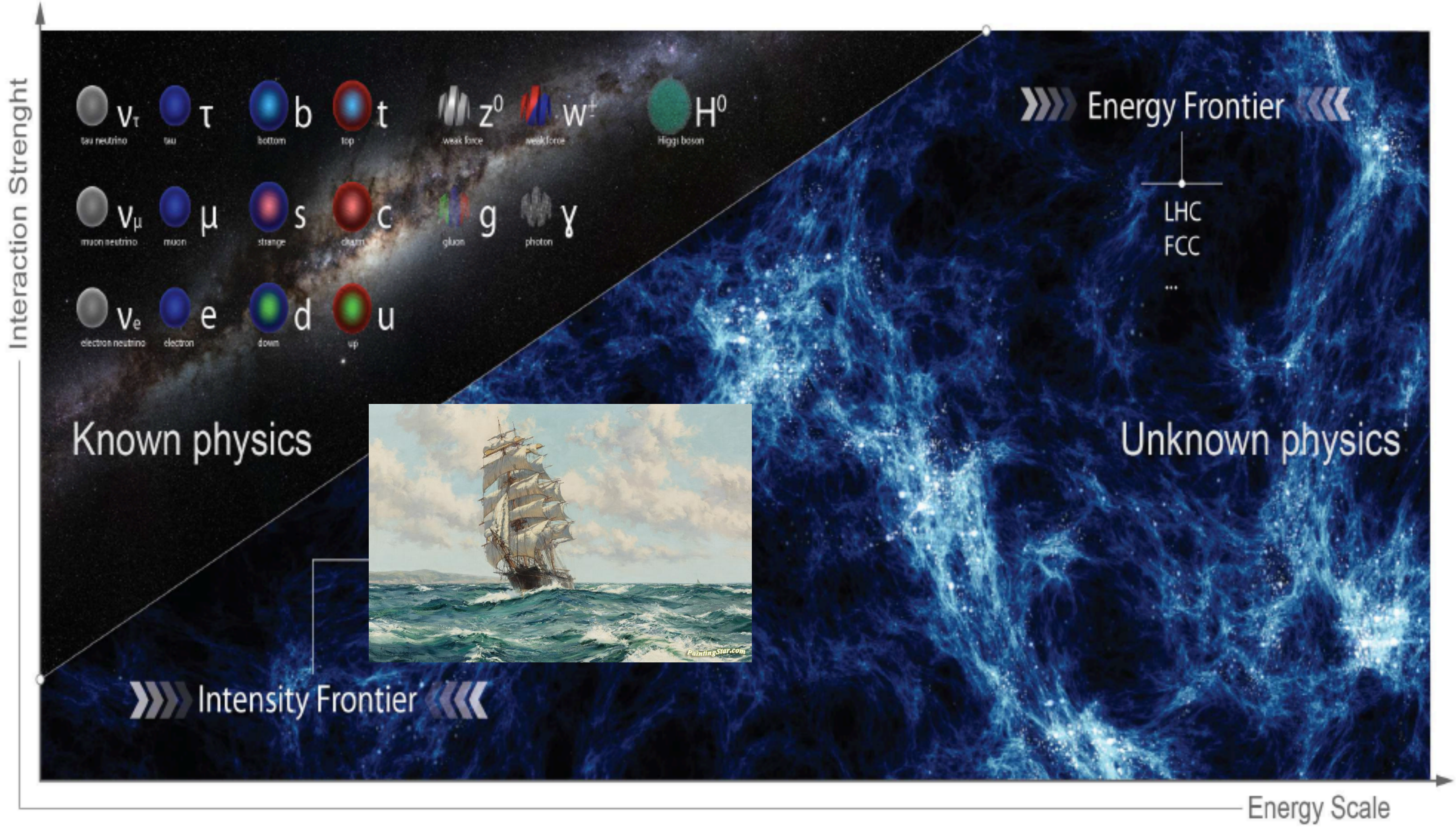
We must continue ….. but…

HOW?

- **Direct observation of new particles** (energy frontier).
- **The searches for extremely feebly interacting relatively light particles** (intensity frontier).
- **Deviations from precise predictions** (precision frontier).

SHiP Experiment

- The SHiP facility will provide a unique experimental platform for physics at the intensity frontier



SHiP: Search for Hidden Particles

- SHiP is a new proposed fixed-target experiment at the CERN SPS accelerator to search for hidden, very weakly interacting new particles.
- At the same time, also ideal for ν_τ physics.

Collaboration

- 52 institutes from 17 countries, plus CERN

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH (CERN)

SHiP
Search for Hidden Particles

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

arXiv:1504.04956v1 [physics.ins-det] 20 Apr 2015

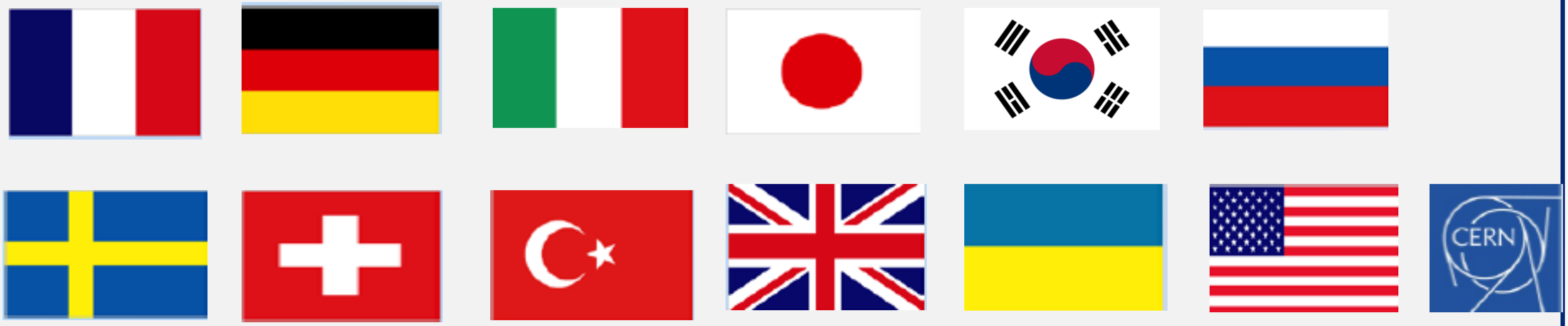
Technical Proposal

A Facility to Search for Hidden Particles (SHiP) at the CERN SPS

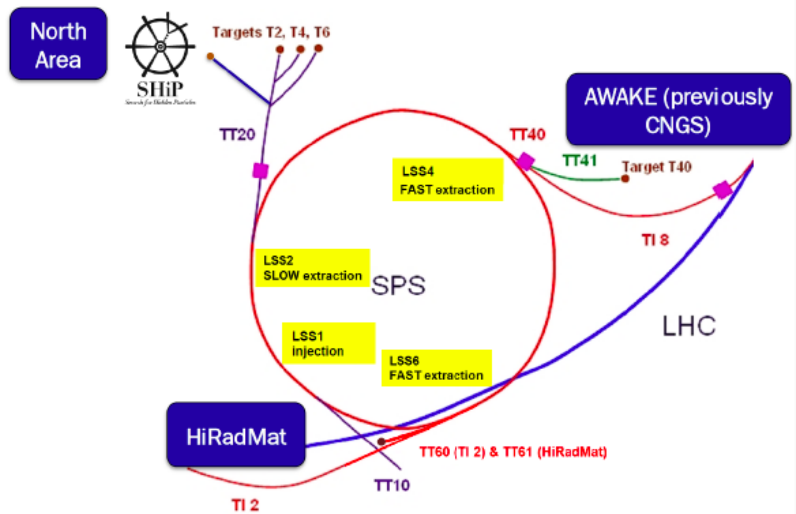
The SHiP Collaboration[1]

Abstract

A new general purpose fixed target facility is proposed at the CERN SPS accelerator which is aimed at exploring the domain of hidden particles and make measurements with tau neutrinos. Hidden particles are predicted by a large number of models beyond the Standard Model. The high intensity of the SPS 400 GeV beam allows probing a wide variety of models containing light long-lived exotic particles with masses below $\mathcal{O}(10)$ GeV/c^2, including very weakly interacting low-energy SUSY states. The experimental programme of the proposed facility is capable of being extended in the future, e.g. to include direct searches for Dark Matter and Lepton Flavour Violation.

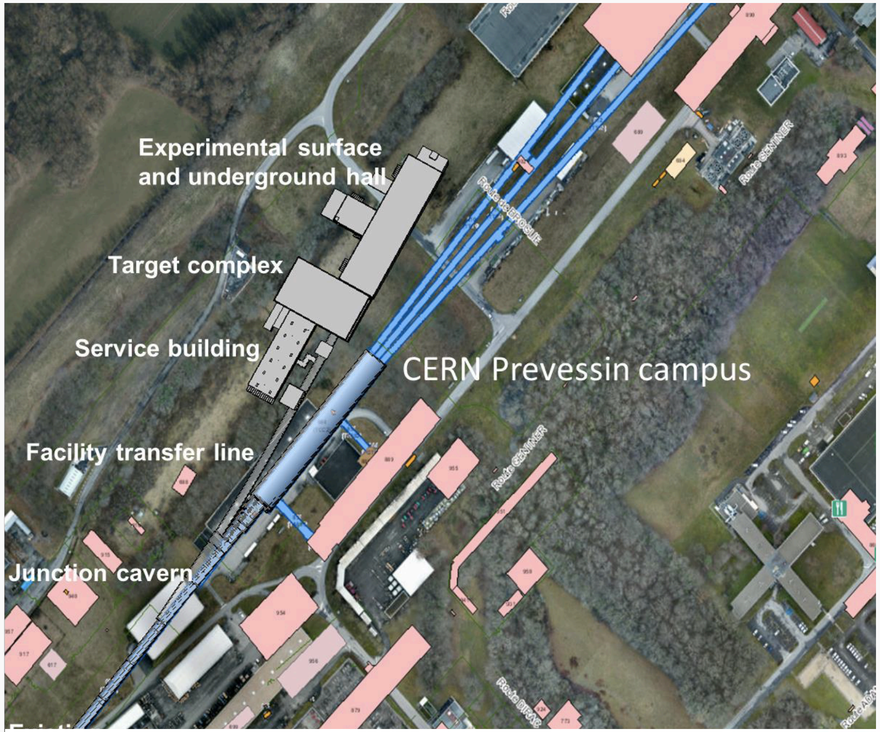


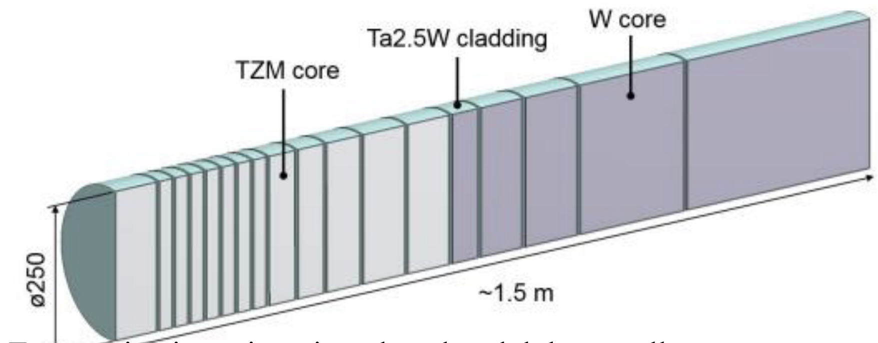
SHiP: a fixed-target facility at the SPS



- Use TT20 area (same as NA62, Compass, testbeams), requires new beam line and dedicated shielded target and detector areas and slow extraction mode.
  - 400 GeV protons from SPS
  - 4×10^{19} pot/year (~200 days of running)
  - Spill = 4×10^{13} pot per cycle of 7.2 s with slow beam extraction (1s)

- **Proposed implementation is based on minimal modification to the SPS**





Target : titanium-zirconium doped molybdenum alloy.

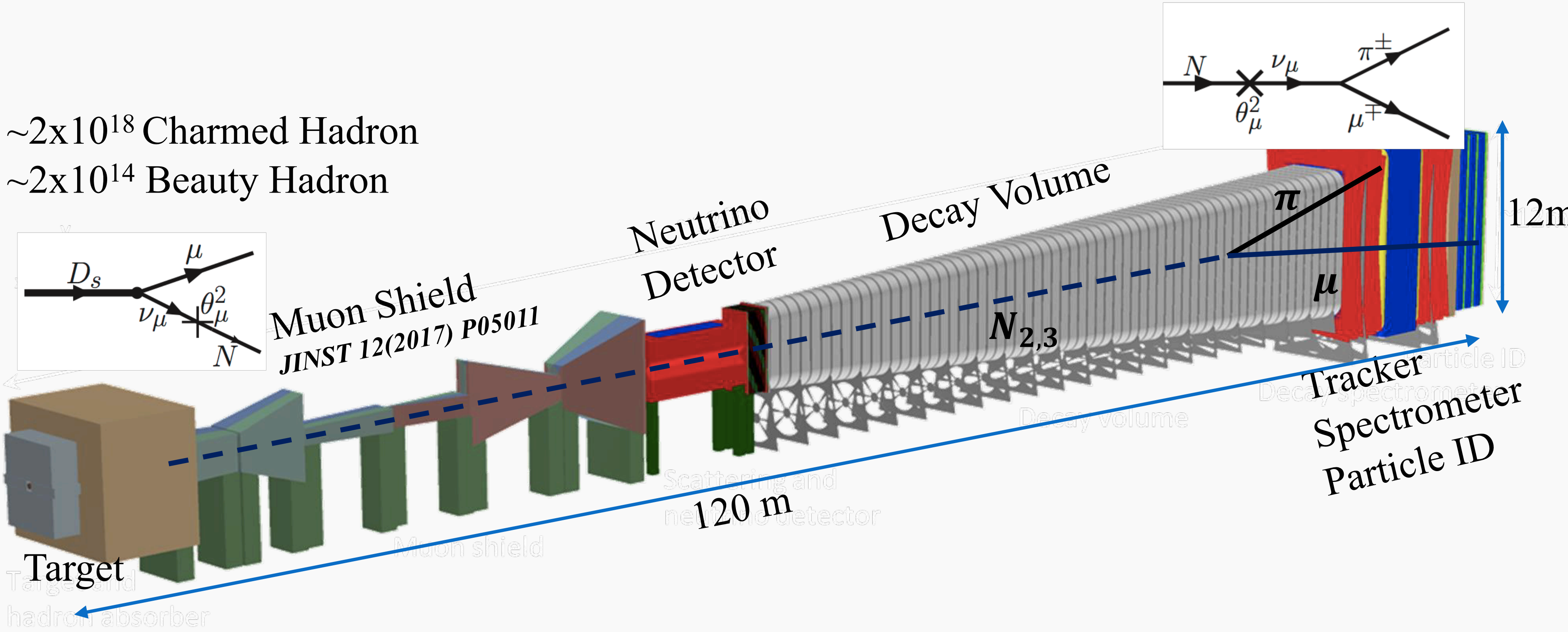
Design Concept of SHiP

"Zero background" experiment:

Reconstruction of HS decays in all possible final states Long decay volume protected by various **Veto Taggers, Magnetic Spectrometer followed by the Timing Detector, Calorimeters and Muon Systems**

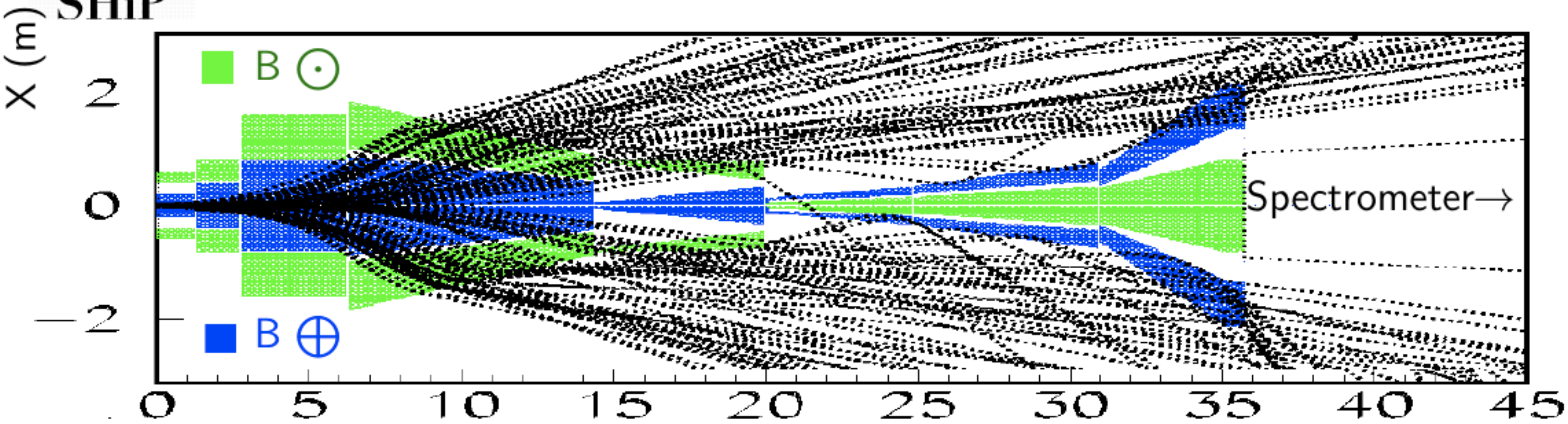
~2x10^{18} Charmed Hadron

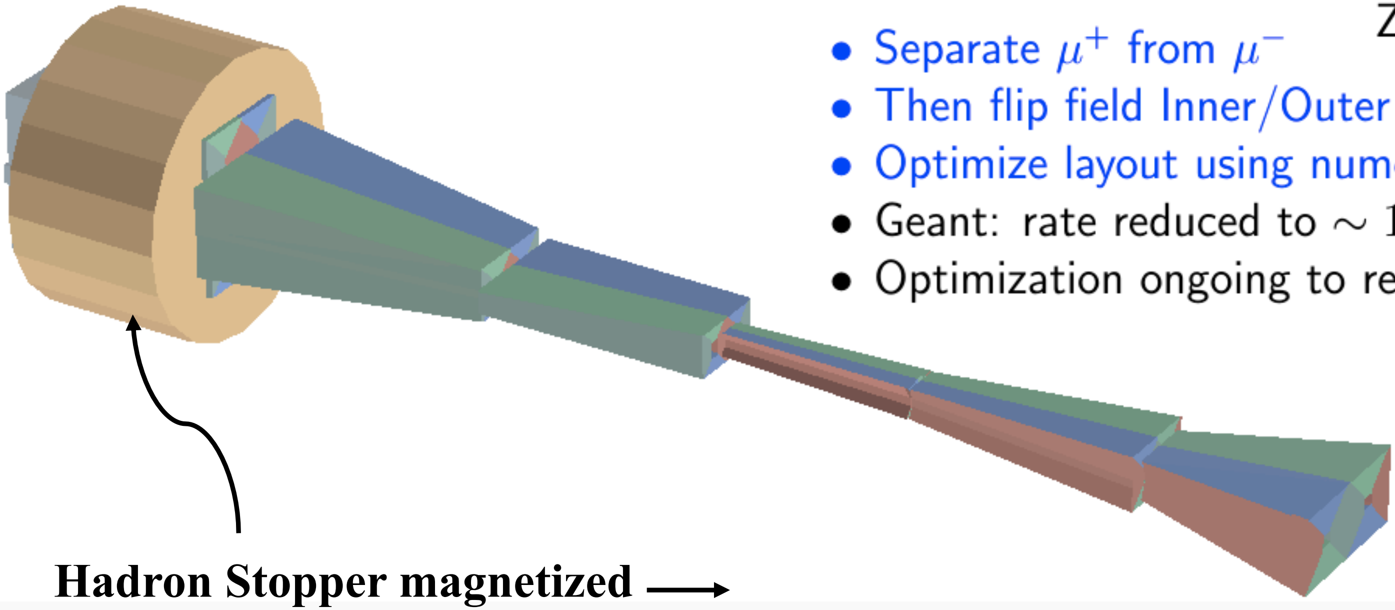
~2x10^{14} Beauty Hadron



Hadron Stopper & μ-Shield

SHiP

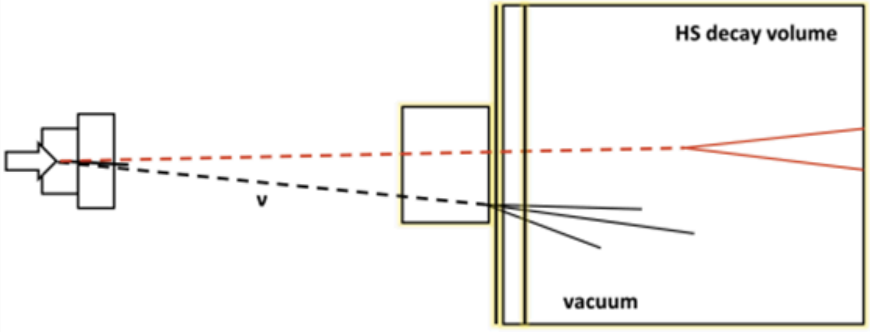




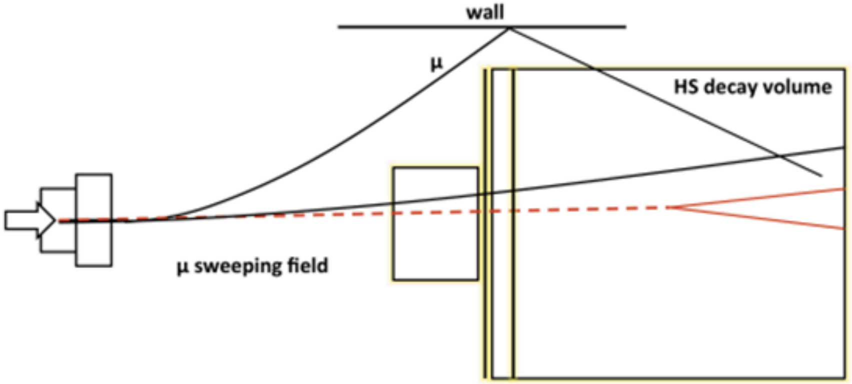
- Separate μ^+ from μ^-
- Then flip field Inner/Outer
- Optimize layout using numerical minimization
- Geant: rate reduced to $\sim 10^5$ μ/s.
- Optimization ongoing to reduce rate even further.

Hadron Stopper magnetized →
Necessary for efficient deflection

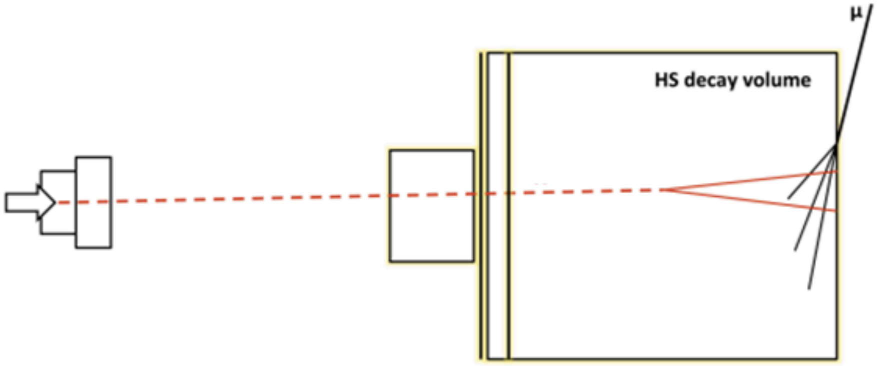
Beam Induced Background



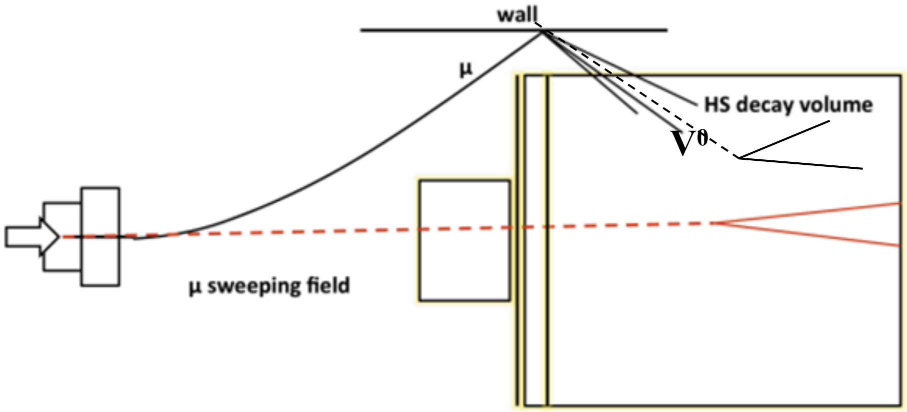
Neutrino interactions



Muon combinatorial



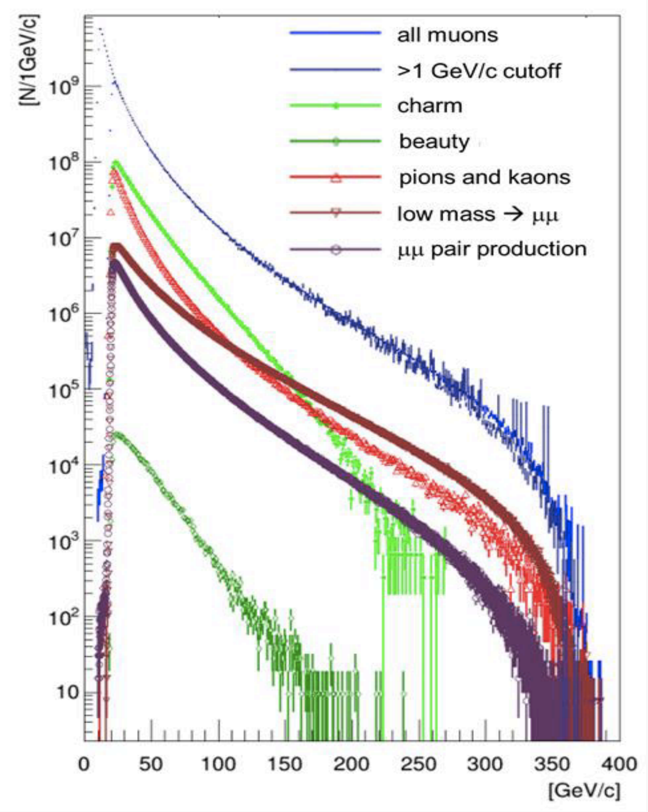
Cosmic muons



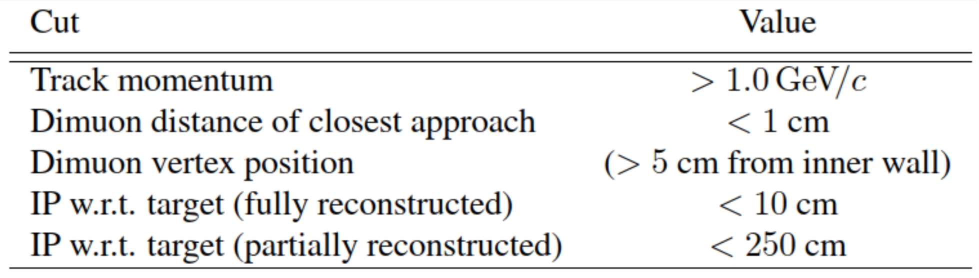
Deep inelastic

Background Suppression

- Beam-induced background flux
  - $\vartheta(10^{11})muons(> 1\frac{GeV}{c})per\ spill$ of $4x10^{13}$
  - $4.5x10^{18}$ neutrinos and $3x10^{18}$ anti-neutrinos in acceptance in 2x1020 proton on target



- For zero background it is critical. to reduce muon flux and neutrino interactions:
  - Background Taggers,
  - Particle ID,
  - Coincidence timing
  - Kinematic analysis



Cut	Value
Track momentum	$> 1.0\,\mathrm{GeV}/c$
Dimuon distance of closest approach	< 1 cm
Dimuon vertex position	($>$ 5 cm from inner wall)
IP w.r.t. target (fully reconstructed)	< 10 cm
IP w.r.t. target (partially reconstructed)	< 250 cm

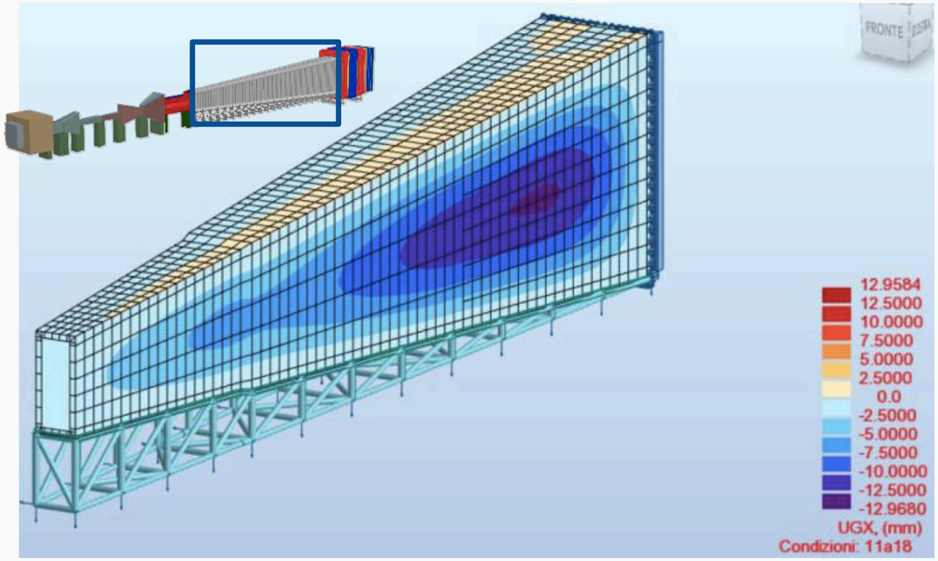
HS Decay Volume& Background Tagger

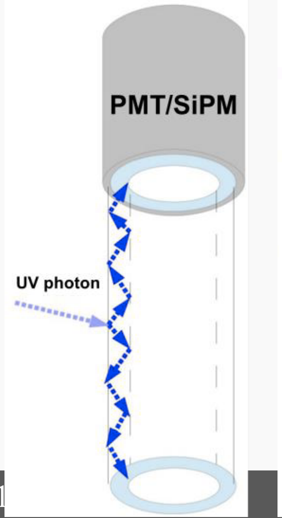
Purpose: Tagging charged particles entering decay volume and tagging ν *and* μ interactions in the vacuum chamber walls.

Air: 2.5×10^3 candidates with small impact parameter to the target→Pump down to vessel pressure: ~10^{-3} bar

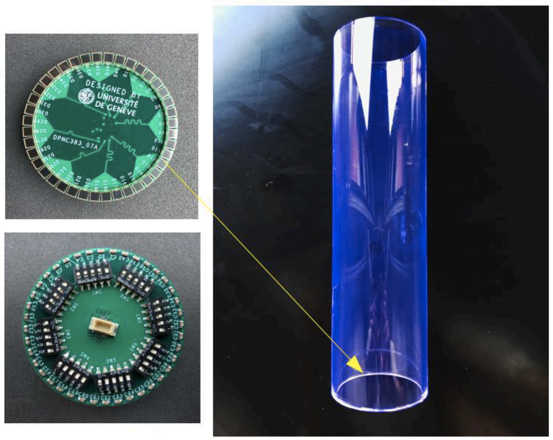
Vacuum Vessel

- 50 m pyramidal frustrum
- Walls thickness: 8 mm (Al) / 30 mm (SS)
- Walls separation: 300 mm
- Liquid scintillator (LS) volume (250 -300 m^3) readout by Wavelength Shifting Optical Modules (WOM) and PMTs
- Vessel weight ~ 480 t

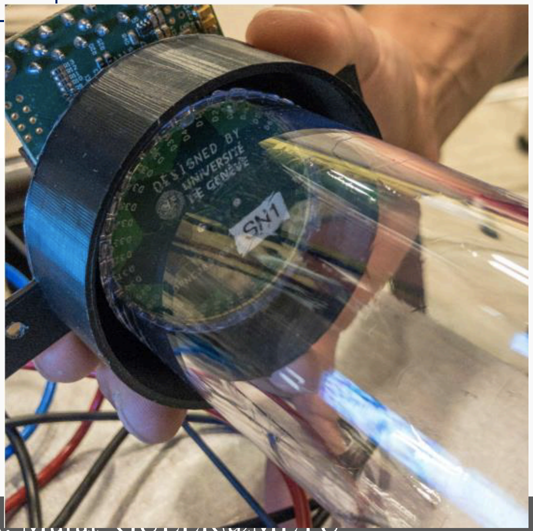


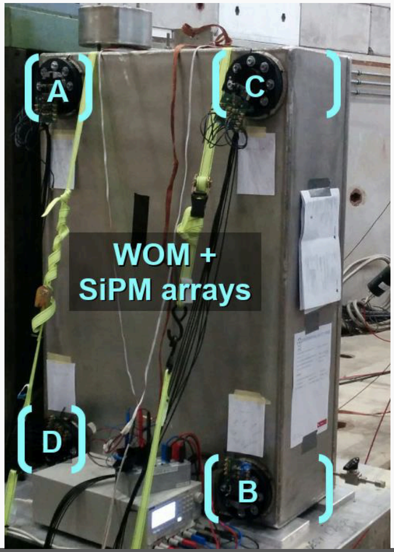


WOM w/o lightguide



40-SiPMs array built by Geneva

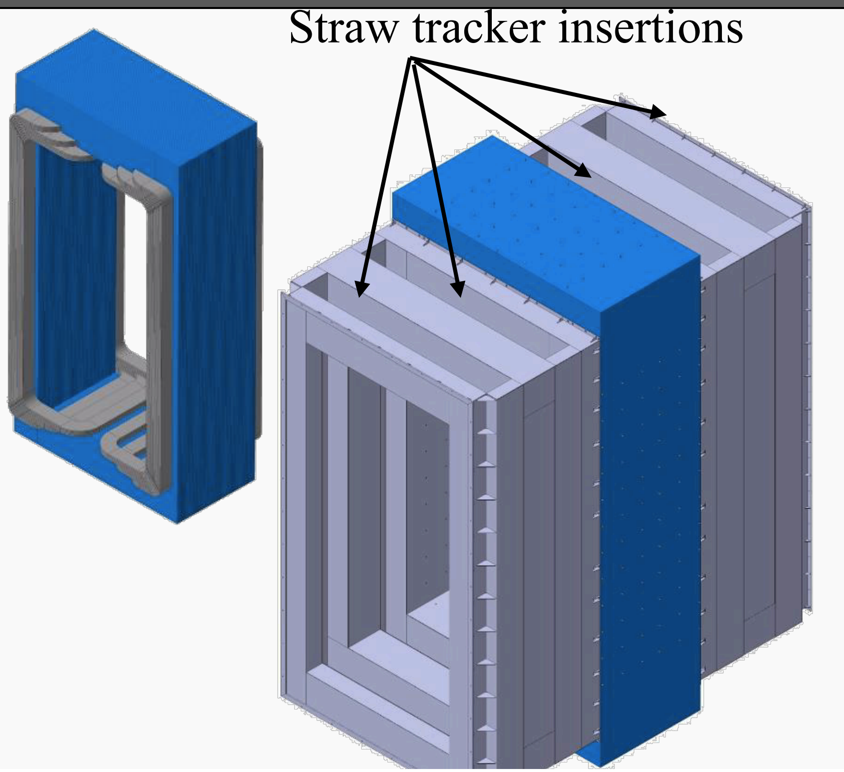


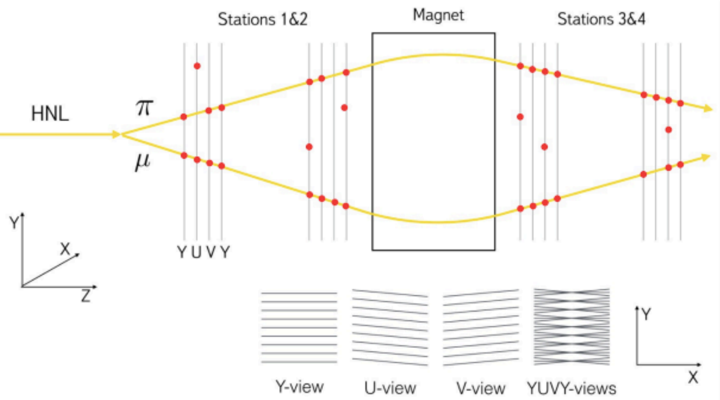


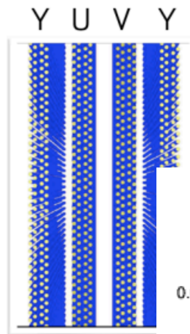
HS Spectrometer

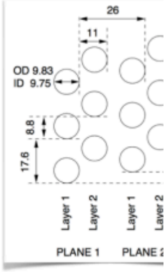
Purpose: Track reconstruction and momentum, reconstruction of origin of neutral particle candidate

- Fiducial rectangular aperture 5x10 m^2 →Horizantal field
- Position resolution 120 μm per straw, 8 hits per station on average

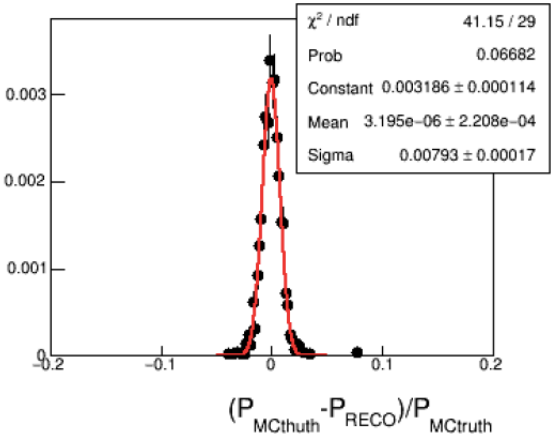

Straw tracker insertions

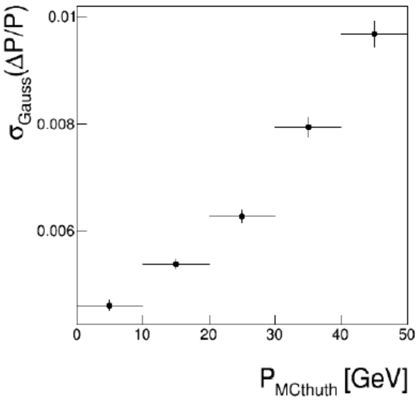






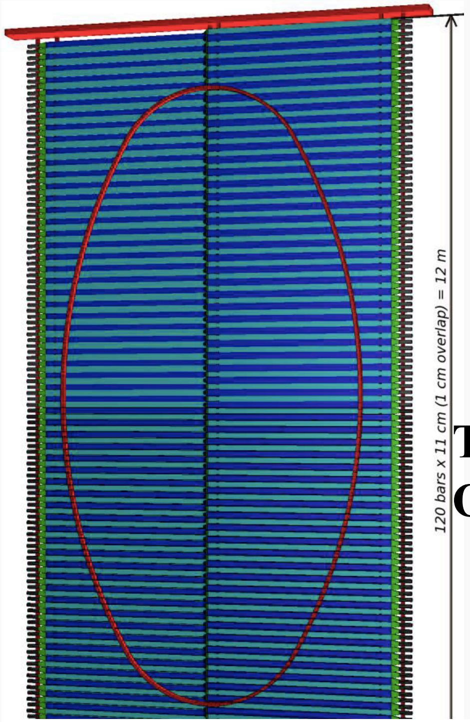
- 2 stations before and after the magnet
- 4 views in each station: 2 Y-views and 2 Stereo-views
- 4 straw tube layers in each view
- $\pm 5^o$ between Y and Stereo views





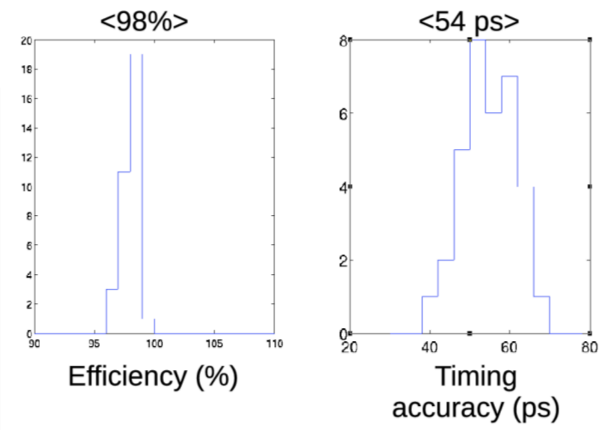
Timing Detector

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



Two Options

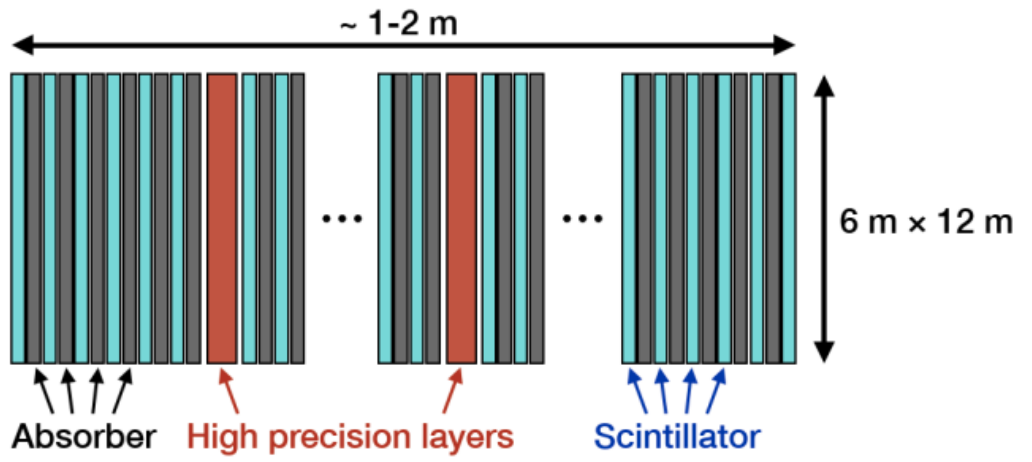
- <u>Multi-gap resistive plate chambers (MRPC)</u>
  - Multi-gap RPC structure : six gas gaps defined by seven 1 mm thick float glass electrodes of about 1550x1250 mm^2 seperated by 0.3 mm nylon mono-filaments.
  - Two identical sensitive modules sandwiched with a plane of pick-up electrodes, consisting of 1600x30 mm^2 Cu strips.
  - Resolution demonstrated to be about 80 ps along the whole length of the bar and over 2 m^2 prototype
- <u>Scintillator bars</u>
  - Three-column with EJ200 plastic bars of 168 cm x 6 cm x 1cm, providing 0.5 cm overlap.
  - Readouts on both ends by array of 8 6x6 mm^2 SiPMs
  - Resolution demonstrated to be demonstrated ~80 ps along the whole length whole length of bar and over $2m^2$ prototype

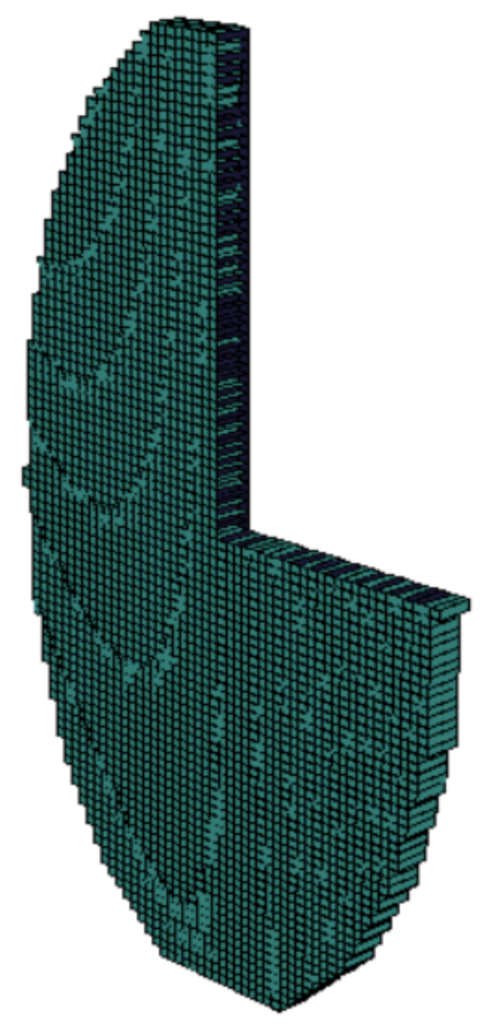


HS ECAL

Purpose: e/γ identification, π^0 reconstruction, photon directionality for ALPS→ $\gamma\gamma$

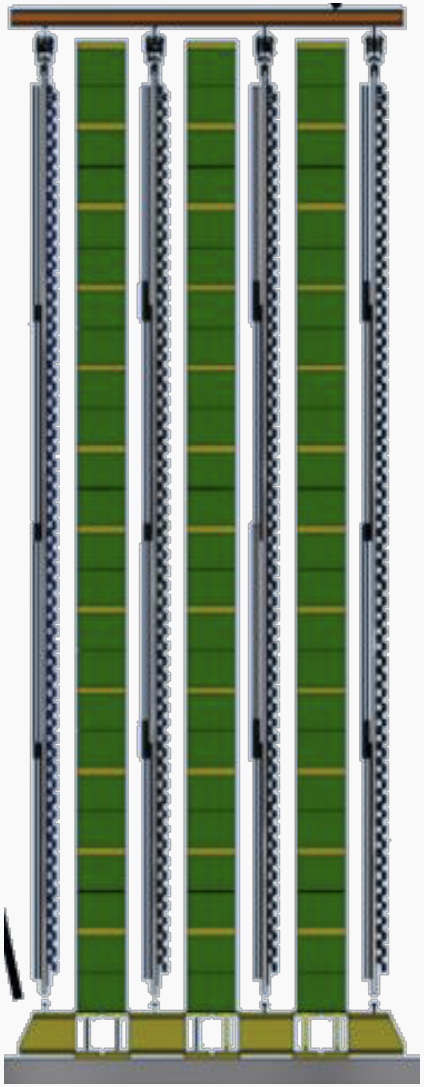
- 25 X_0 longitudially segmented calorimeter with coarse and fine space resolution active layers
- Coarse layers: 40-50 planes of scintillating bar readout by WLS + SiPM
- Fine resolution layers: 3 layers (1.12 cm thick), to provide photon angular resolution of a few mrad.





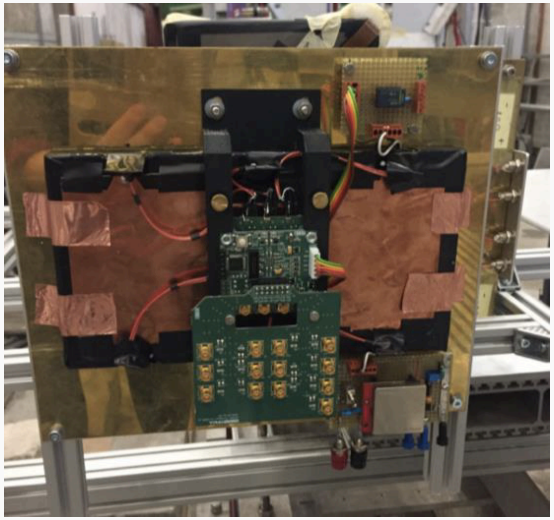
HS Muon System

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

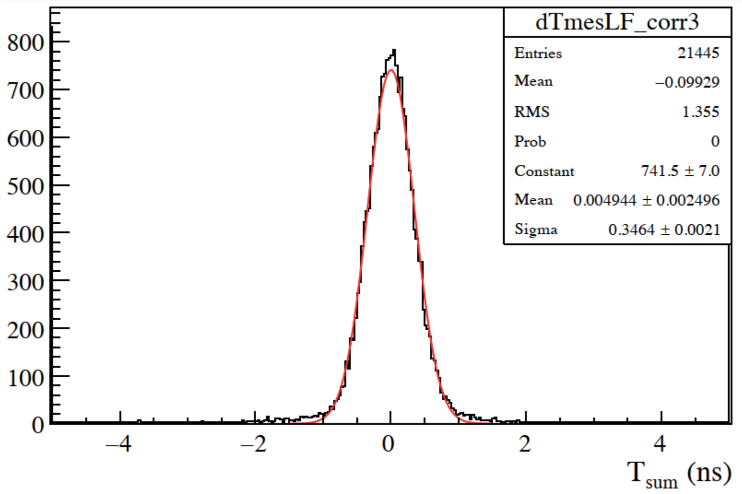


- Three stations with sensitive area of 6x12 m^2
- Calorimeter equivalent to 6.7 λ (P_μ> 2.6 GeV/c)
- Muon filters of 60 cm + 10 cm shielding behind last section
- Baseline scintillating tiles 10x20 cm^2 with SiPM (6 SiPM 4x4 mm^2) readout 3200 channels/station.

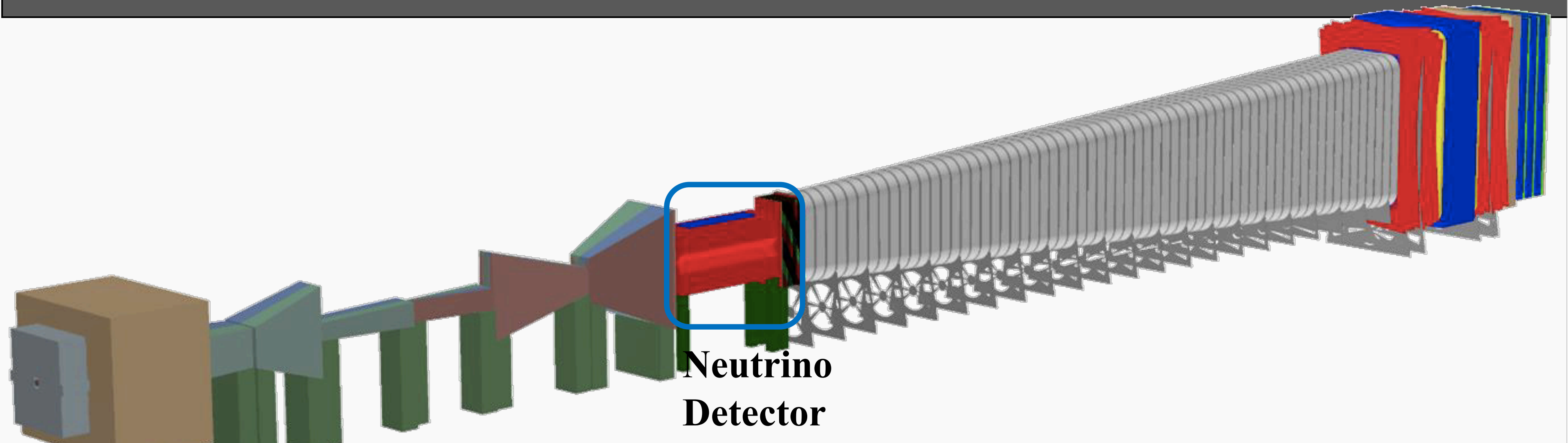
Scintillating tile prototype in PS test beam

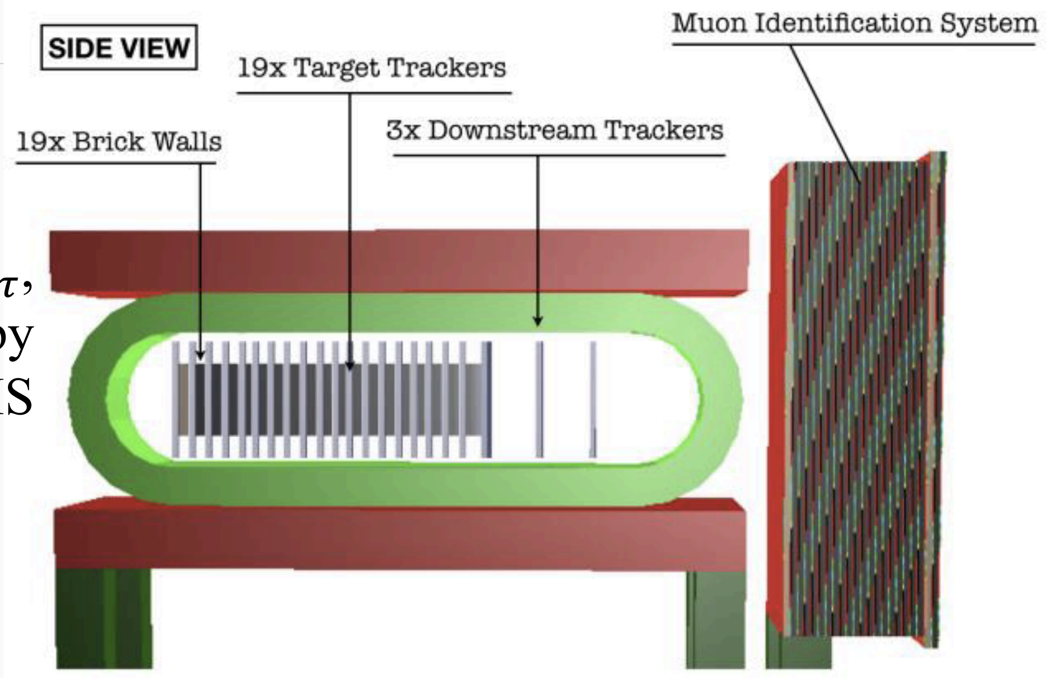


Time resolution of ~340 ps measured in test beam



Neutrino Detector

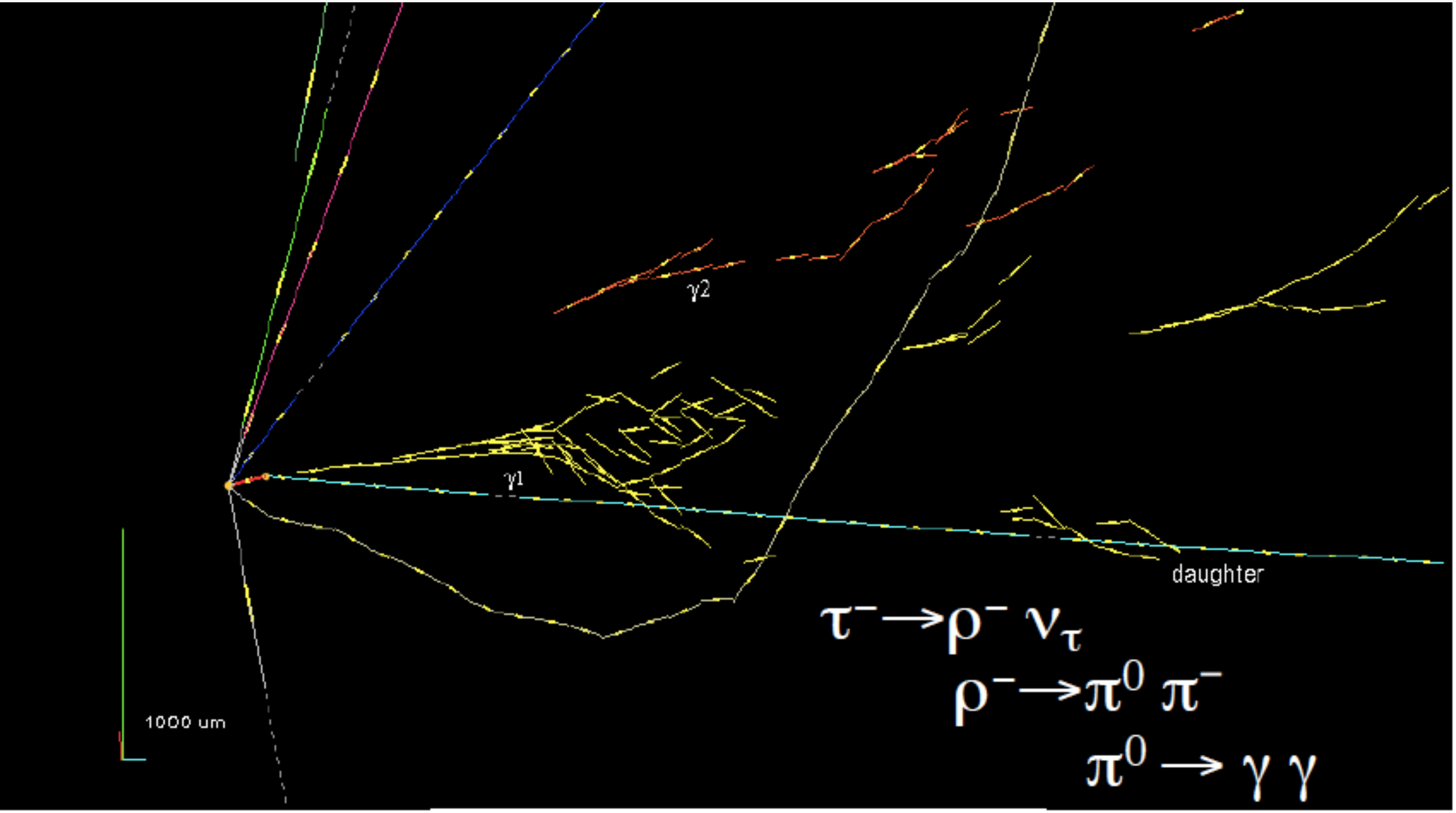




- Studying interactions neutrino of υ_τ, charm production induced by neutrinos, and normalisation of HS yield & LDM search

Design Concept of Neutrino Detector

Design: OPERA Concept: ECC & ED



Discovery of tau neutrino apperarance in a muon neutrino beam PRL 120 (2018) 2011801

Neutrino Detector

Neutrino Detection

Muon momentum measurement

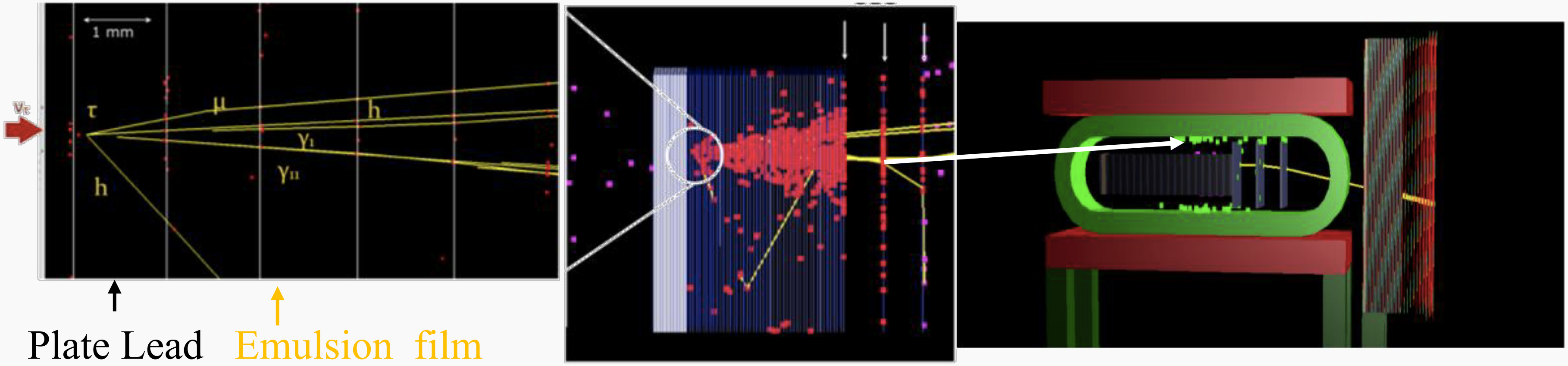
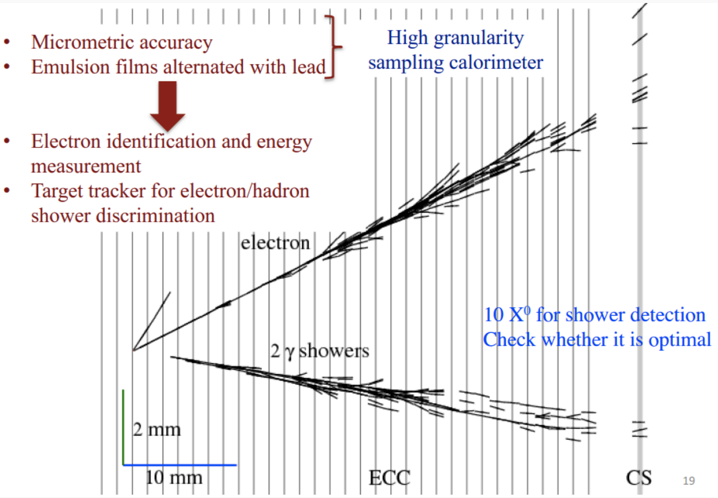


Plate Lead Emulsion film

LDM Detection

Detection of electromagnetic shower and reconstruction origin by electronic target tracker

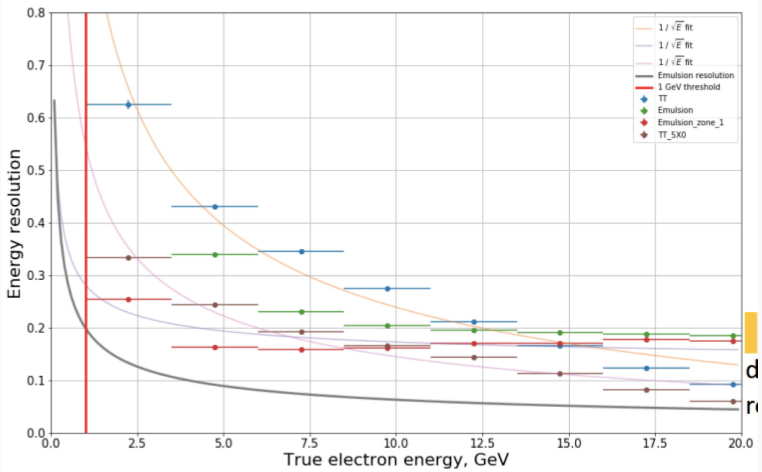


- Micrometric accuracy
- Emulsion films alternated with lead

High granularity sampling calorimeter

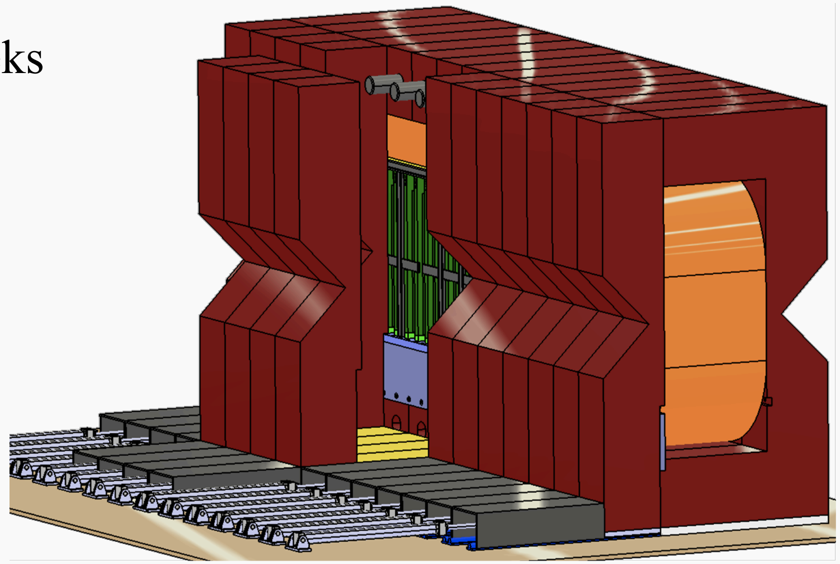
- Electron identification and energy measurement
- Target tracker for electron/hadron shower discrimination

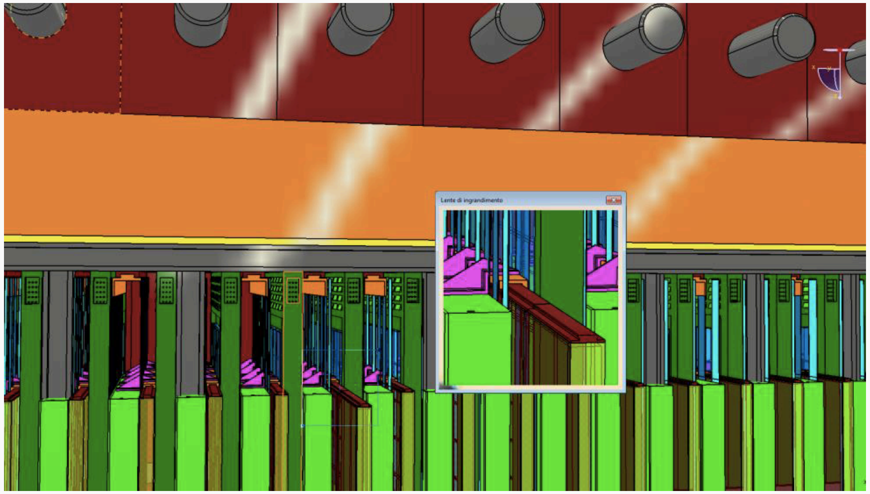
$10\ X^0$ for shower detection
Check whether it is optimal



Neutrino Detector Magnet

- Overall external size 7.2 x 3.6 x 2.2 m^3, weight 300t
- Detector volume 5.6 x 1.6 x 1m^3
- Horizantal field ~1.2 T, 1.5-2 MW
- To respect emulsion limit of 103 tracks/mm^2, replacement every 6 months, CES every few weeks



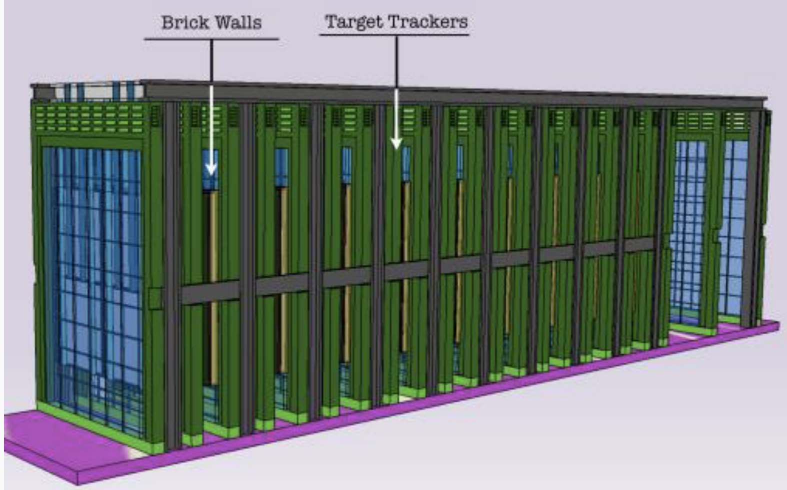


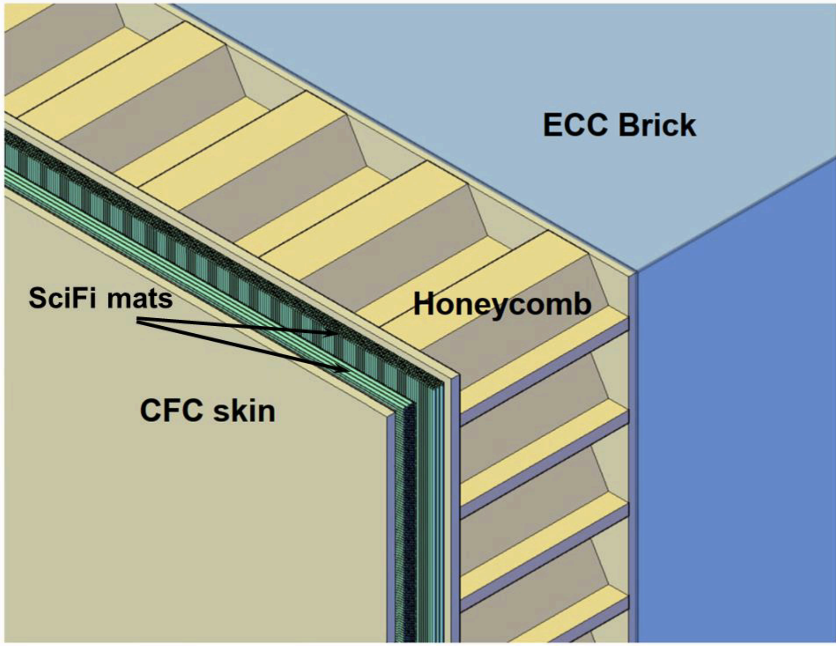
- Superconducting option being investigated

Neutrino Target & Target Tracker

- Target ECC
  - 4 bricks of 40x40 cm^2
  - Thickness~8 cm (57 films/lead plates ~10 X_0)
  - Weight ~100 kg
  - Total 730 m^2 of films x 10 replacements
  - Scanning speed 200 cm^2/h

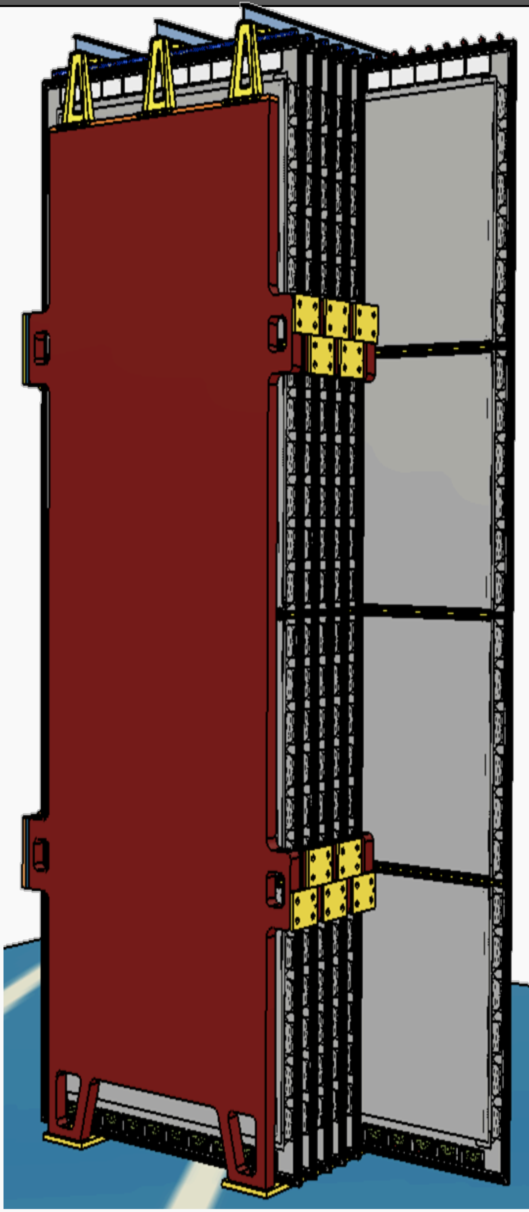
- SciFi target Tracker
  - $\sigma_{x,y}$ ~ 30-50 μm resolution
  - Six scintillating fibre layers, total 3mm thickness ~ 0.05X_0
  - Multi-channel SiPM at one end, ESR foils as mirrors on other
  - Time resolution < 0.5 ns
- Detection combination combination provides a total charge identification efficiency of ~65% for muons produced in ν_μ CC interactions.

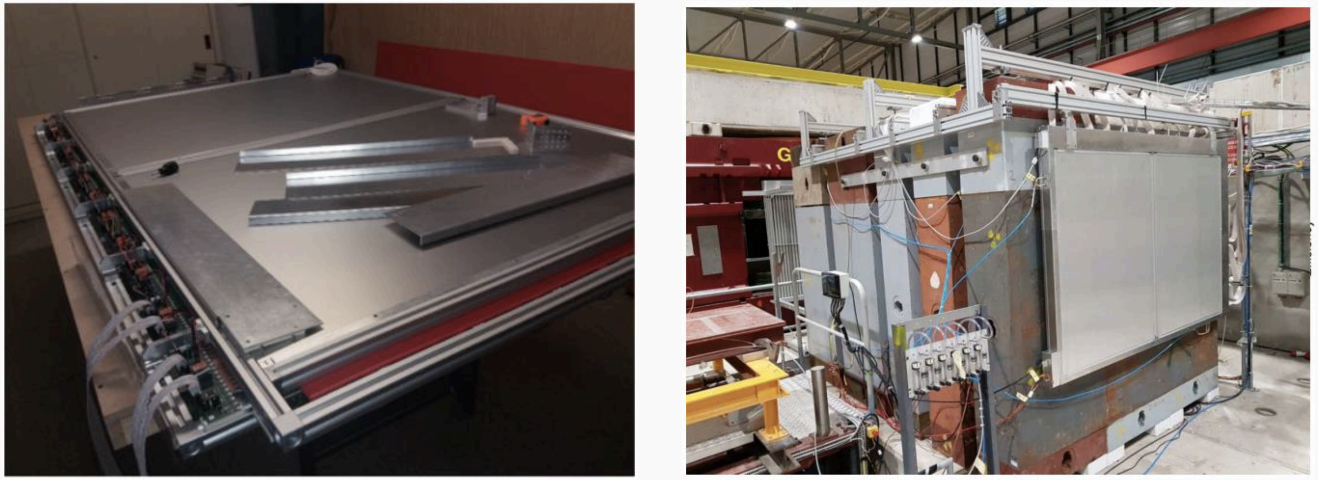




Neutrino Detector Muon System

- Purpose: track and identify muons, and tag ineractions(ν,μ) in the last layers before entrance window to HS decay volüme
  - 15 iron filters, 10 cm thick
  - 13 RPC, and 3 MRPC layers
  - Sensitive area of ~2x5 m^2
  - RPCs operated in avalanche mode due to high rate of muons
  - Geometrical aceptance ~75 % and $\varepsilon_{\mu ID}$ = 96.7 % with a miss-identification of hadrons of 1.5 %.

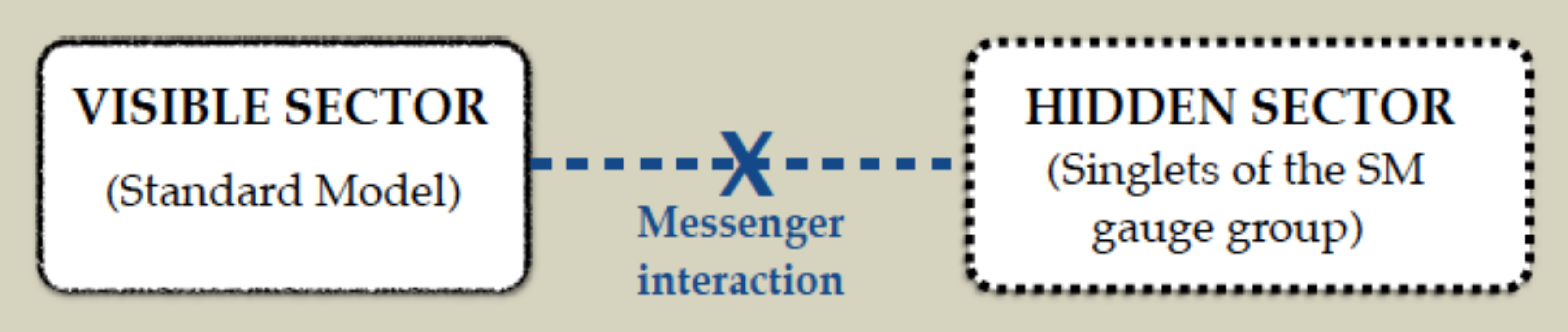




RPC prototypes built for muon flux and charm production

Search for Hidden Sector

- Rather than being heavy, could new particles be light but very weakly interacting?
- Portals : possible interactions between new physics (hidden sector) and the SM particles.



i) Neutrino portal ii)Scalar portal iii) Vector portal iv)Axion portal

- Large number of models investigated.
- Tau Neutrino Physics.

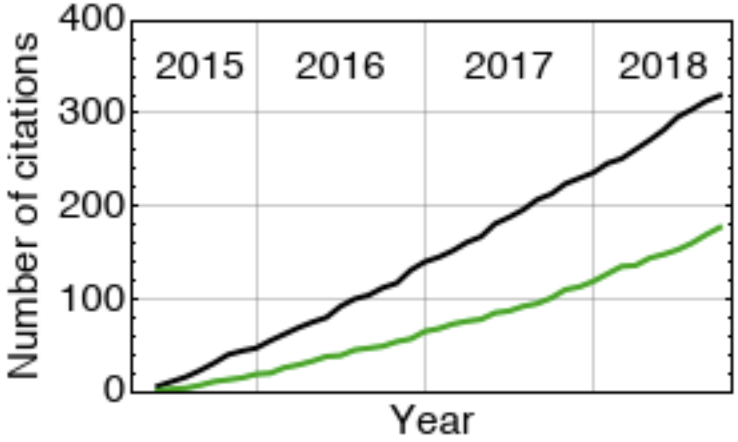
Physics Program

http://arxiv.org/abs/1504.04855

85 theorists
200 pages

A facility to search for hidden particles (SHiP) at the SPS: the physics case

Contents



1 **Introduction**

2 **Vector portal**
  2.1 Classification of vecto
    2.1.1 Kinetic mixing
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3 **Scalar portal**
  3.1 The scalar sector of the Standard Model and Beyond
    3.1.1 Scalar portal effective Lagrangian
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4 **Neutrino portal**
  4.1 Heavy neutral leptons
  4.2 Active neutrino phenomenology
    4.2.1 Three-flavour neutrino oscillations. A theoretical overview
    4.2.2 Present experimental status of neutrino masses and mixings
    4.2.3 Short-Baseline neutrino anomalies
    4.2.4 Future neutrino experiments

other PNGBs) at SHiP
nd why they are interesting
ALP origins
Connection to Dark Matter
ions, phenomenological features and existing limits
oupled to two gauge bosons

ion
ight Supersymmetric Neutralino and R-Parity Violation
otivation for a very light neutralino
-parity Violation
    6.2.3 Finding Neutralinos at SHiP via R–Parity violation

7 **Tau neutrino physics**
  7.1 Physics case
    7.1.1 Tau neutrino physics
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    7.1.4 Tau neutrino magnetic moment

8 **Searches of lepton flavour violating processes $\tau \to 3\mu$**
  8.1 Motivation as a null-test of the standard model
  8.2 $\tau \to 3\mu$ in seesaw scenarios
  8.3 Supersymmetric models

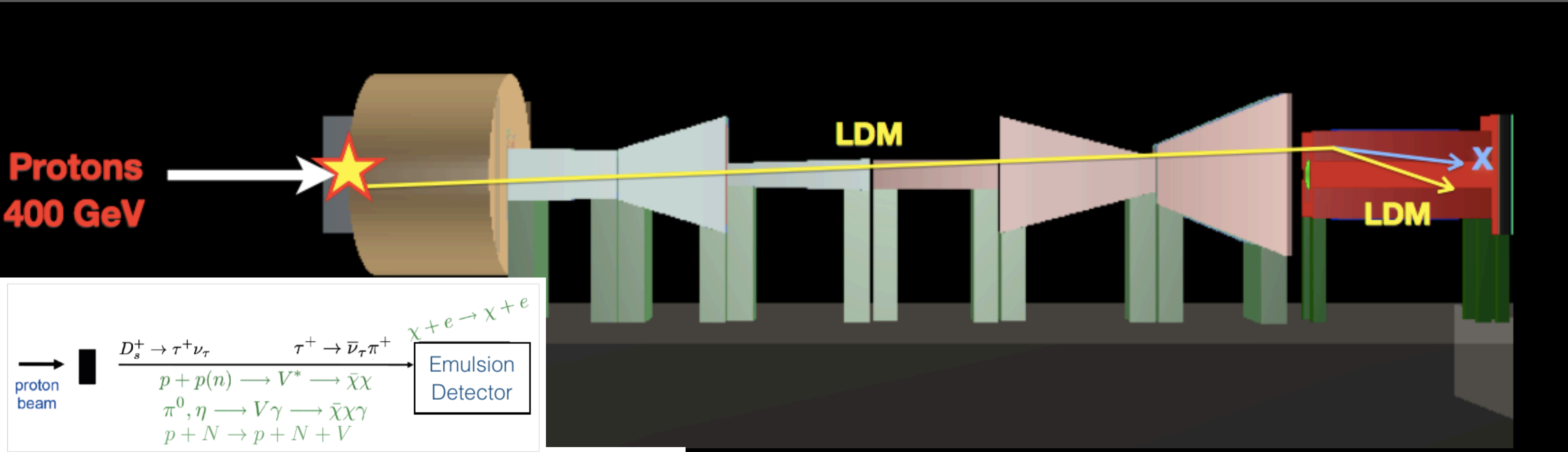
Physics Goals

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

Models tested	Final states
Neutrino portal, SUSY neutralino	$l\pi$, lK, $l\rho$ ($l=e,\mu,\nu$) ($\rho^+ \rightarrow \pi^+\pi^0$)
Vector, scalar, axion portals, SUSY sgoldstino	e^+e^-, $\mu^+\mu^-$
Vector, scalar, axion portals, SUSY sgoldstino	$\pi^+\pi^-$, K^+K^-
Neutrino portal, SUSY neutralino, axino	$l^+ l^- \nu$
Axion portal, SUSY sgoldstino	$\gamma\gamma$
SUSY sgoldstino	$\pi^0 \pi^0$

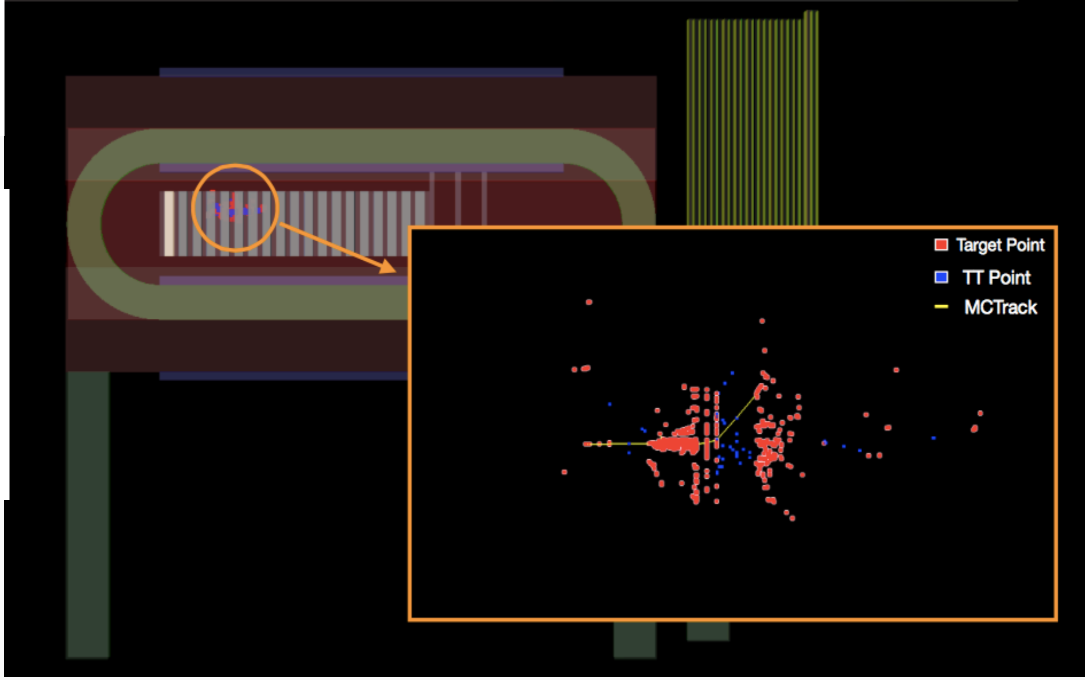
- Production and decay rates are strongly suppressed relative to SM.
  - Production branching ratios $O(10^{-10})$.
  - Long-lived objects.
  - Travel unperturbed through ordinary matter.

LDM Production and Detection

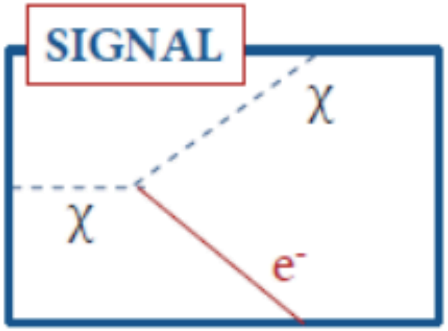


- Production:
  - Decay or mixing of a dark boson

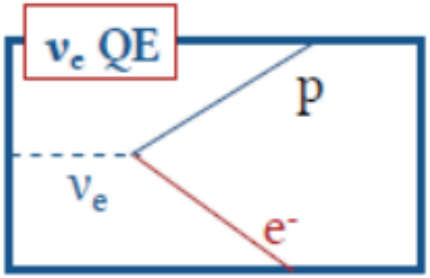
- Detection
  - Elastic scattering on electrons from atoms
  - **Electrons have high energy and emitted in forward direction**

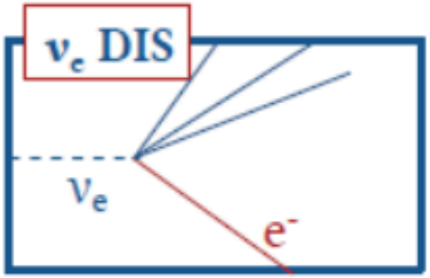


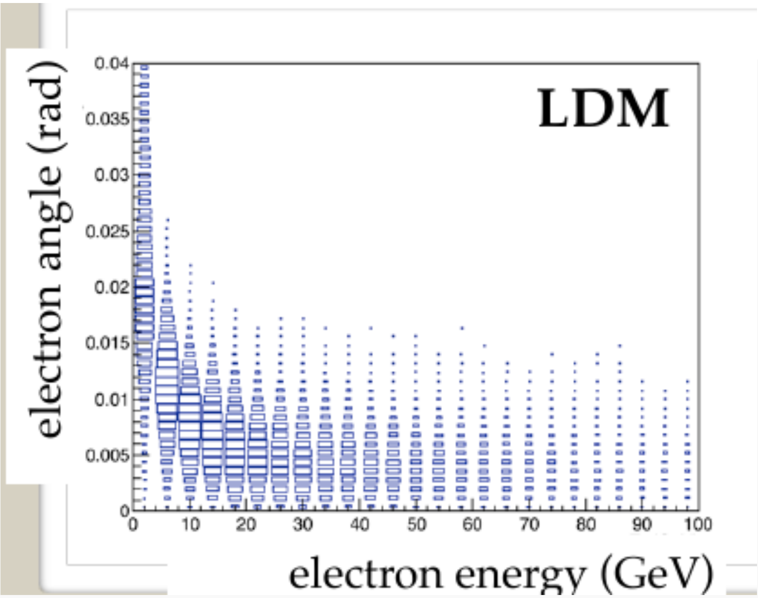
LDM Production and Detection

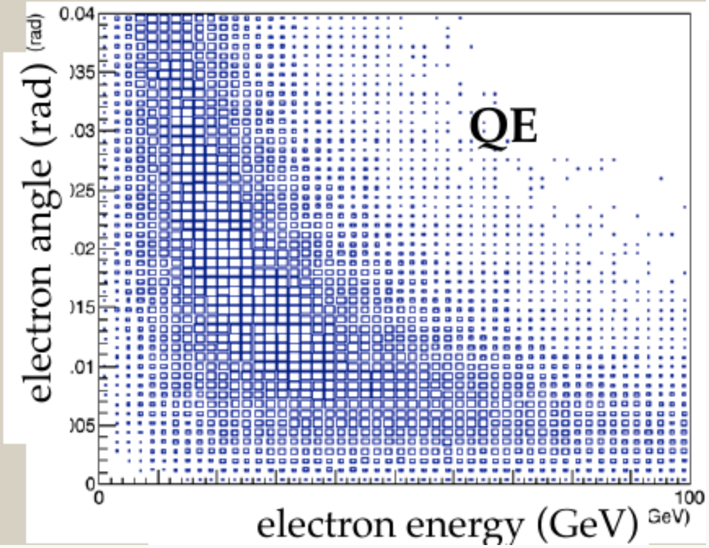


Dominant background





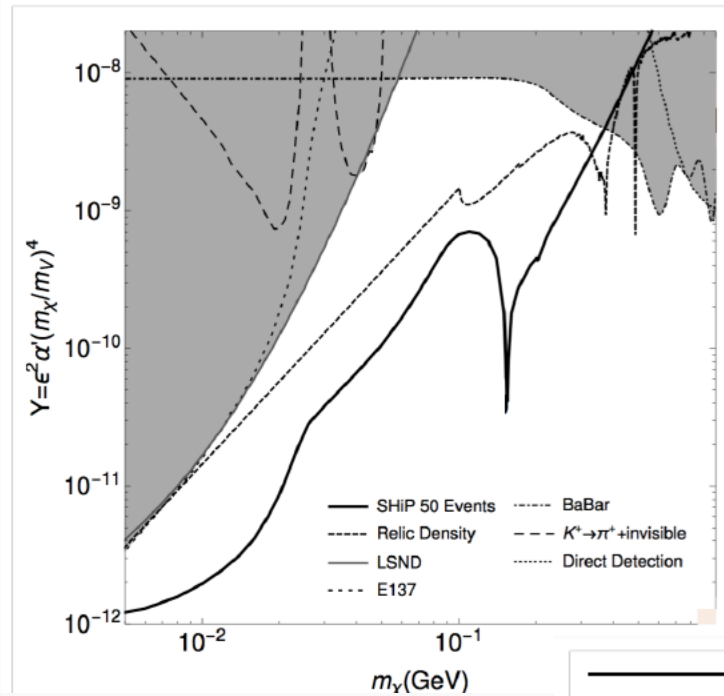




BG rejection:

- Energy-angle correlation and presence of proton rejects QE
- Presence of an hadronic jet rejects DIS

LDM Sensitivity

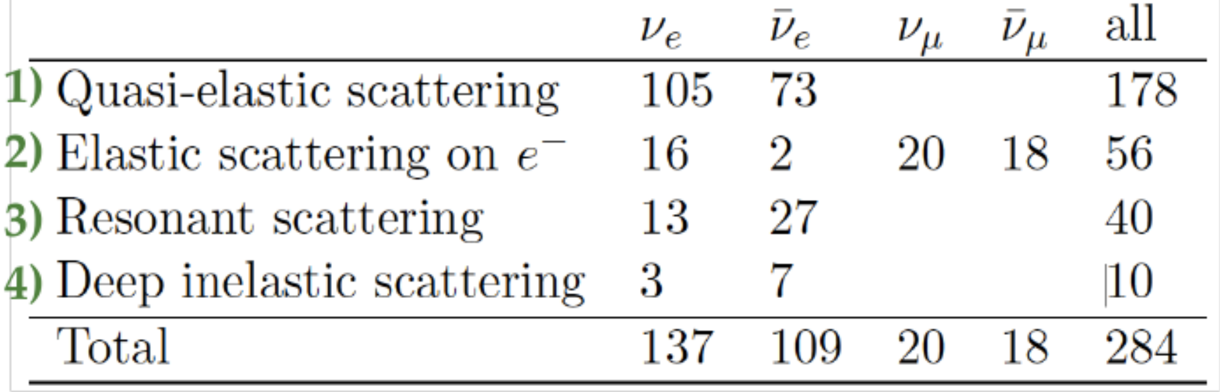


Assumptions

- 10 tons of lead & 2x10^{20} p.o.t

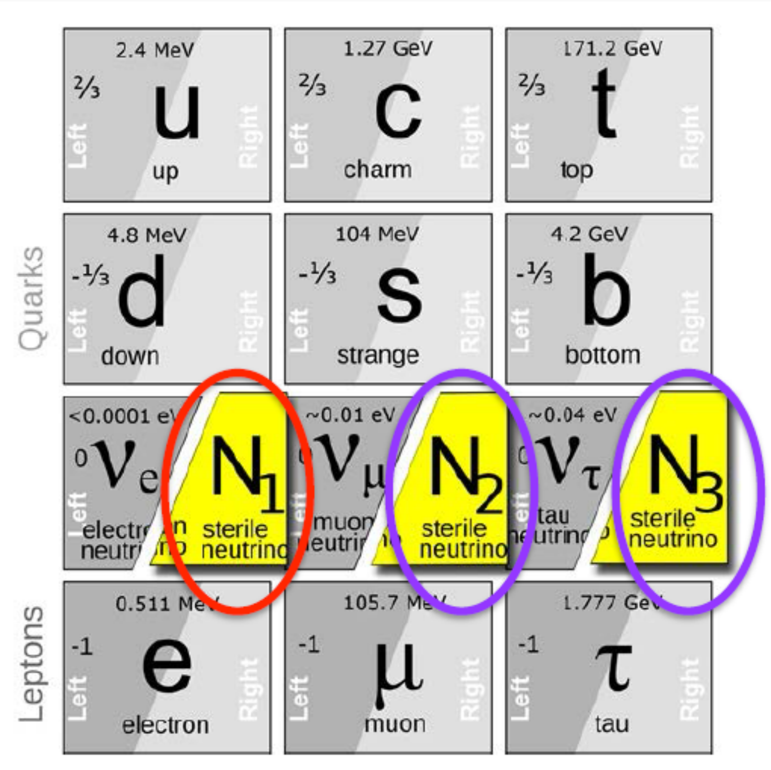
Signal Selection

- Electron angle [10,20] mrad
- Electron energy <20 GeV



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

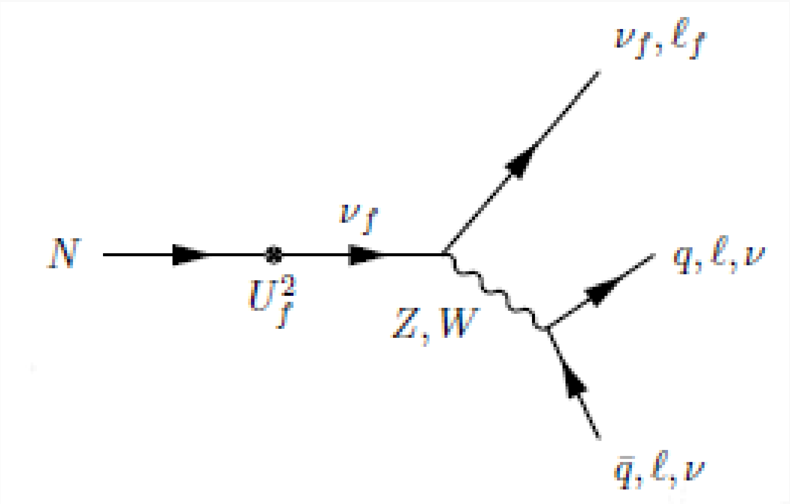
Neutrino Portal



The neutrino Minimal Standard Model (υMSM) aims to explain.

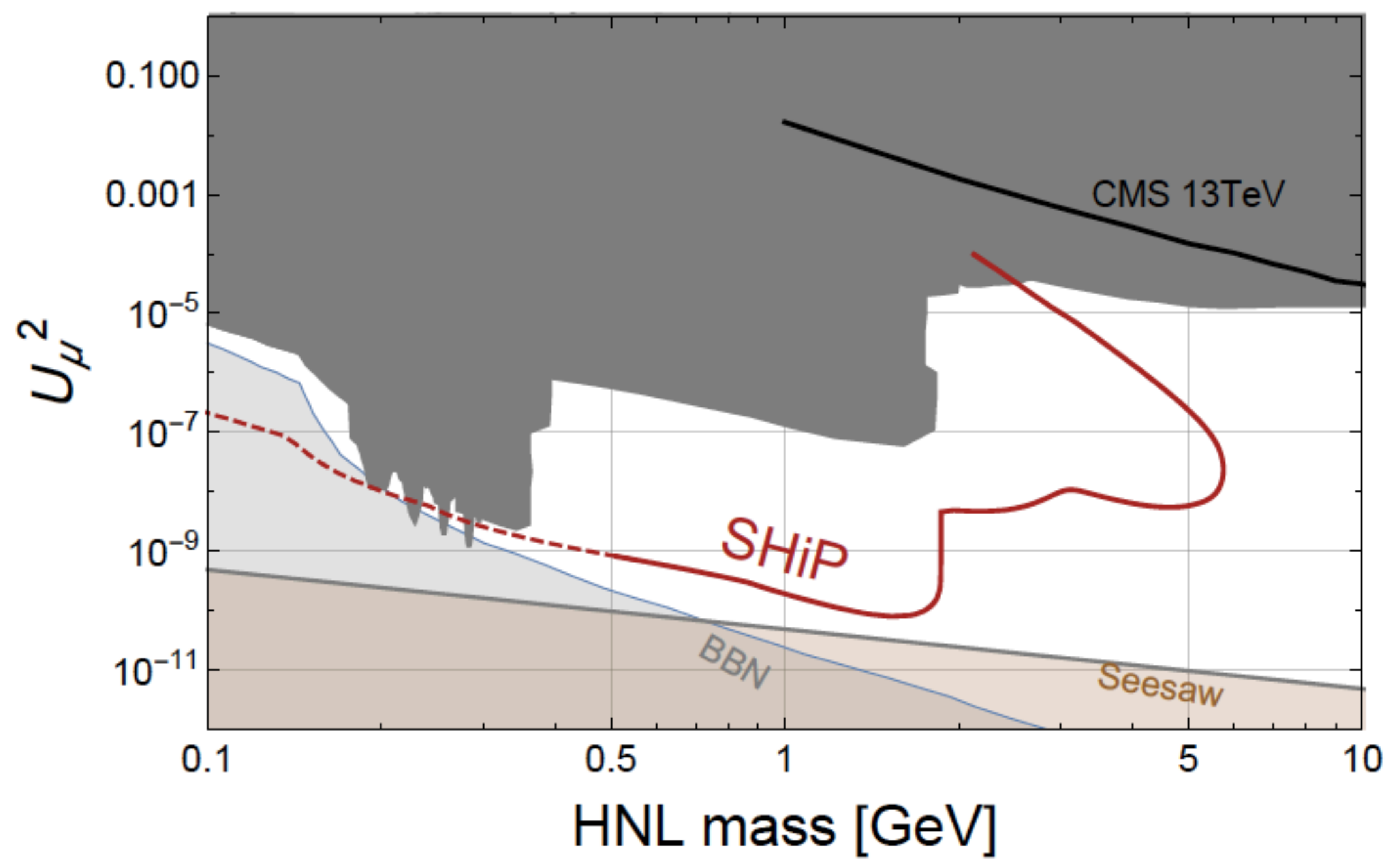
T. Asaka, M. Shaposhnikov PLB620 (2005), 17.

- Matter anti-matter asymmetry in the Universe, neutrino masses and oscillations, non-baryonic dark matter.
- Adds three right-handed, Majorana, Heavy Neutral Leptons (HNL), N1, N2 and N3.



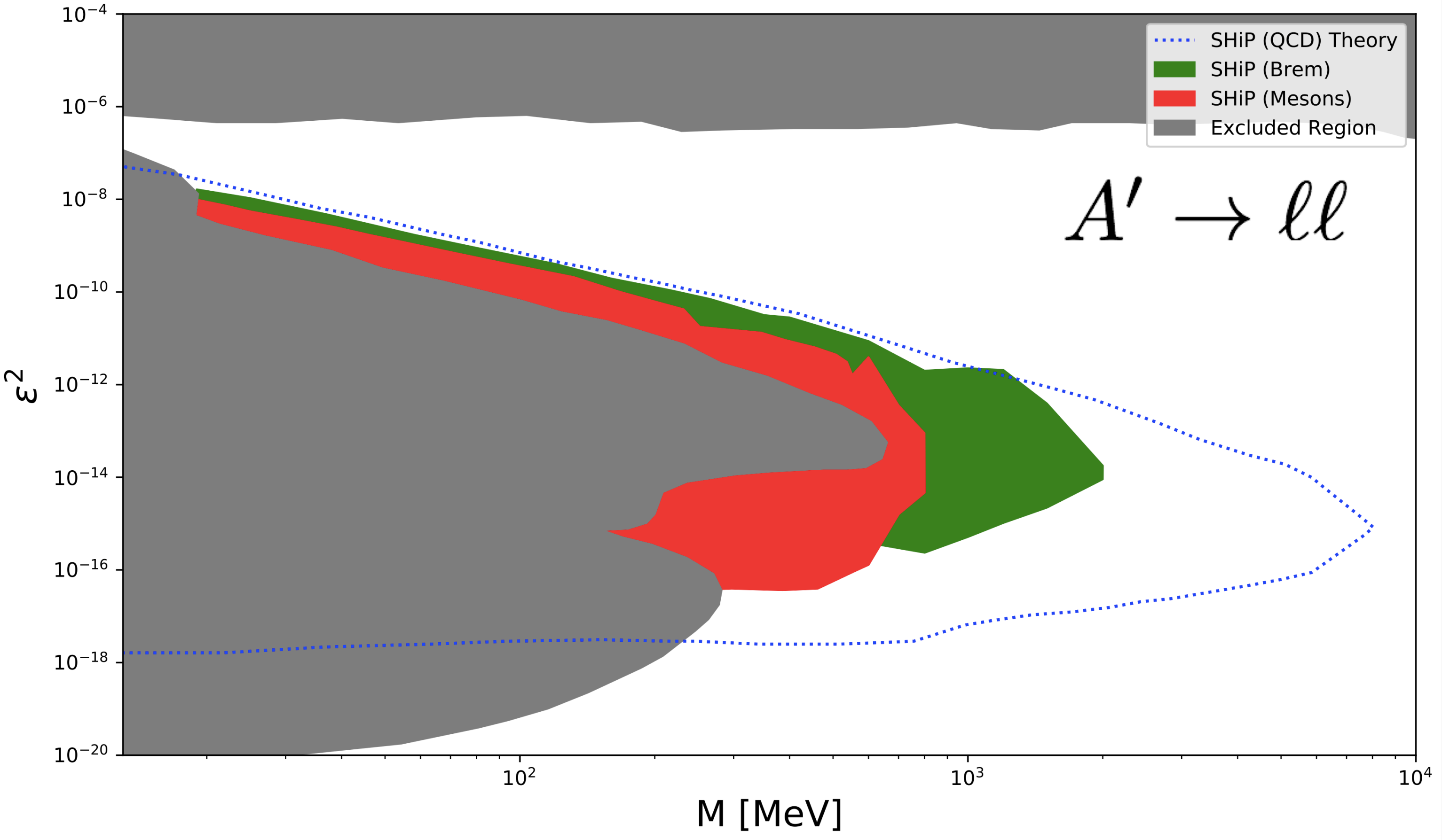
- N1 is a dark matter candidate (m≈ O(1) keV).
- N2, N3 give masses to neutrinos and produce baryon asymmetry of the Universe (m≈ O(100) MeV-GeV)

HNL Sensitivity



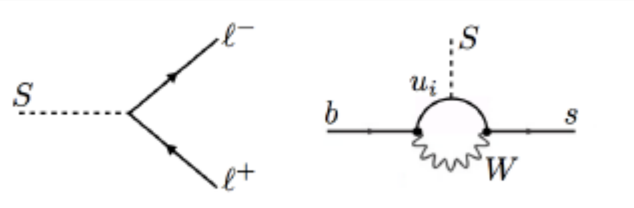
SHiP Sensitivity to Dark Photons

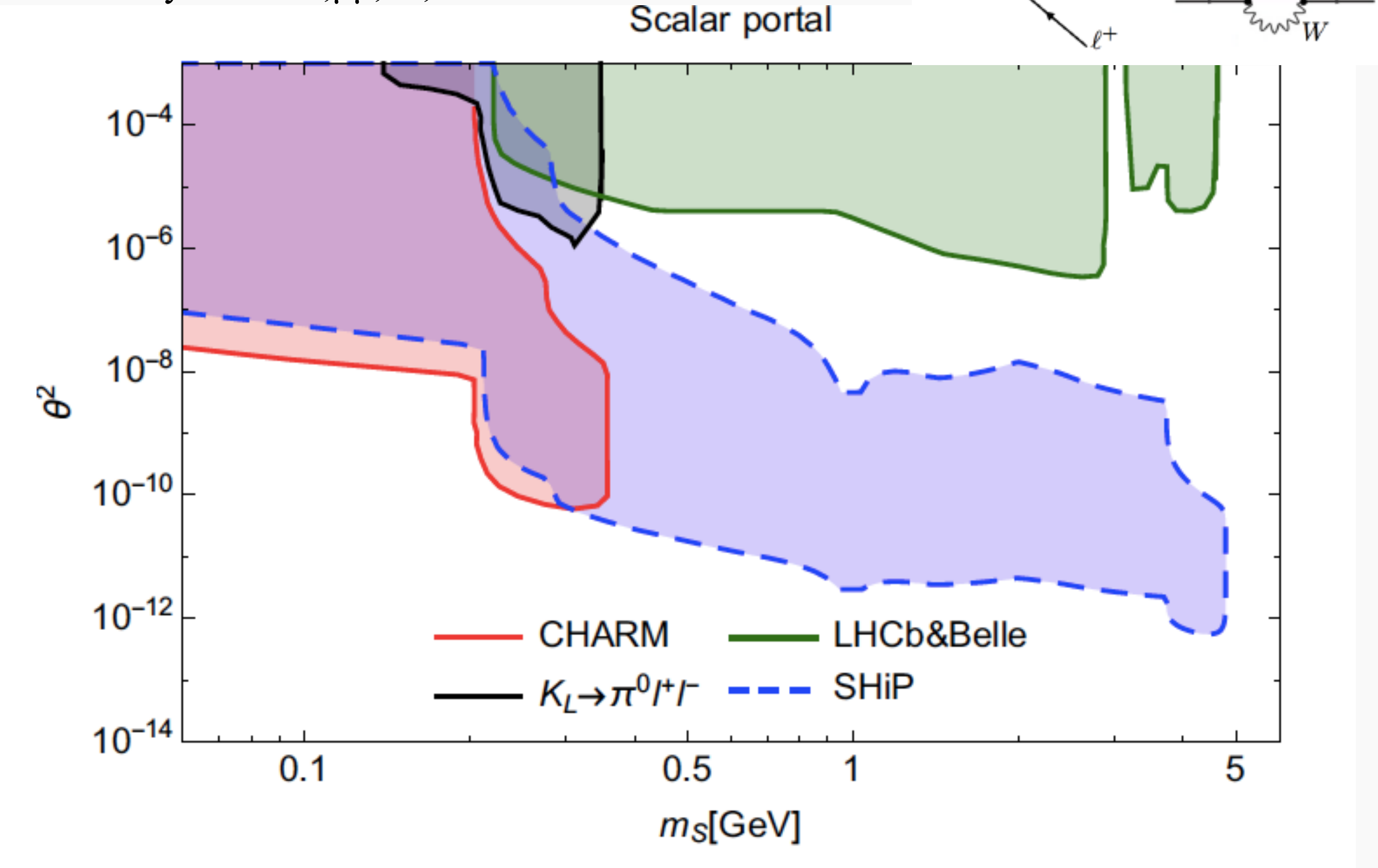
1)Meson decays
2)Bremsstrahlung (pp→ppV)
3)QCD (q+q →V ; q+g →q+V)



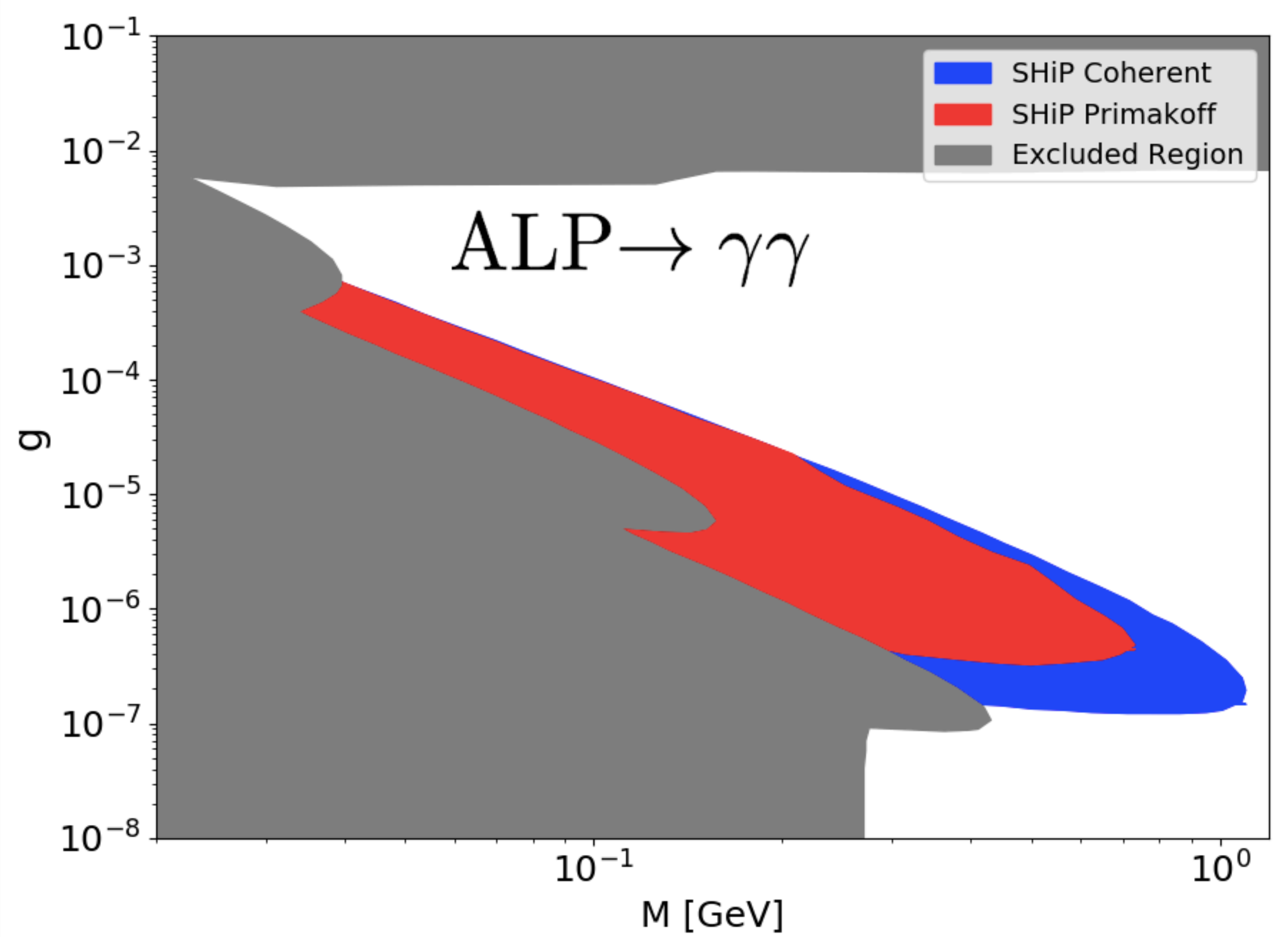
SHiP Sensitvity to Dark Scalars

- S production: from B, D and K decays
- S decays : S→ee,μμ,ππ, KK



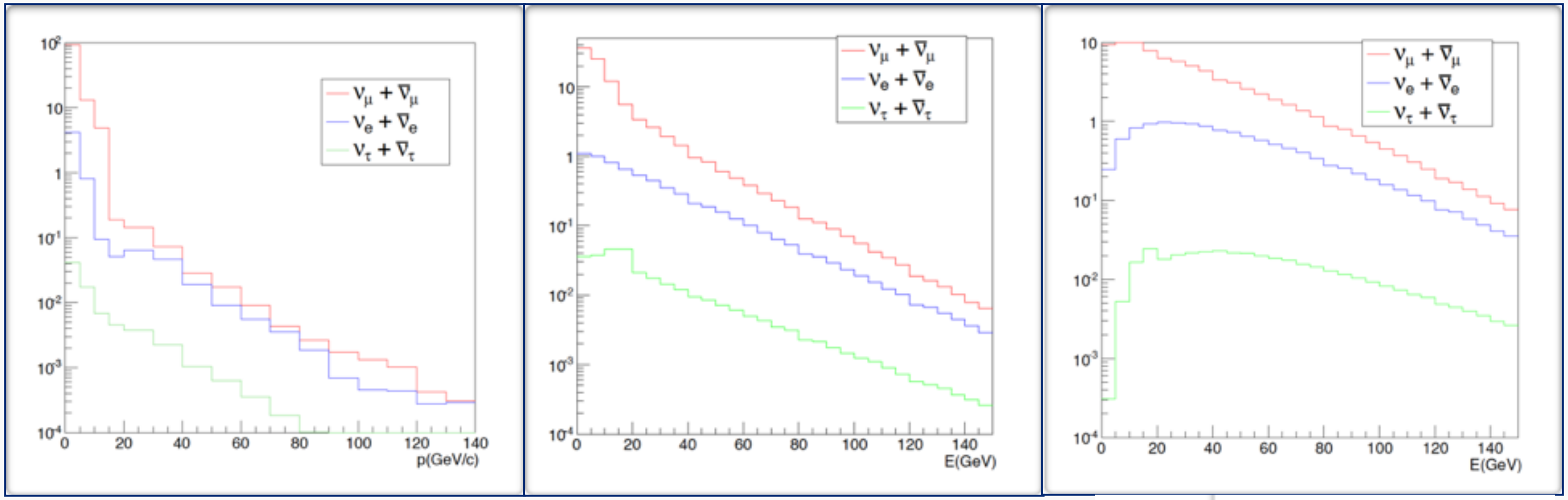


SHiP Sensitvity to Axion-Like Particles



SHiP Neutrino Program

- SHiP setup ideally suited to study neutrino and anti-neutrino physics for all three active flavours.
- High charmed hadrons production rates ⇒ high neutrino fluxes from their decays, including remnant pion and kaon decays.



	<E> (GeV)	Beam dump
N_{ν_μ}	1.4	4.4×10^{18}
N_{ν_e}	3	2.1×10^{17}
N_{ν_τ}	9	2.8×10^{15}
$N_{\bar{\nu}_\mu}$	1.5	2.8×10^{18}
$N_{\bar{\nu}_e}$	4	1.6×10^{17}
$N_{\bar{\nu}_\tau}$	8	2.8×10^{15}

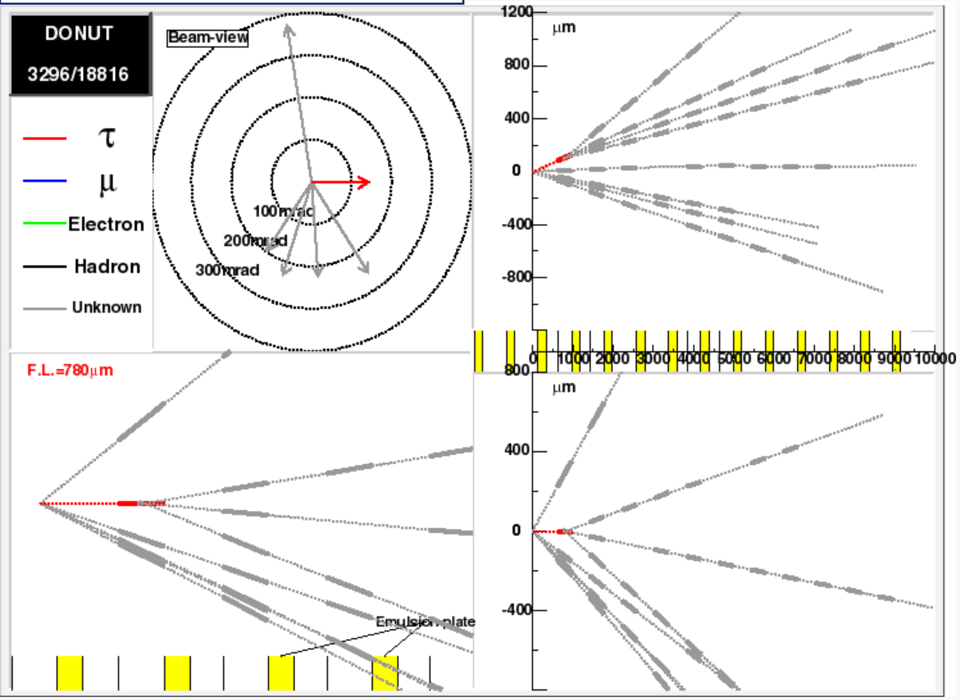
	<E> (GeV)	Neutrino target
N_{ν_μ}	8	5.2×10^{16}
N_{ν_e}	28	3.6×10^{15}
N_{ν_τ}	28	1.4×10^{14}
$N_{\bar{\nu}_\mu}$	8	4.0×10^{16}
$N_{\bar{\nu}_e}$	27	2.7×10^{15}
$N_{\bar{\nu}_\tau}$	26	1.4×10^{14}

	<E> (GeV)	CC DIS interactions
N_{ν_μ}	29	1.7×10^{6}
N_{ν_e}	46	2.5×10^{5}
N_{ν_τ}	59	6.7×10^{3}
$N_{\bar{\nu}_\mu}$	28	6.7×10^{5}
$N_{\bar{\nu}_e}$	46	9.0×10^{4}
$N_{\bar{\nu}_\tau}$	58	3.4×10^{3}

Tau Neutrino Physics

- Less known particle in the Standard Model
  - First observation by DONUT at Fermilab in 2001 *Phys. Lett. B504 (2001) 218-224.*

DONUT ν_τ Candidate



- 9 events (with an estimated background of 1.5) reported in 2008 with looser cuts.

$$\sigma(\nu_\tau) = \sigma^{const}\, EK(E)$$

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

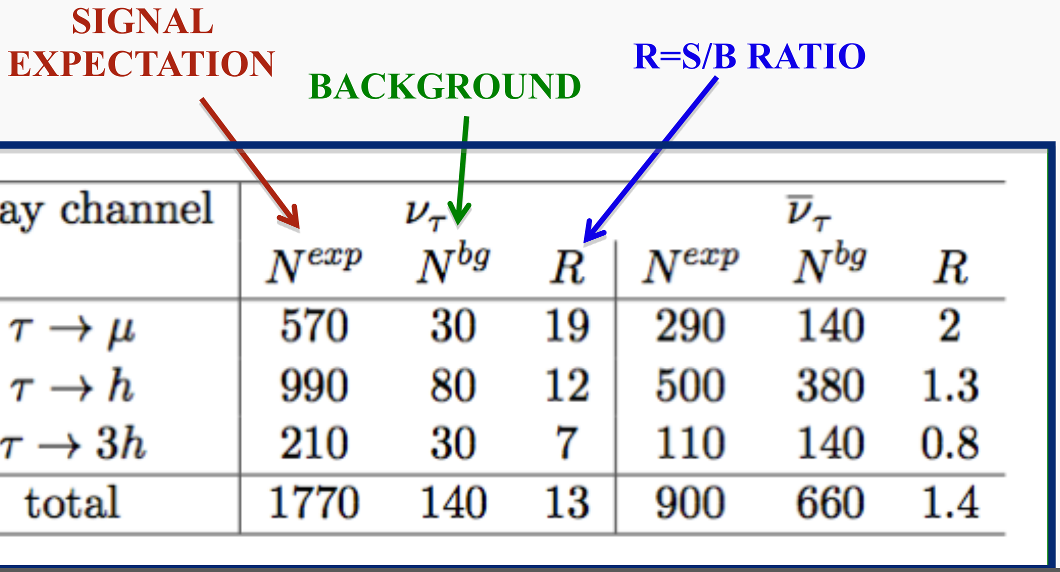
(K(E) describes the kinematical suppression due to the tau mass)

Tau Neutrino Physics

- Number of υ_τ and anti-υ_τ produced in the beam dump.

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

- Main background in υ_τ and anti-υ_τ searches is the charm production in υ_μCC (anti-υ_μCC) and υ_eCC (anti-υ_eCC) interactions, when the primary lepton is not identified.



SIGNAL EXPECTATION

BACKGROUND

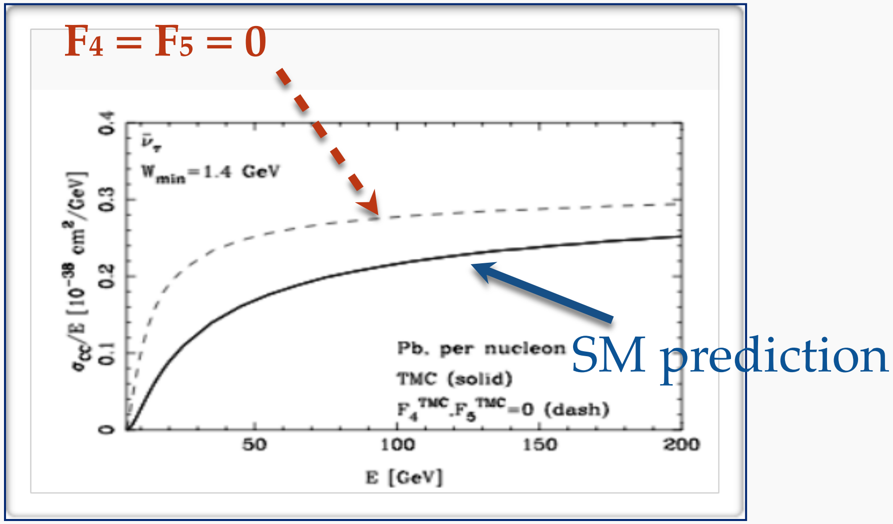
R=S/B RATIO

decay channel	ν_τ			$\bar{\nu}_\tau$		
	N^{exp}	N^{bg}	R	N^{exp}	N^{bg}	R
$\tau \to \mu$	570	30	19	290	140	2
$\tau \to h$	990	80	12	500	380	1.3
$\tau \to 3h$	210	30	7	110	140	0.8
total	1770	140	13	900	660	1.4

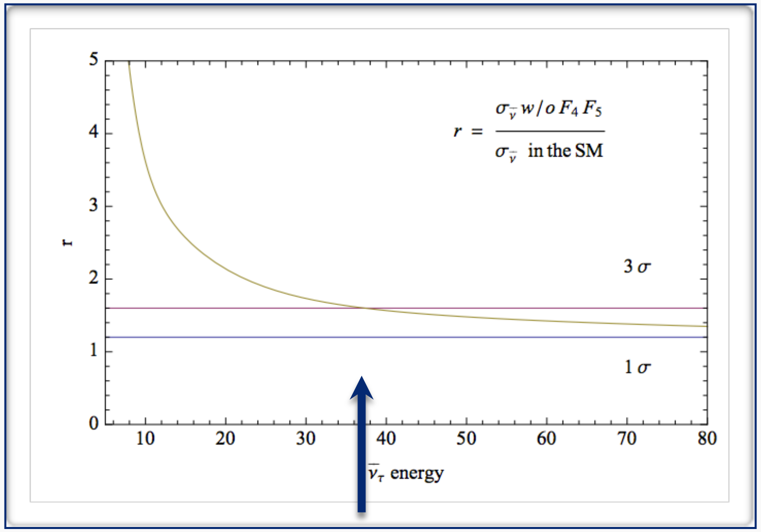
F_4 and F_5 Structure Functions

- Through ν_τ and anti-ν_τ identification: unique capability of being sensitive to F4 and F5

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


$F_4 = F_5 = 0$

SM prediction



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

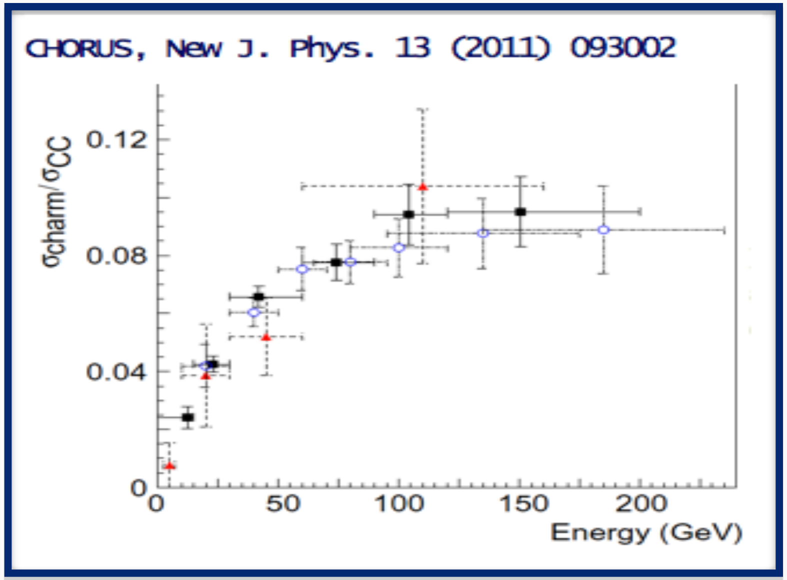
$E(\bar{\nu}_\tau) < 38$ GeV

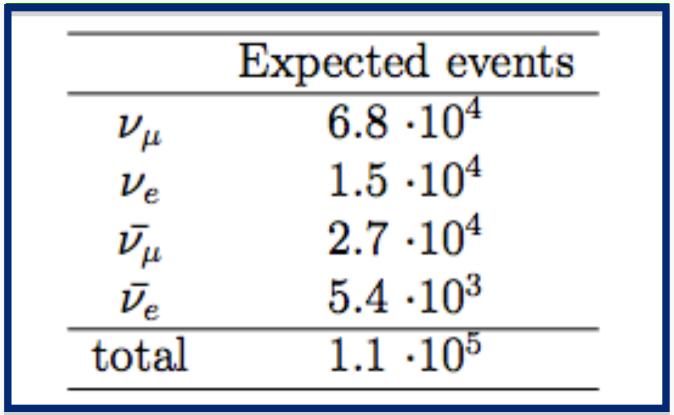
r>1.6 evidence for non-zero values of F_4 and F_5

Charm Physics

- Expected charm exceeds the statistics available in previous experiments by more than one order of magnitude

In NuTeV ~5100 ν_μ , ~ 1460 anti-ν_μ
In CHORUS ~2000 ν_μ , 32 anti-ν_μ


CHORUS, New J. Phys. 13 (2011) 093002



	Expected events
ν_μ	$6.8 \cdot 10^4$
ν_e	$1.5 \cdot 10^4$
$\bar{\nu}_\mu$	$2.7 \cdot 10^4$
$\bar{\nu}_e$	$5.4 \cdot 10^3$
total	$1.1 \cdot 10^5$

ν_μCC

$$f(charm) = \frac{\int \Phi_{\nu_\mu} \sigma^{CC}_{\nu_\mu} \left(\frac{\sigma_{charm}}{\sigma^{CC}_{\nu_\mu}} \right) dE}{\int \Phi_{\nu_\mu} \sigma^{CC}_{\nu_\mu} dE} \approx 4\%$$

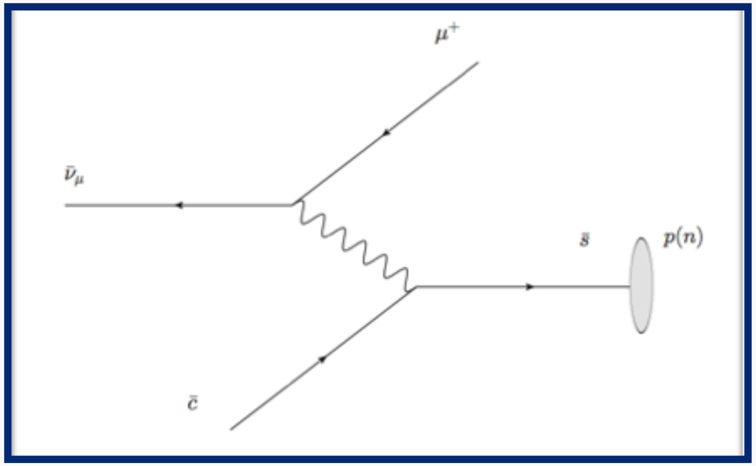
ν_eCC

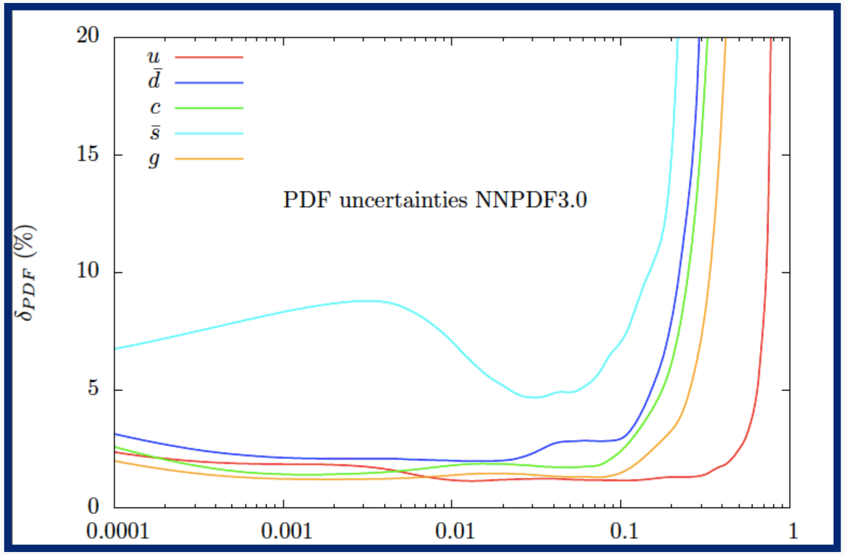
$$f(charm) = \frac{\int \Phi_{\nu_e} \sigma^{CC}_{\nu_e} \left(\frac{\sigma_{charm}}{\sigma^{CC}_{\nu_e}} \right) dE}{\int \Phi_{\nu_e} \sigma^{CC}_{\nu_e} dE} \approx 6\%$$

No charm candidate from ν_e and ν_τ interactions ever reported!

Strange Quark Content

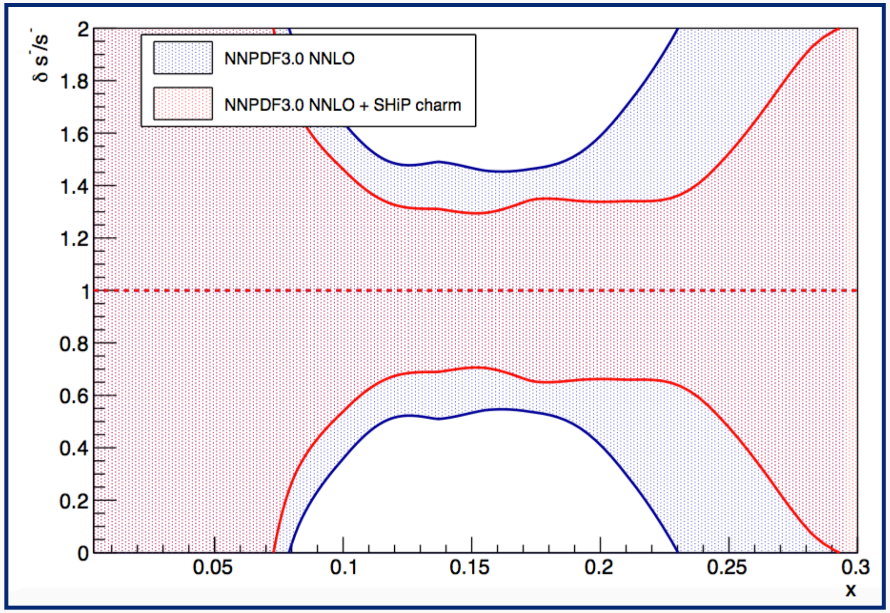
- Charmed hadron production in anti-neutrino interactions selects anti-strange quark in the nucleon.
- Strangeness important for precision SM tests and for BSM searches.
- W boson production at 14 TeV: 80% via *ud* and 20% via *cs*.

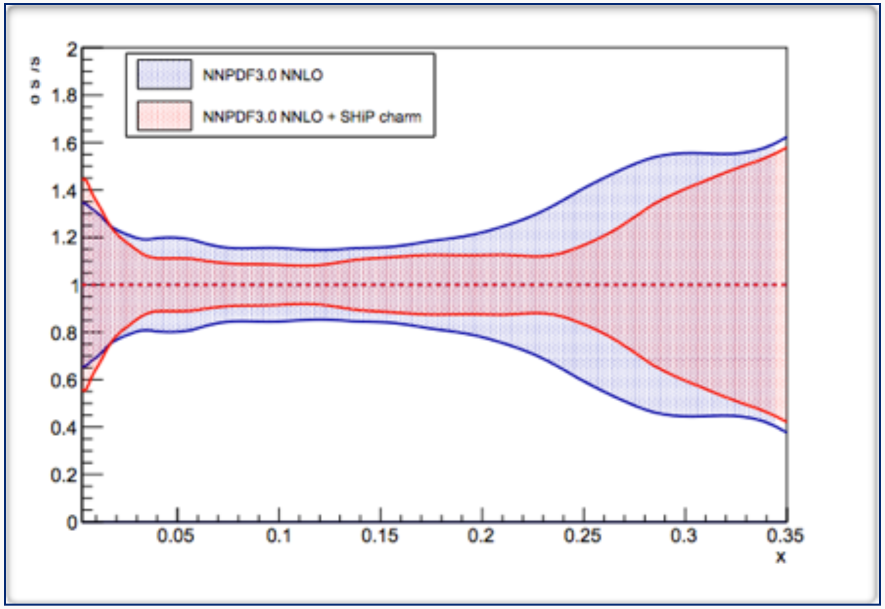




Strange Quark Content

- Improvement achieved on s^{+}/s^{-} versus x
- Significant improvement (factor two) with SHIP data



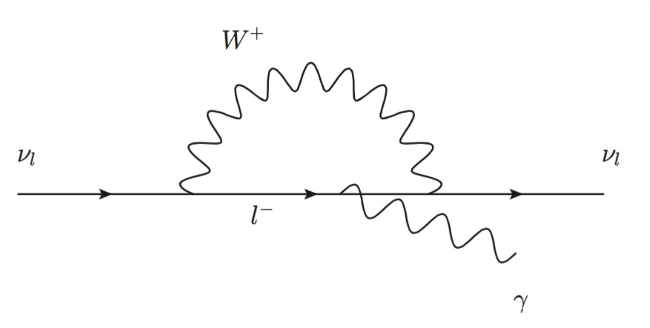


$$s^{-} = s(x) - \bar{s}(x)$$

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

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

Tau Neutrino Magnetic Moment



Current limits

$\mu_{\nu e} < 2.9x10^{-11}\ \mu_B$
$\mu_{\nu\mu} < 6.9x10^{-10}\ \mu_B$

$$\mu_\nu = \frac{3\,e\,G_F\,m_\nu}{8\,\pi^2\,\sqrt{2}} \simeq (3.2\times 10^{-19})\left(\frac{m_\nu}{1\,\mathrm{eV}}\right)\mu_B$$

Background events

$\nu_x(\bar{\nu}_x) + e^- \rightarrow \nu_x(\bar{\nu}_x) + e^-$	NC	750
$\nu_e + e^- \rightarrow e^- + \nu_e$	CC	
$\nu_e + n \rightarrow e^- + p$	QE	11700
$\bar{\nu}_e + p \rightarrow n + e^+$	QE	
$\nu_e(\bar{\nu}_e) + N \rightarrow e^-(e^+) + X$	DIS	1700

Event Selection

$\theta_{\nu-e} < 30\,mrad$
$E_e > 1$ GeV

SHiP can reach

$$\boxed{\mu_\nu = 1.3\times 10^{-7}\mu_B}$$

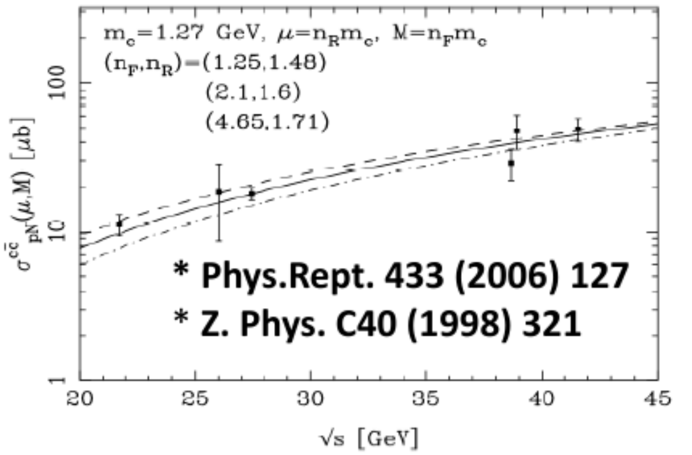
Charm Cross-Section Measurement

- Measurement of dσ/(dE dΩ) associated charmed hadron production in a 400 GeV proton beam on SHiP target

Aim:

HNL normalisation + ν_τ cross-section measurements

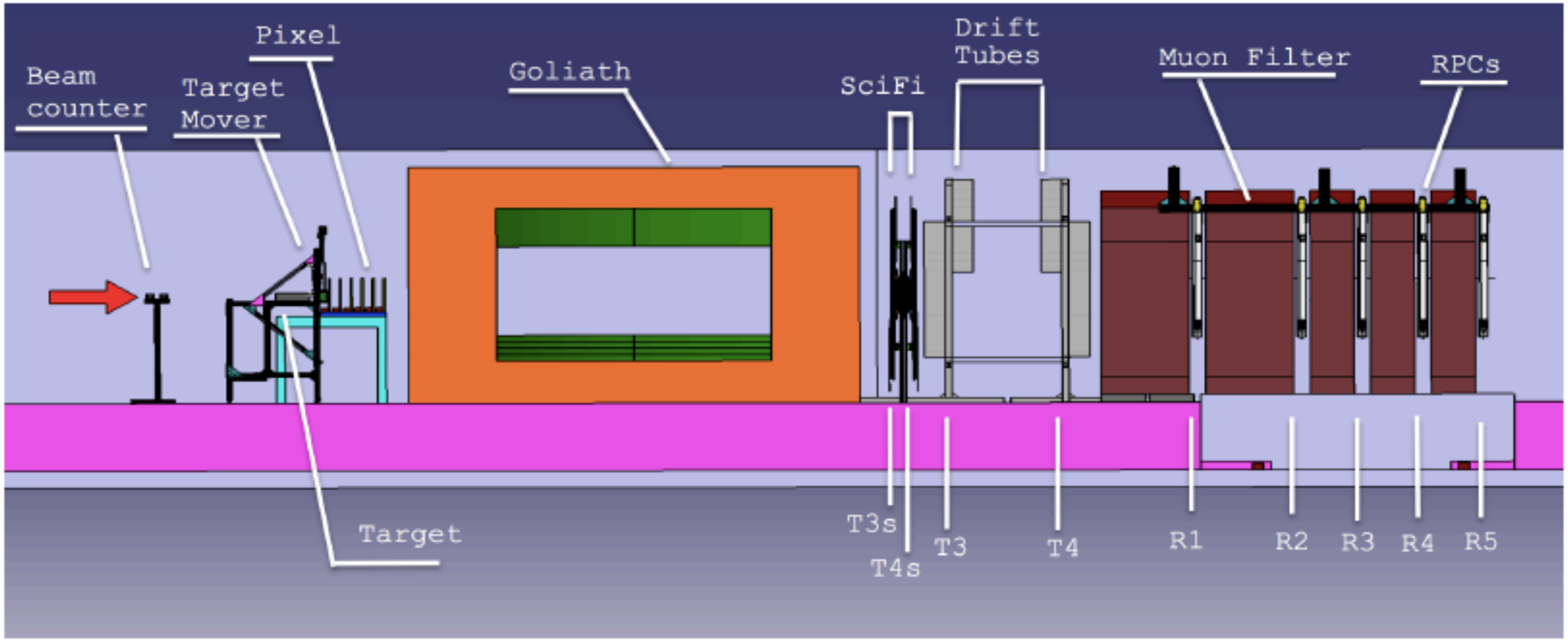
Precise inclusive cross-section by NA27 (σCC = 18.1 ± 1.7 μm), but no info on angular/energy distribution for charm from 400 GeV proton For simulations used differential cross-section measured with 500 GeV pions



* Phys.Rept. 433 (2006) 127

* Z. Phys. C40 (1998) 321

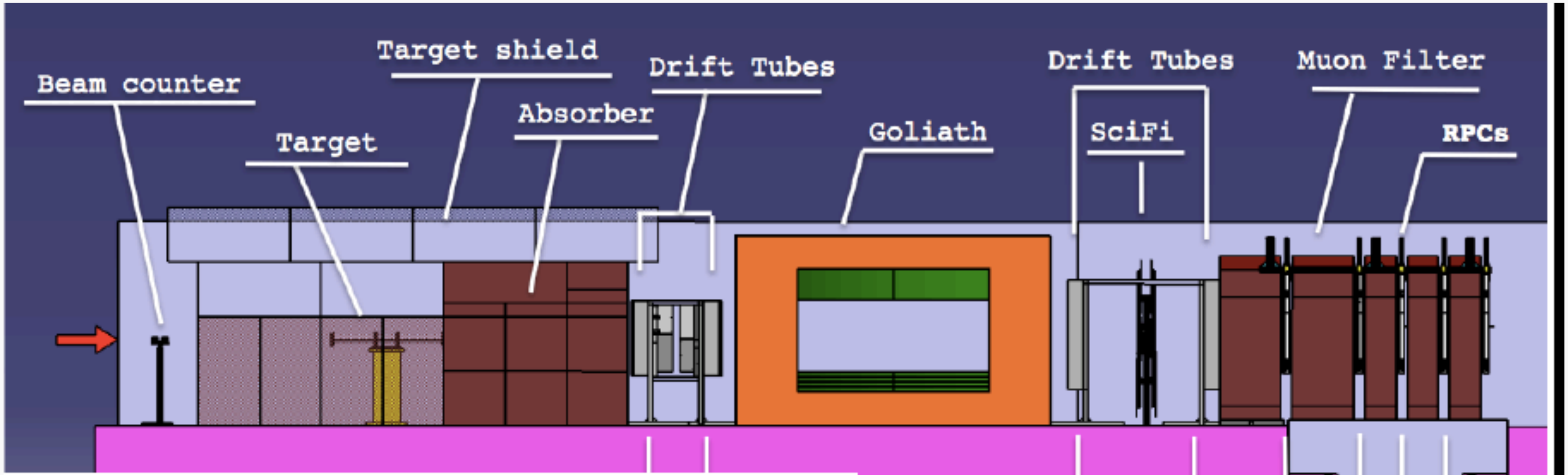
Charm Cross-Section Measurement



- **Lead target**, 12×10 cm^2 Pb blocks (few cm) interleaved with emulsion to identify charm topology
- **Spectrometer** to measure momentum and charge of the charm daughters
- **Muon tagger** to identify muons

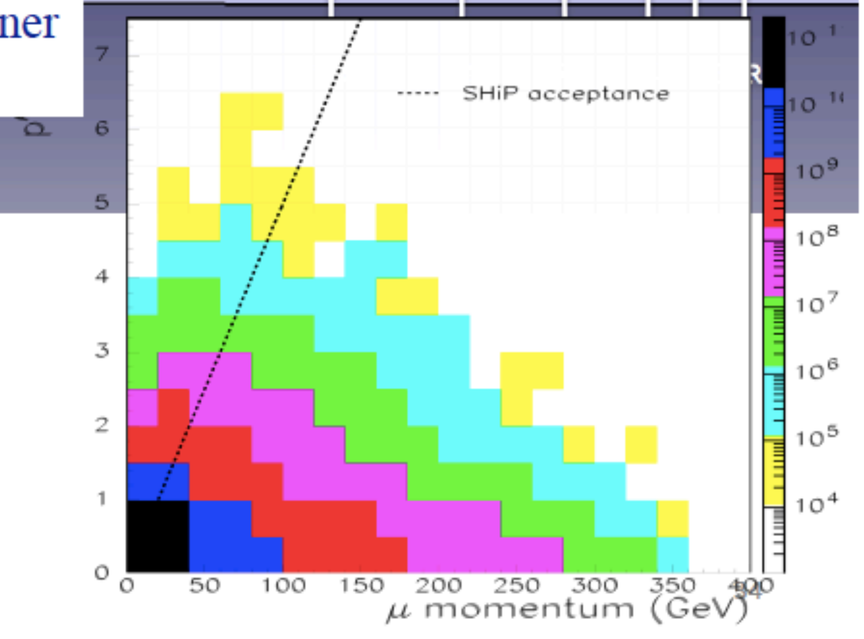
- Instrument ~1.6 λ to study charm production including the cascade effect
- July 2108: ~150 fully reconstructed charm-pais
- Data taking after LS2: > 1000 fully reconstructed charmed pairs

Muon Flux Measurement

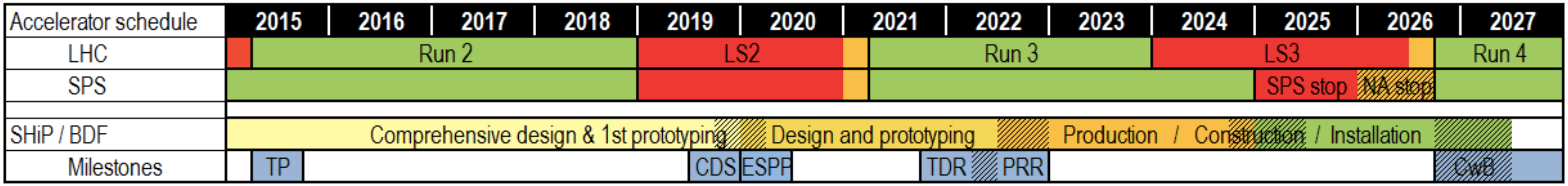


10^{11} pot → 100 events in the dangerous corner
Validate simulation

Replica of the SHiP target, TZM and W



Project Schedule



Accelerator schedule	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
LHC			Run 2		LS2			Run 3			LS3		Run 4
SPS											SPS stop	NA stop	
SHiP / BDF			Comprehensive design & 1st prototyping			Design and prototyping			Production /	Construction	/ Installation		
Milestones	TP				CDS	ESPP	TDR	PRR				CwB	

Four years for detector construction, plus two years for installation

➔Data taking 2026

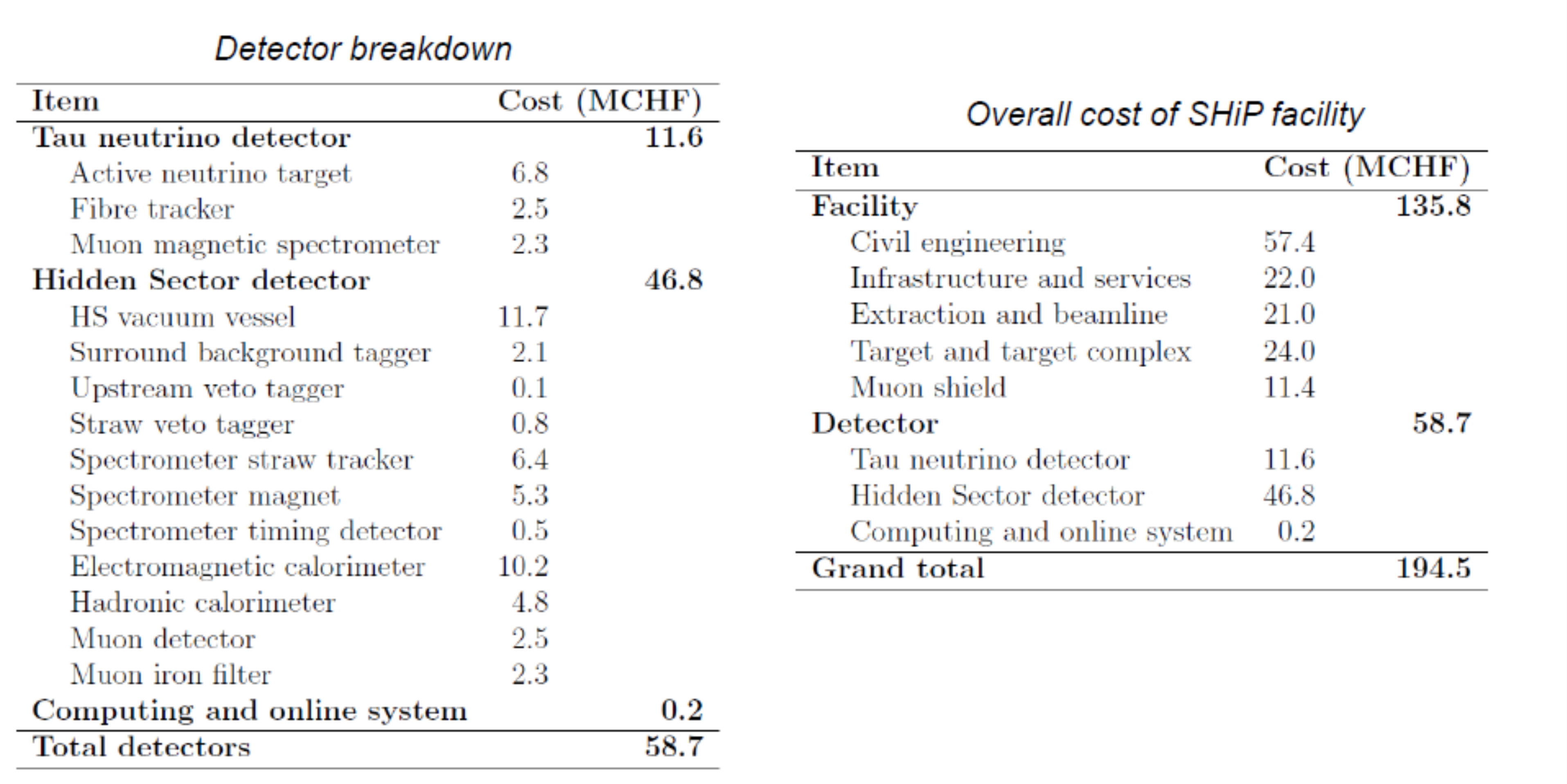
Summary

- SHiP experiment at CERN is proposed to search for New Physics in the largely unexplored domain of new, very weakly interacting particles with mass O(10) GeV.

- SHiP will perform a complement searches for new searches at energy frontier at CERN.

- Also unique detector for neutrino physics/charm physics.

Cost



Detector breakdown

Item	Cost (MCHF)	
Tau neutrino detector		**11.6**
Active neutrino target	6.8	
Fibre tracker	2.5	
Muon magnetic spectrometer	2.3	
Hidden Sector detector		**46.8**
HS vacuum vessel	11.7	
Surround background tagger	2.1	
Upstream veto tagger	0.1	
Straw veto tagger	0.8	
Spectrometer straw tracker	6.4	
Spectrometer magnet	5.3	
Spectrometer timing detector	0.5	
Electromagnetic calorimeter	10.2	
Hadronic calorimeter	4.8	
Muon detector	2.5	
Muon iron filter	2.3	
Computing and online system		**0.2**
Total detectors		**58.7**

Overall cost of SHiP facility

Item	Cost (MCHF)	
Facility		**135.8**
Civil engineering	57.4	
Infrastructure and services	22.0	
Extraction and beamline	21.0	
Target and target complex	24.0	
Muon shield	11.4	
Detector		**58.7**
Tau neutrino detector	11.6	
Hidden Sector detector	46.8	
Computing and online system	0.2	
Grand total		**194.5**