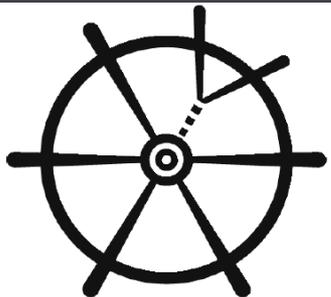


SHiP : a new facility with a dedicated detector for studying tau neutrino properties

M. Komatsu (Nagoya Univ. JAPAN) on behalf of the SHiP collaboration



SHiP

Search for Hidden Particles

The 14th International Workshop on Tau Lepton Physics (Tau2016)
IHEP, Beijing, 18-23 September 2016

The SHiP experiment

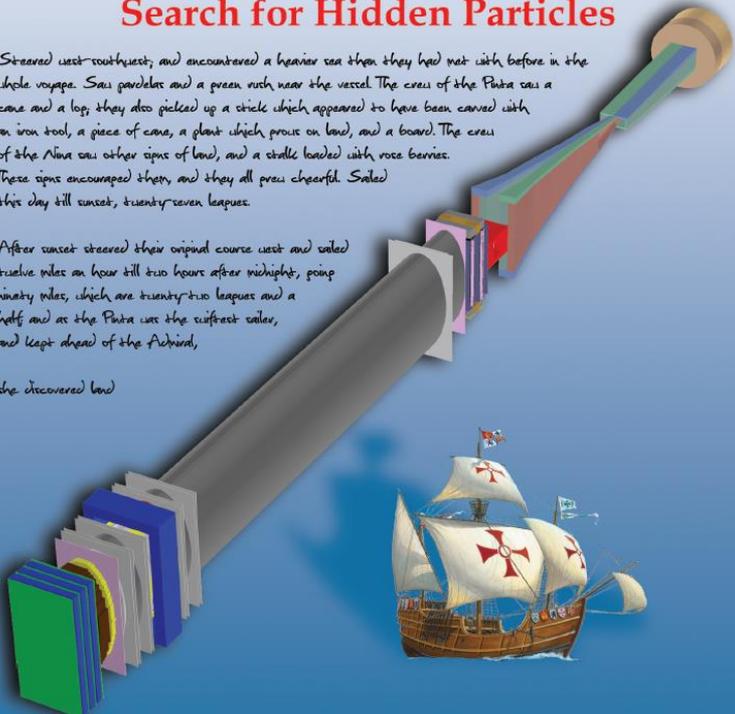


CERN-SPSC-2015-016
SPSC-P-350
8 April 2015

Search for Hidden Particles

Streared west-southwest, and encountered a heavier sea than they had met with before in the whole voyage. Saw pavolots and a green rish near the vessel. The crew of the Petra saw a cone and a lop, 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 stulle loaded with rose berries. These signs encouraged them, and they all grew cheerful. Sailed this day till sunset, twenty-seven leagues.

After sunset streared 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 at the Petra was the swiftest sailer, and kept ahead of the Archind, the recovered land

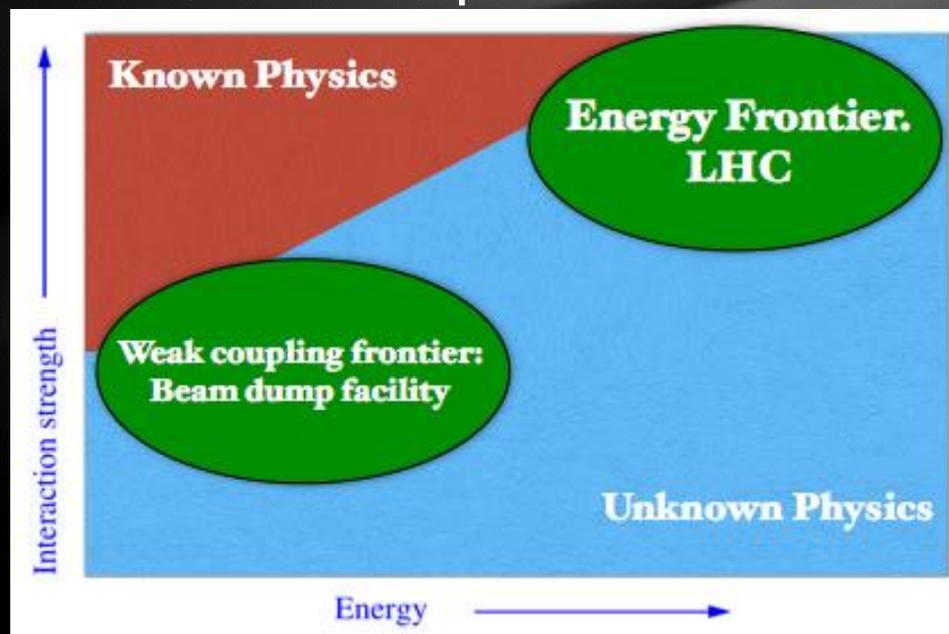


Technical Proposal

- Proposal for a new beam dump facility at the CERN SPS
 - Hidden sector detector
 - Tau neutrino detector
- 235 authors from 45 institutes and 15 countries + CERN
 - Technical Proposal is submitted in April 2015 (arxiv.org/abs/1504.04956)
 - Physics Proposal signed by 85 theorists (arxiv.org/abs/1504.0855)
- **SPSC positive recommendation in January 2016**

Primary motivation

- Look for **Beyond Standard Model** in :
 - High Energy Frontier : LHC
 - **Intensity Frontier : SHiP**
- Look for long lived neutral (hidden) particle from beam dump
- ν_τ beam source
 - $D_s \rightarrow \tau \nu_\tau$



SHiP (Search for Hidden Particles) Physics objectives



- ✓ Explore hidden portals of the SM using $> 2 \times 10^{20}$ p.o.t.
($>10^{17}$ D, $>10^{15}$ τ)
 - ✓ Heavy neutral lepton in various states
 - ✓ Dark photon
 - ✓ SUSY neutralino
 - ✓ See more detail on <http://ship.web.cern.ch/>
- ✓ Neutrino interactions (expect ~ 3500 ν_τ interactions identified in 9.6 tons emulsion target)
 - ✓ ν_τ and anti- ν_τ physics, cross-section
 - ✓ Physics in ν_τ scattering, structure function, magnetic moment.
 - ✓ Charm physics in neutrino and anti-neutrino interactions

Physics programs



Full physics program

2 Vector portal

- 2.1 Classification of vector portals
 - 2.1.1 Kinetic mixing
 - 2.1.2 Anomaly-free gauge groups ($B - L$, $L_\mu - L_\tau$ etc)
 - 2.1.3 Other forms of vector portals.
 - 2.1.4 Chern-Simons portal
- 2.2 Matter states charged under new $U(1)$
 - 2.2.1 Higgs mechanism in the dark sector
 - 2.2.2 Supersymmetric $U(1)'$ models
- 2.3 Physics motivation for light mass (less than weak scale) vector portals
 - 2.3.1 Putative solution to the muon $g - 2$ discrepancy
 - 2.3.2 Mediator of Interaction with DM and possible connection to positron excess
 - 2.3.3 Self-Interaction of dark matter via light mediators
- 2.4 Main features of vector portal phenomenology.
 - 2.4.1 Decay rates, modes, branchings, ϵ for dark photon
 - 2.4.2 Other vector candidates
 - 2.4.3 Higgsstrahlung process for $U(1)'$ and delayed decays of N .
- 2.5 Summary of the existing constraints on light vector and light DM states
 - 2.5.1 Current status of experimental constraints on exotic vector γ
 - 2.5.2 Production and detection of light vector portal DM
 - 2.5.3 Cosmological and astrophysical constraints on vector portals
- 2.6 Case studies for SHiP
 - 2.6.1 Production and detection of kinetically mixed dark photon vectors.
 - 2.6.2 Production and detection of other invisible particles (N , HNL)

3 Scalar portal

- 3.1 The scalar sector of the Standard Model and Beyond
 - 3.1.1 Scalar portal effective Lagrangian
 - 3.1.2 Hidden Valleys
 - 3.1.3 Light scalars in supersymmetry
- 3.2 Linear scalar portals: Higgs-scalar mixing
 - 3.2.1 Existing experimental limits
 - 3.2.2 What SHiP can do
- 3.3 Z_2 scalar portals: pair-production of light hidden particles
 - 3.3.1 Probing Exotic Higgs Decays at SHiP
 - 3.3.2 What SHiP can do
- 3.4 Pseudoscalar portals
- 3.5 Scalar portals and Dark Matter
 - 3.5.1 Scalar as a mediator between DM and the SM
 - 3.5.2 Scalar as a DM candidate
- 3.6 Dark pions
 - 3.6.1 The model and scales
 - 3.6.2 Dark pion lifetime and decay modes
 - 3.6.3 What SHiP could do?
- 3.7 Scalar portals and inflation
 - 3.7.1 Light inflatons

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
- 4.3 HNLs and neutrino masses
 - 4.3.1 Seesaw formalism
 - 4.3.2 Seesaw scales
 - 4.3.3 Beyond the minimal seesaw model
 - 4.3.4 Possible origins of the keV-MeV-GeV scale of HNL masses
- 4.4 Direct HNL searches
 - 4.4.1 Direct signatures of HNL: kink searches, peak searches
 - 4.4.2 Direct signatures of HNL: fixed target experiments
 - 4.4.3 Direct Signatures of HNL: Collider Searches
- 4.5 Indirect HNL probes
 - 4.5.1 Neutrinoless double beta decay for non-seesaw HNL
 - 4.5.2 Neutrinoless double beta decay for two seesaw HNLs
 - 4.5.3 Charged lepton flavour violating processes
 - 4.5.4 HNL and primordial nucleosynthesis
- 4.6 HNL and baryon asymmetry of the Universe:
 - 4.6.1 Sakharov conditions. Leptogenesis
 - 4.6.2 Thermal leptogenesis
 - 4.6.3 Resonant Leptogenesis
 - 4.6.4 Leptogenesis via HNL oscillations
- 4.7 HNL and dark matter
 - 4.7.1 Bounds on HNL as dark matter. No assumptions on production mechanism
 - 4.7.2 Bounds on DM HNL if produced via mixing with active neutrinos only
 - 4.7.3 3.5 keV line
- 4.8 ν MSM

8 Tau neutrino physics and other precision measurements in SHiP

- 8.1 Tau neutrino physics
 - 8.1.1 Flux of tau neutrinos
 - 8.1.2 Expected sensitivity
- 8.2 Deep inelastic muon and electron neutrino scattering
 - 8.2.1 Status of perturbative QCD calculations
 - 8.2.2 Strangeness from heavy-quark DIS in CC interactions
 - 8.2.3 Nuclear effects in νN DIS and global analyses of nuclear PDFs
 - 8.2.4 α_S measurement via Gross-Llewellyn Smith sum rule
 - 8.2.5 Precise Ratios for Neutrino Nucleon Interactions
- 8.3 Limit on Tau neutrino magnetic moment
- 8.4 Charmed pentaquark searches
- 8.5 Summary

9 Searches of lepton flavour violating processes $\tau \rightarrow 3\mu$

- 9.1 Motivation as a null-test of the standard model
- 9.2 $\tau \rightarrow 3\mu$ in seesaw scenarios
- 9.3 Supersymmetric models
- 9.4 Relation to two-body LNV decays of Z boson, neutral pseudoscalar and Higgs boson
- 9.5 Current and future experimental sensitivities
- 9.6 Proposal for a fixed-target facility

5 ALPs and other PNGBs at SHiP

- 5.1 ALPs and why they are interesting
 - 5.1.1 ALP origins
 - 5.1.2 Connection to Dark Matter
- 5.2 Interactions, phenomenological features and existing limits
- 5.3 ALPs coupled to two gauge bosons
 - 5.3.1 Prospects for SHiP
- 5.4 ALPs coupled to SM fermions
 - 5.4.1 Interactions, phenomenological features and existing limits
 - 5.4.2 Prospects at SHiP
- 5.5 Concluding remark

6 SUSY

- 6.1 Introduction
- 6.2 A Very Light Supersymmetric Neutralino and R-Parity Violation
 - 6.2.1 Motivation for a very light neutralino
 - 6.2.2 R-parity Violation
 - 6.2.3 Finding Neutralinos at SHiP via R-Parity violation
 - 6.2.4 Comparison with Previous Bounds
 - 6.2.5 Concluding remarks
- 6.3 Light particles from the SUSY breaking sector
 - 6.3.1 Origin of light sgoldstinos
 - 6.3.2 Sgoldstino couplings and phenomenology
 - 6.3.3 Sgoldstinos at SHiP
 - 6.3.4 Concluding remarks
- Light Dirac gauginos
 - 6.4.1 Origins of Pseudo-Dirac fermions
 - 6.4.2 Effective model, phenomenological features
 - 6.4.3 Origin of the effective model
 - 6.4.4 Detection at SHiP
 - 6.4.5 Concluding remarks
- 6.4 SUSY vector portal I: Hidden Photinos
 - 6.5.1 Motivation
 - 6.5.2 Features
 - 6.5.3 Existing bounds
 - 6.5.4 What SHiP can do
 - 6.5.5 Concluding remarks
- 6.5 SUSY vector portal II: Novel Hidden Photon decays
 - 6.6.1 Setup
 - 6.6.2 SHiP Sensitivity
 - 6.6.3 Concluding remarks
- 6.7 Axinos and saxions, ALPinos and sALPs
 - 6.7.1 Motivation
 - 6.7.2 Phenomenology of saxions and axinos and possibilities at SHiP
 - 6.7.3 Concluding remarks
- 6.8 Additional Possibilities

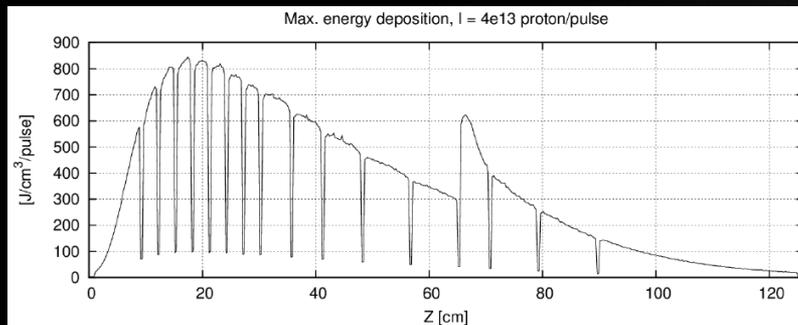
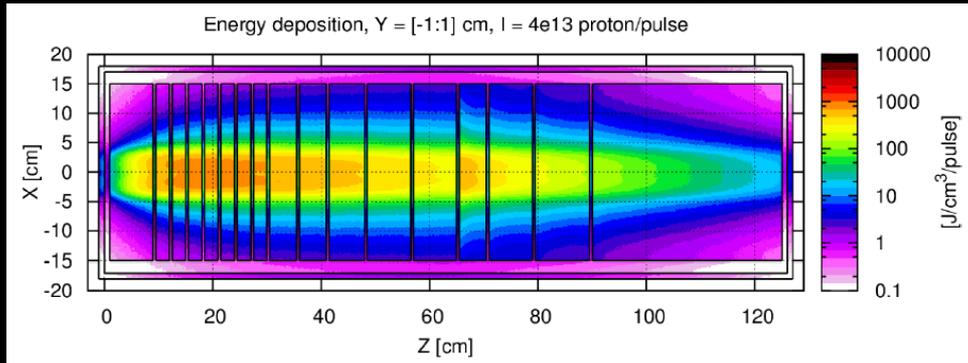
Tau neutrino (Main in this talk)

- We started look for tau neutrino since 1994 in CERN WA95 CHORUS (SBL $\nu_{\mu} \rightarrow \nu_{\tau}$ oscillation).
- Fermilab E872 DONUT (1997)
- First observation : Phys. Lett. B504 (2001) 218-224
- Cross-section : Phys. Rev. D78 (2008) 052002
 - 9(7.5) tau neutrino candidate events
 - $\sigma^{\text{const}}(\nu_{\tau}) = (0.39 \pm 0.13 \pm 0.13) \times 10^{-38} \text{ cm}^2 \text{ GeV}^{-1}$
- CERN CNGS1 OPERA (2008-2012) LBL $\nu_{\mu} \rightarrow \nu_{\tau}$
- 5 tau neutrino, 5.1 σ : Phys. Rev. Lett. 115 (2015) 121802
- Only 14 tau neutrino events ever observed.

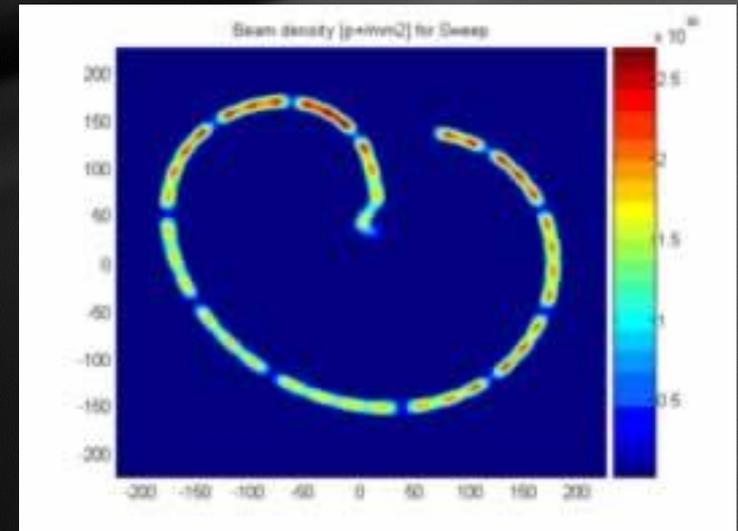
Beam parameters for SHiP

- Proton beam
 - Momentum : $400\text{GeV}/c$
 - Beam intensity : $4\text{-}5 \times 10^{13}$ /cycle
 - Cycle length : 7.2 s
 - Spill duration : 1 s (slow spill)
 - Average power : 400kW (during spill $\sim 3\text{MW}$)
 - Expected spot size (H/V) : 6mm/6mm
- 4×10^{19} pot / year \rightarrow 2×10^{20} pot for 5 years
 - Very same with CNGS performance
 - Plan was 2.25×10^{20} but 1.8×10^{20} was delivered.

Beam dump target



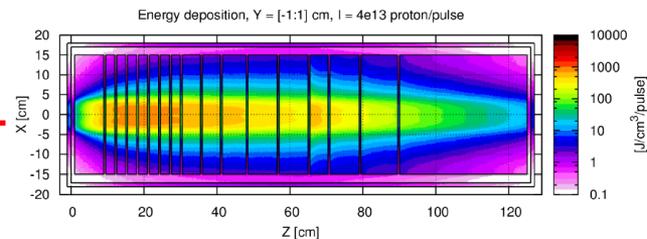
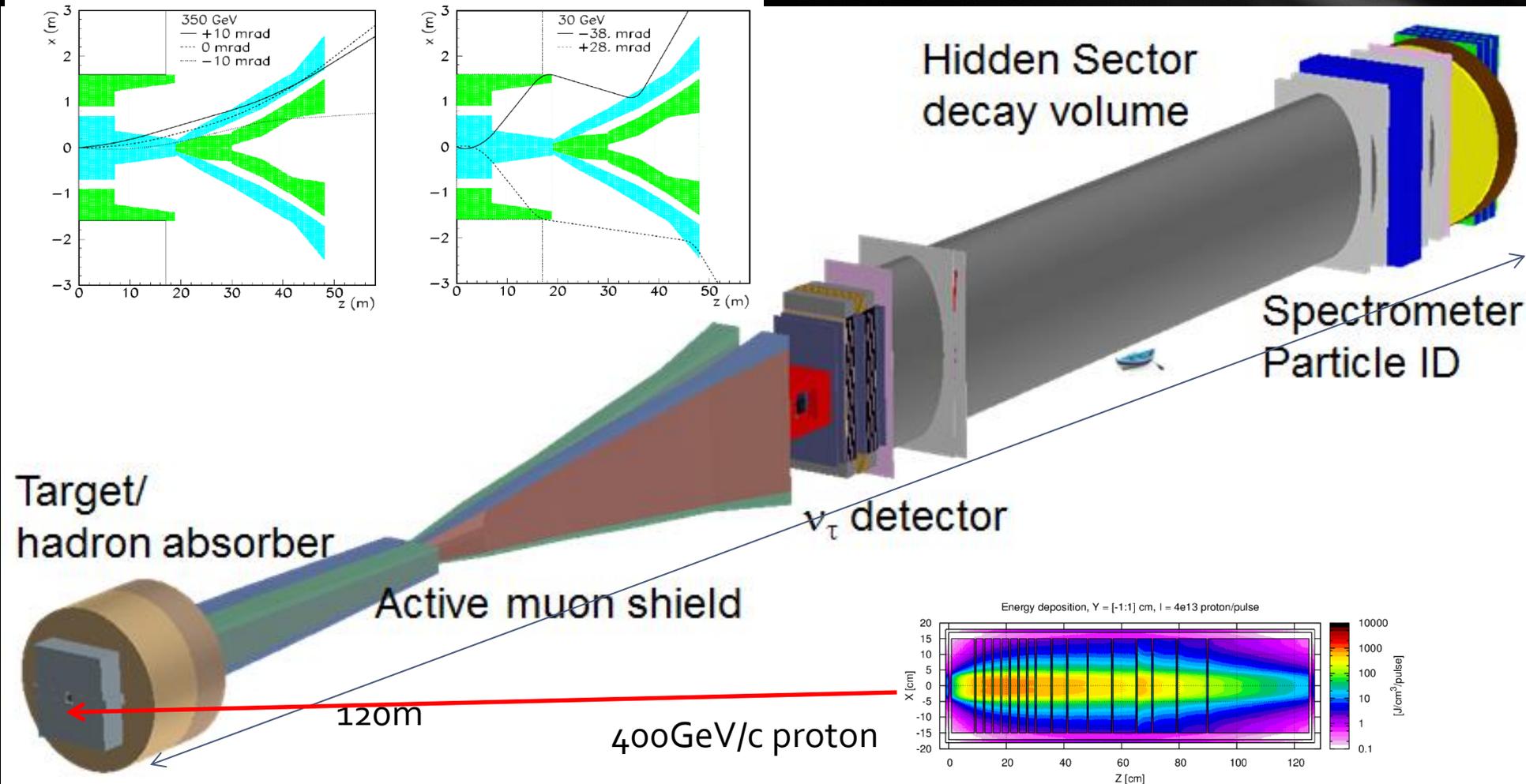
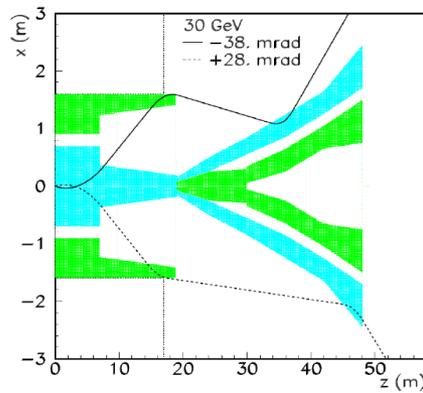
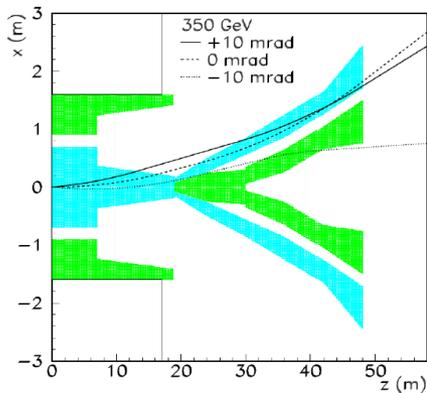
- Segmented Mo and W target actively cooled with water.
- Beam on target
- Sweep is necessary like LHC



- In case of no sweep, the target would not melt but will fail by pressure.
- 1.2 DPA (displacement per atom) with 2×10^{20} pot

SHiP (Search for Hidden Particles) Beam dump experiment like DONUT

Reconstruction of the HNL decays in the final states: $\mu^- \pi^+$, $\mu^- \rho^+$ & $e^- \pi^+$



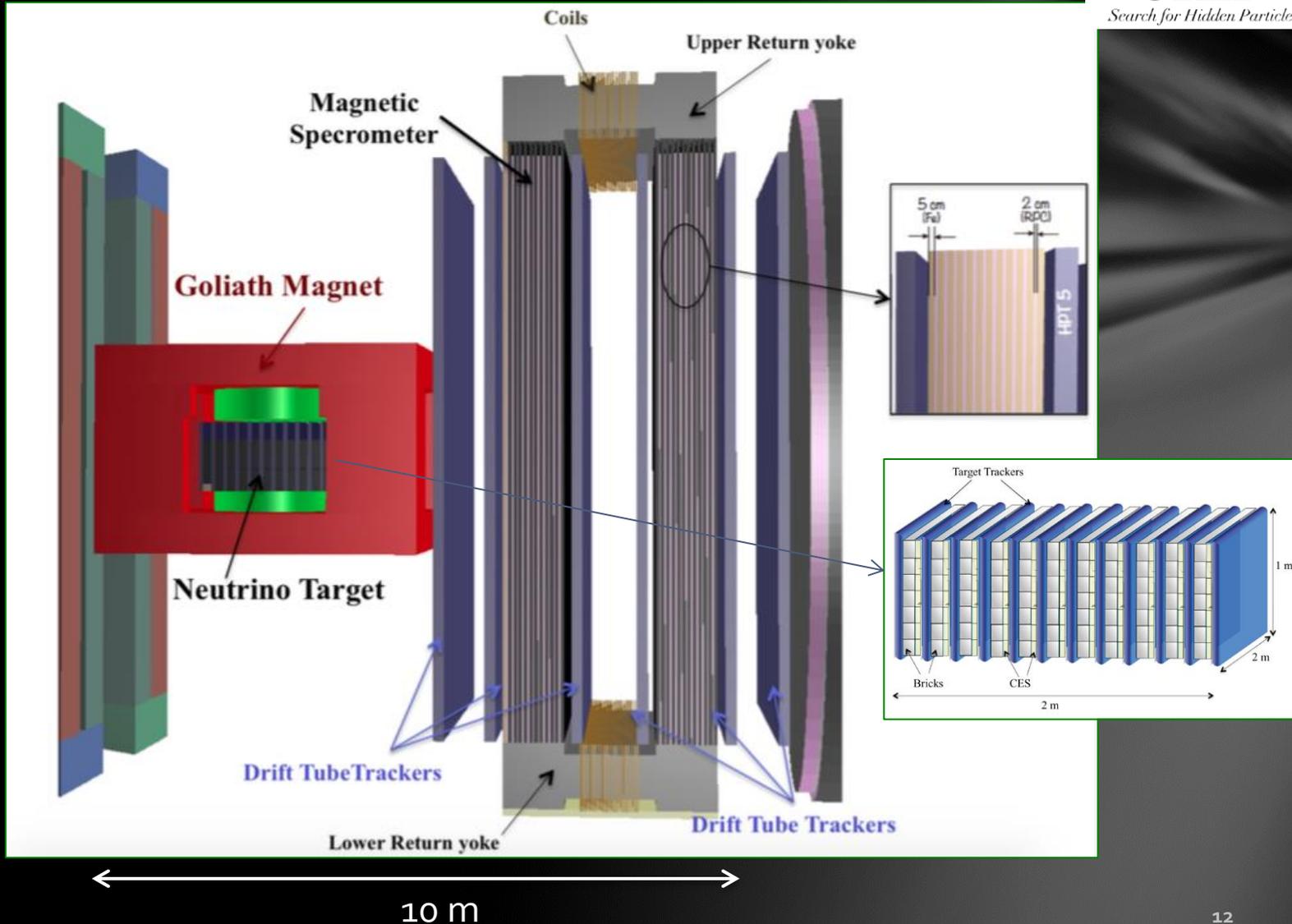
Comparison with DONUT

- ✓ Charm production by 400GeV, detector acceptance at 60m and tau neutrino cross-section
 - ✓ DONUT/SHiP $\rightarrow 1/(0.36 \times 0.2 \times 0.52) \sim 27$
- ✓ Proton on target for SHiP and DONUT
 - ✓ SHiP/DONUT $\rightarrow 2 \times 10^{20} / 3.6 \times 10^{17} \sim 560$
- ✓ Target mass
 - ✓ SHiP/DONUT $\rightarrow 9600\text{kg}/260\text{kg} \sim 37$
- ✓ Overall advantage against DONUT $\rightarrow 560 * 37 / 27 \sim 770$
- ✓ Assuming OPERA like brick (8.3kg) $\rightarrow 1155$ bricks
 - ✓ $1155/150\ 000 = 0.8\%$ of OPERA experiment

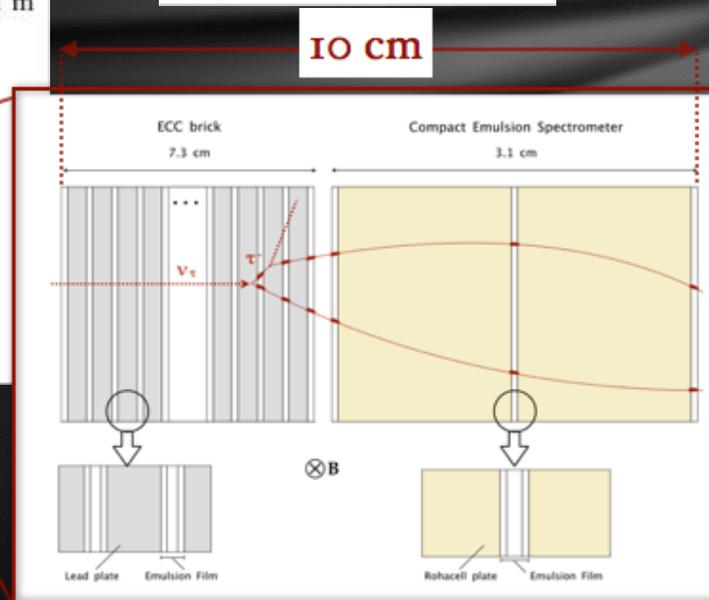
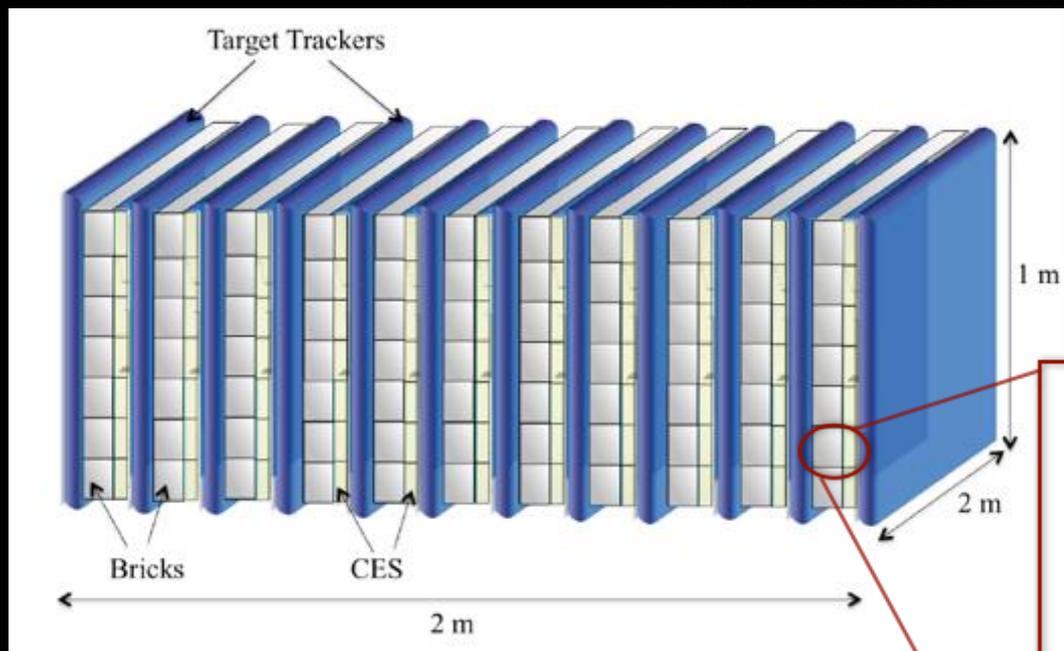
SHiP neutrino detector



Search for Hidden Particles

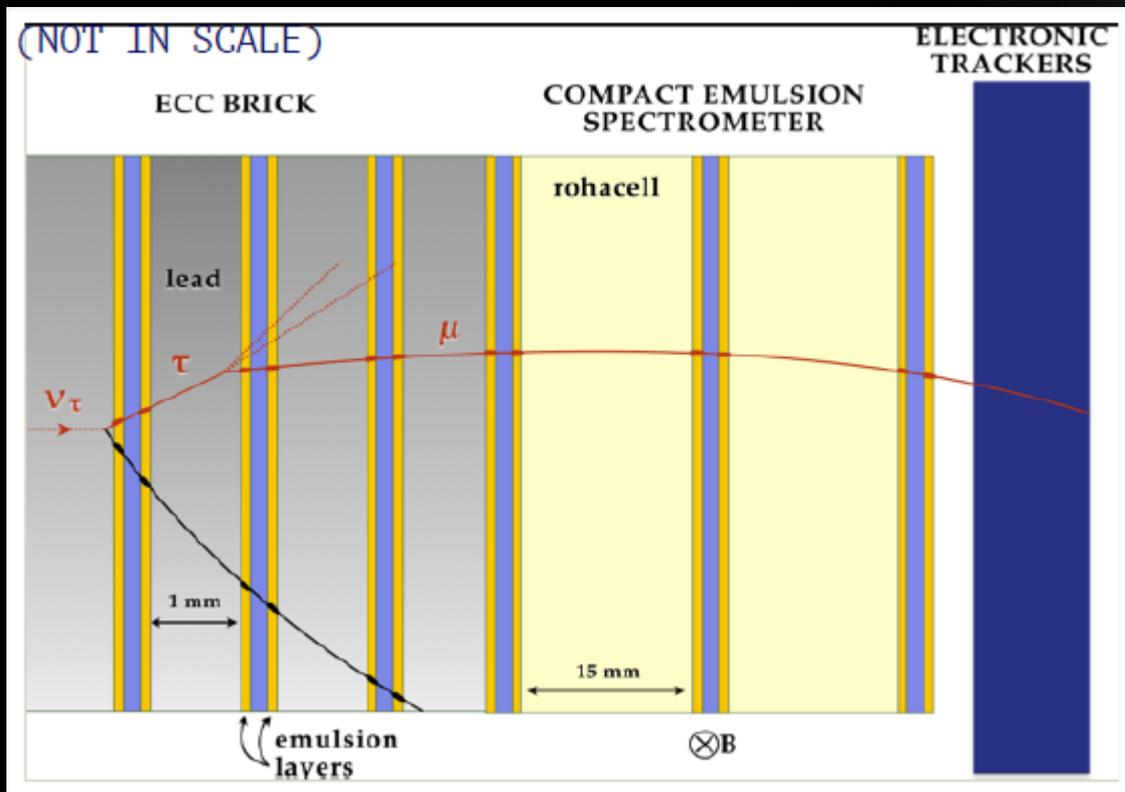


The neutrino target



- **Emulsion Cloud Chamber (ECC)** technology used in OPERA and DONUT
- Lead plates (high density material for the interaction) interleaved with **emulsion films** (tracking devices with μm resolution)

Detector design with CES



Target region: 11 mini-walls
 One wall contains 15x7 bricks
 Mass ~ 8.3kg x 15x7 x 11 ~ 9.6 ton

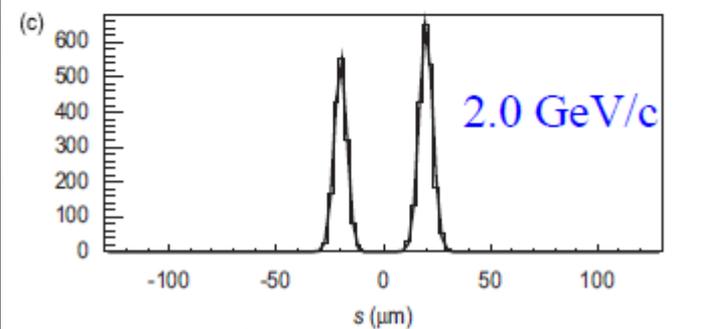
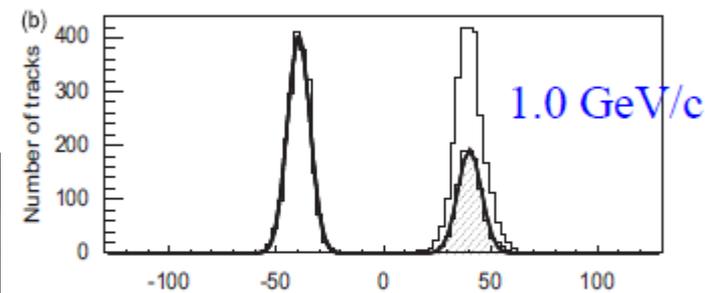
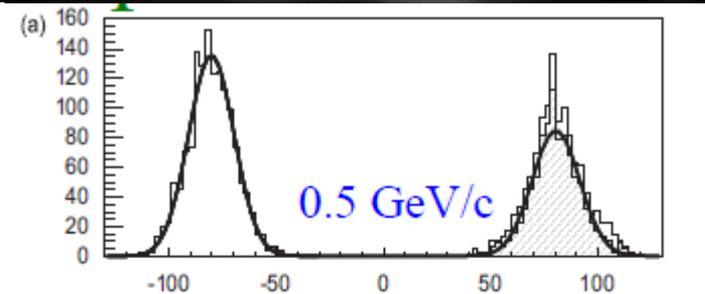
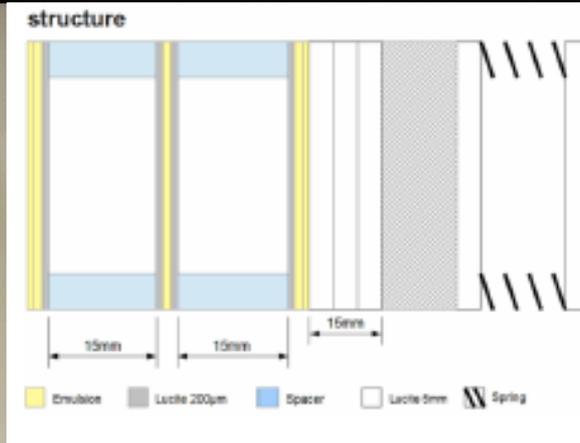
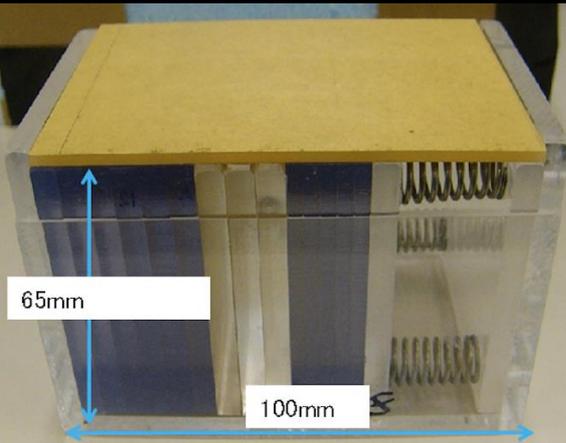
Charge determination not only for muonic channel.

MC simulation of CES provide 53% charge determination for hadrons

Statistical gain due to the CES

$$\frac{\sum_{i=1}^N br_i \varepsilon_i}{br_\mu \varepsilon_\mu} \simeq \frac{18 \cdot 0.95 + 50 \cdot 0.53 + 15 \cdot 0.53^2}{18 \cdot 0.9} \simeq 3$$

Compact Emulsion Spectrometer



Three emulsion films interleaved with 1.5cm air gap in magnetic field ($\sim 1\text{T}$), 3cm thick compact spectrometer.

H. Shibuya et al, NIM A592 (2008) 56

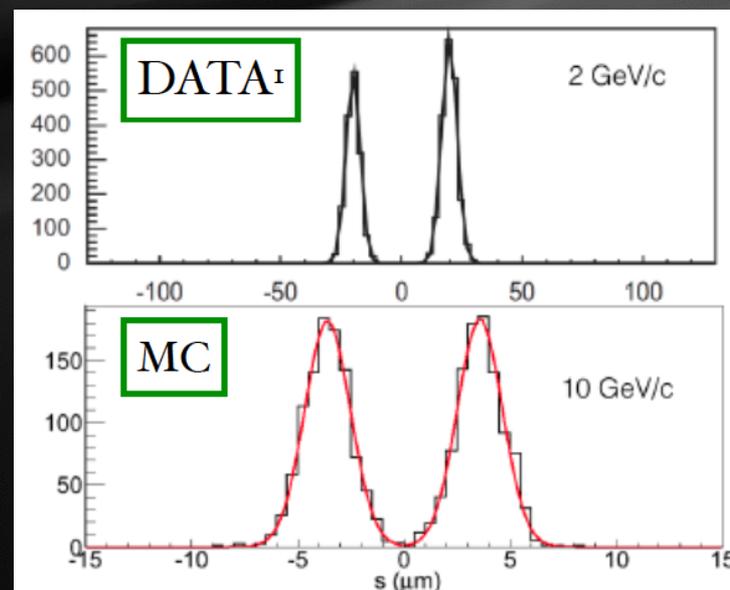
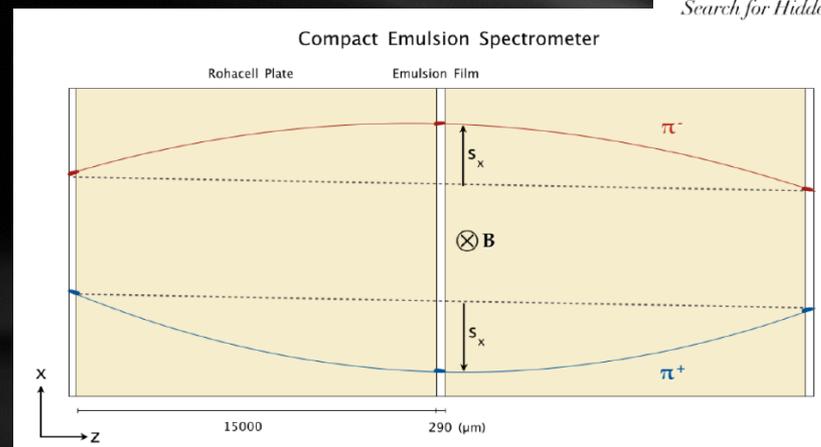
Sagitta measurement

Separation ν_τ /anti- ν_τ

- three emulsion films interleaved with two, 15-mm thick, Rohacell layers
- 90% efficiency for hadronic τ daughters reaching the end of ECC brick in a 1 T field
- sagitta method used to discriminate between positive and negative charge

Performance

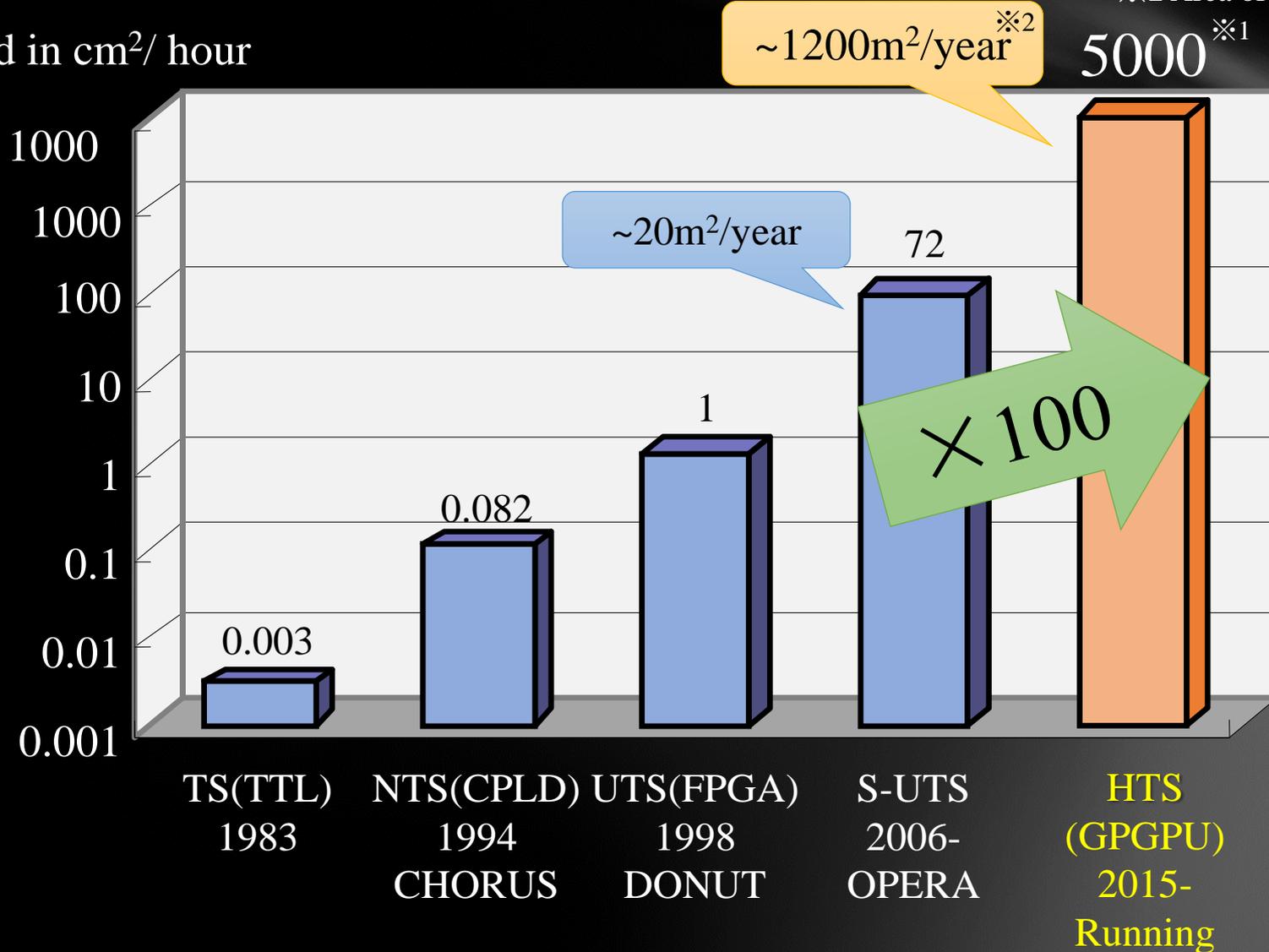
- electric charge can be determined with better than 3σ level up to 10 GeV/c
- Momentum estimated from the sagitta $\Delta p/p < 20\%$ up to 12 GeV/c



Evolution of the Scanning Speed

※1 Area of each layer
 ※2 Area of the films

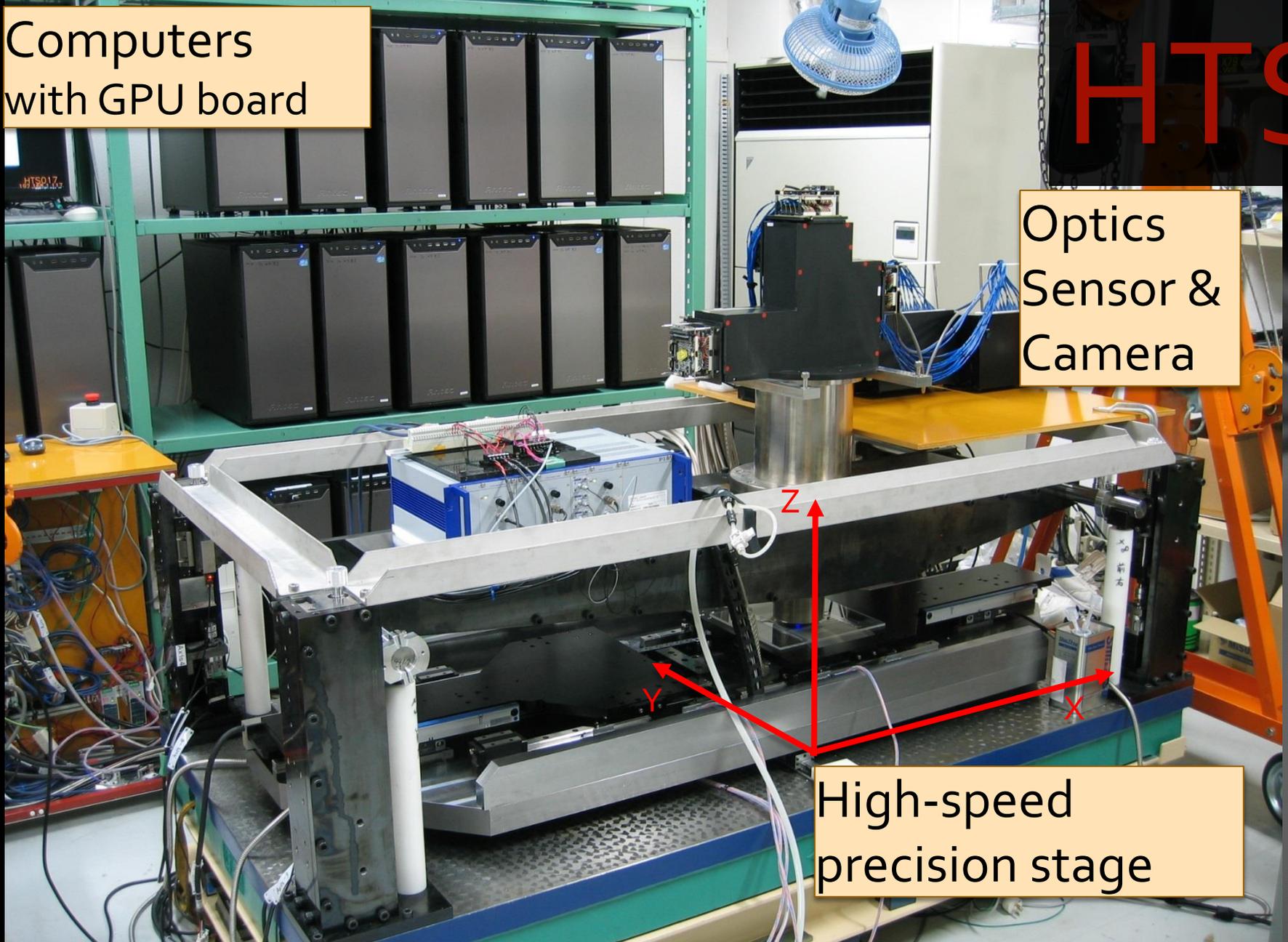
Speed in cm^2/hour



Computers
with GPU board

HTS

Optics
Sensor &
Camera



High-speed
precision stage

Objective lens

Resolution : ~420nm

N.A. : 0.65

Light source : G-line (436nm)

Magnification : $\times 12.2$

F.O.V : 5.1 (H) \times 5.1 (V)mm

#of image plane 6
(by Beam splitter)

Weight : 90kg

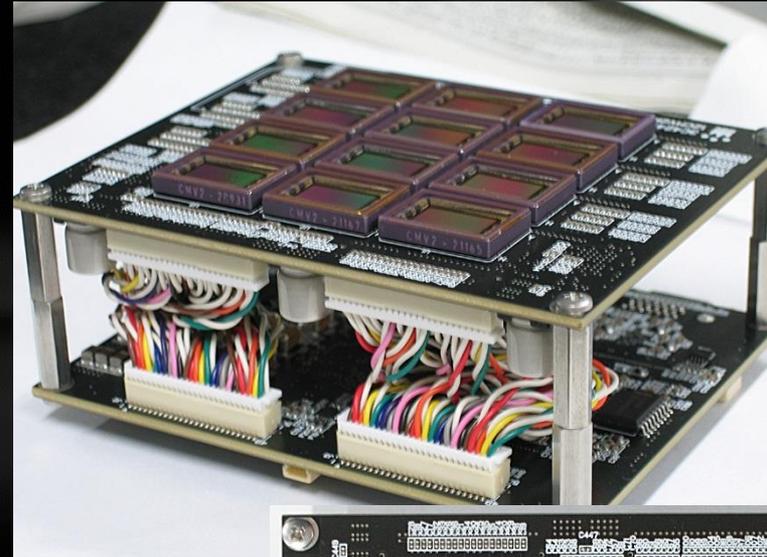
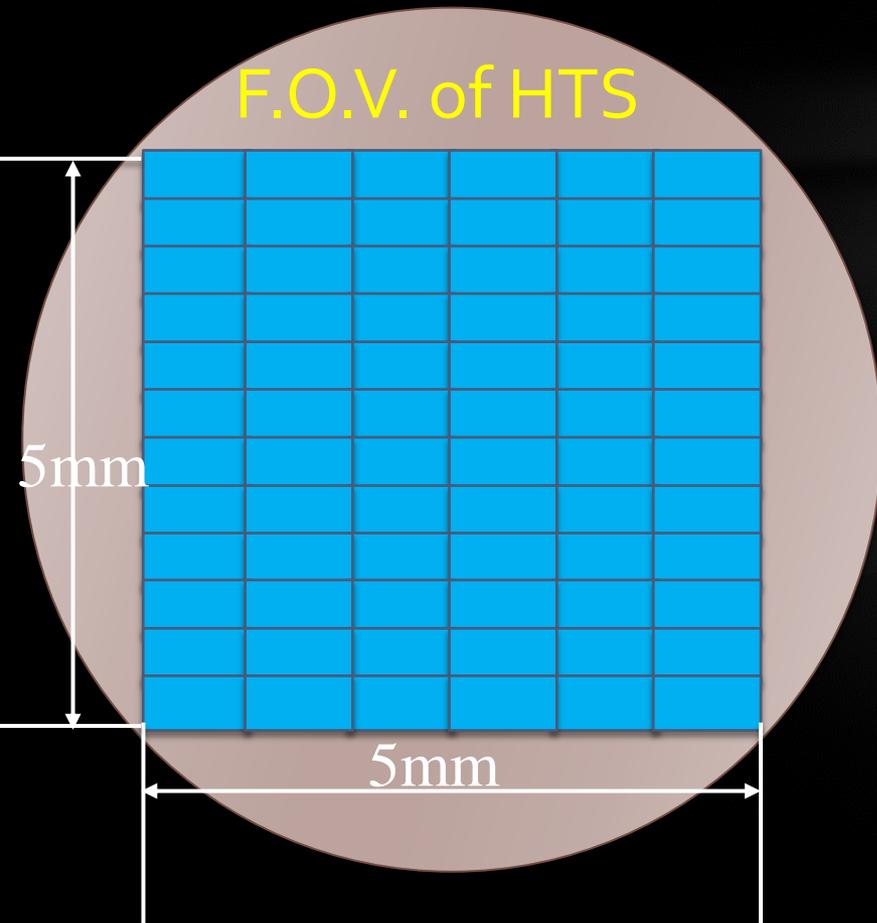
Total length : 844mm



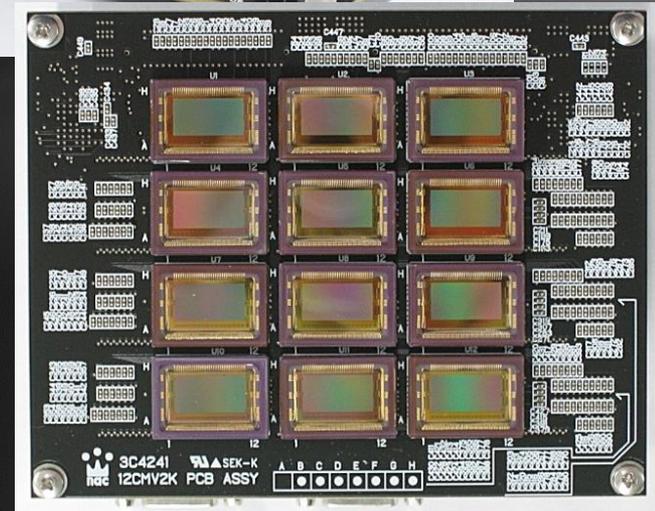
Speed and Coverage of Mosaic Imager

Specially ordered Mosaic Imager

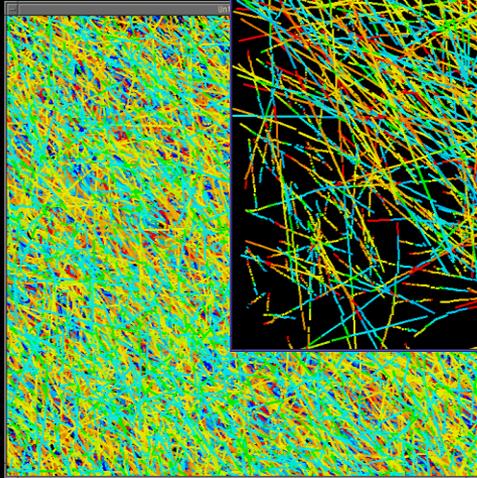
Divide FOV into 72 parts.
Need the sensor of 2M pixel and 340fps.



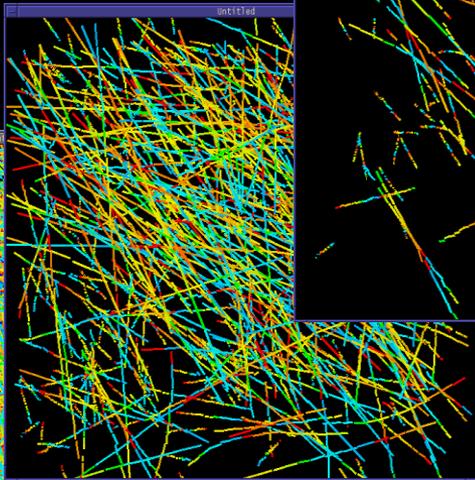
× 6



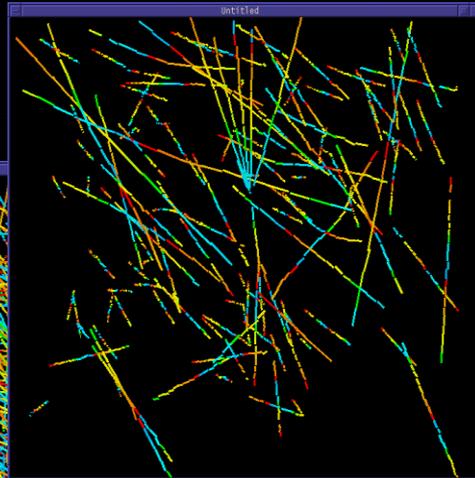
Data taking and offline reconstruction



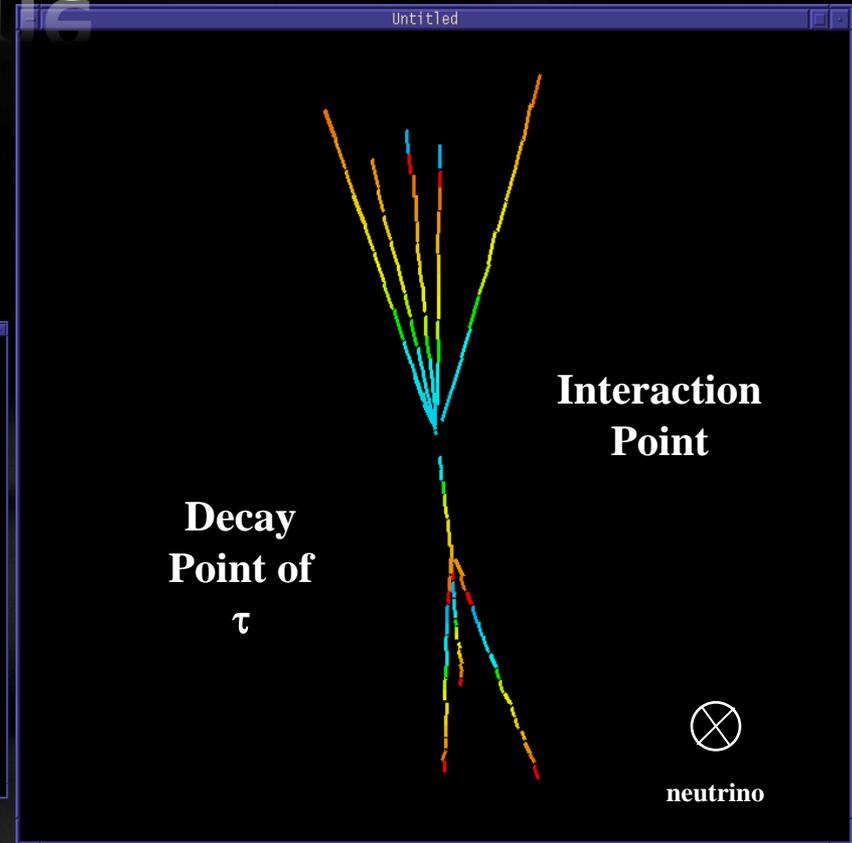
All tracks in the Scanning region (4179 tracks)



Reject passing through tracks (420 tracks remained)



Reject Low momentum tracks (114 tracks remained)



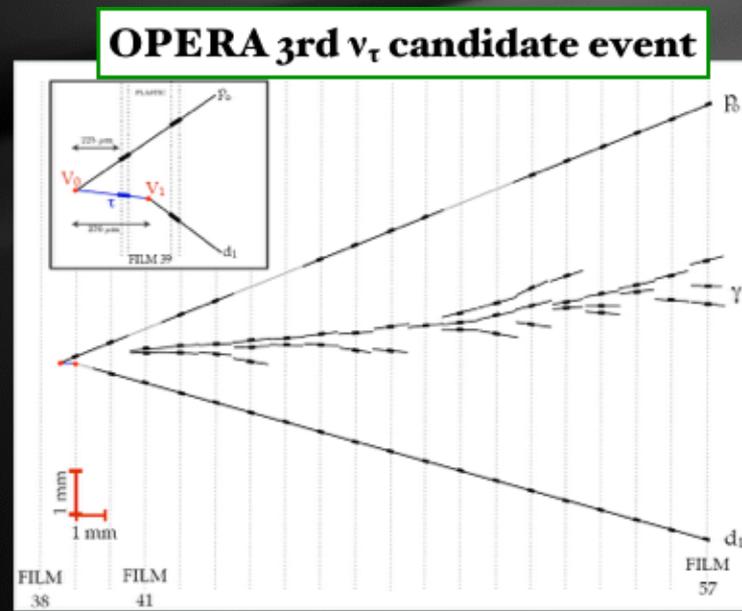
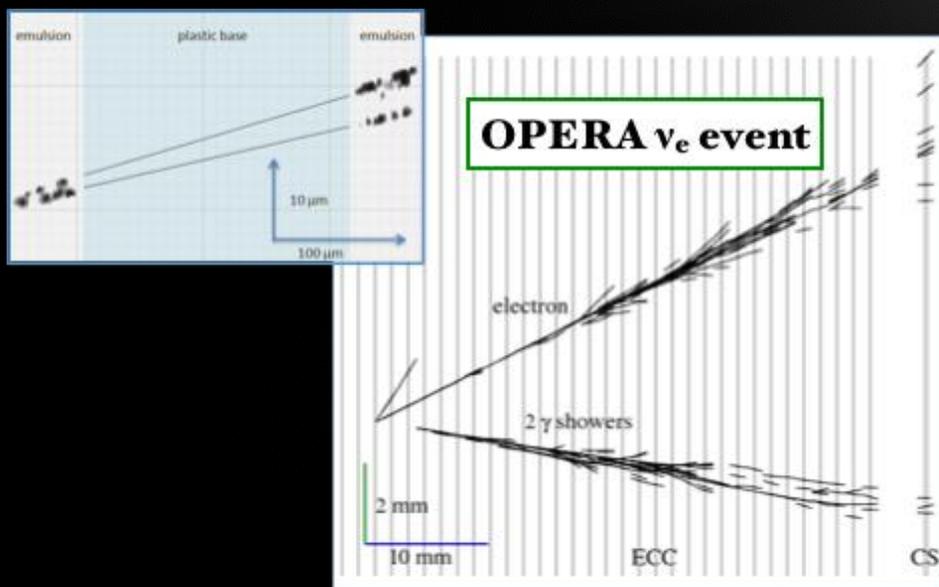
Vertex detection :

Neutrino interaction and decay of short lived particles

Detection of ν_{τ}^{CC} in DONUT

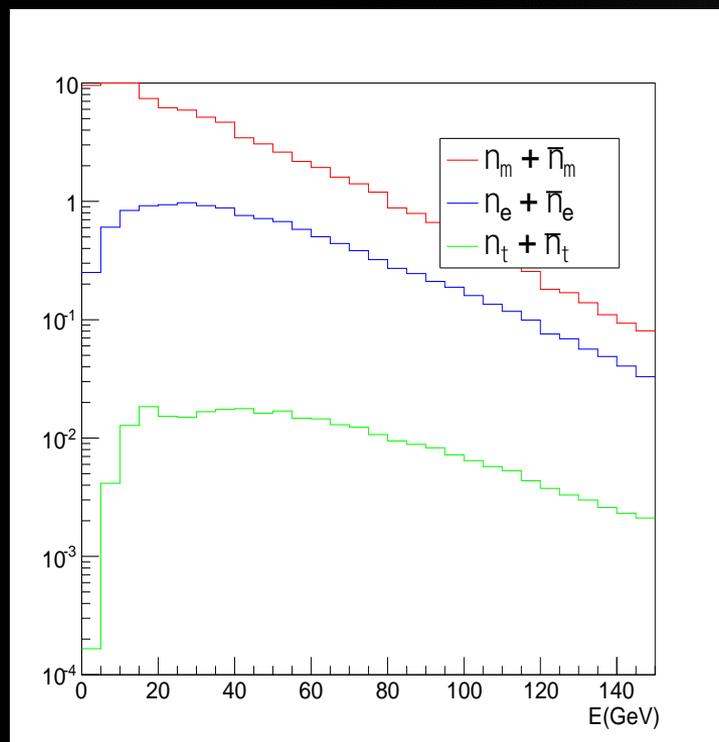
Neutrino Flavor Identification

- ν_μ : muon reconstruction in the magnetic spectrometer
- ν_e : EM shower detection in ECC
- ν_τ : tau decay topological detection and kinematics
 - Also **charge determination by CES**



Neutrino interaction

- Rich tau neutrino content
 - 0.45% relative to muon neutrino
 - 3.0% relative to electron neutrino



	Φ	$\langle E \rangle$ (GeV)
ν_{μ}	1.7×10^6	29
ν_e	2.5×10^5	46
ν_{τ}	7.6×10^3	59
Anti- ν_{μ}	6.7×10^5	28
Anti- ν_e	9.0×10^4	46
Anti- ν_{τ}	3.9×10^3	58

Rates for five years of nominal operation with 2×10^{20} protons on target

Signal and background

**SIGNAL
EXPECTATION**

R=S/B RATIO

BACKGROUND

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

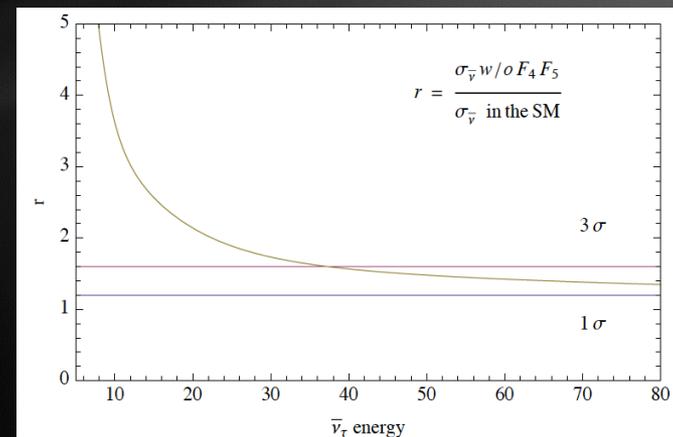
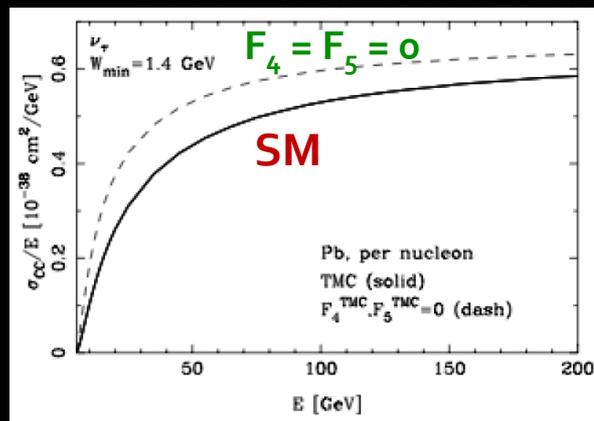
Main background source: **charm production** in ν_μ^{CC} (anti- ν_μ^{CC}) and ν_e^{CC} (anti- ν_e^{CC}) interactions, when the primary lepton is not identified

Physics with tau neutrino DIS

- Structure function only accessible by tau neutrino

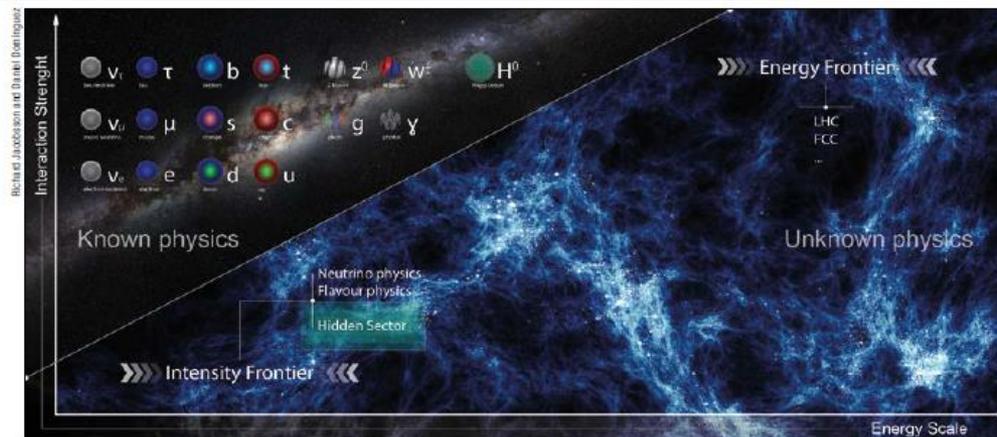
$$\frac{d^2\sigma^{\nu(\bar{\nu})}}{dx dy} = \frac{G_F^2 M E_\nu}{\pi(1 + Q^2/M_W^2)^2} \left((y^2 x + \frac{m_\tau^2 y}{2E_\nu M}) F_1 + \left[(1 - \frac{m_\tau^2}{4E_\nu^2}) - (1 + \frac{Mx}{2E_\nu}) \right] F_2 \right. \\ \left. \pm \left[xy(1 - \frac{y}{2}) - \frac{m_\tau^2 y}{4E_\nu M} \right] F_3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

- Dependent on the lepton mass



Summary and prospect

- ✓ **Unique opportunity to study tau neutrino physics**
 - ✓ We have only 9 (DONUT)+5 (OPERA) tau neutrino CC interactions.
Study with 3500 tau neutrino interaction can be done in SHiP.
 - ✓ Unique chance to study tau and anti tau neutrino cross-section and anti neutrino charm production.
 - ✓ More than one order of magnitude.
- ✓ **Technical Proposal is submitted (April 2015)**
 - ✓ Physics run from 2026 .
 - ✓ Detector design is also under way, CDR in 2018.
- ✓ **SPSC gave positive statement. Proceed to Comprehensive Design Report (CDR) in 2016-2018.**
- ✓ “Physics Beyond Colliders” kickoff workshop just took place at CERN on 6-7 September.



SHiP is a new experiment at the intensity frontier aimed at exploring the hidden sector.

SHiP sets a new course in intensity-frontier exploration

SHiP (Search for Hidden Particles) is a newly proposed experiment for CERN's Super Proton Synchrotron accelerator. Its challenging goals include the direct search for hidden non-Standard Model particles.

A Golutvin, Imperial College London/CERN, and **R Jacobsson**, CERN, on behalf of SHiP.

SHiP is an experiment aimed at exploring the domain of very weakly interacting particles and studying the properties of tau neutrinos. It is designed to be installed downstream of a new beam-dump facility at the Super Proton Synchrotron (SPS). The CERN SPS and PS experiments Committee (SPSC) has recently completed a review of the SHiP Technical and Physics Proposal, and it recommended that the SHiP collaboration proceed towards preparing a Comprehensive Design Report, which will provide input into the next update of the European Strategy for Particle Physics, in 2018/2019.

Why is the SHiP physics programme so timely and attractive? We

have now observed all the particles of the Standard Model, however it is clear that it is not the ultimate theory. Some yet unknown particles or interactions are required to explain a number of observed phenomena in particle physics, astrophysics and cosmology, the so-called beyond-the-Standard Model (BSM) problems, such as dark matter, neutrino masses and oscillations, baryon asymmetry, and the expansion of the universe.

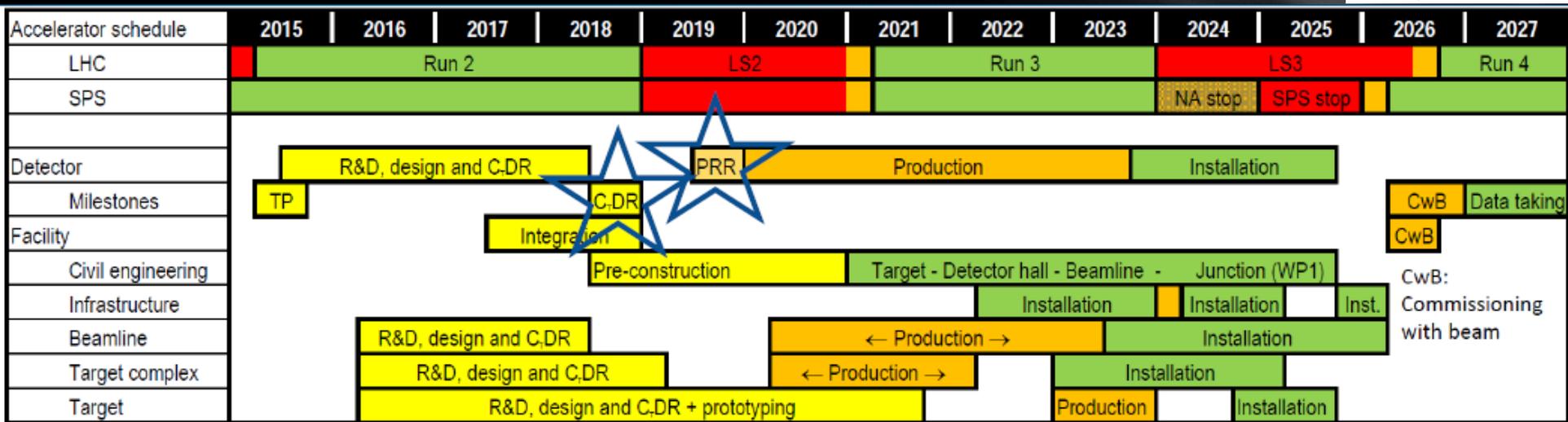
While these phenomena are well-established observationally, they give no indication about the energy scale of the new physics. The analysis of new LHC data collected at $\sqrt{s} = 13$ TeV will soon have directly probed the TeV scale for new particles with couplings at $O(\%)$ level. The experimental effort in flavour physics, and searches for charged lepton flavour violation and electric dipole moments, will continue the quest for specific flavour symmetries to complement direct exploration of the TeV scale.

However, it is possible that we have not observed some of the particles responsible for the BSM problems due to their extremely feeble interactions, rather than due to their heavy masses. Even in the scenarios in which BSM physics is related to high-mass scales, many models contain degrees of freedom with suppressed couplings that stay relevant at much lower energies.

Given the small couplings and mixings, and hence typically long lifetimes, these hidden particles have not been significantly

Backup

Planning schedule of the SHiP



Form SHiP collaboration

→ 2014 Done

Technical Proposal

→ April 2015 Done

Comprehensive Design Report

→ 2016 – 2018

Production Readiness Review

→ End of 2019

Construction / production

→ 2021-

Data taking of 2×10^{20} pot

→ 2026-

Estimated 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

Impact on ν_τ YIELD

$$N_{\nu_\tau + \bar{\nu}_\tau} = 4N_p \frac{\sigma_{c\bar{c}}}{\sigma_{pN}} f_{D_s} Br(D_s \rightarrow \tau) = 2.85 \times 10^{-5} N_p = 5.7 \times 10^{15}$$

$$\sigma_{c\bar{c}} = 18.1 \pm 1.7 \mu\text{barn}$$

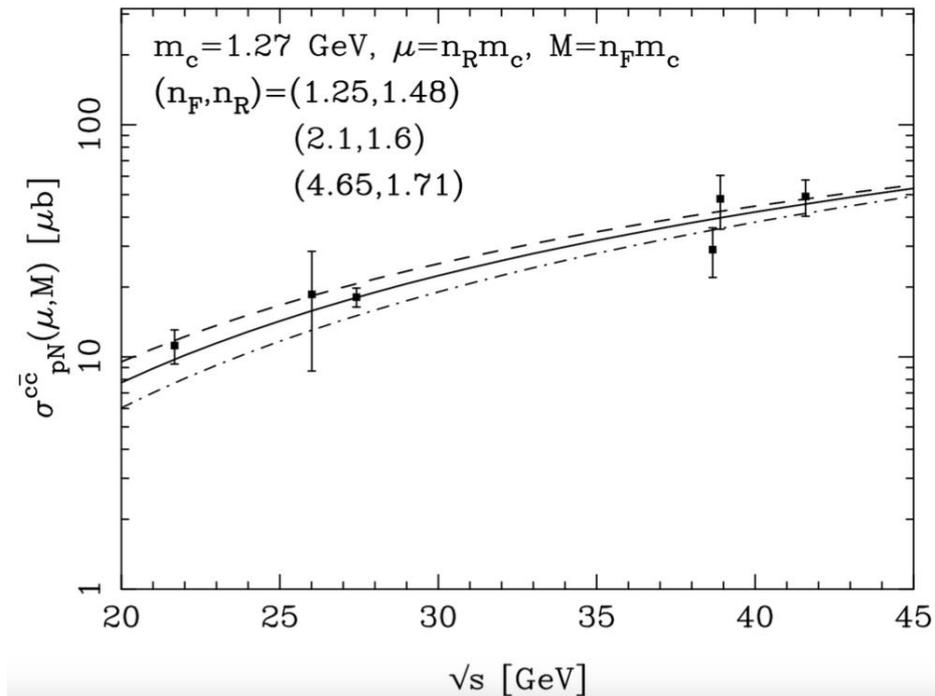
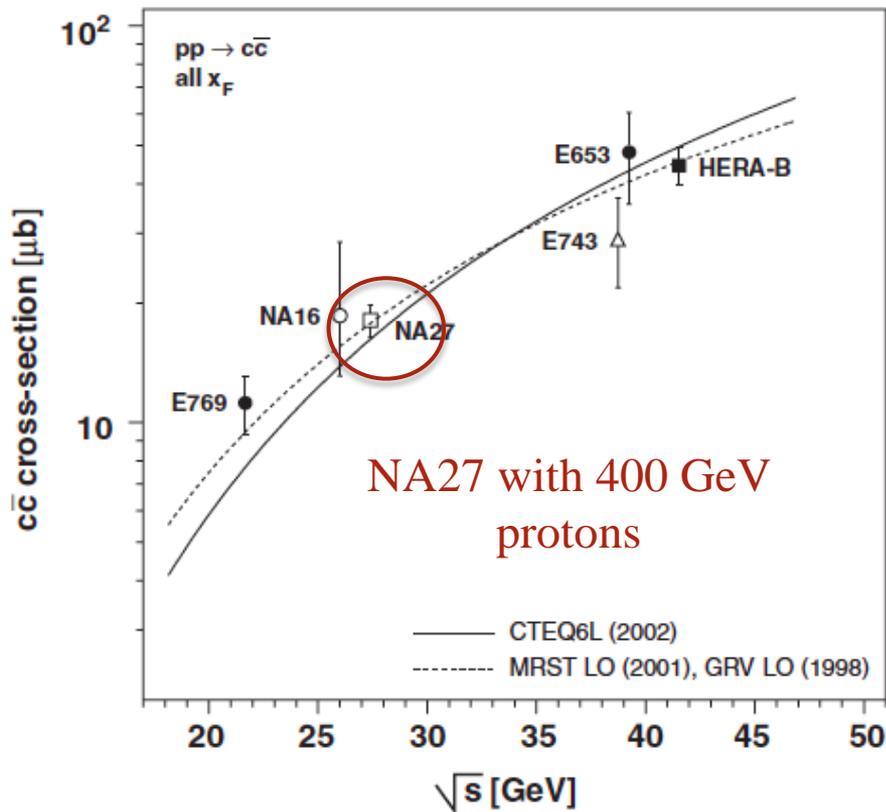
Physics Reports 433 (2006) 127

$$\begin{aligned} \sigma_{c\bar{c}} &\propto A \\ \sigma_{pN} &\propto A^{0.71} \end{aligned}$$

$$Br(D_s \rightarrow \tau) = (5.54 \pm 0.24)\% \quad \text{PDG 2014}$$

$$f_{D_s} = (7.7 \pm 0.6^{+0.5}_{-0.4})\% \quad \text{JHEP 1309 (2013) 058}$$

Charm production vs energy



Cacciari, Greco, Nason JHEP 9805 (1998) 007
 Cacciari, Frixione, Nason JHEP 0103 (2001) 006

[arXiv: 1504.04855](https://arxiv.org/abs/1504.04855) SHiP Physics Proposal

TAU NEUTRINO MAGNETIC MOMENT

A massive neutrino may interact e.m.

→ magnetic moment proportional to its mass

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

Current limits

$$\begin{cases} (\nu_e) & \mu_\nu < 2.9 \cdot 10^{-11} \mu_B \\ (\nu_\mu) & \mu_\nu < 6.9 \cdot 10^{-10} \mu_B \end{cases}$$

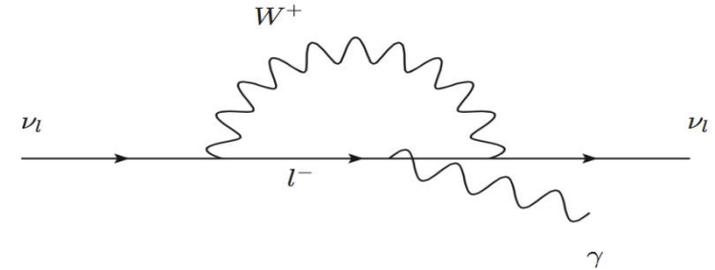
$$\theta_{\nu-e}^2 < 2m_e/E_e$$

SIGNAL SELECTION

$$\begin{cases} \theta_{\nu-e} < 30 \text{ mrad} \\ E_e > 1 \text{ GeV} \end{cases}$$

BACKGROUND PROCESSES

$\nu_x + e^-$	\rightarrow	$\nu_x + e^-$	NC	} 390
$\nu_e(\bar{\nu}_e) + e^-$	\rightarrow	$e^- + \nu_e(\bar{\nu}_e)$	CC	
$\nu_e + n$	\rightarrow	$e^- + p$	QE	} 2440
$\bar{\nu}_e + p$	\rightarrow	$e^+ + n$	QE	
$\nu_e(\bar{\nu}_e) + N$	\rightarrow	$e^-(e^+) + X$	DIS	730



$$\left. \frac{\sigma_{(\nu_e, \bar{\nu}_e)}}{dT} \right|_{\mu_\nu} = \frac{\pi \alpha_{em}^2 \mu_\nu^2}{m_e^2} \left(\frac{1}{T} - \frac{1}{E_\nu} \right)$$

No interference as it involves a spin flip of the neutrino

IN SHiP

$$n_{evt} = \frac{\mu_\nu^2}{\mu_B^2} \int \Phi_{\nu_\tau} \sigma^\mu N_{nucl} dE = 4.3 \times 10^{15} \frac{\mu_\nu^2}{\mu_B^2}$$

Assuming 5% systematics from DIS measurements

SHiP can explore a region down to

$$\mu_\nu = 1.5 \times 10^{-7} \mu_B$$

CHARM PHYSICS @ SHiP

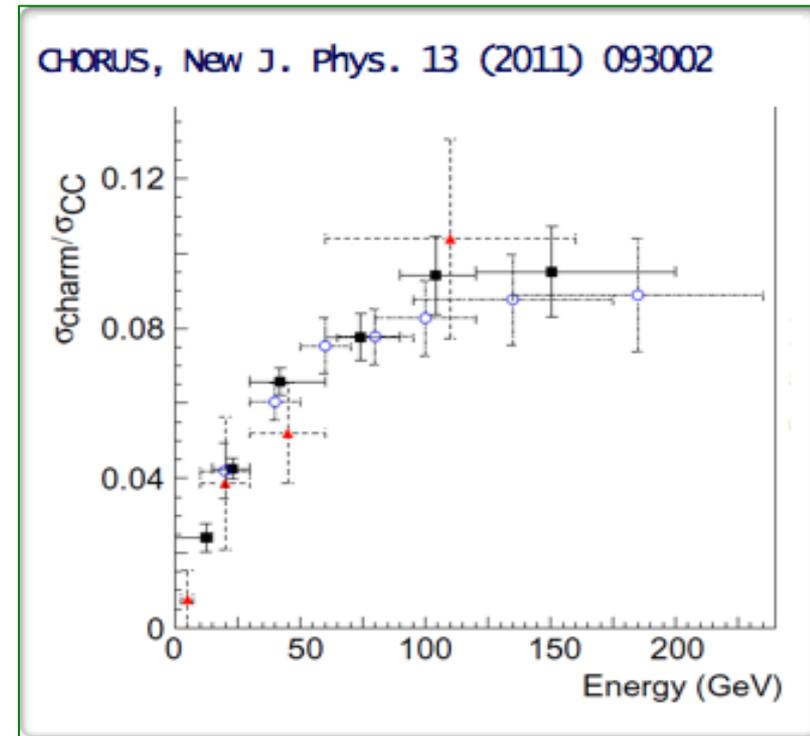
- Fraction of neutrino-induced charm events
- Convolution of CHORUS data with SHiP spectrum

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

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

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

	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	$1.1 \cdot 10^5$



In NuTeV $\sim 5100 \nu_{\mu}$
 $\sim 1460 \text{ anti-}\nu_{\mu}$

In CHORUS $\sim 2000 \nu_{\mu}$
 $32 \text{ anti-}\nu_{\mu}$

No charm candidate from ν_e and ν_{τ} interactions ever reported!