Tau Neutrino Physics in SHiP at CERN

Masahiro Komatsu : Nagoya University

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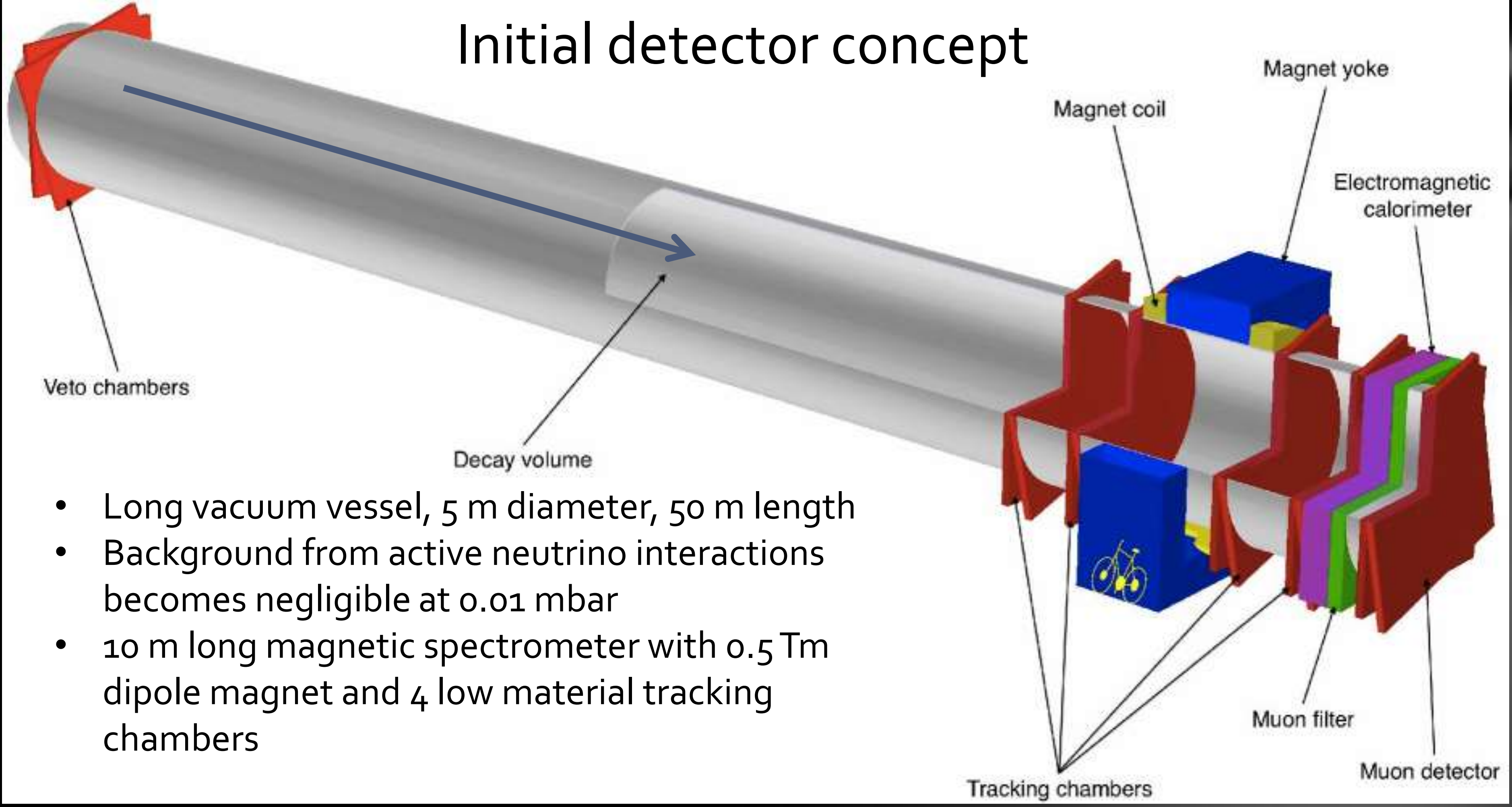
ニュートリノフロンティア研究会

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

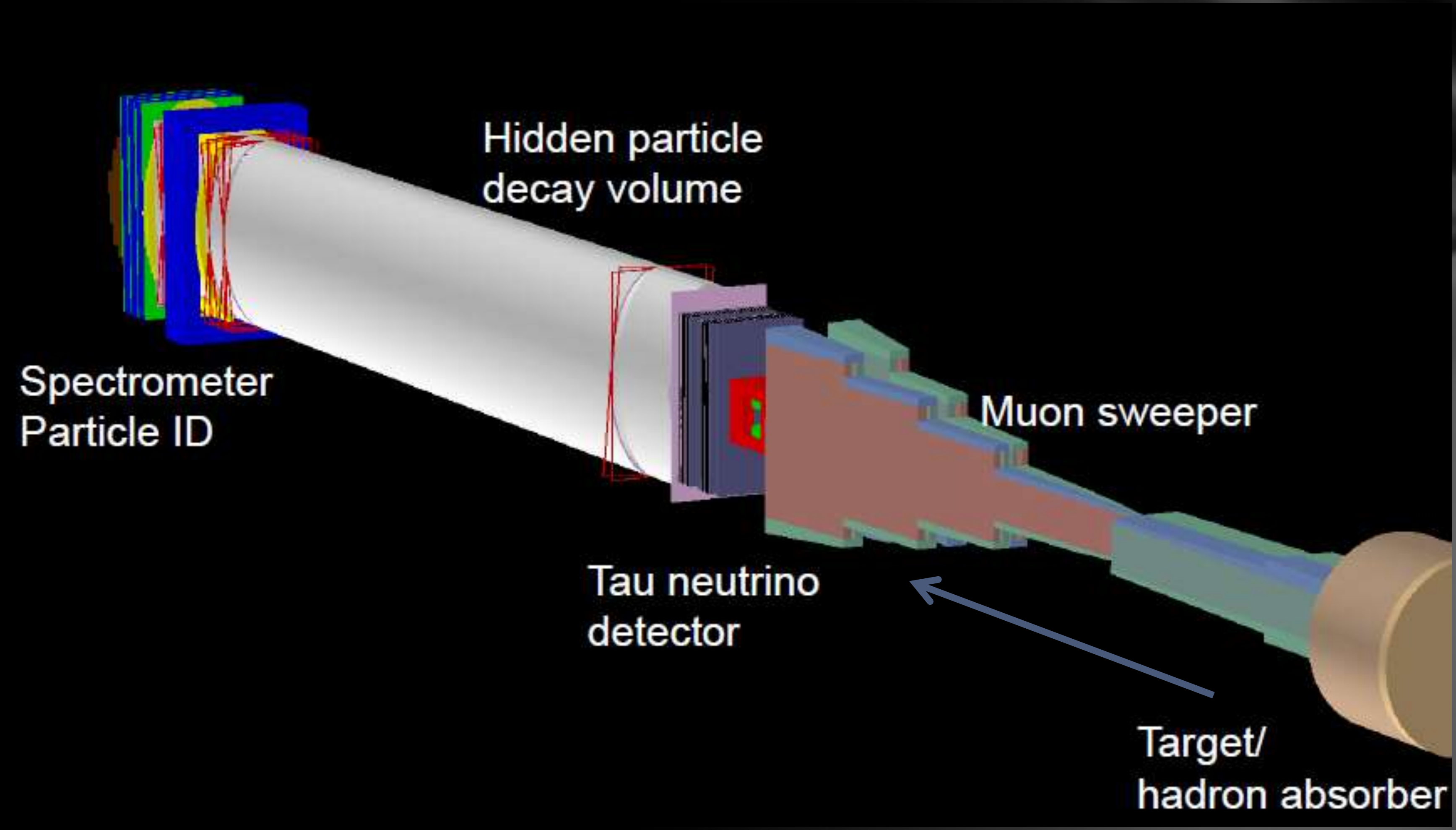
Reconstruction of the HNL decays in the final states: $\mu^-\pi^+$, $\mu^-\rho^+$ & $e^-\pi^+$

Initial detector concept



- Long vacuum vessel, 5 m diameter, 50 m length
- Background from active neutrino interactions becomes negligible at 0.01 mbar
- 10 m long magnetic spectrometer with 0.5 Tm dipole magnet and 4 low material tracking chambers

Design with tau neutrino detector

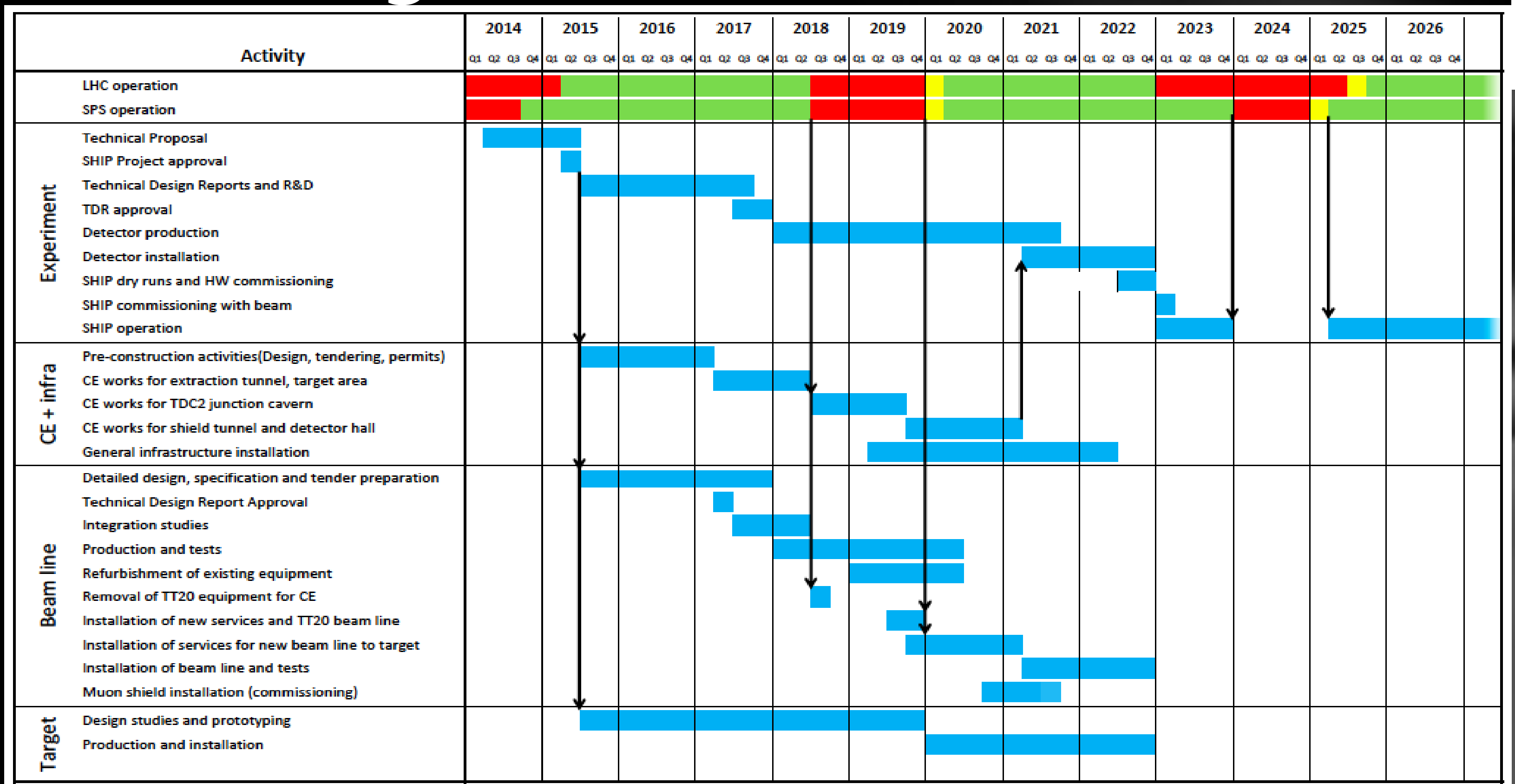


SHiP (Search for Hidden Particles) Main Objectives in Physics

- 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 in 6 tons emulsion target)
  - ν_τ and anti- ν_τ physics
  - Charm physics in neutrino and anti-neutrino interactions
  - Physics in ν_τ scattering, magnetic moment, structure function.

Planning schedule of the SHiP

SHiP
Search for Hidden Particles



Form SHiP collaboration → 2014
Technical Proposal → 2015
Technical Design Report → 2018
Construction and installation → 2018-2022
Commissioning → 2022
Data taking and analysis of $2x10^{20}$pot → 2023-2027

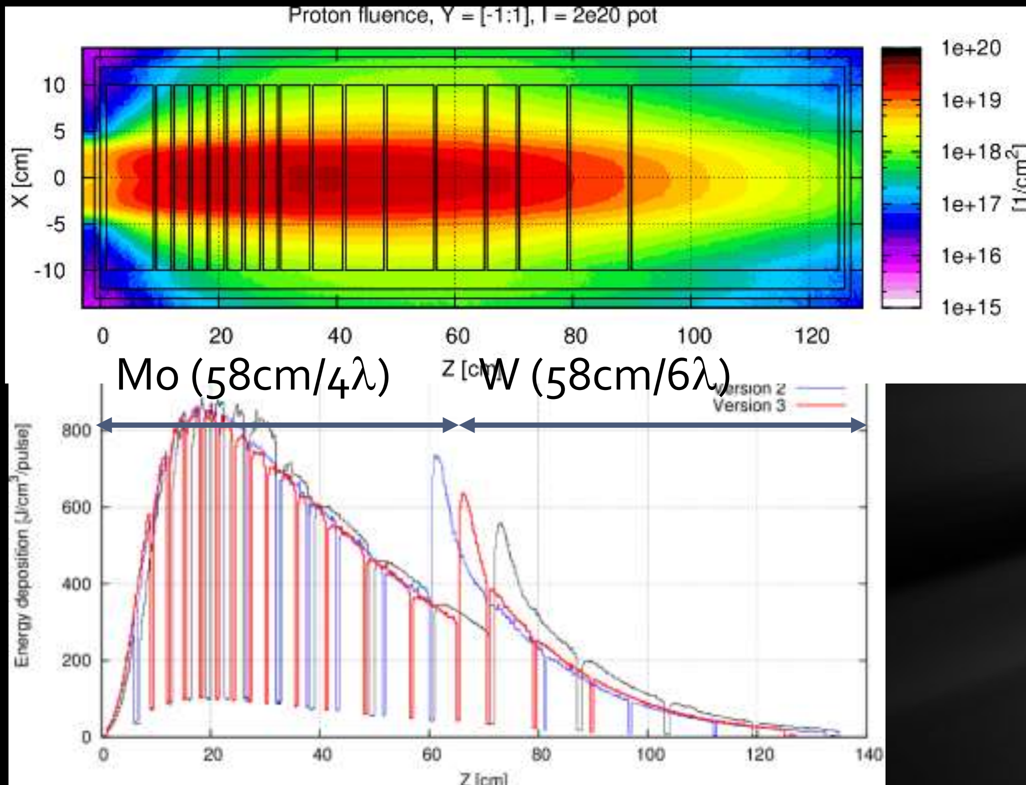
Location

North area

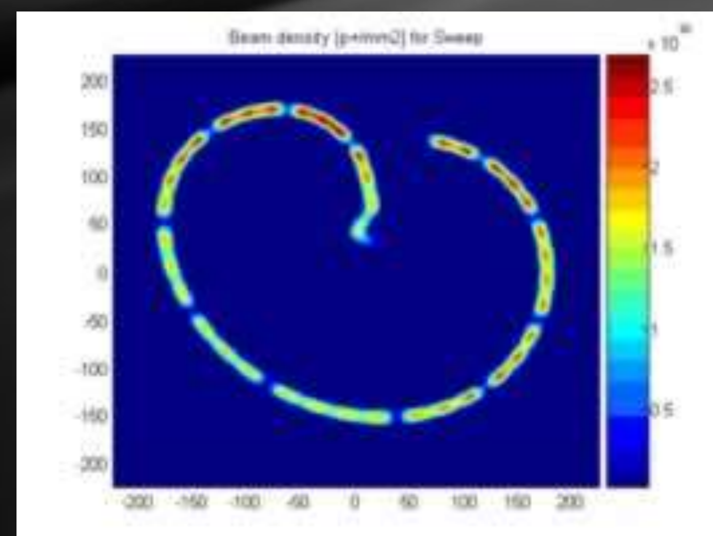
Beam parameters for SHiP

- Proton beam
  - Momentum : 400GeV/c
  - Beam intensity : 4.5×10^{13} /cycle
  - Cycle length : 7.2 s
  - Spill duration : 1 s (slow spill)
  - Average power : 400kW (during spill ~3MW)
  - Expected spot size (H/V) : 6mm/6mm
- 4×10^{19} pot / year → 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

Tau neutrino physics in SHiP

- Tau neutrino so far detected
  - 9 (7.5) in DONUT (first observation)
  - 4 in OPERA (oscillation)
- Tau neutrino cross-section measurement
- Anti tau neutrino detection and cross-section
  - Muonic channel to determine anti neutrino
  - Also hadronic channel in case of magnetized option.
- Charm physics with neutrino and anti neutrino
- Electron neutrino study in high energy range.
  - Also important for normalization of charmed hadron production in the beam dump target. Important for NHL.

Working hypothesis from DONUT

- Charm production by 400GeV, detector acceptance at 60m and tau neutrino cross-section
  - DONUT/SHiP → 1/(0.36 x 0.2 x 0.52) ~ 27
- Proton on target for SHiP and DONUT
  - SHiP/DONUT → $2 \times 10^{20} / 3.6 \times 10^{17}$ ~ 560
- Overall advantage against DONUT → 560/26 ~ 20

- Expected yield with same target mass (260kg)
  - (9 -1.5BG) x 20 ~ 150 tau neutrino events
- Assuming 6 tons of target mass
  - 6000kg / 260kg x 150 ~ 3500 (tau and anti tau neutrino interactions)
- Assuming OPERA like brick (8.3kg) → 750 bricks

Expected neutrino interactions

- Basic number from beam simulation / 10^{18} pot
  - 300 ν CC/190kg → 300 ν CC/ 22 bricks → 13 ν CC / brick
  - 2600 ν CC / brick / 2×10^{20} pot

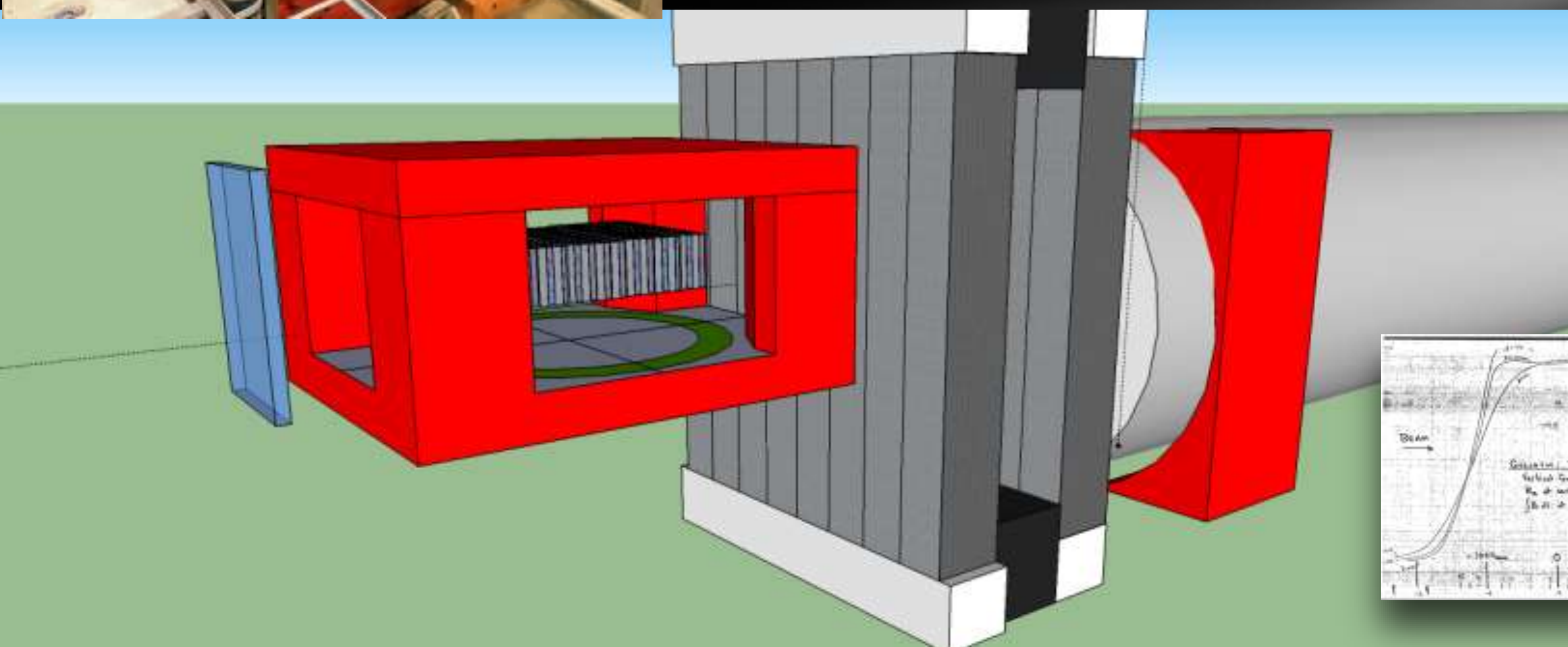
- Other way around : Starting from 3500 tau in 6 tons
  - 30% efficiency → 10000 tau
  - Expected relative ν_τ yield : ν_τ / ν_{int} ~ 0.5%
  - 2×10^6 ν_{int} in 750 bricks for 2×10^{20} pot
  - 2700 ν_{int} / brick / 2×10^{20} pot

- 10 times of exchange reduce to 270 / brick

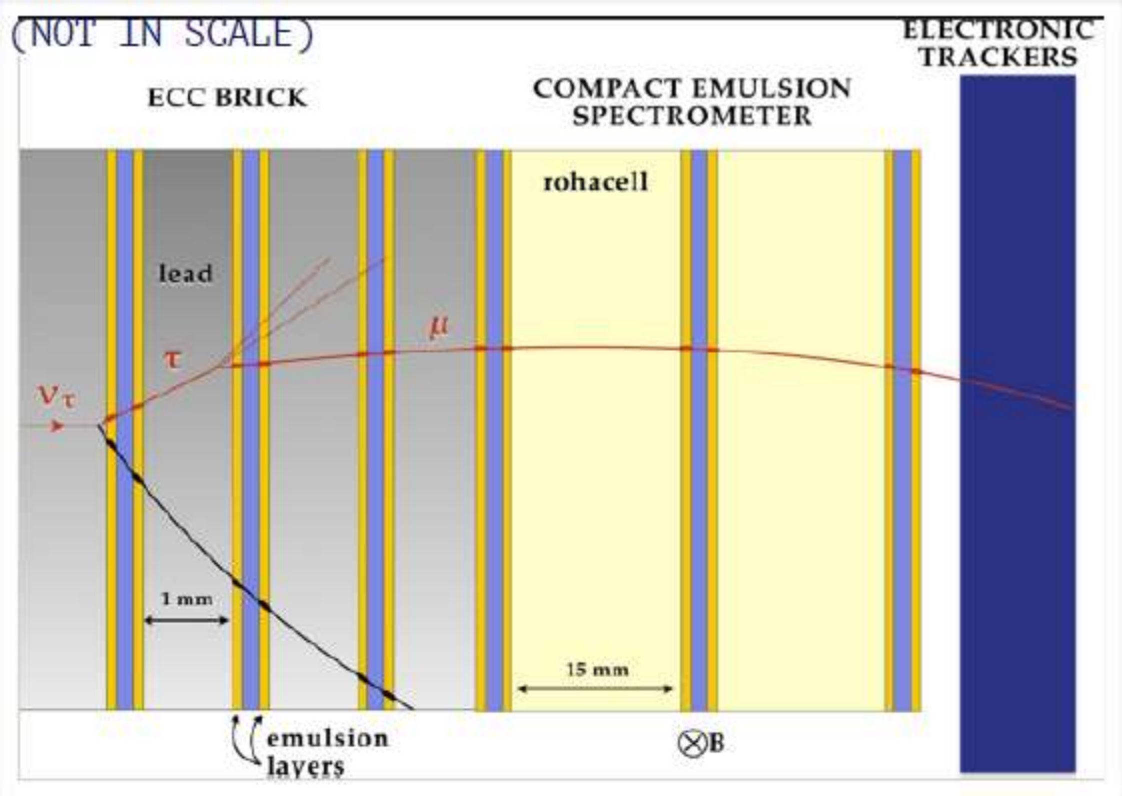
SHiP Search for Hidden Particles

Magnetized option with CES

Charge determination not only for 18% of muonic decay, but also for hadronic decay mode to identify anti neutrino.



Detector design with CES



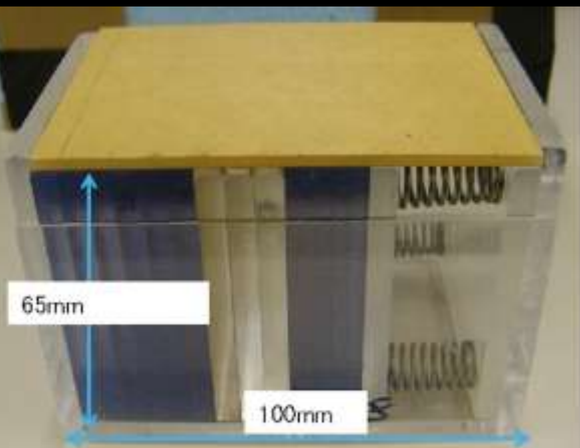
Target region: 15 mini-walls
One wall contains 48 bricks
Mass ~ 8.3kg x 48 x 15 ~ 6 ton

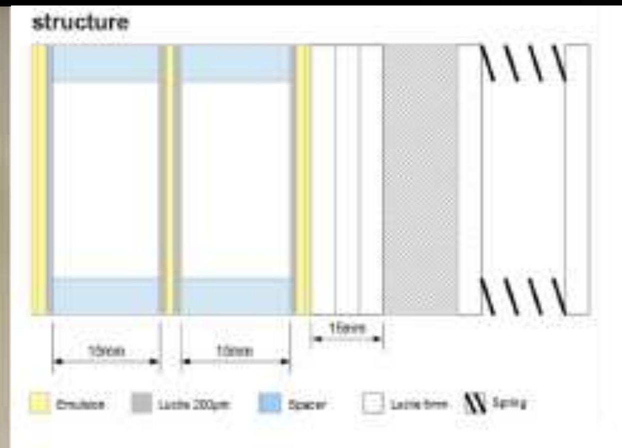
Charge determination not only for muonic channel.

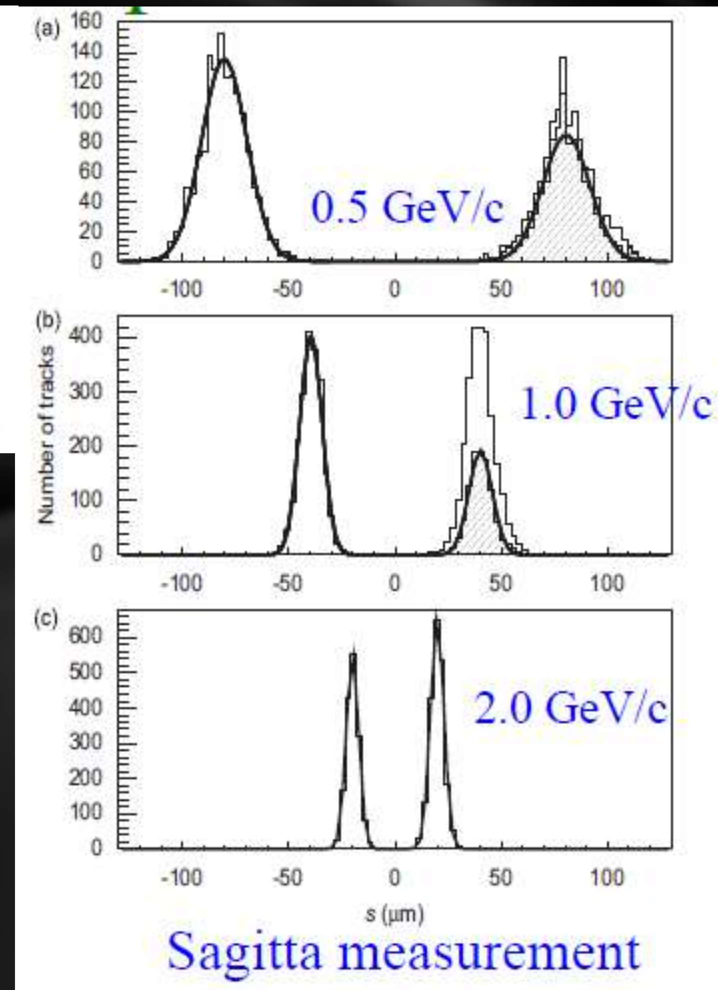
MC simulation of CES provide 53% charge determination for hadrons

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 (~1T), 3cm thick compact spectrometer.

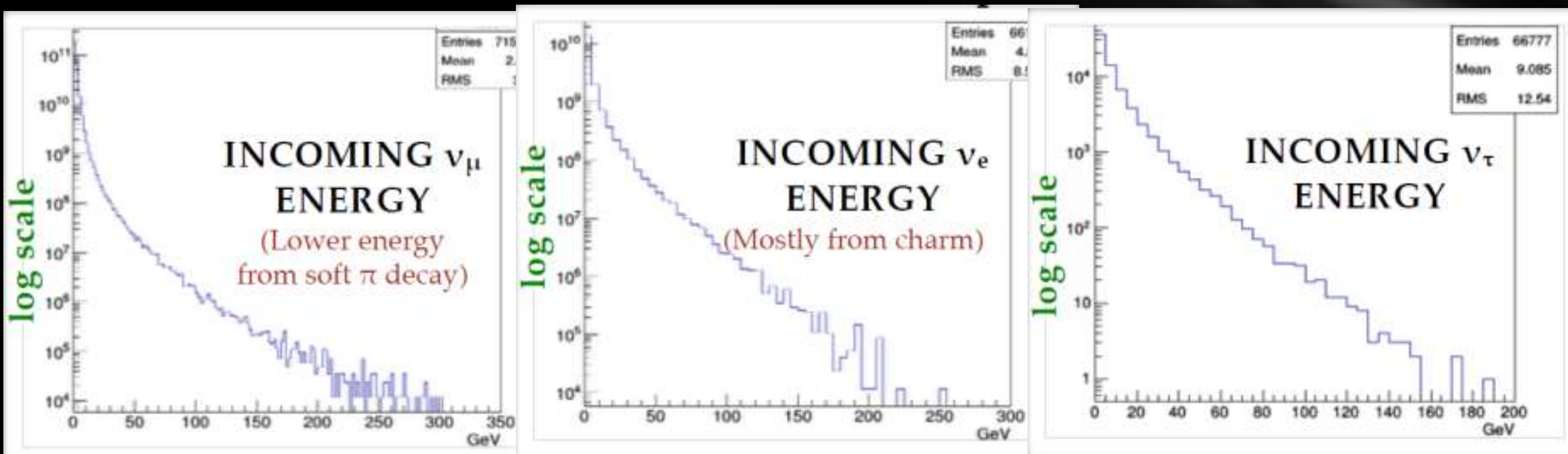
H. Shibuya et al, NIM A592 (2008) 56

Tau Neutrino detector

- 750 bricks to be replaced 10 times, equivalent to 5400 m^2 of emulsion films ~ 5% of the OPERA production (Fujifilm, Japan)
  - New film production (@Nagoya)
  - The exposure will last a few months. T ~ 20 degree is fine, to be kept constant within 1 degree. Humidity around 50 to 60%.
- Scanning time with modern automated technologies is not an issue.
- 750 Brick manufacturing every 6 months demands a single piling station (BAM like or semiautomatic) + manual Al tape wrapping station.

Neutrino beam in SHiP

92.5% 7.1% 0.4%



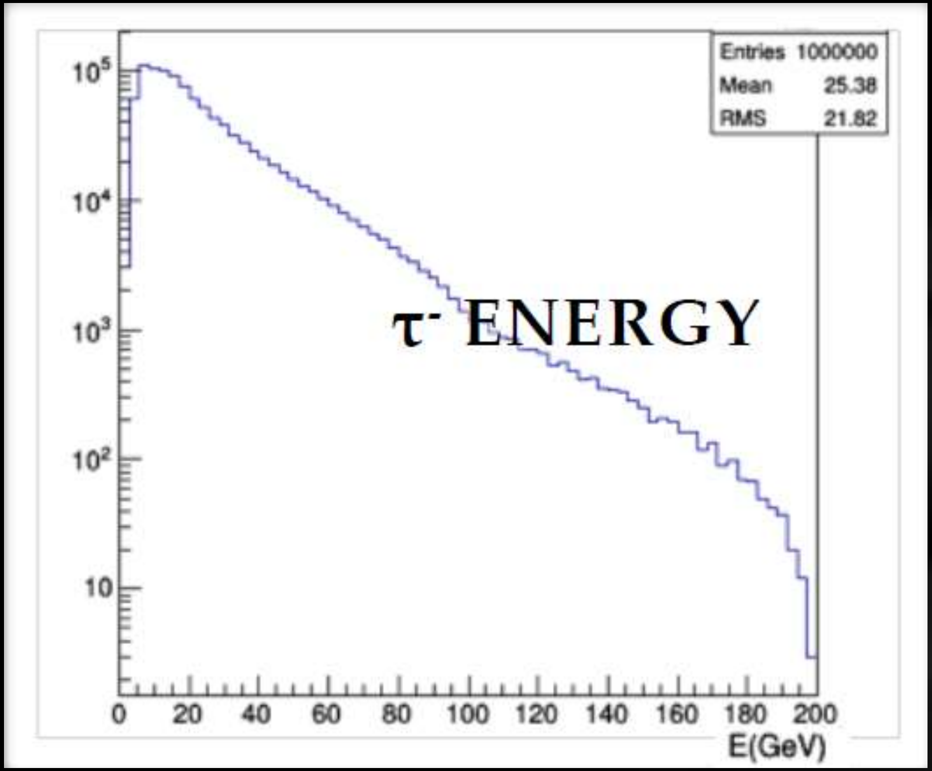
Muon neutrino have low energy component from pion decay.

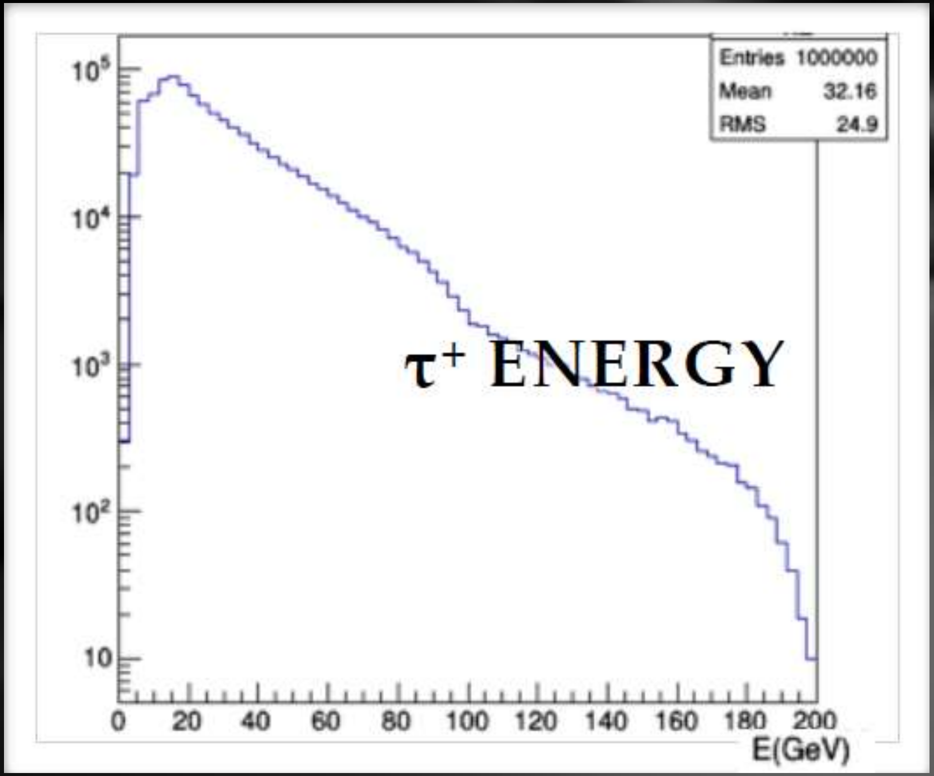
Electron neutrino is mostly coming from charm decay. Good for charm production normalization.

Tau neutrino is coming from Ds and tau decay

New spectrum with 10λ target design is under preparation. Current value is based on 5λ W + 3m iron stopper.

Tau neutrino in SHiP beam





Average interacted tau neutrino energy is 42GeV for both tau and anti-tau neutrino.

Summary and prospect

- Unique opportunity to study tau neutrino physics
  - We have only 9 (DONUT)+4 (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.
    - 11,000 charm + 3500 anti-charm (2000 + 32 in CHORUS)
- Technical Proposal is under way (2015)
  - Physics run from 2023 .
  - Detector design is also under way, TDR in 2018.
- Additional experimental study is required on tau neutrino flux. Better than 10% accuracy is mandatory.
  - Separated experiment is under consideration.

The first skipper of the SHiP

15th December 2014 @ CERN

Andrey Golutvin (Imperial College London)

So far 170 crew on board from 44 groups 13 countries.

Thank you

Backup

Important issues for emulsion

- Integrated μ flux (<< 10^6 / cm2)
  - Fermilab E653 : beam density @ 5×10^5 /cm2
  - Downstream density with 2ry tracks ~ 10^6 /cm2
- Both passive and active (magnet) shield is in study
  - Expected muon flux without shield ~ 350kHz/cm^2
  - 10^{-6} reduction → 0.35Hz/cm^2 and 10 times of emulsion exchange in 5 years.
  - 4.5×10^{13} pot in 1s : 2×10^{19} pot in a half year → 4×10^5 cycles
  - → 1.4×10^5 μ /cm^2
  - New active magnet design provide no muon BG for 10^9 pot
- Combination of active and passive shield will suffice.