Search for Hidden Particles with SHiP

C.S.Yoon (GNU)

On behalf of the SHiP Collaboration

12th Patras Workshop on Axions, WIMPs and WISPs
20-24 June 2016 at Jeju, Korea

Physics Motivation

Higgs discovery

SM very successful but incomplete ···

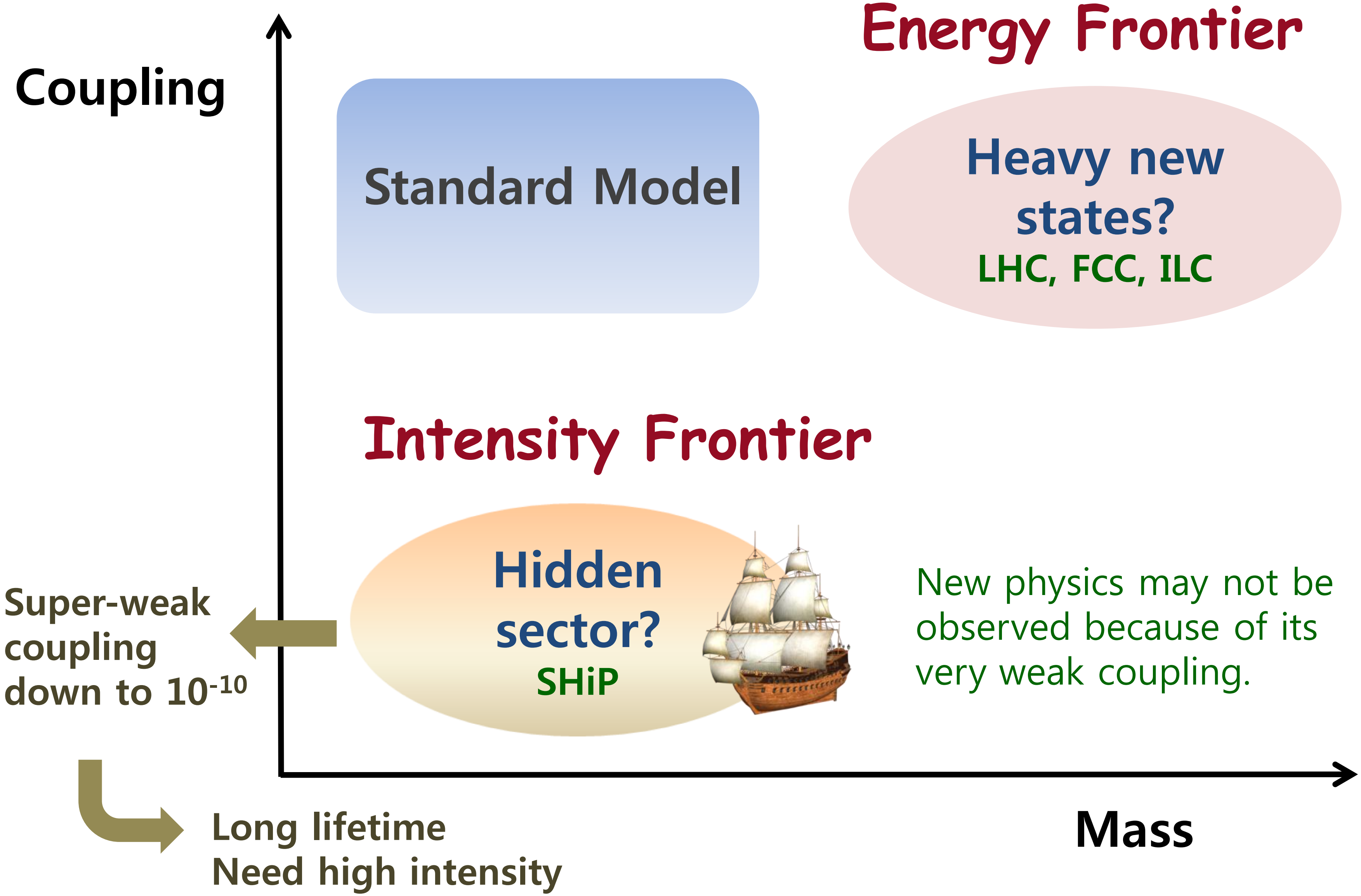
Baryon asymm
Dark matter
Neutrino mass
Inflation …

Beyond SM

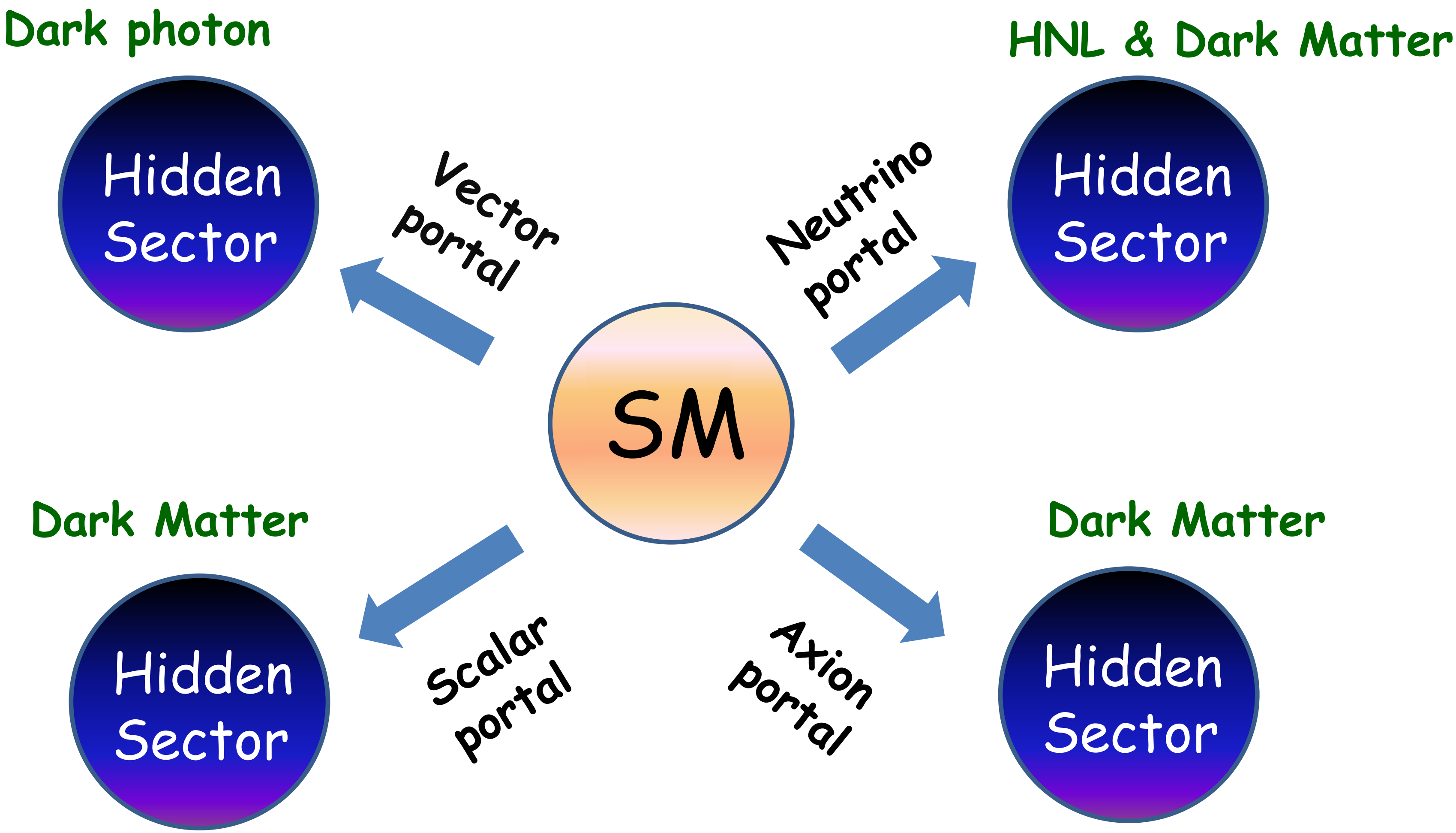
so far Neutrino osc. only

Search for New Physics

Where is the New Physics ?



Extensions of SM



Many hidden sector models often include **low mass particles below the GeV scale** (dark matter candidates).

Neutrino portal

νMSM

↓

Economic theory to be able to explain

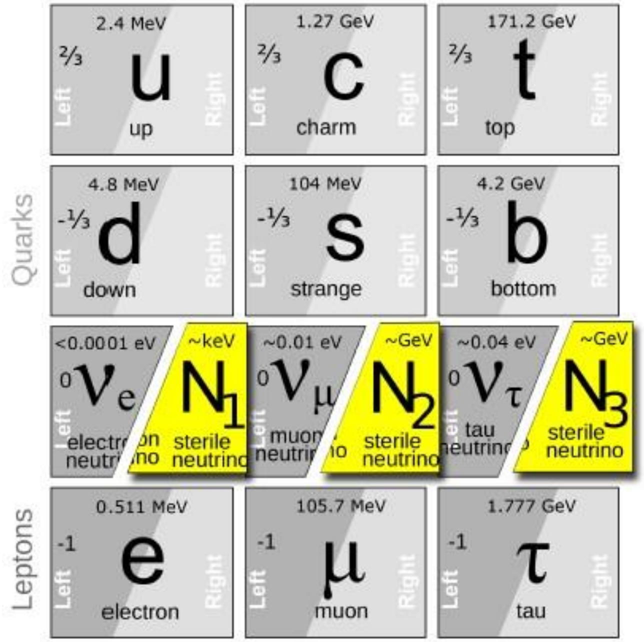
Baryon asymm

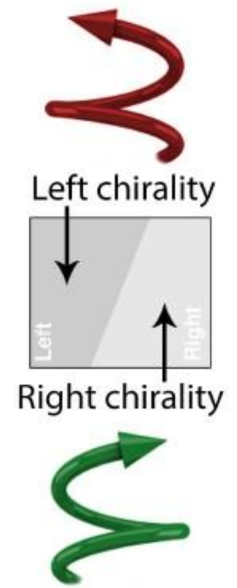
Dark matter

Neutrino mass

νMSM

Extends SM by RH partners of neutrinos
T.Asaka, M.Shaposhnikov
PLB 620 (2005) 17





N_1 (~10 keV)

Dark matter candidate

$N_{2,3}$ (100 MeV~GeV)

Matter−Antimatter asymmetry
Neutrino mass (oscillation)

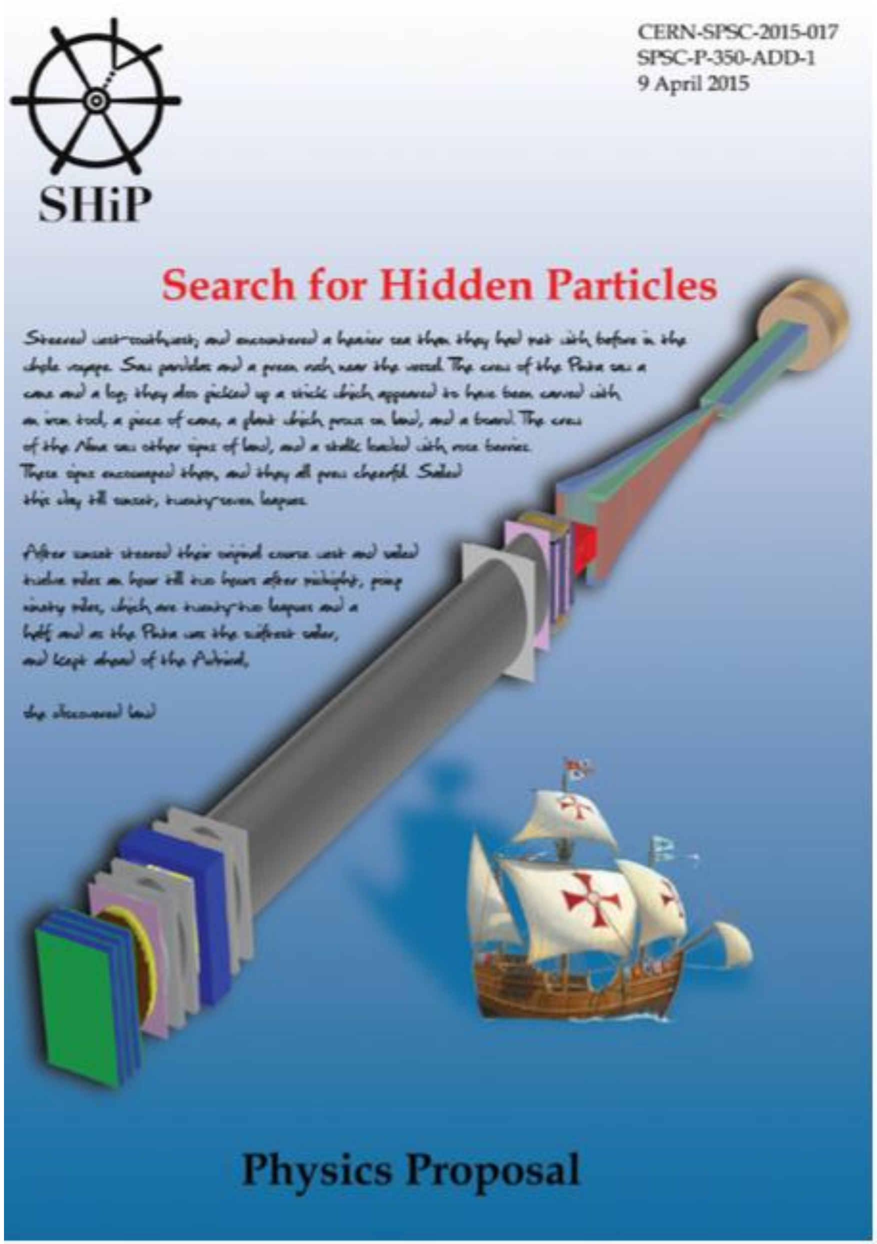
N = Heavy Neutral Lepton (HNL)

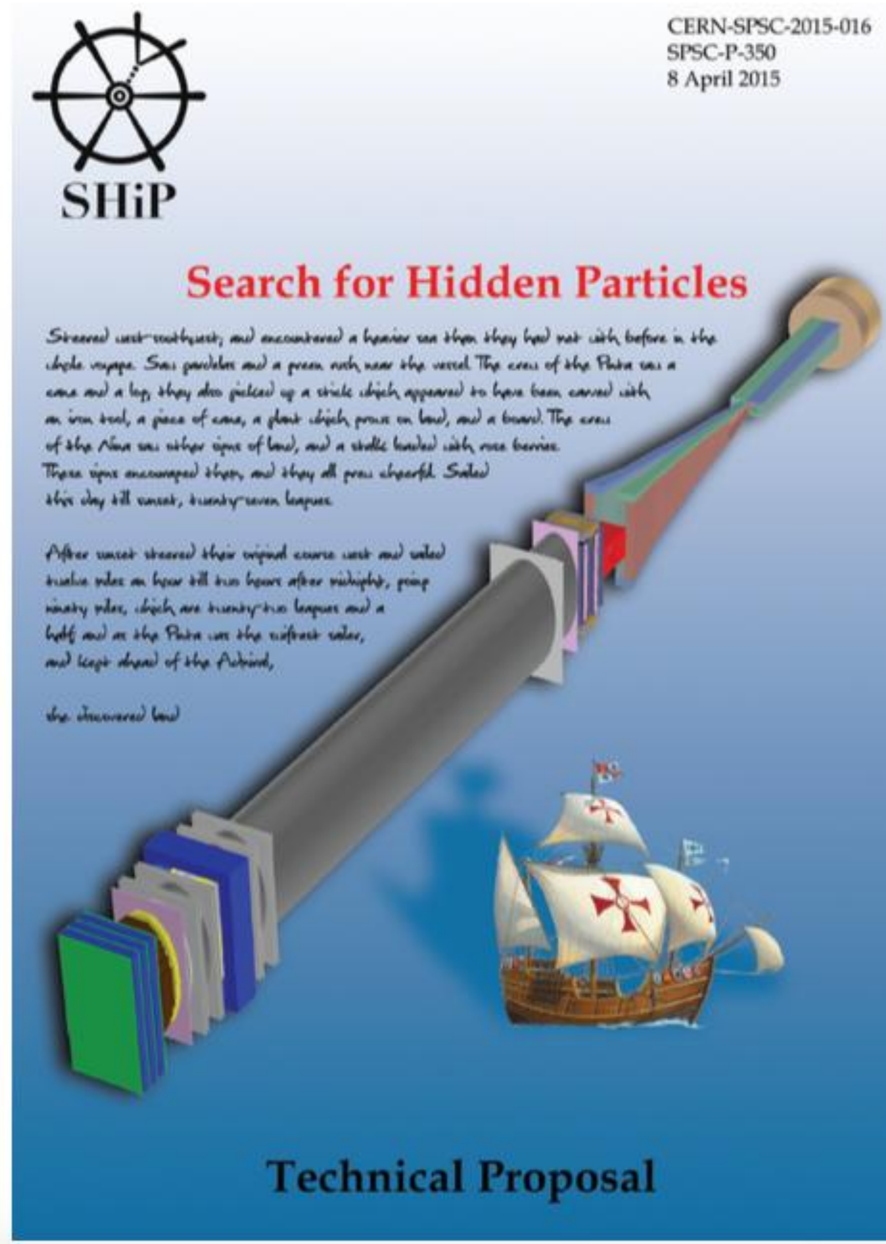
Majorana partners of active neutrinos
Sterile RH neutrinos

SHiP experiment
Search for Hidden Particles

A new experiment proposed at CERN in order to search for **Hidden particles** **with mass from sub-GeV up to *O*(10) GeV** with super-weak coupling down to 10^{-10}, and also to study **Tau neutrino physics**.

Using High-intensity
400 GeV proton beam:
2 x10^{20} pot, 5 years run


CERN-SPSC-2015-017
SPSC-P-350-ADD-1
9 April 2015
SHiP
Search for Hidden Particles
Physics Proposal


CERN-SPSC-2015-016
SPSC-P-350
8 April 2015
SHiP
Search for Hidden Particles
Technical Proposal

Physics proposal

A facility to Search for Hidden Particles at the CERN SPS: the SHiP physics case

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Abstract: Th ... CERN SPS. The SHiP (*Search* ... hunt for new physics in the largely unexplored do ... particles with masses below the Fermi scale, inaccessible to the LH ... experiments, and to study tau neutrino physics. The same proton beam setup can be used later to look for decays of tau-leptons with lepton flavour number non-conservation, $\tau \to 3\mu$ and to search for weakly-interacting sub-GeV dark matter candidates. We discuss the evidence for physics beyond the Standard Model and describe interactions between new particles and four different *portals* — scalars, vectors, fermions or axion-like particles. We discuss motivations for different models, manifesting themselves via these interactions, and how they can be probed with the SHiP experiment and present several case studies. The prospects to search for relatively light SUSY and composite particles at SHiP are also discussed. We demonstrate that the SHiP experiment has a unique potential to discover new physics and can directly probe a number of solutions of beyond the Standard Model puzzles, such as neutrino masses, baryon asymmetry of the Universe, dark matter, and inflation.

85 theorists, 65 institutes
200 pages

arXiv:1504.04855 (hep-ph)

Technical proposal

SHiP

Technical Proposal

Apr 2015

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

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.

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235 physicists, 45 institutes,
13 countries

arXiv:1504.04956 (hep-ph)

Main objectives

SHiP
Search for Hidden Particles

✔ Hidden particles

Heavy Neutral Leptons (HNL)
Dark photons
Hidden Scalar
Axion Like Particles
Low energy SUSY particles etc.

✔ Tau neutrinos

Expect ~3500 ν_τ interactions
in 6 tons Emulsion target

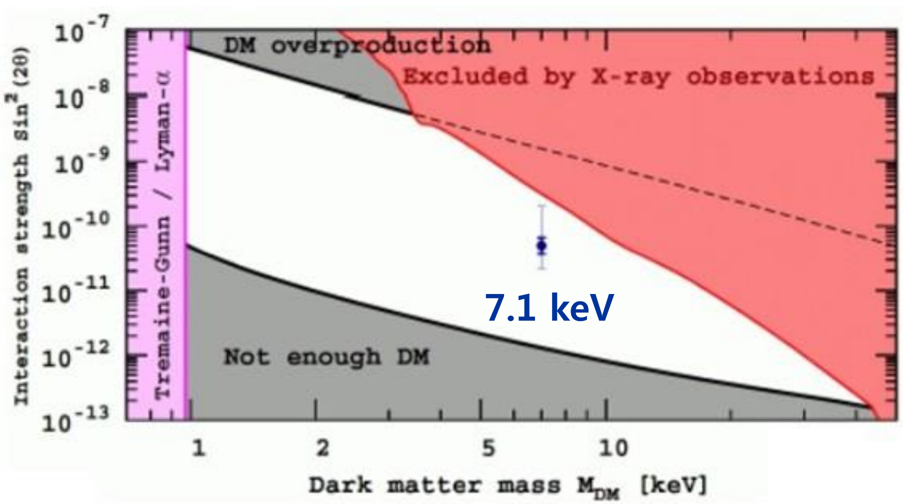
ν_τ and **Anti-ν_τ** physics (Cross section ...)

N_1 Heavy Neutral Lepton

N_1 should be sufficiently stable
→ super-weak N_1-to-ν mixing
such that $\tau(N_1) > \tau(\text{Universe})$

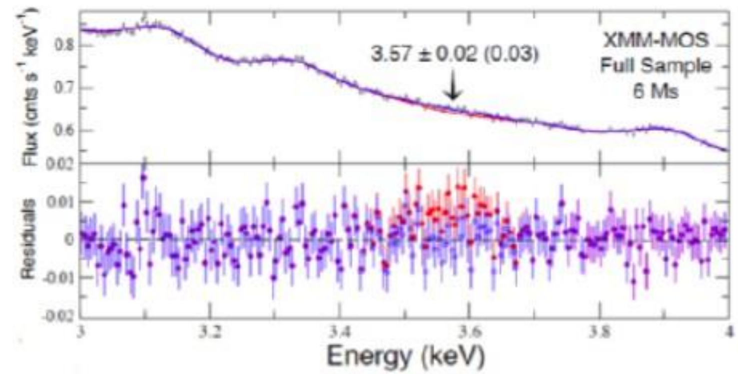
Observable decay mode: $N_1 \rightarrow \nu\gamma$
→ search for mono-line in galactic photon spectrum, $E\gamma = M_N / 2$

can be Light DM candi
hard to see in SHiP



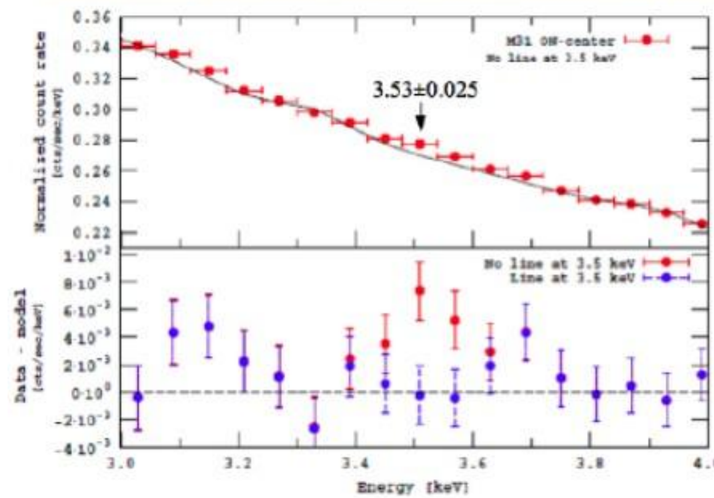
3.5 keV X-ray line
in Galaxy clusters

Bulbul et. al. (1402.2301)



M_{N1} = 7.1 keV
$U^2 \approx 7 \times 10^{-11}$

Boyarsky et. al. (1402.4119, 1408.2503)



M_{N1} = 7.06 ± 0.05 keV
$U^2 \approx (2.2\text{-}20) \times 10^{-11}$

$N_{2,3}$ Production

2×10^{20} pot
(10^{17} D, 10^{14} B,
10^{15} τ)

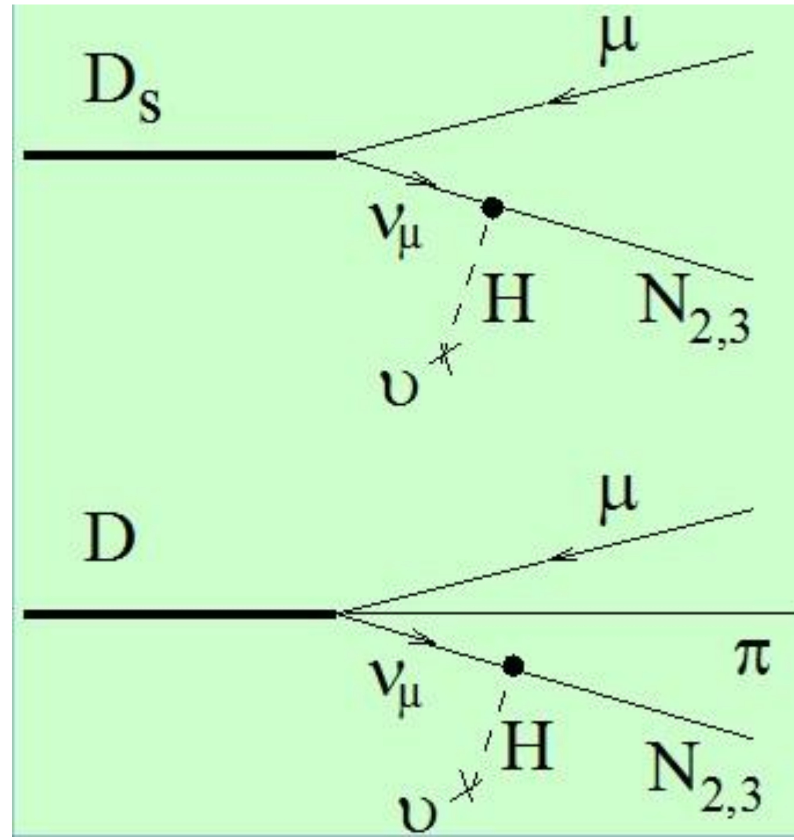
$D_S \rightarrow \mu N_{2,3}$

$D \rightarrow \pi \mu N_{2,3}$

Decay of **Charm & Beauty** Particles (above Kaon mass)

Super-week coupling

→ long lifetime



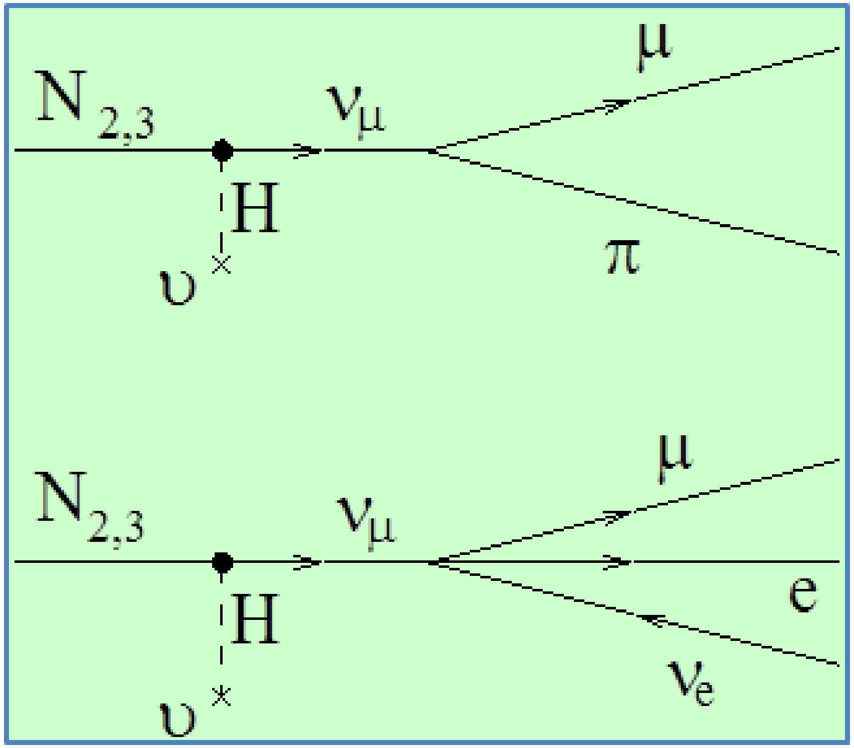
HNL mix with active ν

$N_{2,3}$ Decay

$N \rightarrow \mu^- \pi^+$
$\rightarrow e^- \pi^+$ } 0.1~50%

$N \rightarrow \mu^- \rho^+$
$\rightarrow e^- \rho^+$ } 0.5~20%

$N \rightarrow \nu \mu e$ 1~10%

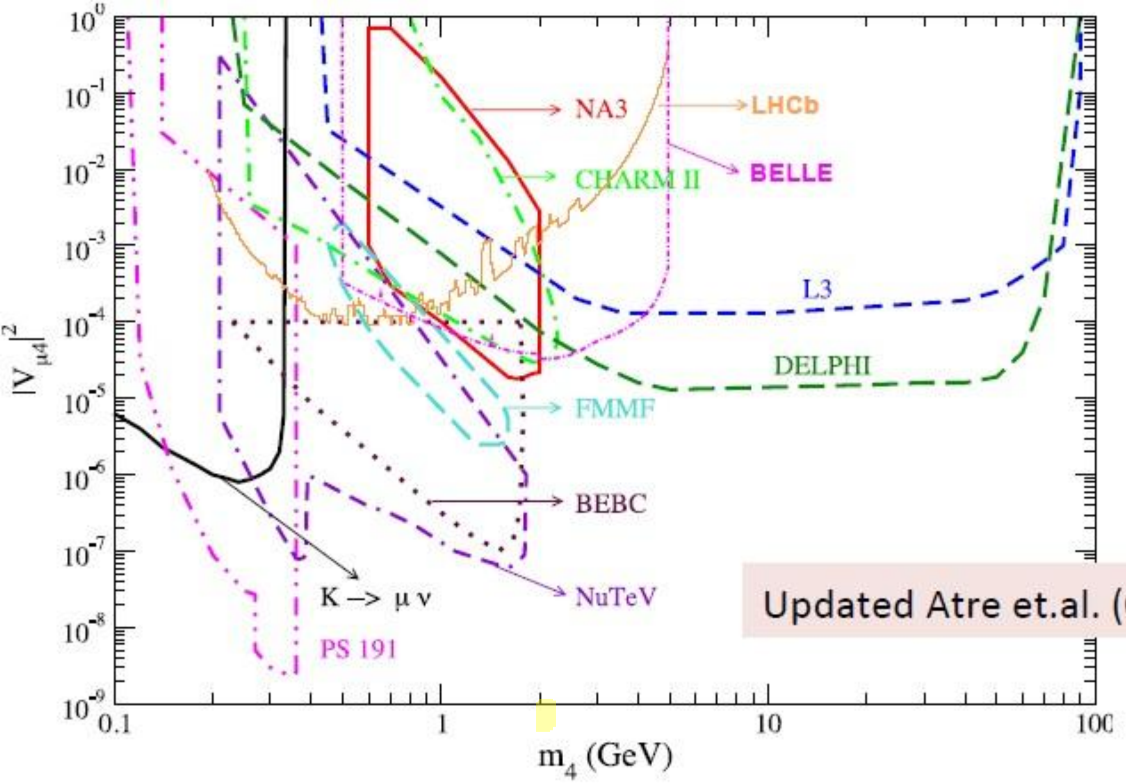


Branching ratio depends on Mixing

Typical lifetime **> 10 μs** for $M(N_{2,3})$ ~ 1 GeV

Decay distance (FL) **~ *O* (km)**

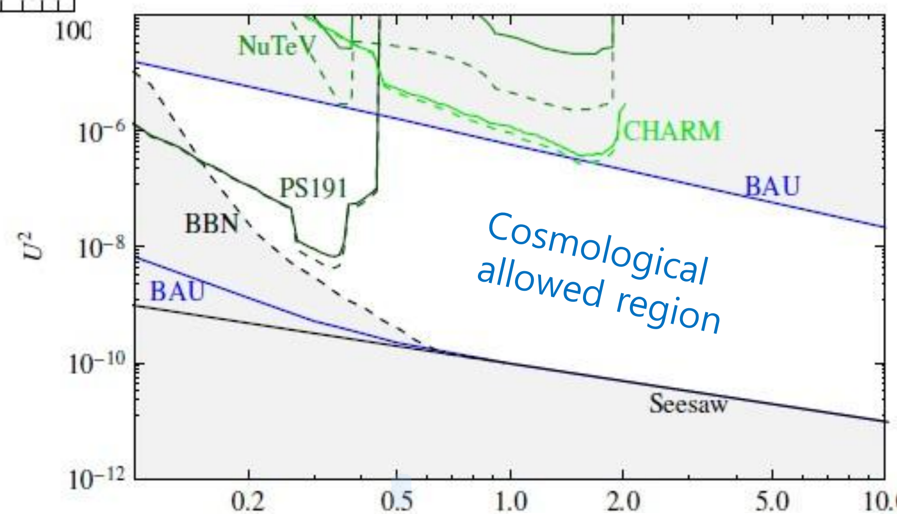
Experimental and Cosmological constraints on HNLs



- ✓ *Coupling to active neutrinos $U^2 = U_e^2 + U_\mu^2 + U_\tau^2$ ($V_{\mu 4}^2 = U_\mu^2$)*
- ✓ *Stringent constraints on light HNLs below kaon mass*
- ✓ *The mass range above charm is relatively poor explored*

Updated Atre et.al. (0901.3589)

- ✓ ***Recent progress in cosmology***



- ✓ *The sensitivity of previous experiments did not probe the interesting region for HNL masses above the kaon mass*

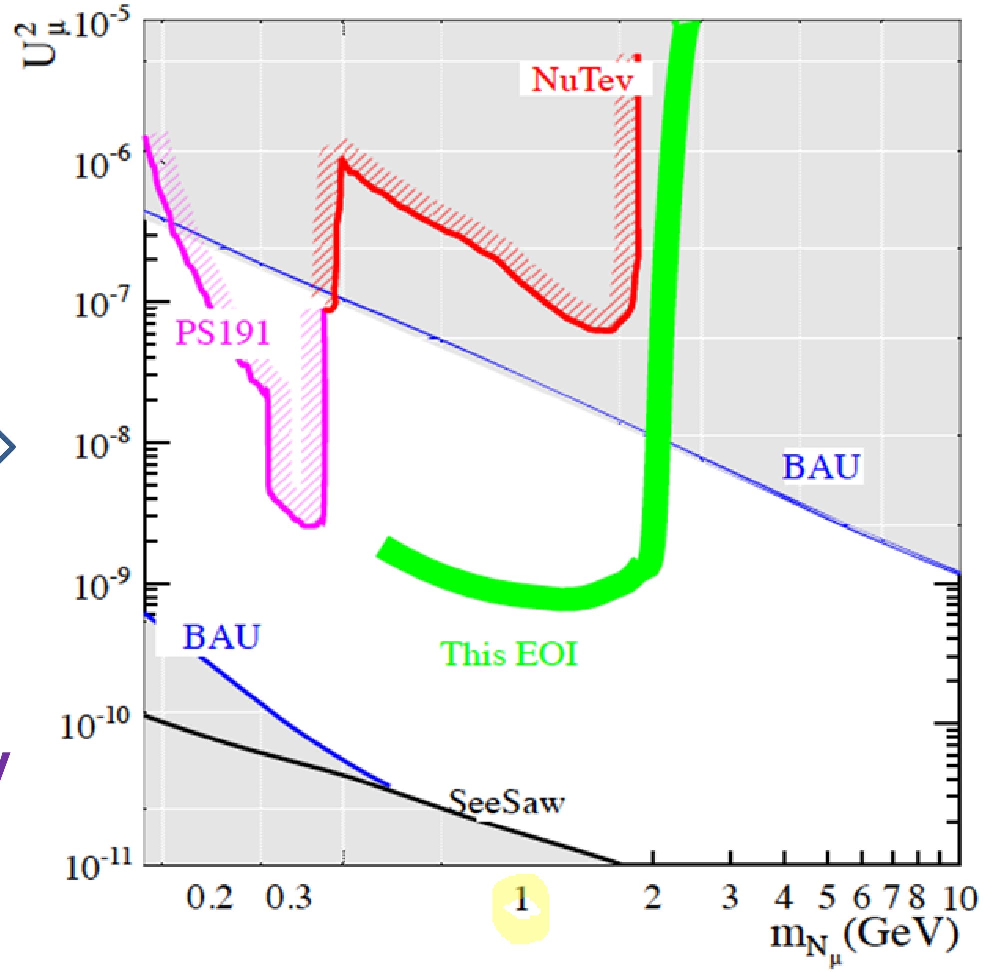
Andrey Golutvin

Cosmological allowed region

The cosmologically interesting region is at low couplings

Assuming $U_\mu^2 = 10^{-7}$
and $\tau_N = 1.8 \times 10^{-5}$ s
~12k fully reconstructed $N_{2,3} \rightarrow \mu^- \pi^+$ events are expected for $M_N = 1$ GeV.

120 events for cosmologically favored region:
$U_\mu^2 = 10^{-8}$ & $\tau_N = 1.8 \times 10^{-4}$ s



Decay of Hidden Particles

Models tested	Final states
Neutrino portal, SUSY neutralino	$\ell^\pm\pi^\mp, \ell^\pm K^\mp, \ell^\pm\rho^\mp$
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	$\ell^+\ell^-\nu$
Axion portal, SUSY sgoldstino	$\gamma\gamma$
SUSY sgoldstino	$\pi^0\pi^0$

$\mu^-\pi^+$

$$\ell = (e, \mu, \nu), \ \ \rho^\pm \to \pi^\pm\pi^0$$

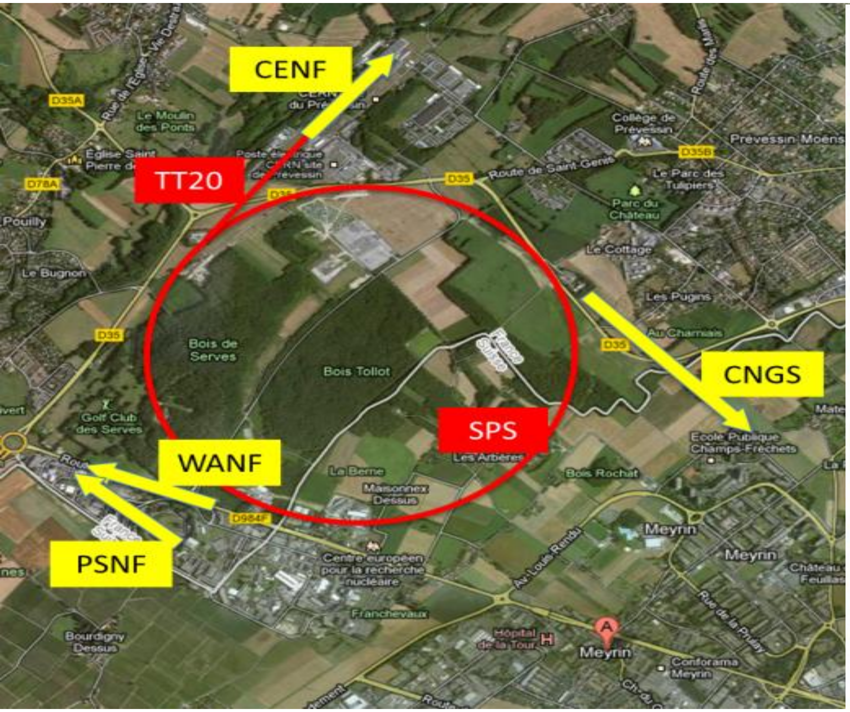
Many Vee decay modes

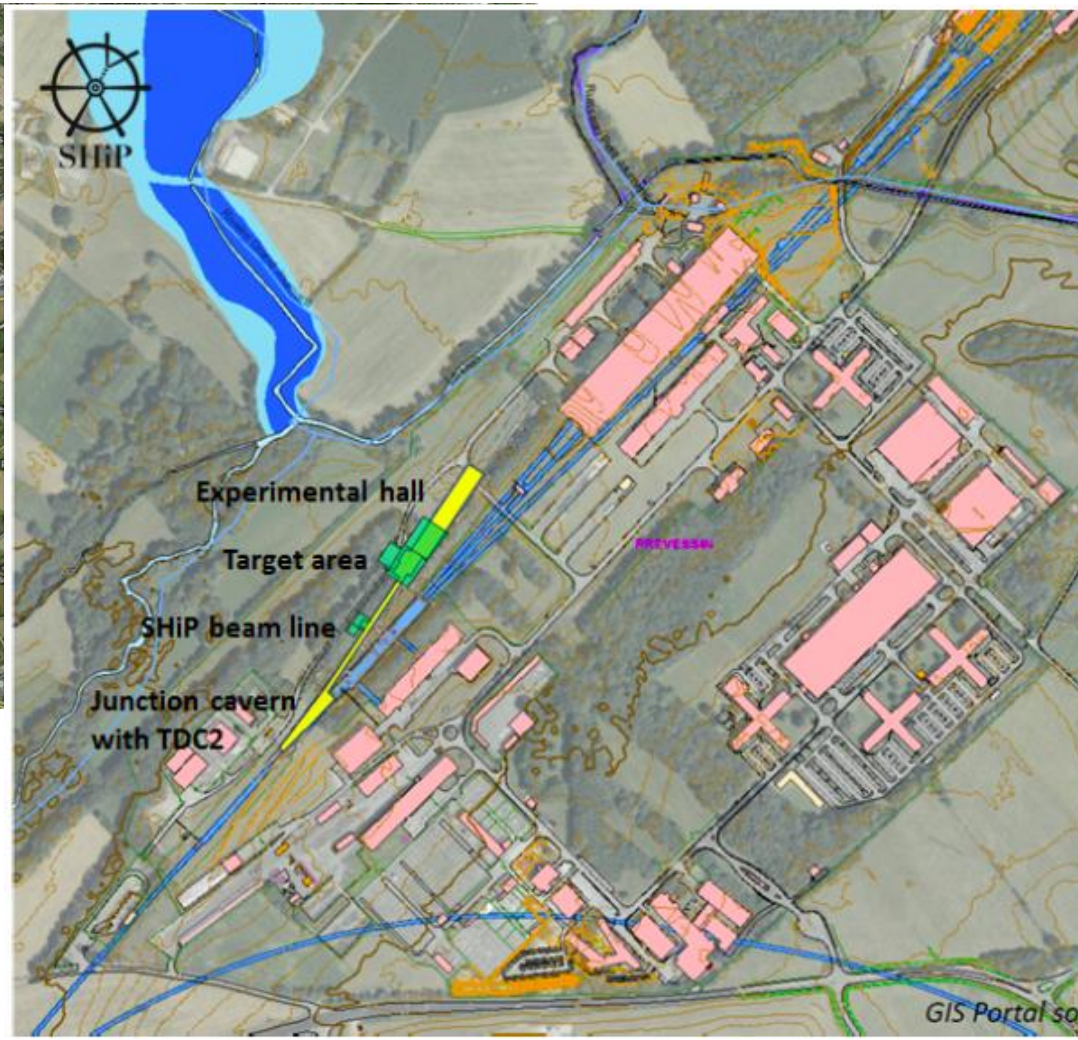
→ ***Particle ID and Full reconstruction** are essential to minimize model dependence.*

The Fixed-target facility at the SPS

Prevessin North Area site

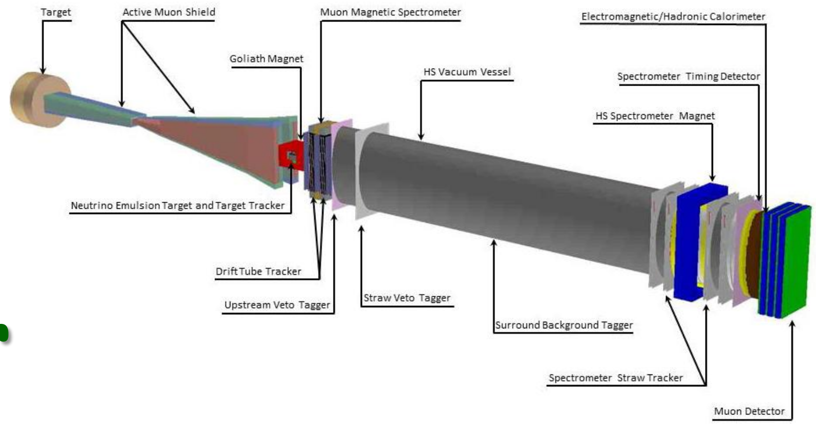
High-intensity proton beam: 2 x10^{20} pot, 5 years run



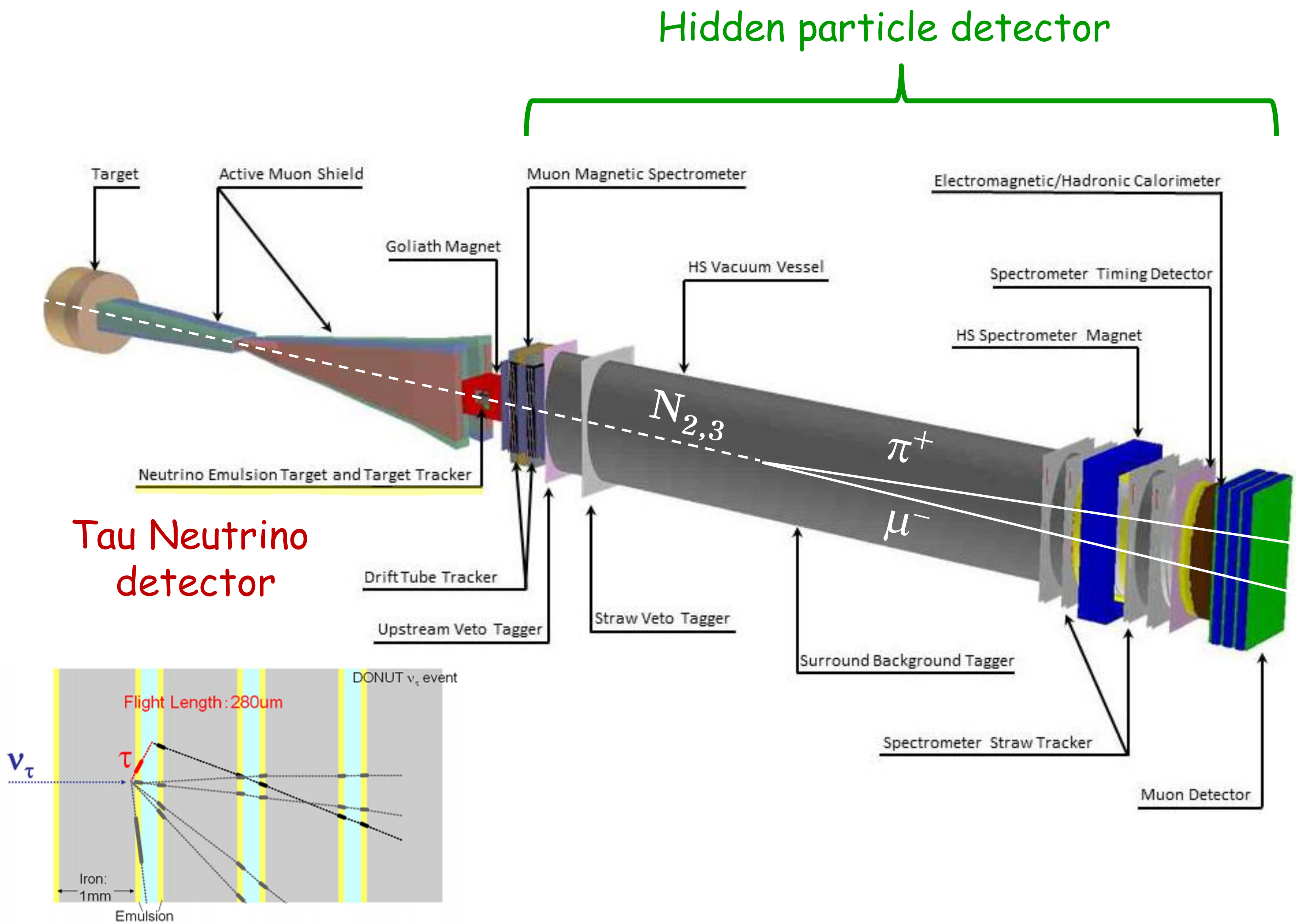


The SHiP facility is located on the North Area, and shares the TT20 transfer line and slow extraction mode with the fixed target programs.

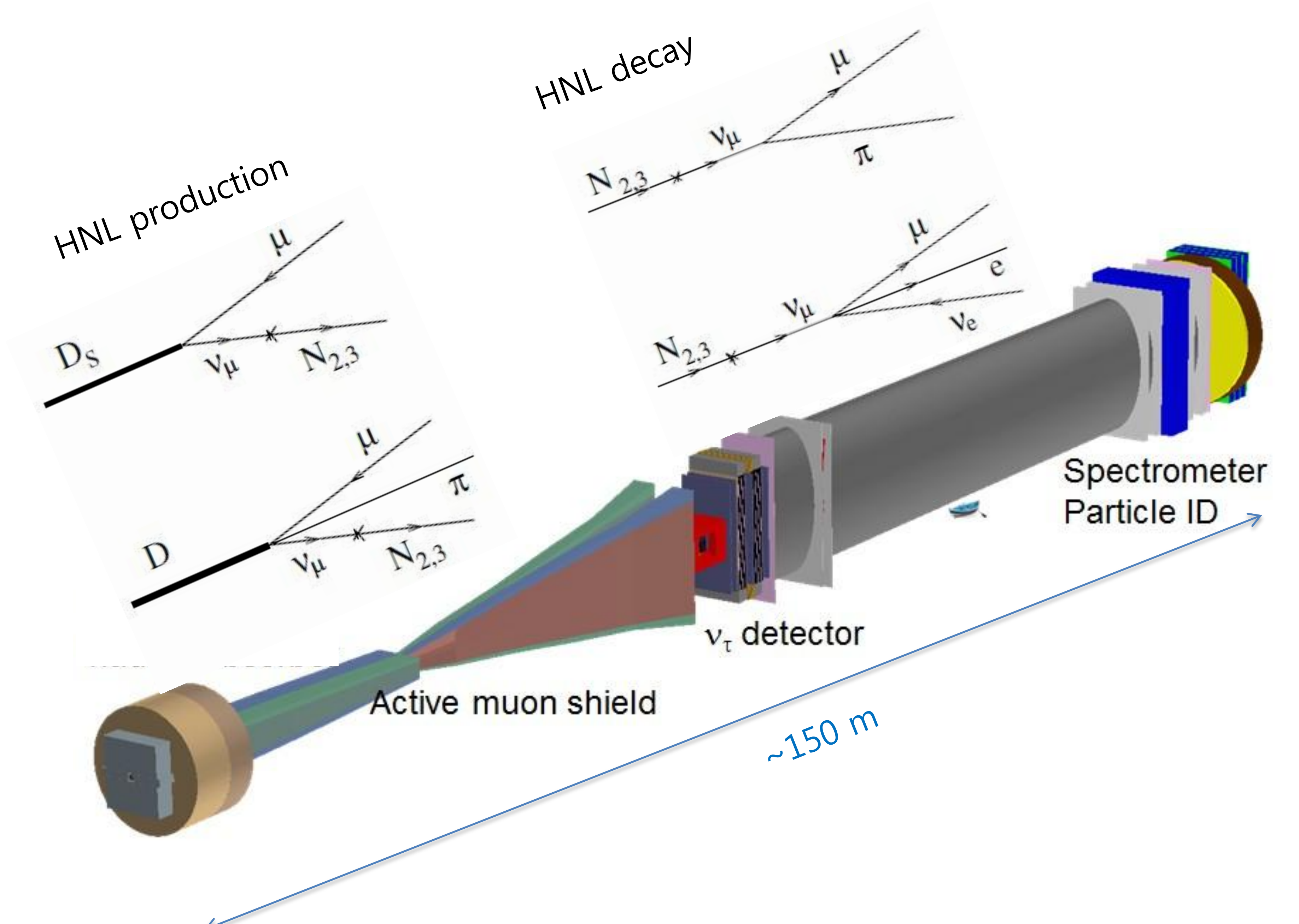
SHiP detectors



- **Hidden particle detector**
  - **Long evacuated decay volume**
  - Straw trackers with magnet
  - Calorimeters and Muon detector …
- **Tau neutrino detector**
  - **Emulsion target (ECC, CES)**
  - Target trackers (TT) in a Magnetic field
  - Muon spectrometer



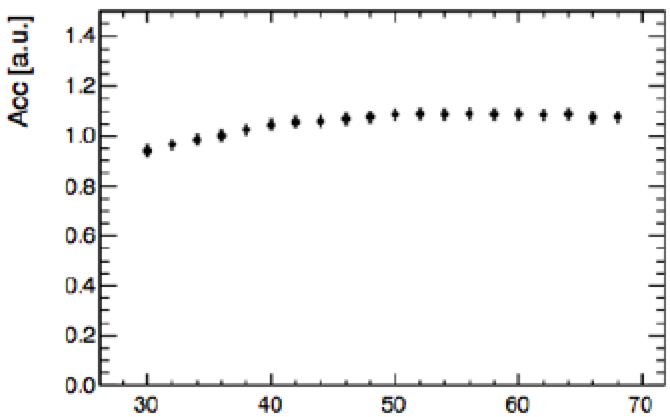
Hidden particle detector
Target
Active Muon Shield
Muon Magnetic Spectrometer
Electromagnetic/Hadronic Calorimeter
Goliath Magnet
HS Vacuum Vessel
Spectrometer Timing Detector
HS Spectrometer Magnet
$N_{2,3}$
π^+
μ^-
Neutrino Emulsion Target and Target Tracker
Tau Neutrino detector
Drift Tube Tracker
Upstream Veto Tagger
Straw Veto Tagger
Surround Background Tagger
Spectrometer Straw Tracker
Muon Detector
DONUT ν_τ event
Flight Length: 280um
ν_τ
τ
Iron: 1mm
Emulsion


HNL production
μ
D_S
ν_μ
$N_{2,3}$
μ
π
D
ν_μ
$N_{2,3}$
HNL decay
μ
ν_μ
$N_{2,3}$
π
μ
e
ν_μ
ν_e
$N_{2,3}$
Spectrometer
Particle ID
ν_τ detector
Active muon shield
~150 m

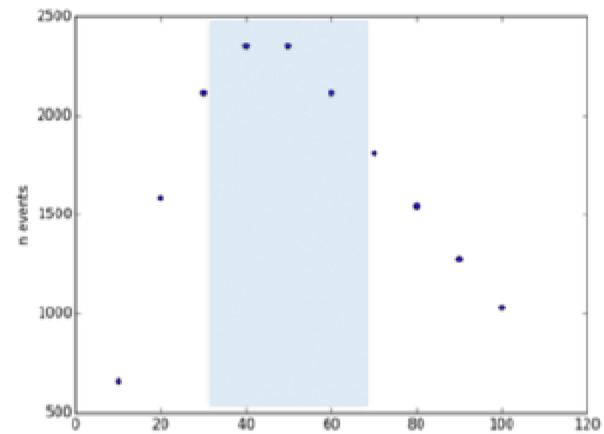
Optimization of the Hidden particle decay volume

Geometrical acceptance as function of the decay volume length
for given cross section 5 × 10 m (mass = 1 GeV)

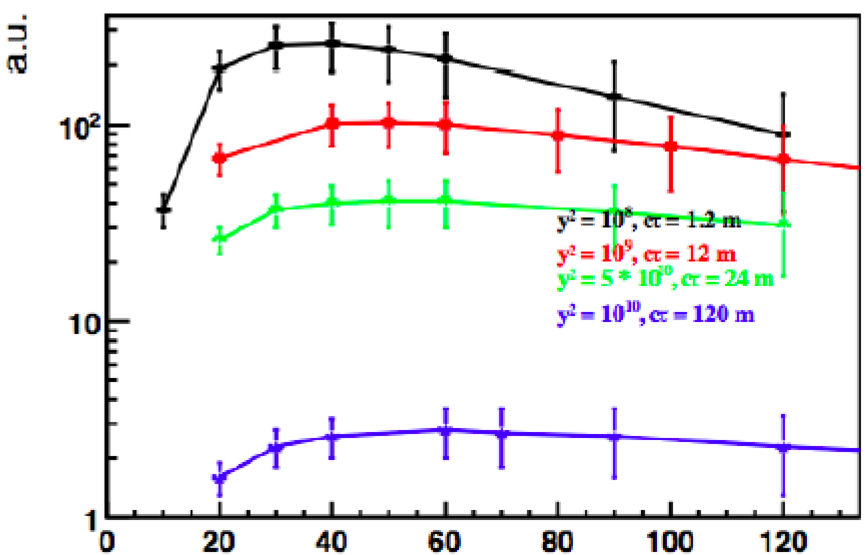
HNL



Dark photon



Hidden scalar



Acceptance saturates at

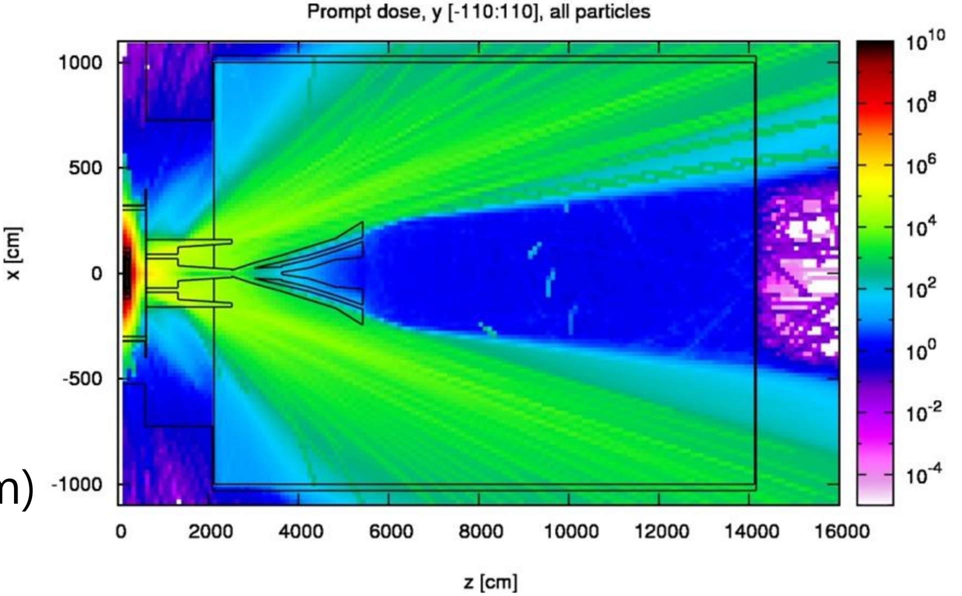
~ 48 m for HNL
~ 40 m for dark photon
~ 40 m is also OK
for hidden scalars
with shorter lifetimes

Hadron stopper

→ eliminate 2ry mesons

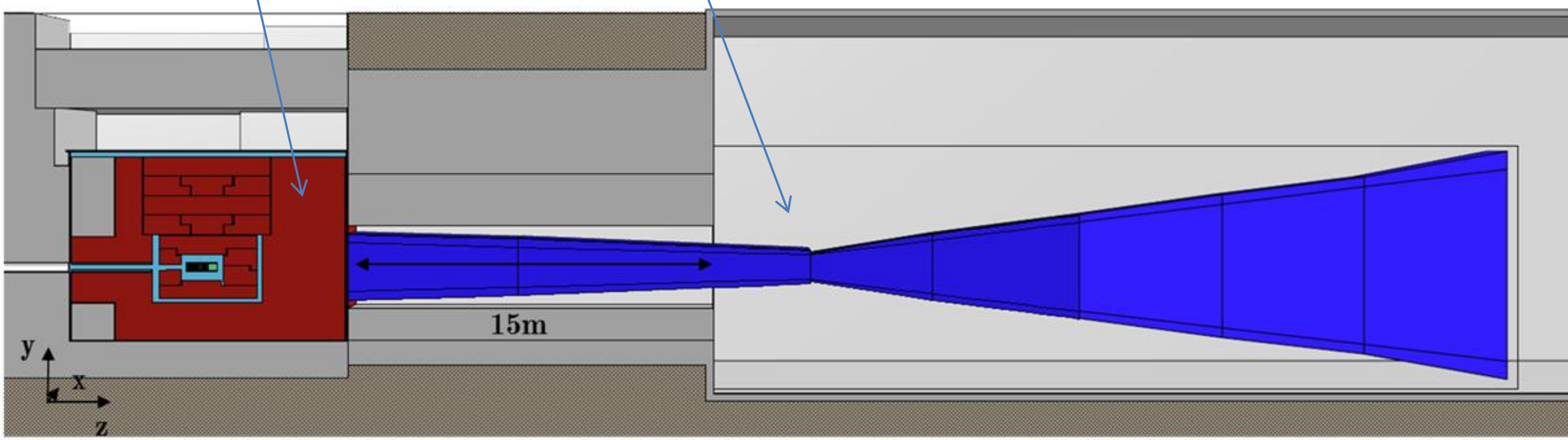
Muon Shield

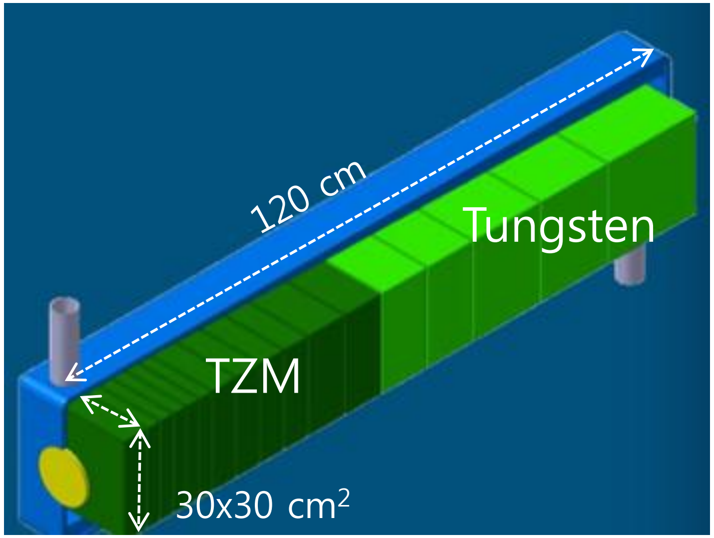
→ deflect muons
from 2ry meson decay

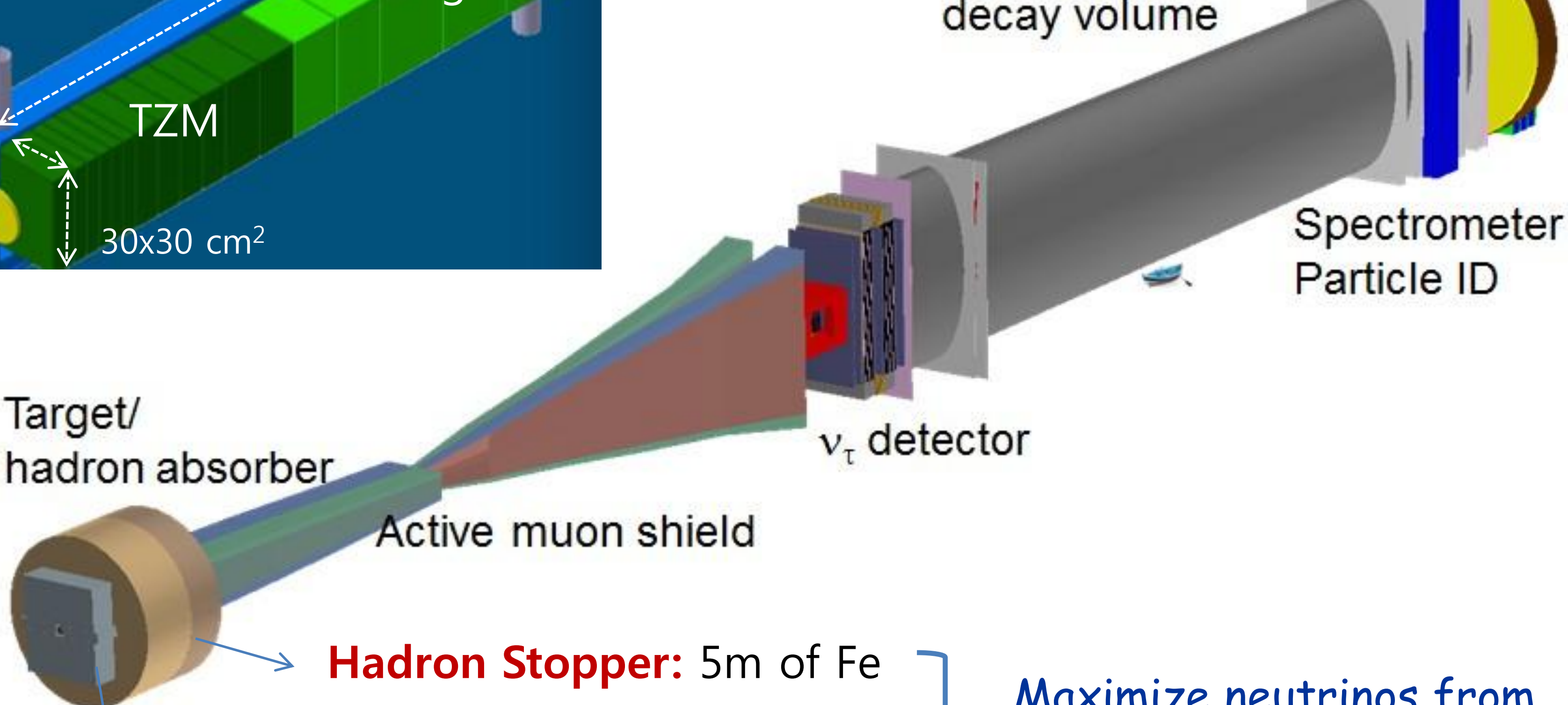


Hadron stopper

Active shield (~50m)
(using magnet)





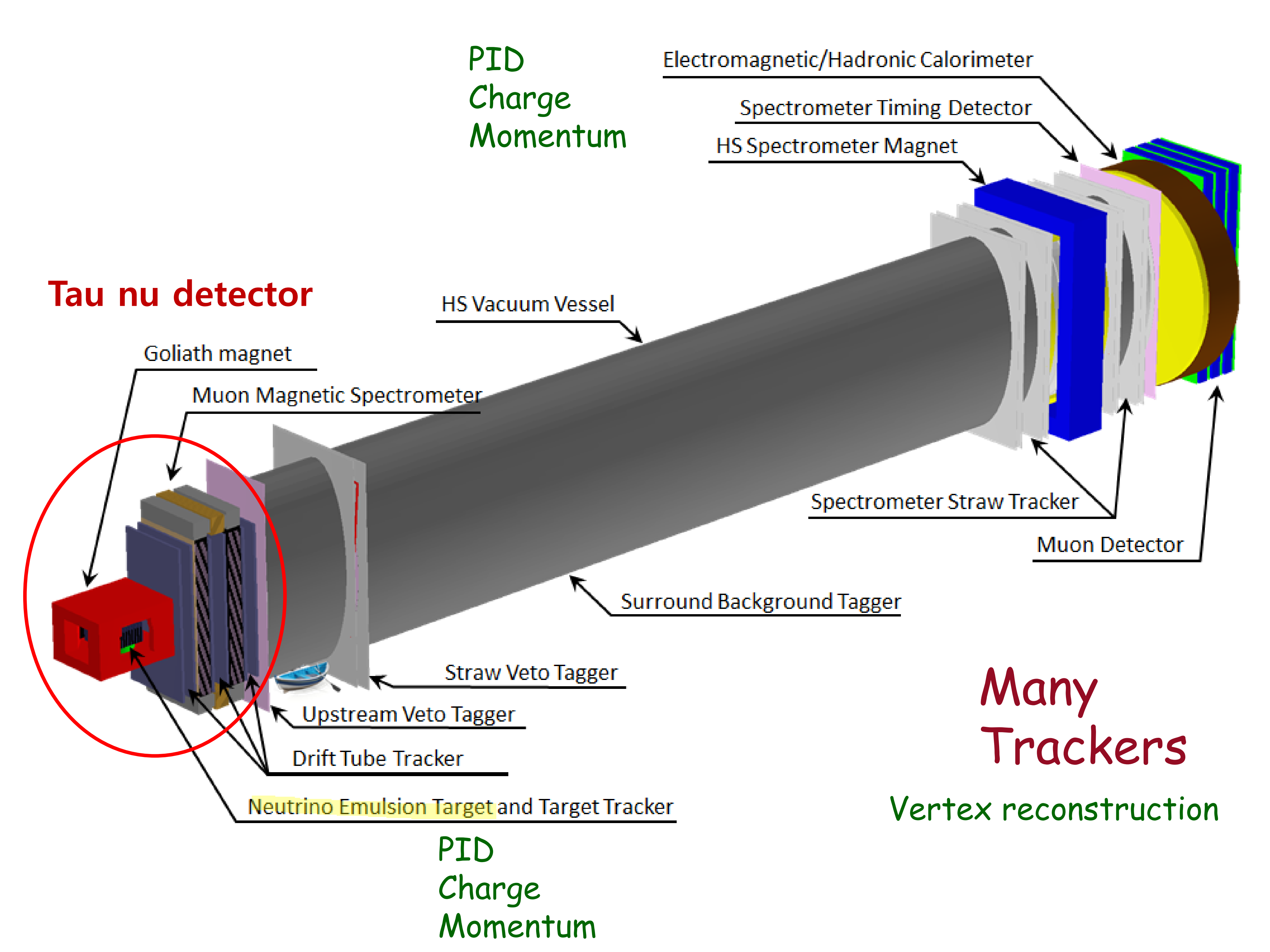


Hadron Stopper: 5m of Fe

Hybrid target:
Blocks of Titanium Zirconium doped Molybdenum (TZM) followed by blocks of pure Tungsten

Maximize neutrinos from charmed hadrons

Minimize neutrinos from π and K


PID
Charge
Momentum
Electromagnetic/Hadronic Calorimeter
Spectrometer Timing Detector
HS Spectrometer Magnet
Tau nu detector
HS Vacuum Vessel
Goliath magnet
Muon Magnetic Spectrometer
Spectrometer Straw Tracker
Muon Detector
Surround Background Tagger
Straw Veto Tagger
Upstream Veto Tagger
Drift Tube Tracker
Neutrino Emulsion Target and Target Tracker
Many
Trackers
Vertex reconstruction
PID
Charge
Momentum

Particle ID

ECAL, HCAL, Muon spectrometer, Emulsion

Tracking

TT (SciFi), Straw tracker, DT, Emulsion

Reconstruction - Decay vtx, IP, mass

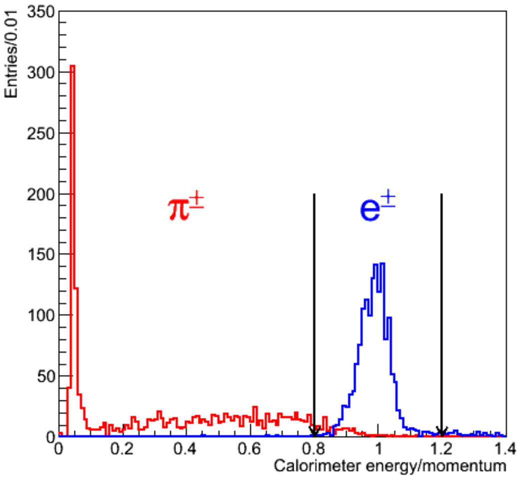
Momentum - ECC, CES with magnet, Muon spectrometer

Charge - CES with magnet, Muon spectrometer

Timing detector

- Plastic scintillator or MRPC (multigap RPC), TT

Calorimeter



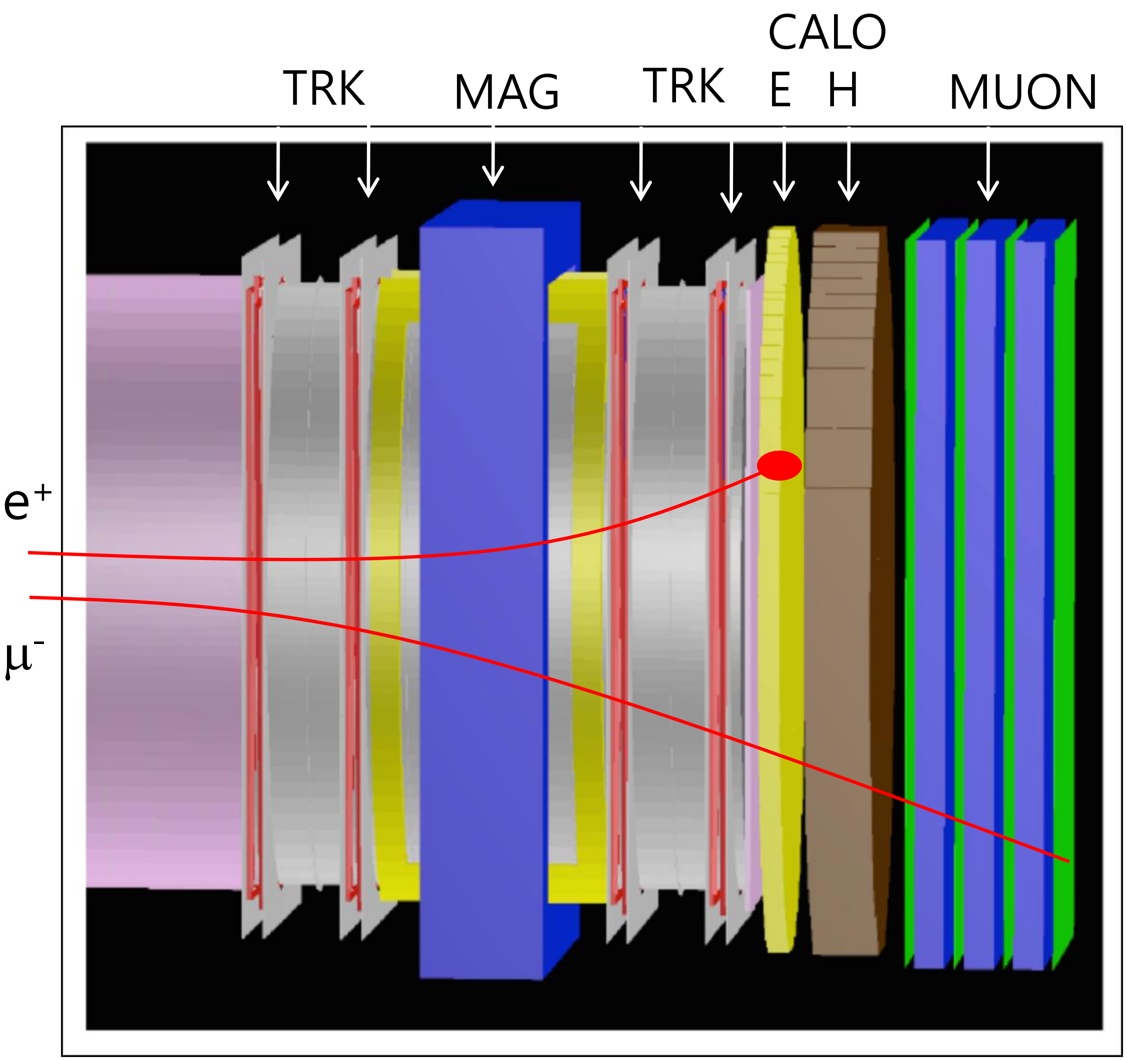
ECAL

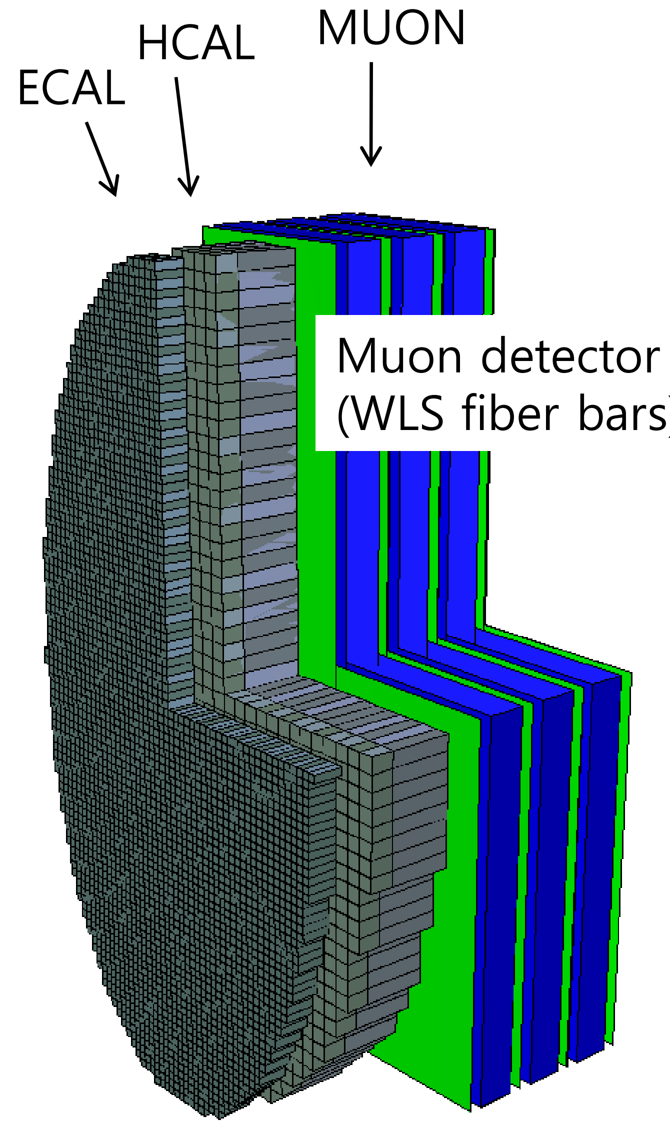
- PID γ π e
- Measure energy of e , γ (0.3~70GeV)
- provide π^0 reconstruction (0.6~100GeV)
- Provide timing info at ns level for signal and bg rejection

HCAL

- π ID
- π / μ discrimination at low mom (p < 5GeV/c)
- Tag neutral particles like K^0_L and n
  (not seen by other detector)
- Provide timing info at ns level

Calorimeter and Muon detector

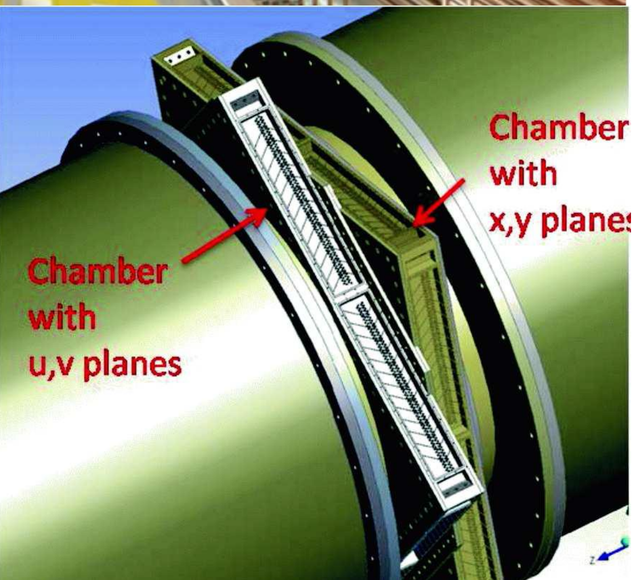


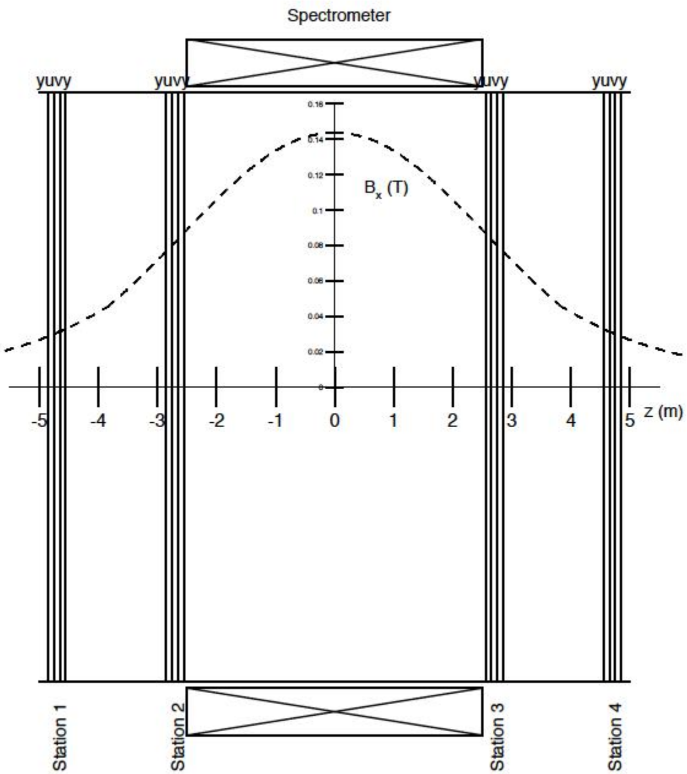


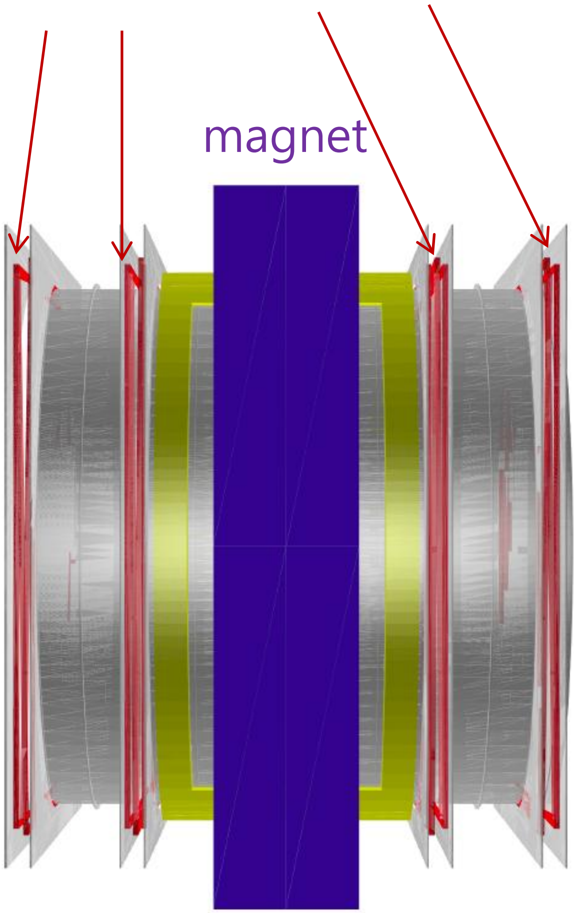
ECAL : e/γ id, π^0 and η reconstruction
(Shashlik technique, LHCb)

HCAL : π/μ separation
(similar technology as ECAL)

Straw Tracker





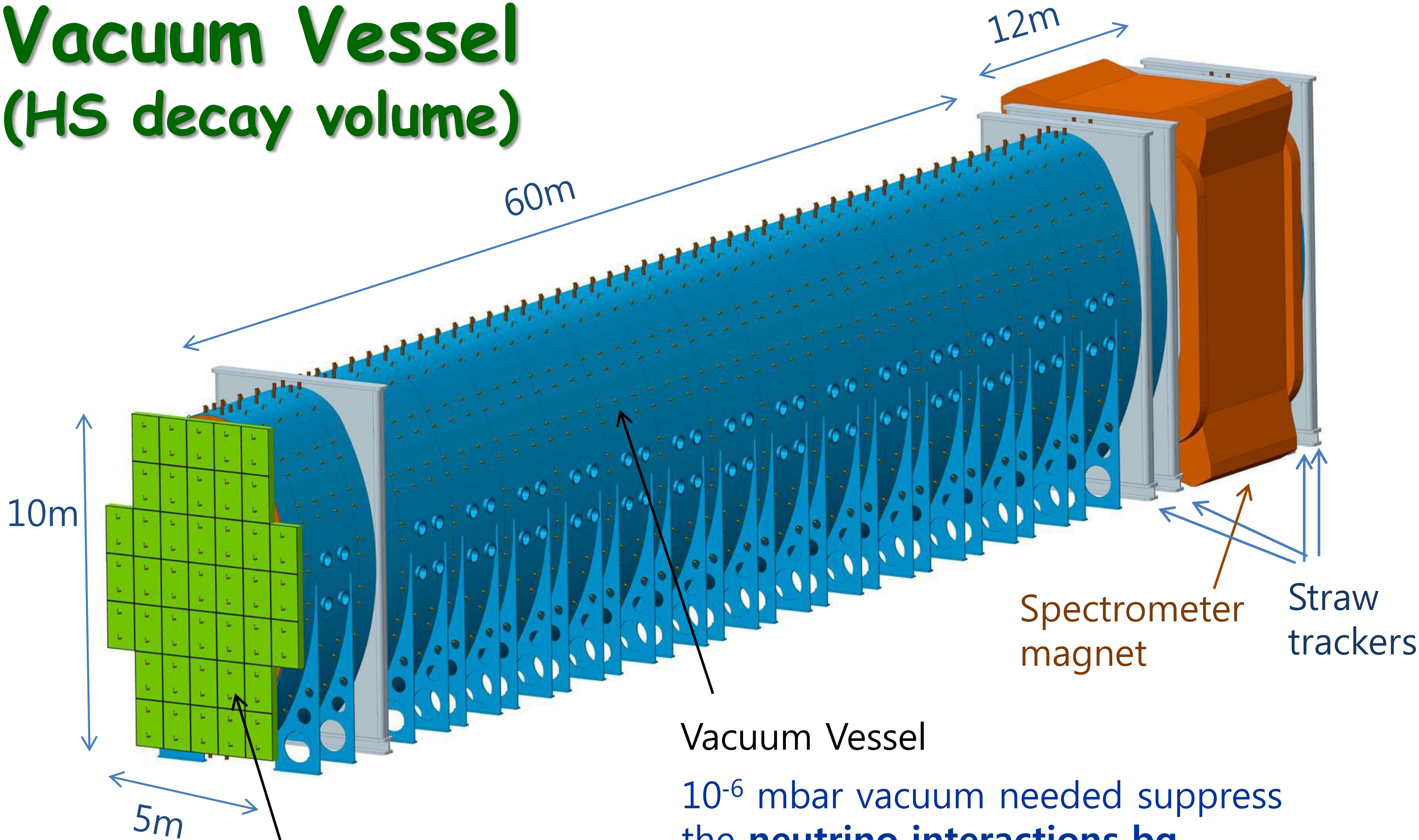


Tracking decay particles at downstream

120 μm resolution/straw

5m length

Vacuum Vessel
(HS decay volume)



Vacuum Vessel

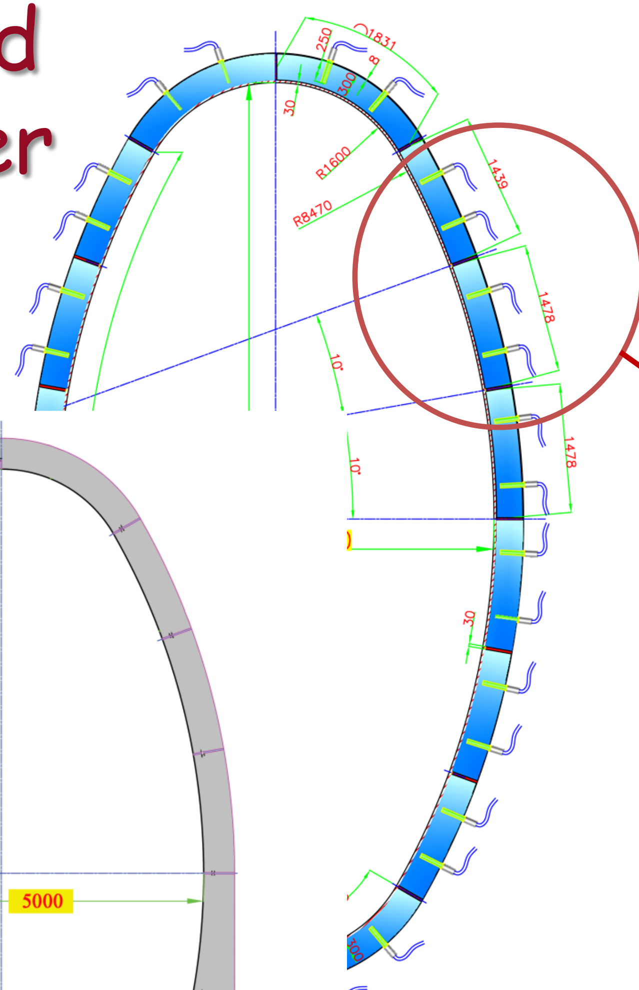
10^{-6} mbar vacuum needed suppress the **neutrino interactions bg**

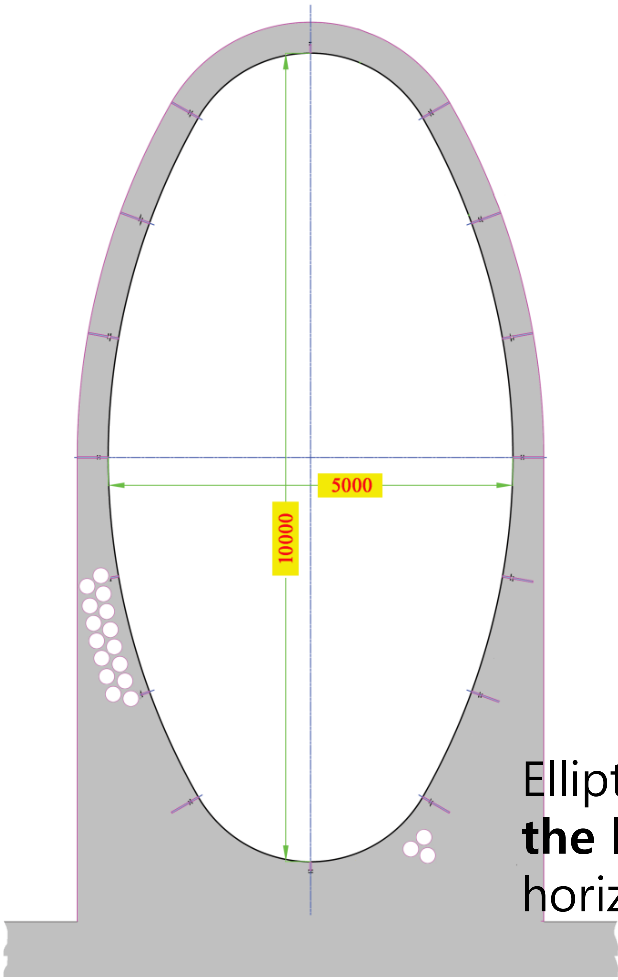
Upstream Veto tagger

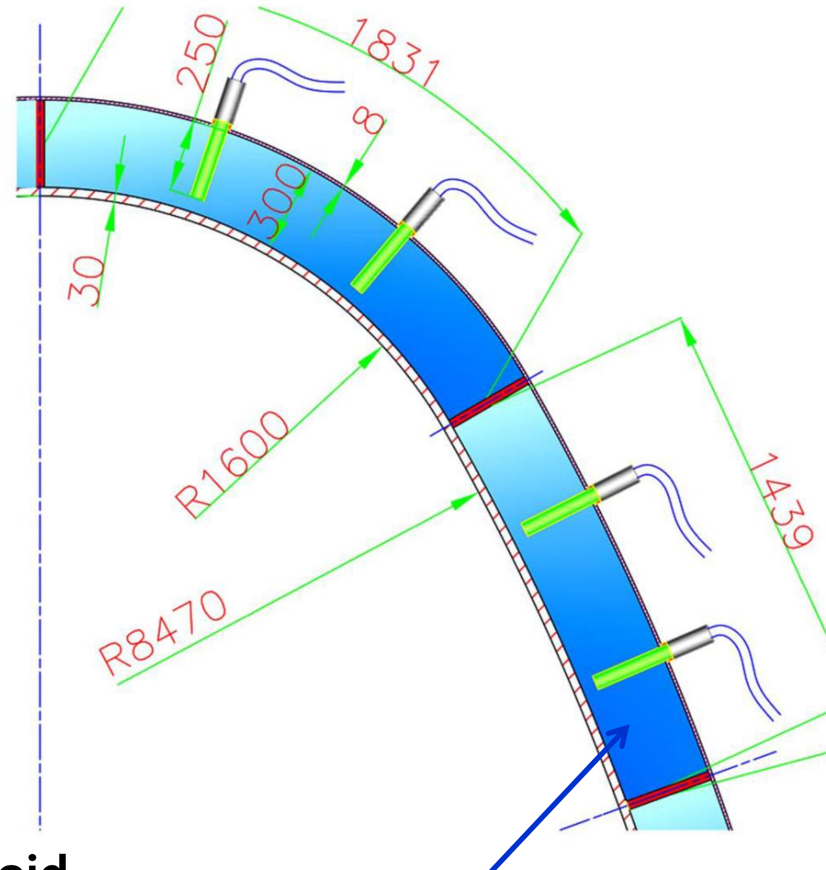
located just after ν_τ detector
to tag **neutral K** produced by ν and μ int
and **μ** entering the vessel from the front

Surround bg tagger

Double wall structure
Space filled with liquid scintillator
to **tag bg entering from outside**







Elliptical structure to **avoid the large μ flux** deflected horizontally by the μ shield

liquid scintillator
filled inside 30cm gap

Timing detector

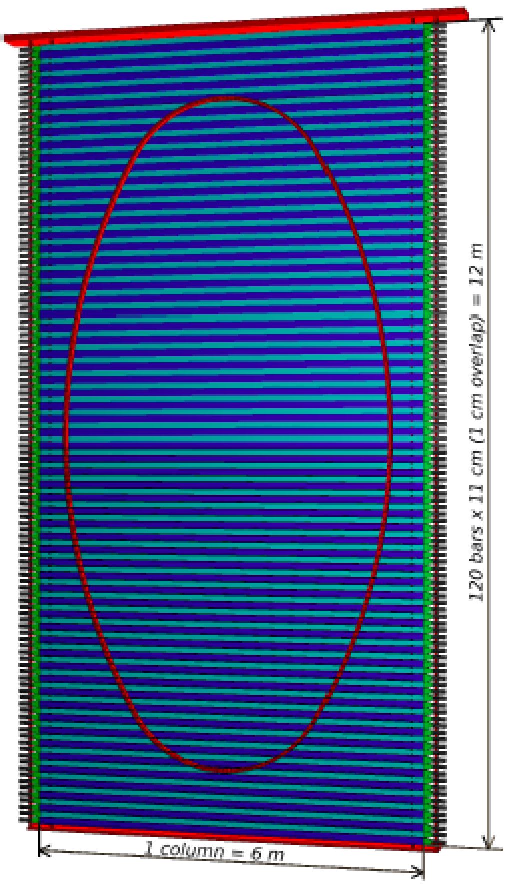
Two alternative tech

distinguish **random crossing**

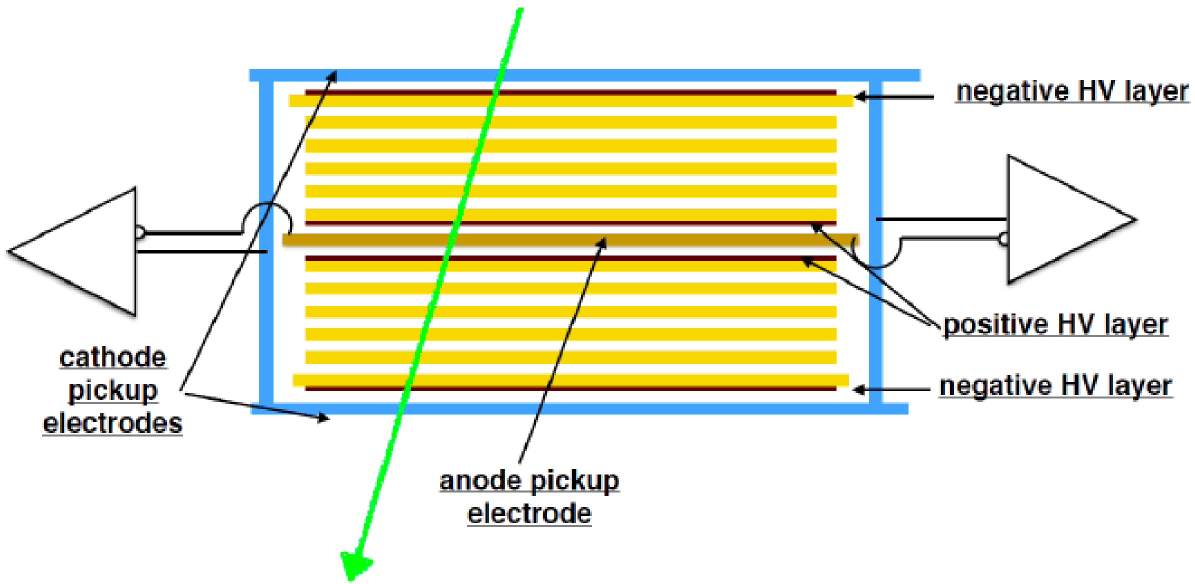
to reduce combinational di-μ bg

Scintillating bars

(NA61/SHINE, COMPASS)



MRPC *(ALICE)*



120 cm long strips, 3 cm wide pitch

Actual intrinsic time resolution ~20ps

Timing resolution **100 ps** is necessary

Main background

mostly K^0_L

Long lived V^0 particles (Vee)

→ from ν inelastic scattering
μ inelastic scattering
in vicinity of detector

Other background

Random combination of tracks in fiducial vol
Residual μ flux
Other charged particles …

Backgrounds

Vee

ν or μ + N → X + K^0_L

ν or μ + N → X + K^0_S

ν or μ + N → X + n

ν or μ + N → X + Λ

n or p + N → X + K_L

$K^0_L \rightarrow \pi\, e\, \mu$

$\pi\, \mu\, \nu$

$\pi^+\pi^-$

$\pi^+\pi^-\pi^0$

$K^0_S \rightarrow \pi^0\, \pi^0$

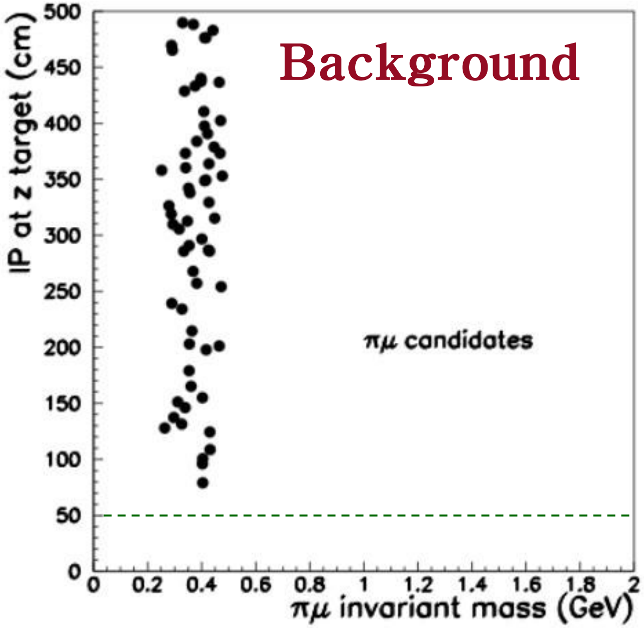
$\pi^+\pi^-$

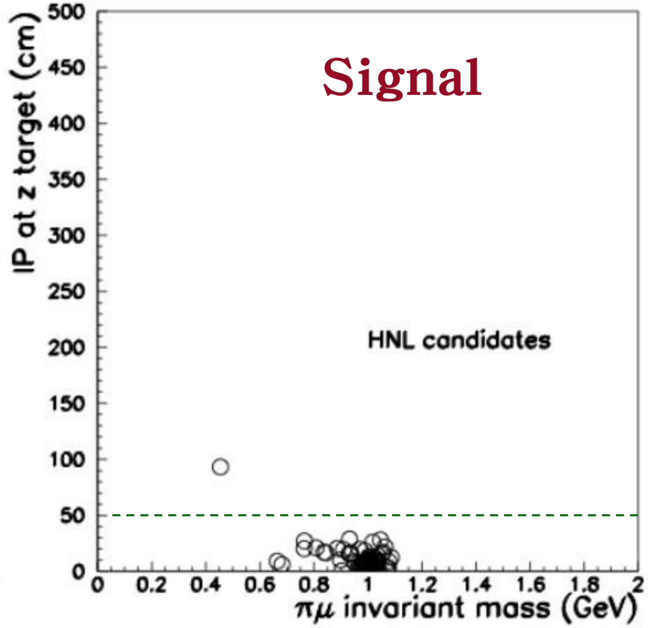
$n \rightarrow p\, e^-\nu$

$\Lambda \rightarrow p\, \pi^-$

Impact parameter

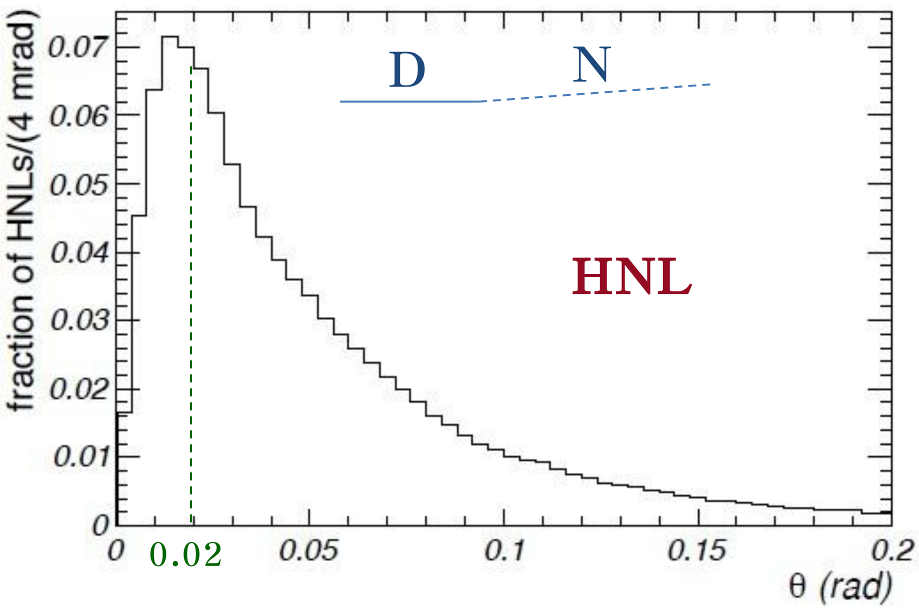
MC

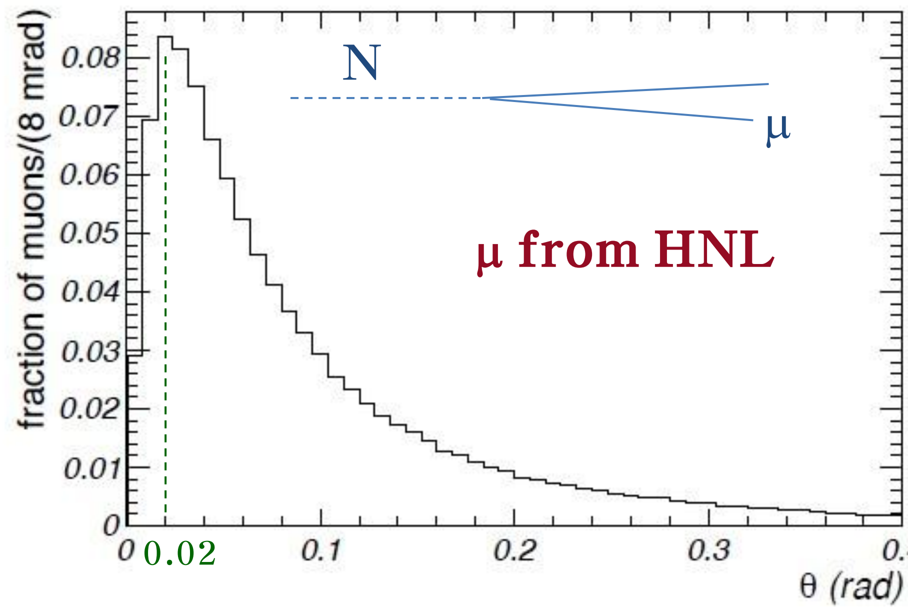




Signal IP
less than 50cm

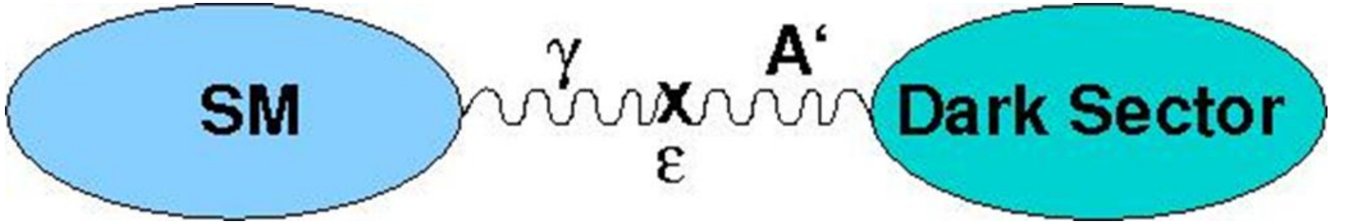
Polar angle





Vector portal

Dark photon
& Light Dark matter



Production of dark photon A'

Meson decay $\pi^0\,(\eta, \eta', \omega) \rightarrow \gamma A'$

decay of K, D, B subdominant

Proton Bremsstrahlung $pp \rightarrow pp A'$

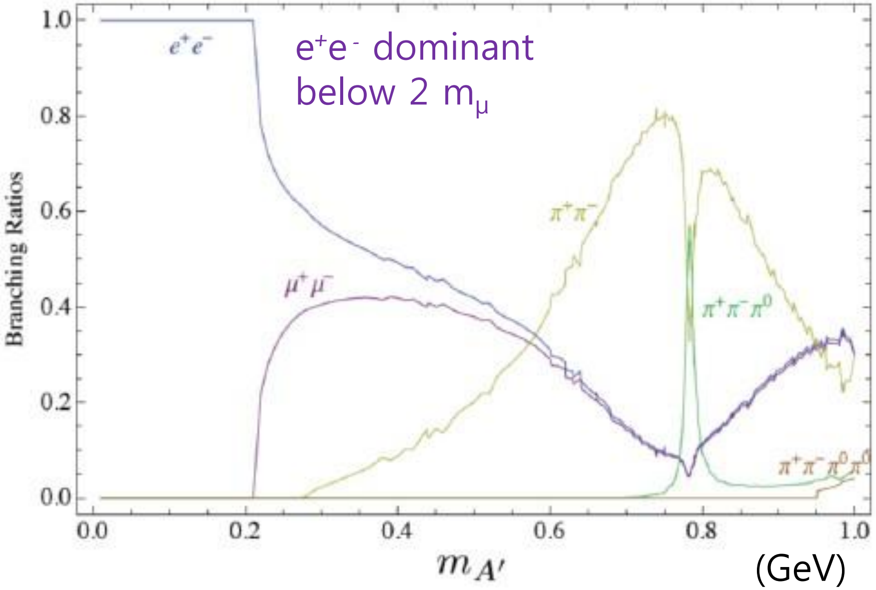
Direct perturbative QCD prod. $q + q \rightarrow A'$, $q + g \rightarrow q + A'$

Decay of dark photon

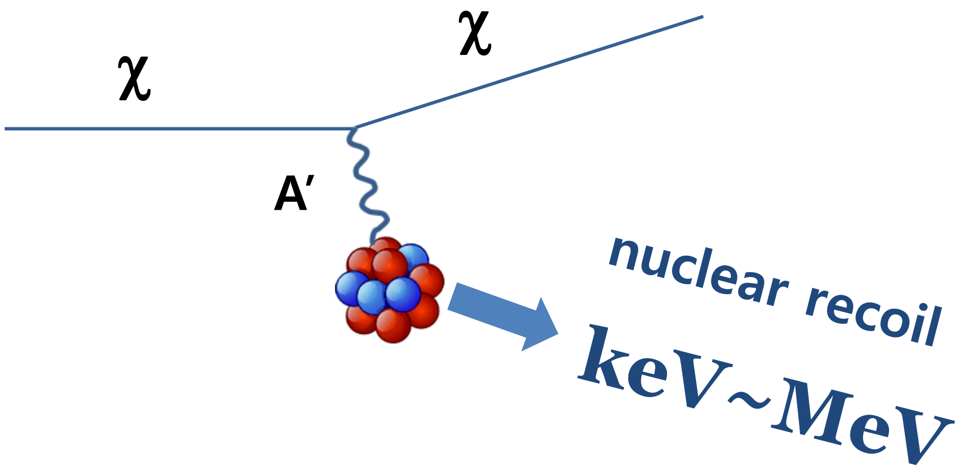
$A' \rightarrow e^+ e^-$, $\mu^+ \mu^-$

$A' \rightarrow$ hadrons

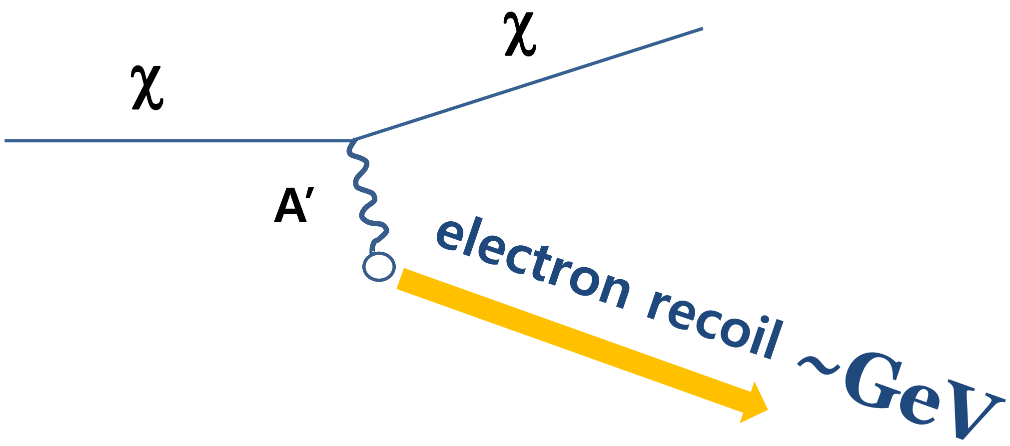
$A' \rightarrow \chi \bar{\chi}$ (χ : Dark matter)



χ scatter on e or n, p $\rightarrow$ DM search



χ elastically scatters on a nuclei in the detector producing a **visible recoil**.



$\chi\, e \rightarrow \chi\, e$

Try to detect DM using Neutrino detector

→ Emulsion, TT, μ-spec

Light DM (χ) can produce via dark photon (A') decay

$$pp \to \pi^0 X$$

$$\pi^0 \to A' \gamma$$

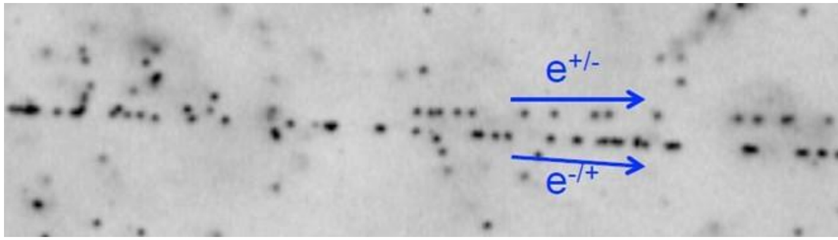
$$A' \to \chi \bar{\chi}$$

χ: DM

Scatter on e / n,p

$$\chi e \to \chi e$$

$$\chi n(p) \to \chi n(p)$$

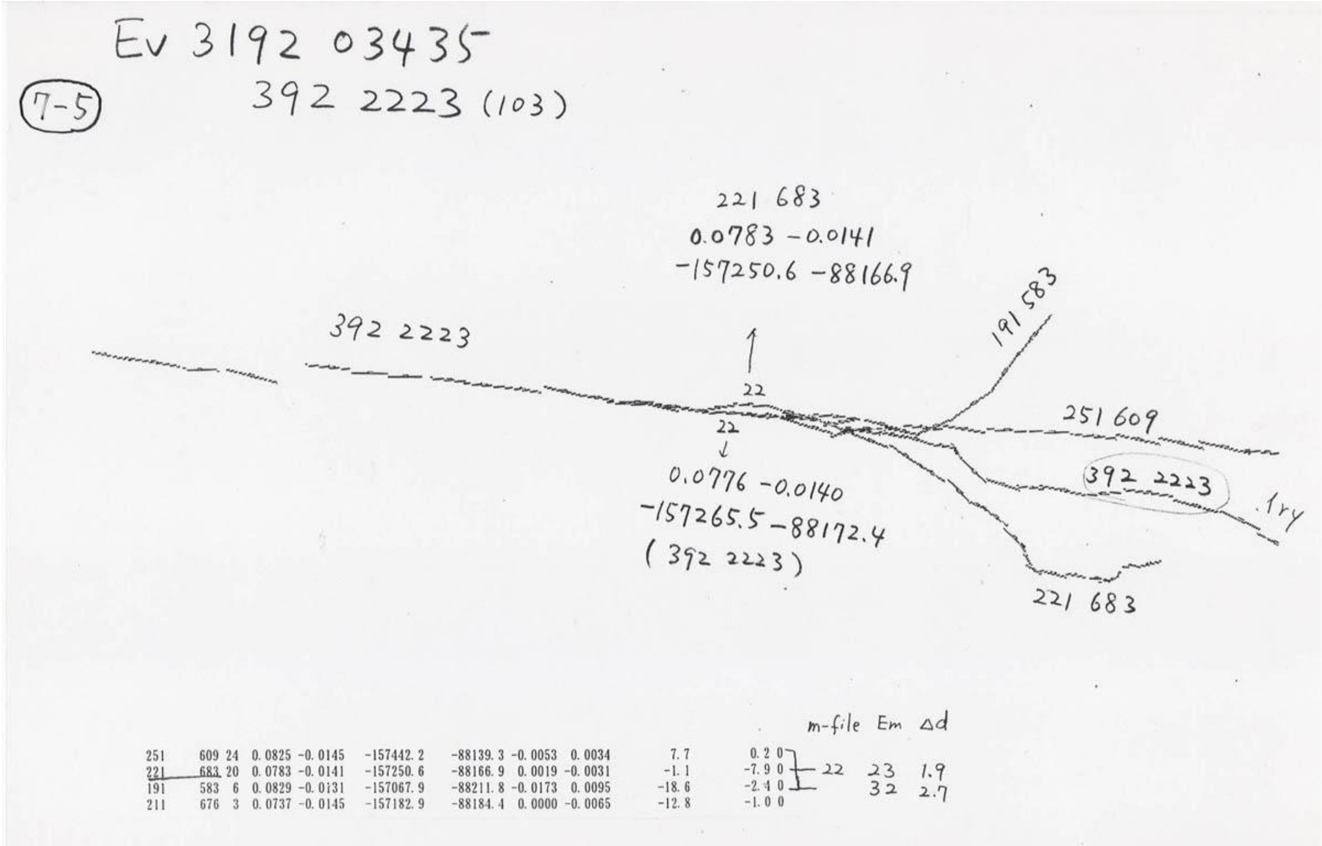


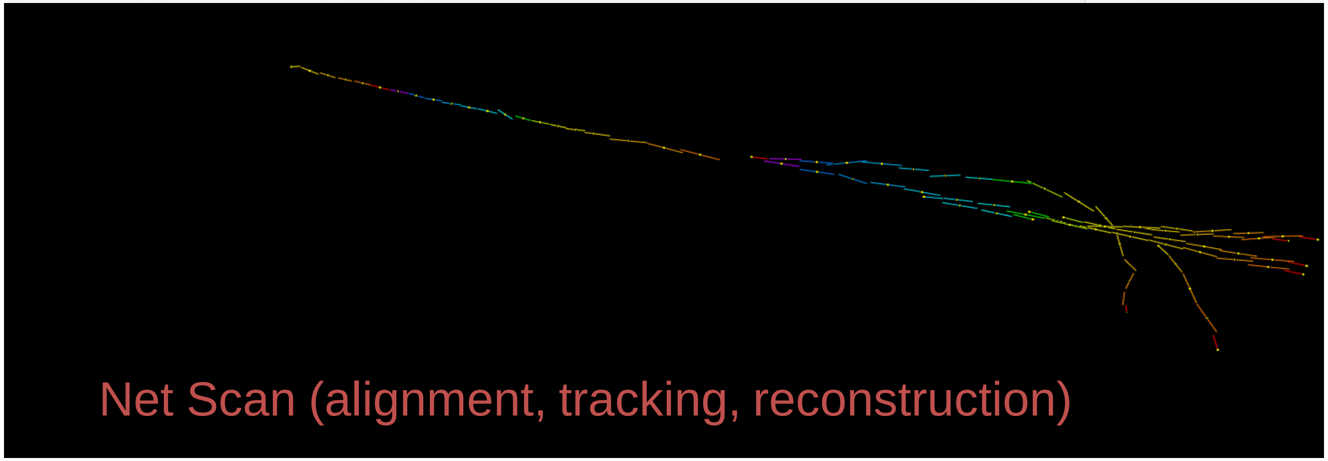
GeV electron

Neutral Current DM-electron scattering is highly peaked in the forward direction. Cutting on very forward scattering can remove most other projected background.

Example of ~GeV electron from ν_e CC events in emulsion

DONuT exp





DM search in emulsion

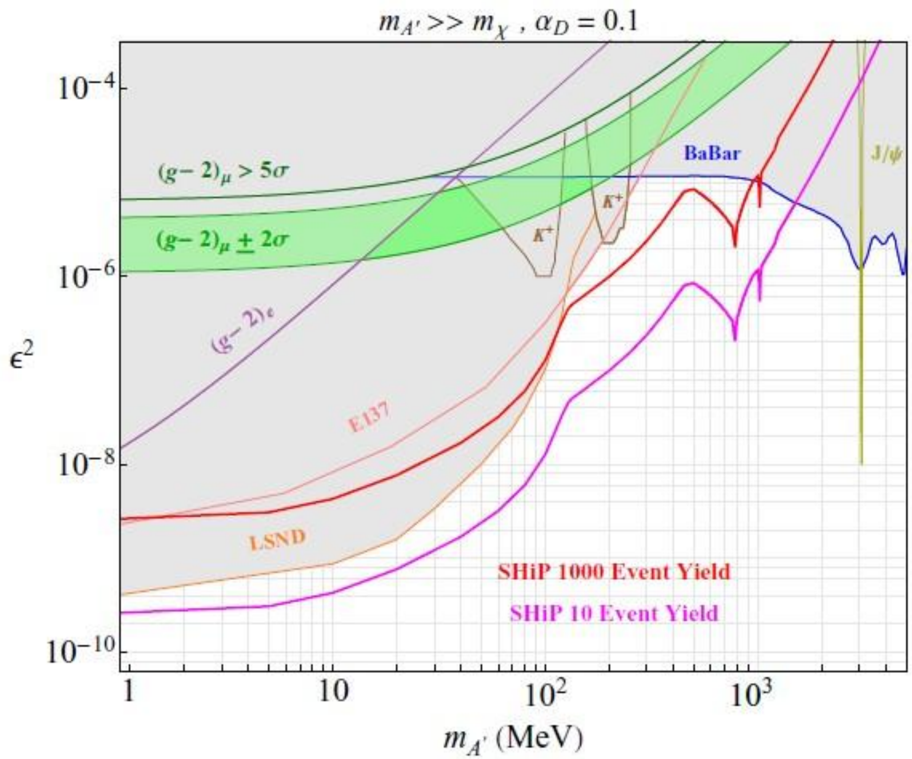
χ produced by a dark photon decay interact with electron.

$$\chi e^- \rightarrow \chi e^-$$

<u>SIGNAL SELECTION</u>

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

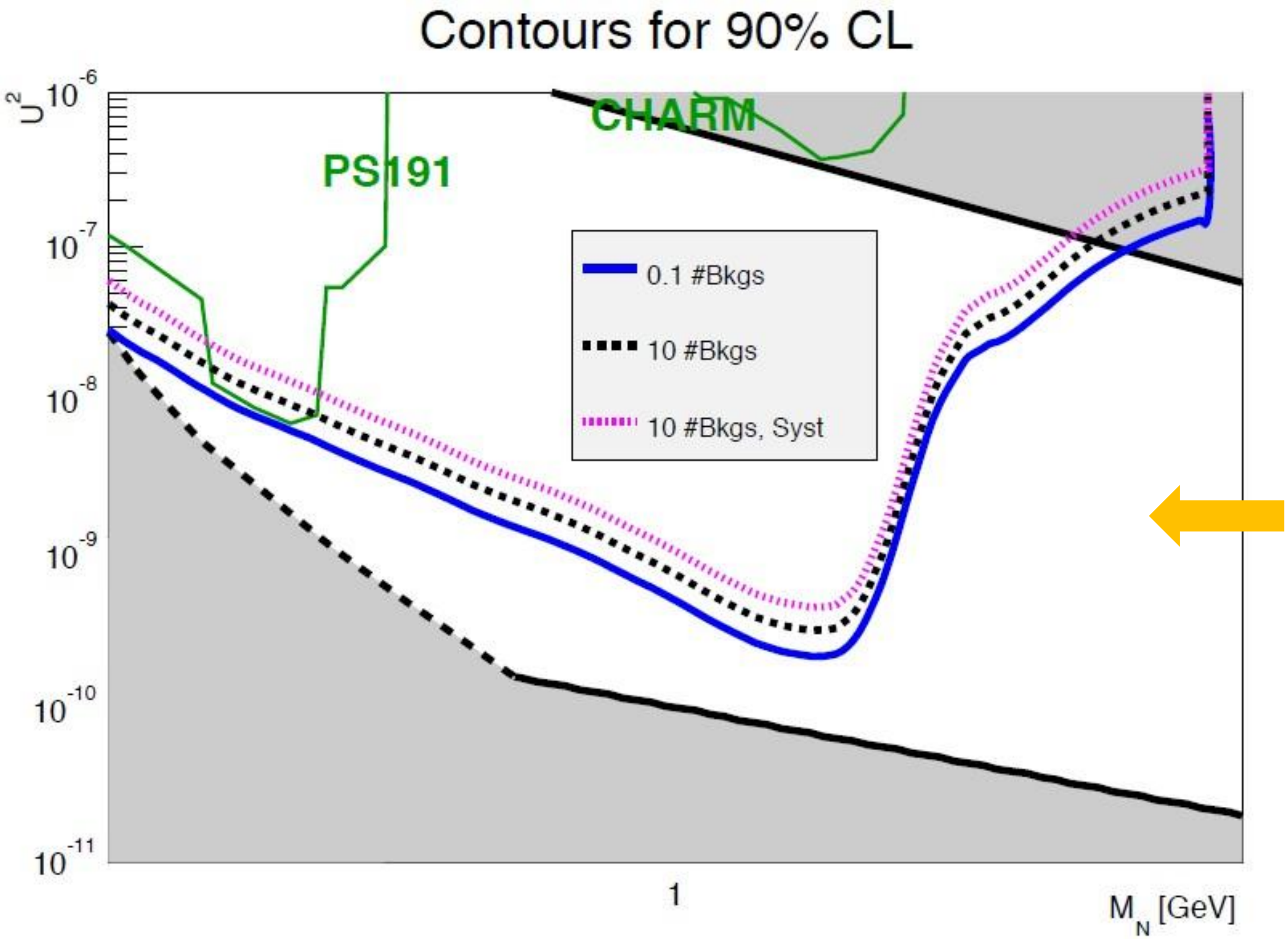
under study ...



SHiP sensitivity contours assuming 10 and 1000 DM-electron scattering events.

SHiP Sensitivity to HNL

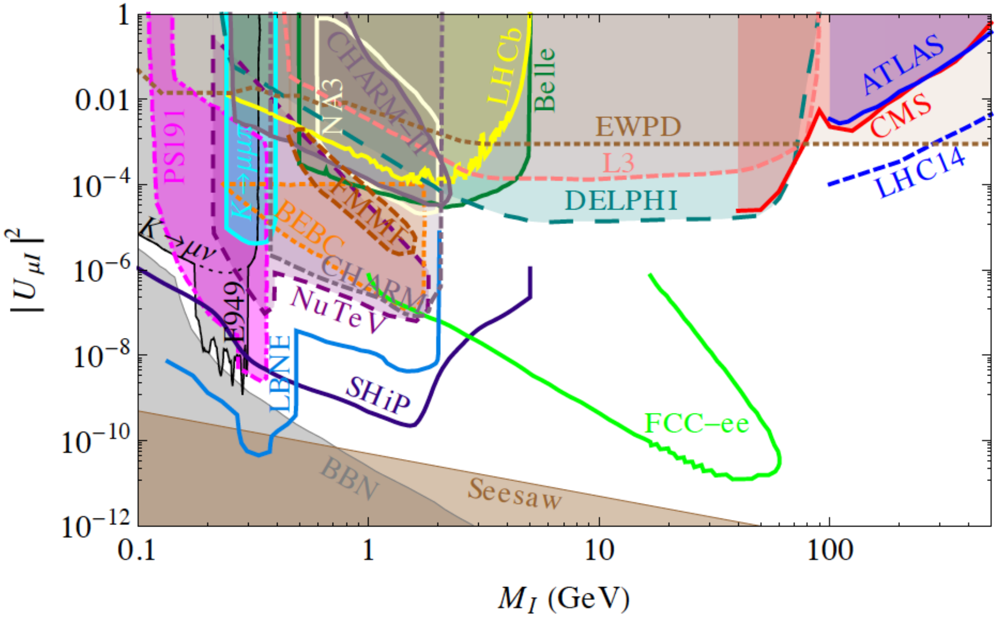
#(HNL)SHiP/CHARM=10k



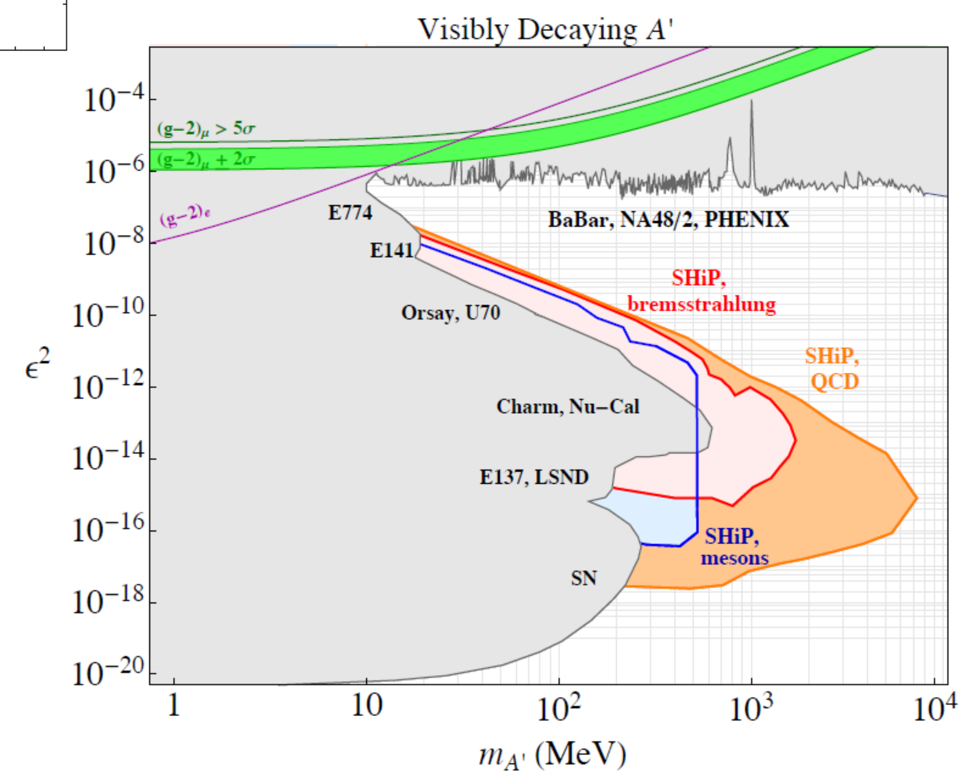
Cosmological allowed region

The blue curve is assuming 0.1 background events in $2 \cdot 10^{20}$ pot.
The dashed black curve corresponds to 10 background events.

Sensitivity to HNL at other facilities



SHiP Sensitivity to Dark Photon



Sensitivity for Hidden Scalars

(mixing with the SM Higgs with $\sin^2\theta$)

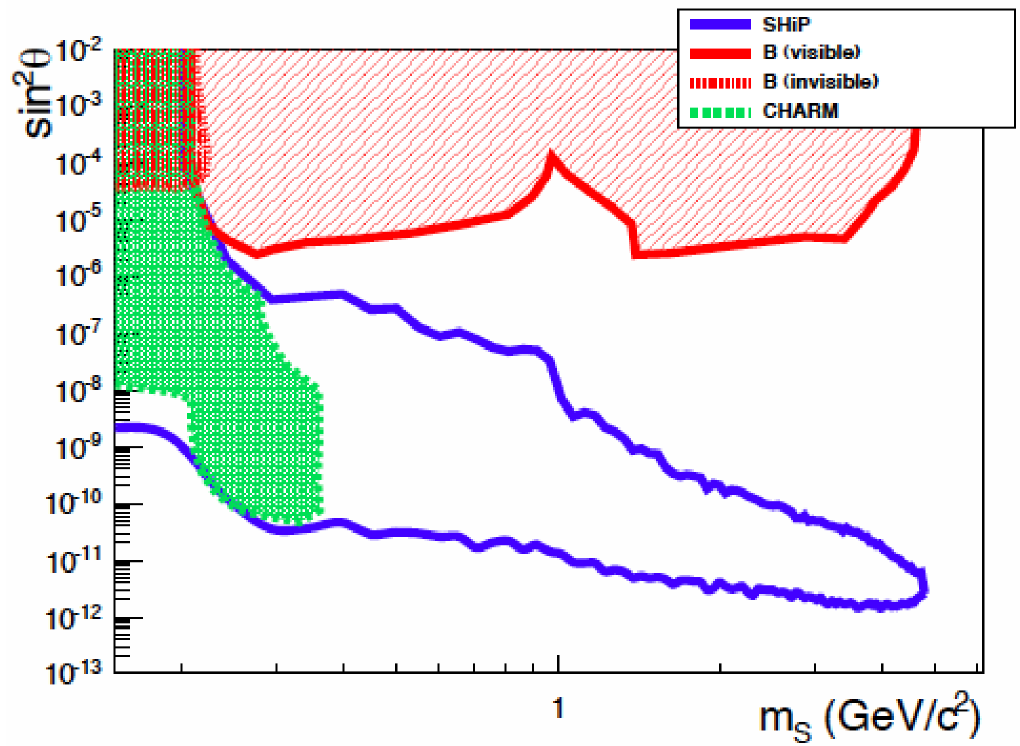
Production:

- mostly penguin-type decays of **B and K decays**
  (D decays are strongly suppressed by CKM)

Decay

into e+e-, μ+μ-, π+π+,KK, ηη, ττ, DD, …

SHiP sensitivity

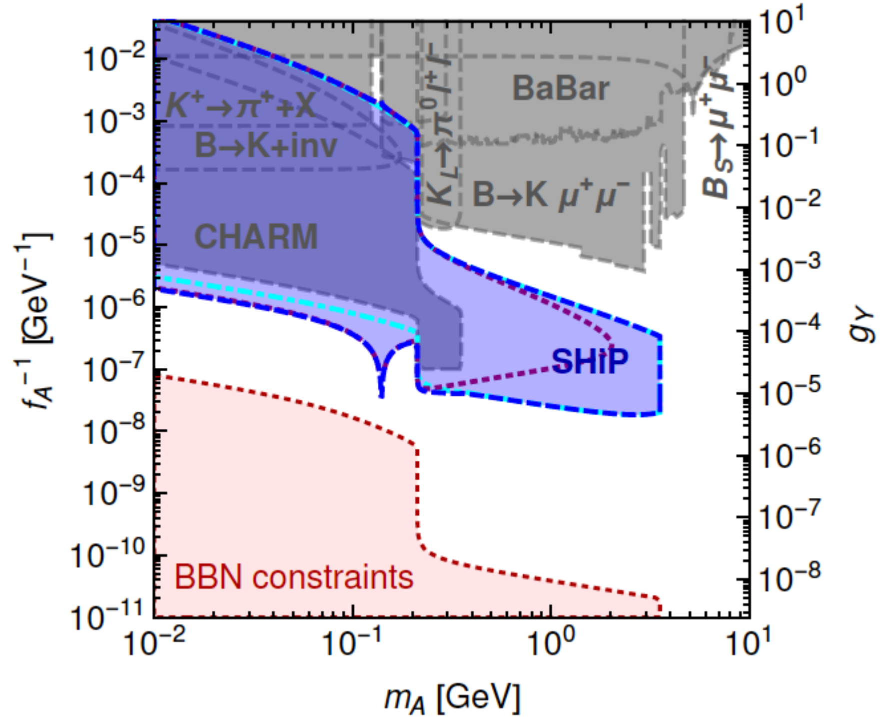


SHiP probes unique range of couplings and masses, thus complementing existing limits from CHARM and B-factories

ALP

If the masses of Axion-like particles (as all the pseudo-Nambu-Goldstone bosons) happed to be in a range $\mathcal{O}$(0.1-1) GeV, SHiP is optimal exp to detect them.

SHiP Sensitivity to ALP



ALPino

$$p\,N \to \tilde{\chi}^0 \to \tilde{A}\ \gamma$$

Light Neutralino

$$\to \tilde{A}\ \ell^+ \ell^-$$

ALPino (~GeV dm)

Light SUSY particles

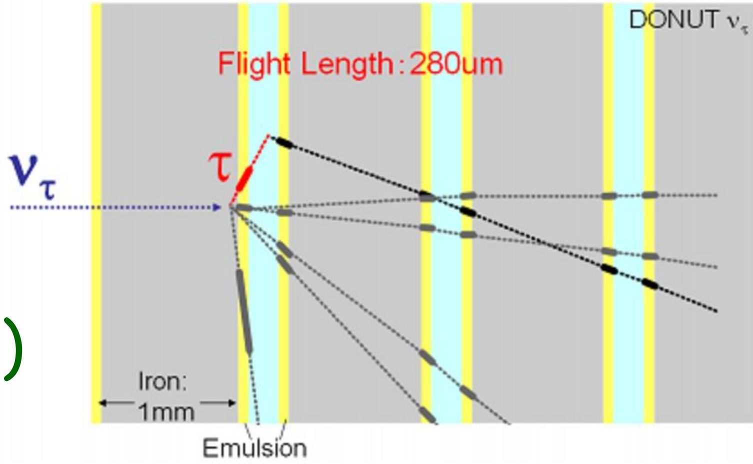
Even in extensively studied MSSM, the existence of light Neutralinos and some other light SUSY particles has not excluded ($\to \ell^+ \ell^- \nu$ etc).

⇨ These are very challenging for SHiP.
Also now under study …

K.Y. Choi

Search for Tau Neutrino & Anti-tau Neutrino

Tau Neutrinos so far



DONuT **9 events** (from Ds decay)
First direct observation
Proton beam dump exp.
Cross section, mag mom

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

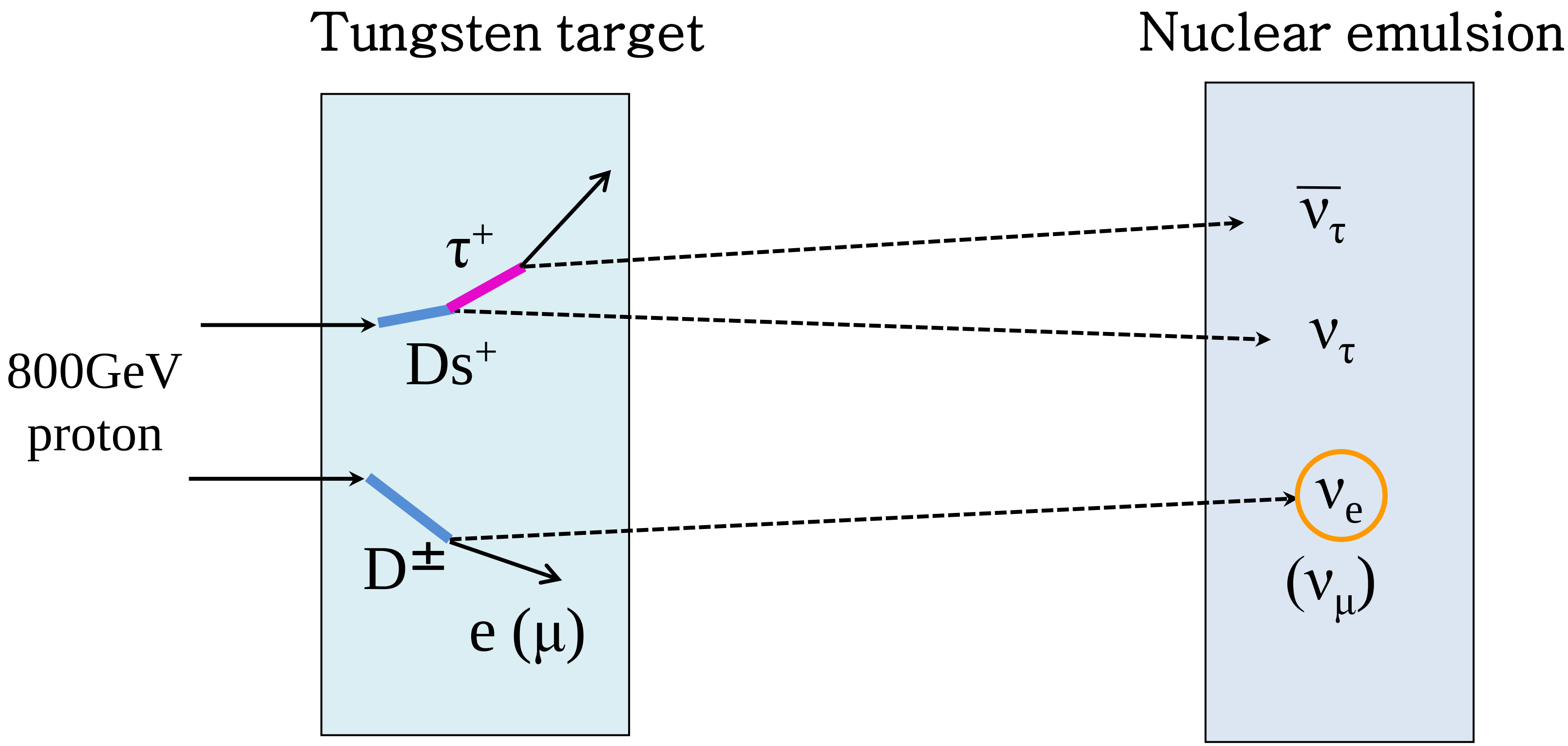
OPERA **5 events + …** (from oscillation)
Discovery of Nu tau appearance
(5.1σ , 2015)

Using Emulsion-Counter hybrid system &
High speed auto scanning system

→ **SHiP almost same method**

DONuT (Direct Observation of Nu Tau)

proton beam dump exp at Fermilab



ν_τ CC events : 9
ν_μ CC events : 225
ν_e CC events : 82

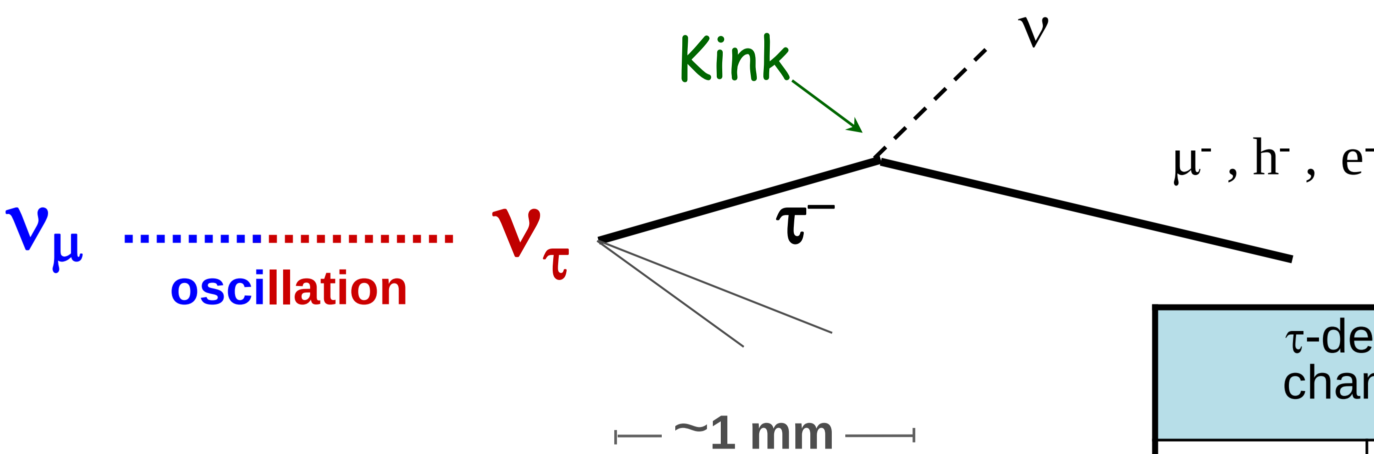
OPERA experiment

(**O**scillation **P**roject with **E**mulsion t**R**acking **A**pparatus)

Direct observation of ν_τ from $\nu_\mu \rightarrow \nu_\tau$ oscillation

Requirements

1) long baseline
2) high neutrino energy
3) high intensity beam
4) τ detection from (very short flight length)



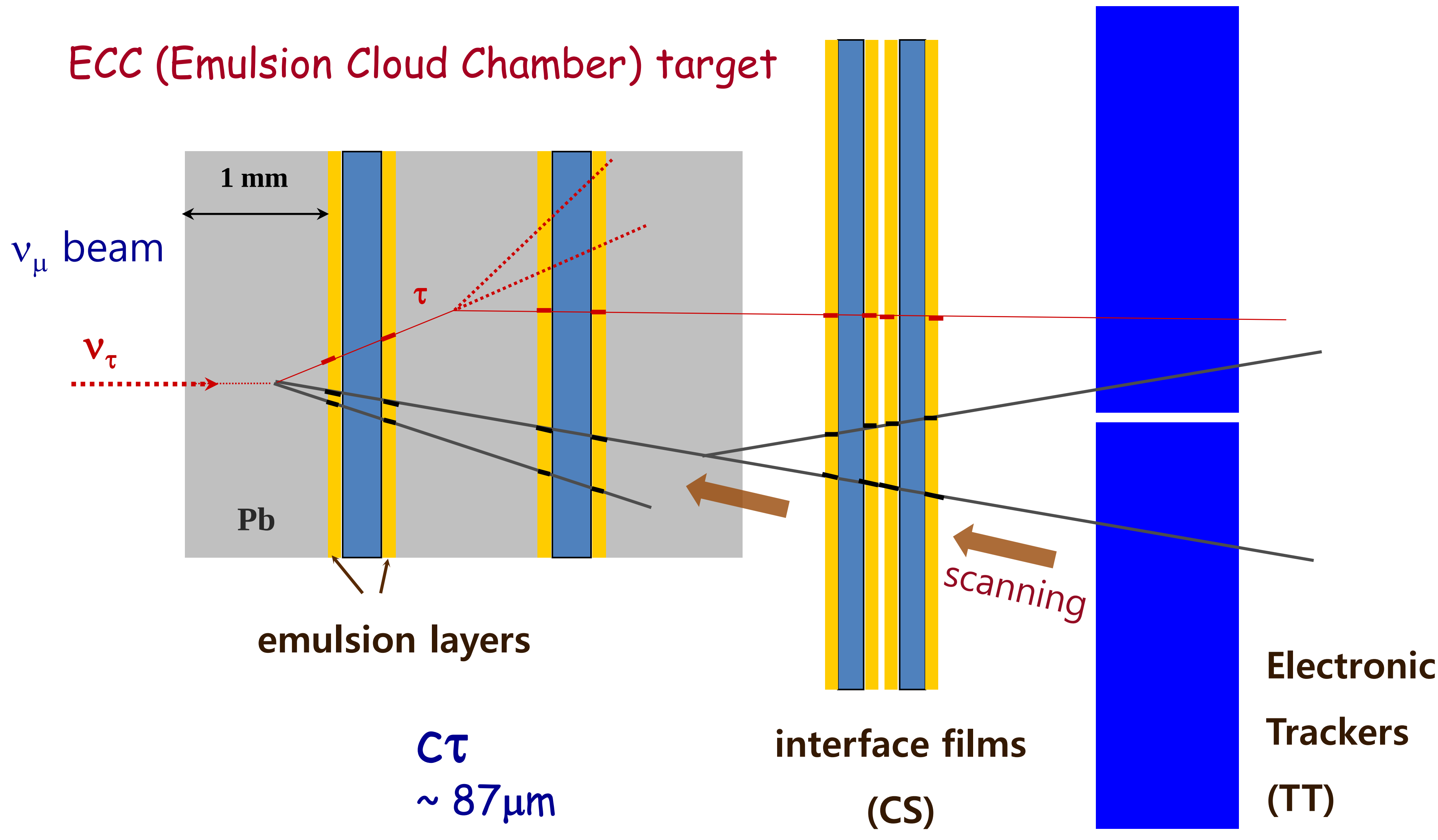
Kink decay 85%

Trident decay 15%

τ-decay channel		B.R (%)
Kink	$\tau \rightarrow e$	18
	$\tau \rightarrow \mu$	18
	$\tau \rightarrow h$	49
Trident	$\tau \rightarrow 3h$	15

ντ detection by identification of Tau lepton

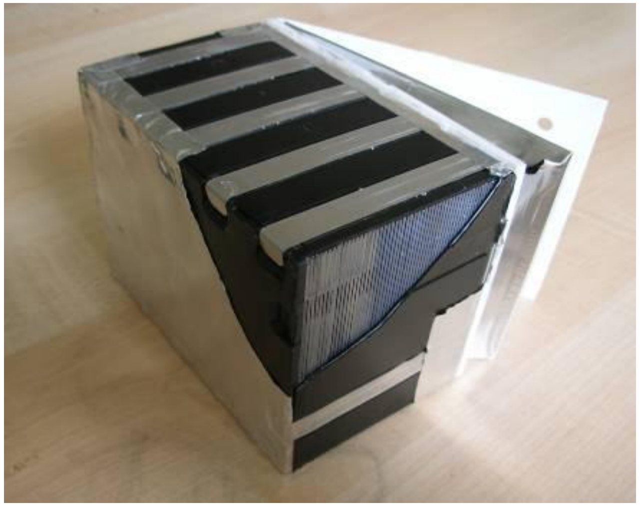
ECC (Emulsion Cloud Chamber) target



Tau Neutrino detector

ECC (Emulsion Cloud Chamber)

TT & Muon Spectrometer



ECC
(Emulsion film + Pb)

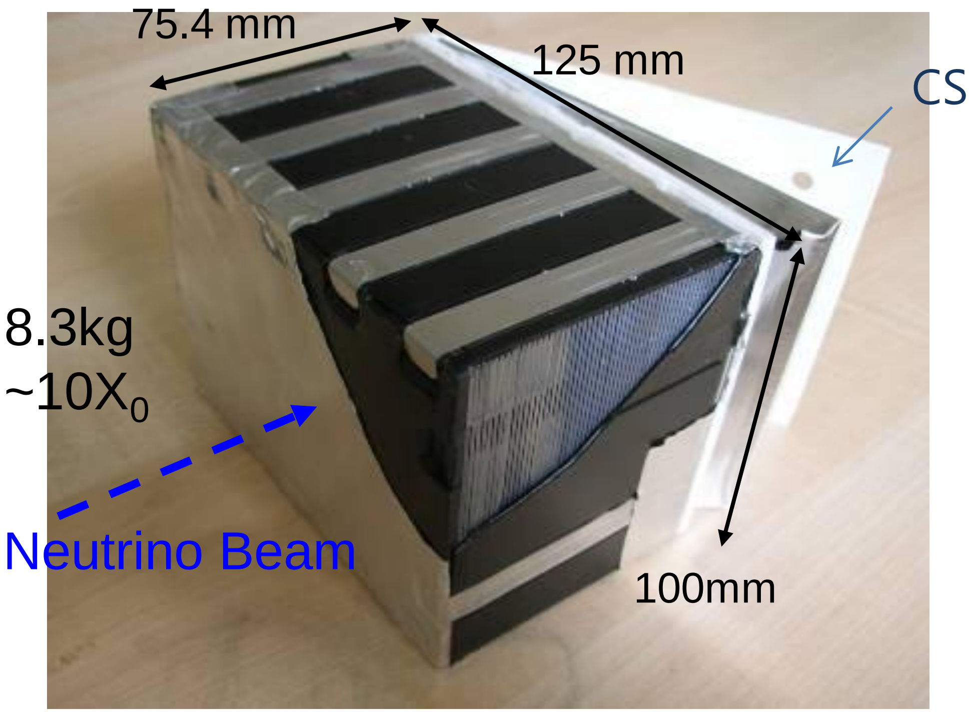
Nuclear emulsion

- Spatial resolution → sub micron
- PID → electron, proton, pion …
- Momemtum measurement – using MCS

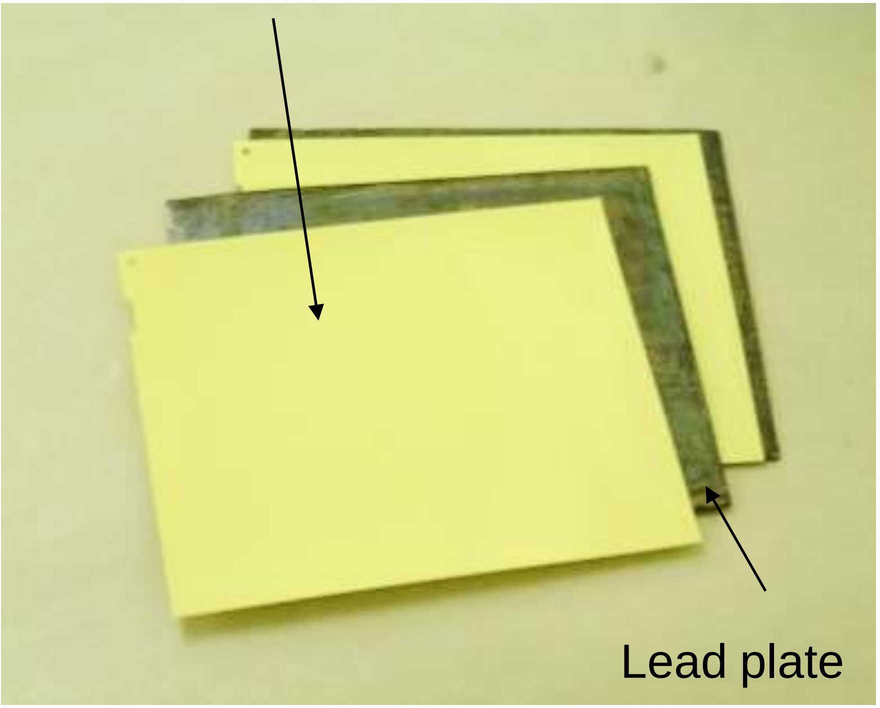
→ Application to various fields

Neutrino exp, DM search, S=-2 nuclei,
Gamma ray telescope, Muon radiography …

ECC (Emulsion Cloud Chamber)

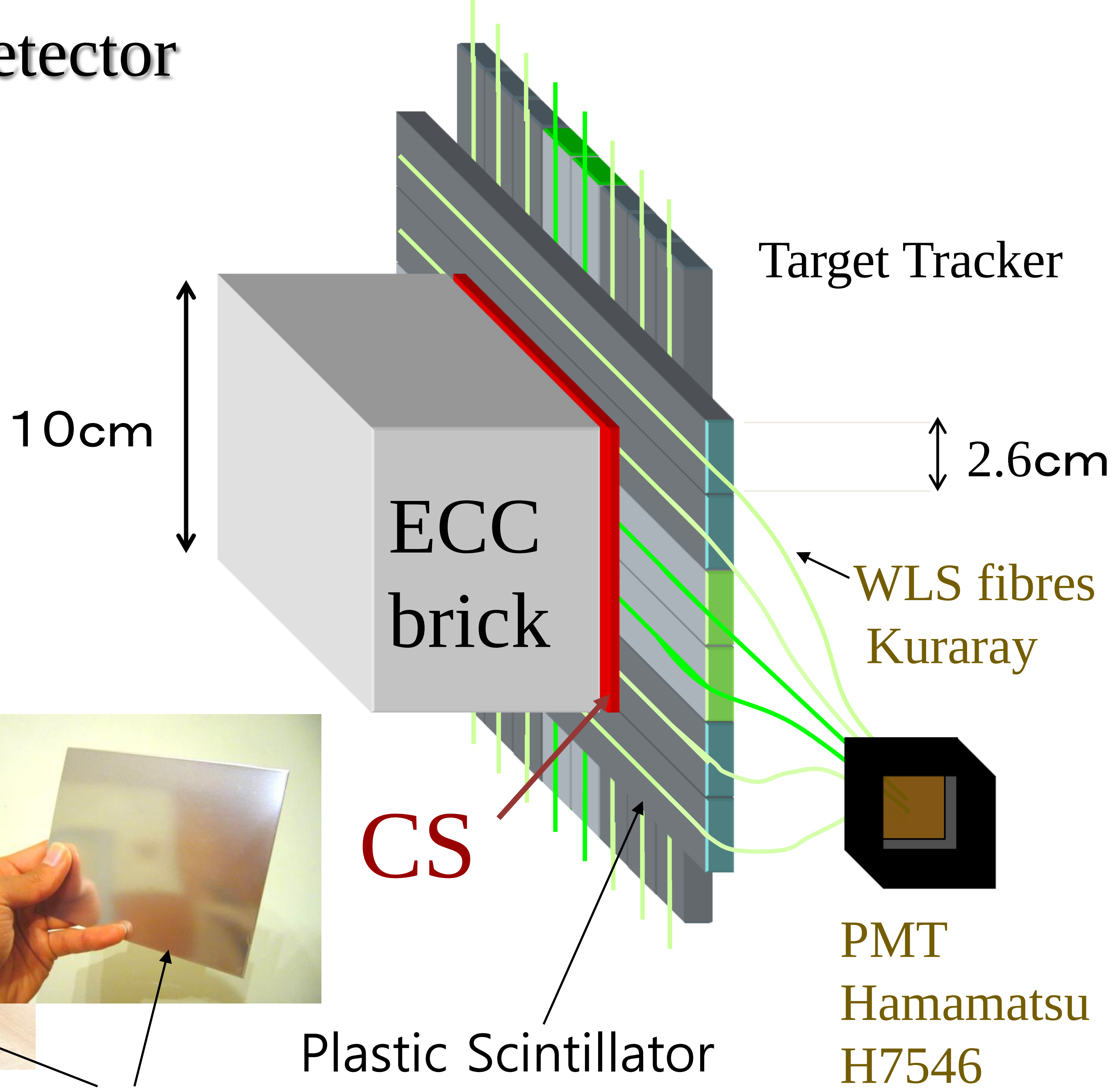


OPERA Film (before development)

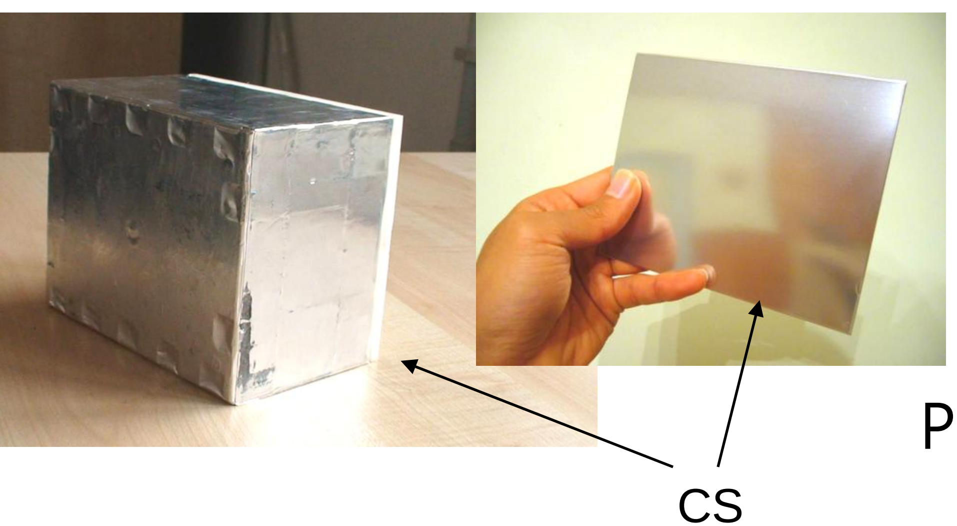


Sandwich structure
  57 nuclear emulsion films
  56 lead plates (1mm thick)

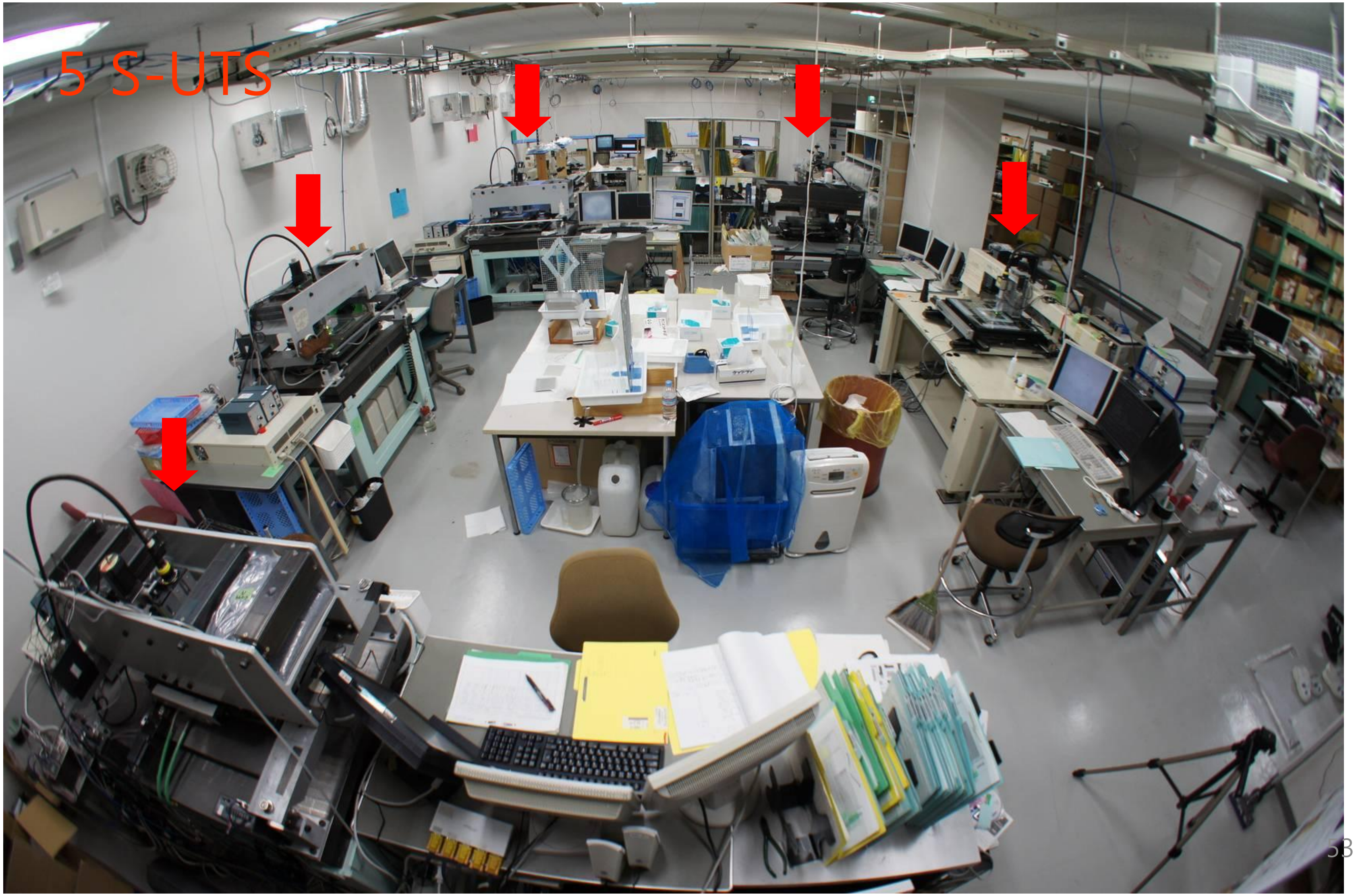
Basic unit of Detector
x 200,000

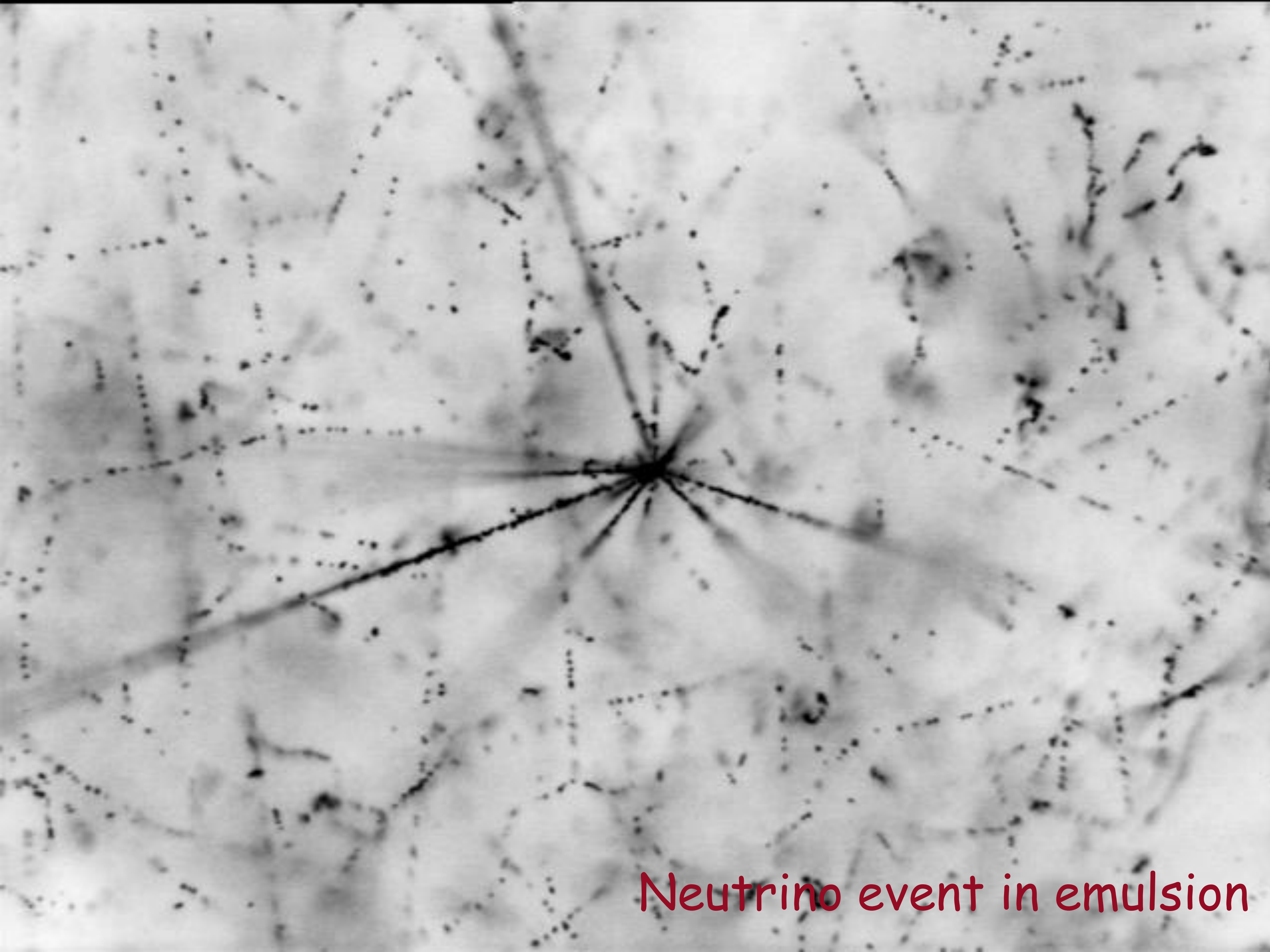


ECC brick



Scanning Lab at Nagoya University





Neutrino event in emulsion

Selection criteria for Tau Neutrino event

At primary vertex

- there are no tracks compatible with that of a muon or an electron;
- the missing transverse momentum (P_T^{miss}) is smaller than 1 GeV/c;
- the angle Φ in the transverse plane between the τ candidate track and the hadronic shower direction is larger than $\pi/2$.

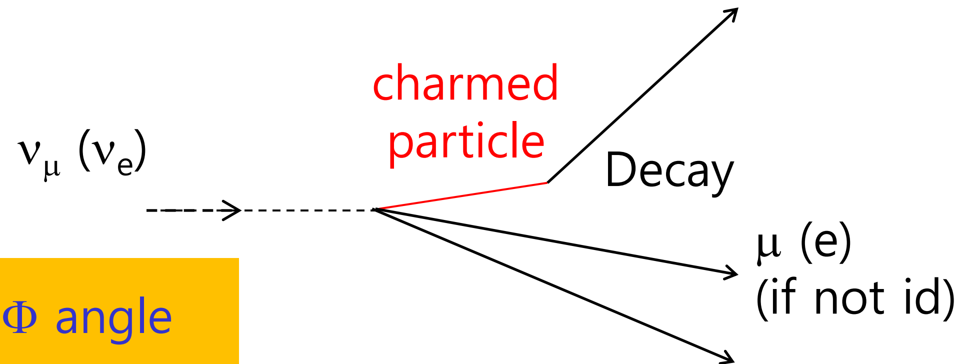
At decay vertex

- the kink angle θ_{kink} is larger than 20 mrad;
- the secondary vertex is within the two lead plates downstream of the primary vertex;
- the momentum of the charged secondary particles is larger than 2 GeV/c;
- the total transverse momentum (P_T) of the decay products is larger than 0.6 GeV/c if there are no photons emitted at the decay vertex, and 0.3 GeV/c otherwise.

Main background of τ decay

(1) **Charged charmed particles** produced in ν_μ (or ν_e) CC interactions where μ (or e) from the primary vertex could not identified
- if id, then ν_μ or ν_e CC

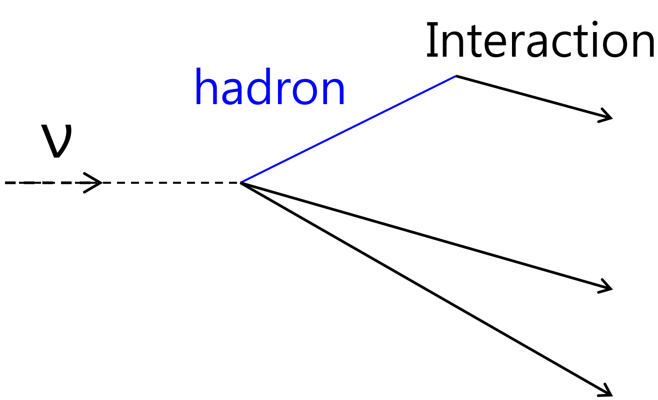
particle	$c\tau(\mu m)$
τ	87
$D^{\pm}$	312
Λ^{+}_{c}	60



Φ angle
μ charge

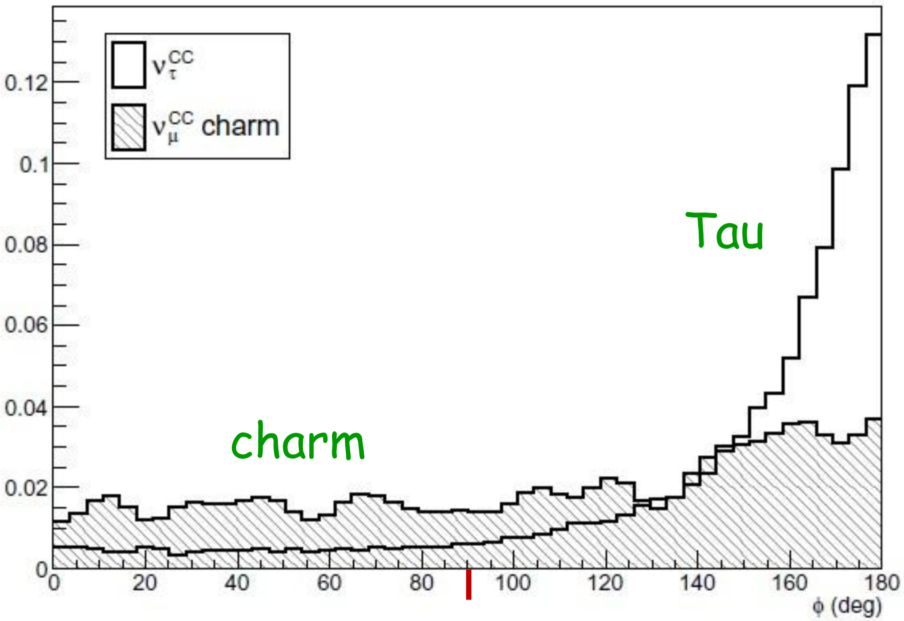
(2) **Hadronic secondary interactions** of charged particles from the 1ry vertex, where no leptons observed
(White kink)

P$_T$ cut
Φ angle

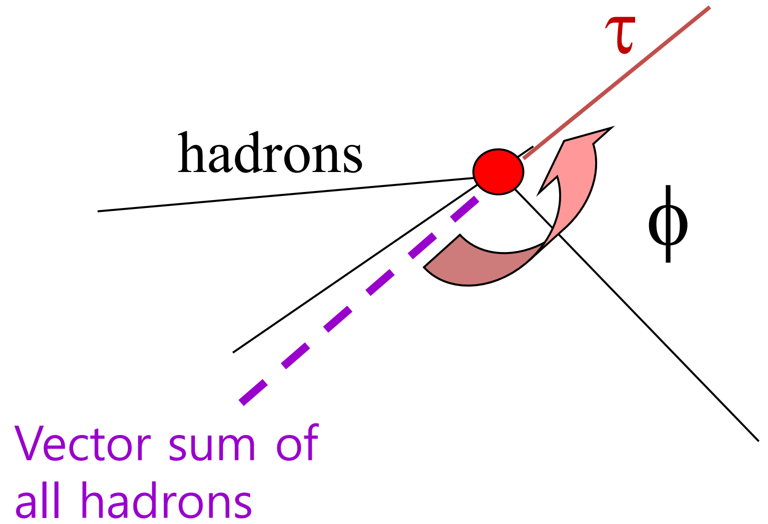


Φ angle

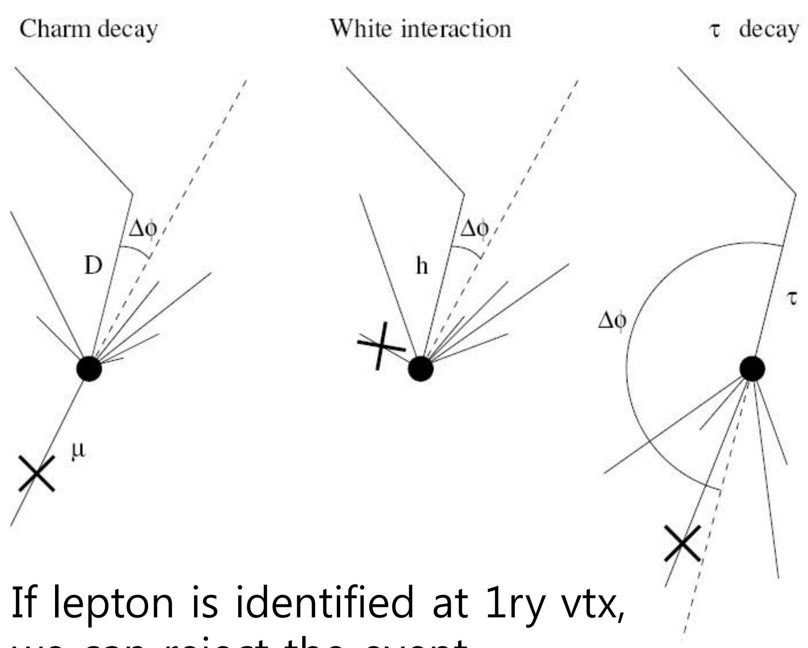
Charm and Tau decay



Distribution of the ϕ variable for the $\nu\tau$ signal (white) and the charmed hadron background (shaded).



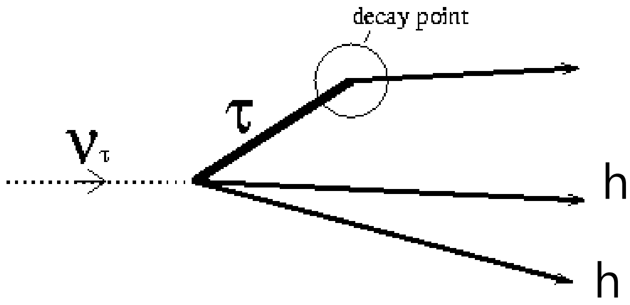
View perpendicular to ν direction



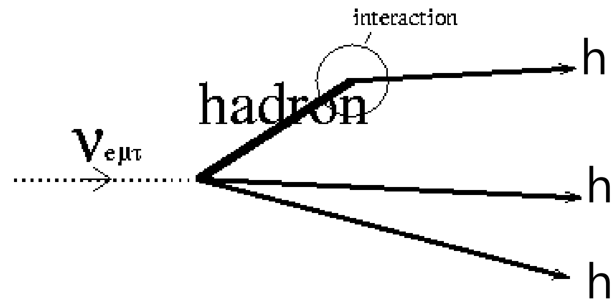
If lepton is identified at 1ry vtx, we can reject the event.

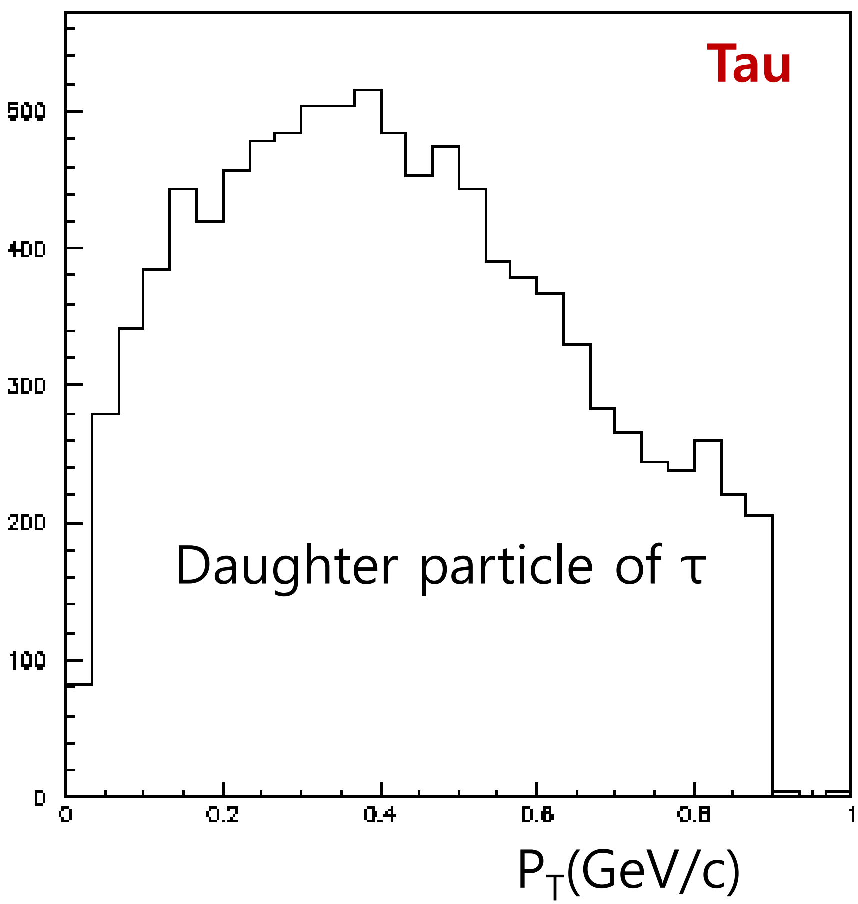
P_T

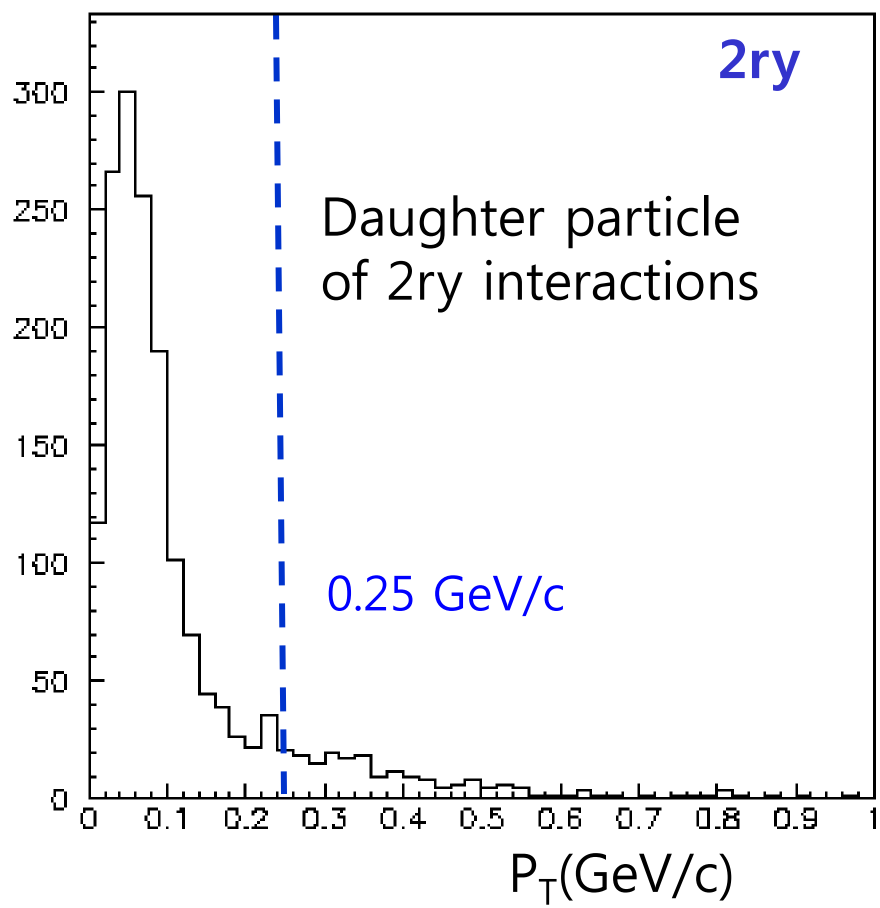
Tau decay



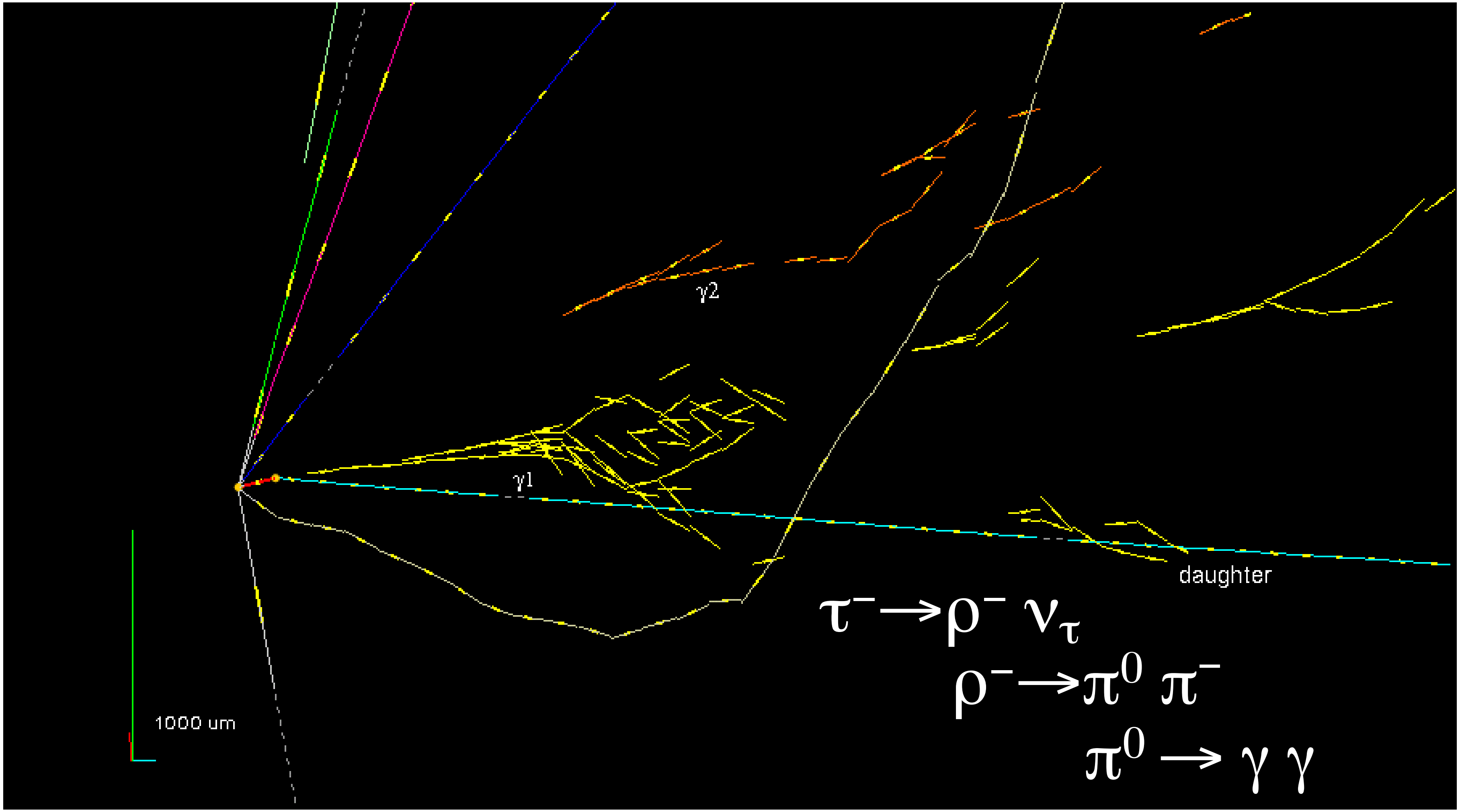
2ry int







The 1st Tau neutrino event in OPERA



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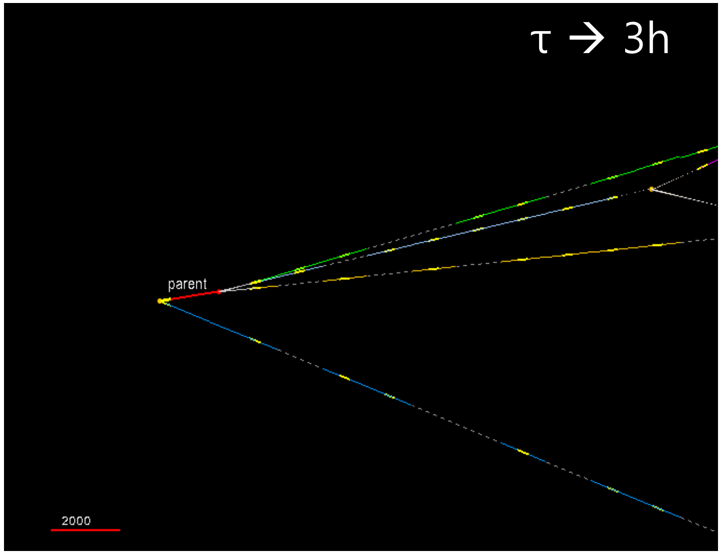
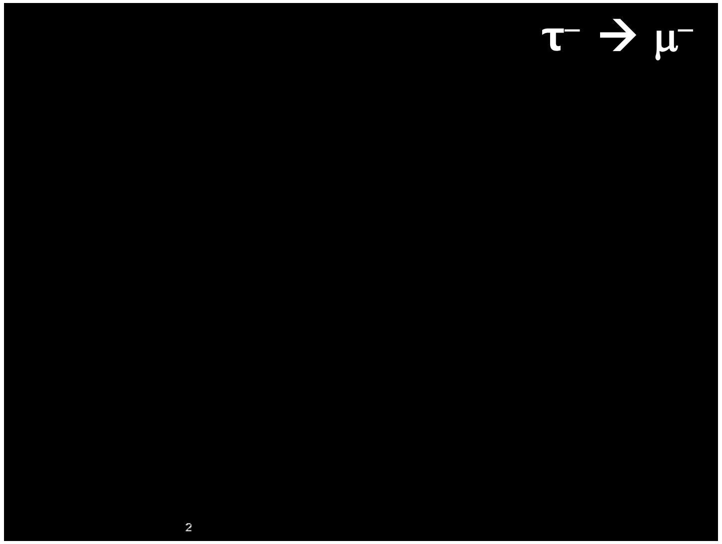
Tau neutrino events in OPERA

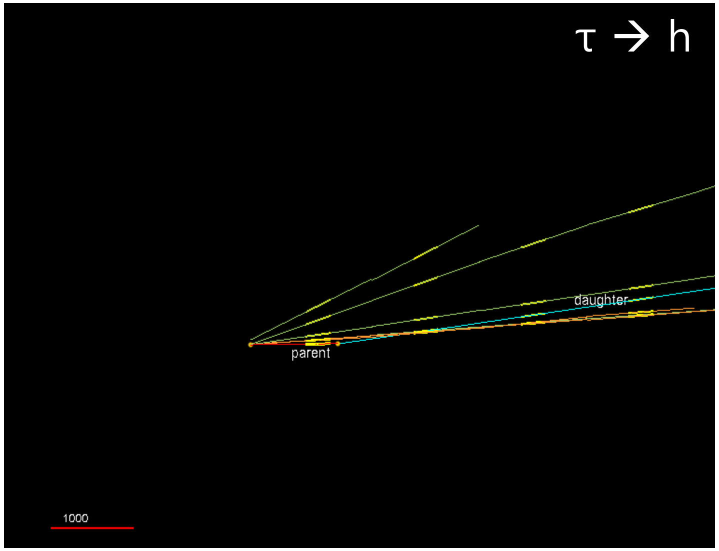
2^{nd} $\nu\tau$



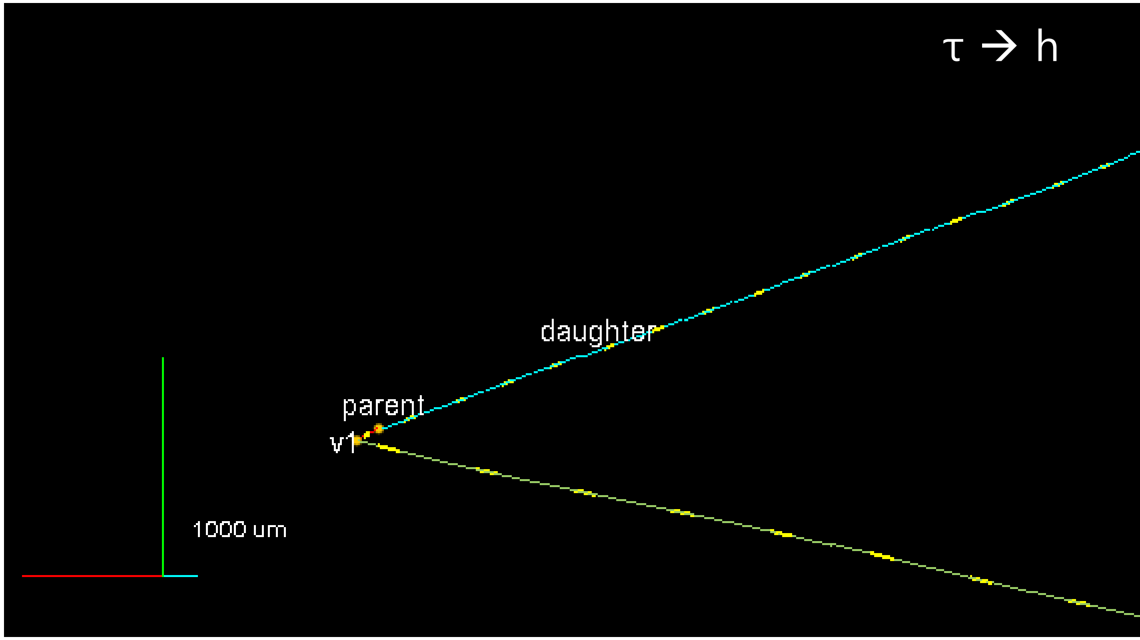
3^{rd} $\nu\tau$



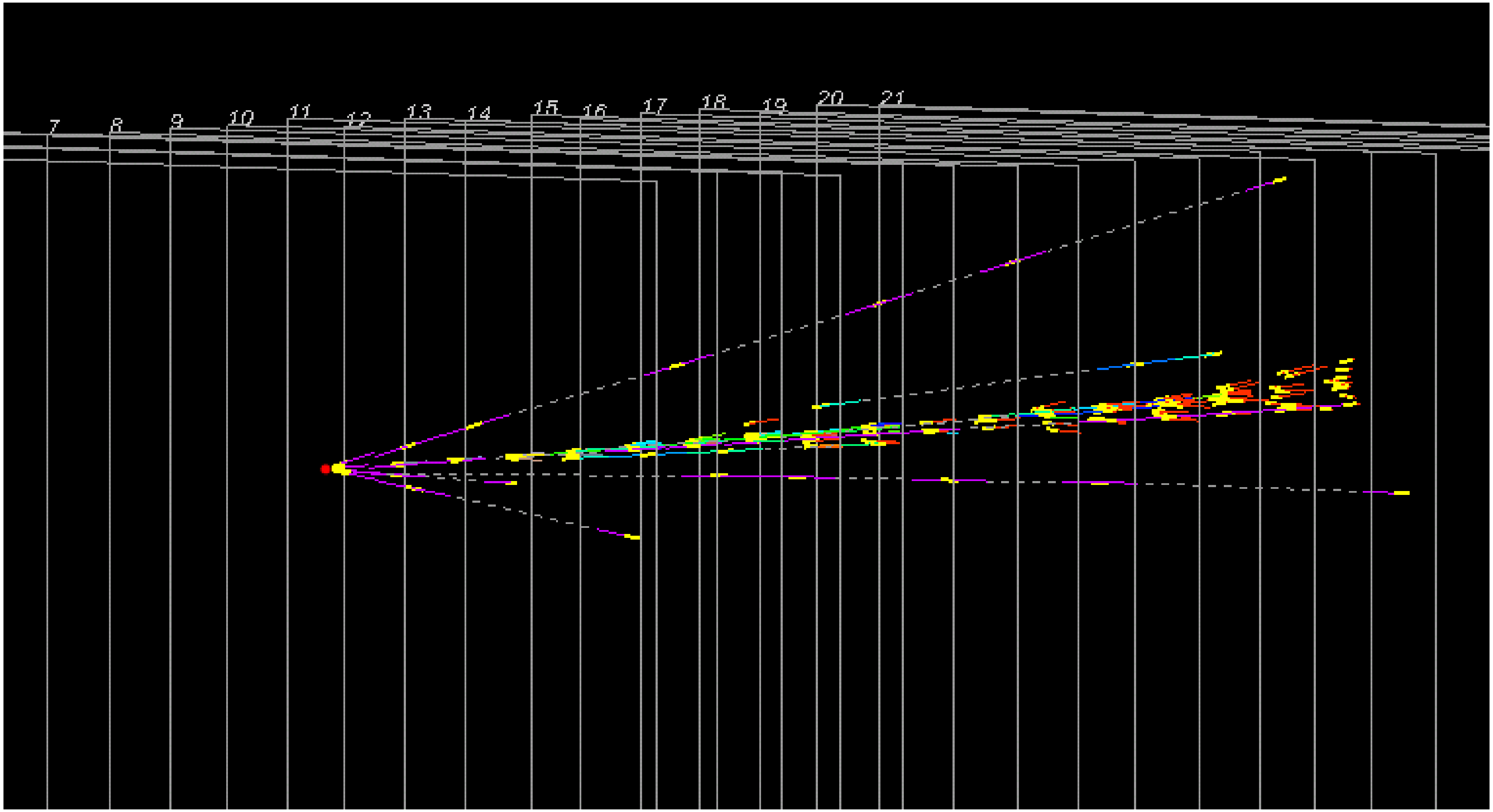
4^{th} $\nu\tau$

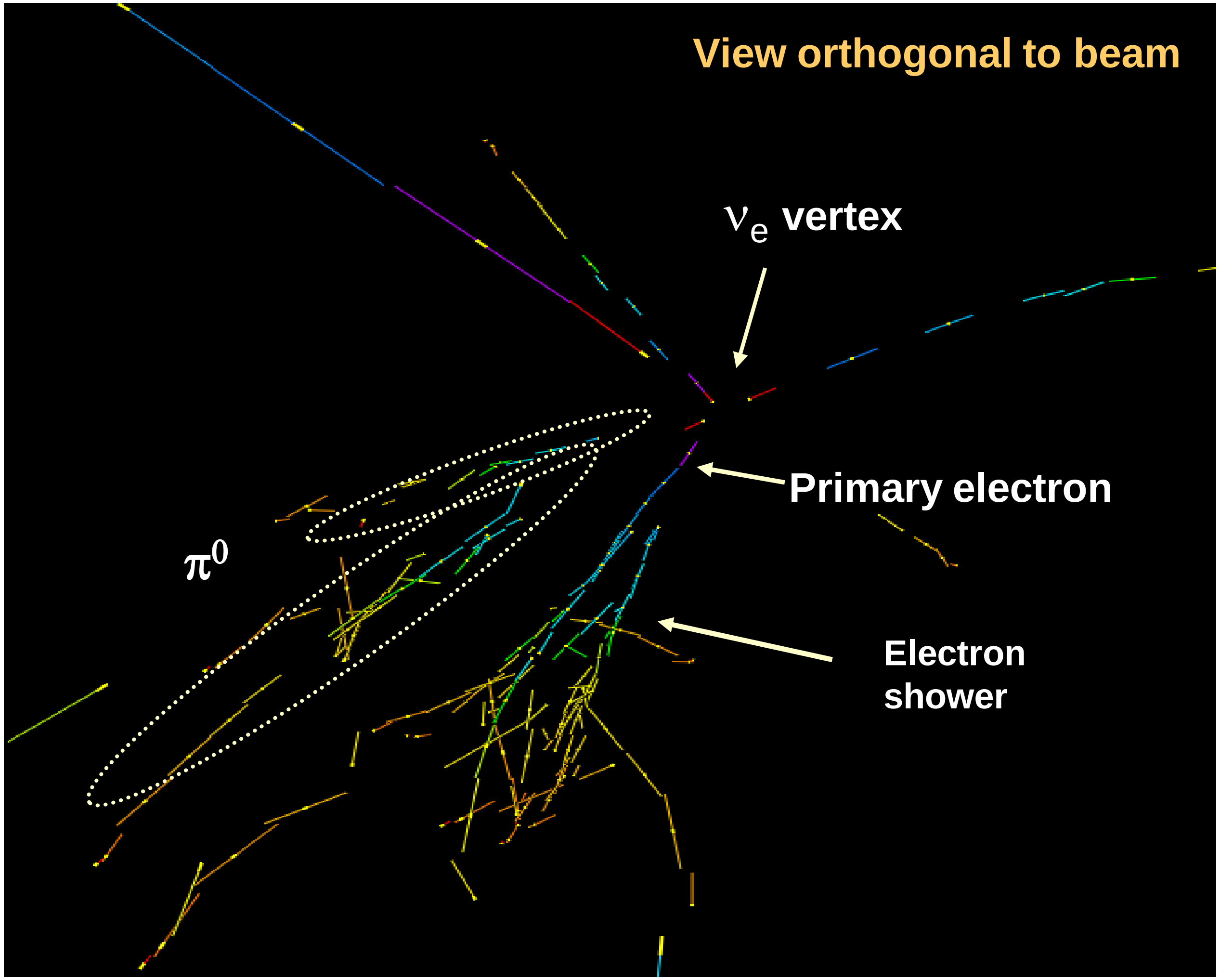


5^{th} $\nu\tau$



ν_e CC event in OPERA





Another ν_e CC event

PID in emulsion → electron, π^0

Tau Neutrino Physics in SHiP

- Tau neutrino ~3500 events
- Anti Tau neutrino – only SM particle not yet observed
- Cross section of Nu tau & Anti Tau Nu
- Structure function (F3, F4)
- Magnetic moment of Tau Nu
- DM search via dark photon decay …

ν_τ fluxes

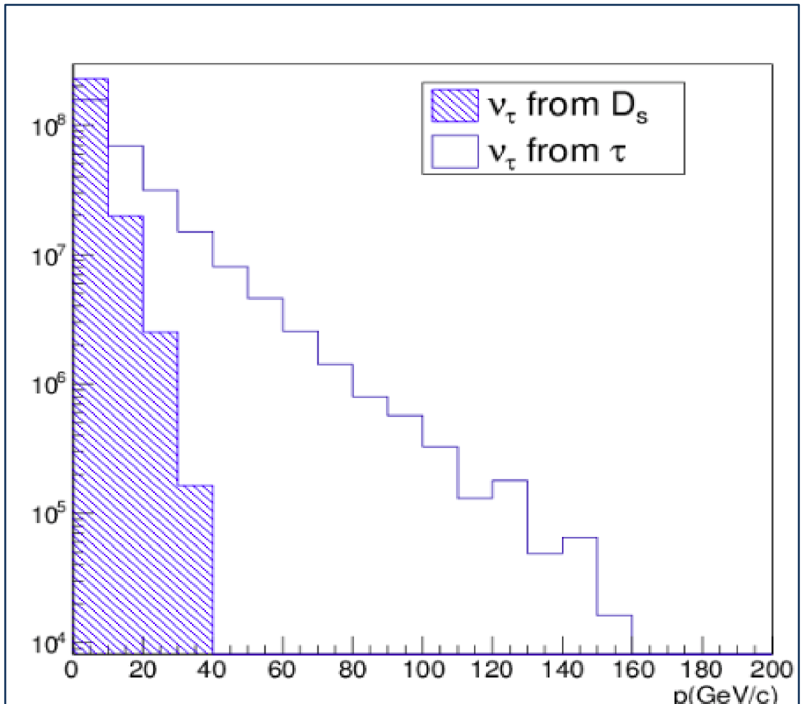
5 years run (2×10^{20} pot)

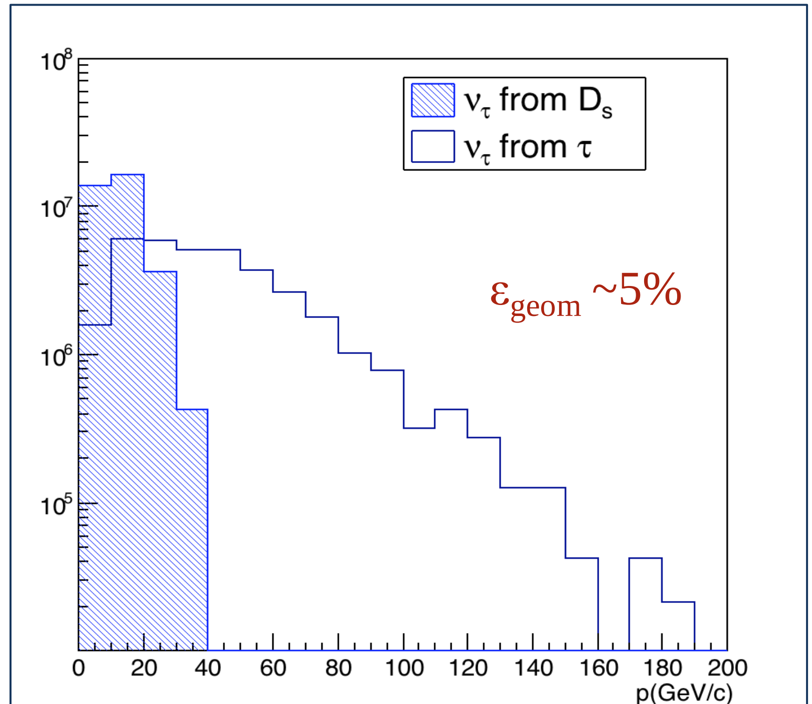
At the beam dump

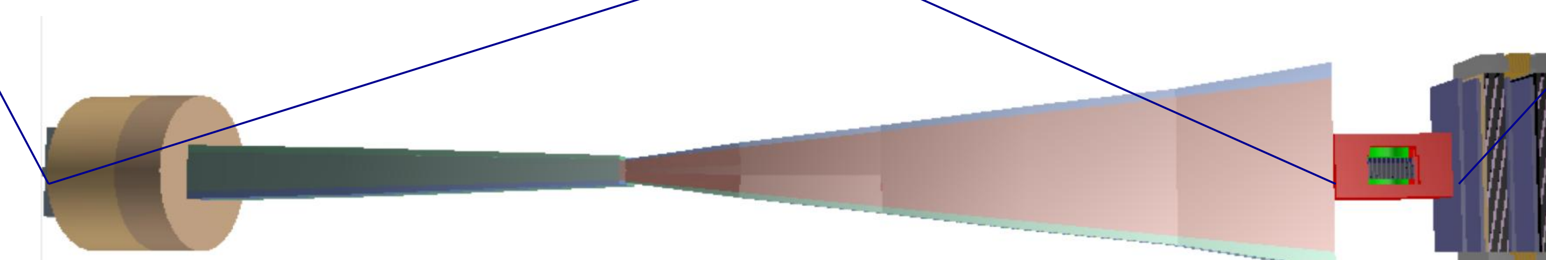
$$N_{\nu_\tau} = N_{\overline{\nu}_\tau} = 2.8 \times 10^{15}$$

At the neutrino detector

$$N_{\nu_\tau} = N_{\overline{\nu}_\tau} = 1.4 \times 10^{14}$$

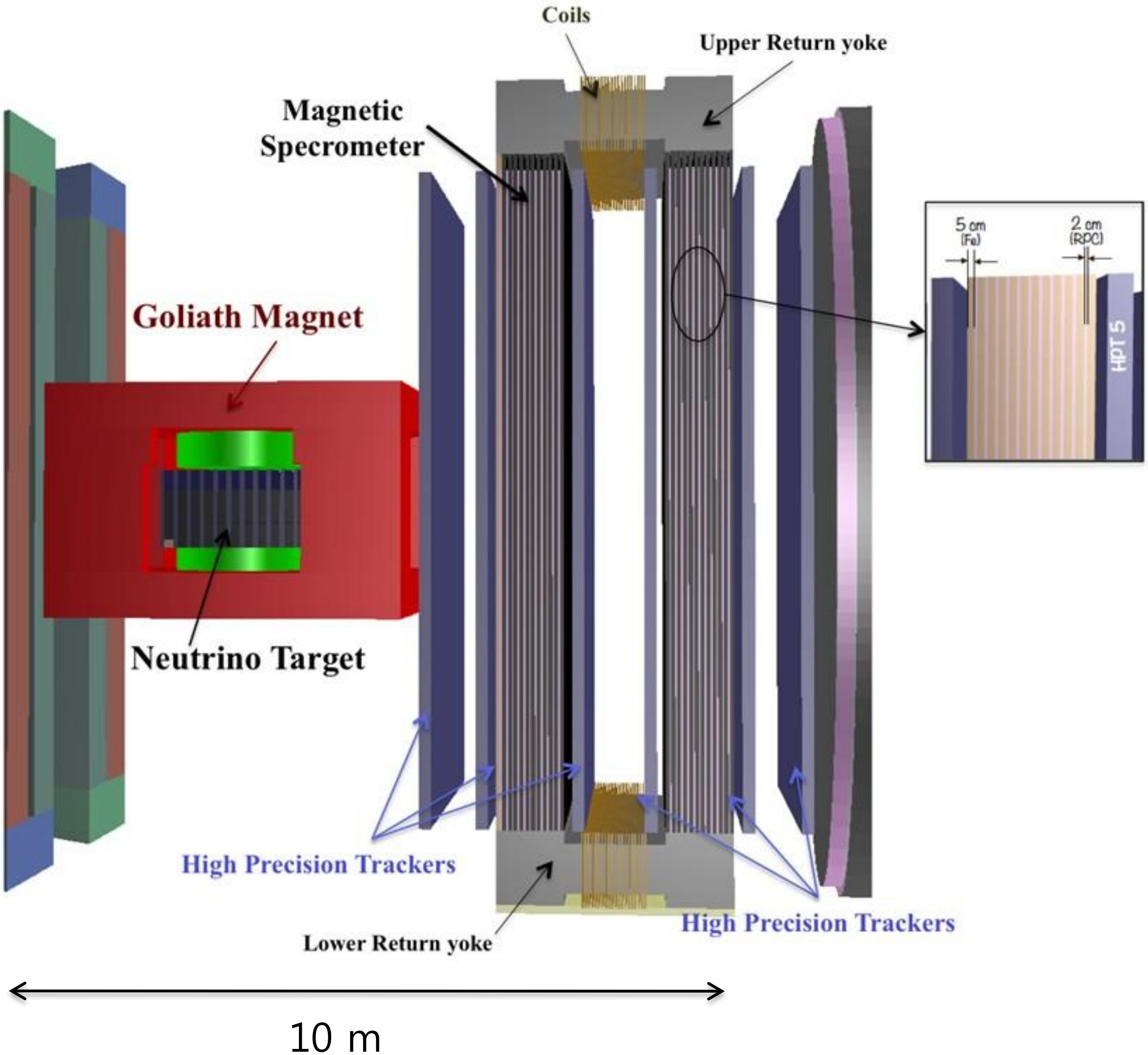






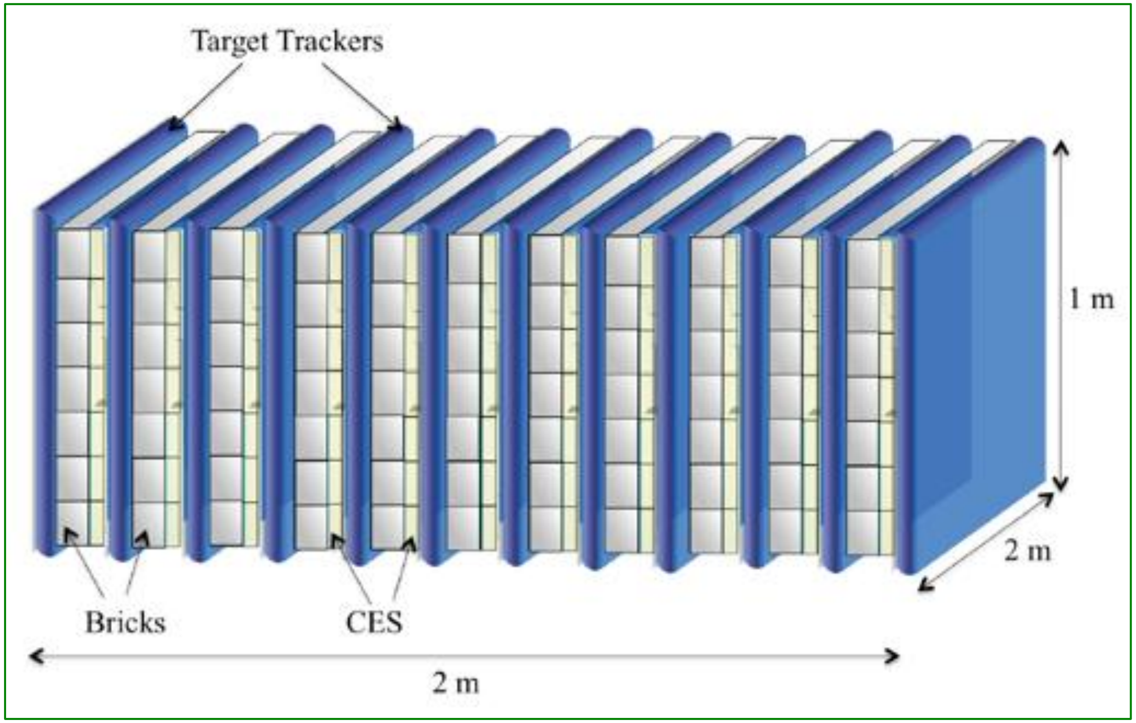
#($\nu\tau$)SHiP/DONUT=600

SHiP Neutrino detector



SHiP Neutrino target

ECC+TT+CES



- 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 100 μm position resolution
- high efficiency (>99%) for angles up to 1 rad

TARGET TRACKER

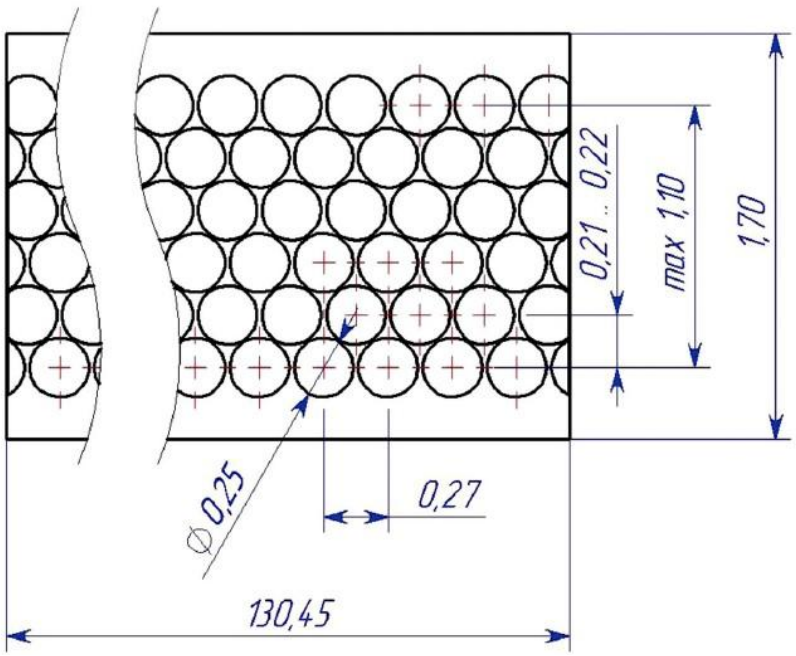
Possible options

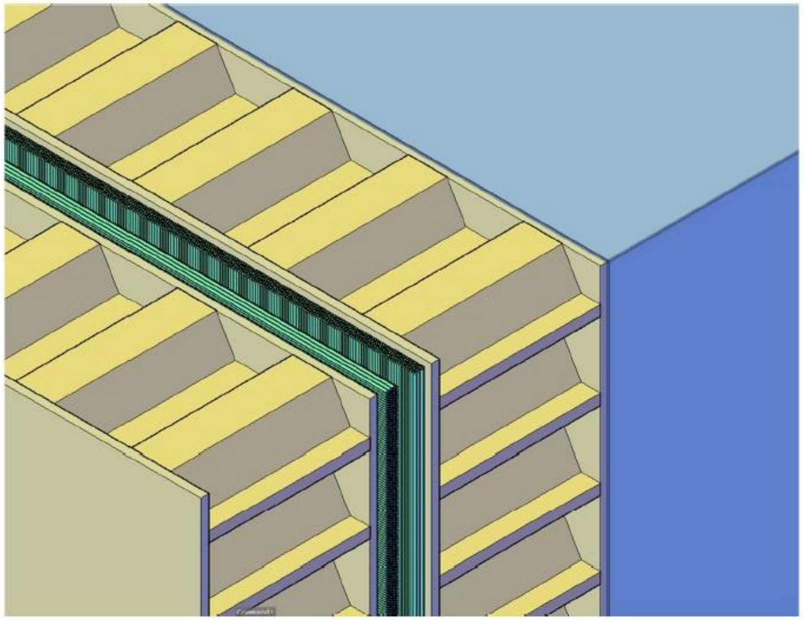
- Scintillating fibre trackers
- Micro-pattern gas detectors (GEM, Micromegas)

TT (Target Tracker) for Tau Neutrino

- Time stamp
- Prediction of the Scan-Back tracks
  (possible to connect tracks to the emulsion)

Scintillating fiber (TT)



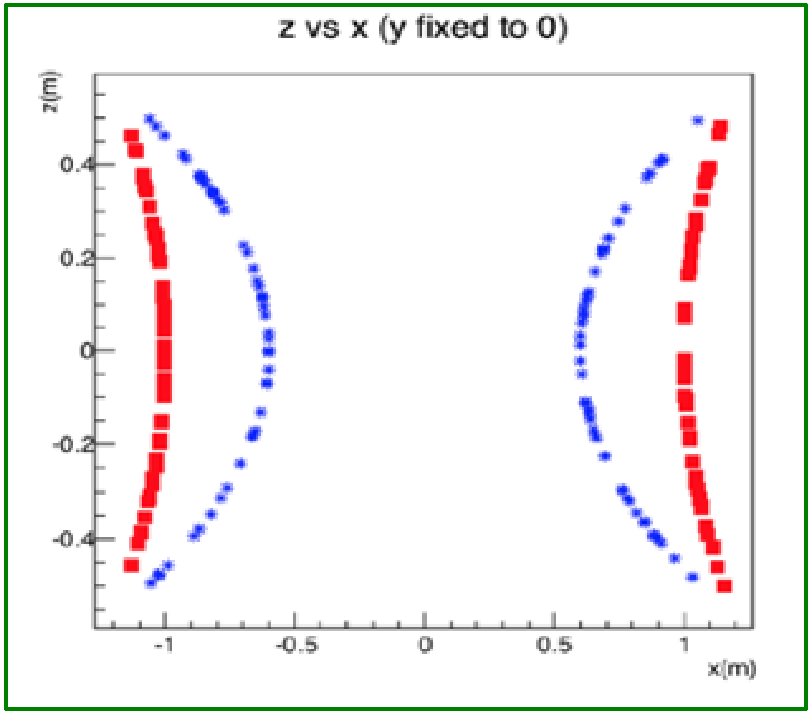


Target magnetization

GOLIATH MAGNET
CERN H4 beam line

- 1 Tesla vertical magnetic field
- few m^3 volume with constant magnetization

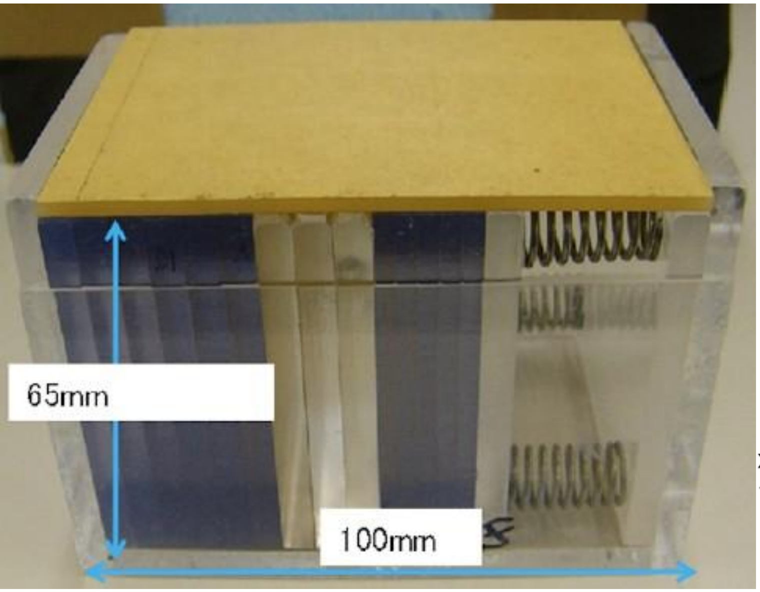
Magnetic field behavior in the target region

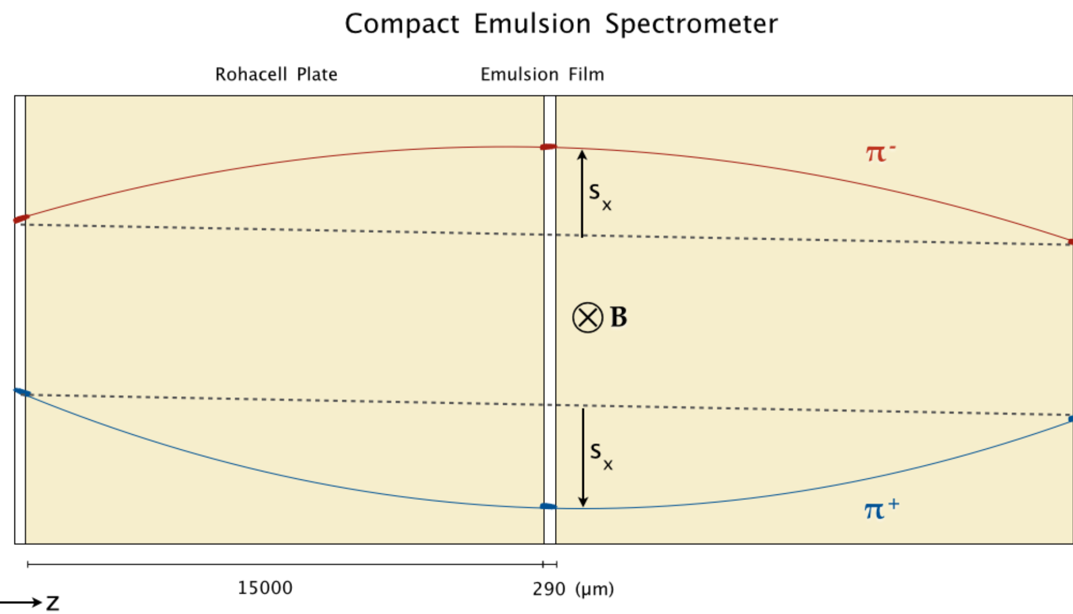


Within the blu curves B ≈ 1.5 T
Within the red curves B >=1 T

Anti-tau neutrino by CES

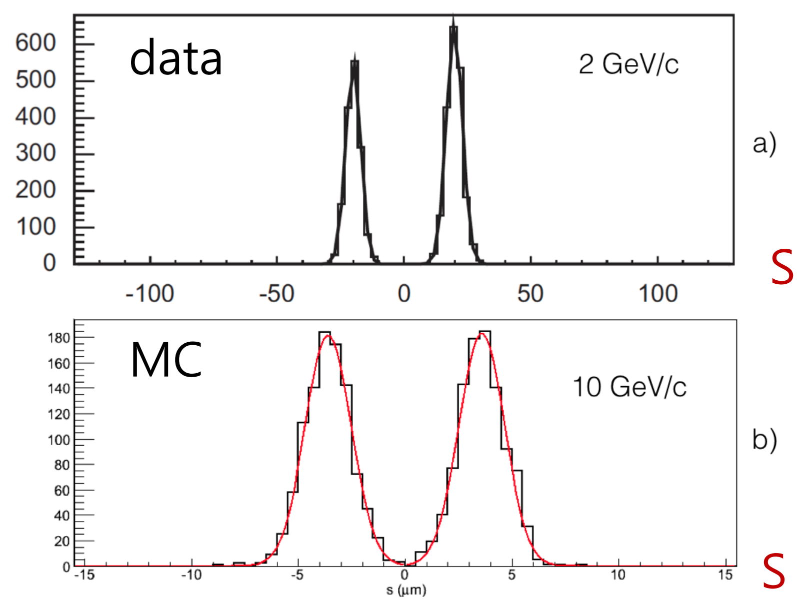
Measurement of Sagitta





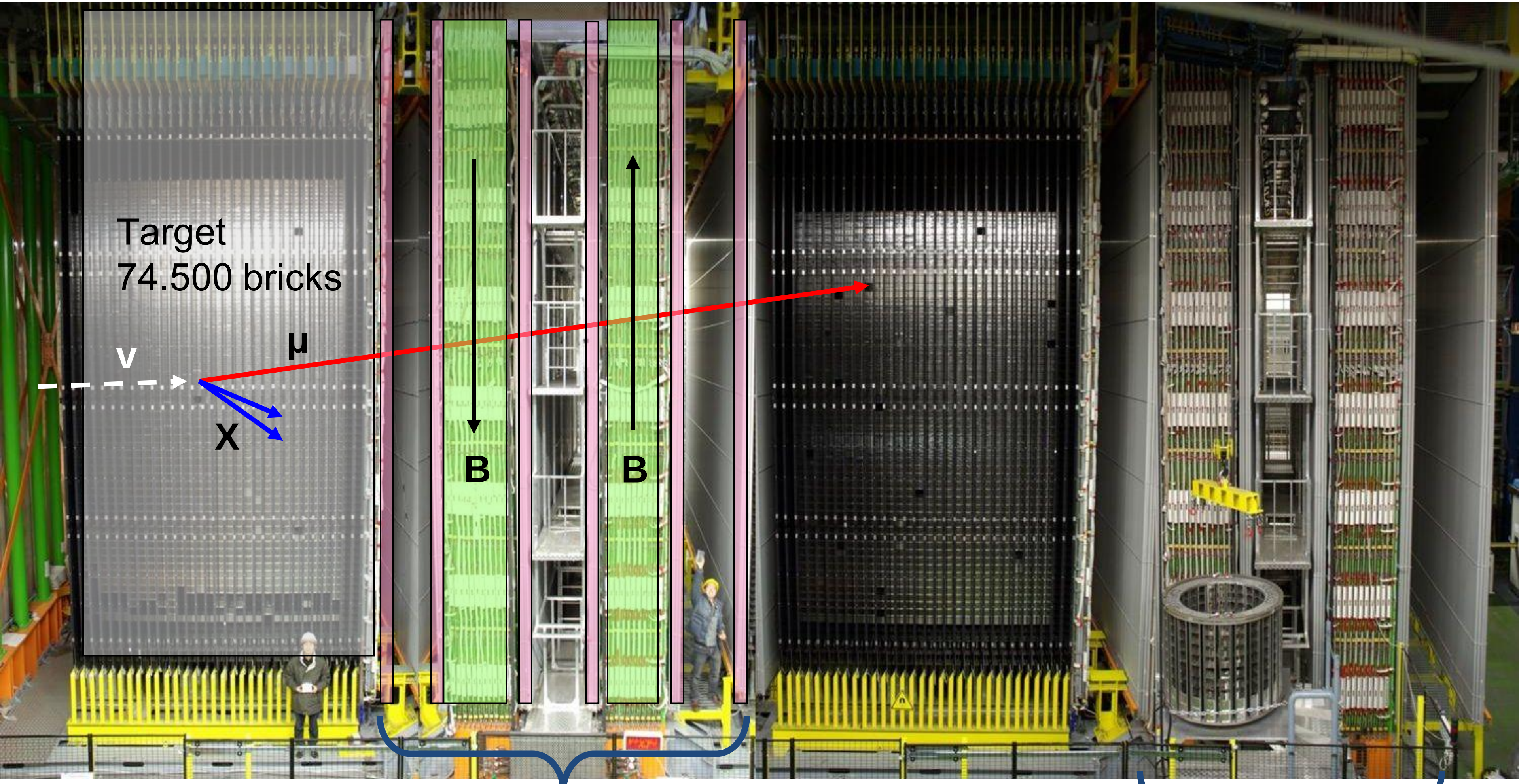
$$\nu_\tau \rightarrow \tau^- \rightarrow \mu^-$$

$$\bar{\nu}_\tau \rightarrow \tau^+ \rightarrow \mu^+$$



- 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

OPERA detector



Muon Spectrometer

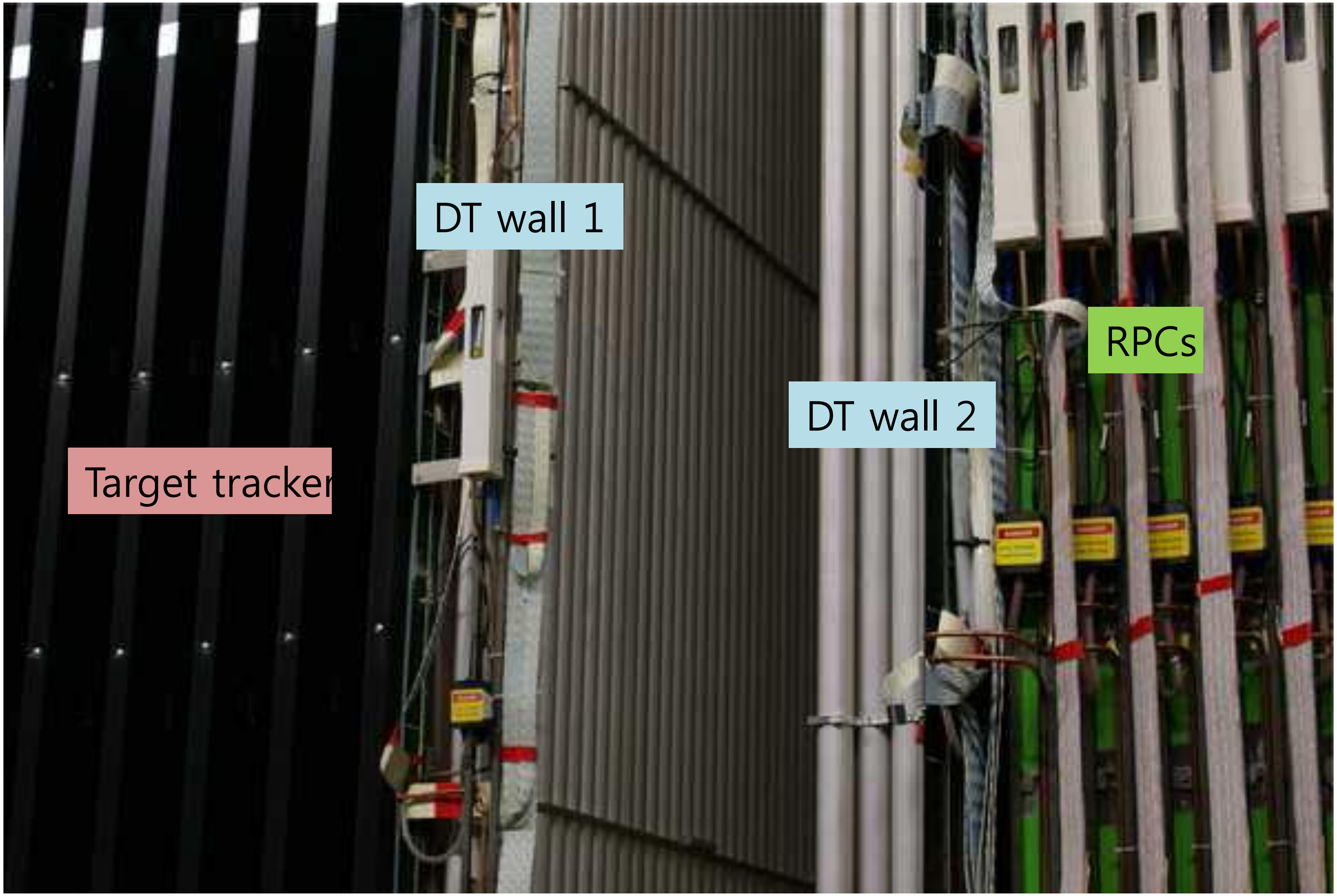
Magnet region:
Iron & RPCs

Precision Tracker:
6 planes of Drift tubes

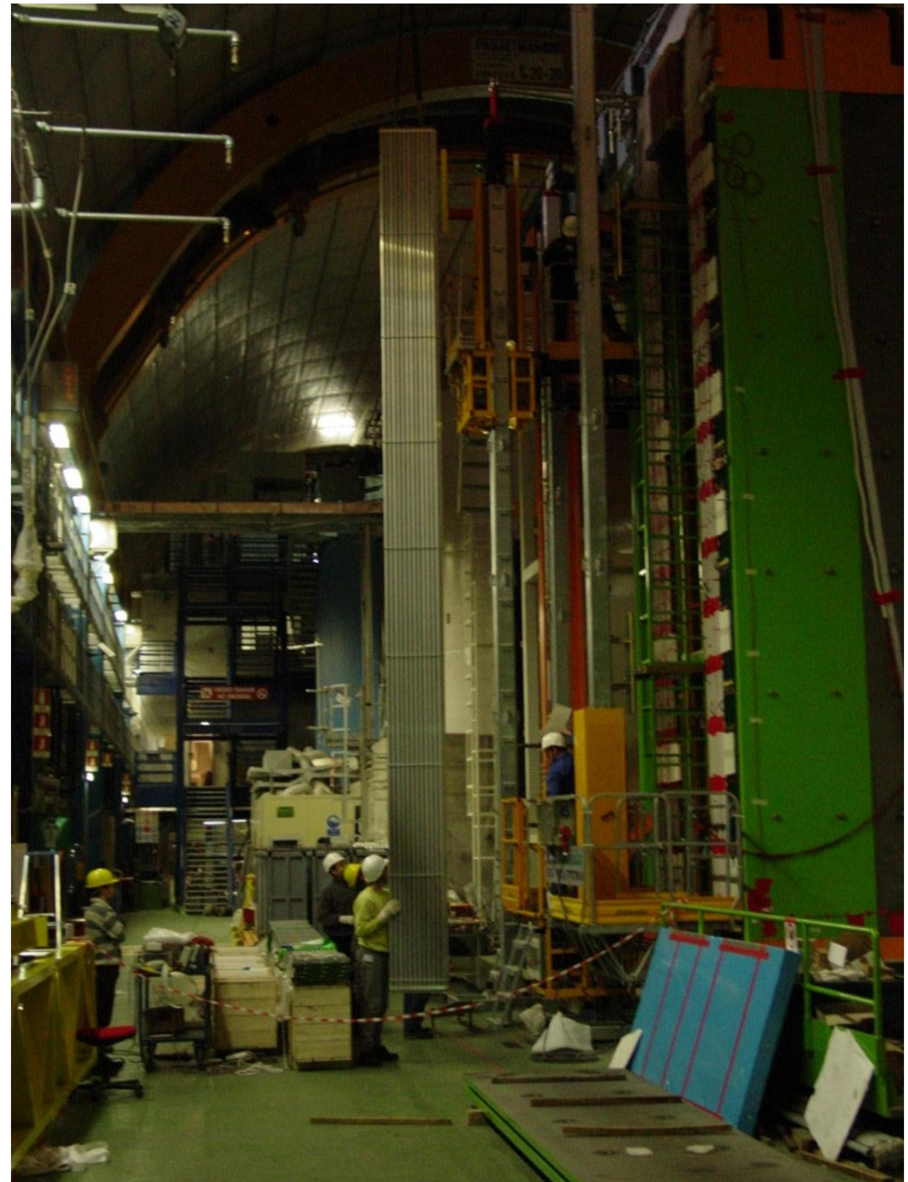
Muon Spectrometer

will be reused at SHiP

DT Walls in OPERA detector



Dismantle at Gran Sasso to be used for SHiP



Expected number of Tau neutrinos

2×10^{20}pot

5.7×10^{15}

$$N^{exp}_{\nu_\tau(\overline{\nu}_\tau)}(\tau\to\mu) = N_{\nu_\tau(\overline{\nu}_\tau)} Br(\tau\to\mu)\epsilon^{\tau\to\mu}_{tot}\epsilon^{tau}_{\mu}\epsilon^{\mu}_{charge}(1-\eta_\mu)$$

$$N^{exp}_{\nu_\tau(\overline{\nu}_\tau)}(\tau\to i) = N_{\nu_\tau(\overline{\nu}_\tau)} Br(\tau\to i)\epsilon^{\tau\to i}_{tot}\epsilon^{i}_{charge}\epsilon^{\tau\to i}_{kin}(1-\eta_\mu) \quad (i = h, 3h)$$

decay channel	ν_τ	
	N^{exp}	N^{bg}
$\tau^-\to\mu^-$	570	30
$\tau^-\to h^-$	990	80
$\tau^-\to h^-h^+h^-$	210	30
Total	1770	140

decay channel	$\overline{\nu}_\tau$	
	N^{exp}	N^{bg}
$\tau^+\to\mu^+$	290	140
$\tau^+\to h^+$	500	380
$\tau^+\to h^-h^+h^+$	110	140
Total	900	660

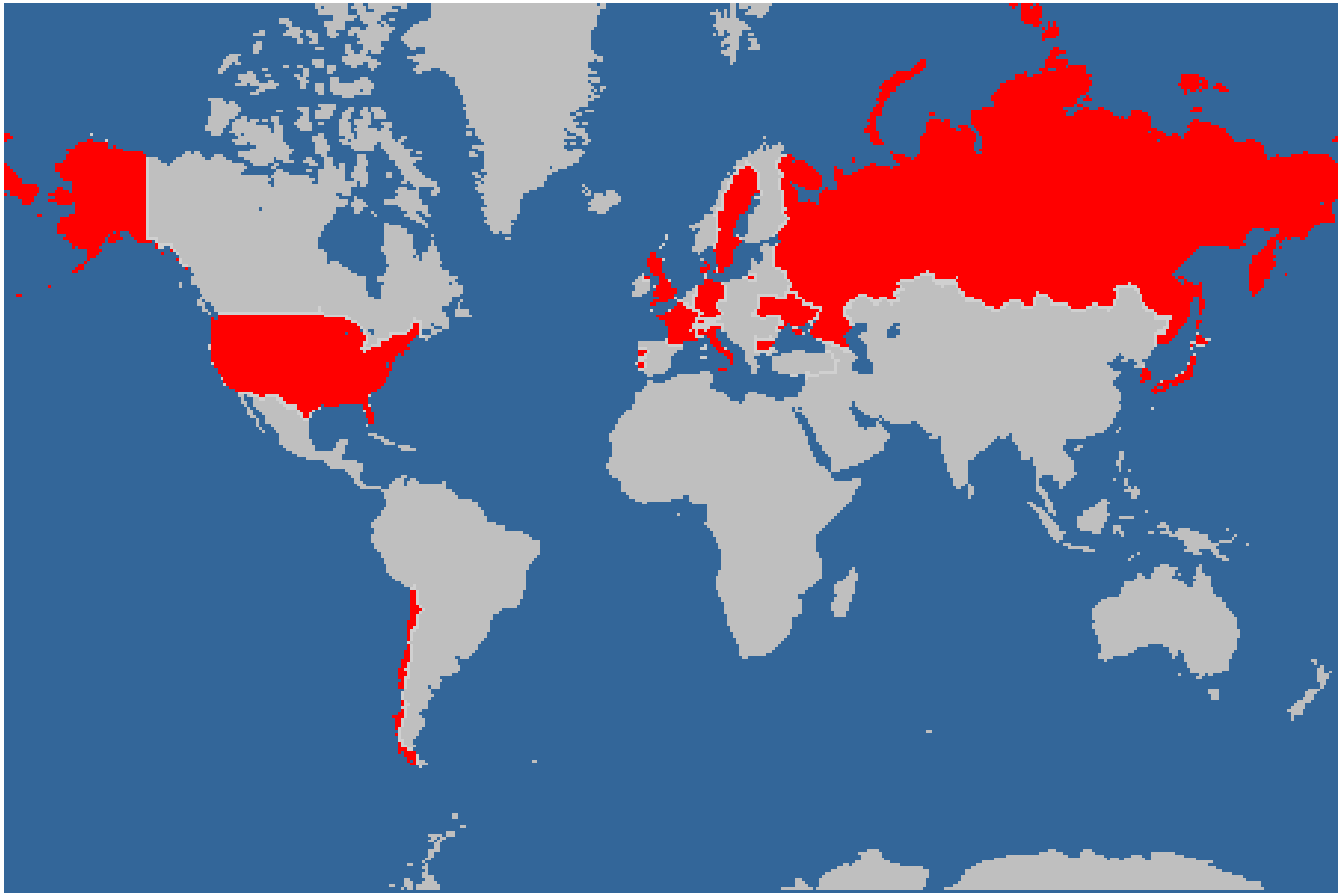
decay channel	ν_τ , $\overline{\nu}_\tau$	
	N^{exp}	N^{bg}
$\tau\to e$	850	160

Since the charge of the electron is not measurable, only an inclusive measurement of tau neutrinos and anti-tau neutrinos is possible in the tau→ e decay channel.

Total expected number of tau neutrinos and anti-tau neutrinos

→ 3520 events with 960 bg events in 5 yrs run

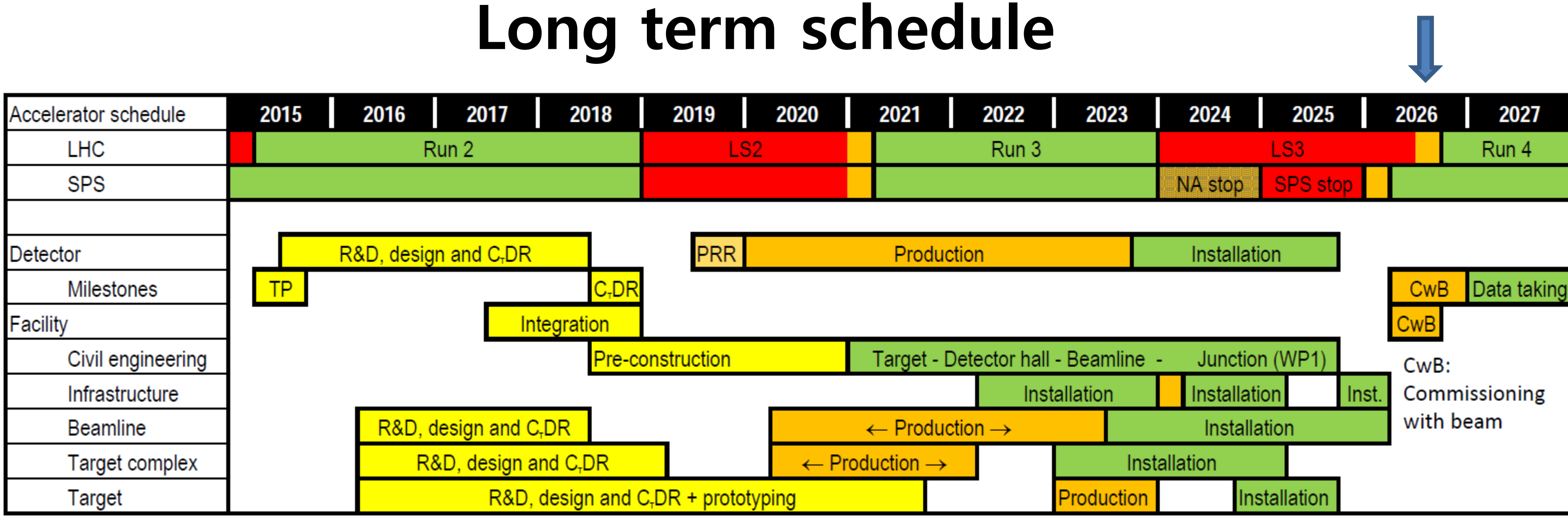
The member countries of SHiP



47 institutes from 16 countries

Andrey Golutvin
Spokesman

Long term schedule



2016-2019: CDR (Comprehensive Design Report) phase

Approval is made after CDR

From 2021: Civil engineering for 5 years after Approval

In parallel, Detector construction for 3 years,

Detector installation and commissioning for 2 years

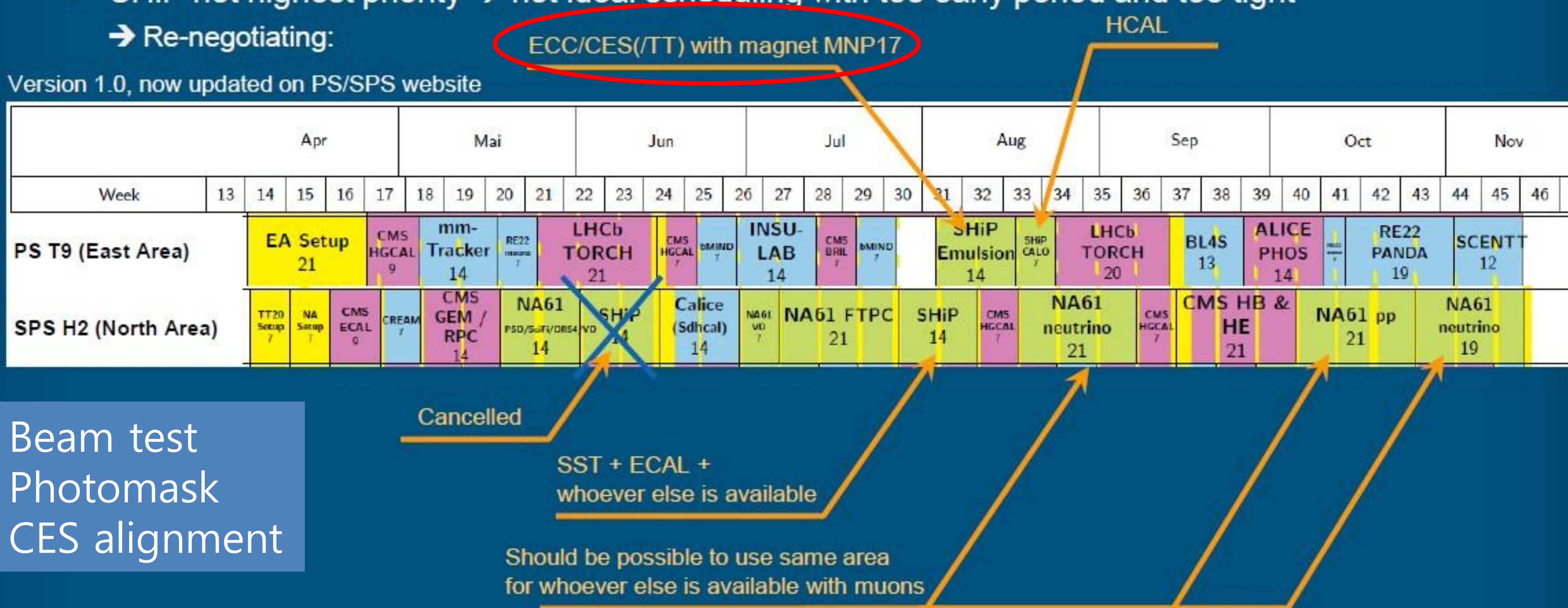
From 2026 : Beam exposure (data taking) after LS3 for LHC for 5 years

Prepare everything before and start the experiment immediately after LS3

2016 Test beams

- Granted 7 weeks following our request to SPSC
  - SST, UVT/STD (SciBar/MRPC), ECAL, HCAL, SBT, MUON, ECC/CES/TT, µRPC?
    - Several uncertainties due to funding
    - ➔ Regrouping of test beam activities to ensure use of beam time
  - SHiP not highest priority → not ideal scheduling with too early period and too tight
    - ➔ Re-negotiating:

Version 1.0, now updated on PS/SPS website



Beam test
Photomask
CES alignment

+ Parasitic area for SST behind H2 throughout the whole year (space for small prototype of other detector)
+ Test beam for CES/TT at SPS H4 together with RD51 collaboration with Goliath magnet.

➔ Tight schedule between SPS H2 (SST+ ECAL) and PS T9 (HCAL) to migrate readout and tracking chamber equipment

➔ Submit your safety form (ISIEC) at least 2 weeks before allocated beam time

Infrastructure at CERN
Emulsion handling room

Laboratory used for past emulsion experiments (CHORUS, OPERA preparatory phase)

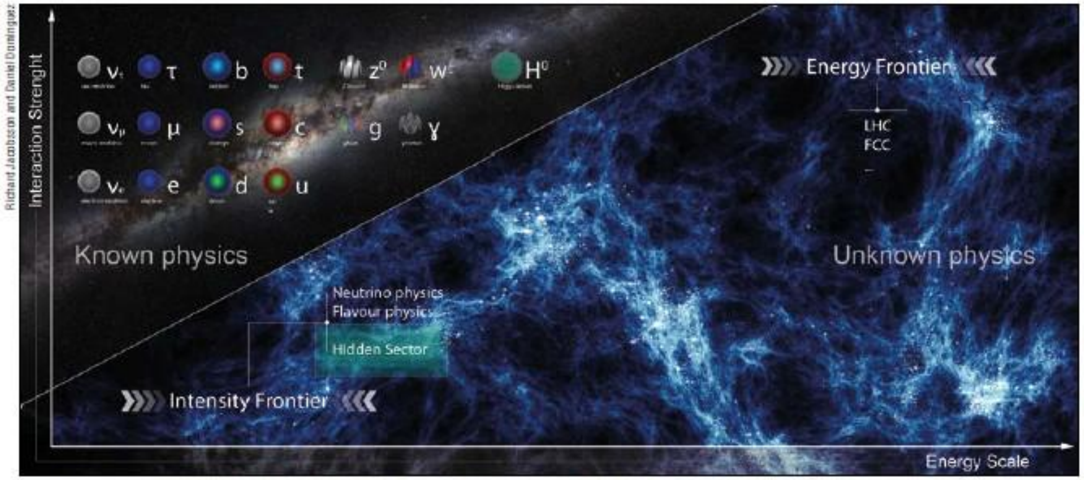
Emulsion development

Flash box used in CHORUS

Brick assembling

Dark room

CES



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

CERN Courier
March 2016

SHiP sets a new course in intensity-frontier exploration

SPSC supported and recommended to make CDR.

SHiP (Search for Hidden Particles) is a newly proposed experiment for CERN's Super Proton Synchrotron ...

...particles.

Why is the SHiP physics programme so timely and attractive?

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 ...

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 ▷

Physics Beyond Colliders Kickoff Workshop

6-7 September 2016
CERN
Europe/Zurich timezone

Search

- Overview
- Scientific Programme
- Call for Abstracts
  - View my Abstracts
  - Submit Abstract
- Timetable
- Registration
- Participant List
- Accommodation

Organisation

PBC2016.cttee@cern.ch
+41754113293

The aim of the workshop is to explore the opportunities offered by the CERN accelerator complex and infrastructure to get new insights into some of today's outstanding questions in particle physics through projects complementary to high-energy colliders and other initiatives in the world. The focus is on fundamental physics questions that are similar in spirit to those addressed by high-energy colliders, but that may require different types of experiments. The kickoff workshop is intended to stimulate new ideas for such projects, for which we encourage the submission of abstracts.

Organizing Committee: Joerg Jaeckel, Mike Lamont, Connie Potter, Claude Vallée

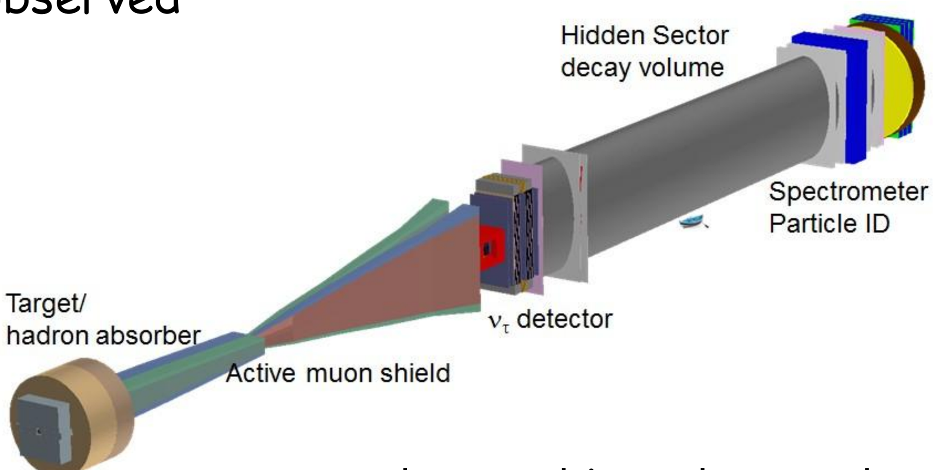
The Physics Beyond Colliders study group was set up at CERN in March 2016.
The CERN Research Board recommended that SHiP preparation for CDR should be performed in close collaboration with the study group.
The CDR will be input to update of European HEP strategy 2019.

Summary

The **SHiP (Search for Hidden Particles)** is a newly proposed experiment at the CERN SPS (P-350) in order to explore the domain of **hidden particles with mass from sub-GeV up to *O* (10) GeV** with super-weak coupling down to 10^{-10}, and also to study **Tau neutrino physics**.

About 3000 tau neutrinos are expected to be observed with an integrated 2×10^{20} protons on target.
In addition, anti-tau neutrinos can be observed for the first time.

CERN SPSC supported the SHiP and recommended to write CDR.



http://ship.web.cern.ch/

Where is New Physics? Can SHiP find it?