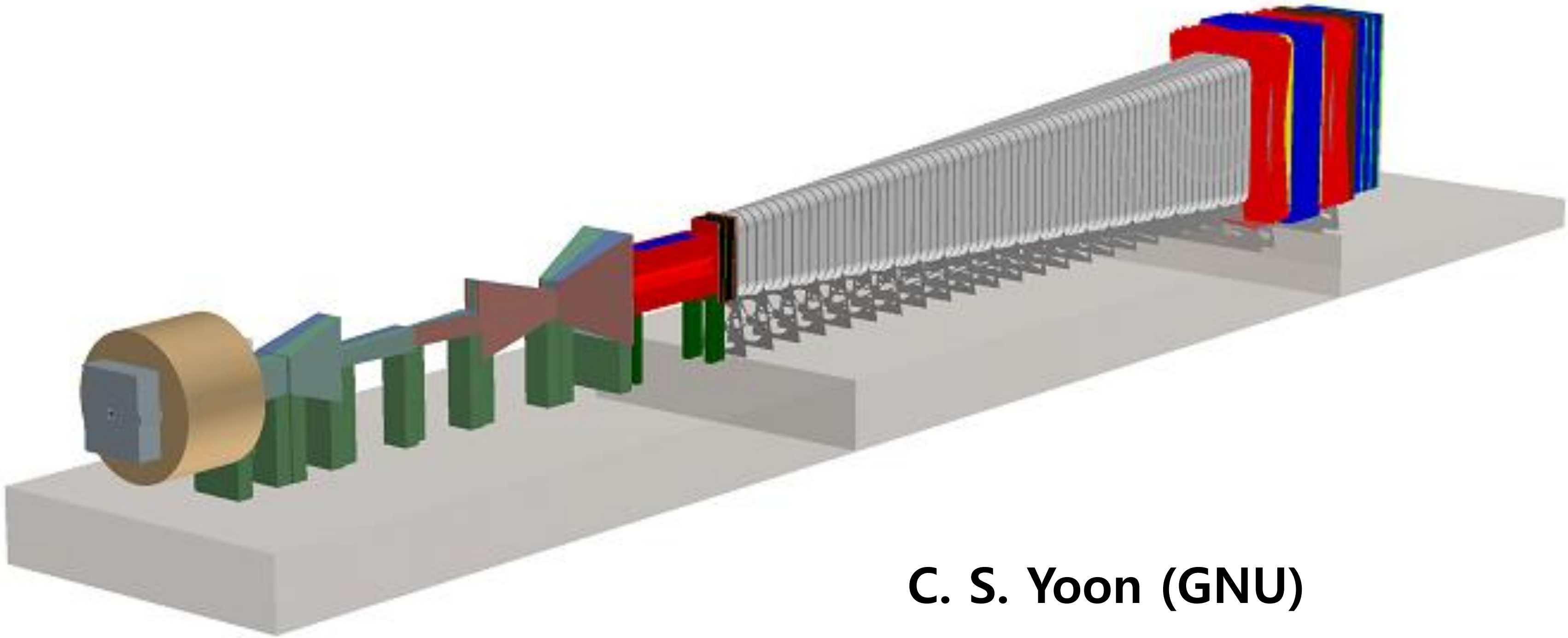
SHiP experiment
- Search for Hidden Particles-



C. S. Yoon (GNU)

On behalf of the Korean SHiP Group

Meeting for Long-term Strategy for HEP in Korea
2019. 9. 20-21, IBS

Contents

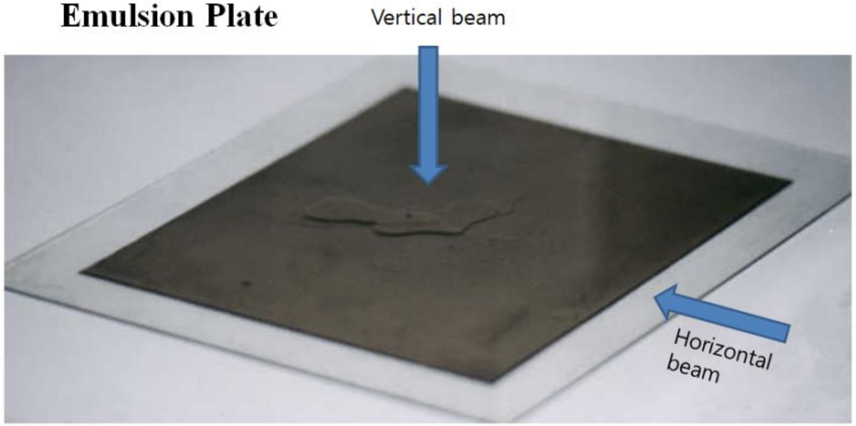
- Nuclear emulsion
- Neutrino exp using Emulsion
- SHiP experiment

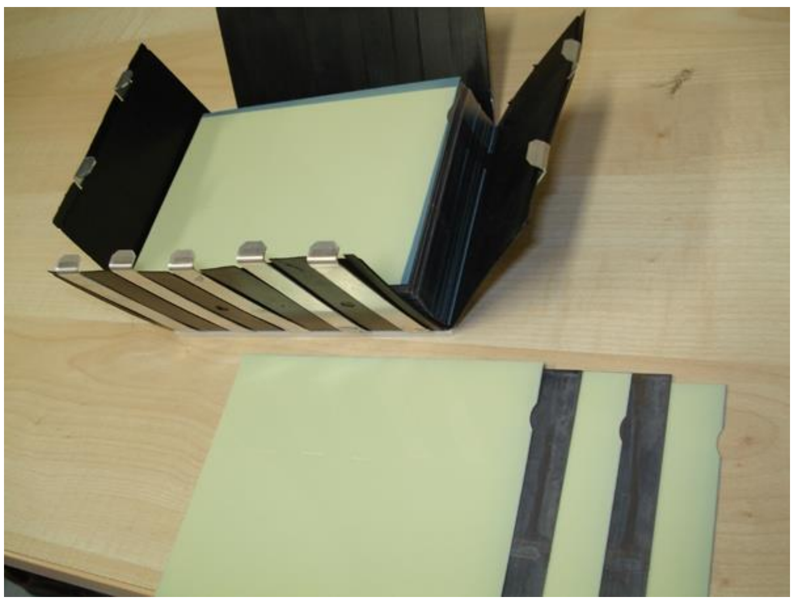
  (Tau neutrinos, LDM, Hidden particles)
- Directional WIMP search

  - NEWSdm experiment

Nuclear Emulsion 원자핵건판

Emulsion Plate





ECC (Emulsion Cloud Chamber)
emulsion films + lead plates

Old type of detector
but still very effective tool
with Counter hybrid method
& Fast auto-scanning system
& New off-line analysis (Net-Scan)

✔ Advantages

Best spatial resolution (sub-μm)

3D visual detector (Int. & decay vertices)

Targets (C, N, O, Ag, Br)

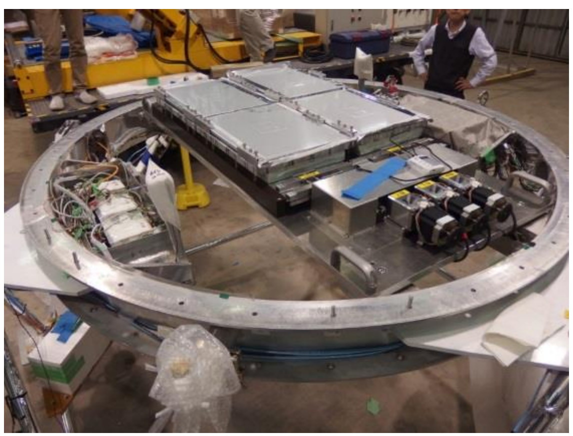
Tracker (ECC) in Neutrino exp

Particle ID (electron, hadrons …)

Calorimeter (Momentum measurement)

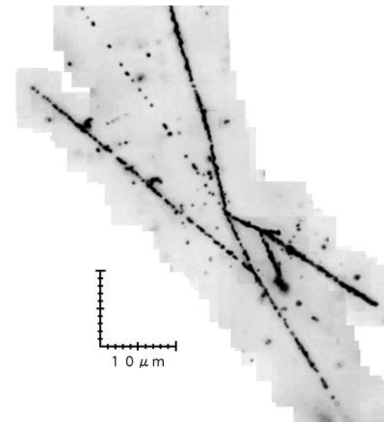
Various applications of Emulsion

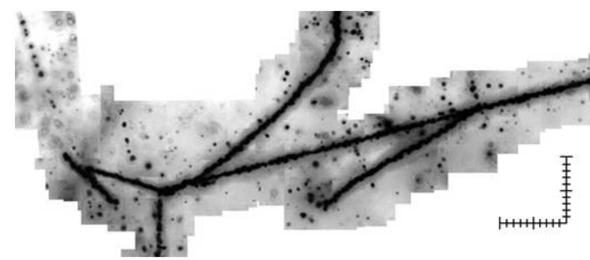
Gamma-ray telescope (GRAINE)



Muon radiography

S=-2 hypernuclei





Dark matter and Neutrino exp …

Neutrino Experiments using Nuclear Emulsion

DONuT

Direct **O**bservation of **Nu** **T**au

CHORUS

CERN **H**ybrid **O**scillation **R**esearch apparat**US**

OPERA

Oscillation **P**roject with **E**mulsion-t**R**acking **A**pparatus

Korean Emulsion Group

1960's C.O.Kim (Korea Univ)

Horizontal type

"The first HEP group in Korea"

Cosmic ray exp

FNAL E531 (charm using Neutrino beam,
by-product Neutrino osc limit
→ **CHORUS**)

FNAL E653 (charm & beauty
by p & π beam) ...

VIEW LETTERS 8 DECEMBER 1986

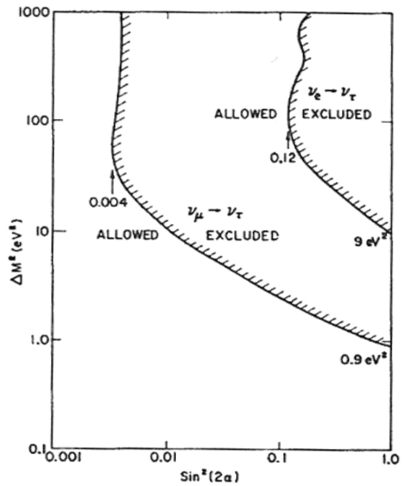


FIG. 2. ΔM^2 vs $\sin^2(2\alpha)$ plane. The curves show the 90%-C.L. limits for $\nu_\mu/\nu_e \to \nu_\tau$ oscillations.

1980's J.S.Song, C.S.Yoon (GNU)

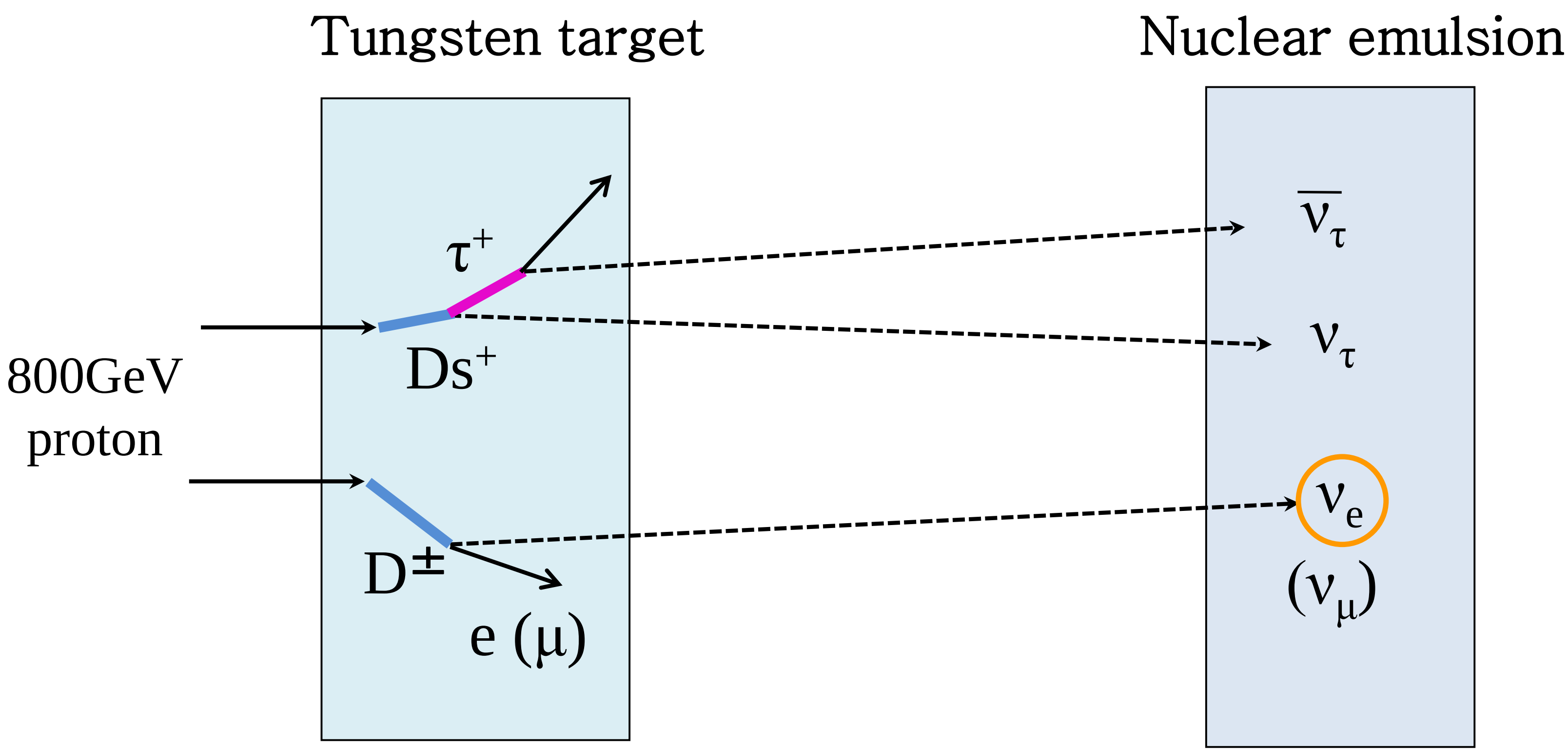
Vertical type & Auto scanning

KEK E176, E373

CHORUS, DONuT, OPERA …

DONuT (Direct Observation of Nu Tau)

Proton beam dump exp at Fermilab → same as SHiP



$$D_s^+ \rightarrow \tau^+ \nu_\tau$$

$$\tau^+ \rightarrow \overline{\nu_\tau}\ X$$

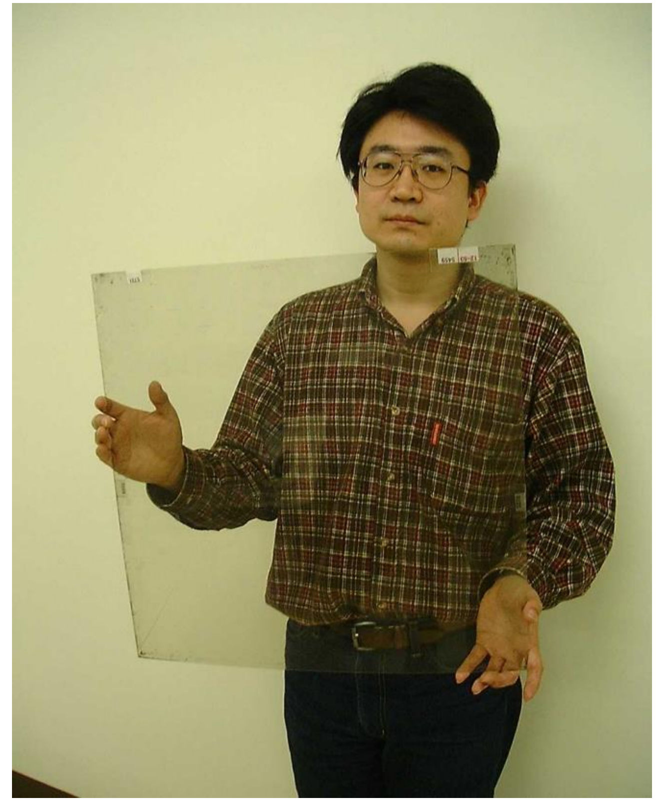
ν_τ CC events : 9

ν_μ CC events : 225

ν_e CC events : 82 (mainly our contrib)

First ECC Target installation
April 1997, Fermilab

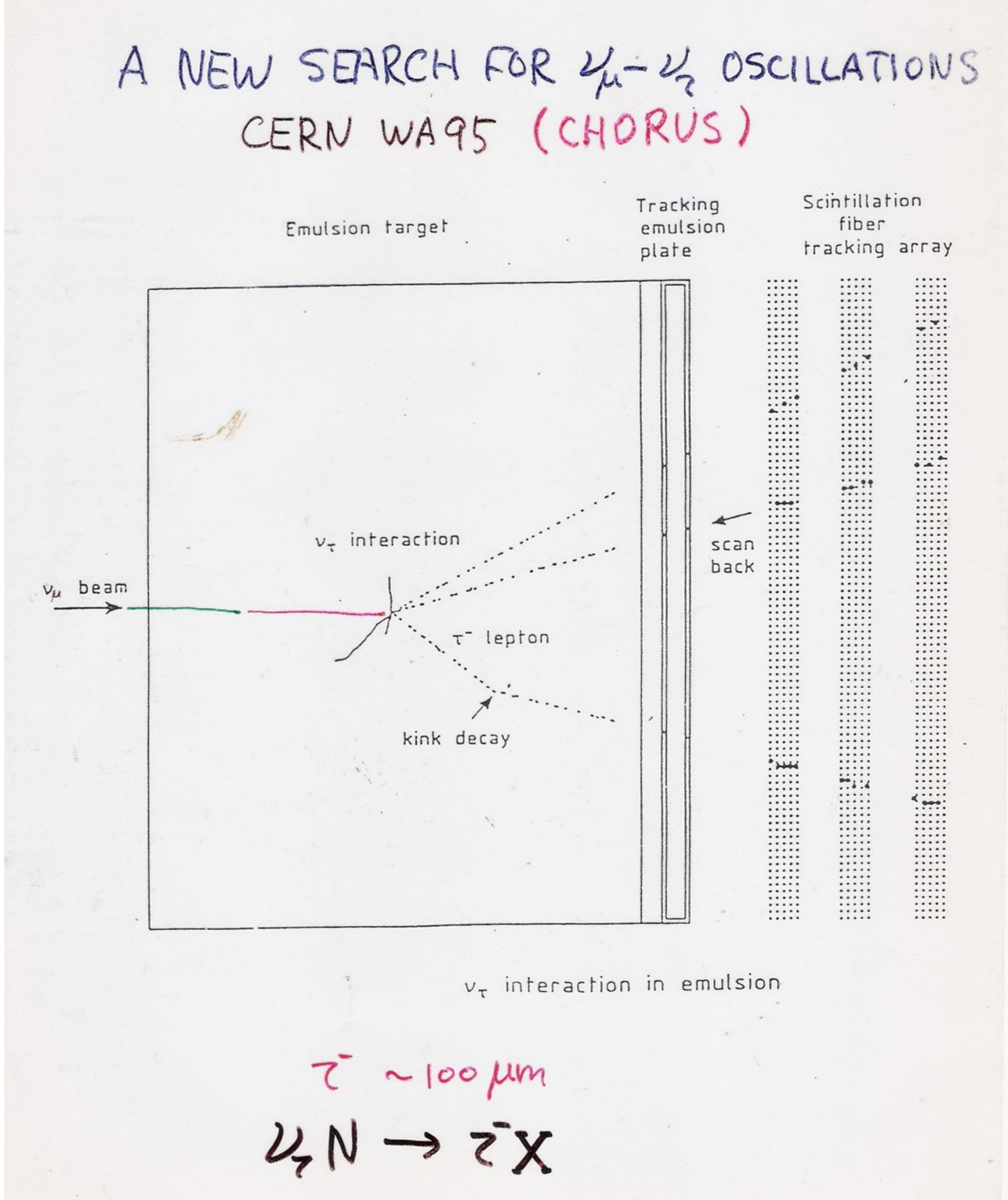
M. Nakamura (Nagoya)
S. H. Chung (GNU)



DONuT Emulsion Plate
50 x 50 cm^2

O. Sato (Nagoya)

CHORUS

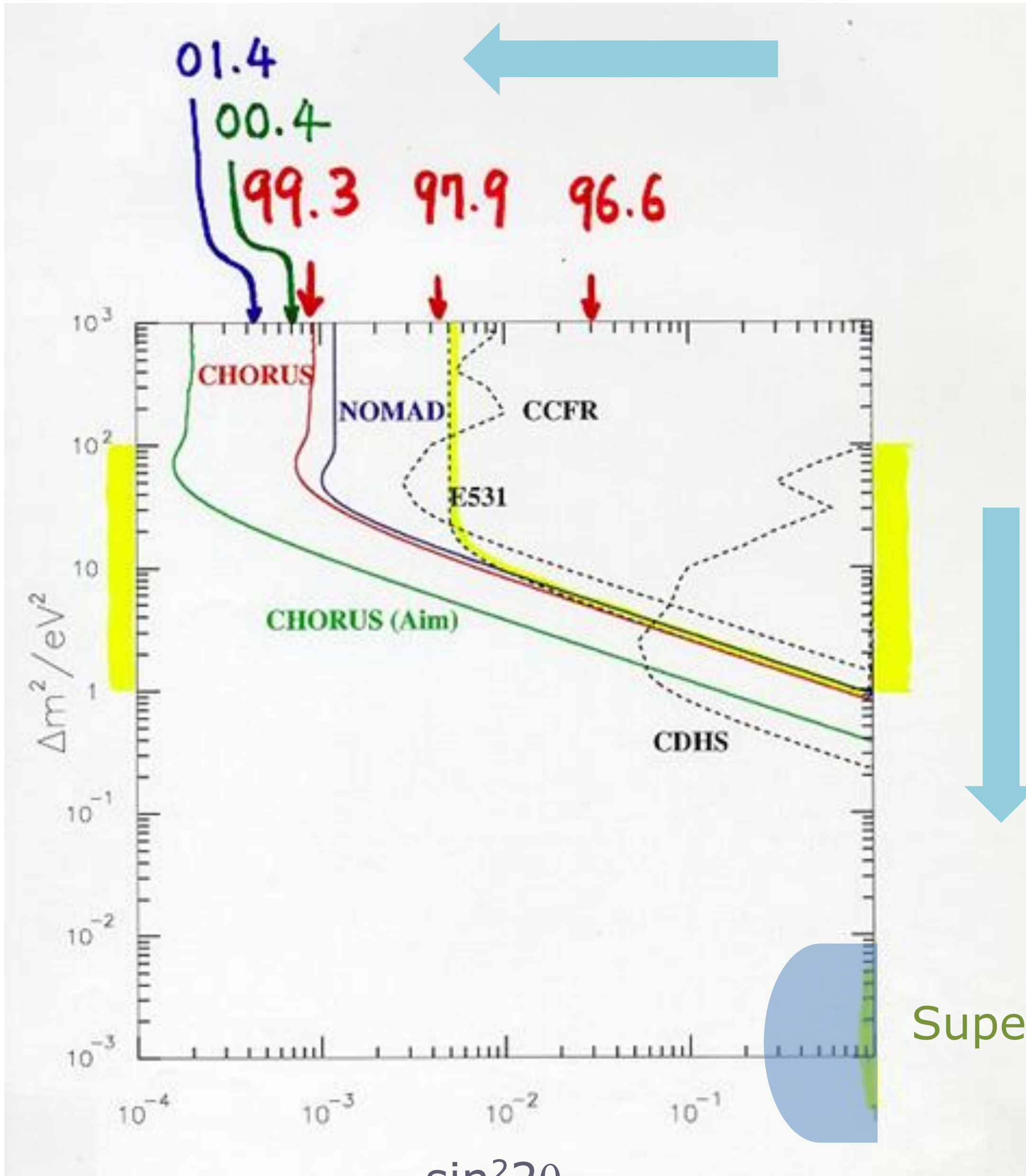


Short-baseline Appearance method

CHORUS
Final result
(2008)
$\sin^2 2\theta_{\mu\tau}$
$< 4.4\times10^{-4}$

No oscillation
→ Go to
Long-baseline

Neutrino as dark matter candidate



$\sin^2 2\theta_{\mu\tau}$

Long-baseline

Super-K

The CHORUS Detector

Calorimeter

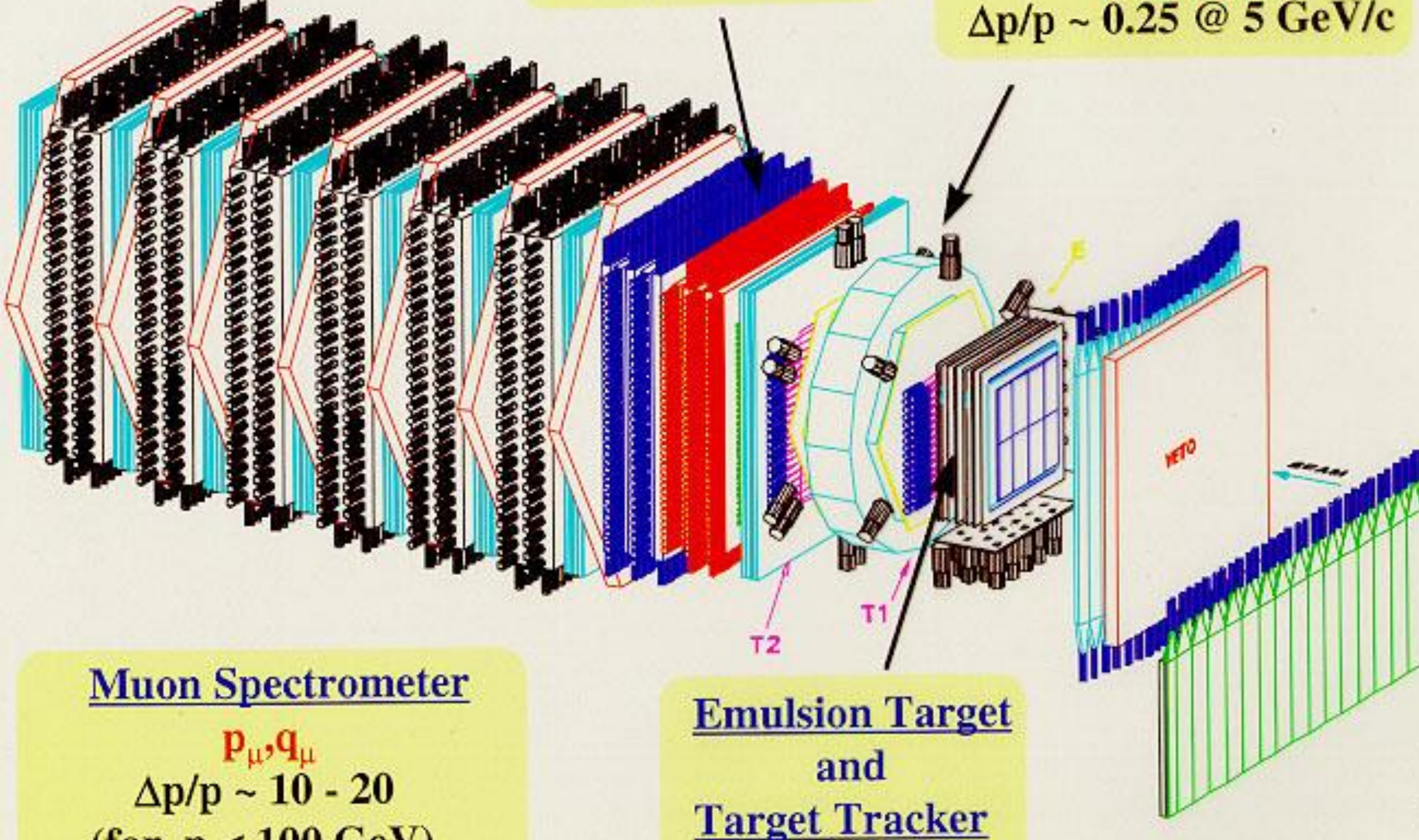
E_{had}, Θ_{had}

$\Delta E/E \sim 0.35/\sqrt{E}$

Magnet Spectrometer

q_{had}, p_{had}

$\Delta p/p \sim 0.25$ @ 5 GeV/c



Muon Spectrometer

p_{μ},q_{μ}

$\Delta p/p \sim 10 - 20$

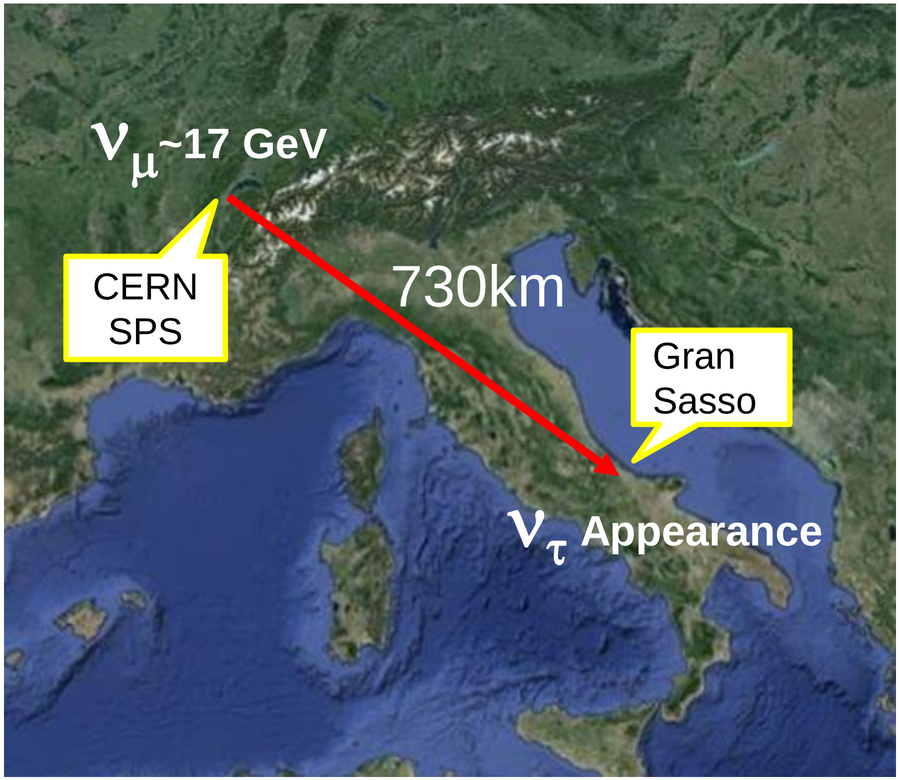
(for $p < 100$ GeV)

Emulsion Target and Target Tracker

CHORUS Collaboration meeting at Korea
Jinju, 24-25 Oct. 1996

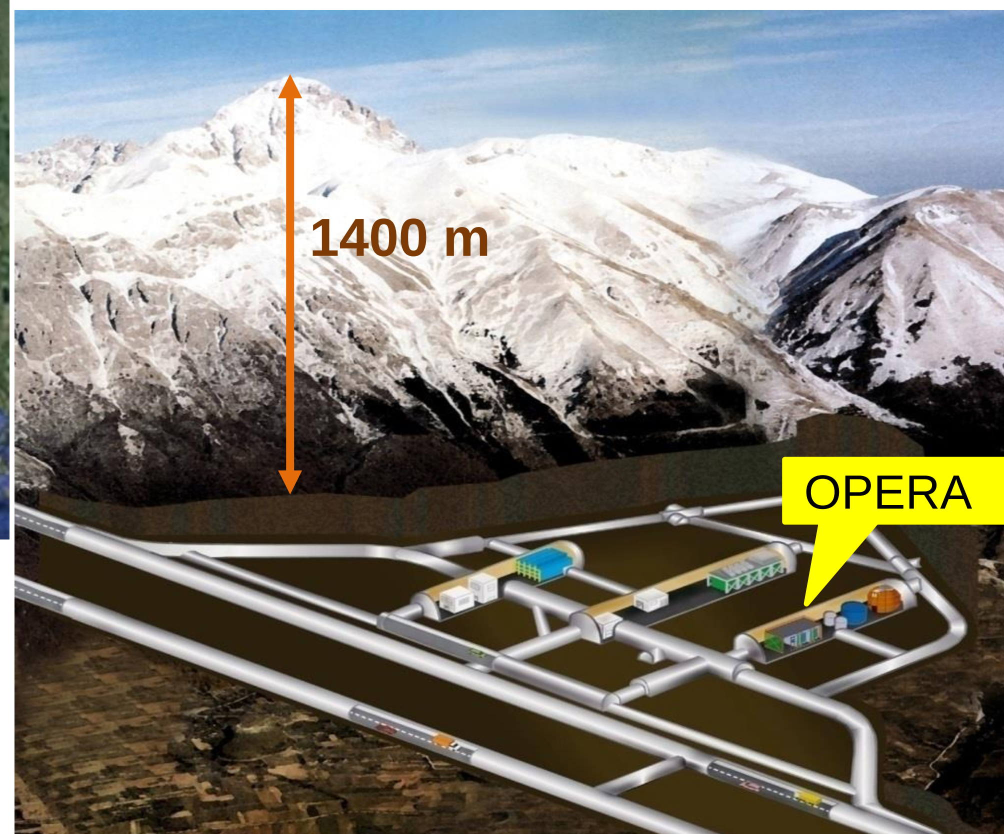
OPERA experiment

Long-baseline Neutrino Oscillation Experiment – Appearance mode



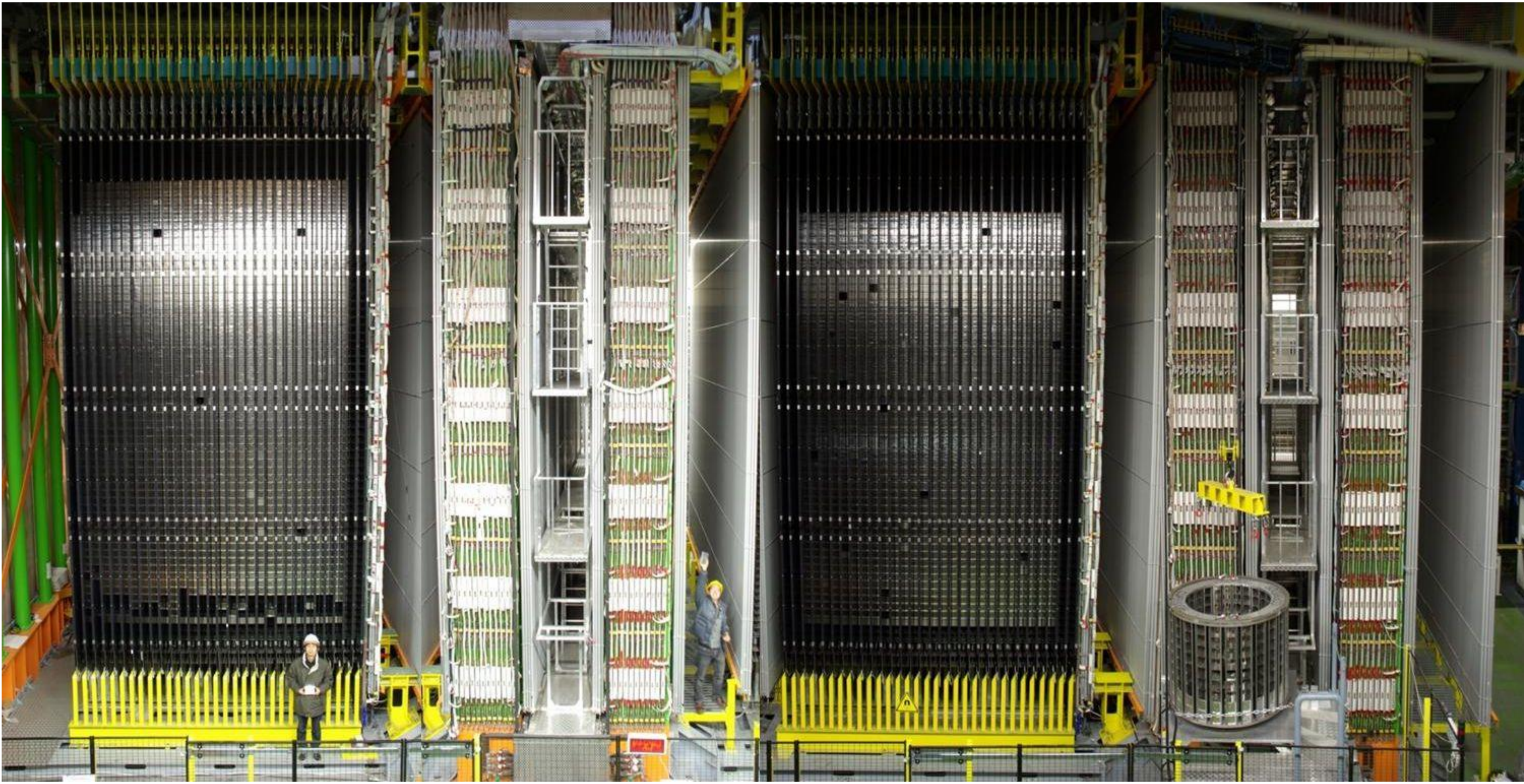
CNGS beam

Gran Sasso
Cosmic-ray flux was reduced
by factor of one million.



LNGS

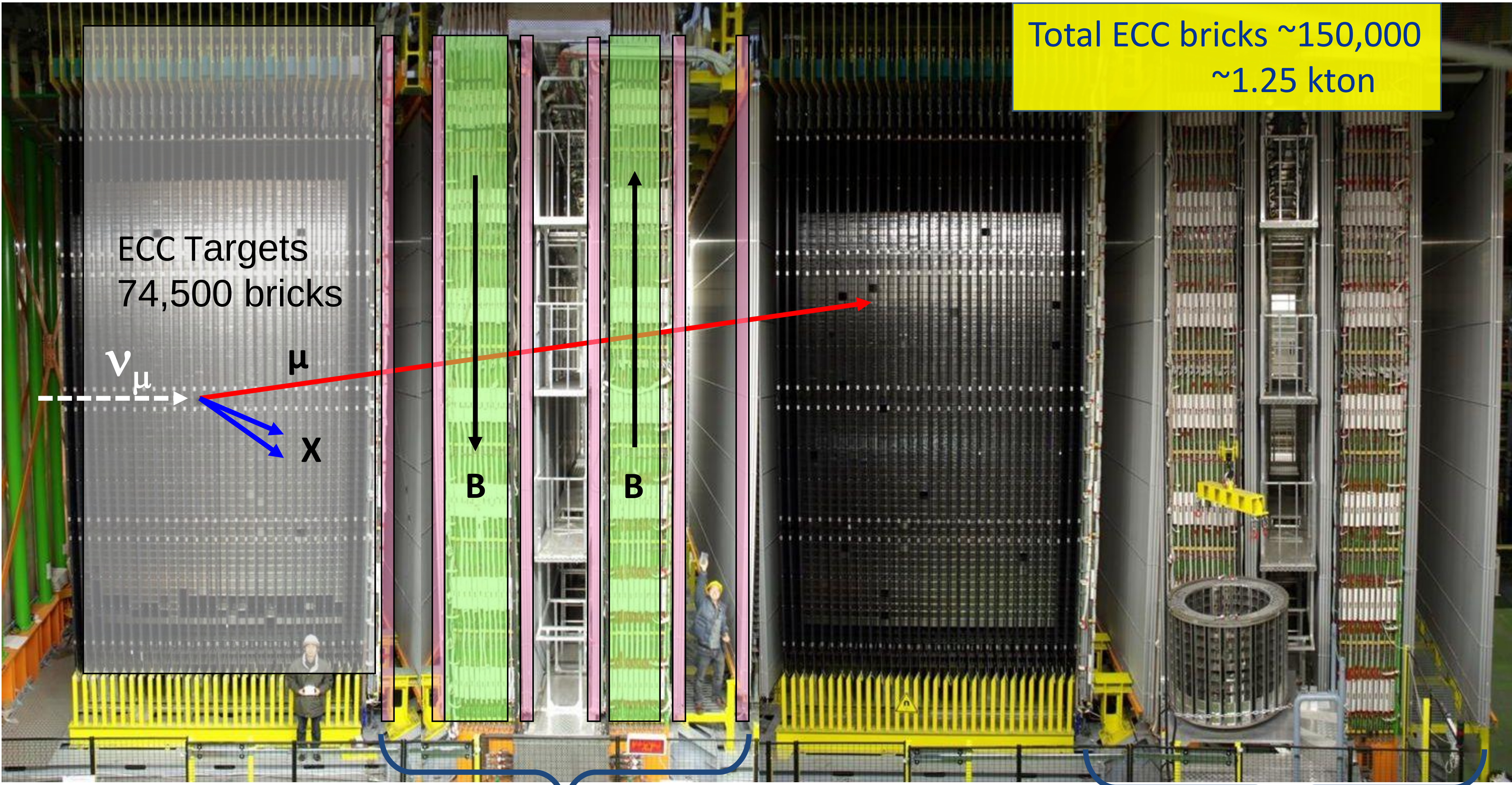
The OPERA detector



Total ECC bricks ~150,000
~1.25 kton

The biggest Emulsion exp
Underground @Gran Sasso ~1400m

The OPERA detector



Muon Spectrometer

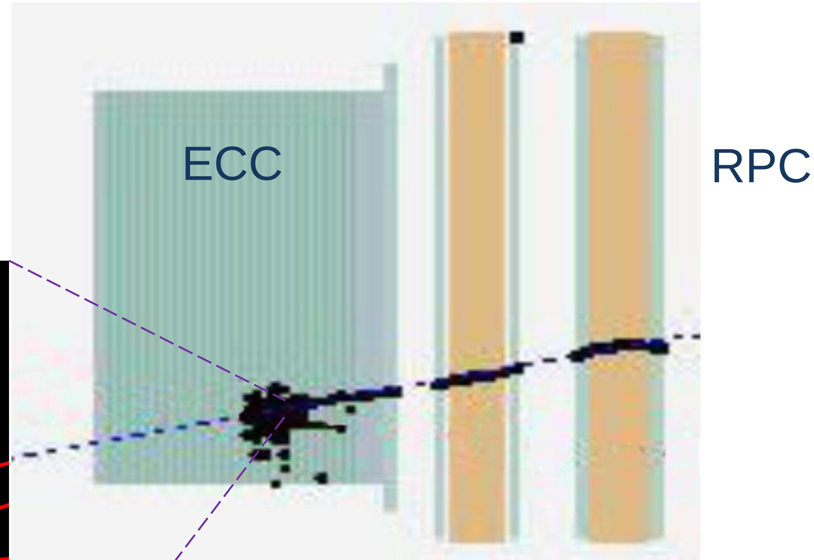
Muon Spectrometer

Magnet region
Iron & RPCs

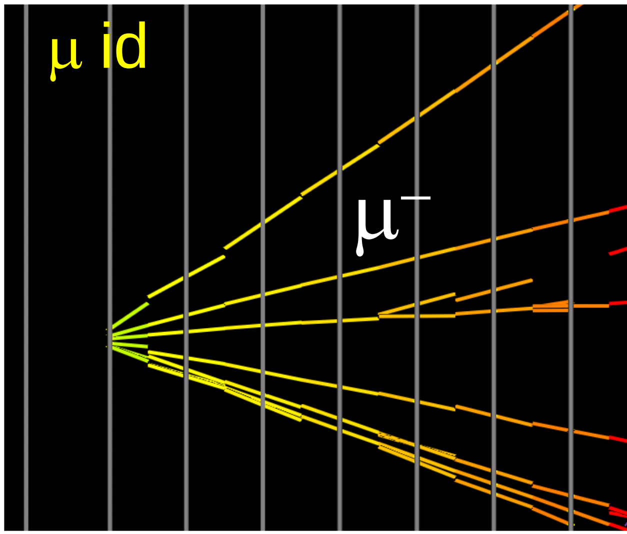
Precision Tracker:
6 planes of Drift tubes

will be reused at SHiP

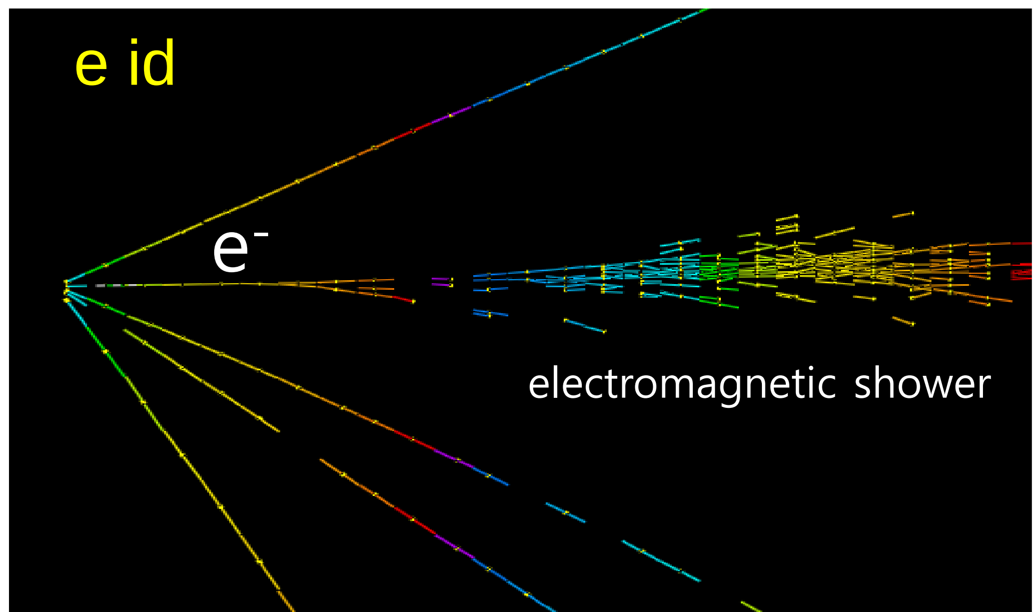
Identification of all neutrino flavors



ν_μ CC interaction



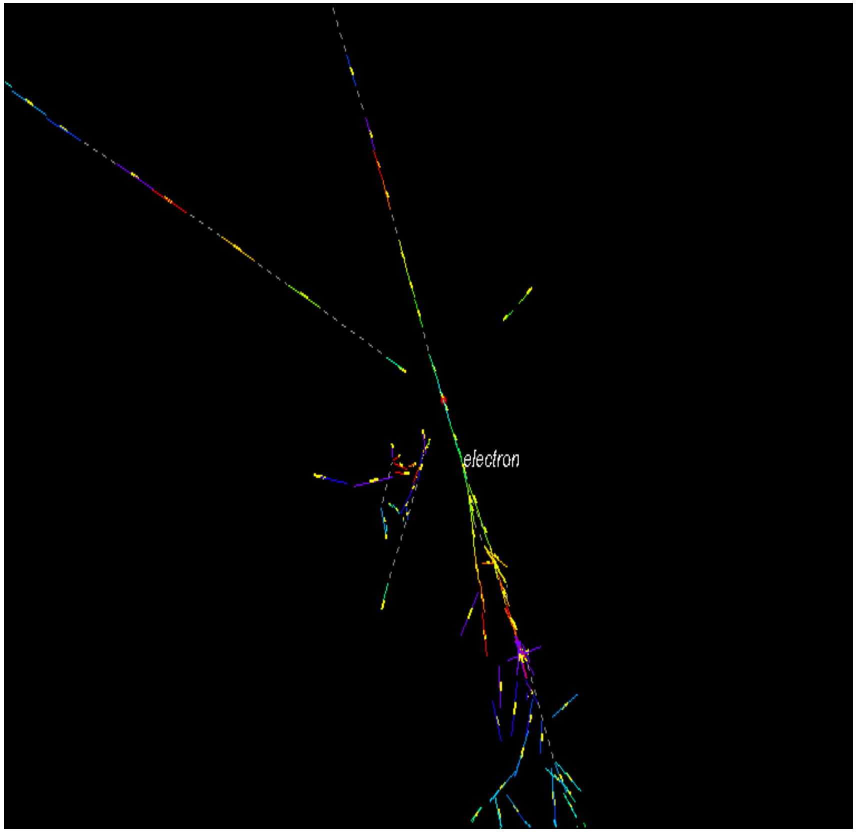
ν_e CC interaction



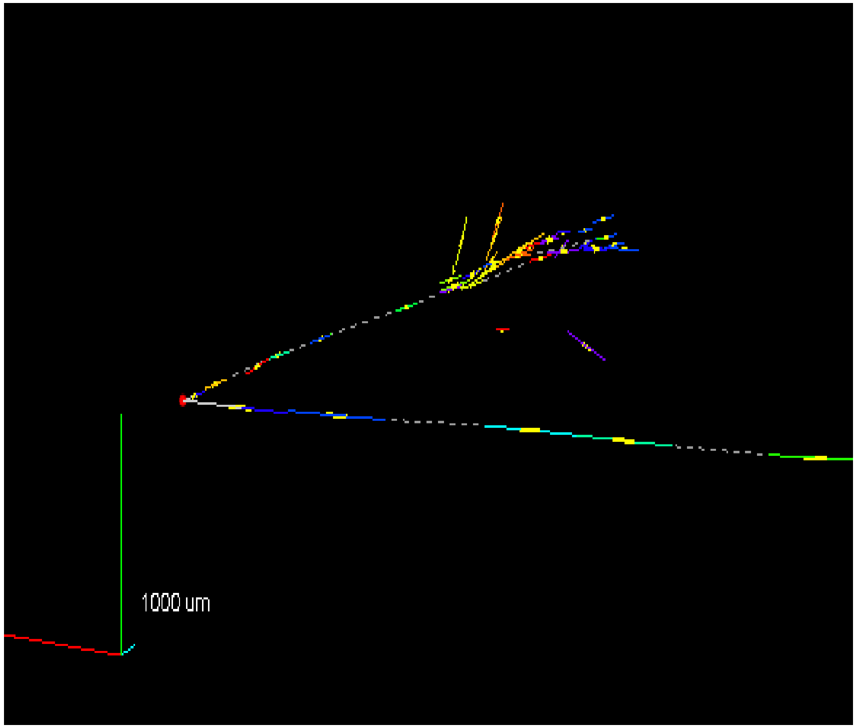
Emulsion film as high precision tracker

→ identification of ν_e , ν_μ , ν_τ is possible by distinguishing e , μ , τ leptons

ν_e CC events

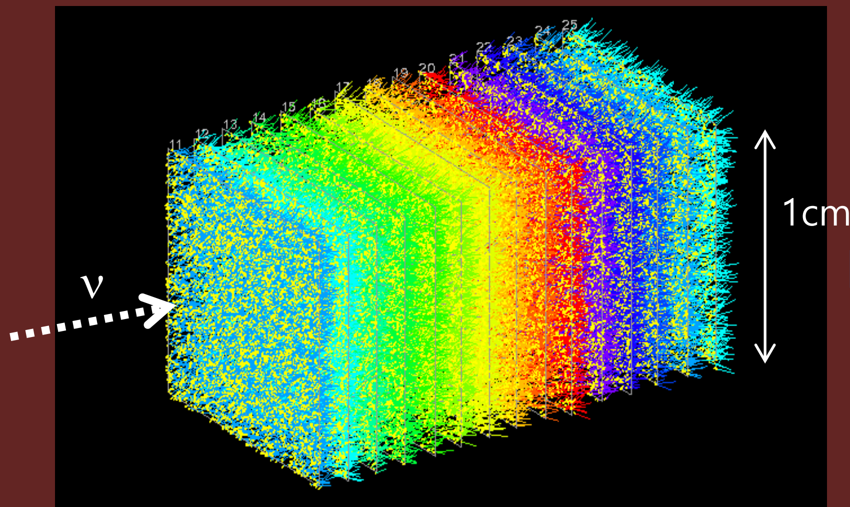


4.1 GeV electron

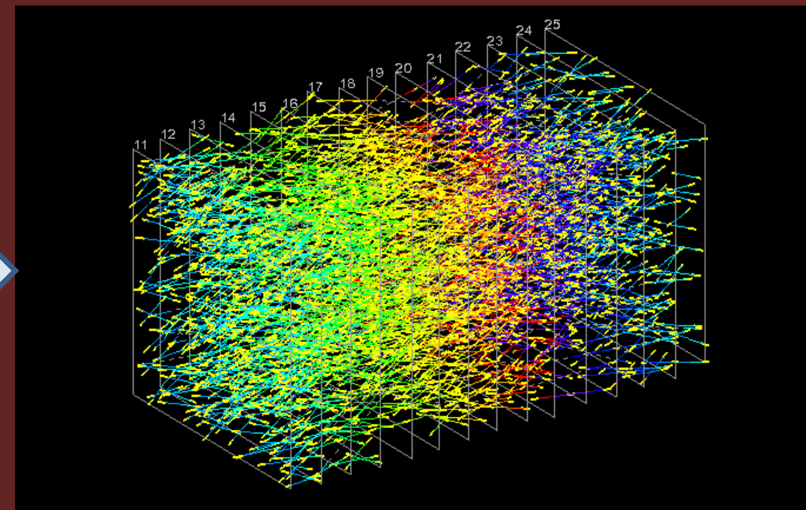


Track reconstruction in ECC brick

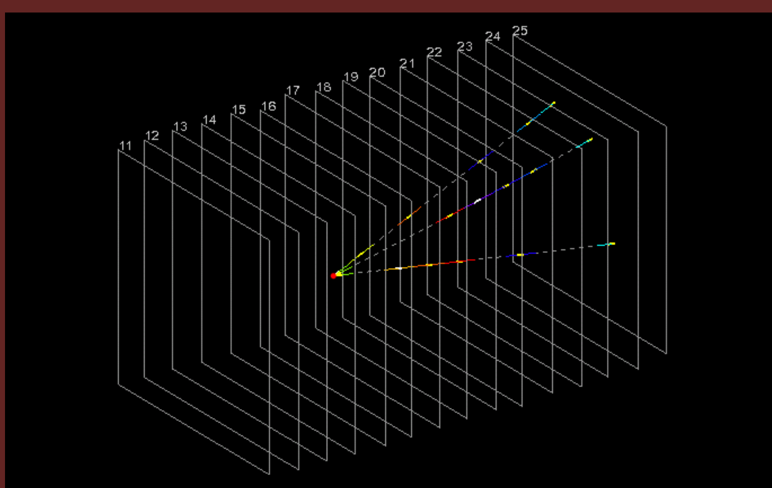
Scan 10 films around vertex plate
and reconstruct tracks



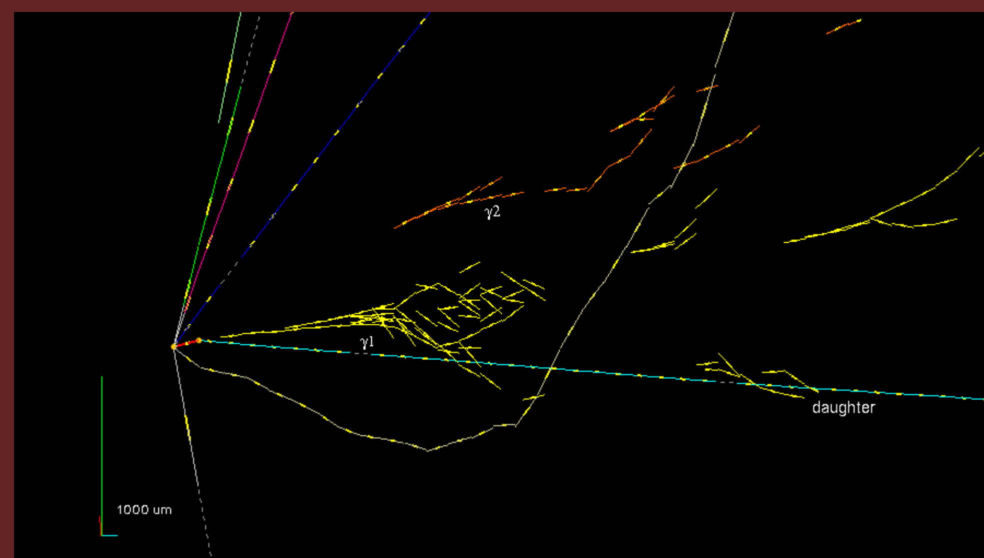
Reject passing-through tracks
& low energy tracks



Neutrino interaction vertex



1st Tau neutrino event (OPERA)

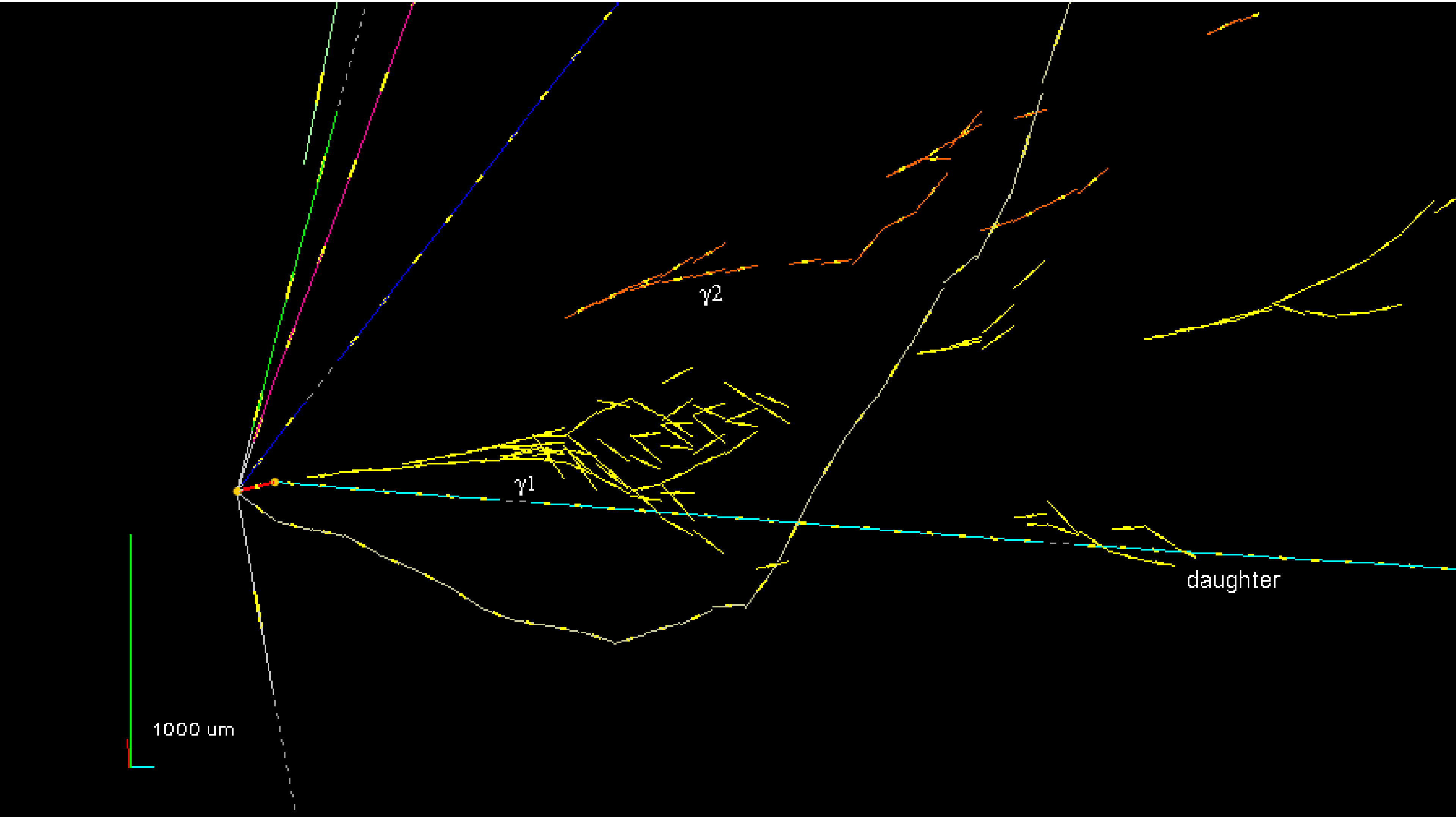


1st ν_τ event (May 2010)

$\tau \rightarrow$ 1h (hadronic kink event)

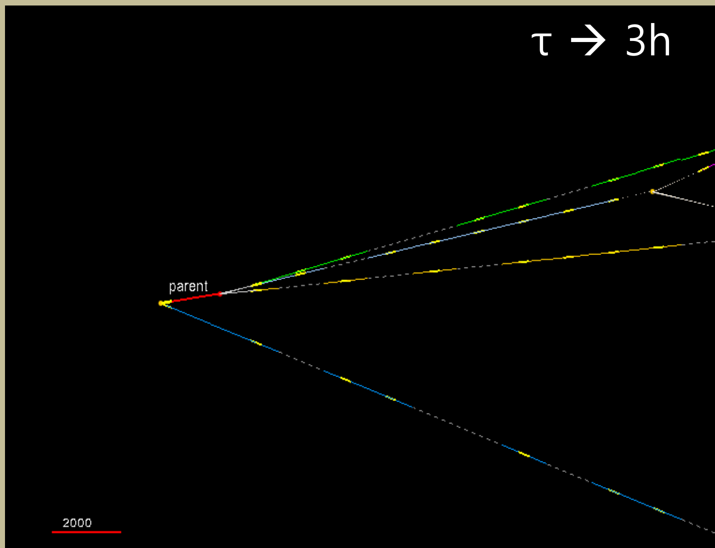
$(\tau^- \rightarrow \rho^- \nu_\tau \,,\ \rho^- \rightarrow \pi^0 \pi^- \,,\ \pi^0 \rightarrow 2\gamma)$

kink angle (mrad)	41 ± 2
τ fight length (μm)	1335 ± 35
Φ (degrees)	173±2

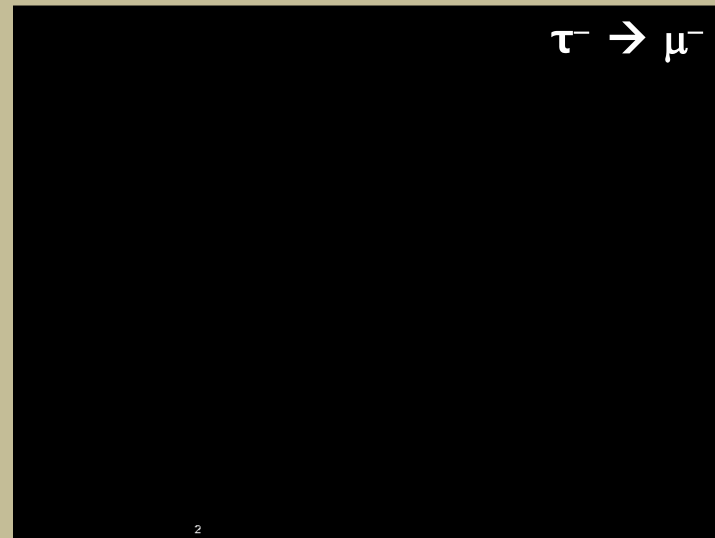


Tau neutrino events in OPERA

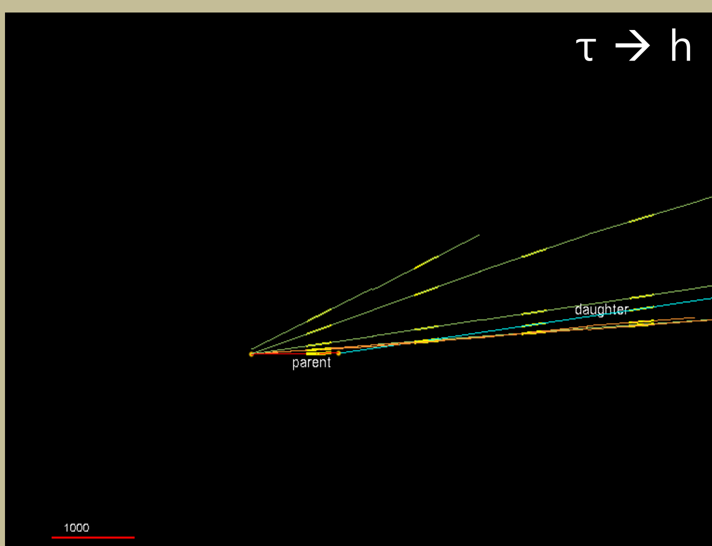
2^{nd} $\nu\tau$



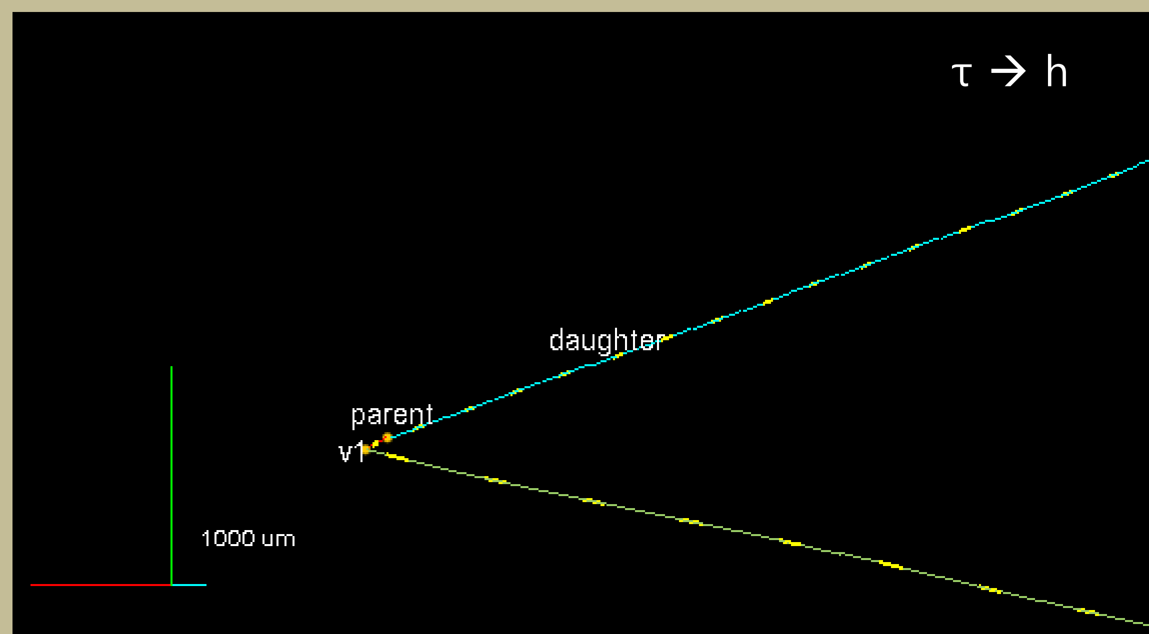
3^{rd} $\nu\tau$



4^{th} $\nu\tau$



5^{th} $\nu\tau$



Scientific Background on the Nobel Prize in Physics 2015

NEUTRINO OSCILLATIONS

compiled by the Class for Physics of the Royal Swedish Academy of Sciences

Super-Kamiokande's oscillation results were later confirmed by the detectors MACRO [55] and Soudan [56], the long-baseline accelerator experiments K2K [57], MINOS [58] and T2K [59] and more recently also by the large neutrino telescopes ANTARES [60] and IceCube [61]. Appearance of tau-neutrinos in a muon-neutrino beam has been demonstrated on an event-by-event basis by the OPERA experiment in Gran Sasso, with a neutrino beam from CERN [62].

Tau neutrino appearance discovery paper: PRL 115 (2015) 121802

OPERA final results

10 ν_τ events (2.0 ± 0.4 expected bg)

Discovery of ν_τ appearance 6.1 σ

$|\Delta m^2_{23\ meas}| = (2.7^{+0.7}_{-0.6}) \times 10^{-3}$ eV^2 in appearance mode

(assuming $\sin^2\theta_{23} = 1$)

17.97×10^{19} pot

PRL 120 (2018) 211801

Scientific Background on the Nobel Prize in Physics 2015

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Tau neutrino appearance c

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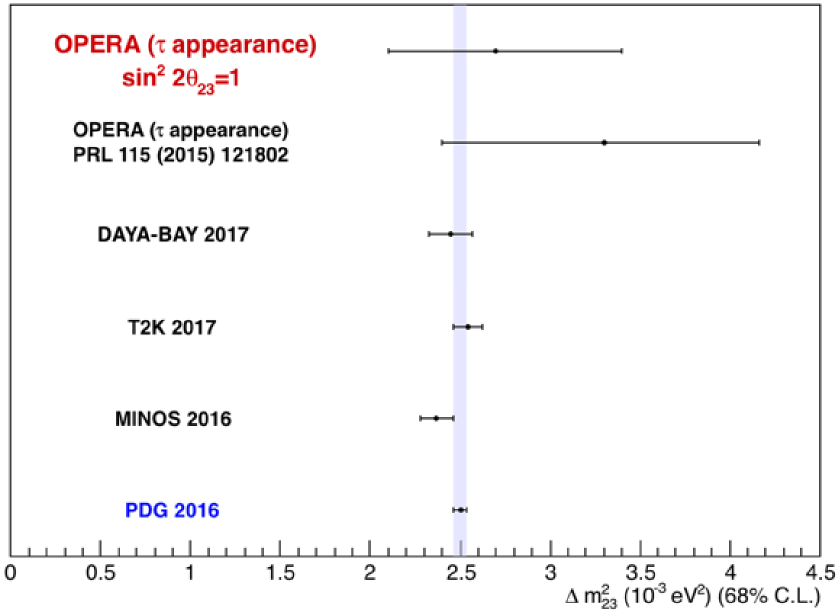
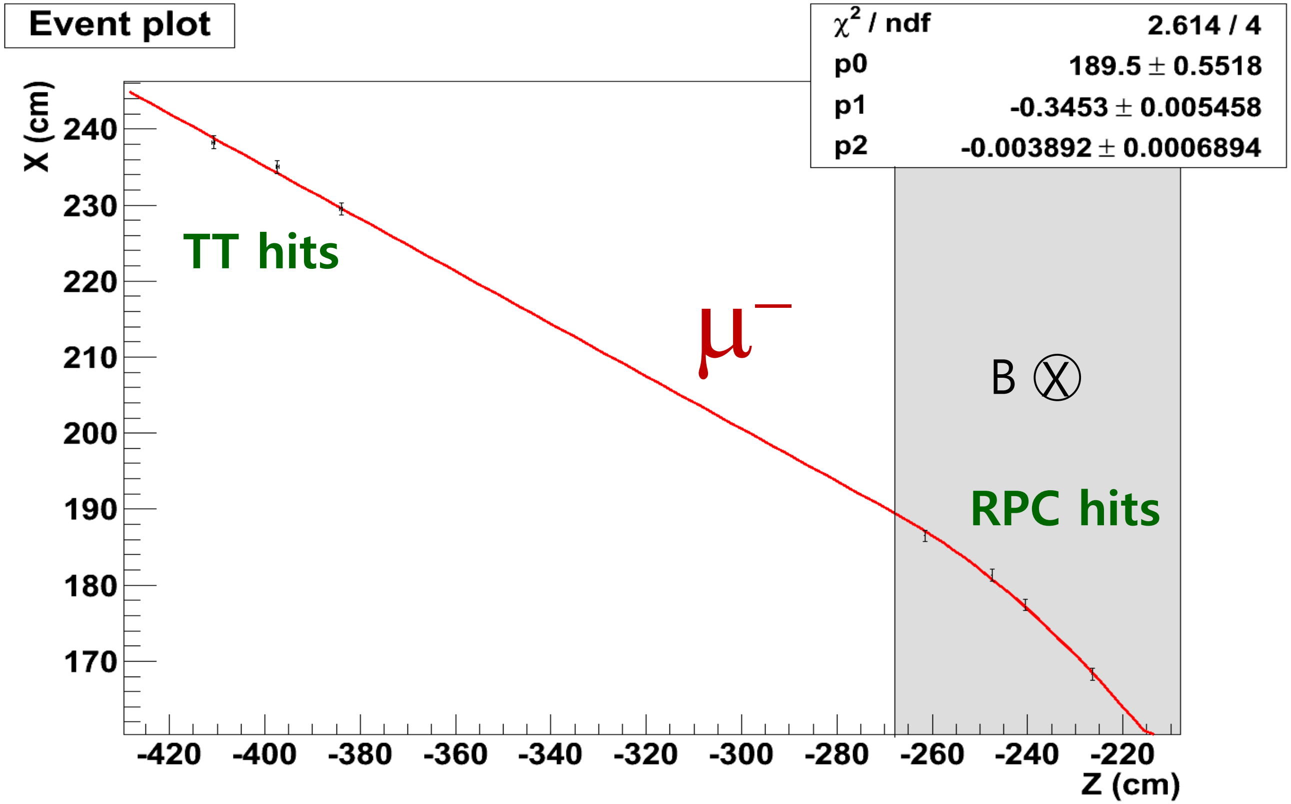
17.97×10^{19} pot

PRL 120 (2018) 211801

Δm^2_{23}



The muon charge of the 3rd event was determined to be **Negative** from track curvature in the spectrometer (RPC hits)



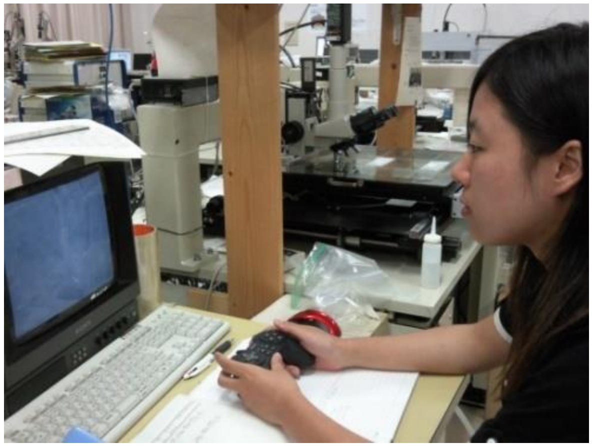
$$\nu_\tau \rightarrow \tau^- \rightarrow \mu^-$$ ○

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

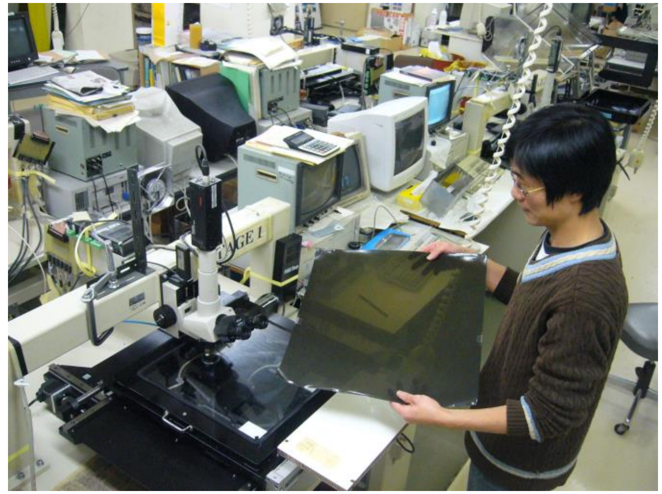
Anti-tau neutrino
not observed so far

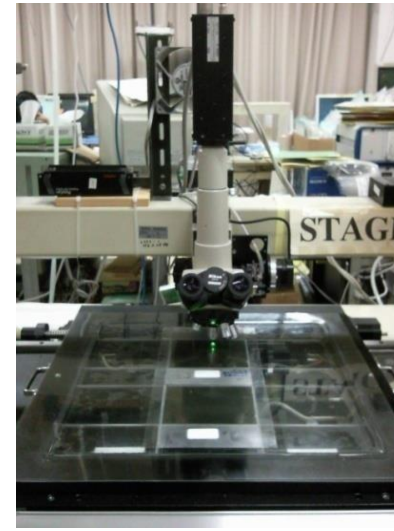
Our contributions to OPERA

- Scanning, Event analysis, ECC alignment, Brick handling



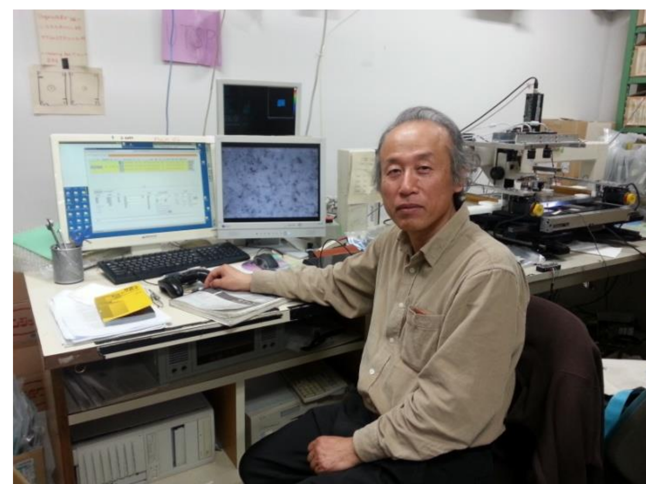
J.H.Kim





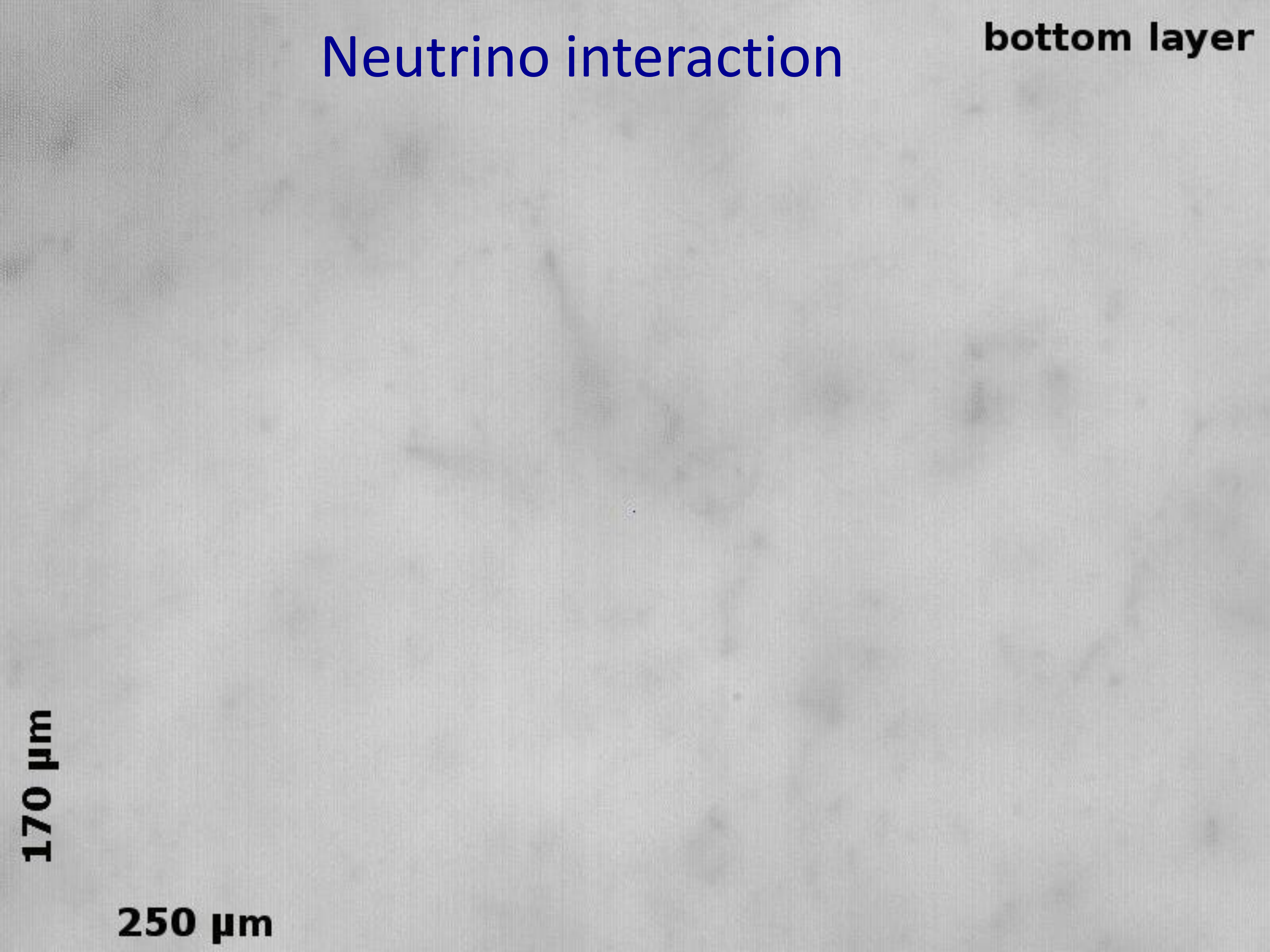
B.D.Park

S.H.Kim



C.S.Yoon

Neutrino interaction



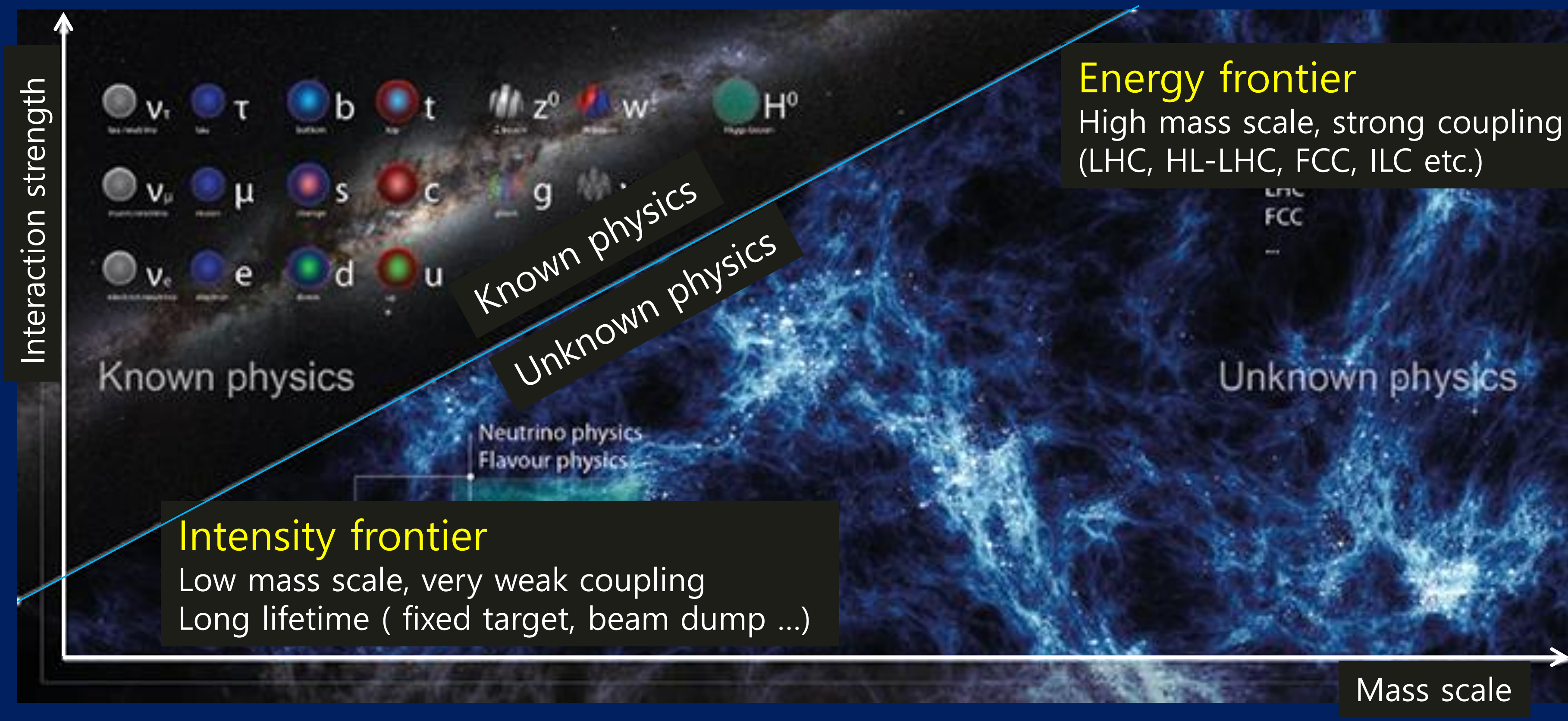
SHiP experiment
- Search for Hidden Particles -

A new experiment proposed at CERN
in order to search for **Hidden particles**
which is **feebly interacting long-lived particles (LLPs)** including **Light dark matter (LDM)**
and to study **Neutrino physics**.

Using High-intensity
400 GeV proton beam
2 x 10^{20} pot, 5 years run

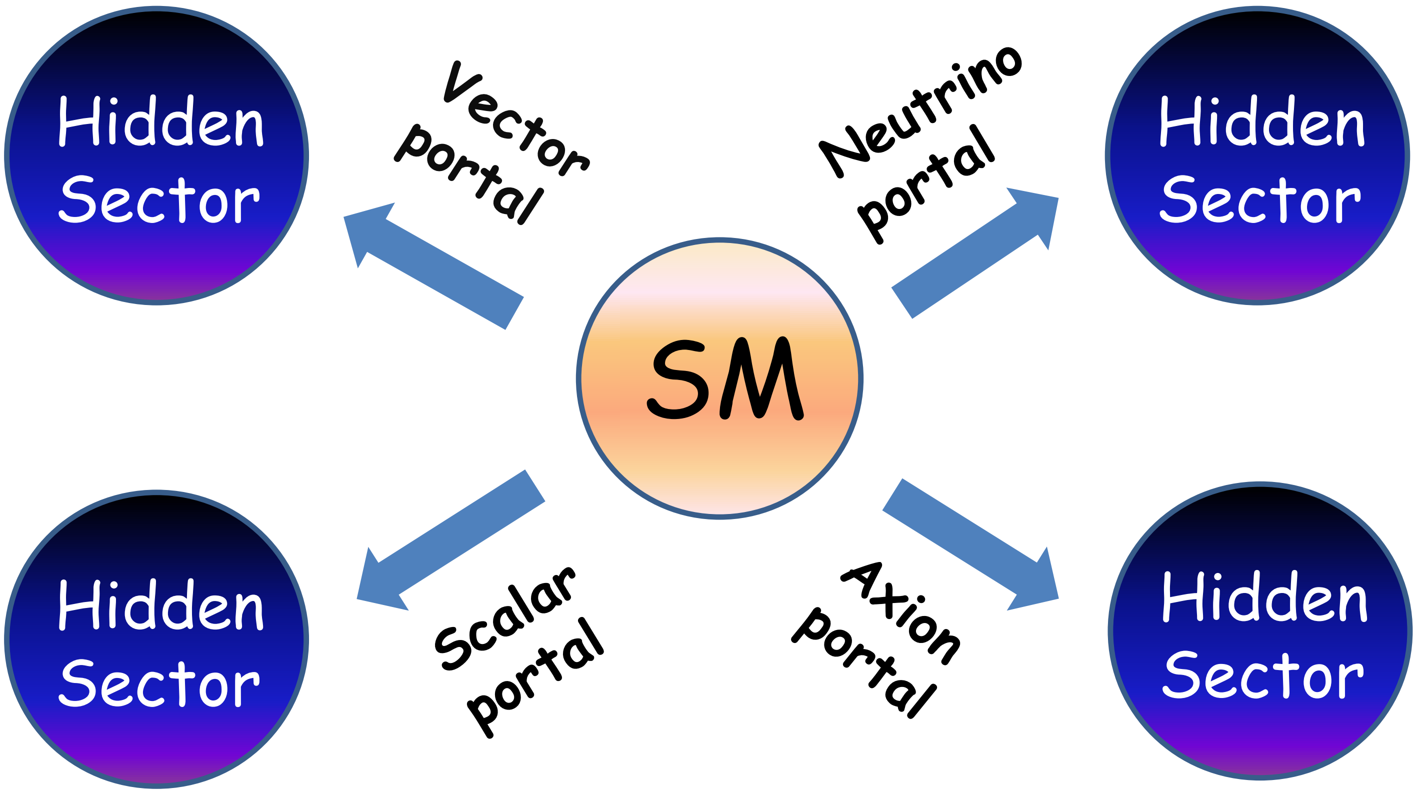
Where is new physics?

Why couldn't we detect them?
→ Too heavy or too weakly interacting



The intensity frontier aimed at exploring the Hidden sector region : Main target of PBC (Physics Beyond Colliders) activity at CERN → SHiP (Search for Hidden Particles)

Extensions of SM



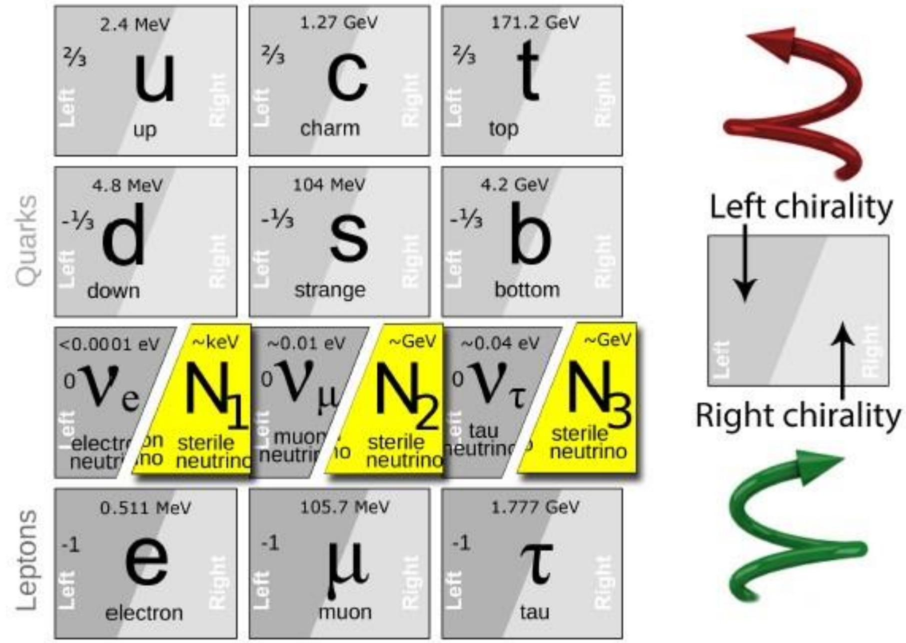
$$\mathcal{L}_{\rm world} = \mathcal{L}_{\rm SM} + \mathcal{L}_{\rm portal} + \mathcal{L}_{\rm HS}$$

Many hidden sector models often include **new light particles around GeV scale** (**LDM candidates**).

Neutrino portal

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)

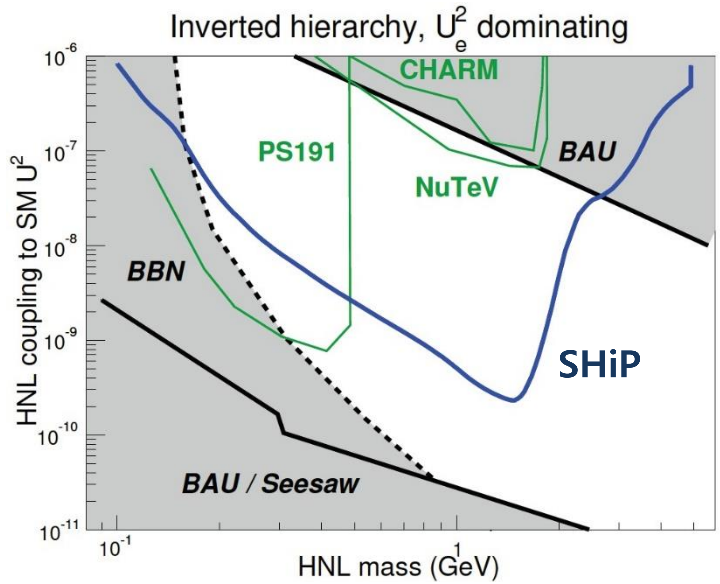
Matter-Antimatter asymmetry
Neutrino mass (oscillation)

N = Heavy Neutral Lepton (HNL)

Heavy RH neutrinos

Experimental and Cosmological constraints on HNL

The cosmologically interesting region is at low couplings



- **$m_{HNL} < m_b$**

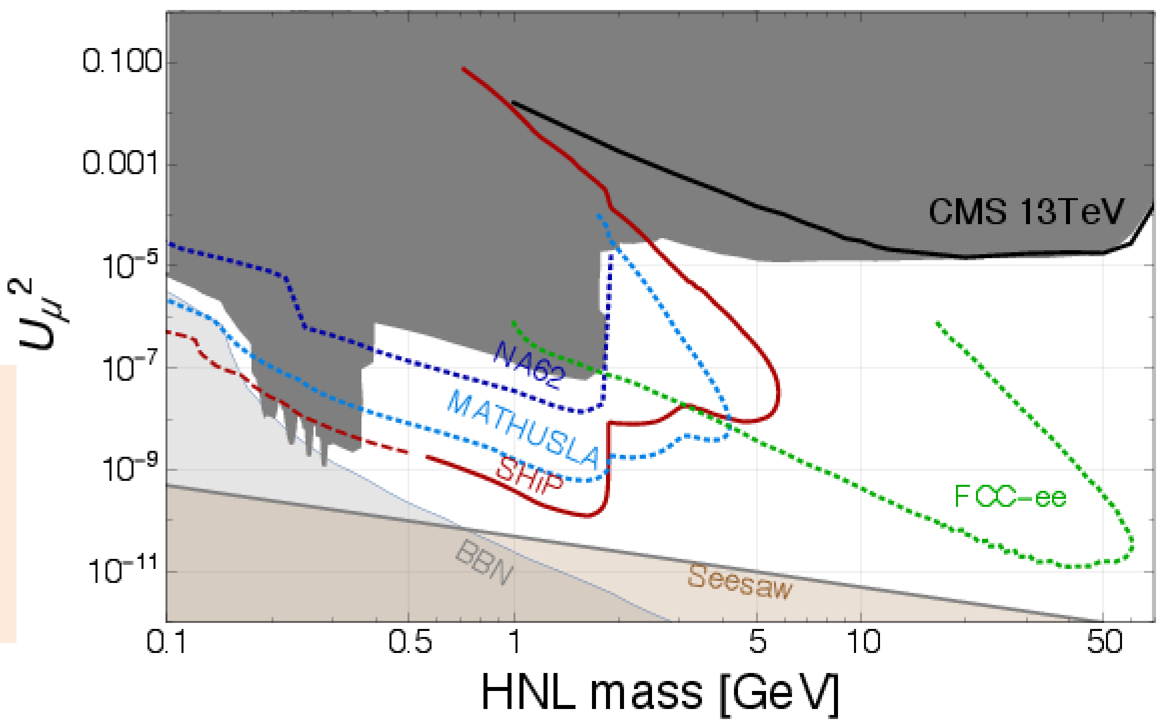
  SHiP will have much better sensitivity than LHCb or Belle2

- **$m_b < m_{HNL} < m_Z$**

  FCC-ee, improvements expected from CMS/ATLAS

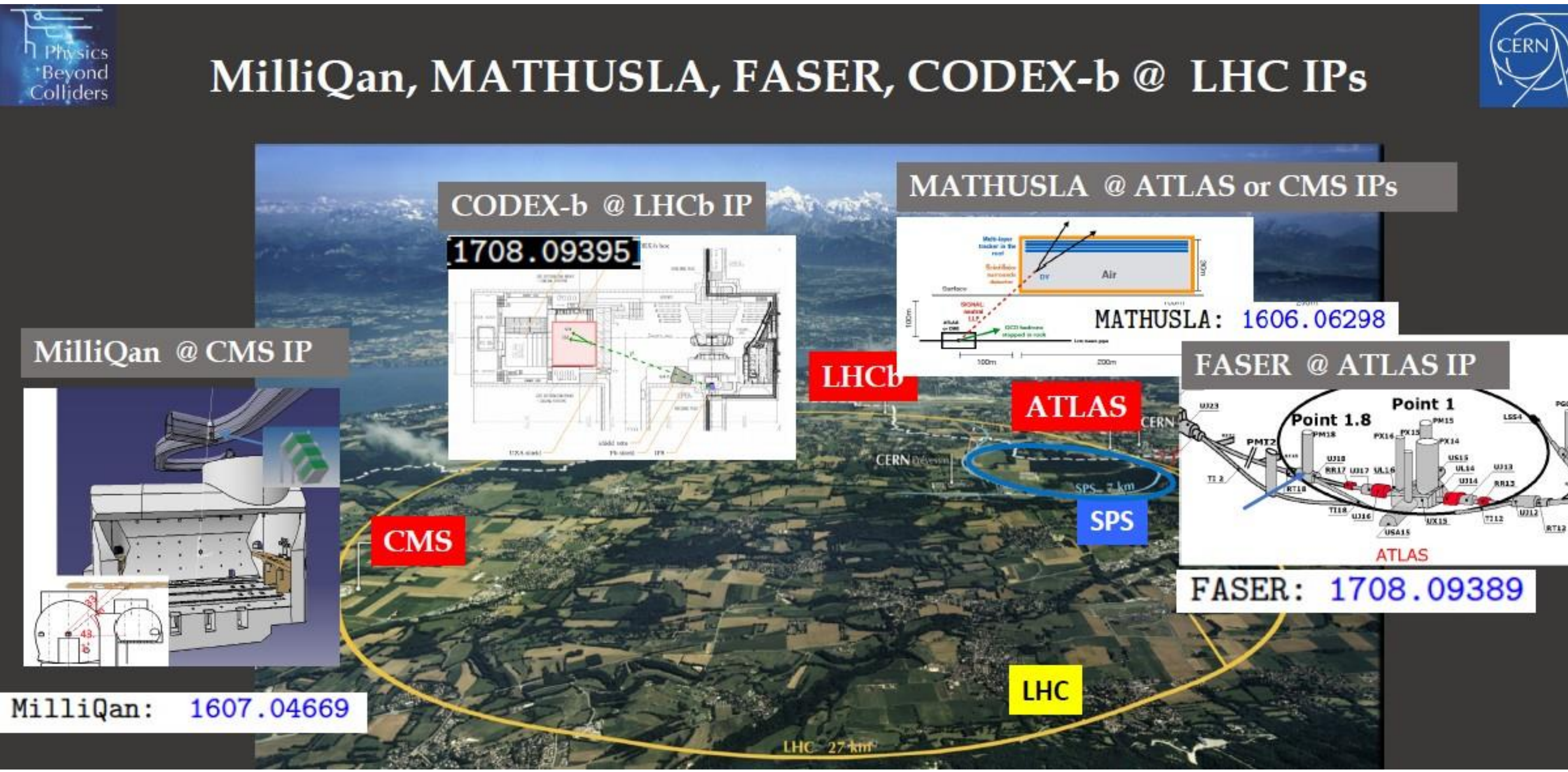
- **$m_{HNL} > m_Z$**

  targeted by CMS/ATLAS at HL-LHC



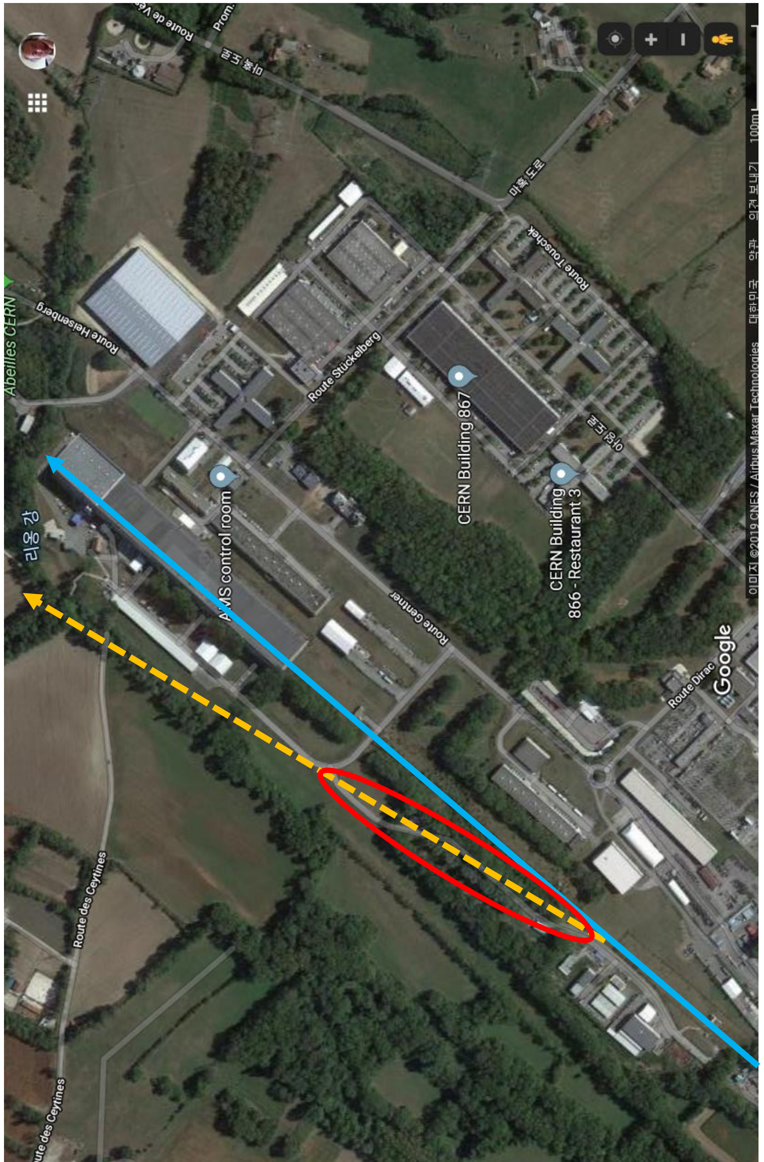
At **m_{HNL} = 1 GeV** and **$U^2 = 10^{-8}$** (50 x lower than present limit), SHiP will see more than **1,000** fully reconstructed events.

SHiP-like LLP projects at LHC



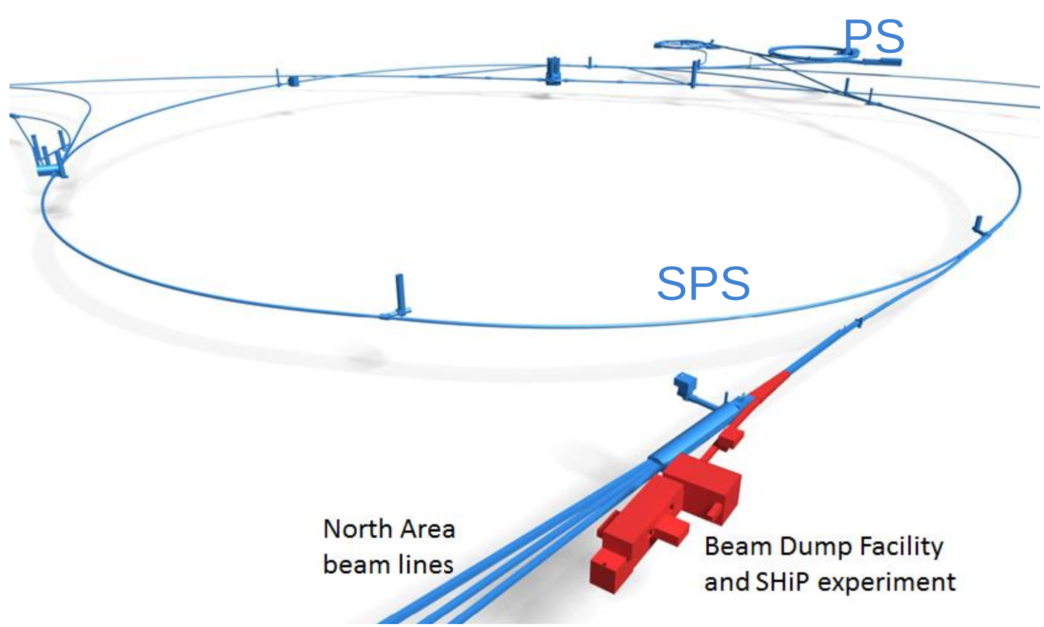
AL3X @ALICE: 1810.03636

Fixed-target facility at the SPS



The SPS provides a unique high-intensity beam of 400 GeV protons: ideal setting for a CERN-based Beam Dump Facility (BDF).

The SHiP facility is located on the North Area (Prévessin site), and shares the TT20 transfer line.

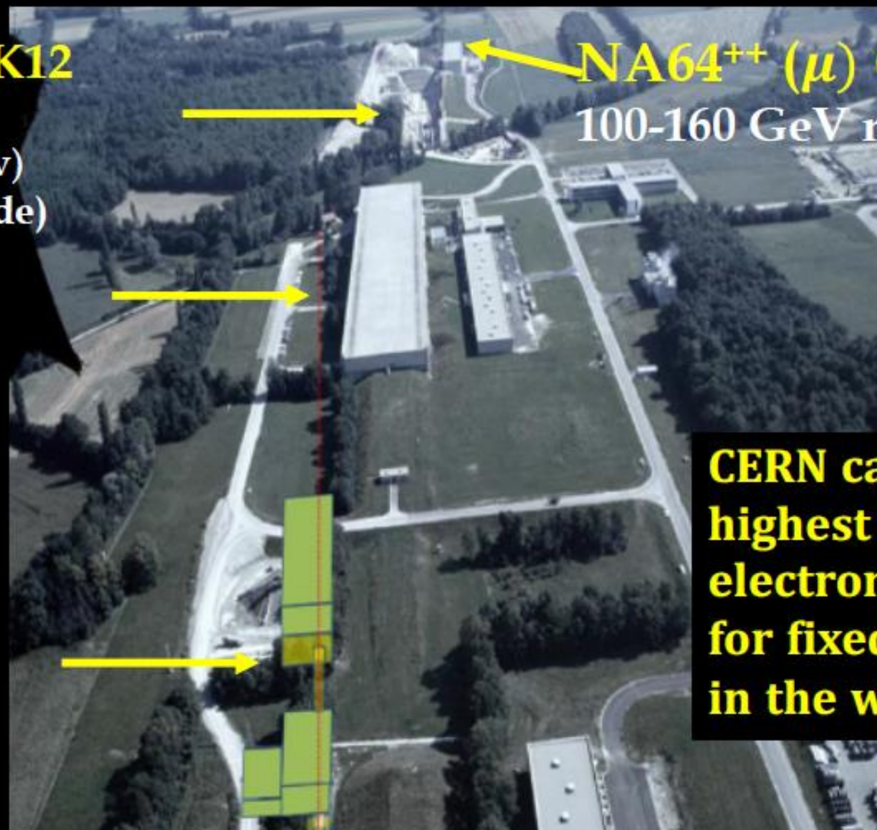


Hidden Sector proposals in CERN North Area

NA62^{++} , KLEVER @ K12
400 GeV p beam
up to 3x10^{18} pot/year (now)
up to 10^{19} pot/year (upgrade)

NA64^{++} (e) @ H4
(100 GeV e- beam
up to 5x10^{12} eot/year)

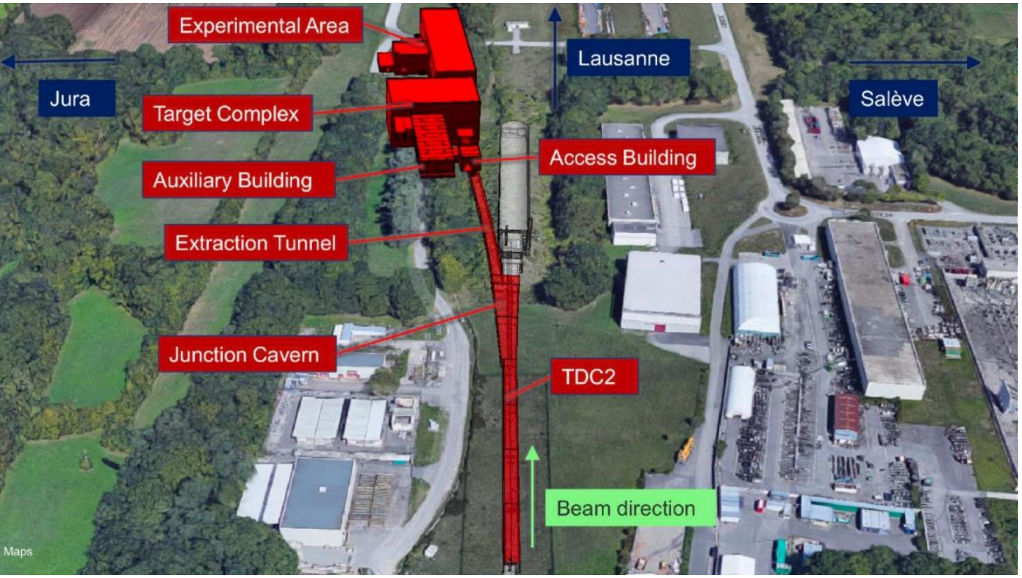
SHiP, TauFV @ BDF
400 GeV p
up to 4x10^{19} pot/year

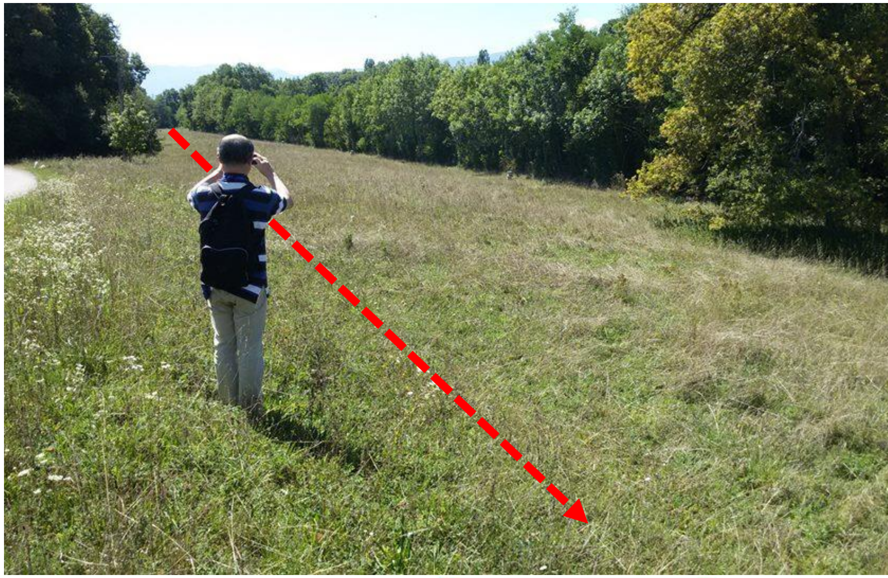


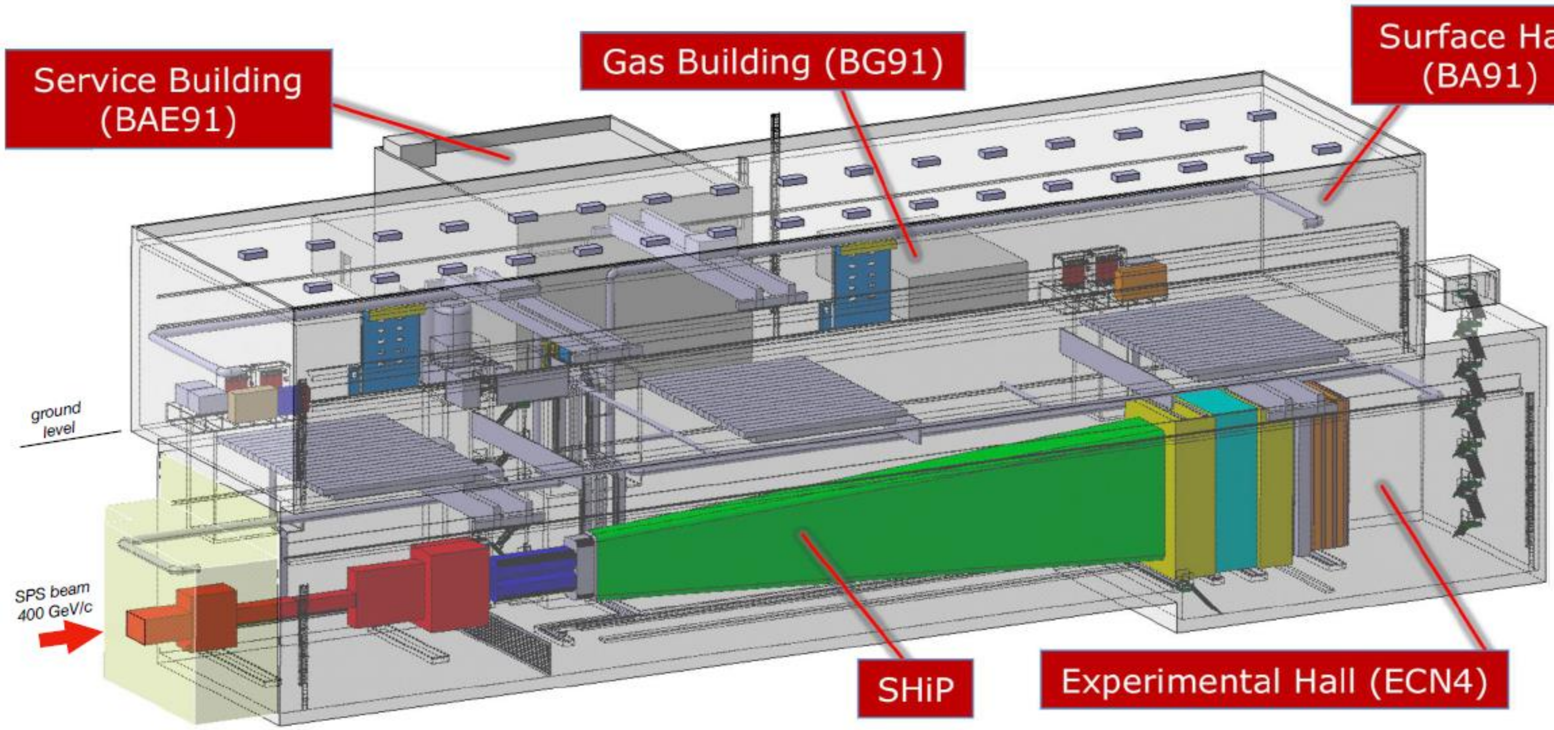
NA64^{++} (μ) @ M2
100-160 GeV muons, up to 10^{13} μ/year

CERN can provide the highest energy proton, electron and muon beams for fixed target experiments in the world.

The "Hidden Sector Campus" (HSC)


Experimental Area
Jura
Target Complex
Lausanne
Salève
Access Building
Auxiliary Building
Extraction Tunnel
Junction Cavern
TDC2
Beam direction
Maps




Service Building (BAE91)
Gas Building (BG91)
Surface Hall (BA91)
ground level
SPS beam 400 GeV/c
SHiP
Experimental Hall (ECN4)

Main objectives of SHiP

SHiP
Search for Hidden Particles

- ✔ **Hidden particles**

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

- ✔ **Tau neutrino physics**

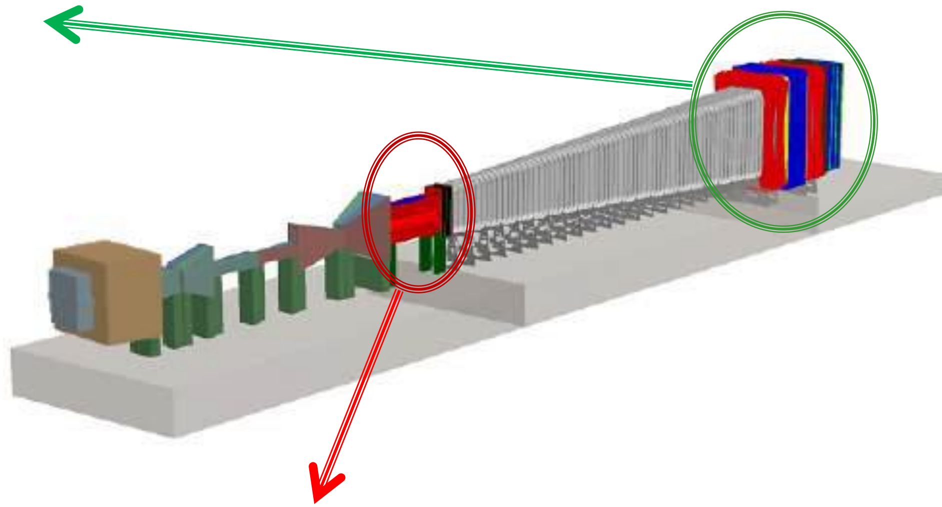
  Expect ~10,000 $\nu\tau$ and Anti-$\nu\tau$ interactions in ~10 tons Emulsion target (Cross-section …)

& LDM …

The SHiP detector

A discovery machine for **feebly coupled LLPs**, with a complementary detector for **Neutrino physics** and **LDM scattering**

✓ HS Decay Spectrometor



ECAL, Muon detector
Straw trackers
Timing detector
Surround bg tagger

→ Large geometrical acceptance :
long decay volume close to dump

✓ Scattering and Neutrino Detector (SND)

Emulsion target (ECC+CES) - [high spatial resolution tracker (sub-μm)
Target Tracker (TT) — charge & momentum measure with magnet
Muon filter (RPC) - muon identification

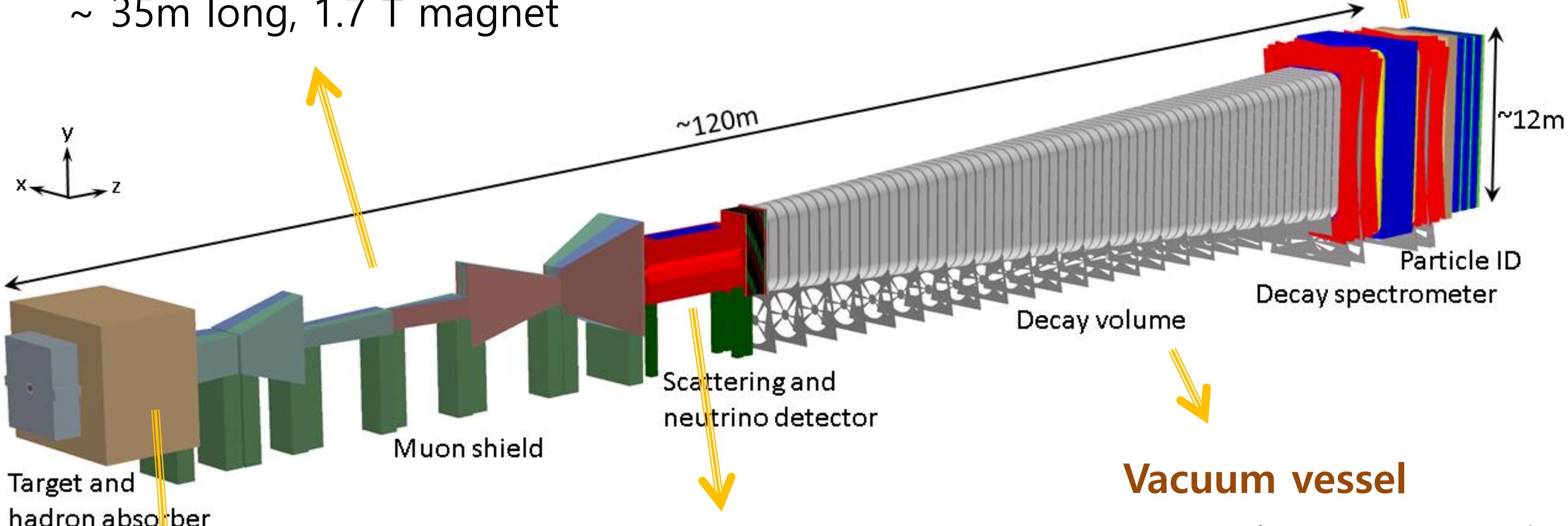
The SHiP detector

HS decay spectrometer

ECAL, Muon detector
PID, Energy & Timing

Active muon shield

deflect μ from 2ry meson decay
~ 35m long, 1.7 T magnet



Vacuum vessel

~50 m long evacuated decay vessel (10^{-3} bar) surrounded by liquid scintillator veto system

Scattering and Neutrino Detector

LDM & Tau neutrino

ECC + CES
(Nuclear emulsion)
TT, RPC

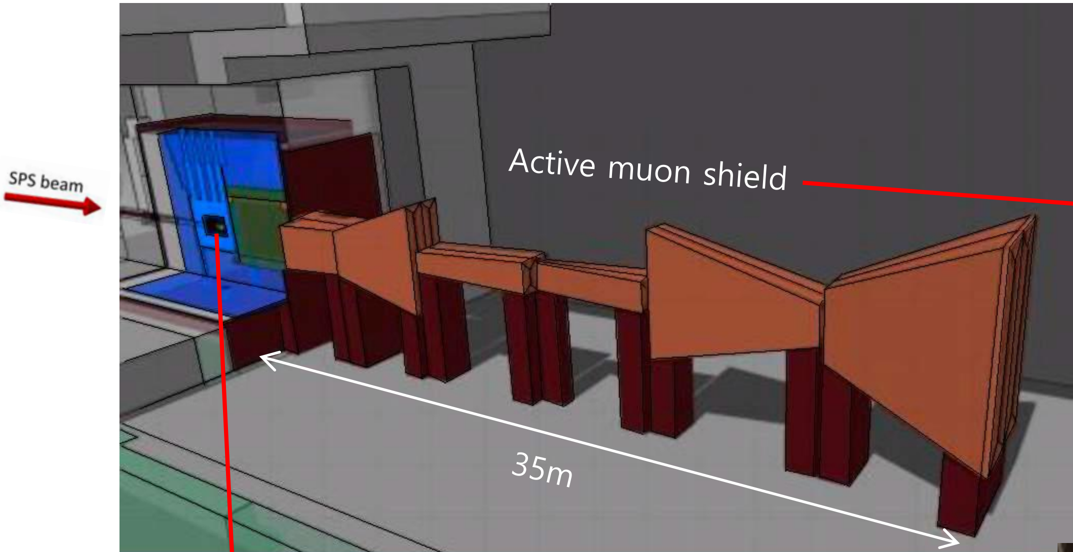
Hadron absorber

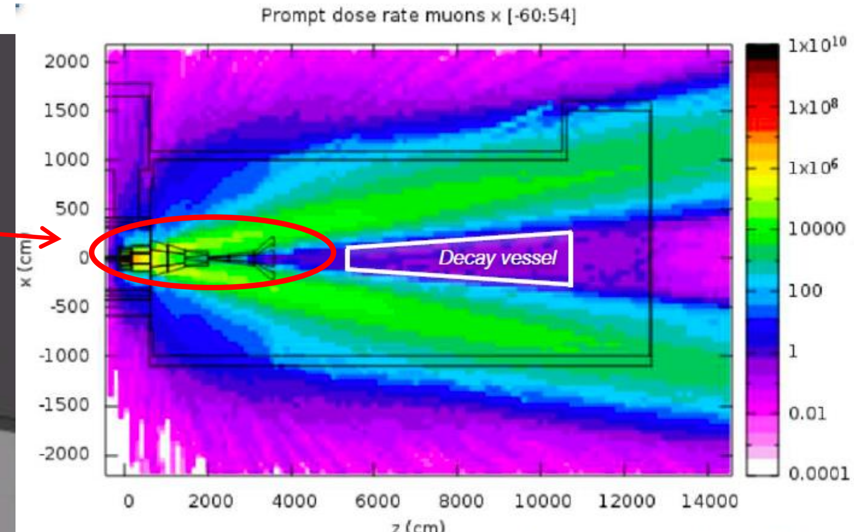
eliminate 2ry mesons
(π, K) ~ 5m Fe

Active muon shield

1400 tons magnet
μ rate reduced to ~ 25 kHz

Top view

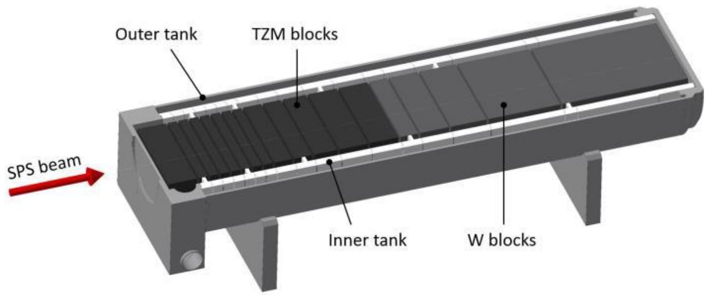




JINST 12 (2017) no.5, P05011

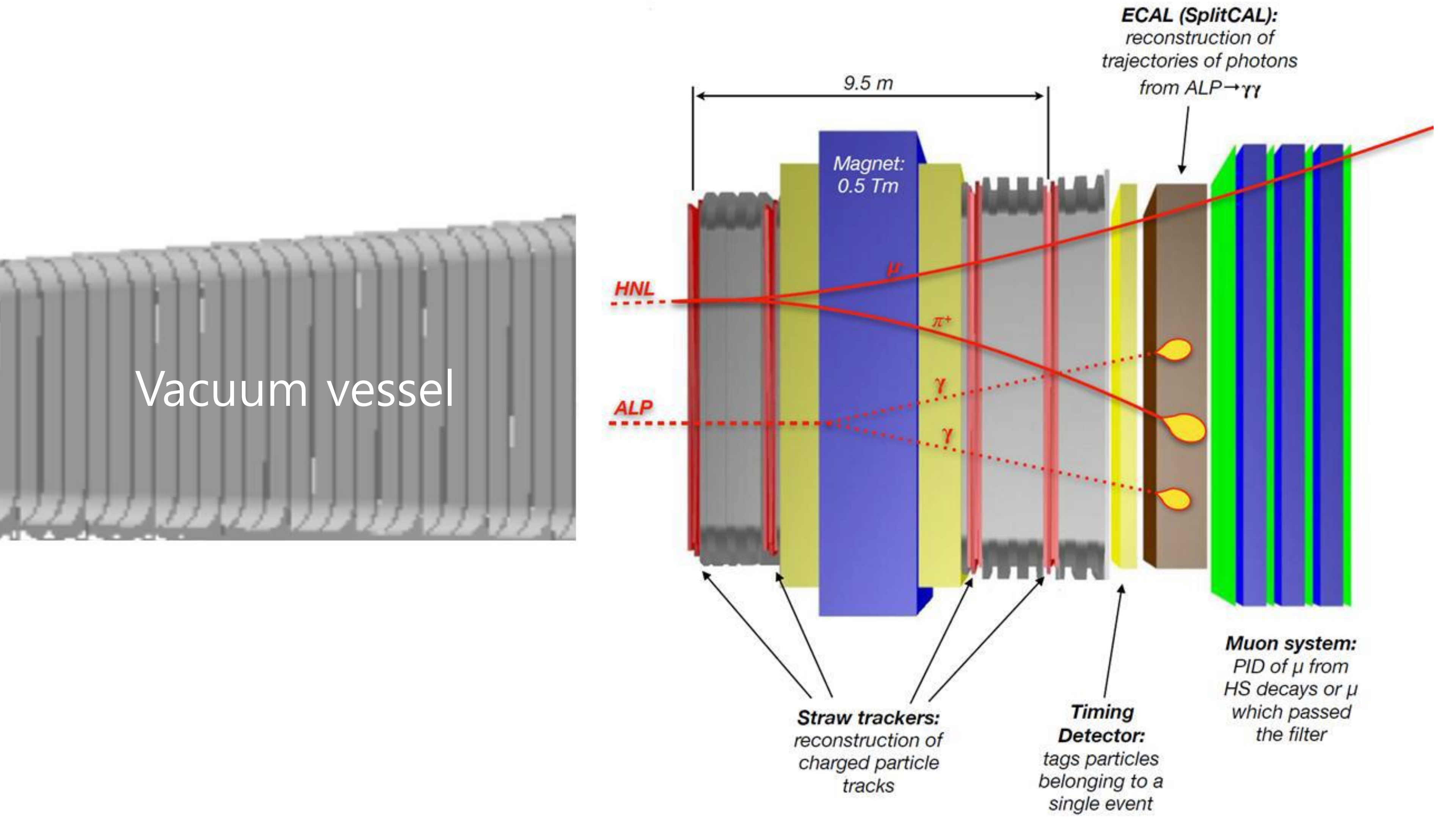
Target

Blocks of TZM (Titanium-Zirconium) doped Molibdenum alloy (10.22 g/cm^3) followed by blocks of pure Tungsten



SHiP replica target used for beam test at SPS H4 beamline in July 2018

HS decay spectrometer



Decay of Hidden Particles

$\mu^-\pi^+$

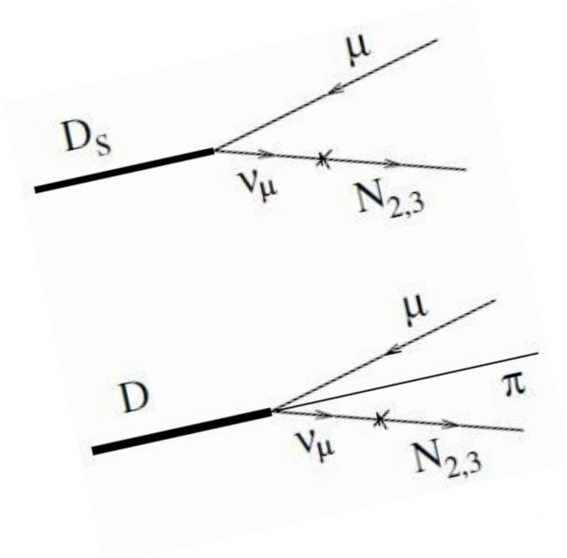
Models tested	Final states
Neutrino portal, SUSY neutralino	$\ell^\pm\pi^\mp$, $\ell^\pm K^\mp$, $\ell^\pm\rho^\mp$
Vector, scalar, axion portals, SUSY sgoldstino	e^+e^-, $\mu^+\mu^-$
Vector, scalar, axion portals, SUSY sgoldstino	$\pi^+\pi^-$, K^+K^-
Neutrino portal ,SUSY neutralino, axino	$\ell^+\ell^-\nu$
Axion portal, SUSY sgoldstino	$\gamma\gamma$
SUSY sgoldstino	$\pi^0\pi^0$

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

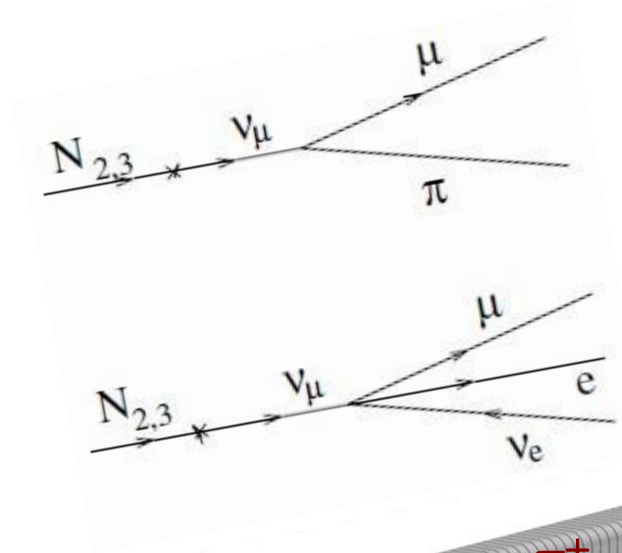
Many Vee decay modes

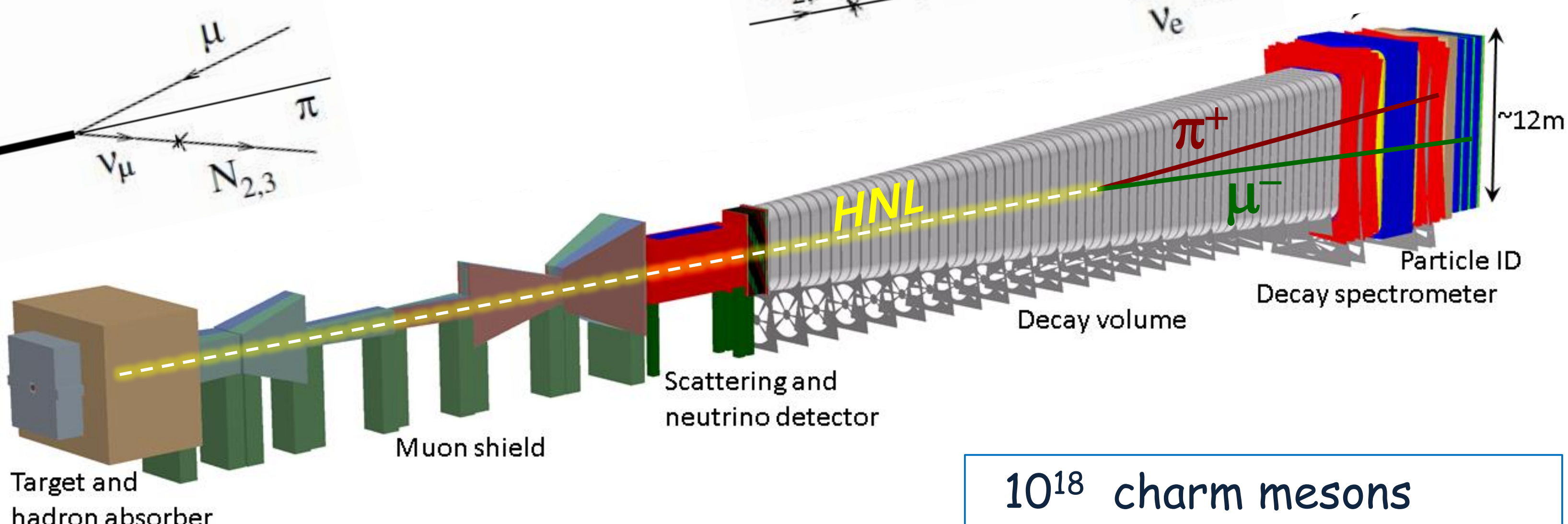
→ *Particle ID and Full reconstruction are essential to minimize model dependence.*

HNL production



HNL decay





10^{18} charm mesons
10^{14} beauty mesons
10^{16} τ leptons
for 2×10^{20} pot (in 5 yrs)

SHiP
Search for Hidden Particles

Neutrino Physics with SHiP

- About **10,000 Tau neutrino & Anti-tau neutrino CC events** can be observed in the ECC target.
  - First observation of the **Anti-tau neutrino**
- **Tau neutrino physics**
  - Cross section, Magnetic moment measurements
  - First evaluation of F4 and F5 structure functions
  - Study of Strange quark content of nucleon
- **LDM search** in Emulsion

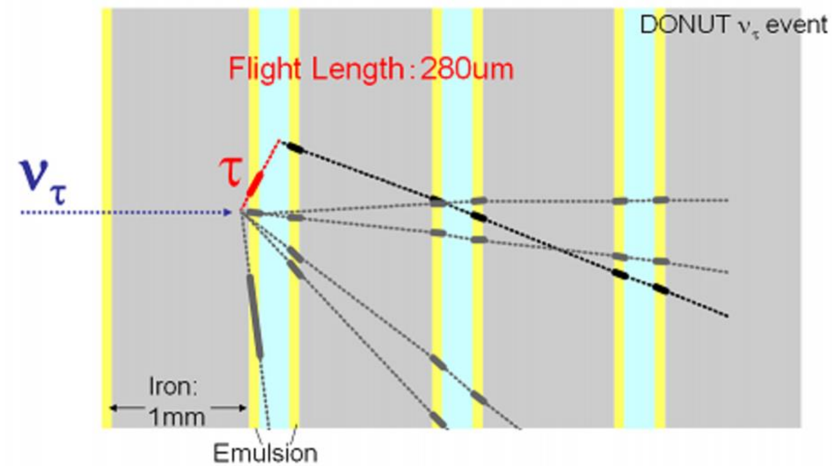
Tau Neutrinos so far

DONuT **9 events**

First direct observation

Proton beam dump exp.

Cross section, mag mom



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

but could not distinguish ν_τ and $\overline{\nu}_\tau$

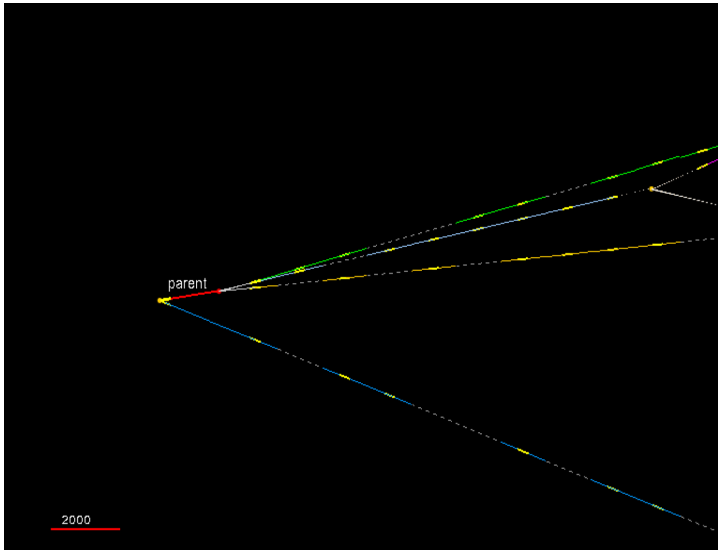
OPERA **10 events** from oscillation

Long-baseline CNGS beam

Discovery of ν_τ appearance

event by event basis (6.1σ)

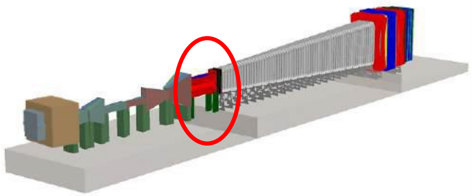
not statistical basis



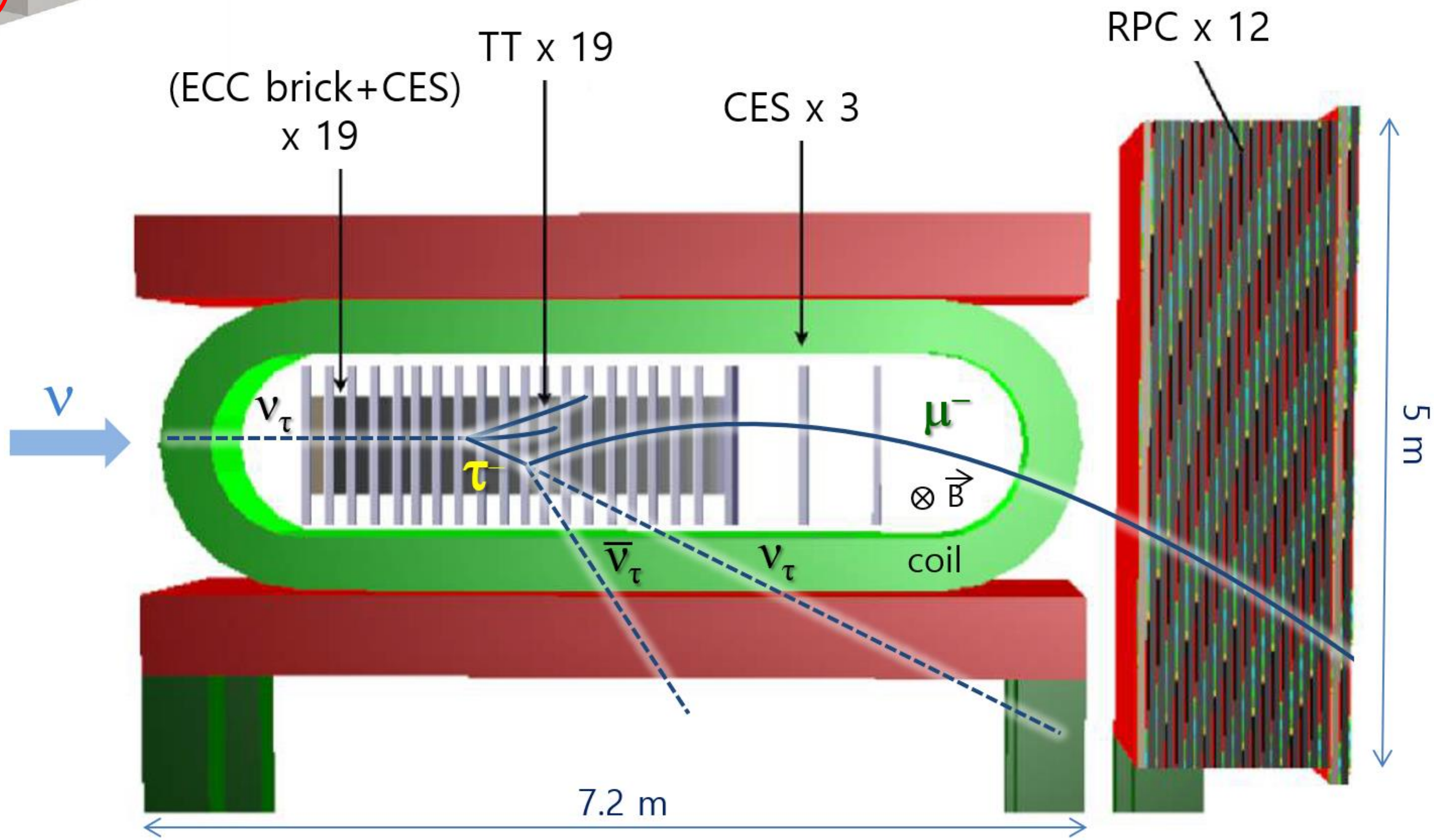
OPERA ν_τ event

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

→ Same technique will be used in the SHiP

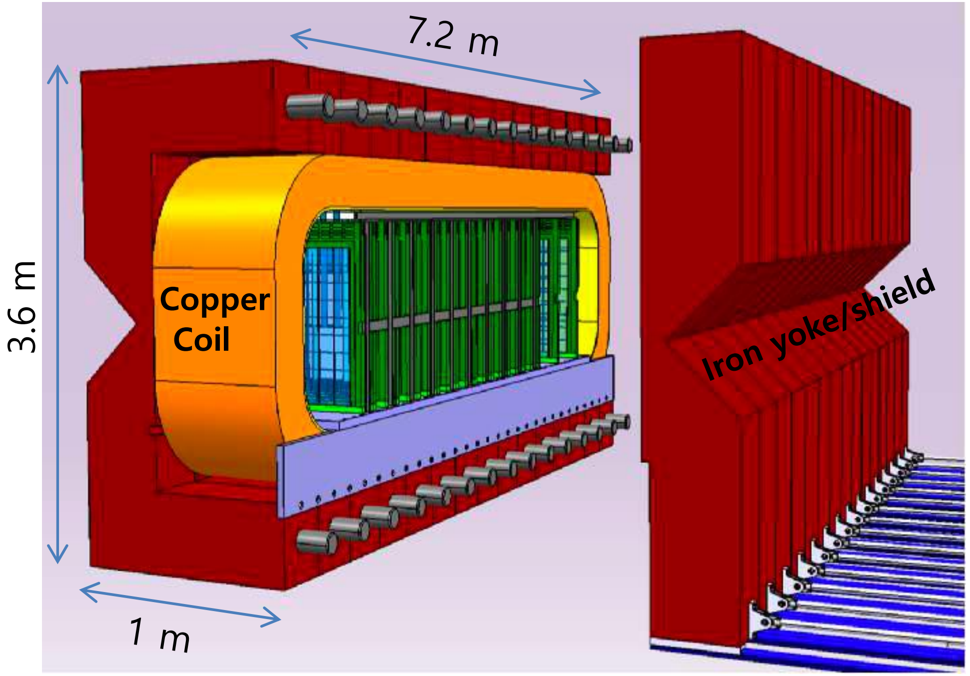


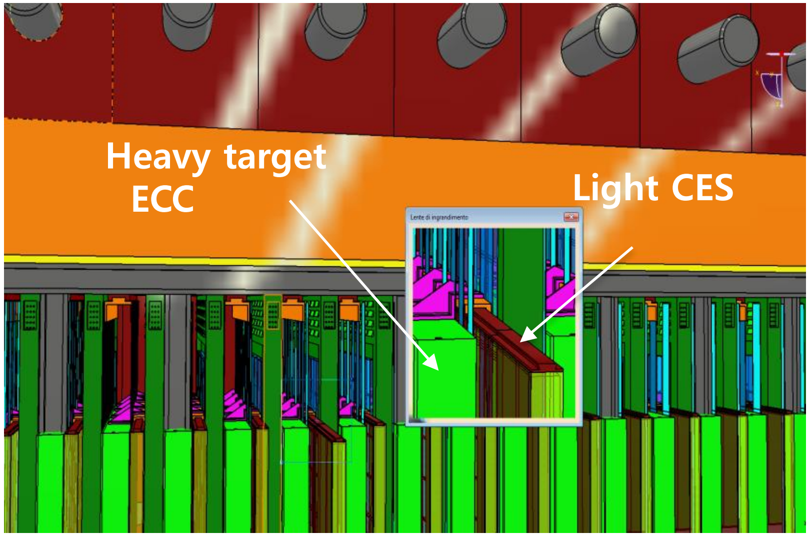
Scattering and Neutrino Detector

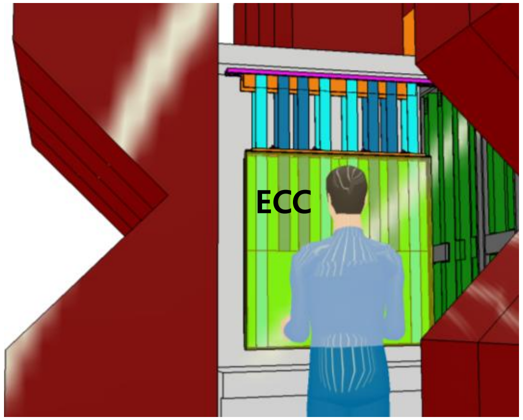


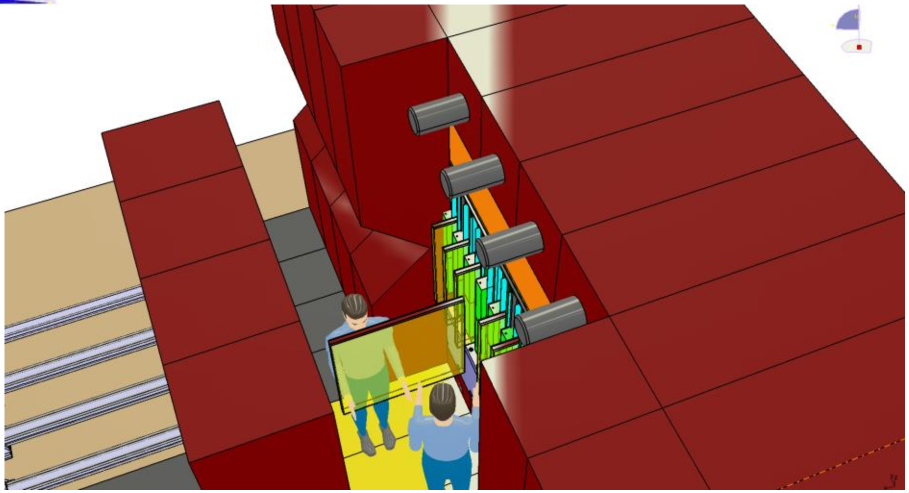
ECC (Emulsion Cloud Chamber) **:** High spatial resolution (~μm) to observe the τ decay
CES (Compact Emulsion Spectrometer) **:** measure muon charge & momentum
TT (Target tracker) **:** Electronic detector to predict ν interaction contained in ECC brick and provide the time stamp
Magnet : to measure the charge of τ products (1.25 T)
Muon filter (RPC) **:** Muon identification and tracking (area 2 x 5 m^2 x 12 planes)

Scattering and Neutrino Detector

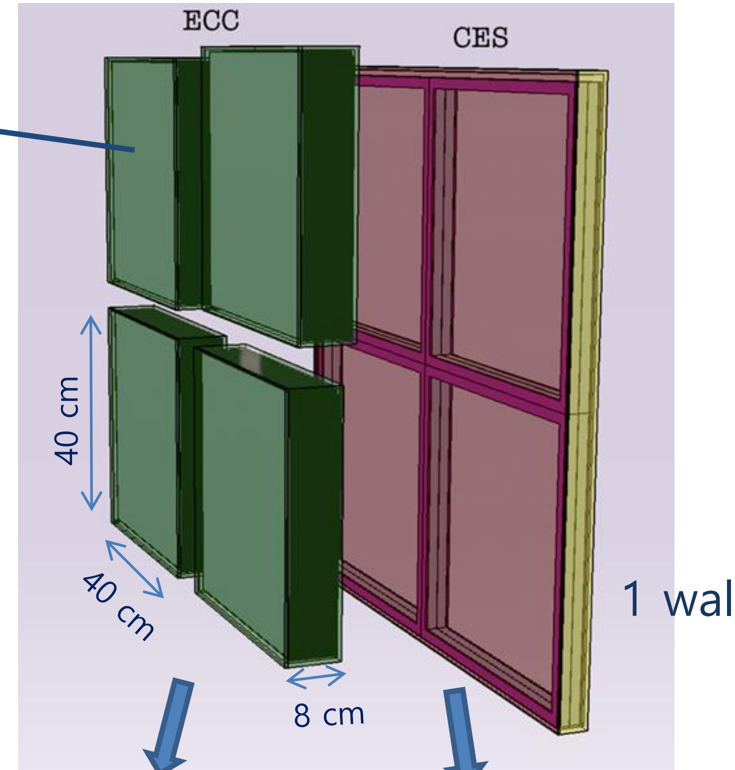


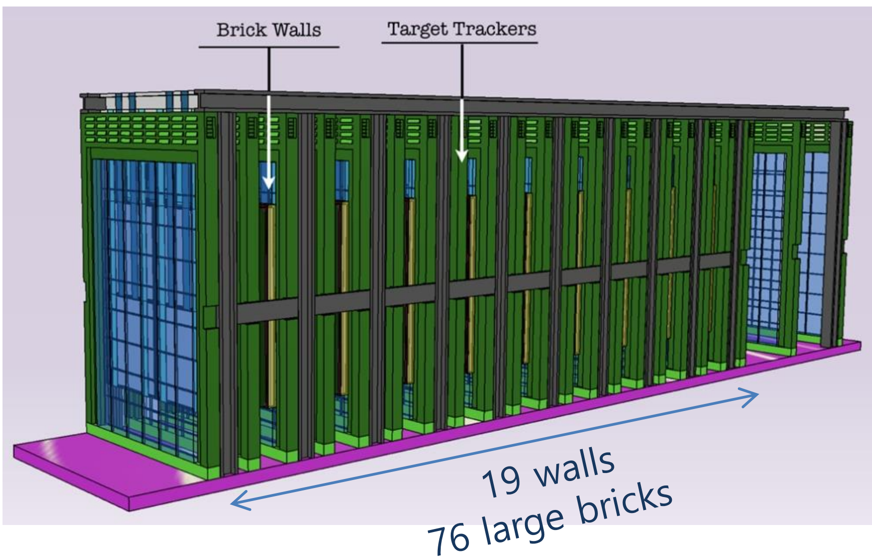


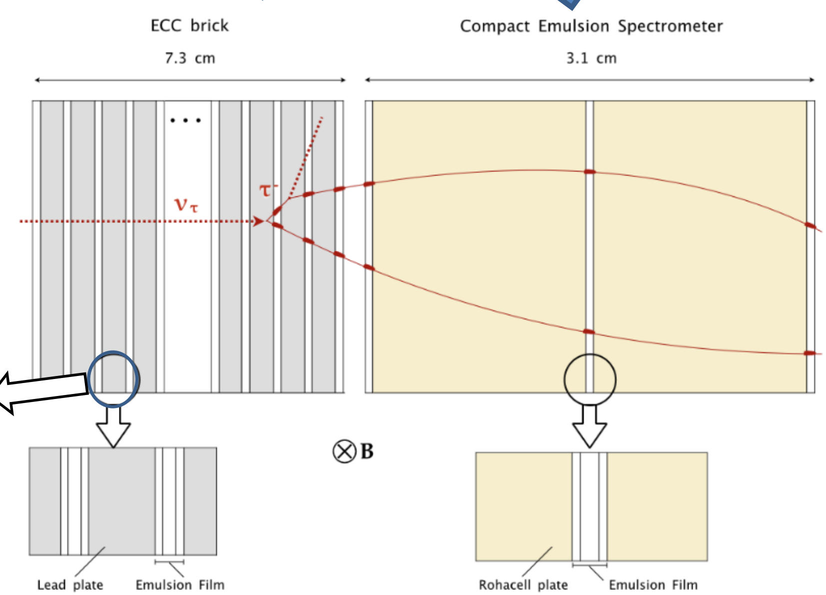




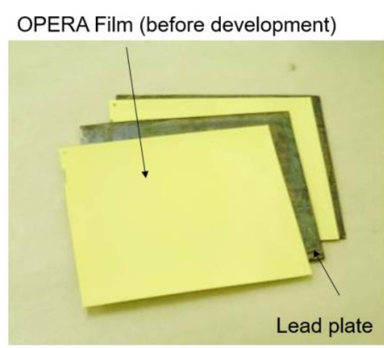
ECC brick
1 brick - 57 Emulsion film (40 x 40 cm^2)
interleaved with 1 mm thick lead plates, ~100 kg
Total 19 walls
76 (=2x2x19) large bricks (~700 m^2), ~10 tons
to be replaced 10 times (~7000 m^2 total)



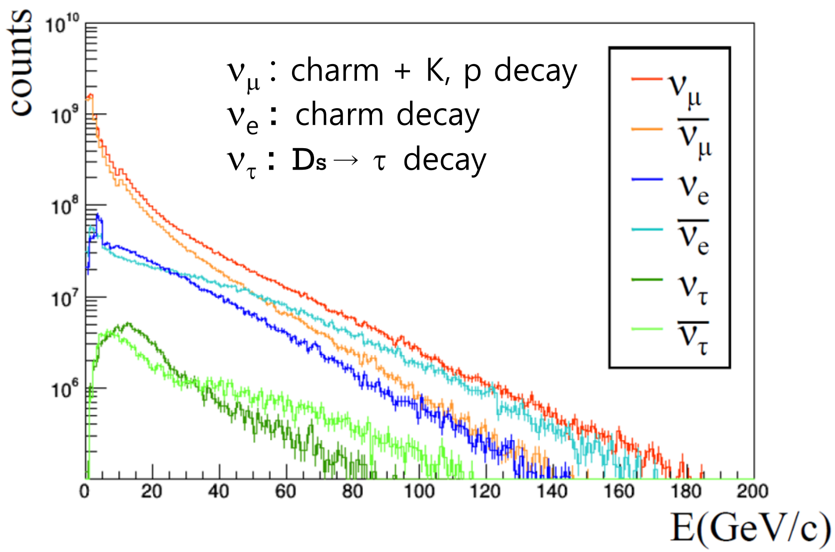




CES
made of 3 emulsion films
interleaved by 2 layers
of low density materials
to be replaced every
~2 weeks
each CES ~ 10kg



Neutrino interactions



Expected yield of Neutrino CC DIS interactions in the **SND** (5 yrs)

	$\bar{E}$ [GeV]	CC DIS int.
ν_e	59	1.1×10^6
ν_μ	42	2.7×10^6
ν_τ	52	3.2×10^4
$\bar{\nu}_e$	46	2.6×10^5
$\bar{\nu}_\mu$	36	6.0×10^5
$\bar{\nu}_\tau$	70	2.1×10^4

Expected Neutrino CC DIS interactions with **Charm production**

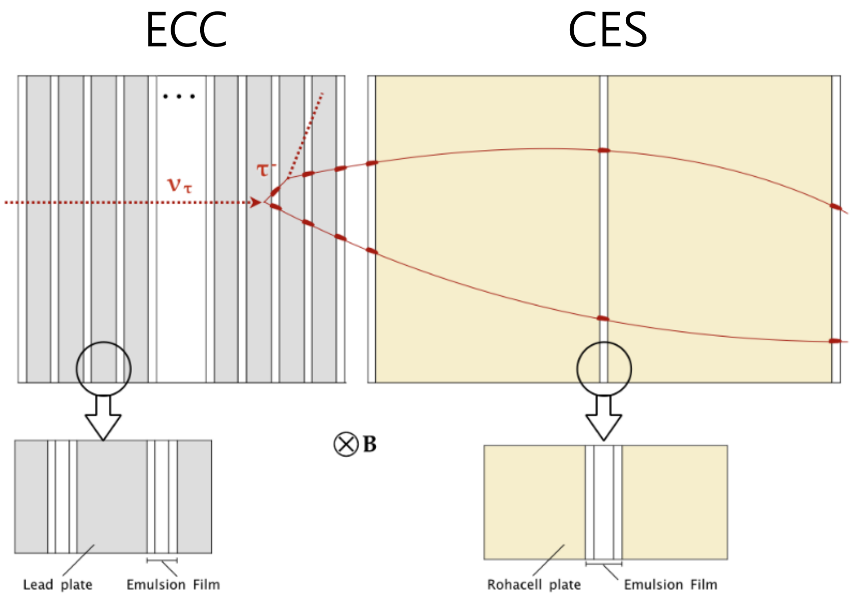
	<E> (GeV)	CC DIS with charm prod
N_{ν_μ}	55	1.3×10^5
N_{ν_e}	66	6.0×10^4
$N_{\bar{\nu}_\mu}$	49	2.5×10^4
$N_{\bar{\nu}_e}$	57	1.3×10^4
total		2.3×10^5

~10,000 Tau & Anti-tau neutrino events
will be observed in ECC (except $\tau \rightarrow e$ channel)

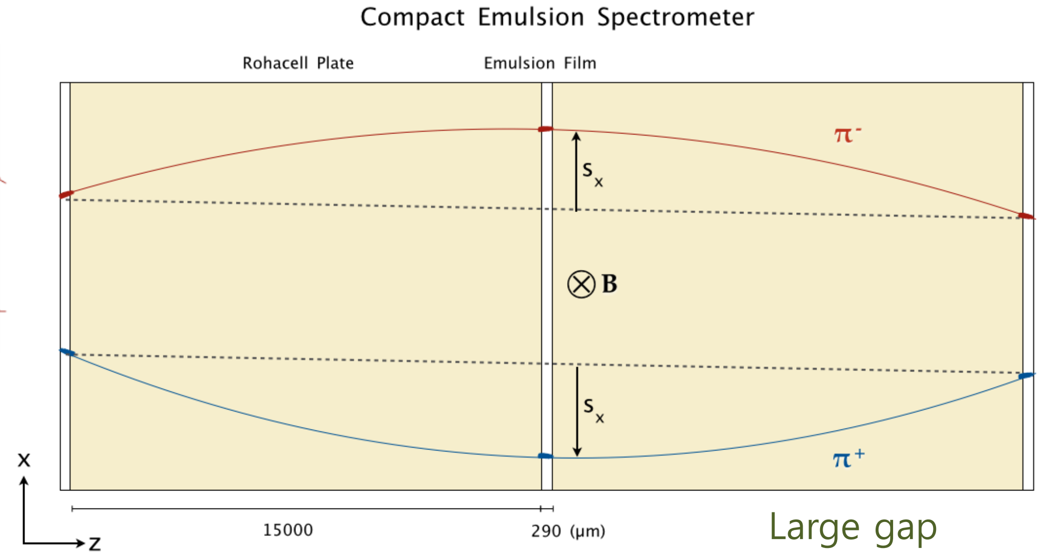
decay channel	ν_τ	$\bar{\nu}_\tau$
$\tau \rightarrow \mu$	1200	1000
$\tau \rightarrow h$	4000	3000
$\tau \rightarrow 3h$	1000	700
total	6200	4700

No charm candidates from electron neutrino was ever reported so far.

Anti-tau neutrino identification by CES



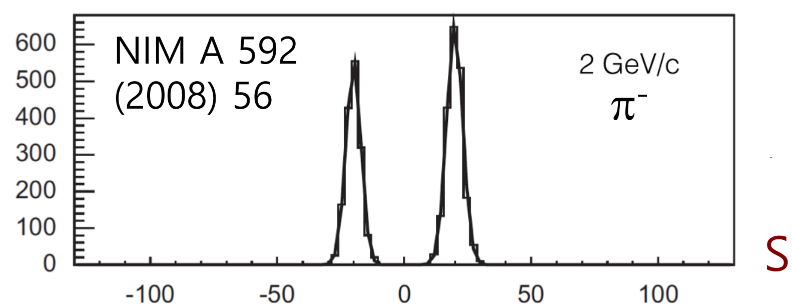
Measurement of Sagitta **S**

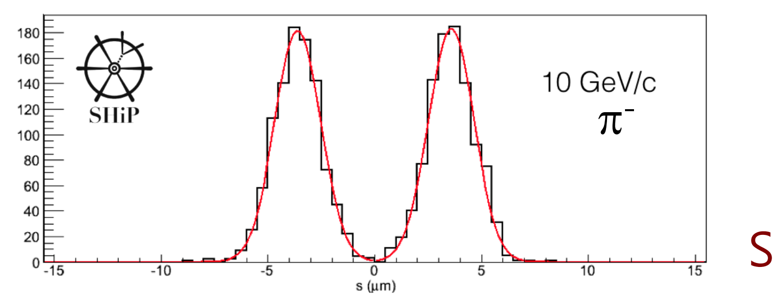


$$\nu_\tau \rightarrow \tau^- \rightarrow \mu^-$$

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

- Electric charge can be determined with better than 3σ level up to 12 GeV/c
- Momentum estimated from the sagitta Δp/p < 20% up to 12 GeV/c





Emulsion Scanning Labs

LNGS

Nagoya

European Scanning System

High speed automatic microscopes

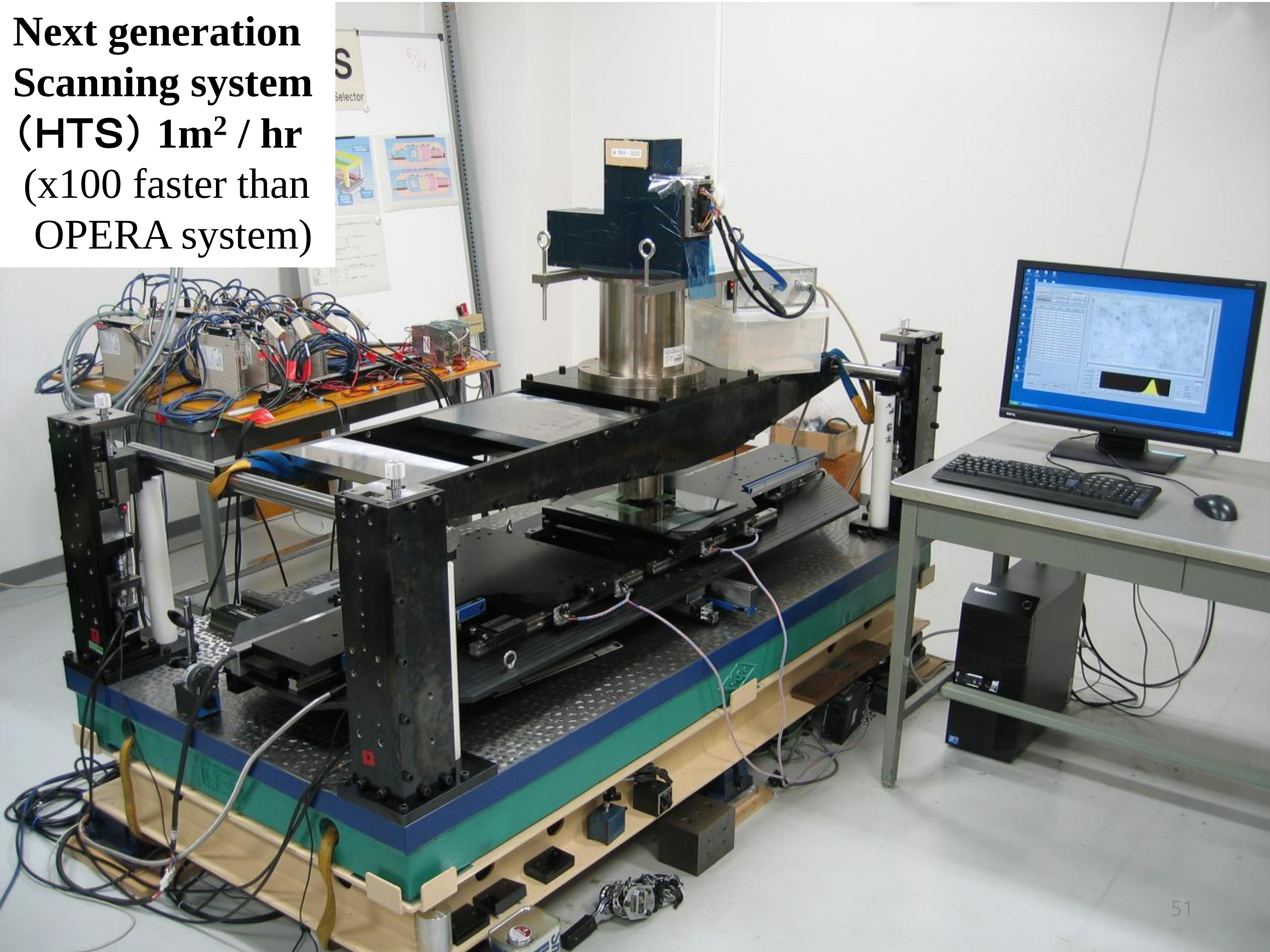
Based on state of the art technologies:
Precision mechanics,
Stepping motors,
CCD readout,
Pattern recognition,
Image analysis …

Super-Ultra Track Selector (Nagoya)

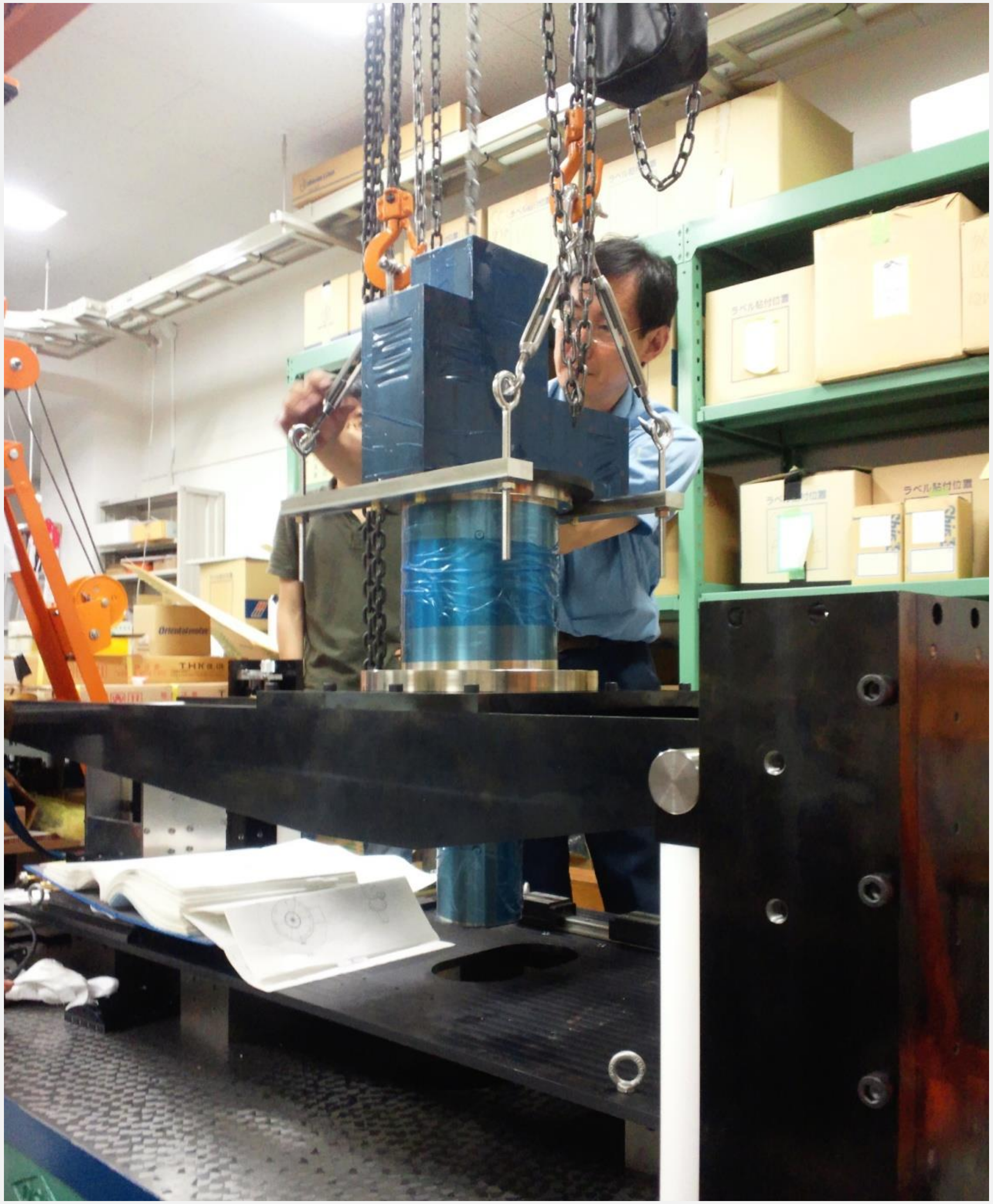
Emulsion Scanning Lab in Nagoya Univ.

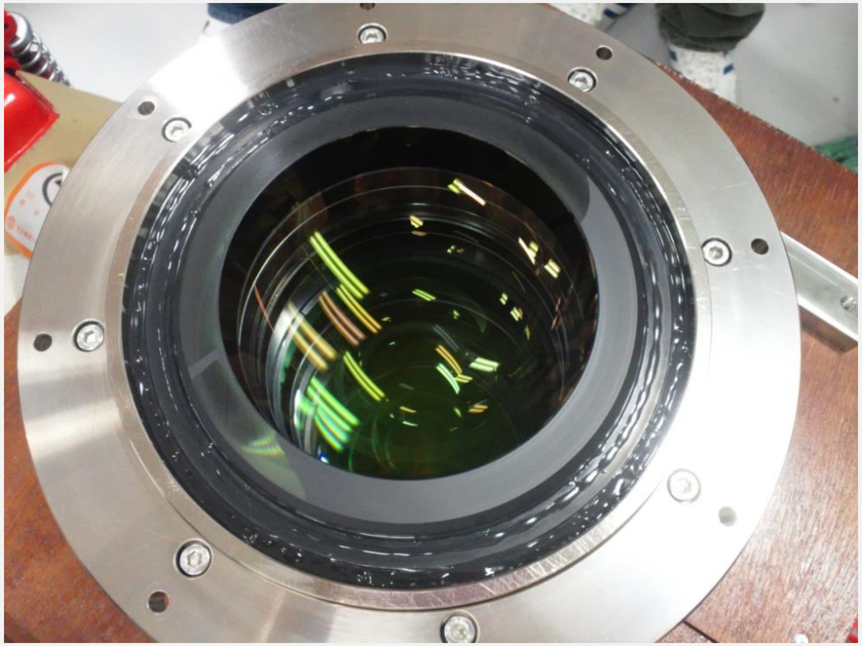
Next generation Scanning system （HTS） 1m² / hr

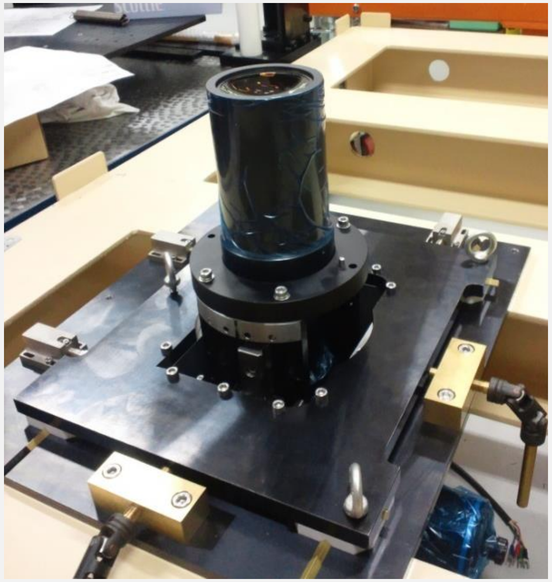
(x100 faster than OPERA system)



Mounting large optics



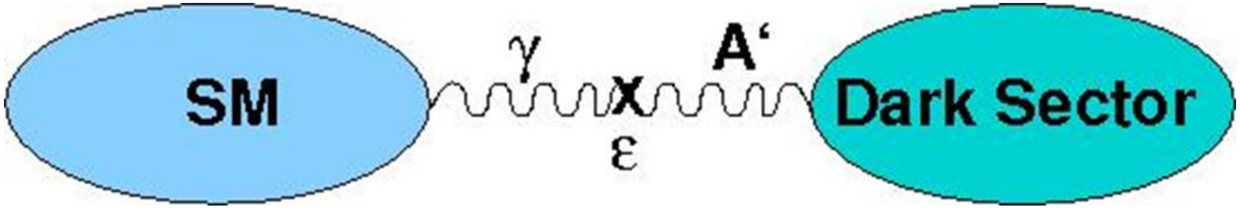




Scanning systems at GNU

LDM & e-recoil

Vector portal



Dark photon can decay into pair of Light dark matter

Production of dark photon A'

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

Proton bremsstrahlung $pp \rightarrow pp A'$

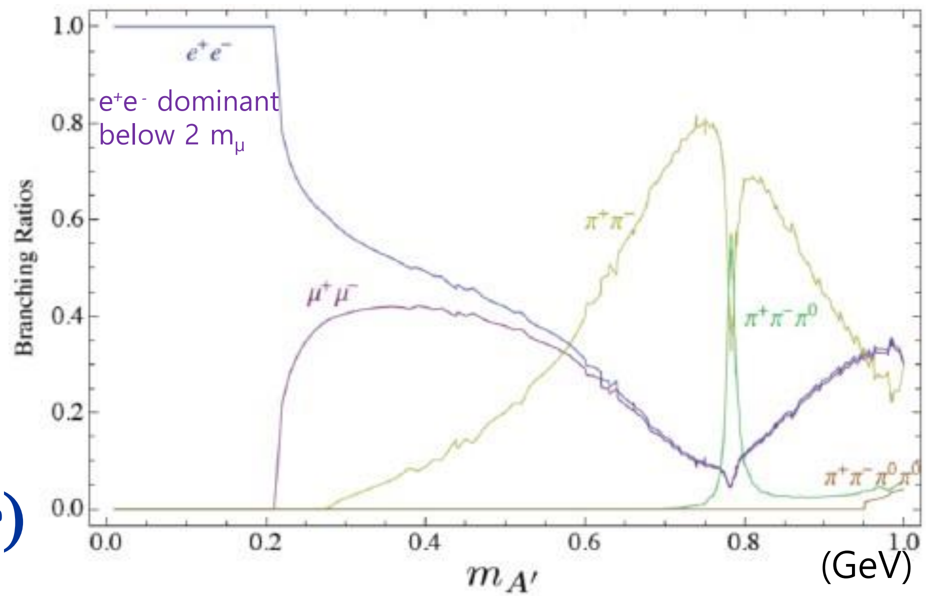
QCD production $q + q \rightarrow A'$, $q + g \rightarrow q + A'$

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

LDM (χ) can produce

via dark photon (A') decay

$$pp \rightarrow \pi^0 X$$

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

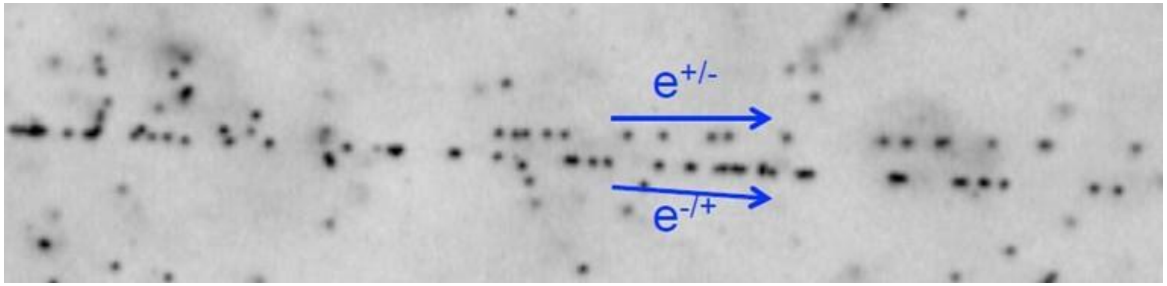
$$A' \rightarrow \chi \bar{\chi}$$

χ: LDM

Scatter on e

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

Electron recoil
high energy



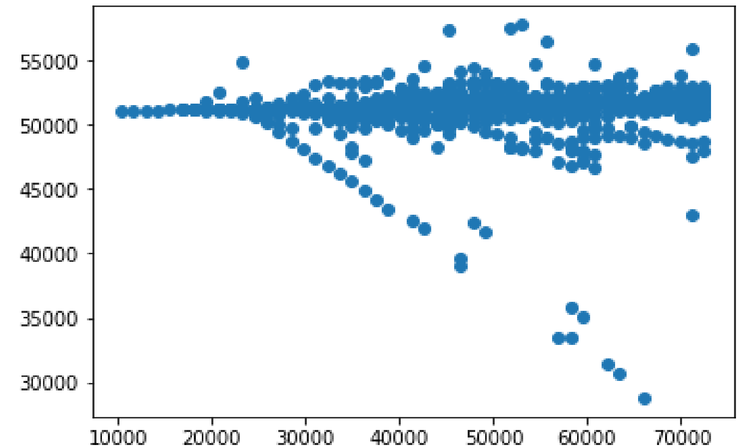
~ GeV electron sample in emulsion

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

Number of background events in the LDM search after the selection for 2 x 10^{20} protons on target.

Background	ν_e	$\bar{\nu}_e$	ν_μ	$\bar{\nu}_\mu$	all
Elastic Scattering on e^-	81	45	56	35	217
Quasi-elastic Scattering	245	236	-	-	481
Resonant Scattering	8	77	-	-	85
Deep Inelastic Scattering	-	14	-	-	14
Total	334	372	56	35	797

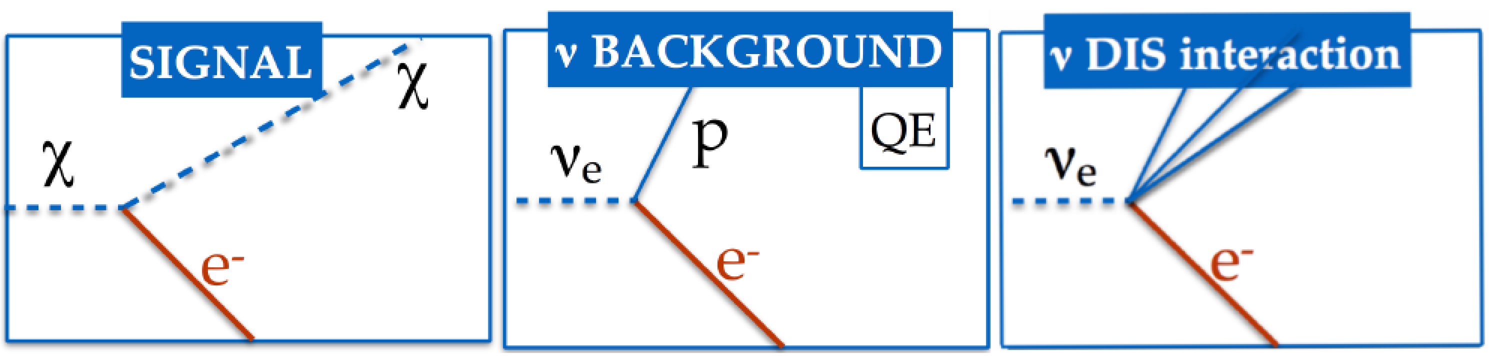
Signal/bg discrimination currently being studied using Machine Learning



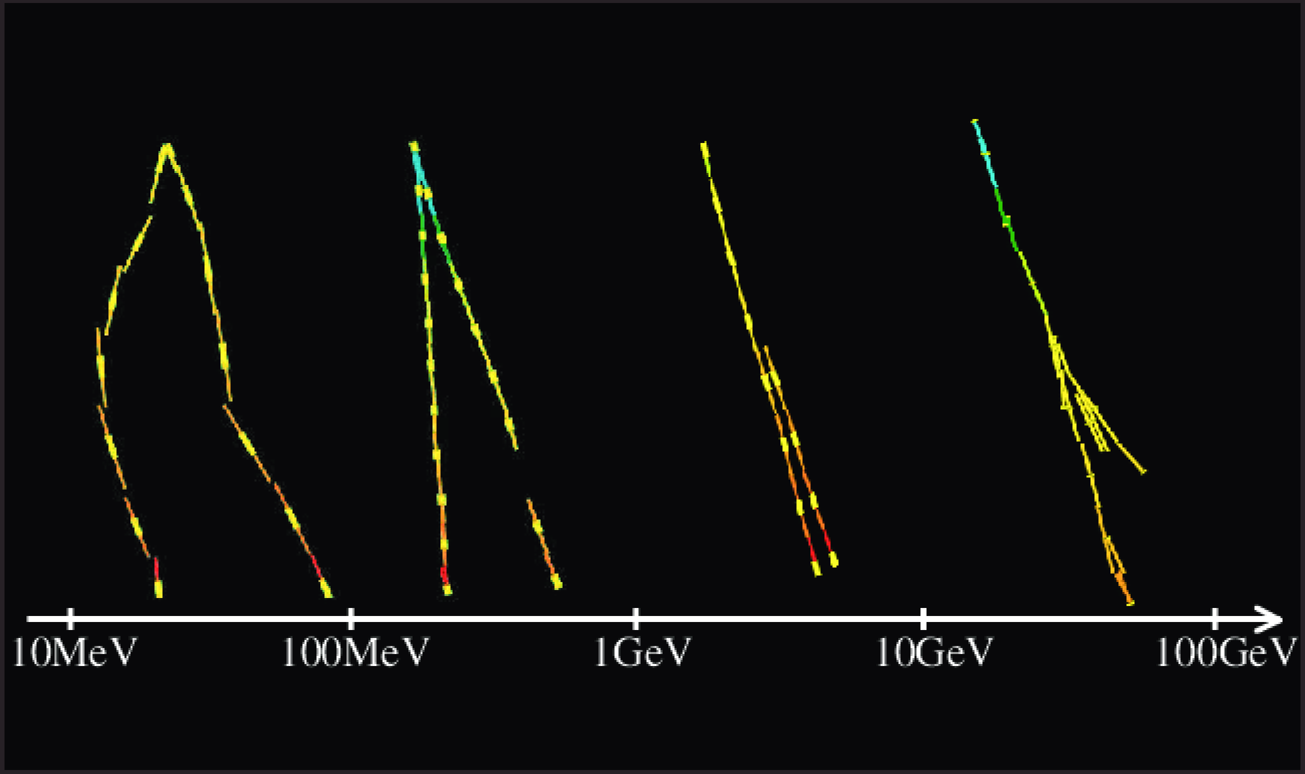
J. Ko, KSC 2019

BG rejection

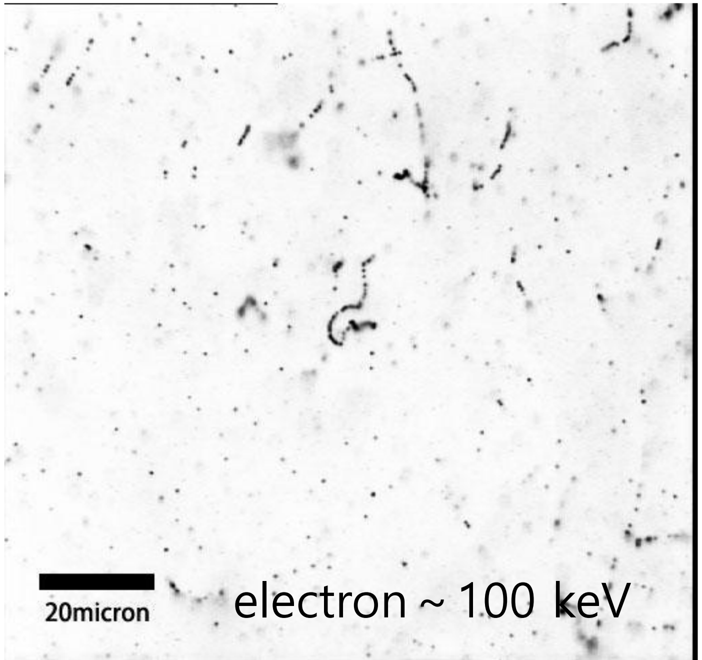
1) Energy–angle correlation
2) Presence of proton rejects
   Quasi-elastic scattering (QE)
3) Presence of hadron jets rejects
   Deep inelastic scattering (DIS)

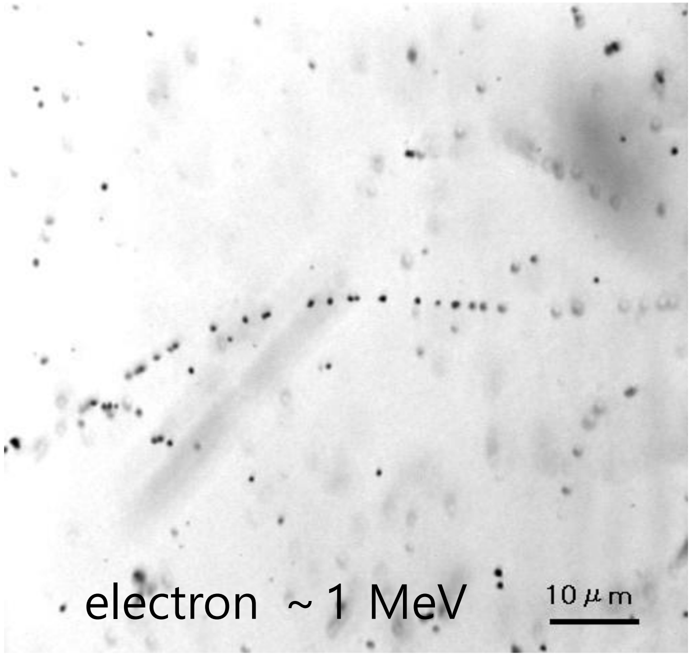


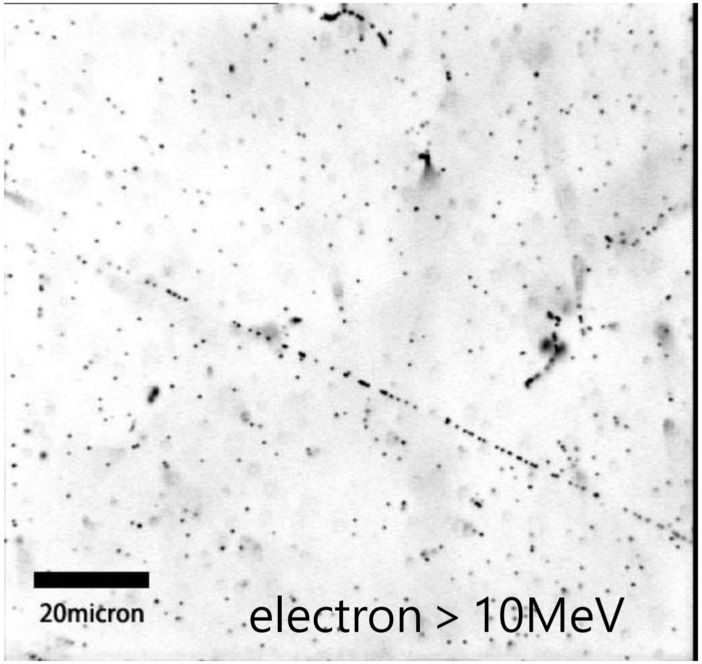
Electron energy in Nuclear emulsion (ECC)

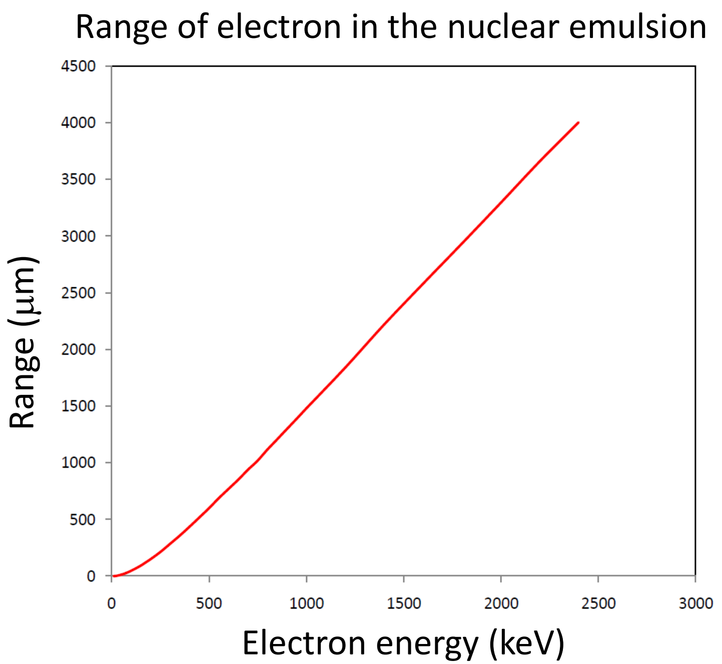


Electron tracks in Nuclear emulsion

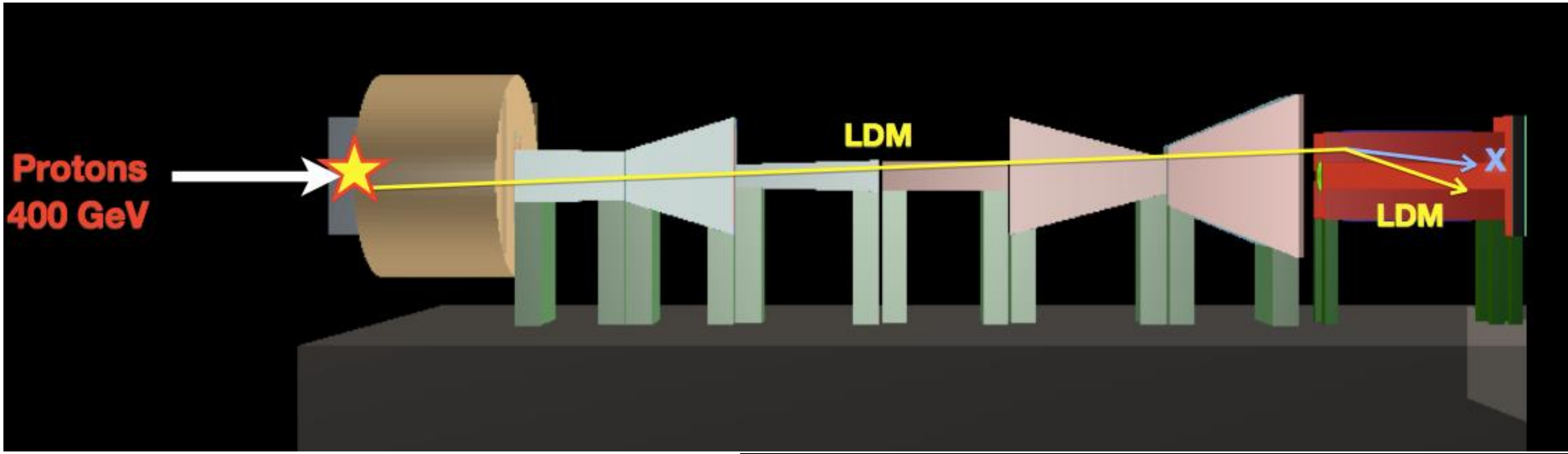








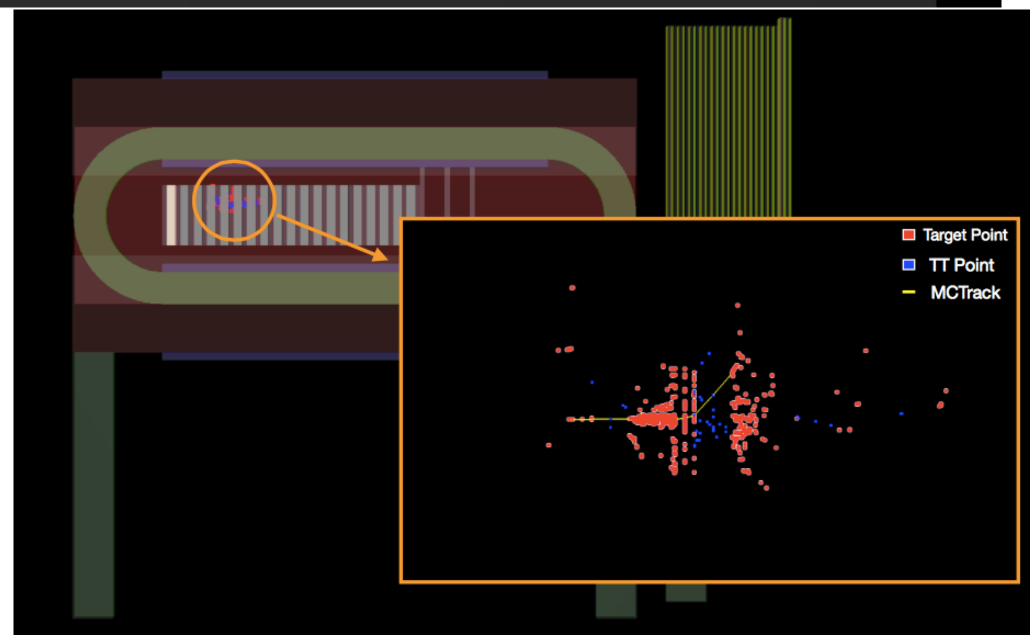
LDM detection in Neutrino detector



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

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

Electron recoil
Cascade shower in Emulsion



Top: LDM simulation process in FairShip.
Bottom : Event display of a LDM scattering process simulated inside the Scattering Spectrometer.

LDM detection in Neutrino detector

Nuclear recoil

using **NIT** (Nano Imaging Tracker)

→ **NEWSdm**

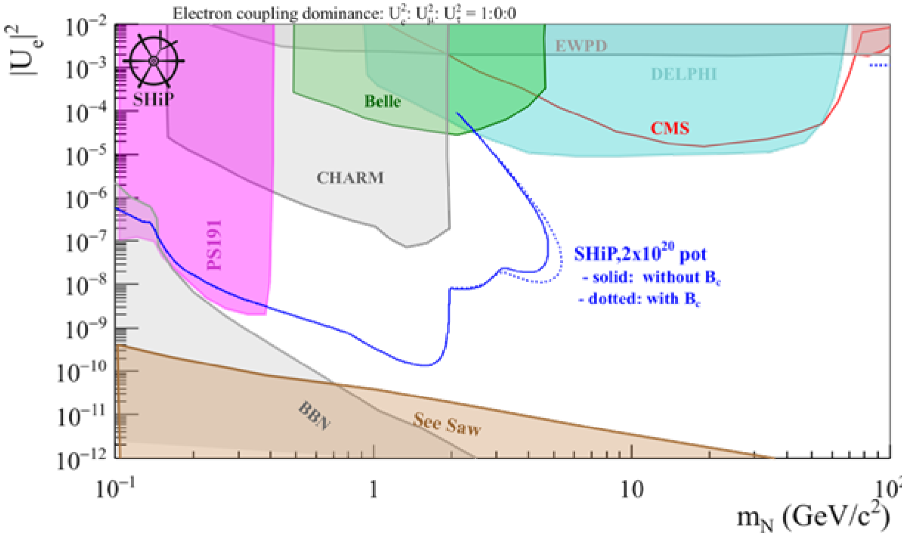
(Nuclear Emulsion WIMP Search - directional measurement)

$$A' \rightarrow \chi \, \bar{\chi}$$

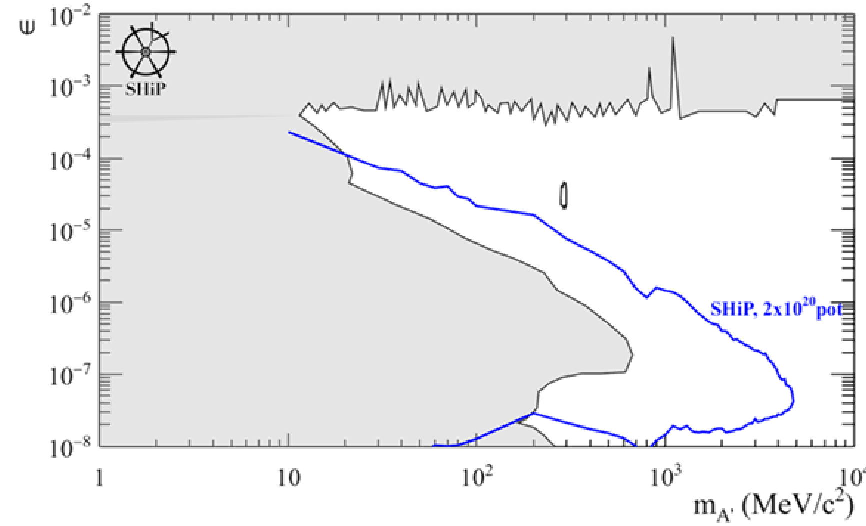
$$\chi \, N \rightarrow \chi \, N$$

Sensitivities of the SHiP to HS particles

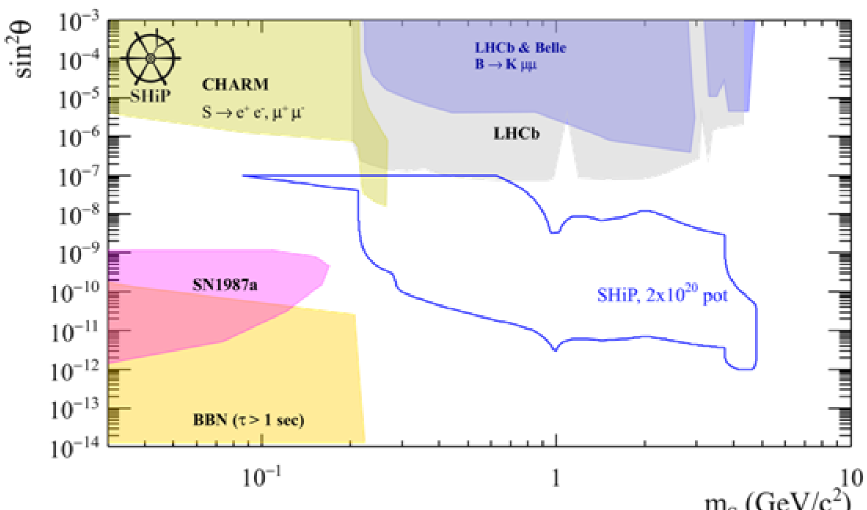
HNL



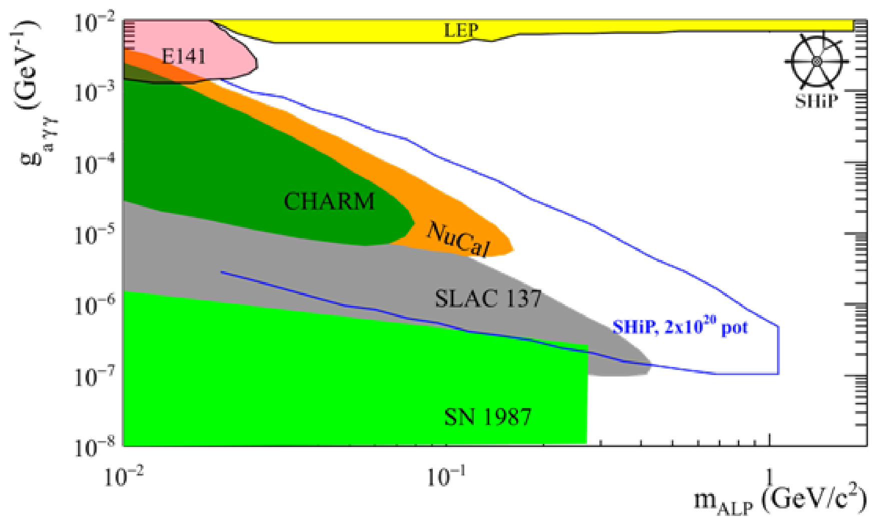
Dark photon



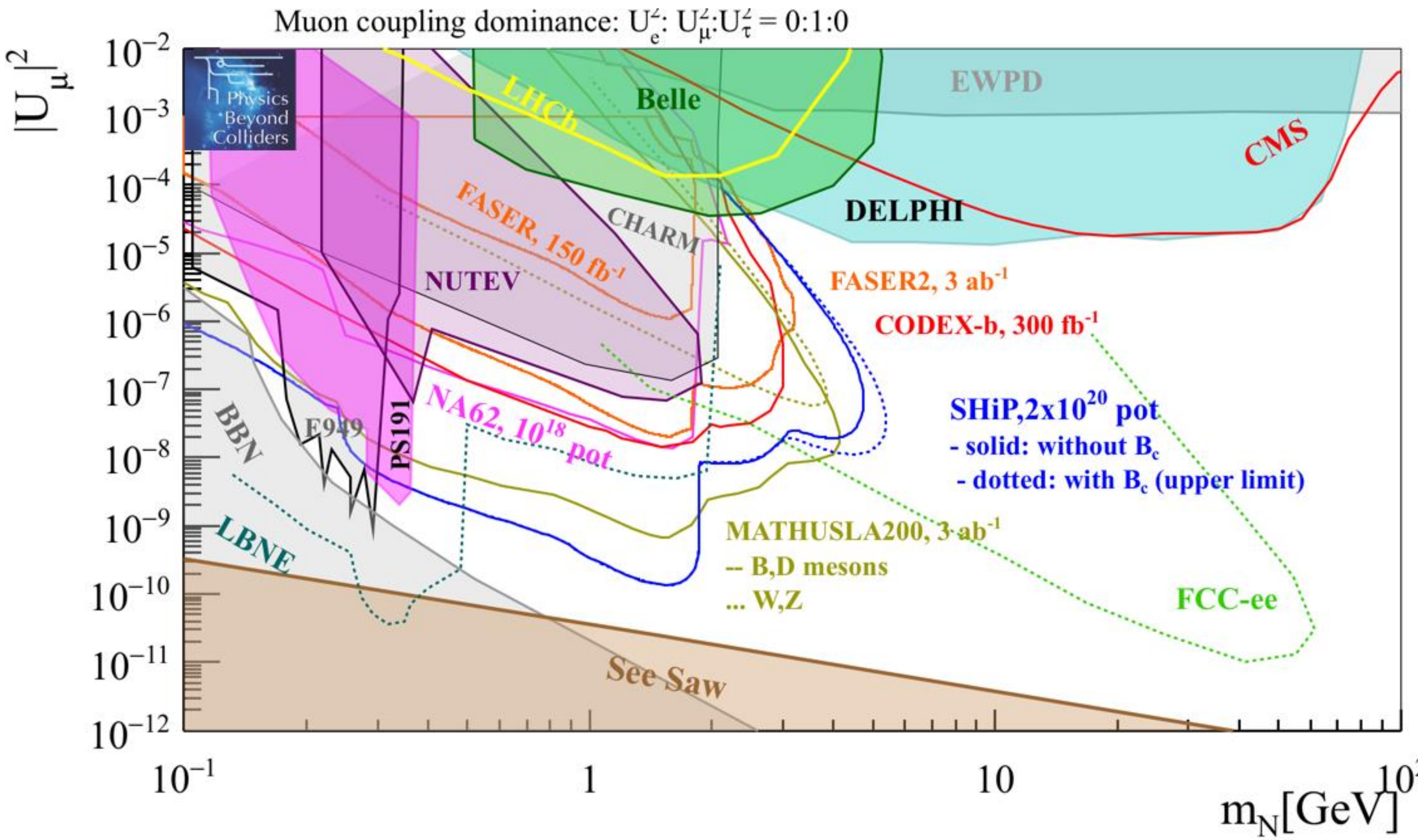
Dark scalar



ALP



Heavy Neutral Lepton



MATHUSLA is not designed as a discovery experiment.
They could indeed provide sensitive constraints in case of seeing zero events.
However, in case of non-zero “signal” they cannot measure the mass of the signal particle since they have no magnetic spectrometer.

CERNCOURIER
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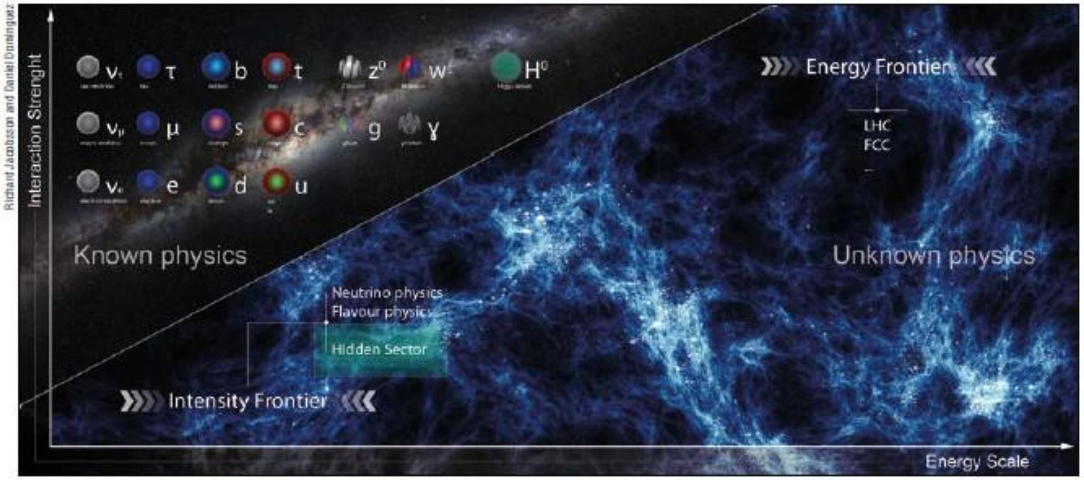


Richard Jacobsson and Daniel Dominguez

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

SPSC supported and recommended to make CDR.

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 di...

Why is the SHiP physics programme so timely and attractive?

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

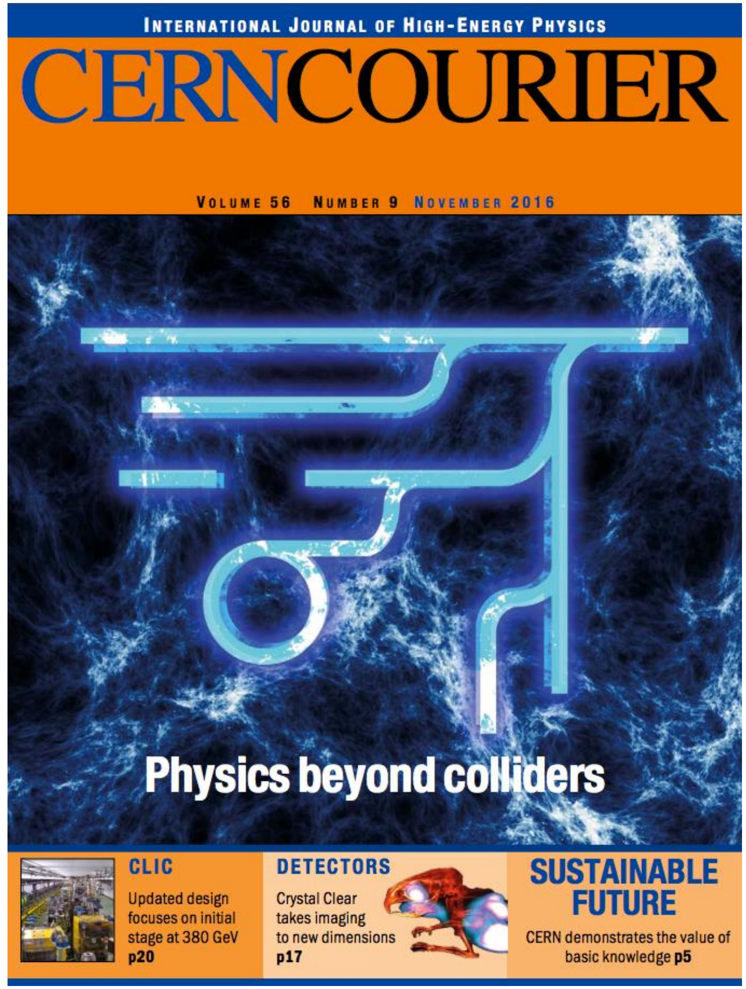
SHiP is an experiment aimed at exploring the domain of very weakly interacting particles and studying the properties of tau neutrinos. It is designed to be installed downstream of a new beam-dump facility at the Super Proton Synchrotron (SPS). The CERN SPS and PS experiments Committee (SPSC) has recently 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 observed phenomena in particle physics, astrophysics and cosmology, the so-called beyond the St...

... 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 $\sqrt{}=13$ 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 ▷

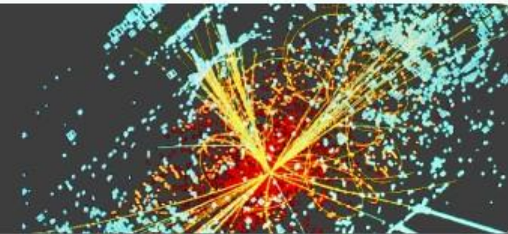


CERN launches Physics Beyond Colliders study group

CERN invites abstract applications for the workshop, which will investigate how CERN's accelerators can help solve questions of particle physics

24 MAY, 2016

CERN Council Open Symposium on the Update of
European Strategy for Particle Physics
13-16 May 2019 - Granada, Spain



Poster

The poster of the European Strategy for Particle Physics 2019 conference can be downloaded from here.

CERN Council Open Symposium on the Update of

European Strategy for Particle Physics

13-16 May 2019 - Granada, Spain

European Strategy Update

Member countries of the SHiP

~290 scientific authors

18 member countries: Bulgaria, Chile, Denmark, France, Germany, Italy, Japan, Korea, Netherlands, Portugal, Russia, Serbia, Sweden, Switzerland, Turkey, United Kingdom, Ukraine, United States of America + CERN, DUBNA

54 member institutes: Sofia, Valparaiso, Niels Bohr Institute Copenhagen, LAL Orsay, LPNHE Paris, Berlin, Bonn, Jülich, Humboldt University Hamburg, Mainz, Bari, Bologna, Cagliari, Ferrara, Lab. Naz. Gran Sasso, Frascati, Naples, Rome, Aichi, Kobe, Nagoya, Nihon, Toho, Gyeongsang, Kodel, Leiden, LIP Coimbra, Dubna, ITEP Moscow, INR Moscow, P.N. Lebedev Physical Institute Moscow, Kurchatov Institute Moscow, National University of Science and Technology "MISIS“ Moscow, IHEP Protvino, Petersburg Nuclear Physics Institute St. Petersburg, Moscow Engineering Physics Institute, Skobeltsyn Institute of Nuclear Physics Moscow, Yandex School of Data Analysis, Belgrado, Stockholm, Uppsala, CERN, Geneva, EPFL Lausanne, Zurich, Middle East Technical University Ankara, Ankara University, Imperial College London, University College London, Rutherford Appleton Laboratory, Bristol, Warwick, Taras Shevchenko National University Kyiv, Florida

4 associated institutes: Sungkyunkwan, Gwangju, Jeju, St. Petersburg Polytechnic University

54 institutes from 18 countries
295 members

Andrey Golutvin (CERN, Imperial College)

SHiP Collaboration meeting

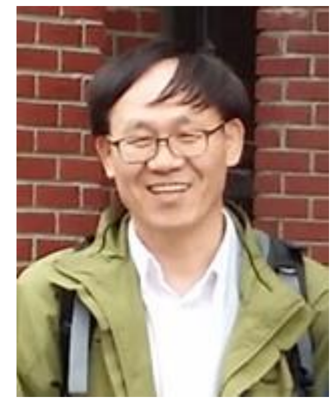
Korean SHiP group 5 institutes, 11 members









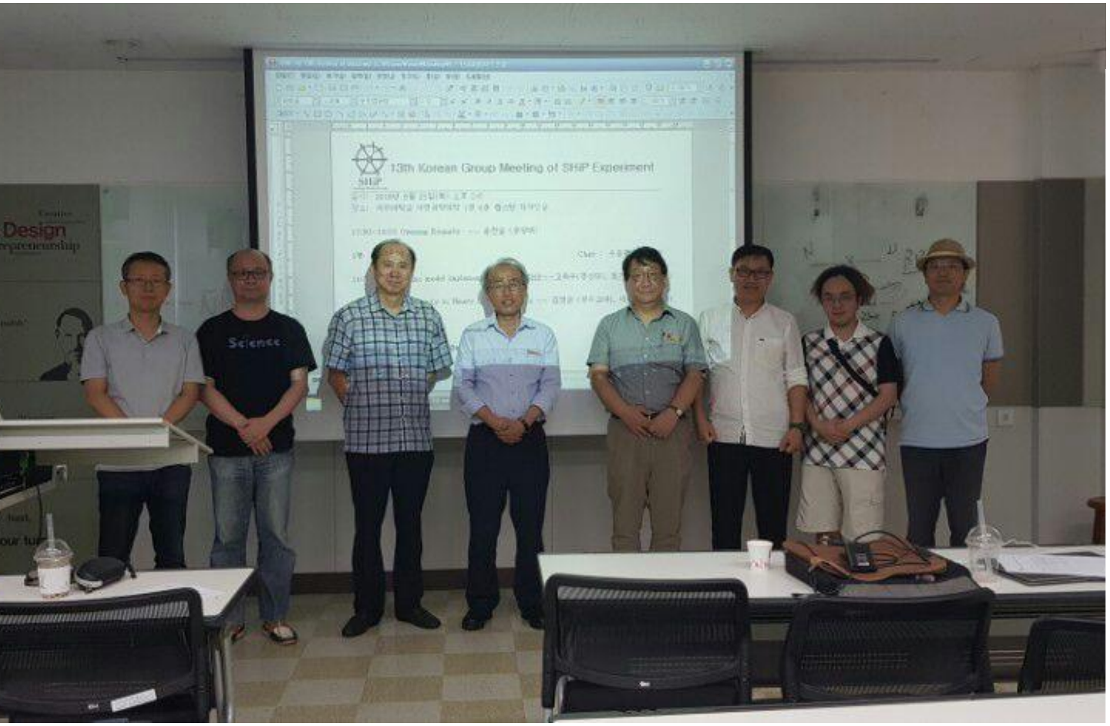
Gyeongsang National University (GNU)
S. H. Kim, J.-W. Ko, K. Y. Lee, B. D. Park, J. Y. Sohn, C. S. Yoon (CR)

Korea University (KU) - KODEL
S. Park, K. S. Lee

Gwangju National University of Education (GNUE)
Y. G. Kim

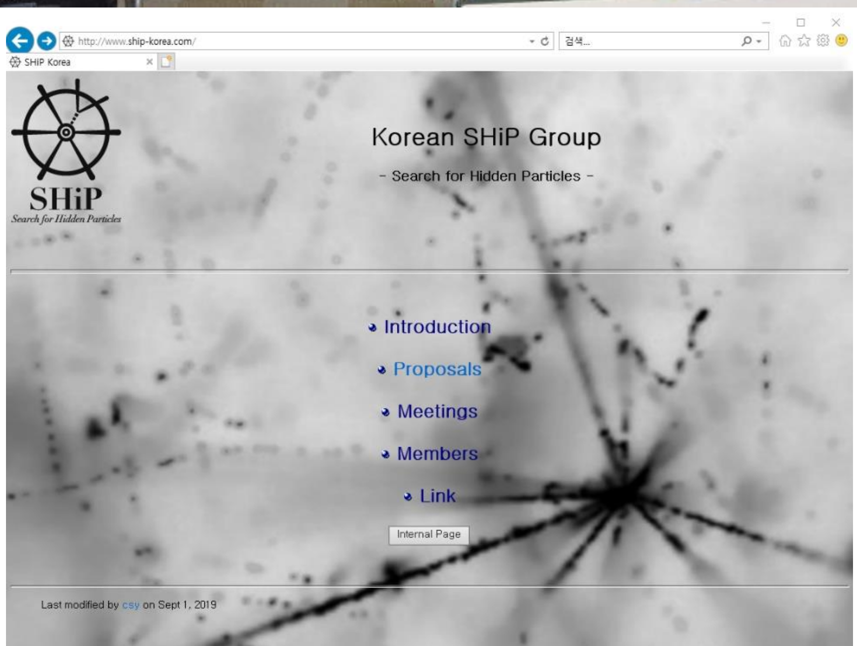
Jeju National University (JNU)
J.-K. Woo

Sungkyunkwan University (SKKU)
K.-Y. Choi



KSHiP meeting

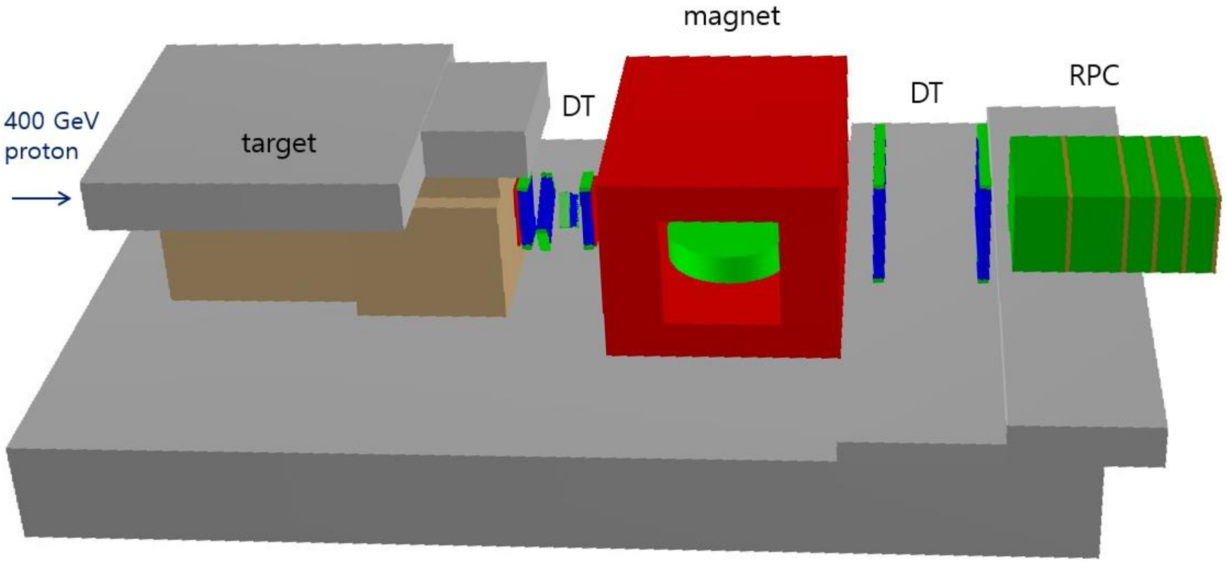
- 1st Workshop, GNU, 4 Apr 2015
- 2nd Workshop, CAU, 23 May 2015
- 3rd Group meeting, JNU, 19 July 2015
- 4th Group meeting, KASI, 23 Jan 2016
- 5th Group meeting, GNUE, 29 Feb 2016
- 6th Group meeting, GNU, 20 May 2016
- 7th Group meeting, Skype, 19 Sep 2016
- 8th Group meeting, GNU, 13 Feb 2017
- 9th Group meeting, KU, 1 Jun 2017
- 10th Group meeting, JNU, 3 Aug 2017
- 11th Group meeting, SKKU, 8 Dec 2017
- 12th Group meeting, GNU, 27 Feb 2018
- 13th Group meeting, JNU, 21 Aug 2018
- Workshop on Hidden Particles, Tongyeong, 14-15 Dec 2018
- 14th Group meeting, GNUE, 21-22 Jun 2019



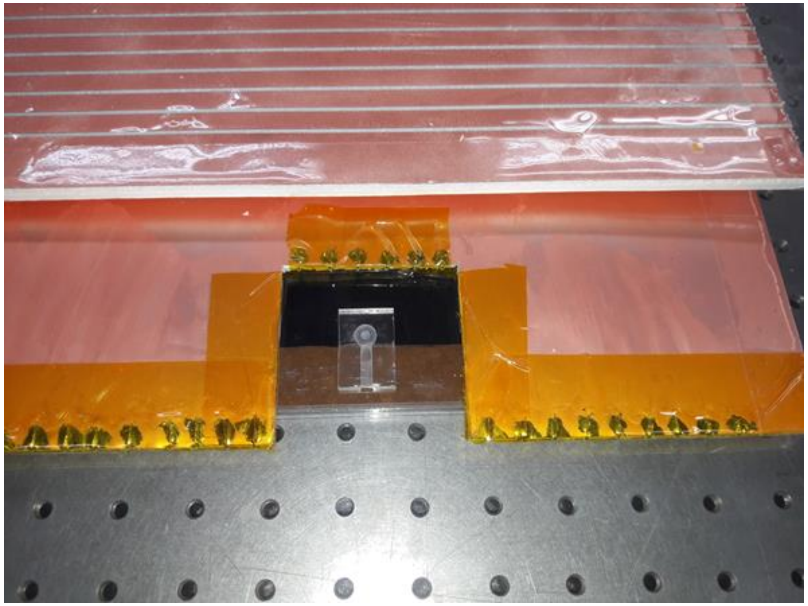
http://www.ship-korea.com/

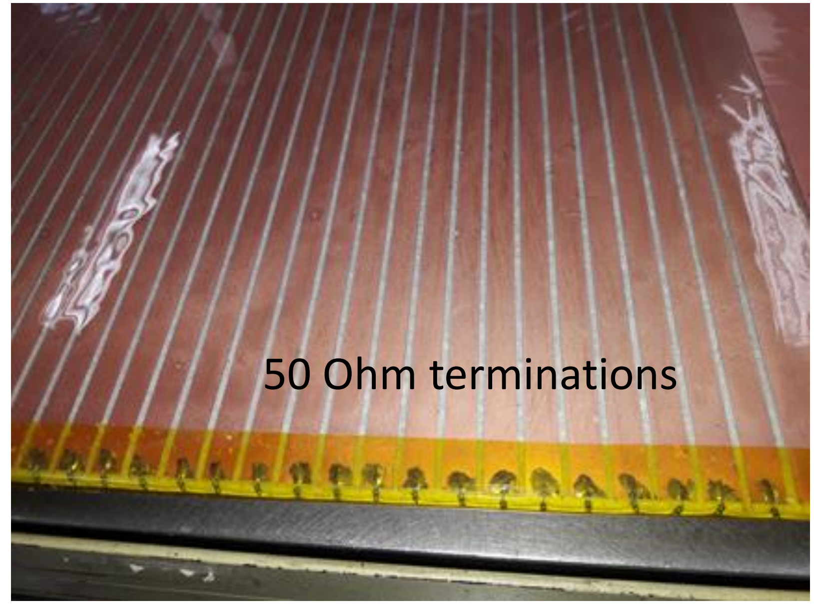
Beam test at SPS H4 beam line (July 2018)

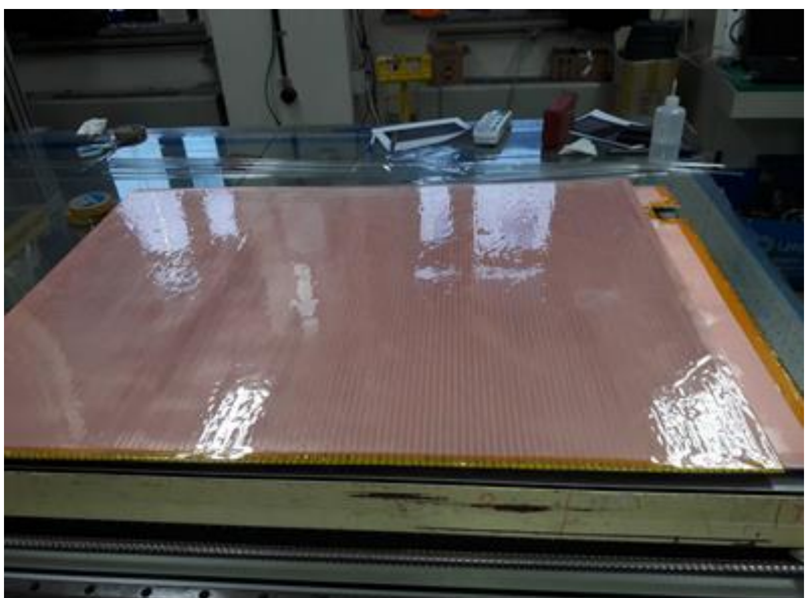
for measurements of muon flux & charm cross section



RPCs were fabricated at KODEL – strips & gaps



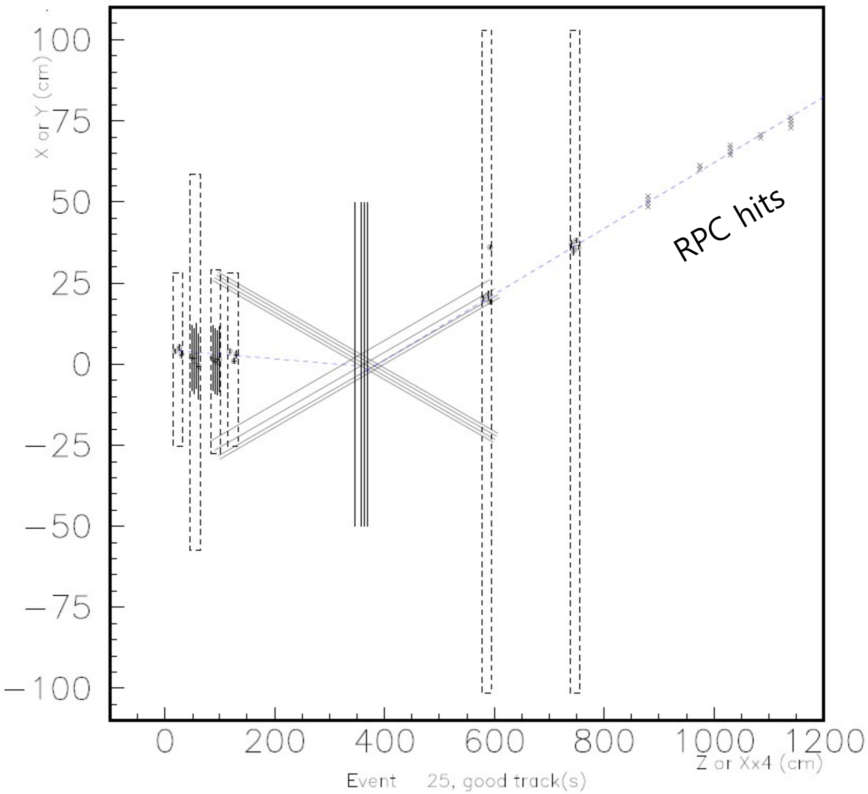




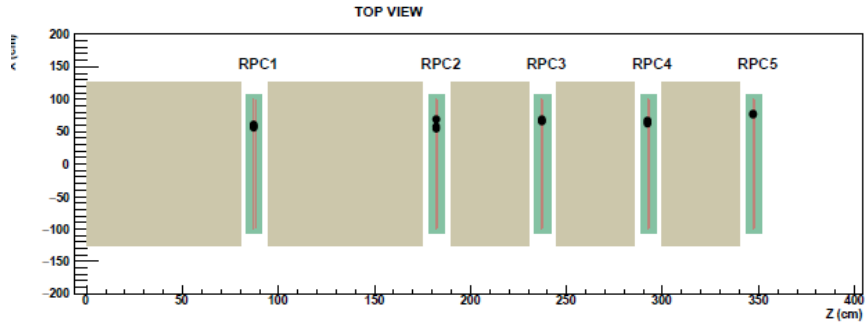
Installation in 6 July 2018
at SPS H4 beam line

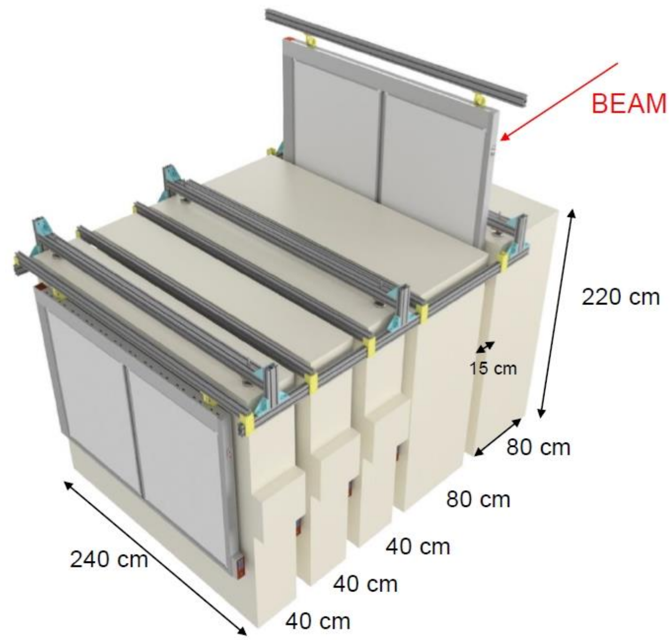
Beam test using prototype RPC, DT, Pixel detector and ECC.
All sub-detector's phase 1 prototypes were tested with nice results.

RPC as Muon Tagger



5 RPC planes





Beam test results : clear 5 hits

RPC plays a crucial role for muon flux and charm cross-section measurements

Infrastructure at CERN

Emulsion handling room

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

Emulsion development

Flash box used in CHORUS

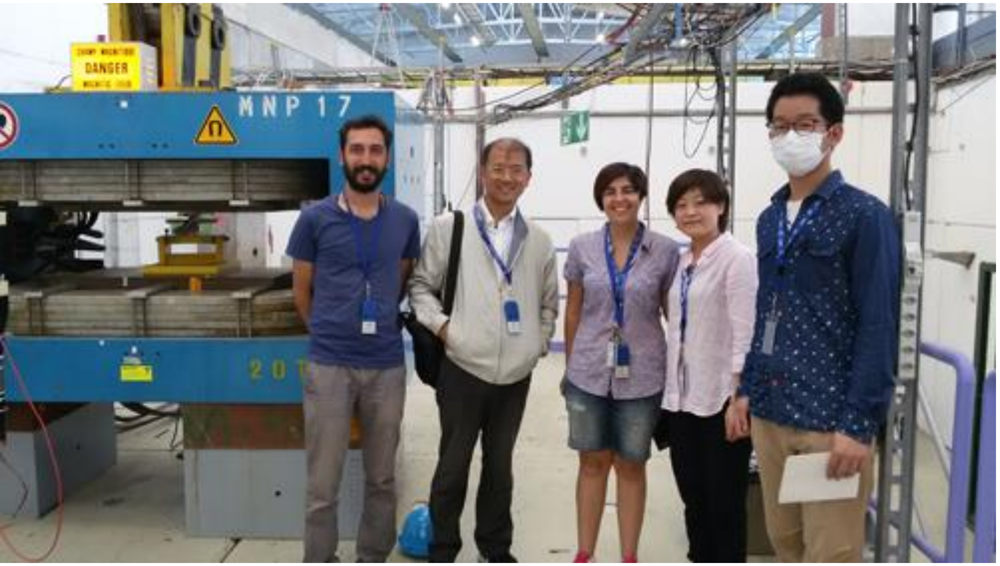
Brick Assembly machine

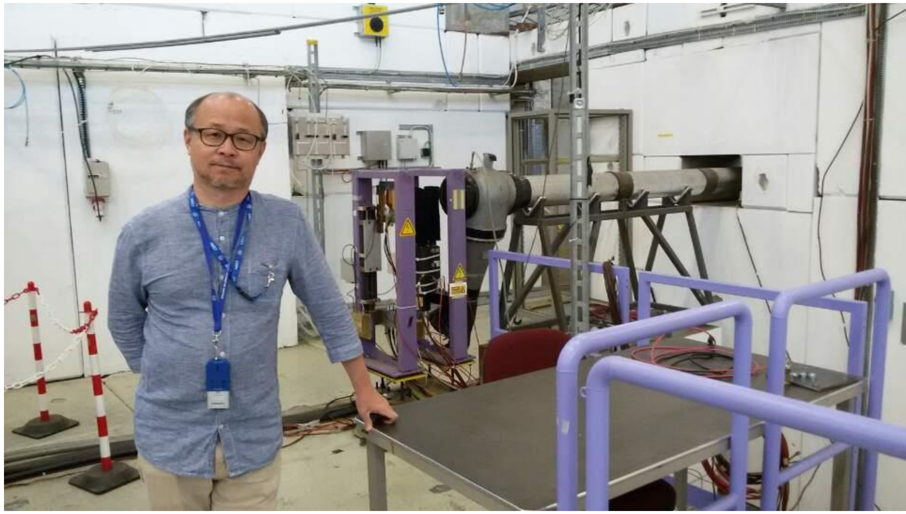
Dark room

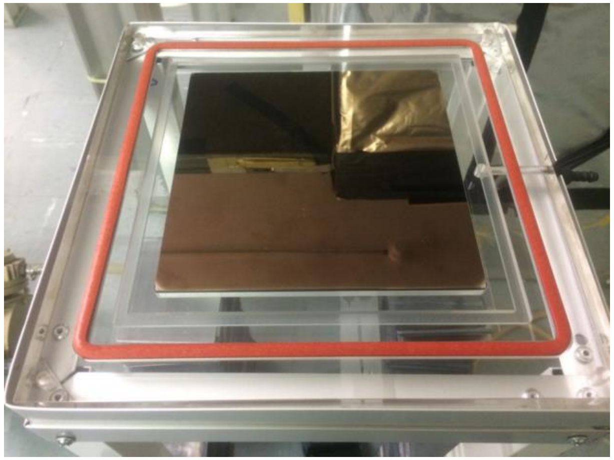
CES

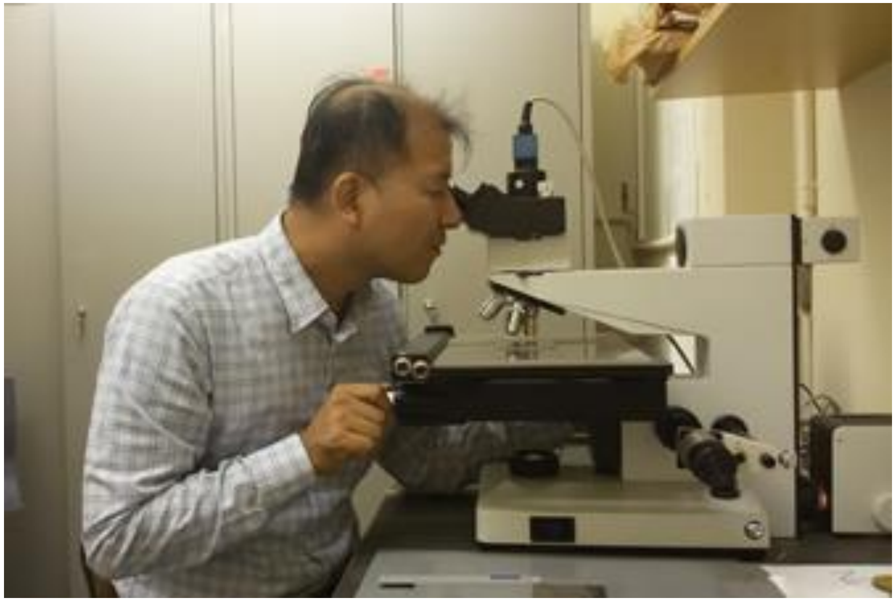
Beam test for CES at T9 beam line at CERN PS

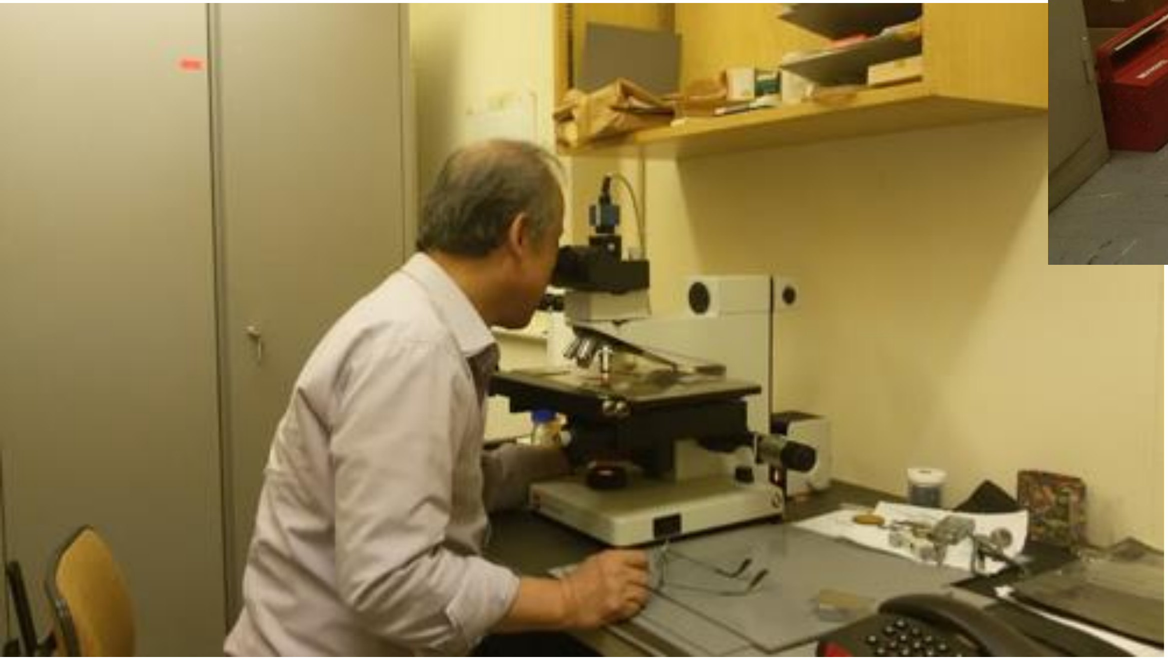
(2016. 8, 2017. 8)











Emulsion scanning
at CERN

3D view of Emulsion tracks

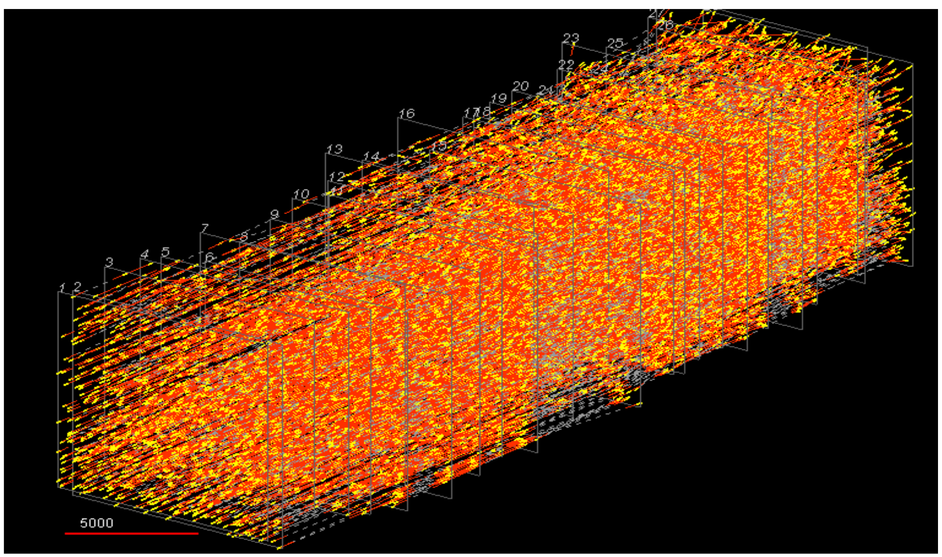
Beam test at SPS H4 beam line

Alignment and tracking

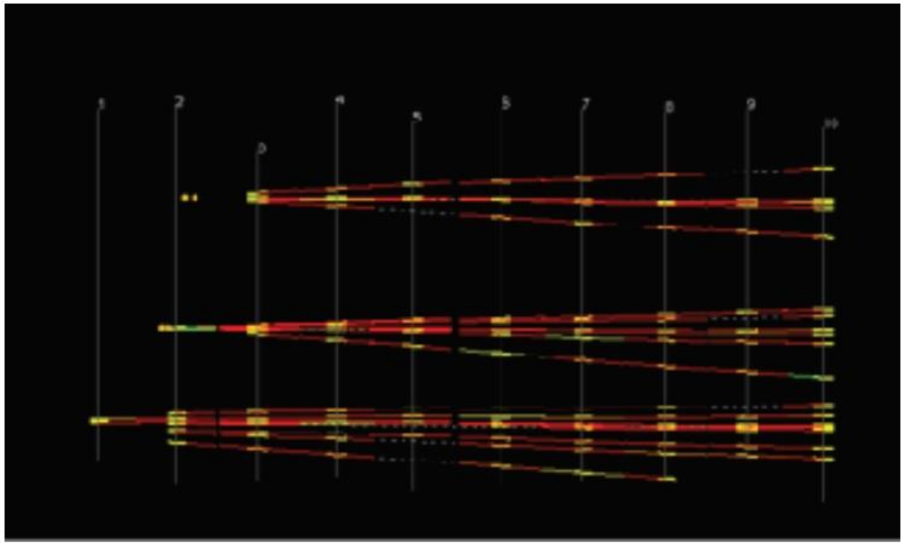
- Alignment
- Tracking using the first 10 films.
- Track segments present in most plates
- The beam clearly seen

Vertexing

Vertices reconstructed with at least 5 tracks with IP< 50 mm



400 GeV proton beam



Proton interactions

Our contribution plan

GNU

Emulsion scanning
Tau & Anti-tau neutrino physics
LDM search in Emulsion – ML

KU - KODEL

RPC – muon tagger

JNU

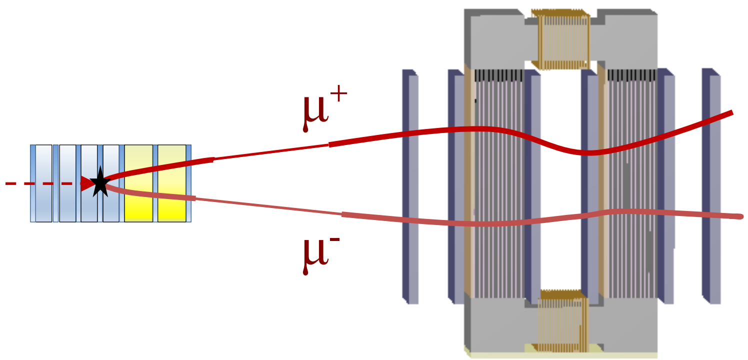
HS particle search in ECAL

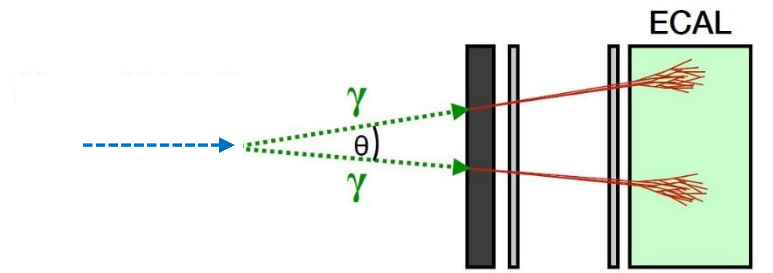
SKKU

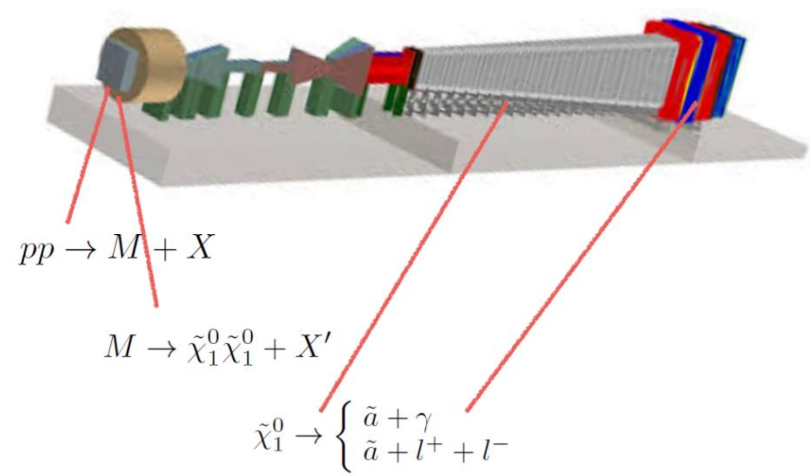
Axino search

GNUE

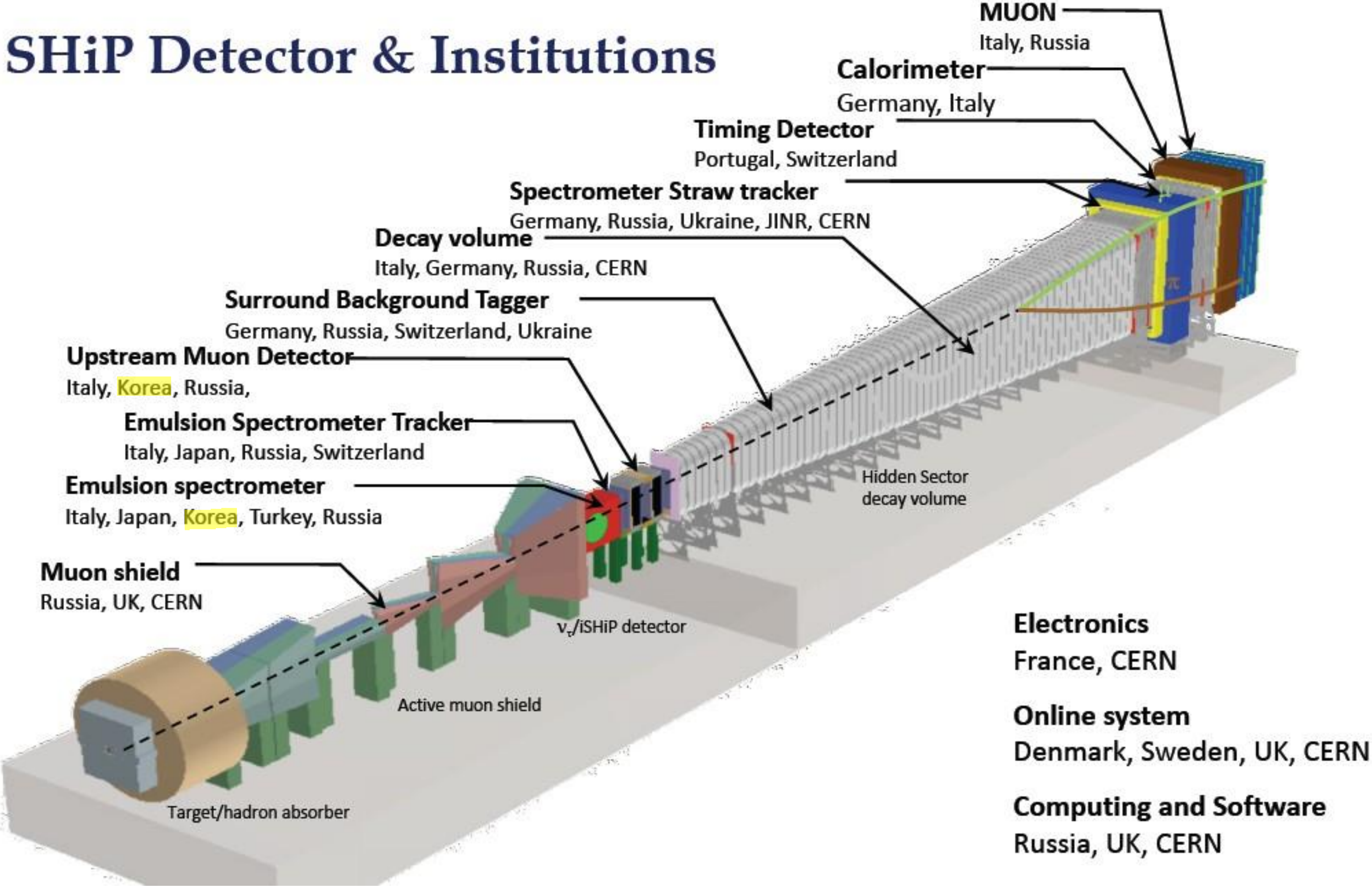
Dark Scalar search
(S→ ee, μμ, ππ, KK)



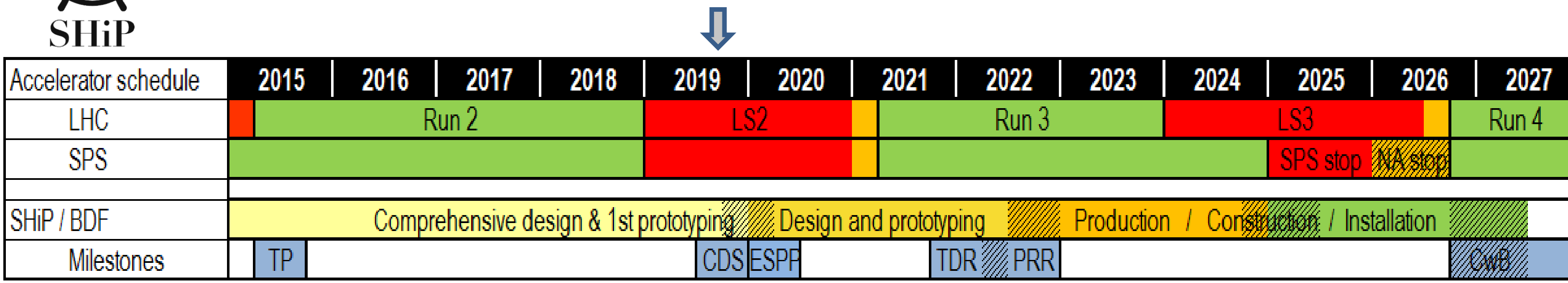




SHiP Detector & Institutions



Project schedule



- Document submitted to **ESPP** on Dec. 2018

  together with CERN Beam Dump Facility (BDF)
- **CDR** (Comprehensive Design Report) is in preparation

  for submission to **SPSC** by the end of 2019 ⇦
- Continue phase 2 module-level prototyping for **Test beams**

  – at DESY (2019-2010), at CERN (2021)
- **Detector engineering design** and preparation of **TDR** from 2021
- Construction, **Detector production** and Installation **~ 5 years**
- **Data taking** expected from 2027.

Our 10-year budget for SHiP
(Long-term plan)

Emulsion (gel & development chemical)

Scanning system upgrade

- High speed digital camera, Large optics etc.

Infrastructure of Scanning Lab ()

- Temperature & Humidity chamber etc.

Cost of RPC fabrication (Bakelite etc.)

Personnel expenses (~5 persons)

Traveling expenses etc.

~5억원/yr x 10 yrs = ~50억원 *

* Common fund is not included

NEWSdm

Nuclear Emulsion for WIMP Search
– directional measurement

try to measure the **"direction"** of
WIMP-induced nuclear recoils

using Newly developed Nuclear emulsion

with Super-fine grain

- NIT (Nano Imaging Tracker)

NEWSdm Collaboration

LOI submitted to LNGS Scientific Committee

https://arxiv.org/abs/1604.04199

NEWSdm Collaboration

70 physicists, 14 institutes

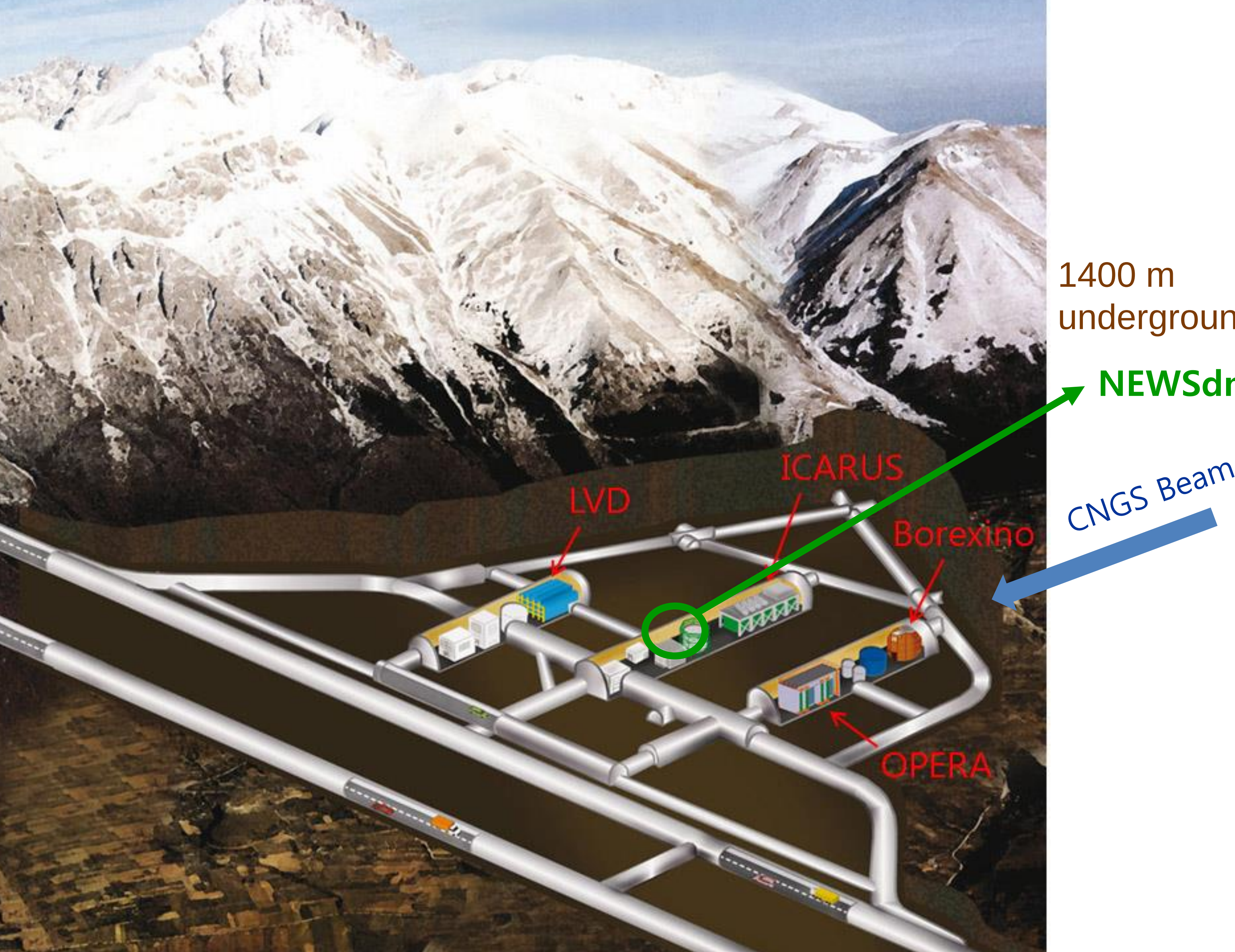
ITALY
INFN e Univ. Bari,
LNGS, INFN e Univ. Napoli,
INFN e Univ. Roma
GSSI Institute

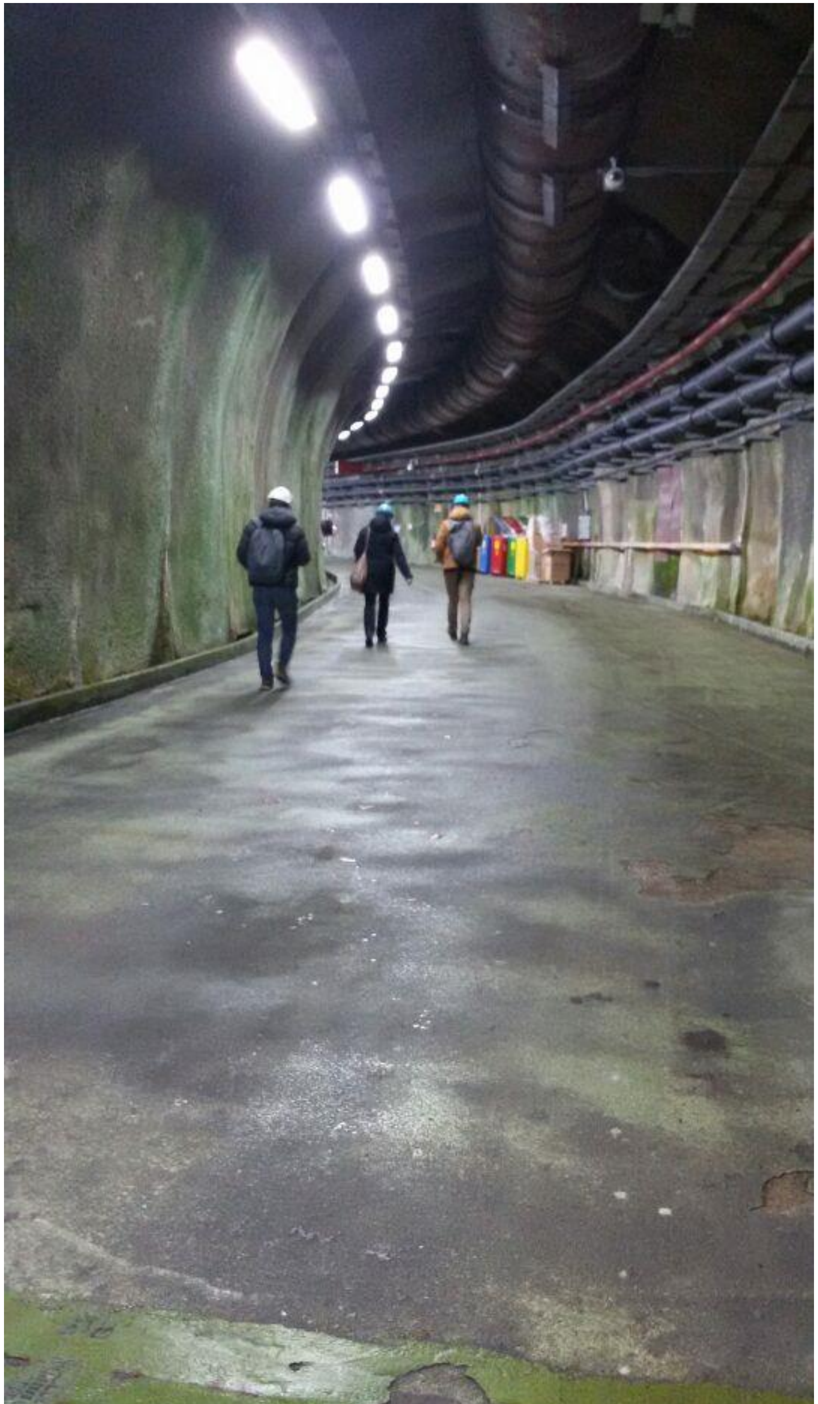
JAPAN
Chiba, Nagoya

RUSSIA
LPI RAS Moscow, JINR Dubna
SINP MSU Moscow, INR Moscow
Yandex School of Data Analysis

KOREA
Gyeongsang

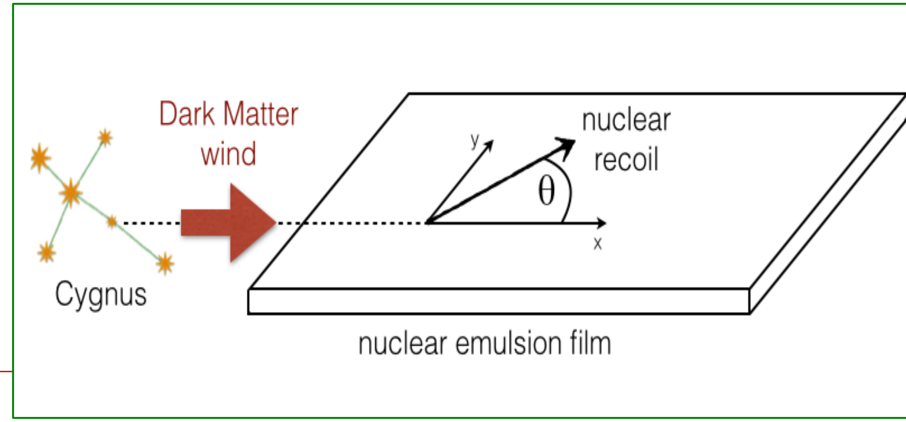
TURKEY
METU Ankara

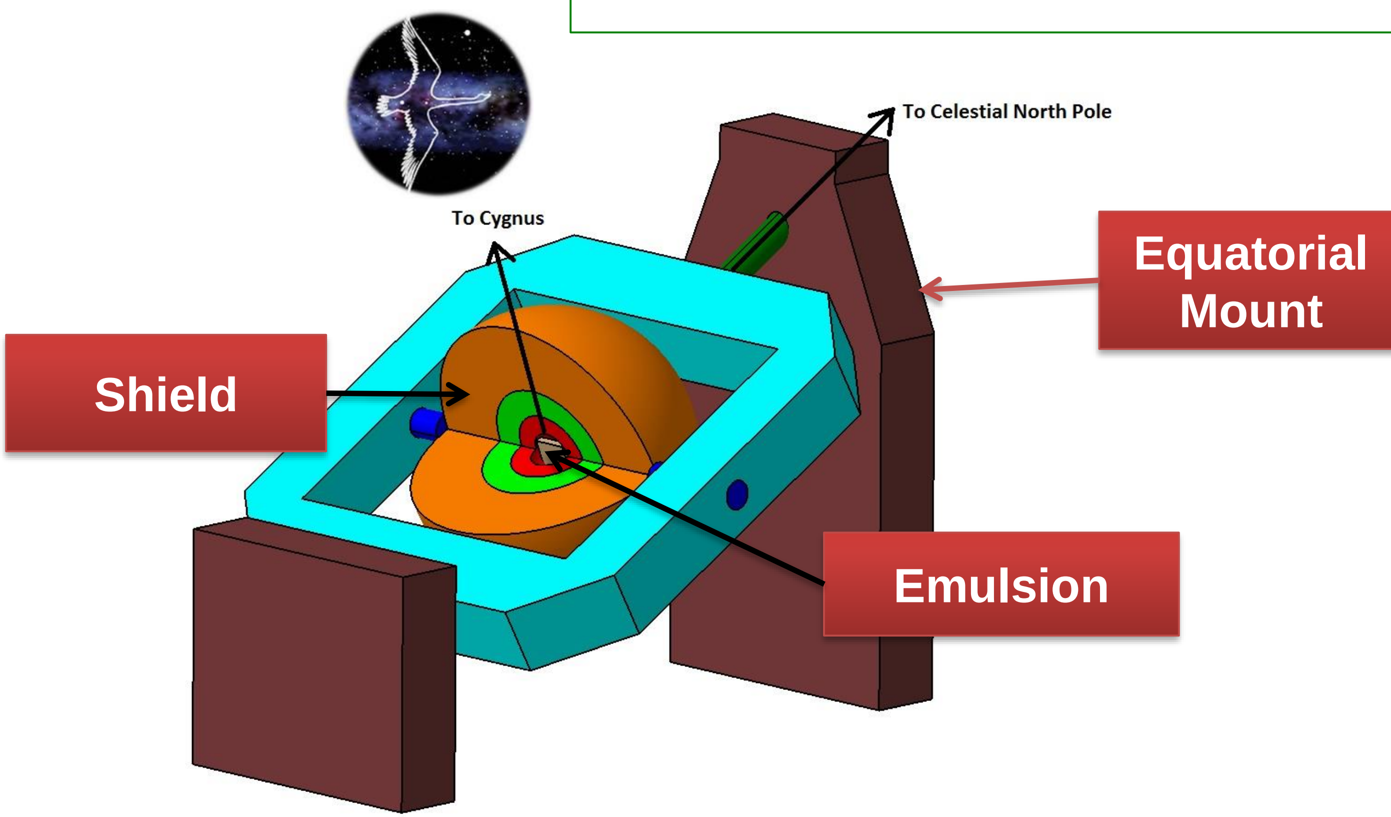

1400 m underground
NEWSdm
ICARUS
LVD
Borexino
CNGS Beam
OPERA



Directionality as a strong signature of the galactic WIMP

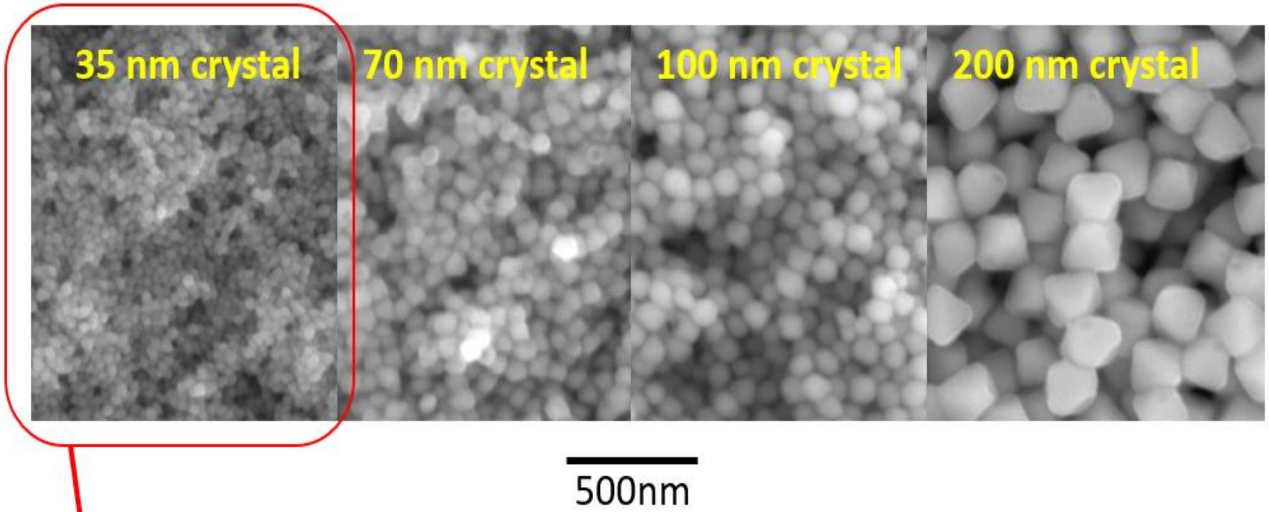
➔ **keep target pointed to DM wind (Cygnus)** by using the Equatorial telescope





The mount has to handle around 100 ton.

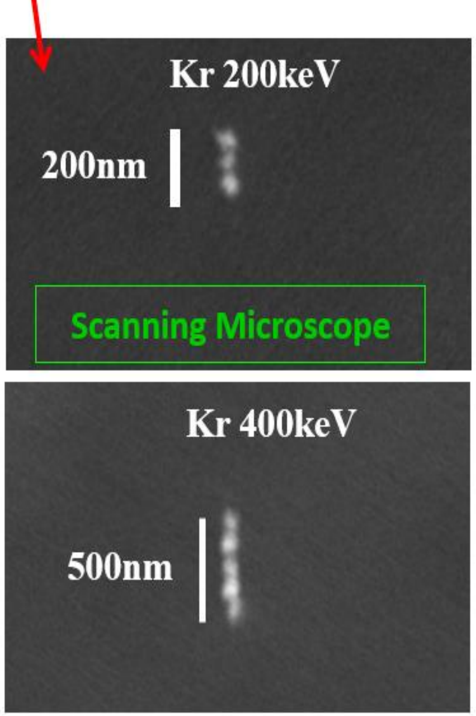
NIT (Nano Imaging Tracker)

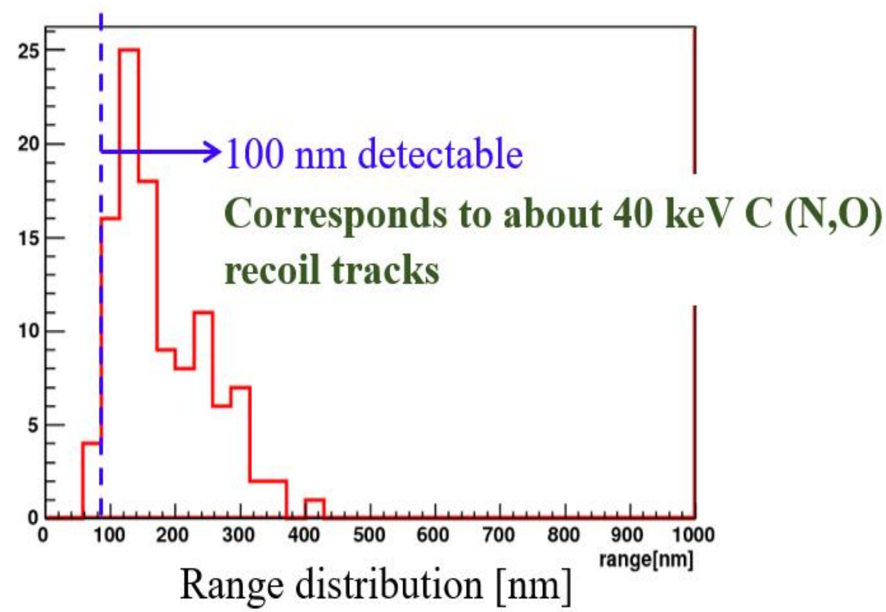


Newly developed emulsion with super-fine grain

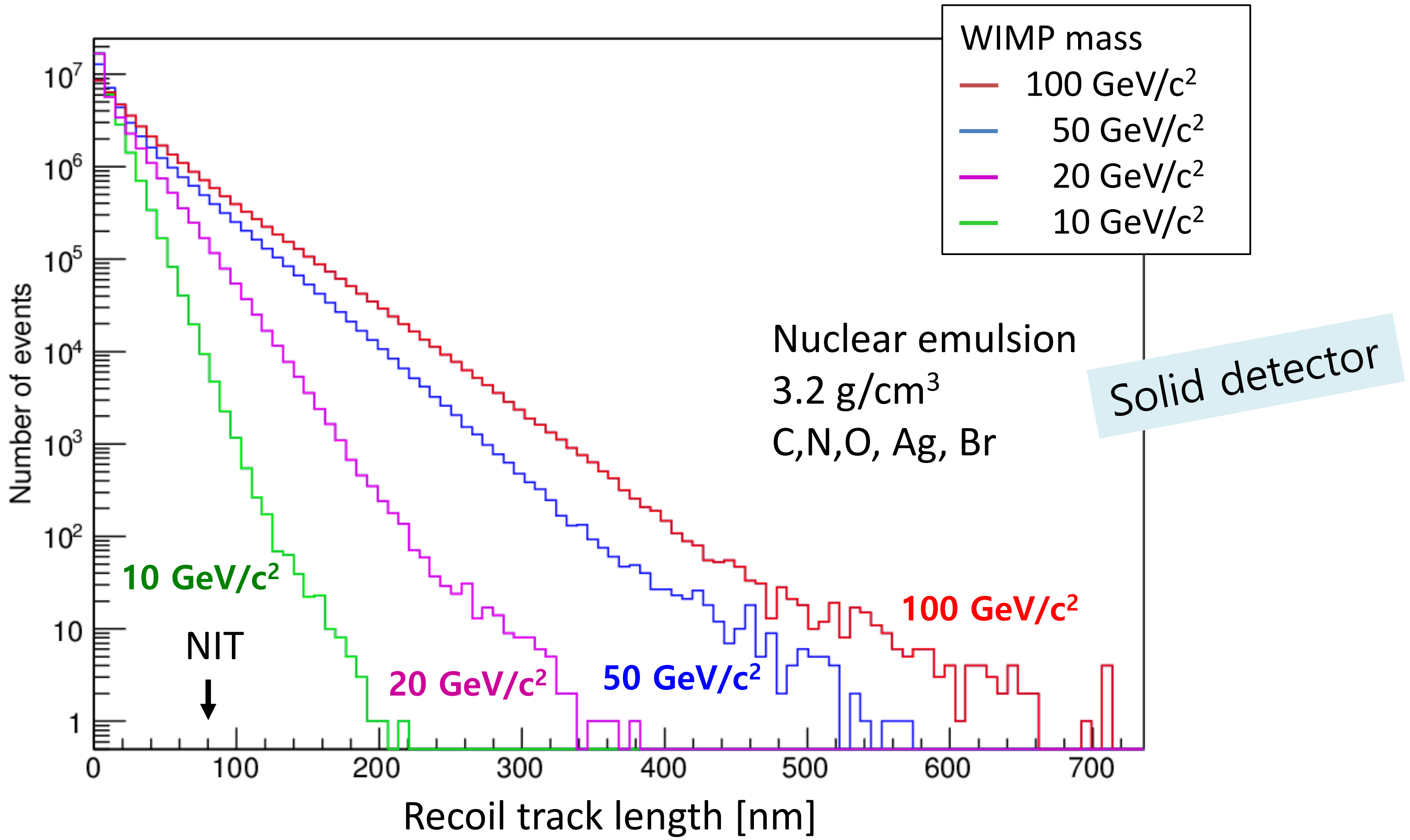
⇩

Intrinsic spatial resolution ~ 10 nm





Expected recoil lengths in the Nuclear emulsion for different WIMP masses



The ranges of the signal tracks can be ~several 100 nm in the Nuclear emulsion.

NIT emulsion

Constituent	Mass Fraction
AgBr-I	0.78
Gelatin	0.17
PVA	0.05

(a) Constituents of nuclear emulsion

- AgBr-I : sensitive elements
- Organic gelatin: retaining structure
- PVA: to stabilize the crystal growth

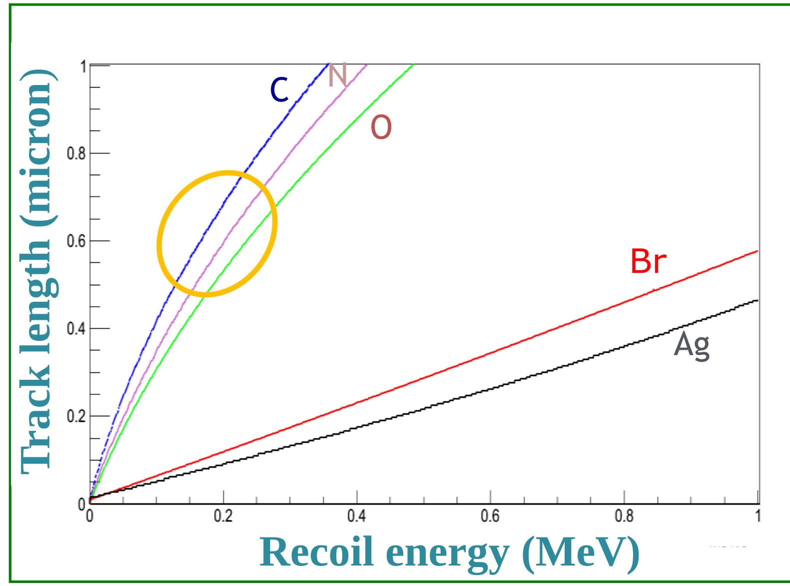
Heavy nuclei: Ag, Br, I

Light nuclei: C, O, N, H, S

Element	Mass Fraction	Atomic Fraction
Ag	0.44	0.12
Br	0.32	0.12
I	0.019	0.003
C	0.101	0.172
O	0.074	0.129
N	0.027	0.057
H	0.016	0.396
S	0.003	0.003

(b) Elemental composition

density 3.3±0.1 g/cm^3



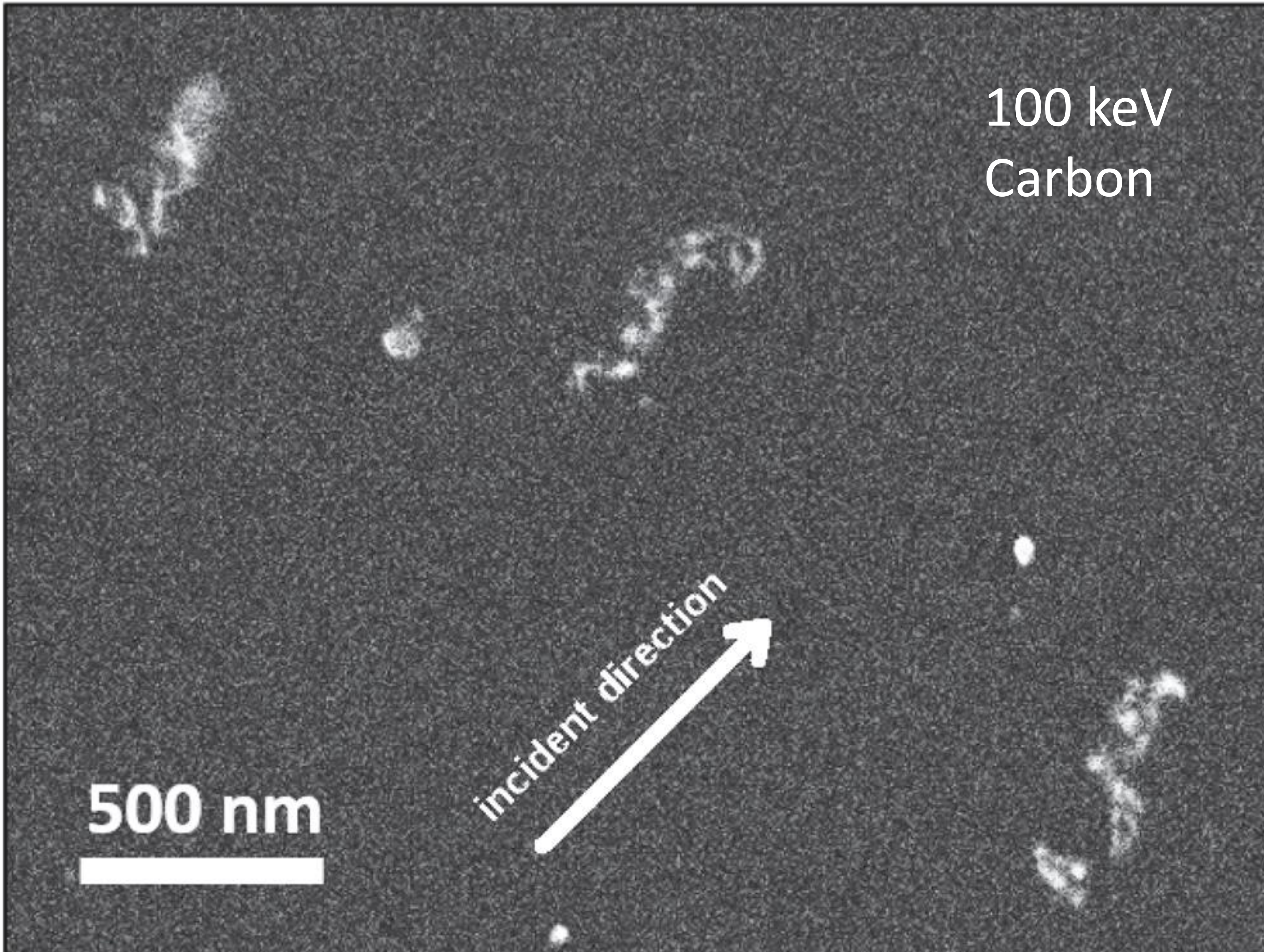
Target elements

Each nucleus gives different contribution to the overall sensitivity

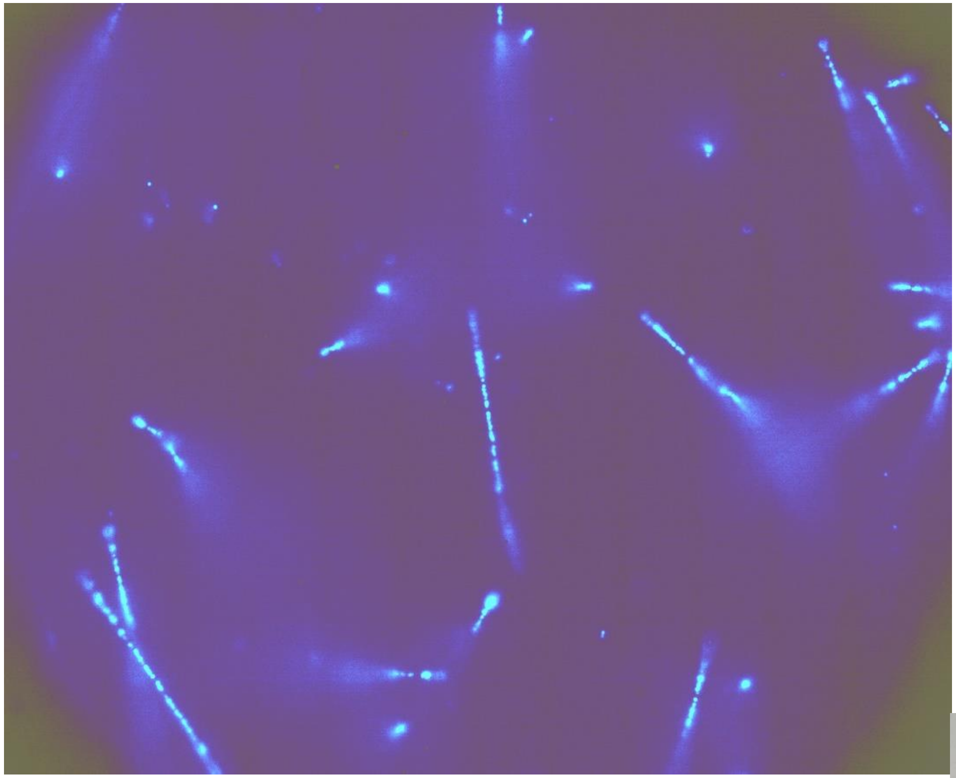
Light nuclei

⇒ Longer range at same recoil energy

⇒ Sensitive to low WIMP mass


100 keV
Carbon
incident direction
500 nm

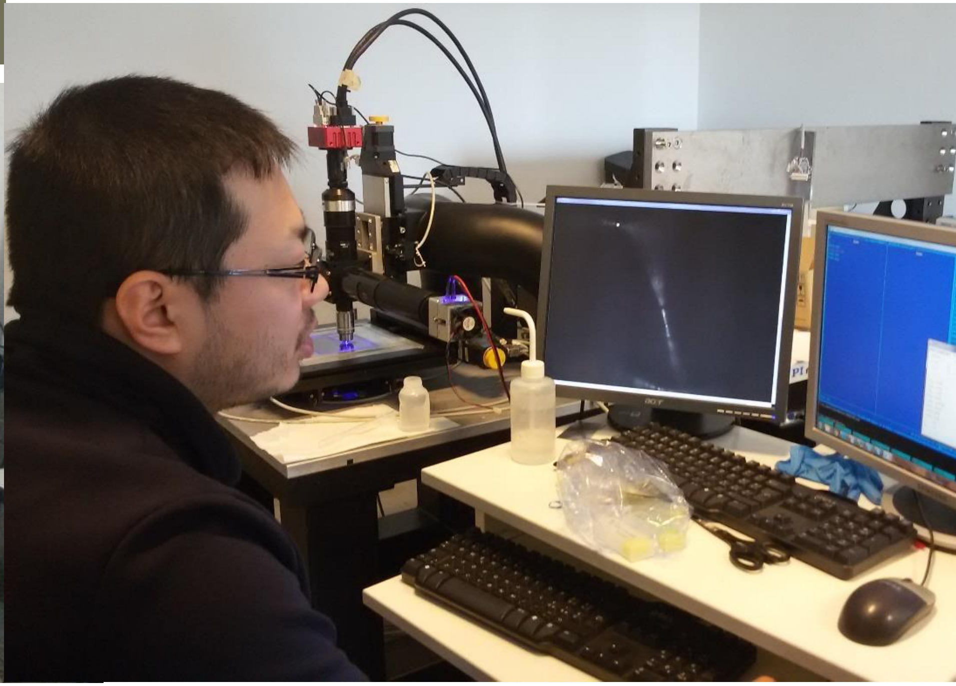
NIT production
2019. 2 Gran Sasso



Scanning at Gran Sasso

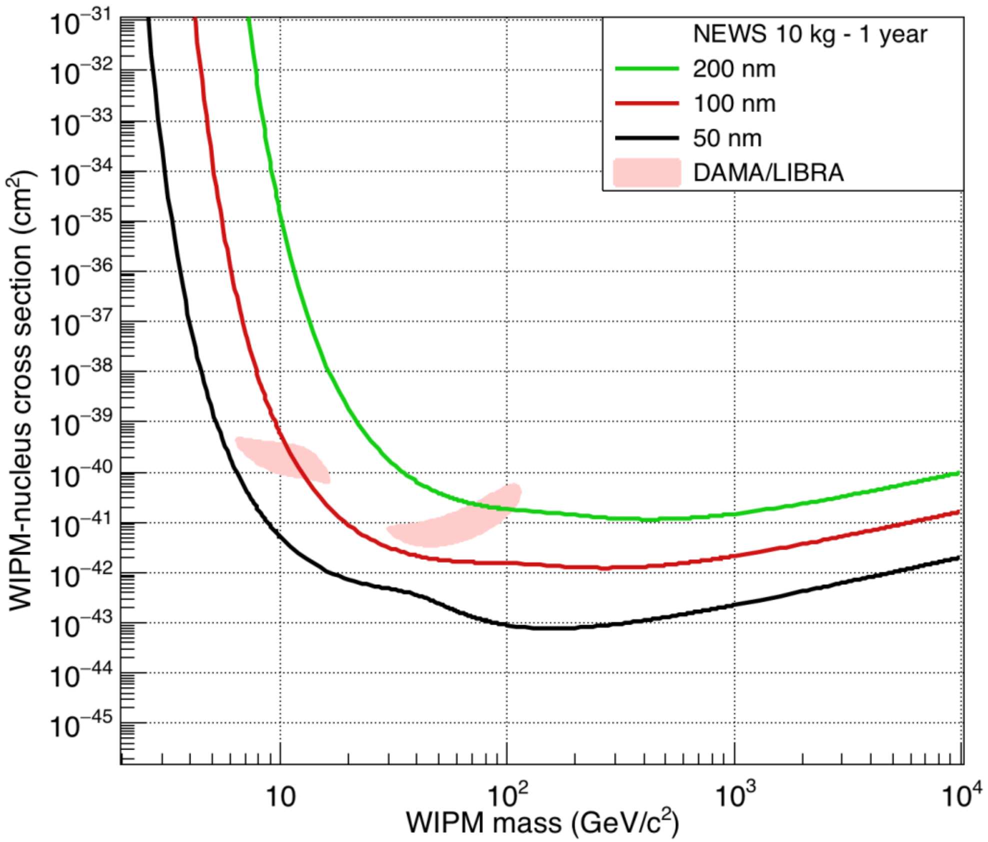
- NIT quality check

  (α particles)



10 kg Pilot Experiment

- Target mass = 10 kg
- Exposure time = 1 year
- Minimum detectable track length from 200 nm to 50 nm
- Zero background hypothesis
- Directionality discrimination of the signal not included.

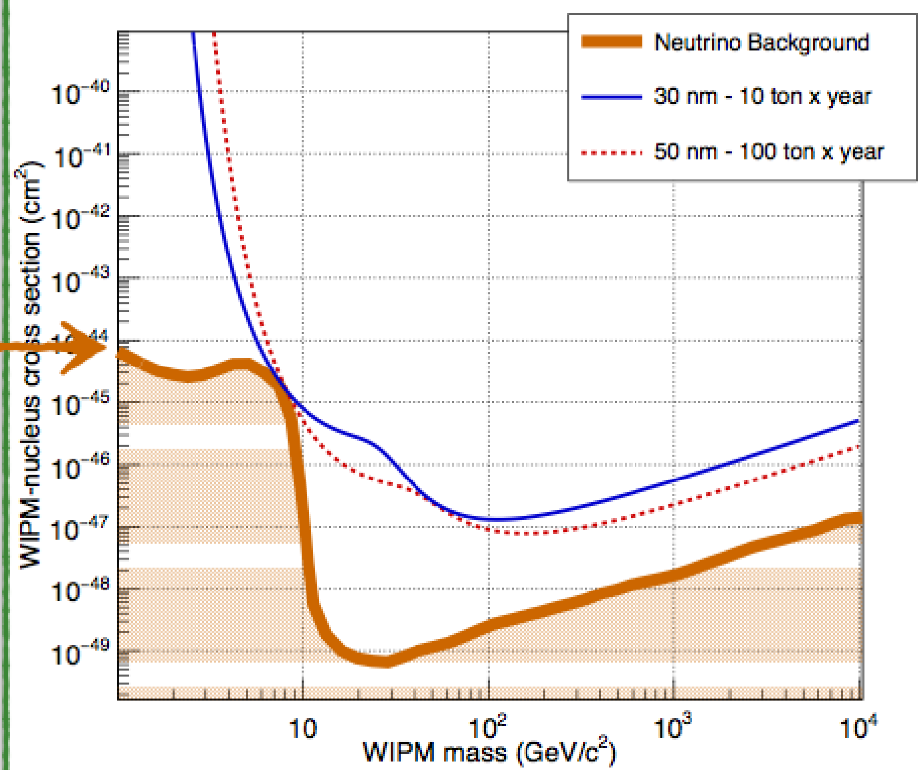


Towards Neutrino floor …

Far future ?

- Discrimination based on measurement of **recoil direction**
- **Unique solid detector** possible to search for WIMP signal **beyond "Neutrino floor"**

Neutrino coherent scattering indistinguishable from WIMP interactions
PRD 89 (2014) no.2, 023524
(Xe/Ge target)



Requirements :

- **Reduction of track threshold**

  Ultra-NIT (25nm) has 40nm resolution

- **Larger mass scale detector**

  Further high speed scanning system

  Extreme low BG detector

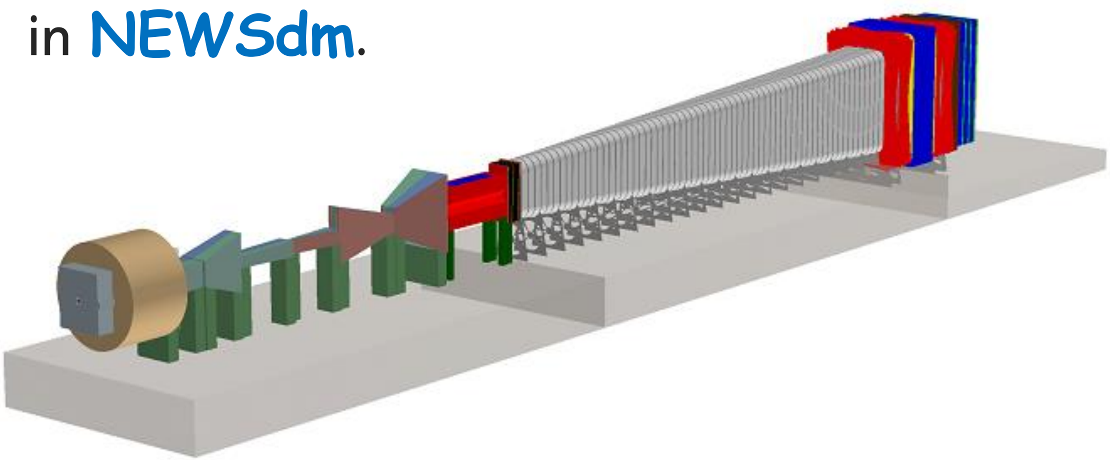
The neutrino bound is reached with:
10 ton x year exposure if **30 nm** threshold
100 ton x year exposure if **50 nm** threshold

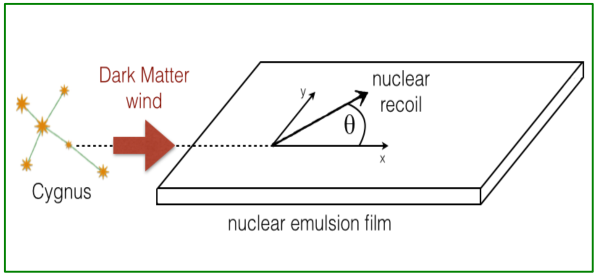
Summary

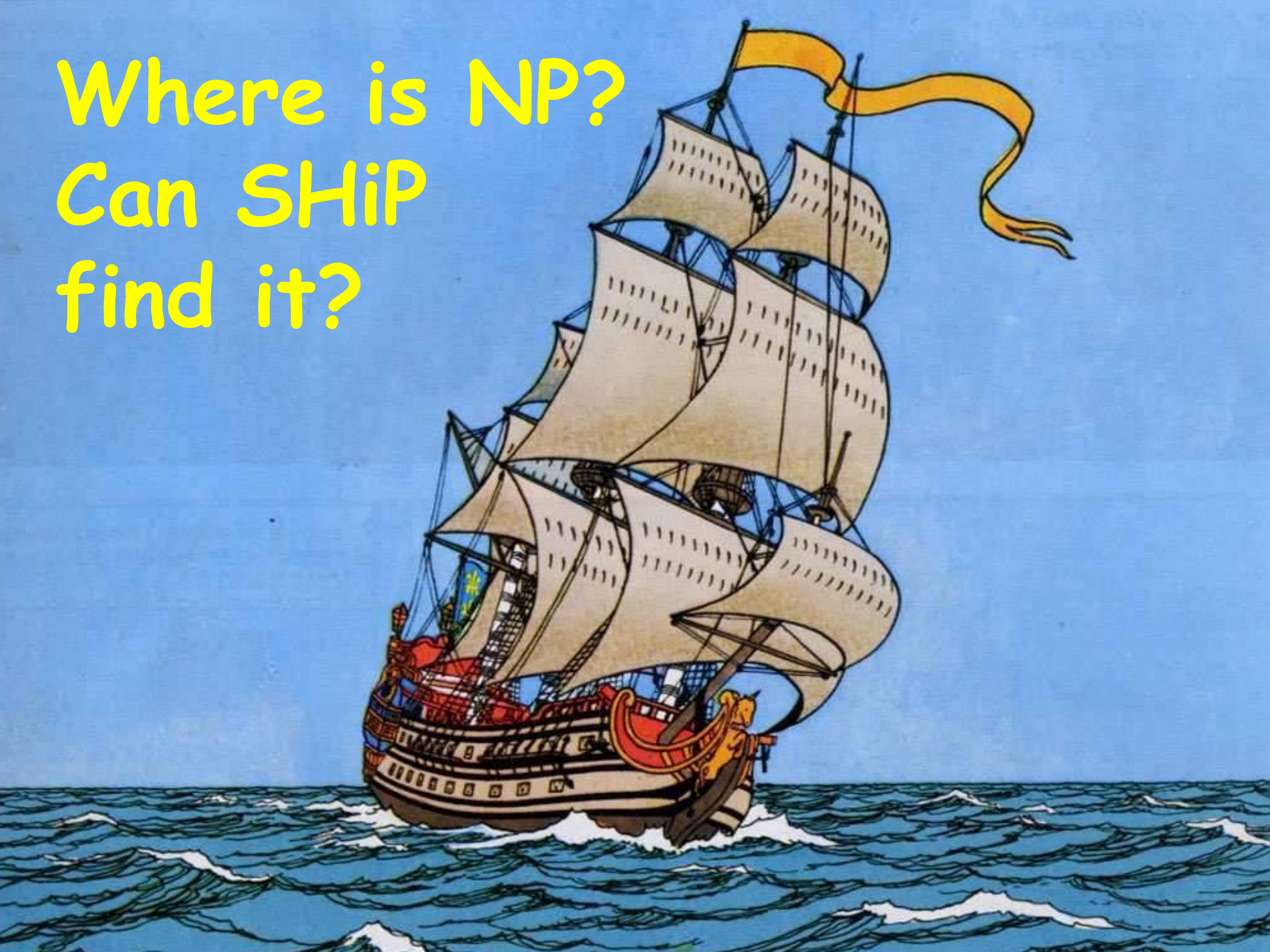
- The **SHiP** aims to search for **New Physics** at the **Intensity frontier** complementary to the Energy frontier such as LHC.
- It is a multi-purpose and very timely experiment for **Hidden particles** which are Feebly interacting particles, **Tau neutrino physics** and **Light dark matter.**

And also,

- The **directionality of the WIMP recoil** will be investigated in **NEWSdm**.






Where is NP?
Can SHiP
find it?

감사합니다