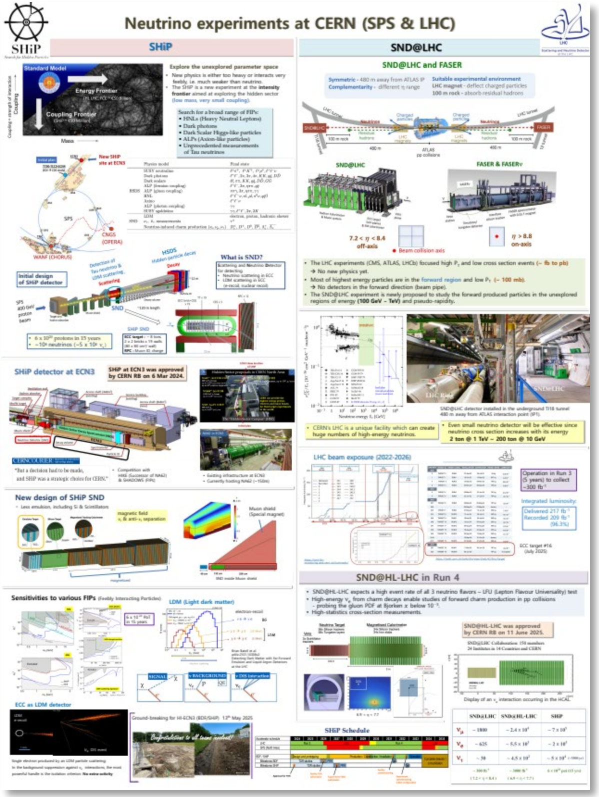
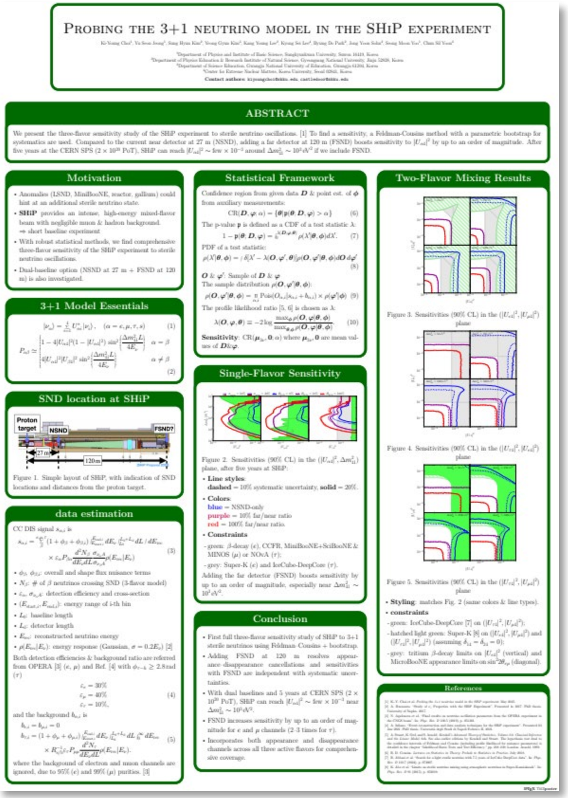
Overview and Status of SND@LHC and SHiP Experiments

C.S. Yoon (GNU)

K-Neutrino Symposiym
2025. 6. 25

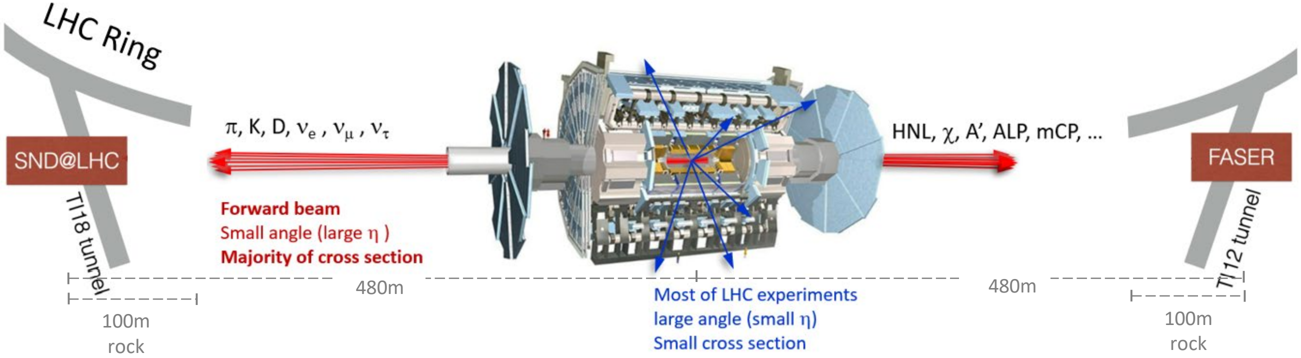

Neutrino experiments at CERN (SPS & LHC)
SHiP
SND@LHC
SND@LHC and FASER
SHiP detector at ECN3
New design of SHiP SND
Sensitivities to various FIPs
LHC beam exposure (2022-2026)
SND@HL-LHC in Run 4
SHiP Schedule


Nuclear emulsion tasks in the SND@LHC experiment
SND (Scattering and Neutrino Detector)
ECC (Emulsion Cloud Chamber) target
Emulsion scanning at CERN
Concept of Emulsion Scanning
Off-line analysis
Emulsion works at CERN
Chemical development
Labeling machine
Progress in vertex reconstruction
Summary

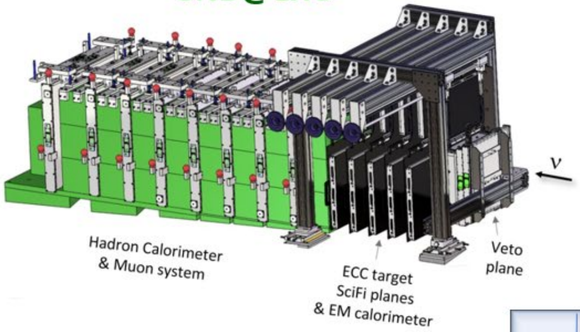

Probing the 3+1 neutrino model in the SHiP experiment
ABSTRACT
Motivation
Statistical Framework
Two-Flavor Mixing Results
3+1 Model Essentials
Single-Flavor Sensitivity
SND location at SHiP
data estimation
Conclusion
References

SND@LHC

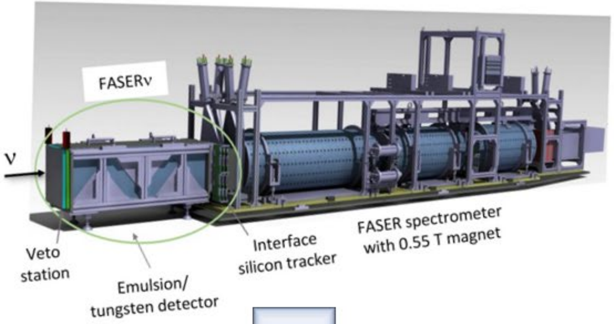
LHC forward experiments



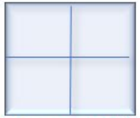
SND@LHC



FASER & FASERν



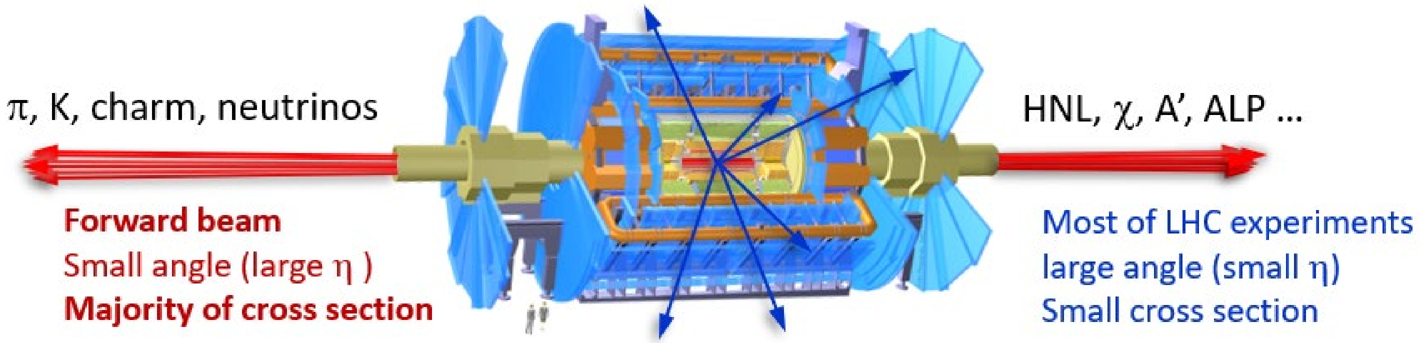
7.2 < η < 8.4
off-axis



● Beam collision axis

η > 8.8
on-axis

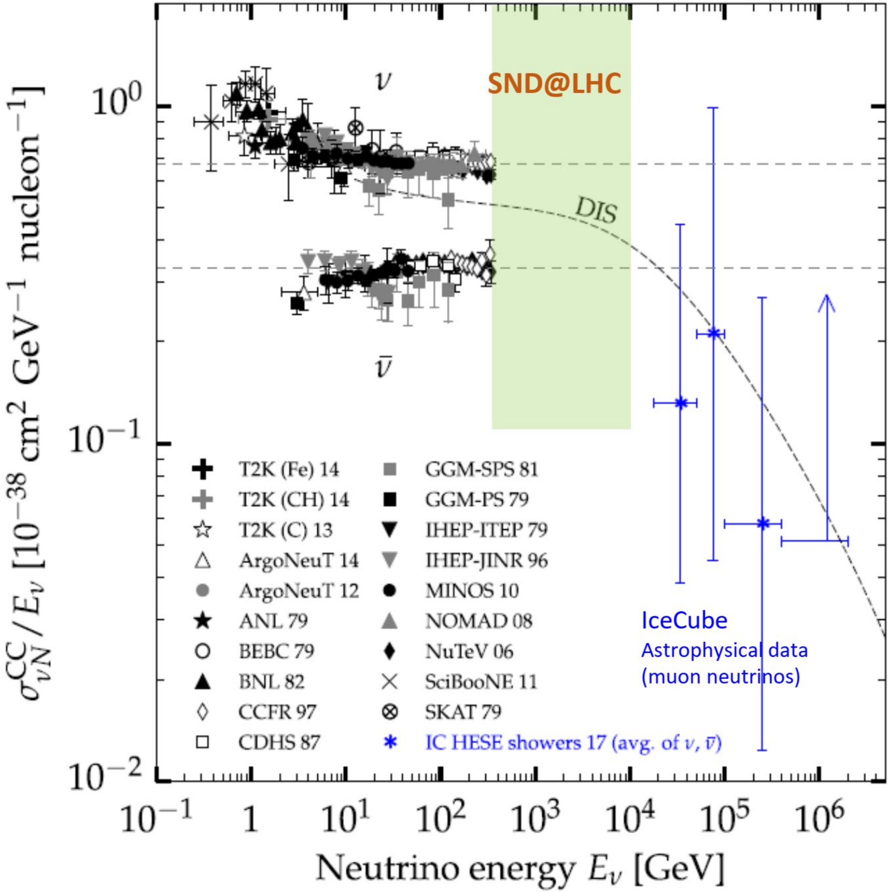
LHC forward particles production

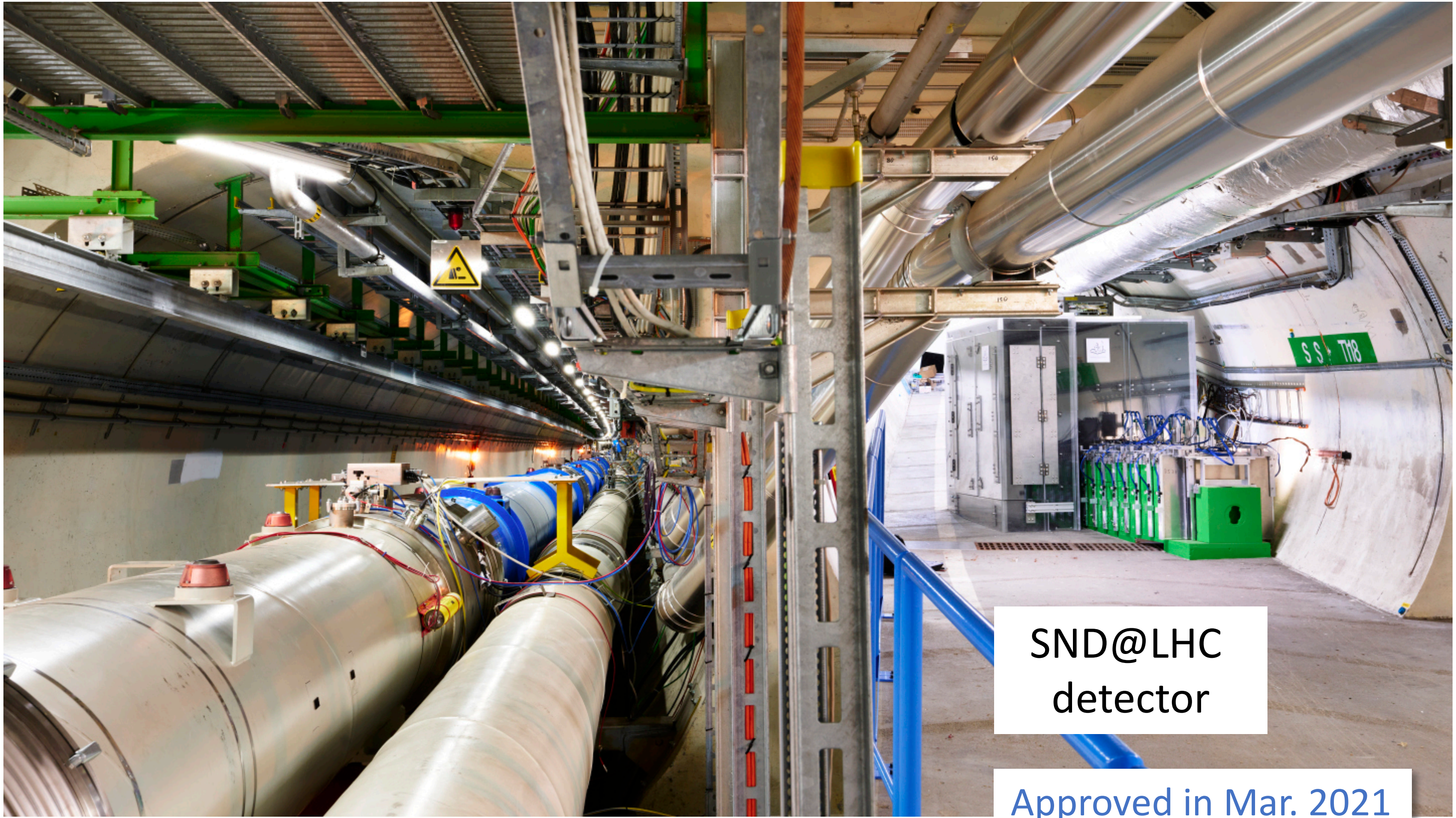


- The LHC experiments (CMS, ATLAS, LHCb) focused high P_T and low cross section events **(~ fb to pb)**
  → No new physics yet.
- Most of highest energy particles are in the **forward region** and low P_T **(~ 100 mb)**.
  → No detectors in the forward direction (beam pipe).
- The SND@LHC experiment is newly proposed to study the forward produced particles in the unexplored regions of energy **(100 GeV – TeV)** and pseudo-rapidity**.**

Neutrinos at the LHC

- LHC is a unique facility which can create huge numbers of high-energy neutrinos.
- Neutrino energy range **350 GeV < E_ν < 10 TeV** is unexplored.
- SND@LHC and FASER can provide the first detection and cross section of the **Collider neutrinos.**

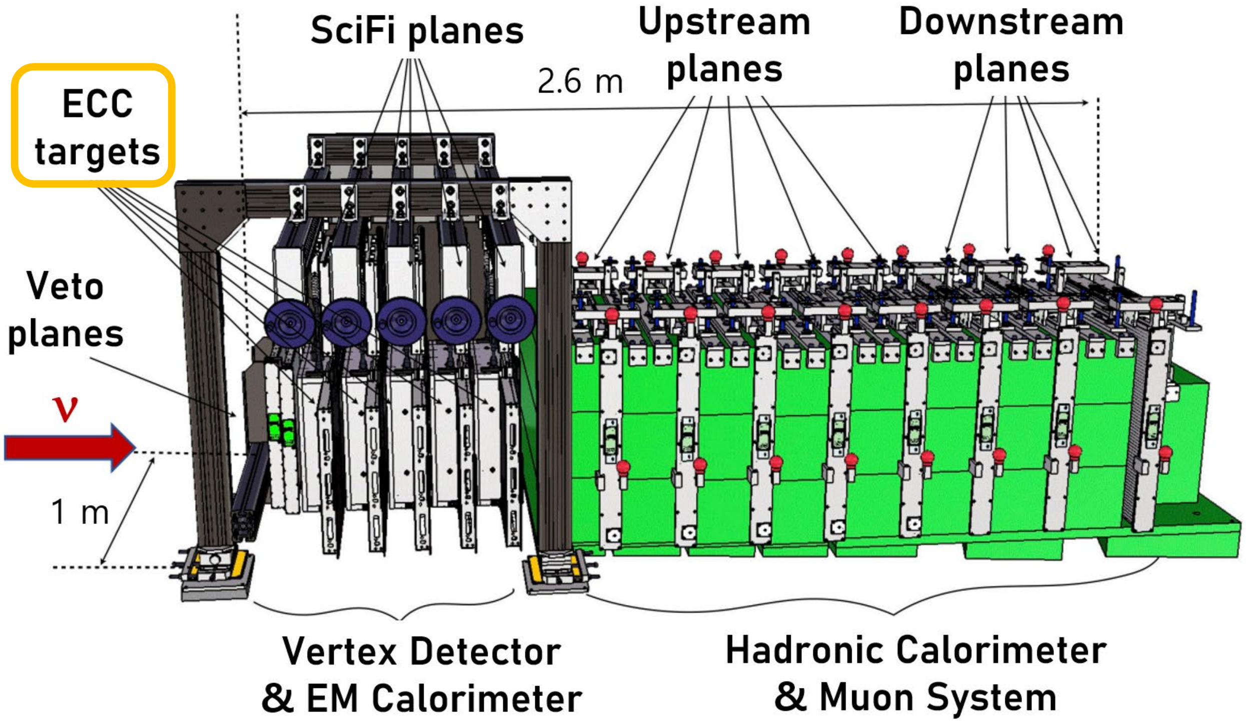




LHC Ring

Approved in Mar. 2021
Installed in Mar. 2022

SND@LHC detector

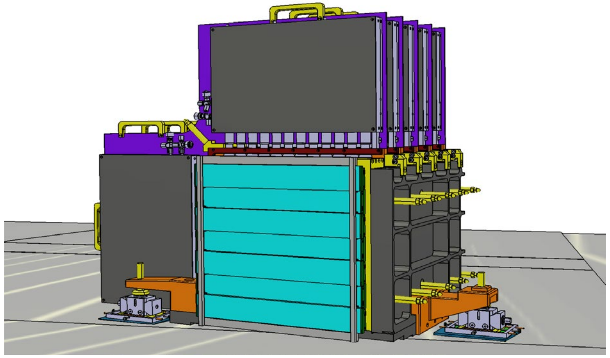


- Even small neutrino detector will be effective since neutrino cross section increases with its energy

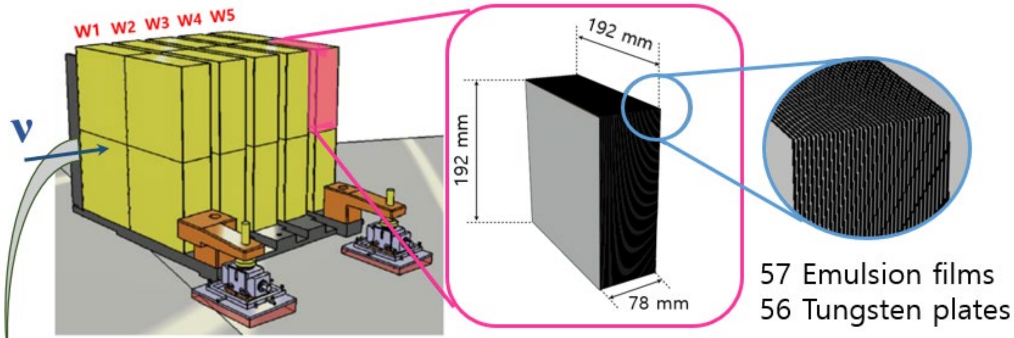
  2 ton @ 1 TeV ~ 200 ton @ 10 GeV

ECC → **Target** (various elements) & **Detector** (3D precision tracker)

(Emulsion Cloud Chamber)

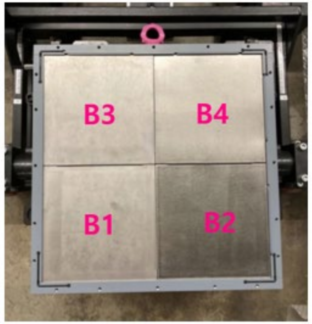


5 ECC brick walls & 5 SciFi walls

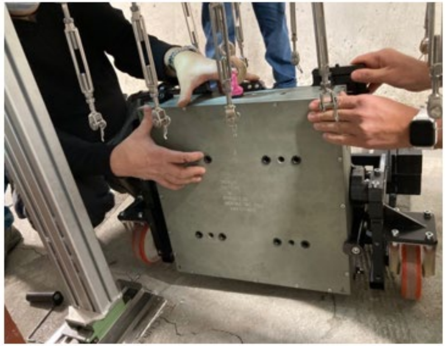


5 walls of ECC target

ECC brick (41.5 kg)



4 bricks per a wall



ECC brick wall installation

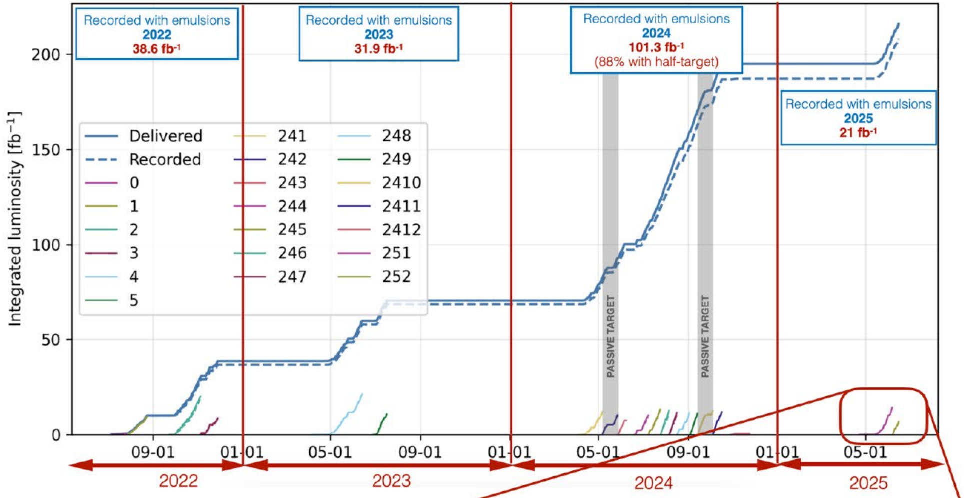
LHC beam exposure (2022-2026)

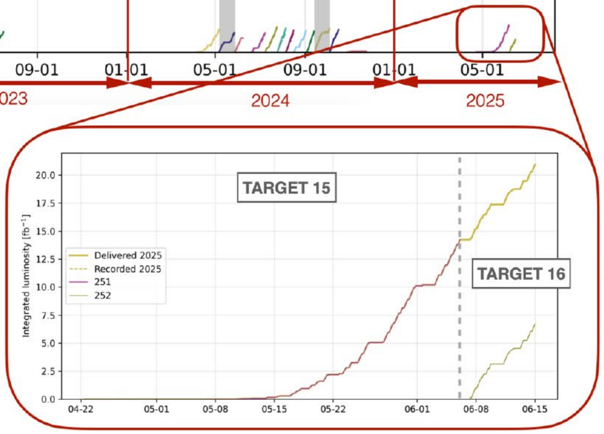
Operation in Run 3 to collect **~300 fb^{-1}**

Integrated luminosity:

Delivered 217 fb^{-1}

Recorded 209 fb^{-1} (96.3%)



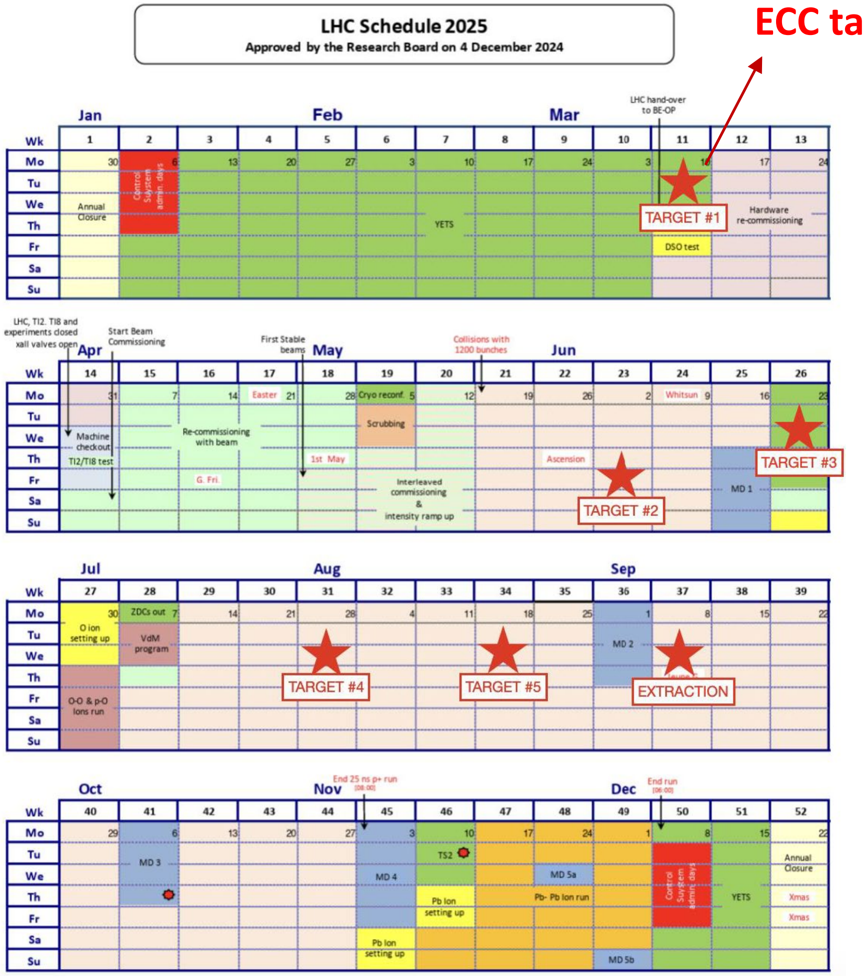


https://snd-lhc-monitoring.web.cern.ch/luminosity/

DAQ RUN	TARGET ID	TARGET LABEL	INSTALLATION	EXTRACTION	TARGET MASS	LUMINOSITY
2022						
0	TARGET 0	RUN0	07-Apr-22	26-Jul-22	39 kg	0.46 fb^{-1}
1	TARGET 1	RUN1	26-Jul-22	13-Sep-22	807 kg	9.5 fb^{-1}
2	TARGET 2	RUN2	13-Sep-22	04-Nov-22	784 kg	20.0 fb^{-1}
3	TARGET 3	RUN3	04-Nov-22	09-Dec-22	792 kg	8.6 fb^{-1}
2023						
4	TARGET 4	RUN4	20-Mar-23	23-Jun-24	797 kg	21.2 fb^{-1}
5	TARGET 5	RUN5	23-Jun-23	27-Jul-24	784 kg	10.7 fb^{-1}
2024						
241	TARGET 6	RUN8	20-Mar-24	06-May-24	797 kg	12.0 fb^{-1}
242	-	-	06-May-24	27-May-24	dummy	-
243	TARGET 7	RUN9	27-May-24	13-Jun-24	392 kg	7.3 fb^{-1}
244	TARGET 8	RUN10	13-Jun-24	08-Jul-24	392 kg	10.1 fb^{-1}
245	TARGET 9	RUN11	08-Jul-24	24-Jul-24	392 kg	13.3 fb^{-1}
246	TARGET 10	RUN12	24-Jul-24	05-Aug-24	392 kg	12.7 fb^{-1}
247	TARGET 11	RUN13	05-Aug-24	06-Aug-24	392 kg	11.5 fb^{-1}
248	TARGET 12	RUN14	16-Aug-24	02-Sep-24	392 kg	11.5 fb^{-1}
249	TARGET 13	RUN15	02-Sep-24	13-Sep-24	392 kg	11.1 fb^{-1}
2410	-	-	13-Sep-24	01-Oct-24	dummy	-
2411	TARGET 14	RUN16	01-Oct-24	21-Oct-24	392 kg	11.8 fb^{-1}
2025						
251	TARGET 15	RUN17	11-Mar-25	06-Jun-25	797 kg	14.2 fb^{-1}
252	TARGET 16	RUN18	06-Jun-25	-	797 kg	in progress

https://twiki.cern.ch/twiki/bin/view/SndLHC/EmuTarget

ECC target #16 (July 2025)



ECC target install

2025

5 ECC targets will be exchanged.

Emulsion works at CERN

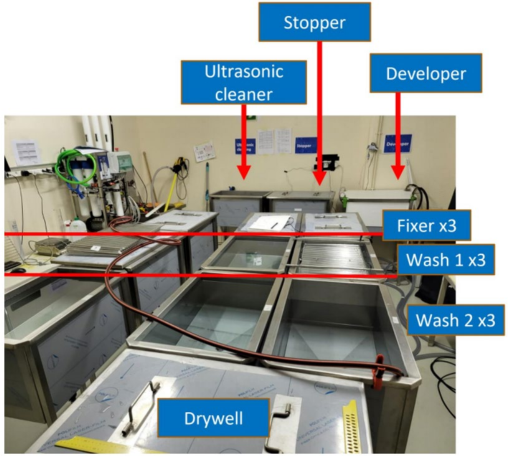
ECC target assembly → Installation → Beam exposure → Extraction → ECC disassembling → Labeling → Emulsion film development → → Drying → Surface cleaning → Packing

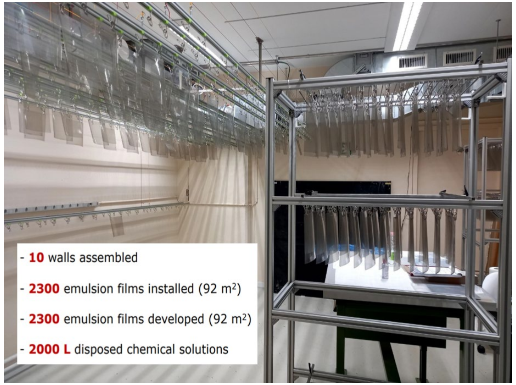
Chemical development

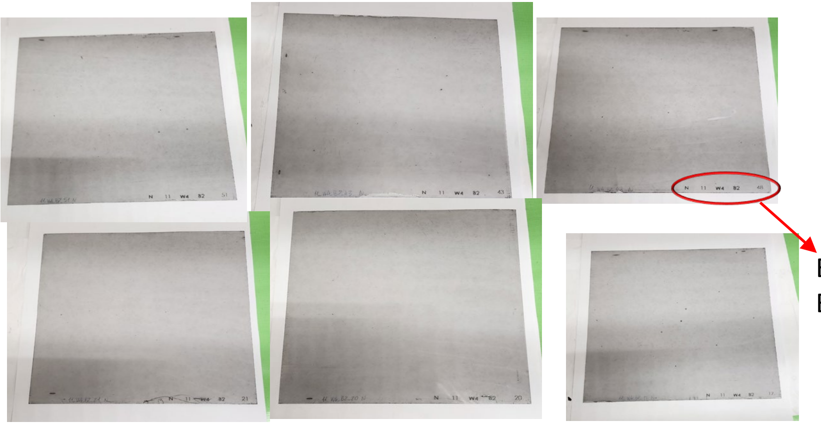
Develop → Stop → Fix → Wash → Dry → Glycerine

Emulsion development facility at CERN

Assembled ECC targets

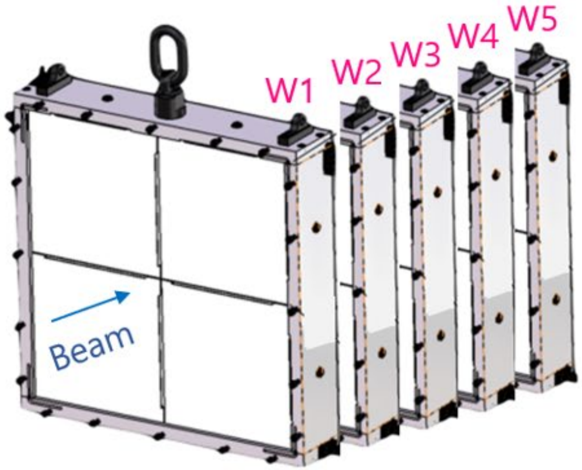


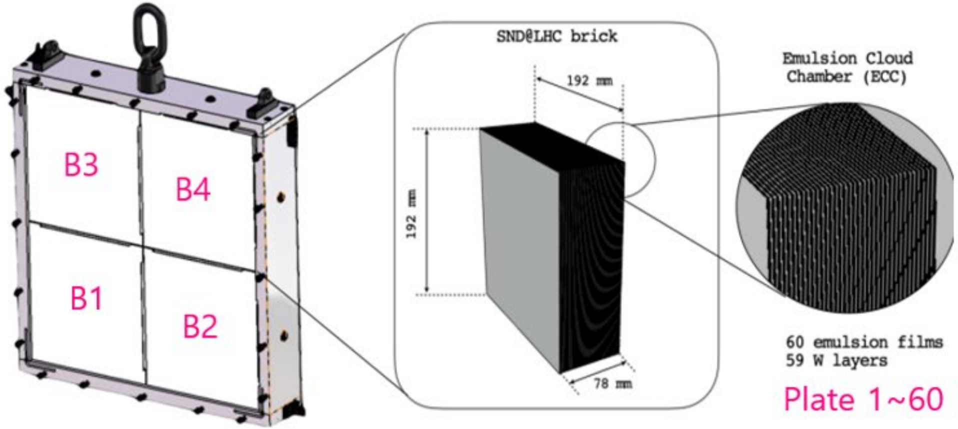


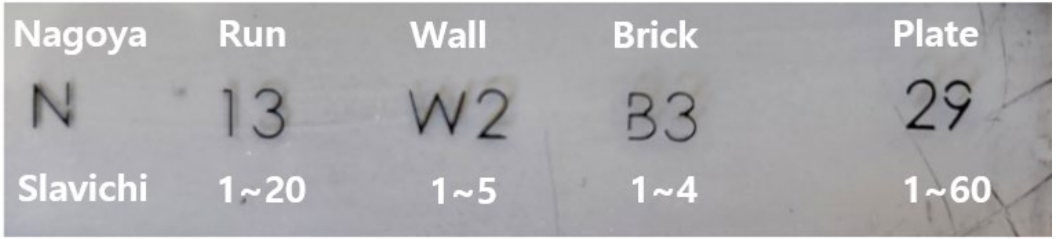


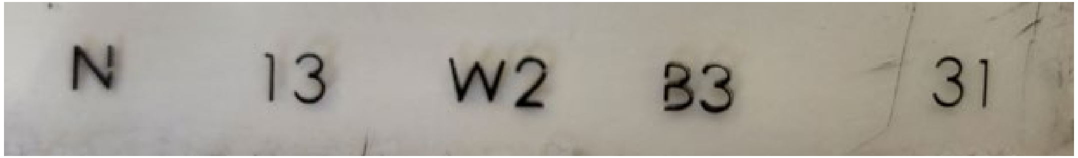
Em Run #, Wall #, Brick #, Plate #

Developed emulsion films



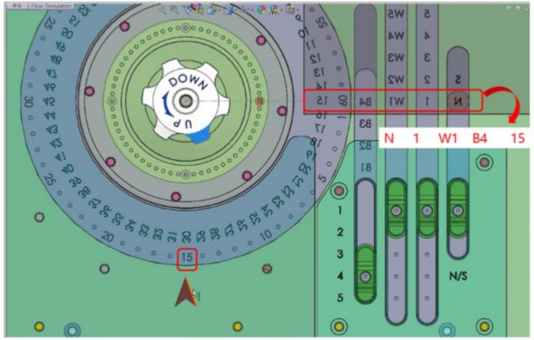


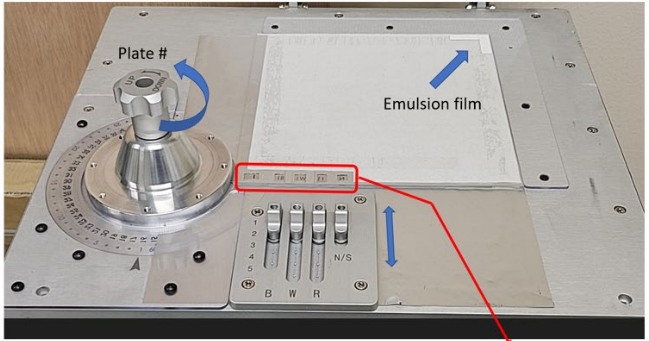




1,200 emulsion plates each run (16 runs so far)
→ Need labelling to the plates

Labeling machine





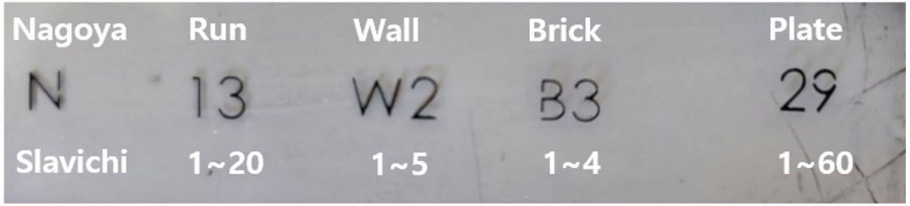
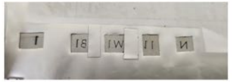
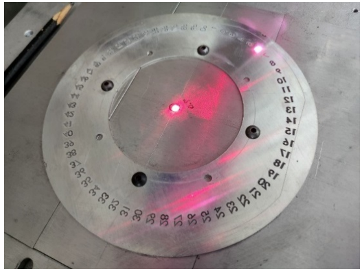
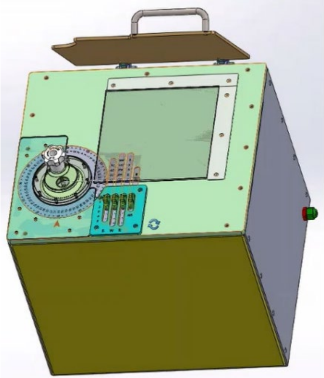
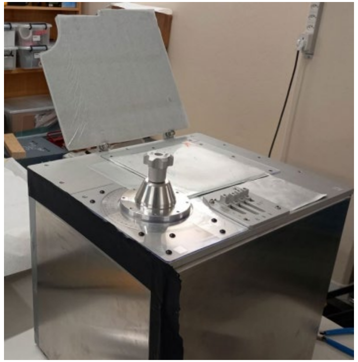


Plate Brick Wall Run N/S









fabricated by our group

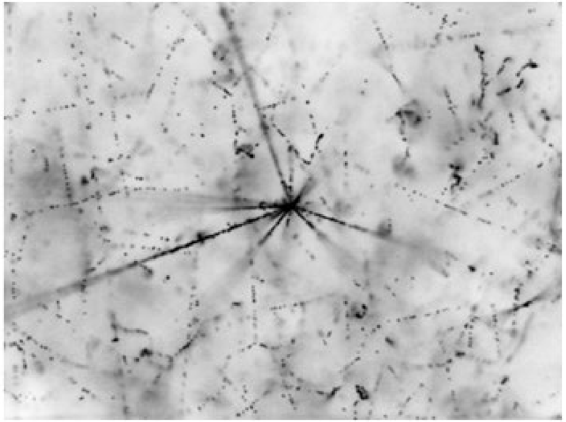
Laser cutting

Conceptual change of Emulsion scanning

3D image detector → **Precision tracker**

Observation of event
& tracks by microscope

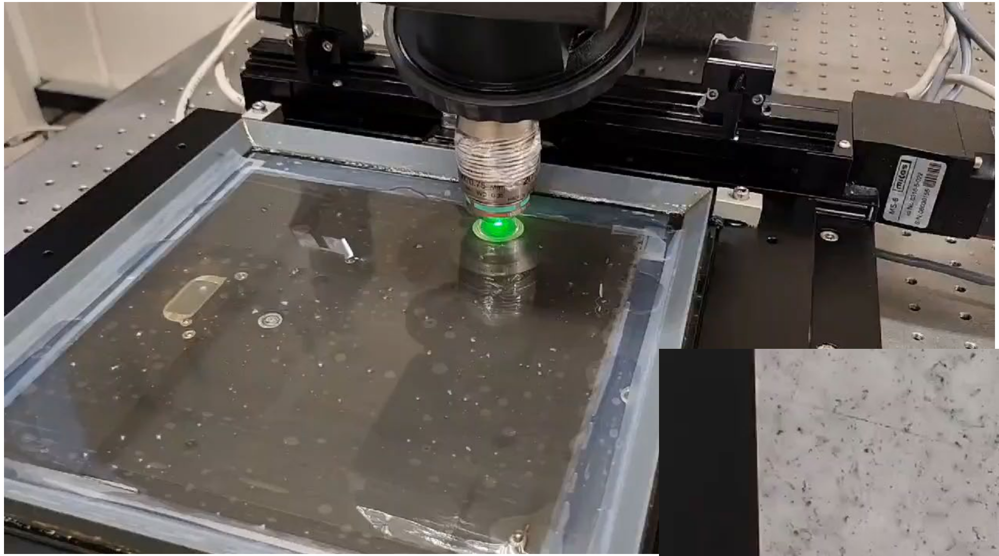
Full automatic record
of all grains (raw data)



Neutrino event in emulsion

Micro-track
↓
Base-track
↓
Volume-track
↓
Event

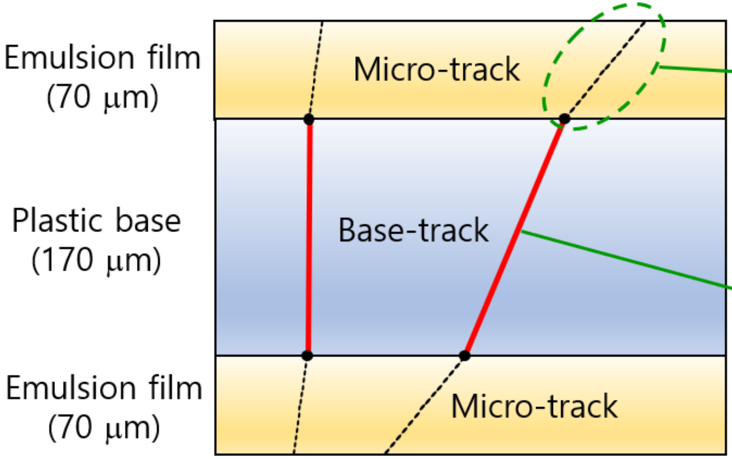
Off-line analysis:
reconstruction of
tracks and events



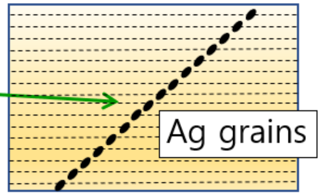

Current Position
151979
47256.3
354.16
Progress
Commands
Status
Stop

Off-line analysis

Reconstructions of Tracks and Neutrino vertices using the Base-tracks

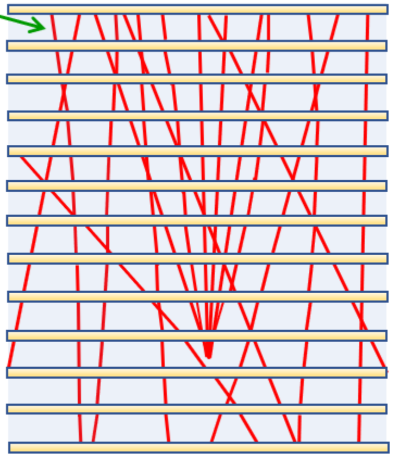


Cross-sectional view of Emulsion plate

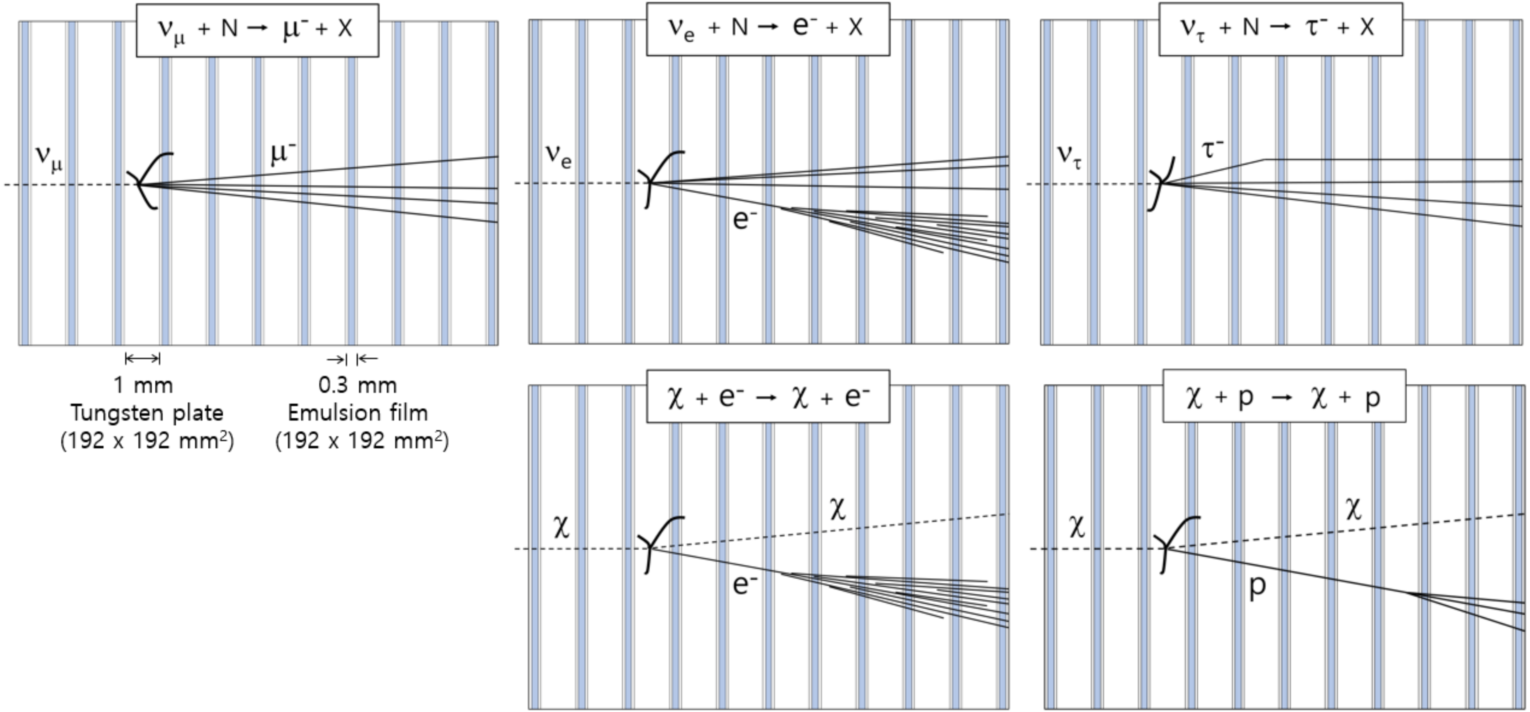


Tomographic images scanned by microscope

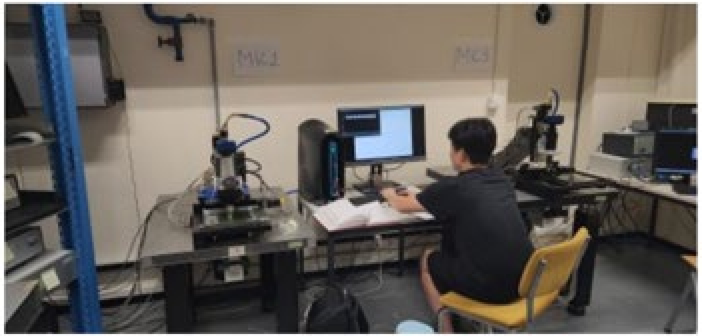
Track & vertex reconstructions by using Base-tracks through consecutive Emulsion films

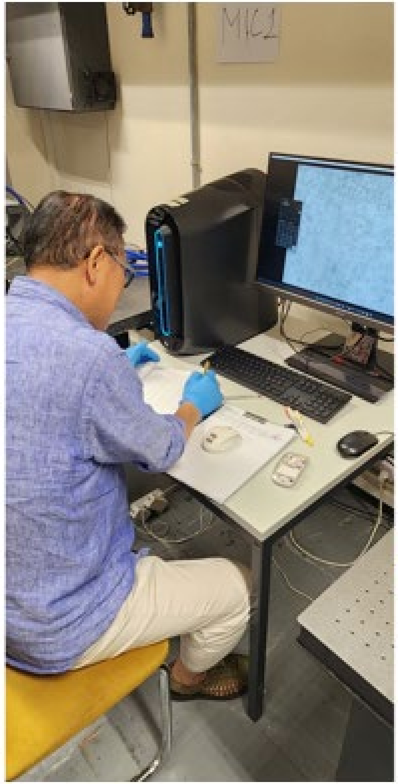


All 3 flavors of neutrino scatterings and FIP scatterings can be observed in the ECC.

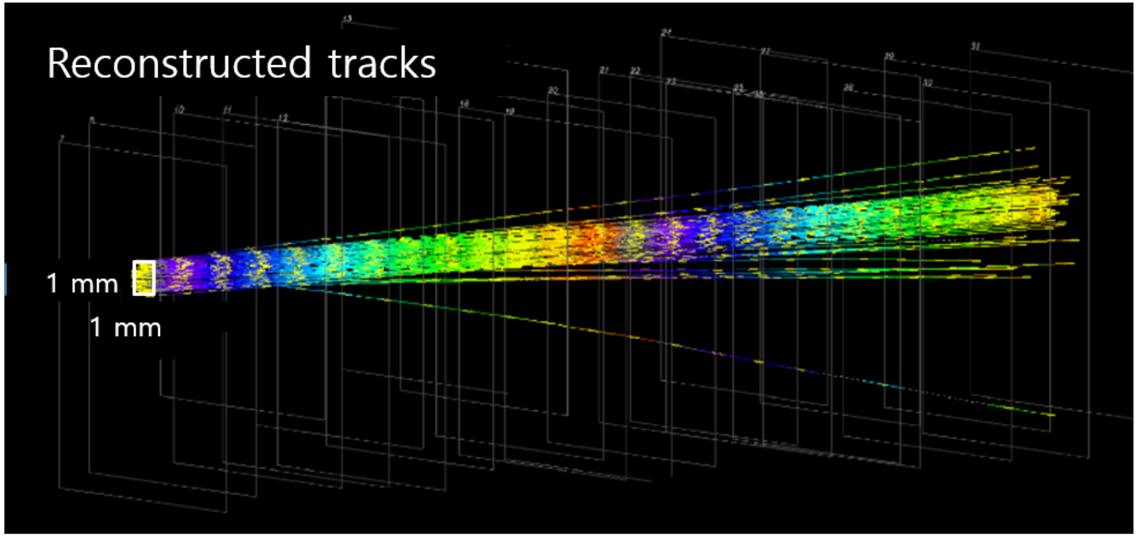


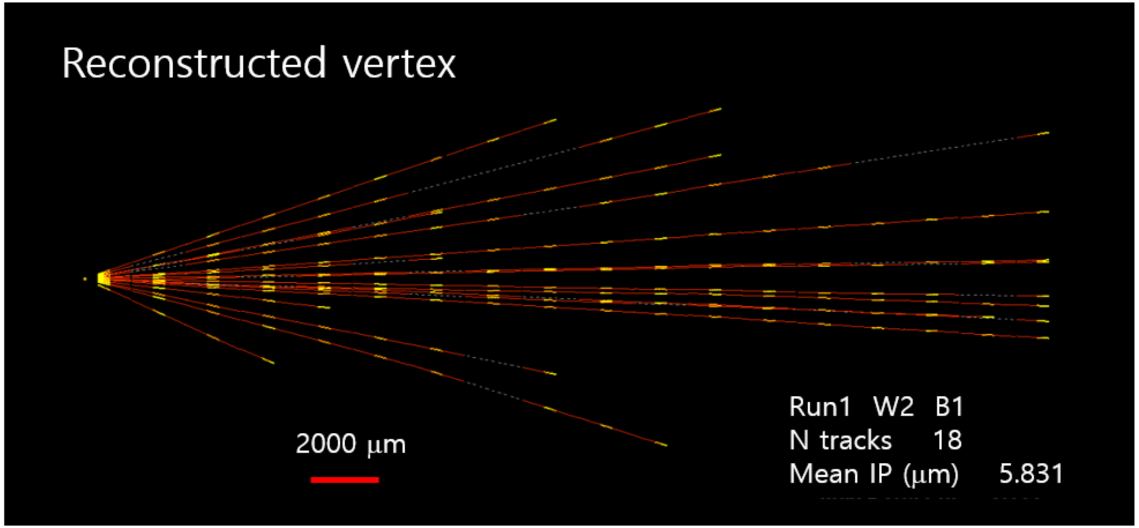
Emulsion scanning at CERN





Emulsion scanning room at CERN

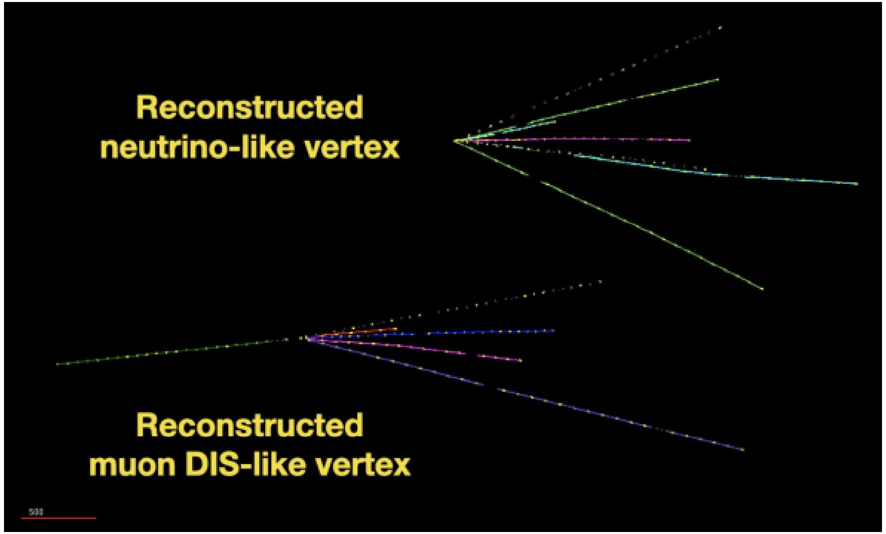


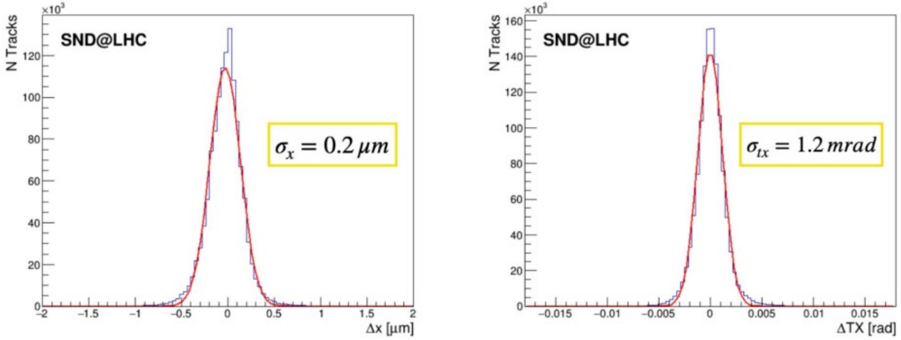


Muon tracks in 1 mm^2 area

10^5 tracks/cm^2 in 10 fb^{-1} exposure

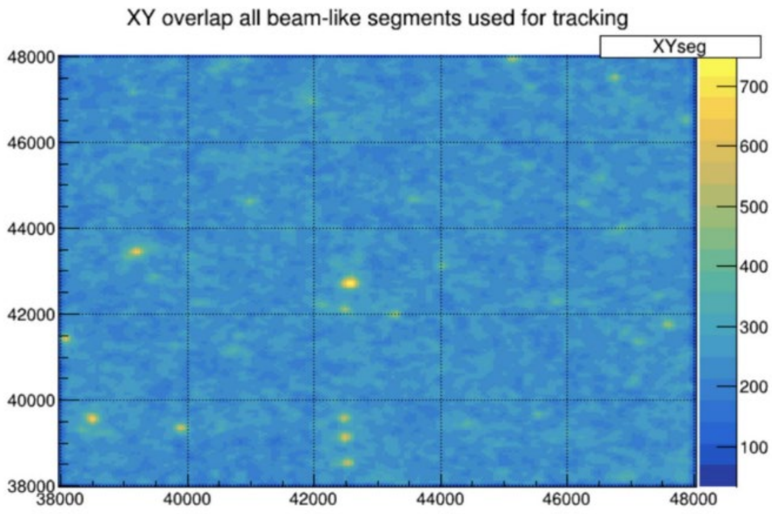
Vertex reconstruction

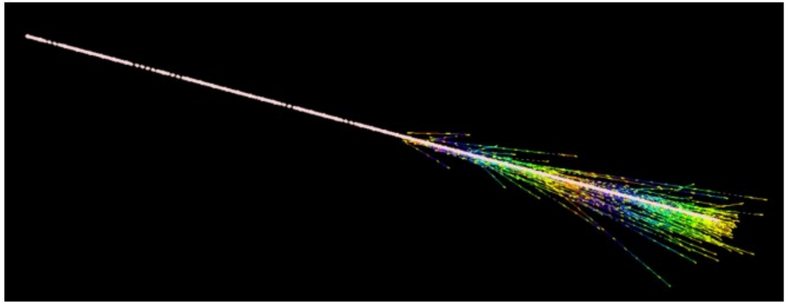




Excellent tracking resolution achieved

ν_e CC candidate event





Electromagnetic shower search based on high density spots (base-tracks, segments)

First direct observation of Collider Neutrinos !

- ν_μ candidates (1μ): **32 events**
- ν_e or NC candidates (0μ): **9 events**

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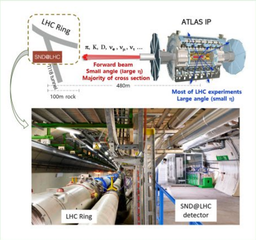

| Highlight Paper |

Nuclear emulsion tasks in the SND@LHC experiment
(Sung Hyun Kim, Kang Young Lee, Byung Do Park, Jong Yoon Sohn, Chun Sil Yoon, Kyong Sei Lee, Yeong Gyun Kim, Ki-Young Choi, Seong Moon Yoo p.215)

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Check for updates

Nuclear emulsion tasks in the SND@LHC experiment

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(Received 1 October 2024 : revised 13 January 2025 : accepted 14 January 2025)

The SND@LHC experiment aims to perform measurements of high energy neutrinos (350 GeV–10 TeV) with the forward pseudo-rapidity region ($7.2 < \eta < 8.4$) not accessible to other LHC experiments so far, and also to search for feebly interacting particles produced in pp collisions at the LHC. To do so, we use ECC as target and tracking detector, where the emulsion cloud chamber (ECC) is a sandwich structure of Nuclear emulsion films and Tungsten plates. Since Nuclear emulsion has best spatial resolution less than 1 μm and angular resolution with several mrad, all three flavors of neutrinos can be identified and measurements of time and energy are possible together with electronic detectors such as SciFi and Muon detector. In this paper, we will introduce whole process of the Nuclear emulsion tasks such as ECC target assembly, chemical development, scanning and event analysis including the current status of the experiment.

Keywords: Nuclear emulsion, SND@LHC, Forward production of neutrino, Collider neutrino

SND@LHC 실험에서의 원자핵건판 작업

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Editors' Suggestion

Observation of Collider Muon Neutrinos with the SND@LHC Experiment

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(SND@LHC Collaboration)

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We report the direct observation of muon neutrino interactions with the SND@LHC detector at the Large Hadron Collider. A dataset of proton-proton collisions at $\sqrt{s} = 13.6$ TeV collected by SND@LHC in 2022 is used, corresponding to an integrated luminosity of 36.8 fb^{-1}. The search is based on information from the active electronic components of the SND@LHC detector, which covers the pseudorapidity region of $7.2 < \eta < 8.4$, inaccessible to the other experiments at the collider. Muon neutrino candidates are identified through their charged-current interaction topology, with a track propagating through the entire length of the muon detector. After selection cuts, 8 ν_μ interaction candidate events remain with an estimated background of 0.086 events, yielding a significance of about 7 standard deviations for the observed ν_μ signal.

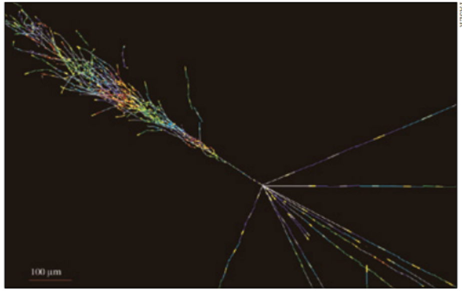
CERNCOURIER Reporting on international high-energy physics

NEUTRINOS

First collider neutrinos detected

Since their discovery 67 years ago, neutrinos from a range of sources – solar, atmospheric, reactor, geological, accelerator and astrophysical – have provided ever more powerful probes of nature. Although neutrinos are also produced abundantly in colliders, until now no neutrinos produced in such a way had been detected, their presence inferred instead via missing energy and momentum.

A new LHC experiment called FASER, which entered operations at the start of Run 3 last year, has changed this picture with the first observation of collider neutrinos. Announcing the result on 19 March at the Rencontres de Moriond, and in a paper submitted to *Physical Review Letters* on 24 March, the FASER collaboration reconstructed 153 candidate muon neutrino and antineutrino interactions in its spectrometer with a significance of 16 standard deviations above the background-only hypothesis. Being consistent with the characteristics expected from neutrino interactions in terms of secondary-particle production and spatial distribution, the results imply the observation of both neutrinos and antineutrinos with an incident neutrino energy significantly above 200 GeV. In addition, an ongoing analysis of data from an emulsion/tungsten subdetector called FASERν revealed a first electron–neutrino interaction candidate (see image above).



FASER

New source *A candidate high-energy electron neutrino charged-current interaction recorded by FASERν, with the electron shower (left of the image) balanced by several charged particle tracks (right).*

"FASER has directly observed the interactions of neutrinos produced at a collider for the first time," explains co-spokesperson Jamie Boyd of CERN. "This result shows the detector worked perfectly in 2022 and opens the door for many important future studies with high-energy neutrinos at the LHC."

The extreme luminosity of proton–proton collisions at the LHC produces a large neutrino flux in the forward direction, with energies leading to cross-sections high enough for neutrinos to be detected using a compact apparatus. FASER is one of two new forward experiments situated at either side of LHC Point 1 to detect neutrinos produced in proton–proton collisions in ATLAS. The other, SND@LHC, also reported its first results at Moriond. The team found eight muon–neutrino candidate events against an expected background of 0.2, with an evaluation of systematic uncertainties ongoing.

Covering energies between a few hundred GeV and several TeV, FASER and SND@LHC narrow the gap between fixed-target and astrophysical neutrinos. One of the unexplored physics topics to which they will contribute is the study of high-energy neutrinos from astrophysical sources. Since the production mechanism and energy of neutrinos at the LHC is similar to that of very-high-energy neutrinos from cosmic-ray collisions with the atmosphere, FASER and SND@LHC can be used to precisely estimate this background. Another application is to measure and compare the production rate of all three types of neutrinos, providing an important test of the Standard Model.

Beyond neutrinos, the two experiments open new searches for feebly interacting particles and other new physics. In a separate analysis, FASER presented first results from a search for dark photons decaying to an electron–positron pair. No events were seen in an almost background-free analysis, yielding new constraints on dark photons with couplings of 10^{-5} to 10^{-4} and masses of between 10 and 100 MeV, in a region of parameter space motivated by dark matter.

Further reading

FASER Collab. 2023 arXiv:2303.14185.
FASER Collab. 2023 CERN-FASER-CONF-2023-001.

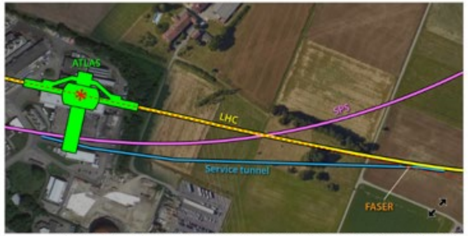
VIEWPOINT

The Dawn of Collider Neutrino Physics

Elizabeth Worcester
Brookhaven National Laboratory, Upton, New York, US

July 19, 2023 • *Physics* 16, 113

The first observation of neutrinos produced at a particle collider opens a new field of study and offers ways to test the limits of the standard model.



Google Earth, imagery (c)2023 Maxar Technologies, map data (c)2023; CERN; adapted by APS/Alan Stonebraker

Figure 1: The Forward Search Experiment (FASER) is installed in a service tunnel that connects the Large Hadron Collider (LHC) and the Super Proton Synchrotron (SPS). Proton collisions at the ATLAS experiment's interaction point (red star) generate beams of neutrinos (dashed red lines) that escape along a tangent to the LHC.

SND@HL-LHC

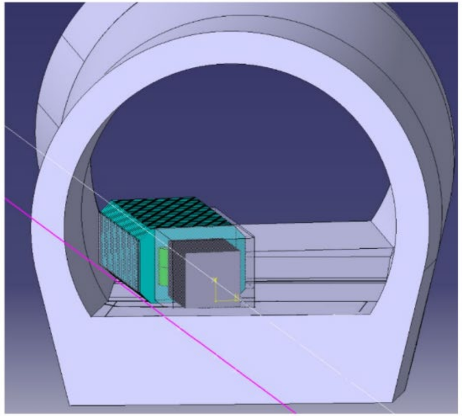
Proposed for the High-Luminosity LHC era (Run 4)

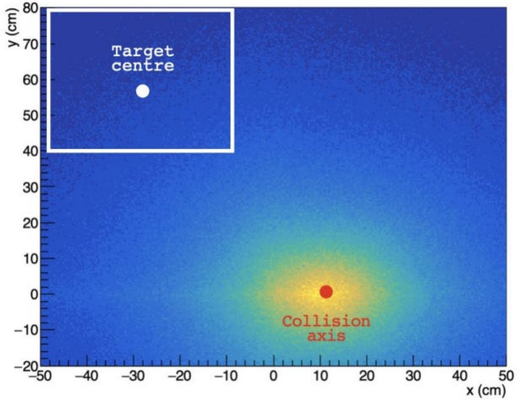
Approved by CERN RB on 11 June 2025.

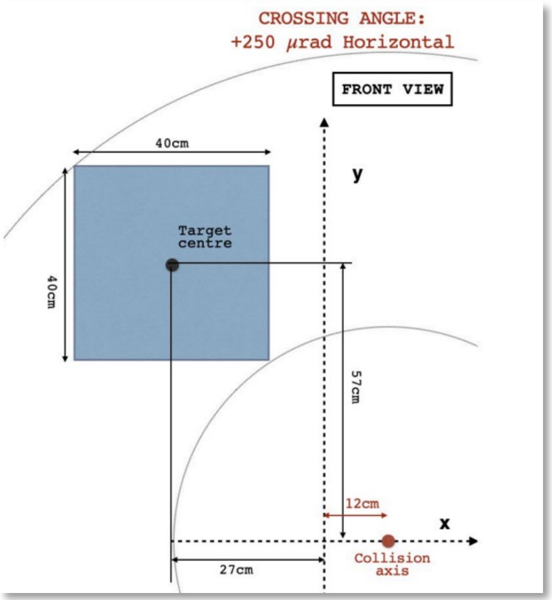
Physics goal

- SND@HL-LHC expects a high event rate of all 3 neutrino flavors
  – LFU (Lepton Flavour Universality) test
- High-energy ν_e from charm decays enable studies of forward charm production in pp collisions
  – probing the gluon PDF at Bjorken x below 10^{-5}.
- High-statistics cross-section measurements.

SND@HL-LHC



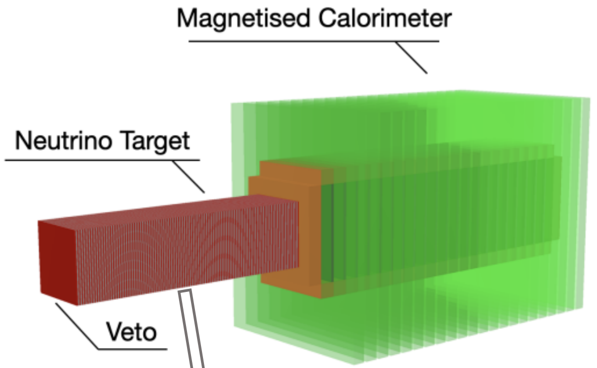


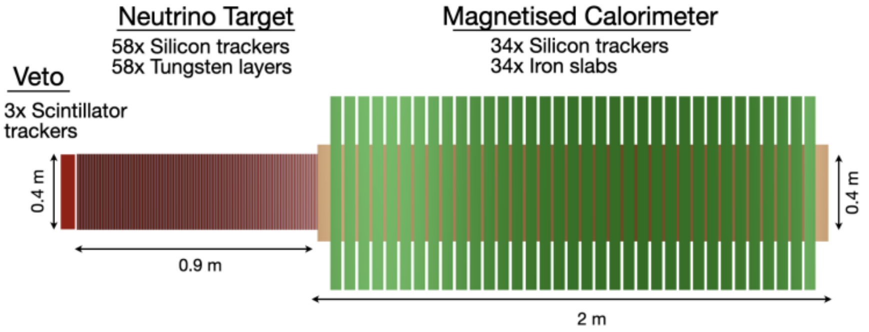


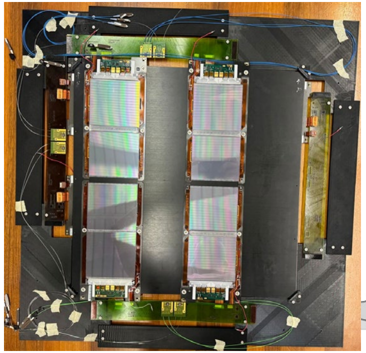
SND@HL-LHC	$6.9 < \eta < 7.7$
SND@LHC	$7.2. < \eta < 8.4$
FASER	$\eta > 8.8$

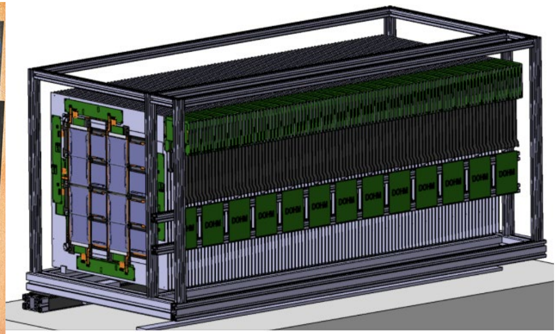
SND@HL-LHC Detector

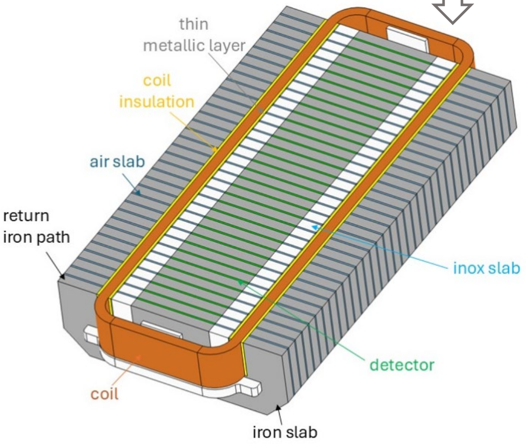
Silicon instead of Emulsion

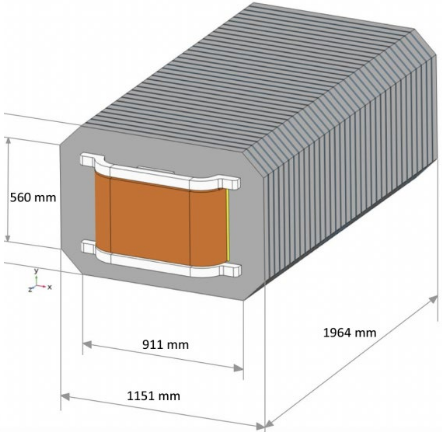








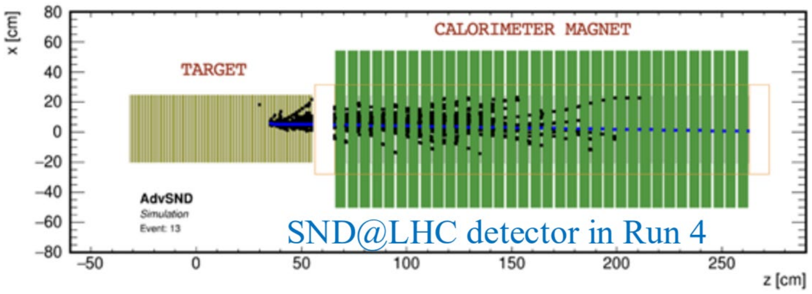


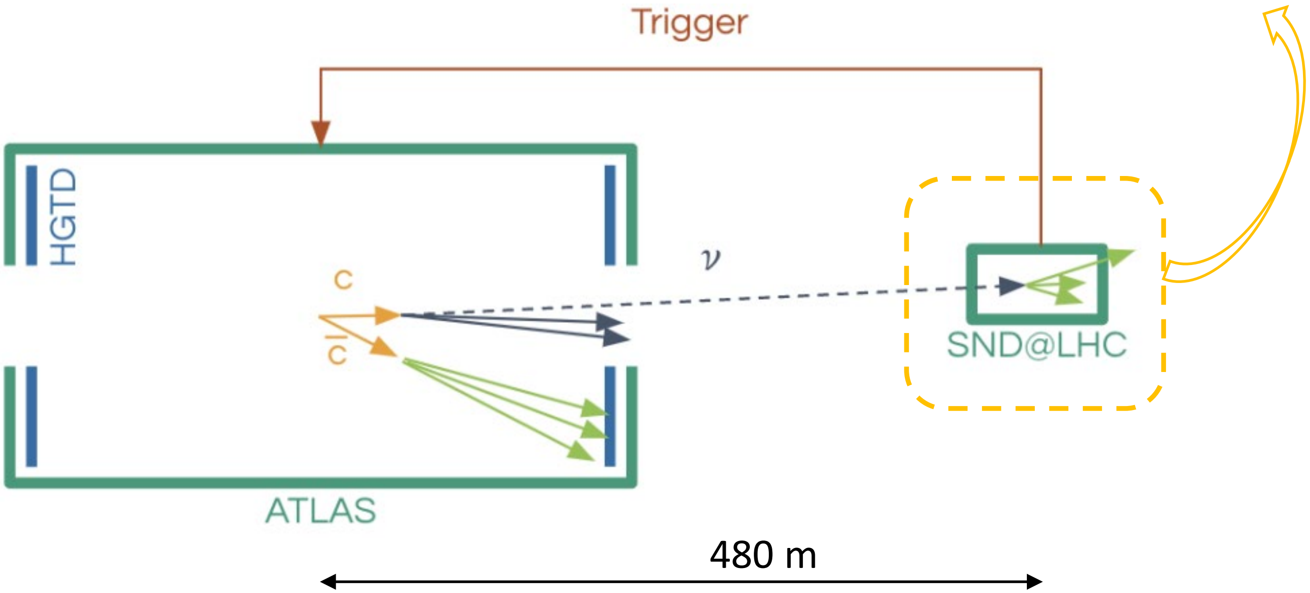


Charm-tagged neutrinos

- Neutrinos originate in charm production at ATLAS
  ~500 events (around 10%) expected

- A charm-tagged neutrino sample would allow for clean flavour ratio measurements

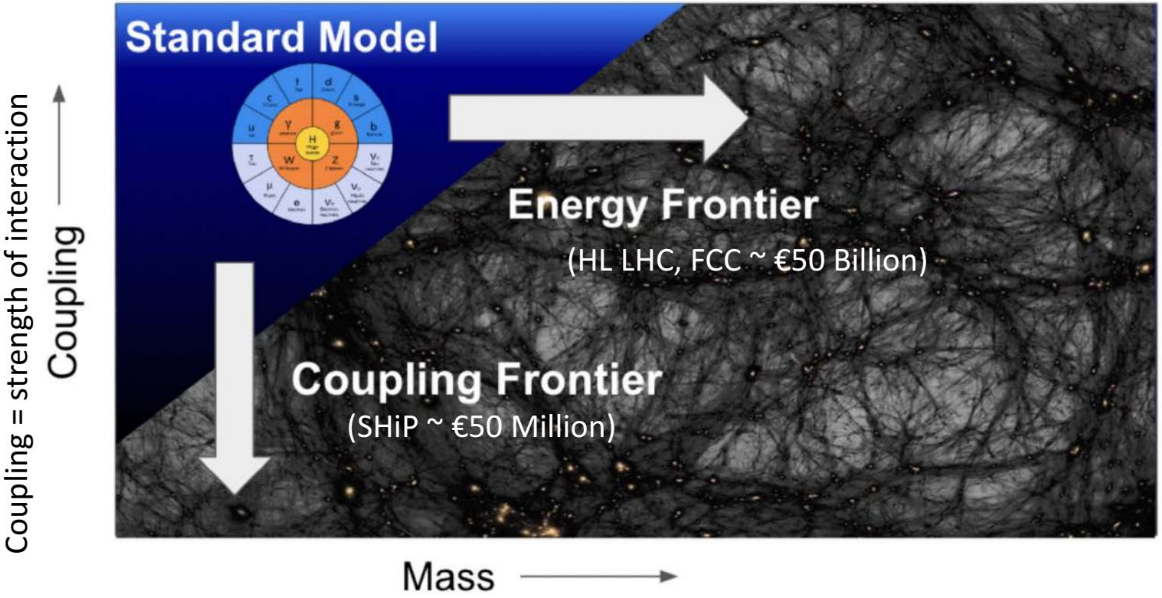




SHiP

Search for Hidden Particles

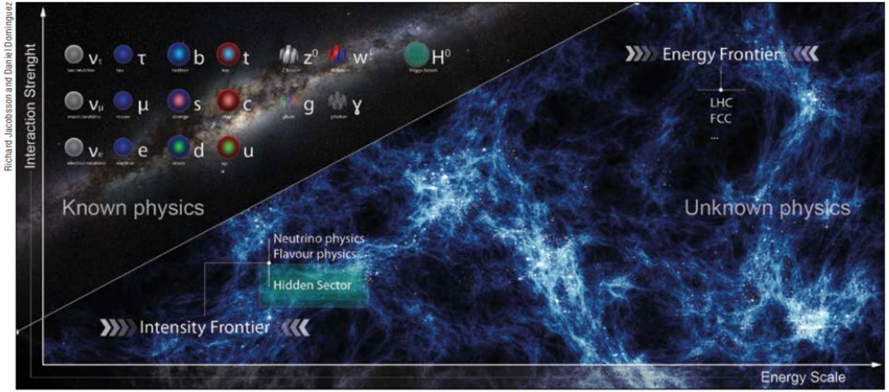
Explore the unexplored parameter space



- New physics is either too heavy or interacts very feebly, i.e. much weaker than neutrino.
- The SHiP is a new experiment at the **intensity frontier** aimed at exploring the hidden sector **(low mass, very small coupling).**

CERNCOURIER | Reporting on international high-energy physics

12 February 2016 New physics



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

SHiP sets a new course in intensity-frontier exploration

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

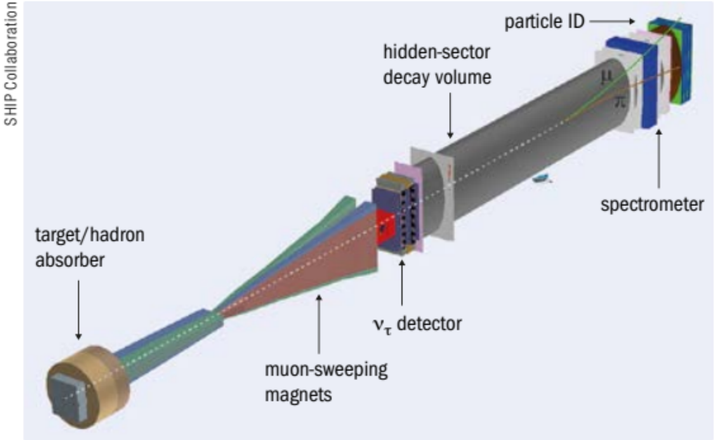
A Golutvin, Imperial College London/CERN, and **R Jacobsson**, CERN, on

have now observed all the particles of tl

it is clear that it is not the ultimate thec

ticles or interactions are required to explain a number of observed phenomena in particle physics, astrophysics and cosmology, the so-called beyond-the-Standard Model (BSM) problems, such as dark matter, neutrino masses and oscillations, baryon asymmetry, and the expansion of the universe.

While these phenomena are well-established observationally, they give no indication about the energy scale of the new physics. The analysis of new LHC data collected at √ = 13 TeV will soon have directly probed the TeV scale for new particles with cou-



Overview of the SHiP experimental set-up. The typical signature of a hidden particle decay is also shown, in this case a heavy neutral lepton decaying to a muon and a pion.

constrained by previous experiments, and the reach of current experiments is limited by both luminosity and acceptance. Hence the search for low-mass BSM physics should also be pursued at the intensity frontier, along with expanding the energy frontier.

...give access to a large class of interesting

...e major observational puz-

...osmology, and can explore

...al "bottom line". SHiP also

has the unique ... flavour universality by comparing interactions of muon and tau neutrinos.

Why is the SHiP physics programme so timely and attractive?

SPS: the ideal machine

SHiP is a new type of intensity-frontier experiment motivated by the possibility to search for any type of neutral hidden particle with mass from sub-GeV up to O(10) GeV with super-weak couplings

Search for a broad range of FIPs:

- HNLs (Heavy Neutral Leptons)
- Dark photons
- Dark Scalar Higgs-like particles
- ALPs (Axion-like particles)
- Unprecedented measurements of Tau neutrinos

Tau neutrinos & Anti Tau neutrinos

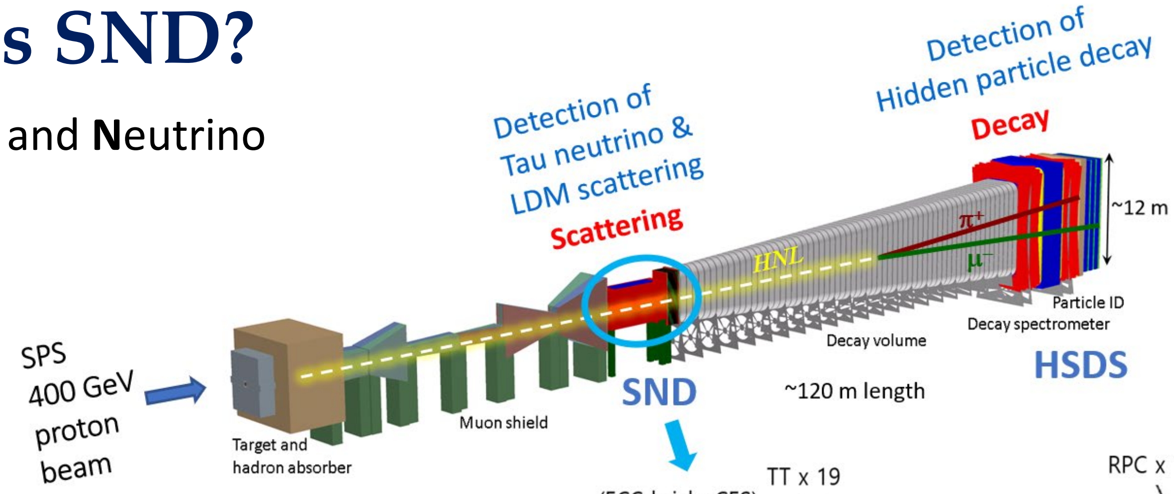
Decay channel	ν_τ	$\overline{\nu}_\tau$
$\tau \to \mu$	4×10^3	3×10^3
$\tau \to h$	27×10^3	
$\tau \to 3h$	11×10^3	
$\tau \to e$	8×10^3	
total	53×10^3	

Hidden particles (FIPs)

	Physics model	Final state
HSDS	SUSY neutralino	$\ell^\pm\pi^\mp,\ \ell^\pm K^\mp,\ \ell^\pm\rho^\mp, \ell^+\ell^-\nu$
	Dark photons	$\ell^+\ell^-, 2\pi, 3\pi, 4\pi, KK, q\bar{q}, D\bar{D}$
	Dark scalars	$\ell\ell, \pi\pi, KK, q\bar{q}, D\bar{D}, GG$
	ALP (fermion coupling)	$\ell^+\ell^-, 3\pi, \eta\pi\pi, q\bar{q}$
	ALP (gluon coupling)	$\pi\pi\gamma, 3\pi, \eta\pi\pi, \gamma\gamma$
	HNL	$\ell^+\ell'^-\nu, \pi l, \rho l, \pi^0\nu, q\bar{q}'l$
	Axino	$\ell^+\ell^-\nu$
	ALP (photon coupling)	$\gamma\gamma$
	SUSY sgoldstino	$\gamma\gamma, \ell^+\ell^-, 2\pi, 2K$
SND	LDM	electron, proton, hadronic shower
	$\nu_\tau,\ \overline{\nu}_\tau$ measurements	$\tau^\pm$
	Neutrino-induced charm production (ν_e, ν_μ, ν_τ)	$D_s^\pm,\ D^\pm,\ D^0,\ \overline{D^0},\ \Lambda_c^+,\ \overline{\Lambda}_c^-$

What is SND?

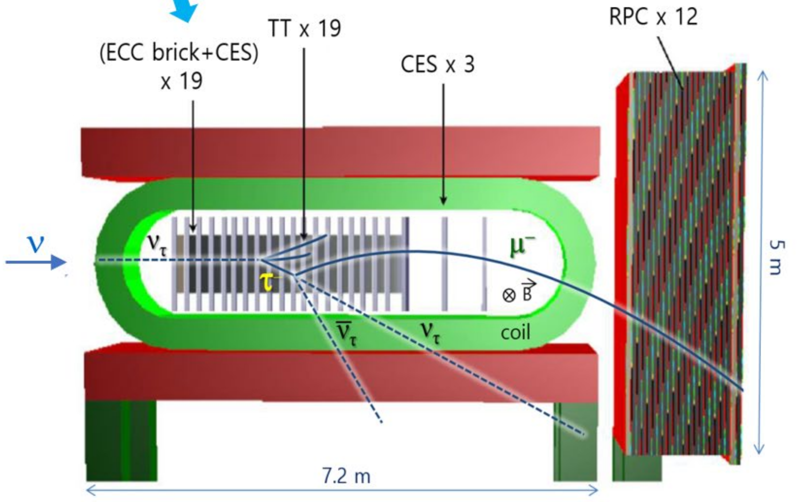
Scattering and **N**eutrino **D**etector



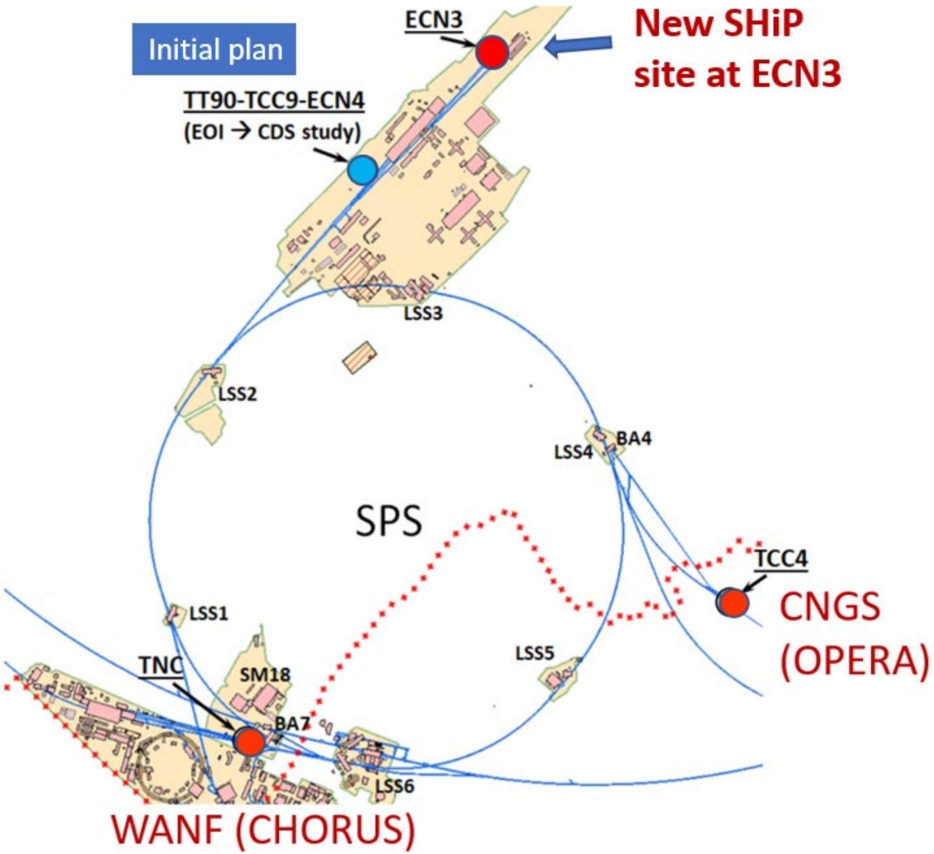
SHiP SND

ECC target : ~ 8 tons
2 x 2 bricks x 19 walls
(80 x 80 cm^2 /wall)

RPC : Muon ID, charge

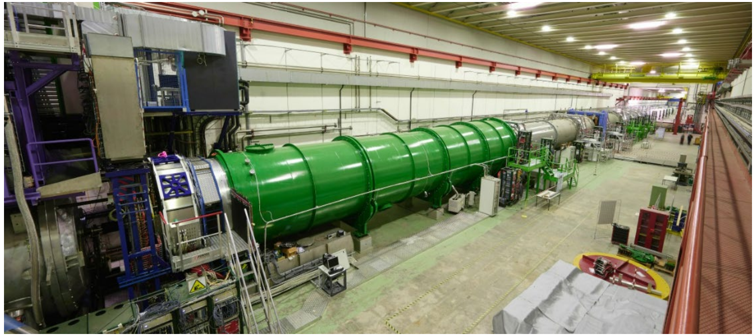


Initial design



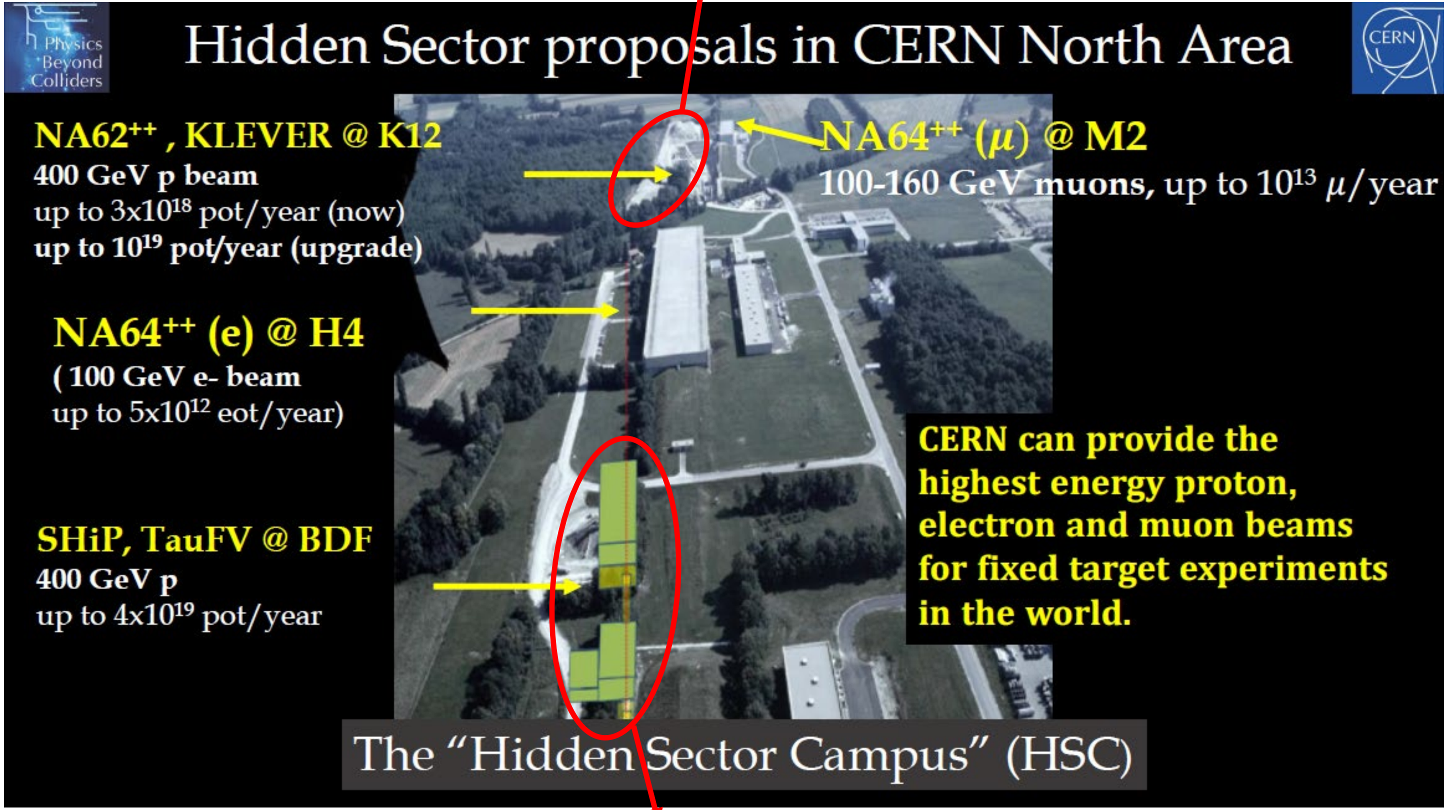
SHiP at ECN3 was approved by CERN RB on 6 Mar 2024.

NA62 in ECN3



- Currently hosting NA62 (~150m)
- Existing infrastructure

ECN3: New location of SHiP

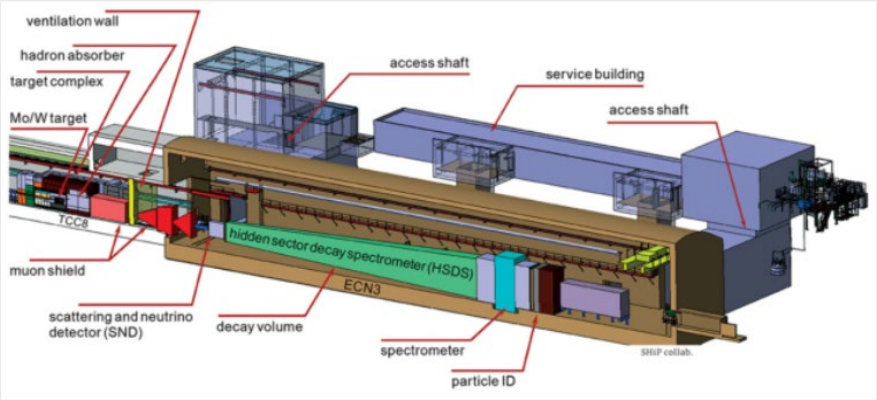


Initial plan

SEARCHES FOR NEW PHYSICS | NEWS

SHiP to chart hidden sector

3 May 2024



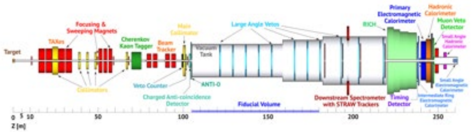
Full speed ahead Layout of the SHiP experiment, with the target on the left and the experiment in the ECN3 hall. Credit: SHiP collab.

"In terms of their science, SHiP and HIKE/SHADOWS were ranked equally by the relevant scientific committees," explains CERN director for research and computing Joachim Mnich. "But a decision had to be made, and

"But a decision had to be made, and SHiP was a strategic choice for CERN."

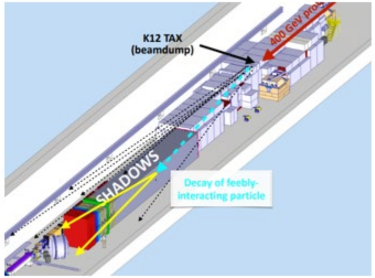
Our competitors : HIKE & SHADOWS

HIKE
High Intensity Kaon Experiments

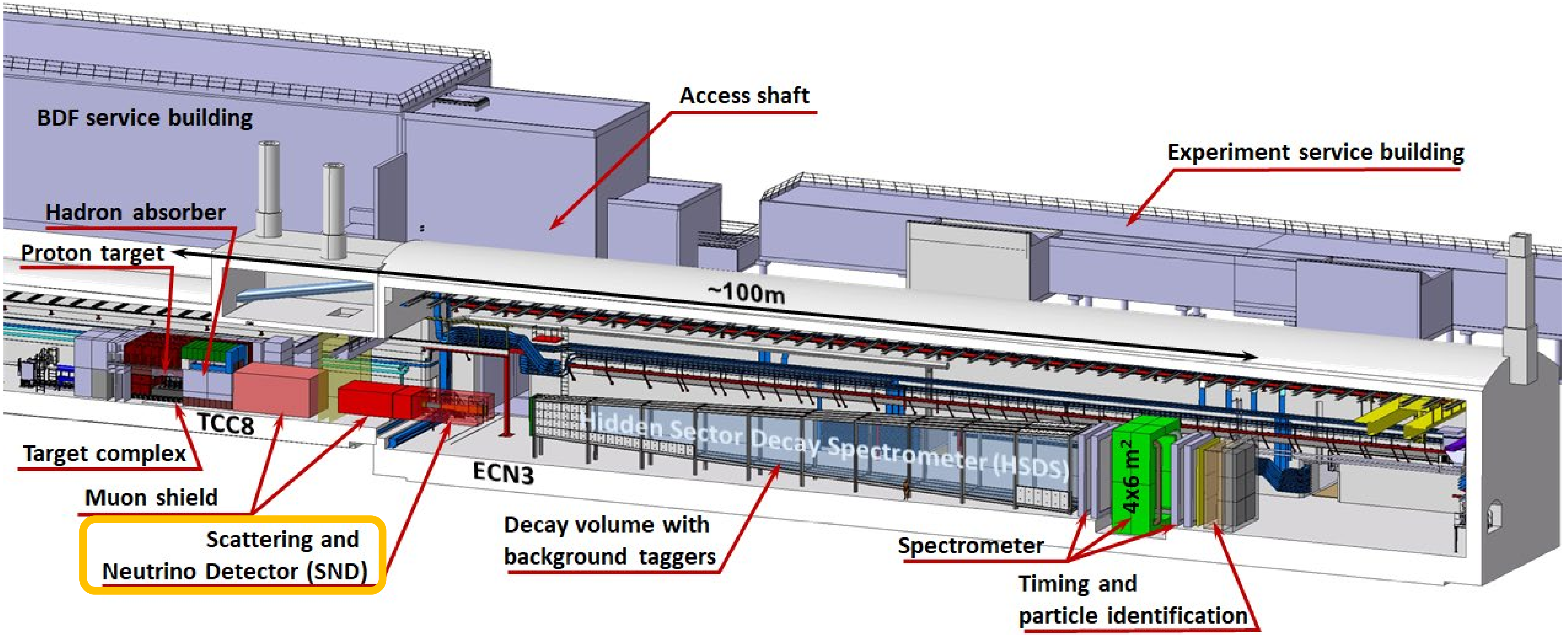


NA62 Successor

SHADOWS
Search for Hidden And Dark Objects With the SPS



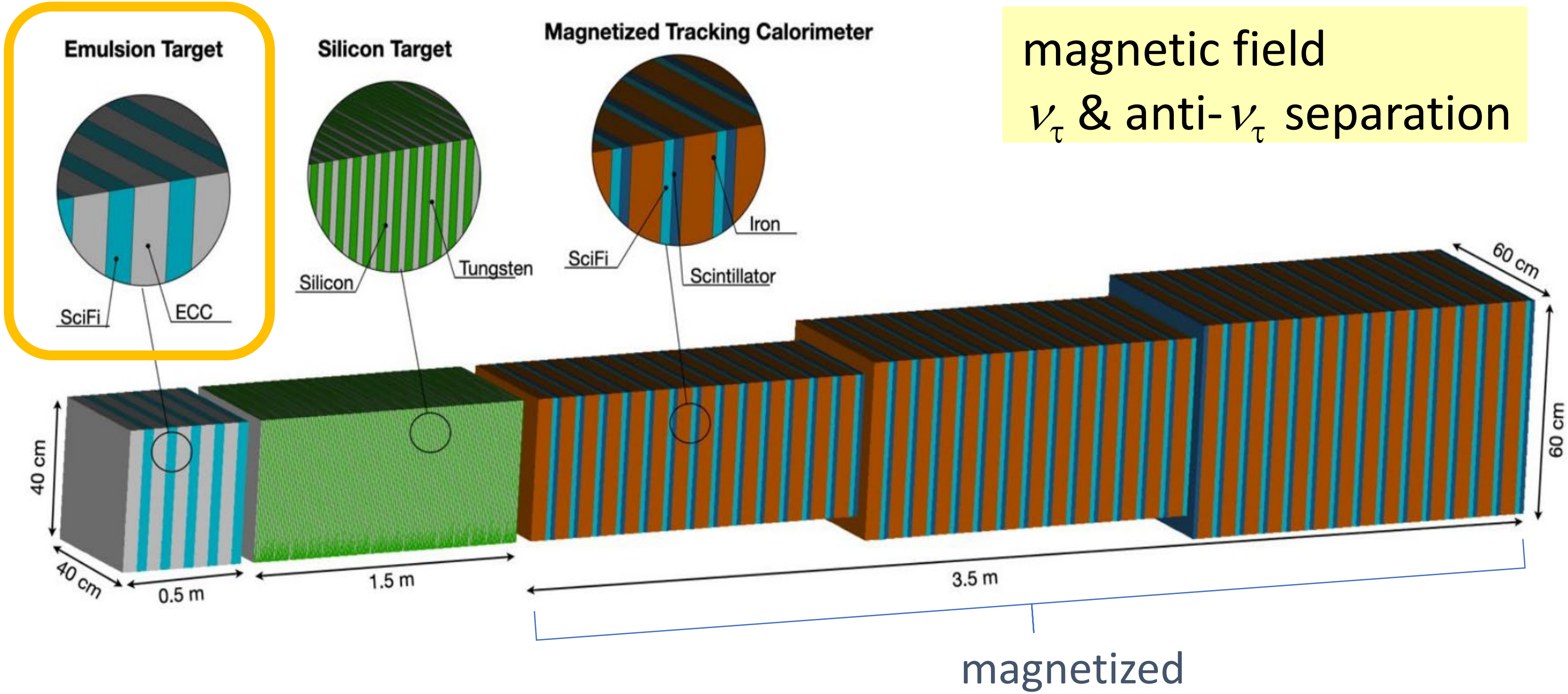
The SHiP detector (New design)



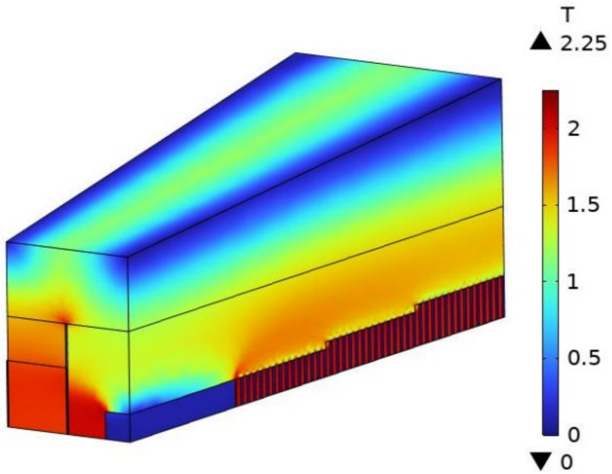
New design of SHiP SND

- Less emulsion, including Si & Scintillators

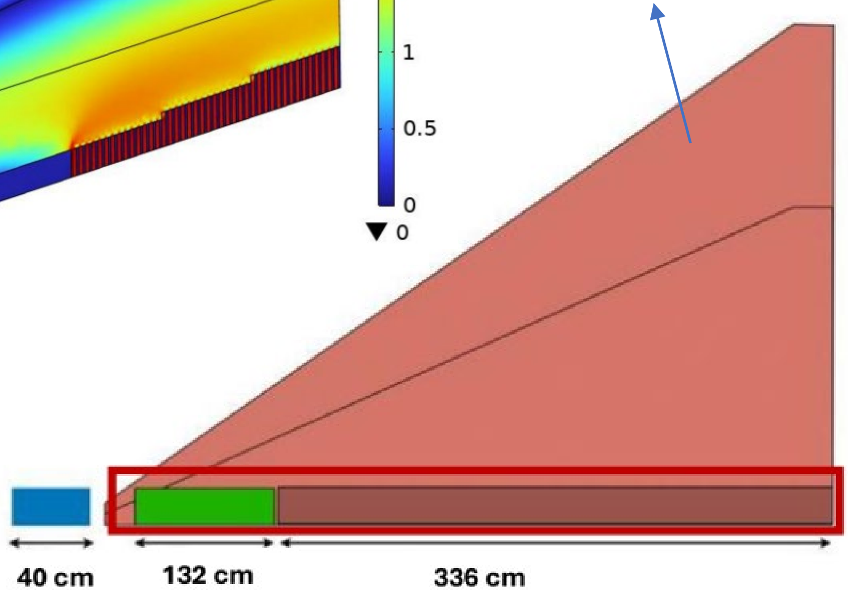
magnetic field
ν_τ & anti-ν_τ separation



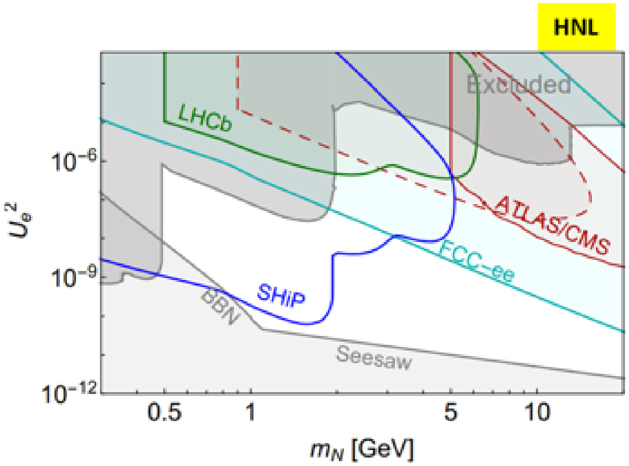
SND inside Muon shield

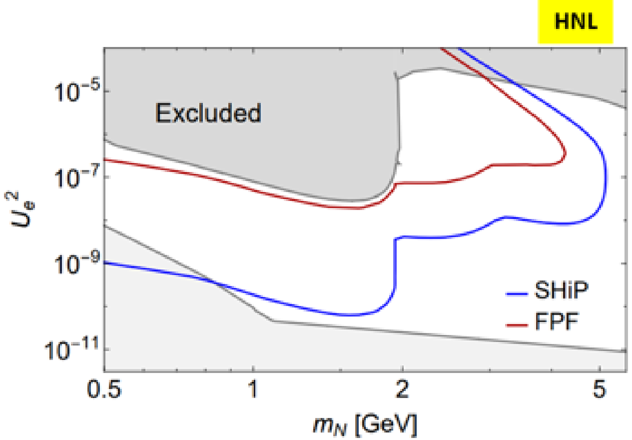


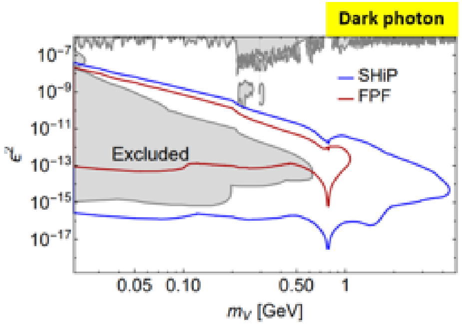
Muon shield
(Special magnet)

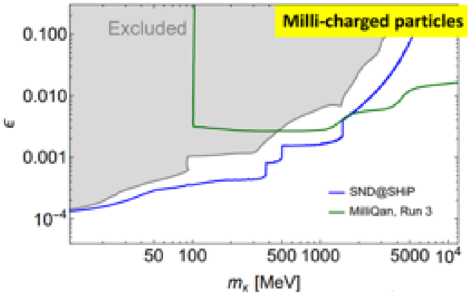


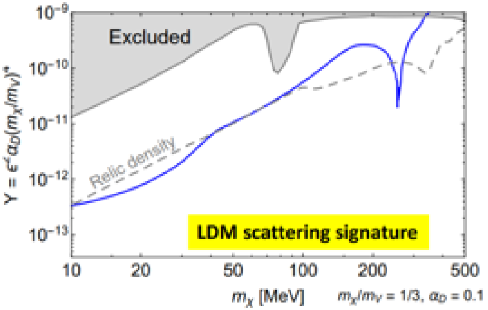
Sensitivities to various FIPs (Feebly Interacting Particles)





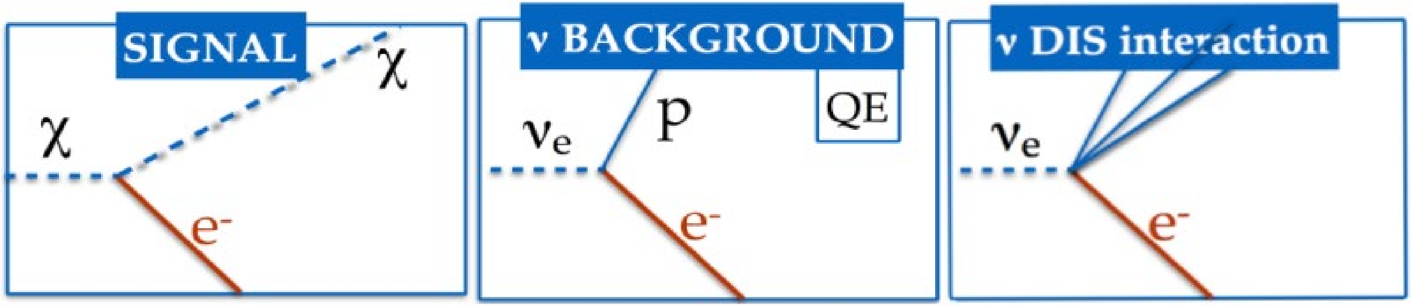


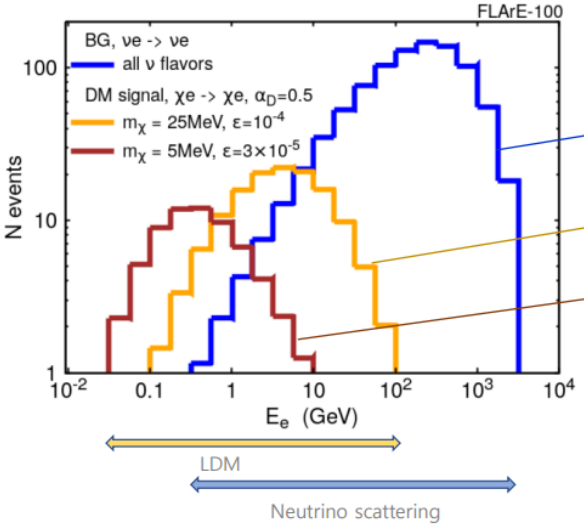




6 x 10^{20} PoT
in 15 years

LDM (Light dark matter)





electron-recoil

ν e → ν e BG

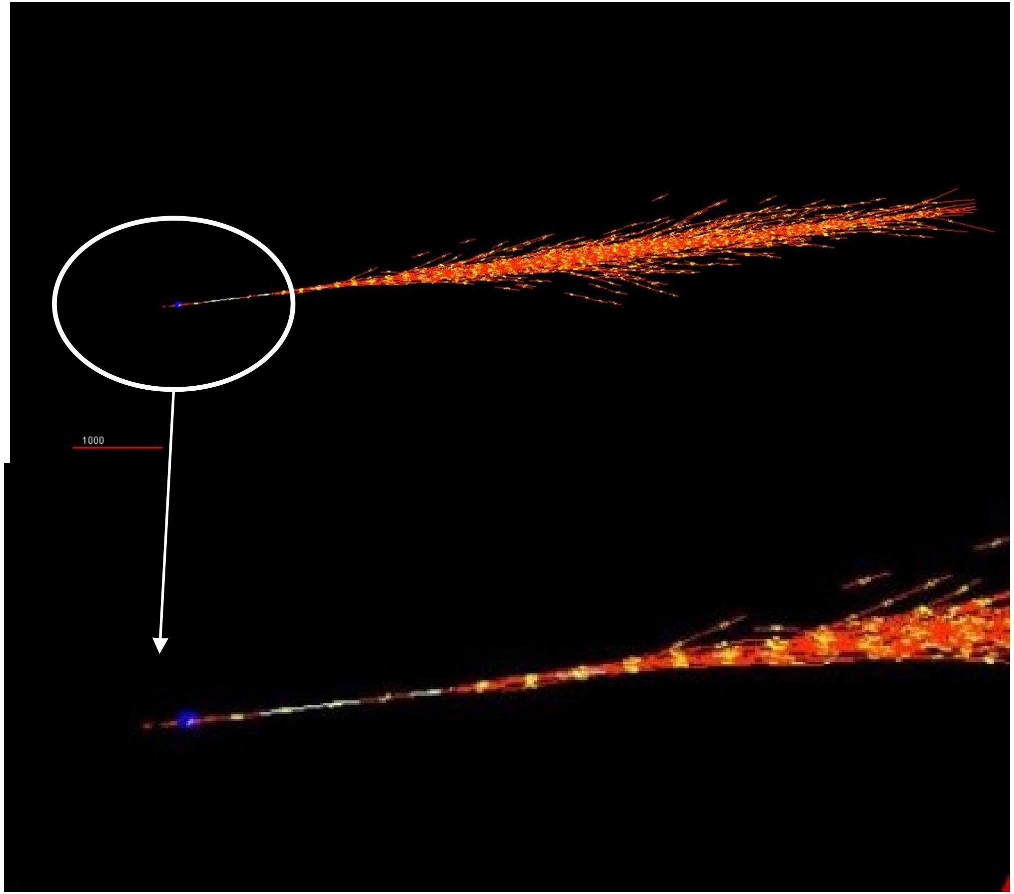
χ e → χ e (25 MeV)

χ e → χ e (5 MeV)

LDM

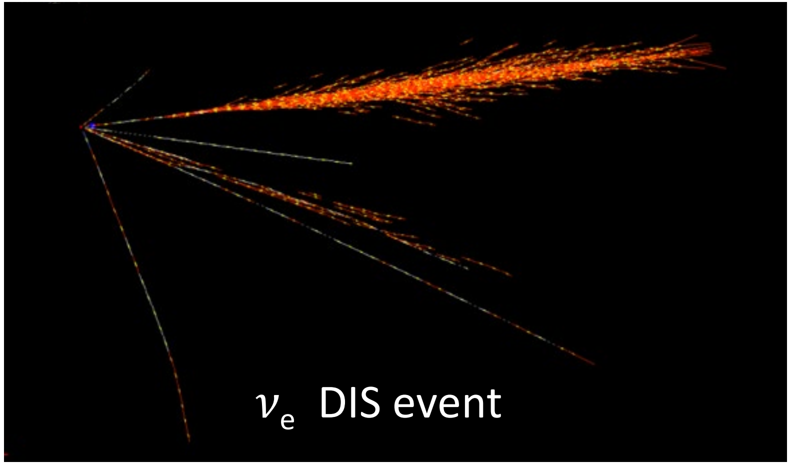
Brian Batell et al.
arXiv:2101.10338v2
Detecting Dark Matter with Far-Forward Emulsion and Liquid Argon Detectors at the LHC

ECC as LDM detector

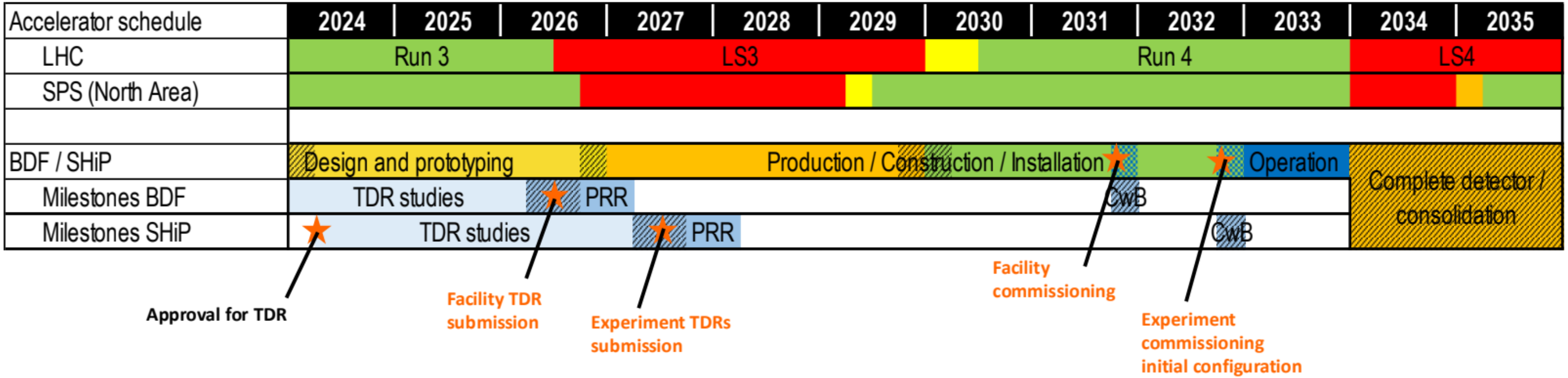


Single electron produced by LDM particle scattering

In the background suppression against ν_e interactions, the most powerful handle is the isolation criterion: **No extra-activity**



SHiP schedule

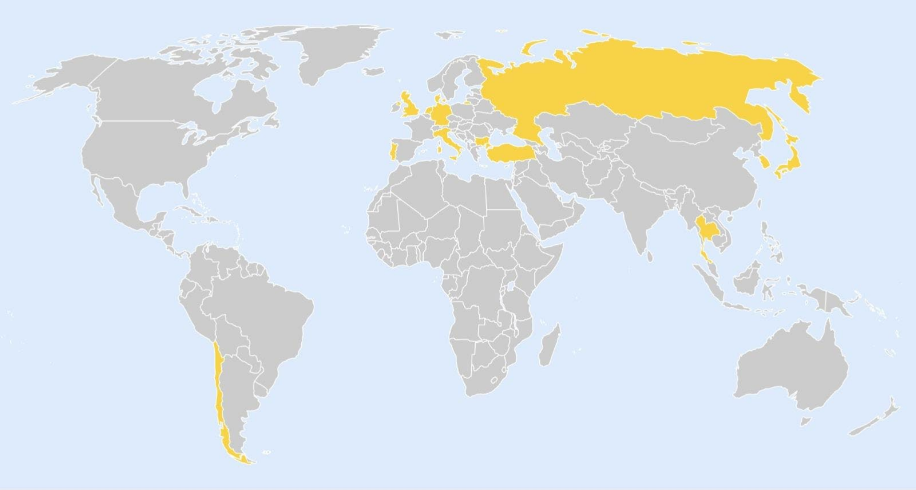


- ~3 years for detector **TDR** from 2024
- Construction / installation of detectors → LS3
- Start data taking (during Run 4) → **2032** (~2 years before LS4)

→ 15 years of Physics exploration (6 x 10^{20} pot)

Ground-breaking for HI-ECN3 (BDF/SHiP) 13th May 2025

SND@LHC Collaboration



~150 members
24 Institutes in 14 Countries and CERN

SHiP Collaboration

~250 members
35 institutes and 5 associated institutes
18 countries and CERN

SHiP
Collaboration

SND@LHC
Collaboration

	SND@LHC	SND@HL-LHC	SHiP
ν_μ	~ 1800	$\sim 2.4 \times 10^4$	$\sim 7 \times 10^5$
ν_e	~ 625	$\sim 5.5 \times 10^3$	$\sim 2 \times 10^5$
ν_τ	~ 30	$\sim 4.5 \times 10^2$	$\sim 5 \times 10^4$ (~3500/yr)
	$\sim 300\ fb^{-1}$ ($7.2 < \eta < 8.4$)	$\sim 3000\ fb^{-1}$ ($6.9 < \eta < 7.7$)	6×10^{20} pot (15 yrs)

Theoretical works

JHEP

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Probing the mixing between sterile and tau neutrinos in the SHiP experiment

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Abstract: We study the expected sensitivity to the mixing between sterile and tau neutrinos directly from the tau neutrino disappearance in the high-energy fixed target experiment. Here, the beam energy is large enough to produce tau neutrinos at the target with large luminosity. During their propagation to the detector, tau neutrinos may oscillate into sterile neutrinos. By examining the energy spectrum of the observed tau neutrino events, we can probe the mixing between sterile and tau neutrinos directly. In this paper, we consider Scattering and Neutrino Detector (SND) at SHiP experiment as a showcase, which uses 400 GeV protons from SPS at CERN, and expect to observe 7,300 tau and anti-tau neutrinos from the 2×10^{20} POT for 5 years operation. Assuming the uncertainty of 10%, we find the sensitivity $|U_{\tau 4}|^2 \sim 0.08$ (90% CL) for $\Delta m^2_{41} \sim 500$ eV^2 with 10% background to the signal. We also consider a far SND at the end of the SHiP Hidden Sector Decay Spectrometer (HSDS), in which case the sensitivity would be enhanced to $|U_{\tau 4}|^2 \sim 0.02$. Away from this mass, the sensitivity becomes lower than $|U_{\tau 4}|^2 \sim 0.15$ for $\Delta m^2_{41} \lesssim 100$ eV^2 or $\Delta m^2_{41} \gtrsim 10^4$eV^2.

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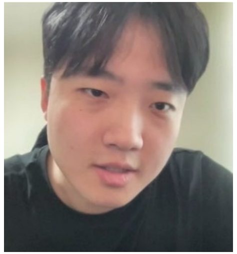

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Regular Article - Theoretical Physics

Novel search for light dark photon in the forward experiments at the LHC

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Abstract We propose a novel approach for discovering a light dark photon in the forward experiments at the LHC, including the SND@LHC and the FASER experiments. Assuming the dark photon is lighter than twice the electron mass and feebly interacts with ordinary matter, it is long-lived enough to pass through 100 m of rock in front of the forward experiments and also through the detector targets. However, some portion of them could be converted into an electron-positron pair inside the detector through their interaction with the detector target, leaving an isolated electromagnetic shower as a clear new physics signature of the dark photon. With copiously produced dark photons from neutral pion decays in the forward region of the LHC, we expect to observe sizable events inside the detector. Our estimation shows that more than 10 signal events of the dark photon could be observed in the range of kinetic mixing parameter, $6.2\times10^{-5} \lesssim \epsilon \lesssim 2\times10^{-1}$ and $3\times10^{-5} \lesssim \epsilon \lesssim 2\times10^{-1}$ for dark photon mass $m_{A'} \lesssim 1$ MeV with integrated luminosities of 150 fb^{-1} and 3 ab^{-1}, respectively.

1 Introduction

The ATLAS and CMS detectors at the Large Hadron Collider (LHC) in CERN have been successfully operating and played pivotal roles in discovering Higgs boson in 2012 [1,2]. While these detectors are well-equipped at large angles relative to the beamline and therefore capable of detecting new physics with high transverse momentum p_T, they have holes in the far-forward direction. This limitation could potentially result in missed opportunities to detect (new) particles produced in the far-forward region.

To address this limitation, the FASER [3] and the SND@LHC [4] experiments were designed to detect high-energy neutrinos and explore new particles that are produced in the far-forward direction at the LHC. These experiments are located 480 m downstream of the ATLAS interaction point (IP) along the beam collision axis. Charged particles from the IP are deflected by LHC magnets, while the remaining particles are further shielded by the 100 m of rock and concrete in front of the detectors. However, neutrinos and feebly interacting new particles would easily pass through this shielding and reach the detectors.

Y. G. Kim

K. Y. Lee

Summary

- **SND@LHC** measures neutrinos in the forward region of pp collisions

  - Forward charm production, lepton flavour universality, neutrino interactions, …

- The experiment has recorded 209 fb^{-1} of data so far.

  Observation of collider muon neutrinos (2023)

  Observation of neutrinos without final state muons (2024)

- **SND@HL-LHC** detector will be instrumented with silicon strip modules and a magnetized calorimeter to run in the HL-LHC era.

SND@HL-LHC was Approved by CERN RB on 11 June 2025.

- **SHiP** SND design is being optimized - less emulsion target, add Si detector
- Ground-breaking was started at ECN3 from May 2025.

We welcome anybody who is interested in SND@LHC, SND@HL-LHC and SHiP.

We wish young people could participate these future CERN neutrino experiments.

Thank you !