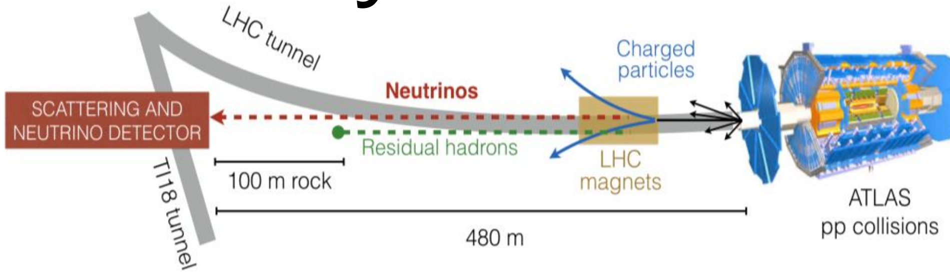
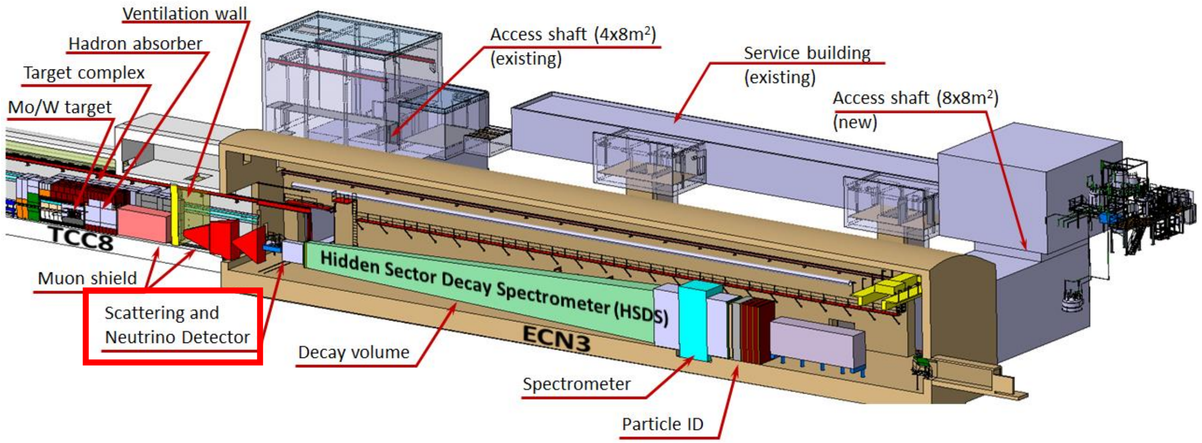
CERN SND@LHC 実験と SHiP 実験の現状

名古屋大学　小松雅宏

Brief history of the two experiments



SND@LHC

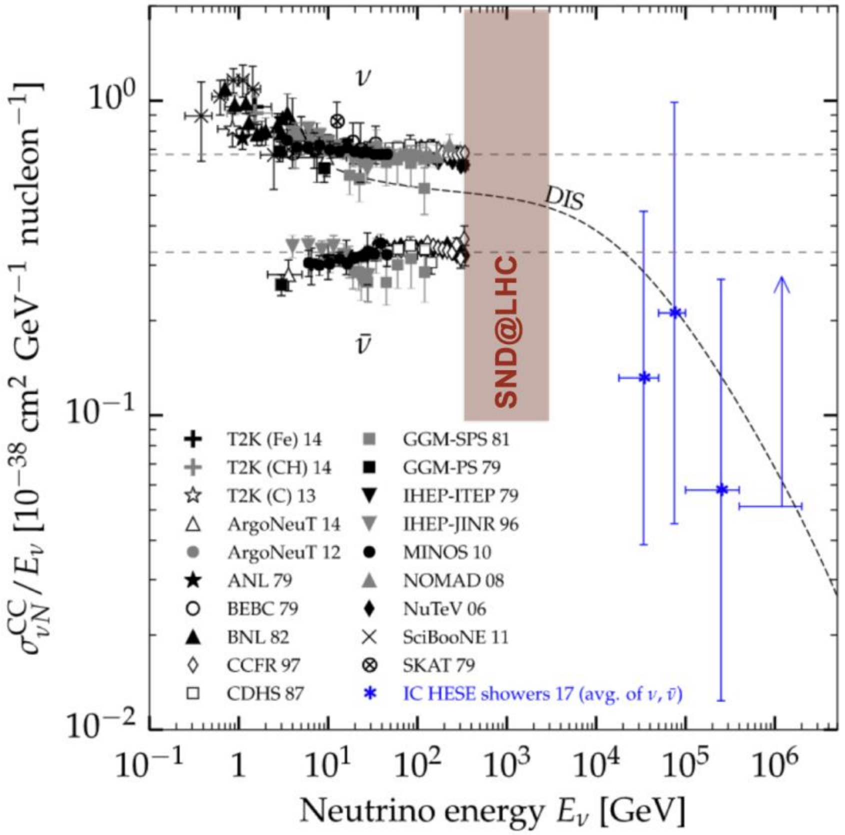


SHiP@ENC3 (Existing North Area Hall)

- **SHiP**
  - Proposal submitted on **April 2015** at new beam line for the experiment (ECN4). ESPP 2020 outcome was unfavorable for SHiP@ENC4.
  - Looked for other existing location can host SHiP. CNGS, WANF and ECN3?
  - **New proposal submitted** at existing hall (ECN3).
- **SND@LHC**
  - **SND**(**S**cattering and **N**eutrino **D**etector)**@LHC** was approved on **March 2021**.
  - Data taking started in April 2022.
- Both beam provides all three(six) neutrino flavors.

Physics Motivation

- 1990, Klaus Winter pointed out possibility of tau neutrino detection at LHC neutrino
  - The first tau neutrino detection done by Fermilab E872 DONUT with 800 GeV proton beam dump in 2000. (Phys.Lett.B 504 (2001) 218-224)
  - Still number of observed tau neutrino interactions are limited (DONUT and OPERA)

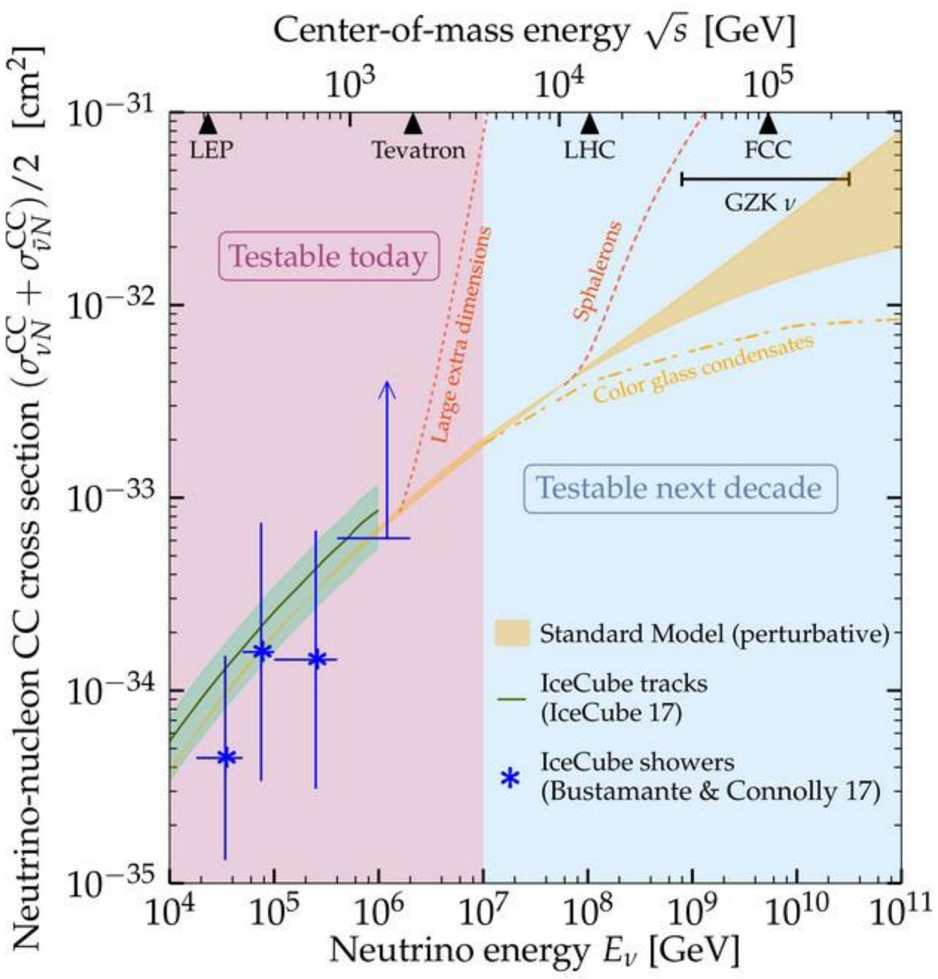


CERN is unique in providing high energy neutrinos in an unexplored energy region from LHC.

Two neutrino experiments, **SND@LHC** and **FASERν**, in operation at ATLAS interaction point. Good for forward heavy flavor production study.

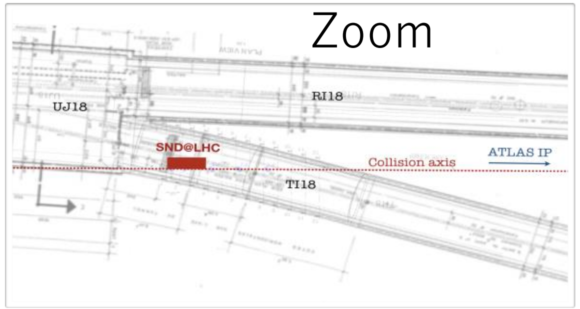
LHC neutrino contains all three kinds of high energy neutrino useful to study lepton flavor universality.

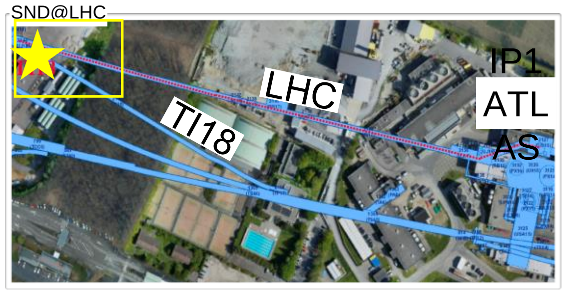
Motivation



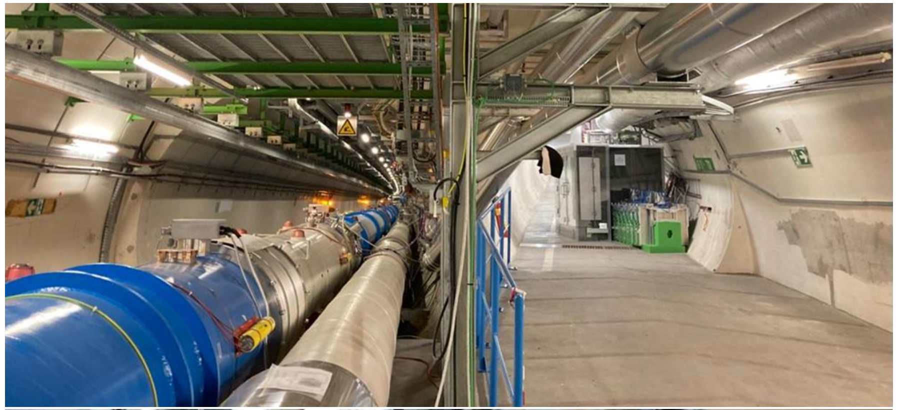
- Unique in measuring pp→**ν**X, equivalent with 10^{17} eV(10^{8} GeV) cosmic ray interaction which produce ultra high energy neutrinos.
- LHC neutrino allows us to reach forward region charm production where even LHCb (2<η<5) can not reach.
- Neutrino is good probe for heavy flavors. LHCf can study forward neutral particles but those are mostly coming from light particles.

Location





- About 480m away from the ATLAS IP
- TI18 tunnel : former service tunnel connected SPS to LEP. Not used anymore.
- Symmetric to TI12 tunnel where FASER is located.



- Charged secondary particles deflected by LHC bending magnets
- Shielded by 100 m of rock
- Located slightly **off axis**
  - Angular acceptance: **7.2<η< 8.4**
  - FASER is placed on axis covering η>8.8
- Aiming to collect 290 fb^{-1} (150 in proposal)
  - More luminosity become available in RUN3

Installation, commissioning and run status

- Installation in TI18 started on November 1st 2021
- Electronic detector installation completed on December 3rd 2021
- Installation of the neutron shield completed on March 15th 2022

September 2021

December 2021

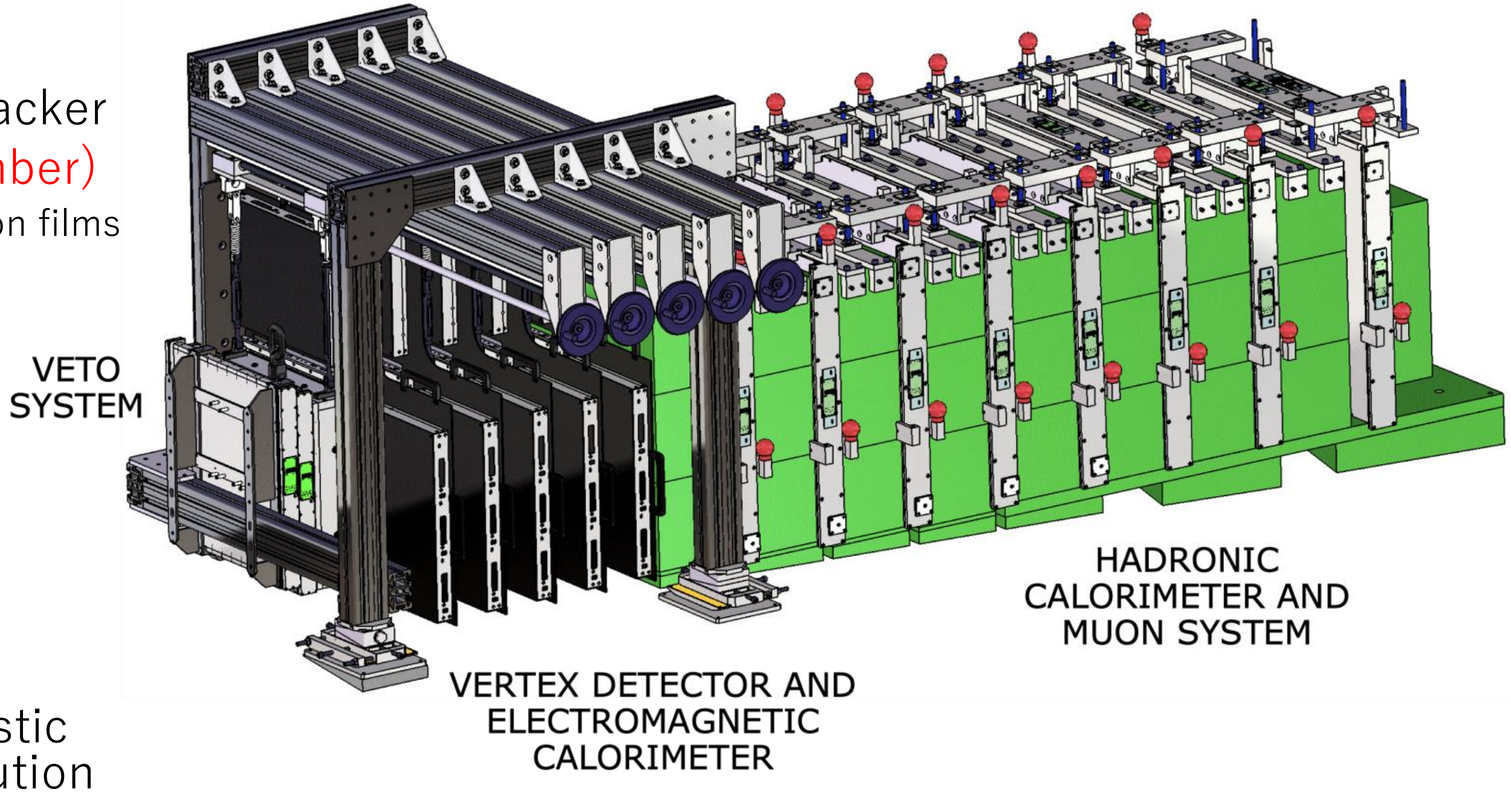
March 2022

SND@LHC detector

- Veto System
  - Tag penetrating muons (Scintillating bars)

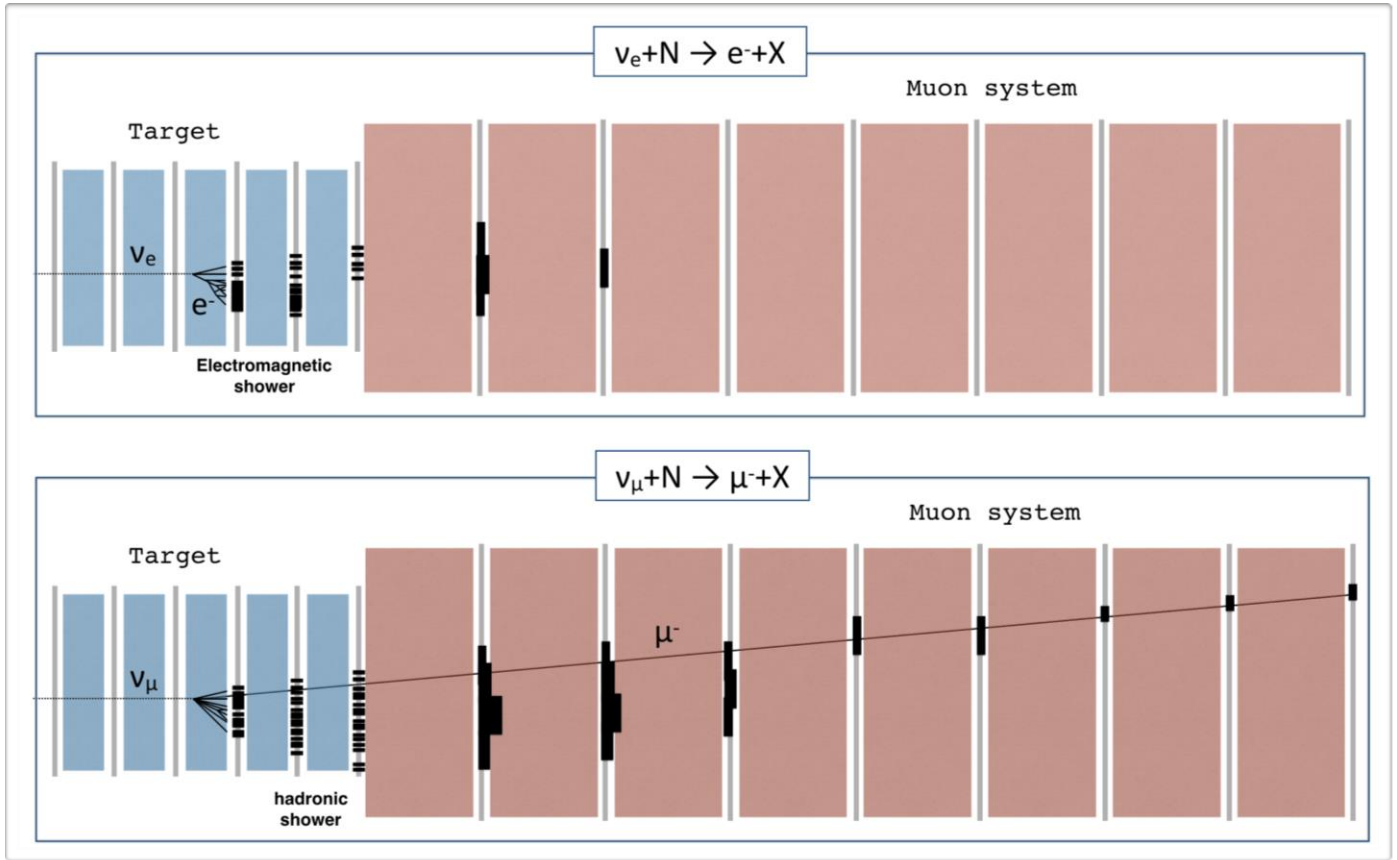
- Vertex Detector and EM Cal
  - Five target walls followed by SciFi tracker
  - Tungsten ECC(Emulsion Cloud Chamber)
    - 59 1mm thick tungsten plate + 60 emulsion films
    - **830 kg target**
    - Neutrino interaction vertex detector
    - Flavor identification for ν_e and ν_τ
  - Scintillating fibers for timing and EM calorimetry
    - 17 X_0 each 5 target walls

- Had Cal and Muon System
  - 8 iron walls (8λ) interleaved with plastic scintillator planes for fast time resolution and hadronic energy measurement

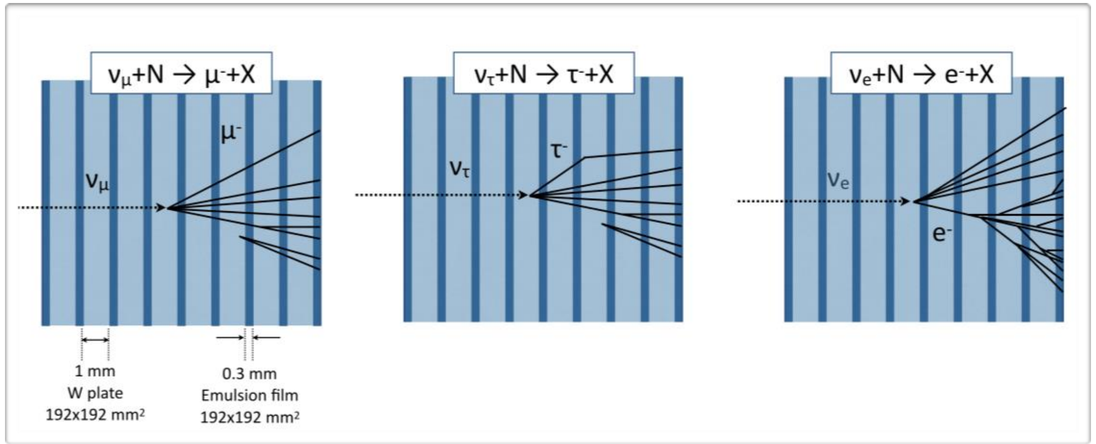


EVENT RECONSTRUCTION

- **FIRST PHASE: electronic detectors**
- Event reconstruction based on Veto, Target Tracker and Muon system
  - Identify neutrino candidates
  - Identify muons in the final state
  - Reconstruction of electromagnetic showers (SciFi)
  - Measure neutrino energy (SciFi+Muon)



- **SECOND PHASE: nuclear emulsions**
- Event reconstruction in the emulsion target
  - Identify e.m. showers
  - Neutrino vertex reconstruction and 2ry search
  - Match with candidates from electronic detectors (time stamp)
  - Complement target tracker for e.m. energy measurement

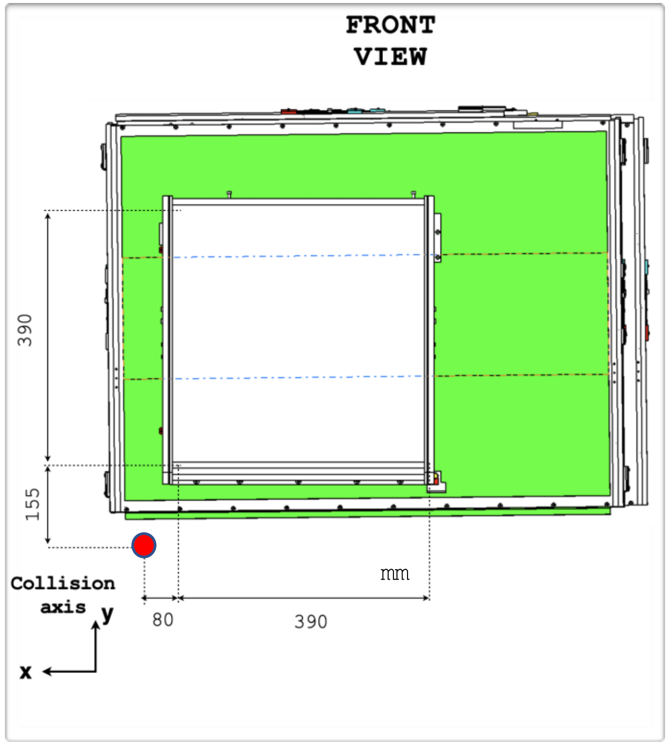


Flavor identification by ECC

Layout

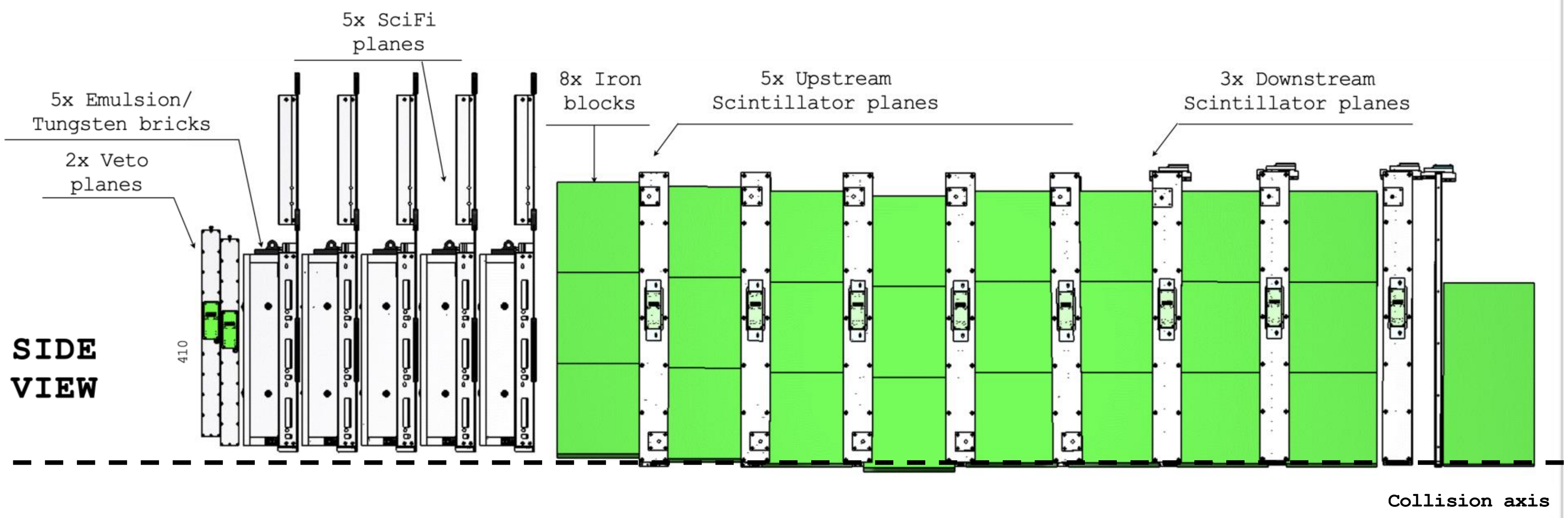
- Angular acceptance: $7.2 < \eta < 8.4$
- Target material: Tungsten
- Target mass: 830 kg
- Surface: 390x390 mm^2

Off axis location

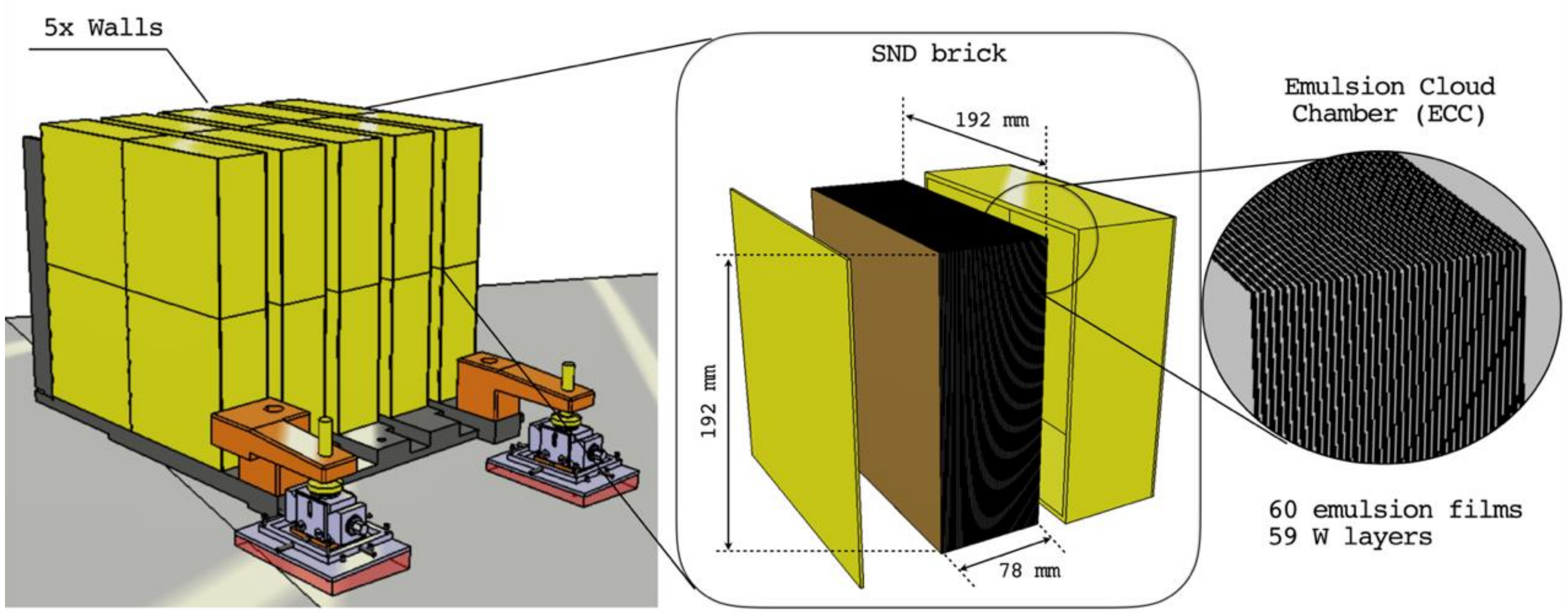


Electromagnetic calorimeter ~40 X_0

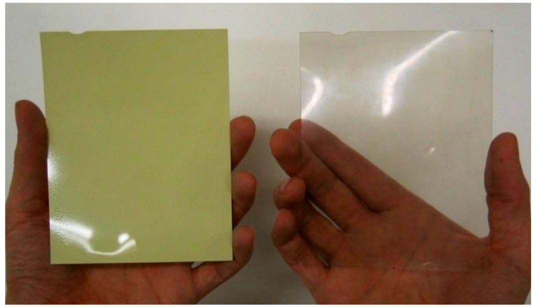
Hadronic calorimeter ~10 λ



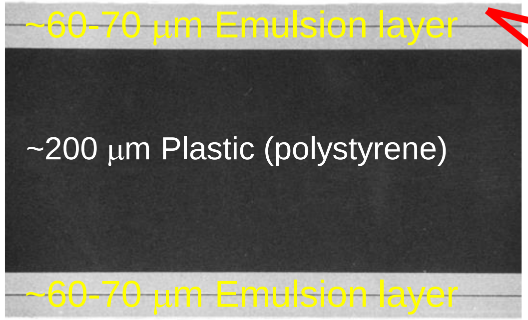
ECC target



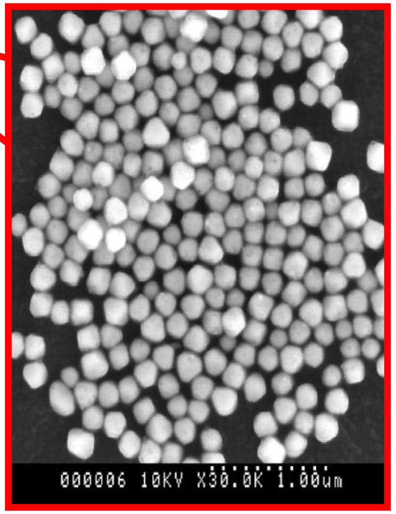
- Number of bricks : 20
  - walls: 5
  - Bricks per wall : 4
- Brick surface: 192x192 mm^2
  - Brick thickness: 78 mm
  - 60 films + 59 W plate
- Passive material : Tungsten
  - Total mass : 830 kg
  - Total emulsion surface : 44 m^2



Before and after development

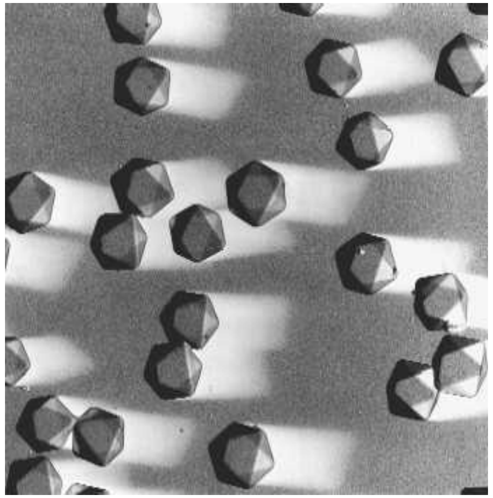


film cross section



Fine 3D tracking detector composed of 0.2 μm diameter AgBr crystal in gelatin.

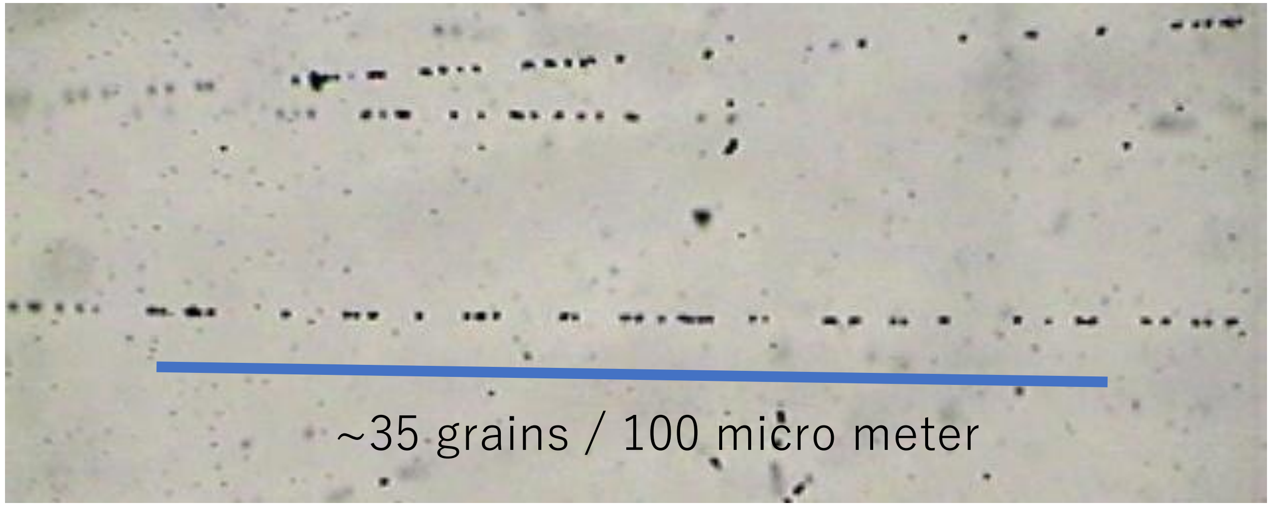
Nuclear emulsion



AgBr crystal : size 0.2 – 0.3 micro meter in diameter.

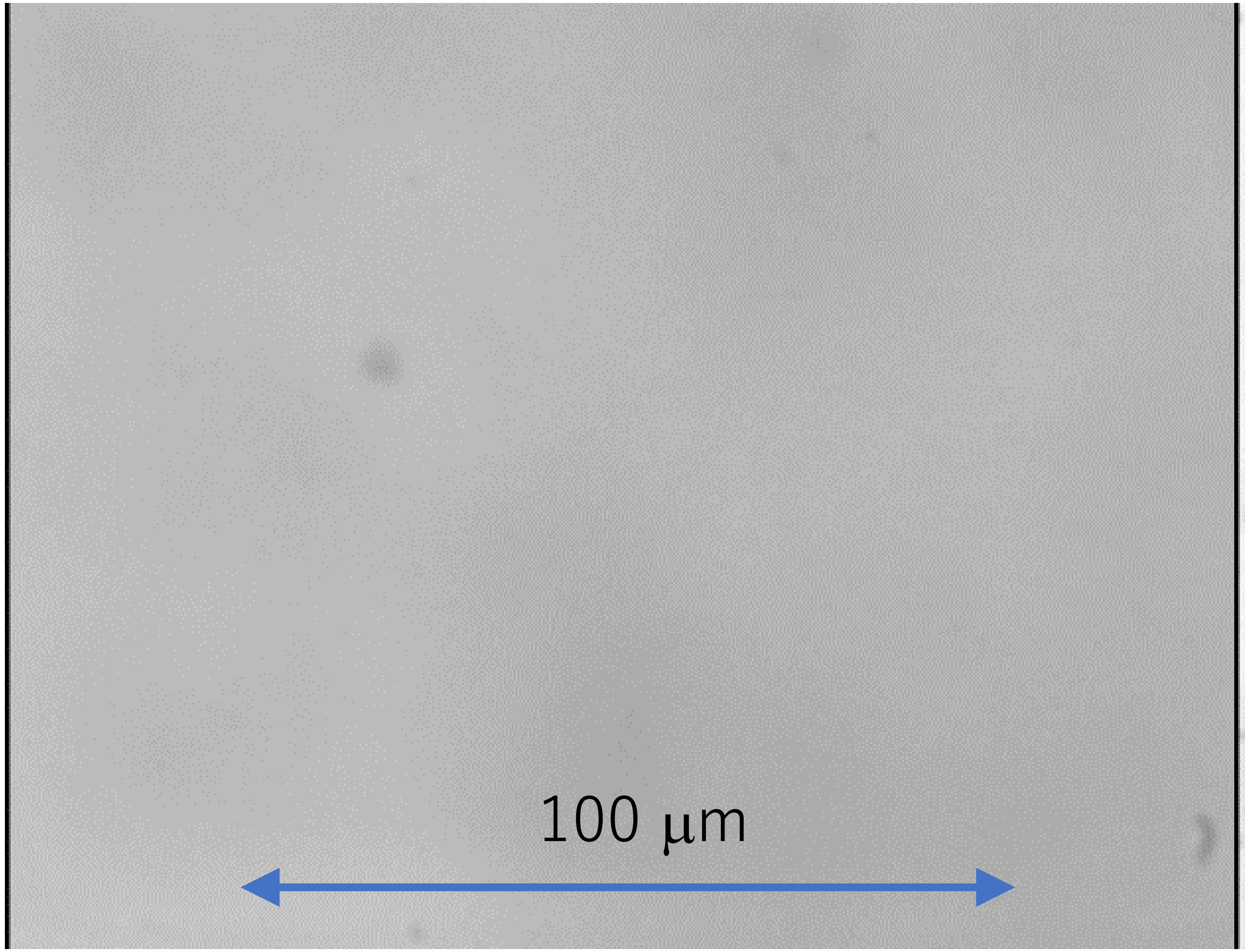
Charged particle produce latent image, developing process make Ag grain visible.

MIP

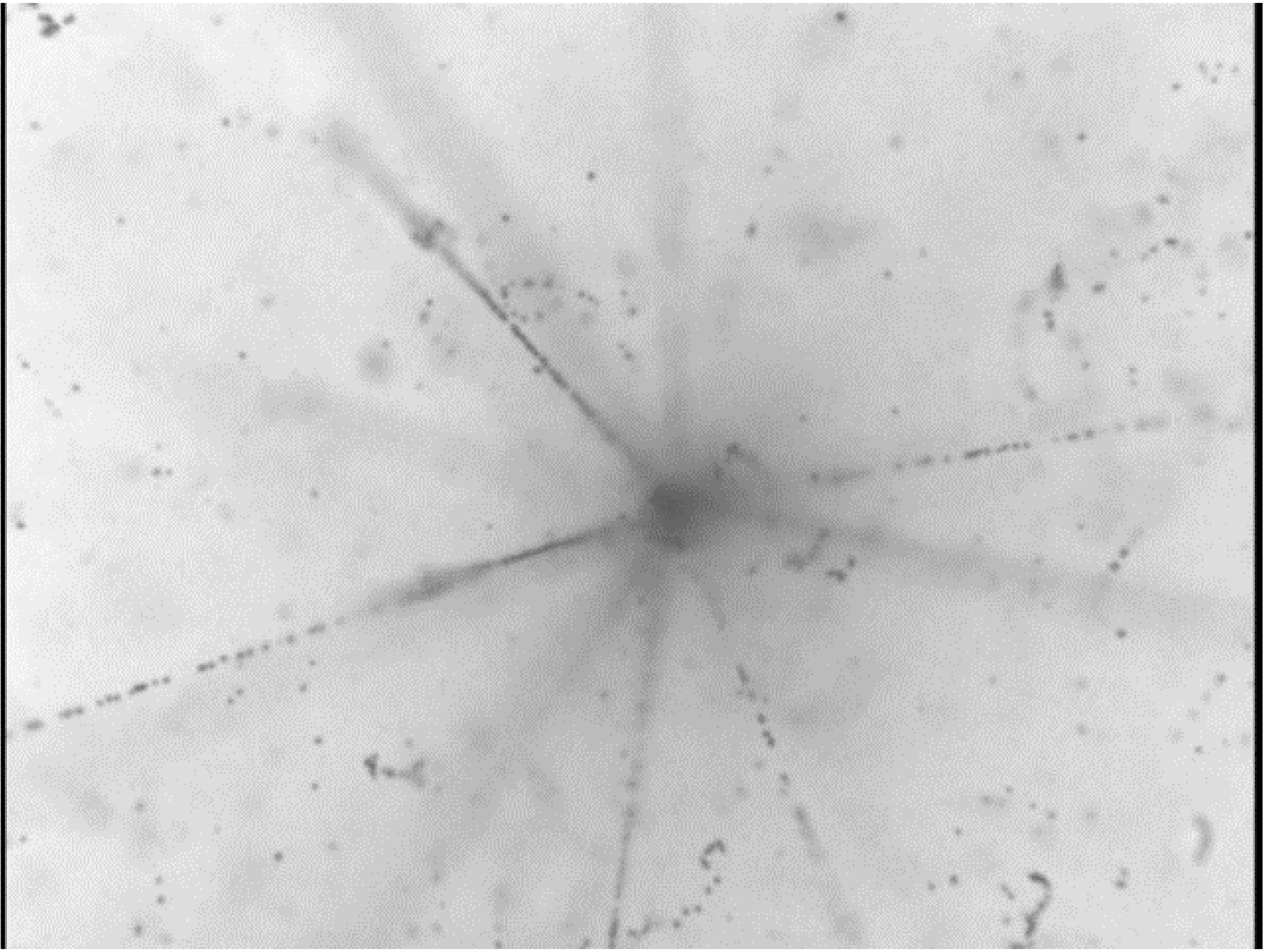


High energy interaction in emulsion

600 GeV π^-

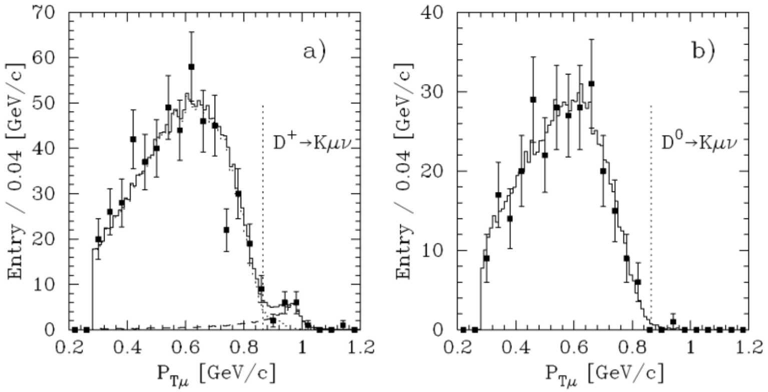


Sulfur 200 GeV/nucleon



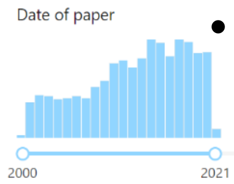
Tau neutrino and Emulsion (自己紹介)

- Tau neutrino source
  - B($D_s \to \mu\nu$) is first measured by emulsion experiment in CERN WA75 (Prog. Theo. Phys. 89:131-138,1993) and Fermilab E653 (Phys.Lett.B 382 (1996) 299-304)

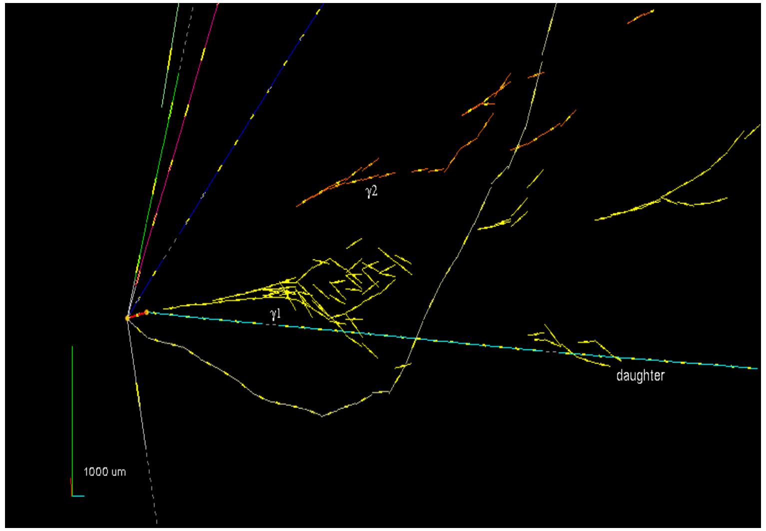


lines represent Monte Carlo results; the contribution from $D_s^\pm \to \mu^\pm \nu_\mu$ in (a) is evaluated to be $9.1^{+3.8}_{-3.0}$ events in the absence of background.

- Tau neutrino detection



  - First observation of tau neutrino interactions by Fermilab E872 DONUT. (Phys. Lett. B504:218-224,2001) citation 1,468 (@'23 Apr.)
  - First tau neutrino appearance in oscillation by OPERA. (Phys.Lett.B691:138-145, 2010)
  - Finally 10 tau neutrinos in OPERA
    - (Phys. Rev. Lett. 115(2015) 12, 121802)
    - (Phys. Rev. Lett. 120(2018) 21, 211801)



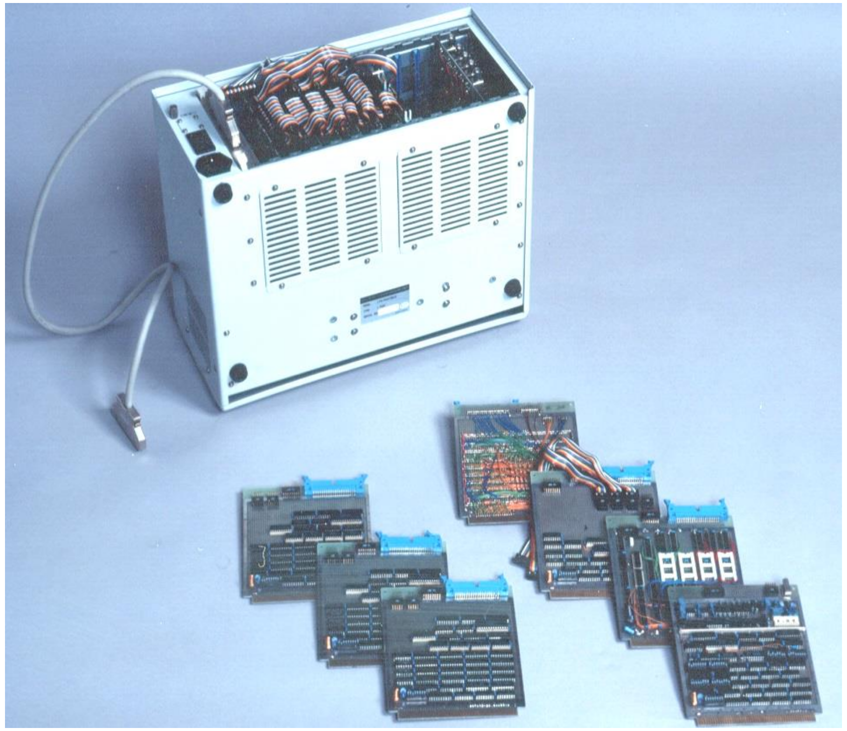
History of scanning system

semi-automatic scanning in late 1980’s.

- Fermilab E653 and CERN WA75 analysis has been done with these systems with human aid.

- Up to 1994, we used these systems for emulsion analysis.

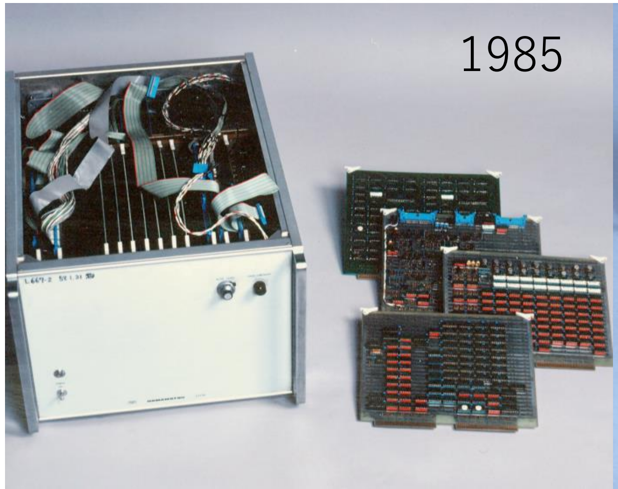
Track Selector (TS) 1994

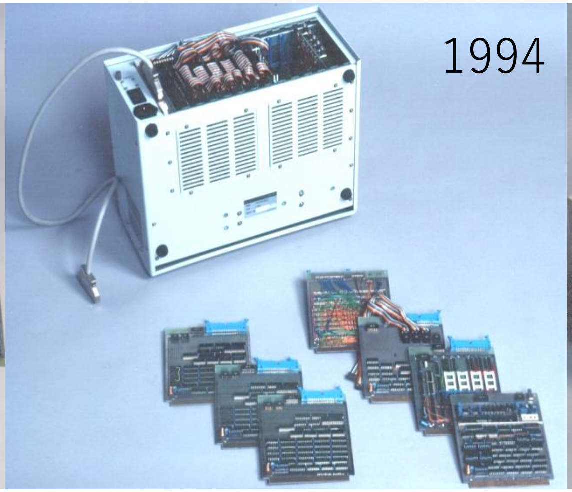


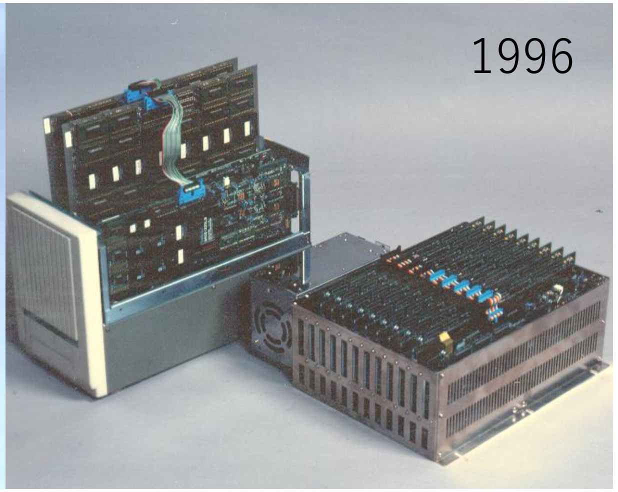
- 30 years ago, for CHORUS.
  - We made big decision to change future (current) emulsion scanning.

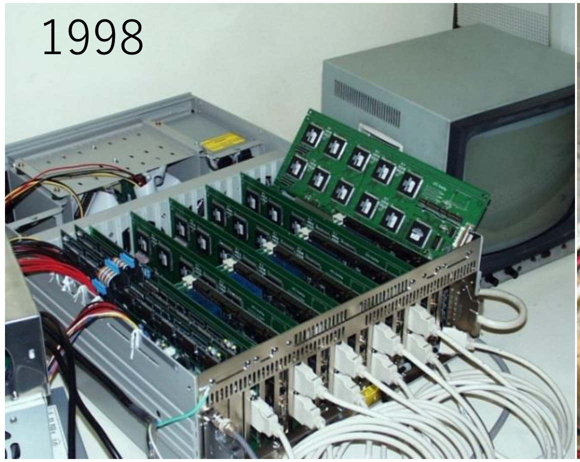
Evolution of the scanning system

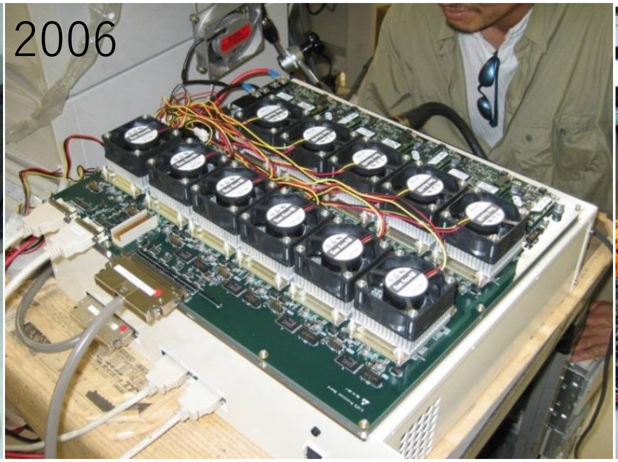
CHORUS, DONUT, OPERA and future…

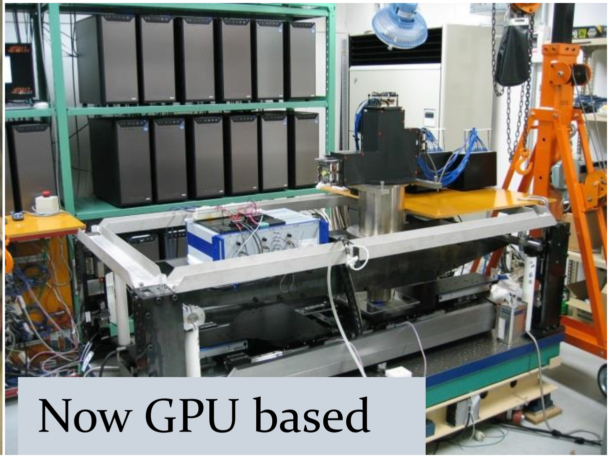




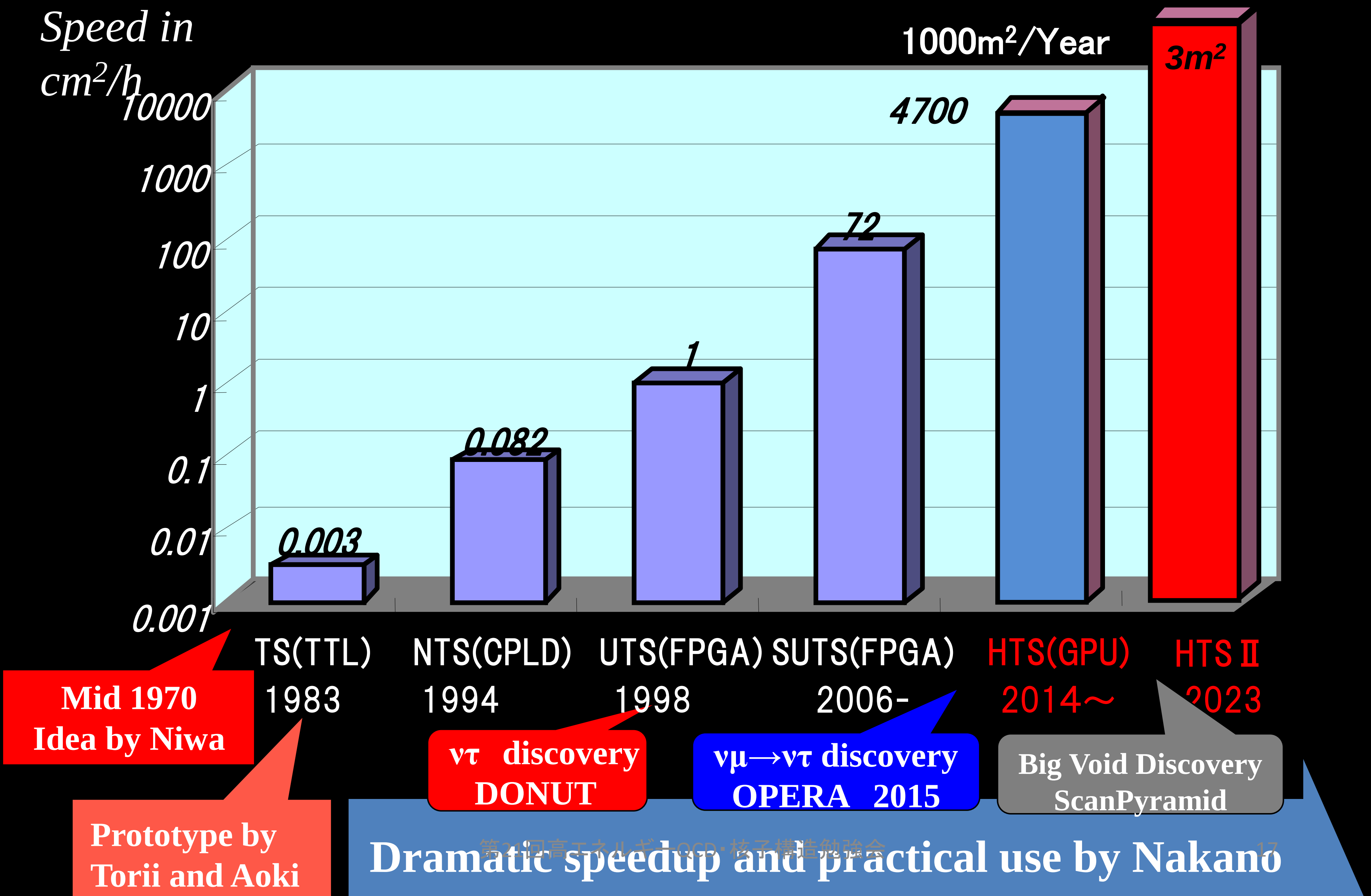








Development of Nuclear Emulsion Read-out System

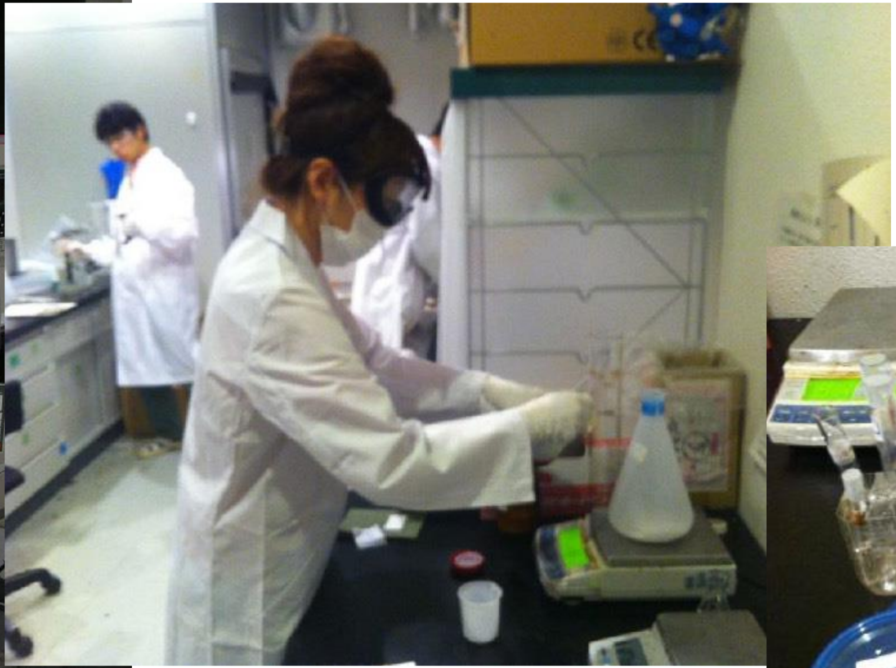


Fully Automated Nuclear Emulsion Read-out System
HTS Ⅰ

Read-out power： ～4500cm^2/h ～1000㎡/year

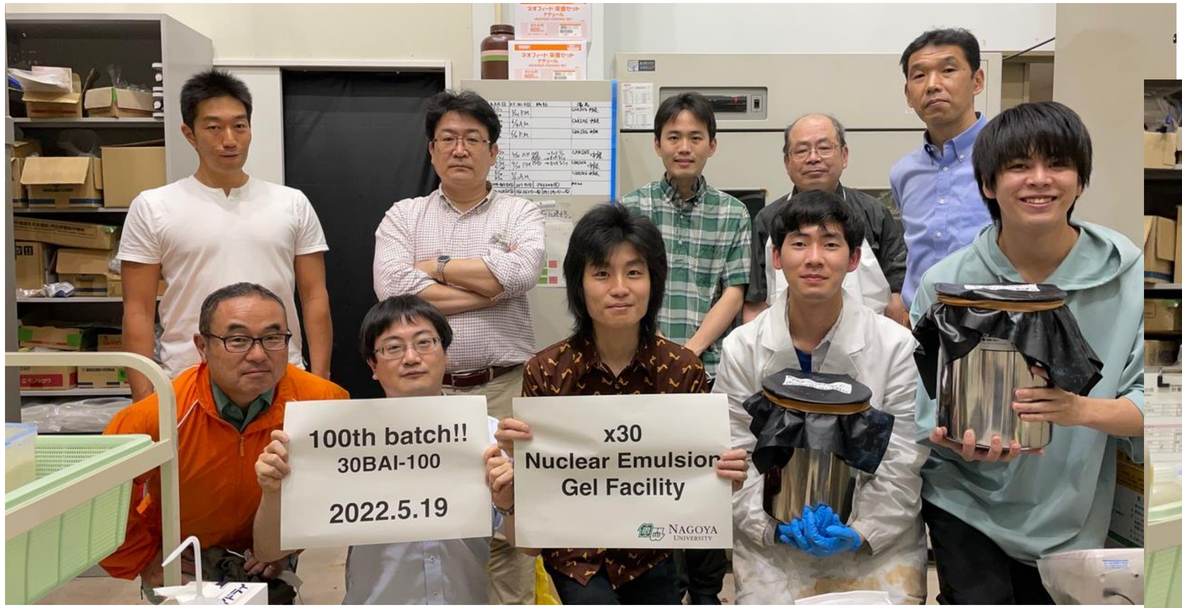
Introduce Emulsion Gel Production System (2010-)

In cooperation with retired researchers of the Fuji Film Co.



Since 2019, upgrade the system for mass production

Gel and Film Production

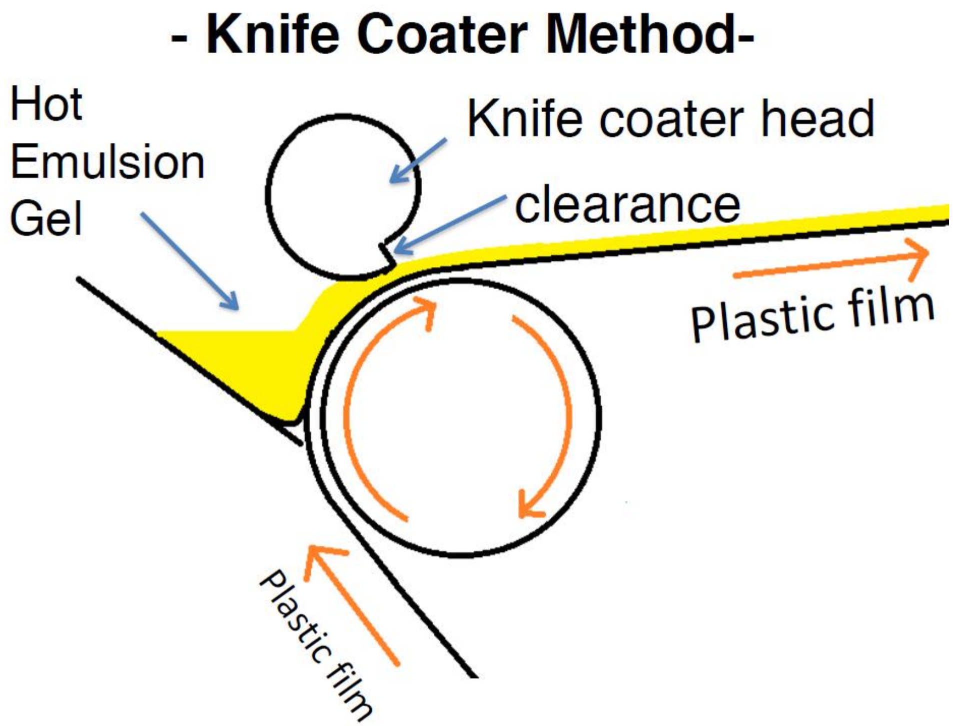


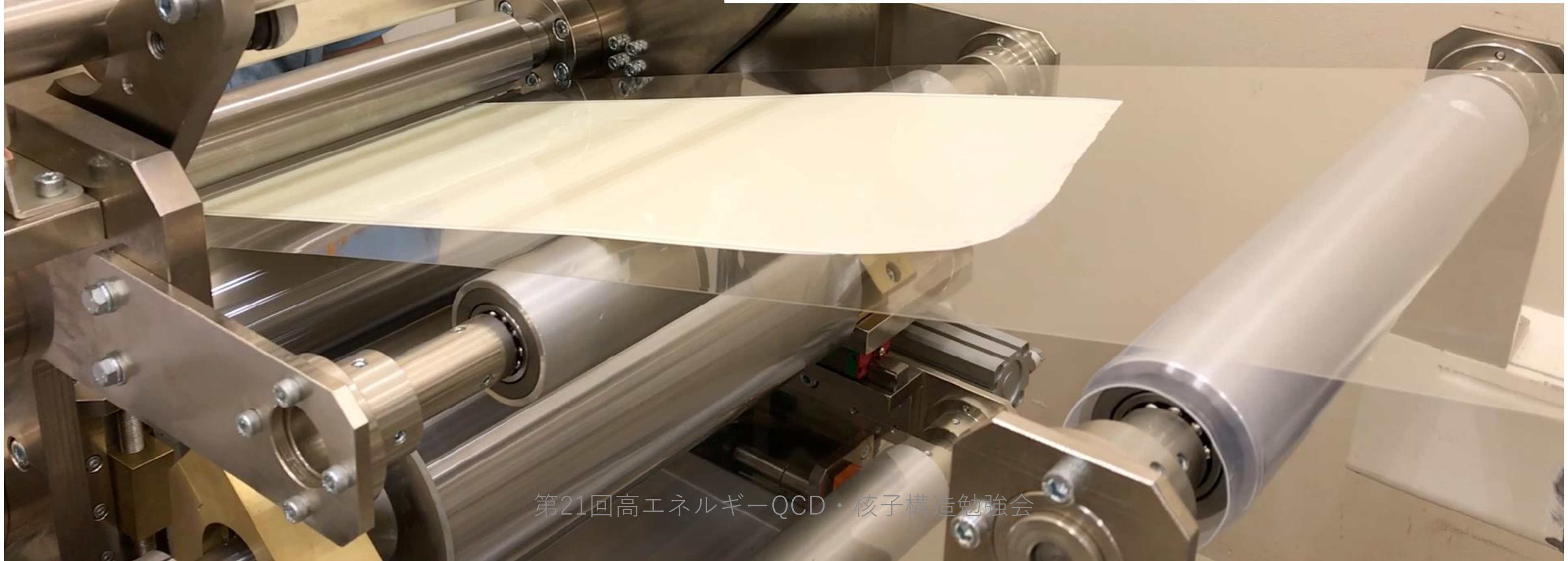
We produced more than 300 batches since May 2021. These films are used for GRAINE, NINJA, DsTau, FASERν and SND@LHC.

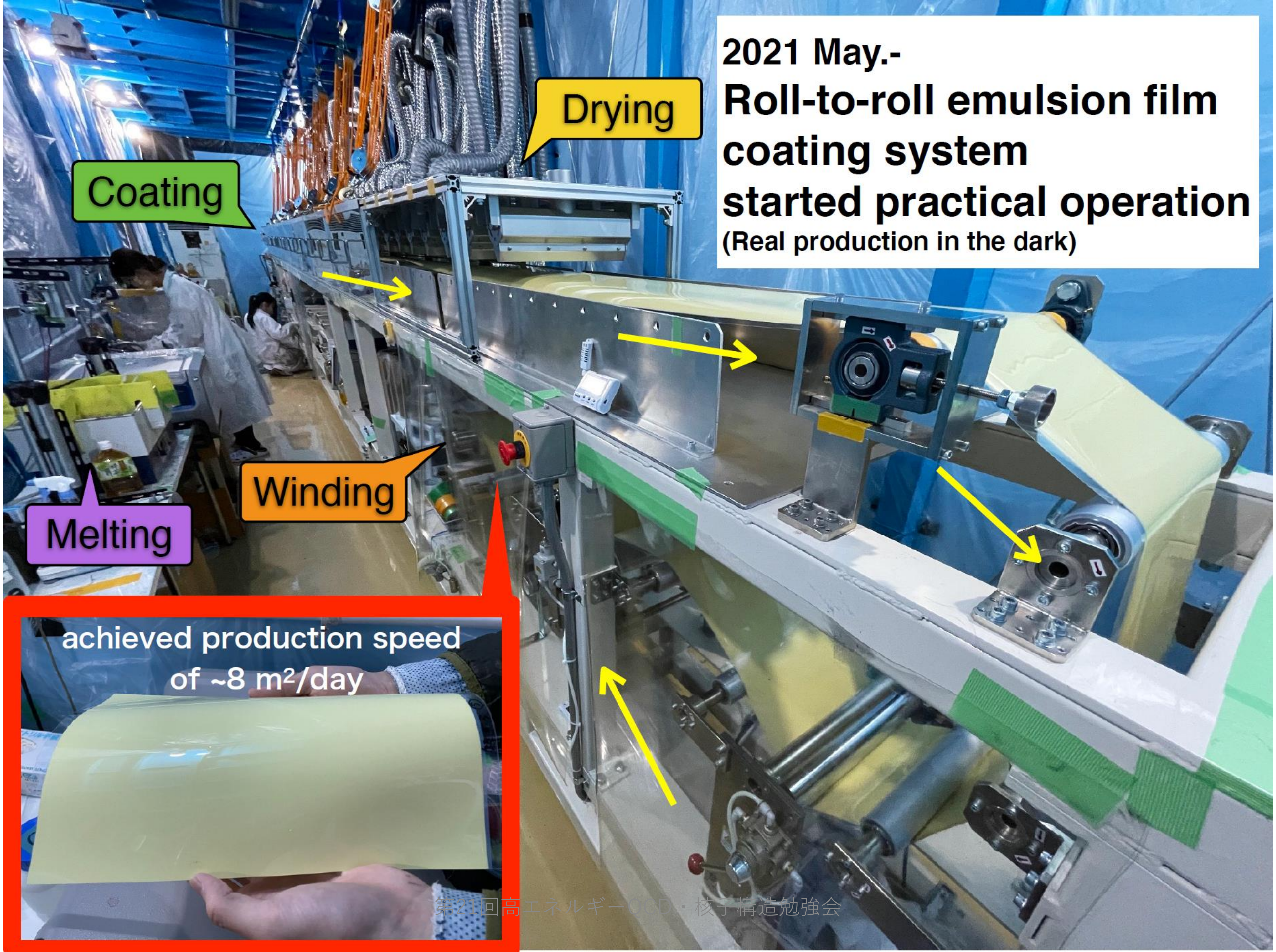
More than 1,000m^2/year.

For SND@LHC 93% of films are produced at Nagoya and 7% are at Slavich Russia.

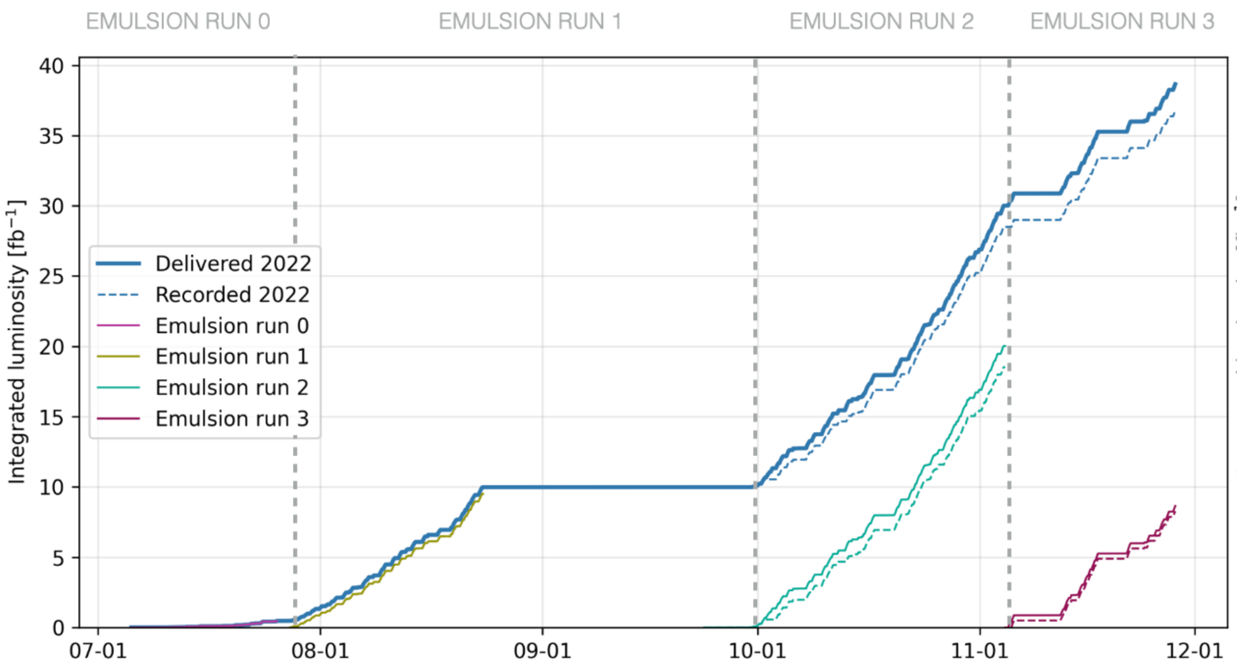
Development of Automatic Coat Method

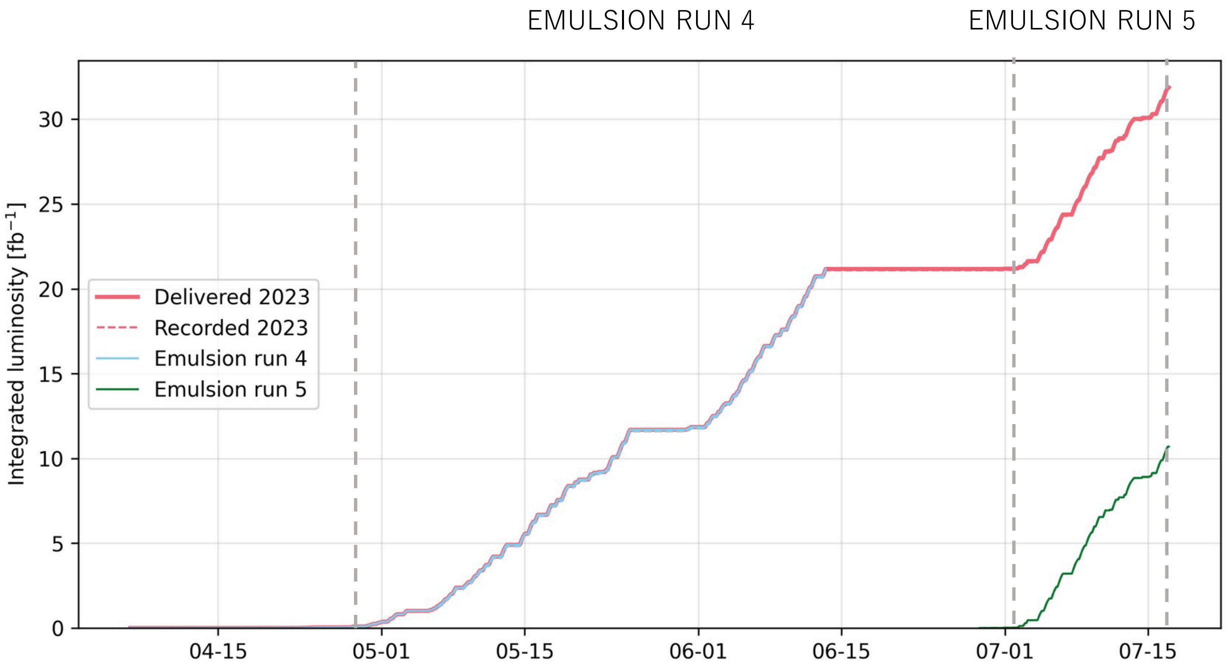





2021 May.-
Roll-to-roll emulsion film coating system started practical operation
(Real production in the dark)
Drying
Coating
Winding
Melting
achieved production speed of ~8 m²/day

Run Status

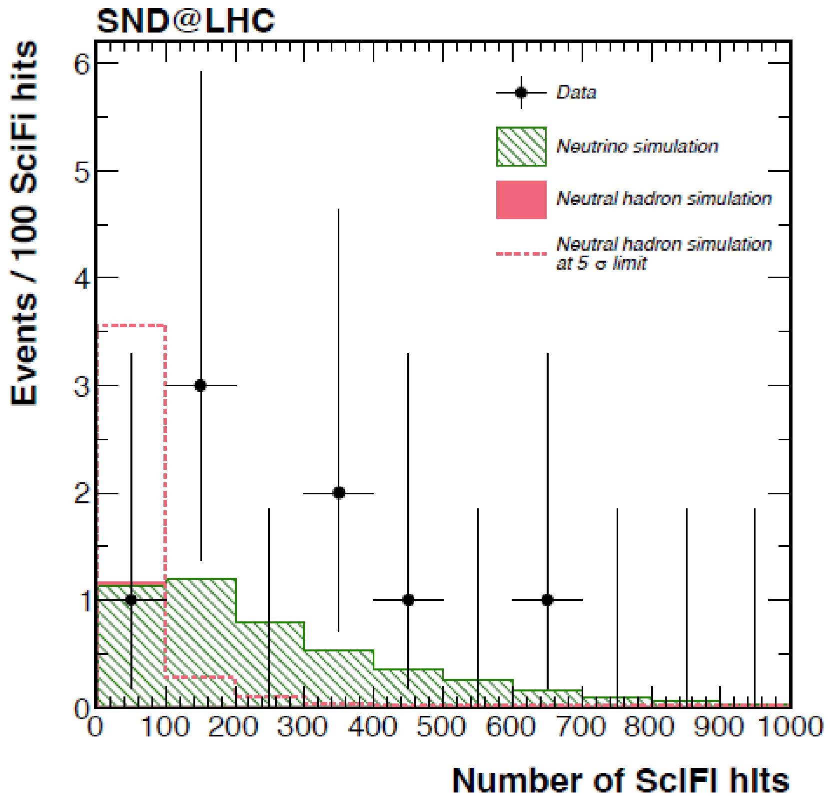


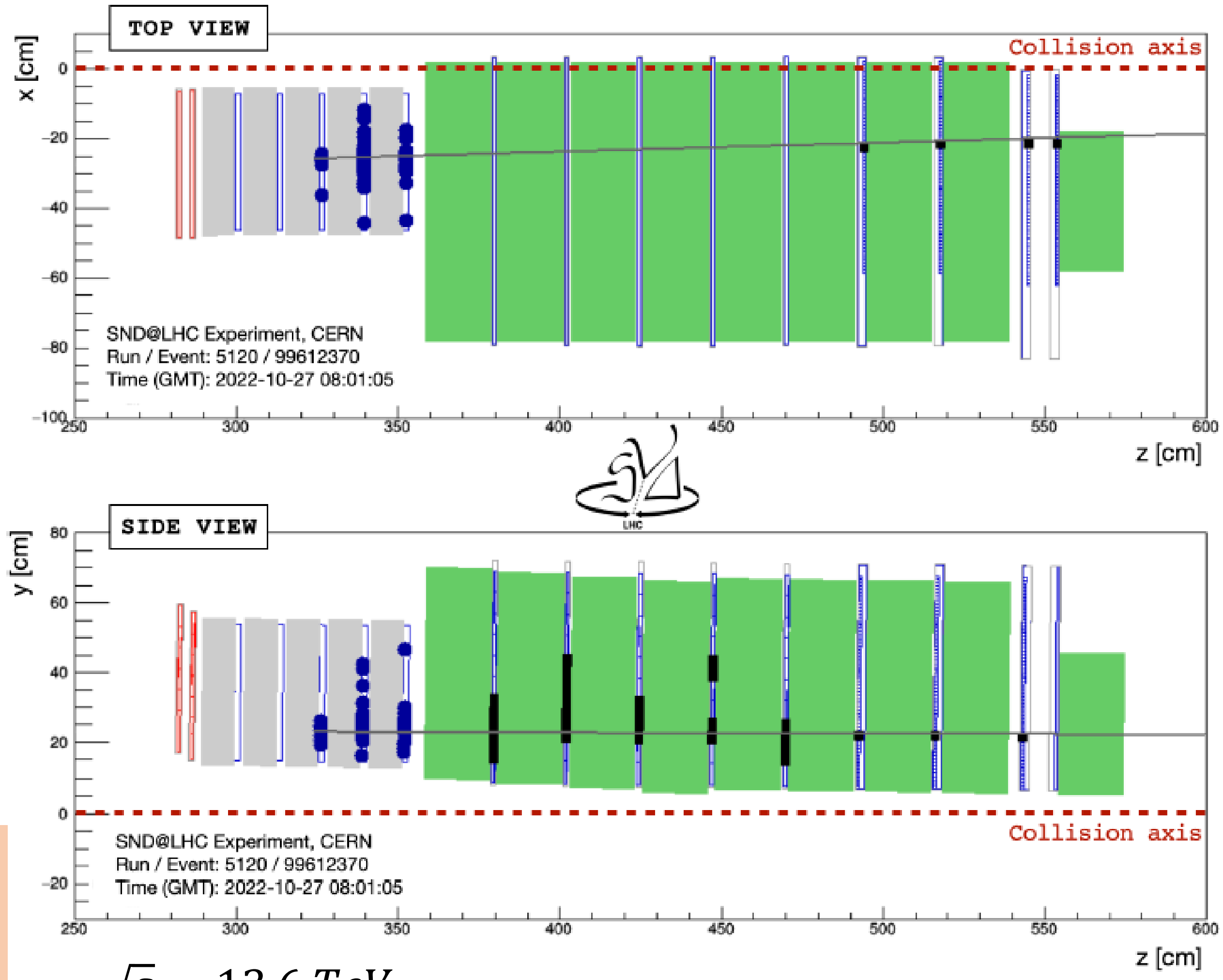


- **2022**
  - Three target replacements in 2022
  - Detector operation uptime: ~95%
  - Total recorded luminosity: 36.8 fb^{-1}

- **2023**
  - Four target replacements expected in 2023
    - Expected luminosity was 80 fb^{-1}
  - On 17th July, LHC machine trouble happened
  - As a result, 2023 pp run was terminated
  - Total recorded luminosity: 31.8 fb^{-1}

First Physics result

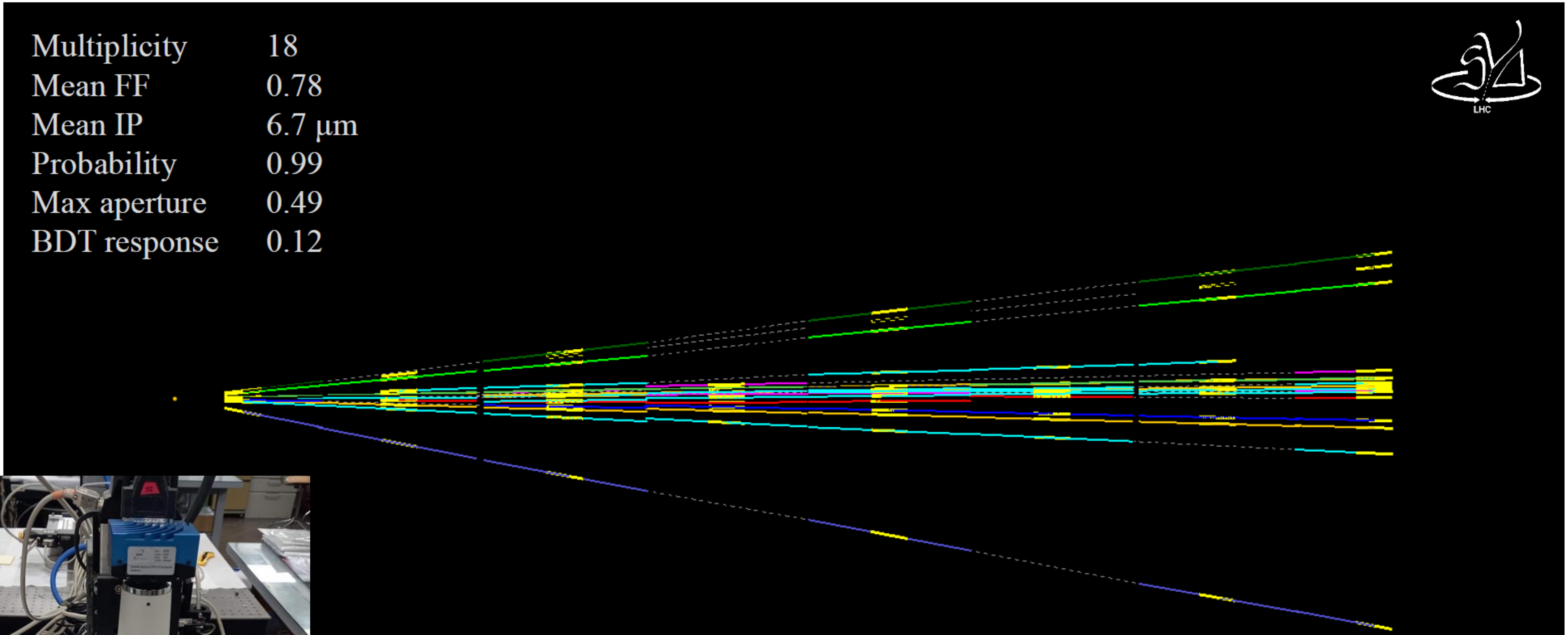


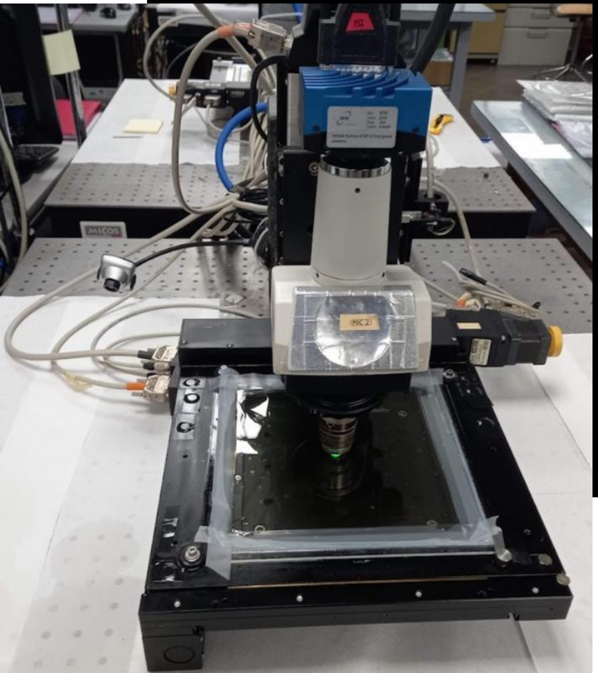


Observed 8 ν_μ CC candidates with a statistical significance of 6.8σ in full 2022 run (36.8 fb^{-1}). 4.2 expected with $(8.6\pm3.8)\times10^{-2}$ BG

$\sqrt{s} = 13.6\ TeV$

PRL 131, 031802 (2023)



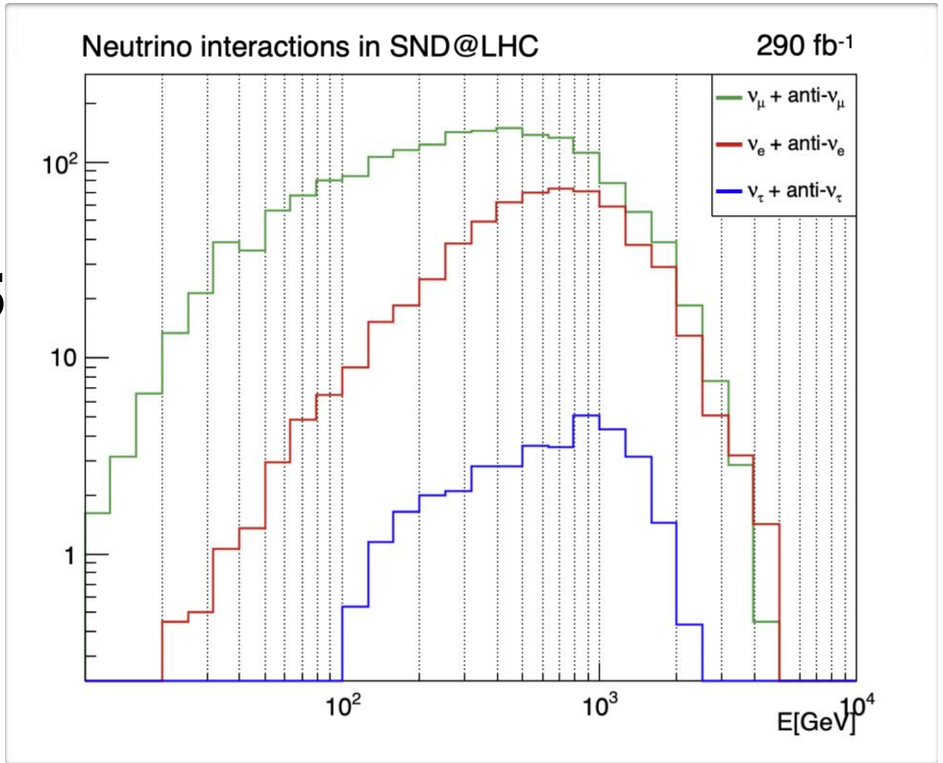


Using European Scanning System

NEUTRINO EXPECTATIONS

- Integrated luminosity: **290 fb^{-1}**
- Upward/downward crossing angle: **0.43/0.5**

- Neutrino production in LHC pp collisions performed with **DPMJET3** embedded in FLUKA
- Particle propagation towards the detector through **FLUKA** model of LHC accelerator

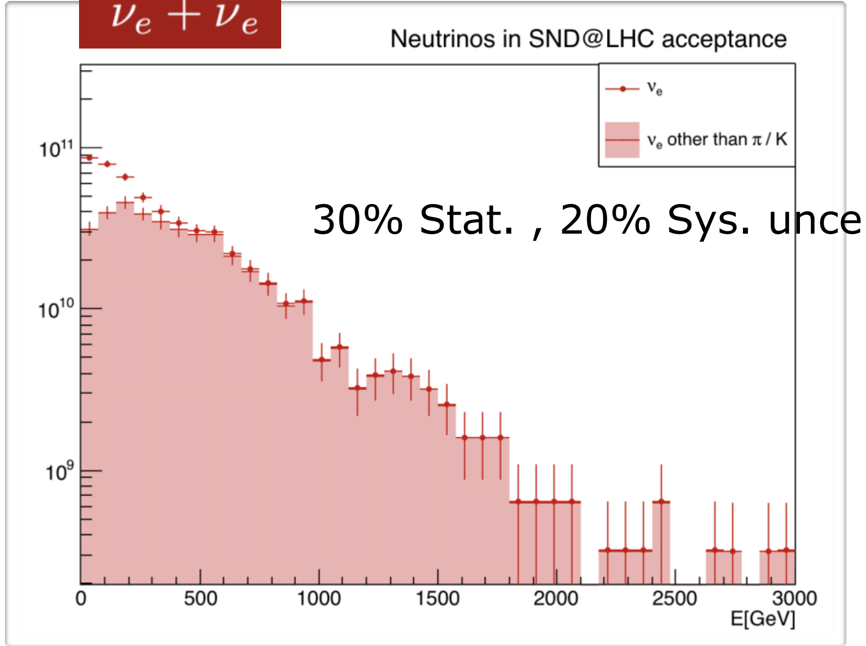


Flavour	Neutrinos in acceptance		CC neutrino interactions		NC neutrino interactions	
	⟨E⟩ [GeV]	Yield	⟨E⟩ [GeV]	Yield	⟨E⟩ [GeV]	Yield
ν_μ	120	3.4×10^{12}	450	1028	480	310
$\bar{\nu}_\mu$	125	3.0×10^{12}	480	419	480	157
ν_e	300	4.0×10^{11}	760	292	720	88
$\bar{\nu}_e$	230	4.4×10^{11}	680	158	720	58
ν_τ	400	2.8×10^{10}	740	23	740	8
$\bar{\nu}_\tau$	380	3.1×10^{10}	740	11	740	5
TOT		7.3×10^{12}		1930		625

Neutrino physics program in RUN3

- Lepton Flavor Universality (LFU) test
  - LHC neutrino beam contain all three neutrino flavors and SND@LHC has flavor identification capability

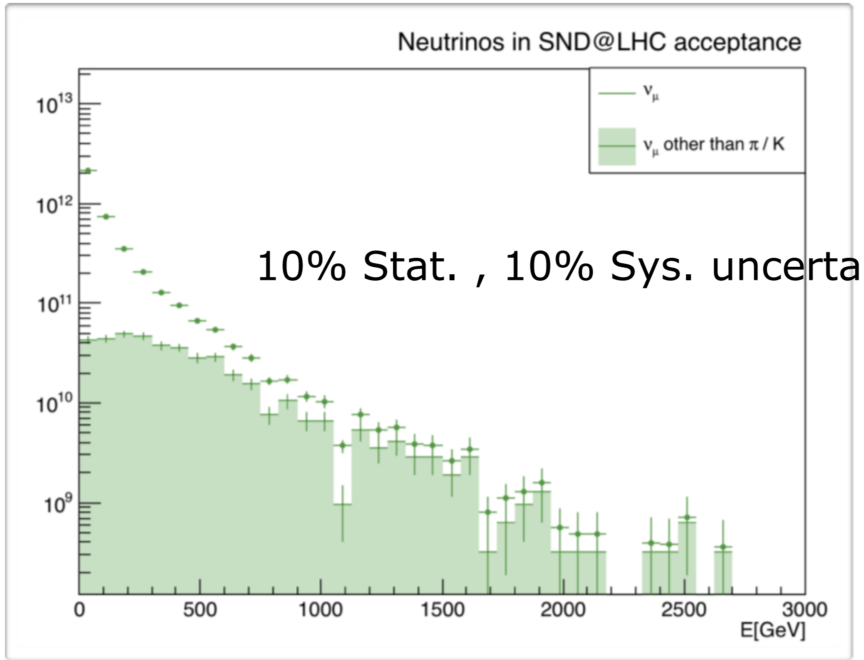
$\nu_e + \overline{\nu}_e$



30% Stat. , 20% Sys. uncertainty

$$R_{13} = \frac{N_{\nu_e+\overline{\nu}_e}}{N_{\nu_\tau+\overline{\nu}_\tau}} = \frac{\sum_i \tilde{f}_{c_i} \tilde{Br}(c_i \to \nu_e)}{\tilde{f}_{D_s} \tilde{Br}(D_s \to \nu_\tau)},$$

- Sensitive to ν-nucleon interaction cross-section ratio of two neutrino species



10% Stat. , 10% Sys. uncertainty

$$R_{12} = \frac{N_{\nu_e+\overline{\nu}_e}}{N_{\nu_\mu+\overline{\nu}_\mu}} = \frac{1}{1+\omega_{\pi/k}}.$$

contamination from π/k

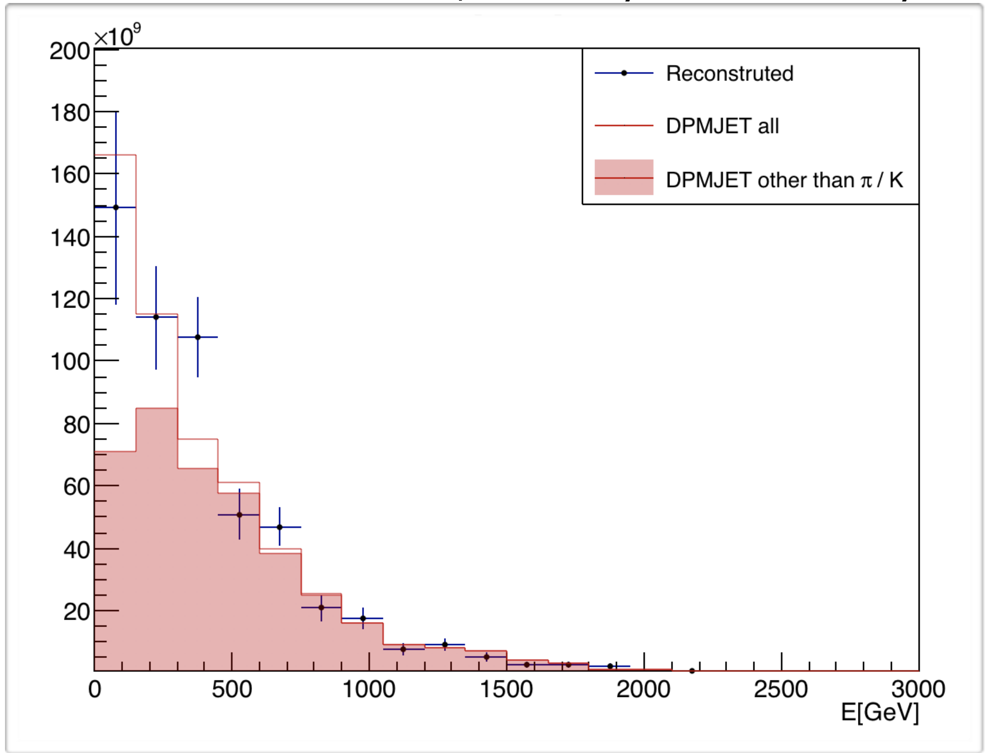
- The measurement of the ν_e/ν_μ ratio can be used as a test of the LFU for E>600 GeV

Neutrino physics program in RUN3

- $pp \rightarrow \nu_e X$ cross section and forward charmed hadron production
  - Neutrino beam simulation predicts that 90% ν_e+anti ν_e come from charmed hadron decays

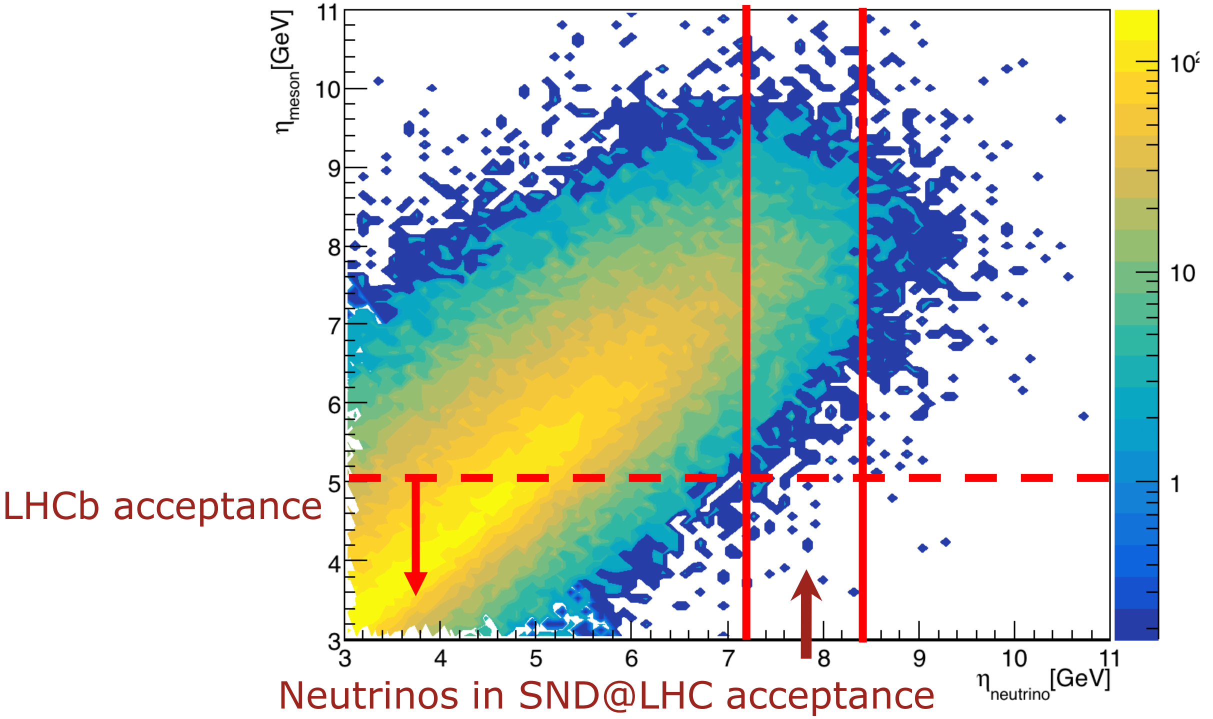
- Reconstructed spectrum of ν_e+anti-ν_e flux in SND@LHC acceptance

5% Stat. , 15% Sys. uncertainty



- Correlation between pseudo-rapidity of the electron (anti-)neutrino and the parent charmed hadron
- Use neutrino as a probe for forward charm production

5% Stat. , 35% Sys. uncertainty

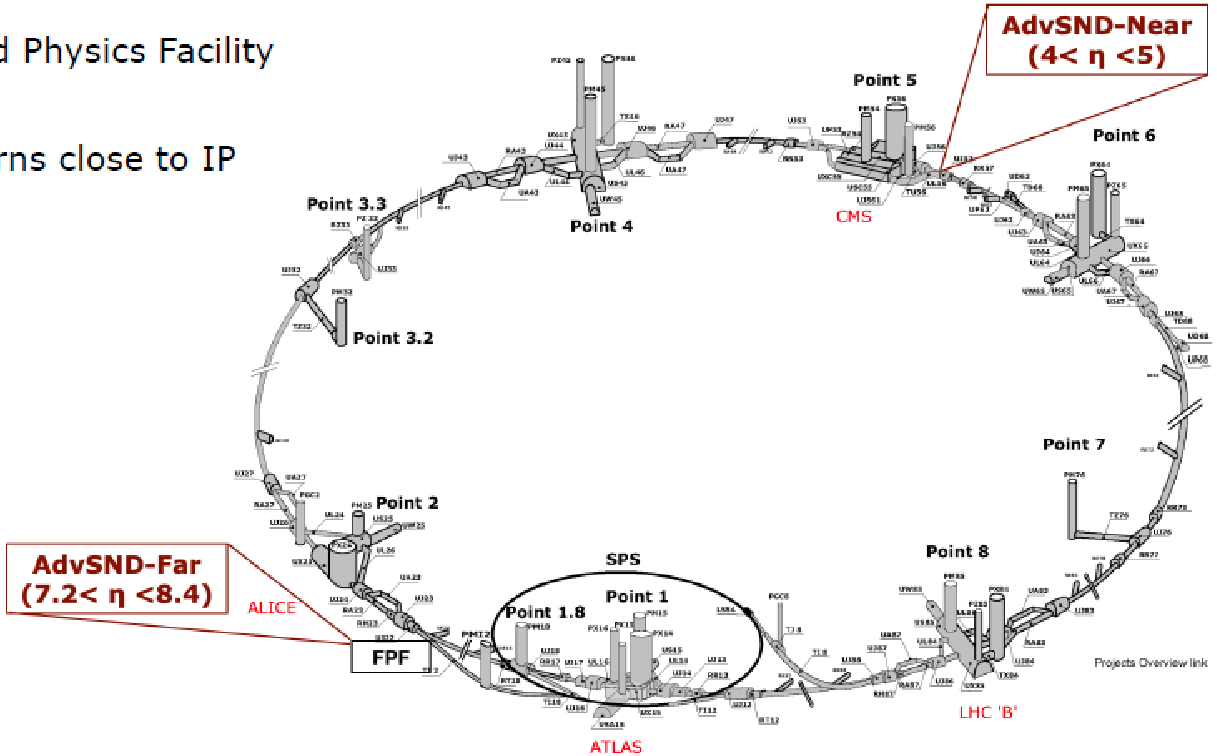


Future neutrino physics program

ADVANCED SND@LHC

2

- Upgrade of SND@LHC in view of an extended run during Run 4:
  - Extension of the physics case
  - New technologies and detector layout
  - Two detectors
    - **AdvSND-Far** ($7.2<\eta<8.4$)
      Possible locations: TI18, Forward Physics Facility
    - **AdvSND-Near** ($4<\eta<5$)
      Possible locations: existing caverns close to IP



ADVANCED SND@LHC

- Upgrade of the detector in view of an extended run during Run 4:
- Two off-axis forward detectors:

• **AdvanceSND-Near**: 4<η<5

Overlap with LHCb pseudo-rapidity coverage

Reduction of systematic uncertainties

Provide normalization for neutrino physics studies

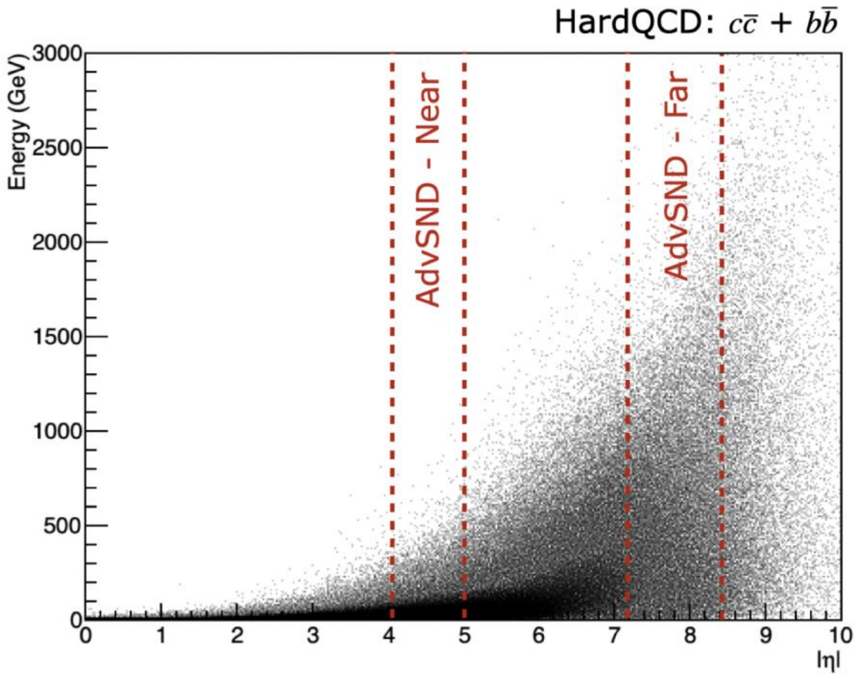
Neutrino cross-section measurements

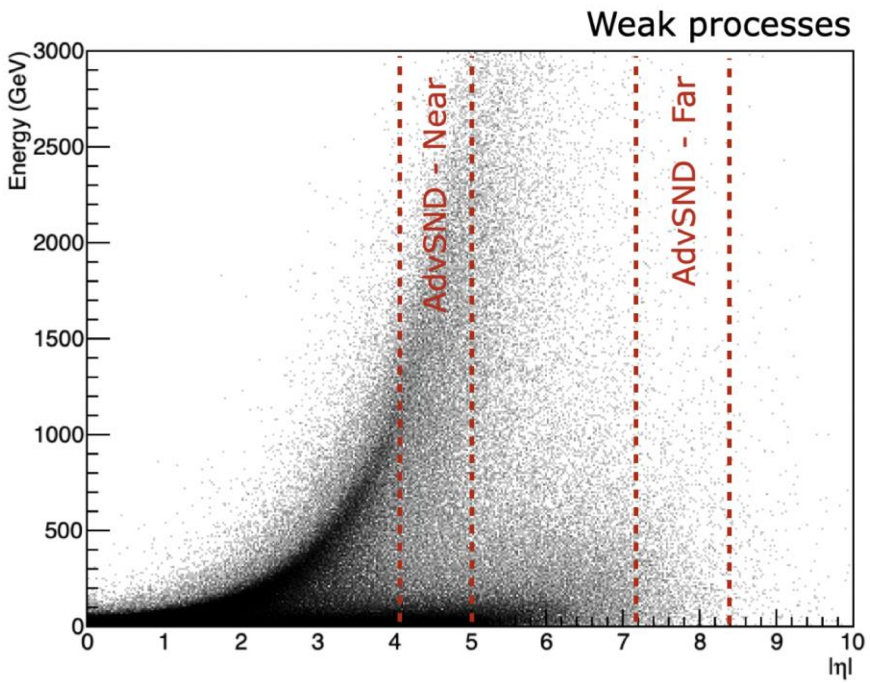
• **AdvancedSND-Far**: 7.2< η <8.4

Overlap Acceptance similar to SND@LHC

Charm production measurements

Lepton flavour universality





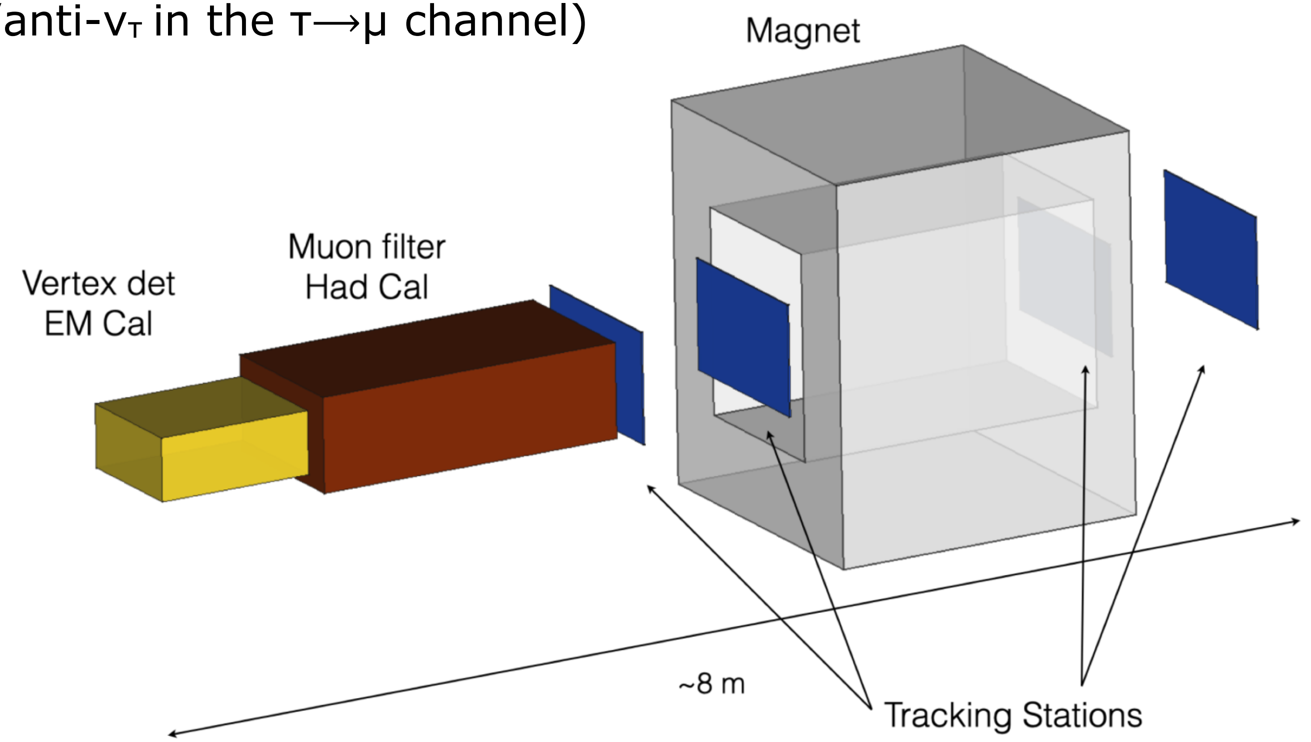
ADVANCED SND@LHC: DETECTOR LAYOUT

1) Target region:
- Vertex identification and electromagnetic calorimeter
- Thin sensitive layers interleaved with Tungsten plates
- Replace emulsions with electronic trackers to cope with high intensity muon rates

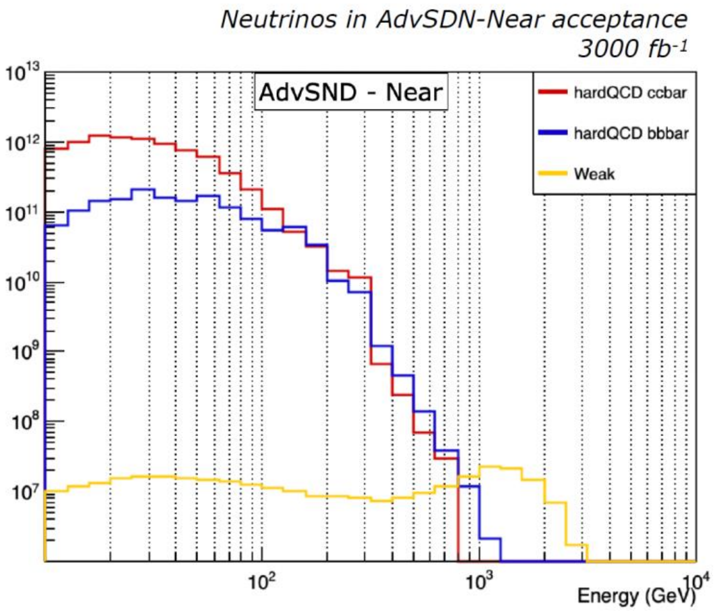
2) Muon ID system and hadronic calorimeter
- 10 interaction lengths

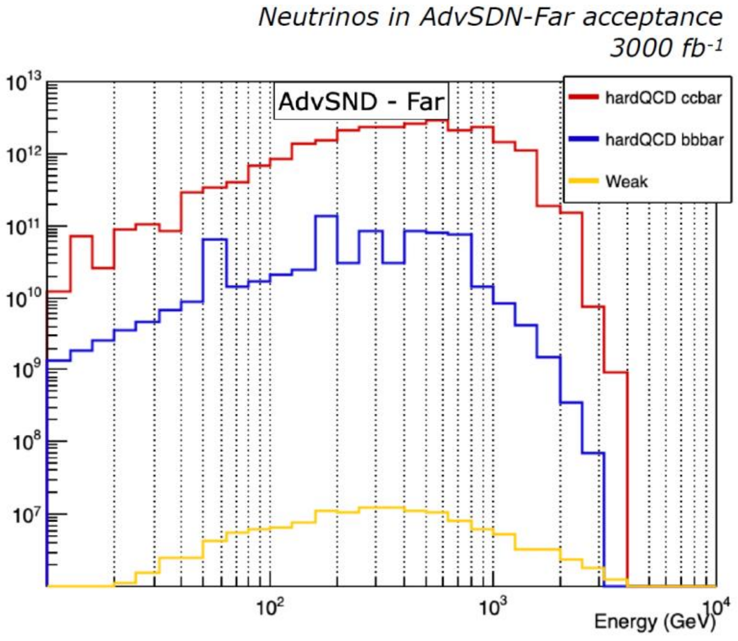
3) Magnet with two high-resolution tracking stations
- measure charge of the muon (ν_μ/anti-ν_μ, ν_τ/anti-ν_τ in the $\tau \to \mu$ channel)
- 1 T field over 2 m length

	AdvSND - NEAR	AdvSND - FAR
η	[4.0, 5.0]	[7.2, 8.4]
mass (ton)	5	5
surface (cm^2)	120 × 120	100 × 55
distance (m)	55	630



ADVANCED SND@LHC: DETECTOR LAYOUT





AdvSND - NEAR				
Flavour	ν in acceptance hardQCD: $c\bar{c}$	ν in acceptance hardQCD: $b\bar{b}$	CC DIS hardQCD: $c\bar{c}$	CC DIS hardQCD: $b\bar{b}$
$\nu_\mu + \bar{\nu}_\mu$	2.1×10^{12}	3.3×10^{11}	980	200
$\nu_e + \bar{\nu}_e$	2.2×10^{12}	3.3×10^{11}	1000	200
$\nu_\tau + \bar{\nu}_\tau$	2.7×10^{11}	1.4×10^{11}	80	50
Tot	5.4×10^{12}		2.5×10^{3}	

Expectations in **3000 fb^{-1}**
Generator: Pythia8

Flavour	ν in acceptance hardQCD: $c\bar{c}$	ν in acceptance hardQCD: $b\bar{b}$	CC DIS hardQCD: $c\bar{c}$	CC DIS hardQCD: $b\bar{b}$
$\nu_\mu + \bar{\nu}_\mu$	6.3×10^{12}	1.5×10^{11}	1.2×10^{4}	200
$\nu_e + \bar{\nu}_e$	6.7×10^{12}	1.7×10^{11}	1.2×10^{4}	220
$\nu_\tau + \bar{\nu}_\tau$	7.1×10^{11}	4.7×10^{10}	880	40
Tot	1.4×10^{13}		2.5×10^{4}	

Expectations in **3000 fb^{-1}**
Generator: Pythia8

QCD MEASUREMENTS

- Electron neutrinos mostly produced by charm decays
- ν_e ca be used as a probe of **charm production** in a region where charm yield has large uncertainties

- Electron neutrinos measurements can constraint the uncertainty on the gluon PDF in x<10-5 region

- Extraction of gluon PDF in very small x-region relevant for:
  1. Future Circular Colliders
  2. Reduction of uncertainty on the flux of very-high-energy atmospheric neutrinos

- **AdvSND-Near:** $4<\eta<5$:
  reduce systematic uncertainties in the correlation between neutrinos and charmed mesons comparing with LHCb direct charm measurements

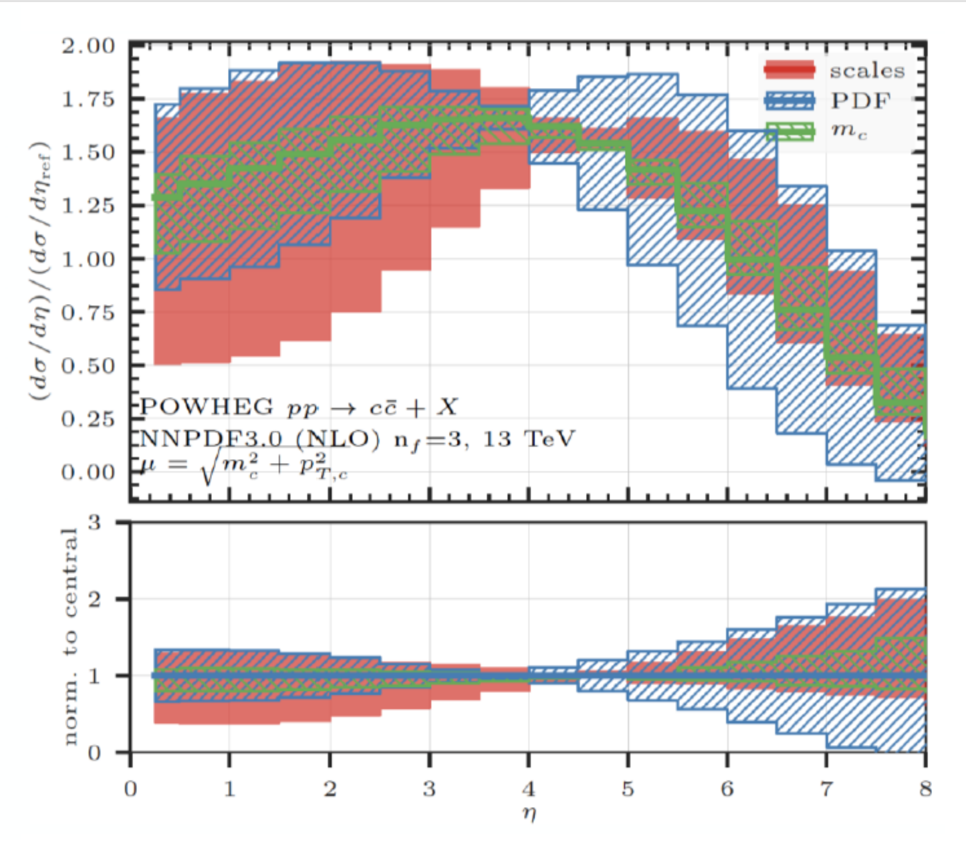
- **AdvSND-Far:** $7.2<\eta<8.4$:
  reduce statistical uncertainties

Ratio between the cross-section measurements at different pseudo-rapidities, normalised to LHCb measurements

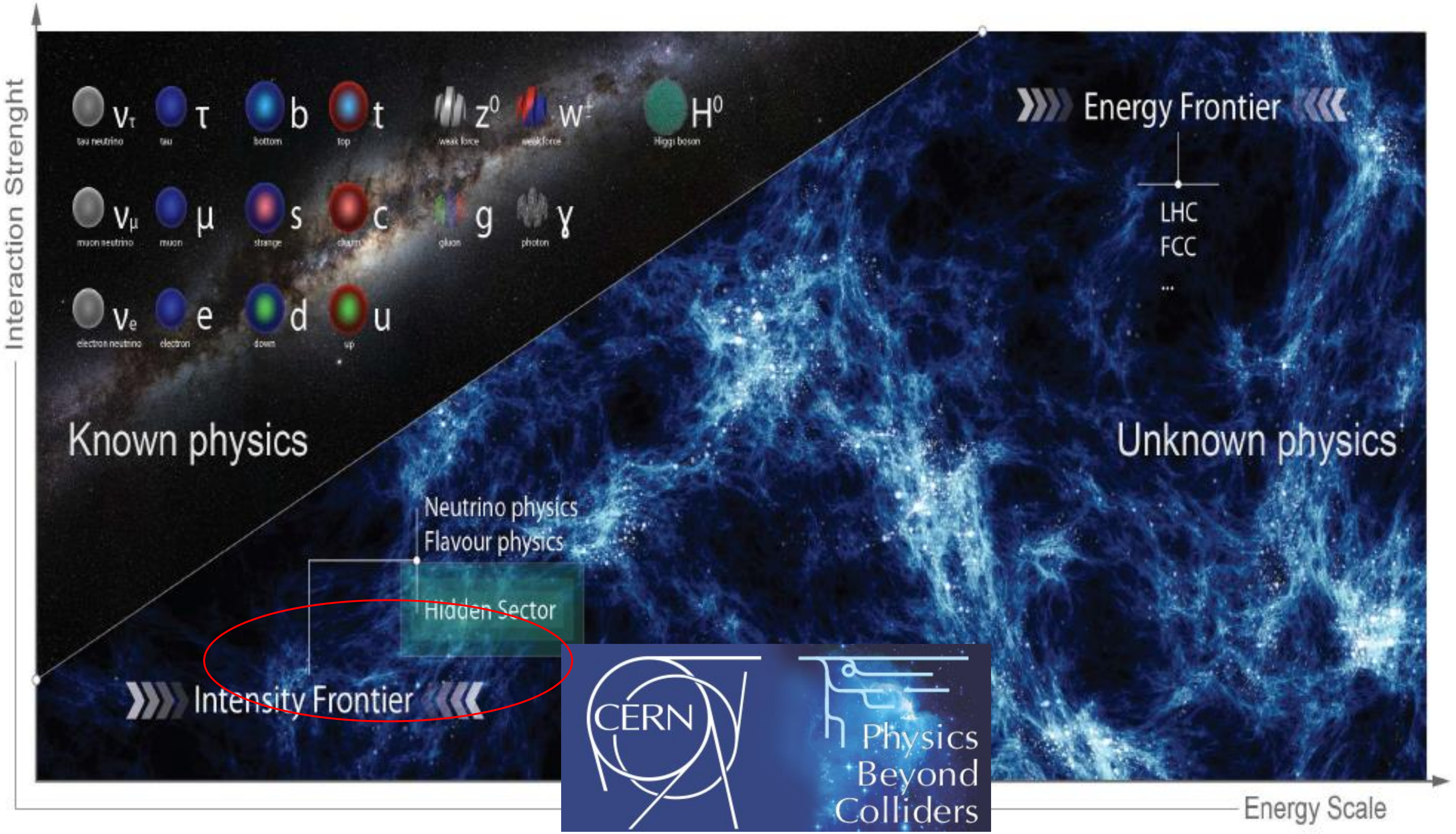
$$R = \frac{d\sigma/d\eta(13\,TeV)}{d\sigma/d\eta_{ref}(7\,TeV)}$$

$$\eta_{ref} = [4,4.5]$$

arxiv:1510.01707

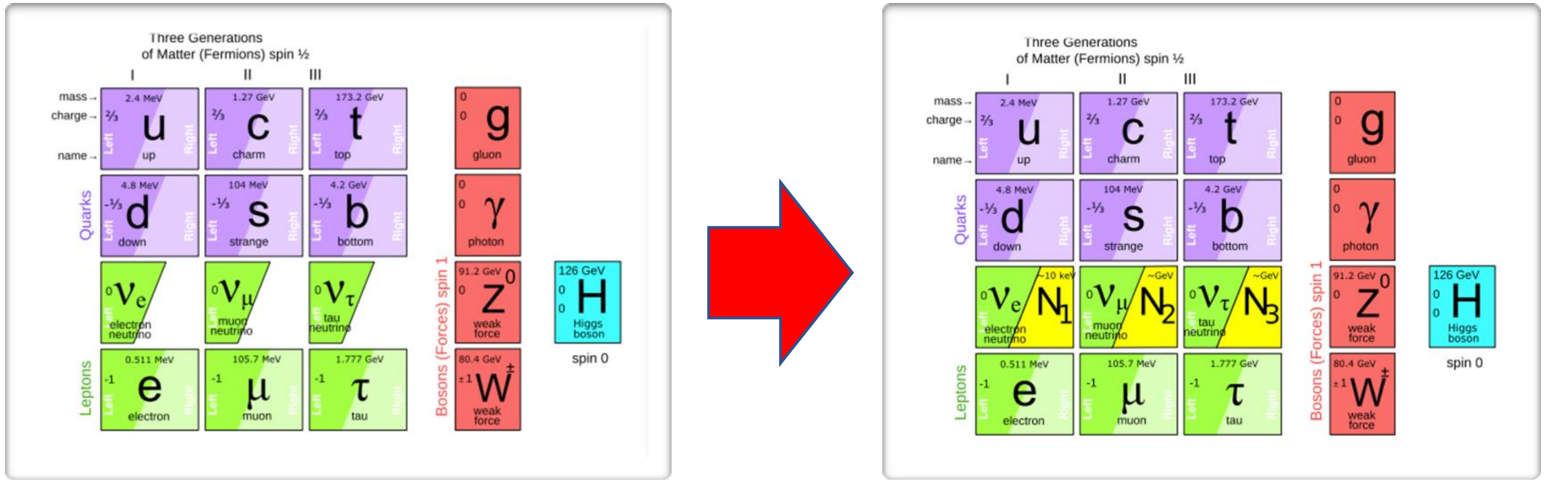


SHiP (Search for Hidden Particle)



Neutrino portal

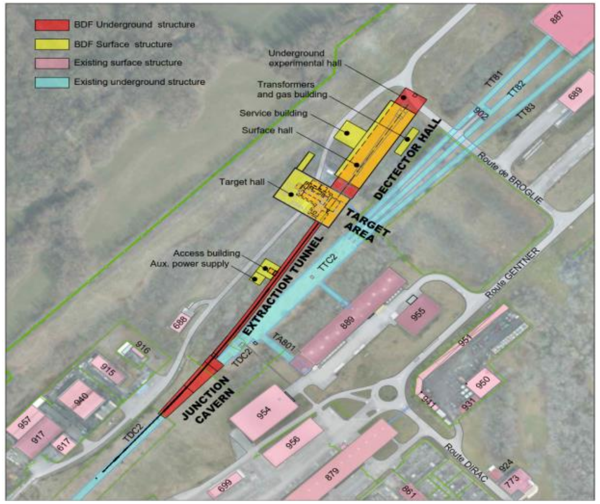
- νMSM (ν Minimal Standard Model)
  - 3 additional Heavy Neutral Leptons

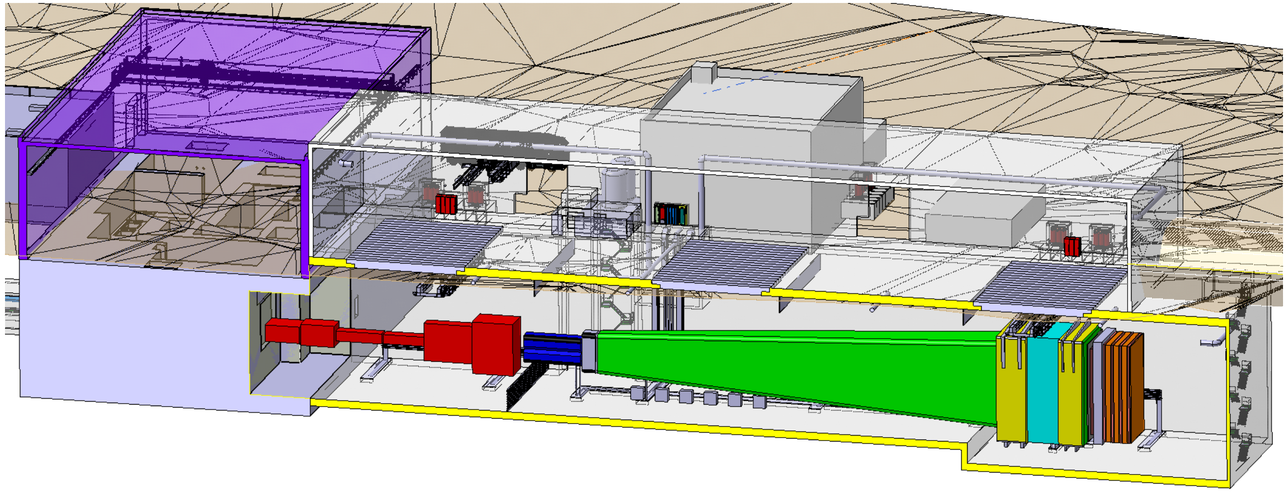


- N_1 : Dark Matter Candidate
- $N_{2,3}$: give mass to neutrino via see-saw mechanism, produce baryon asymmetry

T.Asaka, M.Shaposhnikov PL B620 (2005) 17 , M.Shaposhnikov Nucl. Phys. B763 (2007) 49

Beam Dump Facility (BDF)





Baseline characteristics	
Proton momentum	**400 GeV/c**
Beam intensity	$4.0 \cdot 10^{13}$ p+/cycle
Cycle length	7.2 s
Spill duration **(slow extraction)**	1.0 s
Average beam power deposited on target	**320 kW**
Average beam power on target during spill	2.3 MJ

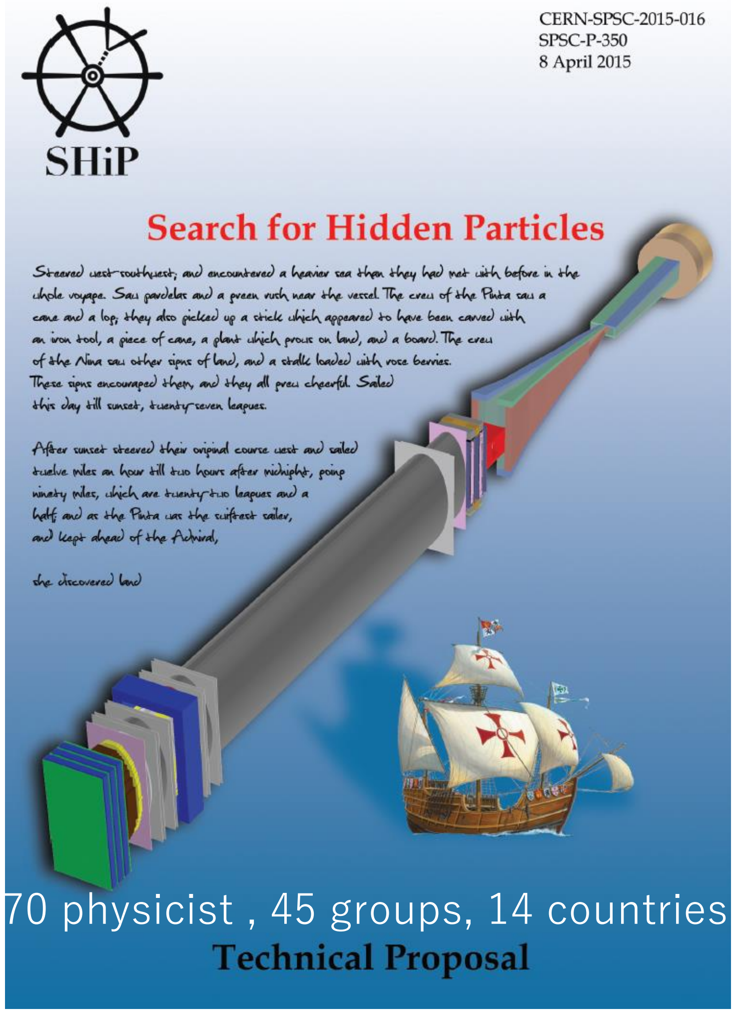
Already huge amount of engineering work has done by CERN engineers for experimental site, beam dump target, radiation protection and installations…..

2×10^{20} PoT in 5 years

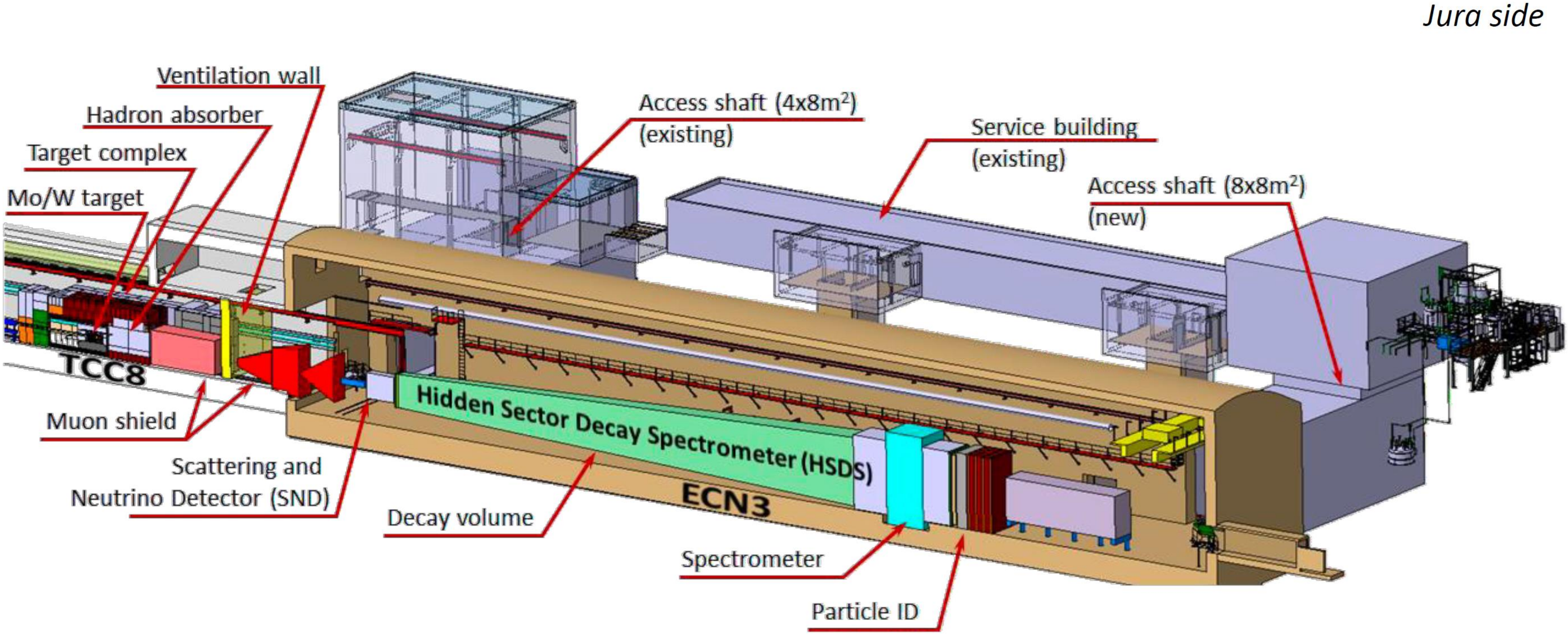
CNGS:1.8×10^{20} PoT in 5years

SHiP experiment @ CERN

- Objective
  - Look for new physics in intensity frontier
  - Rich both tau and anti tau neutrino interactions
    - ~10,000 tau and anti-tau neutrino interactions
- Proposal submitted on April 2015
  - 250 members, 57 institution from 18 countries
- Document submitted to ESPP on Dec. 2018
  - Together with CERN Beam Dump Facility (BDF)
- ESPP outcome on June 2020
  - Physics cases are well accepted
  - But, BDF construction is postponed

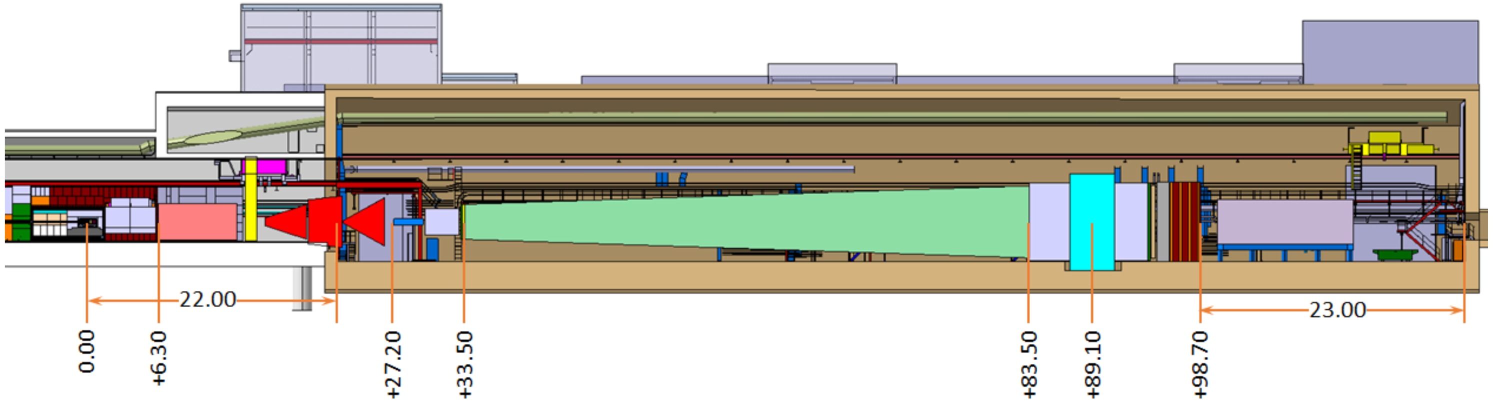


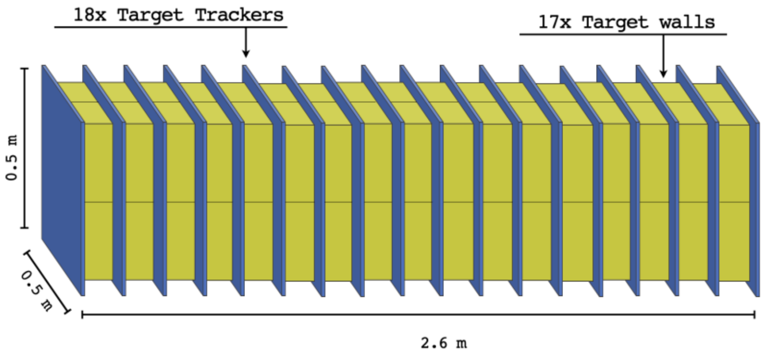
Current SHiP@ECN3 configuration

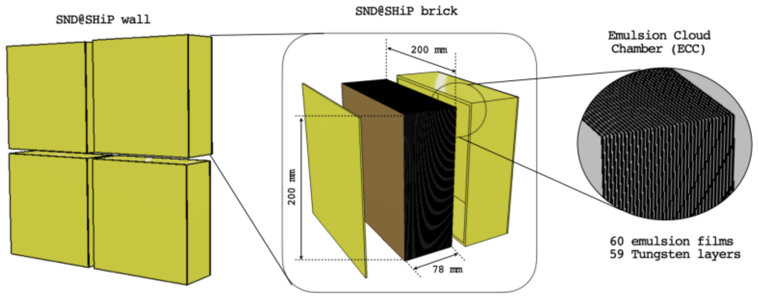


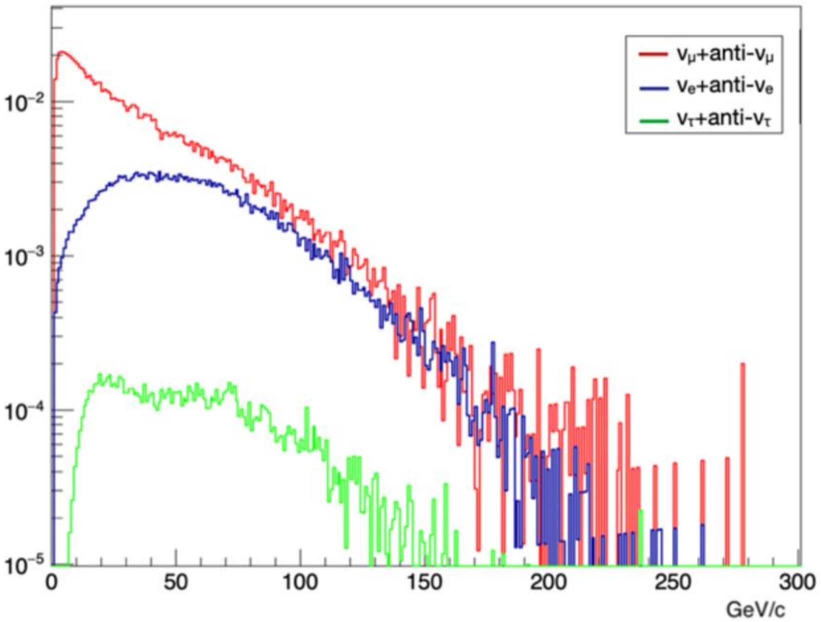
BDF/SHiP@ECN3

- Shorter detector hall
  - Shorten muon shield by using super conducting sweeper magnet.
- **SND**(**S**cattering and **N**eutrino **D**etector) placed at 27m from beam dump.
  - Distance from dump: Factor 1.37 closer to beam dump results about factor **1.9 stronger beam** intensity
  - Cross-section : **¼ in size** 80cmx80cm → 40cm x 40cm
  - Length : Factor **1.5 longer**
  - Mass: **8tons** → **3tons**
  - Tau neutrino yield: **3.2x10^4 → 2.9x10^4** for 2x10^{20} pot.
  - 440m^2 → 160m^2 emulsion surface







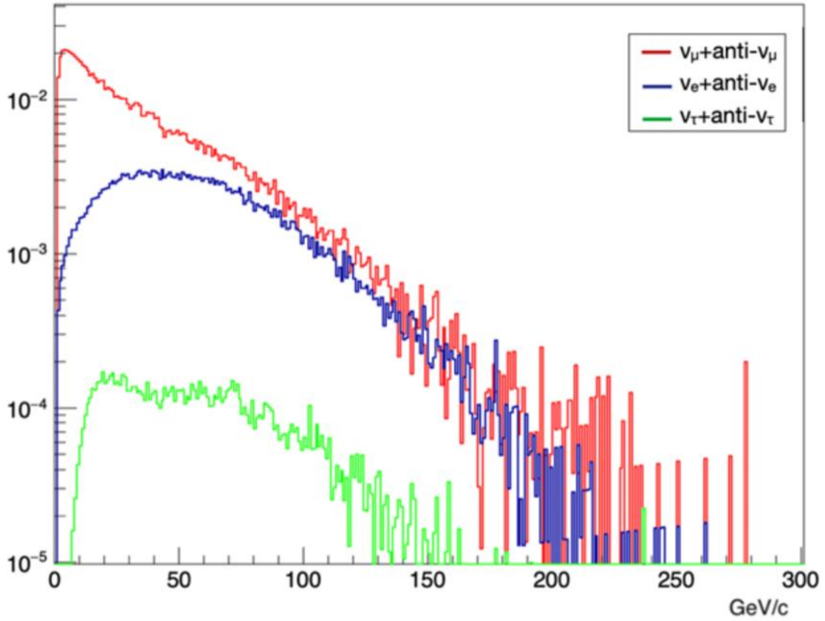


Neutrino interactions in the target

SHiP

	<E> [GeV]	beam dump	<E> [GeV]	SND target acceptance	<E> [GeV]	CC DIS interactions
N_{ν_e}	6.3	4.1×10^{17}	30	1.3×10^{16}	63	2.8×10^{6}
N_{ν_μ}	2.6	5.4×10^{18}	8.4	1.5×10^{17}	40	8.0×10^{6}
N_{ν_τ}	9.0	2.6×10^{16}	22	1.0×10^{15}	54	8.8×10^{4}
$N_{\overline{\nu}_e}$	6.6	3.6×10^{17}	22	9.3×10^{15}	49	5.9×10^{5}
$N_{\overline{\nu}_\mu}$	2.8	3.4×10^{18}	6.8	1.2×10^{17}	33	1.8×10^{6}
$N_{\overline{\nu}_\tau}$	9.6	2.7×10^{16}	32	1.0×10^{15}	74	6.1×10^{4}

For 6 x 10^{20} pot



Expected ν_τ including eff. (~35%)

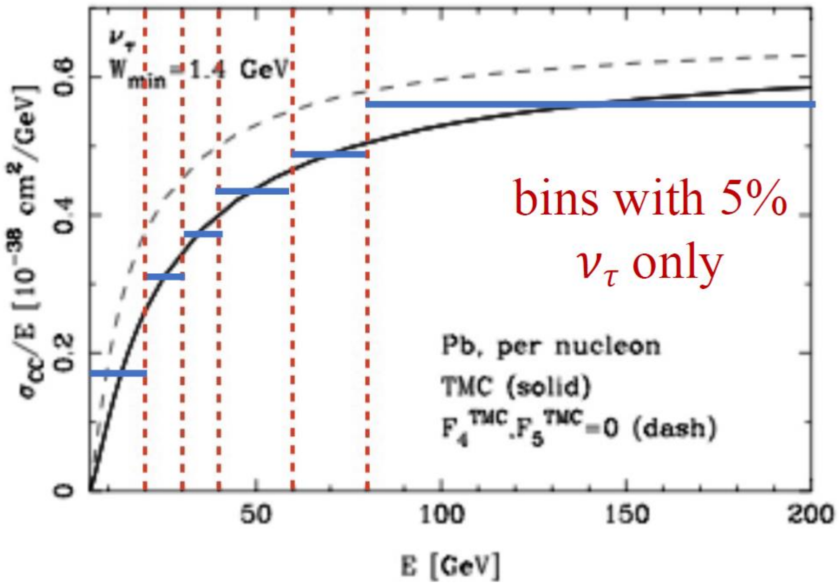
Decay channel	ν_τ	$\overline{\nu}_\tau$
$\tau \to \mu$	4×10^3	3×10^3
$\tau \to h$	27×10^3	
$\tau \to 3h$	11×10^3	
$\tau \to e$	8×10^3	
total	53×10^3	

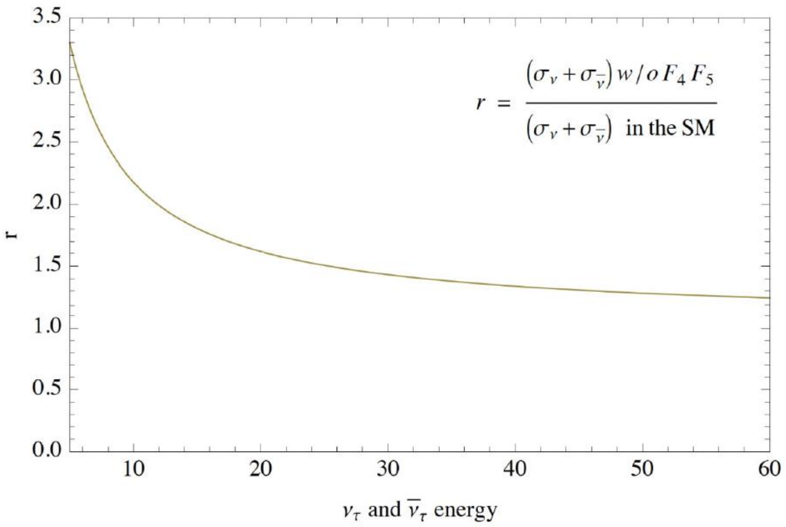
Statistical error < 2% for tau
Neutrino flux prediction can be down to ~3% by NA65 (DsTau experiment)

F4/F5 structure functions by ν_τ

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

- At LO $F_4 = 0$, $2xF_5 = F_2$
- At NLO $F_4 \sim 1\%$ at 10 GeV

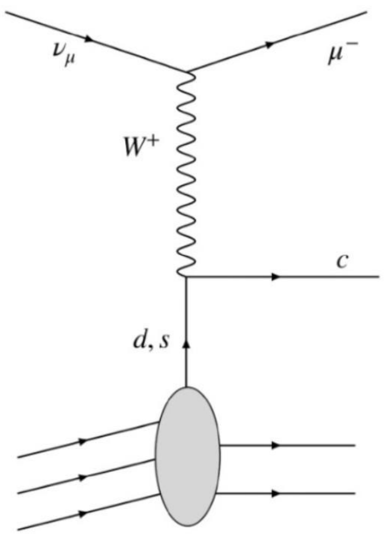


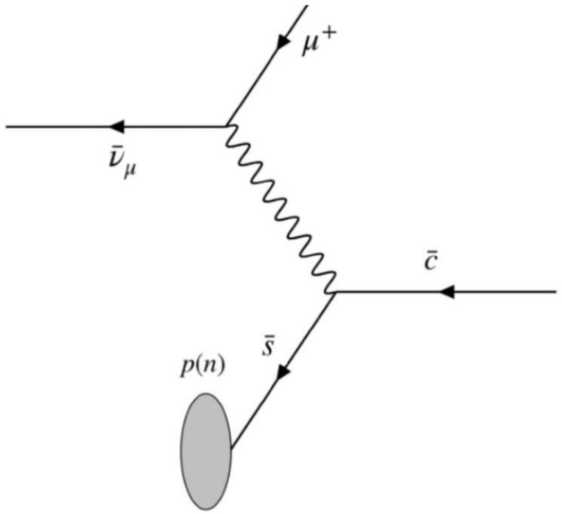


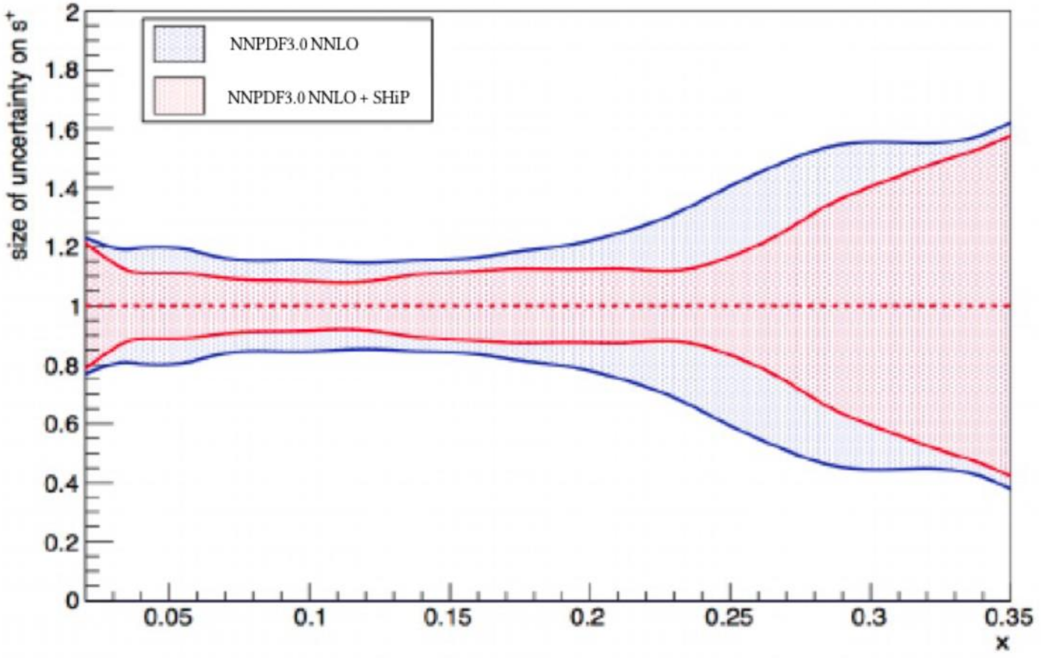
Rep. Prog. Phys. 79 (2016) 124201

Assuming 10 equally populated bins (with 5% uncertainty) for ν_τ + anti- ν_τ
A global 20% effect on the cross-section w/wo F4 and F5

Strange quark content







	<E> (GeV)	CC DIS with charm prod	Charm fractions (%)
N_{ν_μ}	57	3.5×10^5	4.4
N_{ν_e}	71	1.7×10^5	6.0
$N_{\overline{\nu}_\mu}$	50	0.7×10^5	3.8
$N_{\overline{\nu}_e}$	60	0.3×10^5	5.3
total		6.2×10^5	

Charm production via anti-neutrinos dominated by s-bar quarks because of $|V_{cd}/V_{cs}|^2 \sim 1/20$.

Competitors @ECN3

HIKE: The High-Intensity Kaon Experiments at CERN

Proposal for Phase 1 and 2

Prof. Cristina Lazzeroni
University of Birmingham,
on behalf of HIKE

HIKE
High Intensity Kaon Experiments

HIKE: 194 collaborators from 41 institutions
in the Proposal of HIKE Phase 1 and 2

SPSC Open Session, 5 September 2023, CERN

Andrey Golutvin
Imperial College London

BDF/SHiP @ ECN3 Proposal

on behalf of the SHiP collaboration of 33 institutes from 15 countries and CERN

→ Attention is given to changes since LoI [CERN-SPSC-2022-032]

OUTLINE:
- *New configuration of the muon shield with SC section*
- *Modified geometry of SHiP*
- *Re-evaluation of backgrounds*
- *Physics performance (FIPs and neutrino programme)*
- *Possible future upgrades and extensions of BDF*
- *Road map and cost estimate*
- *Status of collaboration*
- *Summary*

SPSC open session, September 2023 1

SHADOWS

Search for **H**idden **A**nd **D**ark **O**bjects **W**ith the **S**PS

(1) *CERN, European Organization for Nuclear Research, CH-1211 Geneva 23, Switzerland*
(2) *INFN, Sezione di Napoli, Napoli, Italy*
(3) *Ruprecht-Karls-Universität Heidelberg, Heidelberg, Germany*
(4) *INFN, Sezione di Ferrara, Ferrara, Italy*
(5) *INFN Laboratori Nazionali di Frascati, Frascati (Rome), Italy*
(6) *INFN, Sezione di Roma III, Roma, Italy*
(7) *Johannes Gutenberg Universitat Mainz, Mainz, Germany*
(8) *INFN, Sezione di Bologna, Bologna, Italy*
(9) *Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany*
(10) *PARTREC and University of Groningen, Groningen, The Netherland*
(11) *INFN, Sezione di Roma III, Roma, Italy*
(12) *University of Freiburg, Freiburg, Germany*
(13) *Charles University, Prague, Czech Republic*
(14) *Royal Holloway, University of London, UK*
(15) *INFN, Sezione di Roma1, Roma, Italy*
(16) *University of Bologna, Bologna, Italy*

+ the invaluable support of the PBC-CBWG, PBC-ECN3 Task Force, NA-CONS team, and CERN EP-DT Group.

150th SPSC meeting – Open Session - 5 September 2023

150th SPSC meeting open session on 5th September

HIKE/SHADOWS (+NaNu) vs. **BDF/SHiP**

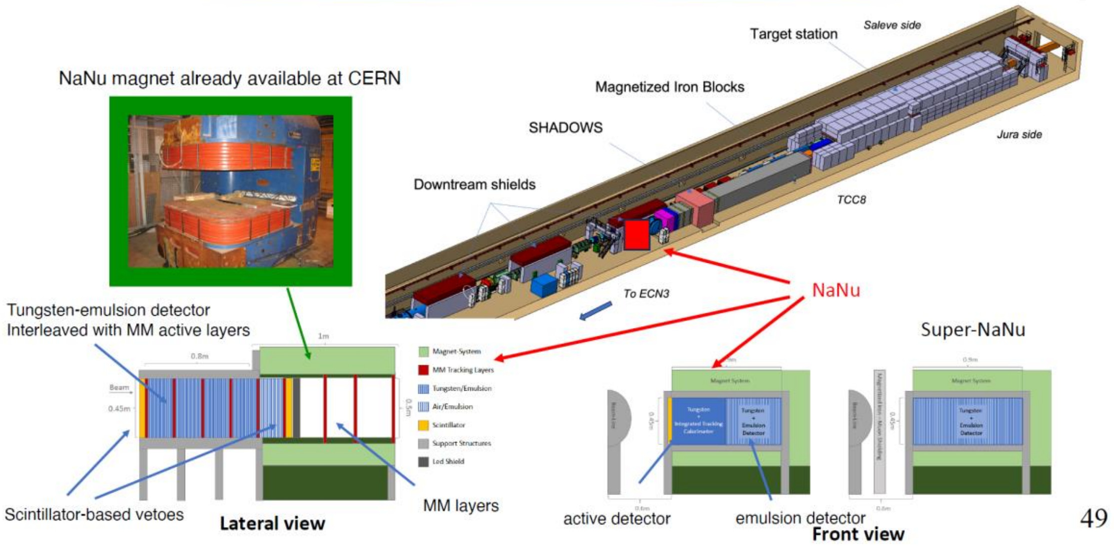
HIKE : Kaon program
SHADOWS : Hidden particle

BDF : Irradiation Facility (400 MGy / year)
SHiP : Hidden particle and Neutrino physics

SHADOWS+NaNu vs. SHiP

SHADOWS

The North Area Neutrino Detector (NaNu)



Expected **number of detectable neutrino interactions** within the NaNu detector for 4 x10^{19} POT for NaNu and Super-NaNu.

Experimental Setup	NaNu	Super-NaNu
ν_e	4.1×10^3	20×10^3
$\bar{\nu}_e$	1.0×10^3	4.5×10^3
ν_μ	40×10^3	40×10^3
$\bar{\nu}_\mu$	9×10^3	9×10^3
ν_τ	0.12×10^3	0.72×10^3
$\bar{\nu}_\tau$	0.07×10^3	0.41×10^3

Neutrino interaction physics

Huge sample of tau neutrinos can be produced at SPS via $D_s \rightarrow \tau\nu_\tau$

	<E>[GeV]	Beam dump	<E>[GeV]	CC DIS interactions
N_{ν_e}	6.3	4.1×10^{17}	63	2.8×10^6
N_{ν_μ}	2.6	5.4×10^{18}	40	8.0×10^6
N_{ν_τ}	9.0	2.6×10^{16}	54	8.8×10^4
$N_{\bar{\nu}_e}$	6.6	3.6×10^{17}	49	5.9×10^5
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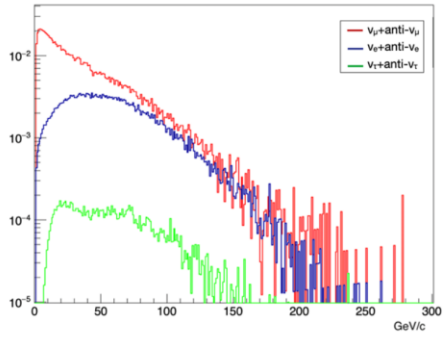

Uncertainty of ν_τ flux is dominated by accuracy in:
- ***D_s production cross-section at SPS,*** *currently 10%, but NA65 expect to reconstruct ~1000 events soon*
- ***BR($D_s \rightarrow \tau\nu_\tau$)*** *~3-4%*
- ***Cascade production of charm in thick target*** *SHiP plans a dedicated experiment in the near future to measure J/ψ and charm production using muons in targets of variable depths*

Plan to reach ≤5% uncertainty in ν_τ flux seems realistic

✓ ***Important tests of SM:***
- *Lepton Flavour Universality in neutrino interactions (1-3% accuracy in ratios: ν_e/ν_μ, ν_e/ν_τ and ν_μ/ν_τ)*
- *Test of F_4 ($F_4 \approx 0$) and F_5 ($F_5 = 2xF_2$) structure functions, accessible only with tau neutrinos* [C.Albright and C.Jarlskog. NP B84 (1975)]

✓ *Measurement of neutrino cross-sections up to 100 GeV as an input to neutrino oscillation programme*

10

	<E>[GeV]	Beam dump	<E>[GeV]	CC DIS interactions
N_{ν_e}	6.3	4.1×10^{17}	63	2.8×10^6
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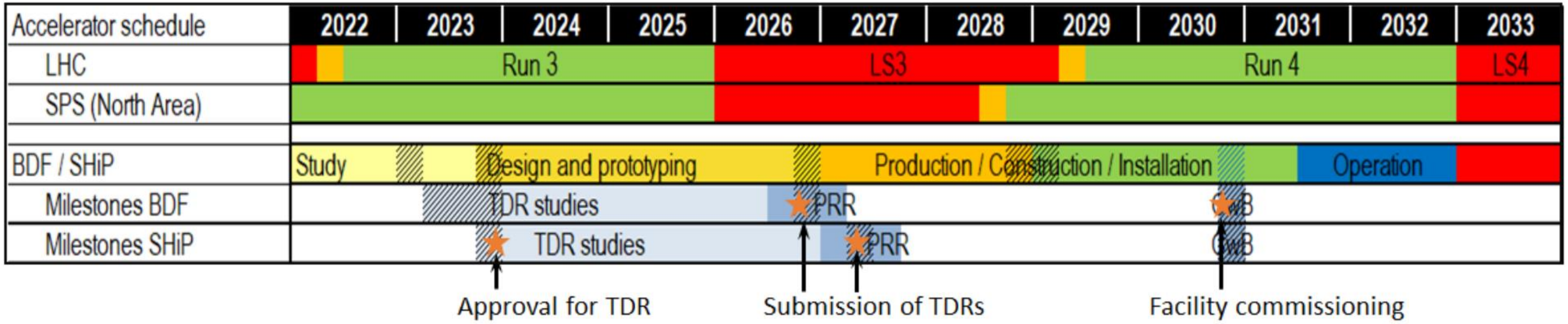
For 6x10^{20} POT

Roadmap

Roadmap



- ✓ ***~3 years for detector TDRs (approval in 2023 is critical to ensure timely funding)***
- ✓ *Construction / installation of facility and detector is decoupled from NA operation*
- ✓ *Availability of test beams challenging*
- ✓ ***Important to start data taking >1 year before LS4***

SPSC open session, September 2023 15

Summary

- **SND@LHC**
  - Accumulated 68.6 fb^{-1} (2022: **36.8** + 2023: **31.8** fb^{-1})
  - Due to LHC machine trouble, only two emulsion targets for 2023.
    - LHC is already back in normal operation but no pp run in 2023.
  - The first physics result, LHC neutrino observation, published on PRL.
    - Both FASERν and SND@LHC result was published and selected for editor's choice on PRL
  - Stay tune for RUN3 result toward RUN4
    - ~2,000 high energy neutrino events in RUN3 with 290 fb^{-1}
    - ~25,000 events in RUN4 with 3000 fb^{-1} by AdvSND@LHC
- **SHiP (BDF/SHiP@ECN3)**
  - New proposal at North Area ECN3 was submitted and under reviewing process at SPSC.
  - HIKE/SHADOWS (+NaNu) is the competitor. HIKE and SHADOWS run simultaneously.
  - Our fate will be decided by early 2024.