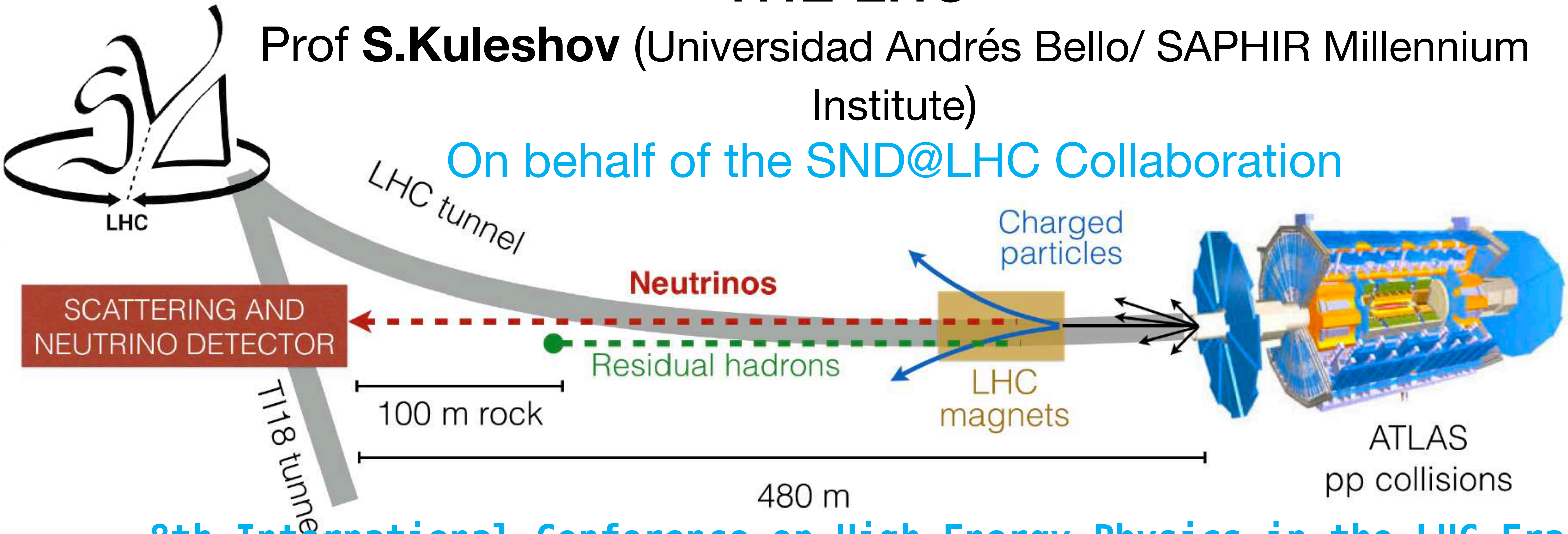
ANID – Millennium Science Initiative Program-ICN2019_044
And FONDECYT 1191103, ANID, Chile

Status of SND@LHC

THE SCATTERING AND NEUTRINO DETECTOR AT THE LHC

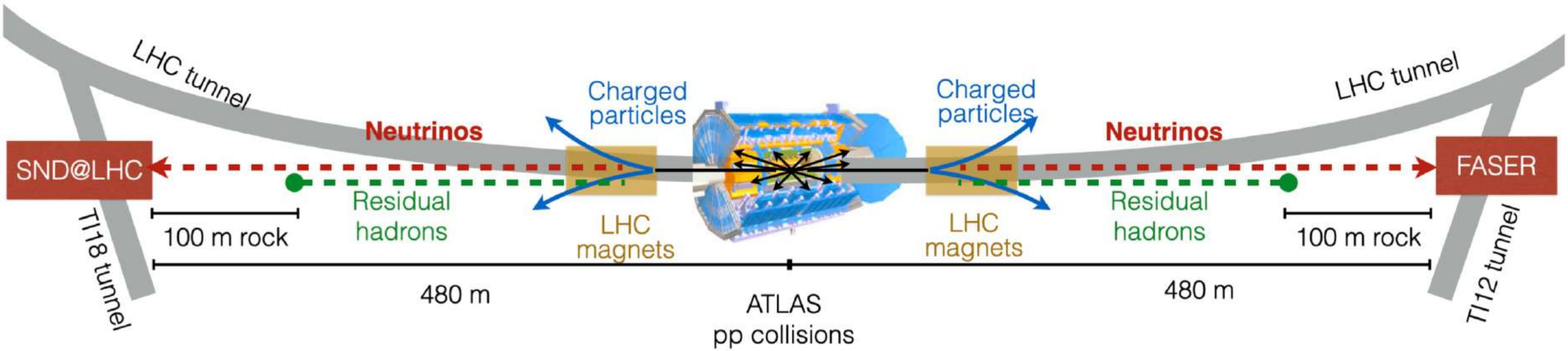
Prof **S.Kuleshov** (Universidad Andrés Bello/ SAPHIR Millennium Institute)

On behalf of the SND@LHC Collaboration



8th International Conference on High Energy Physics in the LHC Era
Jan. 9-13, 2023. Universidad Técnica Federico Santa María, Valparaiso, Chile

Current neutrino physics at LHC experiments

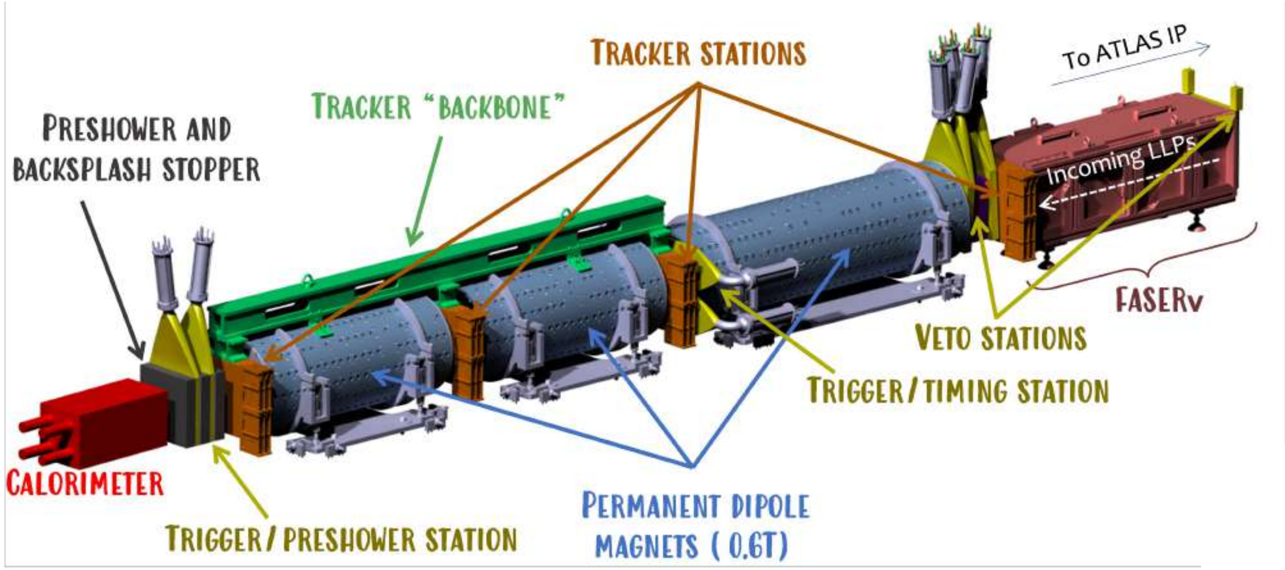


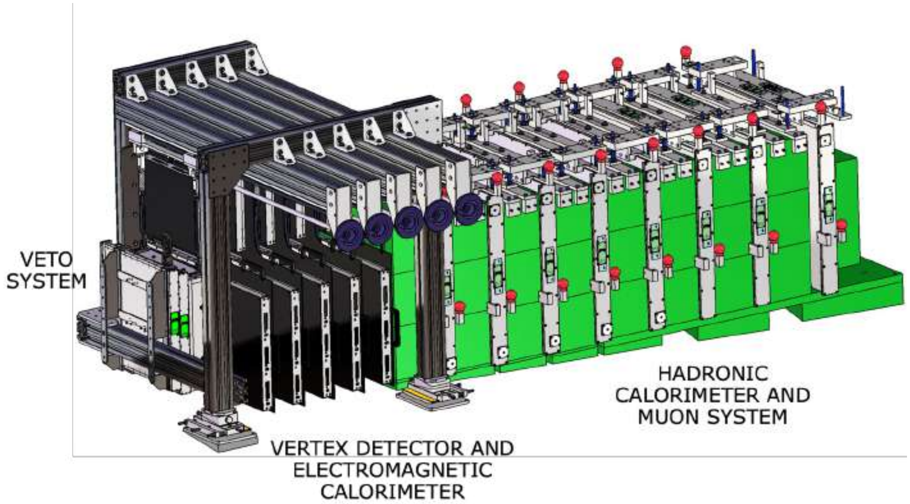
Generally referred as "**forward physics**" , referring to regions of the detector(s) which are close to the beam axis, at **high pseudorapidity** η

$$\eta = arctanh\left(\frac{p_L}{|\boldsymbol{p}|}\right)$$

SND@LHC & FASER

FASER Detector





Lenth: 2.6 m
Aperture 390x390 mm^2

Length: 7 m
Aperture: 20 cm
Length of decay volume: 1.5 m

arXiv:2207.11427

OVERVIEW

- The SND@LHC experiment
- Detector installation
- Data taking in Run3

Physics Program (Backup slides.)

- Neutrino physics program
- QCD measurements
- Search for feebly interacting particles

Advanced SND@LHC (Backup)

SND@LHC Technical Proposal
https://cds.cern.ch/record/2750060/files/LHCC-P-016.pdf

Approved by the Research Board on March 2021

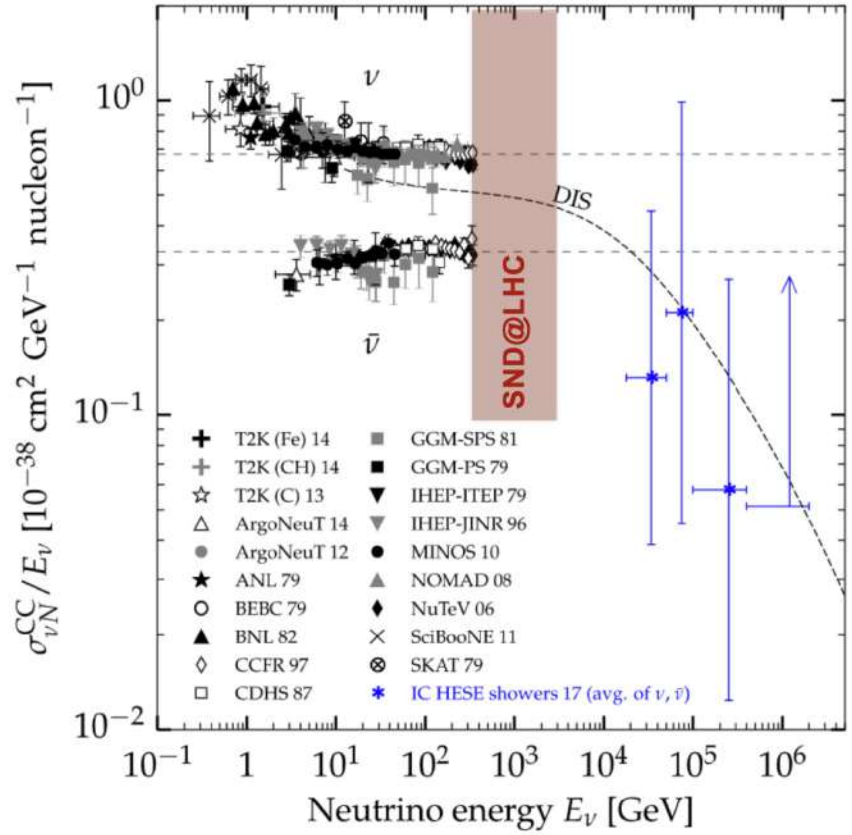
https://snd-lhc.web.cern.ch/

MOTIVATION

Neutrino physics at the LHC

- Klaus Winter, 1990, observing tau neutrinos at the LHC
- A. De Rùjula, E. Fernandez and J. J. Gòmez-Cadenas, 1993, Neutrino fluxes at LHC
- F. Vannucci, 1993, neutrino physics at the LHC
- http://arxiv.org/abs/1804.04413 April 12th 2018

PRL 122 (2019) 041101



CERN is unique in providing energetic **ν** (from LHC) and measure pp →**ν**X in an unexplored domain

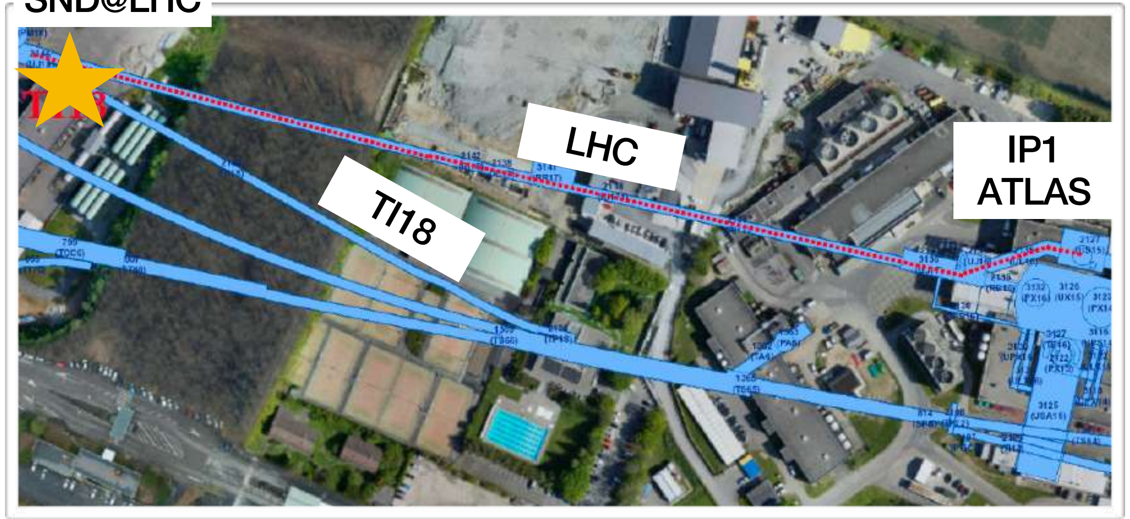
OPEN ACCESS
IOP Publishing — Journal of Physics G: Nuclear and Particle Physics
J. Phys. G: Nucl. Part. Phys. **46** (2019) 115008 (19pp) https://doi.org/10.1088/1361-6471/ab3f7c

Physics potential of an experiment using LHC neutrinos

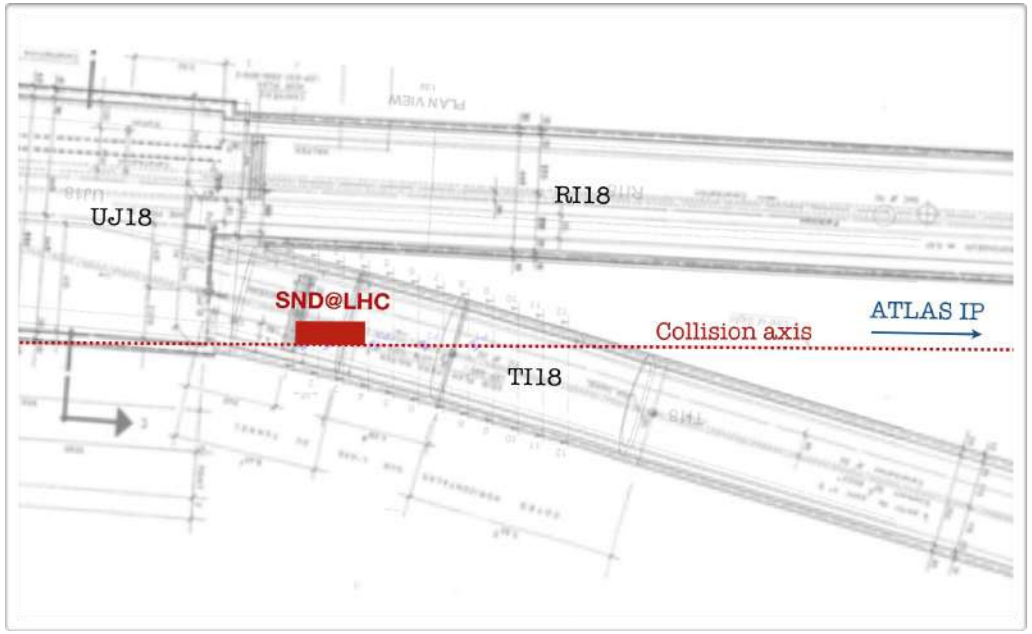
OPEN ACCESS
IOP Publishing — Journal of Physics G: Nuclear and Particle Physics
J. Phys. G: Nucl. Part. Phys. **47** (2020) 125004 (18pp) https://doi.org/10.1088/1361-6471/aba7ad

Further studies on the physics potential of an experiment using LHC neutrinos

LOCATION



- About 480 m away from the ATLAS IP
- Tunnel TI18: former service tunnel connecting SPS to LEP
- Symmetric to TI12 tunnel where the FASER is located



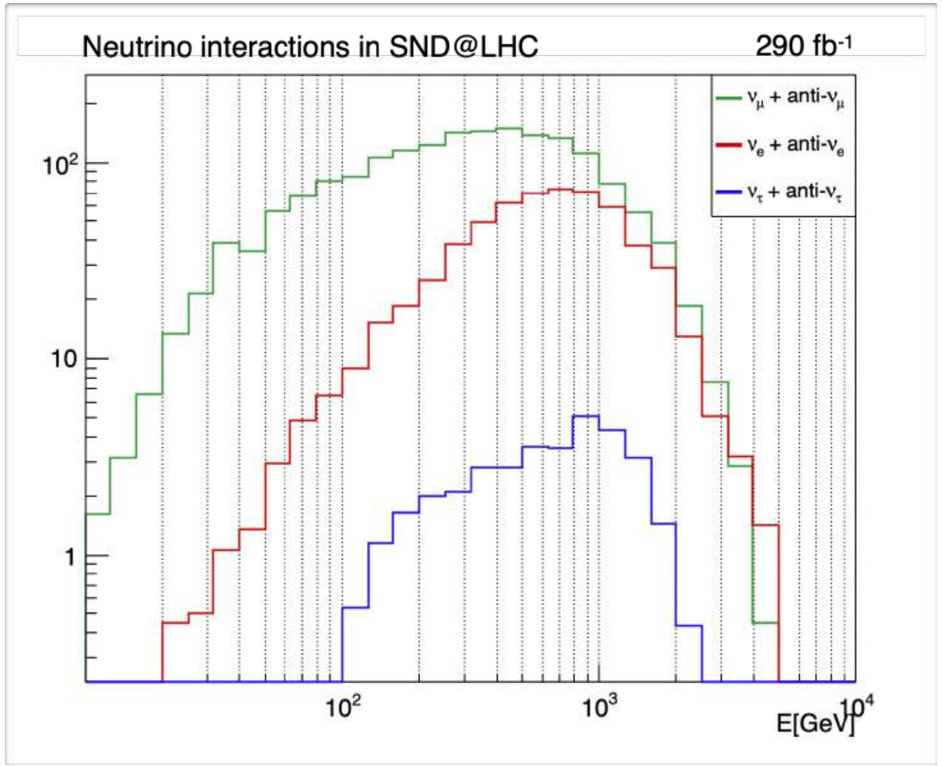
- Charged particles deflected by LHC magnets
- Shielding from the IP provided by 100 m rock

- Angular acceptance: $7.2<\eta< 8.4$
- First phase: operation in Run 3 to collect 150 fb^{-1}

NEUTRINO EXPECTATIONS

- Integrated luminosity: **290 fb^{-1}**
- Upward/downward crossing angle: **0.43/0.57**

- 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 ⟨E⟩ [GeV]	Yield	CC neutrino interactions ⟨E⟩ [GeV]	Yield	NC neutrino interactions ⟨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

Experiment concept

Hybrid detector optimised for the identification of all three neutrino flavours

LHC
Scattering and Neutrino Detector at the LHC

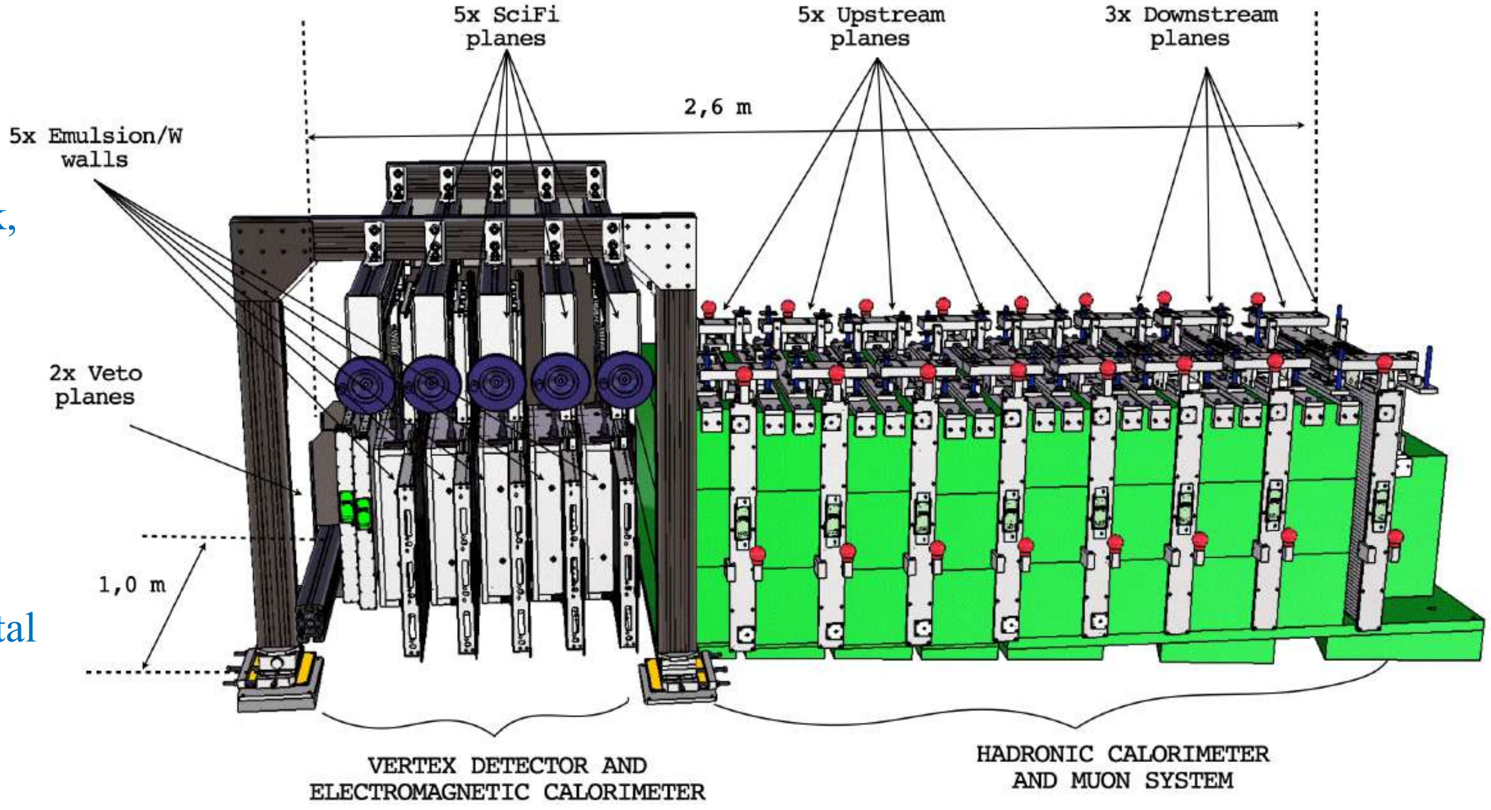
VETO PLANE:
tag penetrating muons

NEUTRINO TARGET & VERTEX DETECTOR:
- Emulsion cloud chambers (60 emulsion films, 300μm thick, interleaved by 1mm thick tungsten plates)

E.M. CAL
- 250μm Scintillating fibres for timing information and e.m. energy measurement

HADRONIC CALO:
iron walls interleaved with plastic scintillator planes for a total of about 11 λ

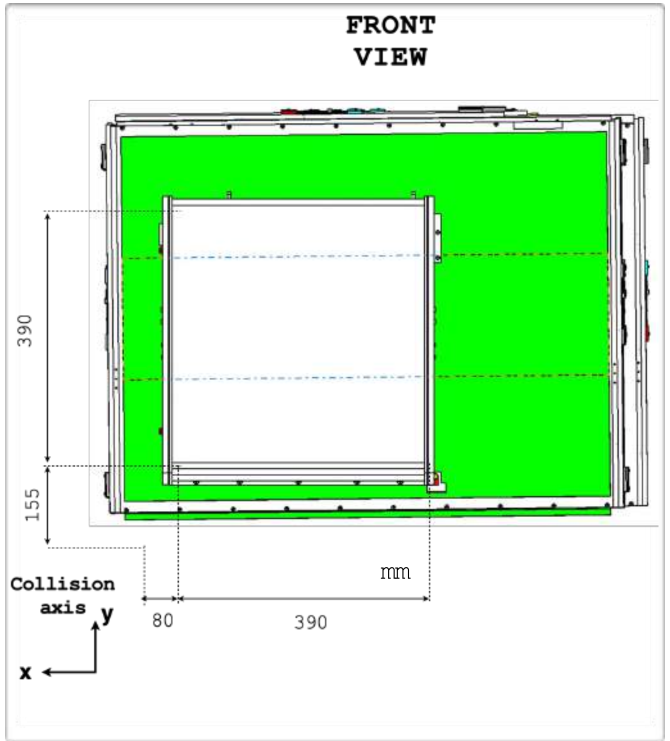
MUON IDENTIFICATION SYSTEM:
3 most downstream plastic scintillator stations based on fine-grained bars, meant for the muon identification and tracking



THE DETECTOR LAYOUT

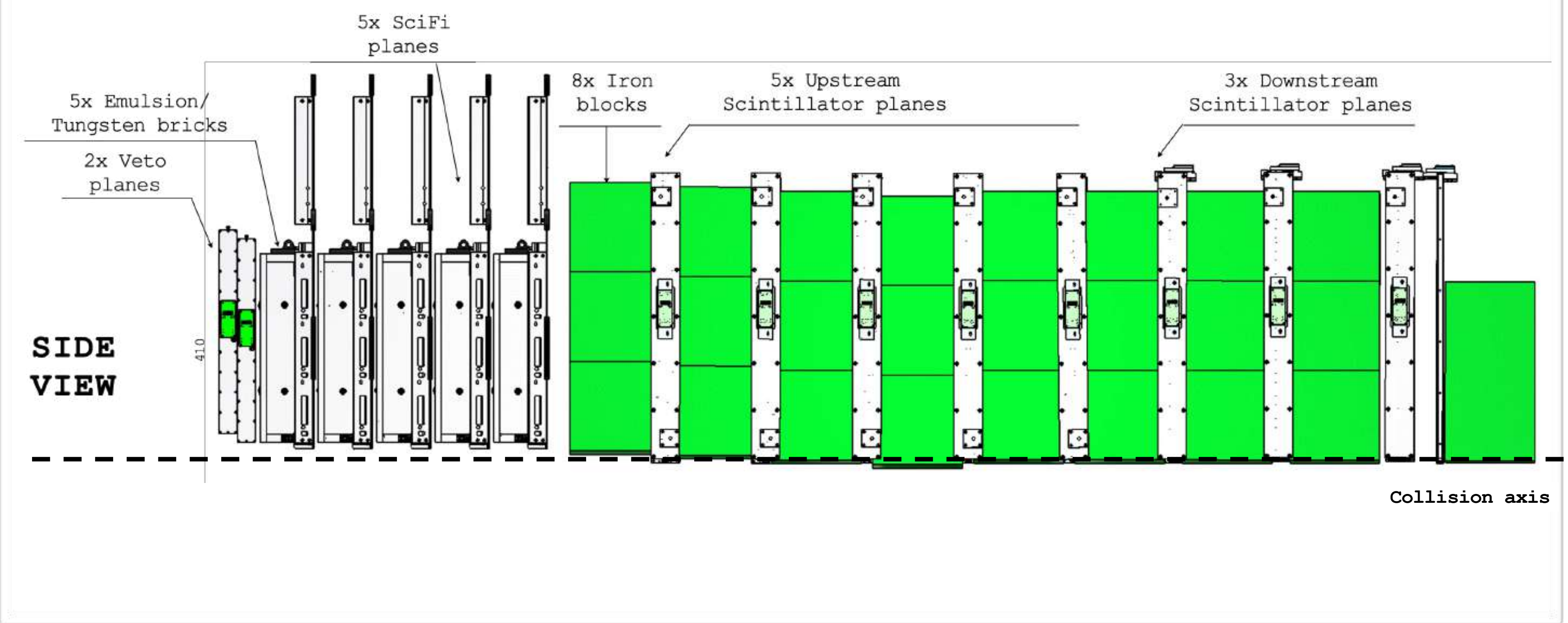
- Angular acceptance: $7.2 < \eta < 8.4$
- Target material: Tungsten
- Target mass: 830 kg
- Surface: 390x390 mm^2

Off axis location

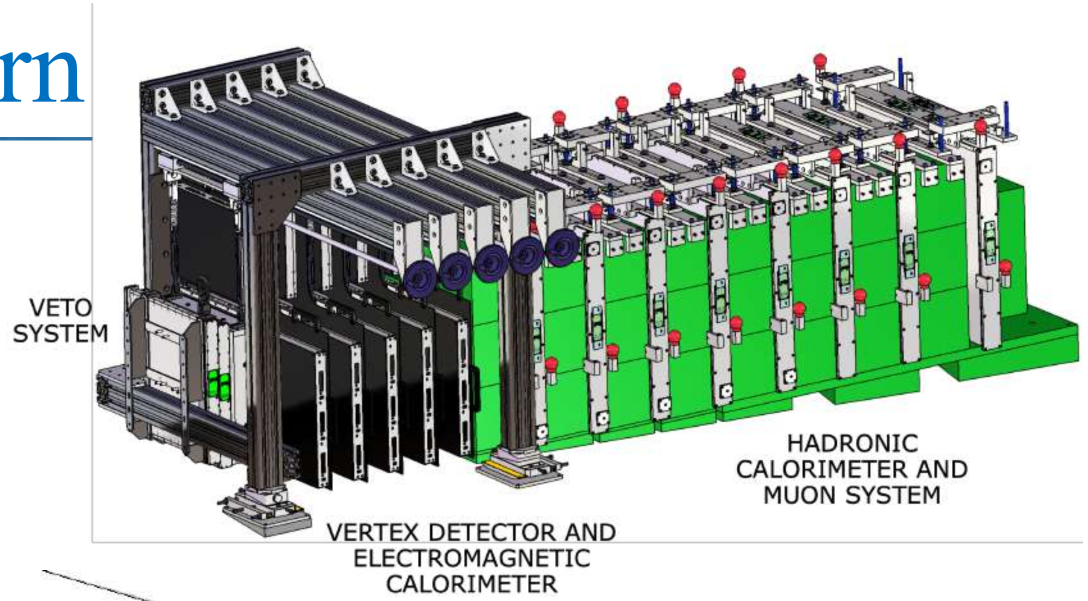


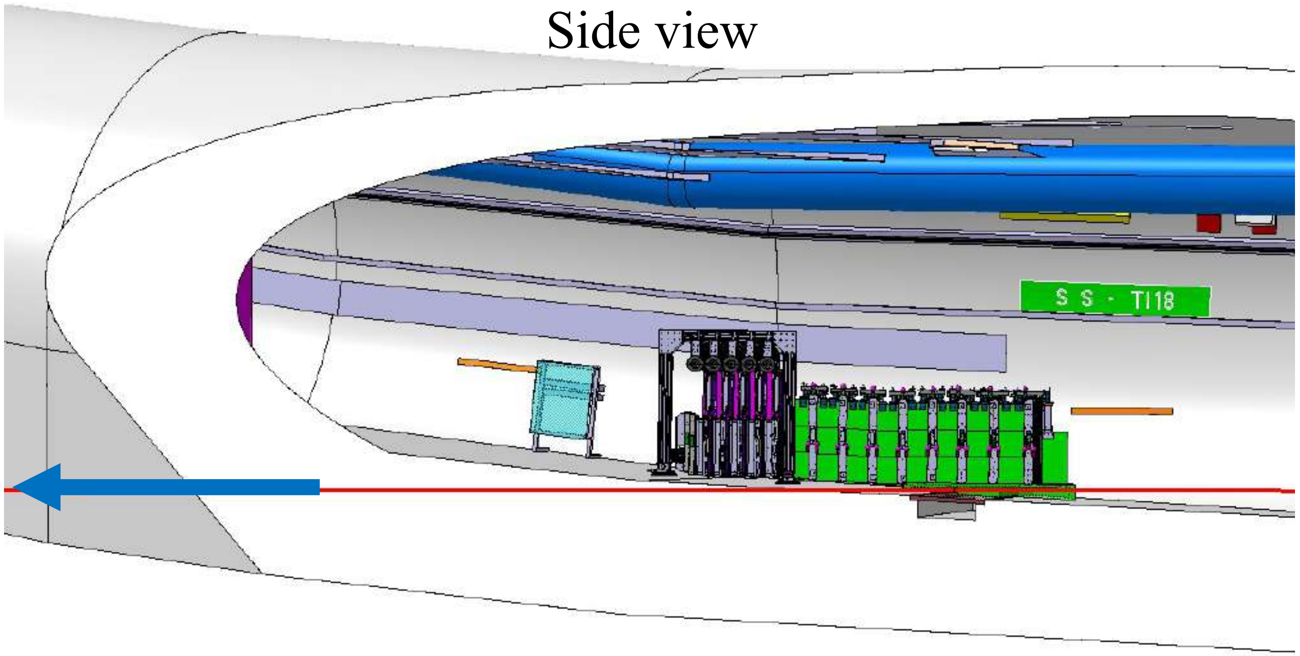
Electromagnetic calorimeter
~40 X_0

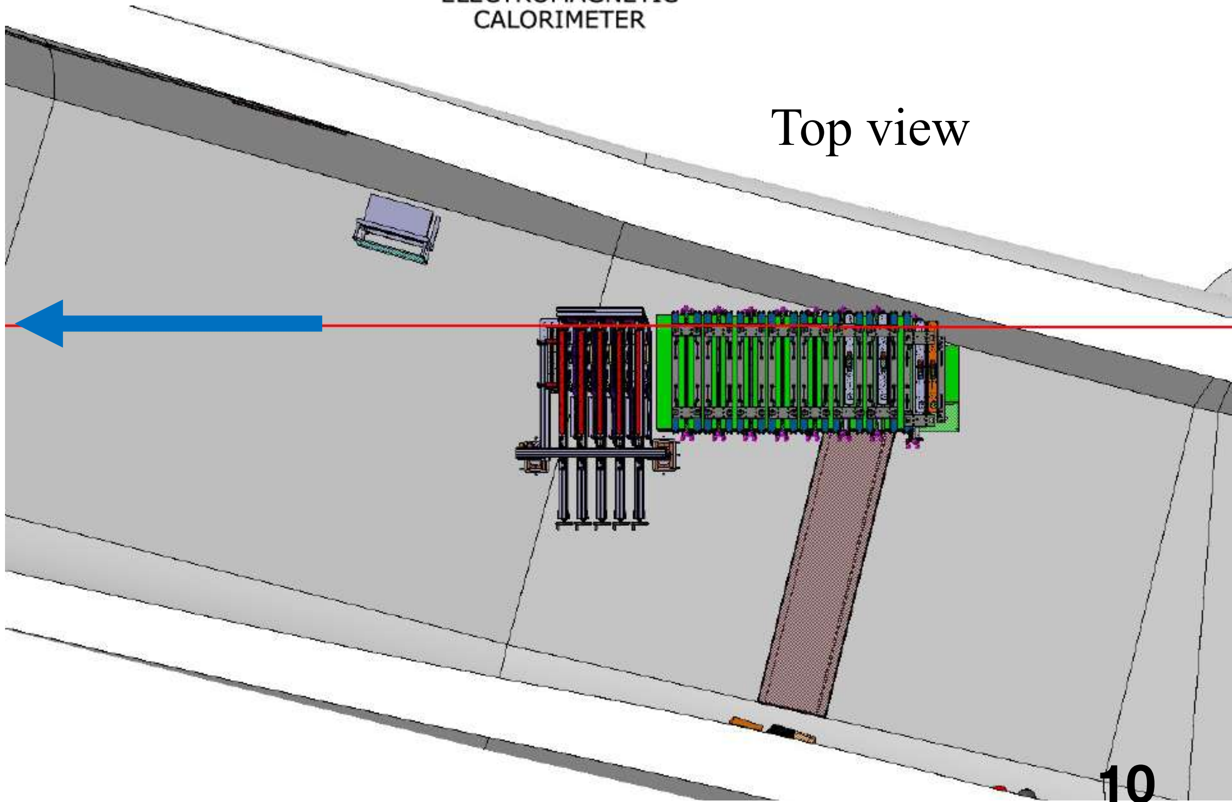
Hadronic calorimeter
~10 λ



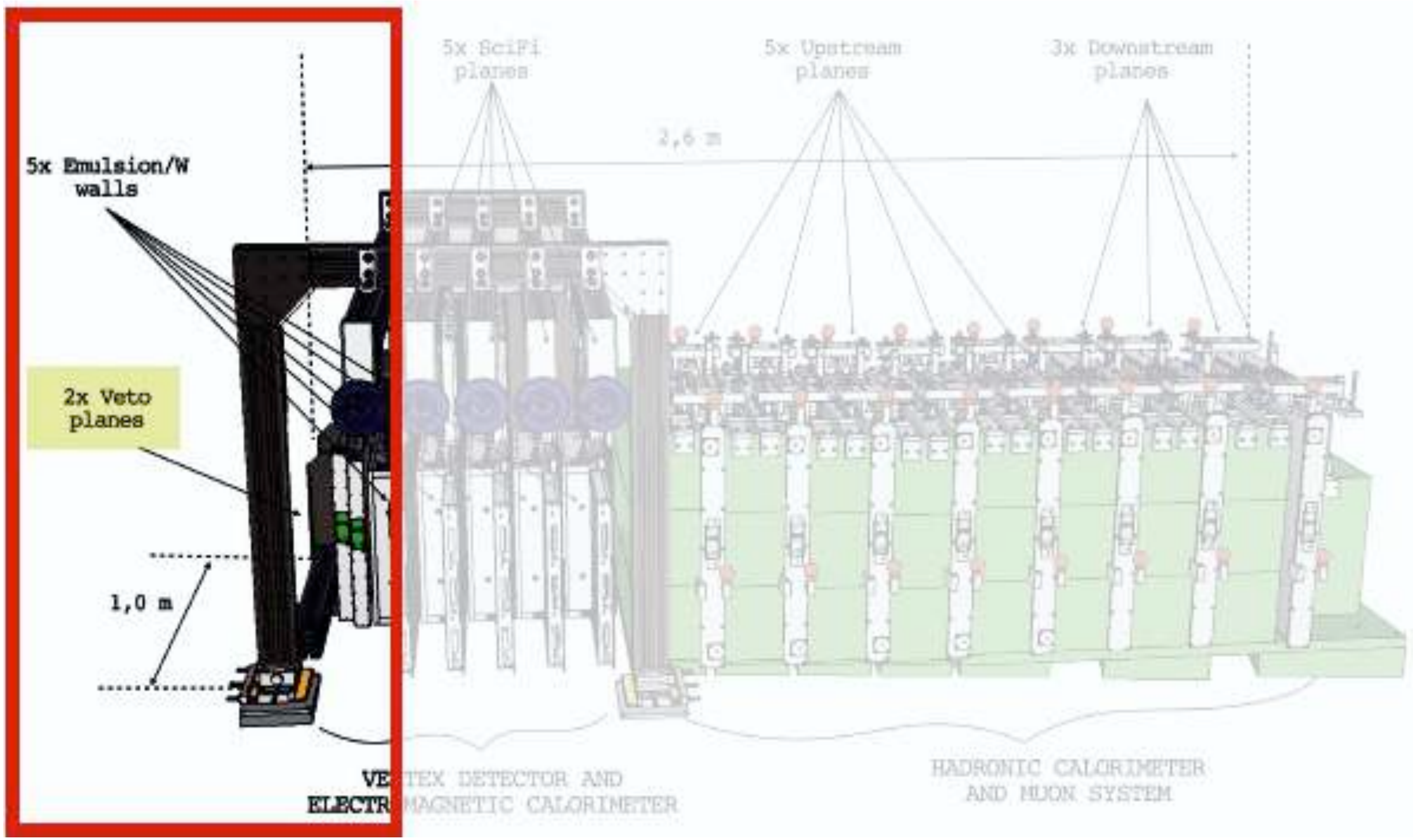
SND@LHC in the TI18 cavern

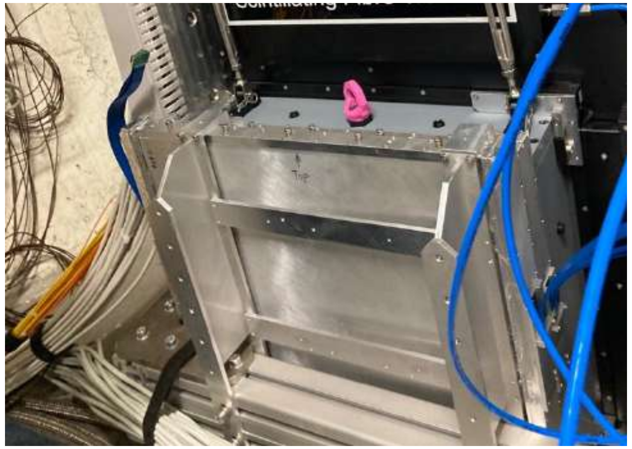






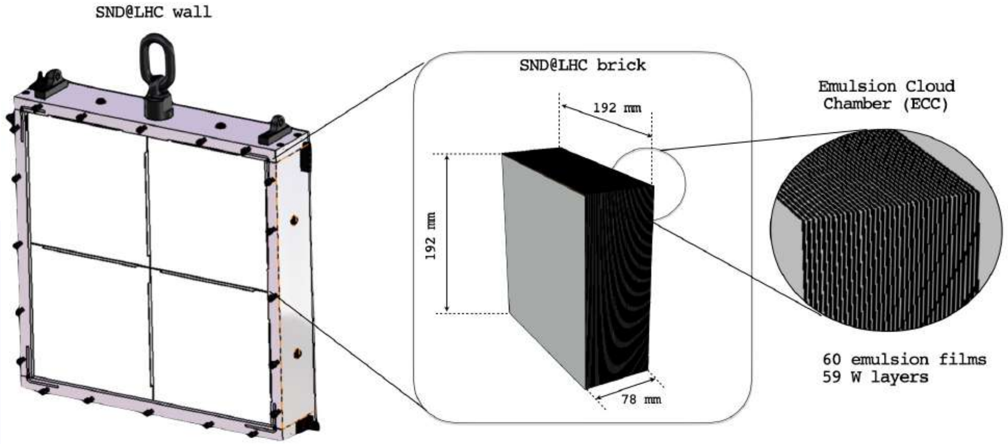
UPSTREAM VETO DETECTOR

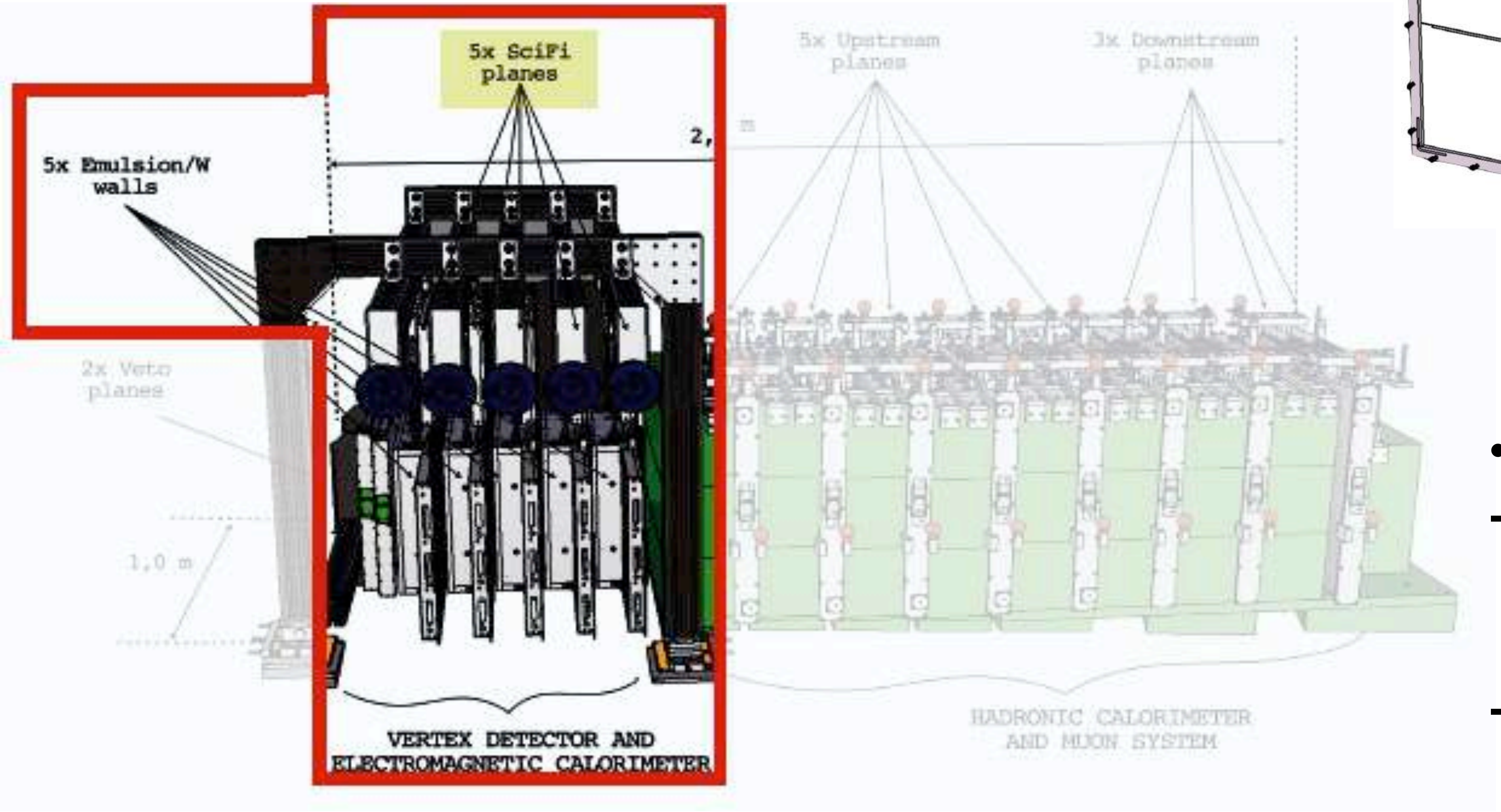




- Goal: charged background particles fixation
- Located upstream of the neutrino target

NEUTRINO TARGET AND VERTEX DETECTOR

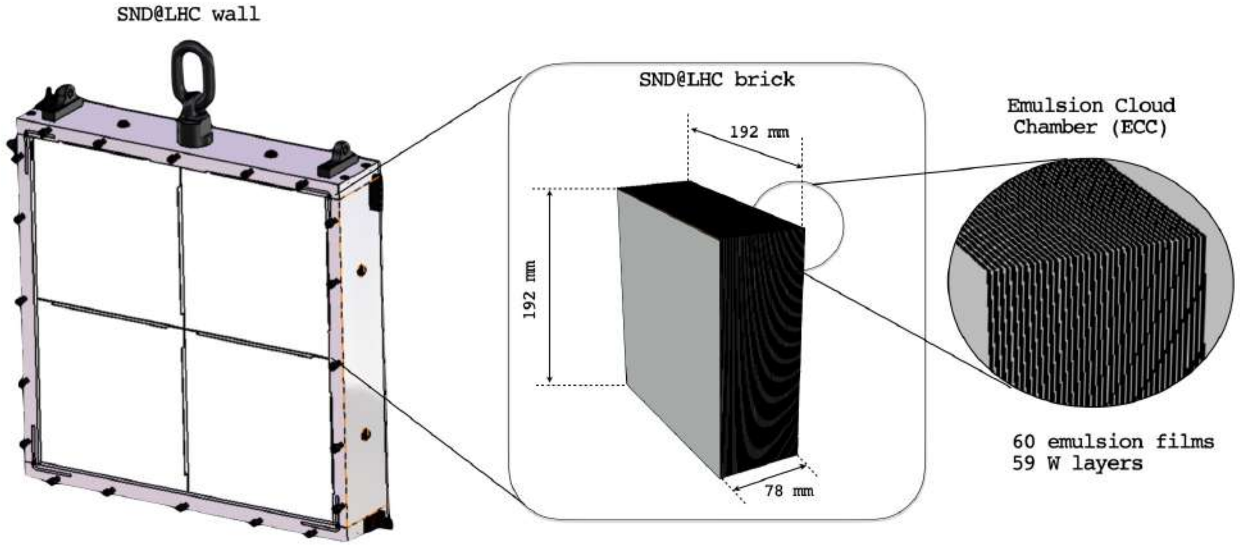




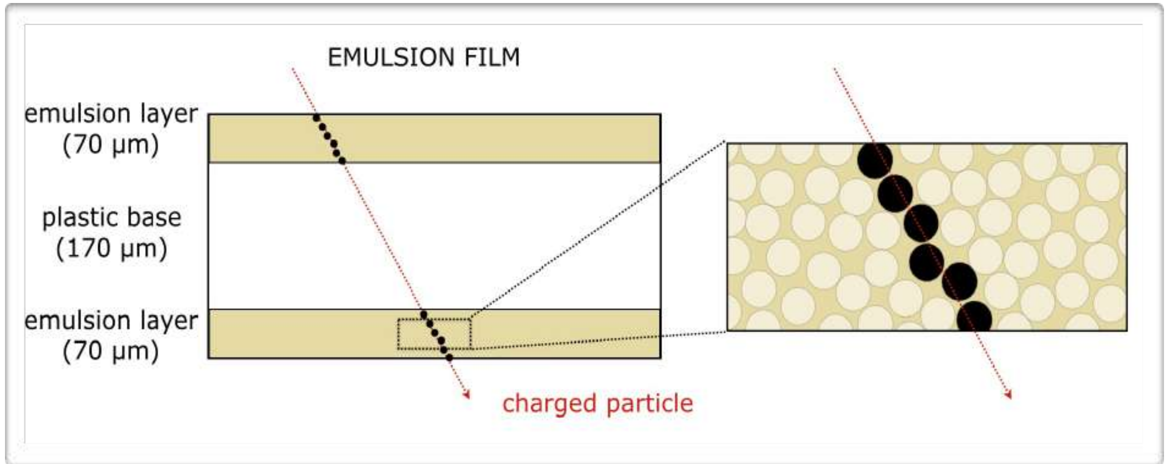
- Goals:
- detecting neutrino interactions (all flavours); energy measurement
- search for FIPs

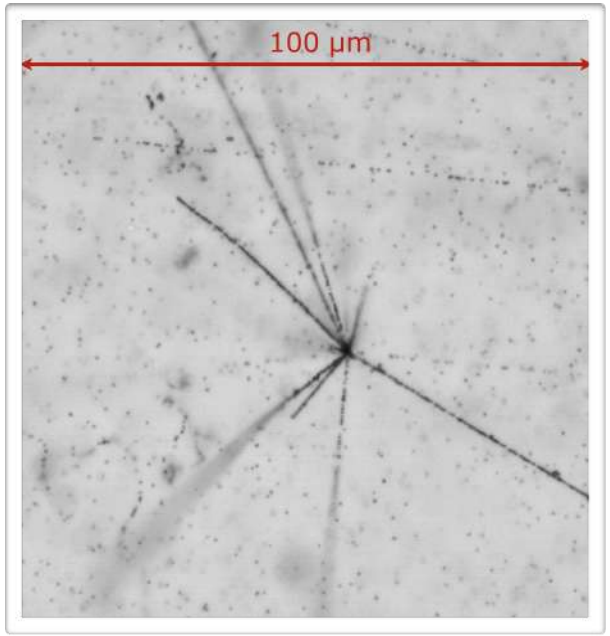
EMULSION TARGET

Target assembled according to the Emulsion Cloud Chamber (ECC) technique:
Tungsten layers (1mm-thick) alternated to nuclear emulsion films



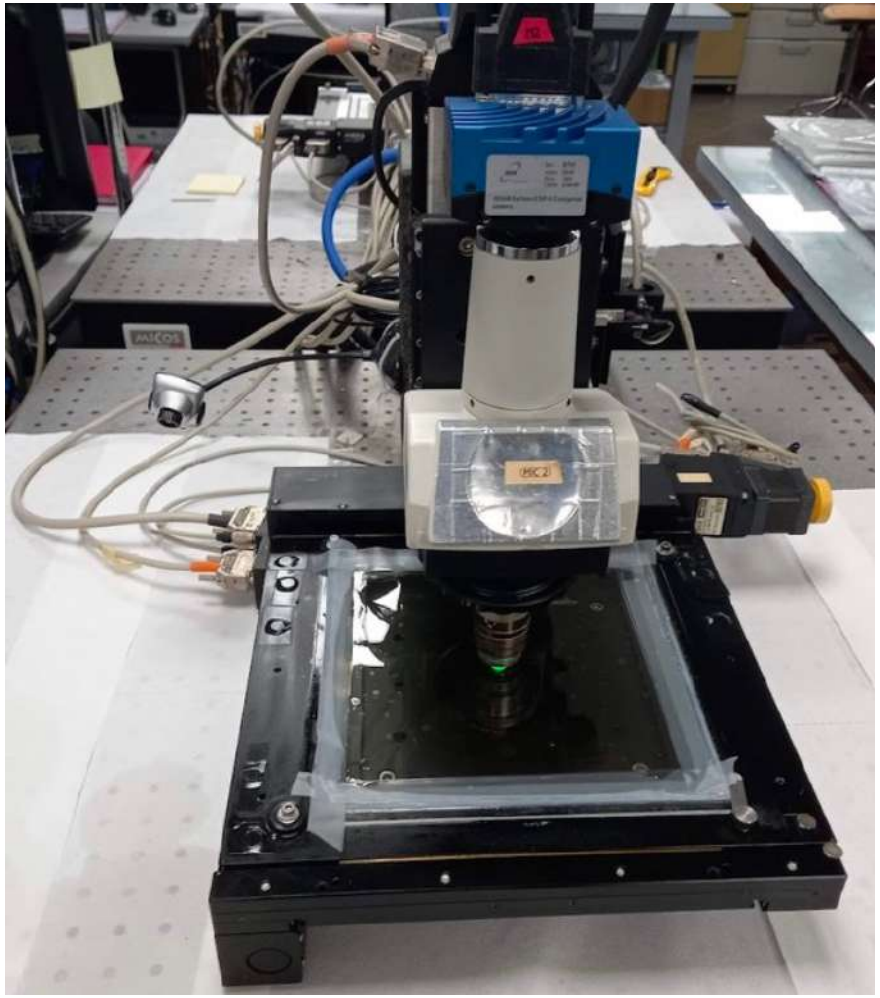
The AgBr crystals, with a diameter of 0.2µm, are sensitive to minimum ionizing particles (MIP). A chemical process, known as development, enhances latent images inducing the growth of silver clusters (grains) with a diameter of 0.6 µm, visible by an optical microscope.



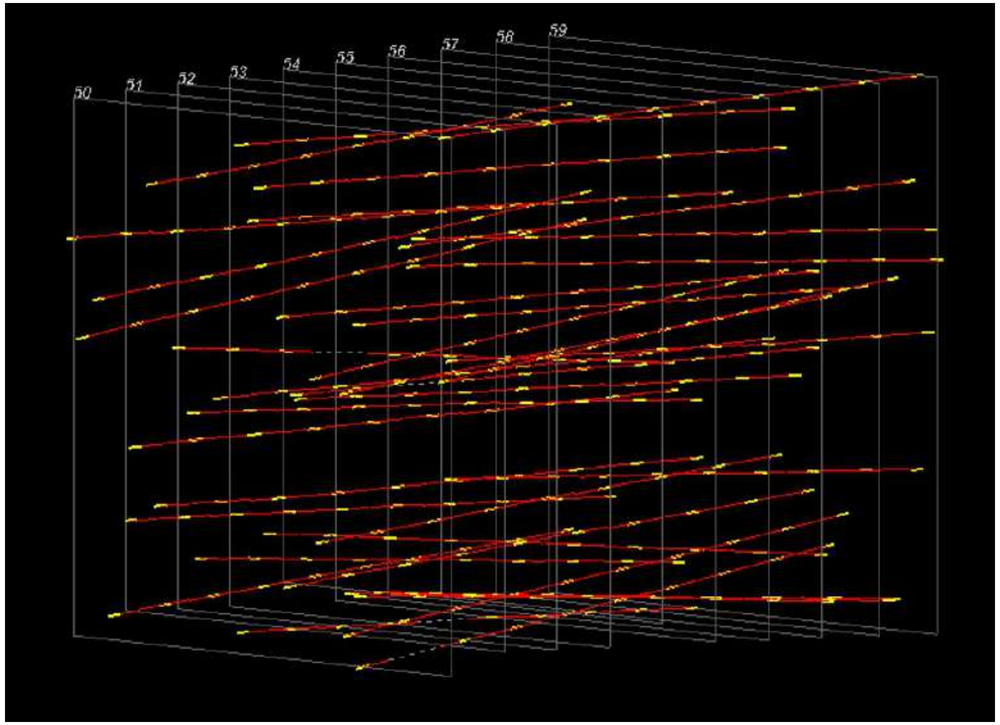


Sub-micrometric position resolution

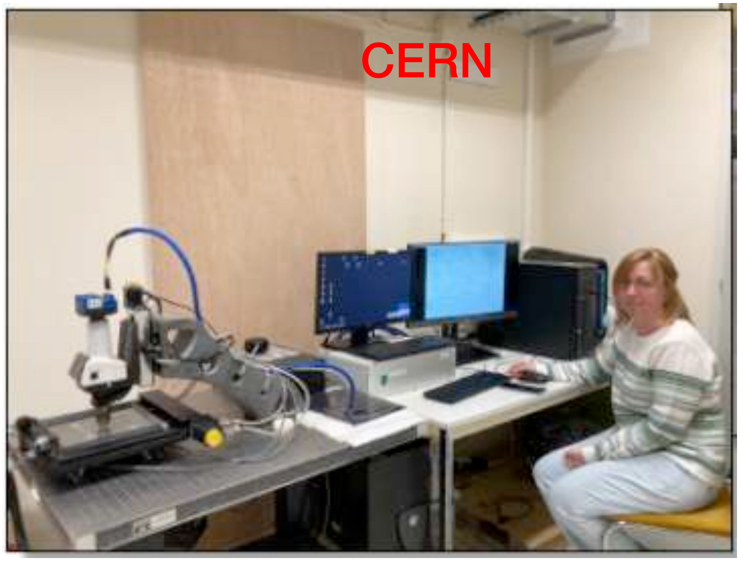
EMULSION SCANNING AND ANALYSIS



Optical system for the scanning of emulsion films @Napoli Laboratory

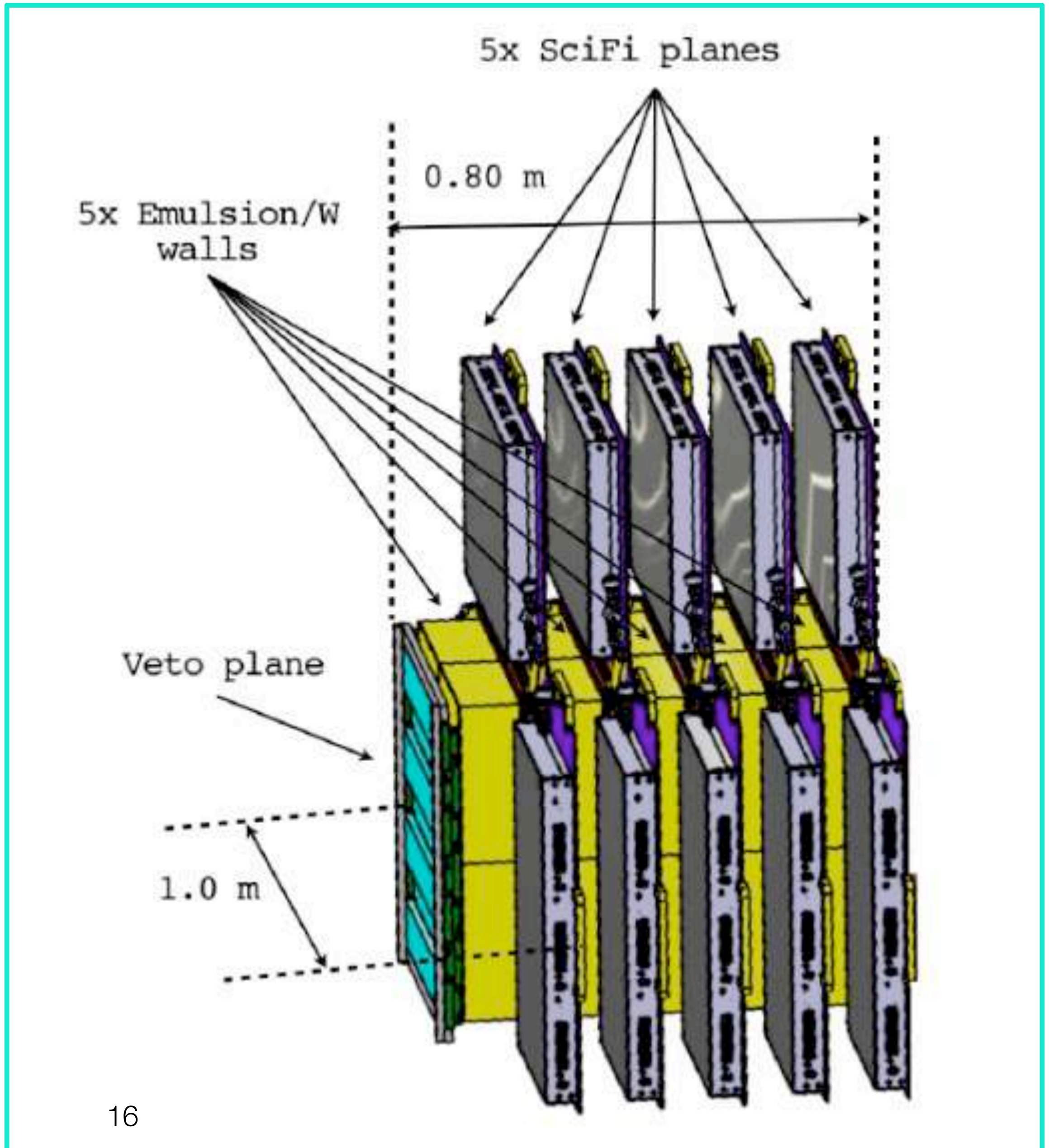


Reconstructed cosmmic-ray tracks in the SND@LHC wall used in the commissioning

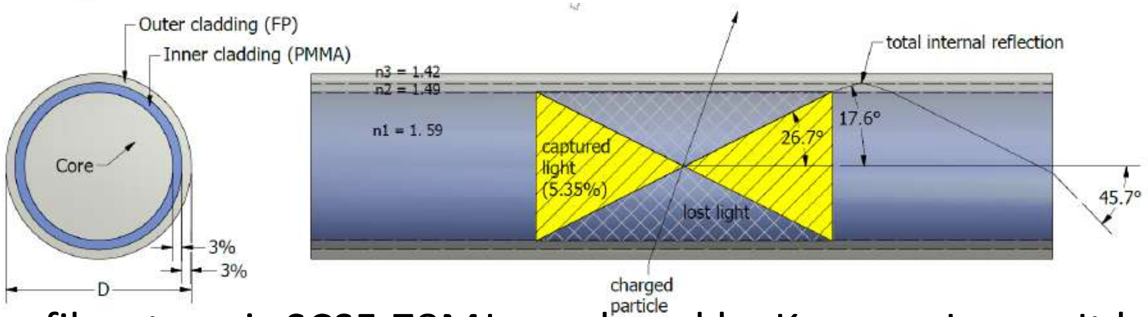


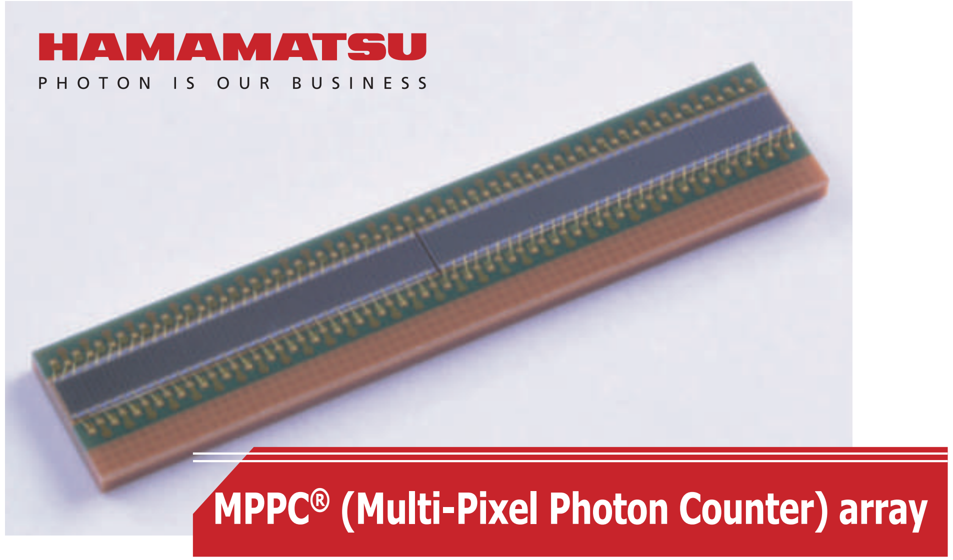
- Bologna: 1 system upgraded, software installation to be performed
- Lebedev: 1 system upgraded, ready to scan
- Napoli: 1 system upgraded, ready to scan
- Zurich: 1 system upgraded, ready to scan
- CERN: 1 system, upgraded, ready to scan NEW

General layout of the target region.
SciFi modules.



SciFi for SND@LHC Fiber module elements.





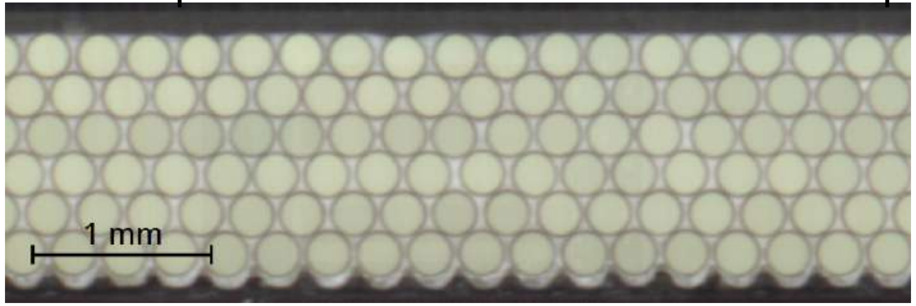
The fiber type is SCSF-78MJ, produced by Kuraray, Japan. It has a diameter of 0.25 mm and is made of polystyrene core with added dye and wavelength shifter, and two claddings with lower refraction index.

10^3 photons/MeV, decay time=2.8 nS,

Emission spectra from 400 nm to 600 nm with peak near 450 nm

S13552

Surface mount type one-dimensional 128-element MPPC array



The S13552 is a one-dimensional 128-element MPPC array. This is used by the SciFi (scintillating fiber) tracker in LHCb (Large Hadron Collider beauty experiment), one of detectors located at the LHC of CERN (European Organization for Nuclear Research).

Structure

Parameter	Specification	Unit
Number of channels	128 (1 × 64 ch, 2 chips)	-
Effective photosensitive area/channel	230 × 1625	μm
Pixel pitch	57.5 × 62.5	μm
Number of pixels/channel	104	-
Fill factor	78	%
Package type	Surface mount	-
Window material	Epoxy resin	-
Refractive index of window material	1.55	-

The active elements of the detector are scintillating fiber mats composed of six fiber layers, with dimensions width × length × height: 130.65 × 800.0 × 1.4 mm.

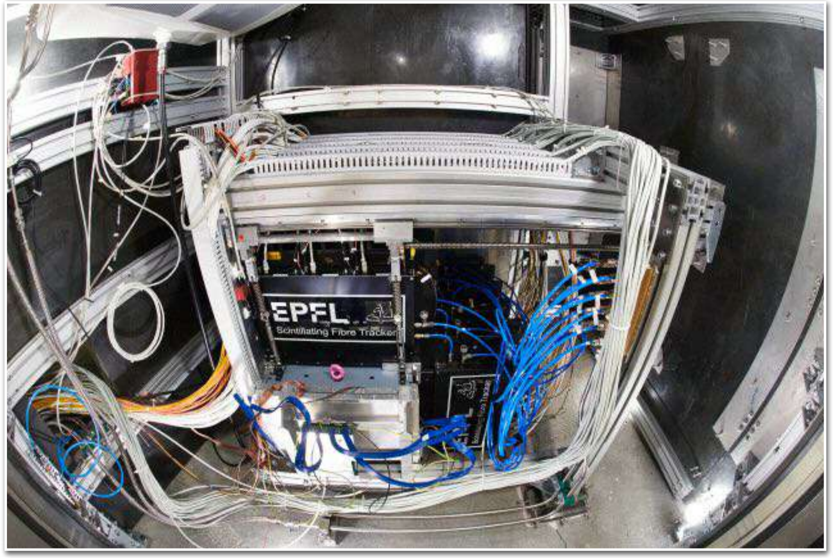
arXiv:1710.084325v1

SciFi for SND@LHC

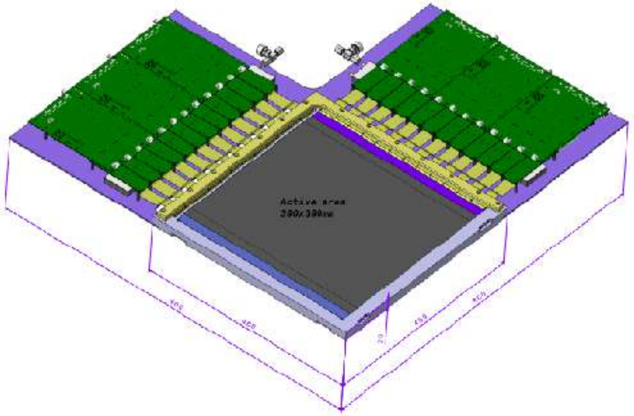
Scintillating fibers read out by SiPMs

- 5 stations interleaved with emulsion targets
- X and Y coordinate measurements in each station

Single SciFi module with X and Y planes



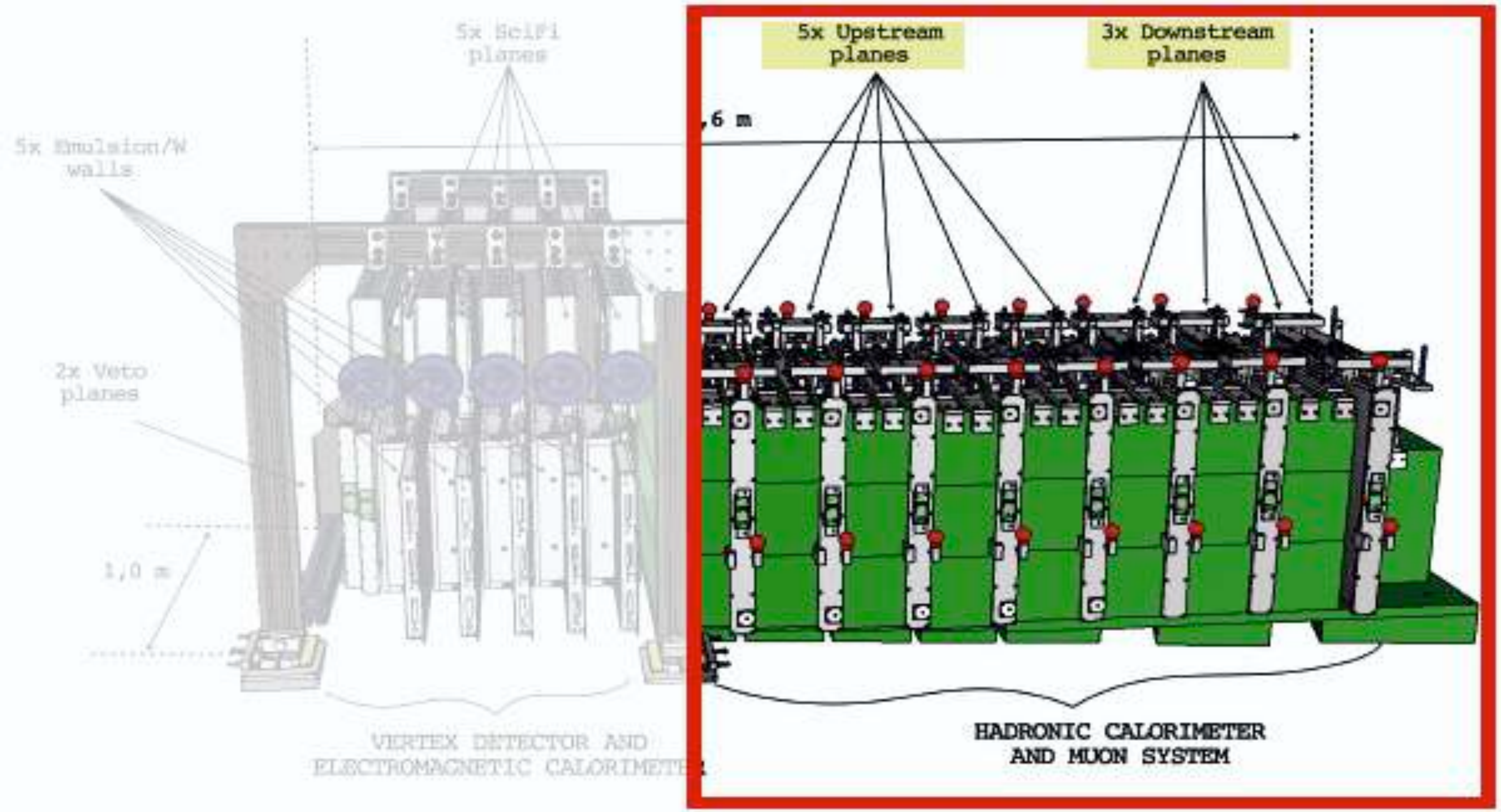
Final detector installation in TI18



1536 readout channels per side

- $250\,\mu m$ pitch, with gaps every 64 channels
- Read out by 3 DAQ boards , 8 TOFPET2 ASICs each

MUON SYSTEM AND HADRONIC CALORIMETER



Goals:

- muon tracking and identification
- measurement of the energy of the hadronic jet

Summary of the experiment main milestones

- Letter of Intent: Aug 27th, 2020
- Technical Proposal: Jan 22nd, 2021
- Approval by CERN RB: Mar 2021
- Experimental area & infrastructure: Jun 28 – end Aug
- Detector construction completion: Oct 13
- Detector surface commissioning: Sep - Oct
- Test beams: Sep 1-5, Oct 1-6
- Start of detector installation in TI18: Nov 1
- Turn on and global commissioning: Dec 7
- Detector commissioning and debugging: Jan-Feb
- Installation of the neutron shield: Mar 15
- Installation of the first emulsion films: Apr 7
- First data from "splash"/collision: Apr, May
- First 13.6 TeV collisions: July 5th

Chilean team and the technical coordinator's team

SND@LHC Technical Proposal
https://cds.cern.ch/record/2750060/files/LHCC-P-016.pdf

DETECTOR INSTALLATION IN TI18

- 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

- Installation of the emulsion detector on April 7th 2022

December 2021

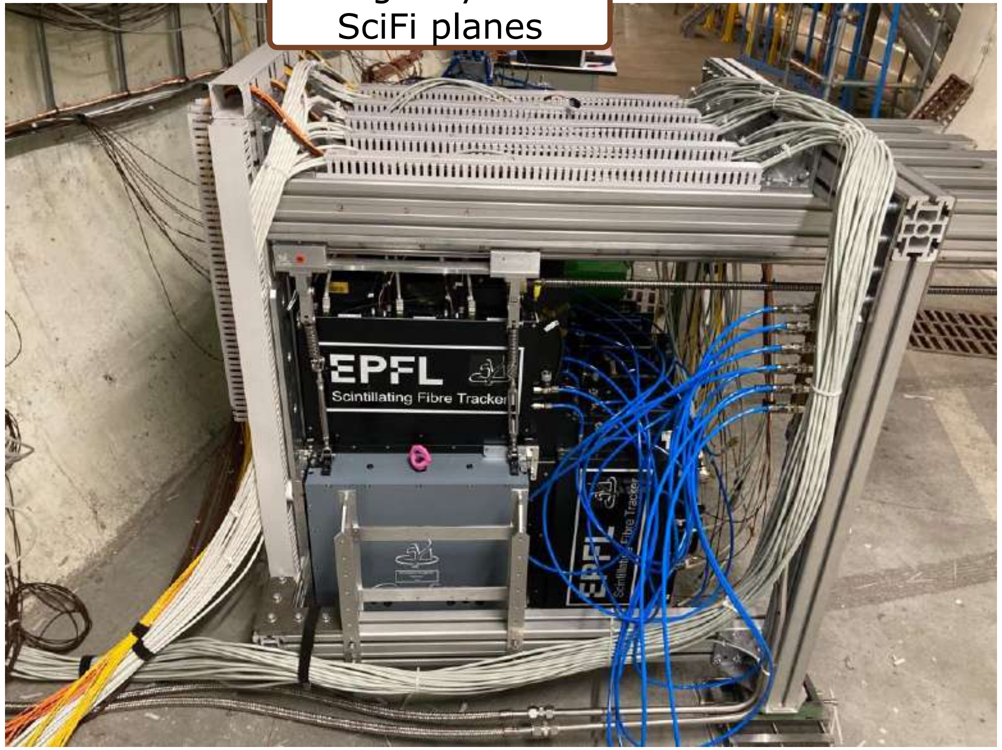
Chillean team contribution.

March 2022

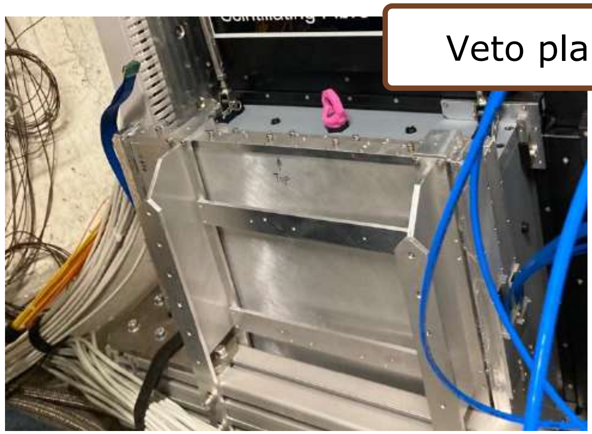
DETECTOR INSTALLATION IN TI18

Target wall

Target system SciFi planes

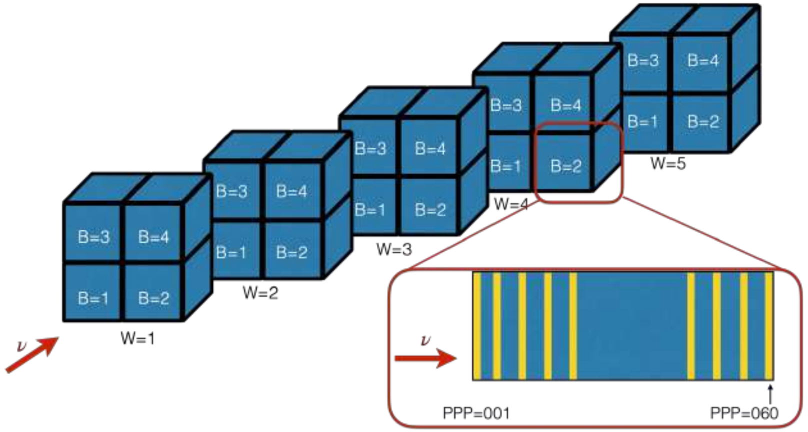


Veto plane



Muon system

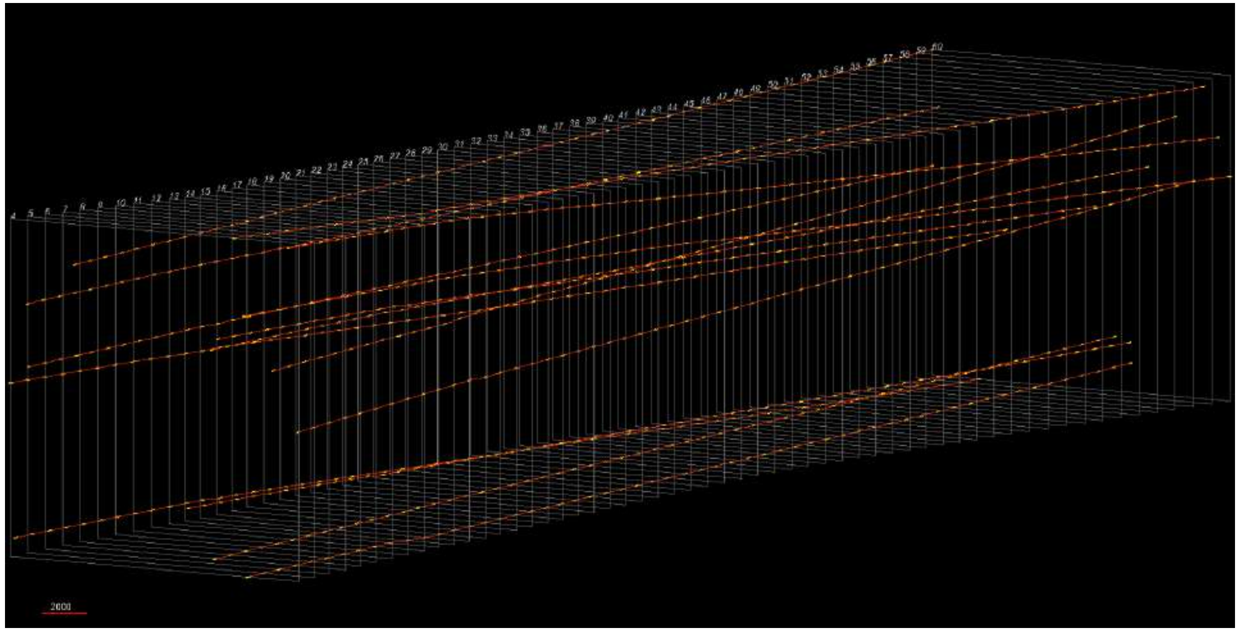
EMULSION TARGET ASSEMBLLY AND INSTALLATION



- Full target system equipped with emulsion films installed on July 26th
- Total mass: 830 kg
- Number of emulsion films: 1200

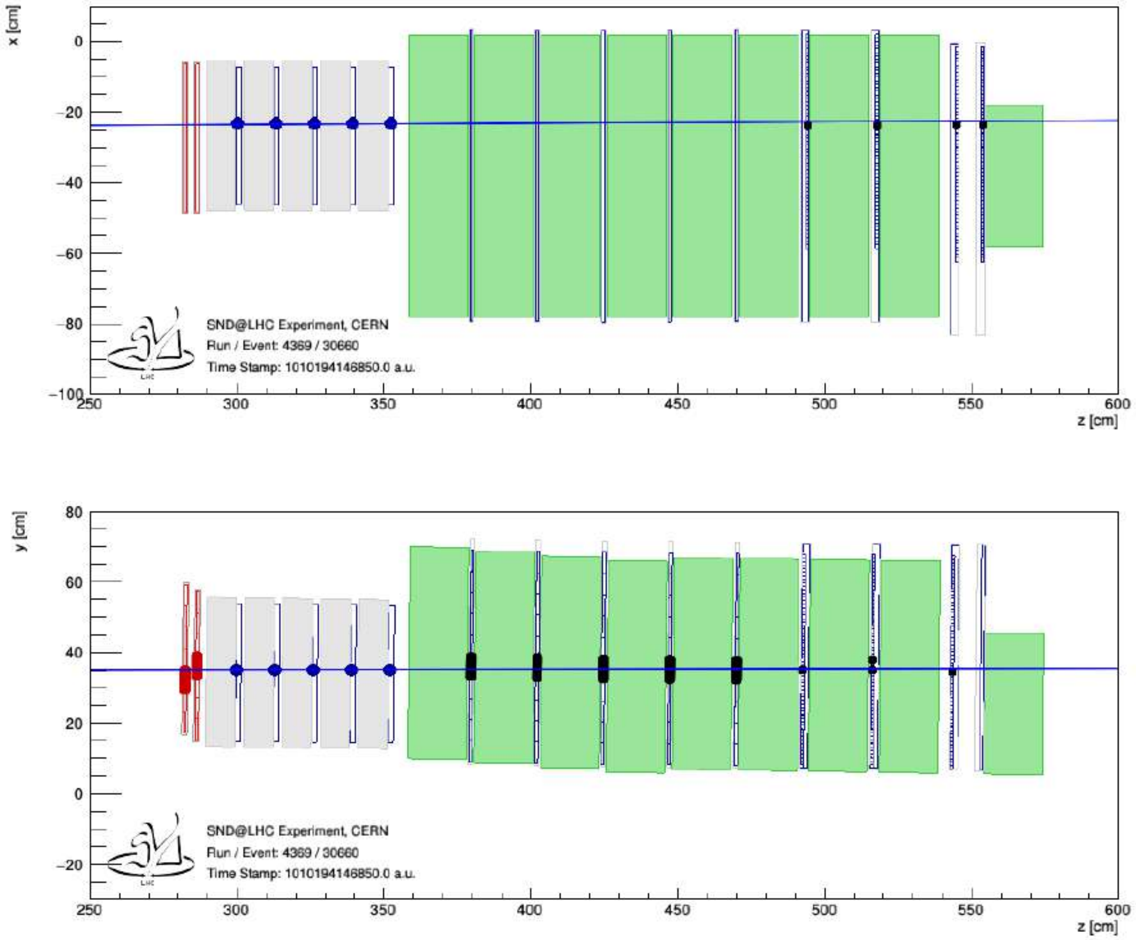
DATA TAKING IN RUN3

Cosmic ray
(March 5th 2022)



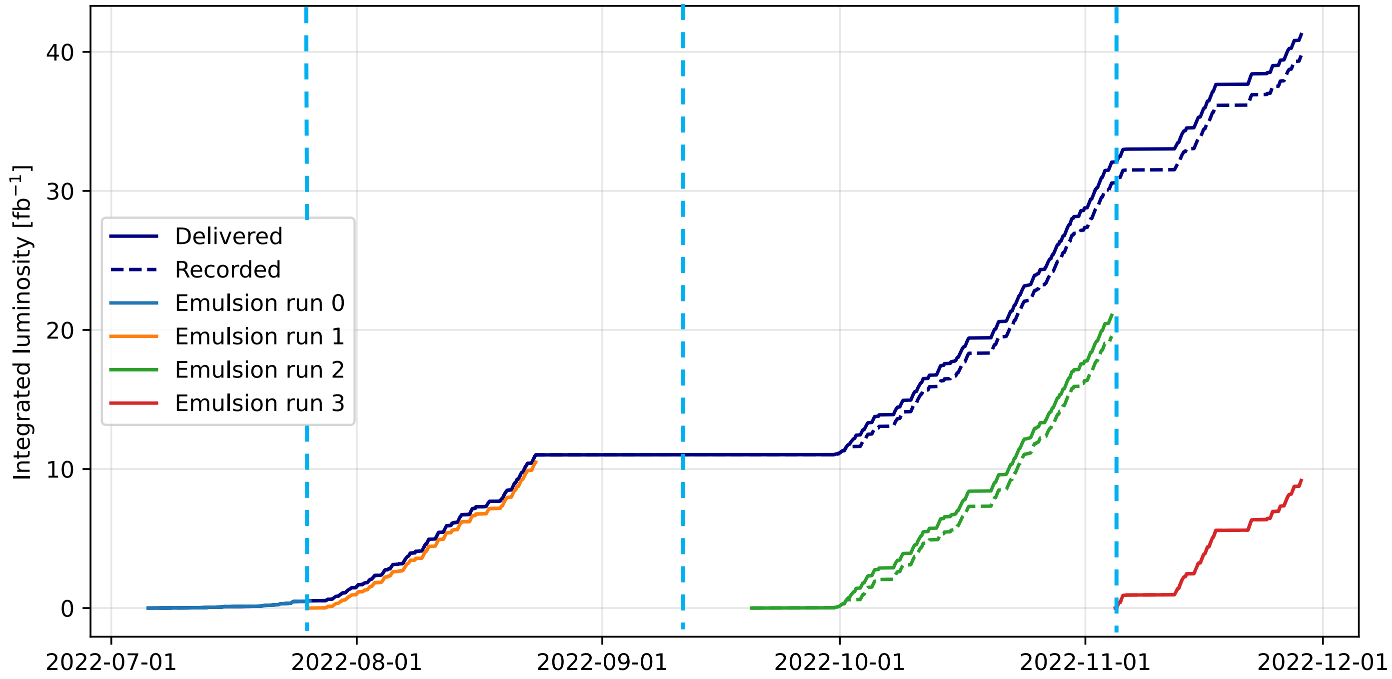
15 tracks selected randomly in 1x1 cm2 - 57 emulsion films
RUN0 emulsion target: April 7th - July 26th (0.51 fb^{-1})

Muon from pp collisions @13.6 TeV
(July 6th 2022)

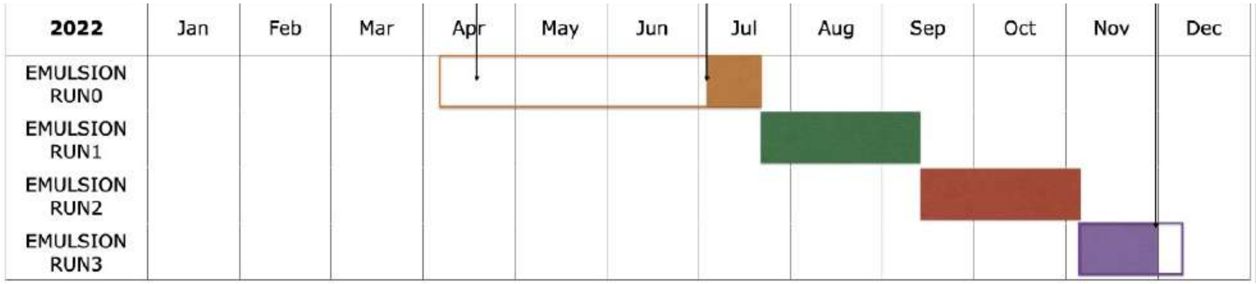


Integrated luminosity in Run 3

for the different emulsion batches



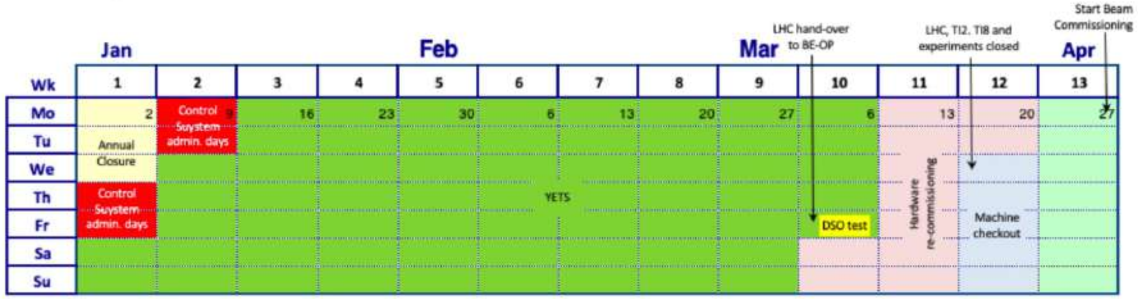
Delivered: 41.3 fb^{-1}
Recorded: 39.8 fb^{-1} (96%)



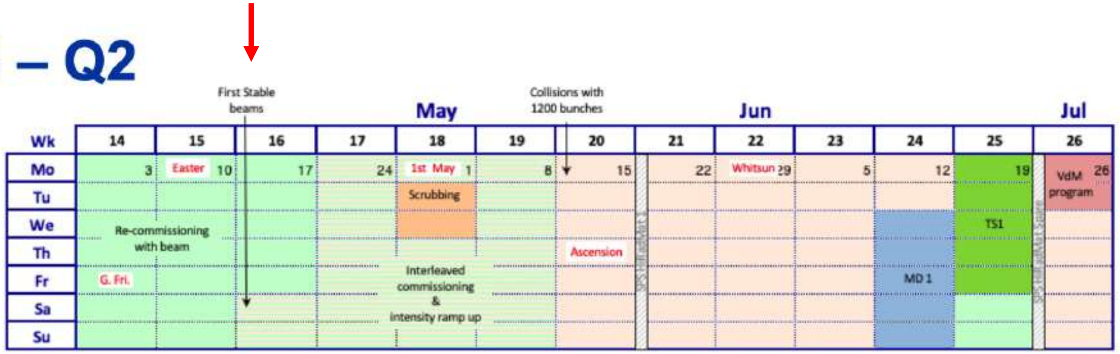
	INSTRUMENTED TARGET MASS	INTEGRATED LUMINOSITY
EMULSION RUN0	39 kg	0.5 fb^{-1}
EMULSION RUN1	807 kg	10.5 fb^{-1}
EMULSION RUN2	784 kg	21.1 fb^{-1}
EMULSION RUN3	792 kg	9.2 fb^{-1}

Plan for the 2023 run

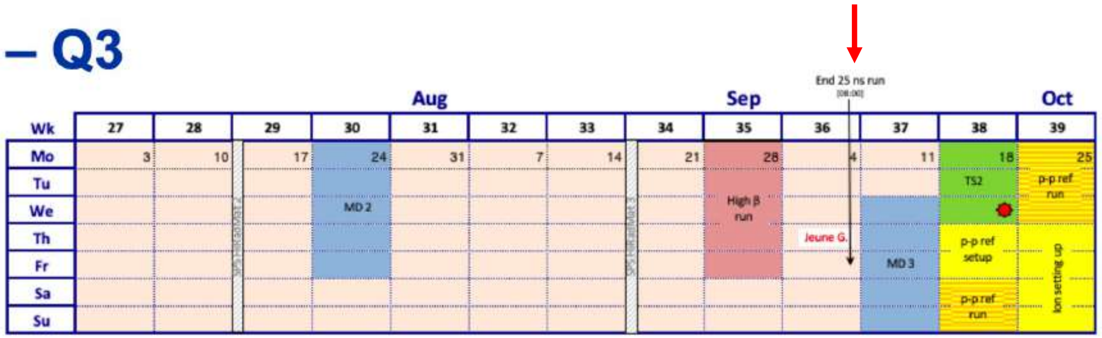
2023 – Q1



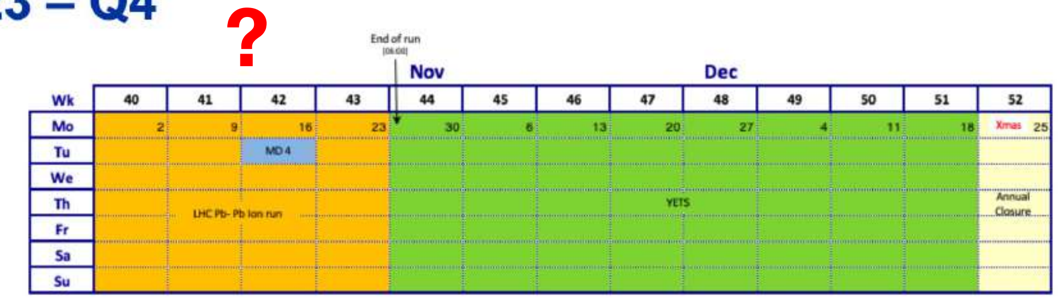
2023 – Q2



2023 – Q3



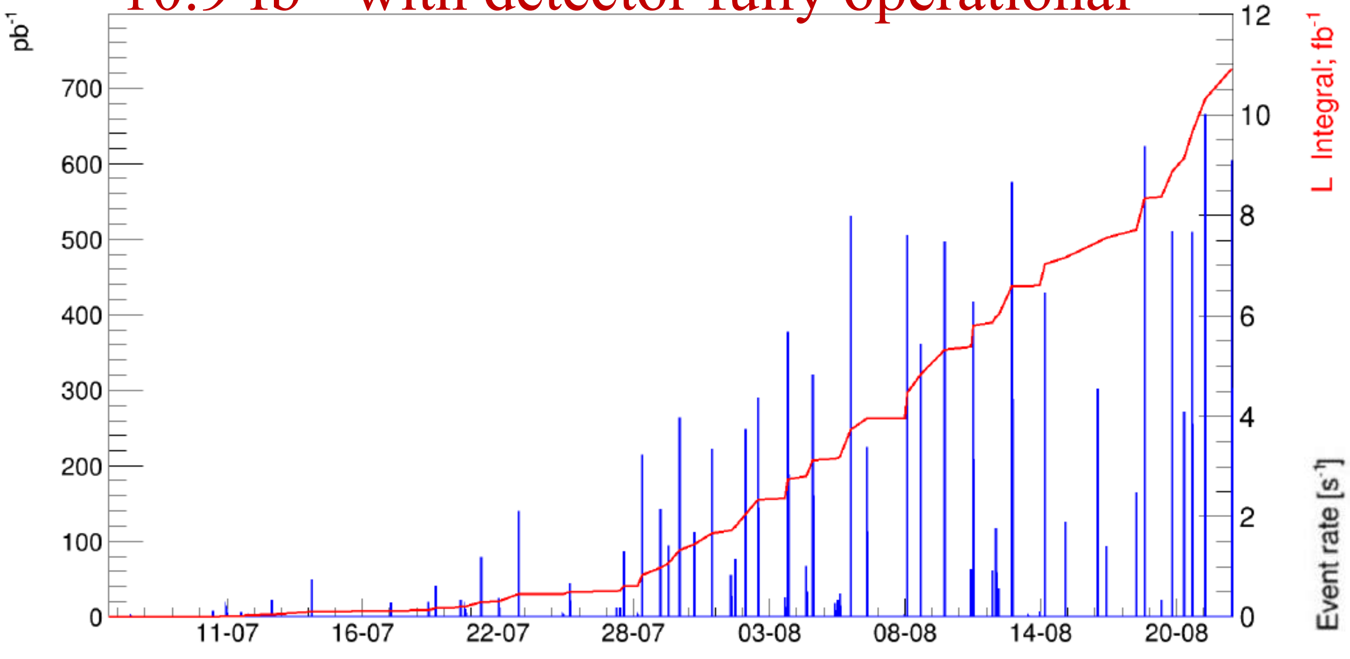
2023 – Q4



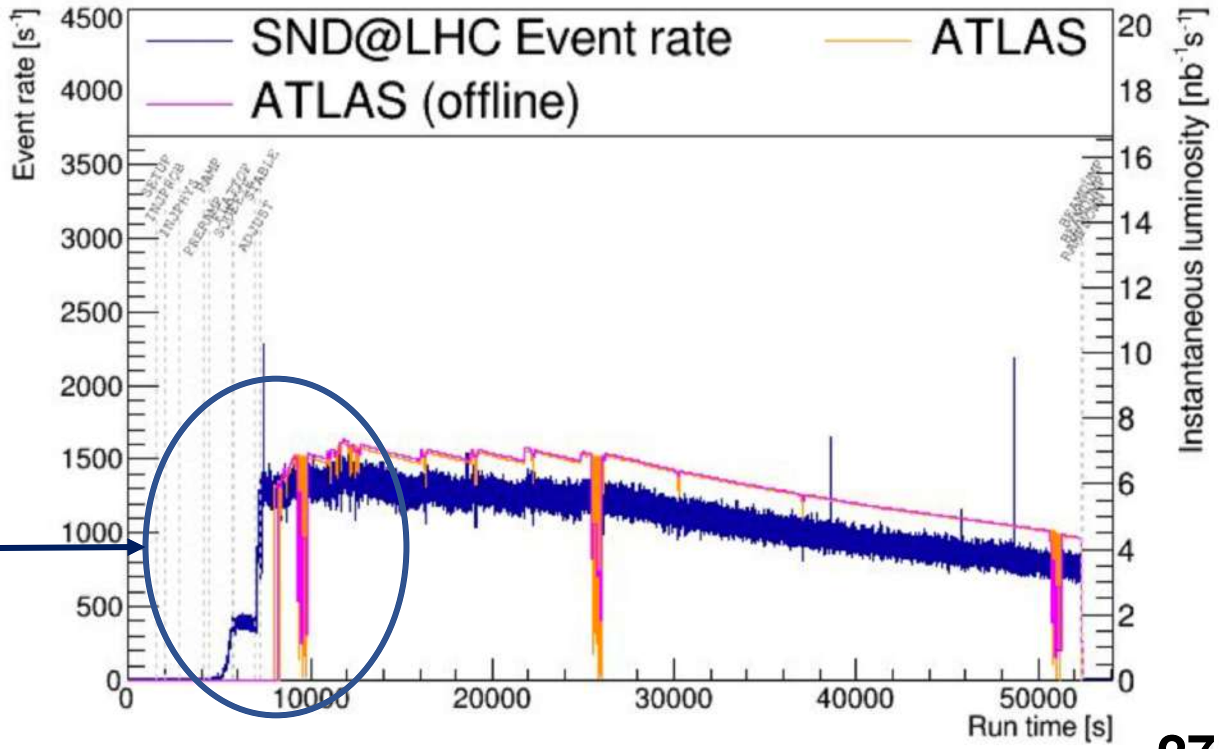
- 14 m^2 emulsion films will be produced by Slavich, ~10 m^2 ready by mid March for the first target (see Tatiana's talk)
- The other part will be produced in Nagoya (see Komatsu-san's talk)

Luminosity

10.9 fb^{-1} with detector fully operational

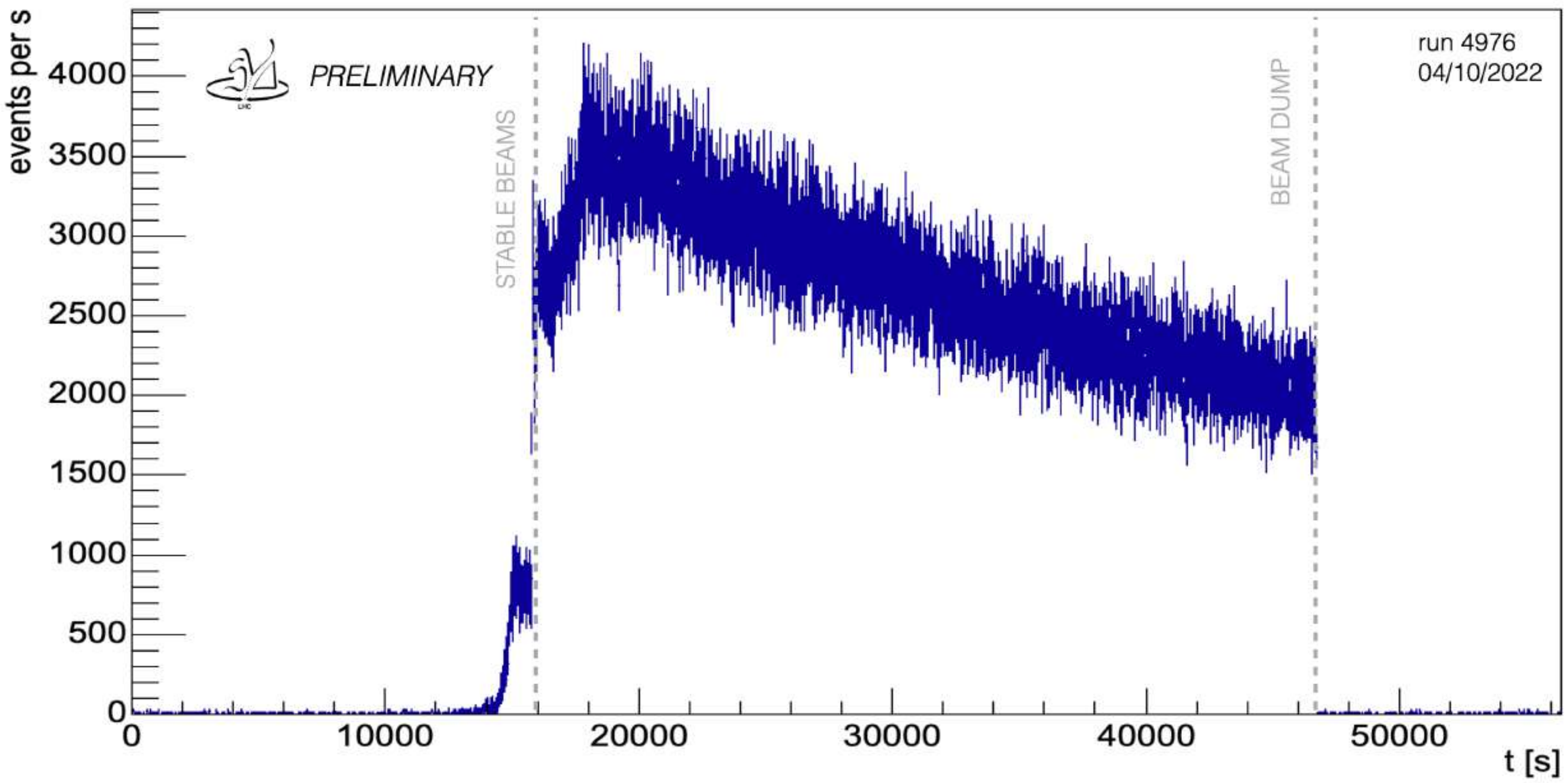


Good proportionality between our event rate and ATLAS measured luminosity except in the beginning of the run (start of the fill, backward events, ….)



EVENT RATE

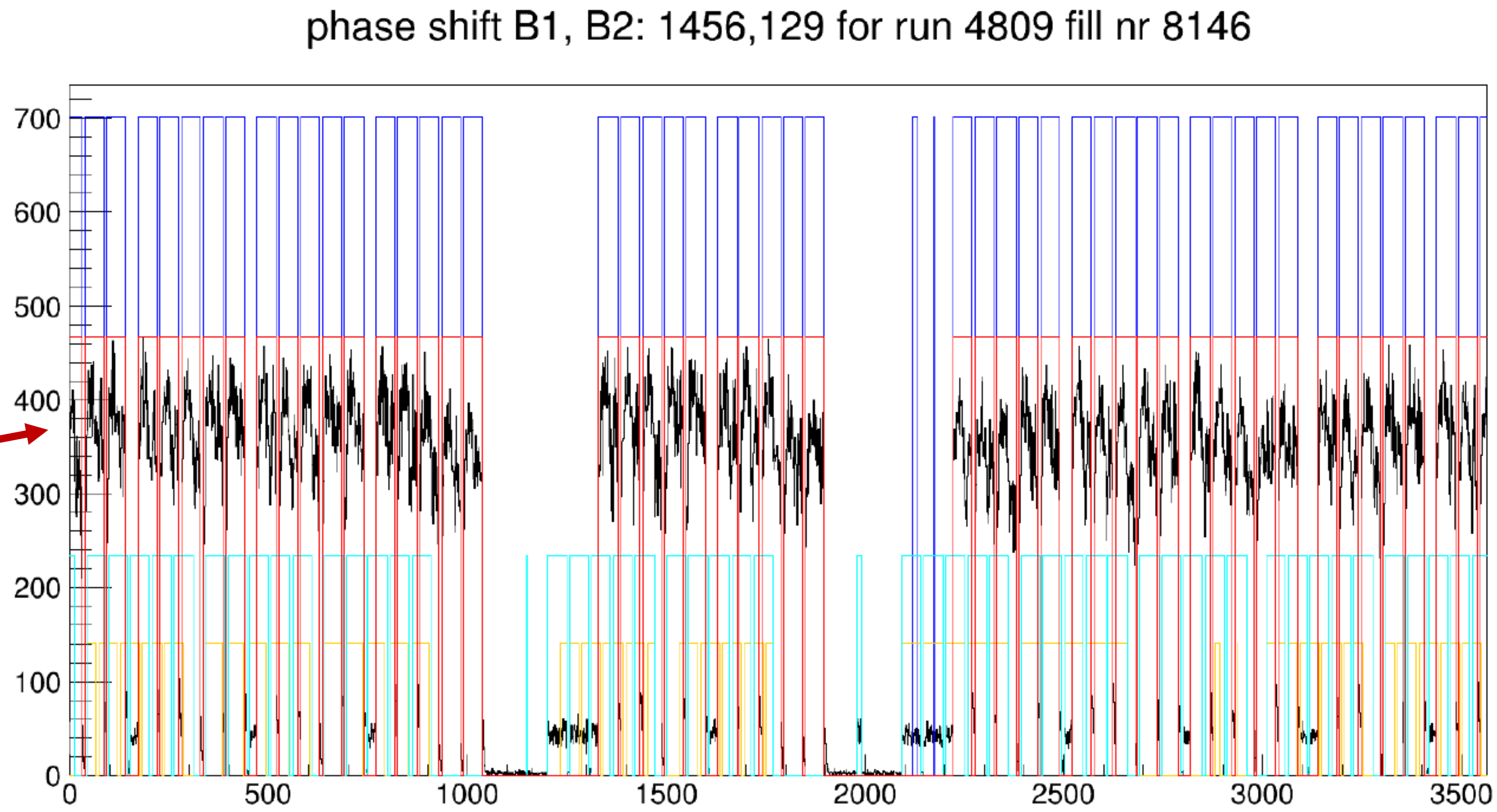
Event rate for one run
Start: October 4th 2022, 18:12:22
End: October 5th 2022, 09:52:21



SND@LHC observed bunch structure overlaid with the LHC filling scheme with phase shift adjusted

Colour coding:
blue Beam1,
red IP1 xing,
cyan Beam2,
yellow IP2 xing

Most of the events from interactions in IP1

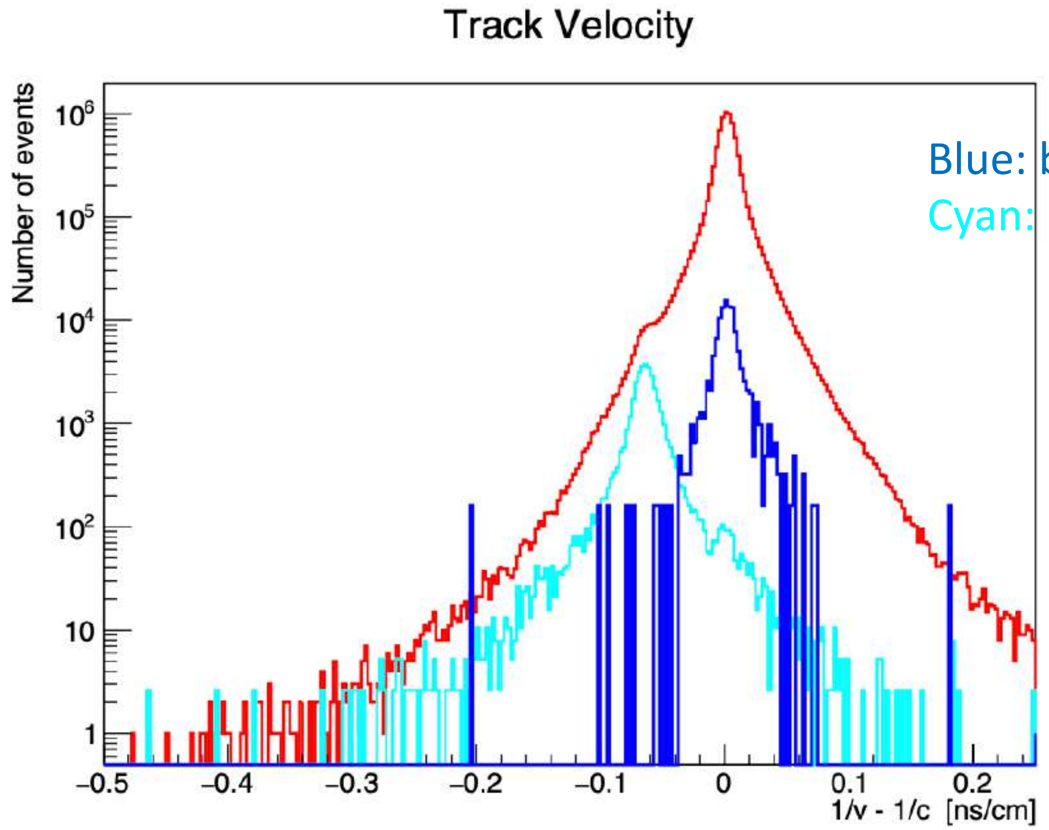


Bunch number

Phase shift of B2 relative to B1 of 129 clock (25ns) cycles is also a measurement of the distance of SND@LHC from IP1:

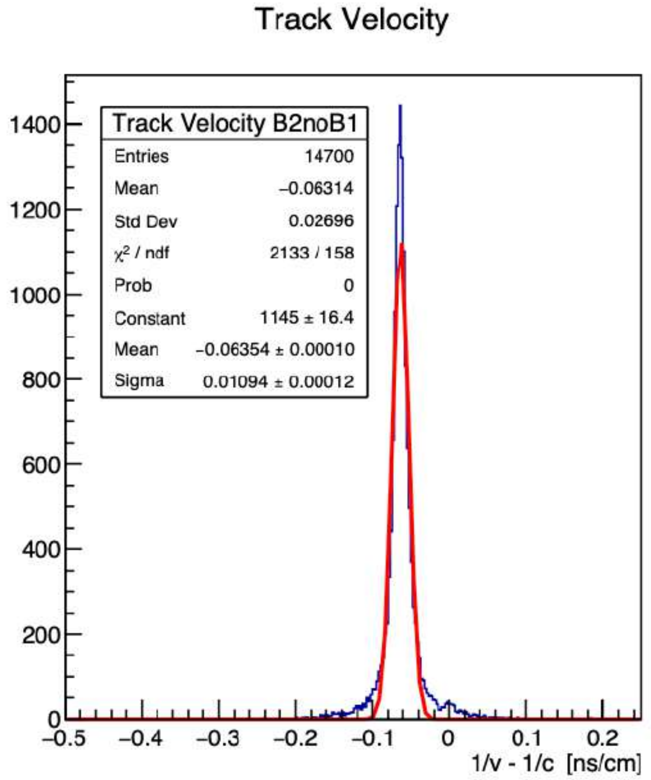
$$2\times\frac{482\ m}{0.3\,\frac{m}{ns}\times 25\ ns} = 128.6$$

Use bunch structure to study event features: the track direction

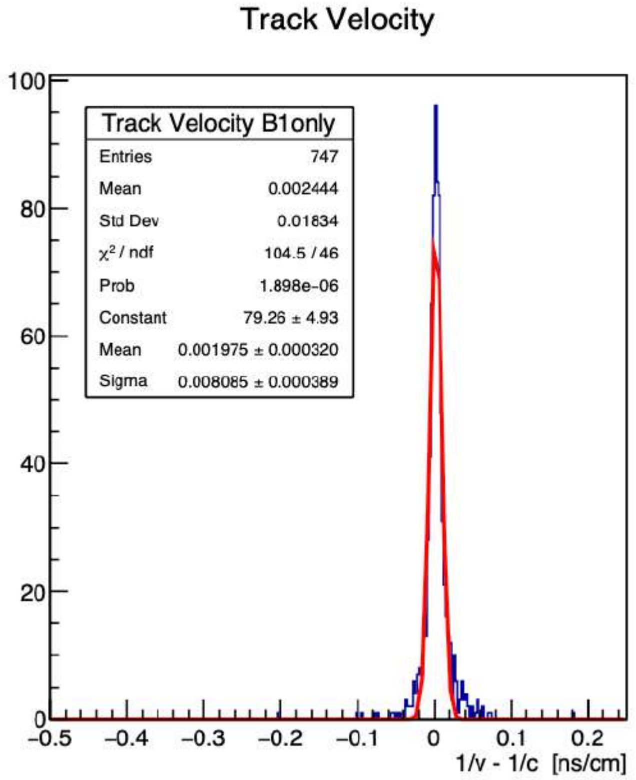


Blue: beam 1
Cyan: beam 2

Beam 2

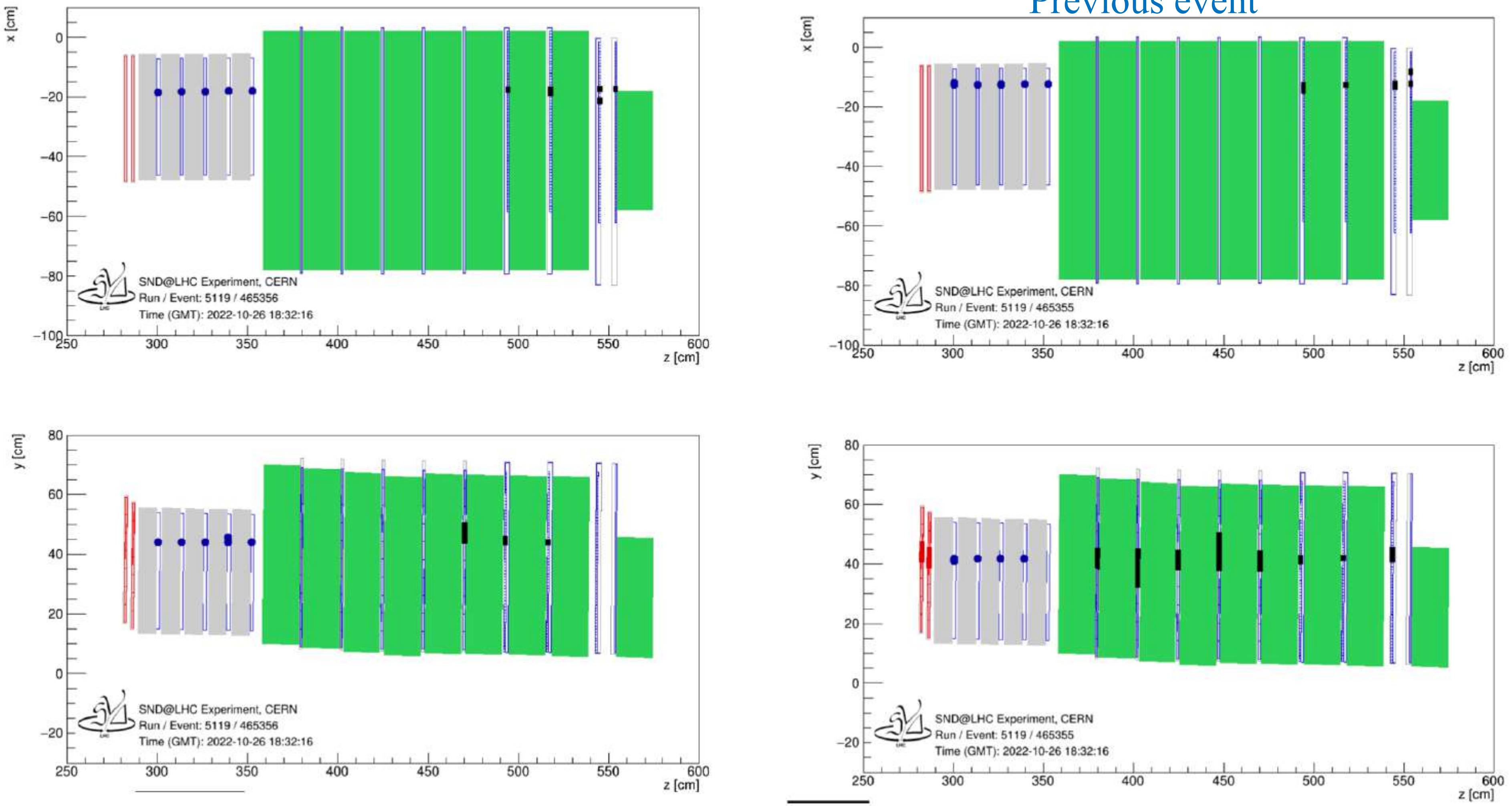


Beam 1



Performance: Veto inefficiency due to deadtime

Previous event



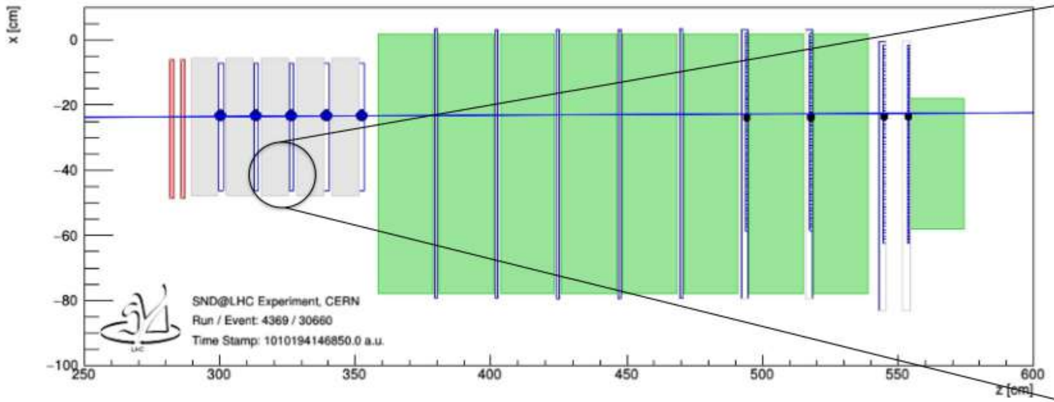
SciFi tracks at the rate of ~500 Hz

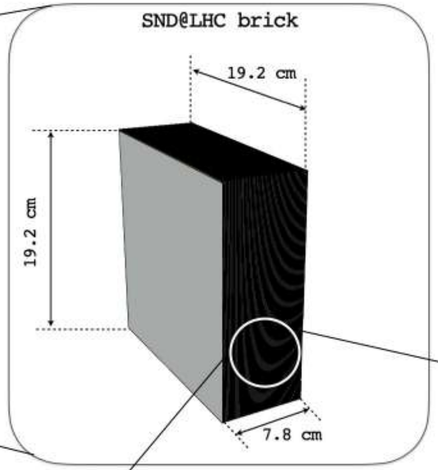
Measured inefficiency of 10^{-4} corresponds to a deadtime of about 200 ns

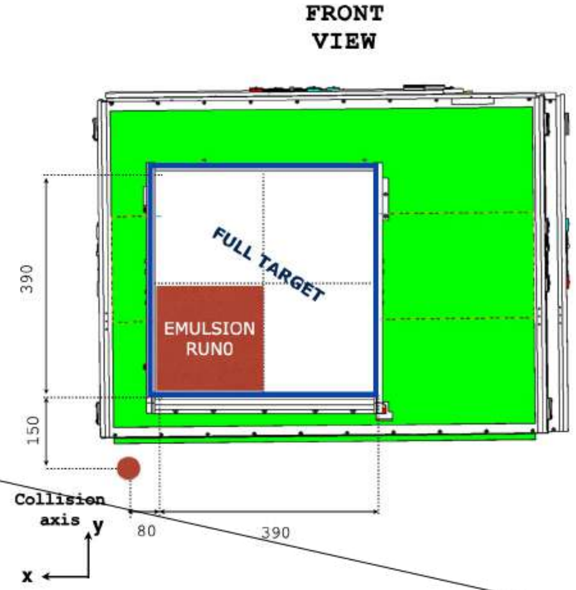
$$\eta = 1 - \varepsilon = 10^{-4}$$

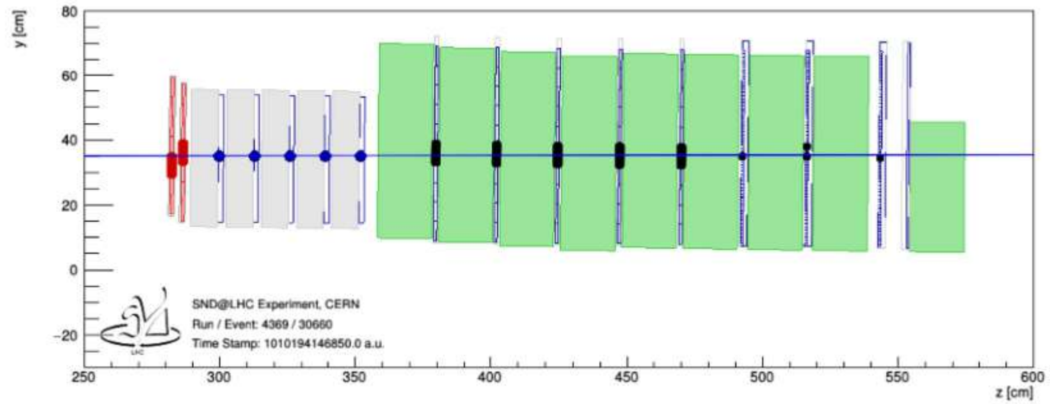
Track reconstruction also with emulsion data

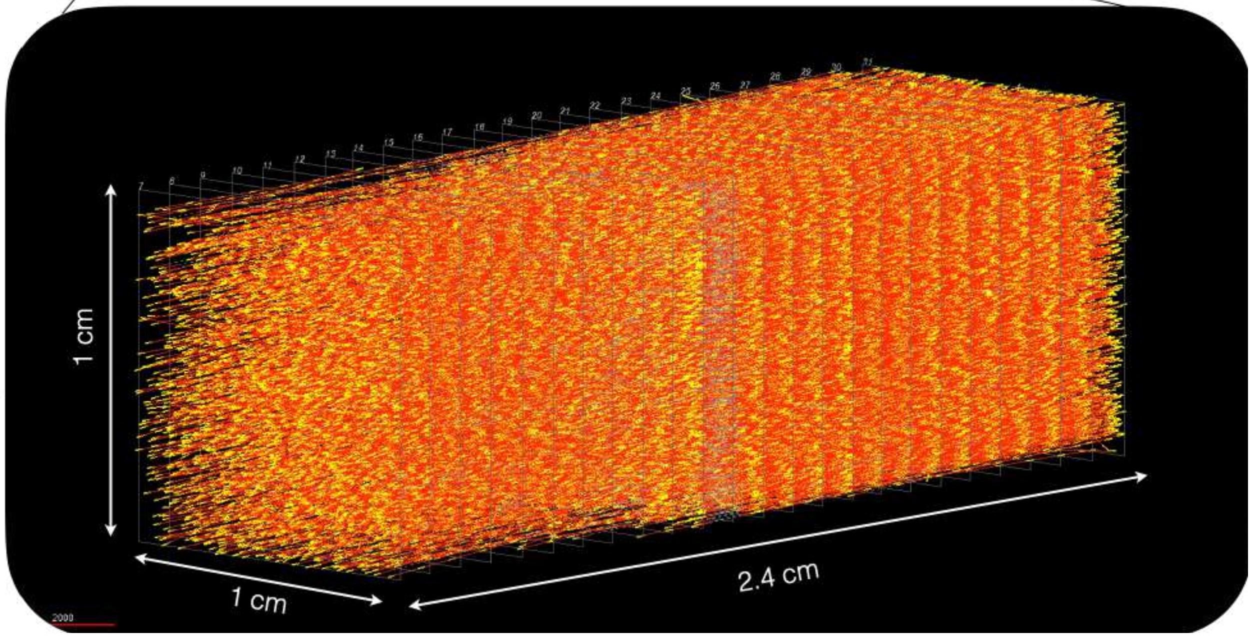
muon track recorded on July 6th from pp @13.6 TeV









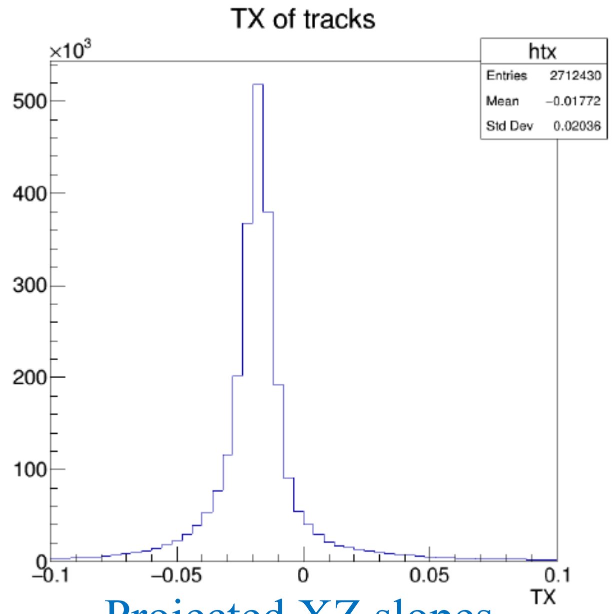


Track rates in emulsion compatible with electronic detectors

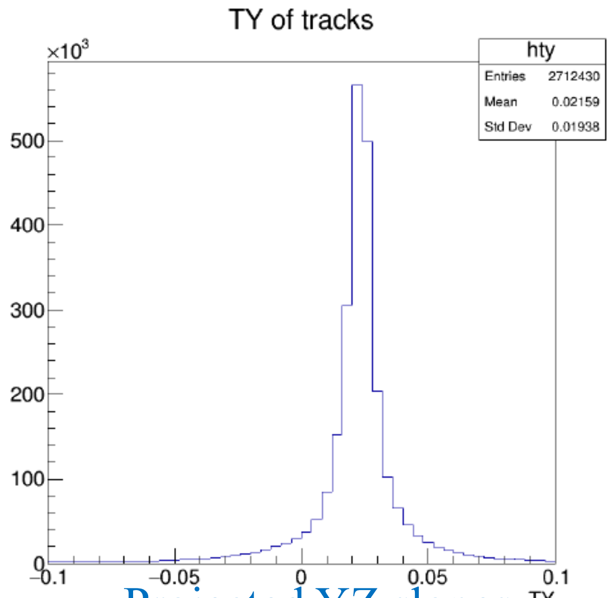
RUN0 from April 7th to July 26th (0.51 fb^{-1})

First look at the emulsion data!

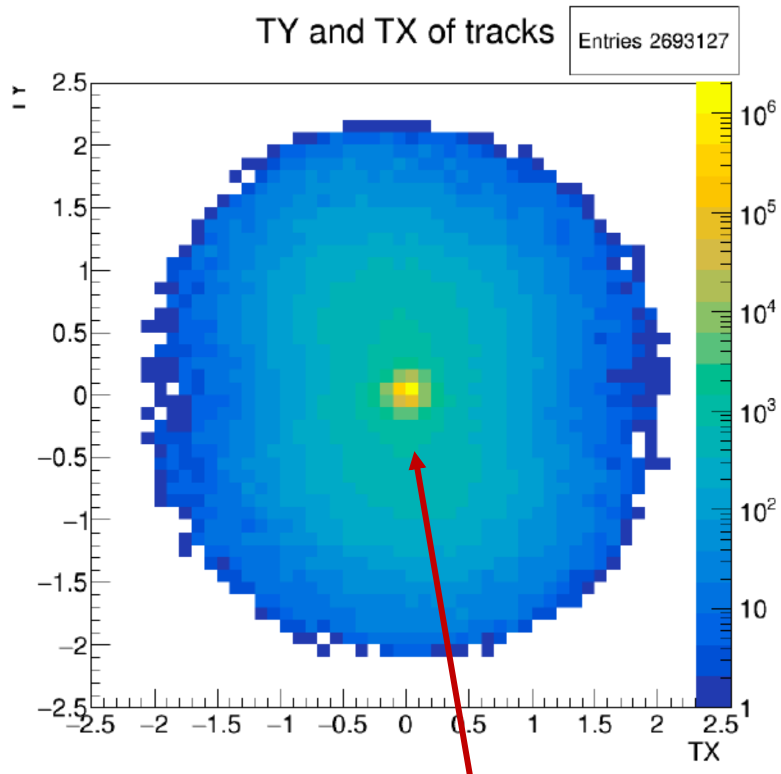
0.5 fb^{-1} integrated from April 7th to July 26th



Projected XZ slopes



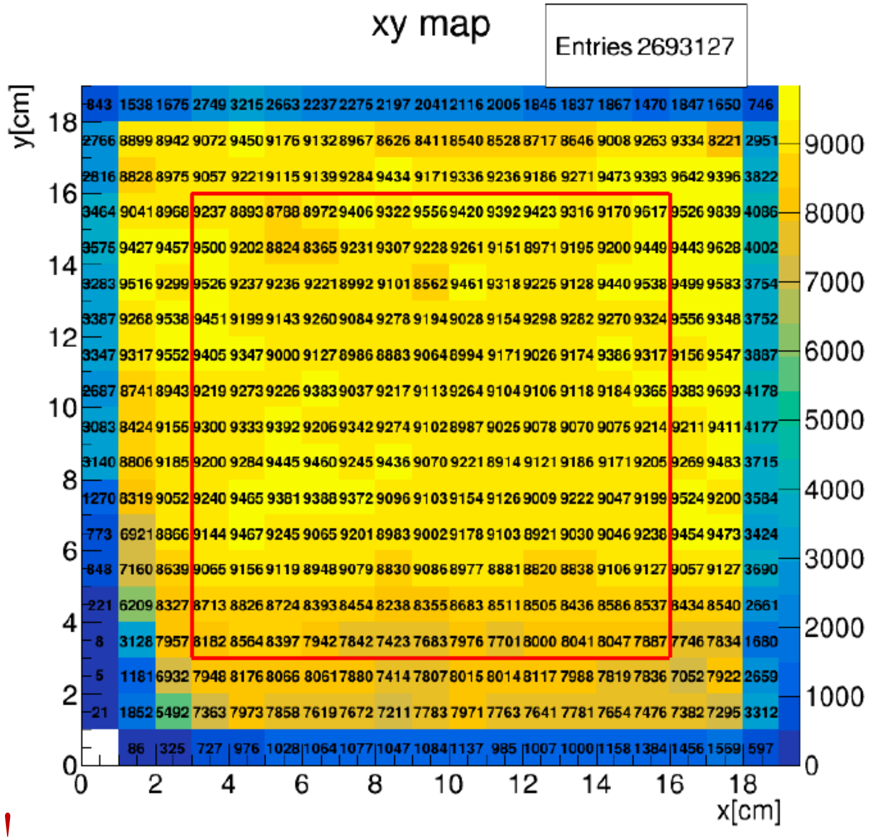
Projected YZ slopes



Beam peak at very small angles as expected

Measured track density in emulsion ~9000/cm^2

With SciFi, average track density ~ 8000/cm^2

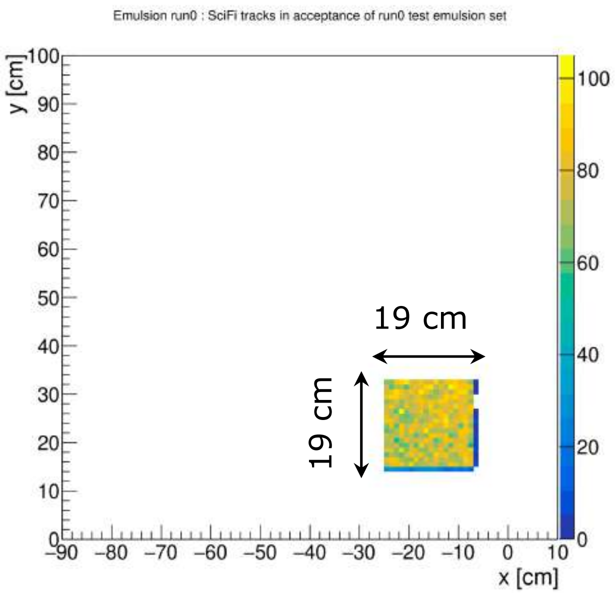


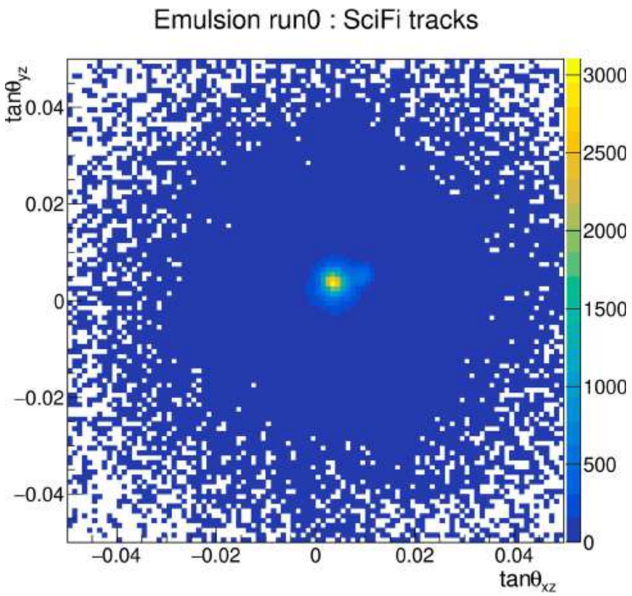
~9000/cm^2 in 0.5 fb-1 → ~ 4 x 10^5/cm^2 in 20 fb^{-1}!

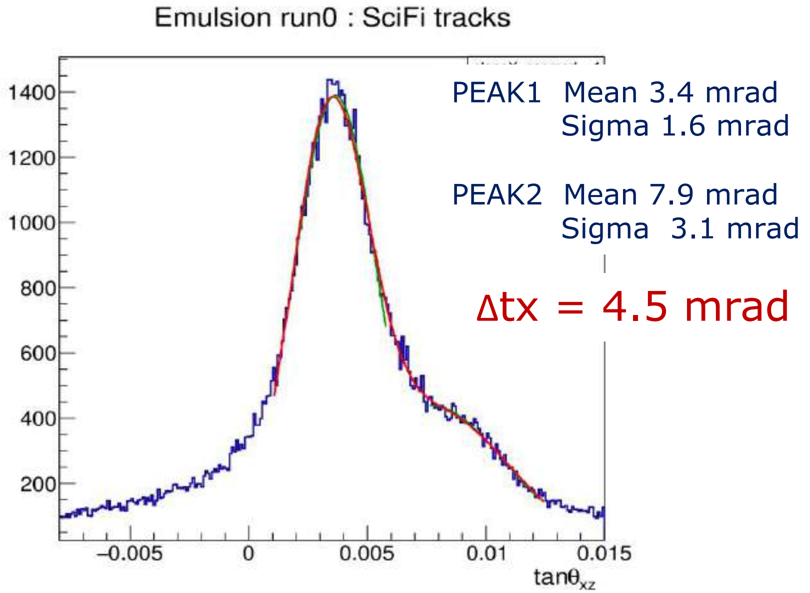
EMULSION / SCIFI COMPARISON

SciFi

Measured rates on BRICK1 surface
1.4×10^4 fb/cm^2

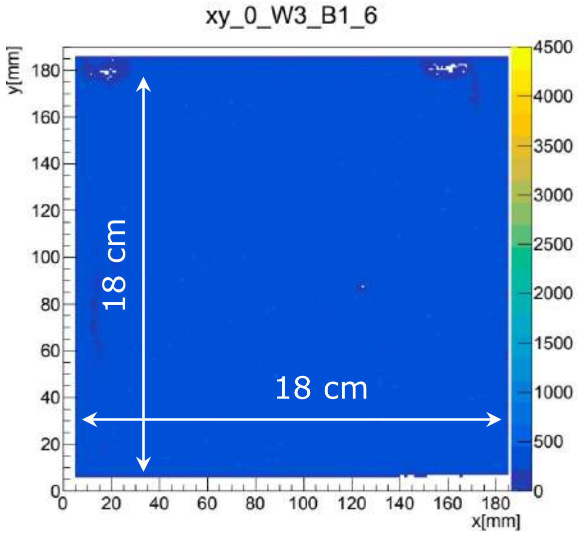


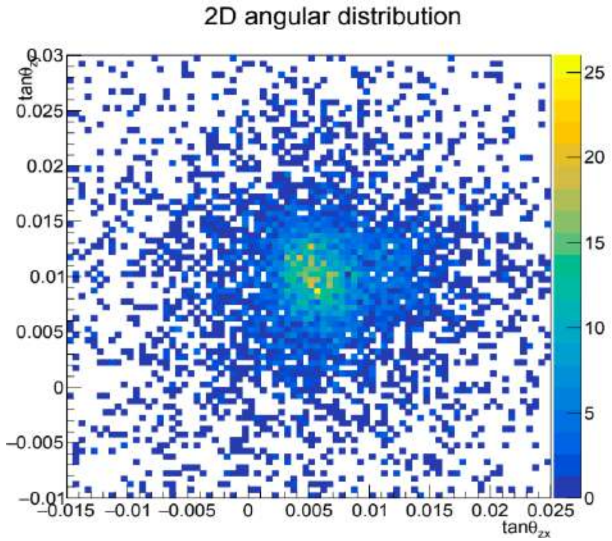


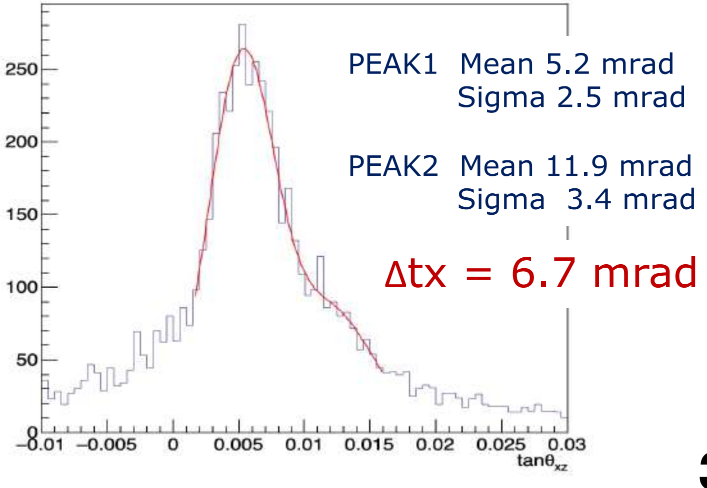


EMULSIONS

Measured rates in BRICK1
1.5×10^4 fb/cm^2

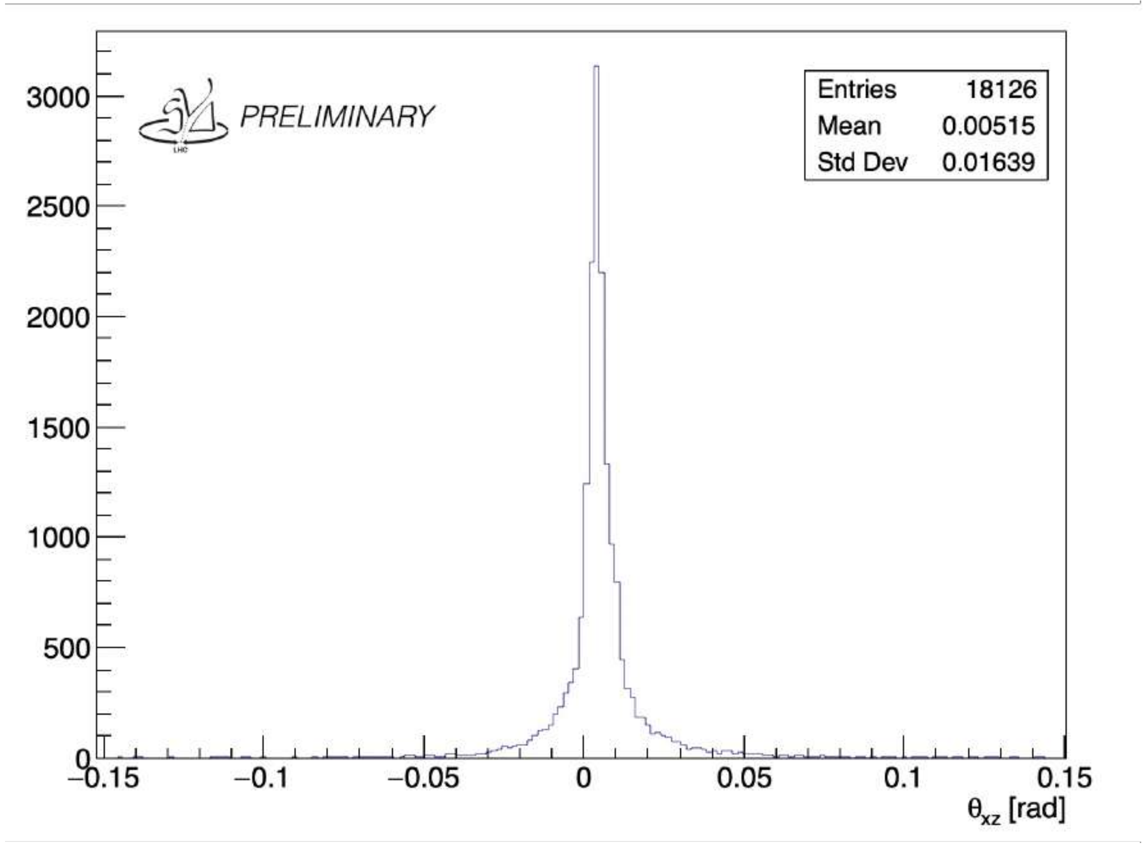


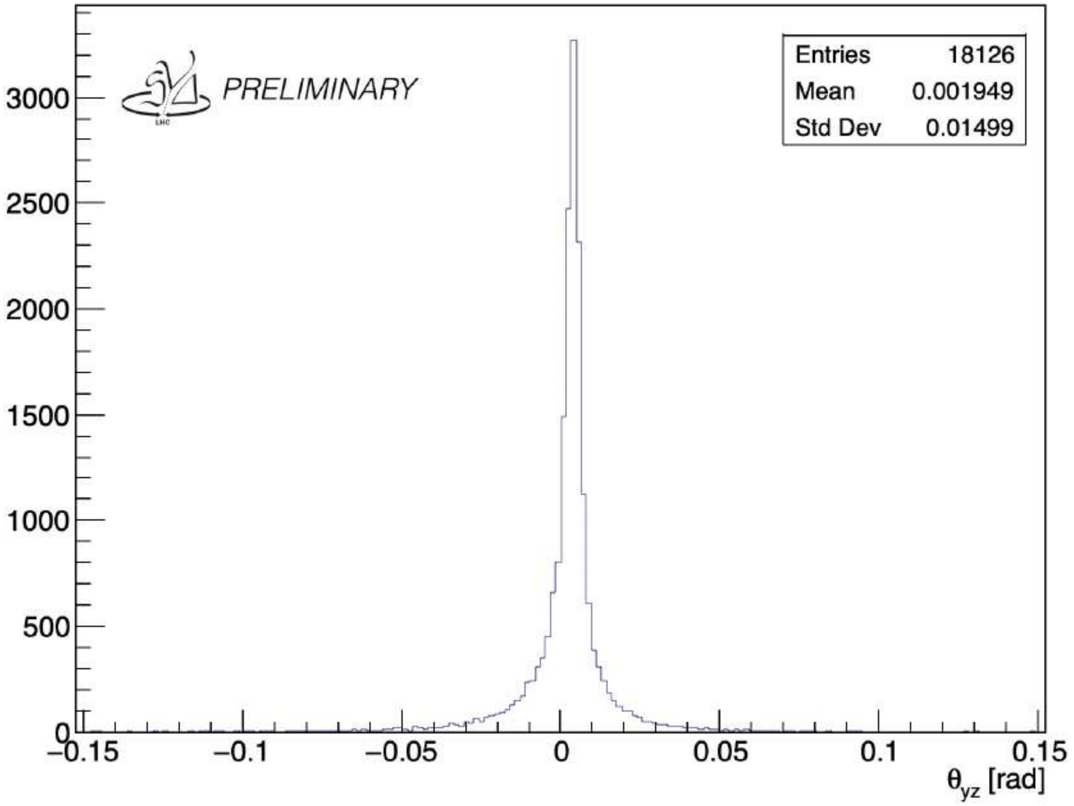




DATA TAKING IN RUN3

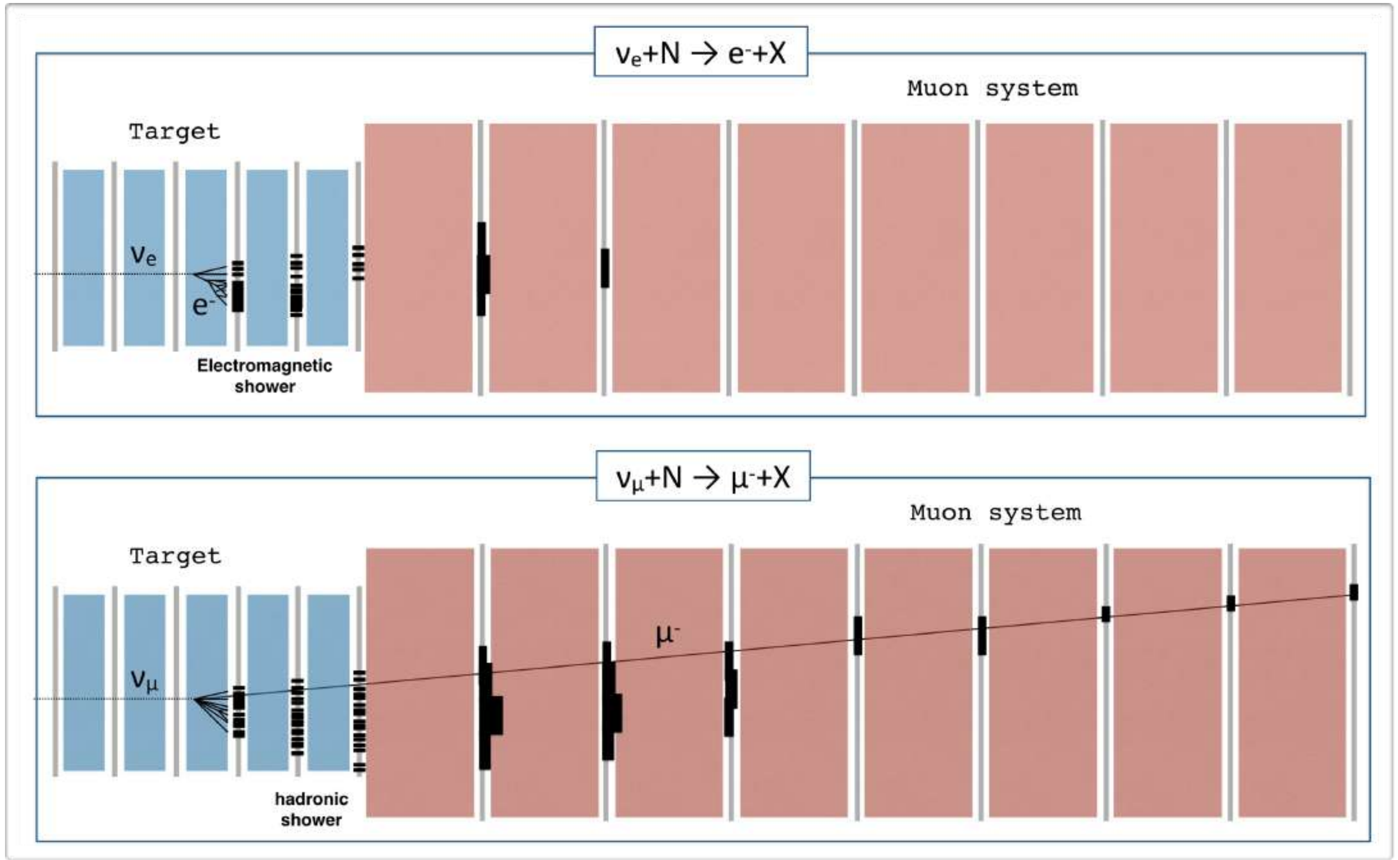
Reconstructed tracks in the first runs @13.6 TeV
Direction compatible with coming from pp collisions at IP1



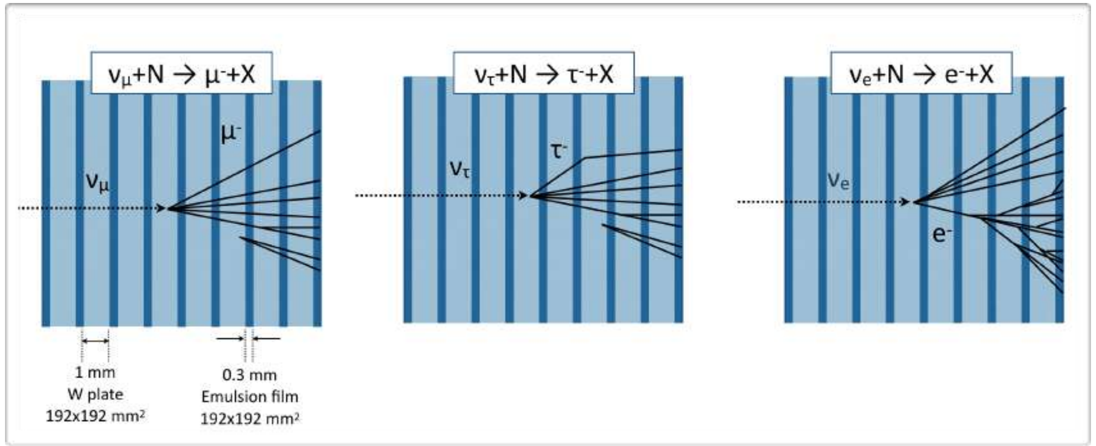


EVENT RECONSTRUCTION

- **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)

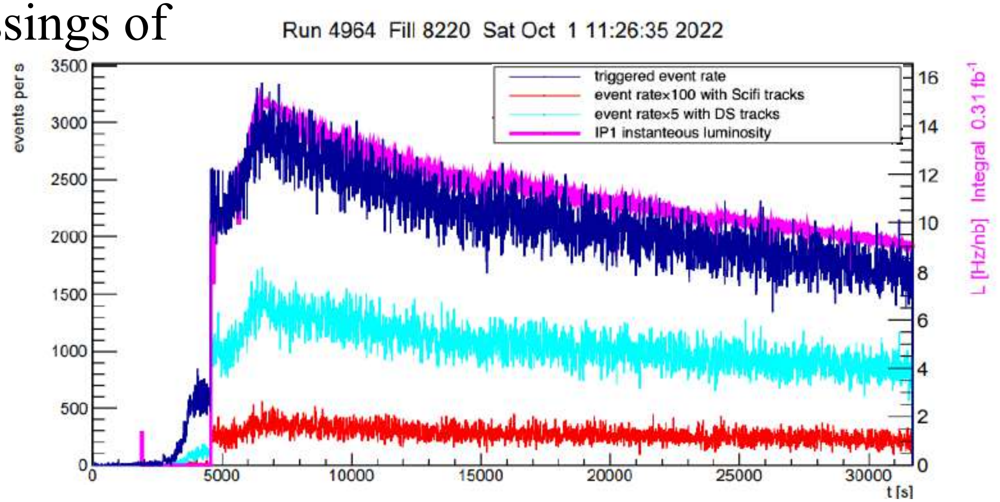


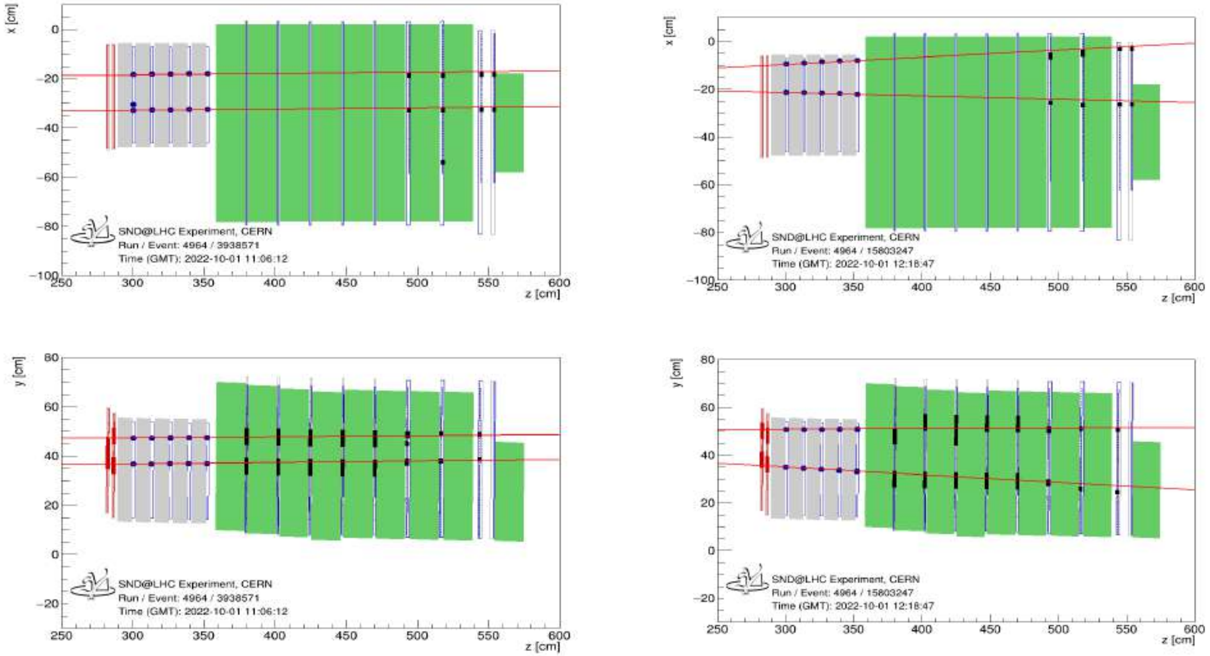
- **SECOND PHASE: nuclear emulsions**
- Event reconstruction in the emulsion target
  - Identify e.m. showers
  - Neutrino vertex reconstruction and 2ry search
  - Match with candidates from electronic detectors (time stamp)
  - Complement target tracker for e.m. energy measurement



Multi-track events

- Run 4964: $\int Ldt = 0.31 fb^{-1}$, $\sigma_{inelastic} = 80\ mb$, 2448 bunch crossings of 3564, $N_{collisions} = 25{\times}10^{12}$, $T = 26{\times}10^{3}s$, $N_{xings} = 0.72{\times}10^{12}$
- Efficiency corrected average over this run: 300 tracks/s
- Single muon per bunch crossing: $\mu = 1.1{\times}10^{-5}$
- Probability for k-track event from pile-up: $\frac{\mu^k e^{-\mu}}{k!}$
- 2 μ per bunch $x$ing: $p_2 = \frac{1}{2}\mu^2$
- 3 μ per bunch $x$ing: $p_3 = \frac{1}{6}\mu^3$
- Expect $N_{2\ track} = 43$,
  observed 224
- Additional rate could be due to trident process, muon pair production in rock, concrete, tungsten.
- Hypothesis supported by 3-track events

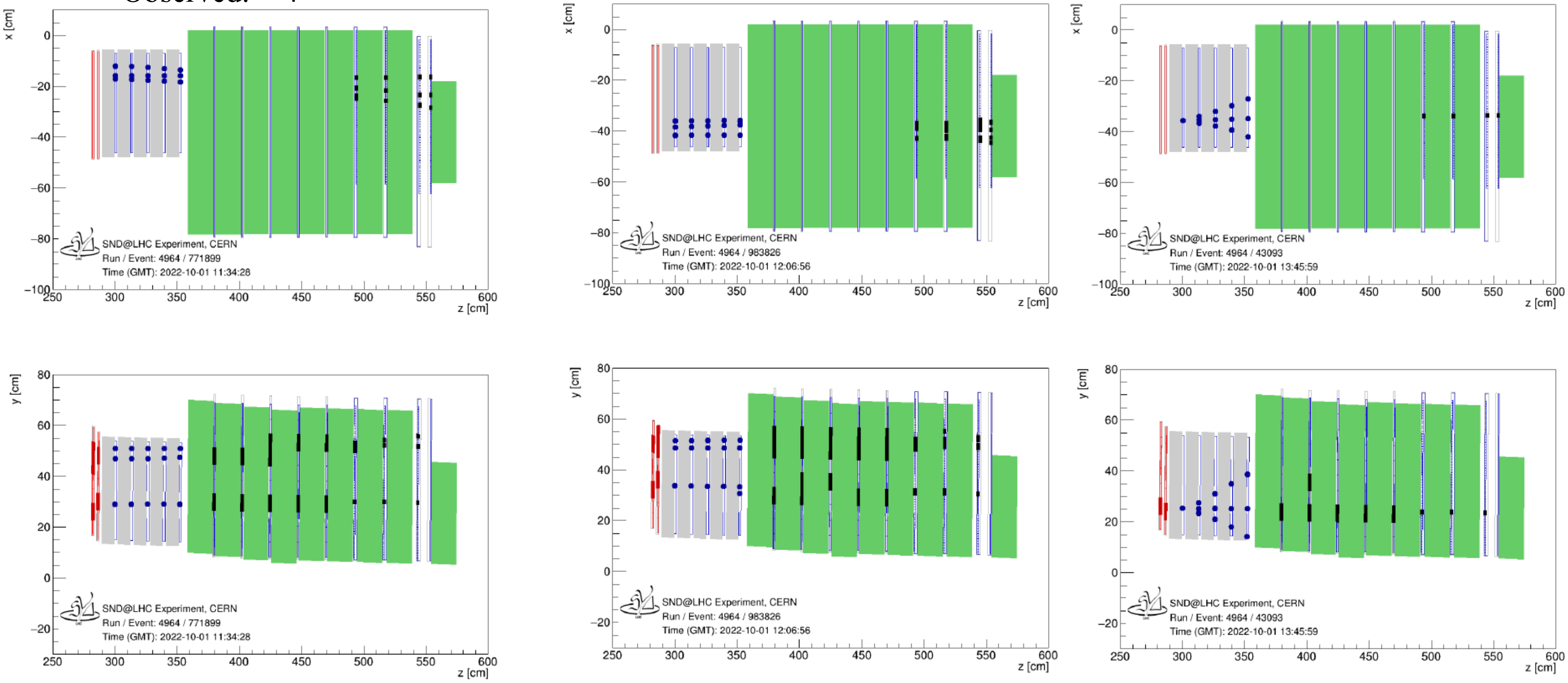




Three-track events

Expect: $N_{3\ track} = 2 \times 10^{-4}$

Observed: > 4



Preliminary Minutes of the LHCC 152

30 Nov/1 December 2022

- The **LHCC commends** SND for the rapid installation and commissioning of the detector which has been ready to collect pp data for physics in complete configuration since the end of July.
- The **LHCC congratulates** SND for the efficient solution of the film procurement, which is now fully guaranteed by Nagoya University for run 3. The **LHCC** also **appreciates** the special effort to procure the needed films for the unexpected extension of the pp running time.
- The **LHCC congratulates** SND, FASERnu and CERN on the well-coordinated development and use of the Emulsion Facility (EF) which now also includes the new scan station.
- The **LHCC recommends** for the next meeting the definition of the process allowing the timely replacement of films during Run 3 for SND and the other experiments and the sharing of the EF with the other users.
- The **LHCC endorses** the energy calibration test beam foreseen in spring 2023 and strongly supports the request for two weeks of beam time.

Concluding remarks:

- Successful operation of the detector over the first Run 3 year
- A third (unforeseen) emulsion target added this year to cope with the extended pp physics run
- Three fully instrumented targets have recorded about 41 fb^{-1}
- Smooth operation with a few hiccups fixed during short accesses
- Data alignment with bunch structures has allowed studying the background component in the reconstructed tracks
- Good correlation between beam1/2 and forward/backward direction
- Muons track reconstruction with electronic detectors working well
- Measured good agreement between emulsion and SciFi tracks for the muon rates
- Multi-track event rates hinting for the presence of additional physics processes on top of the pileup

New era of collider neutrinos started!

https://cerncourier.com/a/collider-neutrinos-on-the-horizon/

LHC
Scattering and Neutrino Detector at the LHC

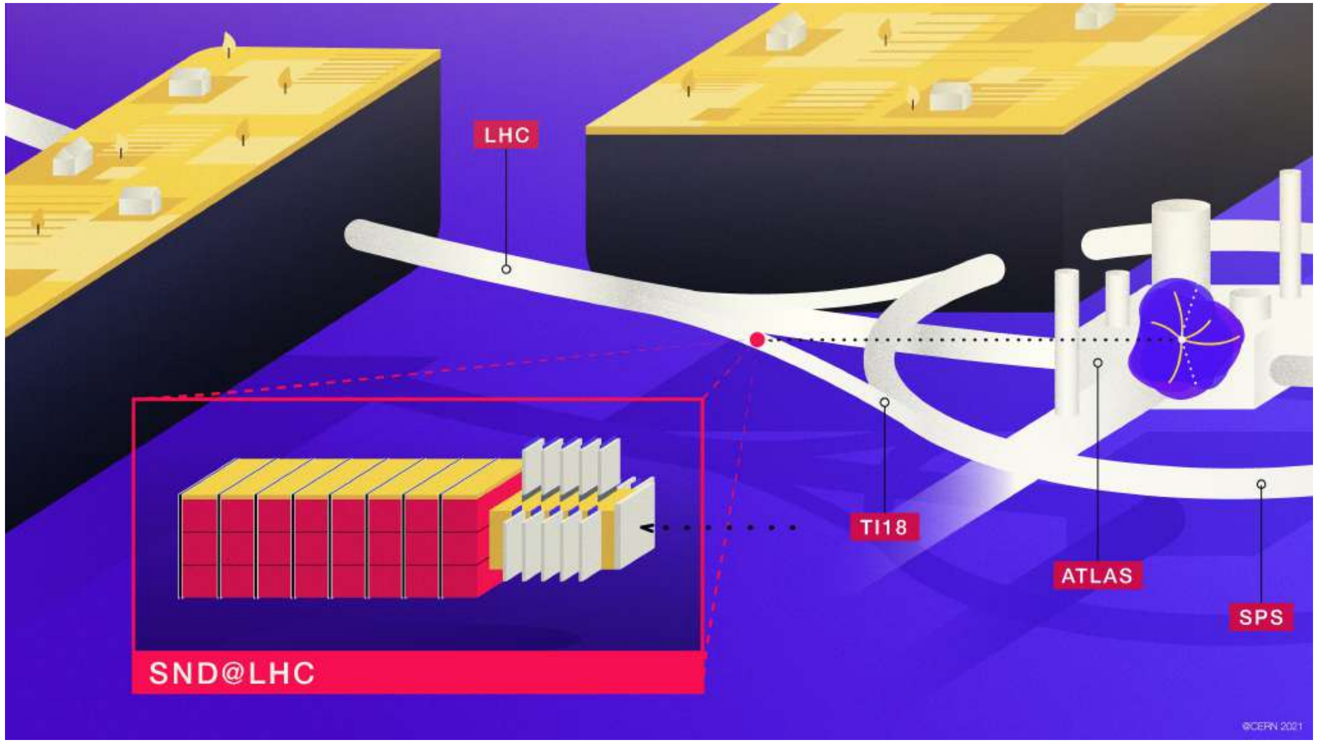
CERNCOURIER | Reporting on international high-energy physics

Physics ▾ | Technology ▾ | Community ▾ | In focus | Magazine

NEUTRINOS | NEWS

Collider neutrinos on the horizon

2 June 2021



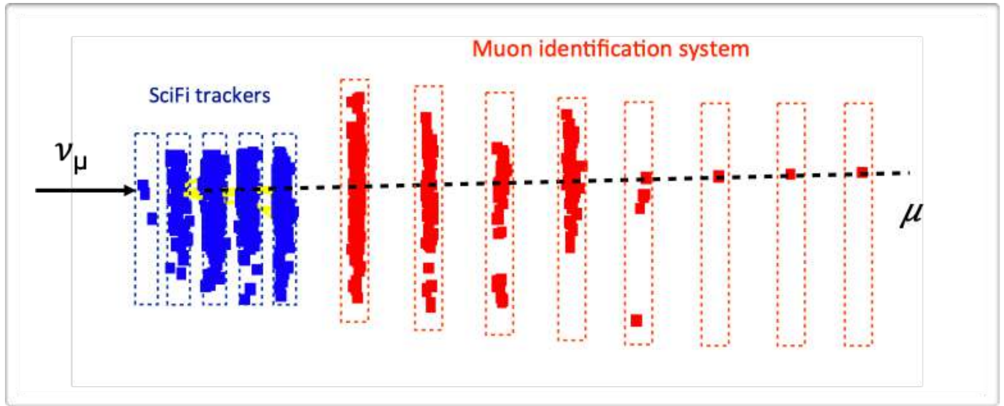
Stay tuned! Data taking just started!
LHC Run3: 2022-2025

BACKUP SLIDES
WITH MORE DETAILED INFORMATION

KEY FEATURES

•Muon identification

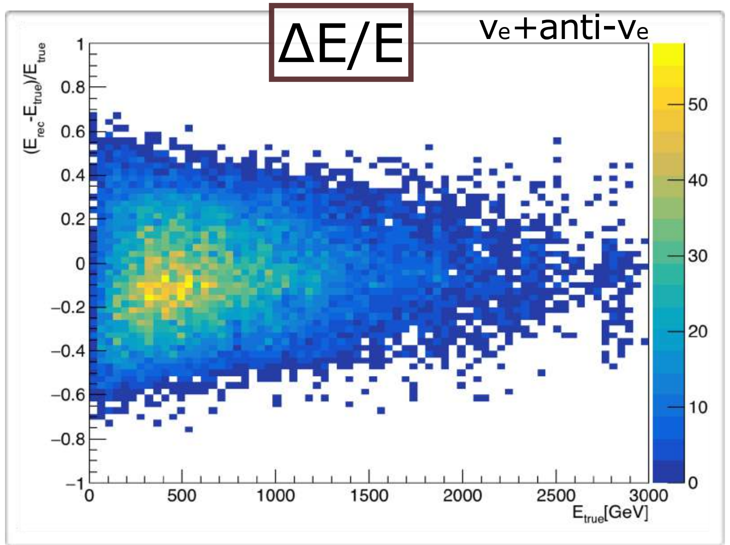
- ν_μ CC interactions identified thanks to the identification of the muon produced in the interaction
- Muon ID at the neutrino vertex crucial to identify charmed hadron production, background to ν_τ detection



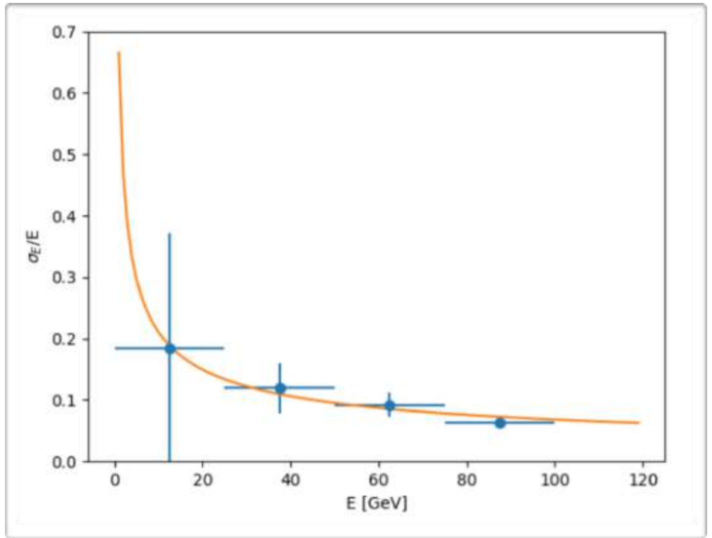
	% evts CC-DIS	% evts NC-DIS
0μ	31.1	99.6
1μ	67.6	0.27
2μ	1.1	0.06

•Energy measurement

- The detector acts as a non-homogeneous sampling calorimeter



- Combing information from SciFi (target region) and Scintillator bars (Muon System)
- Average resolution on ν_e energy: 22%



- Performance of SciFi tracker as sampling calorimeter, using a CNN
- Electron energy resolution

NEUTRINO PHYSICS PROGRAM IN RUN 3

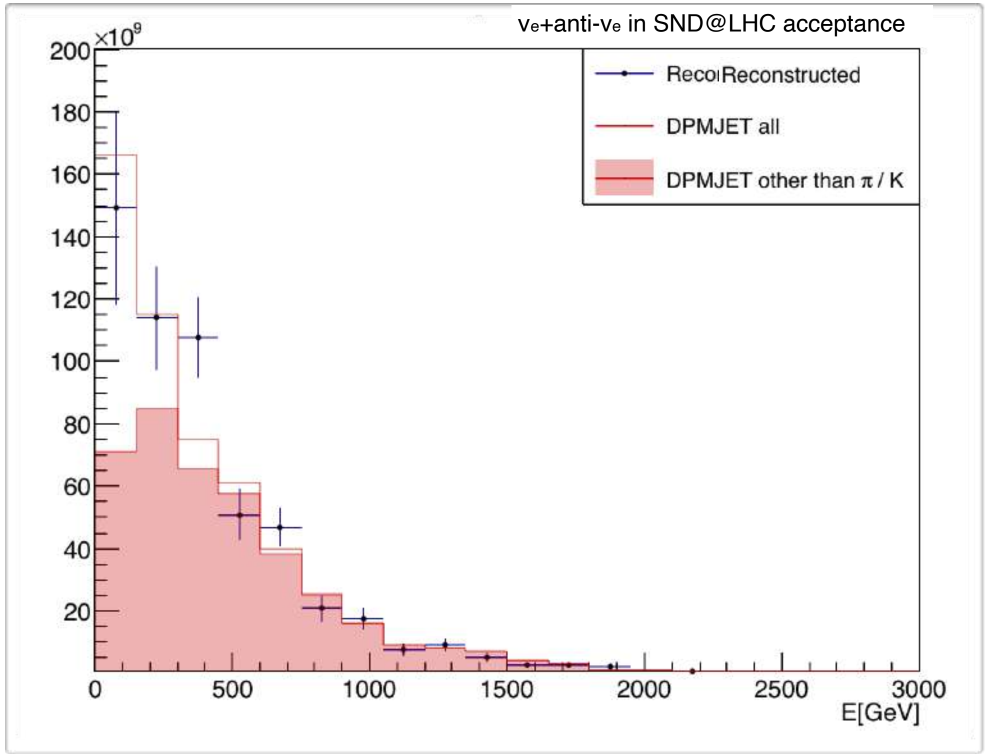
1. Measurement of the *pp*⟶ν_eX cross-section
2. Heavy flavour production in pp collisions
3. Lepton flavour universality in neutrino interactions
4. Measurement of the NC/CC ratio

1. MEASUREMENT OF $pp \rightarrow \nu_e X$ CROSS-SECTION

2. CHARMED HADRON PRODUCTION

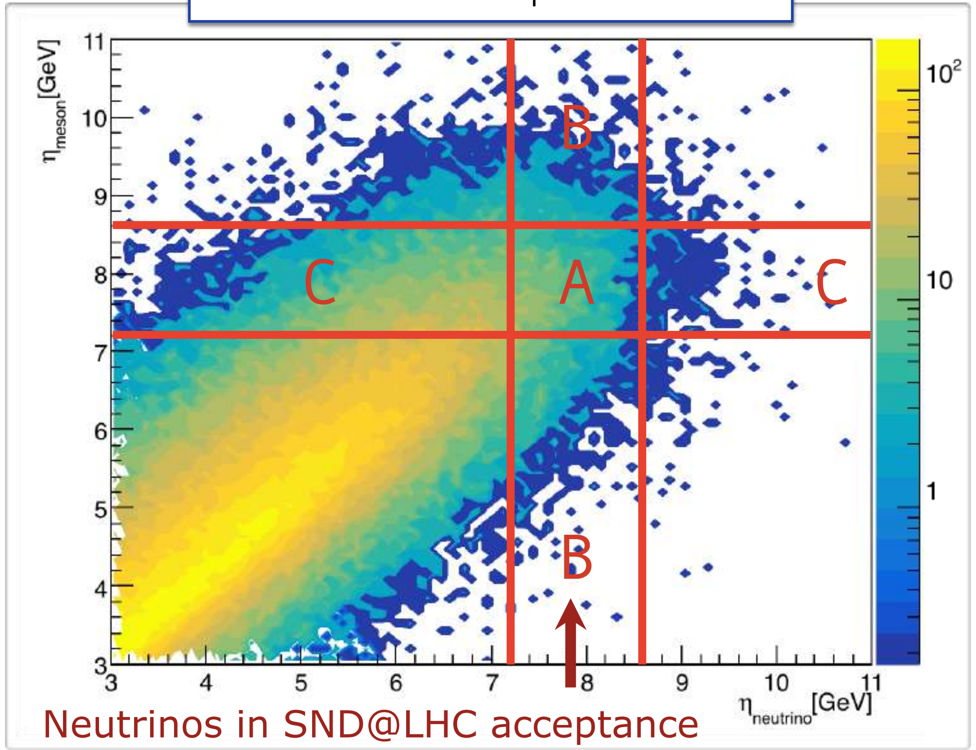
- Simulation predicts that 90% ν_e+anti-ν_e come from the decay of charmed hadrons
- Electron neutrinos can be used as a probe of the production of charm in the relevant pseudo-rapidity range after unfolding the instrumental effects

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



- Correlation between pseudo-rapidity of the electron (anti-)neutrino and the parent charmed hadron

CASE I: $7.2 < \eta_{meson} < 8.6$

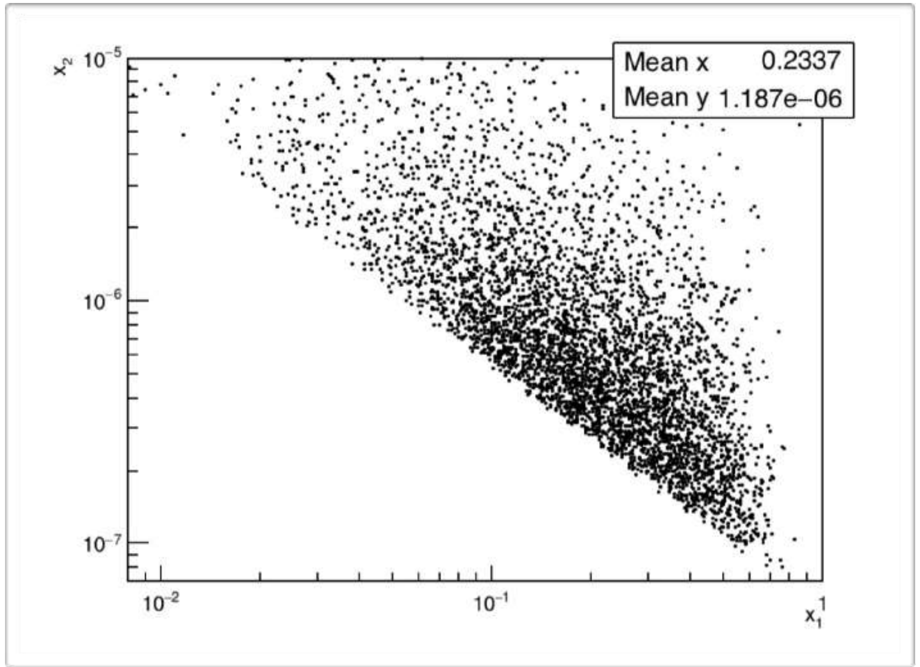


QCD MEASUREMENTS

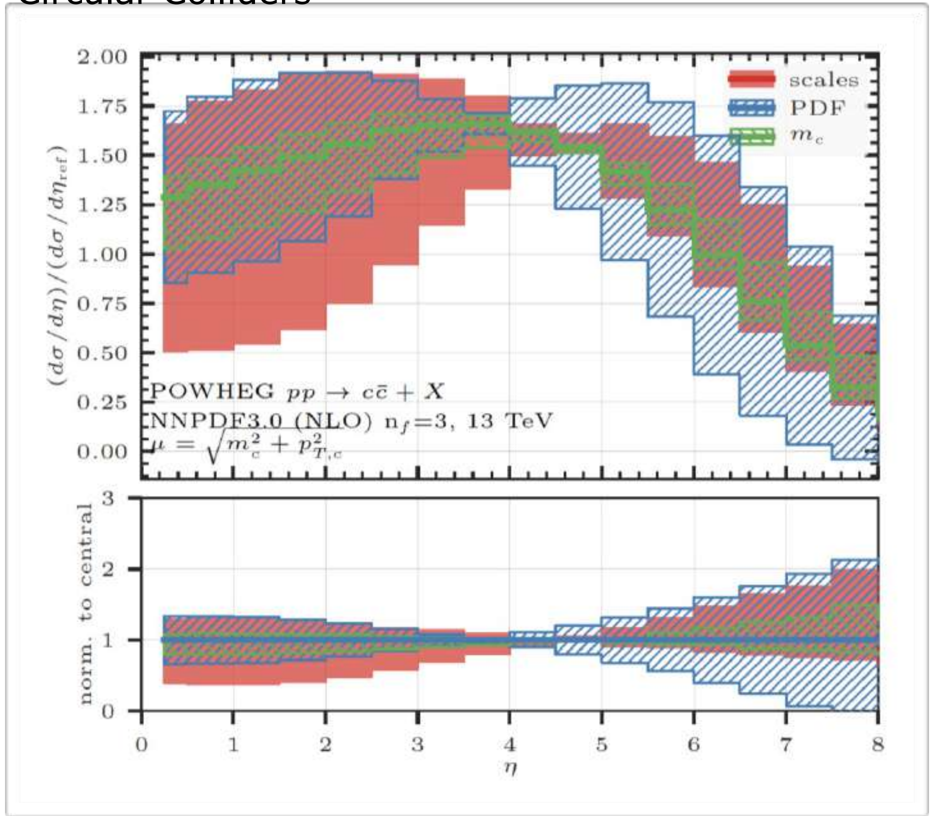
Extraction of gluon PDF in very small x-region relevant for Future Circular Colliders

The dominant partonic process for associated charm production at the LHC is gluon-gluon scattering

Average lowest momentum fraction: 10^{-6}



Correlation between x1 and x2 for events in the SND@LHC acceptance



Ratio between the cross-section measurements at different energies and pseudo-rapidities

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

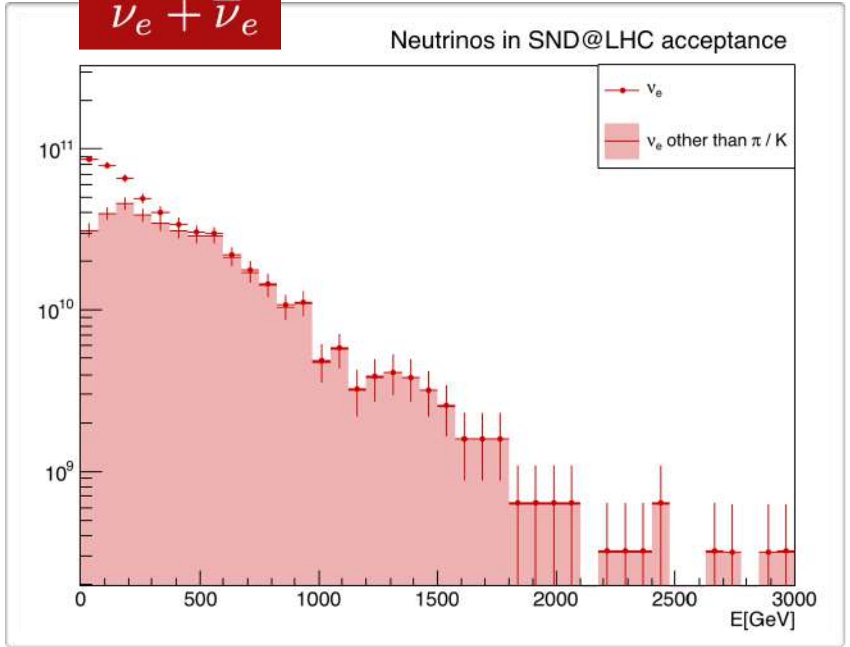
$\eta_{ref} = 4.5$

Reduction of scale uncertainties
Constraint the PDF with data

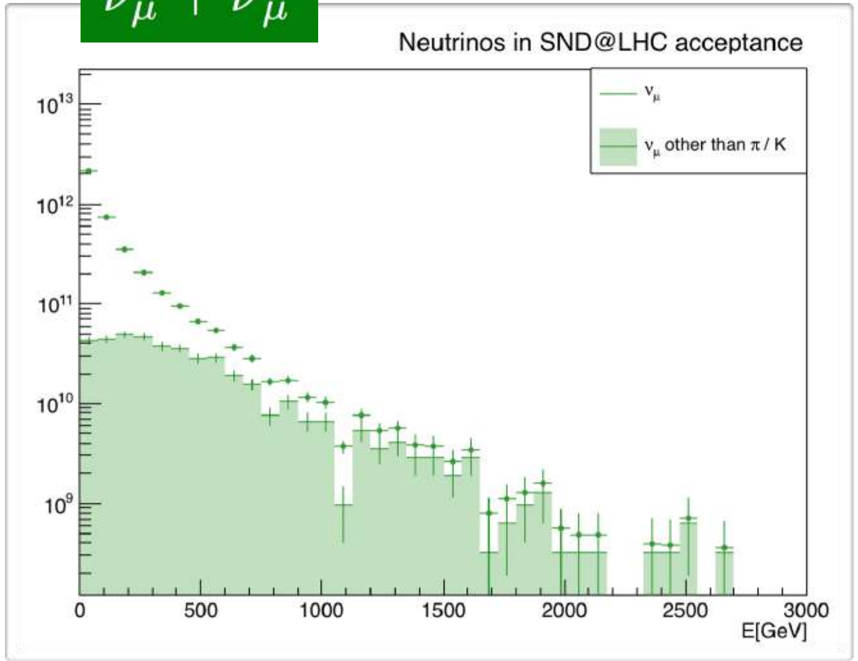
3. LEPTON FLAVOUR UNIVERSALITY TEST

- The identification of three neutrino flavours in the SND@LHC detector offers a unique possibility to test the Lepton Flavor Universality (LFU)

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



$\nu_\mu + \overline{\nu}_\mu$



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

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

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

contamination from π/k

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

4. MEASUREMENT OF NC/CC RATIO

- Lepton identification for the three different flavors allows to distinguish CC to NC interaction at SND@LHC

- If differential neutrino and anti-neutrino fluxes are equal, the NC/CC ratio can be written as

$$P = \frac{\sum_i \sigma_{NC}^{\nu_i} + \sigma_{NC}^{\bar{\nu}_i}}{\sum_i \sigma_{CC}^{\nu_i} + \sigma_{CC}^{\bar{\nu}_i}}$$

- In case of DIS, *P* can be written as

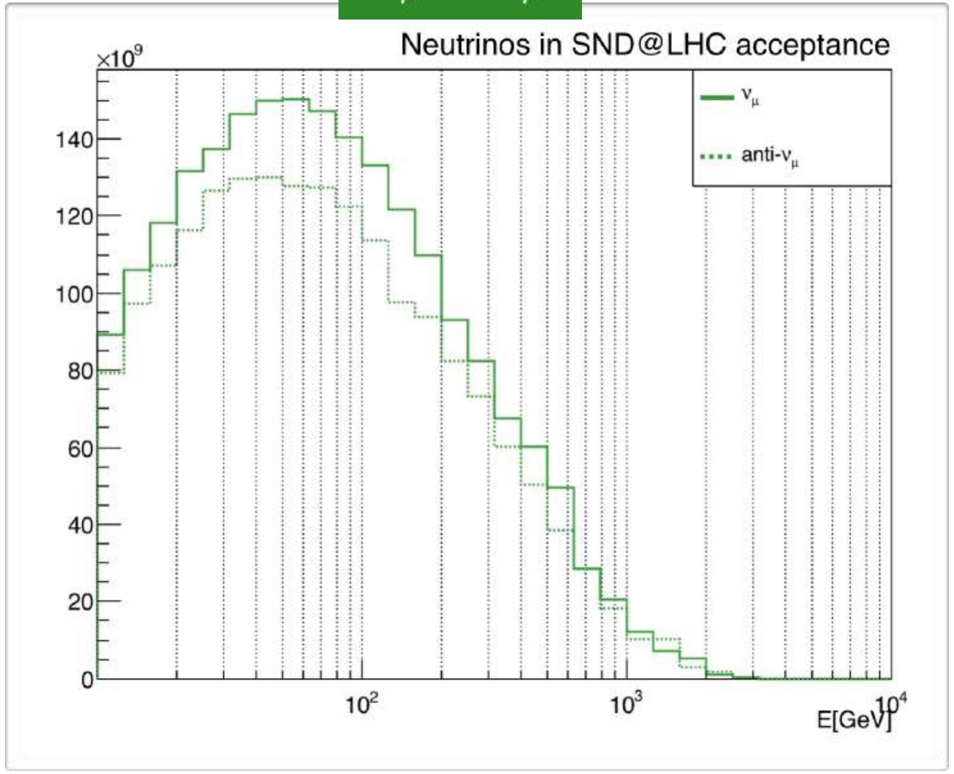
$$P = \frac{1}{2}\left\{1 - 2\sin^2\theta_W + \frac{20}{9}\sin^4\theta_W - \lambda(1 - 2\sin^2\theta_W)\sin^2\theta_W\right\}$$

For a Tungsten target λ=0.04

Rept.Prog.Phys. 79 (2016) 12, 124201

- P measurement used as an internal consistency check

ν_μ vs $\bar{\nu}_\mu$



NEUTRINO PHYSICS IN RUN 3

- Summary of SND@LHC performances

Measurement	Uncertainty Stat.	Uncertainty Sys.
$pp \to \nu_e X$ cross-section	5%	15%
Charmed hadron yield	5%	35%
ν_e/ν_τ ratio for LFU test	30%	20%
ν_e/ν_μ ratio for LFU test	10%	10%
Measurement of NC/CC ratio	5%	10%

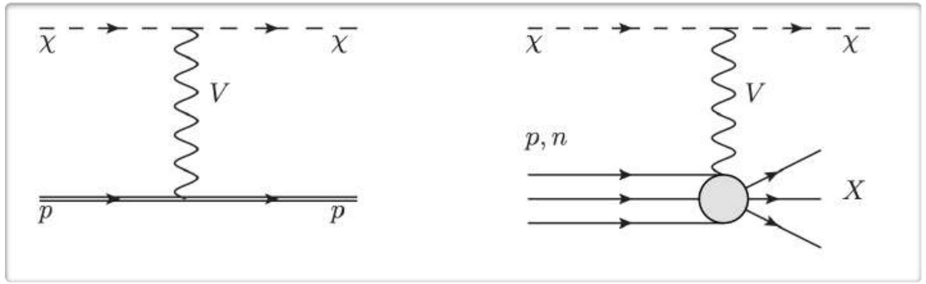
FLEEBLY INTERACTING PARTICLES

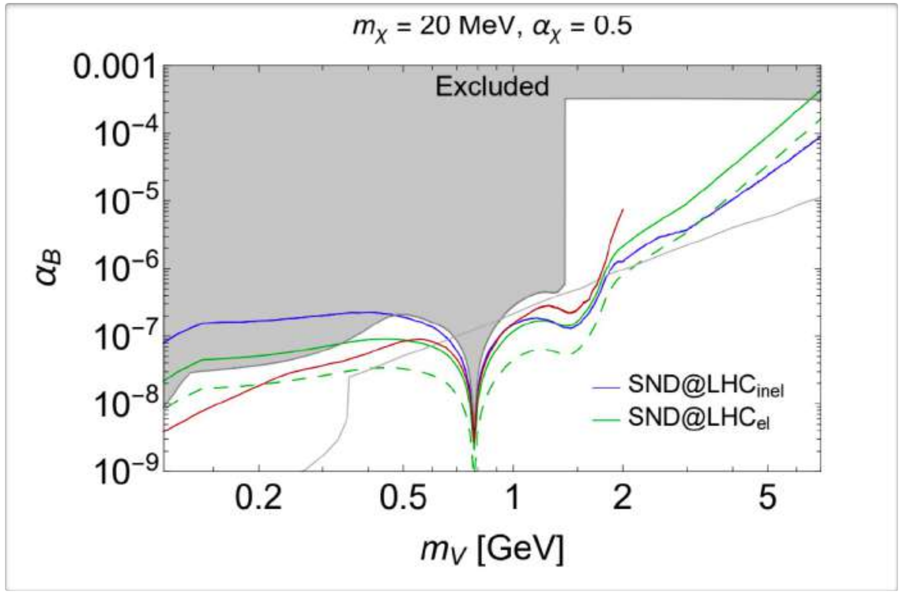
- SND@LHC experiment can explore a large variety of Beyond Standard Model (BSM) scenarios describing Hidden Sector

1. Scattering

Production: scalar χ particle coupled to the Standard Model via a leptophobic portal

Detection: χ elastic/inelastic scattering off nucleons of the target

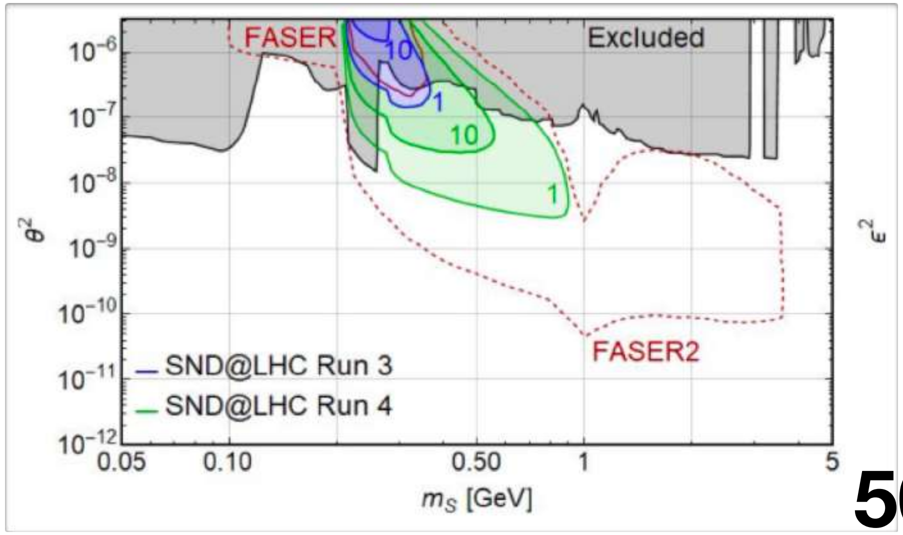




2. Decay of dark scalars, HNLs, dark photons

Production: dark scalars produced in the decay of B mesons, HLNs in the decay of B and D mesons, dark photons via leptophobic mediator

Detection: Decays in a pair of charged tracks or monophotons



UPGRADE FOR HL-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

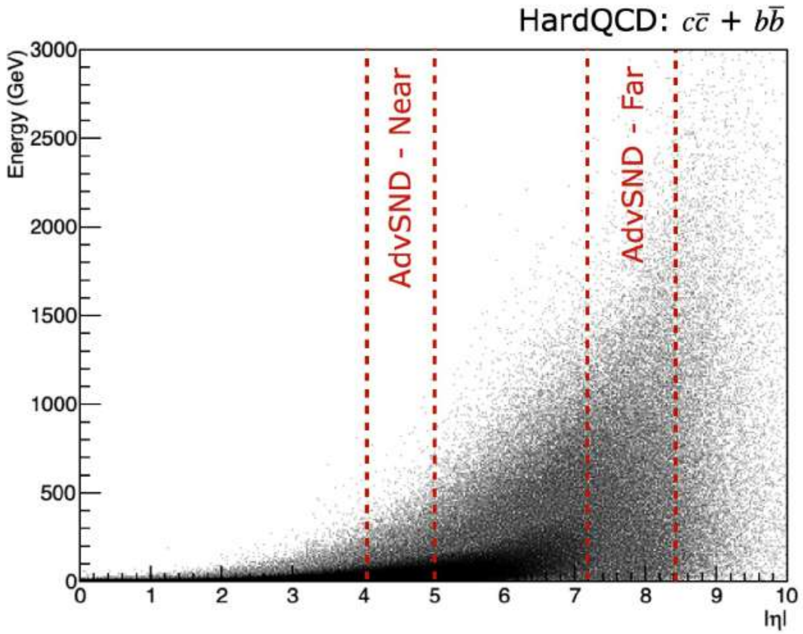
  Neutrino cross-section measurements

- **AdvancedSND-Far**: 7.2< η <8.4

  Overlap Acceptance similar to SND@LHC

  Charm production measurements

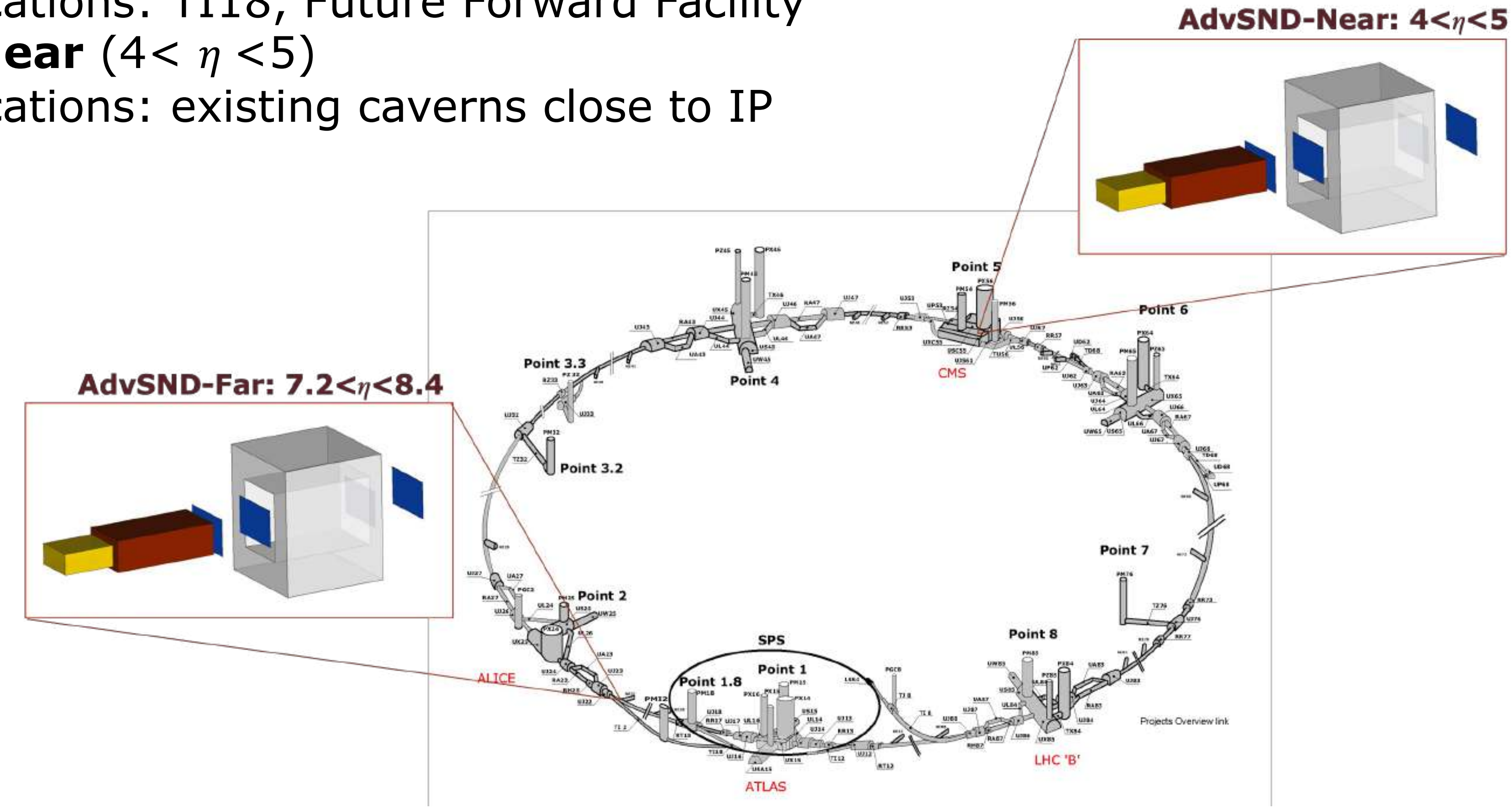
  Lepton flavour universality



UPGRADE FOR HL-LHC

Upgrade of SND@LHC in view of an extended run during Run 4:

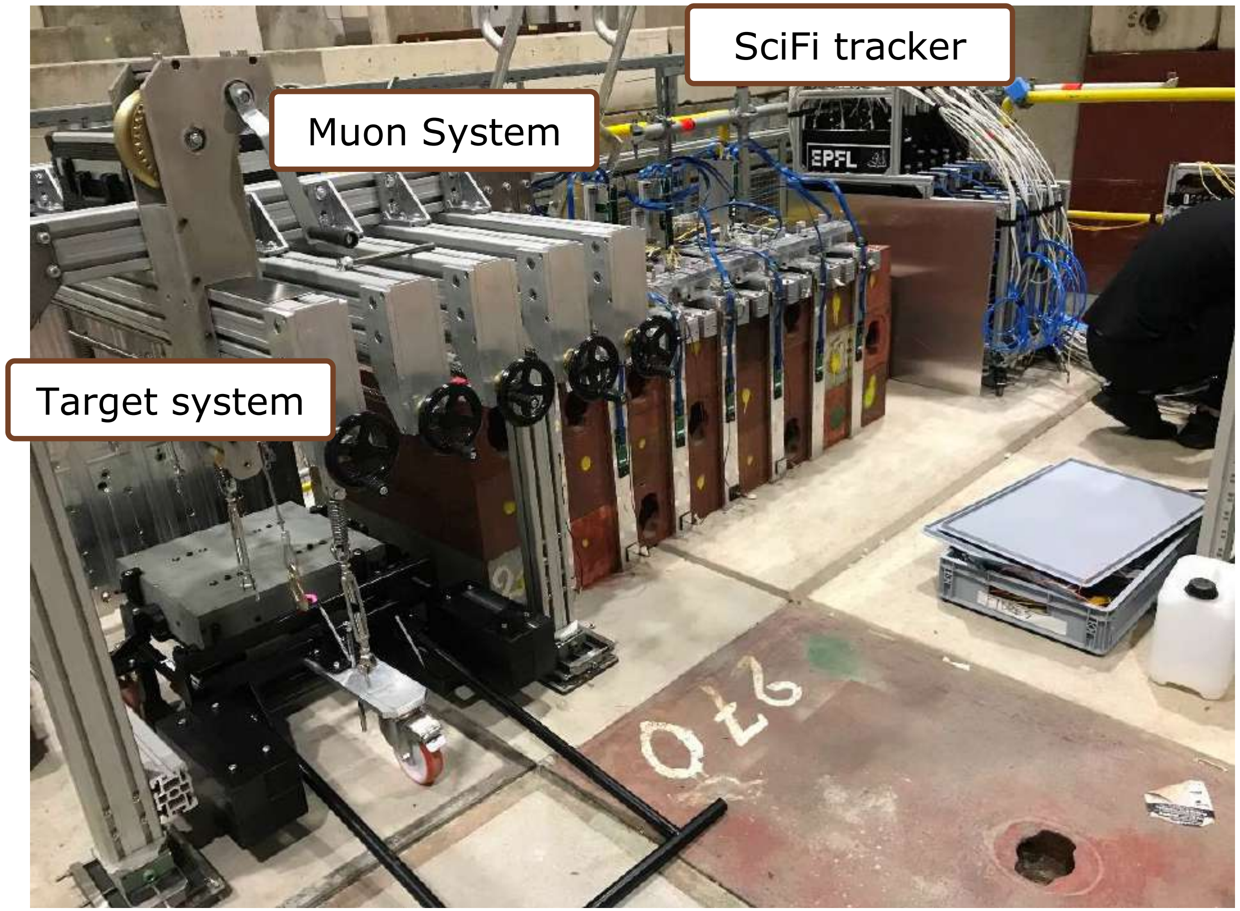
- Extension of the physics case
- New technologies and detector layout
- Two detectors
  - **AdvSND-Far** (7.2< η <8.4)
    Possible locations: TI18, Future Forward Facility
  - **AdvSND-Near** (4< η <5)
    Possible locations: existing caverns close to IP

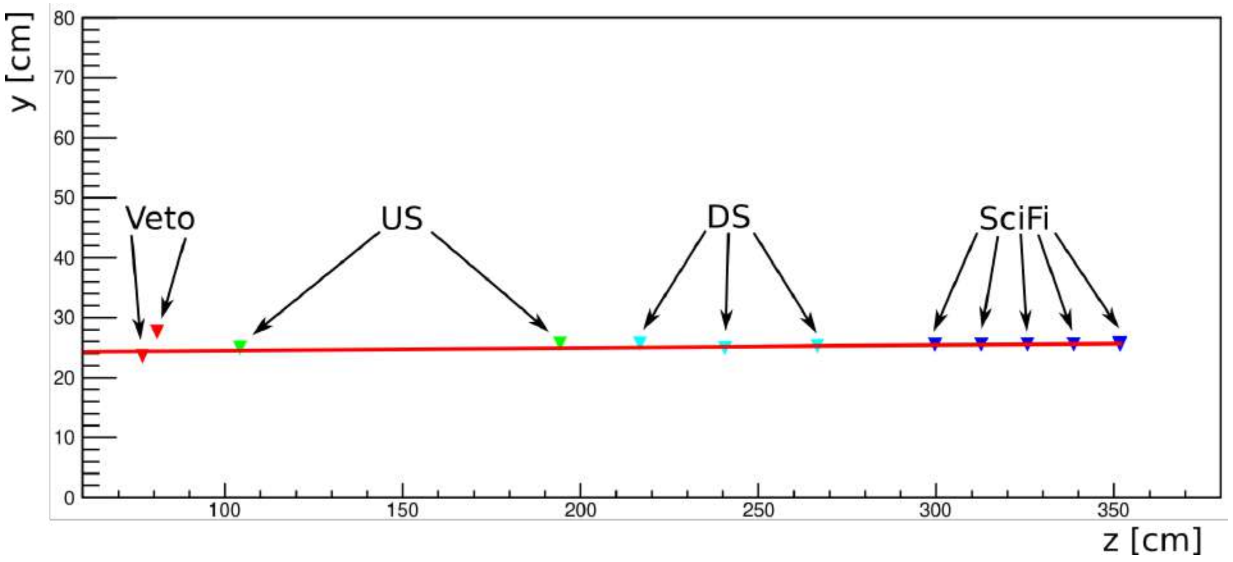


DETECTOR COMMISSIONING ON SURFACE

Sept 2021

- Full assembly of the detector at H6 in the North Area
- Target on a 2.5 degree slope to simulate the TI18 floor inclination
- Successful mechanical test of all subsystems
- Data taking with muon beam

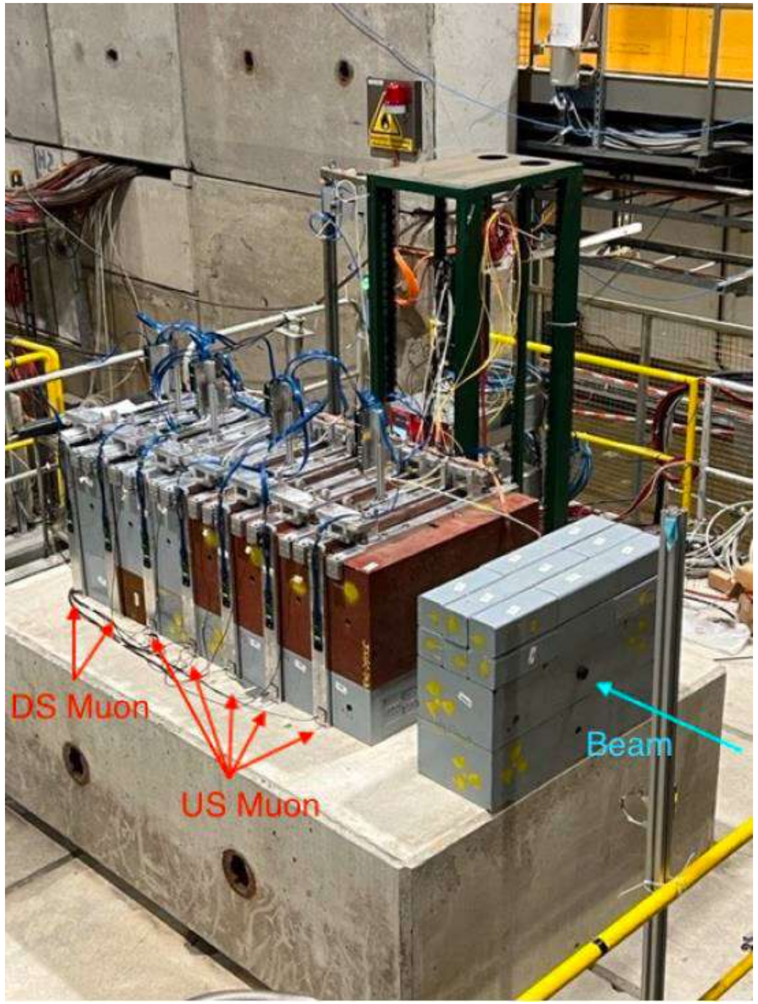




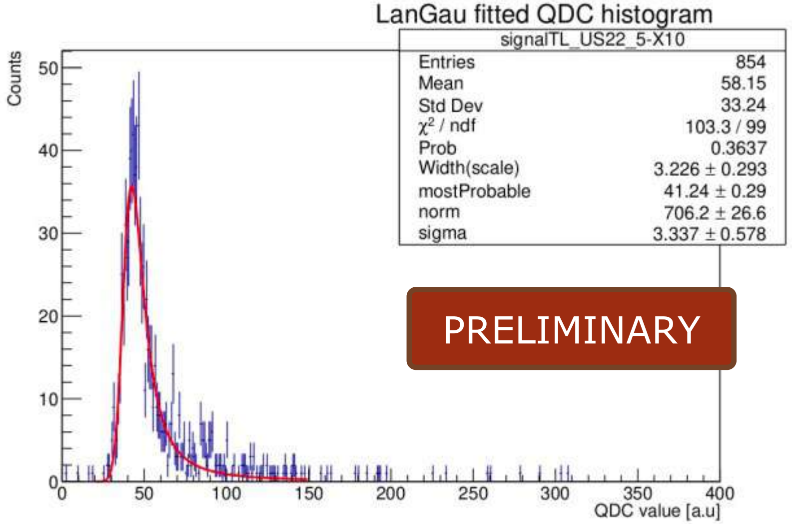
TEST BEAM WITH MUON SYSTEM

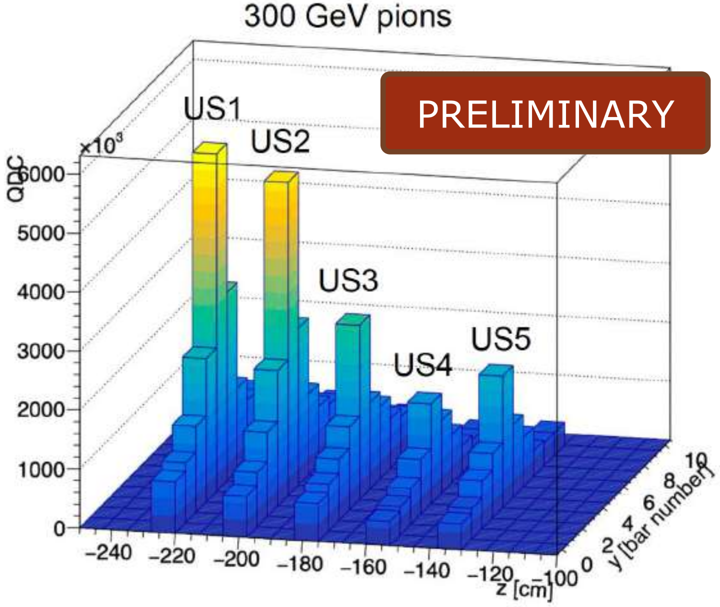
Oct 2021

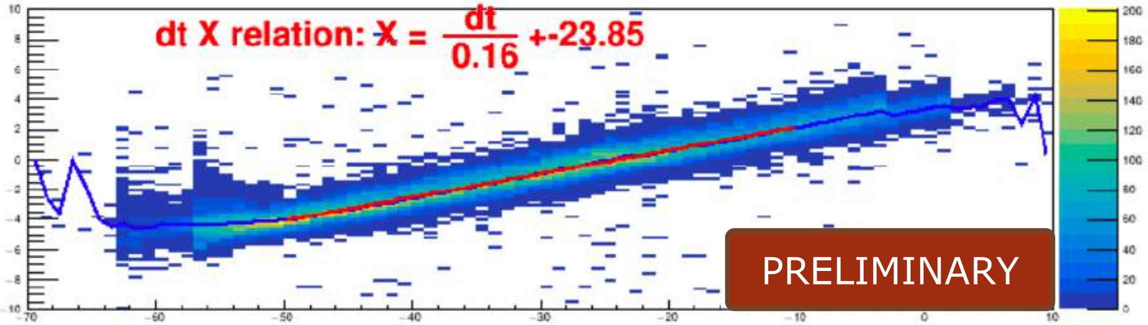
- Installation of the whole muon system at H8 in the North Area
- Energy calibration with 140, 180 240, 300 GeV pion beam



First glance at the signal







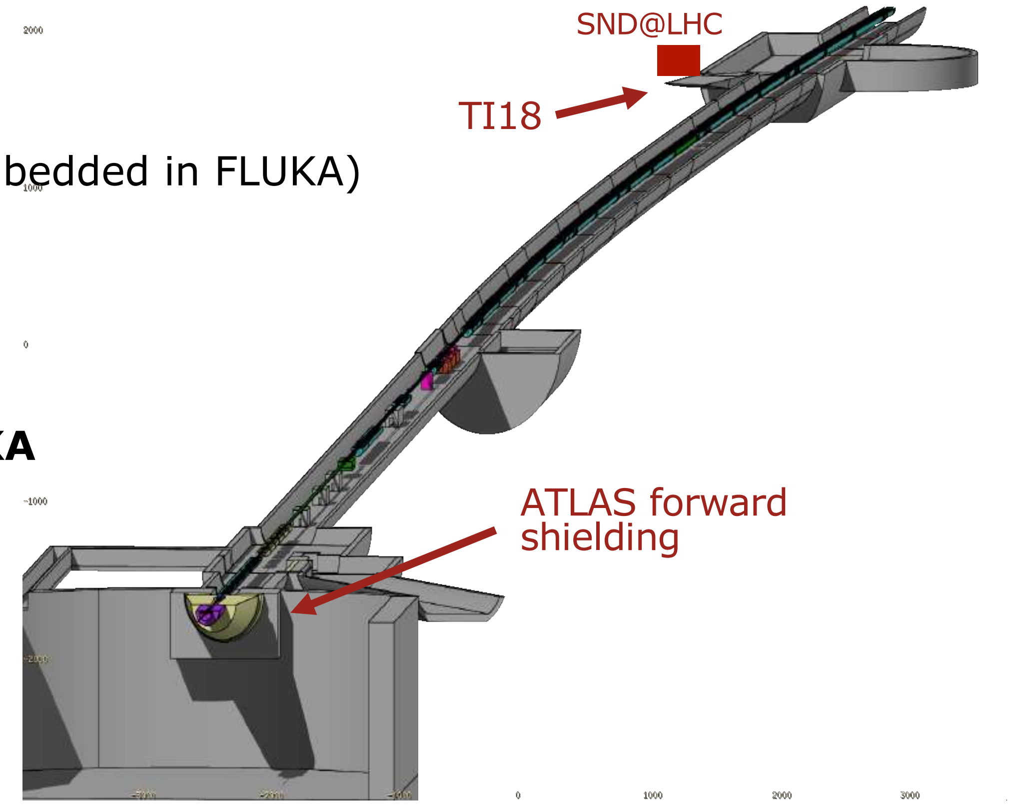
Extrapolated track X position vs mean time difference between left and right side

Position resolution:
σ_x =3.7 cm

SIMULATION

PRODUCTION

- pp collisions at LHC with **DPMJET III - v10** (embedded in FLUKA)
- $\sqrt{s}$ = 13 TeV

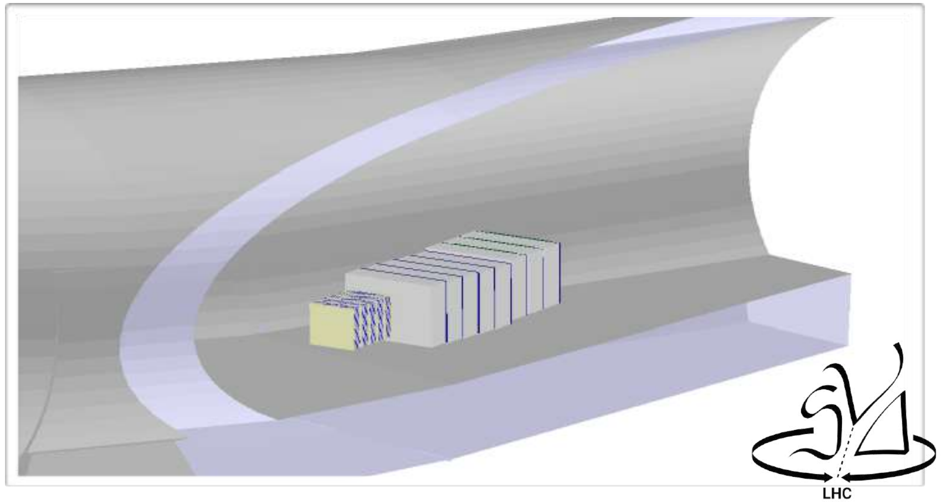


PROPAGATION

- Detailed simulation of LHC beam line with **FLUKA**
- Prediction of neutrino yields and spectra at SND@LHC location
- Prediction of muon population in the upstream rock, 75m from SND@LHC

DETECTOR

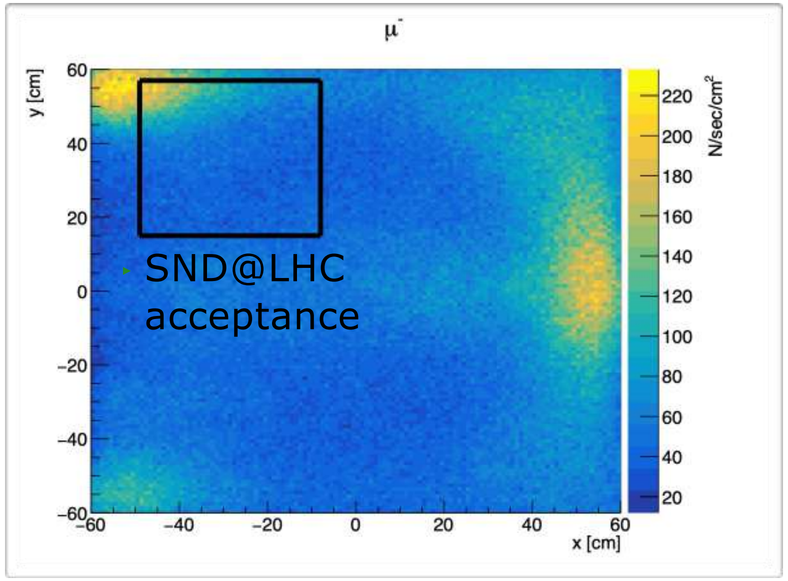
- Neutrino interactions in SND@LHC material simulated with **GENIE**
- Detector geometry and surrounding tunnel implemented in **GEANT4**

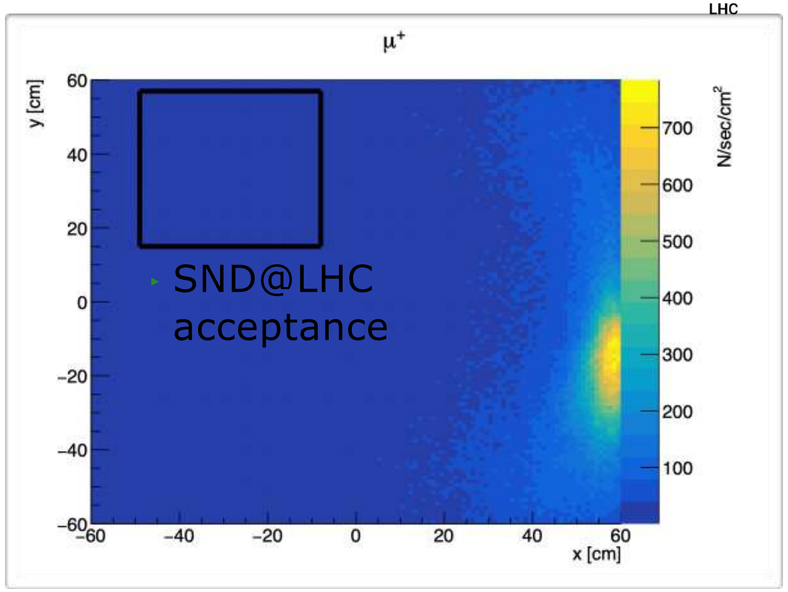


BACKGROUND ESTIMATION

Muon background

- Rates at the SND@LHC location: $4x10^4/cm^2/fb^{-1}$





SND@LHC can perform precise measurements on muon yield and angle to validate predictions and constraint simulations in an unexplored region

- Measurements performed by FASER

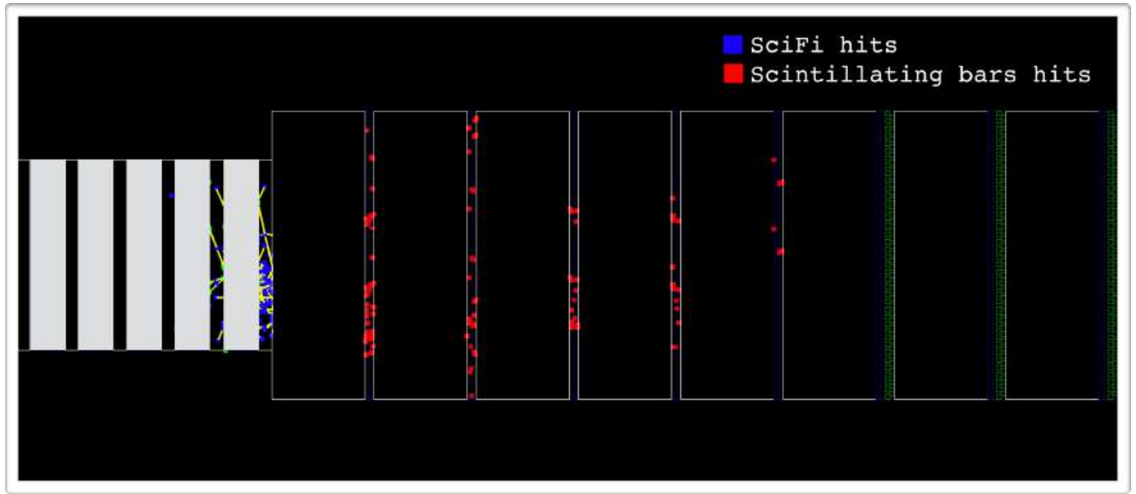
From FASER TP
https://cds.cern.ch/record/2651328

	normalized flux, main peak $[\text{fb cm}^{-2}]$
TI18	$(1.2 \pm 0.4) \times 10^4$
TI12	$(1.9 \pm 0.2) \times 10^4$

ν_e ENERGY ESTIMATION

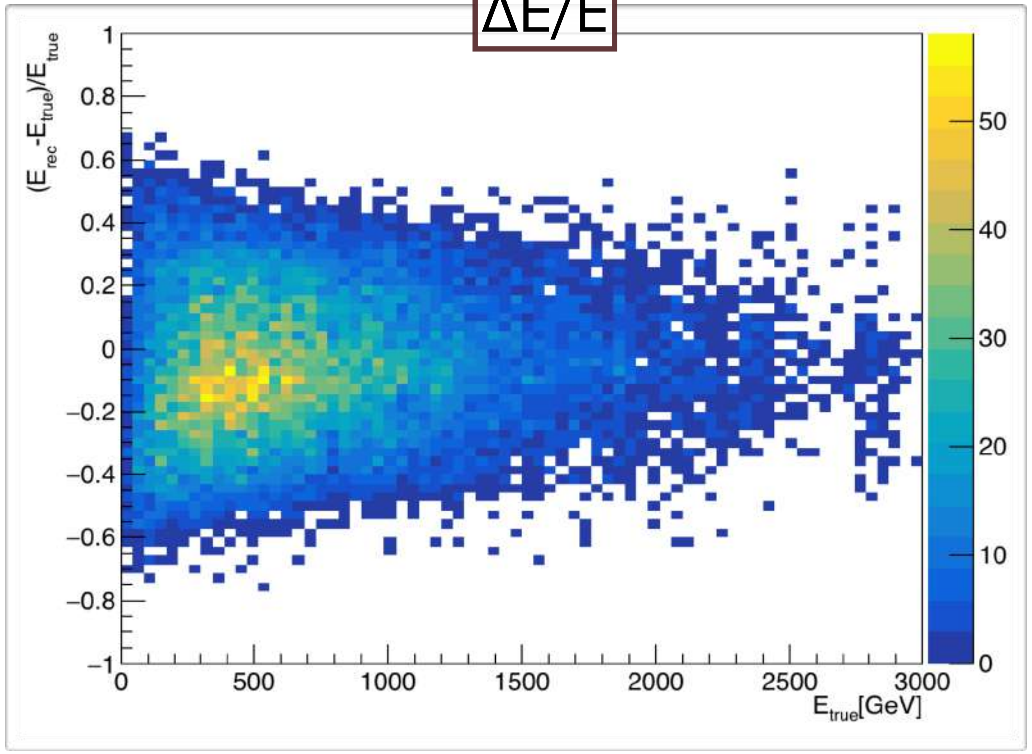
- Estimation of ν_e energy combing information from SciFi (target region) and Scintillator bars (Muon System)
- The detector acts as a non-homogeneous calorimeter

$$E_{rec} = A + B \times Nhits_{SciFi} + C \times Nhits_{Bars}$$



Average resolution: 22%

ΔE/E



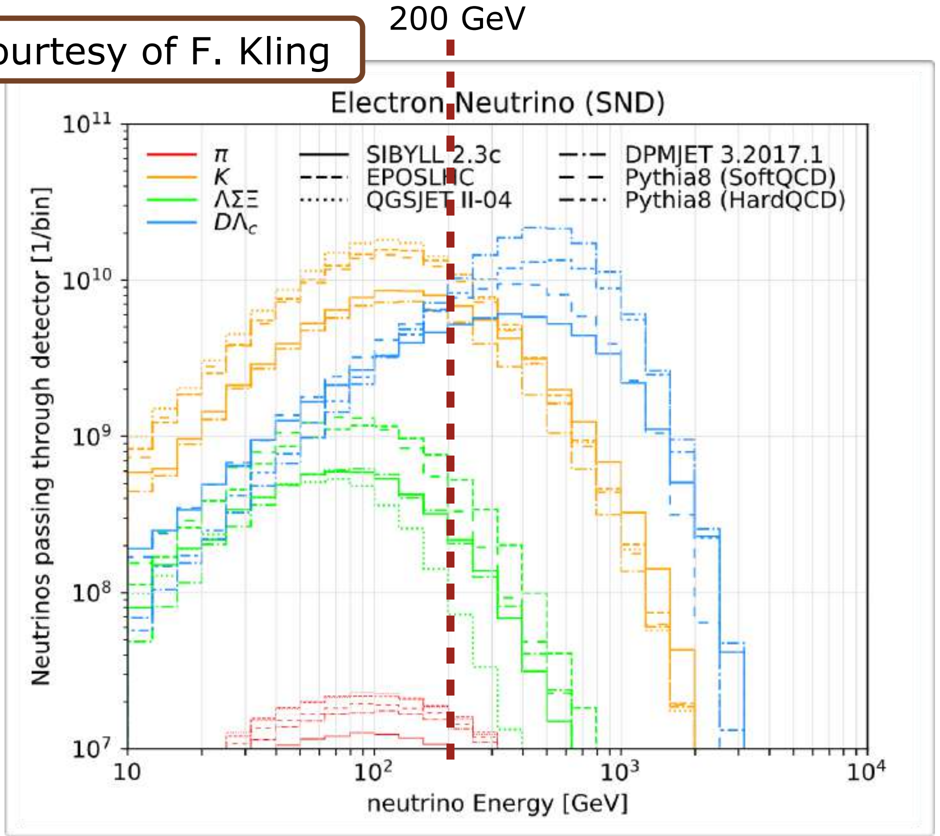
- Monte Carlo hits used in the current estimation
- Parameters A, B and C estimated via a gradient descent minimisation algorithm

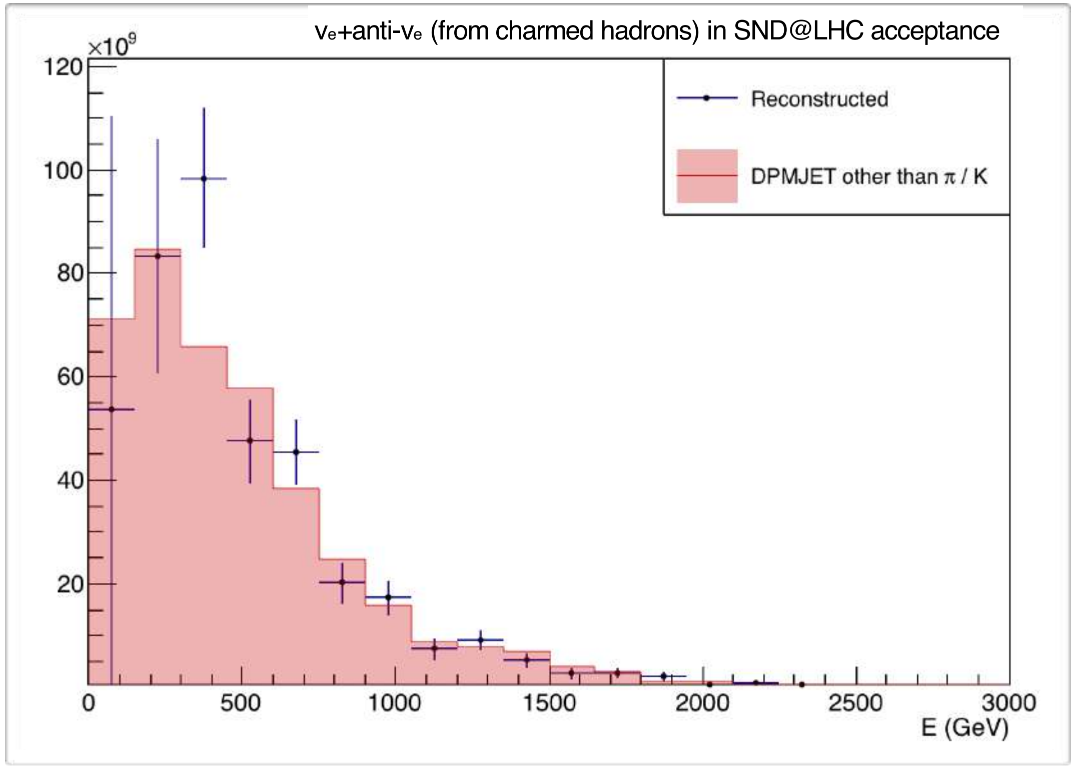
KAON CONTRIBUTION TO ν_e

- In order to extract the ν_e+anti-ν_e component from charmed hadron decay, a statistical subtraction of K component has to be performed
- The K component dominates at low energies (E<200 GeV)
- Predictions from different generators show large uncertainties (factor 2)

- This operation affects the low energy portion of the spectrum where the number of observed neutrino is lower
- The subtraction of the K component introduces an additional systematic error of **~20%**

Courtesy of F. Kling





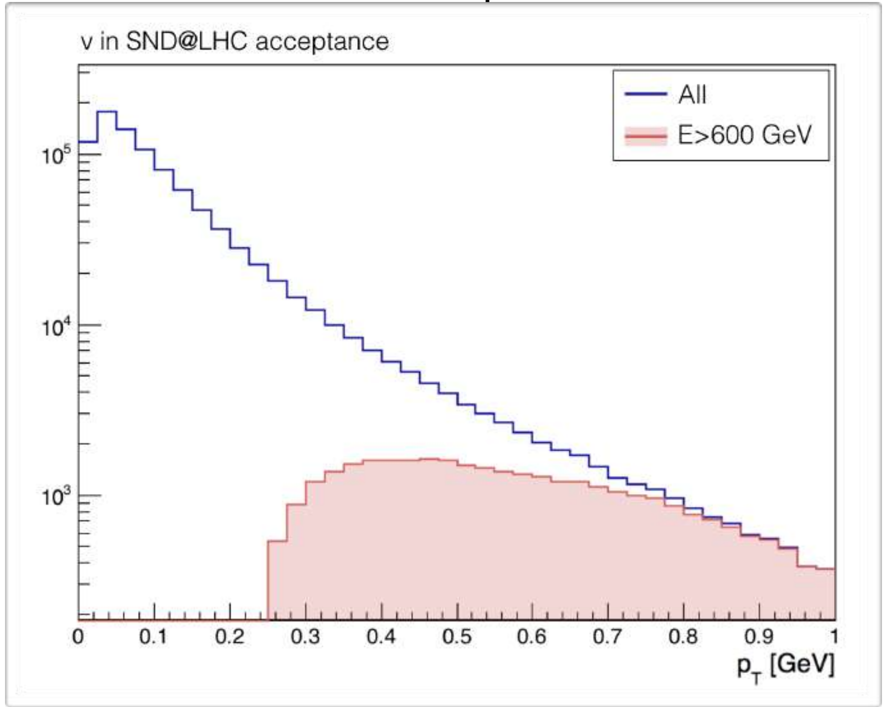
UNCERTAINTY IN PION/KAON CONTAMINATION

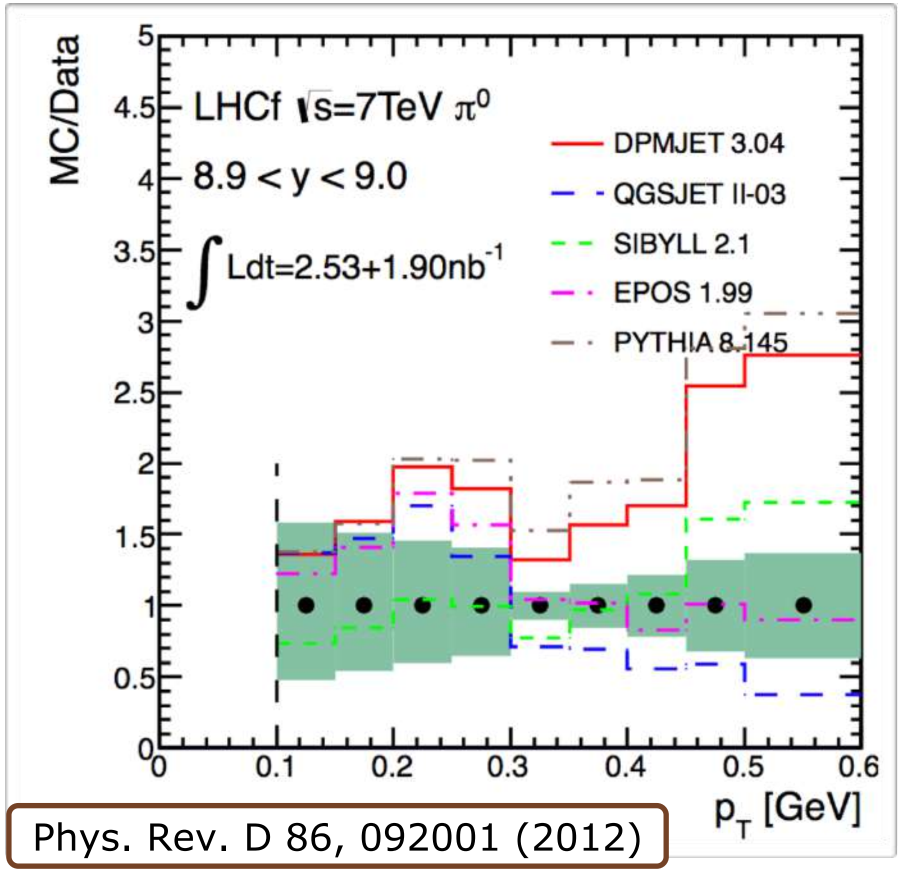
- The uncertainty in the knowledge of π/k contamination has two contributions:

1. Production of π/k
2. Propagation along beamline

- Simulation of light meson production in forward region constrained by LHCf collaboration
- Agreement better than **10%** with EPOS generator for p_T>300 GeV

- Neutrinos in SND@LHC acceptance with E>600 GeV have p_T>250 MeV





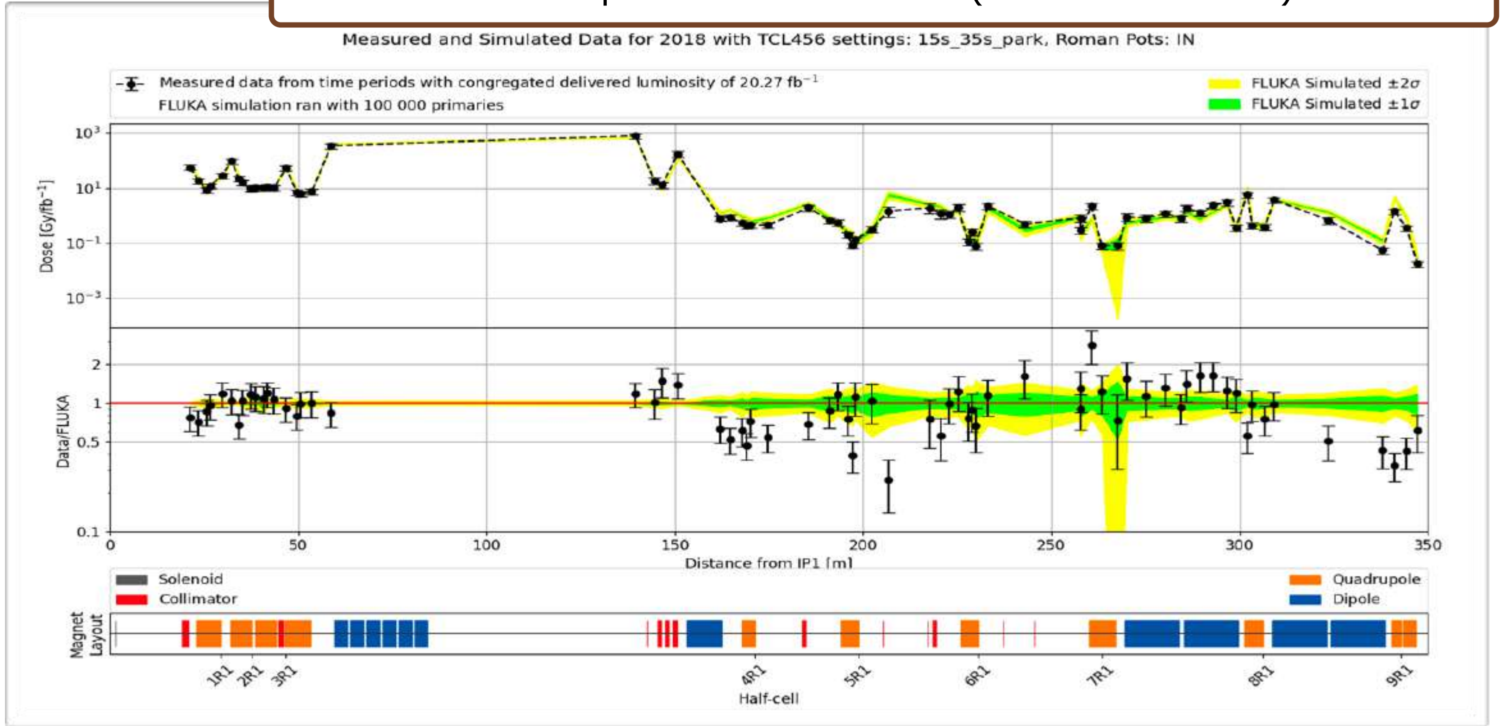
Phys. Rev. D 86, 092001 (2012)

UNCERTAINTY IN PION/KAON CONTAMINATION

- The uncertainty in the knowledge of π/k contamination has two contributions:

1. Production of π/k
2. Propagation along beamline

D. Prelipcean and G. Lerner (CERN-EN-TI-BMI)



- Charged meson propagation performed with FLUKA and show very good agreement with measurements performed along the beamline

- Measurements performed by FASER in TI18 in agreement with FLUKA predictions ($2x10^4/cm^2/fb^{-1}$) within errors

- SND@LHC will measure particle flux in TI18 with high accuracy, using different detectors

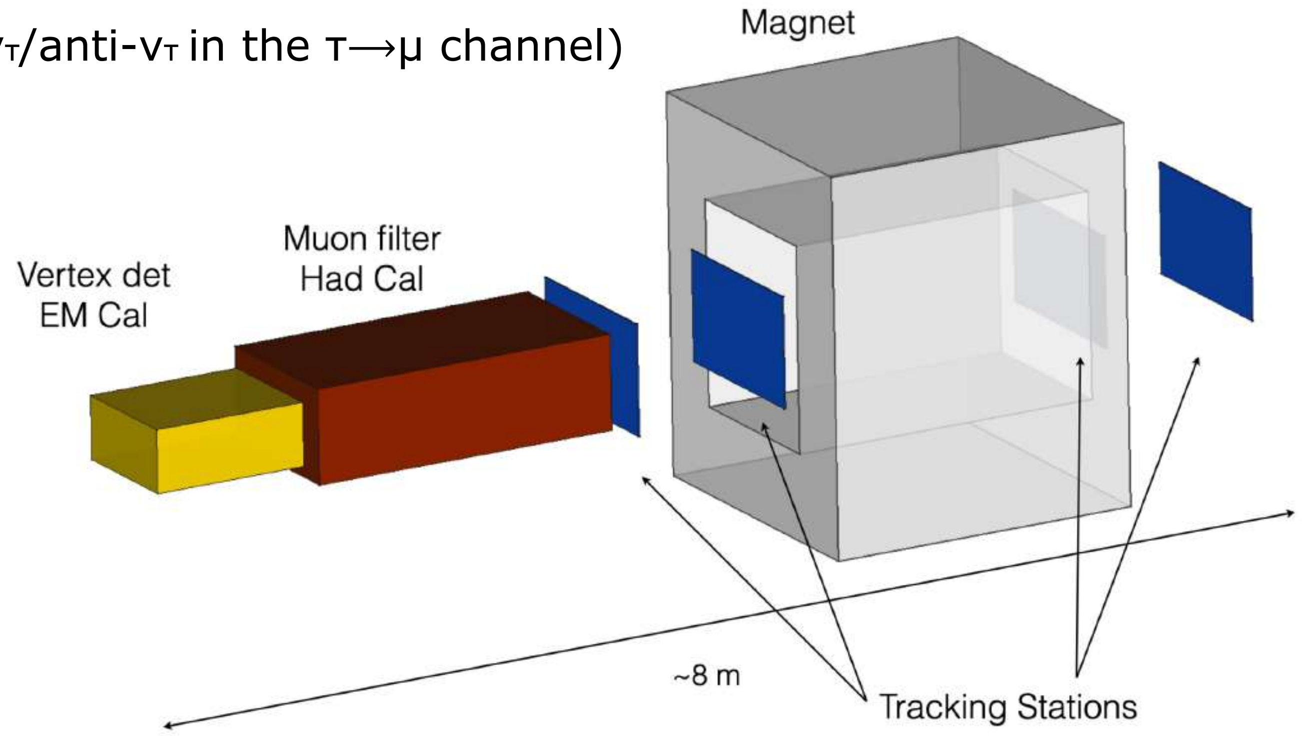
ADVANCED SND@LHC: DETECTOR LAYOUT

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

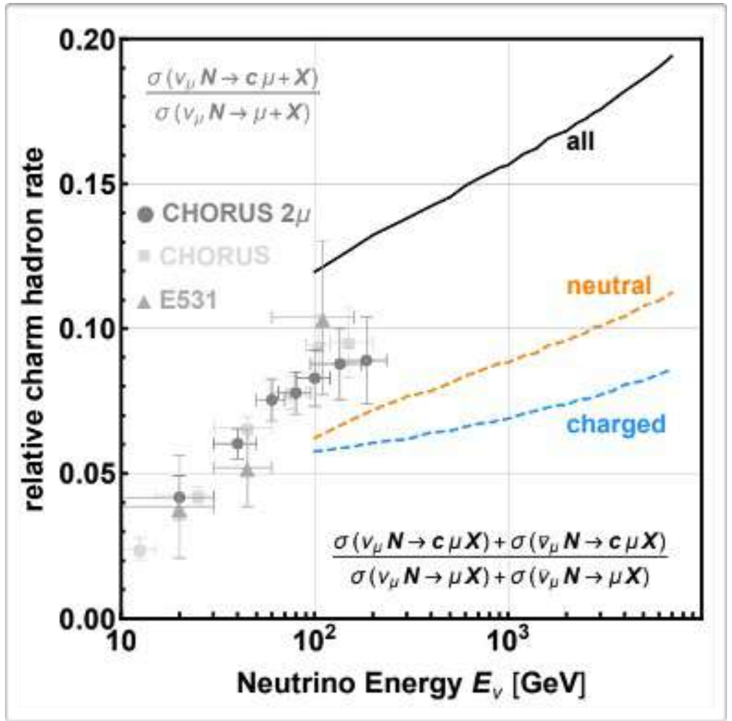
3) Magnet with two high-resolution tracking stations
- measure charge of the muon (ν_μ/anti-ν_μ, ν_τ/anti-ν_τ in the $\tau \to \mu$ channel)
- 1 T field over 2 m length

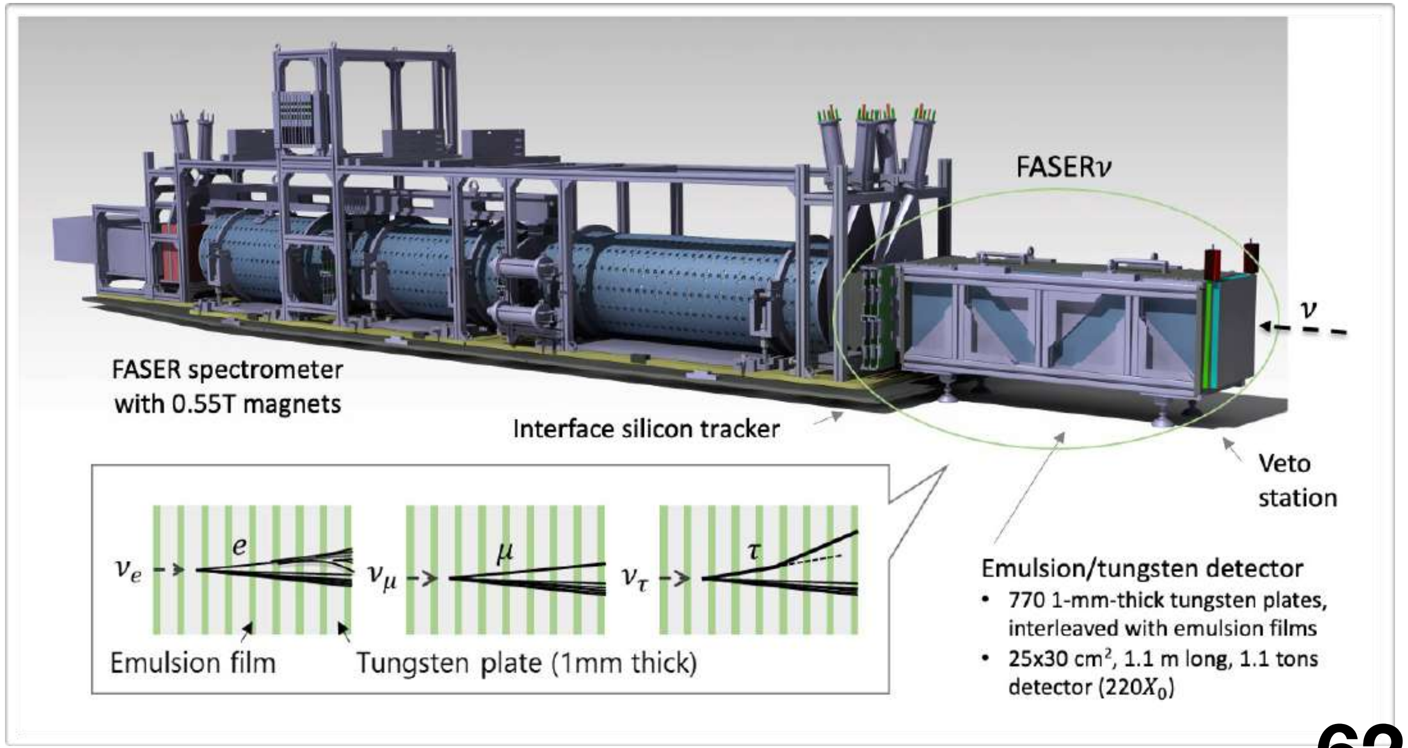
	AdvSND - NEAR	AdvSND - FAR
η	[4.0, 5.0]	[7.2, 8.4]
mass (ton)	5	5
surface (cm^2)	120×120	100×55
distance (m)	55	630



COMPLEMENTARITY WITH FASERnu

- Pseudo-rapidity range: η >8.8
- Main physics goals:
  - ~2000 ν_e, 7000 ν_μ, 50 ν_τ CC interactions expected *[Eur. Phys. J. C 80 (2020) 61]*
  - NC measurements could constrain neutrino non-standard interactions *[Phys. Rev. D 103, 056014 (2021)]*
  - Neutrino CC interaction with charm production ($\nu s \rightarrow l c$)
  - Study the strange quark content





Universidad Andrés Bello

MILLENNIUM INSTITUTE FOR SUBATOMIC PHYSICS AT HIGH-ENERGY FRONTIER
SAPHIR

Universidad Andrés Bello

Possible contributions:

- Hardware – muon detector
- FLUKA simulations
- Data analysis.

Sergey Kuleshov,
Professor

Jilberto Zamora,
Professor

Serguei Kovalenko,
Professor

Francisca Garay
Professor

Ángel Abusleme
Professor

Juan Carlos Helo
Professor

Pablo Ulloa
Professor

+ 2 engineers + 2 technicians

Neutron shield: design and construction

Sergey Kuleshov and Jilberto Zamora-Saa

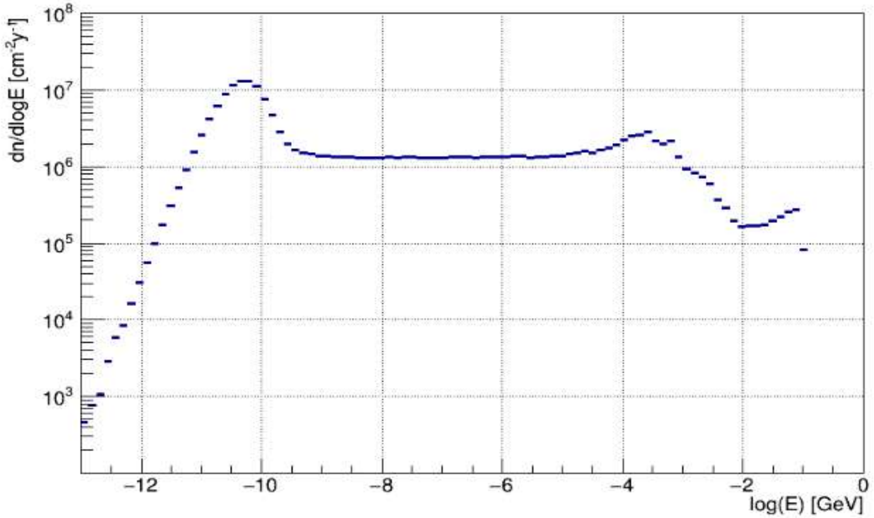
Andres Bello University

And

Millennium Institute
for Subatomic physics at high energy frontier - ANID-ICN2019_044
FONDECYT1191103

19.08.2021

- The neutron source is considered as a spherical surface 200 cm radius, neutrons are isotropically emitted in the space.
- The neutron spectrum was provided by FLUKA team:



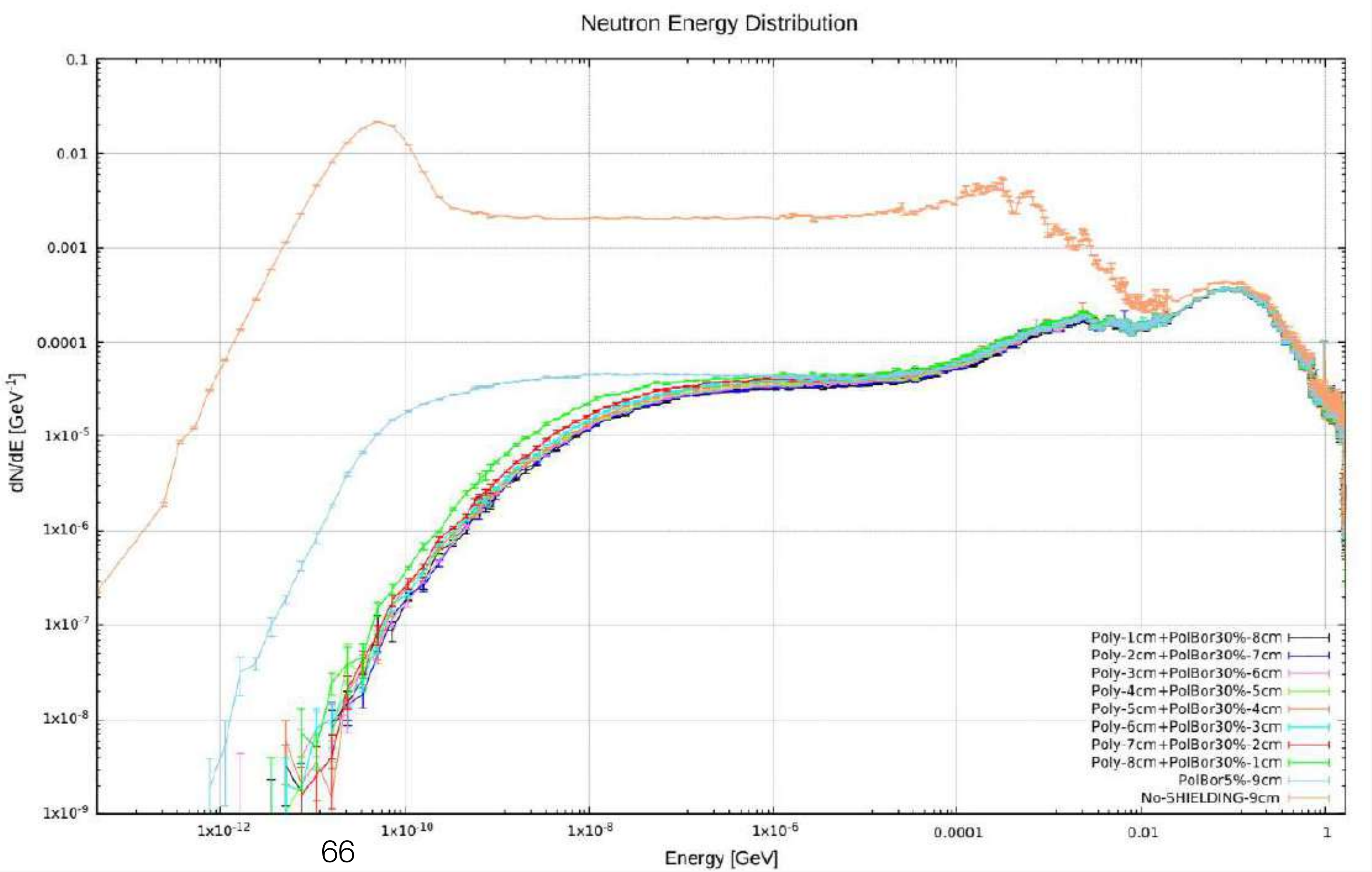
- This FLUKA output will be used as the neutron probability distribution for the shielding simulation.

Shielding Box

The tested shield was composed of an external layer made of Polyethylene (denoted as poly) plus an internal layer made of Borated Polyethylene 30% (denoted as polbor30%). We have simulated 1E9 primaries neutrons in all the studied cases.

Different configurations were tested:

a) 1cm of Poly + 8cm of polbor30%
b) 2cm of Poly + 7cm of polbor30%
c) 3cm of Poly + 6cm of polbor30%
d) 4cm of Poly + 5cm of polbor30%
e) 5cm of Poly + 4cm of polbor30%
f) 6cm of Poly + 3cm of polbor30%
g) 7cm of Poly + 2cm of polbor30%
h) 8cm of Poly + 1cm of polbor30%
i) 9cm of Poly + 8cm of polbor30%)
j) 9cm of polbor5%)



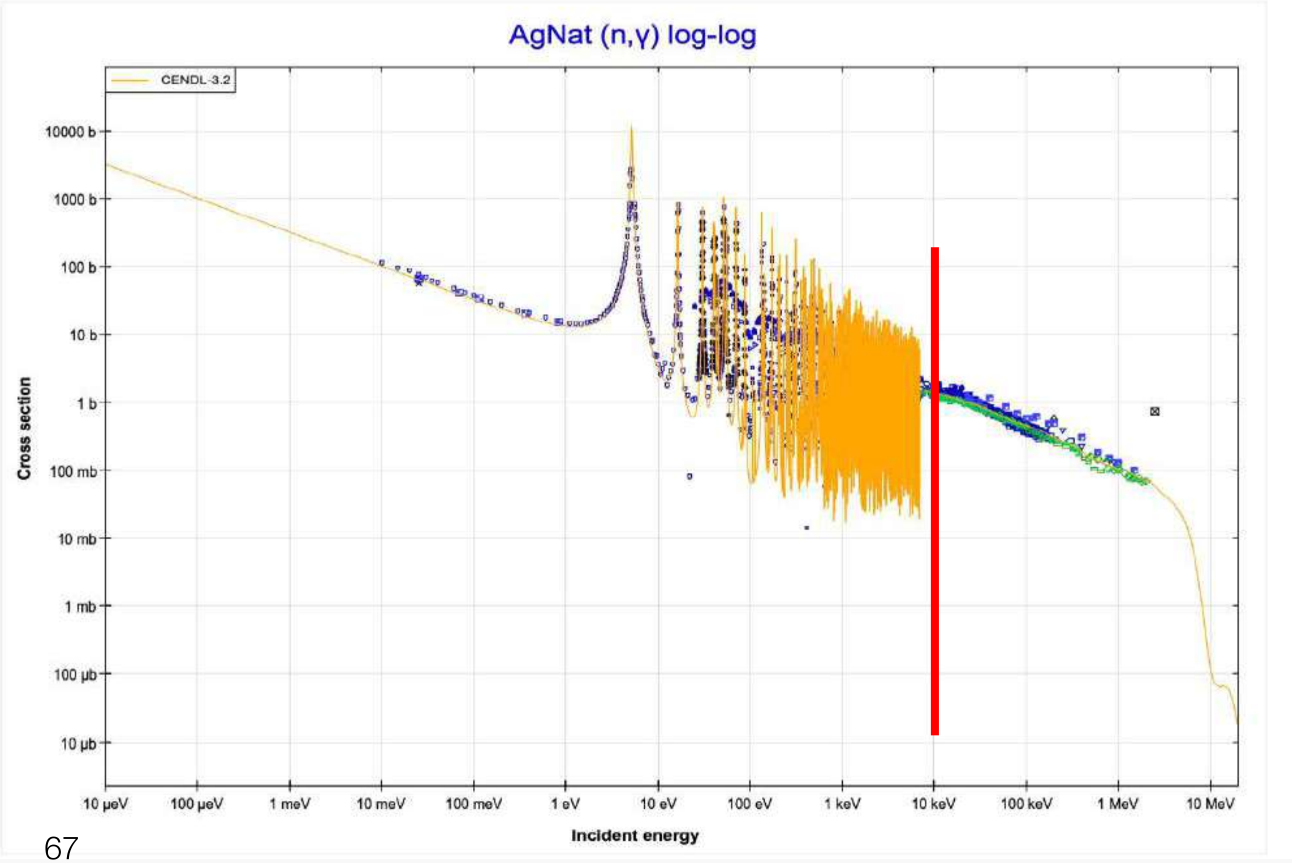
Shielding Box

a) The final selected option is: 5cm of Plexi + 4cm of polbor30%

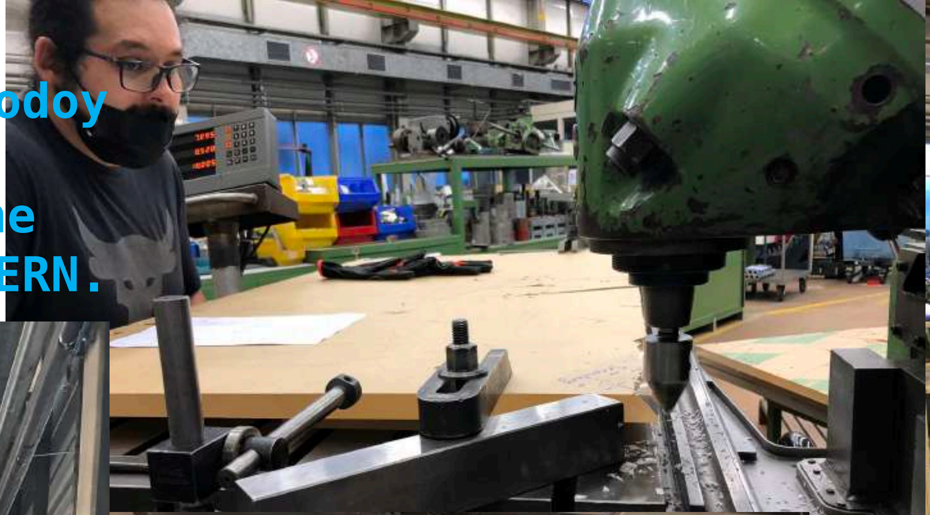
Neutron rejection for selected option.
Here Ratio = Shielding/No-Shielding

	Ratio
< 1ev	7.3E-05
< 100 eV	1.5E-03
< 10 keV	4.3E-03
< 2 MeV	9.7E-03
< 20 MeV	1.4E-02
< 200 MeV	2.3E-02
< 1 GeV	2.5E-02

Natural Silver Neutron Capture Cross-Section



Sebastian Andres Cepeda Godoy and Matias Liz Vargas (UNAB/SAPHIR) work on the ColdBox construction at CERN.




S S TI18