SND@LHC
The Scattering and Neutrino Detector at the LHC

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INFN Napoli

INFN NA Gr1 Meeting - 12 Jan 2023

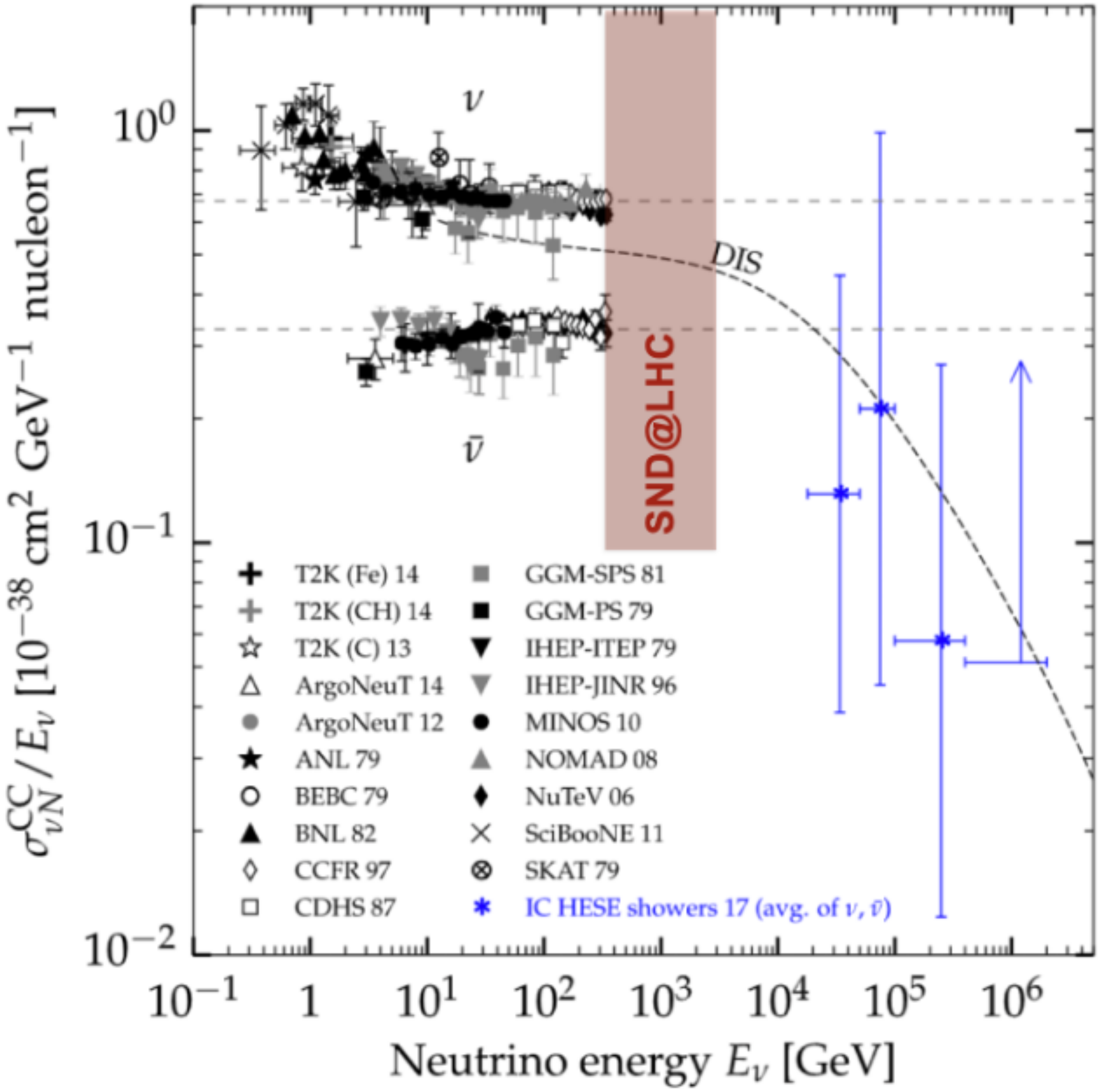
MOTIVATION

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

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

PRL 122 (2019) 041101



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

Eur. Phys. J. C (2020) 80:61
https://doi.org/10.1140/epjc/s10052-020-7631-5

THE EUROPEAN PHYSICAL JOURNAL C

Check for updates

Regular Article - Experimental Physics

Detecting and studying high-energy collider neutrinos with FASER at the LHC

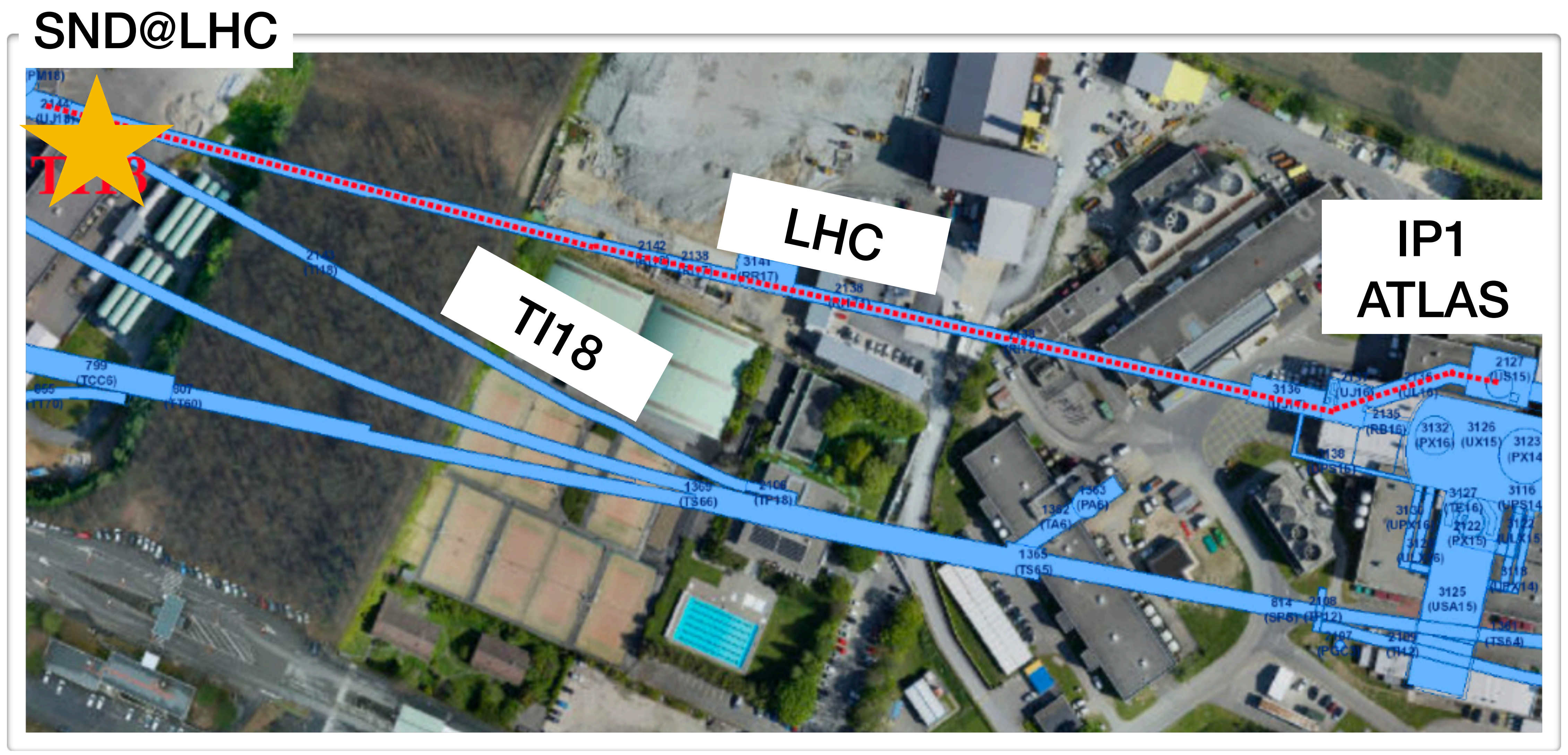
FASER Collaboration

OPEN ACCESS
IOP Publishing — Journal of Physics G: Nuclear and Particle Physics

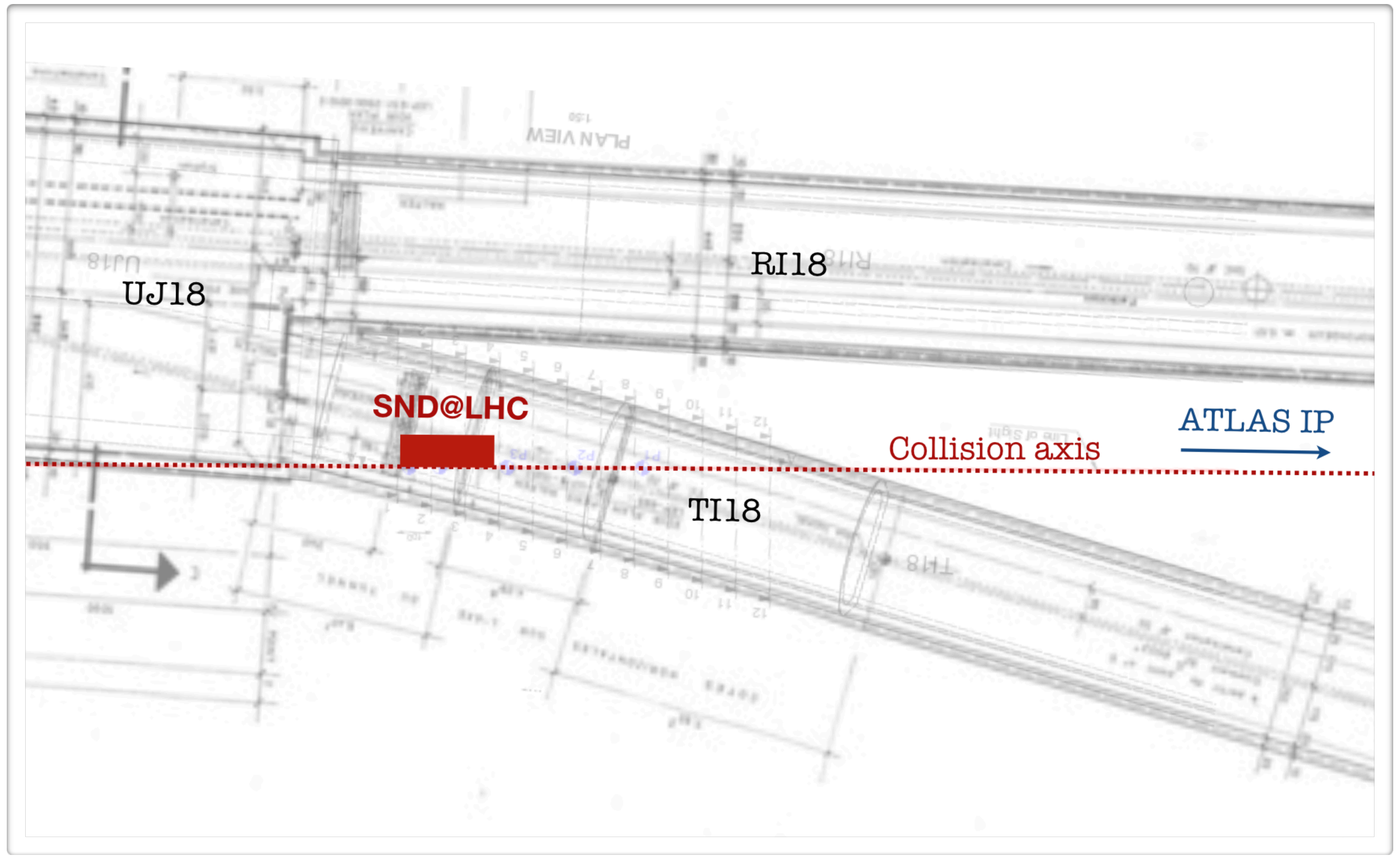
J. Phys. G: Nucl. Part. Phys. **47** (2020) 125004 (18pp) https://doi.org/10.1088/1361-6471/aba7ad

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 FASER is located



- Charged particles deflected by LHC magnets
- Shielding from the IP provided by 100 m rock
- Angular acceptance: $7.2 < \eta < 8.6$
- First phase: operation in Run 3 to collect 250 fb^{-1}

https://cds.cern.ch/record/2750060/files/LHCC-P-016.pdf

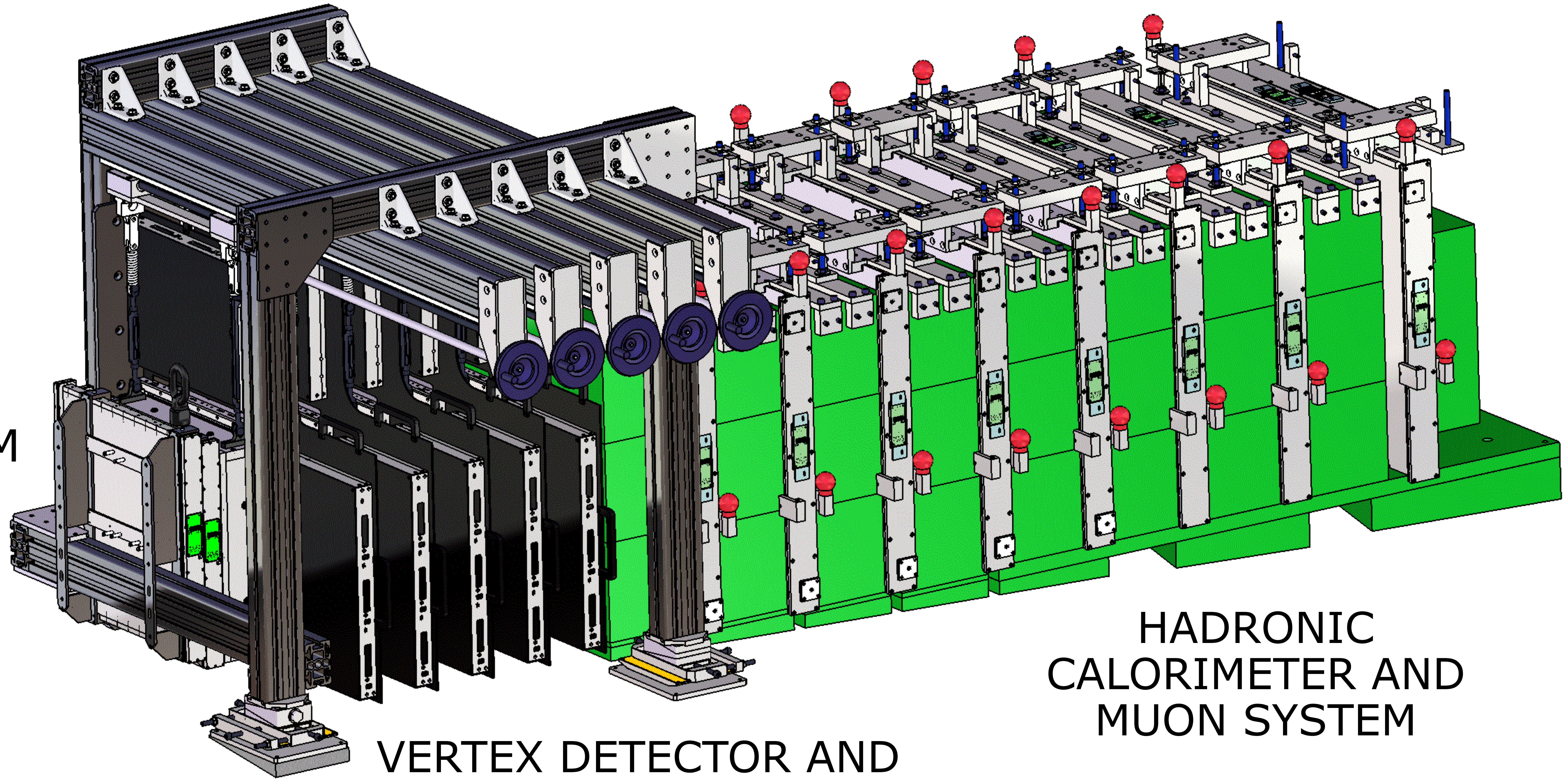
THE SND@LHC CONCEPT

Hybrid detector optimised for the identification of three neutrino flavours and for the detection of feebly interacting particles

VETO PLANE:
tag penetrating muons

TARGET REGION + ECAL:
- Emulsion cloud chambers (Emulsion+Tungsten) for neutrino interaction detection
- Scintillating fibers for timing information and energy measurement

MUON SYSTEM + HCAL:
iron walls interleaved with plastic scintillator planes for fast time resolution and energy measurement



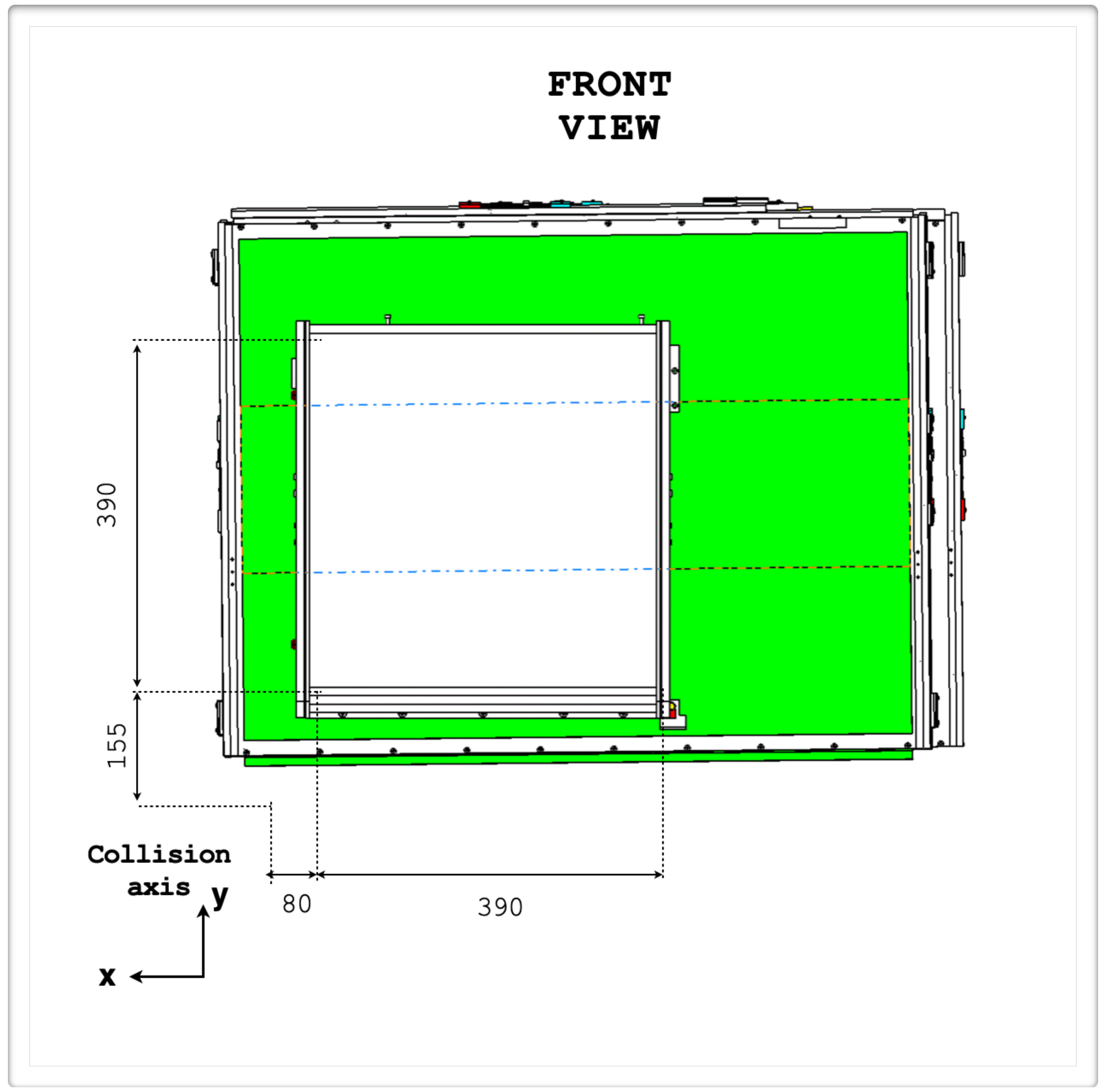
THE SND@LHC DETECTOR LAYOUT

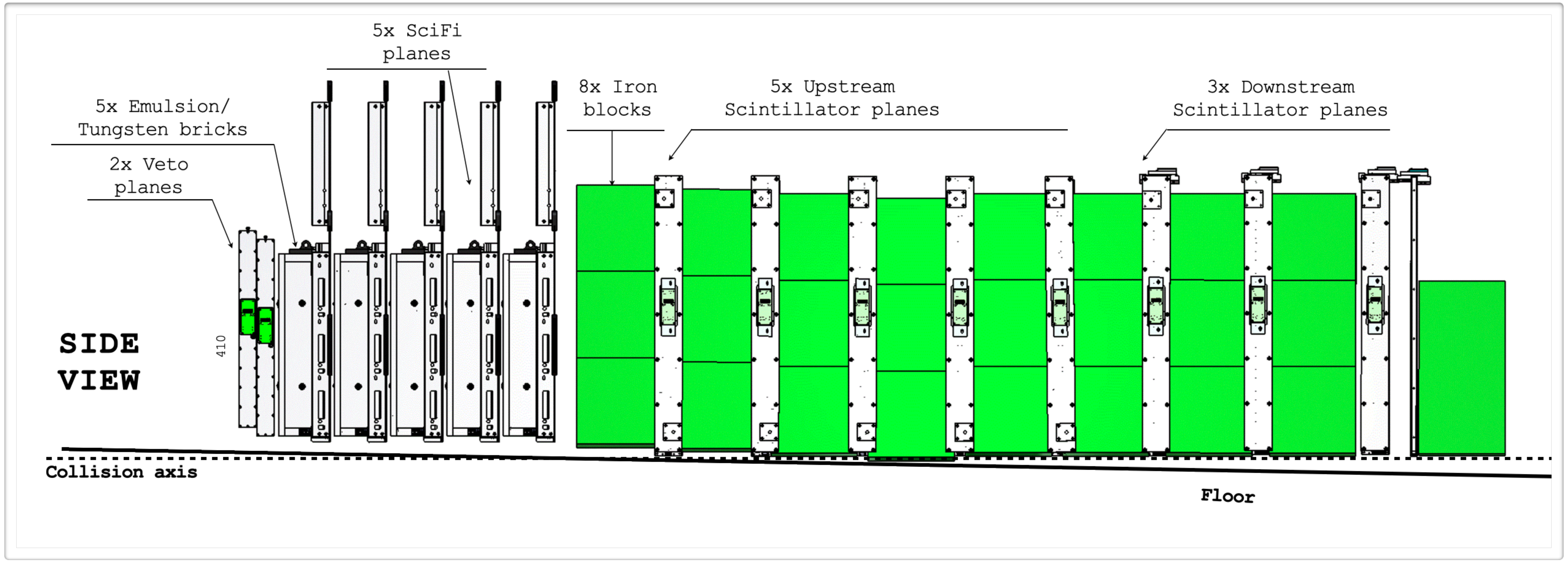
- Angular acceptance: $7.2 < \eta < 8.4$
- Target material: Tungsten
- Target mass: 830 kg
- Surface: 390x390 mm^2

Off axis location

Electromagnetic calorimeter
~40 X_0

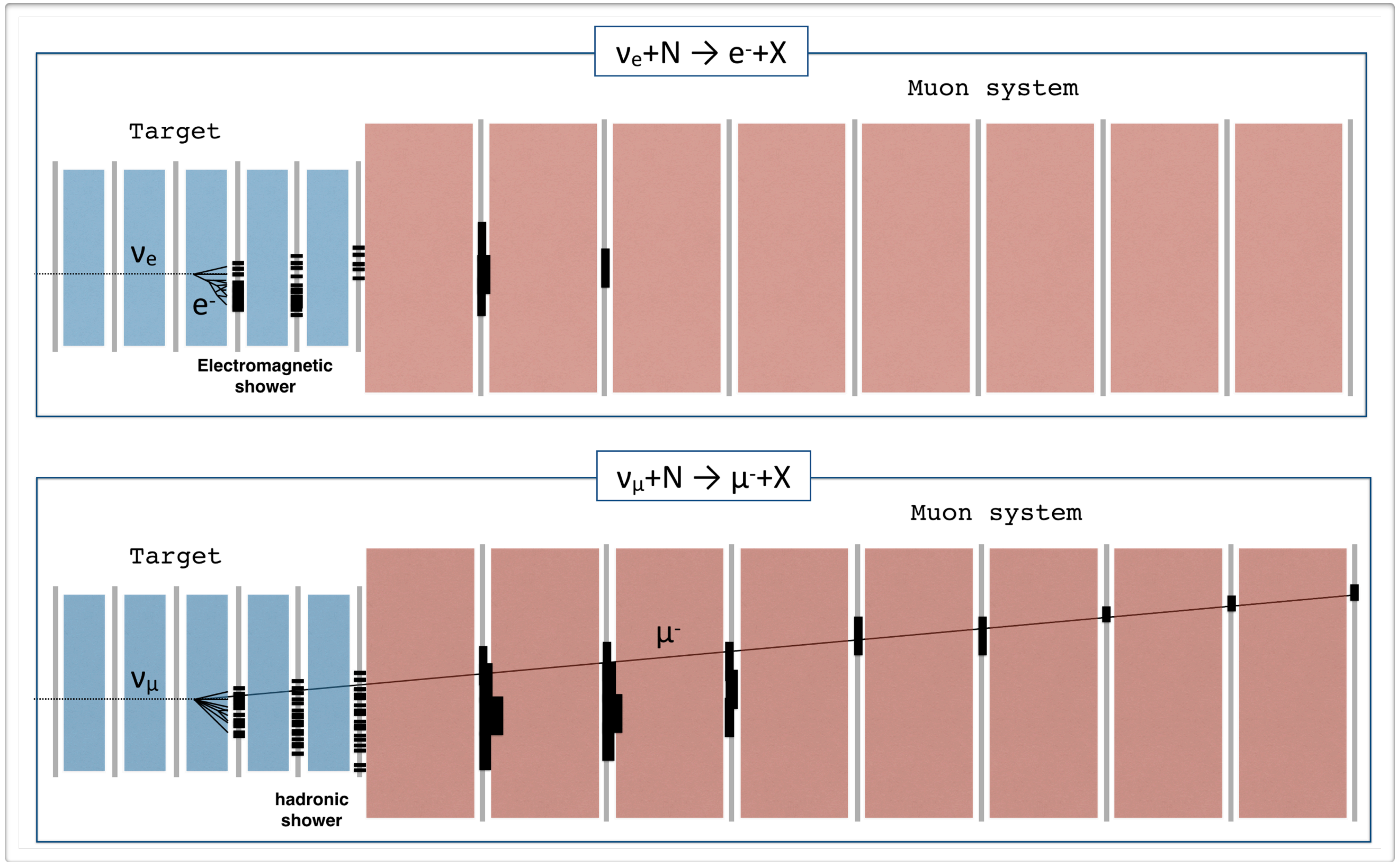
Hadronic calorimeter
~10 λ



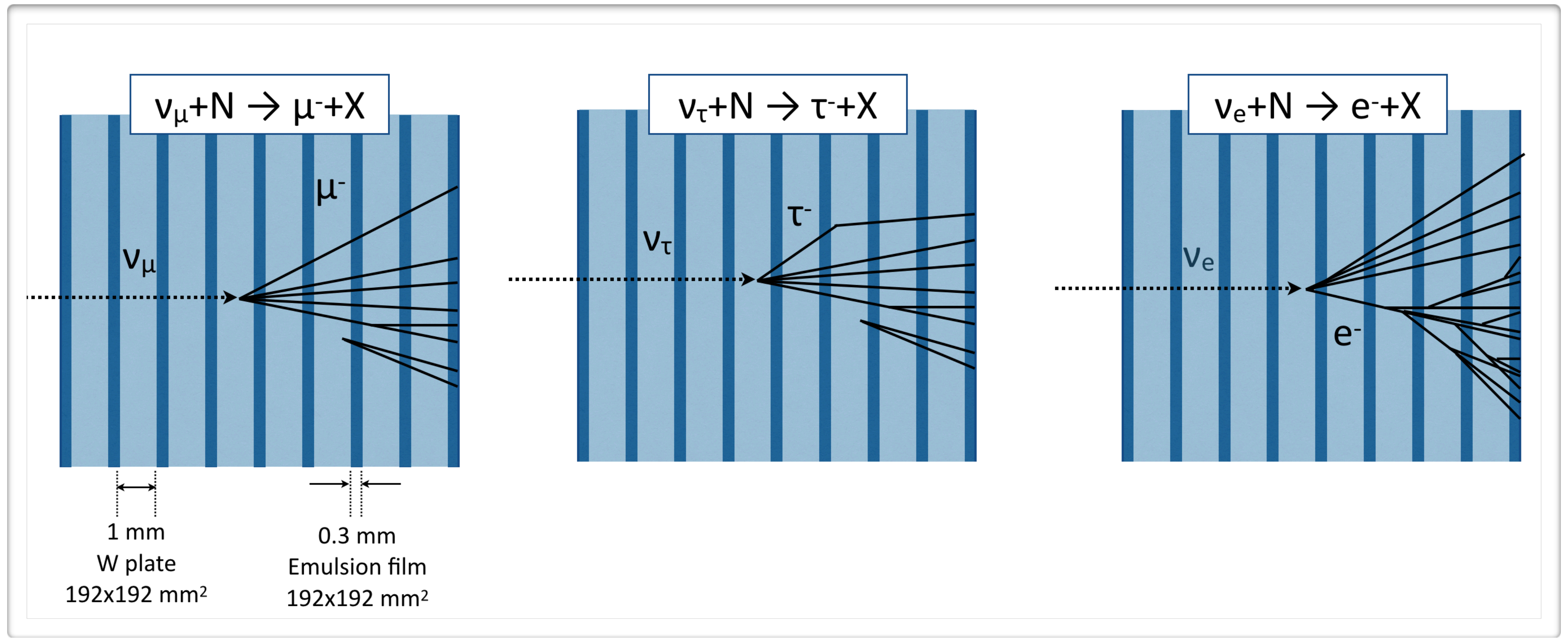


EVENT RECONSTRUCTION

- **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)



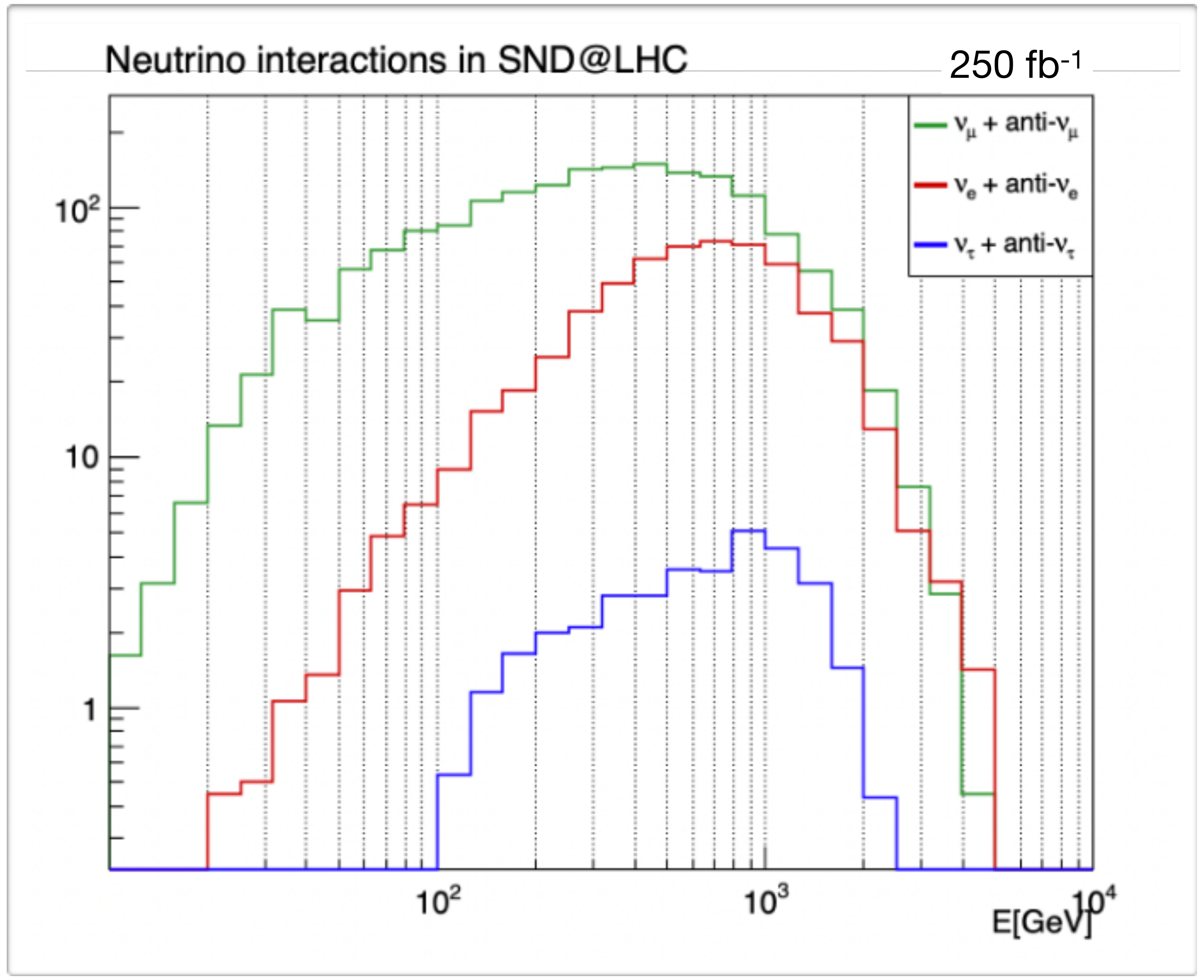
- **SECOND PHASE: nuclear emulsions**
- Event reconstruction in the emulsion target
  - Identify e.m. showers
  - Neutrino vertex reconstruction and 2ry search
  - Match with candidates from electronic detectors (time stamp)
  - Complement target tracker for e.m. energy measurement



NEUTRINO EXPECTATIONS

- Expectations in **250 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	130	3.0×10^{12}	452	910	480	270
$\bar{\nu}_\mu$	133	2.6×10^{12}	485	360	480	140
ν_e	339	3.4×10^{11}	760	250	720	80
$\bar{\nu}_e$	363	3.8×10^{11}	680	140	720	50
ν_τ	415	2.4×10^{10}	740	20	740	10
$\bar{\nu}_\tau$	380	2.7×10^{10}	740	10	740	5
TOT		4.0×10^{12}		1690		555

SND@LHC INSTALLATION IN TI18

- Detector commissioning on surface (North Area @CERN) in September and October 2021
- Installation in TI18 started on November 1^{st} 2021

- Electronic detector installation completed on December 3^{rd} 2021
- Installation of the neutron shield completed on March 15^{th} 2022
- Installation of the first emulsion wall on April 7^{th} 2022

September 2021

December 2021

March 2022

Detector paper published on *https://arxiv.org/abs/2210.02784*
and submitted to the JINST Joint Issue on the LHC experiment upgrades for Run3

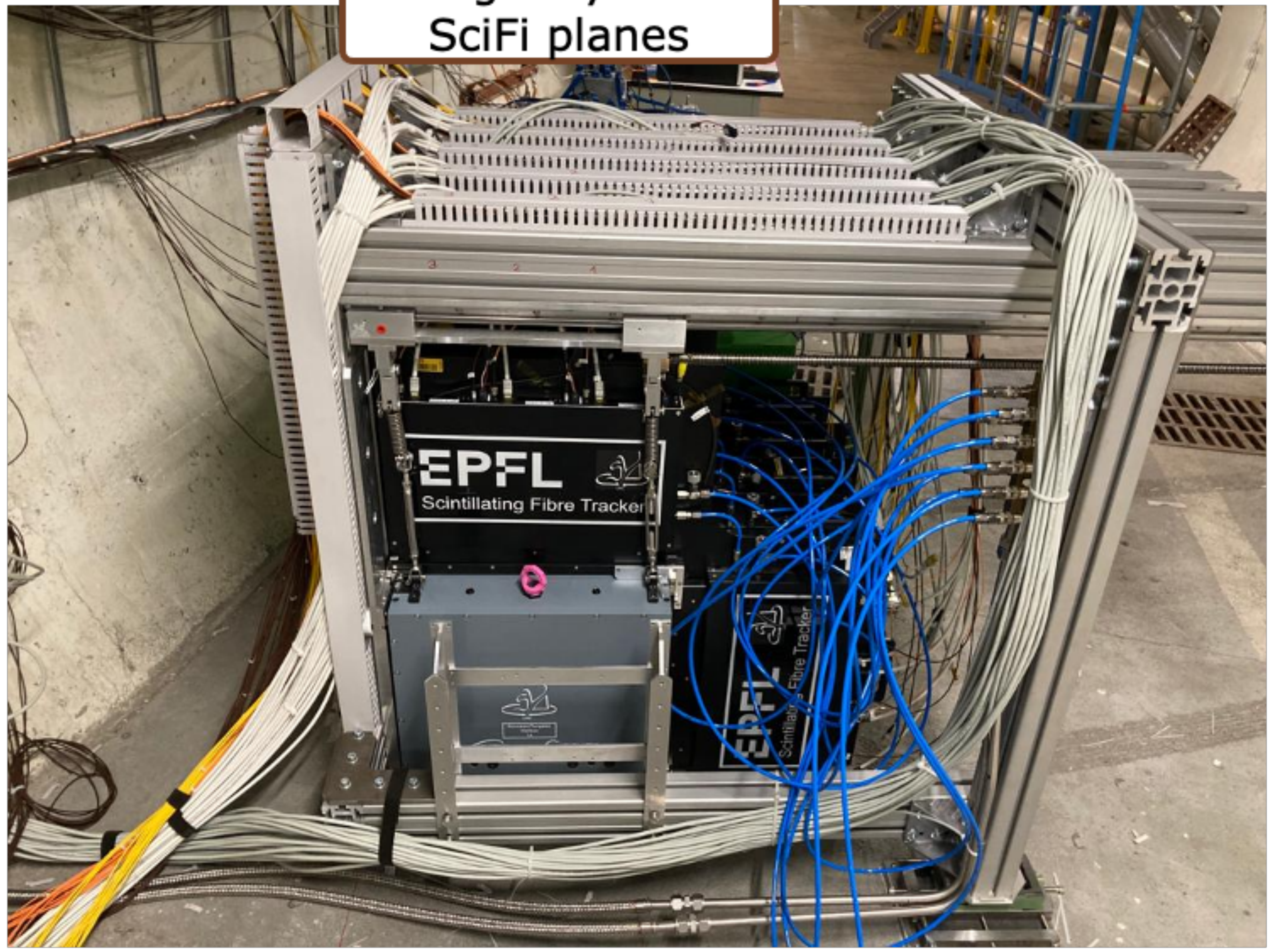
DETECTOR INSTALLATION IN TI18

- View of the machine to the IP (left) and of the detector in TI18 (right)

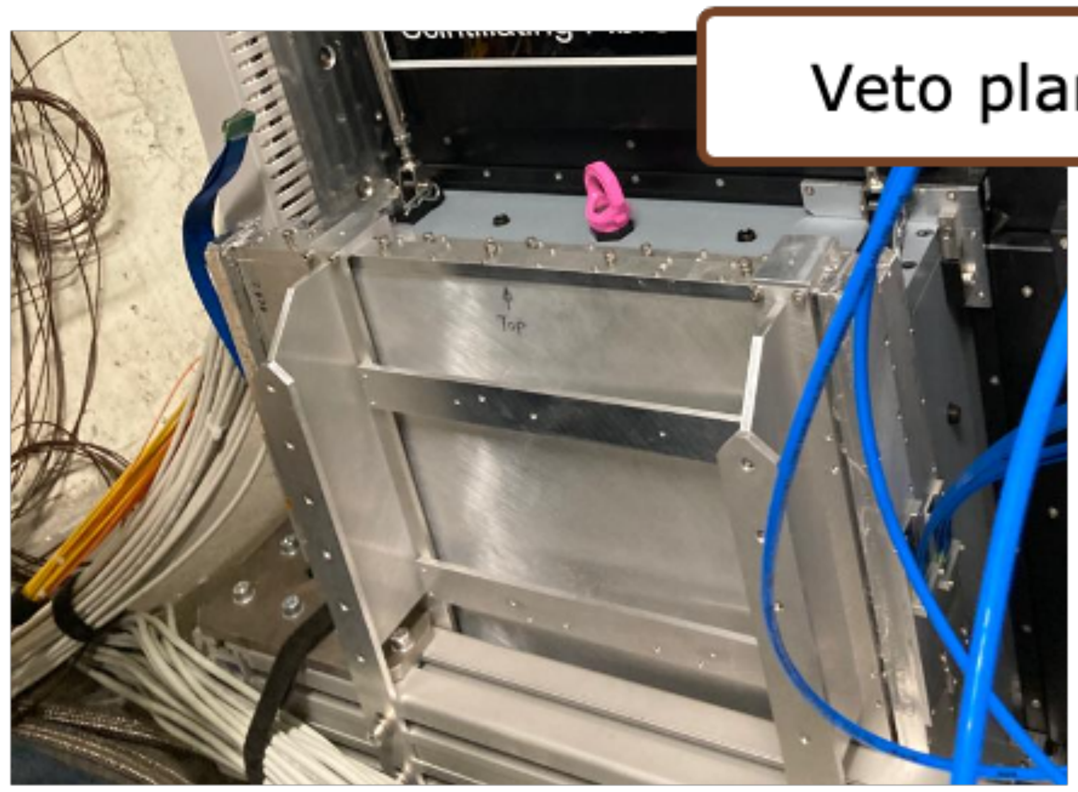
SND@LHC INSTALLATION IN TI18

Target wall

Target system
SciFi planes



Veto plane



Muon system

EMULSION TARGET #0

- 57 emulsion films (B1 in Wall 3) produced in Nagoya (1/20 of the full target)
- **April 7th** : Installation in the detector
- **July 26th** : Extraction
- August 3rd to 8th :Emulsion development

Integrated luminosity: 0.5 fb^{-1}

April 7th - Installation

July 26th - Extraction

August 4th – Emulsion development

EMULSION TARGET #1

- Installation of the full emulsion target for a total mass of **830 kg**
- **1200** emulsion films: 45% Nagoya, 55% Slavich (Moscow region)
- July 4th-12th : Target wall assembly in the CERN Dark Room
- July 13th : Transportation to the AWAKE tunnel for temporary storage
- **July 26th** : Installation in the detector
- **September 13th**: Extraction
- September 14th-21st : Emulsion development

Total time required for underground operations: **5 hours**

Integrated luminosity: 10.5 fb^{-1}

July 26th - Installation

September 13th – Extraction

September 14th – Emulsion development

EMULSION TARGET #2

- Installation of the full emulsion target for a total mass of **830 kg**
- **1140** emulsion films: 100% Nagoya
- September 12th : Target wall assembly in the CERN Dark Room
- **September 13th** : Installation in the detector
- **November 4th** : Extraction
- November 11th-21st : Emulsion development

Total time required for underground operations: **4.5 hours**

Integrated luminosity: 21.4 fb^{-1}

September 12th – Assembly

September 13th – Installation

November 16th – Development

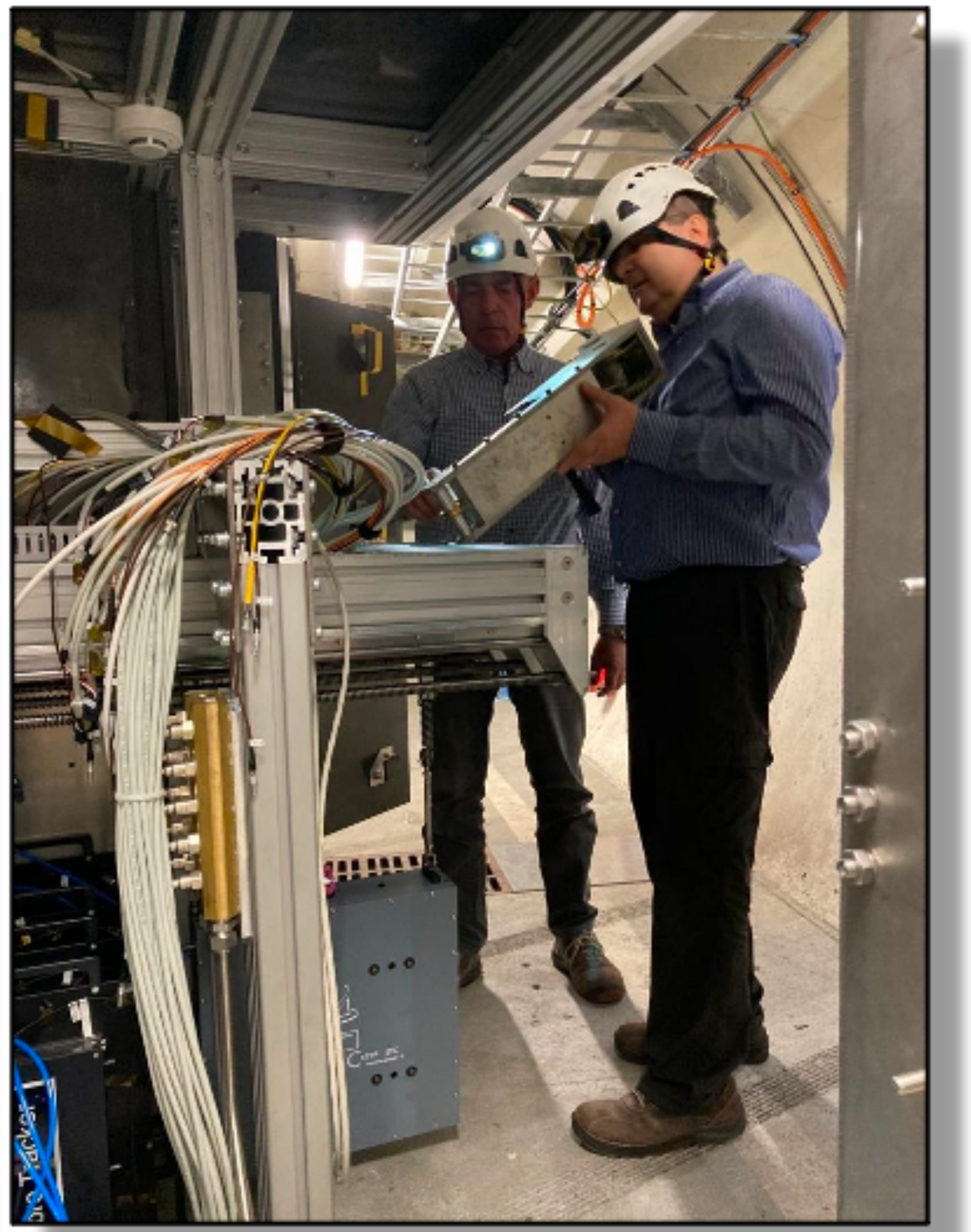
EMULSION TARGET #3

- Installation of the full emulsion target for a total mass of **830 kg**
- **1152** emulsion films: 75% Nagoya, 25% Slavich
- November 2nd : Target wall assembly in the CERN Dark Room
- **November 4th** : Installation in the detector
- **December 9th** : Extraction
- December 10th-21st : Emulsion development

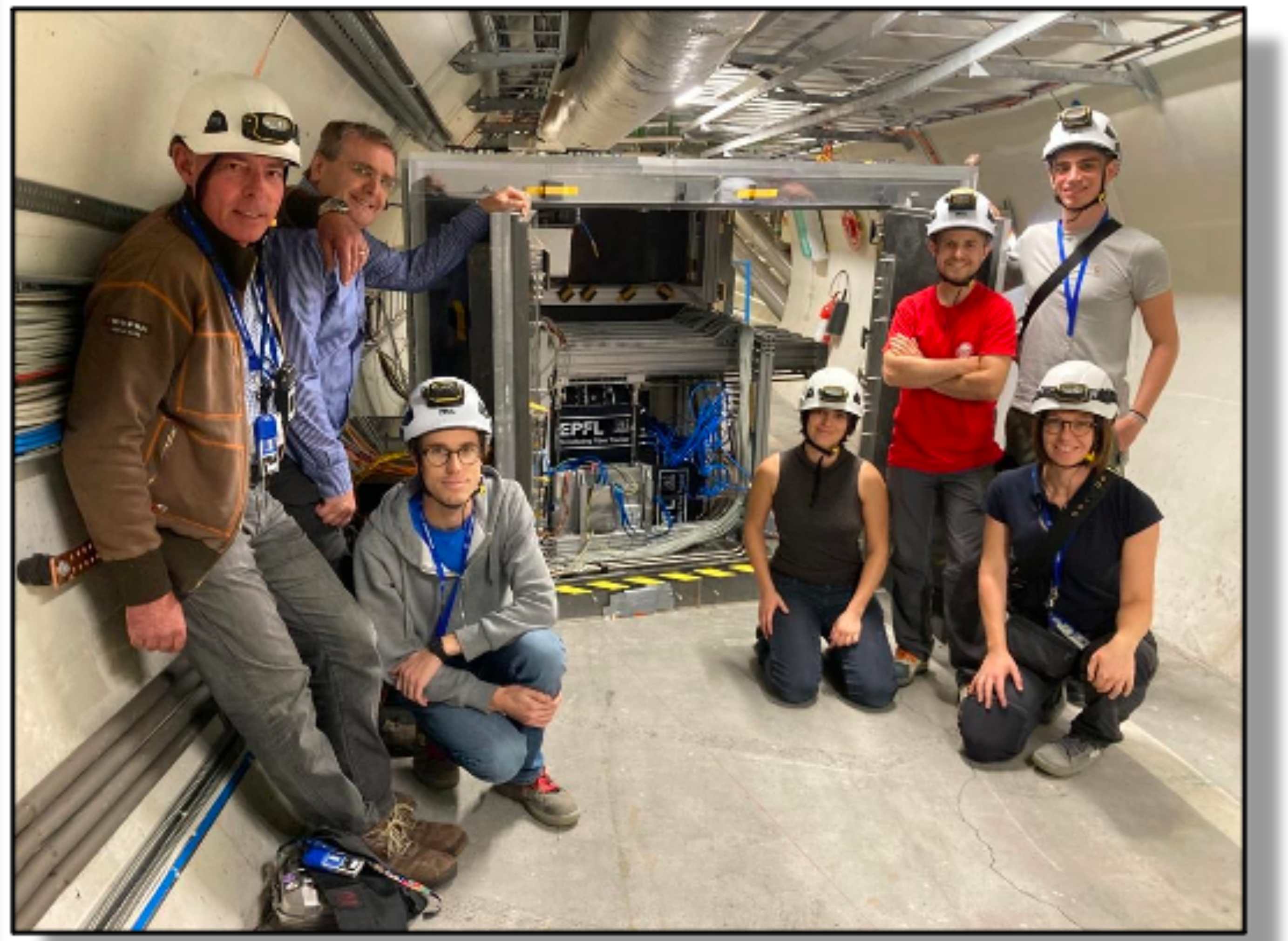
Total time required for underground operations: **6 hours**

Integrated luminosity: 8.7 fb^{-1}

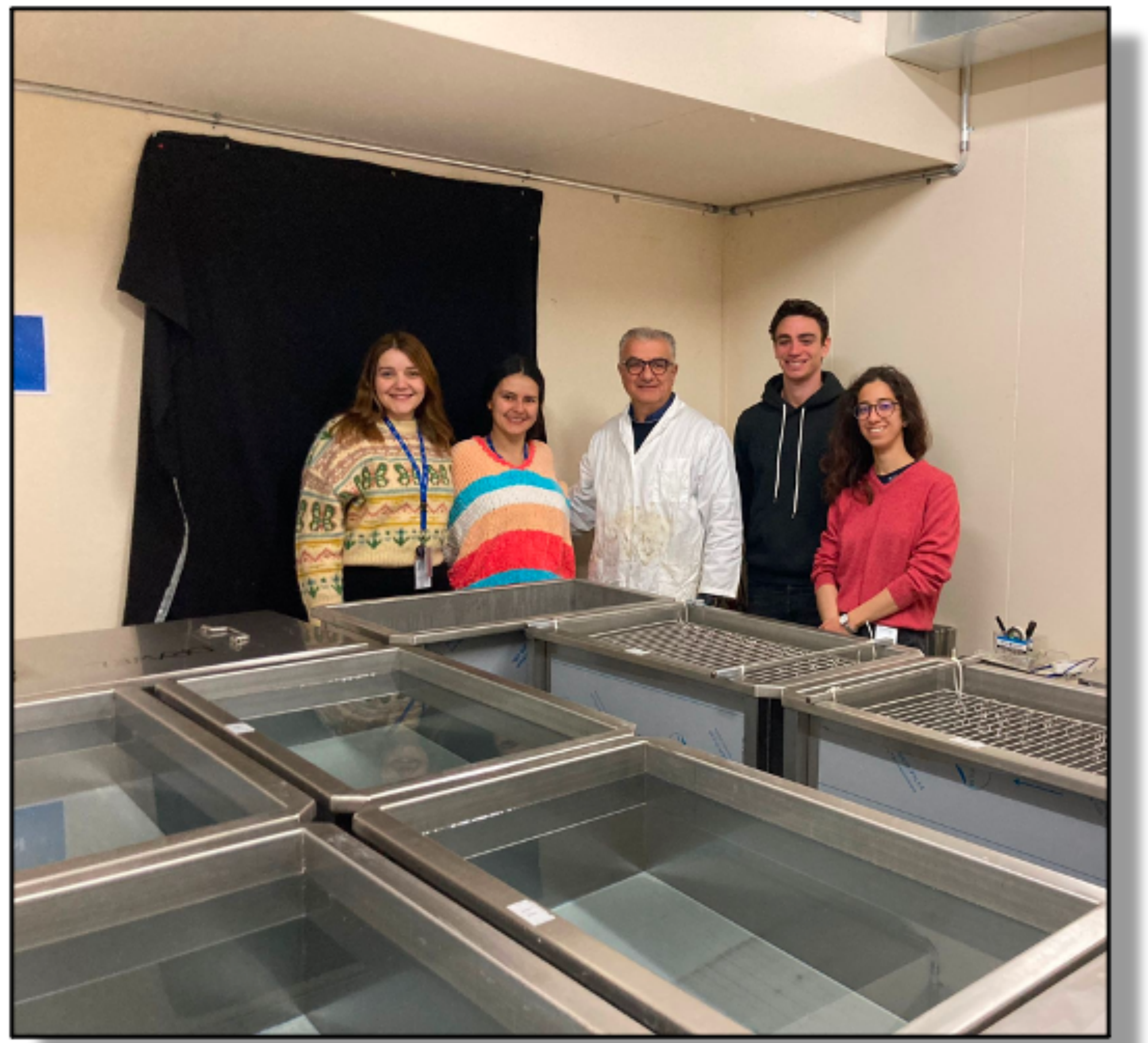
Wall assembly



Target replacement

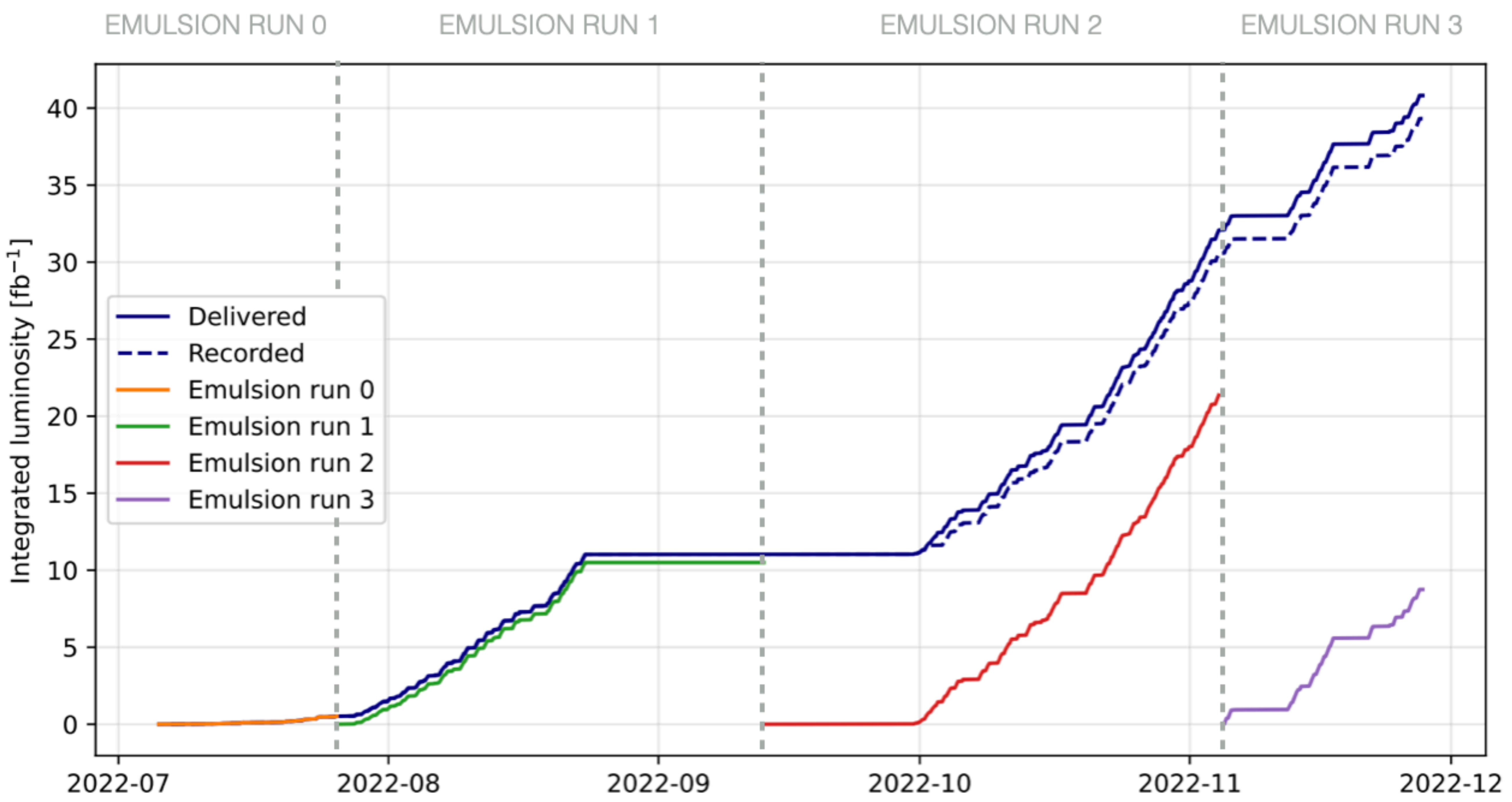


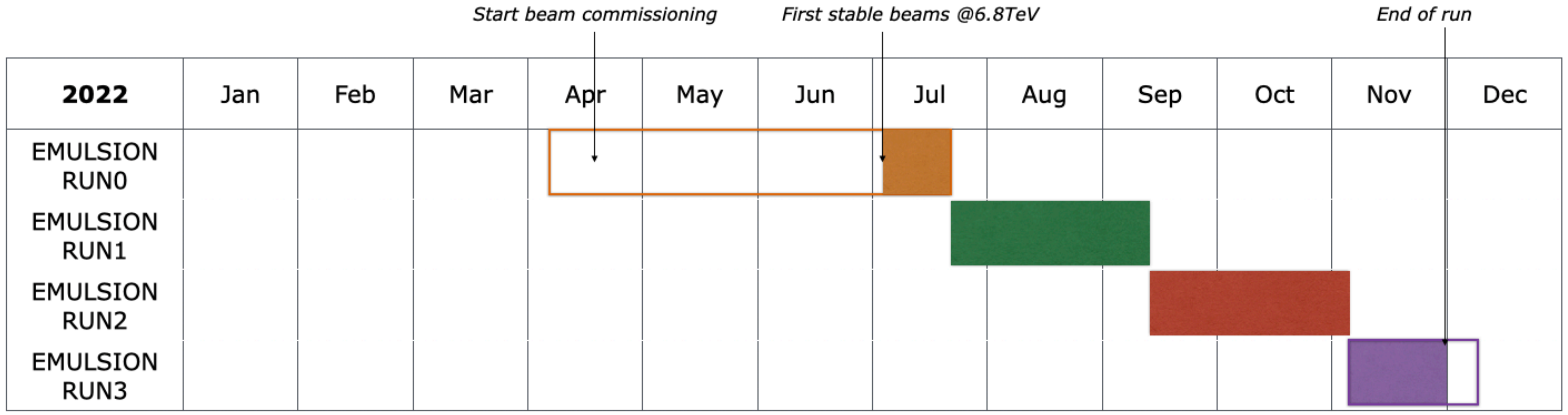
Target#3 walls installed



Emulsion development

DATA TAKING IN RUN3

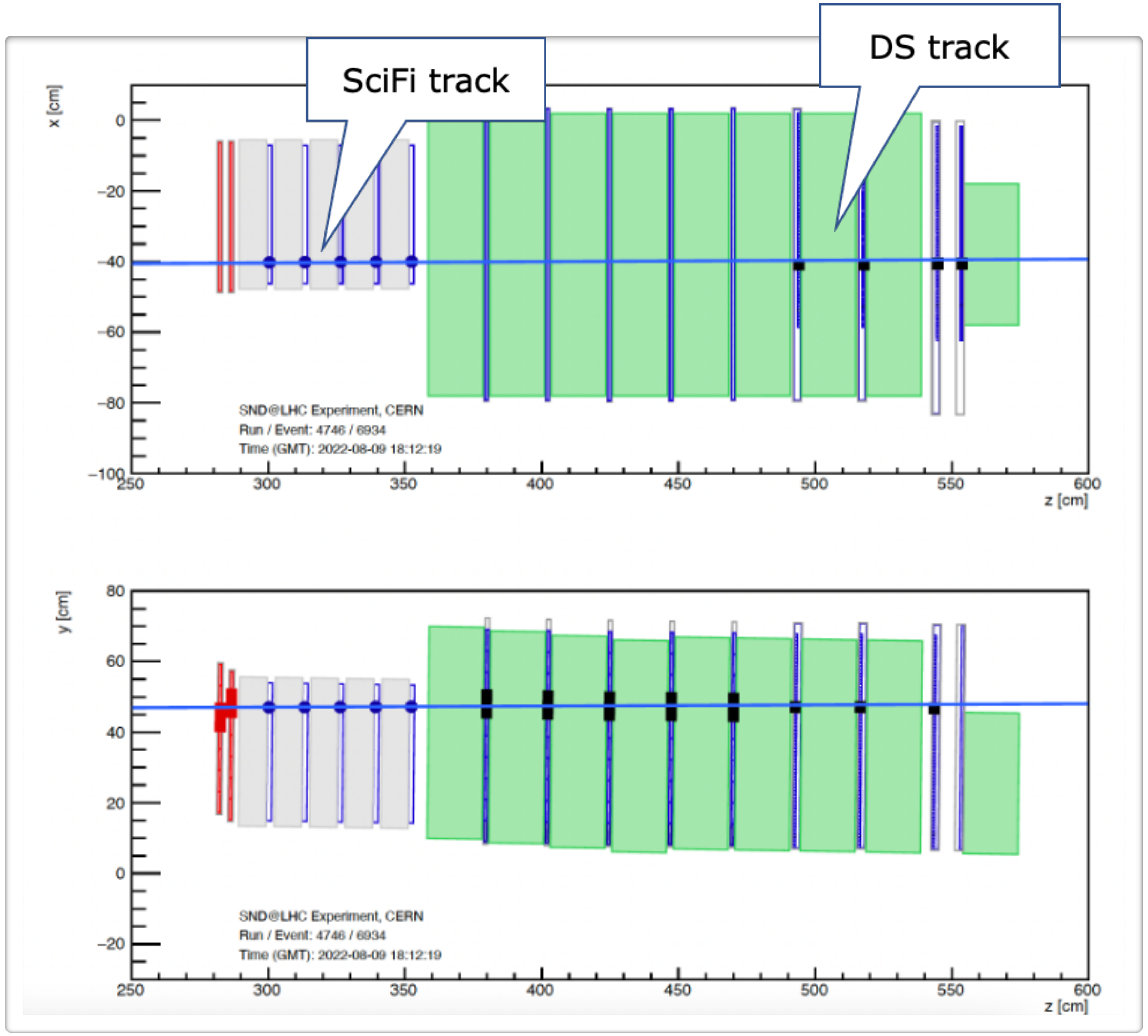




INSTRUMENTED TARGET MASS	INTEGRATED LUMINOSITY
39 kg	0.5 fb^{-1}
807 kg	10.5 fb^{-1}
784 kg	21.4 fb^{-1}
792 kg	8.7 fb^{-1}

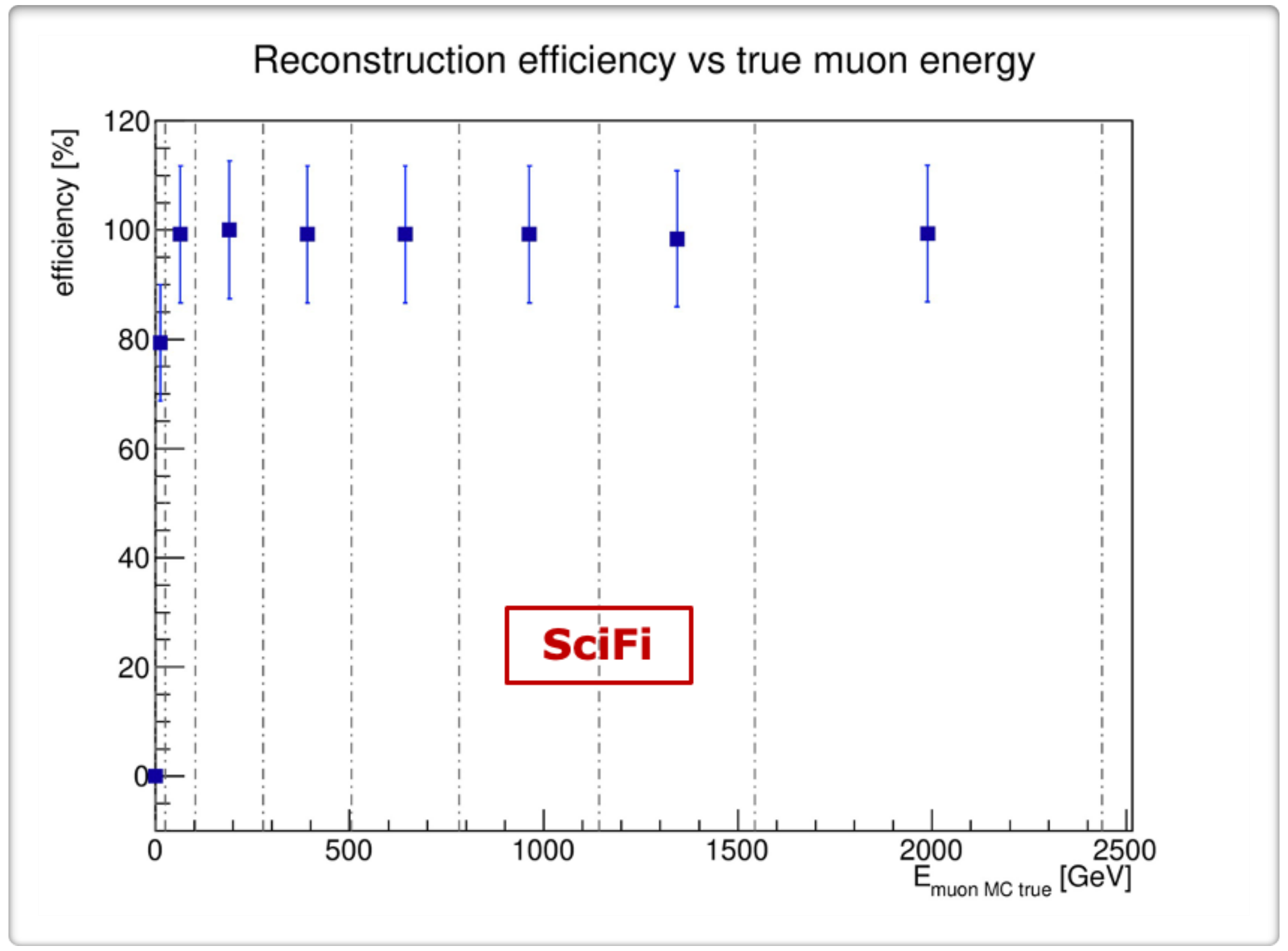
MUON TRACK RECONSTRUCTION

Muon track reconstruction is performed with SciFi tracking stations and with the Downstream Muon System (DS)

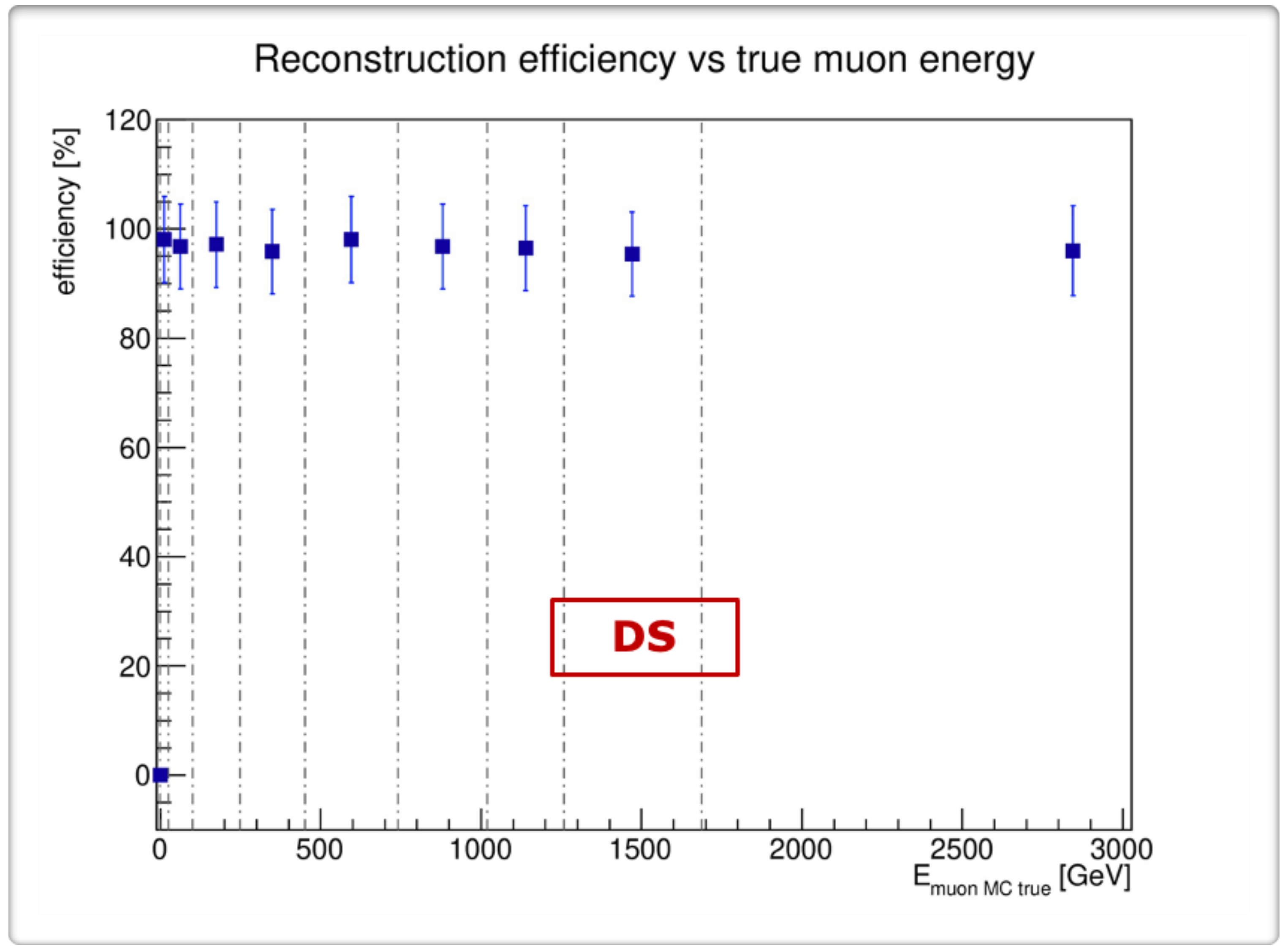


2D display: F. Alicante

S. Ilieva



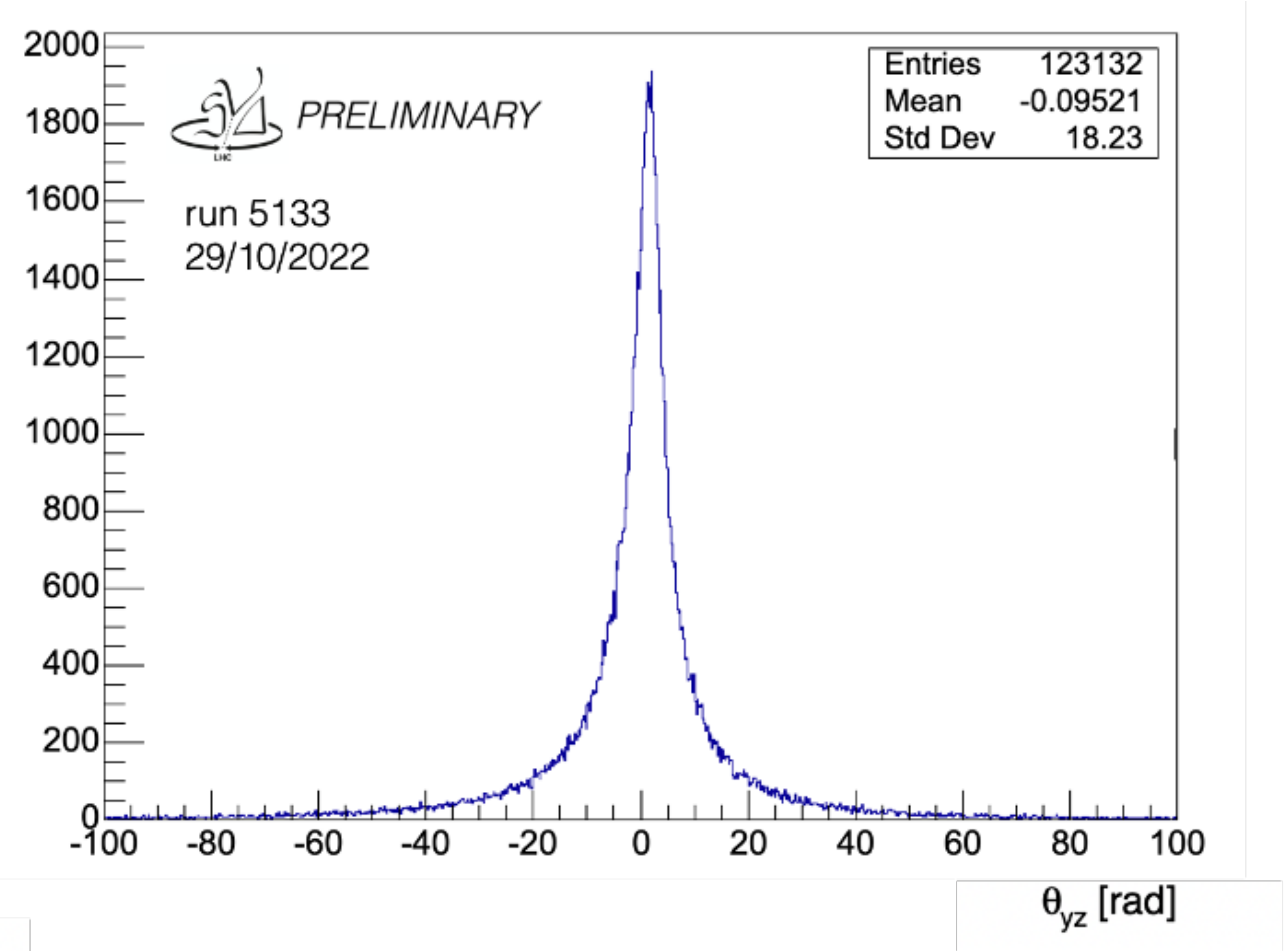
SciFi tracking system
Overall efficiency: **91%**

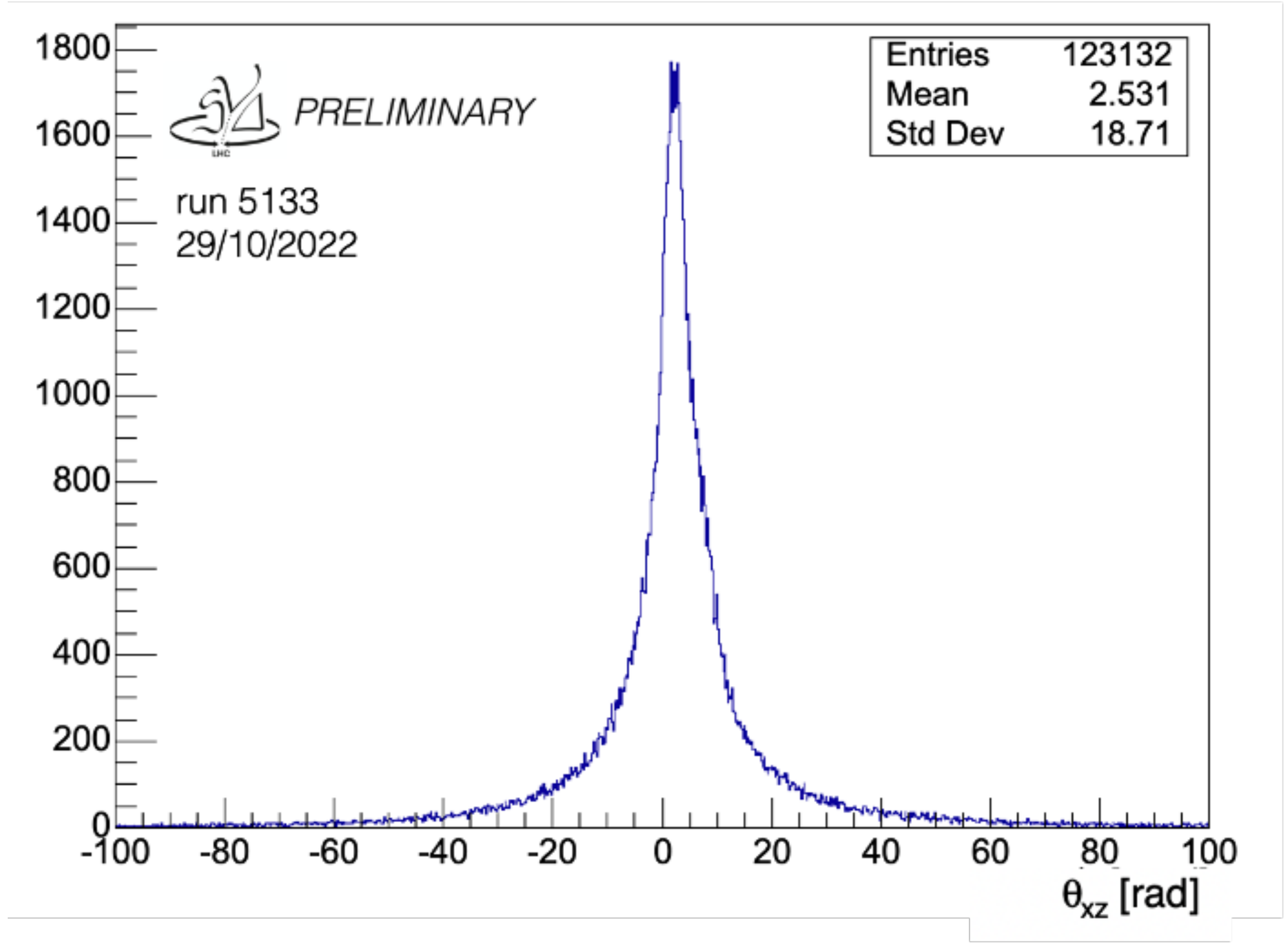


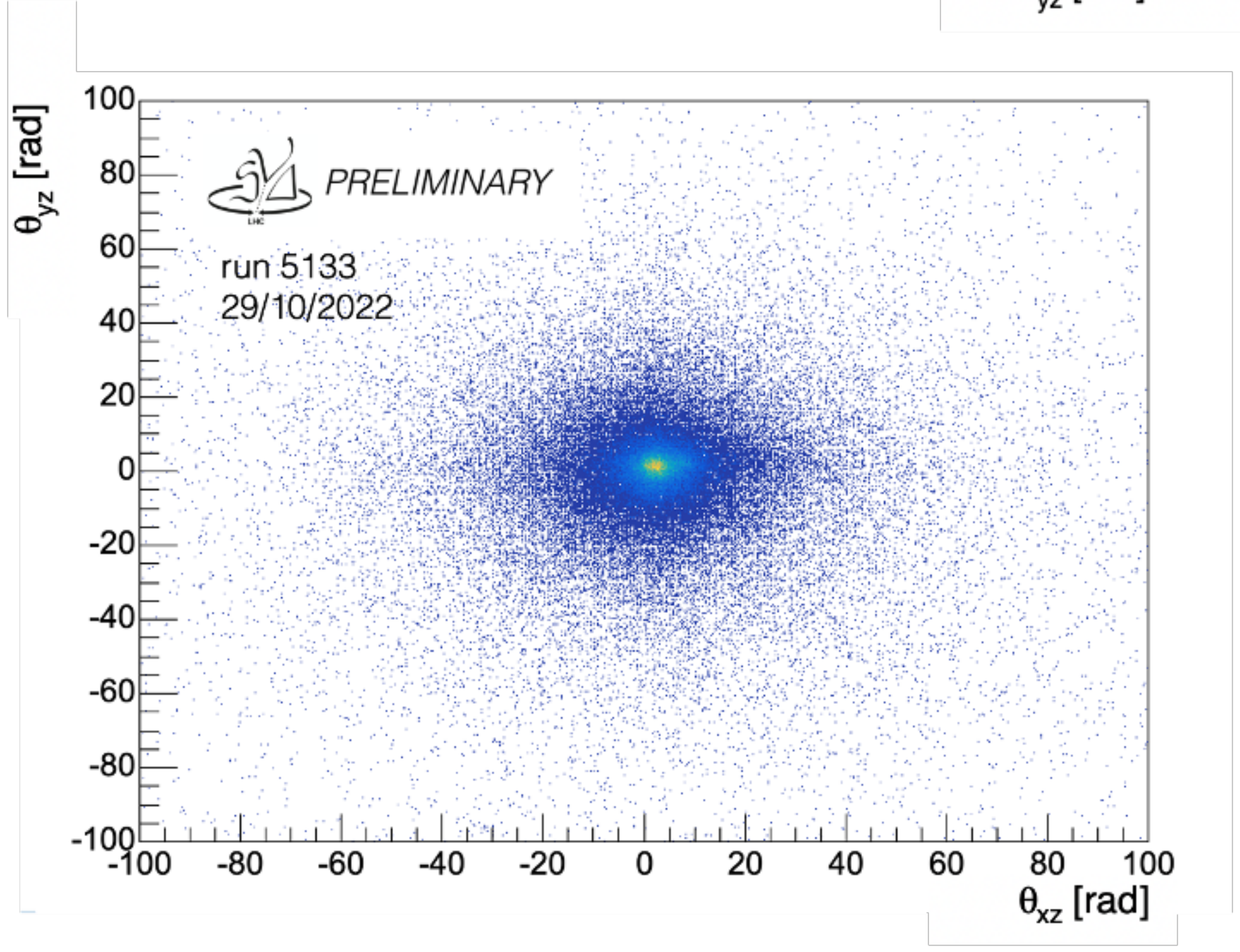
Downstream Muon System
Overall efficiency: **97%**

MUON TRACK DIRECTION

- Reconstructed tracks by electronic detectors in pp collision runs @13.6 TeV
- Direction compatible with coming from pp collisions at IP1

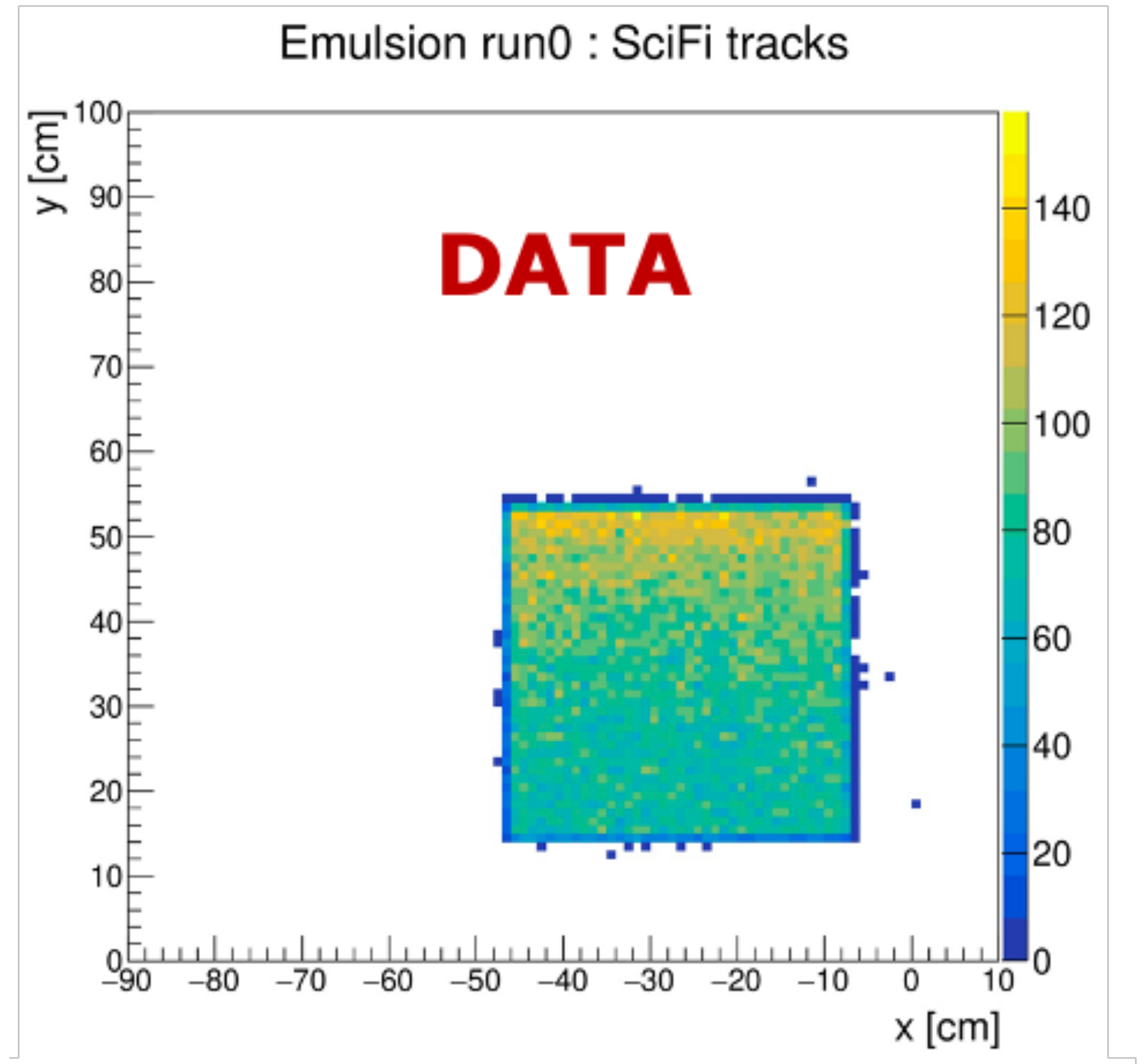






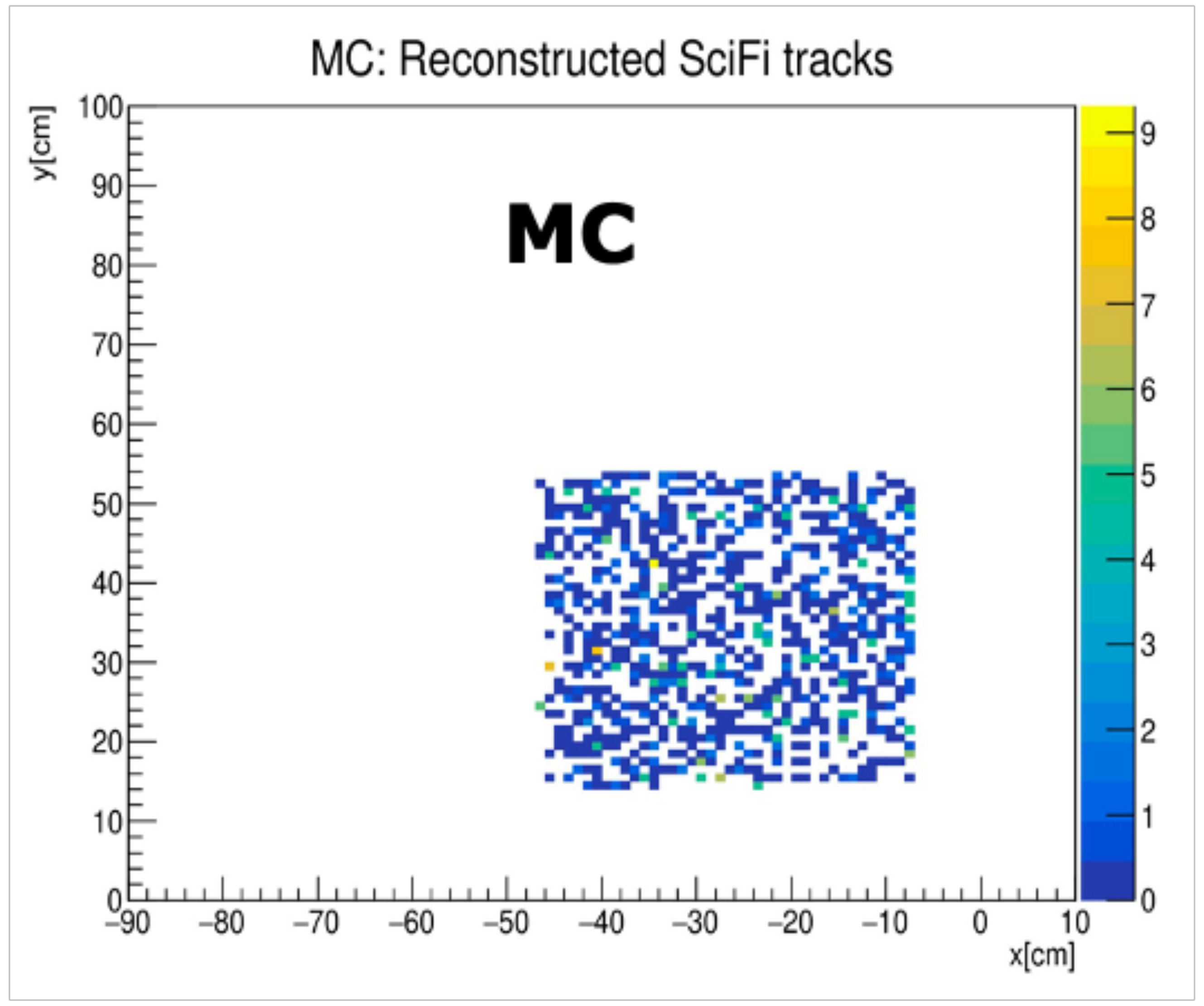
MUON RATES

S. Ilieva



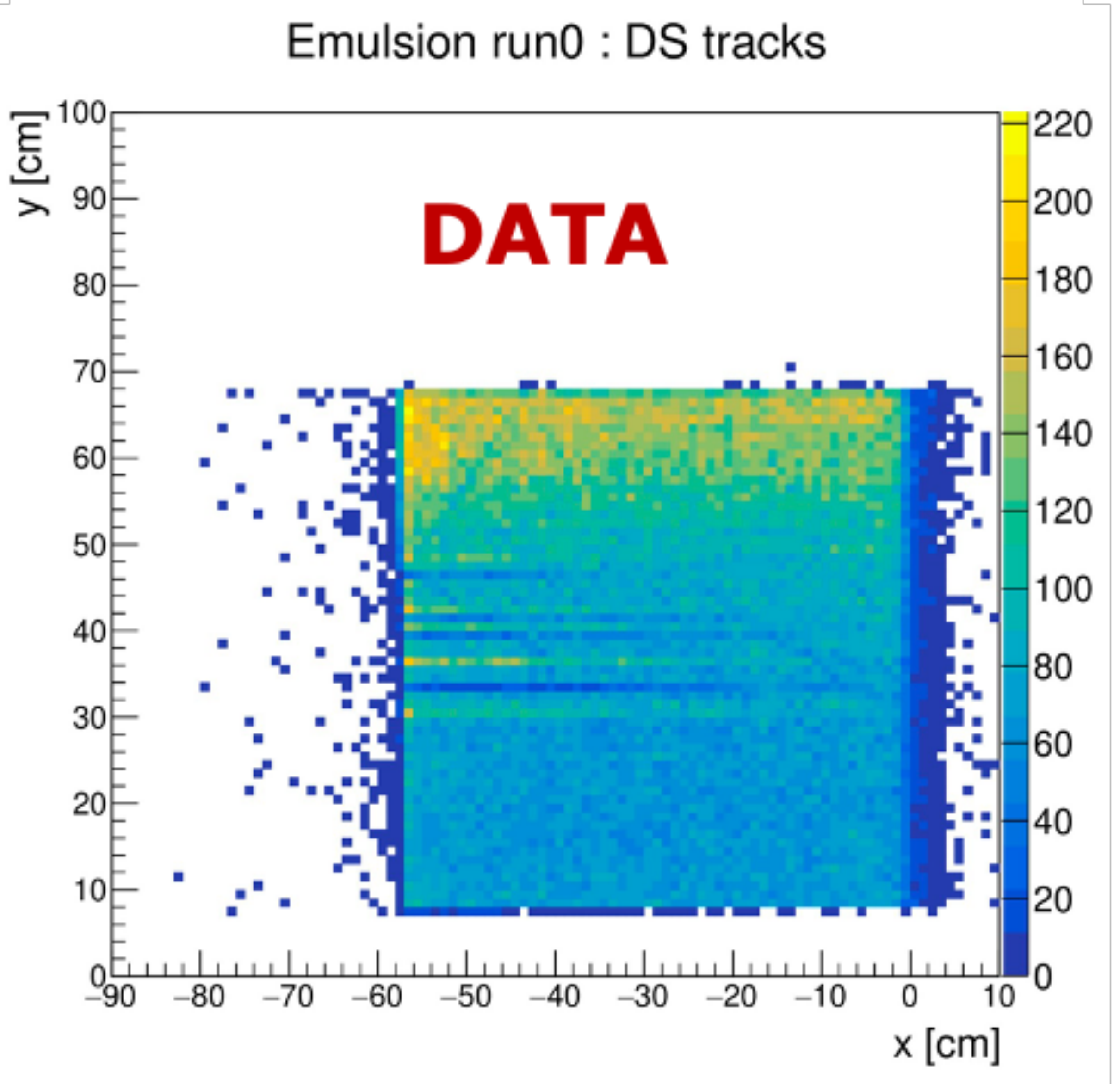
Measured muon track rate in SciFi (39×39 cm^2):

1.8×10^4 fb/cm^2



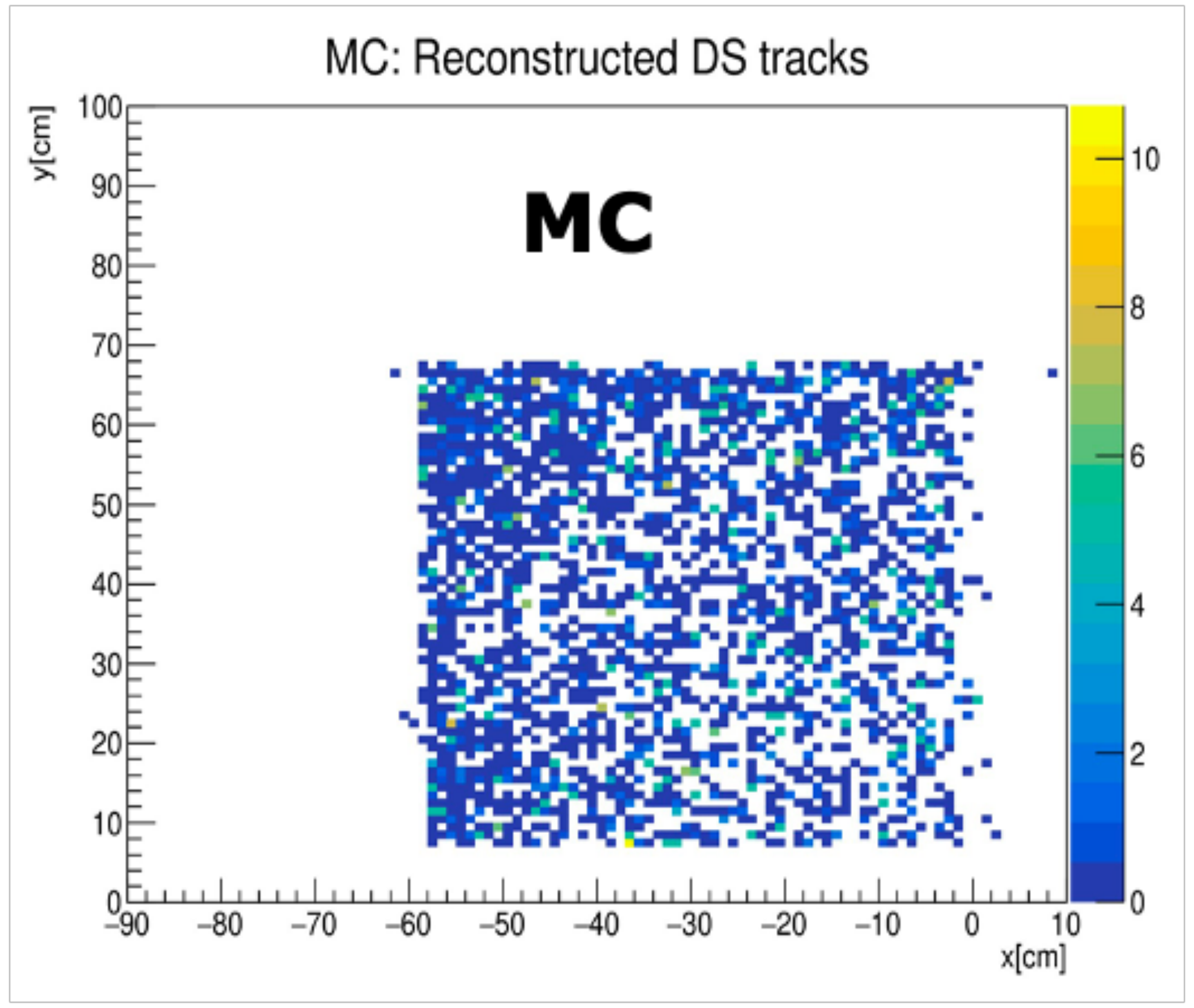
Expected muon track rate in SciFi (39×39 cm^2):

3.6×10^4 fb/cm^2



Measured muon track rate in DS (60×60 cm^2):

2.0×10^4 fb/cm^2



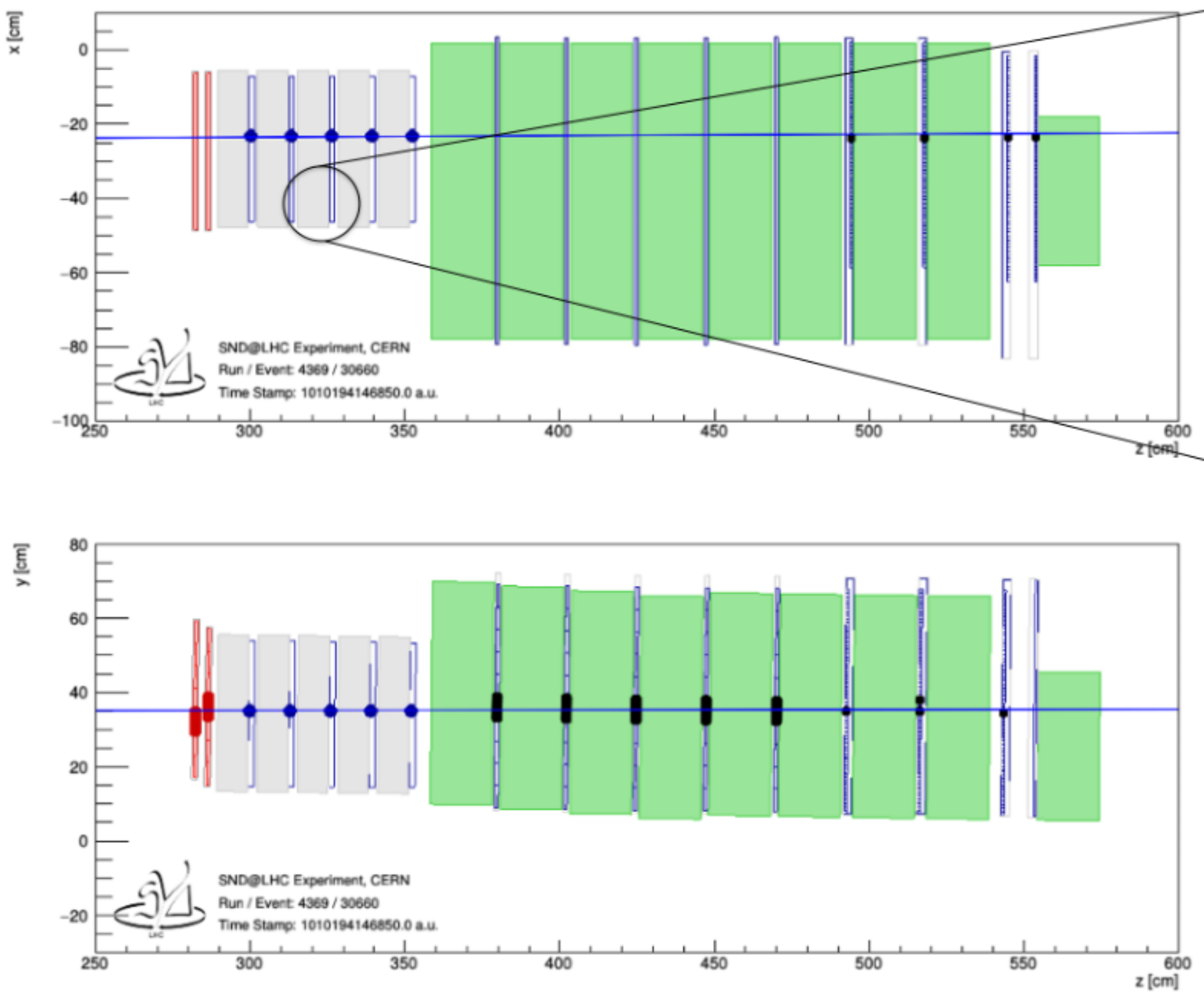
Expected muon track rate in DS (60×60 cm^2):

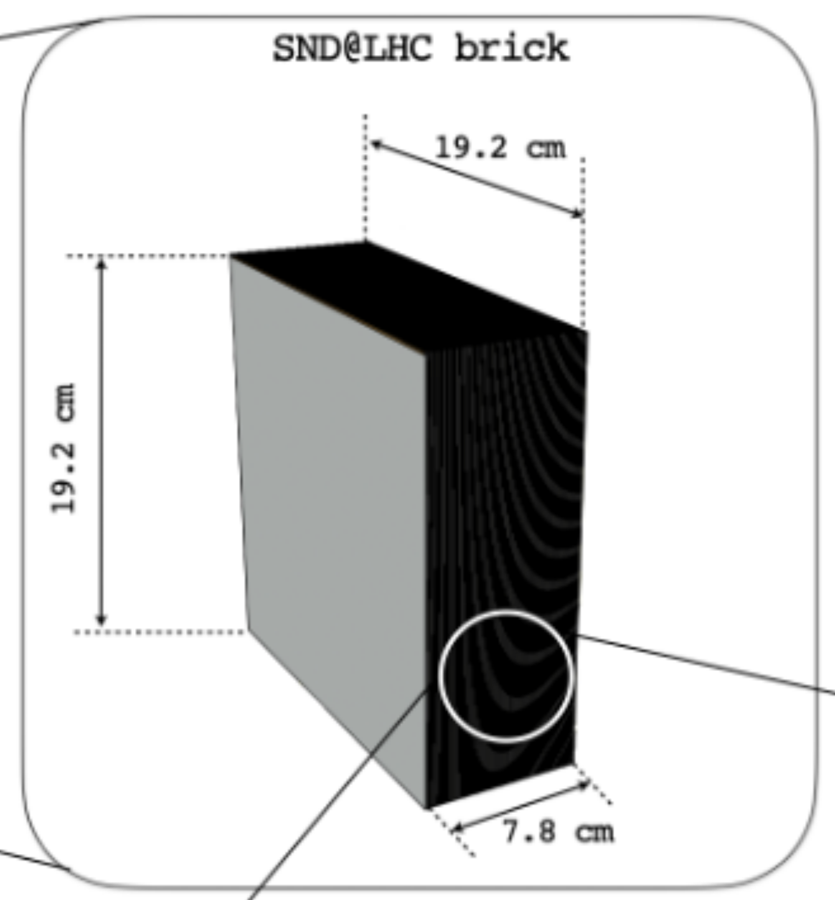
4.4×10^4 fb/cm^2

- New simulation performed by CERN FLUKA team show a reduction of factor ~2 in the expected rates in TI18

TRACK RECONSTRUCTION IN RUN0

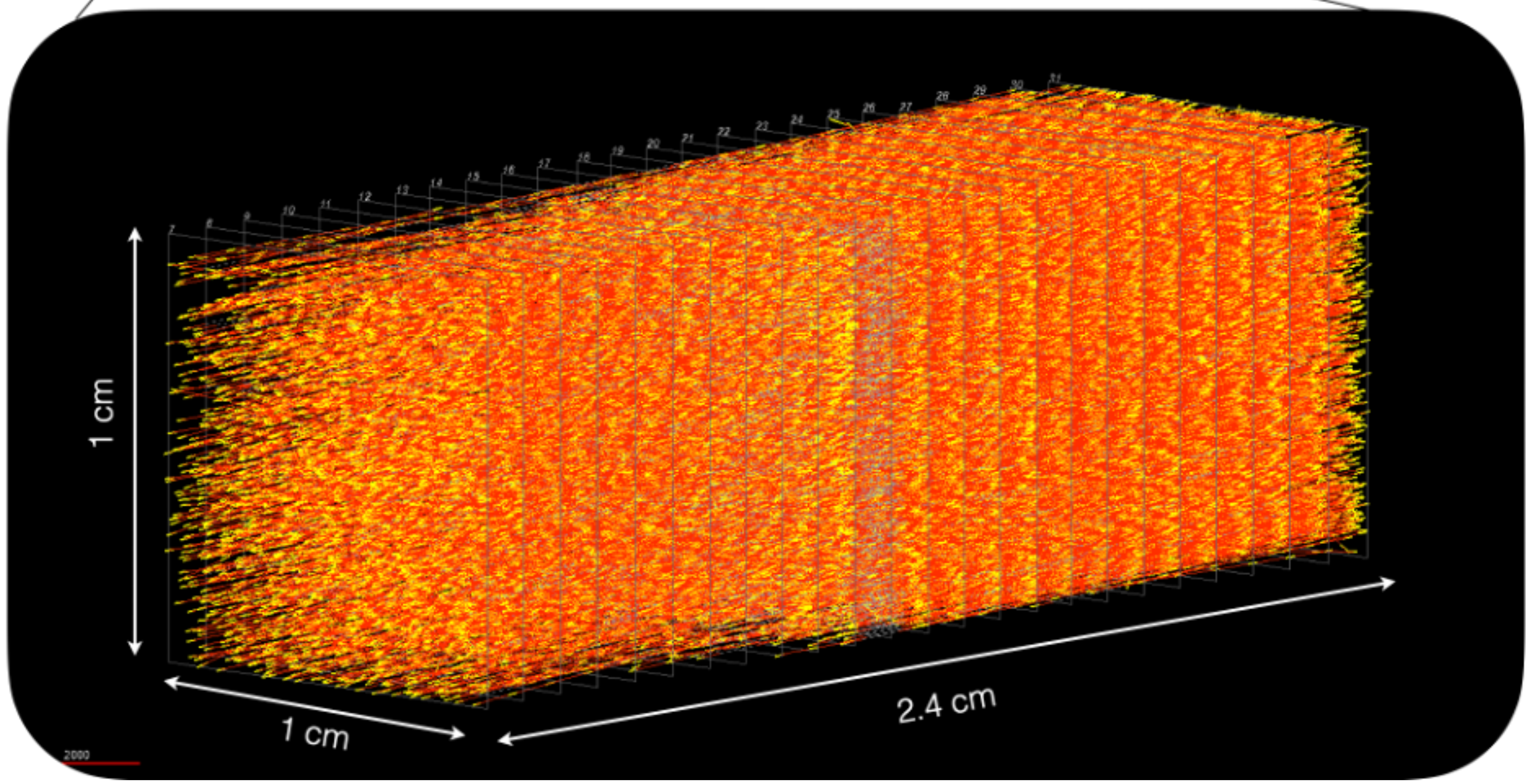
RUN0 emulsion target: April 7th - July 26th (0.51 fb^{-1})





Emulsion reconstruction:
muon tracks in 1x1 cm^2 integrated in EMULSION RUN0

see A. Iuliano's presentation



Electronic detector reconstruction:
muon track from pp collisions @13.6 TeV (July 6th 2022)

EMULSION FACILITY

Full renovation funded by CERN for FASER, SND@LHC and other users:
- Removal of asbestos from the floor
- New floor installation
- Electronic lockers to the doors
- Installation of new cooling and ventilation system

Room 169/S-018
March 15th 2022

Room 169/S-018
July 25th 2022

EMULSION HANDLING IN THE FACILITY

- **16** walls assembled
- **3522** emulsion films installed (130 m^2)
- **3522** emulsion films developed
- **3500 L** disposed chemical solutions

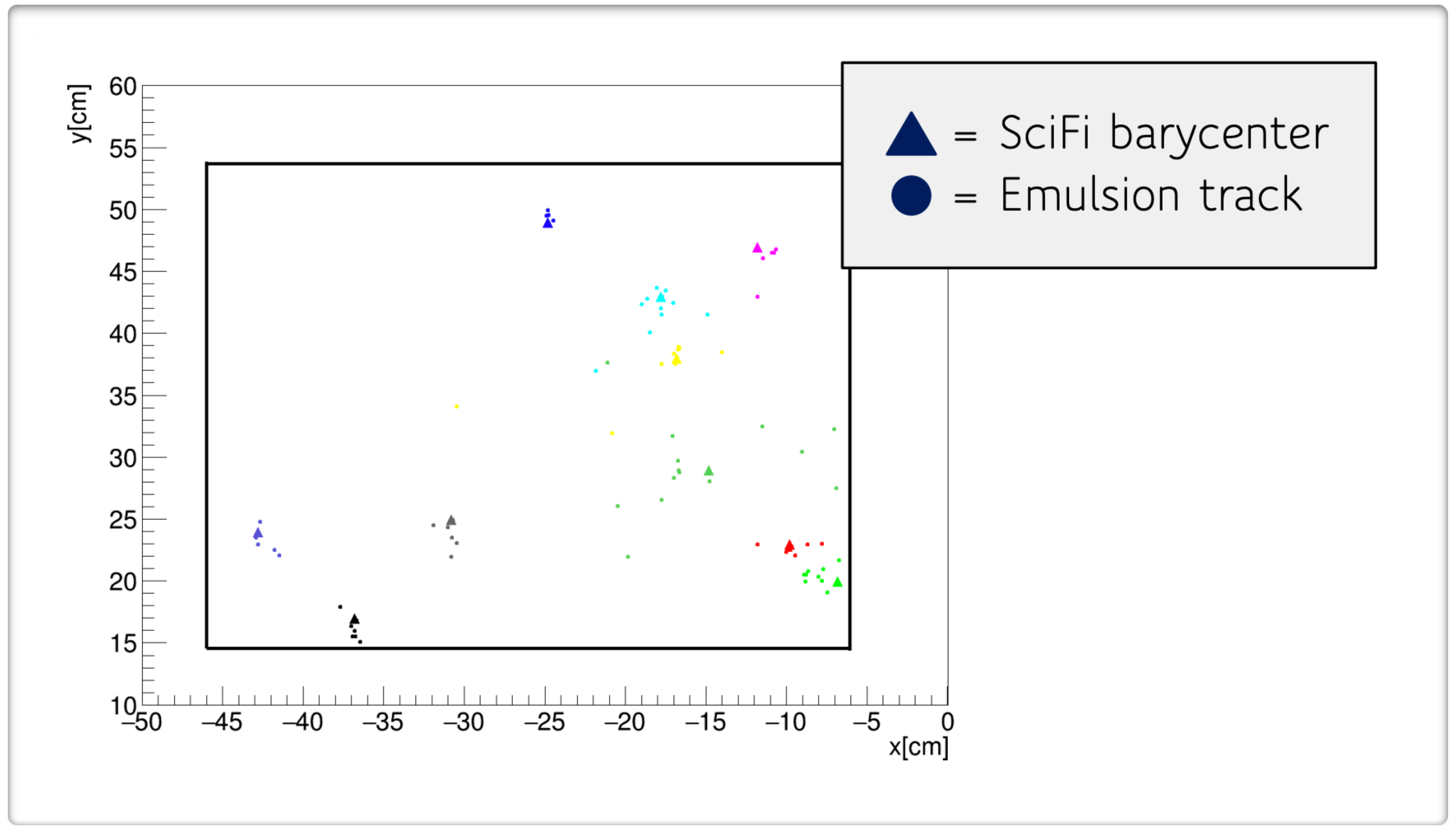
PHYSICS GOALS IN 2023

BACKGROUND

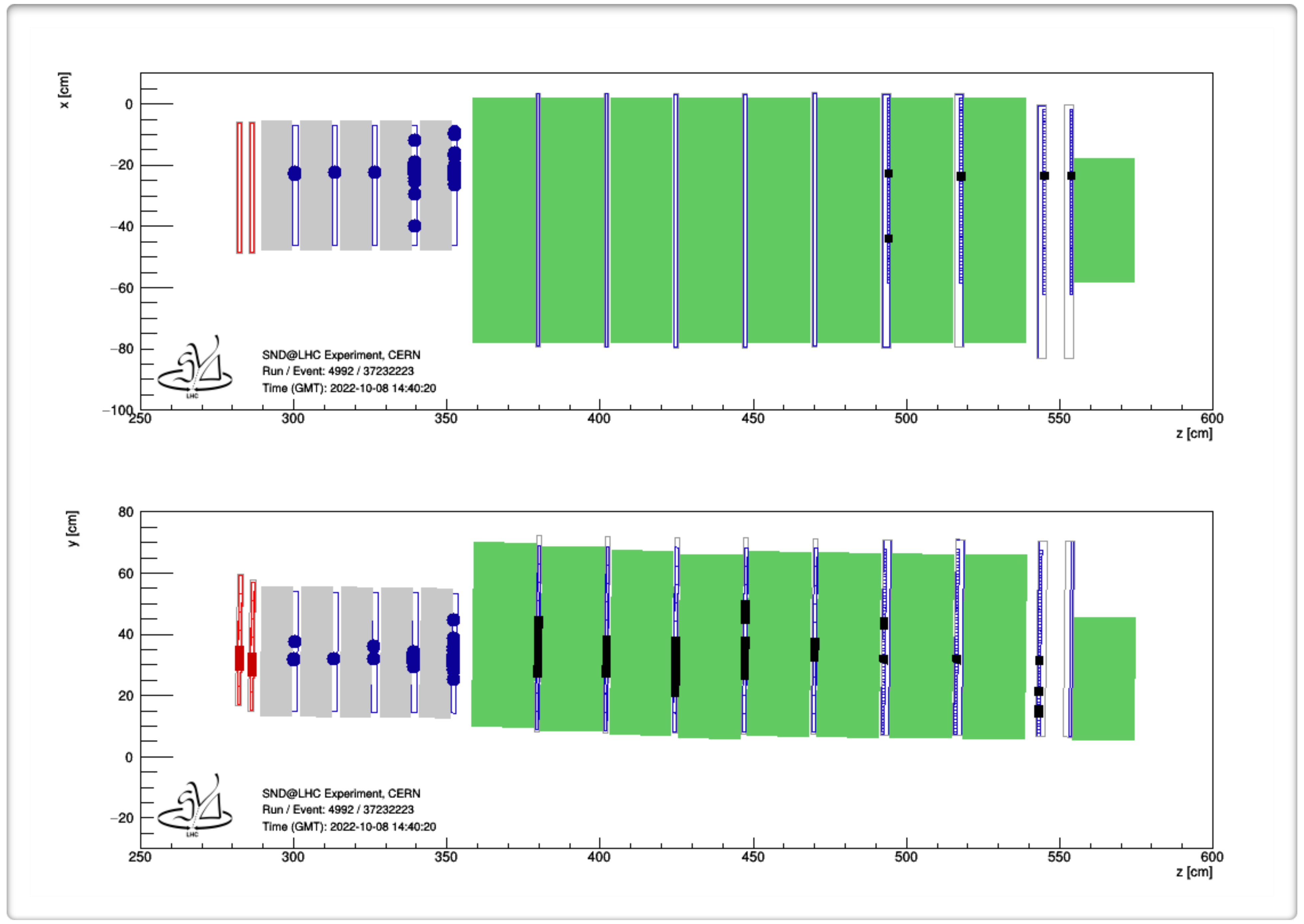
- Measurement of the muon flux in TI18 with electronic detectors (S. Ilieva - analysis note in preparation)
- Measurement of the muon flux with emulsions (A. Iuliano - analysis note in preparation)
- Measurement of muon DIS (D. Centanni)
- Characterisation of high energy neutron interactions

SIGNAL

- Matching between emulsion walls and SciFi tracker (F. Alicante)
- Neutrino event selection with electronic detectors
- First observation of neutrinos with electronic detectors
- Vertex identification in emulsion data (A. Iuliano)
- Neutrino event selection with emulsion data



Emulsion/SciFi matching applied to MC



Muon DIS candidate in RUN3 data

PEOPLE

Ricercatori: 30 **(+8)**
Tecnici: 1
Totale FTE: 13.45 **(+5)**
Totale PhD equivalent: 24 **(+5)**

Officina meccanica: 3 m.u.
Progettazione meccanica: 1 m.u.

Tesi di dottorato in corso:
- D. Centanni

Tesi specialistiche in corso:
- F. Alicante
- V. Albano

Tesi triennali in corso:
- A. Orlando

Richieste personale:
- Assegno di ricerca biennale

cognome	nome	perc
Acampora	Giovanni	40%
Albanese	Raffaele	50%
Alexandrov	Andrey	30%
Arpaia	Pasquale	40%
Asada	Takashi	30%
Buontempo	Salvatore	10%
Canale	Vincenzo	25%
Centanni	Daniele	100%
Davino	Daniele	50%
De Asmundis	Riccardo	20%
De Lellis	Giovanni	40%
De Magistris	Massimiliano	50%
Di Crescenzo	Antonia	50%
Fiorillo	Antimo	50%
Fresa	Raffaele	50%
Golovatiuk	Artem	50%
Iengo	Paolo	20%
Ilieva	Simona	100%
Iuliano	Antonio	100%
Lauria	Adele	20%
Loschiavo	Vincenzo Paolo	50%
Miano	Andrea	50%
Montesi	Maria Cristina	20%
Prota	Andrea	60%
Quercia	Antonio	50%
Scalera	Valentino	50%
Sekhniaidze	Givi	20%
Tioukov	Valeri	30%
Ustyuzhanin	Andrey	50%
Visone	Ciro	50%
Vitiello	Autilia	40%

SUMMARY

- SND@LHC was successfully installed at the beginning of 2022 and started data taking with LHC Run 3

- More than 40 fb^{-1} collected in 2022, with an efficiency of 96%
- Three full emulsion targets installed, equivalent to 130 m^2 of emulsions
- Data analysis in progress, consistent results between electronic detectors and emulsions

- Napoli responsibilities
  - Spokesperson: G. De Lellis
  - Physics Coordinator: A. Di Crescenzo
  - Project managers of emulsion target system: S. Buontempo, A. Di Crescenzo

- Tasks assigned to Napoli group
  - Emulsion data scanning and analysis (A. Iuliano)
  - Optical microscope for emulsion scanning (A. Alexandrov)
  - Target mechanical structure design and construction, target replacement (G. Passeggio, F. Cassese)
  - Fiber optic sensors for temperature and humidity monitoring (G. Breglio)

BACKUP SLIDES

NEUTRINO PHYSICS PROGRAM IN RUN 3

1. Measurement of the $pp \longrightarrow \nu_e X$ cross-section
2. Heavy flavour production in pp collisions
3. Lepton flavour universality in neutrino interactions
4. Measurement of the NC/CC ratio

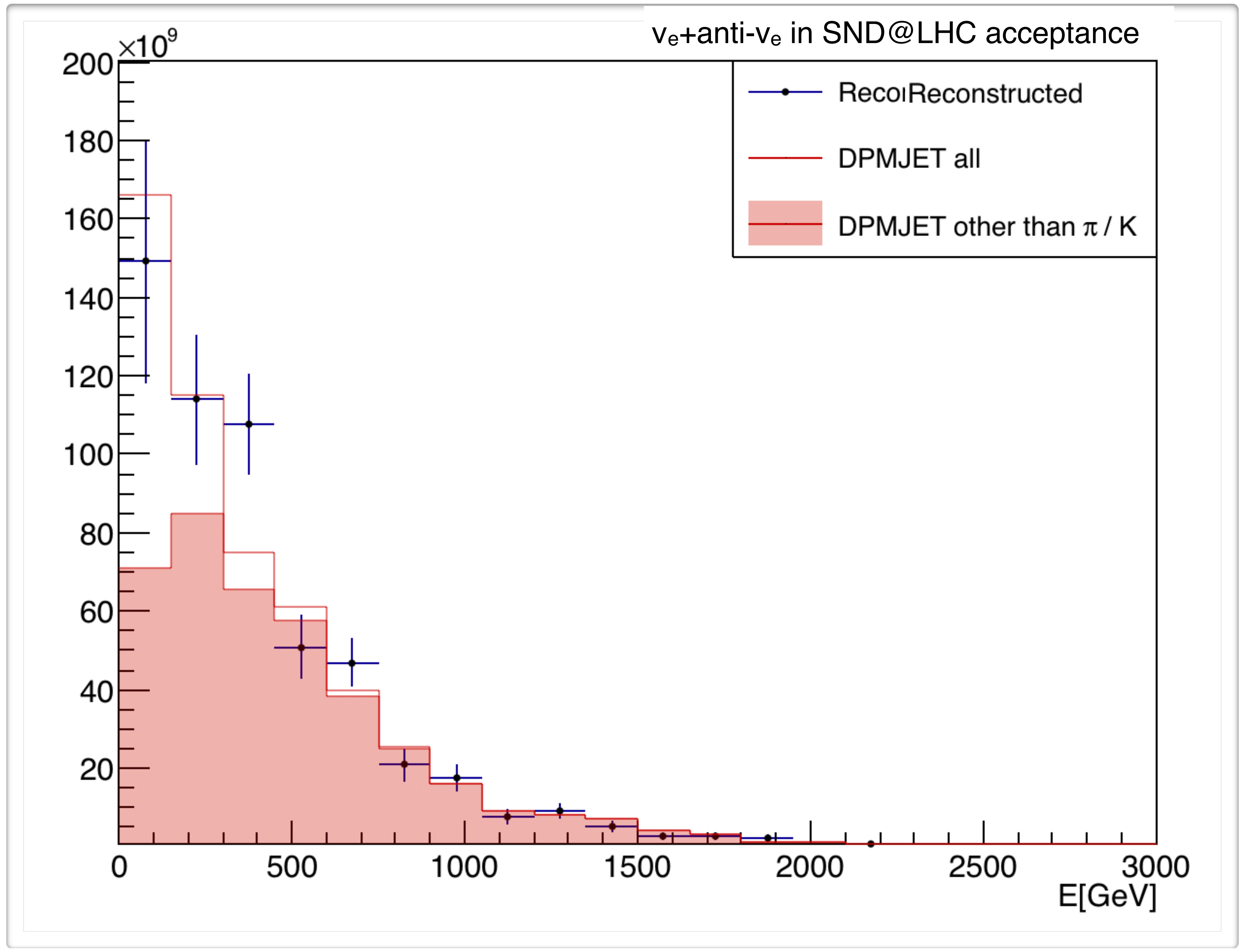
Measurement	Uncertainty Stat.	Uncertainty Sys.
$pp \to \nu_e X$ cross-section	5%	15%
Charmed hadron yield	5%	35%
ν_e/ν_τ ratio for LFU test	30%	22%
ν_e/ν_μ ratio for LFU test	10%	10%

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

2. CHARMED HADRON PRODUCTION

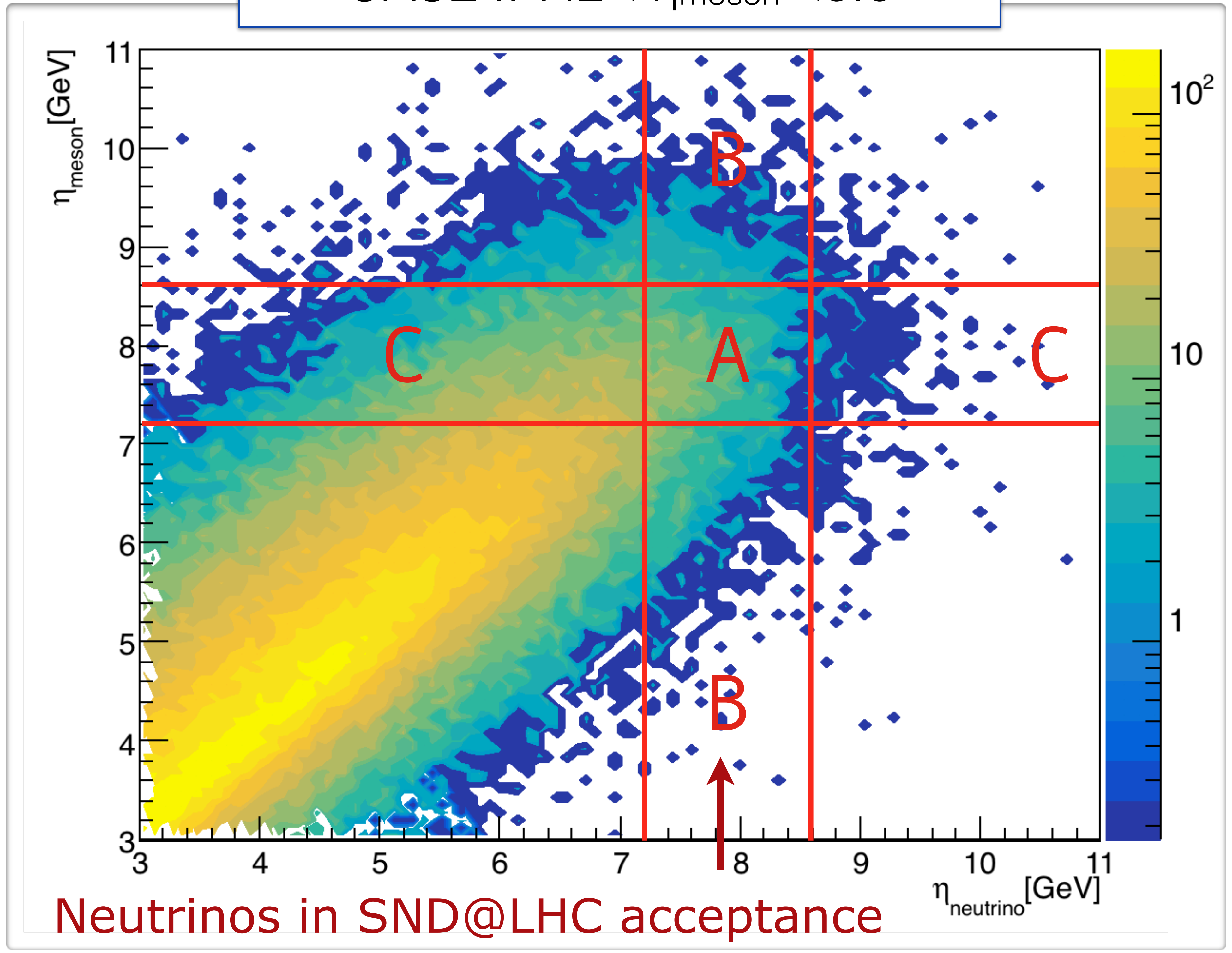
- Simulation predicts that 90% ν_e+anti-ν_e come from the decay of charmed hadrons
- Electron neutrinos can be used as a probe of the production of charm in the relevant pseudo-rapidity range after unfolding the instrumental effects

- 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: $7.2 < \eta_{meson} < 8.6$

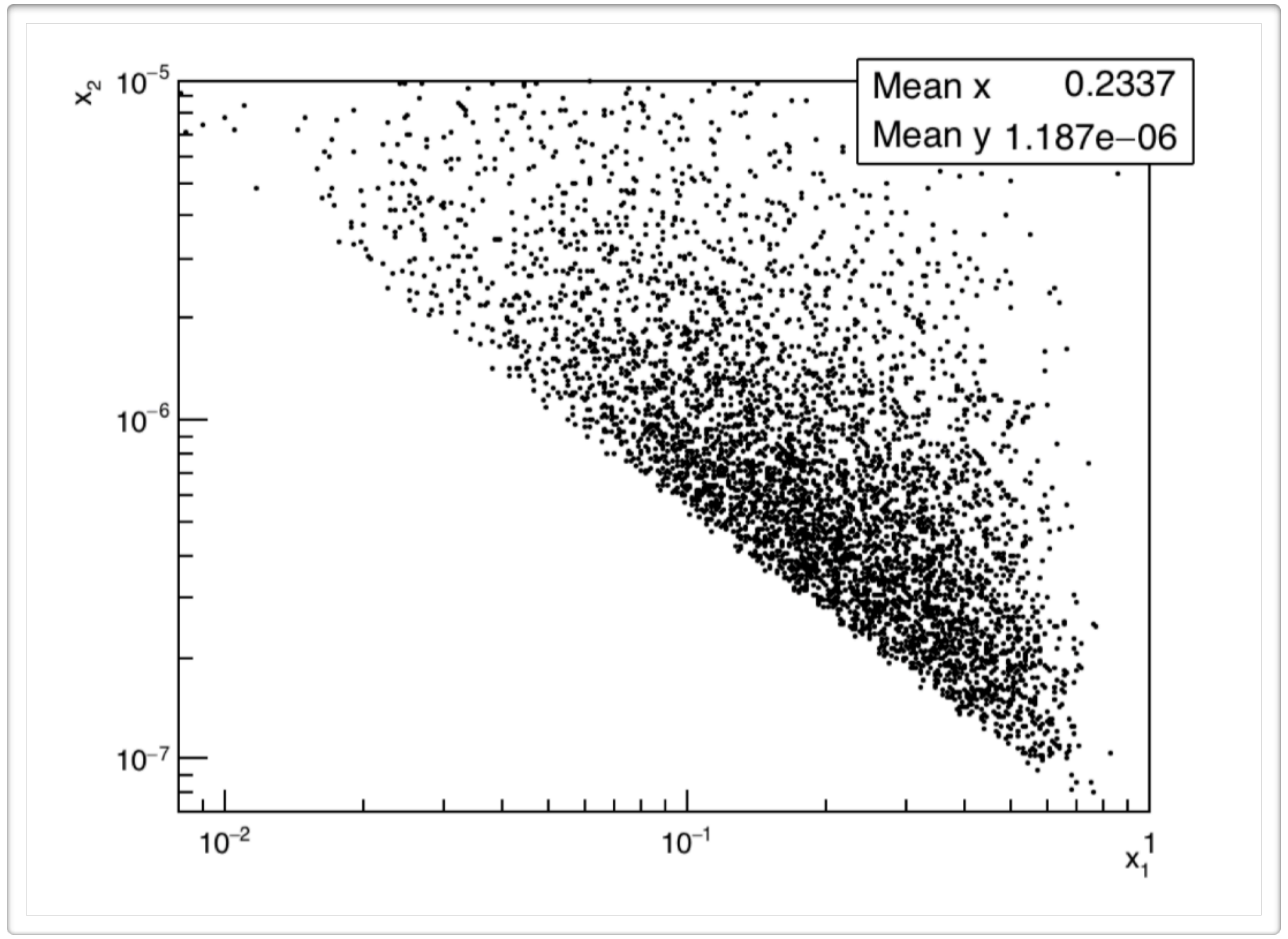


QCD MEASUREMENTS

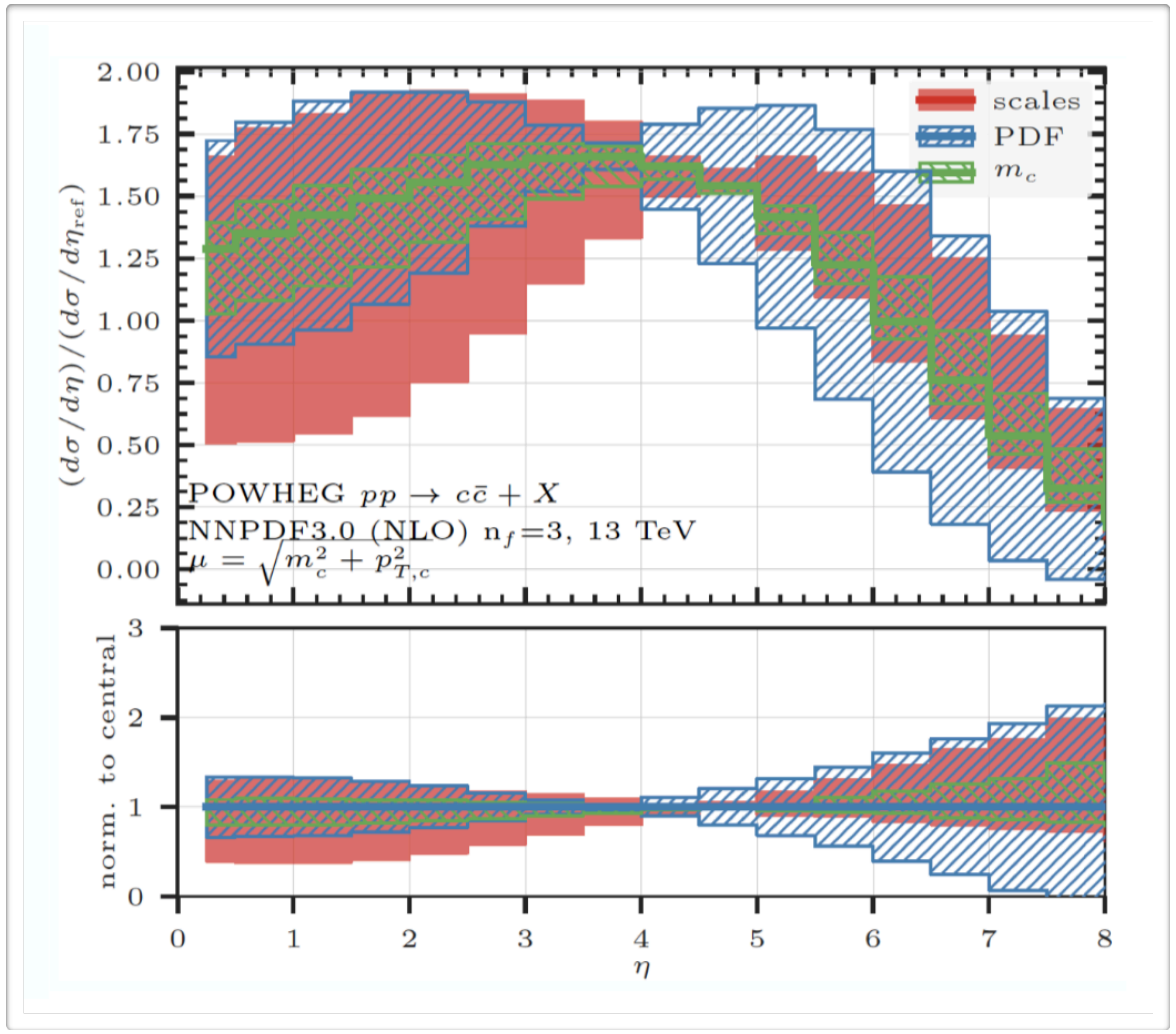
Extraction of gluon PDF in very small x-region relevant for:
- Future Circular Colliders
- predictions of high energy neutrinos production in cosmic rays

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

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

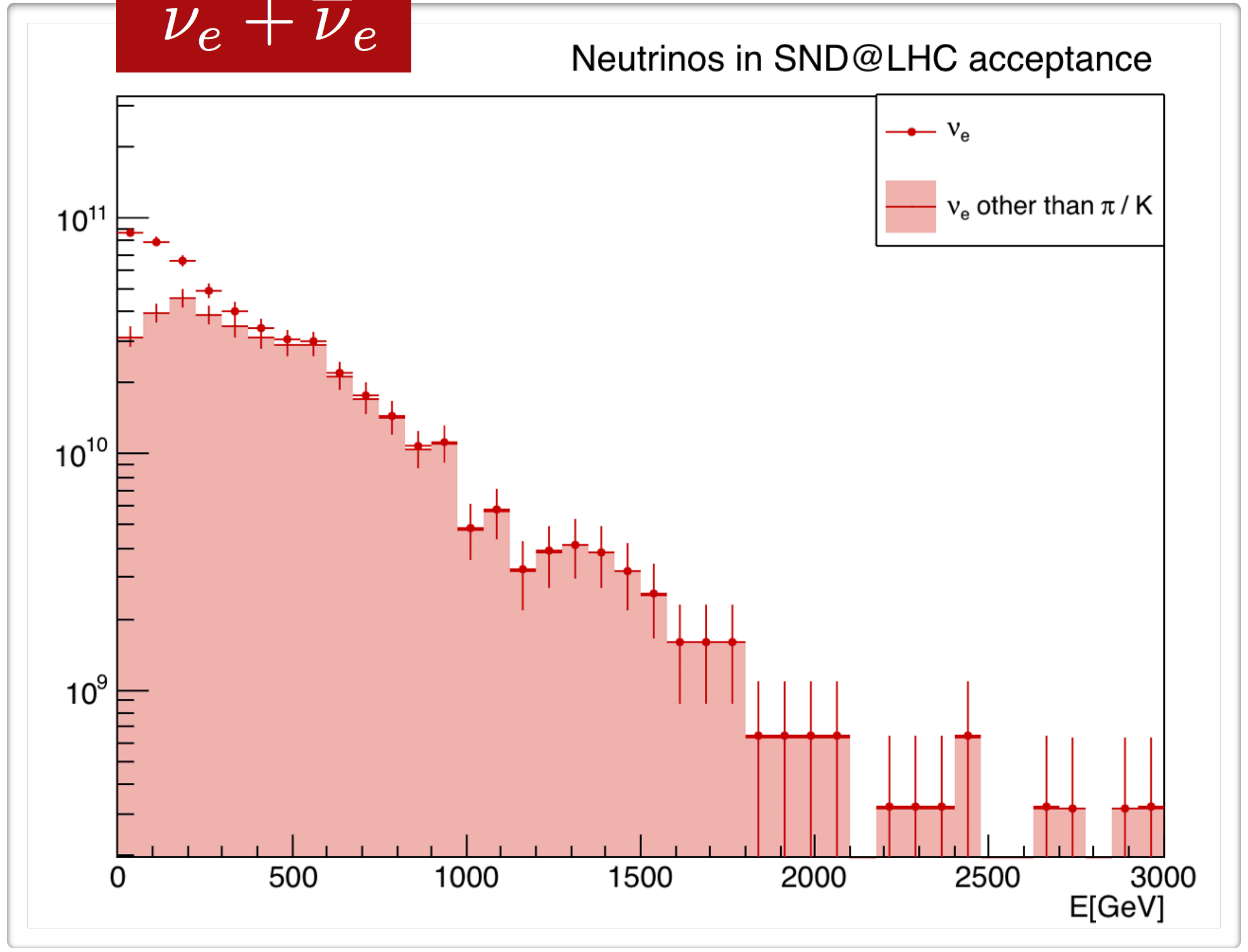
$\eta_{ref} = 4.5$

Reduction of scale uncertainties
Constraint the PDF with data

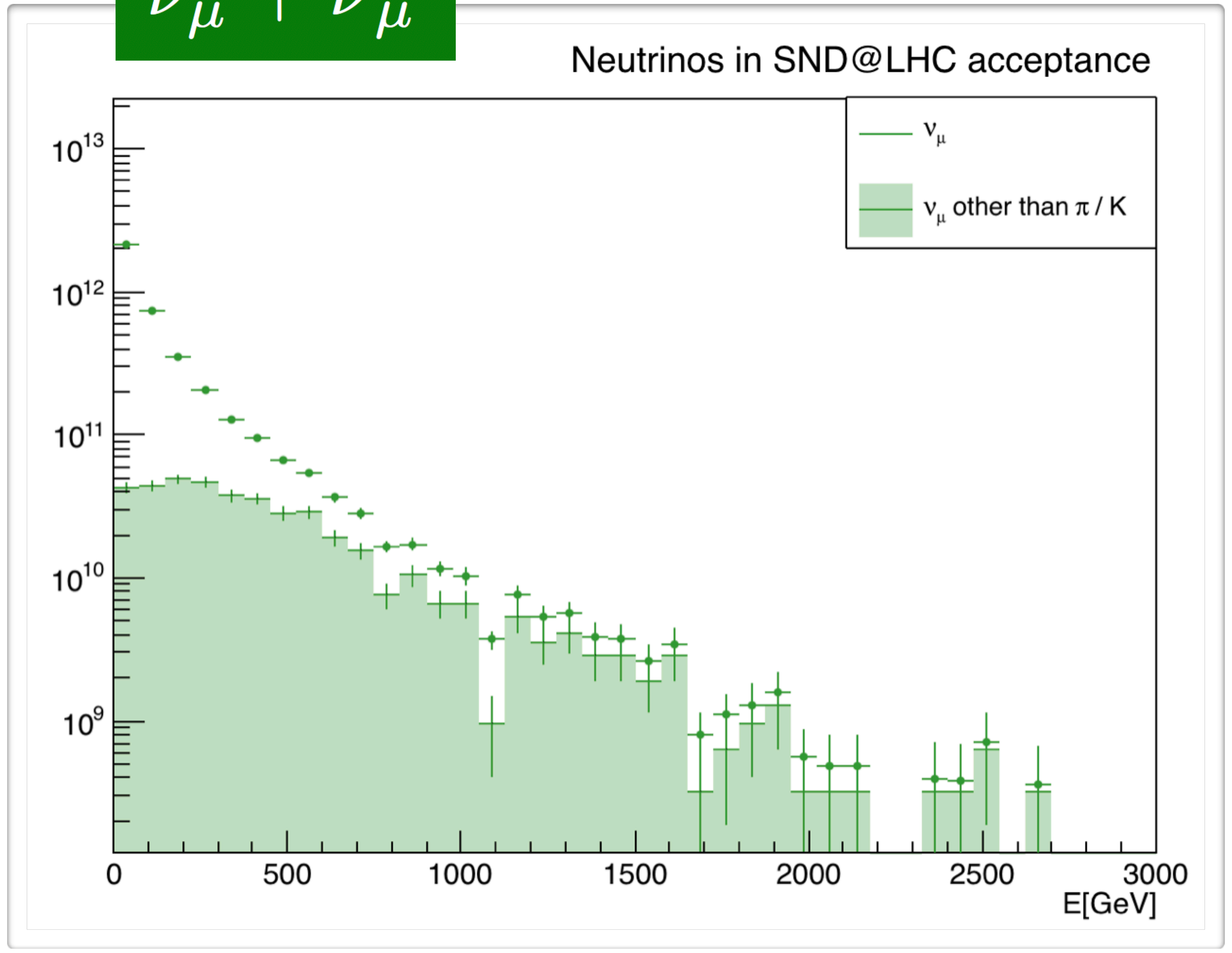
3. LEPTON FLAVOUR UNIVERSALITY TEST

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

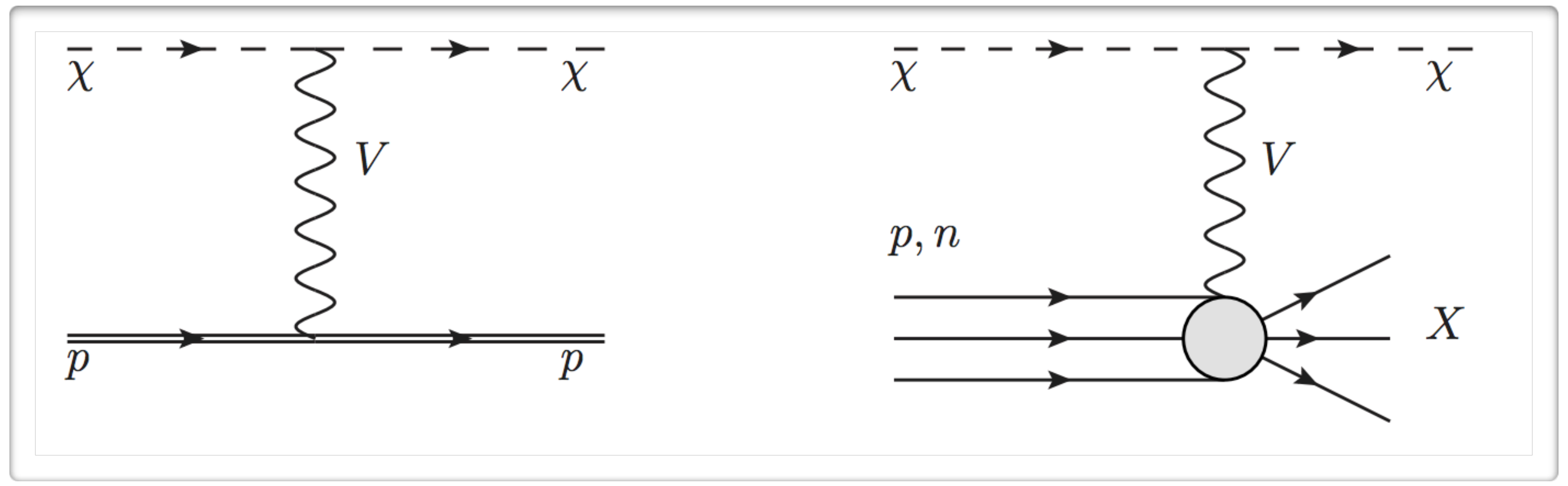
BEYOND STANDARD MODEL

Large variety of 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

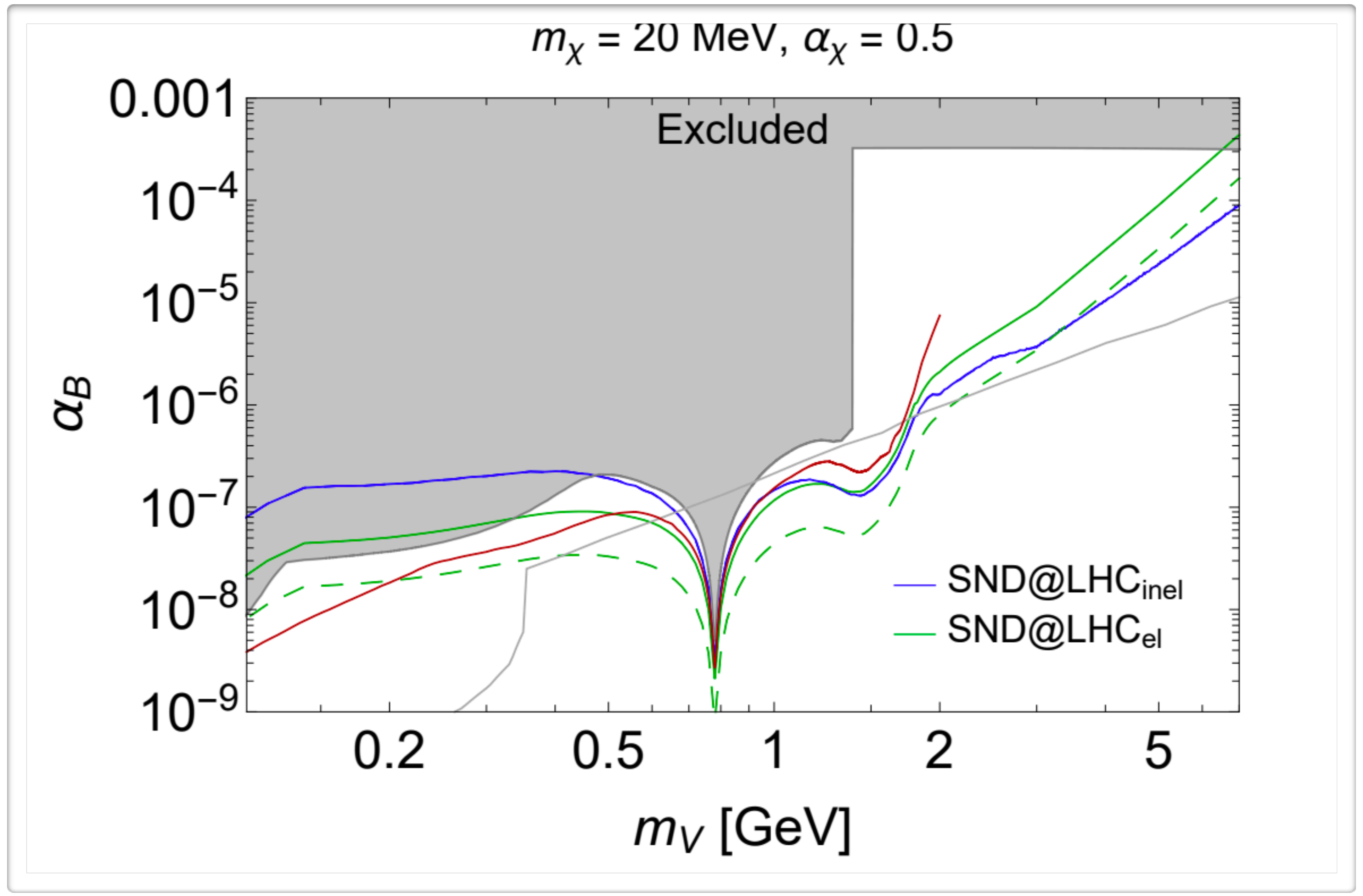


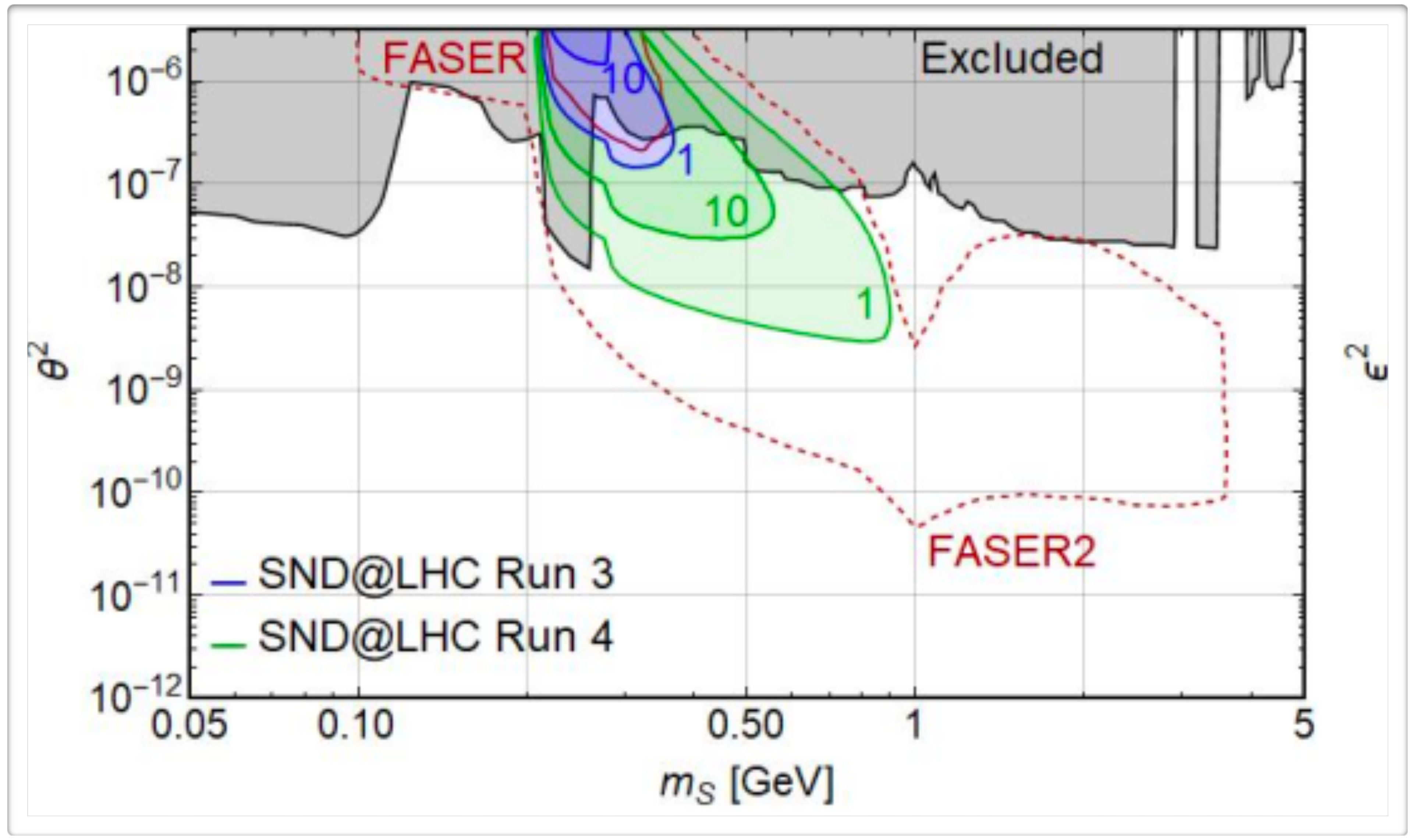
2. Decay of dark scalars, HNLs, dark photons

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

10.1007/JHEP03(2022)006





EVENT RATE AND LUMINOSITY

Event rate for one run
Start: October 29th 2022, 20:38:17
End: October 30th 2022, 06:23:29