THE SND@LHC DETECTOR

Joint Annual Meeting of the Swiss Physical Society and the Austrian Physical Society

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EPFL Swiss National Science Foundation

MOTIVATION

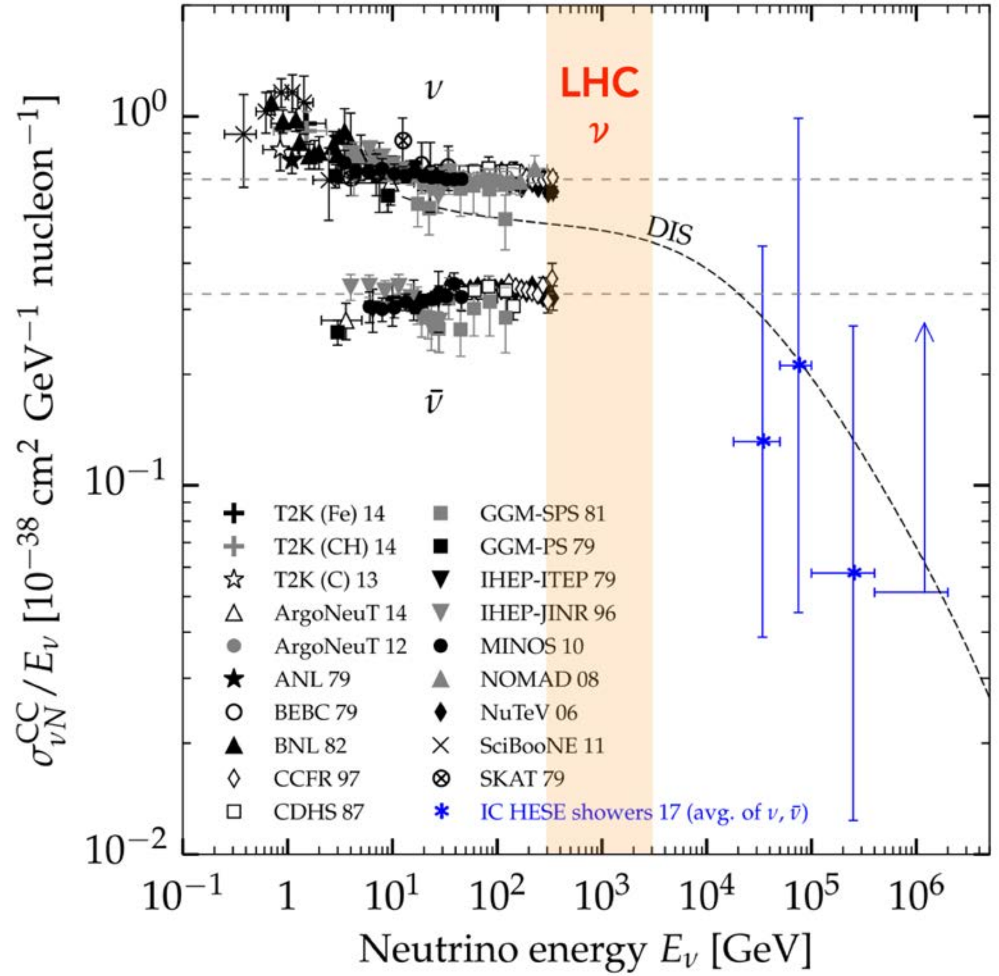
[PRL 122 (2019) 041101]

Colliders offer a novel laboratory for neutrinos:

- At the LHC, a high ν flux in the previously unexplored energies of $E_\nu \in [10^2, 10^3]$ GeV available

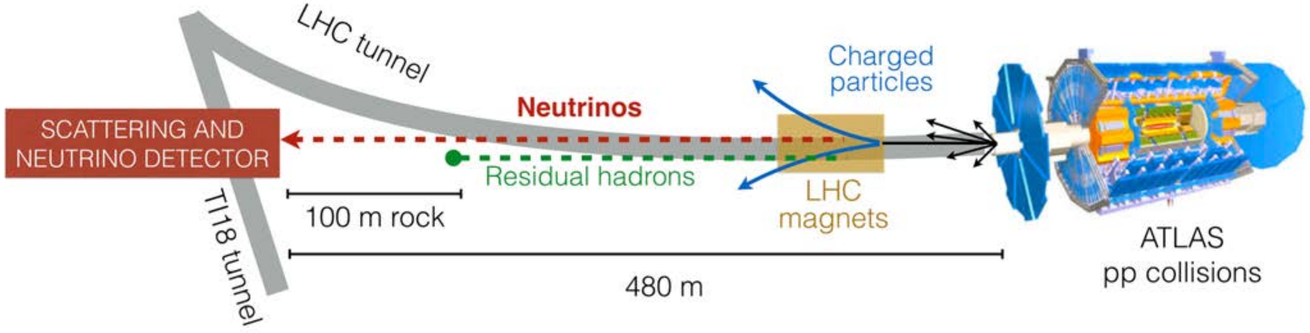
☞A small-scale LHC experiment can observe neutrinos of all flavours

☞Two neutrino detectors in operation at the LHC for Run 3: **SND@LHC** and FASERν



SND@LHC

Scattering and Neutrino Detector at the LHC

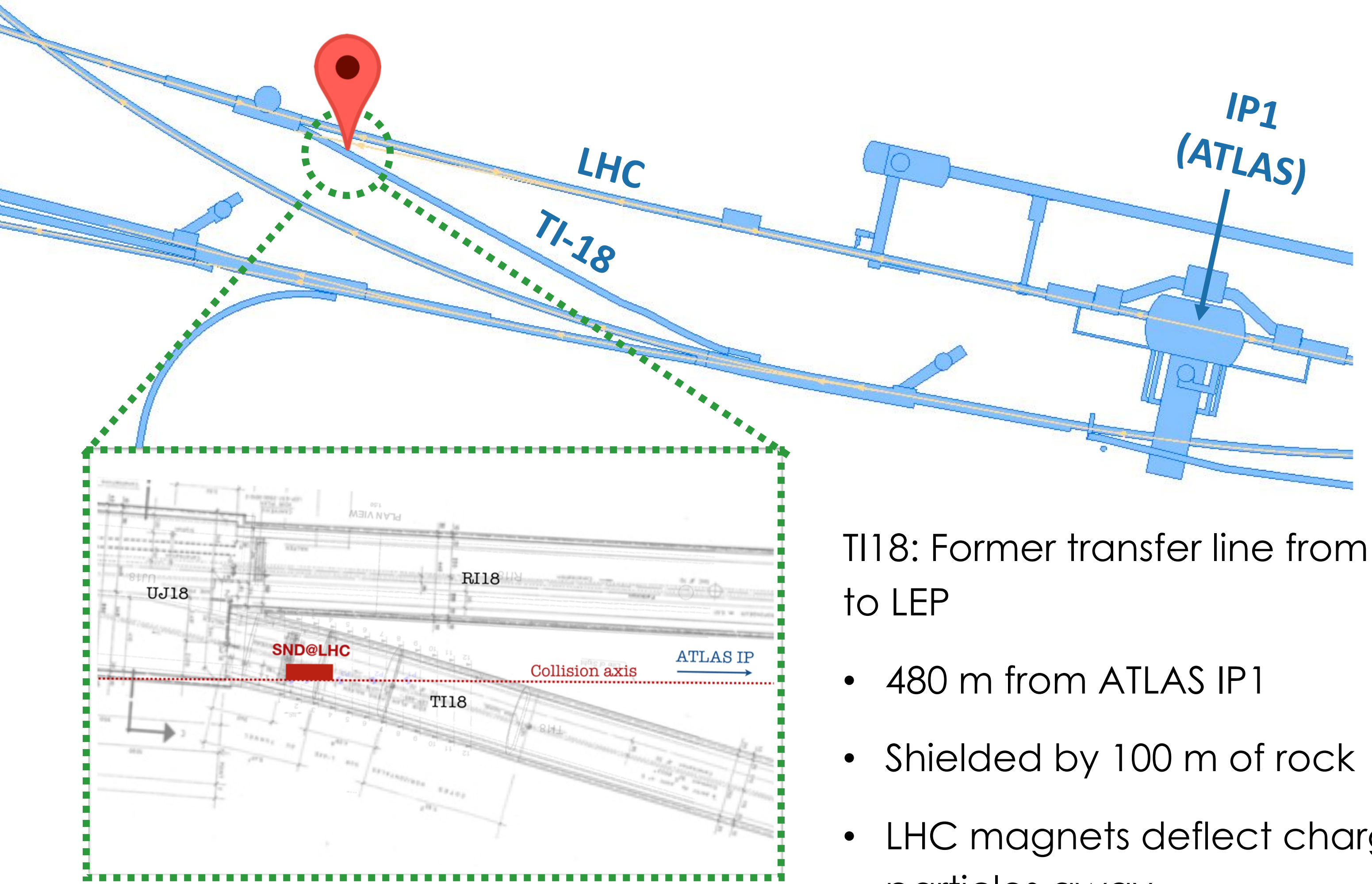


- Measures high energy (~TeV) neutrinos from the LHC at an angular acceptance of $7.2 < \eta < 8.4$
  - Majority of υ from charmed hadron decays → probe heavy flavour production at the LHC
- Designed to distinguish all neutrino flavours

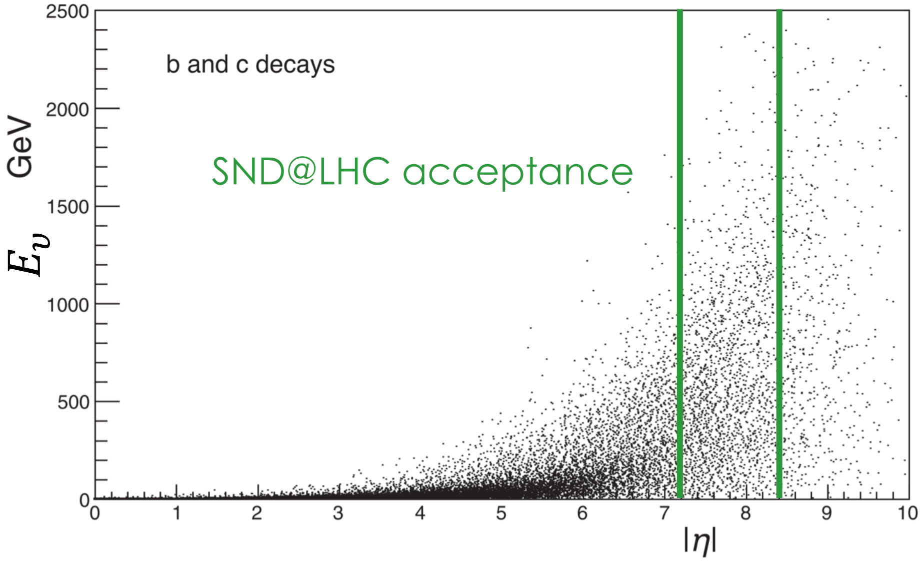
Physics goals

- Charmed hadron production
  - Constrain gluon PDFs at very low (~10^{-6}) momentum fractions
- Lepton flavour universality tests with neutrinos
  - Measure $\upsilon_e / \upsilon_\mu$ and $\upsilon_e / \upsilon_\tau$
- Direct searches of feebly interacting particles

LOCATION



[J. Phys. G: Nucl. Part. Phys. 47 125004]



TI18: Former transfer line from SPS to LEP

- 480 m from ATLAS IP1
- Shielded by 100 m of rock
- LHC magnets deflect charged particles away

Off-axis position with pseudorapidity coverage of $7.2 < \eta < 8.4$

- ~90% of $\upsilon_e, \bar{\upsilon}_e$ coming from charm decays
- Complementary to FASERν

EXPERIMENT TIMELINE

August 2020
- Letter of intent

January 2021
- Technical proposal

March 2021
- Approval by CERN research board

April 2022
- First muons from IP1 measured

DETECTOR DESIGN

Scattering and Neutrino Detector at the LHC

Veto

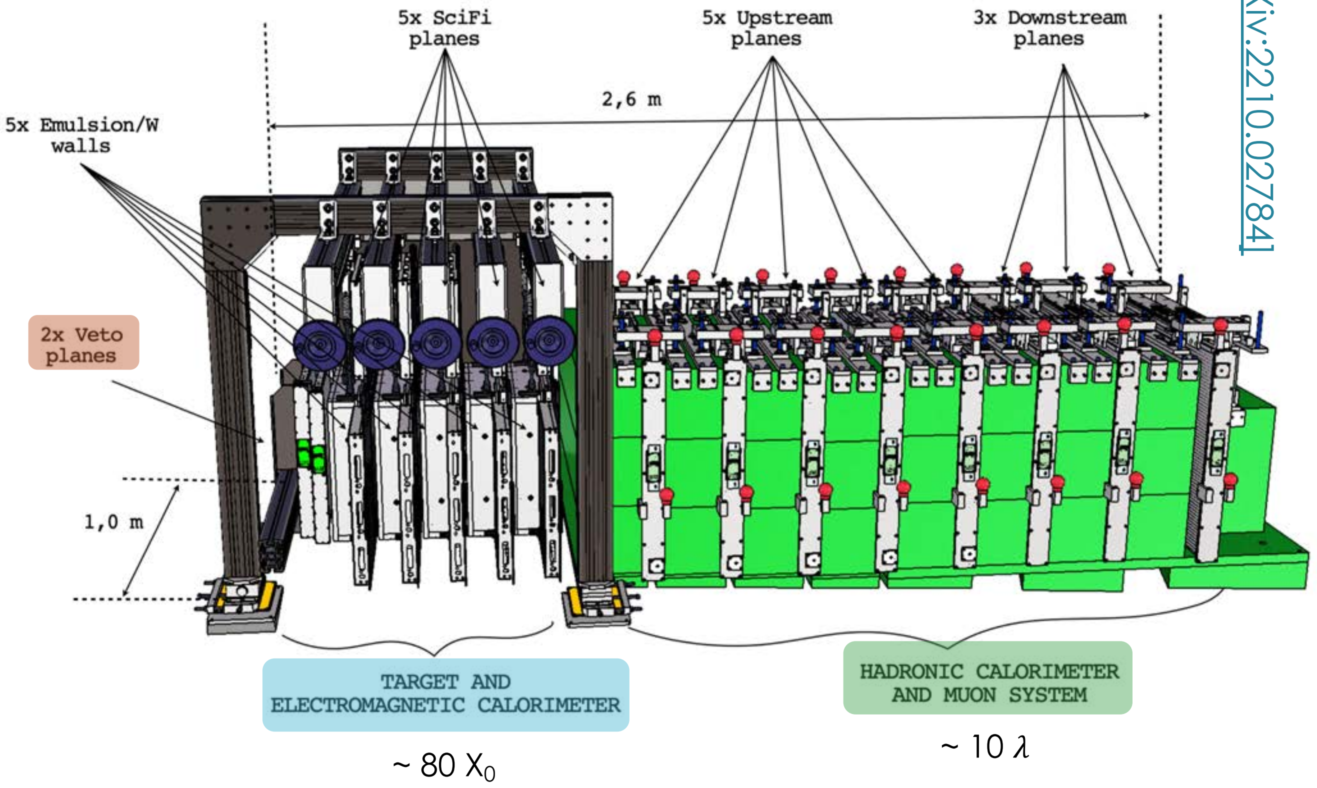
- Two planes of scintillating bars
- Tags charged particles as they enter the detector

Target and vertex detector

- Emulsion Cloud Chambers (ECC) with tungsten for ν identification via precise vertexing
- Scintillating Fiber (SciFi) planes provide timing and calorimetric information

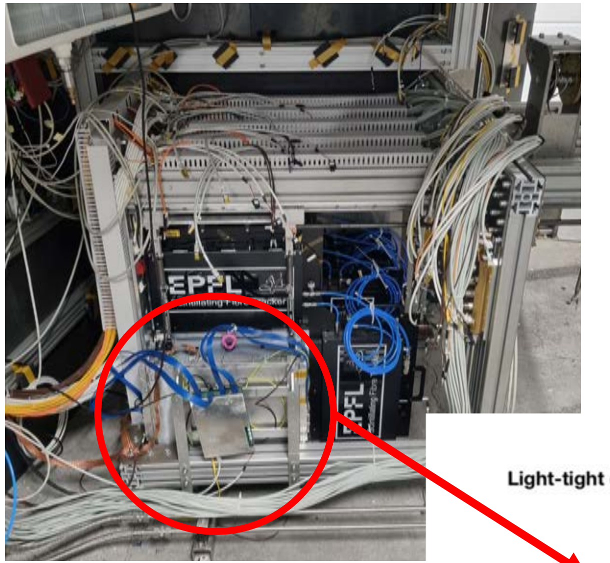
Muon System and HCAL

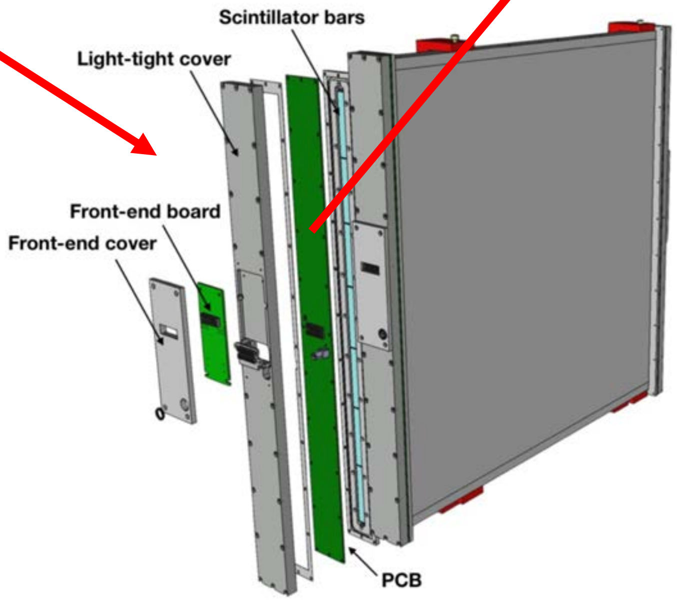
- Scintillating bars interleaved with iron walls, sampling every λ
- Timing, muon ID, and energy measurement
- Higher granularity in downstream stations for muon tracking



[arXiv:2210.02784]

VETO SYSTEM

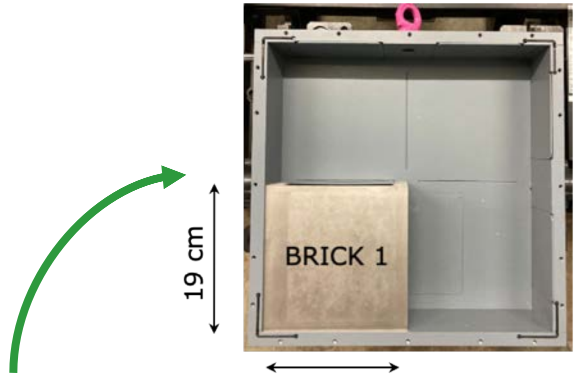


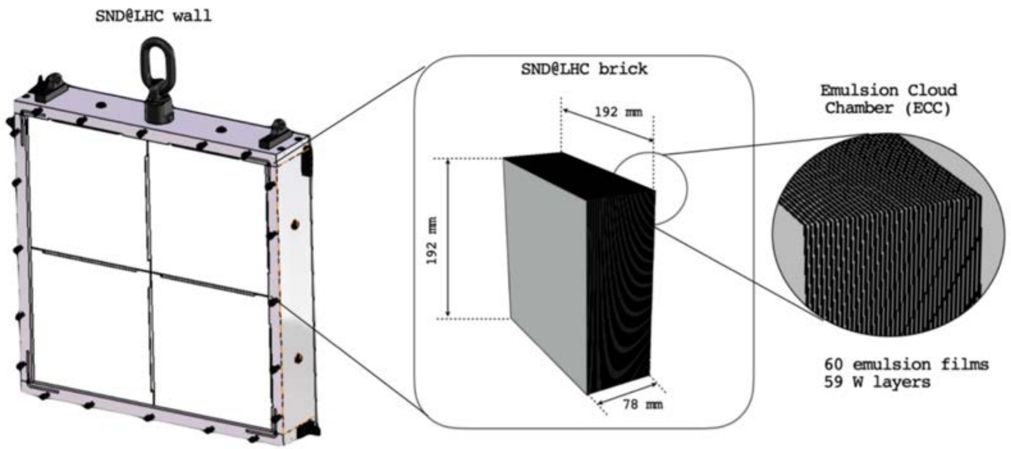


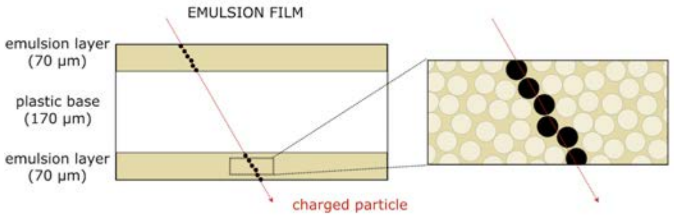
- Two planes for tagging charged particles entering the detector
  - The planes cover the target surface area, and are staggered to mitigate dead zones between bars
- Each plane has 7 scintillating bars
  - Each bar is 1 x 6 x 42 cm^3.
  - Bars read out on both ends by 8 SiPMs, each 6 x 6 mm^2.

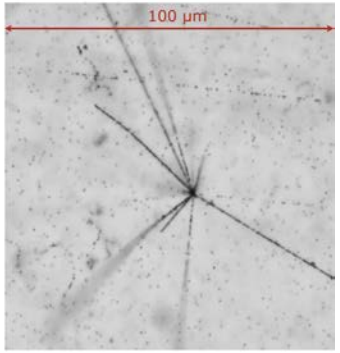
EMULSION TARGET

- Five emulsion cloud chamber (ECC) walls used as a vertex detector
  - Each target wall = four ECC bricks
  - Each brick = 60 layers of emulsion (0.3 mm) and 59 layers of tungsten (1 mm)
  - Wall thickness: 78 mm (17 X_0)
  - Sensitive transverse size: 38.4 x 38.4 cm^2
- Total target mass: 830 kg
- Target enclosed in acrylic and borated polyethylene box: shields from neutrons and controls temperature (15 °C) and humidity (RH=45 %)



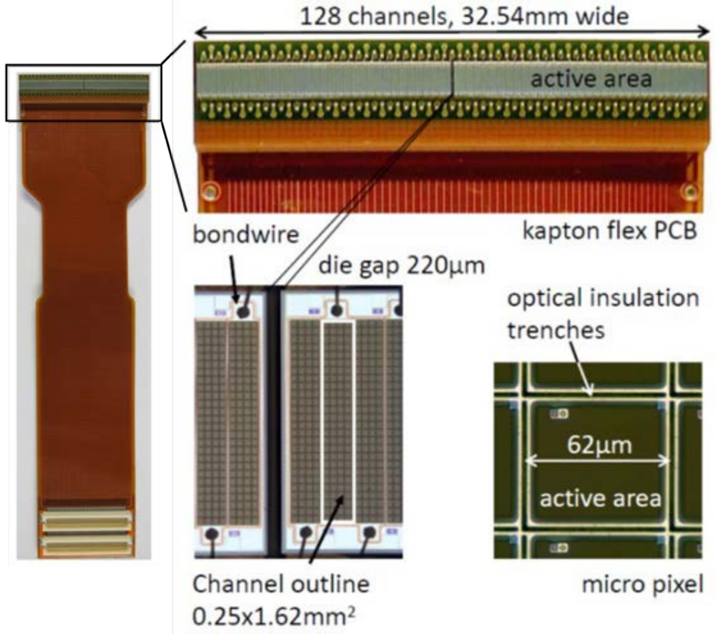


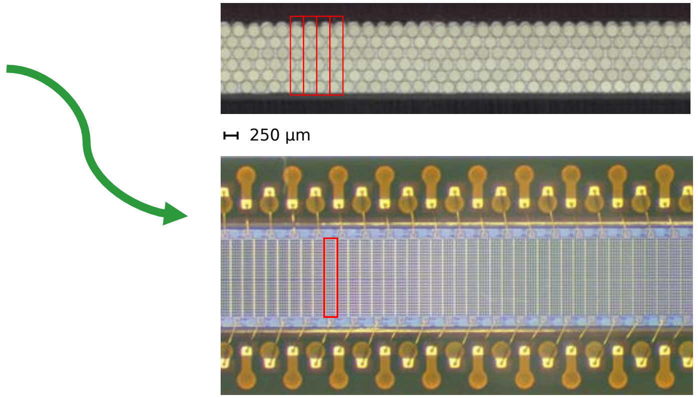




SCINTILLATING FIBRE TRACKER

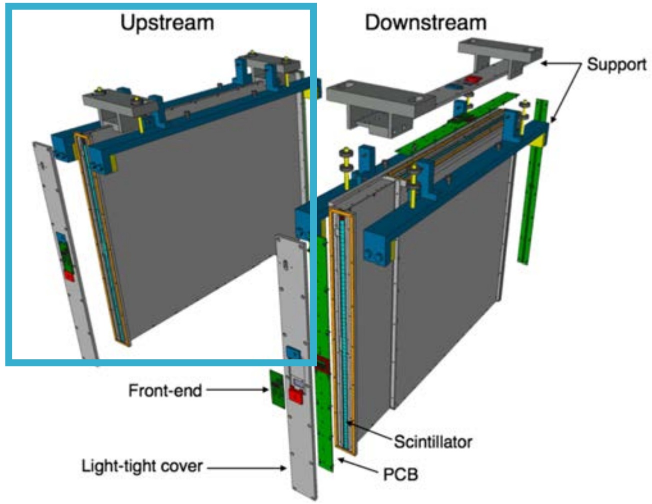
- Five SciFi stations interleaved with ECC walls, each with two perpendicular planes
  - Each plane is made of staggered layers of 250 μm fibre
  - Planes read out by SiPM arrays of 250 μm channel pitch
- Provides time information, and electromagnetic calorimetry together with the emulsions
  - Interfaced with the ECCs by matching the hit pattern in the electronic detector event with a vertex in the emulsions





MUON SYSTEM AND HCAL

- 8 stations made of scintillating bars, interleaved with 20 cm iron slabs (1 slab ~ 1 λ_{int})
  - Five **upstream** stations - hadronic calorimetry
  - Three **downstream** stations - muon identification



Upstream system

5 stations, each with 10 horizontal scintillating bars

- Bar dimension: 1 x 6 x 81 cm^3
- Read out: both sides, 6 large (6 x 6 mm^2), 2 small (3 x 3 mm^2) SiPMs
- Small SiPMs have more pixels → extend the dynamic range

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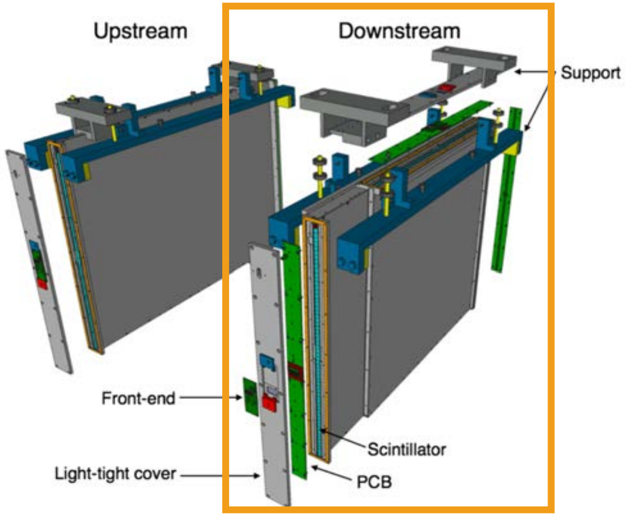
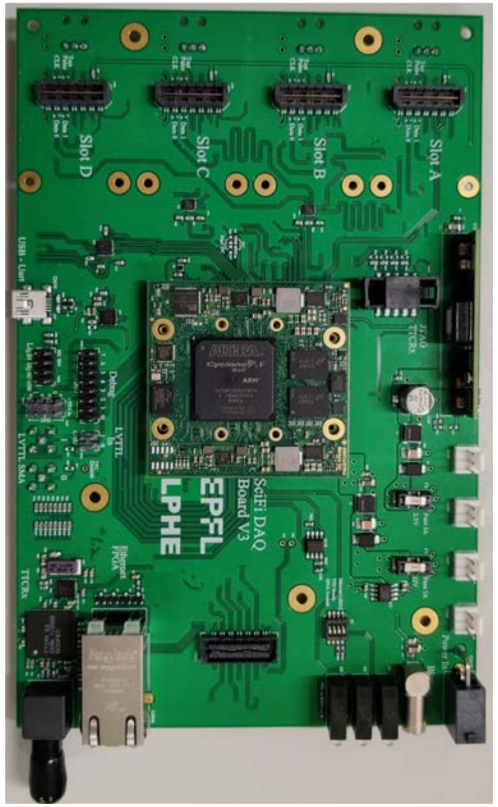


Downstream system

3 stations, each with 60 horizontal bars and 60 vertical bars (+ additional vertical plane in the last station)

- Bar cross-section: 1 x 1 cm^2
- Length: 81 cm (horizontal), 60 cm (vertical)
- Read out: large SiPMs, 1 SiPM each side of horizontal bars, only 1 SiPM on top of vertical bars

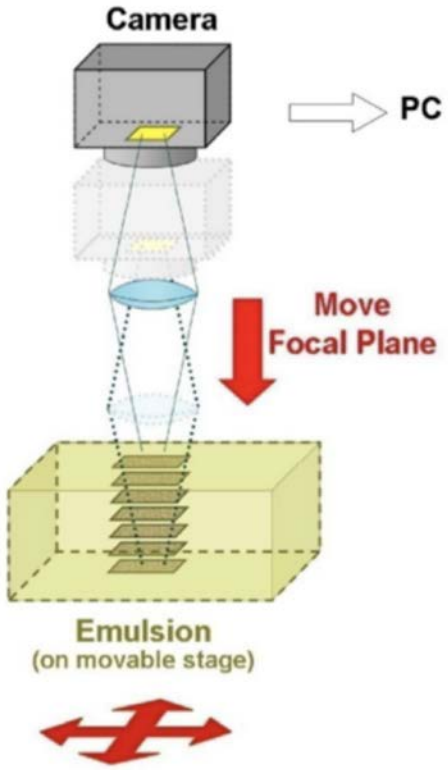
DATA ACQUISITION

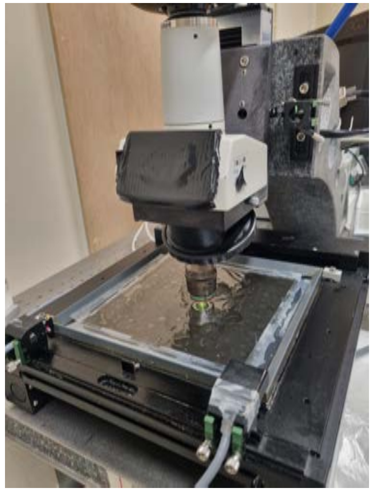


- All electronic detectors are read out by TOFPET2-based front-end boards
  - Low signal threshold
  - Good timing: 40 ps binning
  - 128 channels
- DAQ boards based on Cyclone V FPGA.
  - Runs at 160 MHz, aligned with the LHC clock
  - Collects data from four front-end boards (4x128=512 channels)
  - Gets clock from LHC via optical fibre
  - Triggerless DAQ: all hits above threshold sent to server over ethernet.
- DAQ server
  - Receives hits from DAQ boards, 17k channels in total
  - Runs timestamp-based event-building code
  - Applies online noise filter
  - Saves data to disk in ROOT format

EMULSION SCANNING

- ECC target data is extracted by developing and scanning the emulsion films (emulsion changed every < 20 fb^{-1})
- Five scanning stations, each microscope currently scans one emulsion film per day
- Raw microscope images not stored on disk
  - Single emulsion film ≈ 3TB of data
  - Processing the images is the bottleneck
- Speed up foreseen:
  - More microscopes coming online
  - Distributed data processing





EVENT RECONSTRUCTION

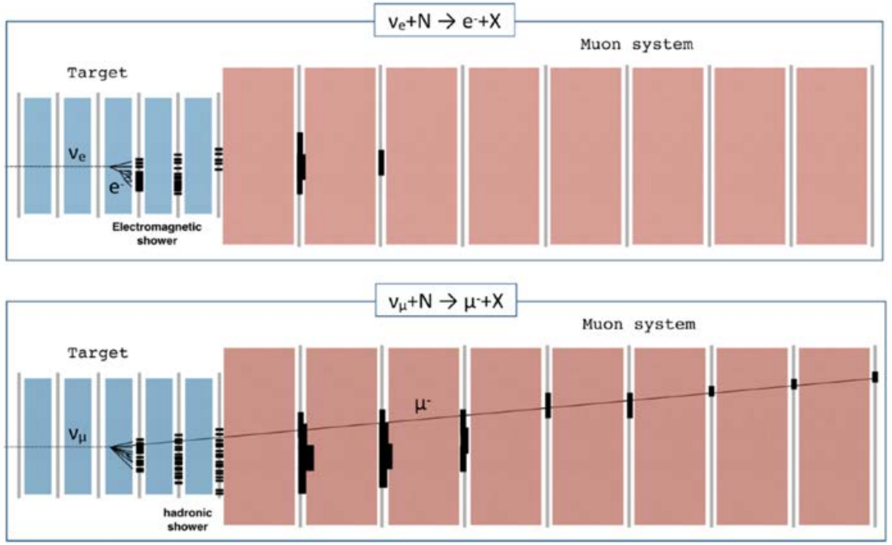
Two-phase event reconstruction:

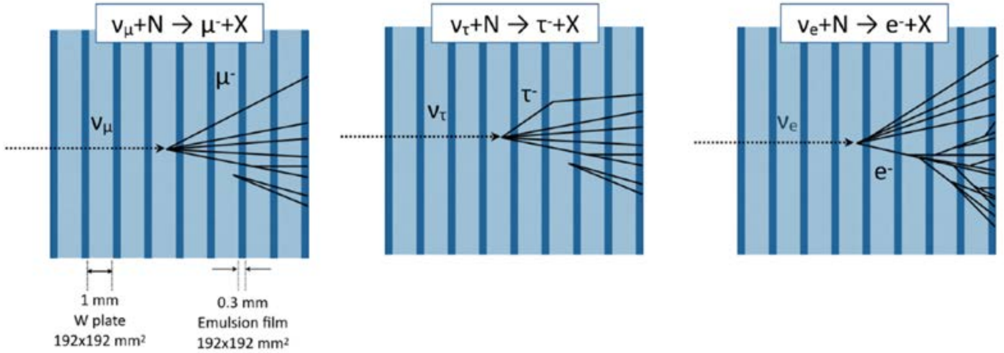
1

Online with electronic detectors
- Select υ candidates
- Identify muons (Muon system)
- Measure energy (SciFi+ECC & HCAL)

2

Offline with nuclear emulsions
- Extract, develop, scan, and analyse emulsion data
- Reconstruct υ primary and secondary candidates
- Match emulsion and electronics reconstruction

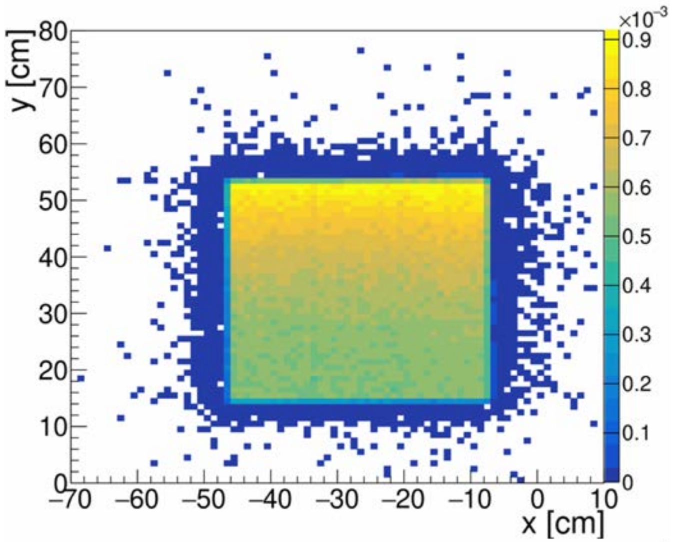




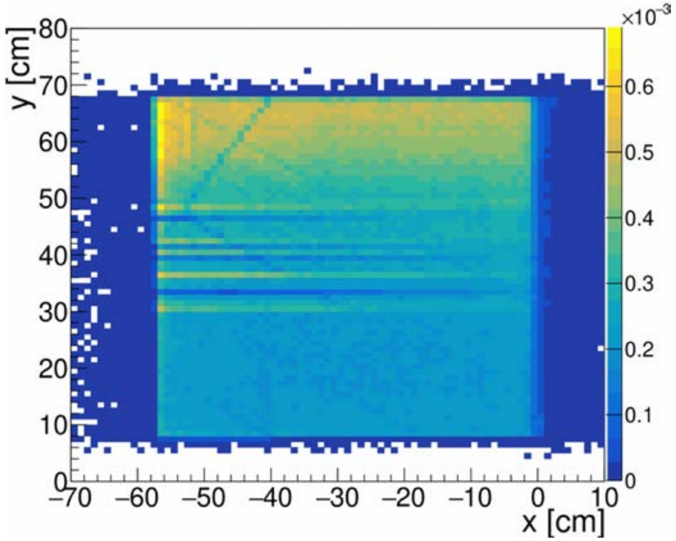
MUON FLUX MEASUREMENT

[SNDLHC-NOTE-2023-001]

SciFi-data



DS-data



SND@LHC Preliminary

- Muon flux measured using electronic detectors
  - Agreement between SciFi/DS: 2%
  - Agreement with Monte Carlo on ~20%-25% level
  - ➢ Input given to CERN SY-STI team for the FLUKA simulation, better agreement expected with new simulation
- Muon flux in SciFi vs. emulsions in 1 brick
  - **SciFi**: 1.4×10^4 fb/cm^2
  - **Emulsions**: 1.5×10^4 fb/cm^2

	Data	**Simulation**
SciFi	2.06×10^4 fb/cm^2 (syst. uncert. 3%)	1.60×10^4 fb/cm^2 (syst.uncert. 12%)
DS	2.35×10^4 fb/cm^2 (syst.uncert. 5%)	1.79×10^4 fb/cm^2 (syst.uncert. 8%)

CONCLUSION

- SND@LHC is a compact neutrino experiment at the LHC, operating since the start of Run 3
  - Installed and commissioned in less than two years
  - Collected ~70 fb^{-1} of data with an uptime efficiency of ~97%
- The hybrid detector design combines emulsion cloud chambers with scintillator-based electronic detectors
- Physics analyses are now in progress – follow the next talk from M.Ferrillo for first results!

BACKUP

PERFORMANCE SUMMARY

Veto

- Inefficiency around 10^{-4} seen in LHC Run 3 data
- Inefficiency dominated by detector dead time of ~200 ns. Can be mitigated by requiring good time separation of signal candidates

Emulsions

- Spatial resolution: ~ μm
- Angular resolution: ~ m rad

SciFi

- Spatial resolution with muon testbeam data (SciFi only): ~ 100 μm
- Time resolution with Run 3 data: ~ 250 ps

HCAL

- Very high (>99%) efficiency of upstream system in Run 3 data