SND@LHC

A new Scattering and Neutrino Detector at the LHC

Ettore Zaffaroni

ICHEP 2022, Bologna

07/07/2022

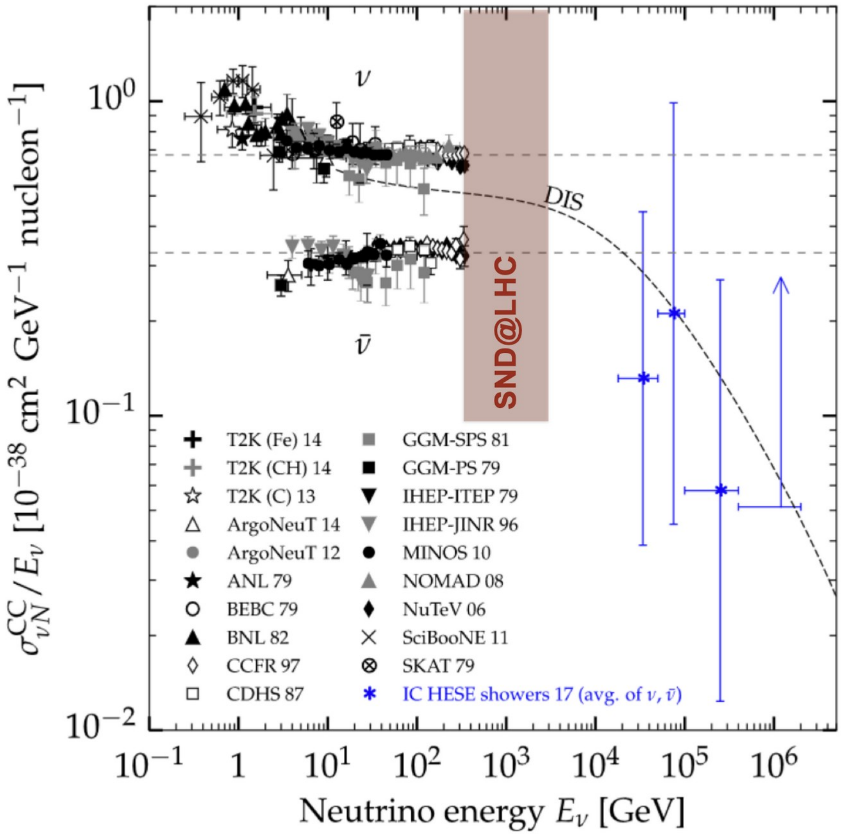
EPFL

Outline

- The physics programme
- The SND@LHC detector
- Data acquisition system
- First data

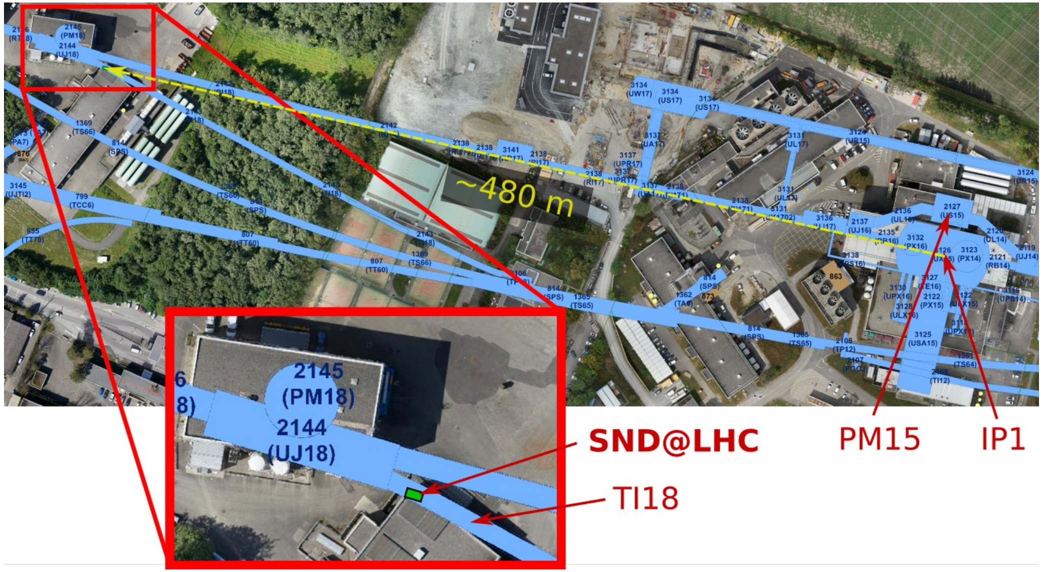
Motivation

- LHC provides high-energy neutrinos
  - Use of LHC for neutrino studies proposed ~30 years ago
- Measure of pp→νX in unexplored domain
  - Energy range from 100s GeV to few TeV
  - Mainly produced in hadron decays for η > 7
- 2 experiments
  - FASERν, on axis
  - SND@LHC, off axis



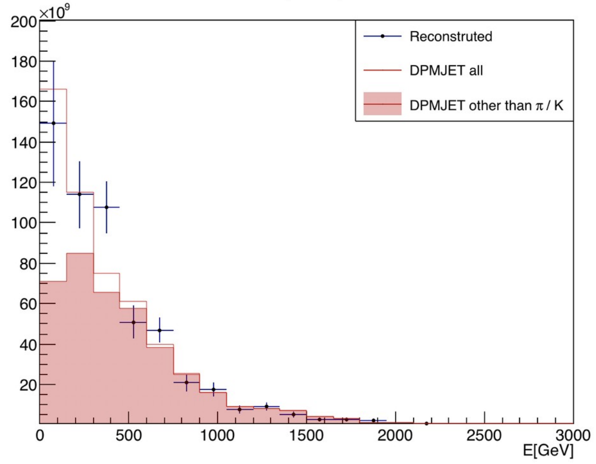
Detector location

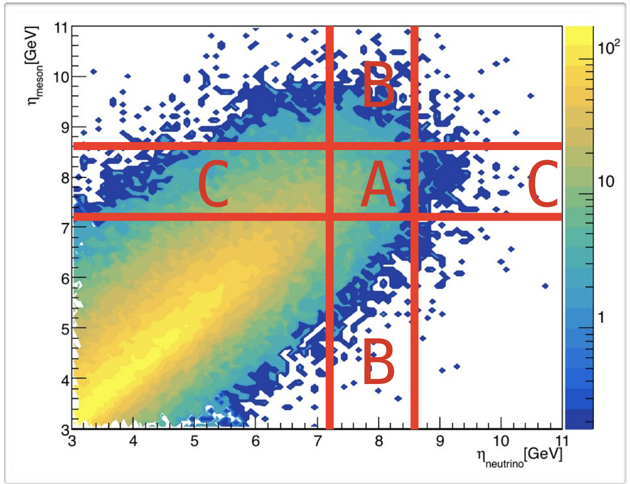
- About 480 m from ATLAS interaction point
- TI18 tunnel
  - Used in the past as transfer line from SPS to LEP
  - Symmetric to TI12, where FASER is located
- Shielded by 100 m of rock
- Angular acceptance: $7.2 < \eta < 8.4$
- First phase: collect 290 fb^{-1} in Run 3



Neutrino physics – charm production

- 90% of ν_e events produced in charm decays
  - Measurement of heavy quark production at high η
- Measure $\sigma(pp \rightarrow \nu_e X)$
  - Unfold detector response and find energy spectrum
  - Use SM σ_ν for CC interactions
- Derive charmed hadrons yield
  - Remove contribution from K decays
  - Exploit angular correlation between neutrino and parent hadron

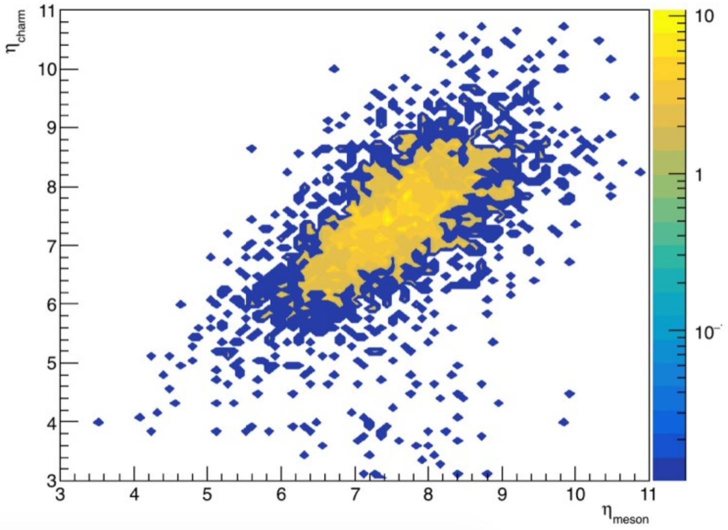


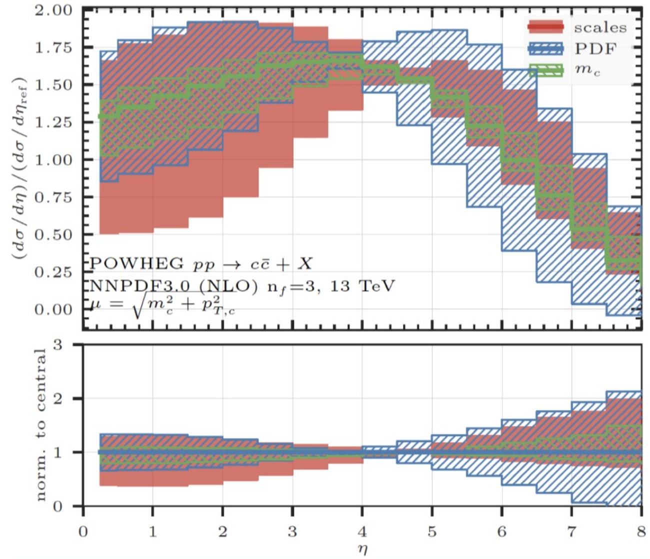


LHCC-P-016

Neutrino physics – QCD

- Angular correlation between charmed hadron and parent quark
- Dominant $c\bar{c}$ production process is gg scattering in this η range
  - SND@LHC probes lowest momentum fraction $x \sim 10^{-6}$, gluon PDF unknown
- Constrain PDF with data
  - e.g. take ratio of cross sections at different energy and η to reduce scale uncertainty (use LHCb measurement at 7 TeV and 4<η<4.5 as reference)





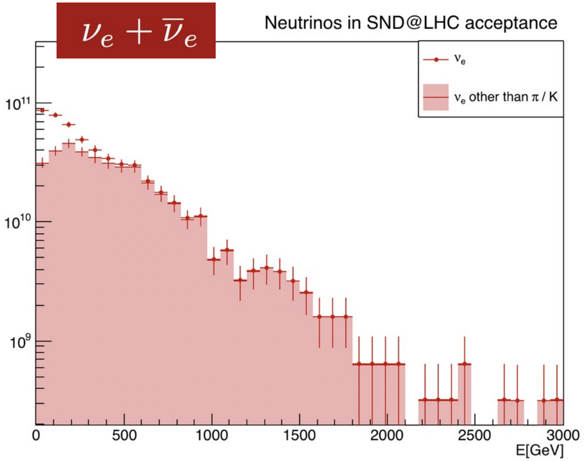
LHCC-P-016

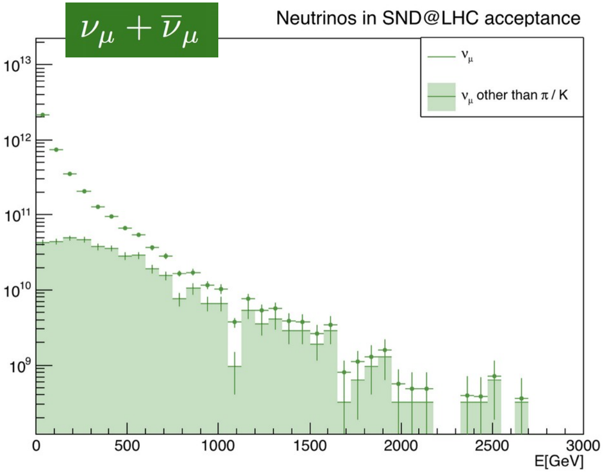
Neutrino physics – LFU

- ν_e and ν_τ mostly come from charm decays
  - R_{13} independent on charm production systematics
  - Depends on decay BR and charm fractions
- Similar for ν_e and ν_μ, R_{12} with contamination by π/K
  - Contamination flat ~35% above 600 GeV
  - No systematics from BR and charm fractions

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

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

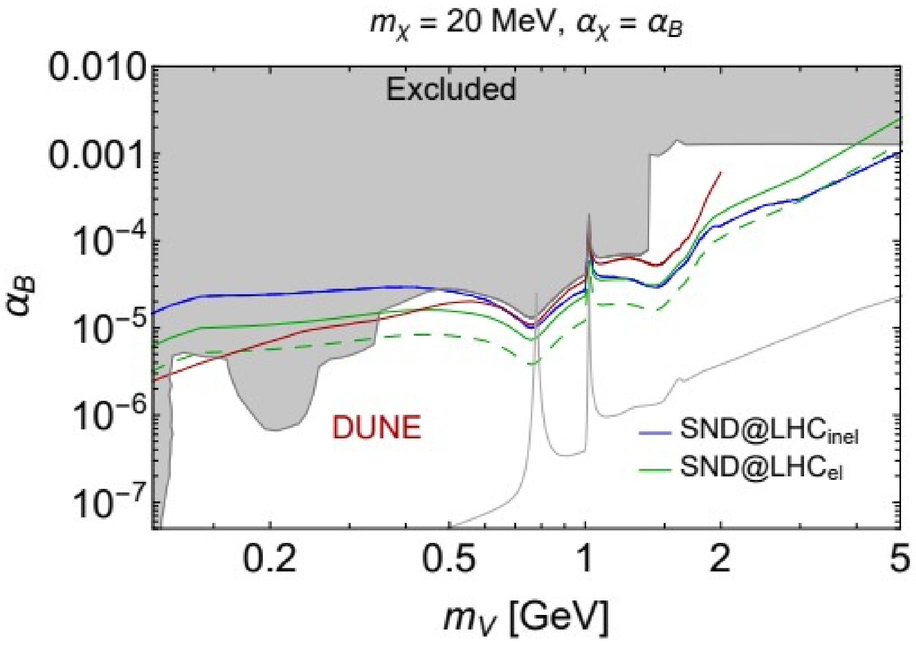




LHCC-P-016

BSM physics - scattering

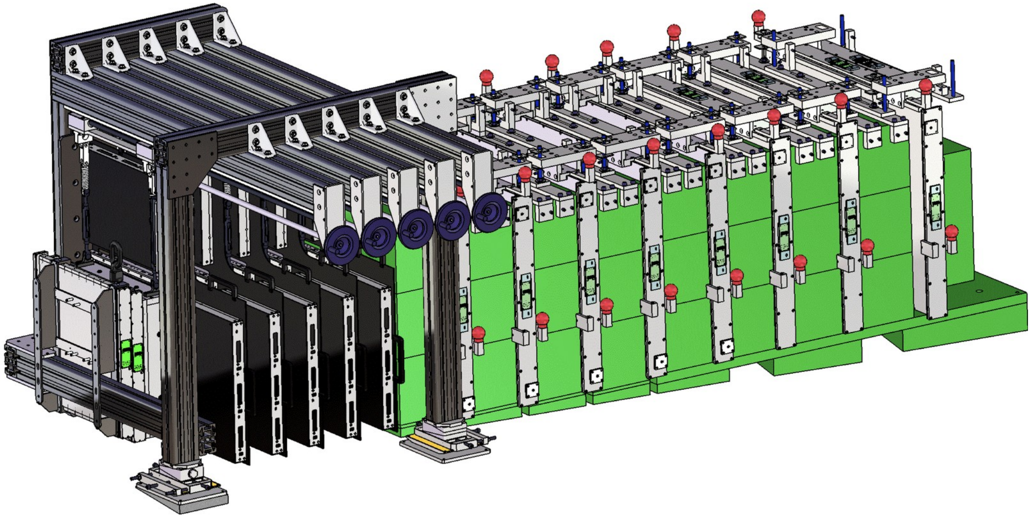
- Dense target also suited to search for feebly interacting particles
- E.g. search for light dark matter (< 1 GeV)
  - Other direct detection experiments sensitive lo large masses
  - Complementary to missing energy technique
- Several models and signatures
  - Elastic or inelastic scattering off nucleons
  - Elastic scattering off electrons
  - Time-of-flight techniques (sensitive to larger masses)



JHEP03(2022)006

Detector

- Veto
  - Scintillators: tag incoming muons
- Target region
  - Emulsion cloud chambers (830 kg): neutrino interaction detection
  - Scintillating fibres (SciFi) tracker: timestamp, position and energy measurement
- HCAL-Muon system
  - Iron walls and scintillators: energy measurement and muon detection

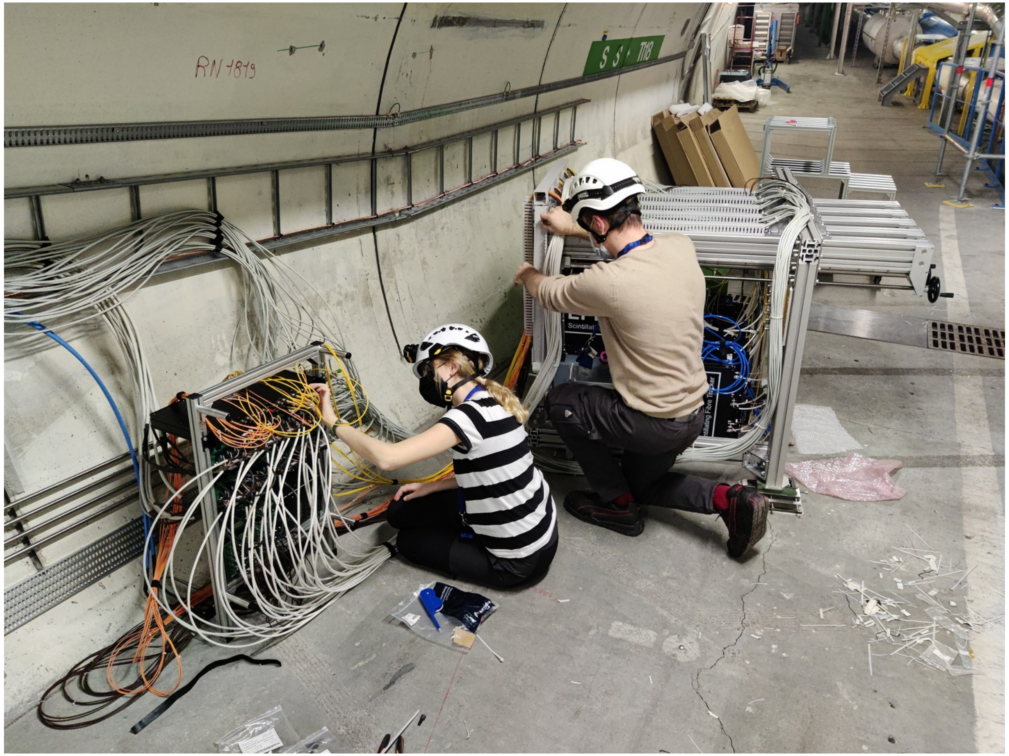


Detector installation

- Mechanics and SciFi installed in November 2021
- HCAL-muon system installed in December 2021
  - Commissioning could begin
- Neutron shield completed in March 2022

Detector installation

- Mechanics and SciFi installed in November 2021
- HCAL-muon system installed in December 2021
  - Commissioning could begin
- Neutron shield completed in March 2022

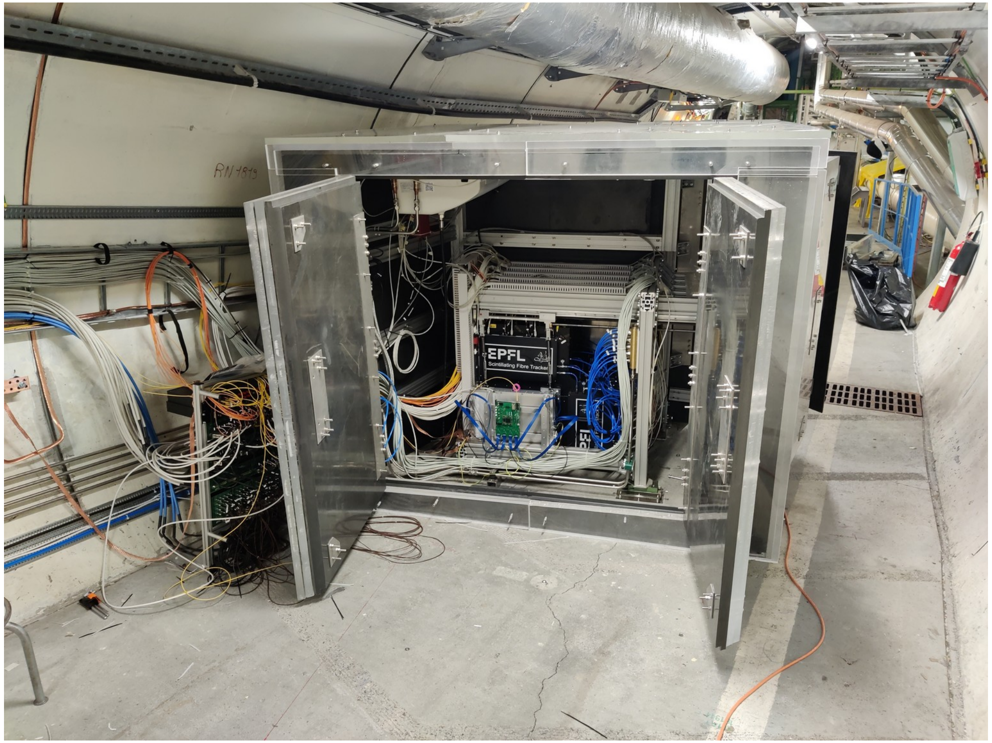


Detector installation

- Mechanics and SciFi installed in November 2021
- HCAL-muon system installed in December 2021
  - Commissioning could begin
- Neutron shield completed in March 2022

Detector installation

- Mechanics and SciFi installed in November 2021
- HCAL-muon system installed in December 2021
  - Commissioning could begin
- Neutron shield completed in March 2022

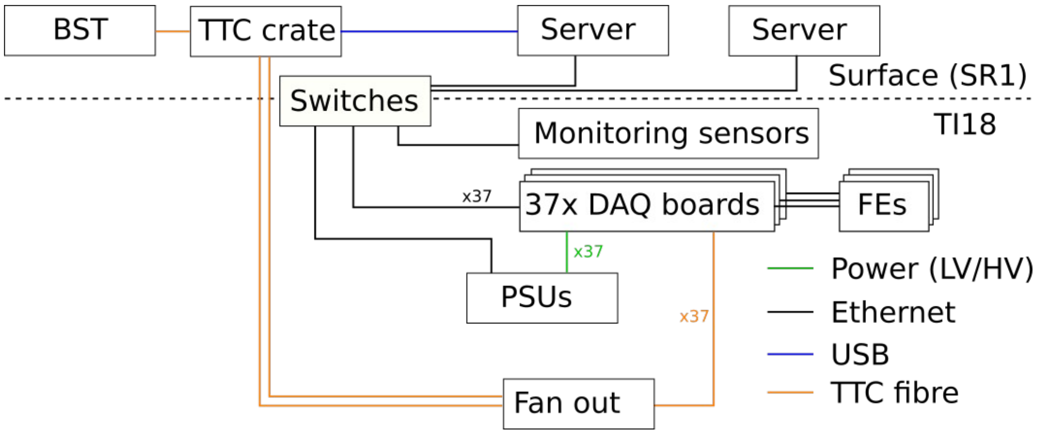


Detector installation

Scattering and Neutrino Detector at the LHC

Data acquisition system

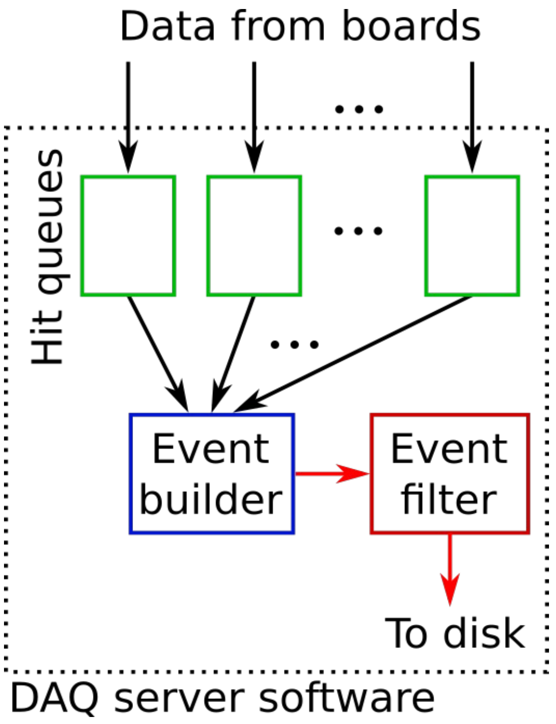
- Veto, SciFi tracker, HCAL-muon system read-out with common DAQ board
  - 37 boards used
  - Synchronous to LHC clock
  - Data transmitted to server on the surface
- TTC system receives LHC clock from BST and distributes it to DAQ boards



TTC: Timing, Trigger and Control
BST: Beam Synchronous Timing

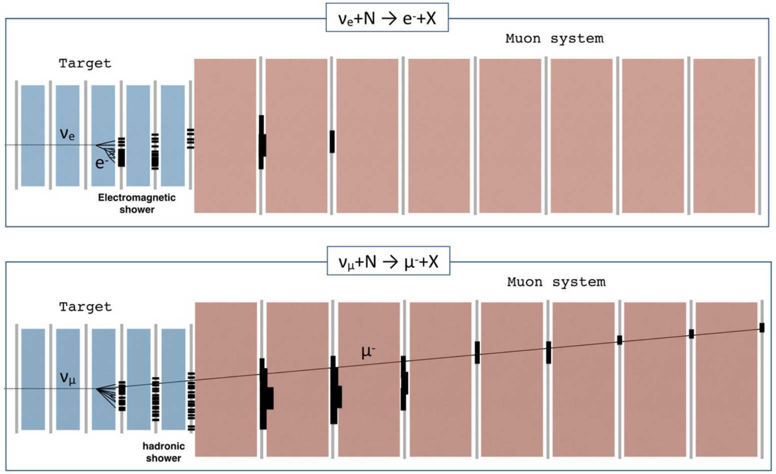
Data acquisition system

- Trigger-less data acquisition
  - All hits are recorded and sent to the DAQ server
- Online event building
  - Hits within 25 ns are grouped into events
- Online event filtering
  - Noise reduced by requiring several planes in each event to detect signal

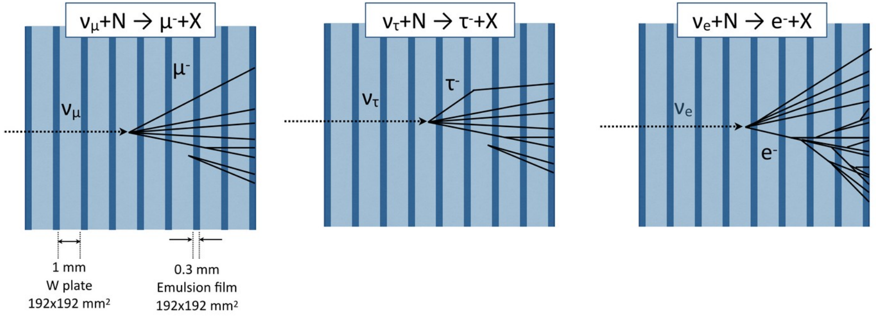


Event reconstruction

- FIRST PHASE electronic detectors
  - Identify neutrino candidates
  - Identify muons in the final state
  - Reconstruction of electromagnetic showers (SciFi)
  - Measure neutrino energy (SciFi+HCAL)



- SECOND PHASE nuclear emulsions
  - Identify EM showers
  - Neutrino vertex reconstruction and secondary search
  - Match with candidates from electronic detectors (timestamp)
  - Complement target tracker for EM energy measurement

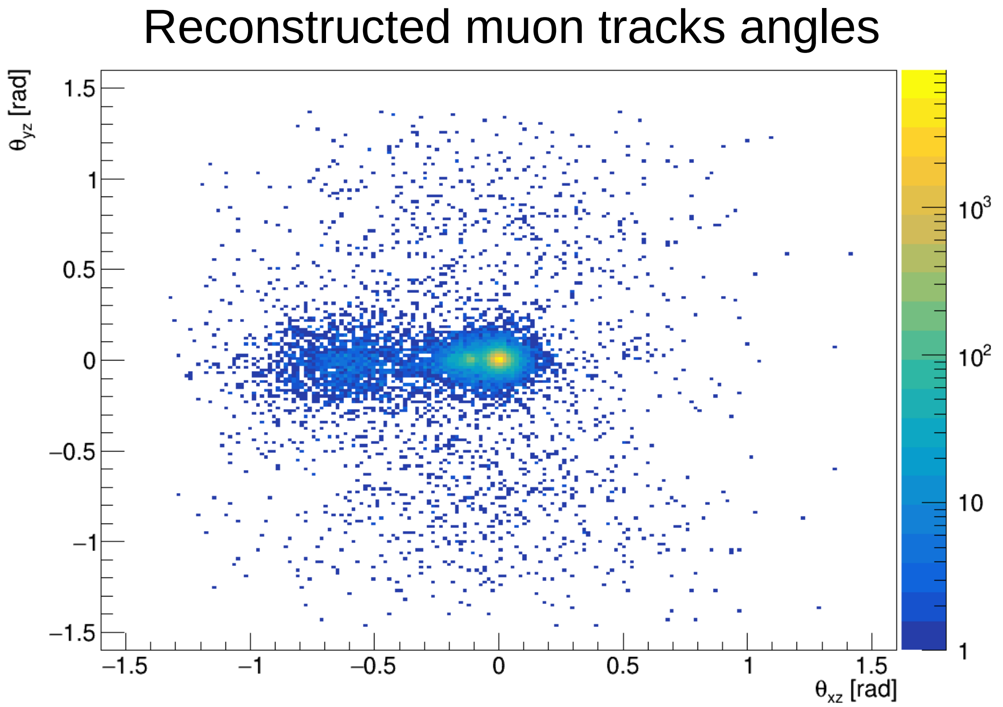


SND@LHC Scattering and Neutrino Detector at the LHC

EPFL

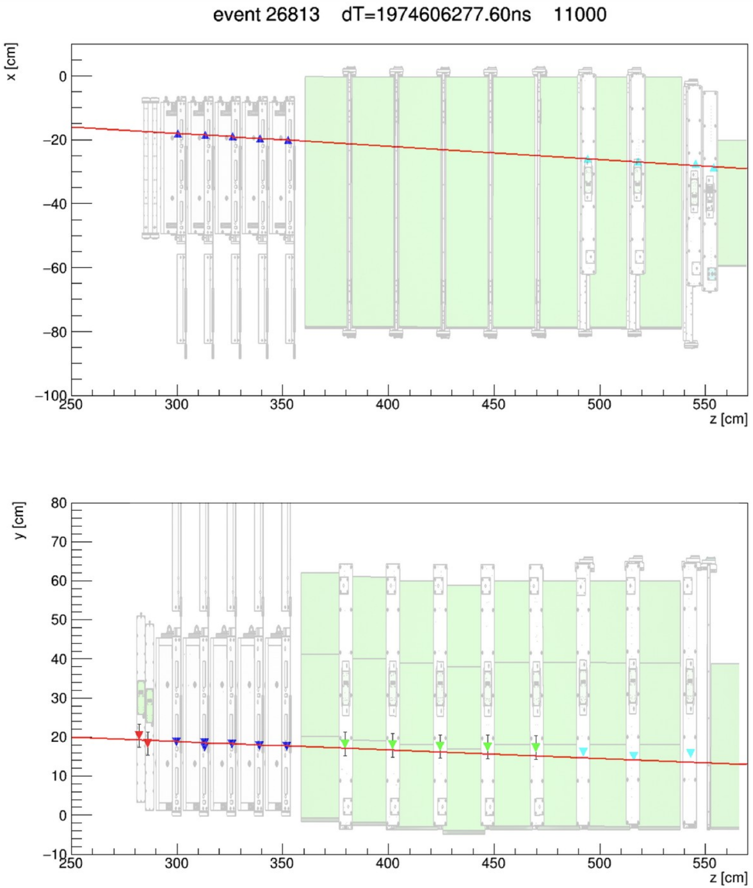
First data – collisions

- Collisions began at the end of May
- Slowly increasing beam intensity
- Collected many thousands of events with muons from collisions



Early measurements (2022)

- Muon background with electronics detectors
  - Muon rates and direction
  - Comparison with simulation
- Neutrino interactions with electronic detectors
  - e.g. shower with no activity in the veto
- Analysis of emulsions
  - 1/20 of the target instrumented with emulsions
  - Extraction in July 2022
  - Evaluation of background, refinement of replacement frequency
- Full emulsion target in July 2022



Summary

- SND@LHC aims at
  - Measuring neutrinos produced at the LHC
  - Search for BSM physics
- SND@LHC has been installed at the end of 2021 and is currently taking data

Backup

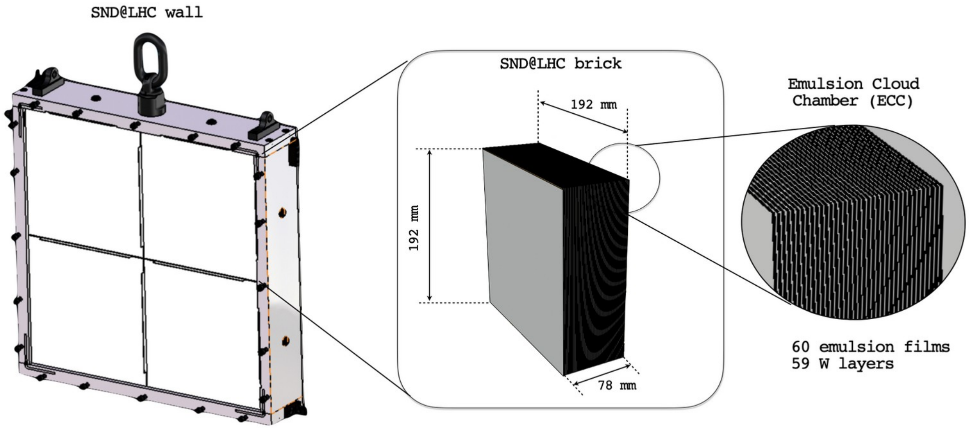
Neutrino physics in Run 3

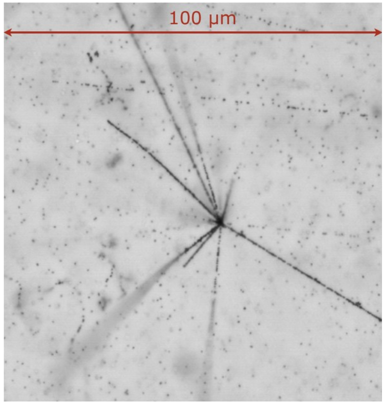
Measurement	Uncertainty Stat.	Uncertainty Sys.
$pp \to \nu_e X$ cross-section	5%	15%
Charmed hadron yield	5%	35%
ν_e/ν_τ ratio for LFU test	30%	20%
ν_e/ν_μ ratio for LFU test	10%	10%
Measurement of NC/CC ratio	5%	10%

Flavour	Neutrinos in acceptance $\langle E\rangle$ [GeV]	Neutrinos in acceptance Yield	CC neutrino interactions $\langle E\rangle$ [GeV]	CC neutrino interactions Yield	NC neutrino interactions $\langle E\rangle$ [GeV]	NC neutrino interactions 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

Emulsion cloud chambers

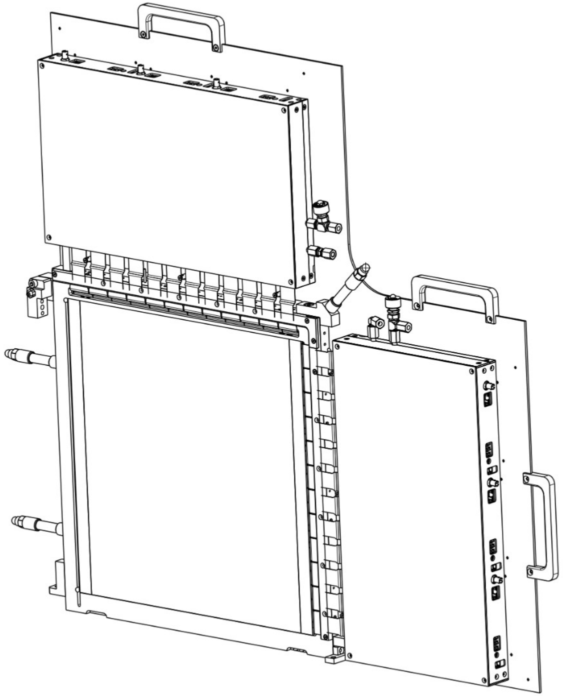
- 5 walls interleaved with SciFi modules
  - 1 wall: 60 alternating layers of tungsten sheets (1 mm) and emulsion films (0.3 mm)
- Micrometric spatial resolution but no timestamp
- Vertex detector, ecal (40 X_0 per wall)
  - Allow to identify tau neutrinos
- Exposed for ~25 fb^{-1}, then developed and scanned

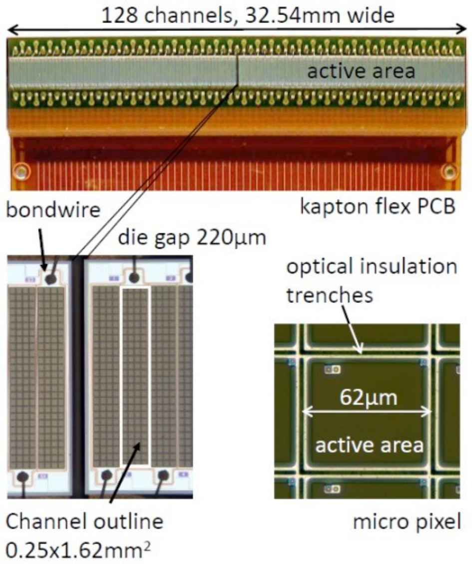


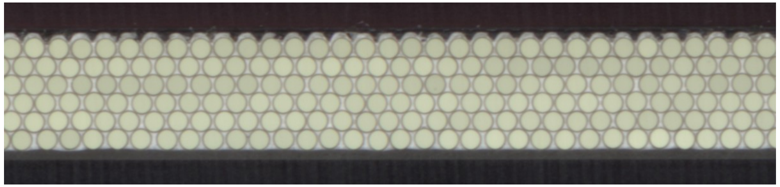


Target tracker

- Based on LHCb SciFi technology
- Scintillating fibre mats read out by SiPMs
  - 39x39 cm^2 active area
- < 100 um spatial resolution
- ~350 ps time resolution
- Locate neutrino interactions in emulsions and assign timestamp
- First energy measurement (refined after emulsions development)

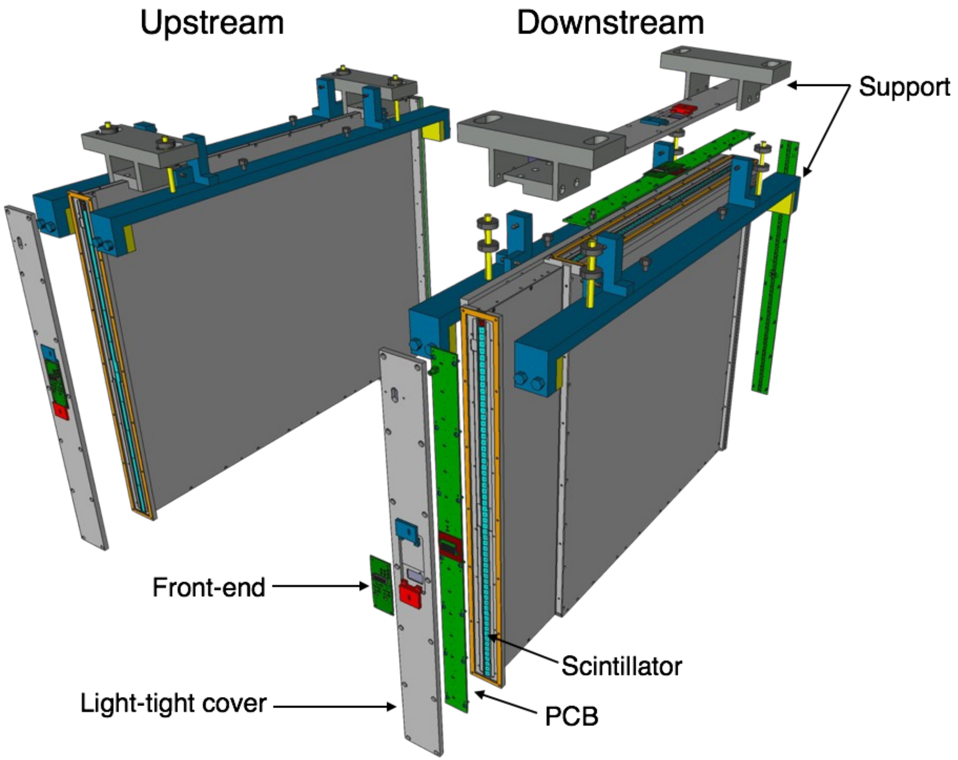






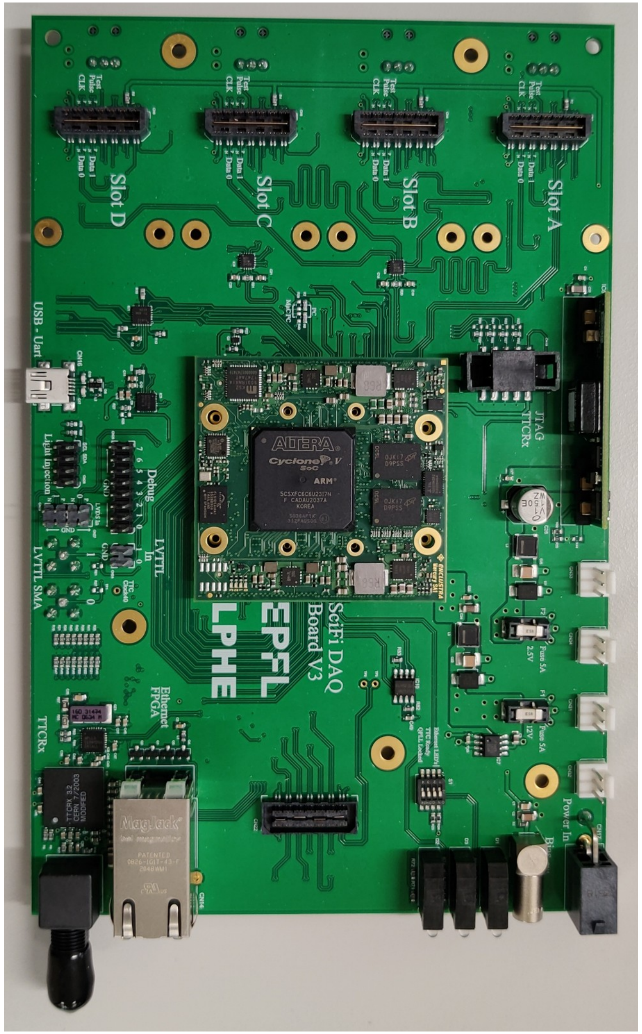
Veto and HCAL-muon system

- Scintillator bar of different sizes
- Veto 42x42 cm^2
  - Optimized for particle detection efficiency
- Upstream HCAL-muon 80x60 cm^2
  - Optimized for energy measurement
- Downstream HCAL-muon 80x60 cm^2
  - Optimized for muon isolation and detection efficiency



The DAQ boards

- Same DAQ board for all subsystems
- Developed at EPFL, based on Cyclone V processor+FPGA
  - Clock from TTC system, using TTCrx chip
  - Data transmitted over Ethernet to the server
- 4 front-end board slots
  - 512 channels in total

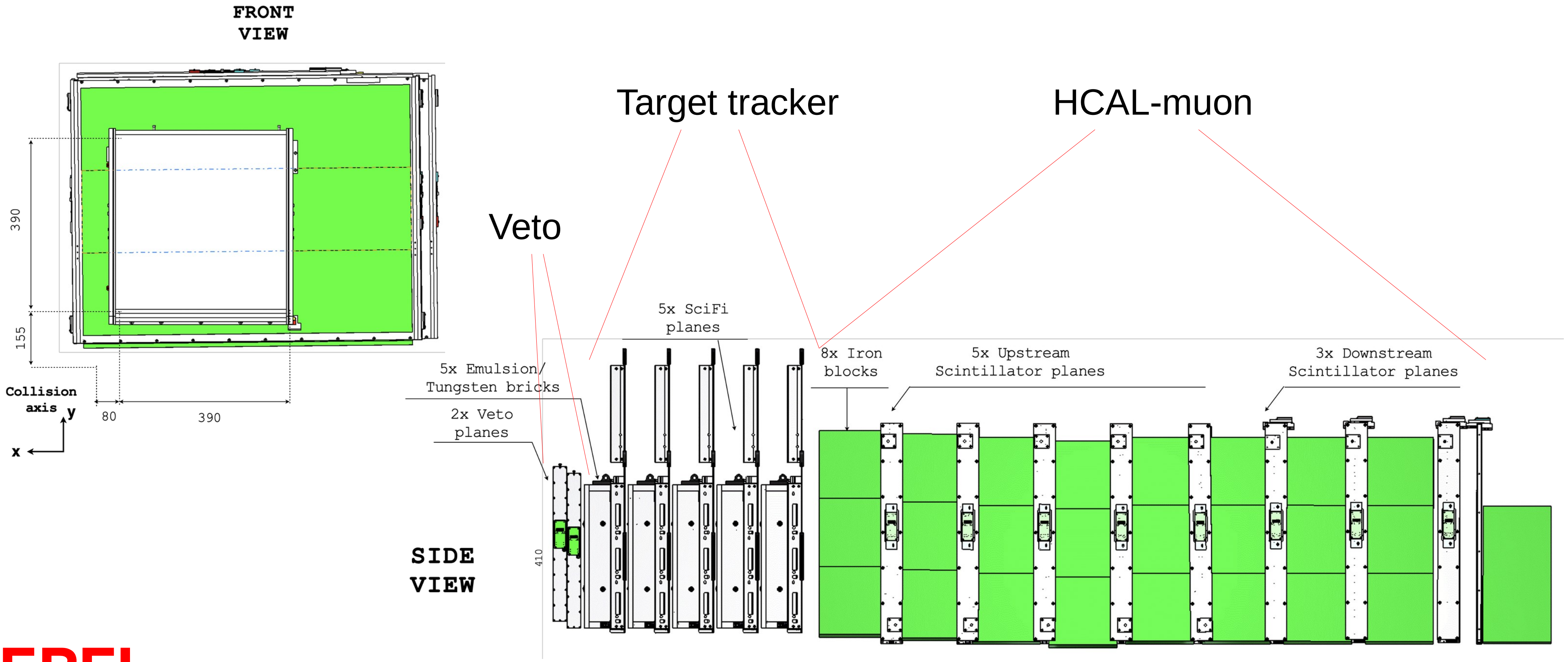


The front-end boards

- Each board contains 2 TOFPET2 chips
  - Analogue front-end and ADCs
  - Data fully digitized
  - 128 channels in total
- Allows for low signal thresholds (0.5 pe)
  - 3-threshold system for best time and amplitude resolution and dark noise reduction
- Good timing (40 ps resolution) and amplitude measurement with charge integration or time-over-threshold

Detector

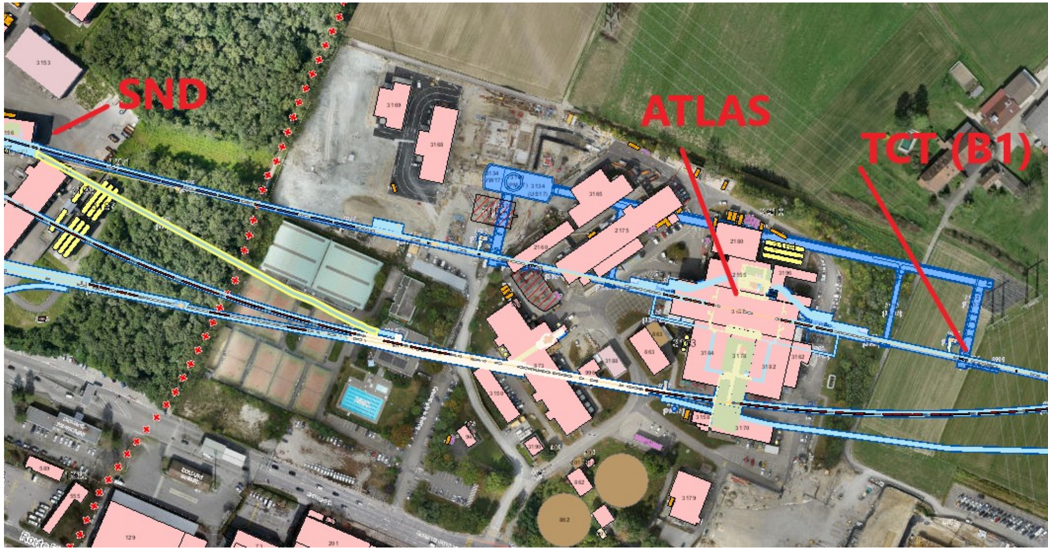
SND LHC
Scattering and Neutrino Detector
at the LHC



FRONT
VIEW
390
155
Collision
axis
y
x
80
390
Target tracker
HCAL-muon
Veto
5x SciFi
planes
5x Emulsion/
Tungsten bricks
2x Veto
planes
8x Iron
blocks
5x Upstream
Scintillator planes
3x Downstream
Scintillator planes
410
SIDE
VIEW

Beam splashes

- Beam 1 hits a collimator on the left side of ATLAS
- A shower of particles is generated
  - O(10^6) muons
- We also see particles coming from Beam 2 splashes in ALICE



Beam splashes

- Beam 1 hits a collimator on the left side of ATLAS
- A shower of particles is generated
  - $O(10^6)$ muons
- We also see particles coming from Beam 2 splashes in ALICE