Scattering and Neutrino Detector at the LHC

Results and plans of SND@LHC

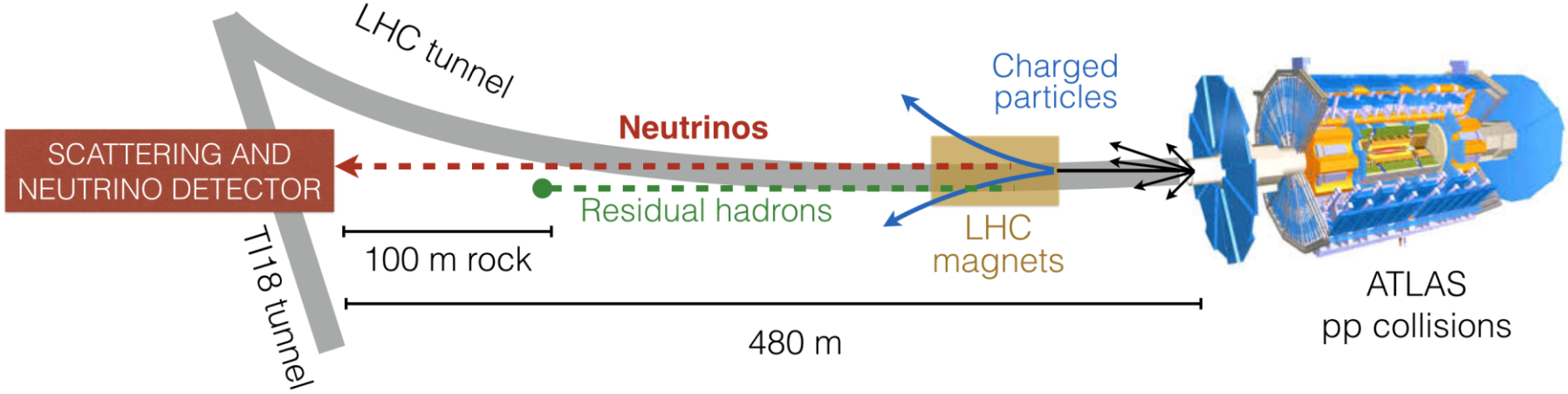
Eric van Herwijnen (Imperial College London)

On behalf of the SND@LHC Collaboration

15 March 2024

LHC Forward Physics Working Group

Scattering and Neutrino Detector @ LHC

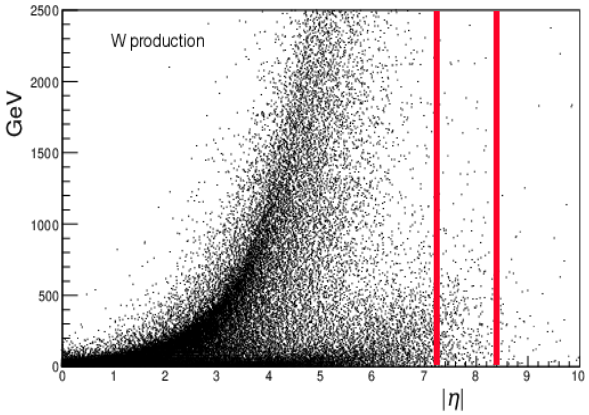


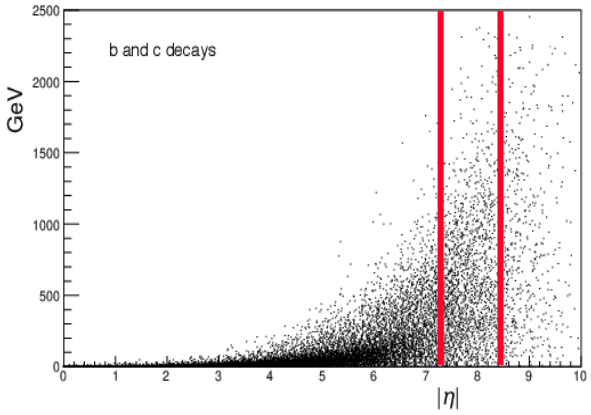
480m downstream of IP1

- off-axis
- $7.2 < \eta < 8.4$

Motivation

- **Large expected ν flux in forward direction**
- **High ν energies: relatively large ν cross sections**
  - **7.2 < η < 8.4: large nb high energy ν from heavy flavour**





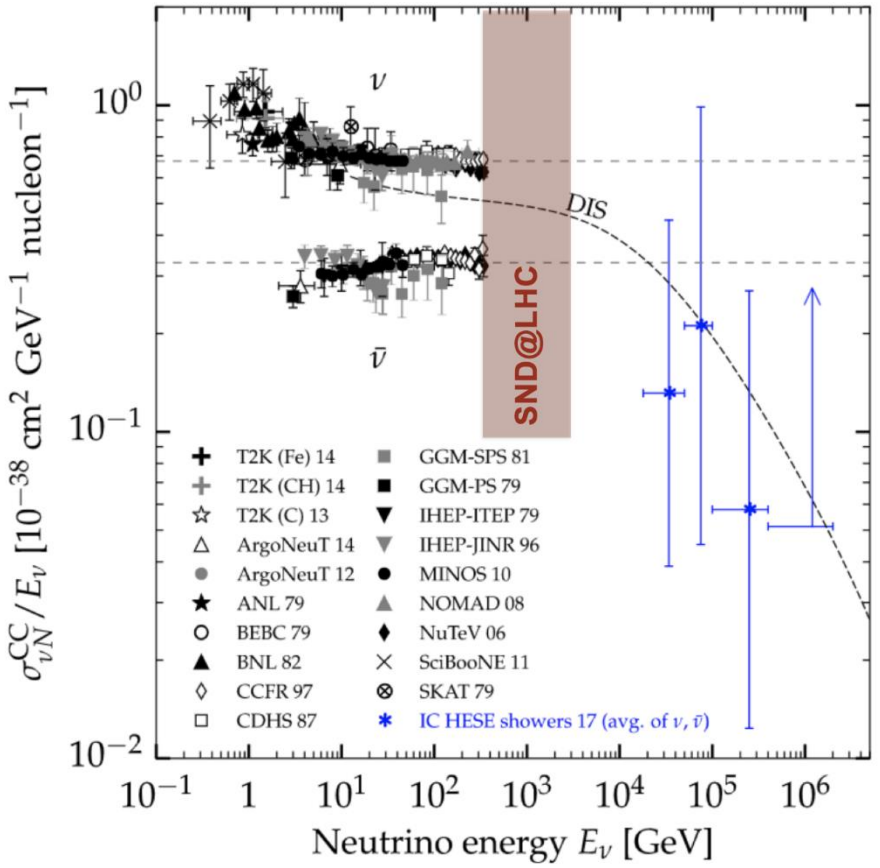
Run3: 250fb^{-1}

Flavour	Neutrinos in acceptance ⟨E⟩ [GeV]	Neutrinos in acceptance Yield	CC neutrino interactions ⟨E⟩ [GeV]	CC neutrino interactions Yield
ν_μ	130	3.0×10^{12}	452	910
$\bar{\nu}_\mu$	133	2.6×10^{12}	485	360
ν_e	339	3.4×10^{11}	760	250
$\bar{\nu}_e$	363	3.8×10^{11}	680	140
ν_τ	415	2.4×10^{10}	740	20
$\bar{\nu}_\tau$	380	2.7×10^{10}	740	10
TOT		4.0×10^{12}		1690

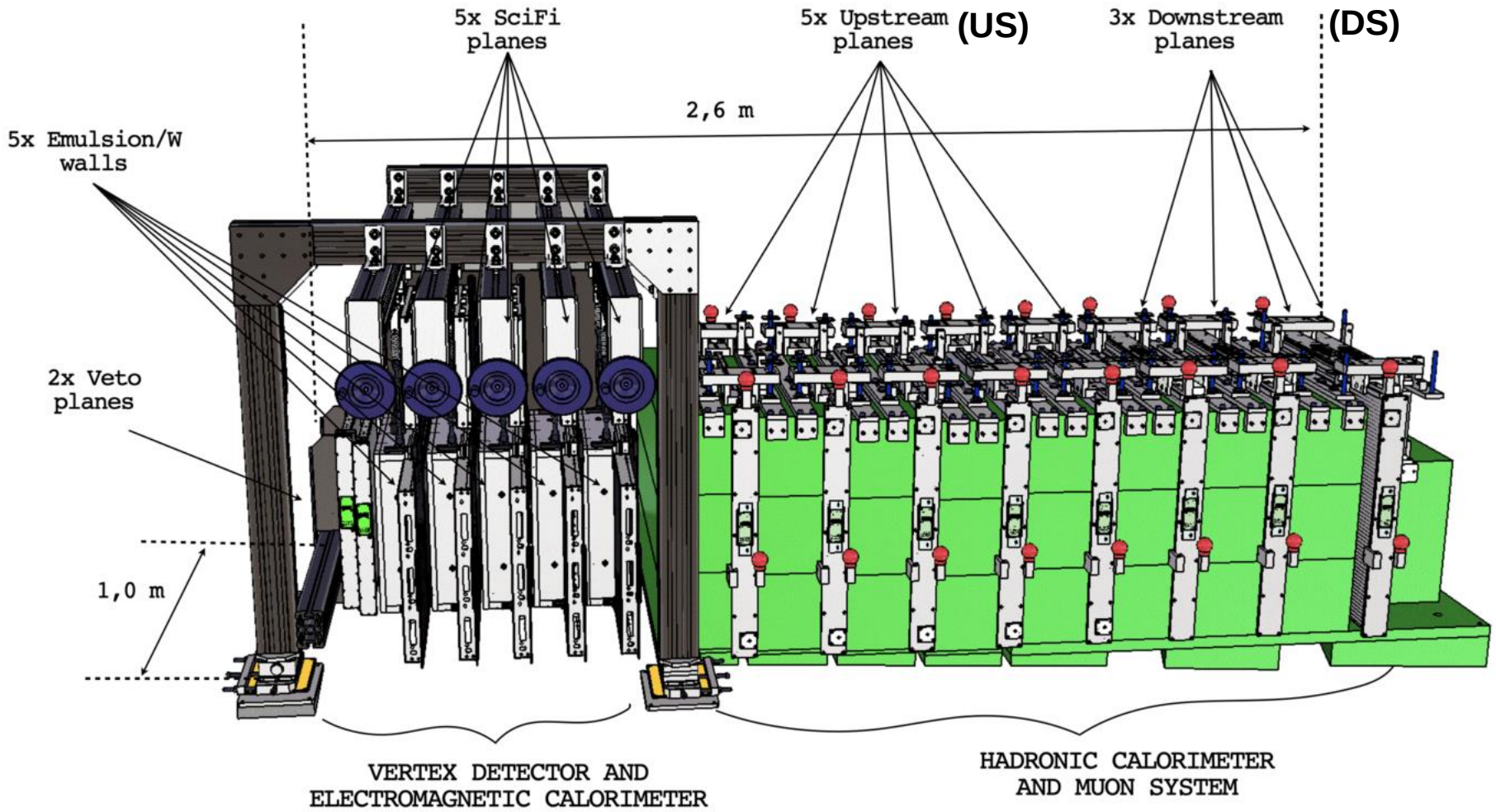
N. Beni et al., "Physics Potential of an Experiment using LHC Neutrinos", J. Phys. G: Nucl. Part. Phys. 46 (2019) 115008, doi:10.1088/1361-6471/ab3f7c [arXiv:1903.06564]

Physics program

- $\sigma_{pp \to \nu X}$ in 7.4 < η < 8.7 range
- ν_e as a probe of charm quark production
- Lepton universality test: ν_τ/ν_e and ν_μ/ν_e
- Measurement of the NC/CC ratio
- Direct search for feebly interacting particles through their scattering



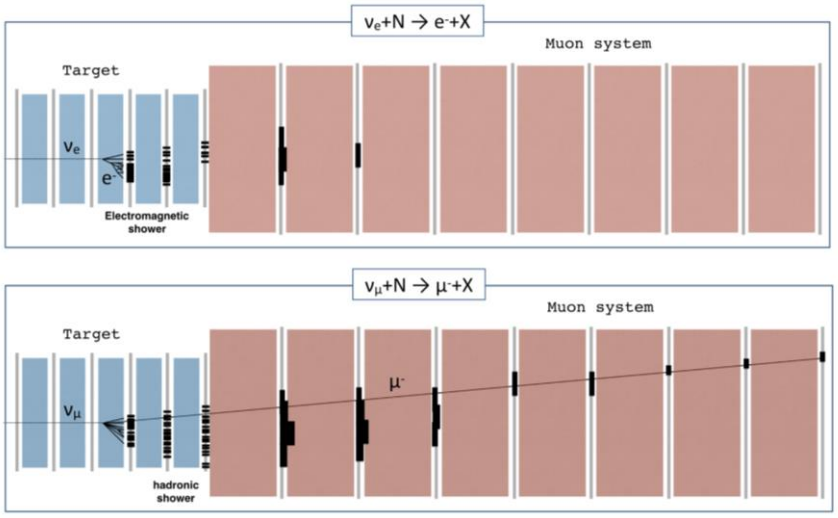
Detector


5x SciFi planes
5x Upstream planes (US)
3x Downstream planes (DS)
2,6 m
5x Emulsion/W walls
2x Veto planes
1,0 m
VERTEX DETECTOR AND ELECTROMAGNETIC CALORIMETER
HADRONIC CALORIMETER AND MUON SYSTEM

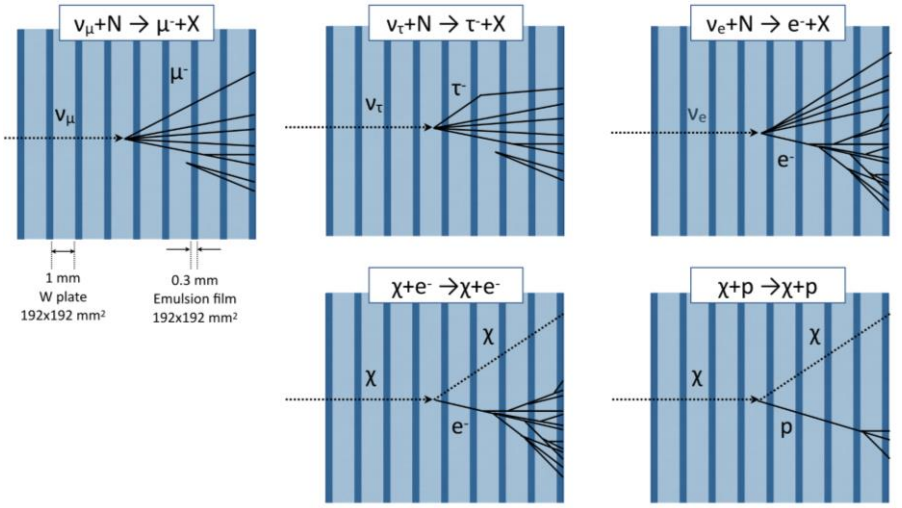
Event reconstruction

- **First phase: electronic detectors**
  - ν candidates
  - μ's
  - em showers (SciFi)
  - ν energy (SciFi+Muon)

- **Second phase: nuclear emulsion**
  - em showers
  - ν vertex reconstruction
  - match with candidates from electronic detectors



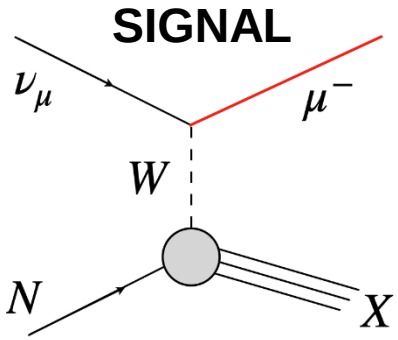
ν_e (top) and ν_μ (bottom) CC interactions

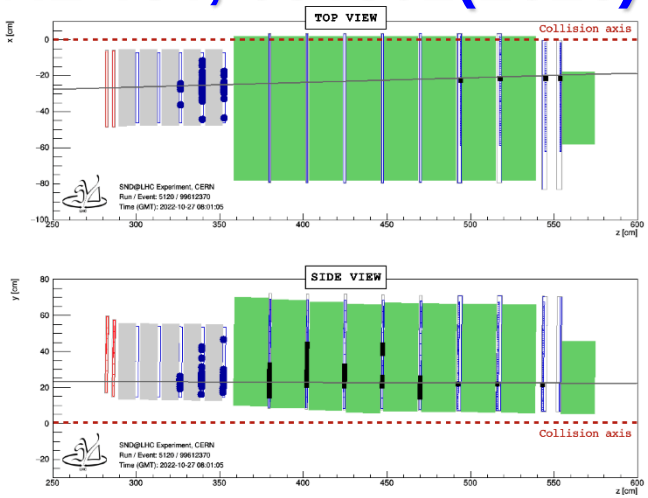


Reconstructible signal topologies in emulsion

ν_μ observation

- **Observation of collider muon neutrinos with the SND@LHC experiment PRL 131, 031802(2023)**



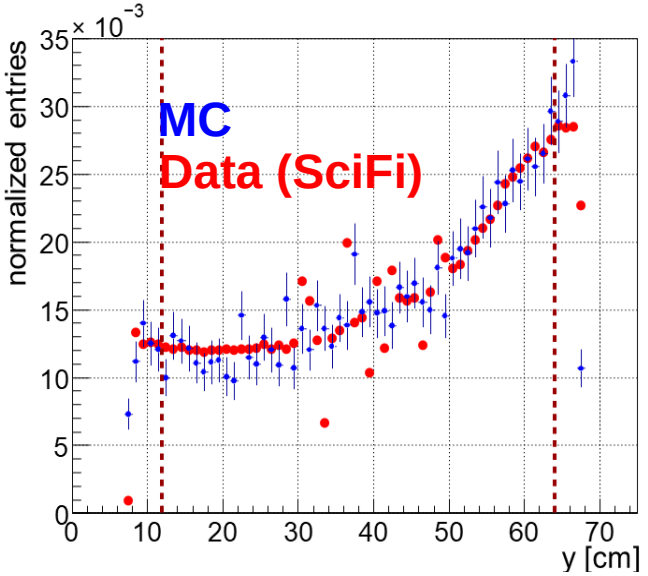


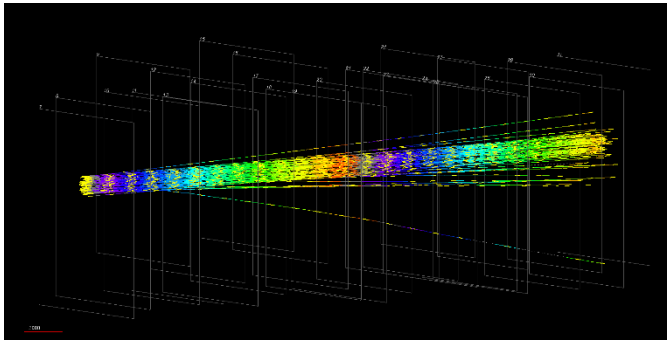
- **Expected 157 ± 37 events in 36.8 fb^{-1} (2022), 4.2 after cuts**
- **Found: 8 with 6.8σ significance**

	Data	Signal simulation
All	8.4×10^9	157
Fiducial volume	4.9×10^5	11.9
One muon-like track	17	6.1
Large SciFi activity	13	5.1
Large hadronic activity	12	4.7
Low muon system activity	8	4.2

Muon flux measurement

- **Measurement of the muon flux at the SND@LHC experiment EPJC 84, 90, (2024)**
  - **SciFi: 2.06± 0.01(stat.) ± 0.12(sys.) ×10^4 cm^{-2}/fb^{-1}**
  - **DS: 2.02 ± 0.01(stat.) ± 0.08(sys.) ×10^4 cm^{-2}/fb^{-1}**
- **Data/MC simulation agreement 25%**
- **Results in emulsion:**
  - **Data: 1.5± 0.01×10^4 cm^{-2}/fb^{-1}**
  - **MC: 1.4×10^4 cm^{-2}/fb^{-1}**

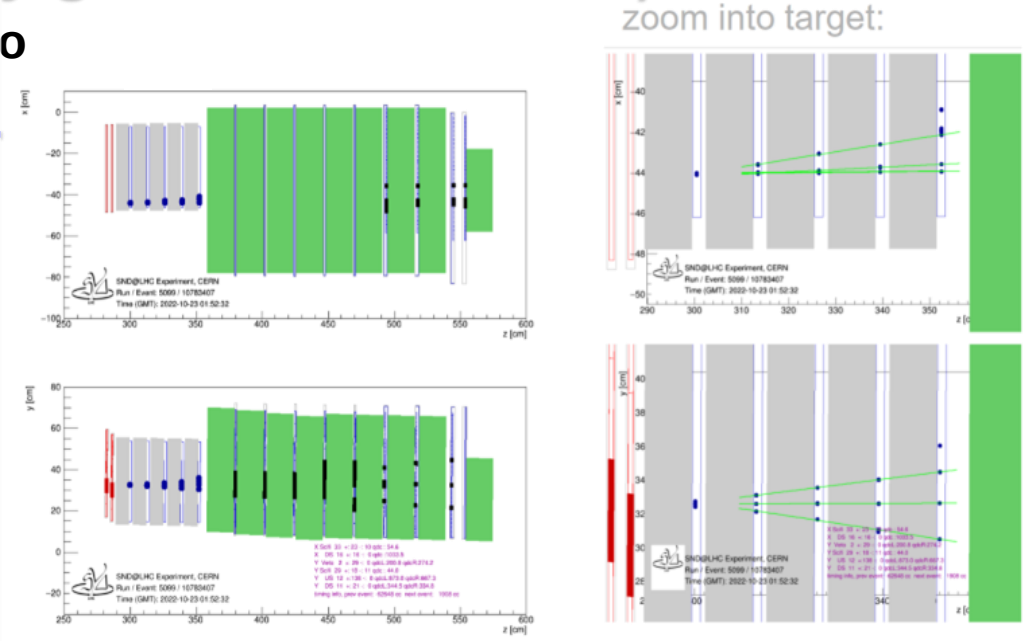




Track display in 25 films, starting from 1 mm^2 around the emulsion film center. The colors represent base-tracks in the different emulsion films of the target.

Muon tridents

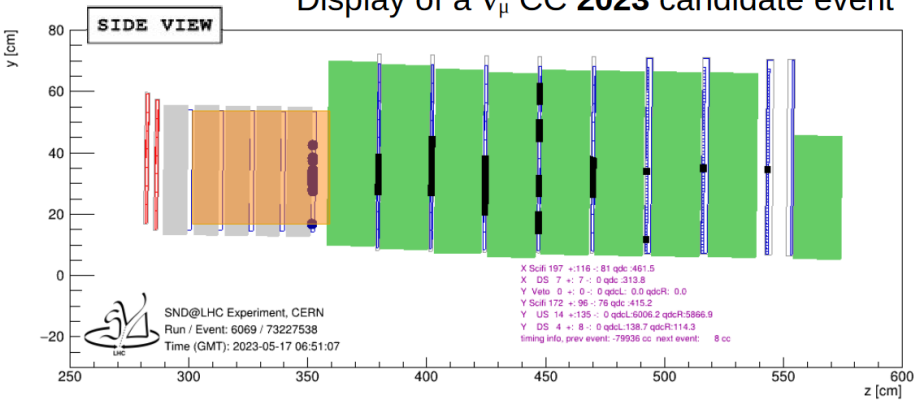
- $\mu^{\pm} + N \rightarrow \mu^{+}\mu^{-}\mu^{\pm} + N$ **(genuine trident)**
- $\mu^{\pm} + N \rightarrow \mu^{\pm} + N + \gamma, \gamma + N \rightarrow N + \mu^{+} + \mu^{-}$ **(muon bremsstrahlung followed by gamma conversion)**
  - **Can distinguish between the two**
- **Process recently in Geant4**
  - **Validation**
  - **Also in heavy ion collisions**

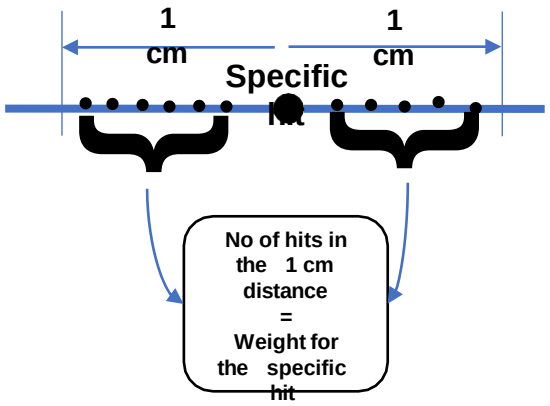


2023 update

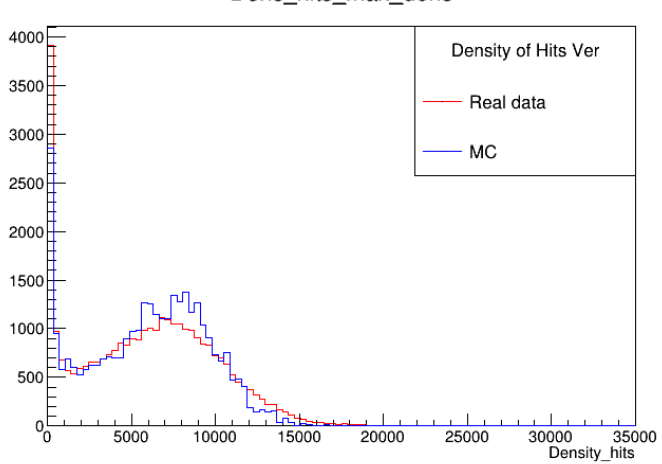
- **Muon neutrinos. Relaxed fiducial volume cuts:**
  - **15 events (2022), 17 events (2023)**
  - **Factor 2 analysis improvements**
- **Electron neutrinos**
  - **Use SciFi hit density as discriminating variable**

Display of a ν_μ CC **2023** candidate event





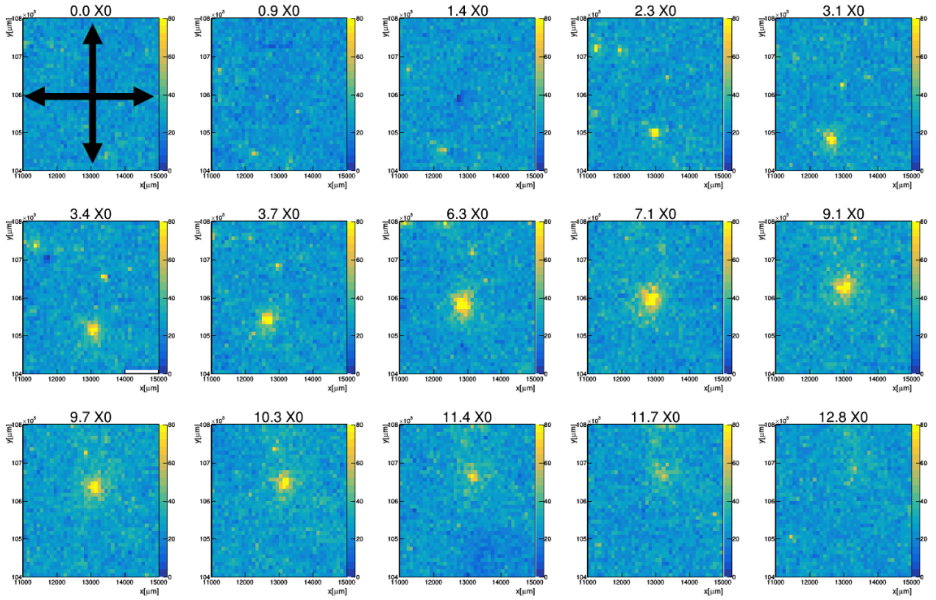
SciFi hit density distribution in Test beam



Emulsion

- **Hints for neutrino interactions seen**

Cluster development



4x4 mm² region
100 µm binning

Global aligned reference frame

Starting plate 12

X0 = 3,504 mm
Only tungsten

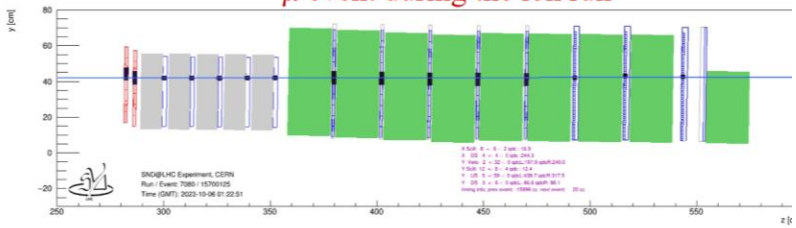
Maximum width at 7.4 X0 = P38

Muon flux in 2023 ion run

- **Preliminary results**

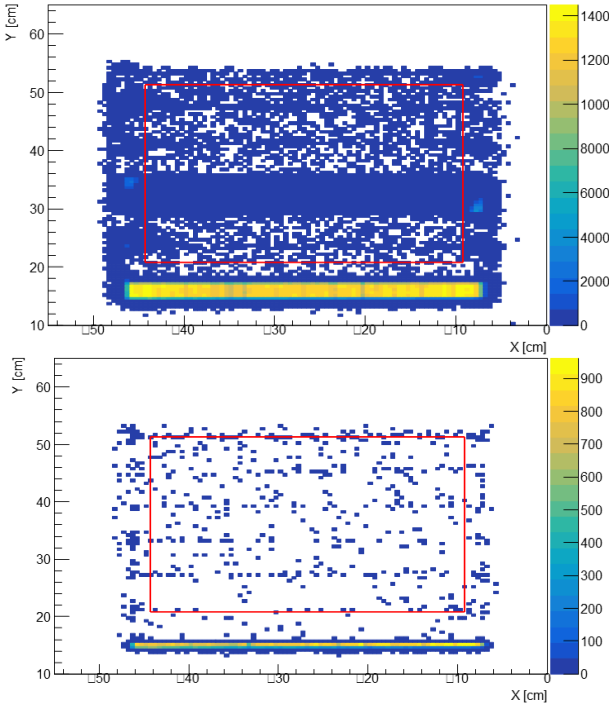
- SciFi: $\Phi_\mu = (4.8 \pm 0.1) \times 10^4$ nb/cm^2
- DS: $\Phi_\mu = (4.4 \pm 0.1) \times 10^4$ nb/cm^2
- MC $\Phi_\mu = 2.9 \times 10^4$ nb/cm^2
- $\Phi_\mu^{ion}/\Phi_\mu^{pp} = 2 \times 10^6$
- Cross section ratio: $\sigma_{inel}^{ion}/\sigma_{inel}^{pp} = 0.6 \times 10^4$
- Collision rate @IP1: 1.6 GHz (pp), 2.9 MHz (ions)
- μ rate @detector: 0.4 Hz/cm^2 for pp, 0.05 Hz/cm^2 for ions
- μs per collision in ion run ~65 times larger than in pp

μ event during the ion run

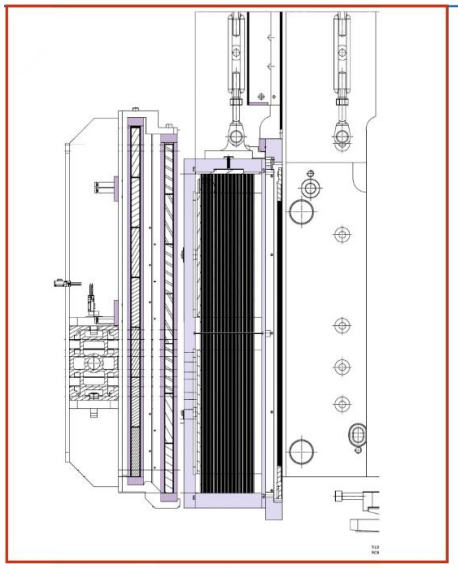


Veto upgrade (2023-2024 YETS)

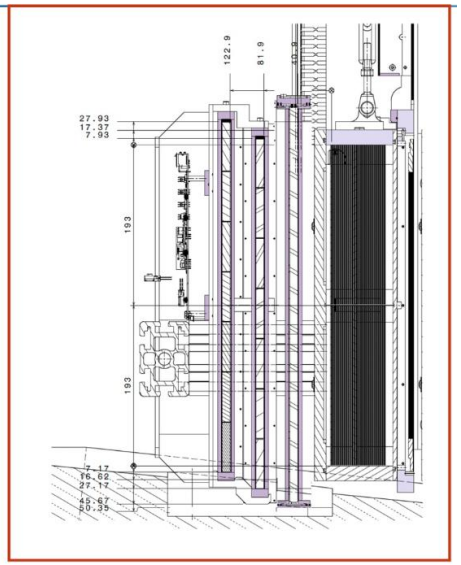
- **Fiducial volume cut removes 92% of ν CC interactions**



Extrapolated position of the reconstructed Scifi track at Veto plane 0 (top) and Veto plane 1 (bottom)

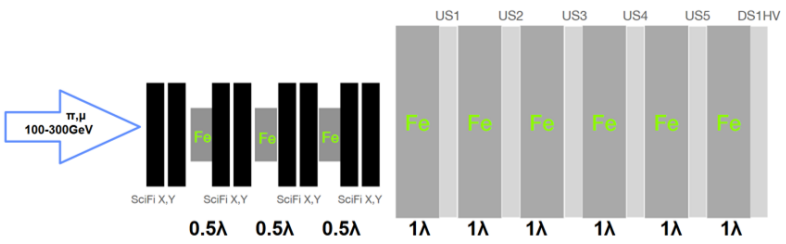


Previous layout: two planes with H bars

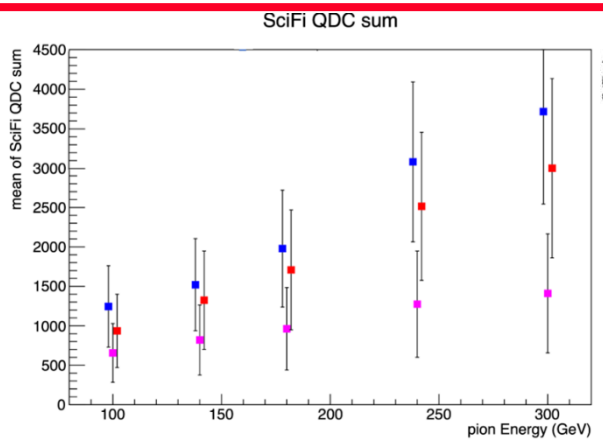


Upgraded layout: third plane with vertical bars

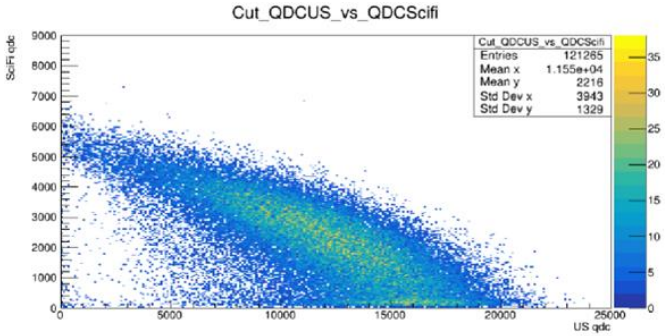
Energy calibration



Testbeam layout

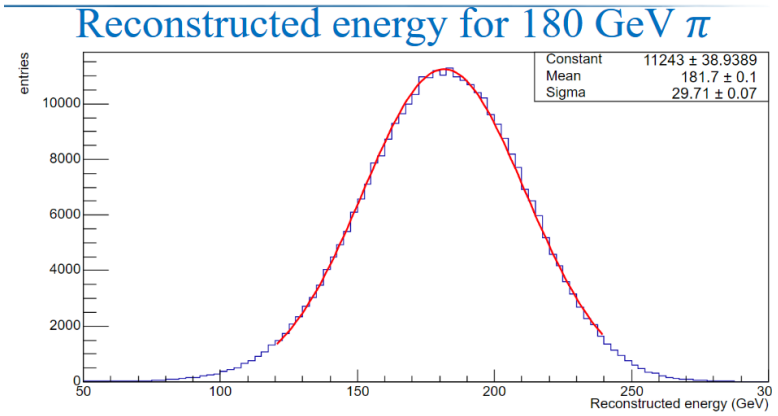


SciFi response for particles of various energy



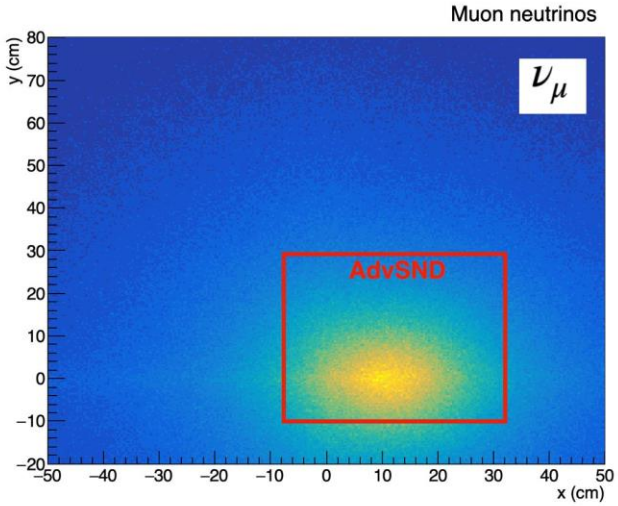
Linear correlation between the energy response of SciFi and US

$$E = k \times QDC_{SciFi} + \alpha \times QDC_{US}$$

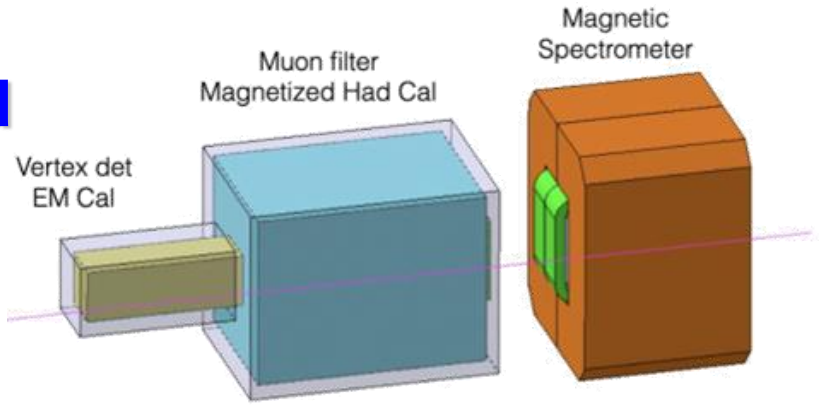


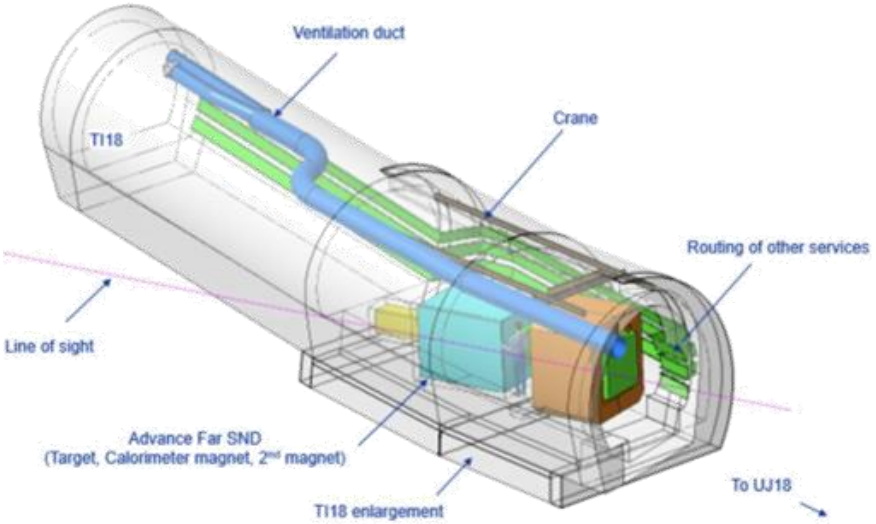
AdvSND (for HL-LHC)

- **Silicon vertex detector required**
  - **Re-use CMS tracker**
- **2.5 x 10^5 ν and $\bar{\nu}$ CC DIS ints of all flavours (for 3 ab^{-1})**



η > 7.9

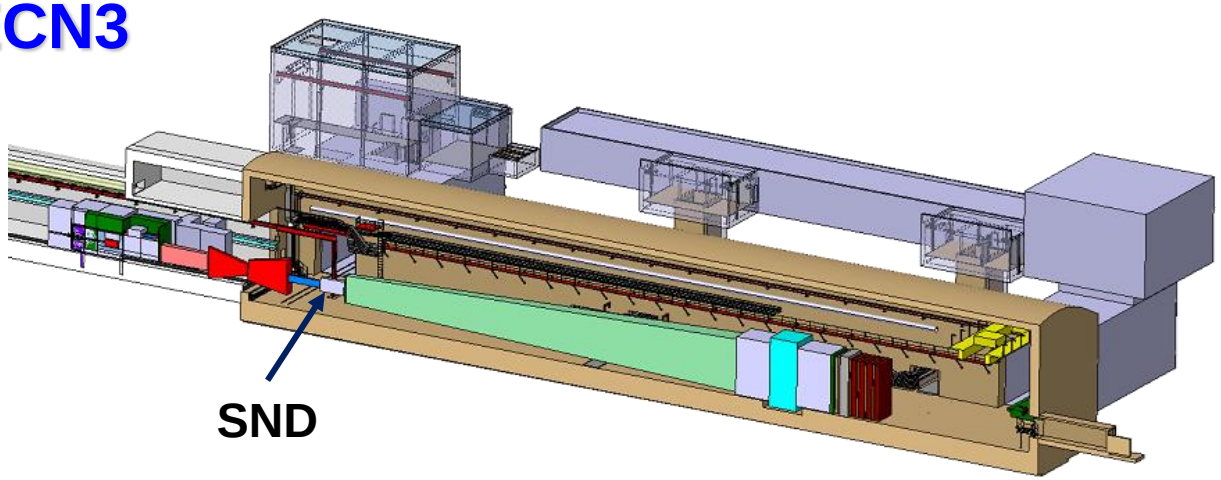




- **LOI being prepared**

SHiP

- **Approved in ECN3**



- **AdvSND will be a prototype for SHiP's SND detector**

Conclusions

- **Efficient data taking in 2022 (95%) and 2023 (99.7%)**
- **Relaxed fiducial volume cut: ν_μ ints doubled**
- **Muon flux measured, also in heavy ion data**
- **ν_e interactions**
  - **hints in electronic detectors and emulsion**
- **Veto upgrade will enhance rejection power**
- **Muon trident-like events seen**
  - **Validate MC**
- **Energy calibration**
  - **Estimate hadronic energy in ν_μ candidates**