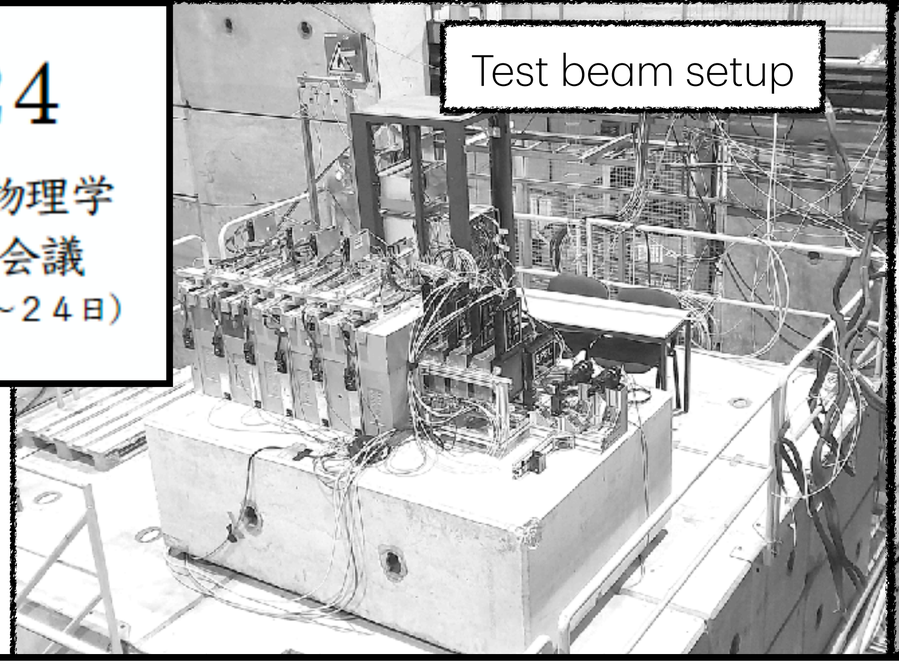
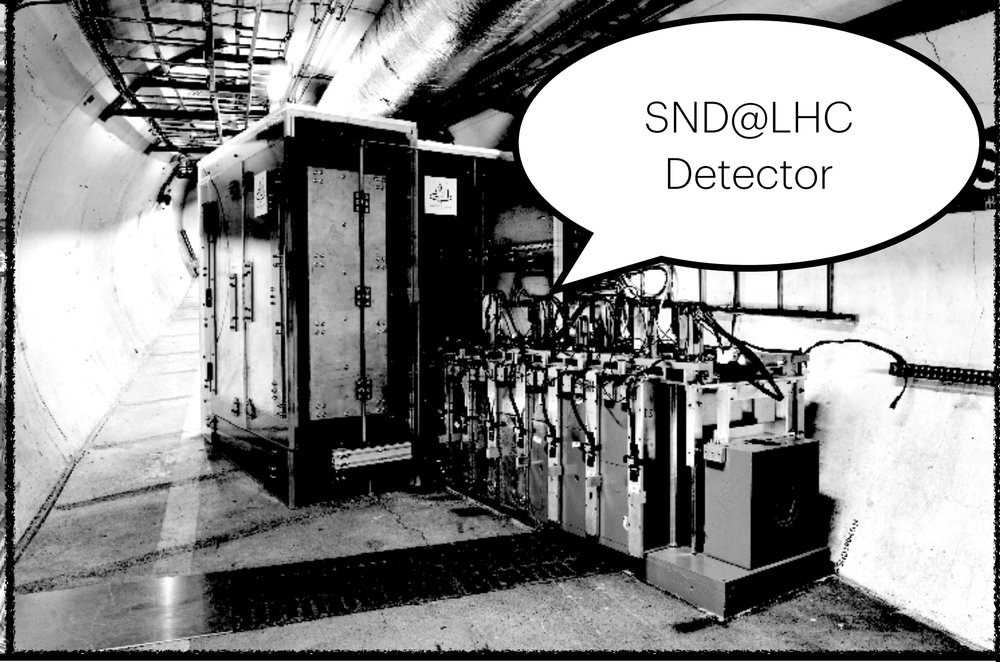
CALOR 2024

第２０回 素粒子・原子核物理学
カロリメータ検出器国際会議
（つくば国際会議場, 2024年5月20日～２４日）





Test Beam results of the Hadronic Calorimeter of the SND@LHC experiment

Gerardo Vasquez
SND@LHC collaboration

LHC
Scattering and Neutrino Detector
at the LHC

Universität Zürich[UZH]

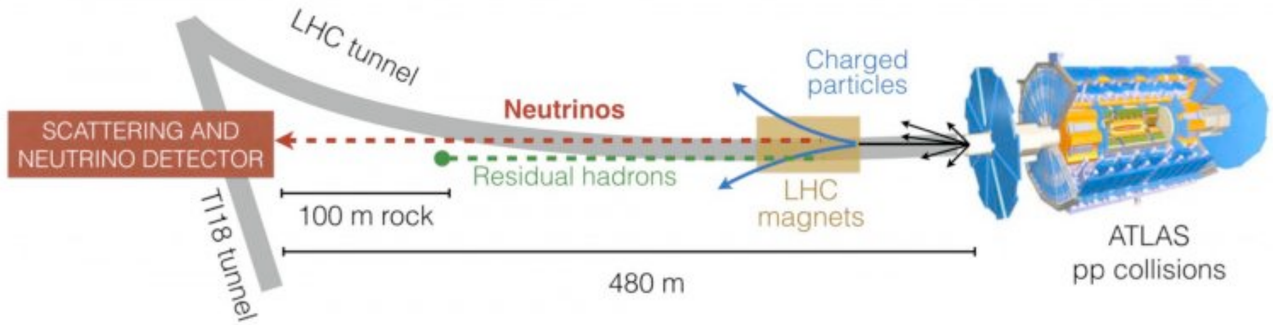
Outline

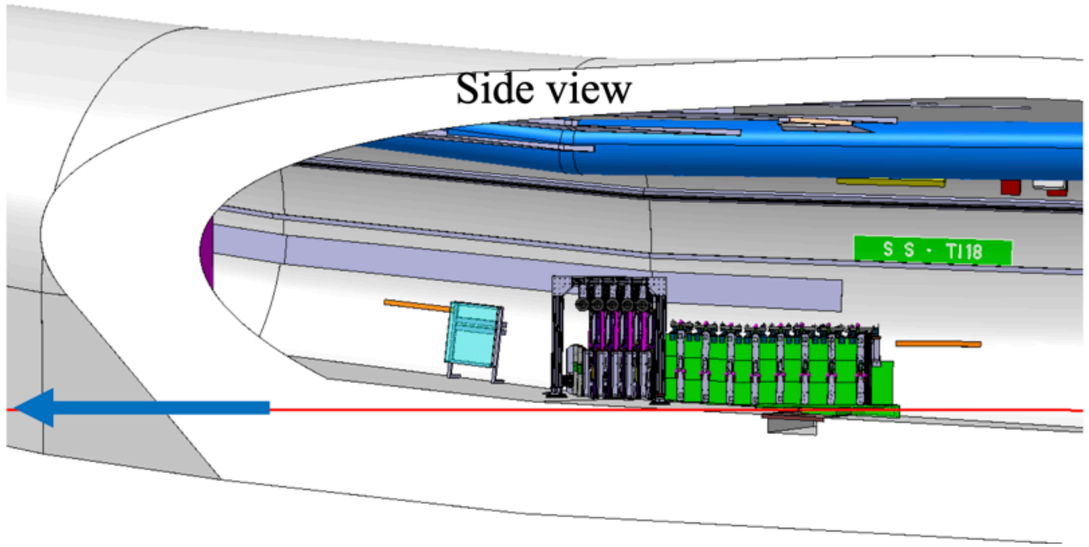
LHC
Scattering and Neutrino Detector at the LHC

* SND Experiment
* SND Detector
* Test Beam setup
* Sampling on Muons and HCAL Efficiency
* Saturation Observed
* Shower Profile
* First Energy calibrations
* Summary & Conclusions

SND@LHC Experiment

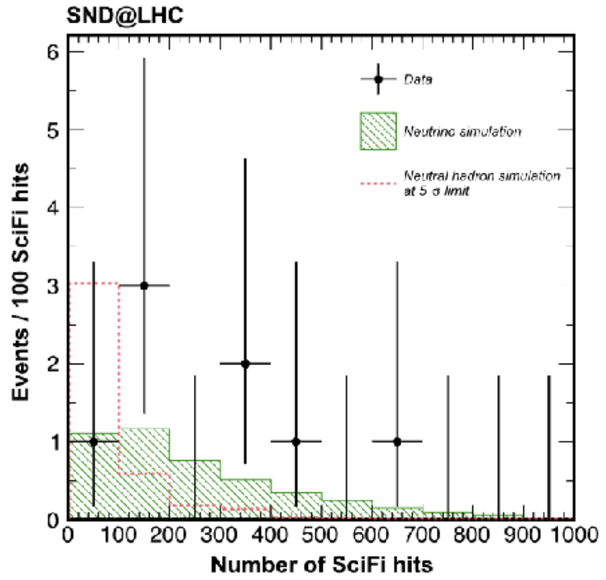
Designed to perform measurements with high-energy neutrinos (100 GeV to a few TeV) produced at the LHC in the region $7.2 < \eta < 8.4$.





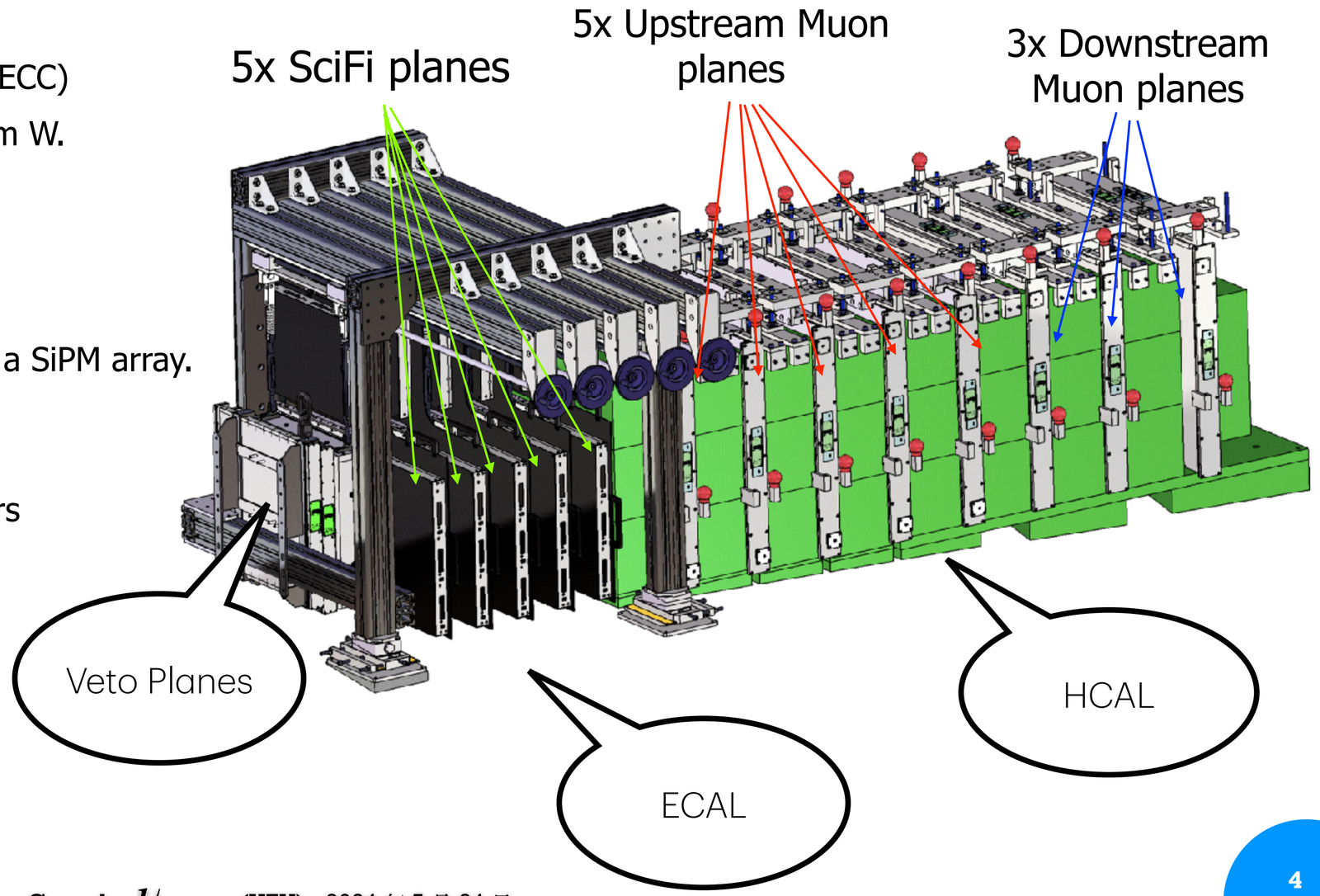
- Study ν interactions of all flavours at unexplored energy scale
- Probe heavy flavour production (off-axis location) with ν at unexplored rapidity range
- Search for recoil signatures of FIPs

First Observation of ν_μ publication



SND Detector

- **VETO** system:
  - 3 layers of Plastic Scintillating to tag incoming muons
- **Neutrino Target & Vertex Detector** ~830kg
  - 5 Walls of 4 units of Emulsion Cloud chambers (ECC)
  - Each ECC is 60 emulsion film interleaved with 1m W.
- **Tracker and ECAL**
  - Scintillating Fibres (**SciFI**) between each wall
  - 40x40cm^2 planes, alternating X and Y
  - Staggered 250um polystyrene fibres readout by a SiPM array.
- **Hadronic Calorimeter**:
  - 5 Upstream Layers (**US**):
  - Sampling of 20cm Fe + 1cm thickness Scint. Bars
  - Dual readout of Scint. Bars with 8 SiPM
  - Horizontal bars of 6cm x 1cm x 81cm
- **Muon System:**
  - 3 Downstream Layers (**DS**):
  - Horizontal and Vertical Scintillating bars
  - Bars of 1cm x 1cm x 80 cm



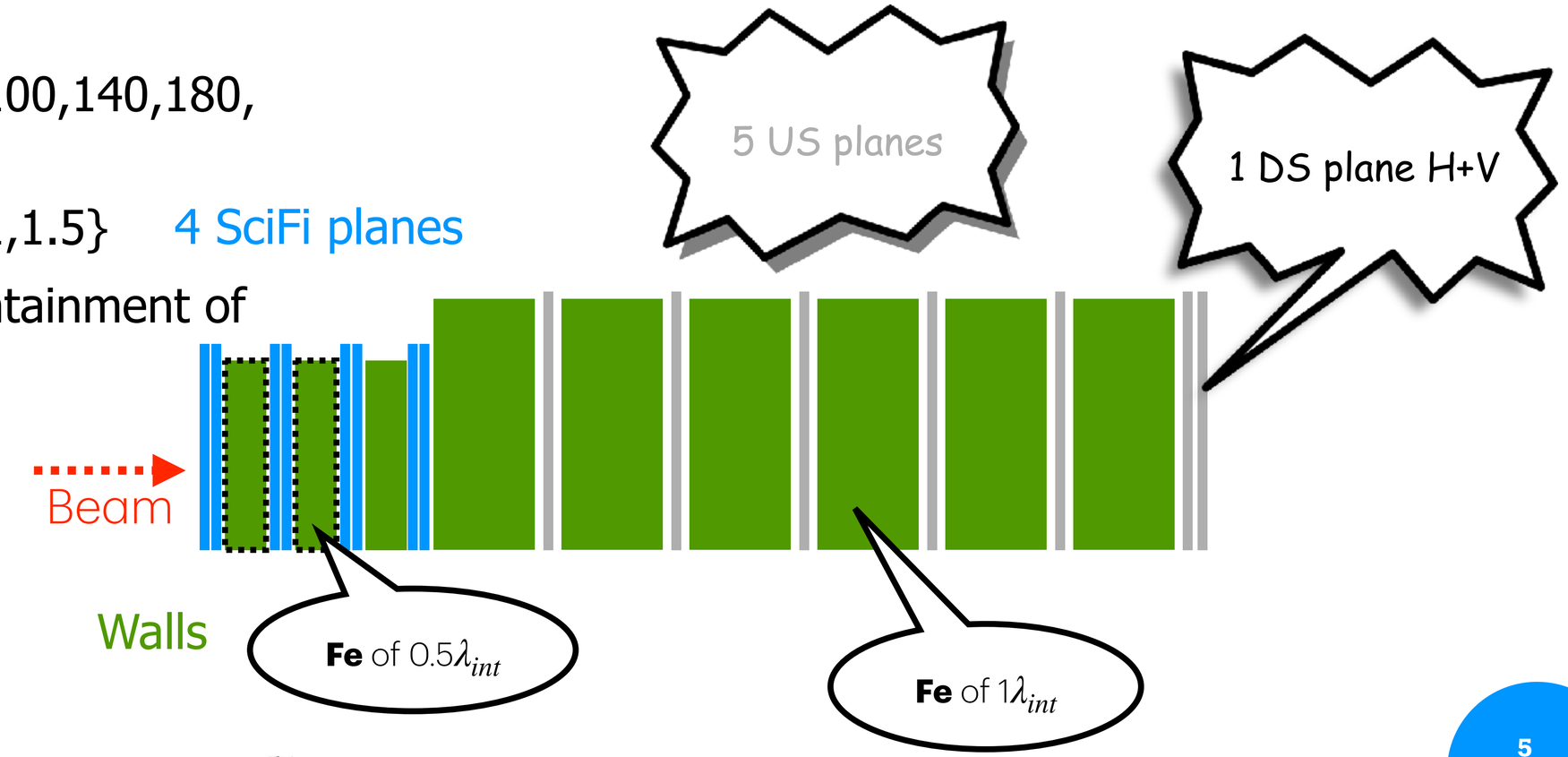
Test Beam 2023

All energetic νN collisions produce hadronic showers

* Understand the share between ECAL and HCAL
* Energy response, Shower profile, signal linearity, detectors effects…

Setup

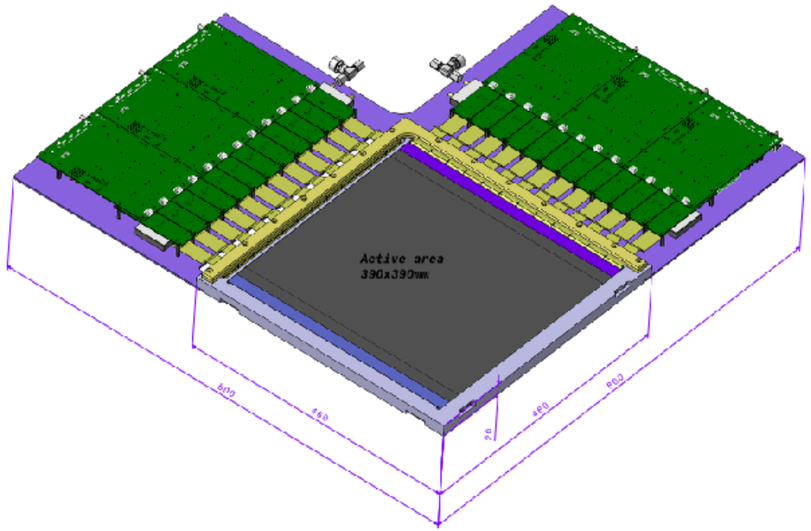
* SPS H8 Beam line - Hadrons {100,140,180, 240, 300} GeV
* Different λ_{int} on **target** - {0.5,1,1.5}
* Total of 7.5λ_{int} for a shower containment of 95% at 300 GeV
* 4 SciFi layers (x and y planes)
* 5 Planes of US and 1 DS plane
* Same DAQ as SND@LHC



Readout and DAQ

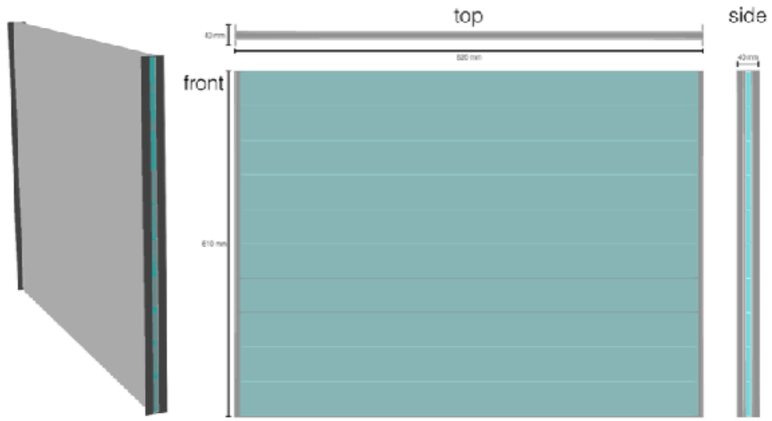
SciFi

- 4 13x13cm^2 SciFi stations
- 512 SiPM channels available per X and Y to readout a 250um fibre



US layers (HCAL)

- 10 bars per layer, with 8 SiPM readout per side.
- **6 Large SiPM** and **2 Small SiPM** per side
- MIP response with 60 p.e. (sum of 6 channels)



US Layers

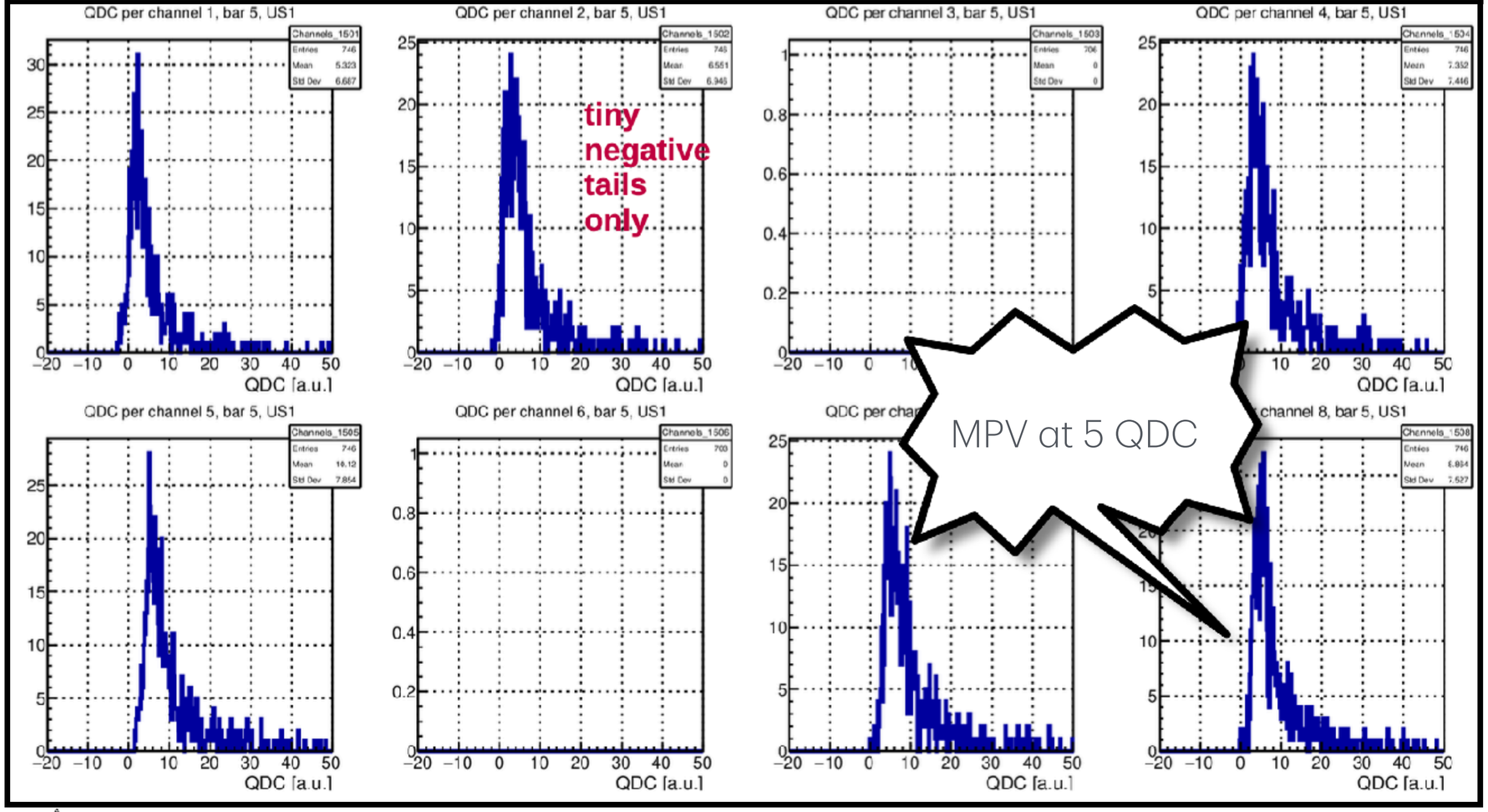
DAQ

- Readout through TOFPET2.
- Time and charge are calibrated using test pulse.
- Working on TriggerLess mode
- All signals exceeding threshold are readout by the FE electronics and **clustered in time to form events**

Sampling on MIPs

US QDC distribution

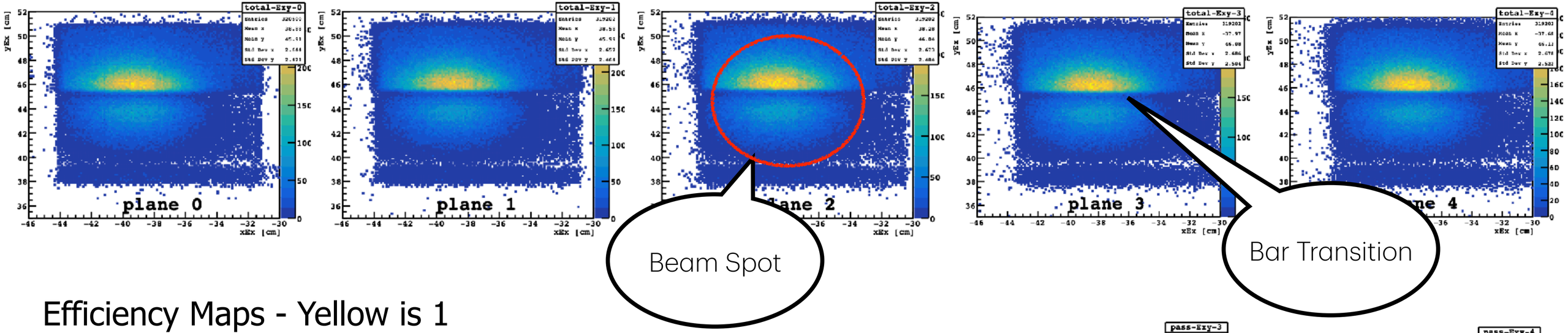
QDC dist. on US1 (all 12 SiPM fired) - Bar on Beam



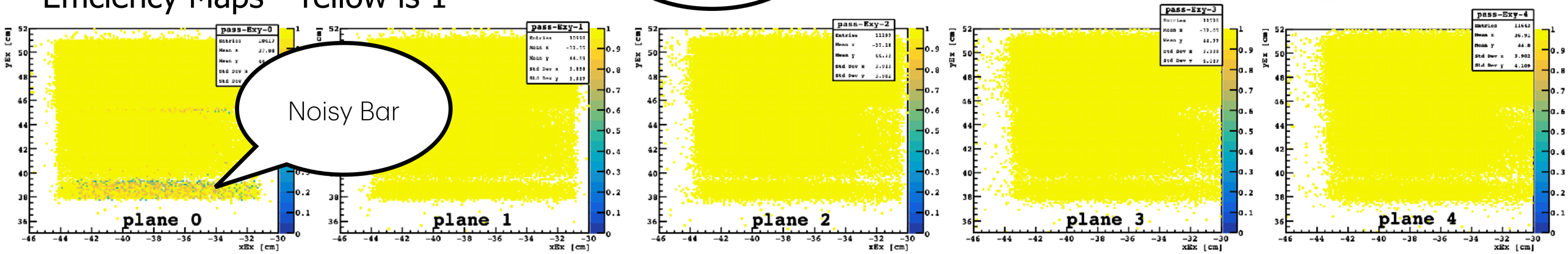
HCAL Efficiency

Scattering and Neutrino Detector at the LHC

Extrapolated **tracks with good quality** ($\chi^2/NDF < 20$) from **SciFI-DS** to **US** planes, with hits >10 SiPM (out of 12)

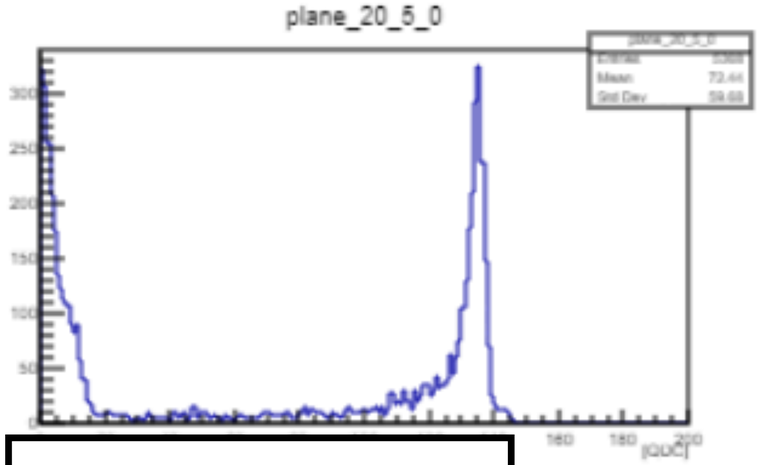


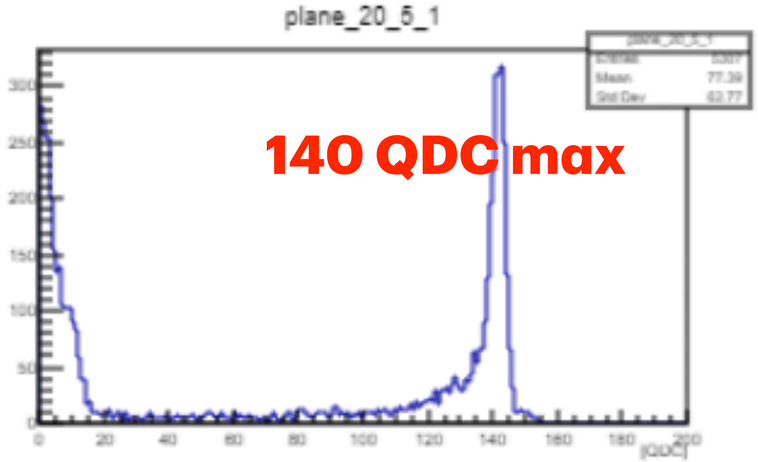
Efficiency Maps - Yellow is 1

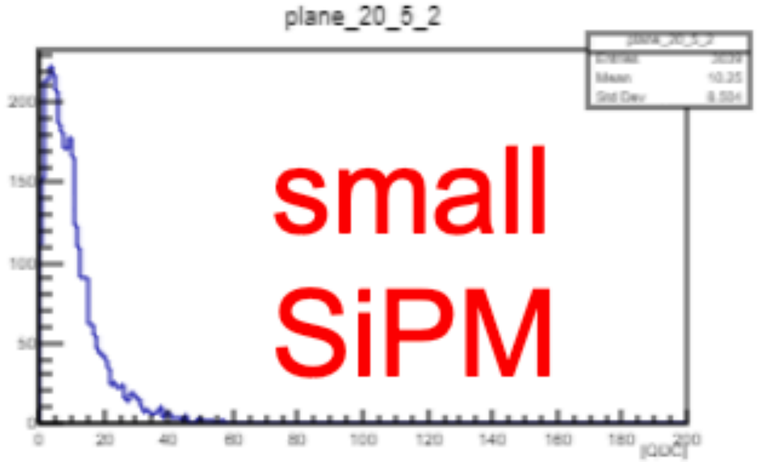


Saturation on US

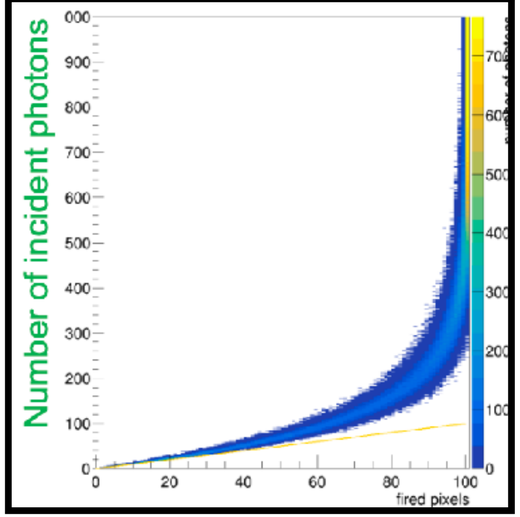
US1 bar central bar - 300 GeV pion 3 Walls





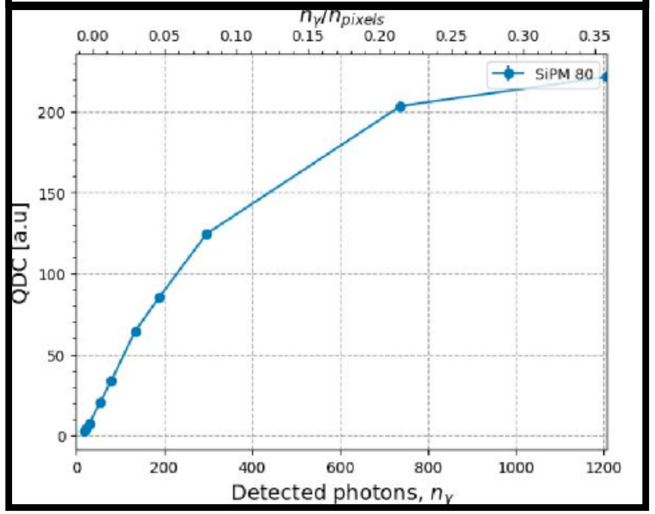


Toy MC with 100 pixels



- SiPM channels working under same gain as the experiment.
- TOFPET QDC **range max at 180?**, saturation observed at 140 QDC units.
  - Large SiPM not saturated (S14160-6050HS have 14k pixels)
- Electronic saturation a 1k Photons agreement on Laser measurement and MC

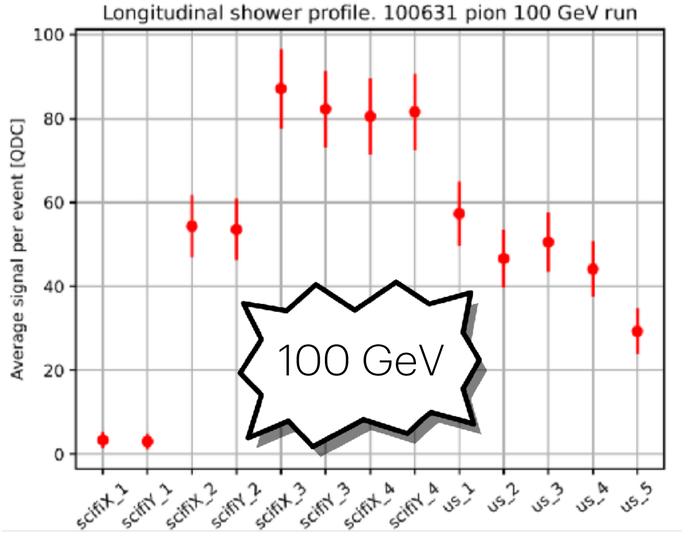
Laser Measurement on a Single

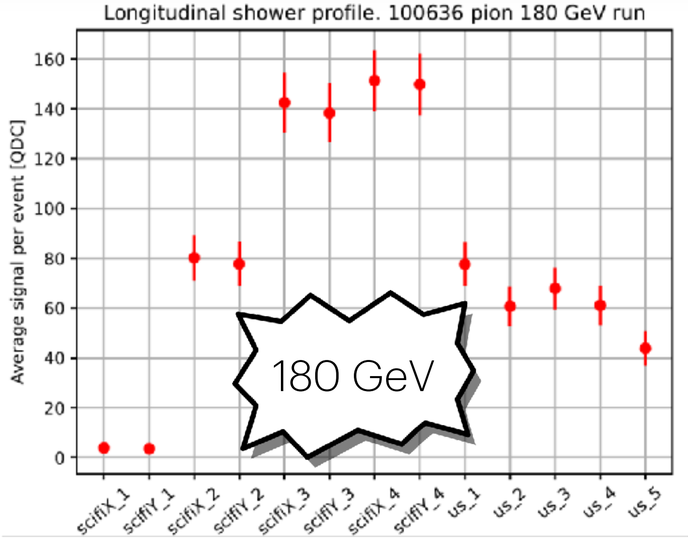


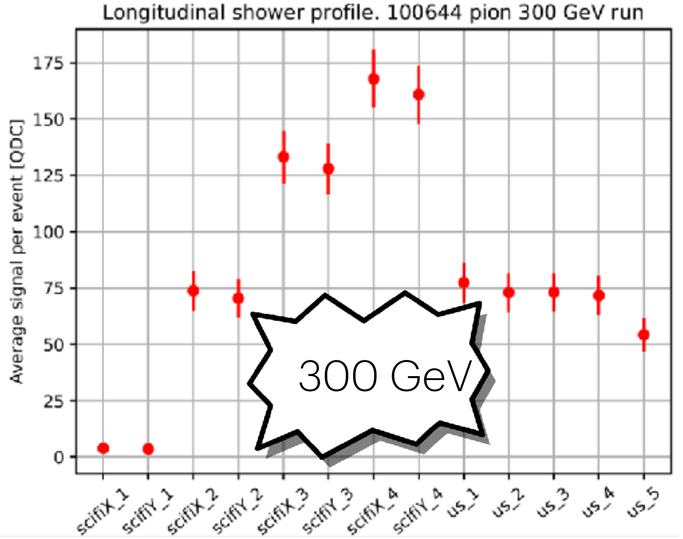
Shower Profile

- **Longitudinal** shower profile for pions on Fe; expected maximum between 1.6λ and 1.9λ for 100-300 GeV range -> SciFi3 - SciFi 4/US1
- Observable: Average signal per event per detector plane.

Preliminary Results - 3 Walls example





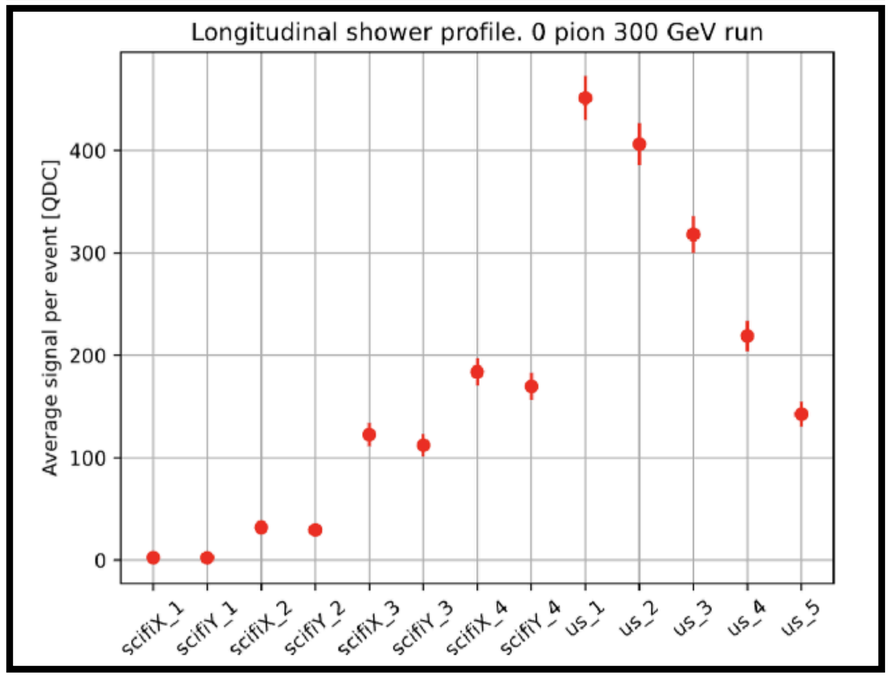


- Maximum well reproduced.
- Large difference of #ch between US and SciFi. Saturation on first layers of US.

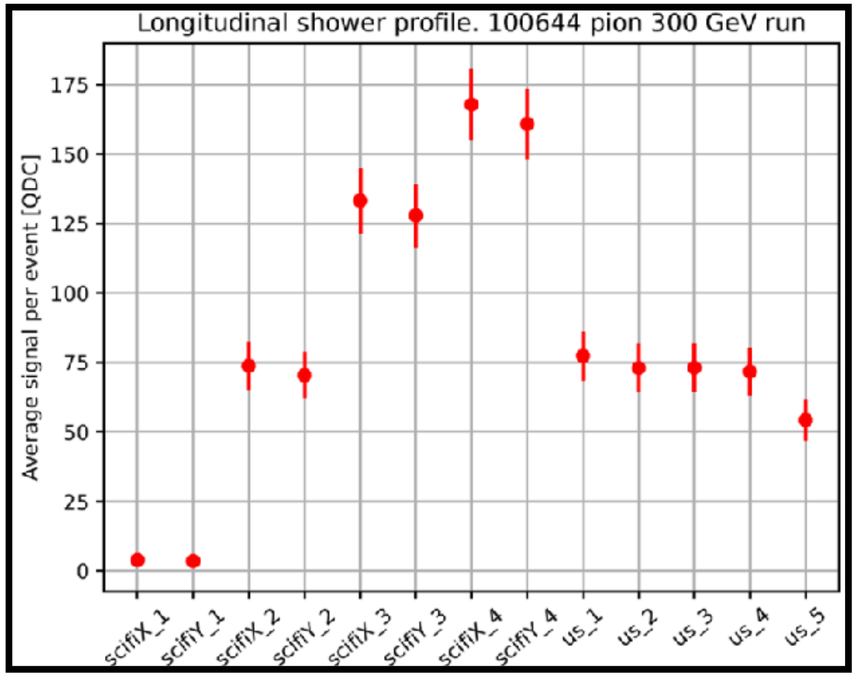
Shower Profile

MC vs Data - longitudinal shower profile

MC 300 Gev - 3 Walls



TB data 300 Gev - 3 Walls



3Walls -300 GeV

- Detector length capable of 95% shower containment, tail not observable.
- Problem of proportionality on US, maybe US saturation (data) and digitation (MC).

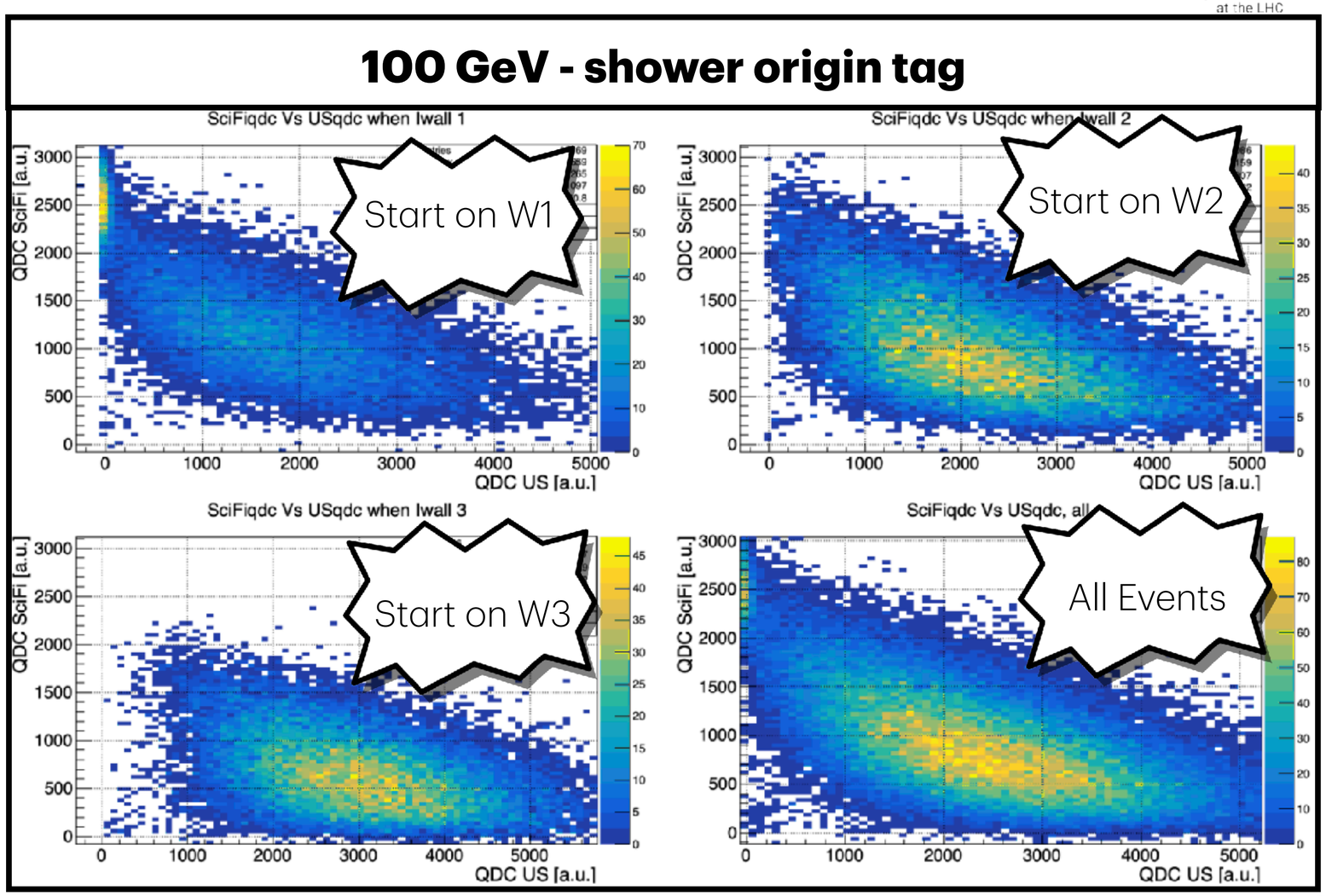
Shower in SciFi vs US

Selection

- **Shower Origin tag:**
  - Most upstream **SciFi layer with >36 hits**
- Time Cut: **0.1 Clock Cycle for SciFi**
- **US: 3 Clock Cycle** difference wrt SciFi shower (1.5ns)

Distributions

- **Sum up all QDC:**
  - From shower origin from SciFi
  - All US planes



Energy Calibration

LHC
Scattering and Neutrino Detector at the LHC

First Attempt

* Consider non-homogenous calo model

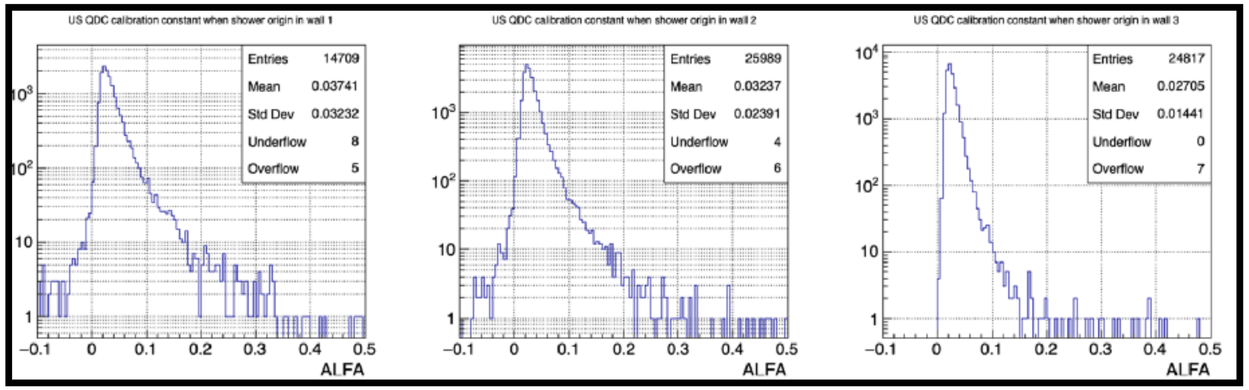
$$E_{shower} = kS + \alpha U$$

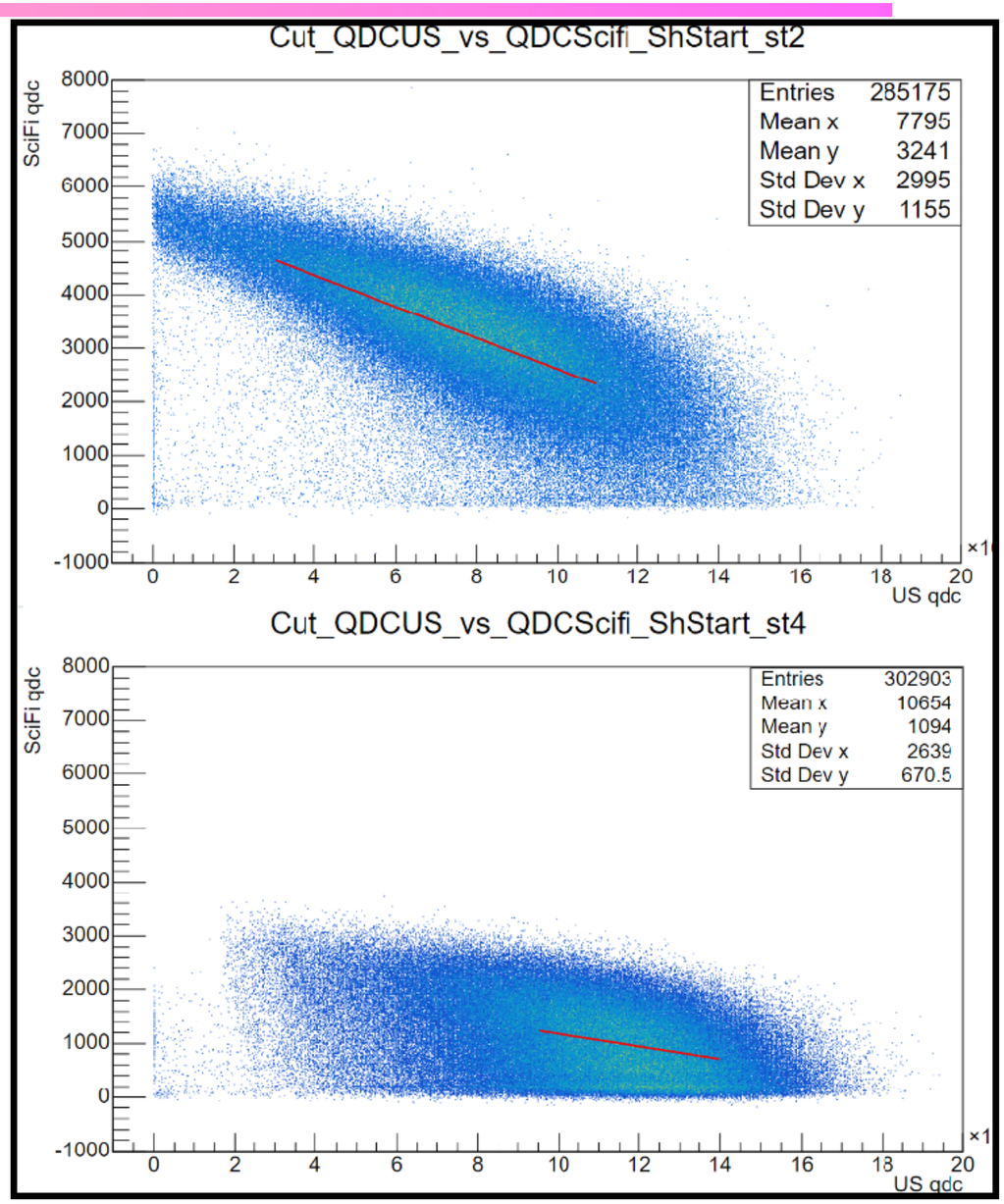
* k can be taken from 100 GeV pions (0 energy on US)
* The parameter α can be obtained from:

$$< \alpha >_N = \left[100 - k < S >_N - Cov(\alpha, U)_N\right] / < U >$$

* It depends on the shower origins and beam energy.

α estimation from 100 GeV pion





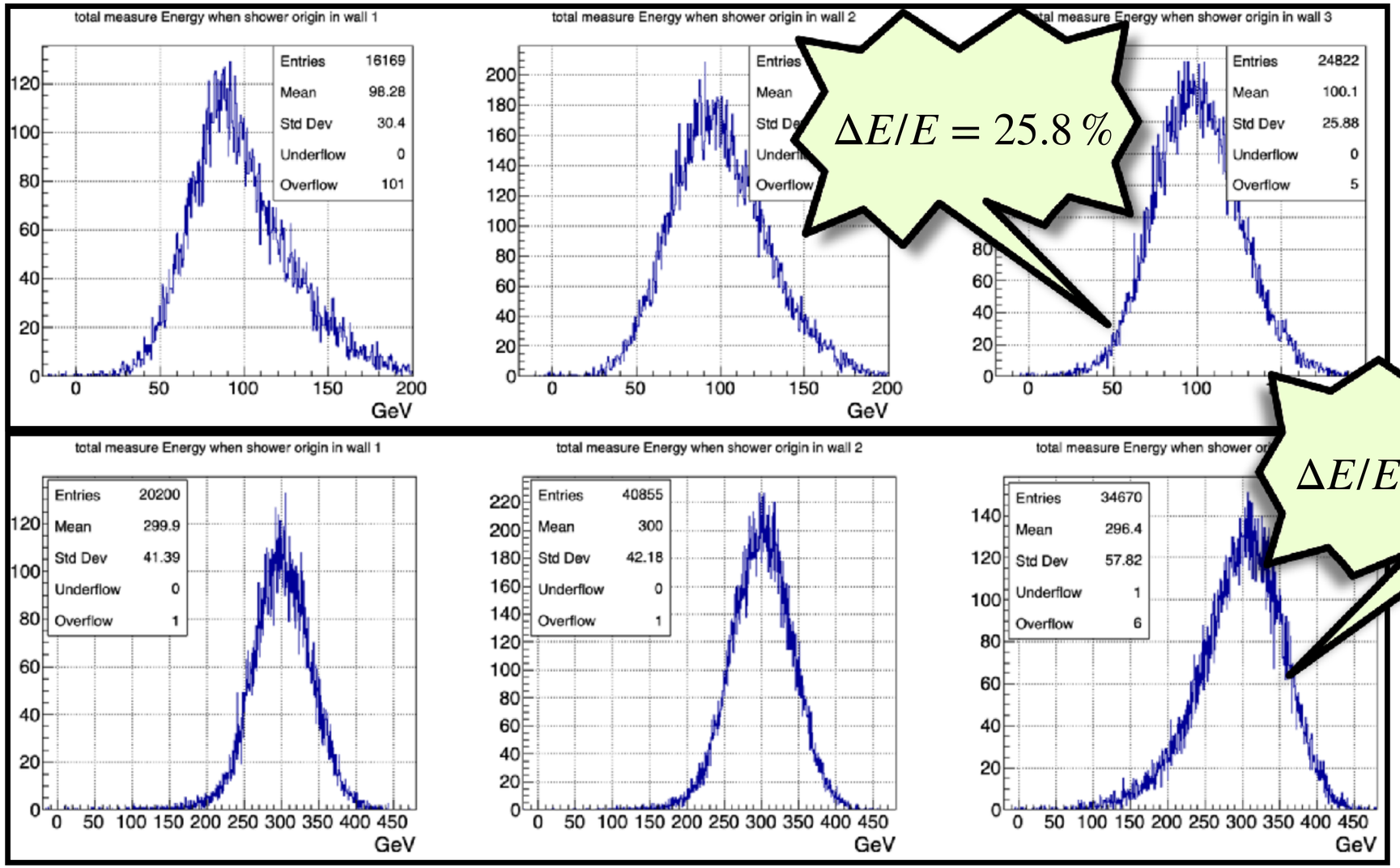
Energy Resolution

LHC
Scattering and Neutrino Detector at the LHC

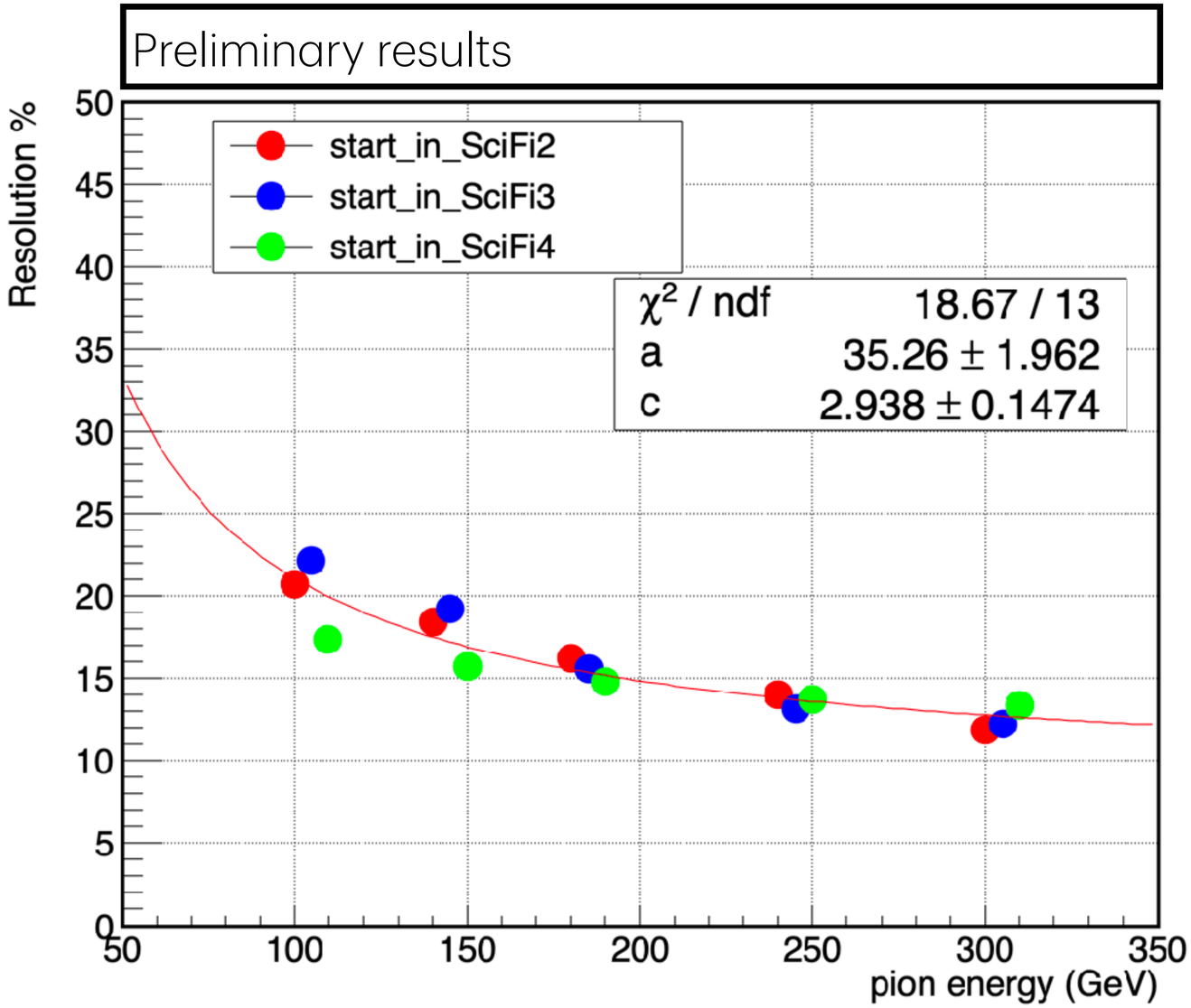
E Resolution of US at different shower origins

100 GeV π

300 GeV π



Energy SciFi vs US



* Model fit:

$$\frac{\sigma_E}{E} = \frac{a}{\sqrt{E}} \oplus c$$

* Stochastic term can be improved, by understanding better lateral shower profile using x position
* Main contribution to the constant factor from the saturation on different planes of the US

Summary & Prospects

Scattering and Neutrino Detector at the LHC

Results, progress, missing items, open points

- **Successful Test Beam** with large statistics collected
- Sampling per **MIP seems to agree** with what **observed on SND@LHC detector.**
- Clear observation of **Saturation on US** channels on hadronic showers
  - Possible to explore the use of small SiPM
- MC: Understand **US digitation** for proper **shower profile**
- Data: Use small SiPM to provide accurate shower profile.
- **Good Proportionality of SciFi** response to particle energy
- Energy share between ECAL and HCAL presented
- Preliminary energy calibration process gives good resolution of 14% for 300 GeV π

Ultimate goal: Make a full validation of MC and apply calibrations factors to HCAL of SND@LHC

LHC
Scattering and Neutrino Detector at the LHC

ありがとうございました
(Thank you)

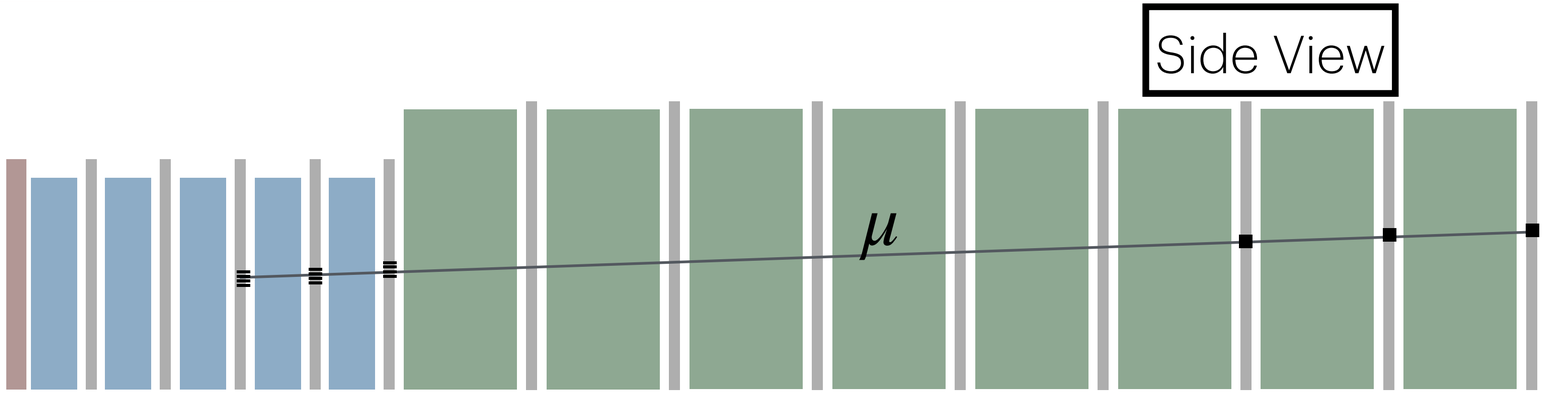
LHC
Scattering and Neutrino Detector at the LHC

予備品
(Backup)

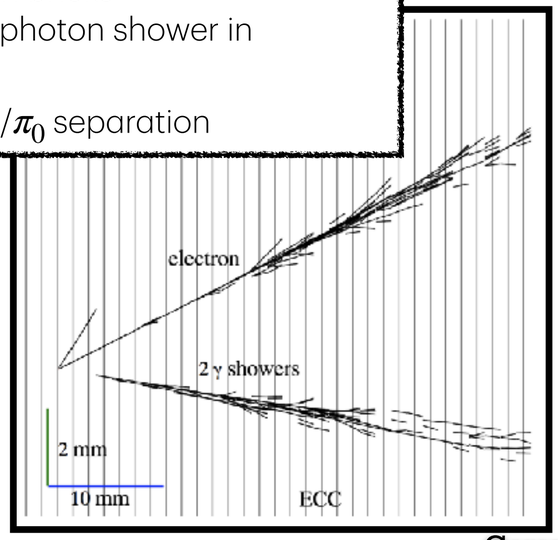
e, μ, τ Identification

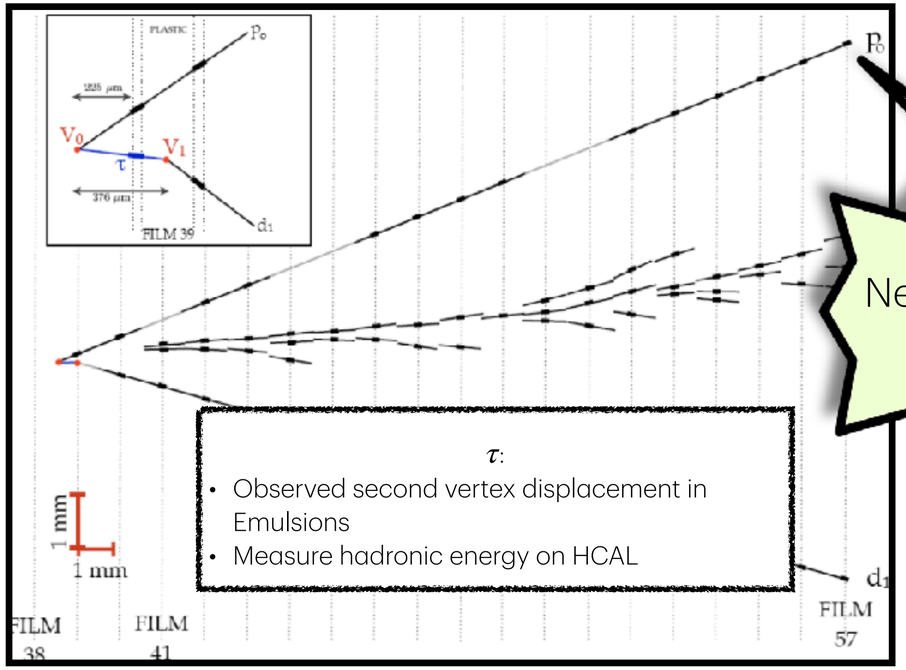
LHC
Scattering and Neutrino Detector at the LHC

μ:
- Track found in all three DS layers and projected to SciFI
- Isolated track in 1cm bar



e:
- Electron shower ID on emulsion bricks
- Observe displace vertex from photon shower in emulsion layers
- SciFi complement for electron/π_0 separation

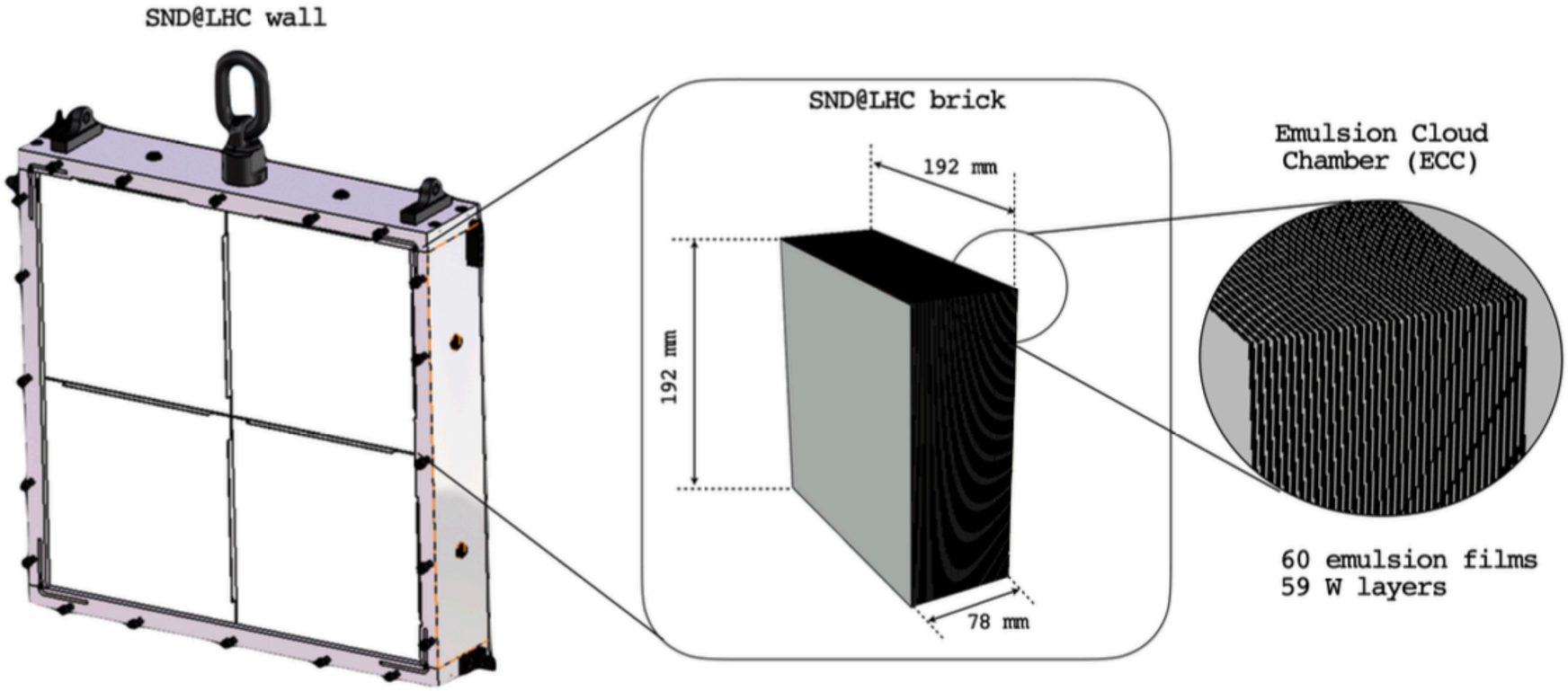




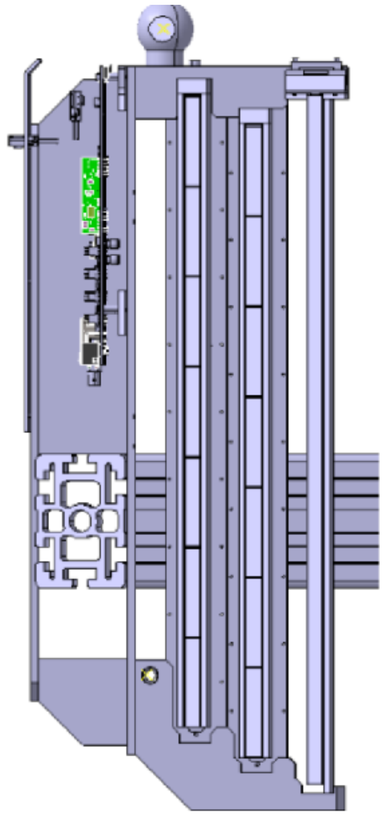
τ:
- Observed second vertex displacement in Emulsions
- Measure hadronic energy on HCAL

Need of calibrated HCAL

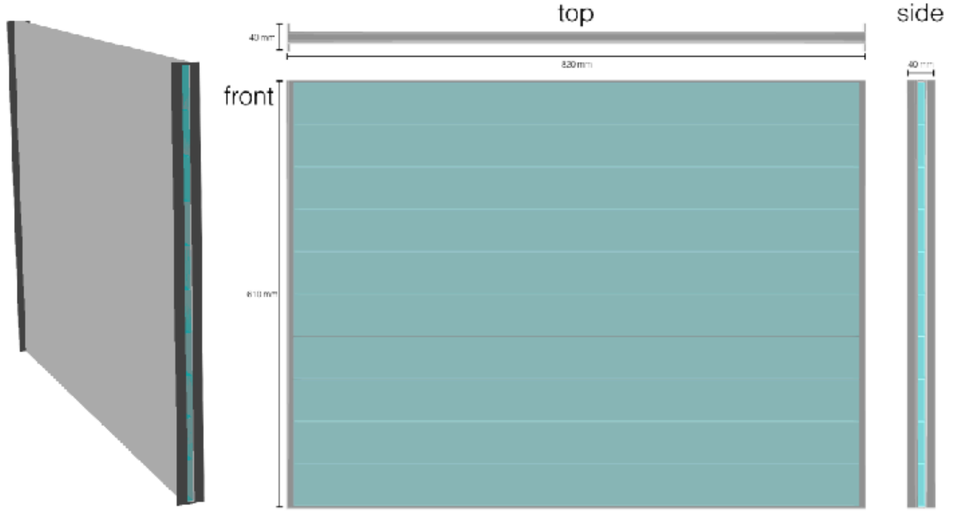
Emulsion Target



Veto & Muon system

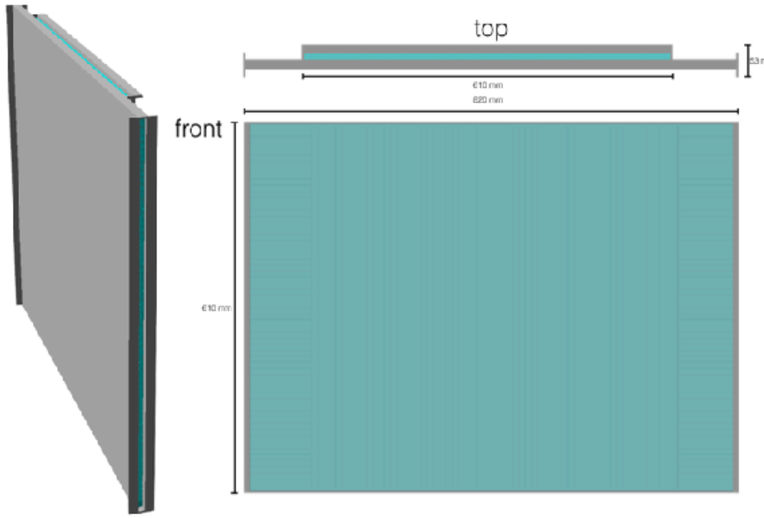


Veto system



US Layers

Veto PCB with 8 SiPM per bar



DS Layers