Shower Tagging and Energy Reconstruction in SND@LHC

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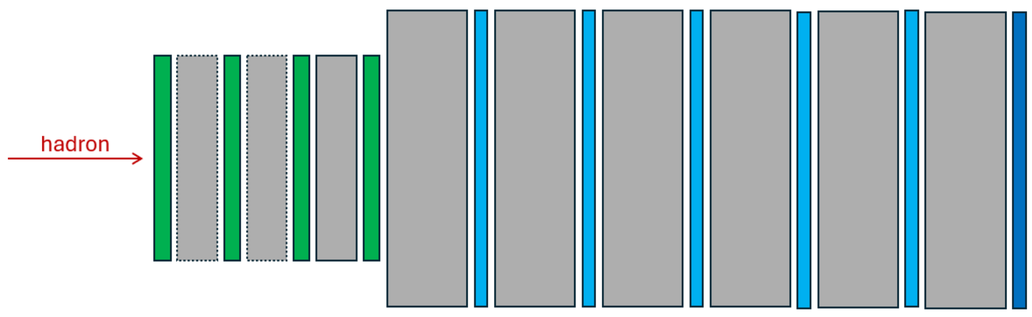
Motivation

Neutrinos of any flavor interacting in the target give always rise to **hadronic showers**. To calibrate the measurement of hadronic showers, a replica of the SND@LHC detector was exposed to hadron beams of different energies in the H8 test beam line of the CERN North area.

Test beam setup

The setup consisted of:
→ 4 **scintillating fibres** (**SciFi**) modules, each made of an x and y plane;
→ 5 **upstream** modules (**US**), made of horizontal 6 cm thick scintillating bars;
→ 1 **downstream** module (**DS**), divided in a horizontal a vertical plane, made of 1 cm thick scintillating bars.

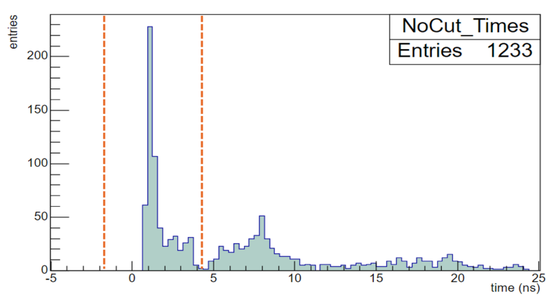
The active modules are interleaved by iron blocks, that are 0.5 λ_{int} thick for the target part, equipped with SciFi stations, and 1 λ_{int} thick in between the US and DS modules.
Data were collected with different configuration, with 1, 2 or 3 iron blocks in between the SciFi modules, to study the behavior of the calorimeters as a function of the position of the shower origin.



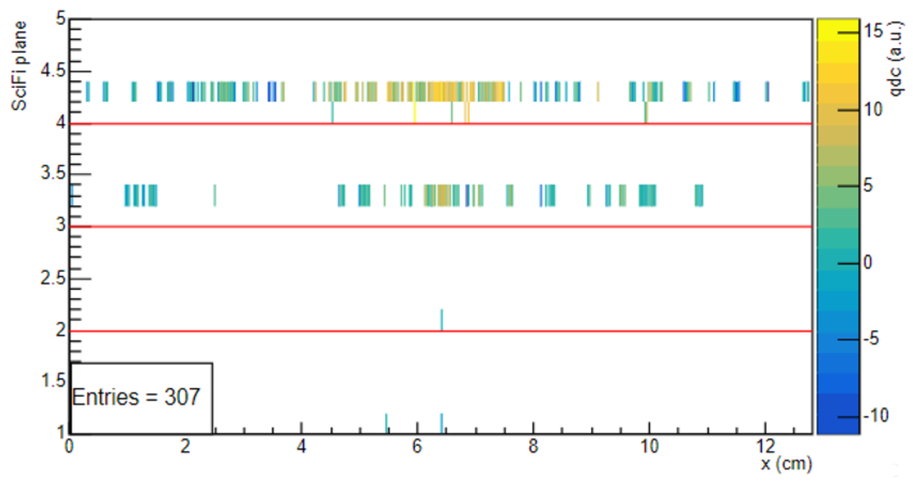
Data were collected with:
→ Positive hadrons at 100 – 140 – 180 GeV
→ Negative hadrons at 240 – 300 GeV

Event selection and shower tagging

Every hit is assigned a timestamp. Within one event, **in time** hits are:
→ SciFi hits within **3 ns** within the most probable value t_{ref} of the SciFi hit distribution in time;
→ US hits if earlier then t_{ref} **+19 ns**.

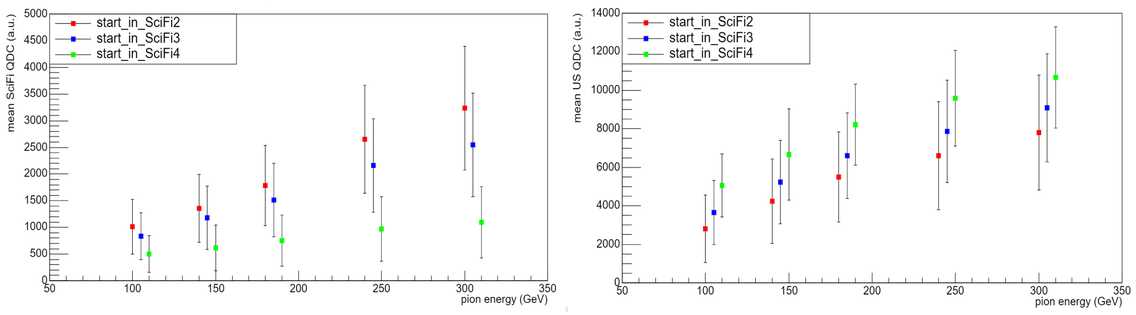


The most upstream SciFi station satisfying the **shower tagging** requirement marks the start of the shower.
The shower tagging algorithm checks for at least 36 hits within a sliding window of length 128 channels along both X and Y SciFi planes. This tagging algorithm resulted consistent across different runs, energies, number of blocks in the target.
Only events tagged as showers are considered for energy calibration.



Calibration

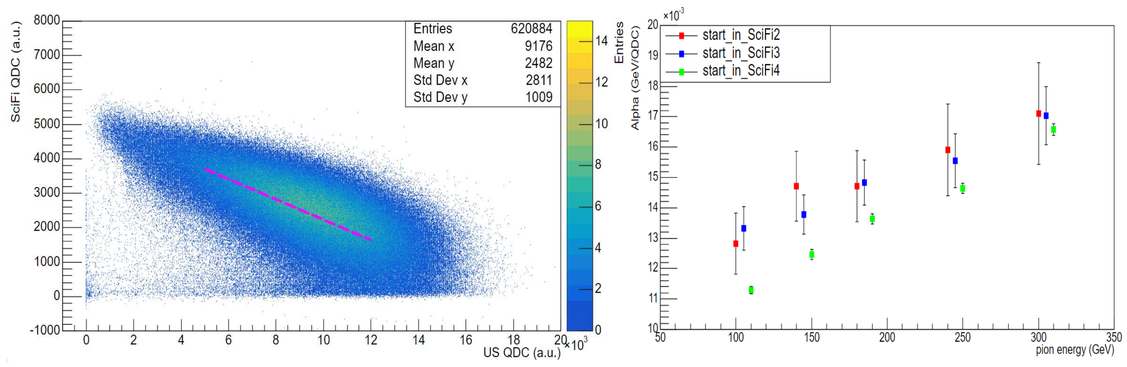
Event by event the relevant quantities are:
→ start of shower given by the shower tagging;
→ Integral charge signal of in time hits in
  → SciFi ($\mathbf{QDC_{SciFi}}$);
  → US ($\mathbf{QDC_{US}}$).



The hadronic shower energy is estimated by:

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

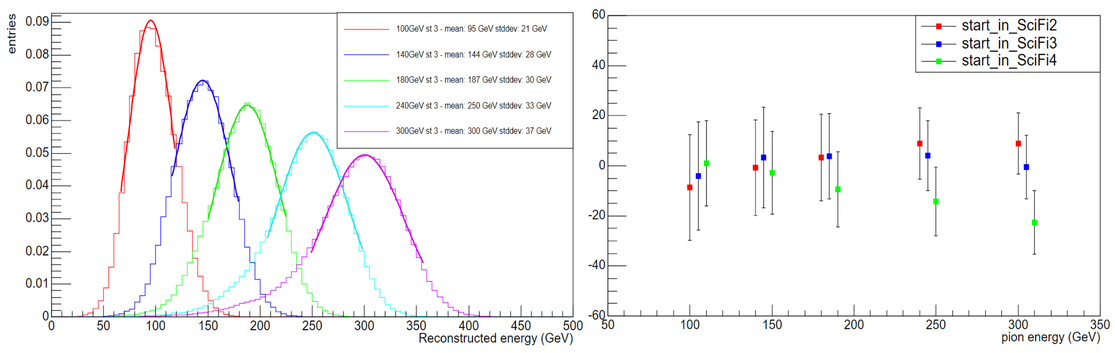
where E is the hadron energy, **k** and **α** two calibration constants to be determined. Calibration data is split into samples representing all 15 combinations of beam energy and start of shower.
For each sample **Principal Component Analysis** (PCA) is used to determine k and α.



Showers starting late in the target (SciFi4) tend to cause signal saturation in the first US station and need ad-hoc calibration constants. Excluding the results from SciFi4, the average calibration constants would be:
→ k = (0.059 ± 0.001) GeV/[QDC];
→ α = (0.0150 ± 0.0003) GeV/[QDC].

Energy resolution

The reconstructed energy for showers starting in SciFi2 and SciFi3 is consistent across the whole energy range. For showers starting in SciFi4 it is underestimated at higher energies due to US saturation, as mentioned before.
The **energy resolution ranges from 12% to 22%.**



Using this calibration, the energy of hadronic showers in 32 **muon neutrino interactions** from 2022 and 2023 SND@LHC data was reconstructed and compared to Monte Carlo.