SND@LHC Run 4 Hit Density Study

Project Report
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With the current report I present my results on how the concept of hit density applies in the analysis of electromagnetic and hadronic showers in the Run 4 phase of the SND@LHC experiment. Testbeam data and Monte Carlo simulations are compared in the particular geometry and we see that the software function is applicable after the detector upgrade.

Introduction

When particles interact with the detector, they produce so-called ‘hits’ – above-background signal is observed in the specific detector component. The granularity of the Run 4 SND electronic detectors allows hits to be measured and timed with a higher precision than with the Run 3 SciFi planes and scintillator bars. As hits start to appear closer to one another in the case of a secondary particle shower, the notion of hit density of each hit can be studied – that is the number of other hits within a radius r of said reference hit.

The SND Run 4 detector system

During the HL-LHC phase the SND experiment will switch to entirely electronic detectors – silicon microfibre modules that will be repurposed from the CMS tracker outer barrel. Each hit is the activation of a single strip within said module which allows for a spatial resolution of 122 μm, corresponding to the strips’ pitch[1]. Hits are then grouped into events depending on their timestamp[2].

Hit density – application in Run 3

During Run 3 the notion of hit density was used for the scintillating fibre modules – neutrino events without a muon in the final state($\nu 0\mu$ events) were observed to possess a higher sum of individual hit densities in the sSiFi detector than other neutrino candidates, as we see in Figure 1. This allows us to improve the neutrino flavour identification and helps us in the search for ν_e and ν_τ, that have been less studied in the experiment compared to ν_μ[3].

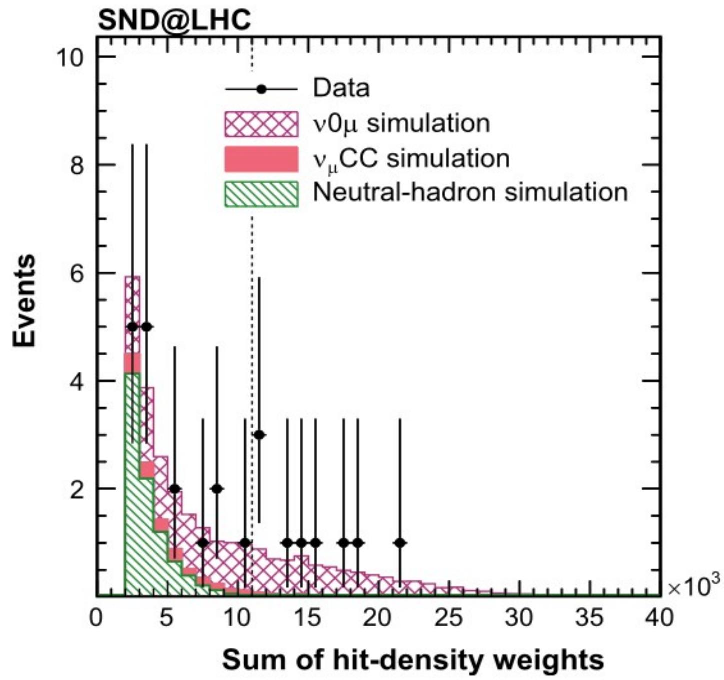

Figure 1. Distribution of the sum of hit density weights per neutrino event candidate[3]

Hit density – application in Run 4

We will observe how it can be used to distinguish electromagnetic from hadronic shower-like events, both in simulations and data.

How we calculate hit density

In the Run 4 configuration it is possible to count the number of neighbouring hits within an individual module(Figure 2a) or across each half of a vertical or horizontal plane(Figure 2b) with the help of the software function AdvHitDensity I adapted from the SciFi density Run 3 function. In this analysis we used the case across multiple modules. The radius we placed is 100 strips or about 1.22 cm in each coordinate.

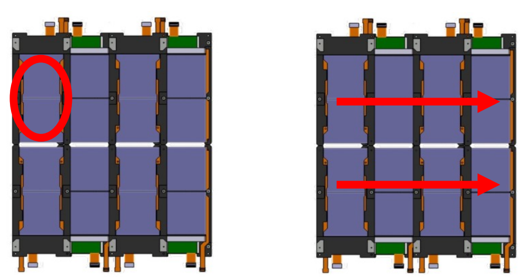

Figure 2. a) Single module - b) Multiple modules taken into account for the hit density weight

Testbeam geometry

The data we used for this study is the one taken from the 15-22 July 2026 testbeam of the detector prototype. The configuration takes some of the available Si modules and tungsten target plates[4]. A scintillator trigger is placed between the beam and the target detector to ensure the beam is in the right position and events are recorded during the proper time interval. 21 W target planes(detector layers) are stationed, each covering 1⁄4 of the design detector area(Figure 3). The beam is taken from the PS Booster at the T9 beamline, as electron and negatively charged pion beams are chosen for irradiation. The electron beams possess energies of 3 GeV and 5 GeV and the pion ones 10 GeV and 15 GeV. The same energies are set in the simulated detector response.

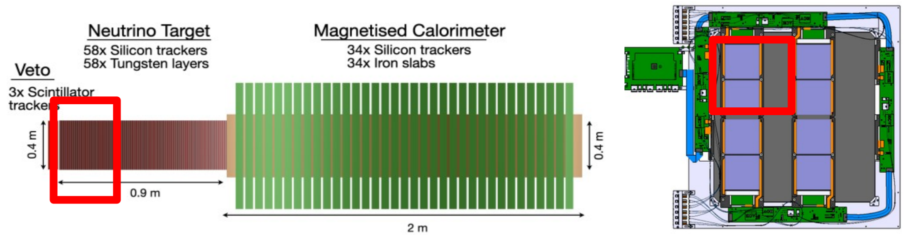

Figure 3. Testbeam detector prototype(circled in red) w.r.t. the final Run 4 design

Results

To ensure we have a shower-like event, a perliminary filtering of events is required - noise is observed for the lower hit counts per event. As electromagnetic showers are in general of smaller size than hadronic ones, they can produce more hits within a single detector layer which explains the Gaussian peak in their hit count distribution(Figure 4). Pion events on the other hand, with hadronic showers being more spread out across the detector layers, exhibit a higher peak in the lower hit counts range, but a long tail towards higher counts. We set the threshold for shower-like events to be 200 hits per event, both for electrons and pions for consistency. The higher beam energies are taken, namely 5 GeV for electrons and 15 GeV for pions from the testbeam data.

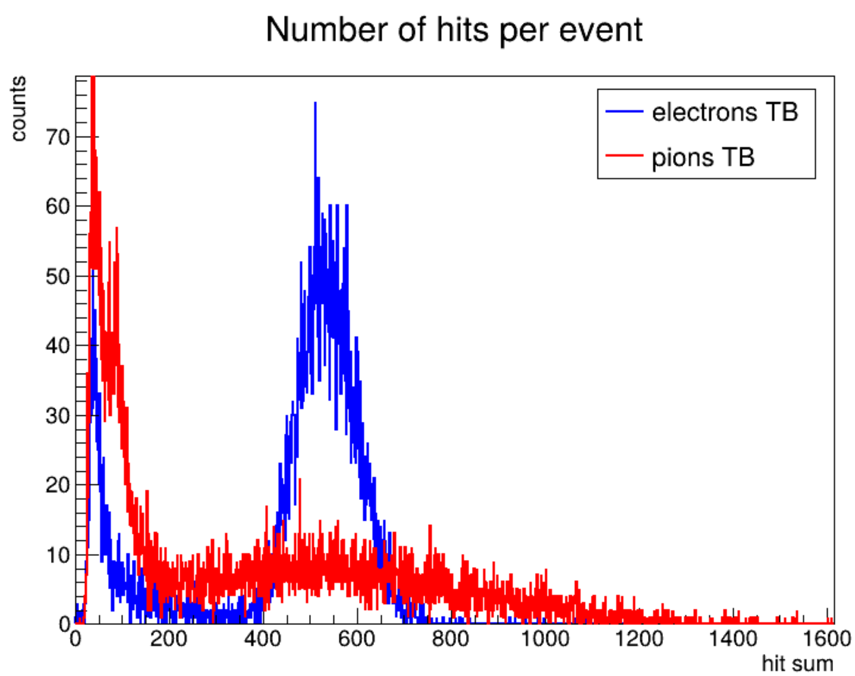

Figure 4. Distribution of the number of hits per event type, testbeam data

Next we view each hit's hit density – again we see the effect of the Gaussian peak for electron events whereas for the pion events there is a smooth decrease with slight noise in the data(Figure 5). There is conceptual agreement between simulation and data on the shape of the curves, albeit with deviations.

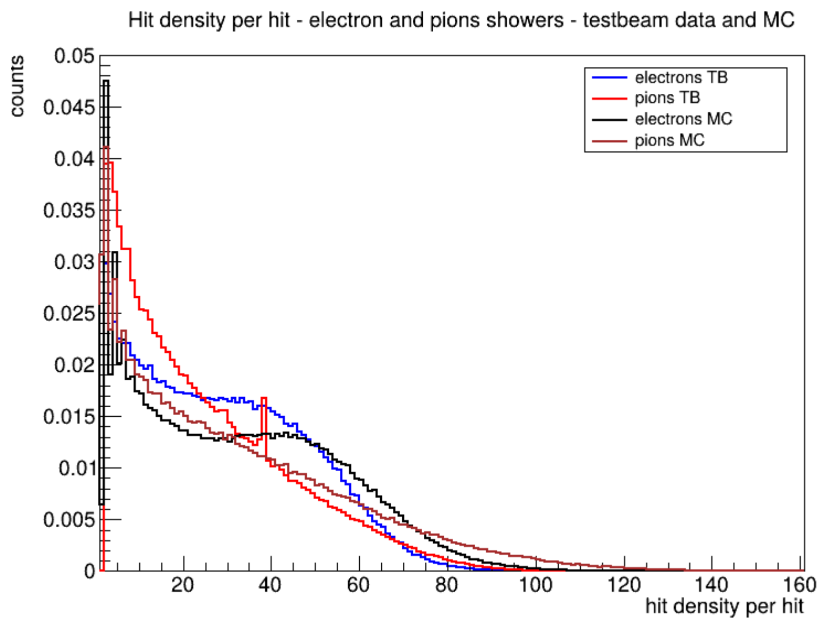

Figure 5. Hit density per individual hit – distribution for 5 GeV electrons and 15 GeV pions

When summed across all planes, the hit density weights show similar distributions – a Gaussian peak for the electron events – as they possess higher hit density sums in general, and a sharp increase followed by a long tail for the pion events that are of lower hit density sums, but are recognizeable by said tail in the higher range. Here the difference between data and MC is obvious.

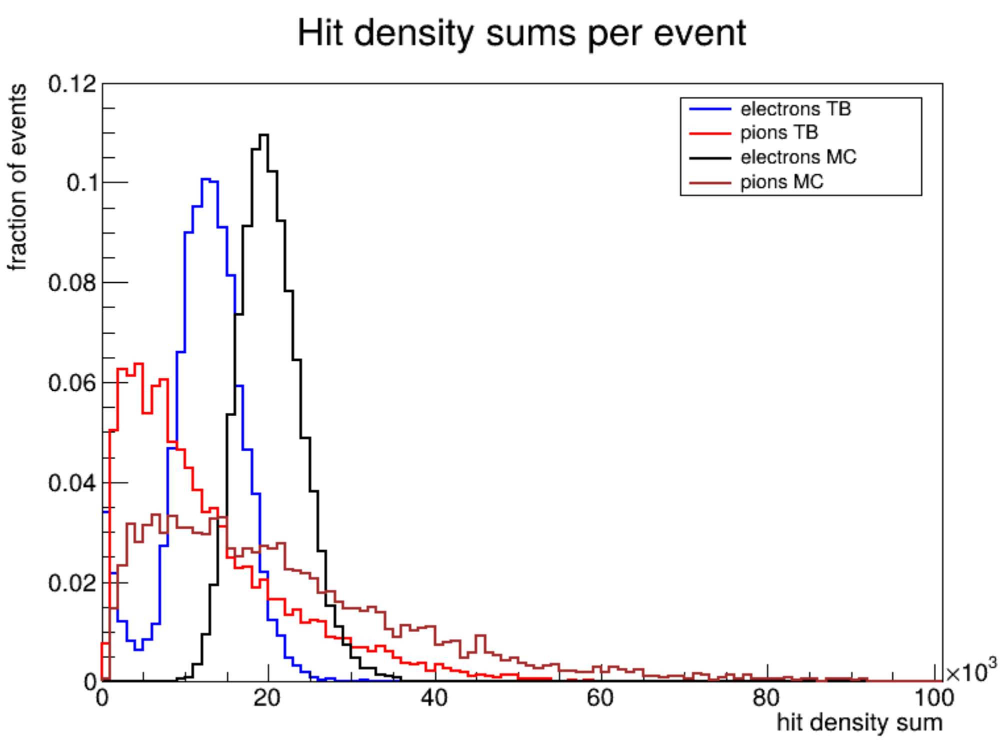

Figure 6. Sum of hit densities per event - 5 GeV electrons and 15 GeV pions

To further examine the disagreement between simulated and recorded data, we see the hit density distributions for all event energies(Figure 7a, 7b).

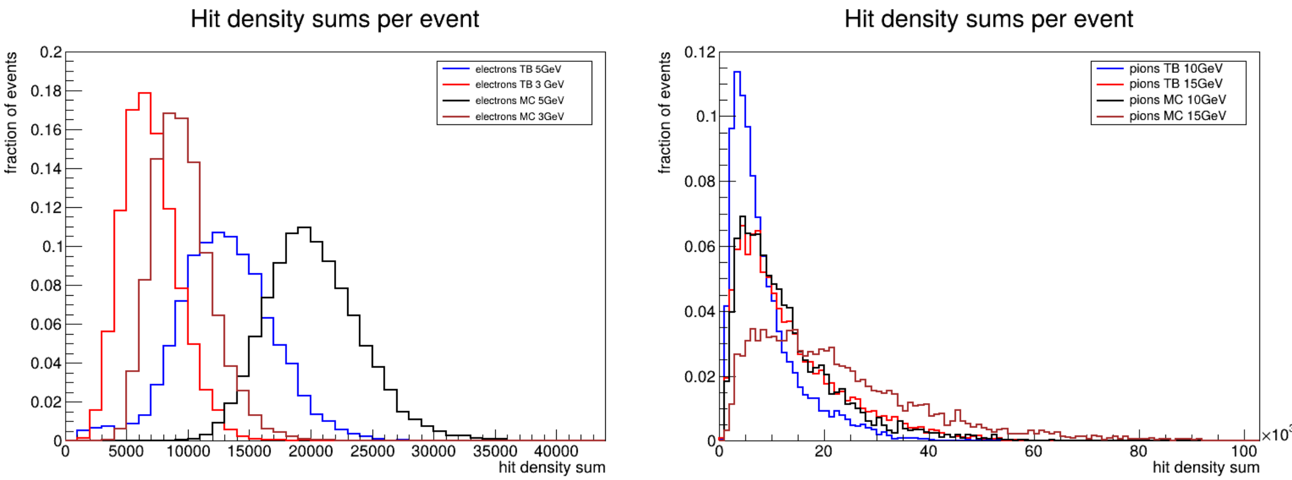

Figure 7. a) Hit density sums per electron event b) Hit density sums per pion event

When summed across all detector layers(as we see above), the discrepancy is about 38% for 3 GeV electrons and 56% for 5 GeV electrons. This is a striking disagreement from the simulations and shows ground for their improvement w.r.t. this particular task. When only the layer with the highest hit density sum in a particular event is taken into account, the distributions are the following:

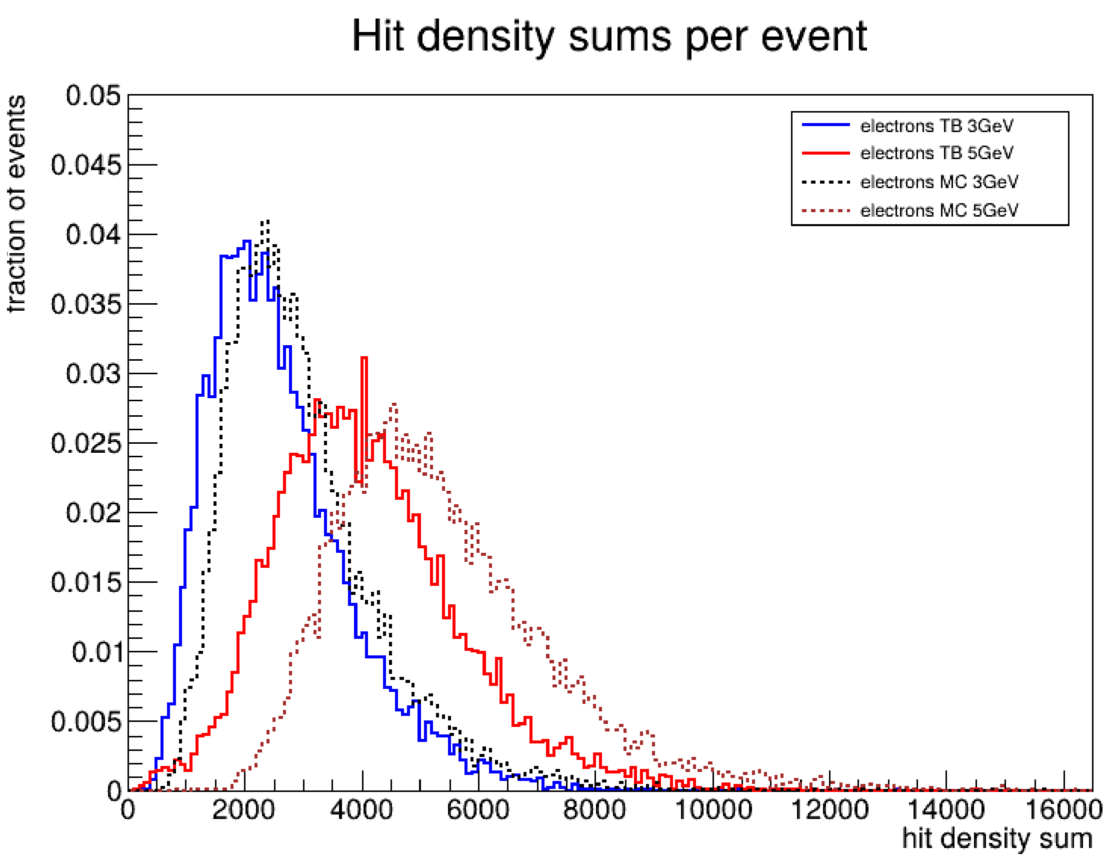

Figure 8. Hit density sums per electron event, most active detector layer

Here the disagreement is of 25% between data and simulations for 3 GeV electrons and 29% for 5 GeV electrons. It is lower than in the previous case, but still significant. Another test of the data-MC correspondance is the grouping of hits into larger hit clusters – it is known that the simulations package performs better with that data format. This could be the potential next step of the study.

Conclusion

We see from our results that the concept of hit density can find application in the Run 4 phase of the SND@LHC experiment. With regards to individual hits, there is disagreement between data and MC. Both confirm, however, that electromagnetic shower-like events exhibit higher hit density sums in general and are recognizeable by the Gaussian-like peak in their hit density sum distributions. The hadronic shower-like events on the other hand are recognizeable by the tail extending to higher hit density sums, albeit them possessing lower hit densities in general. The parameter could be used to distinguish between such event types in the future.

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References:

[1] SND@LHC Collaboration, TECHNICAL PROPOSAL SND@HL-LHC-Scattering and Neutrino Detector in Run 4 of the LHC. (CERN-LHCC-PROPOSAL-2025-004) (2025)

[2] SND@LHC Collaboration, SND@LHC: The Scattering and Neutrino Detector at the LHC. (arXiv:2210.02784 [hep-ex]) (2023)

[3] SND@LHC Collaboration, Observation of Collider Neutrinos without Final State Muons with the SND@LHC Experiment. Phys. Rev. Lett. 134, 231802 (2025)

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