The role of Time Advancing LHCb ECAL Upgrade II Clustering

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1. Actual ECAL besides the future Upgrade II

- Purpose: Efficient reconstruction of photons, precise measurement of photon energy and position, and particle identification, especially electrons.
- Features: Scintillating sampling calorimeter providing good energy resolution and stable performance [1].
- Geometry: The actual ECAL Consists of modules with varying cell sizes (4x4 cm^2, 6x6 cm^2, 12x12 cm^2).
- Energy Resolution: $\sigma(E)/E = 10\%/\sqrt{E} \oplus 1\%$, achieving about 9 MeV/c^2 for π0 mass resolution [1] .

Motivation for the upgrade

- Increased Luminosity: To handle up to 1.5×10^{34} $cm^{-2}s^{-1}$, requiring major redesign.
- Radiation Damage: Current modules suffer performance degradation under high radiation, necessitating replacement and improvement (LHCB-TDR-024) .

Actual methods and hardware

- New Modules: Implementation of SpaCal technology with tungsten and lead absorbers.
- Cell Sizes: Introduction of smaller cells (1.5x1.5cm^2, 3x3 cm^2) for better granularity, covering regions with high photon and neutral pion production.

Proposition of cells

- Measurement Capabilities: New cells will measure both energy and time, improving the overall performance of the ECAL .
- Improved Radiation Tolerance: New SpaCal modules offer better resistance to radiation damage [2] .

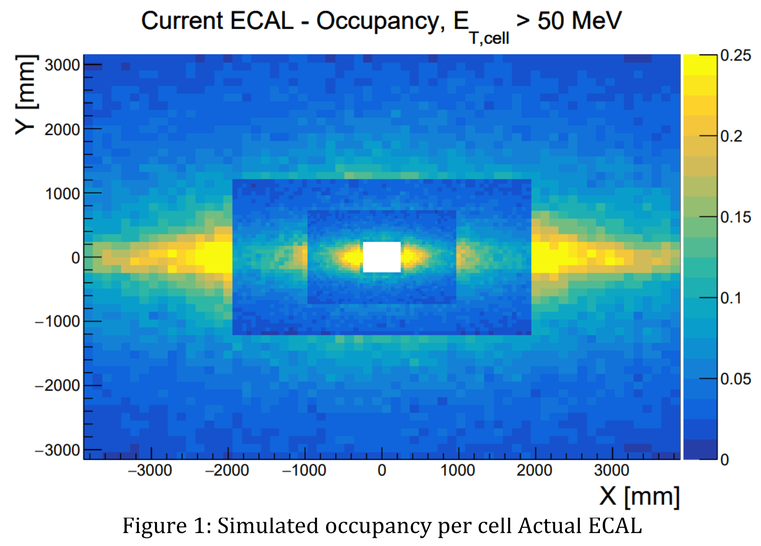


Figure 1: Simulated occupancy per cell Actual ECAL

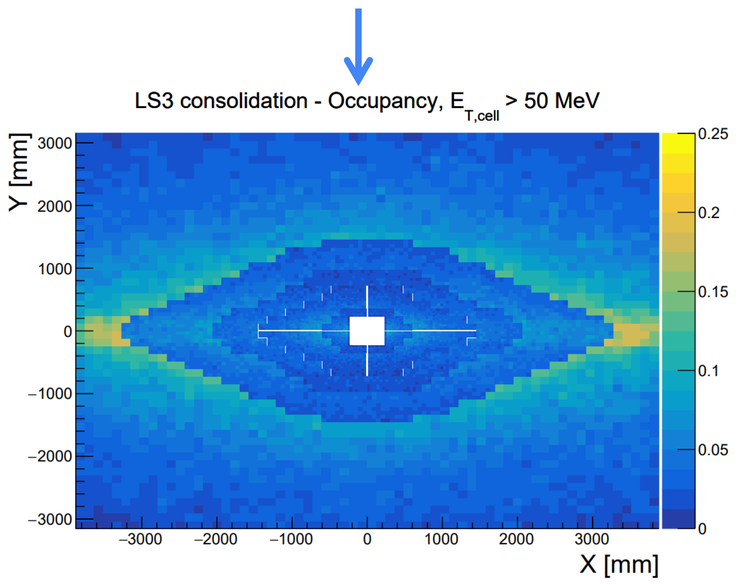
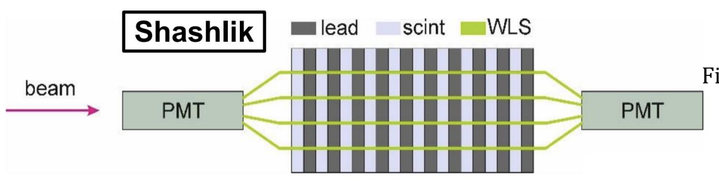


Figure 2: Simulated occupancy per cell ECAL

Energy Collection

•Mechanism: The current ECAL collects energy through a shashlik structure with alternating scintillator tiles and lead absorber layers.
•Readout: Scintillation light is read by photomultipliers (PMTs).
•Reconstruction: Energy is digitized with a 12-bit precision, converted to MeV, and transverse energy is computed based on angular position .



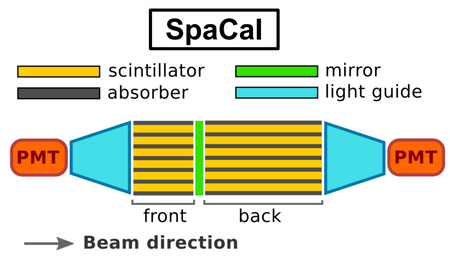


Figure 4: New PicoCal cells, Shashhlik and SpaCal

2. Data Reconstruction

Upgraded Energy Collection

•Materials: Enhanced with new modules using scintillating crystals and plastic fibers for improved radiation hardness.
•Readout: Incorporates both front and back readouts for better energy resolution and timing.
•Simulation: Hybrid Monte Carlo simulations validate the new configurations, showing improved performance over current setups .

Energy Reconstruction Algorithms

- **Current Algorithm**
  - Cellular Automaton based Algorithm: Identifies local maxima, forming 3×3 cell clusters. Applies corrections for longitudinal (L-correction), transverse (S-correction), and energy leakage (E-correction) to refine cluster properties .
  - The recontruction is carried out by off defining first the front and previously the back clusters which are then matched with the following clusters
  - The Upgrade II simulations show significant improvements in energy resolution and distribution uniformity in the upgraded ECAL compared to the current system .

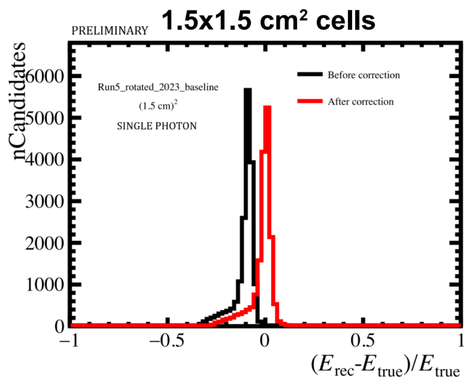
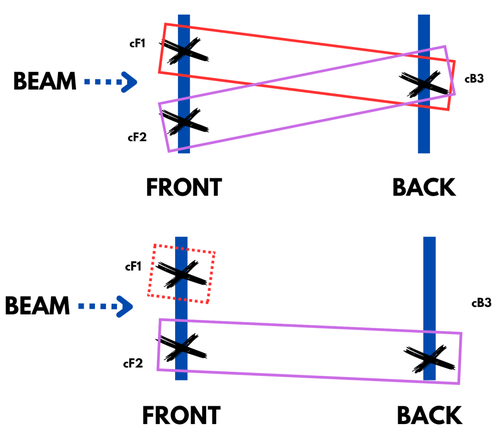


Figure 5: Energy resolution based on the reconstructed and the real one, as it is observed an improved distribution to that of the current ECAL.

Energy Front and Back Sections

- **The longitudinal segmentation allows better handling of overlapping clusters and more precise energy measurements .**



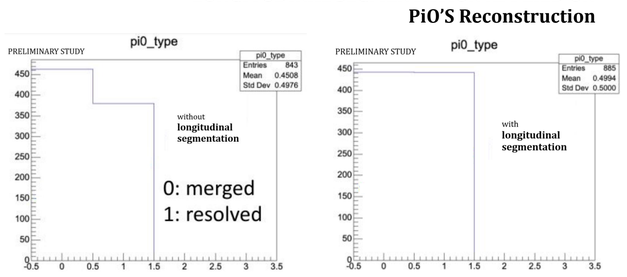


Figure 6: Longitudinal segmentation, Matching between back and front clusters to join them as one same collision

Figure 7: Reconstruction of pi0's reconstruction, where after applying the longitudinal improves the ratio.

3. How can we use time in the reconstruction?

Time Collection

•Having seen the effect of the new design applied to energy, a study has been started on the effect of time and correlations on the reconstruction of new clusters to improve the efficiency of the reconstruction.

•Important factors preliminary to the study:

ROOT Data Analysis Framework

Important variables for this study

- e (Cluster Energy)
- eF (Cluster Front Energy)
- eB (Cluster Back Energy)
- e_perCell (Cell Energy)
- eF_percCell (Cell Front Energy)
- eB_perCell (Cell Back Energy)
- t (Cluster Time)
- tF (Cluster Front Time)
- tB (Cluster Back Time)
- tF_percCell (Cell Front Time)
- tB_perCell (Cell Back Time)
- Region [1,2,4,5,6]

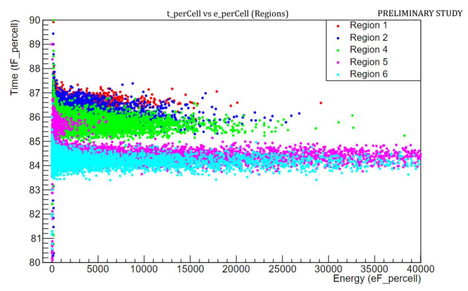


Figure 8 :Correlation between tF_percell and eF_percell, filtered by color for the value of the region of that cell. Remarkable difference in time between regions

•The correlation of energy with time clearly shows being filtered by regions that there is a variation due to cells that are found in boundaries, clusters made of cells from different regions.
•More than one peak can be observed in the same region as in region 5 indicating that it could be a cluster sharing cells from different regions.

•The time variation based on the TB - TF resolution is clearly affected by three technologies; in this case it is the representation of the 3 peaks in the figure showing the different regions.

•Due to larger distance between PMT front and PMT back in some cells of different regions.

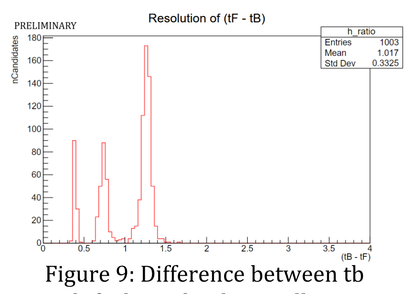


Figure 9: Difference between tb and tf where the three cell types are displayed

The project continues!

•To finish investigating the effect of time and how it can improve the performance of ECAL reconstruction algorithms.
•Define more clearly what limits we place on time variables and their 3 new technologies.
•Make the most of this new variable (time) as important or more important as energy.

References
[1] LHCb collaboration. *LHCb Particle Identification Enhancement Technical Design Report*, CERN-LHCC-2023-005, 2024.
[2] LHCb collaboration, *PicoCal baseline for the Scoping Document*, Philipp Roloff (CERN) , 2024.
[3] LHCb collaboration,. Status of the simulation and reconstruction studies, Marco Pizzichemi, 13/05/2024.

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