Frozen-shower simulation of electromagnetic showers in the ATLAS forward calorimeter

Ksenia Gasnikova, Alexander Glazov (DESY, Hamburg, Germany)
on behalf of the ATLAS Collaboration

Fast simulation model at ATLAS experiment

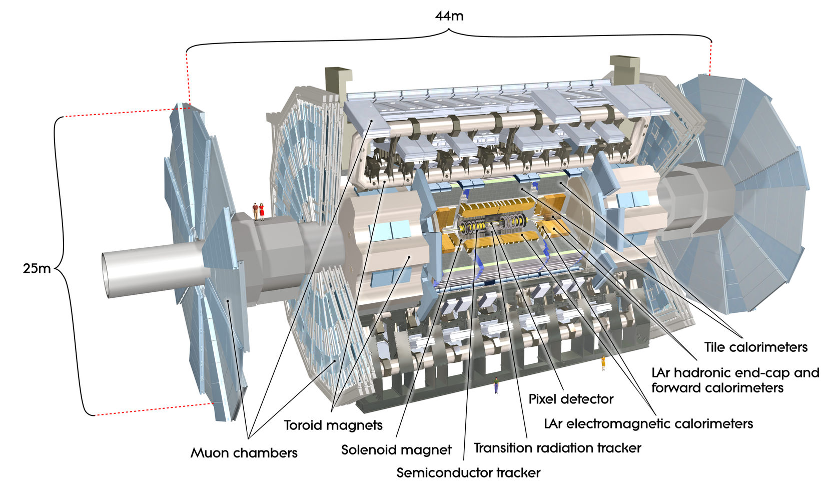

Fig. 1 the ATLAS detector

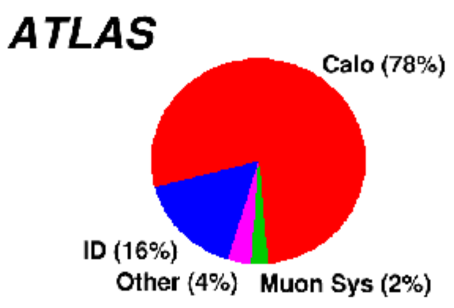

Fig. 2 Subdetector CPU fraction for 50 ttbar events
MC16 Candidate Release

ATLAS simulation is done using Geant4.
For a typical ATLAS event most of CPU time is spend on calorimeters, mainly on endcap and forward

Calorimeter simulation approach

- Parametrisation (high energy particles)
  parametrisation of longitudial and transverse shower profile
- Frozen Showers library (low energy particles)
  substituting with pre-simulated shower, stored in library
- One spot model
  substituting by single energy deposit

Detectors used	FCAL1, FCAL2, FCAL3
`IsApplicable` for	photons, electrons, neutrons
Energy range	$E_\gamma < 10$ MeV, $E_e < 1000$ MeV, $T_n < 100$ MeV
Containment requirement	$\Delta E_{shower} > 98\%$
Generation clustering cutoff	$(\Delta R_{cluster})^2 < 25$ mm
Generation truncation cutoff	$R^2_{hit} < 50000$ mm, $\Delta E_{shower} < 1\%$

Fig. 3 Main parameters of Frozen Showers

Forward calorimeter simulation

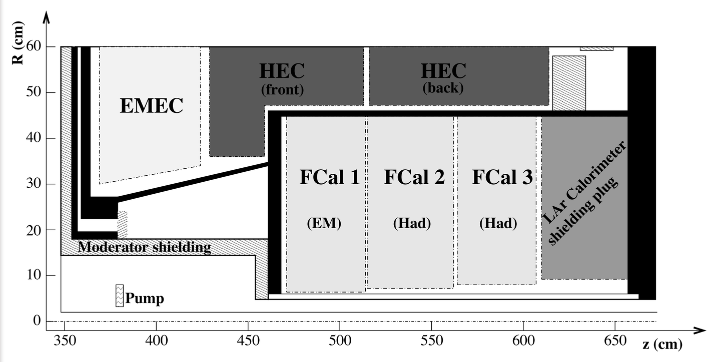

Fig. 4 Calorimeters

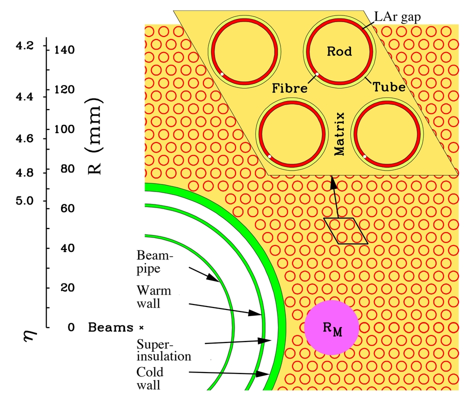

Fig. 5 FCAL scheme

The ATLAS detector has dedicated calorimeters for electromagnetic interactions with almost 4π acceptance.
Forward calorimeters cover the pseudorapidity region from 3.0 up to 4.9. They consist of a metal matrix with regularly spaced longitudinal channels filled with concentric rods and tubes. Liquid argon is used as active material and copper or tungsten as absorber.

Resolution of non-uniform calorimeter

$$\frac{\sigma_E}{E} \approx \frac{1}{E} \oplus \frac{1}{\sqrt{E}} \oplus const$$

The constant term derives from the non-uniformities of the detector, and is very high for the FCAL. It is hard to describe because of little and irregular amount of sensitive material

Library overview

Frozen shower library structure

Electrons with energy less than cut-off (1 GeV) are replaced by shower from pre-simulated library. The library is organised in pseudorapidity bins. To take into account the non-uniformity of forward calorimeter, space bins have been introduced. It uses the distance between a hit and the closest rod center.
The energy remains unbinned. If a shower with this energy is not present in a bin, the shower with the closest energy is taken and scaled to the needed energy.

Library generation

1) Generation of entry points from physics samples (e.g. ttbar).
2) Generation of showers from starting points using Geant4
3) Compression of library

Library compression

- Clustering: Merging space deposits with distance smaller than cutoff distance R_{min}
- Truncation: Deletion of showers with total energy deposit fraction less than cutoff fraction f
- Rescaling: Rescaling of the remaining deposits such that the second momentum of the original shower is preserved

Typical library size ~ 1 MB, 50 000 events

Binning problem

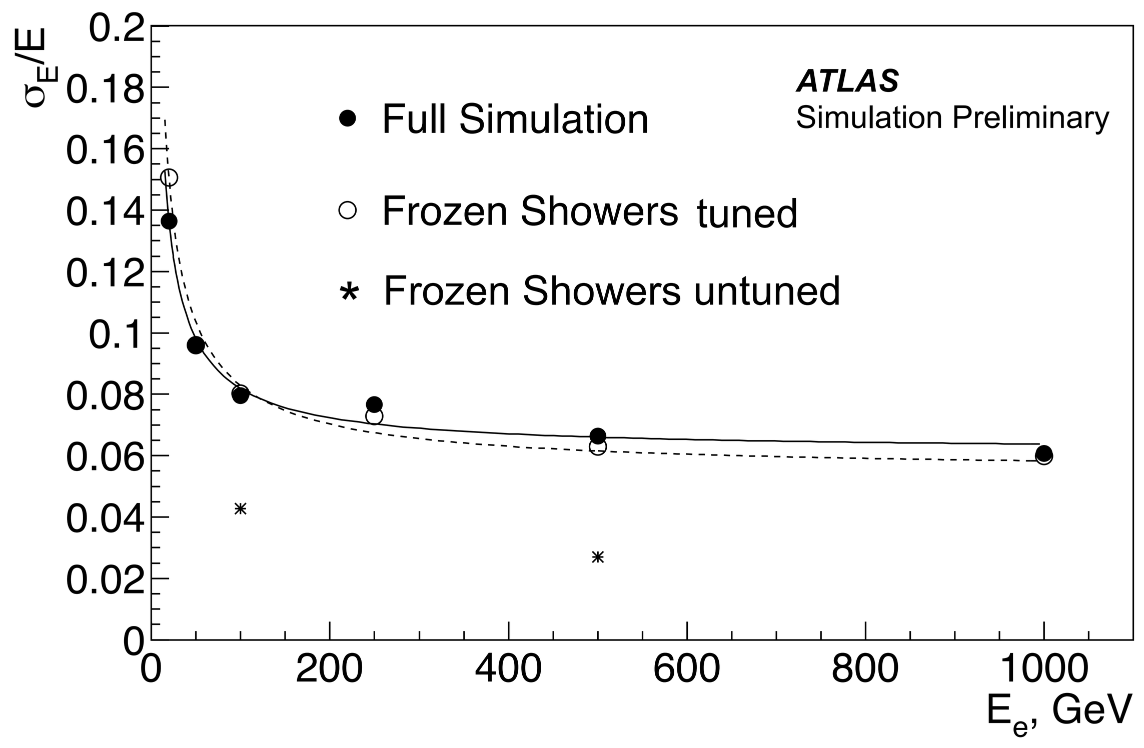

Fig. 6 Electron resolution for full simulation, tuned and untuned frozen showers

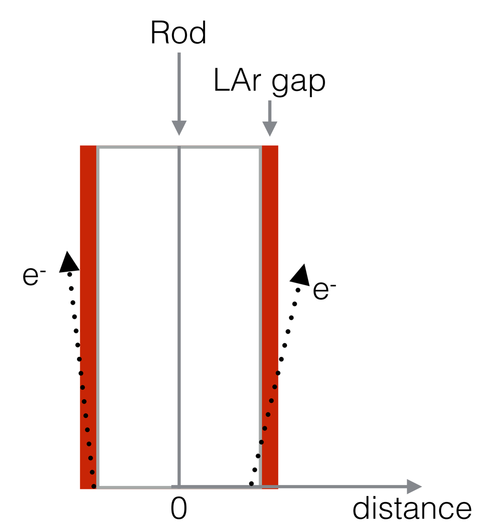

Fig. 7 FCAL binning scheme

Electrons in sensitive material tend to have larger response, than electrons in dead material, so right binning is essential part of frozen showers. At first library generations bin positions have been corresponding to LAr gap.
However if shown that this naive approach is not working in this case, since LAr gap is wider, since responses for particles, born inside LAr gap and near it are undistinguishable. It was proposed to use machine learning tools to find right binning for library

Automatic bin finding procedure

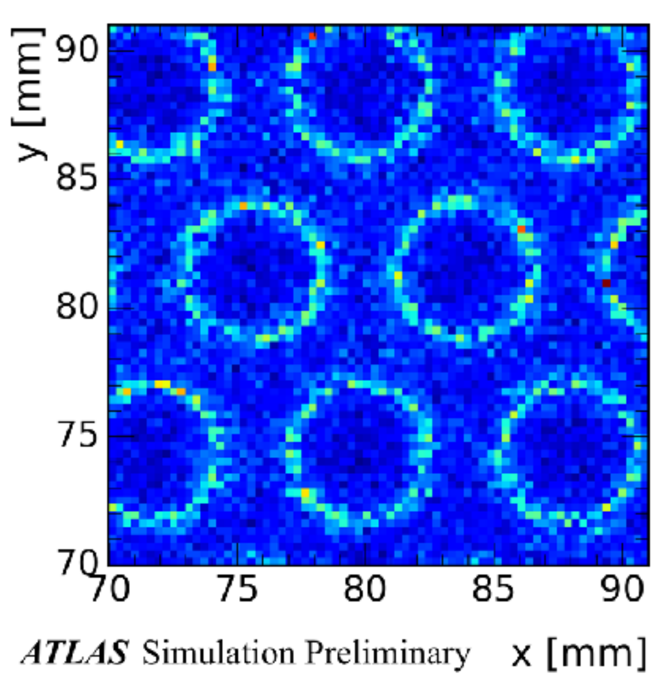

Fig. 8 x vs y distribution histogram with biggest energy deposit weights

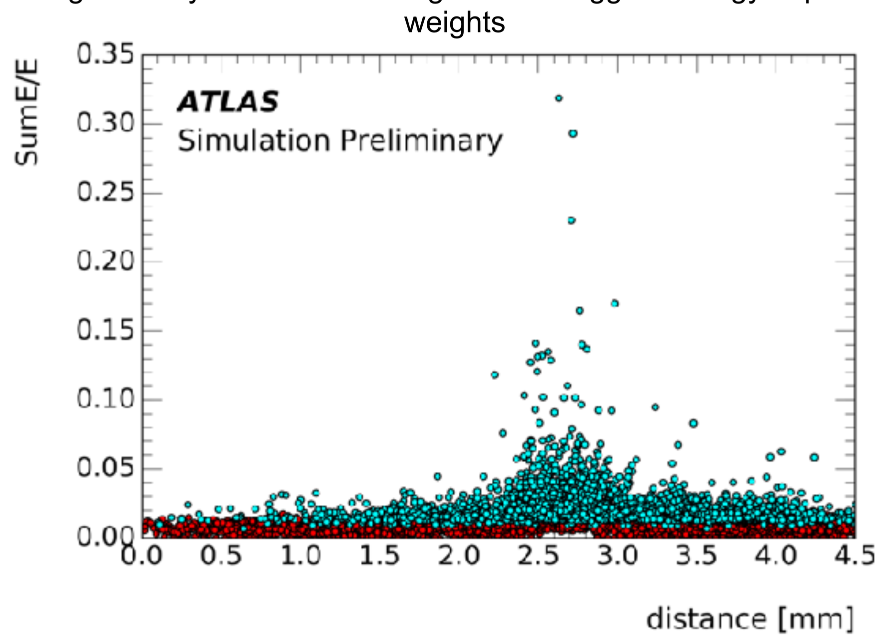

Fig. 9 Output of first classifier.

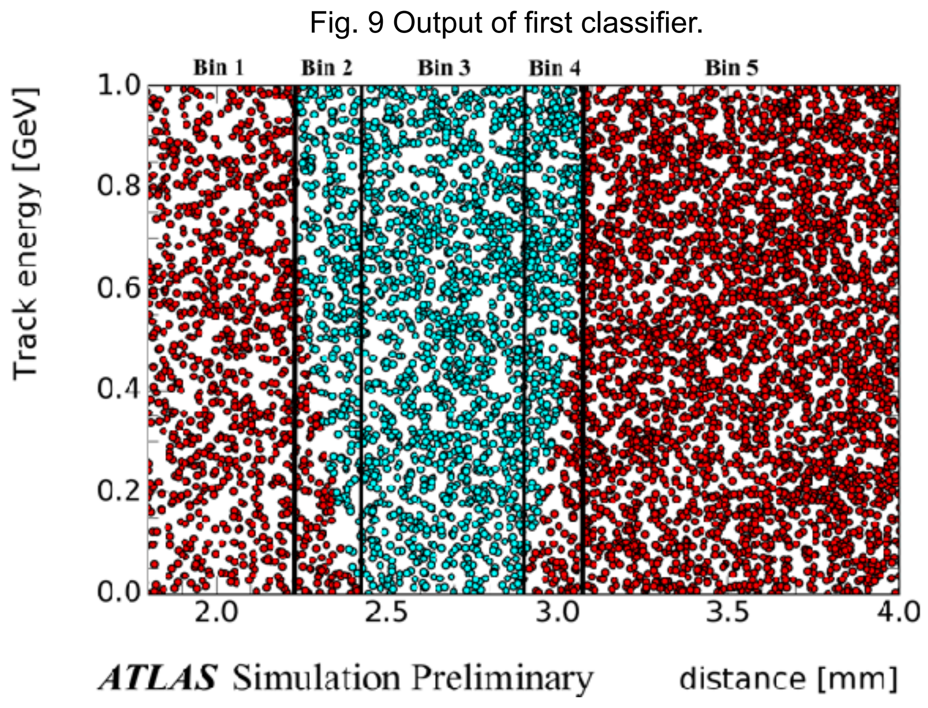

Fig. 10 output of second classifier and new bins positions.

For finding right bin position set of 2 classifiers is used. First one is classifying showers on two categories, second one is finding separating hyperplane, using as an input results of first classifier

Dots in cyan on fig. 9 and 10 are corresponding to showers classified as showers, that have been born in a sensitive material, and red dots for showers that are classified they have been born in a dead material

Input parameters

First classifier:

- Sum of energy deposits energy divided by generated energy of particle (noted as SumE/E on plots)
- Energy of biggest energy deposit divided by generated energy of particle
- RMS of energy deposits

Second classifier:

- Track energy
- Distance to closest rod centre

Results

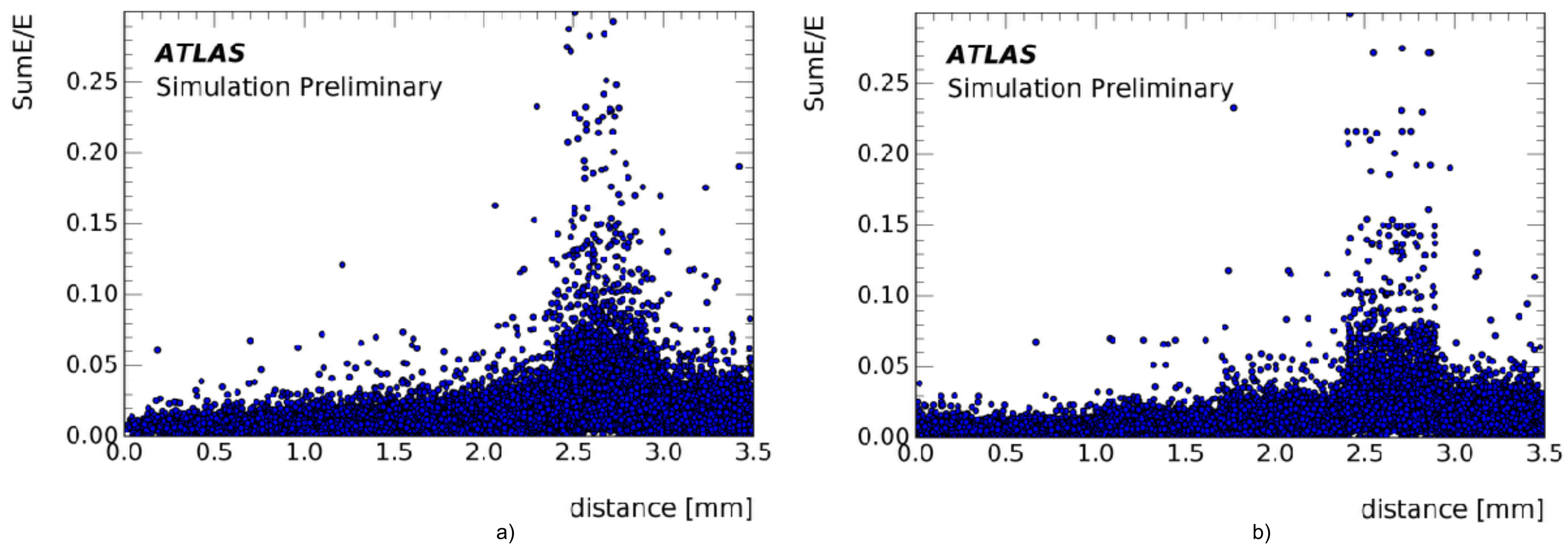

Fig. 13 Summed energy of hits distribution for different distances for showers from electrons with energy less than 1 GeV generated in a) full simulation b) toy MC from frozen shower library with new distance binning

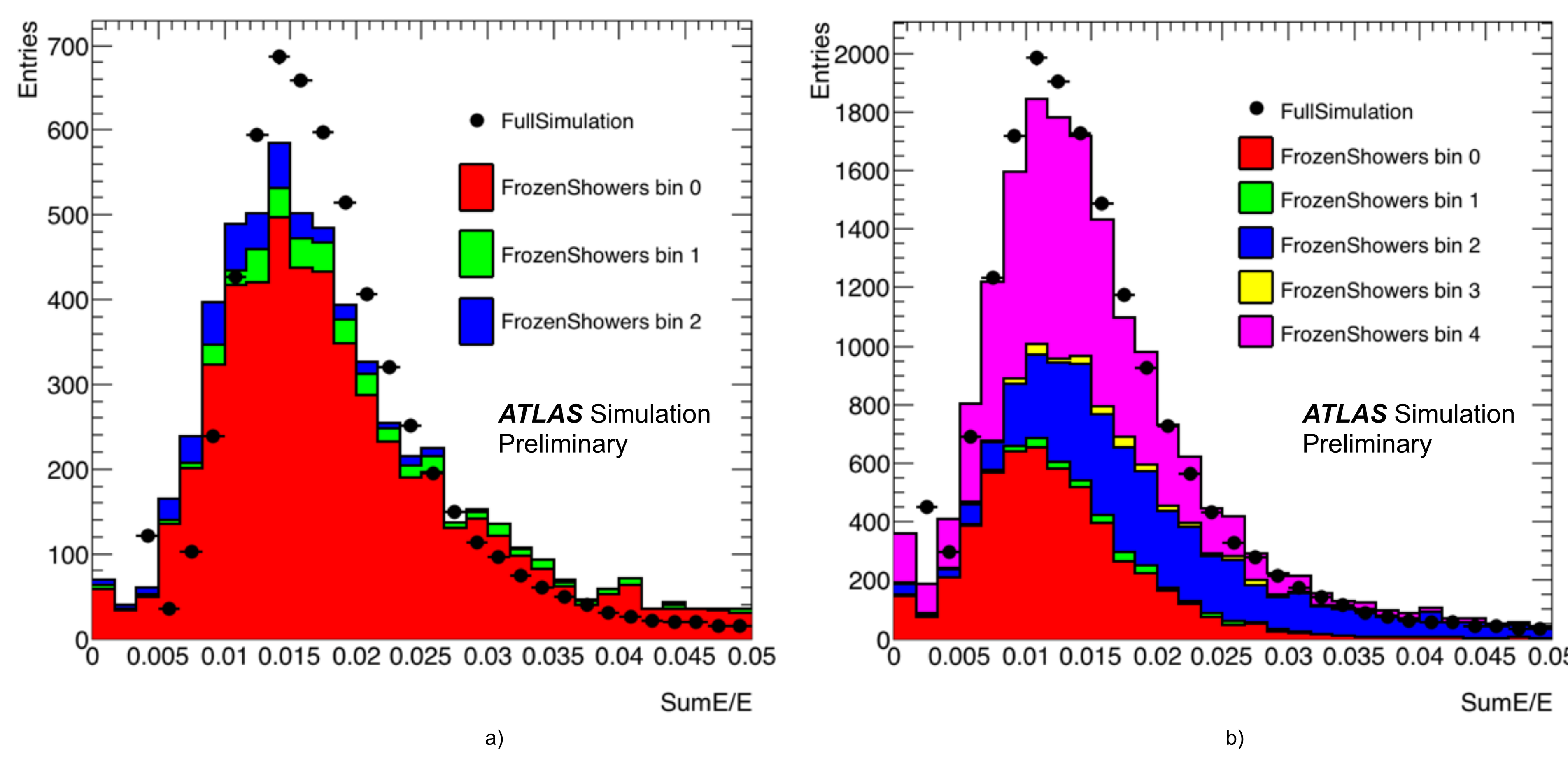

Fig. 14 Summed energy of hits histogram for closest to LAr gap bins for toy MC electrons with energy less than 1 GeV generated from frozen showers library with a)old distance binning b) new distance binning compared to full simulation results.