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A first look at LAr full simulation using FCCSW

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Introduction

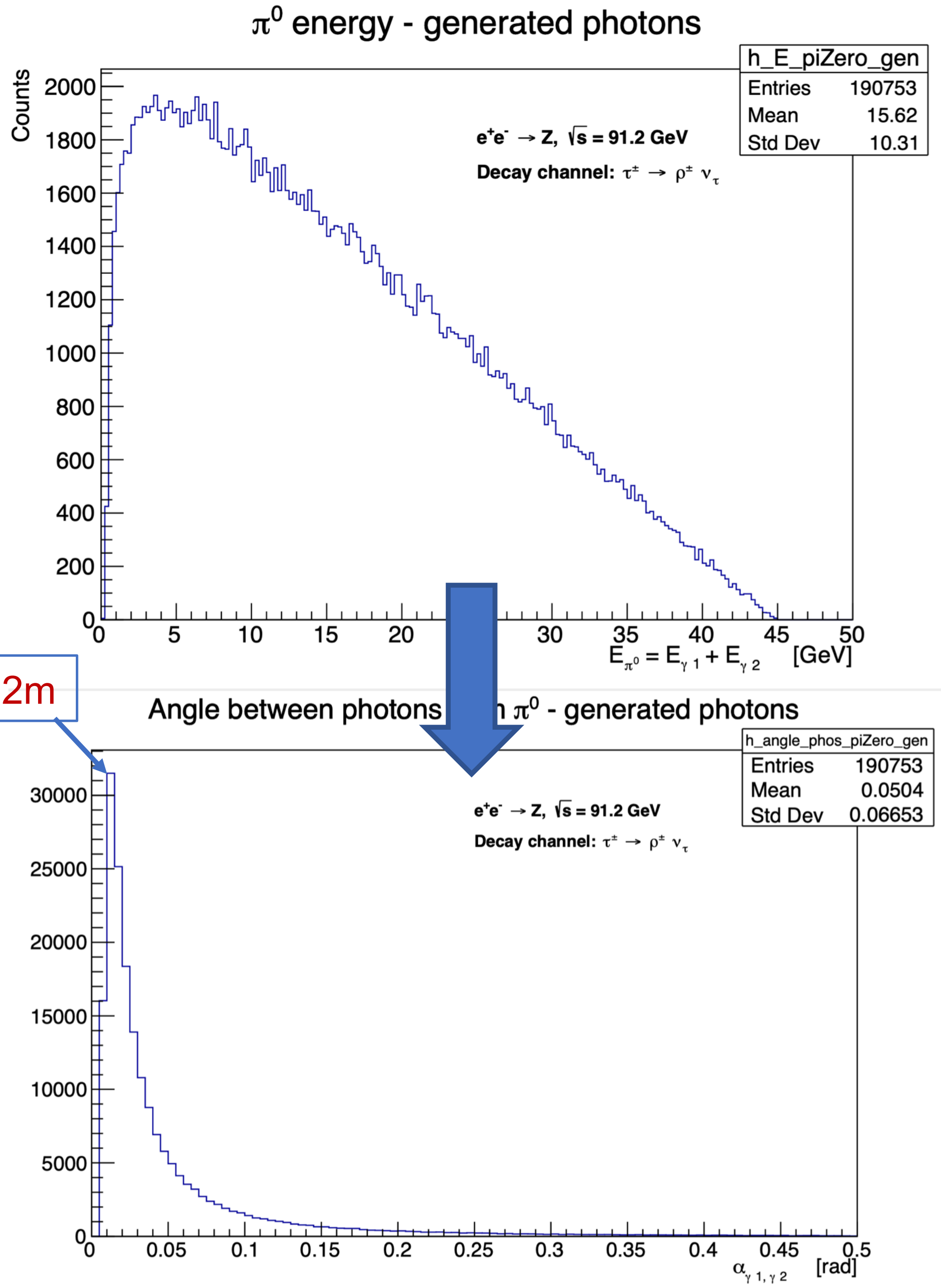
- Goal: investigate proposed LAr electromagnetic calorimeter for the purpose of precision physics at FCC-ee
- In particular, concentrate on tau lepton physics, which poses strict requirements on the detector performance.
  - Perfect test bench to evaluate detector performance
  - Major experimental challenge:

    Clean separation and measurement of tau decay modes

    $\tau^- \rightarrow \pi^-\nu$, $\pi^-\pi^0\nu$, $\pi^-2\pi^0\nu$, $\pi^- 3\pi^0\nu$, $\pi^- 4\pi^0$

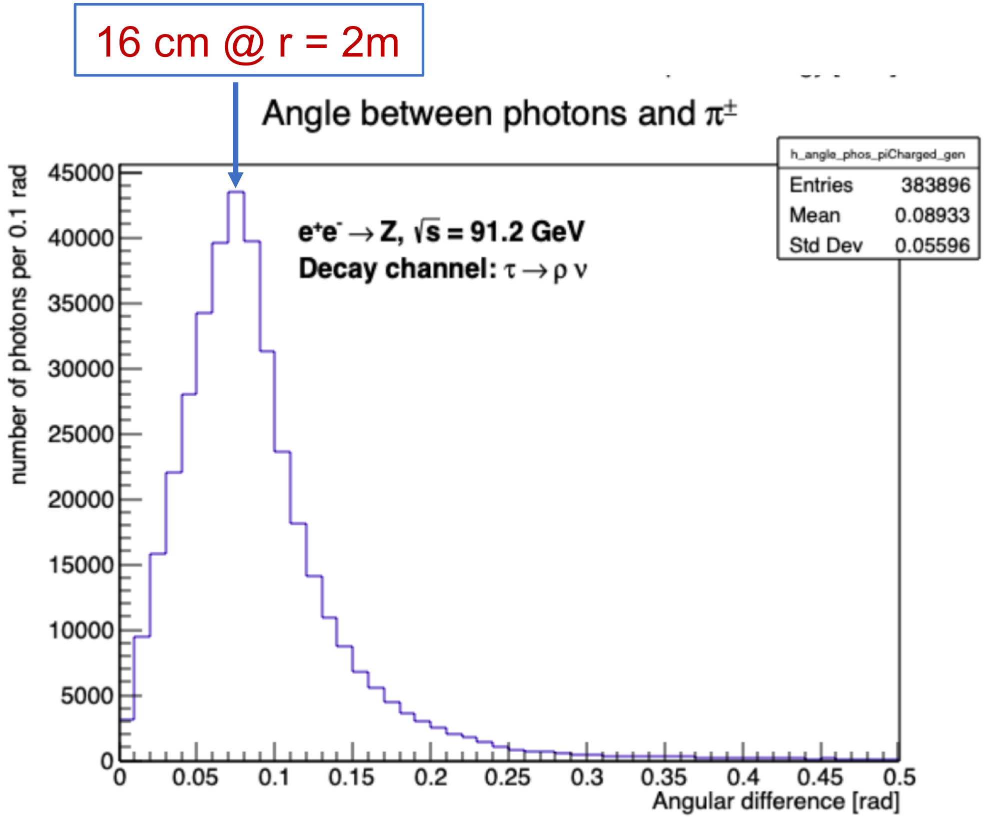
    Identification and measurement of π^0 in colimated topologies close to hadronic environment from π^- impact
- Study/development of clustering methods for LAr calorimerter
  - MSc project (→ summer 2021) for Katinka Wandall-Chistensen

τ → ρν decays



2.5 cm @ r = 2m

Plots by Katinka



Reminder: $\pi^0 \rightarrow \gamma\gamma$ opening angle is minimal when two photon energies are identical $E_\gamma = E_\pi/2$

$$\alpha = m_\pi / E_\gamma$$

γ / π^0 separation

- For tau physics one does not necessarily have to positively identify all π^0 s
  - A high energy neutral electromagnetic shower assumed to be a merged π^0
- However, a more requiring challenge:
  - Normalisation of cross section using $e^+e^- \to \gamma\gamma$ events. Goal: 10^{-4}

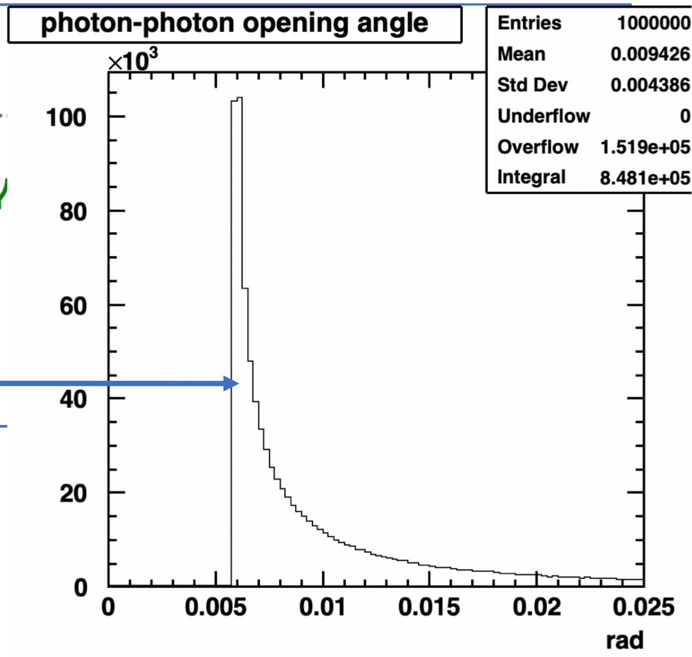
One of the backgrounds

MD, talk at 4th FCC Workshop: [A detector for precise cross section measurements]

❑ **$Z \to \pi^0 \gamma$** ($Z \to \gamma\gamma$, $Z \to \pi^0\pi^0$ disallowed)

- ❖ Z production rate at pole ~10^3 times $e^+e^- \to \gamma\gamma$ rate
- ❖ Need to know $\mathcal{B}(Z \to \pi^0 \gamma) \times F$ to 10^{-7}, where F is fraction of $\pi^0\gamma$ being identified as $\gamma\gamma$
- ❖ Current limit: $\mathcal{B}(Z \to \pi^0 \gamma) < 2 \times 10^{-5}$
- ❖ Have to be able to make per mille experimental separation of γ and π^0 at 45.6 GeV
  - ▪ $\gamma\gamma$ separated by ~~~2~~ 1.2 cm at ECAL

1.2 cm @ r = 2 m



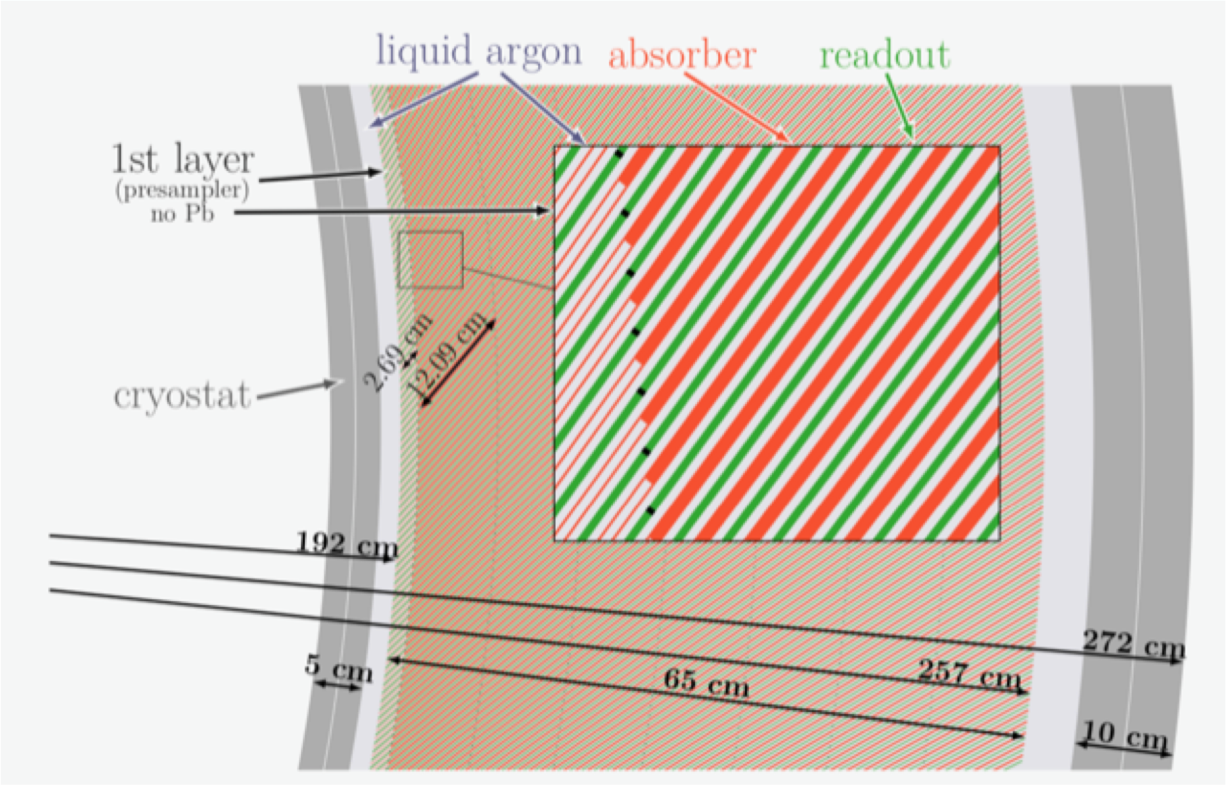
- Separation of high energy photons at 1.2 cm

Experiences from starting out full simulation in FCCSW *)

It took me quite some time to realize what this simulated geometry implies

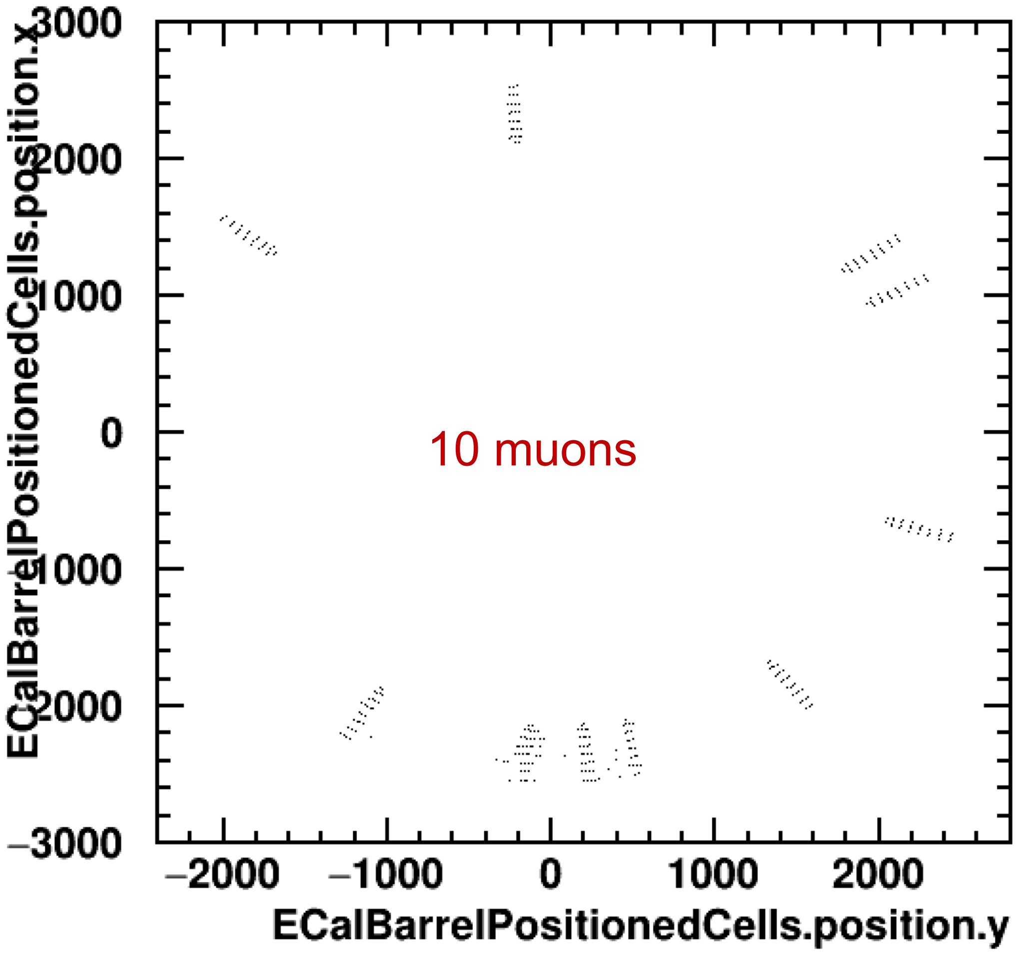
For example:

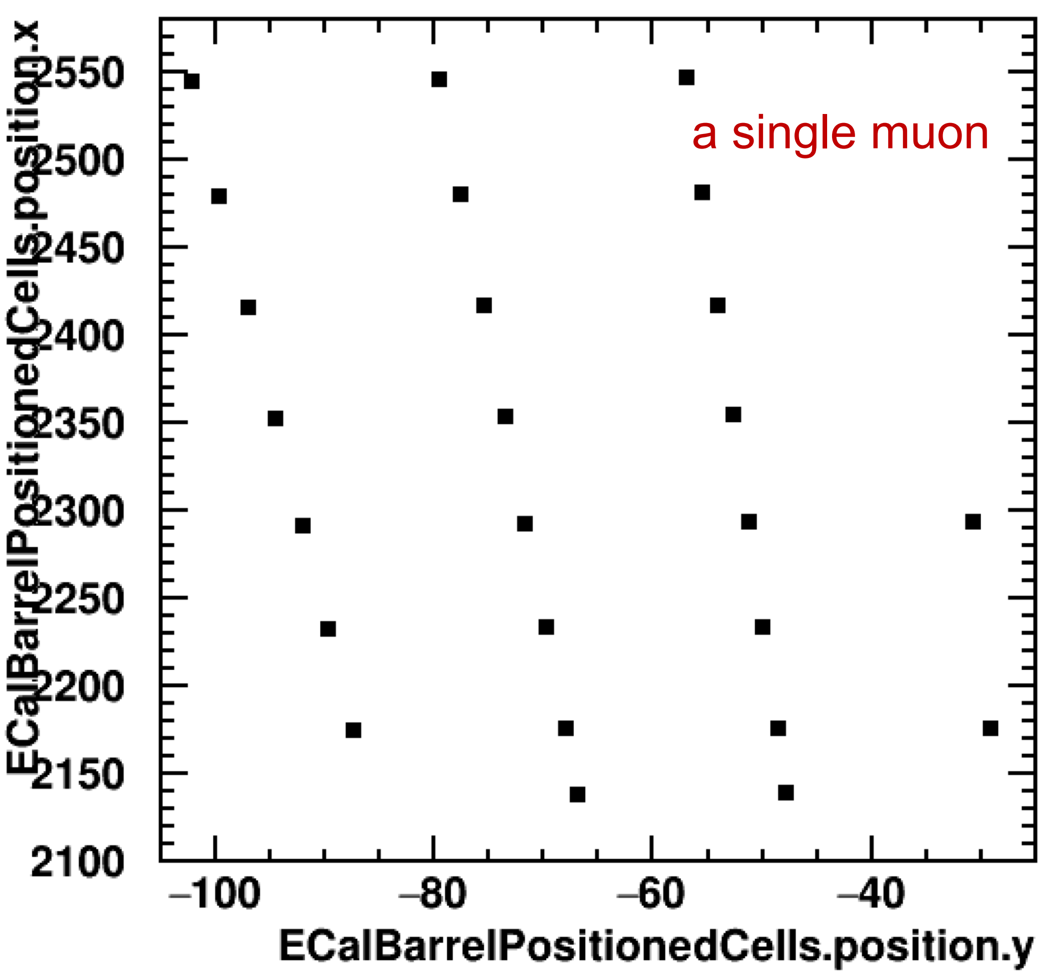
Why ~35 hits from penetrating muon track, when there are only 8 samplings?



*) With lots of thanks to the FCCSW team, in particular Clement and Brieuc! Without their help this would have never happened!

Muon track

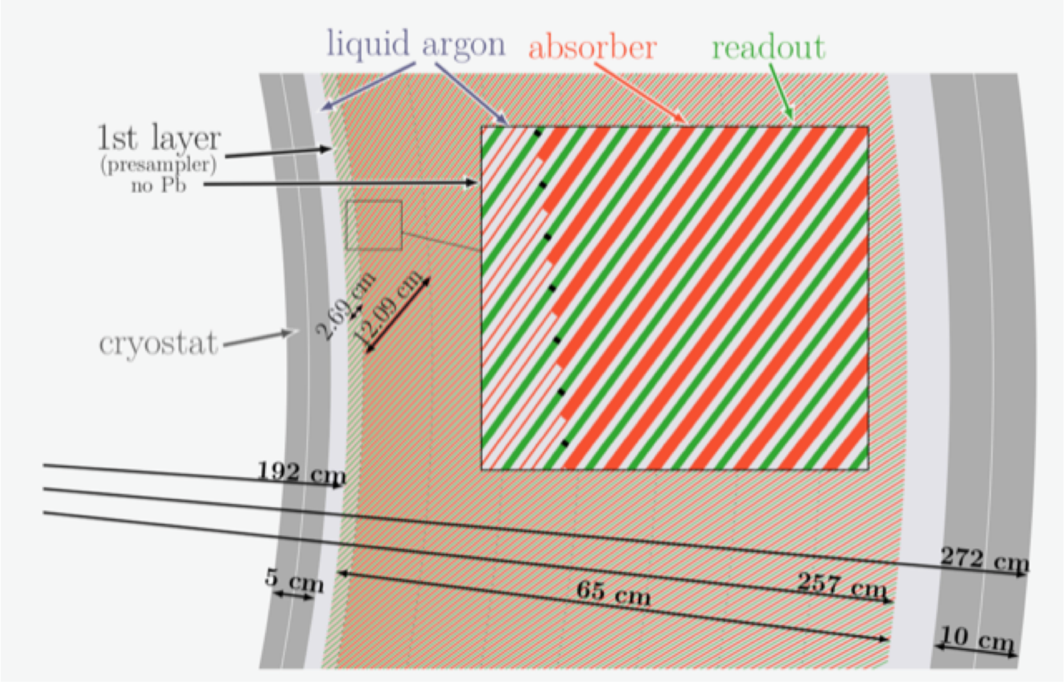


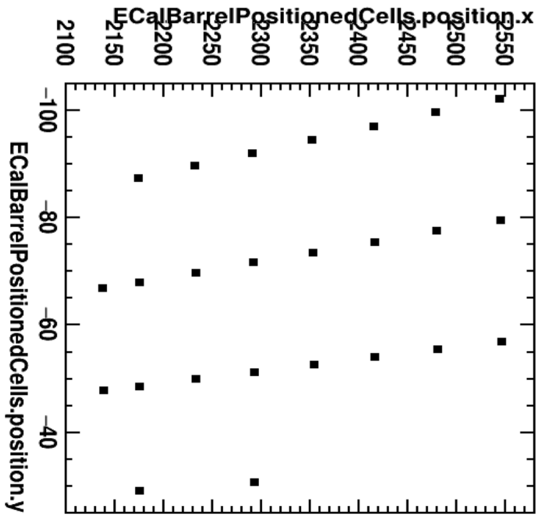


- Of course, this (at first surprising) pattern with ~4 hits for each measured r is a simple result of the detector readout geometry.
- The tilted readout cells gives a $\mathcal{O}$(5cm) transverse smearing of the (otherwise delta function-like) muon signal

ECAL clustering ?

- Have been studying various modern clustering algos
  - PandoraPDF, Arbor, CLUE
- All of them are based on a strict division of calorimeter coordinates into transverse and longitudinal components
  - Follow shower development in → out
  - Collect signal in layer i, then connect to layer i+1
- With the LAr readout organisation this is no longer obvious
  - r and rϕ coordinates are mixed at the 8 cm scale
  - Not obvious (to me!) how then to do clustering





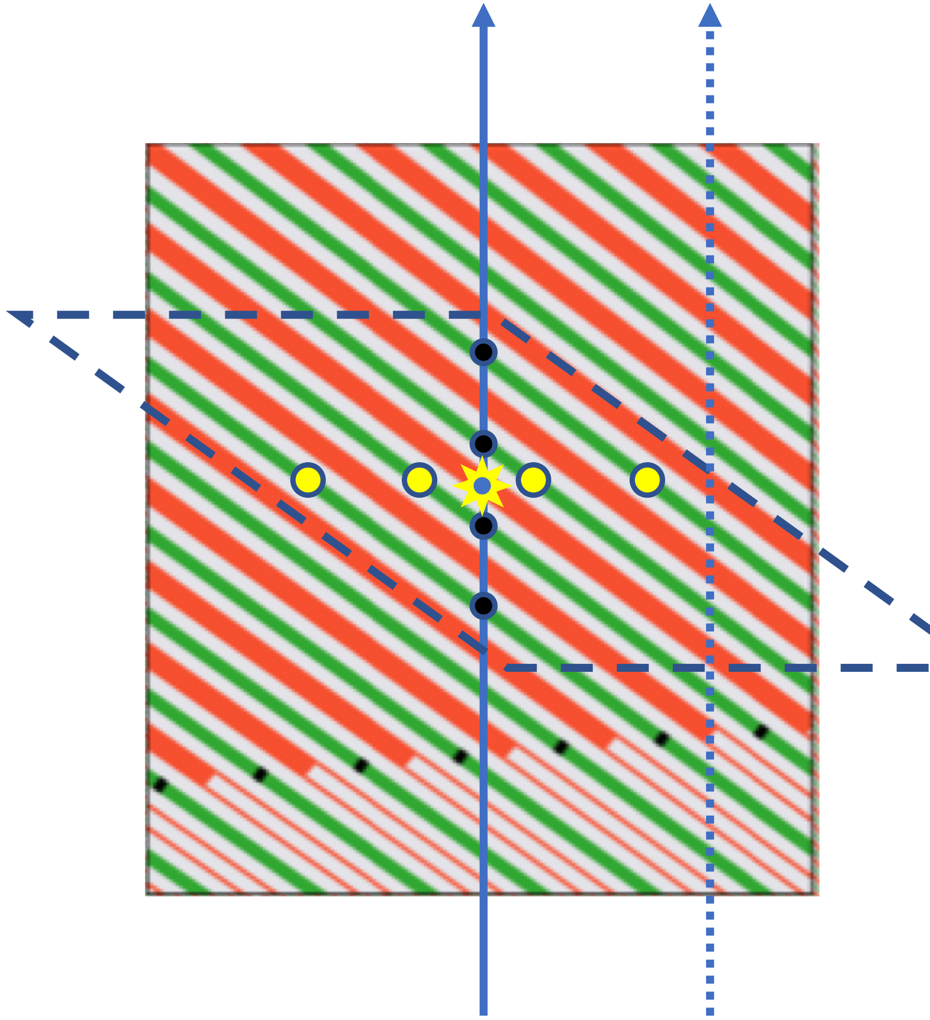
In retrospect…

Rethinking the clustering problem, probably conceptually it is not too different from a "standard" situation:

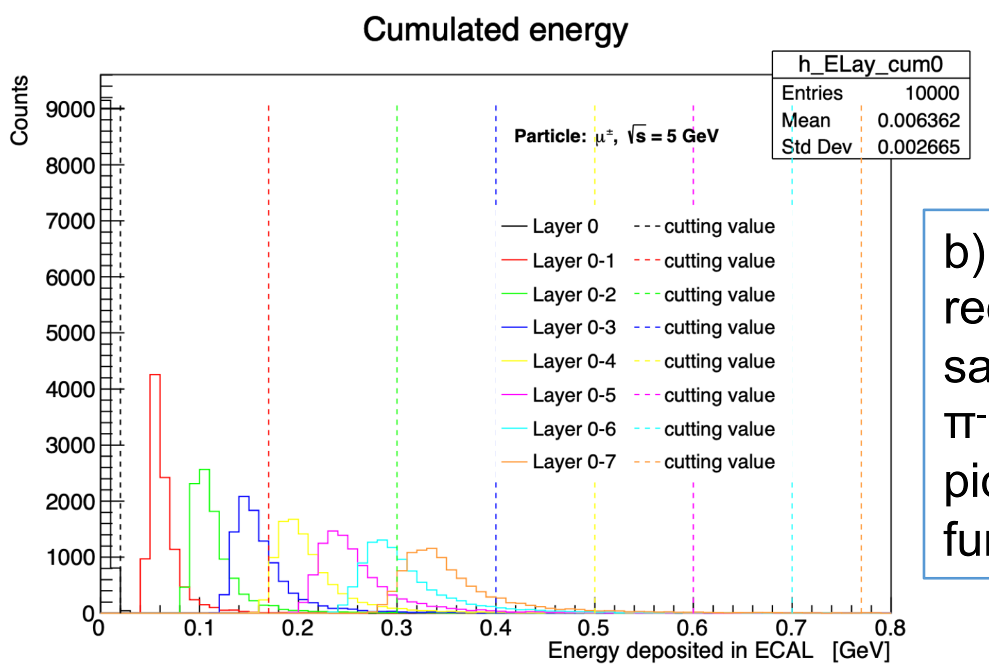
a) Collect signal in layer i into clusters
b) Connect to layer i+1

Still, the tilt of the readout cells does provide

- A strong correlation between the r and rφ coordinate of a measurement
- And hence, an additional "smearing" of the rφ coordinate given r

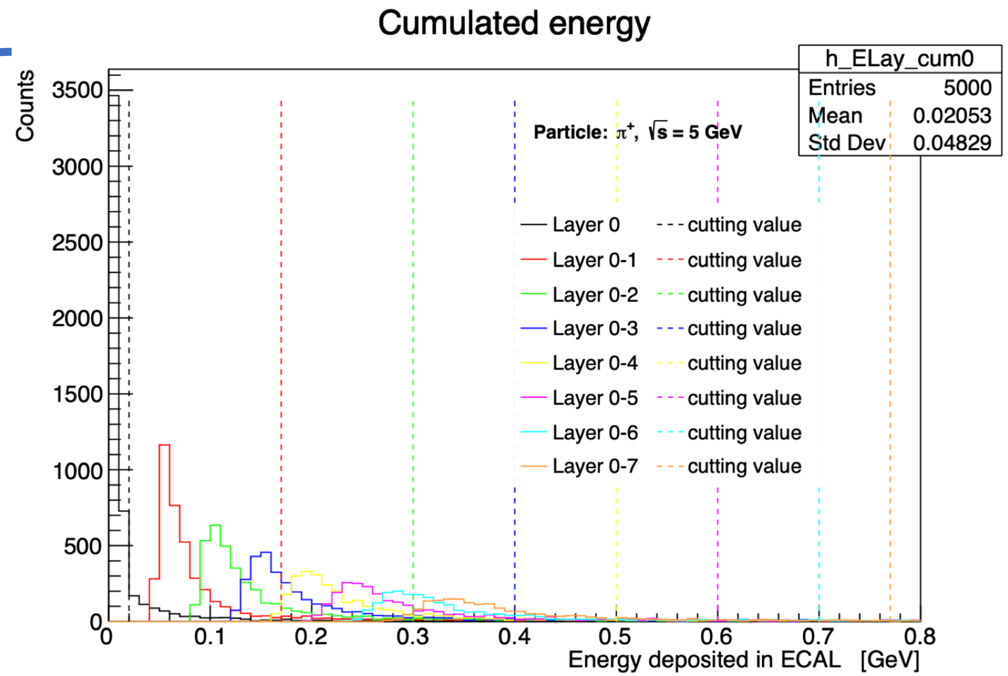


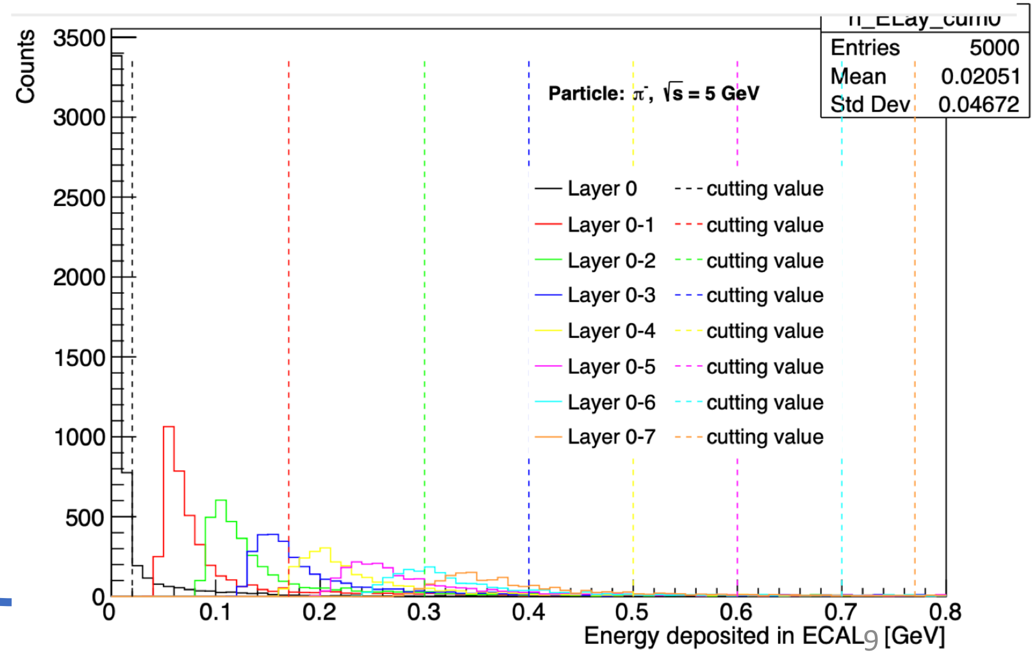
Some initial single particle study



a) Use muon sample to define 99% efficient mip requirement layer-by-layer

b) Apply this requirement to samples of π^+ and π^- in order to study pion interaction as function of depth

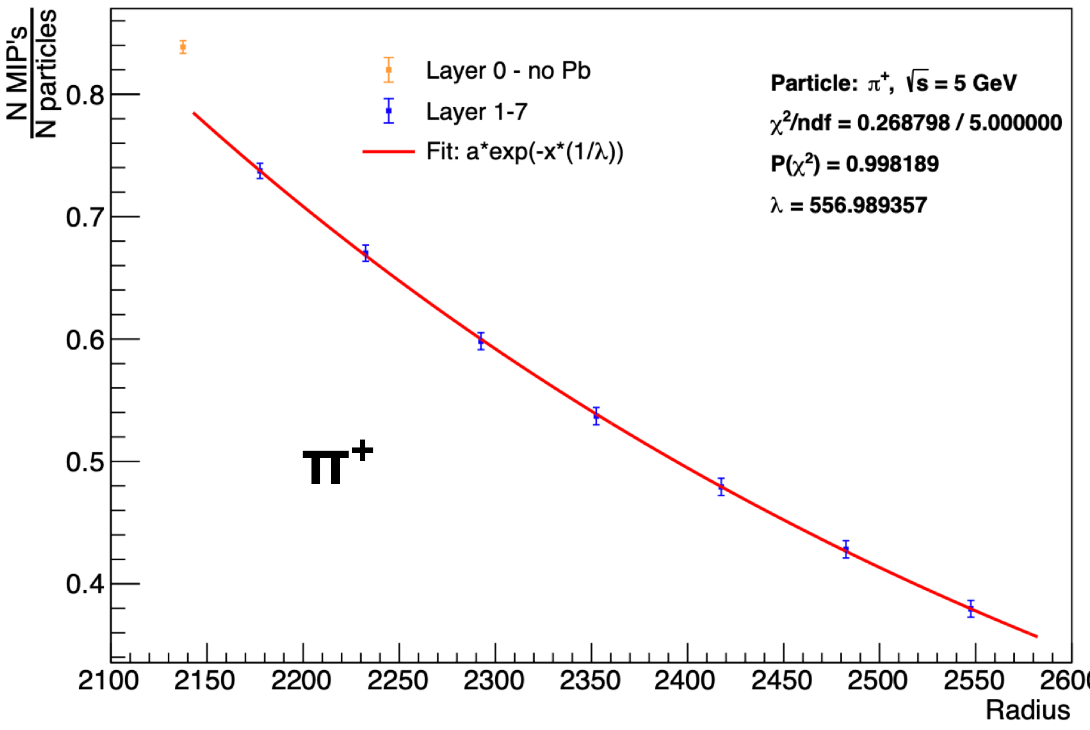


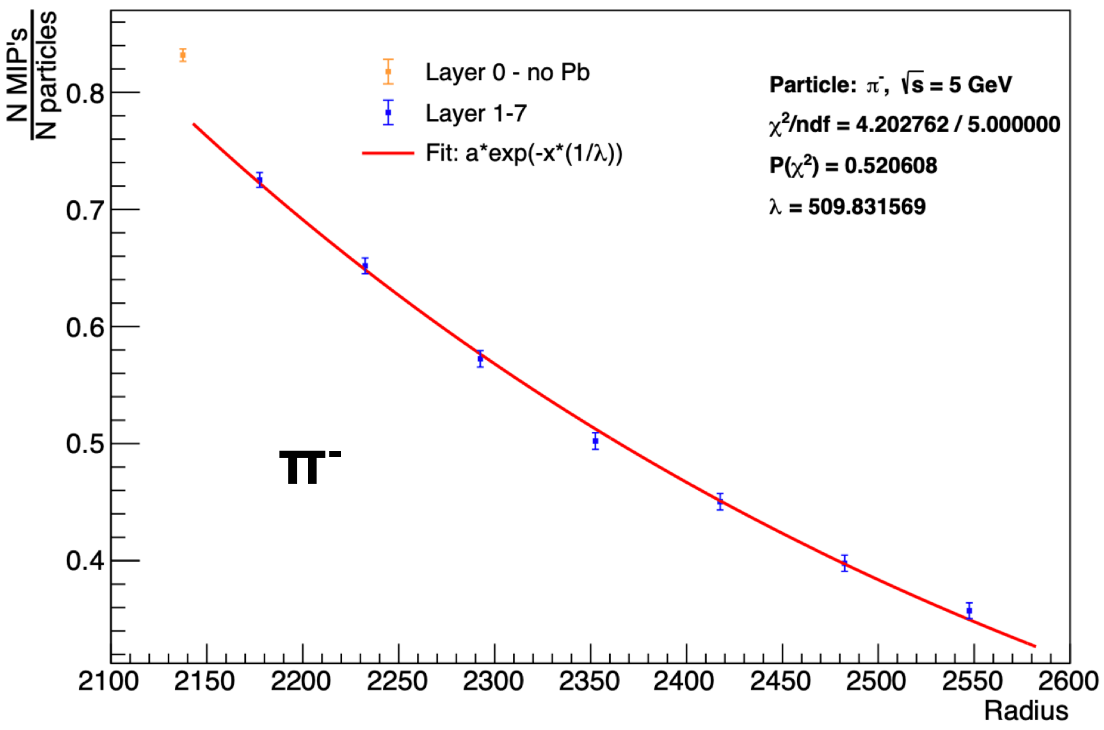


Katinka

Some initial single particle study (ii)

Fraction of pions appearing as mip vs. calorimeter depth





λ = 557 mm

λ = 510 mm

Resonable agreement with calculated value for material mixture:

λ_n = 414 mm

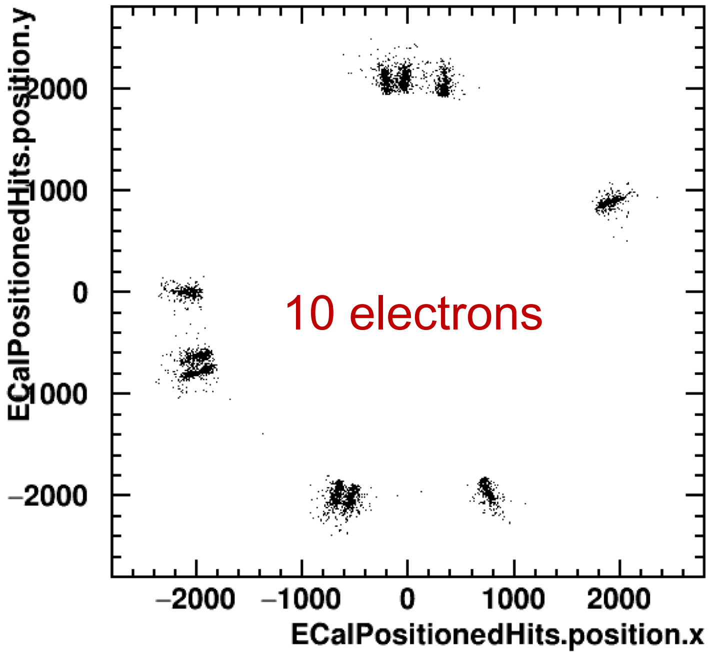
λ_π = 495 mm

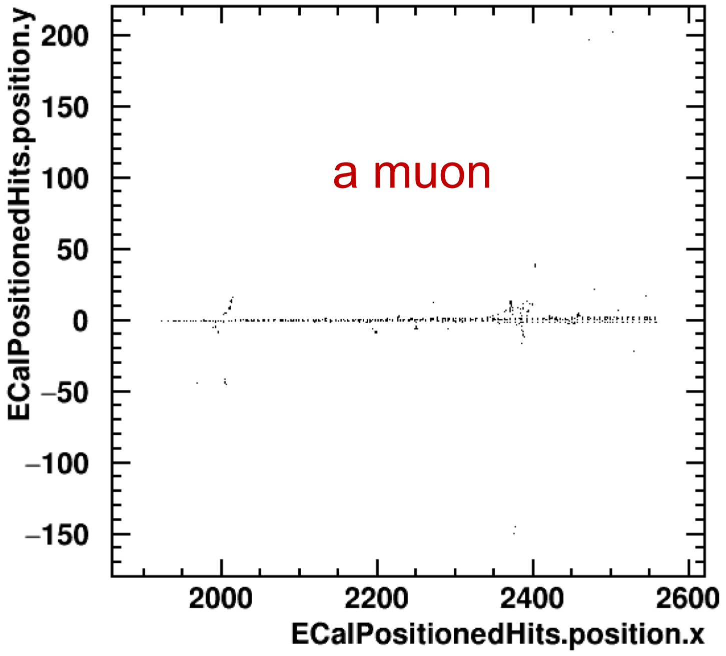
Katinka

Simulation of a fictitious geometry

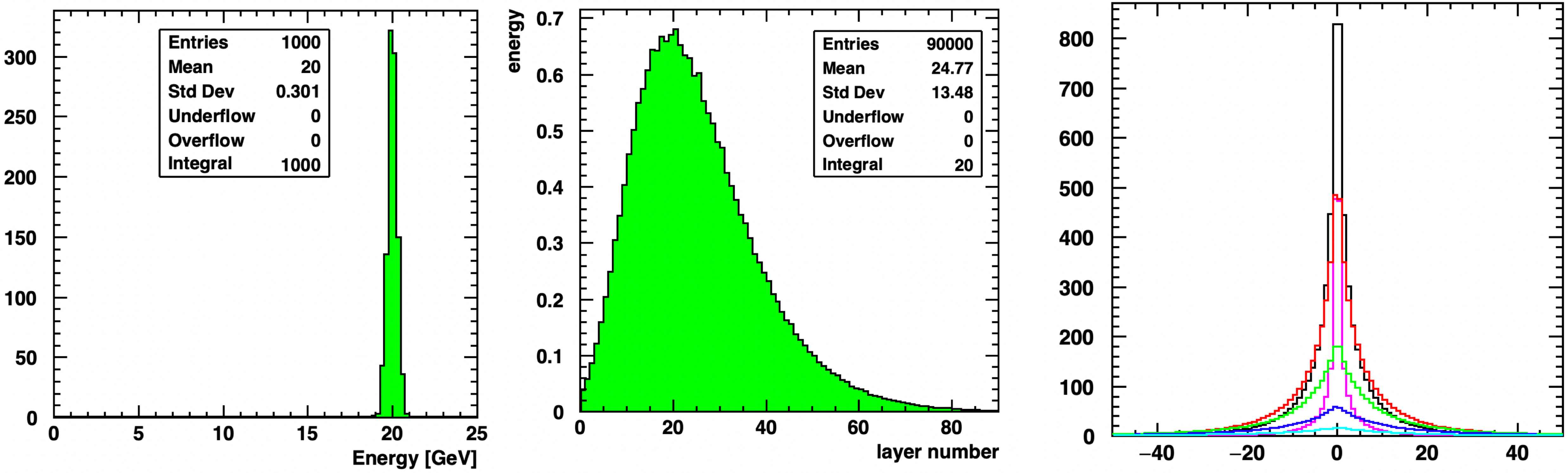
- Again with ample help from FSCSW, now simulating a calorimeter made of 90 concetric, cylindrical 7.2 mm layers (4 mm LAr, 2 mm absorber, 1.2 mm PCB)
- Save all geant4 hits deposited in LAr.
- Can in principle build « any » readout geometry

- This geometry is close to a « traditional » calorimeter geometry
    - Aleph, delphi, CALICE, …
- But is probably not possible for LAr (?).





A few plots – 20 GeV electrons



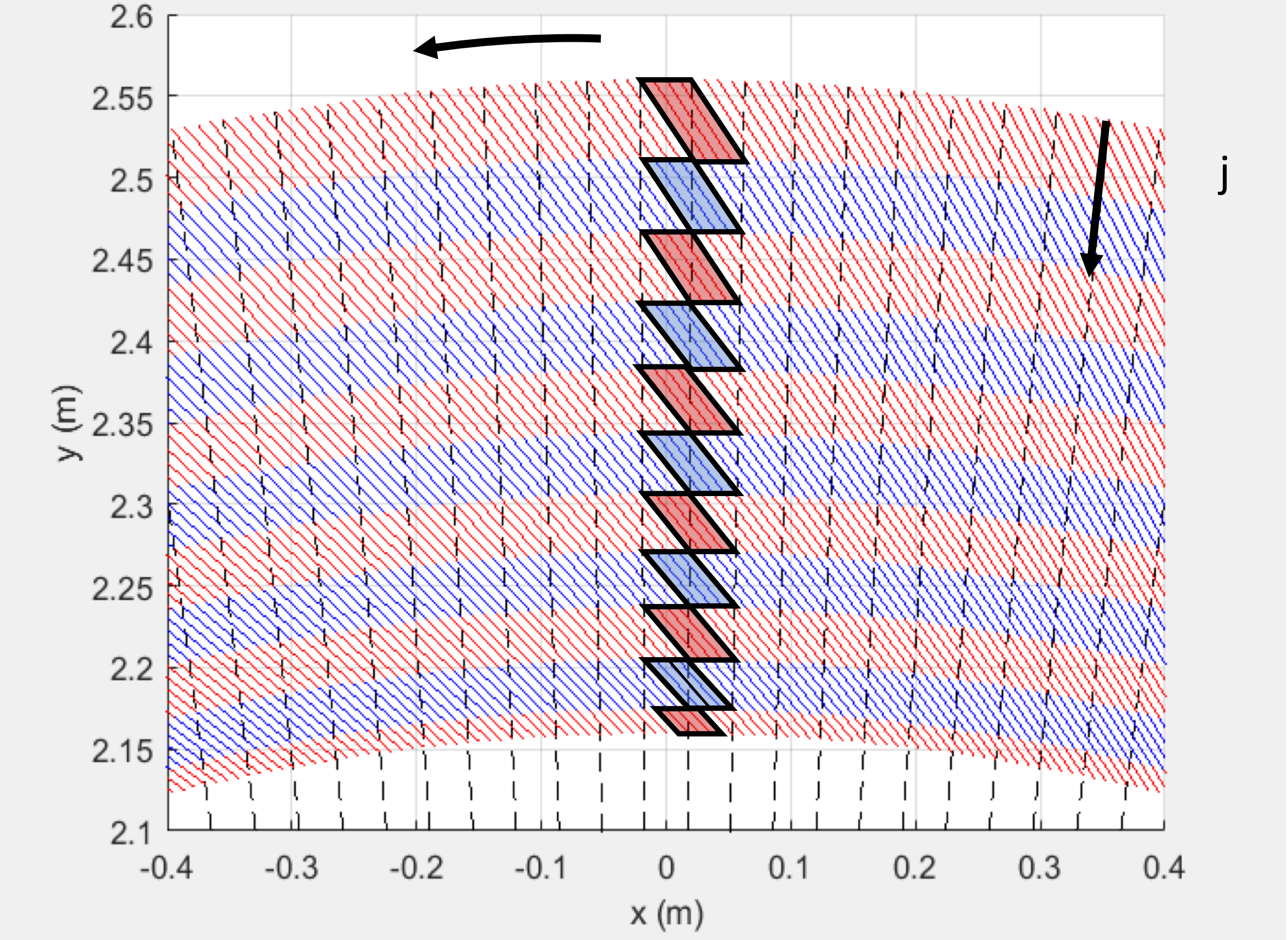
Energy resolution of 1.5%, i.e. 6.7%/√E

Longitudinal shower development. Maximum at about layer 20, i.e. after ~6 X_0

Transverse shower development in 5 first 10 layer deep (~3 X_0) samplings. Largely inside 5 mm in first 2 samplings (until shower max at 6X_0)

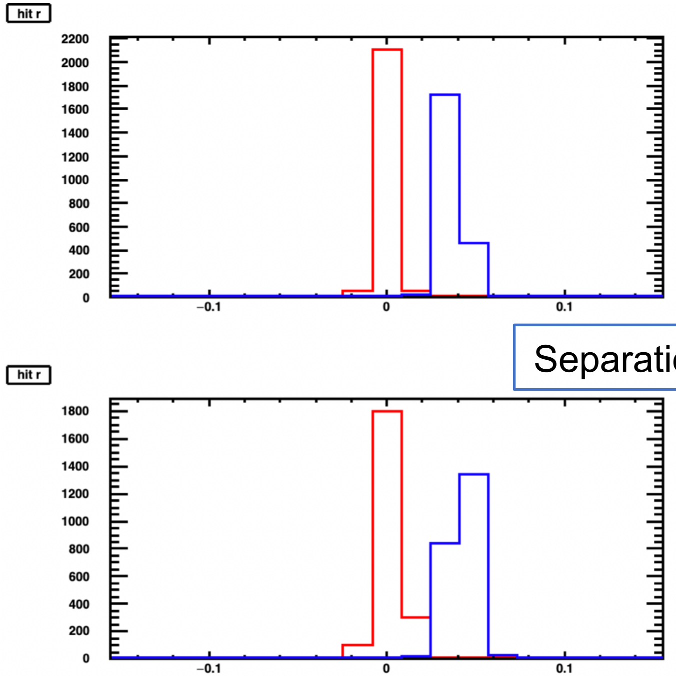
Possible new electrodes segmentation

Figure lifted from previous talk



Typical size of the largest cell is ~ 4,2 x 4,8 cm
Typical size of the smallest cell is ~ 3,5 x 1,5 cm

From simulation files with all geant hits recorded, try to emulate two cell structures
- at top: ”regular” cells following grid (16 mrad)
- at bottom: tilted cells

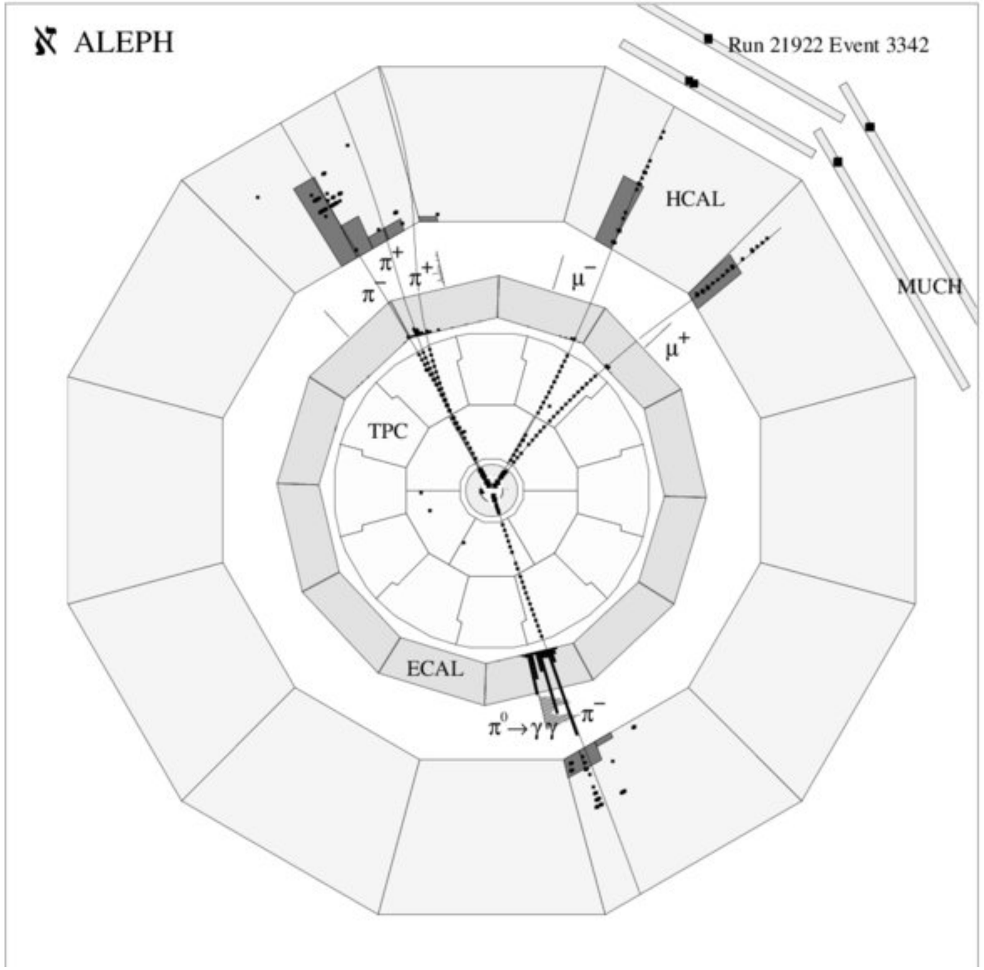


Separation for a 7 GeV π^0

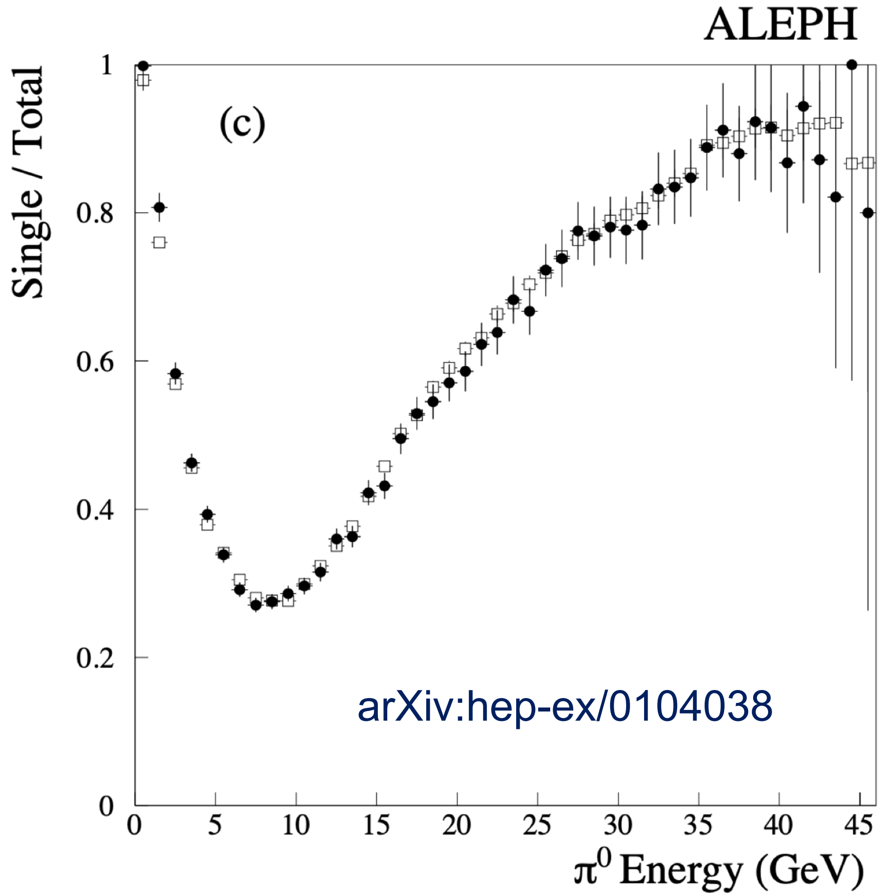
Emulate 2 em showers ~2.5 cell widths (~8 cm) apart.
- Red shower right in center of cell
- Blue shower right between two cells

Some extra smearing apparent from cell structure.
Much more systematic study required!

A LEP Reminder - aleph

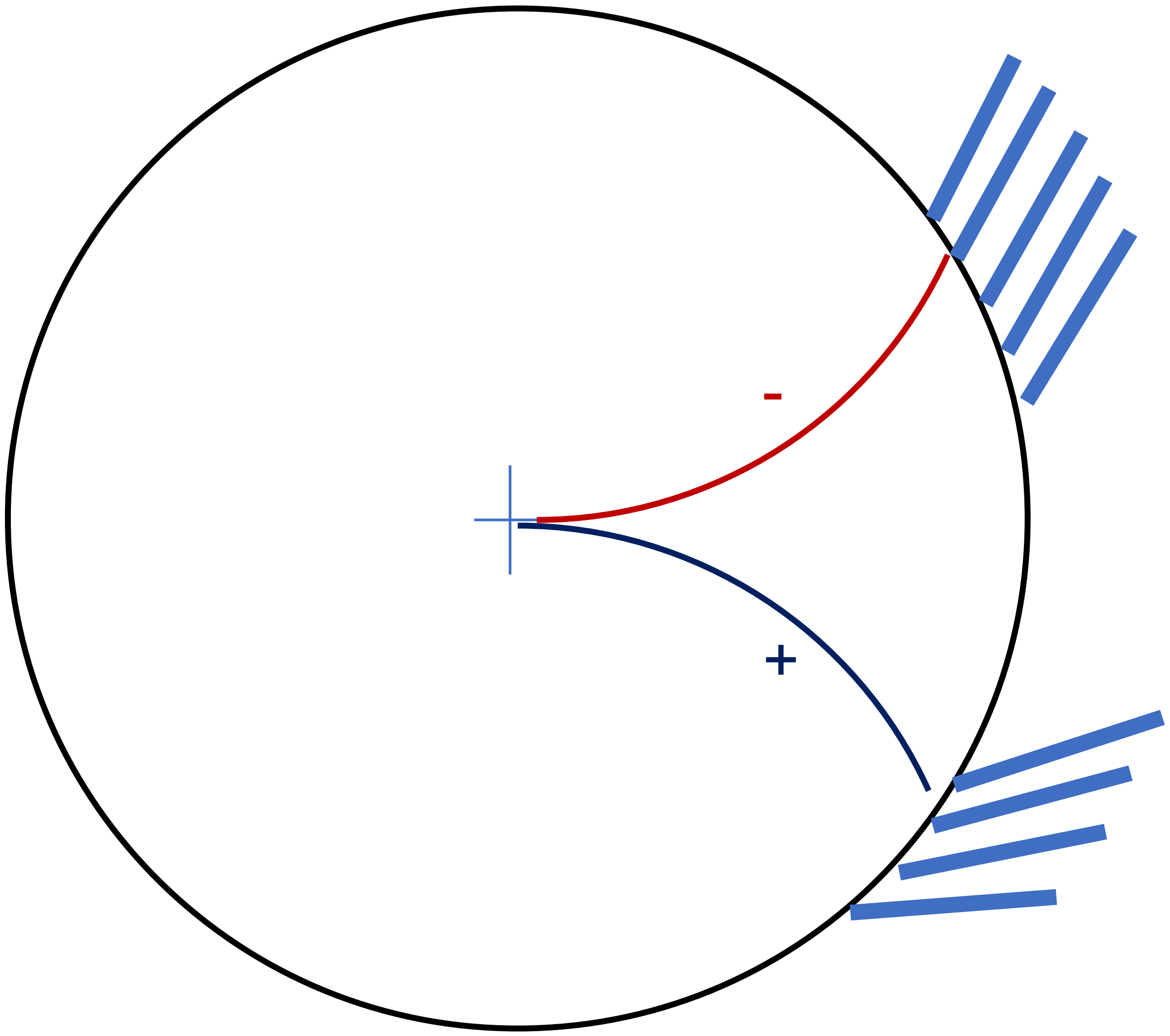


3 x 3 cm^2 ECAL cells with fine-grained longidudinal sampling



Tau polarisation analysis:
Single photon fraction in π^0 sample

Another concern: Charge asymmetry?



The tilted geometry represents a manifest violation of change symmetry

Positively and negatively charged particles see a different ECAL

Summary

- Have started full simulation study of LAr concept ECAL for FCC-ee with the scope of understanding its performance for precision reconstruction of $Z \rightarrow \tau\tau$ events
- The FCCSW environment looks very promising
  - And has good support (and is fun to use!)
- Initial struggles to understand (and accept!) proposed readout geometry
  - Tilted geometry is different and a challenge, I think
    - Correlation r / rϕ
    - Charge asymmetric detector (is this a problem?)
  - Would be nice to have a spatial segmentation *at least* as good as in aleph (3x3 cm^2)
    - Γ / π^0 separation at $E_{\pi 0}$ = 45.6 GeV is a requirement for background rejection for luminosity measurement via $e^+e^- \rightarrow \gamma\gamma$.
      - Photons from $\pi^0 \rightarrow \gamma\gamma$ separated by 1.2 cm at ECAL.