LAr calorimeter R&D for FCC-ee
Performance and electrodes

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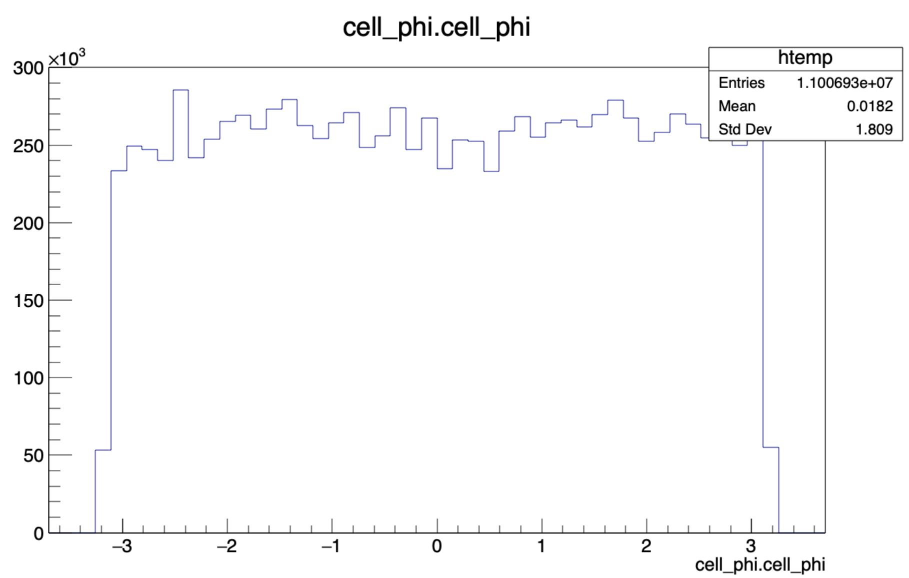
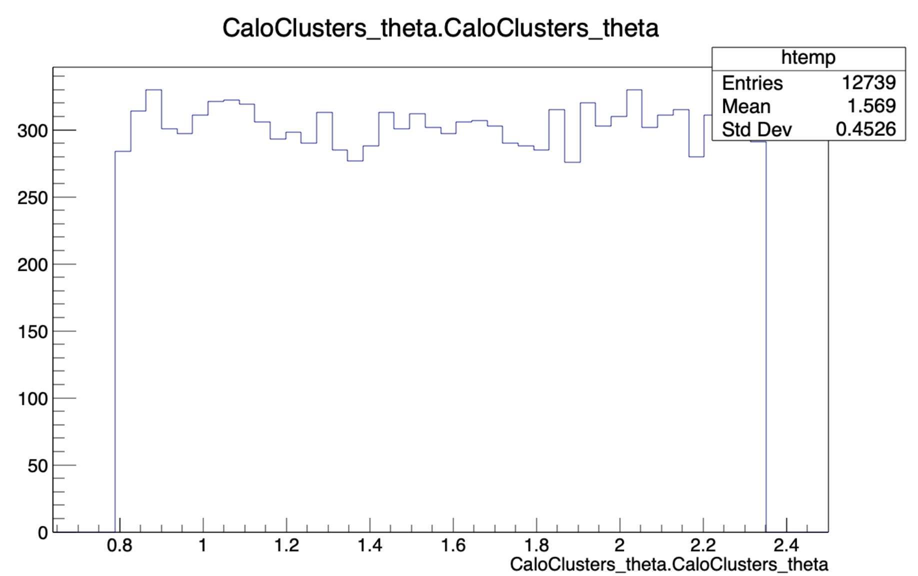
LAr Calo for FCC working meeting
Nov. 26th, 2020

Performances from FCCSW

FCCSW status

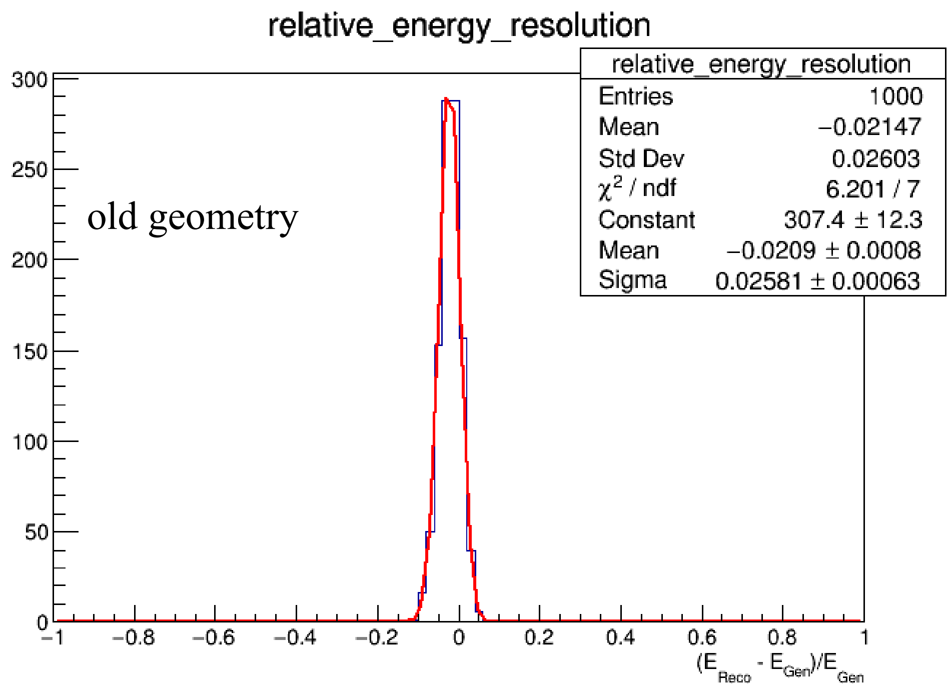
- The new FCC-ee LAr ECAL geometry has been validated
- Pull request on the master branch for the new geometry is opened: PR#433
  - Electrode segmentation with constant $\Delta\Theta$ tool is included in the PR but not used in the detector description (still using $\Delta\eta$=0.01 at the moment)
    - Need first to transition everything (e.g. caloTowerTool rely on the eta separation...)
- A first version of the Calo n-tuple maker is ready
  - Allows to produce basic plots out of the box and to do performance studies with simple scripts (free from fcc or edm4hep dataformat)

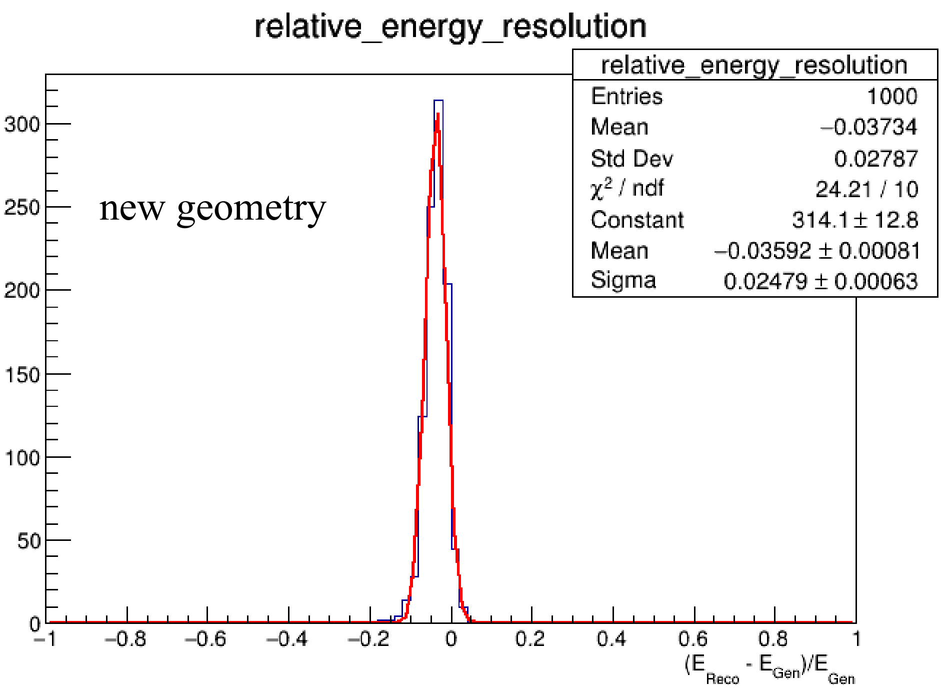




Performance comparison

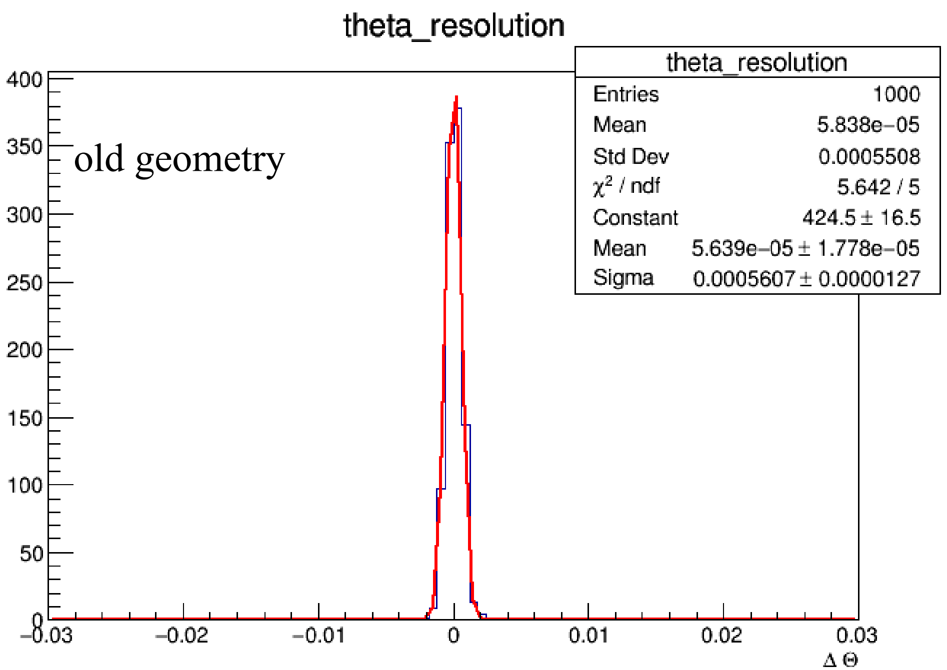
- Energy resolution: old geometry (left) VS new geometry (right)
    - New(old) geometry: 12(8) layers, 1(2) cm LAr bath front, 1.24(0.9) mm LAr gap, 1.4(1.39) mm Pb, 0.4(0.37) mm steel, 0.2(0.24) mm glue, 210(206) cm R_{min}, 226(221) cm dZ
- 10 GeV electrons shot at 90^o (full phi range), sliding window clustering, SF applied, no upstream material correction, no noise, no magnetic field
    - Consistent cluster energy resolution

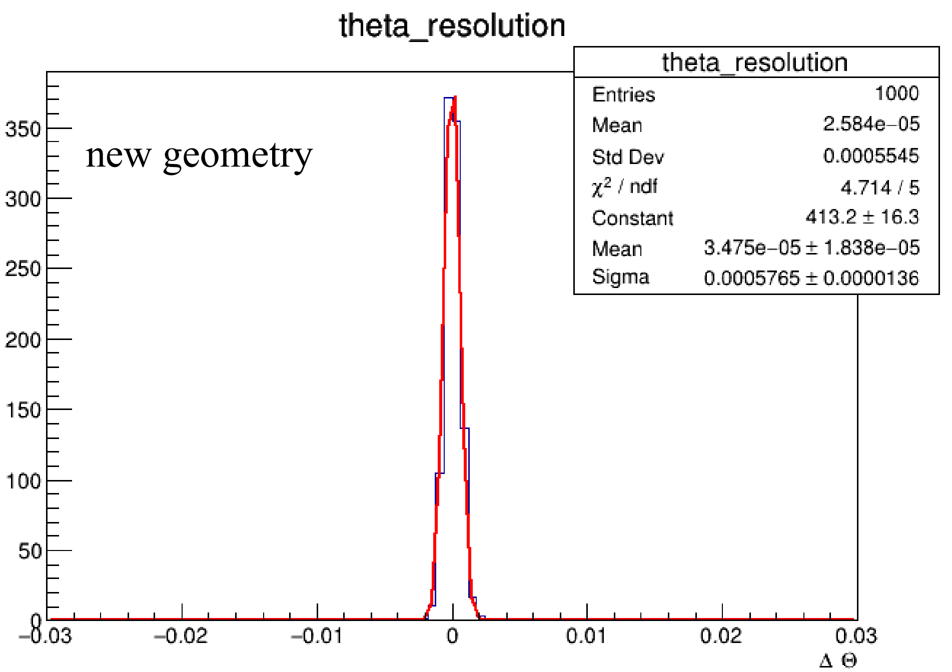




Performance comparison

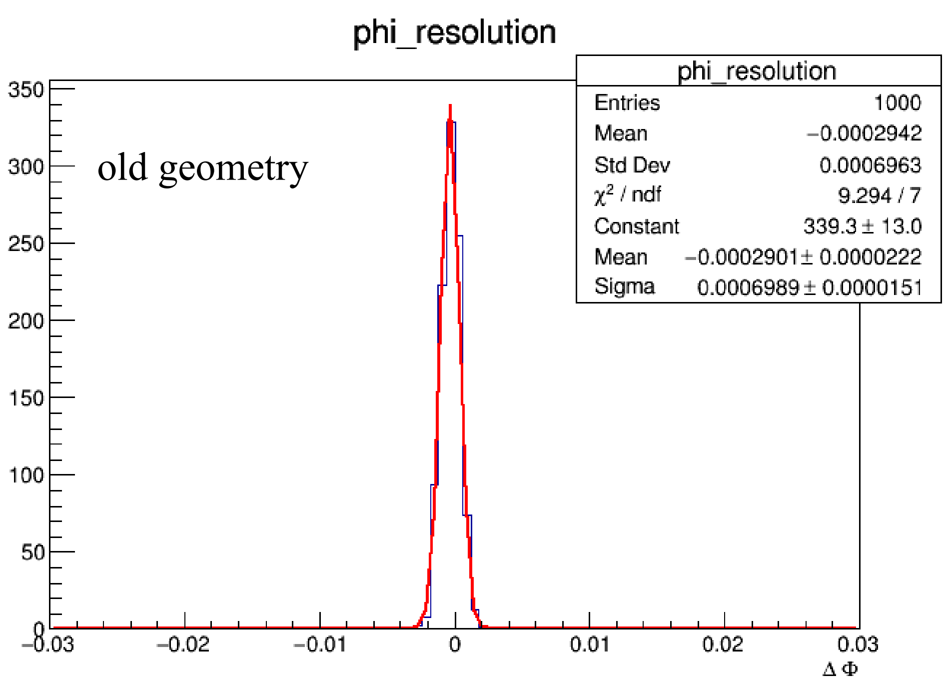
- Theta resolution: old geometry (left) VS new geometry (right)
  - New(old) geometry: 12(8) layers, 1(2) cm LAr bath front, 1.24(0.9) mm LAr gap, 1.4(1.39) mm Pb, 0.4(0.37) mm steel, 0.2(0.24) mm glue, 210(206) cm R_{min}, 226(221) cm dZ
- 10 GeV electrons shot at 90° (full phi range), sliding window clustering, SF applied, no upstream material correction, no noise, no magnetic field
  - Similar cluster theta resolution: ~0.57 mrad

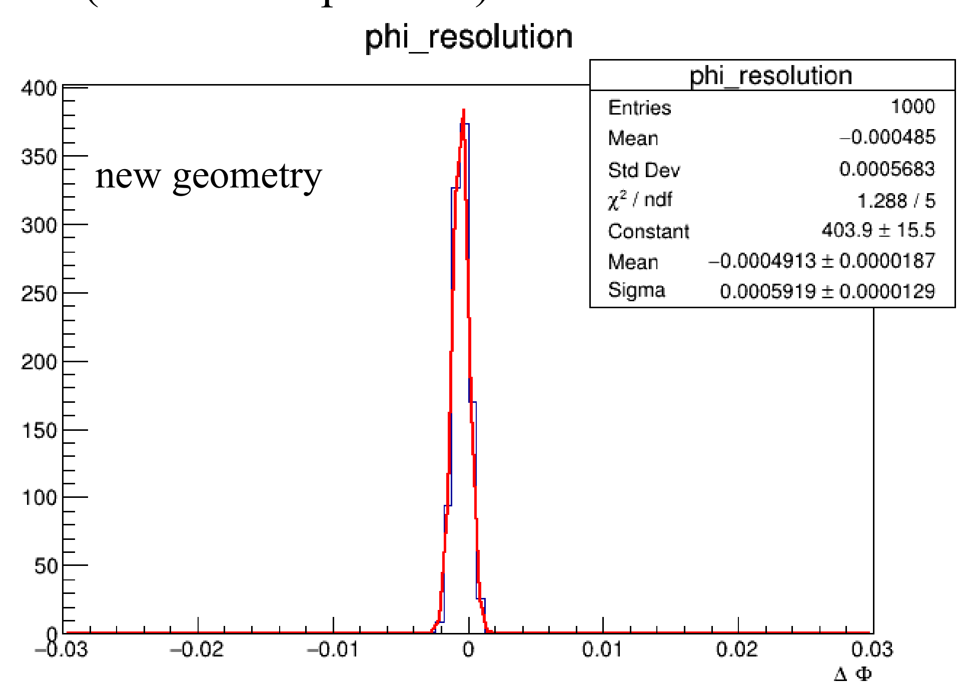




Performance comparison

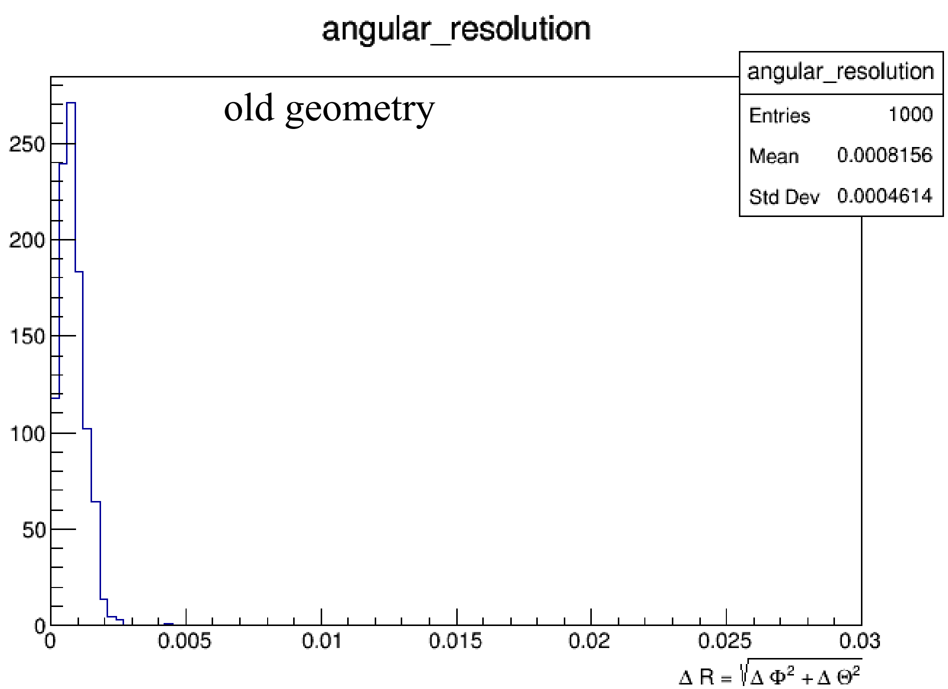
- Phi resolution: old geometry (left) VS new geometry (right)
  - New(old) geometry: 12(8) layers, 1(2) cm LAr bath front, 1.24(0.9) mm LAr gap, 1.4(1.39) mm Pb, 0.4(0.37) mm steel, 0.2(0.24) mm glue, 210(206) cm R_{min}, 226(221) cm dZ
- 10 GeV electrons shot at 90° (full phi range), sliding window clustering, SF applied, no upstream material correction, no noise, no magnetic field
  - Slightly better phi resolution: ~0.6 mrad (768 vs 704 phi bins)

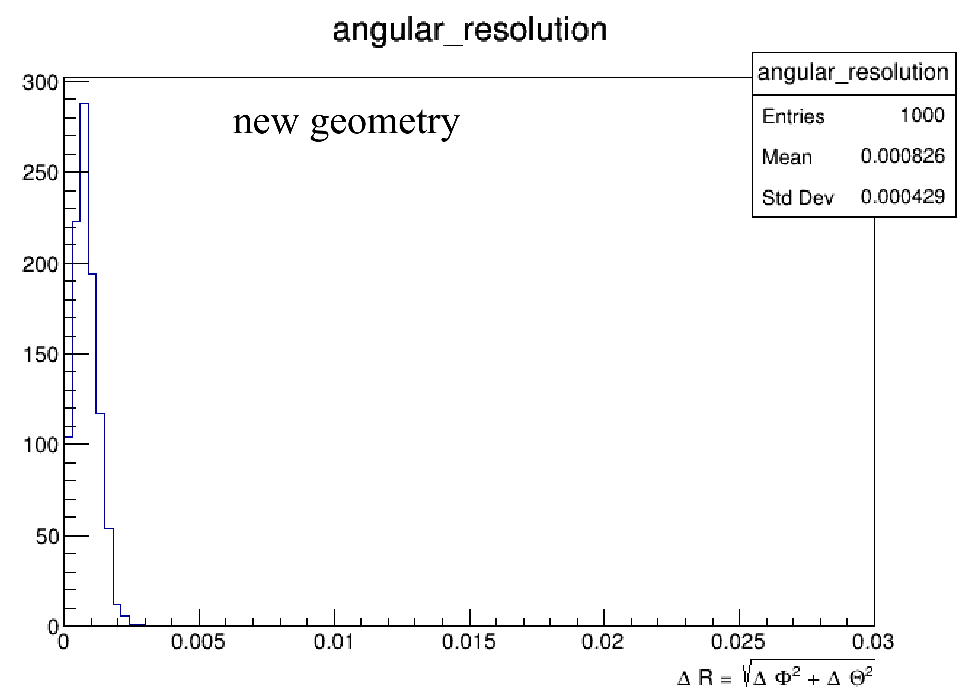




Performance comparison

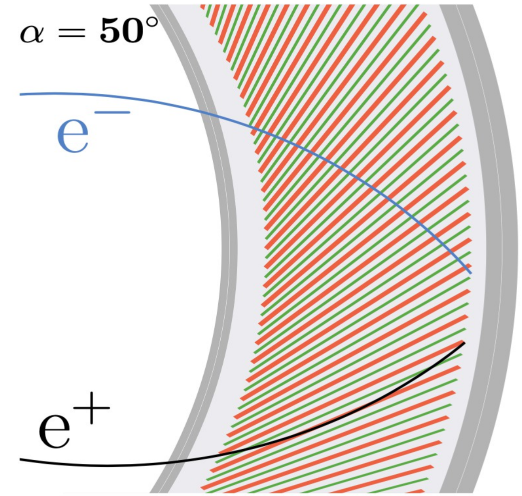
- Angular resolution: old geometry (left) VS new geometry (right)
  - New(old) geometry: 12(8) layers, 1(2) cm cryostat front, 1.24(0.9) mm LAr gap, 1.4(1.39) mm Pb, 0.4(0.37) mm steel, 0.2(0.24) mm glue, 210(206) cm R_{min}, 226(221) cm dZ
- 10 GeV electrons shot at 90° (full phi range), sliding window clustering, SF applied, no upstream material correction, no noise, no magnetic field

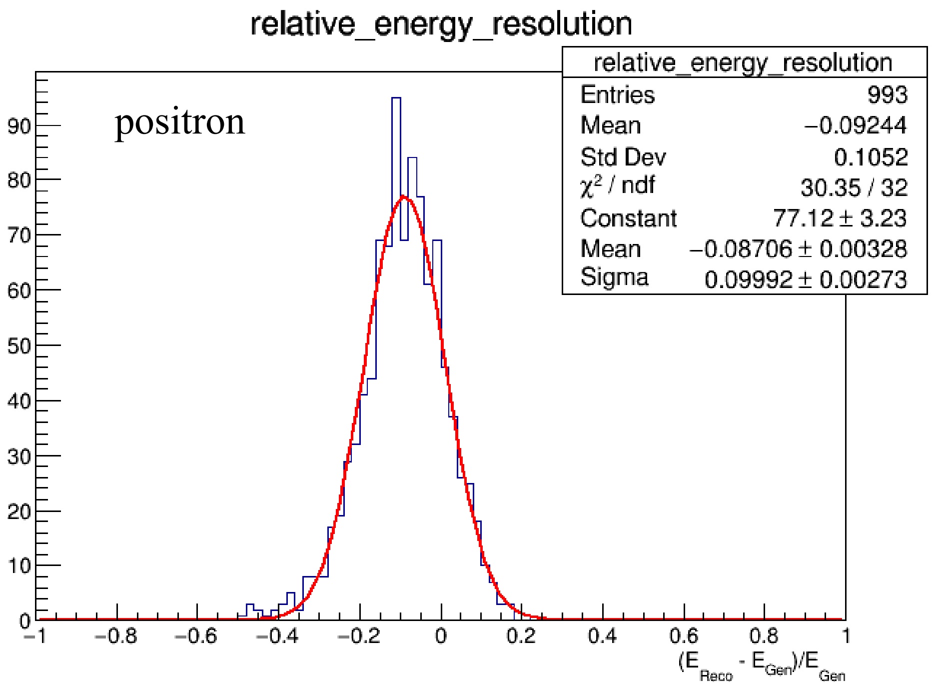


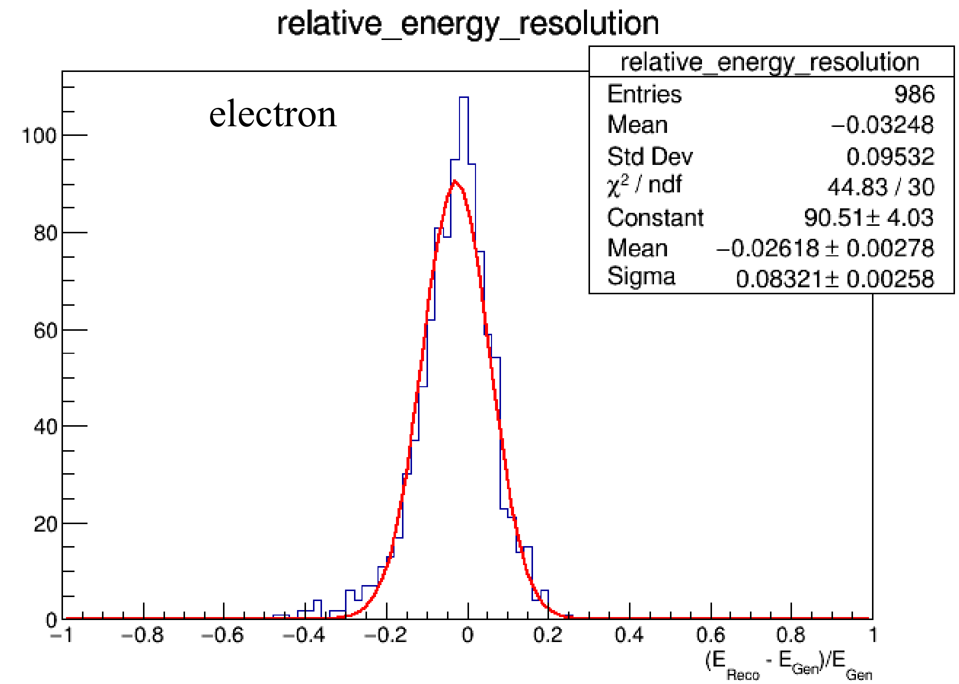


Performance comparison

- Energy resolution: new geometry, positron (left) vs electron (right)
  - 1 GeV electrons (full phi and theta range)
  - Magnetic field ON (2T)
  - Energy resolution is better for electrons (~18%)

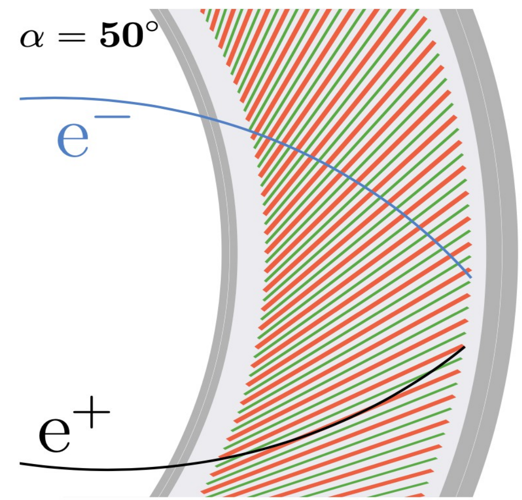


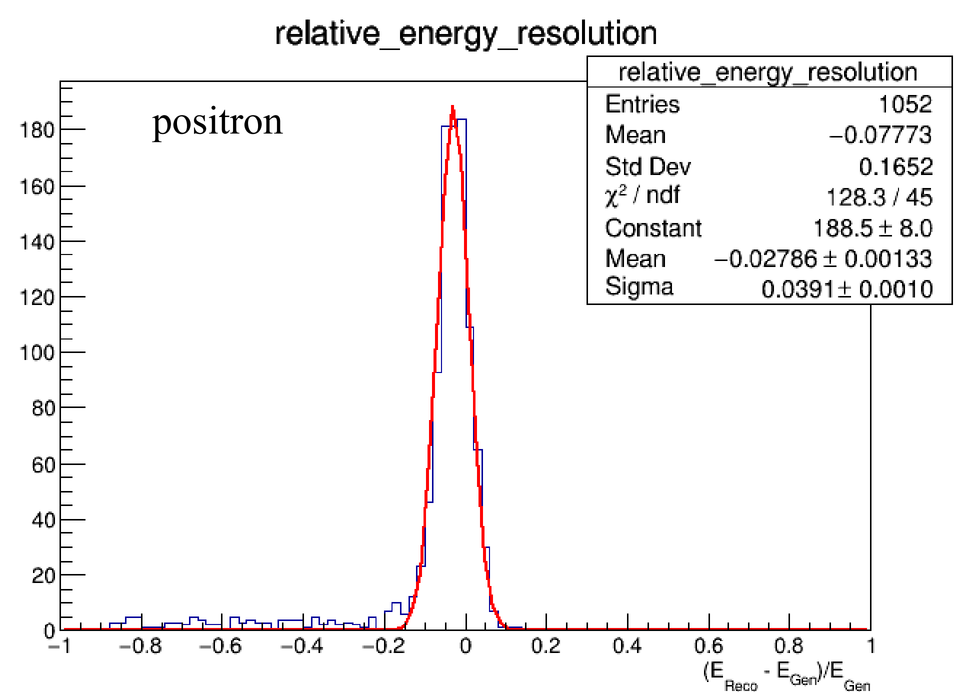


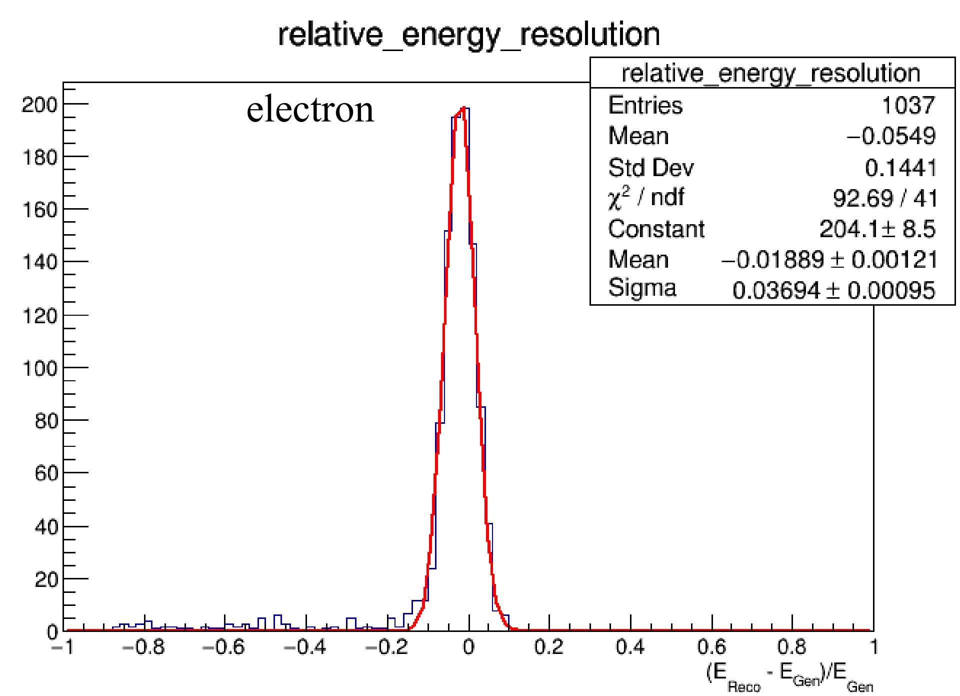


Performance comparison

- Energy resolution: new geometry, positron (left) vs electron (right)
  - 4 GeV electrons (full phi and theta range)
  - Magnetic field ON (2T)
  - Energy resolution is better for electrons (~ 6%)

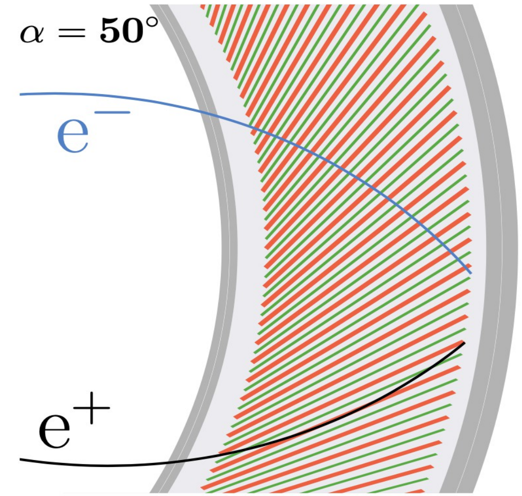


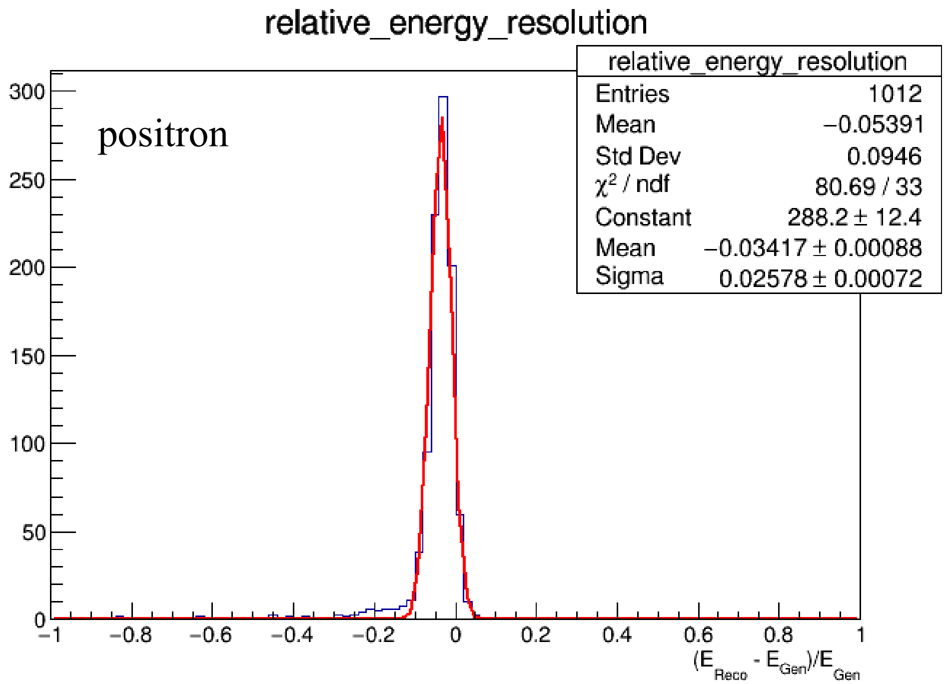


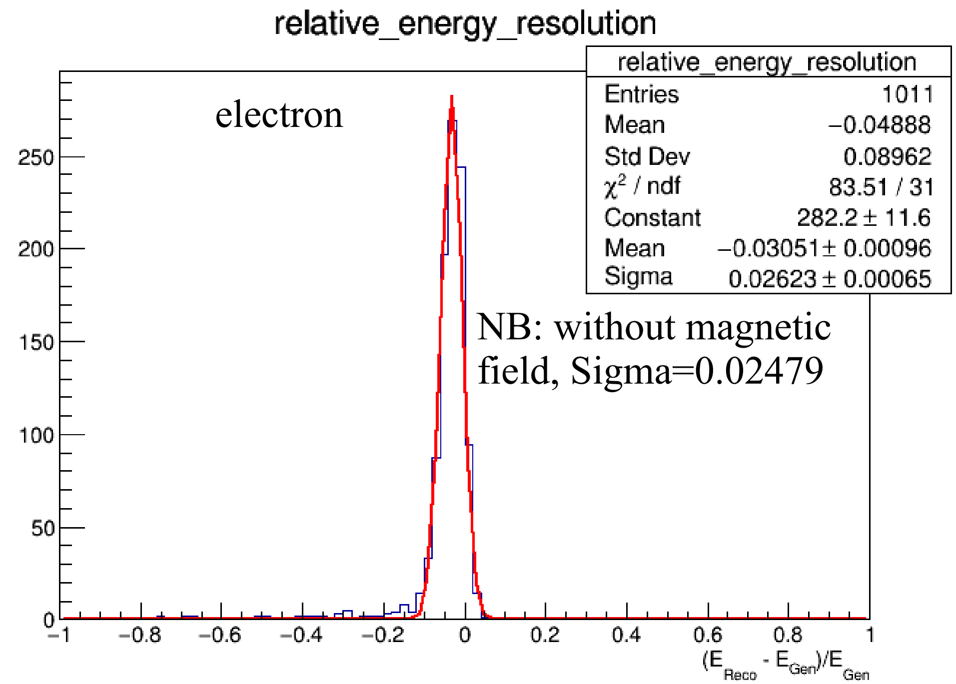


Performance comparison

- Energy resolution: new geometry, positron (left) vs electron (right)
  - 10 GeV electrons (full phi and theta range)
  - Magnetic field ON (2T)
  - The difference disappears at 10 GeV (~1.7 % in the other direction)



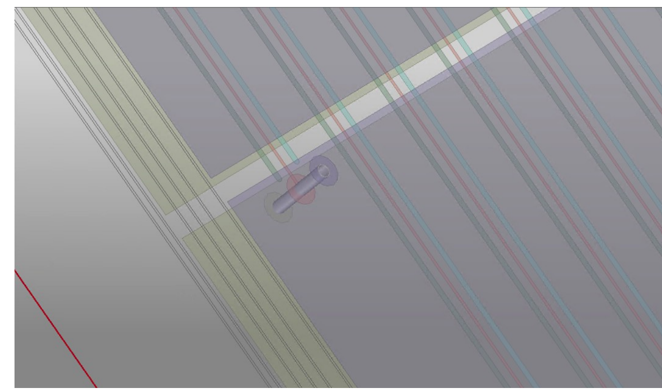


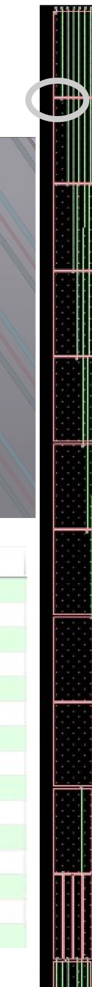


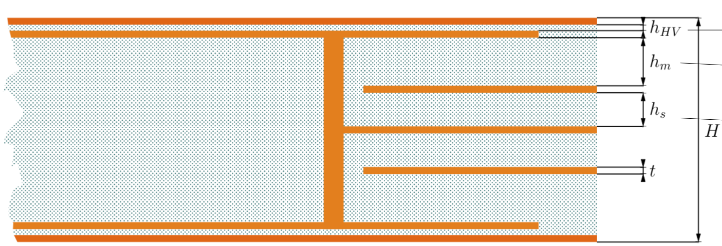
Electrode Design

Electrode Simulation

- Implemented a first Cadence model with one theta tower and imported it in ANSYS
  - ~56 cm long electrode, ~2.1 cm wide (theta = 90°), 12 layers, one trace extract from two signal pads, 2 shields (above and below the trace), 1 mm distance between signal pads
  - Stack-up close to FCC-hh calorimeter paper
    - 1.3 mm thick PCB (easy to change)
    - Internal metallic layers could have a 17 µm thickness
    - h_{HV} : assuming FR4 electrical rigidity of 20 kV/mm, 1.24 kV on the plates → electrical breakdown would occur at 62 µm



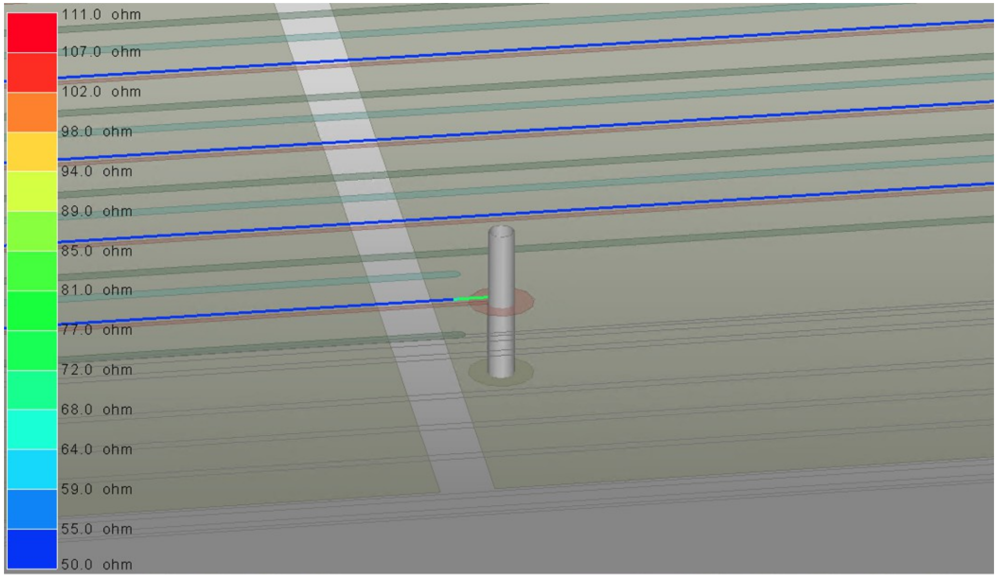


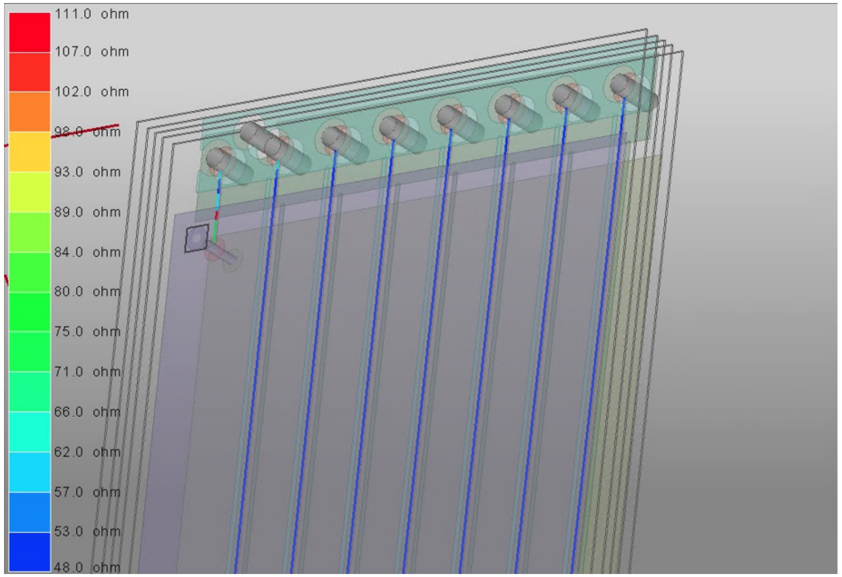


Color	Name	Type	Thickness (mm)	Mate...	Conductivity (S/m)	Diel...	Dielec...	Loss tang...	Translucency	Elevation (mm)
	smt	DIELECTRIC	0.02	FR-4	0		4.4	0.02		1.305
	top	METAL	0.035	copper	5.8E+07	FR-4	4.4	0.02	60	1.27
	dielectric_0	DIELECTRIC	0.1	FR-4	0		4.4	0.02		1.17
	l2	METAL	0.035	copper	5.8E+07	FR-4	4.4	0.02	60	1.135
	dielectric_1	DIELECTRIC	0.25	FR-4	0		4.4	0.02		0.885
	l3	METAL	0.035	copper	5.8E+07	FR-4	4.4	0.02	60	0.85
	dielectric_2	DIELECTRIC	0.17	FR-4	0		4.4	0.02		0.68
	l4	METAL	0.035	copper	5.8E+07	FR-4	4.4	0.02	60	0.645
	dielectric_3	DIELECTRIC	0.17	FR-4	0		4.4	0.02		0.475
	l5	METAL	0.035	copper	5.8E+07	FR-4	4.4	0.02	60	0.44
	dielectric_4	DIELECTRIC	0.25	FR-4	0		4.4	0.02		0.19
	l6	METAL	0.035	copper	5.8E+07	FR-4	4.4	0.02	60	0.155
	dielectric_5	DIELECTRIC	0.1	FR-4	0		4.4	0.02		0.055
	bottom	METAL	0.035	copper	5.8E+07	FR-4	4.4	0.02	60	0.02
	smb	DIELECTRIC	0.02	FR-4	0		4.4	0.02		0

Electrode Simulation

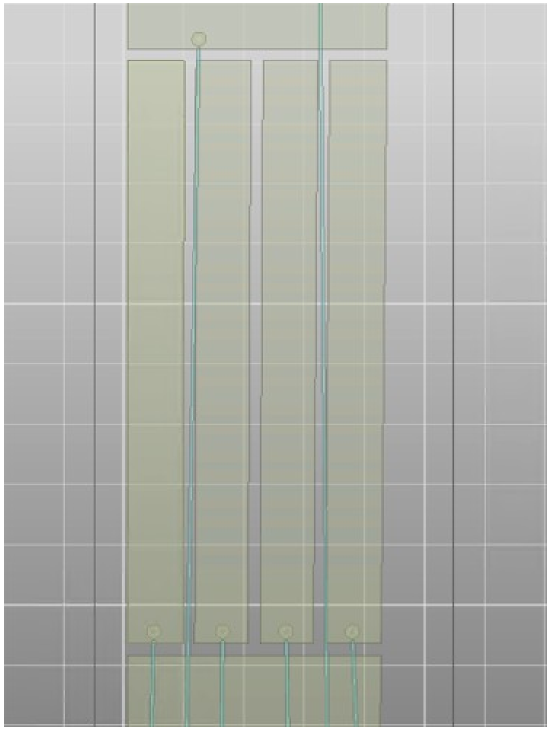
- Impedance scan with ANSYS: all lines are at 50 Ohm except in the junction to the vias
  - Try to go as close from the via as we can with the shields
  - Signal termination and ground distribution
    - Current implementation: one through pin distributes the ground to a plate, traversed by signal through pins
    - Alternative: one through pin for every shield (without plate) → need to get around the signal vias with the shield traces
  - Shields run inside the cell of the given signal trace to avoid big impedance gap





Separation between pads

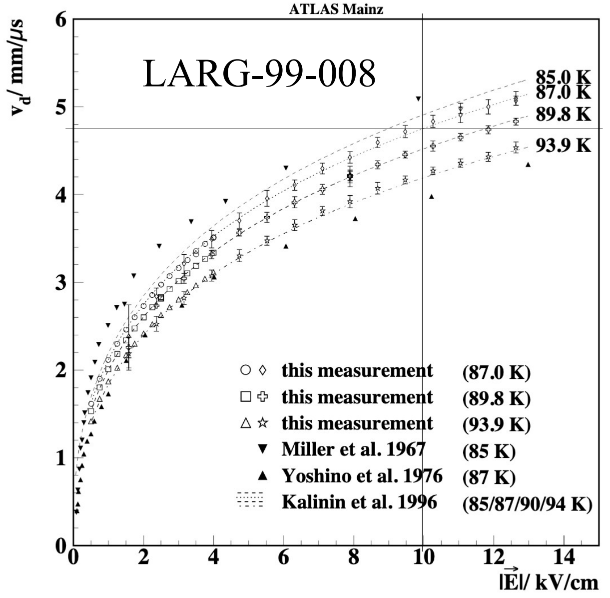
- First four longitudinal layers extracted from front
- 1 mm pad separation also in the strip layer with the transmission line from layer 3 and four running beneath the strip pad separation



PCB design issue

- ANSYS only available for Windows (and a few RedHat distributions)
  - Had to deploy it on CERN OpenStack virtual machines
  - Even the highest OpensStack VM has very poor specs
    - Especially disk space, already filled with Windows 10 + ANSYS
    - Solving models generates big files → run very quickly out of disk space
    - It seems to be possible to launch ANSYS job on the CERN clusters directly from the VMs → will be investigated
      - Would solve the disk issue and speed up the execution of these very demanding simulations (one single cell simulation with COMSOL was taking ~50 minutes on the VM)
- Once we have the capacitance matrix, will investigate cross-talk in an equivalent circuit (or directly from ANSYS if possible)
- Typical signal to be injected described in next slides

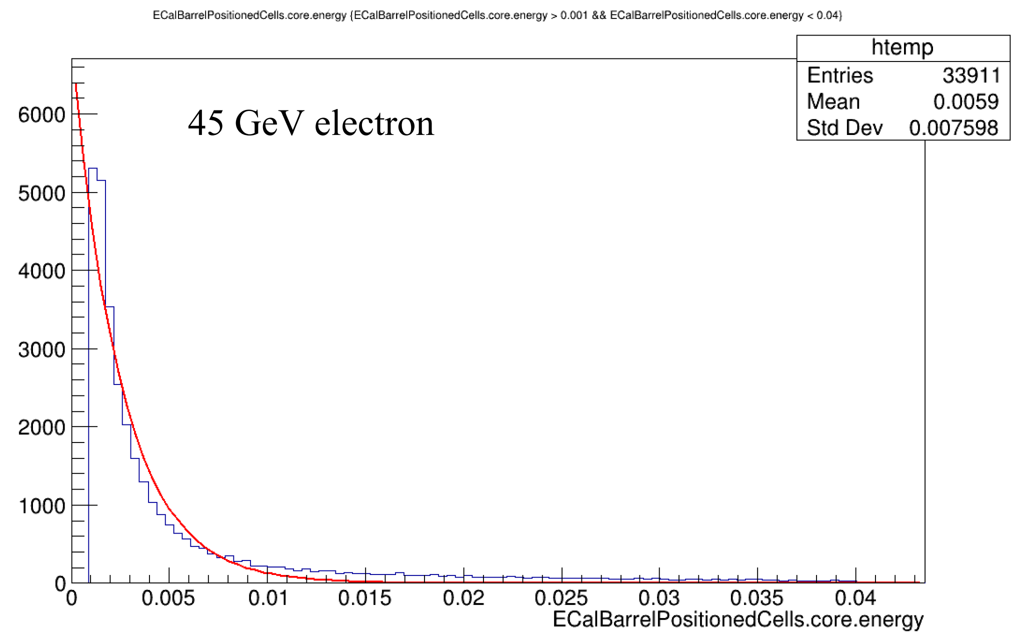
Detector Signal

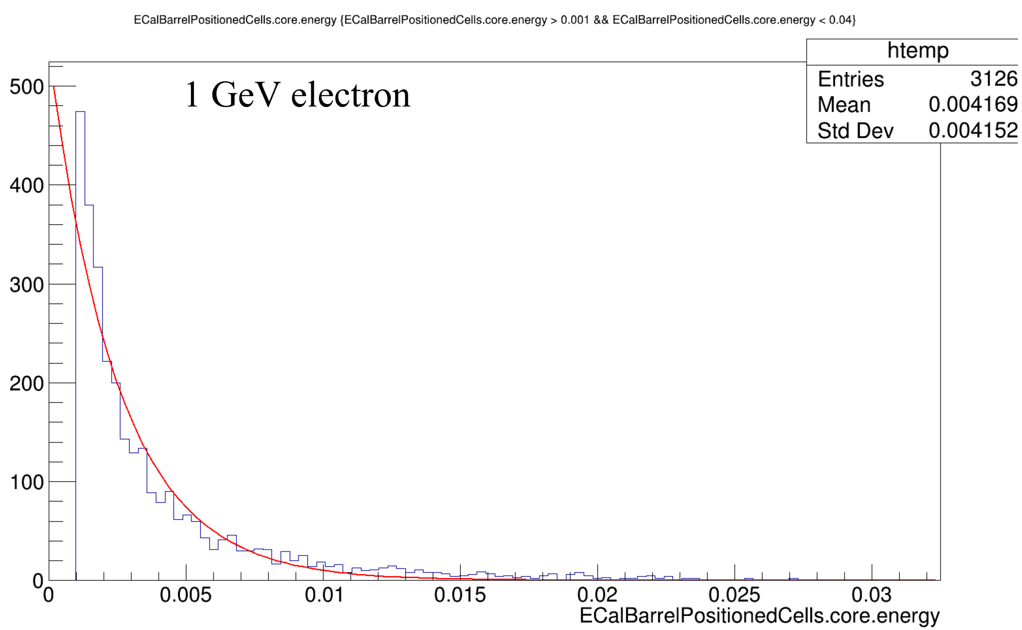


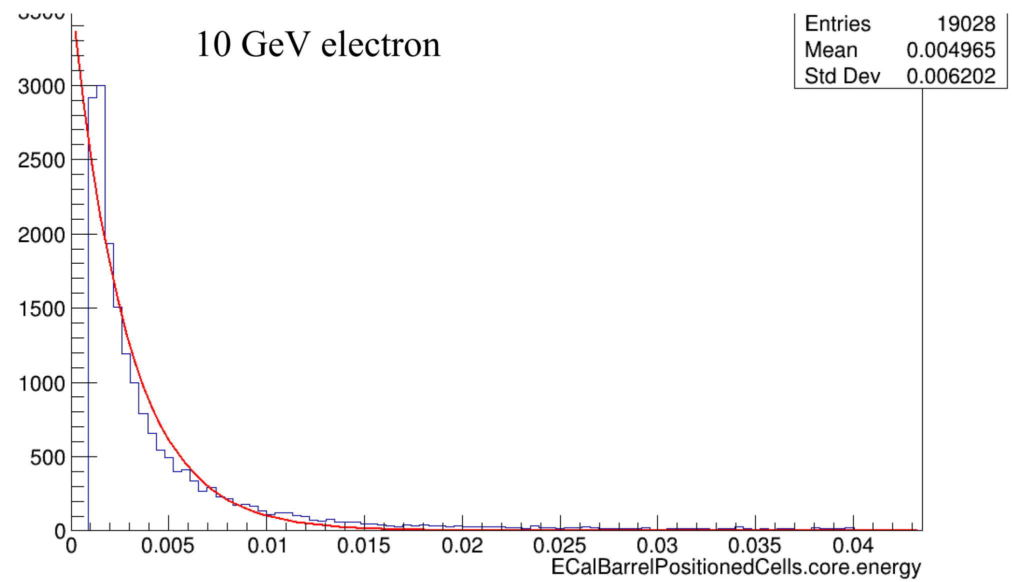
- Drift velocity in LAr for 1 kV/mm at 87 K ~ 4.75 μm/ns
- New geometry: 1.24 mm LAr gaps → ~ 260 ns drift time
- Before shaping, signal is triangular with rising time < 1 ns and decay time ~ 260 ns
- Signal heights described in next slides

Signal height

- Cell energy deposit for 1, 10 and 45 GeV electrons simulation (no noise included, no sampling fraction)
  - Show only energy deposit with E > 1 MeV and E < 40 MeV
- Once tails are cut, incident particle energy does not seem to have a big impact on the average energy per cell





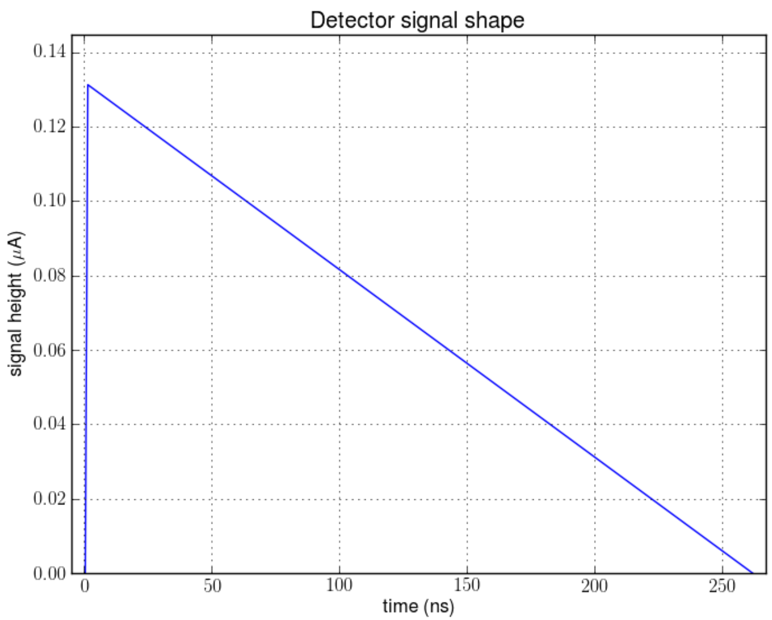


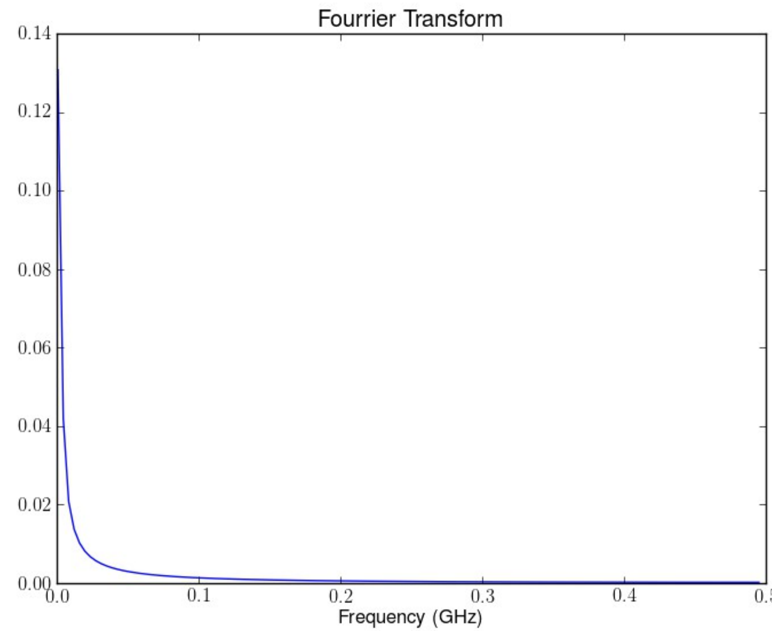
Signal height

- Goal: get the **order of magnitude** of the signal height to inject in Signal Integrity studies
- First numbers derived with <5 MeV> per cell
  - ~ 216 k electron/ion pairs (assuming 23.3* eV per pair)
- Shockley–Ramo's theorem: current induced on an electrode due to motion of a charge is $i = qv_D/d_{gap}$ with
  - q = elementary charge ($1.6\ 10^{-19}$ C)
  - v_D = drift velocity (4.75 µm/ns)
  - d_{gap} is the LAr gap size (1.24 mm)
- Leads to a signal height of 0.13 µA
  - ATLAS quoted ~ 3 µA/GeV in the LAr TDR ("/GeV" refers to the deposit in the whole cell including absorber)
  - Rescaling my number by the sampling fraction (say, 15%) gives 3.93 µA / GeV
  - No signal attenuation taken into account

* 23.6 eV/pair quoted here

Signal shape





- Signal: 1 ns rising time, 260 ns decay time, 0.13 μA height
  - Fourier transform (signal sampled every ns i.e. 261 sampling points) shows that most frequency components sit below 100 MHz

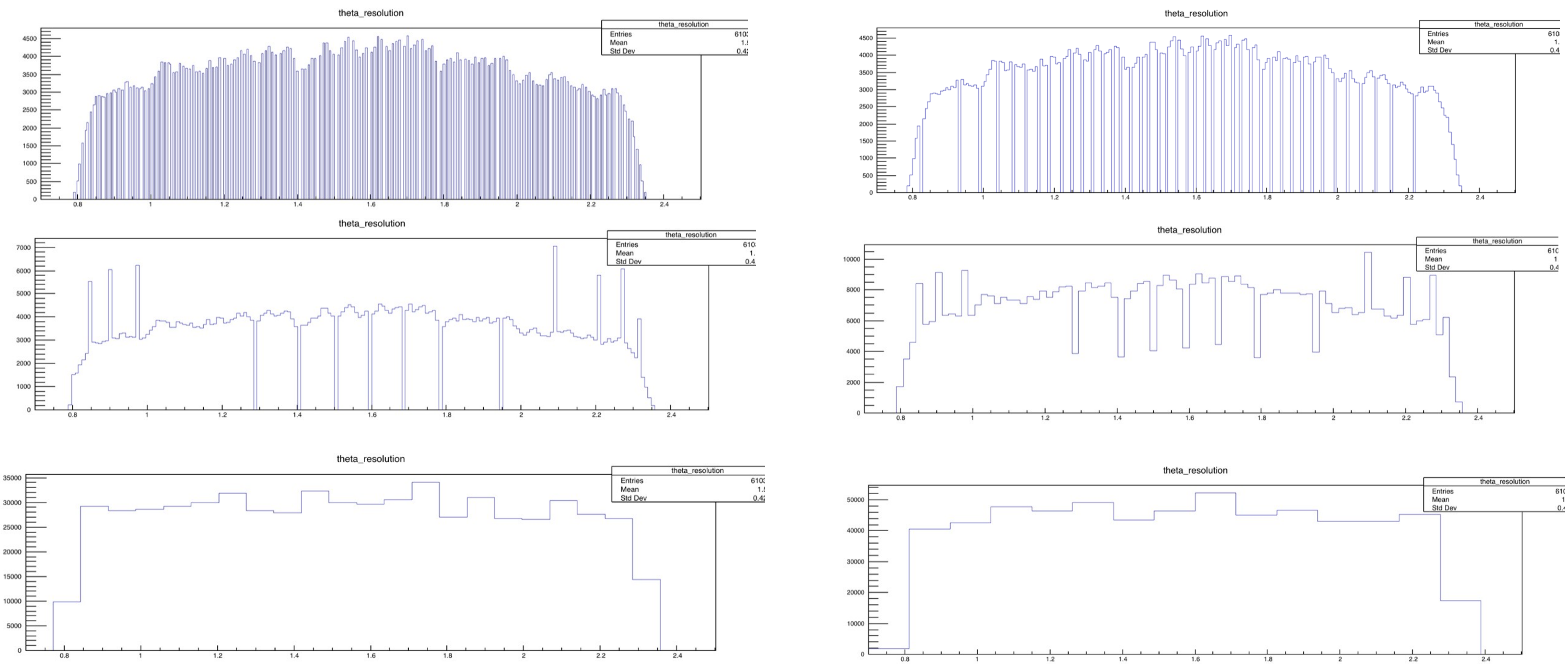
Summary

- Machinery to get performance plots from FCCSW Full Sim with the new geometry is getting in place
  - Next steps
    - Extend it to derive relative energy resolution VS energy + fit
    - Produce performances for various design (will investigate e.g. what we get with different Noble Liquid/absorber material)
    - Use the shower axis to be able to produce angular resolution with magnetic field ON (will probably wait for key4hep transition as shower axis information is not foreseen in fcc:edm)
- First design of a complete electrode theta tower implemented in Cadence
  - Imported in ANSYS → impedance scan
  - Investigating how to get capacitance matrix
    - Might need to run on the CERN cluster, under investigation with the support team

Additional material

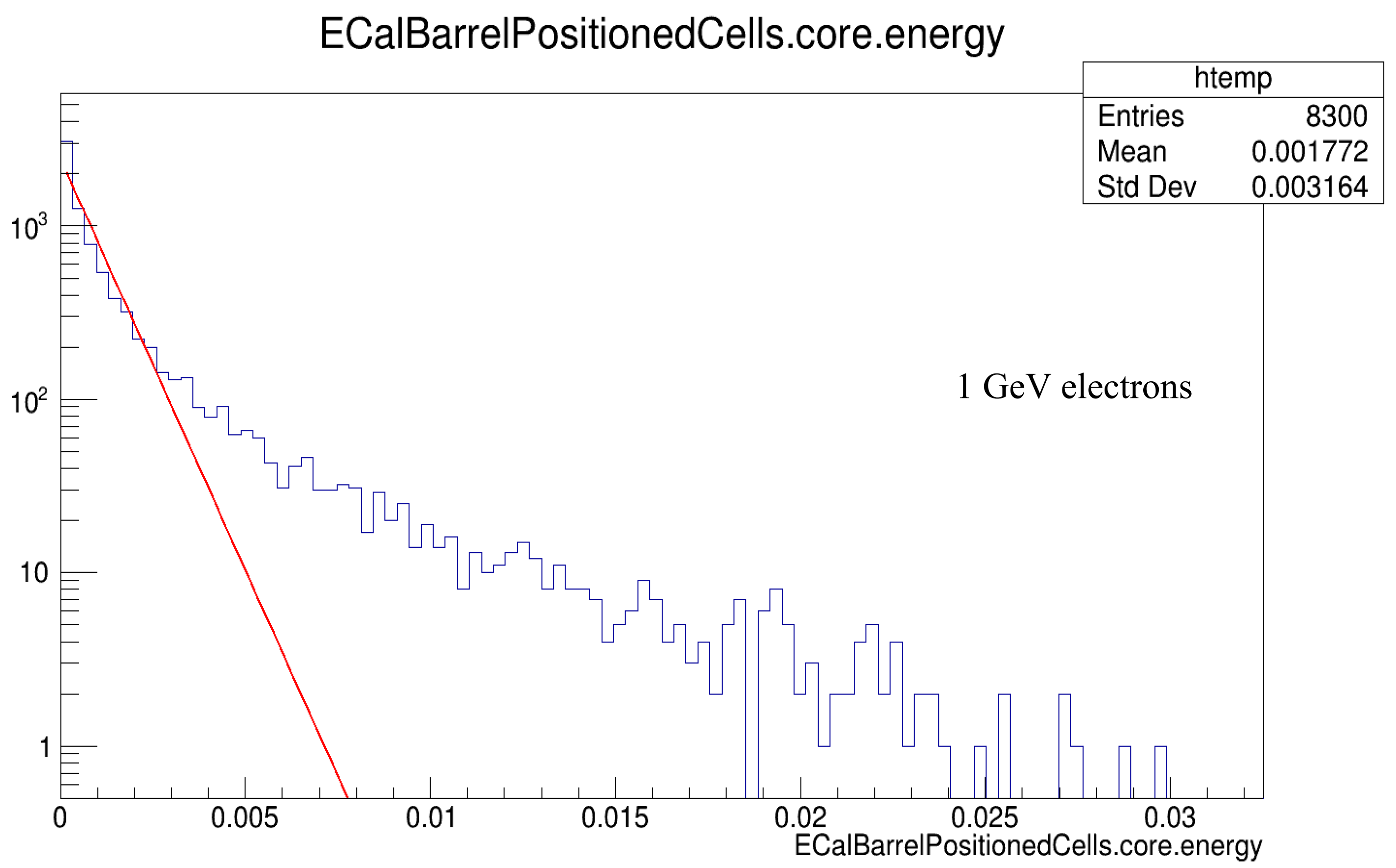
Binning issues

- Cell position is defined as cell center and cell have a non zero size → discretized quantity → some binning choice can show spurious patterns



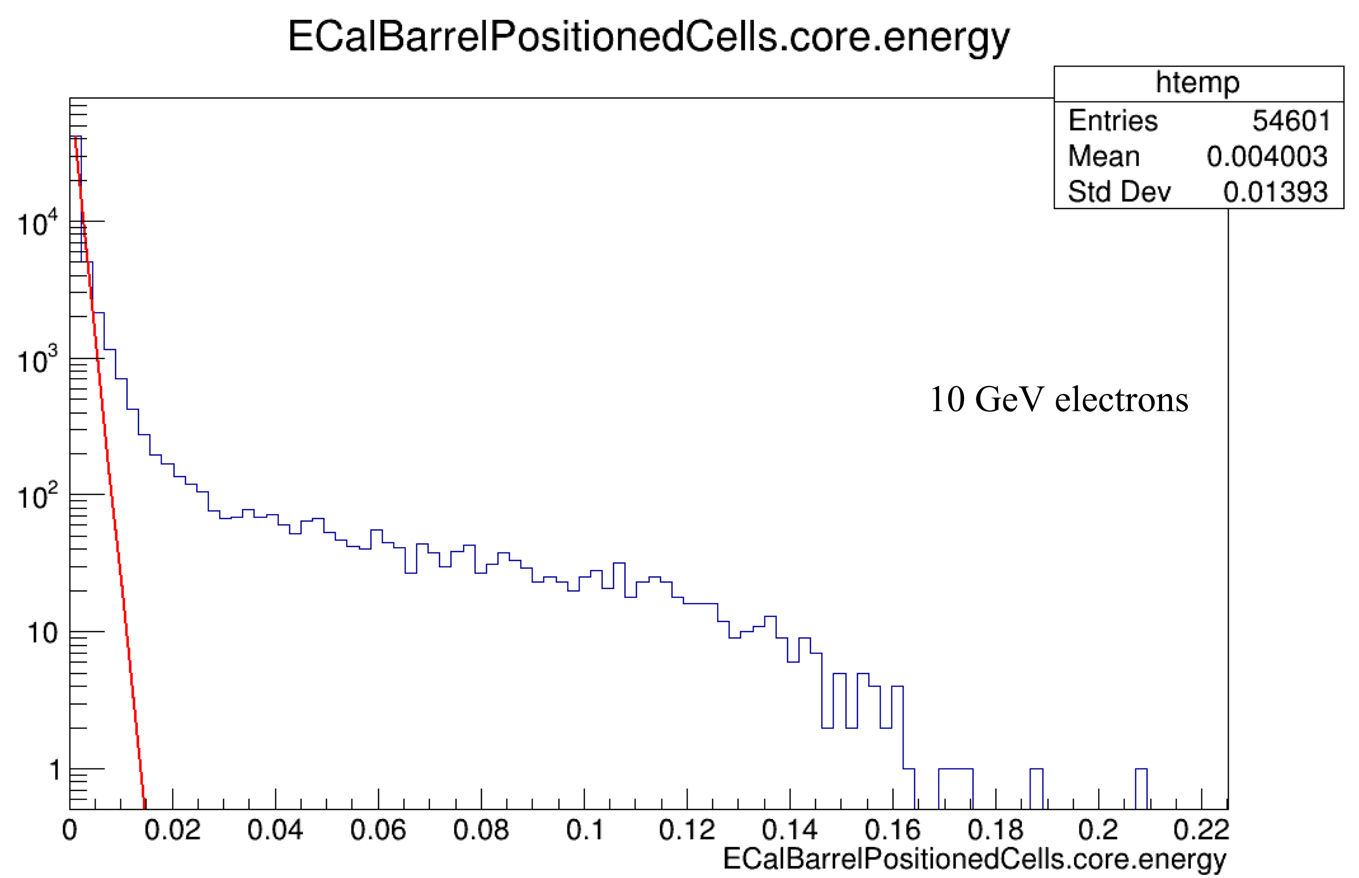
Cell energy deposit

- No sampling fraction applied



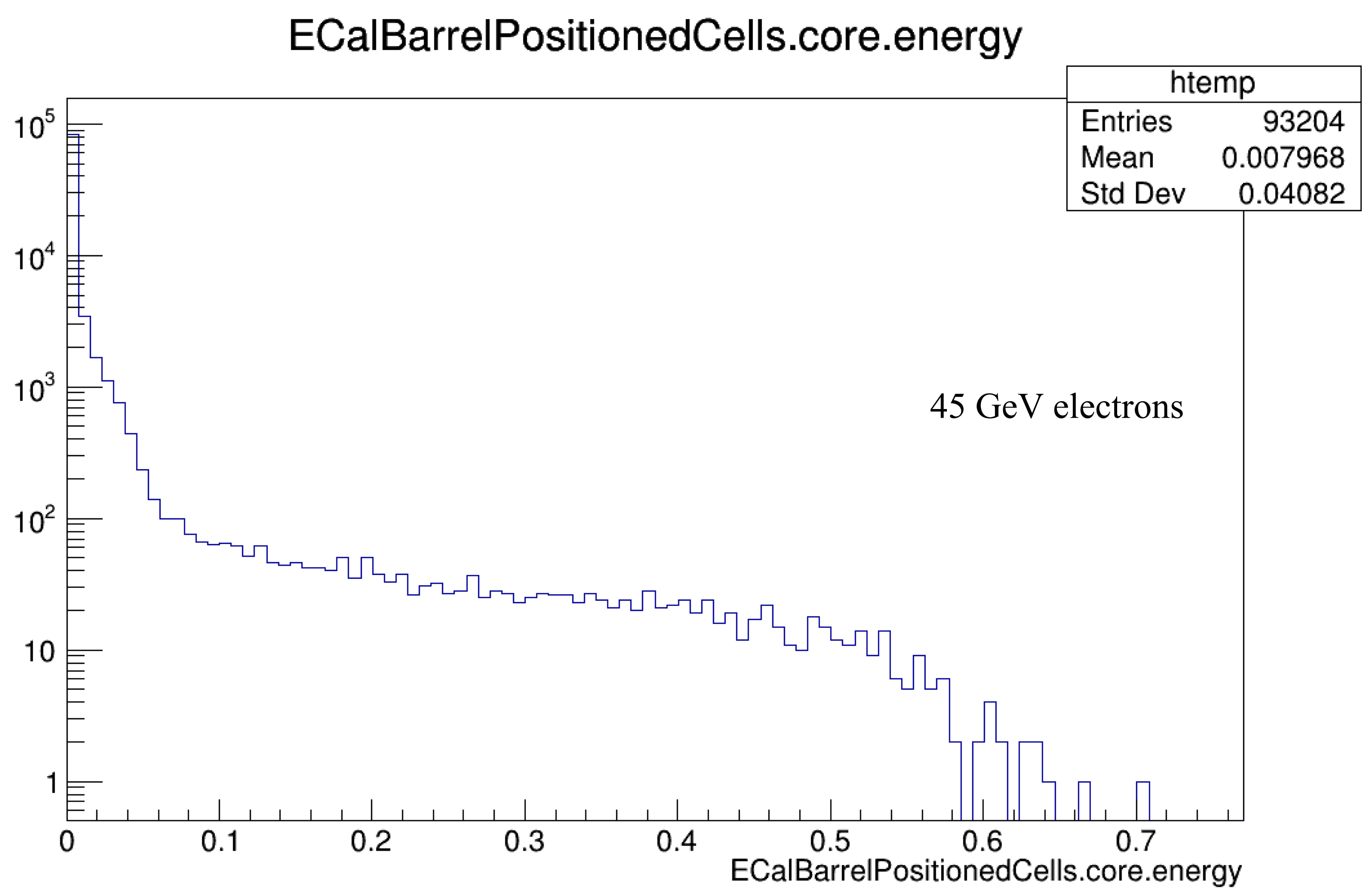
Cell energy deposit

- No sampling fraction applied



Cell energy deposit

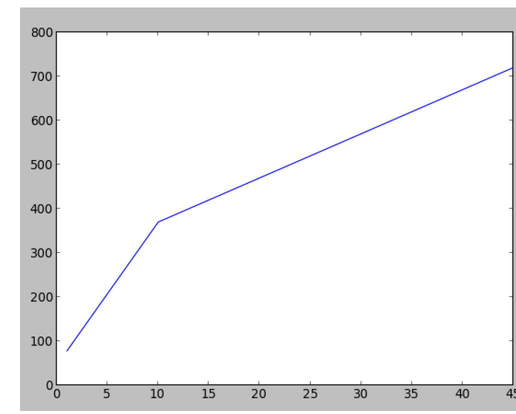
- No sampling fraction applied

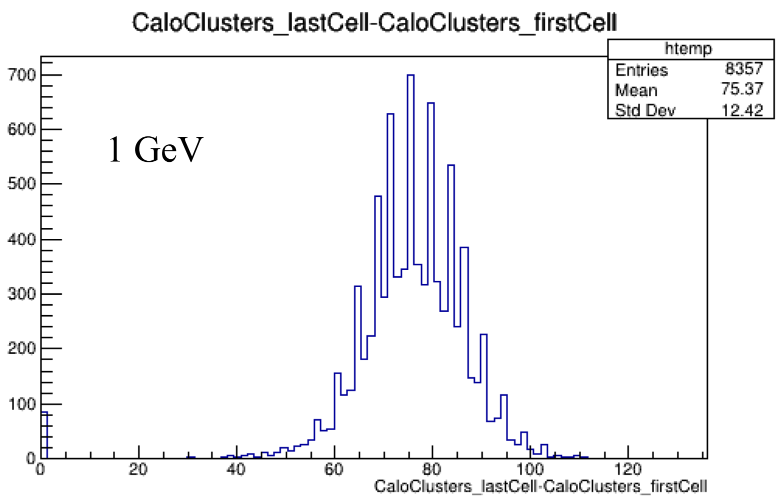


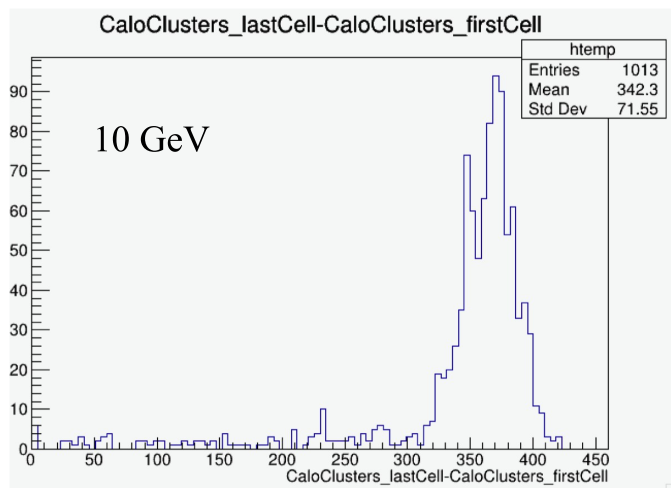
Number of fired cells

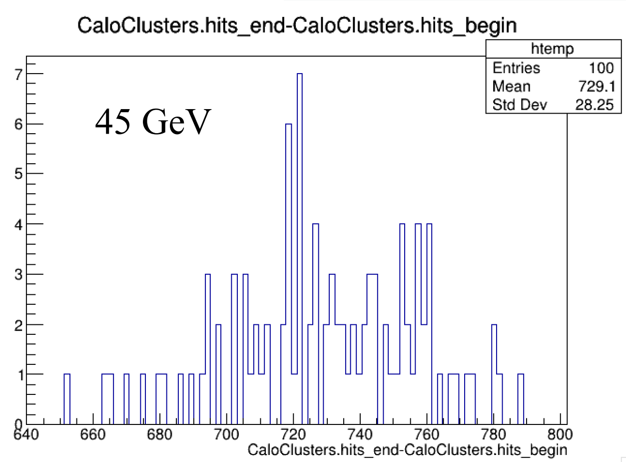
- Number of fired cell for different energies (no noise, no zero suppression, theta from 45° to 135°)

Average number of fired cell VS electron energy - only three points: 1, 10, 45 GeV









FCC-hh angular resolution

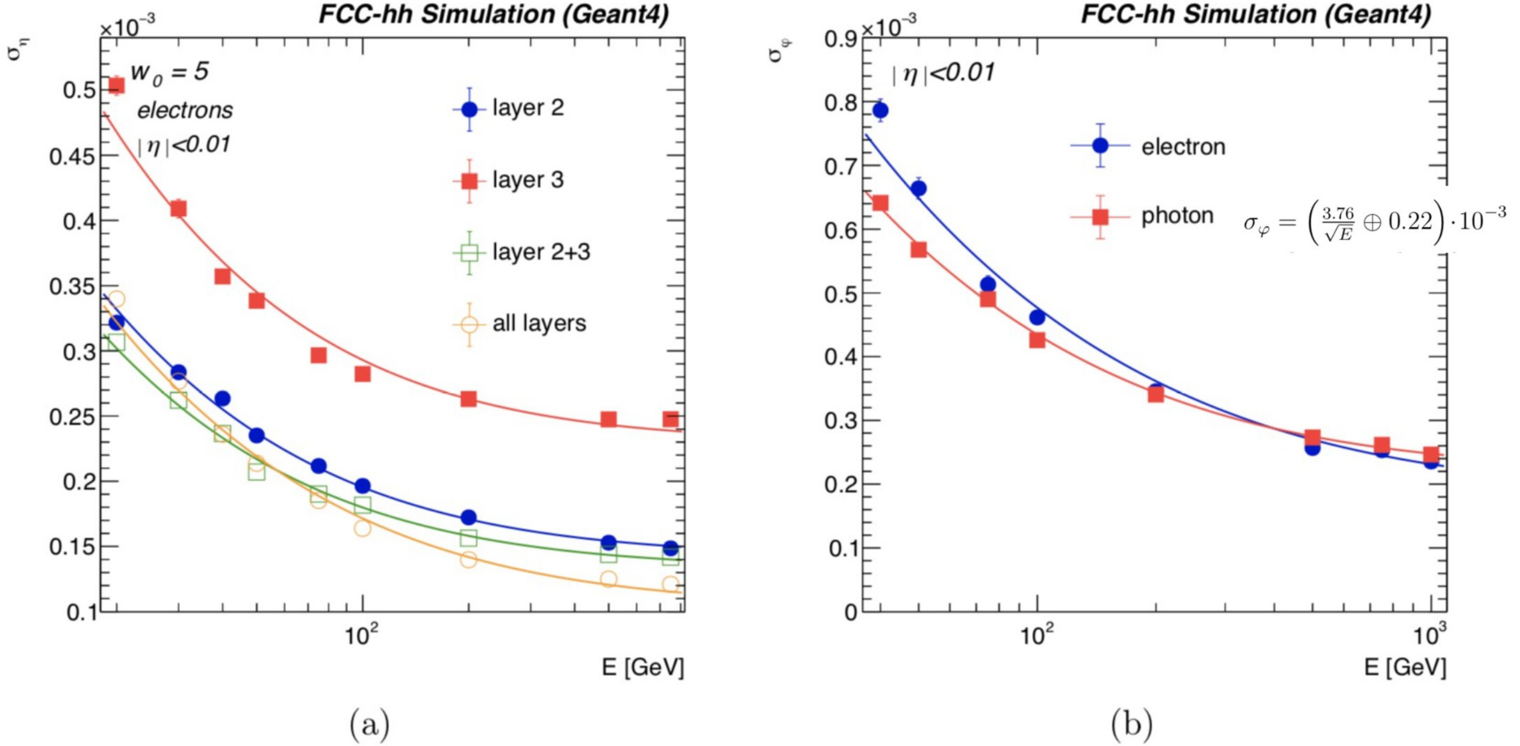


Figure 51: (a) Pseudorapidity resolution for two best calorimeter layers: second (red full circles) and third (blue full squares), as well as combined measurements of those two layers (green hollow squares) and from all EMB layers (yellow hollow circles). (b) Azimuthal angle resolution for electrons (blue circles) and photons (red squares).

Full readout theta view