Steps Toward Including Endcap EM Calorimeter in Full ALLEGRO Simulation

E. Varnes, J. Rutherfoord, R. Walker

University of Arizona

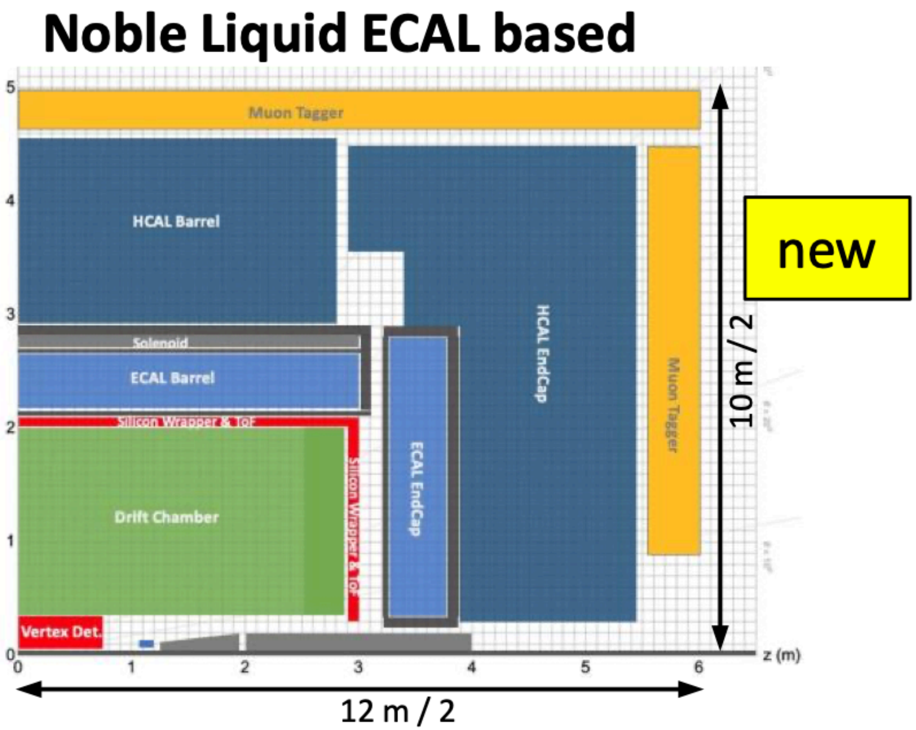
December 6, 2023

Calorimetry and the Arizona Group

- By way of introduction, the Arizona group has extensive experience in LAr calorimetry
  - notably in the design and construction of the ATLAS forward calorimeter (Rutherfoord, Shupe)
  - we maintain a LAr cryostat for small-scale lab testing/test beams
  - expertise in mechanical and electrical engineering, including PCB design
- We would like to apply these resources to the design of a noble-liquid endcap EM calorimeter for the FCCee

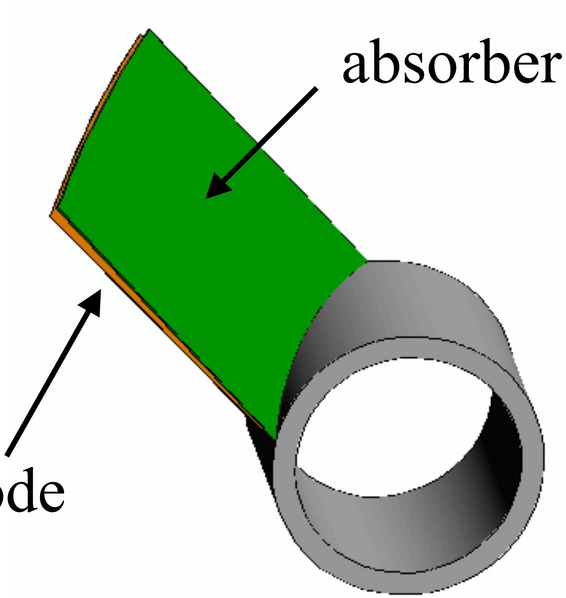
General considerations

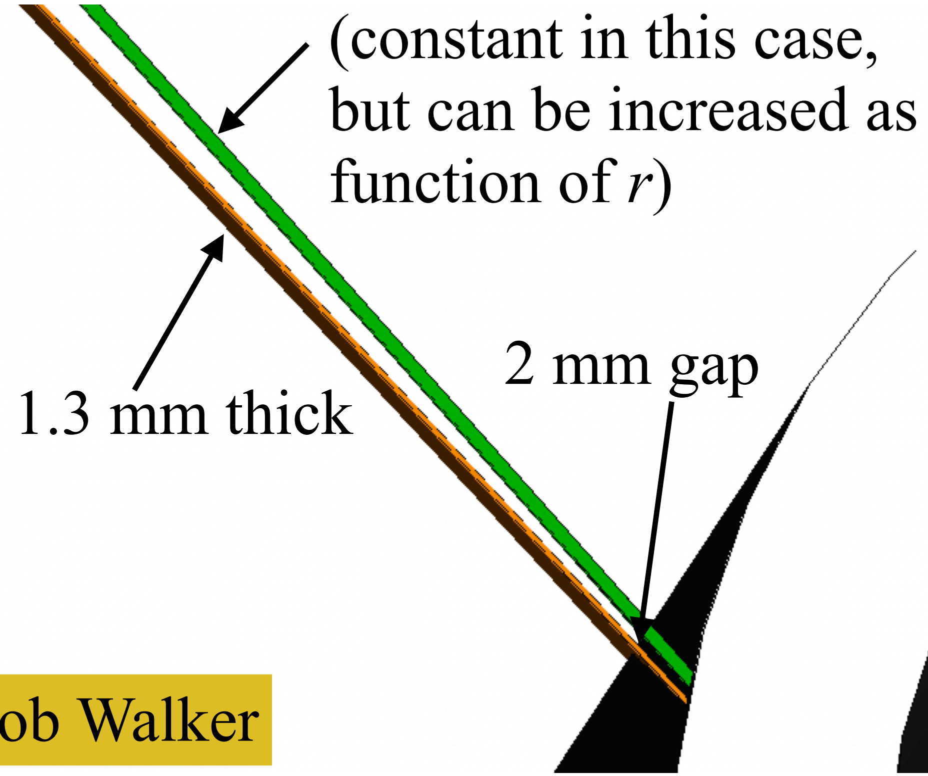
- The endcap EC dimensions are taken from the envelope that exists in the ALLEGRO simulation setup
  - midplane is taken to be at z = 348.5 cm
  - depth in *z* is set to 45 cm
- Consistent with the sketch presented by Martin Aleksa at the US FCC workshop (link):



- Tentative absorber geometry motivated by
  - desire to have many thin absorber plates (for spatial and energy resolution)
  - desire to have readout solely from high-|z| face
  - desire for as much uniformity as possible
- Led to the following concept (“turbine geometry”):

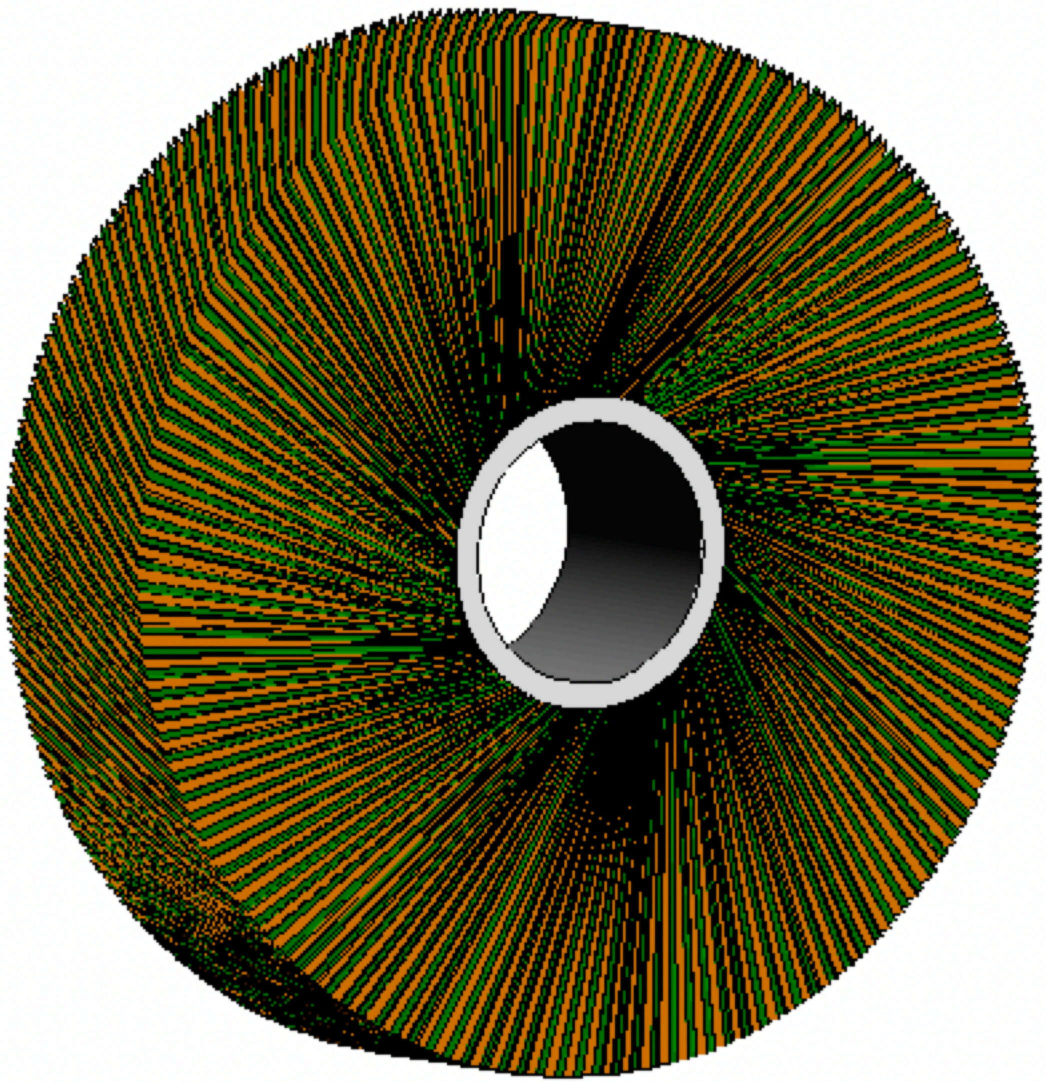
single unit cell:



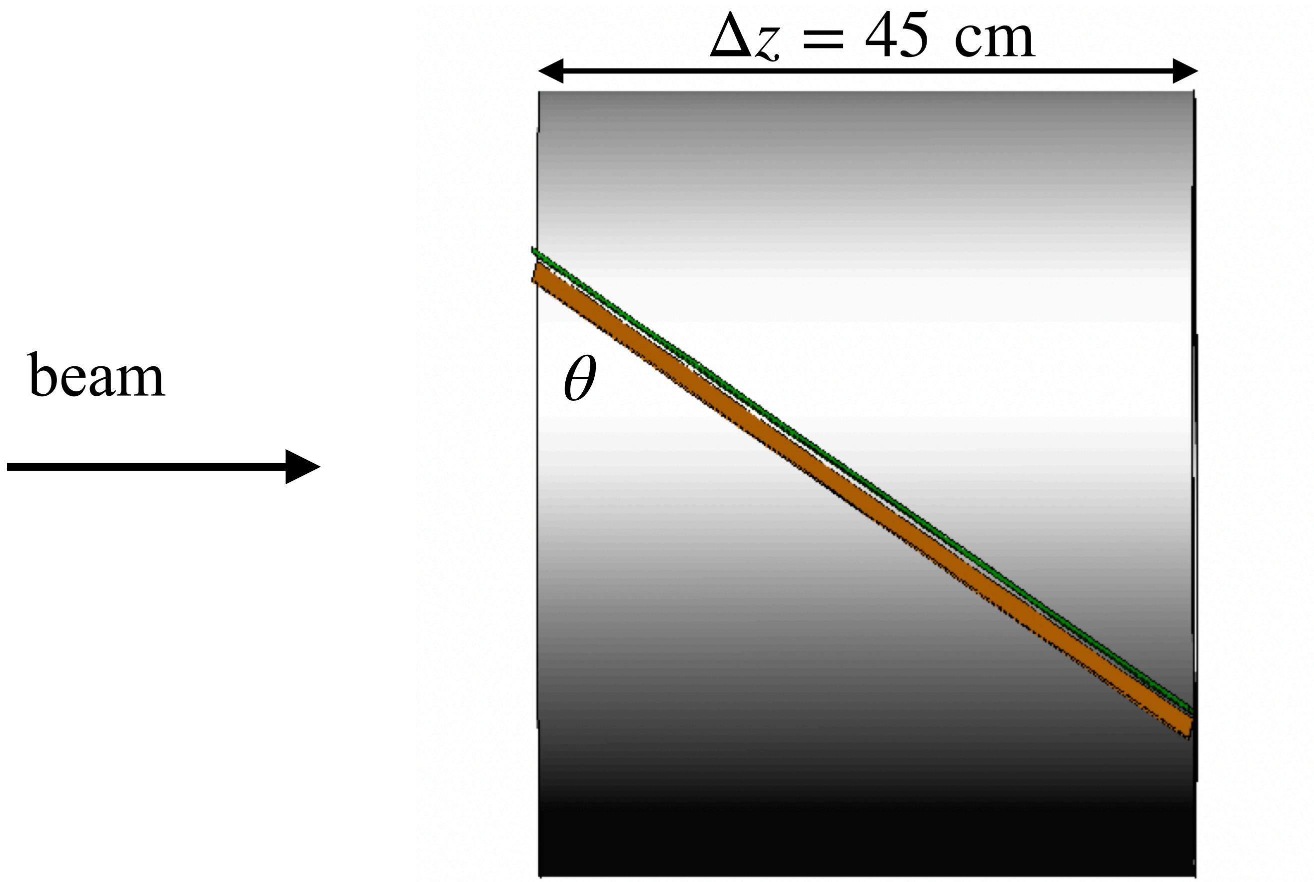


Mechanical drawings by Rob Walker

- Inner radius portion with the full set of absorbers and electrodes (~240 of each):



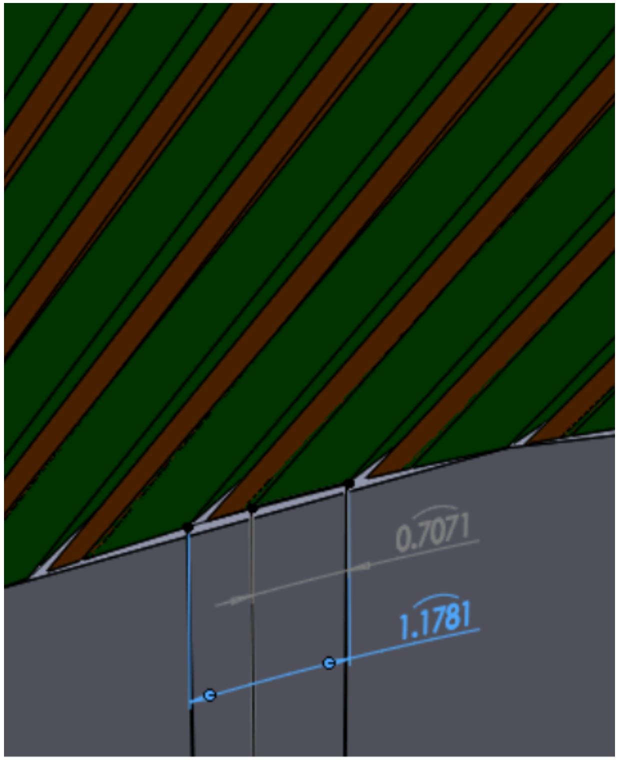
- Some notable parameters:
  - angle of plates wrt face of the cylinder:



- Optimization studies indicate that θ should be as small as possible
  - theoretical minimum is $\tan^{-1}\left(\Delta z/2r_i\right) = 28.7°$

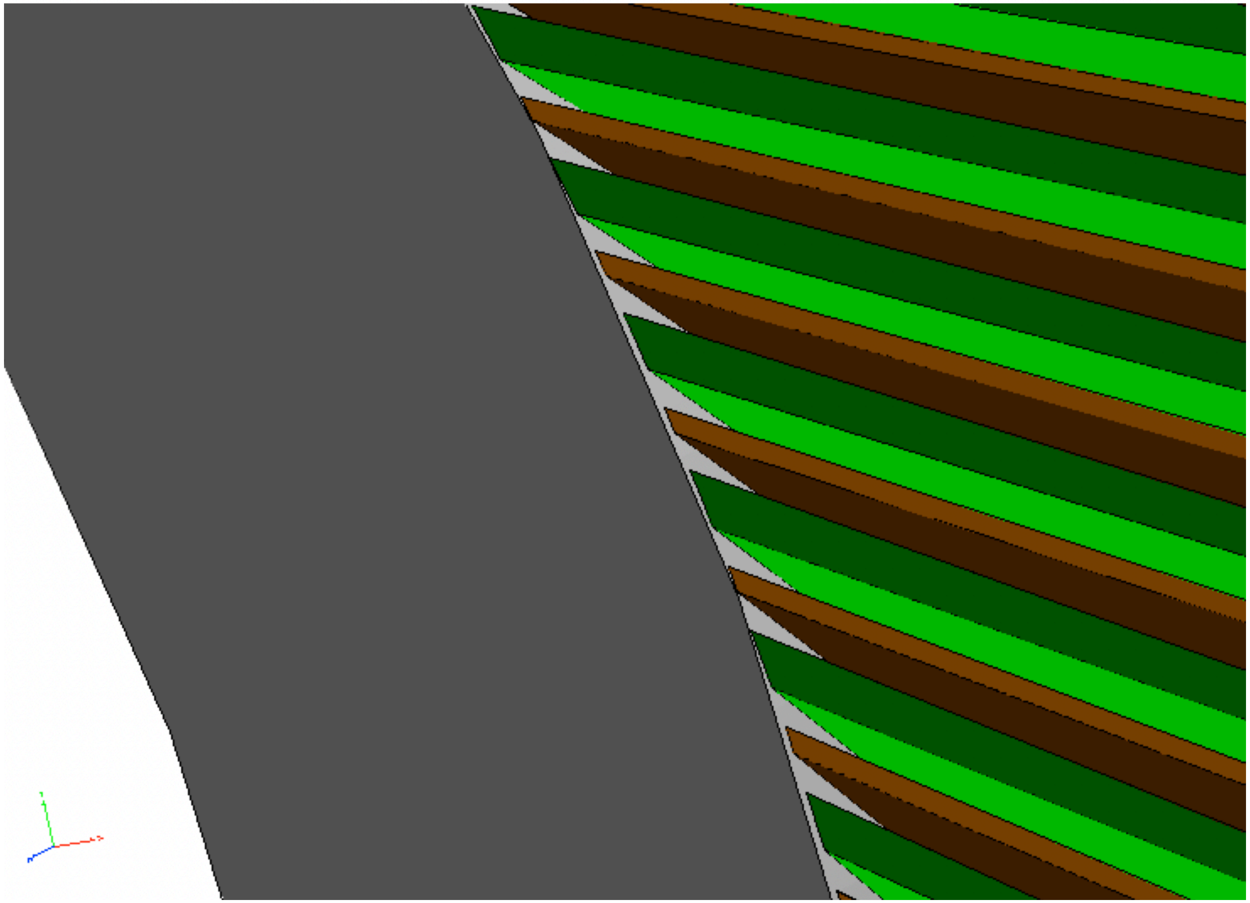
- But there are practical problems with an angle too near that minimum
  - leads to tiny gap or even interference between plates at inner radius

Example for $\theta = 45^{\circ}$

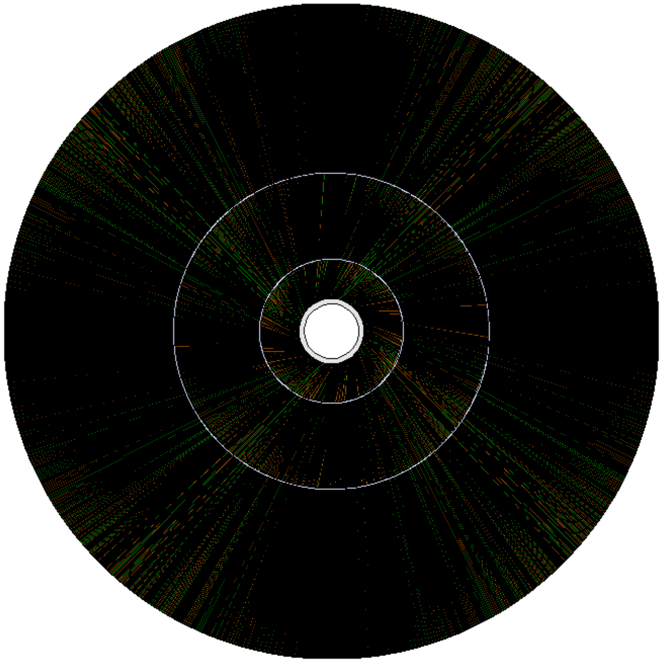


- θ is set to 55° for the studies shown here
  - NB that all parameters (blade angle, absorber and gap thicknesses, etc) are subject to optimization

- This allows even gap spacing at the inner radius while keeping a relatively large number of plates
  - necessary for containing the EM shower

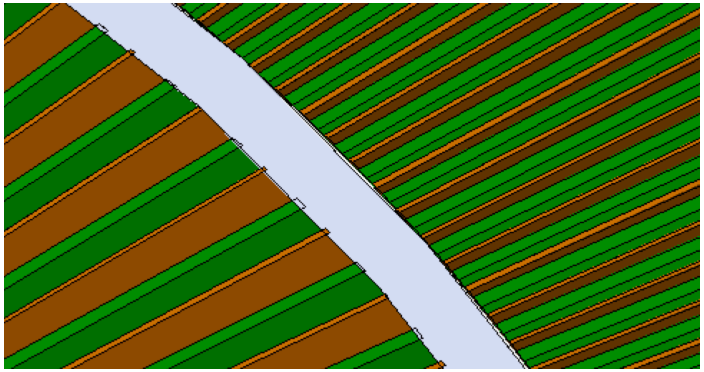


- Another consideration is the variation of the gap with radius
  - means that response is very different at the inner and outer radii (41 cm and 275 cm)
- To mitigate this, the detector can be subdivided into a set of nested cylinders:



Tradeoff between minimizing variation in gap width vs. minimizing transitions/dead areas

In this example, each cylinder has $r_o/r_i \approx 1.9$



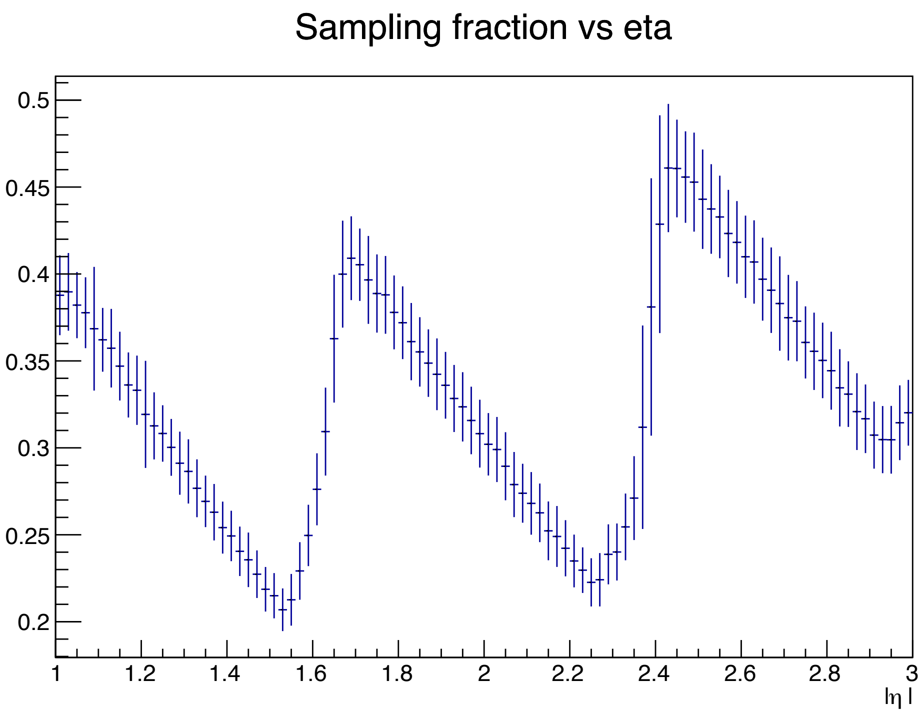
Assessing Performance

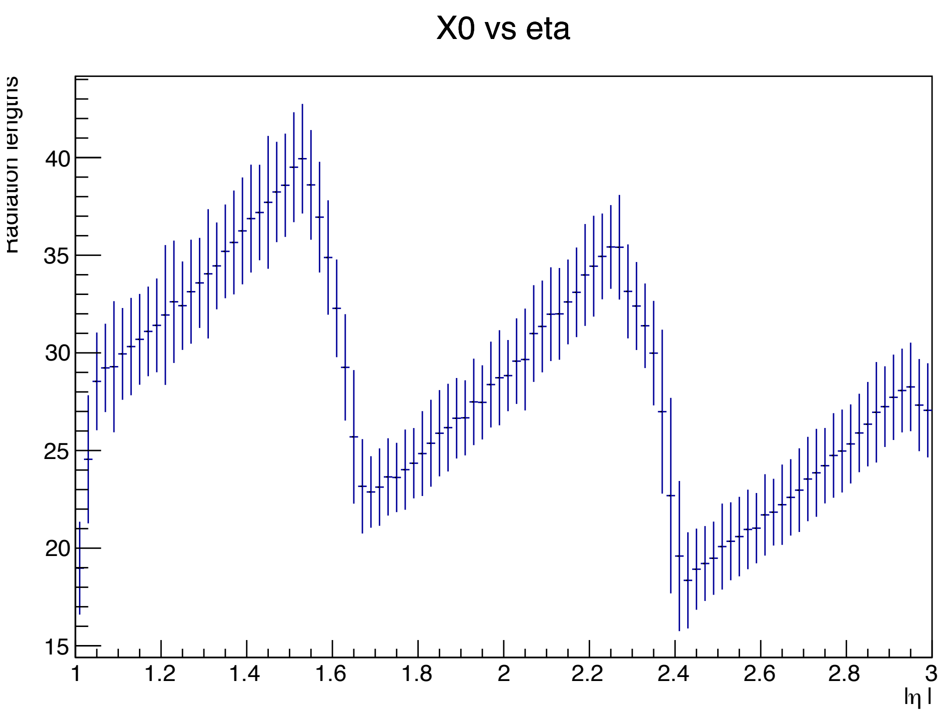
- For initial tests of the viability of this concept, the geometry was created in ROOT, then exported as GDML for use in Geant4
- Use particle gun to fire mono-energetic electrons uniformly in η and ϕ, originating from the IP

  showing my pp collider influence —

  - energies were set to 1, 10, and 100 GeV
- Estimated response and resolution based on the standard deviation of the energy deposited in the noble liquid
  - so generally this is quite optimistic (no electronics noise or other effects considered)
- All of this was standalone, not integrated into the ALLEGRO simulation framework

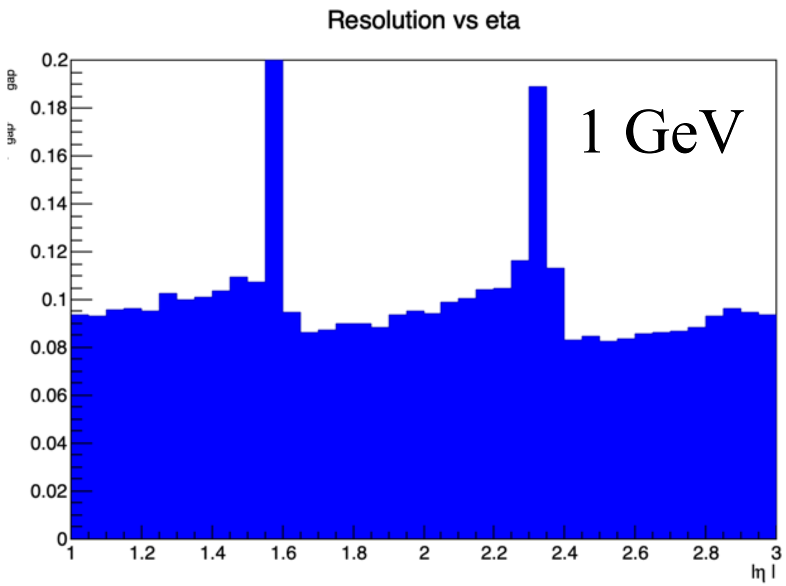
Sampling Fraction and Depth

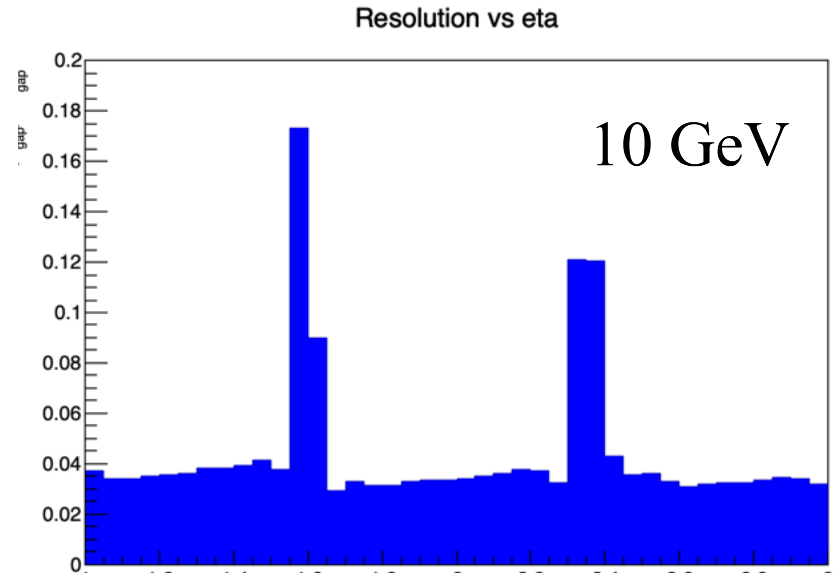


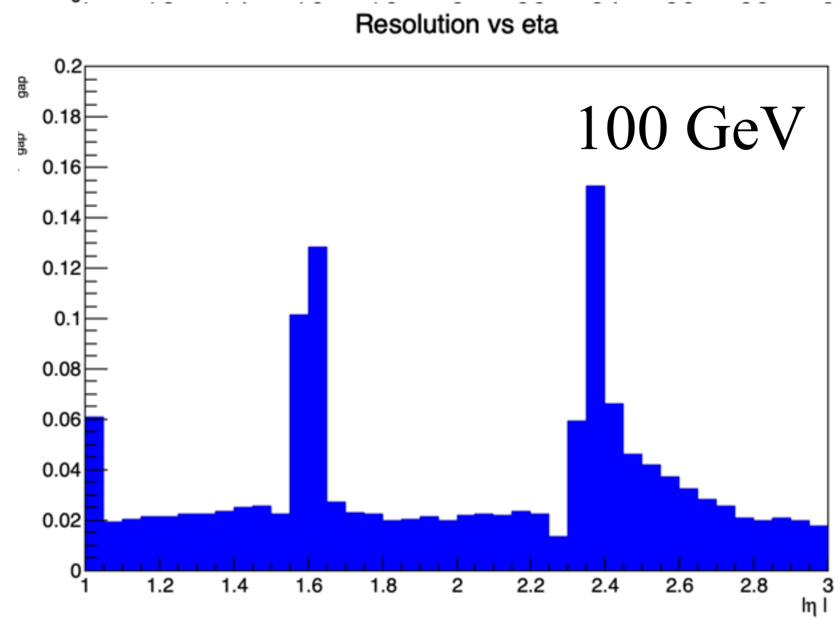


- NB that slightly different values for r_i, r_o, and Δz were used for these standalone tests

Energy resolution





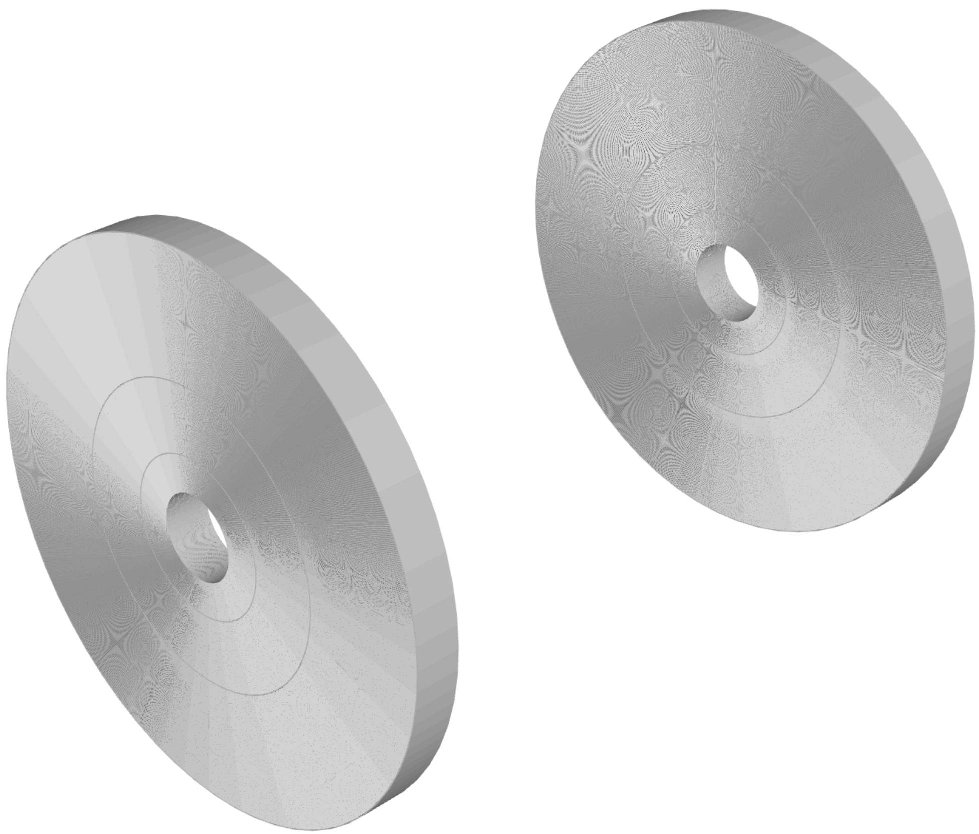


- Spikes at transitions between cylinders likely due to non-uniformity in response as shower traverses the boundary
  - could be mitigated using detailed shower shape information

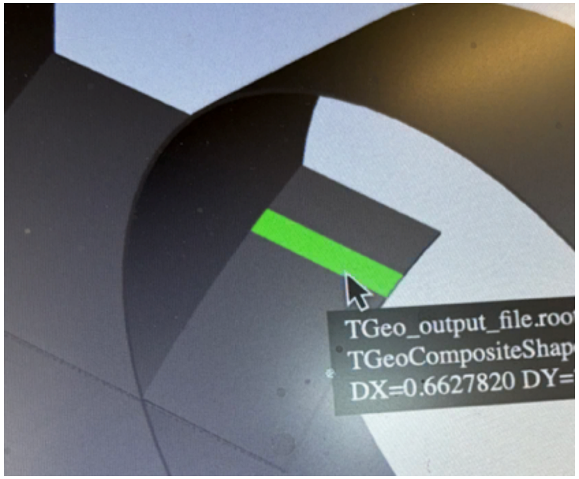
Towards Integration in the FCC Framework

- We are at the point now where a more realistic simulation (including actual reconstruction, etc.) is needed
- Therefore a good moment to integrate the geometry concept into the FCC software framework

- Status: the geometry has now been ported to the dd4hep/ k4geo framework used for FCCee simulations (thanks to patient guidance from Brieuc)
  - in my k4geo fork at https://github.com/varnes/k4geo
    - xml to set parameters
    - cpp file
- As seen in JSROOT viewer, after running dd4hep2root:



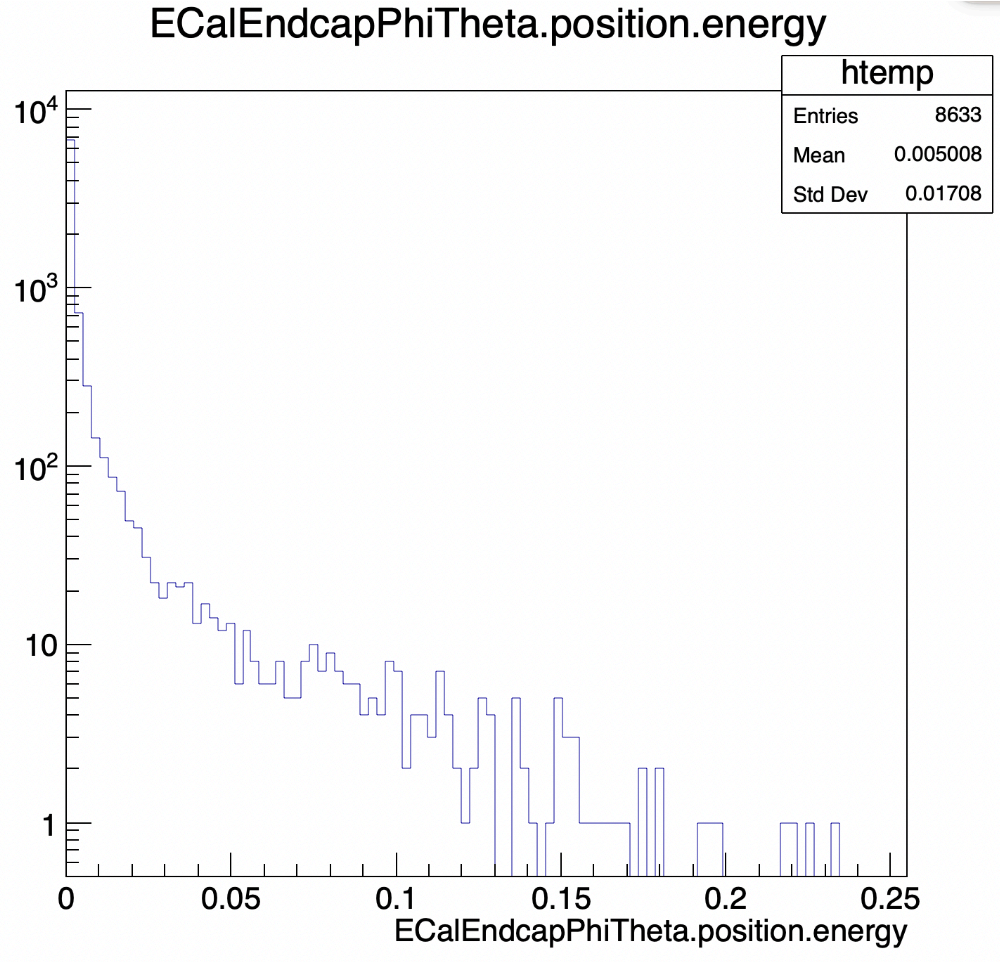
- Some initial choices made:
  - ID bits/flags are defined as:
    - system: 4 bits, set to EndcapECal_id value
    - cryo: 1 bit, true for cryostat elements
    - type: 3 bits, 0 = active, 1 = passive, 2 = readout
    - subtype: 3 bits, unused
    - layer: 8 bits, represents segmentation in z
    - module: 14 bits, counts each active/passive/readout unit
    - theta: 16 bits, not explicitly used
    - phi, 10 bits, not explicitly used



LAr volume with one "layer" highlighted

Simulation

- Running GEANT4 via ddsim also seems to work
  - produces root file, with reasonable-looking energy deposits:



Summary and Next Steps

- Have taken initial steps towards incorporating a geometry concept for the endcap ECal into the FCC software framework
  - NB that we view this geometry concept mostly as a way to learn the ropes of the FCC software
    - i.e. we plan to play a major role in the endcap ECal regardless of the geometry that is eventually chosen
- Current status is that initial version of geometry is implemented, and appears to be recognized correctly by ddsim
- Next steps will be to define a readout segmentation and run reconstruction
  - I have a lot to learn about how to do this!