Noble Liquid Endcap EM Calorimeter: Geometry and Simulation

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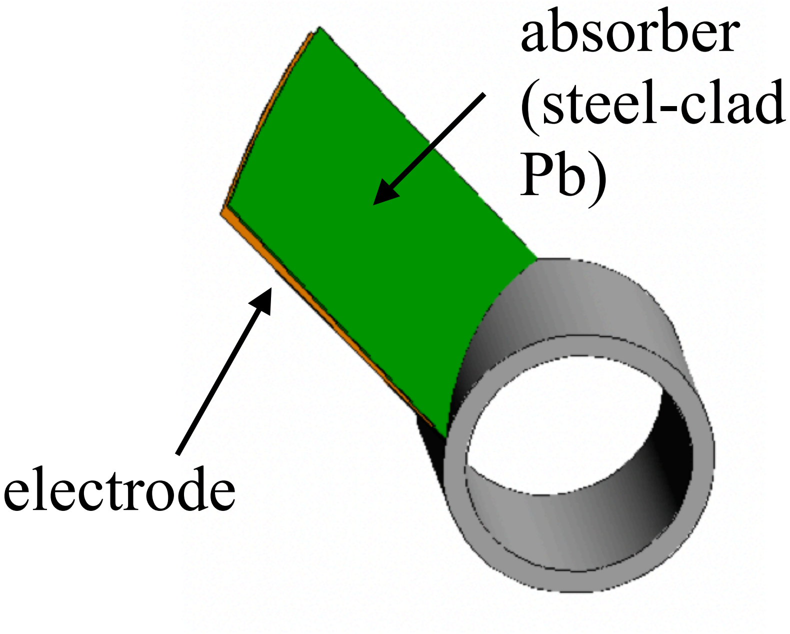
Introduction and Overview

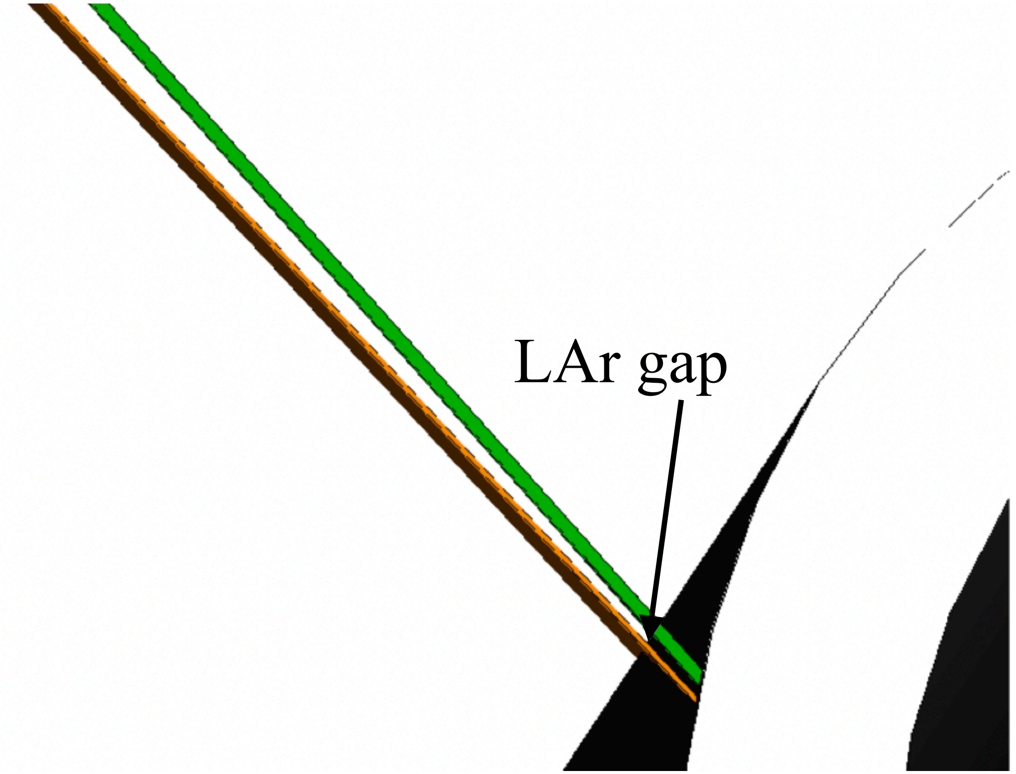
- As detailed in Juska's talk, the ALLEGRO detector features a noble-liquid EM calorimeter
- The design for the barrel portion is well advanced
  - but less so for the endcap calorimeter

Motivation for “Turbine” Geometry

- The Arizona group has longstanding expertise in NL calorimetry (e.g. ATLAS forward calorimeter design and construction), so we have taken up the challenge of exploring designs for the ALLEGRO endcap ECAL
- As a starting point, we can incorporate many of the advantages of the barrel (inclined plane) concept:
  - particles should traverse many thin absorber/sampler/ electrode unit cells (for spatial and energy resolution)
  - uniformity in ϕ
  - ability to read out solely from the high-$|z|$ face
    - to minimize dead material upstream of calorimeter
  - can be constructed with multiple copies of a small number of electrode/absorber designs
- These considerations lead naturally to the “turbine” design shown on the following slides

single unit cell:

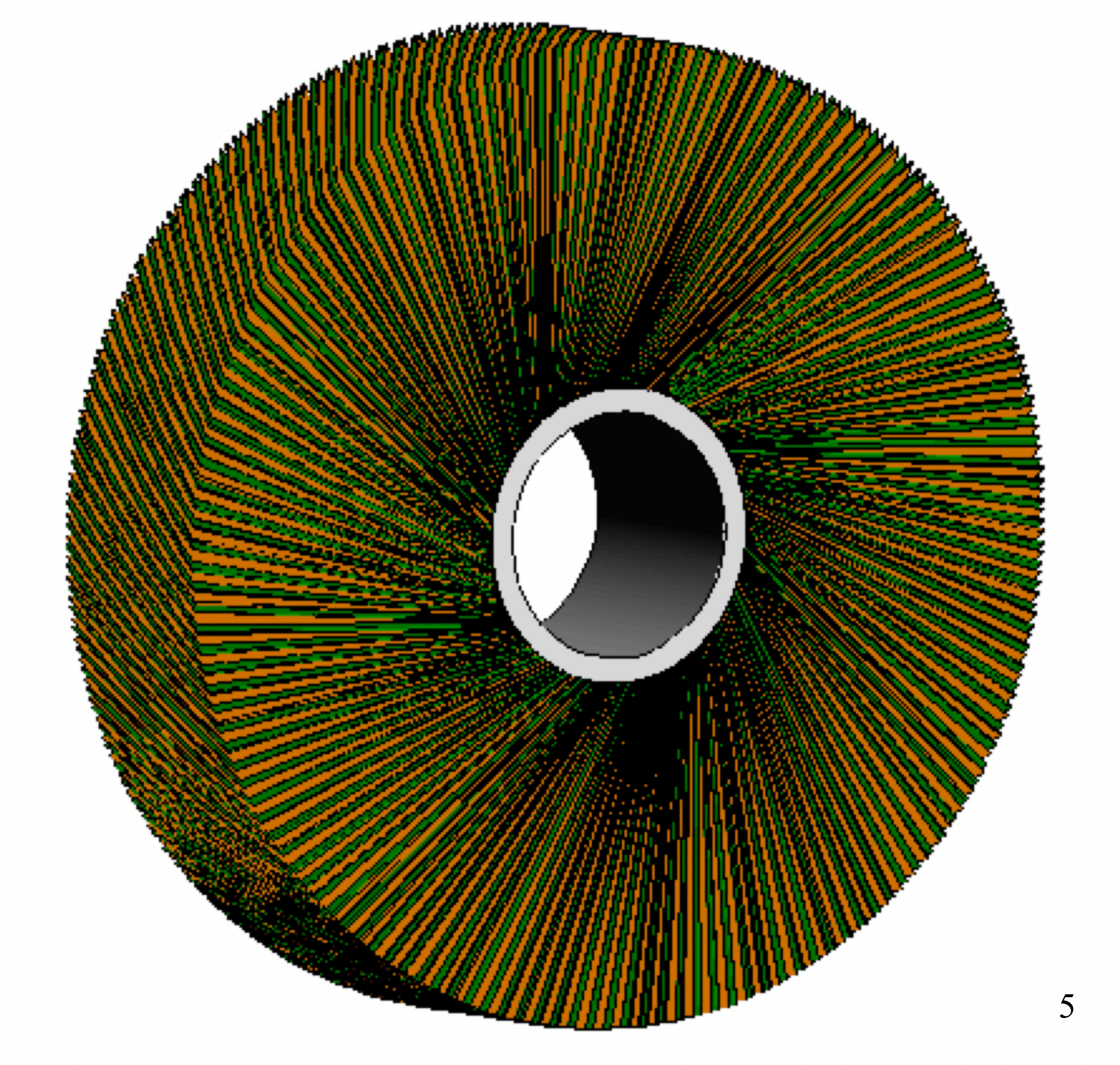




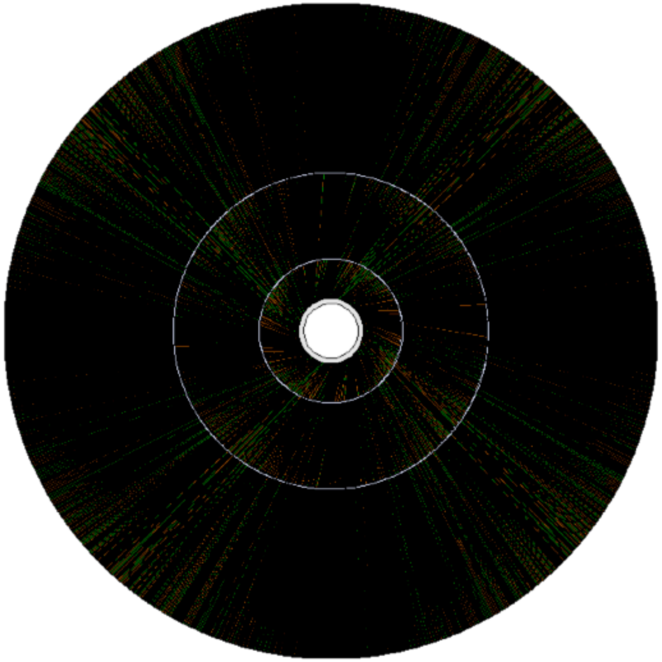
- We refer to both the absorber and electrodes as “blades”

Mechanical drawings by Rob Walker

- Inner radius portion with the full set of absorbers and electrodes:

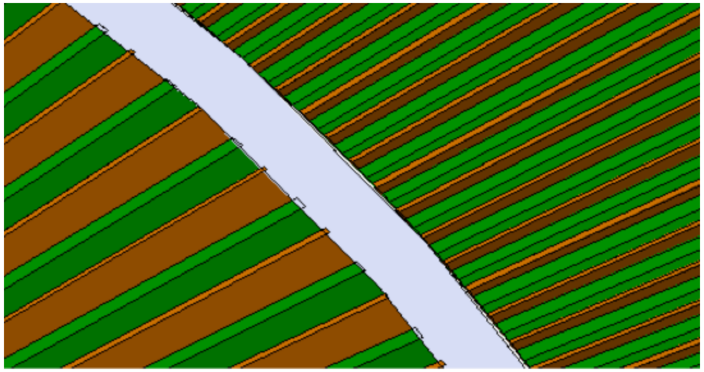


- One consideration is the variation of the gap with radius
  - means that response is very different at the inner and outer radii (42 cm and 275 cm)
  - minor issue for barrel, large issue for endcap
- To mitigate this, the detector can be subdivided into a set of nested wheels:



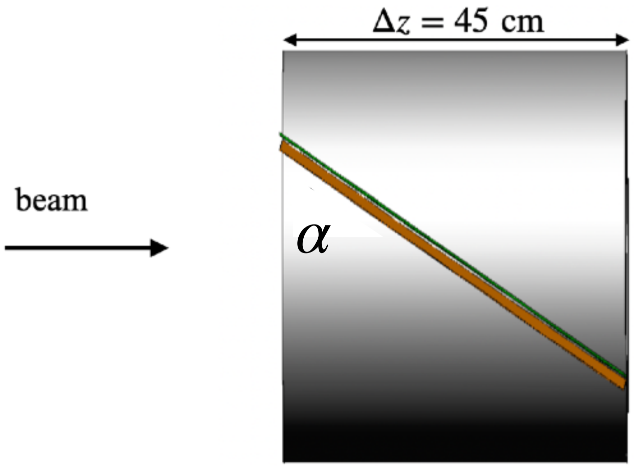
Tradeoff between minimizing variation in gap width vs. minimizing transitions/dead areas

In this example, each cylinder has $r_o/r_i = (275/42)^{1/3} \approx 1.9$



Parameter Tuning

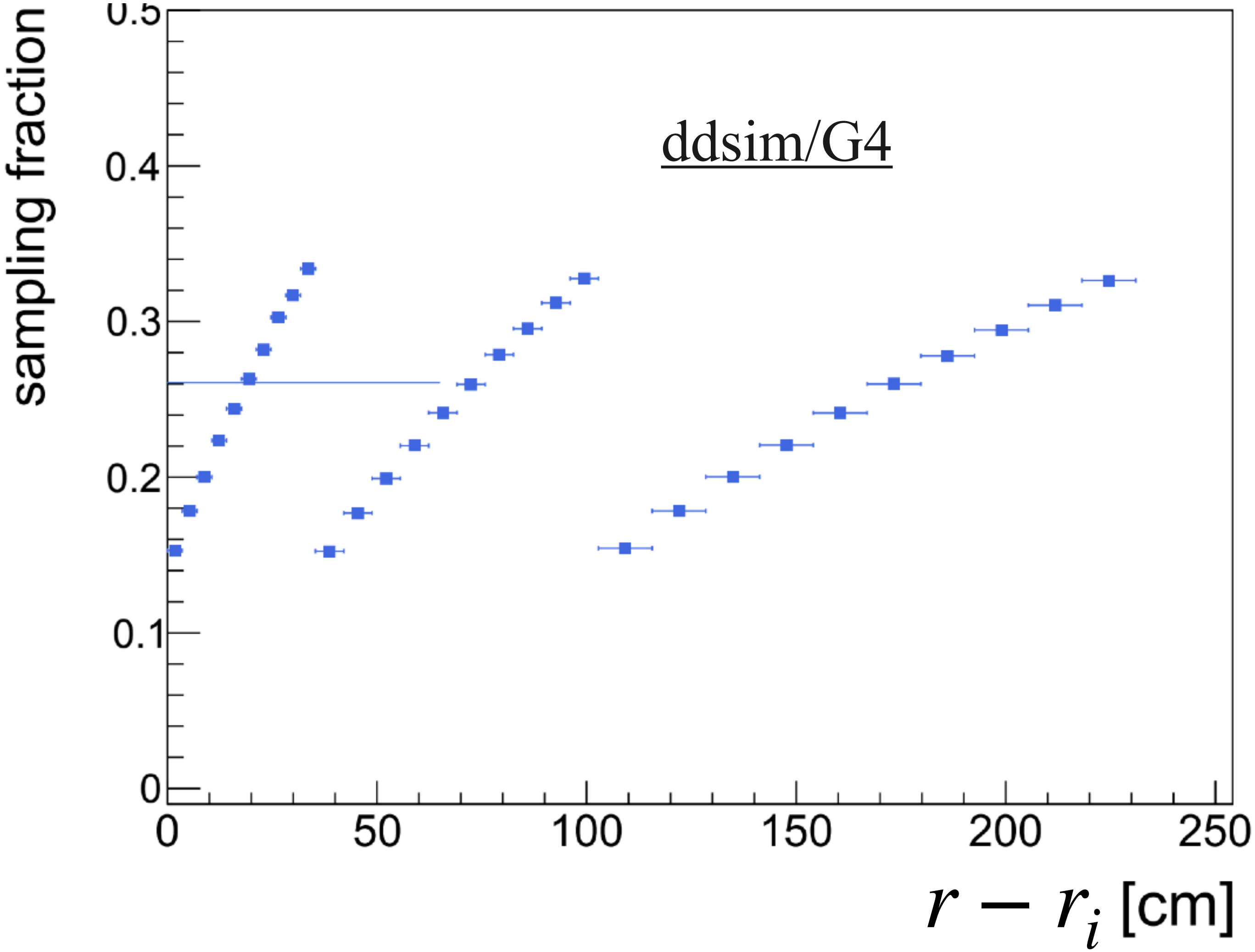
- Within the framework of the turbine design, there are several parameters than can be optimized:
  - width of LAr gap (t_L)
  - thickness of absorbers (t_A)
  - angle of turbine blades



  - should absorbers be flat or tapered (i.e. thicker at outer radius)?
    - and if tapered, by how much?
- A combination of a simple parameterized simulation and the full G4 simulation (ddsim) have been used to address these questions

Absorber Tapering

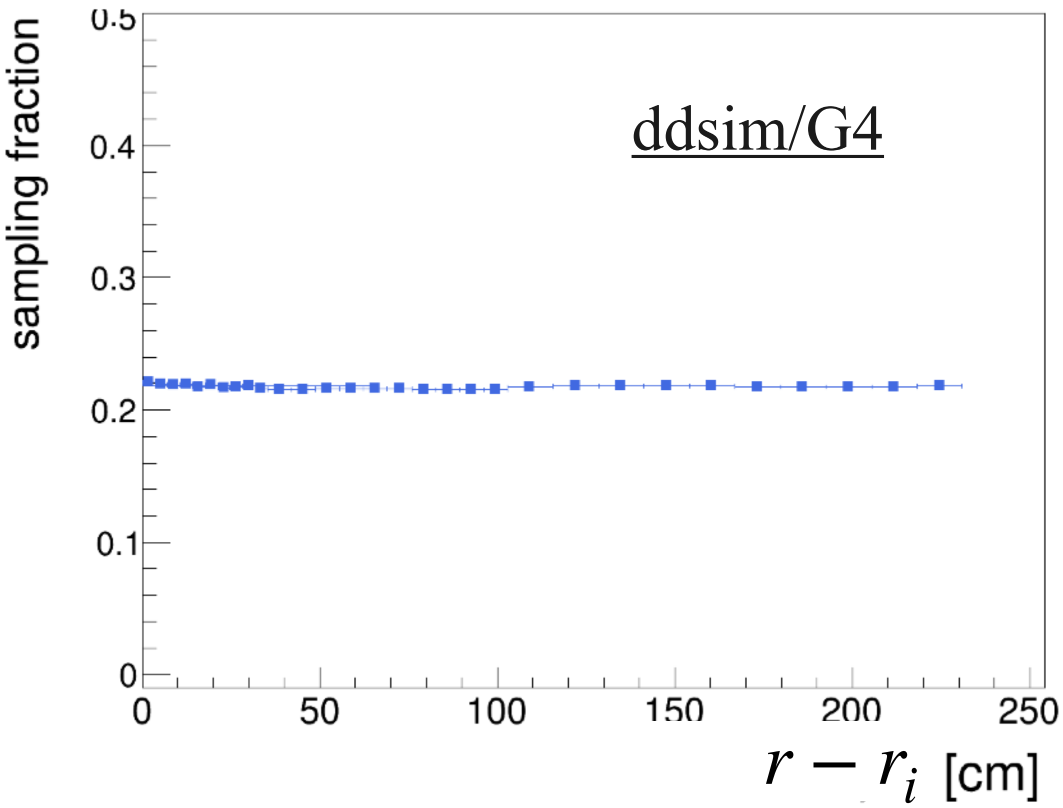
- With flat absorber blades, the sampling fraction varies strongly with radius:



- With tapering, this can be greatly mitigated, simplifying calibration:

$$t_A(r) = t_A(r_i)\left(1 + f\frac{r - r_i}{r_i}\right)$$

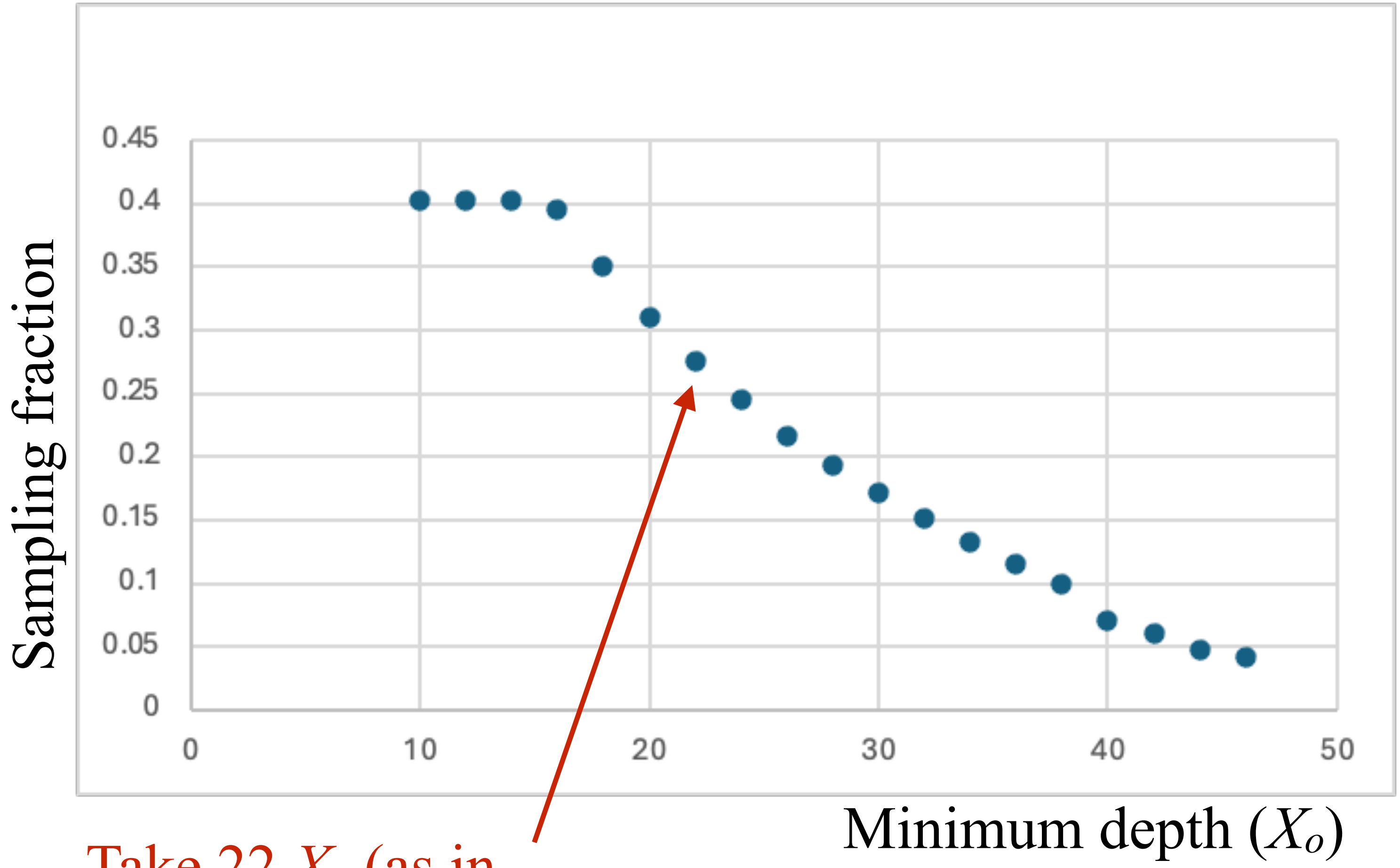
- f and $t_A(r_i)$ can be tuned. Will discuss $t_A(r_i)$ later; some trial and error shows that f=1.17 is optimal for flattening the sampling fraction



Tuning $\alpha, t_A(r_i), t_L(r_i)$

- There is still a multidimensional parameter space to explore
  - full G4 would be computationally expensive
- Therefore a simple parameterization of the sampling fraction and depth in X_o as a function of these parameters was developed
- Goal is to have as large a sampling fraction as possible while also having sufficient depth to contain the shower
- There is also a practical lower limit of $\sim 40^\circ$ for α
  - to avoid having LAr gap being severely “pinched” at inner edges
- To keep the desired frequent sampling of the shower, designs that would result in fewer than 15 unit cell crossings are rejected

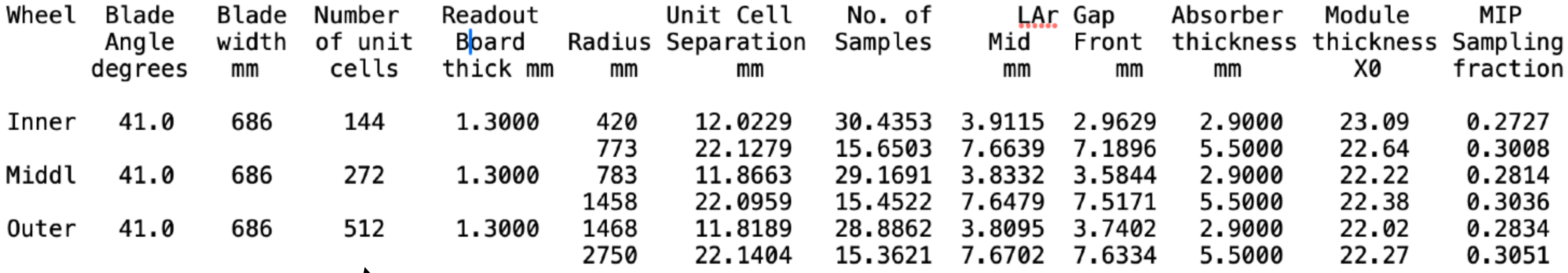
- Best attainable sampling fraction as a function of minimum depth required:



Take 22 X_o (as in barrel) to be smallest acceptable depth

Tuned Parameters

- Resulting best values are:
  - $\alpha = 41°$ (i.e. near lower allowed limit)
  - $t_A(r_i) = 3.8$ mm
  - $t_L(r_i) = 2.9$ mm
- Corresponding output of parameterization



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Wheel  Blade    Blade  Number   Readout            Unit Cell    No. of     LAr  Gap     Absorber  Module    MIP
       Angle    width  of unit  Board      Radius  Separation   Samples    Mid   Front  thickness thickness Sampling
       degrees   mm     cells   thick mm    mm        mm                   mm     mm       mm        X0     fraction

Inner   41.0    686     144     1.3000      420    12.0229     30.4353  3.9115 2.9629   2.9000    23.09    0.2727
                                            773    22.1279     15.6503  7.6639 7.1896   5.5000    22.64    0.3008
Middl   41.0    686     272     1.3000      783    11.8663     29.1691  3.8332 3.5844   2.9000    22.22    0.2814
                                           1458    22.0959     15.4522  7.6479 7.5171   5.5000    22.38    0.3036
Outer   41.0    686     512     1.3000     1468    11.8189     28.8862  3.8095 3.7402   2.9000    22.02    0.2834
                                           2750    22.1404     15.3621  7.6702 7.6334   5.5000    22.27    0.3051
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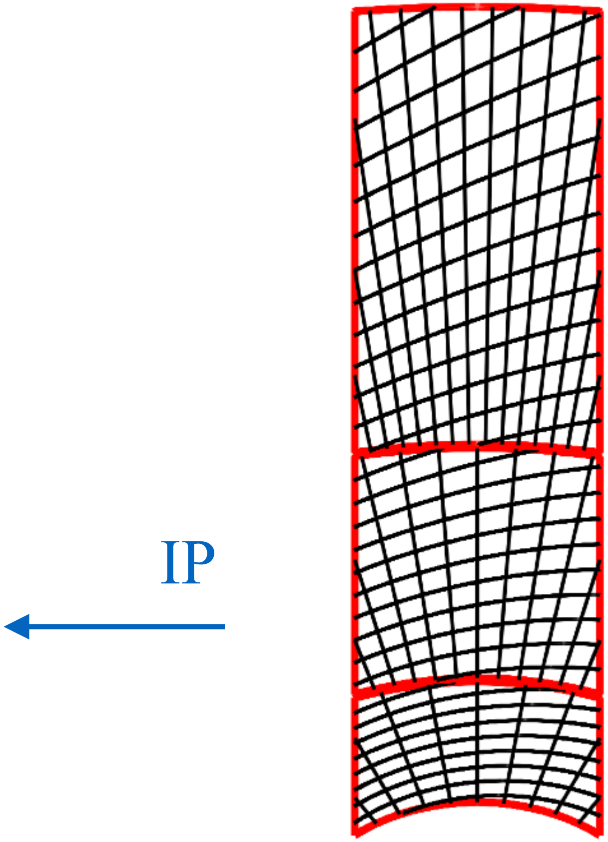
constrained to
be multiple
of 16

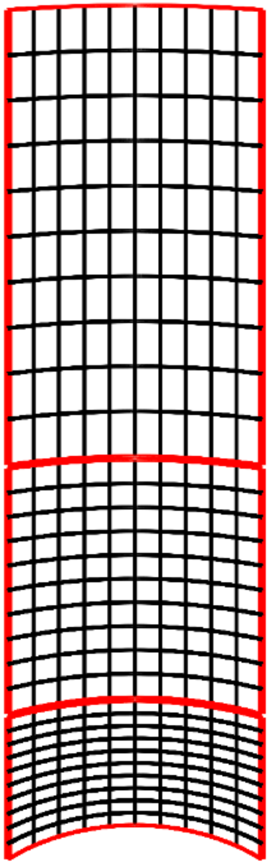
Readout Segmentation

- Exploring options for readout cell boundaries

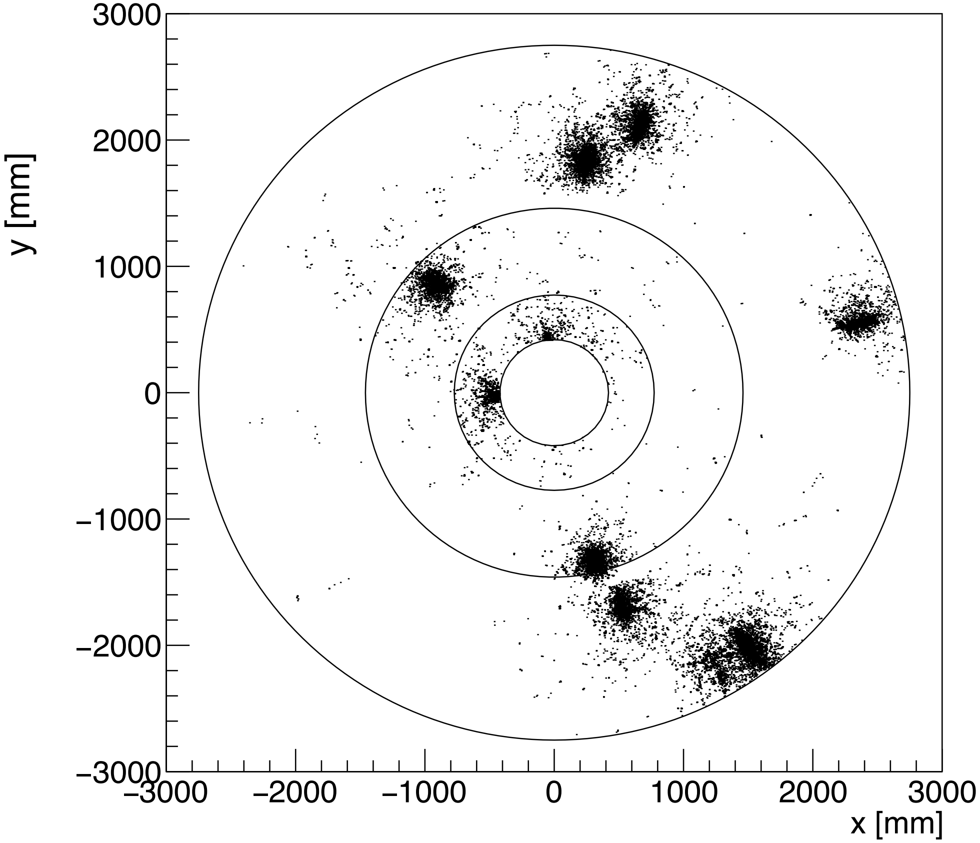
pseudo-projective in ϕ, θ

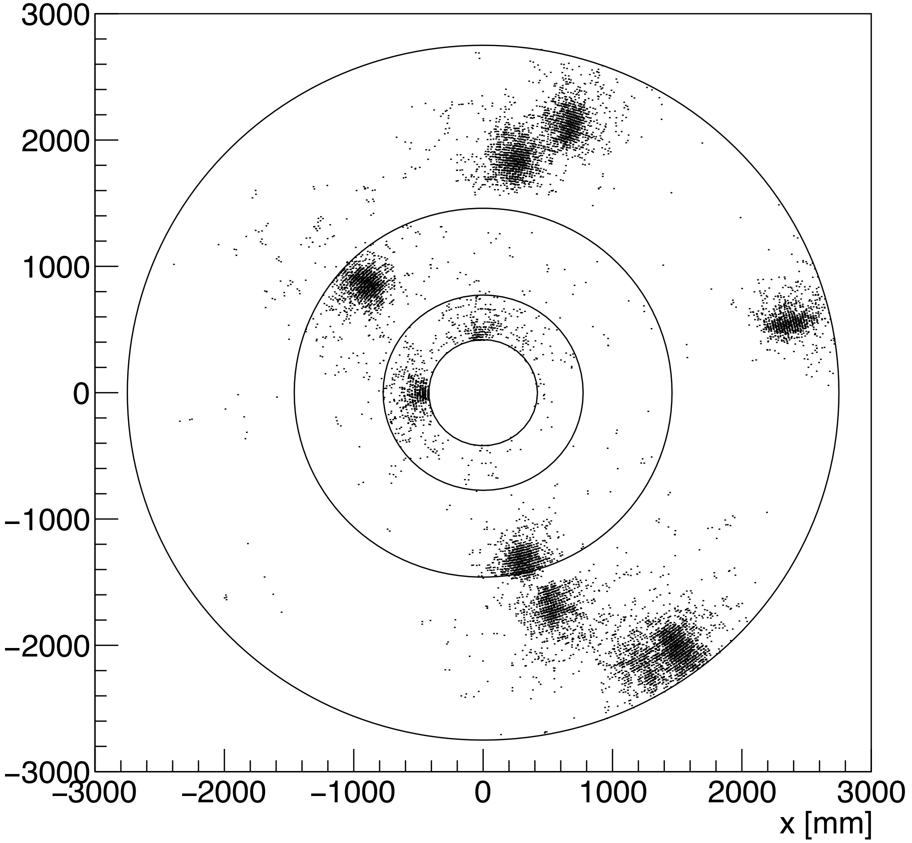


cells defined by ρ, z



- Initial tests done using ρ, z segmentation
  - should simplify calibration since cells with given ρ have the same sampling fraction
- Test of cell positioning tool (10 single-electron events):


G4 hit positions


Hit cell positions

Summary and Next Steps

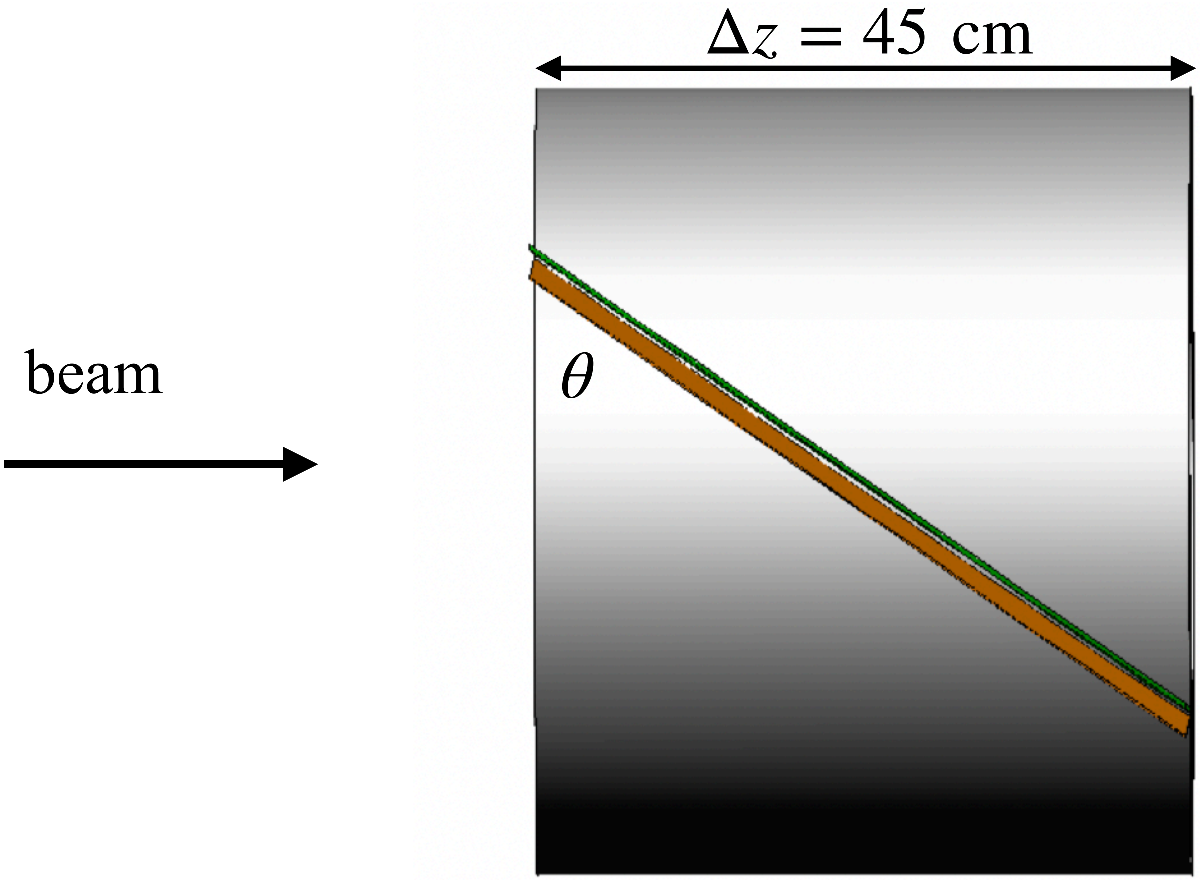
- Have been exploring a “turbine” geometry for the ALLEGRO endcap ECAL
- Initial studies look promising
  - can attain reasonably large sampling fraction with required depth and frequency of sampling
  - variation of sampling fraction with radius can be controlled by tapering absorbers
- Integration into FCC simulation framework is well along
  - clustering algorithm needs to be extended to include endcap cells
- And then there is all the engineering (both electrical and mechanical) to convert this concept into a feasible device…

Backup

Finding the Code

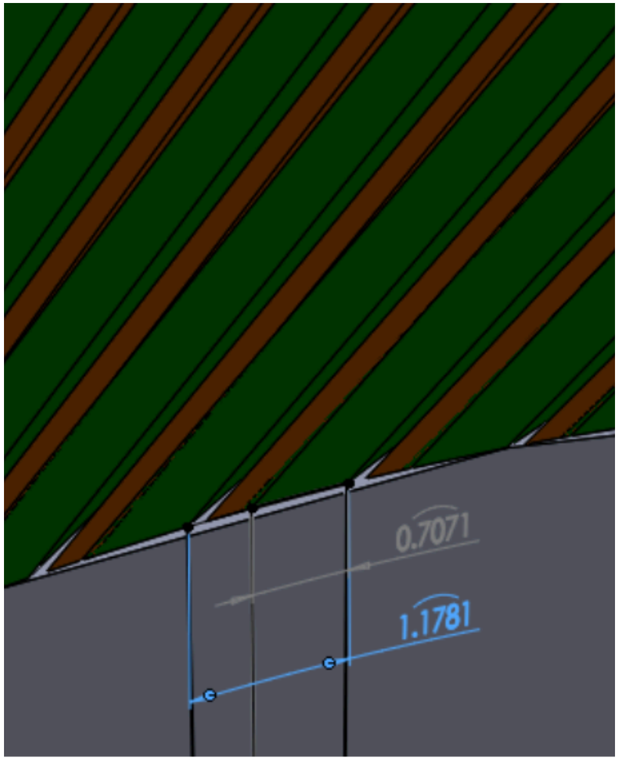
- Implementation in G4 in my k4geo fork at https://github.com/varnes/k4geo
    - xml to set parameters
    - cpp file
- Parameterized simulation is in my CERN gitlab repository: https://gitlab.cern.ch/evarnes/fcc/-/blob/master/TurbineParameters.C?ref_type=heads

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



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

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



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