Status of “Turbine” Endcap EM Calorimeter in Full ALLEGRO Simulation

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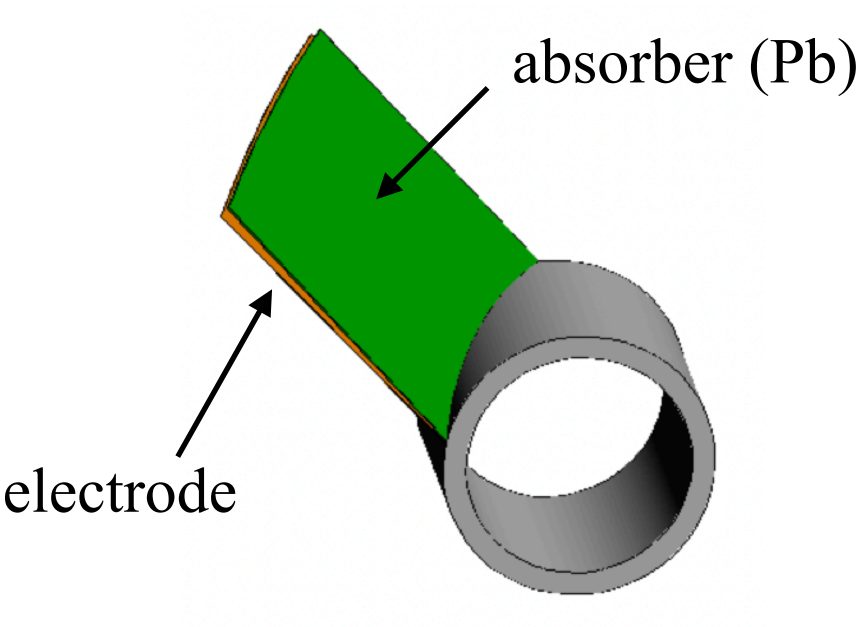
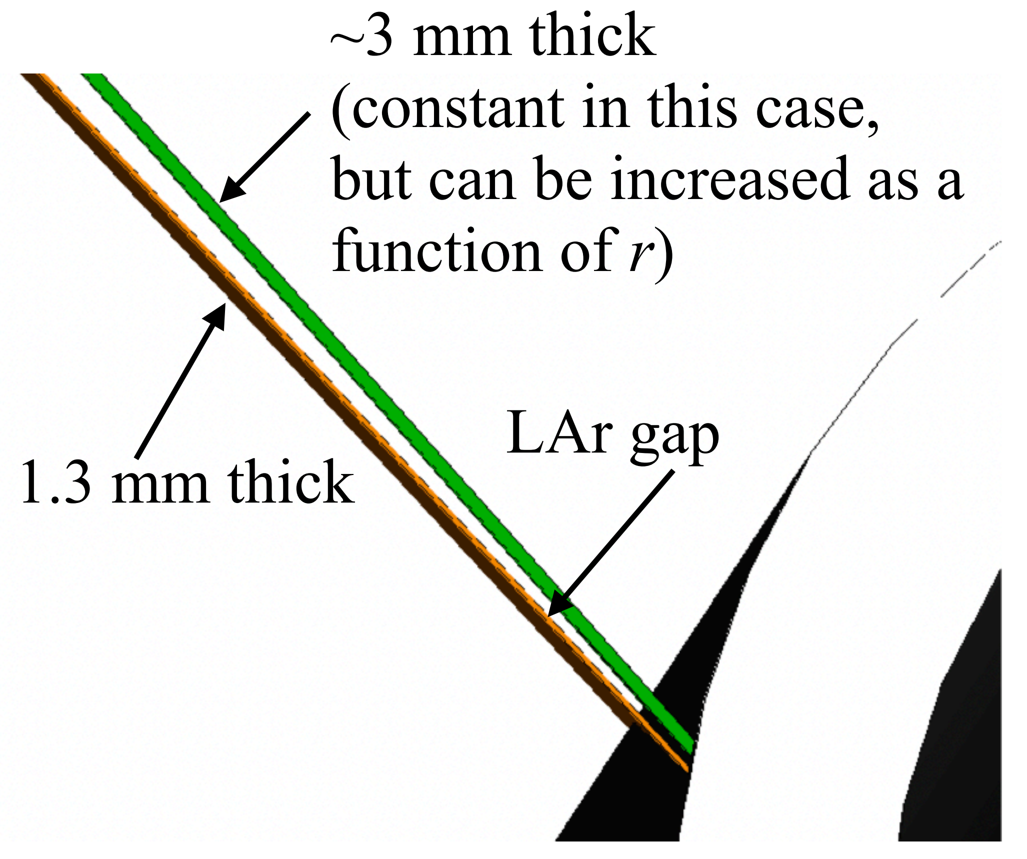
- Have been developing the following geometry for absorbers and electrodes ("turbine geometry"):

single unit cell:

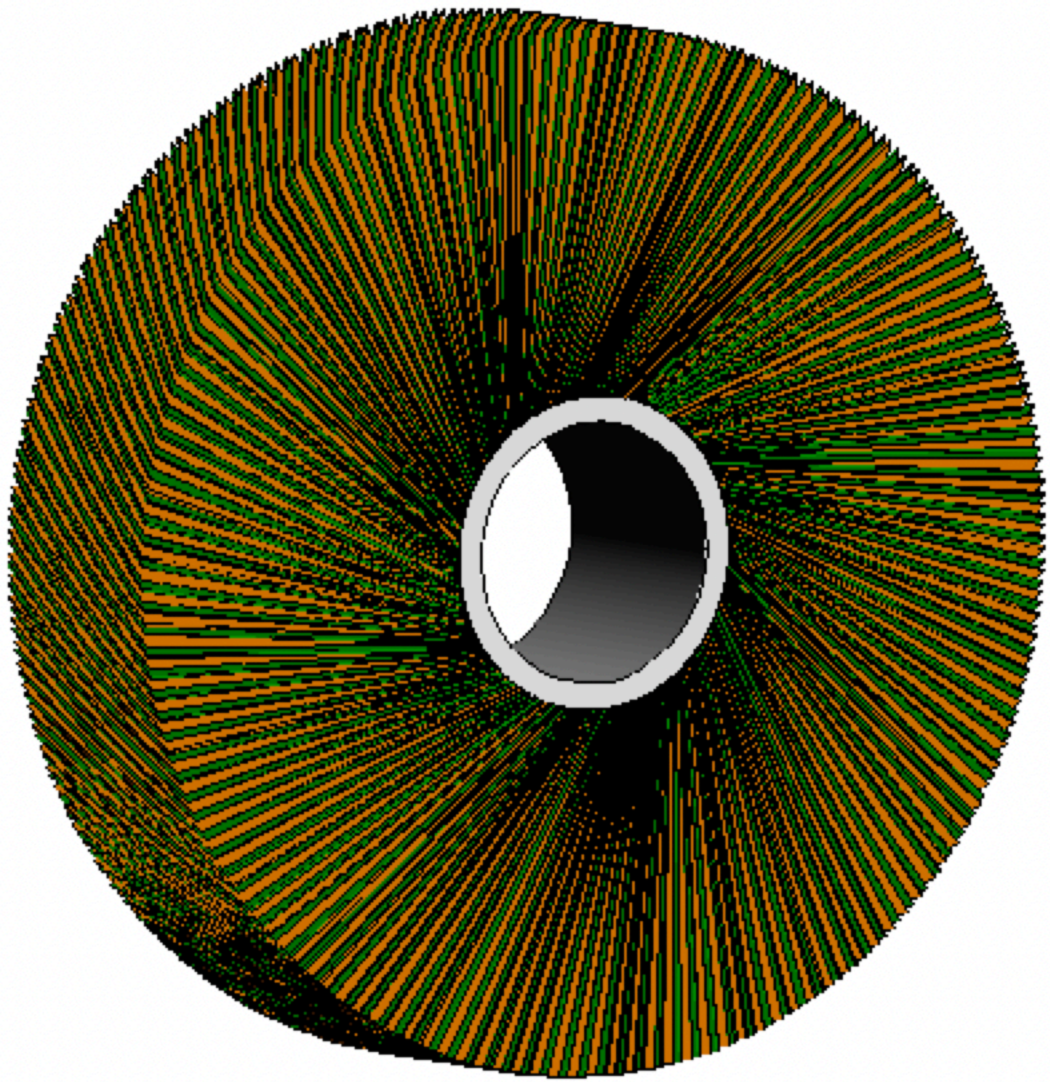




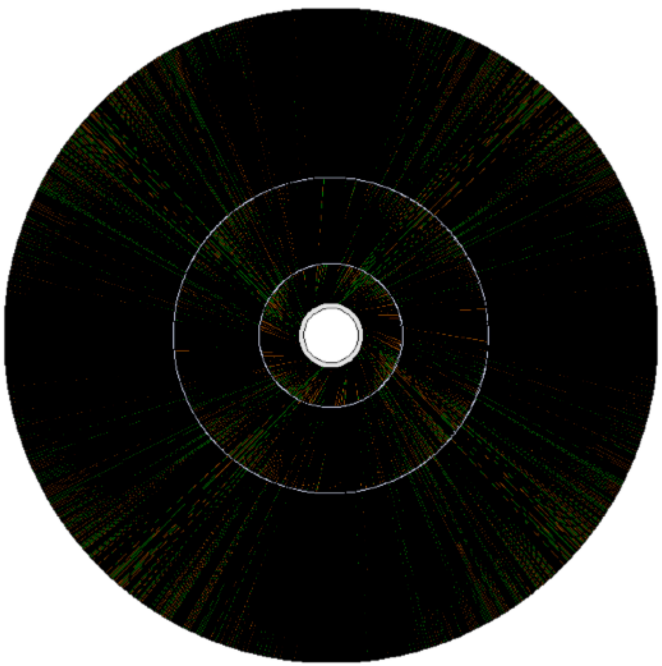
- We refer to both the absorber and electrodes as "blades"

Mechanical drawings by Rob Walker

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

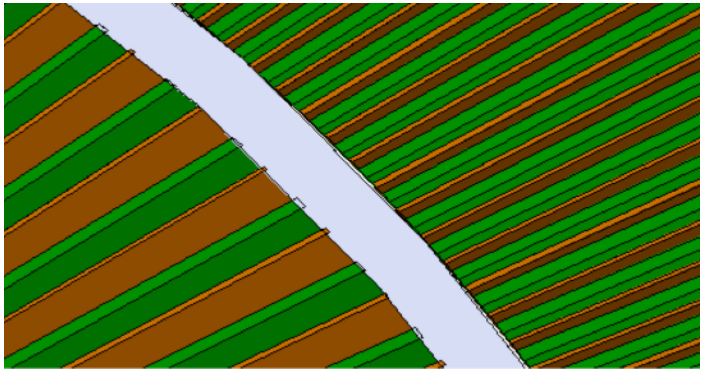


- One consideration is the variation of the gap with radius
  - means that response is very different at the inner and outer radii (42 cm and 275 cm)
- To mitigate this, the detector can be subdivided into a set of nested wheels:



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

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



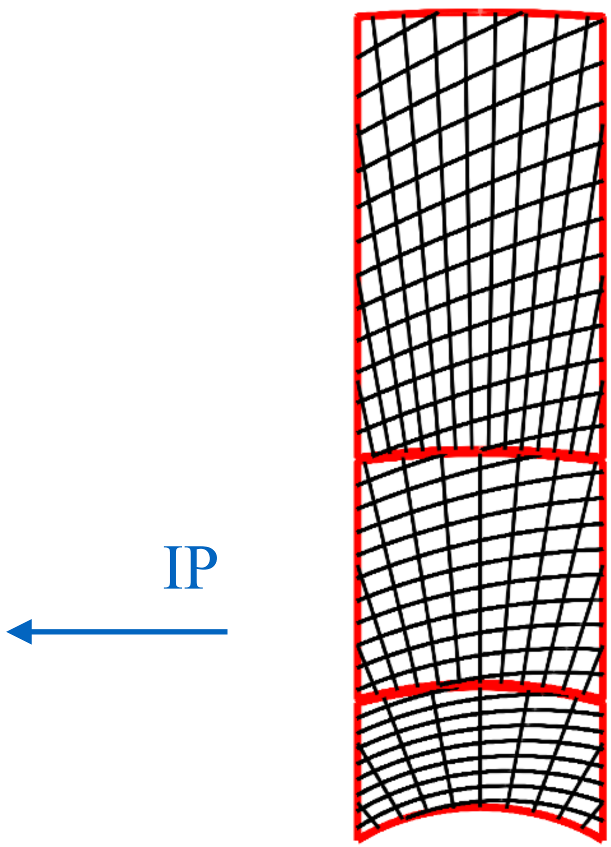
Motivation for "Turbine" Geometry

- Turbine design incorporates 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

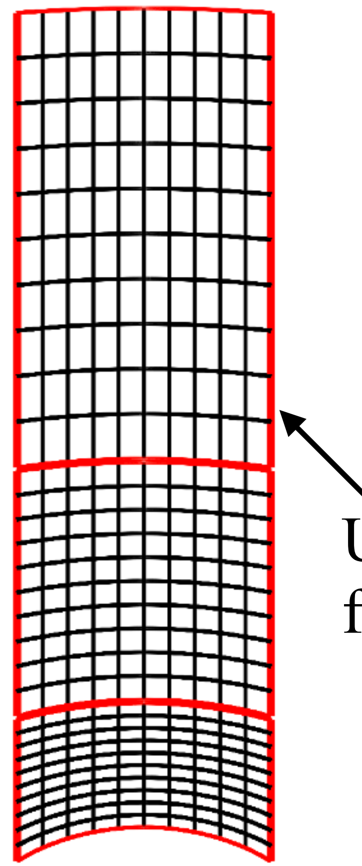
Readout Segmentation

- Exploring options for readout cell boundaries

pseudo-projective in ϕ, θ



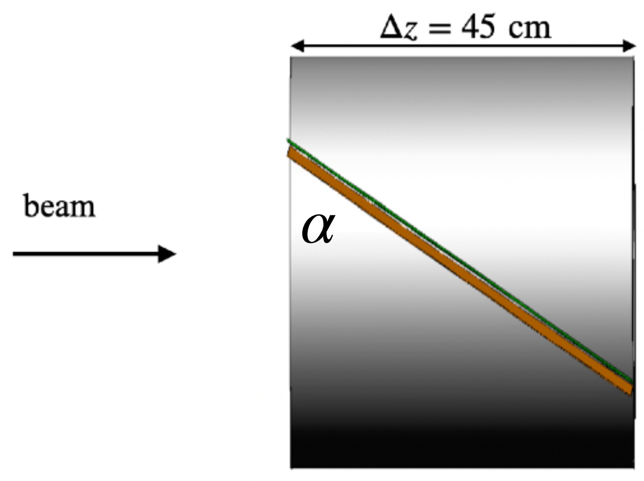
cells defined by ρ, z



Using this one for initial tests

Parameter Tuning

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



  - should absorbers be flat or tapered (i.e. thicker at outer radius)?
    - and if tapered, by how much (*f* in the equation below)?

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

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
  - taken to be 22 X_o
- 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

Tuned Parameters

- Resulting best values are:
  - $\alpha = 41^{\circ}$ (i.e. at lower allowed limit)
  - $t_A(r_i) = 3.8$ mm
  - $t_L(r_i) = 2.9$ mm
  - $f = 1.0$
- Corresponding output of parameterization:

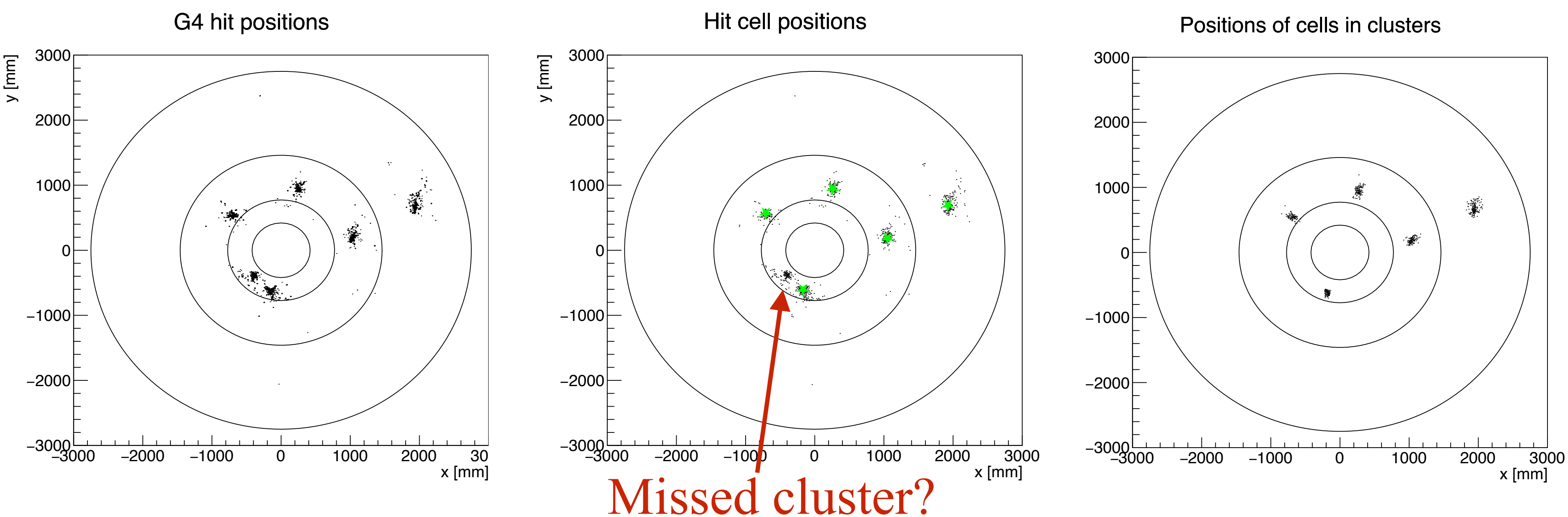
Wheel	Blade Angle degrees	Blade width mm	Number of unit cells	Readout Board thick mm	Radius mm	Unit Cell Separation mm	No. of Samples	LAr Gap Mid mm	LAr Gap Front mm	Absorber thickness mm	Module thickness X0	MIP Sampling fraction
Inner	41.0	686	144	1.3000	420	12.0229	30.4353	3.9115	2.9629	2.9000	23.09	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

Constrained to be multiple of 16, to allow flexibility in ganging signals

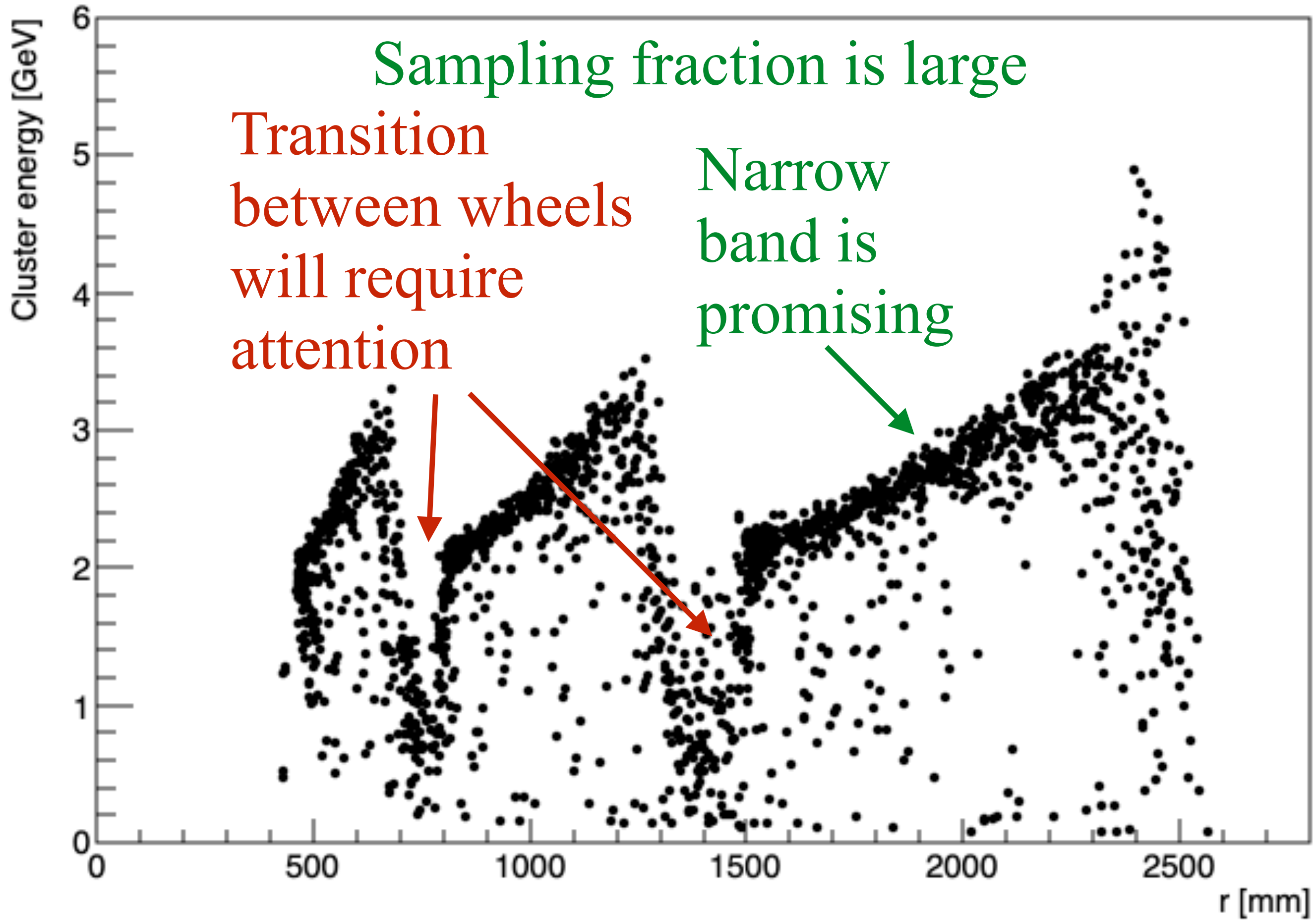
Variation in gap will add complexity to calibration (not yet accounted for)

Cluster Reconstruction

- Have implemented a positioning tool and adapted/extended the sliding windows clustering tool to include the turbine endcap
  - i.e. making it understand how to handle the new segmentation class
- Full sim sanity check, with single 1-GeV electrons:



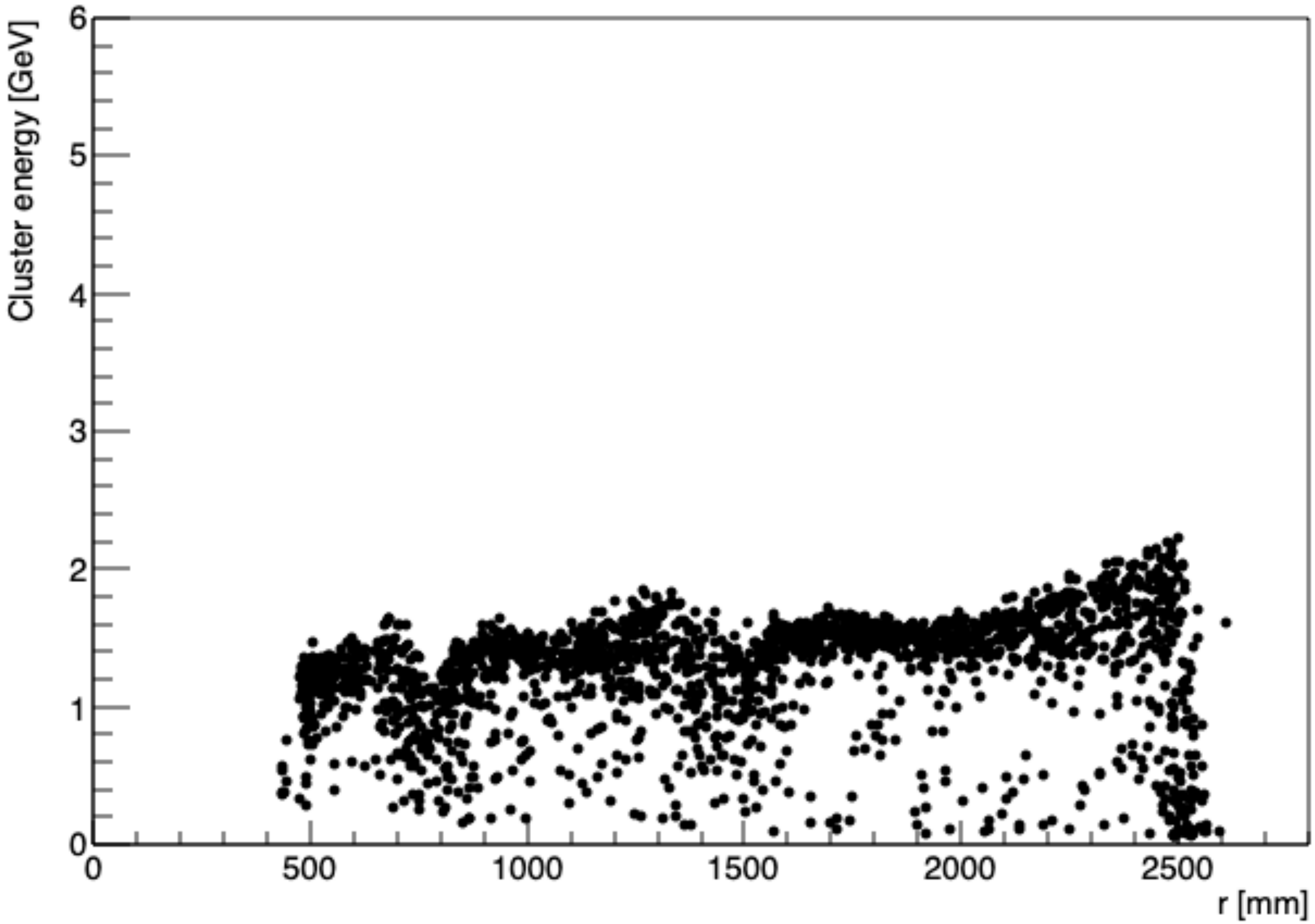
- With 5000 10-GeV electrons the response vs radius can be studied
  - no calibration applied, so the cluster energies are just the sums of the energy deposited in the LAr



Code Status

- Given that reasonable results are now coming from the simulation, a pull request was opened to add support for the turbine endcap in both k4geo and k4RecCalorimeter
  - https://github.com/key4hep/k4geo/pull/347
  - https://github.com/HEP-FCC/k4RecCalorimeter/pull/88
- The k4RecCalorimeter PR depends upon the k4geo one
- Status:
  - review of the geometry (Alvaro and Brieuc) showed issues with overlapping volumes and several ways in which the implementation could be made more efficient (e.g. reduce usage of boolean operations)
  - some of these are now implemented, and initial tests show that memory usage is reduced substantially (from 2.4 to 1.5 GB)
    - warnings about overlaps are also gone

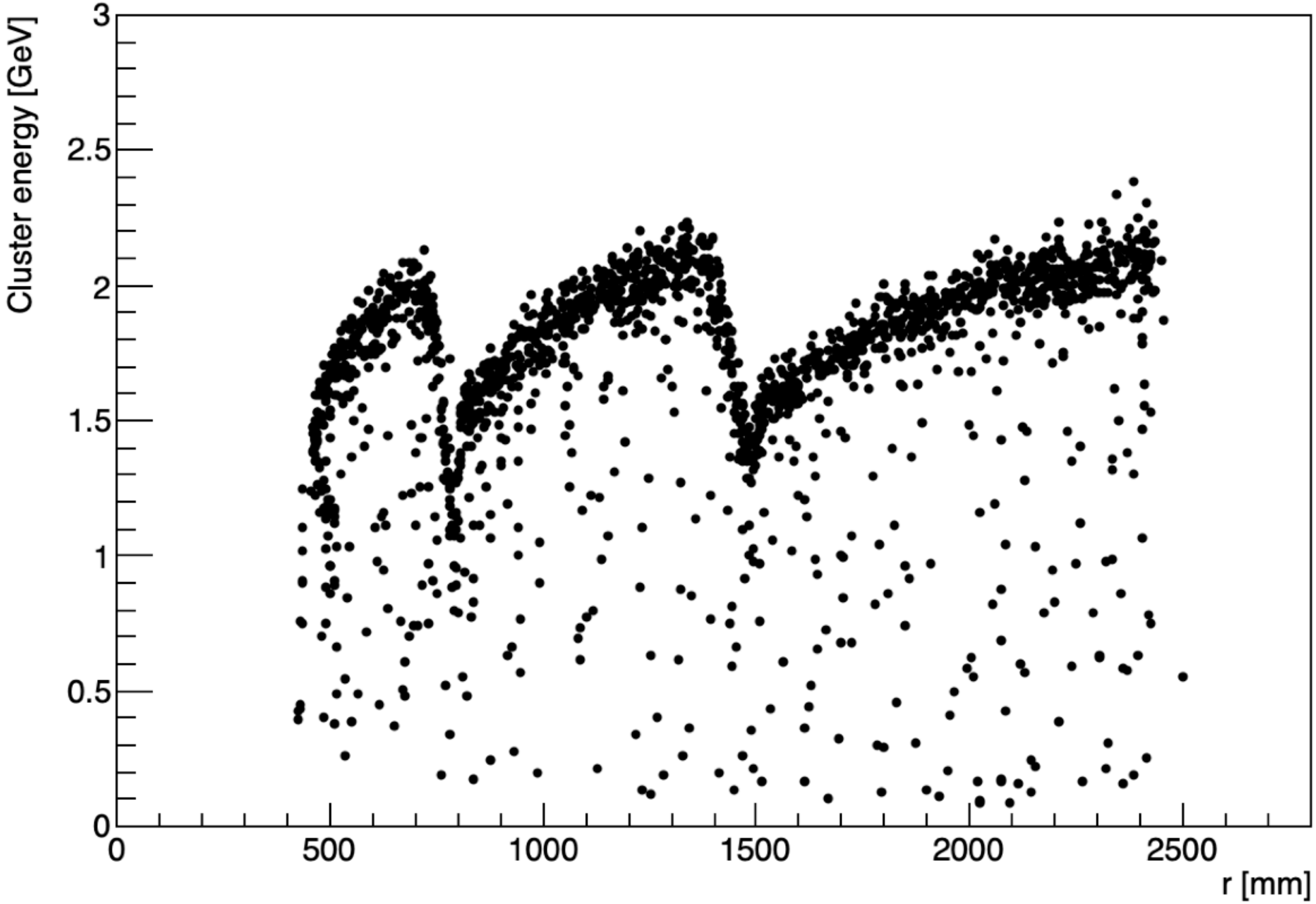
- Repeat 10-GeV electron test, with same geometry but new implementation:
  - seems more uniform, but with much smaller overall response
  - problem with new implementation (or with old one)?



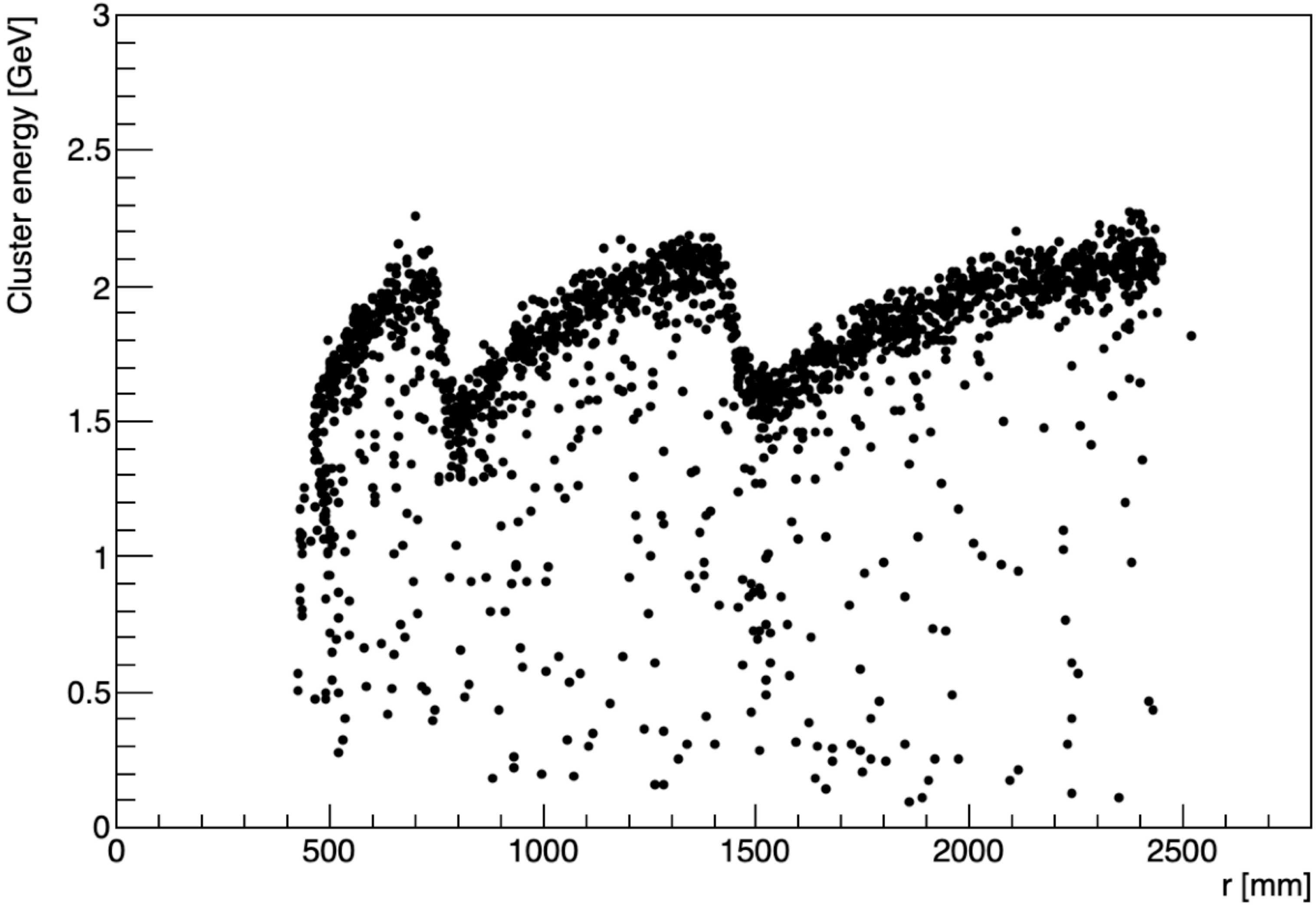
Summary

- Main news is that cluster reconstruction is now working for the turbine endcap
- Pull request is in progress to add this to main ALLEGRO repository
  - review revealed that substantial optimizations of the geometry were possible
  - some of these are now implemented, but result in unexpected performance changes
    - may indicate problems with the new and/or old implementations
- After debugging, the process of calibrating and optimizing will begin

- Response to 10 GeV electrons, steel support tube, no calibration:

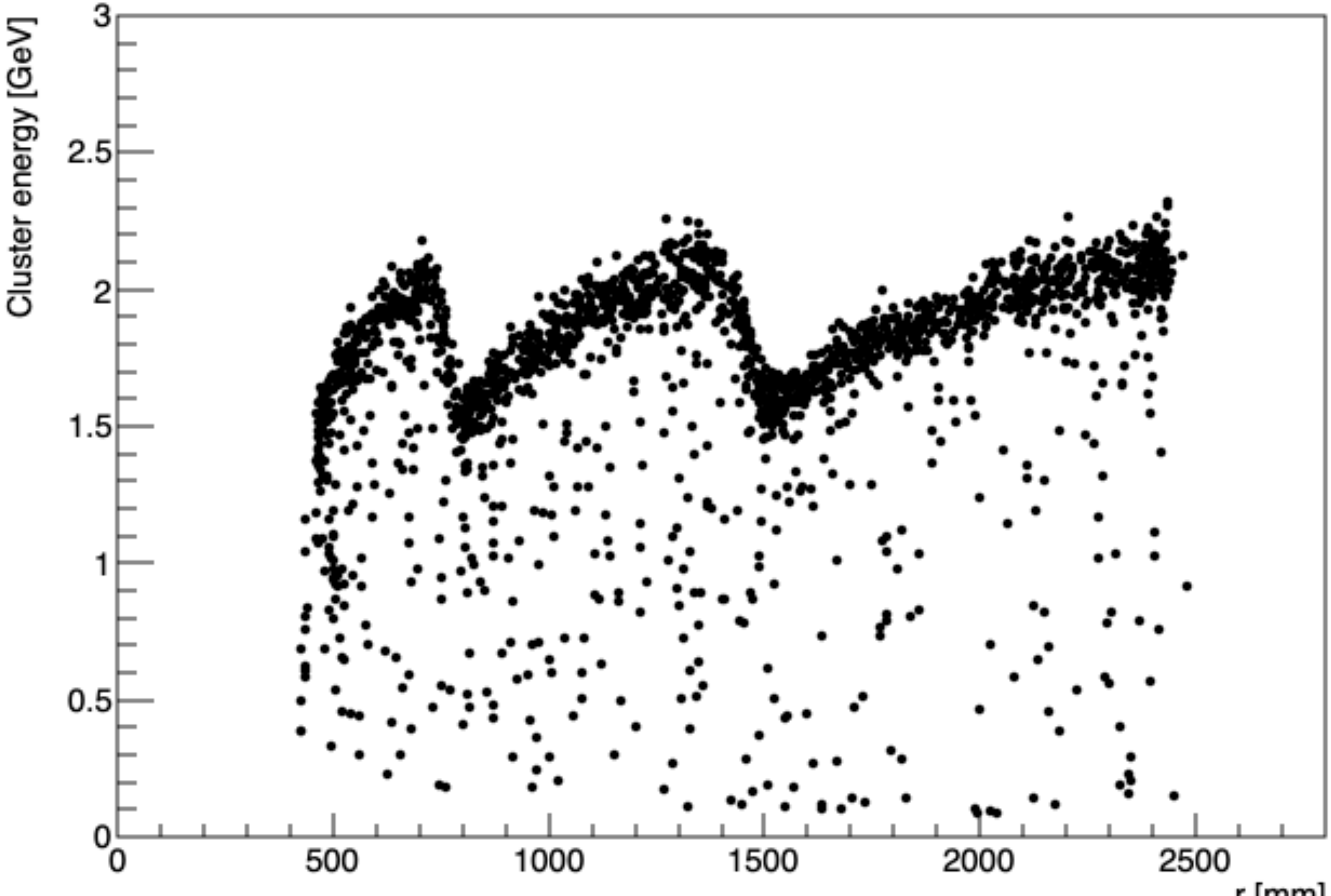


- Response to 10 GeV electrons, aluminum support tube, no calibration:

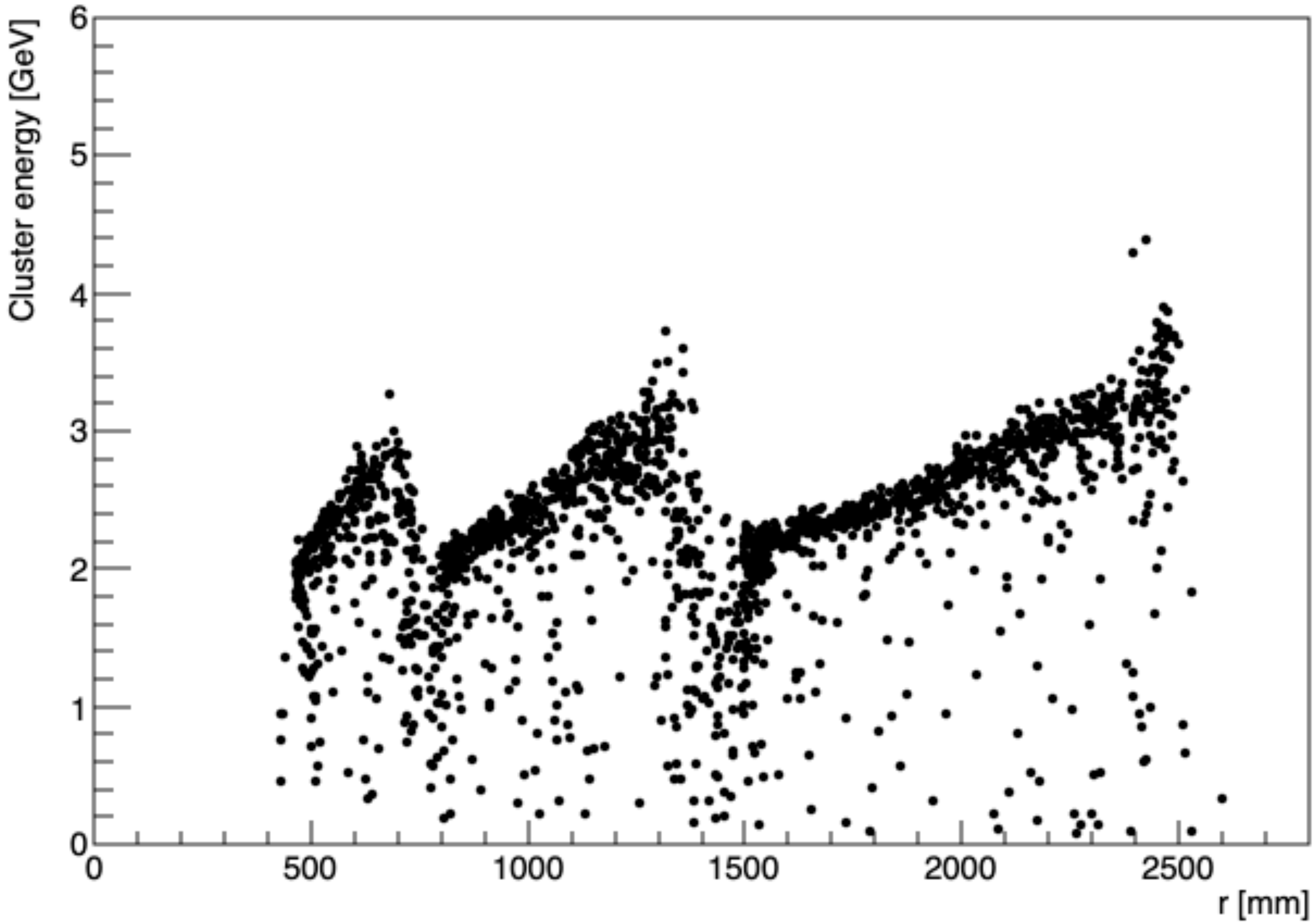


Backup

- Response to 10 GeV electrons, carbon fiber support tube, no calibration:



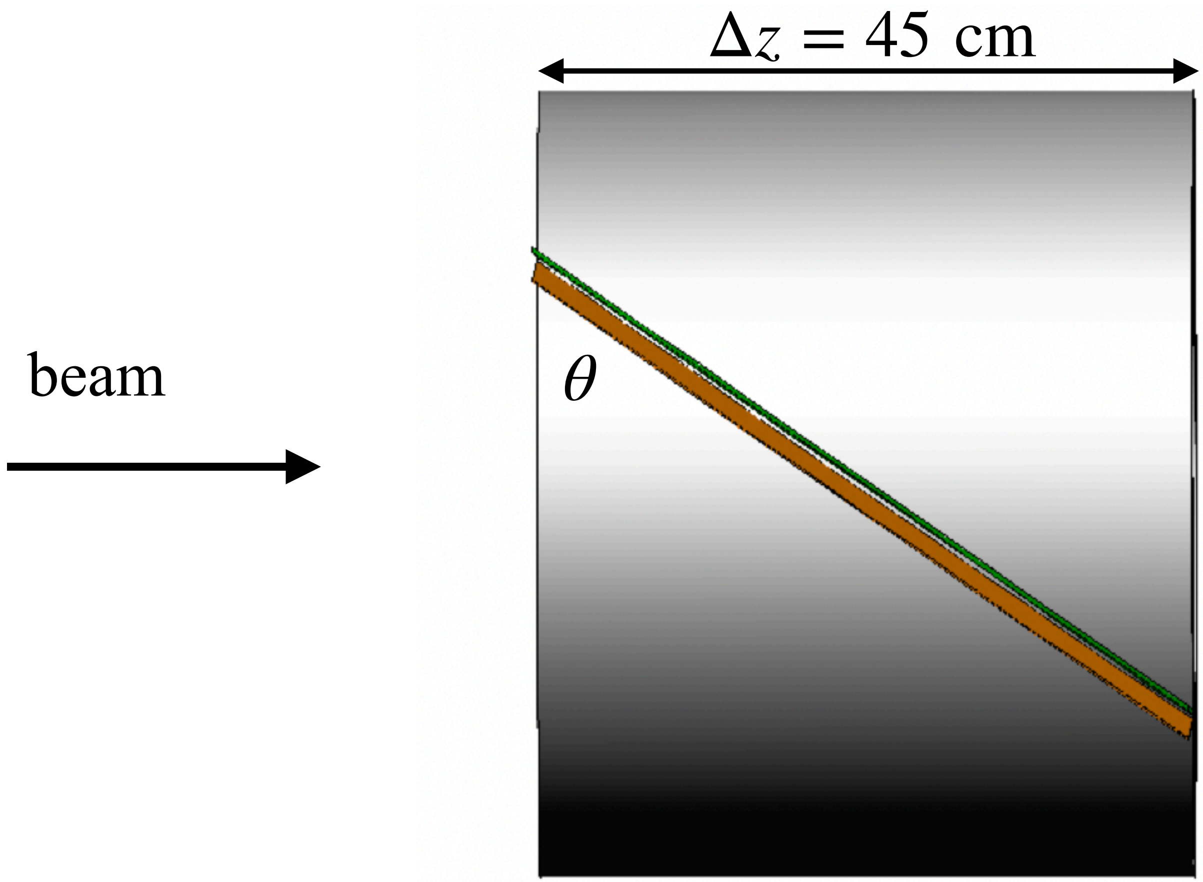
- Response to 10 GeV electrons, carbon fiber support tube, no calibration, ecal_v02:



Finding the Code

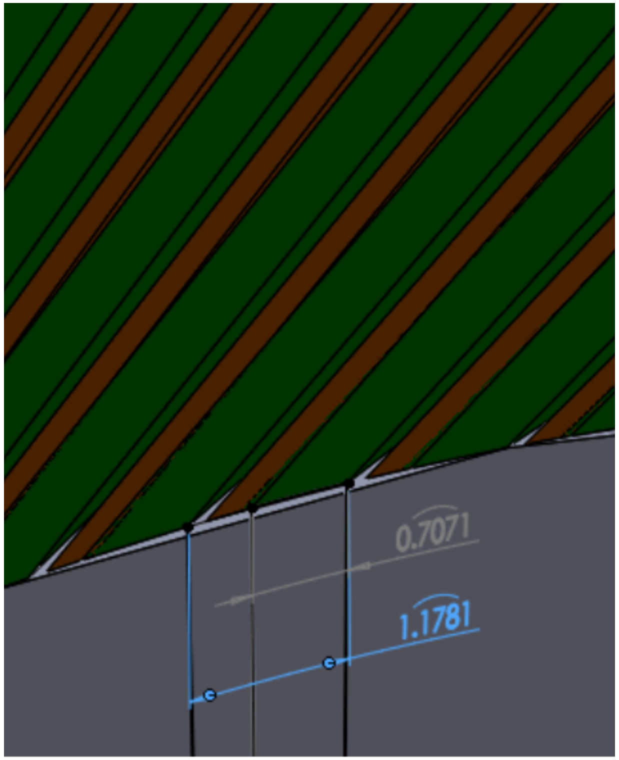
- Implementation in G4 in my k4geo fork at https://github.com/varnes/k4geo
    - xml to set parameters
    - cpp file
- Parameterized simulation is in my CERN gitlab repository: https://gitlab.cern.ch/evarnes/fcc/-/blob/master/TurbineParameters.C?ref_type=heads

- 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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