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

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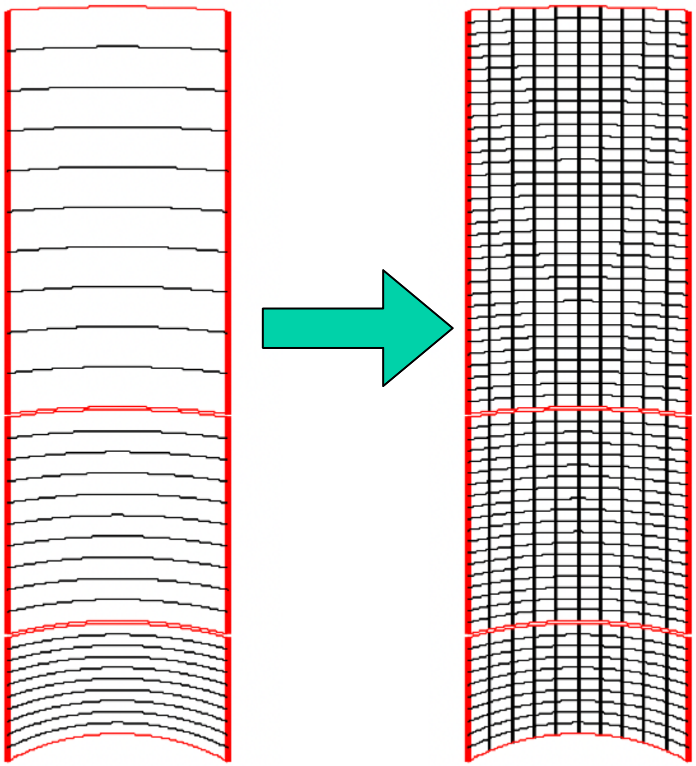
Reminder of Previous Status (October)

- Implemented 2nd pass (v02) of “turbine” geometry in k4geo and k4RecCalorimeter:

- Separated into three wheels
- Sliding-window cluster reconstruction algorithm implemented
- Biggest changes wrt v01:
  - flexibility to set different parameters in the three wheels (blade angles, absorber thickness, etc.)
  - simplified segmentation

What's New (now v03)?

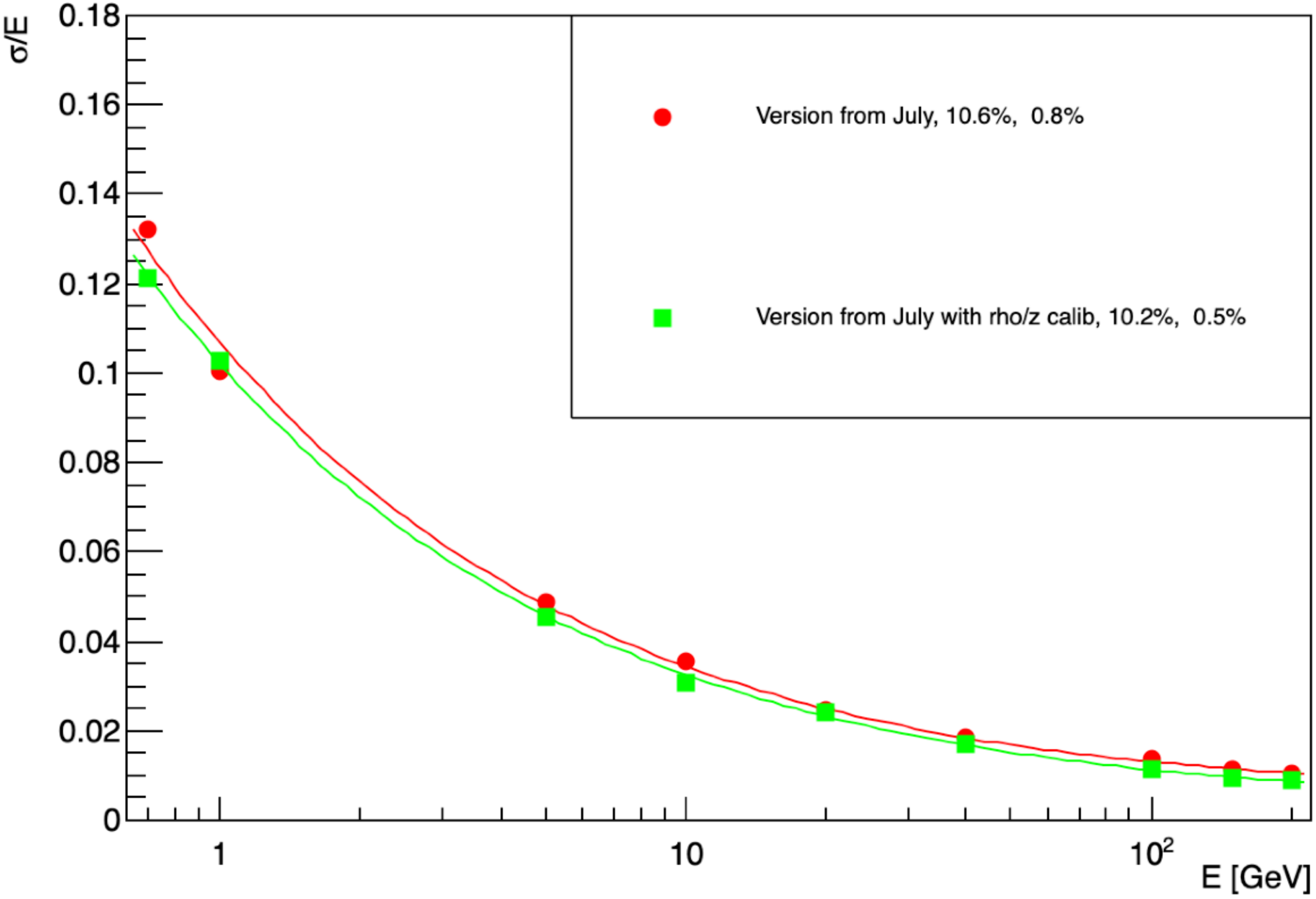
- Implemented calibration in both rho and *z* directions:



Reflects the fact that the LAr gap varies in both dimensions

- For now, calibration "layers" are the same as readout segmentation
  - though it would probably make sense to decouple the concepts

- Effect of calibration change (same geometry)



Optimizing the geometry

- As before, a parameterized tool is used to select promising configurations
  - this adjusts parameters so that the sampling fraction is maximized, subject to some constraints. Previously these were:
    - minimum depth of 22 X_o
    - at least 15 absorbers crossed
    - variation in LAr gap width across z < 25%
    - number of absorbers in each wheel is a multiple of 16
  - recent change:
    - at least 30 absorbers crossed
      - about as far as one can go without specifying sub-mm absorber/gap thicknesses

Old vs New optimizations

- Old:

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

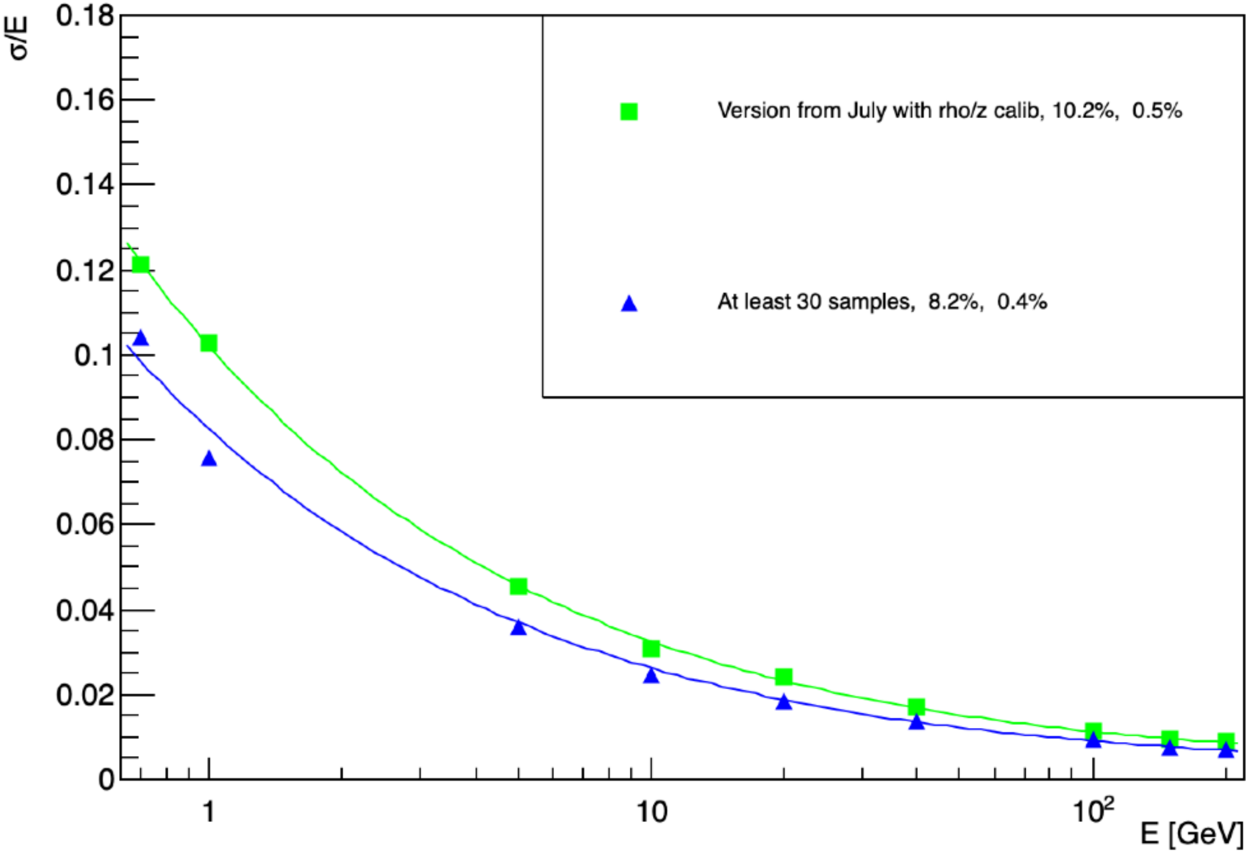
- New:

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
Wheel 0	48.0	606	368	1.3000	420	5.3291	58.9610	1.3646	1.1228	1.3000	22.43	0.2133
					786	9.9697	30.5474	3.0622	2.9389	2.5452	22.88	0.2622
Wheel 1	31.0	874	384	1.3000	796	6.7059	59.8877	1.9030	1.6120	1.6000	22.04	0.2425
					1489	12.5454	31.0801	4.0564	3.9076	3.1326	22.48	0.2805
Wheel 2	20.0	1316	416	1.3000	1499	7.7418	56.3016	2.2709	2.0108	1.9000	22.43	0.2501
					2750	14.2060	30.0230	4.7098	4.5726	3.4864	22.12	0.2913

From Parameterized to Full Sim

- Promising geometries identified by the parameterized scan are implemented in full sim (ddsim, in the ALLEGRO framework)
- Calibration is done using 40 GeV single electrons, with constants chosen to minimize average $|E_{\text{clus,reco}} - E_{\text{true}}|$
  - the constants are then applied to single electrons from 0.7 to 200 GeV
  - calibrated cluster energy distribution is fit to a Gaussian
  - Gaussian σ/E_{true} is then plotted
- NB: solenoid field is turned off in the simulation to allow direct comparison to results from July
  - will revisit this near the end of the talk

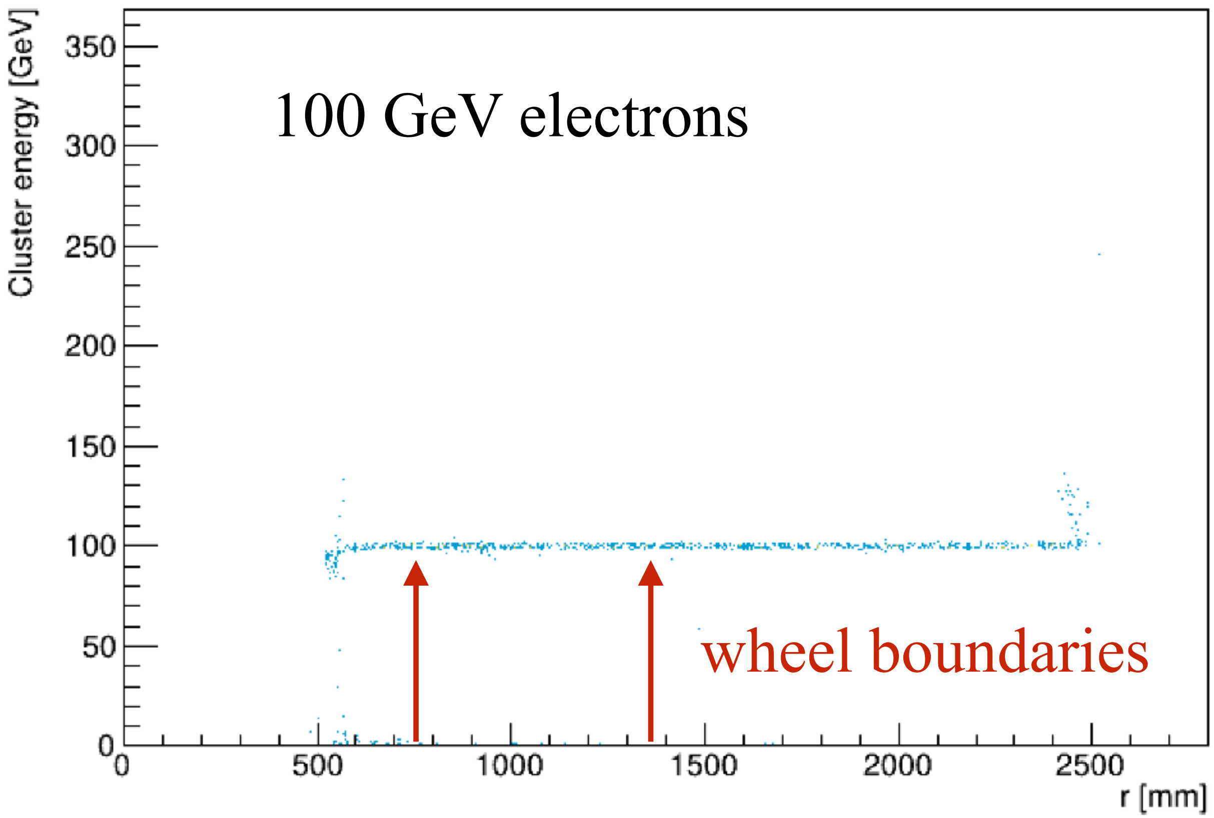
Result



- New version is clearly better
  - sampling frequency is more important than sampling fraction (at least to some extent)

Aside: Calibration across wheel boundaries

- The multi-wheel design my raise concerns about calibrating clusters that straddle wheel boundaries
  – but this does not seem to be a big problem:



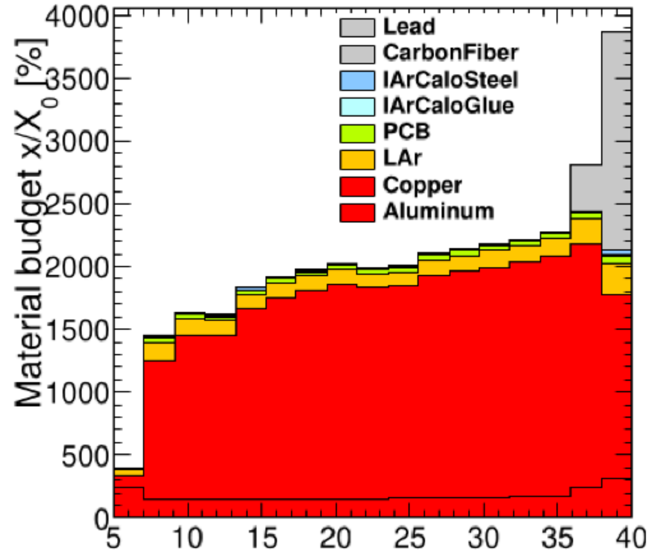
Different absorber material?

- Lead is difficult to work with
  - at a minimum, required sheets of material such as stainless steel to be glued on for mechanical stability
- What about copper instead?
- Parameterized optimization:

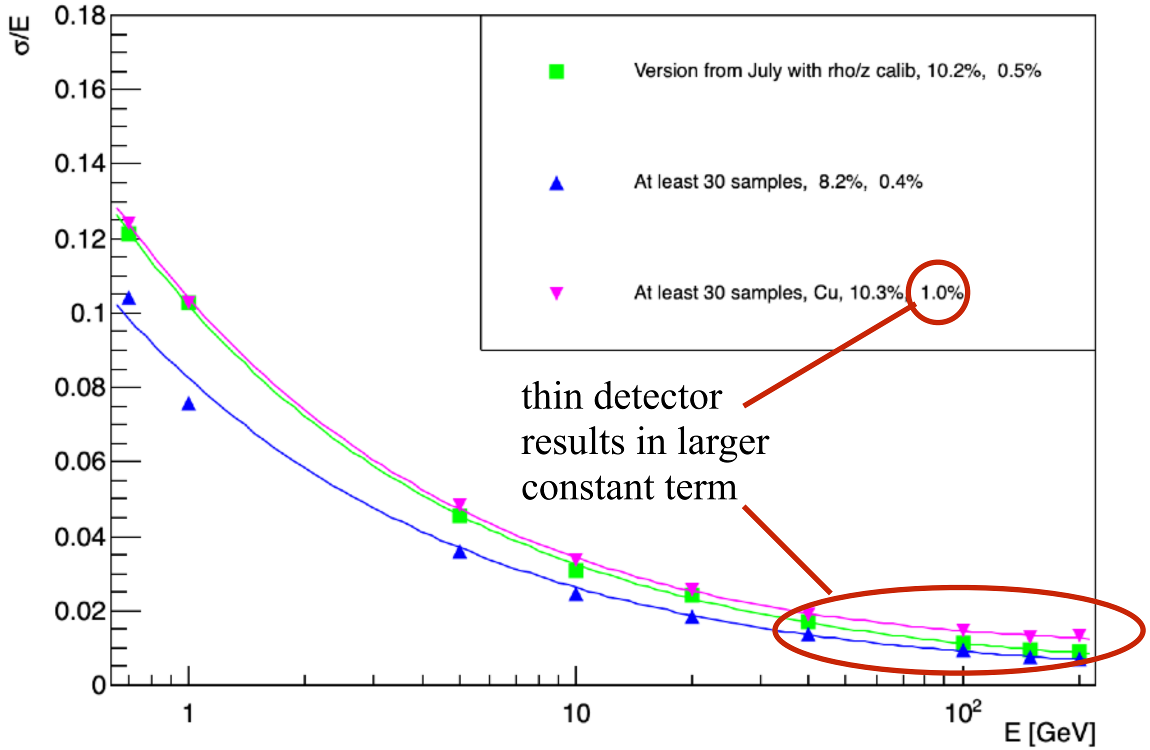
Wheel	Blade Angle degrees	Blade width mm	Number of unit cells	Readout Board thick mm	Radius mm	Unit Cell Separation mm	No. of Samples	LAr Gap Mid mm	LAr Gap Front mm	Absorber thickness mm	Module thickness X0	MIP Sampling fraction
Wheel 0	29.0	928	176	1.3000	420	7.2692	73.4481	1.2346	1.0045	3.5000	22.23	0.0930
					786	13.5993	30.4132	1.5042	1.4209	9.2908	23.39	0.0492
Wheel 1	20.0	1316	224	1.3000	796	7.6340	63.4352	0.9170	0.7533	4.5000	22.29	0.0570
					1489	14.2817	30.5333	1.3019	1.2272	10.3779	24.22	0.0386
Wheel 2	20.0	1316	416	1.3000	1499	7.7418	56.3016	0.6209	0.5078	5.2000	22.47	0.0345
					2750	14.2060	30.0230	1.6821	1.6224	9.5418	22.13	0.0537

- In this case I needed to make the absorbers 1mm thinner in the full simulation to maintain reasonable LAr gap near inner radii

- Result was a detector with fewer radiation lengths:



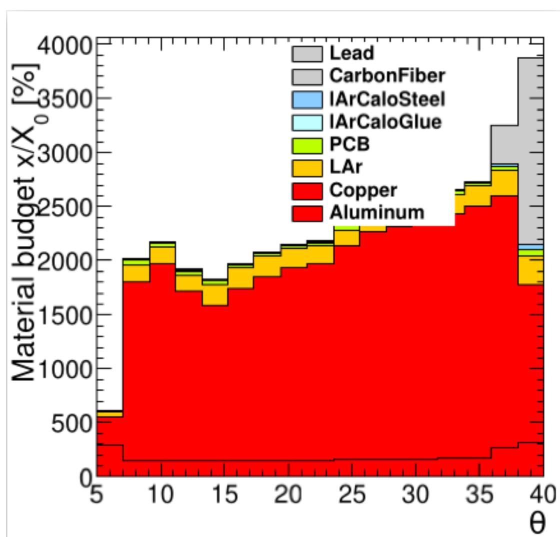
- But still reasonable resolution:

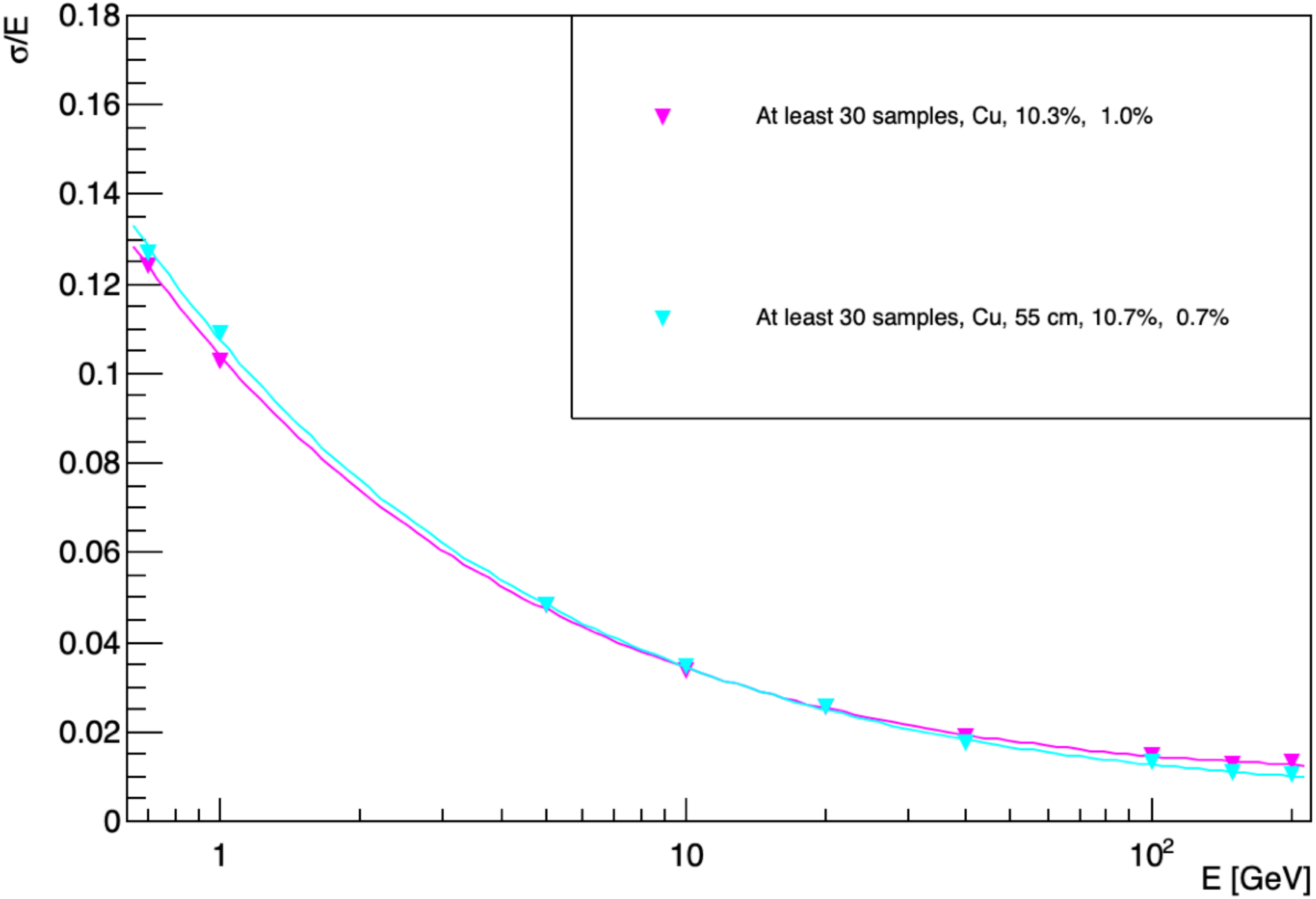


Possible Solution — thicker ECal?

- What if the entire endcap ECal was thicker?
  - try 55 cm depth in z instead of the nominal 45 cm
- Parameterized optimization:

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
Wheel 0	38.0	893	224	1.3000	420	7.2531	70.8531	1.3765	1.1100	3.2000	22.10	0.1104
					786	13.5691	33.1188	1.8873	1.7711	8.4945	26.16	0.0660
Wheel 1	22.0	1468	208	1.3000	796	9.0045	67.9473	1.8523	1.5138	4.0000	22.56	0.1199
					1489	16.8457	31.4403	2.4638	2.3184	10.6181	26.40	0.0692
Wheel 2	21.0	1535	368	1.3000	1499	9.1699	58.3821	1.5850	1.3417	4.7000	22.10	0.0920
					2750	16.8265	30.8716	3.2549	3.1282	9.0168	22.43	0.1039



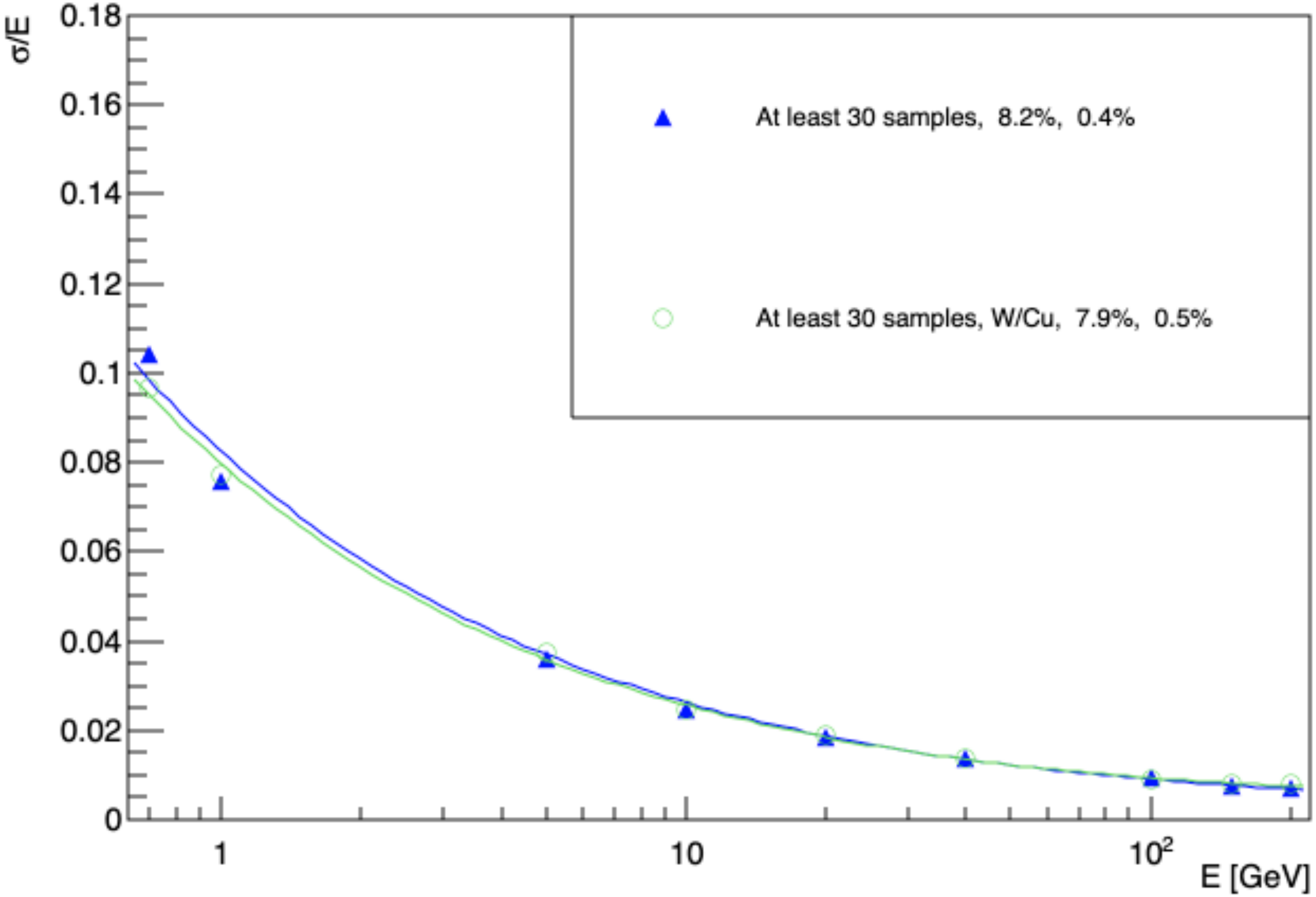


- Resolution at high energy improves somewhat

Another Material: Sintered tungsten

- Tungsten/copper mix (created from powders) has some attractive properties
  - rigid, dense, can create complex shapes
- Assume 90% W, 10% Cu by volume
- Back to 45cm depth in *z*

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
Wheel 0	54.0	680	368	1.3000	420	5.8015	58.0740	1.7507	1.4376	1.0000	26.87	0.2204
					786	10.8534	30.1169	4.0155	3.8555	1.5225	22.16	0.3193
Wheel 1	34.0	984	352	1.3000	796	7.9427	60.2726	2.7714	2.2882	1.1000	22.55	0.2920
					1489	14.8592	31.0832	5.7507	5.5059	2.0579	22.03	0.3373
Wheel 2	27.0	1211	496	1.3000	1499	8.6189	58.1651	3.0594	2.8105	1.2000	22.18	0.3036
					2750	15.8153	31.1885	6.1567	6.0243	2.2020	22.02	0.3401



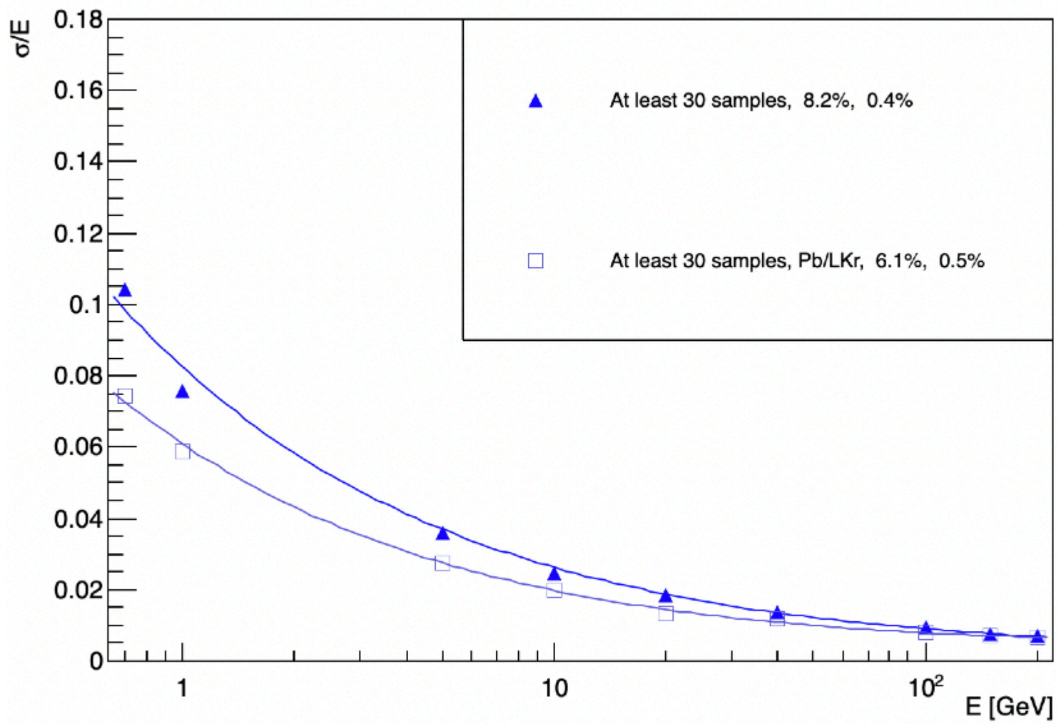
σ/E
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
1
10
10^2
E [GeV]
At least 30 samples, 8.2%, 0.4%
At least 30 samples, W/Cu, 7.9%, 0.5%

What about LKr instead of LAr?

- Optimized parameters for lead absorber:

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
Wheel 0	47.0	615	352	1.3000	420	5.4829	58.6100	1.5415	1.2411	1.1000	22.50	0.3524
					786	10.2575	30.2870	3.4977	3.3451	1.9621	22.24	0.4437
Wheel 1	29.0	928	352	1.3000	796	6.8862	59.9787	2.1431	1.7524	1.3000	22.06	0.3985
					1489	12.8827	30.9429	4.5753	4.3773	2.4320	22.28	0.4628
Wheel 2	20.0	1316	416	1.3000	1499	7.7418	56.3016	2.4709	2.1864	1.5000	22.34	0.4096
					2750	14.2060	30.0230	5.1394	4.9893	2.6272	22.02	0.4756

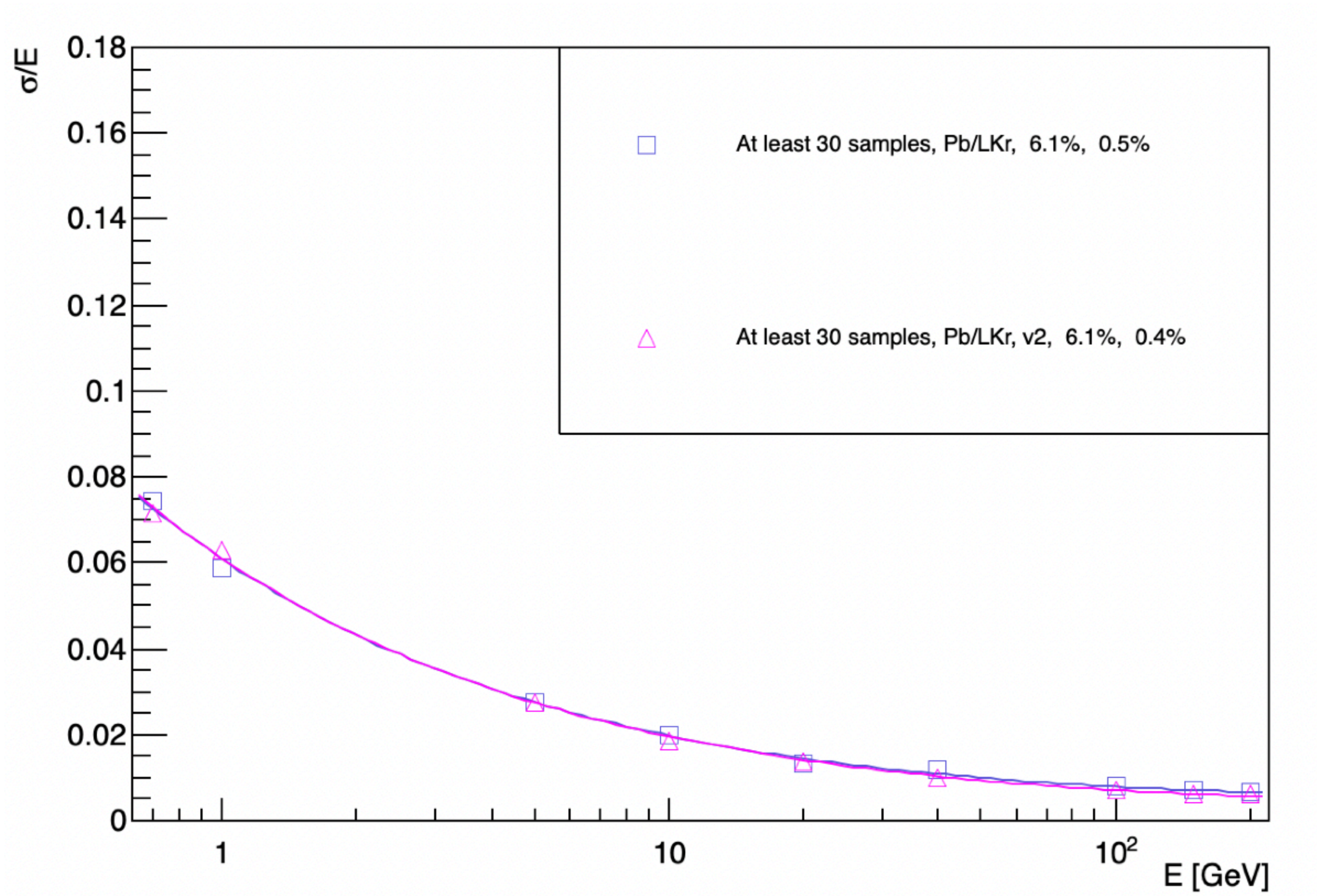
- Result:



Other questions

- How much does optimizing parameters separately for each wheel actually help?
- Test by re-optimizing the best configuration (Pb/LKr) with same parameters for all wheels (call this "v2"):

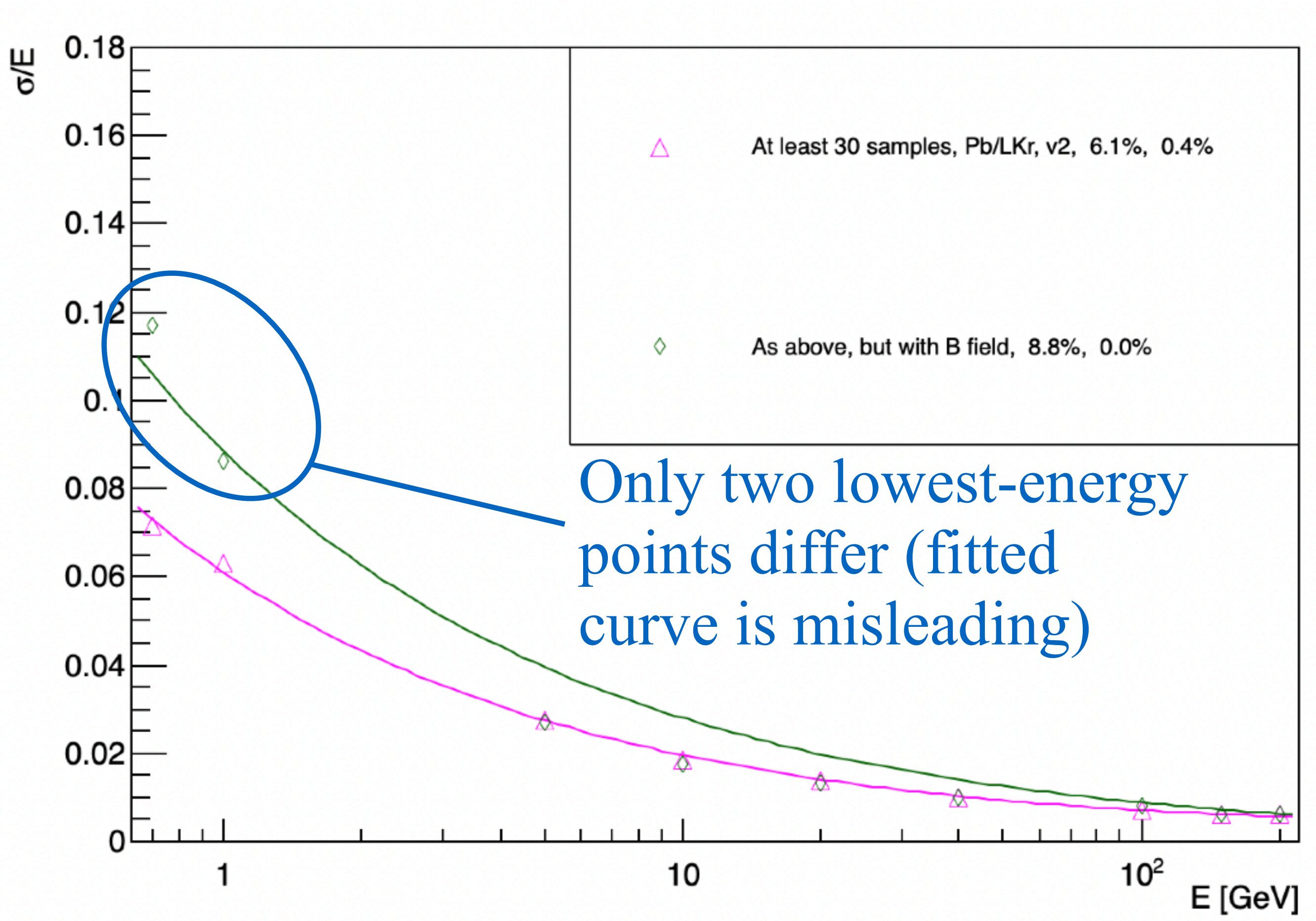
Wheel	Blade Angle degrees	Blade width mm	Number of unit cells	Readout Board thick mm	Radius mm	Unit Cell Separation mm	No. of Samples	LAr Gap Mid mm	LAr Gap Front mm	Absorber thickness mm	Module thickness X0	MIP Sampling fraction
Wheel 0	47.0	615	352	1.3000	420	5.4829	58.6100	1.5415	1.2411	1.1000	22.50	0.3524
					786	10.2575	30.2870	3.4977	3.3451	1.9621	22.24	0.4437
Wheel 1	47.0	615	672	1.3000	796	5.4414	57.0761	1.5207	1.4419	1.1000	22.10	0.3608
					1489	10.1797	30.2489	3.4588	3.4172	1.9621	22.21	0.4436
Wheel 2	47.0	615	1280	1.3000	1499	5.3802	57.2299	1.4901	1.4685	1.1000	22.12	0.3590
					2750	9.8726	31.1163	3.3230	3.3112	1.9266	22.31	0.4384



- Doesn’t matter!

What about solenoid field?

- Keep the same geometry ("v2" from the previous slide) but turn the solenoid on
  - use same calibration constants



- Suggestion from John: maybe the low-energy electrons are crossing only a few absorbers due to curvature in the field
- Check by running with positrons instead:

	Width of Gaussian [Gev]		
True energy [Gev]	No B field, e^-	With B field, e^-	With B field, e^+
0.7	0.050	0.082	0.070
1.0	0.063	0.086	0.075

Summary

- New calibration scheme (with layers in rho and z) implemented, and improves performance somewhat
- Increasing the sampling frequency has a larger effect
- Alternate absorber and sampling materials explored
  - no absorber material that performs better than lead found
    - but sintered tungsten is equivalent and copper not too far behind
    - choice will likely come down to cost and ability to form the tapered blades
  - LKr shows better performance than LAr
    - worth the added cost?
- Optimizing blade angles etc per wheel has little effect
  - likely means that performance only weakly depends on these parameters
  - choice can be made for practical considerations
    - e.g. relatively few large blades vs more but smaller blades…

Next Steps

- Implement topological clustering
  - will be important for anything beyond single-particle studies, since right now the "window" in ϕ is large to collect all energy from clusters near the inner radius
- Study parameters beyond energy resolution (e.g. spatial resolution for distinguishing γs from π^0 decay)
- Prepare pull request to integrate the new version into the main branch
  - probably makes sense to do this once topo-clustering is working(?)