Shower-max Progress and Radiation Hardness QC Plans

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For Daniel Sluder and ISU Parity Group

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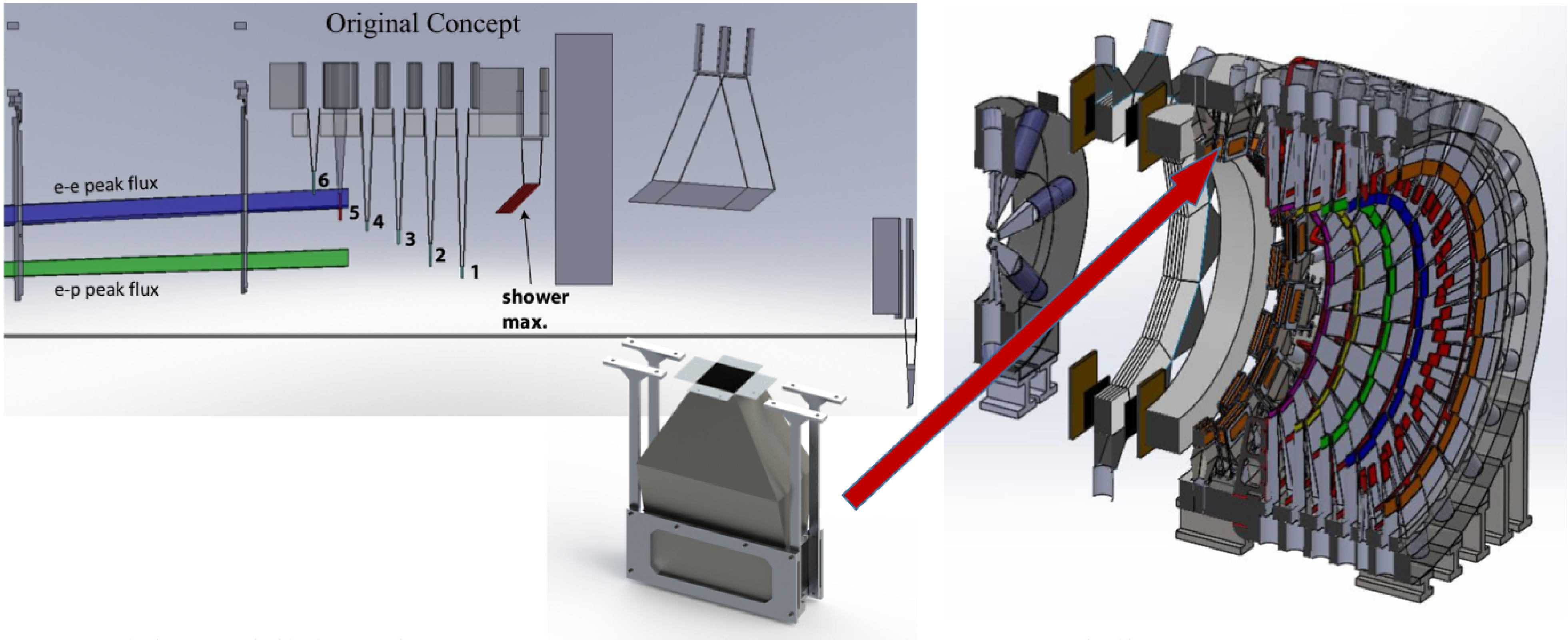
ShowerMax Progress and Plans

Outline

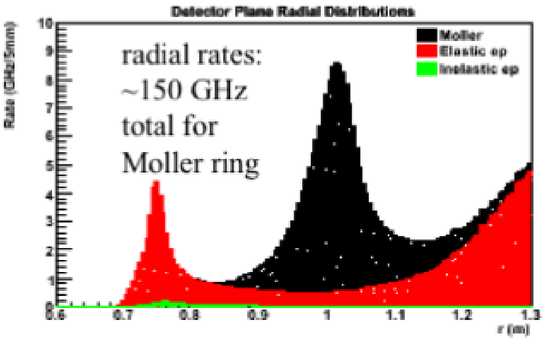
- Review baseline design and ring concept
- Understanding detector resolution
  - Exploring alternative phi segmentations
- Prototyping for test-beam
  - Optical MC benchmarking prototype
  - Updated Full-scale prototype and new MC results
  - Test-beam benchmarking strategy
- Summary
- Plans for Rad. Hardness QC Studies

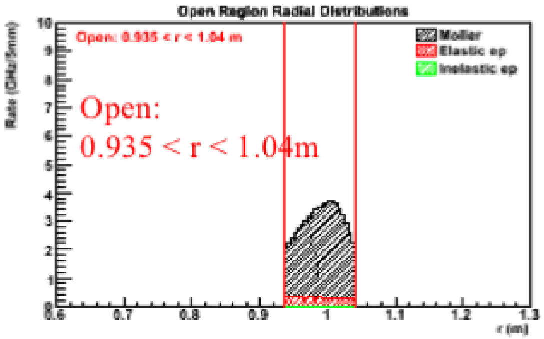
Motivation & Requirements

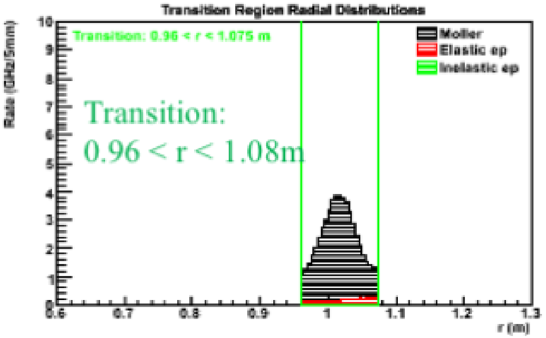


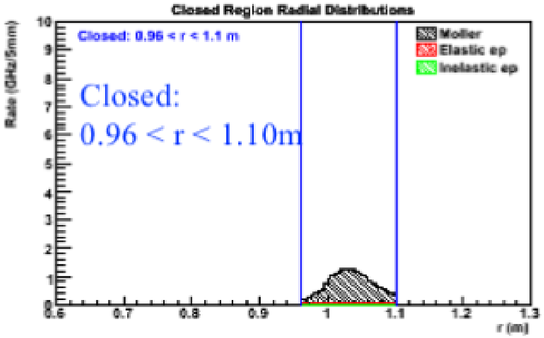
- Provides additional measurement of e-e ring integrated flux
- Weights flux by energy $\Longrightarrow$ less sensitive to low energy and hadronic backgrounds
- Will also operate in tracking mode to give additional handle on background (pion) identification – gives MIP-like signal
- Should have good resolution over full energy range ($\frac{\sigma}{\langle n\rangle} \lesssim 25\%$), long term stability and be radiation hard

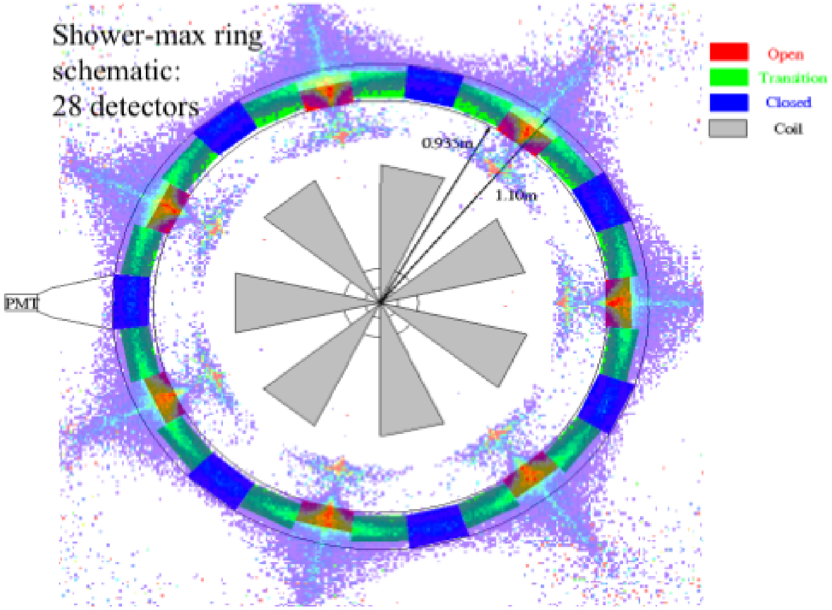
Shower-max phi-segmentation, rates and energies



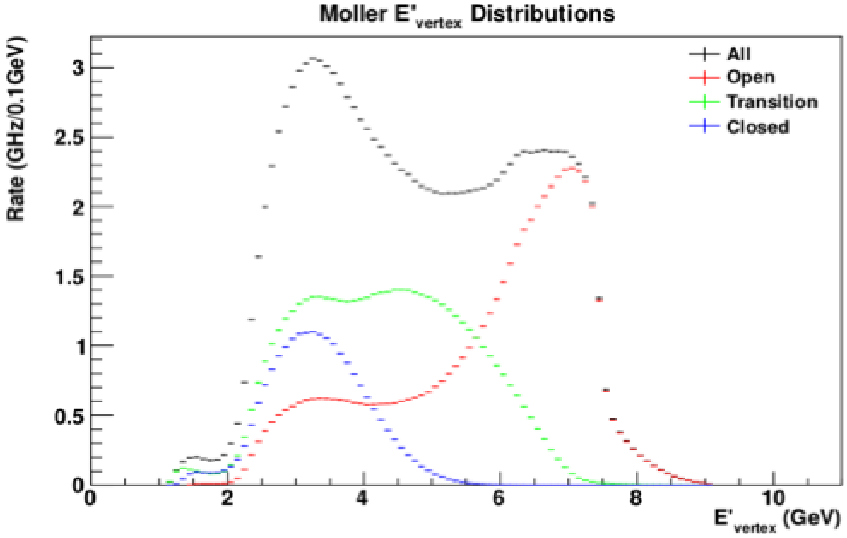








- Large range of rates and energies for different phi-region detectors:
  - ○ Open ~9 GHz/det; 2 - 9 GeV, peak at 7 GeV…
  - ○ Closed ~3.5 GHz/det; 2 - 5 GeV, peak at ~3 GeV
  - ○ Transition ~4.5 GHz/det; 2 - 7 GeV, 3 – 5 GeV plateau

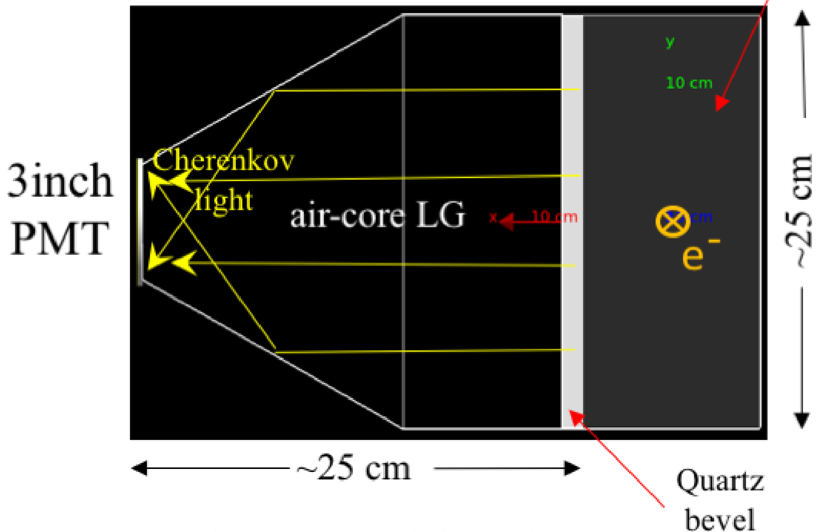


Baseline Design Stack and Light Guide Concepts

- Detector concept uses a layered "stack" of tungsten and fused silica (quartz) to induce EM showering and produce Cherenkov light
- "Baseline" design developed using GEANT4 optical MC simulation:
  - Current design uses a **4-layer stack** with **8mm tungsten** and **12.5mm quartz** pieces
  - Cherenkov light directed to **3inch PMT** using **air-core, aluminum light guide**

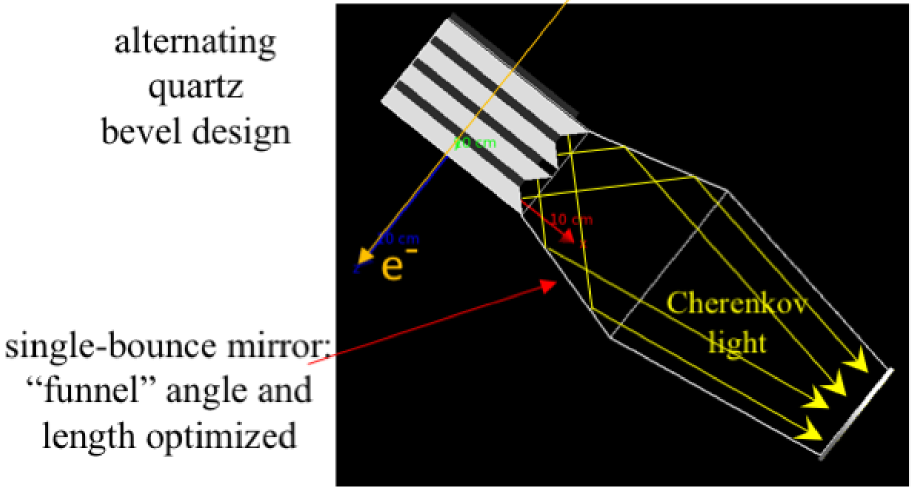
"Baseline" LG Design
(front face view)

tungsten: 1st upstream piece (dark grey)



4-layer Stack: 8mm thick tungsten (dark grey), interleaved with 12.5mm thick quartz (white)

alternating quartz bevel design



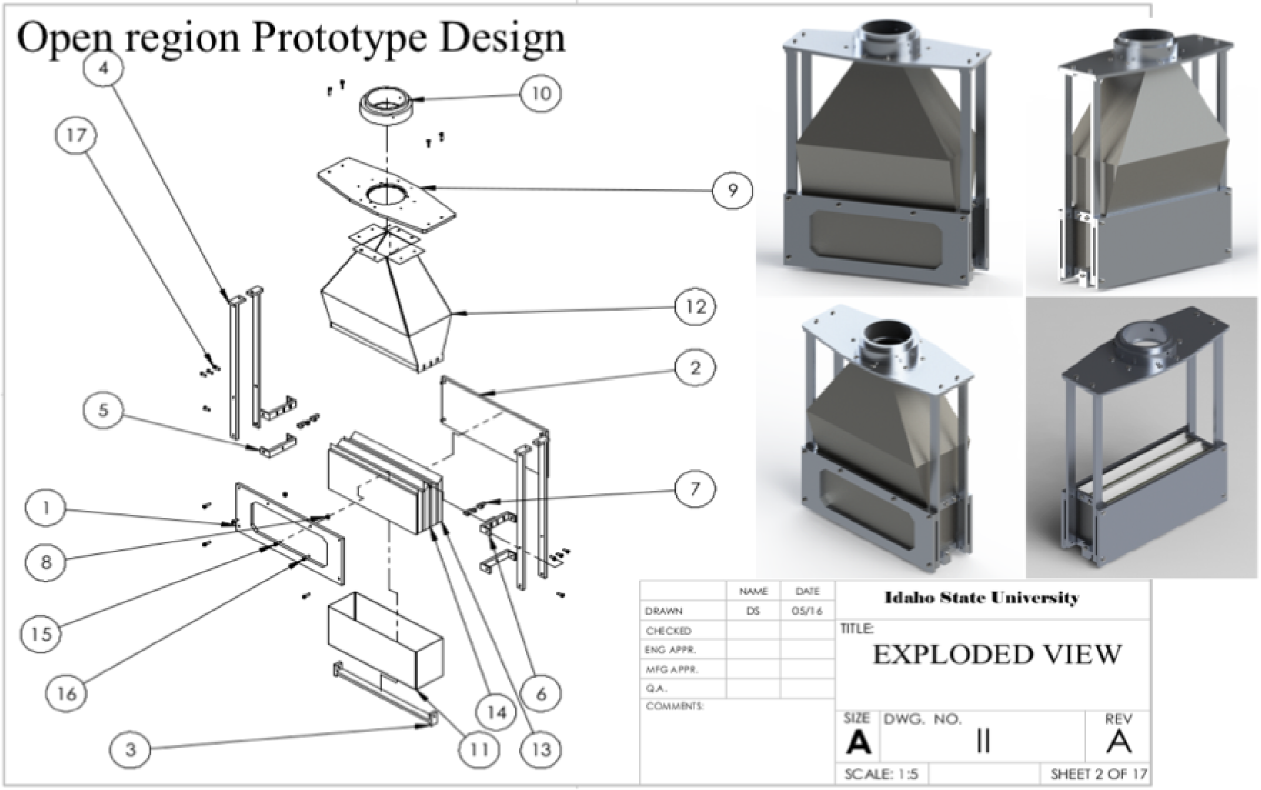
single-bounce mirror: "funnel" angle and length optimized

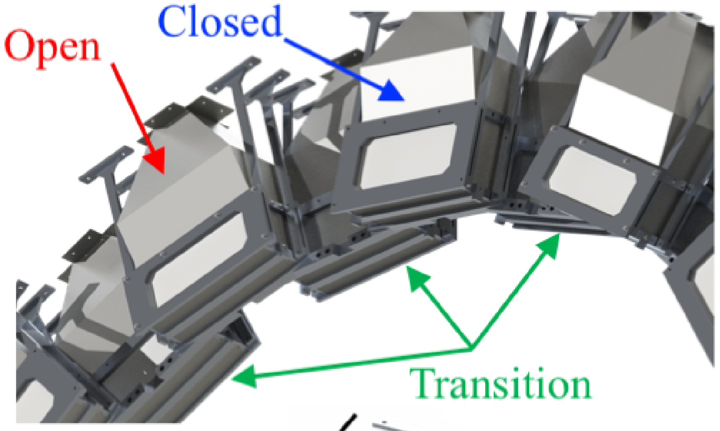
"Baseline" Design
(side view)

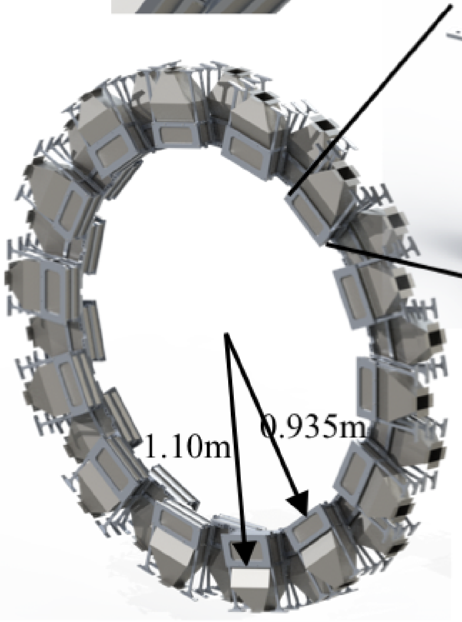
Materials (all rad-hard):

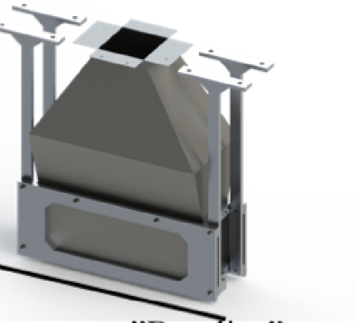
- Tungsten is high purity (99.95%) and quartz is optically polished Spectrosil 2000
- Light guides are aluminum specular reflectors (Miro-silver 27, Anolux, or al. mylar, …)
- Total radiation length: 9.1 X_0 tungsten + 0.4 X_0 quartz = 9.5 X_0

Prototype Baseline Design and ring concept









<u>Costs: Total w/ spares</u>
quartz: $150k (Heraeus)
tungsten: $60k
<u>alum.: $10k (machined)</u>
grand total: $220k

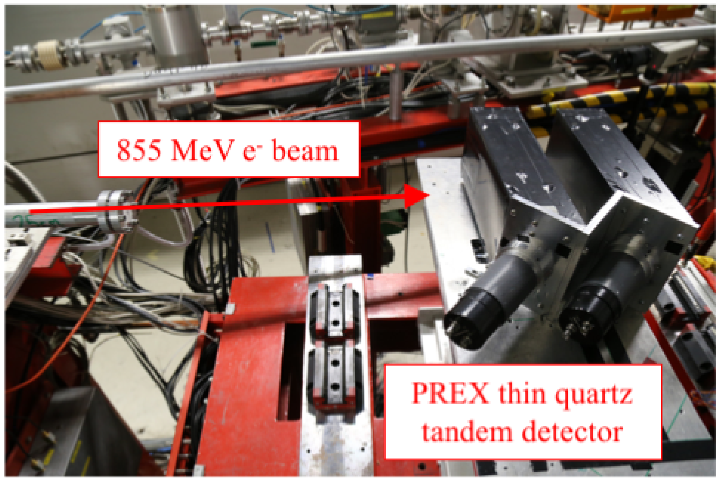
<u>Weights of each assembly:</u>
Open: 39.7 lbs.
Transition: 42.5 lbs.
Closed: 50.8 lbs.
ring weight: 1230 lbs.

- Engineered shop drawings and Prototype CADs in hand
- ***<u>PLANS</u>***: Finalize prototype Stack designs this summer, order quartz by fall, construct in winter 2018 and test in spring using 5 - 8 GeV electron testbeam at SLAC
- Shower-max ring design concept: staggered in $\hat{z}$ with reinforced struts and brackets. 28 detectors in ring: 7 Open, 7 Closed, and 14 Transition

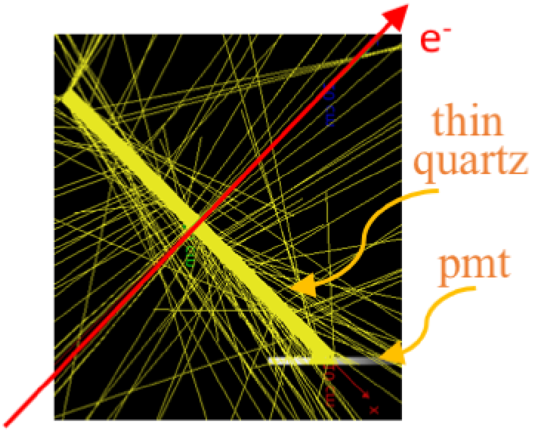
Understanding Showermax Resolution

Monte Carlo tuning and Shower-max Simulations

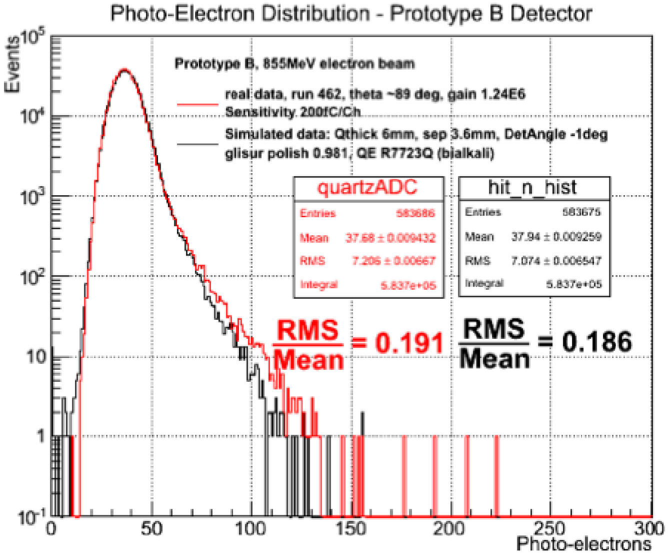
- Quartz optical G4 properties benchmarked at MAMI: Glisur ground polish parameter ~0.981



MAMI testbeam with PREX detector



G4 event visualization for PREX detector

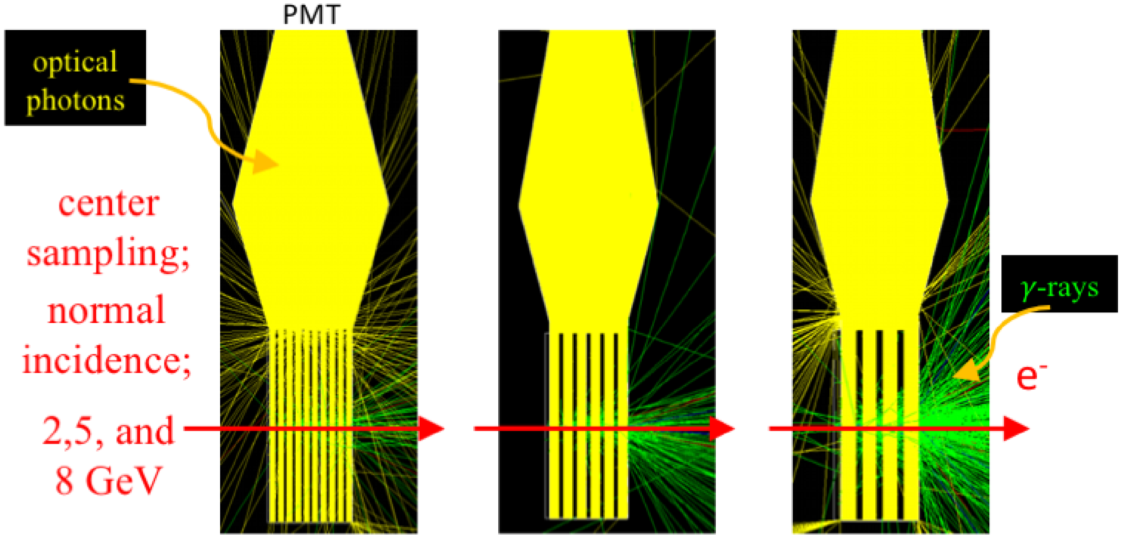


PE dists: *Real data* vs. *Sim data*

- Stack configuration MC study:
  - Stack thicknesses all same (7.2 X_0)
  - 2, 5, and 8 GeV incident electrons
  - PE dists generated using tuned polish parameter and 60% LG reflectivity

Conclusion:

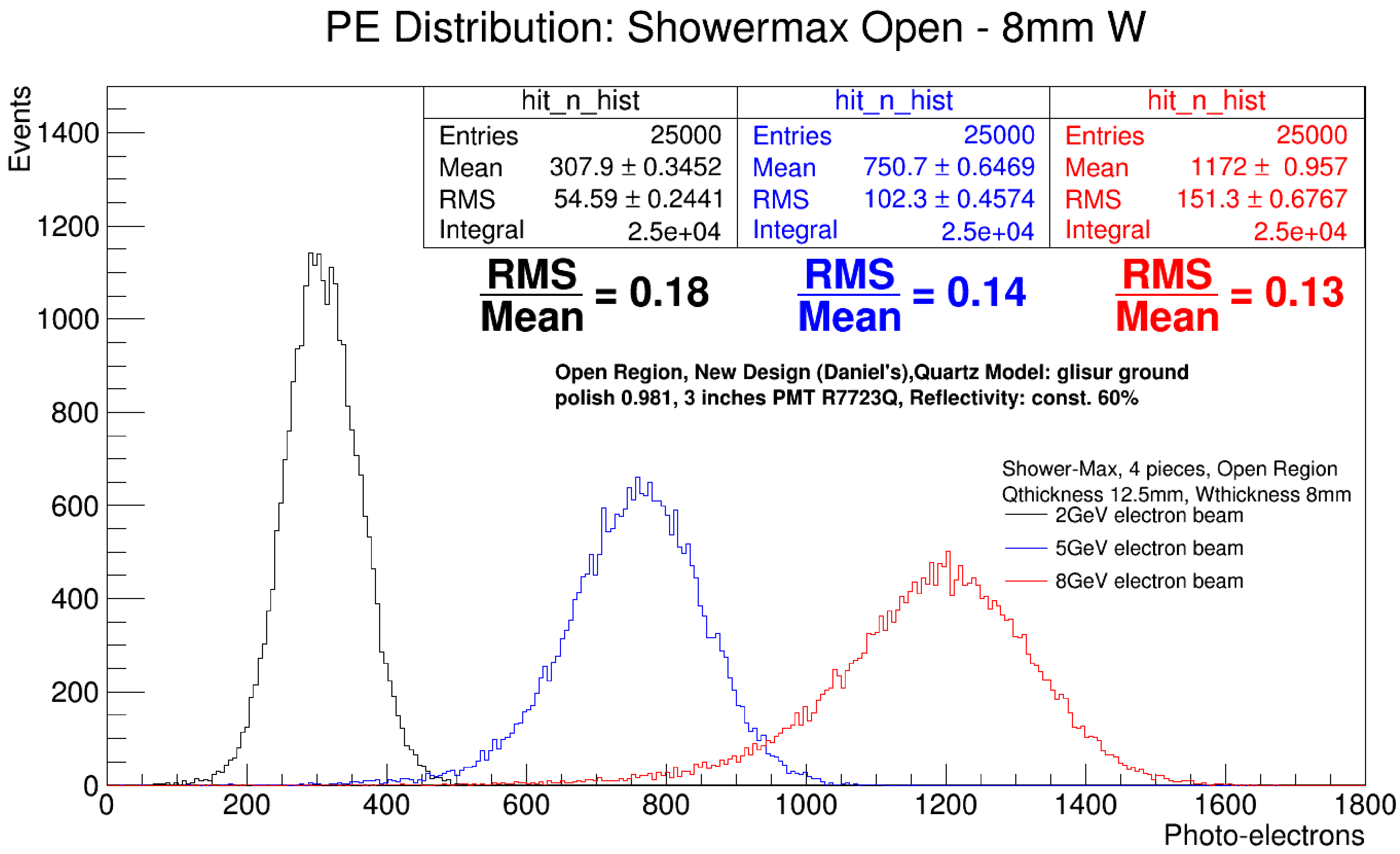
4-layer gives comparable performance to 10-layer (and is easier and cheaper to build)



10-layer 6-layer 4-layer

Shower-max event visualizations

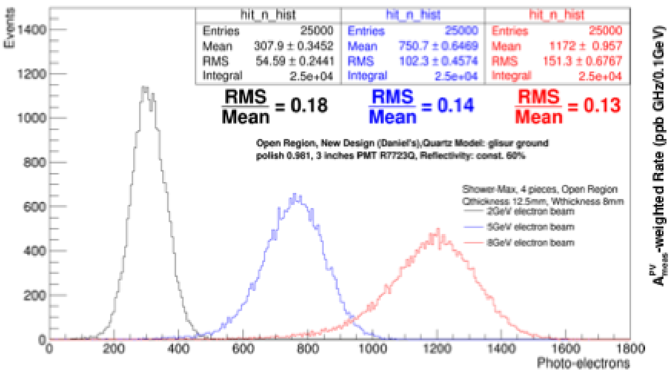
4-layer baseline PE Dists for 2, 5, and 8 GeV

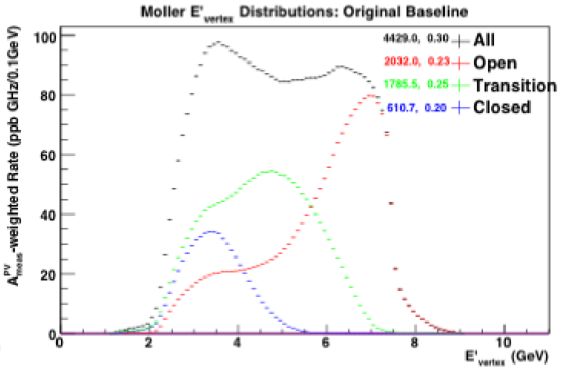


What is Resolution of Showermax (Open Septant)

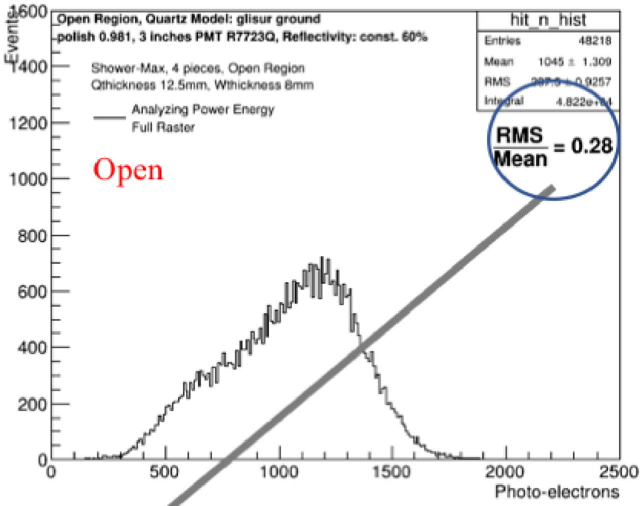
How well does the Showermax count electrons?

PE Distribution: Showermax Open - 8mm W

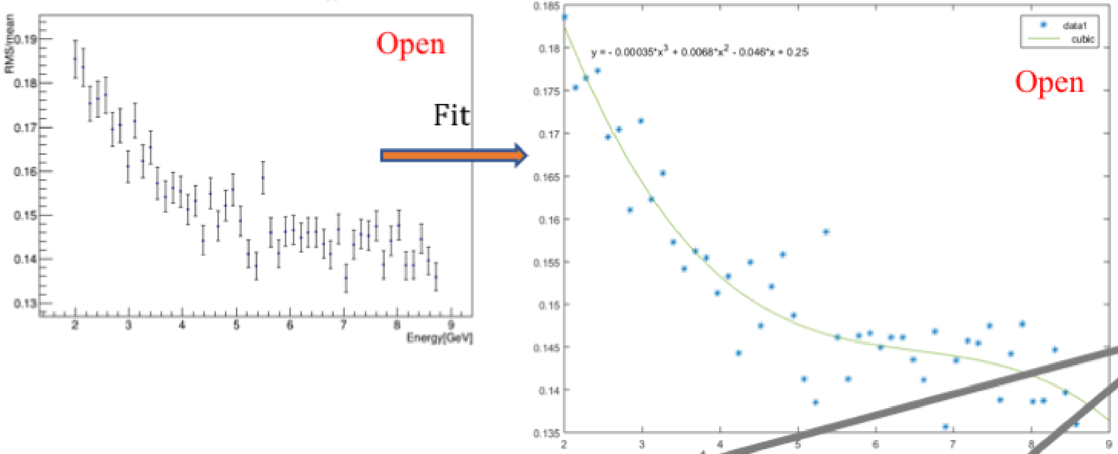




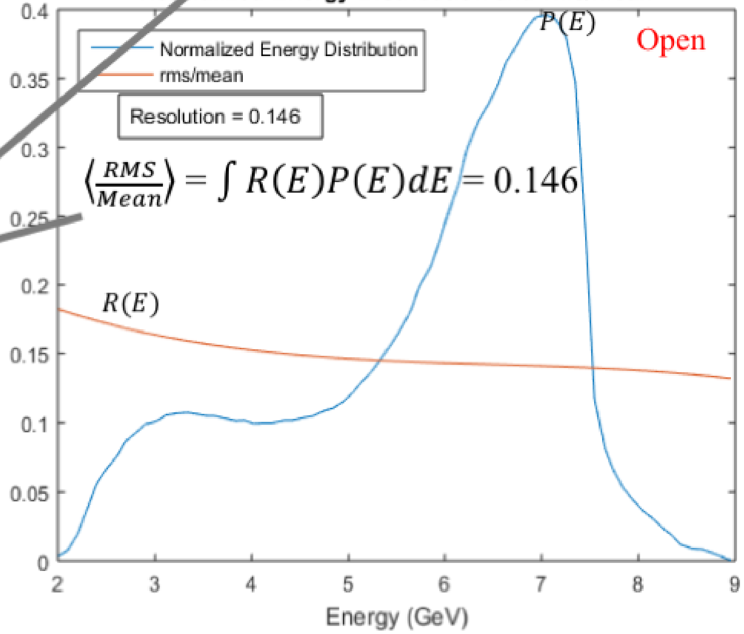
Open ShowerMax Photo-Electron Distribution



Resolution vs. Energy



Normalized Energy Distribution and rms/mean



$$\left\langle \frac{RMS}{Mean} \right\rangle = \int R(E)P(E)dE = 0.146$$

Individually, it counts electrons with 14.6% resolution on average. Using this leads to:

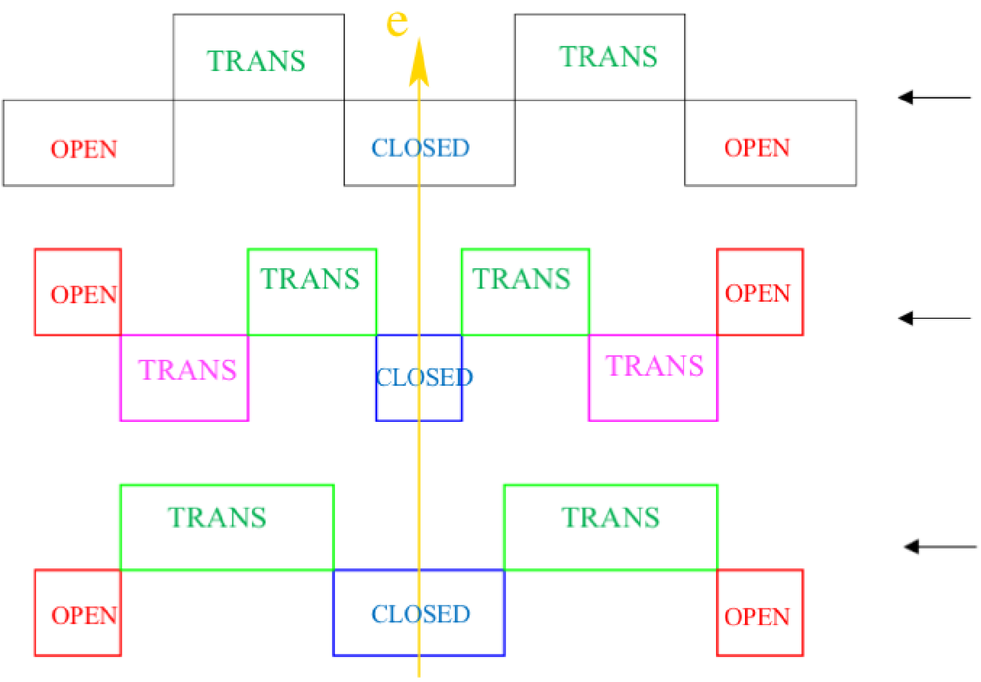
- Excess Noise = $\sqrt{1 + \left\langle \frac{RMS}{Mean} \right\rangle^2} - 1 = 1.1\%$

However collectively, it counts the group with ~30% resolution overall, which leads to:

- Excess Noise = $\sqrt{1 + \left(\frac{RMS}{Mean} \right)^2} - 1 = 4.4\%$

Attempts to improve Showermax resolution

Exploring Different phi Segmentation for Shower-max



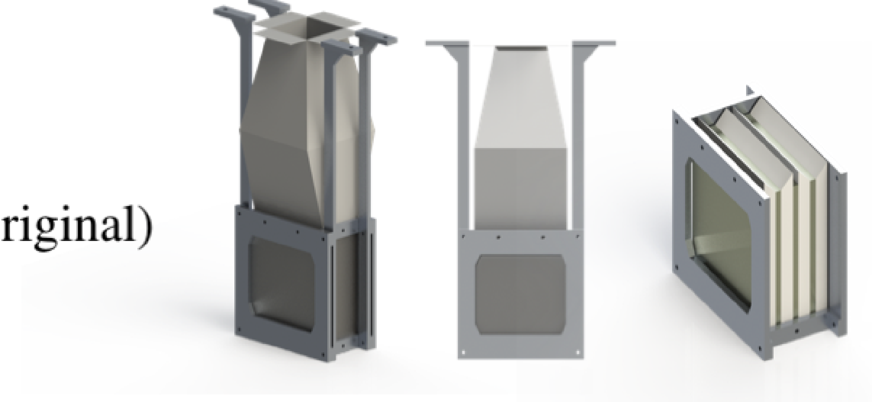
← Baseline (original)

← HalfOpen/HalfClosed

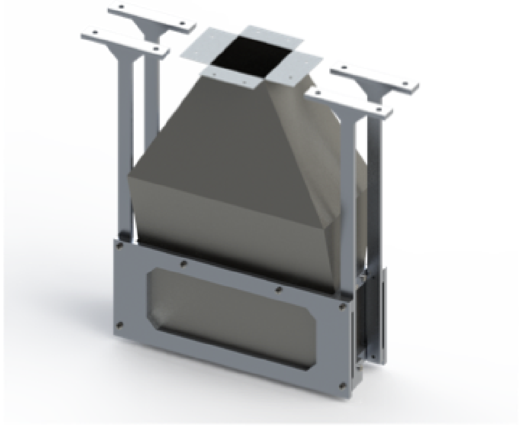
← HalfOpen/FullClosed

Radial view of various phi segmentation ideas

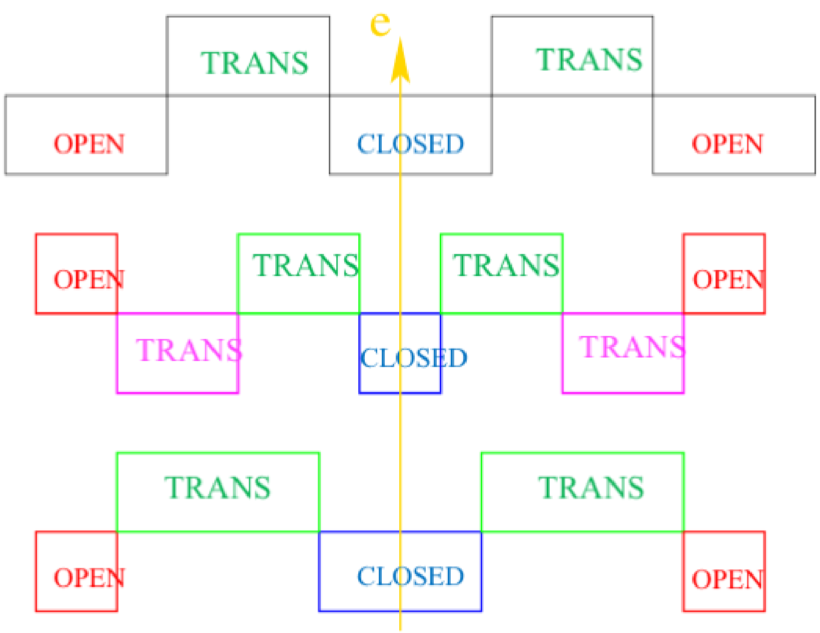
Half-width, “full-stack” Shower-max



Full-width, “full-stack” Shower-max



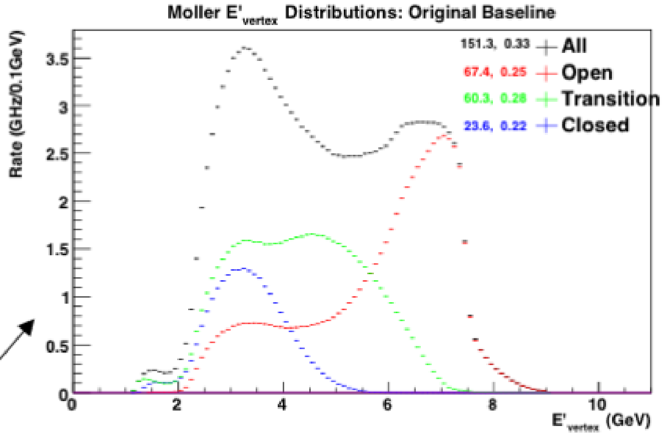
Energy Acceptance for Different phi Segmentation

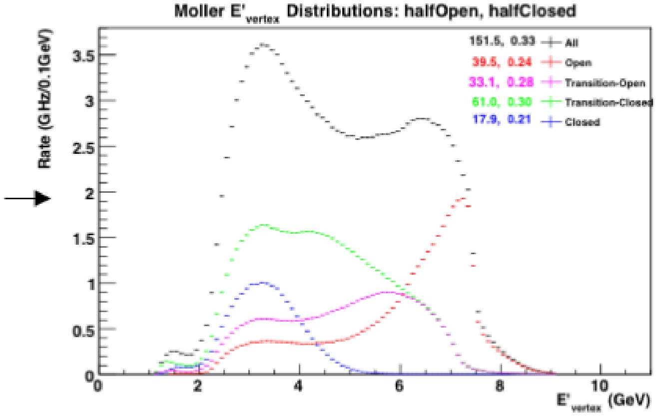


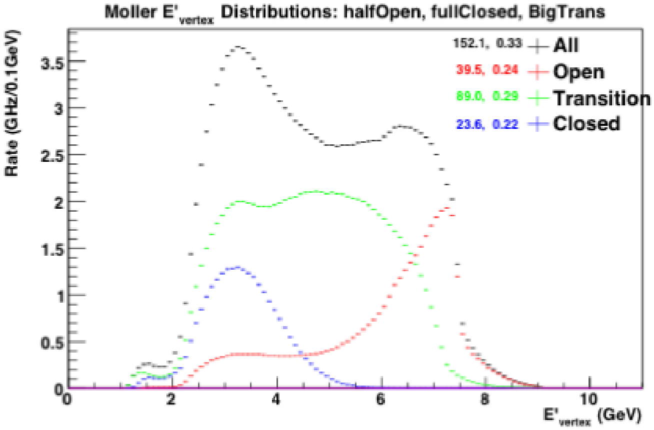
← Baseline (original)

← HalfOpen/HalfClosed →

←HalfOpen/FullClosed





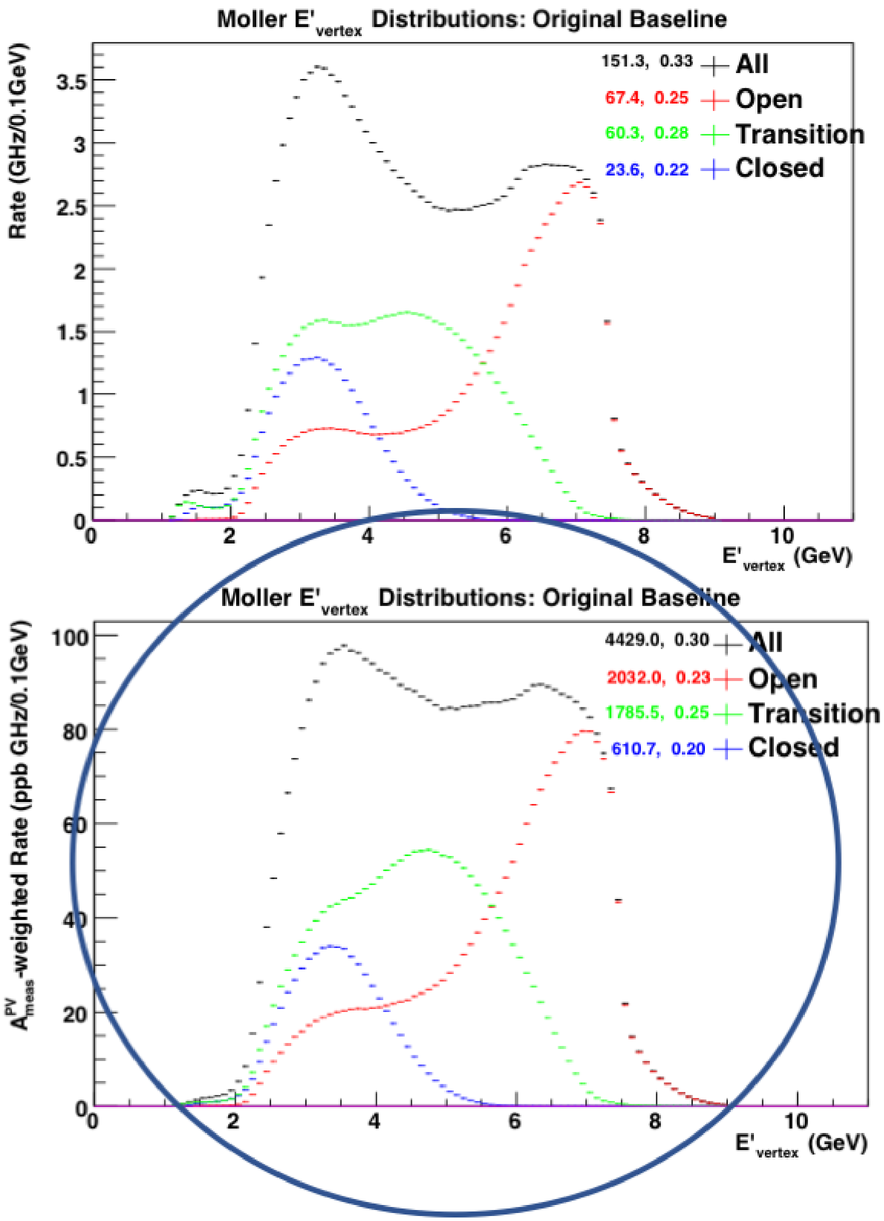


Radial view of various phi segmentation ideas

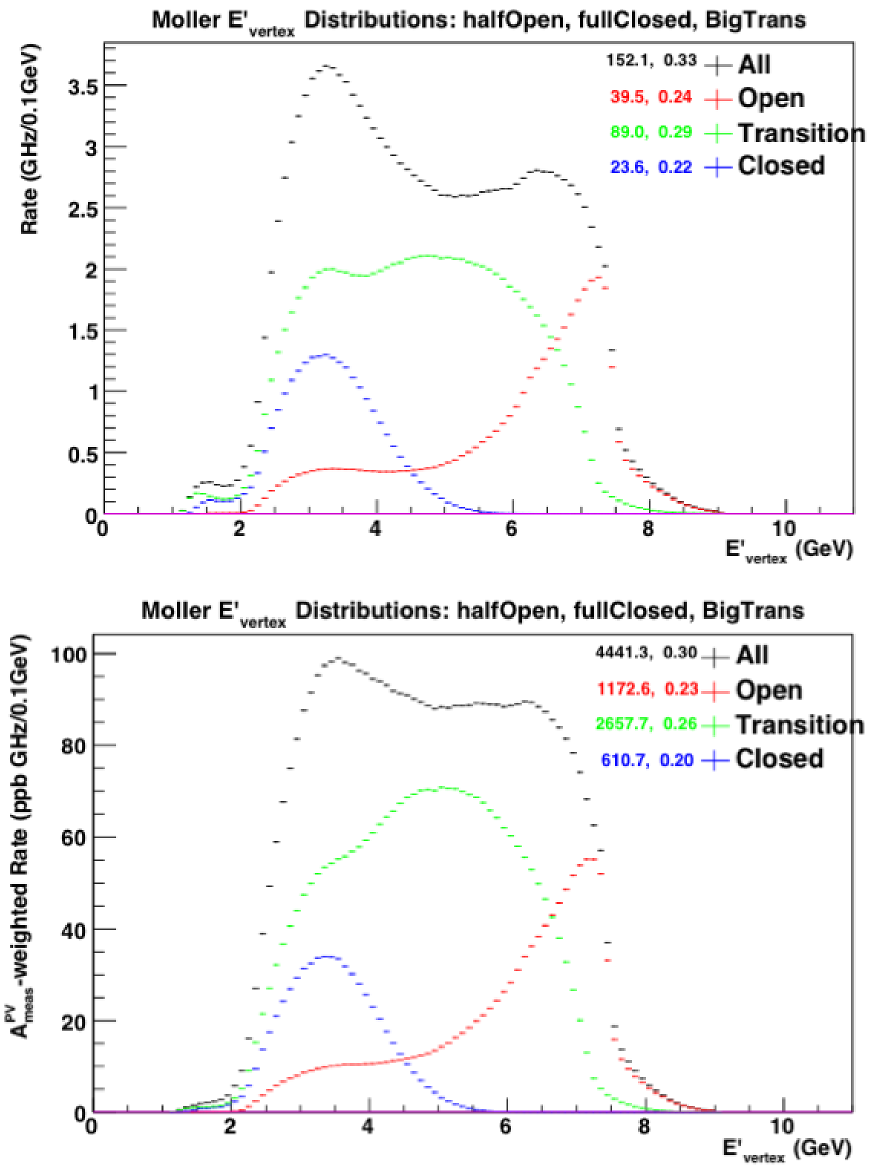
- These ideas give no improvement due to the spectrometer's significant phi defocusing…The original segmentation is best

Rate and A^{PV}_{meas}*Rate – weighted Energy Acceptance

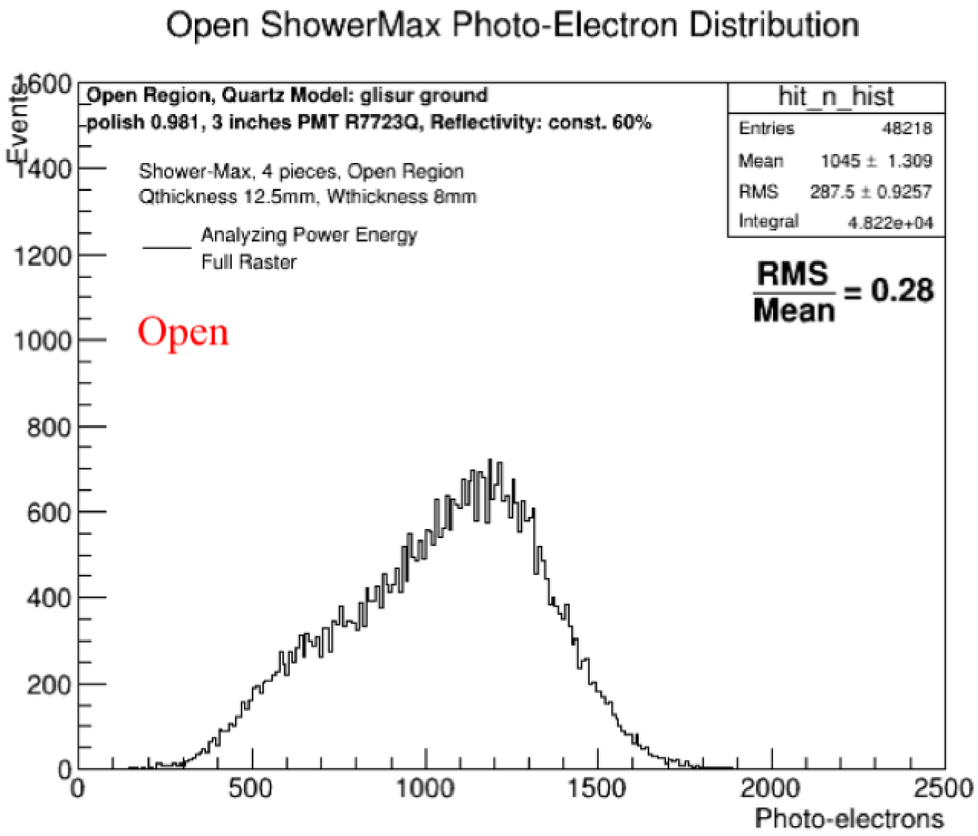
Original Baseline

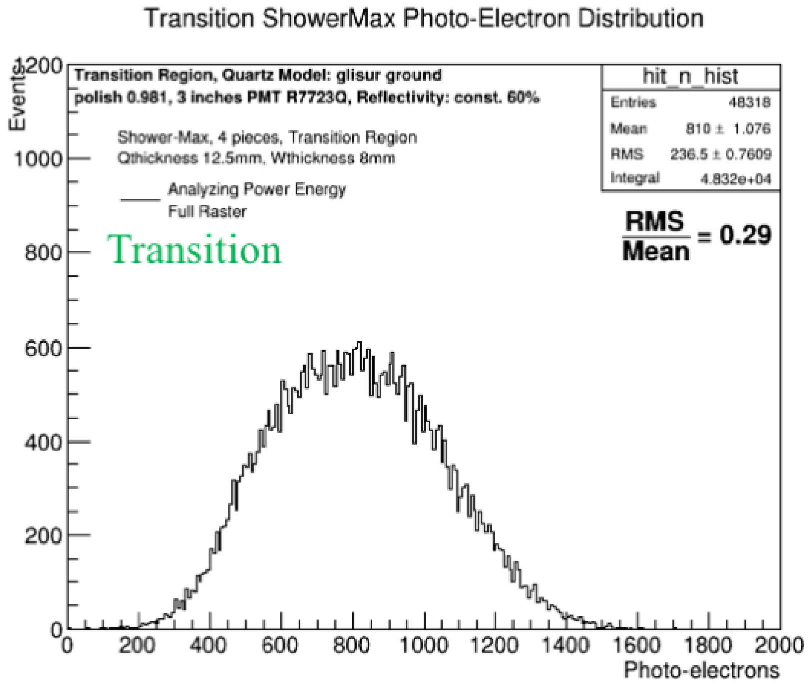


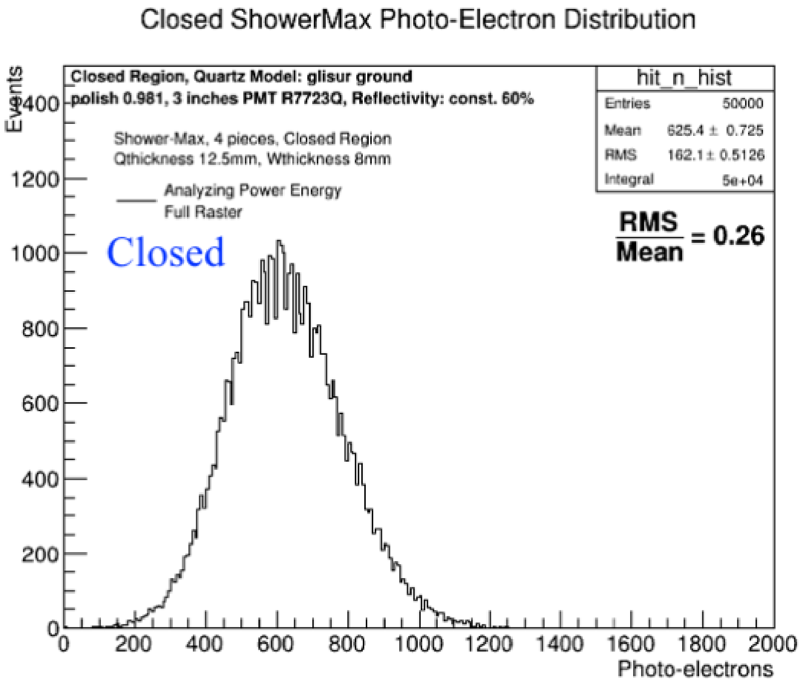
half Open/ Full Closed



Baseline PE distributions weighted by A^{meas}_{PV}



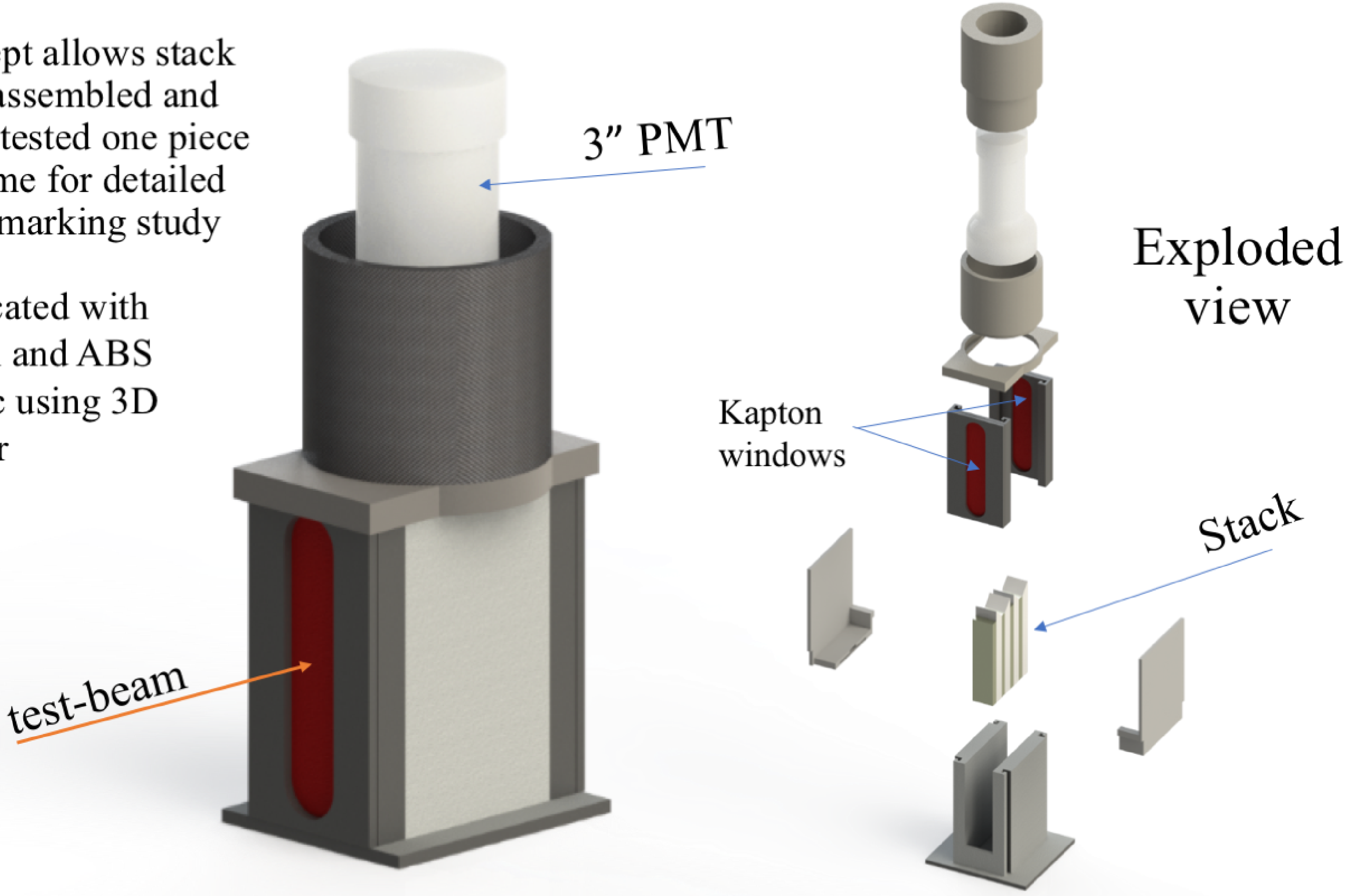




Prototyping for Test-beam

Shower-max Benchmarking Prototype concept

- Concept allows stack to be assembled and beam-tested one piece at a time for detailed benchmarking study
- Fabricated with Nylon and ABS plastic using 3D printer



Config #1 (original baseline) benchmarking Prototype

Lateral size of EM Shower: Moliere Radius

- Lateral or transverse EM shower development and size dominated by multiple scattering
- One Moliere radius contains 90% of shower and characterizes width of shower; two Moliere radii contain ~95%
- For single material calorimeter:

Moliere Radius: $R_M = \frac{E_s}{E_c} X_0 \simeq 7\frac{A}{Z} \ (\frac{g}{cm2})$

--where $E_s = \sqrt{\frac{4\pi}{\alpha}}\, mc^2 = 21.2$ MeV (Multiple Scattering Energy for electrons)

➢ $E_c \sim 610/(Z+1.2)$ MeV (Critical Energy)

- For a mixed, homogenous material calorimeter:

Moliere Radius^{-1}: $\frac{1}{R_M} = \sum_i \frac{w_i}{R_{Mi}} = \frac{1}{E_s}\sum_i \frac{E_{ci}}{X_{0i}}$

−where w_i is the weight fraction of the ith material in the stack

Material	$\rho \cdot R_M$ (g/cm^2)	R_M (cm)	X_0 (g/cm)	X_0/ρ (cm)	Z	$E_c(e)$ (MeV)
tungsten	18.00	0.933	6.76	0.35	74	8.0
Copper	14.05	1.57	12.9	1.44	29	20
SiO_2	11.3	5.15	27.05	12.3	~11	57

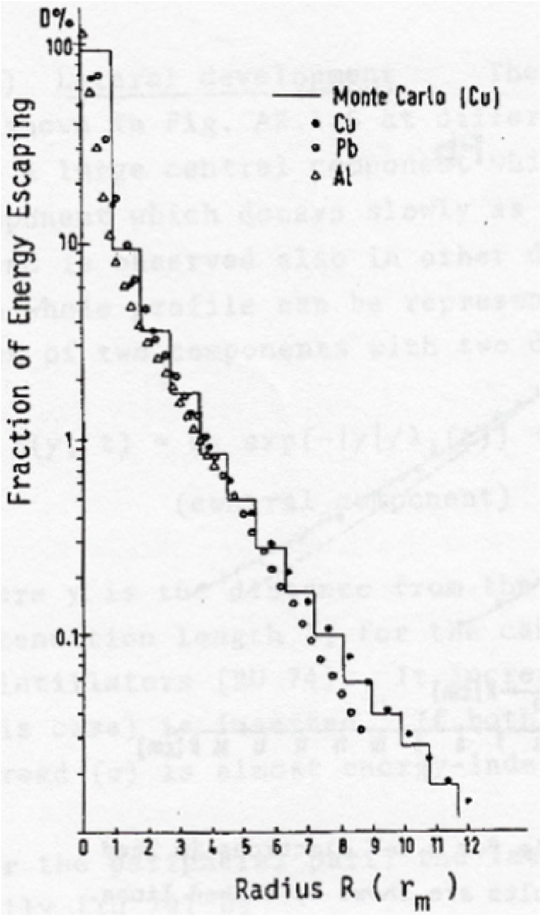
- For the baseline design:

$$\left.\begin{array}{l} w_{tungsten} \simeq 0.812 \\ w_{quartz} \simeq 0.188 \end{array}\right\} R_M \simeq 1.10cm$$

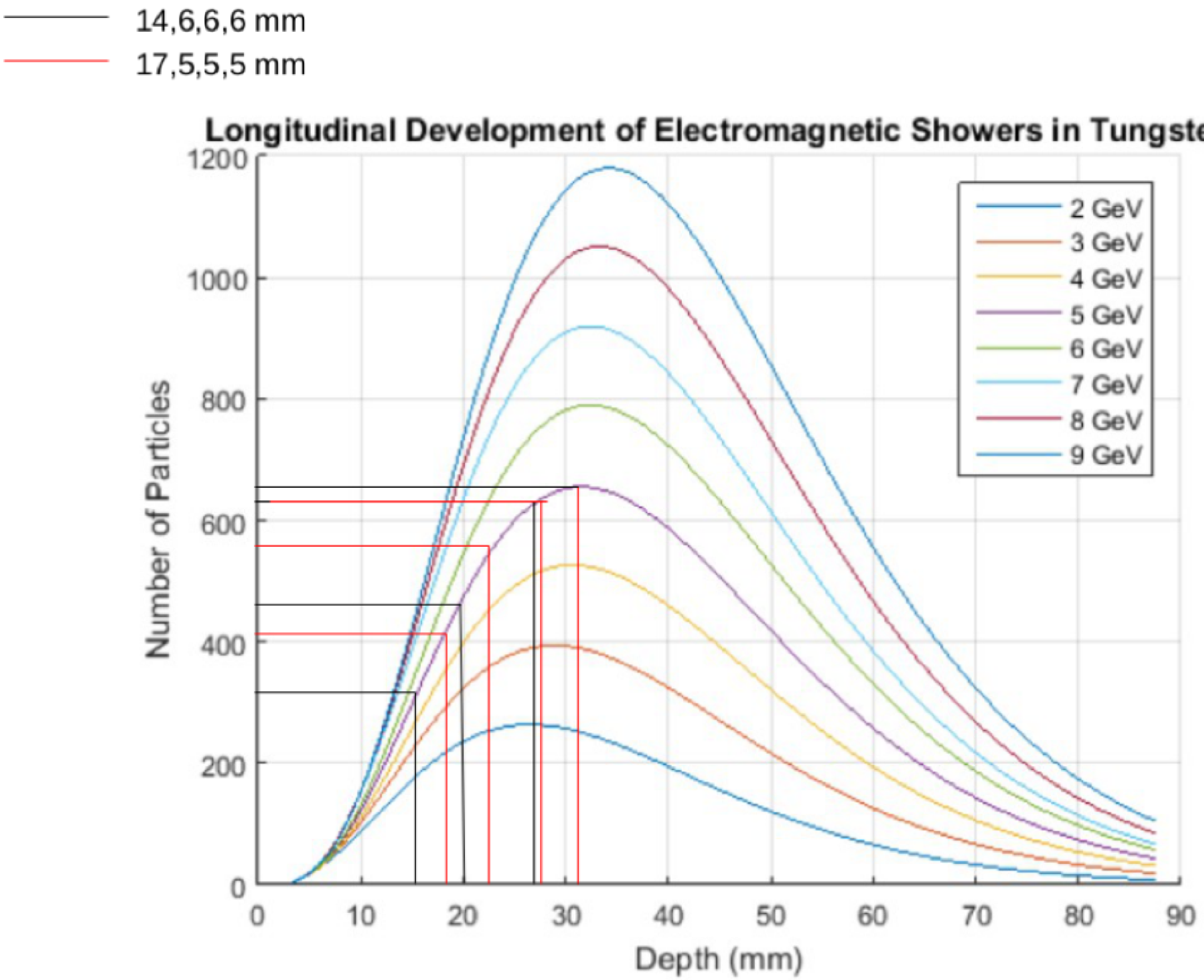
- If use 10/90 Cu/W:

$$\left.\begin{array}{l} w_{tungsten} \simeq 0.724 \\ w_{quartz} \simeq 0.196 \\ w_{copper} \simeq 0.080 \end{array}\right\} R_M \simeq 1.16cm$$

- Also note for tungsten, at shower max: $\langle\theta_{SM}\rangle \simeq m_e/E_c \simeq 3.6^o$



Longitudinal Development of EM Shower



- Red and black lines indicate points of quartz sampling for Config #2 and #3 (see next slide)

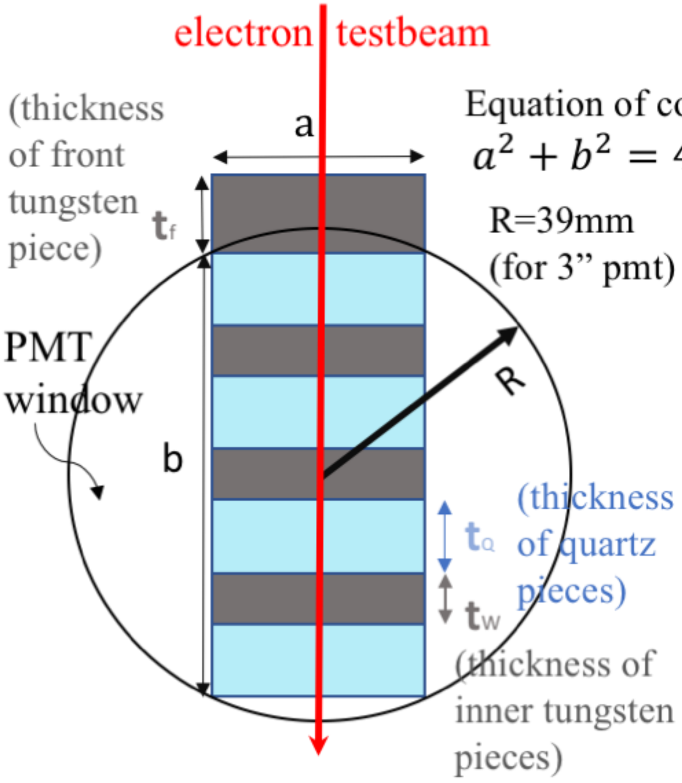
- The shower maximum depth scales logarithmically with particle energy, while the peak # of particles scales linearly

- For pure tungsten, shower max occurs at ~24mm for 2 GeV and ~33mm for 8 GeV

  --Baseline design uses 32mm of tungsten (and 50 mm of quartz)

ShowerMax "Benchmarking" Stack Configs

- As part of the shower-max prototype test plans, we are constructing and testing a "benchmarking" prototype with same stack configuration as "full-scale" but with no light guide
    - This provides a first step toward benchmarking our G4 ShowerMax MC results.
- The "benchmarking" prototype Stack would be inscribed inside a 3 inch PMT window:



Equation of constraint:

$$a^2 + b^2 = 4R^2$$

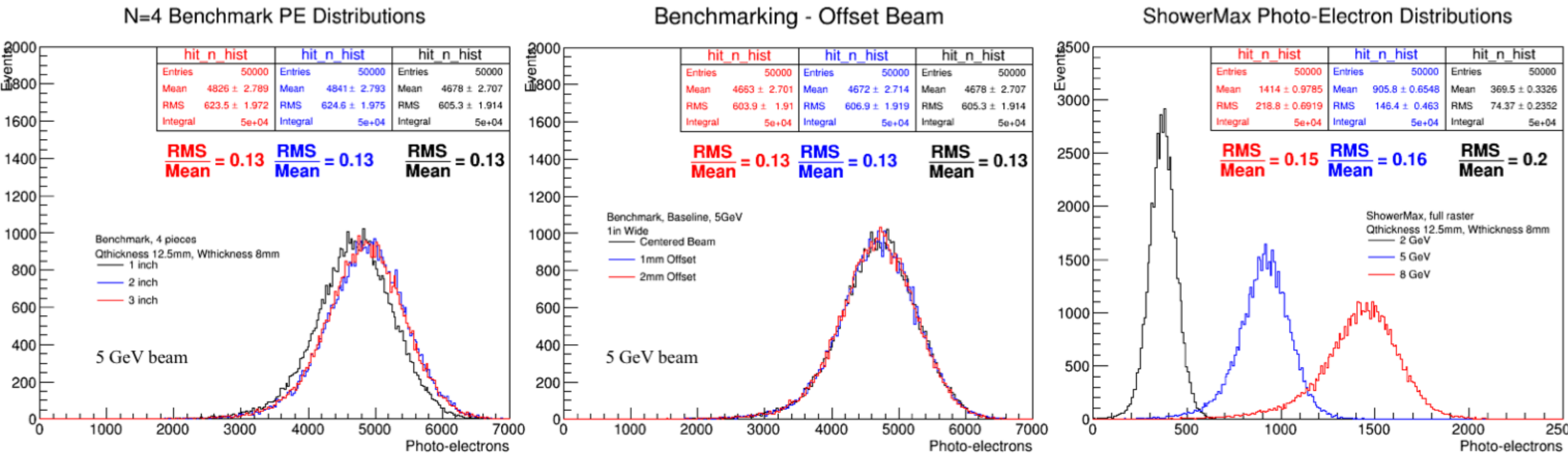
R=39mm (for 3" pmt)

- This table gives 4 candidate stack configurations under study

Config #1 is the baseline. Column "a" represents the allowed widths of the stacks given their thicknesses (Col "b"). Leakage represents the amount of transverse shower (light) leakage due to the ~narrow benchmarking stacks.

Config #	t_f (mm)	t_Q (mm)	t_W (mm)	b (mm)	a (mm)	X_0	R_{mol} (mm)	Leakage (%) 2, 5, 8 GeV from G4 MC	1mm offset Leakage (%)	2mm offset Leakage (%)
1	8	12.5	8	74	24.7	9.5	11.0	3.0, 3.5	3.1, 3.6	3.3, 3.8
2	17	12.5	5	65	43.2	9.5	11.0	~0, ~0	~0, ~0	~0, ~0
3	14	12.5	6	68	38.2	9.5	11.0	0.5, 0.3	0.6, 0.4	0.8, 0.5
4	6	12.5	6	68	38.2	7.3	11.5	~0, ~0	0.2, ~0	0.2, ~0

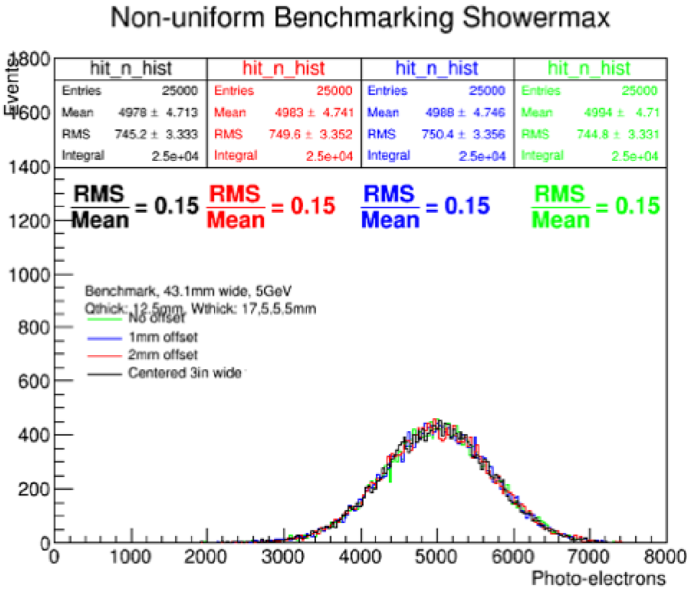
Candidate Design for Stack Prototype: Config #1



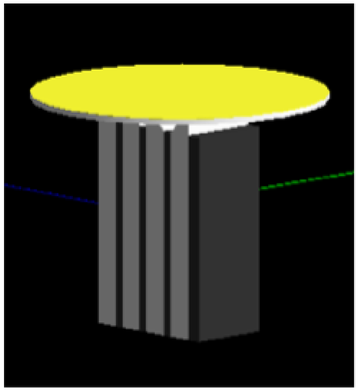
Config #	t_f (mm)	t_Q (mm)	t_W (mm)	b (mm)	a (mm)	X_0	R_{molier} (mm)	Leakage (%) 2, 5, 8 GeV from G4 MC	1mm offset Leakage (%)	2mm offset Leakage (%)	Bench. Mean PEs	Bench. RMS / Mean	full-scale Mean PEs	full-scale RMS / Mean
1	8	12.5	8	74	24.7	9.5	11.0	3.0 3.5	3.1 3.6	3.3 3.8	4678	0.13	370 906 1414	0.20 0.16 0.15

- This stack config is too narrow, due to its large thickness, causing significant lateral shower leakage—which could really complicate our benchmarking goal…

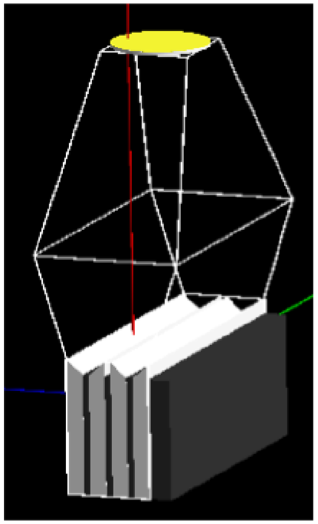
Candidate Design for Stack Prototype: Config #2

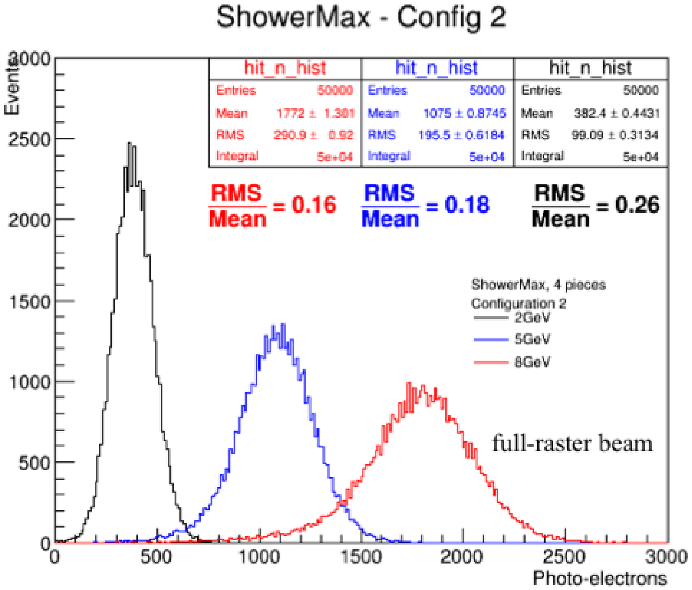


BenchMarking MC Visualization



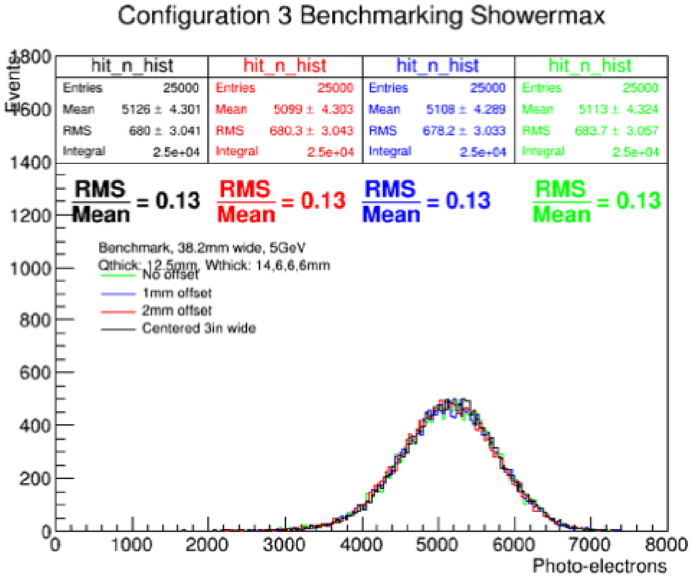
Full Scale MC Vis.



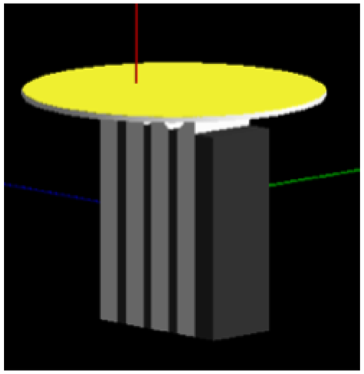


Config #	t_f (mm)	t_Q (mm)	t_W (mm)	b (mm)	a (mm)	X_0	R_{mol} (mm)	Leakage (%) 2, 5, 8 GeV from G4 MC	1mm offset Leakage (%)	2mm offset Leakage (%)	Bench. Mean PEs	Bench. RMS / Mean	full-scale Mean PEs	full-scale RMS / Mean
2	17	12.5	5	65	43.2	9.5	11.0	~0 ~0	~0 ~0	~0 ~0	2412 4994	0.19 0.15	382 1075 1772	0.26 0.18 0.16

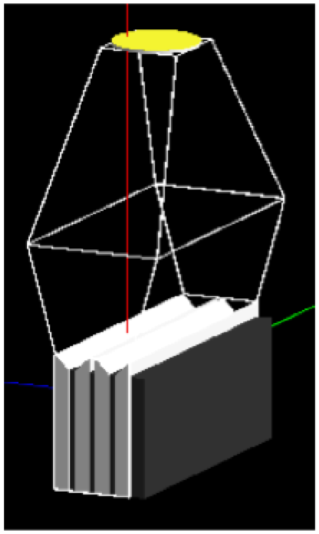
Candidate Design for Stack Prototype: Config #3

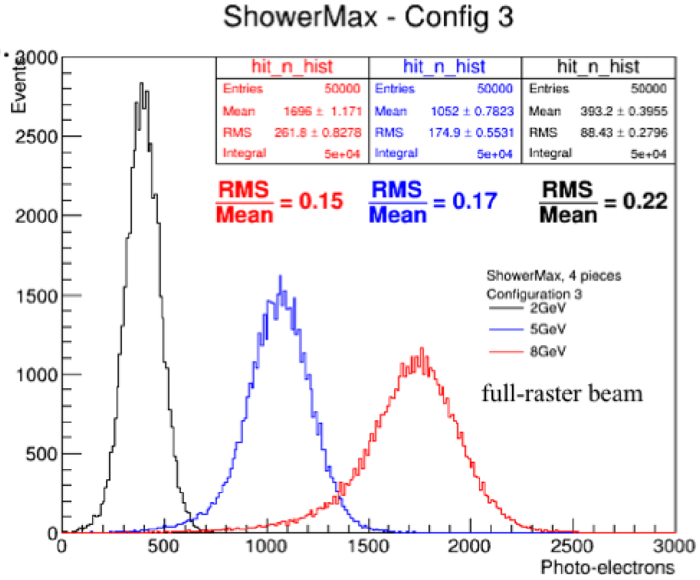


BenchMarking MC Visualization



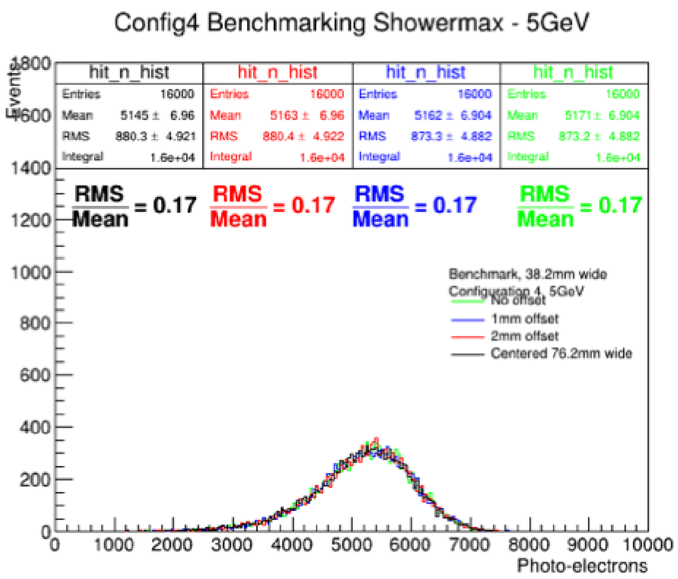
Full Scale MC Vis.



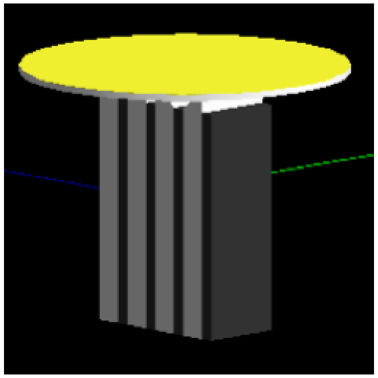


Config #	t_f (mm)	t_Q (mm)	t_W (mm)	b (mm)	a (mm)	X_0	R_{mol} (mm)	Leakage (%) 2, 5, 8 GeV from G4 MC	1mm offset Leakage (%)	2mm offset Leakage (%)	Bench. Mean PEs	Bench. RMS / Mean	full-scale Mean PEs	full-scale RMS / Mean
3	14	12.5	6	68	38.2	9.5	11.0	0.5 0.3	0.6 0.4	0.8 0.5	2412 5113	0.19 0.13	393 1052 1696	0.22 0.17 0.15

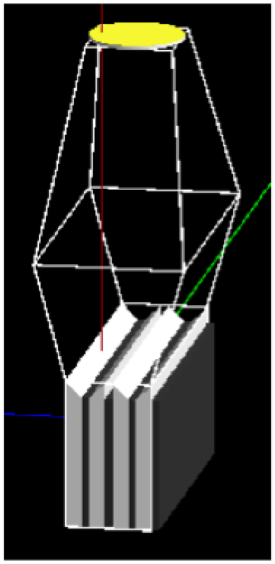
Candidate Design for Stack Prototype: Config #4

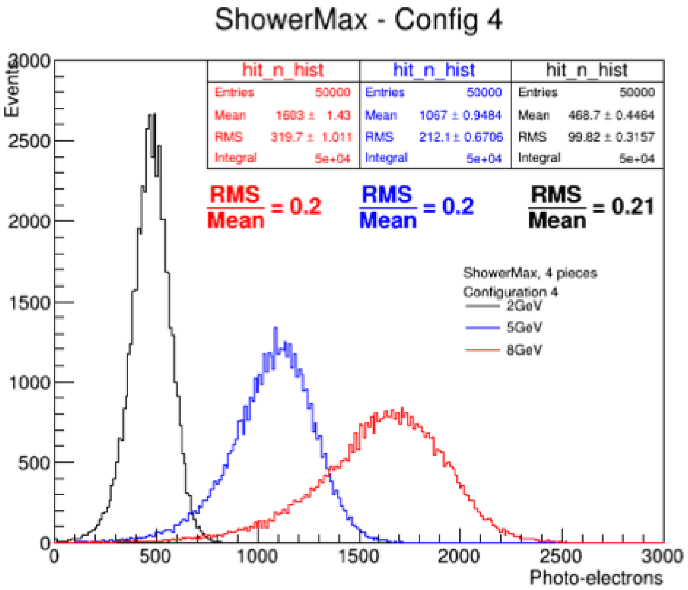


BenchMarking MC Visualization



Full Scale MC Vis.





Config #	t_f (mm)	t_Q (mm)	t_W (mm)	b (mm)	a (mm)	X_0	R_{mol} (mm)	Leakage (%) 2, 5, 8 GeV from G4 MC	1mm offset Leakage (%)	2mm offset Leakage (%)	Bench. Mean PEs	Bench. RMS / Mean	full-scale Mean PEs	full-scale RMS / Mean
4	6	12.5	6	68	38.2	7.3	11.0	~0 ~0	~0 ~0	~0 ~0	5171	0.17	469 1067 1603	0.21 0.20 0.20

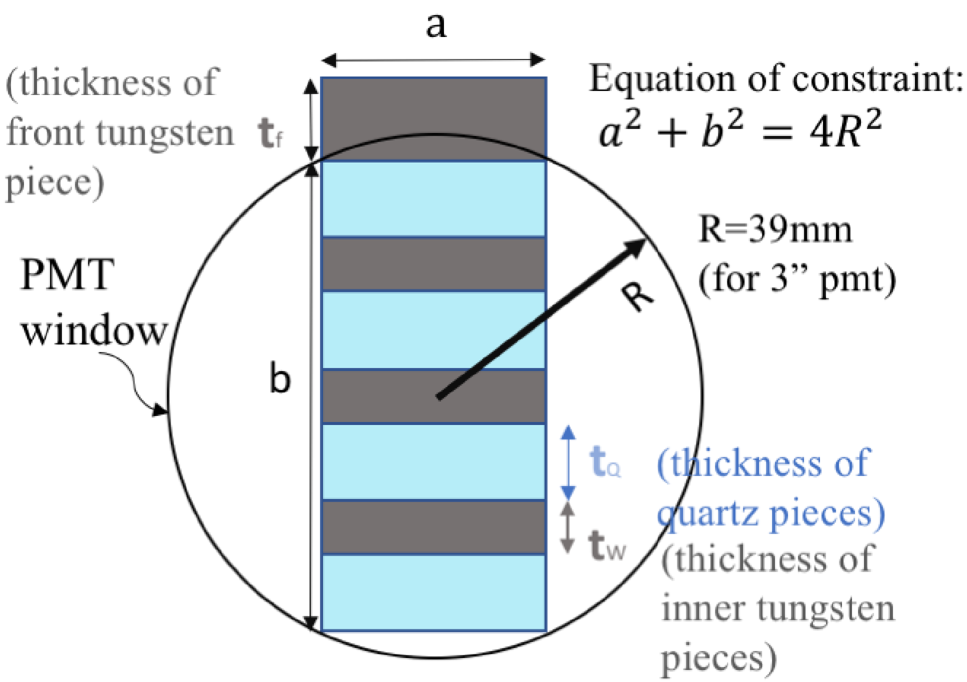
What if the quartz thickness is reduced?

Highlighted columns show changes due to quartz thickness change: Examined 6 mm and 10 mm thick tiles

Config #	t_f (mm)	t_Q (mm)	t_W (mm)	b (mm)	a (mm)	X_0	R_{molier} (mm)
1A	8	10	8	64	44	9.5	11.0
2A	17	10	5	55	55	9.5	11.0
3A	14	10	6	58	52	9.5	11.0
4A	6	10	6	58	52	7.3	11.5

Config #	t_f (mm)	t_Q (mm)	t_W (mm)	b (mm)	a (mm)	X_0	R_{molier} (mm)
1B	8	6	8	48	61	9.5	11.0
2B	17	6	5	39	67	9.5	11.0
3B	14	6	6	42	65	9.5	11.0
4B	6	6	6	42	65	7.3	11.5

- Key benefit here is that the parameter “a” (the width of the benchmarking quartz tiles) can now be comfortably large to ensure negligible transverse shower leakage.



Equation of constraint:

$$a^2 + b^2 = 4R^2$$

Reduced Quartz Configuration Results

Config #	t_f (mm)	t_q (mm)	t_w (mm)	b (mm)	Max A (mm)	X	Tungsten Weight (N)	Quartz Weight (N)	Total Weight (N)	Moliere R_m (mm)
1A	8	10	8	64	44.59	9.46	156.09	35.57	191.66	11.00
1B	8	6	8	48	61.48	9.33	156.09	35.57	191.66	11.00
4A	6	10	8	64	44.59	8.89	146.33	35.57	181.91	11.11
4B	6	6	6	42	65.73	7.04	117.07	35.57	152.64	11.53

	Benchmark - 2GeV			
Config #	RMS/Mean	Leakage (%)	Leakage 2mm offset (%)	Leakage 2° angle (%)
1A	0.17	0	0	-0.1
1B	0.19	0	0	0.2
4A	0.19	0	0	-
4B	0.21	0	0	-

	Benchmark - 5GeV			
Config #	RMS/Mean	Leakage (%)	Leakage 2mm offset (%)	Leakage 2° angle (%)
1A	0.13	0.04	0.09	-0.4
1B	0.14	0	0	0.2
4A	0.17	0.06	0.3	-
4B	0.19	0	0	-

	Benchmark – 8GeV			
Config #	RMS/Mean	Leakage (%)	Leakage 2mm offset (%)	Leakage 2° angle (%)
1A	0.12	0	0	-
1B	0.13	0	0	-
4A*	0.18	0	0	-
4B	0.19	0	0	-

	Full Scale ShowerMax – 2GeV		
Config #	RMS	Mean	RMS/Mean
1A	63.36	315.9	0.20
1B	45.46	197.7	0.23
4A**	60.16	300.2	0.20
4B**	39.67	179.3	0.22

	Full Scale ShowerMax – 5GeV		
Config #	RMS	Mean	RMS/Mean
1A	123.7	768.5	0.16
1B	87.82	473.6	0.19
4A**	126.8	677.4	0.19
4B**	80.61	397.4	0.20

	Full Scale ShowerMax – 8GeV		
Config #	RMS	Mean	RMS/Mean
1A	183.2	1197	0.15
1B	129.1	732.3	0.18
4A**	187.9	1012	0.19
4B**	118.8	591.3	0.20

Quartz and Tungsten Ordered in Nov 2017

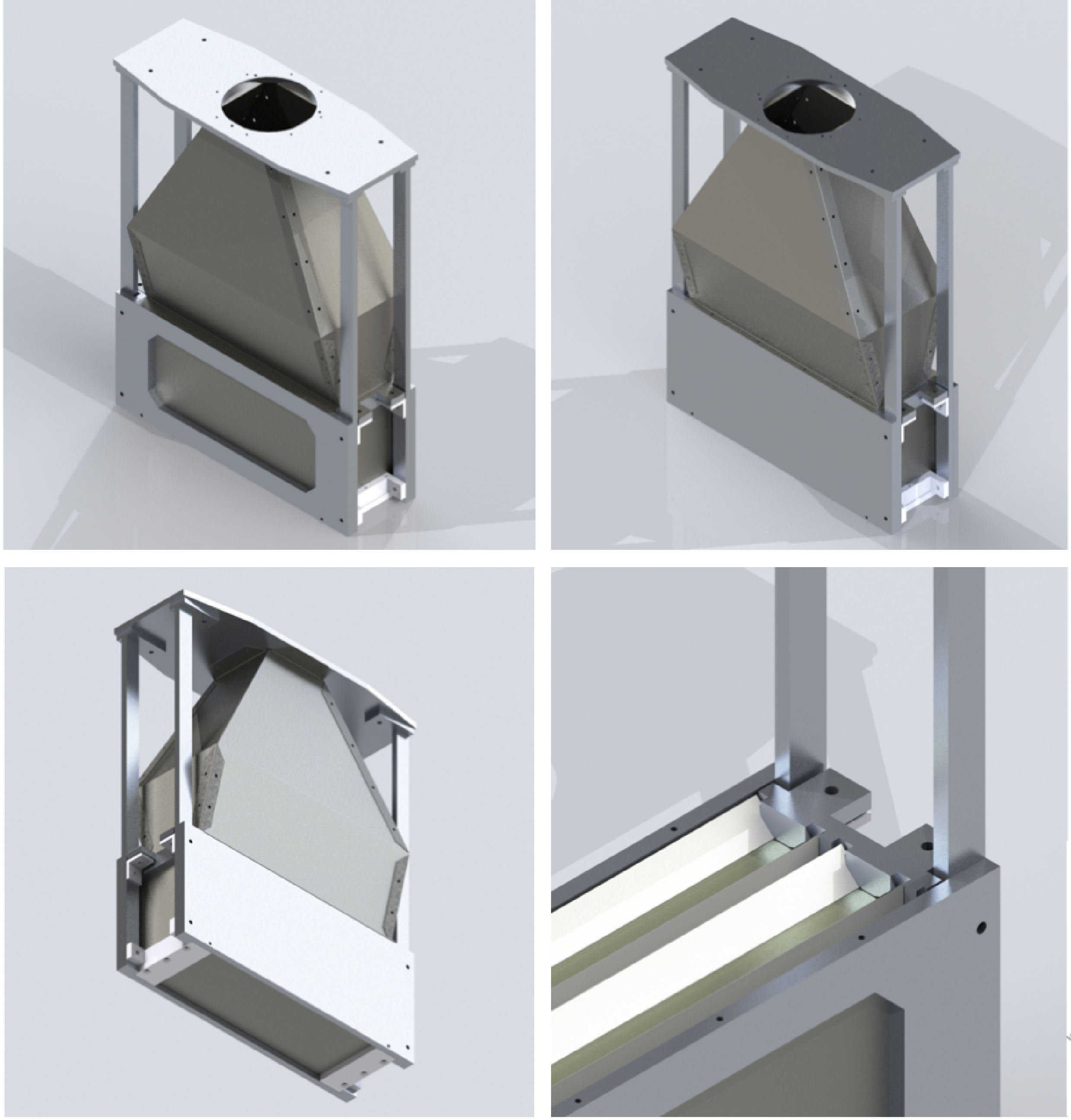
- For “benchmarking” prototype stack:
  - Quartz: 6 mm (thick) by 86 mm (tall) by 40 mm (wide) --4 pieces ($975/piece = $3.9k)
  - Quartz: 10 mm (thick) by 90 mm (tall) by 40 mm (wide) --4 pieces ($1005/piece = $4.0k)
  - Tungsten: 6 mm (thick) by 80 mm (tall) by 40 mm (wide) – 4 pieces ($85/piece = $340)
  - Tungsten: 8 mm (thick) by 80 mm (tall) by 40 mm (wide) – 4 pieces ($110/piece = $440)
  - Tungsten: 2 mm (thick) by 80 mm (tall) by 40 mm (wide) – 4 pieces ($25/piece = $100)
- For “full-scale” prototype stack:
  - Quartz: 6 mm (thick) by 111 mm (tall) by 246 mm (wide) -- 4 pieces (~$1750/piece = $7.0k)
  - Quartz: 10 mm (thick) by 115 mm (tall) by 246 mm (wide) -- 4 pieces (~$1940/piece = $7.8k)
  - Tungsten: 6 mm (thick) by 105 mm (tall) by 246 mm (wide) – 4 pieces ($600/piece = $2.5k)
  - Tungsten: 8 mm (thick) by 105 mm (tall) by 246 mm (wide) – 4 pieces ($820/piece = $3.2k)
  - Tungsten: 2 mm (thick) by 105 mm (tall) by 246 mm (wide) – 4 pieces ($200/piece = $0.8k)

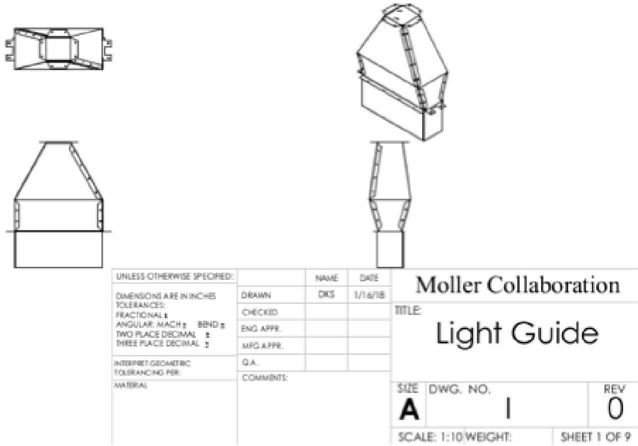
Purchasing these pieces allows for Configs 1, 3, and 4 (A and B) to be tested

Total quartz: $25k, total tungsten: $7.5k: Total = $32.5k

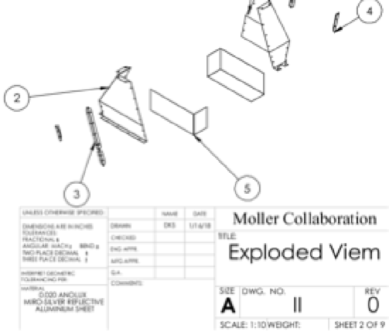
- Going with 6mm tiles allows construction of two benchmarking and two full-scale prototype sets
- Building two sets of prototypes will allow for more efficient testing during both SLAC testbeam and cosmic tests at SBU and ISU. We can each build a different configuration to test

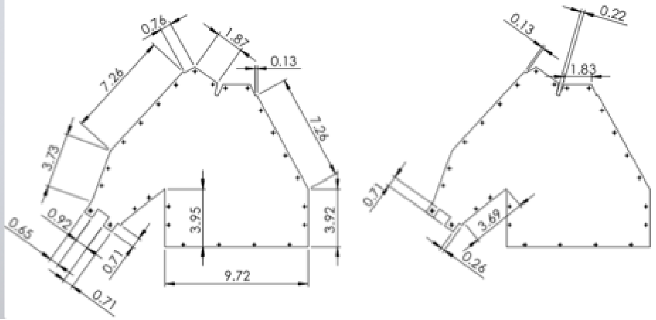
Updated Full-Scale Prototype (1A) for Beamtest



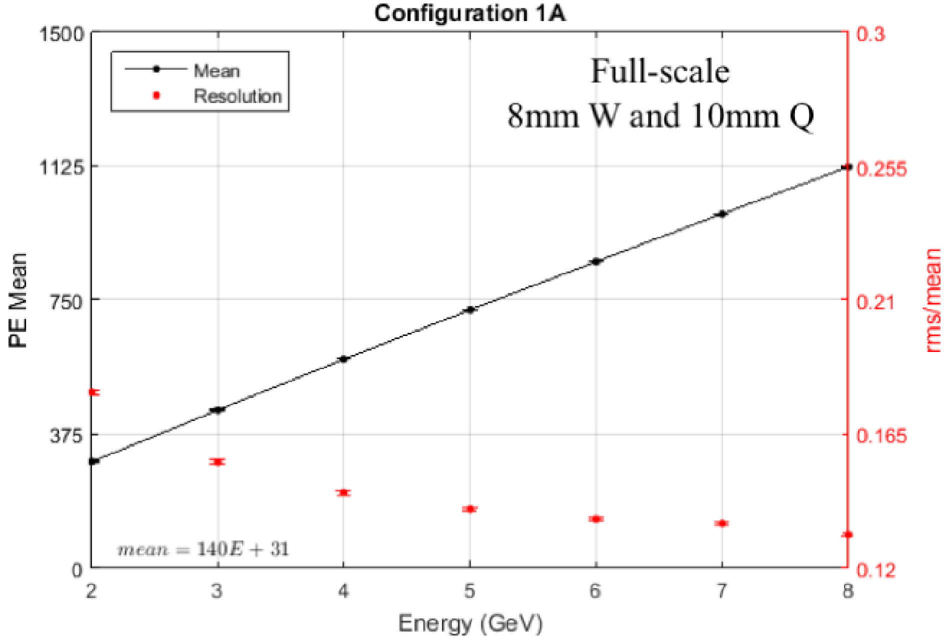


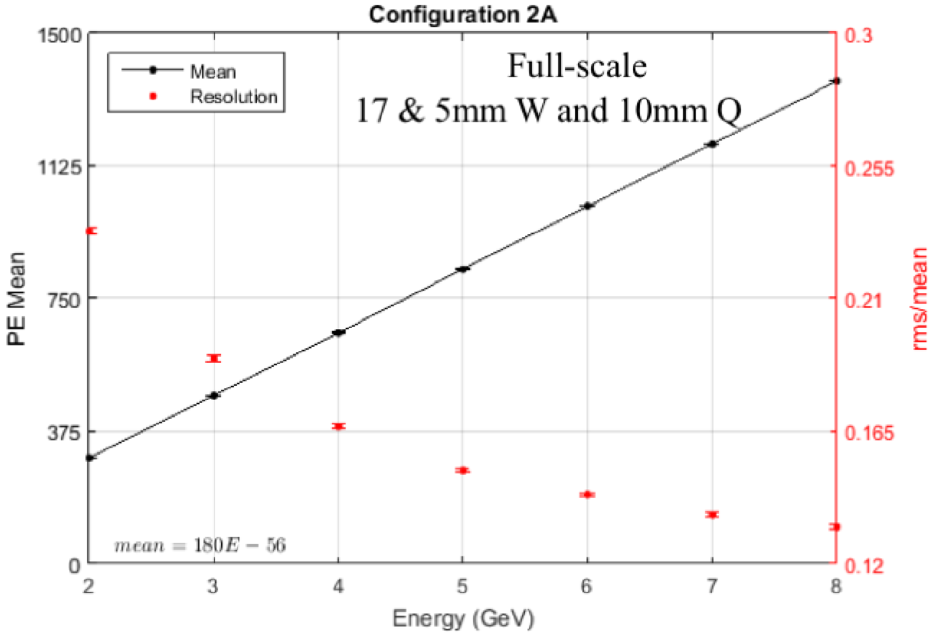
ITEM NO.	PART	MATERIAL	QTY.
1	Light Guide - Back	0.020 ANOLUX MIRO-SILVER REFLECTIVE ALUMINIUM SHEET	1
2	Light Guide - Front	0.020 ANOLUX MIRO-SILVER REFLECTIVE ALUMINIUM SHEET	1
3	Long Flap	0.020 ANOLUX MIRO-SILVER REFLECTIVE ALUMINIUM SHEET	2
4	Short Flap	0.020 ANOLUX MIRO-SILVER REFLECTIVE ALUMINIUM SHEET	4
5	Suitcase	0.020 ANOLUX MIRO-SILVER REFLECTIVE ALUMINIUM SHEET	2

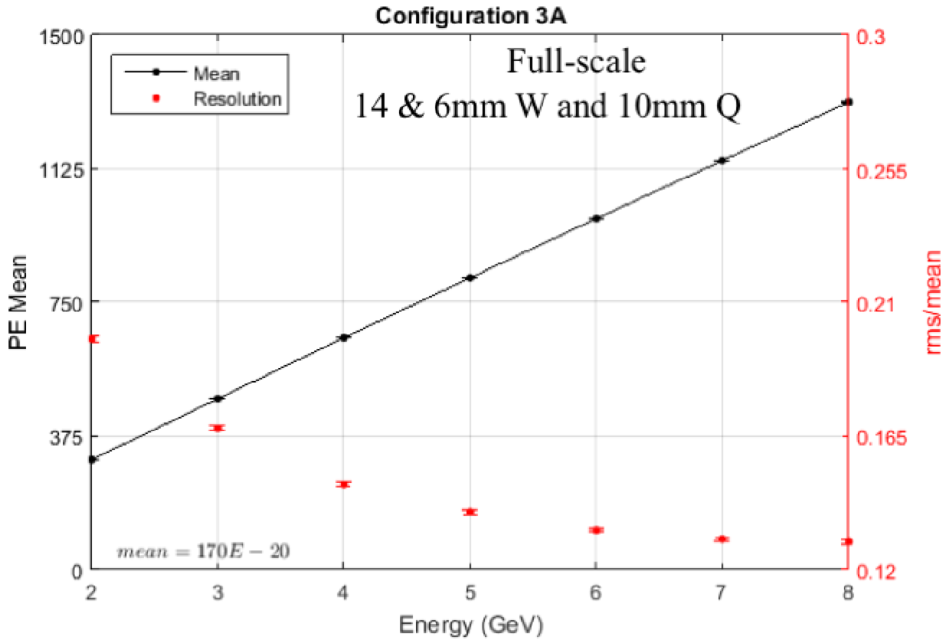




1A - 4A Mean PE and Resolution versus Energy

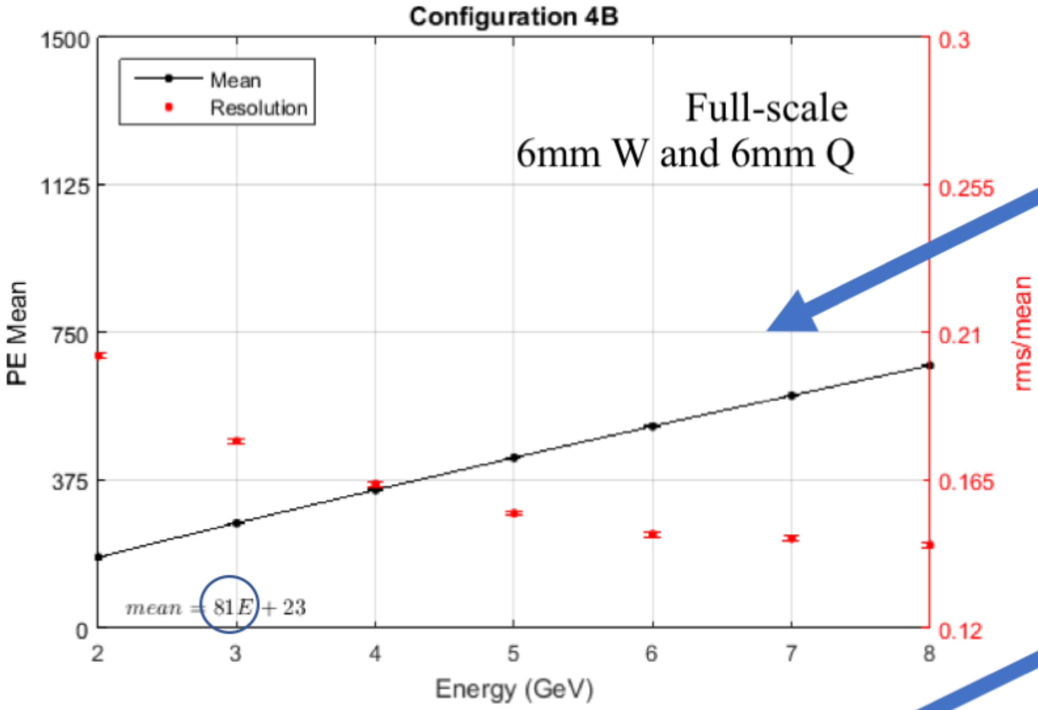






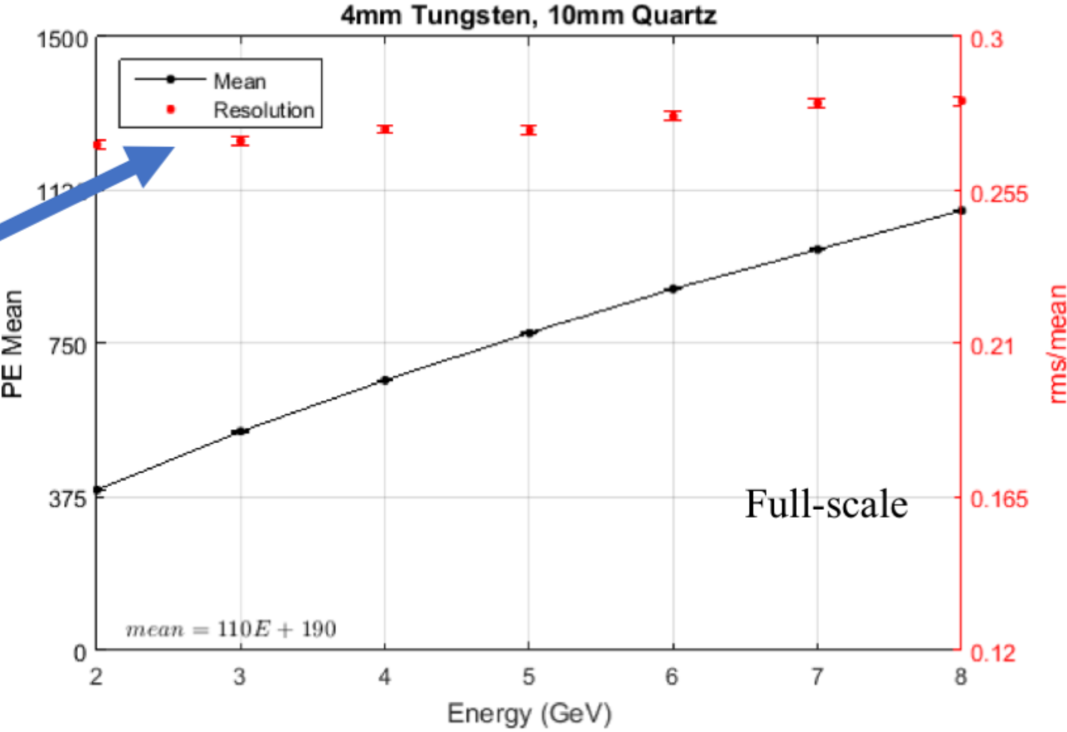
- Results for config 4A (6 mm W and 10 mm quartz) are still in progress

Interesting result for 4B (thinnest) configuration



Full-scale
6mm W and 6mm Q

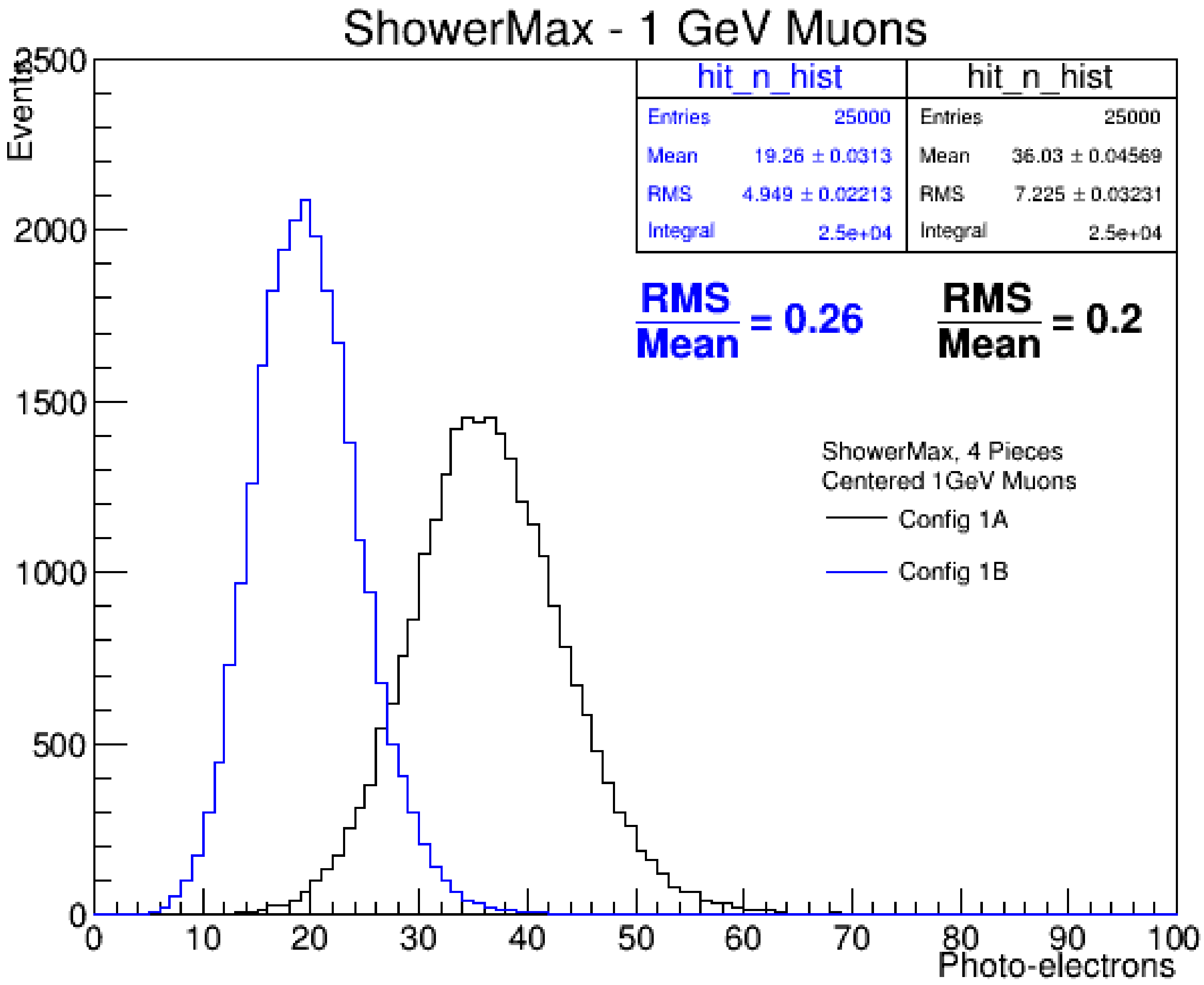
- Config 4B has ~half the slope of the other configs – 80 PEs/GeV – while maintaining good resolution and with lower light levels.
- The reduced slope means less variation in PE yields with energy--which will reduce the widths measured during helicity window (it seems a potential win win win situation).



Full-scale

- Also interesting is that if you reduce the layers of tungsten to 4mm, the resolution worsens ~drastically (even with 10 mm quartz)

Simulated MIP signal for cosmic-ray tests



Testbeam and MC benchmarking strategy

- Engineer benchmarking prototype capable of operation with systematically more stack layers added and with no light guide
- Basic strategy outline:
  - First take data with only one piece of quartz
  - Then add the front tungsten plate and take data, then the next layer of tungsten and quartz, then next, then next
  - This will facilitate benchmarking of optical quartz properties and G4's showering process without light guide complication
- Also construct and test full scale prototypes (with same exact stack configuration) and with full light guide; this will be constructed with machined aluminum
- Note that ND filters are needed if use conventional PMT; could possibly use vacuum photodiode or maybe unity-gain PMT

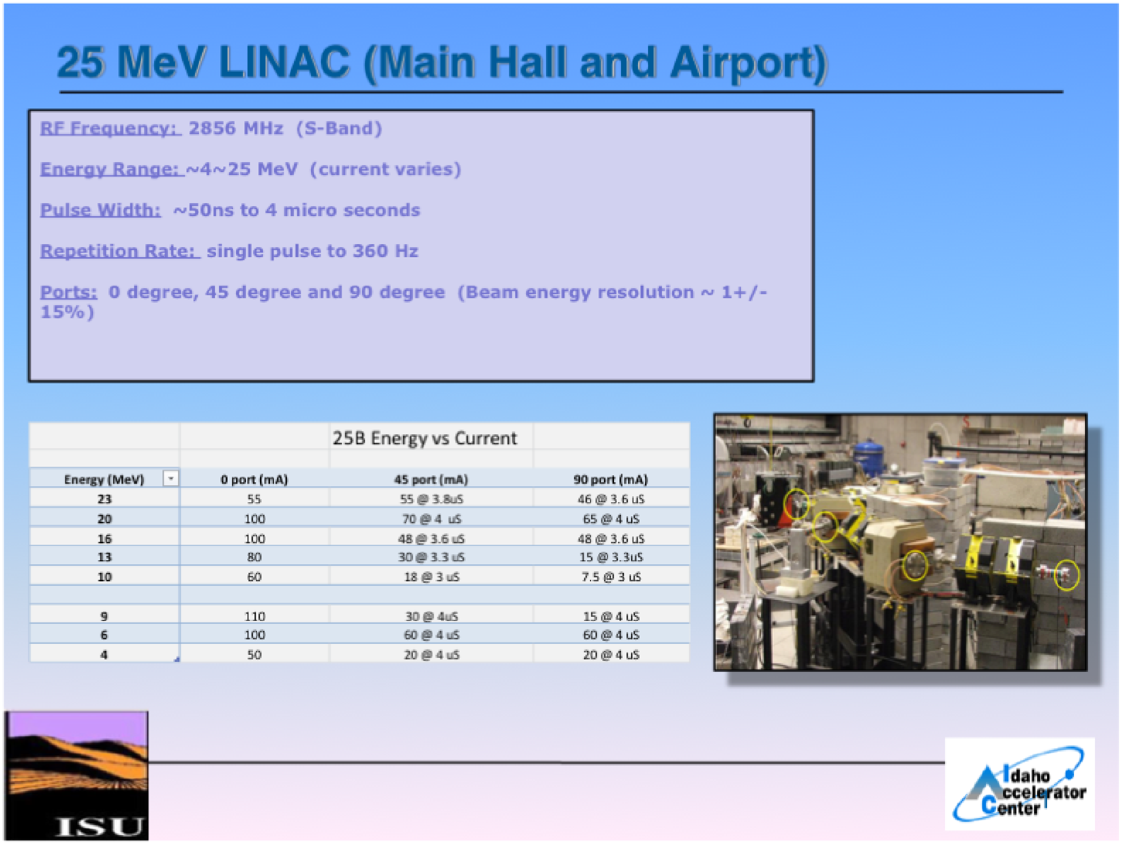
Summary and future work

- Showermax prototype designs near finalized
  - Benchmarking prototypes under construction and nearly finished
  - Full-scale prototype shop drawings in hand – will send to shop this month
- Quartz and Tungsten purchased for beam tests at SLAC (planned for this spring)
- Ongoing and future work:
  - Incorporate LG reflectivity lookup tables; using 60%
  - Sample realistic e^- energy and position (and angle)
  - Study det. res. uniformity over entire face; edge effects
  - Determine shower-max excess noise for statistical power

Director's Review Recommendations (Shower-max related)

- Splashback from the Shower Max Detector should be simulated to see the impact on the Thin Detector ring signals.
- Estimate the Qweak double-difference systematic (go beyond crude estimate presented by Kent on the second morning in closed session) for both quartz and shower-max detectors.
- Conduct radiation damage tests to at least 50MRad to qualify fused silica for use in the thin detector (see next few slides).

Radiation Hardness QC for quartz and other components



25 MeV LINAC (Main Hall and Airport)

RF Frequency: 2856 MHz (S-Band)

Energy Range: ~4~25 MeV (current varies)

Pulse Width: ~50ns to 4 micro seconds

Repetition Rate: single pulse to 360 Hz

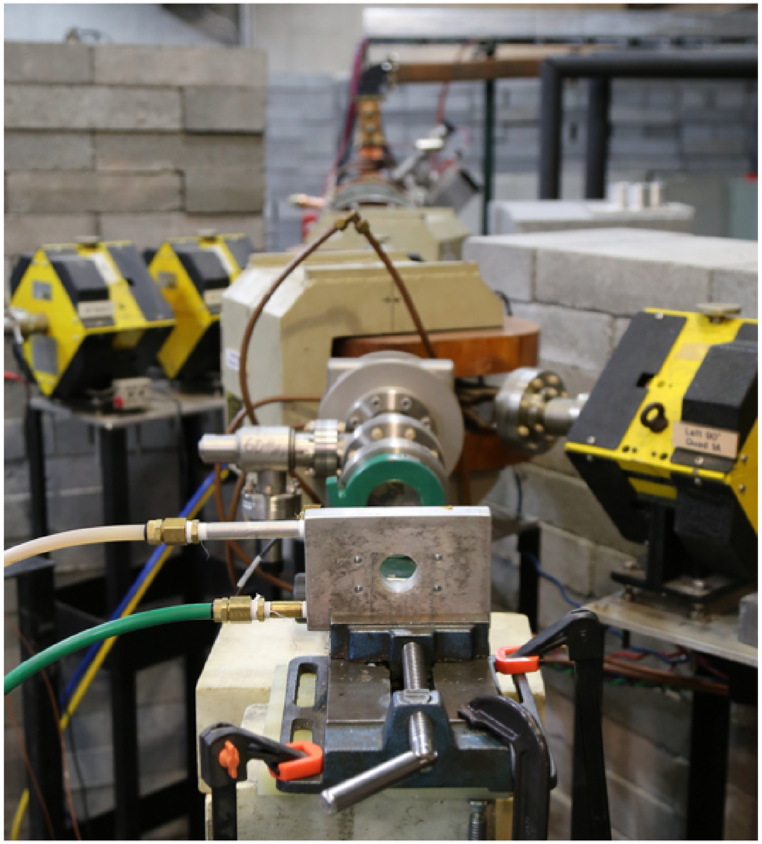
Ports: 0 degree, 45 degree and 90 degree (Beam energy resolution ~ 1+/-15%)

25B Energy vs Current

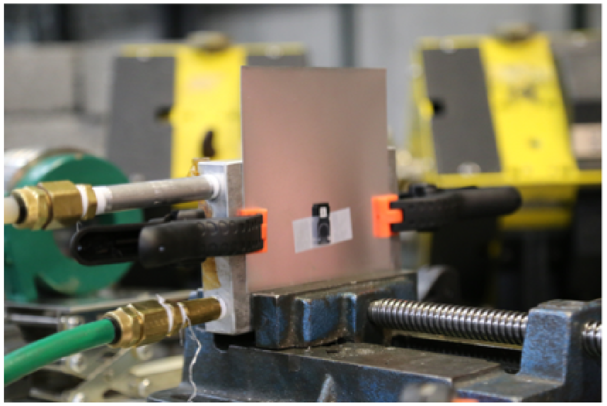
Energy (MeV)	0 port (mA)	45 port (mA)	90 port (mA)
23	55	55 @ 3.8uS	46 @ 3.6 uS
20	100	70 @ 4 uS	65 @ 4 uS
16	100	48 @ 3.6 uS	48 @ 3.6 uS
13	80	30 @ 3.3 uS	15 @ 3.3uS
10	60	18 @ 3 uS	7.5 @ 3 uS
9	110	30 @ 4uS	15 @ 4 uS
6	100	60 @ 4 uS	60 @ 4 uS
4	50	20 @ 4 uS	20 @ 4 uS

ISU

Idaho Accelerator Center



- A key issue is how well can we calibrate dose exposure?
- Another issue is how low can we go in beam current (while still monitoring it)



- Planning for a 1 - 2 day engineering run late spring or early summer to address these questions.

Plans to address relevant MOLLER Task List Items

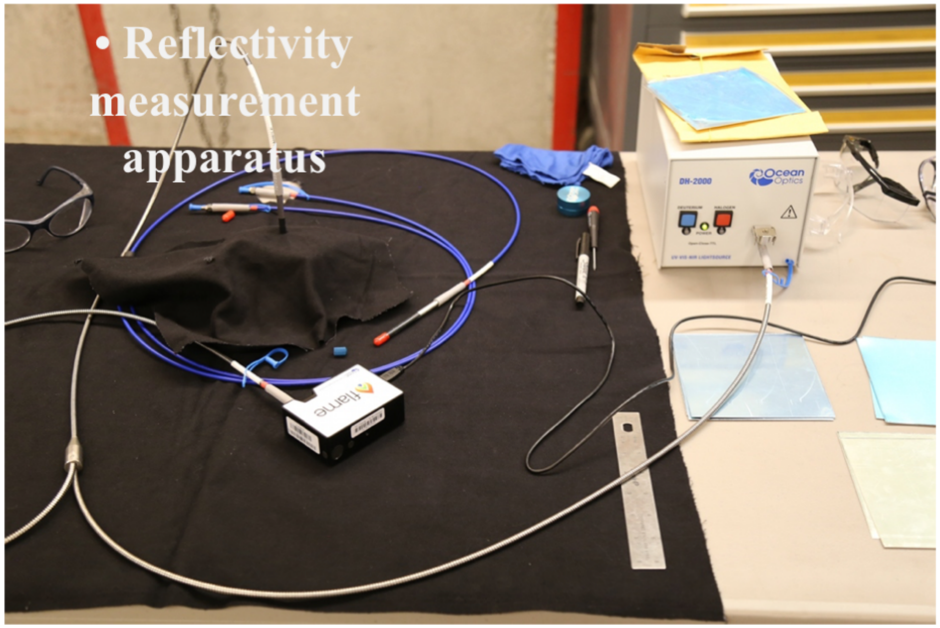
- QC plan for main detector quartz (radiation hardness, etc.) (ISU, UM)
  - ❖ Preparations underway to measure quartz optical transparency during irradiation dose study at the IAC:
    - Apparatus developed to make relative transparency measurements between 200 – 800 nm
      - ➢ Uses Ocean Optics USB spectrometer, UV-Visible light source, custom holder/stand
    - Energy deposition calculations (dE/dx and brem) underway for 8 MeV beam and 1.5 cm thick quartz—for heating and thermal expansion considerations (do not want to crack quartz)--have 5 pieces of experimental SAM quartz for this study…so can afford to sacrifice one
    - Investigating ability to calibrate and monitor beam dose exposure during study
    - Planning for 1-2 day test run this spring or early summer and then longer run when ready

- Radiation hardness of detector components (ISU, UM)
  - ❖ Irradiated several light-guide (LG) material samples over a 3 day test run from Mar 22 - 24, 2016 at the Idaho Accelerator Center (IAC) using 8 MeV, 65 - 110mA I_{pk}, 4μs pulse width at 250 Hz rep-rate:
    - Measured LG specular reflectivity for 200 – 800 nm at 90, 60, 45, and 30 degrees.
    - No measurable change in reflectivity was detected for >>50M rad exposure (but did not successfully calibrate dose exposure for these tests (film dosimeter was saturated)
  - ❖ Other assembly materials to test could include Kapton and Tedlar (light tight wrappings) and possibly 3D-printed plastic assembly components (Nylon, ABS, PLA, …)
    - Could plan for future irradiation test at IAC *but not yet sure how to quantify rad-hardness of tested materials—need guidance on what materials to test and how to access*

Backup Slides

Light guide reflectivity measurements

- Measuring light guide (LG) reflectivity as function of angle (10 – 90°) and λ (200 – 800nm); ongoing

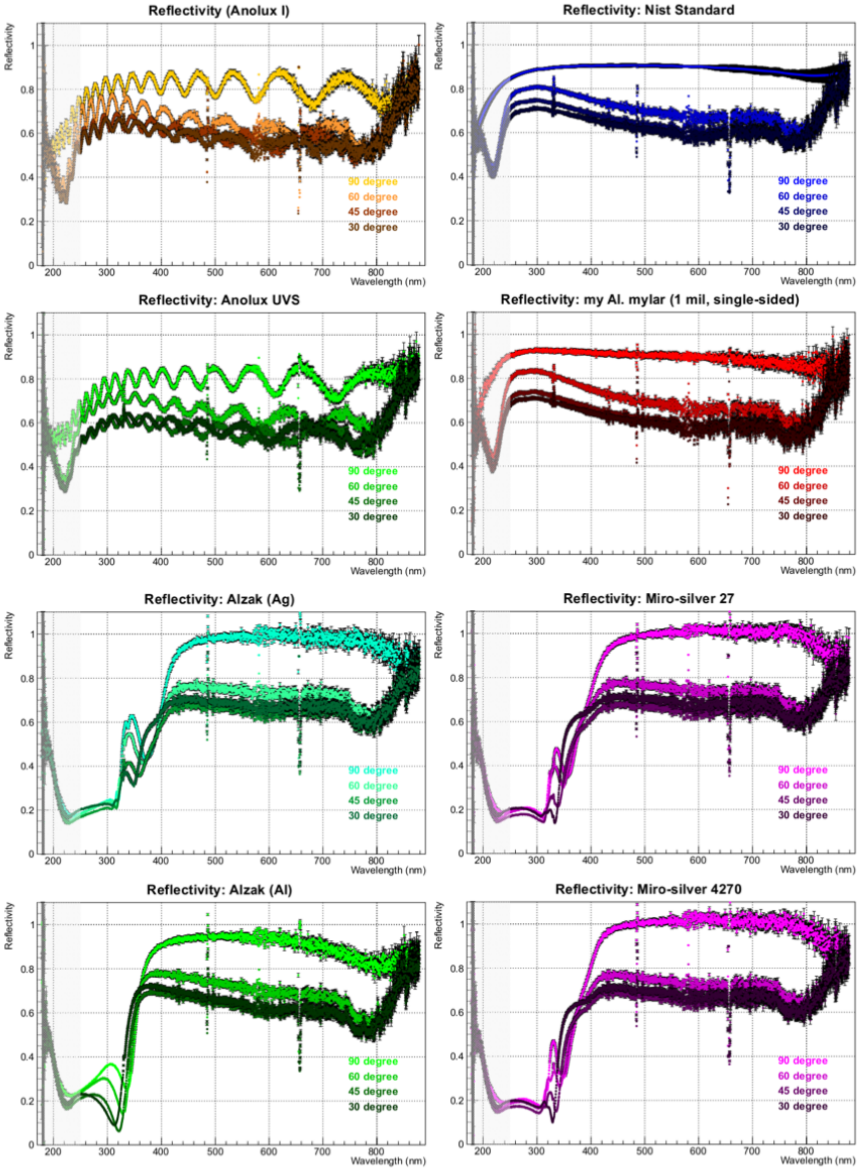


- Light source: Ocean Optics DH2000: 200 - 800nm, 25W Deuterium bulb
- Spectrometer: Ocean Optics USB Flame, enhanced sensitivity, UV-VIS grating
- NIST specular calibration standard

Light guide materials tested:

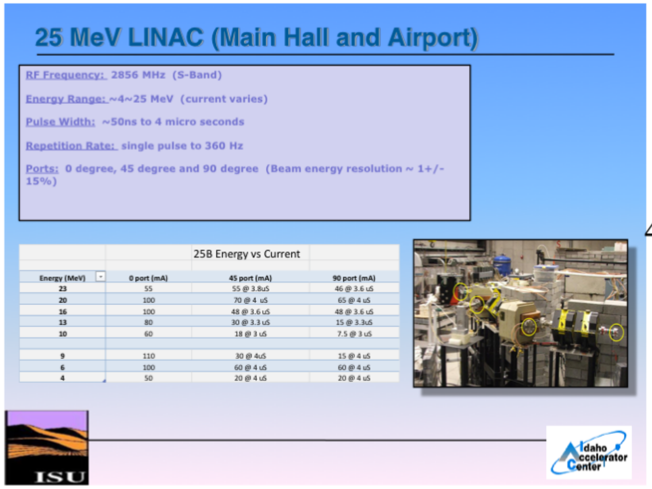
Miro-silver 4270
Anolux I and UVS
Miro 2000Ag (diffuse)

Miro-silver 27
Alzak-Al and Alzak-Ag
1 mil, single-sided aluminized mylar



Reflectivity vs. λ for various materials at diff. angles

LG reflectivity radiation hardness study



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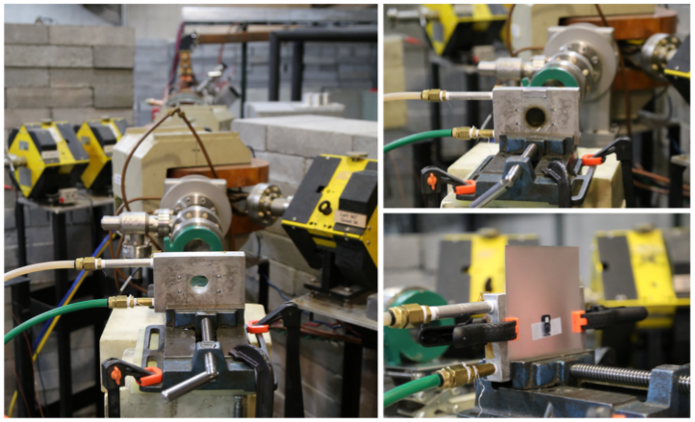
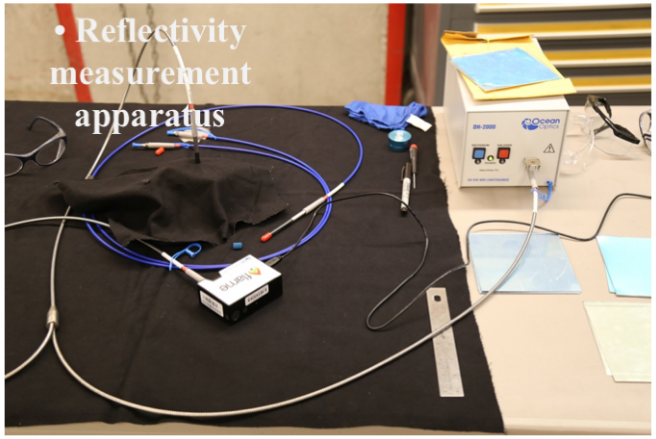
10	60	18 @ 3 uS	7.5 @ 3 uS
9	110	30 @ 4uS	15 @ 4 uS
6	100	60 @ 4 uS	60 @ 4 uS
4	50	20 @ 4 uS	20 @ 4 uS

- Used 8 MeV e^- beam, 65 - 110mA I_{peak}, 4μs pulse width at 250 Hz, 310 – 880 W

- Water-cooled (15° C) aluminum brick w/ 1.5 cm radius hole (for beam) – more than adequate cooling.

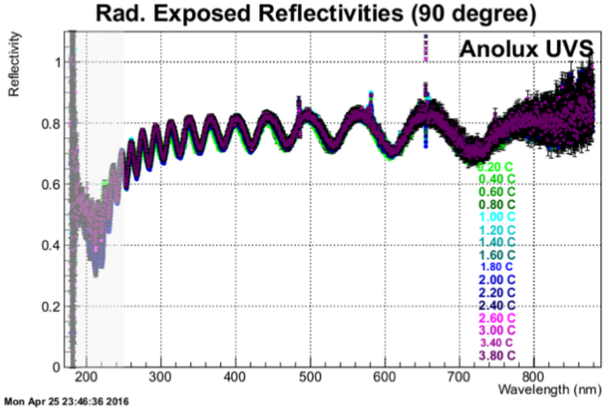




- Reflectivity measurement apparatus

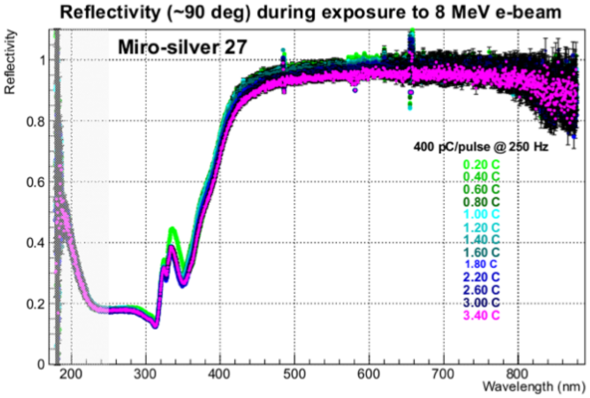
Irradiated several light guide material samples over a 3 day period from Mar 22 - 24, 2016:

Miro-silver 4270
  Anolux UVS
    Miro 2000Ag (diffuse)
      Miro-silver 27 (from Michael)
        Alzak-Al and Alzak-Ag (from KK)
          1 mil, single-sided aluminized mylar

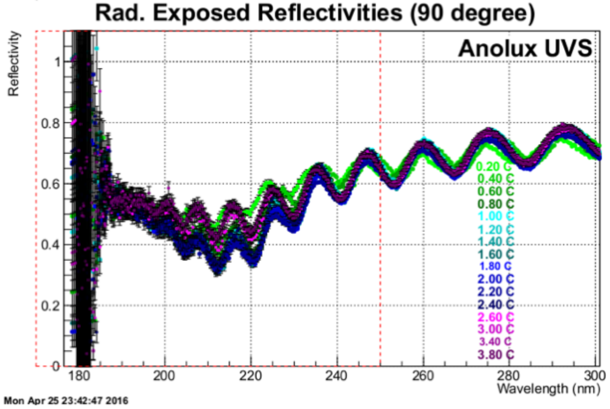


Rad. Exposed Reflectivities (90 degree)

Mon Apr 25 23:46:36 2016

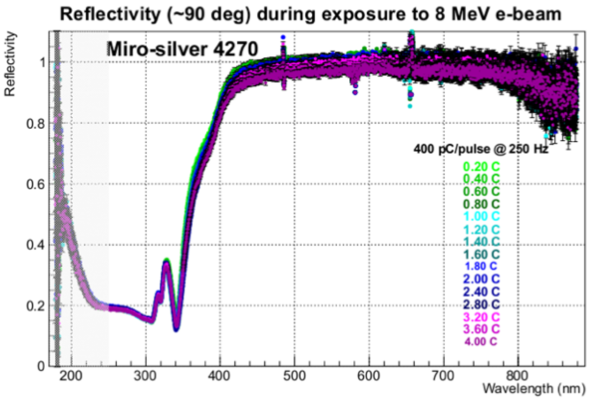


Reflectivity (~90 deg) during exposure to 8 MeV e-beam



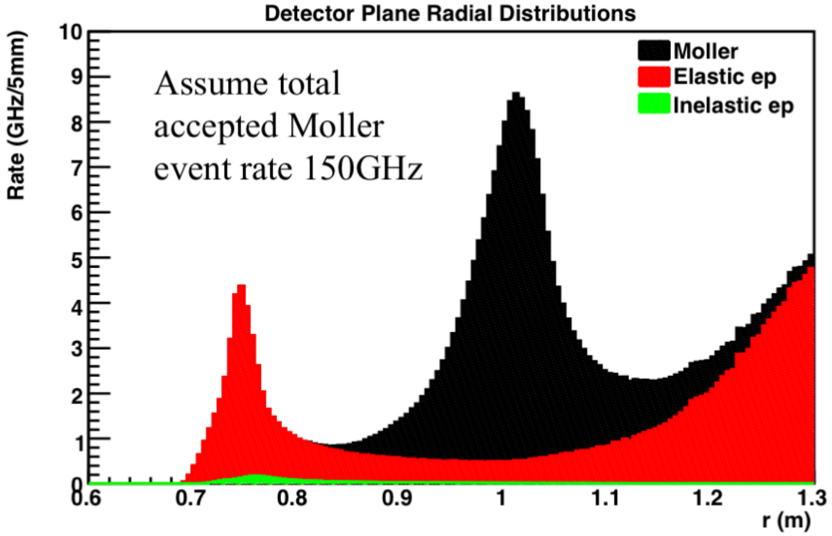
Rad. Exposed Reflectivities (90 degree)

Mon Apr 25 23:42:47 2016

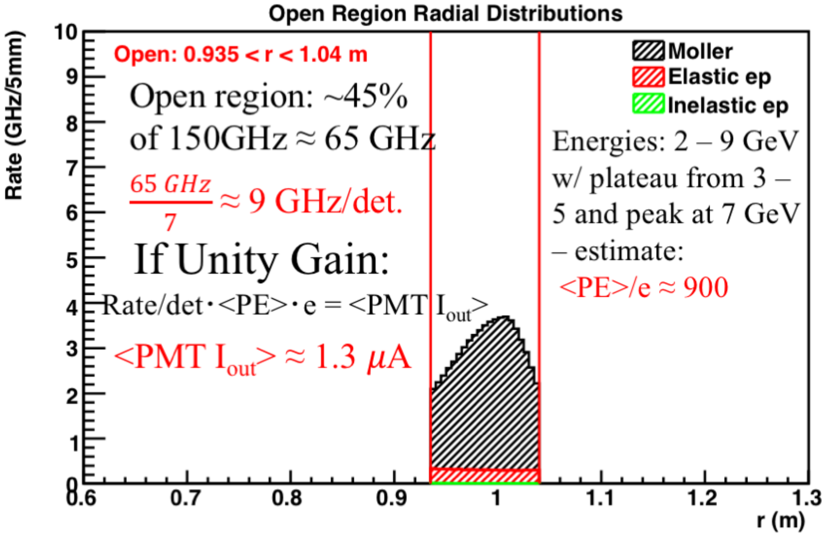


Reflectivity (~90 deg) during exposure to 8 MeV e-beam

Unity Gain operation with Baseline design?



Assume total accepted Moller event rate 150GHz



Open region: ~45% of 150GHz ≈ 65 GHz

$\frac{65\,GHz}{7} \approx 9$ GHz/det.

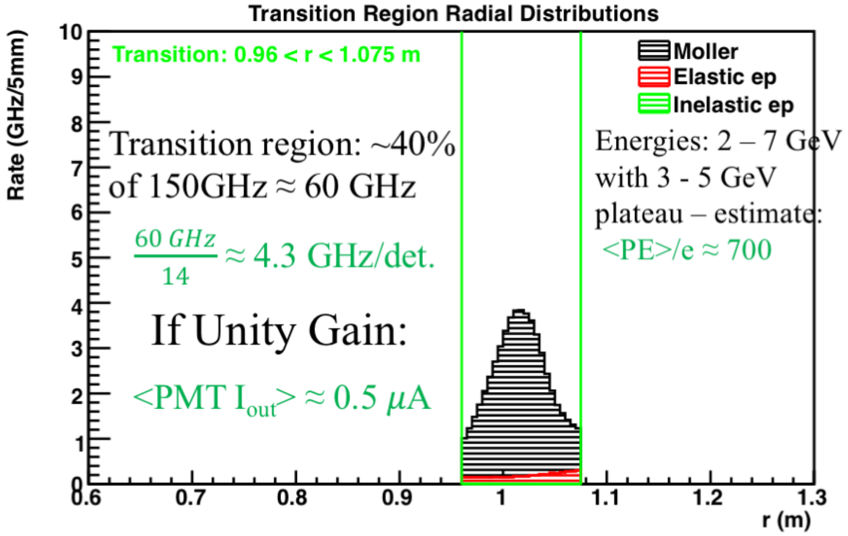
If Unity Gain:

$\text{Rate/det} \cdot \langle PE \rangle \cdot e = \langle PMT\ I_{out} \rangle$

$\langle PMT\ I_{out} \rangle \approx 1.3\ \mu A$

Energies: 2 – 9 GeV w/ plateau from 3 – 5 and peak at 7 GeV – estimate:

$\langle PE \rangle / e \approx 900$



Transition region: ~40% of 150GHz ≈ 60 GHz

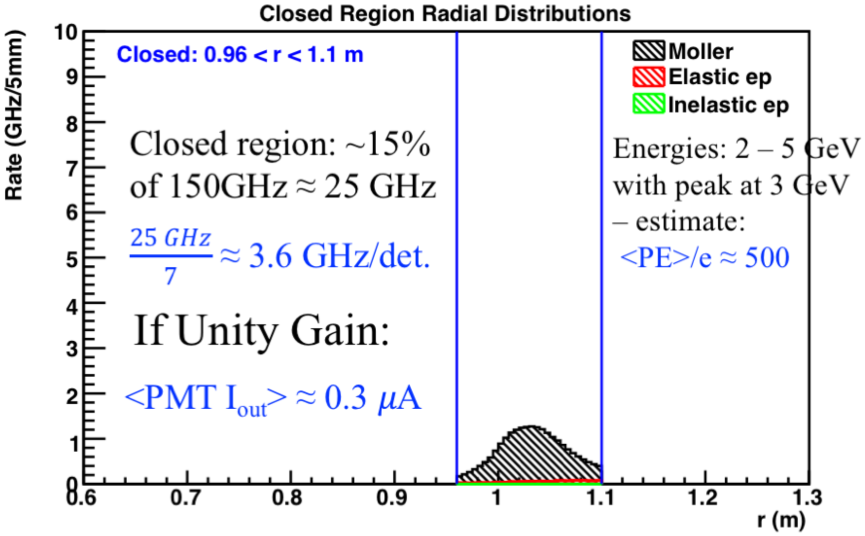
$\frac{60\,GHz}{14} \approx 4.3$ GHz/det.

If Unity Gain:

$\langle PMT\ I_{out} \rangle \approx 0.5\ \mu A$

Energies: 2 – 7 GeV with 3 - 5 GeV plateau – estimate:

$\langle PE \rangle / e \approx 700$



Closed region: ~15% of 150GHz ≈ 25 GHz

$\frac{25\,GHz}{7} \approx 3.6$ GHz/det.

If Unity Gain:

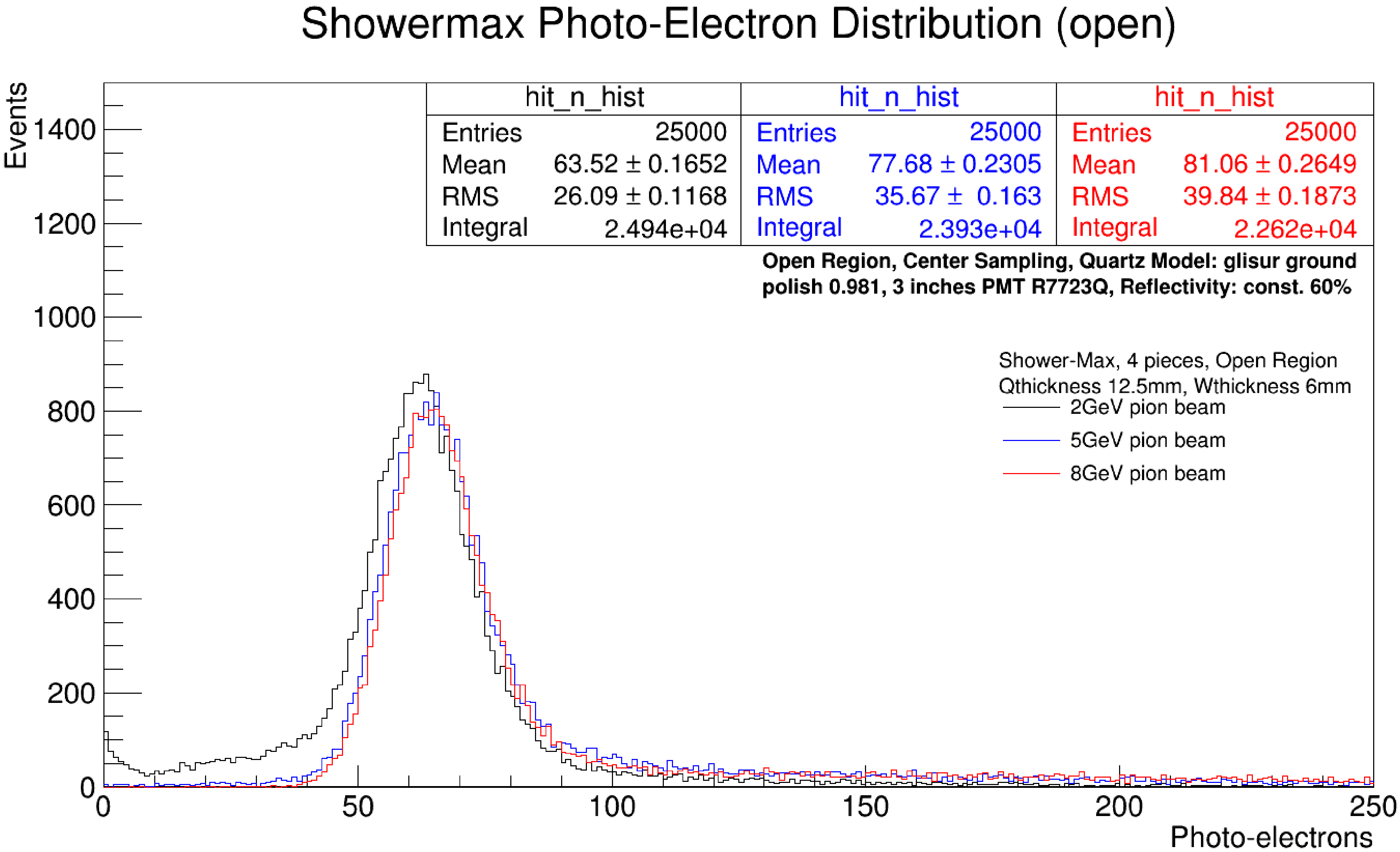
$\langle PMT\ I_{out} \rangle \approx 0.3\ \mu A$

Energies: 2 – 5 GeV with peak at 3 GeV – estimate:

$\langle PE \rangle / e \approx 500$

- Could be possible to use conventional 3” pmts with electronic switching between unity gain base (integrating mode) and high gain base (counting mode)

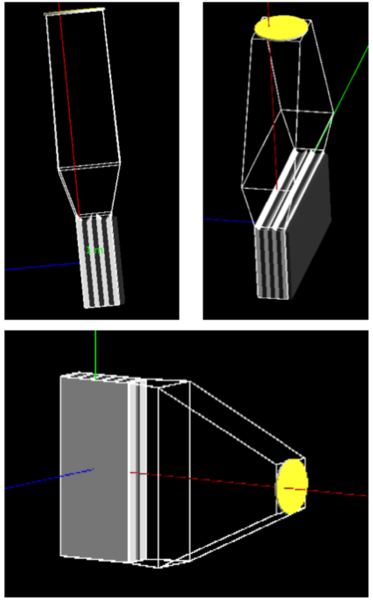
Baseline design PE Distributions for Pions

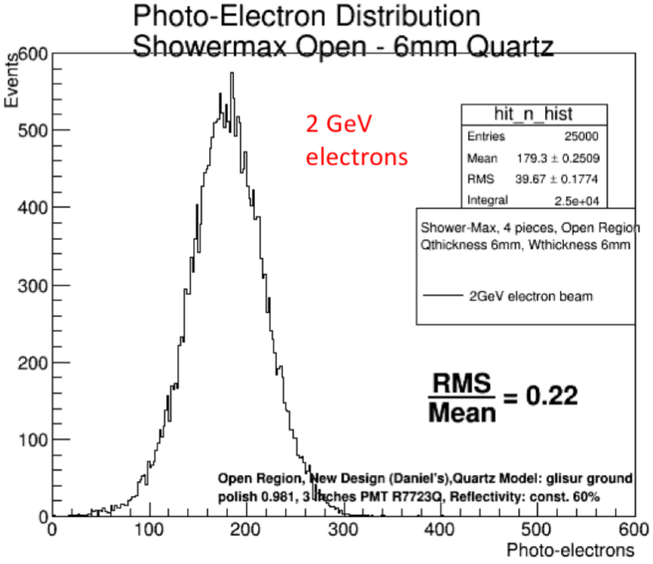


Optimization study1 (2 GeV):

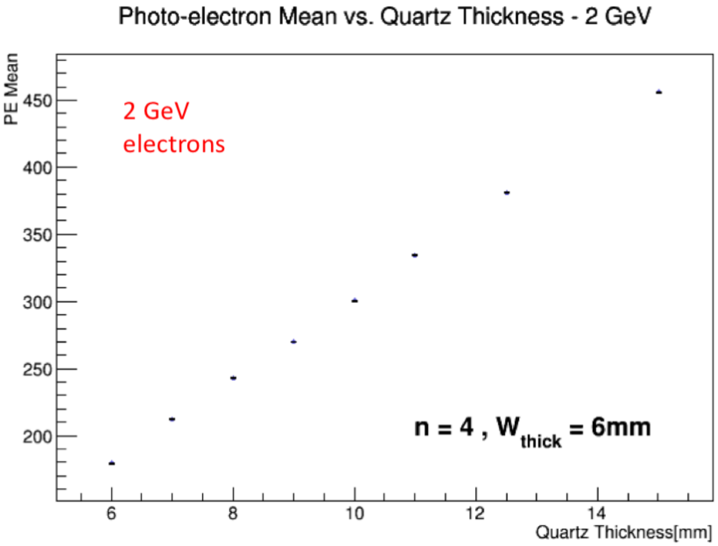
6mm thick tungsten, variable quartz thickness

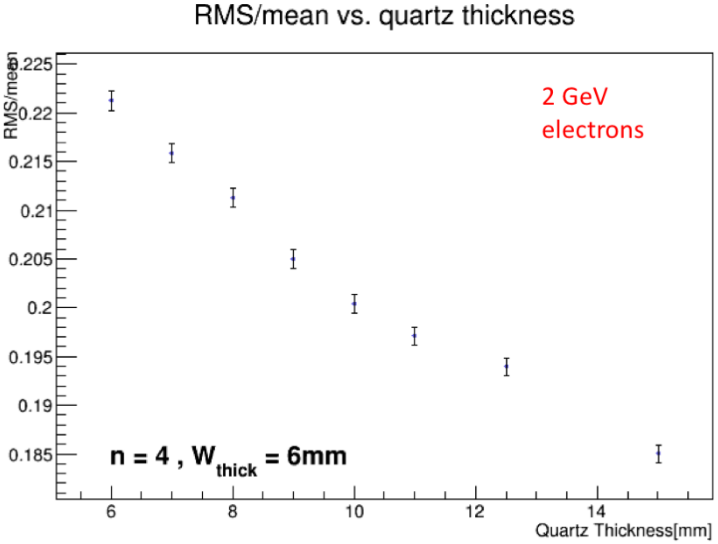
6mm quartz



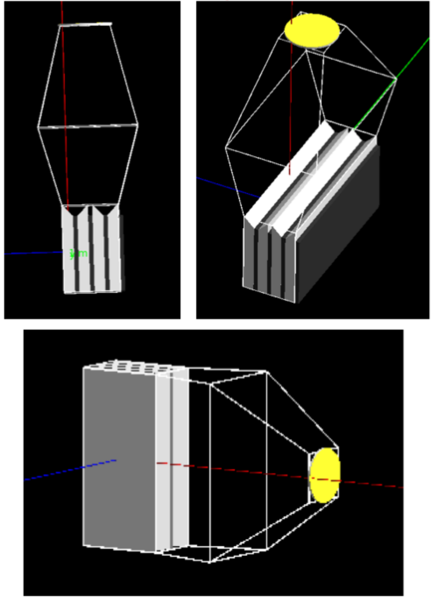


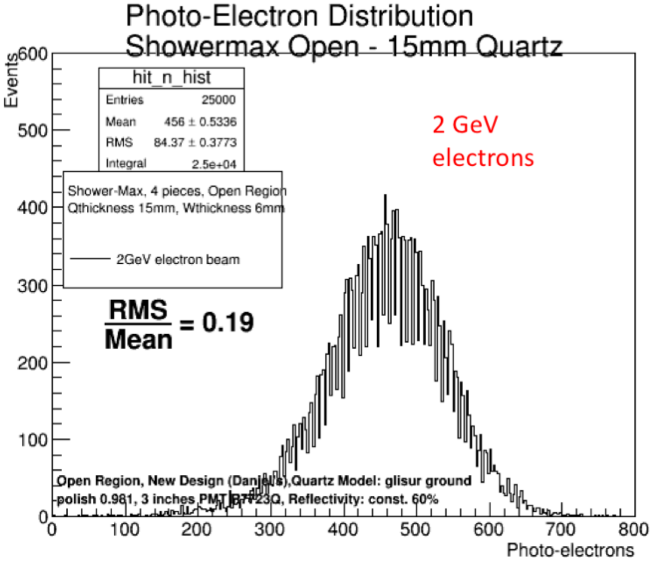
$$\frac{\textbf{RMS}}{\textbf{Mean}} = 0.22$$





15mm quartz



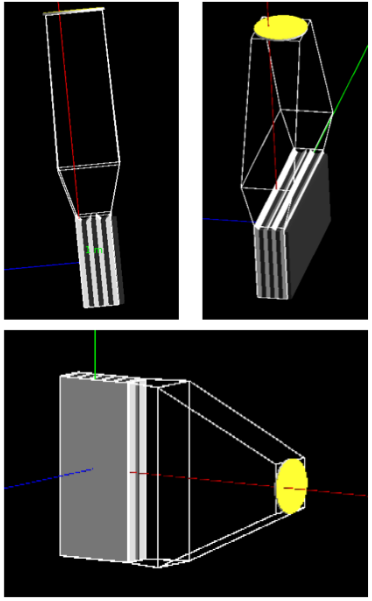


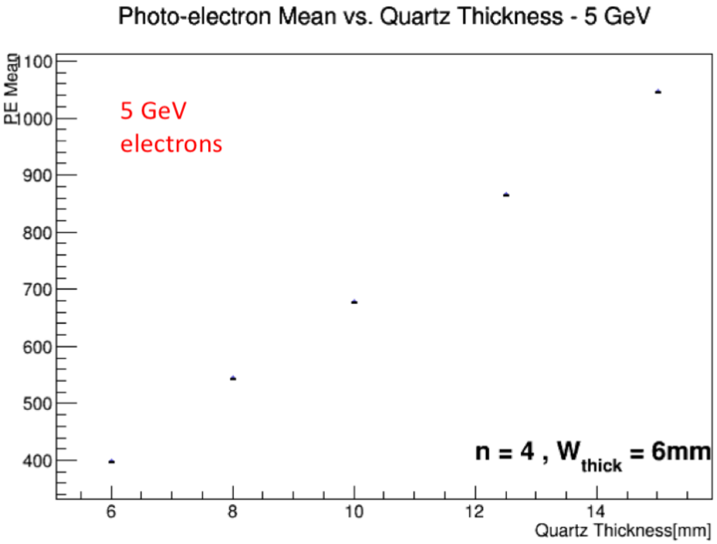
$$\frac{\textbf{RMS}}{\textbf{Mean}} = 0.19$$

Optimization study1 (5 GeV):

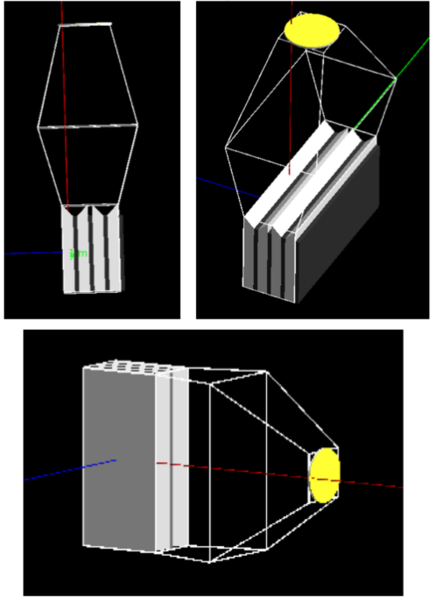
- 6mm thick tungsten, variable quartz thickness

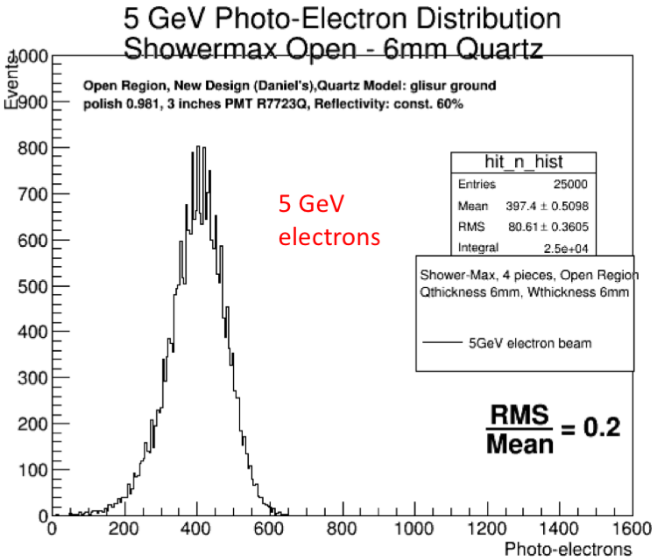
6mm quartz

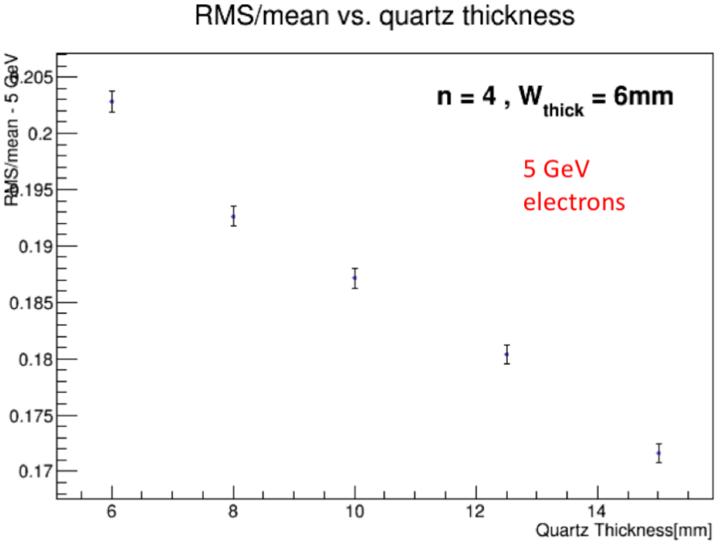


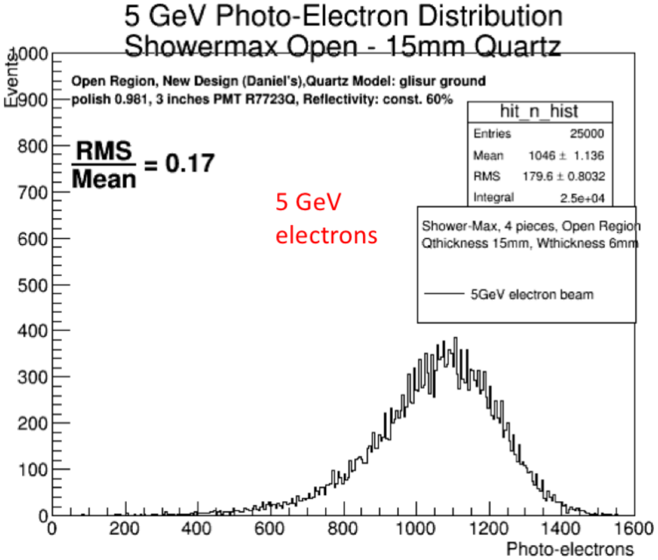


15mm quartz





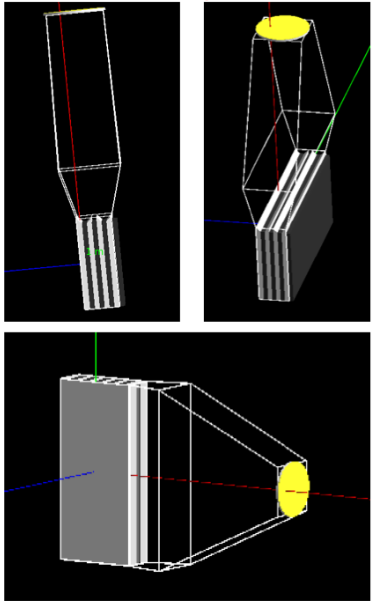


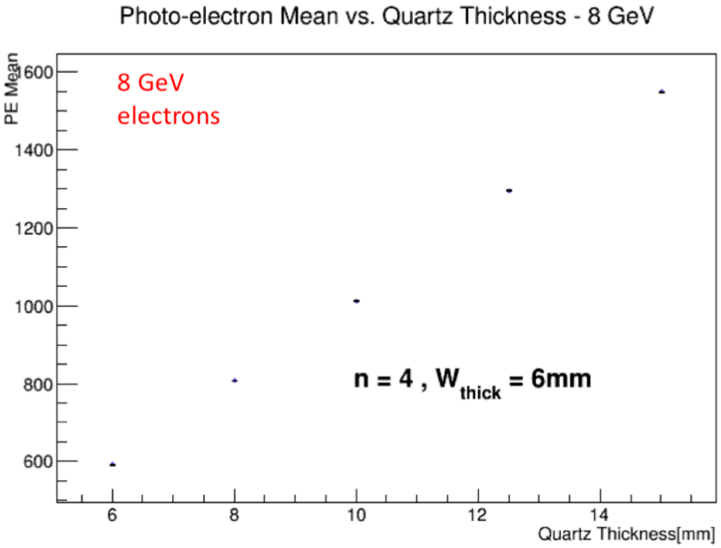


Optimization study (8 GeV):

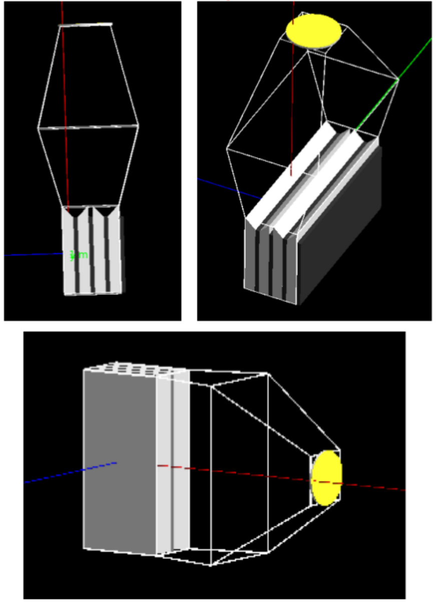
6mm thick tungsten, variable quartz thickness

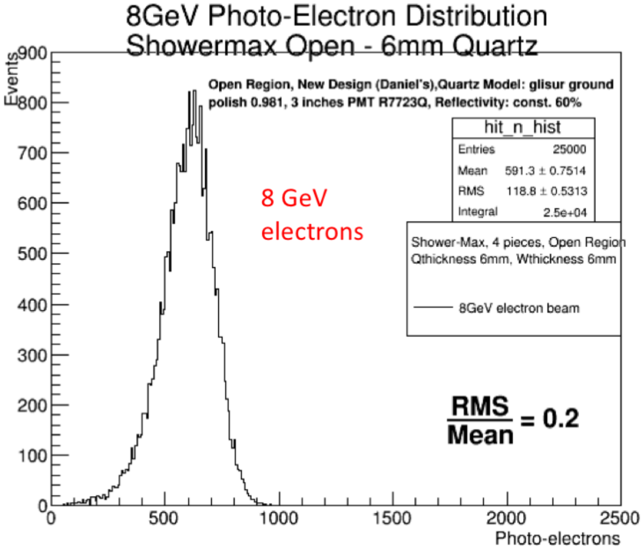
6mm quartz

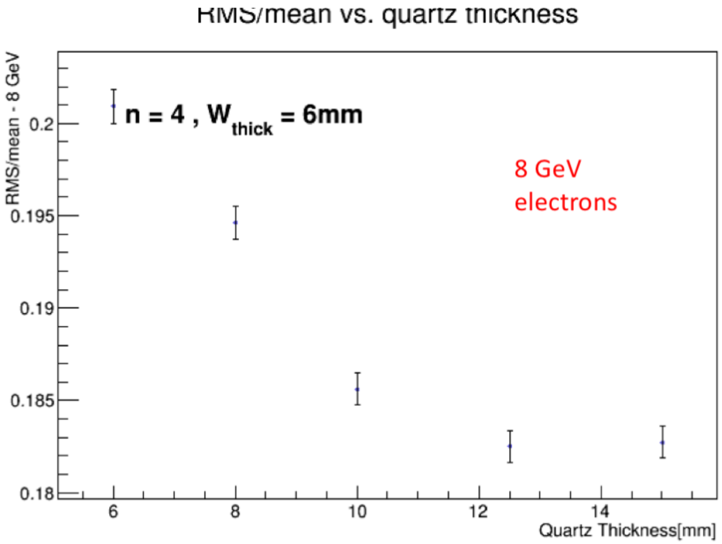


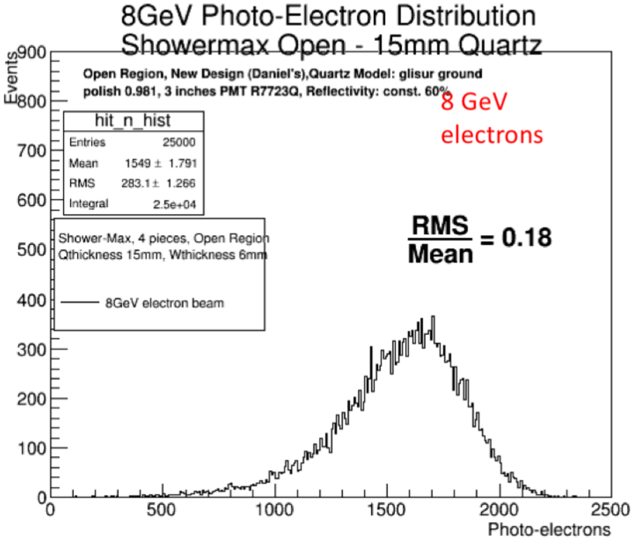


15mm quartz



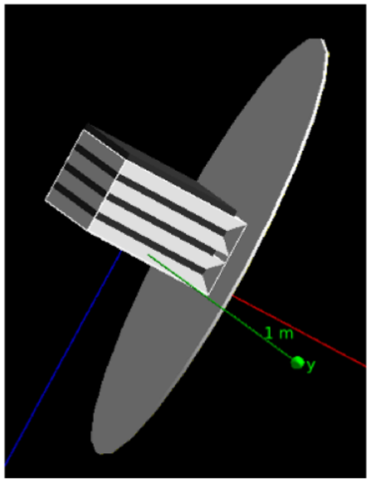




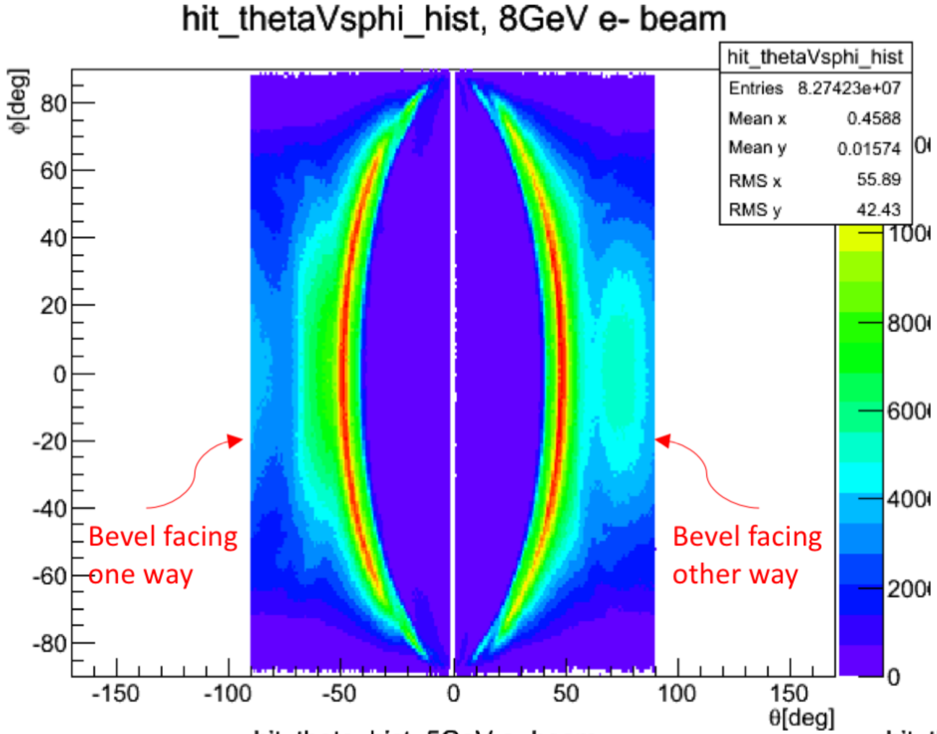


Optimal funnel-mirror angle and length study

Light exit angle study for optimizing funnel mirror



12.5mm quartz, 6mm tungsten, n = 4 layers

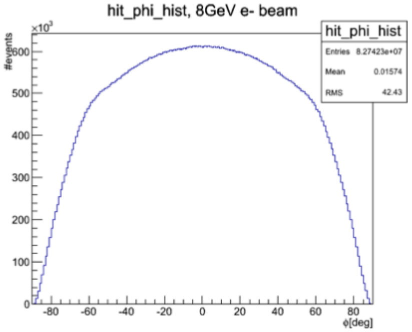


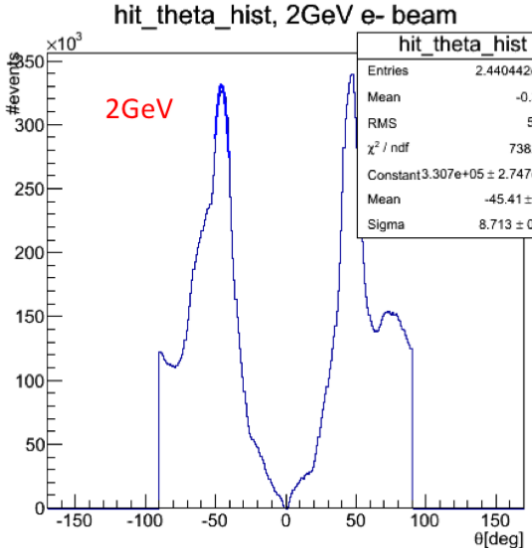
Results:

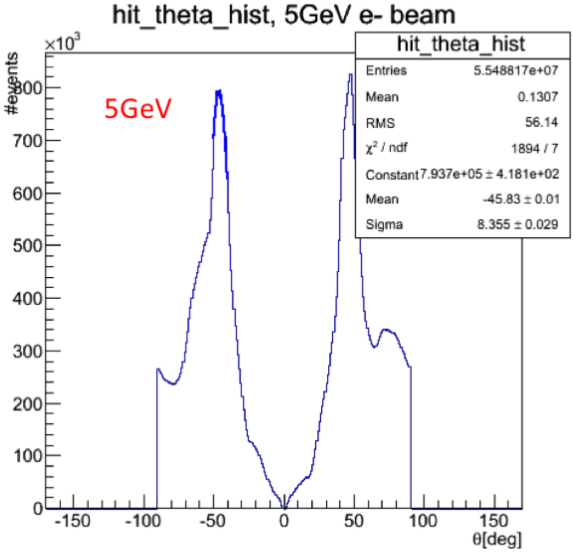
2GeV → θ_{peak} = 45.4°

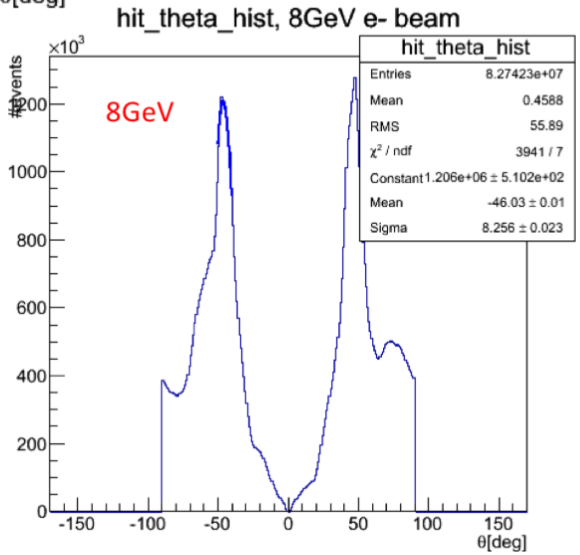
5GeV → θ_{peak} = 45.8°

8GeV → θ_{peak} = 46.0°



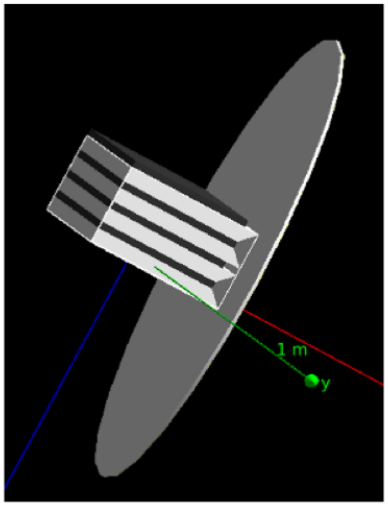






Which layers give the most light?

Light exit study for optimizing No. of layers



12.5mm quartz, 6mm tungsten, n = 4 layers