Shower-max Detector Plans and Radiation Hardness Testing

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For Daniel Sluder and ISU Parity Group

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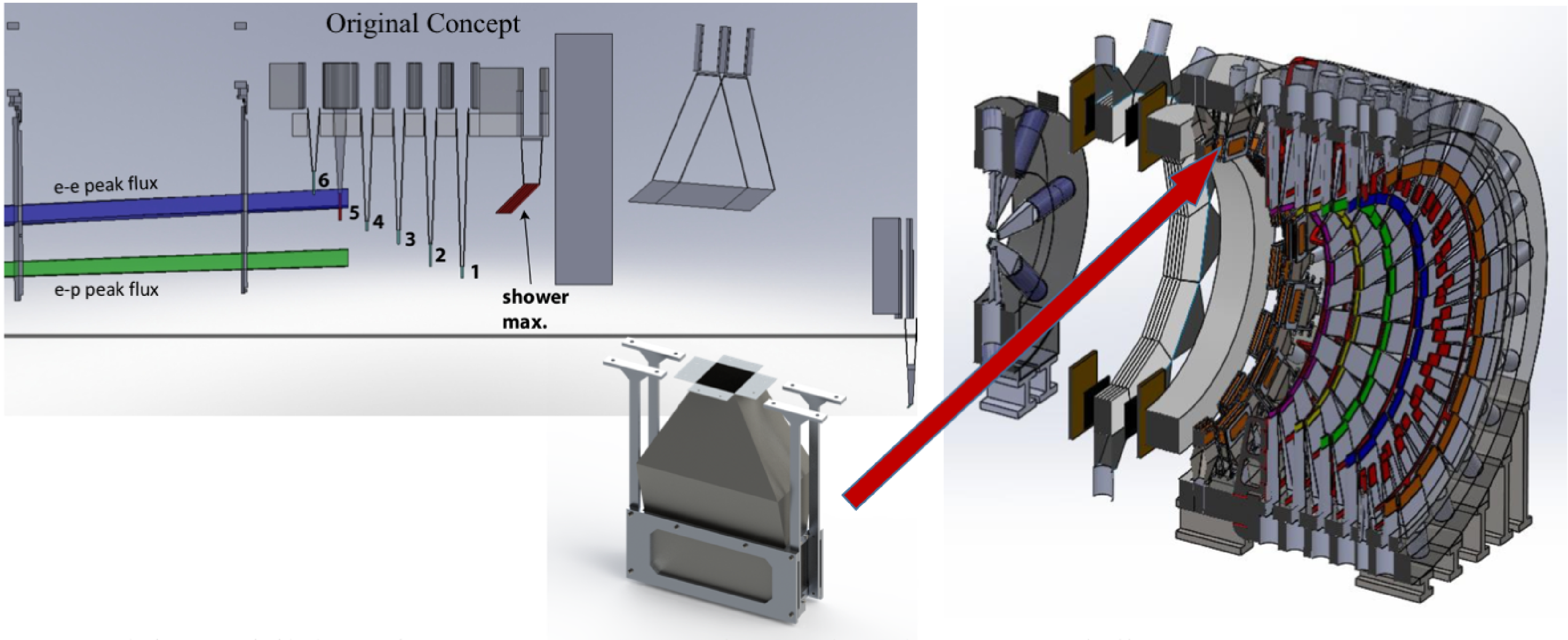
Shower-max Detector Plans and Radiation Hardness Testing

Outline

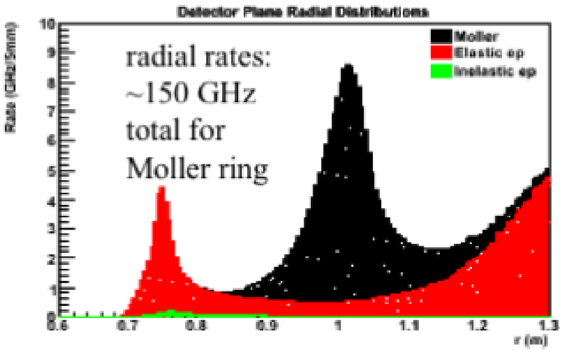
- Review baseline design and ring concept
- Understanding Shower-max resolution
- Prototype designs for testbeam
- Prototype construction and testbeam Plans
- Summary and Future Work
- Rad Hard Tests at the Idaho Accelerator Center
- Summary and Future Work

Shower-max Motivation & Requirements

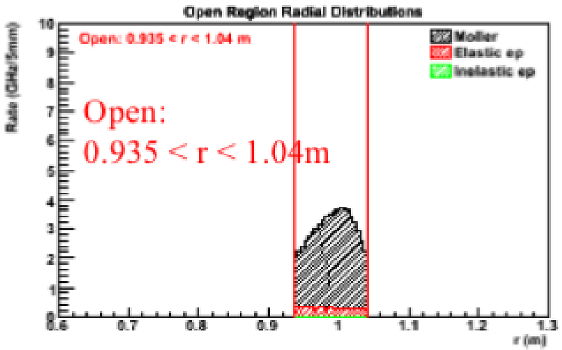


- Provides additional measurement of e-e ring integrated flux
- Weights flux by energy ⟹ less sensitive to low energy and hadronic backgrounds
- Will also operate in tracking mode to give additional handle on background (pion) identification – gives MIP-like signal
- Should have good resolution over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

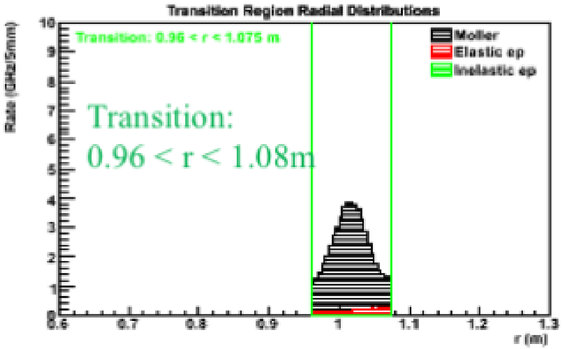
Shower-max phi-segmentation, rates and energies



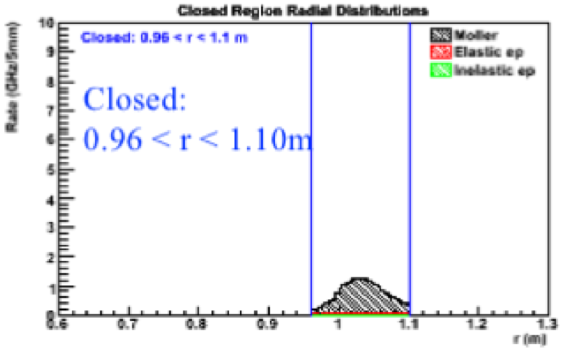
radial rates:
~150 GHz
total for
Moller ring



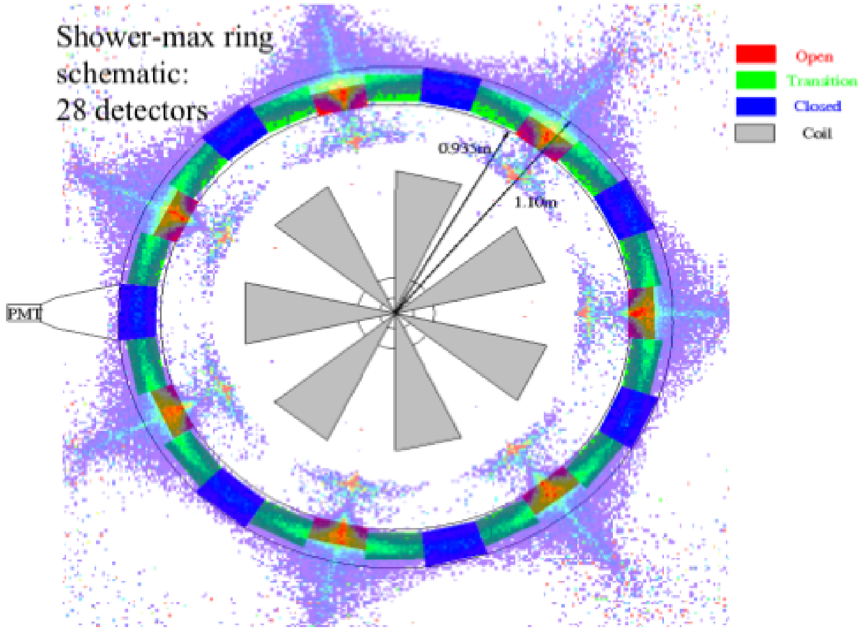
Open:
0.935 < r < 1.04m



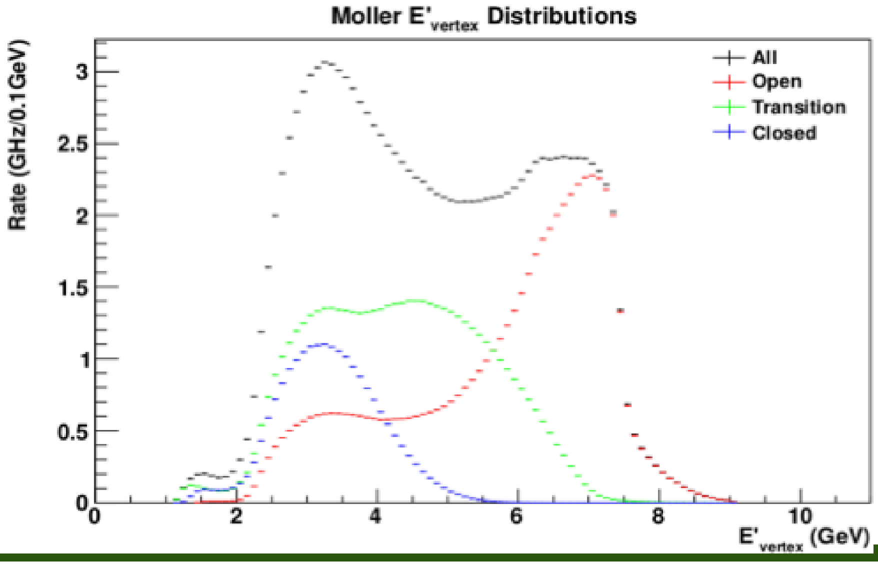
Transition:
0.96 < r < 1.08m



Closed:
0.96 < r < 1.10m



Shower-max ring
schematic:
28 detectors

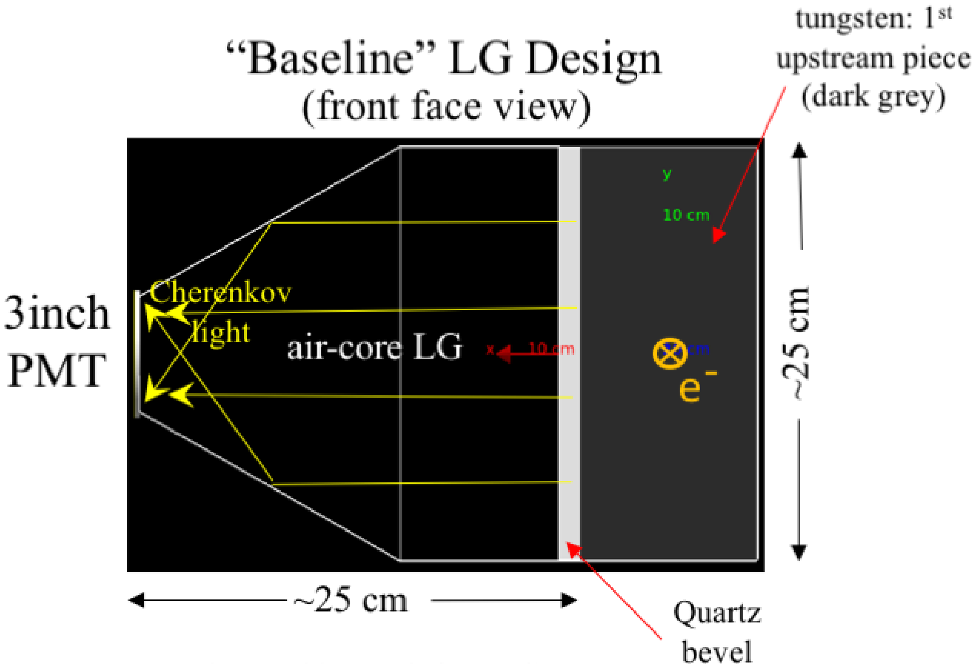


- Large range of rates and energies for different phi-region detectors:
  - Open ~9 GHz/det; 2 - 9 GeV, peak at 7 GeV…
  - Closed ~3.5 GHz/det; 2 - 5 GeV, peak at ~3 GeV
  - Transition ~4.5 GHz/det; 2 - 7 GeV, 3 – 5 GeV plateau

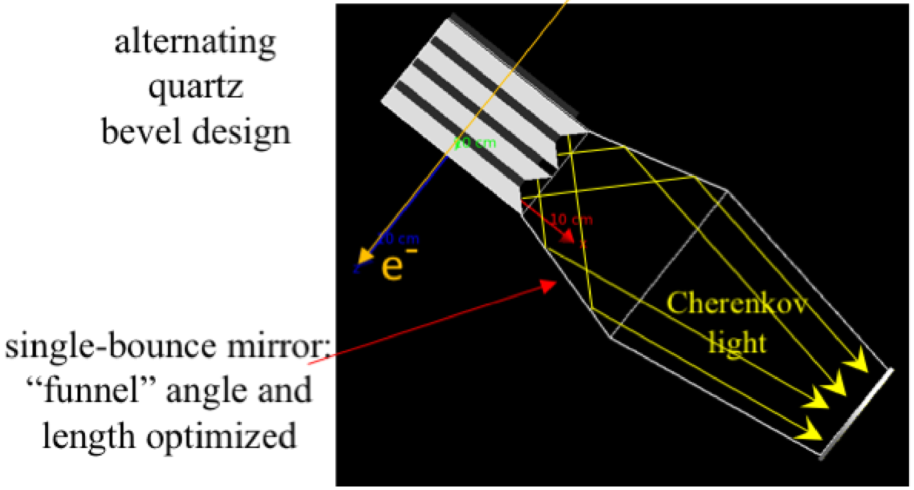
Baseline Design Stack and Light Guide Concepts

- 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)



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

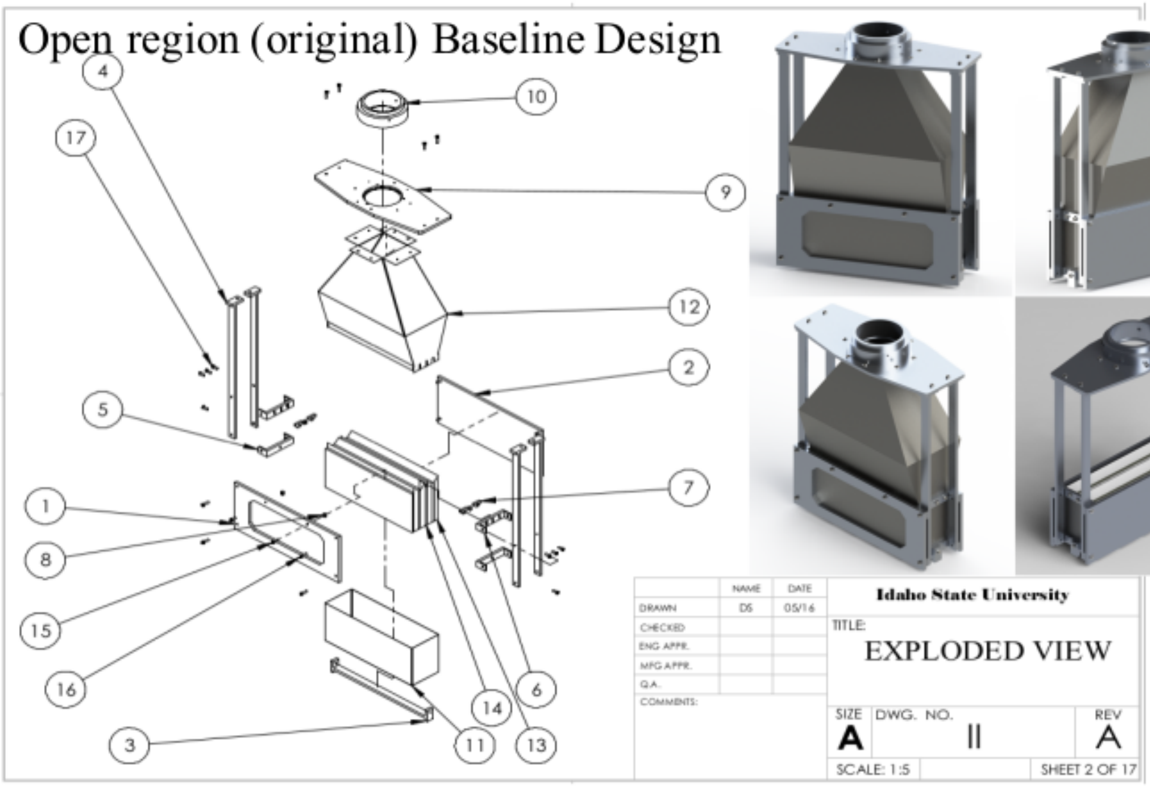


“Baseline” Design
(side view)

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

Baseline ShowerMax Design and Ring Concept



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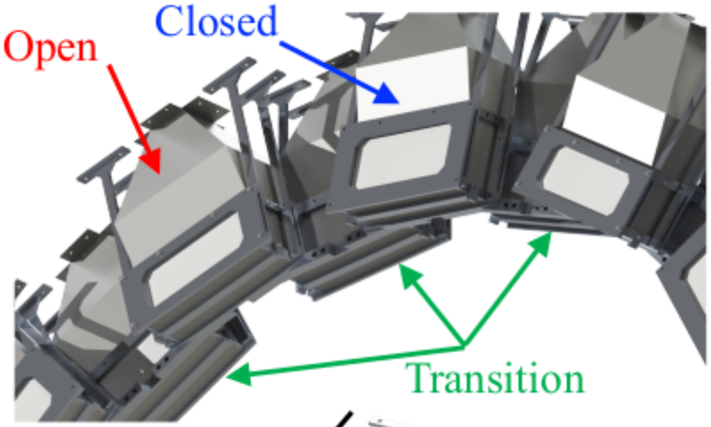
MFG APPR.		
Q.A.		
COMMENTS:		

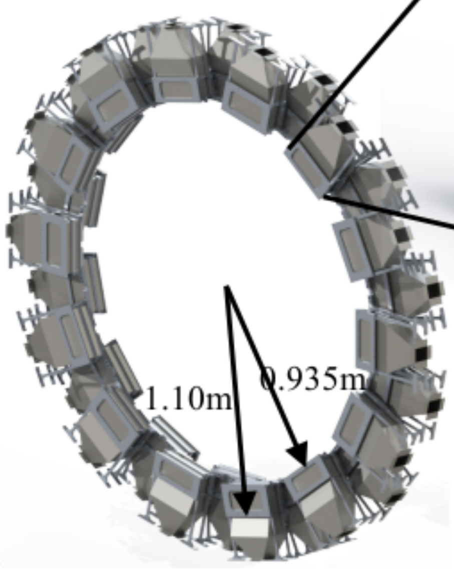
Idaho State University

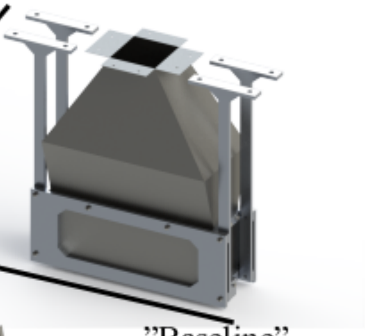
TITLE:
EXPLODED VIEW

SIZE A DWG. NO. 11 REV A

SCALE: 1:5 SHEET 2 OF 17







"Baseline"

- Engineered shop drawings for full-scale prototypes in hand
- ***PLANS***: Finalized prototype Stack designs last fall and ordered prototype quartz in Nov 2017, construct in winter/spring 2018 and test in summer/fall using 2 - 10 GeV electron SLAC testbeam
- 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

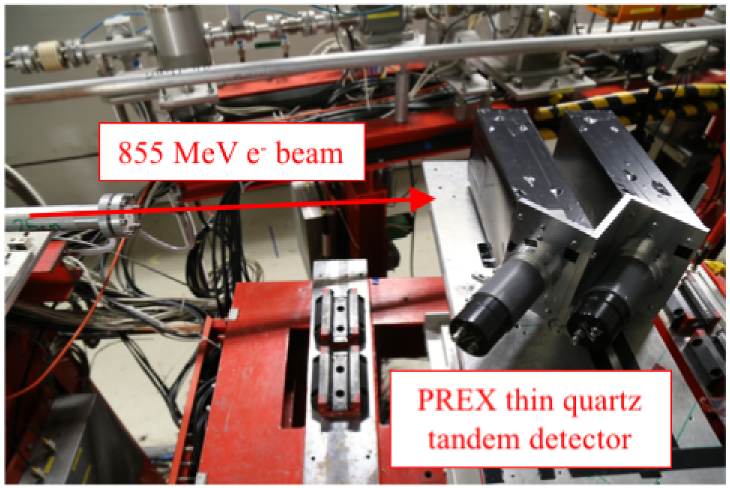
Costs: Total w/ spares
quartz: $150k (Heraeus)
tungsten: $60k
alum.: $10k (machined)
grand total: $220k

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

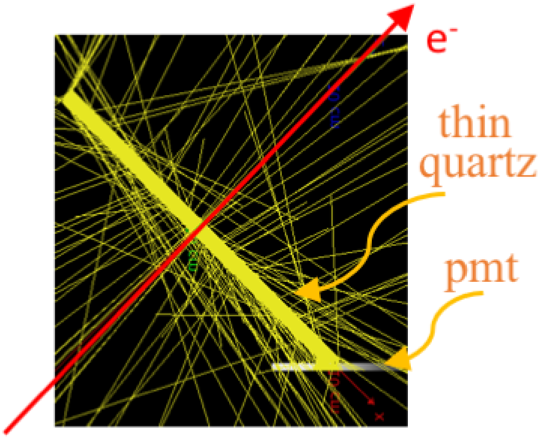
Understanding Showermax Resolution

Monte Carlo tuning and Shower-max Simulations

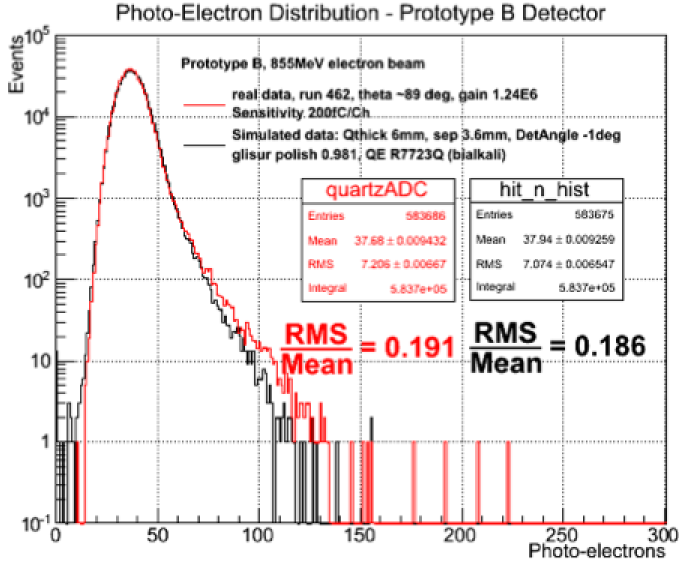
- Quartz optical G4 properties benchmarked at MAMI: Glisur ground polish parameter ~0.981



MAMI testbeam with PREX detector



G4 event visualization for PREX detector

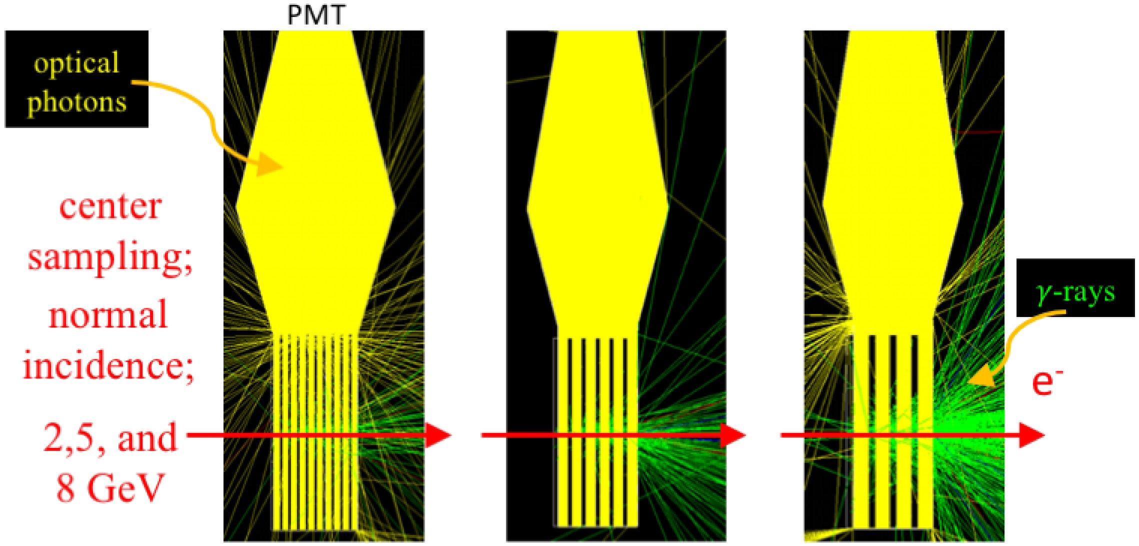


PE dists: *Real data* vs. *Sim data*

- 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

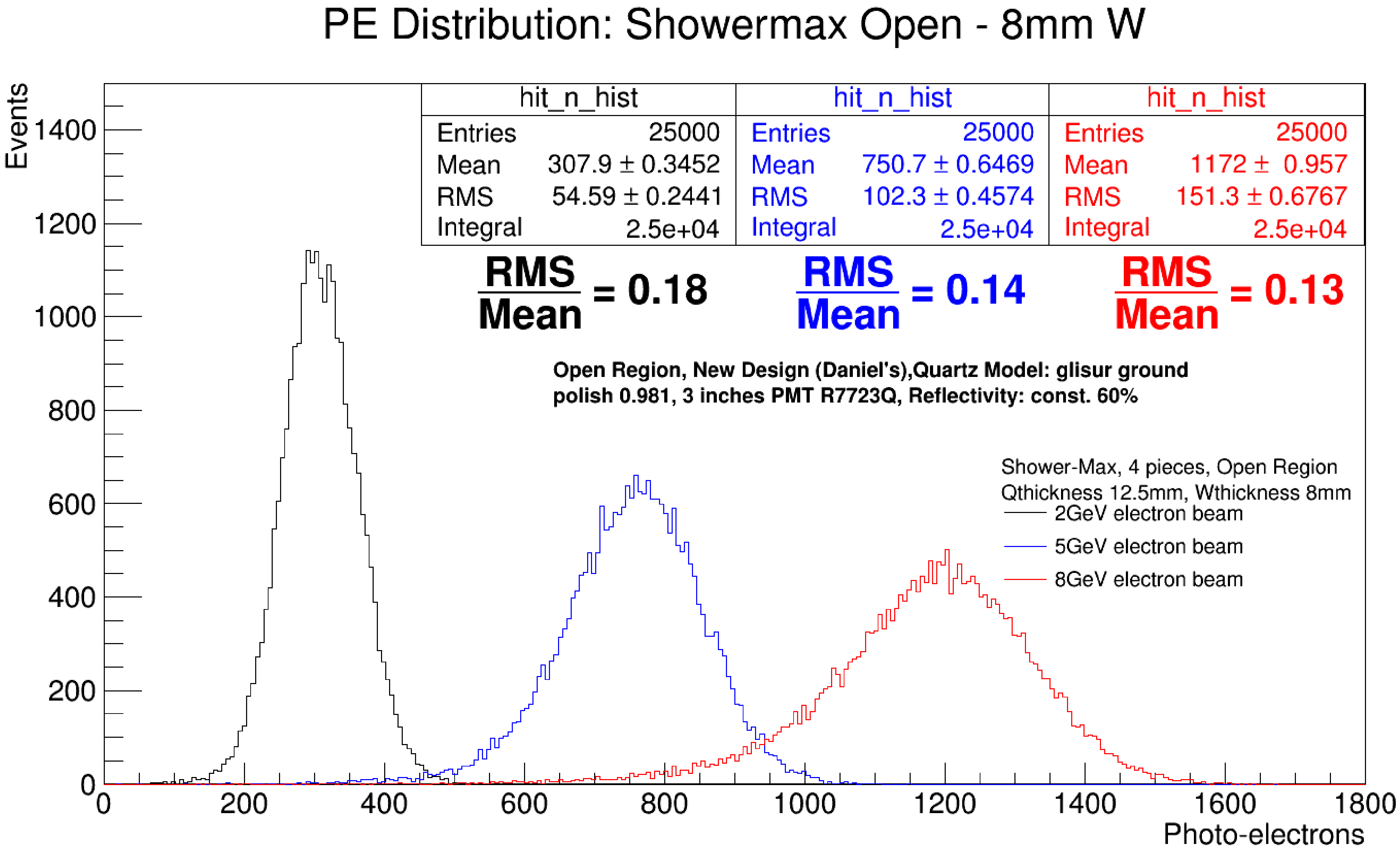
Conclusion:

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



Shower-max event visualizations

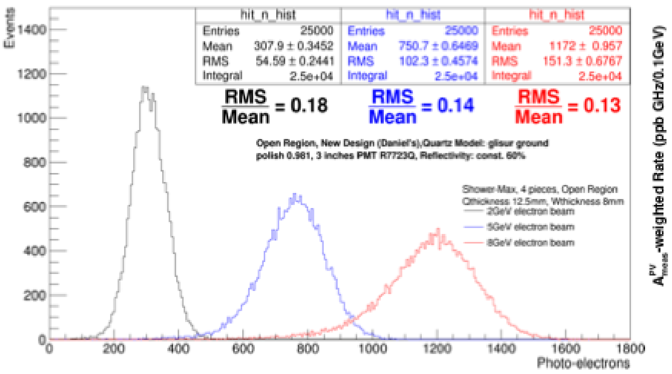
4-layer baseline PE Dists for 2, 5, and 8 GeV

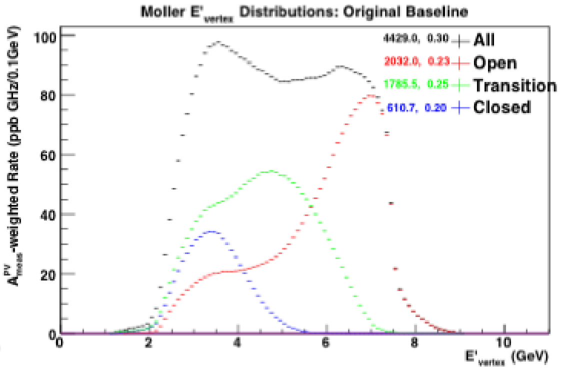


What is Resolution of Showermax (Open Septant)

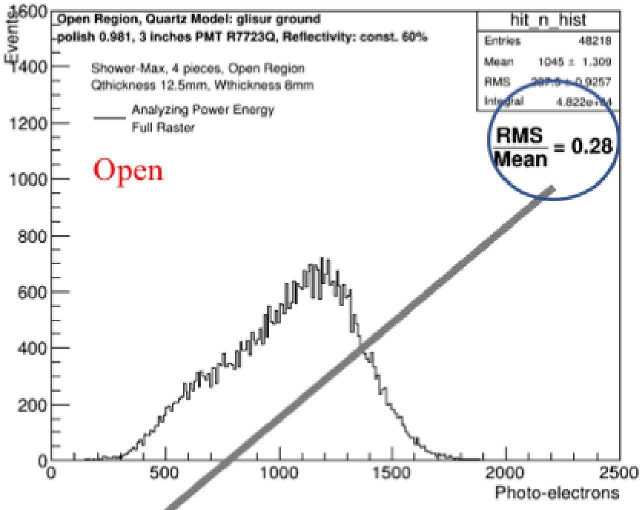
How well does the Showermax count electrons?

PE Distribution: Showermax Open - 8mm W

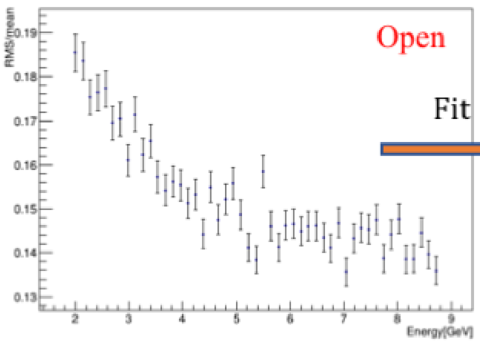




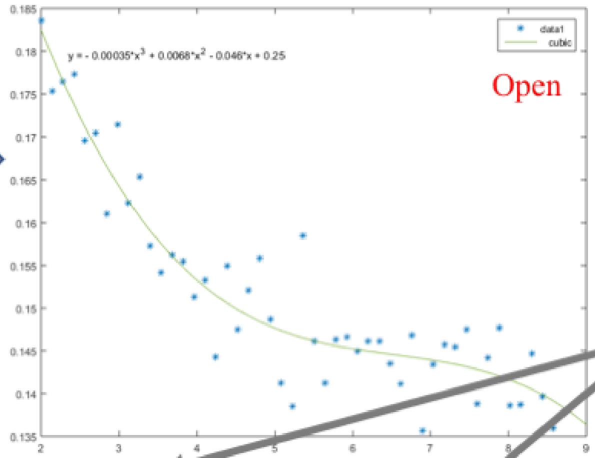
Open ShowerMax Photo-Electron Distribution



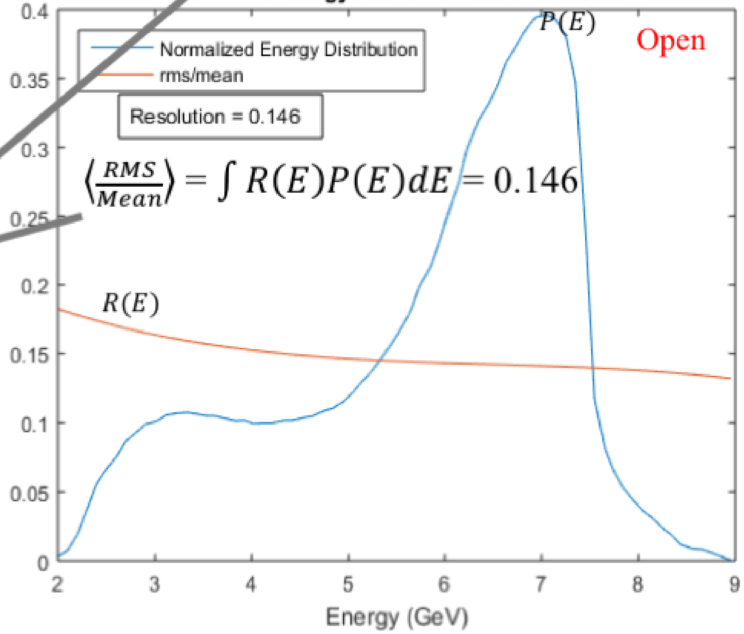
Resolution vs. Energy



Fit



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:

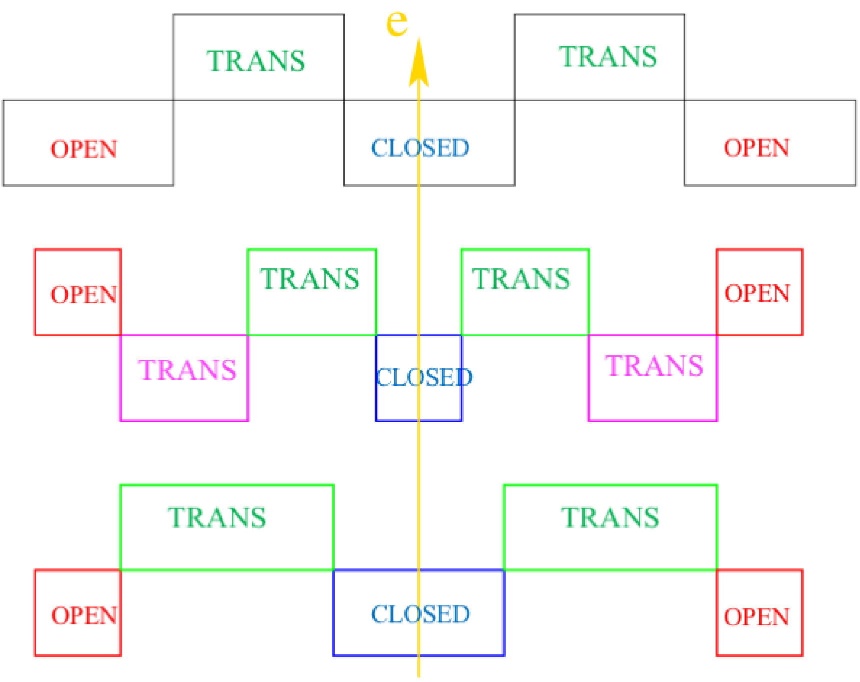
- Excess Noise = $\sqrt{1+\left\langle \frac{RMS}{Mean}\right\rangle^2}$ - 1 = 1.1%

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



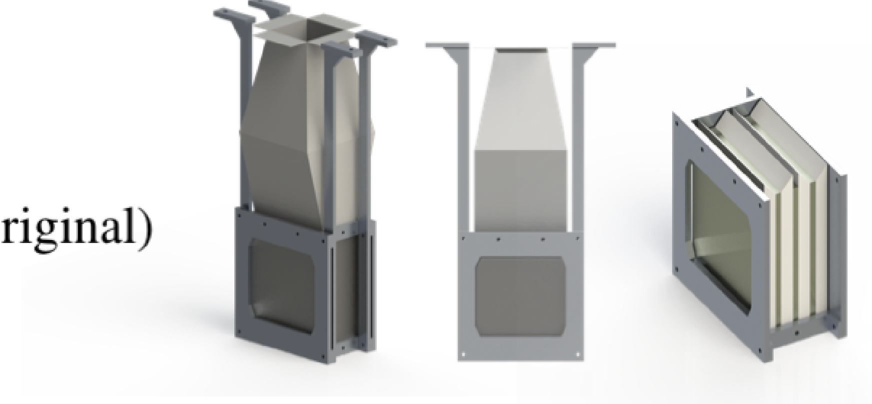
Baseline (original)

HalfOpen/HalfClosed

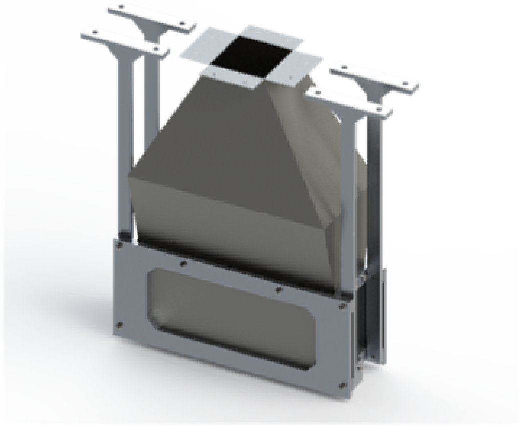
HalfOpen/FullClosed

Radial view of various phi segmentation ideas

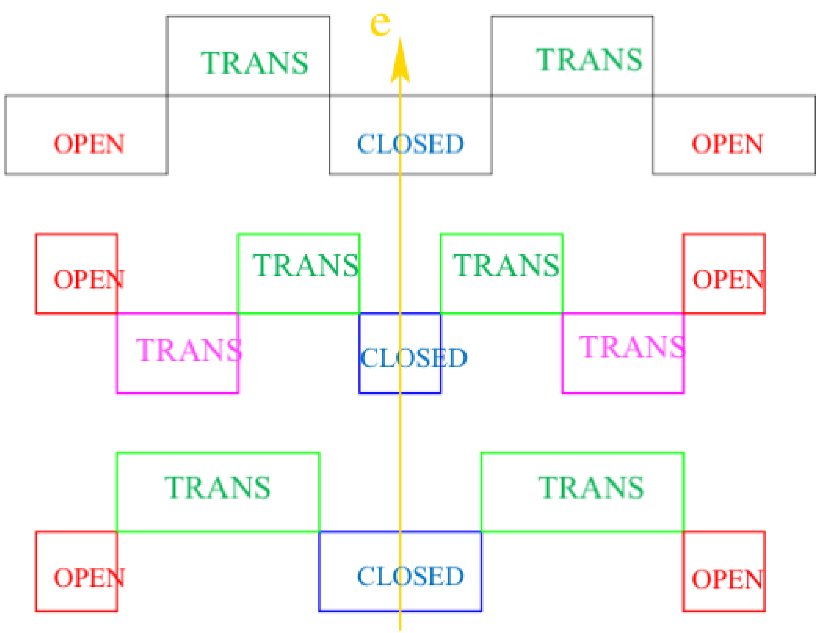
Half-width, “full-stack” Shower-max



Full-width, “full-stack” Shower-max



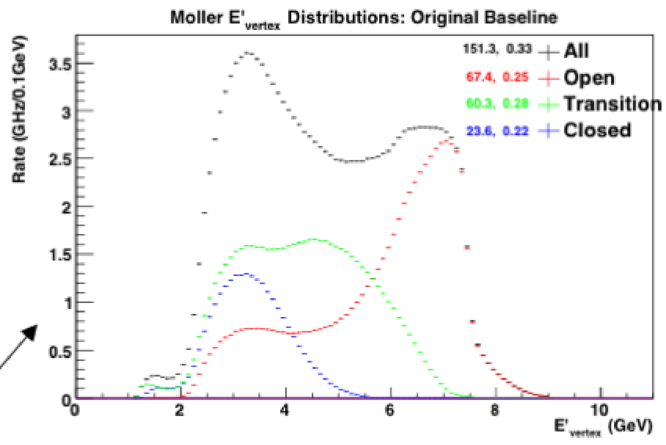
Energy Acceptance for Different phi Segmentation

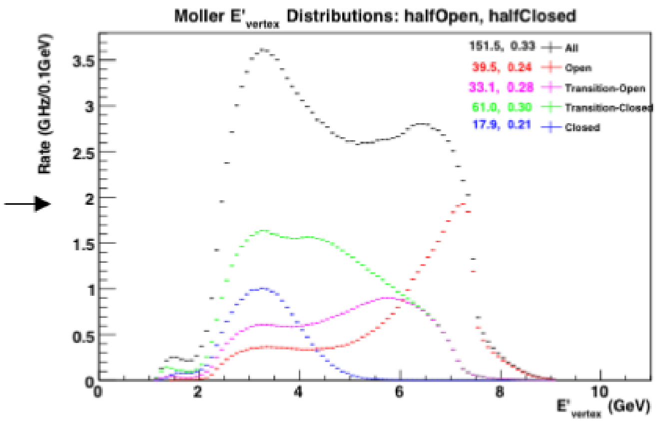


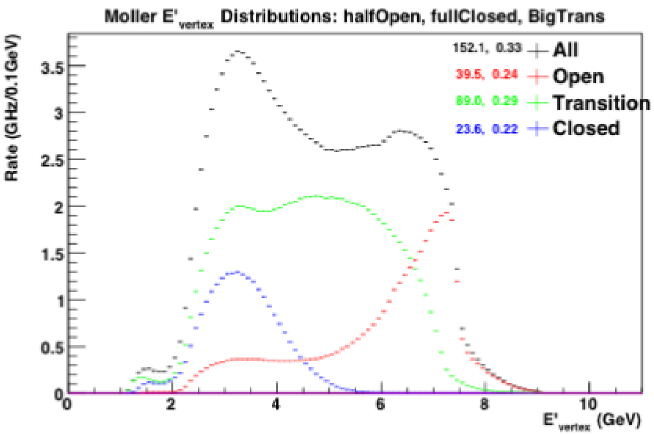
← Baseline (original)

← HalfOpen/HalfClosed →

←HalfOpen/FullClosed







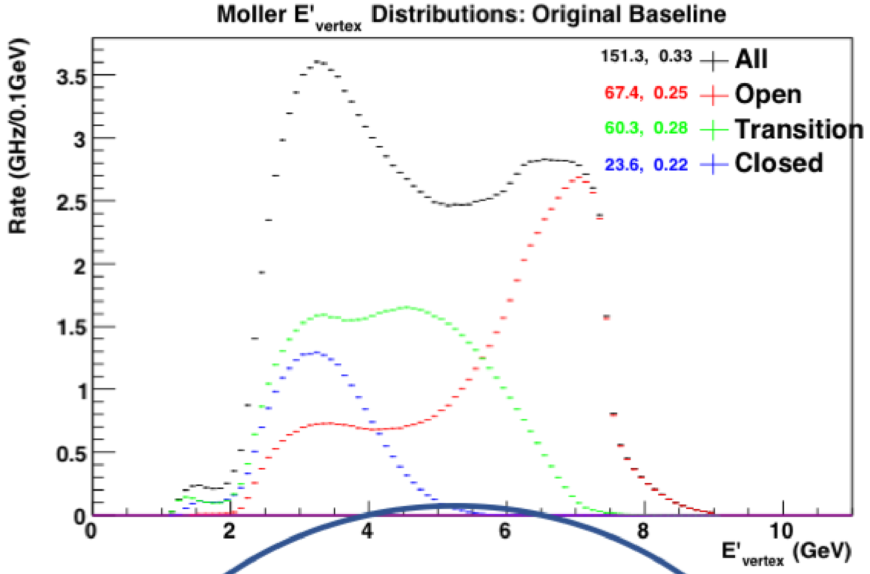
Radial view of various phi segmentation ideas

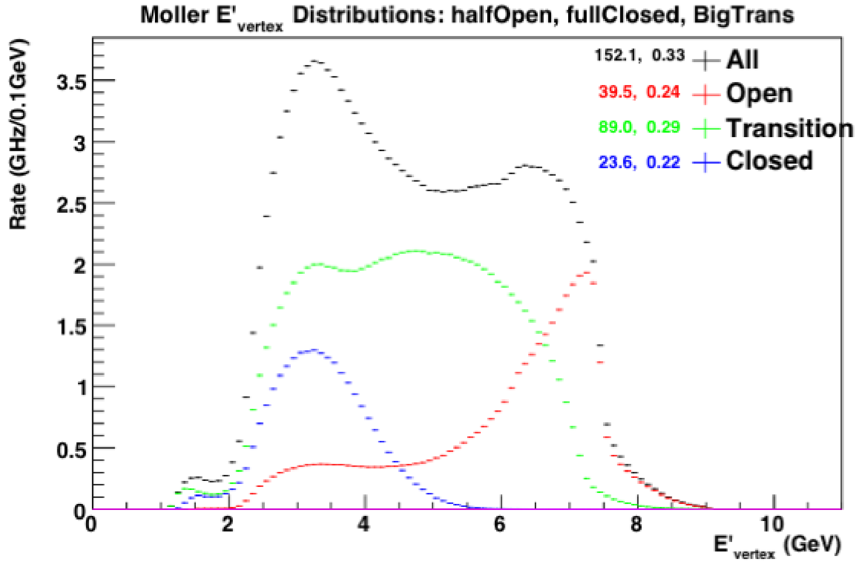
- These ideas give no improvement due to the spectrometer's significant phi defocusing…The original segmentation is best

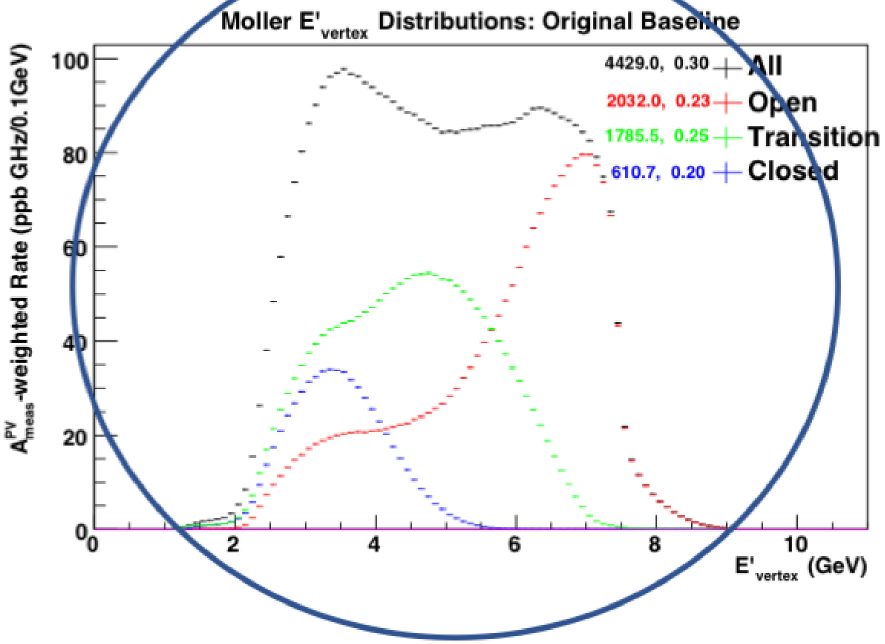
Rate and A^{PV}_{meas}*Rate – weighted Energy Acceptance

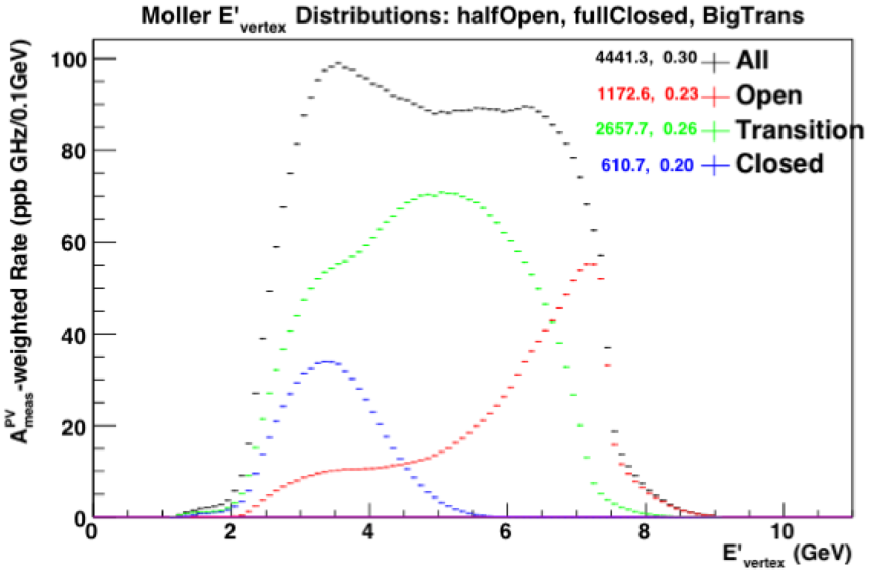
Original Baseline

half Open/ Full Closed

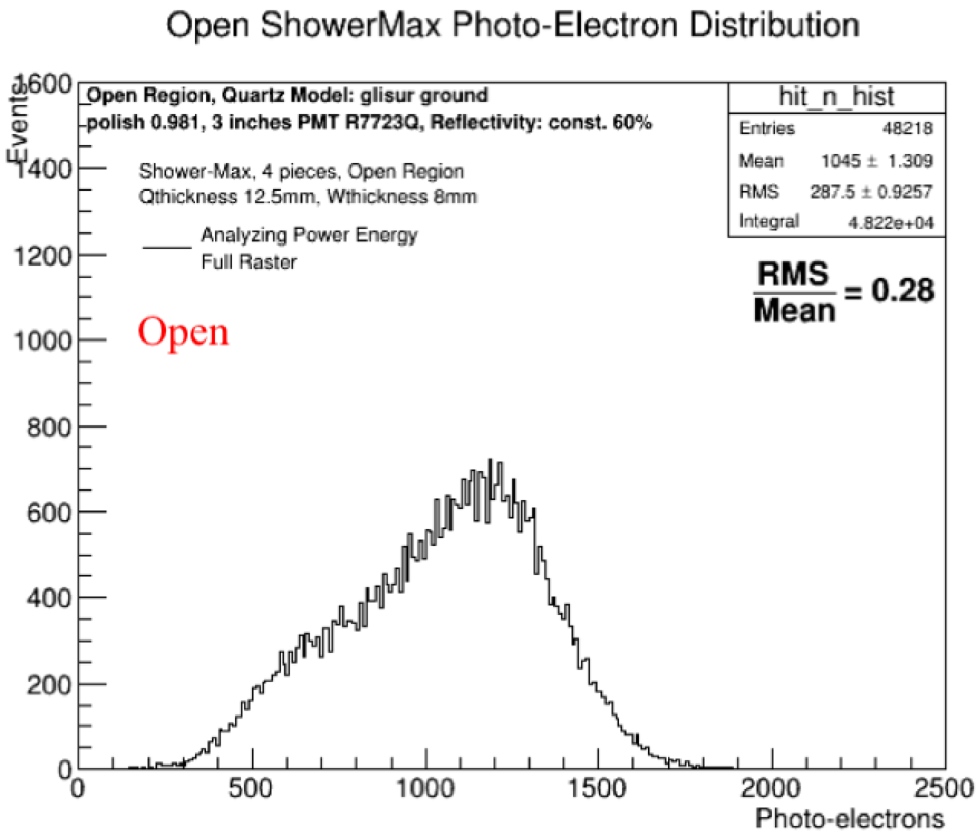


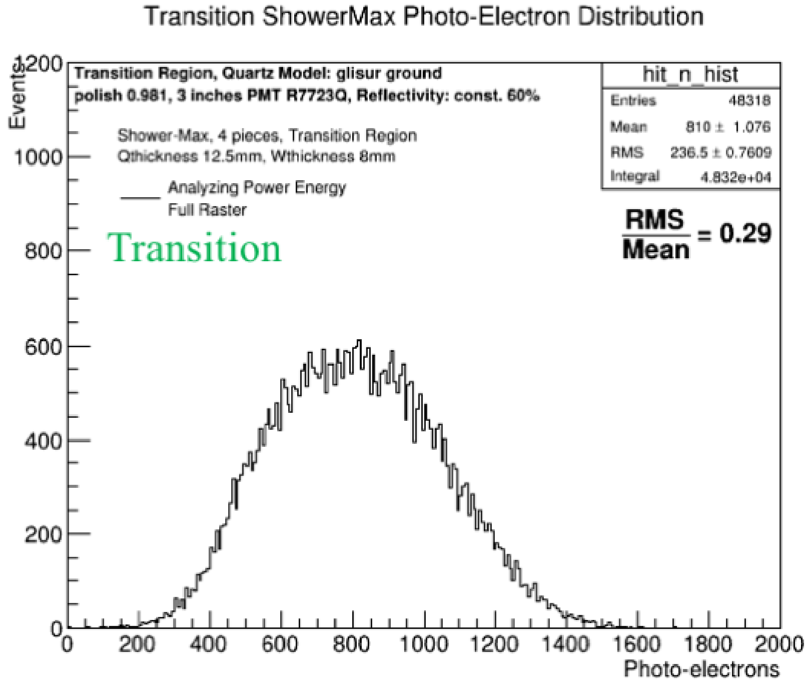


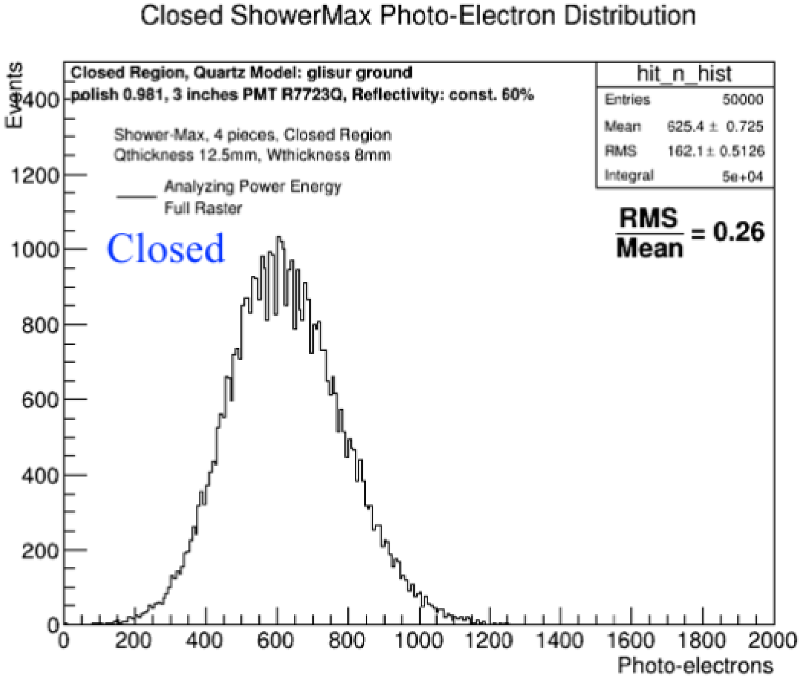




Baseline PE distributions weighted by A^{meas}_{PV}



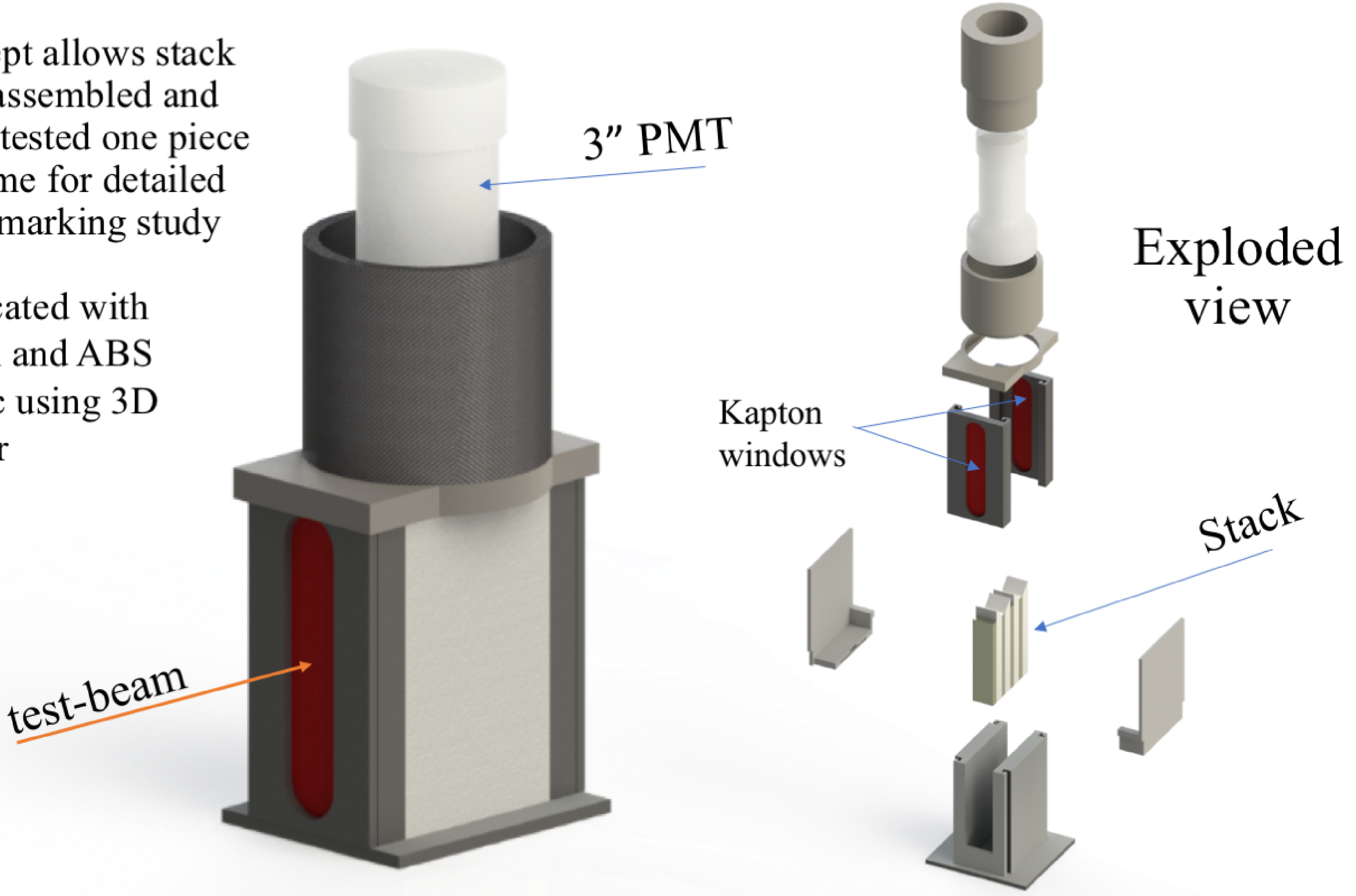




Prototype Designs for Testbeam

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

--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

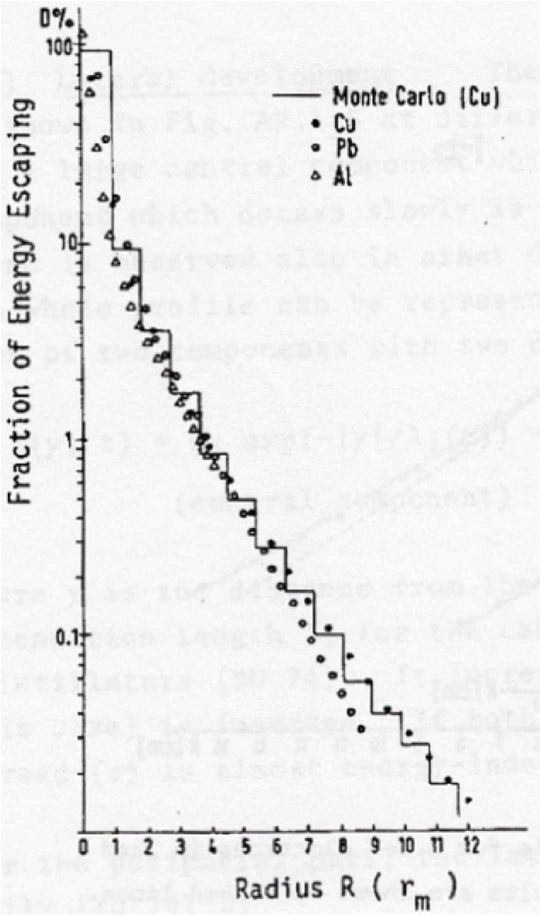
- For the baseline design:

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

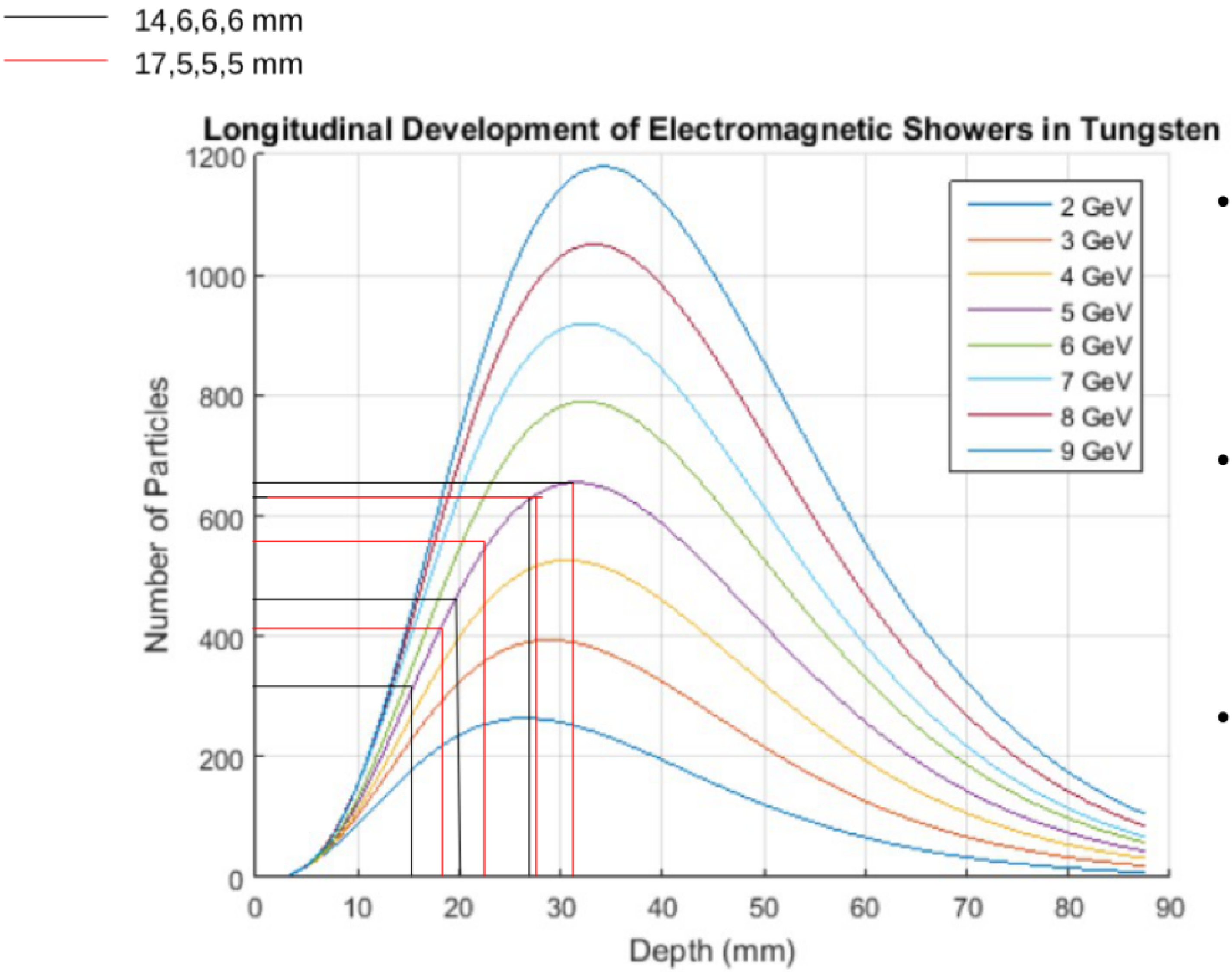
- If use 10/90 Cu/W:

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

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



Longitudinal Development of EM Shower

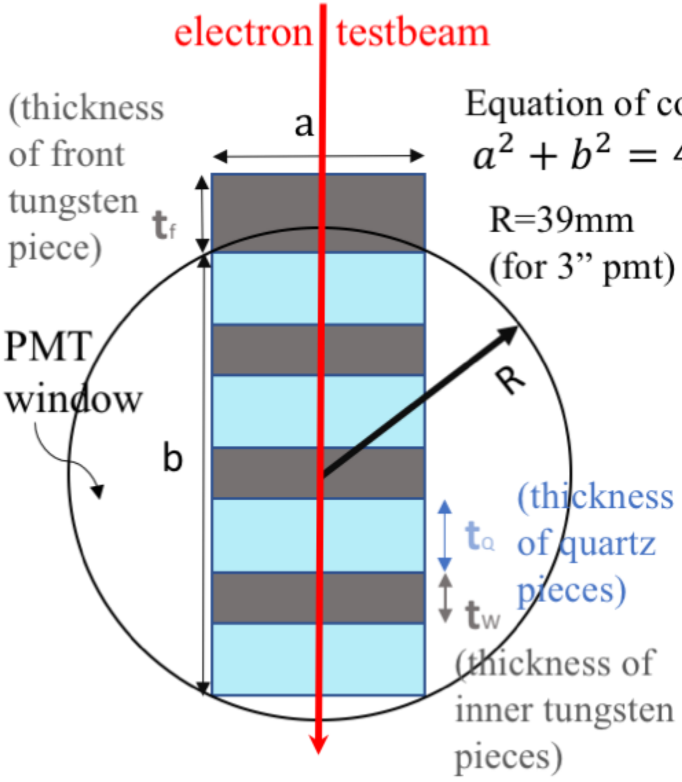


- Red and black lines indicate points of quartz sampling for Config #2 and #3 (see next slide)
- The shower maximum depth scales logarithmically with particle energy, while the peak # of particles scales linearly
- For pure tungsten, shower max occurs at ~24mm for 2 GeV and ~33mm for 8 GeV

  --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:

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

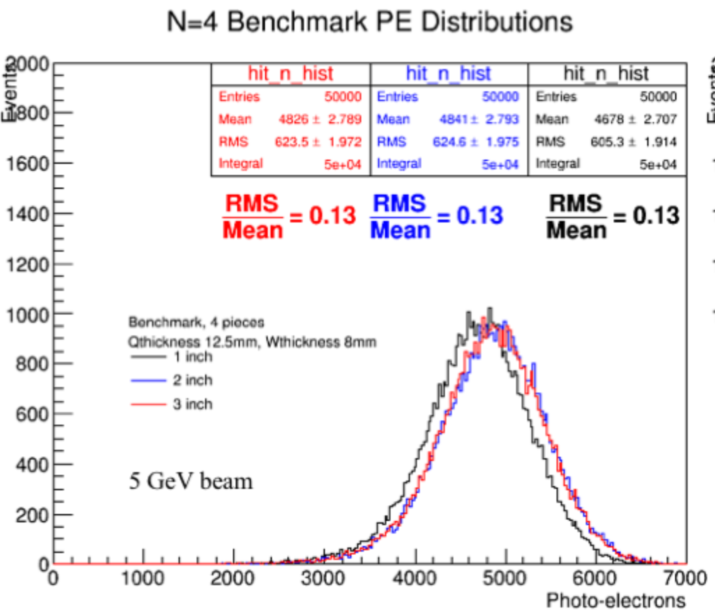
R=39mm (for 3” pmt)

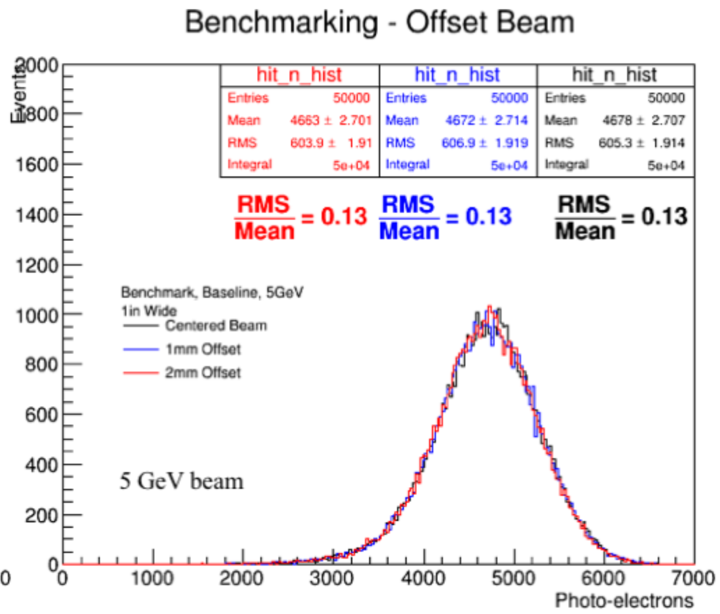
- This table gives 4 candidate stack configurations under study

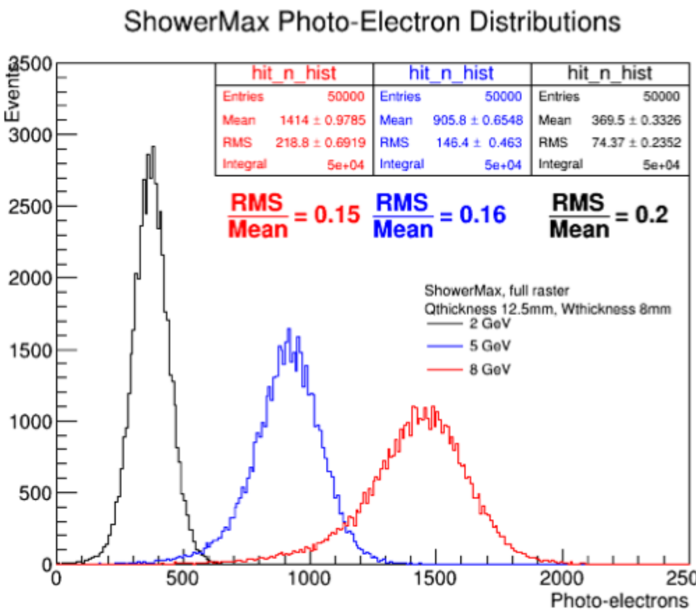
Config #1 is the baseline. Column “a” represents the allowed widths of the stacks given their thicknesses (Col “b”). Leakage represents the amount of transverse shower (light) leakage due to the ~narrow benchmarking stacks.

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…

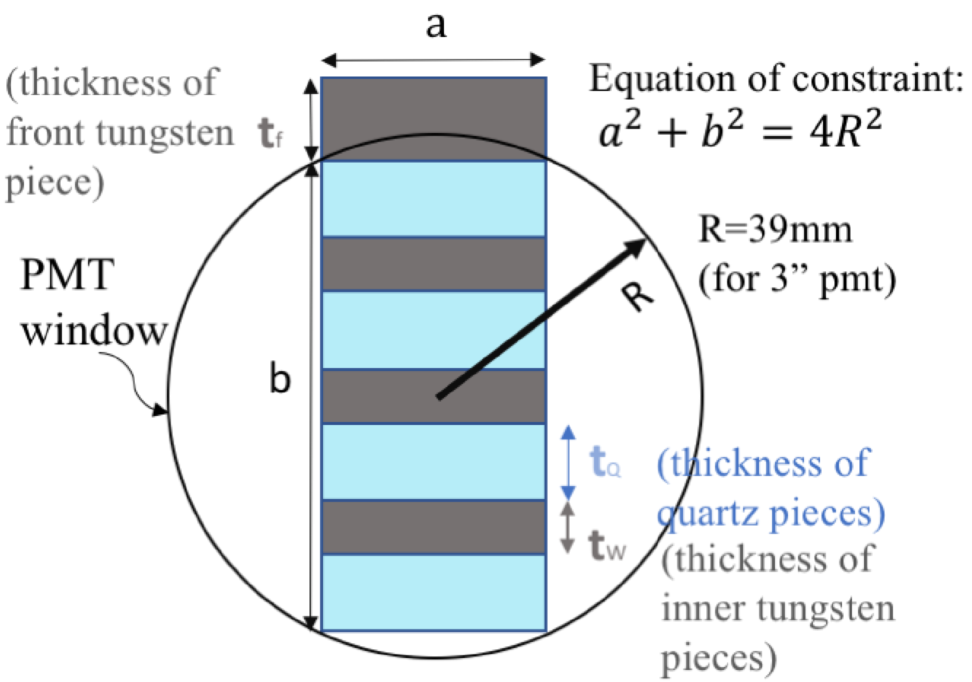
What if the quartz thickness is reduced?

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:

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

R=39mm (for 3” pmt)

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	-

	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

	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	-

	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

	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 – 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

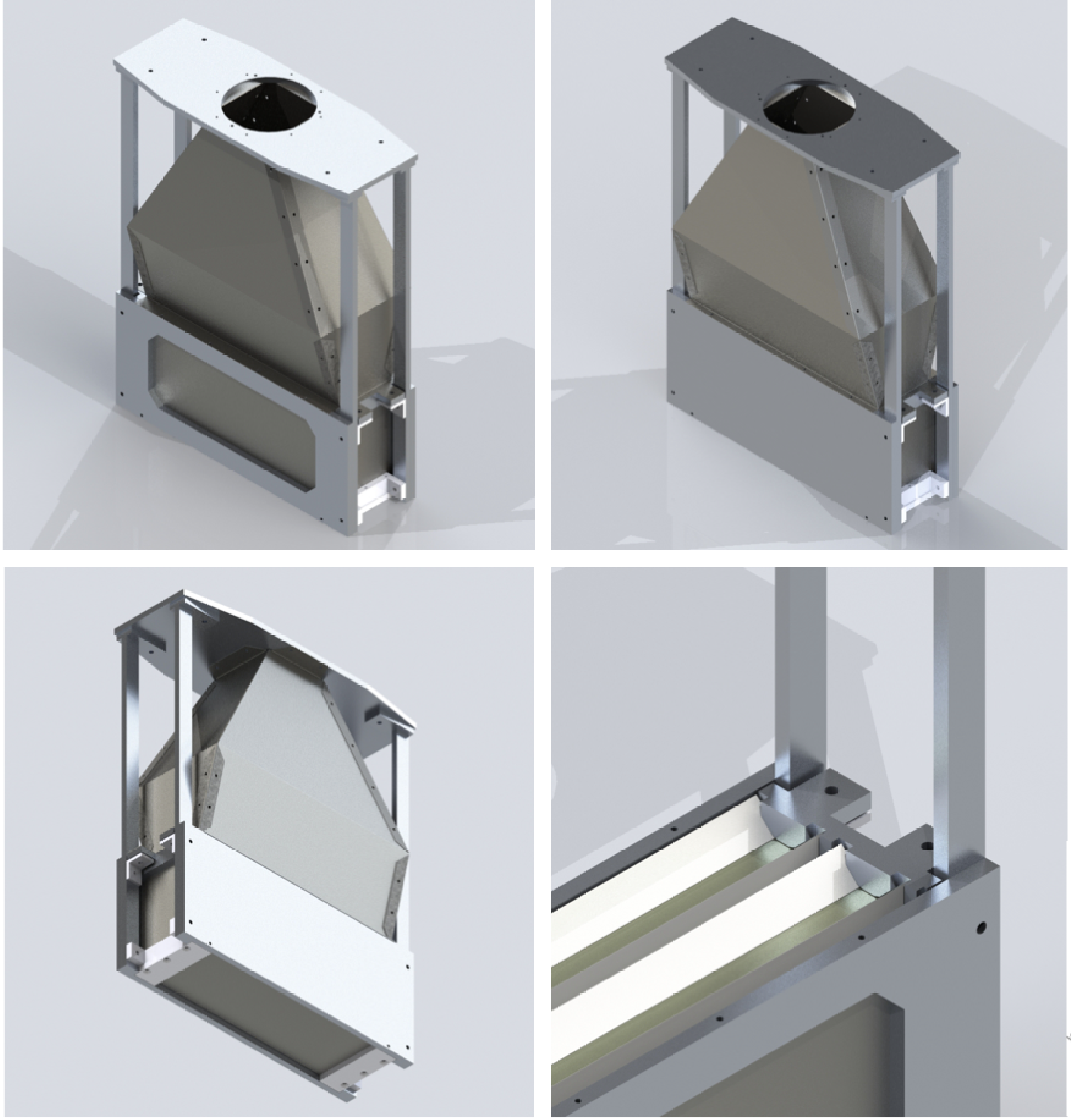
- For "benchmarking" prototype stack:
  - Quartz: 6 mm (thick) by 86 mm (tall) by 40 mm (wide) --4 pieces ($975/piece = $3.9k)
  - Quartz: 10 mm (thick) by 90 mm (tall) by 40 mm (wide) --4 pieces ($1005/piece = $4.0k)
  - Tungsten: 6 mm (thick) by 80 mm (tall) by 40 mm (wide) – 4 pieces ($85/piece = $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)

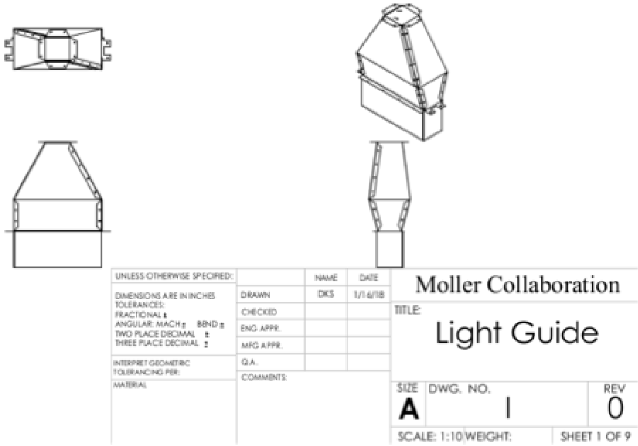
Purchasing these pieces allows for Configs 1, 3, and 4 (A and B) to be tested

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

- This purchase enables 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 Testbeam



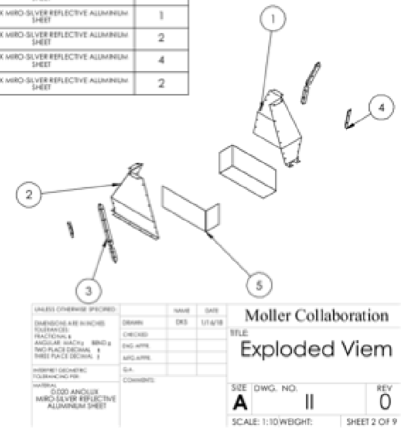


UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC
TOLERANCING PER:
MATERIAL

	NAME	DATE
DRAWN	DKS	1/16/18
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		
COMMENTS:		

Moller Collaboration
TITLE:
Light Guide
SIZE A DWG. NO. I REV 0
SCALE: 1:10 WEIGHT: SHEET 1 OF 9

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



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0.020 ANOLUX
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DRAWN	DKS	1/16/18
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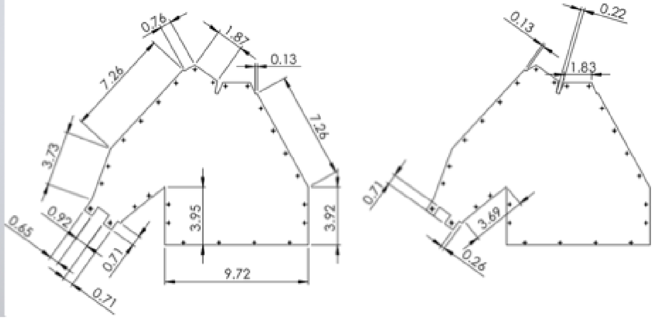
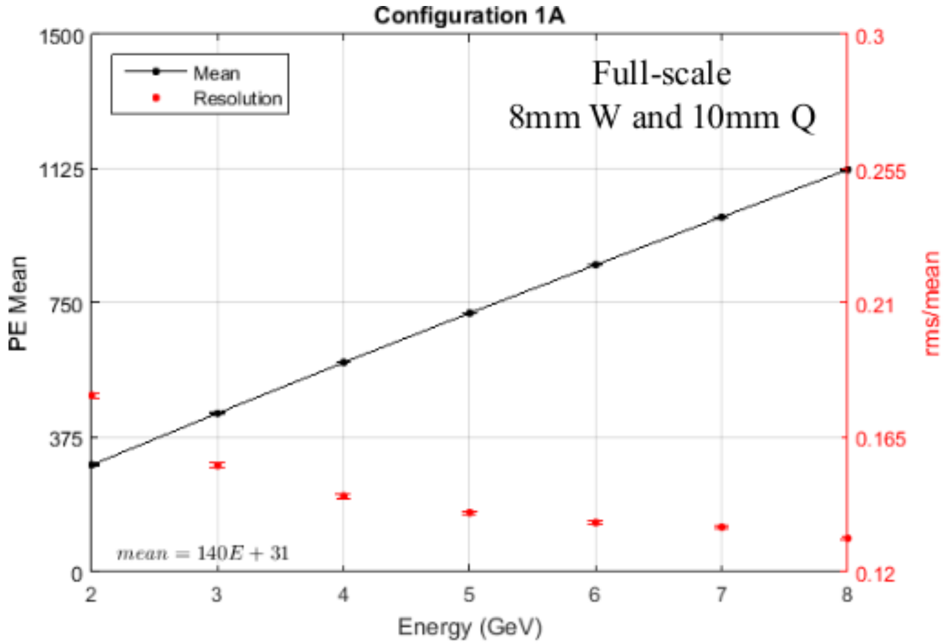
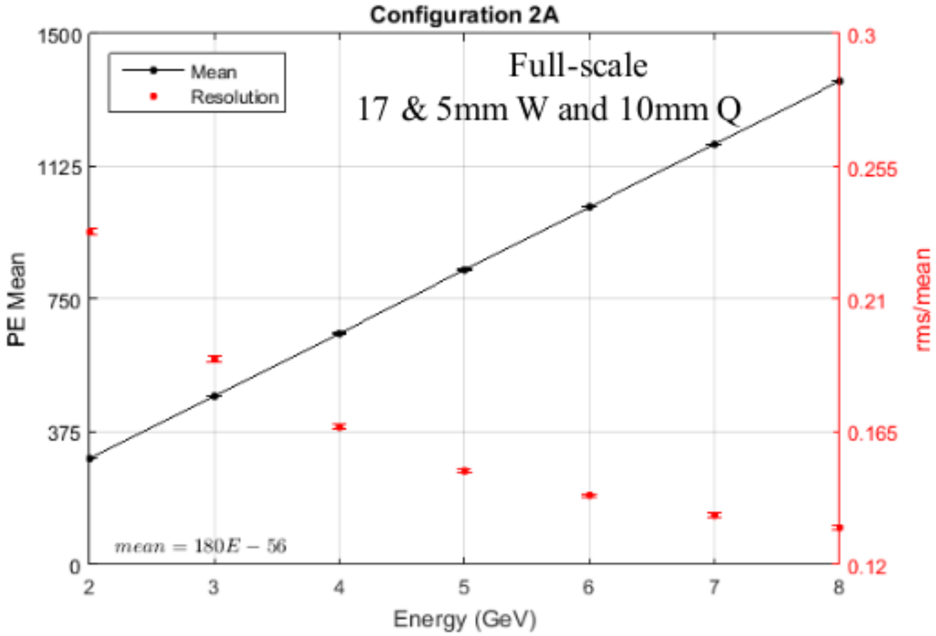


1A - 4A Mean PE and Resolution versus Energy



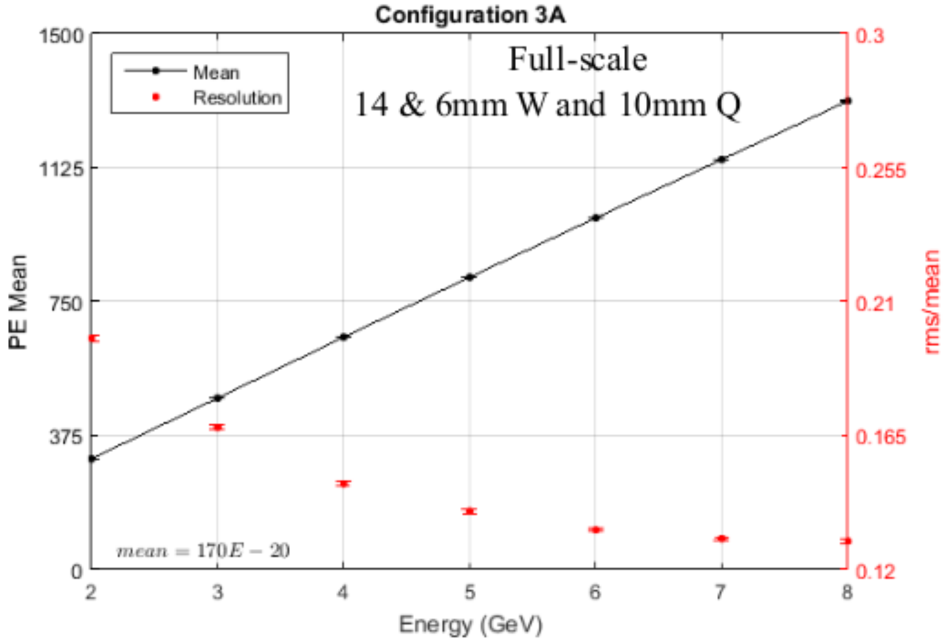
Full-scale
8mm W and 10mm Q

$mean = 140E + 31$



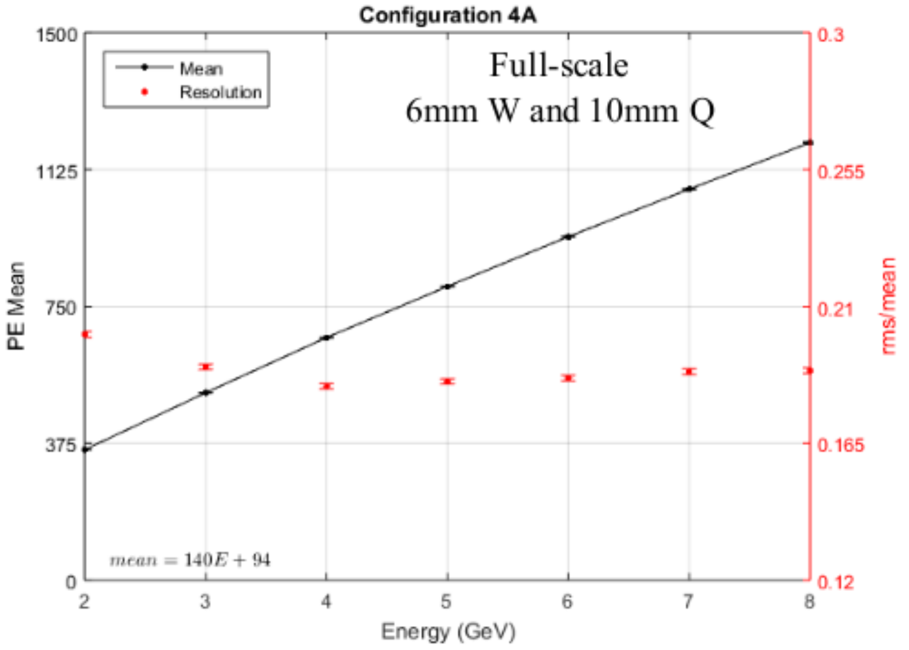
Full-scale
17 & 5mm W and 10mm Q

$mean = 180E - 56$



Full-scale
14 & 6mm W and 10mm Q

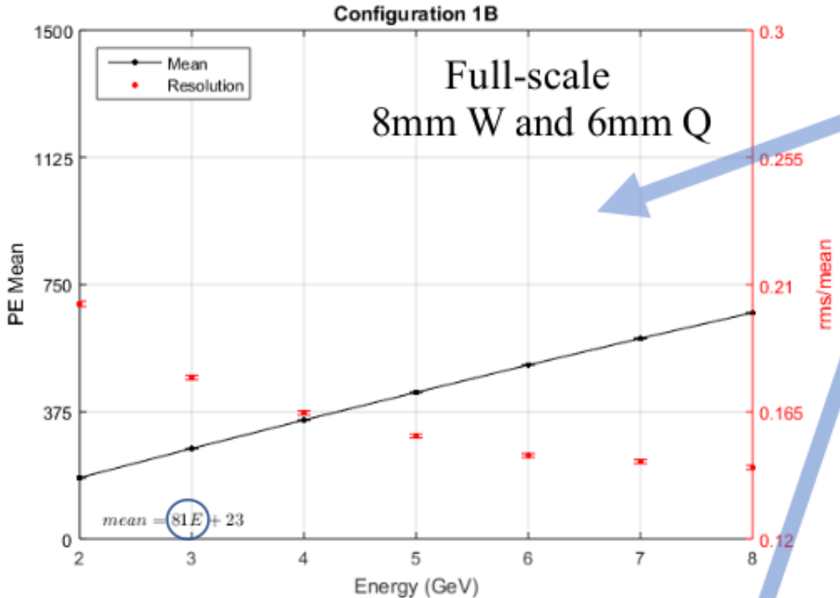
$mean = 170E - 20$

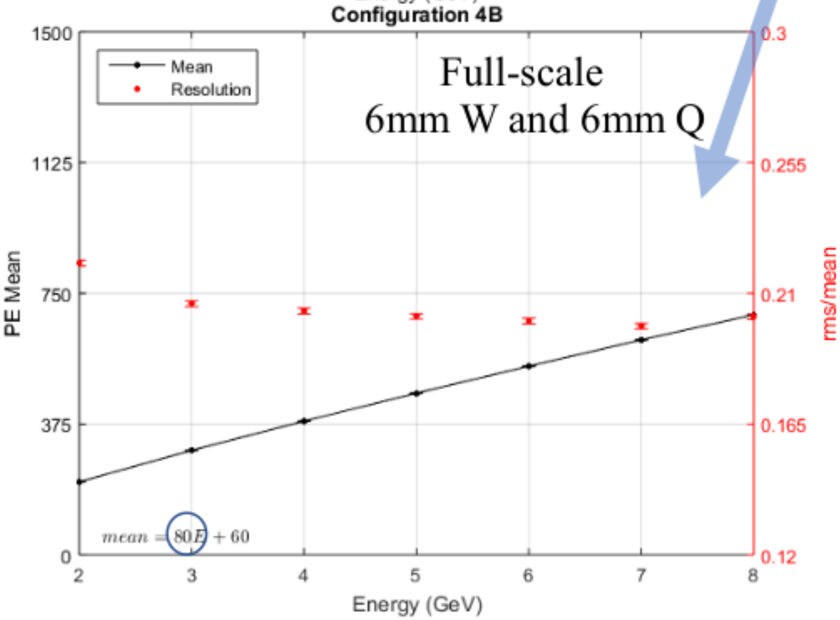


Full-scale
6mm W and 10mm Q

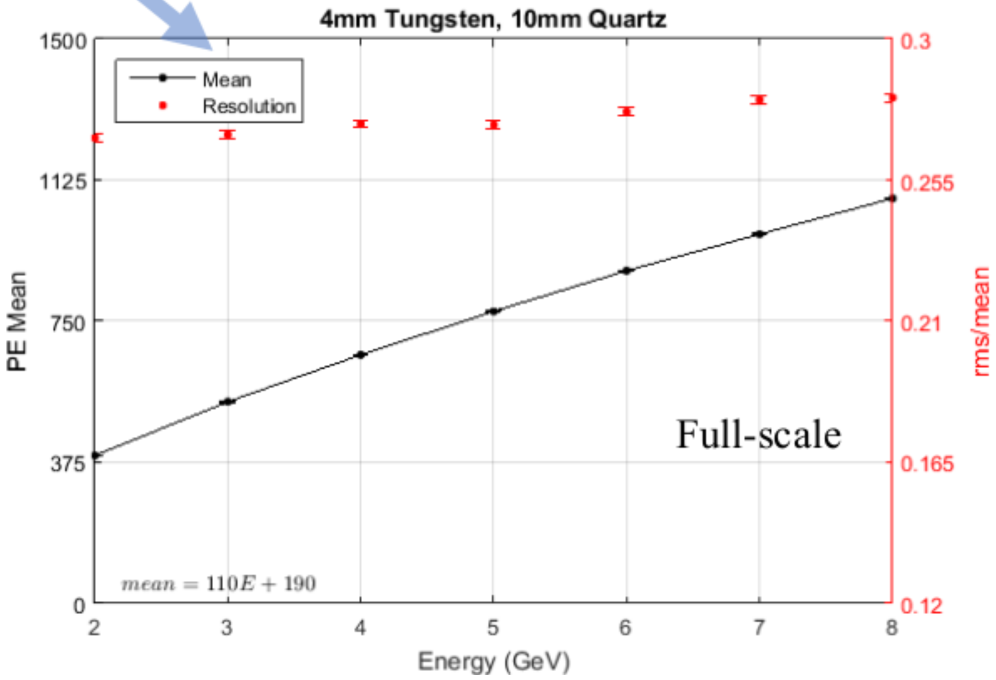
$mean = 140E + 94$

Promising results for B configs (6mm quartz)

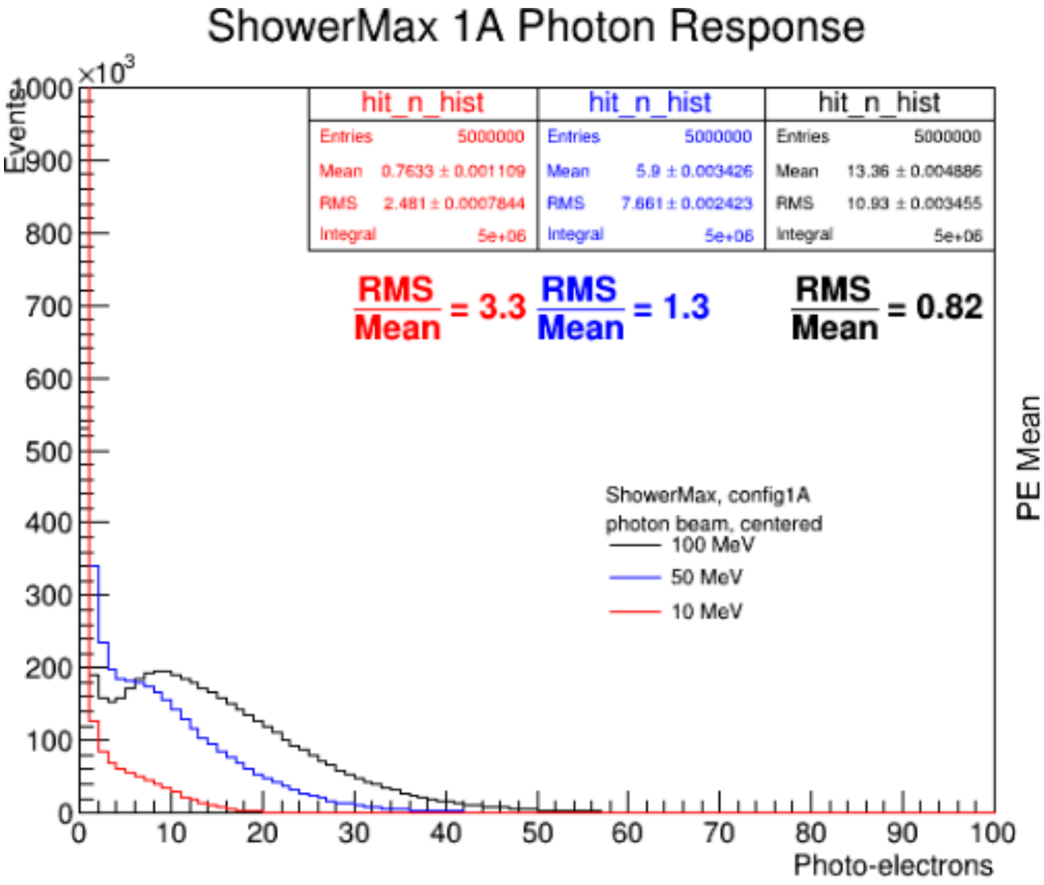


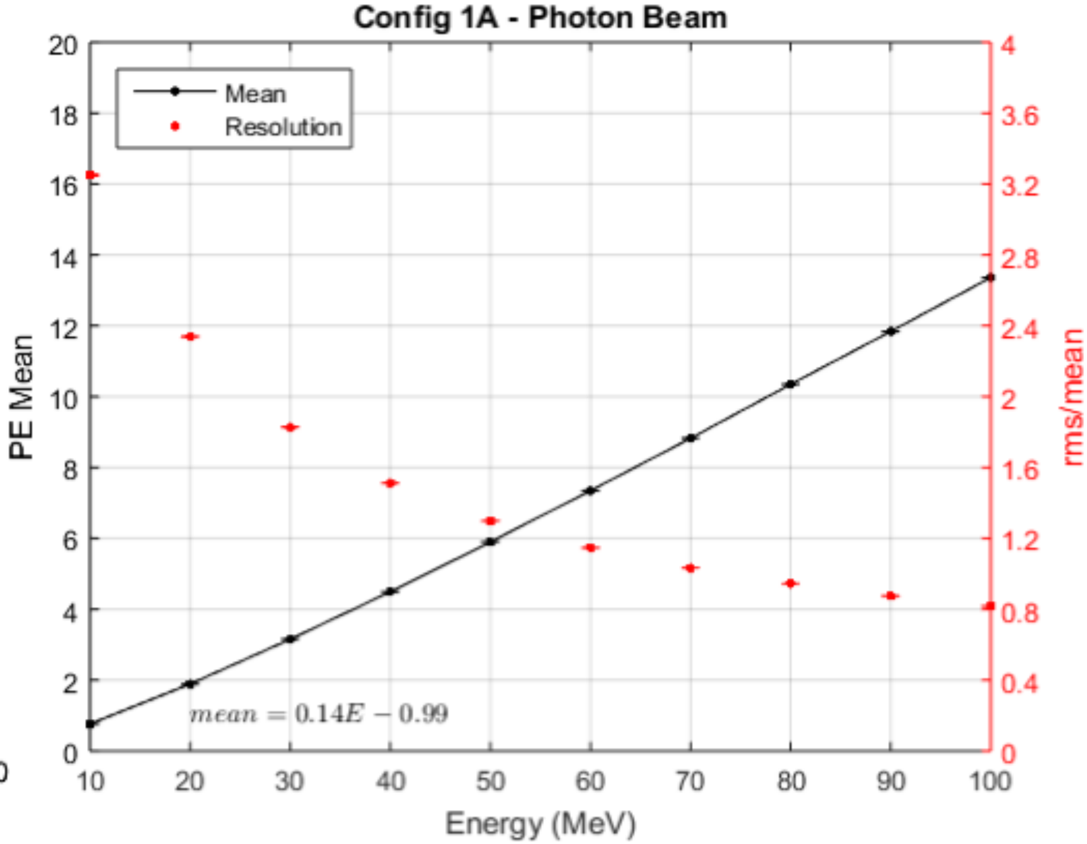


- The B configs have ~half the slope of the other configs – 80 PEs/GeV – while maintaining good resolution and with lower light levels.
- The reduced slope means less variation in PE yields with energy--which will reduce the widths measured during helicity window (it seems a potential win win win situation)
- Also interesting is that if you reduce the layers of tungsten to 4mm, the resolution worsens ~drastically (even with 10 mm quartz)

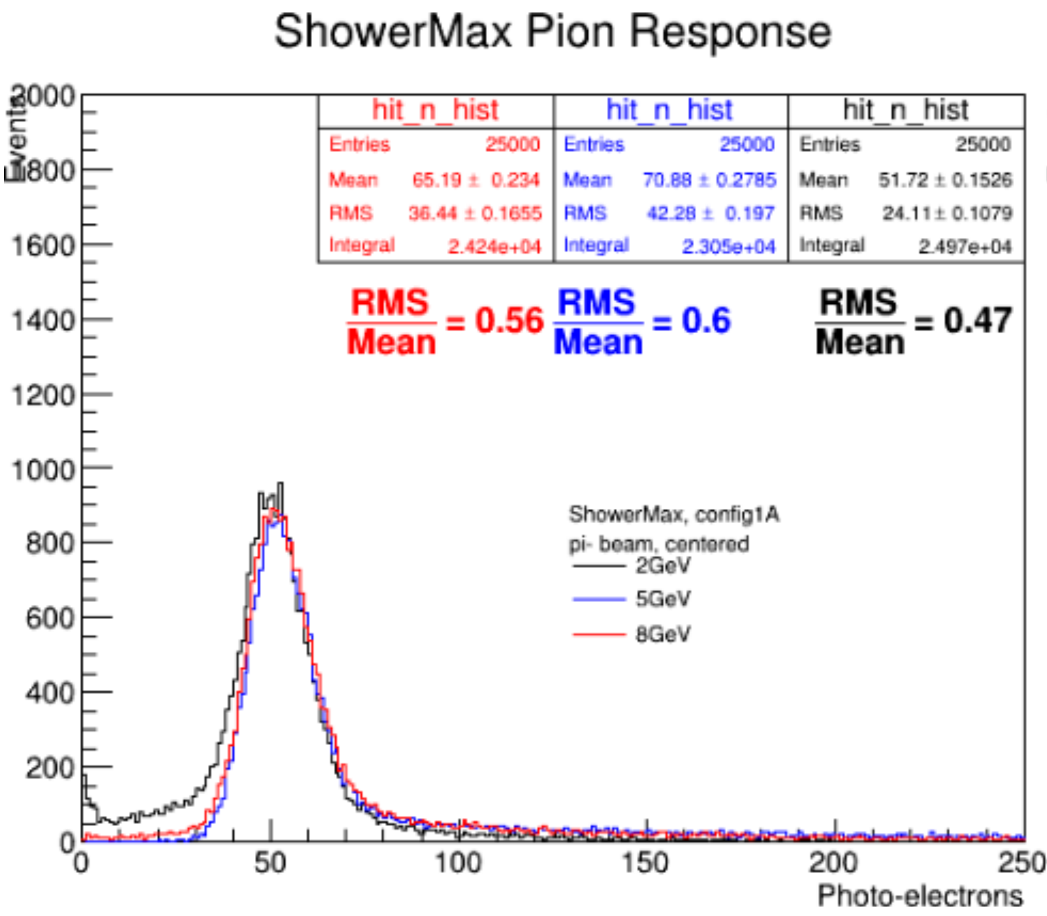


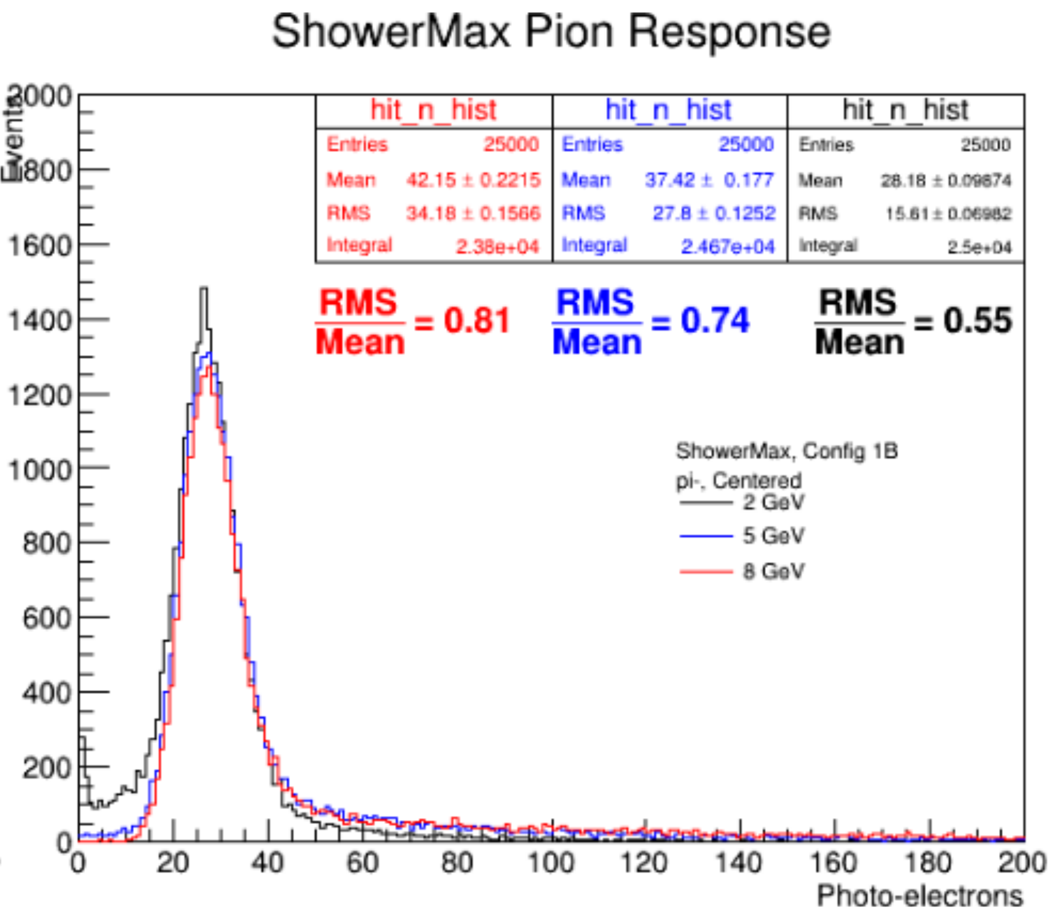
Simulated Yields from Photons (1A Full-scale)



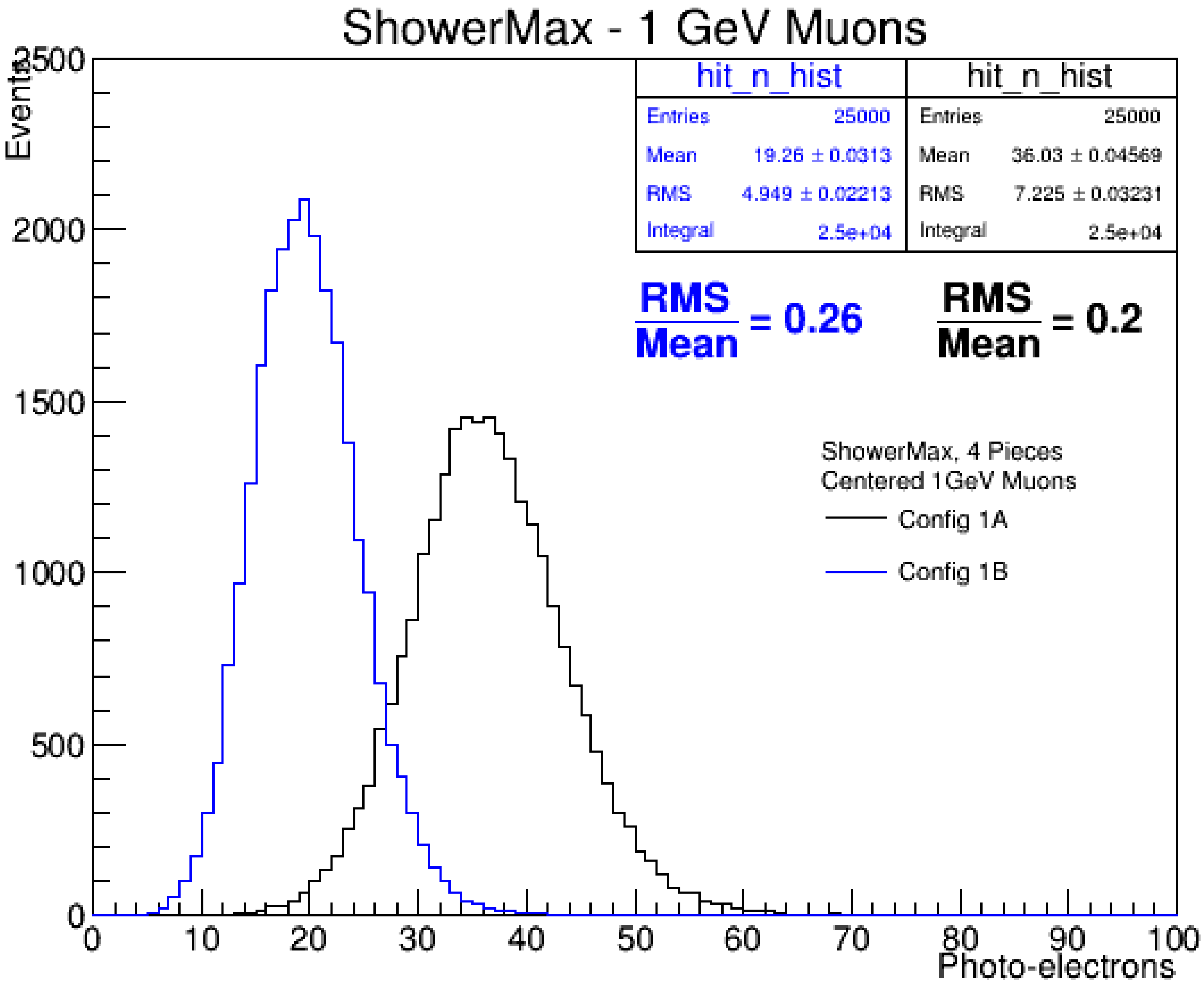


Simulated Yields from Pions (1A & 1B Full-scale)





Simulated MIP signal for cosmic-ray tests (Full-scale)



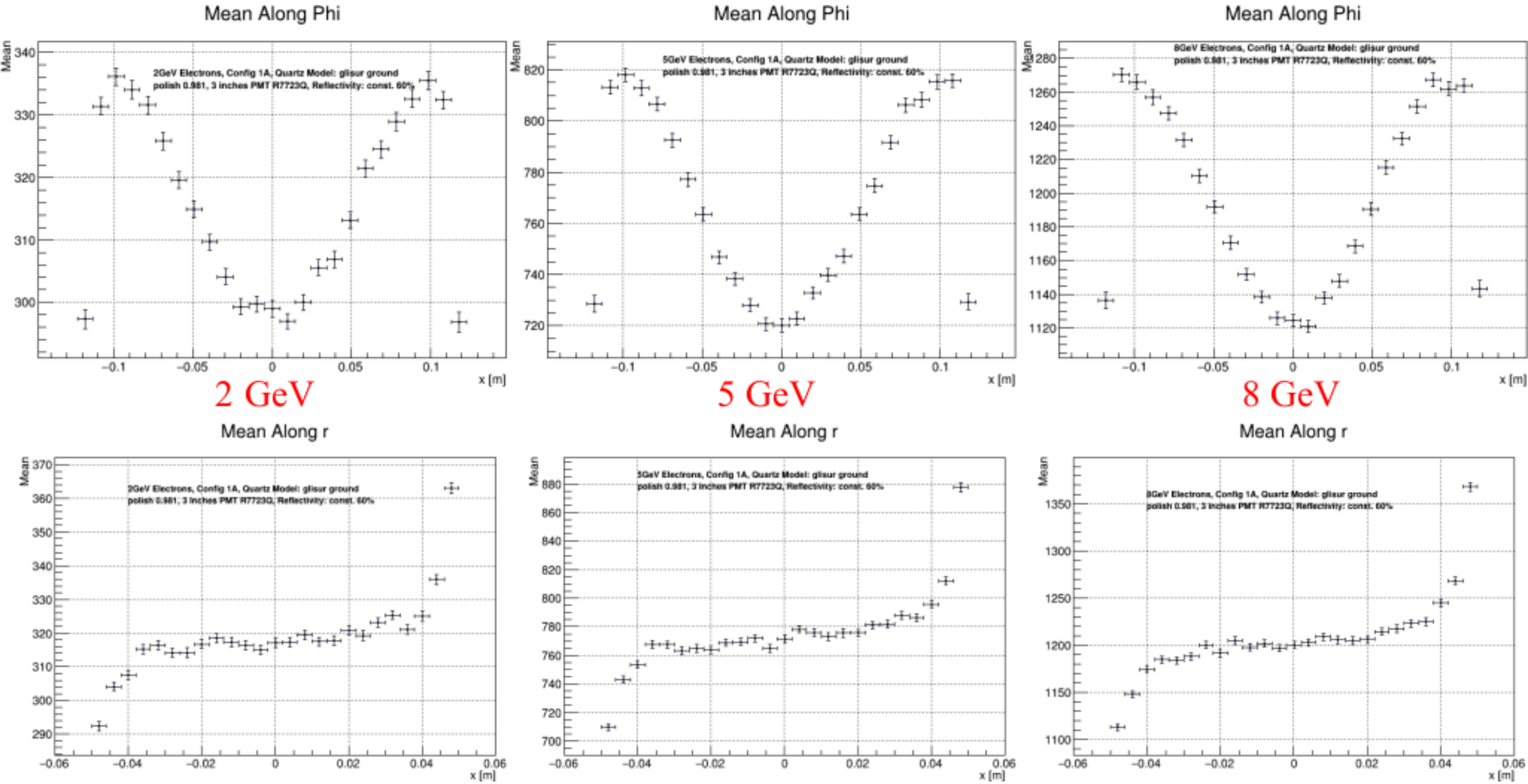
hit_n_hist	
Entries	25000
Mean	19.26 ± 0.0313
RMS	4.949 ± 0.02213
Integral	2.5e+04

hit_n_hist	
Entries	25000
Mean	36.03 ± 0.04569
RMS	7.225 ± 0.03231
Integral	2.5e+04

$$\frac{\mathrm{RMS}}{\mathrm{Mean}} = 0.26$$

$$\frac{\mathrm{RMS}}{\mathrm{Mean}} = 0.2$$

Uniformity Studies: 1A PE means along ϕ and r



Uniformity Studies: 1A Resolutions along ϕ and r

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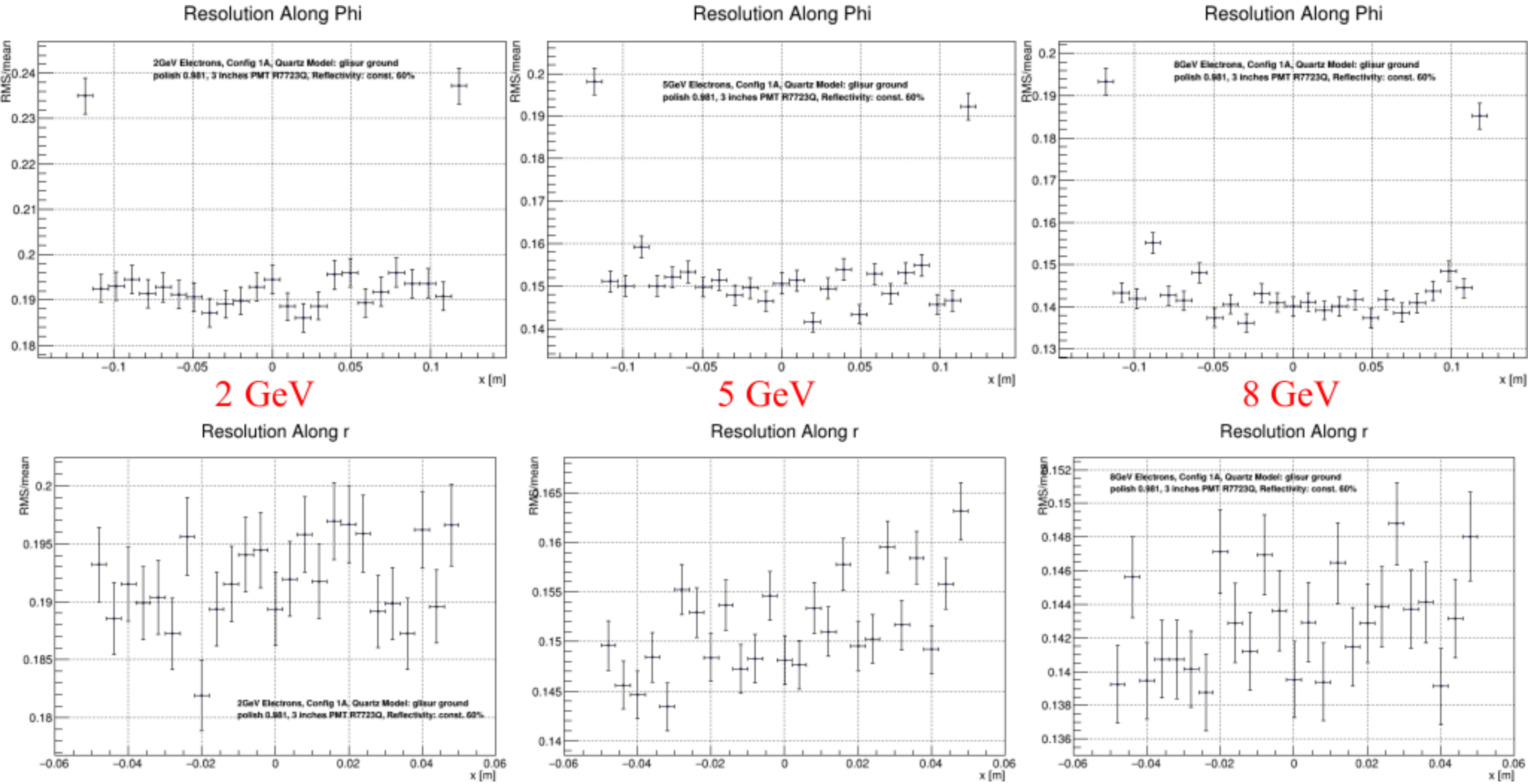
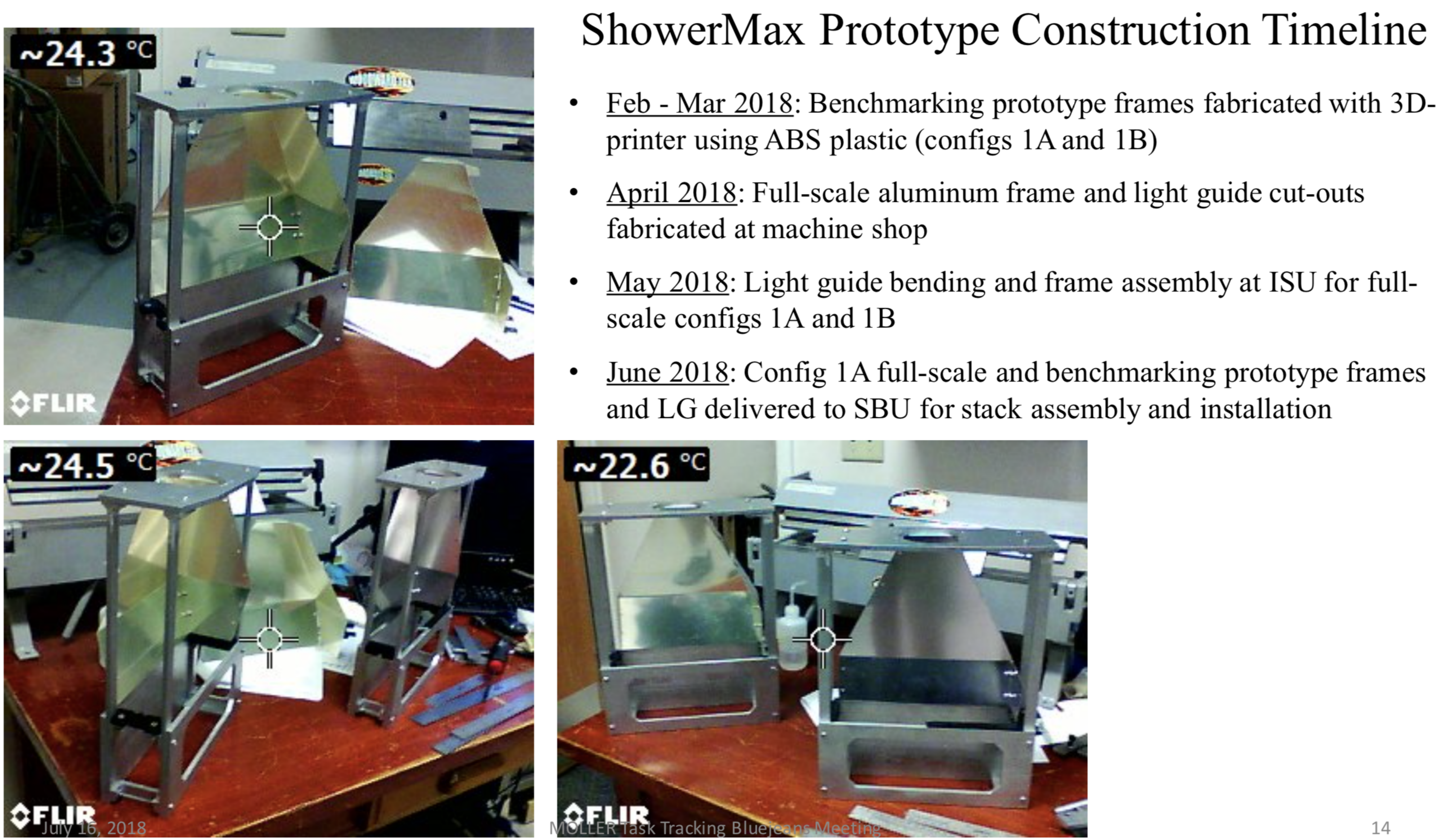


Prototype Construction and Testbeam Plans

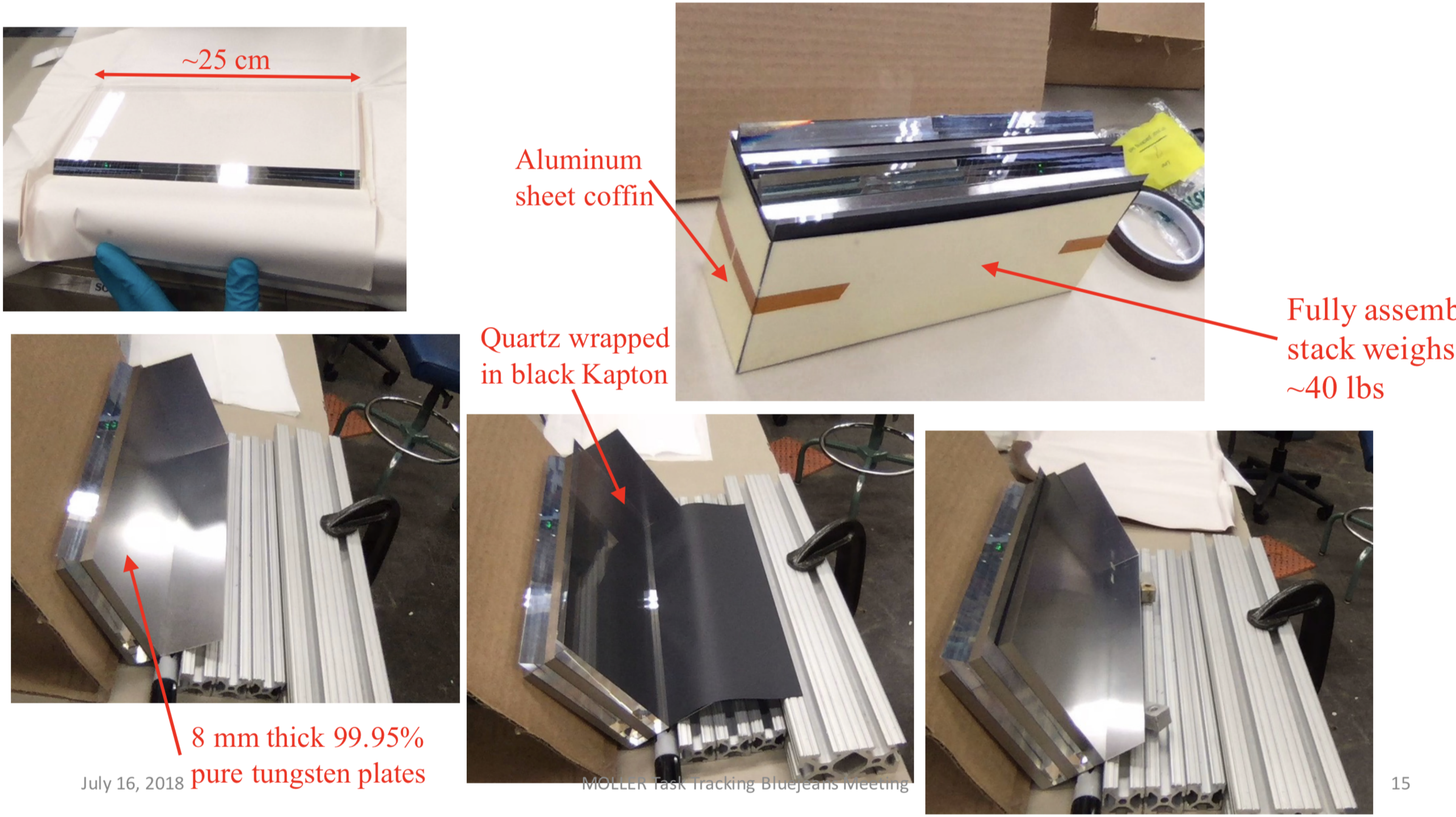


ShowerMax Prototype Construction Timeline

- Feb - Mar 2018: Benchmarking prototype frames fabricated with 3D-printer using ABS plastic (configs 1A and 1B)
- April 2018: Full-scale aluminum frame and light guide cut-outs fabricated at machine shop
- May 2018: Light guide bending and frame assembly at ISU for full-scale configs 1A and 1B
- June 2018: Config 1A full-scale and benchmarking prototype frames and LG delivered to SBU for stack assembly and installation

July 16, 2018 MOLLER Task Tracking BlueJeans Meeting 14

1A Full-scale Stack Assembly at SBU, June 2018



Aluminum sheet coffin

Quartz wrapped in black Kapton

Fully assemb
stack weighs
~40 lbs

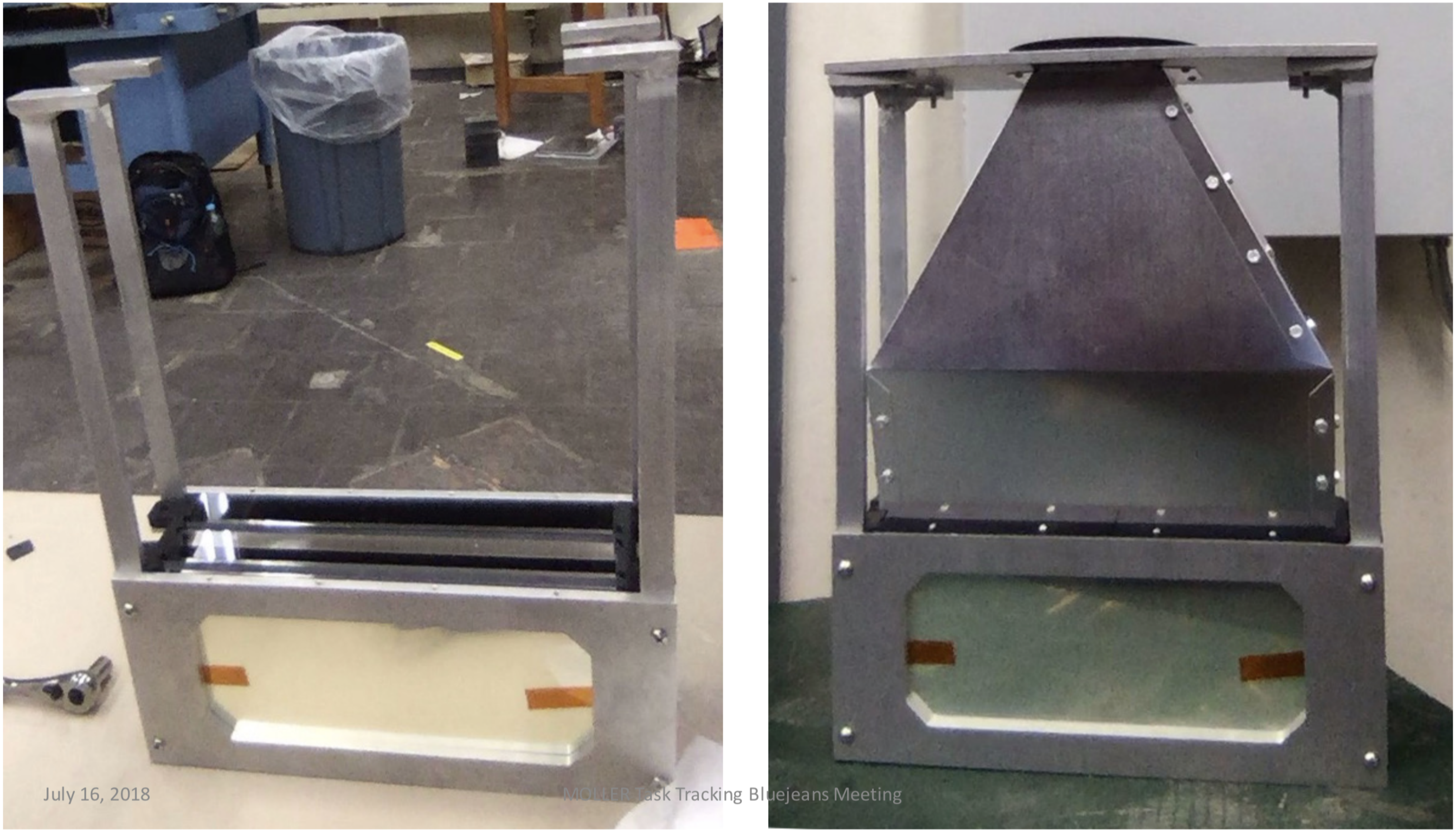
8 mm thick 99.95% pure tungsten plates

July 16, 2018

MOLLER Task Tracking Bluejeans Meeting

15

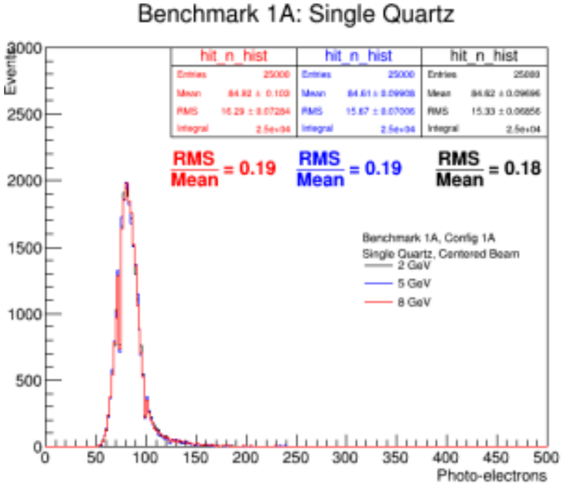
Assembled 1A Full-scale ShowerMax Prototype

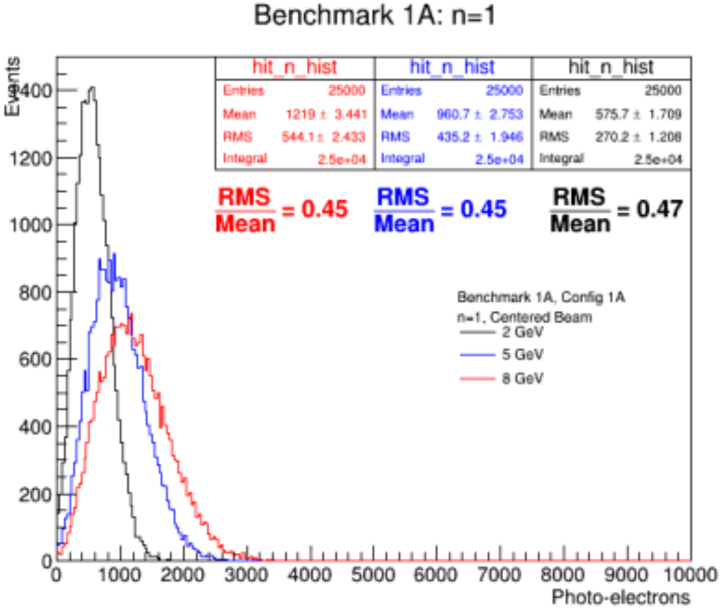


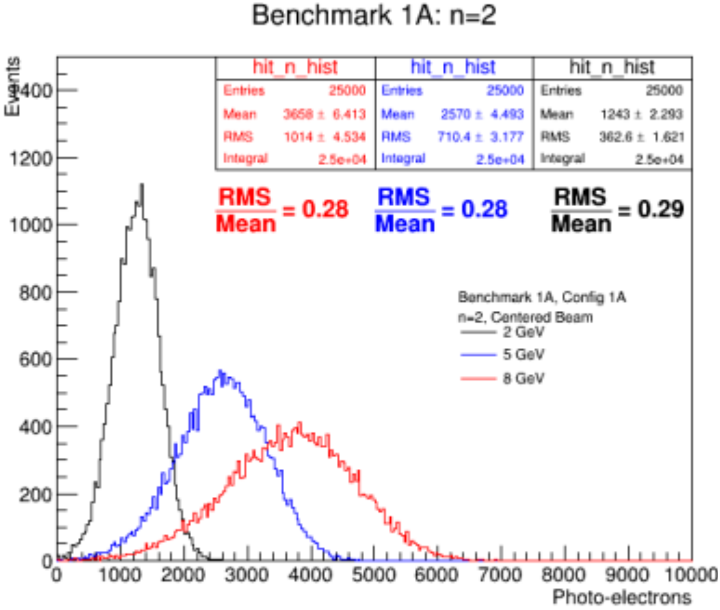
Testbeam and MC benchmarking strategy

- 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

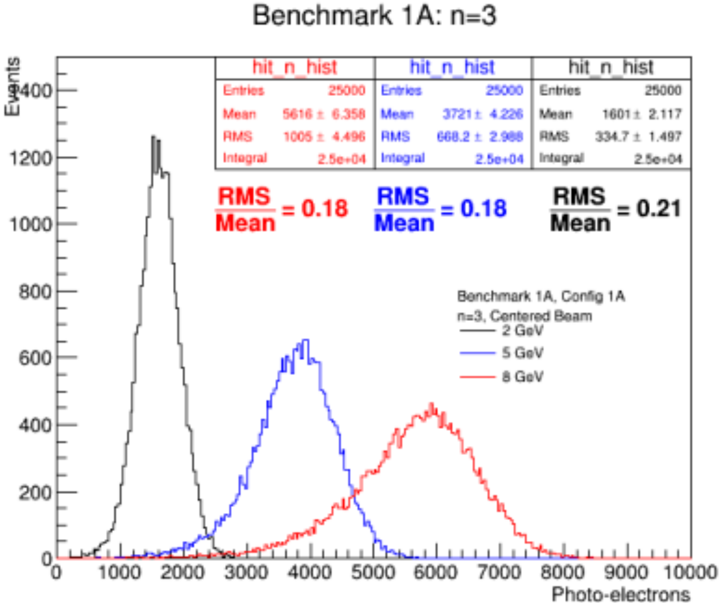
Benchmarking Prototype (1A) Expectations

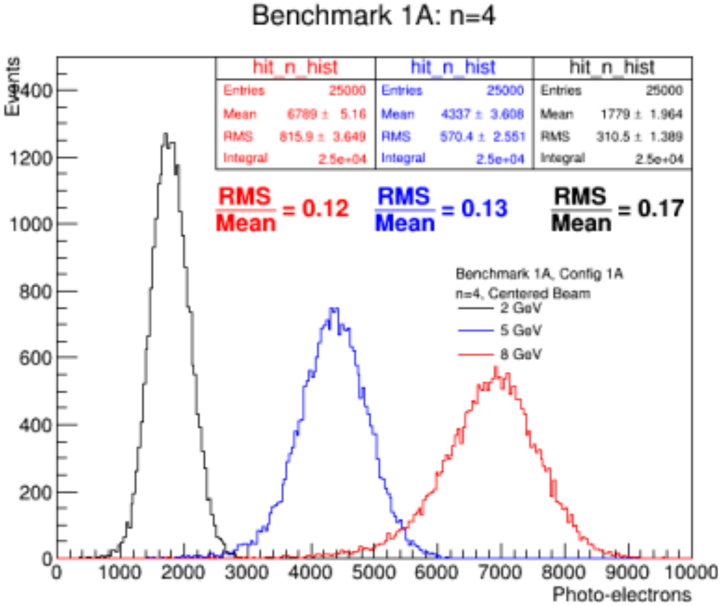






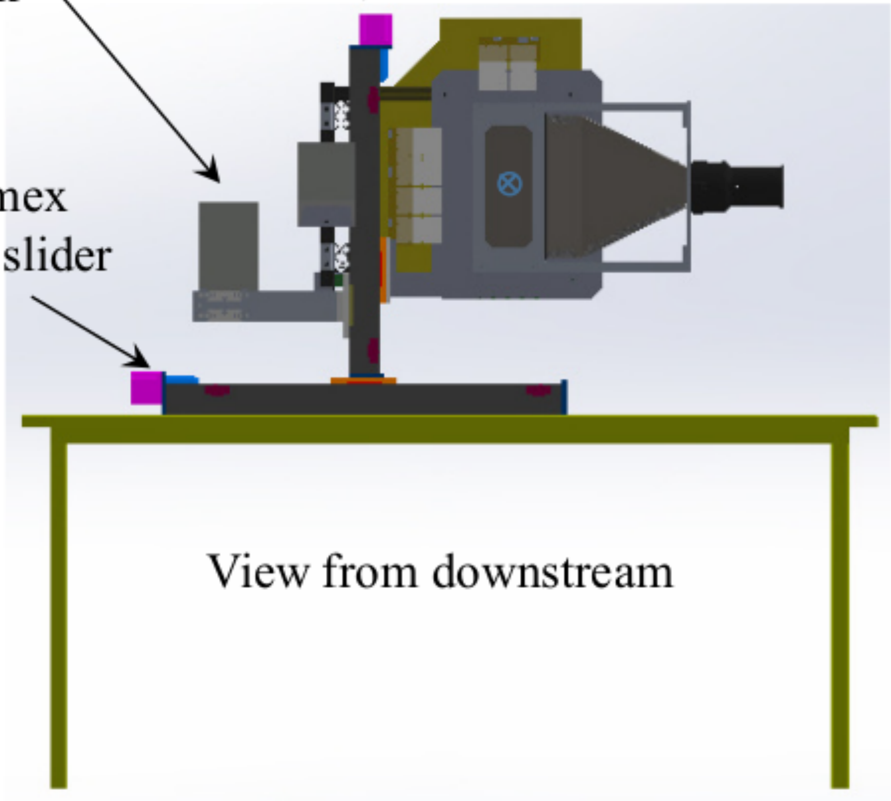
- Benchmarking PE yields are incredibly high for n =1 to 4
- Will use 3” ET PMTs: 9305QKB
- ND filters purchased: 1, 10, 25, 50, and 80% transmission





Preliminary CAD of the primary SLAC testbeam setup

- Testbeam scheduled for Dec 5 – 10 (we may get more time)
- Setup allows testbeam to cover entire active area of full-scale prototypes

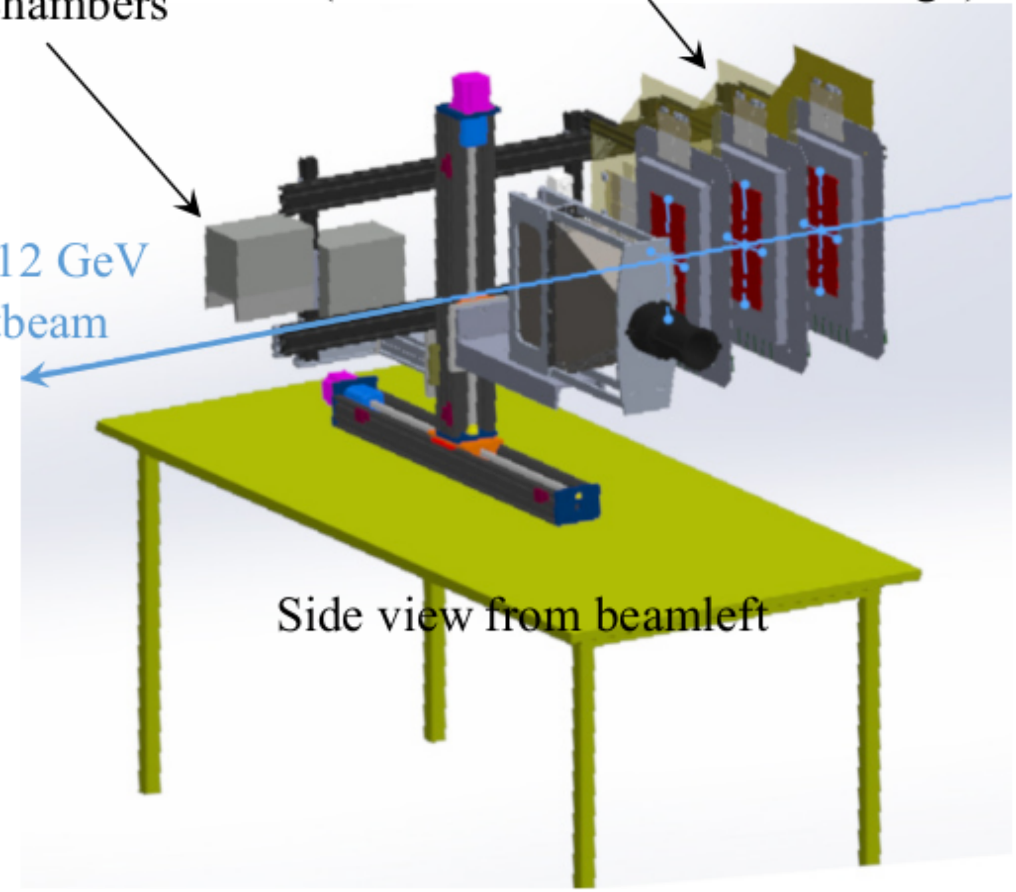


Counter weight for full-scale stack

Velmex 15” slider

Velmex 20” slider

View from downstream



Counter weight for GEM chambers

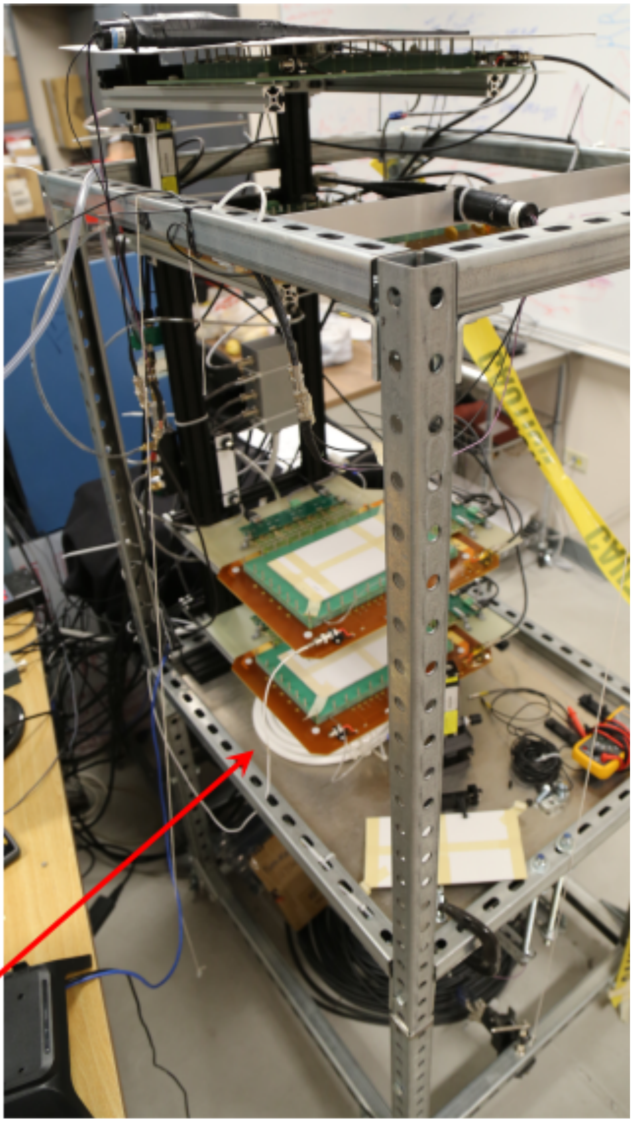
Array of 3 upstream GEMs for tracking (based on PREX-II frame design)

2 – 12 GeV Testbeam

Side view from beamleft

Teatbeam Apparatus under construction

- Testbeam stand under construction
- Motion control system in place
- GEM system is operational, analysis software under development



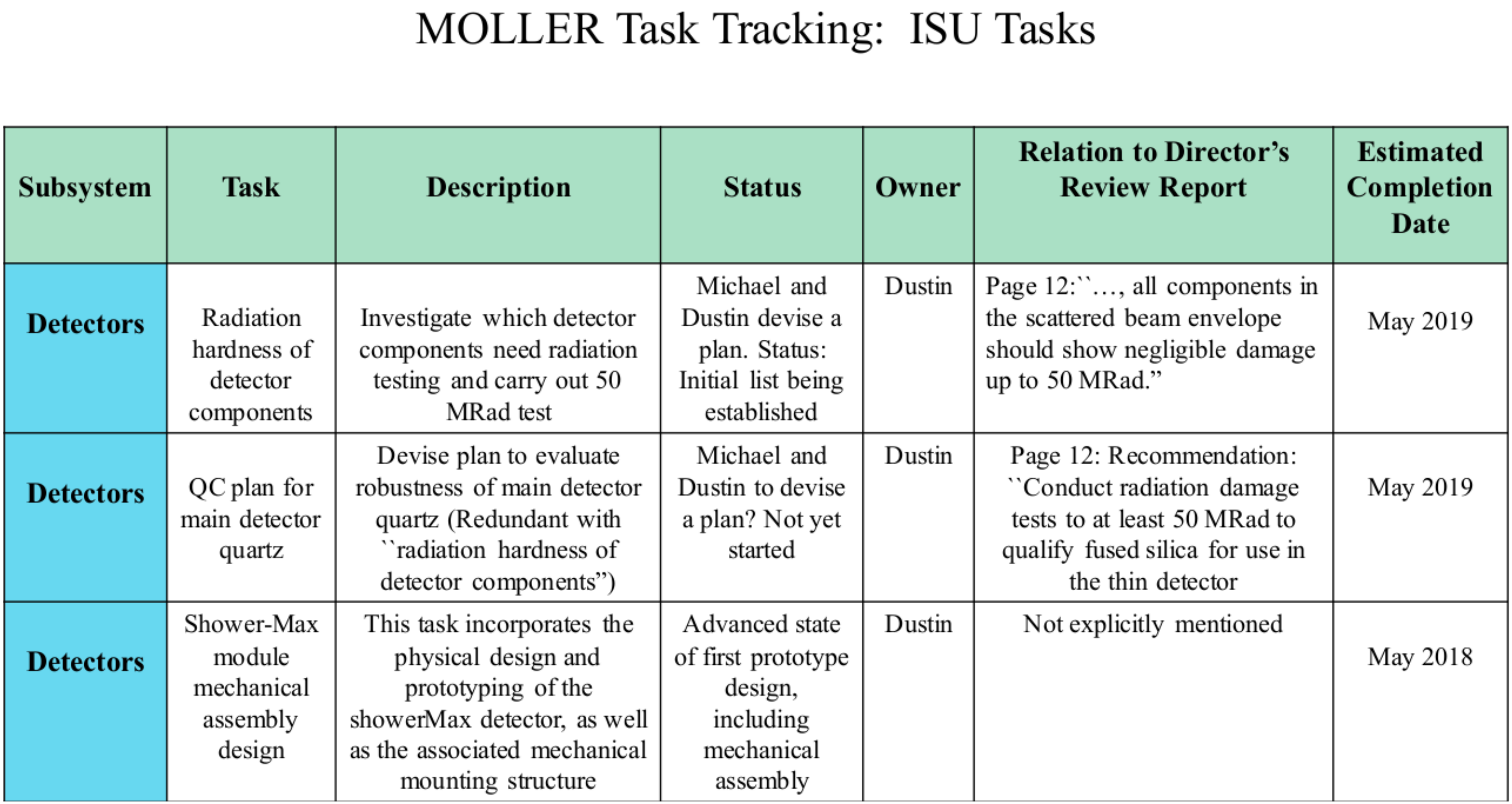
ISU Cosmic stand with 4 GEM chambers

Summary and future work

- Showermax prototype designs finalized
  - Write up found in D. Sluder's MS thesis: www2.cose.isu.edu/∼mcnudust/publication/studentWork/sluderThesis.pdf
- Benchmarking prototypes constructed
- Full-scale prototypes constructed
- Ongoing and future work:
  - Incorporate LG reflectivity lookup tables; using 60%
  - Sample realistic e^- energy, position, and angle
  - Study det. res. unif. over entire face; edge effects (∼done)
  - Determine shower-max excess noise for stat. power (∼done)
  - Continue preparing for December SLAC testbeam

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).



MOLLER Task Tracking: ISU Tasks

Subsystem	**Task**	**Description**	**Status**	**Owner**	**Relation to Director's Review Report**	**Estimated Completion Date**
Detectors	Radiation hardness of detector components	Investigate which detector components need radiation testing and carry out 50 MRad test	Michael and Dustin devise a plan. Status: Initial list being established	Dustin	Page 12:``…, all components in the scattered beam envelope should show negligible damage up to 50 MRad."	May 2019
Detectors	QC plan for main detector quartz	Devise plan to evaluate robustness of main detector quartz (Redundant with ``radiation hardness of detector components")	Michael and Dustin to devise a plan? Not yet started	Dustin	Page 12: Recommendation: ``Conduct radiation damage tests to at least 50 MRad to qualify fused silica for use in the thin detector	May 2019
Detectors	Shower-Max module mechanical assembly design	This task incorporates the physical design and prototyping of the showerMax detector, as well as the associated mechanical mounting structure	Advanced state of first prototype design, including mechanical assembly	Dustin	Not explicitly mentioned	May 2018

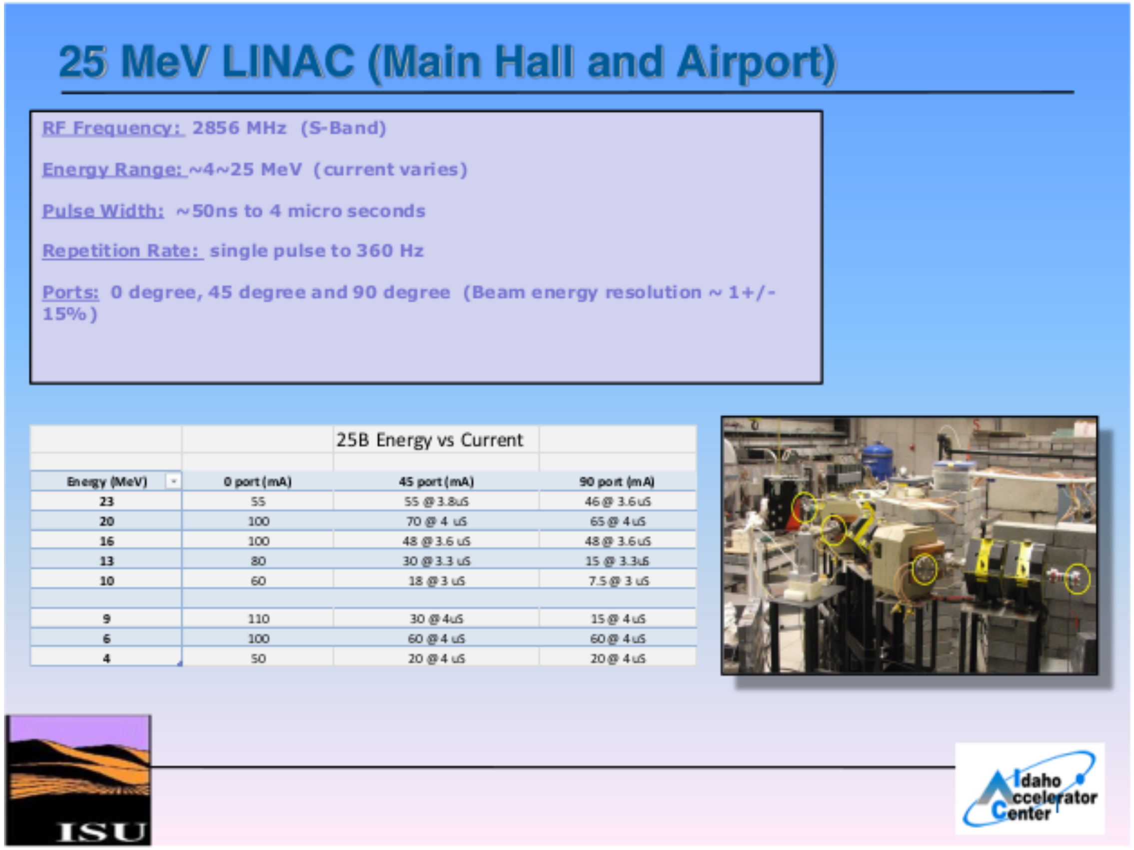
Radiation Hardness Test plan Update

- Radiation hardness testing of mechanical assembly materials and parts (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 mA I_{peak}, 4μs pulse width at 250 Hz rep-rate (dose exposure rate was calculated but too high to measure):
    - Measured LG specular reflectivity for 200 – 800 nm at 90, 60, 45, and 30 degrees.
    - No measurable change in reflectivity was detected for >>50 MRad exposure
  - ❖ Other assembly materials to test could include Kapton and Tedlar (light tight wrappings) and possibly 3D-printed custom plastic assembly components (Nylon, ABS, PLA, …) as well as high-density shielding plastics, epoxies, …

- Radiation hardness testing of electronic components: active bases, preamps, …(ISU, UM)

- Main Detector Quartz Robustness (radiation hardness, QA, etc.) (ISU, UM)
  - ❖ 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)
  - ❖ Developed plan to calibrate and monitor beam dose exposure during study
  - ❖ Had a 1 day IAC test run on May 31, 2018; dose exposure rates calibrated; performed preliminar quartz irradiation test

Radiation Hardness QA 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

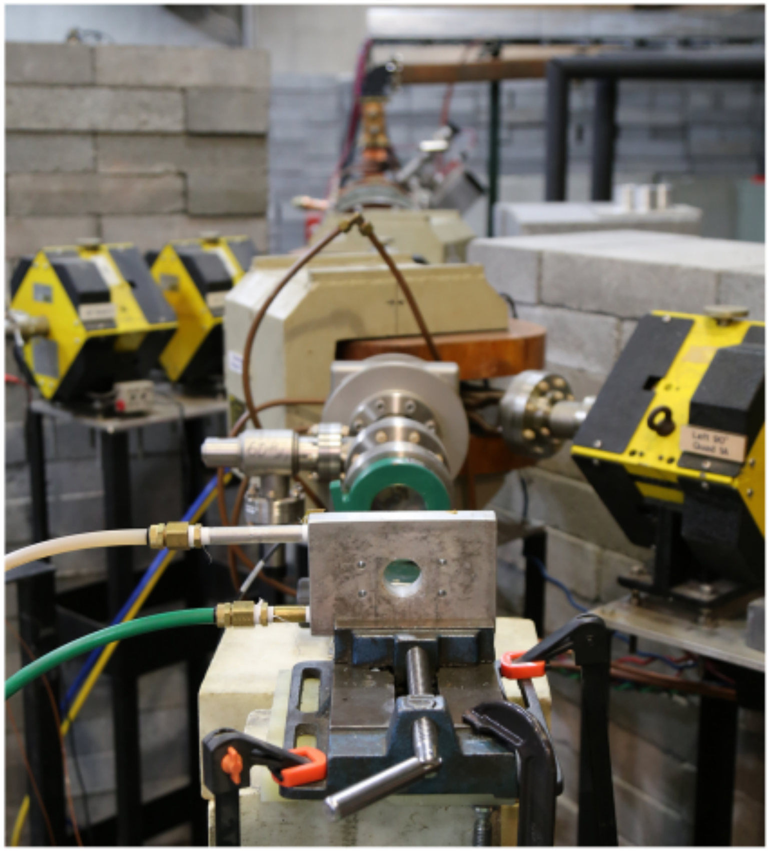
Ports: 0 degree, 45 degree and 90 degree (Beam energy resolution ~ 1+/- 15%)

25B Energy vs Current

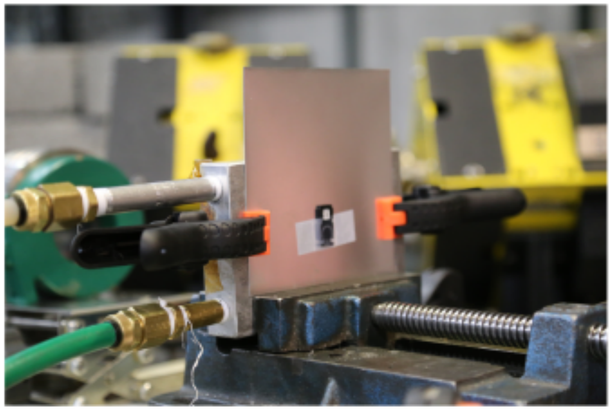
Energy (MeV)	0 port (mA)	45 port (mA)	90 port (mA)
23	55	55 @ 3.8uS	46 @ 3.6 uS
20	100	70 @ 4 uS	65 @ 4 uS
16	100	48 @ 3.6 uS	48 @ 3.6 uS
13	80	30 @ 3.3 uS	15 @ 3.3uS
10	60	18 @ 3 uS	7.5 @ 3 uS
9	110	30 @ 4uS	15 @ 4 uS
6	100	60 @ 4 uS	60 @ 4 uS
4	50	20 @ 4 uS	20 @ 4 uS

ISU

Idaho Accelerator Center



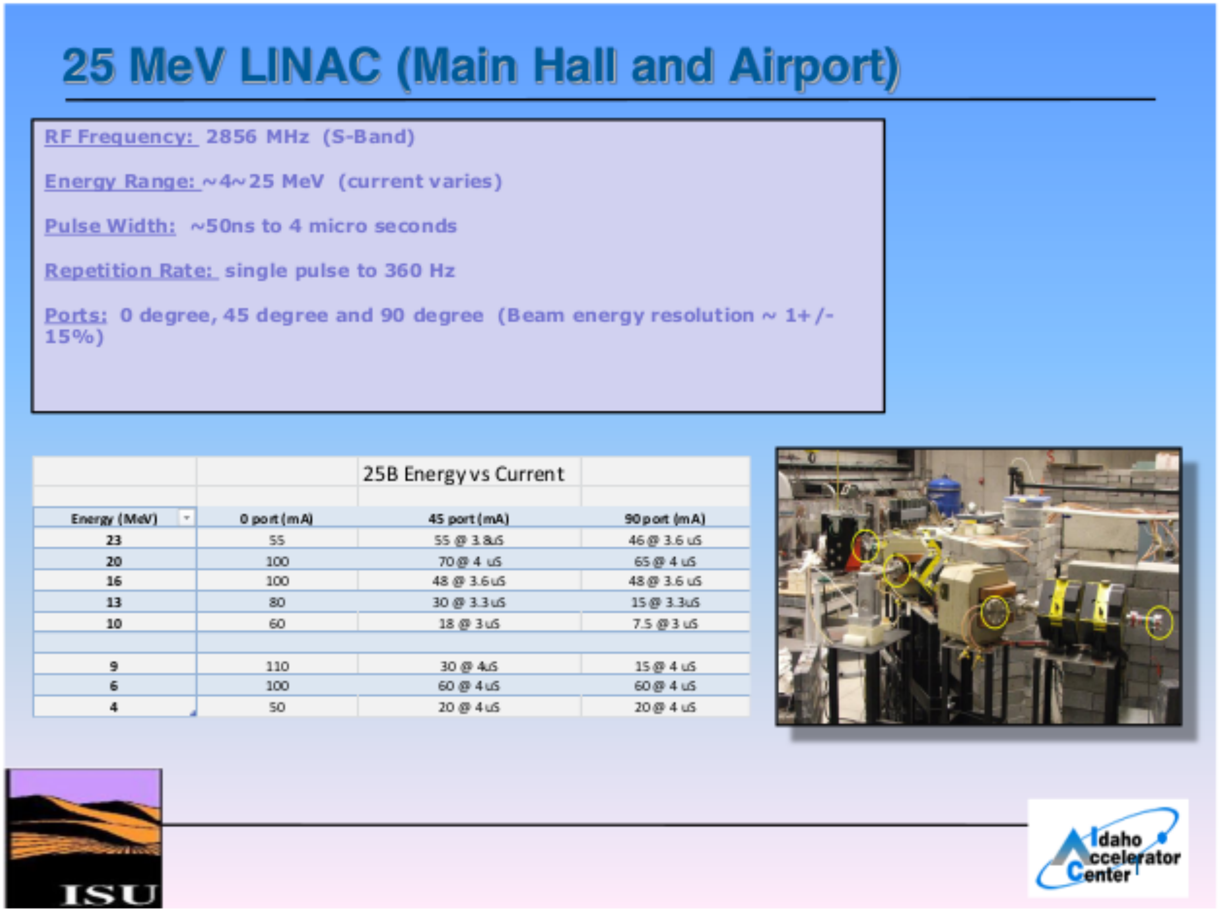
- The key issue is how well can we calibrate dose exposure?



- Performed a 1 day engineering run this past spring to address this question as well as perform preliminary radiation hardness QA quartz studies

Radiation Hardness QA for quartz and other components

- Performed 1 day irradiation study on Spectrosil 2000 quartz and 3D printed ABS plastic samples
- Tests performed on May 31, 2018 at the Idaho Accelerator Center (IAC) using 8 GeV electrons
- Dose exposure rates calibrated using thermographic film dosimetry measurements
- Quartz transparency measurements taken at 10, 30, and 60 MRad exposure levels
- Plastic dogbones radiated at similar levels and tensile strength (stretching) measurements made



25 MeV LINAC (Main Hall and Airport)

RF Frequency: 2856 MHz (S-Band)

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

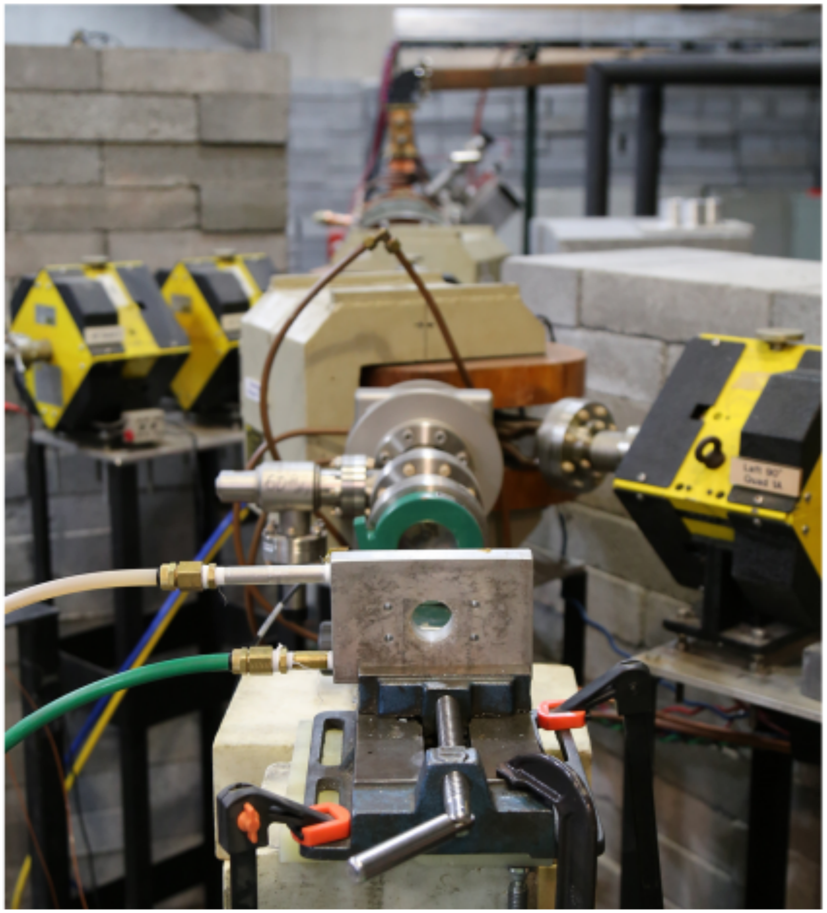
Pulse Width: ~50ns to 4 micro seconds

Repetition Rate: single pulse to 360 Hz

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

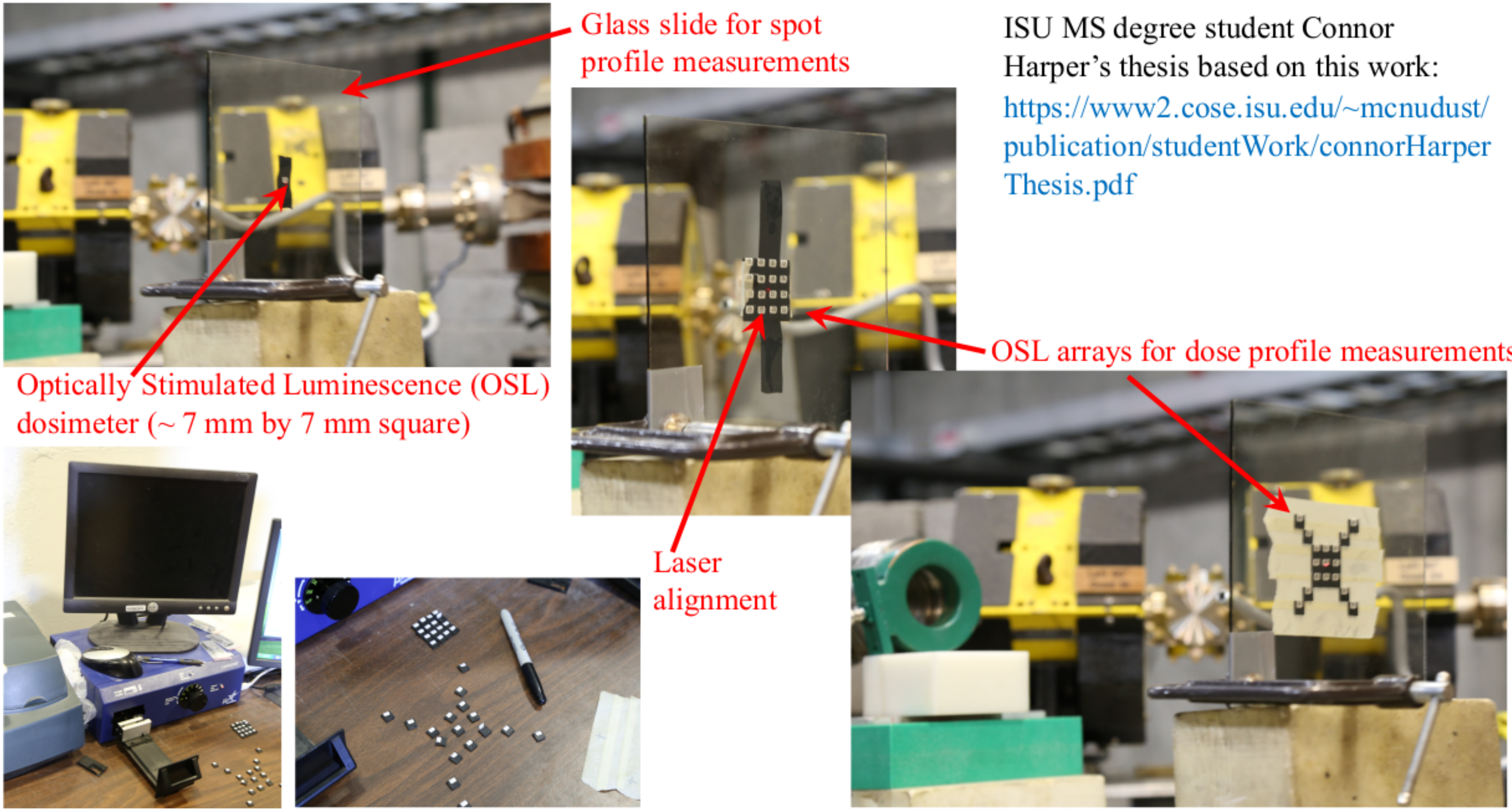
25B Energy vs Current

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 @ 3.6uS	48 @ 3.6 uS
13	80	30 @ 3.3uS	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



Beam Dose Exposure Rate Calibrations (May 2018)

ISU MS degree student Connor Harper's thesis based on this work: https://www2.cose.isu.edu/~mcnudust/publication/studentWork/connorHarperThesis.pdf



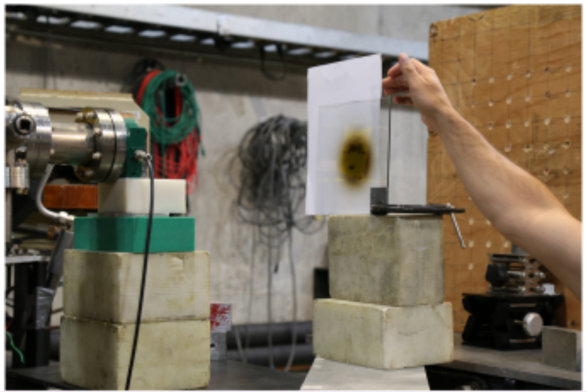
Glass slide for spot profile measurements

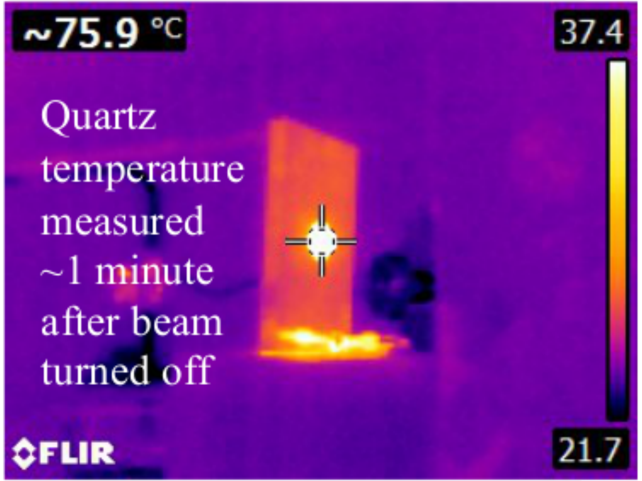
Optically Stimulated Luminescence (OSL) dosimeter (~ 7 mm by 7 mm square)

OSL arrays for dose profile measurements

Laser alignment

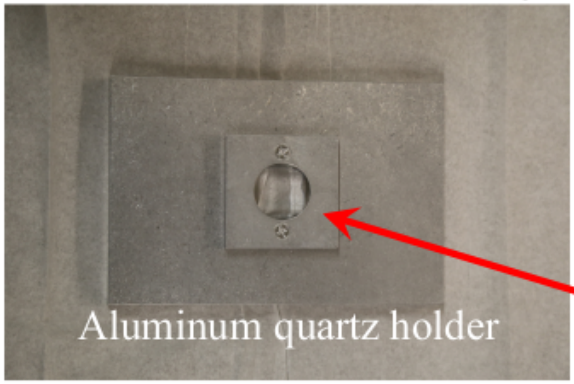
Quartz Irradiations (May 2018)



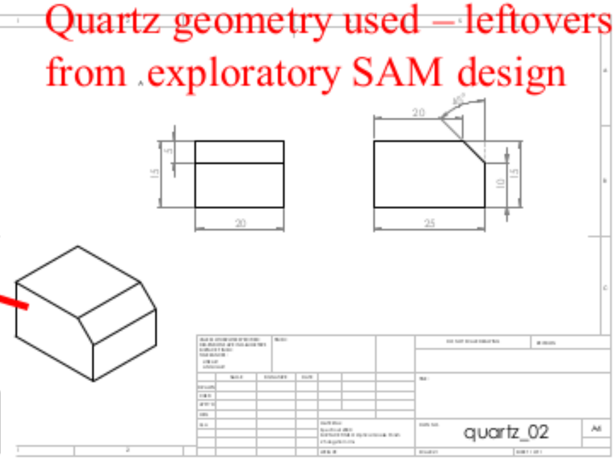


Quartz temperature measured ~1 minute after beam turned off

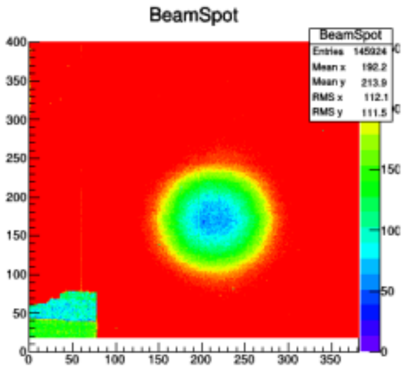
Bright Cerenkov light generation during irradiation

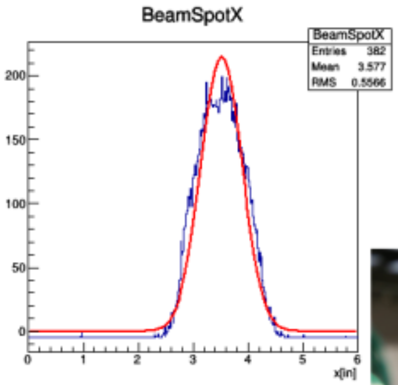


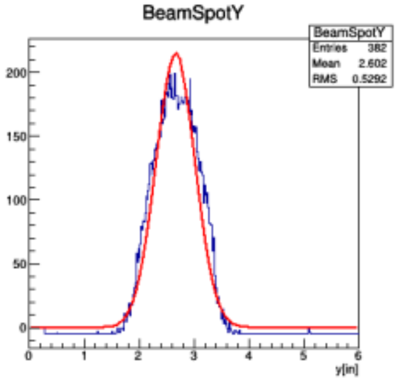
Aluminum quartz holder



Quartz geometry used – leftovers from exploratory SAM design





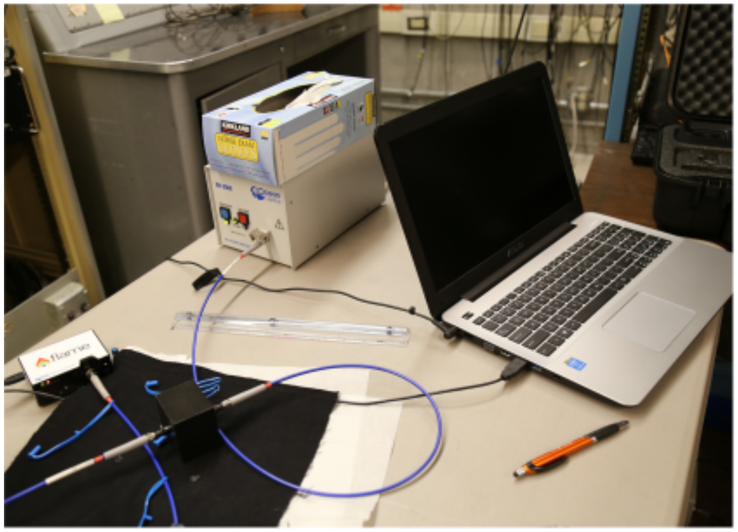


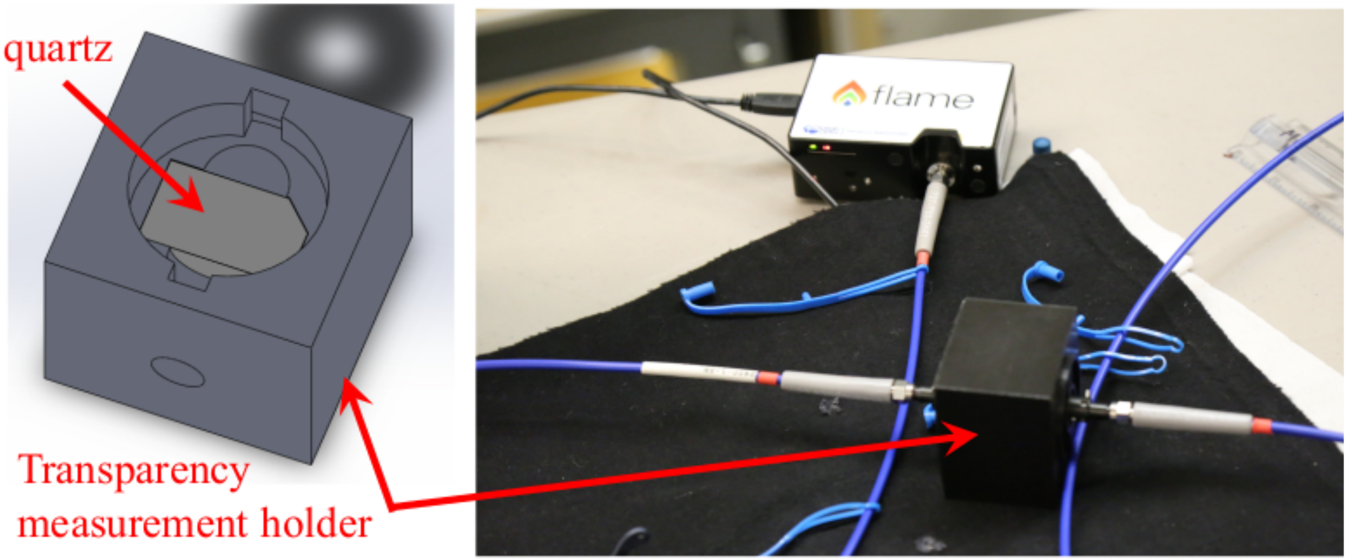
2018-05-31_15-01_Pulses_1006_50cm.png

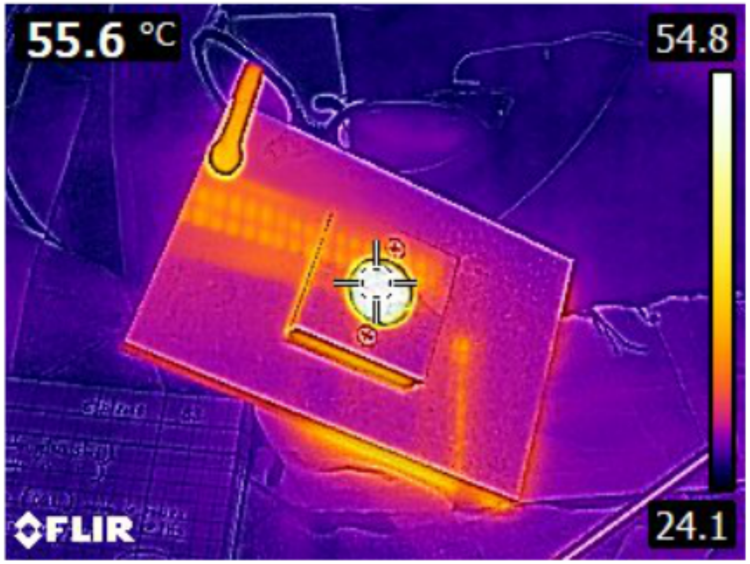
x-center = 3.512 in, y-center = 2.661 in

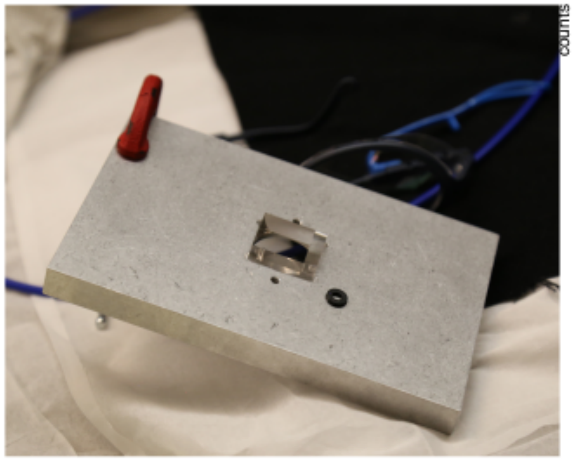
glass plate at 50cm from beam window

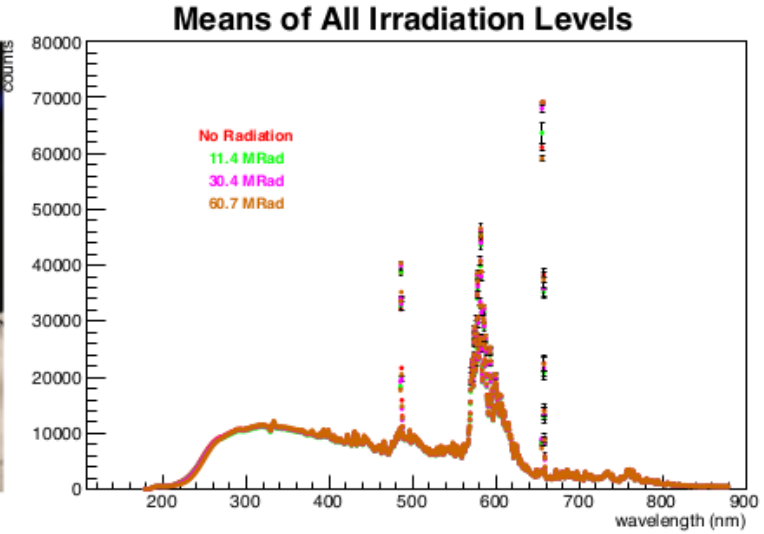
Quartz Transparency Measurements



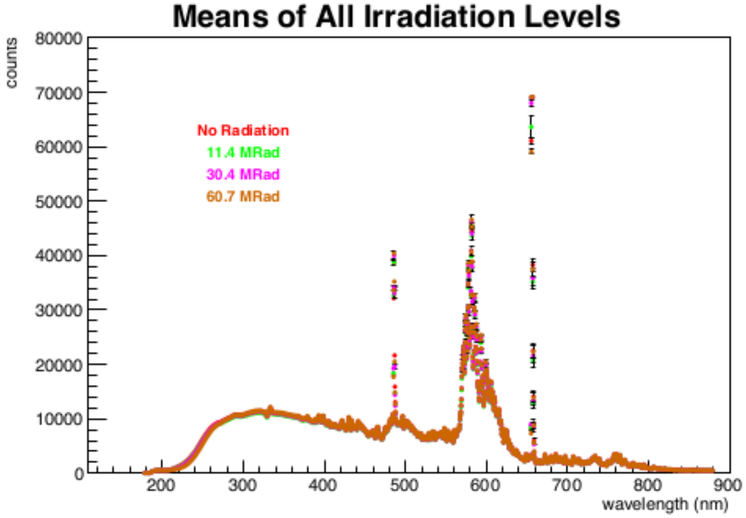




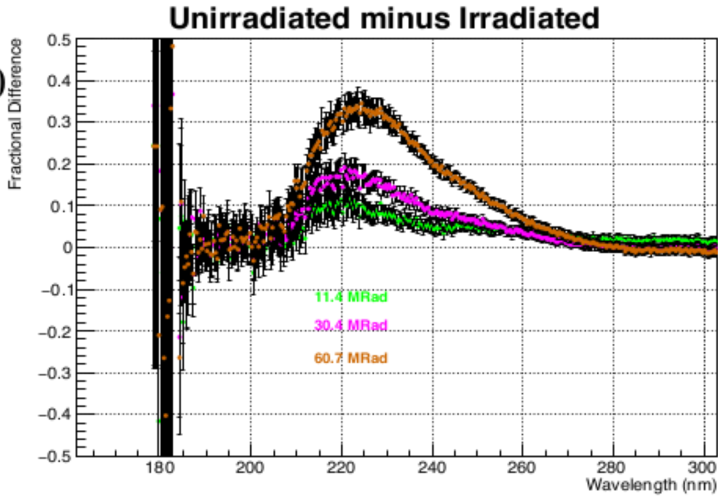


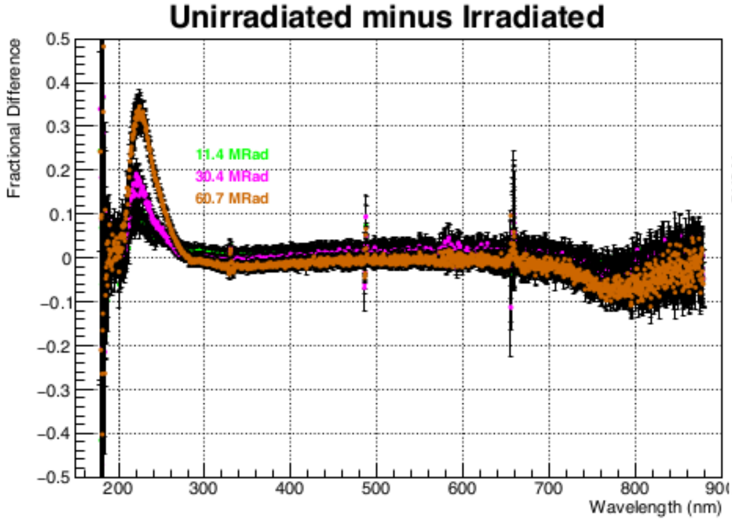


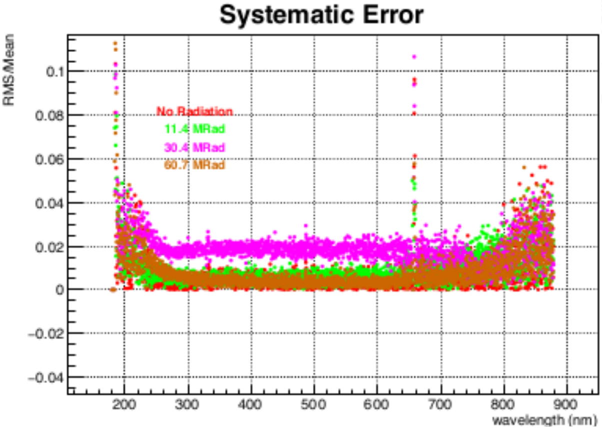
Quartz Transparency Preliminary Results

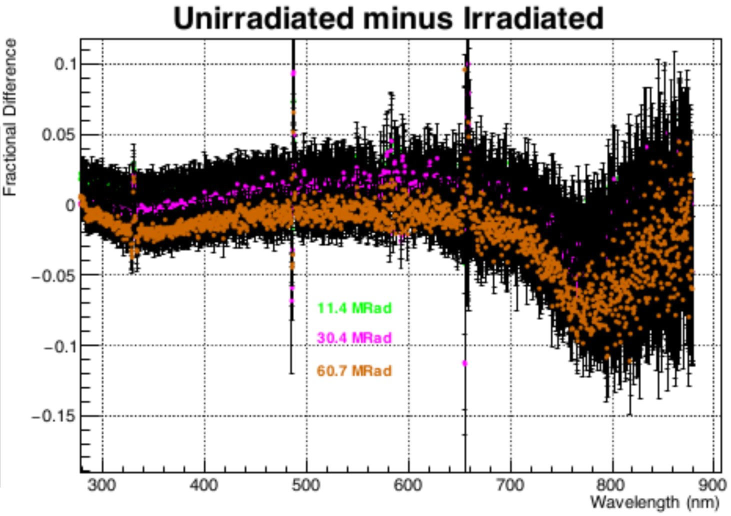

Means of All Irradiation Levels

- Beam setup: 8 MeV, 50 mA I_{peak}, 500 ns pulse width at 250 Hz rep-rate
- Quartz sample mounted 0.5 m from beampipe exit window
- Dose exposure calibrations give ~253 Rad/pulse
- Irradiated sample for 3, 8, and then 16 minutes
- Measured light transmission (four times) after each irradiation and averaged


Unirradiated minus Irradiated


Unirradiated minus Irradiated


Systematic Error


Unirradiated minus Irradiated

Quartz Rad Hardness Preliminary Results Summary

•Apparent onset of radiation damage seen in the UV region (between 200 – 270 nm)

•These results need to be double-checked:

➢ Perform more in-depth future irradiation study

➢ Examine a few different pieces (same geometry), perform more transparency measurements at smaller intervals of exposure, and redesign apparatus to give less systematic variations

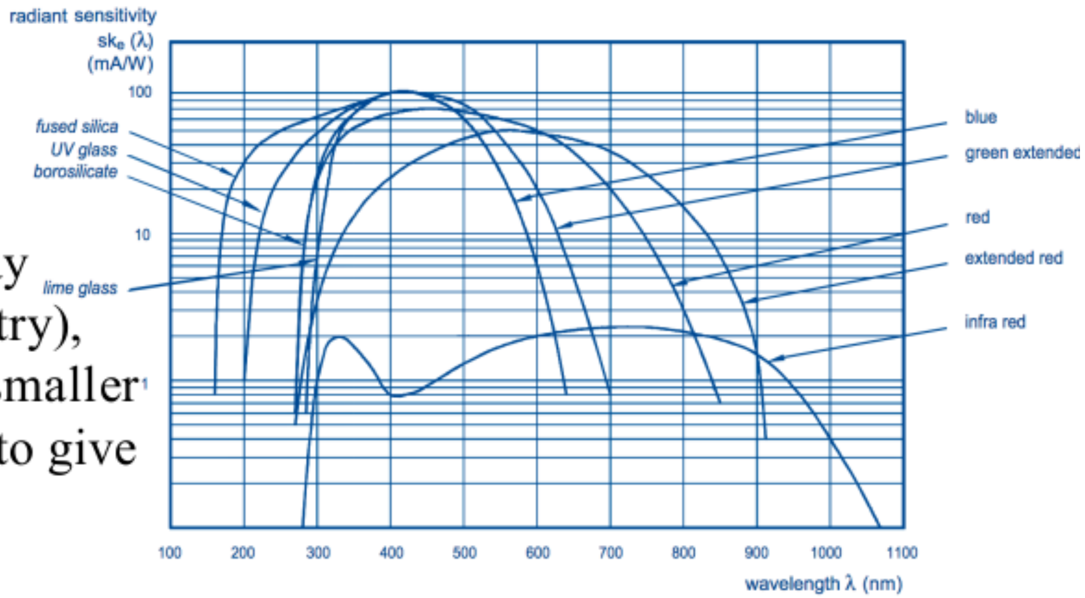


Fig.2 Typical spectral sensitivity characteristics of standard photocathodes with associated window materials.

$$\text{QE}\ (\%) \simeq \frac{124}{\lambda(\text{nm})}\ \text{x radiant sensitivity (mA/W)}$$

•We've already seen from reflectivity measurements, combined with MAMI testbeam results, that the deep UV part of the spectrum does not seem as important or contributing as the UV/Vis part--due to cathode sensitivity and QE

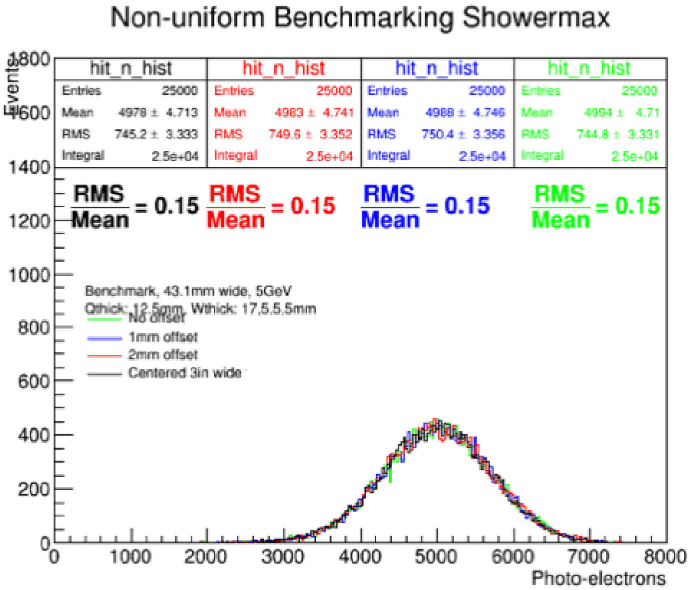
•Perhaps a measurement using a SAM-type or even Moller ring-5 prototype detector during irradiations could show how this effect is dampened by the PMT; use a cathode with very low QE in the < 280 nm region

PMT Window Characteristics

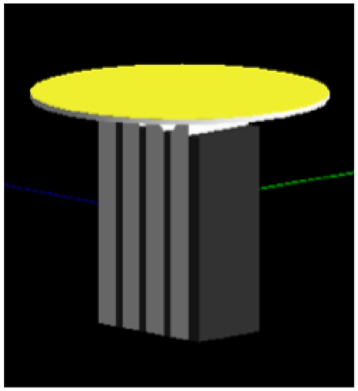
type of window glass	cut-off wavelength, -10% (nm)	refractive index
lime glass	300	1.54 (at 400 nm)
borosilicate	270	1.50 (at 400 nm)
UV glass	190	1.49 (at 400 nm)
fused silica	160	1.47 (at 400 nm)
		1.50 (at 250 nm)
sapphire	150	1.80 (at 400 nm)

Backup Slides

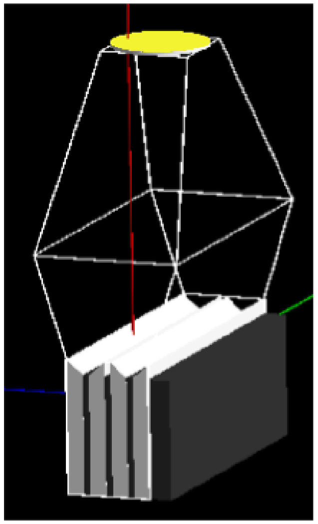
Candidate Design for Stack Prototype: Config #2

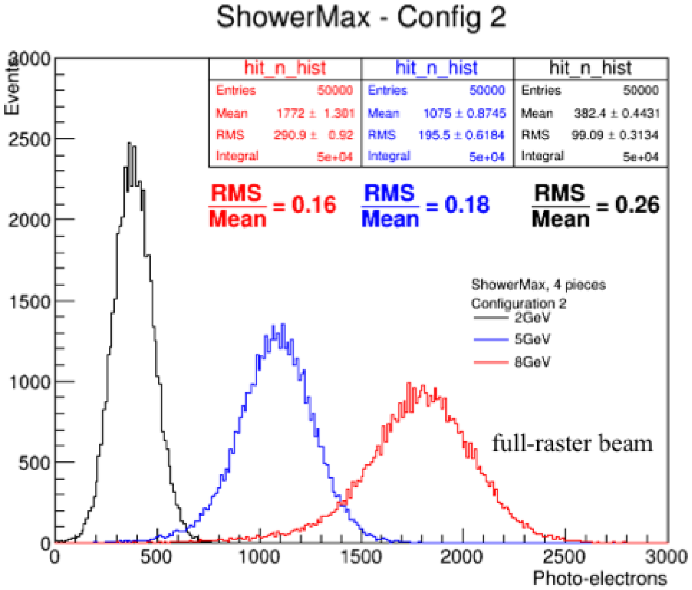

Non-uniform Benchmarking Showermax

BenchMarking MC Visualization



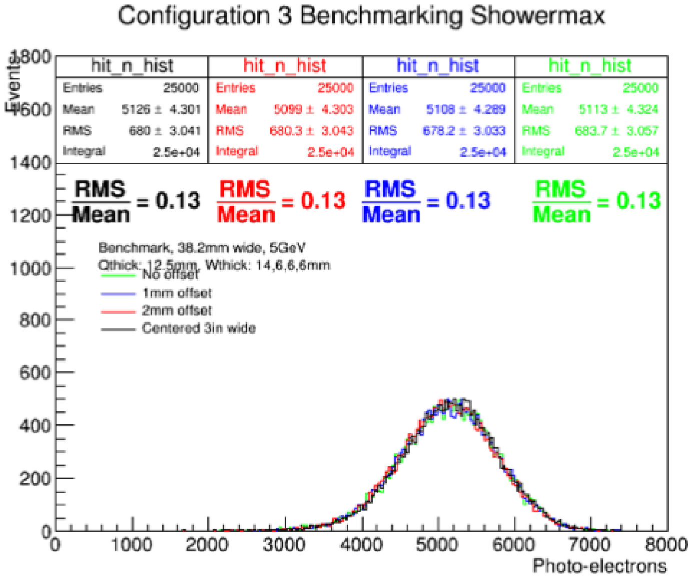
Full Scale MC Vis.



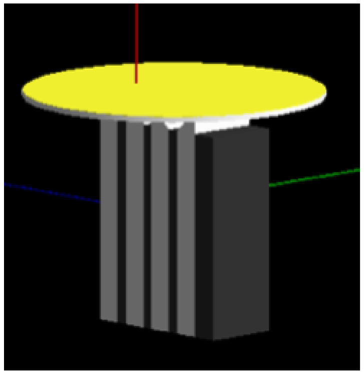

ShowerMax - Config 2

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

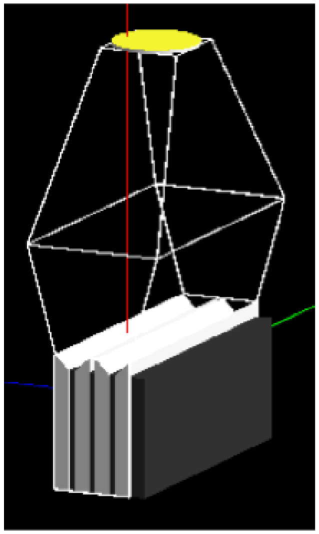
Candidate Design for Stack Prototype: Config #3

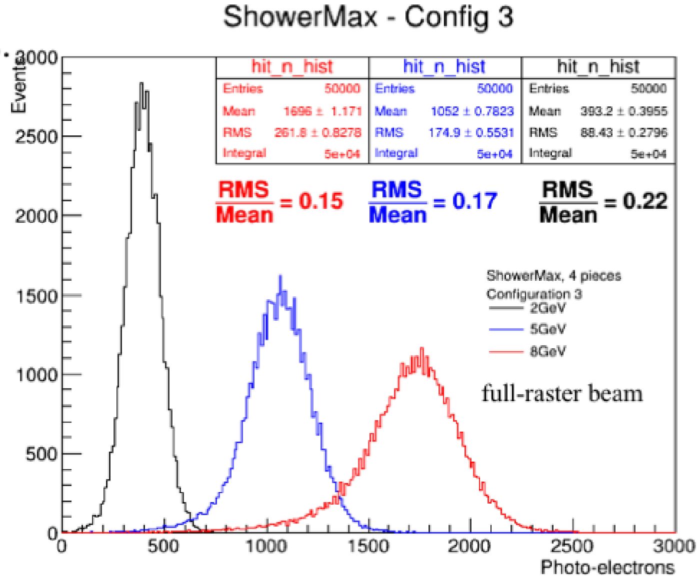


BenchMarking MC Visualization



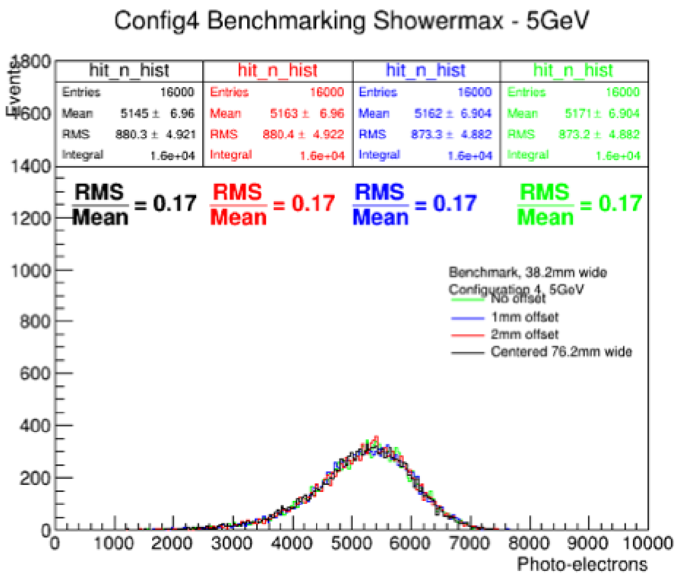
Full Scale MC Vis.





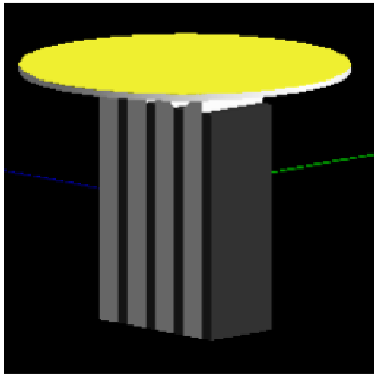
Config #	t_f (mm)	t_Q (mm)	t_W (mm)	b (mm)	a (mm)	X_0	R_{mol} (mm)	Leakage (%) 2, 5, 8 GeV from G4 MC	1mm offset Leakage (%)	2mm offset Leakage (%)	Bench. Mean PEs	Bench. RMS / Mean	full-scale Mean PEs	full-scale RMS / Mean
3	14	12.5	6	68	38.2	9.5	11.0	0.5 0.3	0.6 0.4	0.8 0.5	2412 5113	0.19 0.13	393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

Candidate Design for Stack Prototype: Config #4

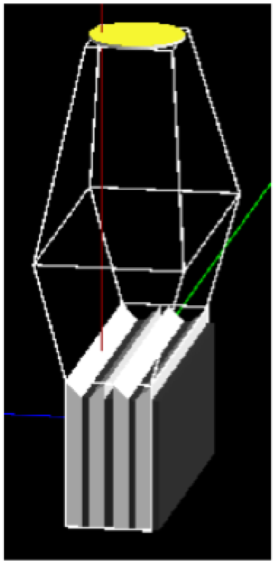


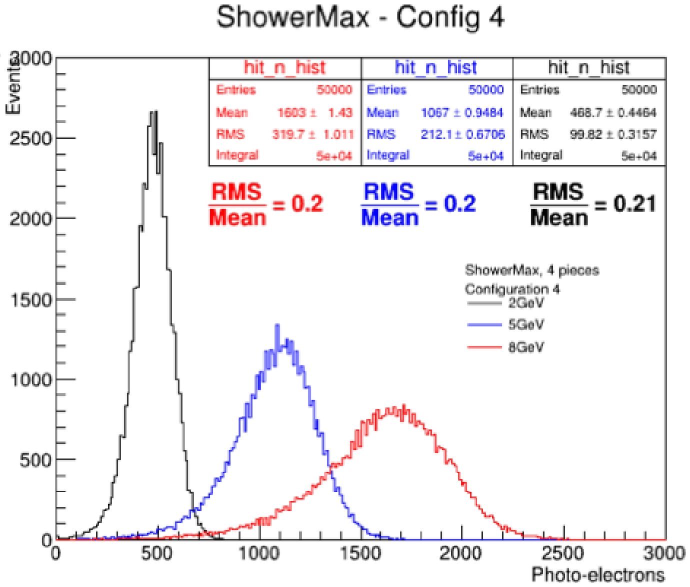
Config4 Benchmarking Showermax - 5GeV

BenchMarking MC Visualization



Full Scale MC Vis.

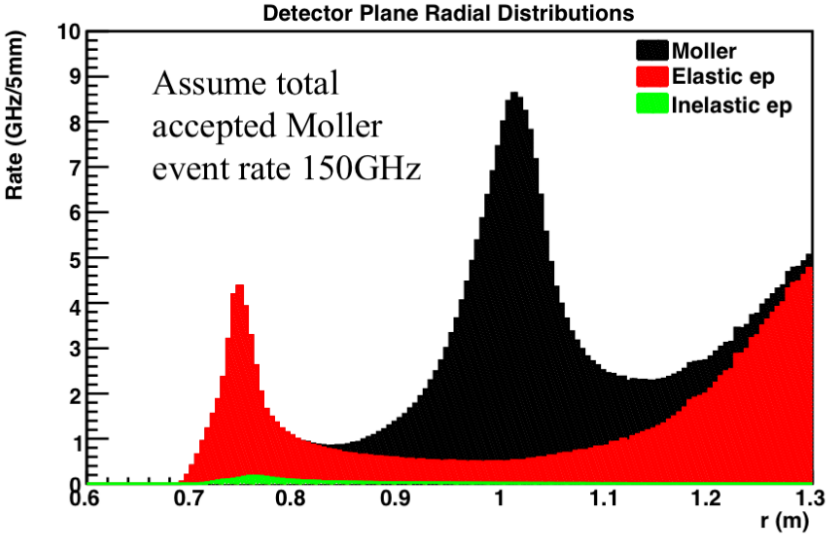




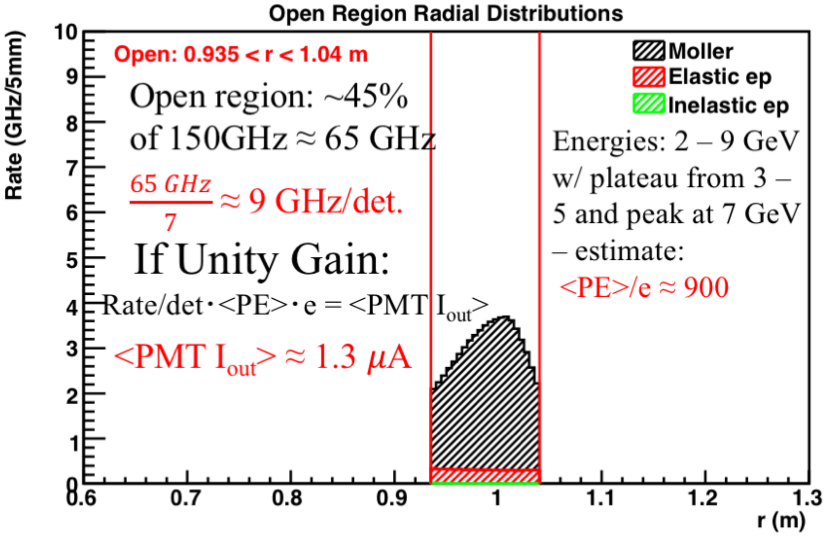
ShowerMax - Config 4

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

Unity Gain operation with Baseline design?



Assume total accepted Moller event rate 150GHz



Open: $0.935 < r < 1.04$ m

Open region: ~45% of 150GHz ≈ 65 GHz

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

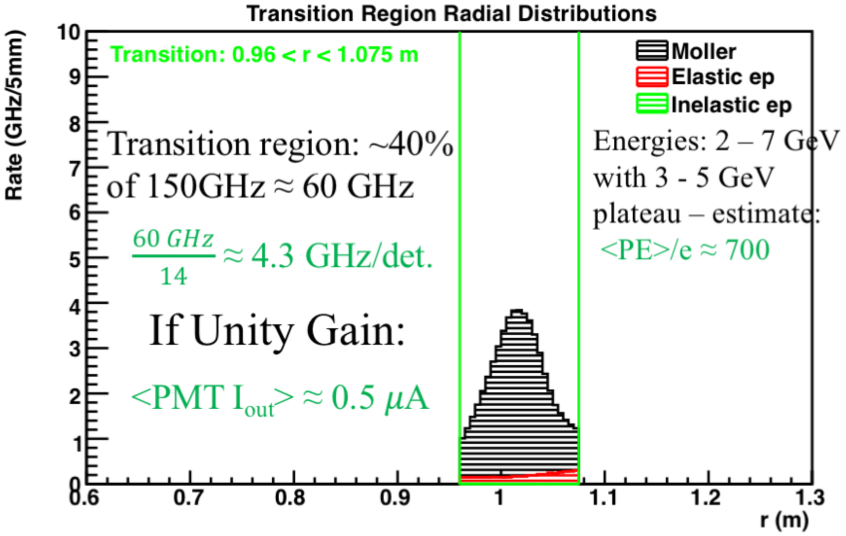
If Unity Gain:

Rate/det·<PE>·e = <PMT I_{out}>

<PMT I_{out}> ≈ 1.3 μA

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

<PE>/e ≈ 900



Transition: $0.96 < r < 1.075$ m

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

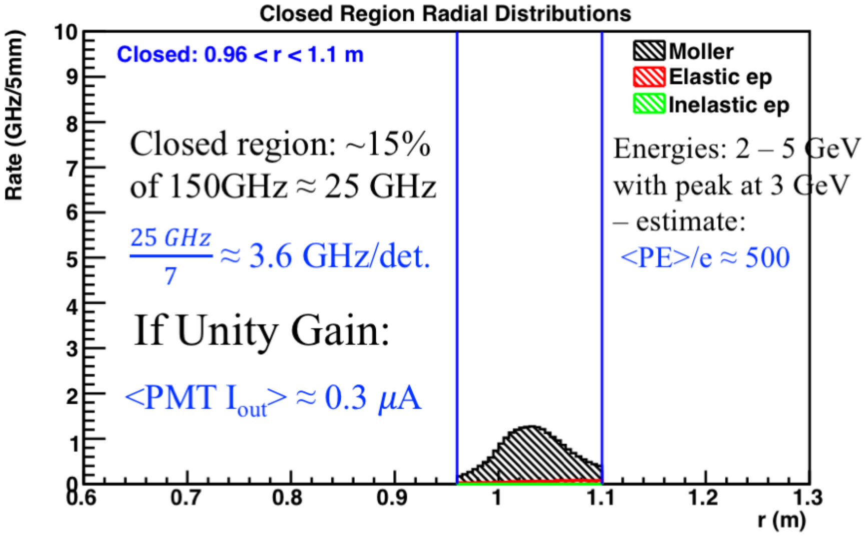
$\frac{60\ GHz}{14} \approx 4.3$ GHz/det.

If Unity Gain:

<PMT I_{out}> ≈ 0.5 μA

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

<PE>/e ≈ 700



Closed: $0.96 < r < 1.1$ m

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

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

If Unity Gain:

<PMT I_{out}> ≈ 0.3 μA

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

<PE>/e ≈ 500

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