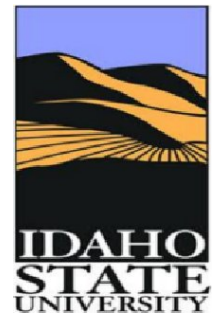
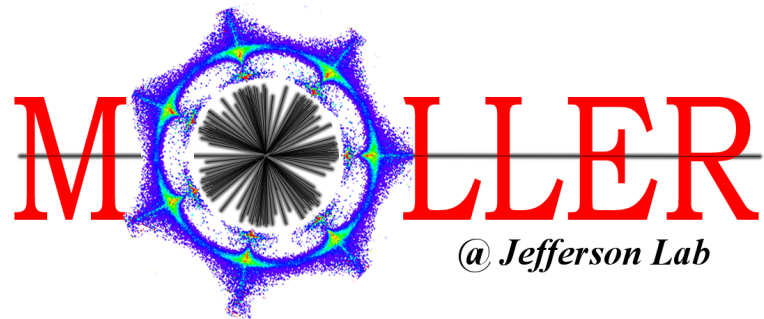


Baseline Shower-max Design and Preliminary Testbeam Results

Dustin McNulty
Idaho State University
mcnulty@jlab.org

March 21, 2019

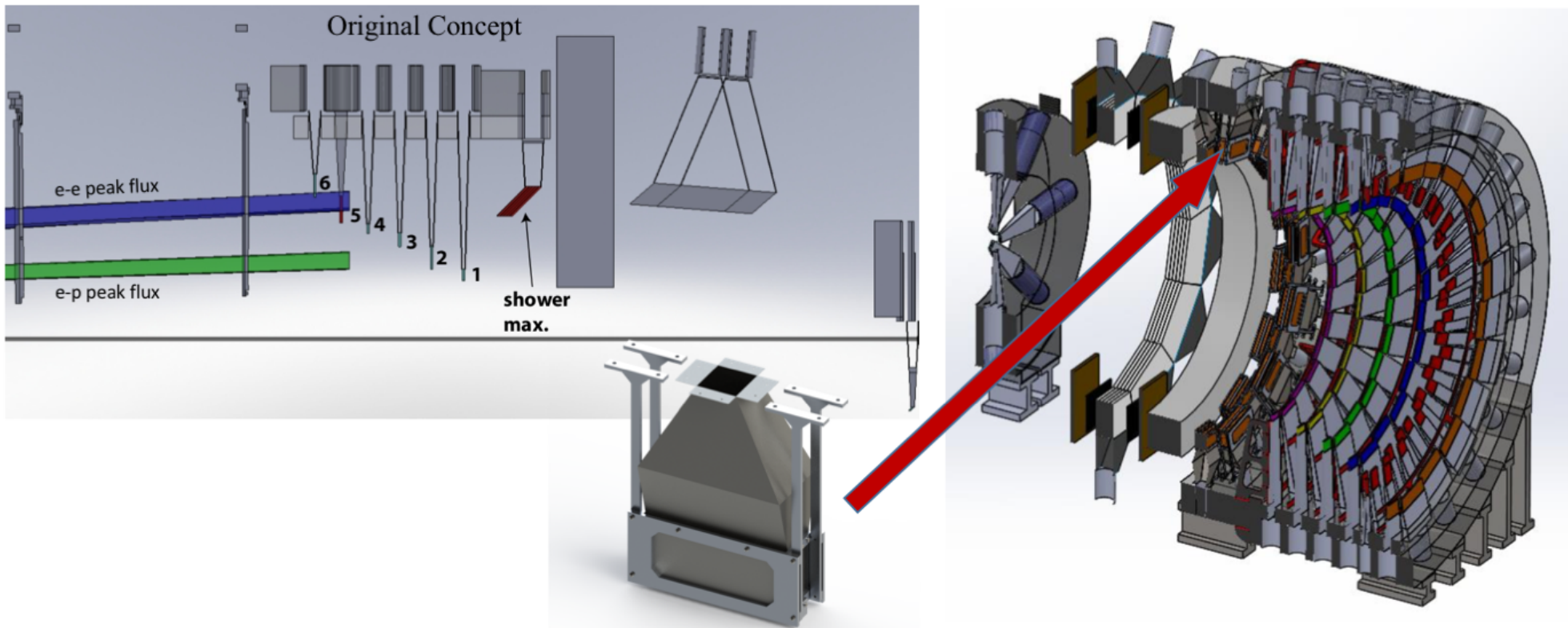


Baseline Shower-max Design and Preliminary Testbeam Results

Outline

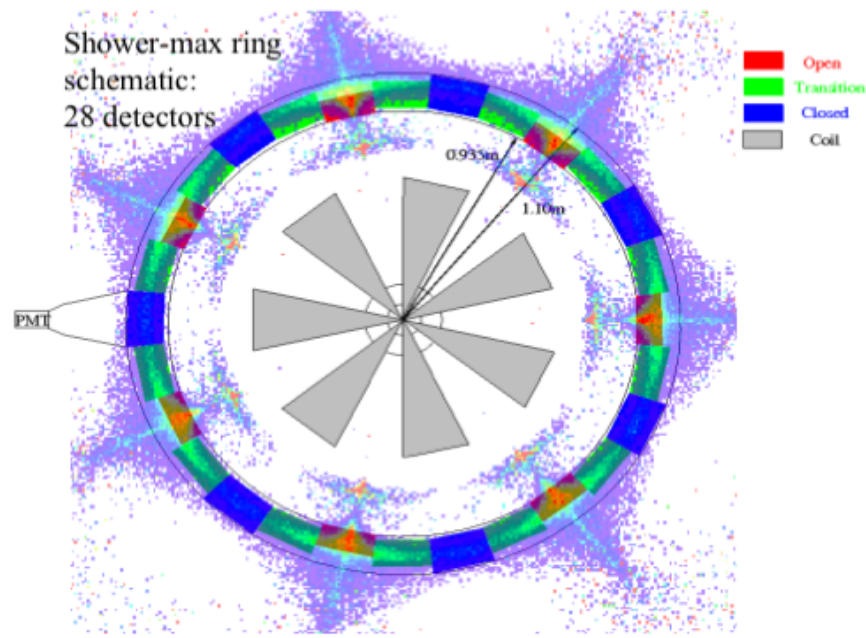
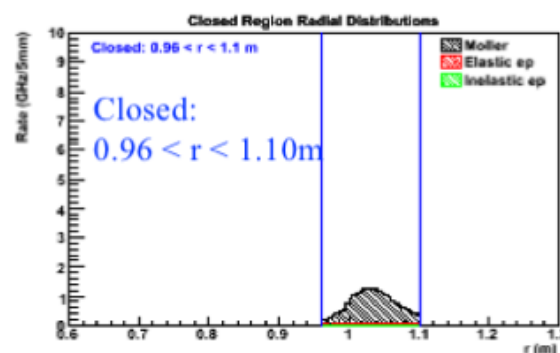
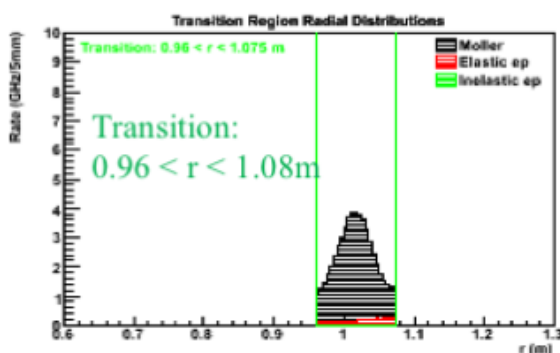
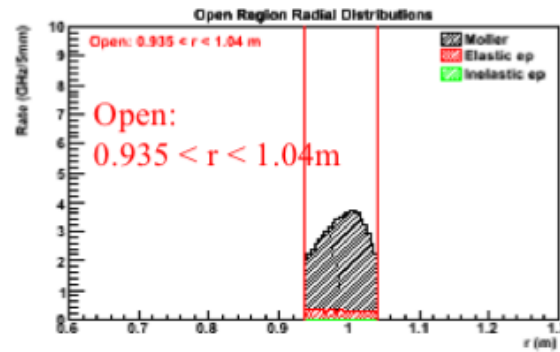
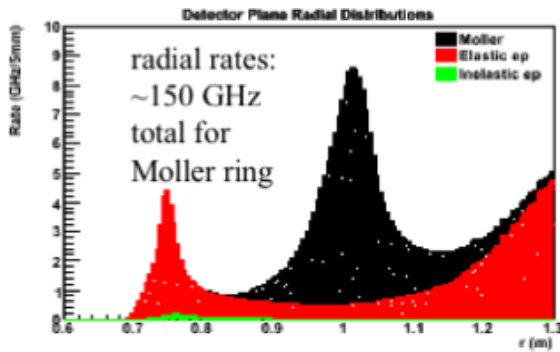
- Review baseline design and ring concept
- Prototype designs for testbeam (Baseline Designs)
- Prototype construction and testbeam Run
- Some Preliminary Testbeam Results
- Summary and Future Work

Shower-max Motivation & Requirements

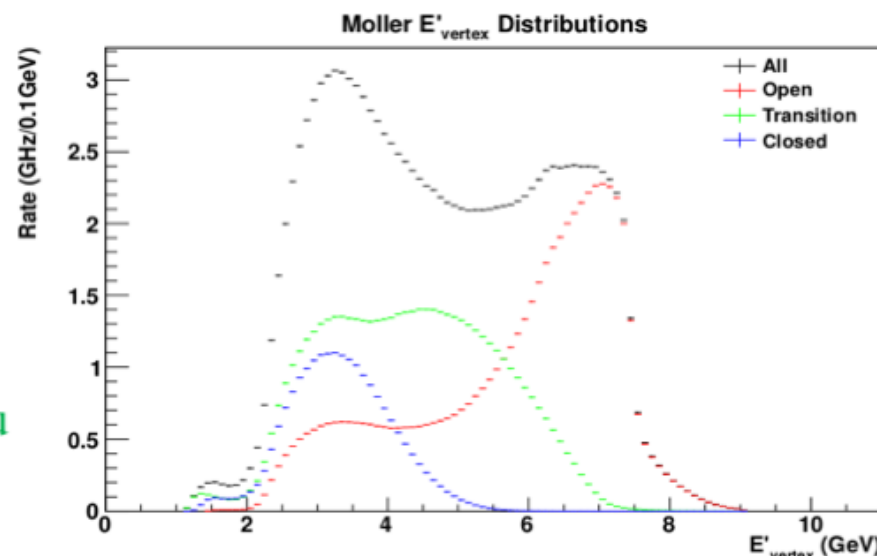


- Provides additional measurement of e-e ring integrated flux
- Weights flux by energy \Rightarrow less sensitive to low energy and hadronic backgrounds
- Will also operate in tracking mode to give additional handle on background (pion) identification – gives MIP-like signal
- Should have good resolution 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

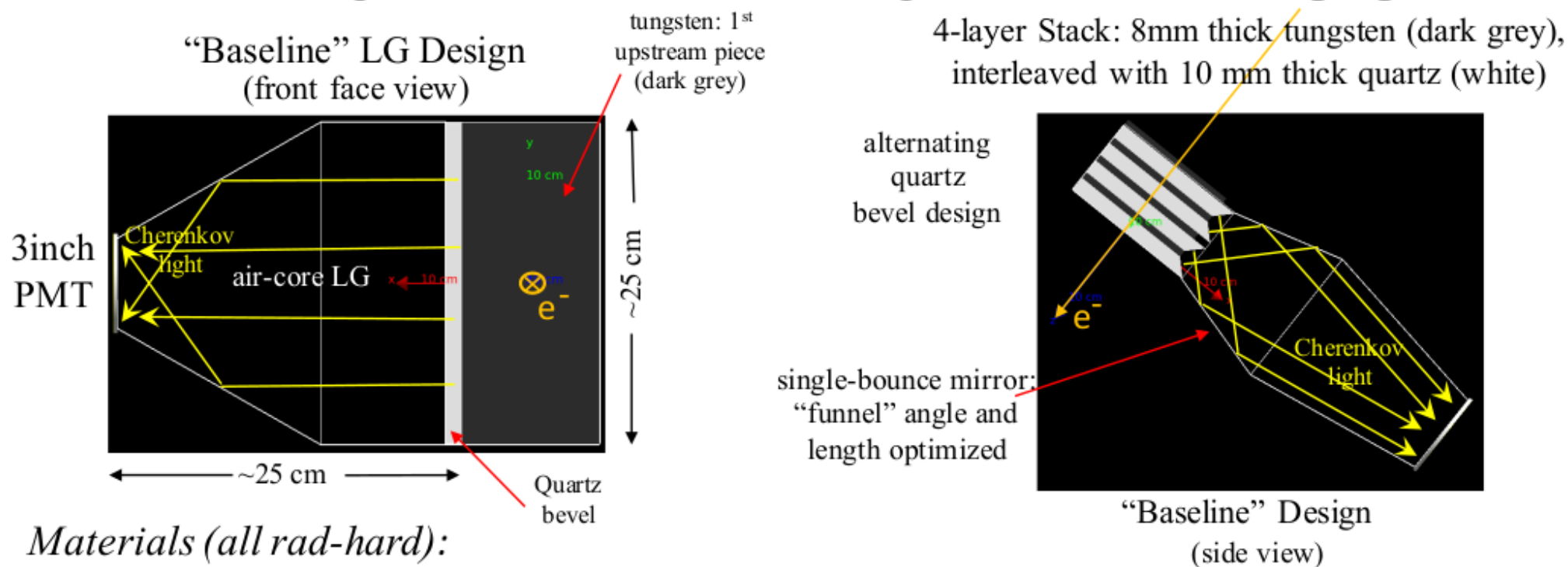


- Large range of rates and energies for different phi-region detectors:
 - Open ~9 GHz/det; 2 - 9 GeV, peak at 7 GeV...
 - Closed ~3.5 GHz/det; 2 - 5 GeV, peak at ~3 GeV
 - Transition ~4.5 GHz/det; 2 - 7 GeV, 3 - 5 GeV plateau



Baseline Design Stack and Light Guide Concepts

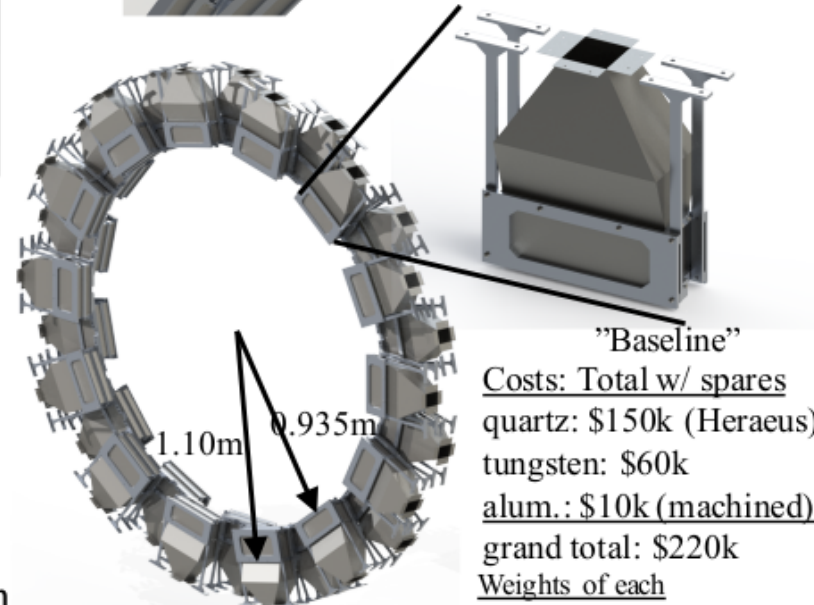
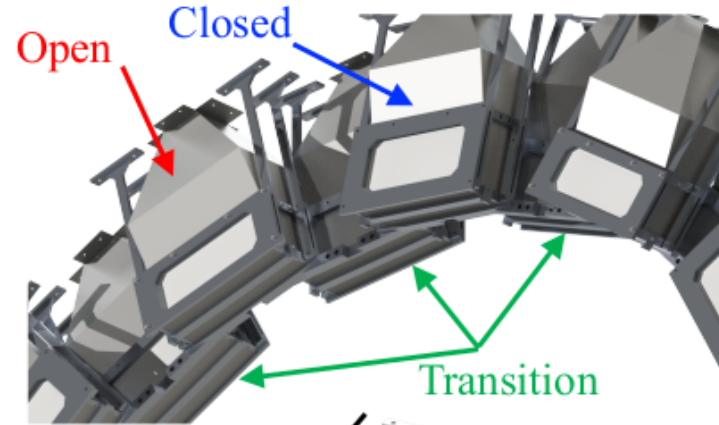
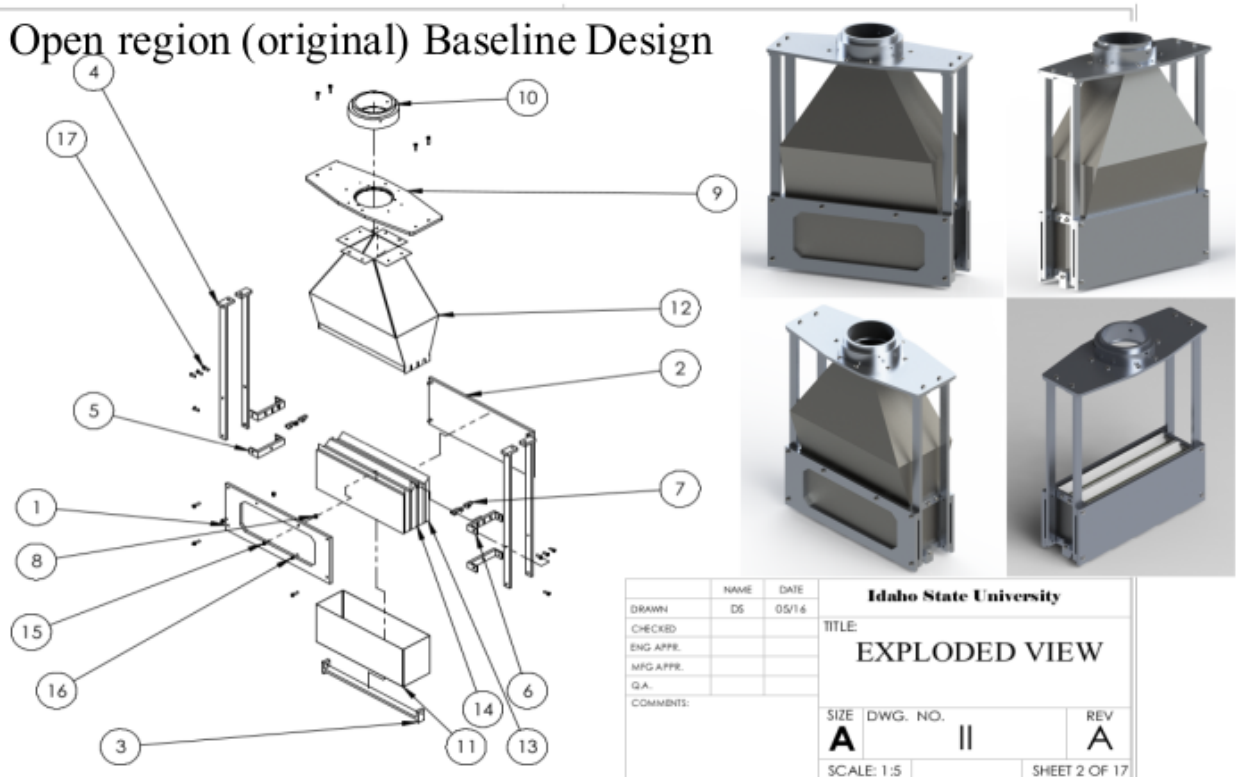
- Detector concept uses a layered “stack” of tungsten and fused silica (quartz) to induce EM showering and produce Cherenkov light
- “Baseline” design developed using GEANT4 optical MC simulation:
 - Current design uses a **4-layer stack** with **8 mm tungsten** and **10 mm quartz** pieces
 - Cherenkov light directed to **3 inch PMT** using **air-core, aluminum light guide**



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



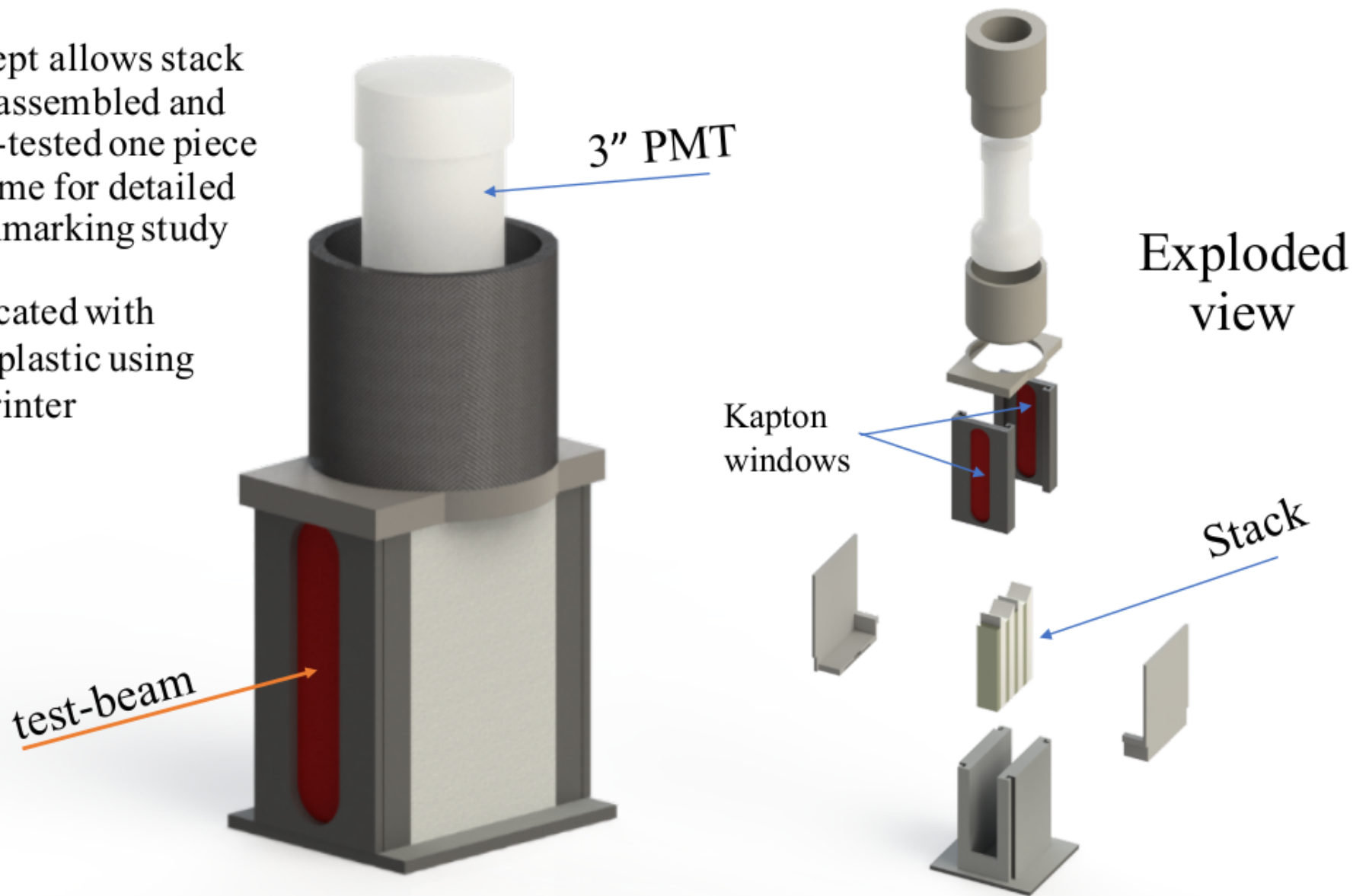
"Baseline"
 Costs: Total w/ spares
 quartz: \$150k (Heraeus)
 tungsten: \$60k
 alum.: \$10k (mached)
 grand total: \$220k
Weights of each assembly:
 Open: 39.7 lbs.
 Transition: 42.5 lbs.
 Closed: 50.8 lbs.
 ring weight: 1230 lbs.

- 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

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 ABS plastic using 3D printer



Config #1 (original baseline) benchmarking Prototype

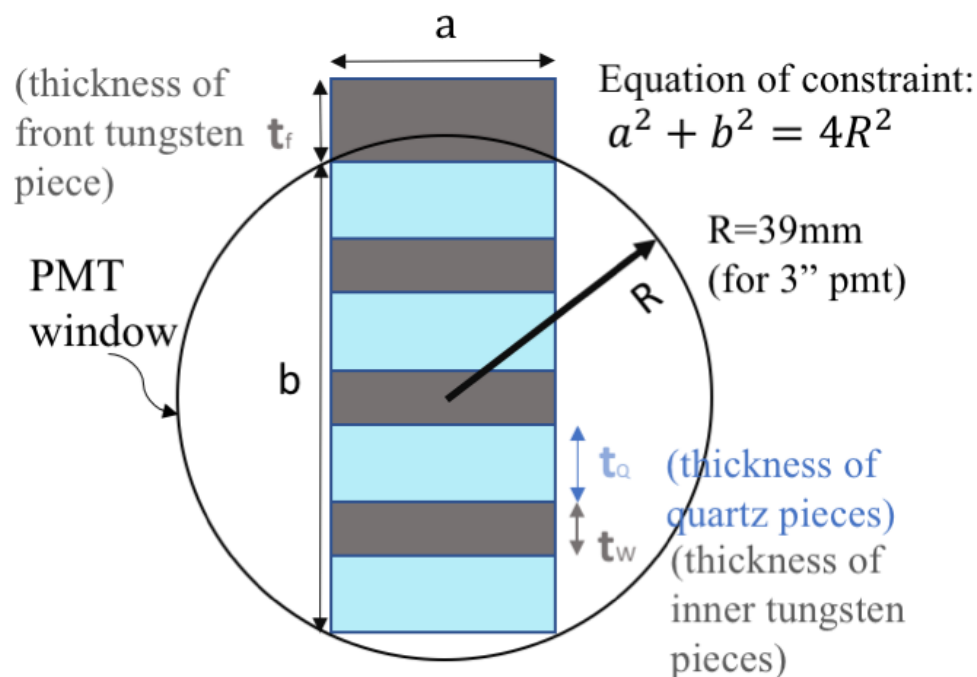
Benchmarking Stack Configurations

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.



Quartz and Tungsten Ordered in Nov 2017

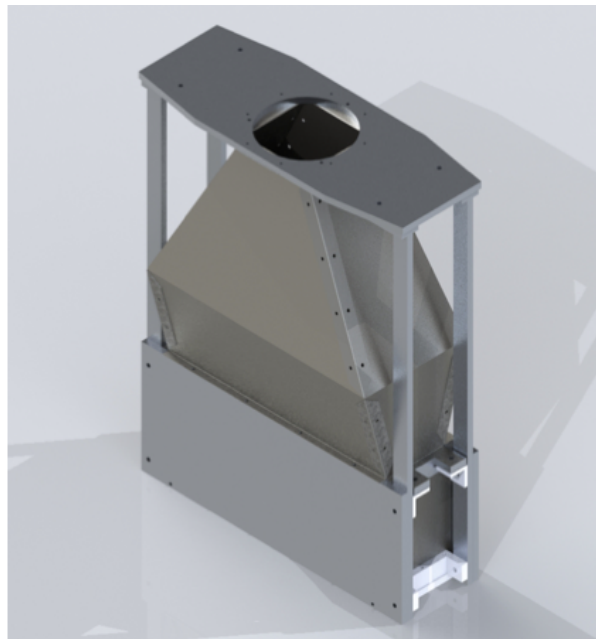
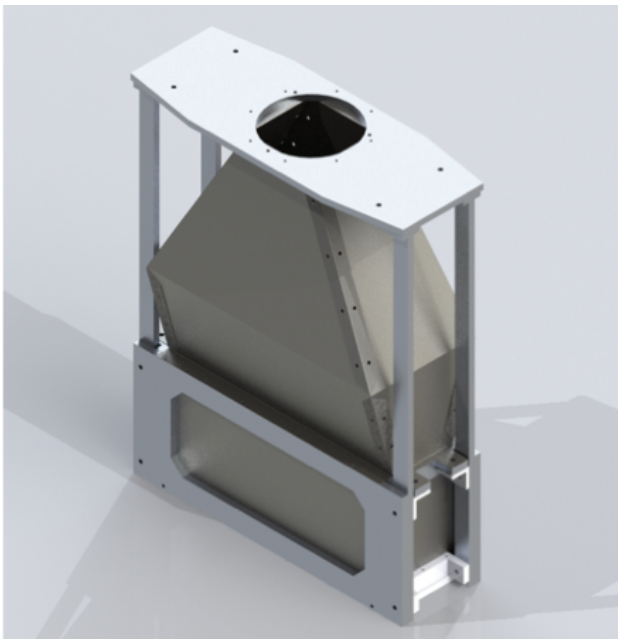
- For “benchmarking” prototype stack:
 - Quartz: 6 mm (thick) by 86 mm (tall) by 40 mm (wide) --4 pieces (\$975/piece = \$3.9k)
 - Quartz: 10 mm (thick) by 90 mm (tall) by 40 mm (wide) --4 pieces (\$1005/piece = \$4.0k)
 - Tungsten: 6 mm (thick) by 80 mm (tall) by 40 mm (wide) – 4 pieces (\$85/piece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

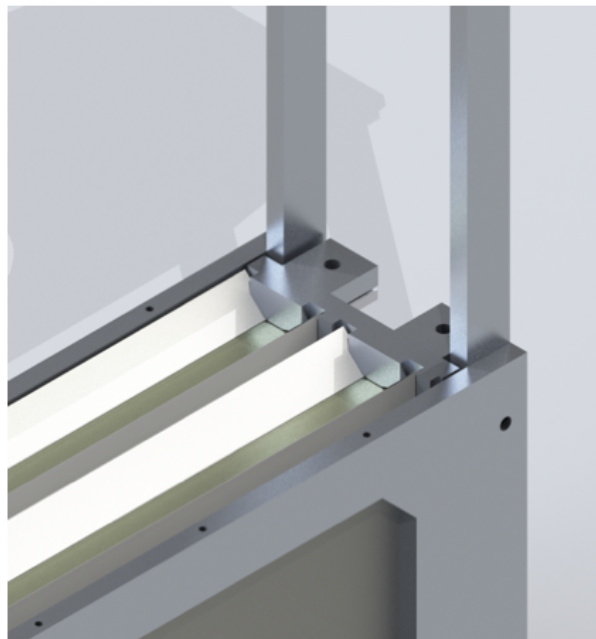
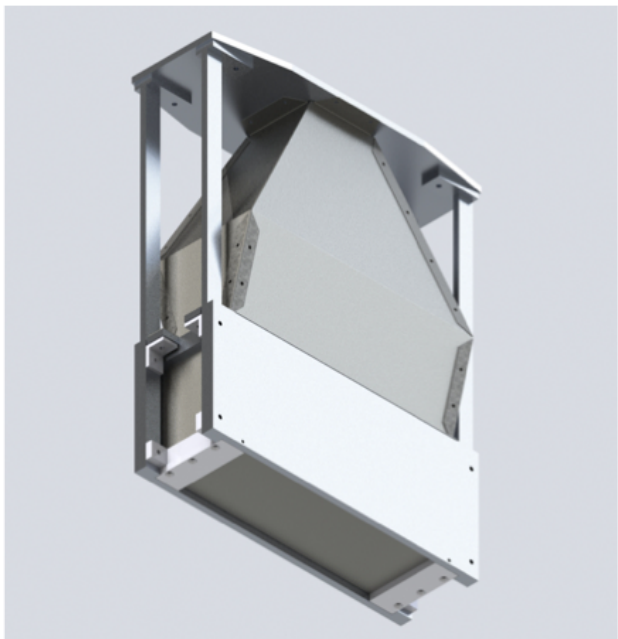
- This purchase enables construction of two benchmarking and two full-scale prototype sets
- Building two sets of prototypes will allow for more efficient testing during both SLAC testbeam and cosmic tests at SBU and ISU. We can each build a different configuration to test

Updated Full-Scale Prototype (1A) for Testbeam

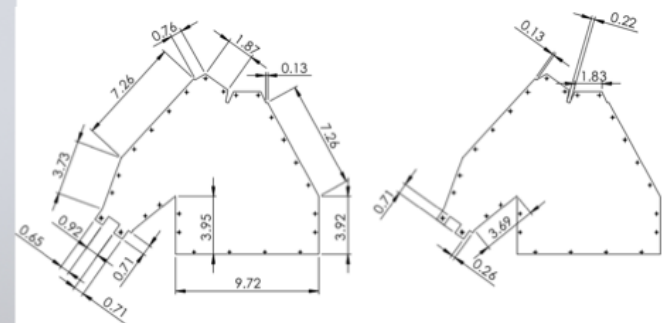


UNLESS OTHERWISE SPECIFIED:	NAME	DATE	Moller Collaboration	
DIMENSIONS ARE IN INCHES	DRAWN	DKS	1/14/18	TITLE
TOLERANCES:	CHECKED			Light Guide
FRACTIONAL ±	END APPR.			SIZE
ANGULAR: MACH ± BEND ±	MFG APPR.			DWG. NO. I
TWO PLACE DECIMAL ±	Q.A.			REV 0
THREE PLACE DECIMAL ±	COMMENTS:			SCALE: 1:10WEIGHT:
INTERPRET GEOMETRIC TOLERANCING PER:				SHEET 1 OF 9
MATERIAL:				

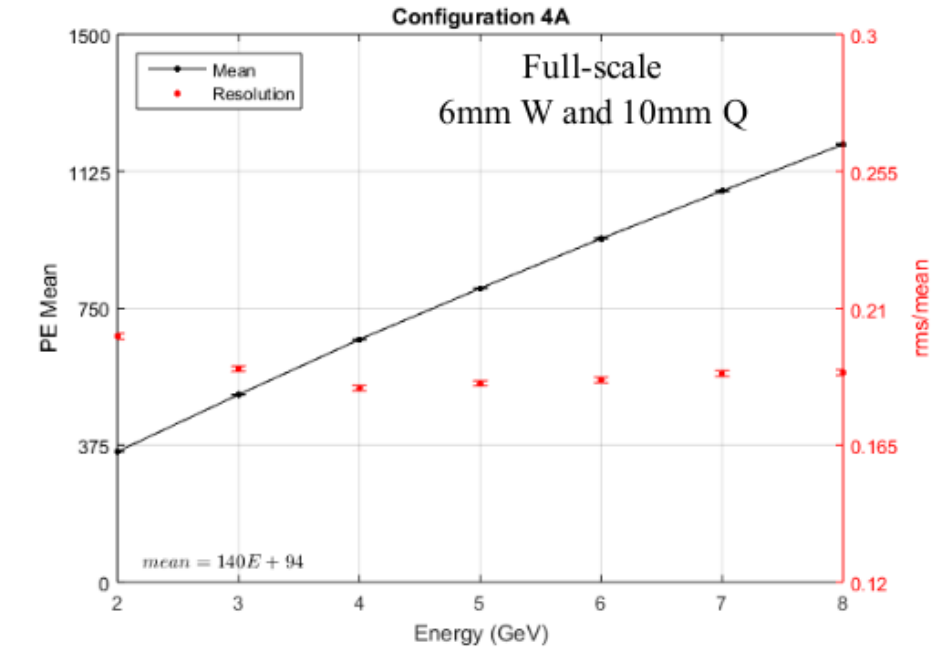
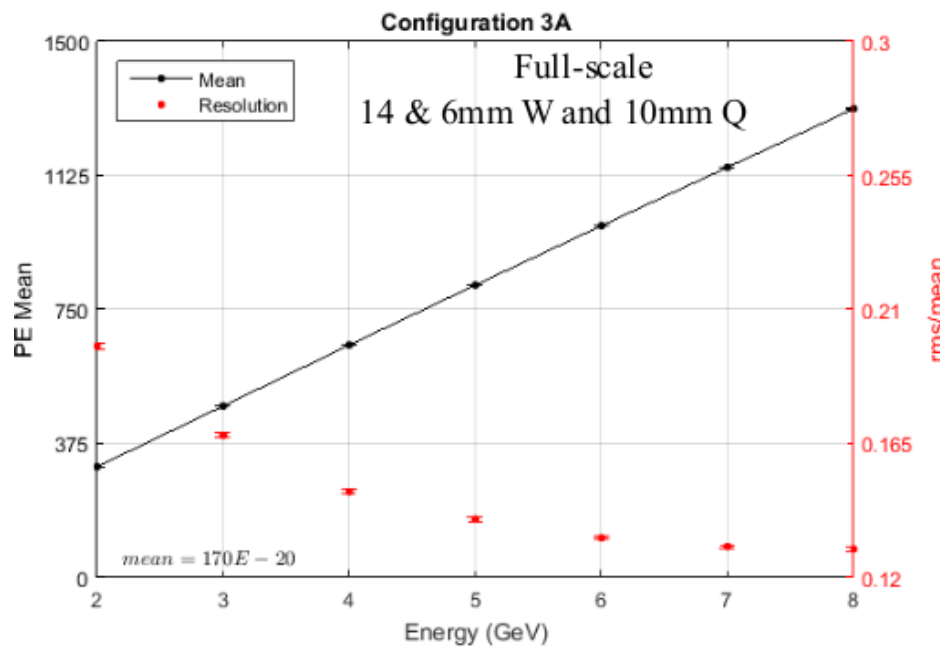
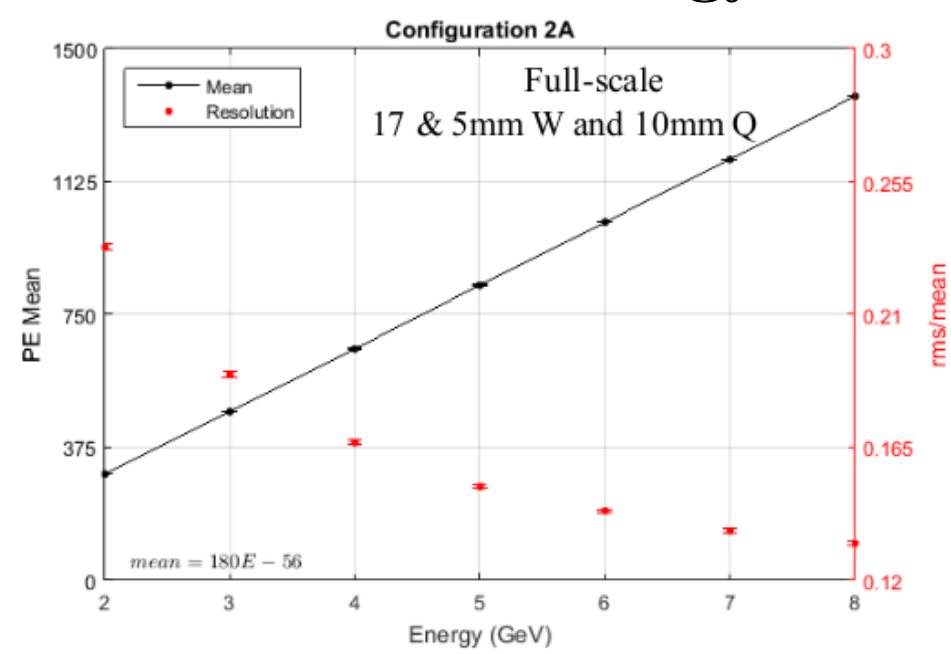
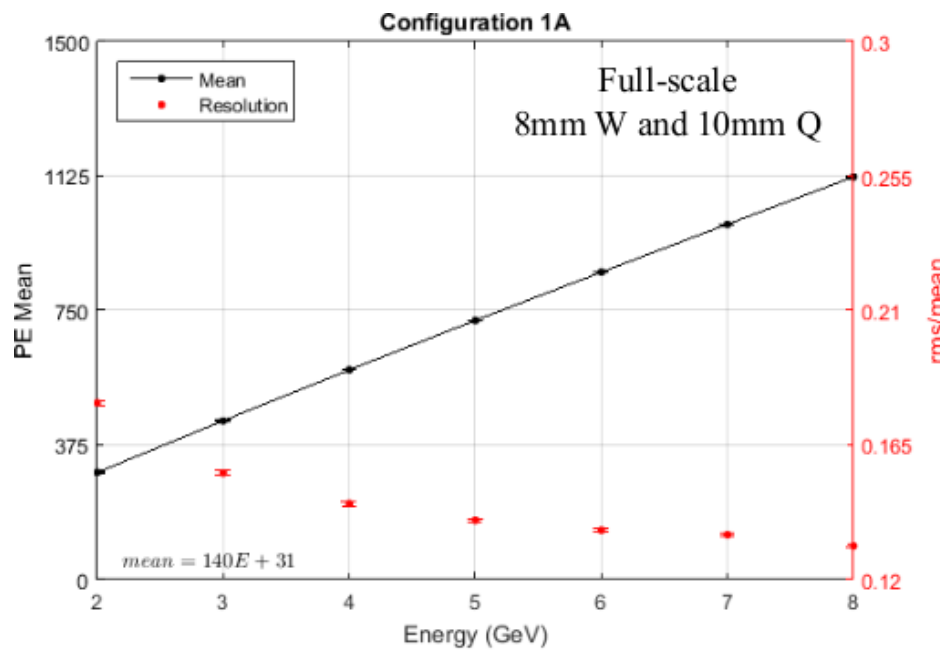
ITEM NO.	PART	MATERIAL	QTY.
1	Light Guide - Back	0.002 ANODIZED MIRROR SILVER REFLECTIVE ALUMINUM SHEET	1
2	Light Guide - Front	0.002 ANODIZED MIRROR SILVER REFLECTIVE ALUMINUM SHEET	1
3	Long Flap	0.002 ANODIZED MIRROR SILVER REFLECTIVE ALUMINUM SHEET	2
4	Short Flap	0.002 ANODIZED MIRROR SILVER REFLECTIVE ALUMINUM SHEET	4
5	Suitcase	0.002 ANODIZED MIRROR SILVER REFLECTIVE ALUMINUM SHEET	2



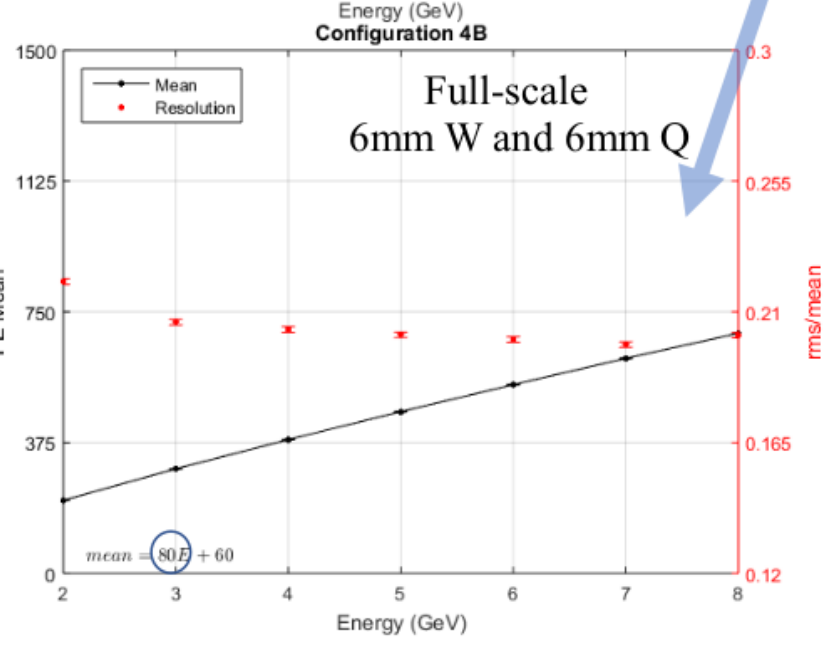
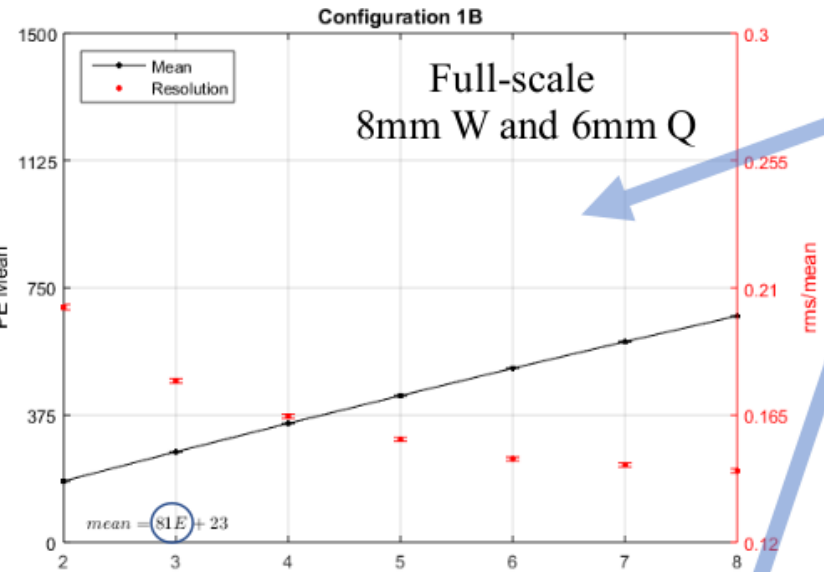
UNLESS OTHERWISE SPECIFIED:	NAME	DATE	Moller Collaboration	
DIMENSIONS ARE IN INCHES	DRAWN	DKS	1/14/18	TITLE
TOLERANCES:	CHECKED			Exploded View
FRACTIONAL ±	END APPR.			SIZE
ANGULAR: MACH ± BEND ±	MFG APPR.			DWG. NO. II
TWO PLACE DECIMAL ±	Q.A.			REV 0
THREE PLACE DECIMAL ±	COMMENTS:			SCALE: 1:10WEIGHT:
INTERPRET GEOMETRIC TOLERANCING PER:				SHEET 2 OF 9
MATERIAL:				



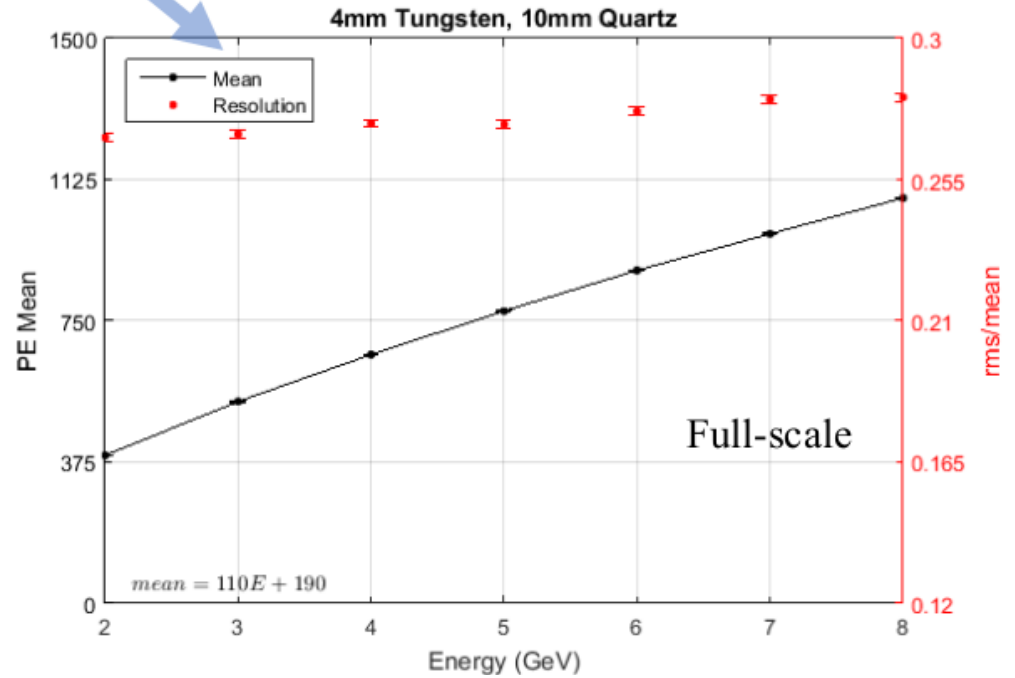
1A - 4A Mean PE and Resolution versus Energy



Simulation results for B configs (6mm quartz)

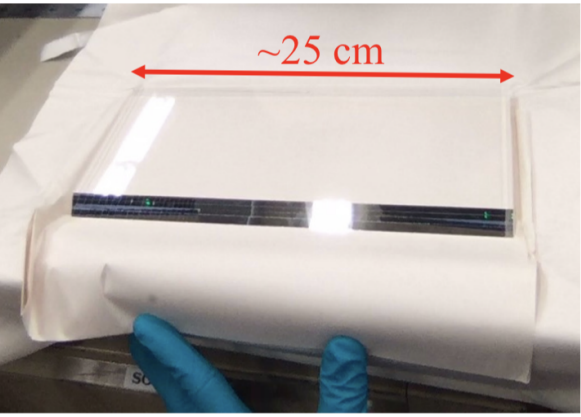


- The B configs have ~half the slope of the other configs – 80 PEs/GeV – while maintaining good resolution and with lower light levels.
- The reduced slope means less variation in PE yields with energy--which will reduce the widths measured during helicity window (it seems a potential win win win situation)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

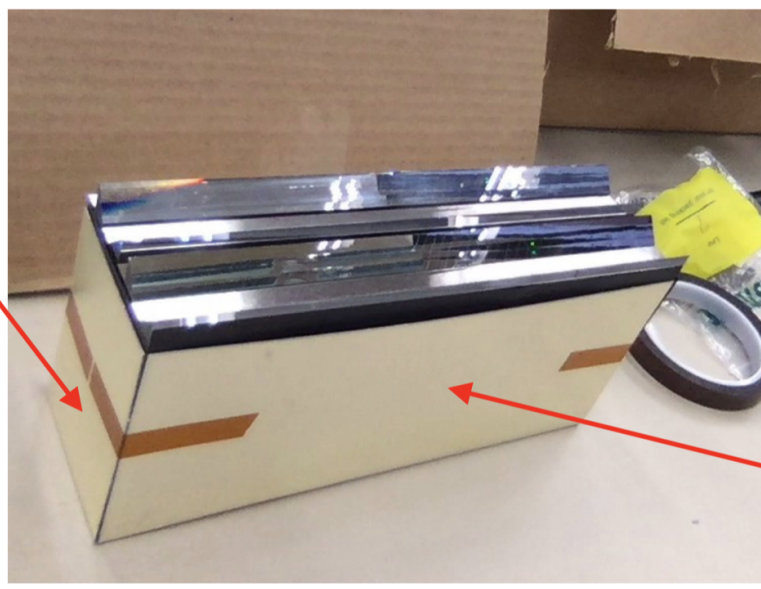


Prototype Construction and SLAC Testbeam Run

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



~25 cm



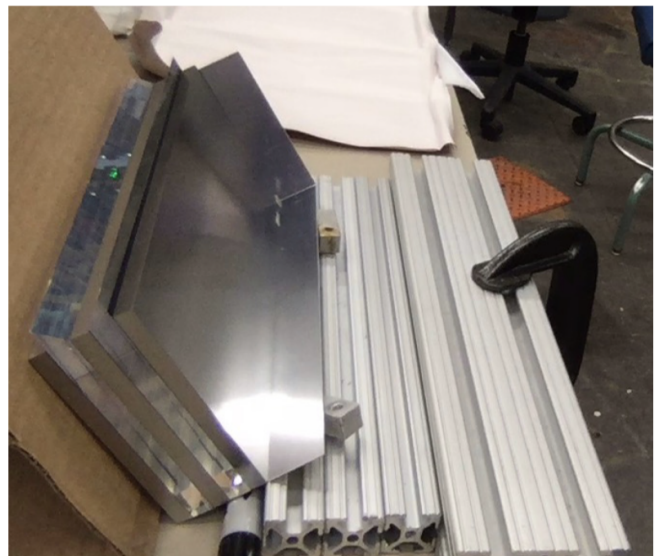
Aluminum sheet coffin

Fully assembled stack weighs ~40 lbs



8 mm thick 99.95% pure tungsten plates

Quartz wrapped in black Kapton

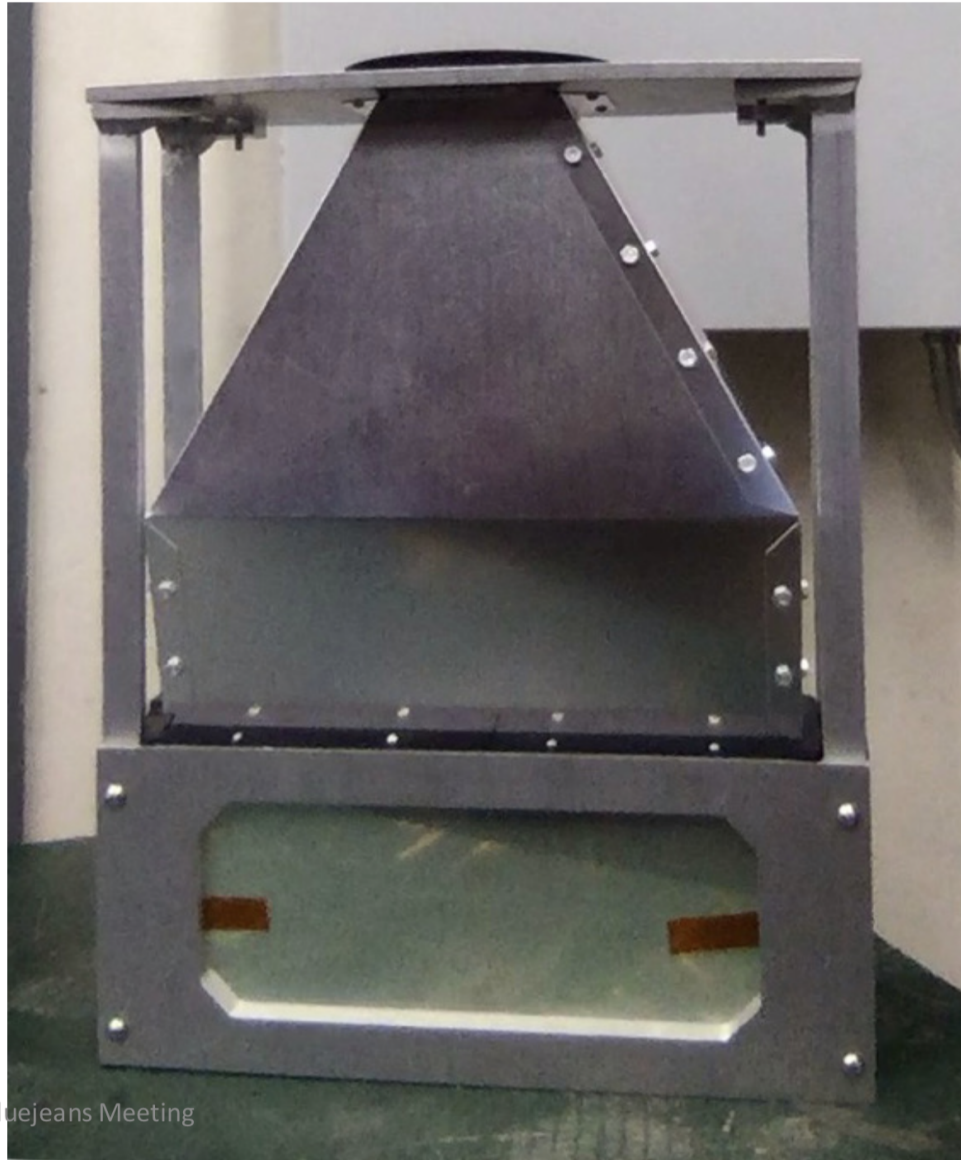
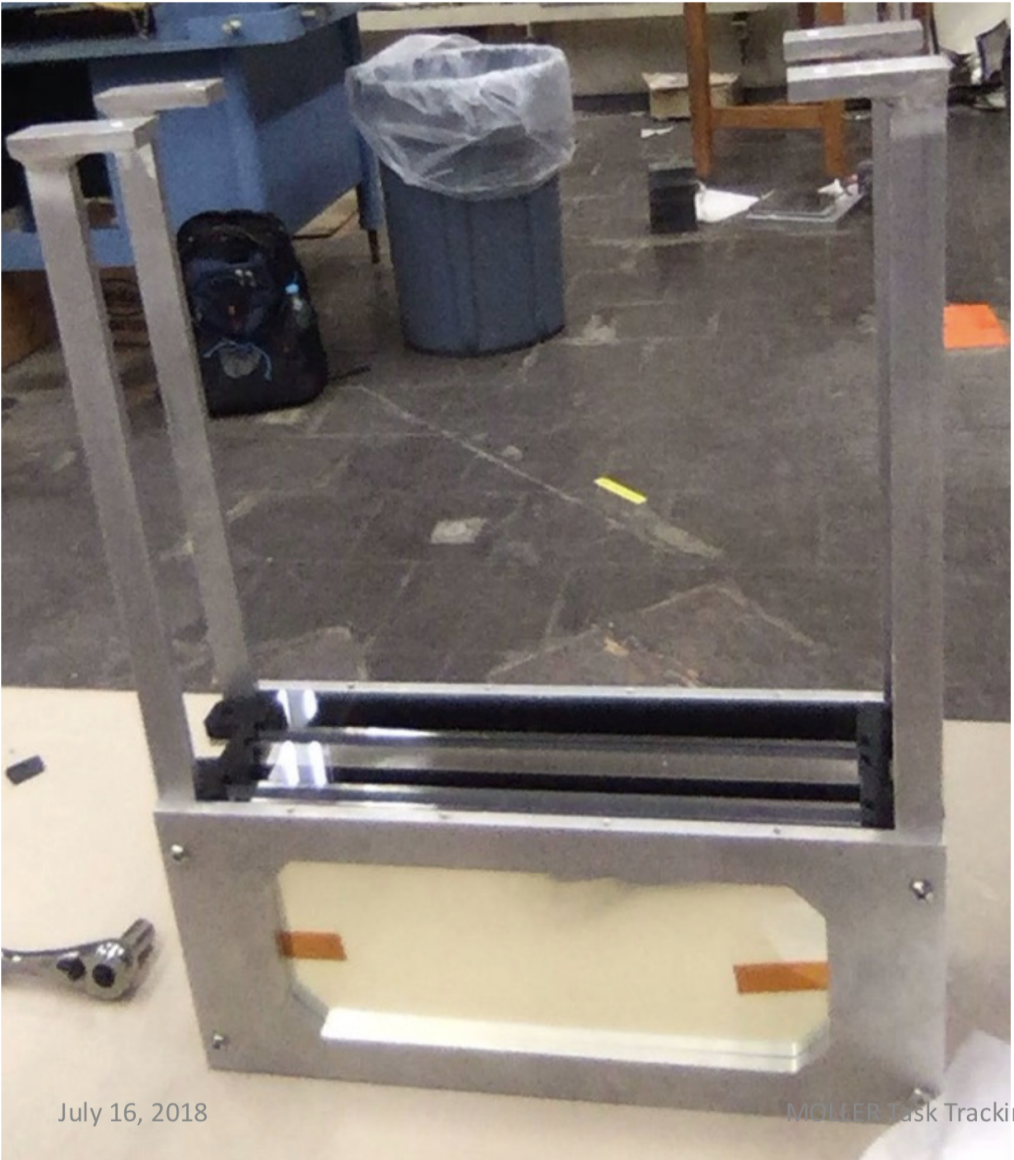


July 16, 2018

MOLLER Task Tracking Bluejeans Meeting

15

Assembled 1A Full-scale ShowerMax Prototype

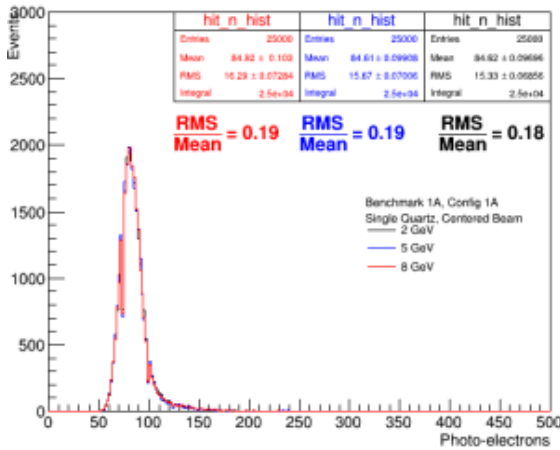


Testbeam and MC benchmarking strategy

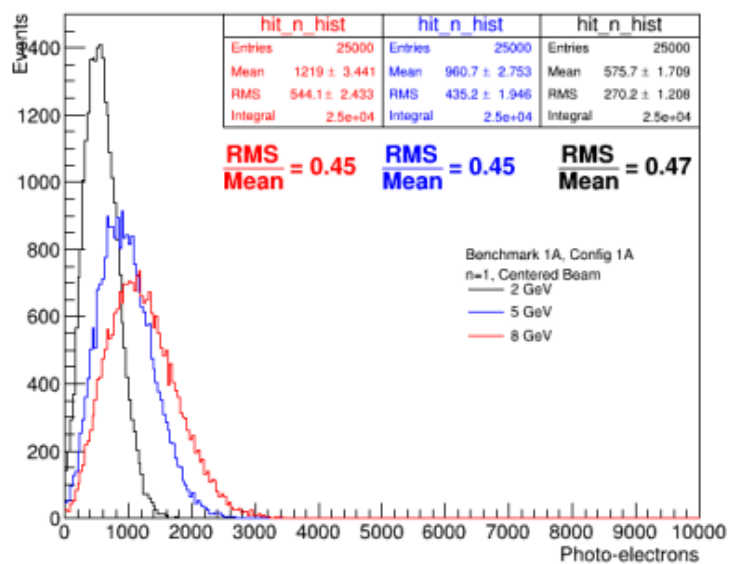
- Engineer benchmarking prototype capable of operation with systematically more stack layers added and with no light guide
- Basic strategy outline:
 - First take data with only one piece of quartz
 - Then add the front tungsten plate and take data, then the next layer of tungsten and quartz, then next, 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 as benchmarking prototype) and with full light guide; this will be constructed with machined aluminum

Benchmarking Prototype (1A) Expectations

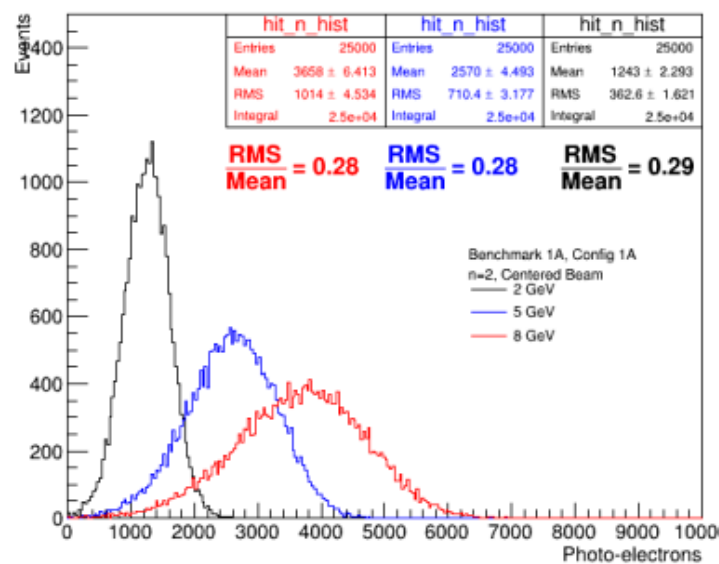
Benchmark 1A: Single Quartz



Benchmark 1A: n=1



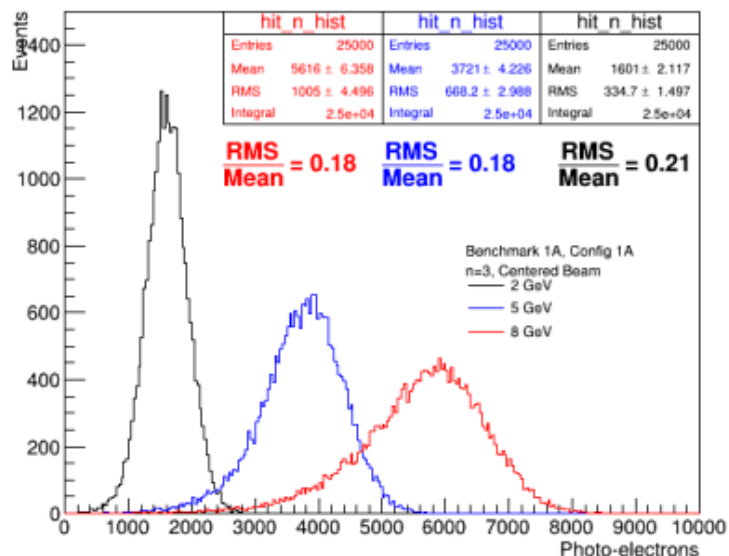
Benchmark 1A: n=2



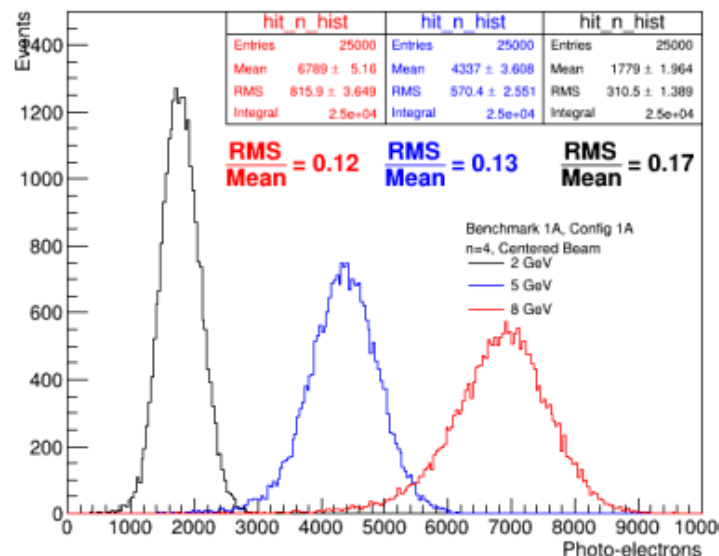
• Benchmarking PE yields are incredibly high for n=1 to 4

• Will use 3" ET PMTs: 9305QKB

Benchmark 1A: n=3

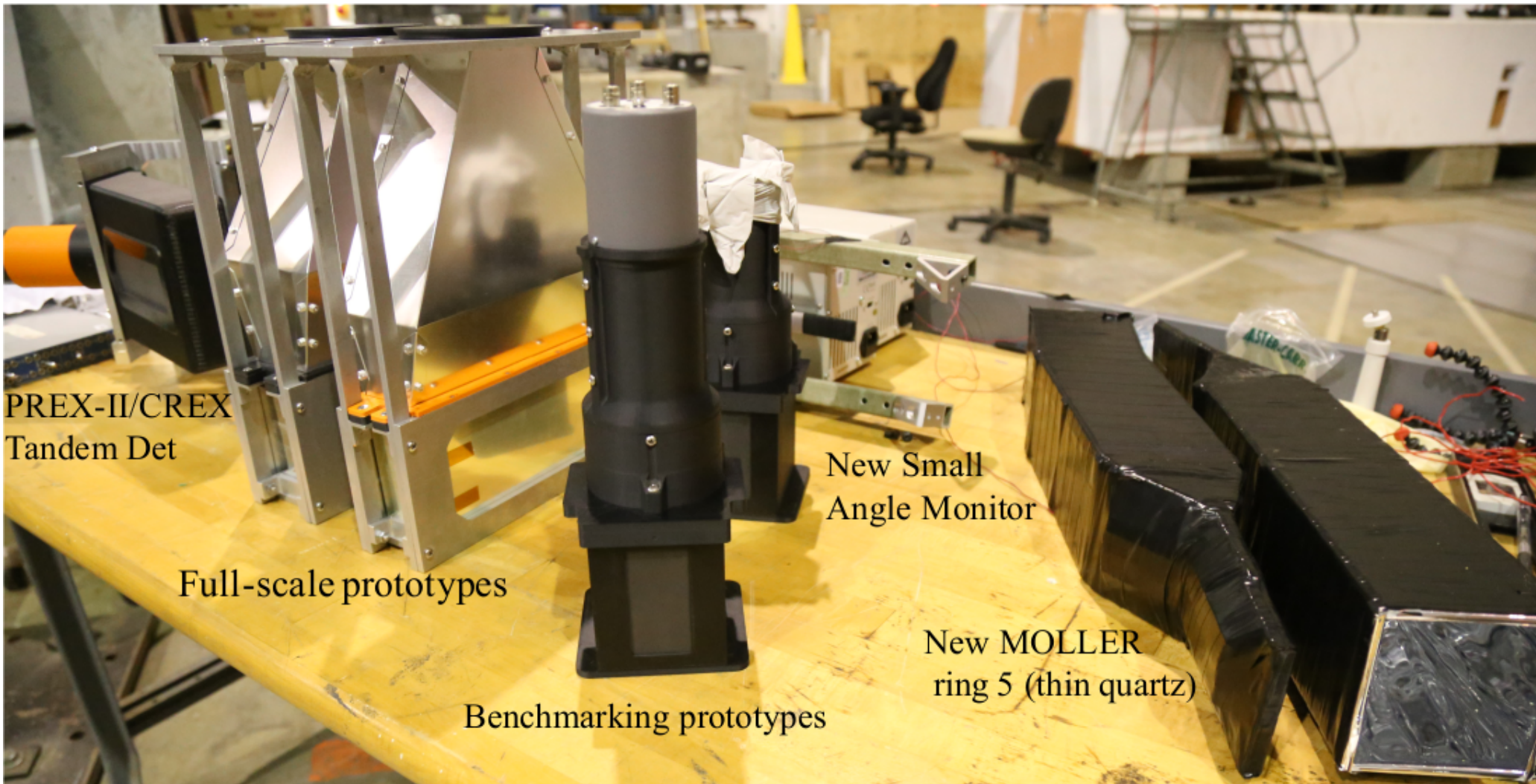


Benchmark 1A: n=4



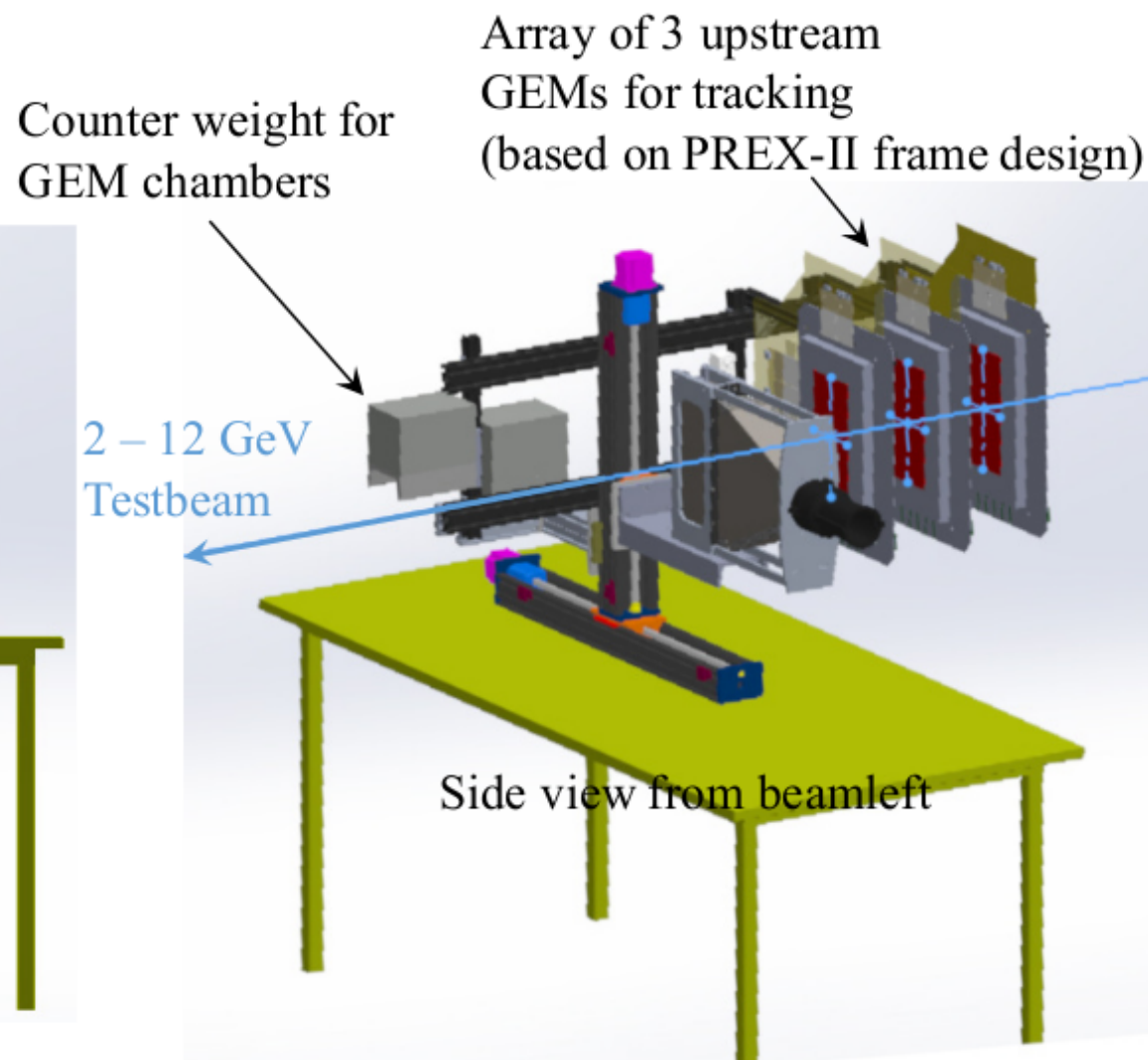
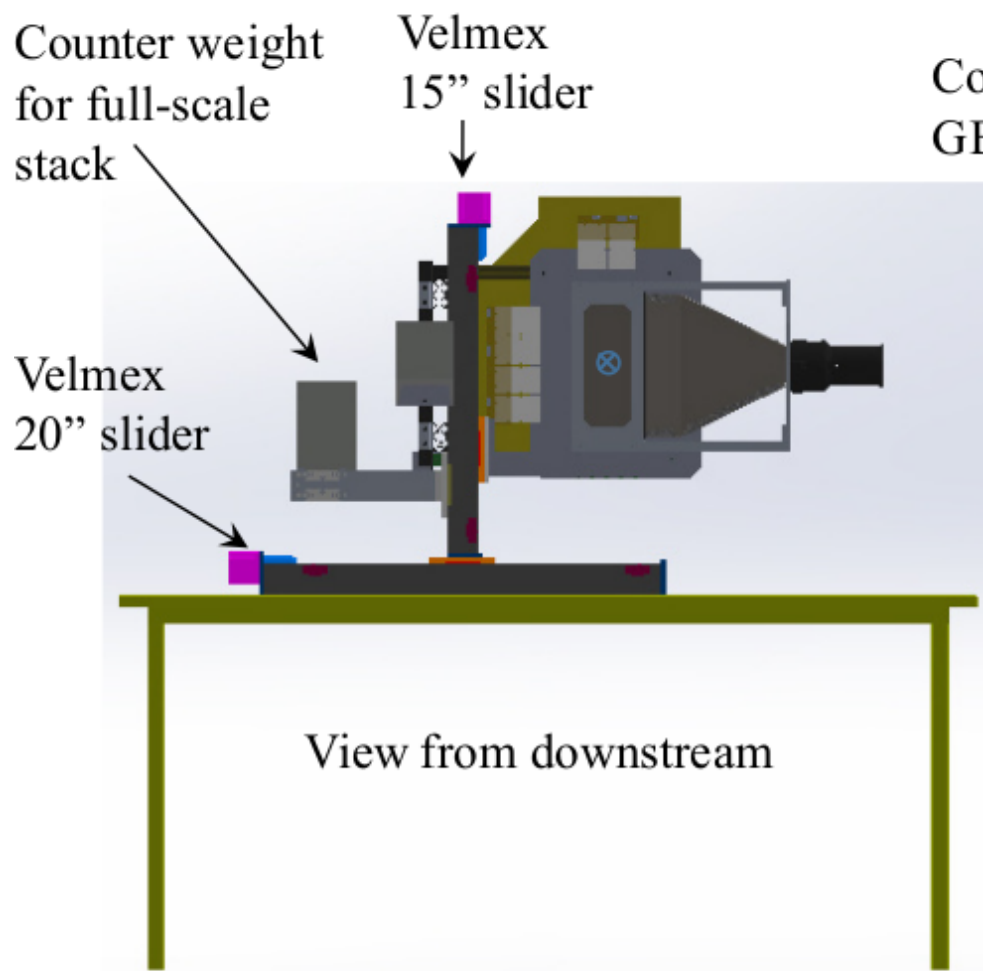
T-577: SLAC Testbeam, Dec 6 – 12, 2018

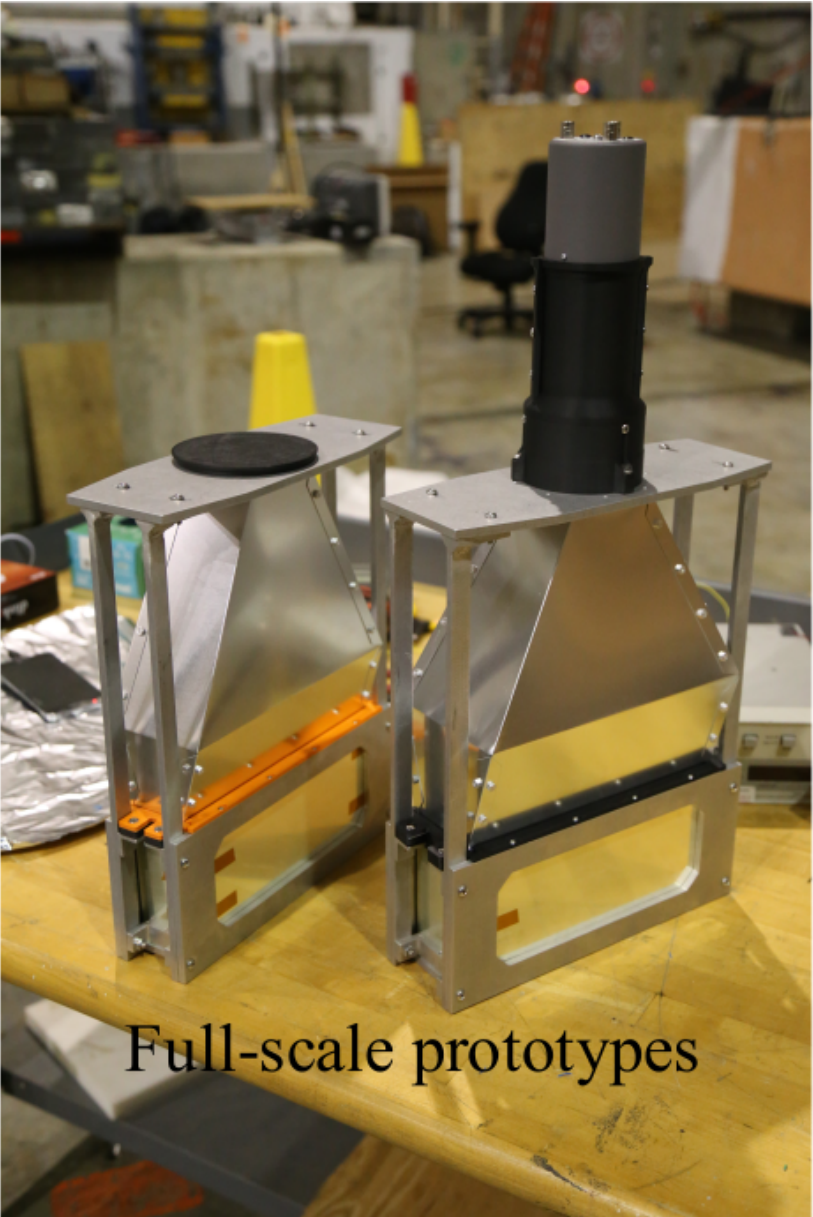
- Tested ShowerMax full-scale and benchmarking detectors and new ring5 thin detector designs
- Used 3, 5.5 and 8 GeV electrons with multiplicity of a Poisson distribution with $\mu \approx 1$
- Overall beam rate only 5 Hz (parasitic from LCLS beam) with $\sim 1/3$ of those being single e^-



CAD of the SLAC testbeam setup

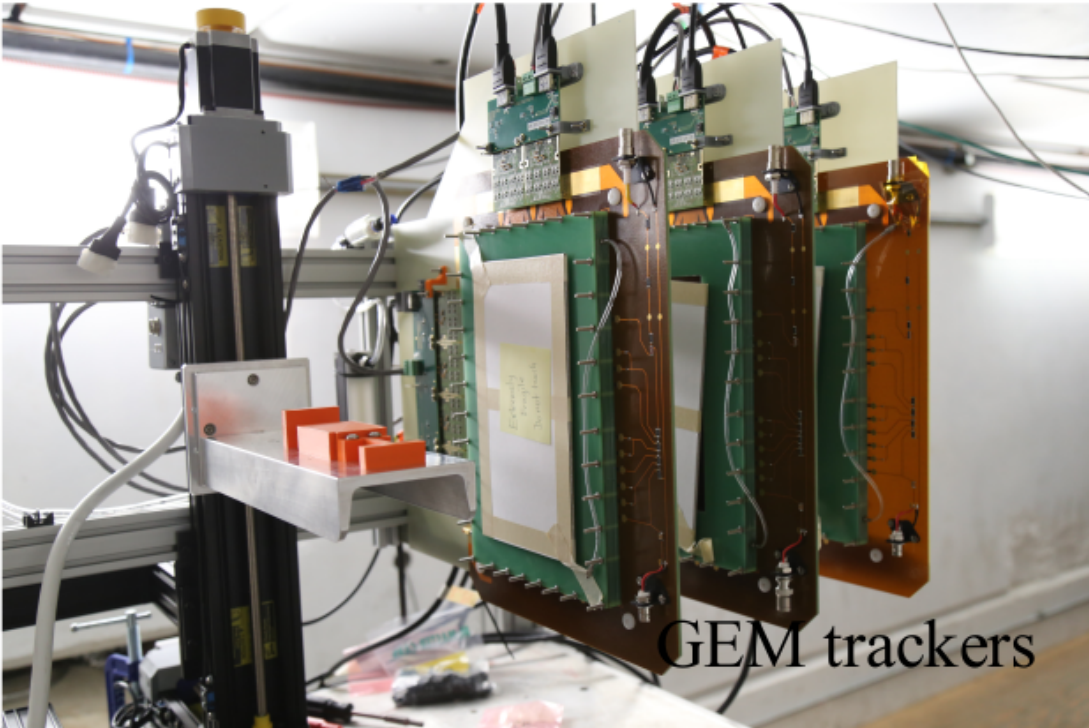
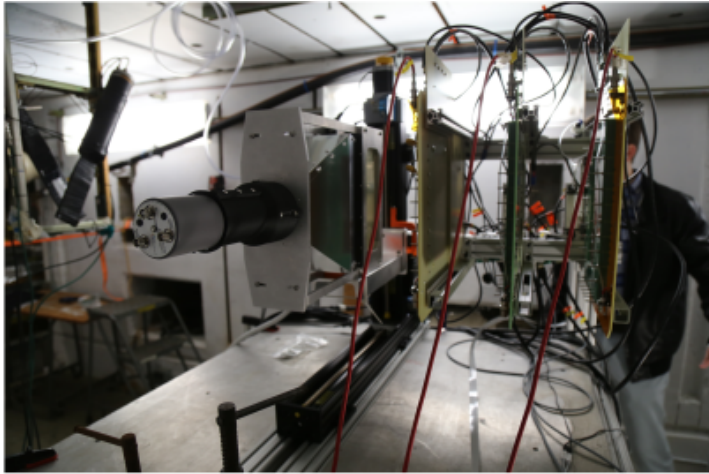
- Testbeam scheduled for Dec 5 – 10 (we may get more time)
- Setup allows testbeam to cover entire active area of full-scale prototypes





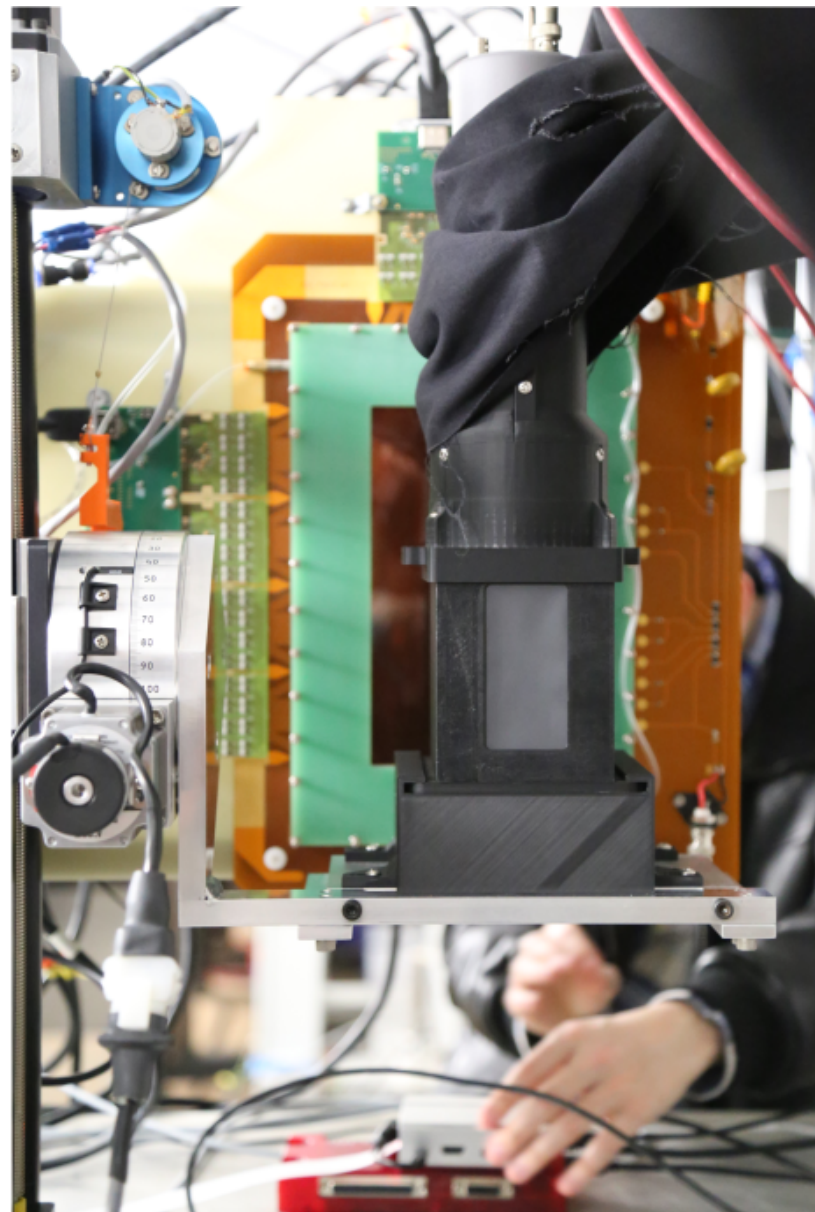
Full-scale prototypes

T-577: SLAC Testbeam Setup for Full-Scale ShowerMax



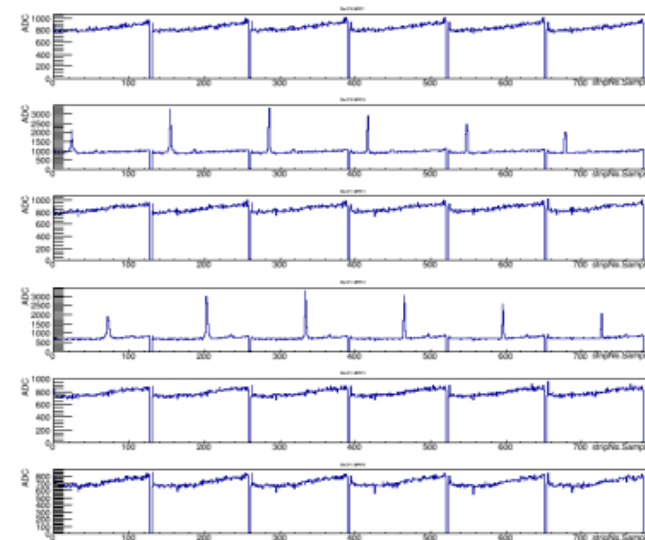
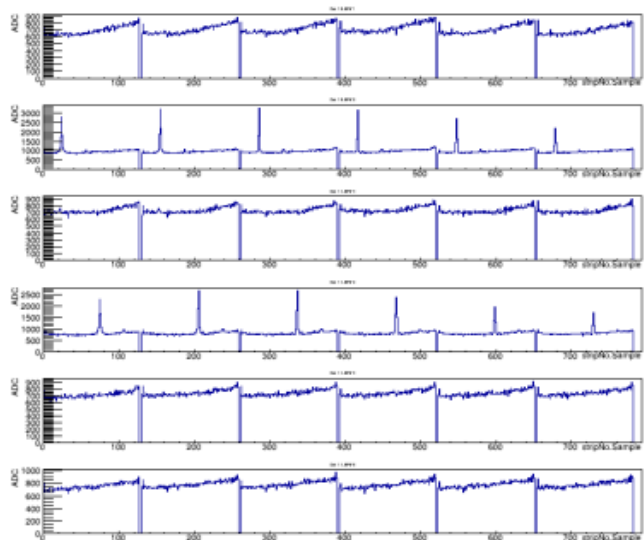
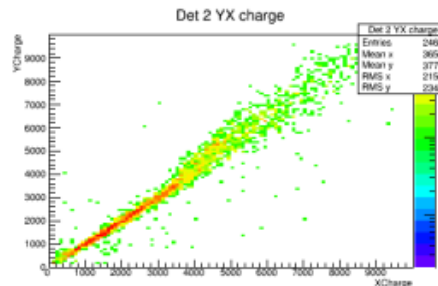
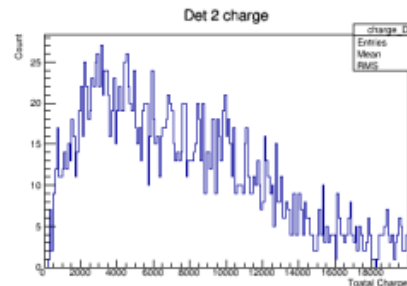
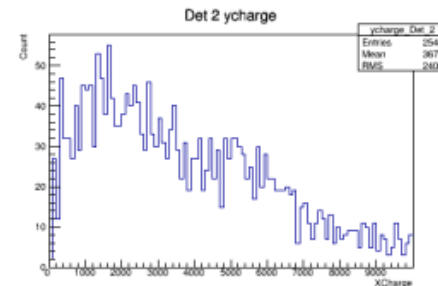
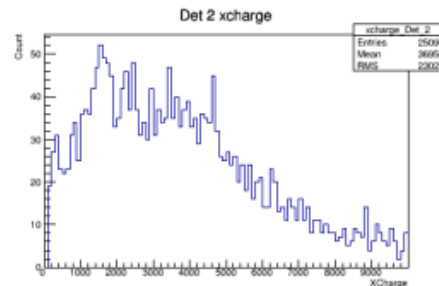
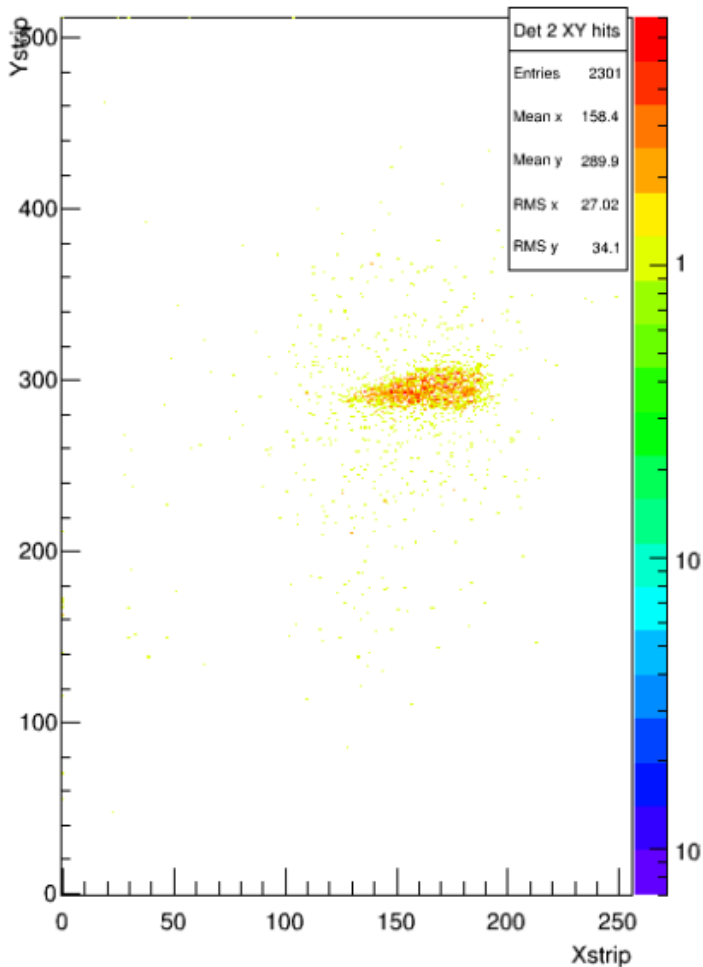
GEM trackers

T-577: SLAC Testbeam Setup: Benchmarking ShowerMax

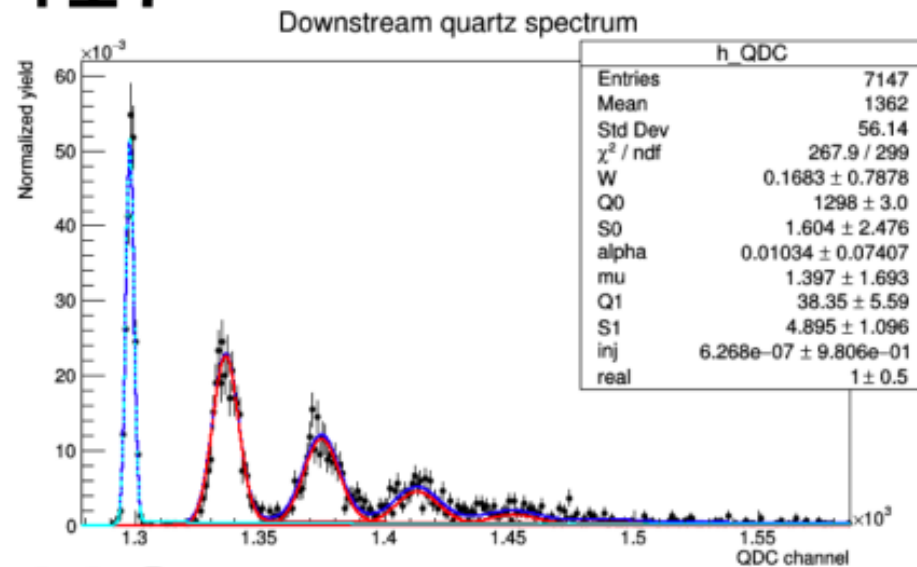
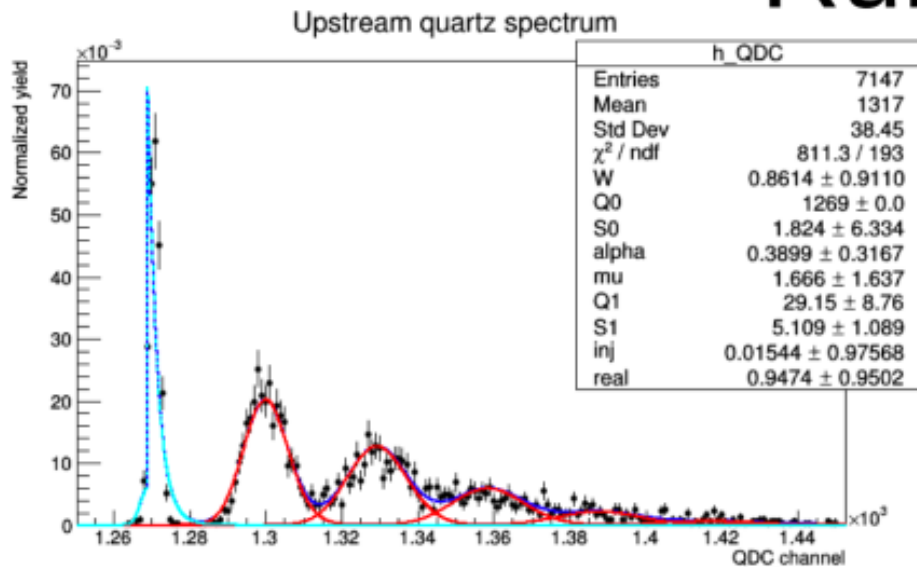


Beam Spot (5.5 GeV): ~1 cm by 2 cm

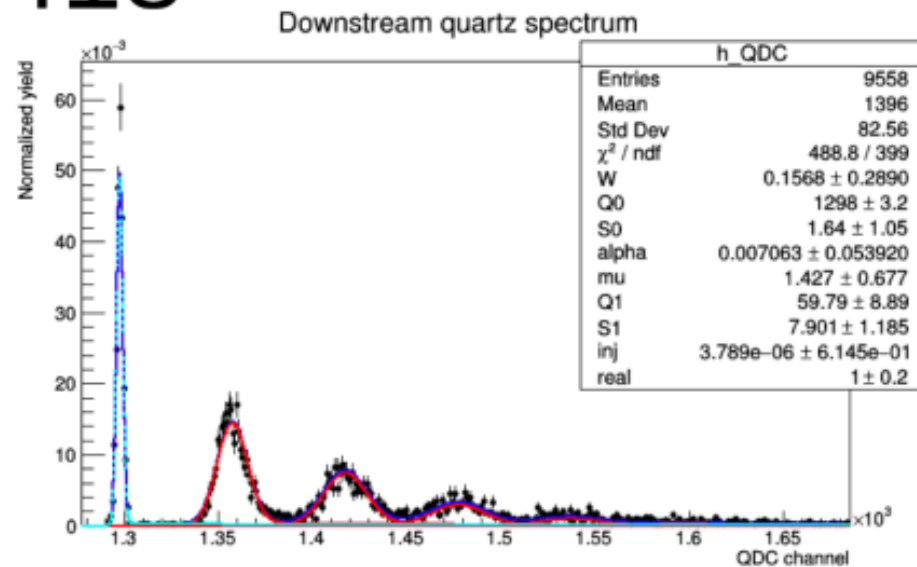
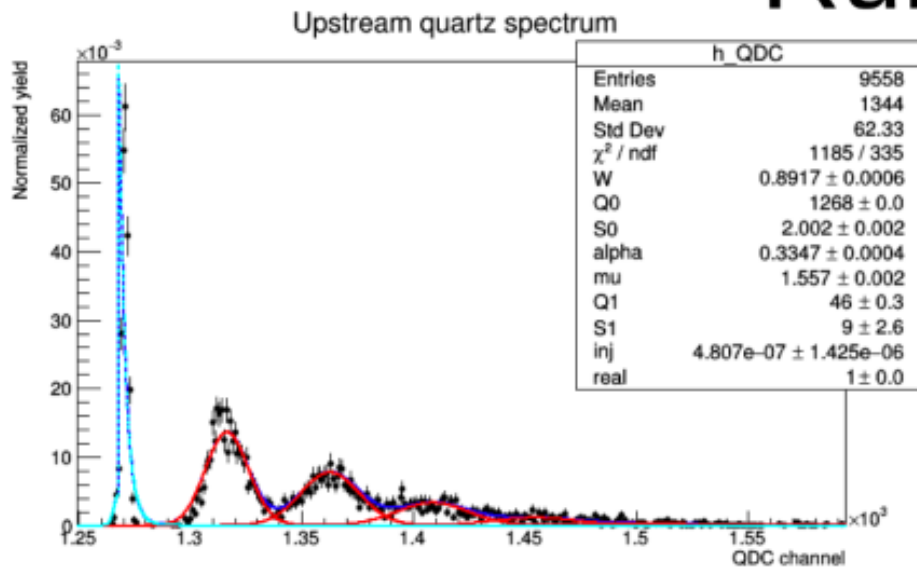
Det 2 XY hits



SLAC Testbeam sample data (from PREX Tandem Det) Run 417

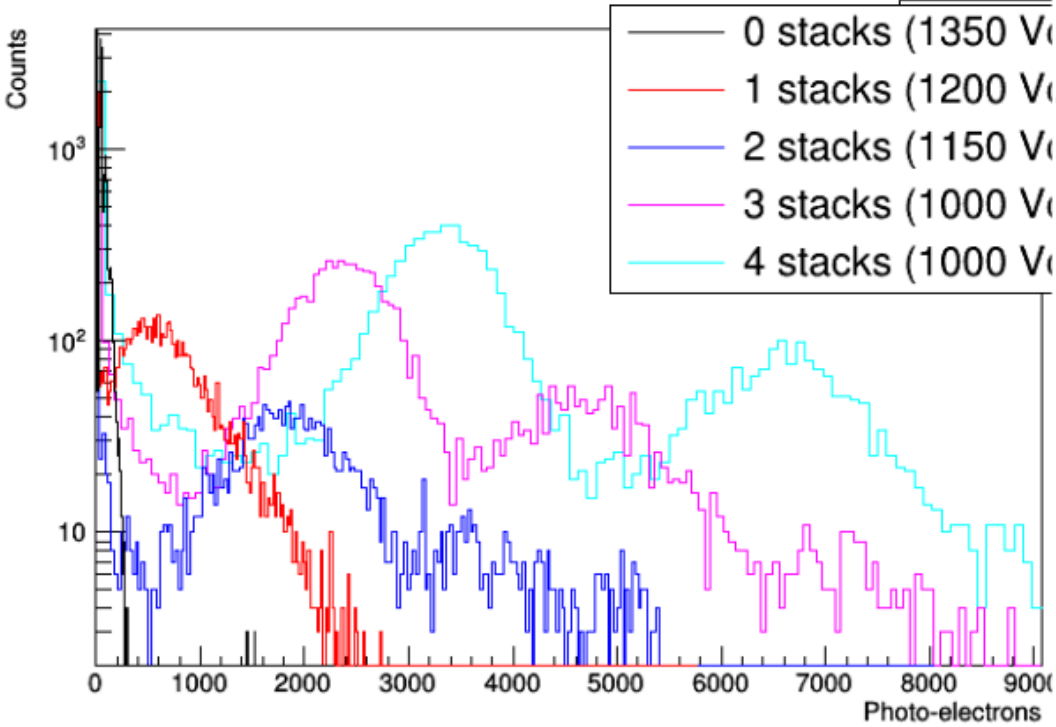


Run 418

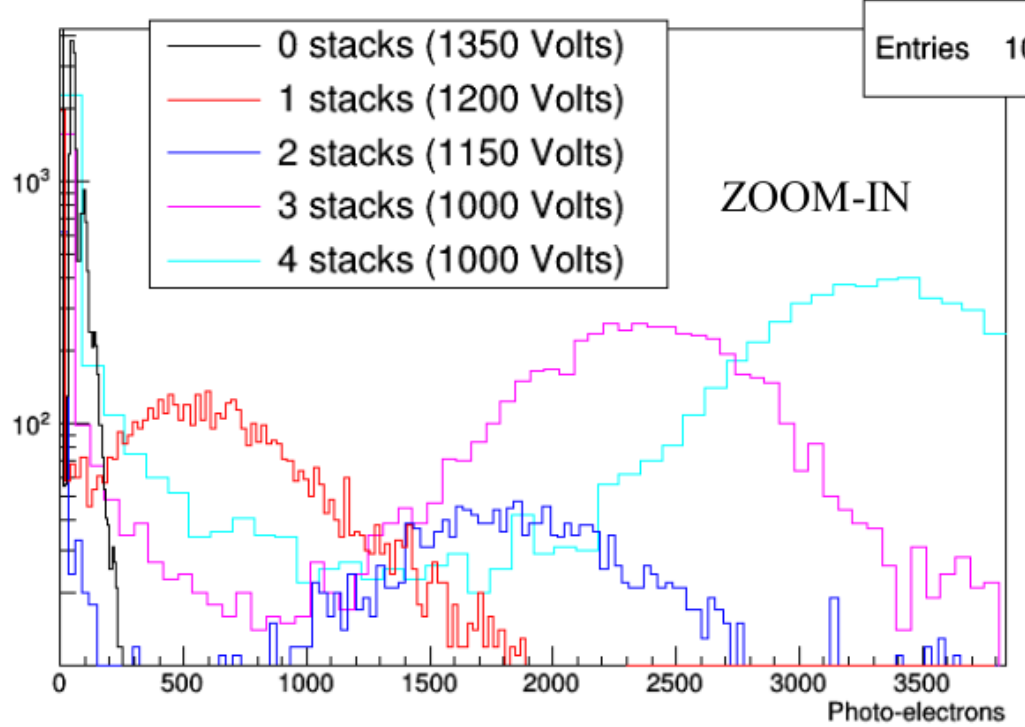


ShowerMax Benchmarking Prototype Testbeam Results (1B response vs. stack layers)

Benchmarking 1B: Compare stacks



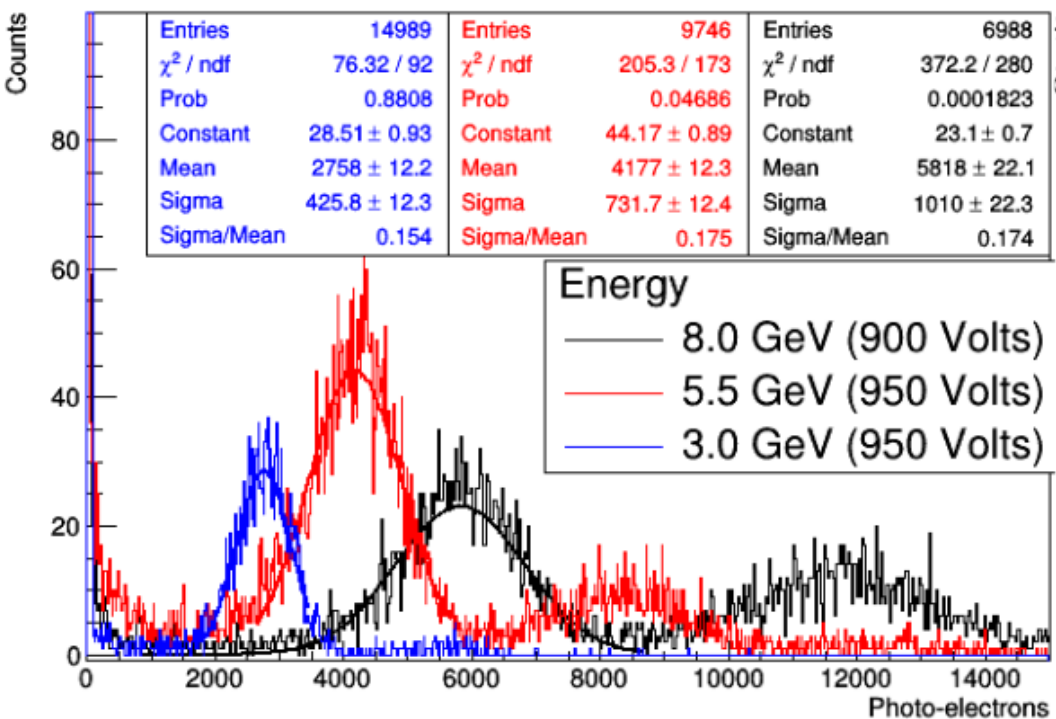
Benchmarking 1B: Compare stacks



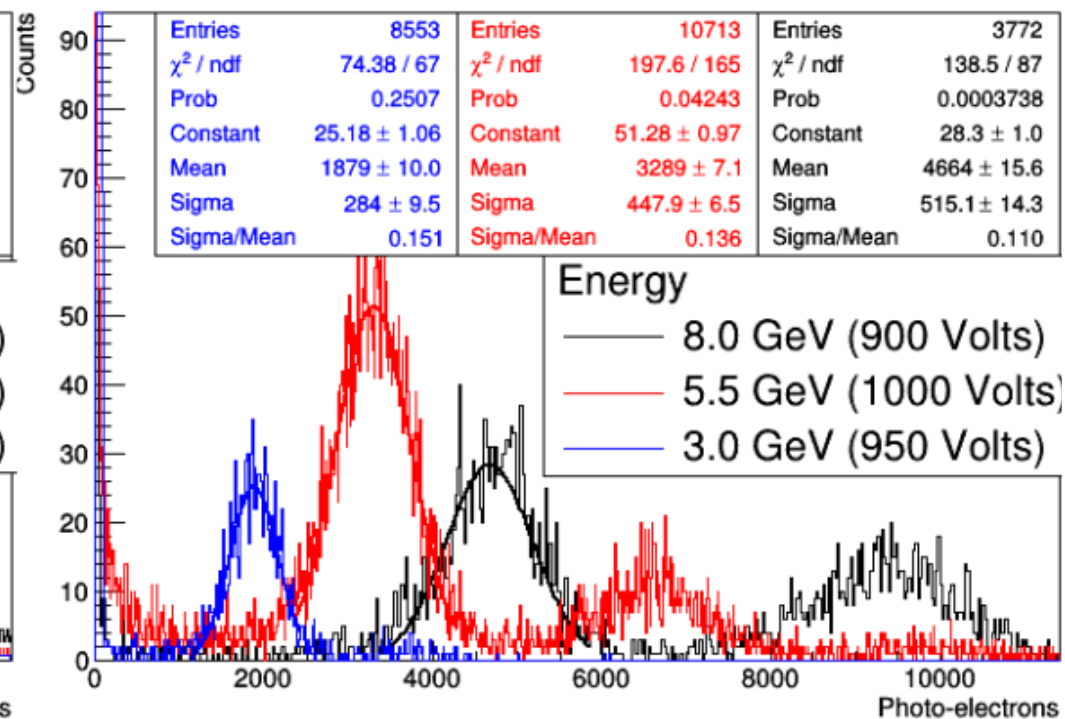
- Results are very reasonable—the means and relative widths behave as expected
- Simulations are underway for comparison and MC tuning/benchmarking

ShowerMax Benchmarking Prototype Testbeam Results (1A and 1B full stack response vs energy)

Benchmarking 1A: Full stack



Benchmarking 1B: full stack



- Comparing these results with previous simulations:
 - For 1A simulation: Mean PEs are ~ 1800 , ~ 4300 , and ~ 6800 for 2, 5, and 8 GeV, respectively
 - For 1A real data: Mean PEs are ~ 2760 , ~ 4200 , and ~ 5800 for 3, 5.5, and 8 GeV, resp.
- Comparisons are promising, new simulations are underway and further refinement of data analysis

Summary and future work

- Showermax baseline prototypes constructed and tested
 - Analyses of testbeam data are ongoing
 - Preliminary results for benchmarking prototypes in good agreement with baseline MC
 - Full-scale results and uniformity scans still in progress
- Starting shower-max MC tuning process now to benchmark amount of light exiting the stack; light guide performance can then be more accurately modeled to make data and sim agree
- Shower-max detector design and cost is firming-up: possible cost reductions – use 90/10 W/Cu alloy, thinner quartz bars (marginal saving), PMTs are already one of least expensive options

Backup 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} , 4 μ s 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 $\gg 50$ 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 preliminary quartz irradiation test

Radiation Hardness QA for quartz and other components

25 MeV LINAC (Main Hall and Airport)

RF Frequency: 2856 MHz (S-Band)

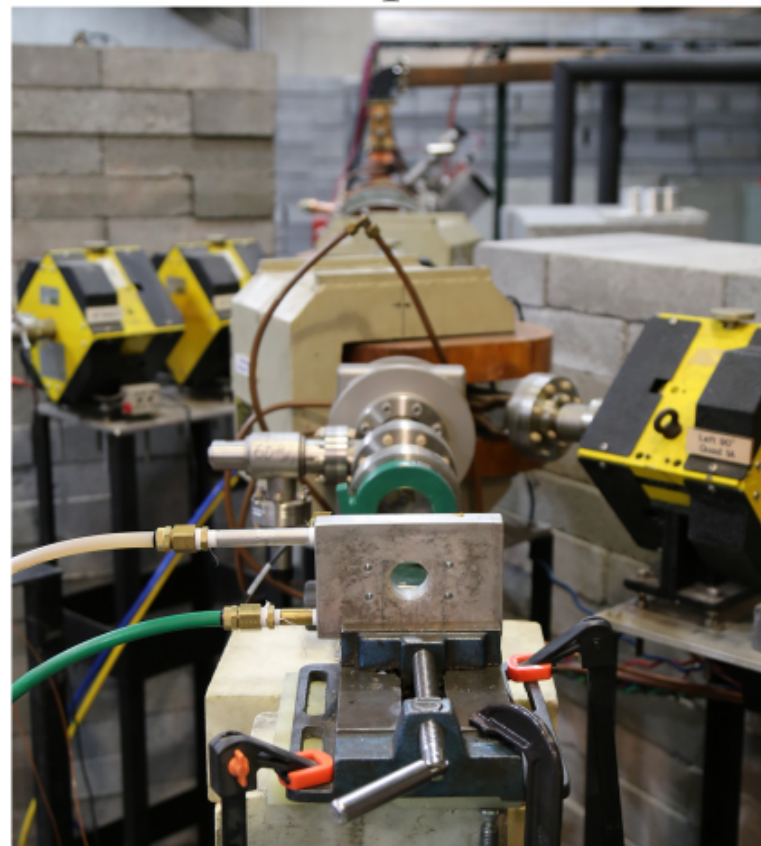
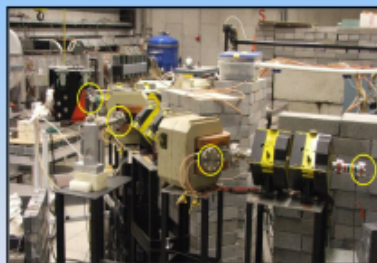
Energy Range: ~4~25 MeV (current varies)

Pulse Width: ~50ns to 4 micro seconds

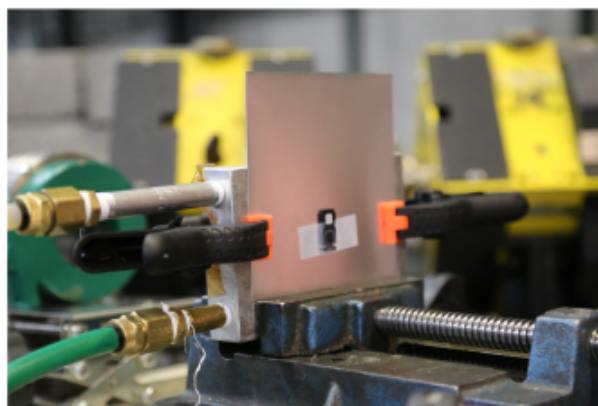
Repetition Rate: single pulse to 360 Hz

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

Energy (MeV)	25B Energy vs Current		
	0 port (mA)	45 port (mA)	90 port (mA)
23	55	55 @ 3.8uS	46 @ 3.6uS
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



- 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)

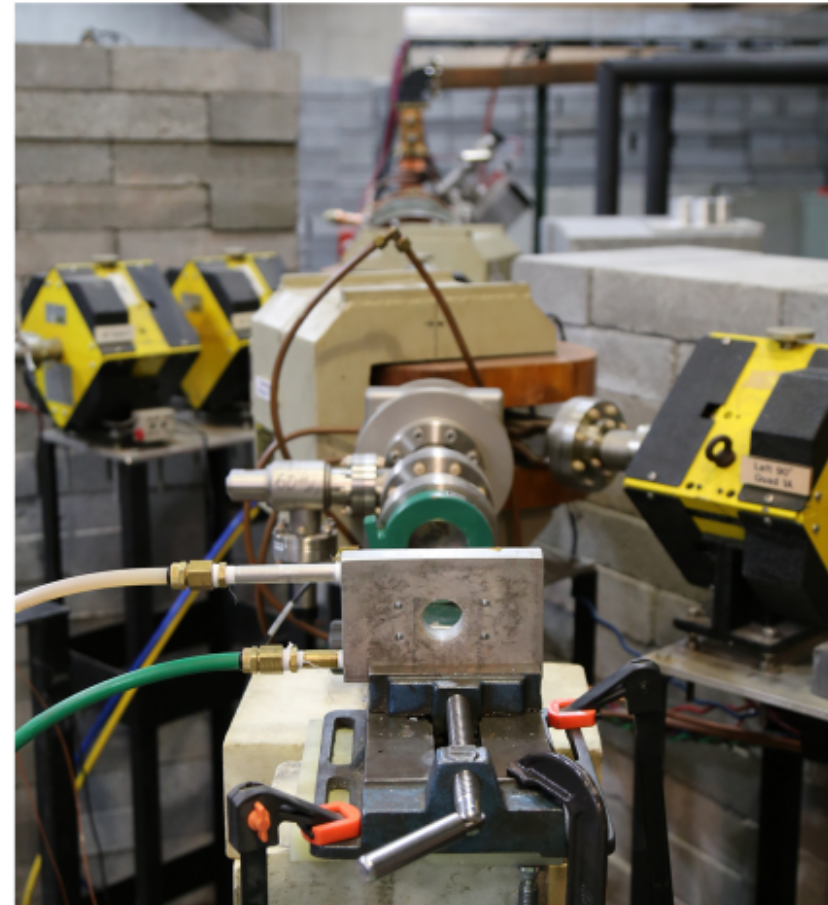
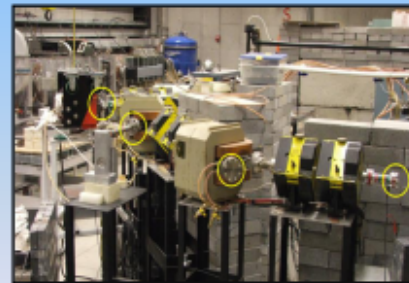
Pulse Width: ~50ns to 4 micro seconds

Repetition Rate: single pulse to 360 Hz

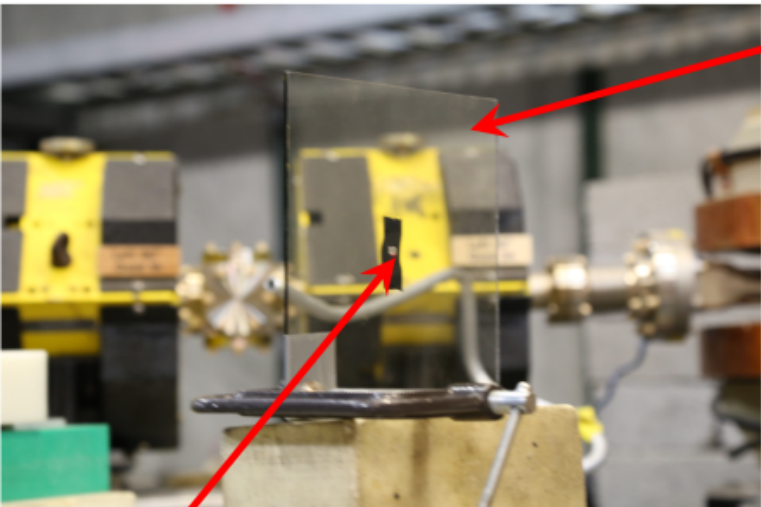
Ports: 0 degree, 45 degree and 90 degree (Beam energy resolution ~ 1+/- 15%)

25B Energy vs Current

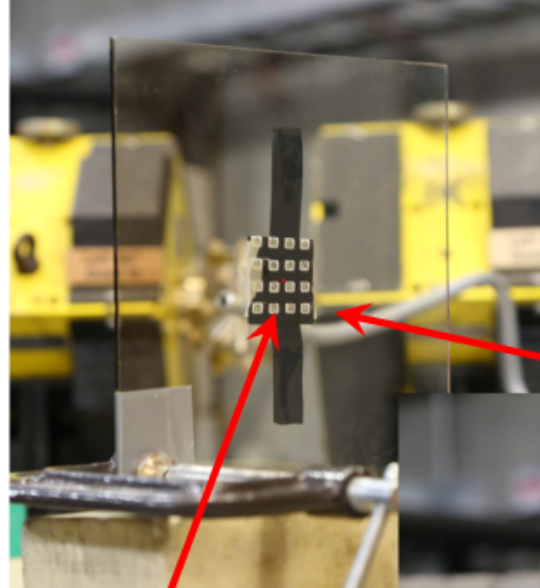
Energy (MeV)	0 port (mA)	45 port (mA)	90 port (mA)
23	55	55 @ 3.8 μ s	46 @ 3.6 μ s
20	100	70 @ 4 μ s	65 @ 4 μ s
16	100	48 @ 3.6 μ s	48 @ 3.6 μ s
13	80	30 @ 3.3 μ s	15 @ 3.3 μ s
10	60	18 @ 3 μ s	7.5 @ 3 μ s
9	110	30 @ 4 μ s	15 @ 4 μ s
6	100	60 @ 4 μ s	60 @ 4 μ s
4	50	20 @ 4 μ s	20 @ 4 μ s



Beam Dose Exposure Rate Calibrations (May 2018)



Glass slide for spot profile measurements



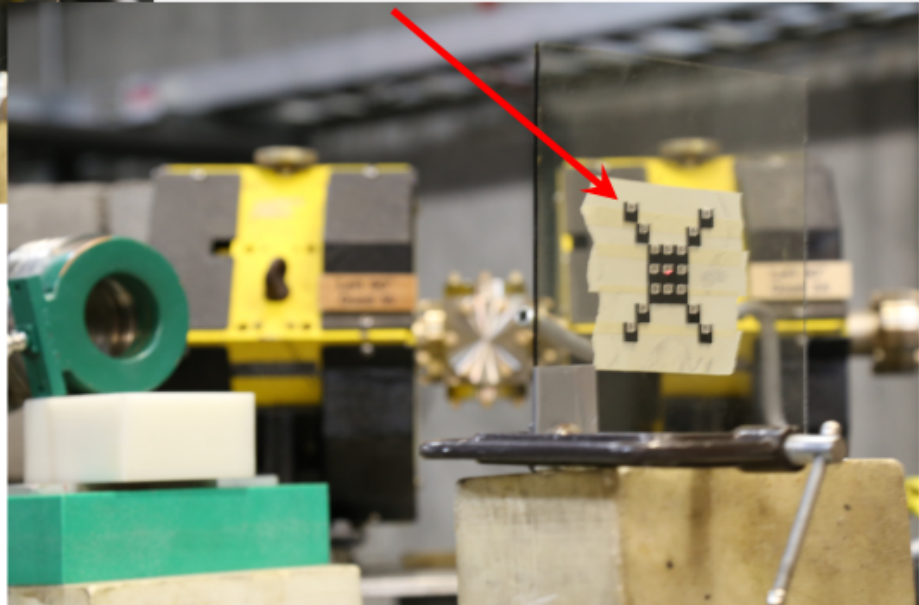
ISU MS degree student Connor Harper's thesis based on this work:
<https://www2.cose.isu.edu/~mcnudust/publication/studentWork/connorHarperThesis.pdf>

OSL arrays for dose profile measurements

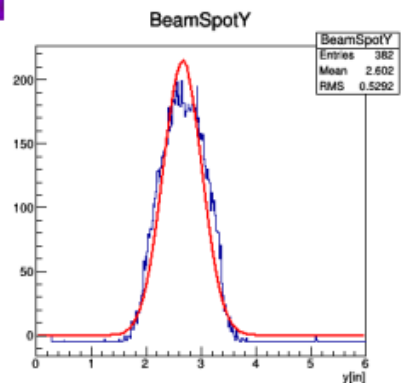
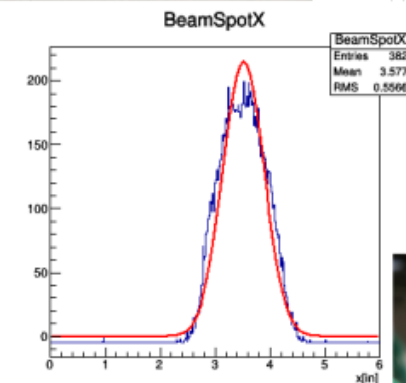
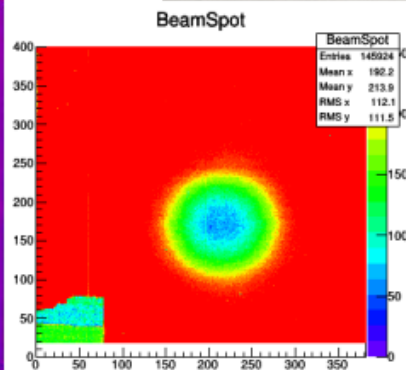
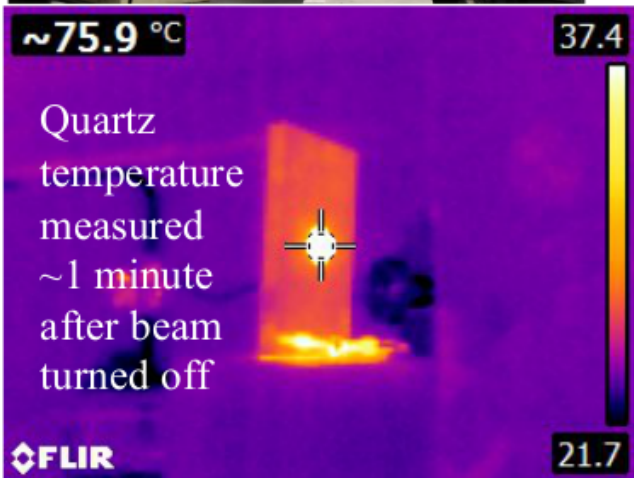
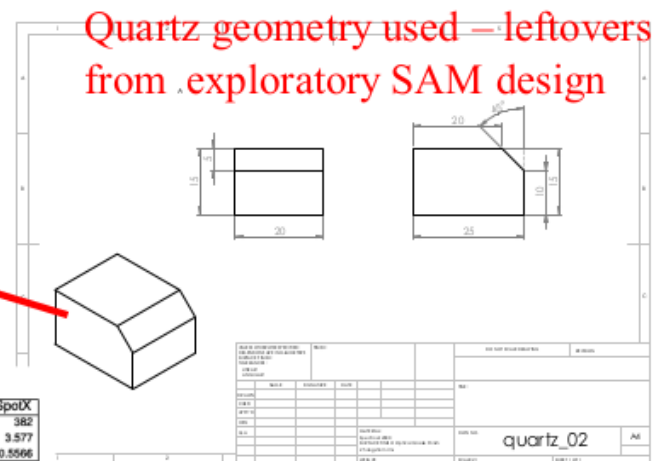
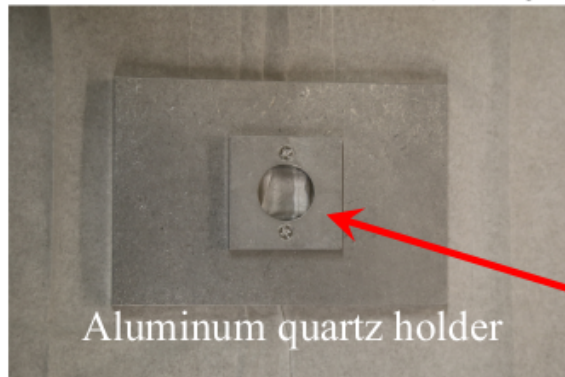
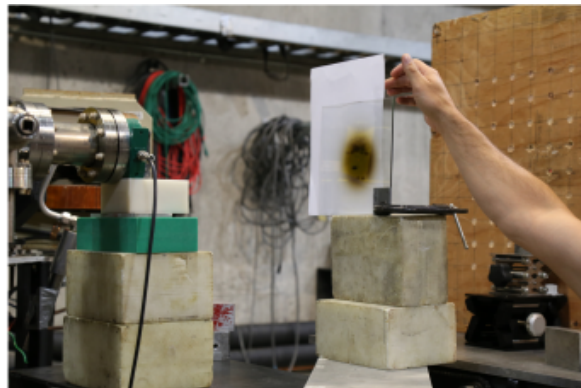
Optically Stimulated Luminescence (OSL) dosimeter (~ 7 mm by 7 mm square)



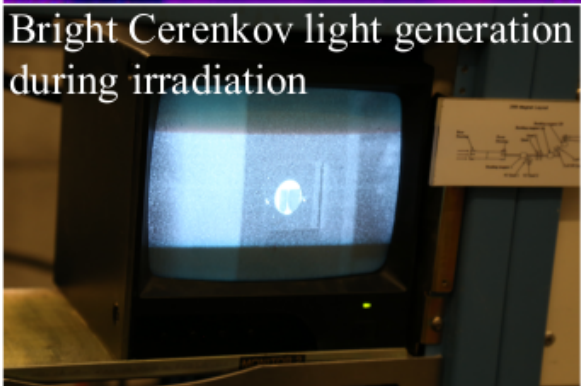
Laser alignment



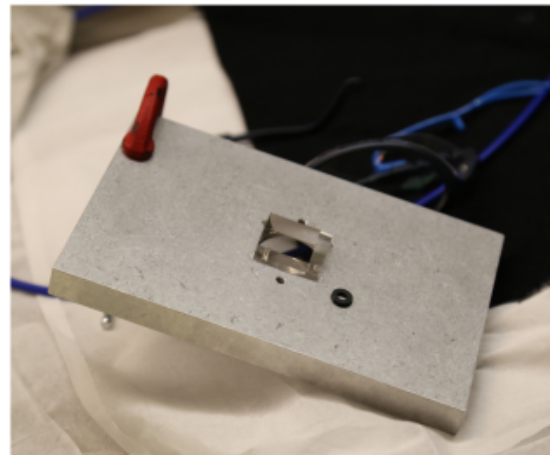
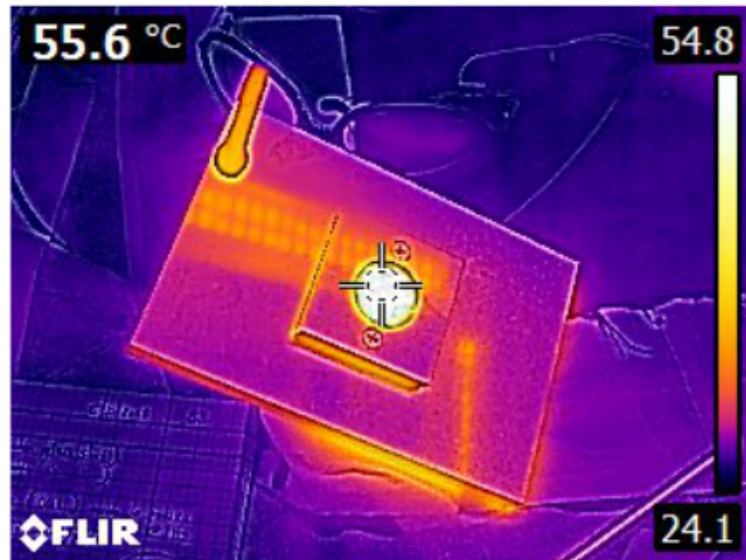
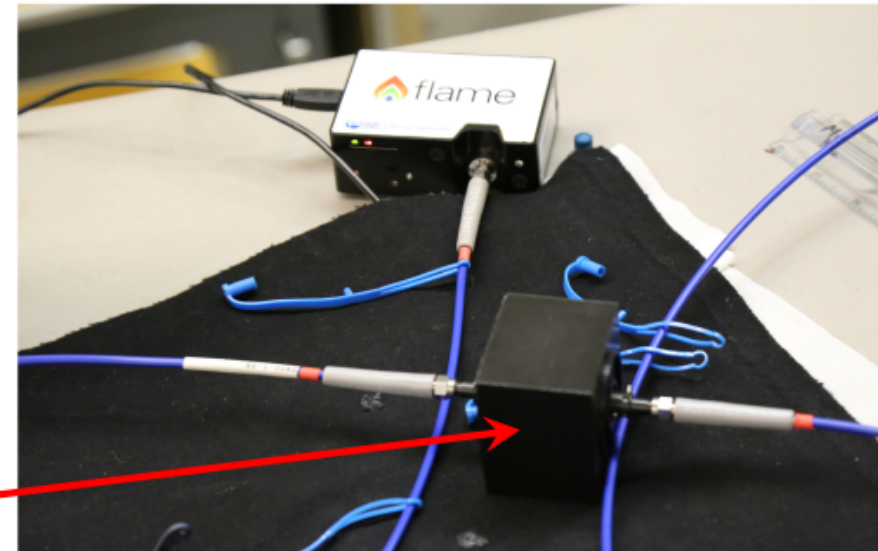
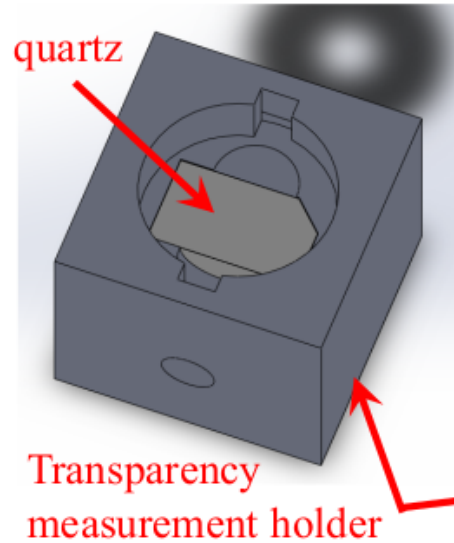
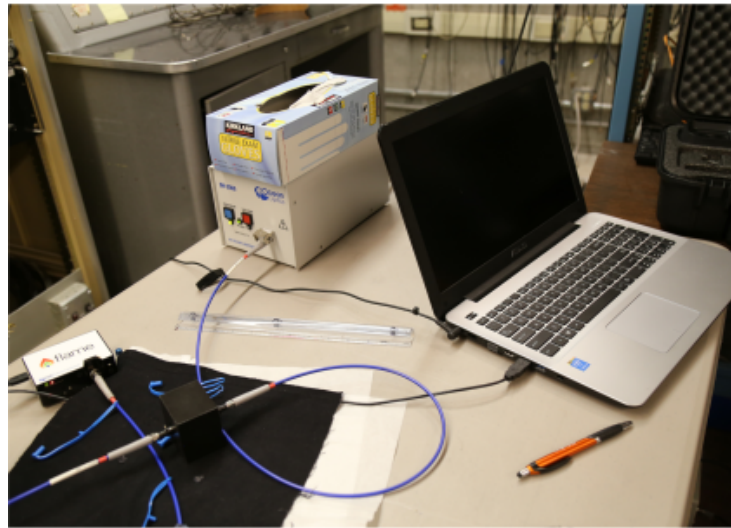
Quartz Irradiations (May 2018)



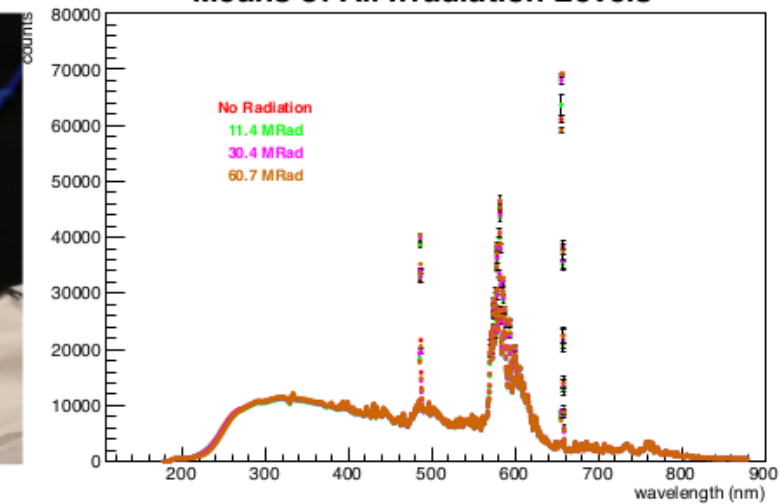
2018-05-31_15-01_Pulses_1006_50cm.png
 x-center = 3.512 in, y-center = 2.661 in
 glass plate at 50cm from beam window



Quartz Transparency Measurements

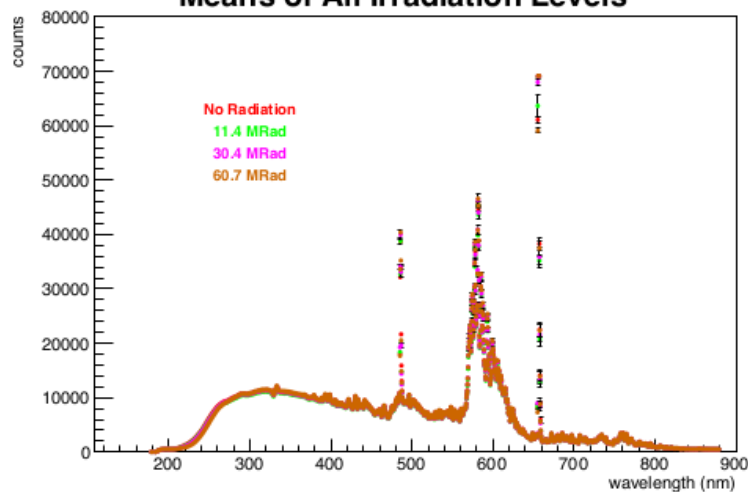


Means of All Irradiation Levels



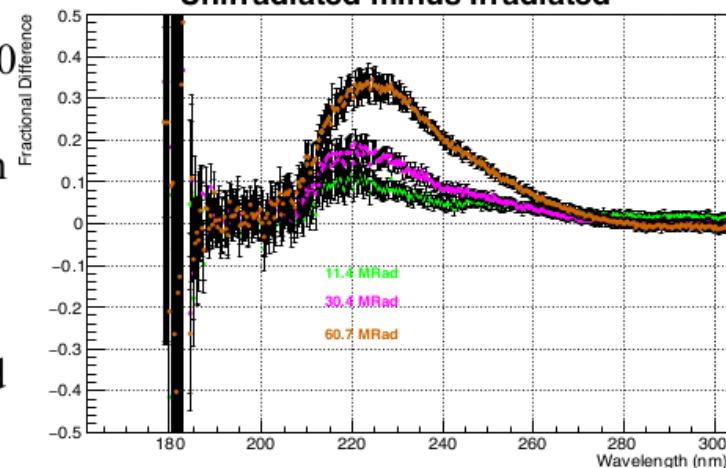
Quartz Transparency Preliminary Results

Means of All Irradiation Levels

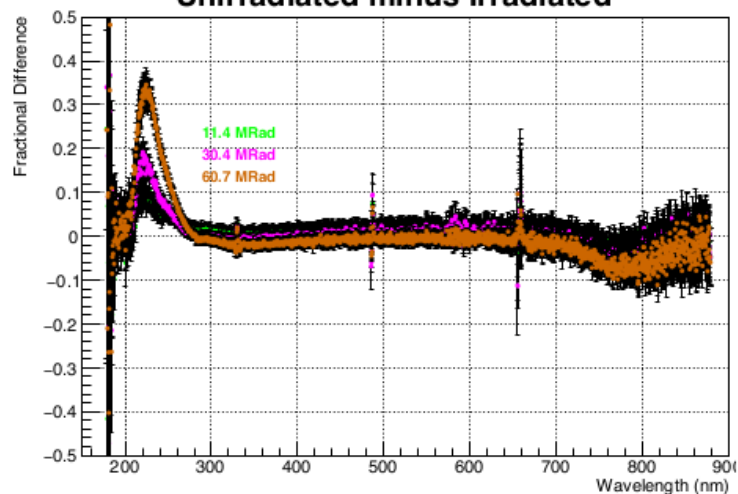


- Beam setup: 8 MeV, 50 mA I_{peak} , 500 ns pulse width at 250 Hz rep-rate
- Quartz sample mounted 0.5 m from beampipe exit window
- Dose exposure calibrations give ~ 253 Rad/pulse
- Irradiated sample for 3, 8, and then 16 minutes
- Measured light transmission (four times) after each irradiation and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

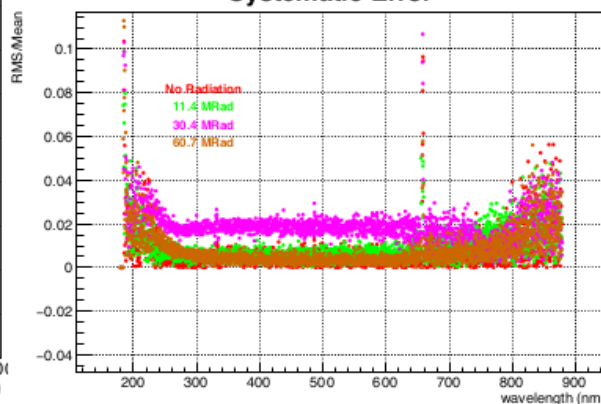
Unirradiated minus Irradiated



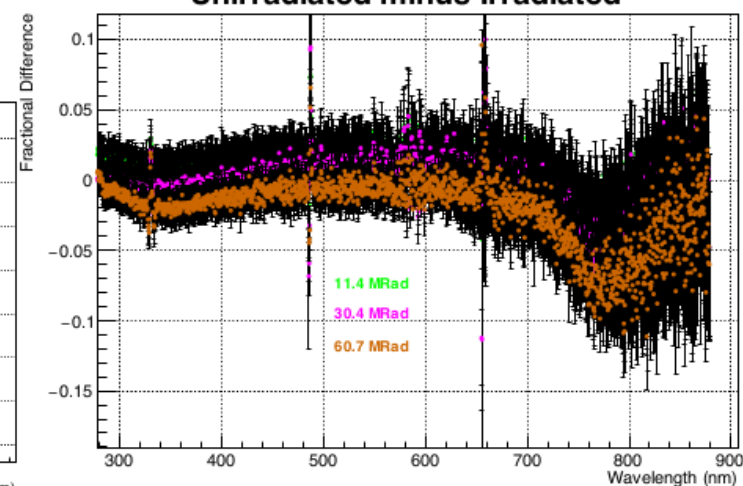
Unirradiated minus Irradiated



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
- 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

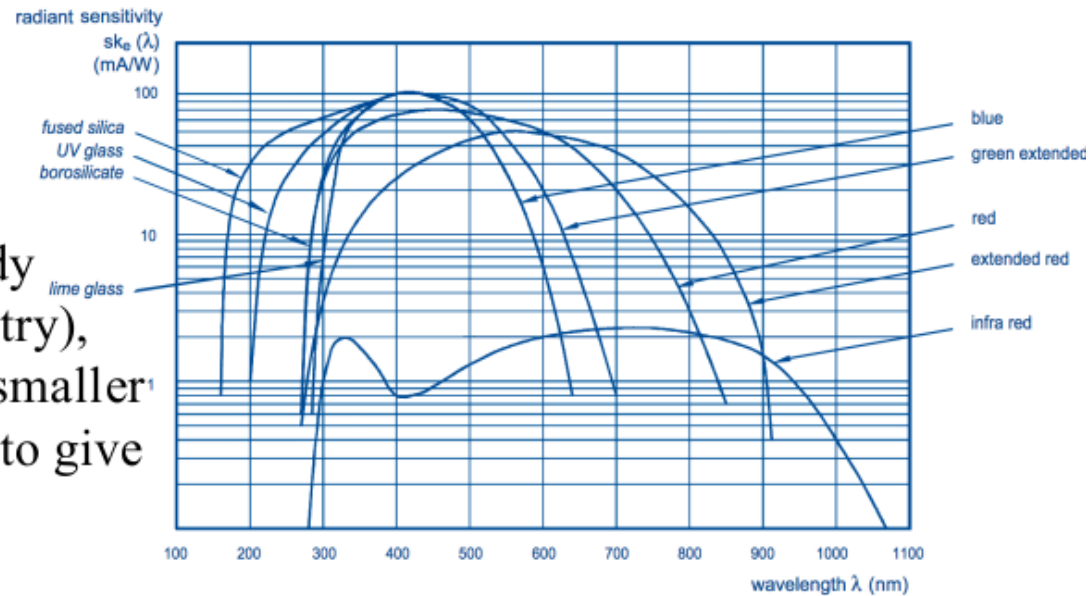


Fig.2 Typical spectral sensitivity characteristics of standard photocathodes with associated window materials.

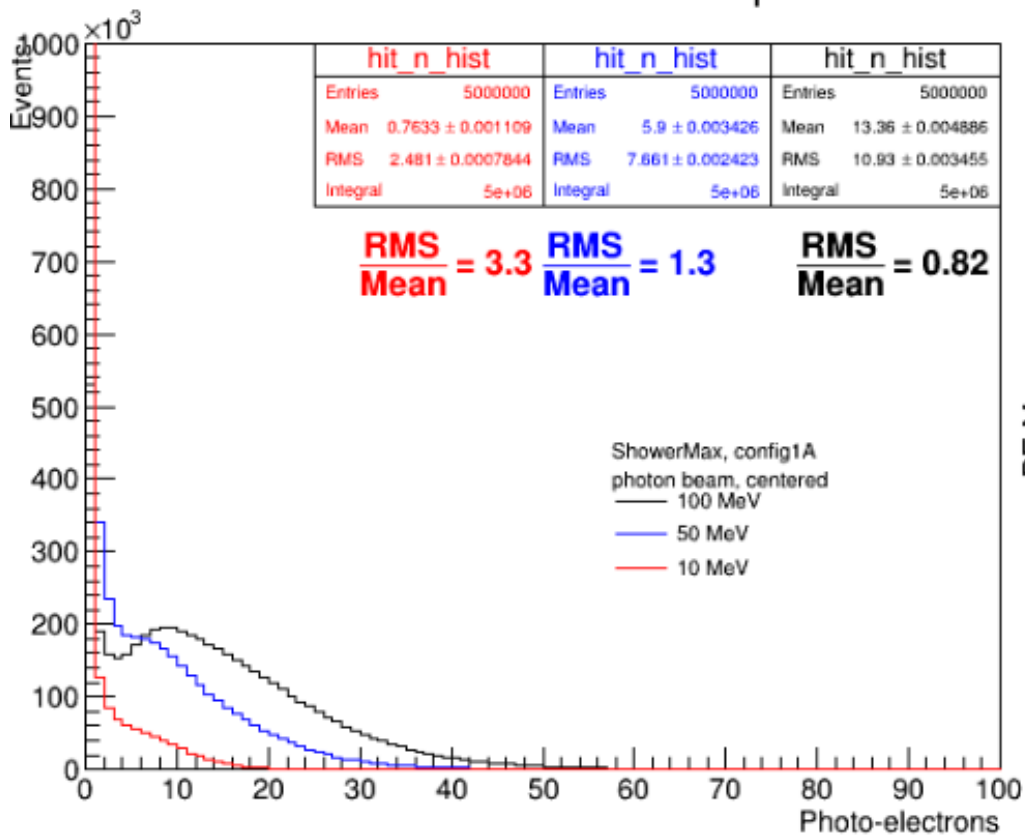
$$QE (\%) \approx \frac{124}{\lambda(\text{nm})} \times \text{radiant sensitivity (mA/W)}$$

PMT Window Characteristics

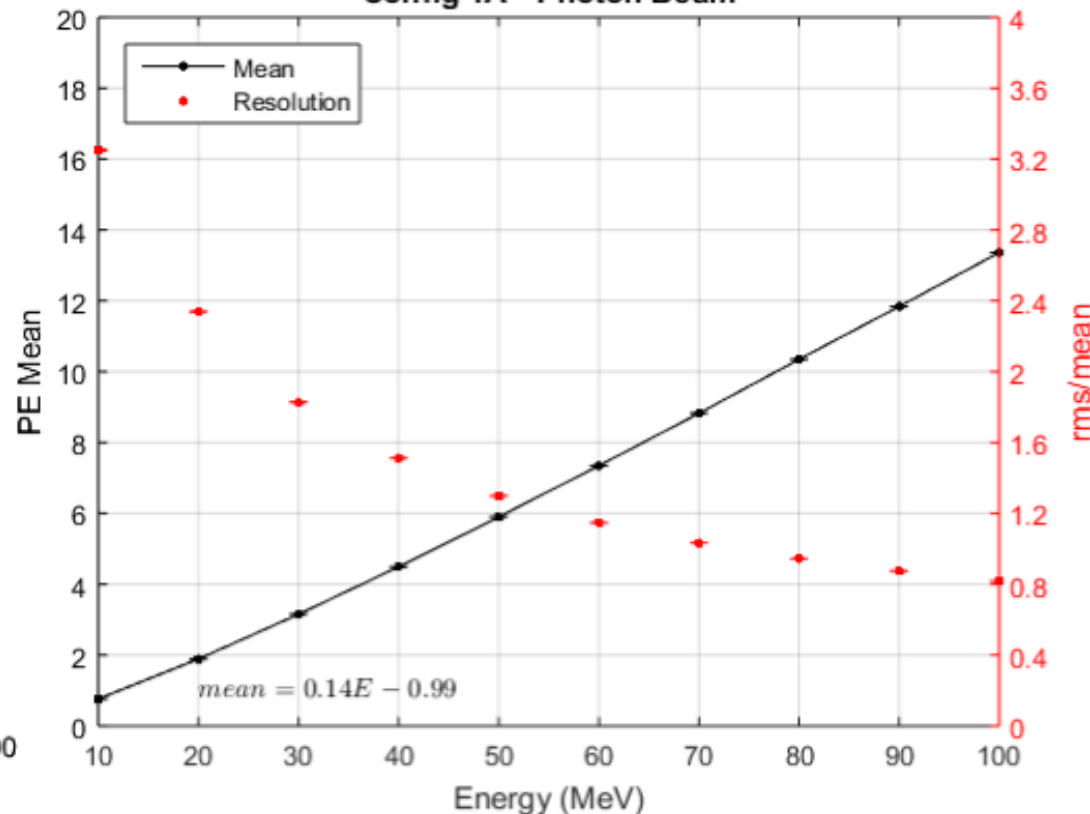
type of window glass	cut-off wavelength, -10% (nm)	refractive index
lime glass	300	1.54 (at 400 nm)
borosilicate	270	1.50 (at 400 nm)
UV glass	190	1.49 (at 400 nm)
fused silica	160	1.47 (at 400 nm)
		1.50 (at 250 nm)
sapphire	150	1.80 (at 400 nm)

Simulated Yields from Photons (1A Full-scale)

ShowerMax 1A Photon Response



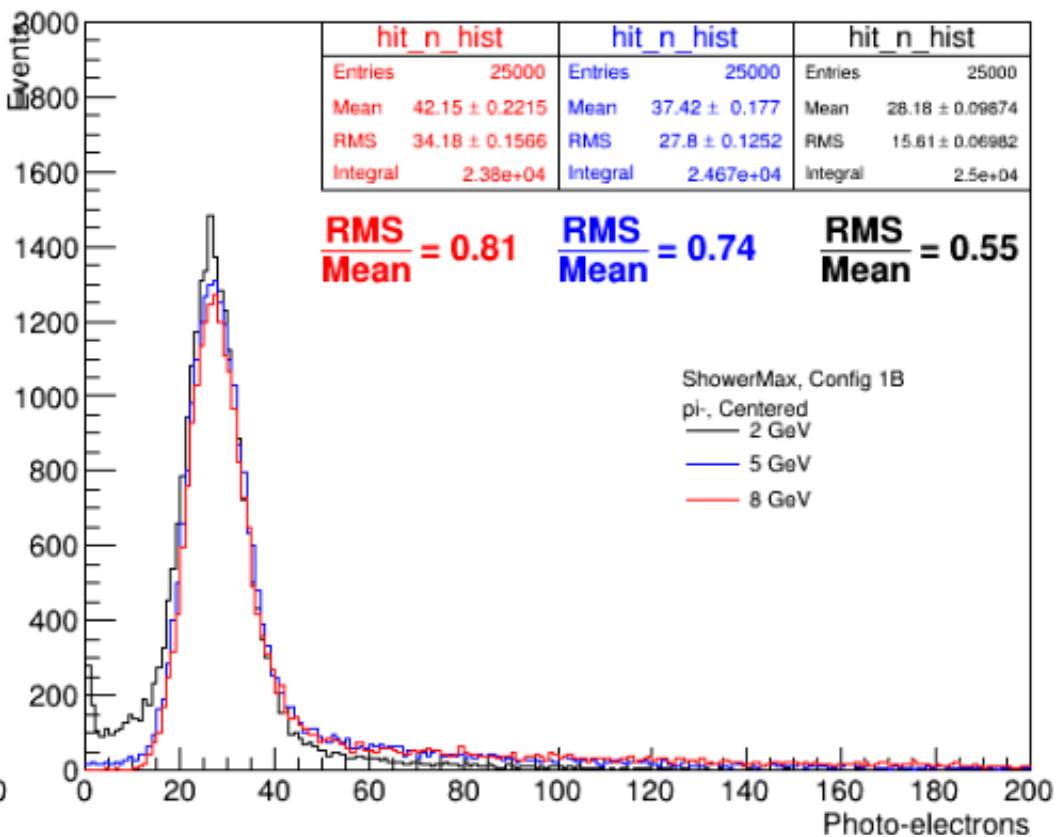
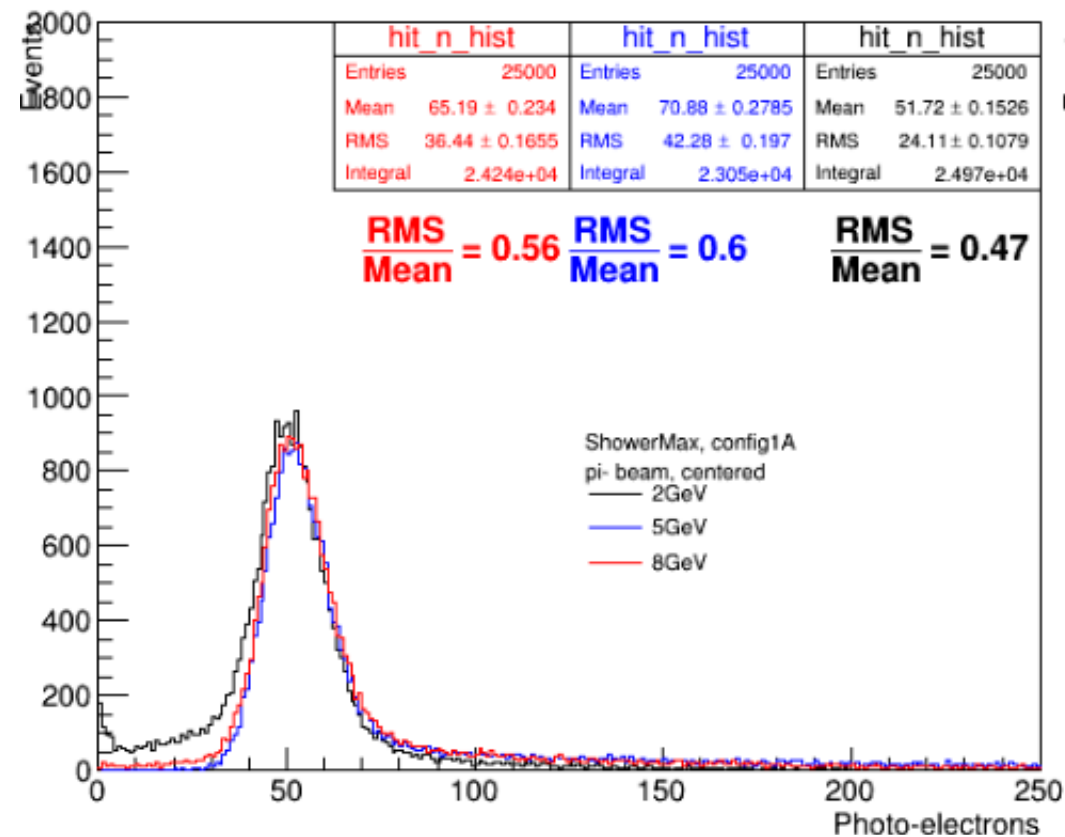
Config 1A - Photon Beam



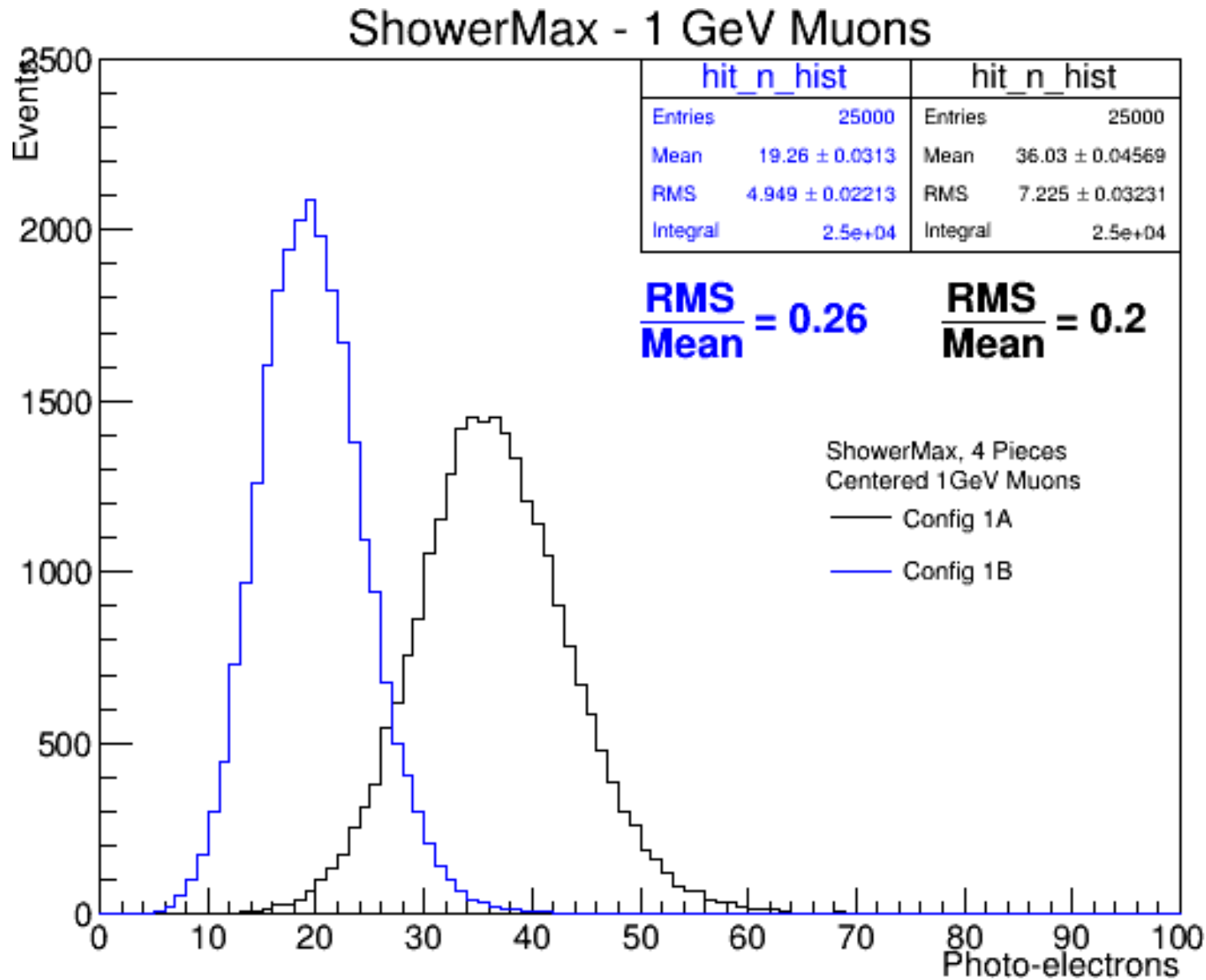
Simulated Yields from Pions (1A & 1B Full-scale)

ShowerMax Pion Response

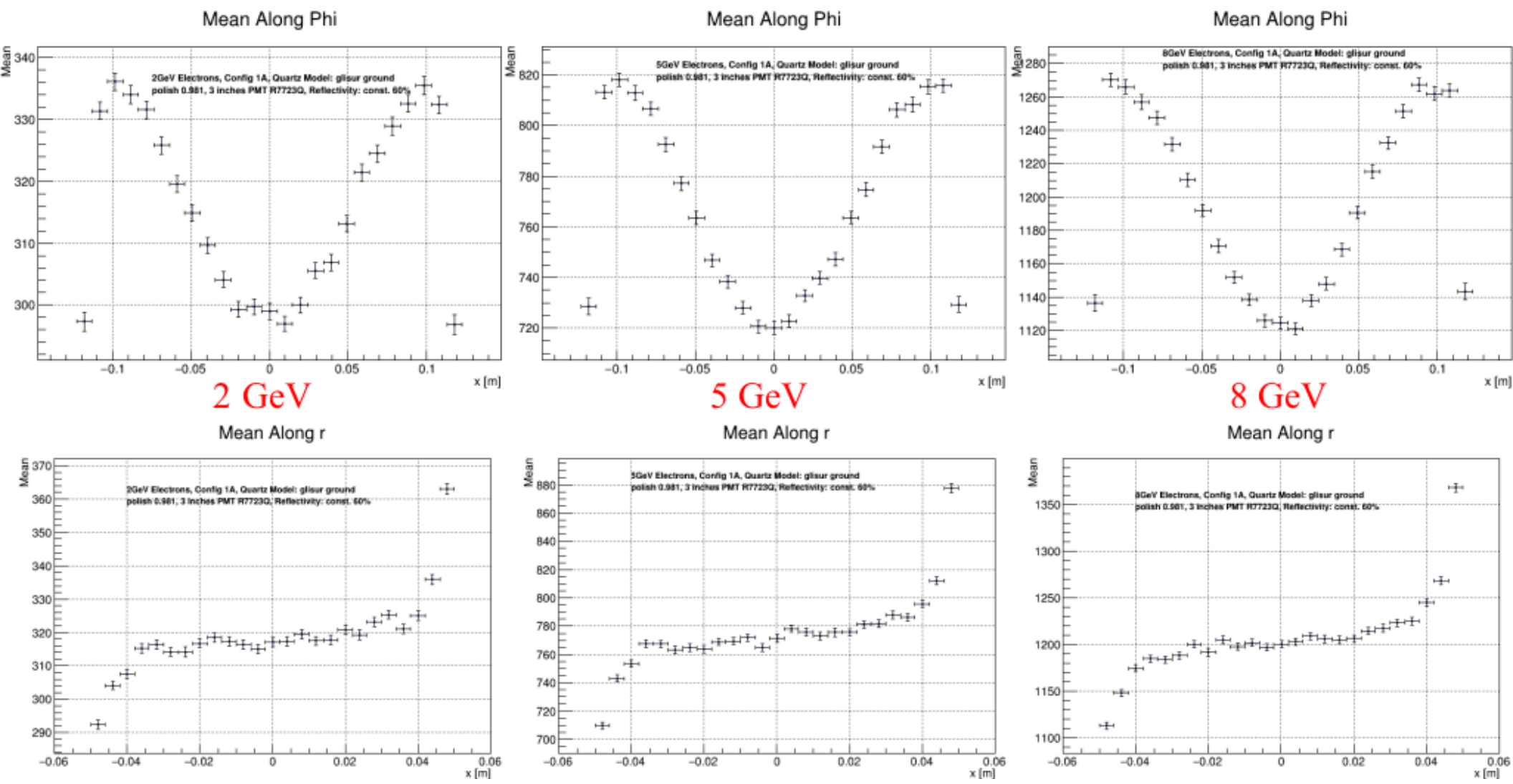
ShowerMax Pion Response



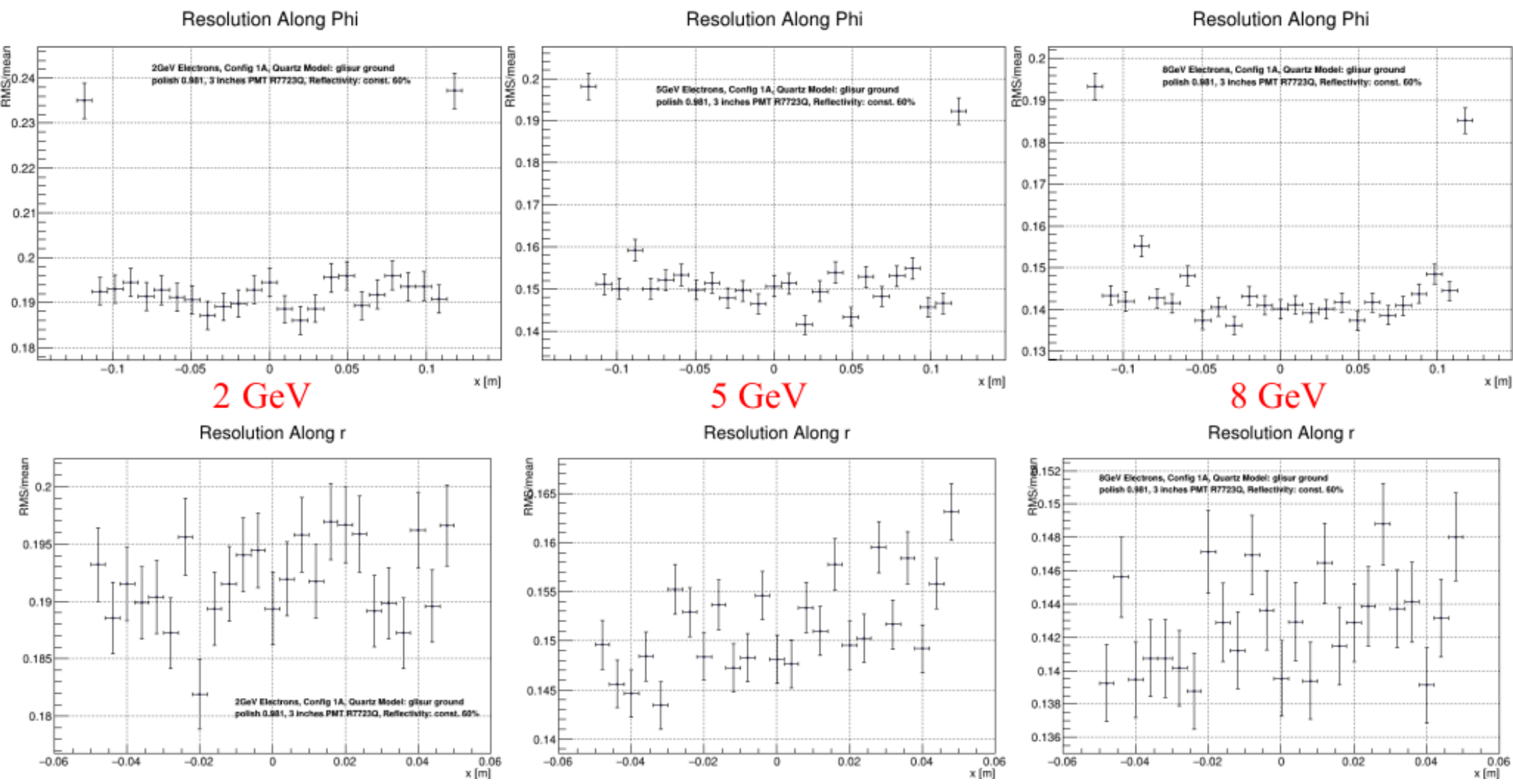
Simulated MIP signal for cosmic-ray tests (Full-scale)



Uniformity Studies: 1A PE means along ϕ and r

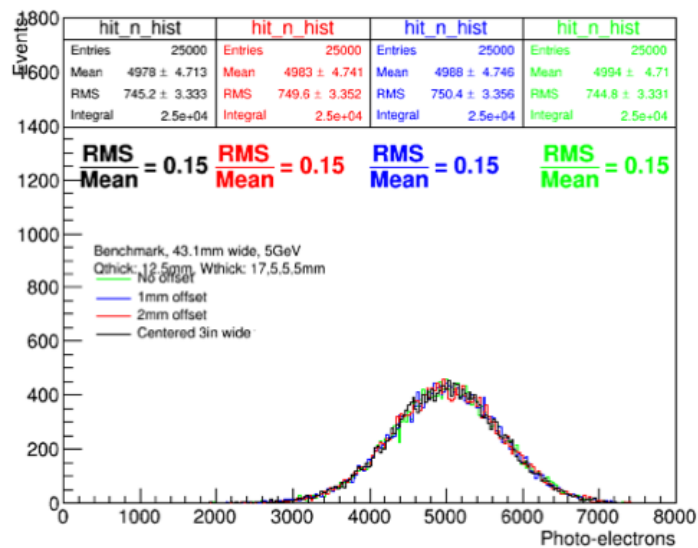


Uniformity Studies: 1A Resolutions along ϕ and r

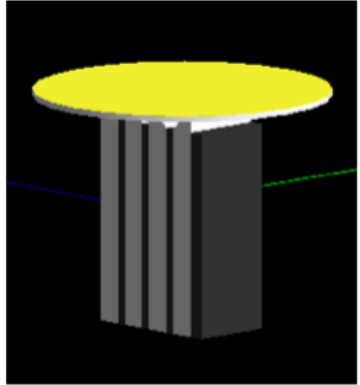


Candidate Design for Stack Prototype: Config #2

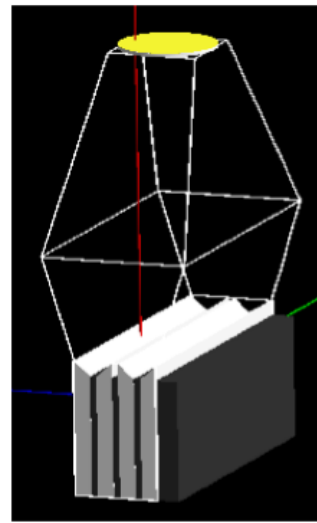
Non-uniform Benchmarking Showermax



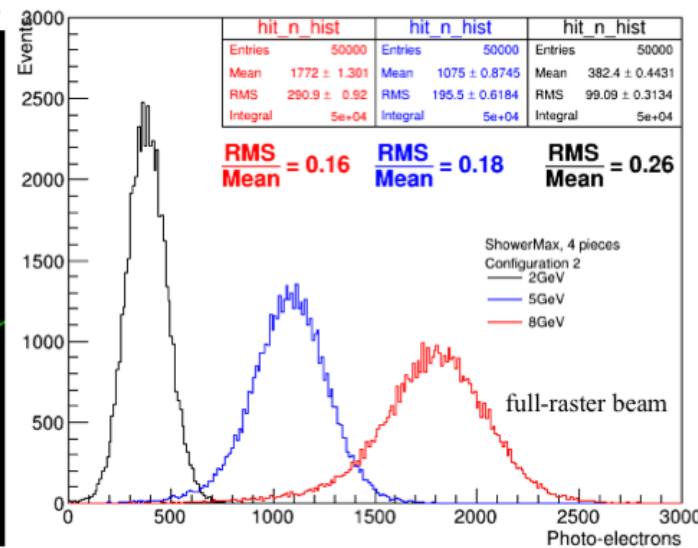
BenchMarking MC Visualization



Full Scale MC Vis.



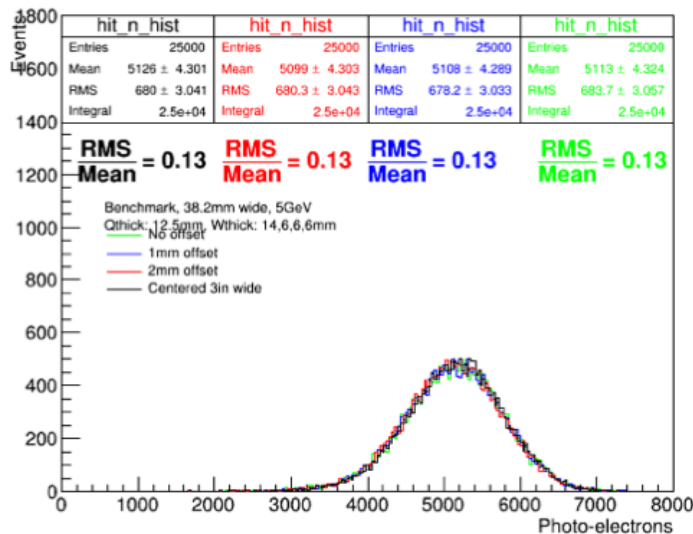
ShowerMax - Config 2



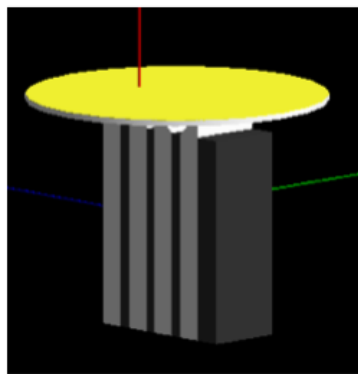
Config #	t_f (mm)	t_q (mm)	t_w (mm)	b (mm)	a (mm)	X_0	R_{mol} (mm)	Leakage (%) 2, 5, 8 GeV from G4 MC	1mm offset Leakage (%)	2mm offset Leakage (%)	Bench. Mean PEs	Bench. RMS / Mean	full- scale Mean PEs	full-scale RMS / Mean
2	17	12.5	5	65	43.2	9.5	11.0	~0 ~0	~0 ~0	~0 ~0	2412 4994	0.19 0.15	382 1075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

Candidate Design for Stack Prototype: Config #3

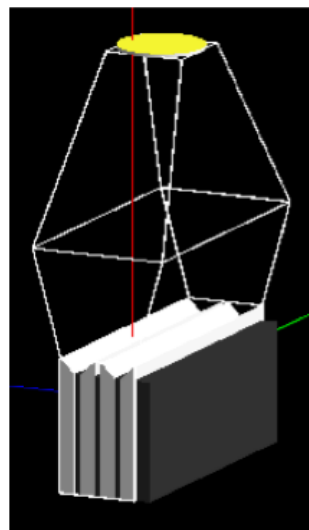
Configuration 3 Benchmarking Showermax



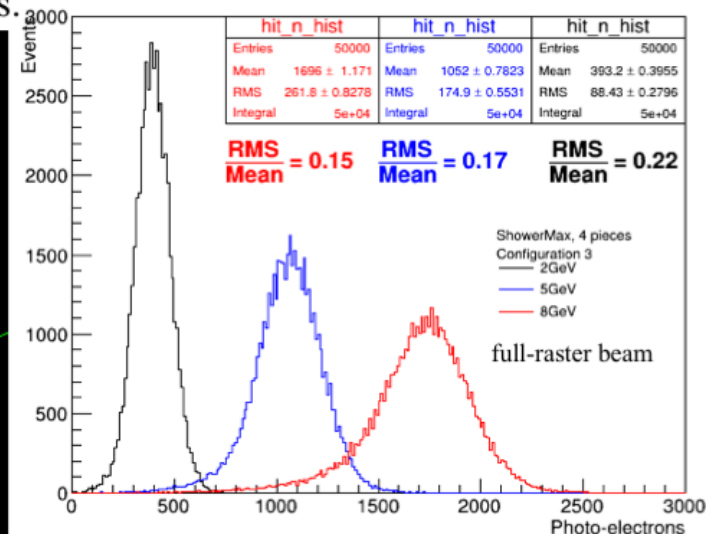
BenchMarking MC Visualization



Full Scale MC Vis.



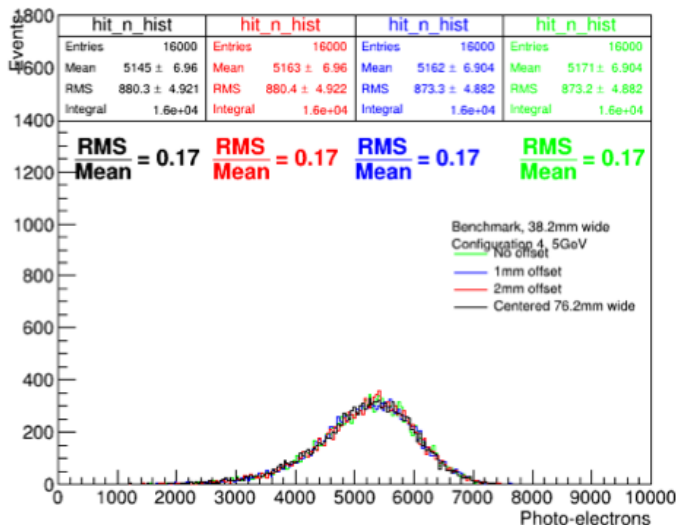
ShowerMax - Config 3



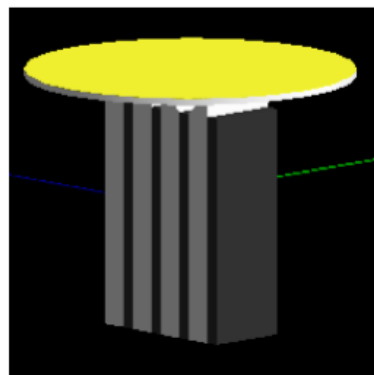
Config #	t_f (mm)	t_q (mm)	t_w (mm)	b (mm)	a (mm)	X_0	R_{mol} (mm)	Leakage (%) 2, 5, 8 GeV from G4 MC	1mm offset Leakage (%)	2mm offset Leakage (%)	Bench. Mean PEs	Bench. RMS / Mean	full- scale Mean PEs	full-scale RMS / Mean
3	14	12.5	6	68	38.2	9.5	11.0	0.5 0.3	0.6 0.4	0.8 0.5	2412 5113	0.19 0.13	393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

Candidate Design for Stack Prototype: Config #4

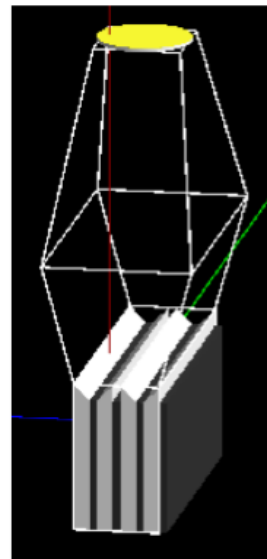
Config4 Benchmarking Showermax - 5GeV



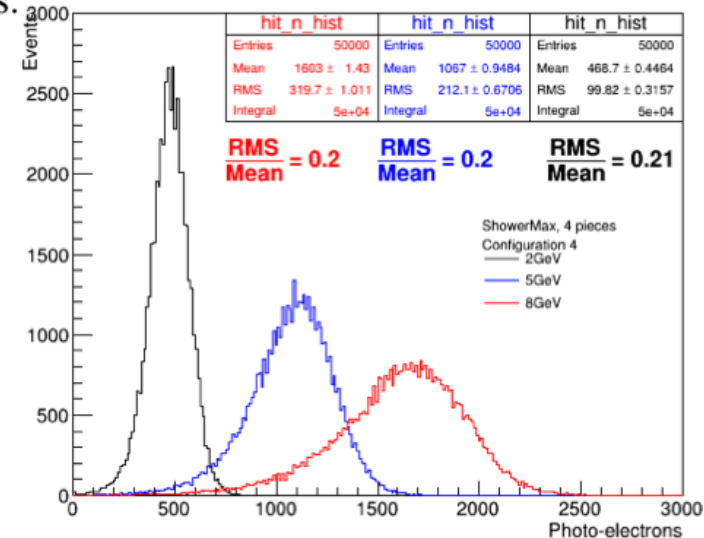
BenchMarking MC Visualization



Full Scale MC Vis.



ShowerMax - Config 4



Config #	t_f (mm)	t_a (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

Simulation Results for new Stack Configs

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

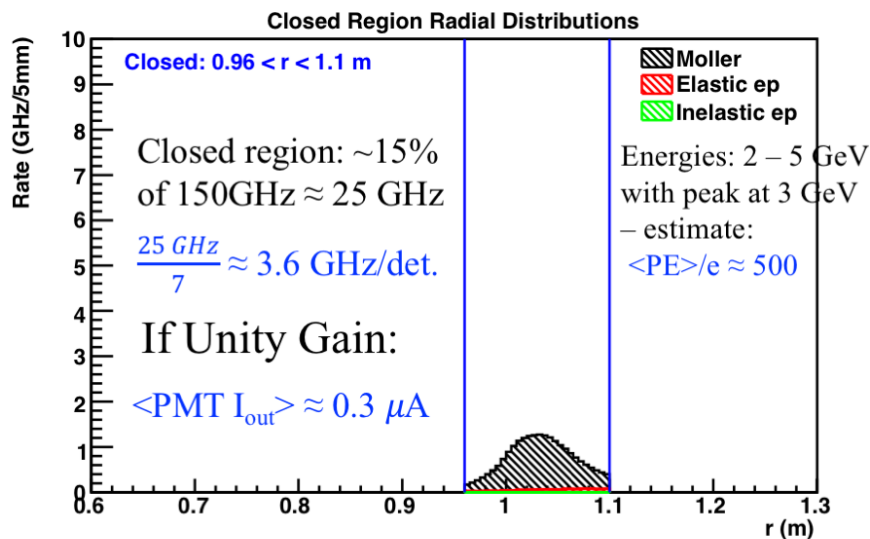
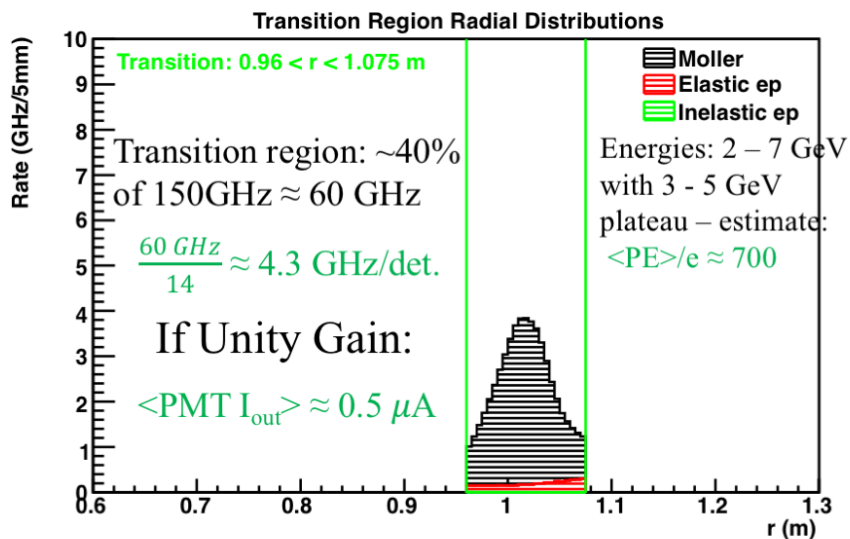
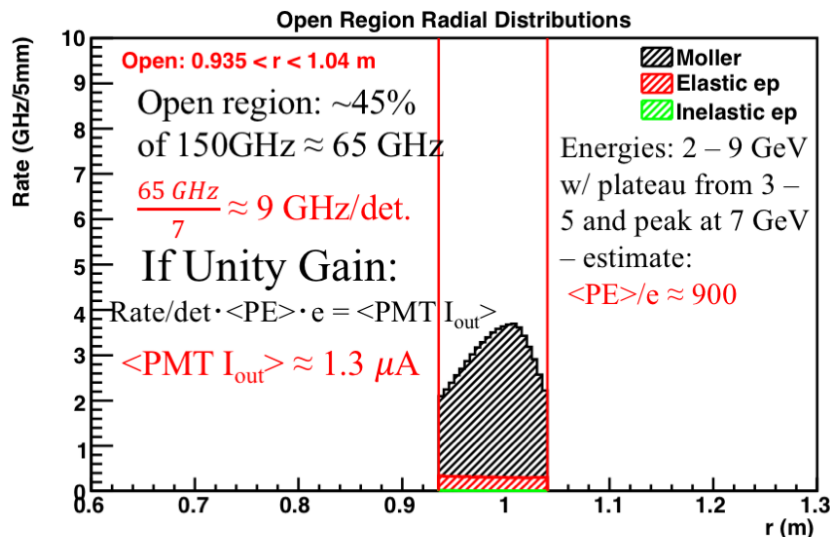
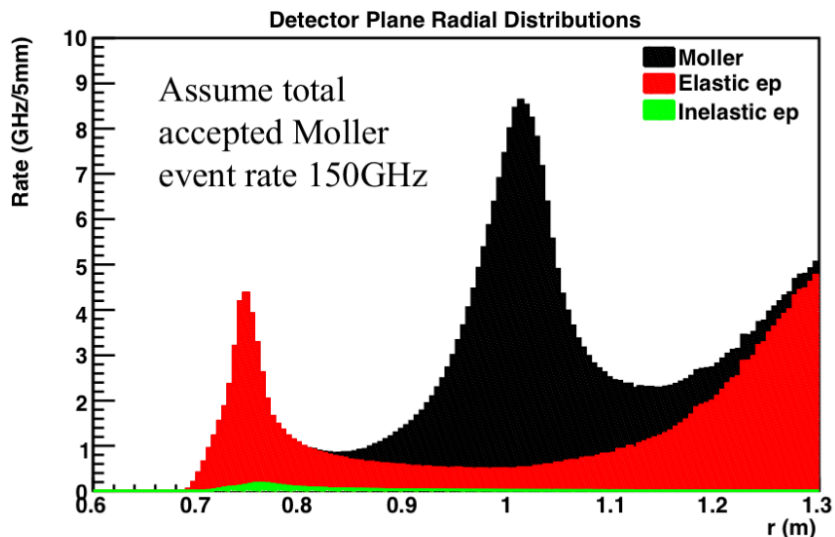
Benchmark - 5GeV				
Config #	RMS/Mean	Leakage (%)	Leakage 2mm offset (%)	Leakage 2° angle (%)
1A	0.13	0.04	0.09	-0.4
1B	0.14	0	0	0.2
4A	0.17	0.06	0.3	-
4B	0.19	0	0	-

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

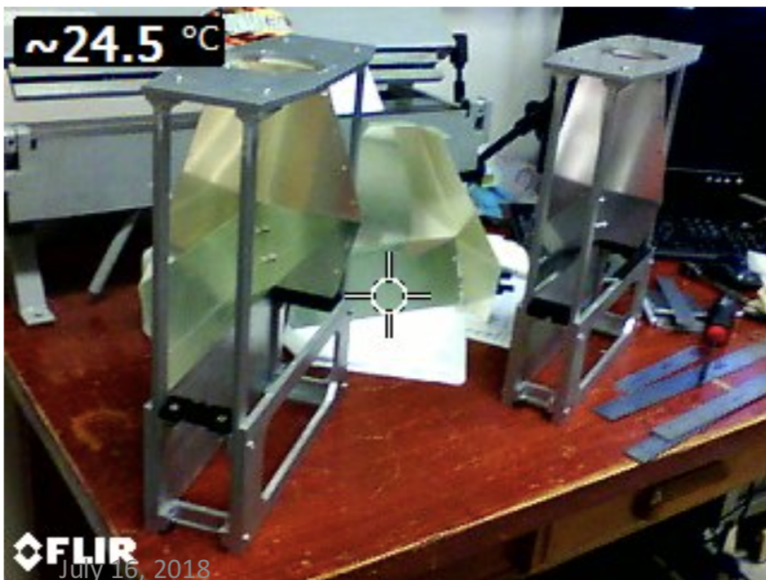
Unity Gain operation with Baseline design?



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

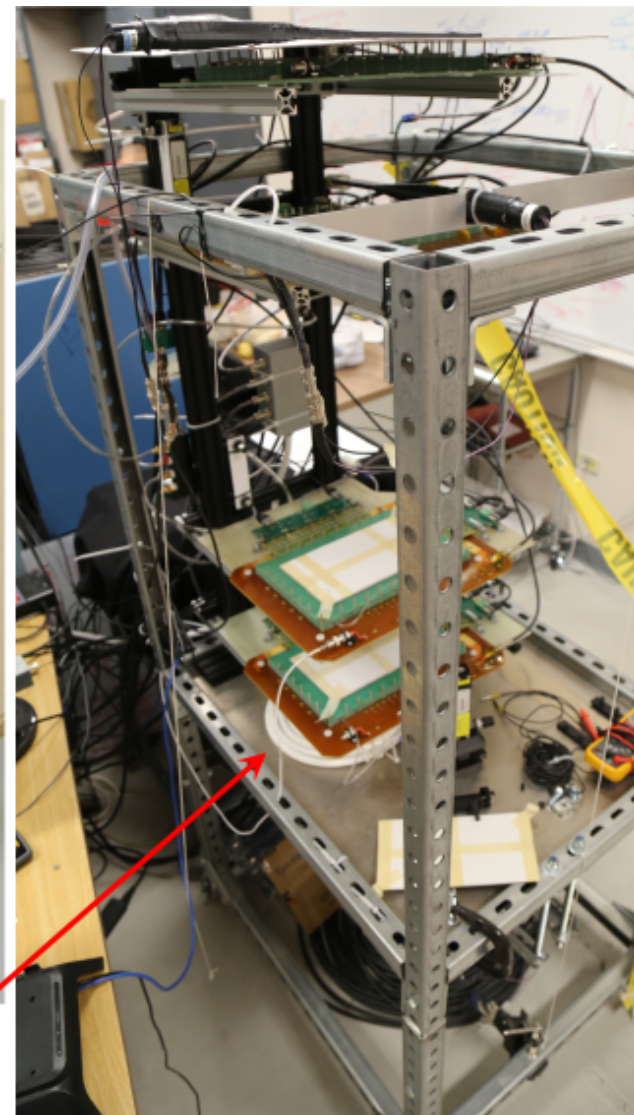
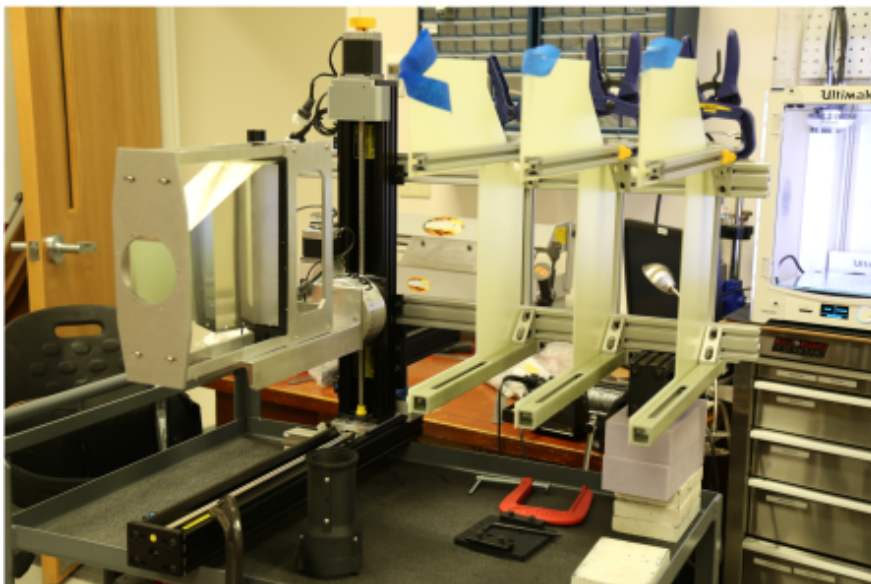
ShowerMax Prototype Construction Timeline

- 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



Testbeam 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