Prototype Shower-max Testbeam Results (preliminary)

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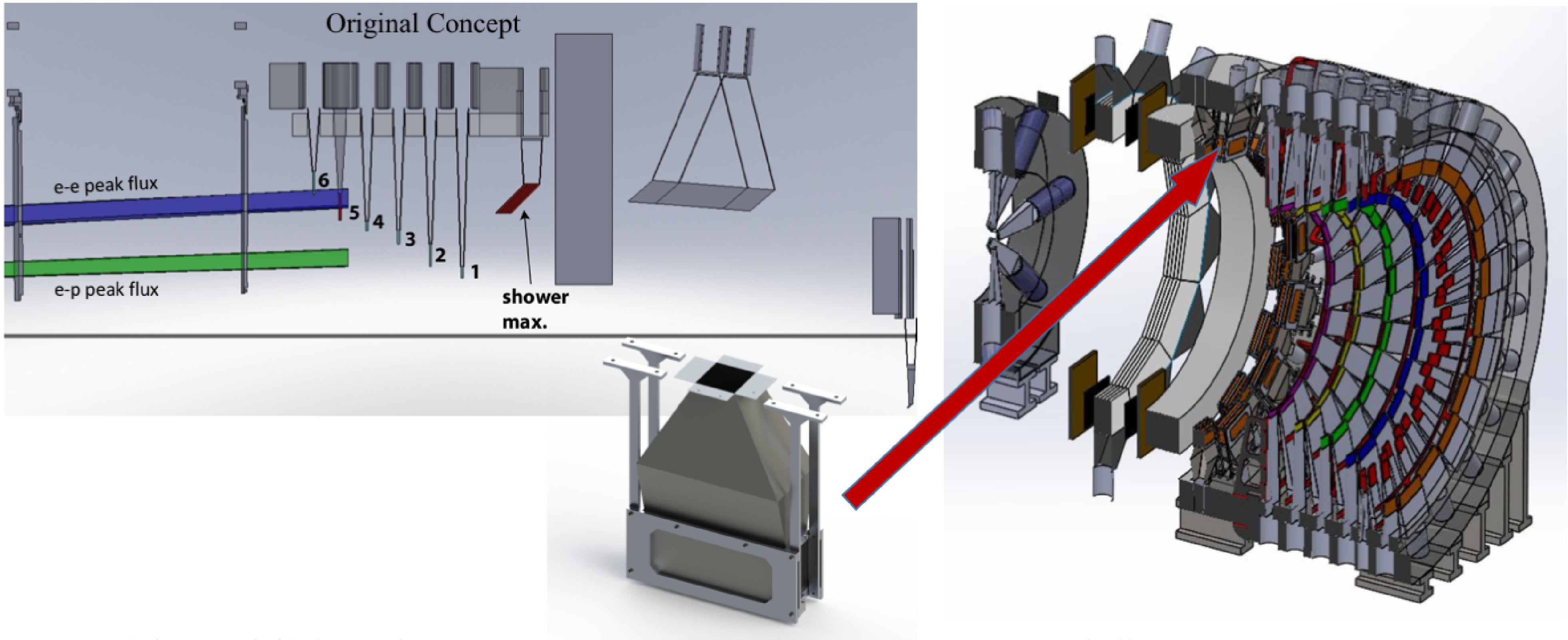
Prototype Shower-max Testbeam Results

Outline

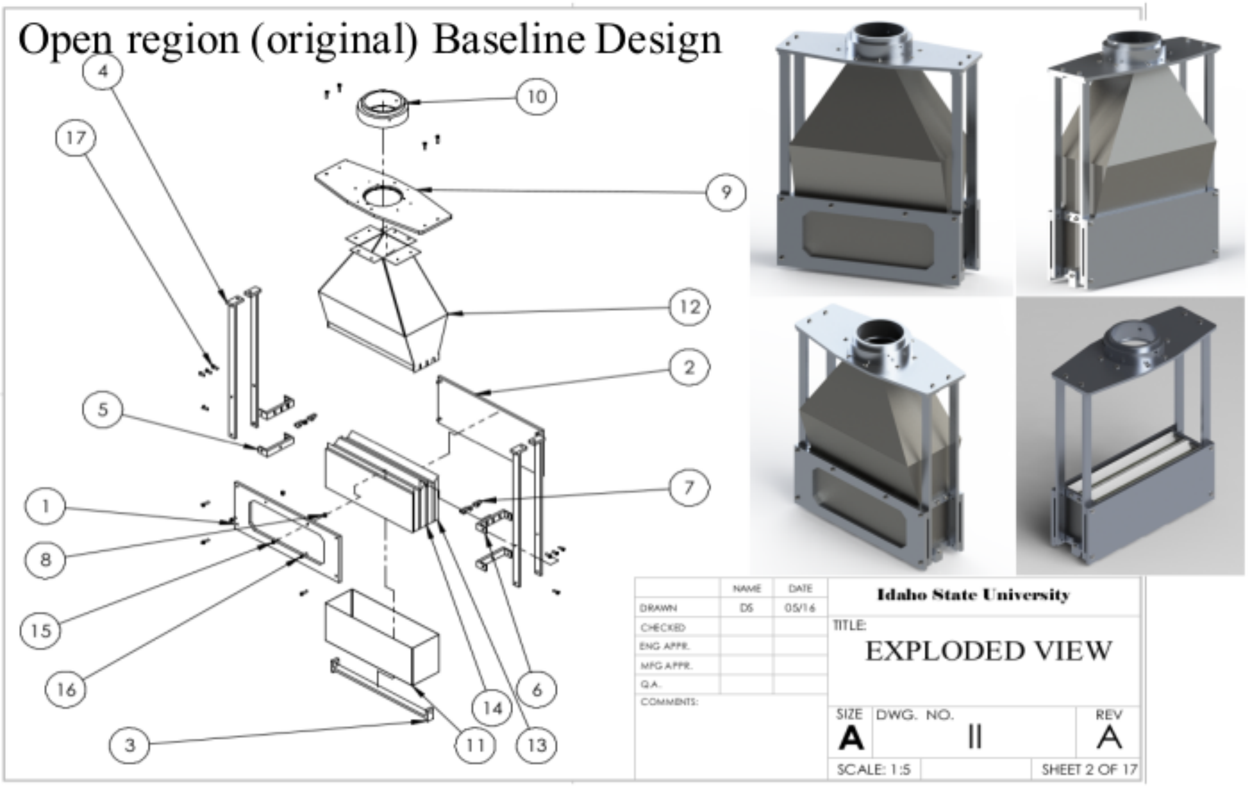
- Review baseline design and ring concept
- Prototype designs for testbeam (Baseline Designs)
- Prototype construction and testbeam Run
- Some Preliminary Testbeam Results
- Summary and Future Work

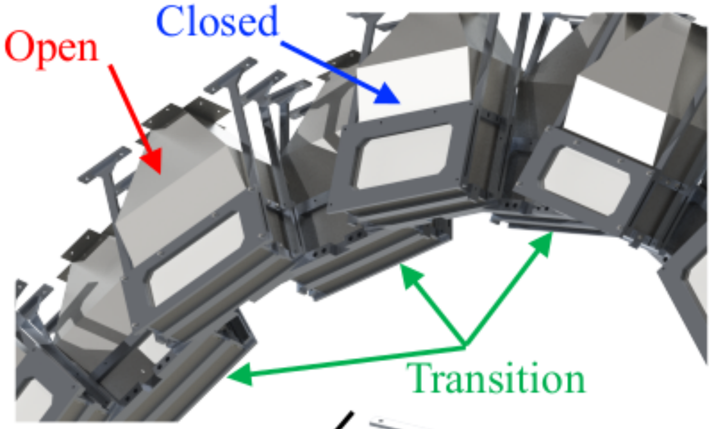
Shower-max Motivation & Requirements

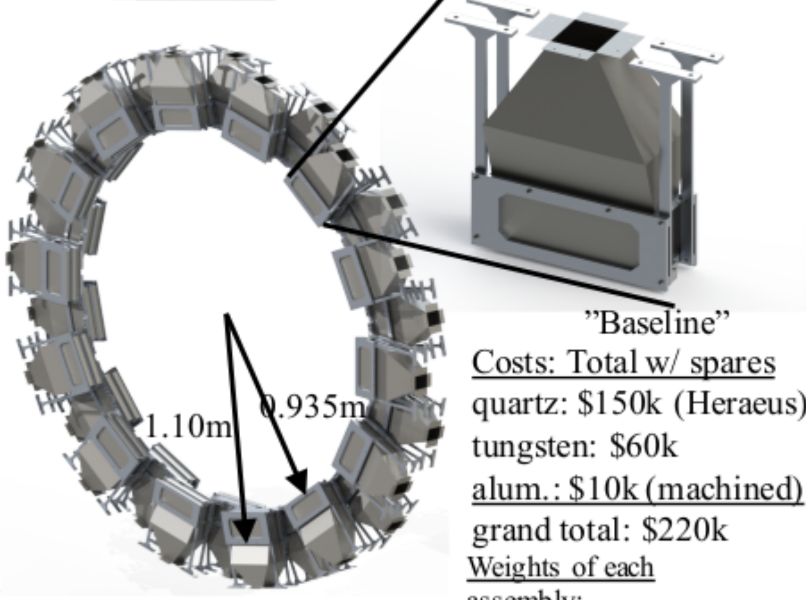


- Provides additional measurement of e-e ring integrated flux
- Weights flux by energy ⟹ less sensitive to low energy and hadronic backgrounds
- Will also operate in tracking mode to give additional handle on background (pion) identification – gives MIP-like signal
- Should have good resolution over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

Baseline ShowerMax Design and Ring Concept







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

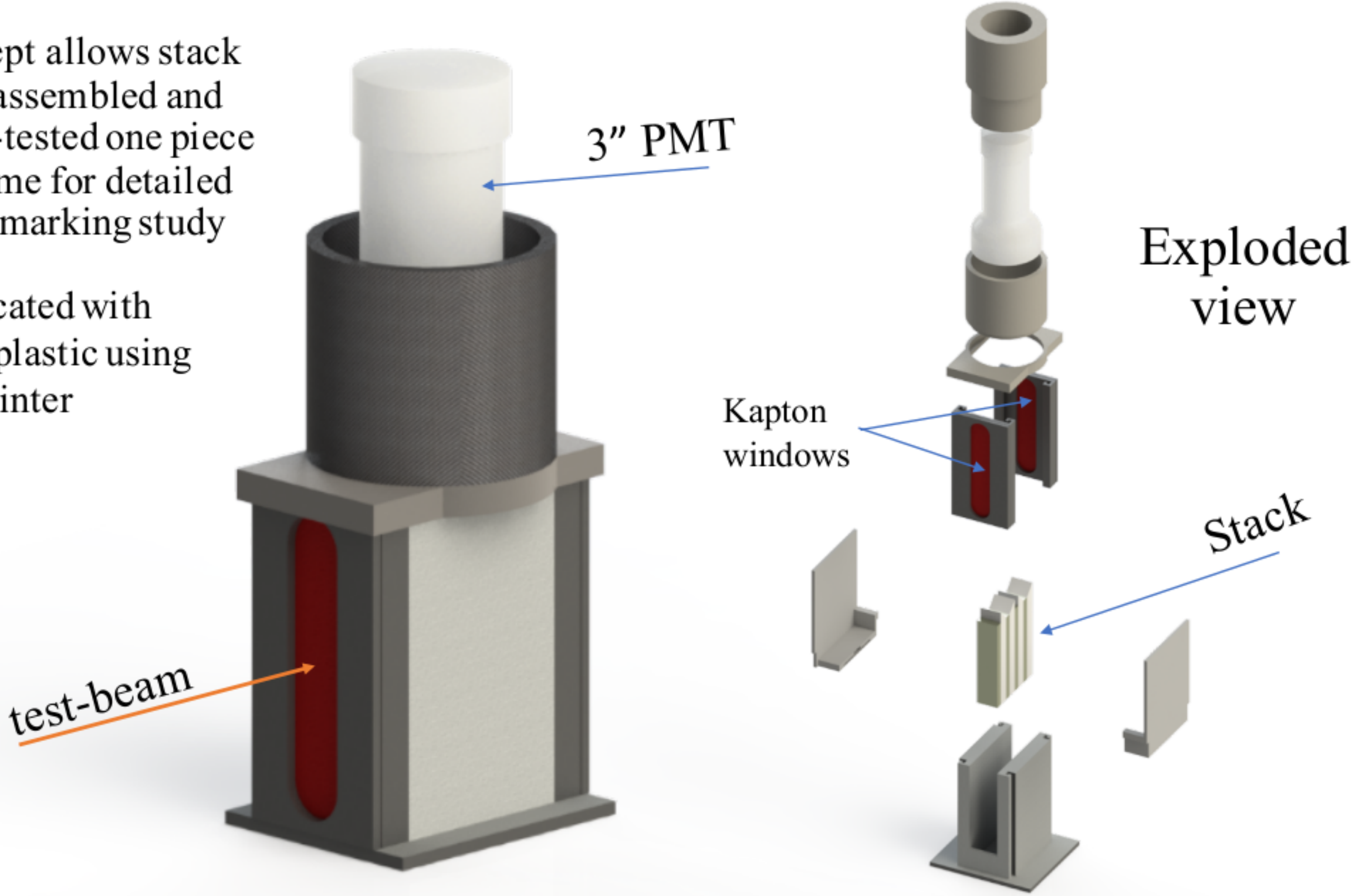
Weights of each assembly:
Open: 39.7 lbs.
Transition: 42.5 lbs.
Closed: 50.8 lbs.
ring weight: 1230 lbs.

- 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

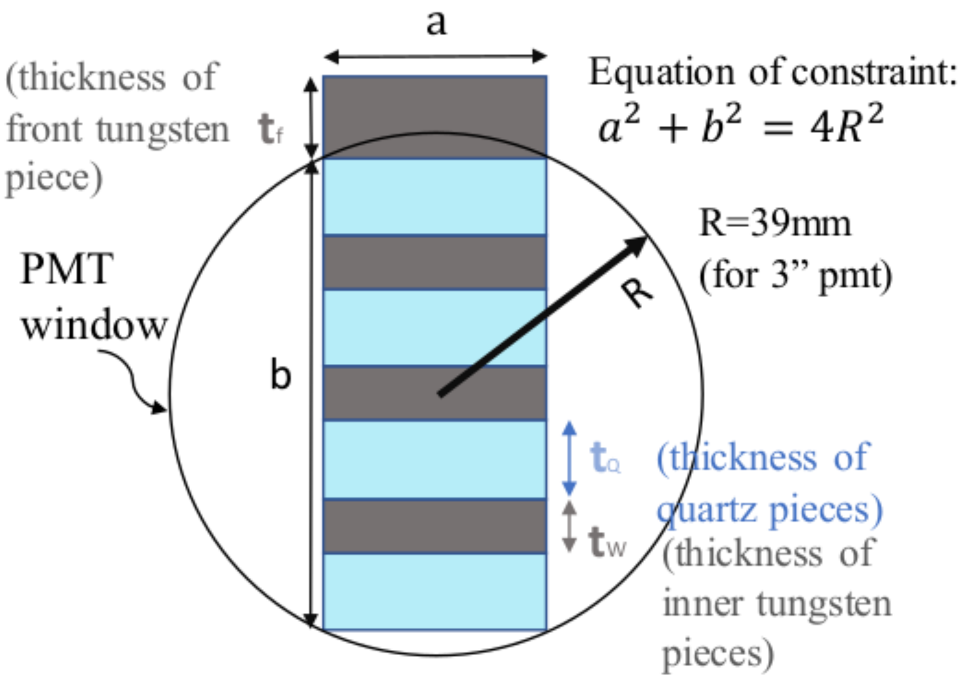
Benchmarking Stack Configurations

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

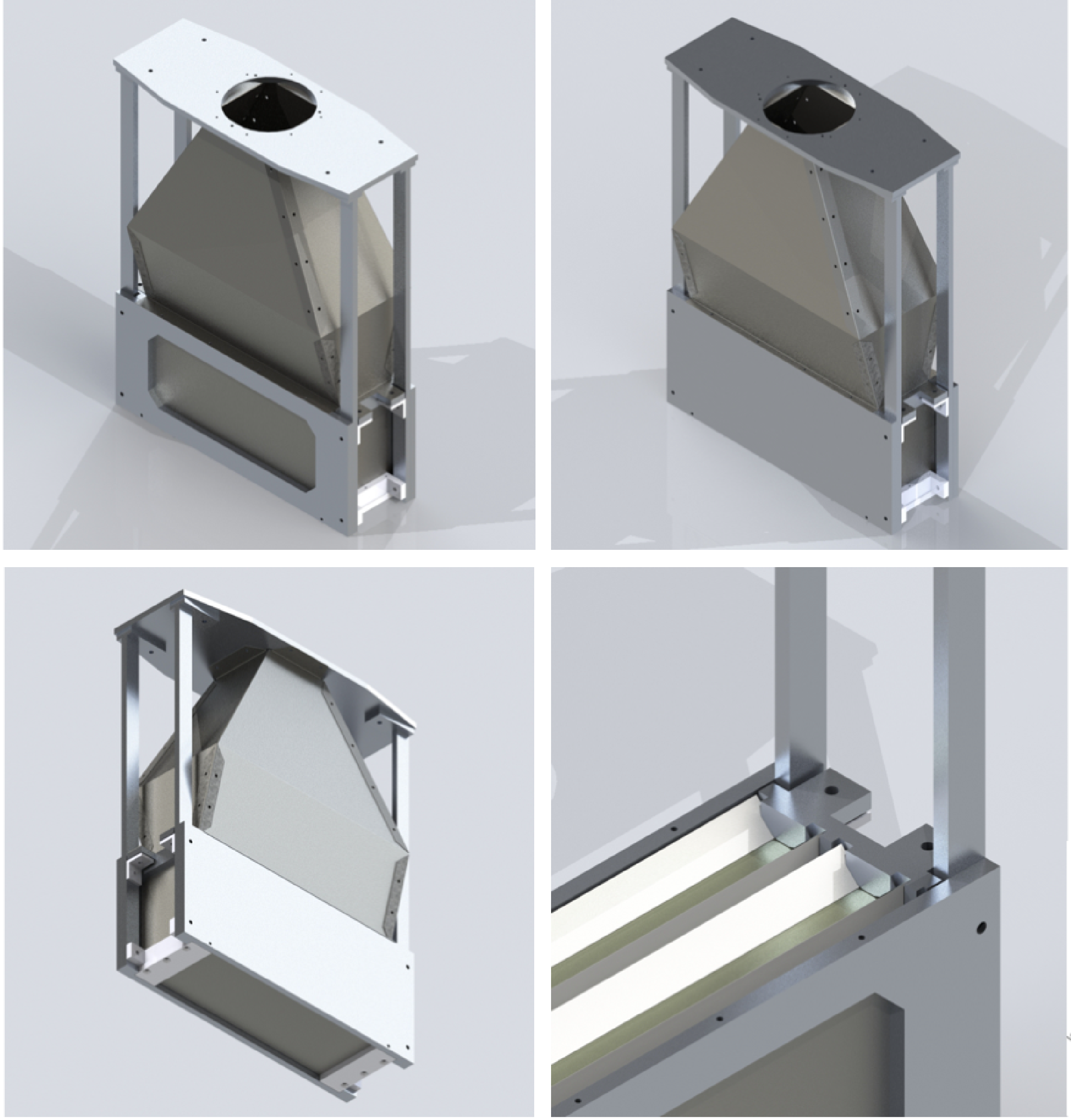
- Key benefit here is that the parameter “a” (the width of the benchmarking quartz tiles) can now be comfortably large to ensure negligible transverse shower leakage.

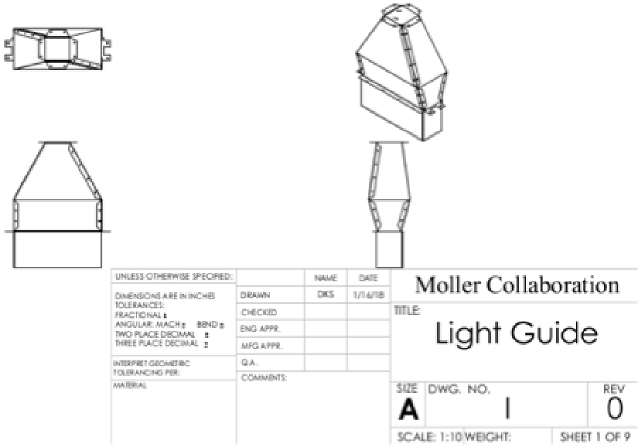


Equation of constraint:

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

Updated Full-Scale Prototype (1A) for Testbeam



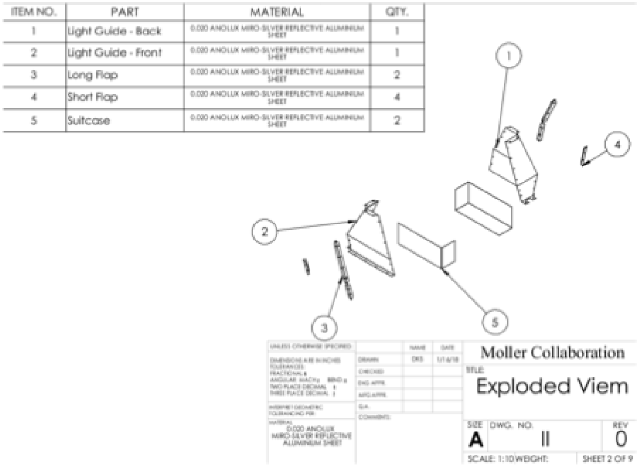


UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL

	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

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
0.020 ANOLUX MIRO-SILVER REFLECTIVE ALUMINIUM SHEET

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DRAWN	DKS	1/16/18
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MFG APPR.		
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COMMENTS:

Moller Collaboration
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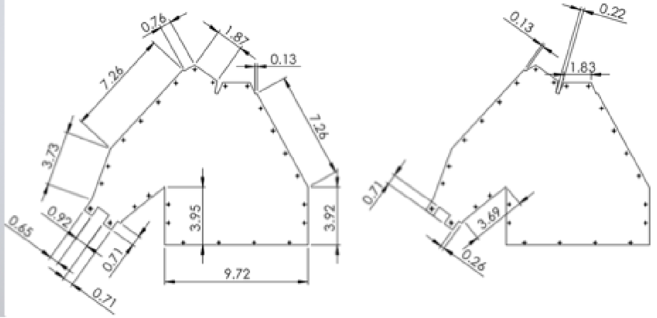
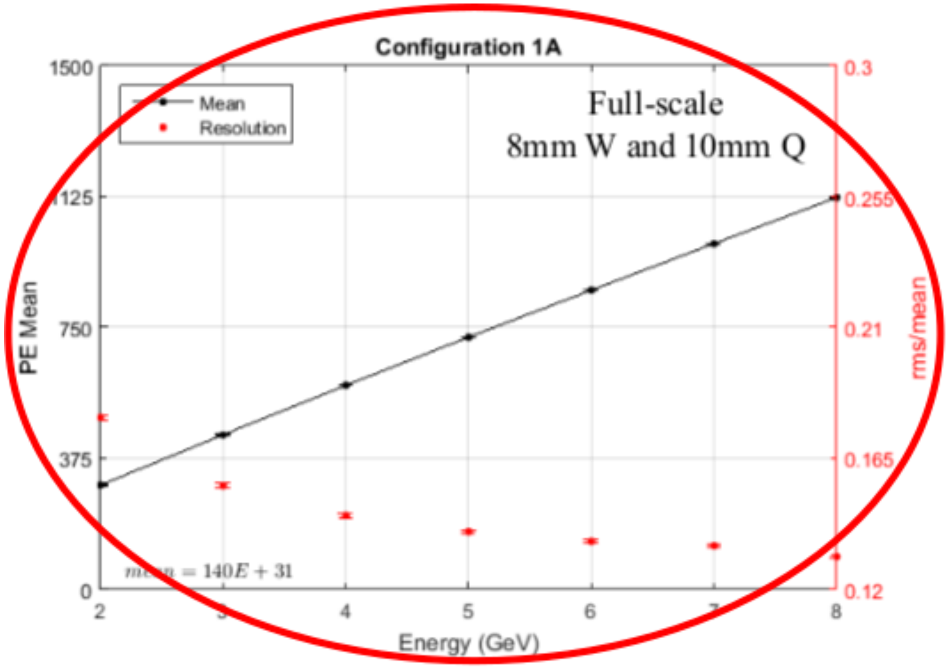
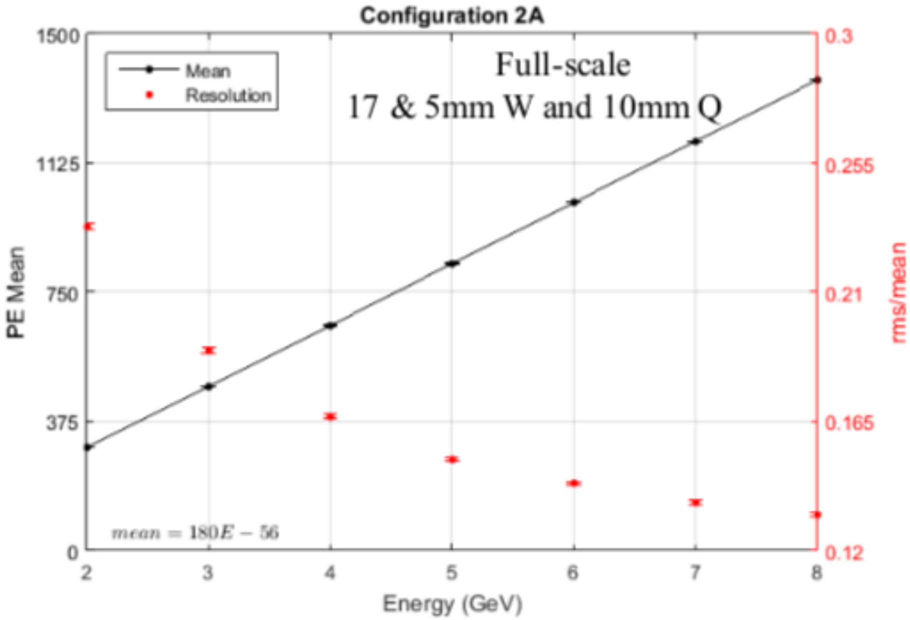
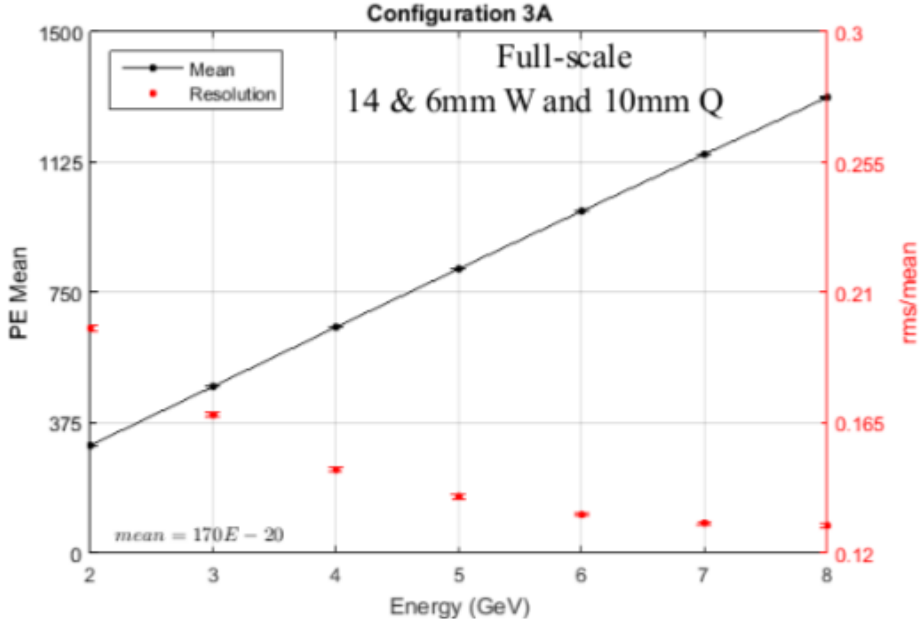
SIZE A DWG. NO. II REV 0
SCALE: 1:10 WEIGHT: SHEET 2 OF 9

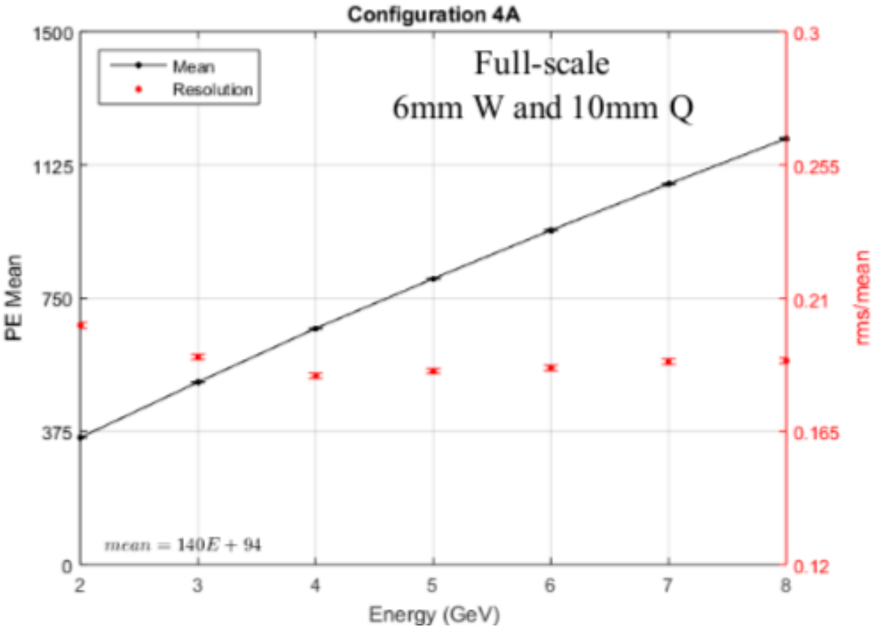


1A - 4A Mean PE and Resolution versus Energy

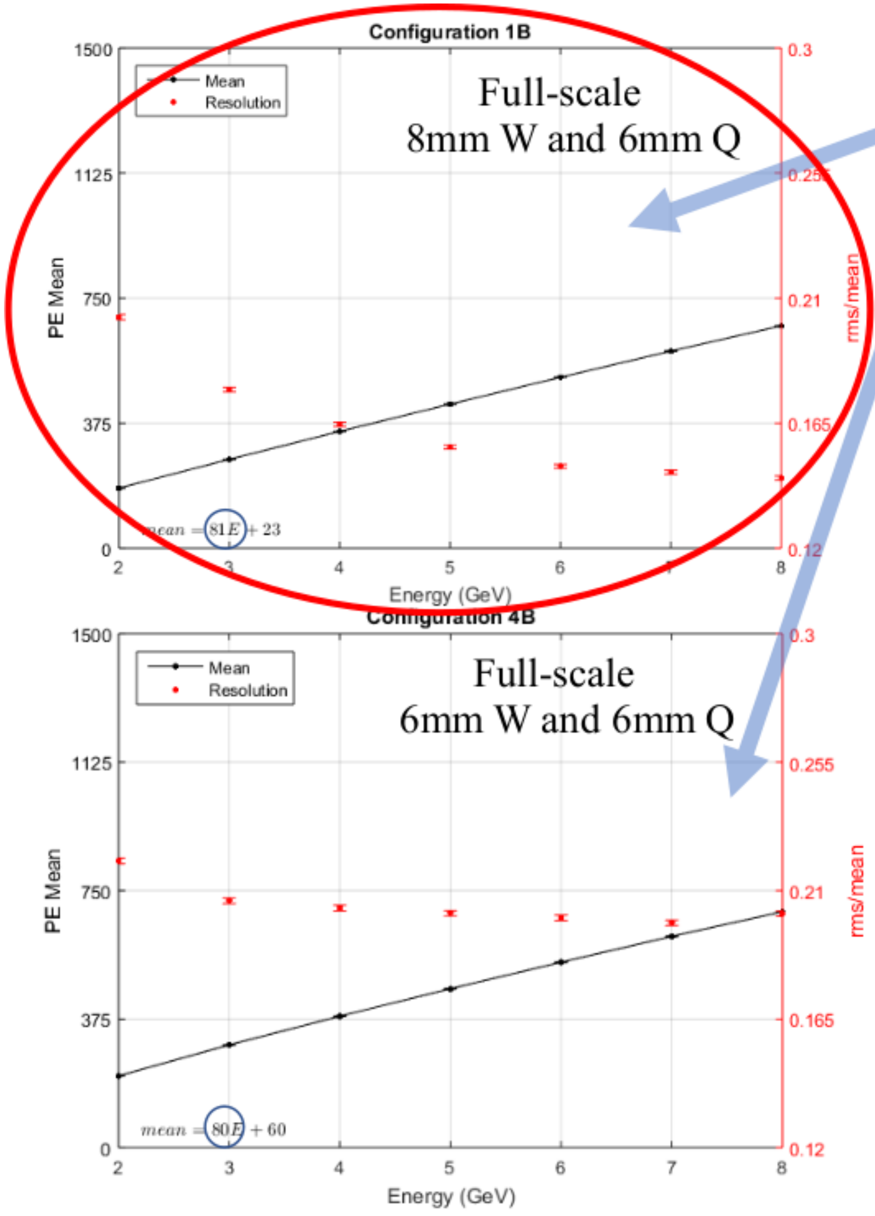

Full-scale
8mm W and 10mm Q


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


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


Full-scale
6mm W and 10mm Q

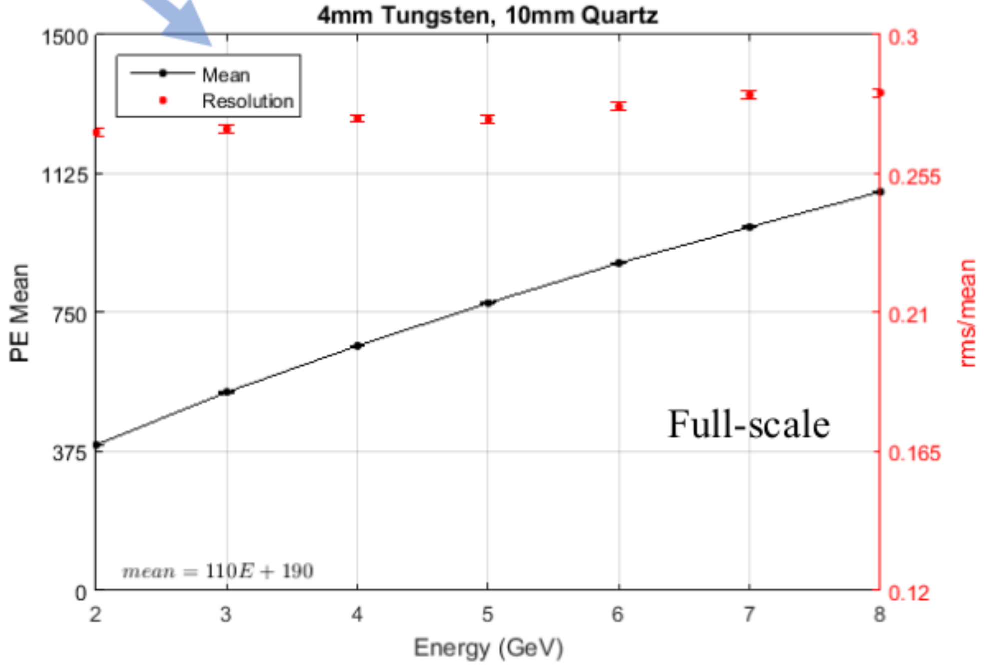
Simulation results for B configs (6mm quartz)



Full-scale
8mm W and 6mm Q

Full-scale
6mm W and 6mm Q

- 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)



Full-scale

Prototype Construction and SLAC Testbeam Run

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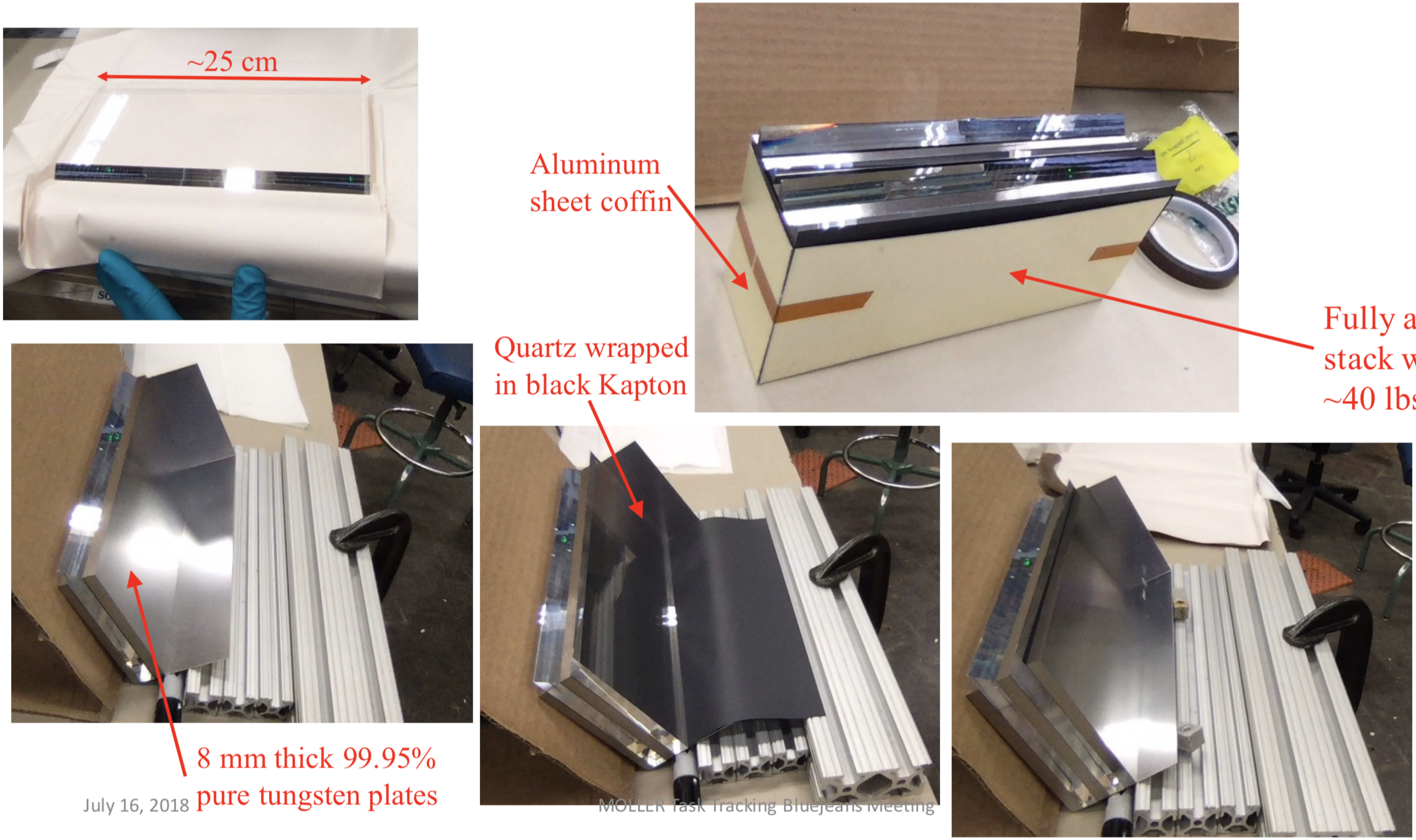
1A Full-scale Stack Assembly at SBU, June 2018



Aluminum sheet coffin

Quartz wrapped in black Kapton

Fully assemb
stack weighs
~40 lbs

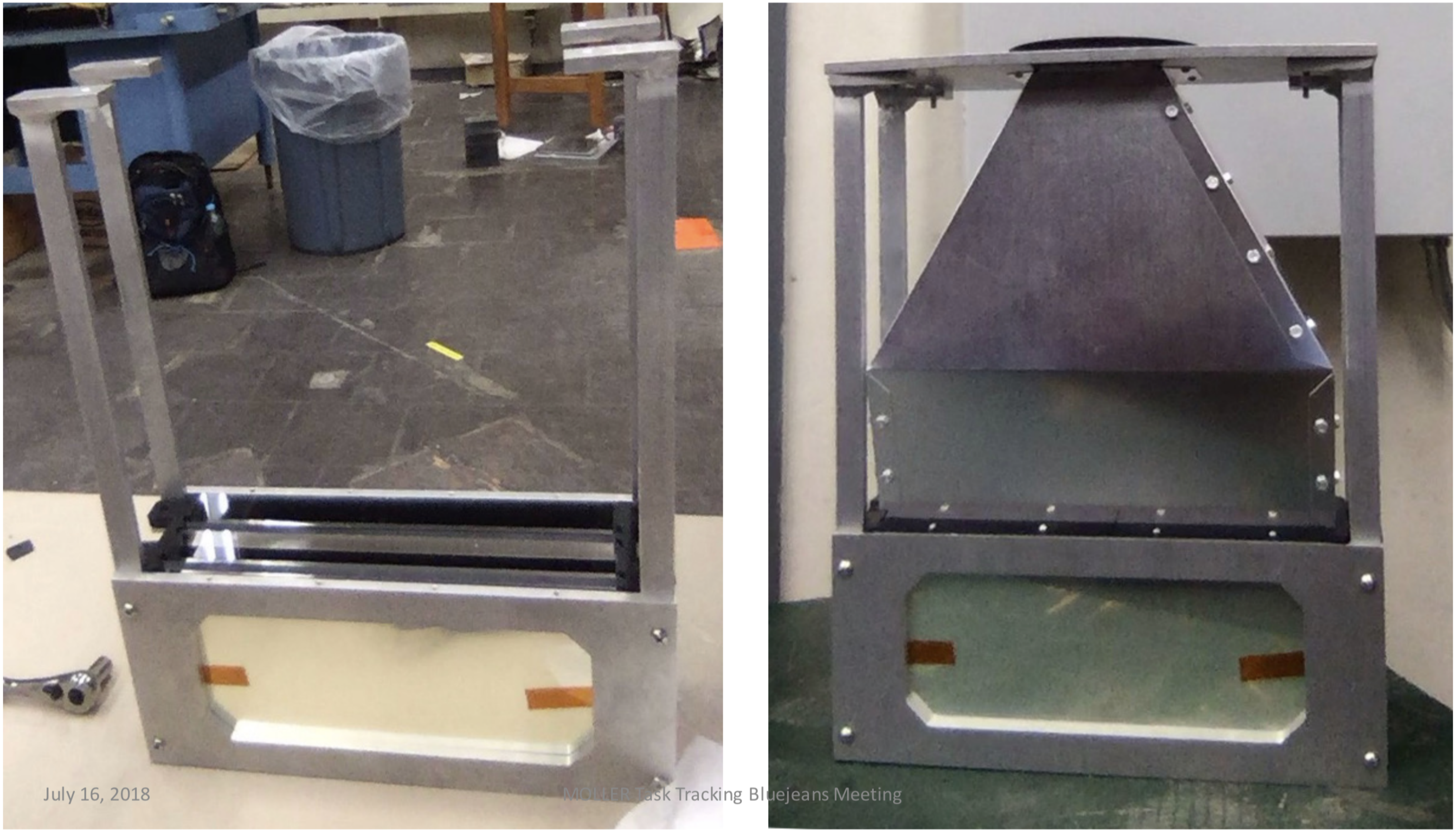
8 mm thick 99.95% pure tungsten plates

July 16, 2018

MOLLER Task Tracking Bluejeans Meeting

15

Assembled 1A Full-scale ShowerMax Prototype



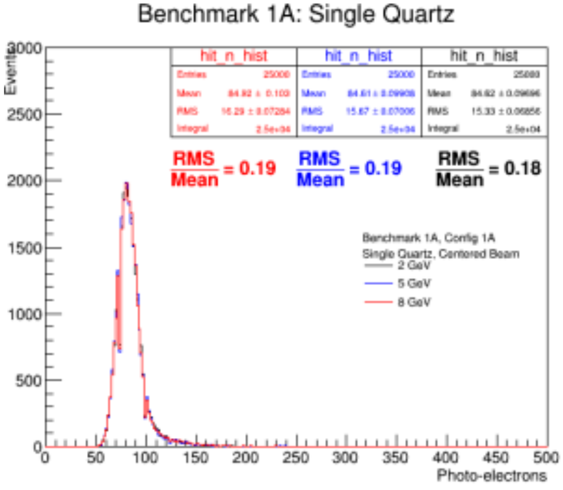
July 16, 2018

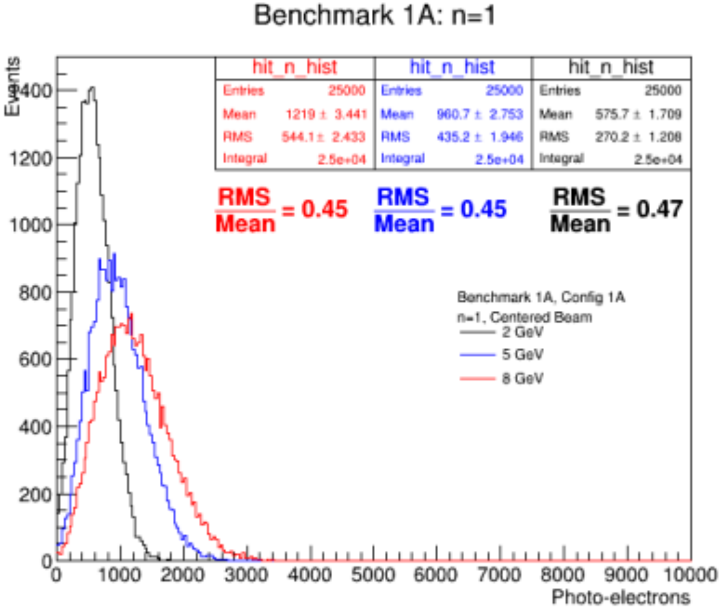
MOLLER Task Tracking Bluejeans Meeting

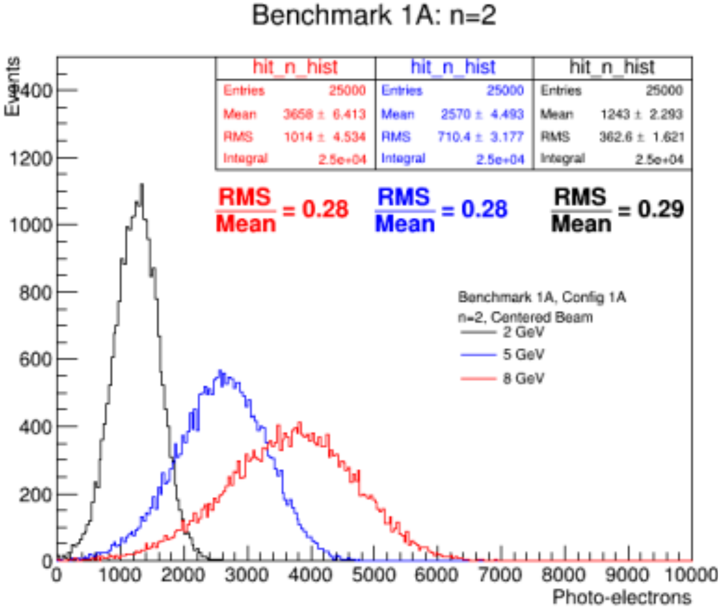
Testbeam and MC benchmarking strategy

- 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

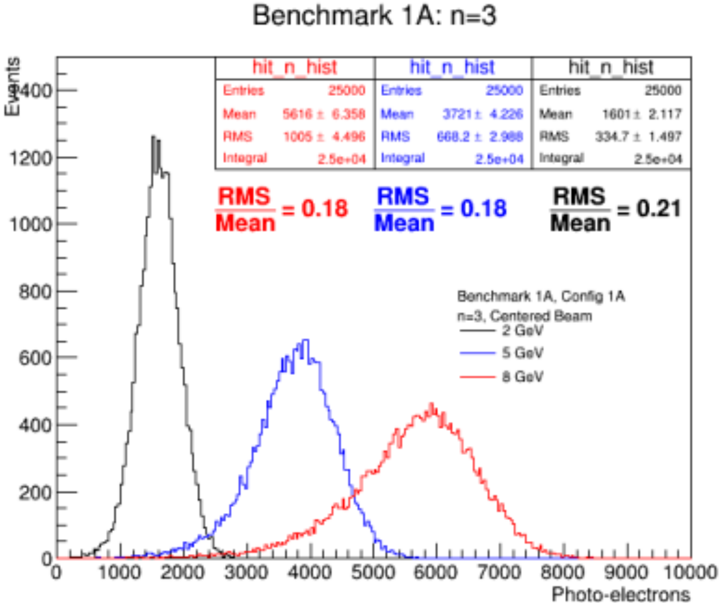


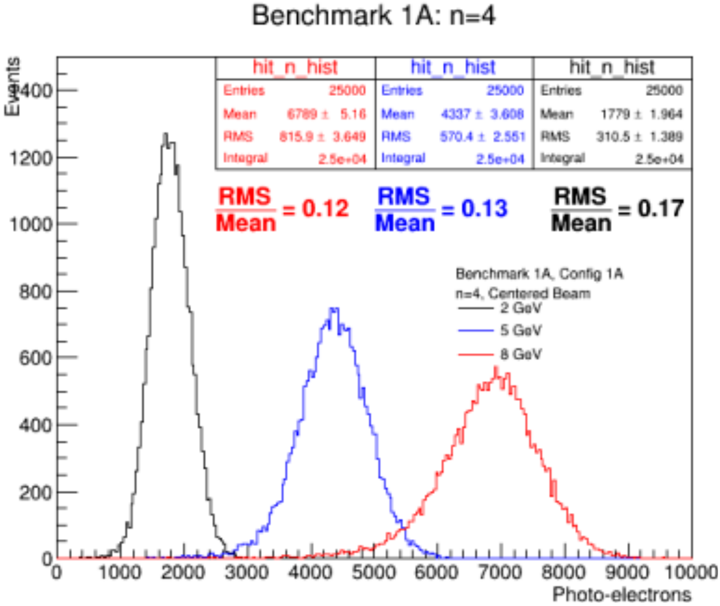




- Benchmarking PE yields are incredibly high for n =1 to 4

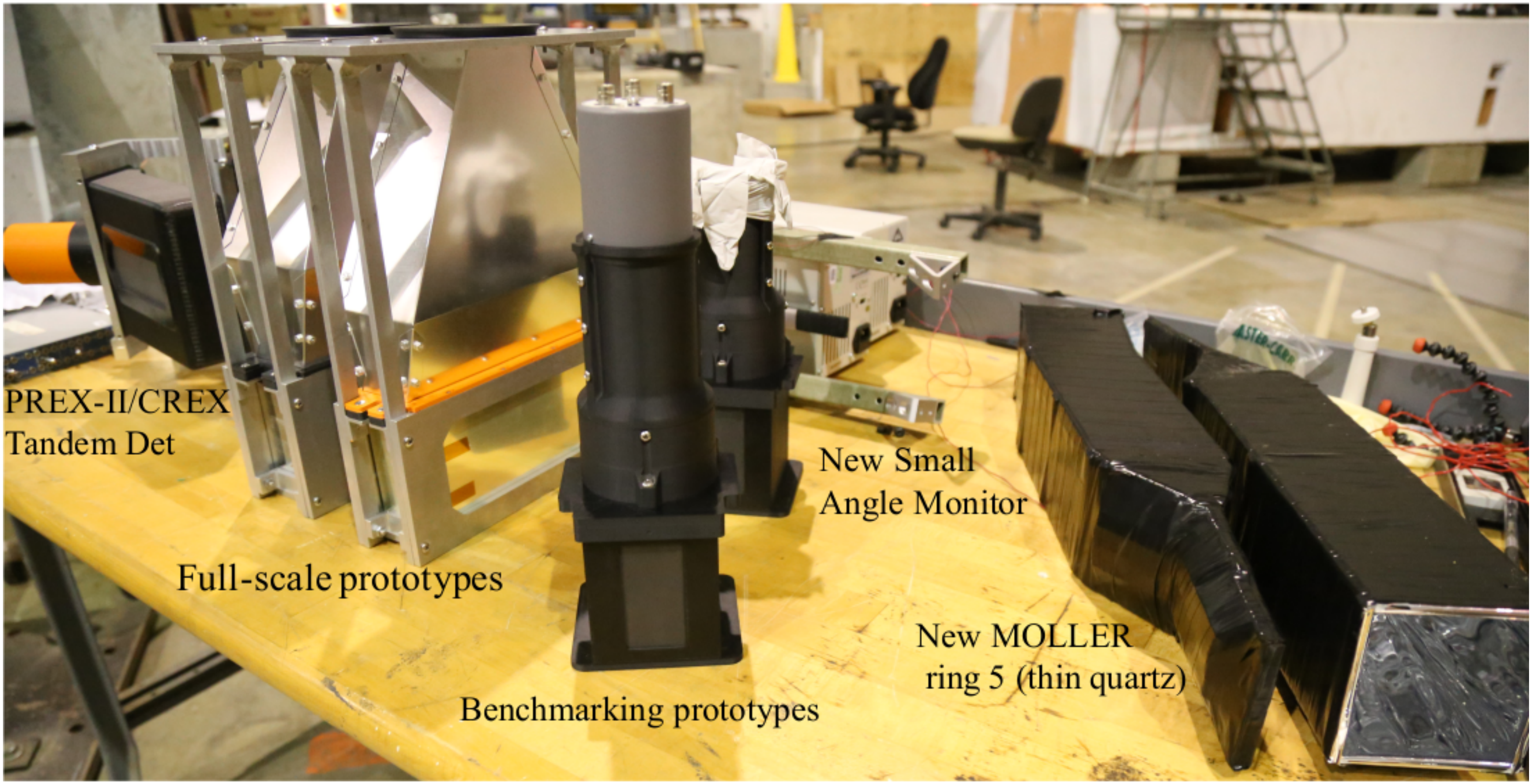
- Will use 3” ET PMTs: 9305QKB





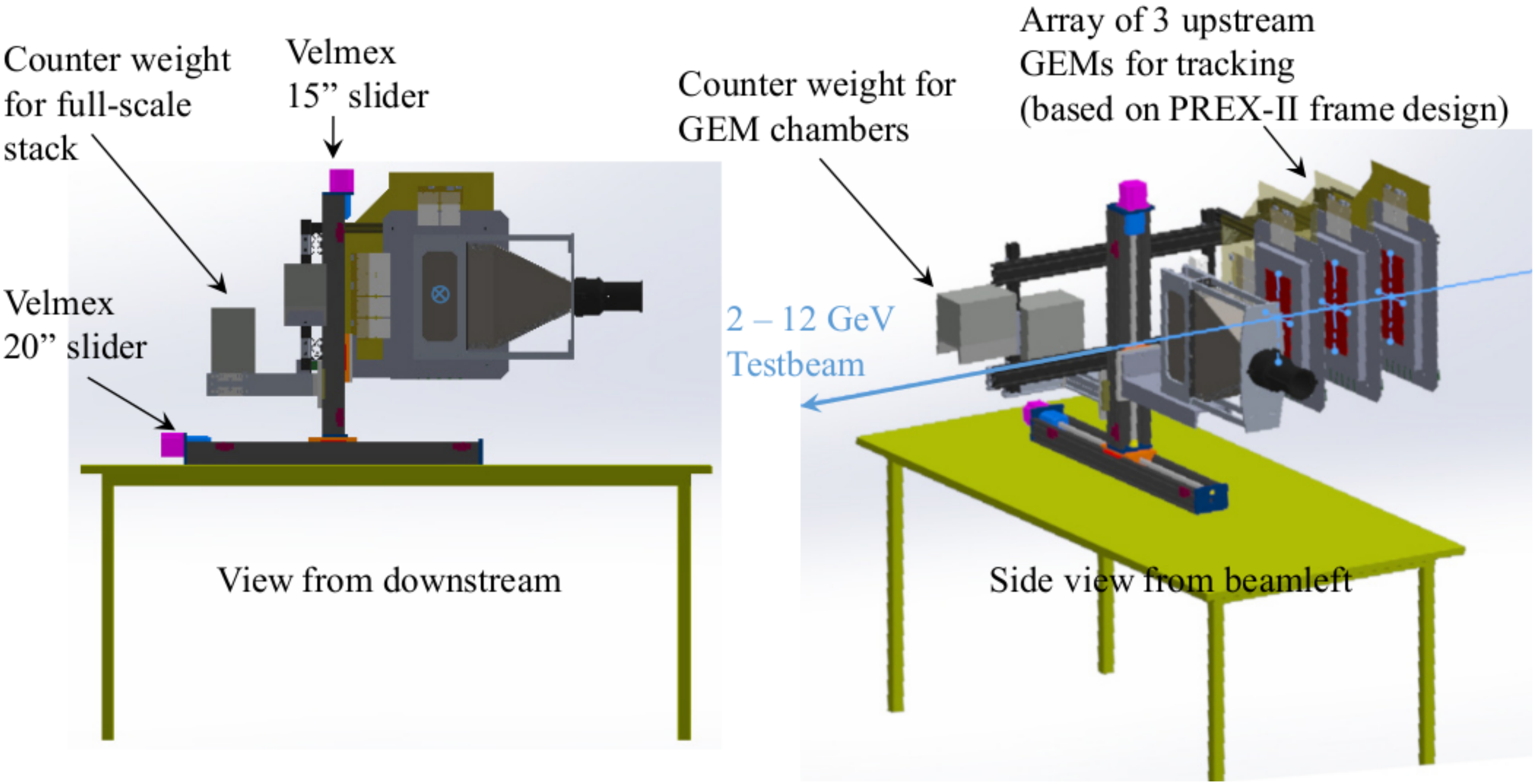
T-577: SLAC Testbeam, Dec 6 – 12, 2018

- 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 ~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



Counter weight for full-scale stack

Velmex 15” slider

Velmex 20” slider

View from downstream

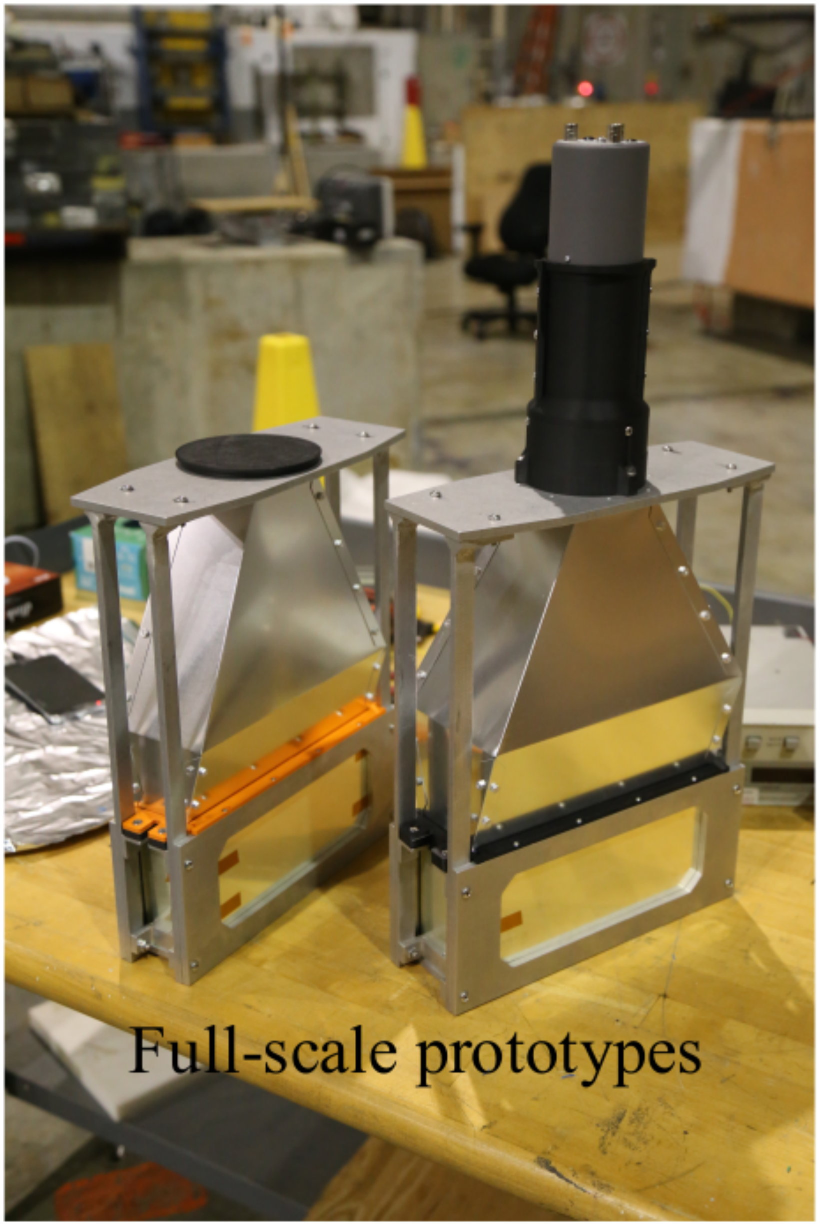
Counter weight for GEM chambers

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

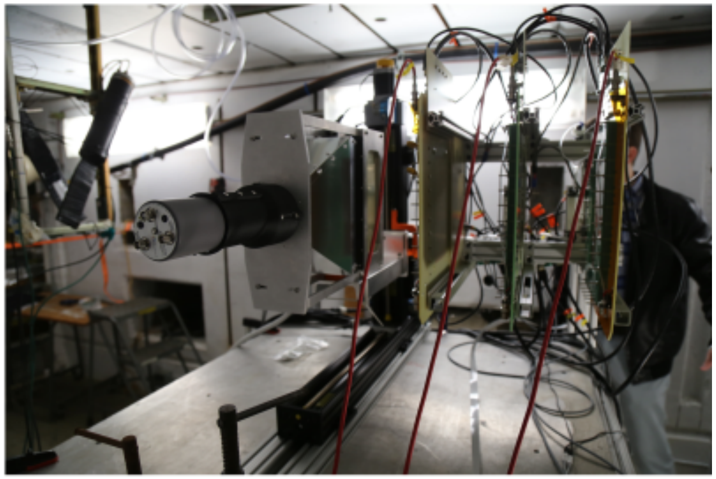
2 – 12 GeV Testbeam

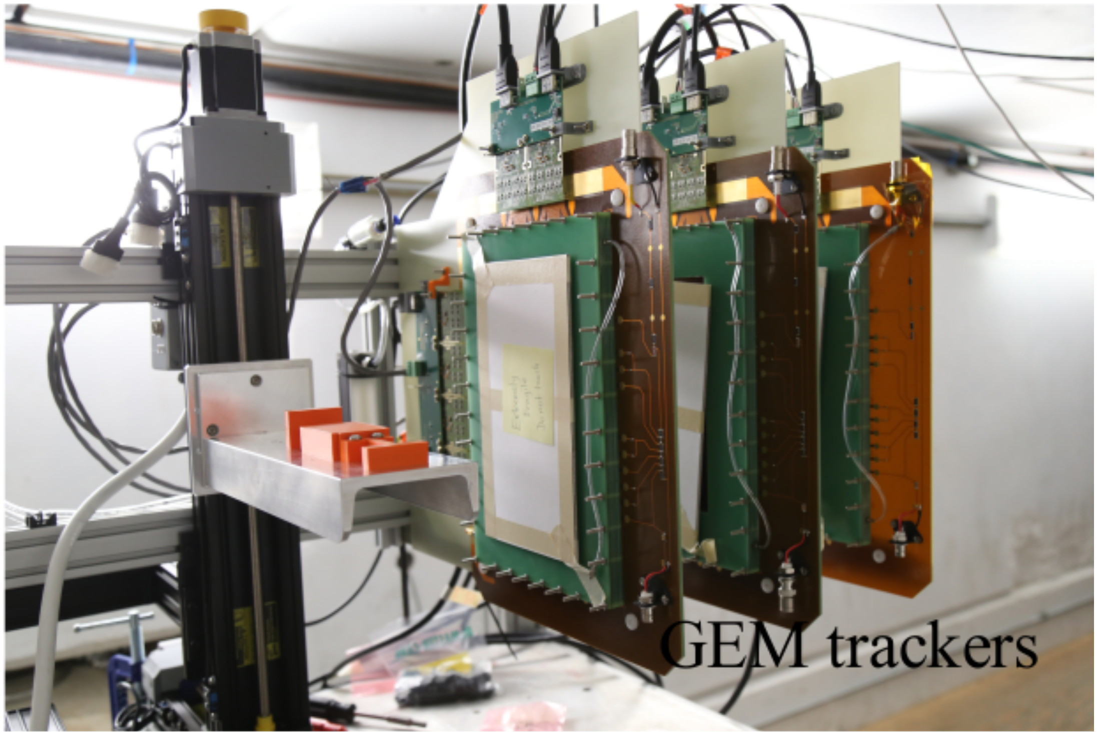
Side view from beamleft

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



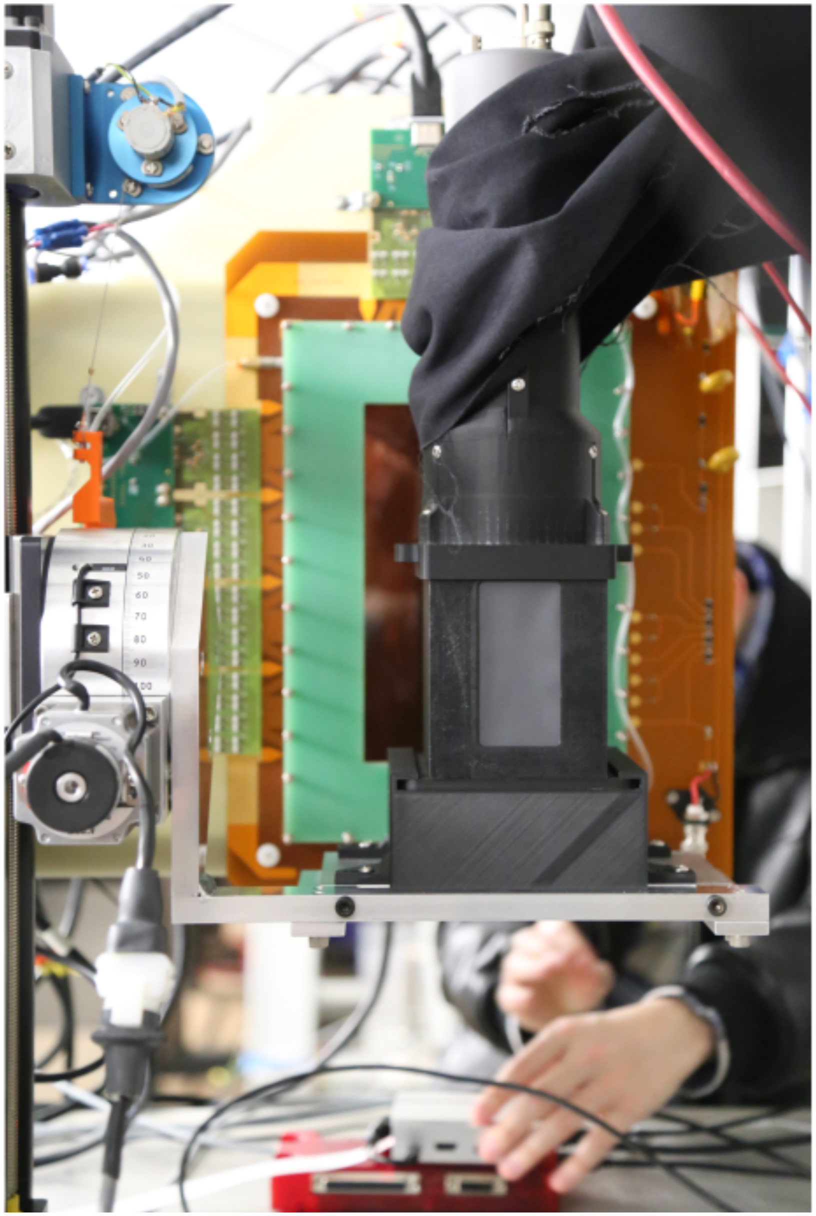
Full-scale prototypes



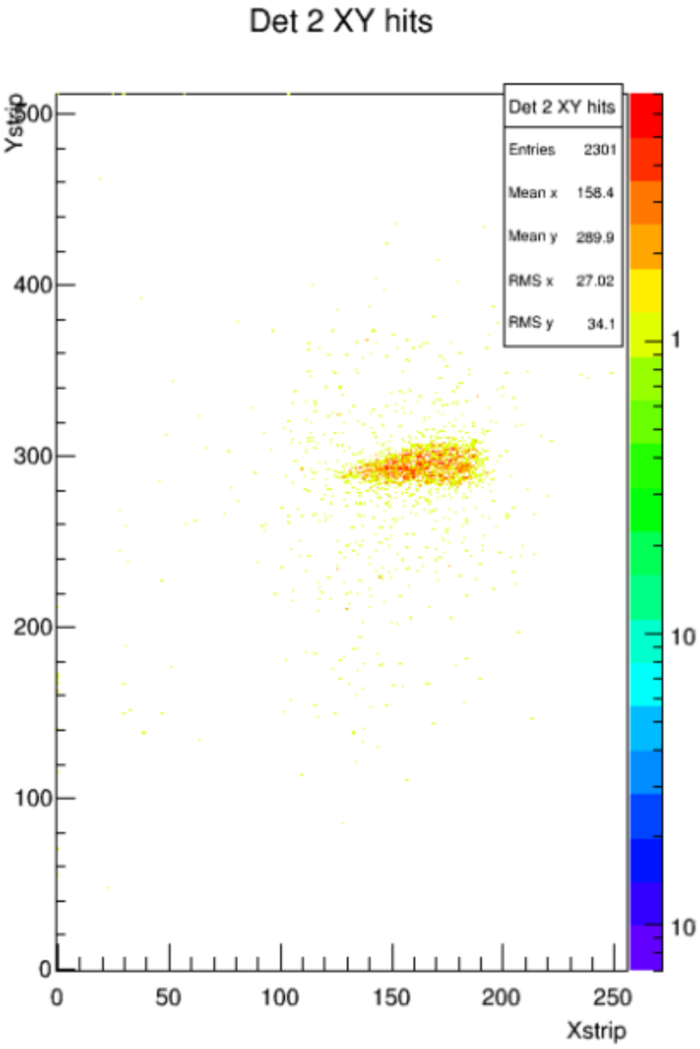


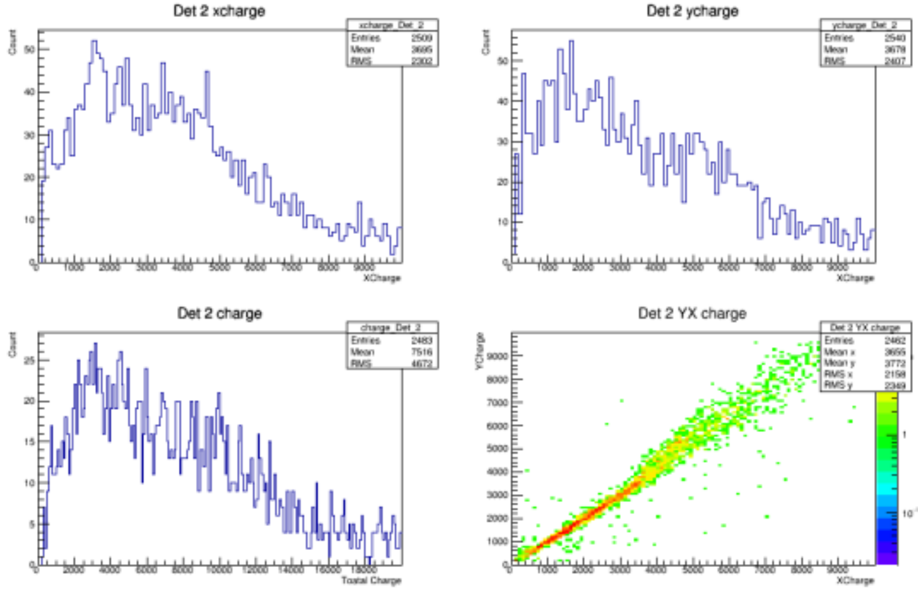
GEM trackers

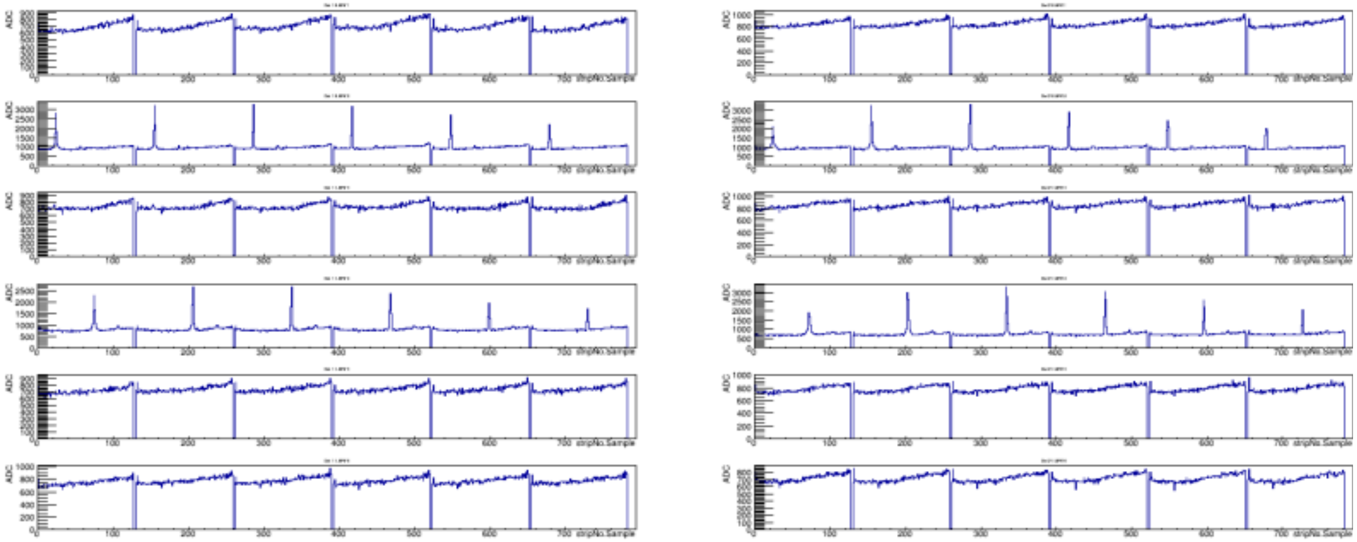
T-577: SLAC Testbeam Setup: Benchmarking ShowerMax



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

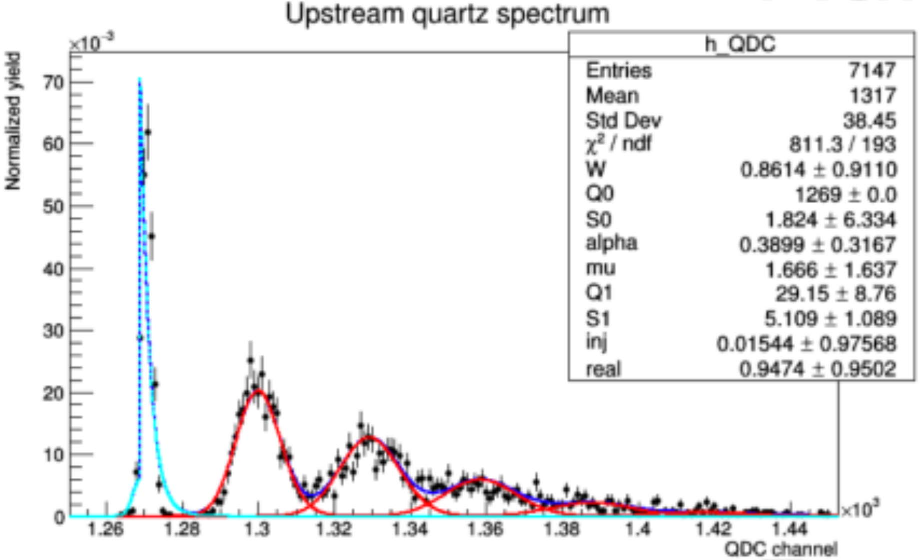




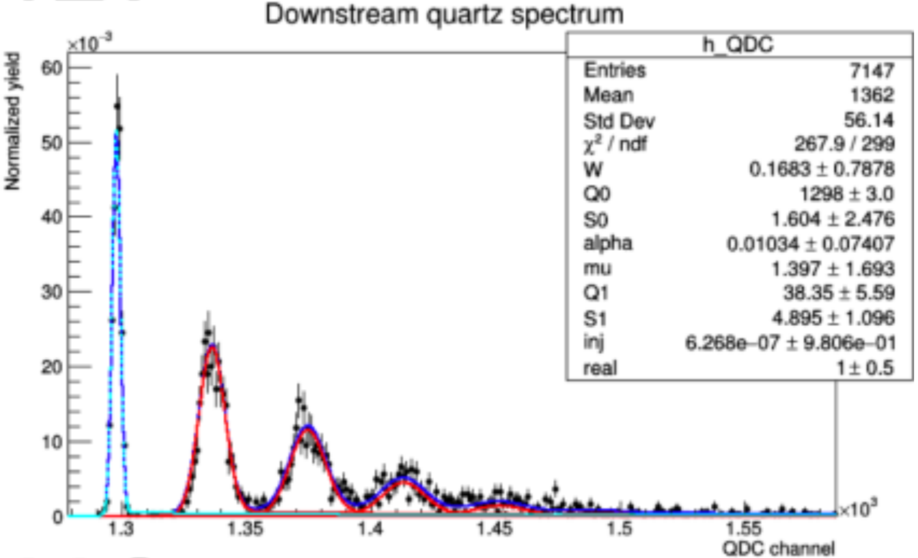


SLAC Testbeam sample data (from PREX Tandem Det)

Run 417

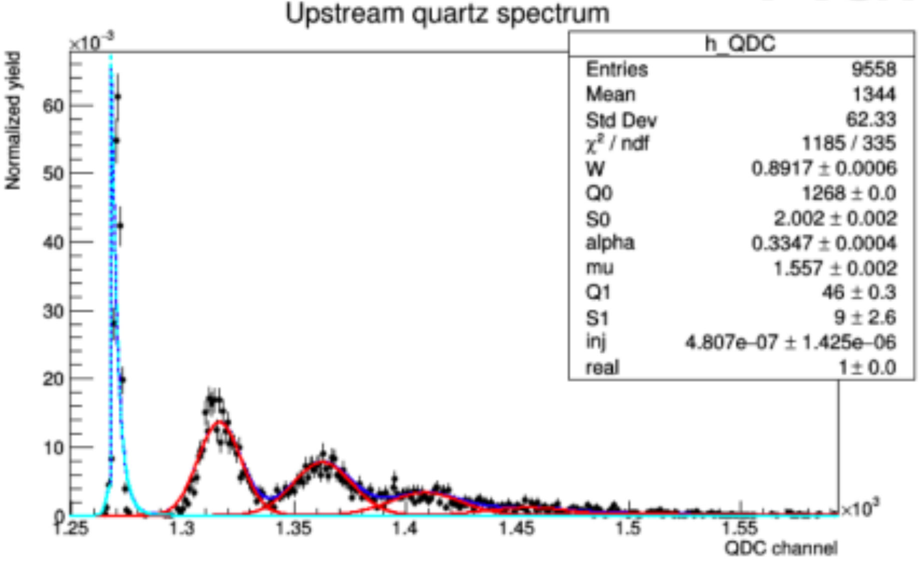

Upstream quartz spectrum

h_QDC	
Entries	7147
Mean	1317
Std Dev	38.45
χ^2 / ndf	811.3 / 193
W	0.8614 ± 0.9110
Q0	1269 ± 0.0
S0	1.824 ± 6.334
alpha	0.3899 ± 0.3167
mu	1.666 ± 1.637
Q1	29.15 ± 8.76
S1	5.109 ± 1.089
inj	0.01544 ± 0.97568
real	0.9474 ± 0.9502

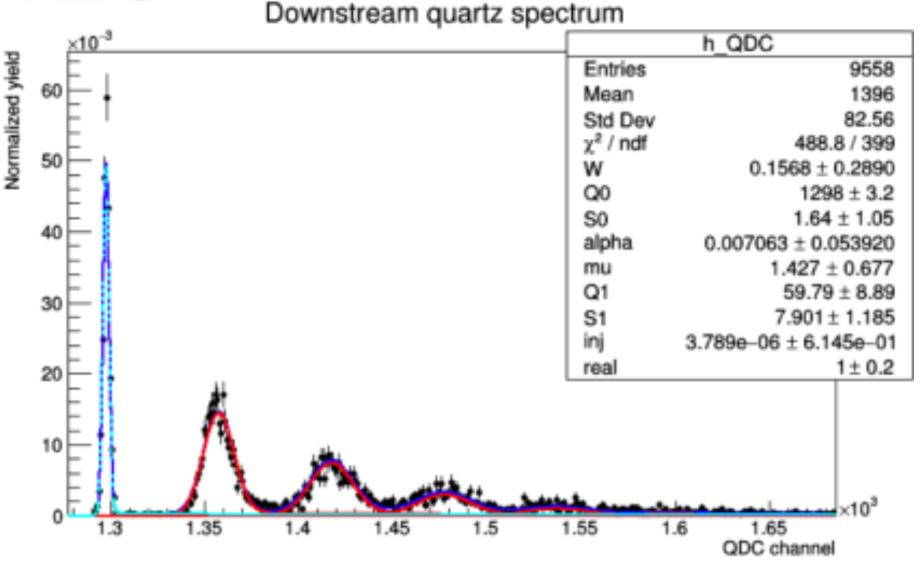

Downstream quartz spectrum

h_QDC	
Entries	7147
Mean	1362
Std Dev	56.14
χ^2 / ndf	267.9 / 299
W	0.1683 ± 0.7878
Q0	1298 ± 3.0
S0	1.604 ± 2.476
alpha	0.01034 ± 0.07407
mu	1.397 ± 1.693
Q1	38.35 ± 5.59
S1	4.895 ± 1.096
inj	6.268e-07 ± 9.806e-01
real	1 ± 0.5

Run 418

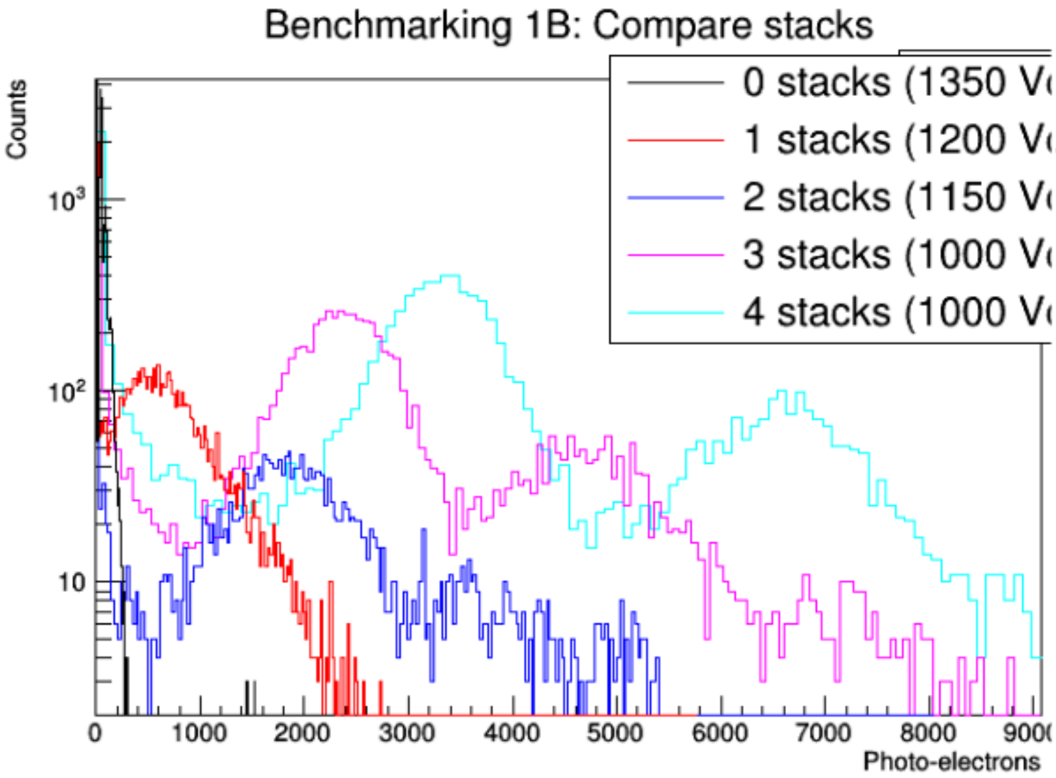

Upstream quartz spectrum

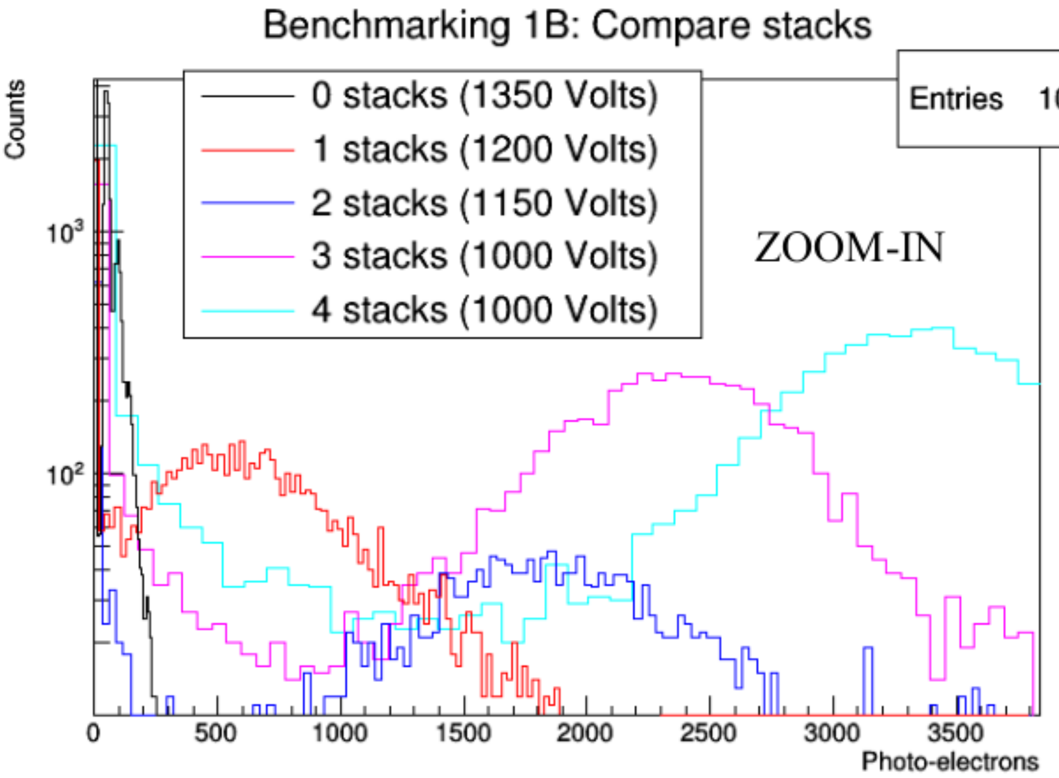
h_QDC	
Entries	9558
Mean	1344
Std Dev	62.33
χ^2 / ndf	1185 / 335
W	0.8917 ± 0.0006
Q0	1268 ± 0.0
S0	2.002 ± 0.002
alpha	0.3347 ± 0.0004
mu	1.557 ± 0.002
Q1	46 ± 0.3
S1	9 ± 2.6
inj	4.807e-07 ± 1.425e-06
real	1 ± 0.0


Downstream quartz spectrum

h_QDC	
Entries	9558
Mean	1396
Std Dev	82.56
χ^2 / ndf	488.8 / 399
W	0.1568 ± 0.2890
Q0	1298 ± 3.2
S0	1.64 ± 1.05
alpha	0.007063 ± 0.053920
mu	1.427 ± 0.677
Q1	59.79 ± 8.89
S1	7.901 ± 1.185
inj	3.789e-06 ± 6.145e-01
real	1 ± 0.2

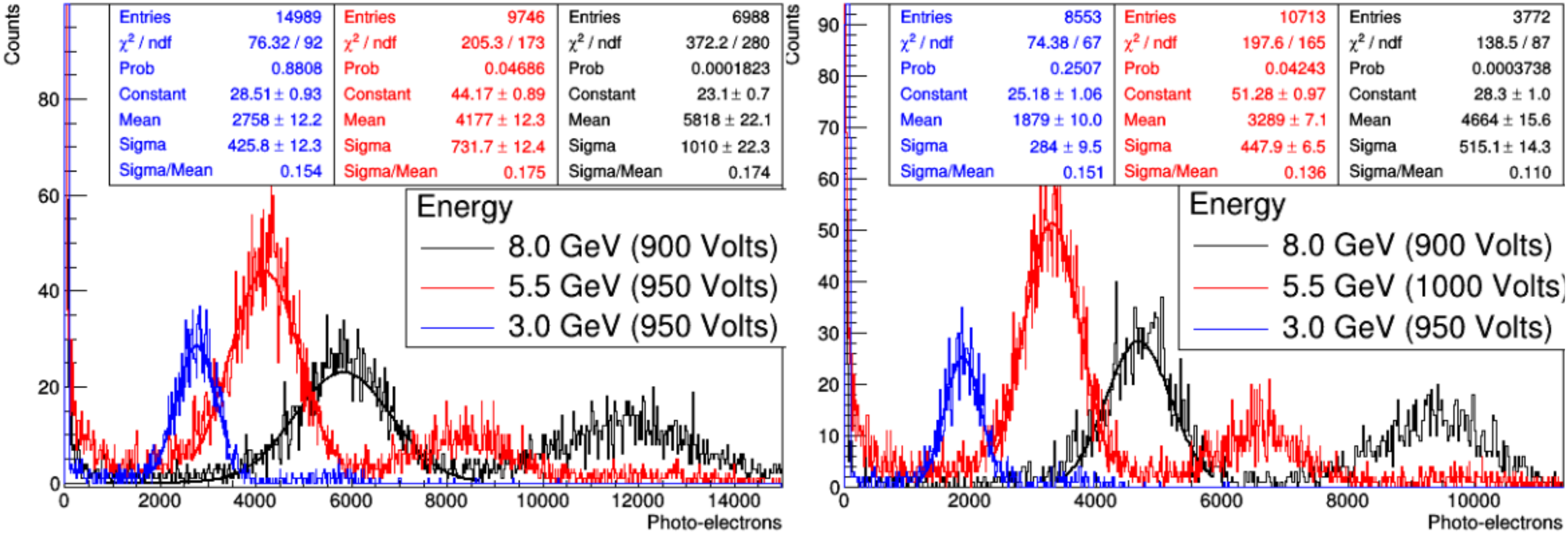
ShowerMax Benchmarking Prototype Testbeam Results
(1B response vs. stack layers)





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

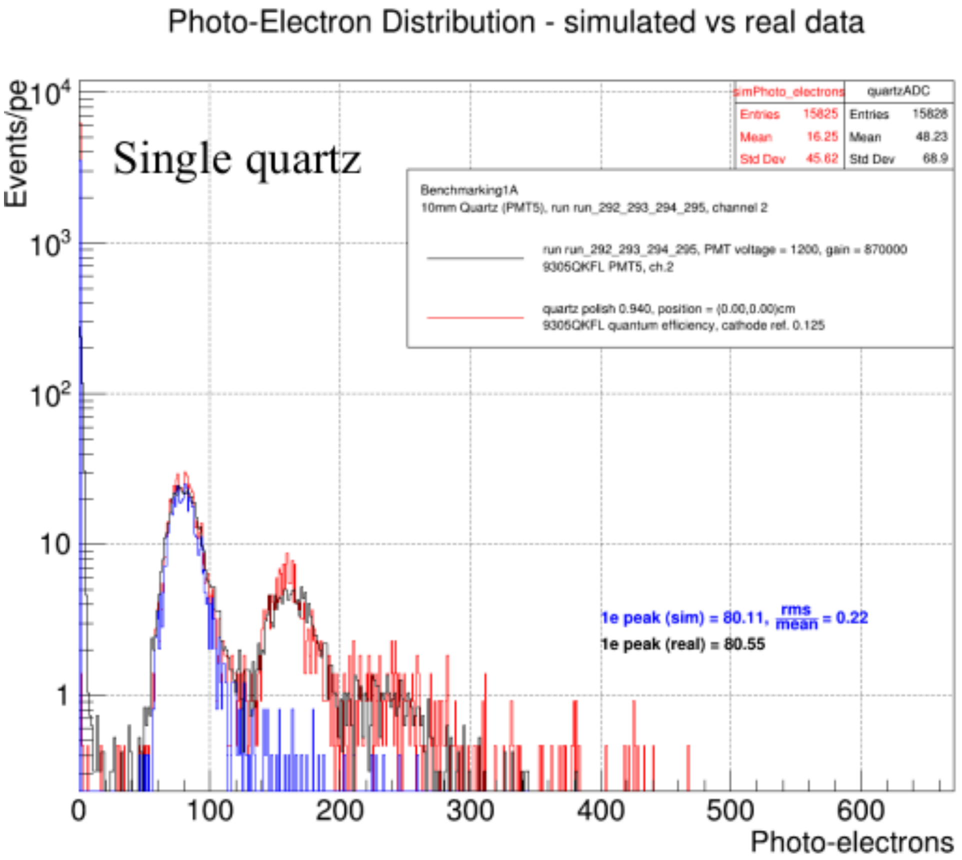
ShowerMax Benchmarking Prototype Testbeam Results
(1A and 1B full stack response vs energy)

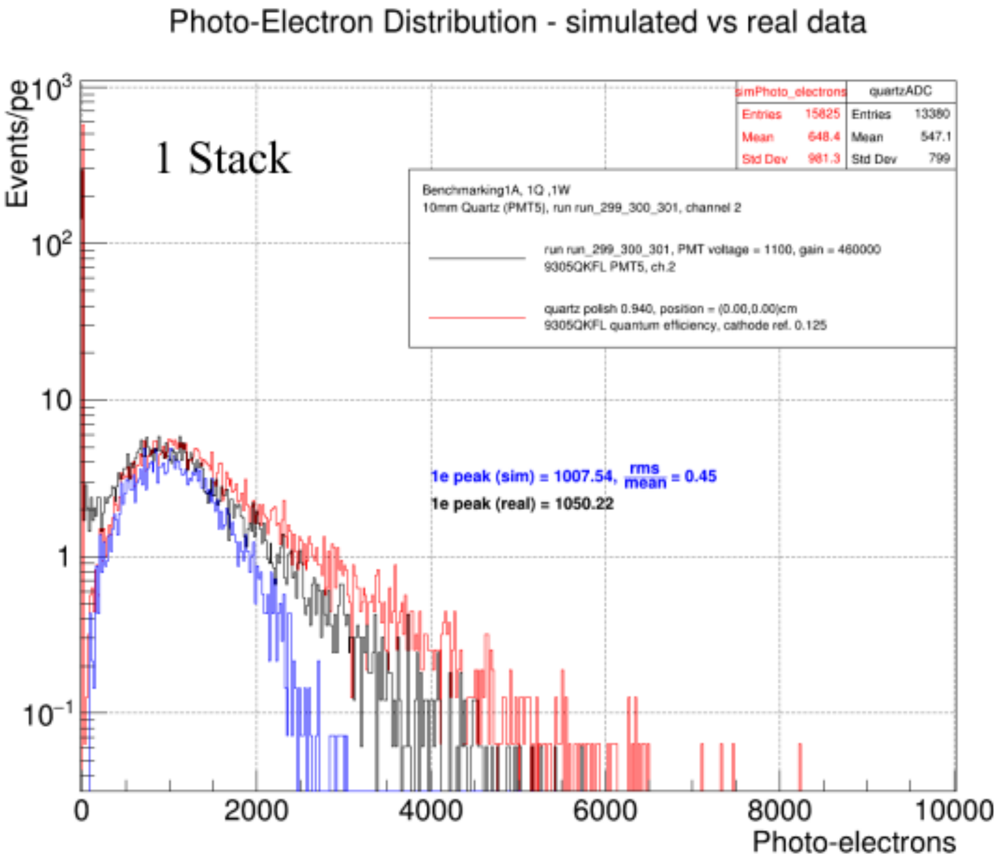

Benchmarking 1A: Full stack

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

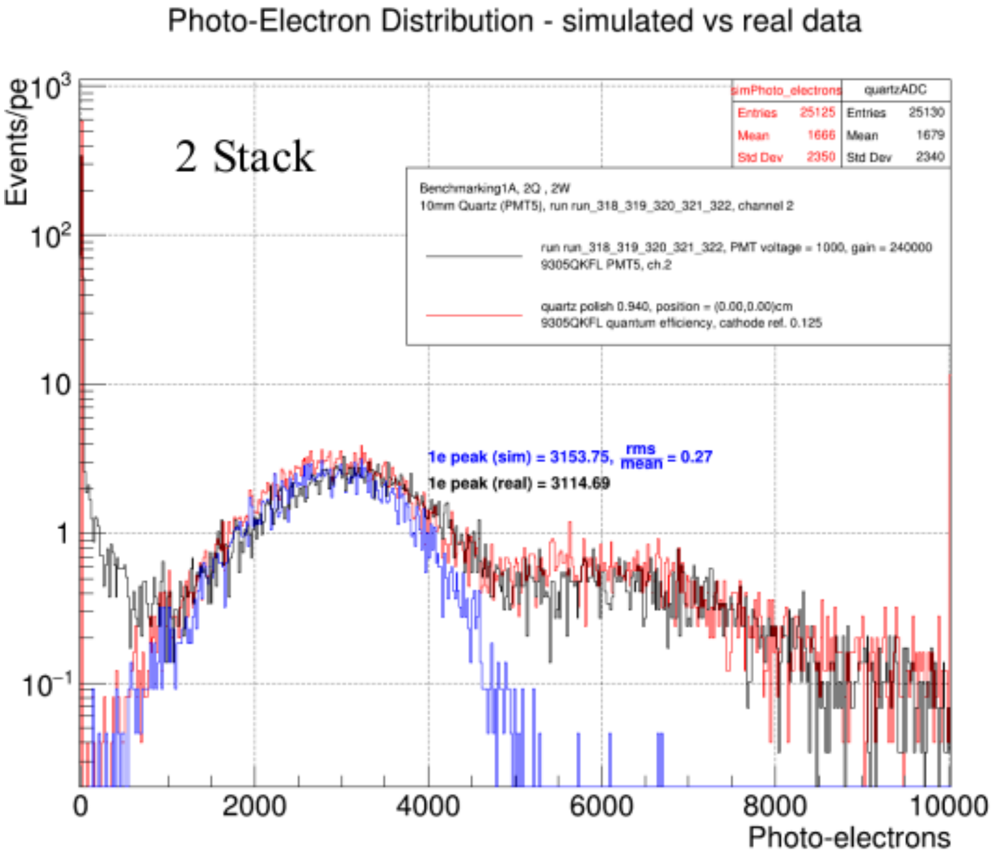
Benchmarking 1A testbeam results compared with simulation (5.5 GeV electron response vs. stack layers)

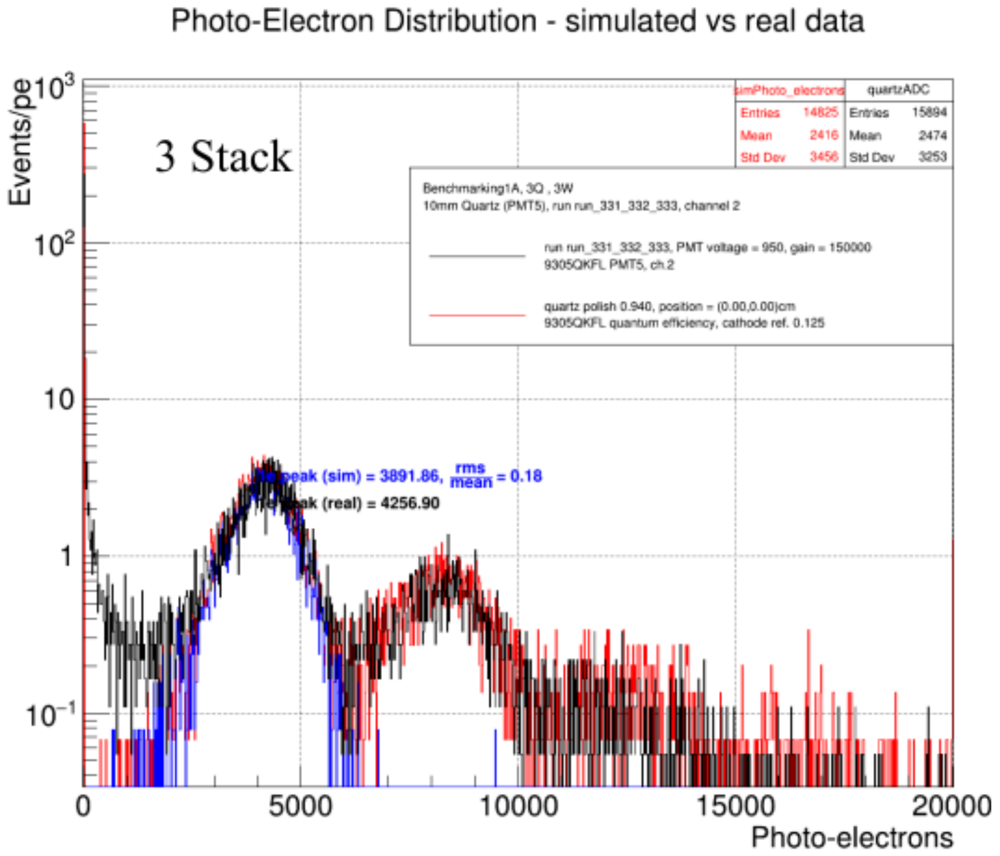




- Single quartz data used to benchmark quartz optical polish parameter
- With quartz polish calibrated, simulations performed with successively more stack layers and compared with SLAC data

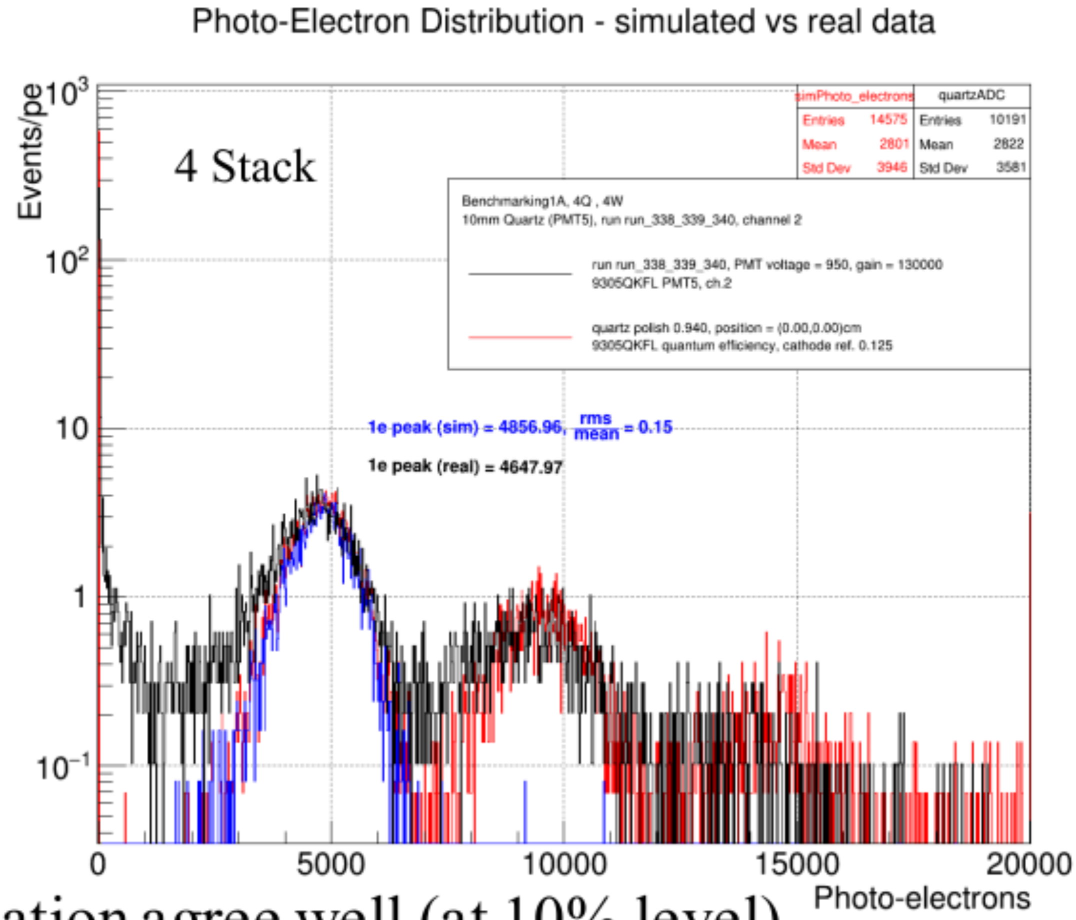
Benchmarking 1A testbeam results compared with simulation (5.5 GeV electron response vs. stack layers)





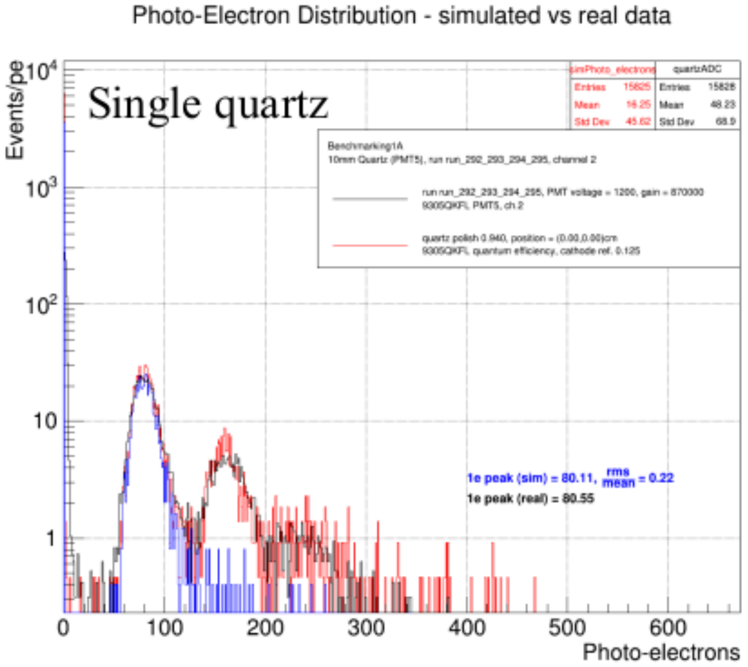
- Data and simulation agree well (at 10% level)
- Resolution of single electron photopeak goes from 27% to 18% (simulated)

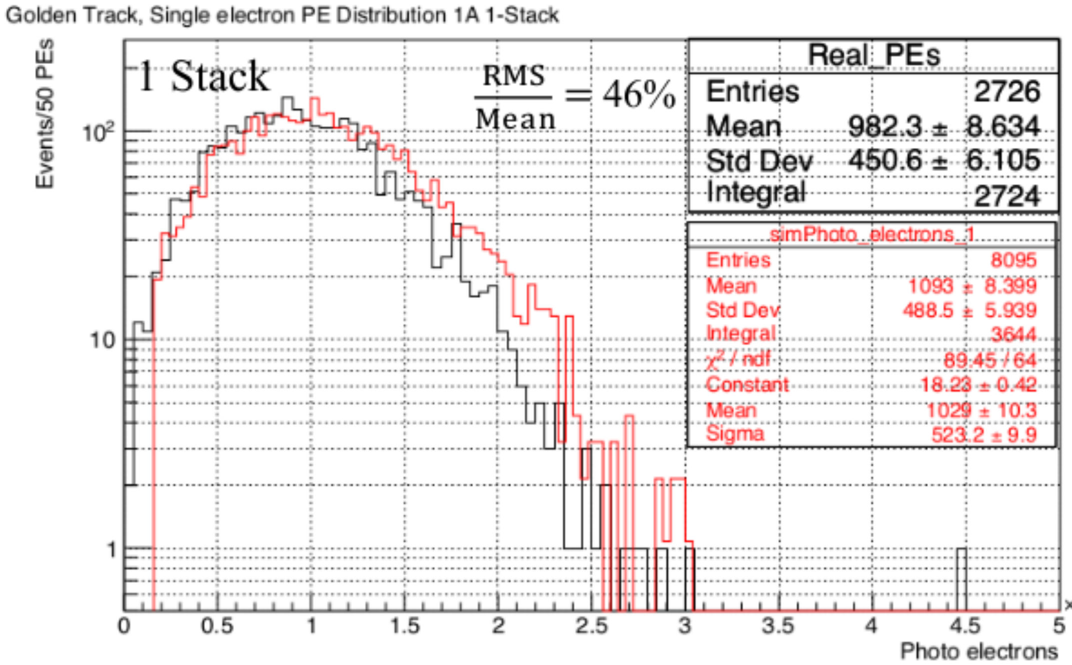
Benchmarking 1A testbeam results compared with simulation (5.5 GeV electron response vs. stack layers)



- Data and simulation agree well (at 10% level)
- Resolution of single electron photopeak is 15% (simulated). Analysis of real data resolutions are on-going using GEM tracking data

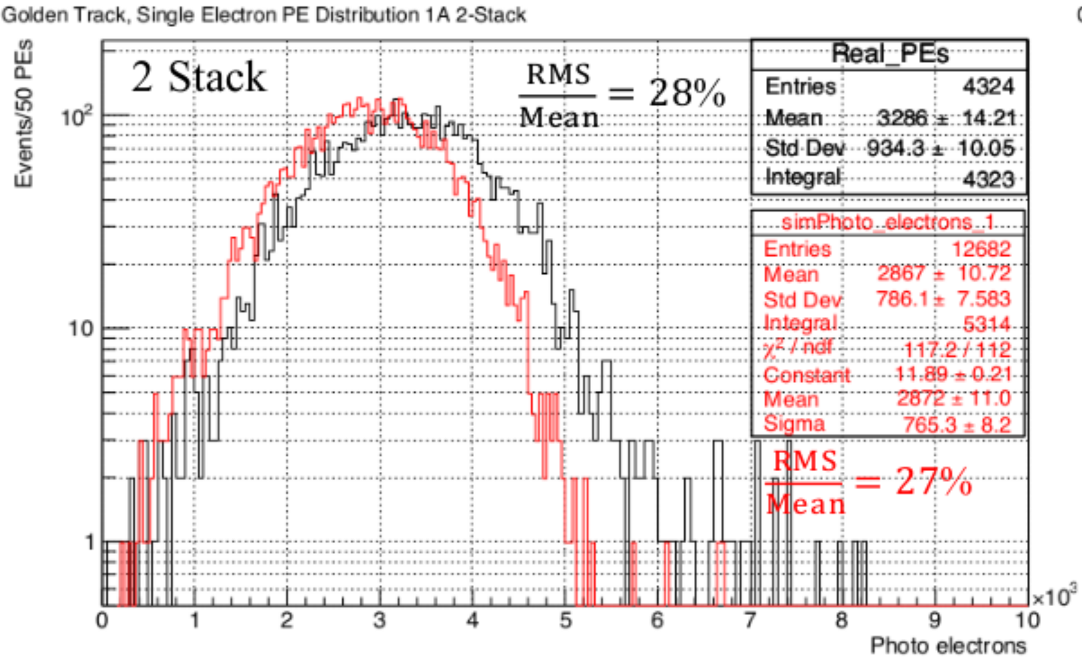
Benchmarking 1A Golden Track, single e^- data compared with simulation (5.5 GeV electron response vs. stack layers)

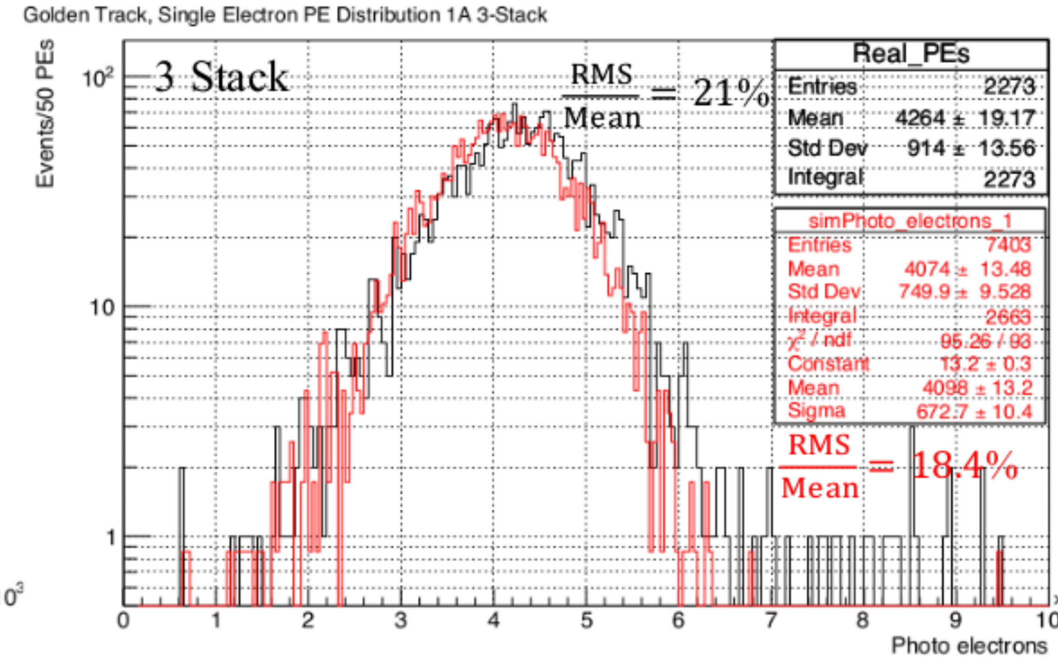




- Note that polish parameter was decreased from 0.98 (PREX)to 0.94 (4% decrease)
- Simulation uses state of the art understanding of optical properties of active material including attenuation and dispersion inside quartz and pmt window, reflectivity at air-pmt window interface & photocathode, and factory QE of photocathode
- Note: All comparisons and polish benchmarking rely on knowing operational pmt gain (5 – 10% uncertainty (as well as QDC charge sensitivity))

Benchmarking 1A Golden Track, single e^- data compared with simulation (5.5 GeV electron response vs. stack layers)



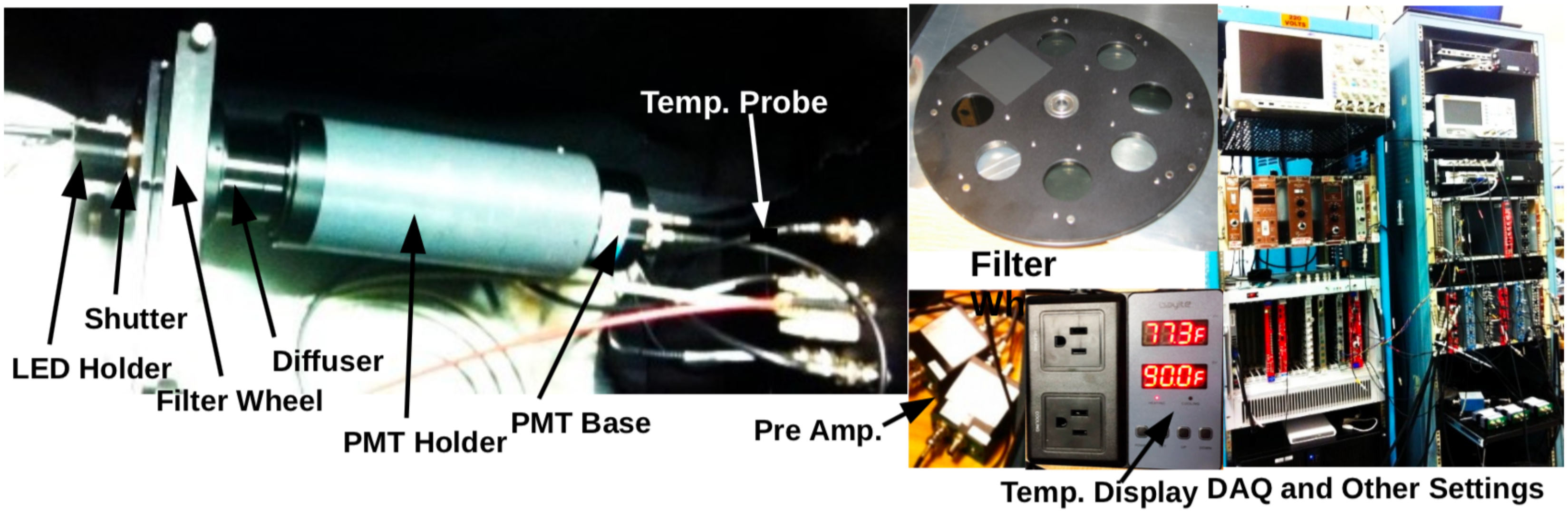


- Data and simulations agree at 10% level
- Data shows larger high-light tails indicating potential mis-identified single e^- tracks
- Resolutions get steadily better and agree well with simulated distributions
  --This tells us there was good alignment and minimal lateral shower leakage

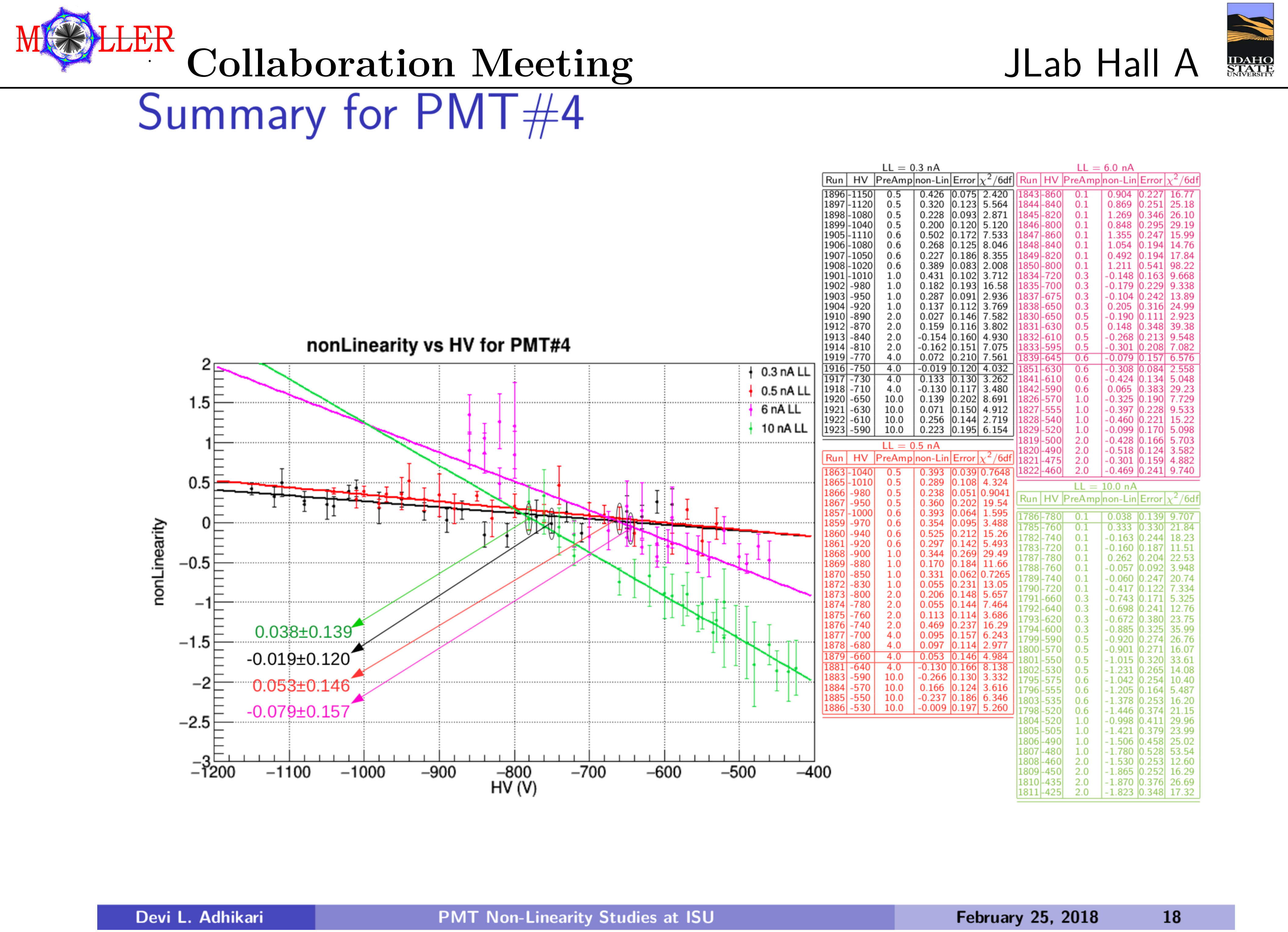
Summary and future work

- Showermax baseline prototypes constructed and tested
  - Analyses of testbeam data still ongoing but converging fast
  - Preliminary results for benchmarking prototypes in good agreement with simulations
  - Full-scale results and uniformity scans still in progress
- First results for full-scale tests show significant difference between data and sims–PE yields ∼2.5x lower than expected; likely culprit is light guide but could also include broken TIR–due to excessive pressure on Kapton quartz wrapping
- Shower-max detector design and cost is firm: possible cost reductions – use 90/10 W/Cu alloy, thinner quartz bars (marginal saving), PMTs are already one of least expensive options

Linearity Test Box And Integrating DAQ



- LED Holder → holds two LEDs, each with 2 mm diameter collimation
- Electronic Shutter → has now been connected with a relay to turn it “ON” and “OFF” automatically at any interval with computer script
- Filter Wheel → Computer Controlled Edmund Optics’ Absorptive ND filters (400-700 nm) with 8 (100, 79, 63, 50, 40, 25, 10, 1)% transmission settings (~randomly ordered)
- Filter Wheel is now controlled automatically using a shell script
- UV Diffuser → Edmund Optics’ ground fused silica
- PMT Holder → 2” PMT with modified base for improved linearity
- Different pre-Amp settings with different resistances and offsets tested (MAIN, LUMI, KDPA, and SNS)



MOLLER Collaboration Meeting

JLab Hall A

Summary for PMT#4

LL = 0.3 nA

Run	HV	PreAmp	non-Lin	Error	χ^2/6df
1896	-1150	0.5	0.426	0.075	2.420
1897	-1120	0.5	0.320	0.123	5.564
1898	-1080	0.5	0.228	0.093	2.871
1899	-1040	0.5	0.200	0.120	5.120
1905	-1110	0.6	0.502	0.172	7.533
1906	-1080	0.6	0.268	0.125	8.046
1907	-1050	0.6	0.227	0.186	8.355
1908	-1020	0.6	0.389	0.083	2.008
1901	-1010	1.0	0.431	0.102	3.712
1902	-980	1.0	0.182	0.193	16.58
1903	-950	1.0	0.287	0.091	2.936
1904	-920	1.0	0.137	0.112	3.769
1910	-890	2.0	0.027	0.146	7.582
1912	-870	2.0	0.159	0.116	3.802
1913	-840	2.0	-0.154	0.160	4.930
1914	-810	2.0	-0.162	0.151	7.075
1919	-770	4.0	0.072	0.210	7.561
1916	-750	4.0	-0.019	0.120	4.032
1917	-730	4.0	0.133	0.130	3.262
1918	-710	4.0	-0.130	0.117	3.480
1920	-650	10.0	0.139	0.202	8.691
1921	-630	10.0	0.071	0.150	4.912
1922	-610	10.0	0.256	0.144	2.719
1923	-590	10.0	0.223	0.195	6.154

LL = 0.5 nA

Run	HV	PreAmp	non-Lin	Error	χ^2/6df
1863	-1040	0.5	0.393	0.039	0.7648
1865	-1010	0.5	0.289	0.108	4.324
1866	-980	0.5	0.238	0.051	0.9041
1867	-950	0.5	0.360	0.202	19.54
1857	-1000	0.6	0.393	0.064	1.595
1859	-970	0.6	0.354	0.095	3.488
1860	-940	0.6	0.525	0.212	15.26
1861	-920	0.6	0.297	0.142	5.493
1868	-900	1.0	0.344	0.269	29.49
1869	-880	1.0	0.170	0.184	11.66
1870	-850	1.0	0.331	0.062	0.7265
1872	-830	1.0	0.055	0.231	13.05
1873	-800	2.0	0.206	0.148	5.657
1874	-780	2.0	0.055	0.144	7.464
1875	-760	2.0	0.113	0.114	3.686
1876	-740	2.0	0.469	0.237	16.29
1877	-700	4.0	0.095	0.157	6.243
1878	-680	4.0	0.097	0.114	2.977
1879	-660	4.0	0.053	0.146	4.984
1881	-640	4.0	-0.130	0.166	8.138
1883	-590	10.0	-0.266	0.130	3.332
1884	-570	10.0	0.166	0.124	3.616
1885	-550	10.0	-0.237	0.186	6.346
1886	-530	10.0	-0.009	0.197	5.260

LL = 6.0 nA

Run	HV	PreAmp	non-Lin	Error	χ^2/6df
1843	-860	0.1	0.904	0.227	16.77
1844	-840	0.1	0.869	0.251	25.18
1845	-820	0.1	1.269	0.346	26.10
1846	-800	0.1	0.848	0.295	29.19
1847	-860	0.1	1.355	0.247	15.99
1848	-840	0.1	1.054	0.194	14.76
1849	-820	0.1	0.492	0.194	17.84
1850	-800	0.1	1.211	0.541	98.22
1834	-720	0.3	-0.148	0.163	9.668
1835	-700	0.3	-0.179	0.229	9.338
1837	-675	0.3	-0.104	0.242	13.89
1838	-650	0.3	0.205	0.316	24.99
1830	-650	0.5	-0.190	0.111	2.923
1831	-630	0.5	0.148	0.348	39.38
1832	-610	0.5	-0.268	0.213	9.548
1833	-595	0.5	-0.301	0.208	7.082
1839	-645	0.6	-0.079	0.157	6.576
1851	-630	0.6	-0.308	0.084	2.558
1841	-610	0.6	-0.424	0.134	5.048
1842	-590	0.6	0.065	0.383	29.23
1826	-570	1.0	-0.325	0.190	7.729
1827	-555	1.0	-0.397	0.228	9.533
1828	-540	1.0	-0.460	0.221	15.22
1829	-520	1.0	-0.099	0.170	5.098
1819	-500	2.0	-0.428	0.166	5.703
1820	-490	2.0	-0.518	0.124	3.582
1821	-475	2.0	-0.301	0.159	4.882
1822	-460	2.0	-0.469	0.241	9.740

LL = 10.0 nA

Run	HV	PreAmp	non-Lin	Error	χ^2/6df
1786	-780	0.1	0.038	0.139	9.707
1785	-760	0.1	0.333	0.330	21.84
1782	-740	0.1	-0.163	0.244	18.23
1783	-720	0.1	-0.160	0.187	11.51
1787	-780	0.1	0.262	0.204	22.53
1788	-760	0.1	-0.057	0.092	3.948
1789	-740	0.1	-0.060	0.247	20.74
1790	-720	0.1	-0.417	0.122	7.334
1791	-660	0.3	-0.743	0.171	5.325
1792	-640	0.3	-0.698	0.241	12.76
1793	-620	0.3	-0.672	0.380	23.75
1794	-600	0.3	-0.885	0.325	35.99
1799	-590	0.5	-0.920	0.274	26.76
1800	-570	0.5	-0.901	0.271	16.07
1801	-550	0.5	-1.015	0.320	33.61
1802	-530	0.5	-1.231	0.265	14.08
1795	-575	0.6	-1.042	0.254	10.40
1796	-555	0.6	-1.205	0.164	5.487
1803	-535	0.6	-1.378	0.253	16.20
1798	-520	0.6	-1.446	0.374	21.15
1804	-520	1.0	-0.998	0.411	29.96
1805	-505	1.0	-1.421	0.379	23.99
1806	-490	1.0	-1.506	0.458	25.02
1807	-480	1.0	-1.780	0.528	53.54
1808	-460	2.0	-1.530	0.253	12.60
1809	-450	2.0	-1.865	0.252	16.29
1810	-435	2.0	-1.870	0.376	26.69
1811	-425	2.0	-1.823	0.348	17.32

Devi L. Adhikari | PMT Non-Linearity Studies at ISU | February 25, 2018 | 18

Plans for MOLLER pmt Linearity Measurements

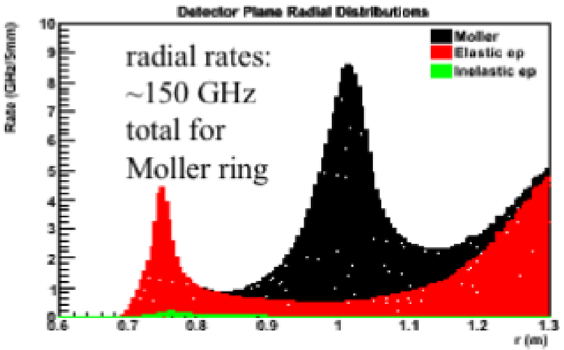
- Apparatus and technique validated for PREX pmts at 240 Hz ff
  - Conclusion: want pmt $I_C \lesssim 15$nA and $I_A \sim 20$ - 30 μA
  - Anticipate $< 0.5\%$ non-linearity systematic for PREX-II and even better for CREX
  - Measurements routinely find HV and preamp settings with non-linearity deviations at 0.1 - 0.2% level
- While 30, 120, and 240 Hz ff data give very similar/same results, we see differences at 480 Hz ff–possibly a result of thermal or other instabilities in the flashing LED
- To address expected problems at 960 Hz ff, we plan to implement a chopper wheel setup with phase-locked controller to shutter the LED instead of flash it (M. Gericke's idea)

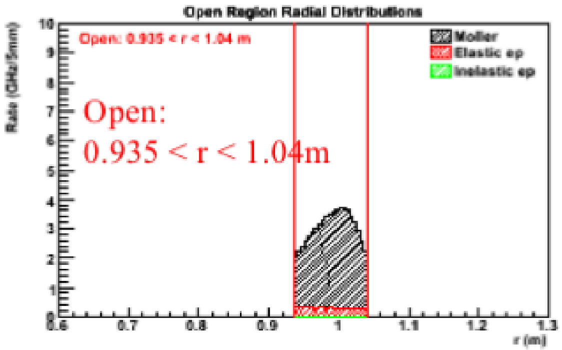
Plans for MOLLER pmt Linearity Measurements

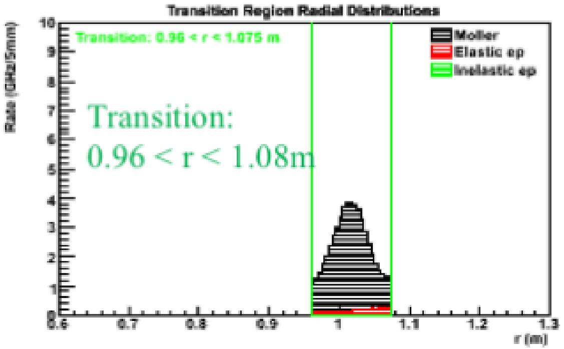
- ISU group has two ET 9305KQB pmts with factory bases in hand to start testing this fall
  - Anticipated light levels or PE (I_C) currents for central-open ring5 pmts at ∼16 nA (∼4 GHz, ∼25 PEs/e^-)
  - Will require custom tuned base divider to achieve desired 0.1% non-linearity
  - M. Gericke and group will design bases for future tests; for now, two different factory bases were purchased: one standard circuit and one tapered (for high pulsed linearity)
- A non-trivial complication for precision measurements is calibrating the incident light level or photocathode current. We use special unity gain bases for PREX/CREX; need this for MOLLER

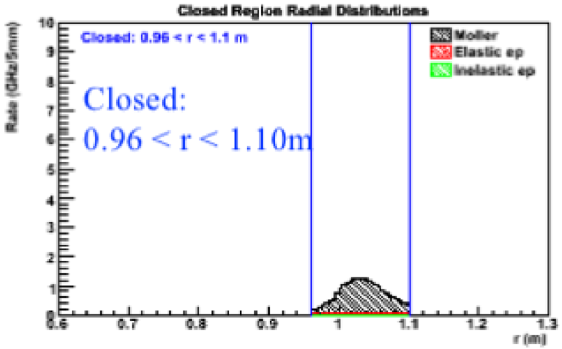
Backup Slides

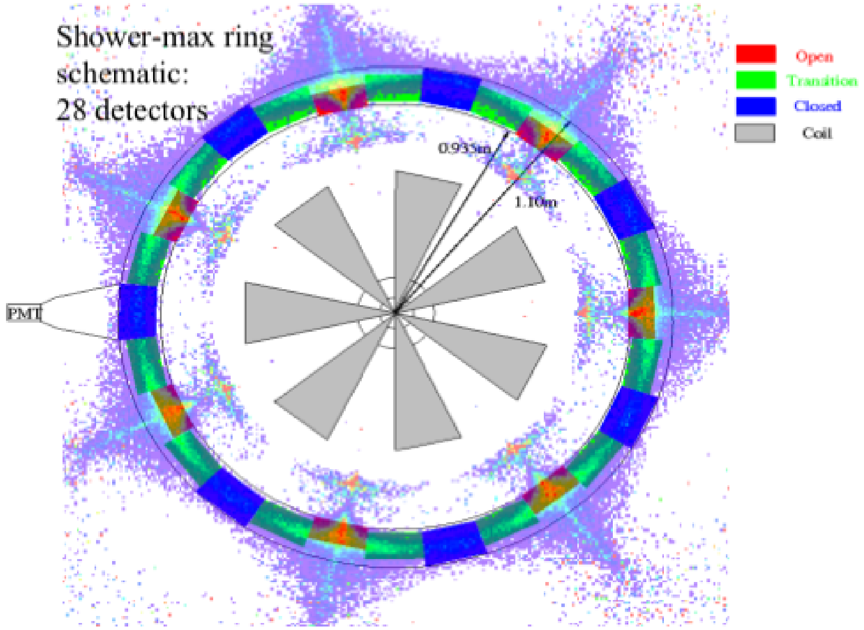
Shower-max phi-segmentation, rates and energies



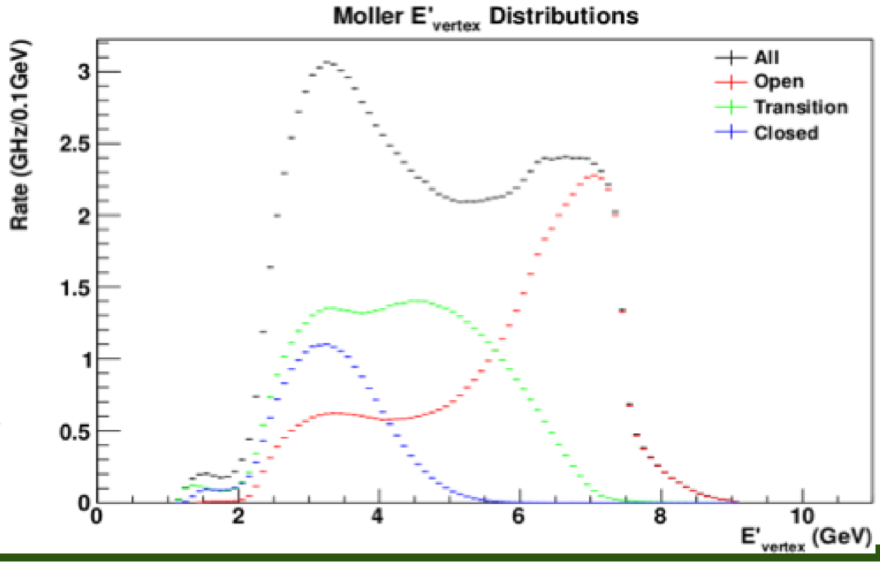








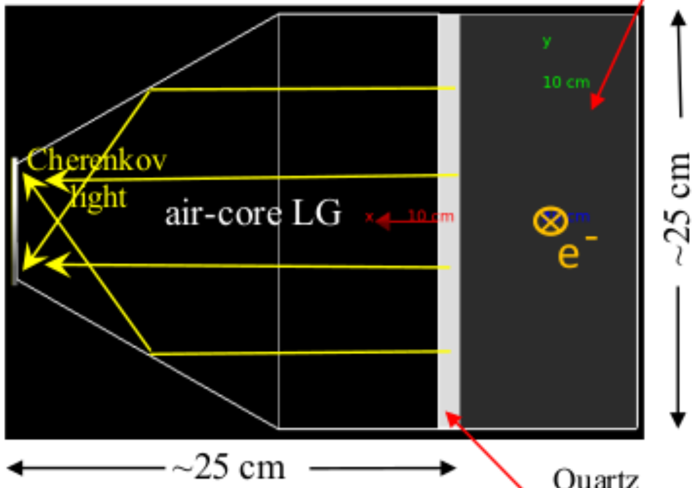
- Large range of rates and energies for different phi-region detectors:
  - Open ~9 GHz/det; 2 - 9 GeV, peak at 7 GeV…
  - Closed ~3.5 GHz/det; 2 - 5 GeV, peak at ~3 GeV
  - Transition ~4.5 GHz/det; 2 - 7 GeV, 3 – 5 GeV plateau



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**

“Baseline” LG Design
(front face view)



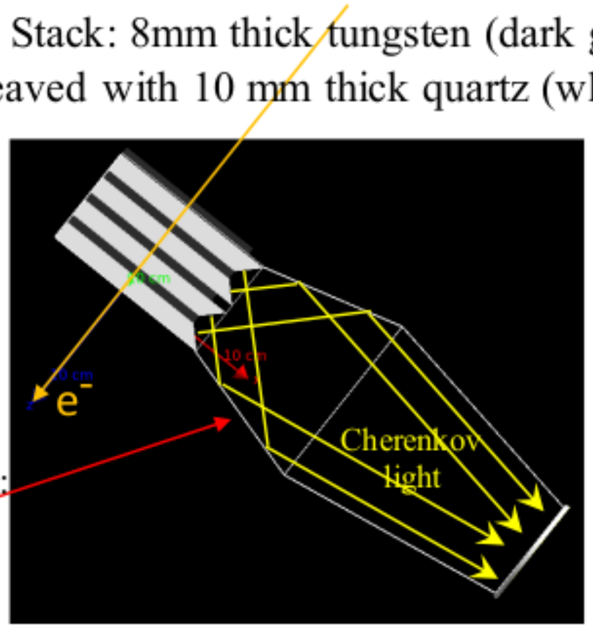
3inch PMT

tungsten: 1st upstream piece (dark grey)

Quartz bevel

4-layer Stack: 8mm thick tungsten (dark grey), interleaved with 10 mm thick quartz (white)

alternating quartz bevel design



single-bounce mirror: “funnel” angle and length optimized

“Baseline” Design
(side view)

Materials (all rad-hard):

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

Quartz and Tungsten Ordered in Nov 2017

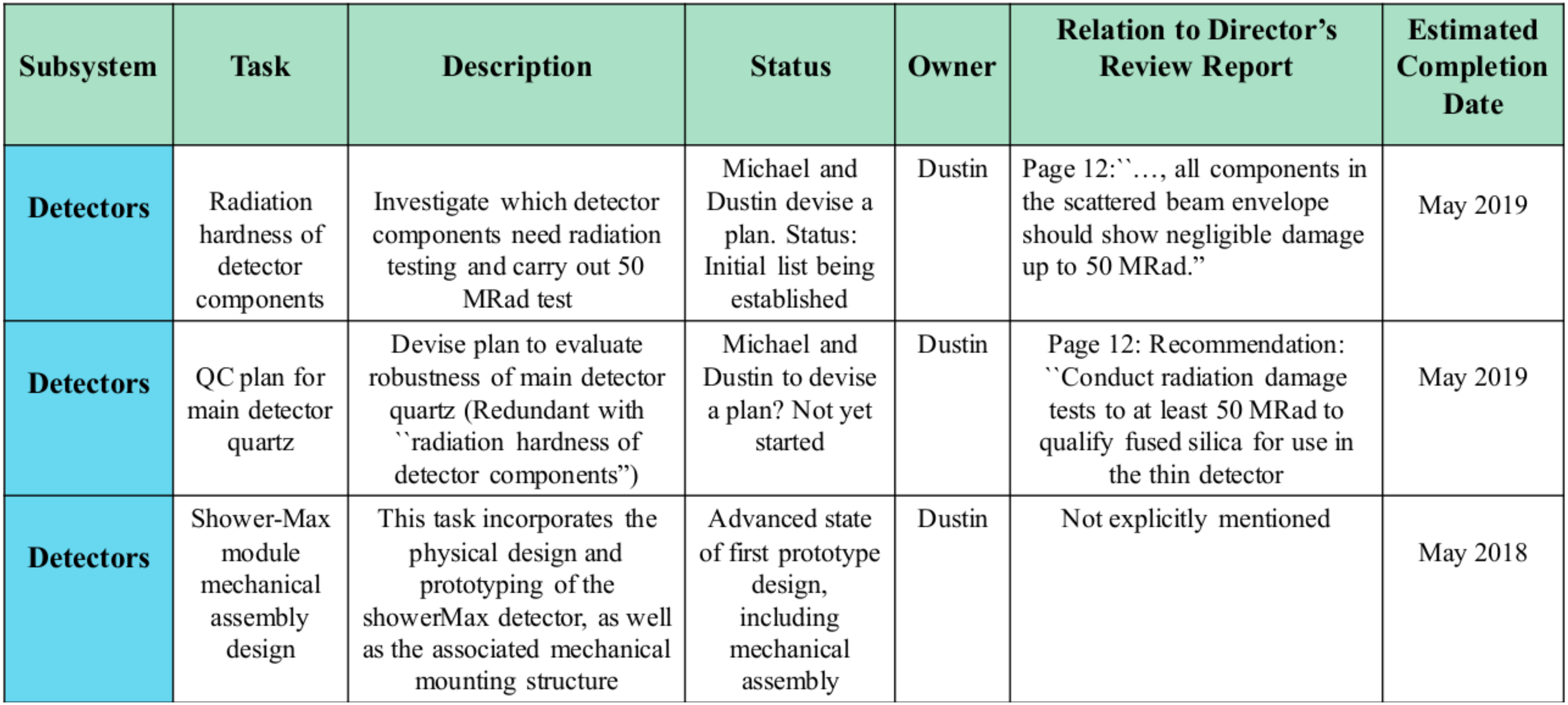
- For “benchmarking” prototype stack:
  - Quartz: 6 mm (thick) by 86 mm (tall) by 40 mm (wide) --4 pieces ($975/piece = $3.9k)
  - Quartz: 10 mm (thick) by 90 mm (tall) by 40 mm (wide) --4 pieces ($1005/piece = $4.0k)
  - Tungsten: 6 mm (thick) by 80 mm (tall) by 40 mm (wide) – 4 pieces ($85/piece =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

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

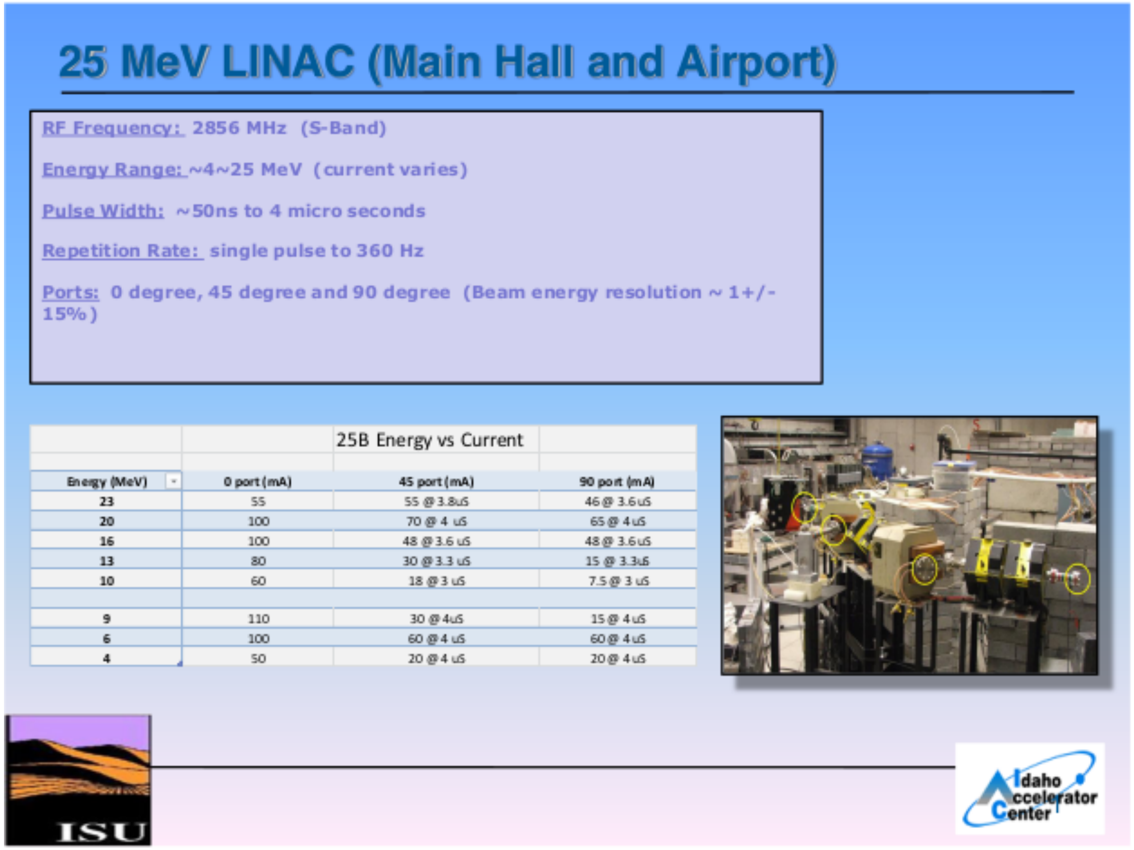
Radiation Hardness Test plan Update

- 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 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)

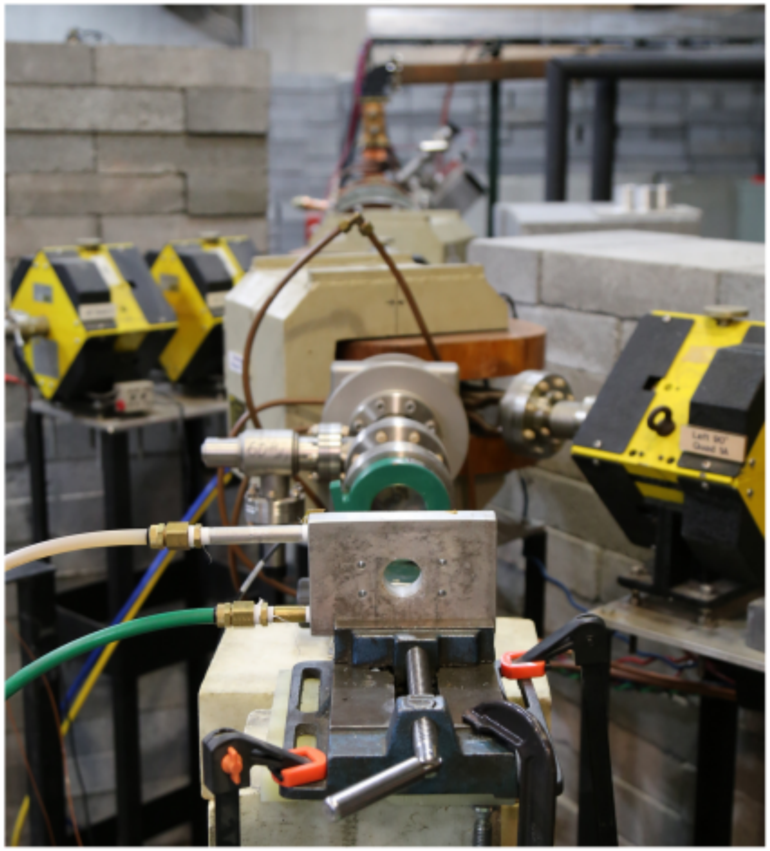
Pulse Width: ~50ns to 4 micro seconds

Repetition Rate: single pulse to 360 Hz

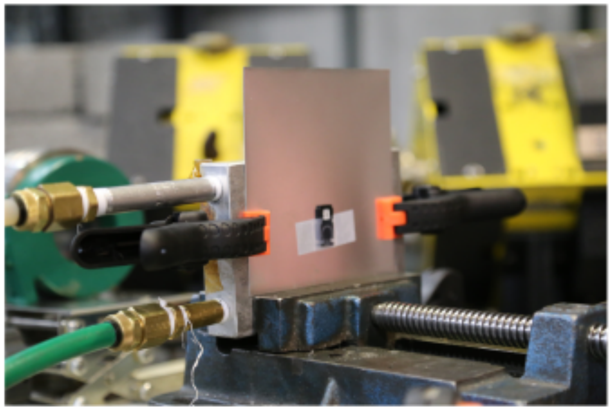
Ports: 0 degree, 45 degree and 90 degree (Beam energy resolution ~ 1+/-15%)

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



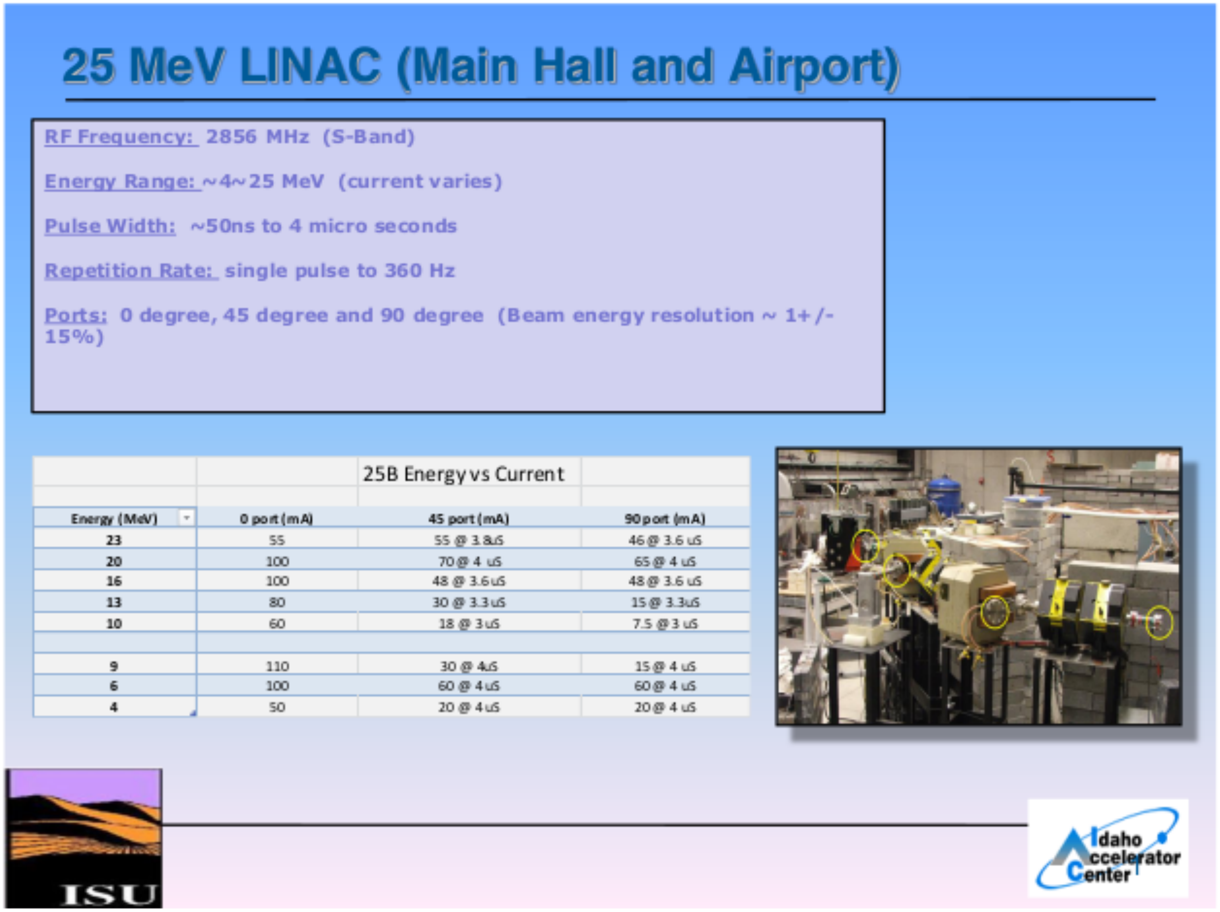
- The key issue is how well can we calibrate dose exposure?



- 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)

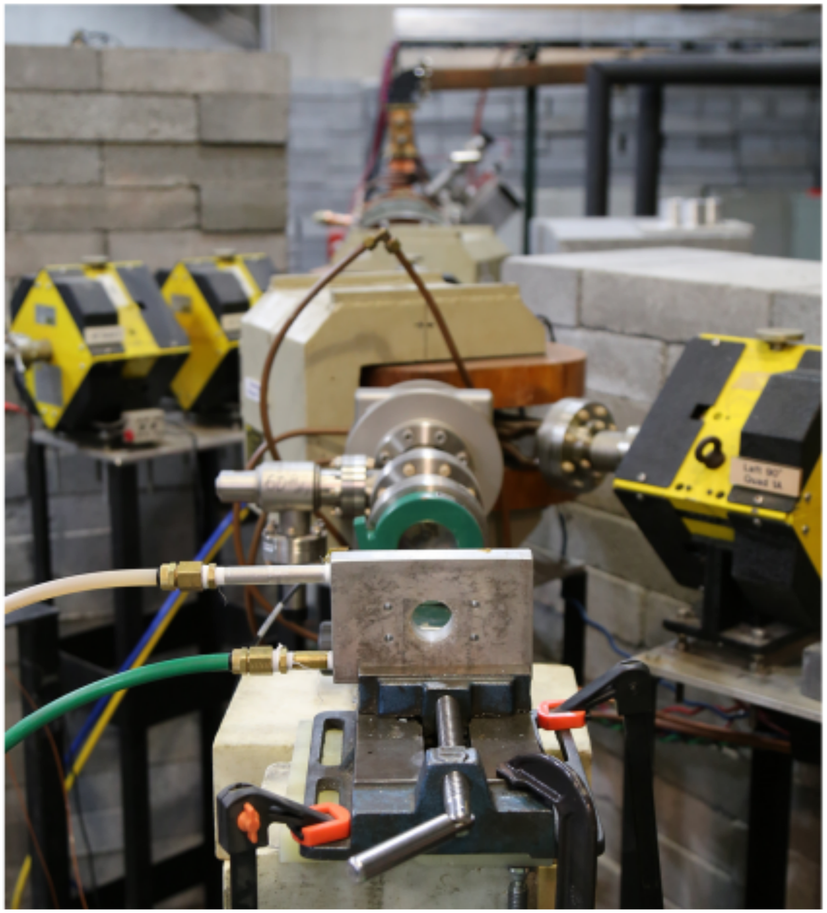
Pulse Width: ~50ns to 4 micro seconds

Repetition Rate: single pulse to 360 Hz

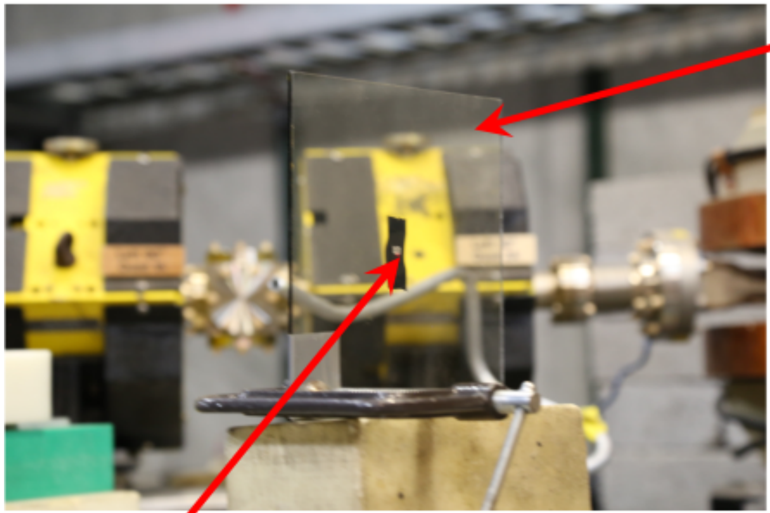
Ports: 0 degree, 45 degree and 90 degree (Beam energy resolution ~ 1+/-15%)

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 @ 3.6 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

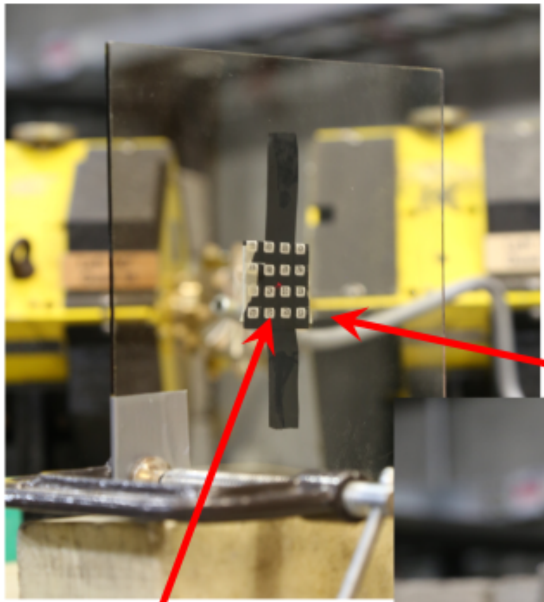


Beam Dose Exposure Rate Calibrations (May 2018)



Glass slide for spot profile measurements

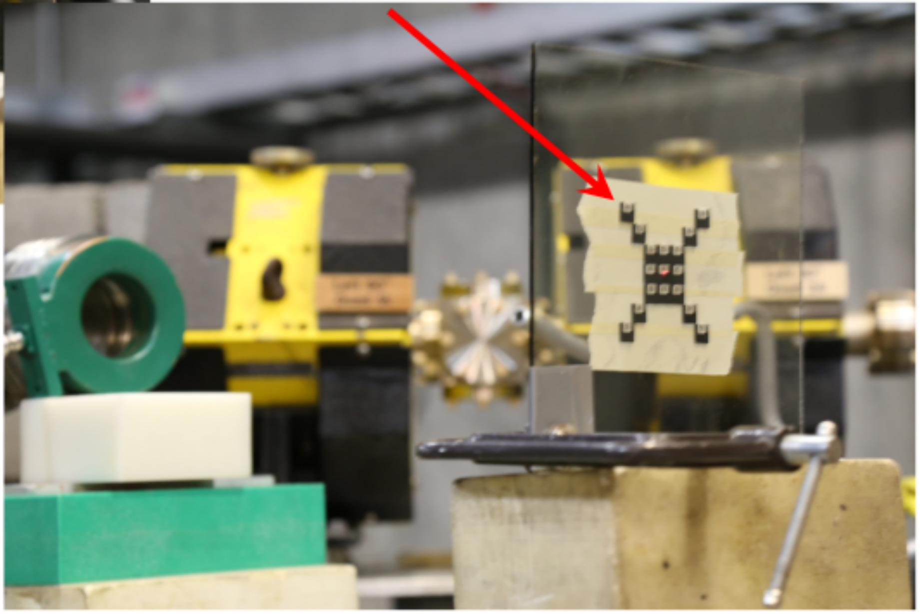
Optically Stimulated Luminescence (OSL) dosimeter (~ 7 mm by 7 mm square)



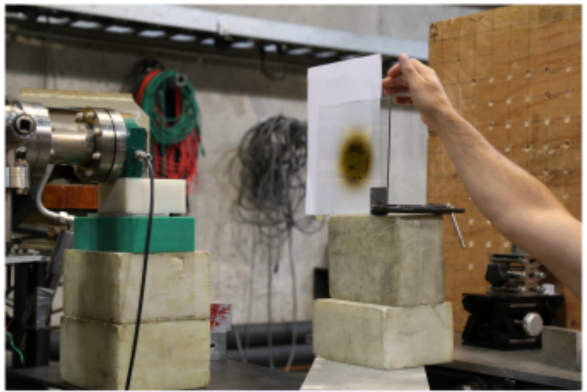
ISU MS degree student Connor Harper's thesis based on this work: https://www2.cose.isu.edu/~mcnudust/publication/studentWork/connorHarperThesis.pdf

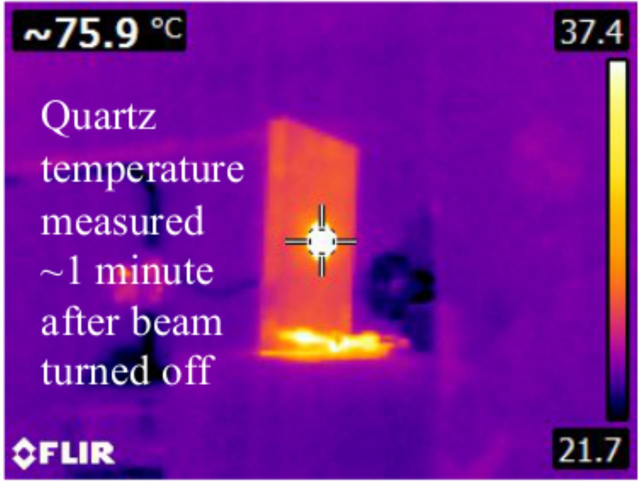
OSL arrays for dose profile measurements

Laser alignment



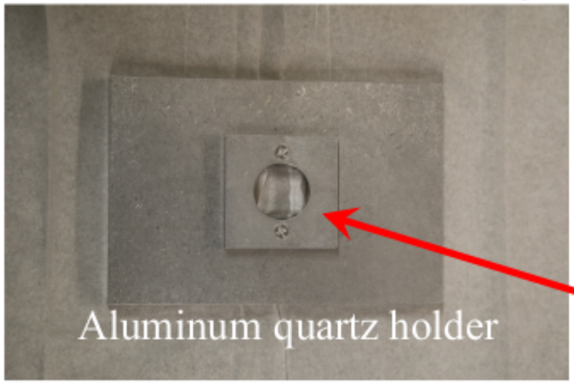
Quartz Irradiations (May 2018)



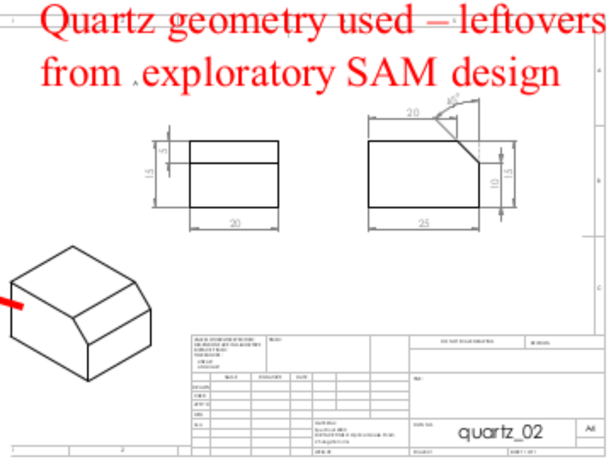


Quartz temperature measured ~1 minute after beam turned off

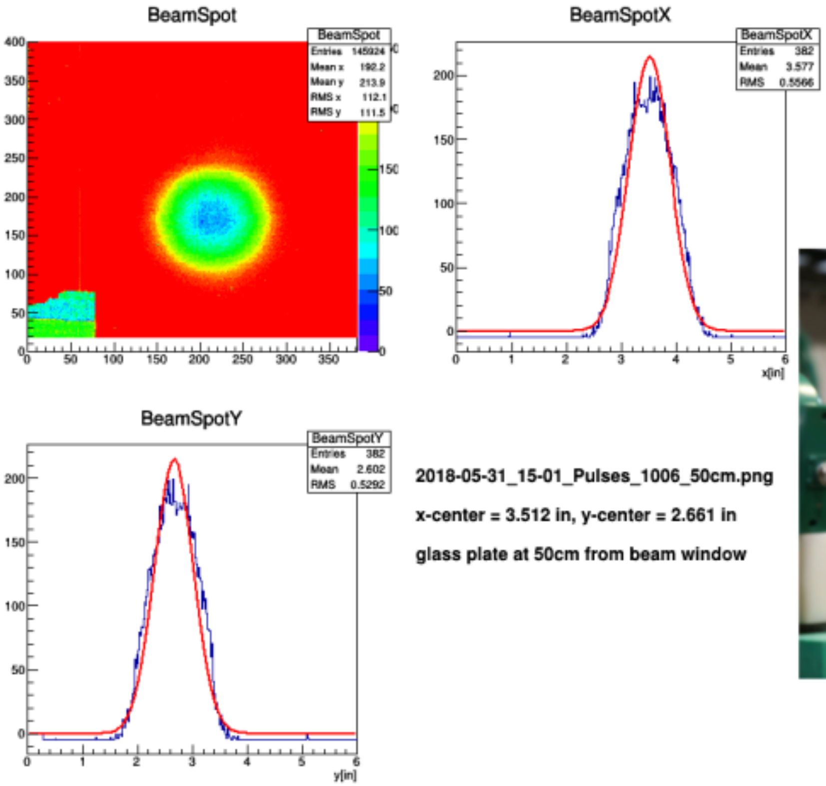
Bright Cerenkov light generation during irradiation



Aluminum quartz holder



Quartz geometry used – leftovers from exploratory SAM design

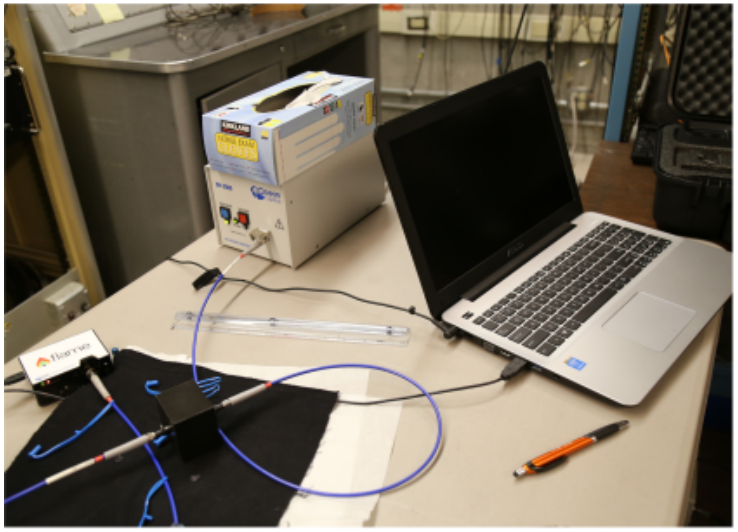


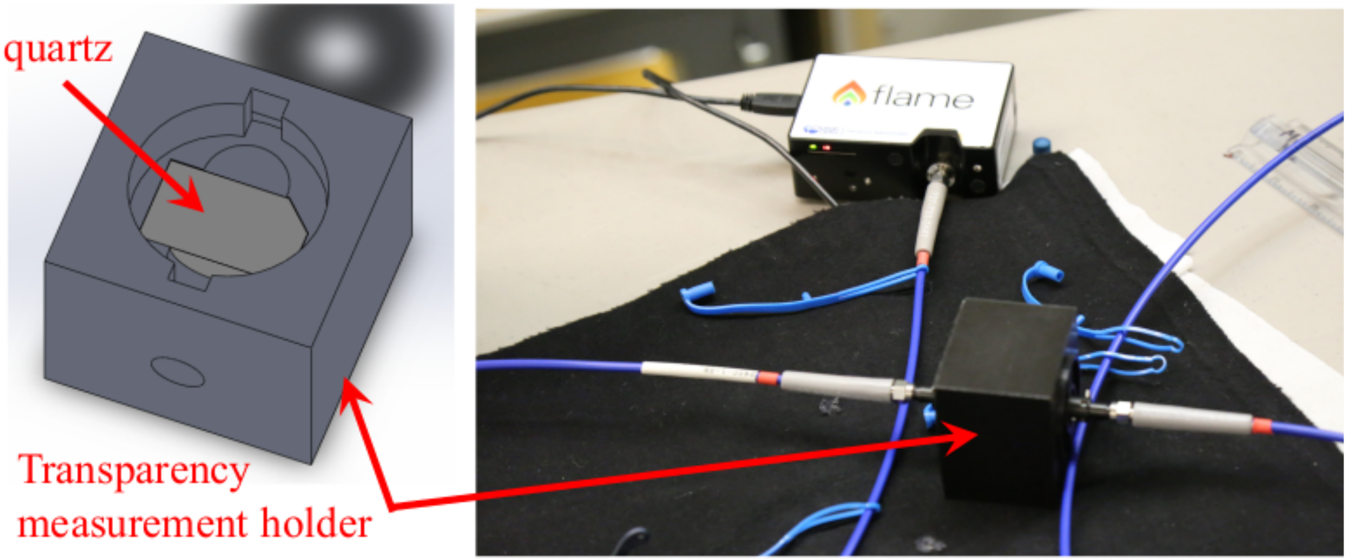
2018-05-31_15-01_Pulses_1006_50cm.png

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

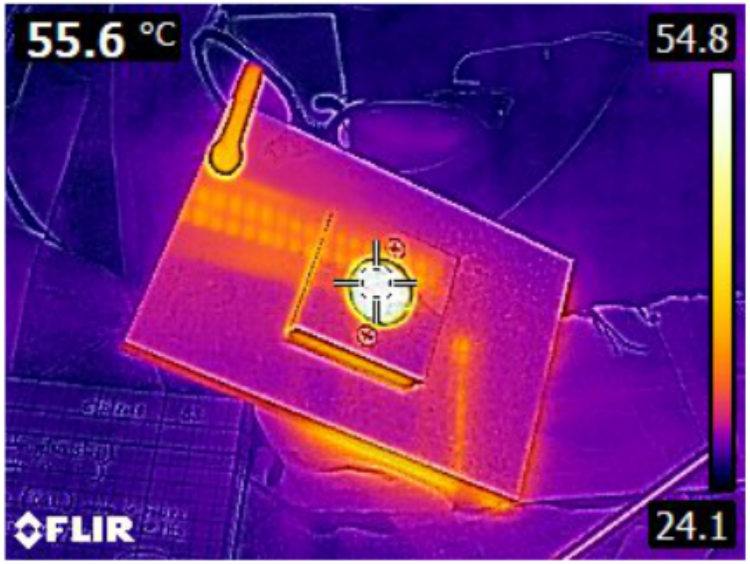
glass plate at 50cm from beam window

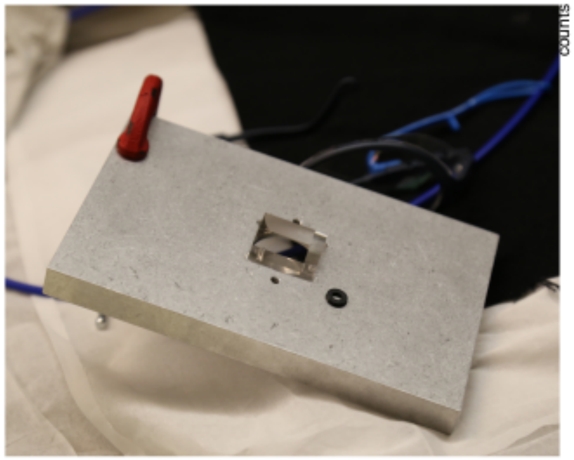
Quartz Transparency Measurements

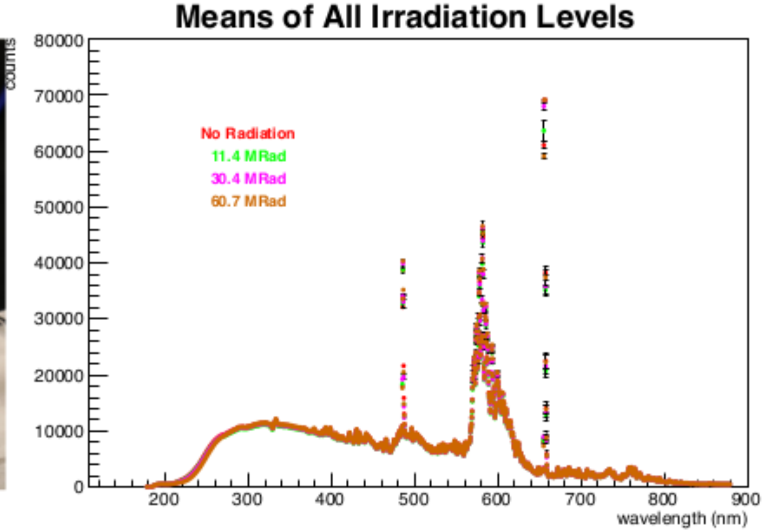



quartz

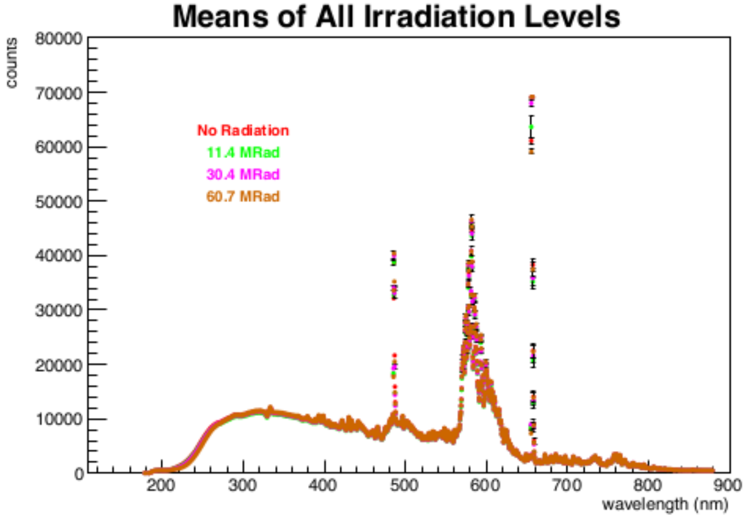
Transparency measurement holder



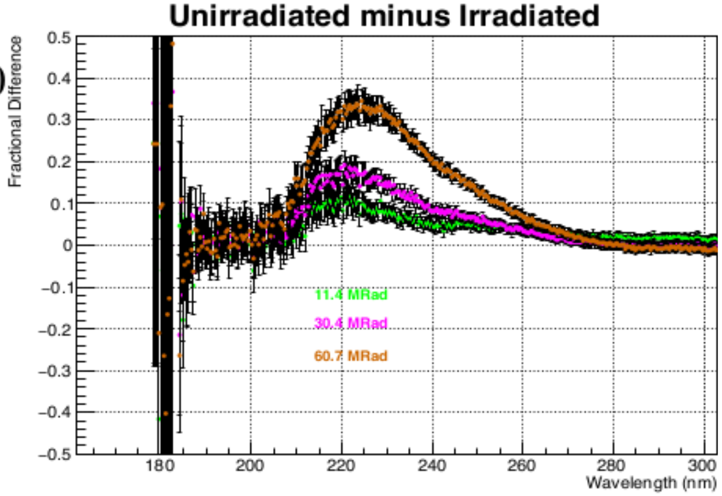


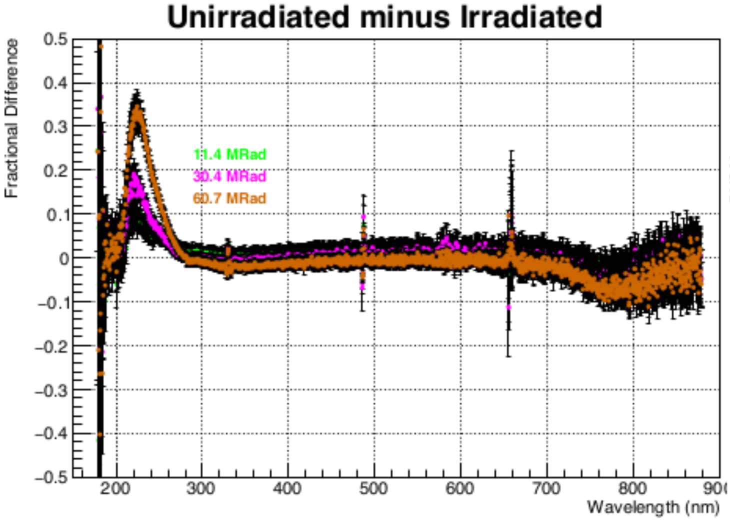


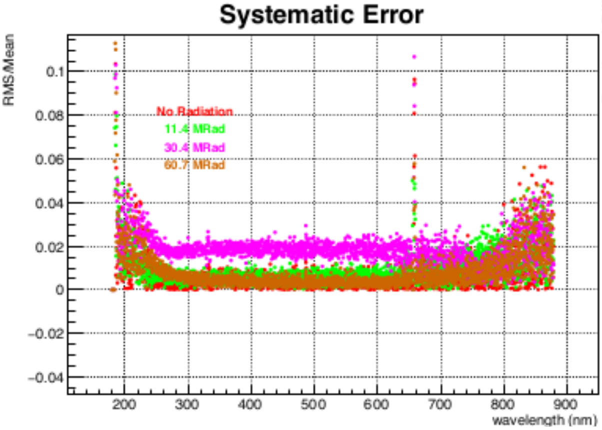
Quartz Transparency Preliminary Results

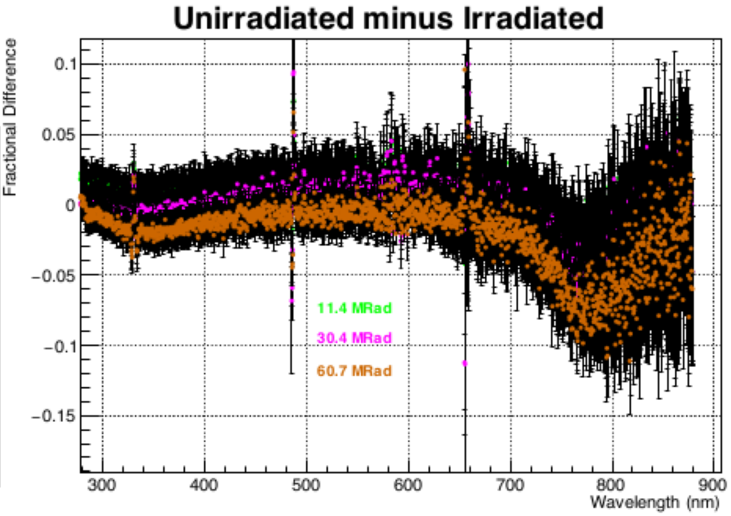

Means of All Irradiation Levels

- 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

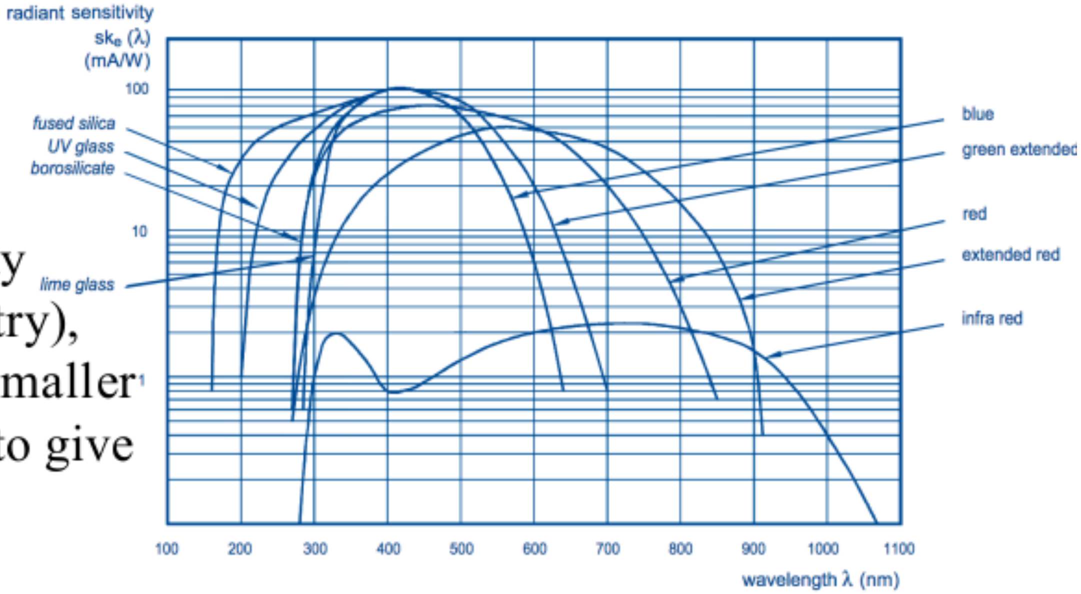


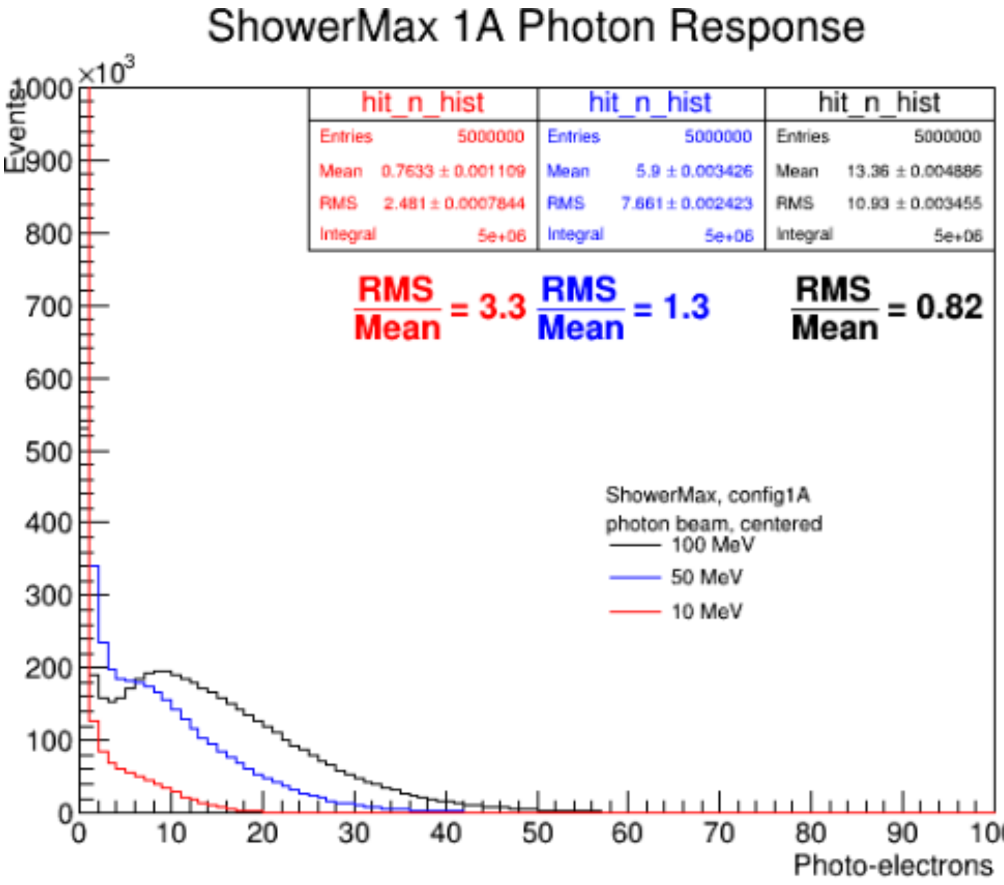
Fig.2 Typical spectral sensitivity characteristics of standard photocathodes with associated window materials.

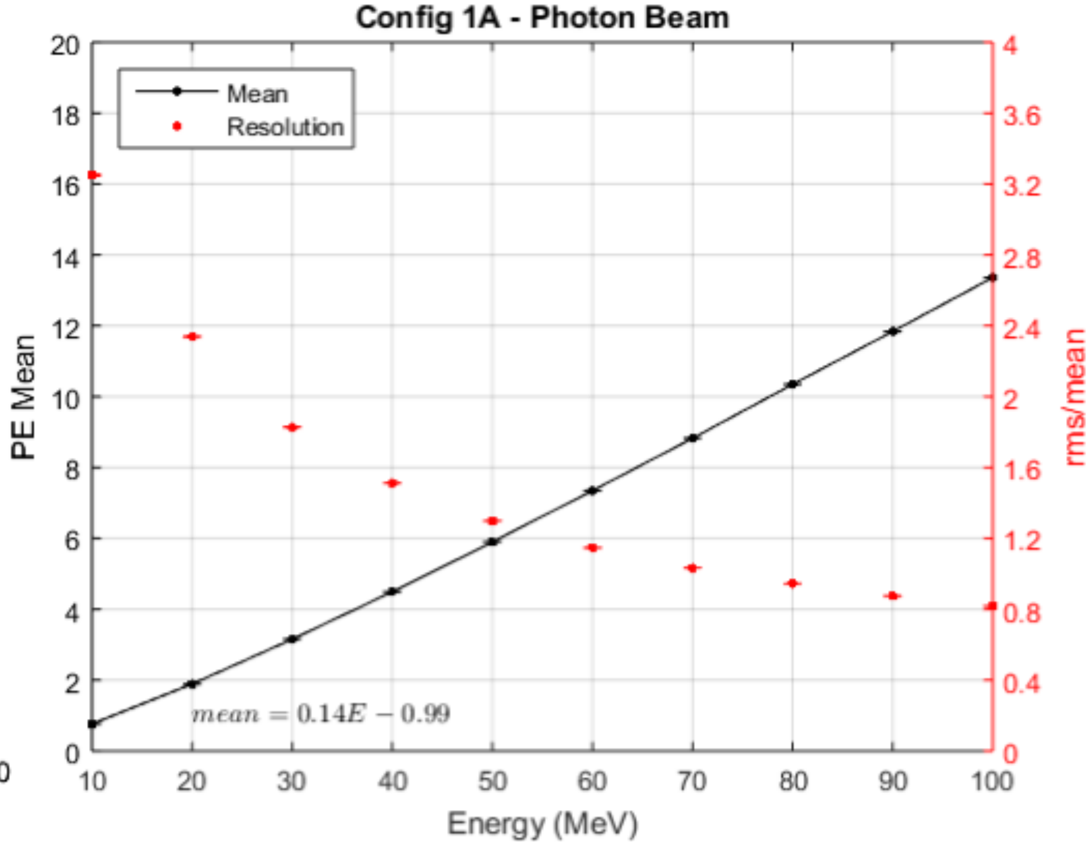
$$\mathrm{QE}\ (\%) \simeq \frac{124}{\lambda(\mathrm{nm})} \times \text{radiant sensitivity (mA/W)}$$

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)





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

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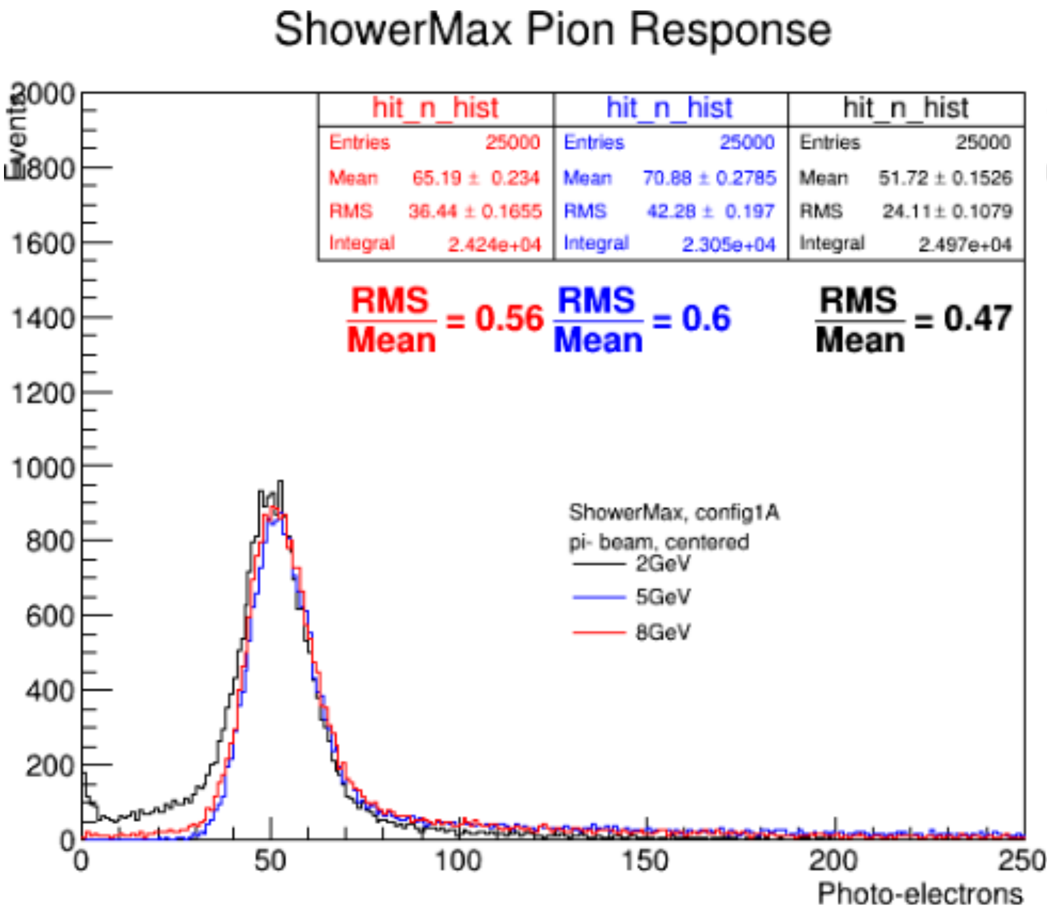
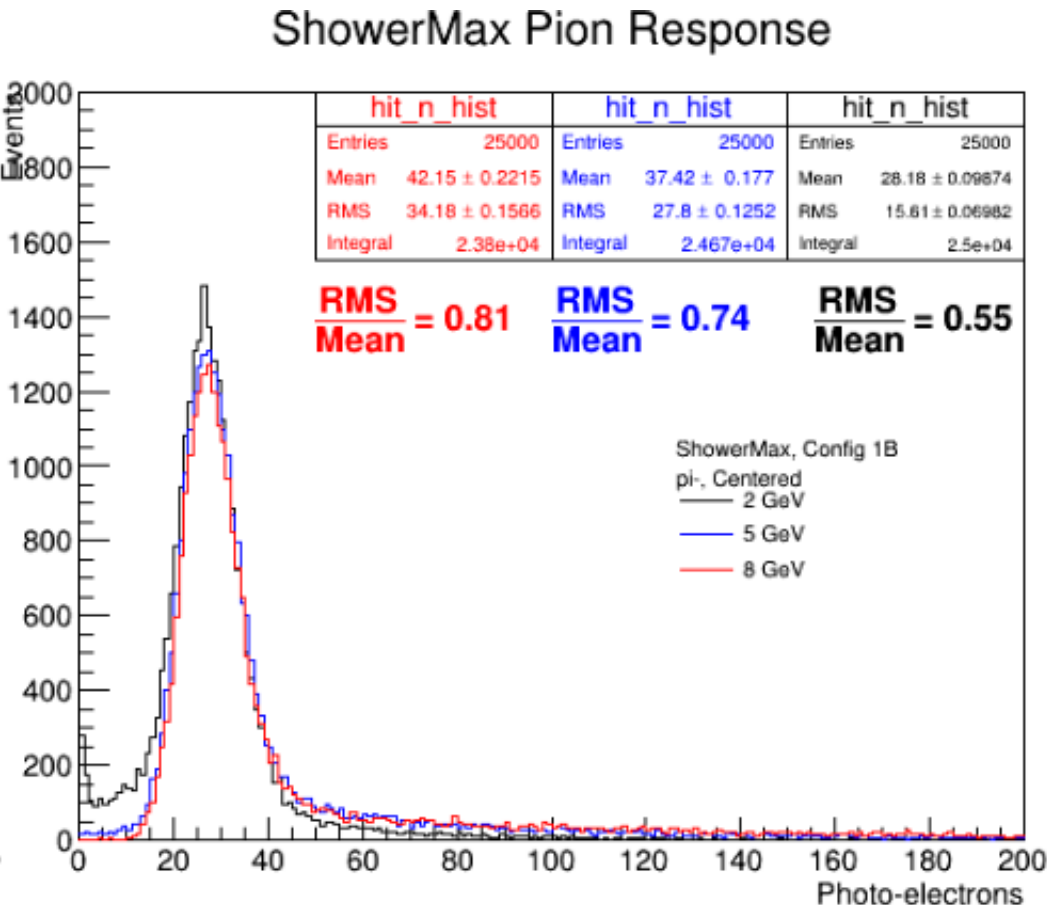
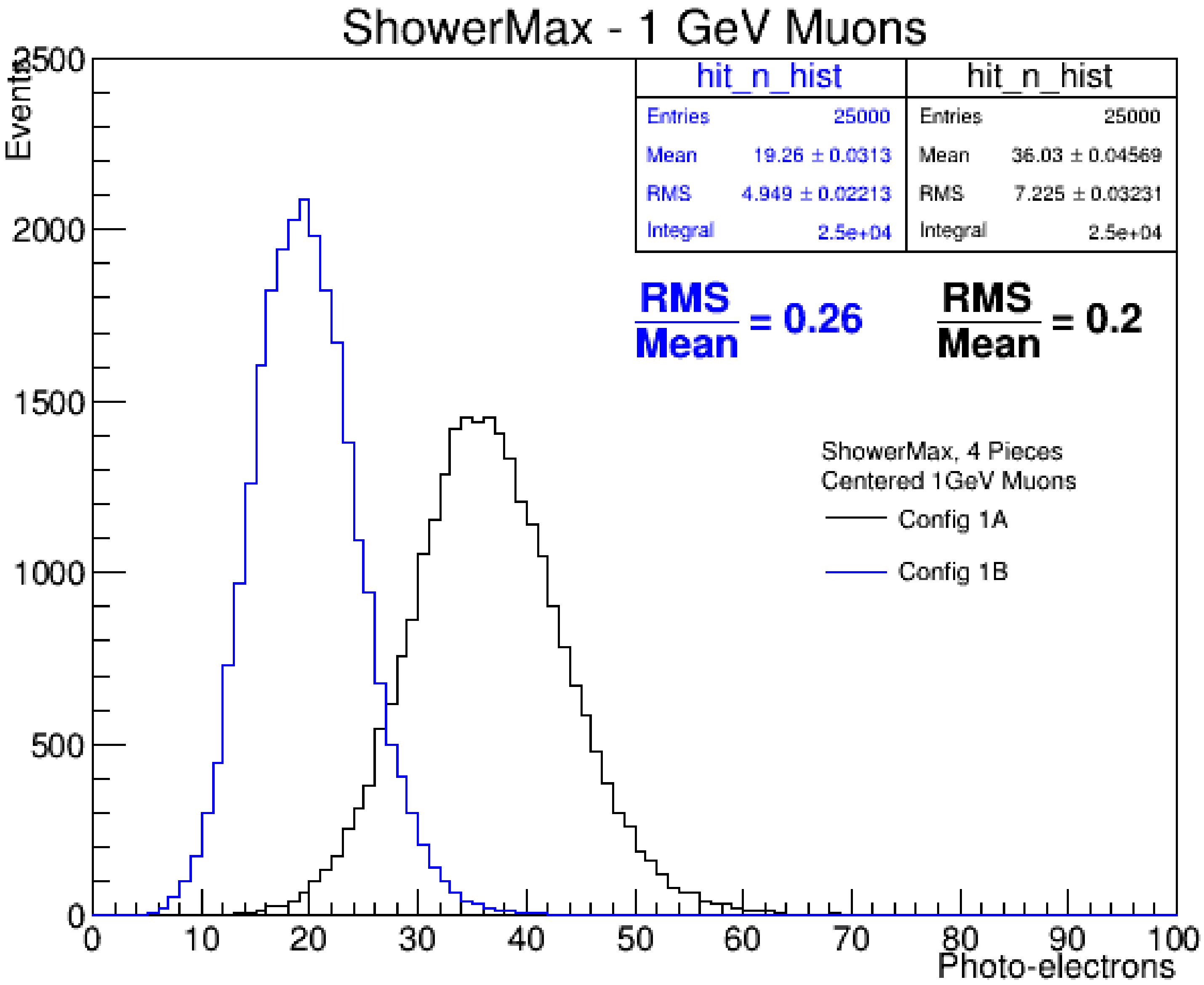
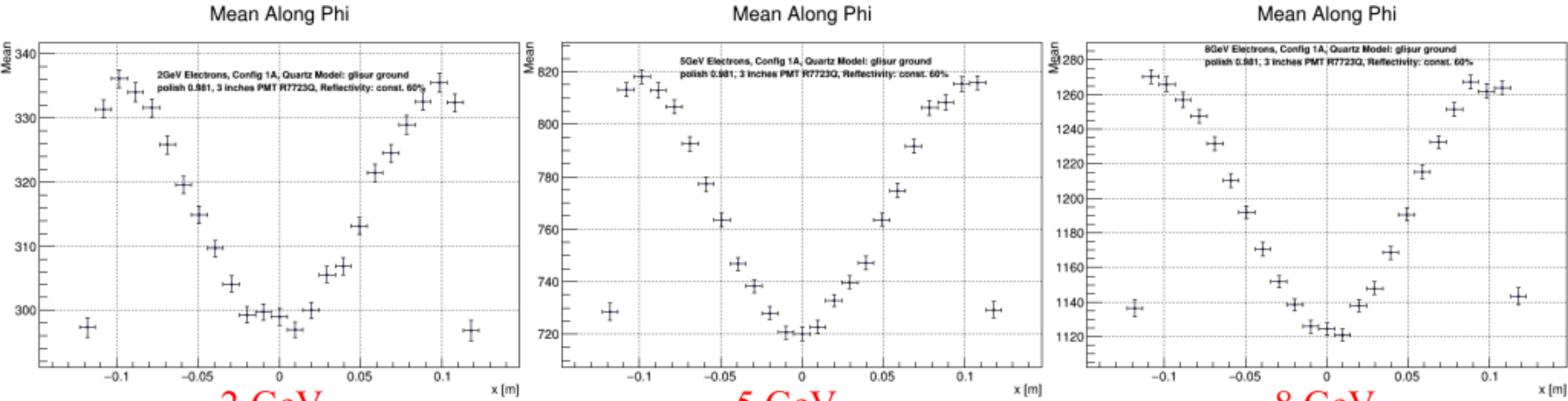




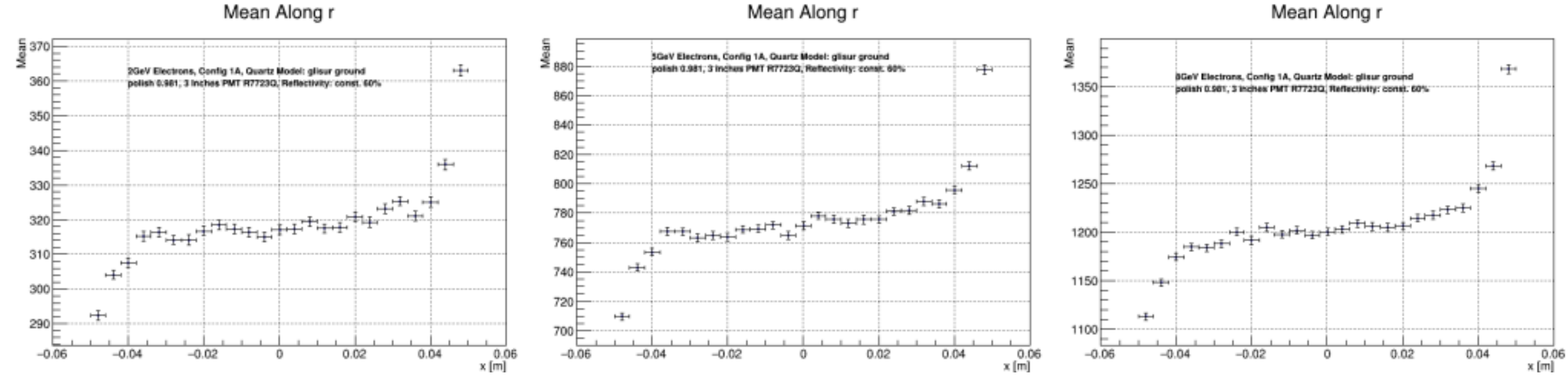
Simulated MIP signal for cosmic-ray tests (Full-scale)



Uniformity Studies: 1A PE means along ϕ and r

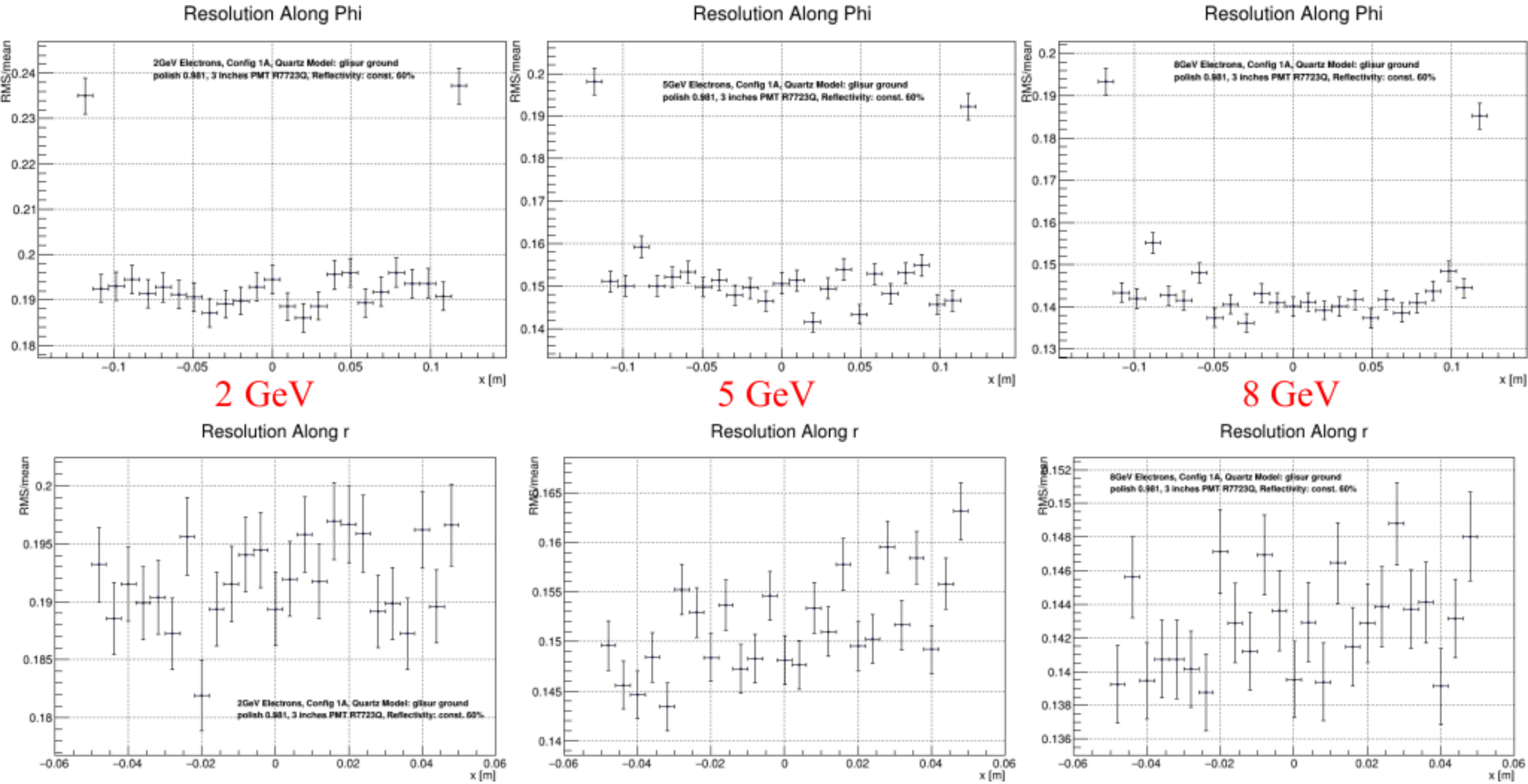


2 GeV 5 GeV 8 GeV

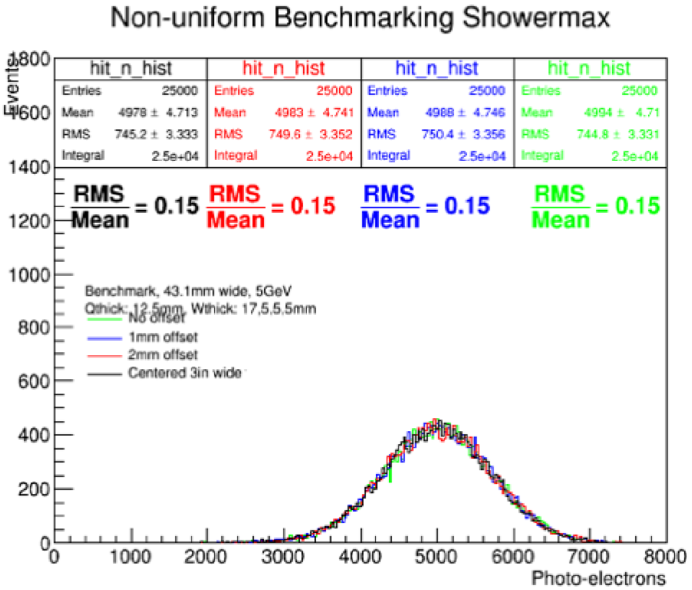


Uniformity Studies: 1A Resolutions along ϕ and r

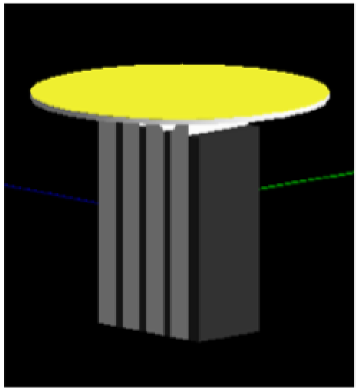
.



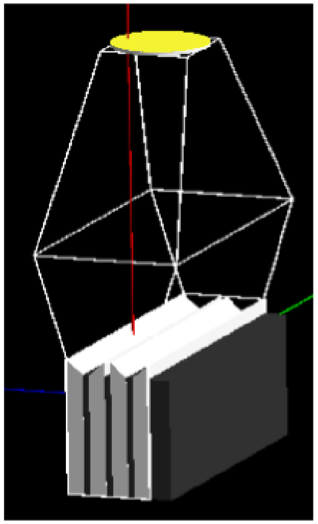
Candidate Design for Stack Prototype: Config #2

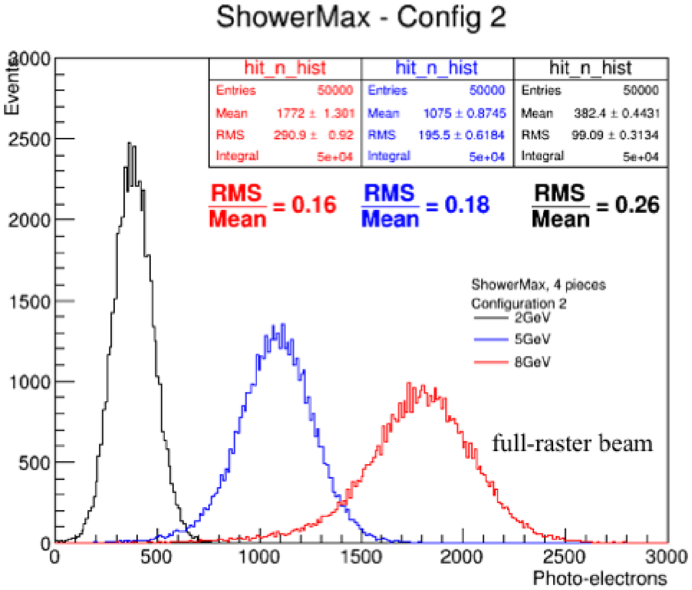


BenchMarking MC Visualization



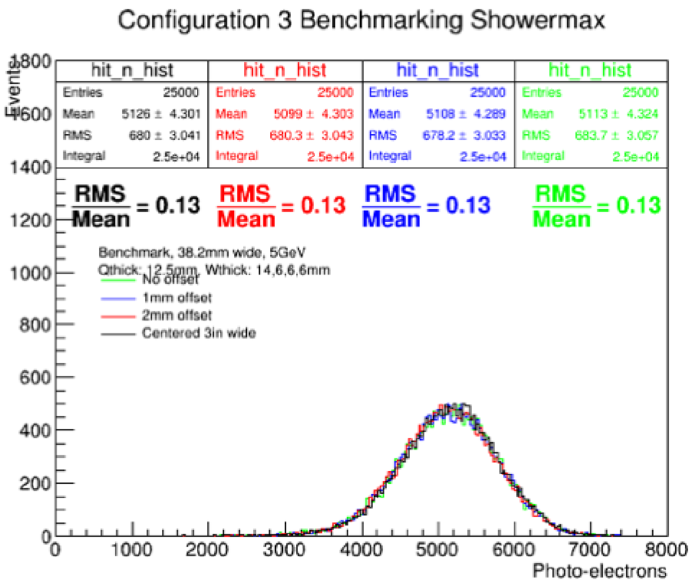
Full Scale MC Vis.



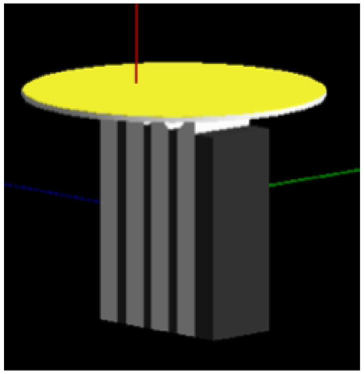


Config #	t_f (mm)	t_Q (mm)	t_W (mm)	b (mm)	a (mm)	X_0	R_{mol} (mm)	Leakage (%) 2, 5, 8 GeV from G4 MC	1mm offset Leakage (%)	2mm offset Leakage (%)	Bench. Mean PEs	Bench. RMS / Mean	full-scale Mean PEs	full-scale RMS / Mean
2	17	12.5	5	65	43.2	9.5	11.0	~0 ~0	~0 ~0	~0 ~0	2412 4994	0.19 0.15	382 1075 1772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

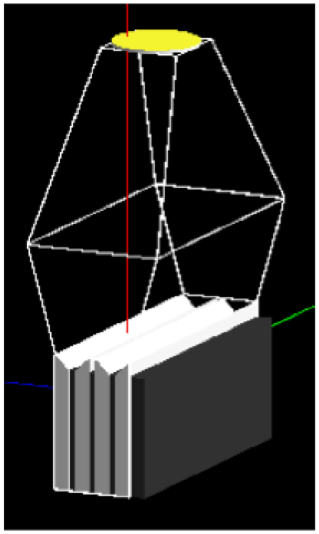
Candidate Design for Stack Prototype: Config #3

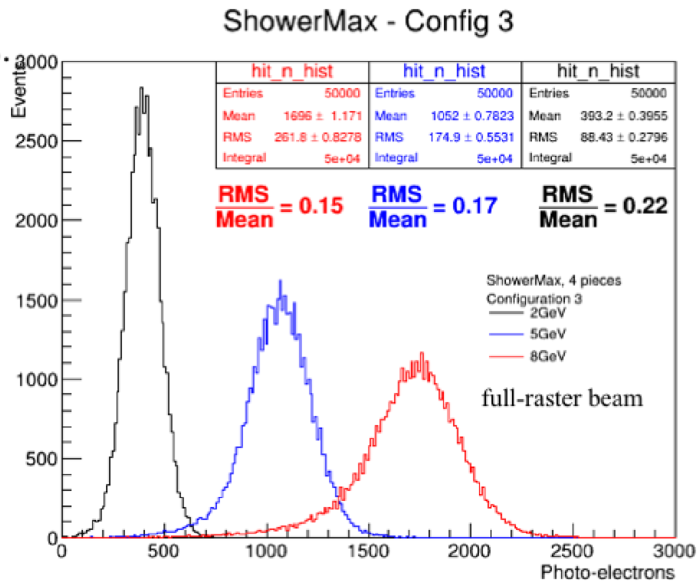


BenchMarking MC Visualization



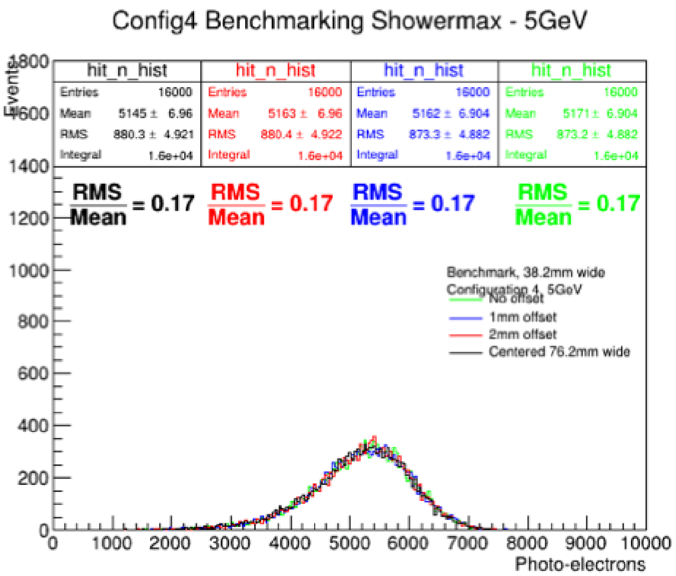
Full Scale MC Vis.



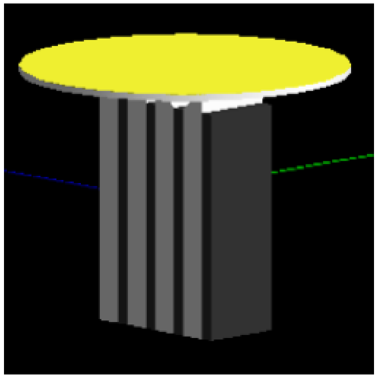


Config #	t_f (mm)	t_Q (mm)	t_W (mm)	b (mm)	a (mm)	X_0	R_{mol} (mm)	Leakage (%) 2, 5, 8 GeV from G4 MC	1mm offset Leakage (%)	2mm offset Leakage (%)	Bench. Mean PEs	Bench. RMS / Mean	full-scale Mean PEs	full-scale RMS / Mean
3	14	12.5	6	68	38.2	9.5	11.0	0.5 0.3	0.6 0.4	0.8 0.5	2412 5113	0.19 0.13	393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

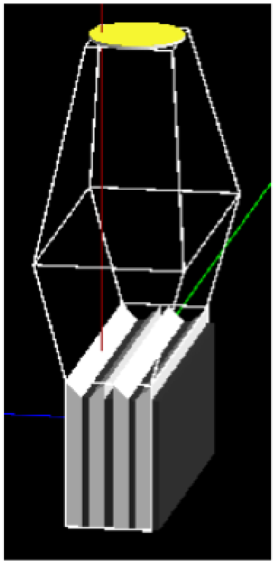
Candidate Design for Stack Prototype: Config #4

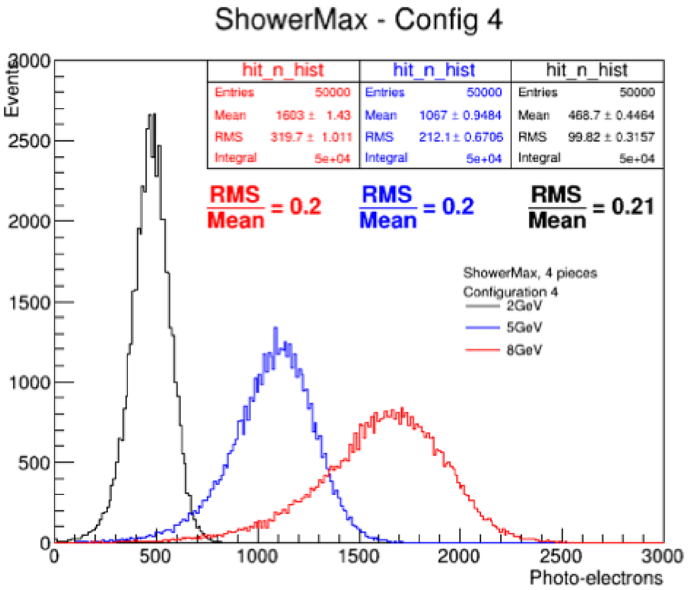


BenchMarking MC Visualization



Full Scale MC Vis.





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

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

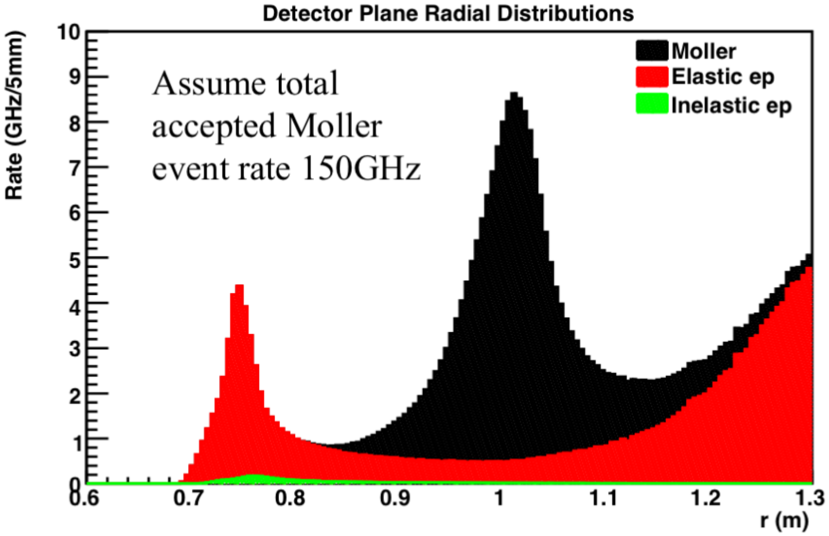
	Benchmark - 5GeV			
Config #	RMS/Mean	Leakage (%)	Leakage 2mm offset (%)	Leakage 2° angle (%)
1A	0.13	0.04	0.09	-0.4
1B	0.14	0	0	0.2
4A	0.17	0.06	0.3	-
4B	0.19	0	0	-

	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	-

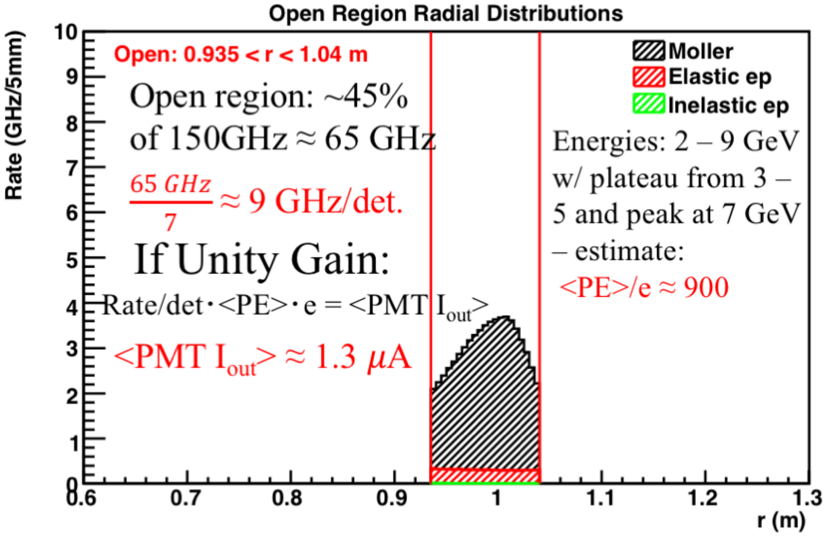
	Full Scale ShowerMax – 8GeV		
Config #	RMS	Mean	RMS/Mean
1A	183.2	1197	0.15
1B	129.1	732.3	0.18
4A**	187.9	1012	0.19
4B**	118.8	591.3	0.20

Unity Gain operation with Baseline design?



Detector Plane Radial Distributions

Assume total accepted Moller event rate 150GHz



Open Region Radial Distributions

Open: 0.935 < r < 1.04 m

Open region: ~45% of 150GHz ≈ 65 GHz

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

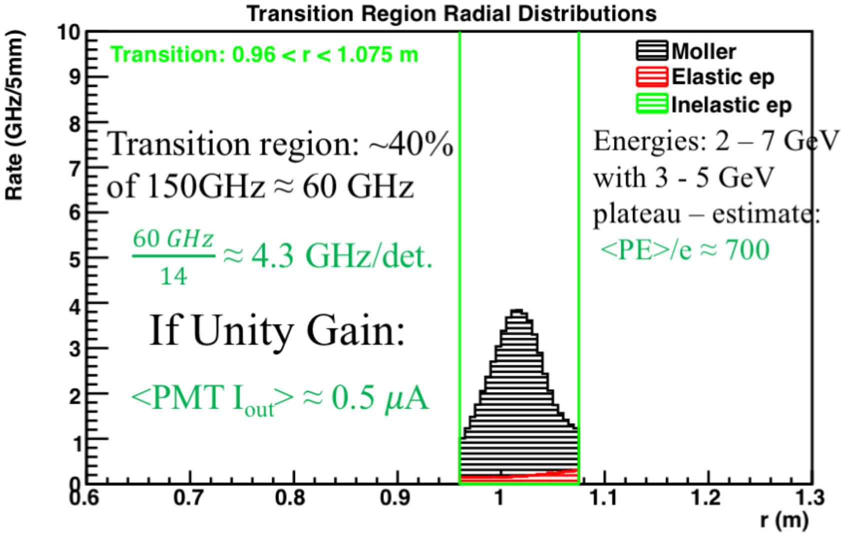
If Unity Gain:

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 Region Radial Distributions

Transition: 0.96 < r < 1.075 m

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

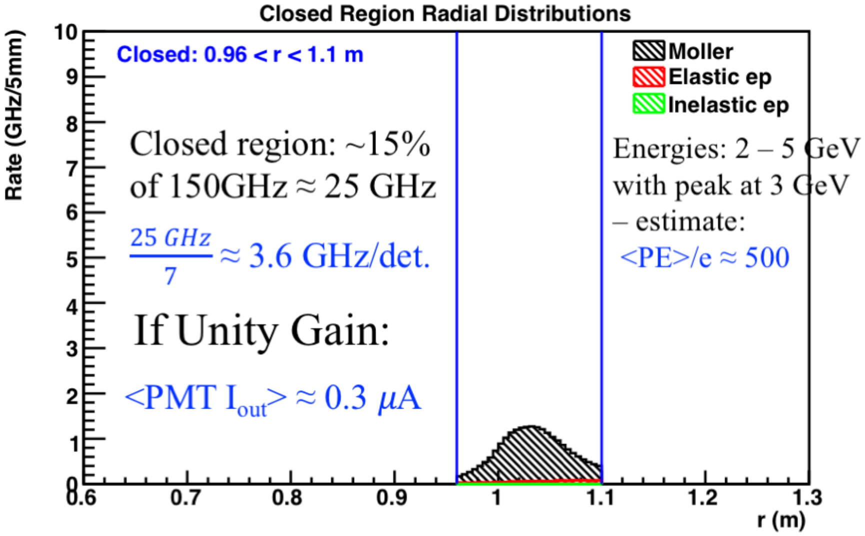
$\frac{60\ GHz}{14} \approx$ 4.3 GHz/det.

If Unity Gain:

<PMT I_{out}> ≈ 0.5 μA

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

<PE>/e ≈ 700



Closed Region Radial Distributions

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

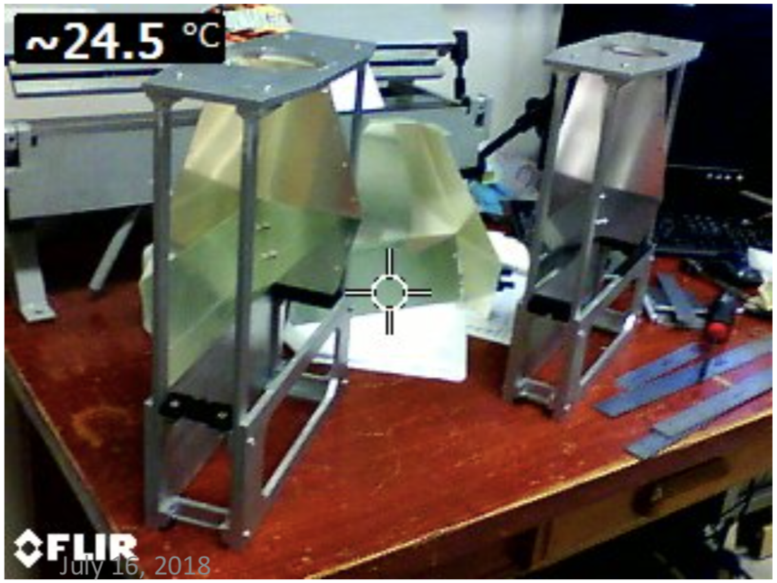
Energies: 2 – 5 GeV with peak at 3 GeV – estimate:

<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)

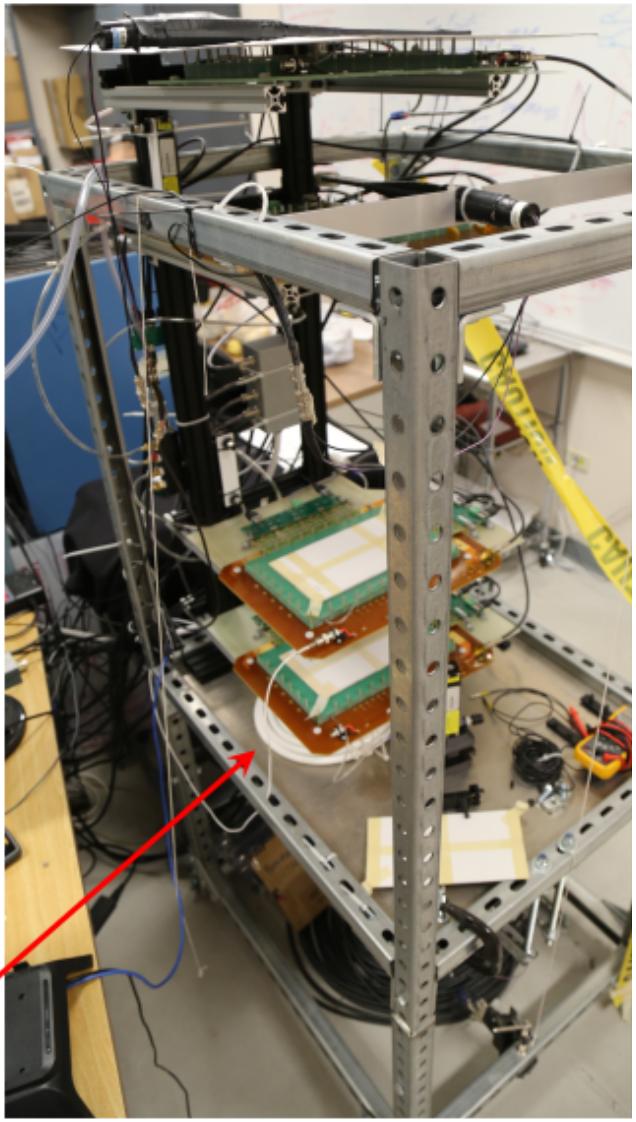
ShowerMax Prototype Construction Timeline

- 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



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