Shower-max Progress

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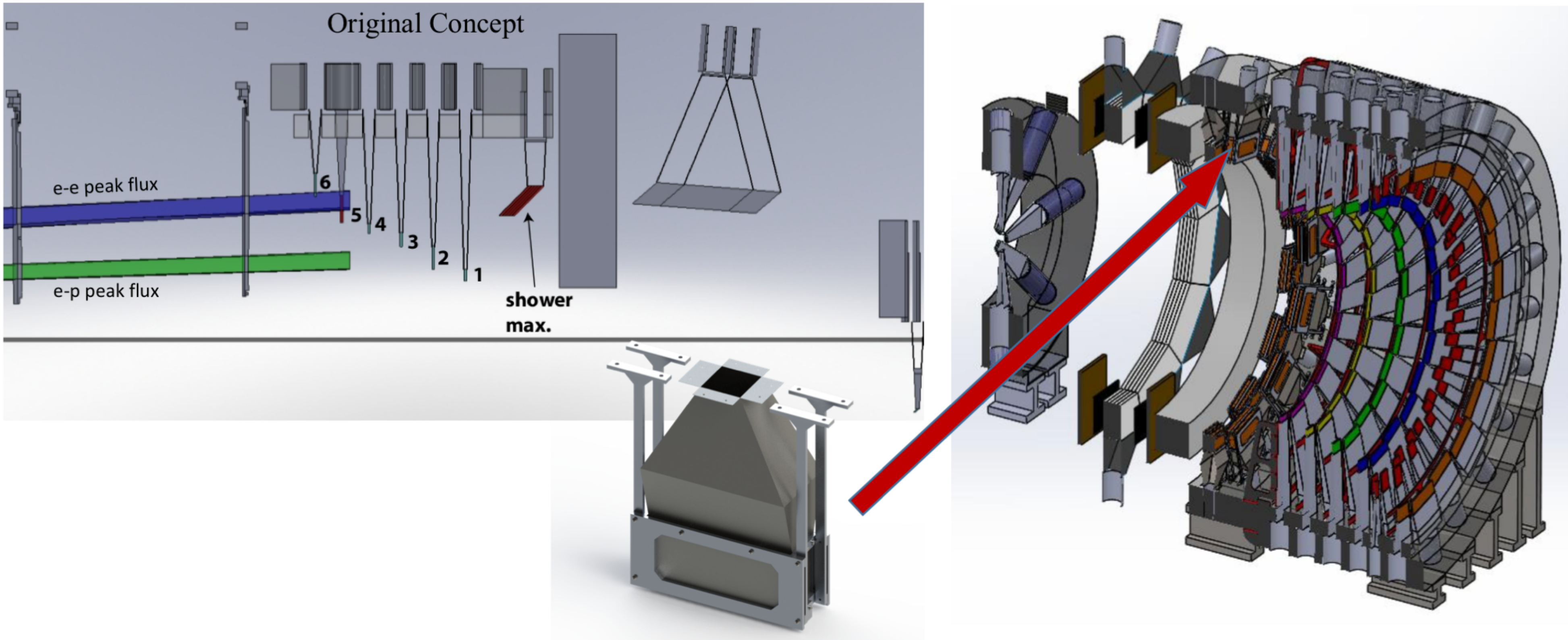
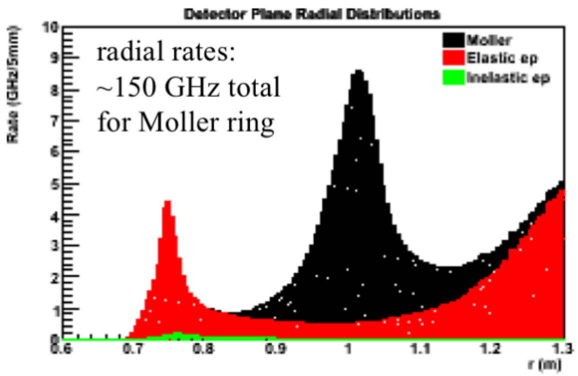
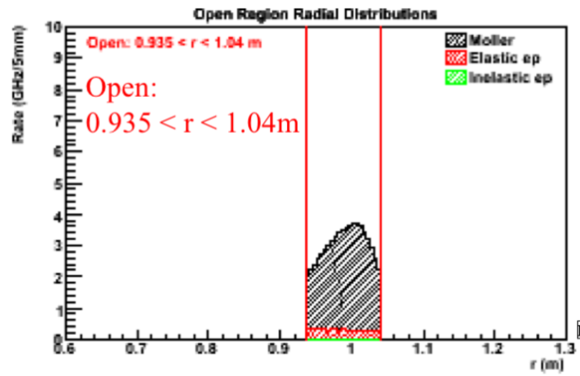
Motivation & Requirements

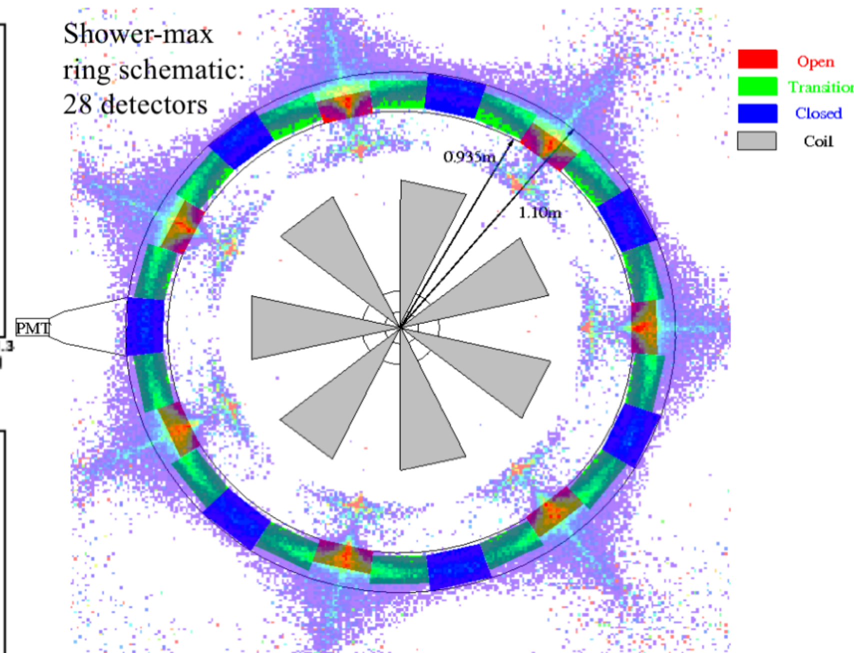


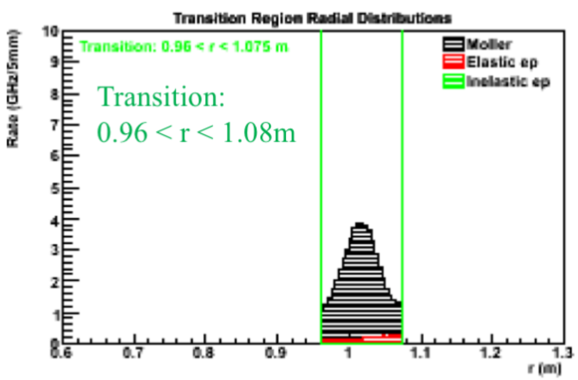
- Provides additional measurement of e-e ring integrated flux
- Weights flux by energy $\Longrightarrow$ less sensitive to low energy and hadronic backgrounds
- Will also operate in tracking mode to give additional handle on background (pion) identification – gives MIP signal
- Should have good resolution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

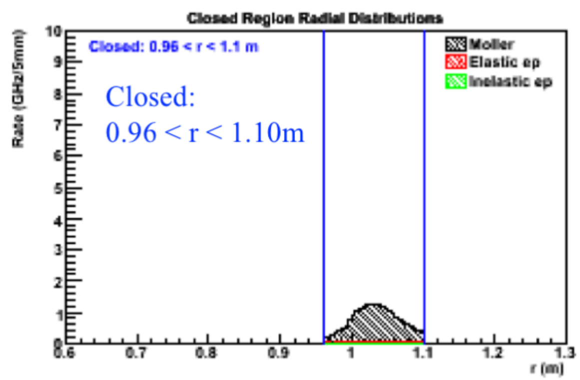
Shower-max phi-segmentation, rates and energies

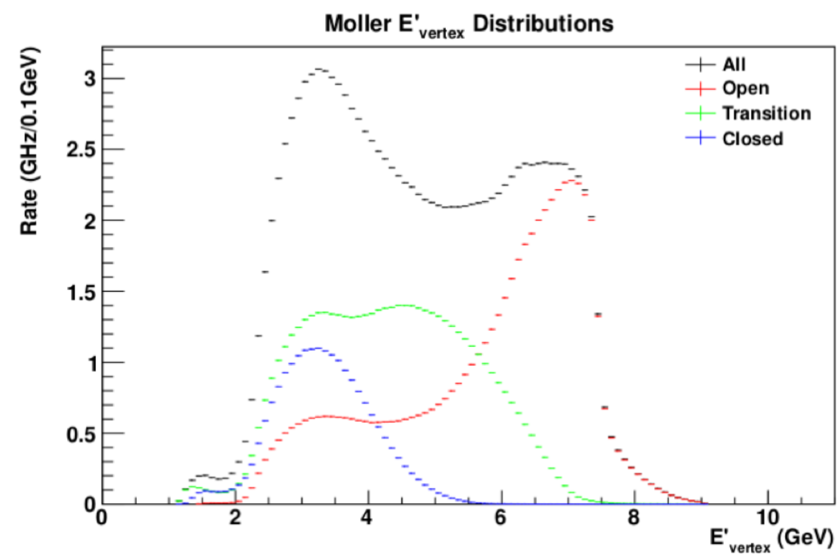










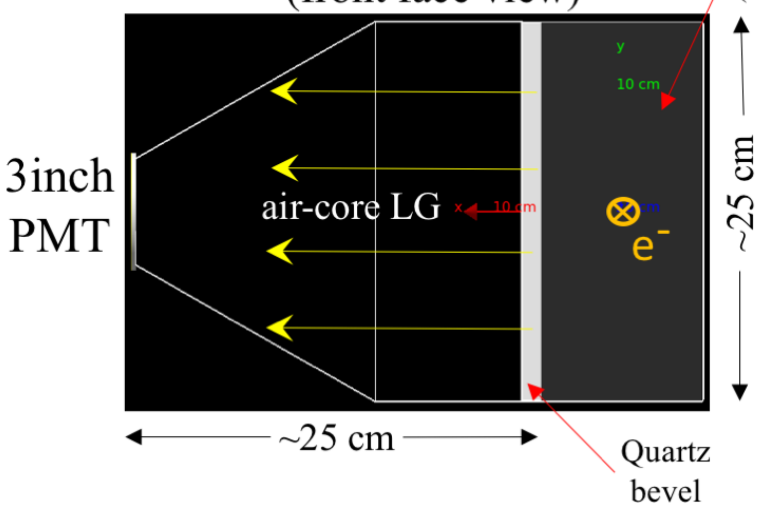


- Large range of rates and energies for different phi-region detectors:
  - Open ~9 GHz/det; 2 - 9 GeV, peak at 7 GeV…
  - Closed ~3.5 GHz/det; 2 - 5 GeV, peak at ~3 GeV
  - Transition ~4.5 GHz/det; 2 - 7 GeV, 3 – 5 GeV plateau

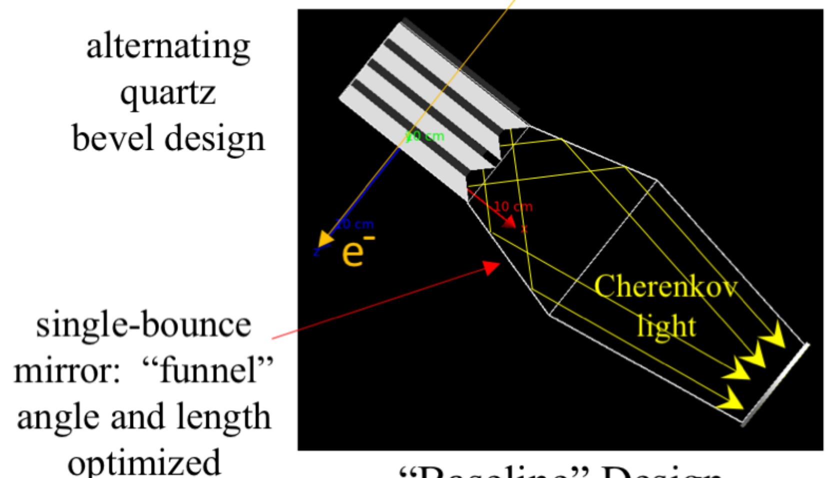
Baseline Shower-max Design: 4-layer Stack

- 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 6mm tungsten and 12.5mm quartz pieces
  - Cherenkov light directed to 3inch PMT using air-core, aluminum light guide

"Baseline" LG Design
(front face view)



4-layer Stack: 6mm thick tungsten (dark grey), interleaved with 12.5mm thick quartz (white)



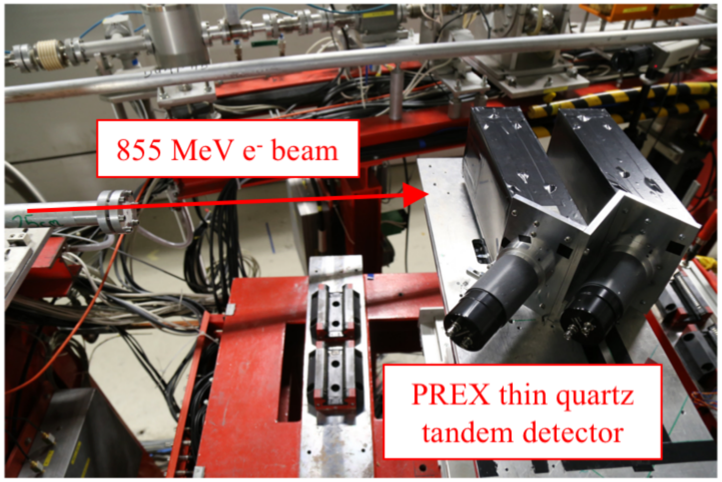
"Baseline" Design
(side view)

Materials (all rad-hard):

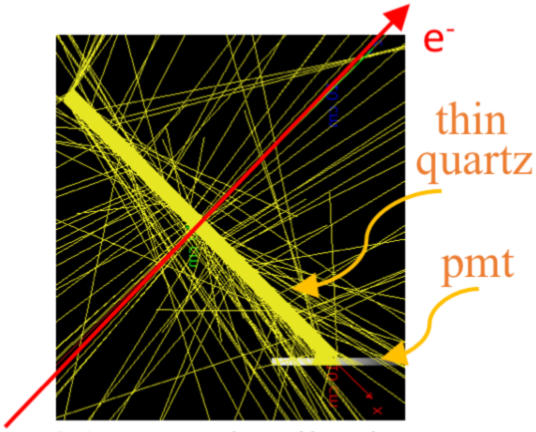
- Tungsten is high purity (99.95%) and quartz is optically polished Spectrosil 2000
- Light guides are aluminum specular reflectors (Miro-silver 27, Anolux, or al. mylar, …)
- Total radiation length: 6.8 X_0 tungsten + 0.4 X_0 quartz = 7.2 X_0

Monte Carlo tuning and Shower-max Simulations

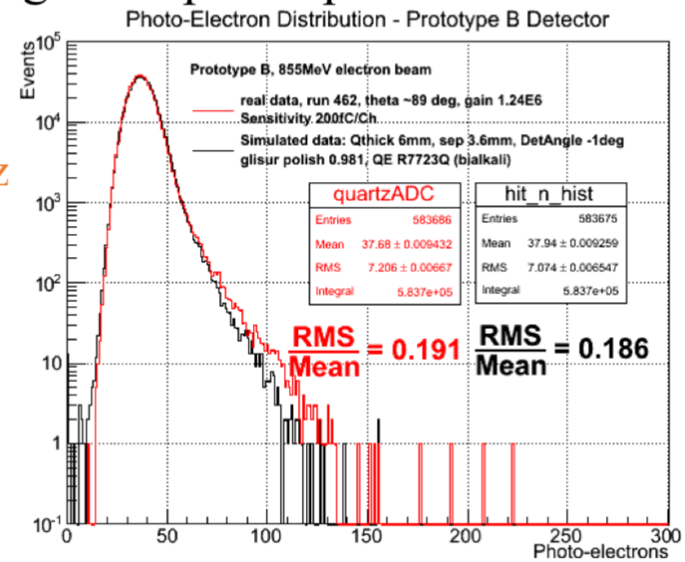
- Quartz optical G4 properties benchmarked at MAMI: Glisur ground polish parameter ~0.981



MAMI testbeam with PREX detector



G4 event visualization for PREX detector

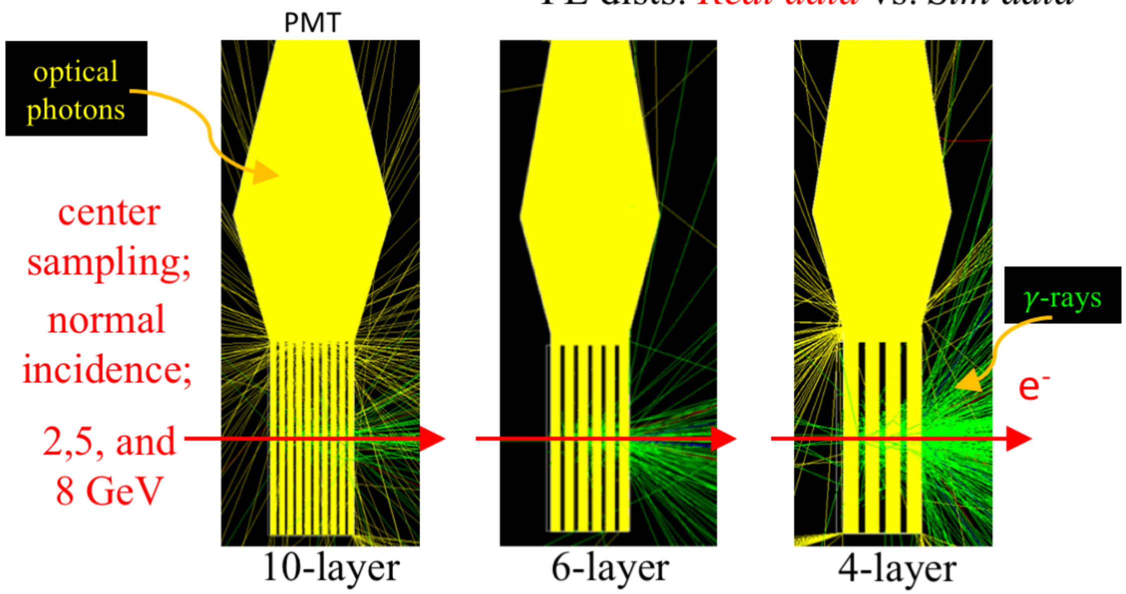


PE dists: *Real data* vs. *Sim data*

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

Conclusion:

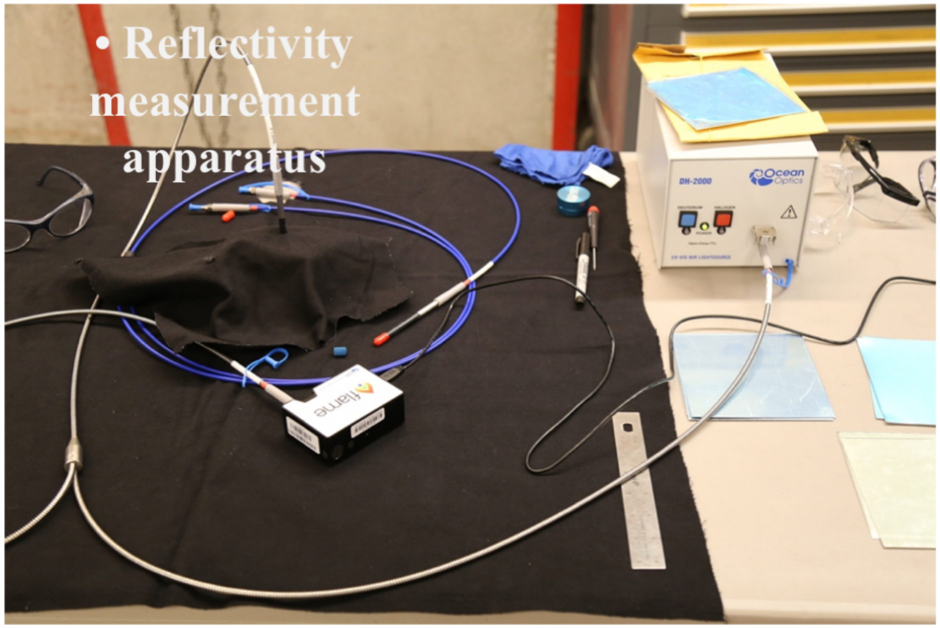
4-layer gives comparable performance to 10-layer (and is much cheaper to build)



Shower-max event visualizations

Light guide reflectivity measurements

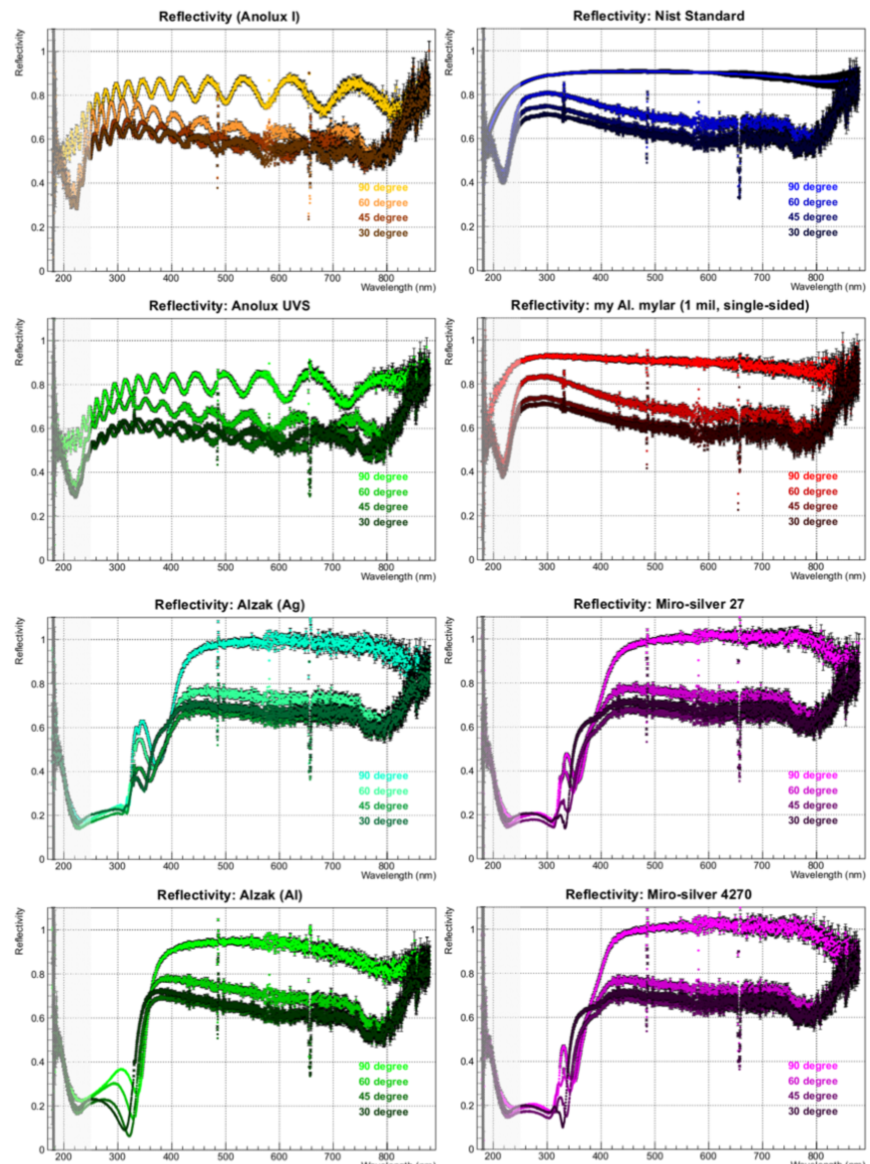
- Measuring light guide (LG) reflectivity as function of angle (10 – 90°) and λ (200 – 800nm); ongoing



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

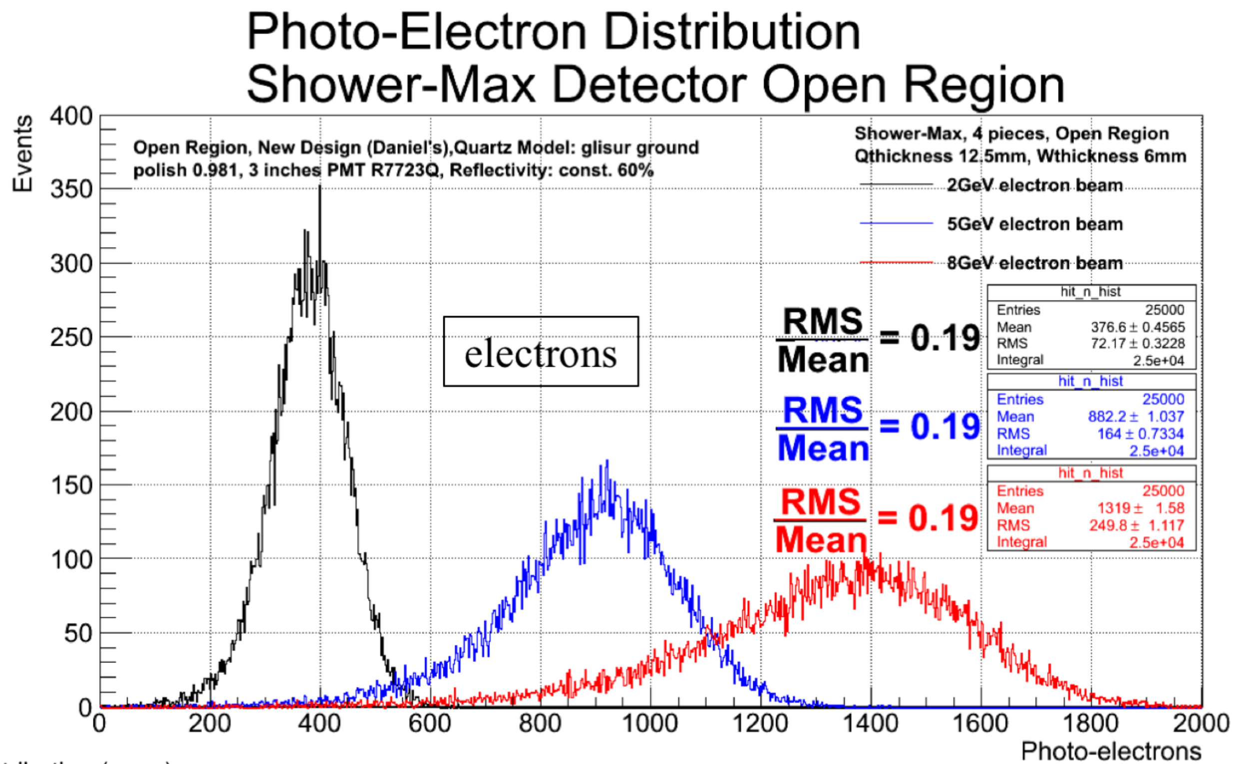
Light guide materials tested:

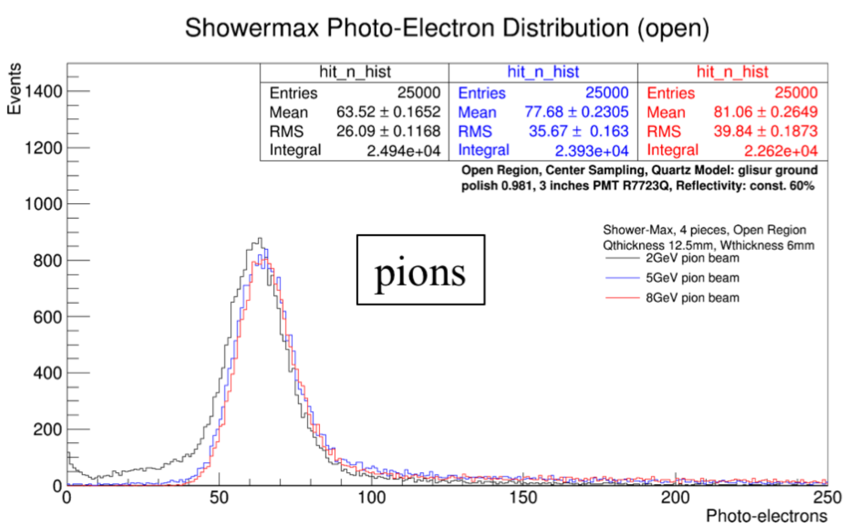
Miro-silver 4270	Miro-silver 27
Anolux I and UVS	Alzak-Al and Alzak-Ag
Miro 2000Ag (diffuse)	1 mil, single-sided aluminized mylar



Reflectivity vs. λ for various materials at diff. angles

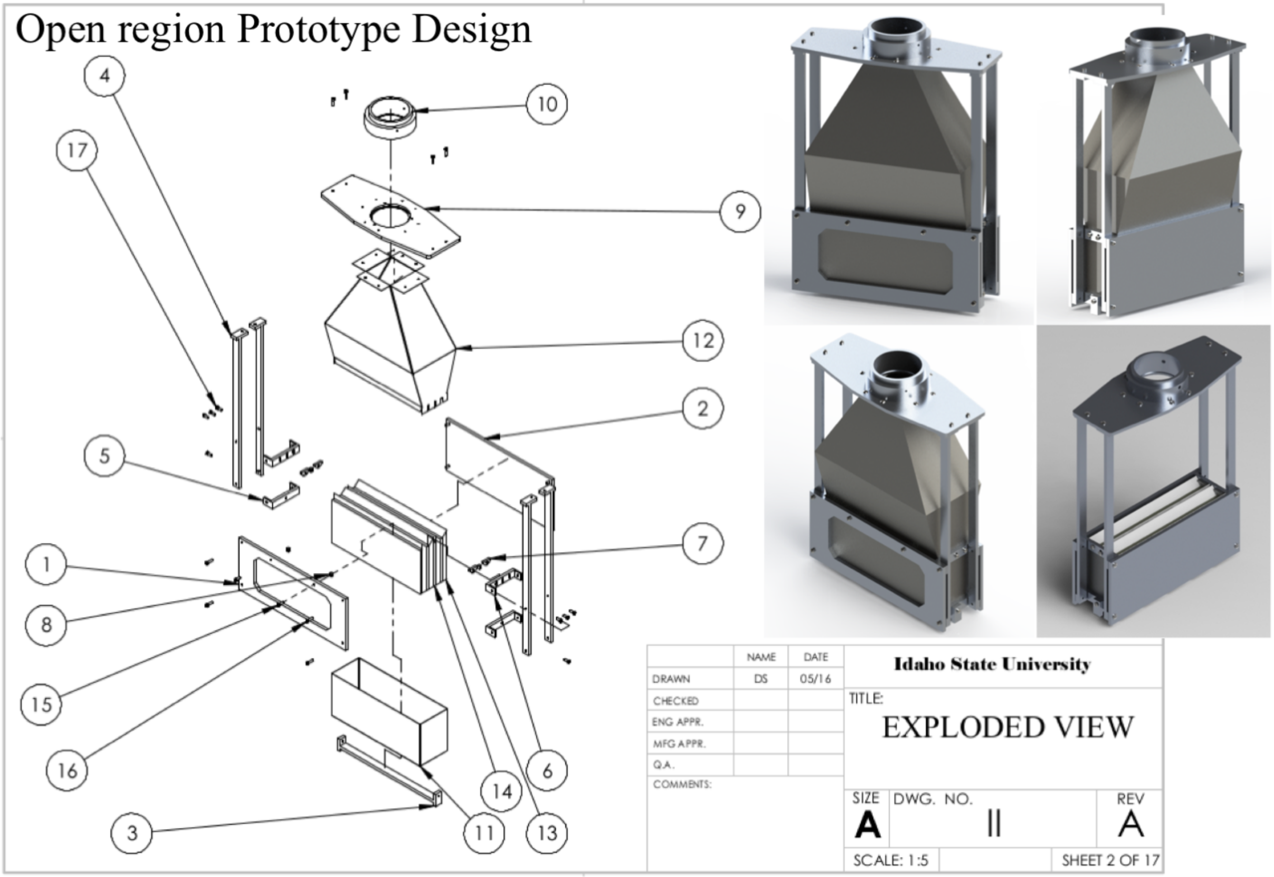
4-layer baseline PE Dists for 2, 5, and 8 GeV

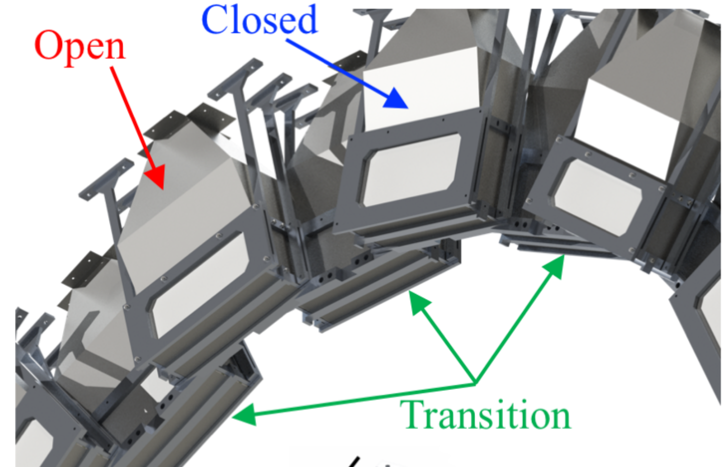


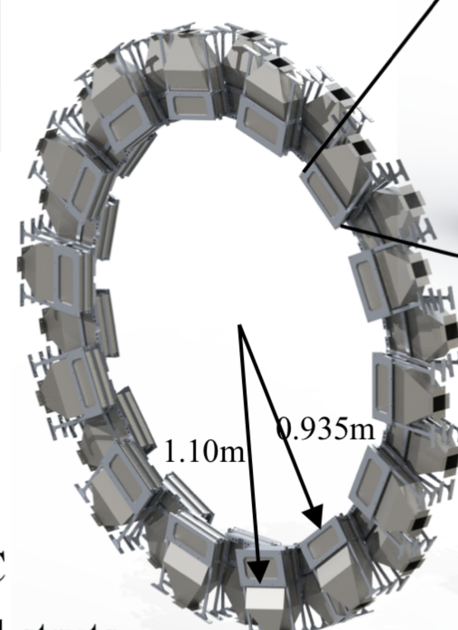


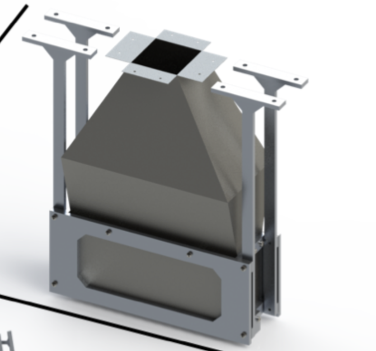
- Healthy ~65 peak-PE signal for pion tagging during tracking mode operation

Prototype build/test plans and ring concept









"Baseline"

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

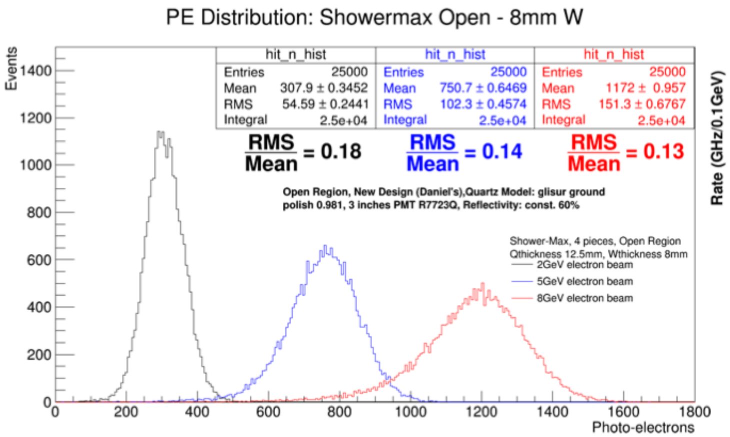
Weights of each assembly:
Open: 39.7 lbs.
Transition: 42.5 lbs.
Closed: 50.8 lbs.
ring weight: 1230 lbs.

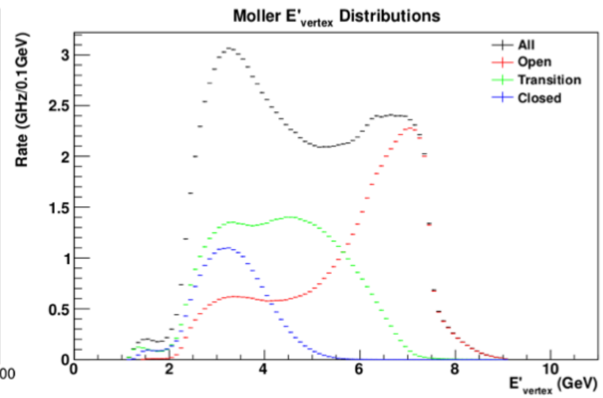
- Engineered shop drawings and Prototype CADs in hand
- Will finalize prototype Stack designs this winter, construct in spring/summer and test using 8 GeV electron testbeam at SLAC
- Shower-max ring design concept: staggered in $\hat{z}$ with reinforced struts and brackets. 28 detectors in ring: 7 Open, 7 Closed, and 14 Transition

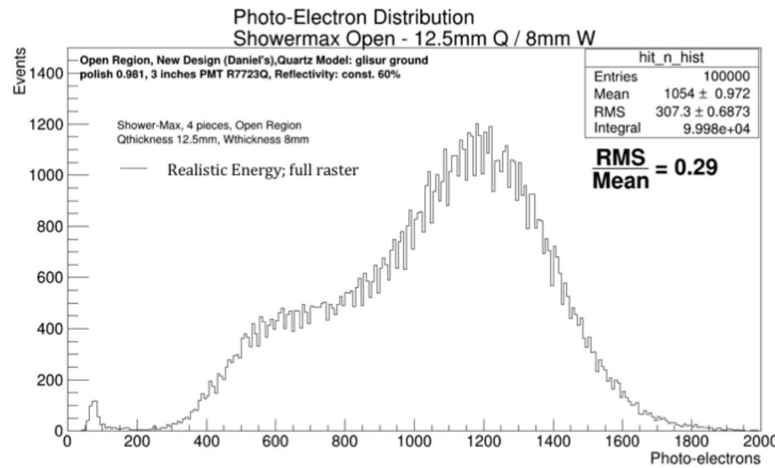
Summary and future work

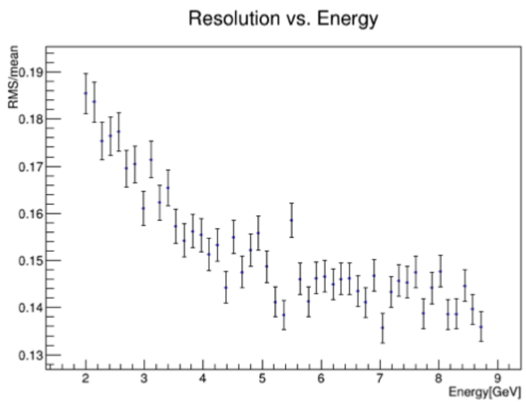
- MOLLER Shower-max baseline detector design developed
  - Meets requirement criteria: linear energy-dependent yields with good resolution; constructed with rad-hard materials
- G4 Monte Carlo work ongoing:
  - Continue to study/optimize Stack configurations
  - Study det. res. uniformity over entire face; edge effects
  - Sample realistic e^- energy and position (and angle)
  - Determine shower-max excess noise for statistical power
  - Benchmark G4 MC for shower-max: start with MAMI SAM+W data at $\sim$1 GeV (all we have right now)
  - Incorporate LG reflectivity lookup tables; using 60%
- Pre-R&D funds in place for prototyping and test at SLAC?

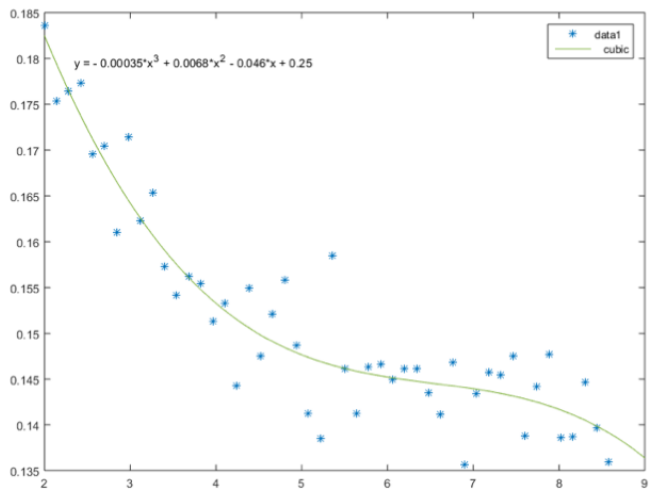
Excess Noise for Shower-max (OPEN Septant)

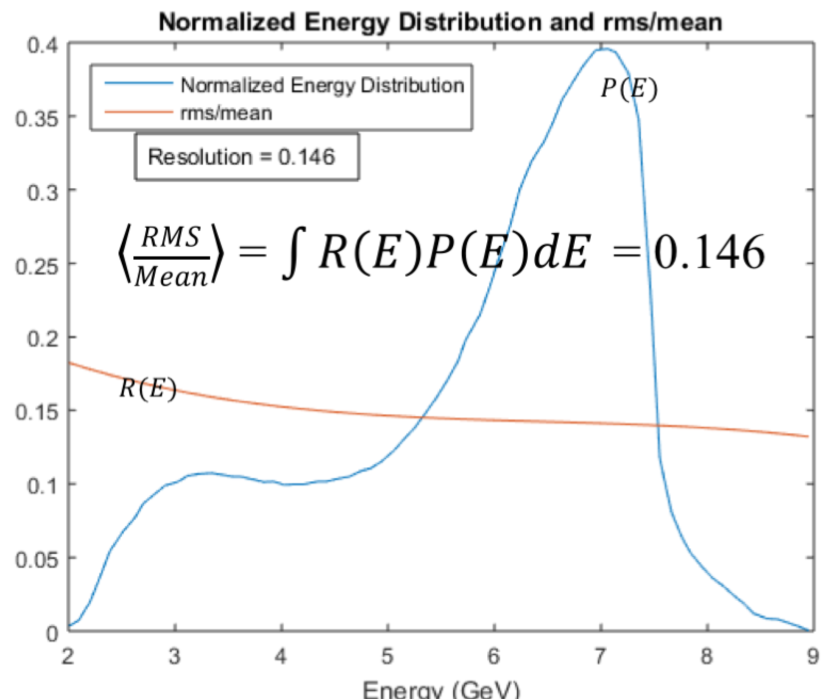










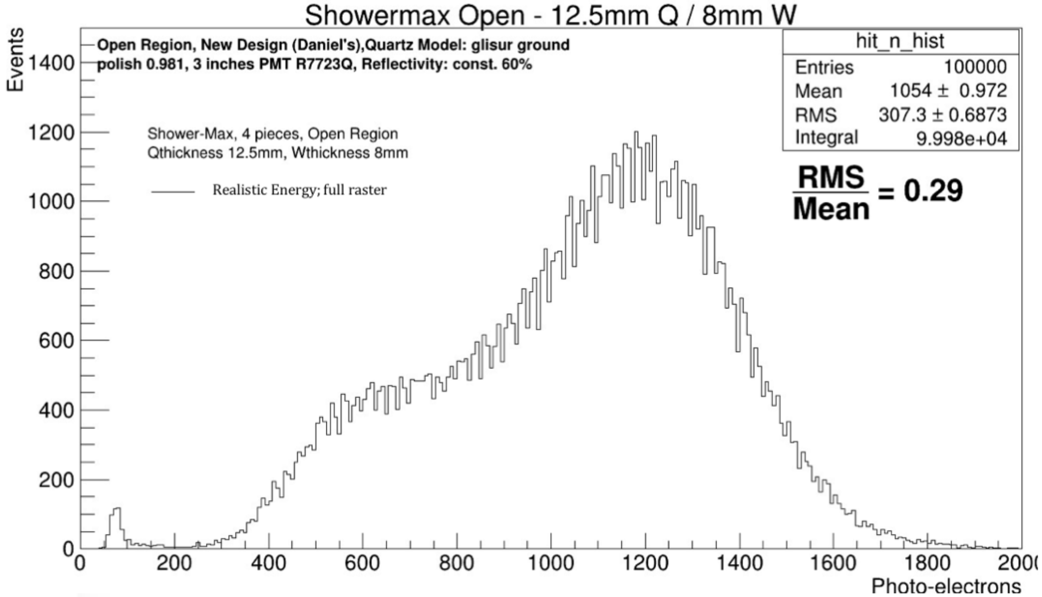


- Excess Noise = $\sqrt{1 + \left\langle \frac{RMS}{Mean} \right\rangle^2}$ - 1 = 1.06%

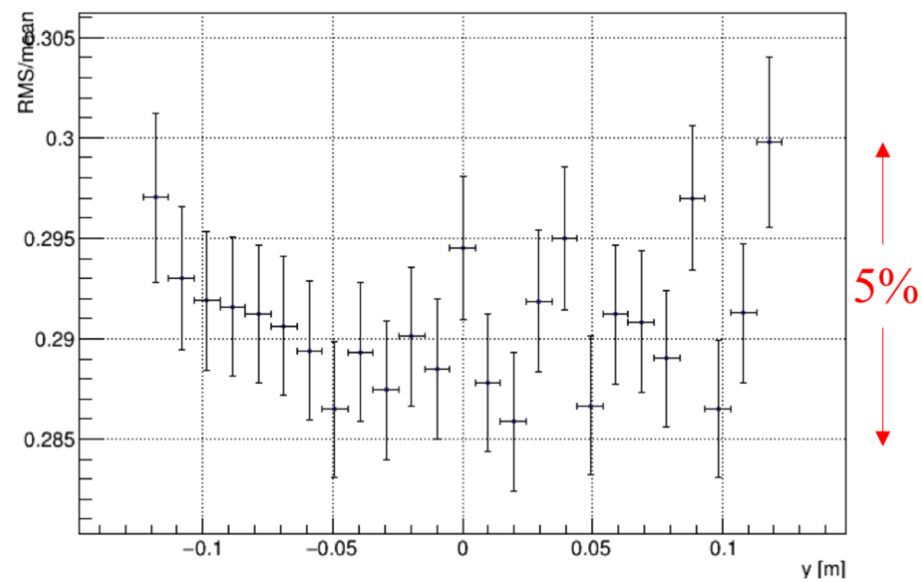
Much better than needed! Can reduce layer thicknesses and save $

Shower-max Response Uniformity (along $\hat{\phi}$)

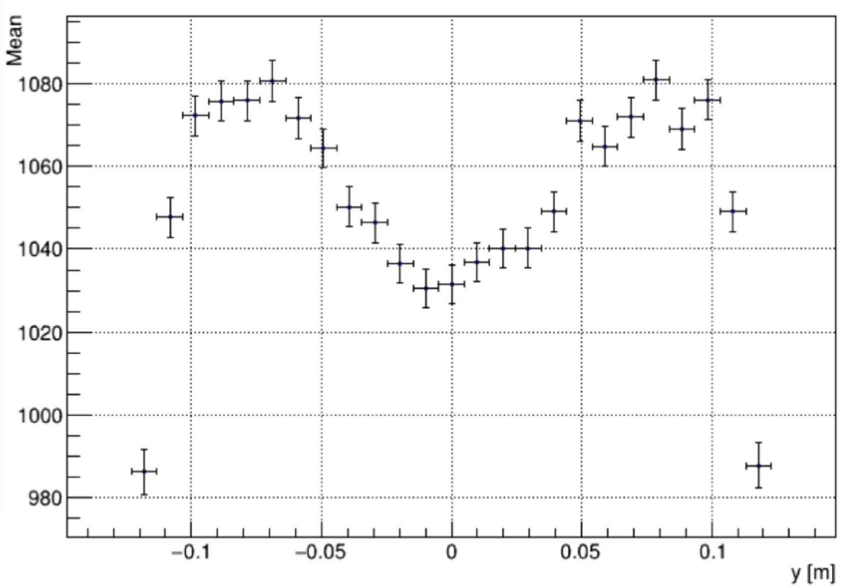
Photo-Electron Distribution
Showermax Open - 12.5mm Q / 8mm W



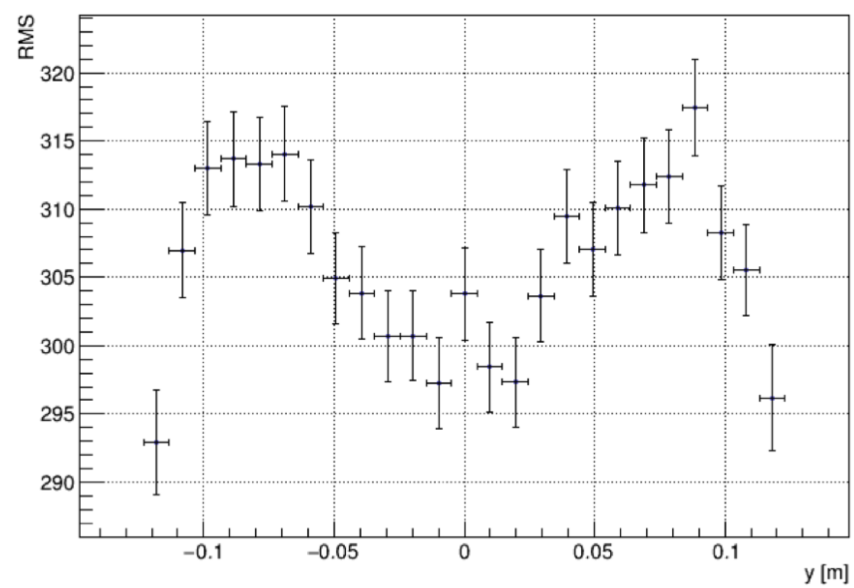
Overall RMS/Mean vs. Horizontal Position (along phi)



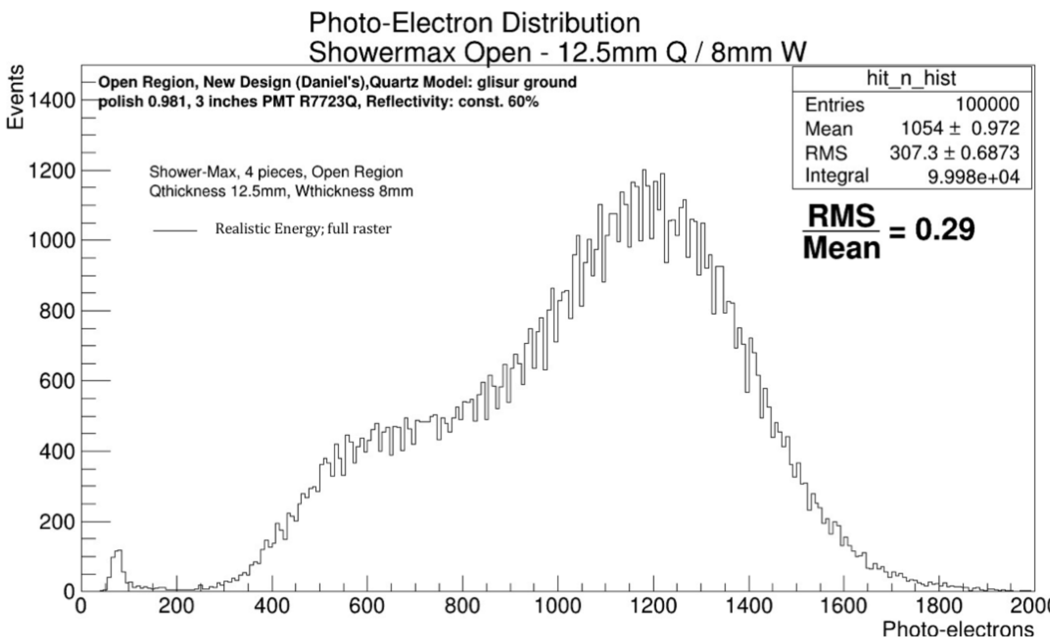
Mean vs. Horizontal Position (along phi)

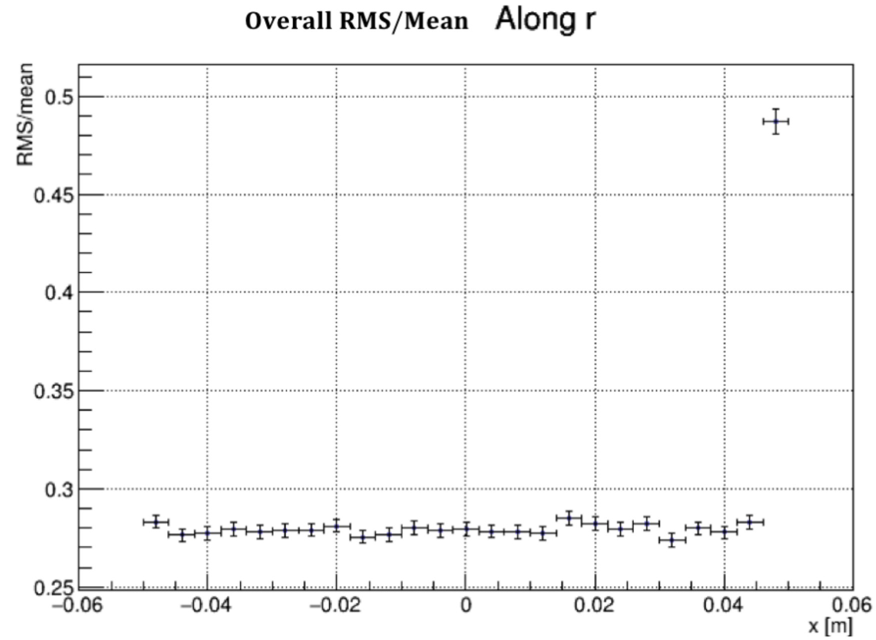


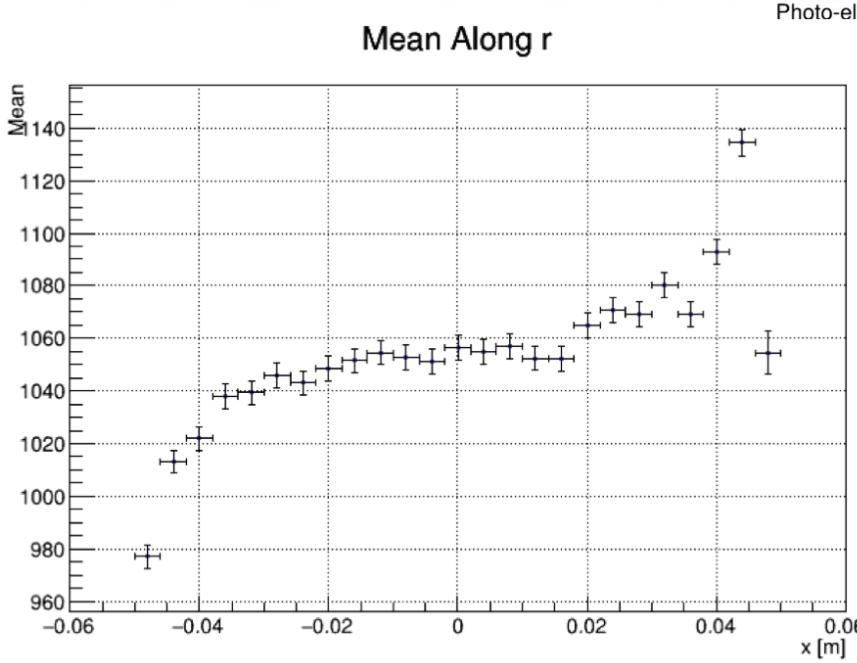
Rms vs. Horizontal Position (along phi)

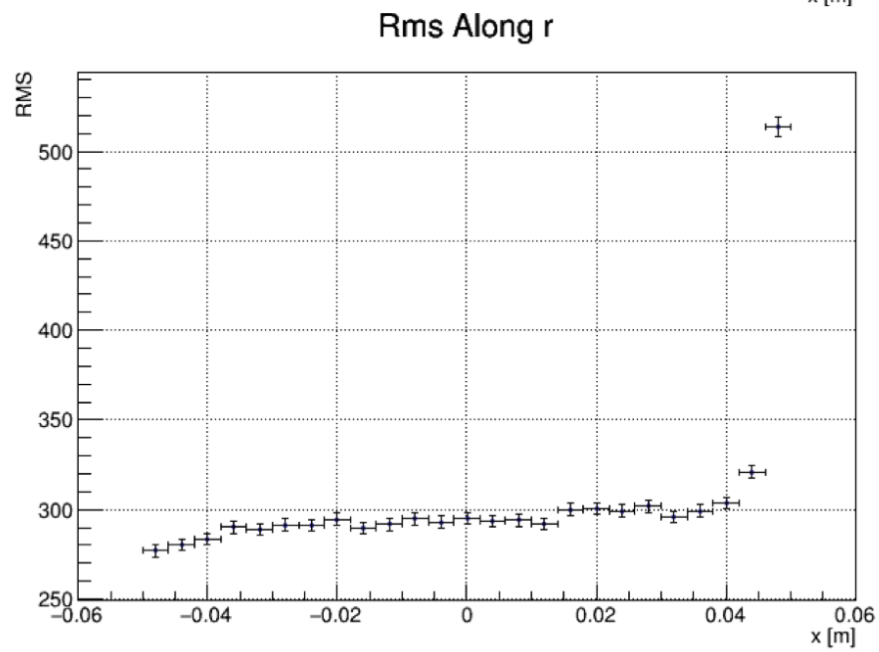


Shower-max Response Uniformity (along $\hat{r}$)

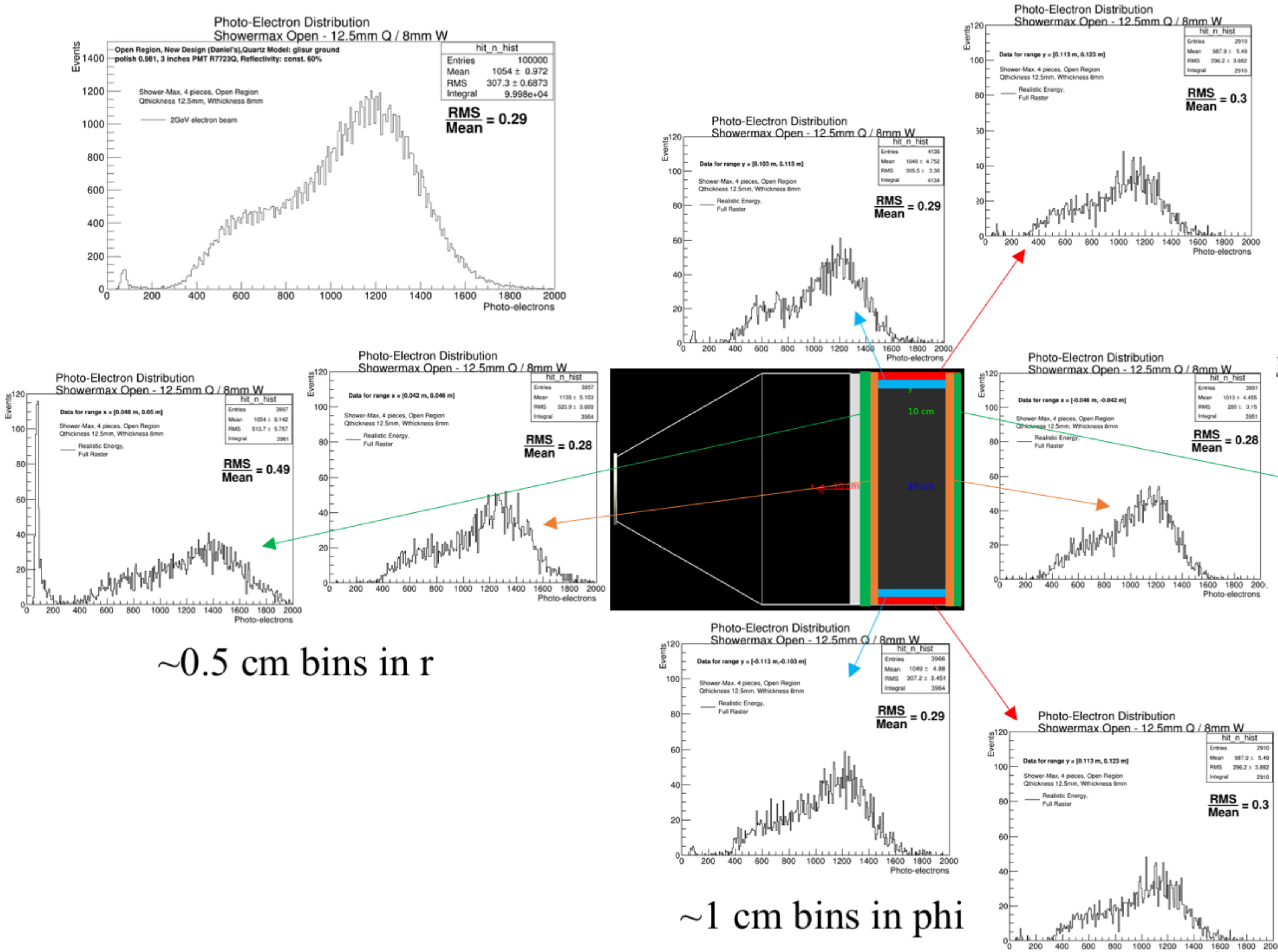








Shower-max Edge PE Distributions

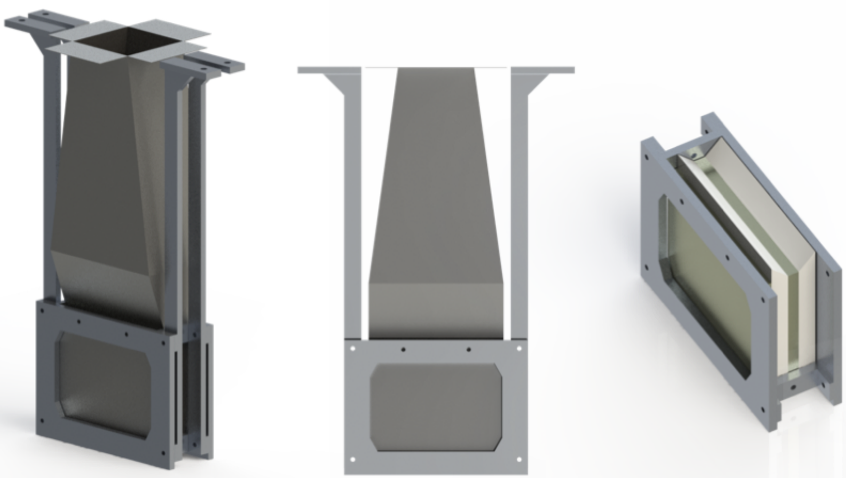


~0.5 cm bins in r

~1 cm bins in phi

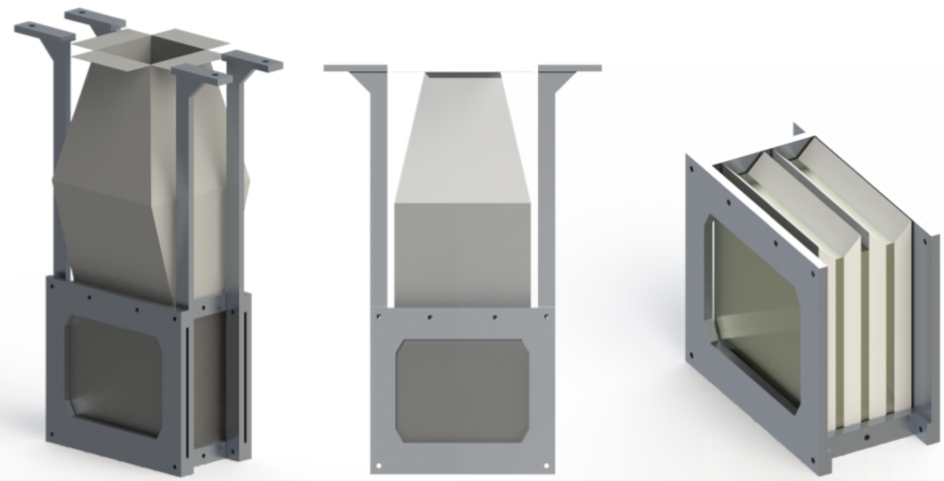
New Idea for Shower-max Detectors and Ring

Half-width, "half-stack" OPEN Shower-max



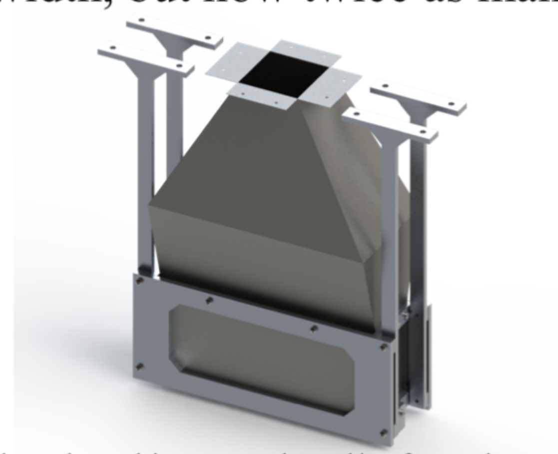
Rational: Resolution was too good; this provides more focused energy acceptance; fewer layers/thinner (less $)

Half-width, "full-stack" CLOSED Shower-max



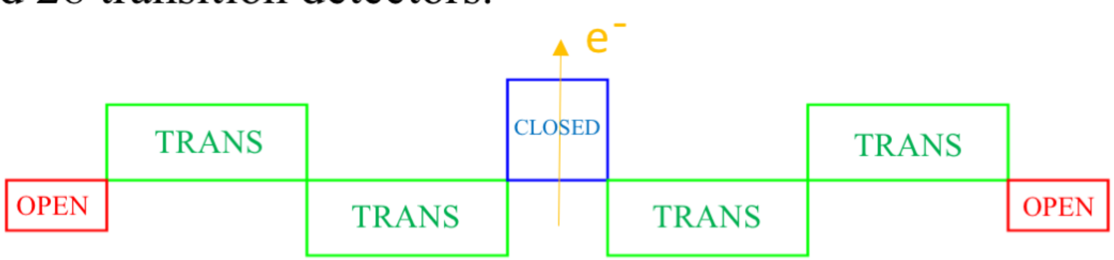
Rational: Provides more focused energy acceptance; still may want 4 layers but could be thinner (less $)

TRANSITION Shower-max: Still full width, but now twice as many



Will explore thinner stack and/or fewer layers

- New idea for ring configuration (radial view): 7 open, 7 closed, and 28 transition detectors.



Prototype, Testbeam and MC benchmarking

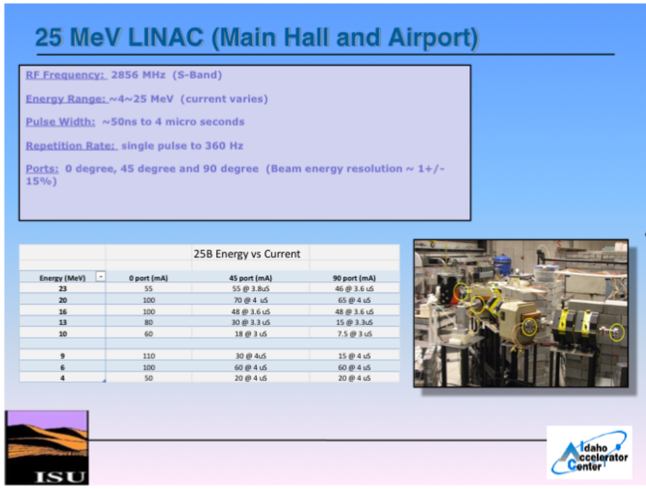
- Goal: Construct prototype(s) and test with 5 - 8 GeV electrons (somewhere: SLAC, FNAL ???); have $15k pre-R&D funds
- Engineer special prototype capable of operation with systematically more stack layers added and with no light guide
  - First take data with only one piece of quartz
  - Then add the first tungsten pre-radiator, then the next layer of tungsten and quartz...
  - This will facilitate Monte Carlo Benchmarking of optical quartz properties and G4's showering process without light guide complication
  - Then add a simple light guide and collect data
- Also construct full scale prototype (with same stack configuration) and with full light guide

Director's Review Recommendations (Shower-max related)

- Splashback from the Shower Max Detector should be simulated to see the impact on the Thin Detector ring signals
- Cross-talk between detector regions due to showering in the support structure of the Thin Detector should be simulated. If a straightforward aluminum frame turns out to be problematic, a more expensive and challenging carbon frame option could be investigated.
- Conduct radiation damage tests to at least 50MRad to qualify fused silica for use in the thin detector.
- Estimate the Qweak double-difference systematic (go beyond crude estimate presented by Kent on the second morning in closed session) for both quartz and shower-max detectors.

Backup Slides

LG reflectivity radiation hardness study


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

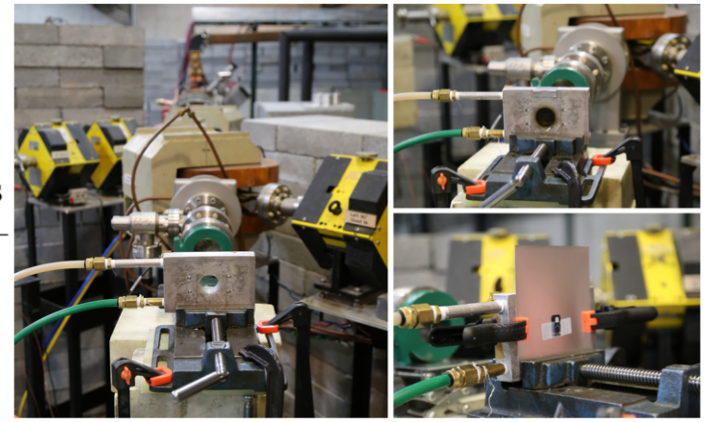
Ports: 0 degree, 45 degree and 90 degree (Beam energy resolution ~ 1+/-15%)

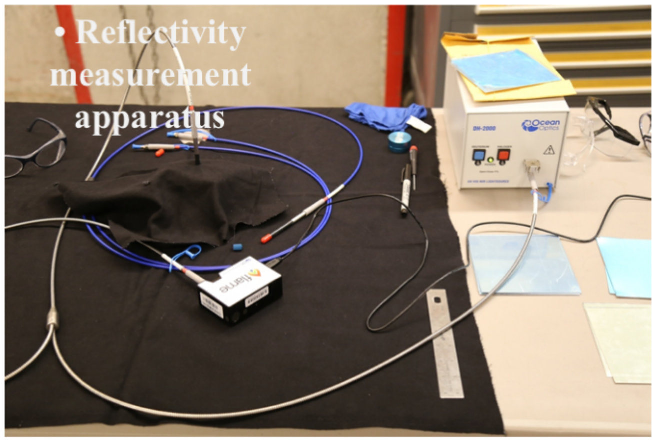
25B Energy vs Current

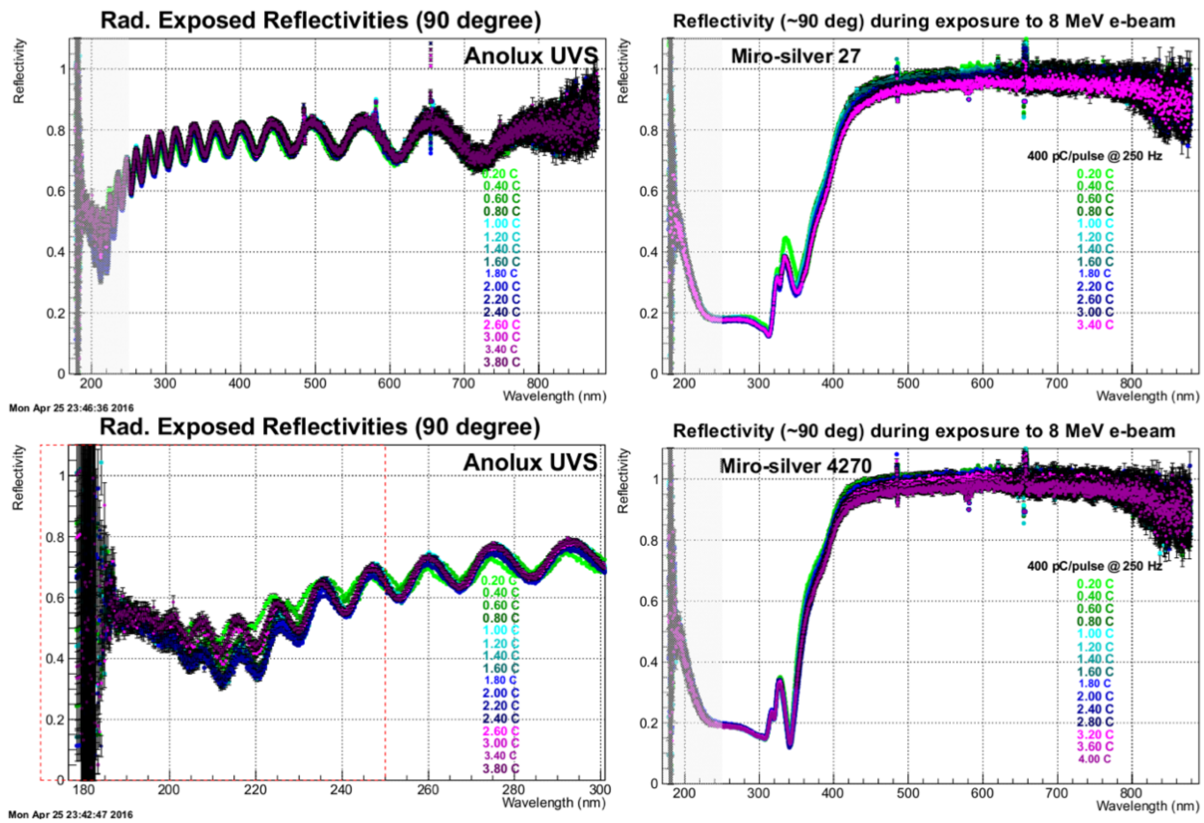
Energy (MeV)	0 port (mA)	45 port (mA)	90 port (mA)
23	55	55 @ 3.8uS	46 @ 3.6 uS
20	100	70 @ 4 uS	65 @ 4 uS
16	100	48 @ 3.6 uS	48 @ 3.6 uS
13	80	30 @ 3.3 uS	15 @ 3.3uS
10	60	18 @ 3 uS	7.5 @ 3 uS
9	110	30 @ 4uS	15 @ 4 uS
6	100	60 @ 4 uS	60 @ 4 uS
4	50	20 @ 4 uS	20 @ 4 uS

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

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



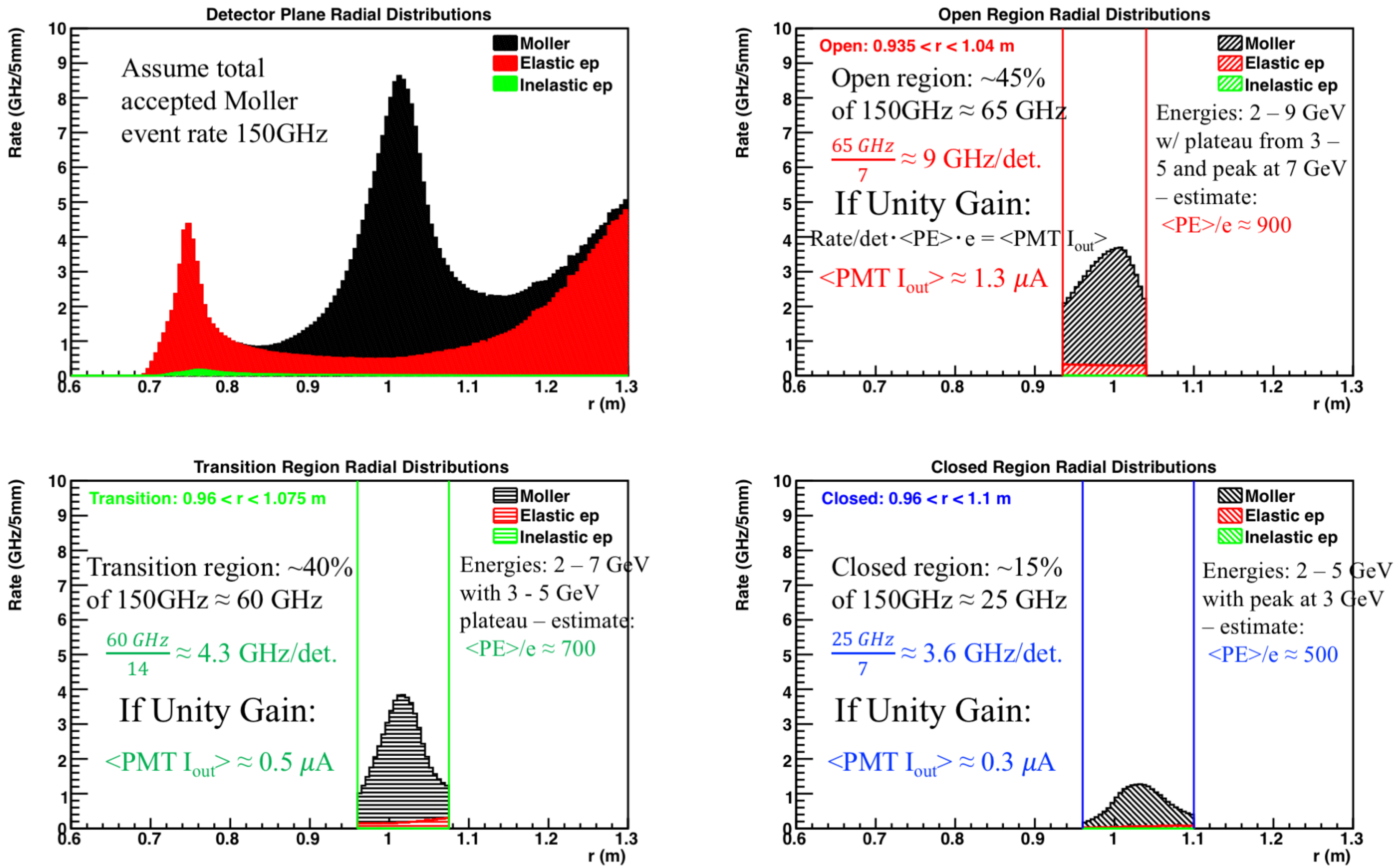




Irradiated several light guide material samples over a 3 day period from Mar 22 - 24, 2016:

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

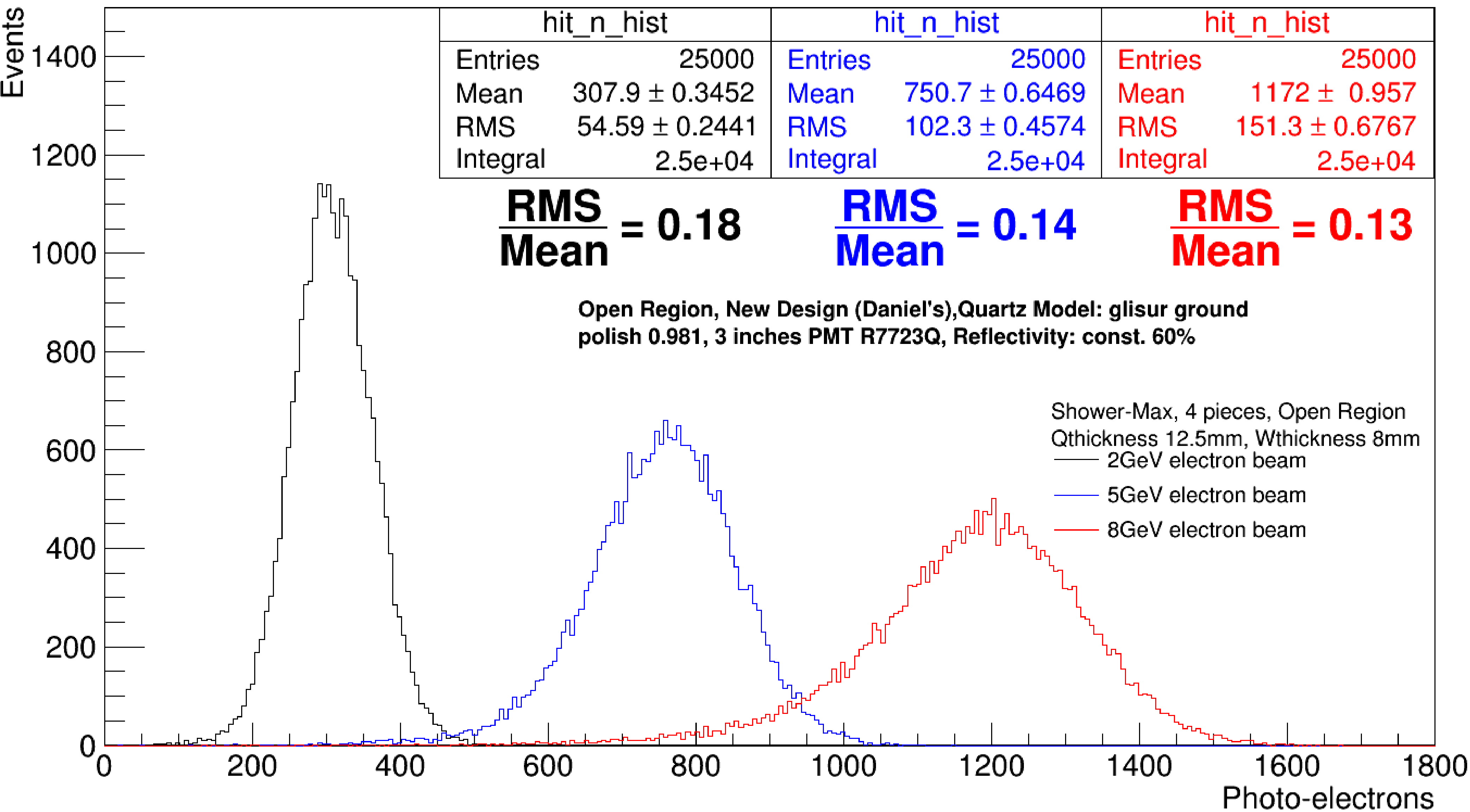
Unity Gain operation with Baseline design?



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

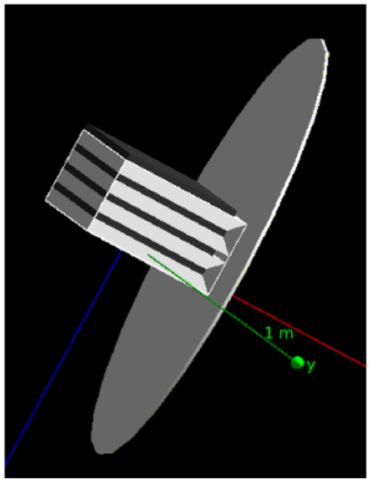
New results from W thickness optimization study

PE Distribution: Showermax Open - 8mm W

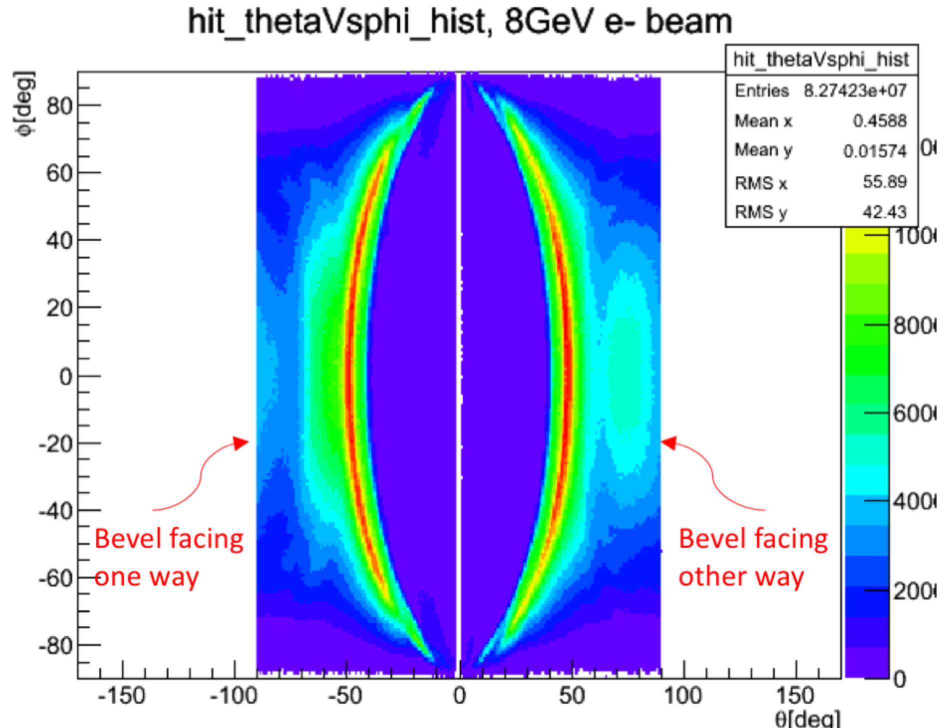


Optimal funnel-mirror angle and length study

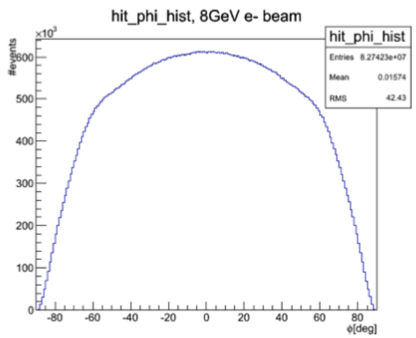
Light exit angle study for optimizing funnel mirror

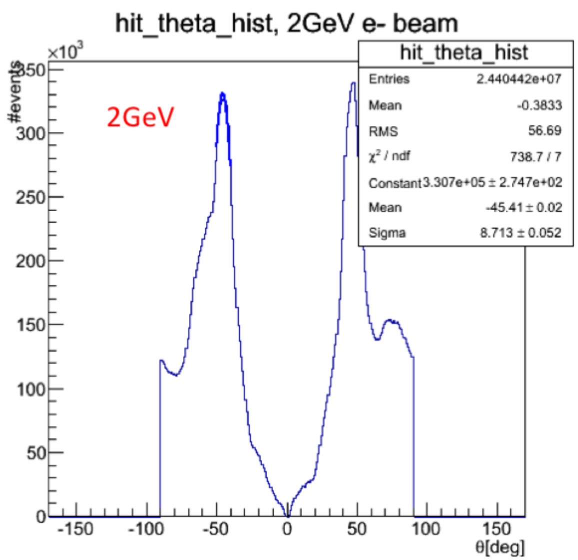


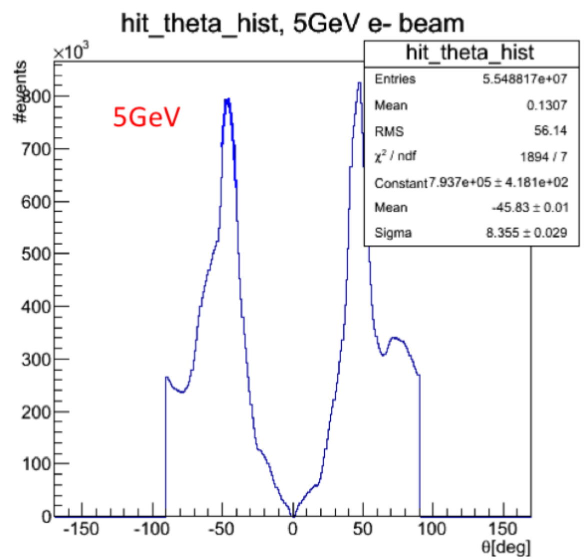
12.5mm quartz, 6mm tungsten, n = 4 layers

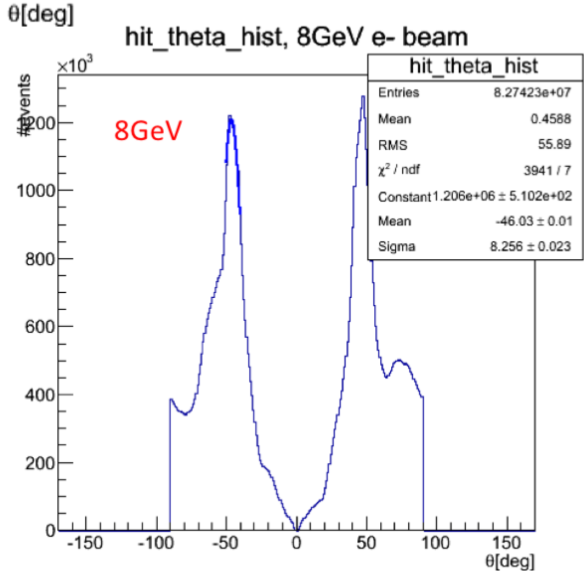


Results:
2GeV → θ_{peak} = 45.4°
5GeV → θ_{peak} = 45.8°
8GeV → θ_{peak} = 46.0°



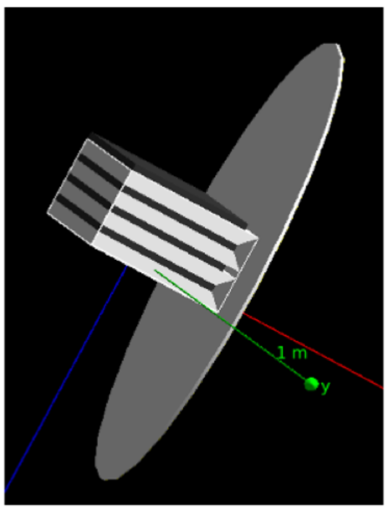




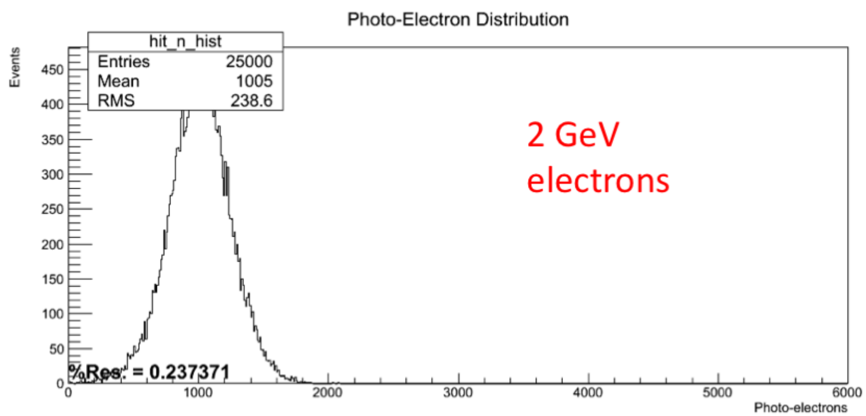


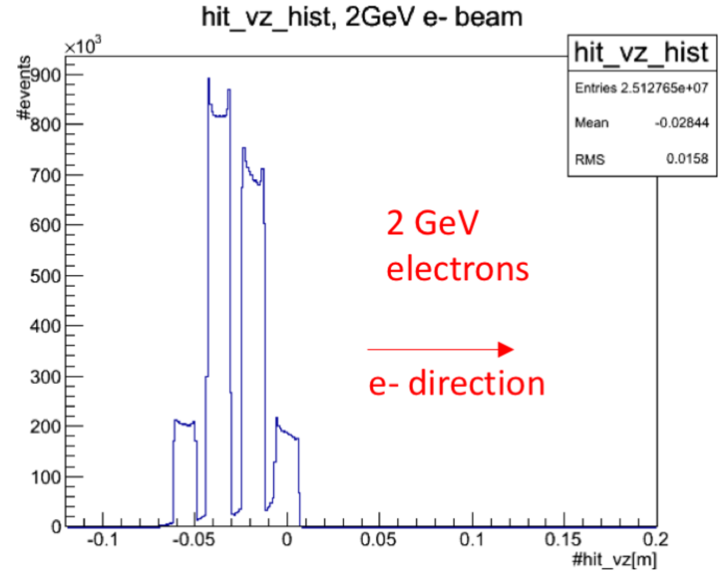
Which layers give the most light?

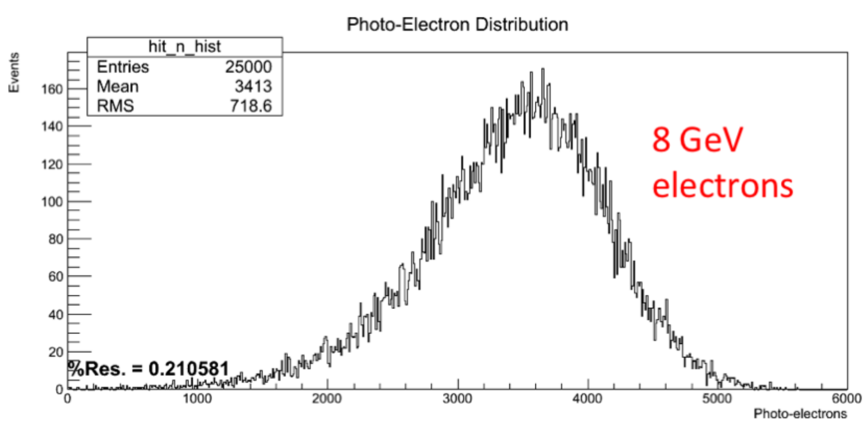
Light exit study for optimizing No. of layers

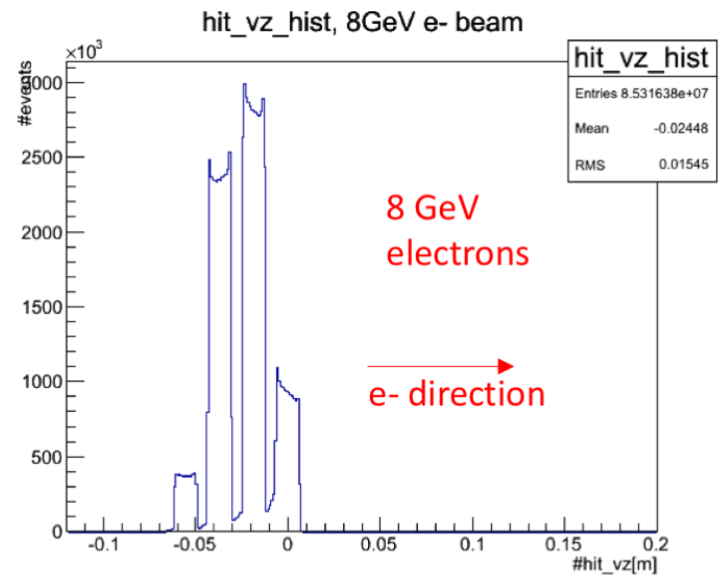


12.5mm quartz, 6mm tungsten, n = 4 layers





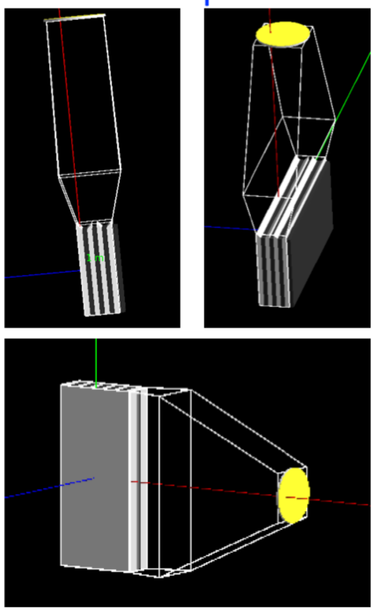


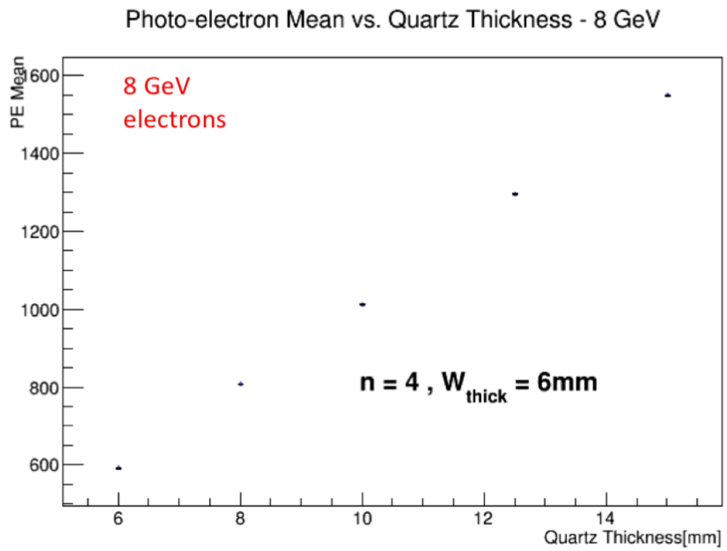


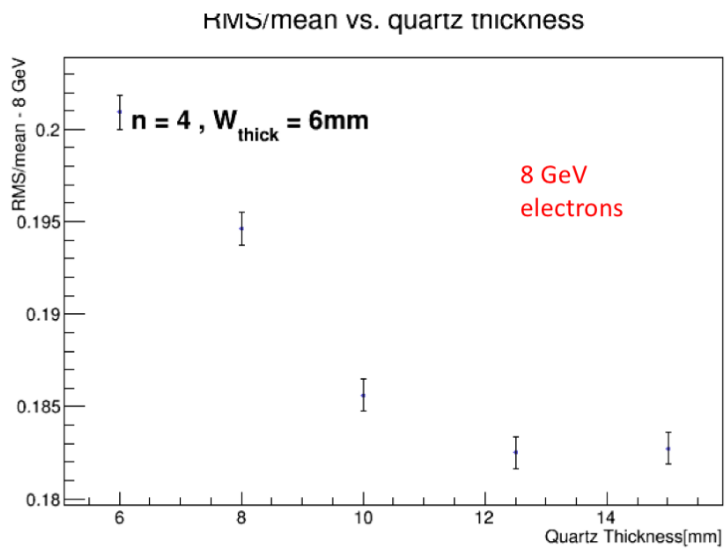
Optimization study (8 GeV):

6mm thick tungsten, variable quartz thickness

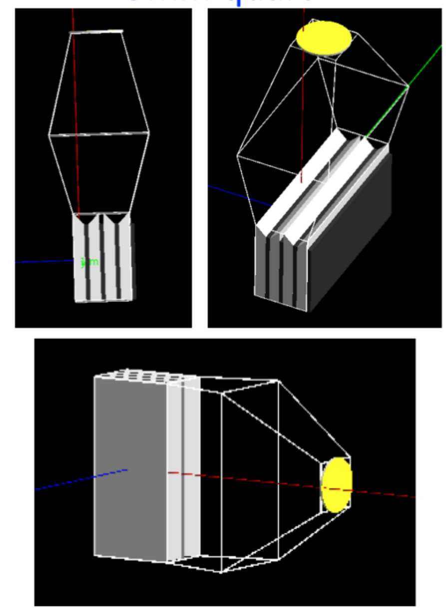
6mm quartz

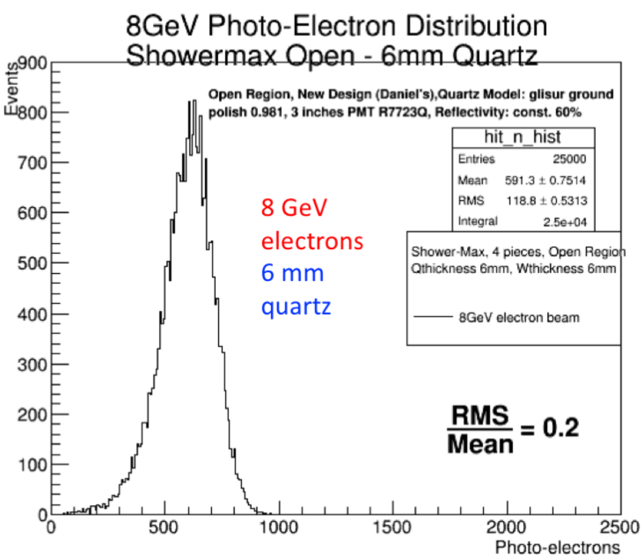


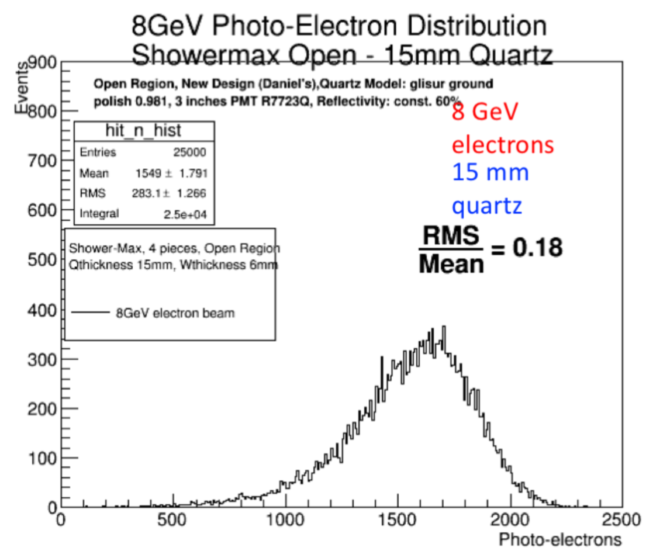




15mm quartz

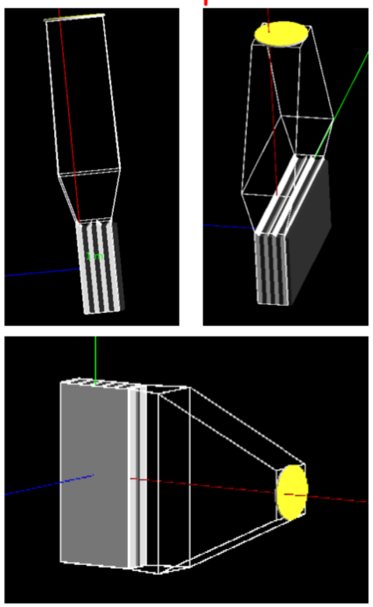


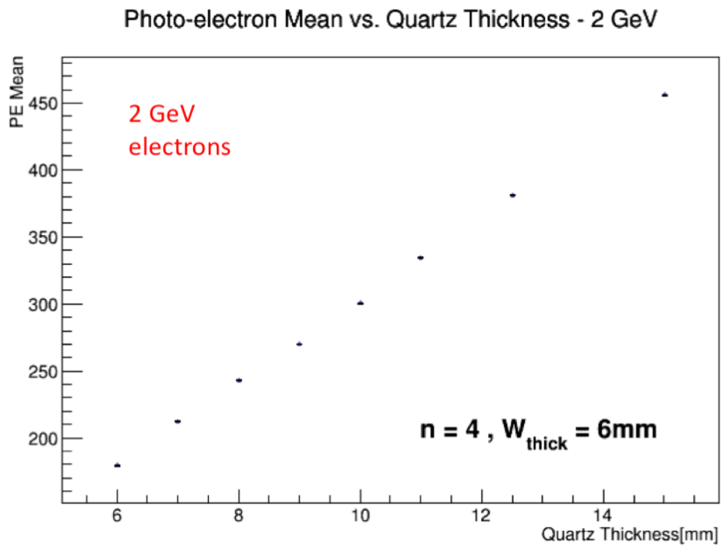




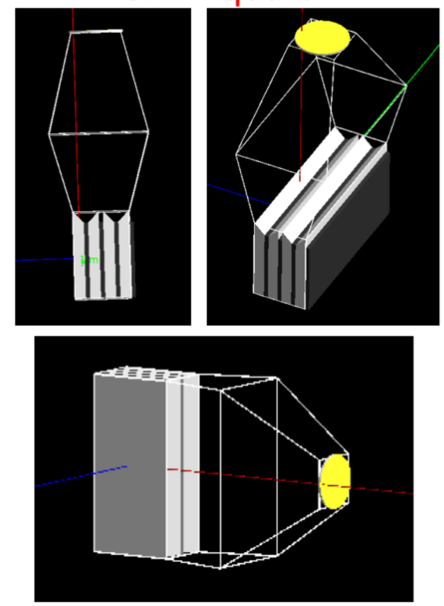
Optimization study1 (2 GeV): 6mm thick tungsten, variable quartz thickness

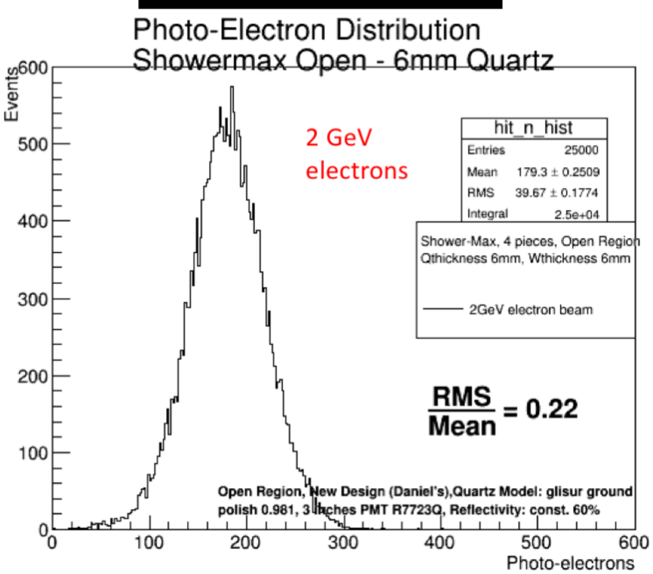
6mm quartz

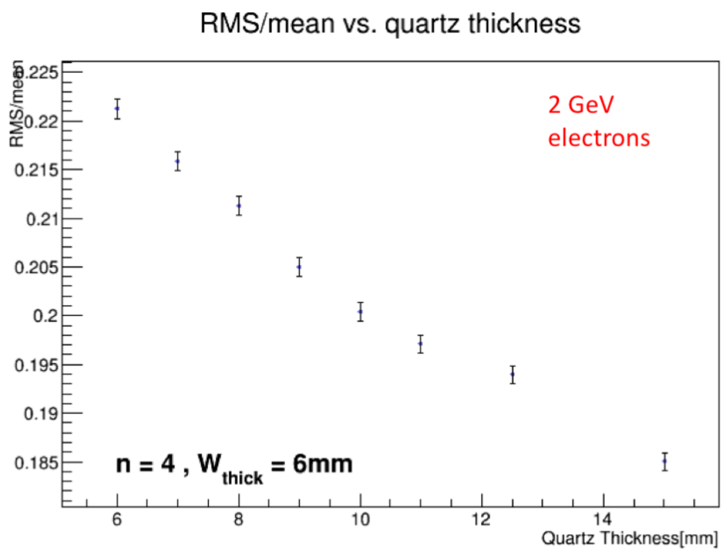


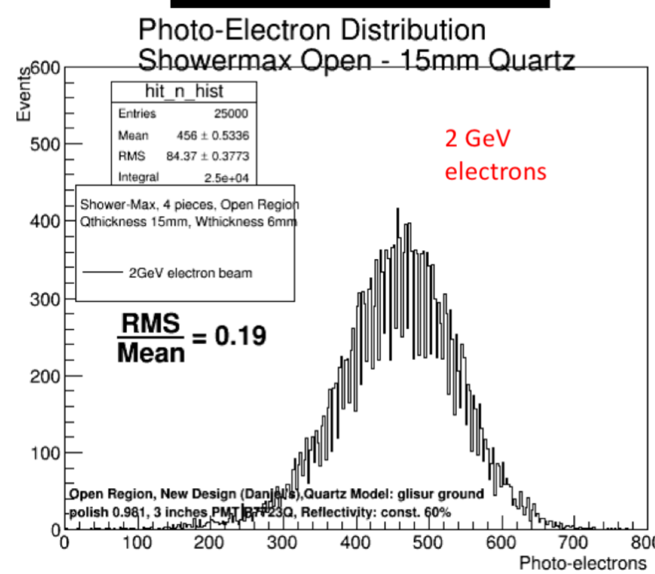


15mm quartz





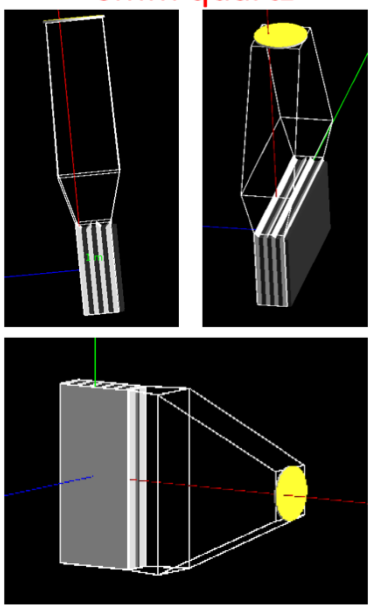


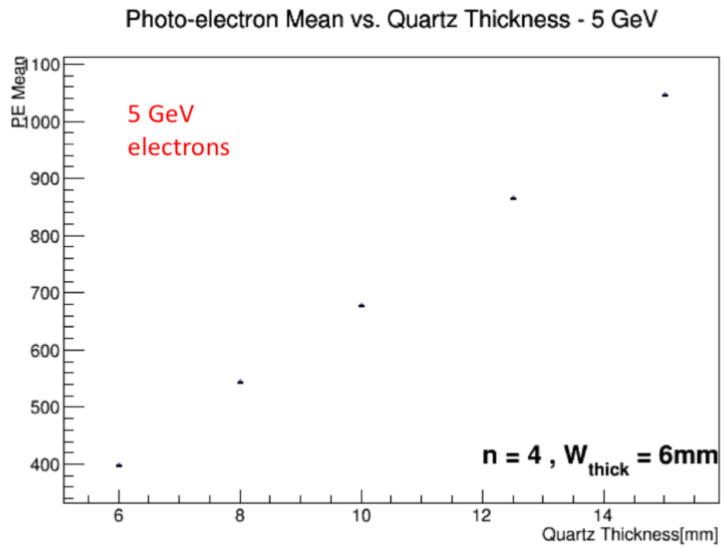


Optimization study1 (5 GeV):

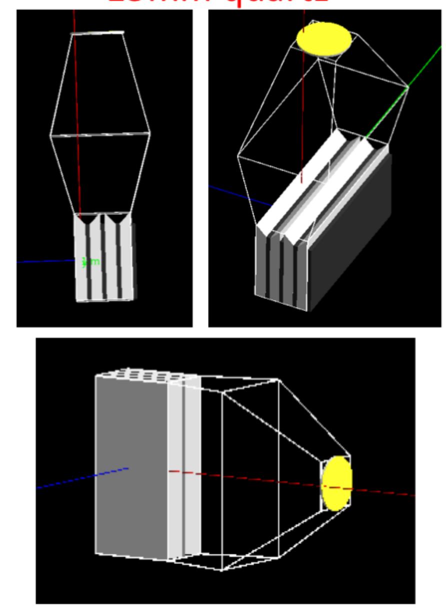
6mm thick tungsten, variable quartz thickness

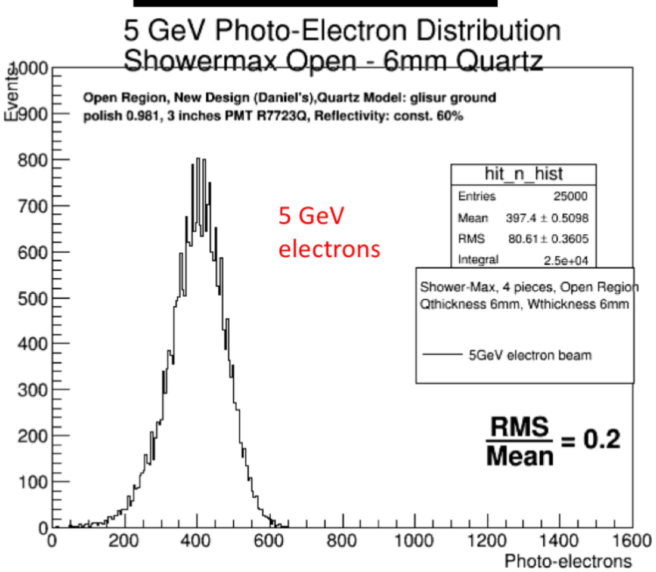
6mm quartz

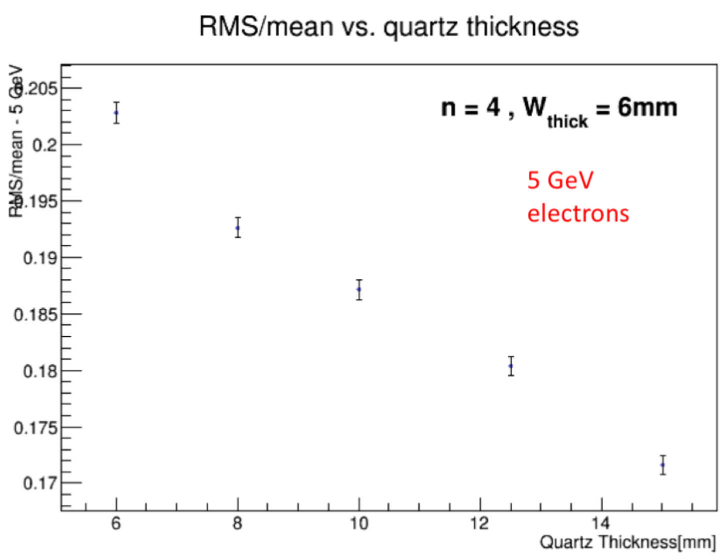


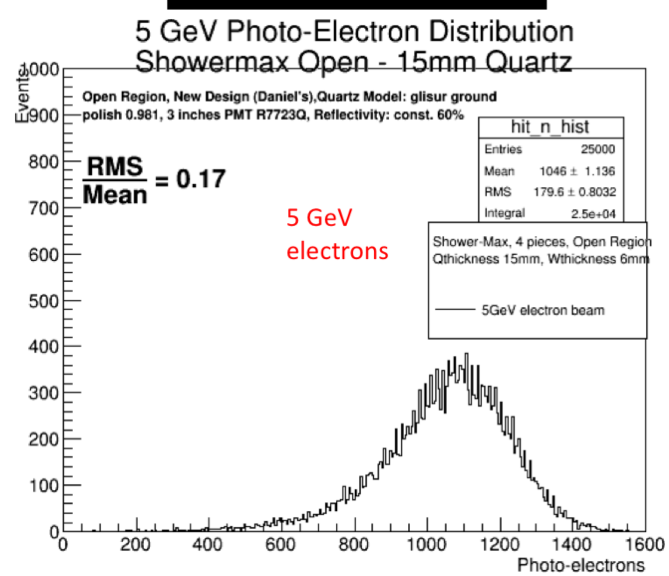


15mm quartz

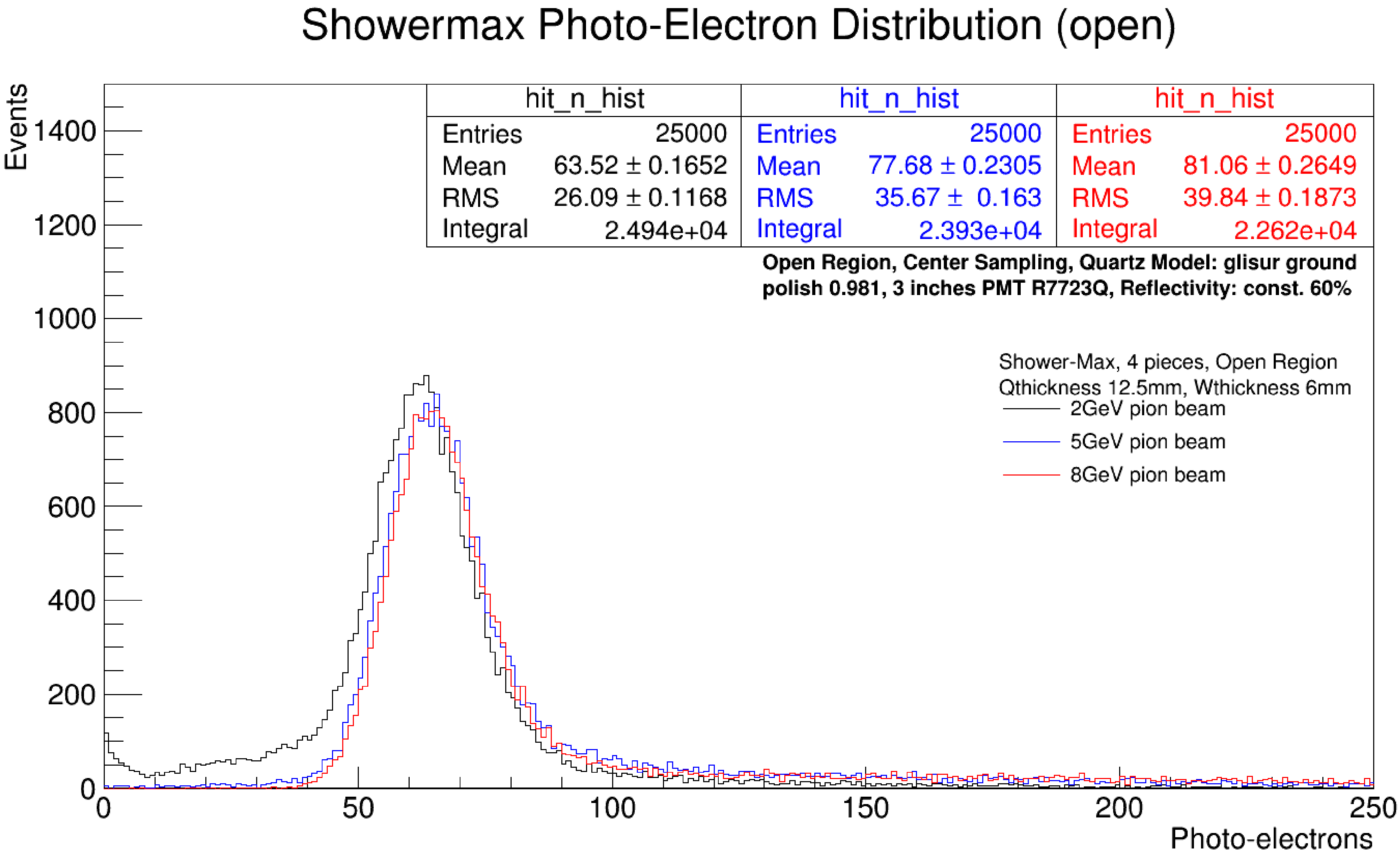




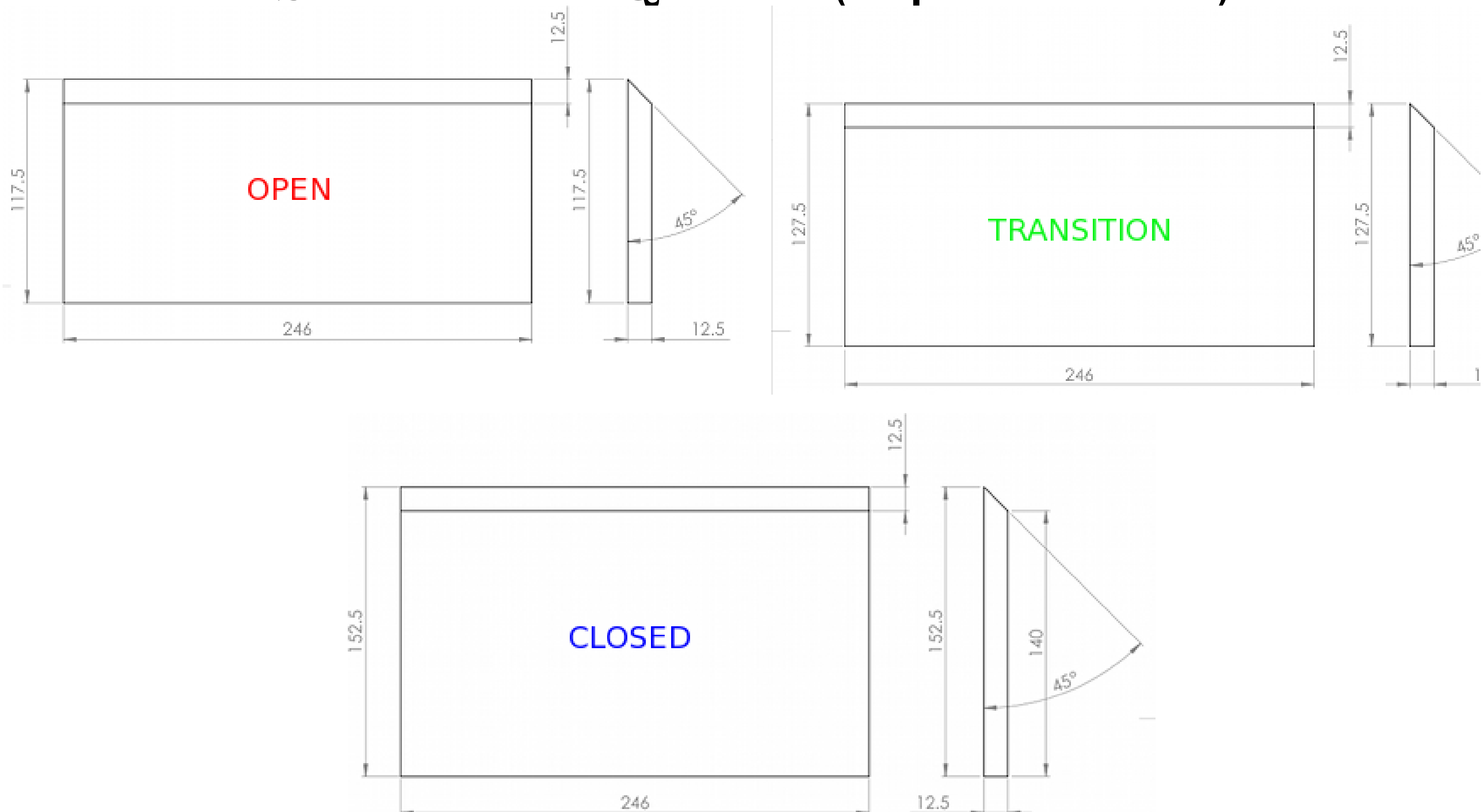




Baseline design PE Distributions for Pions

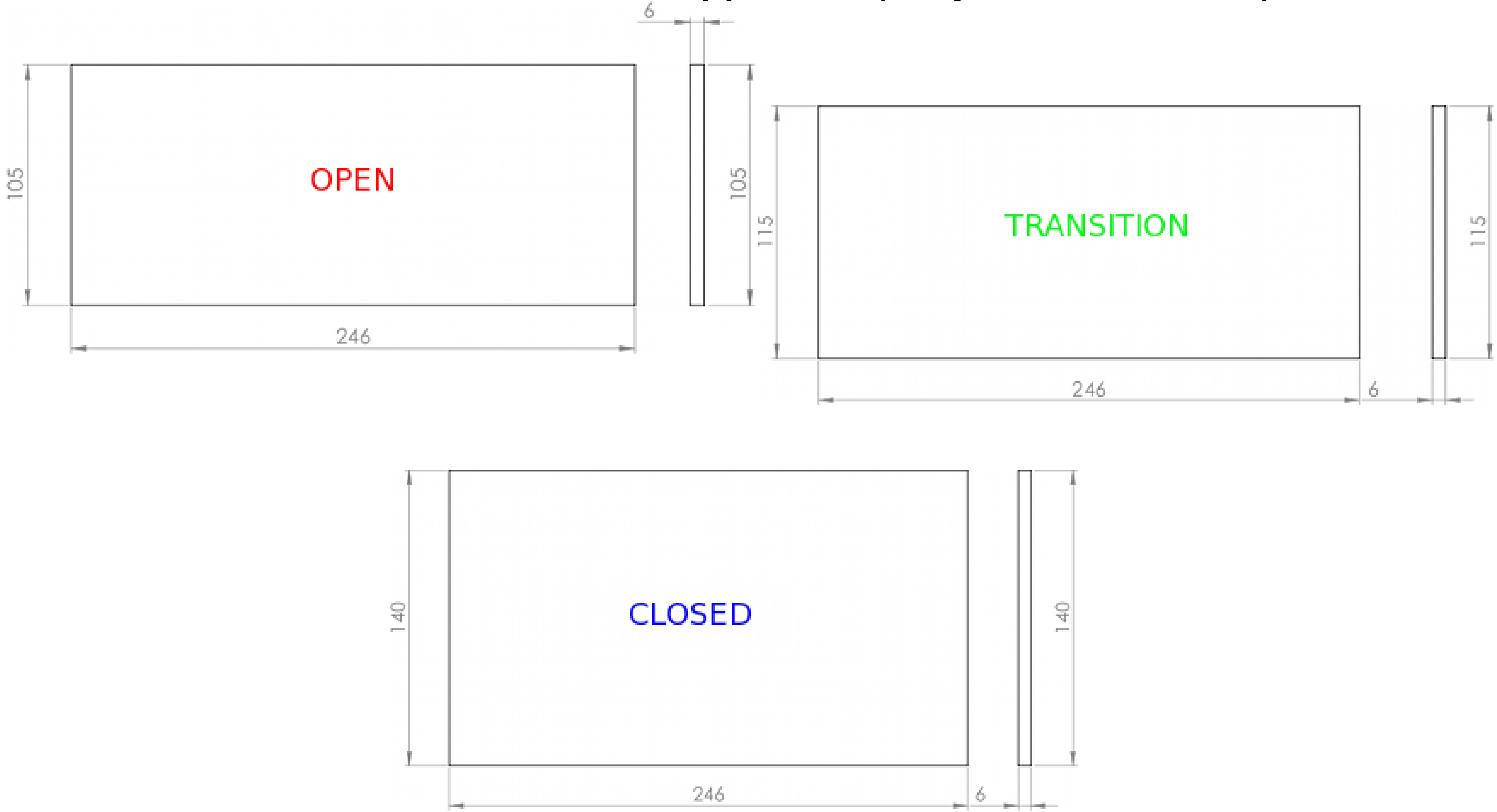


Showermax Quartz (4 piece stack)



Spectrosil 2000: One 45 degree polished face, all surfaces polished to 20 Angstroms or better, no small edge/corner bevels. Heraeus quote: ~$1100 per piece. $150k total.

Showermax Tungsten (4 piece stack)



99.95% purity; ±0.005” tolerances. Received quote from company ”Marketech”: OPEN–\$484/piece (\$13.6k), CLOSED–\$647/piece (\$18.1k) TRANSITION–\$511/piece (\$28.6k); total tungsten cost is \$60.2k.

Prototype stack support structure and LG

(CAD and renders by Daniel)