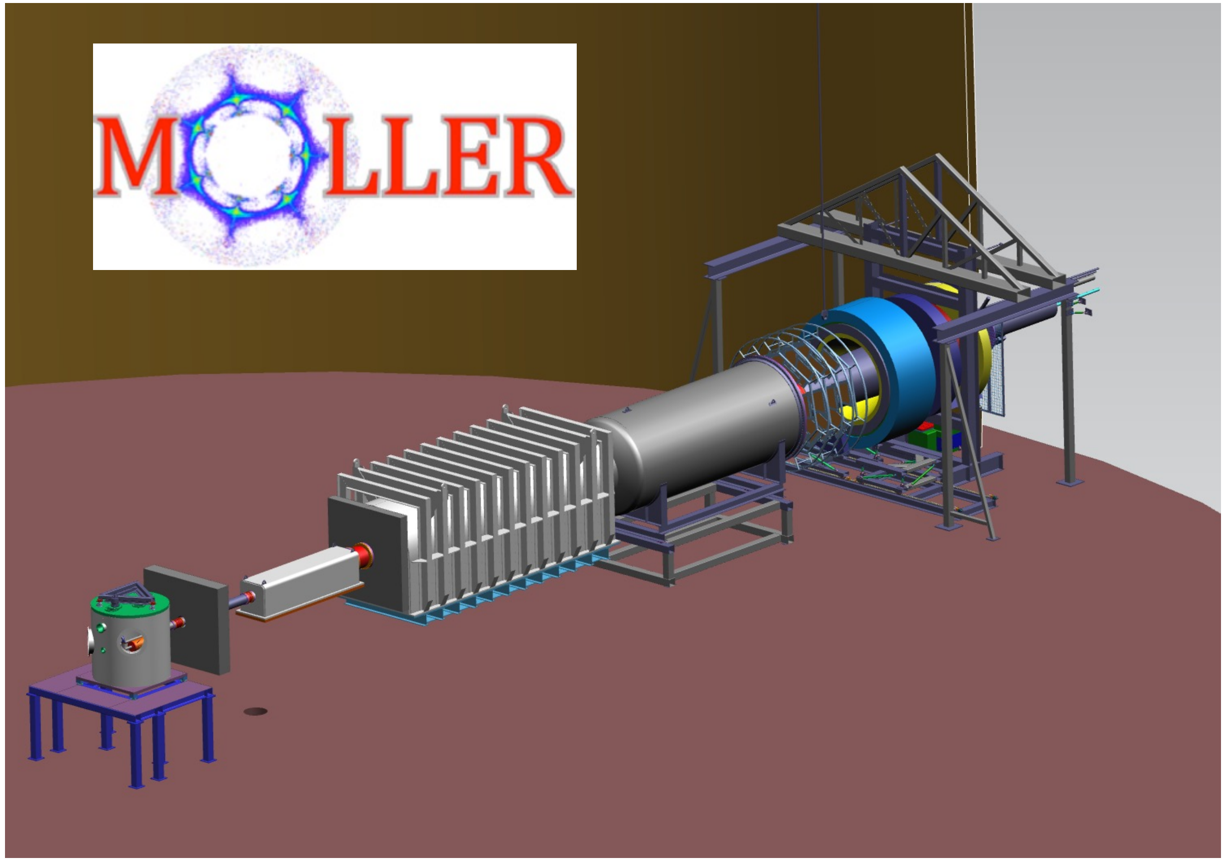
Shower-max, Main Detector cabling, Quartz Irradiation Tests



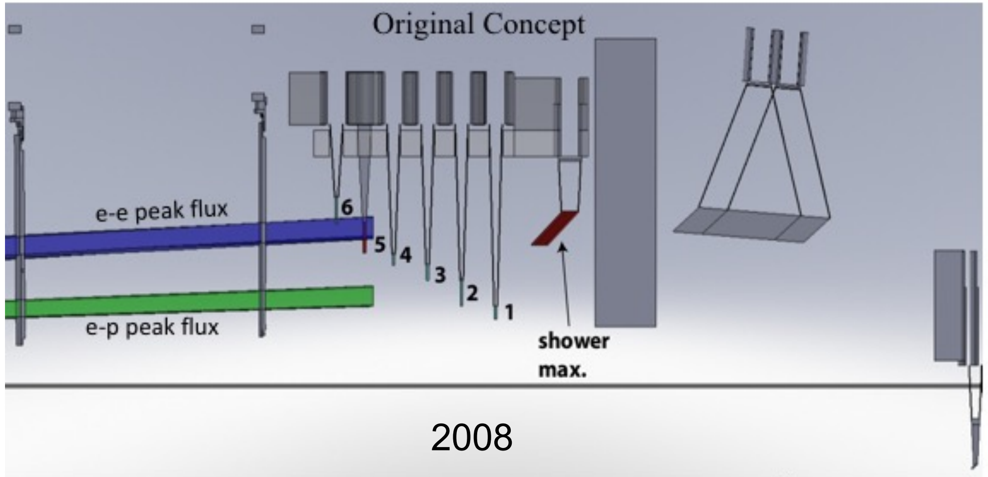
Dustin McNulty – Idaho State University

Outline

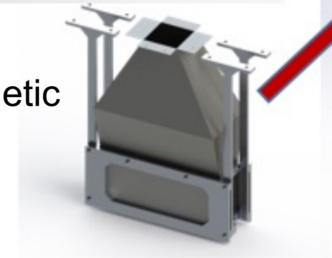
- Shower-max update
  - Subsystem review
  - Schedule timeline and budget
  - Recent design updates and preparations for 60% Design Review
  - Summary and future work
- Detector Cabling
  - Overview: cabling infrastructure
  - Patch panels and cable routing
  - Main detector barrel 1/28 segment wiring (initial ideas)
  - Summary and future work
- Quartz Irradiation Testing
  - Overview:
  - Recent Tests: details and data
  - Summary and future tests

Shower-max Description

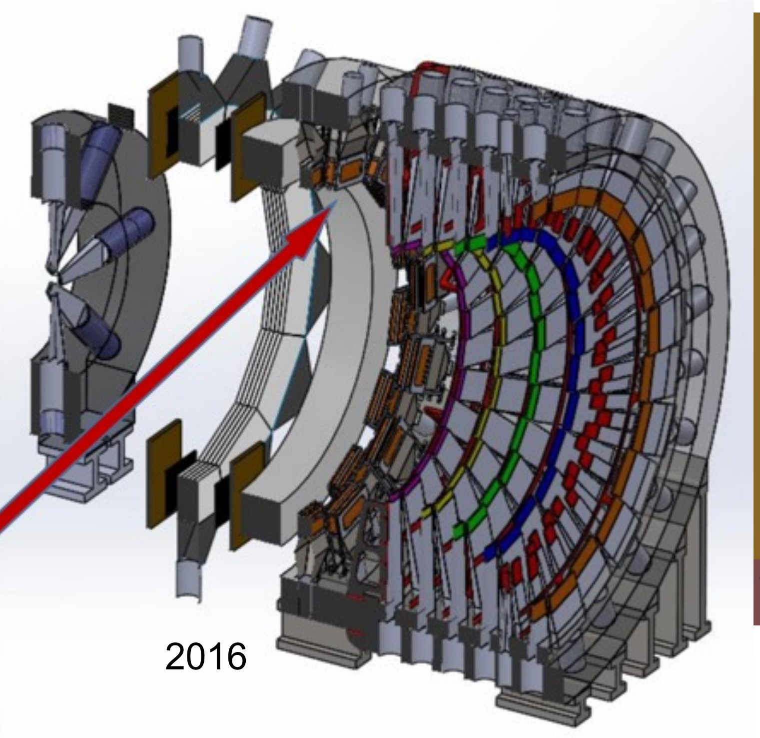
2.04.03	Shower Max Detector	Design, Procurement, Assembly, and Test of the Shower-Max detector system. It is composed of an array interleaved layers of quartz radiatiors and thin tungsten sheets making up an EM shower detector system.



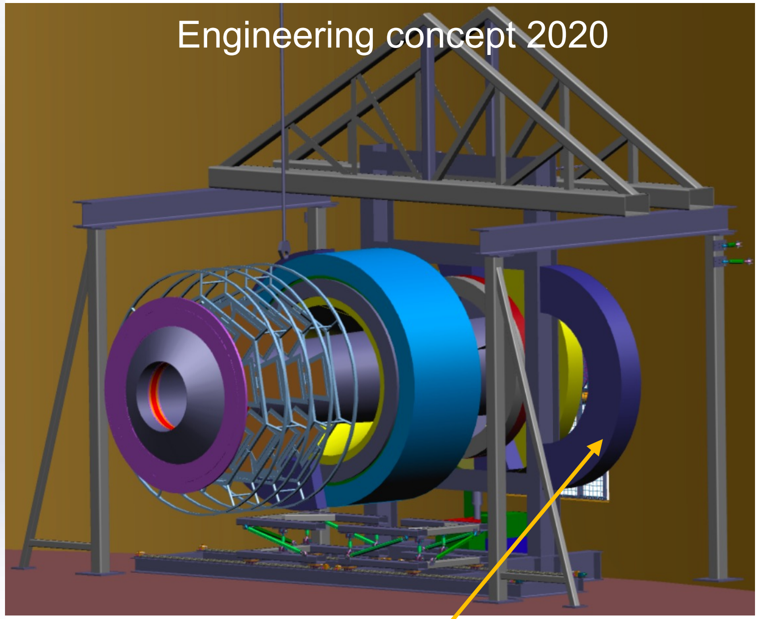
2008



Electromagnetic sampling calorimeter



2016



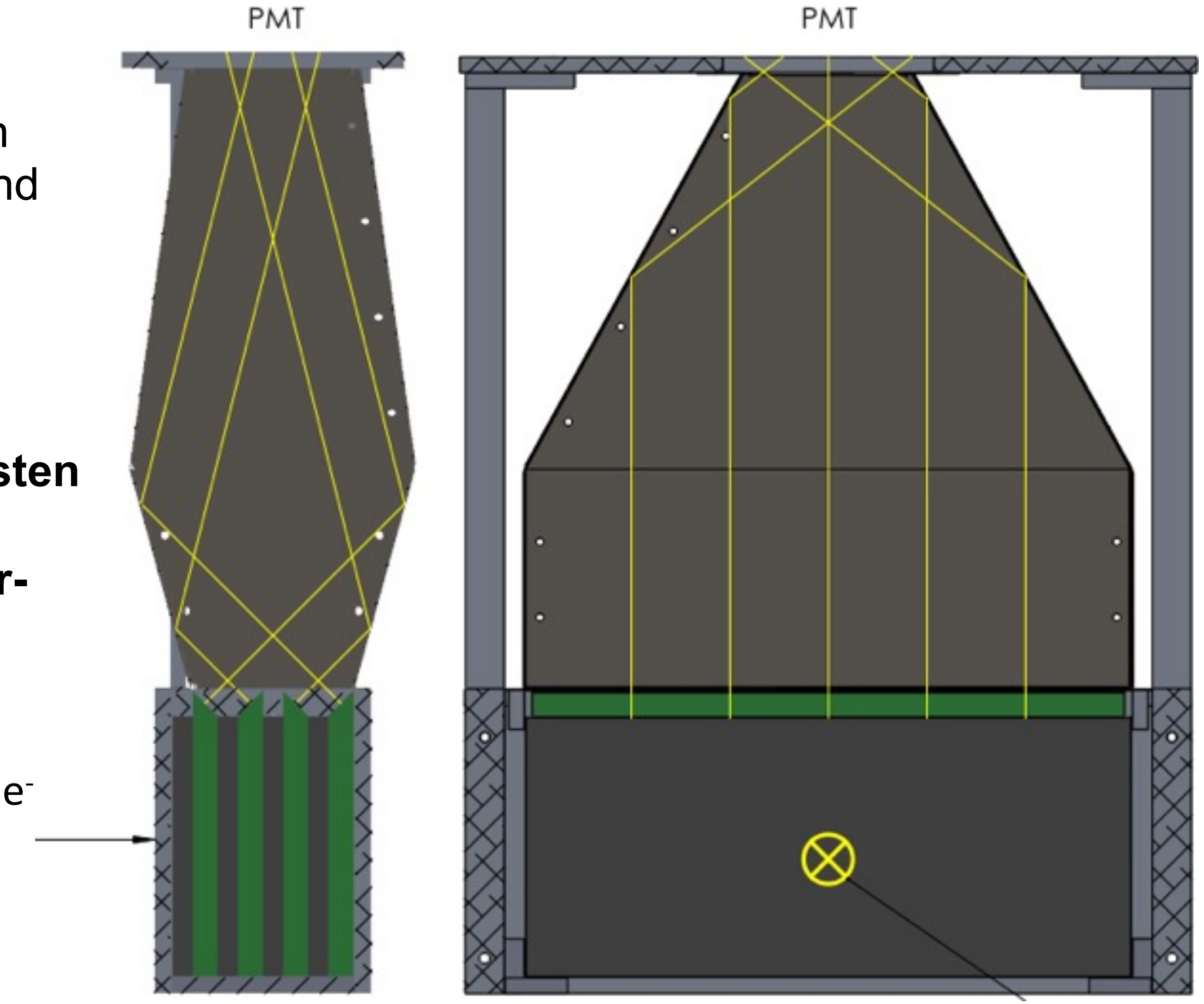
Shower-max Clam shell

- Provides additional measurement of Ring-5 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
- Will have good resolution over full energy range ($\lesssim 25\%$), radiation hard with long term stability and good linearity

Shower-max: Detector Concept and Materials

- 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:
    - ➢ Design uses a **4-layer "stack"** with **8 mm tungsten** and **10 (or 6) mm quartz** pieces
    - ➢ Cherenkov light directed to **3 inch PMT** using **air-core, aluminum light guide**



Materials:

- Aluminum chassis
- Light guides are aluminum specular reflectors (Anolux Miro-silver 27)
- High purity tungsten and quartz
- Total radiation length: 9.1 X_0 tungsten + 0.4 X_0 quartz = 9.5 X_0; Molière radius ~ 1.1 cm

Shower-max: Past Prototyping and Testbeam

Prototypes constructed in 2018: both Full-scale and Benchmarking versions with two different "stack" configurations:

- 8 mm thick tungsten and 10 mm thick quartz (1A)
- 8 mm thick tungsten and 6 mm thick quartz (1B)

SLAC testbeam T-577 run: Dec 6 – 12, 2018

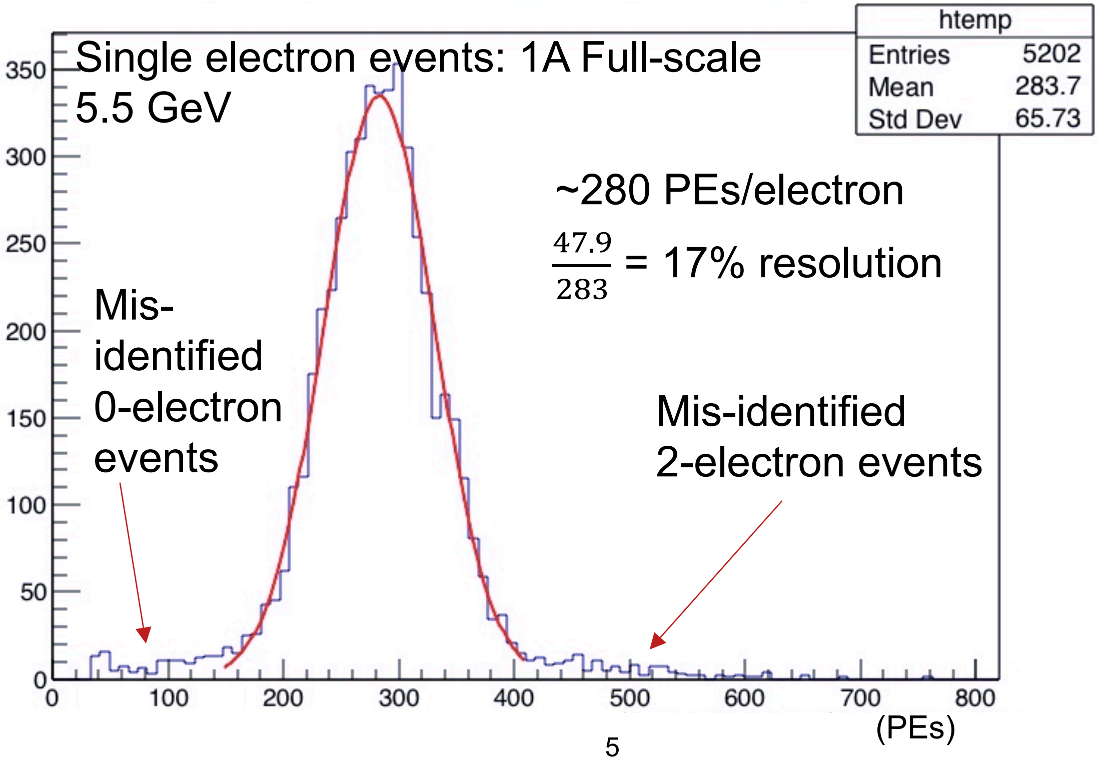
- Exposed prototypes to 3, 5.5, and 8 GeV electrons
- Validated our optical Monte Carlo with benchmarking prototype

--Stack design validated: number of layers/thicknesses; yields and resolutions match G4 predictions

- Prototype beam performance sufficient for MOLLER and 2nd pass mechanical design improvements underway →

Full-scale prototype: 12 cm x 25 cm active area

- 1st-pass engineered design concept vetted
- Light guide construction techniques developed



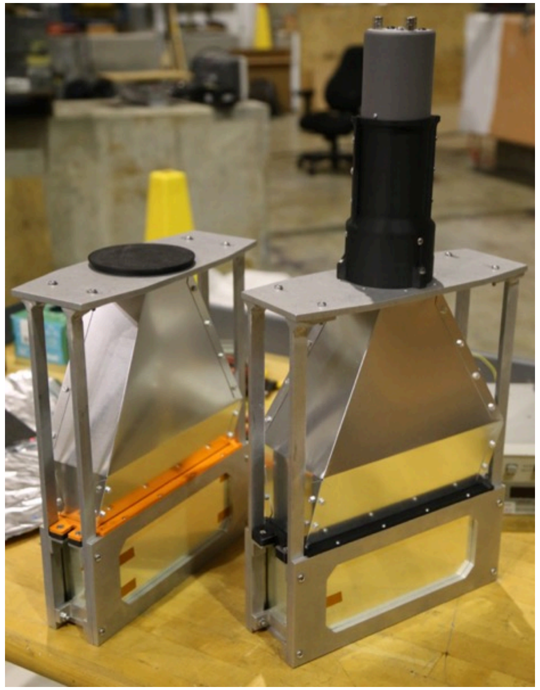
Single electron events: 1A Full-scale 5.5 GeV

~280 PEs/electron

$\frac{47.9}{283}$ = 17% resolution

Mis-identified 0-electron events

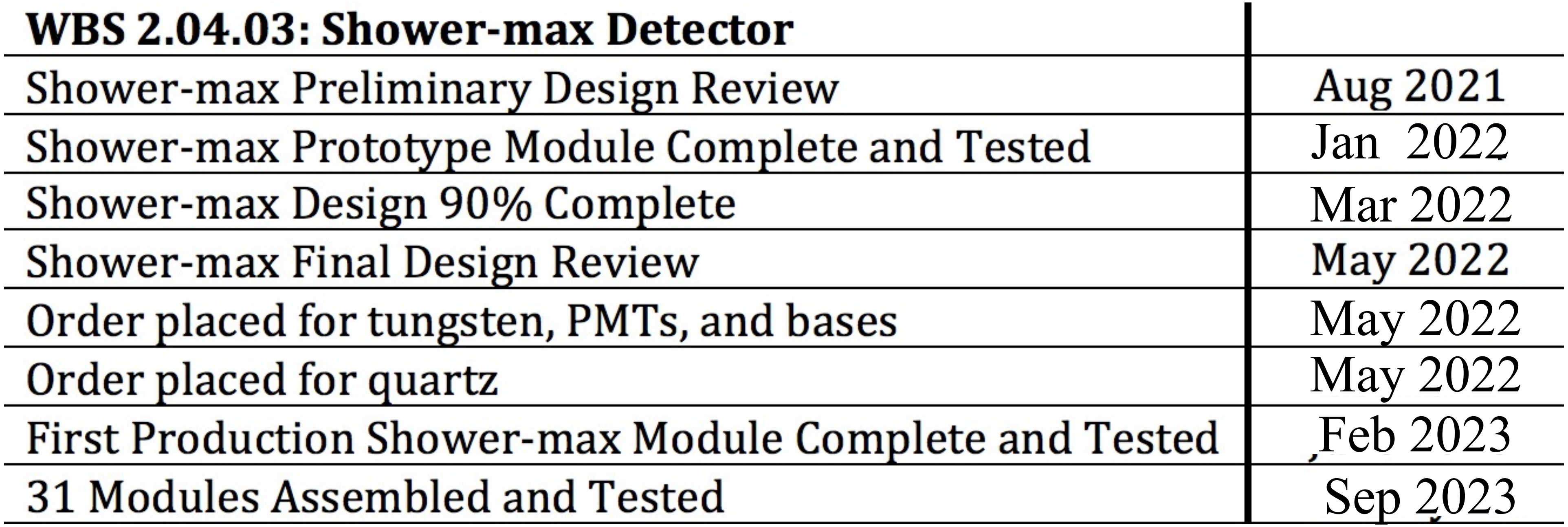
Mis-identified 2-electron events



Shower-max Construction Plans

- Year-1: includes minor design tweaks, optical and mechanical, based on initial SLAC testbeam results; construction of a “production-level” prototype and second beamtest at FNAL in late 2021
- Year-2: design finalized and reviewed before planned large equipment purchases
- Year-3: construction/assembly and testing of all 28 production + 7 spare modules
- Year-4: shower-max modules delivered to Jefferson Lab. Note that shower-max *stack layers* will need to be disassembled for transport and reassembled at JLab

Shower-max Milestone Schedule

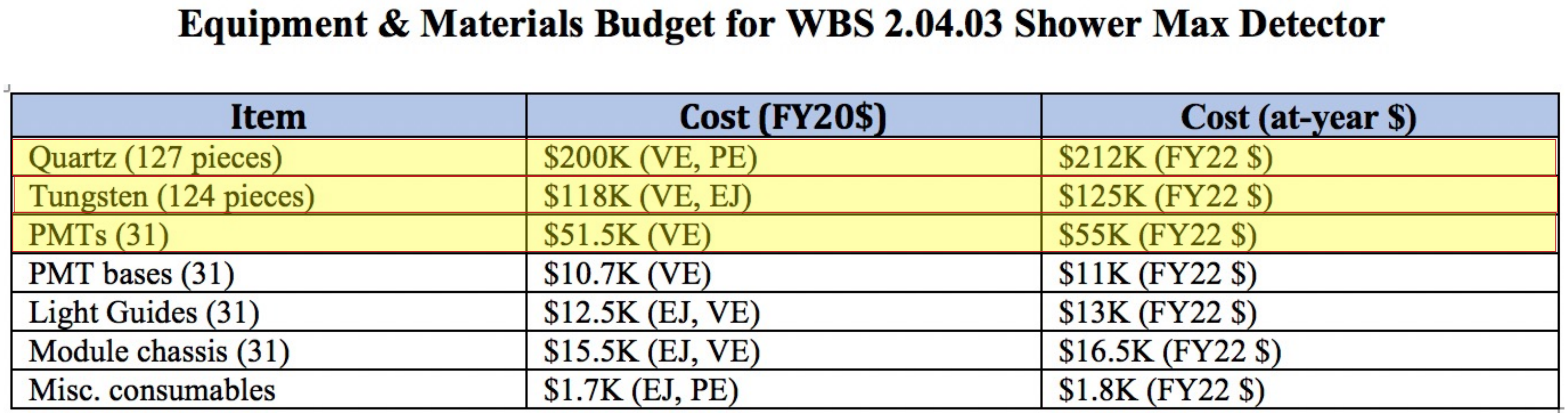


WBS 2.04.03: Shower-max Detector	
Shower-max Preliminary Design Review	Aug 2021
Shower-max Prototype Module Complete and Tested	Jan 2022
Shower-max Design 90% Complete	Mar 2022
Shower-max Final Design Review	May 2022
Order placed for tungsten, PMTs, and bases	May 2022
Order placed for quartz	May 2022
First Production Shower-max Module Complete and Tested	Feb 2023
31 Modules Assembled and Tested	Sep 2023

WBS Activity Schedule

Activity ID	Activity Name	BL Project Start Date	BL Project Finish date
new	Quartz rad-hard testing	1-Apr-21	1-Apr-22
20403010	Shower Max Detector 60% Design Effort	14-Jul-21	20-Aug-21
20403015	Write Specification and Prepare Procurement Package for Shower Max Detector Quartz Prototype	23-Aug-21	27-Aug-21
204030155	Vendor effort Materials for Shower Max Quartz Prototype Module	30-Aug-21	22-Nov-21
204030156	RCV: Materials for Shower Max Quartz Prototype Module	23-Nov-21	23-Nov-21
204030157	Assemble and Test Prototype Shower Max Quartz Module	24-Nov-21	31-Jan-22
20403012	Shower Max Detector 90% Design Effort	1-Feb-22	10-Mar-22
20403025	Prepare Shower Max Detector Quartz Procurement Package (Production)	1-Feb-22	7-Feb-22
20403055	Write Specification and Prepare Procurement Package for the Air Light Guides	8-Feb-22	14-Feb-22
20403095	Write Specification and Prepare Procurement Package for Tungsten Sheets	15-Feb-22	21-Feb-22
20403135	Write Specification and Prepare Procurement Package for Shower Max Detector Phototubes	22-Feb-22	28-Feb-22
20403175	Write Specification and Prepare Procurement Package for Phototube Bases	1-Mar-22	7-Mar-22
20403220	Prepare Shower Max Detector Preamplifier Bases for Photomultiplier Bases Procurement Package	8-Mar-22	14-Mar-22
20403040	Vendor effort Shower Max Detector Quartz	24-May-22	17-Aug-22
20403080	Vendor effort Shower Max Detector Air Light Guides	24-May-22	20-Jul-22
20403120	Vendor effort Shower Max Detector Tungsten Sheets	24-May-22	17-Aug-22
20403160	Vendor effort Shower Max Detector Phototubes	24-May-22	10-Nov-22
20403200	Vendor effort Shower Max Detector Phototube Bases	24-May-22	24-Aug-22
20403235	Vendor effort Shower Max Detector Preamplifier Bases for Photomultiplier Bases	24-May-22	24-Aug-22
20403085	RCV: Shower Max Detector Air Light Guides	21-Jul-22	21-Jul-22
20403090	Assemble and Inspect Air Light Guides	22-Jul-22	15-Aug-22
20403045	RCV: Shower Max Detector Quartz	18-Aug-22	18-Aug-22
20403125	RCV: Shower Max Detector Tungsten Sheets	18-Aug-22	18-Aug-22
20403050	Inspect Quartz	19-Aug-22	16-Sep-22
20403130	Inspect Tungsten Sheets	19-Aug-22	1-Sep-22
20403205	RCV: Shower Max Detector Phototube Bases	25-Aug-22	25-Aug-22
20403240	RCV: Shower Max Detector Preamplifier Bases for Photomultiplier Bases	25-Aug-22	25-Aug-22
20403210	Inspect Phototube Bases	26-Aug-22	20-Sep-22
20403165	RCV: Shower Max Detector Phototubes	11-Nov-22	11-Nov-22
20403170	Inspect Phototubes	14-Nov-22	6-Dec-22
20403245	Assemble and Test Shower Max Defector Modules	7-Dec-22	1-Aug-23

Budget – equipment/materials



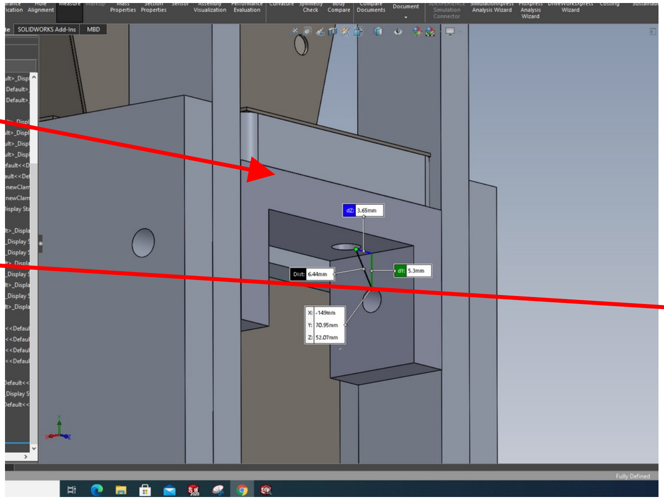
Equipment & Materials Budget for WBS 2.04.03 Shower Max Detector

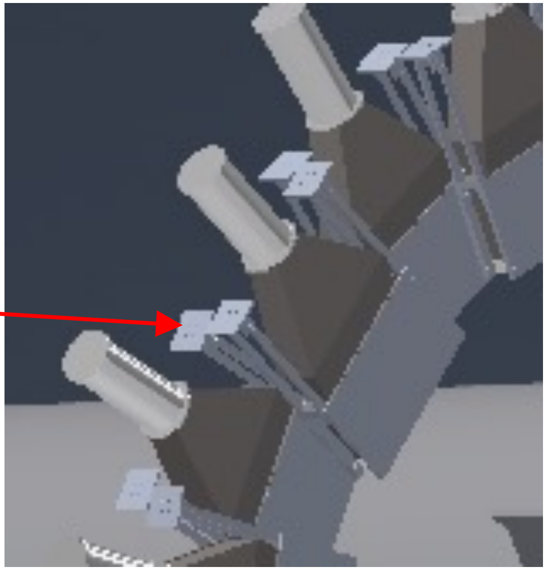
Item	Cost (FY20$)	Cost (at-year $)
Quartz (127 pieces)	$200K (VE, PE)	$212K (FY22 $)
Tungsten (124 pieces)	$118K (VE, EJ)	$125K (FY22 $)
PMTs (31)	$51.5K (VE)	$55K (FY22 $)
PMT bases (31)	$10.7K (VE)	$11K (FY22 $)
Light Guides (31)	$12.5K (EJ, VE)	$13K (FY22 $)
Module chassis (31)	$15.5K (EJ, VE)	$16.5K (FY22 $)
Misc. consumables	$1.7K (EJ, PE)	$1.8K (FY22 $)

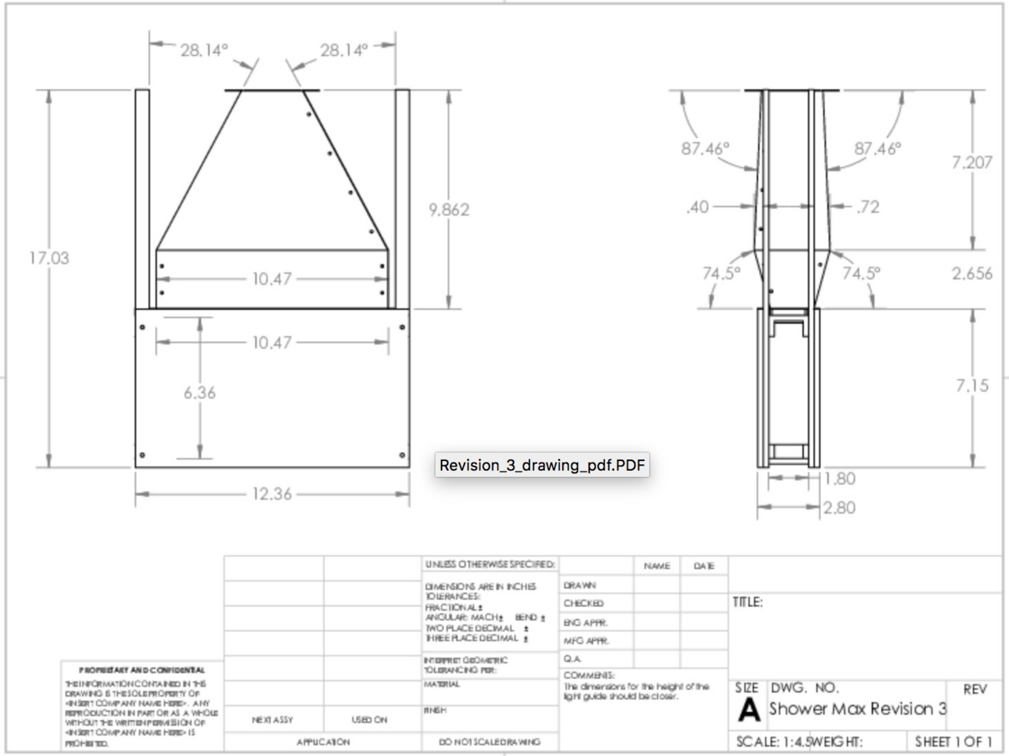
- Large cost items, requiring formal review before purchase, are high-lighted
- FY20 costs have been increased by 3% per year to account for expenditures in FY22. The average equipment and material cost per module is $14K (FY22 $)

Shower-max Design Updates

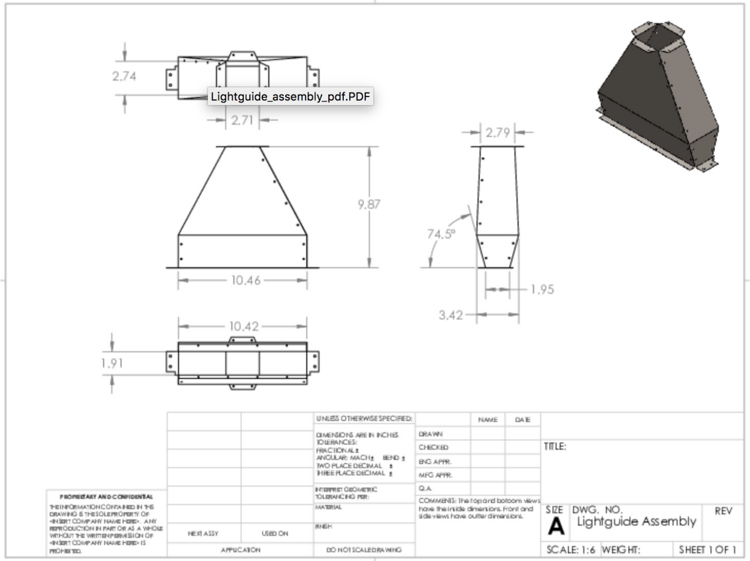
- Beefed up chassis cross-strut supports
- Welds are no longer used on the outer supports, instead use a U-channel cross-strut support with square mounting plate
- Active area 16 cm x 26.5 cm
- 6 mm thick quartz and 8 mm thick tungsten







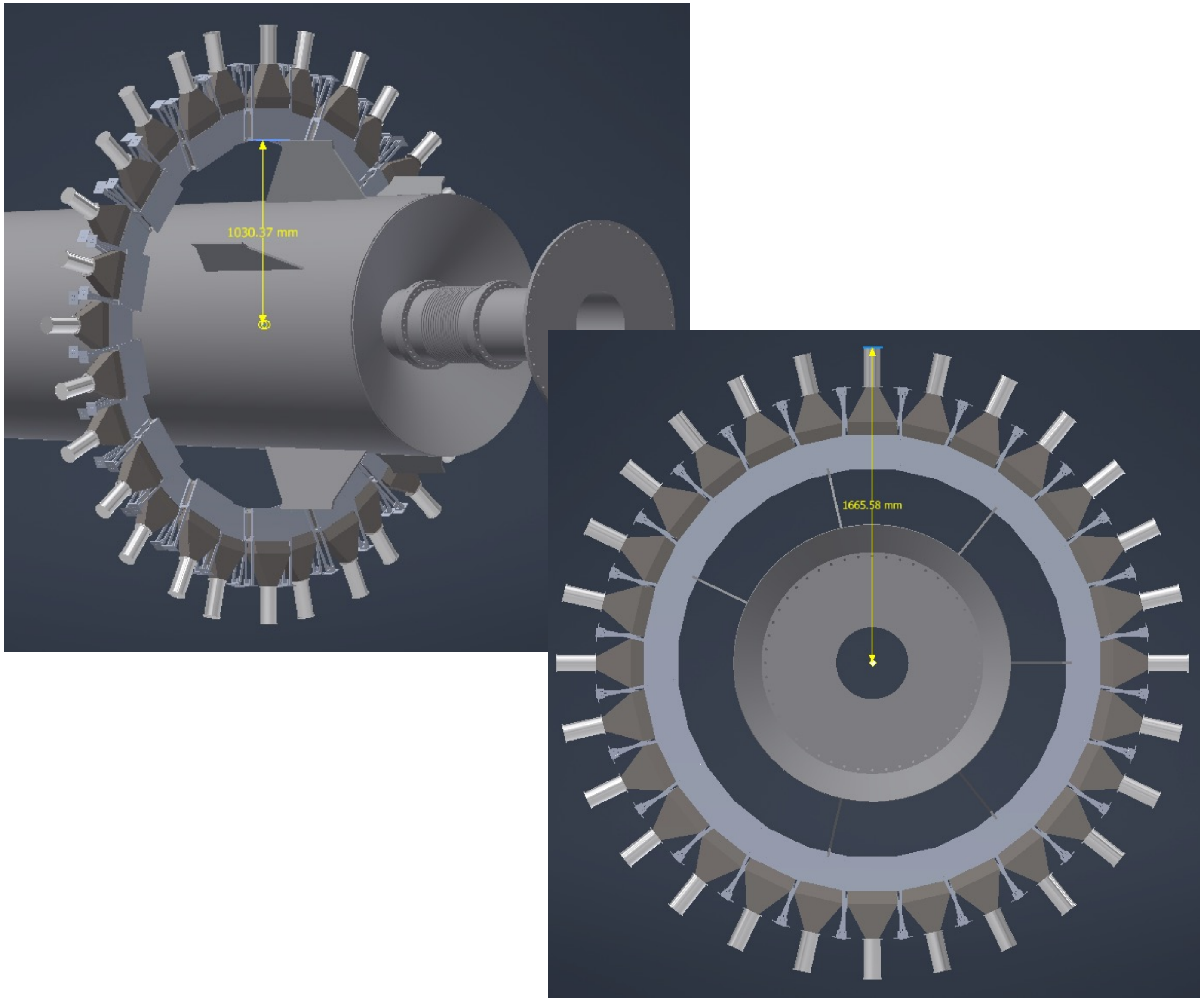
COMMENTS: The dimensions for the height of the light guide should be closer.

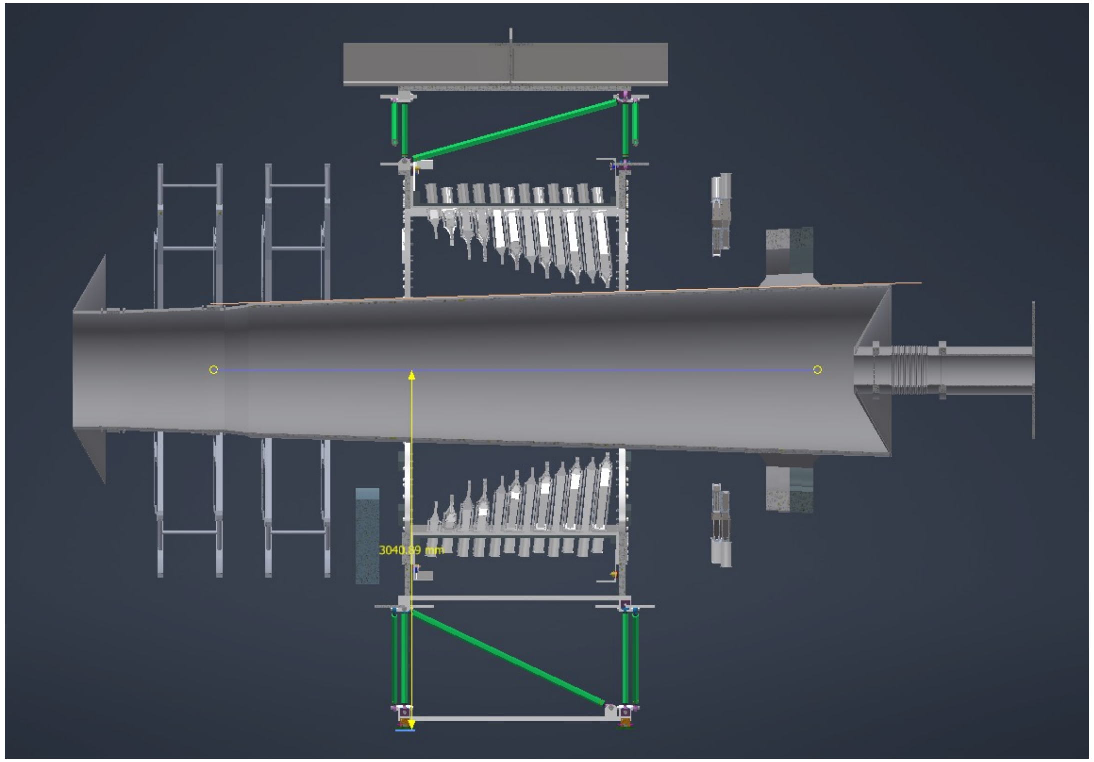


COMMENTS: The top and bottom views have the inside dimensions. Front and side views have outer dimensions.

- Two piece LG design

Shower-max Design Updates





- **Note**: precise z-location and detector tile size and radial position not frozen yet

Shower-max Summary and future work

- Shower-max needs a testbeam somewhere, but can use cosmic-ray test stand for muon beam and connect measurements to the 2018 SLAC testbeam results using Qsim (optical G4 simulator)

- Shower-max z-location and tiling will be 'frozen' within weeks – SM position based on the 'freezing' of ring 5

- We are preparing for the preliminary design review at end of Aug 2021:
  --We are ready to make final adjustments to radiator size, chassis, and lightguide drawings for prototyping
  --Gravity stress tests on the chassis for various ring positions are underway. The chassis appears to work well and may be a bit over-engineered (preliminary). We're looking primarily at deformation/deflections

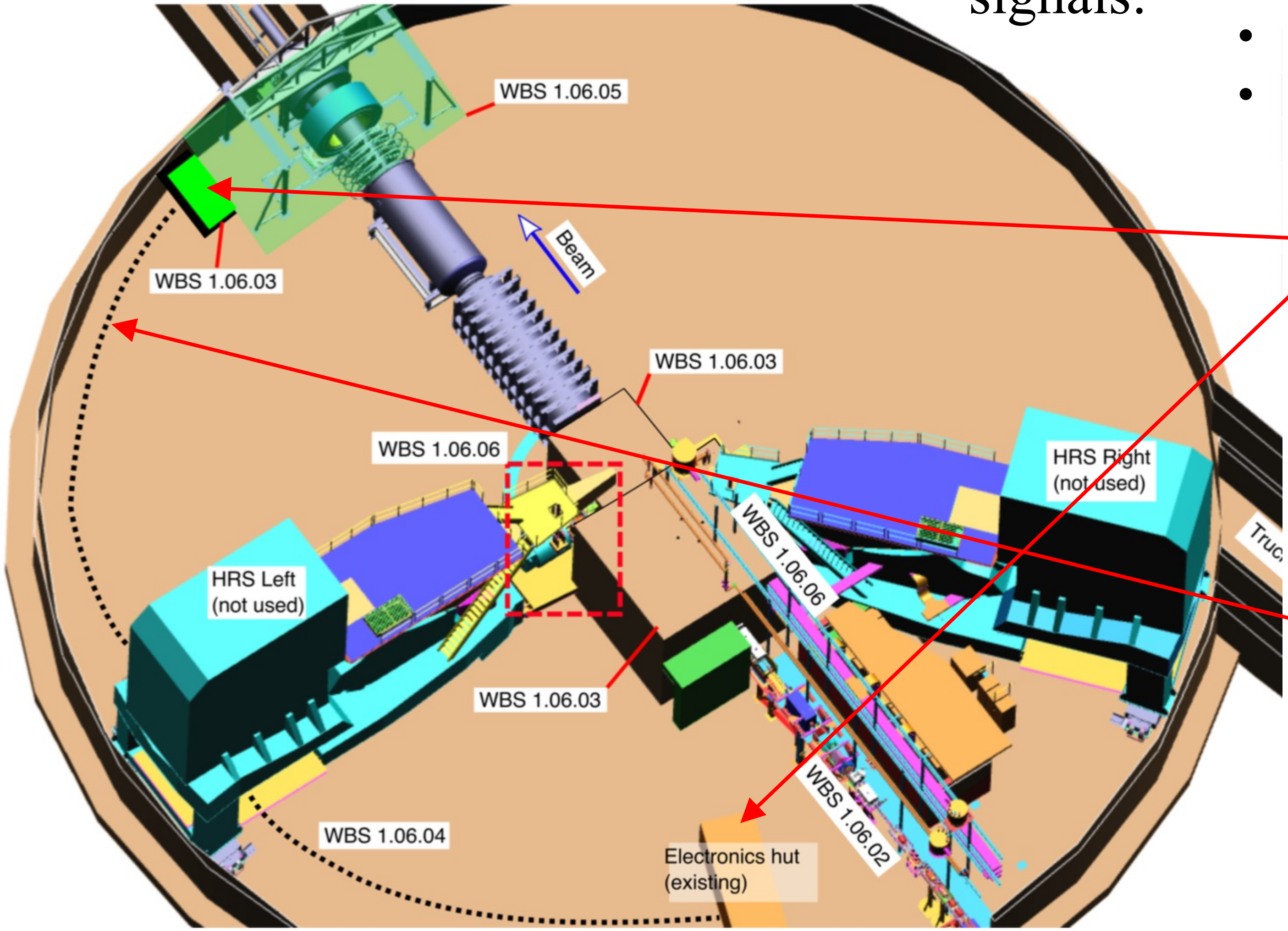
- Waiting for engineered design of outer support (super) structure for finalizing the new outer strut mounting brackets

- New student, Sudip Bhattarai, is/has learned remoll and will perform radiation dose simulation for shower-max quartz layers (and SM PMT location) – plan to complete this summer

- Devising plans for the stack assembly procedure and how to both provide spacing between layers and protect the quartz from scratches: use wrappings or engineer some mechanical way (important for SM)

Detector Cabling

MOLLER Hall Layout



--400 (300) channels integration (counting) mode signals:

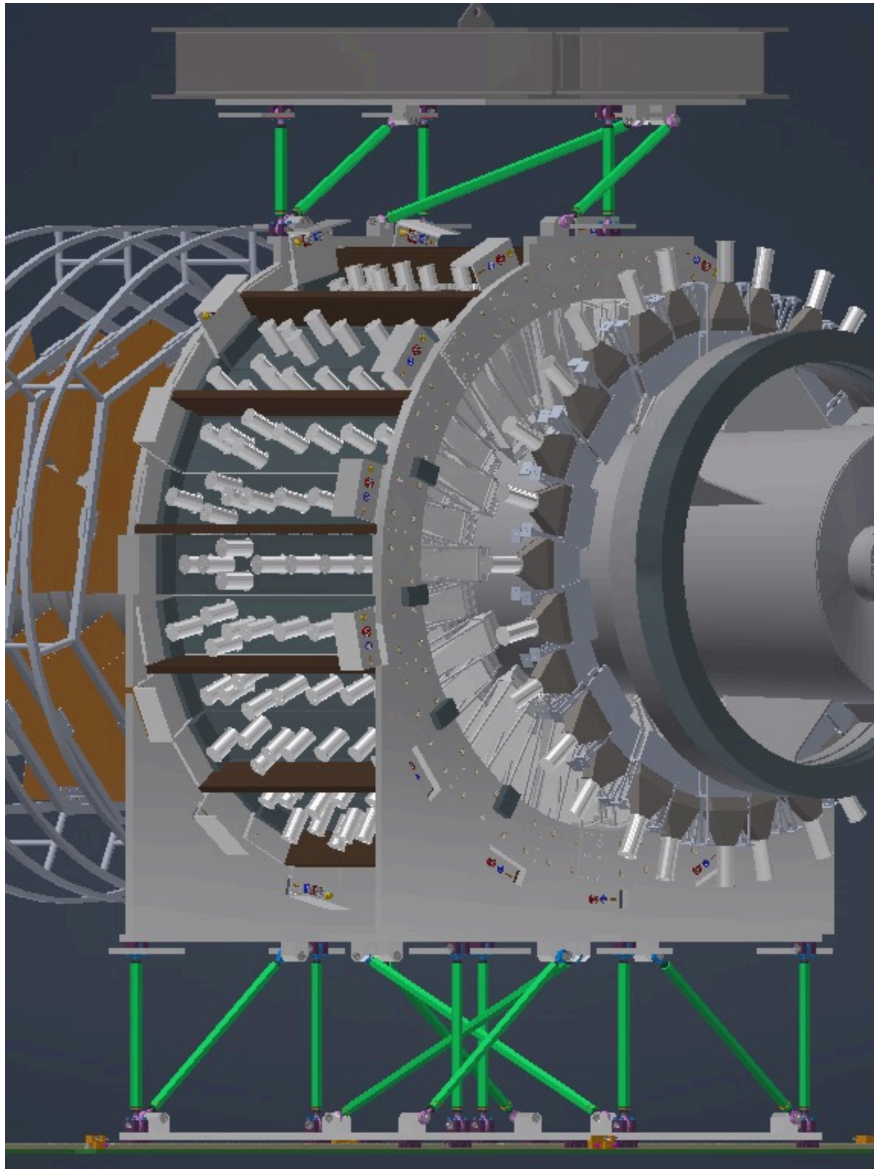
- 224 main detector channels
- 28 SM channels, 14 pion, 8 SAM, LAMs, DBMs, US and DS scanners

- Two electronics huts – one downstream and one upstream for shielding
- ~50 ft runs from detectors to ‘near’ patch panels
  - --Counting signals go to DS hut fast amps
  - --Integrated signals go to US hut ADCs
- 320 ft runs go between US and DS huts

--HV (Radiall BB’s) and LV(18 AWG)

- For powering PMT, divider relay, and pre-amplifier
- And for switching between dividers (high and low gain) and preamp settings

Signal breaks/patch panels



Integration mode signals

--Two patch panels for 400 det channels: one near detectors and other in US hut

If pre-amp is integrated into PMT enclosure (for main dets):

--25 m long, 9 ch high density twinax cable from each 1/28 segment patch panel to patch panels on floor near the detectors
--then use 100 m cables from here to US hut patch panels (RG-108 twinax)
--15 m cable from US hut patch panel to integrating ADC (twinax)

Counting mode signals

--Two patch panels for 302 det channels: one near detectors? and other in US bunker

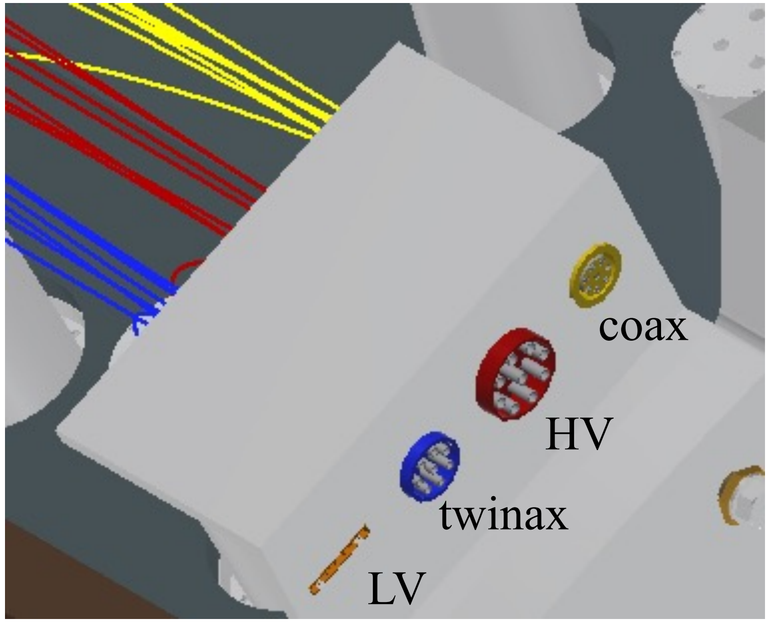
*The near detector PP needs to be close to the fast amplifiers

--25 m long, 9 ch high density coax cable from each 1/28 segment patch panel to the patch panel on floor near the detectors and fast amps*
--then use 100 m cables (RG58) between fast amps and US hut patch panels(?)
--15 m cable from US hut patch panel to flash ADC (RG-58)

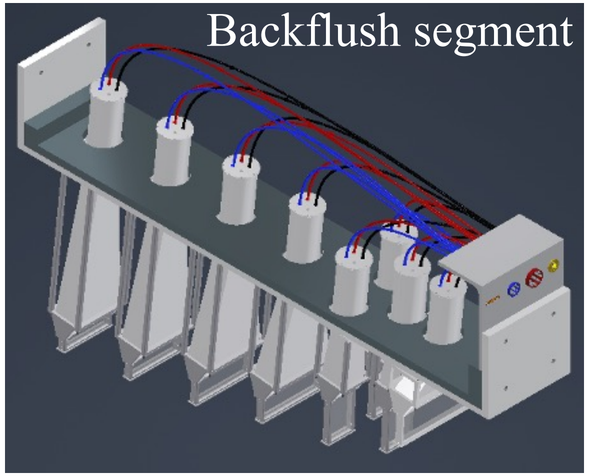
1/28 Segment Patch Panel

Each segment's patch panel is essentially an aluminum angle bracket with 4 high density connectors for passing signals

Patch panels are installed on alternating, up- and down-stream faces

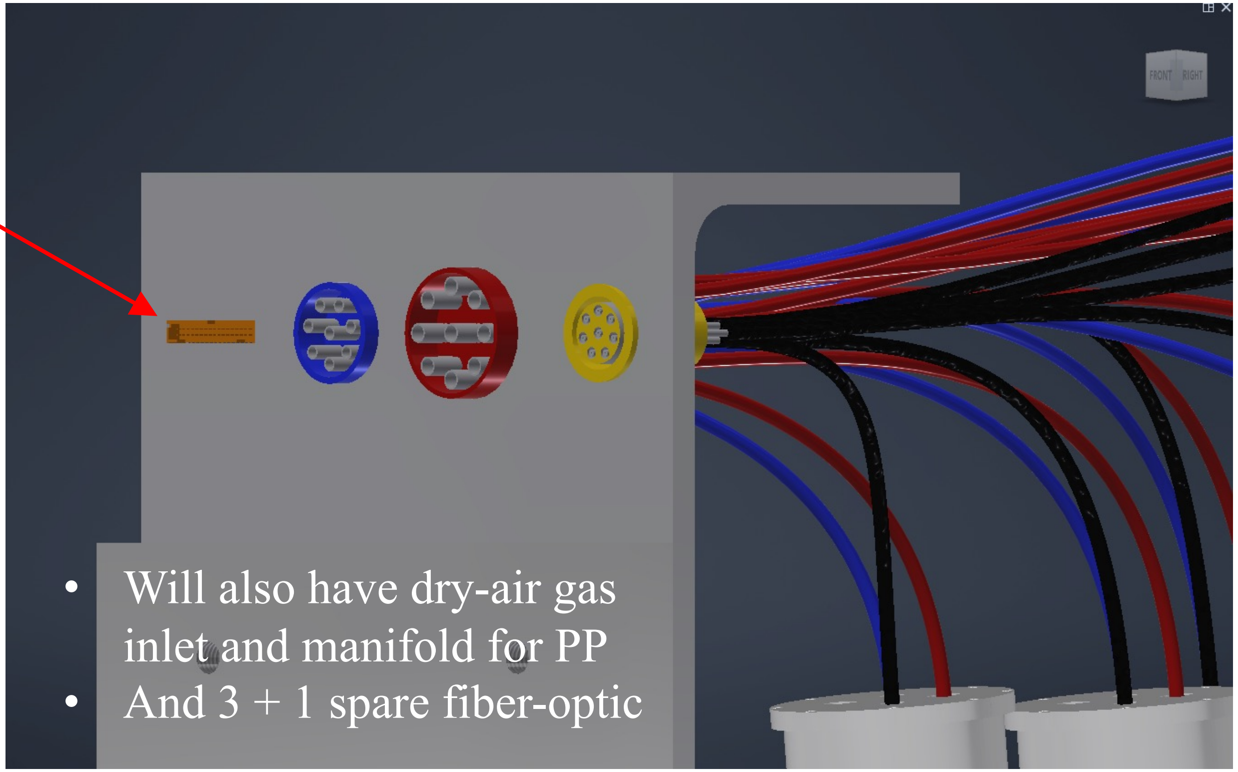


There are 8 detectors per segment



Each det requires:
1 HV cable
2 coax signal cables
4 LV and control wires

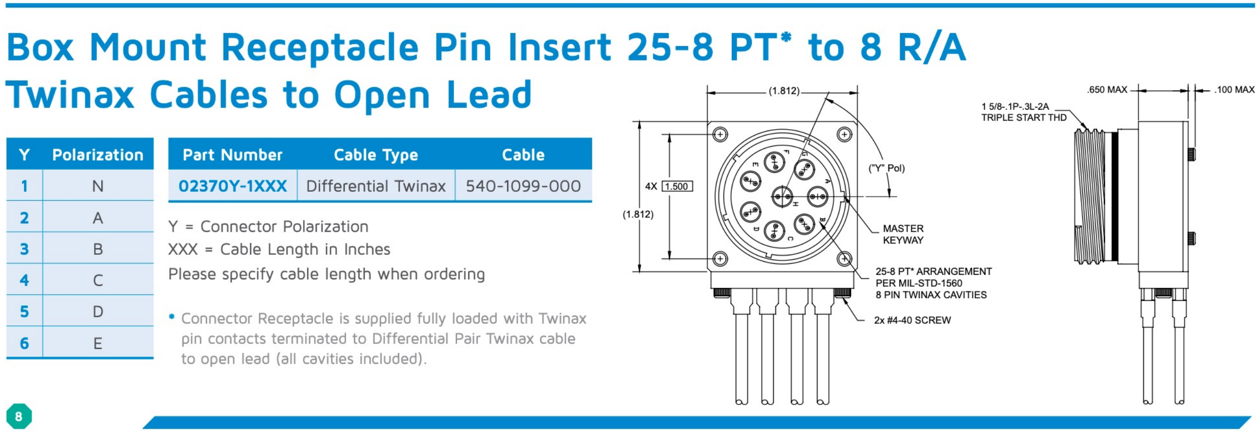
LV 32 ch ribbon cable connector in process of being replaced with larger connector for 18 AWG wires



- Will also have dry-air gas inlet and manifold for PP
- And 3 + 1 spare fiber-optic

High Density connectors (candidates)

Twinax: (smithsinterconnect.com)



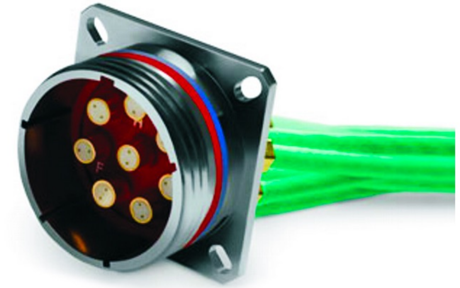
Box Mount Receptacle Pin Insert 25-8 PT* to 8 R/A Twinax Cables to Open Lead

Y	Polarization
1	N
2	A
3	B
4	C
5	D
6	E

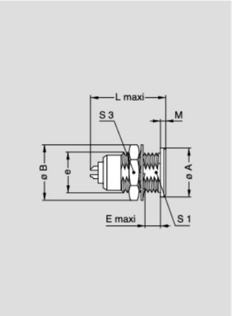
Part Number	Cable Type	Cable
02370Y-1XXX	Differential Twinax	540-1099-000

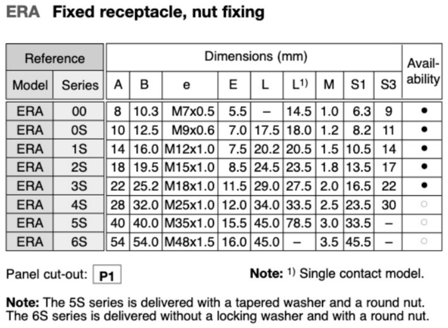
Y = Connector Polarization
XXX = Cable Length in Inches
Please specify cable length when ordering

- Connector Receptacle is supplied fully loaded with Twinax pin contacts terminated to Differential Pair Twinax cable to open lead (all cavities included).



Coax: (LEMO 5B/5S series)





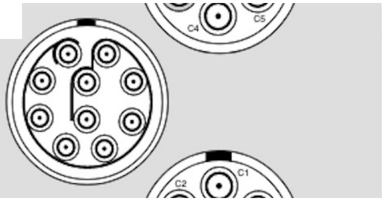
ERA **Fixed receptacle, nut fixing**

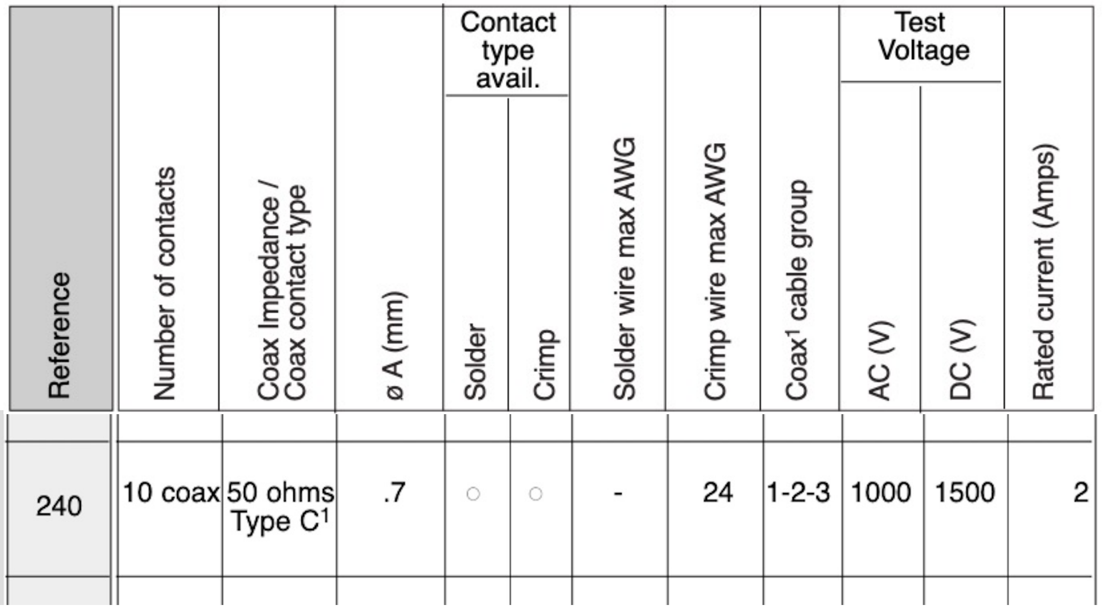
Reference		Dimensions (mm)									Avail-ability
Model	Series	A	B	e	E	L	L1)	M	S1	S3	
ERA	00	8	10.3	M7x0.5	5.5	–	14.5	1.0	6.3	9	●
ERA	0S	10	12.5	M9x0.6	7.0	17.5	18.0	1.2	8.2	11	●
ERA	1S	14	16.0	M12x1.0	7.5	20.2	20.5	1.5	10.5	14	●
ERA	2S	18	19.5	M15x1.0	8.5	24.5	23.5	1.8	13.5	17	●
ERA	3S	22	25.2	M18x1.0	11.5	29.0	27.5	2.0	16.5	22	●
ERA	4S	28	32.0	M25x1.0	12.0	34.0	33.5	2.5	23.5	30	○
ERA	5S	40	40.0	M35x1.0	15.5	45.0	78.5	3.0	33.5	–	○
ERA	6S	54	54.0	M48x1.5	16.0	45.0	–	3.5	45.5	–	○

Panel cut-out: P1

Note: 1) Single contact model.

Note: The 5S series is delivered with a tapered washer and a round nut. The 6S series is delivered without a locking washer and with a round nut.

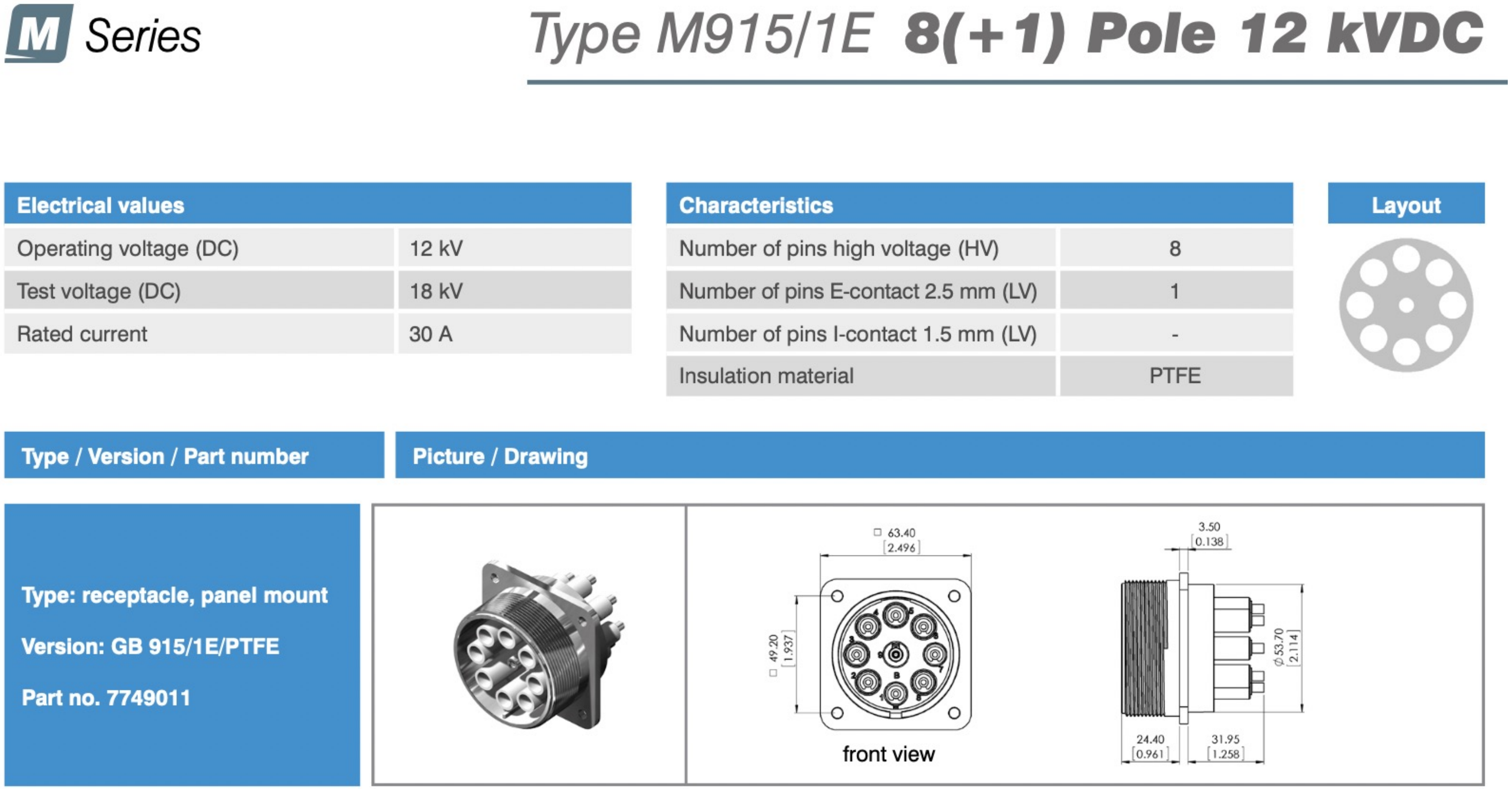




Reference	Number of contacts	Coax Impedance / Coax contact type	ø A (mm)	Contact type avail.		Solder wire max AWG	Crimp wire max AWG	Coax¹ cable group	Test Voltage		Rated current (Amps)
				Solder	Crimp				AC (V)	DC (V)	
240	10 coax	50 ohms Type C1	.7	○	○	-	24	1-2-3	1000	1500	2

High Density connectors (candidates)

HV: (ges-highvoltage.com)



M Series

Type M915/1E **8(+1) Pole 12 kVDC**

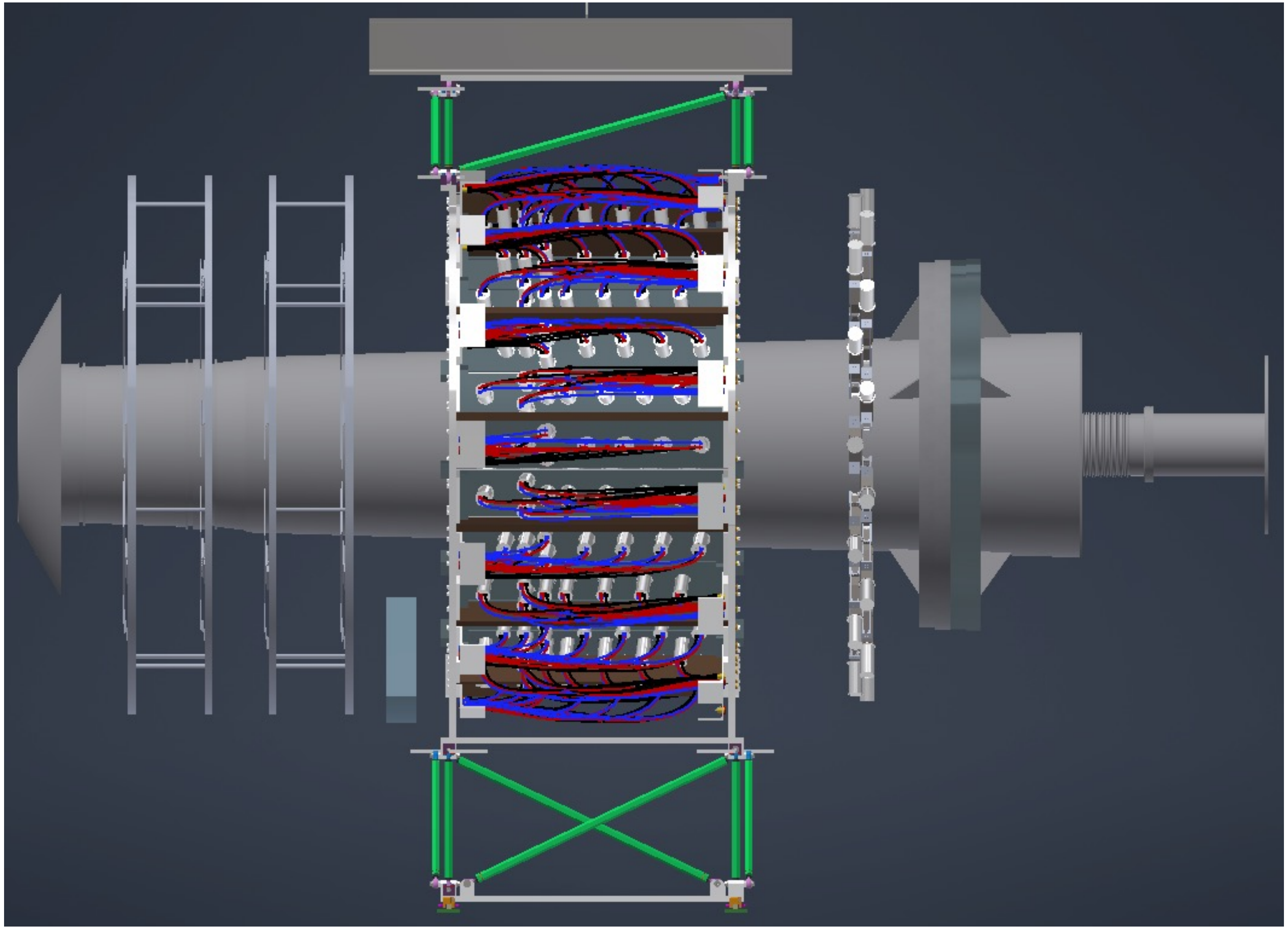
Electrical values	
Operating voltage (DC)	12 kV
Test voltage (DC)	18 kV
Rated current	30 A

Characteristics	
Number of pins high voltage (HV)	8
Number of pins E-contact 2.5 mm (LV)	1
Number of pins I-contact 1.5 mm (LV)	-
Insulation material	PTFE

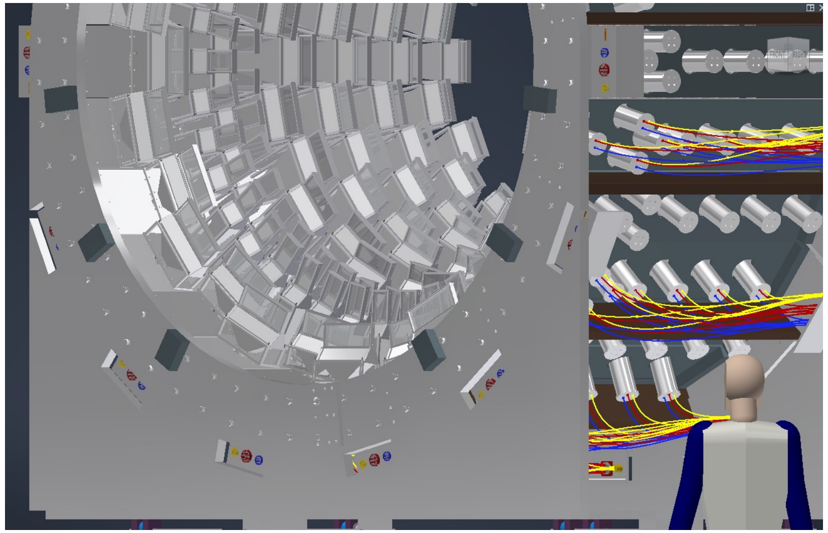
Layout

Type / Version / Part number	Picture / Drawing
Type: receptacle, panel mount **Version: GB 915/1E/PTFE** **Part no. 7749011**	front view

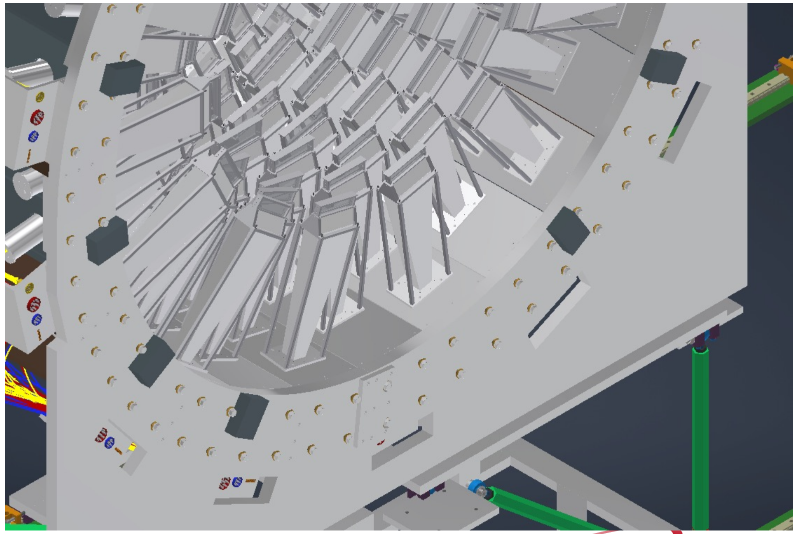
More views



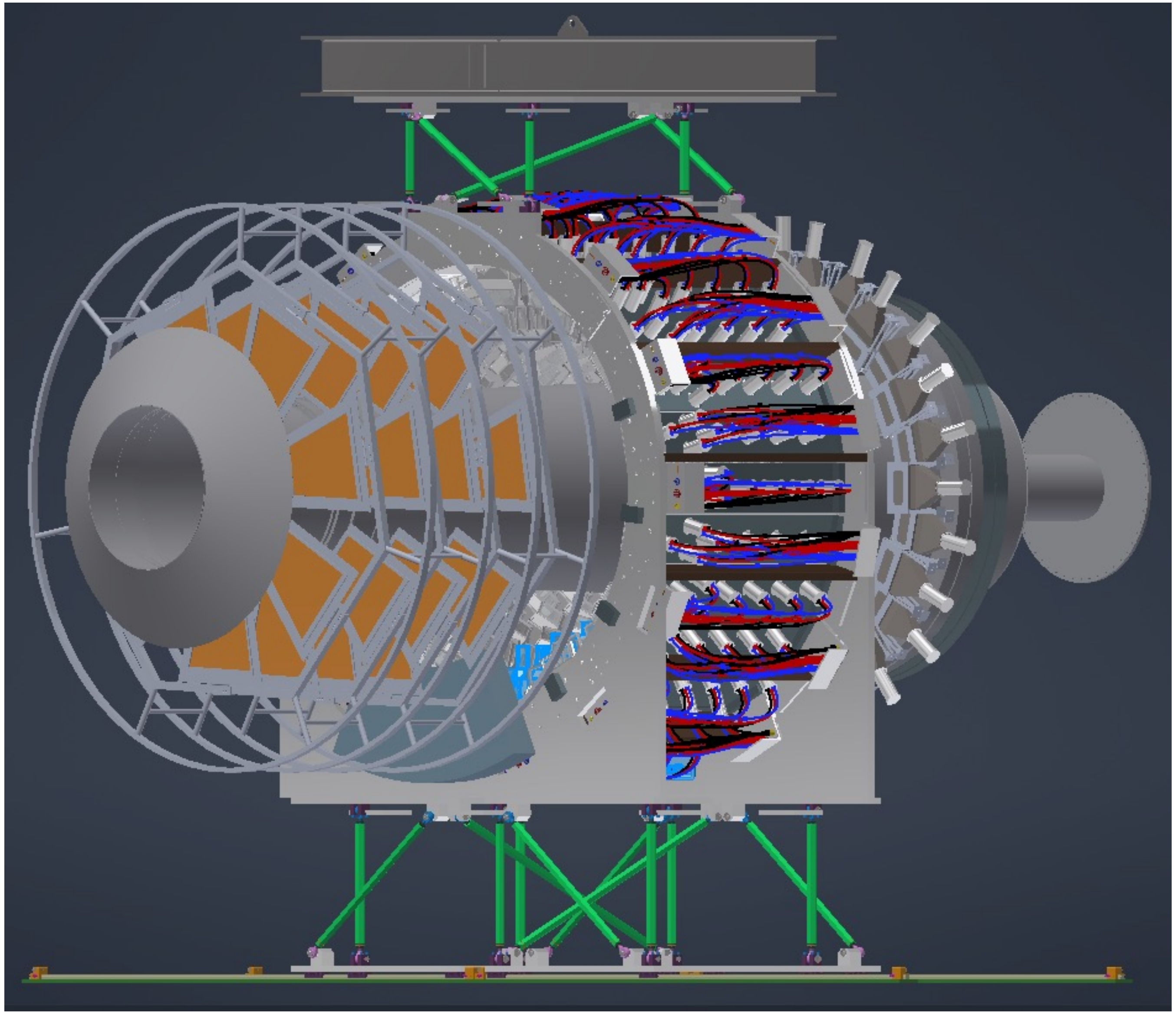
Upstream Face View

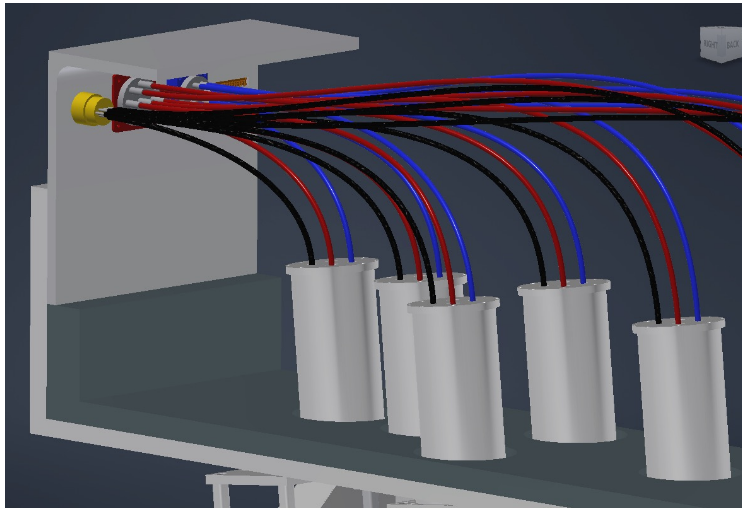


Downstream Face View

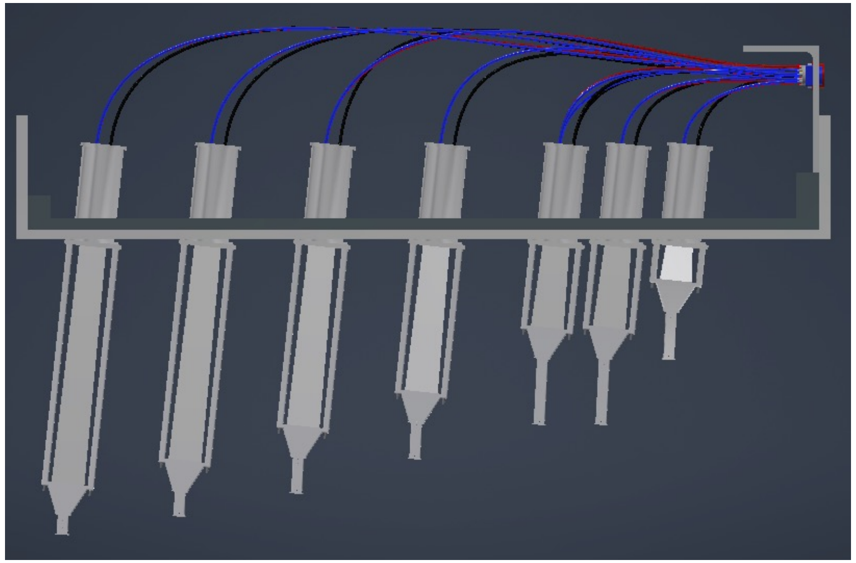


More Views





Front-flush segment

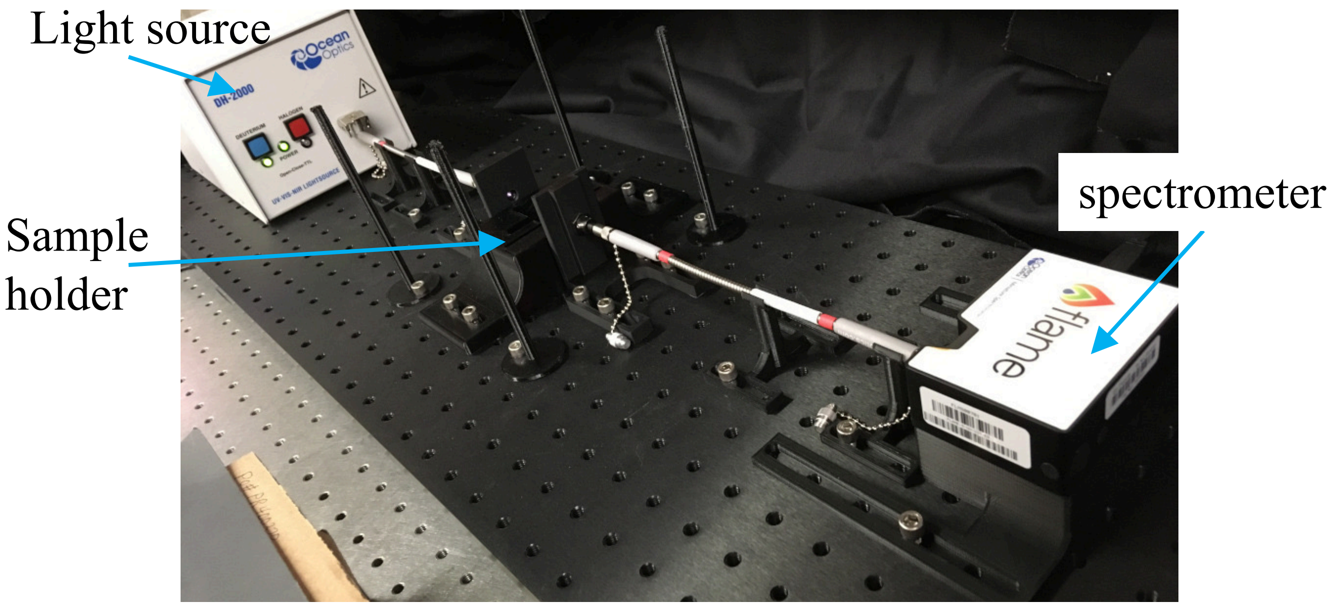


Cabling Summary and future work

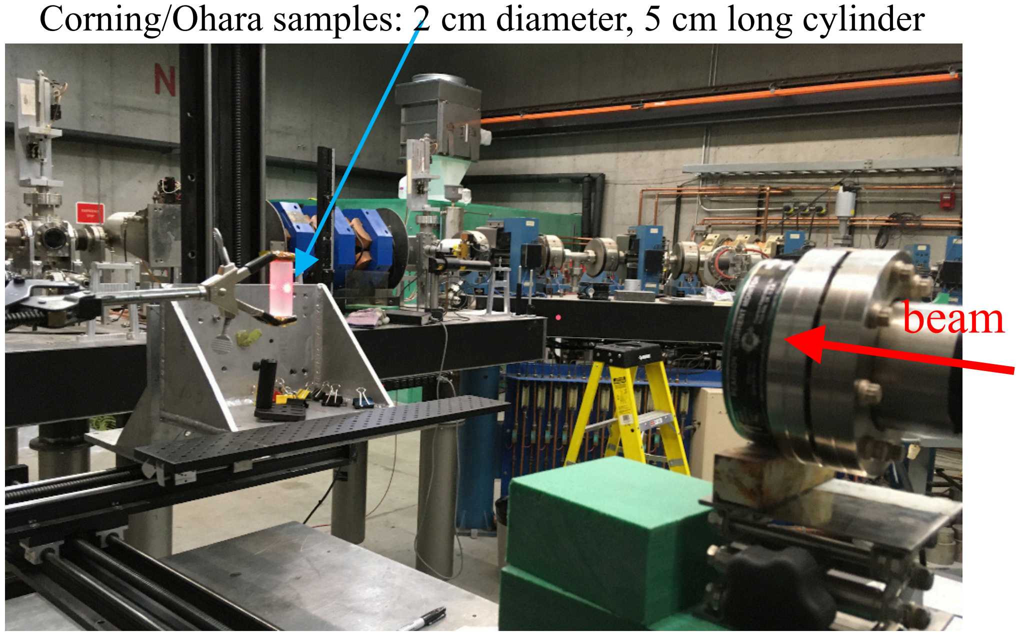
- We at preliminary idea stage and invite those interested to attend meetings (fort-nightly on Tues 3pm Eastern)
- There are many details still evolving: keep-out areas and potential interferences that are not shown in these drawings
  --Multi-level scaffolding around the main detector barrel that can move in and out
  --A large robot arm centered at the z-location of the barrel just on either side: beam-right or beam-left
- Need to find HD connectors we can purchase and build a patch panel prototype (and eventually test on bench with a parity setup, such as our PMT non-linearity system)
- A suitable and available HD coax connector has not been found yet; we are looking into LV now
- Next steps are to start developing outer barrel HD cable routing and strain-relief mechanics
- Note that the 15 m length of cables (from detector to floor PP) currently in the infrastructure budget will need to be longer (~2x longer).

Quartz Irradiation Tests

- Goal: quantify light transmission losses in detector radiators due to damage from anticipated levels of radiation dose: 70 Mrad and 170 Mrad peak doses for rings 5 and 2, repectively
- Several candidate artificial fused silica (quartz) samples chosen for testing: from Corning, Ohara, Heraeus, and Isuzu
- Irradiations conducted at the Idaho Accelerator Center using 8 MeV pulsed electron beam, ~45 mA peak current, ~0.5 us pulse width at 200 Hz repetition rate
- Dose depositions quantified through G4 simulation benchmarked to beam dosimetry measurements
- Light transmission measurement apparatus uses UV-Vis light source and USB spectrometer



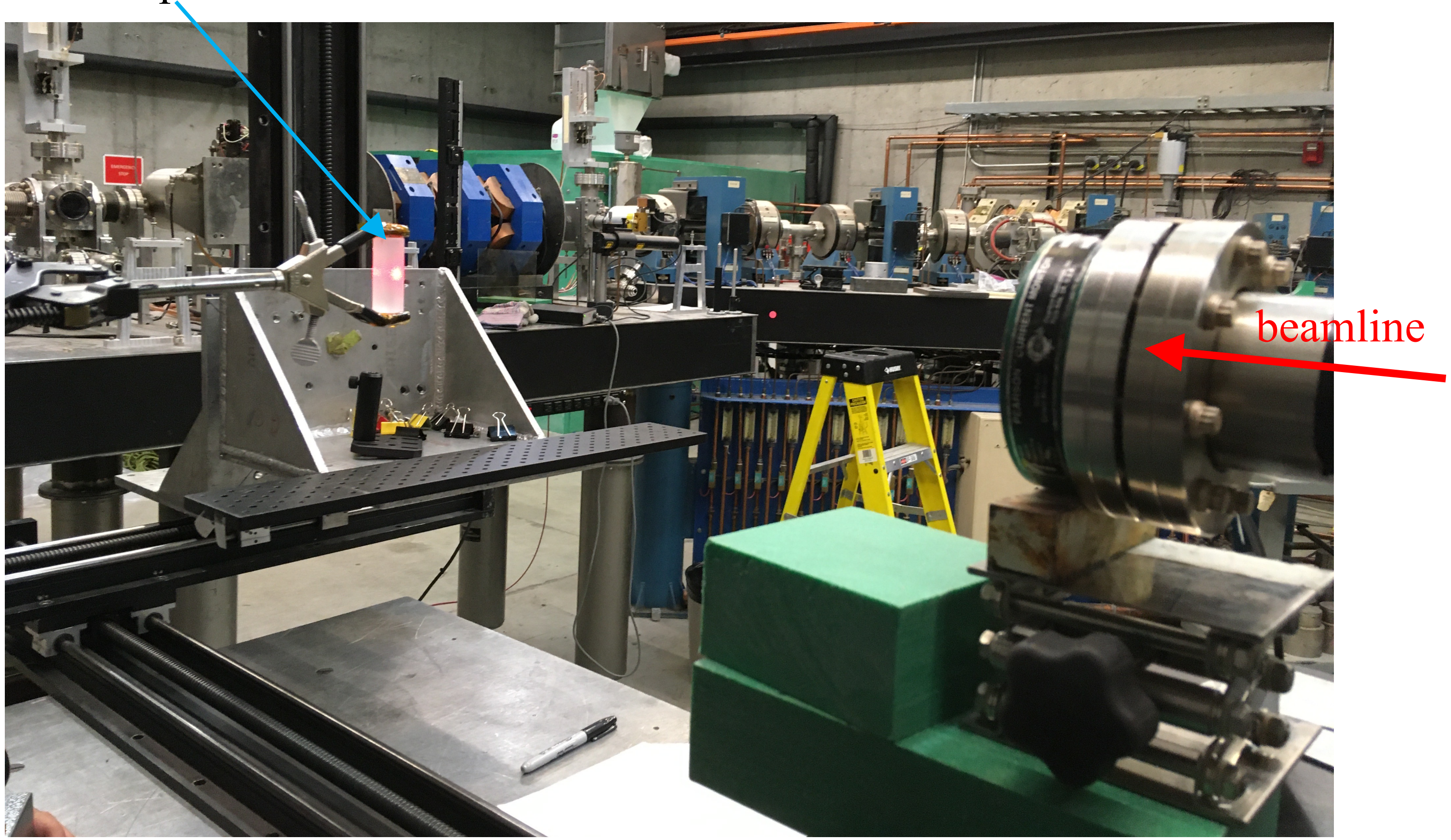
Transmission measurement apparatus



Idaho Accelerator Center

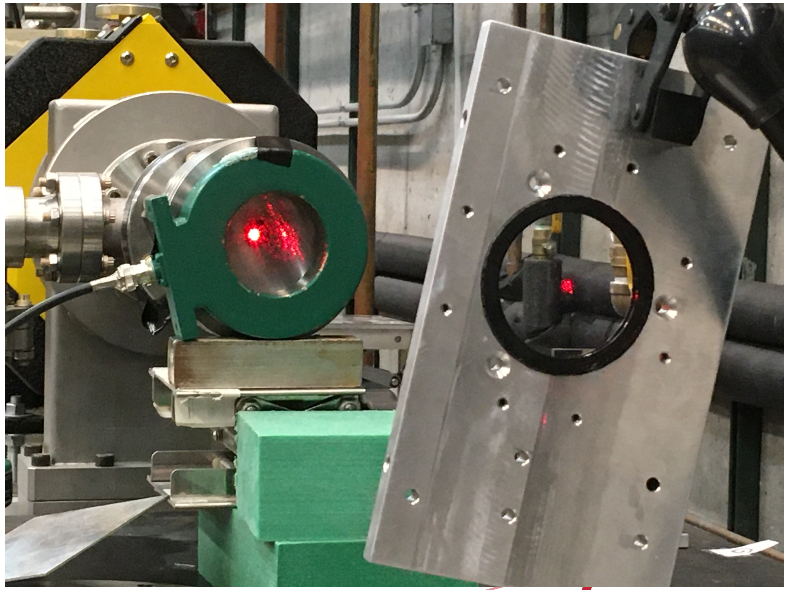
Recent Irradiations (beam and sample setup)

- Very preliminary results from May 19, 2021 quartz irradiation run at Idaho Accel. Center (Next run this Friday)
- Used 25 MeV machine 0 deg port with: 8 MeV peak energy, 45 mA peak current, 700 ns pulse width and 200 Hz rep rate. Samples exposed for 2.5, 12.5, 32.5, 52.5, 72.5 minutes total; transmission measured after each exposure
- Corning (UVHGrade-F and Eximer) and Ohara (SK-1300) samples: 2 cm diameter by 5 cm long; polished on flat ends only
  - Samples are 50 cm from beam exit window



**MS Thesis Project for Justin Gahley

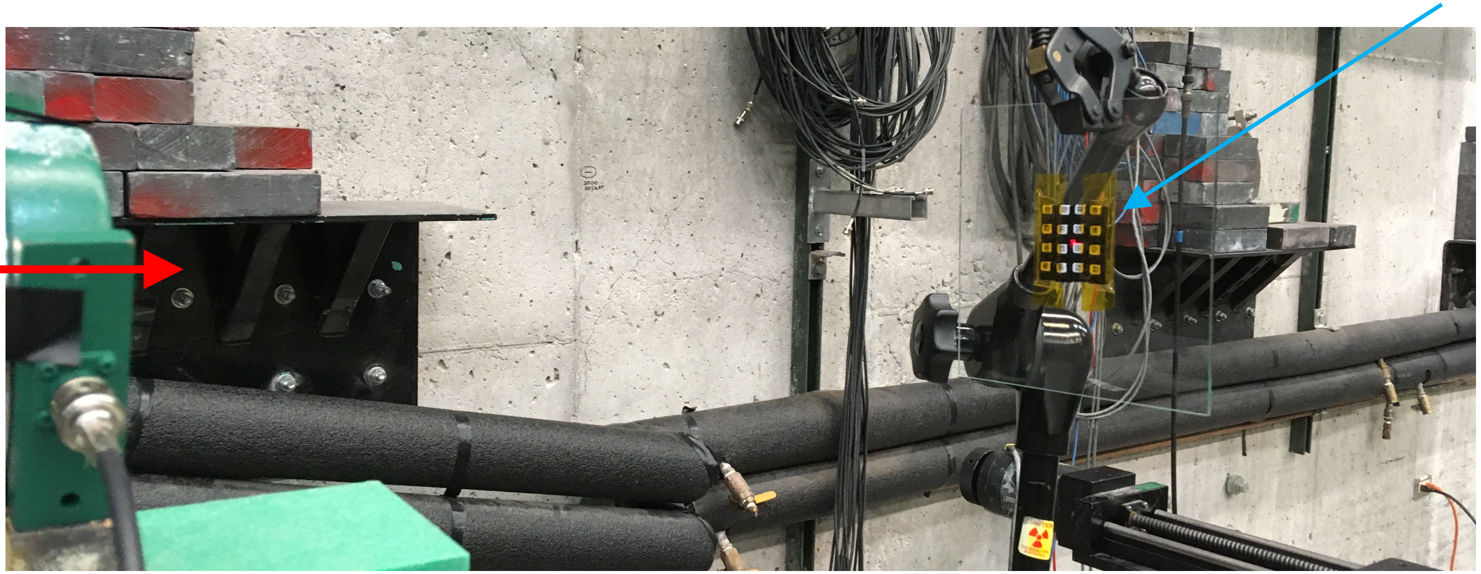
Longpass filter dose test



Dose and beamspot measurements for G4 simulation

OSL dosimeter array

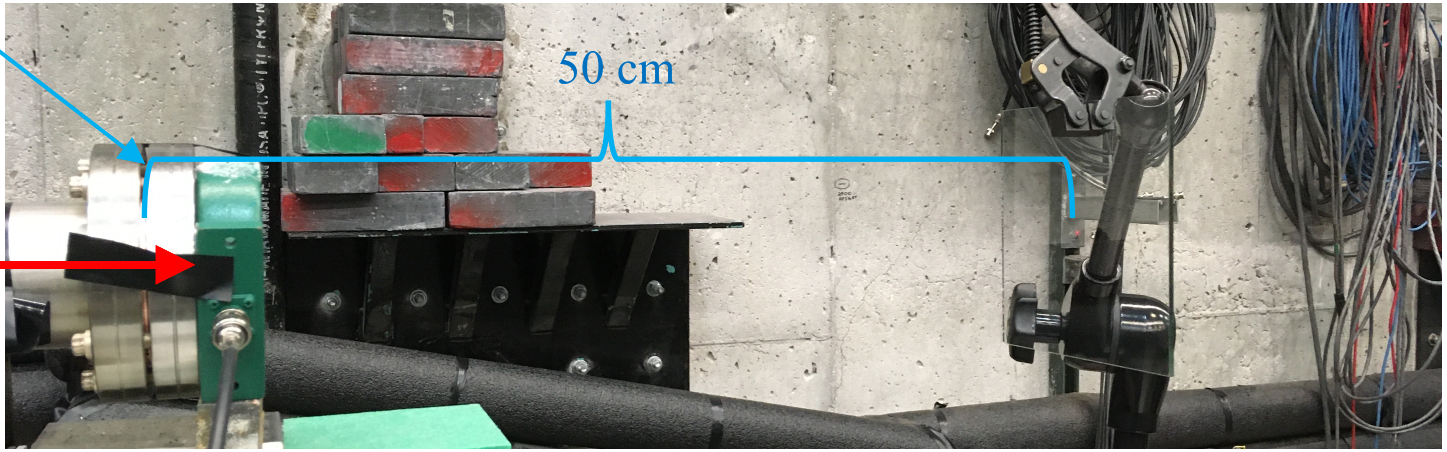
beam



Titanium window

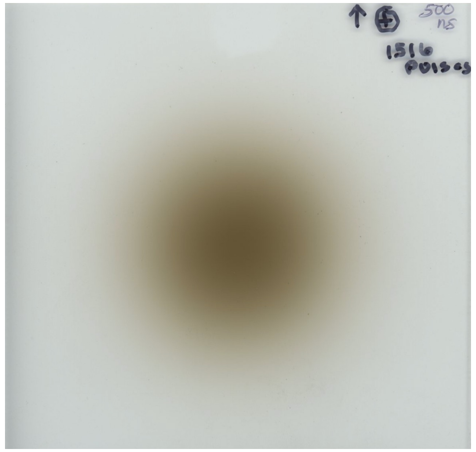
50 cm

beam



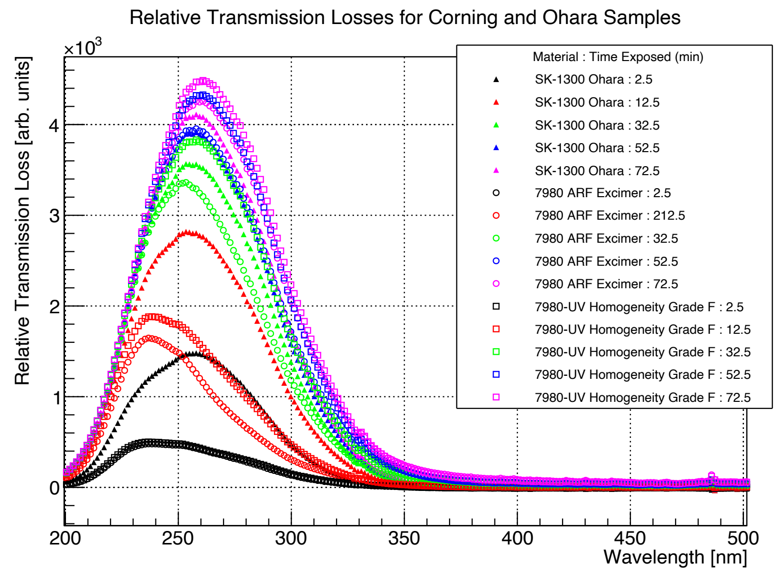
OSLs read using microStar

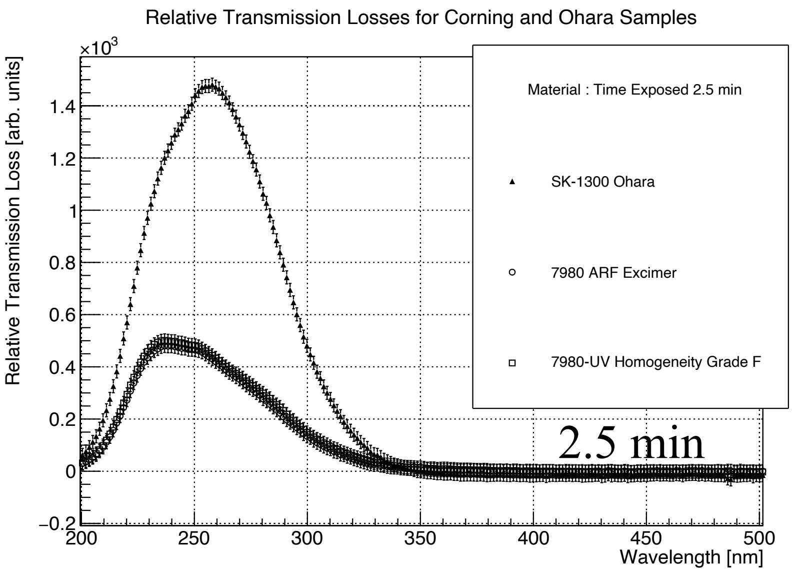
Glass slide

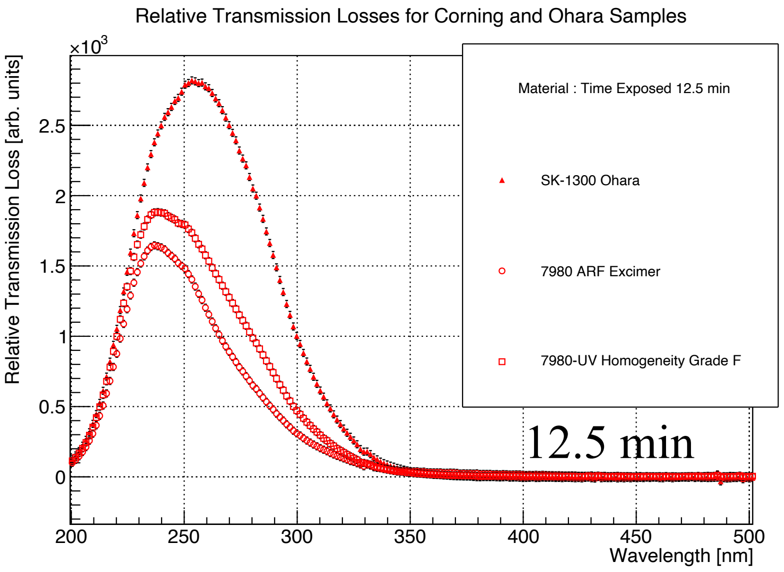


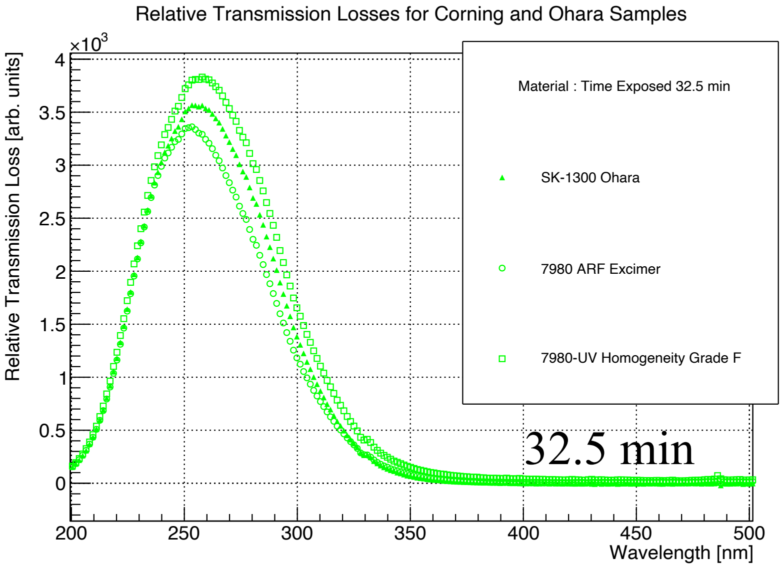
6 in

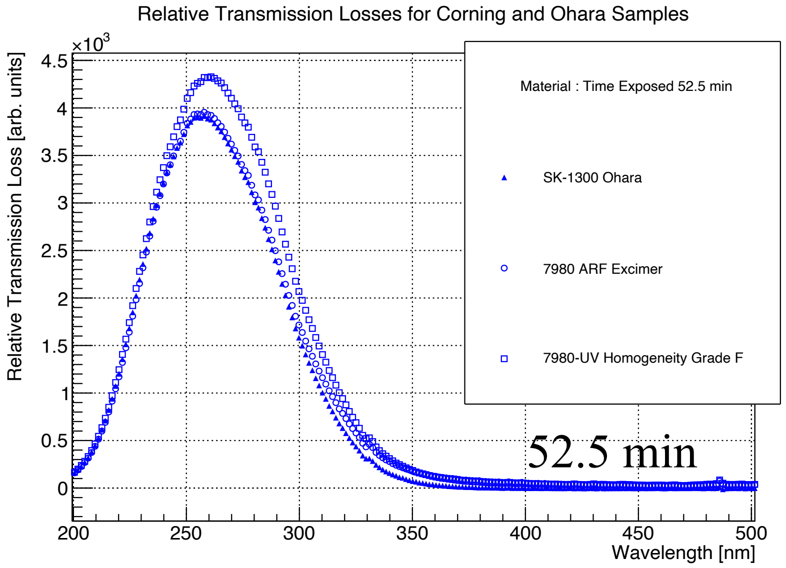
Results from recent measurements: Corning and Ohara

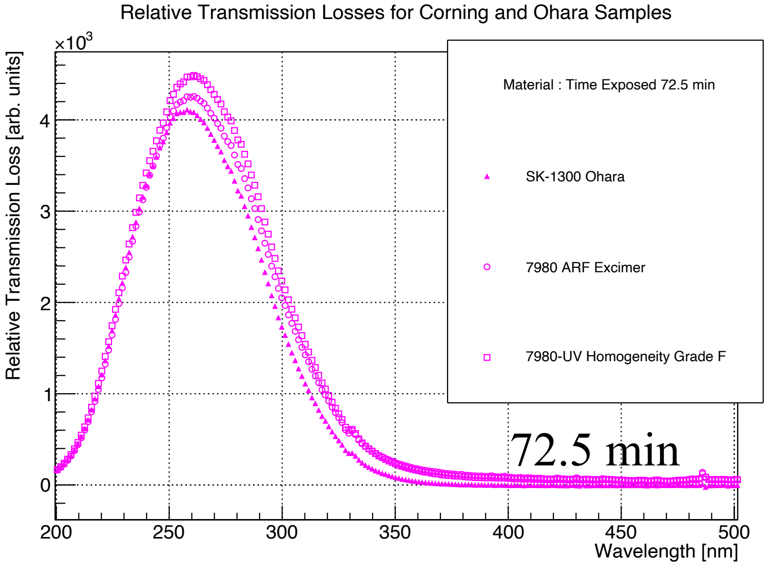








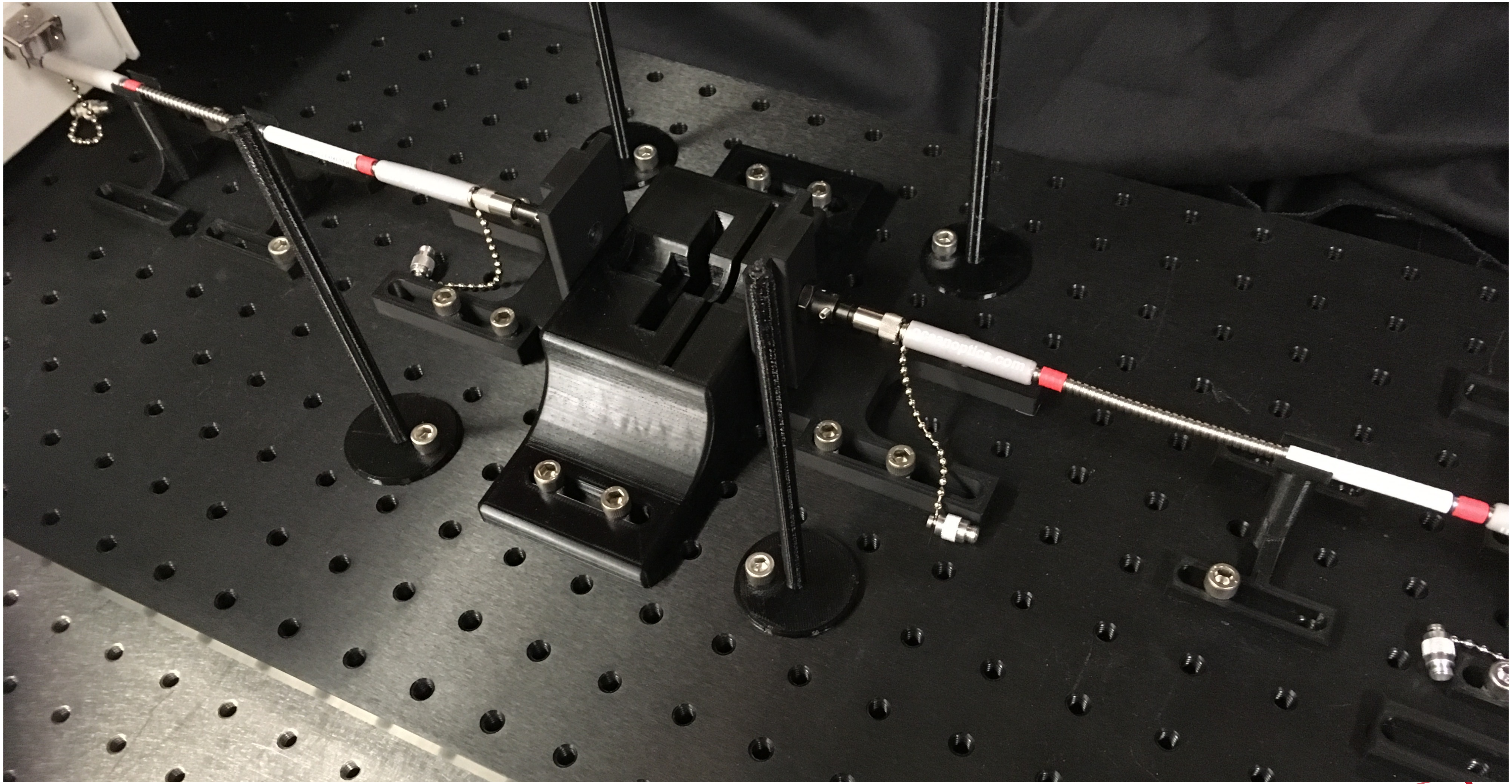




Quartz Irradiation Summary and future work

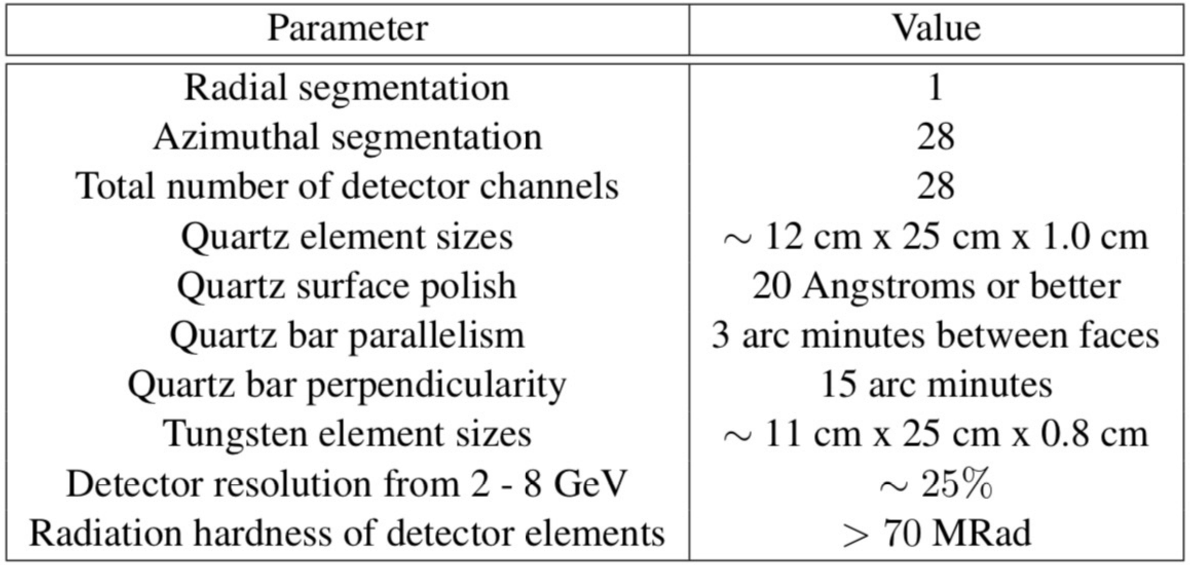
- Light source drift and measurement reproducibility errors are each at ~0.1% level
- New apparatus (static arrangement) has greatly reduced repeatability systematics! However, dose estimates are currently at 20 % level (we are focused on reducing this)
- Corning sample transmission losses both fairly similar; at higher doses (~100 Mrad) Ohara SK-1300 was best and at lower doses (~10 Mrad) Corning is much better
- Edmund Optics 2” longpass filter did not show any signs of losses up to the max tested which was ~10 Mrad (~3 Mrad peak/5x5mm^2)
- The G4 dose simulation is benchmarked to the OSL measurements and beamspot size and divergence at the sample; we are refining simulation to give more information (to get dose depth profiles, etc.)
- Next irradiation run is this Friday; we plan to perform a more detailed accounting of the beam setup and monitor drifts with dosimetry measurements before and after each exposure. We will test 1 cm thick Heraeus, Corning, and Ohara samples and the 1 mm thick Isuzu glass

Appendix – backup slides

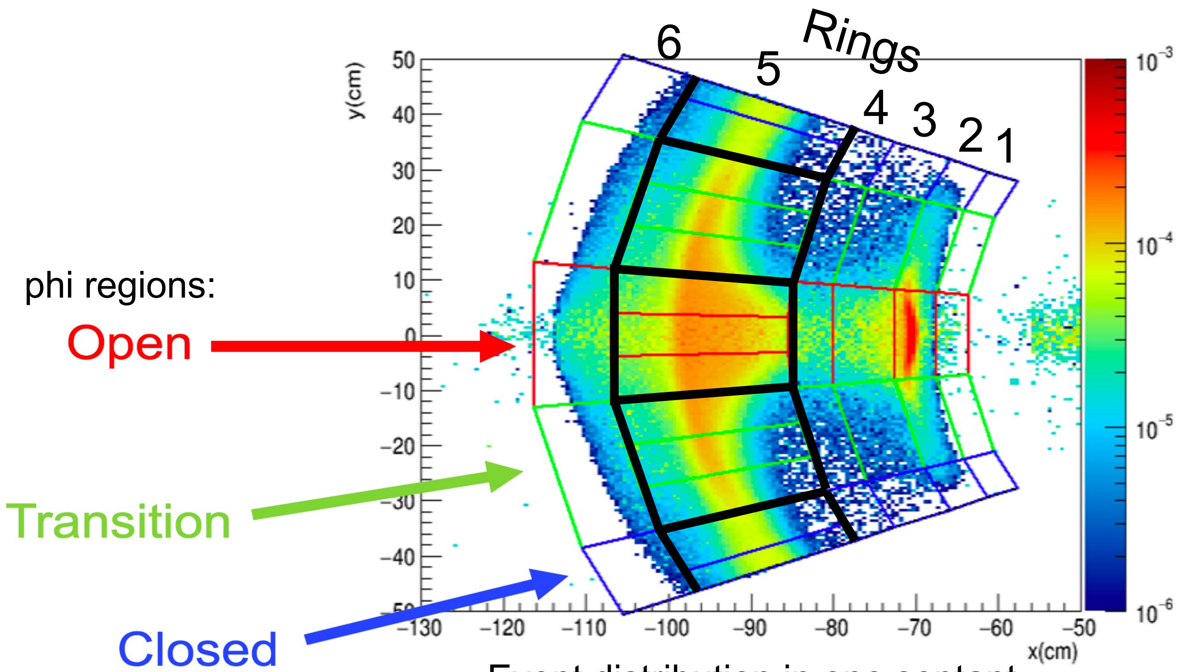


Requirements on Shower-max

Requirements Table from MOLLER-NSF CDR



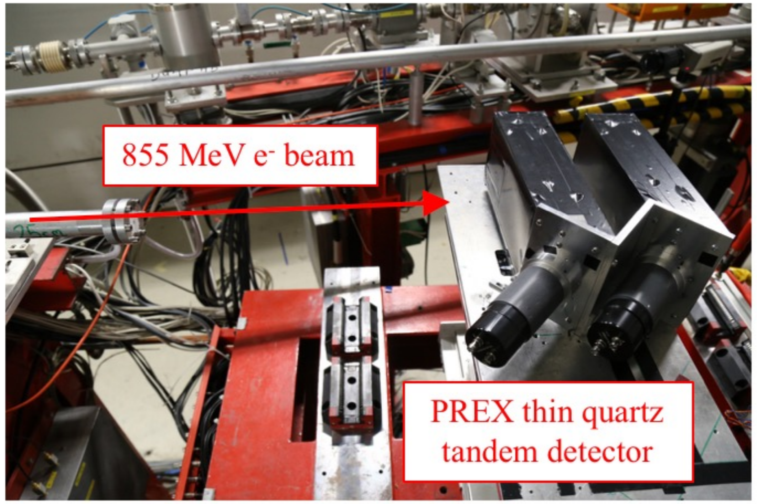
Parameter	Value
Radial segmentation	1
Azimuthal segmentation	28
Total number of detector channels	28
Quartz element sizes	~ 12 cm x 25 cm x 1.0 cm
Quartz surface polish	20 Angstroms or better
Quartz bar parallelism	3 arc minutes between faces
Quartz bar perpendicularity	15 arc minutes
Tungsten element sizes	~ 11 cm x 25 cm x 0.8 cm
Detector resolution from 2 - 8 GeV	~ 25%
Radiation hardness of detector elements	> 70 MRad



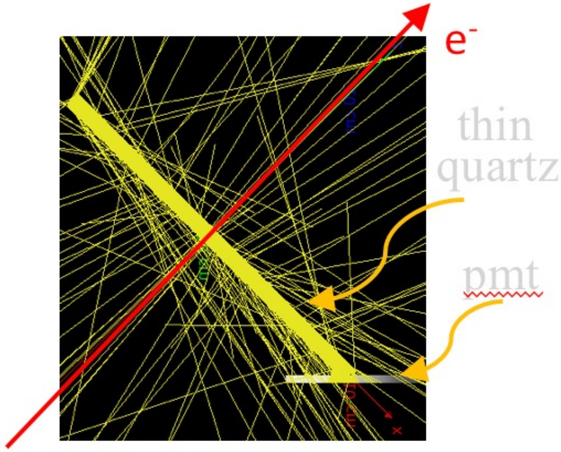
Event distribution in one septant

- Shower-max required to ~match flux acceptance of Ring-5 but with a 3:1 reduction in azimuthal segmentation
- Quartz elements optically polished with stringent geometrical tolerances for TIR considerations
- Tungsten is high purity (99.95%) with dimensional tolerances of ±0.005 inch
- Detector resolution for single-electron response at least 25% to avoid excessive error inflation
- Optical detector elements must be sufficiently radiation-hard to allow Shower-max to preform as required for the duration of the experiment

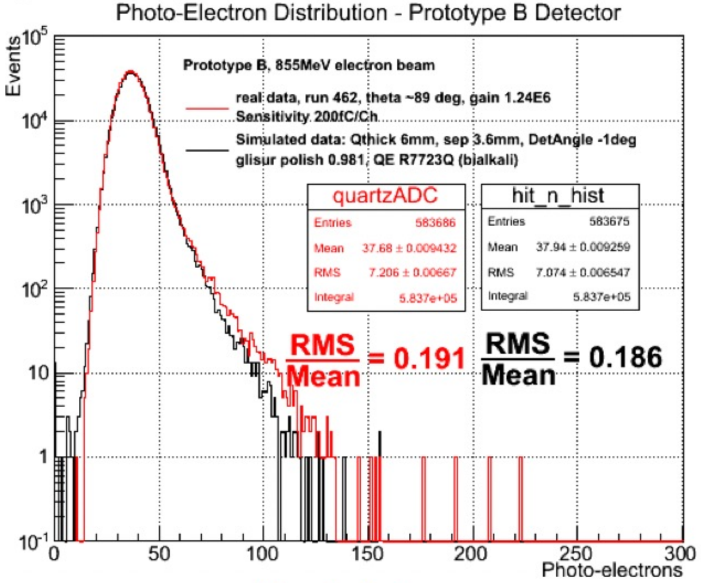
- Quartz optical G4 properties benchmarked at MAMI: Glisur ground polish parameter ~0.981



MAMI testbeam with PREX detector



G4 event visualization for PREX detector



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

- Stack configuration MC study:

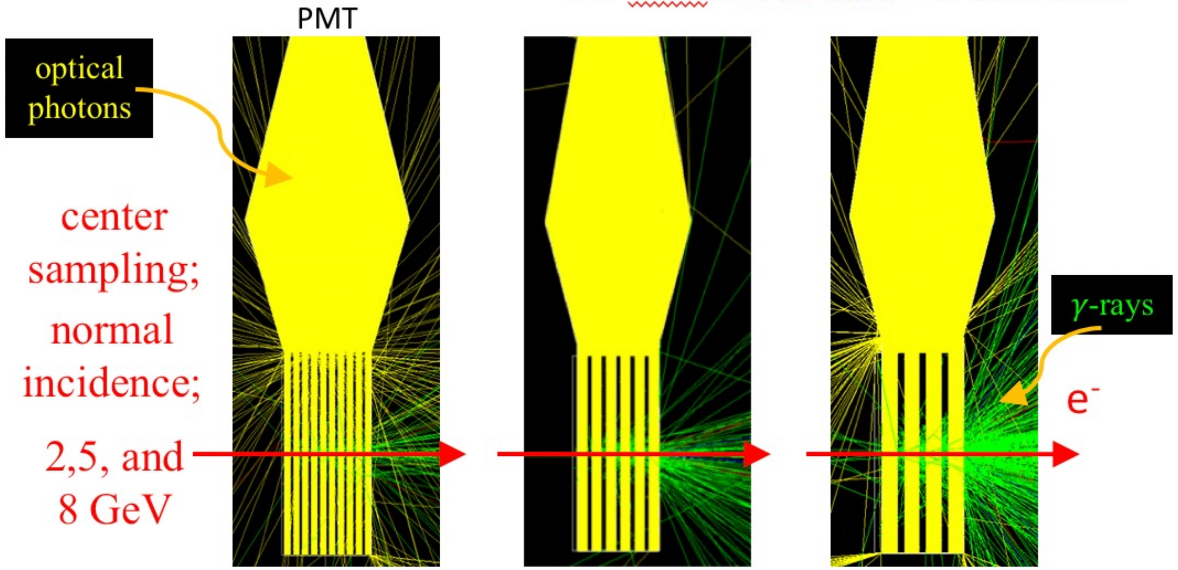
❖ Stack thicknesses all same (7.2 X_0)

❖ 2, 5, and 8 GeV incident electrons

❖ PE dists generated using tuned polish parameter and 60% LG reflectivity

Conclusion:

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



10-layer 6-layer 4-layer

Shower-max event visualizations