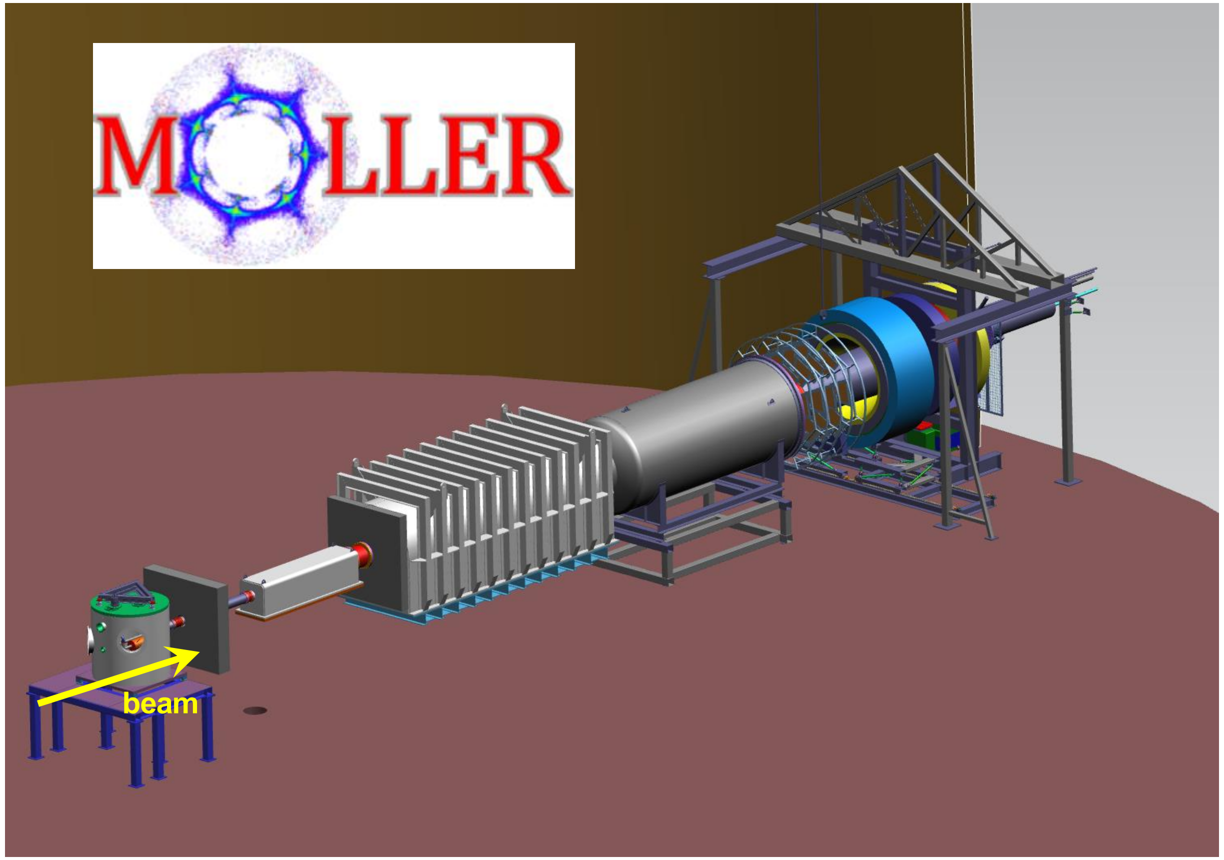
MOLLER Experiment Readiness Review 2

MOLLER Auxiliary Detectors



Dustin McNulty
Idaho State University

Tuesday, July 29, 2025

Outline: MOLLER Auxiliary Detectors

- Auxiliary detector system overview
- Construction status
- Radiation hardness studies
- Testbeam studies and results
- Additional comments
- Summary

This talk addresses Committee Charges 1b and 2a

Charge 1b:

--What is the status of the construction of the equipment, including controls, instrumentations and electronics, required for this experiment towards operation?
--Are the responsibilities for carrying out each job identified, and are the workforce and other resources necessary to complete them on time in place?
--What is the completion/commissioning schedule and tasks?

Charge 2a:

--Have the equipment listed above been demonstrated for readiness to operate and to achieve the scientific goals of the experiment?
--Some specific questions are provided below.

1. Have the quartz detectors been evaluated for radiation hardness and long-term durability? Is there a contingency plan in place in case they will not survive the full experimental run?
2. What measures ensure the uniformity of light collection and minimize potential systematics?
3. Has the optical transmission been tested under actual beam conditions?
4. Will the shower max provide sufficient detector response to achieve the goals of the experiment?
5. How are the detectors calibrated to ensure optimal performance in high-radiation environments, and have calibration procedures been implemented to account for variations in detector response over time?
6. Are there concerns about signal loss or degradation due to aging effects?
7. What are the failure modes of the Integrating Detector System, and how is redundancy incorporated into the design?

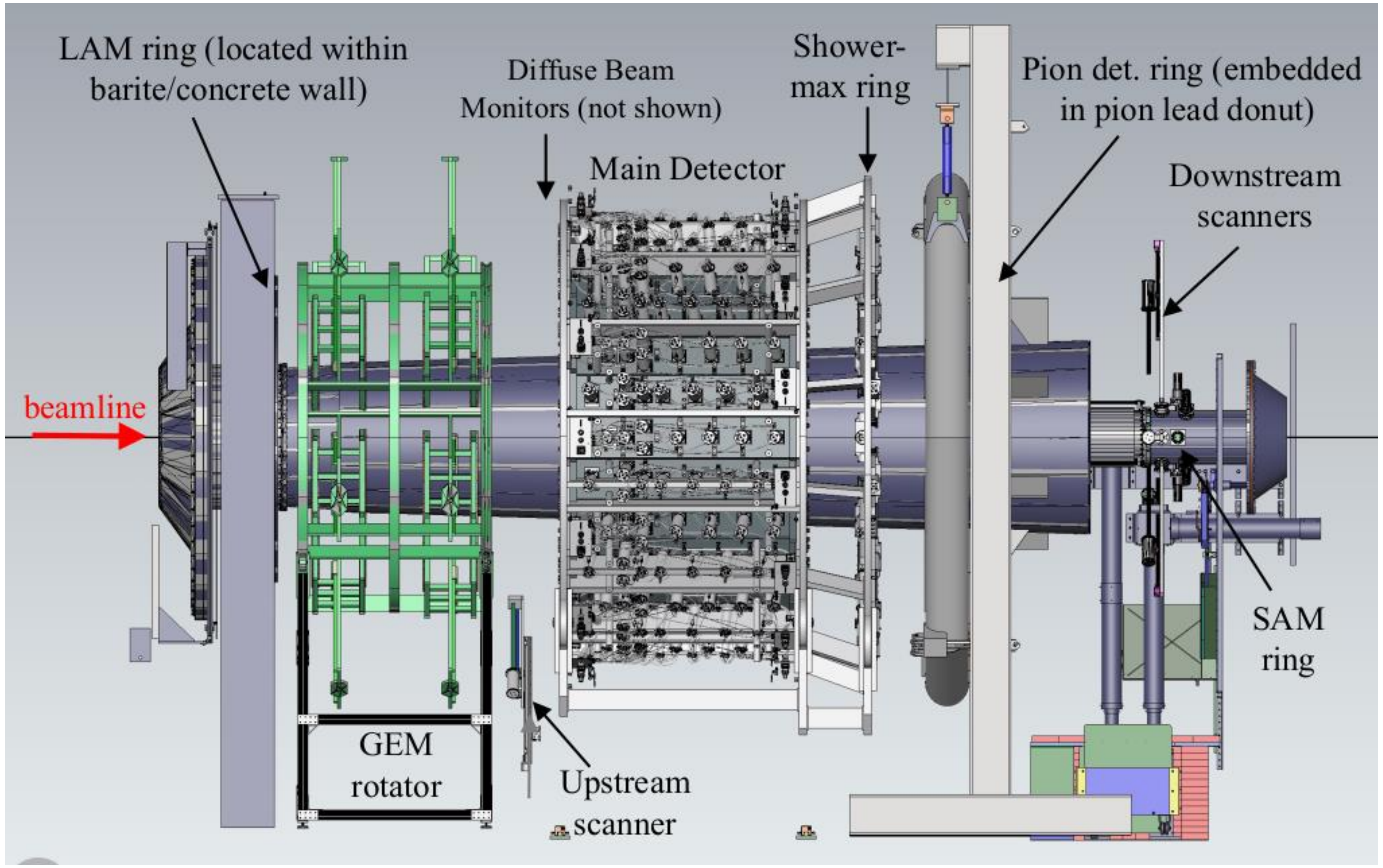
Auxiliary Detector Overview

- Aux Dets enable increased understanding and control of systematic effects and backgrounds

Systems include:

- **Shower-max**: performs additional meas of Moller A_{PV} (powerful cross check of Ring 5)
- **Pion Detector** (covered in next talk)
- **Scattered Beam Monitors**:
  --LAM (Large Angle Monitor): monitors beamline background asymmetries
  --SAM (Small Angle Monitor): monitors beamline background asymmetries, target density fluctuations, and electronics noise
  --DBM (Diffuse Beam Monitor): monitors beamline background asymmetries
- **Scanners**:
  --Upstream: used with tracking system and monitoring detector plane flux distribution
  --Downstream: verify alignment of primary acceptance-defining collimator

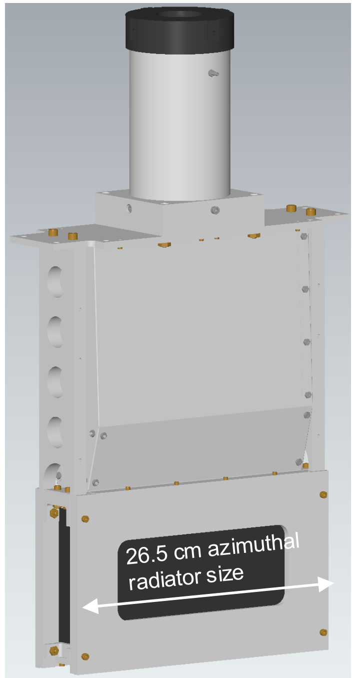
MOLLER Detector Package
(”physicist’s CAD model”)



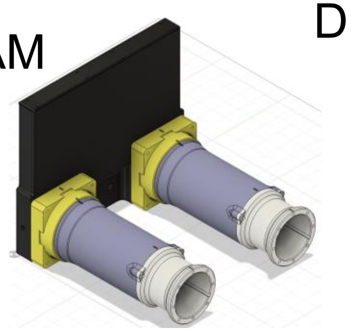
Auxiliary Detector Overview

- Shower-max: 28 detectors, aluminum chassis, quartz and tungsten radiator, aluminum air-core light guide, and 3” pmt
- LAM: 7 detectors, carbon fiber (CF) embedded ABS enclosure, quartz radiator, and two 3” pmts each
- SAM: 8 detectors, aluminum chassis, uses quartz radiator, air-core light guide, and 2” pmt
- DBM: 14 detectors, CF ABS enclosure, two 3” pmts – one with quartz radiator, the other with no radiator
- Upstream Scanner: coincidence between 2 detectors, each uses quartz, tubular light guide and 3” pmt
- Downstream Scanner: 4 detectors, uses quartz, tubular light guide and 3” pmt

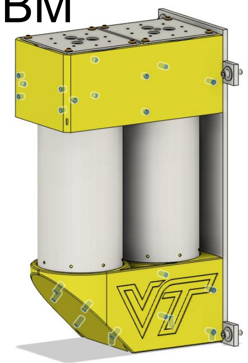
Shower-max



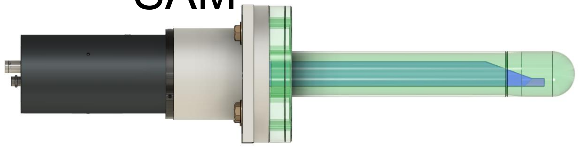
LAM



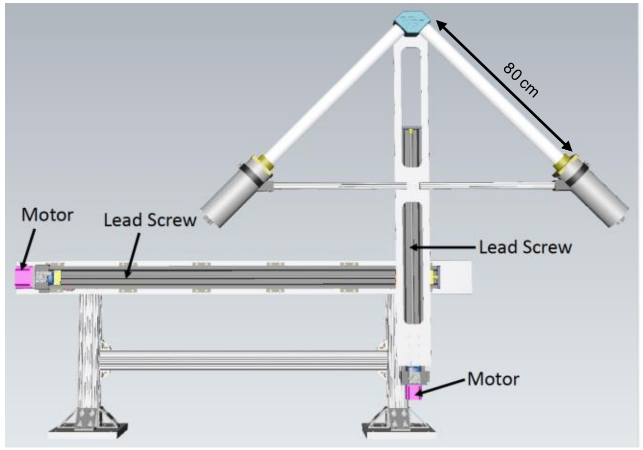
DBM

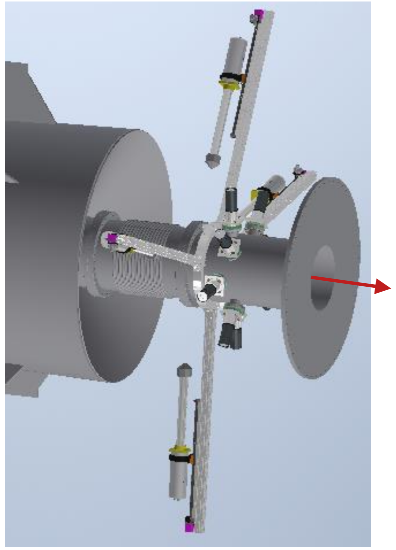


SAM



US Scanner





DS Scanners

DS Scanner

Shower-max: construction summary and delivery timeline

Addresses Charge 1b

- All 31 production Shower-max modules (28 + 3 test-spares) have been assembled and cosmic-ray tested in Idaho (completed in Feb 2025)
- 28 modules have been disassembled (partially) and shipped to JLab; three separate shipments in Sept 2024, Nov 2024, and Feb 2025
  -- 25 modules have been re-assembed so far and cosmic testing is ongoing in addition to Hall D Testbeam studies
- All detector support struts received and inspected; custom alignment fixture and lifting fixture are received and inspected; all are currently at Jlab stored in the high-bay testlab area
- All 31 PMTs have been received and inspected—gain and linearity characteristics have been measured
- PMT base and pre-amp electronics are in production process and will be ready by early fall
- Custom (78 mm diameter) longpass filters have been received and inspected
- The Shower-max uses the same ADCs, HV and LV supplies, and dry-air gas system as the Main detector
- The Shower-max detector system is on schedule to be ready for transport to Hall A by end of the year
  -- Fully assembled, ready-to-go detector modules will be stored in two heavy duty plastic palette enclosures. These enclosures also accommodate transport to the Hall.
  -- All resources and workforce needs in place to deliver the Shower-max detector system as designed

Scattered Beam Monitors: construction summary and delivery timeline

Addresses Charge 1b

Large Angle Monitor:
- Production module assembly completed in May 2025 (7 + 2 spares)
- All PMTs received and inspected
- Hall D Testbeam run in June 2025 and cosmic-ray testing in progress

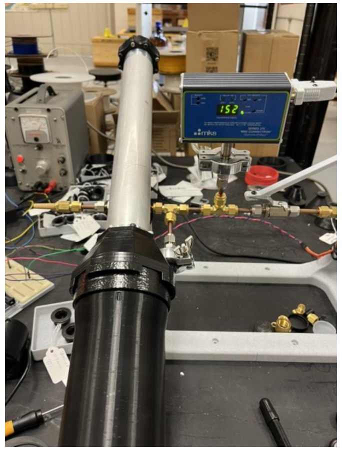
Small Angle Monitor:
- Production parts machining and module assembly starting early fall
- All quartz and PMTs received and inspected
- Hall D Testbeam run in June 2025 (pre-production module)
- Beampipe insertion tubes to be ordered late summer

Diffuse Beam Monitor:
- Production module parts fabrication and assembly in process
- All quartz and PMTs received and inspected
- Hall D Testbeam run in June 2025 (pre-production module)


LAM production

- ➢ Order for all production FE electronics (base and preamps) in process
- ➢ The SBMs and Scanners uses the same ADCs, HV and LV supplies, and dry-air gas system (SAM only) as the Main detector.
- ➢ All resources and workforce needs are in place to complete construction and testing
- ➢ All SBM detectors on schedule to be delivered to JLab by end of Jan 2026

Scanners: construction summary and delivery timeline



Addresses Charge 1b

Upstream Scanner:

- Production module parts fabrication and assembly starting early fall
- All quartz and PMTs received and inspected
- Custom machined and 8020 support frame parts procured
- Hall D Testbeam run in June 2025 (pre-production module)

Downstream Scanner:

- Production module parts fabrication and assembly starting early fall
- All quartz and PMTs received and inspected
- Beampipe mounting collar manufacturing - complete March 2025
- Hall D Testbeam run in June 2025 (pre-production module)

Motion and vacuum systems:

- Motion systems will use off the shelf Velmex sliders and controllers to be procured this fall
- Tubular light guides will be under quasi-medium vacuum; the system uses custom plastic and aluminum components; design tested on the bench and during Hall D Testbeam run; parts production starting early fall

- ➢ Order for all production FE electronics (base and preamps) in process (prototype testing complete)
- ➢ All resources and workforce needs are in place to complete construction and testing
- ➢ All Scanner detectors on schedule to be delivered to JLab by end of Nov 2025

Radiation hardness testing of detector components

Addresses Charge 2a, bullet-points 1,5 and 6

- Testing goals:

  --Quartz: quantify light transmission losses in HPFS radiators due to damage from anticipated lifetime maximum radiation dose – up to 45 MRad and 120 MRad for ring 5 and ring 2, respectively

  --3D-printed plastics: quantify tensile properties of various plastics under expected radiation loads – test up to 150 MRad

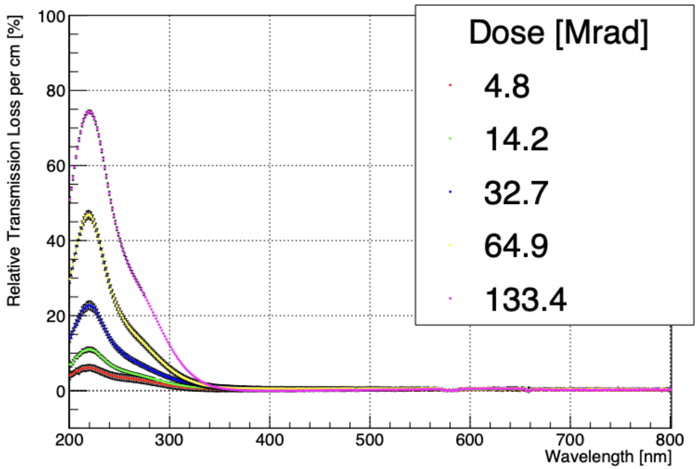
  --PMT FE electronics: quantify pmt base and pre-amp functionality in both integrate and event mode under anticipated radiation loads with a factor of 2 safety margin (~120 kRad lifetime)

- We used the Idaho Accelerator Center (IAC) for irradiations: 25 MeV linac operated at 8 MeV peak energy; Beam is setup to give ~40 nC/pulse for quartz and plastic dosing and ~1 nC/pulse for electronics
- Five candidate fused silica (quartz) samples chosen for testing: from Corning, Ohara, and Heraeus
- We tested several types of 3D printer filaments: PLA, ABS, Nylon, CF-ABS, CF-Nylon, Onyx, UltrasintPA11; PEEK
- We tested multiple prototype generations of our PMT FE electronics, including integrating and event-mode amplifiers, voltage regulators and two different types DC-DC converter chip sets

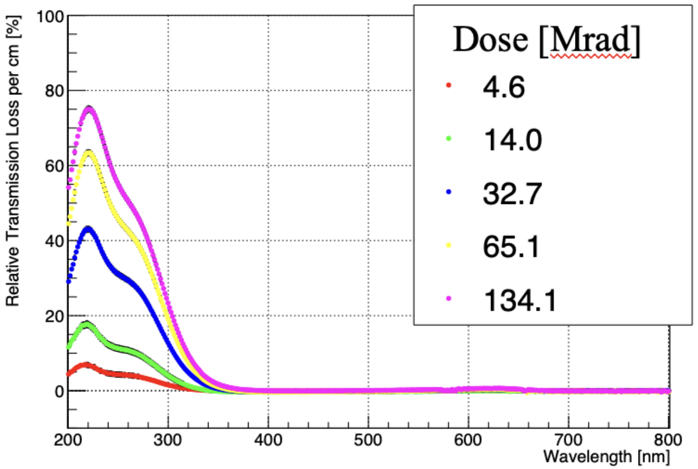
Quartz radiation hardness results: relative light transmission losses

Addresses Charge 2a, bullet-points 1,5 and 6

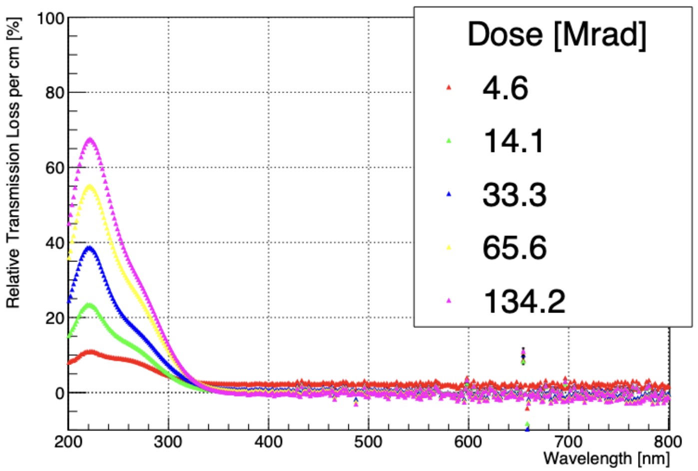
Corning 7980 UV Homogeneity Grade F



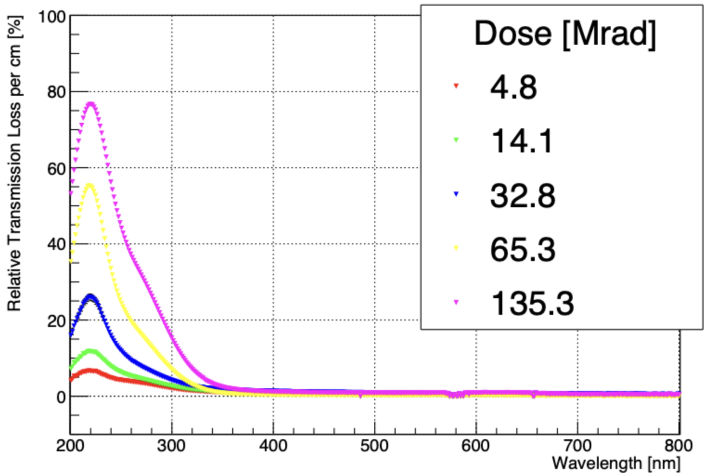
Heraeus Spectrosil 2000 Standard



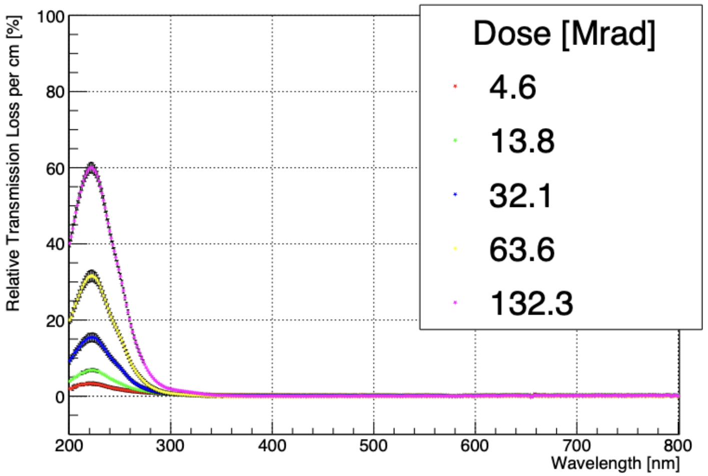
O'Hara SK-1300



Corning 7980 ArF Excimer



Heraeus Spectrosil 2000 High H2



--All samples are wet (> 200 ppm OH content), except SK-1300 which is dry; doped Heraeus has high OH and high H2 content

--Main absorption center at 5.6 eV is the E' – unavoidable point-like defects that cause dangling Si atoms which absorb light

--The shoulder structures are from non-binding hydroxide absorption centers around 4.5 – 5 eV

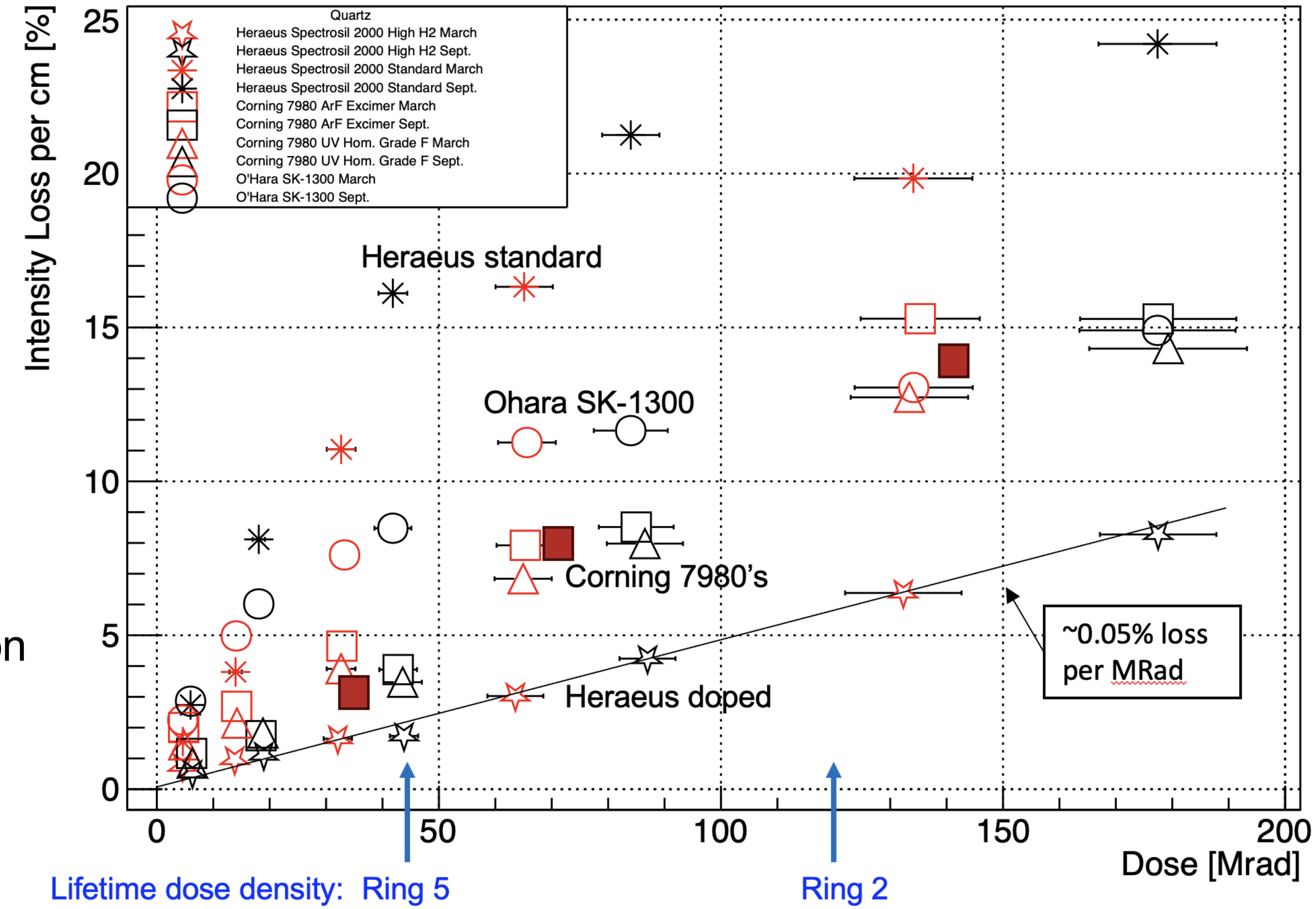
--the high H_2 doped Heraeus shows very little of this damage center at our doses

Quartz radiation hardness summary results

Addresses Charge 2a, bullet-points 1,5 and 6

- Quartz radiation damage study completed in April 2022 (docDB #886); data used to select material and inform our optical simulations
- Dose estimates for radiation tests are at 10% precision level
- Heraeus high H_2 doped Spectrosil 2000 is best performing (clearly) – ~no shoulder structure in losses.
- Heraeus standard sample is worst performing – it has greatest light loss above 15 - 20 MRad dose
- QA tested Corning 7980 samples from production vendor (■)
- Main detector uses Heraeus high H_2 doped Spectrosil 2000 while all auxiliary detectors use Corning 7980 homogeneity grade 5F

Total Intensity Loss Across Wavelengths 220-400 [nm]



3D-printed plastic radiation hardness test results

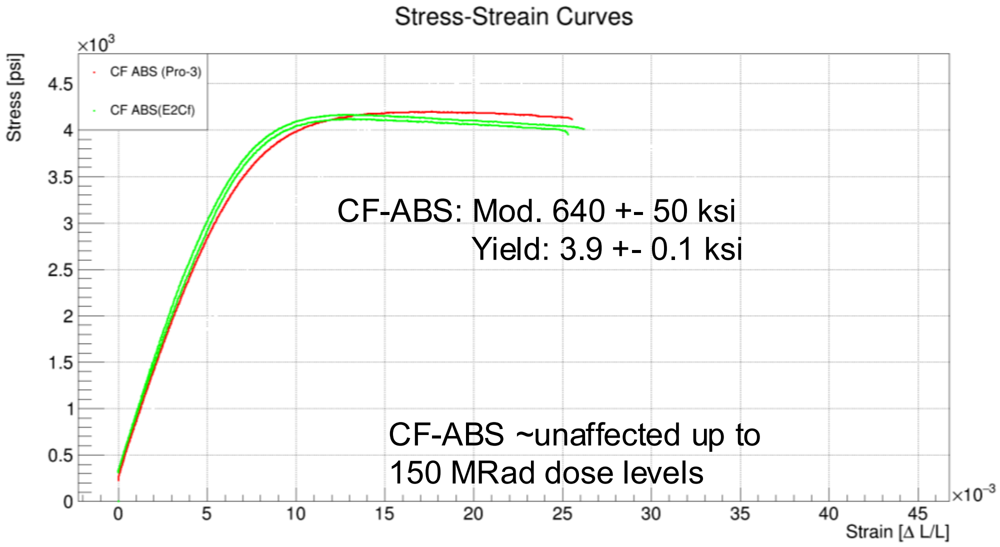
Addresses Charge 2a, bullet-points 1,5 and 6

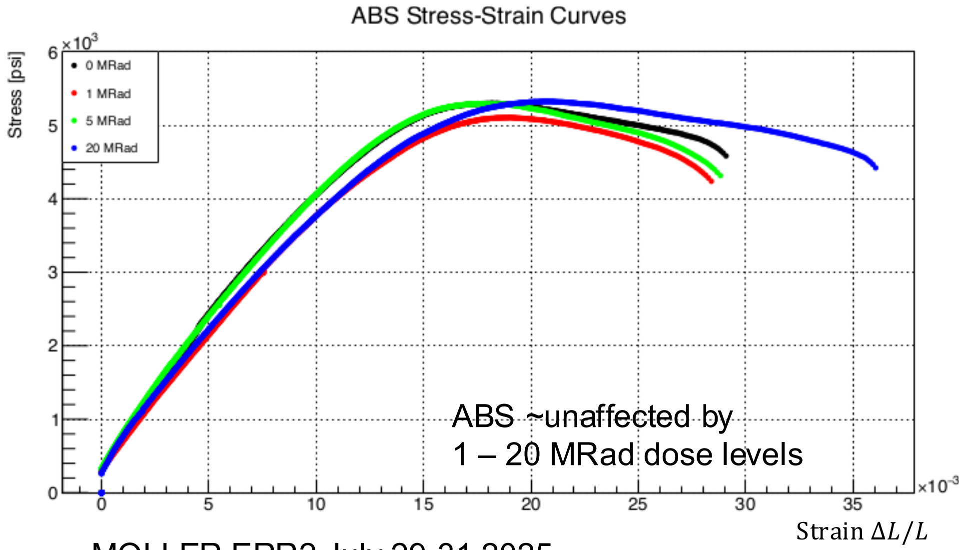
- Results following irradiations:
  - PLA has high stiffness but is weakened by radiation
  - Nylon has low stiffness but is not weakened by dose
  - ABS is least affected by tested radiation levels
  - CF-ABS is 40% stiffer and also ~unaffected by radiation

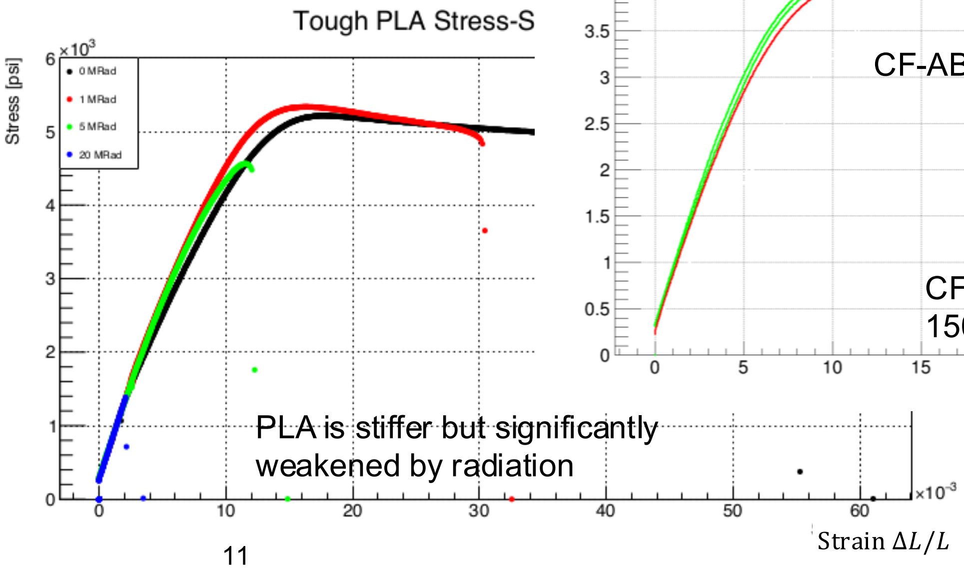
- Tensile strength results for non-irradiated plastic

	0 Mrad (baseline)	
Material	Modulus [ksi]	Yield [ksi]
ABS	390 ± 20	4.7 ± 0.2
tough PLA	430 ± 20	4.8 ± 0.2
Nylon	250 ± 30	6.1 ± 0.2
C-fiber Nylon	520 ± 50	5.6 ± 0.3

	1 Mrad		5 Mrad		20 Mrad	
Material	Modulus [ksi]	Yield [ksi]	Modulus [ksi]	Yield [ksi]	Modulus [ksi]	Yield [ksi]
ABS	390 ± 30	4.7 ± 0.2	380 ± 20	4.7 ± 0.2	370 ± 30	4.7 ± 0.2
toughPLA	480 ± 20	5.1 ± 0.2	460 ± 30	4.3 ± 0.1	480 ± 30	1.2 ±
Nylon	380 ± 30	5.0 ± 0.2	230 ± 70	6.2 ± 0.3	220 ± 60	6.1 ±







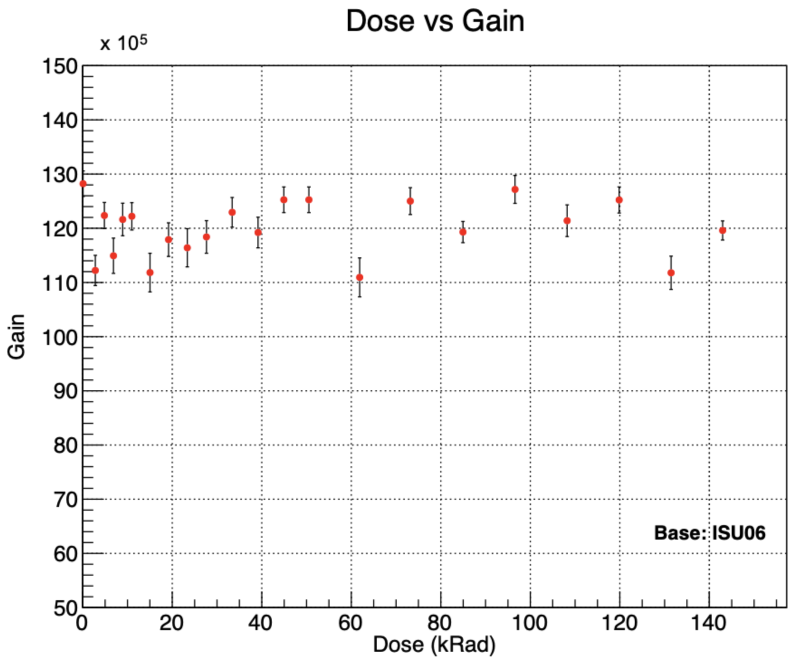
PMT electronics radiation hardness test results

Addresses Charge 2a, bullet-points 1,5 and 6

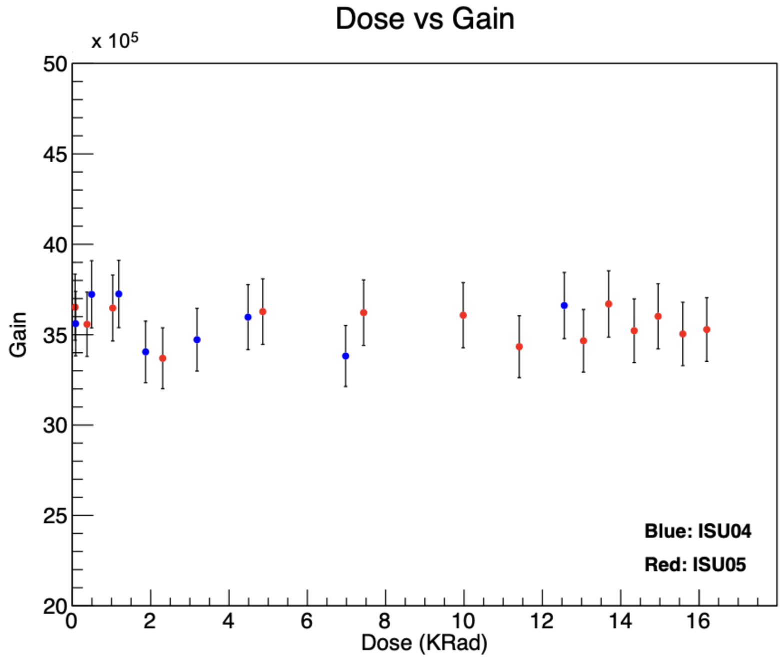
PMT Base 1: Op amp	Dose (kRad)	Total Dose (kRad)
Run 0	106	106
Run 1	106	210
Run 2	210	420
Run 3	210	630
Run 4	106	740
Run 5	106	845
Run 6**	106	950
Run 7	318	1,300
Run 8	106	1,500
Run 9	210	1,600

Integrate-mode op-amp
Survived up to ~1 MRad
!

***Run at which Op-amp started to fail*



Event-mode op-amp dosing
Never died; went up to ~140 kRad



DC-DC (10 V) converter dosing
Tested two bases: Both died around ~20 kRad

- Dose levels per run determined from OSL measurements, beam charge/pulse measurements and conversion factor from benchmarked simulation

Radiation hardness tests summary

Addresses Charge 2a, bullet-points 1,5 and 6

Plastics and FE Electronics:

- CF-ABS is 40% stiffer than ABS while yield strength is 20% lower; both plastics are ~unaffected by radiation up to 150 MRad. DocDB technical summary in process
- PMT base electronics' critical IC chips have been tested. Results show that op-amps and regulator chips are robust at the >120 kRad level, but the DC-DC converters are not
- Risk mitigation strategy for DC-DC converters developed by U. Manitoba group – We will use the +- 10 V DC-DC converter, but remove it from the base assembly and install in a separate PC board using a pin socket mount – This will allow us to better shield the component and facilitate easier replacement if needed

Quartz radiators:

- Heraeus H_2 doped Spectrosil 2000 is used for all Main detector tiles and shows 2% total intensity loss per cm at the peak lifetime expected dose for Ring 5 (and 6% for Ring 2). Note that peak doses only occur in the center of Open region detector quartz; and our air-core light guides are not great reflectors in the UV.
- Doses in Shower-max quartz are 10 – 20 times higher due to showering. To mitigate this issue, we use longpass filters to reject all light below 400 nm (which is the region of transmission loss); this also lowers the PMT's cathode and anode currents to acceptable levels for long term operation.
- DBMs and scanner quartz will have much lower lifetime doses than Ring 5; LAM will have comparable dose to Ring 5 and the SAMs will get lifetime doses similar to Shower-max.

Shower-max: prototyping and testbeams

Addresses Charge 2a, bullet-points 2, 3 and 4

- 2018: SLAC ESTB Facility – 3, 5.5, and 8 GeV electrons; very low rates

  --tested benchmarking and early full-scale prototypes over 5 day period in early December

- 2022: MAMI Testbeam – 855 MeV electrons; high rates

  --used 2018 quartz and tungsten in 2022 prototype chassis (so-called Retro v1)

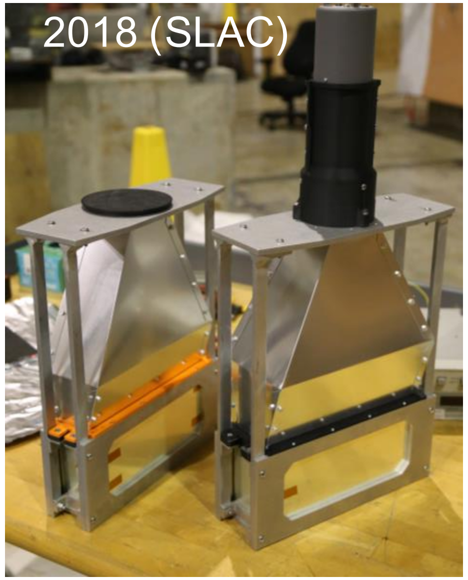
  --Key findings – wrapping quartz in aluminized-mylar improves performance: gives better resolution and more uniform PE response; azimuthal non-uniformity is ~25%

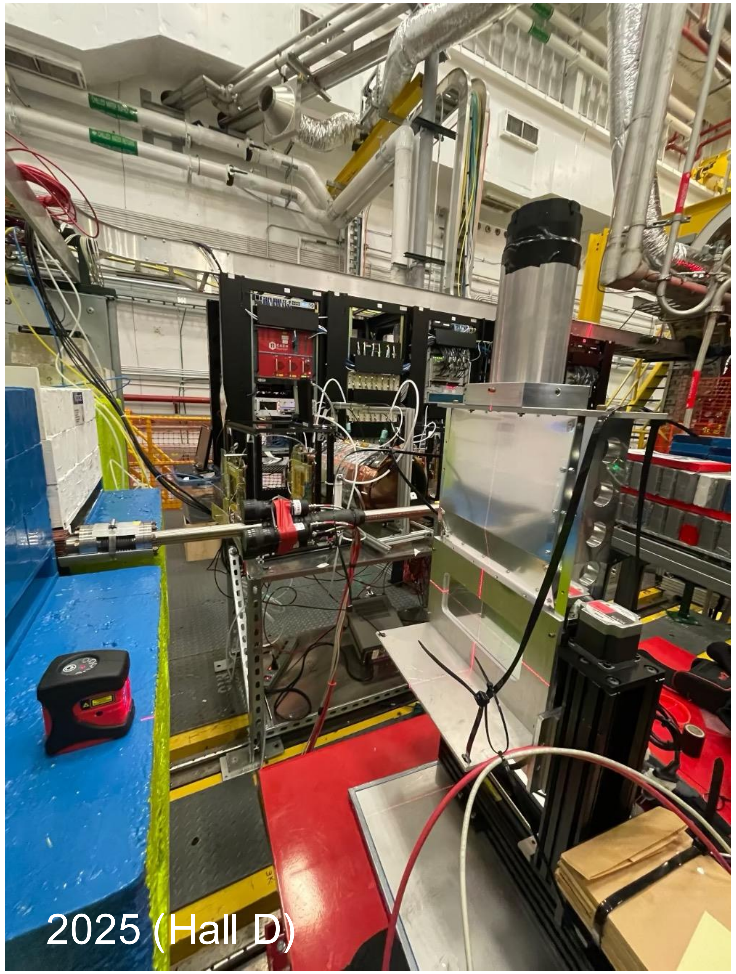
- 2023: MAMI Testbeam – 855 MeV electrons; high rates

  --used production quartz cut and polish with 2018 tungsten in 2022 prototype chassis (so-called Retro v2)

  --Key findings – benchmarked PE response for production quartz and custom 350 nm and 400 nm long pass filters

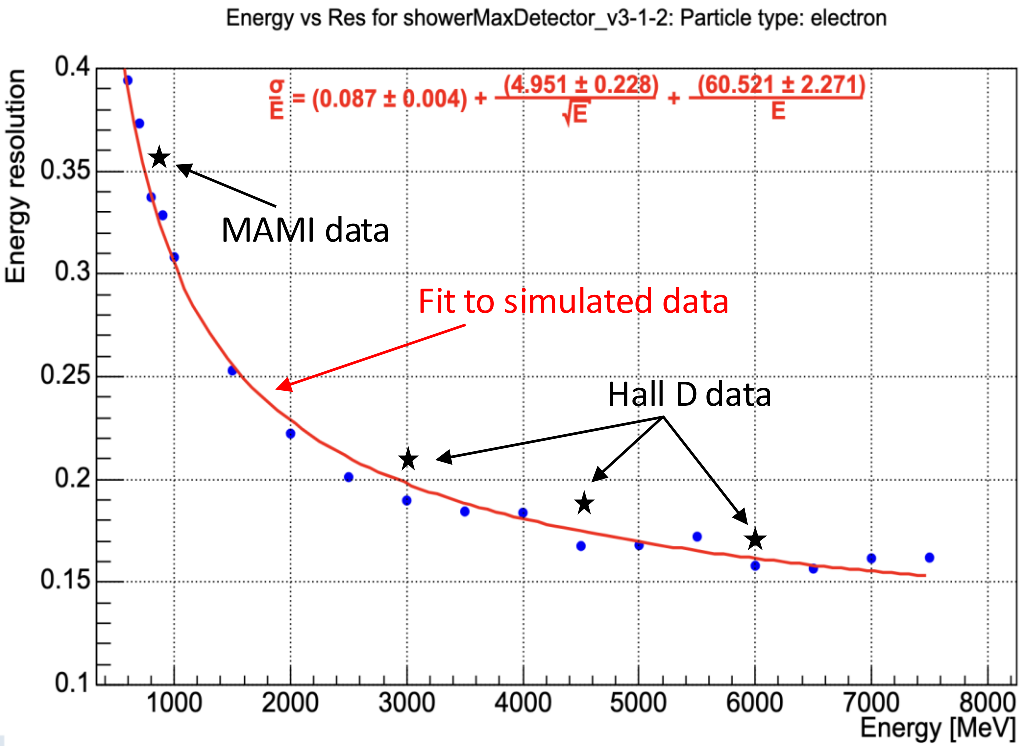
- 2025: Hall D Testbeam – 3 - 6 GeV positrons; high rates

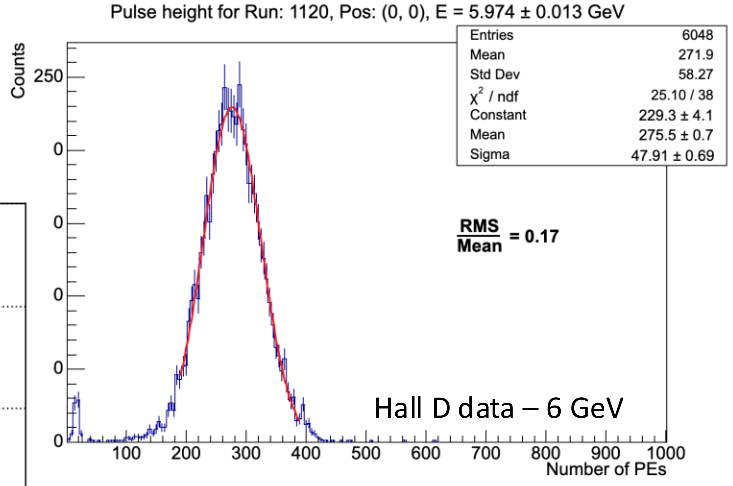


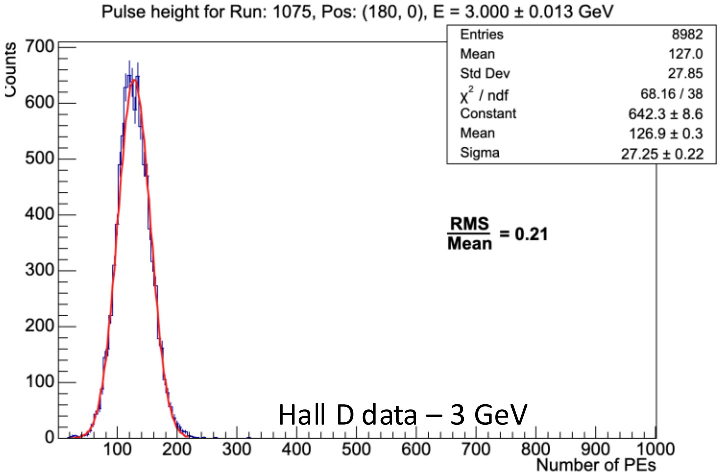


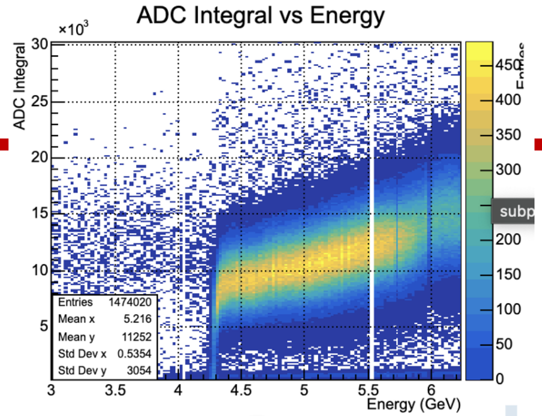
Shower-max: testbeam studies at MAMI and Hall D

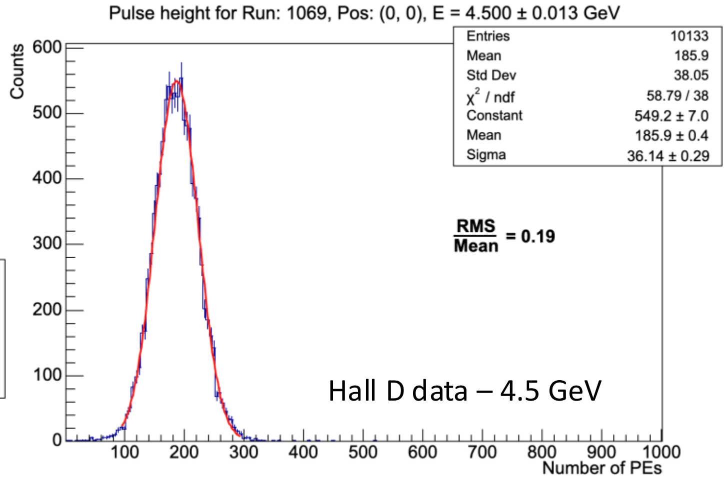
Addresses Charge 2a, bullet-points 2, 3 and 4

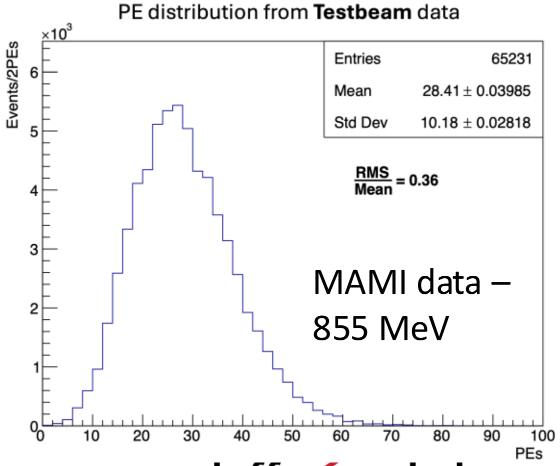












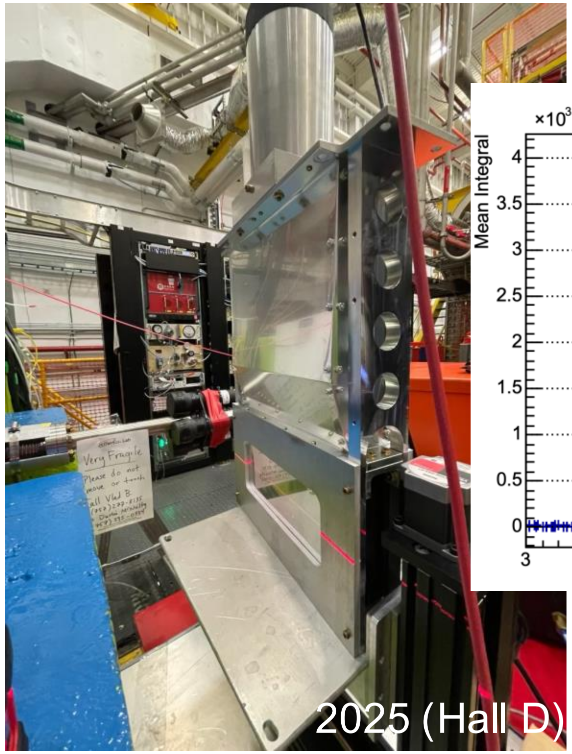
- Hall D Testbeam results (very fresh) give our first ever look at multi-GeV shower responses
- Preliminary PE yield (~40 PEs/GeV) and det resolution results match simulation within 10 - 20%
- The optical transmission has been tested under actual beam conditions and the Shower-max provides sufficient detector response to achieve the goals of the experiment

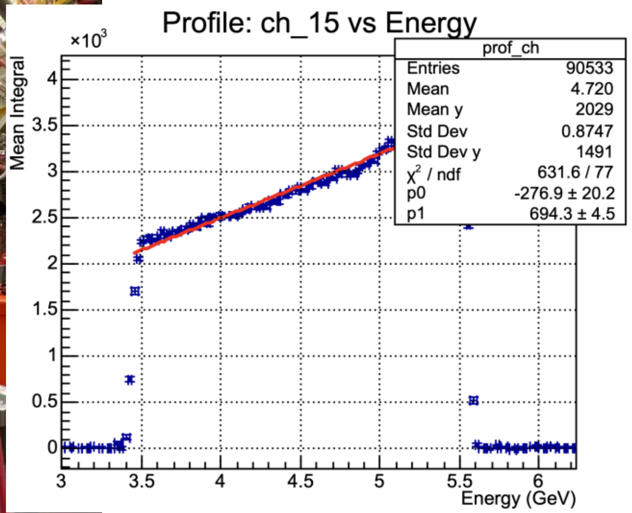
Shower-max: testbeam studies at MAMI and Hall D

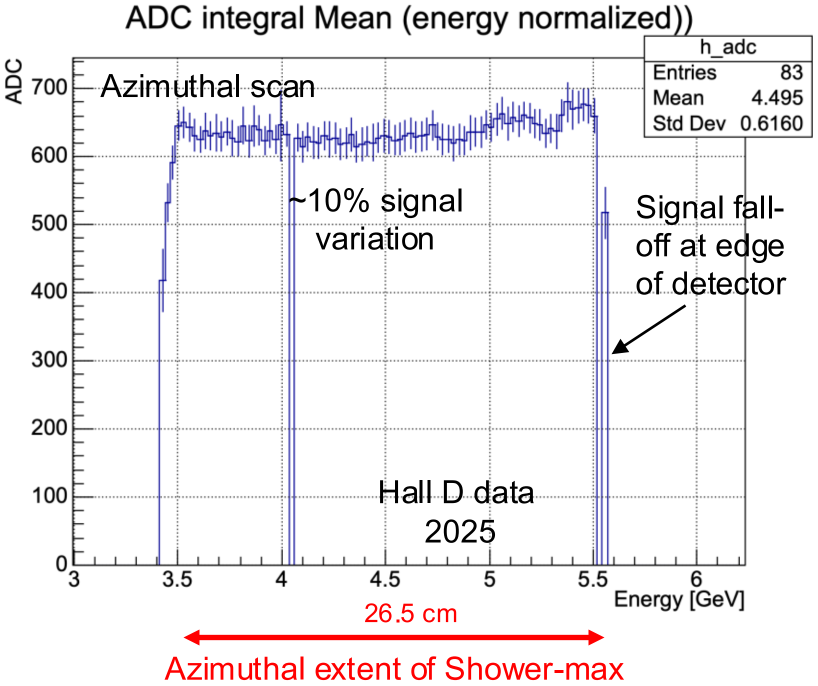
Addresses Charge 2a, bullet-point 2

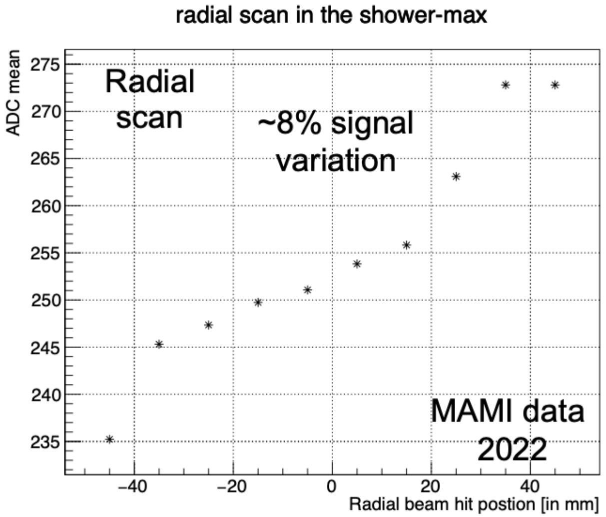
Light collection uniformity studies

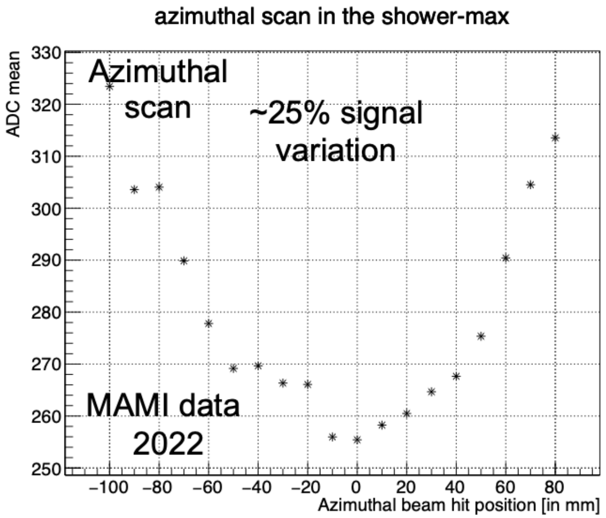
- Shower-max has an irreducible ~10% non-uniformity for light collection along the quartz radial direction (due to absorption length of the quartz and the large tile size (265 x 160 x 6 mm^3)
- The Shower-max non-uniformity along the azimuthal direction has been reduced from ~25% to ~10% (preliminary hall D data) by modifications to the light guide design. Shower-max also has reduced signal at edges due to shower containment; Moliere radius is ~1.1 cm







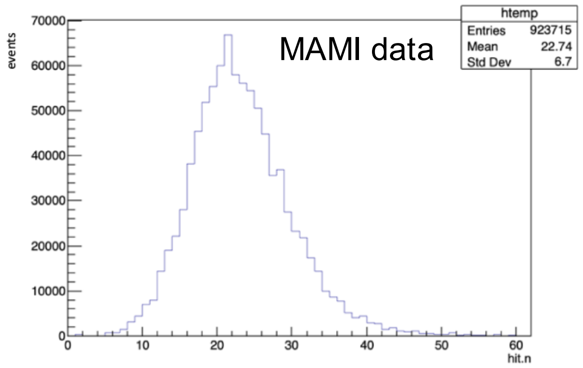




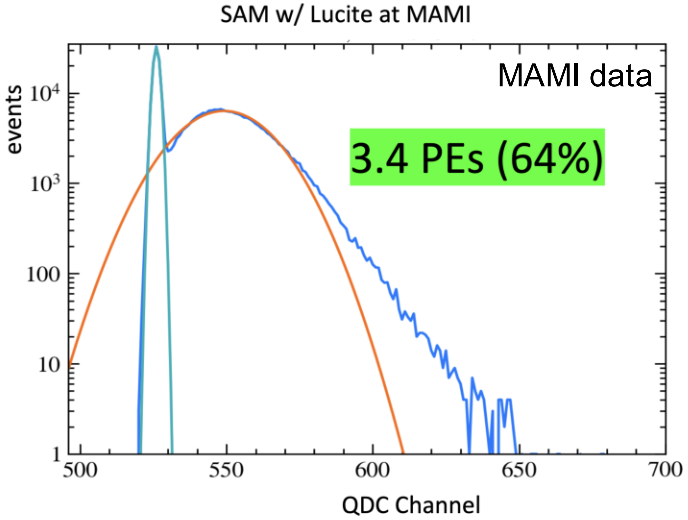
SBM and Scanner: prototyping and testbeams

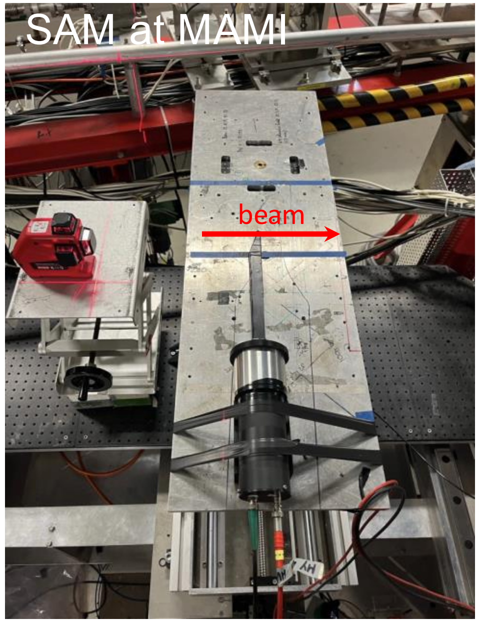
Addresses Charge 2a, bullet-points 2 and 3

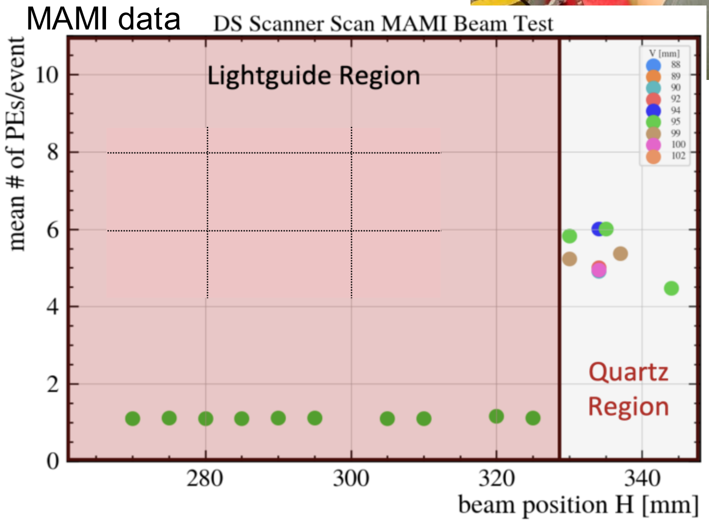
- 2023: MAMI Testbeam – 855 MeV electrons; high rates
  --tested prototype LAM, SAM, and DS Scanner detectors (lucite radiators)



LAM pulse-height-dist.







- 2025: Hall D Testbeam – 3 - 6 GeV positrons; high rates
  --tested all pre-production SBM and Scanner detectors
  --analysis in process

Additional info

Addresses Charge 2a, bullet-points 2 and 3

Calibrating detector responses:

- During low current, event-mode running with the tracking detector system, pulse height distributions for all thin quartz detectors (SBMs Scanners, and Main) are acquired and used to calibrate their yield response and resolution. These measurements are done routinely throughout experiment and allow for monitoring changes.
- For Shower-max, we will get the energy-weighted pulse height distributions in event-mode. GEM data cuts combined with MC simulation will be used to provide energy bins

Concerns about signal degradation over time:

- For Shower-max: The anticipated PMT cathode currents are expected to be ~50, 25, and 20 nA for the Open, Transition, and Closed regions, respectively. Our nominal PMT gain in integrate-mode is 500, which gives PMT anode currents of 25, 12.5, and 10 uA in the respective regions. Our PMT lifetime is expected to be ~1 year of continuous running with a 10 uA anode current. It is anticipated that the Open region detector PMTs will need to be replaced during the experiment due to dynode gain degradation.
- For SBMs and Scanners:

  --The LAM will experience some signal loss due to radiation damage to quartz, but it is anticipated to have PMT cathode and anode currents of only 10 nA and 5 uA, respectively, and should last the entire experiment.

  --The SAM will experience extremely high rates (~400 GHz level) and so will employ a unity-gain PMT base during integrate-mode operation. This allows the PMT to operate linearly and without gain degradation over time. Signal degradation due to quartz radiation damage is not expected to be critical based on PREX-2 and Qweak operating experience.

Summary

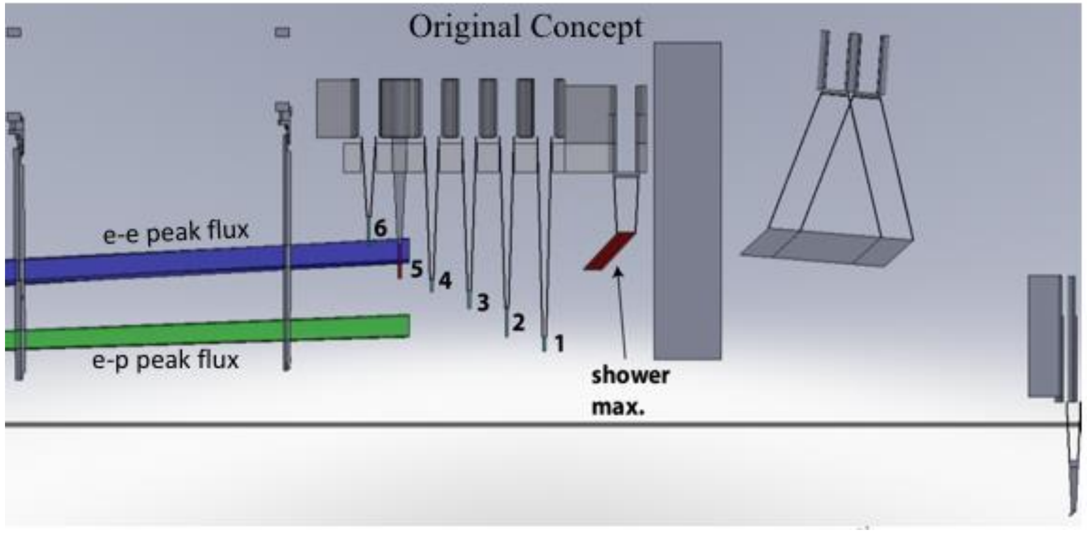
- All Auxiliary detector systems are on schedule to be fully complete and at Jefferson Lab ready for installation in the hall by end of January 2026, including all electronics, instrumentation, and hardware needed for installation and operation: FE electronics, ADCs, power supplies, cables, motion systems, vac. pumps, mounting structures and fixtures, small patch panels (LAM and Shower-max)

- Radiation hardness studies informed our choice of radiator and expectations for light-signal loss over the experiment lifetime. (also informed choice of 3D printed plastic and FE electronics design and shielding)
  --Ring 2 and 5 Open-region quartz will have largest losses
  --Longpass filters for Shower-max eliminate light signal degradation; LAM and SAM are deemed okay
  --there is possibility of contingency funds to purchase replacement quartz for Ring 5 Open (and PMTs for Ring 5 and Shower-max) – make decision this summer

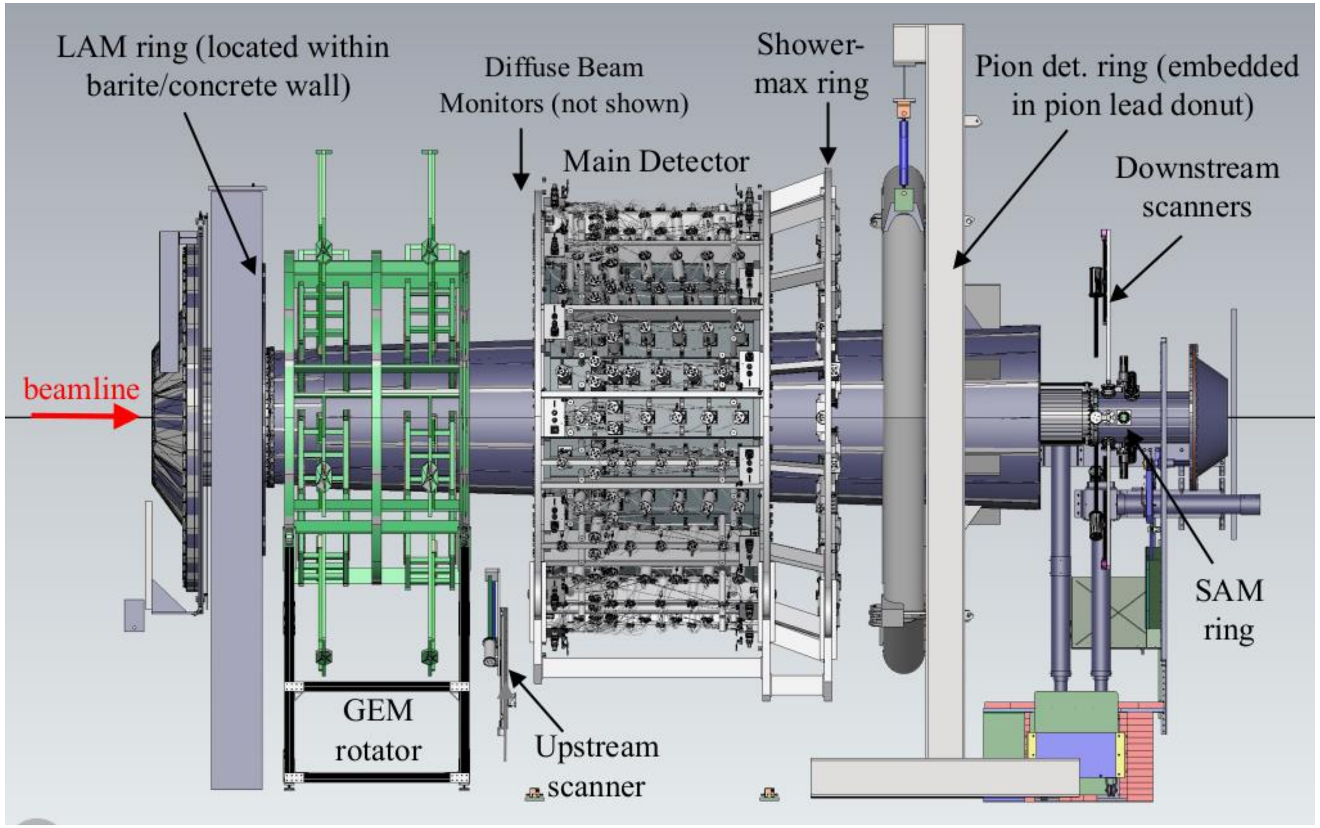
- All Auxiliary detector systems have undergone multiple stages of prototyping and testbeam studies and have been demonstrated to be ready for operation and achieve the scientific goals of the experiment.

Appendix Slides

Shower-max subsystem overview



MOLLER Detector Package

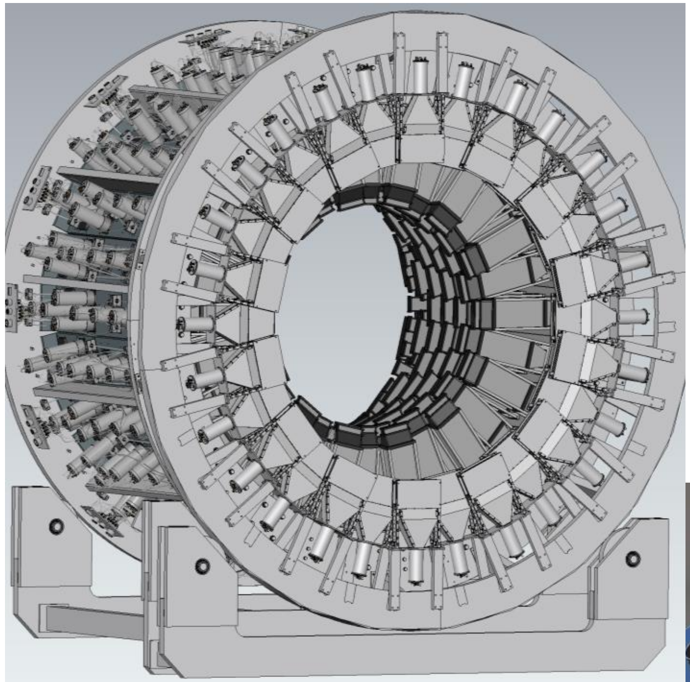


- Shower-max is an electromagnetic sampling calorimeter
- Designed and positioned to provide additional meas of Ring-5 integrated flux (MOLLER A_{PV})
- Weights flux by energy $\Longrightarrow$ less sensitive to soft and hadronic backgrounds
- Also operates in event mode for calibrations and will give additional handle on background pion identification
- Designed to have $\lesssim 25\%$ resolution over full energy range and constructed with rad hard components for long term stability

Shower-max module and ring geometry

Idaho State University

ShowerMax detector: ring of 28 sampling calorimeters intercepting physics signal flux 1.7 m downstream of ring 5



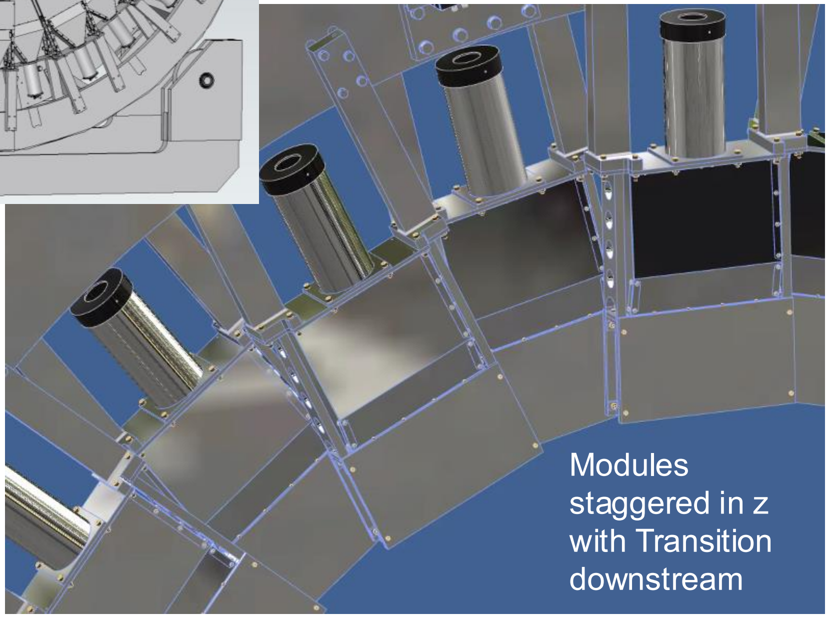
- Aluminum 6061 chassis and air-core light guide
- 99.95% pure tungsten and HPFS radiators
- Radiation length: ~9.5 X_0
- Molière radius ~ 1.1 cm

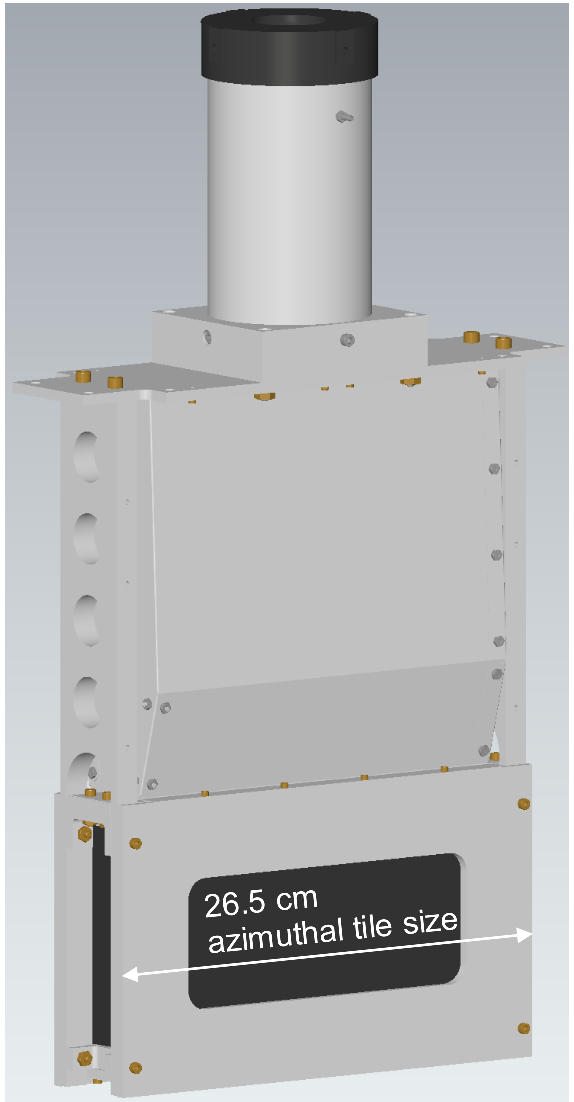
Active region

IR: 1020 mm

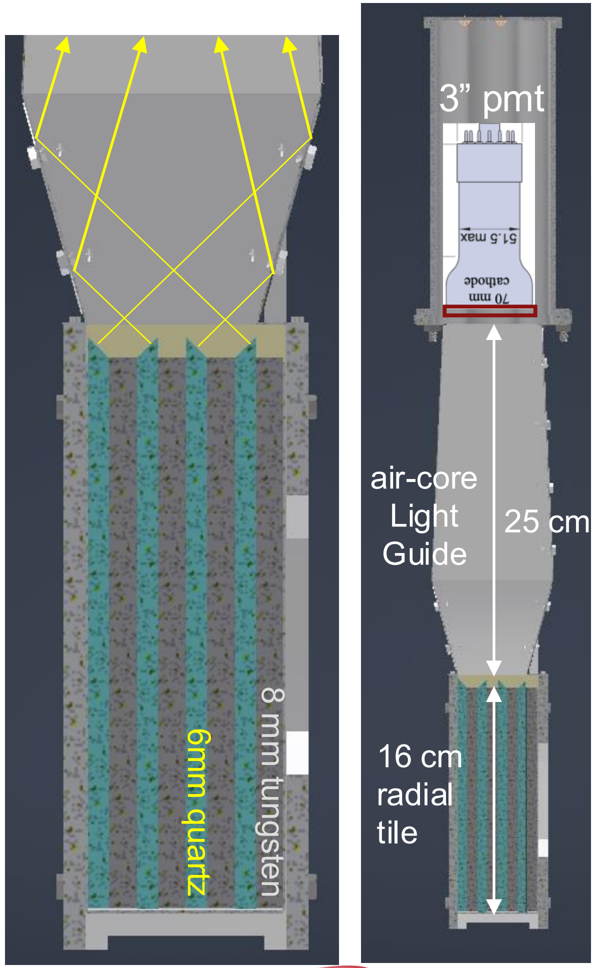
OR: 1180 mm

z-loc: 23920 mm from hall center





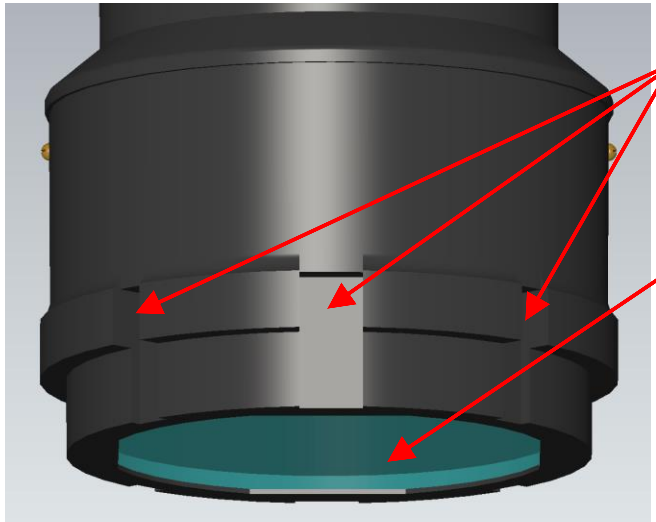
Module Weight: ~ 80 lbs



Shower-max module pmt cradle

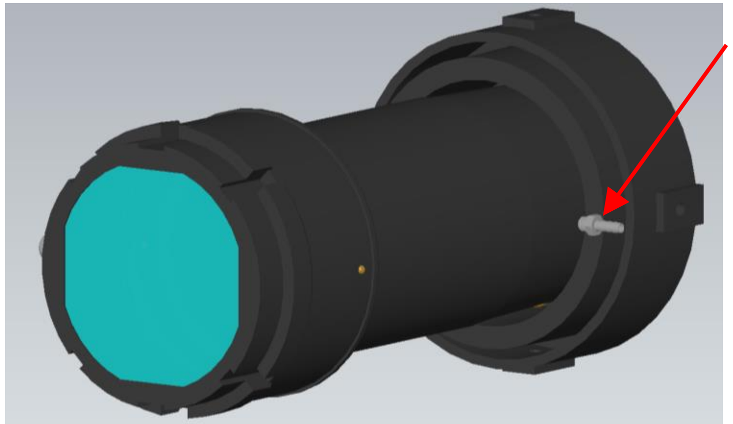
- 4 piece, 3D-printed ABS plastic pmt cradle

--provides pmt protection, holds long pass filter, and facilitates gas flow into lightguide volume

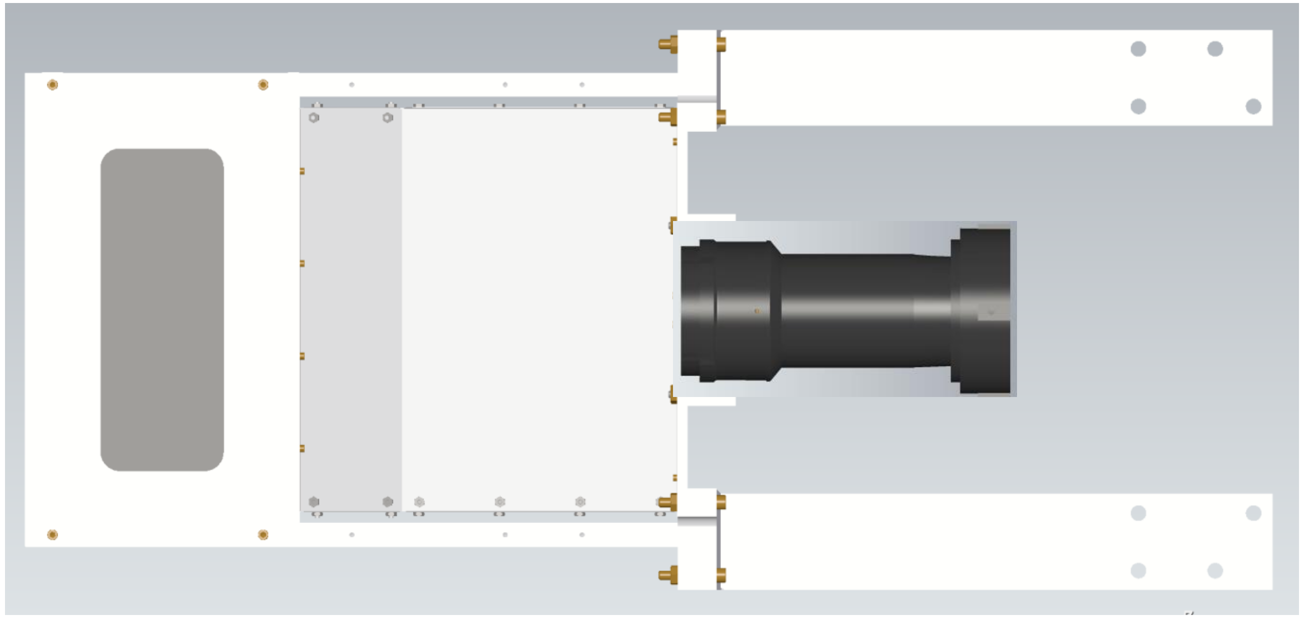


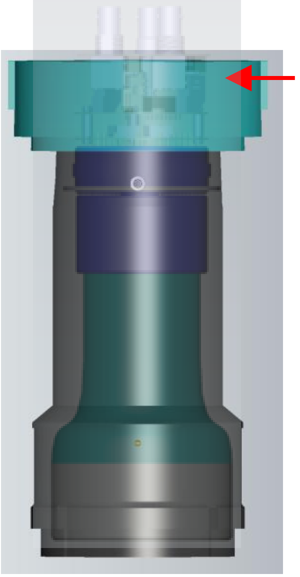
8 channels around the cradle base allow gas to flow into lightguide

Long pass filter: Corning 7980, 78 mm diameter, 3 mm thick



Barbed gas inlet threaded into outer aluminum cylinder



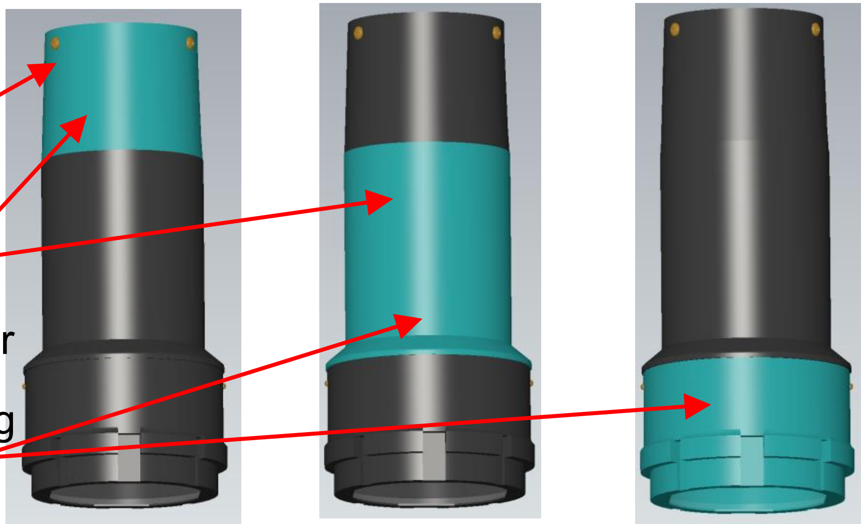


Gasket used to seal lid

Inner alum. cylinder here

These parts screw together

Attached using brass inserts and screws

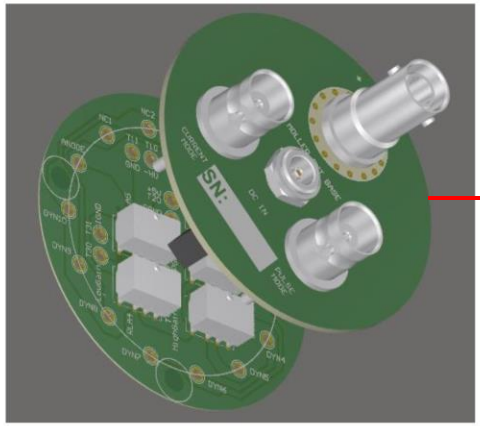


Shower-max module pmt electronics

Idaho State University

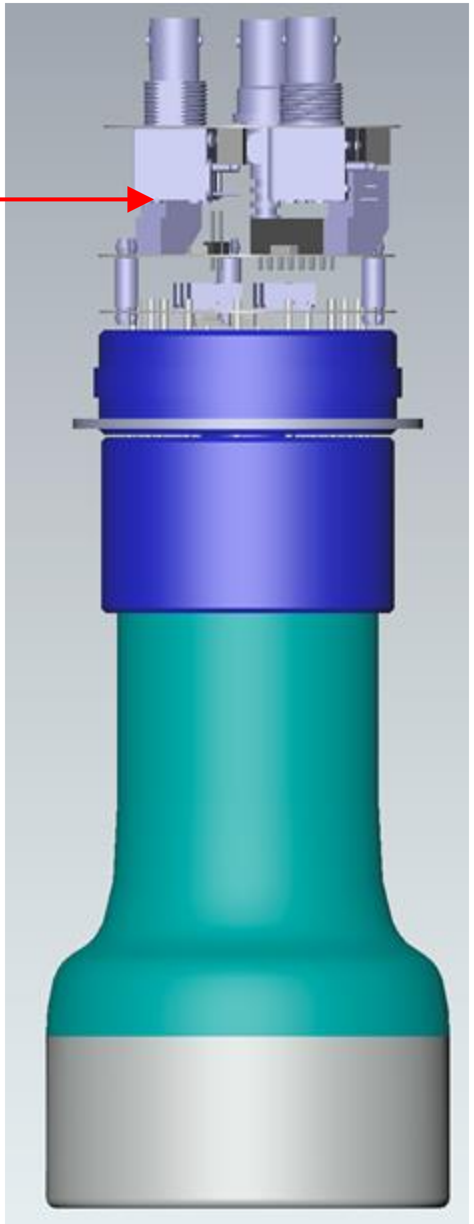
- Due to space constraints, SM pmt base electronics form factor is different than the main detectors
- Both event- and integrate-mode preamps have been moved to external box mounted on SM ring
- We ordered 35 4-stage,15 3-stage bases and 40 preamp assemblies

  ❖ Designs by Jie Pan, U. Manitoba



Output connectors:
SHV, Two BNCs & a LEMO (panel mount)

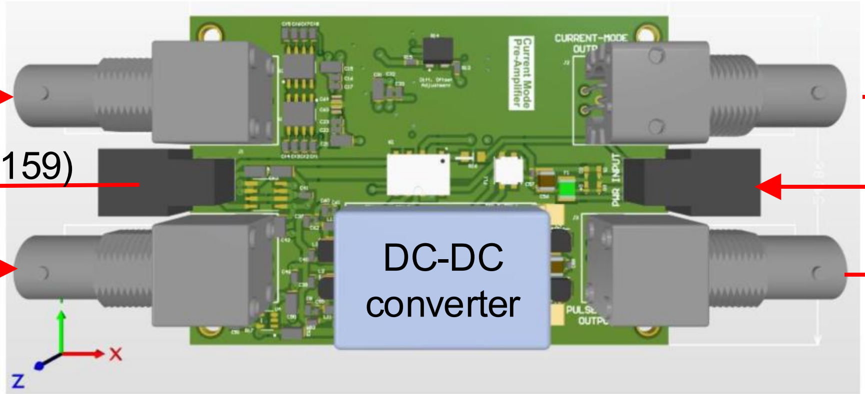
Compact design



Integrate-mode signal from PMT (RG58)

To PMT (LV switch) (RG159)

Event-mode signal from PMT (RG58)



To MOLLER Integrating ADC (RG108 Twinax)

LV input from PS (+- 10 V) (twisted pair to RG159)

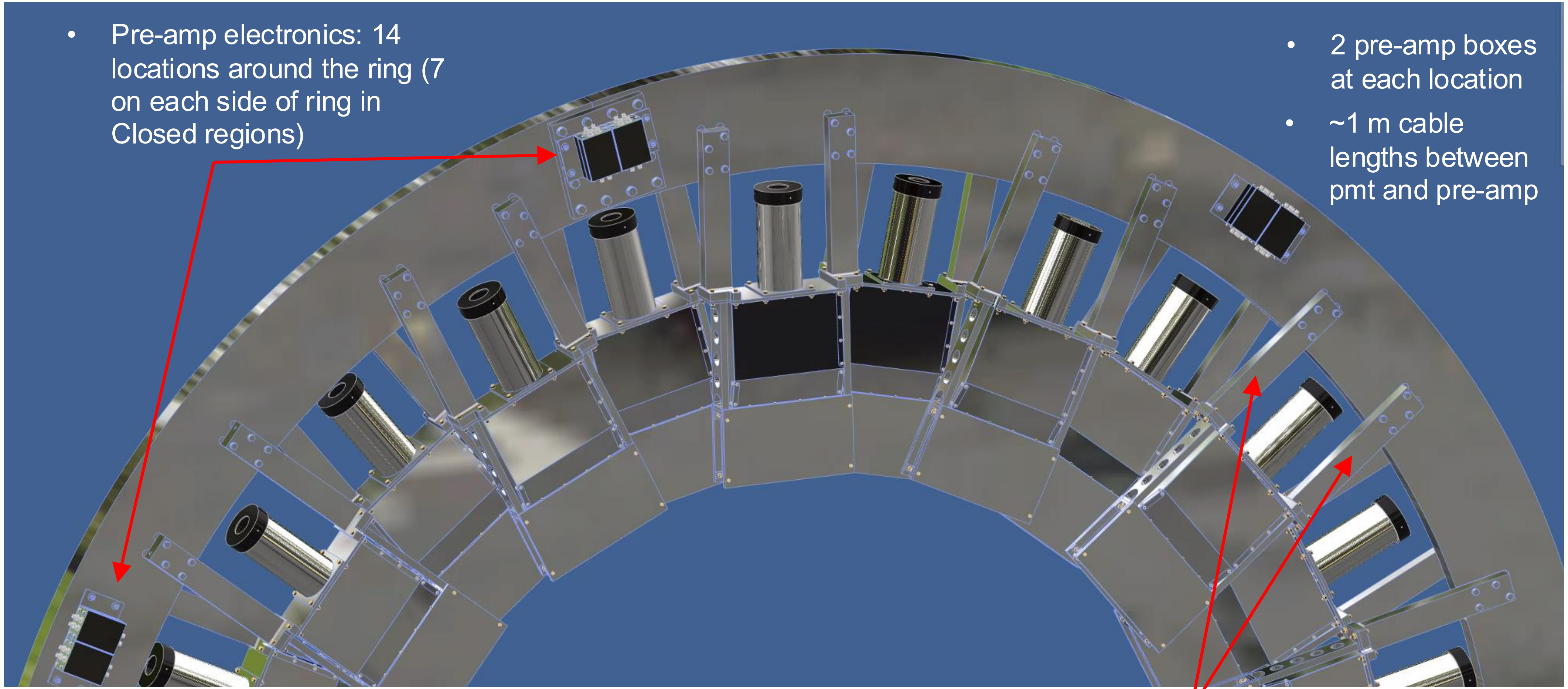
To event-mode FADC (RG58 Coax)

Connectors on left:
Two BNCs & a LEMO

Connectors on right:
BNC, BNC Twinax & a LEMO

Preamp enclosure (off-the-shelf)

Shower-max ring support structure and preamp locations



- Due to space constraints, SM pmt base electronics form factor is different than the main detectors
- Both the integrate and event mode preamps are external to the pmt and mounted on the SM ring

- Aluminum bars (15 x 1.25 x 2.5 in^3) welded to footplates attach modules to ring structure

Shower-max: prototyping and testbeams

- 2018: SLAC ESTB Facility – 3, 5.5, and 8 GeV electrons; very low rates

  --tested benchmarking and early full-scale prototypes over 5 day period in early December

- 2022: MAMI Testbeam – 855 MeV electrons; high rates

  --used 2018 quartz and tungsten in 2022 prototype chassis (so-called Retro v1)

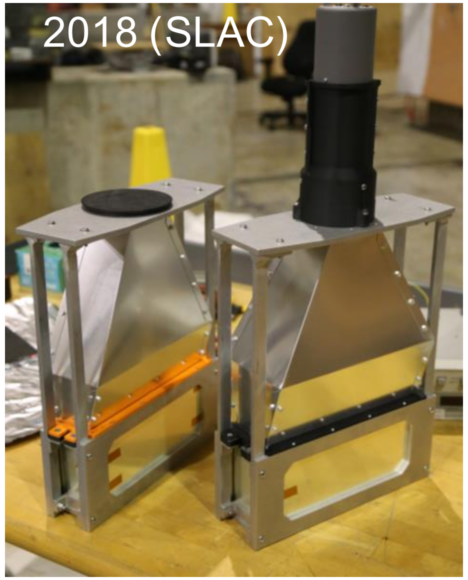
  --Key findings – wrapping quartz in aluminized-mylar improves performance: gives better resolution and more uniform PE response; azimuthal non-uniformity is large

- 2023: MAMI Testbeam – 855 MeV electrons; high rates

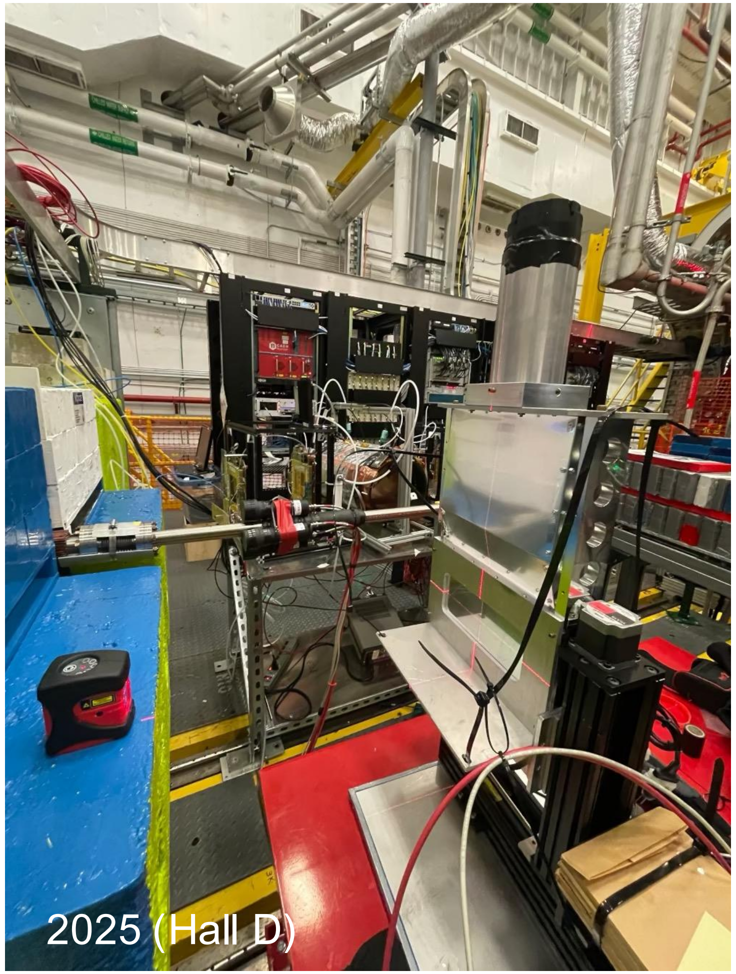
  --used production quartz cut and polish with 2018 tungsten in 2022 prototype chassis (so-called Retro v2)

  --Key findings – benchmarked PE response for production quartz and custom 350 nm and 400 nm long pass filters

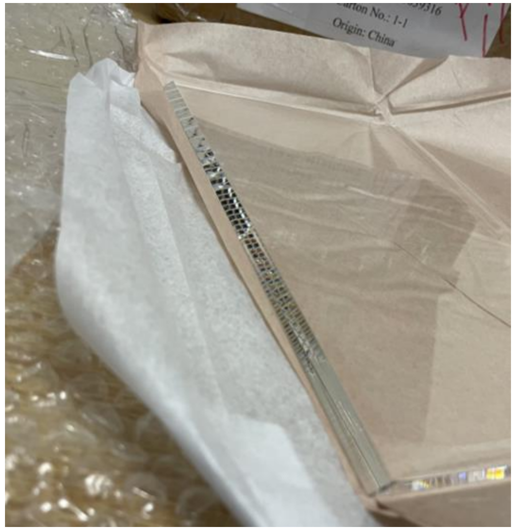
- 2025: Hall D Testbeam – 3 - 6 GeV positrons; high rates


2018 (SLAC)


2022 (MAMI)


2025 (Hall D)

Shower-max procurements status (May 2024)



- Purchased 130 quartz tiles from HYRD Photonics (Corning 7980 grade 5F; $133k)

  --Received and inspected half of the order (65 tiles); second half delivery is expected by mid July

- Purchased 116 tungsten plates from EdgeTech Industries. (99.95% pure; $118k)

  --Received and inspected full order; have an additional 8 plates from pre-production prototyping

- Purchased 30 sets of chassis parts ($42k) and ring support struts with certified weldment ($19k) from Accelerated Machine Design & Engineering (using 17 2D drawings from Larry)

  --Order placed on 4/16: 6 – 8 week leadtime for Chassis parts, 9 – 11 weeks for support struts-- weld Qualification AWS D1.2

- Purchased 31 pmts (3" Electron Tubes 9305QKB; $59k)

  --Have received 19 of them so far; remaining 12 to be delivered sometime this summer

- Purchased 30 sets of lightguide cutouts ($6k) from Richards Sheet Metal Works Inc.

  --Have received and inspected 5 sets and completely folded 2 of them so far; remaining parts expected by end of June

- Purchased all materials needed for assembly: 25 sheets of MIRO-IV mirrored aluminum (0.02" thick, 2' by 4'), 50 rolls of Ultimaker ABS filament for printing pmt cradle parts, 0.005" thick black polyimide film (20" by 36 yds) for light tightening, 0.002" thick roll aluminized mylar for quartz wrapping, and all needed machine screws, nuts and gas fixtures
- Orders for pmt base electronics will take place this summer; long pass filters to be ordered by end of year

Shower-max 2024 procurements

All 130 quartz plates received/inspected

All 31 pmts received/inspected

--18 small wooden crates each holding 7 tungsten plates (~110 lbs each)

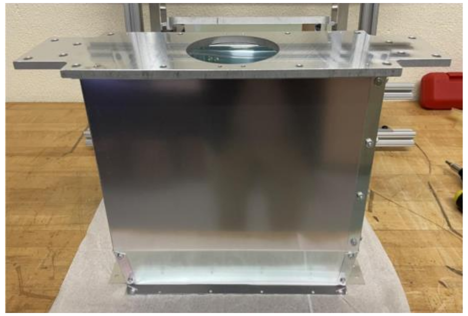
All tungsten plates received/inspected:

All chassis and light guide parts received/inspected

Shower-max initial assembly in Idaho

Idaho State University

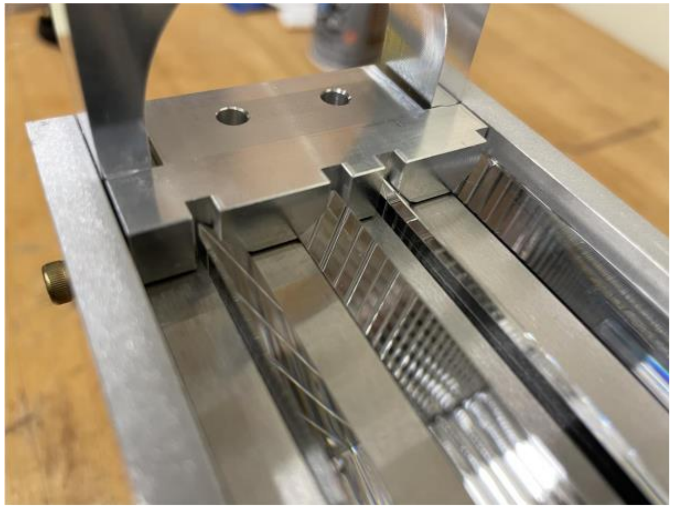
- All 31 modules have been assembled and cosmic-ray tested

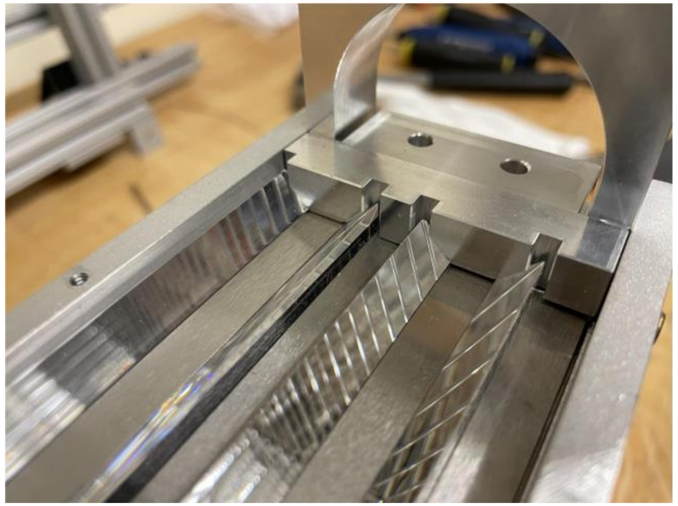


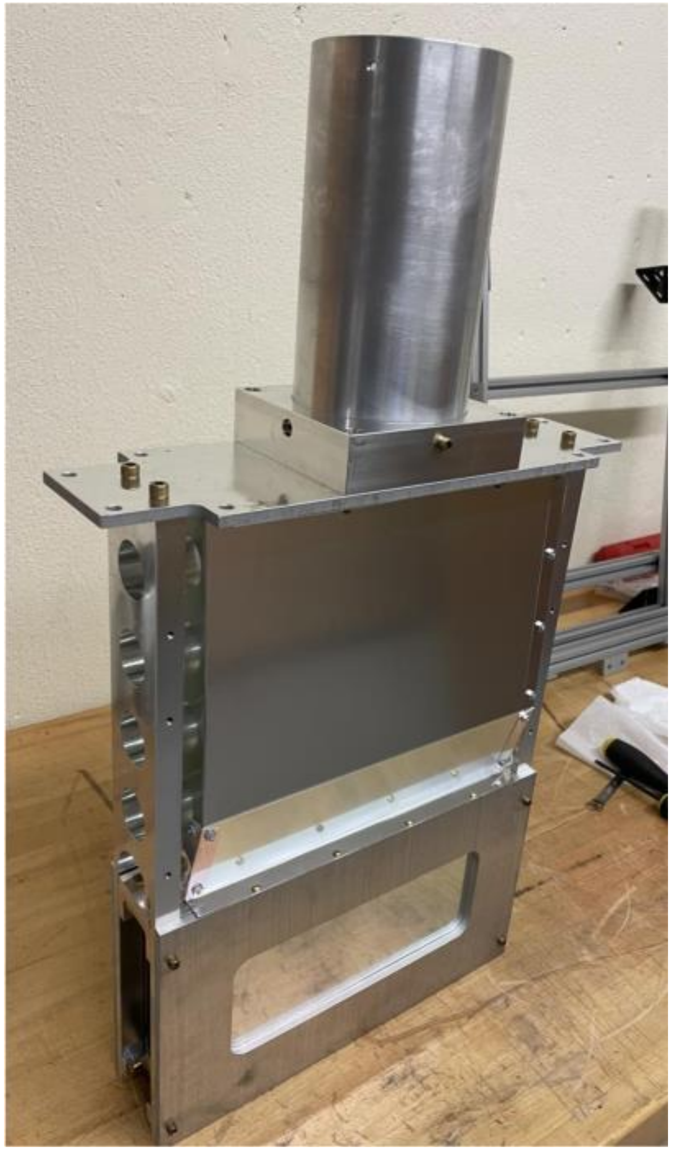
Light guide assemblies

Quartz wrapped in al. mylar for protection

8020 assembly fixture







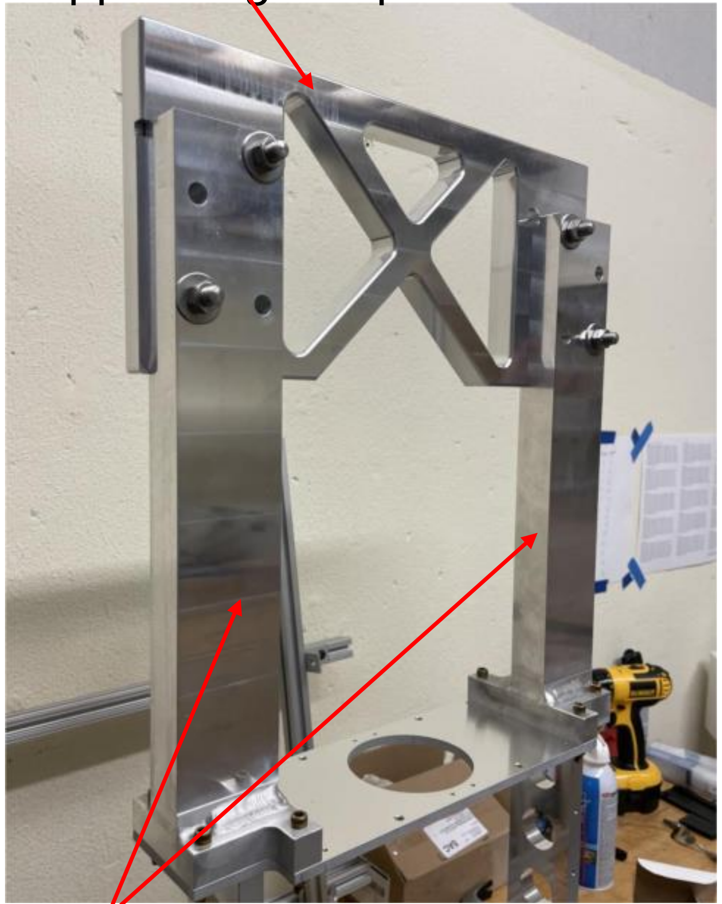
Shower-max assembly in Idaho

Idaho State University

- Photograph of Shower-max modules recently assembled and tested
- A few of the modules shown have been test-fitted with their support struts--used to mount the modules to the main ring structure

Shower-max support struts; alignment and lifting fixtures

<u>Alignment fixture</u> for mounting struts to modules; matches the support ring bolt patterns



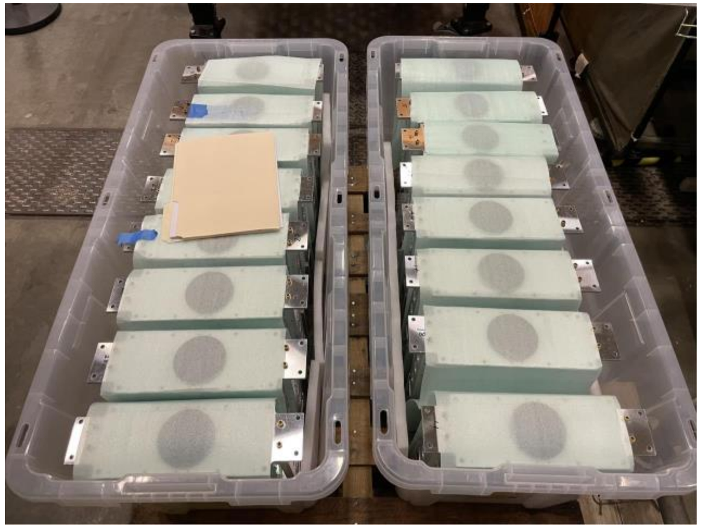
<u>Support struts</u>—for attaching modules to the support ring

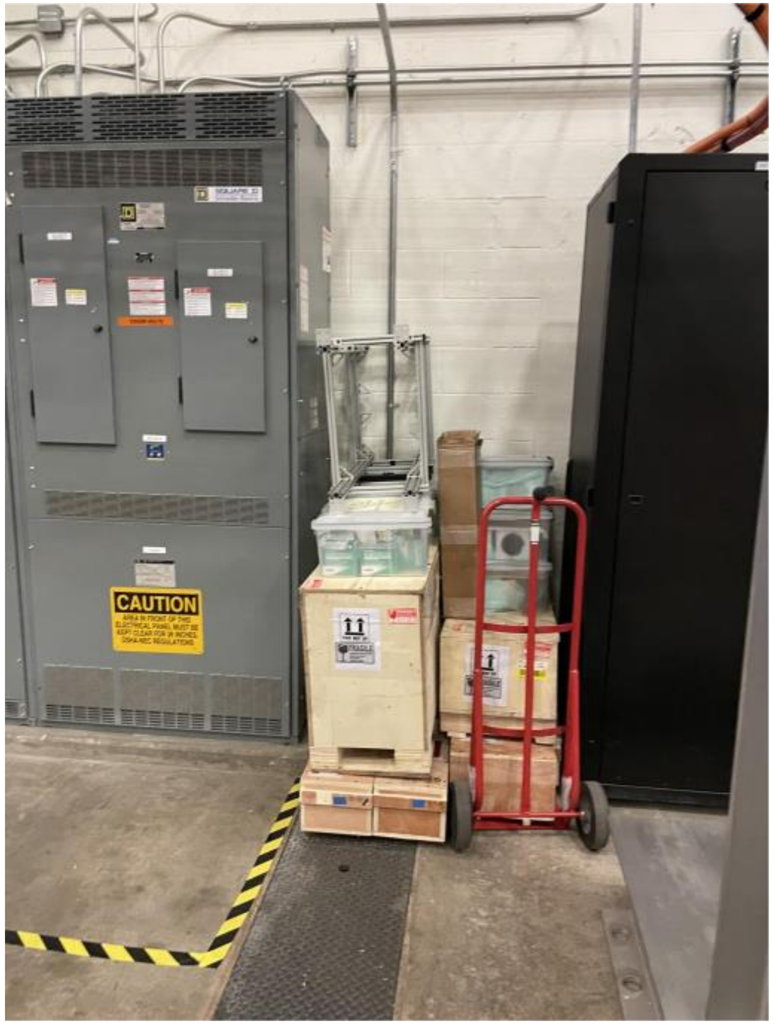
Support strut base weldment

Lifting Fixture (orange painted steel)—used to mount modules to the ring

Shower-max storage at JLab

Chassis and light guide assemblies stored in high-bay area of testlab



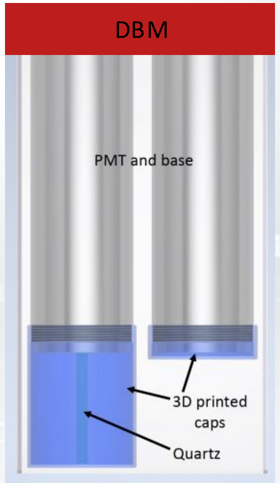


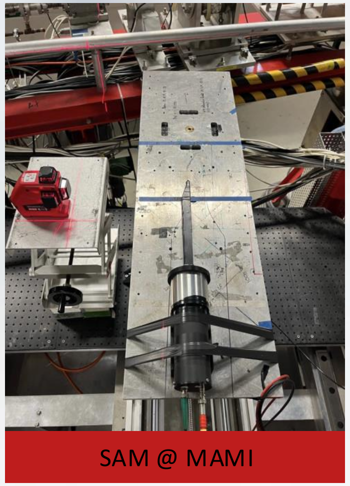
16 module's worth of quartz, tungsten, and pmt cans in testlab

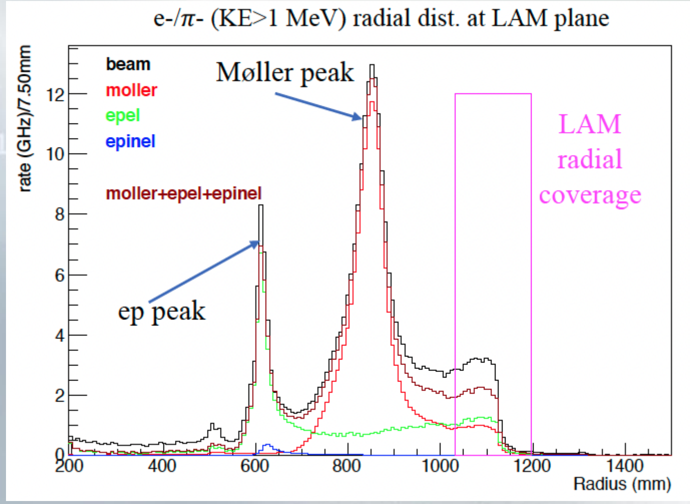
- All 28 detectors/components are now at JLab

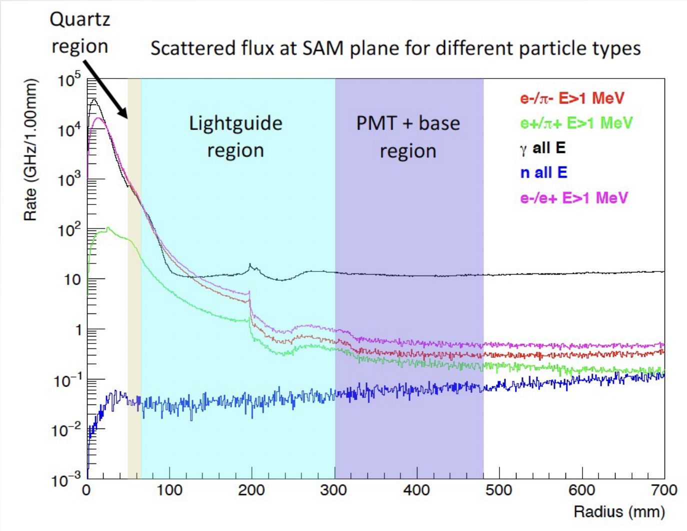
Scattered Beam Monitors

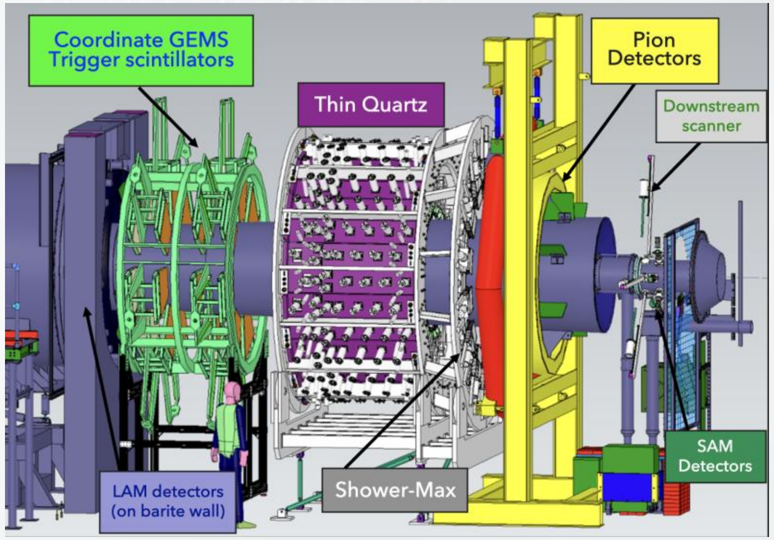
- Monitors for potential false asymmetries from re-scattered backgrounds
- "Null" asymmetry monitors as a check of helicity-correlated beam correction procedure
  - LAM and SAM lie in high rate regions where the expected physics asymmetry is low
  - DBMs reside in regions where direct target and secondary signals are small





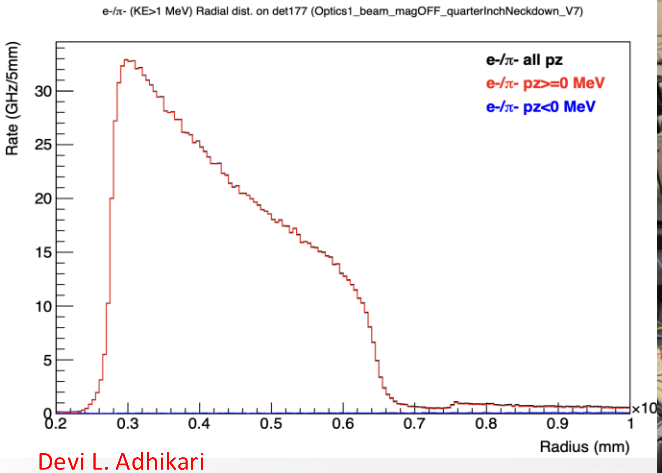




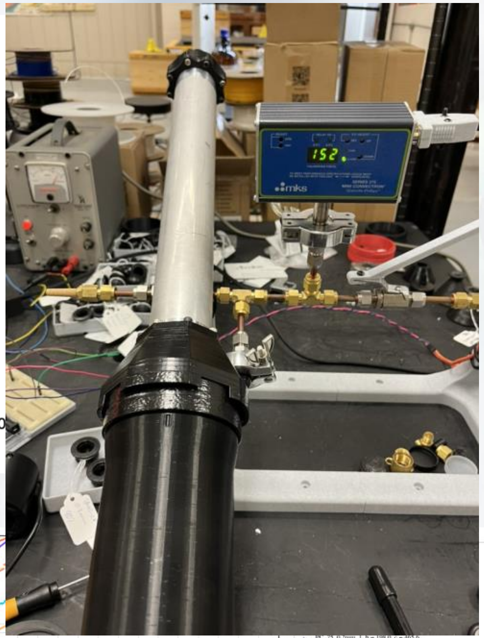


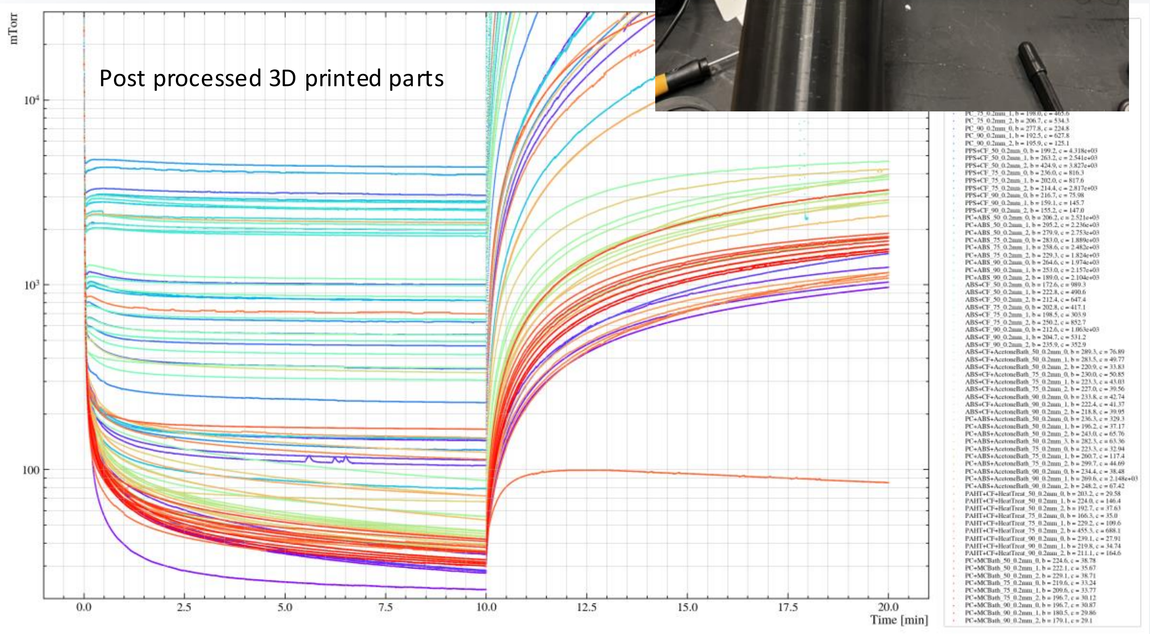
Scanner Detectors

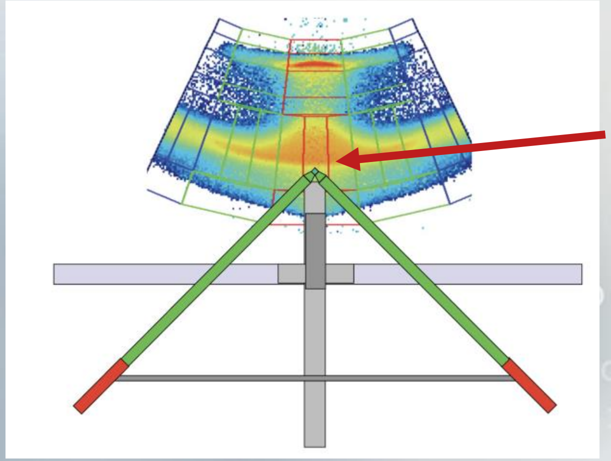
- Downstream Scanner Collar Manufacturing - Complete March 2025
- Vacuum Tight Solution - Complete March 2025
  - Reduce unwanted background
- Magnetic Field Variation Study - In Progress
- US Support Redesign
  - SS lead screw passed ferrous materials study
  - 80/20 parts procured

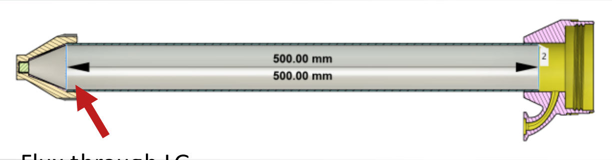


Devi L. Adhikari

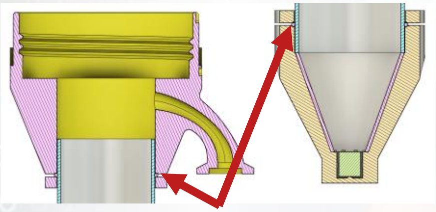








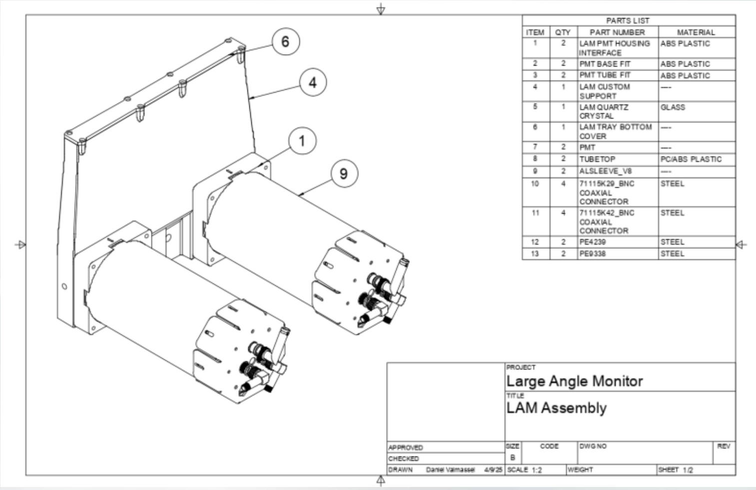
Flux through LG makes unwanted background



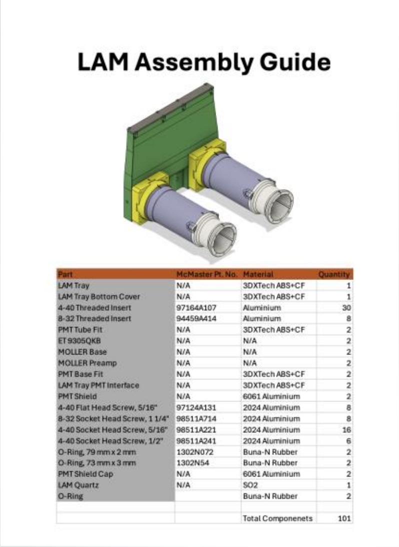
O-Ring seals + PC printed at 75% infill overlap dipped in methylene chloride

Large Angle Monitor

- LAM 3D printing - Complete October 2024
- Quartz Audit - Complete March 2025
- 7 Production + 2 Spare Modules assembly - Complete May 2025
- Hall D Test Beam - In Progress
  - Determine yield & resolution with fused silica radiator
- Cosmic Testing - In Progress
  - Test detector construction consistency



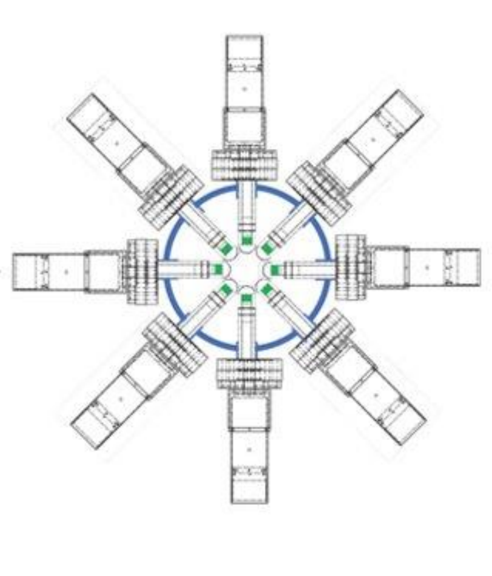
PARTS LIST			
ITEM	QTY	PART NUMBER	MATERIAL
1	2	LAM PMT HOUSING INTERFACE	ABS PLASTIC
2	2	PMT BASE FIT	ABS PLASTIC
3	2	PMT TUBE FIT	ABS PLASTIC
4	1	LAM CUSTOM SUPPORT	----
5	1	LAM QUARTZ CRYSTAL	GLASS
6	1	LAM TRAY BOTTOM COVER	----
7	2	PMT	----
8	2	TUBETOP	PC/ABS PLASTIC
9	2	ALSLEEVE_V8	----
10	4	71115K29_BNC COAXIAL CONNECTOR	STEEL
11	4	71115K42_BNC COAXIAL CONNECTOR	STEEL
12	2	PE4239	STEEL
13	2	PE9338	STEEL

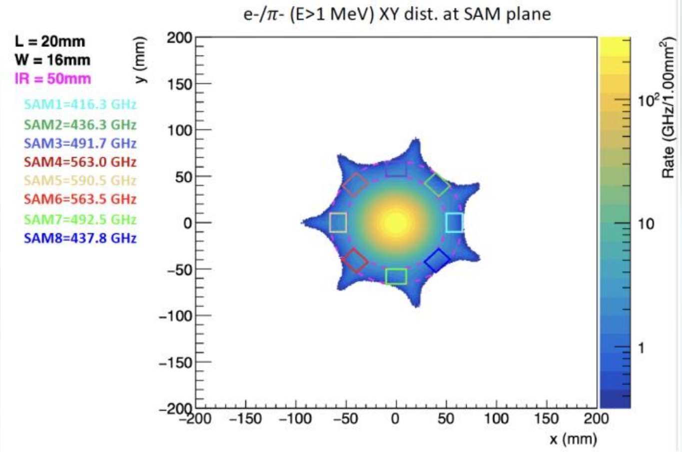


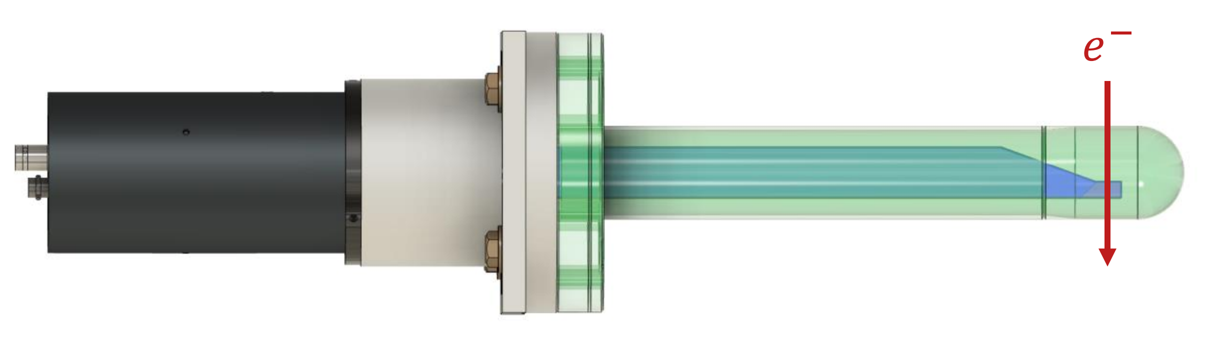
Part	McMaster Pt. No.	Material	Quantity
LAM Tray	N/A	3DXTech ABS+CF	1
LAM Tray Bottom Cover	N/A	3DXTech ABS+CF	1
4-40 Threaded Insert	97164A107	Aluminium	30
8-32 Threaded Insert	94459A414	Aluminium	8
PMT Tube Fit	N/A	3DXTech ABS+CF	2
ET 9305QKB	N/A	N/A	2
MOLLER Base	N/A	N/A	2
MOLLER Preamp	N/A	N/A	2
PMT Base Fit	N/A	3DXTech ABS+CF	2
LAM Tray PMT Interface	N/A	3DXTech ABS+CF	2
PMT Shield	N/A	6061 Aluminium	2
4-40 Flat Head Screw, 5/16"	97124A131	2024 Aluminium	8
8-32 Socket Head Screw, 1 1/4"	98511A714	2024 Aluminium	8
4-40 Socket Head Screw, 5/16"	98511A221	2024 Aluminium	16
4-40 Socket Head Screw, 1/2"	98511A241	2024 Aluminium	6
O-Ring, 79 mm x 2 mm	1302N072	Buna-N Rubber	2
O-Ring, 73 mm x 3 mm	1302N54	Buna-N Rubber	2
PMT Shield Cap	N/A	6061 Aluminium	2
LAM Quartz	N/A	SO2	1
O-Ring		Buna-N Rubber	2
		Total Componenets	101

Small Angle Monitor

- Cut light guides received
  - A big thank you to UManitoba!
- Designs frozen - fall 2024
- Fused Silica Received - March 2025
- Hall D Test Beam - In Progress
  - Determine yield & resolution with fused silica radiator
- Beampipe inserts to be ordered - Late summer
- Machining and Assembly - Early fall 2025

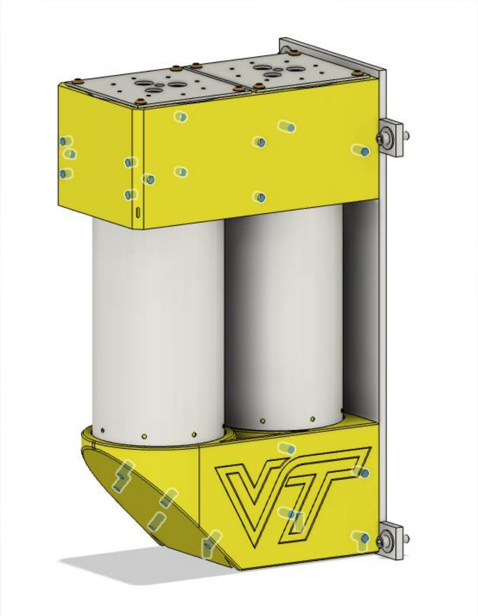


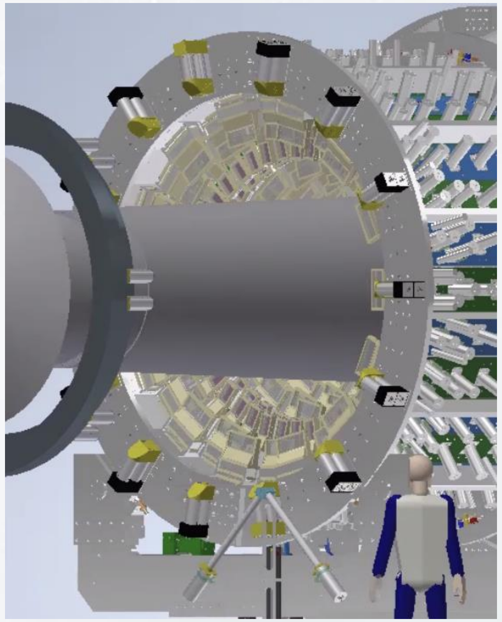




Diffuse Beam Monitor

- Fused Silica Received - Complete March 2025
- Hall D Test Beam - In Progress
  - Determine yield & resolution with fused silica radiator
- Pre-Production Review - January 2025
- Production and Assembly - Late summer 2025



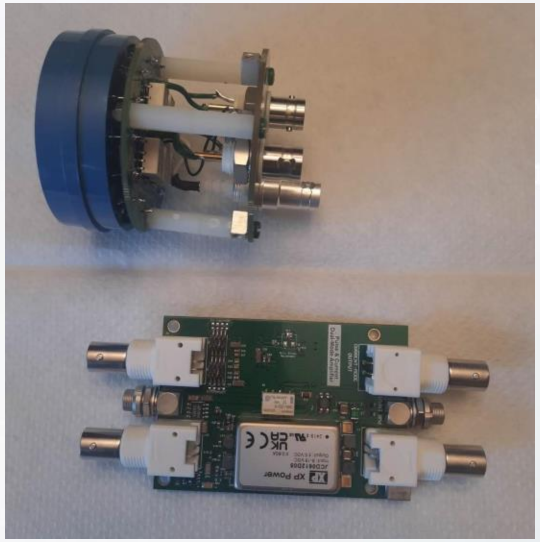


PMT Bases and Preamps

Detector	PMT type	PE	Rate (GHz)	I_cathode (nA)	PMT gain	I_anode (uA)	I-V gain (MOhm)	Vout (V)
SAM	R375, 2 inch	7	450	504	1	0.6	2.00	1.2
LAM	ET9305, 3 inch	12	4	8	521	4.0	0.50	2.0
US scanner	ET9305, 3 inch	6	0.170	0.16	12255	2.0	1.00	2.0
DS scanner	ET9305, 3 inch	9	1.390	2	1998	4.0	0.50	2.0
DBM	ET9305, 3 inch	55	0.036	0	12626	4.0	0.50	2.0

- U. Manitoba has designed and provided prototypes for three configurations:
  - LAM: separate base and preamp; likely will adopt 4 stage design
  - SAM: unity gain base for integration mode; separate preamp
  - US/DS scanners, DBM: integrated base and preamp
- Final testing in early summer; order production boards by mid-summer

LAM Base and Preamp



Radiation hardness testing of detector components

- Testing goals:

  --Quartz: quantify light transmission losses in HPFS radiators due to damage from anticipated lifetime maximum radiation dose – up to 45 MRad and 120 MRad for ring 5 and ring 2, respectively

  --3D-printed plastics: quantify tensile properties of various plastics under expected radiation loads – test up to 150 MRad

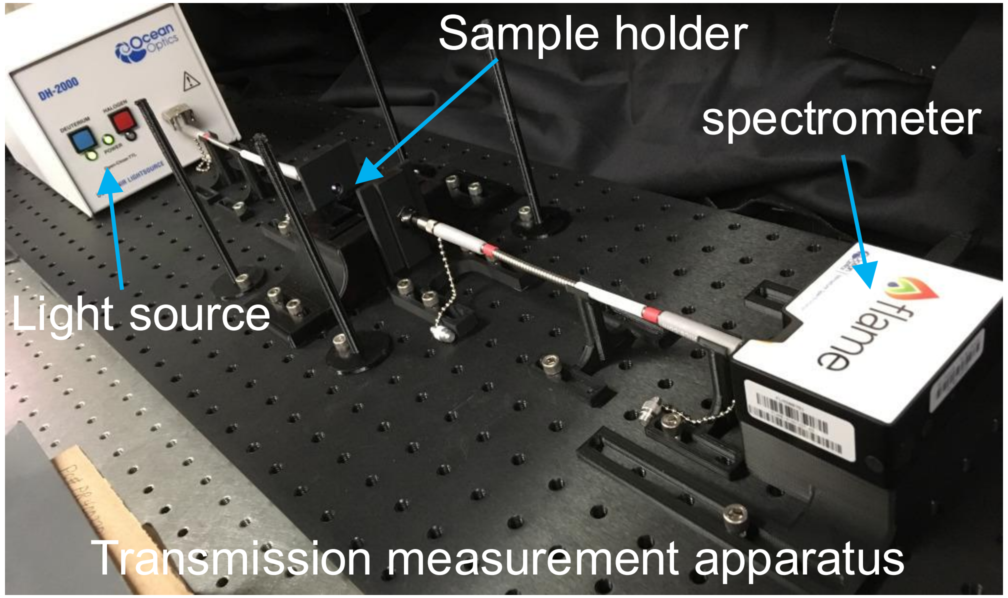
  --PMT FE electronics: quantify pmt base and pre-amp functionality in both integrate and event mode under anticipated radiation loads with a factor of 2 safety margin (~120 kRad lifetime)

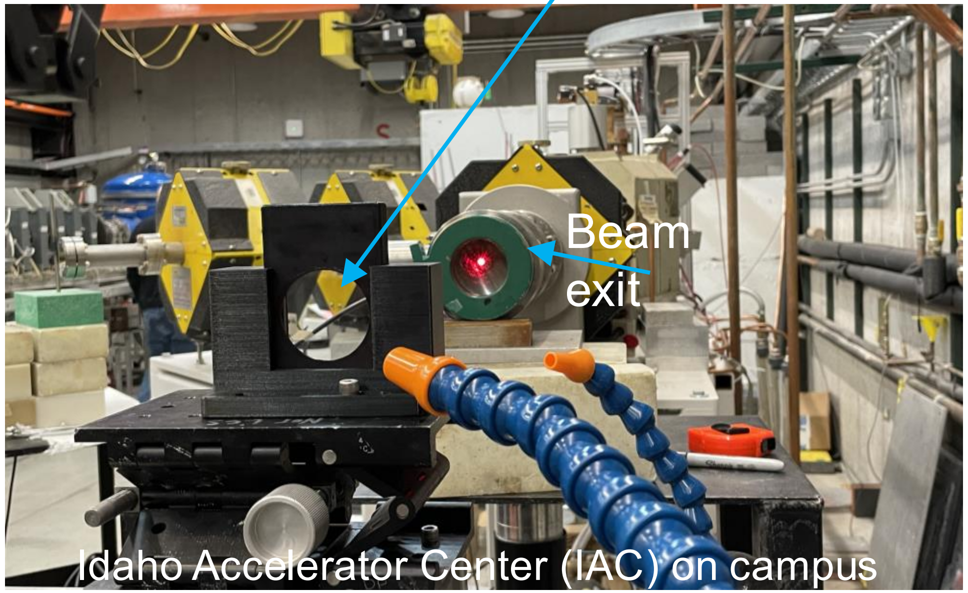
- We use the Idaho Accelerator Center (IAC) for irradiations: 25 MeV linac operated at 8 MeV peak energy Beam is setup to give ~40 nC/pulse for quartz and plastic dosing and ~1 nC/pulse for electronics
- Samples are positioned at 50 or 75 cm from beam exit window and laser aligned to beam center; vortex chiller used for quartz and plastic to limit sample temperature to 30 C
- Beam pulse dose profile is measured using OSL “nanodot” dosimeter arrays
- Beam charge per pulse is measured during sample dosing for normalization
- We use simulation, OSL measurements, and beam charge data to determine dose per nC in the sample

Detector Radiation Harness Qualification Studies at ISU

- Goal: quantify light transmission losses in detector radiators due to damage from anticipated radiation dose (for lifetime of MOLLER) – 45 MRad peak and 120 MRad peak per 5x5 mm^2 for ring 5 and ring 2, respectively
- Five candidate fused silica (quartz) samples chosen for testing: from Corning, Ohara, and Heraeus
- Irradiations conducted at the Idaho Accelerator Center using 8 MeV pulsed electron beam, ~40 mA peak current, ~1 μs pulse width (~40 nC/pulse) at 200 Hz repetition rate; samples are 50 cm from beam exit window
- Dose deposition quantified with beam dosimetry and G4 simulation benchmarked to source measurements
- Work by Justin Gahley; report in [docDB #886]

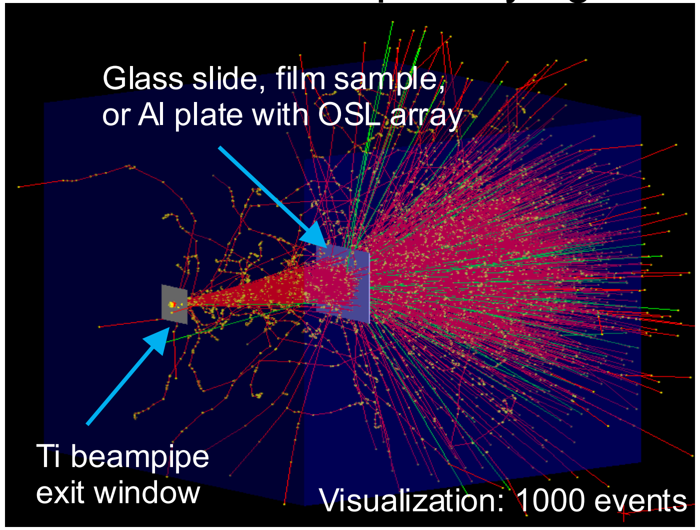
Samples: 5 cm diameter or square, 1 cm thick; polished faces



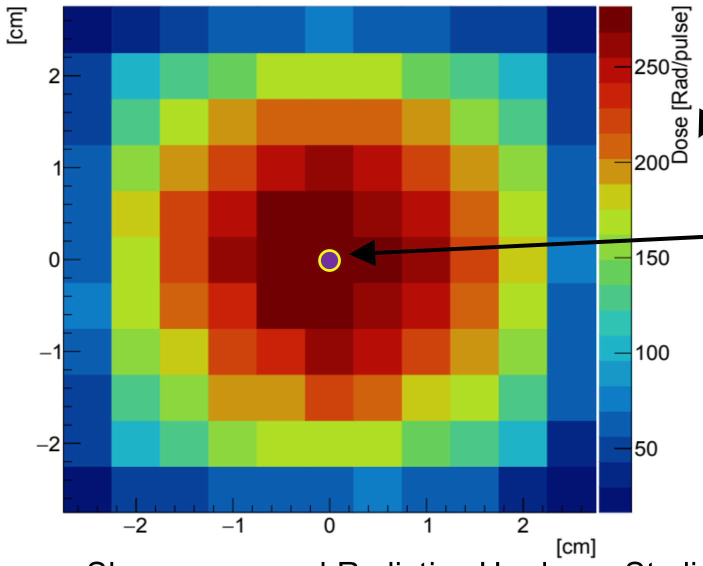


Dose simulation for quartz irradiations

G4 simulation for quantifying dose



Dose Profile Quartz 5x5x10 [mm]



Simulated beam calibrated with beamspot measurements at 3 distances

Sample irradiated at 50 cm

Beam energy scans taken at beginning and end of tests

Beam charge data acquired throughout exposures

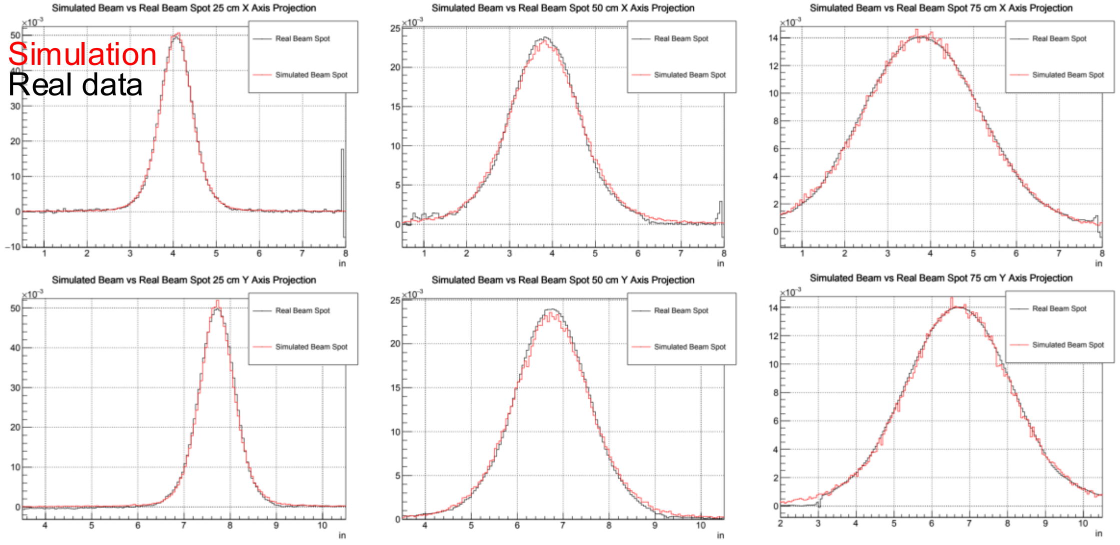
Simulated dose per 5x5 mm^2 normalized to average charge per beam pulse

Sample thickness is 10 mm

Location of light transmission measurements (within single 5 x 5 mm^2 pixel)

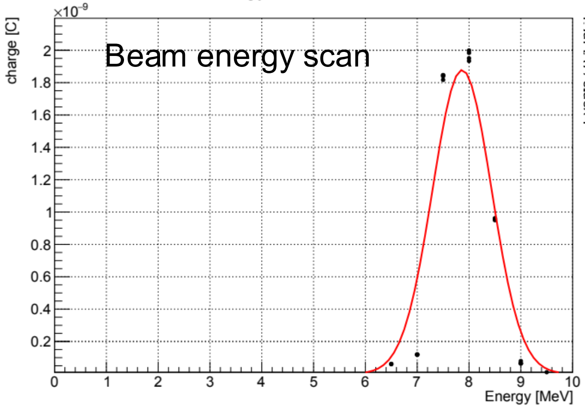
Beamspot measurement scans

Distance from beampipe window:

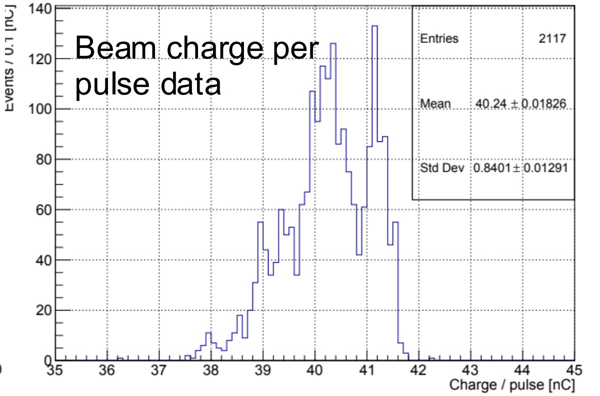


- Simulation
- Real data

Beam Energy Distribution 09/02/2021



Beam Charge Distribution for all Sample runs

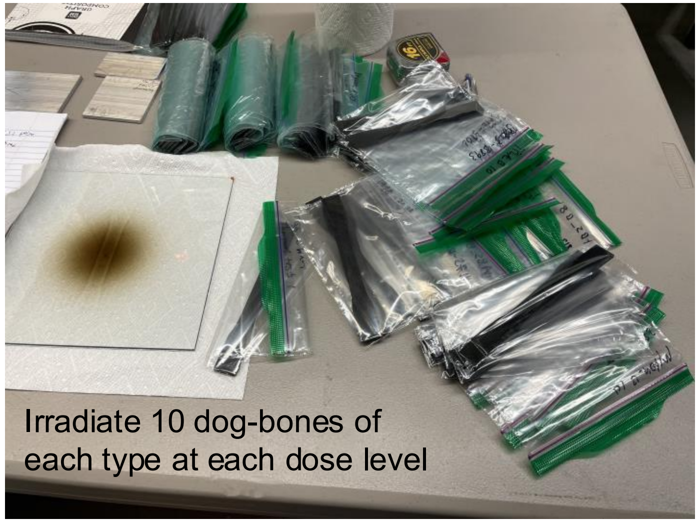


3D-printed plastic irradiation tests

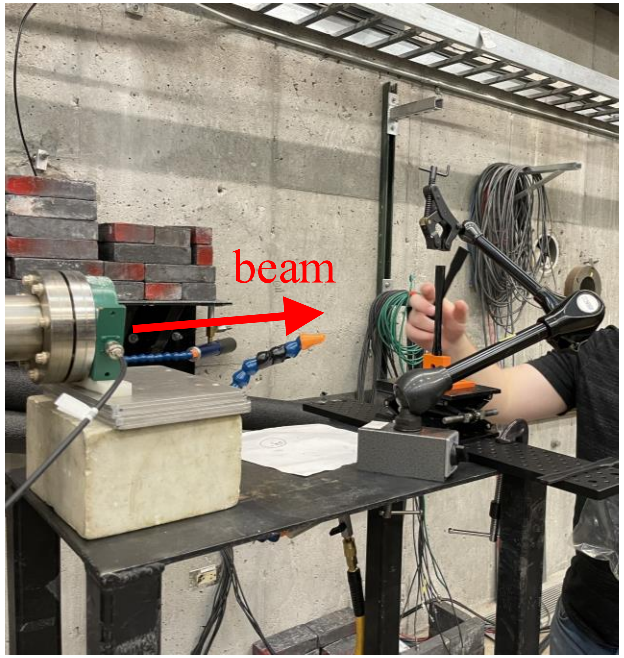
--We irradiate and break 3D-printed plastic dog bone samples (ASTM D638 Type I standard)

--We tested: PLA, ABS, Nylon, CF-ABS, CF-Nylon, Onyx, UltrasintPA11, and PEEK

--We irradiate samples to various dose levels and break them in tensile strength machine measuring elastic moduli and yield strength



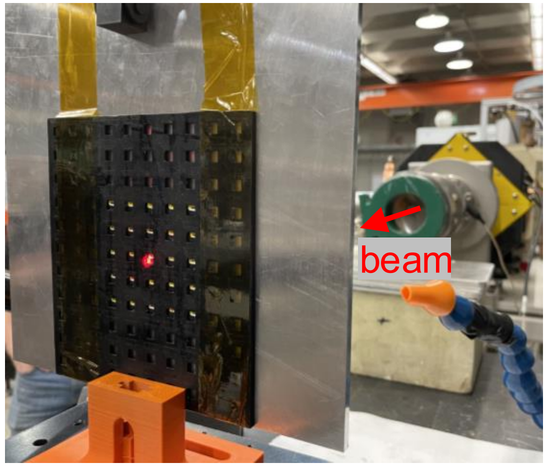
Irradiate 10 dog-bones of each type at each dose level



Tensile strength testing apparatus

View inside printer

3D-printed ASTM-D638 dog-bones

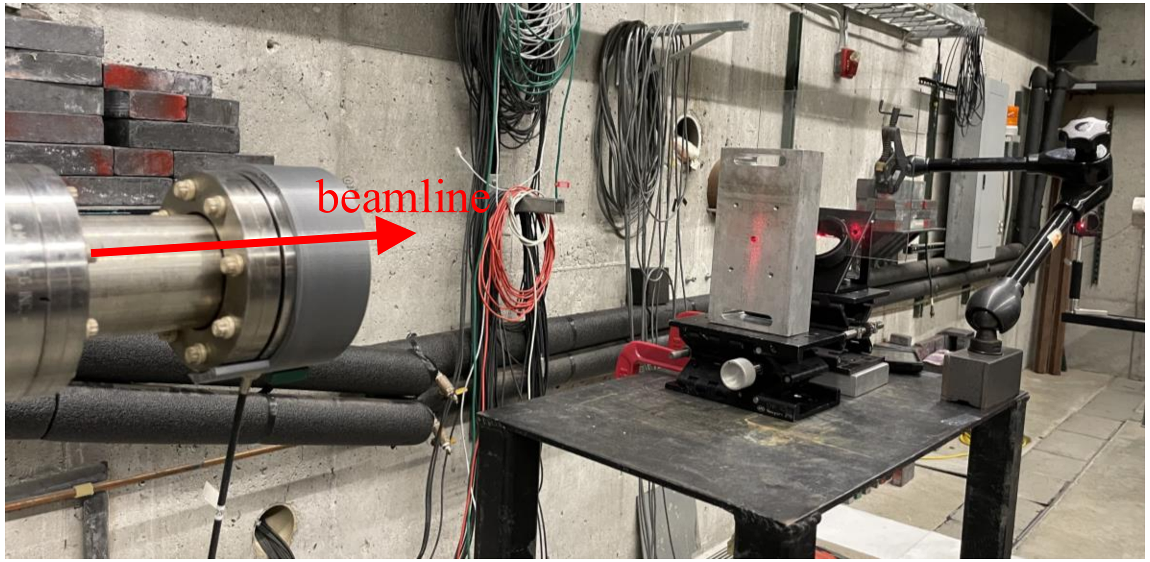


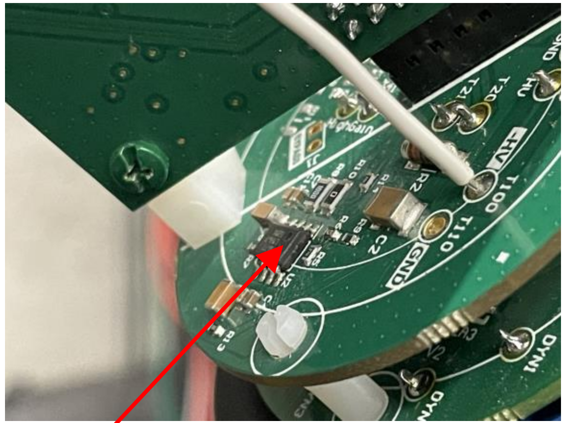
Nanodot OSL array beam dosimetry

PMT electronics irradiation tests (5 days of beam total)

--Initial tests took place December 2022

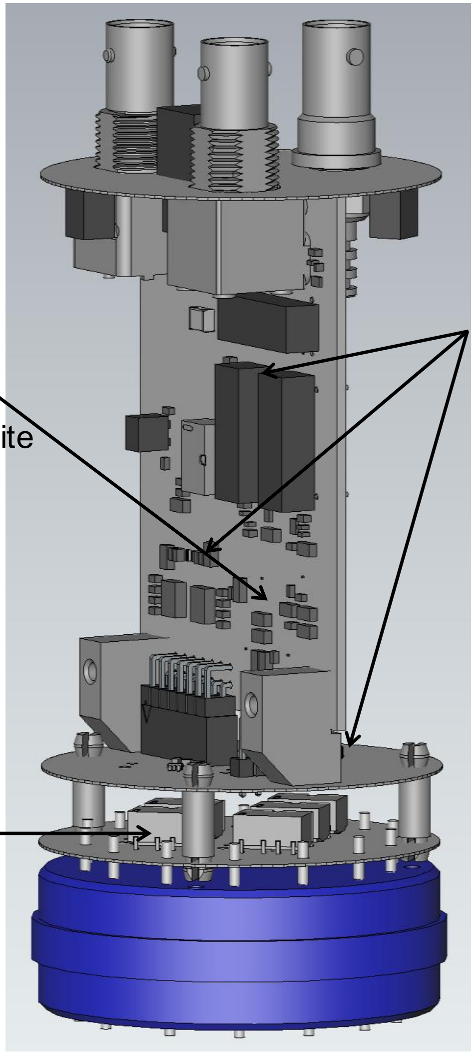
--Additional tests in May 2023, December 2023, and May 2024





Event-mode op-amp dosed

PMT electronics
(2022 – 5.6 V DC-DC converter)



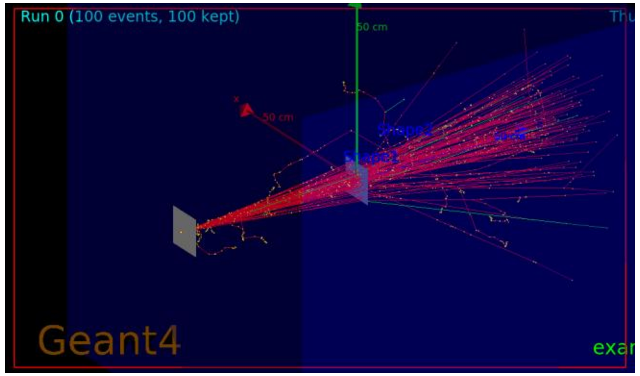
Integrate-mode Op-amp. (on opposite side)

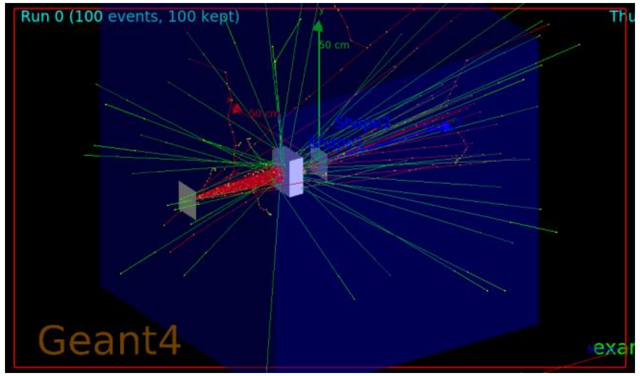
Regions of sensitive electronics to irradiate and test

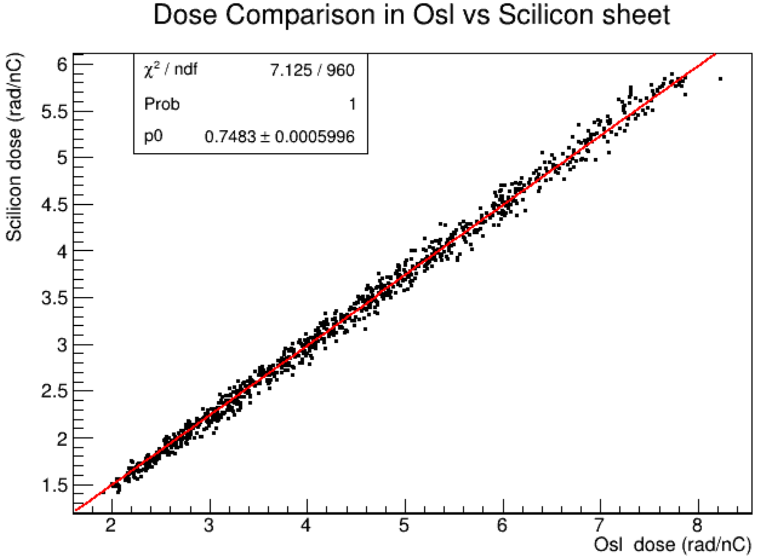
Voltage divider (not sensitive)

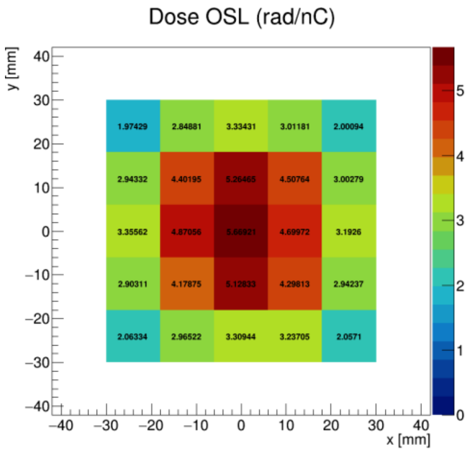
PMT electronics irradiation tests (Simulations)

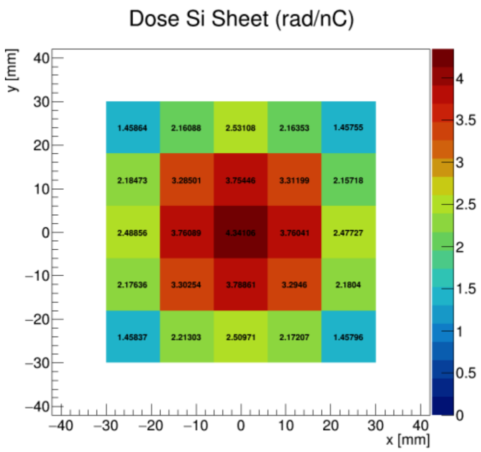
- Realistic geometry: beam exit window, air, collimator, and sensitive volumes of either OSL array or Si sheet (0.6 mm thick)
- Use similar technique as used for quartz tests – vary beam parameters to sample phase space of possible beam profiles (~30 x 30 different simulations for OSL array and separately for Si sheet)
- Bin the Si sheet data into 1.2 x 1.2 mm^2 pixels to match the OSL array simulation and real data measurements; tally energy deposition in bins
- Plot Si sheet dose/nC versus OSL dose/nC – gives linear correlation
- Conclusion: sample receives 75% of OSL dose





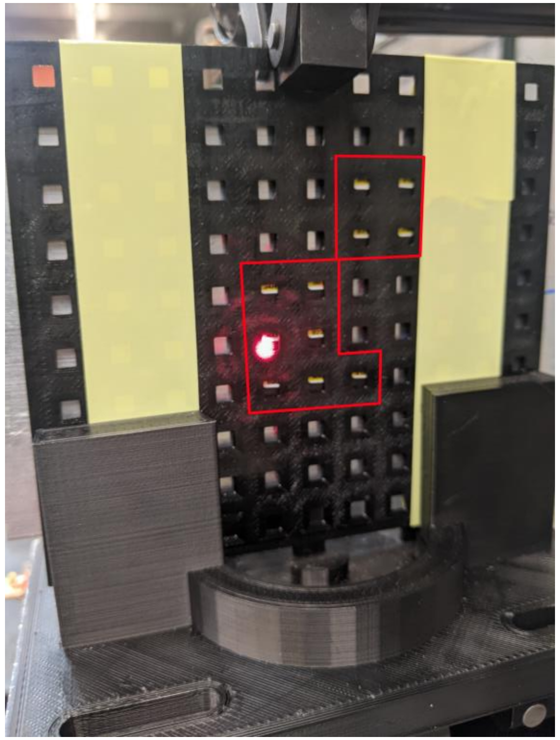




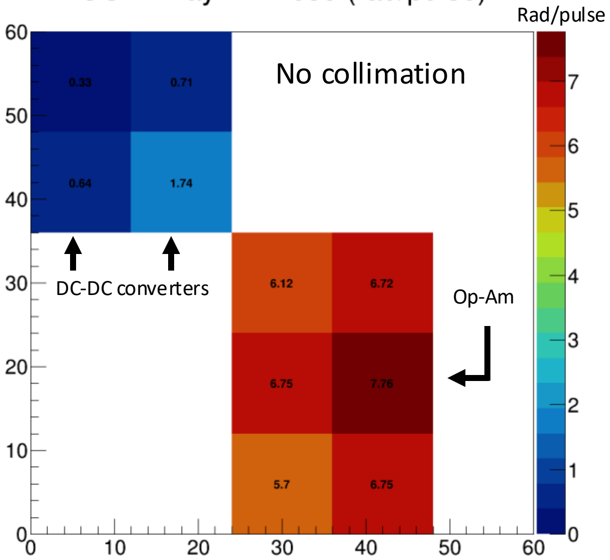


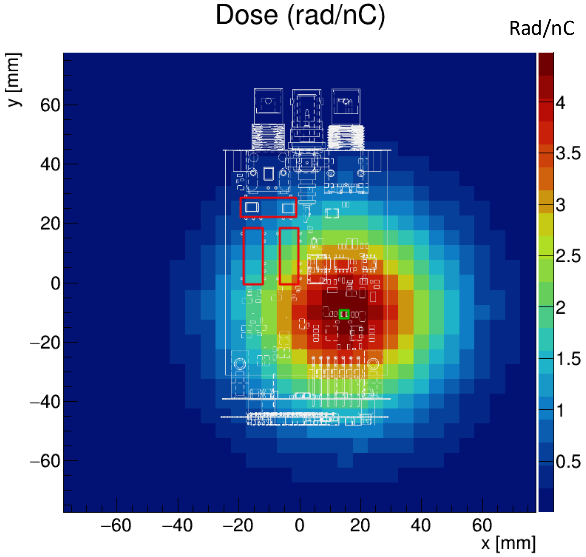
PMT electronics irradiation tests (Beam pulse dosimetry)

- Performed beam dose measurements with specialized OSL array shapes overlaying the chip locations of interest

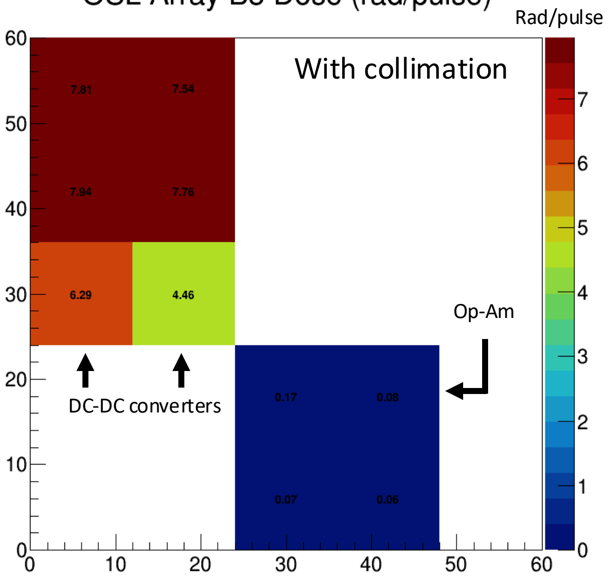


OSL Array A1 Dose (rad/pulse)

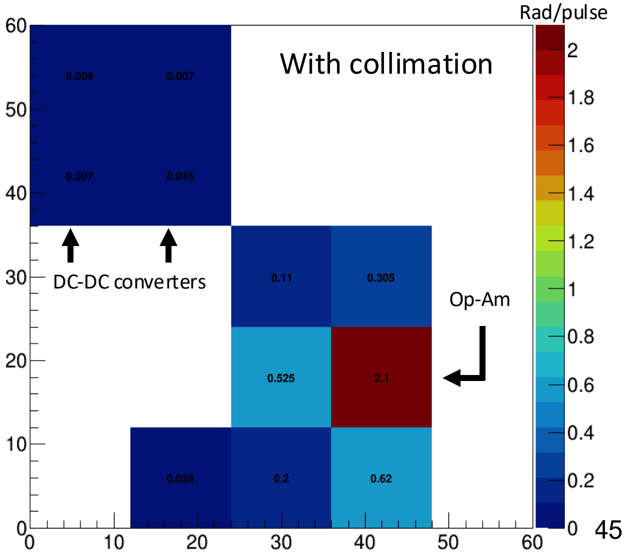


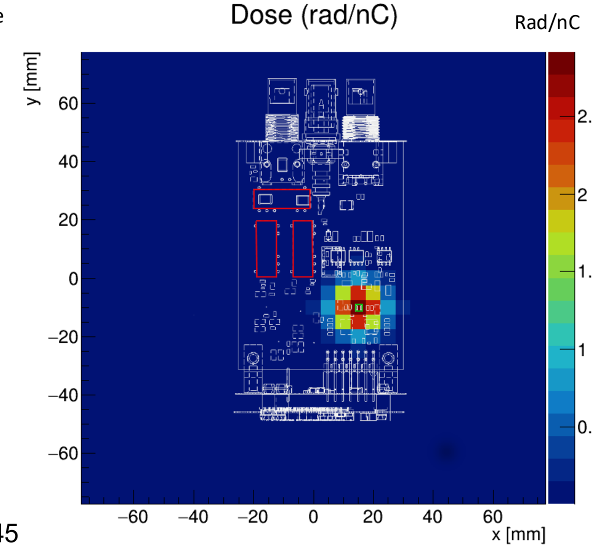


OSL Array B3 Dose (rad/pulse)



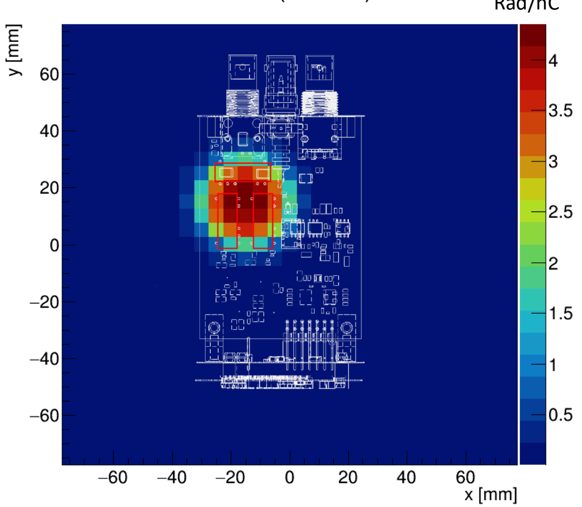
OSL Array A7 Dose (rad/pulse)





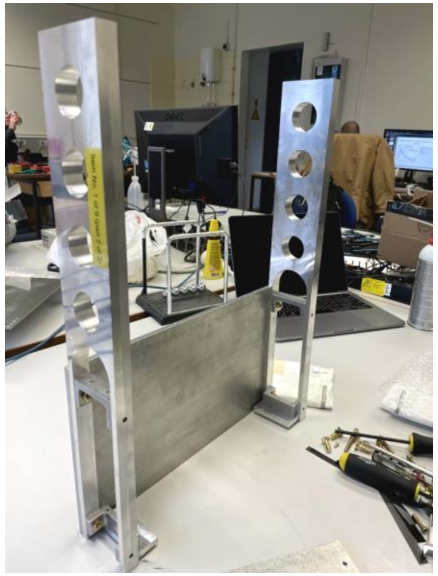
Beam center on Op Amp

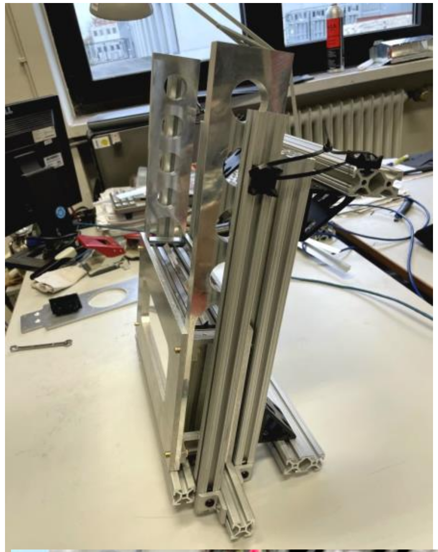
Beam center on DC-DC converters

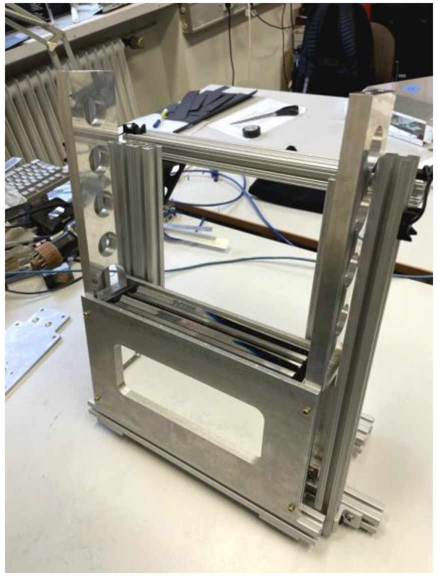


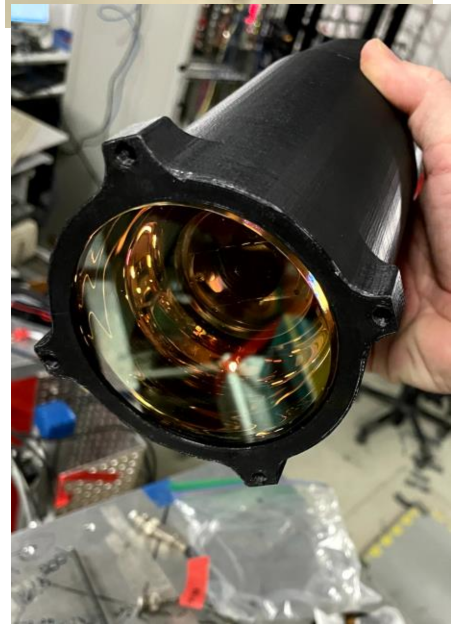
Shower-max: MAMI testbeam (Nov 21 – 28, 2022)

Idaho State University

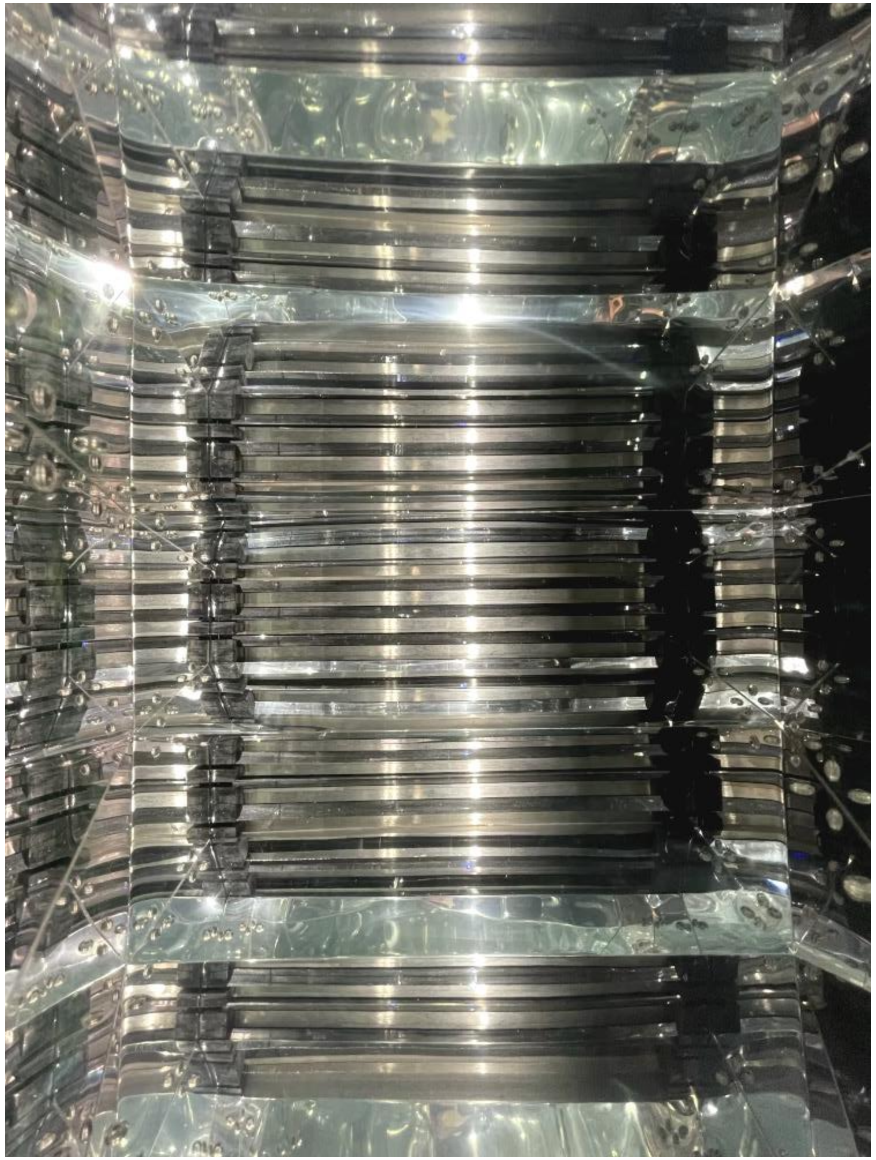








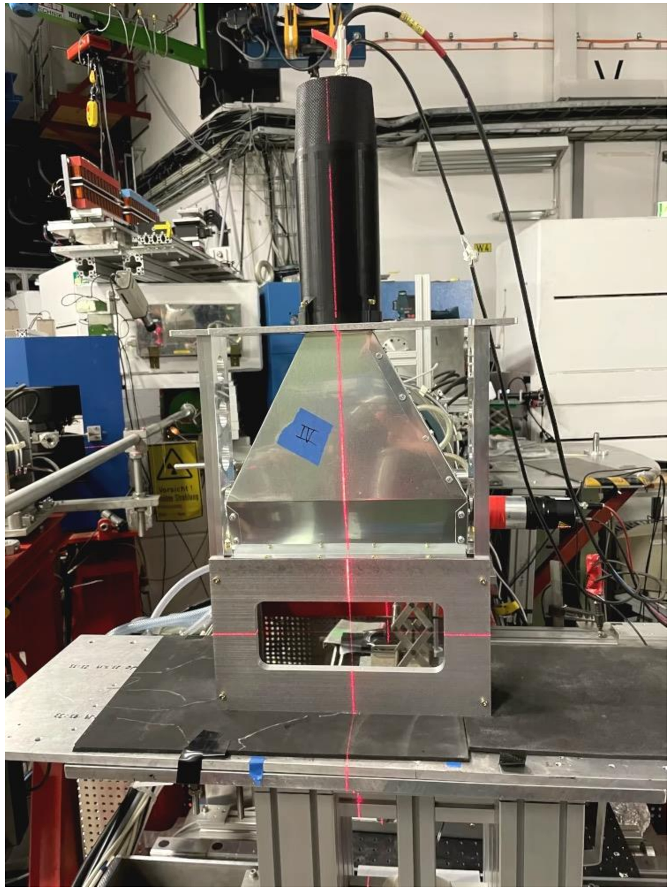
Assembly Photos

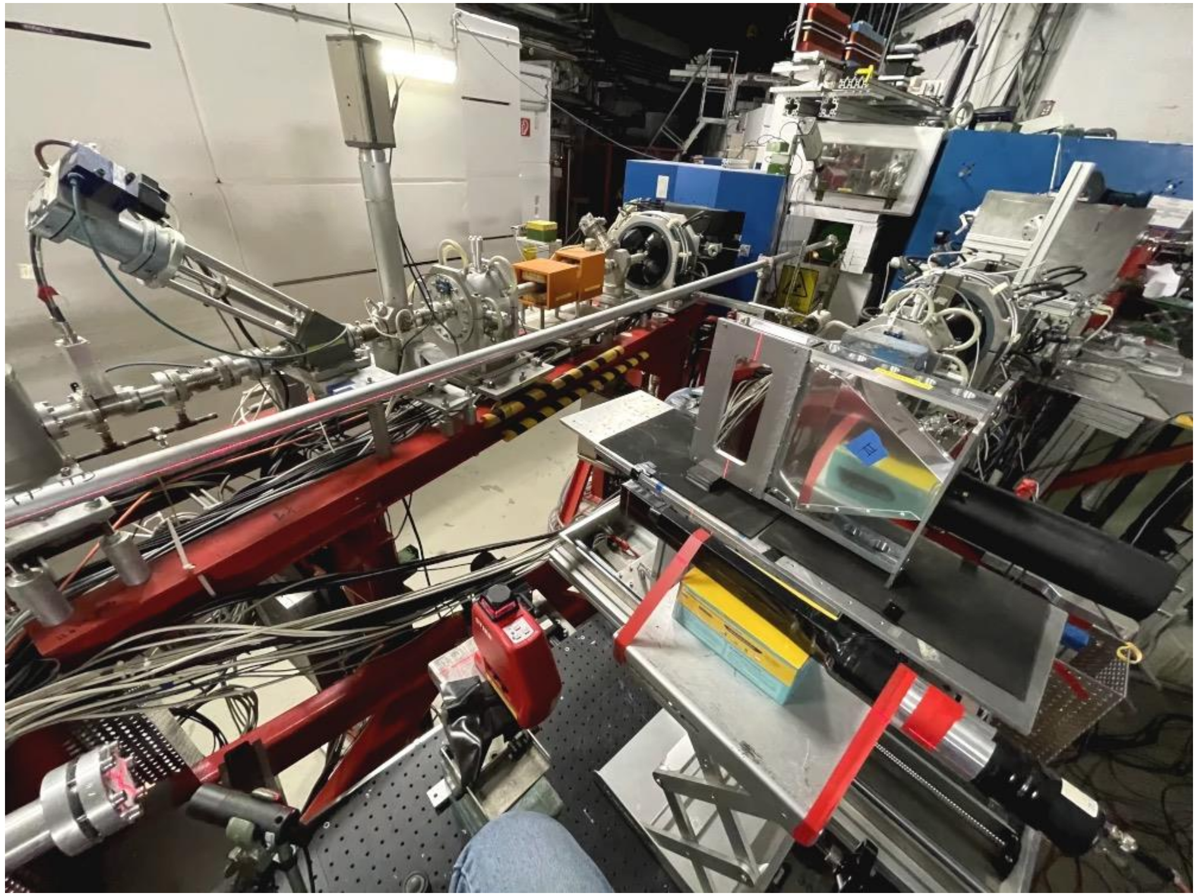


Shower-max: MAMI testbeam Setup

Studies performed over 3 shifts:

- Azimuthal position scan
- HV scan with beam centered on stack
- Radial position scan, including scan along lightguide
- Longpass filter study – 280, 320, and 400nm
- Above tests were performed for both unwrapped (bare) quartz and aluminized-mylar wrapped quartz configs

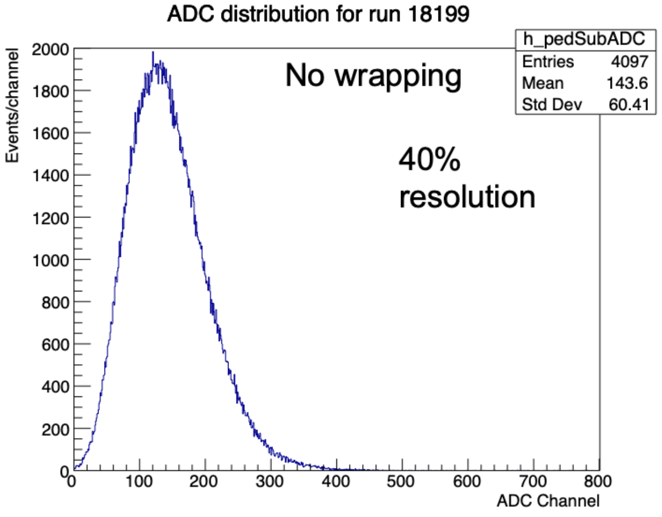




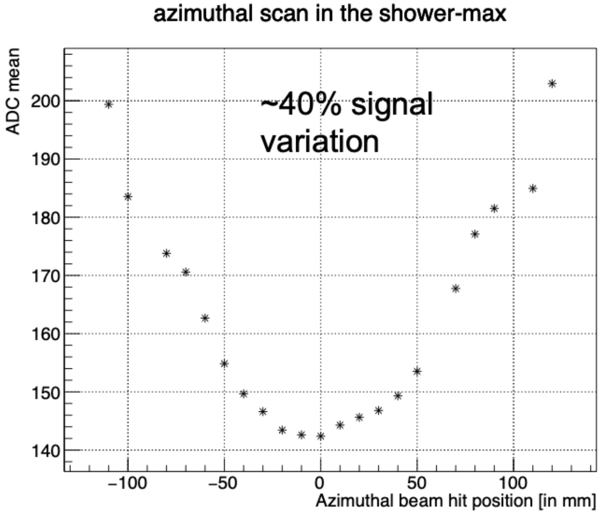
Shower-max: 2022 prototype tests (855 MeV electrons)

Idaho State University

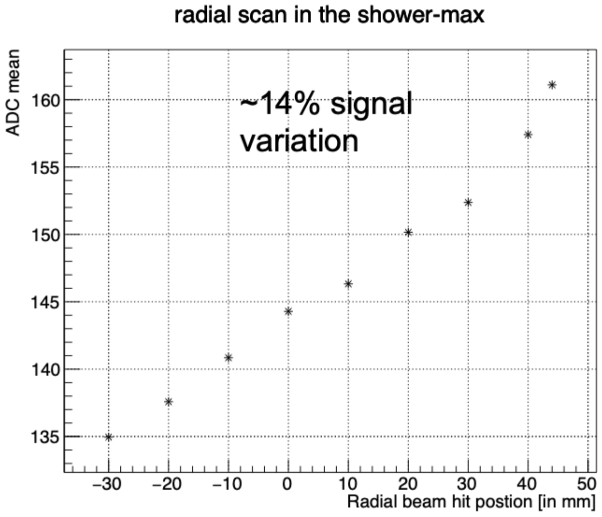
Pulse height Dists



Azimuthal Scans



Radial Scans



Filter Studies