MOLLER Detector system status update

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Hall A/C Summer Meeting

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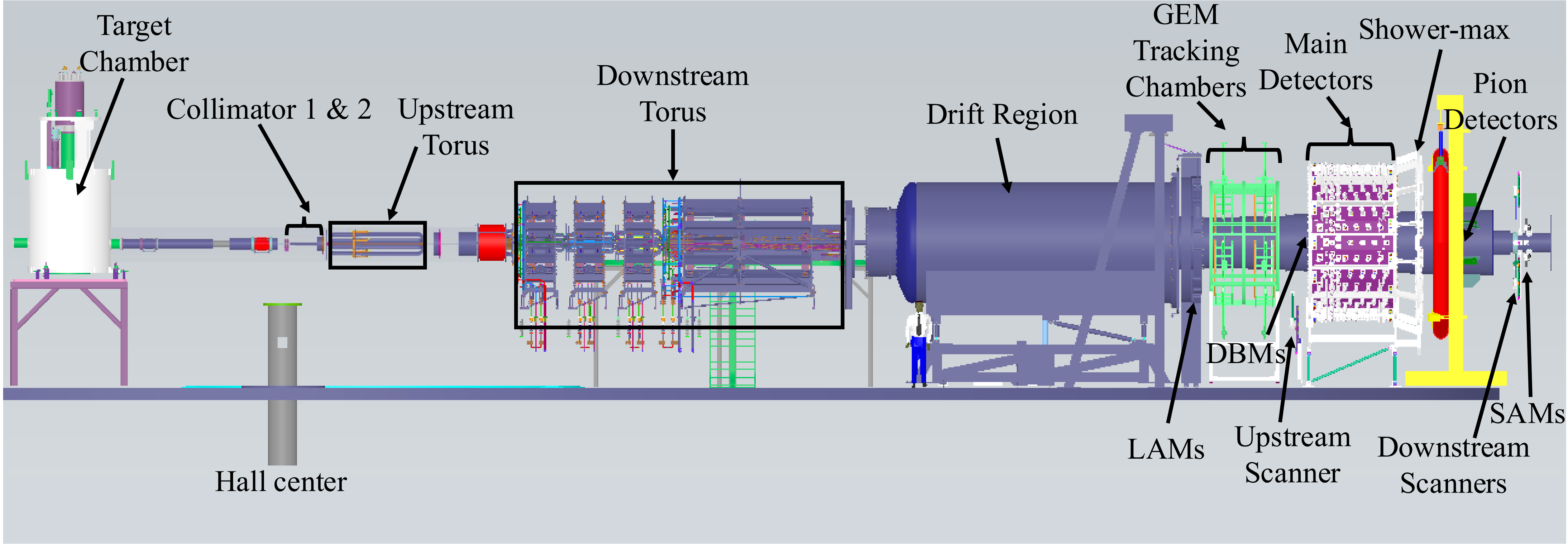
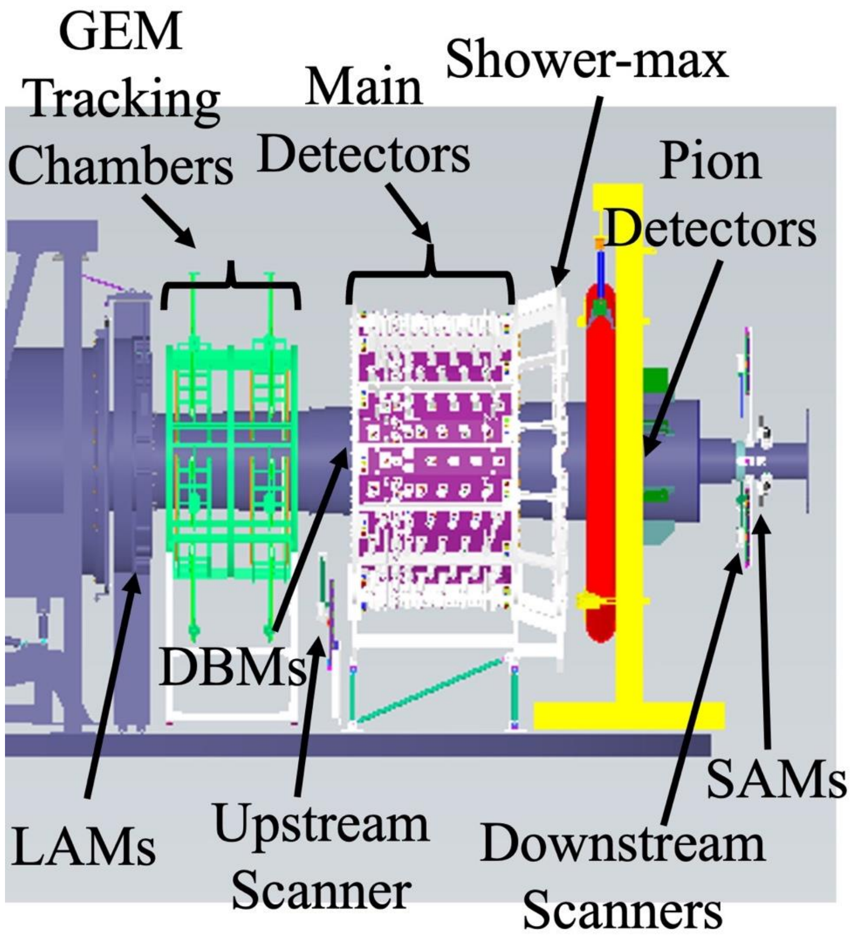
Idaho State University · Jefferson Lab · U.S. Department of Energy Office of Science · NSF · Innovation – Canada Foundation for Innovation / Fondation canadienne pour l'innovation

MOLLER Experiment Equipment

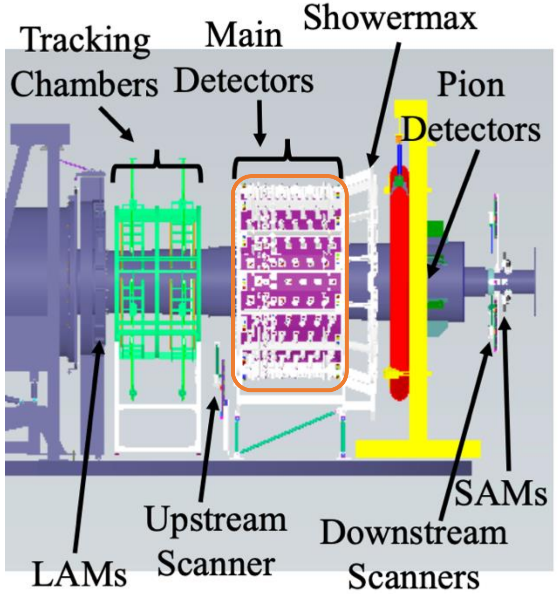


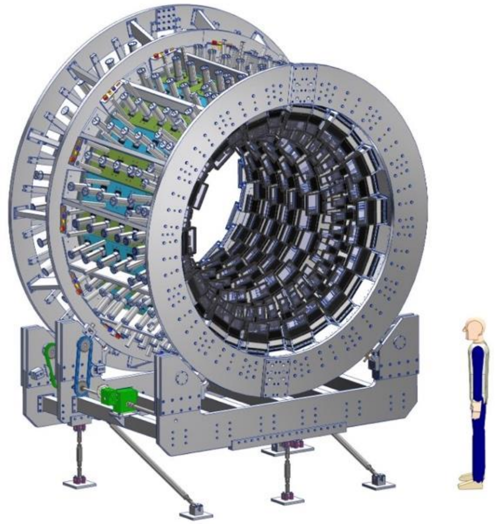
Outline:

- Main integrating Detector
  - Components
  - Detector testing
  - Module productions and assembly status
- Shower-max detector
  - Testing and status update
- Pion detector
  - Testing and status update
- Scattered beam monitors (LAM, SAM, DBM)
  - Testing and status update
- Scanners detectors (upstream, downstream)
  - Testing and status update
- HVMAPS
  - Planning and production status

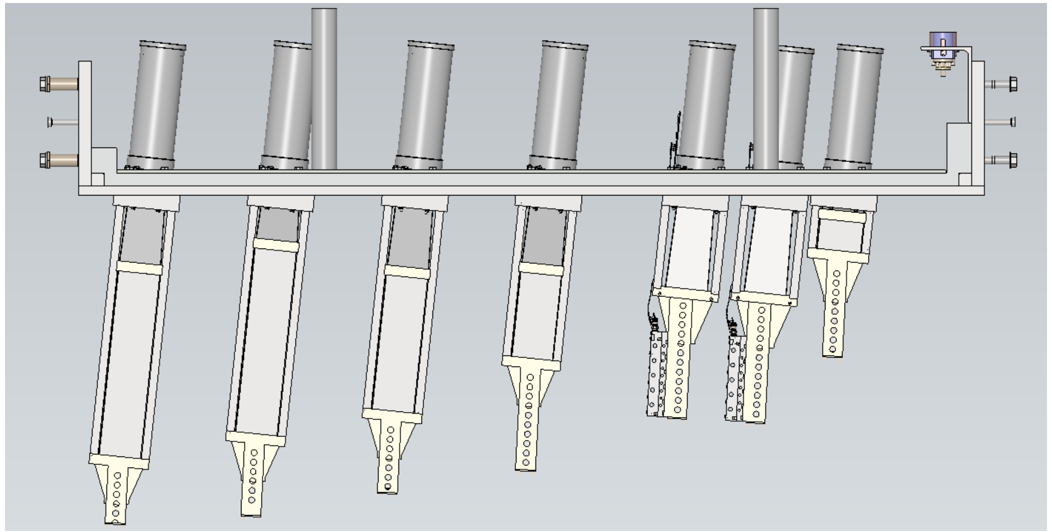


Main integrating detector Components





- **Full assembly : 28 segments around ring with 8 detectors each; covers 6 radial regions, total 224 detector modules**
- **Quartz: High Purity Fused Silica (Heraeus Spectrosil 2000--H_2)**
- **Light guide: air-core aluminum-mirror (Anolux UVS and UVC)**
- **PMT: 3" ET 9305QKB (HPFS window, bialkali cathode, 10-stage)**
- **Chassis: aluminum and 3D-printed components**



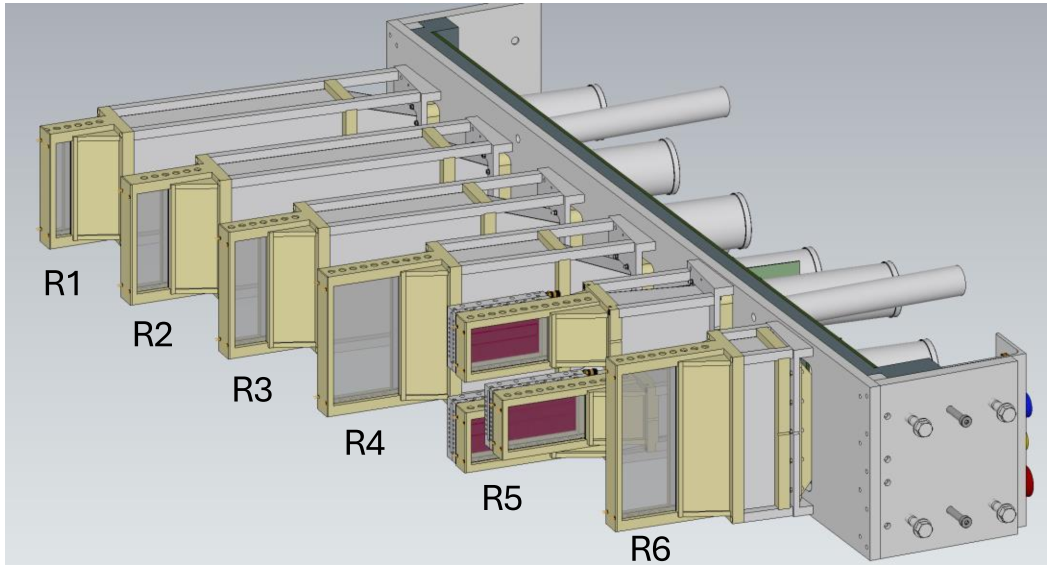


Fig: CAD model of a segment of the main integrating detector

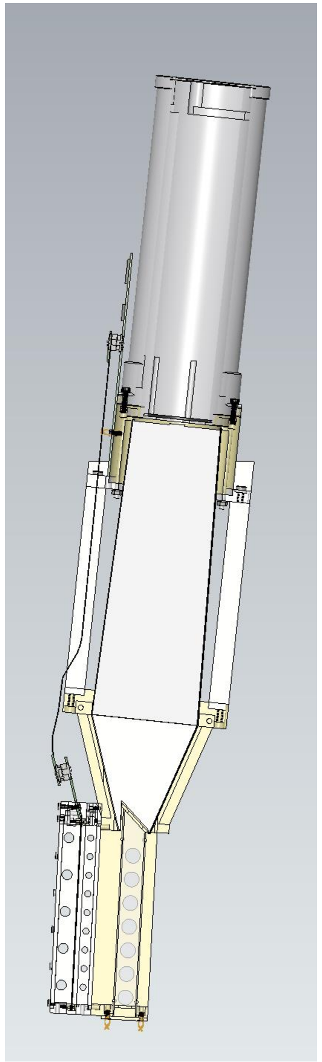


Fig: R5 module section view

Image courtesy: Michael Gericke, Larry Bartoszek

MAMI Testbeam 2023

- Mainz Microtron (855 MeV electron beam)
- Front flush segment prototype fully instrumented with 8 detector modules
  - Test detectors performance with different quartz (Heraeus and Corning), light guide material and configurations
  - Pulse height distributions (yield and resolution), uniformity scans, quartz position validation

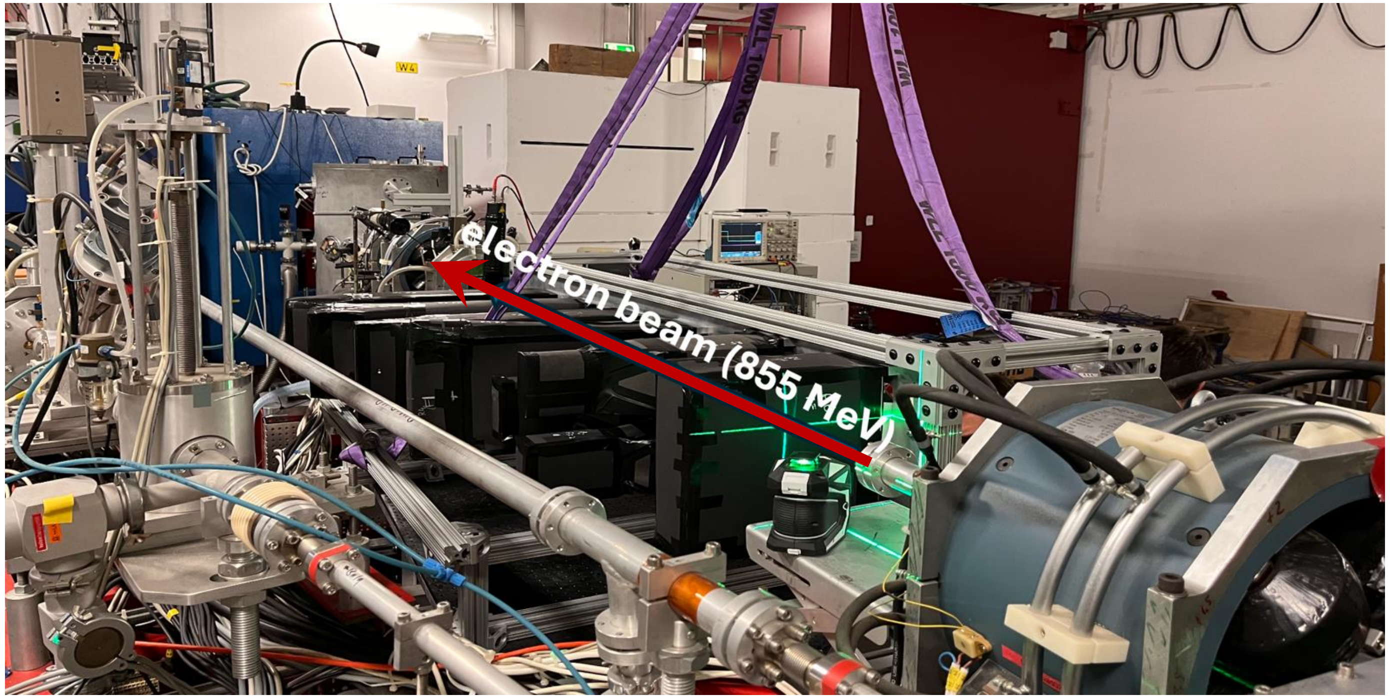
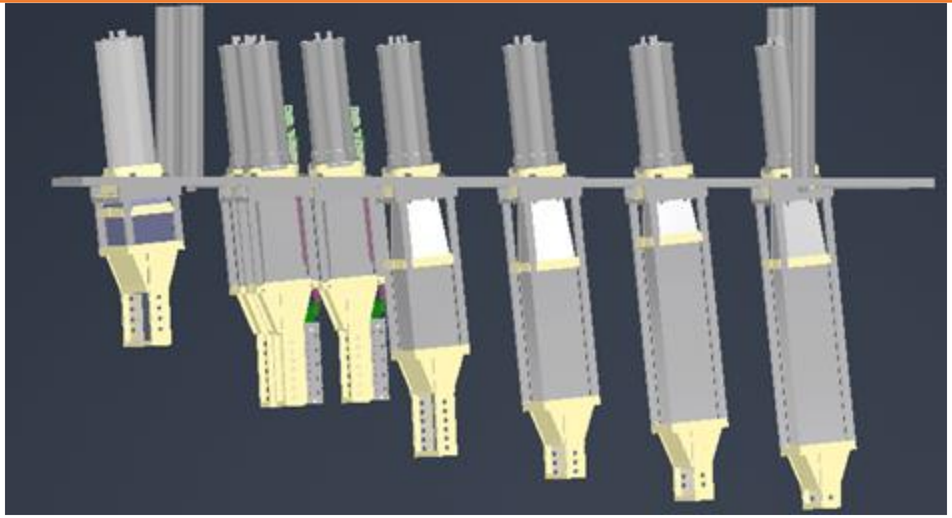
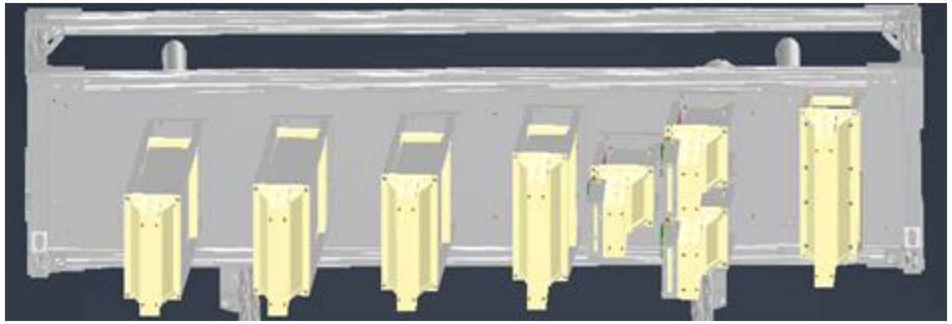


Fig: Photograph of MOLLER Main detector full segment test





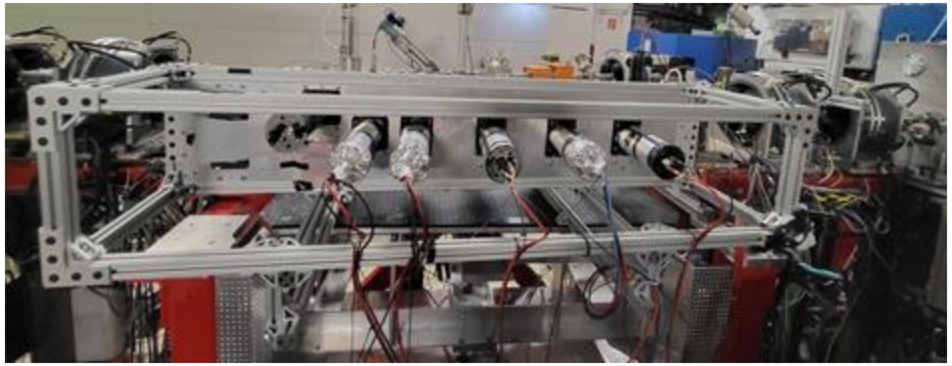


Image courtesy: Sayak Chatterjee

MAMI Testbeam 2023

MAMI Testbeam results:

- Both the Corning and Heraeus give comparable results, validating the material and vendor polish
- All detector rings have RMS/Mean of ≲30% which MOLLER requires
- New UVC light guide performed as expected, giving greater than 30 PE mean response for R5 modules
- Good agreement with Monte Carlo simulation

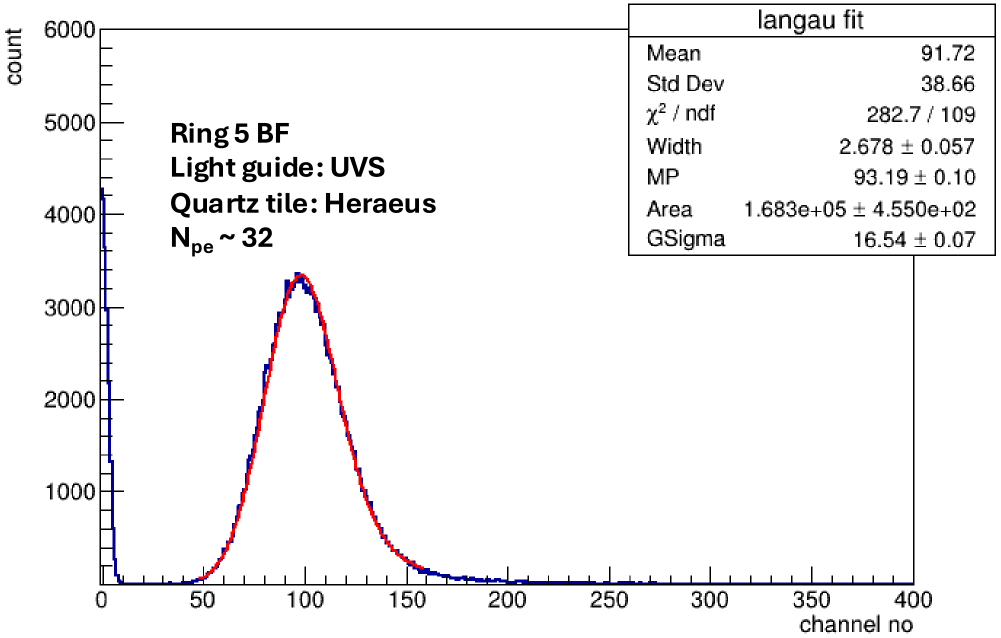


Fig: Pulse height distribution of the R5 detector

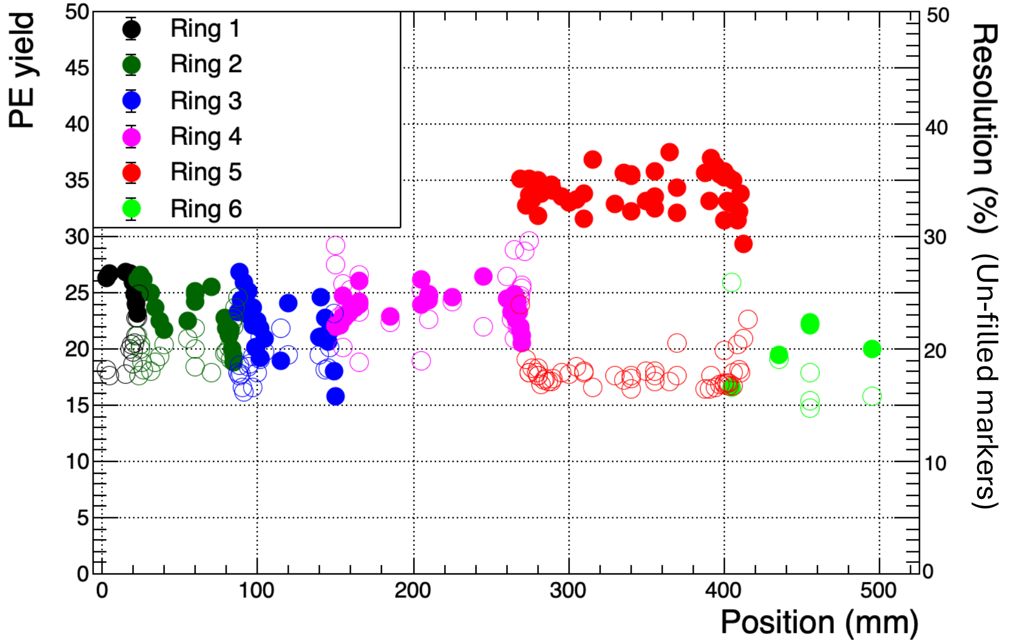


Fig: PE and Resolution vs radial position for R1-R6 detectors

Image courtesy: Sayak Chatterjee

Cosmic testing

- **Cosmic stand for prototype segment at UMass**
  - Validate/match detector performance between testbeam and cosmic stand (using MC simulation)
  - QDC + CODA based DAQ System
  - Data matches MC simulations within ~15 %
- **Cosmic stand at W&M**
  - For testing fully assembled production segments and MOLLER event-mode DAQ system
- **Other tests:**
  - New LV and HV supplies, cabling

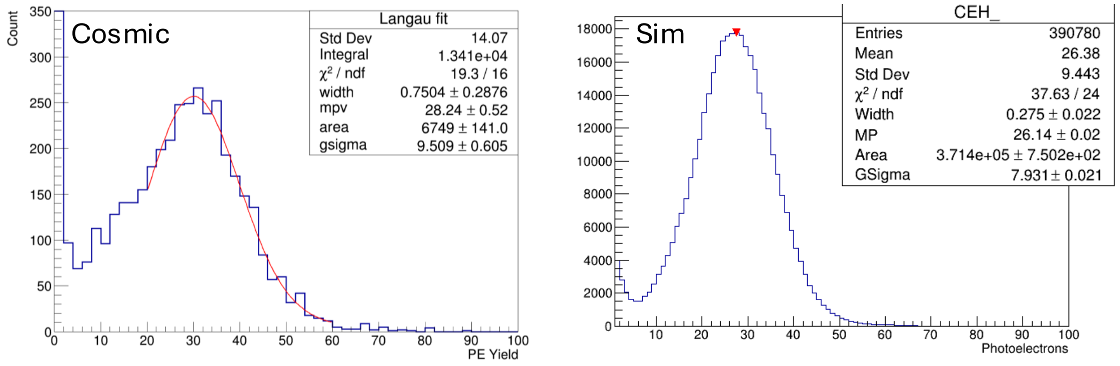
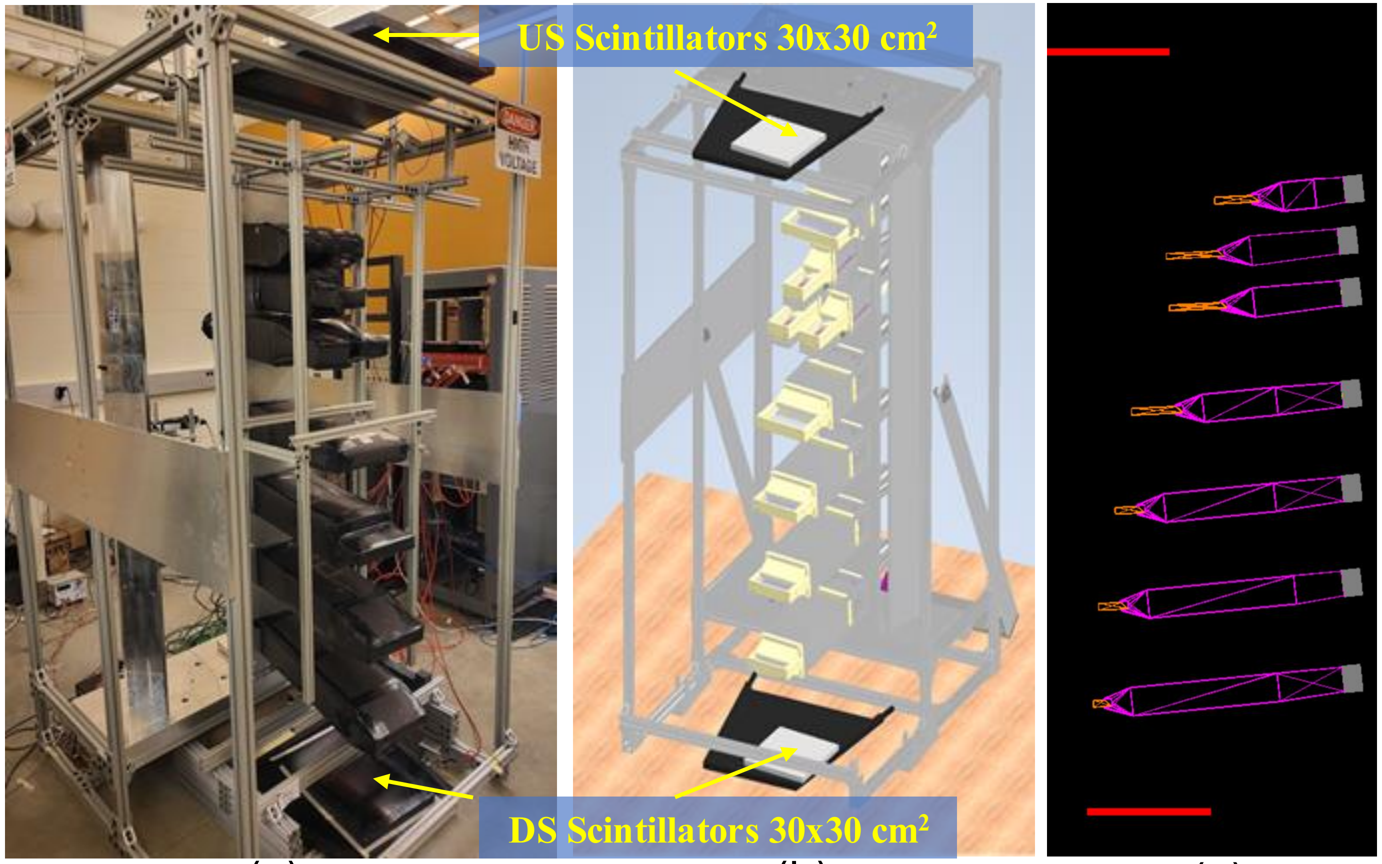


*Fig: Typical PE distribution from UMass cosmic stand (left) and simulation (right) with the prototype detector module **Ring 5.***



(a) (b) (c)

Fig: (a) Umass Cosmics stand taking data, (b) CAD model of the the same stand and (c) the visualization of the detectors from Monte Carlo simulation

Image courtesy: Sayak Chatterjee, Jon Mott

Module production at UManitoba

- **Light guides:**
  - Completed laser cut production in UofM machine shop
  - Stored with protective film on
- **3D printed parts: enclosures and supports**
  - Using carbon-fiber embedded ABS filament
  - Producing parts with array of 7+ printers
- **PMT FE electronics: base dividers + pre-amps and DC-DC Converter assemblies**
  - 270 out of 300 sets completed; ~180 have been tested

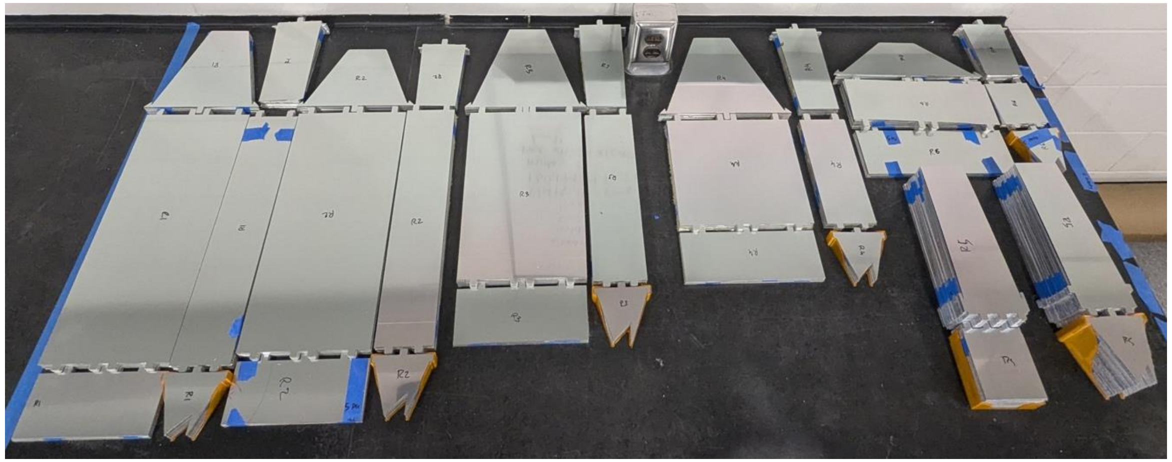


Fig: Laser cut aluminum light guides for all rings (R1 – R6).

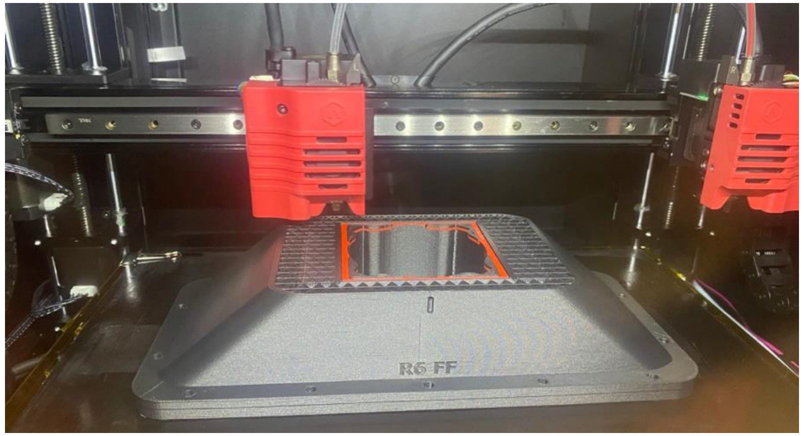



Fig: (left) Printing ring6 component, (right) printed parts on the shelf in cleanroom

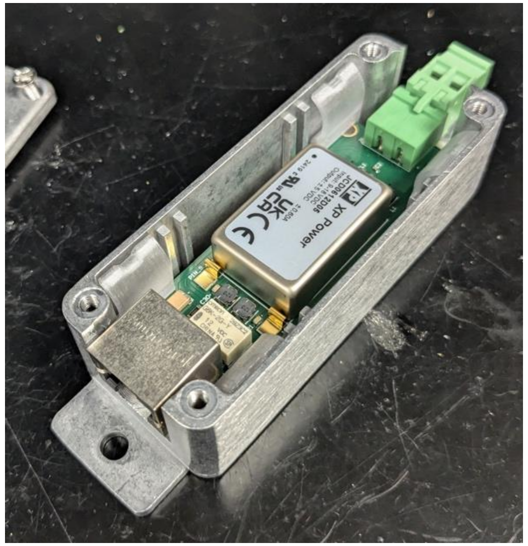


Fig: DC-DC converters

Image courtesy: Jie Pan, Kristofer Isaak, Mohammad Laheji

Module production at UManitoba

- **PMT components:**
  - PMT housing light seal caps, cradle rings, interface gaskets, interface lids
- **Sub-assemblies:**
  - All Upper and Straight sub-assemblies to be completed soon
- **Packing and shipping to W&M**
  - Assembled modules are light tight tested, vacuum sealed and crated for shipment
  - Segments 1-4 shipped and received by W&M, segments 5-10 in process of shipping
  - On track for goal of 20 segments by end of summer and all segments by end of year

Fig: Prusa XL printer in use to print interface lids

Fig: Sub-assemblies for detectors

Fig: Segment 5 to 8 ready to ship

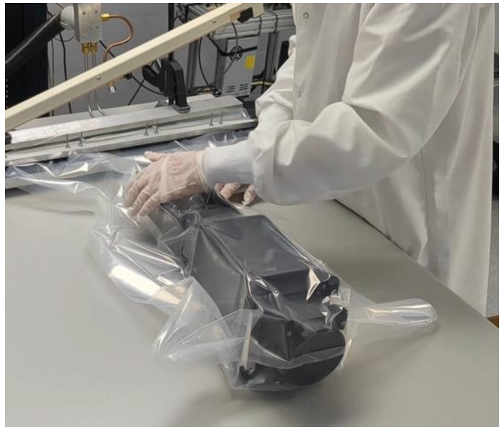


Fig: Vacuum sealing the module

Image courtesy: Brynne Blaikie

Module and segment assembly and testing at W&M

- 179 out of 224+ polished quartz pieces received
- All components for segments 1 – 4 received
- Modules are unpacked and fully assembled with quartz in cleanroom
- Components (aluminum and lead) for all segment frames are in hand
- Segment frames 1 – 4 have been assembled, 5 – 6 in process
- Instrumentation and testing of segments 1 – 2 complete, segments 3 – 4 in process

Fig: Cosmic stand (AT Box) at W&M

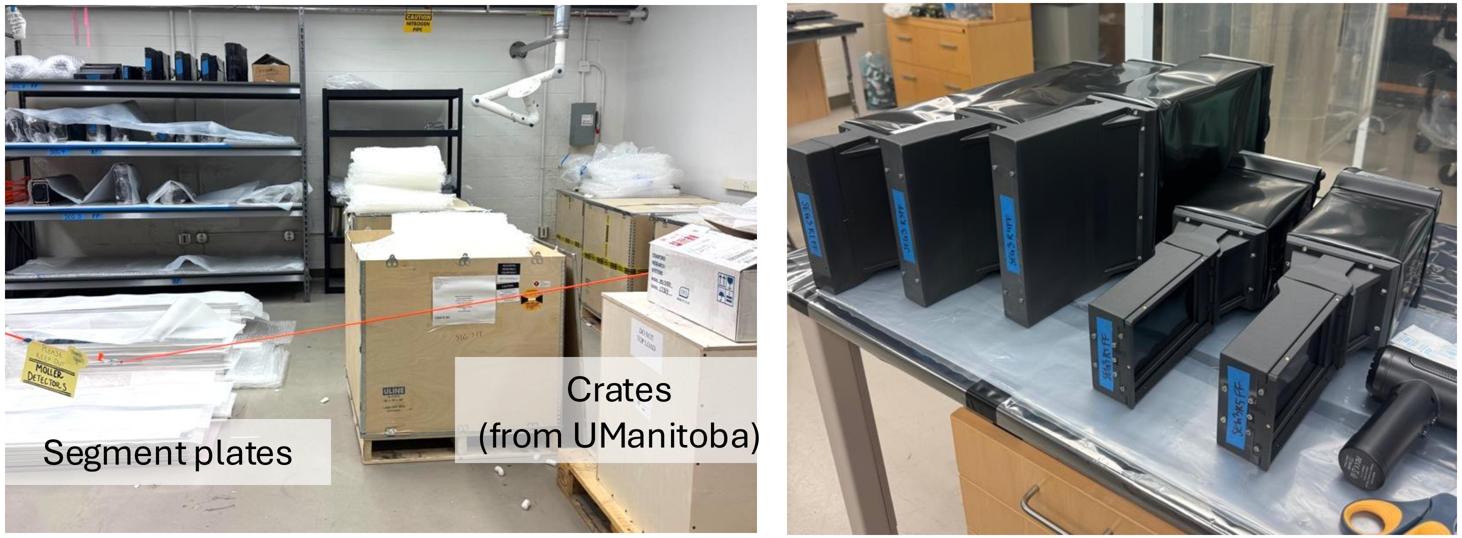


Fig: (left) components at W&M, (right) assembled modules ready to mount

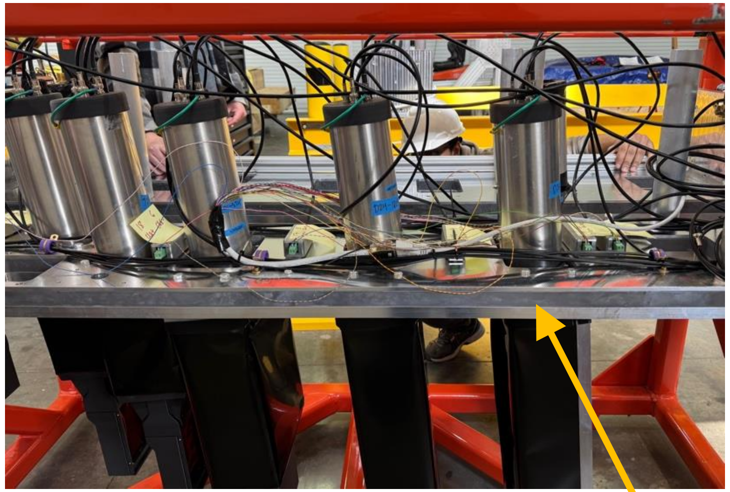


Fig: Segment frame: aluminum lead sandwich

Image courtesy: Brynne Blaikie, Sayak Chatterjee

Shower-max detector system

- Shower-max is a Cherenkov-based electromagnetic sampling calorimeter.
- Positioned 1.7 m downstream of Ring-5 to intercept the same Møller flux. Designed to provide additional MOLLER A_{PV} measurement.
- The active part uses 4 interleaved layers of 99.95% pure tungsten and high-purity fused silica (quartz radiators).
- Gives response proportional to energy of incident particle
- Less sensitive to low energy and hadronic backgrounds
- Active region geometric size/acceptance:
  - Each detector: 265 mm x 160 mm x (6mm x 4 quartz + 8mm x 4 tungsten -- ~10 X_0)
  - Radial coverage: 1020 mm to 1180 mm; no gaps around the ring

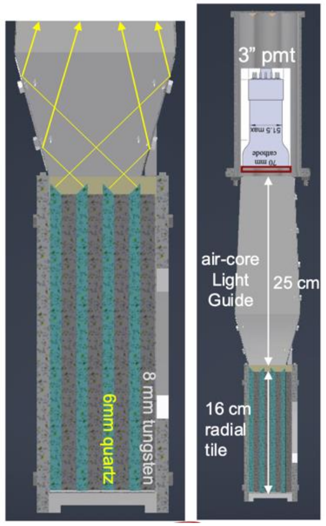
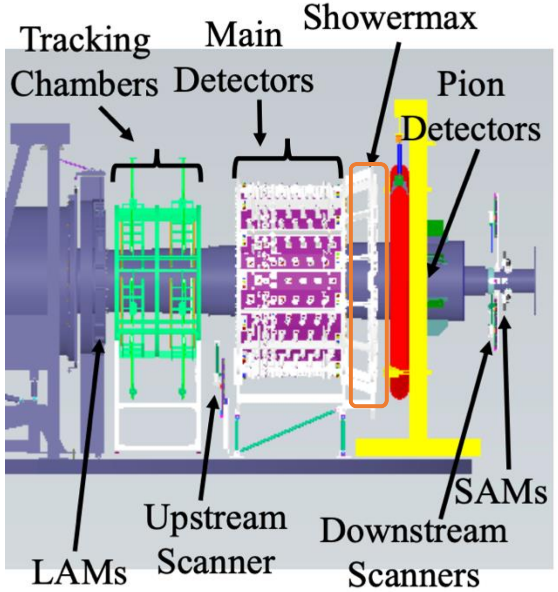


Fig: Cross section view



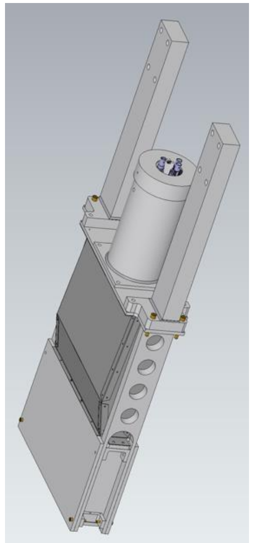


Fig: Single module

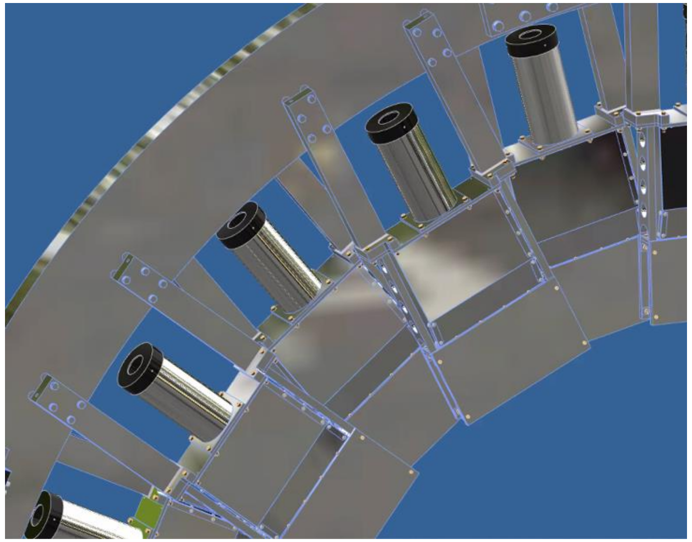


Fig: Shower-max detectors in its support ring

Image courtesy: Dustin McNulty

Shower-max detector testing

- **Beam Tests:**
  - 2018 (SLAC): 3, 5.5, and 8 GeV electrons, tested benchmarking and early full-scale prototypes
  - 2022 (MAMI): 855 MeV electrons, tested the quartz wrapping to improve performance; new chassis and light guide
  - 2023 (MAMI): 855 MeV electrons, tested production quartz and long pass filter performance
  - 2025 (Jlab HallD): 3 - 6 GeV positrons, testing signal yield, resolution, and uniformity. Analysis in process
- **Cosmic Testing:**
  - 2022-2025 (Idaho)
  - 2025- present (Jlab testlab)

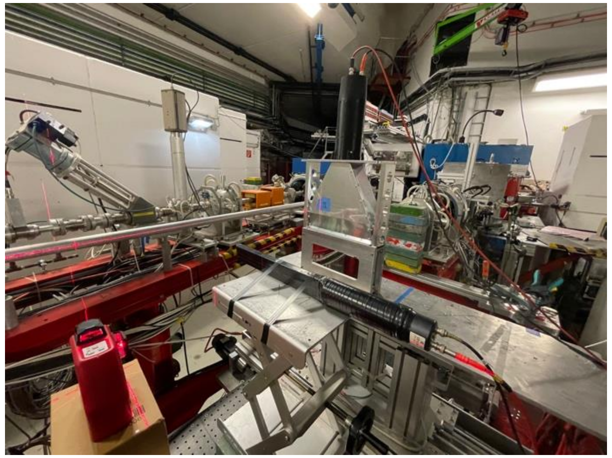


Fig: 2022 MAMI Testbeam

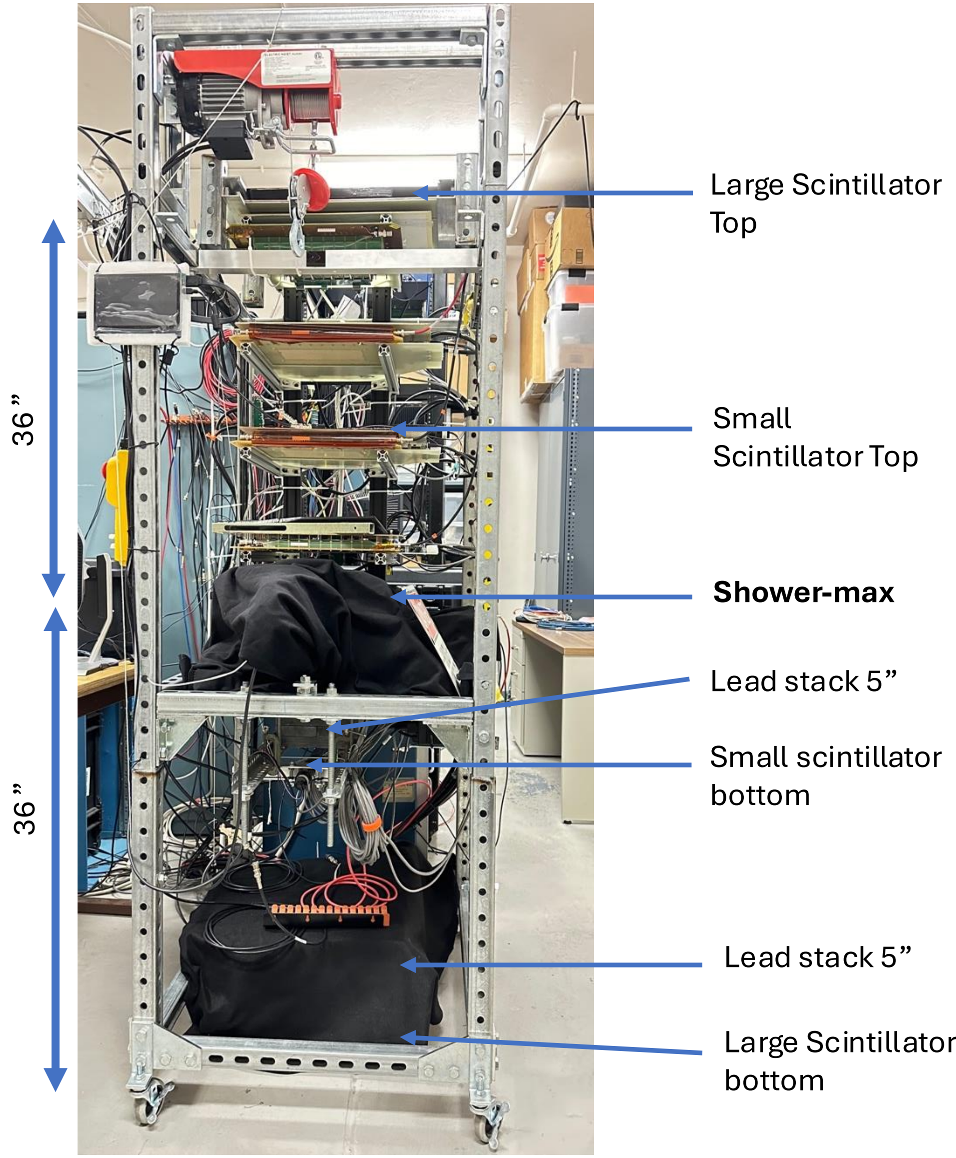


Fig: Cosmic stand at Idaho State

Shower-max module production

- **Procurement:**
  - 2024: All 130 quartz plates, 124 tungsten plates, 31 PMTs, 31 chassis and light guide assemblies (received and inspected)
  - 2025: Support struts for ring mount, alignment and lifting fixtures, custom 78 mm longpass filters (received and inspected)
- **Assembly:**
  - All 31 modules assembled, and cosmic ray tested in Idaho
  - Partially disassembled and shipped to Jlab in 3 separate shipments (Sept 2024, Nov 2024, and Feb 2025)
  - 2 Modules reassembled for cosmic tests and Hall D testbeam, rest to reassemble this summer
  - PMT cradle design finalized, 3D printing in progress
  - Light tightening Kapton wrap design complete and in production
- **Ready to transport to hall A by end of the year.**

Fig: Quartz

Fig: Tungsten

Fig: PMTs

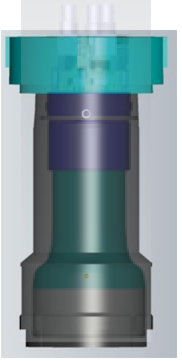


Fig: PMT Cradle

Fig: Chassis and light guide parts

Fig: Assembled modules

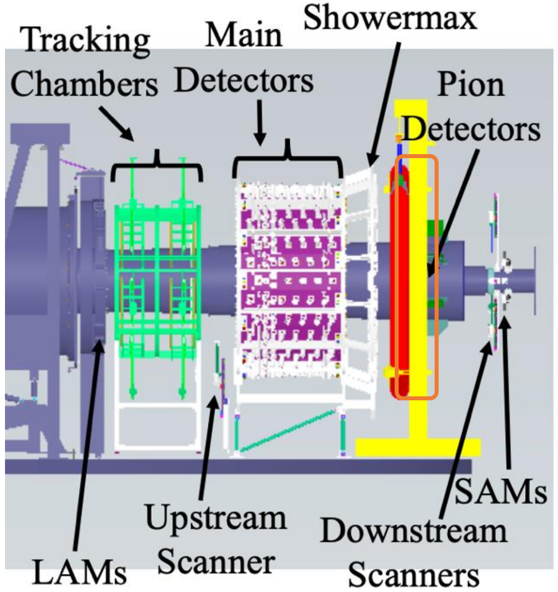
Fig: Chassis and light guide assemblies stored in high bay area of testlab

Image courtesy: Dustin McNulty

Pion Detector

- **Components**
  - 28 identical UVT-acrylic detectors (7 cm deep, 21 cm wide, 2.54 cm thick).
  - Each read out by single 1” diameter PMT (ET 9125BQ)
- Detectors encased in Pb Donut to range-out Møller electron signal

Fig: Pion detector prototype



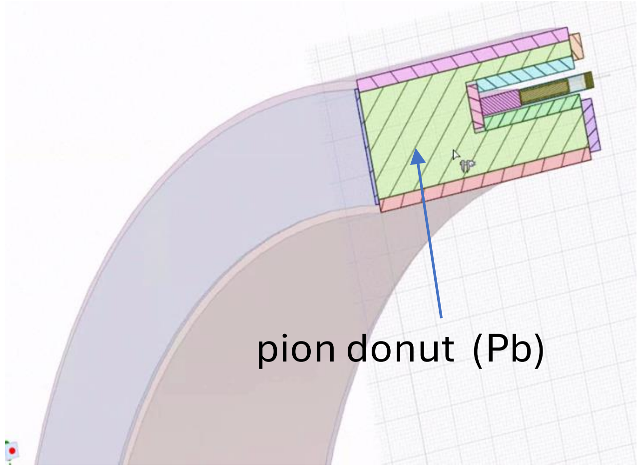


Fig: Cross section of the lead donut

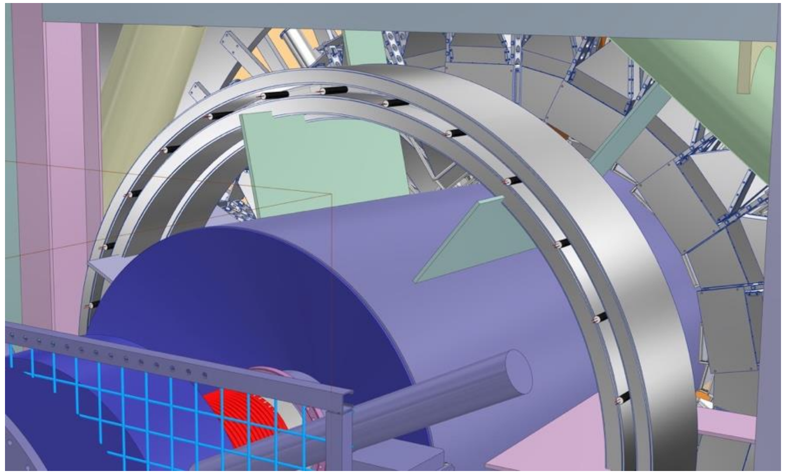


Fig: Pion detector in the lead donut

Image courtesy: David Armstrong

Pion Detector Status

- **Prototypes Testing:**
  - 2022 (MAMI) 855 MeV electron
    - Measured det response vs position for two different detector prototypes
  - Cosmic Testing:
    - 4 scintillator paddles stand at JLab
    - Detector read out via fADC250, VTP trigger
- **Procurement Status:**
  - UVT-Acrylic, PMTs, base sockets: all procured
  - PMT Q/A testing: about to start
  - Prototyped 3D-printed enclosure
  - Prototyped PMT base/HV divider, fast amplifier
    - testing underway
  - All assembled detectors to be cosmic tested

Fig: (left) Pion detector prototype in MAMI e- beam , (right) prototype being tested in cosmic ray at jlab

Fig: (left) Acrylic modules, (middle) prototype fast amplifier, (right) prototype base/divider.

Image courtesy: David Armstrong

Large Angle Monitor (LAM)

- **Detector system and components:**
  - 7 LAM detector modules around beamline, embedded in Pb Collar-2 in the Open phi-regions
  - Each module has a quartz radiator with two 3” ET 9305QKB PMTs and 3D printed housing
- **Prototype Testing:**
  - 2023 (MAMI) 855 MeV electron – used acrylic radiator
  - 2025 Hall D testbeam –preproduction module (quartz radiator)
  - Cosmic testing in process at VaTech
- **Procurement/Production Status:**
  - All 7+2 quartz radiators received/inspected
  - All PMTs received/inspected
  - Completed 3D printing of parts

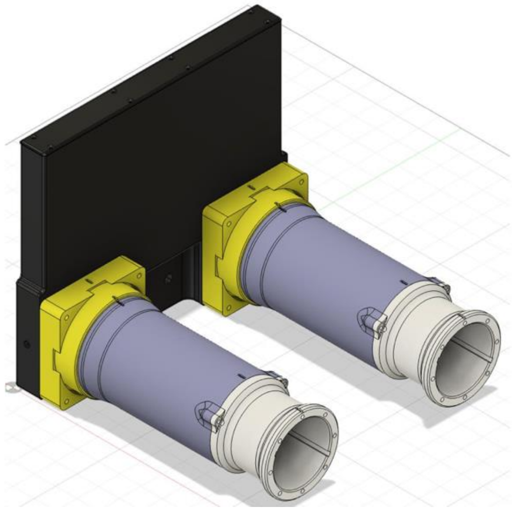


Fig: CAD assembly of LAM

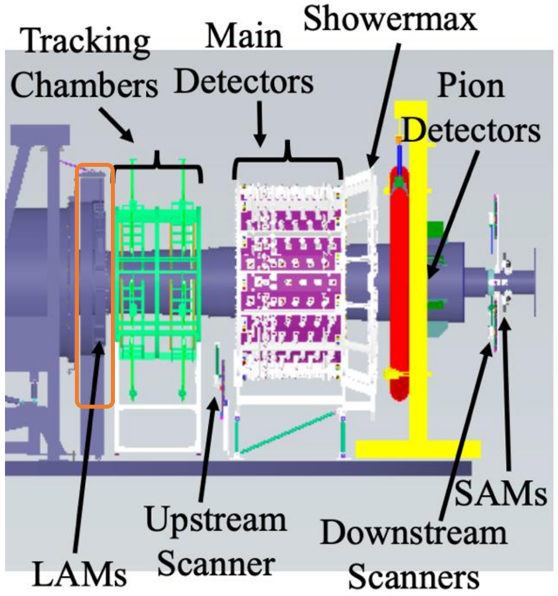
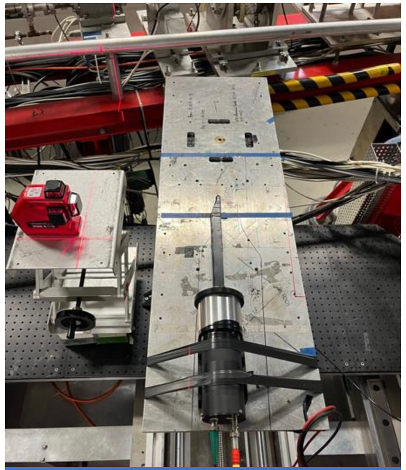


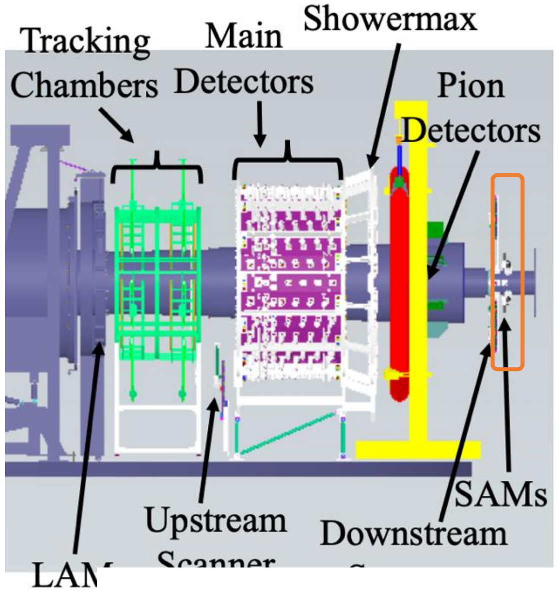
Fig: (left) LAM prototype, (right) 3D printed and aluminum components for LAMs

Image courtesy: Daniel Valmassie

Small Angle Monitors (SAM)

- **Detector system and components:**
  - 8 SAM detector modules positioned symmetrically around beamline (diametrically opposed); monitors target density fluctuations
  - Each module has 8 small quartz radiators (1.6 x 2.0 x 0.6 cm^3) with air-core light guide and Hamamatsu 2" R375 PMT
- **Prototypes Testing:**
  - 2023 (MAMI) 855 MeV electron
  - 2025 Hall D Testbeam (analysis in process)
  - Cosmic testing at VaTech
- **Procurement/Production Status:**
  - All quartz received/inspected (March 2025)
  - All PMTs received/inspected
  - Cut light guides received from UManitoba
  - Beampipe inserts to order this summer
  - Machining and assembly (early fall 2025)


SAM @ MAMI



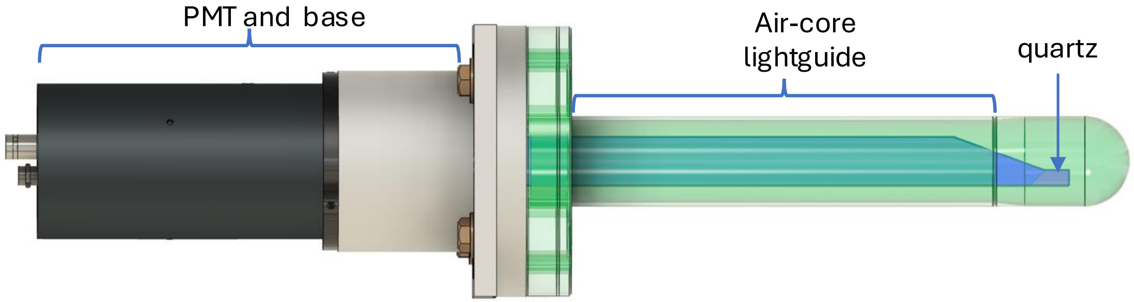


Fig: CAD model of SAM

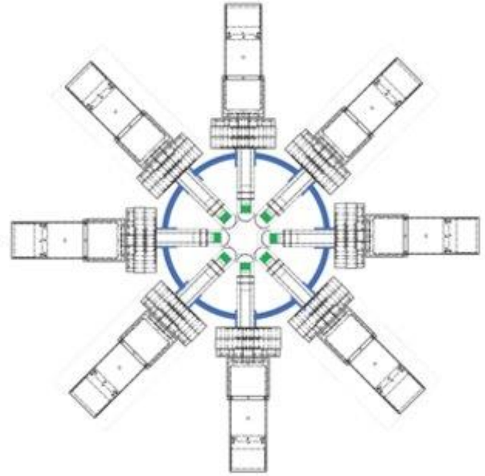


Fig: CAD assembly of SAMs looking downstream

Image courtesy: Daniel Valmassie

Diffuse Beam Monitor (DBM)

- **Detector system and components:**
  - 14 DBM detector modules around the ring, attached to upstream face of Main detector support ring at radius greater than R6
  - Each module has one "bare" PMT (no radiator) and one PMT attached to quartz (10 x 7.1 x 1.0 cm^3)
  - 3D printed holder
- **Prototypes Testing:**
  - 2025 Hall D Testbeam (analysis in process)
- **Procurement/Production Status:**
  - All quartz received/inspected (March 2025)
  - All PMTs received/inspected
  - Completed pre-production review
  - Full production and assembly in late summer 2025

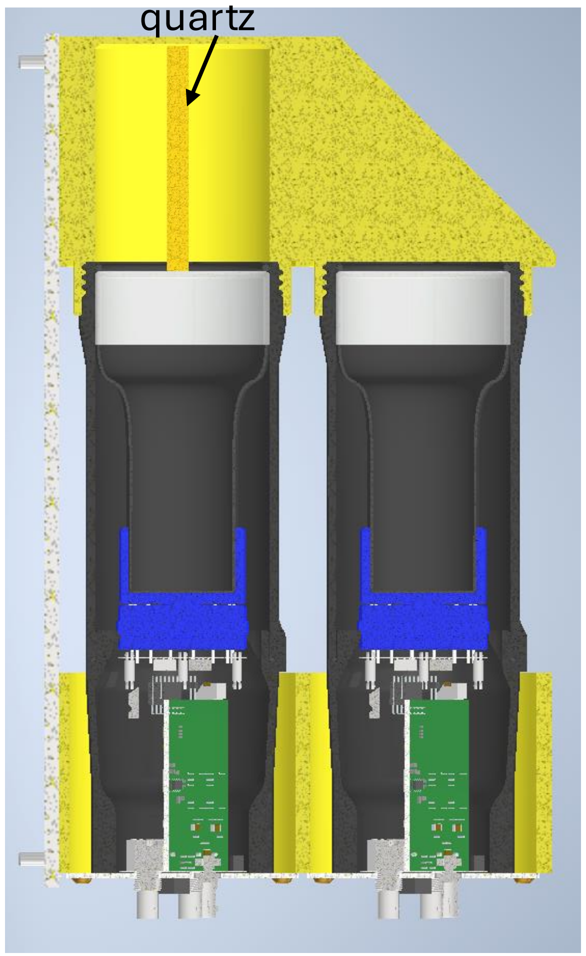
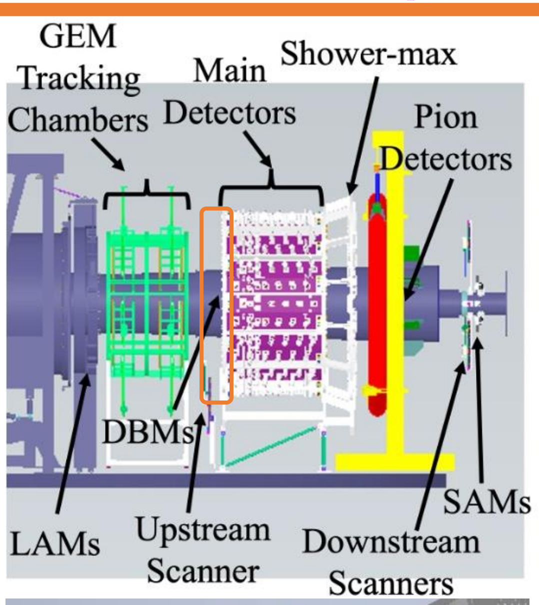


Fig: Cross section view of DBM



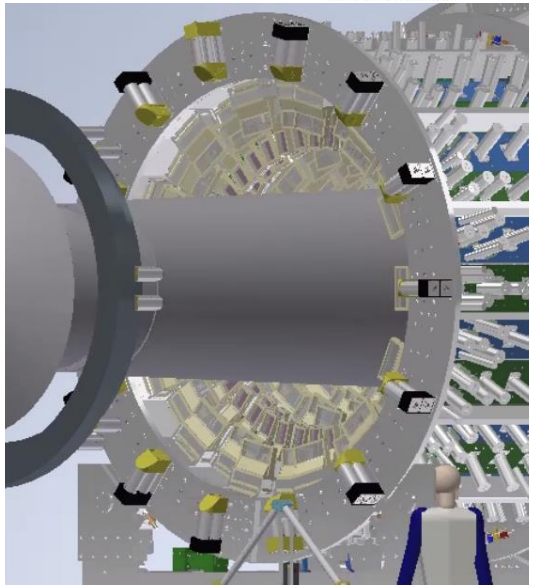
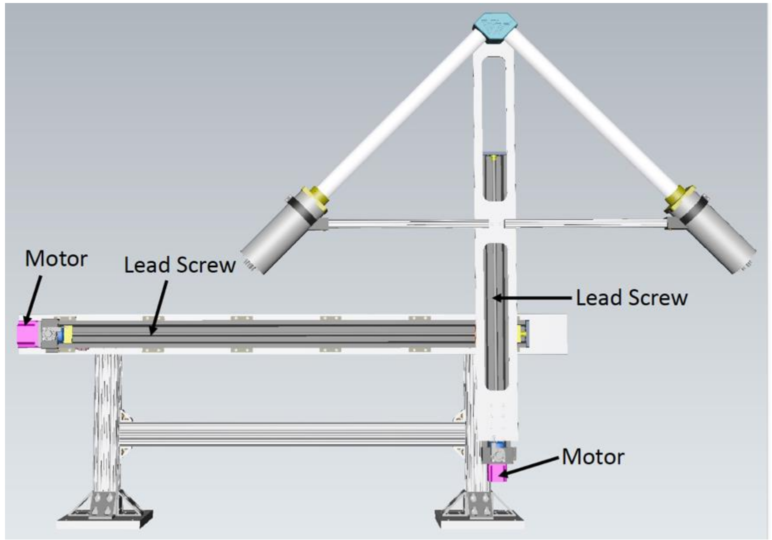


Fig: 14 DBMs around the beam line

Image courtesy: Devi Adhikari, Daniel Valmassie

Scanners (Upstream and Downstream)

- **Components:**
  - Upstream: 1 module with 2 pieces of 1 x 1 cm^2 quartz, low-pressure air core light guide. Downstream: 4 modules, each with 1 piece of quartz
  - Position controlled by Velmex 2D motion control system
  - Supports use 8020, custom aluminum, and 3D printed components
- **Prototypes Testing:**
  - 2025 Hall D Testbeam (analysis in process)
- **Procurement/Production Status:**
  - All quartz received/inspected (March 2025)
  - All PMTs received/inspected
  - Vacuum components verified (March 2025)
  - Support structure redesigned and procured 8020 parts



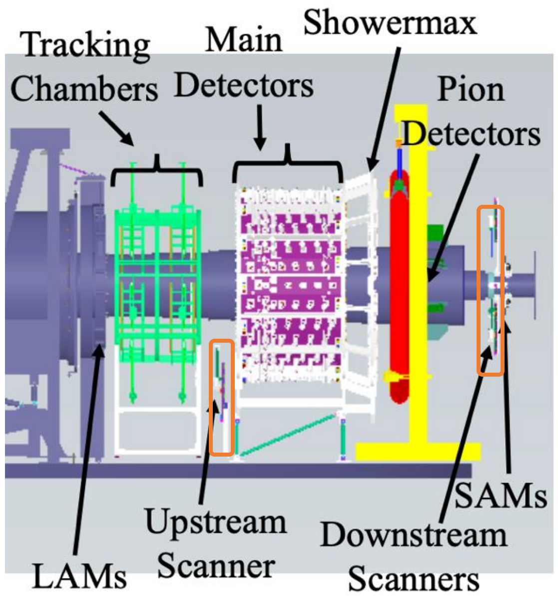


Fig: CAD assembly of upstream scanner

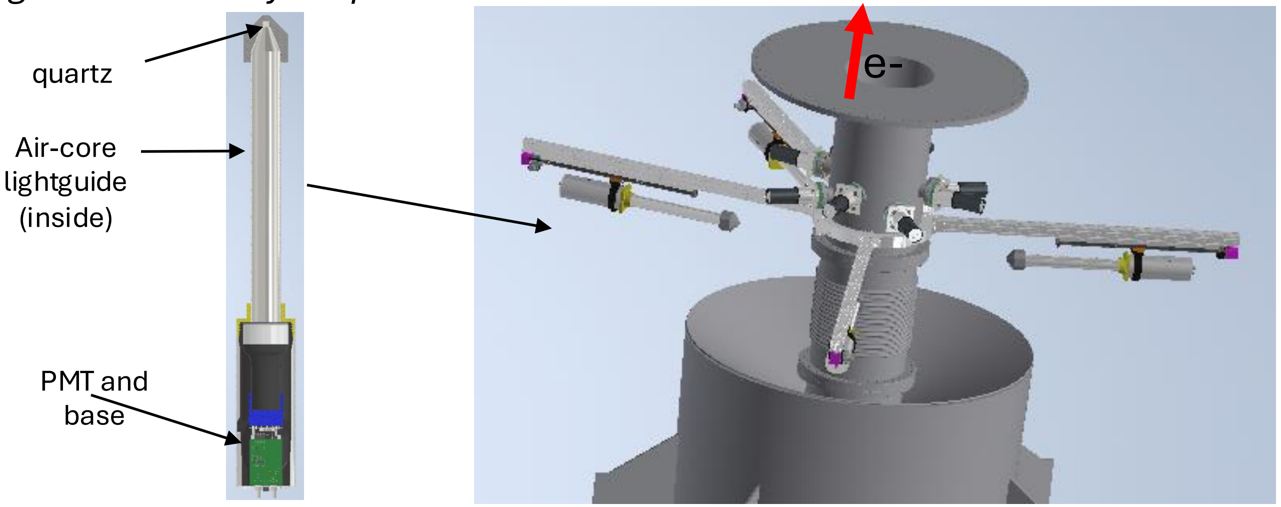
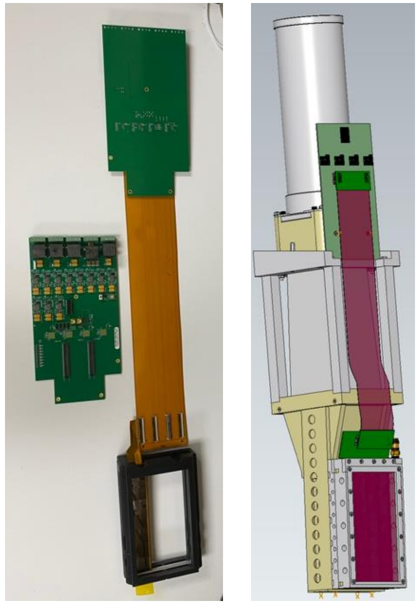


Fig: (left)CAD assembly of downstream scanner, (right) assembly around the beam line

Image courtesy: Devi Adhikari, Daniel Valmassie

HVMAPS

- **H**igh **V**oltage **M**onolithic **A**ctive **P**ixel **S**ensor
  - Works as additional tracking plane just behind the ring5 quartz.
  - Verifies the event profile at higher beam currents; is radiation hard with high event processing speed
- **Components:**
  - 2352 HVMAPS (84 R5 modules x 4 flexprint/modules x 7 Sensors/flexprint) – 28 sensor chips per detector, 64k pixels/chip
- **Prototyping/planning:**
  - Chilled air manifold design tested to cool HVMAPS
  - Robotic assembly/cell integration in progress
  - Working with machine shop for carrier fixtures (for gluing, bonding, etc.)
- **Procurement/Production Status:**
  - Engineering run sensors (P2Pix) to be delivered by June 2025
  - Production wafers to deliver early 2026



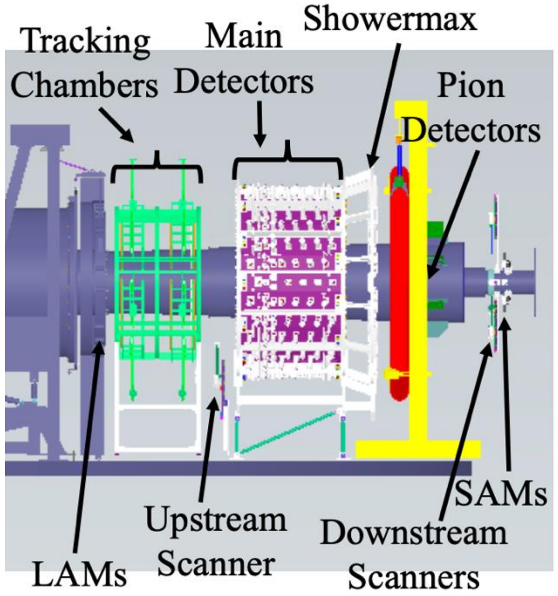
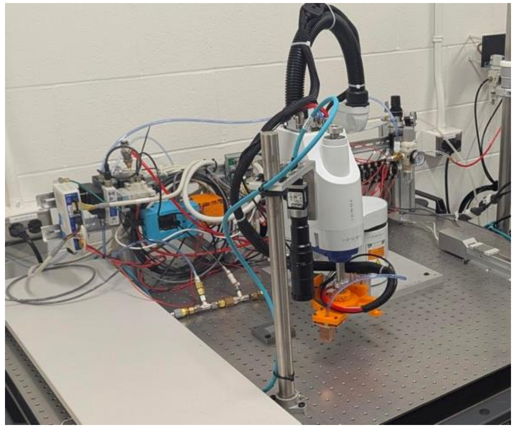


Fig: (left)single sensor chip, (right) full flex behind R5



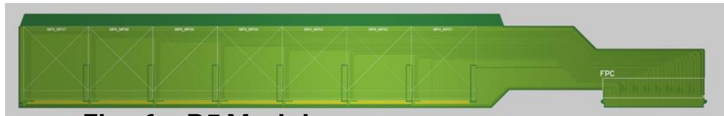


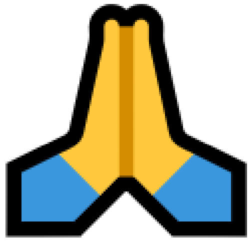
Fig: (left) robot at work, (left) 3D printed R5 carrier fixture protype

Image courtesy: Nafis Rafat, Kristofer Isaak

Summary

- **Main integrating detector modules are in production and testing phase**
  - Regular shipments of components are arriving at W&M
  - The process of full segment assembly, testing, and storage is ongoing
- **Shower-max:** All detector components are at JLab. System ready to move to hall A by early 2026
- **Pion detector:** Procurements completed, cosmic testing ongoing
- **Scattered beam monitors:** Procurements completed, full production and assembly by fall 2025
- **Scanners:** Procurements completed, testing ongoing
- **HVMAPS:** Preparations nearly completed, production wafers to be delivered early 2026

Thank you



Additional Slides

Team members

- Dustin McNulty (Idaho State U.)
- Sudip Bhattarai (Idaho State U.)
- Sagar Regmi (Idaho State U.)
- Justin Gahley (Idaho State U.)
- Edwin Sosa (Idaho State U.)

- Michael Gericke (U. Manitoba)
- Juliette Mammei (U. Manitoba)
- Wouter Deconinck (U. Manitoba)
- Savino Longo (U. Manitoba)
- Brynne Blakie (U. Manitoba)
- Anuradha Gunawardhana (U. Manitoba)
- Kristofer Isaak (U. Manitoba)
- Laheji Mohammad (U. Manitoba)
- Tawleen Kainth (U. Manitoba)
- Nafis Niloy (U. Manitoba)

- Jie Pan (U. Manitoba)
- Sakib Rahman (U. Manitoba)
- Nazanin Roshanshah (U. Manitoba)
- Elham Gorgannejad (U. Manitoba)

- Krishna Kumar (U. Massachusetts)
- Sayak Chatterjee (U. Massachusetts)
- Jonathan Mott (U. Massachusetts)
- Sakib Sarkar (U. Massachusetts)
- Kashish Singh (U. Massachusetts)
- K Yabe (U. Massachusetts)

- Carl Zorn (Jefferson Lab)
- Ciprian Gal (Jefferson Lab)
- Chandan Gosh (Jefferson Lab)

- Mark Pitt (VaTech)
- Devi Adhikari (VaTech)
- Daniel Valmessie (VaTech)
- Andrew Gunsch (VaTech)

- David Armstrong (W&M)
- Kate Evans (W&M)
- Tasneem Raza (W&M)

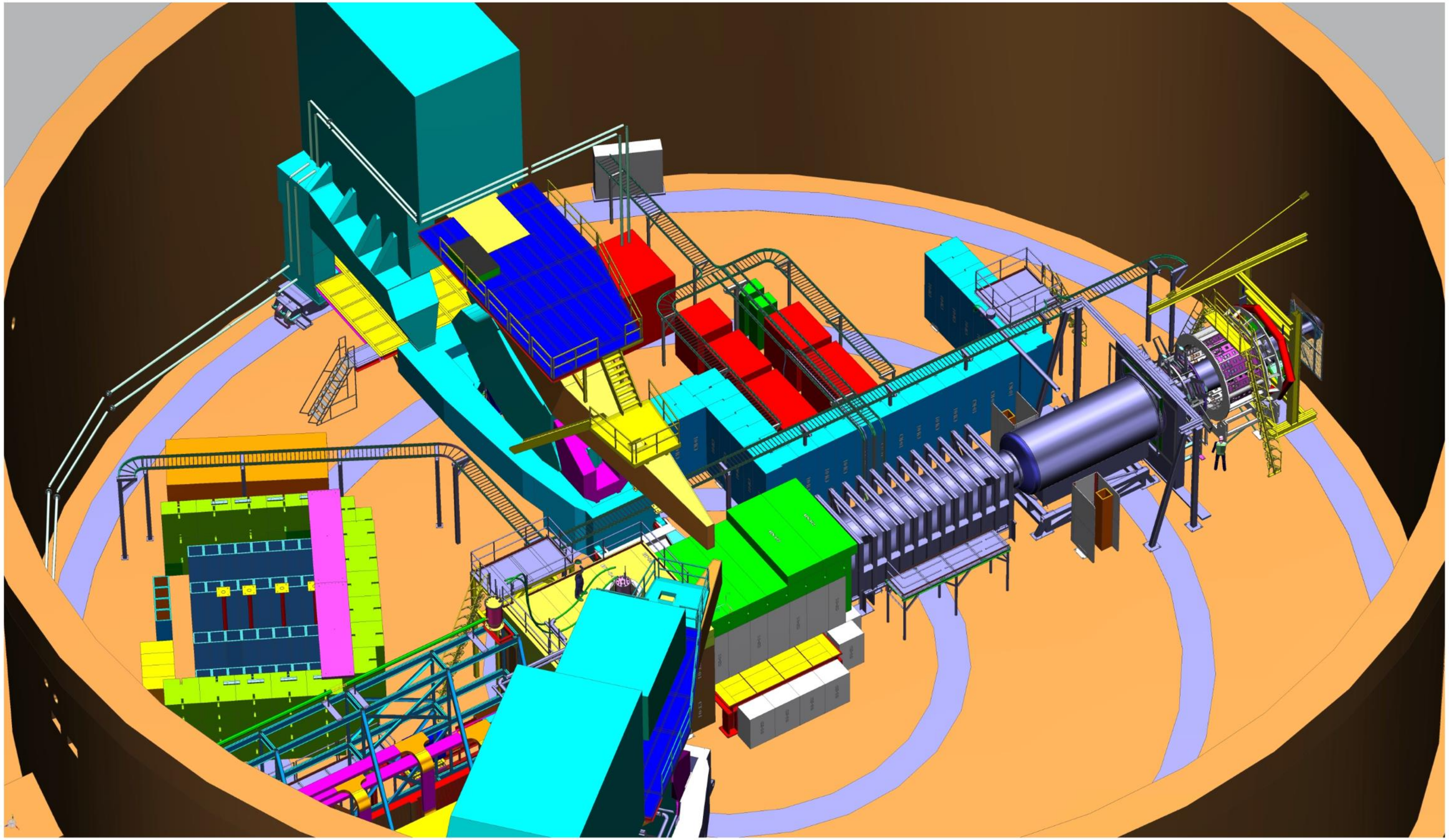
- Paul King (Ohio U.)
- Arindam Sen (Ohio U.)
- Ryan Conaway (Ohio U.)

- Sebastian Baunack (JGU, Mainz)
- Boris Gläser (JGU, Mainz)
- Malte Wilfert (JGU, Mainz)

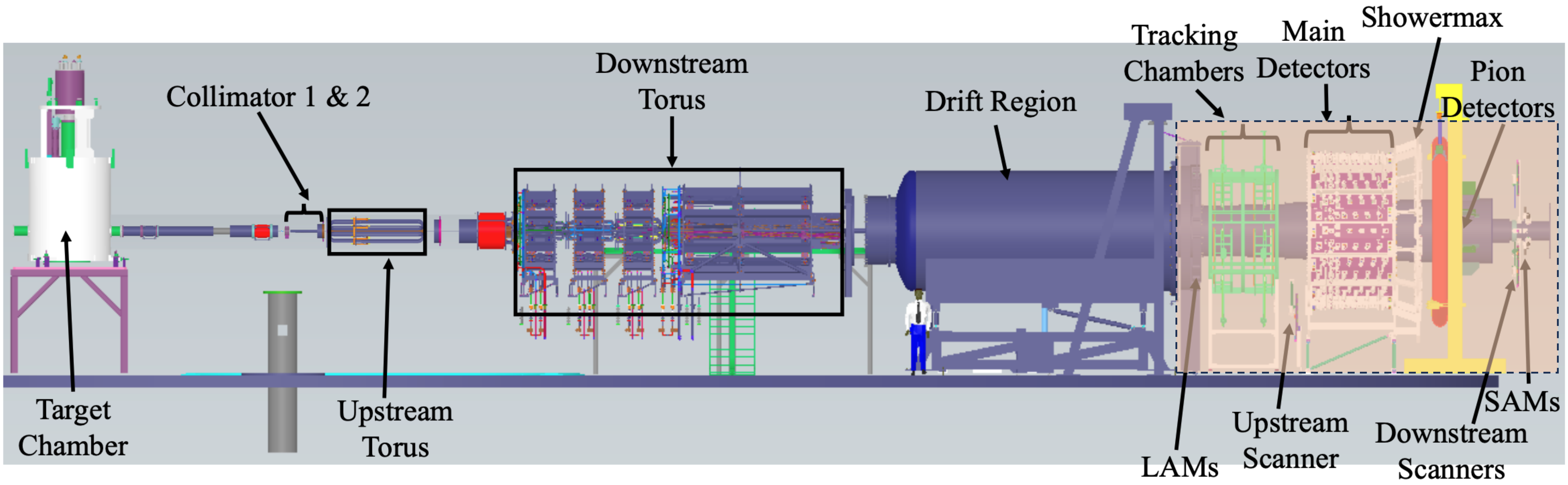
- Rahima Krini (JGU, Mainz)

- Paul Souder (Syracuse)
- Larry Bartoszek (Bartoszek Engineering)

MOLLER in Hall A



MOLLER Experiment Equipments



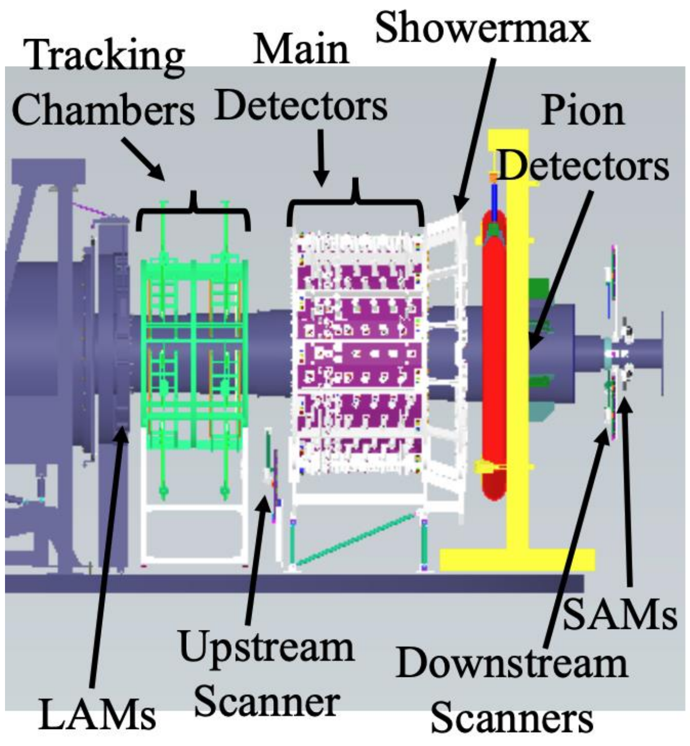
MOLLER Experiment:

- Detailed information on Vassu's presentation
- US and DS Torus magnets in combination separates the moller scattered electrons from backgrounds
- ~400 individual detector modules from different subsystem are used in the experiment

MOLLER Detectors Requirements

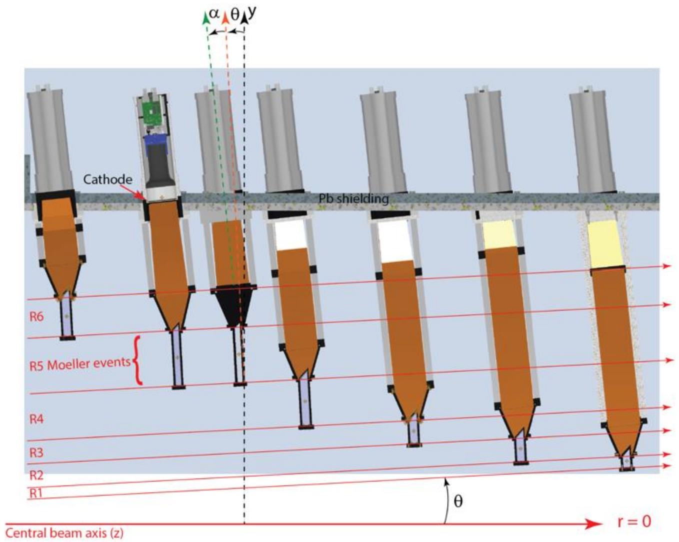
MOLLER Detector Requirements:

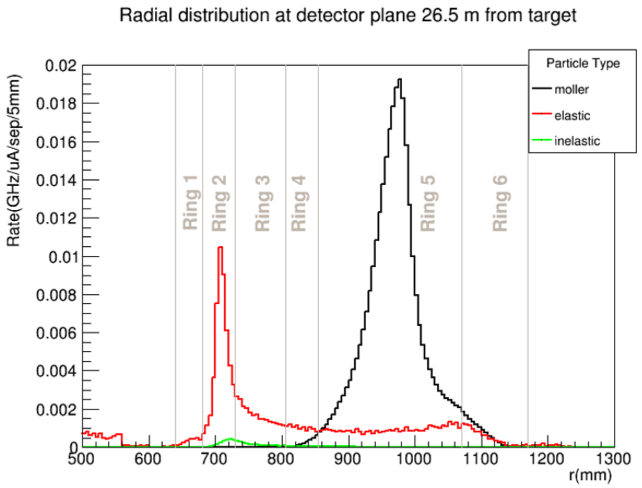
- Full azimuthal coverage of Møller scattered electrons and backgrounds
- Maximize the light yield, minimize the excess noise above counting statistics
- Detector non-linearity
- Radiation hardness and shielding

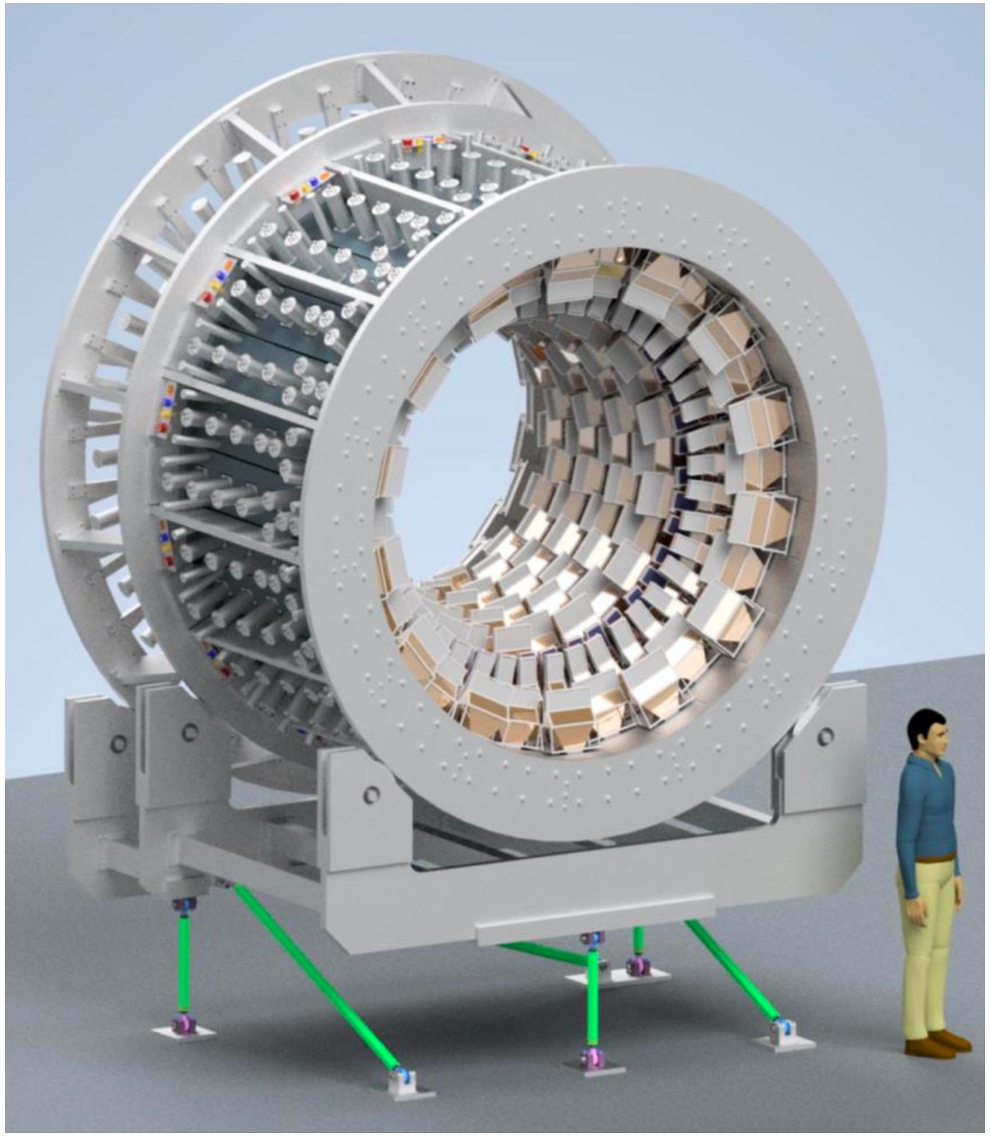


Main integrating detector

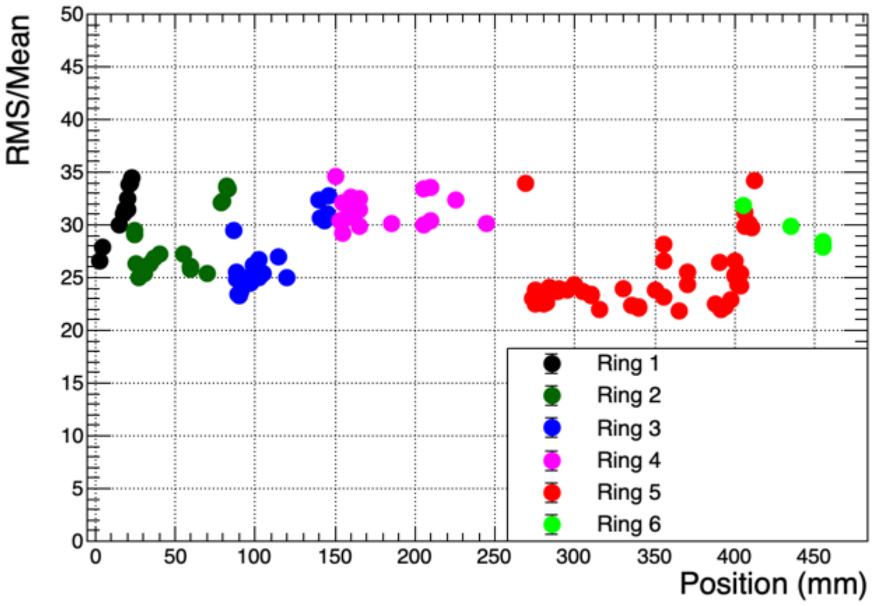
- Position: ~27 m downstream from target
- Total 6 rings around the beam
  - For full radial and azimuthal coverage of main Moller and background
  - Each rings has 28 quartz tiles except ring 5 which has 84







Main int det MAMI Testbeam result

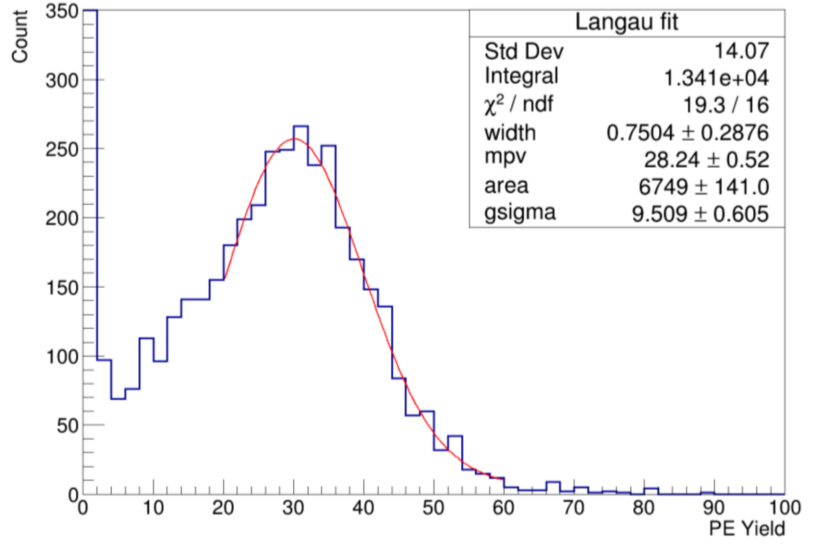


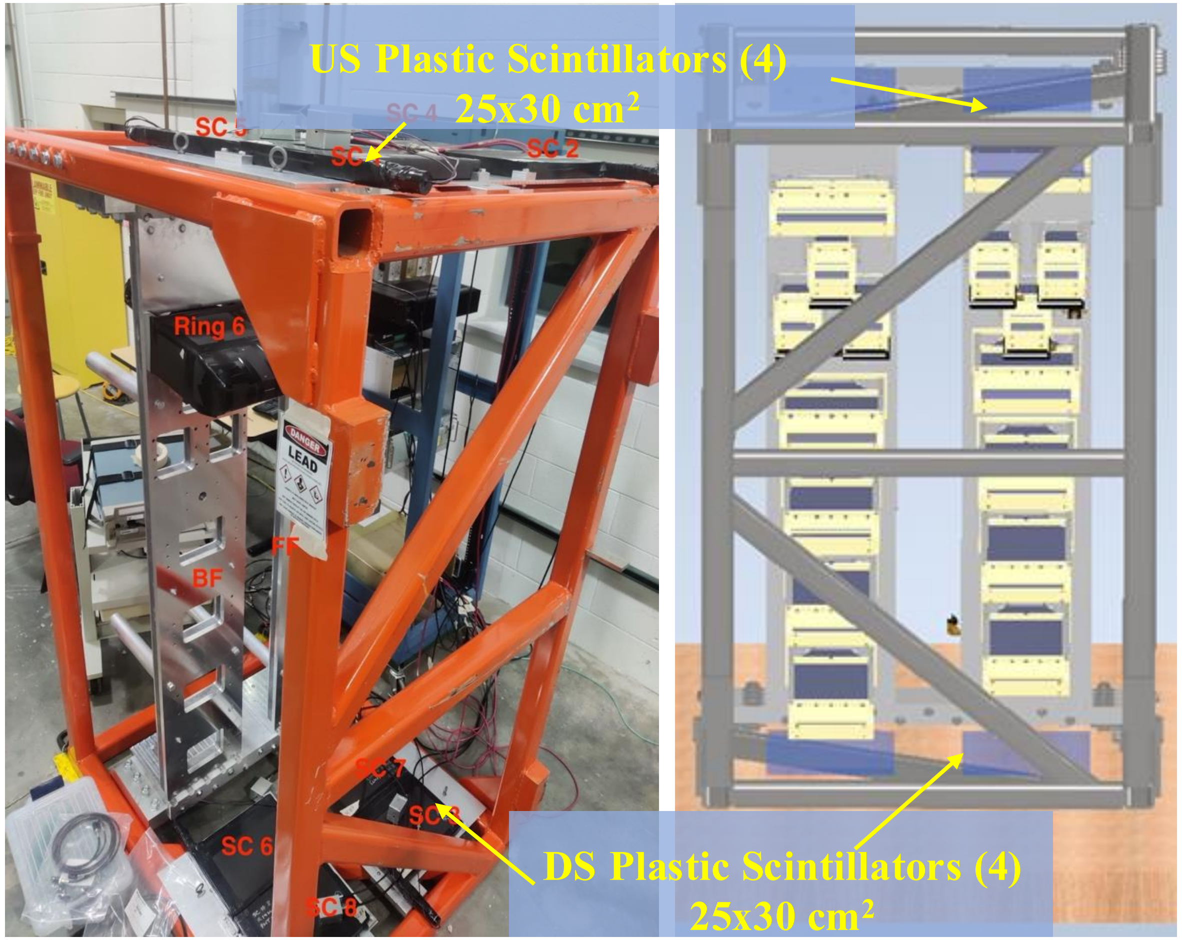
Rings	PE yield	Resolution (Gsigma/Mean)	RMS/MEAN
1	26.6 ± 0.1	~ 20 %	~ 30 %
2	25.0 ± 0.1	~ 22 %	~ 28 %
3	22.5 ± 0.8	~ 21 %	~ 28 %
4	23.6 ± 0.2	~ 23 %	~ 30 %
5 BF	32.0 ± 0.2	~ 18 %	~ 25 %
6	20.7 ± 0.2	~ 22 %	~ 32 %

Cosmic Testing at W&M

- **Cosmic stand**
  - Validate the detector performance
  - 4 scintillators to cover all 6 rings
  - fADC + CODA based DAQ Systems

- Low voltage and

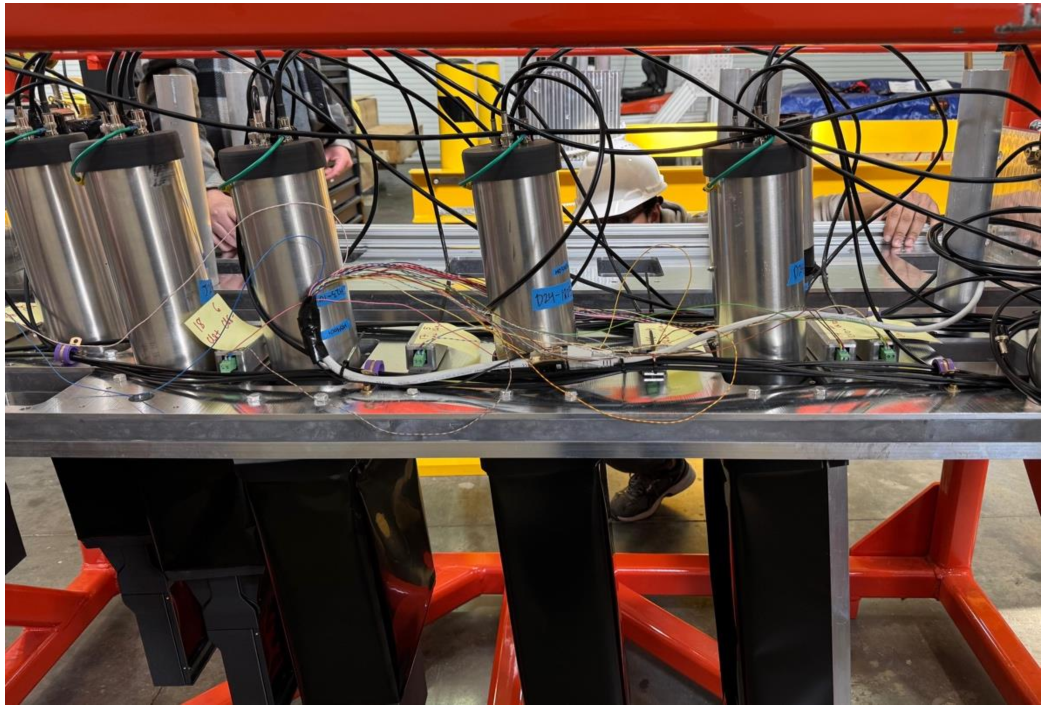




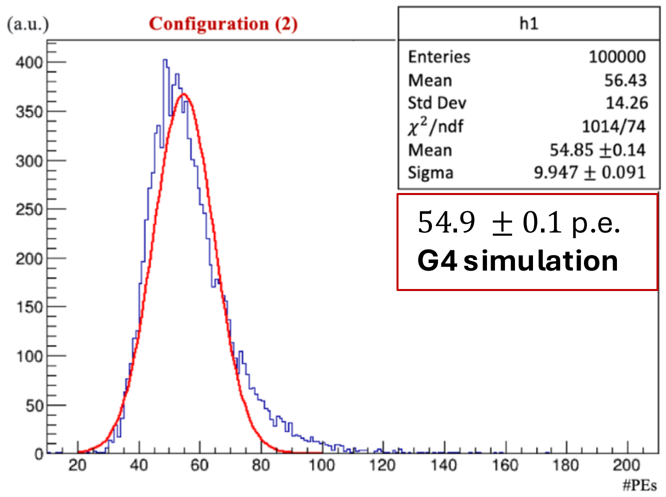
Modules assembly: W&M

- **AT Assembly:**
  - After clean room assembly, modules are mounted into the segment plate
  - The full segment plate in mounted into the AT box, which will be brought to the jlab later.

Quartz of	Received (06/17/2025)
Ring 1	12
Ring 2	24
Ring 3	13
Ring 4	21
Ring 5	89
Ring 6	20
Total:	179/224+

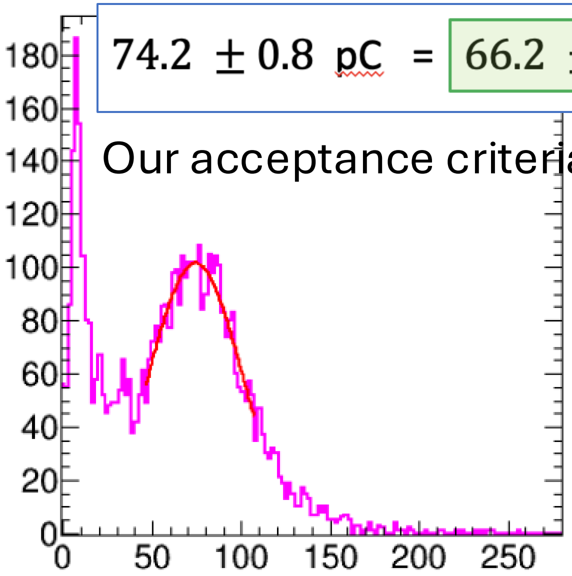


Pion Detector Prototypes test results:



74.2 ± 0.8 pC = 66.2 ± 0.7 p.e. **Prototype**

Our acceptance criteria: > 30 pe



HVMAPS

- **Assembly delivery status**
  - ~100 P2Pix sensors from engineering run to be delivered (June 2025).
  - P2Pix collaboration meeting and training session in Germany (July 2025).
  - Implement readout chain for HVMAPS (overlaps with both Compton EDet and Main Detector HVMAPS) (Summer 2025).
  - Develop P2Pix readout firmware allowing control of sensors via external FPGA boards and test MOLLER HVMAPS readout board
  - Continue development and verification of SCARA for HVMAPS assembly (Summer/Fall 2025).
  - Implement P2Pix testing setup into the assembly process (Summer 2025).
  - Assemble and test Compton detector planes using sensors obtained from engineering run, followed by delivery to JLab (Fall 2025).
  - Proceed to assembling FPCs and HVMAPS enclosures for R5 using remaining sensors from engineering run (Fall 2025 onwards).
  - Further delivery of production wafers expected early 2026, will continue to manufacture Ring 5 HVMAPS enclosures for the main integrating detector afterwards (2026).
  - Assemble and mount as many R5 enclosures as possible before segment is installed into main detector array. Any remaining enclosures will be installed later during possible downtime.