Overview of the MOLLER experimental apparatus

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Outline

- MOLLER experimental apparatus
- R&D of the detector prototypes
- Outlook

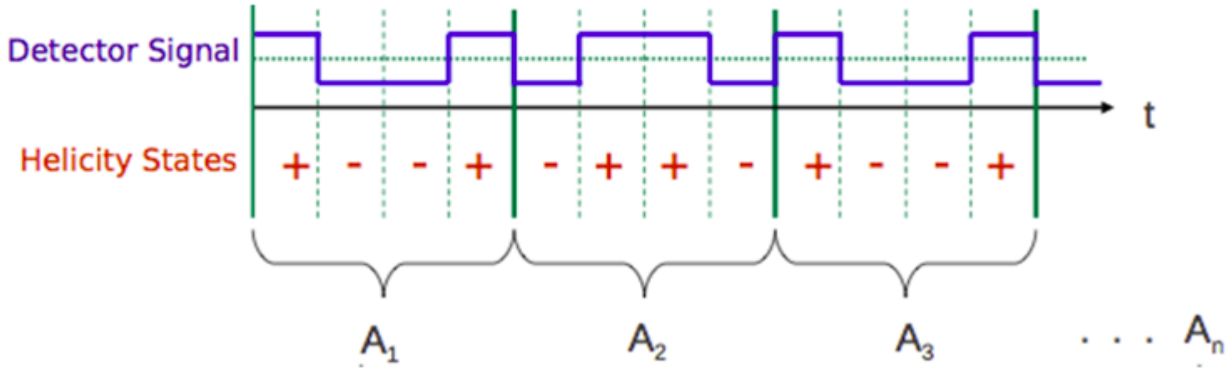
References

- MOLLER Technical Design Report
- MOLLER collaboration meeting 2023

Jlab Hall A winter meeting
17th January 2024

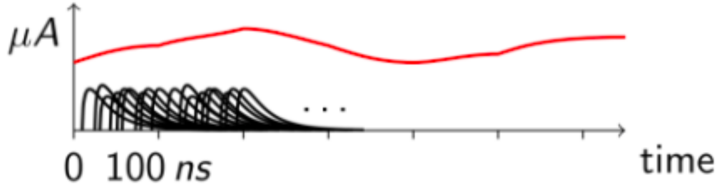
Measuring the small asymmetry

Rapid (2kHz) helicity reversals



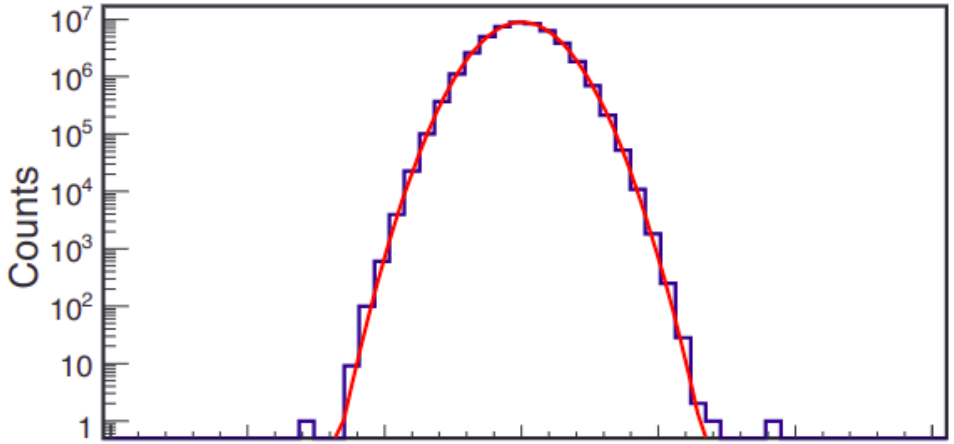
Place a detector where it sees the Møller scattered electron

Analog integrate detector current



Form an asymmetry over the helicity reversal

Measure to 0.01% at 1 kHz, repeat for a year straight

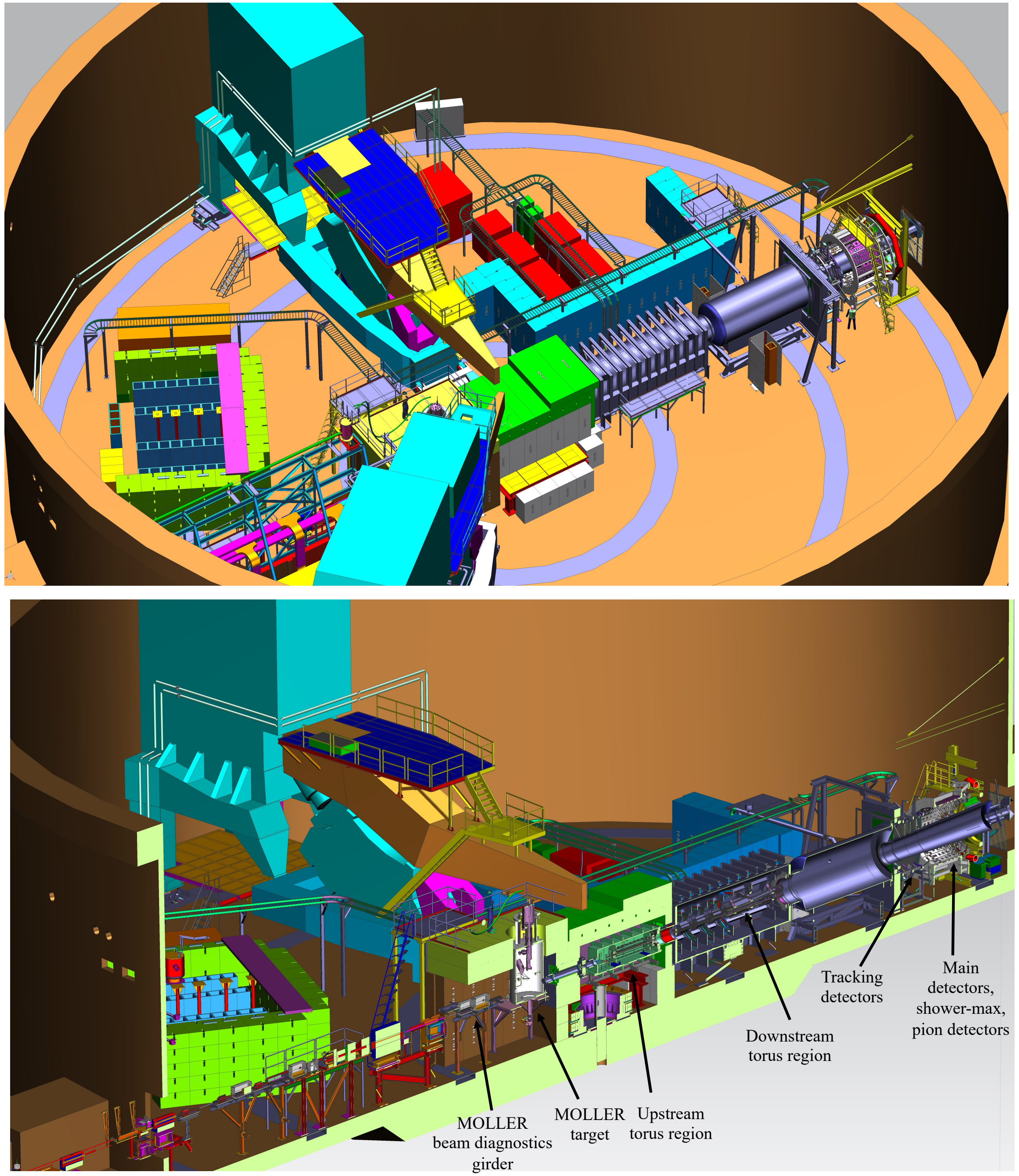


Specialized experimental techniques

- Precise spectrometer to separate signal
- Low noise electronics
- Precise beam control and measurement
- ...

MOLLER apparatus

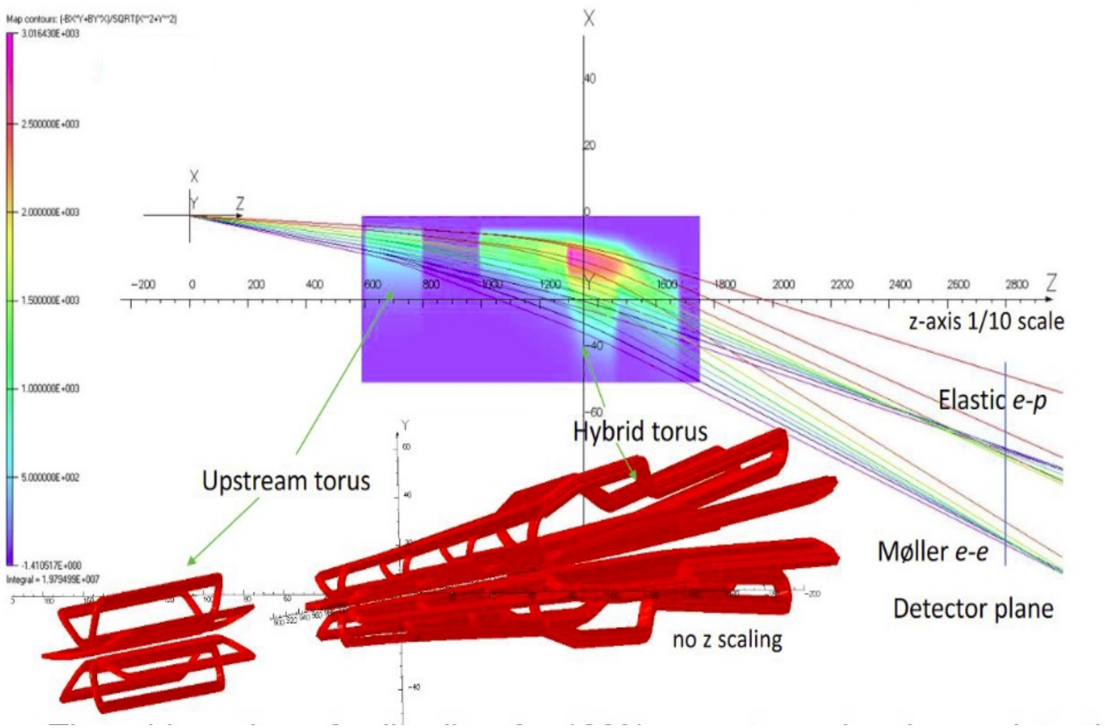
- **Polarized beam monitoring**
- **Target System:**
  - ➢ A high power, very stable cryogenic LH_2 target
- **Spectrometer:**
  - ➢ A 7-fold symmetric toroidal magnet
- **Main Detector array:**
  - ➢ Radiation hard thin quartz Cherenkov radiators
- **Auxiliary detectors:**
  - ➢ Shower max => Cross-check of the Møller flux
  - ➢ Pion detector => Pion background asymmetries
- **Tracking Detectors**
  - ➢ GEM detectors for background study and calibration
- **Data Acquisition system (DAQ)**

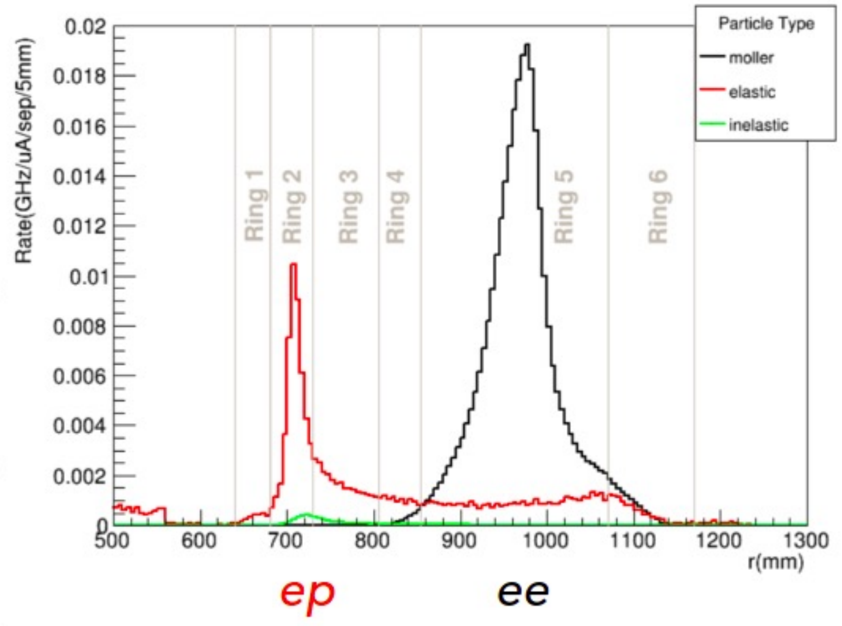


CAD model of the MOLLER apparatus

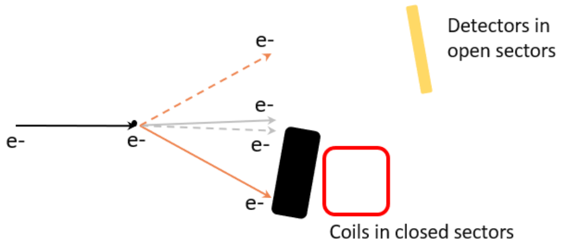
Picture courtesy: MOLLER TDR

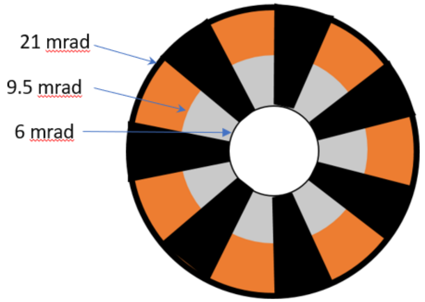
Spectrometer





Unique concept allows for full azimuthal acceptance (effectively) because of the identical particle scattering



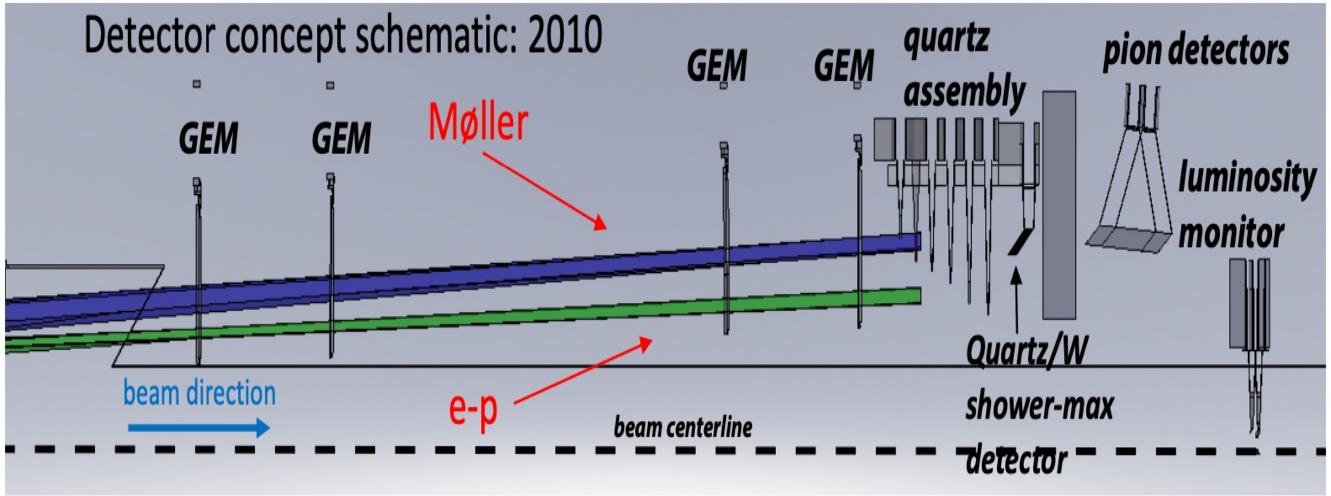


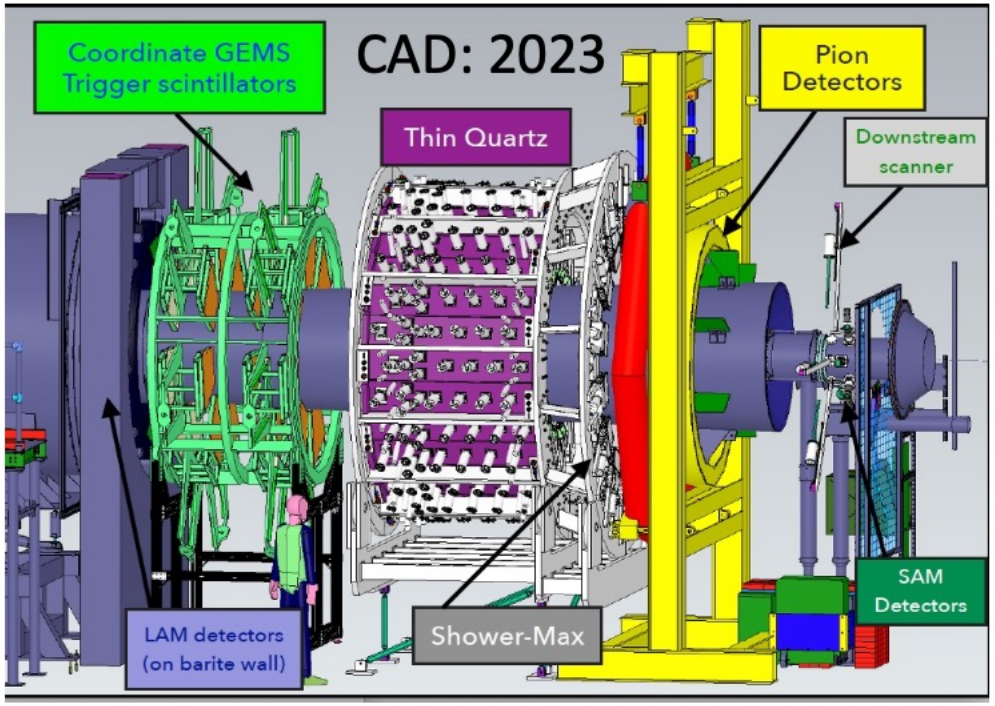
- Full azimuthal acceptance for Møller scattering events
- Clean separation of Møller electrons from the primary background of elastic and inelastic electron- proton scattering
- Collimation such that detectors do not have line-of-sight to the target
- Minimization of soft photon backgrounds by designing a “two-bounce” system via judiciously placed collimators

Picture courtesy: MOLLER TDR

Overview of the detector sub-systems functional requirements

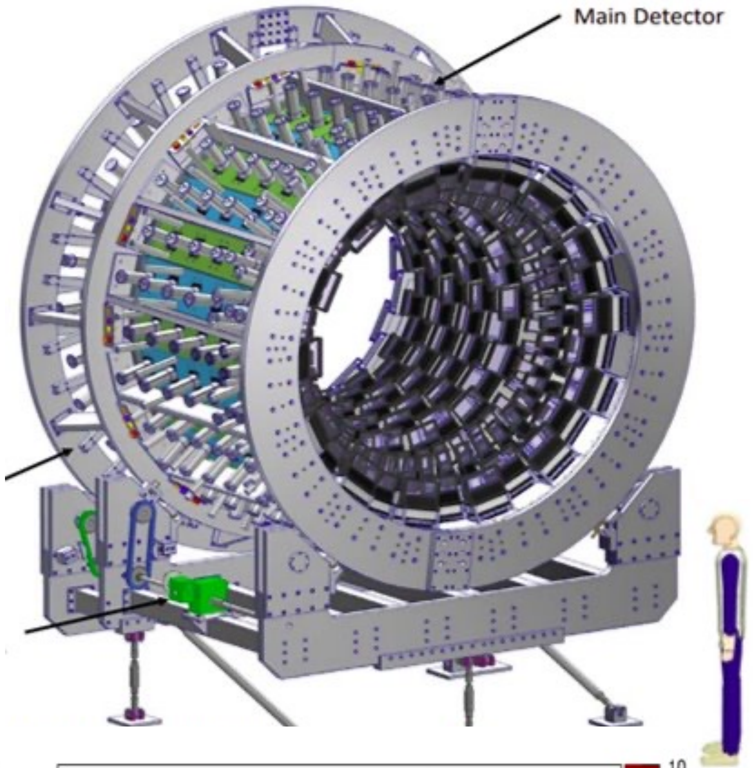
- Intercept the primary electron flux with a radiation hard pure Cherenkov radiator (fused silica or “quartz”) with high radial and azimuthal segmentation
- Ensure the required sensitivity to the electron flux asymmetry in the quartz tiles, approaching the shot-noise-limit with little additional background or crosstalk; have a redundant way to measure this asymmetry
- Calibrate the primary electron flux, the irreducible electron background and their relationship to the spectrometer optics and acceptance collimators
- Measure the anticipated few per mille pion/muon background flux rate and asymmetry in the Møller ring
- Monitor the small/large angle and diffuse scattered flux as an additional monitor of beam helicity correlations in the primary beam parameters and the beam halo





Work by: M. Pitt’s talk at MOLLER CD-2/3 Independent Project Review

Main integrating detector

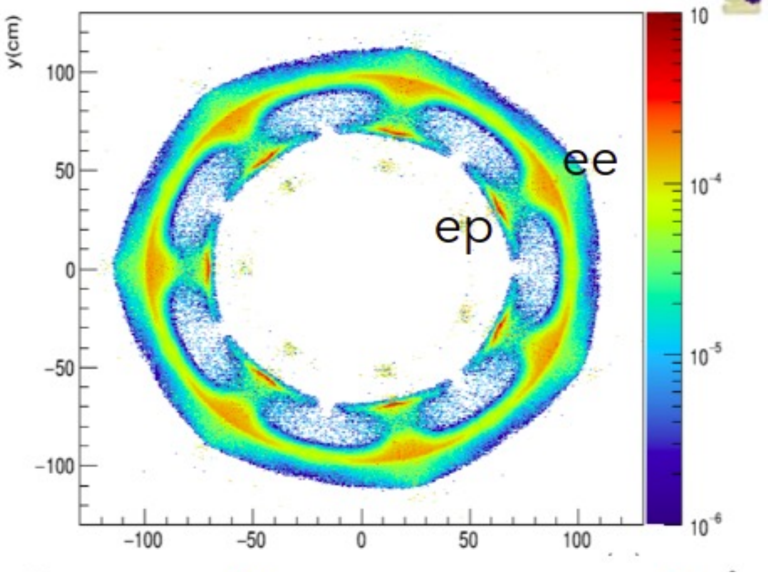


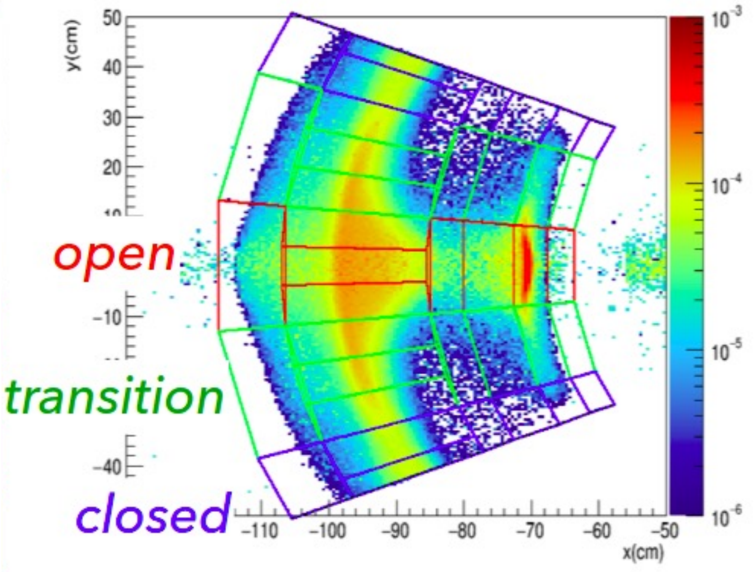
Requirements :

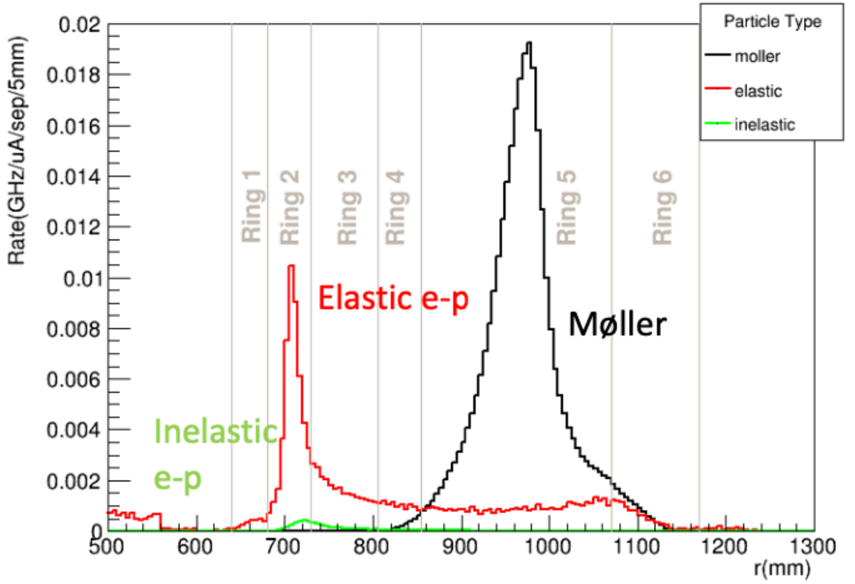
- Radial segmentation to isolate Møller signal in one radial segment and adequately map backgrounds
- Azimuthal segmentation–correlation between azimuthal angle and scattered electron energy
- Segmentation facilitates deconvolution procedure to extract signal and background asymmetries from the data

Design :

- 224 thin detector modules
- 6 radial rings
- 28 azimuthal channels per radial ring (84 azimuthal channels in Møller Ring 5)



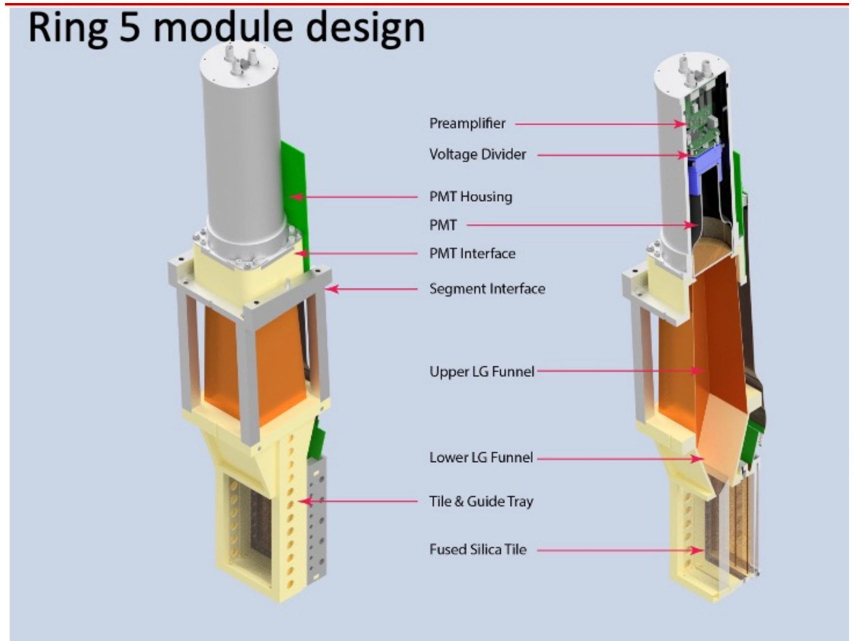


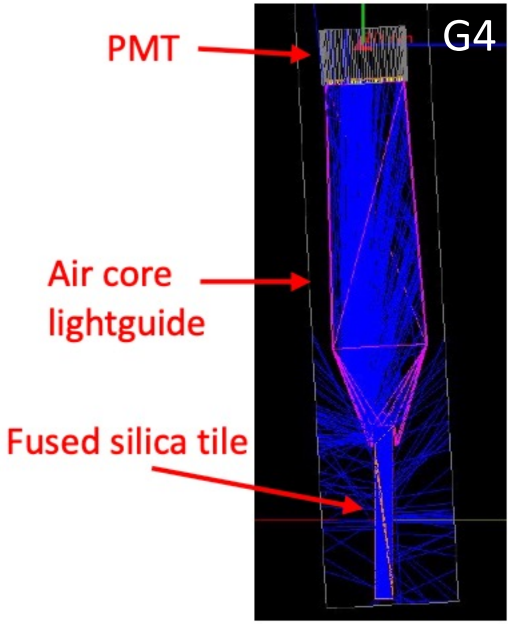


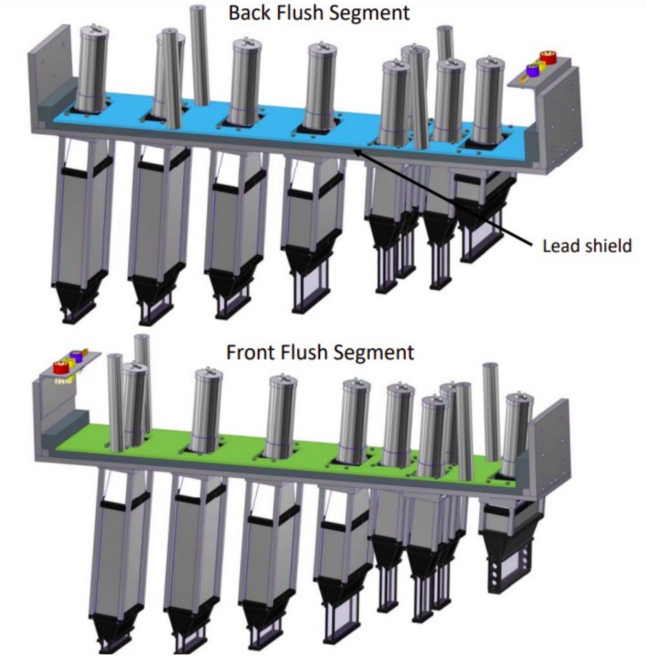
Main thin quartz detector modules

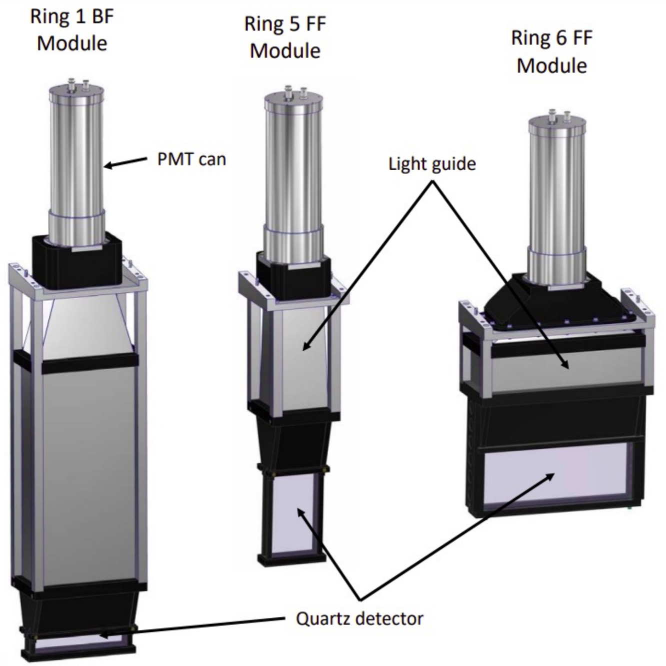
Requirements :

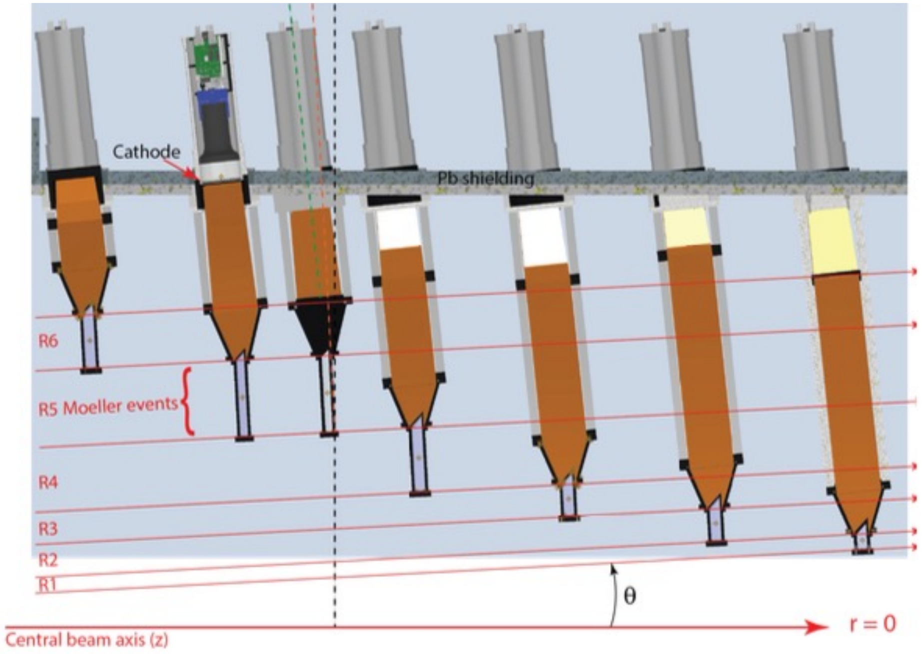
- Signal yield and noise:>25 photoelectrons and <4% excess noise from all sources
- Operate in both integration and counting mode
- Detector material chosen to minimize backgrounds
- Radiation hardness of all materials to maintain structural functional integrity for duration of experiment





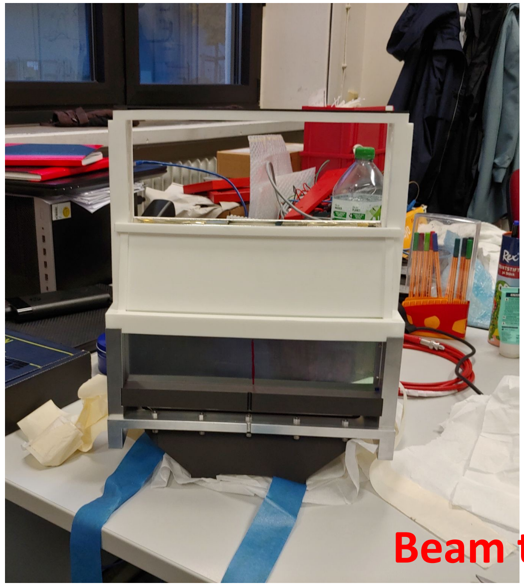




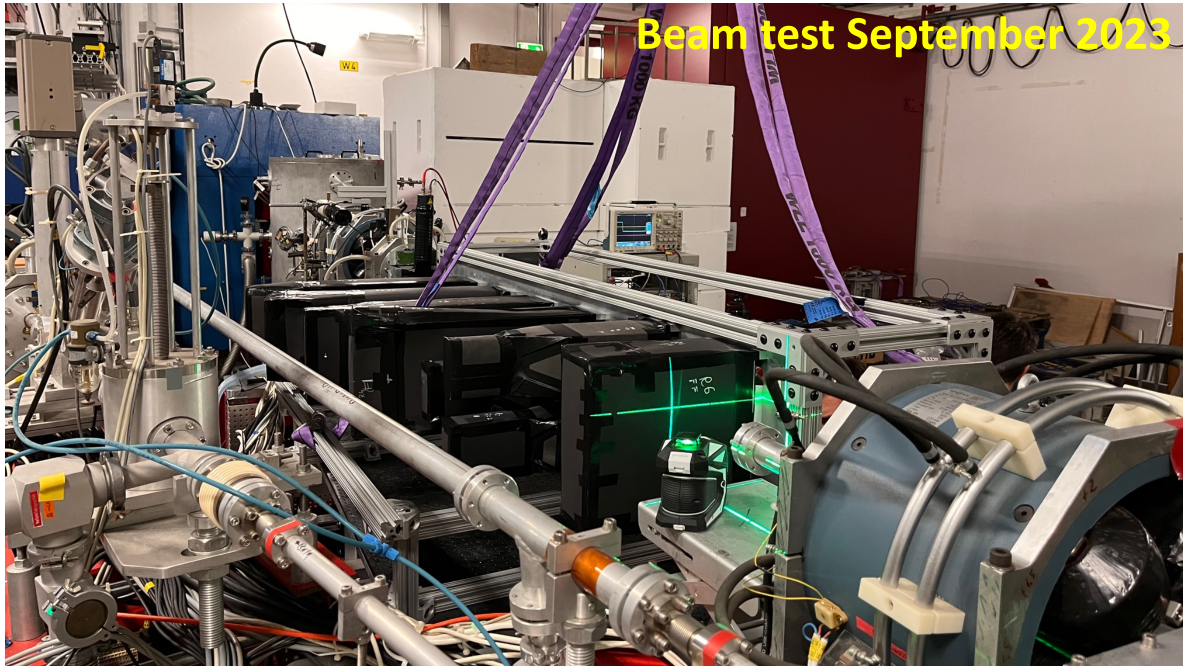


R&D of main thin quartz detector prototypes

- Testing of the Cherenkov detector prototypes at MAMI accelerator facility in Germany with electron beam of energy ~ 855 MeV
  - ➢ Performance study of the individual modules
  - ➢ Performance study with an entire front flush segment
- Characterization of the Cherenkov detector with cosmic muons
- Testing of different quartz tiles (Tosoh, Heraeus, Corning)
- Optimization of the light guide material
- Optimization of the light tightening of the detector modules
- Beam test at MAINZ (November 2022 & September 2023)




Beam test November 2022

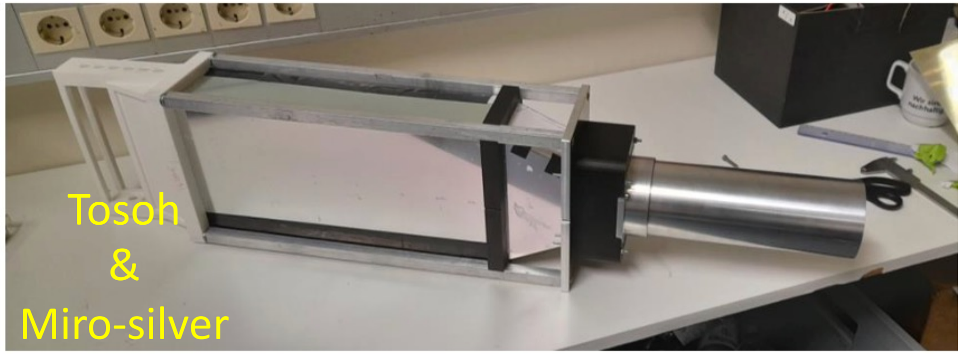


Beam test September 2023

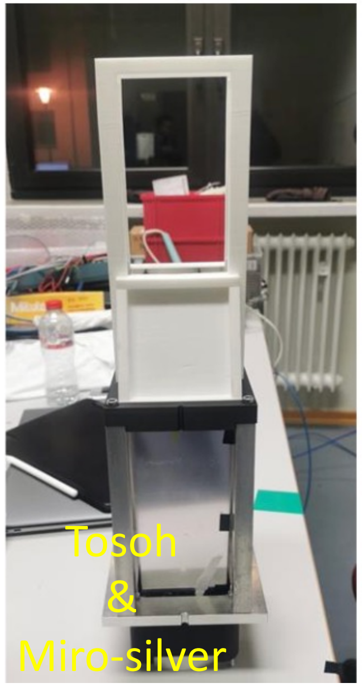
Results from beam (Nov 2022) test

Ring 1

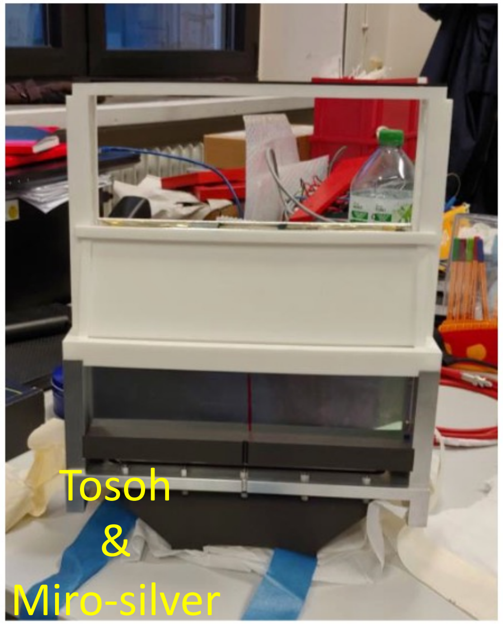
Ring 2

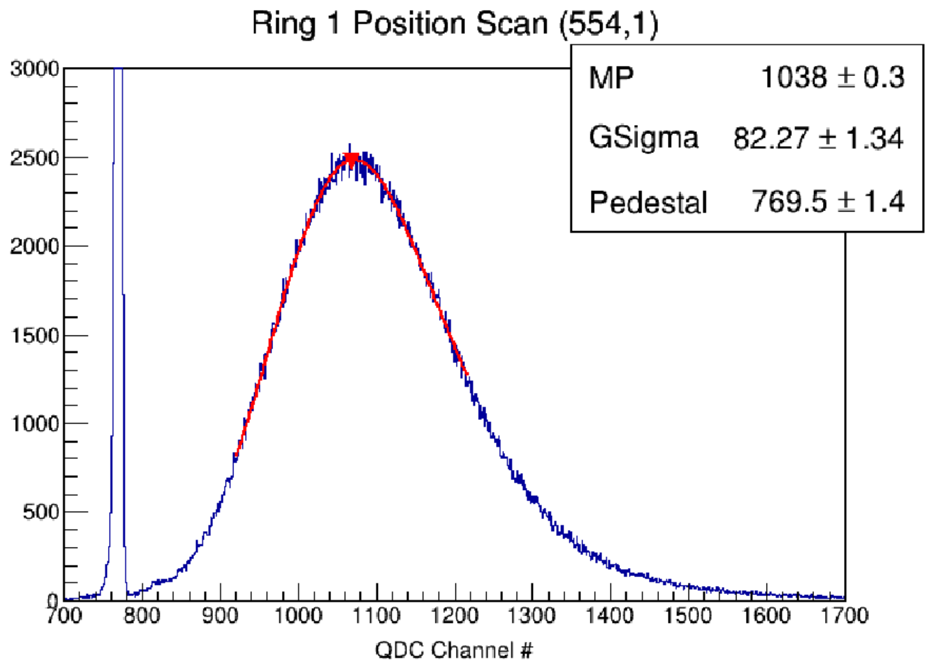


Ring 5



Ring 6





- Identify pedestal and event peaks
- Event peak fitted with a Landau-Gauss convolution
- The "most probable value" (MP) and the fit sigma (GSigma) were extracted to record the mean photo-electron yield

$$n_{pe} = (\text{MP} - \text{Ped})^2/\sigma^2$$

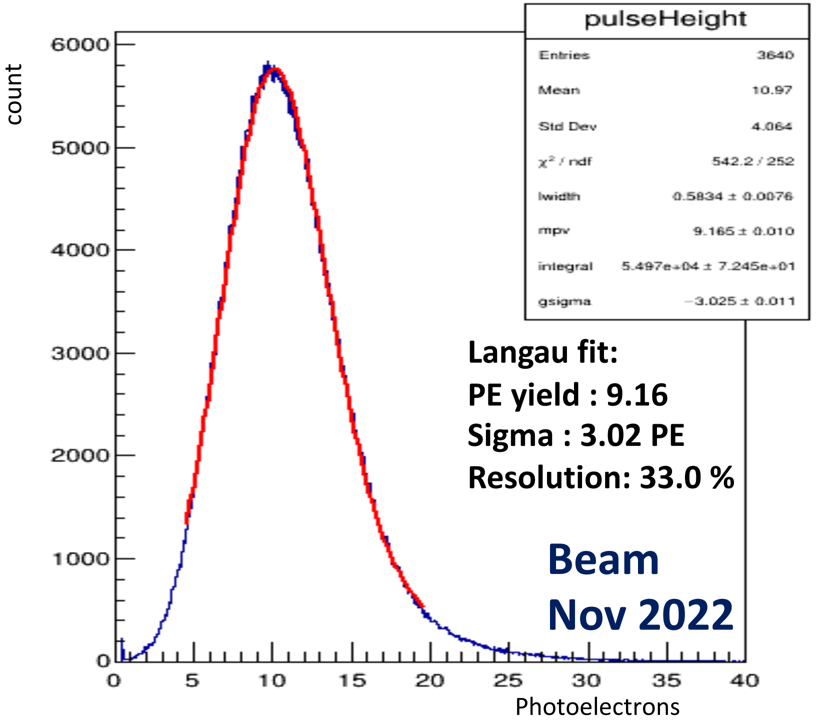
- Photoelectron yields:

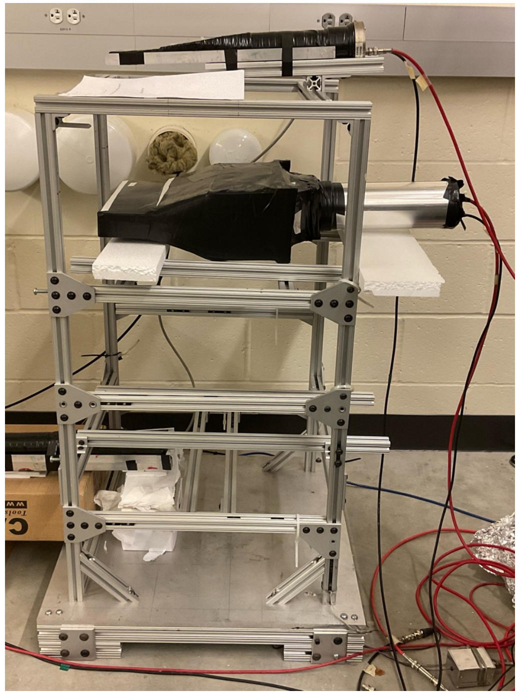
  Ring 1 $n_{pe} \approx 9$
  Ring 2 $n_{pe} \approx 15$
  Ring 5 $n_{pe} \approx 21$
  Ring 6 $n_{pe} \approx 9$

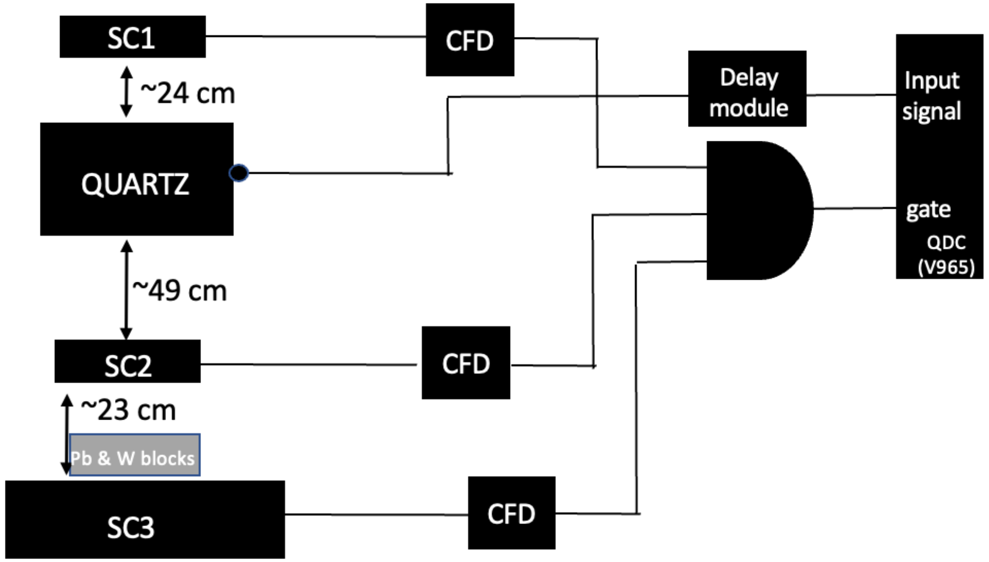
Work by: B. Blaikie's talk at MOLLER collaboration meeting 2023

Results from beam (Nov 2022) & cosmic test

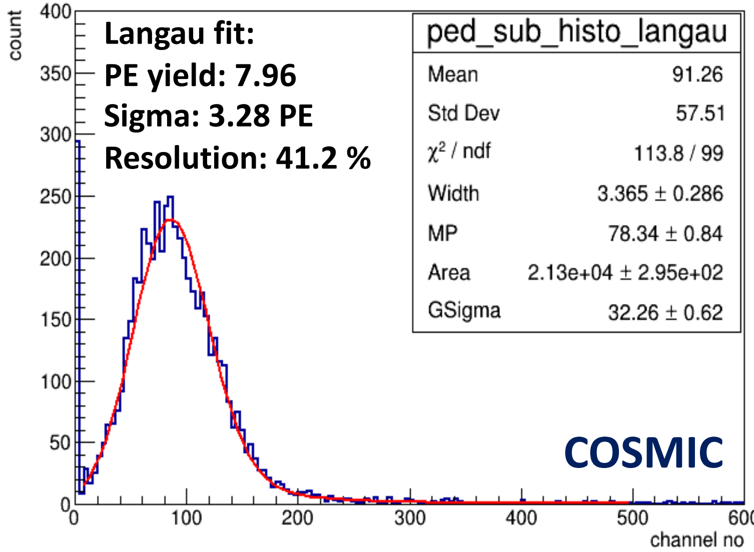
Ring 6; Quartz: Tosoh; Light guide: Miro-silver







Cosmic test setup at UMass

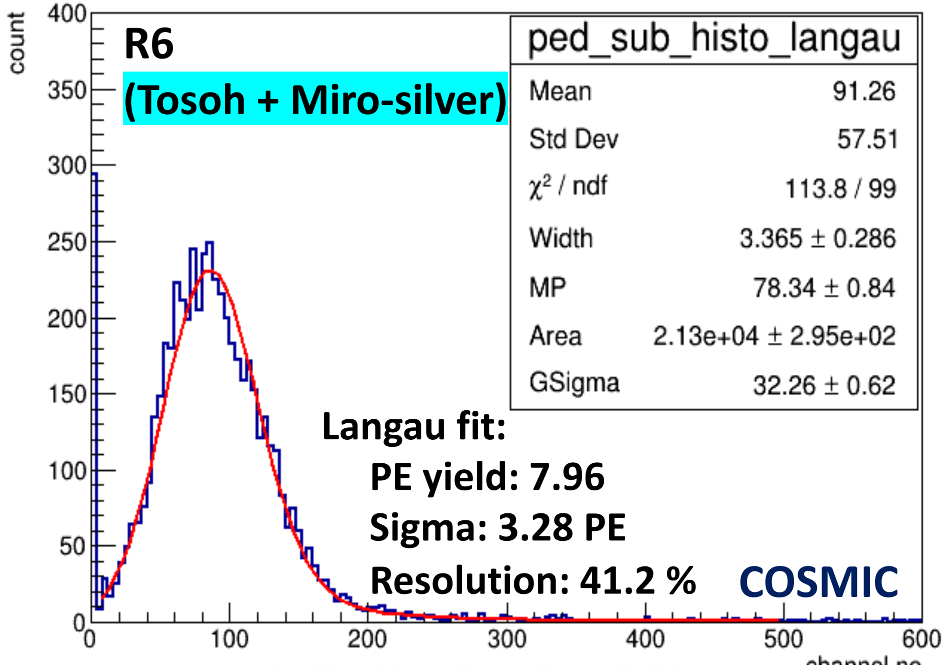


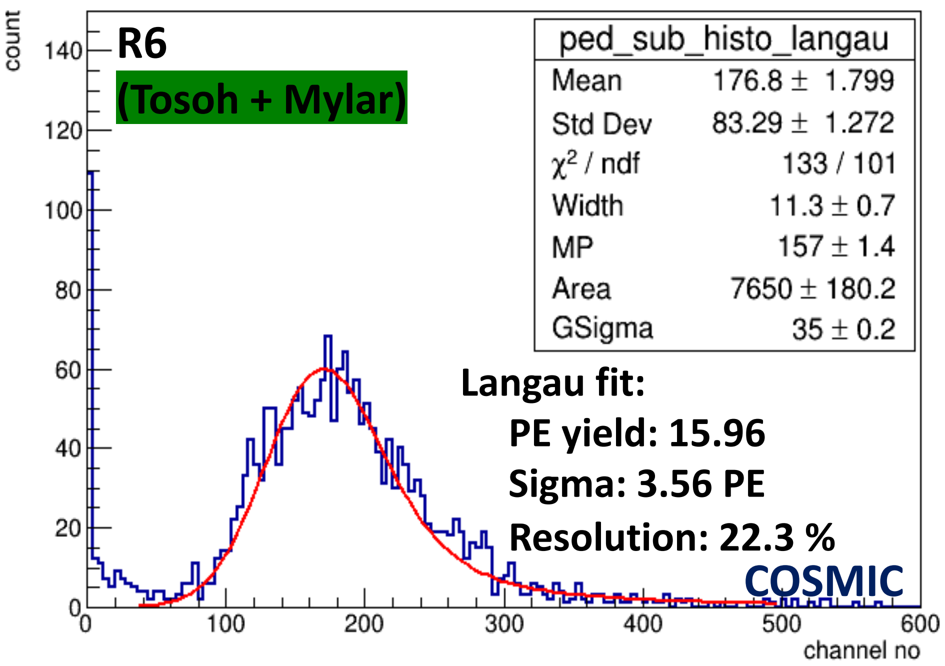
- ✓ Good agreement (~ 15 %) among beam & cosmic data
- ✓ The lower PE yield and broader spectra with cosmic is due to the solid angle subtended by the triggering scintillators
- ✓ **Benchmarking the beam test data with cosmic muons**

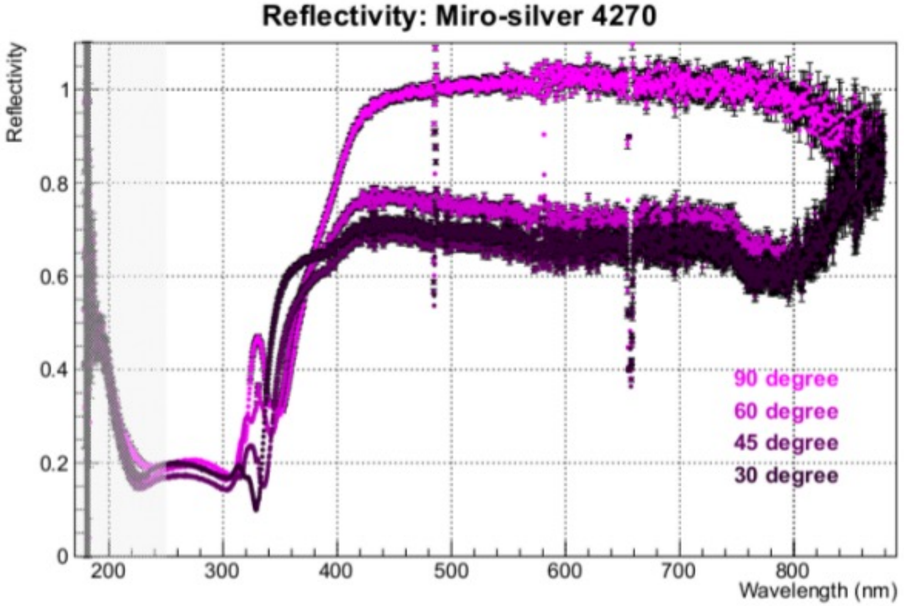
Quartz tile	PE yield (Beam)	PE yield (Cosmic)	Sigma (PE) (Beam)	Sigma (PE) (Cosmic)
R6; Tosoh; Miro-silver	9.16	7.96	3.02	3.28

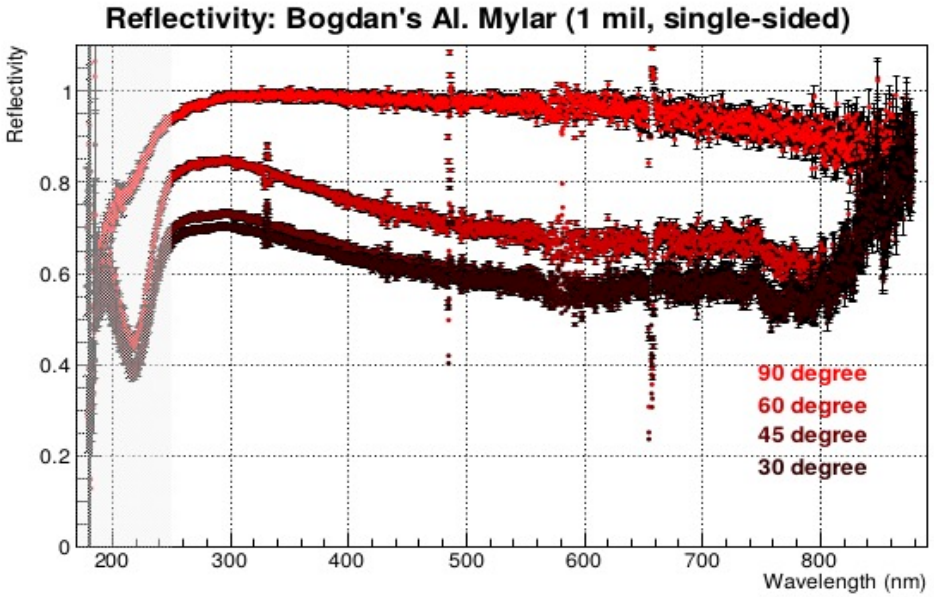
Work by: S. Chatterjee's talk at MOLLER collaboration meeting 2023

R&D of the light guide material for R6





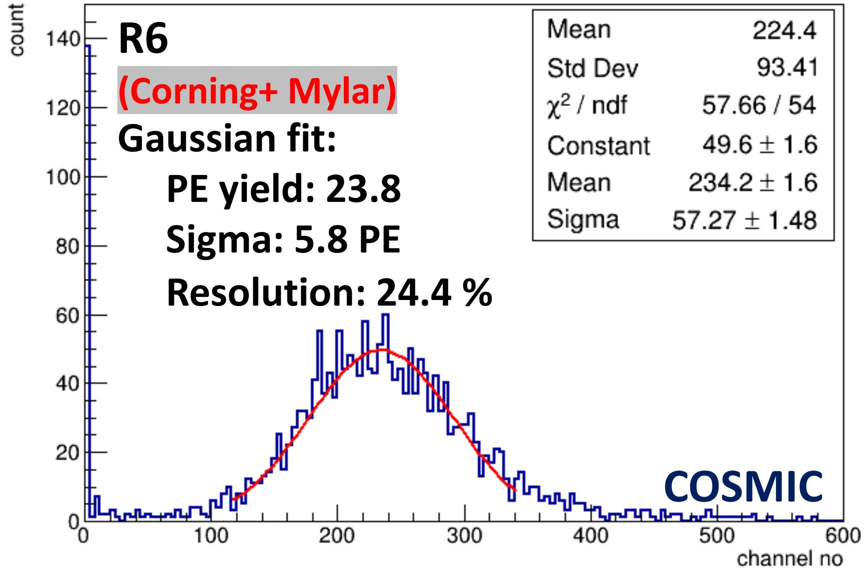


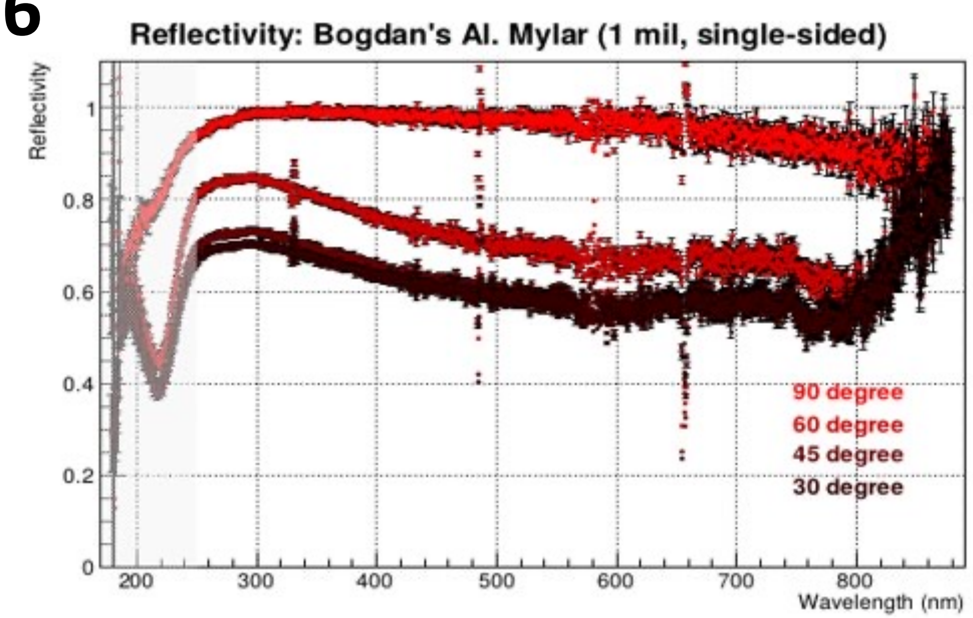


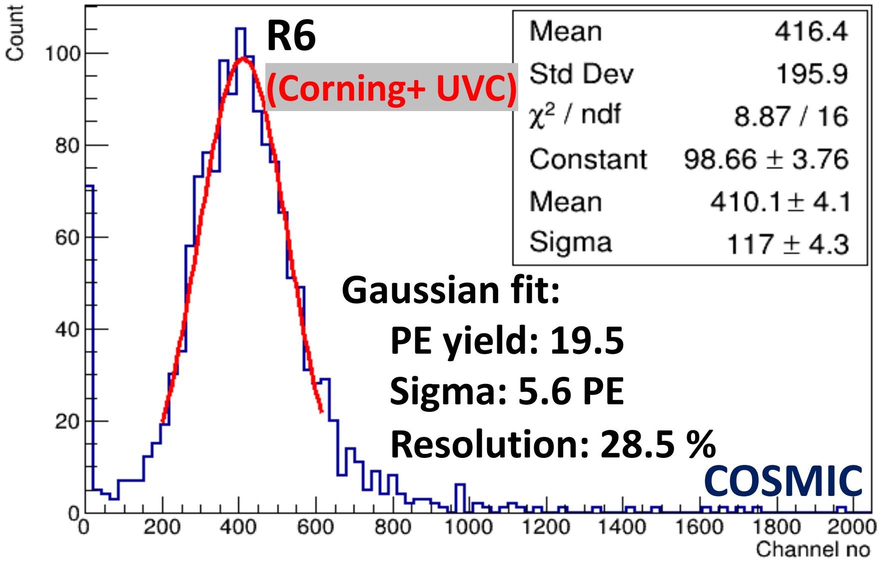
- Mylar gives better results
- However, it is difficult to use Mylar as a light guide material
- Not radiation hard

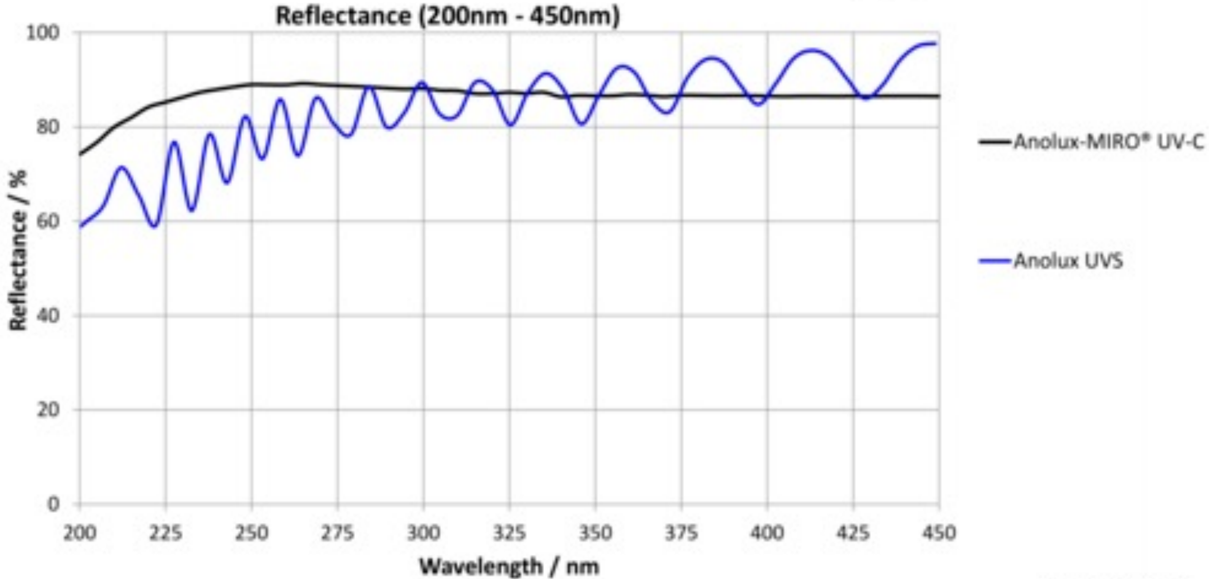
Work by: S. Chatterjee's talk at MOLLER collaboration meeting 2023

R&D of the light guide material for R6





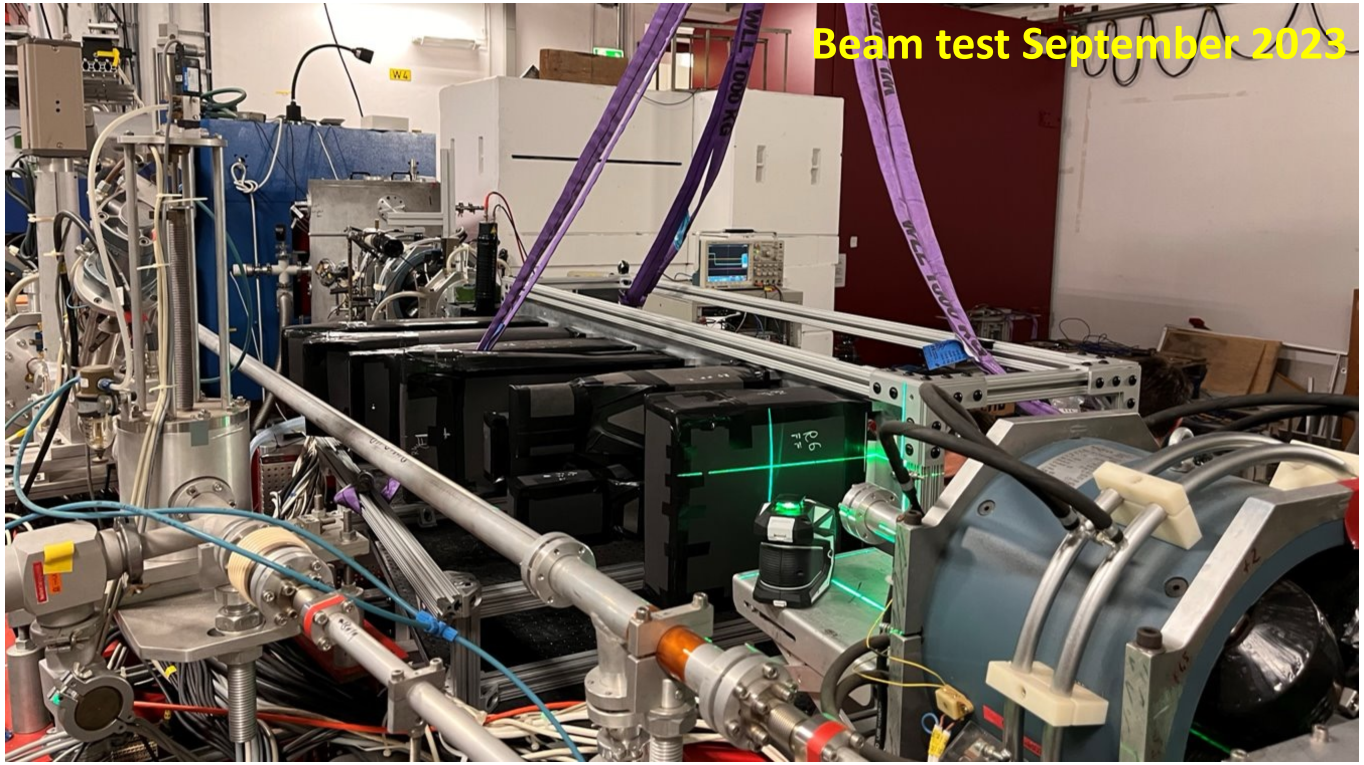




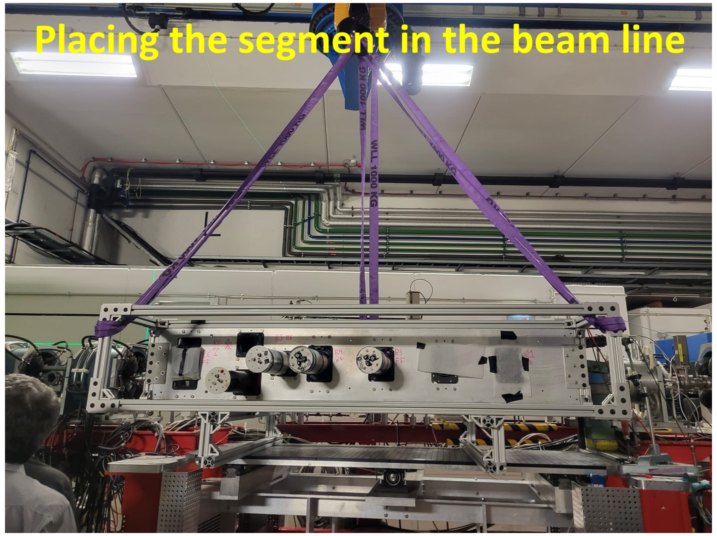
Anolux UVC gives the required performance in terms of the PE yield with Corning tiles

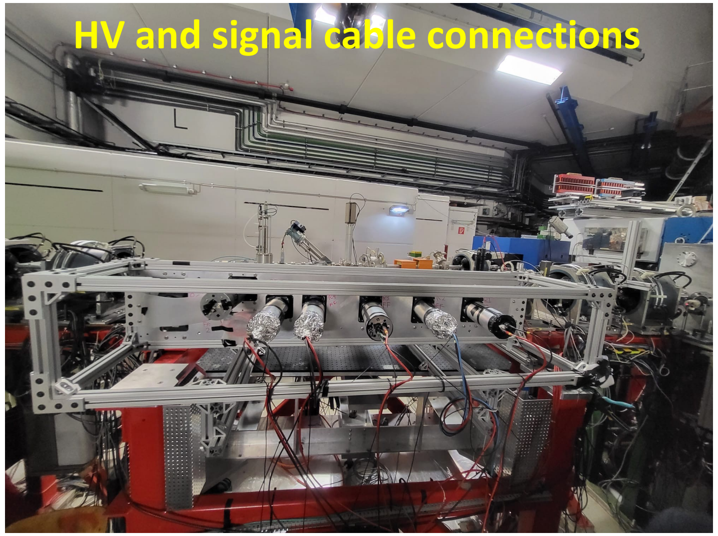
Work by: S. Chatterjee's talk at MOLLER collaboration meeting 2023

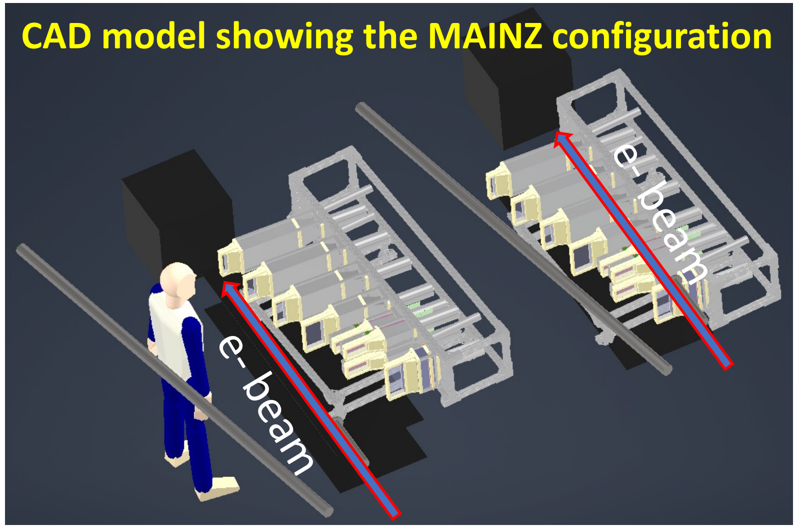
Beam test with full segment: September 2023



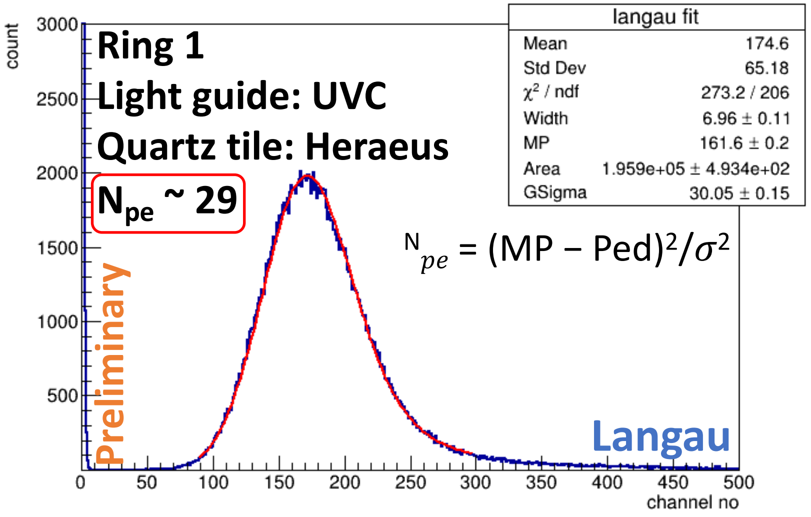
- Entire front flush segment is scanned with electron beam (~ 855 MeV)
- Performance with different quartz tiles and reflective light guide materials are investigated
  - Quartz tiles: Corning & Heraeus
  - Light guide: UVC & UVS
- Detectors are tested in event mode as well as in the integrated mode

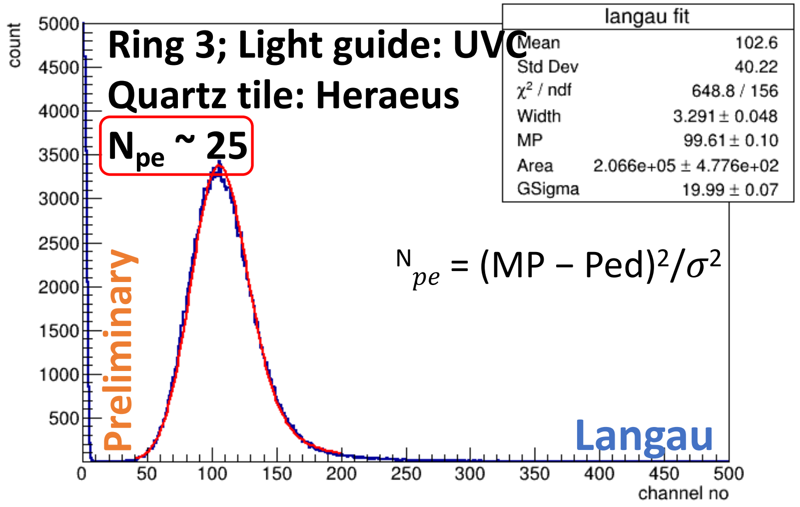


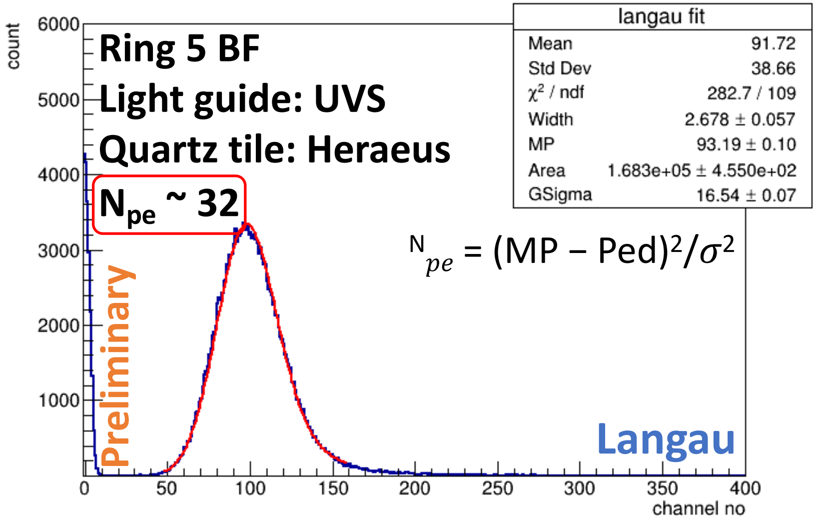




Beam test with full segment: September 2023

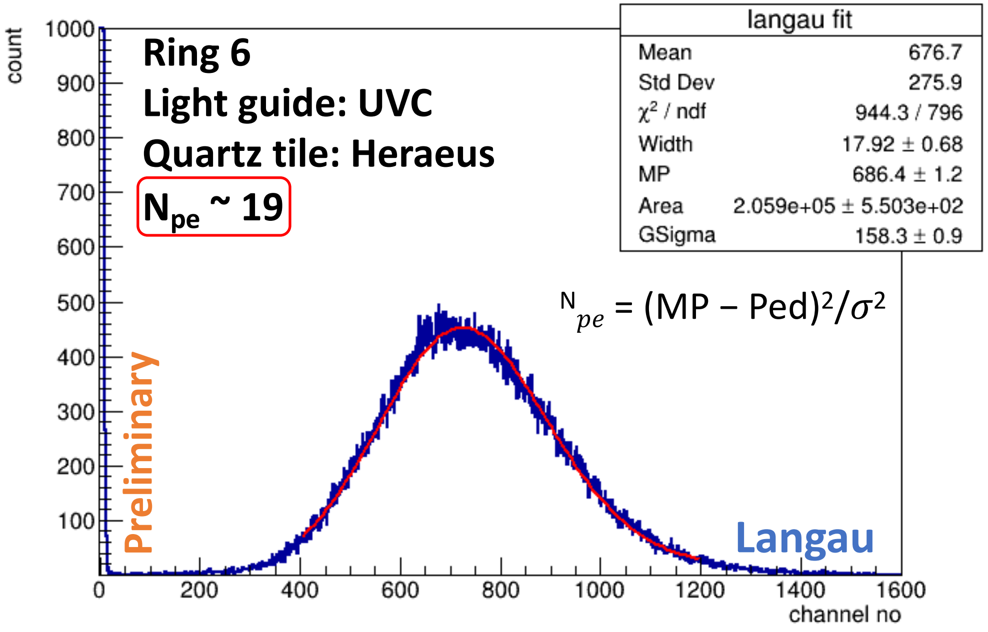






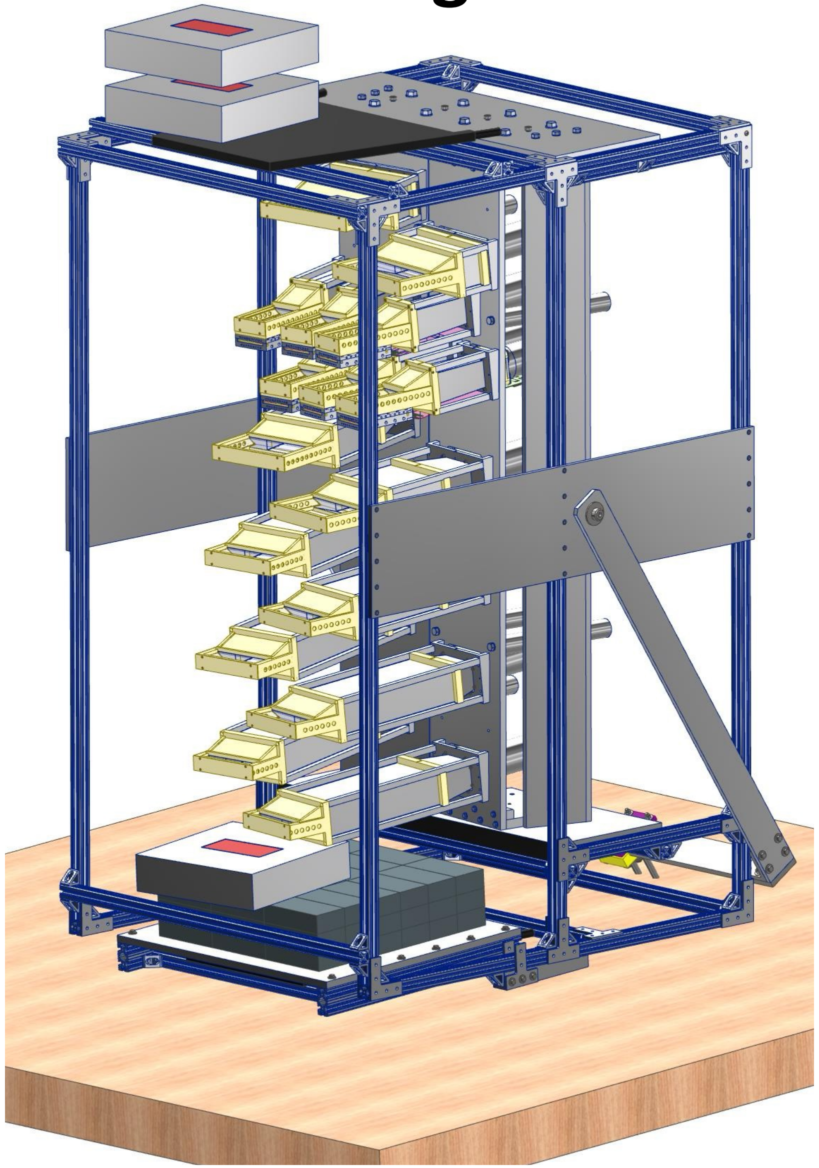
Beam is hitting at the center of the quartz

Detector	Quartz	Light guide	PE yield (N_{pe})	Resolution (%)	RMS/Mean
Ring 1	Heraeus	UVC	~ 29	~ 19	~ 29 %
Ring 2	Heraeus	UVC	~ 26	~ 20	~ 26 %
Ring 3	Heraeus	UVC	~ 25	~ 20	~ 26 %
Ring 4	Heraeus	UVC	~ 21	~ 22	~ 31 %
Ring 5 (BF)	Heraeus	UVS	~ 32	~ 18	~ 24 %
Ring 5 (FF)	Heraeus	UVS	~ 31	~ 18	~ 26 %
Ring 6	Heraeus	UVC	~ 19	~ 23	~ 26 %

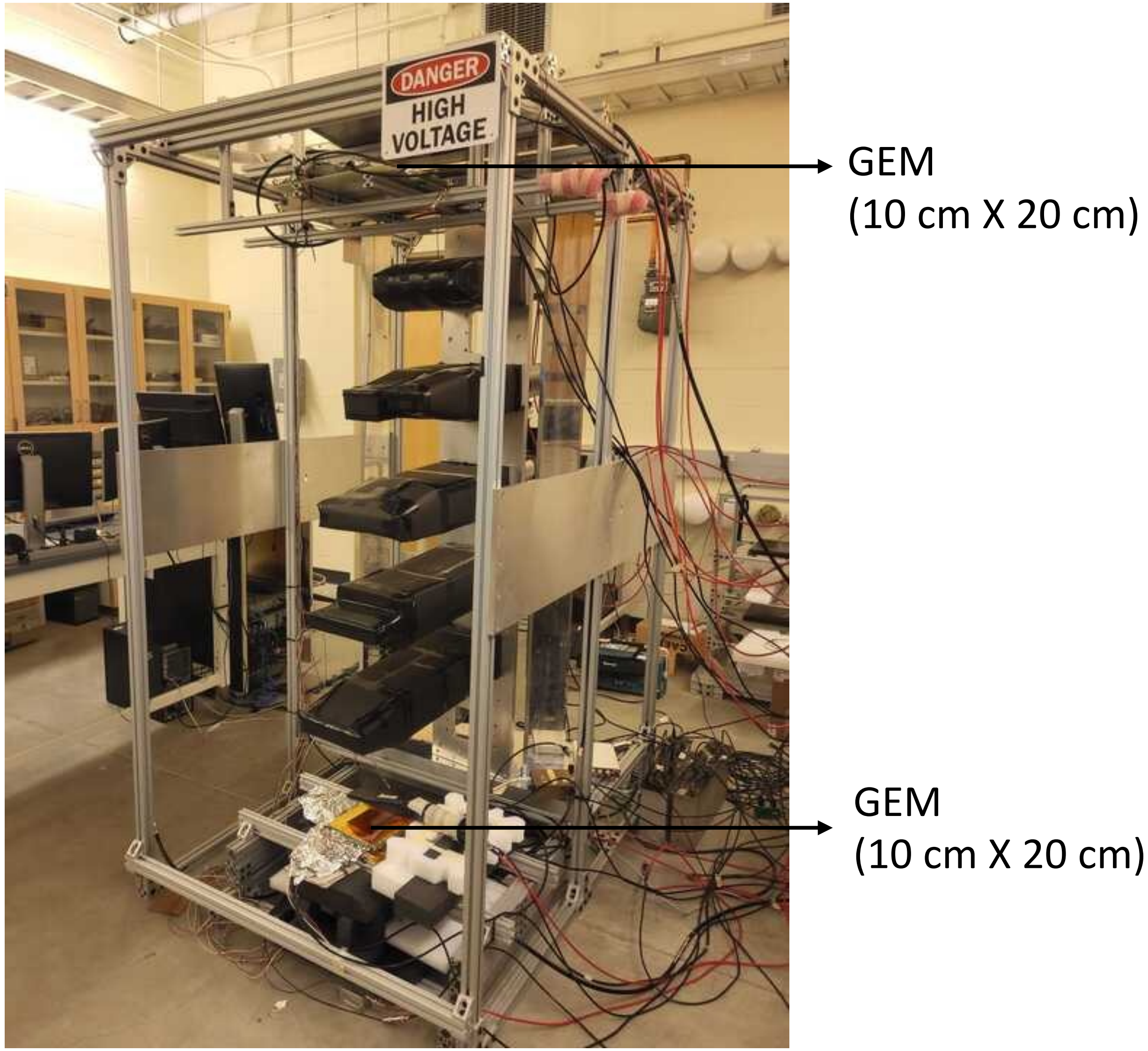


RMS/Mean is ~ 30 %

Cosmic test with full segment



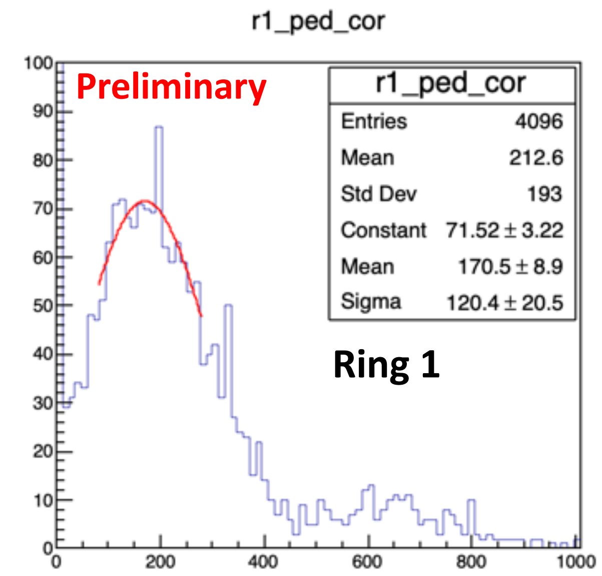
CAD model

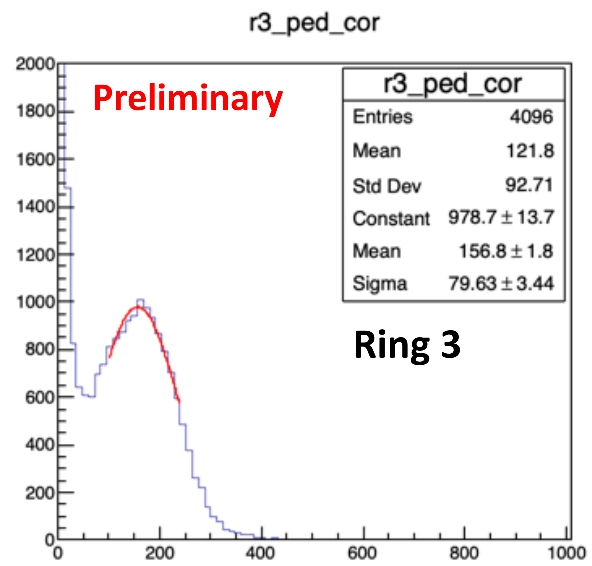


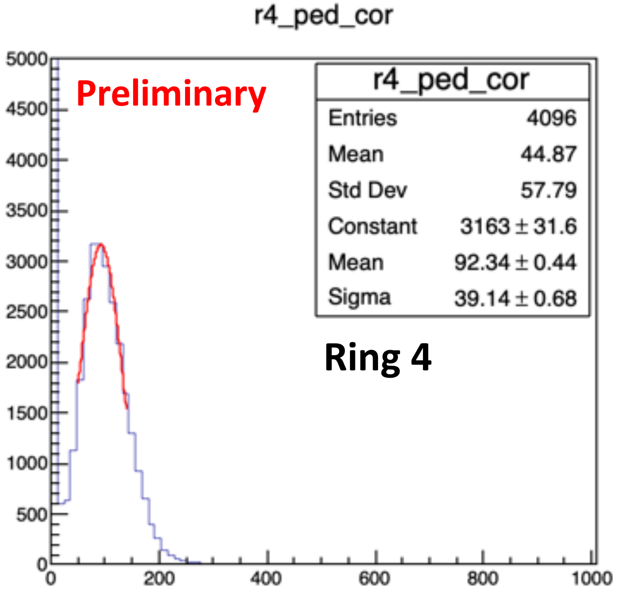
Setup at UMass

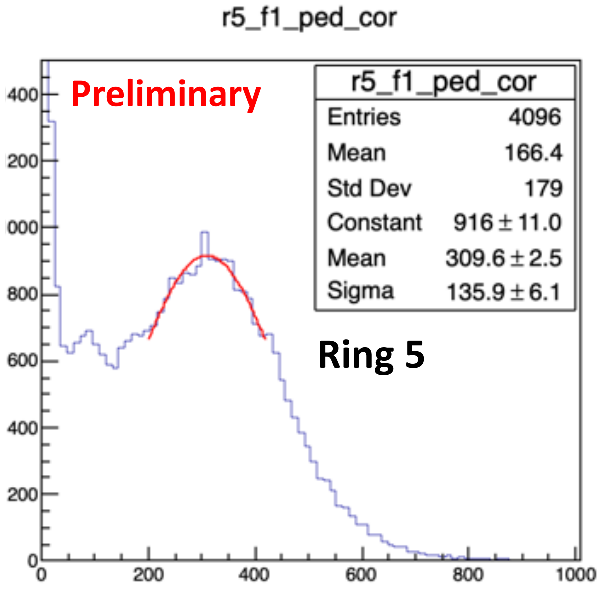
Work is ongoing to benchmark the performance of the full segment with cosmic muons

Preliminary data with cosmic muon stand

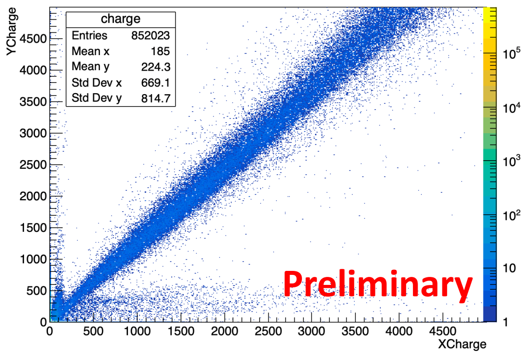


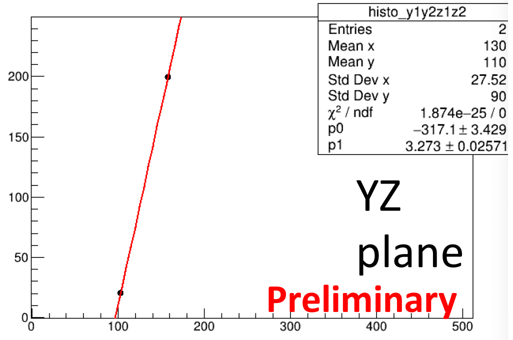


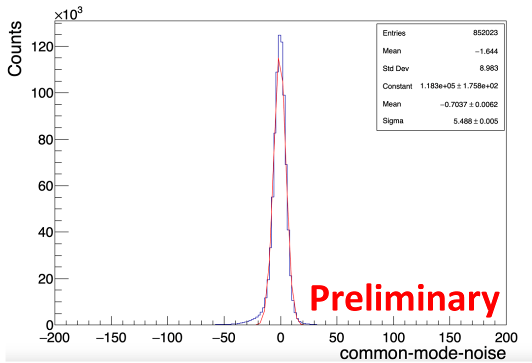


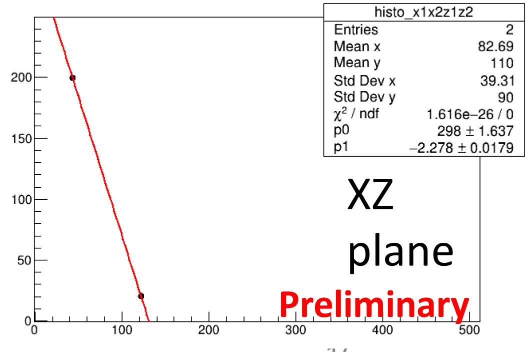


- Benchmarking the performance of the rings at the beam with the cosmic muons
- Cosmic muon tracking using triple Gas Electron Multiplier (GEM) detector for studying the effect of inclined tracks on the performance of the Cherenkov detectors
- Data taking and preliminary data analysis is ongoing









Status of main integrating detector

The detector tiling is nearly (~98%) finalized:

- The tiles are positioned and sized in accordance with the deconvolution/error and physical requirement

Module structure:

- Materials testing is progressing (radiation hardness and humidity)
- Ring 1 through 6 modules were constructed & tested at MAMI
- PMT housing redesign nearly finished (95%)
- Module cooling and air flushing simulations nearly completed
- Mounting structure is nearly final & Cabling planning in progress

Front-end electronics

- Voltage divider design is complete – switching between event mode and integration mode included
- Event mode amplifier is undergoing small redesign to address high frequency noise
- Integration mode amplifier is undergoing DC/DC converter redesign to address radiation hardness concerns and improve power supply needs

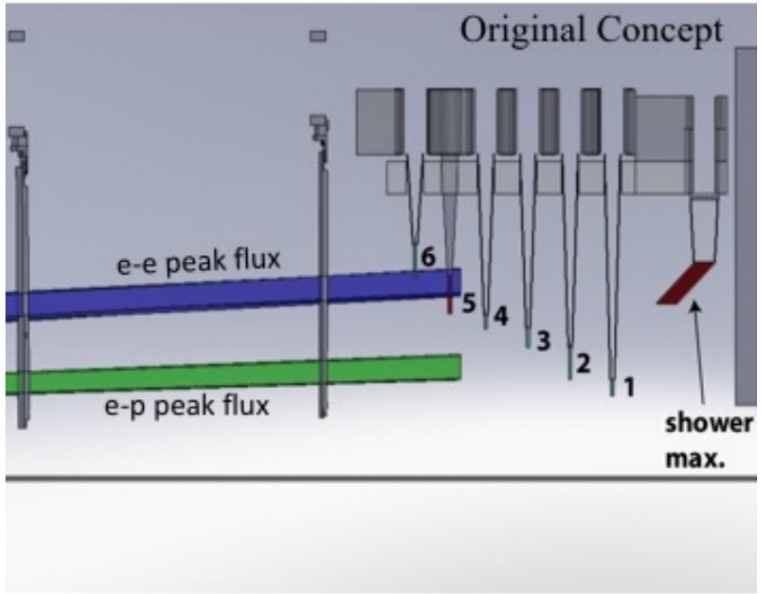
ADC board progress

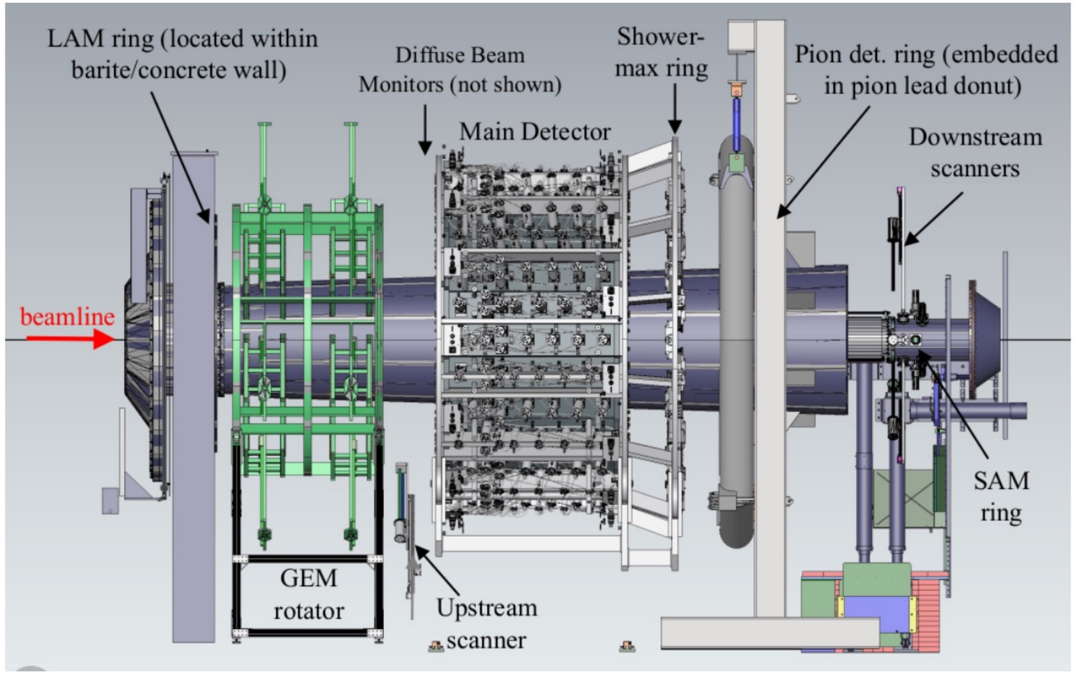
- The ADC board is fully functional with Firmware running to take streaming data (firmware for helicity averages exists but is not currently read out)

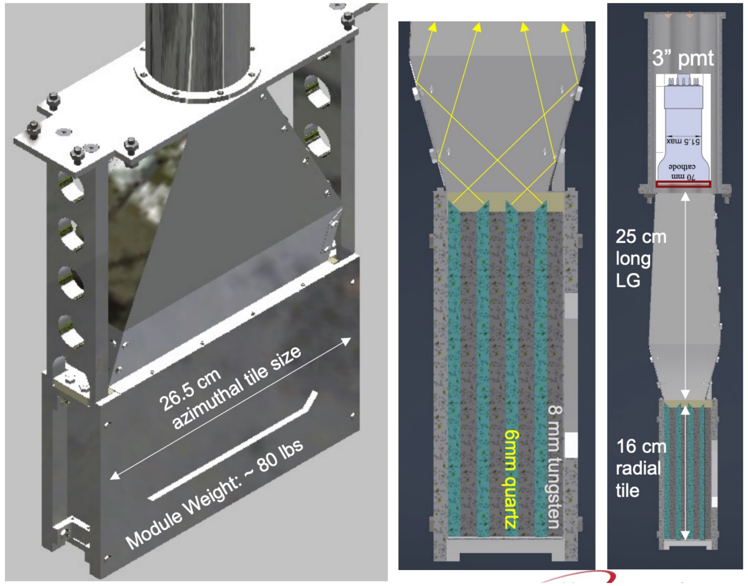
The QA planning for the detector sub-systems, mounting structures, PMTs and electronics is currently ongoing

Work by: M. Gericke's talk at MOLLER collaboration meeting 2023

Shower-max







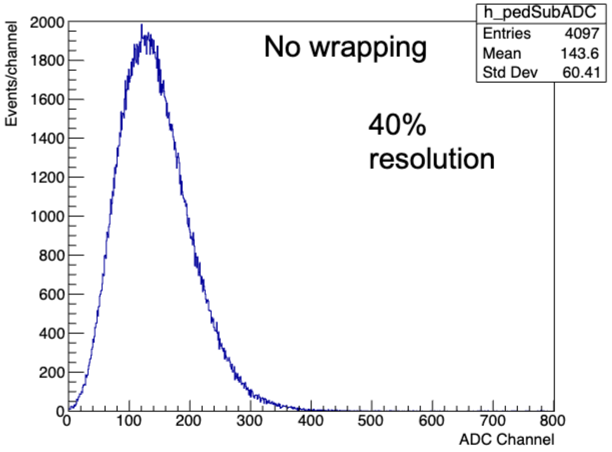
Design of the shower-max module

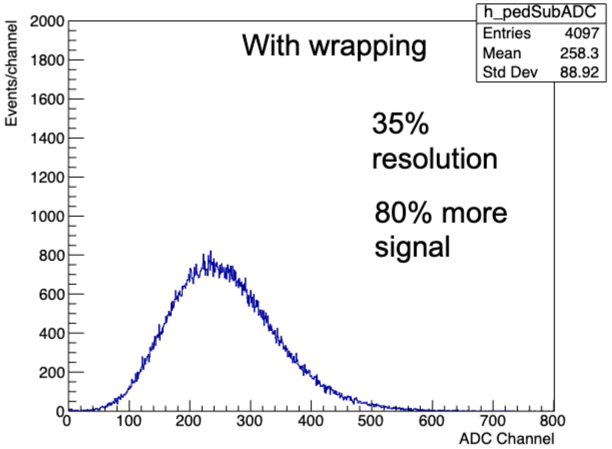
- Shower-max is an electromagnetic sampling calorimeter (Radiation length ~ 9.5 X_0, Molière radius ~ 1.1 cm)
- 28 shower-max modules is intercepting physics signal flux at ~1.7 m downstream of ring 5
- Designed and positioned to provide additional measurement of Ring5 integrated flux (MOLLER APV)
- Weights flux by energy $\Longrightarrow$ less sensitive to soft and hadronic backgrounds
- Designed to have $\lesssim$ 25% resolution over full energy range and constructed with radiation hard components

Work by: D. McNulty's talk at MOLLER collaboration meeting 2023

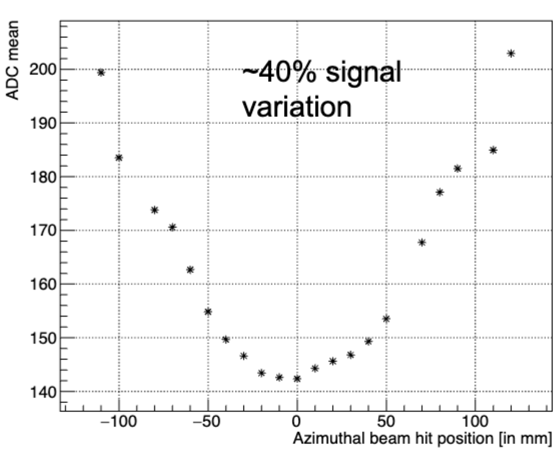
R&D of Shower-max prototypes

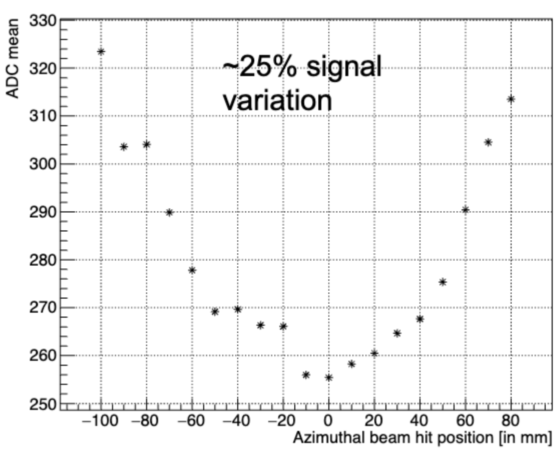
Pulse height Dists



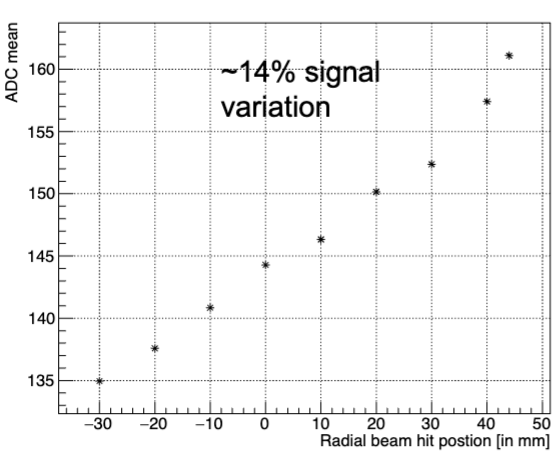


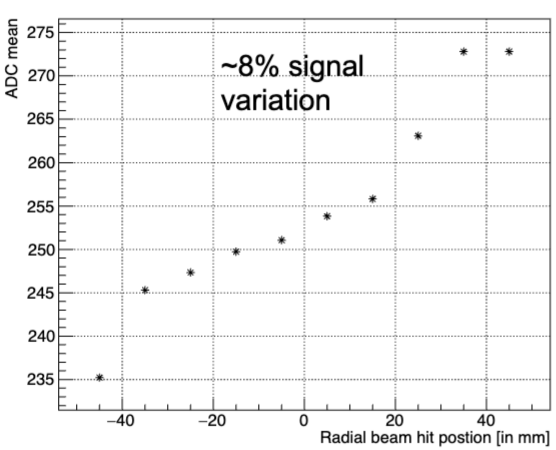
Azimuthal Scans

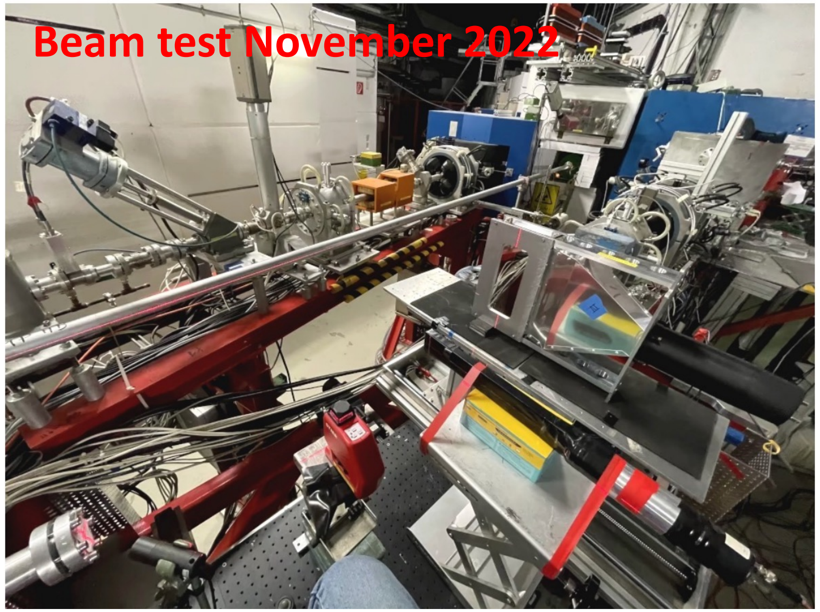




Radial Scans





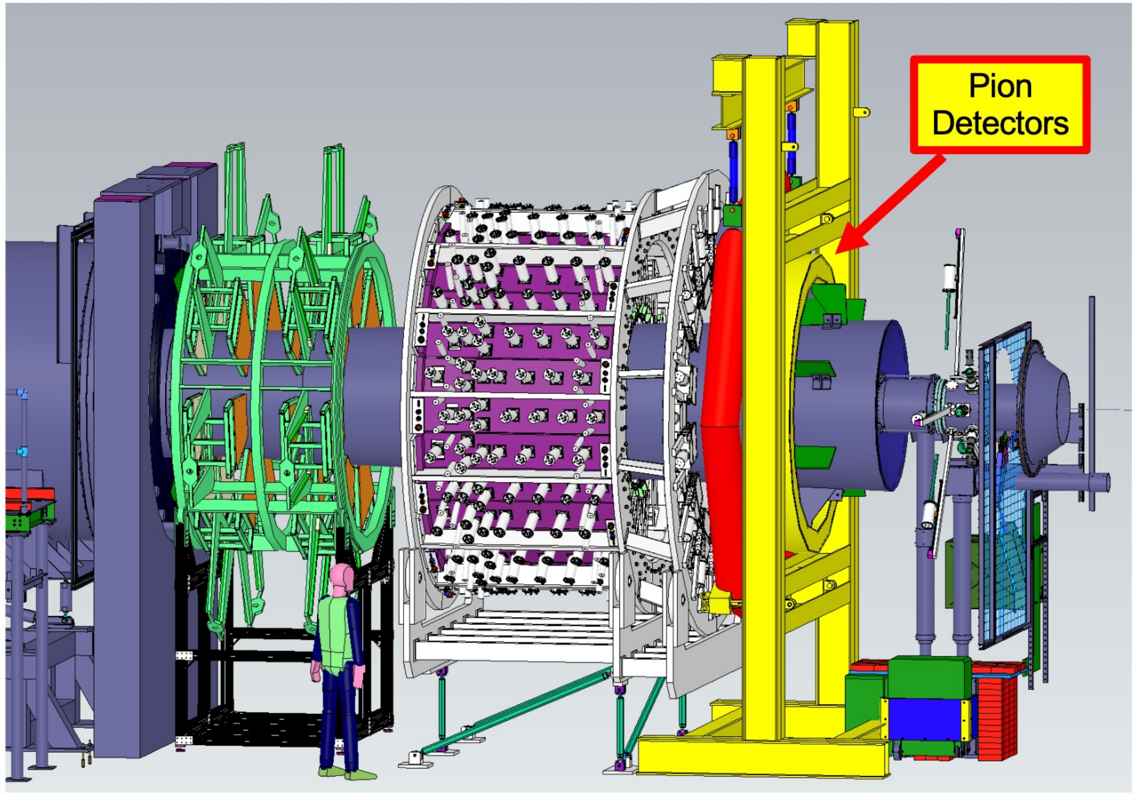


- Shower-max prototype is tested at MAMI with electron beam (~ 855 MeV)
- Azimuthal and radial position scan with bare and aluminized-mylar wrapped quartz configurations
- Healthy pulse height distribution is observed

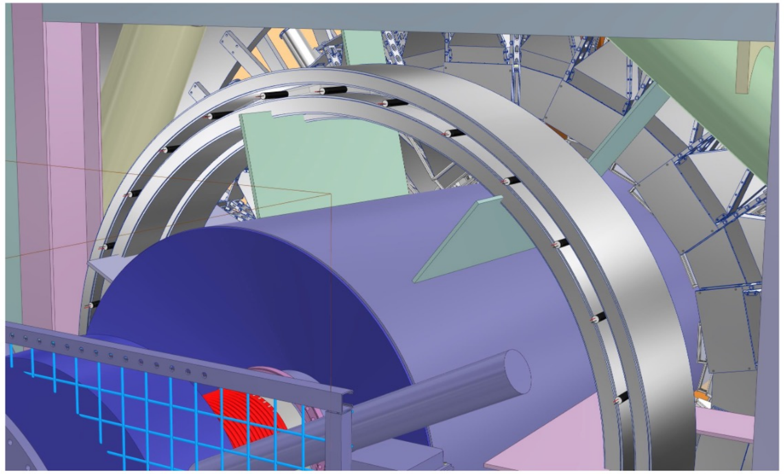
- **Pre-production prototype has been tested in Sep 2023 at MAMI. Preliminary analysis shows expected performance**
- **Preparing for placing the large orders for the final productions**

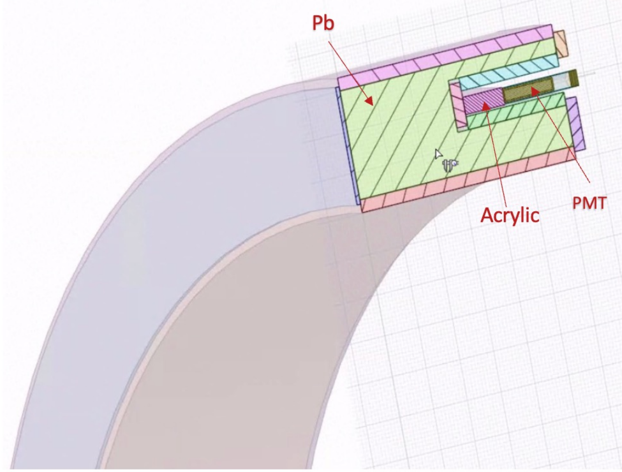
Work by: D. McNulty's talk at MOLLER collaboration meeting 2023

Pion detector



- Modular system of acrylic Cherenkov detectors covering full azimuth
- Samples Ring 5 & Shower-max acceptance
- Downstream of Main Detectors, Shower-max Detectors
- 20 cm thick Pb "donut" to range out Moller electrons
- Asymmetry measurement in integrating-mode
- Pion flux determination in counting mode data-taking

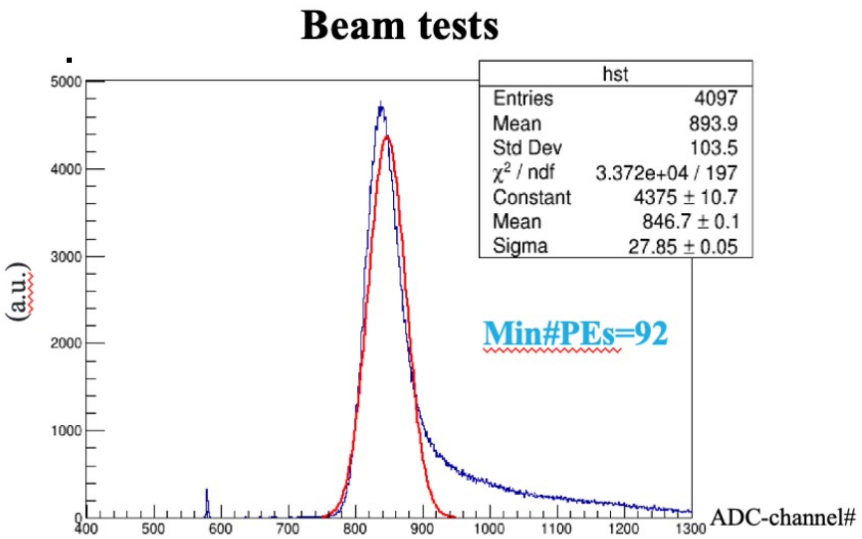


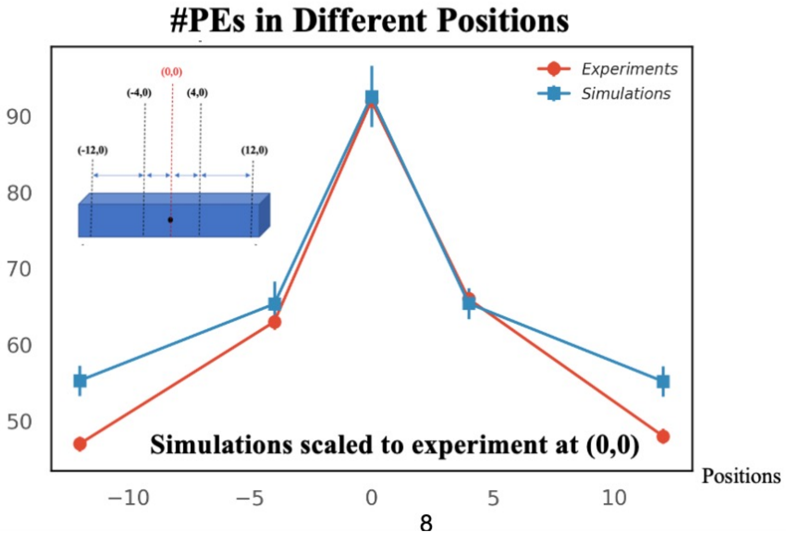


- 45 X_0 in direction of scattered Moller electrons (9.5 X_0 from Shower-max, 35.5 X_0 from Pb donut)
- π/e ratio of photoelectrons in pion detector: design goal: > 50%
- σ/peak < 25 % , so detector response doesn't broaden asymmetry width

Work by: D. Armstrong's talk at MOLLER collaboration meeting 2023

Pion detector prototype testing at MAMI

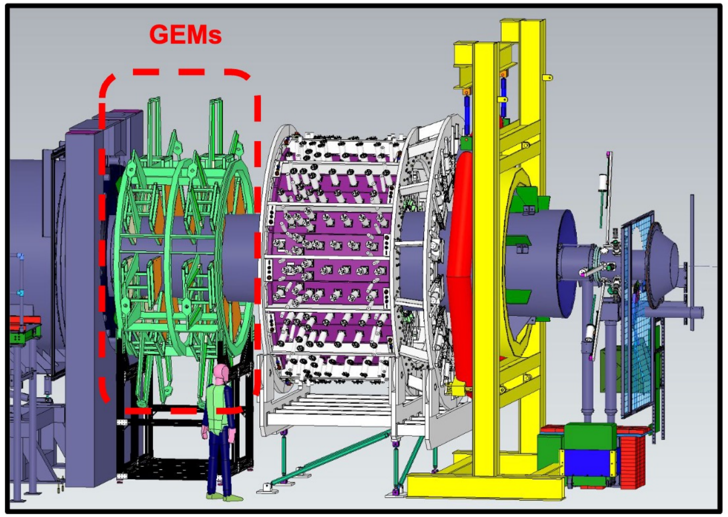


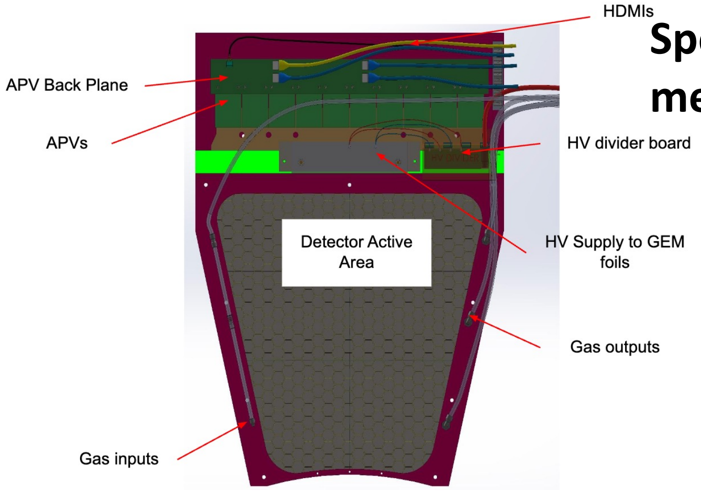


- 28 identical pion detectors with same modularity and azimuthal locations as the shower-max will be used
- Good agreement between beam and simulated data
- Work is ongoing for improving the pion flux determination
- Machine learning based approach is being investigated to improve the pion identification
- Work is ongoing for finalizing the mechanical design

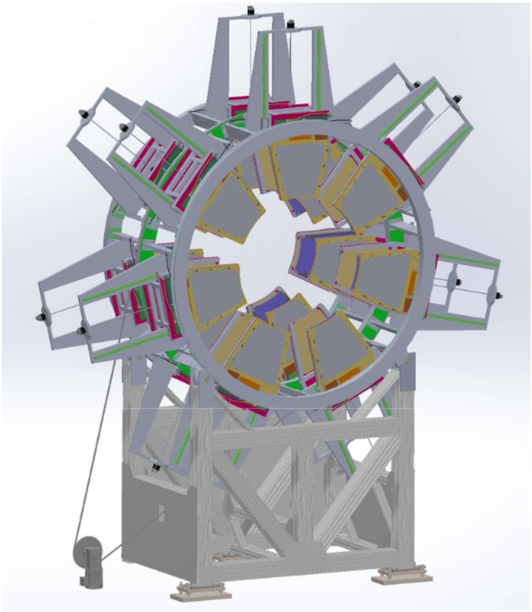
Work by: D. Armstrong's talk at MOLLER collaboration meeting 2023

Gas Electron Multipliers

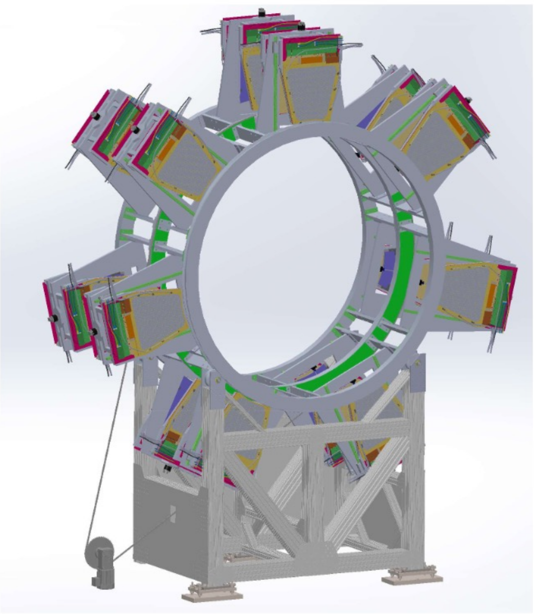




Measurement position



Parked position

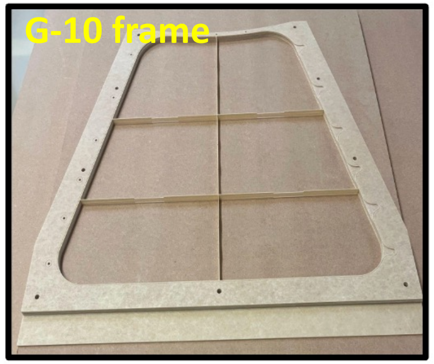


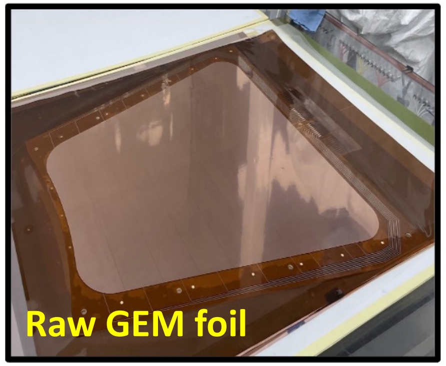
GEMs will be Used only during the calibration runs for Spectrometer calibration, Kinematics and background measurements

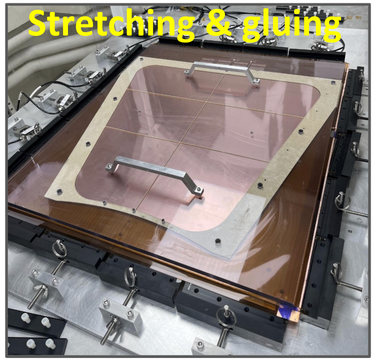
- Trapezoidal shaped
- Active area of each module ~2000 cm^2
- Can hold rates more than 400 kHz/cm^2 (expected experiment flux less than 200 kHz/cm^2)
- 26.5-degree Readout stereo angle
- ~1280 channels per module
- High position resolution (required resolution ~ 0.5 mm)
- 4 GEM tracking layers, 7 trapezoidal shaped GEMs at each layer
- Only ~50% azimuthal coverage
- 3 rotations to cover the full azimuthal
- Pulled out during production runs (as shown in the bottom right picture)

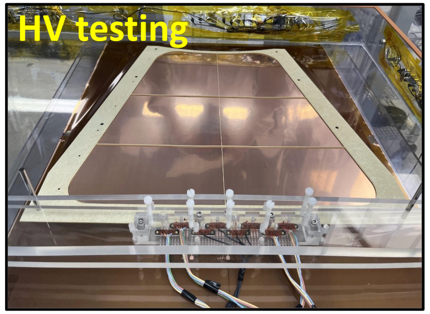
Work by: B. Dharmasena's talk at MOLLER collaboration meeting 2023

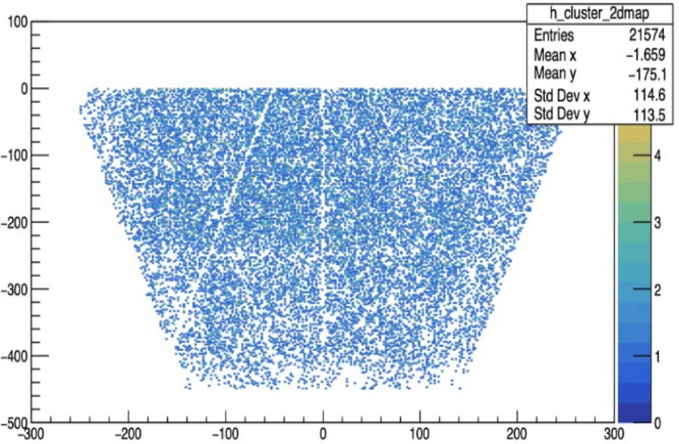
GEM construction and testing



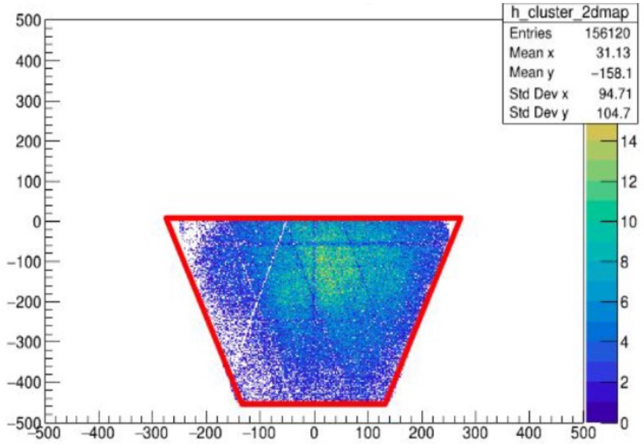






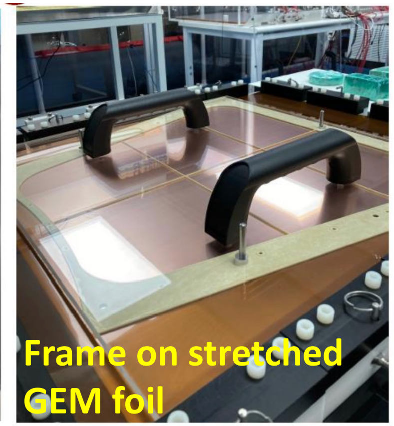


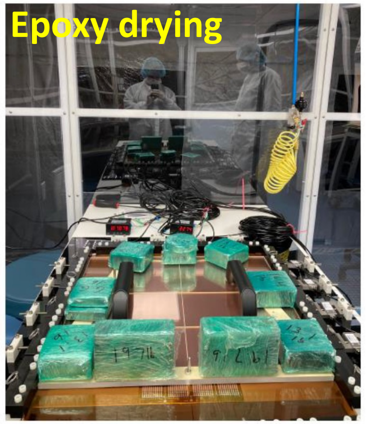
Cosmic data 2D cluster map

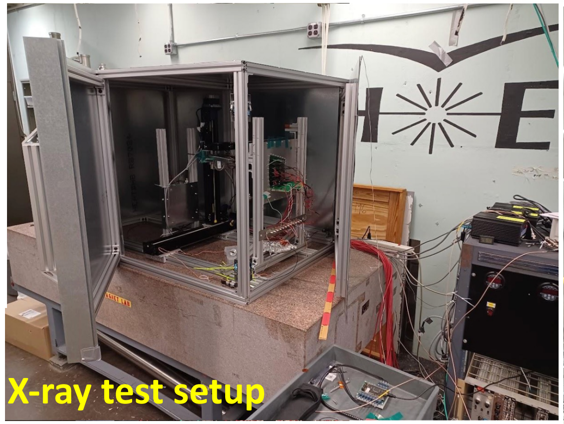


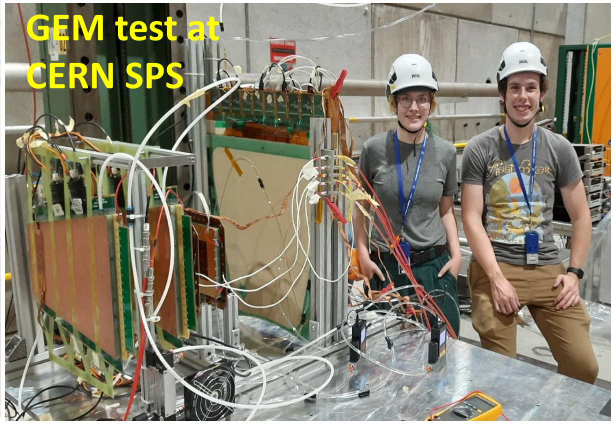
Overlapped X-Ray data 2D cluster map

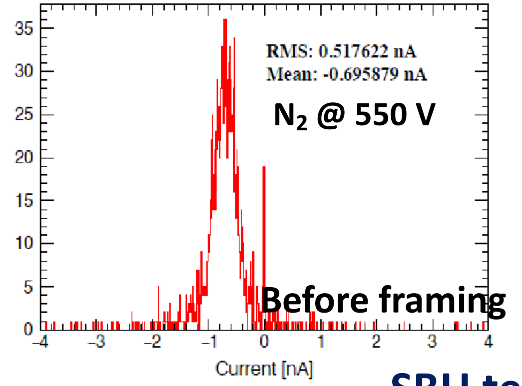
UVa test setup

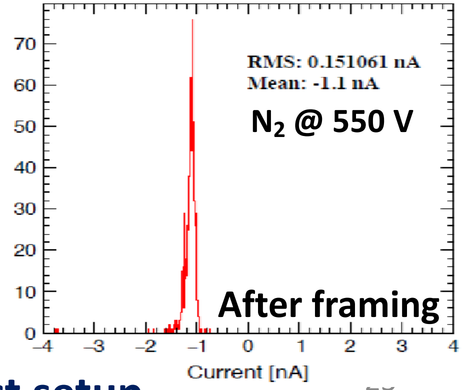








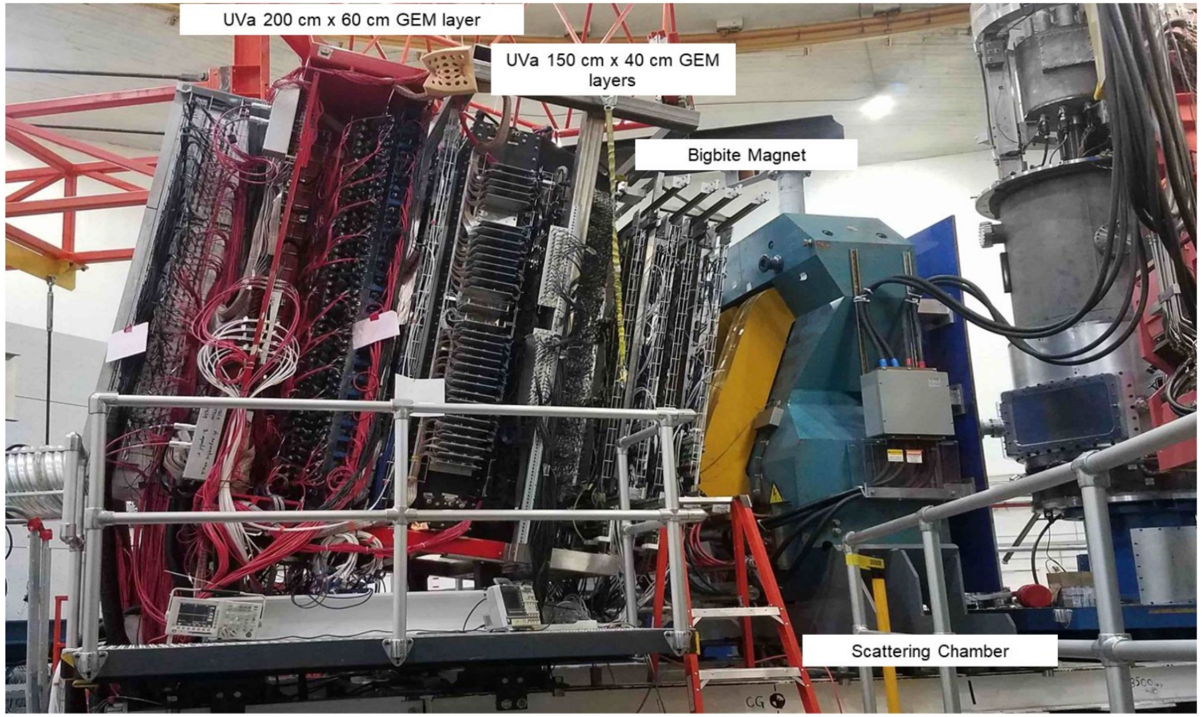


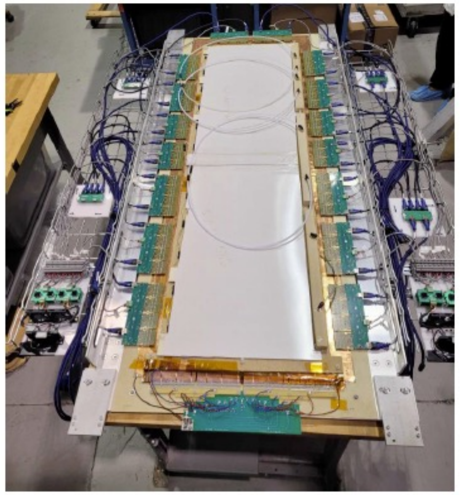


SBU test setup

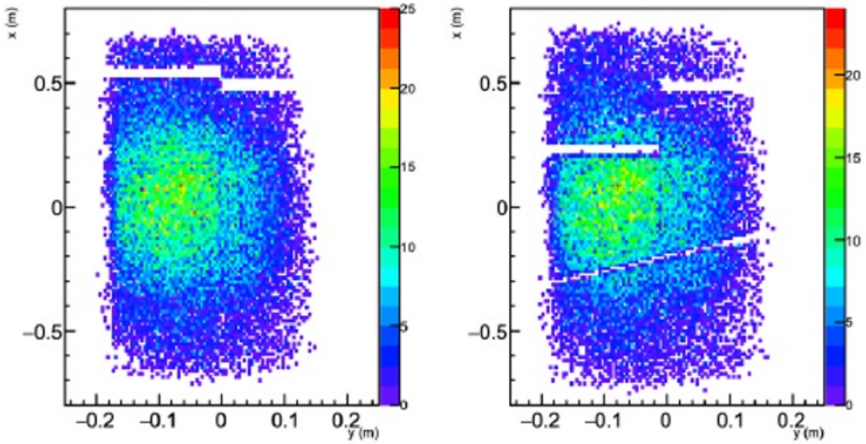
Work by: C. Annasiwatta's & K. Dehmelt's talk at MOLLER collaboration meeting 2023

GEM experience & status





UV module
(40 X 150 sq. cm)



Hit map of the UV layers

- UVa GEM tracker layers at SBS have been working very well:
  - Stable operation and robust under harsh conditions
  - No radiation damage observed
  - No detector aging effects observed
  - Noise levels sufficiently low
  - Good gain: signals well above noise
  - Very good resolution: ~ 70 um for tracks perpendicular to detector
  - Data volumes manageable
- The current drain to detector is too high for the resistive voltage dividers to handle; caused efficiency drop
- The Good solution with new power supply scheme: tested and demonstrated to work

Experience with SBS gives us great confidence to use similar type of Gems at MOLLER.

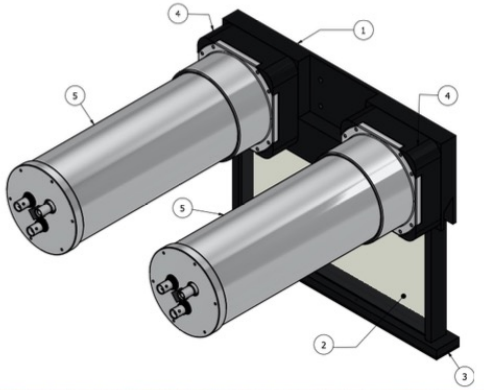
Work is ongoing to finalize the production design and placing the order

Work by: Nilanga Liyanage

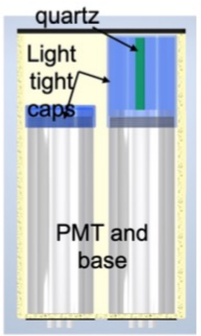
Scattered Beam Monitor Detectors

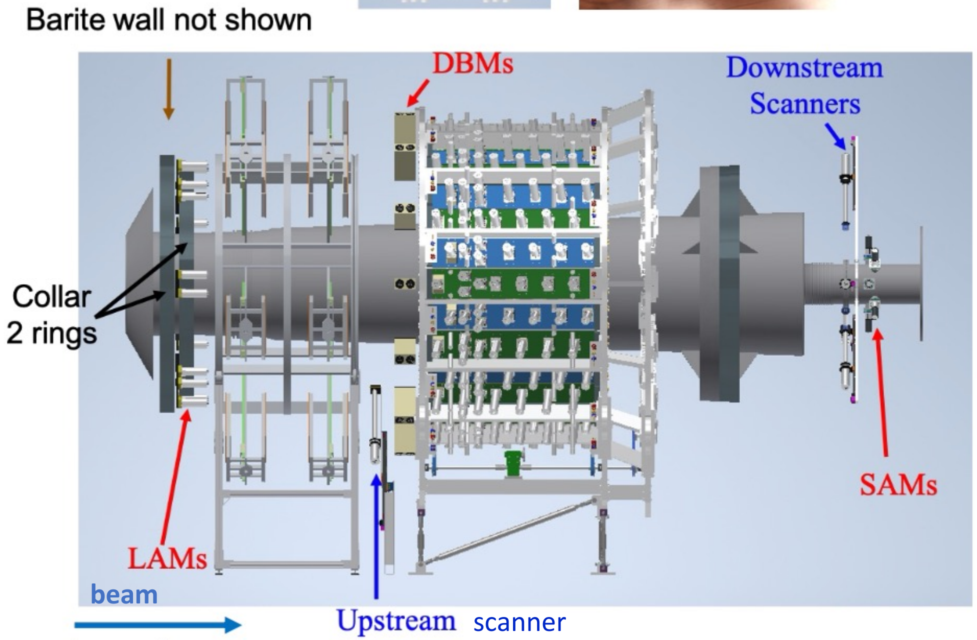
- Monitor potential false asymmetries in reducible background
  - Primary scattered beam interacting in downstream collimators, beampipes, and shielding
- Locate in regions of high flux/small physics asymmetry and where flux from primary target is small

LAM (large angle monitor) detectors: 25 x 16.5 x 1 cm^3 quartz radiator read out by two 3 inch PMTs

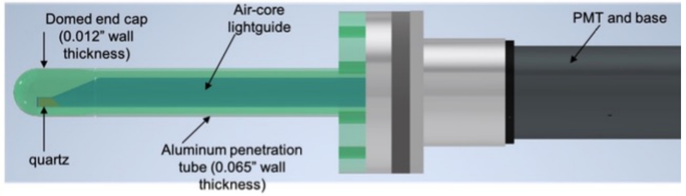


DBM (diffuse beam monitor) detectors: Bare PMT and PMT + quartz





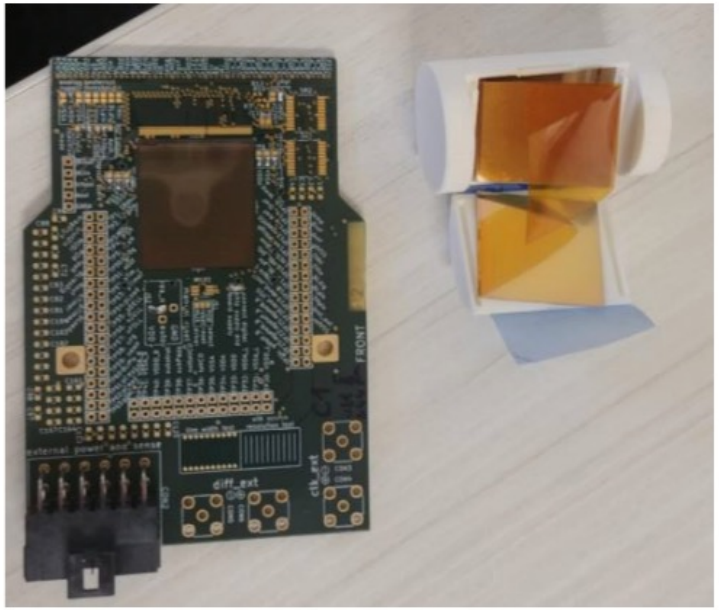
SAM (small angle monitor) detectors: Small quartz block, air-core light guide, 2 inch PMT detecting at small (0.1^o) lab scattering angle

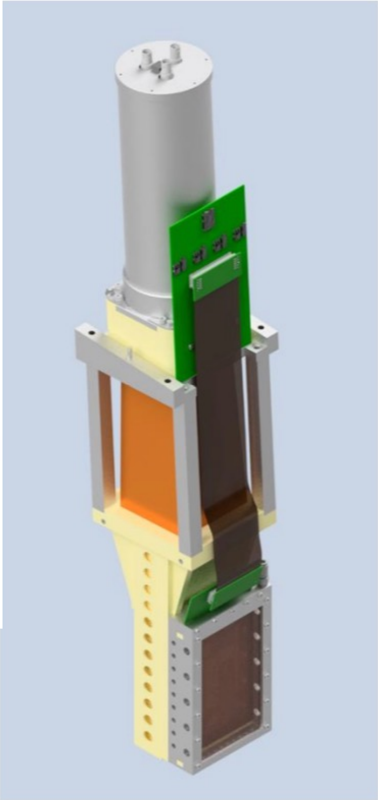


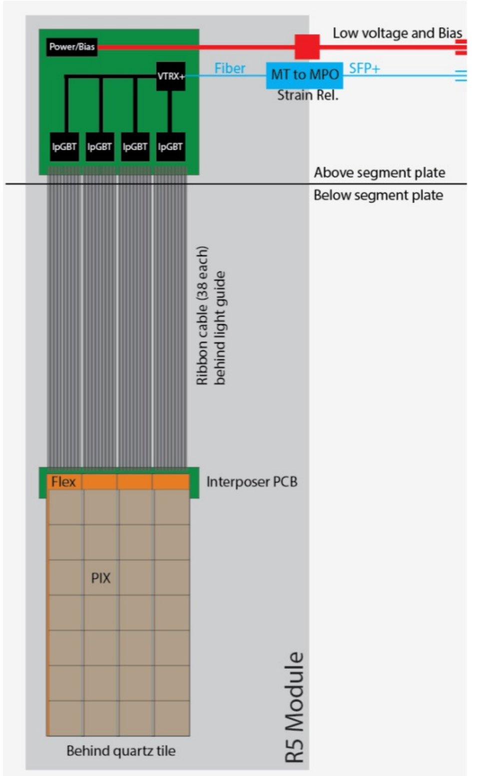
Work by: M. Pitt's talk at MOLLER CD-2/3 Independent Project Review

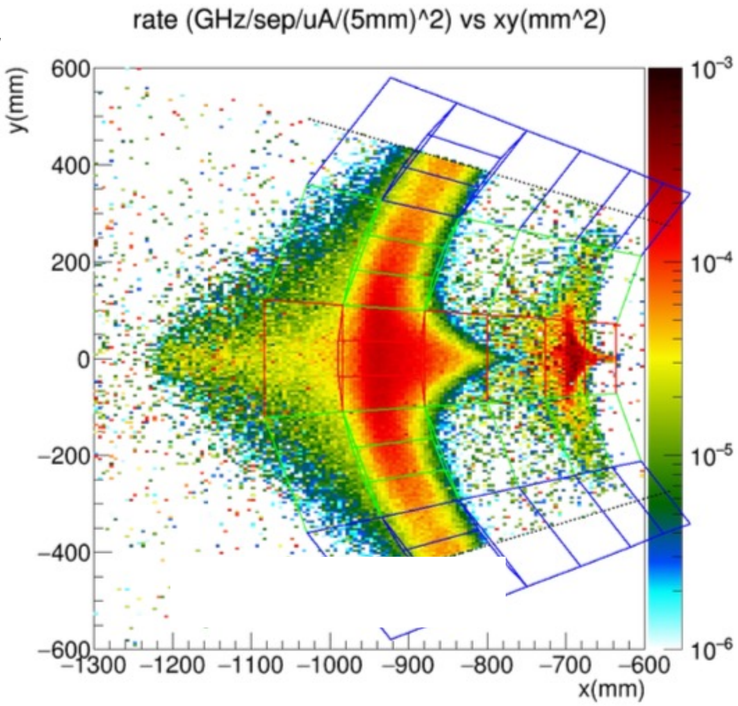
HVMAPS

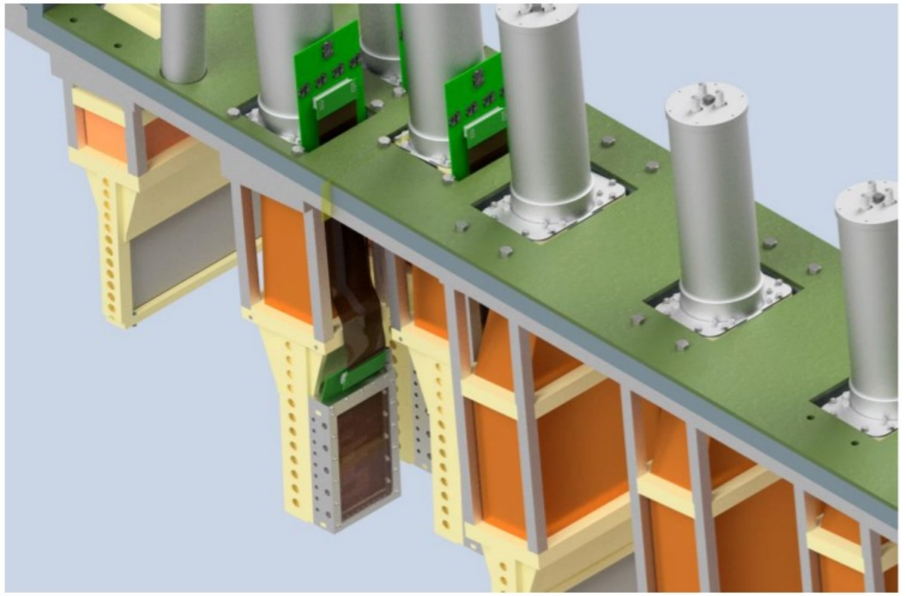
- Motivation: Monitor the spatial flux profile in Ring 5 (Møller ring) up to production beam currents
- Technology: HVMAPS - high voltage monolithic active pixel sensors
- The 84 ring-5 main detectors will each be equipped with an array of 28 (2x2 cm^2) HVMAPS pixel chips
- Can be mounted independently of the quartz tray R5 module
- HVMAPS is designed for small material budget and to facilitate cooling with chilled air
- Will measure the main Møller flux spatial profile at any beam current (counting mode or production integration mode beam currents)





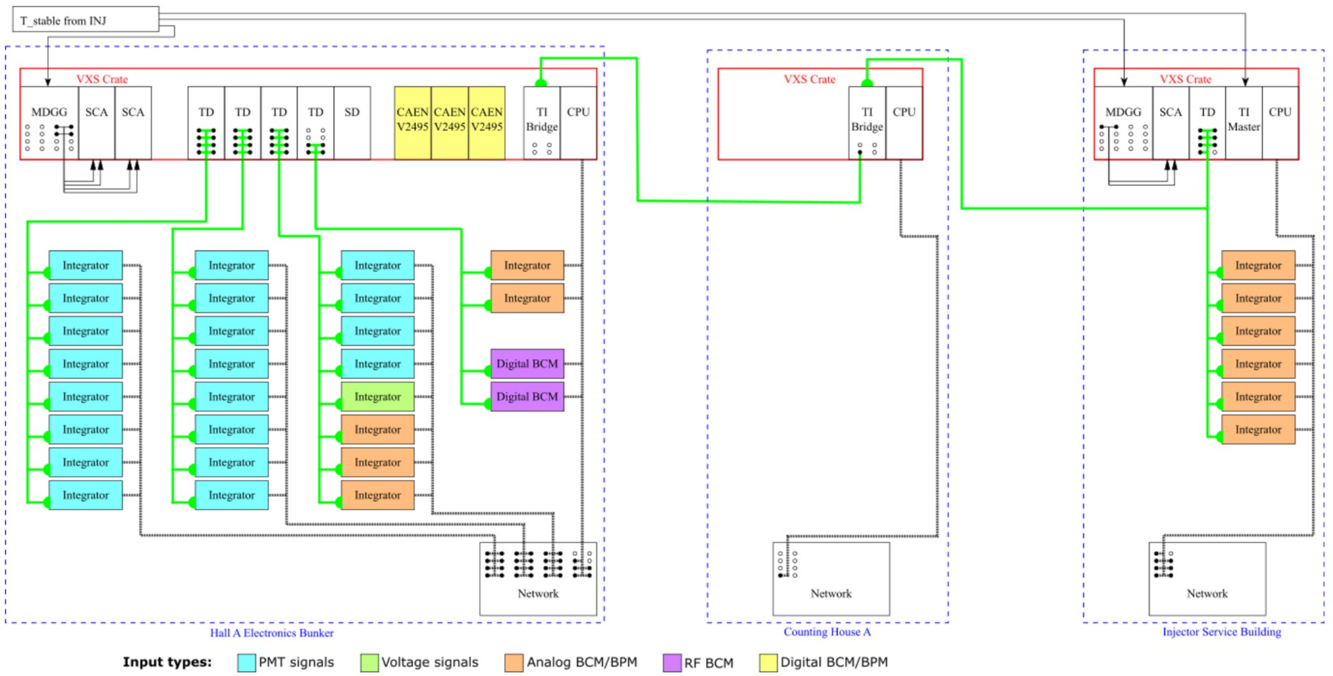




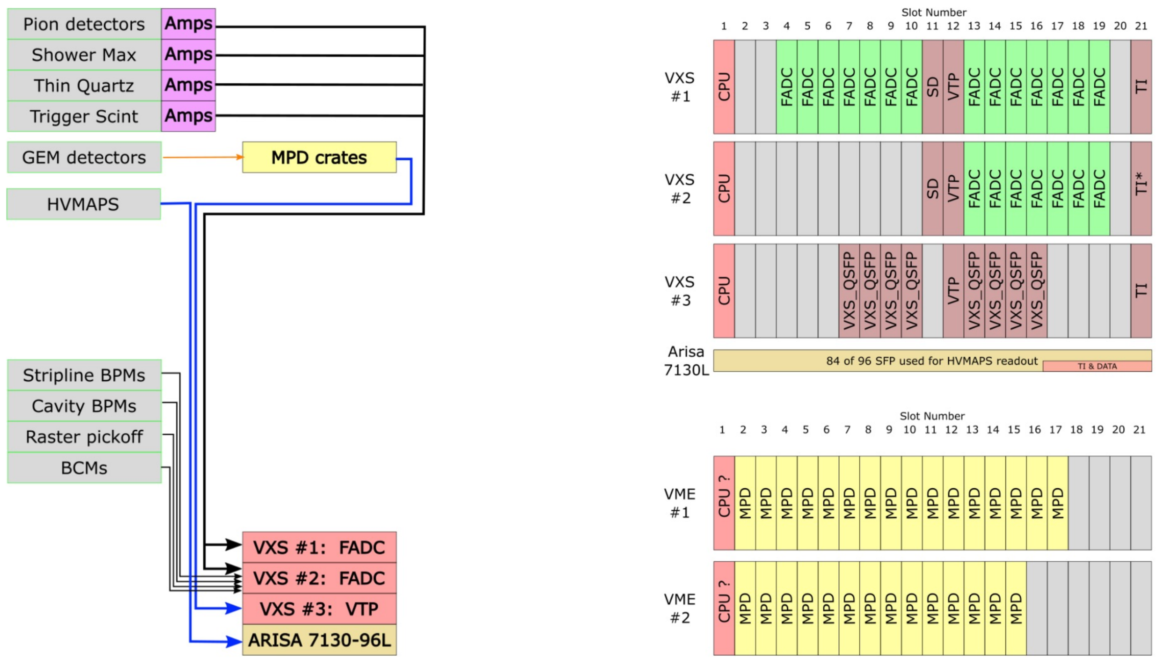


Work by: M. Gericke's talk at MOLLER CD-2/3 Independent Project Review

Data acquisition system



Integrating DAQ overview



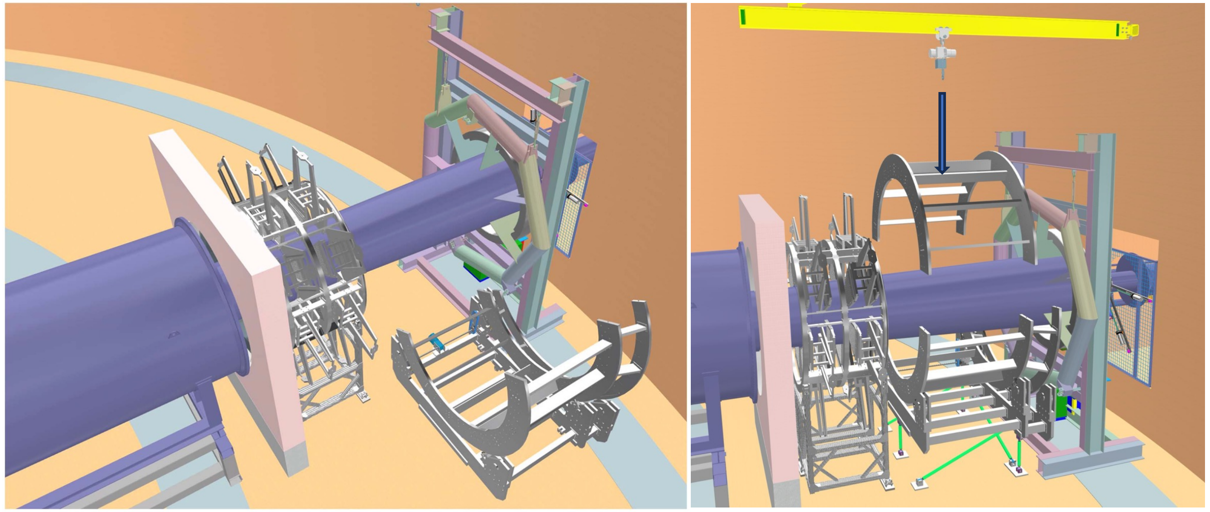
Counting DAQ overview

Integrating ADC module prototype

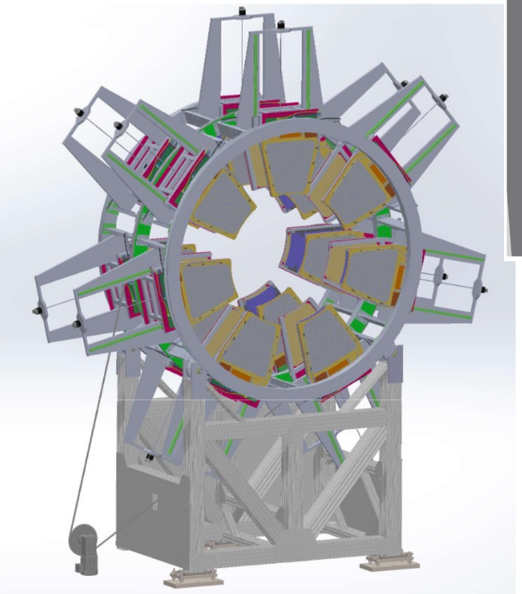
- **Integrating ADC prototype has been tested with beam at Mainz**
- **MPD based readout systems (like SBS) will be used for GEMs**
- **Work is ongoing on the FPGA firmware to optimize the DAQ system**
- **Mock data structure is under development to optimize the data analysis algorithm**

Work by: P. King's talk at MOLLER collaboration meeting 2023

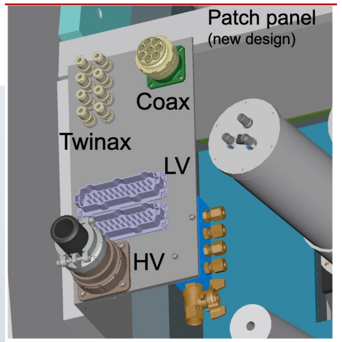
Detector mechanics

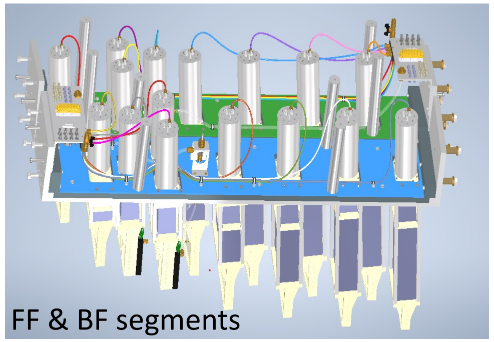


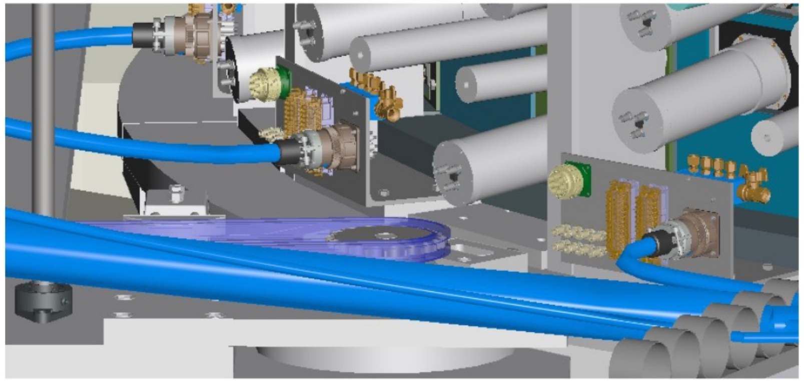
Installing the ring support structure under the beam pipe



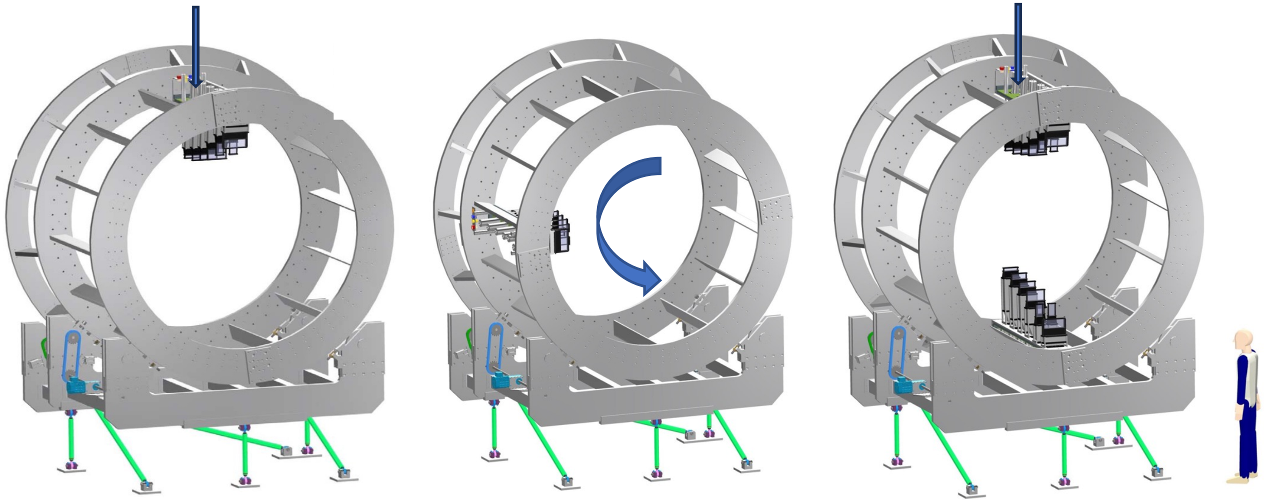
GEM rotator design







Patch panel connections for main integrating detector array



Installing the segments in the support structure

- Detailed design and analysis of the Main detector and Shower-max overall assembly is completed
- Installation process for the individual detector sub-systems is thought through
- Cable management scheme and personnel access scheme are being developed currently

Collaboration with Bartoszek Engineering

Work by: L. Bartoszek’s talk at MOLLER collaboration meeting 2023

Summary

- **Design and critical detector prototyping for integrating and counting mode detectors is complete**
- **On track to proceed to procurement and fabrication stage**

Team members

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- Brynne Blakie (U. Manitoba)
- Sayak Chatterjee (U. Massachusetts)
- Sakib Sarker (U. Massachusetts)
- Wouter Deconinck (U. Manitoba)
- Cyprian Gal (Jefferson Lab)
- Michael Gericke (U. Manitoba)
- Chandan Ghosh (JLab)
- Kristofer Isaak (U. Manitoba)
- Rahima Krini (JGU, Mainz)
- Krishna Kumar (U. Massachusetts)
- Savino Longo (U. Manitoba)
- Dustin McNulty (Idaho State U.)
- Justin Gahley (Idaho State U.)
- Juliette Mammei (U. Manitoba)
- Laheji Mohammad (U. Manitoba)
- Liyanage Nilanga (UVa)
- Jonathan Mott (U. Massachusetts)
- Nafis Niloy (U. Manitoba)
- Jie Pan (U. Manitoba)
- Sakib Rahman (U. Manitoba)
- Nazanin Roshanshah (U. Manitoba)
- Paul Souder (Syracuse)
- Noel Alberto Cruz Venegas (U. Manitoba)
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- Sudip Bhattarai (Idaho State U.)
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- Elena Goldflower (Idaho State U.)
- Katherine Burke (Idaho State U.)
- Edwin Sosa (Idaho State U.)
- Freddy Kouakou (Idaho State U.)
- Coltyn Fisher (Idaho State U.)
- Mitchell Frasure (Idaho State U.)
- Bhasitha Dharmasena (UVa)
- Gabriel Ladipo (Idaho State U.)
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- Michael Ladipo (Idaho State U.)
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- D. Armstrong (W&M)
- K.T. Evans (W&M)
- K. Paschke (UVa)
- P. Gautam (UVa)
- A. Hurley (U. Massachusetts)
- M. Pitt (Virginia Tech)
- Devi Adhikari (Virginia Tech)
- Andrew Gunsch (Virginia Tech)
- Daniel Valmassei (Virginia Tech)
- Huong Nguyen (UVa)
- Xinzhan Bai (UVa)
- Asar Ahmed (UVa)
- Vimkukthi Gamage (UVa)
- Jacob McMurtry (UVa)
- Minh Dao (UVa)
- Sourav Tarafdar (SBU)
- Jaydeep Datta (SBU)
- brynna Moran (SBU)
- James Shirk (SBU)
- Wenlian Li (SBU)
- Zuhal Demiroglu (SBU)
- Vassu Doomra (SBU)
- Klaus Dehmelt (SBU)
- Abhay Deshpande (SBU)
- Paul King (Ohio University)

And

- Larry Bartoszek (Bartoszek Engineering)
- Other members of the MOLLER collaboration

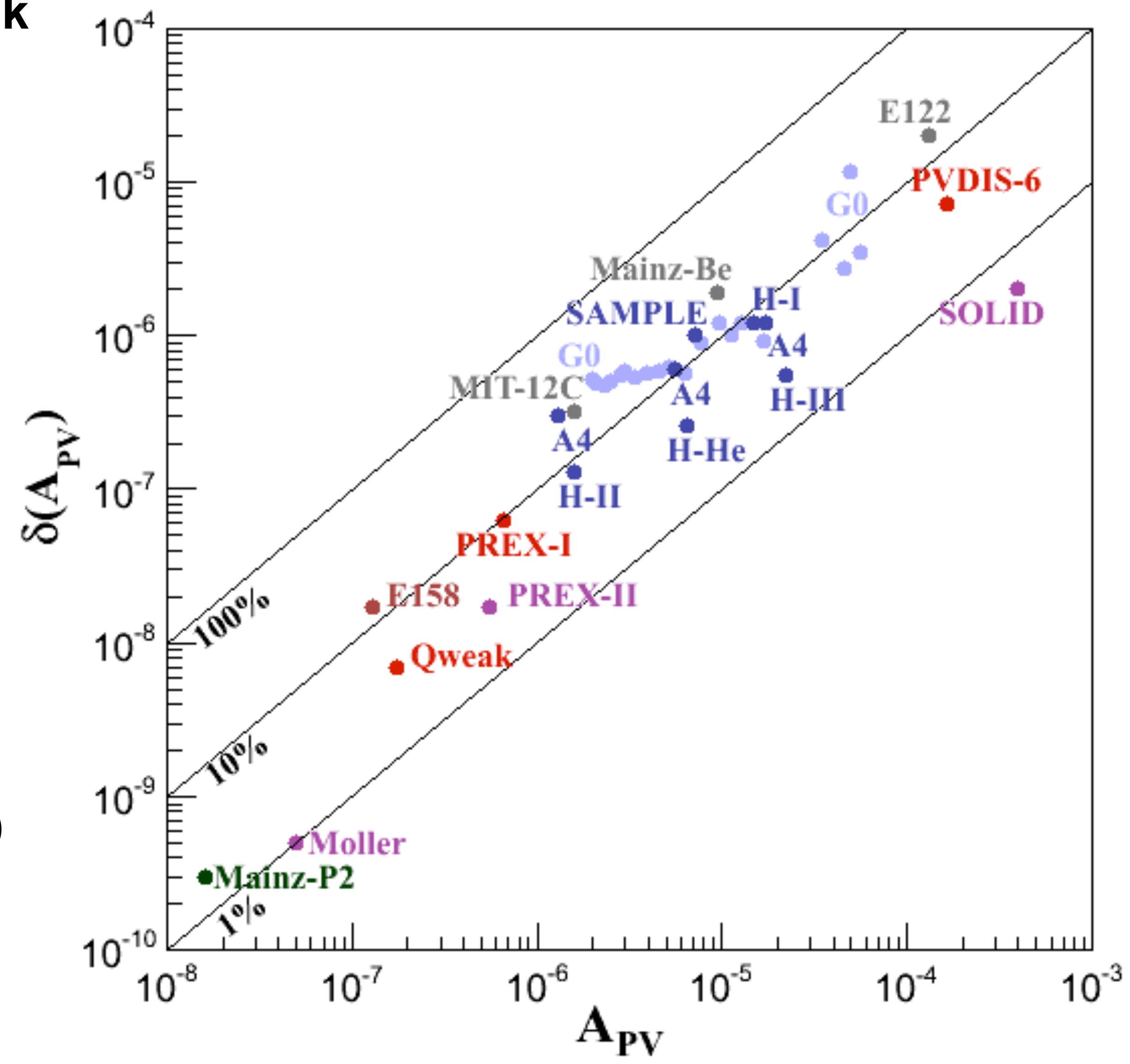
Thanks to the MOLLER collaboration, the US Department of Energy and the National Science Foundation

Thank you for your attention…

BACKUP

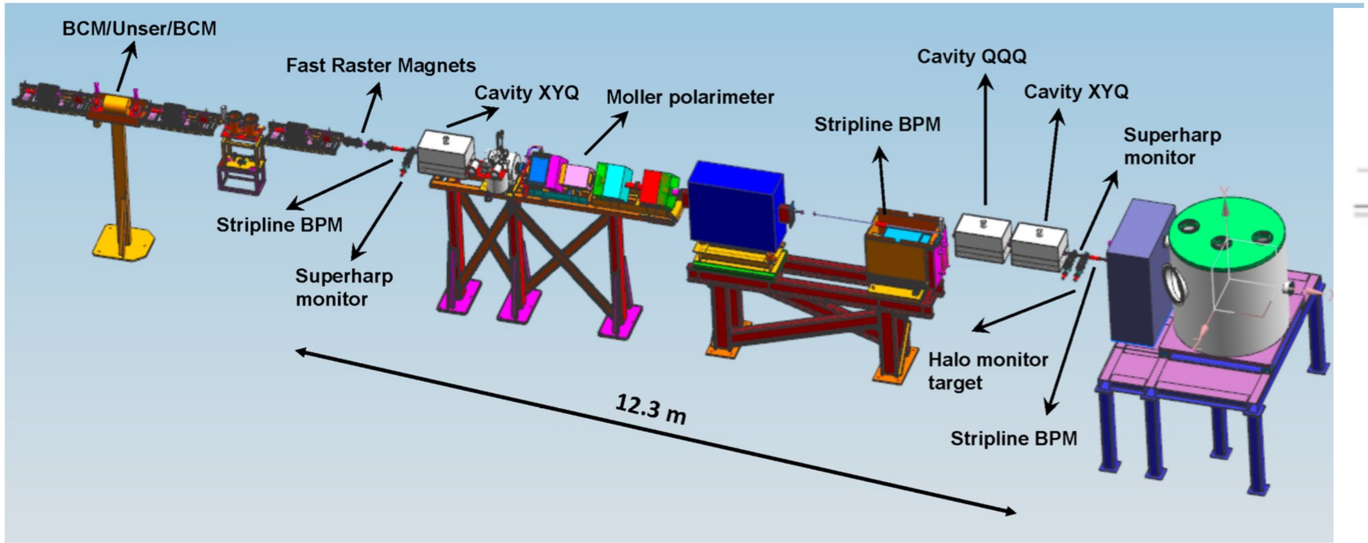
Measurement Of a Lepton Lepton Electroweak Reaction (MOLLER)

- **An Ultra-Precise Measurement of the Weak Mixing Angle using Møller scattering**
- **Parity violating asymmetry:**
  - A_{PV} ~ 35 × 10^{-9} or 35 ppb (parts per billion)
  - δA_{PV} ~ ± 0.7 ppb (2.4% precision)
- **$A_{PV} \propto Q_W^e = 1 - 4\sin^2\theta_w$ (at tree level)**
  - 2.4 % precession on $Q_W^e \Rightarrow$ 0.1 % on $\sin^2\theta_w$
- **Measuring A_{PV} with the MOLLER apparatus**
  - 11 GeV, 90% polarized, 70 μA electron beam
  - 1.25 m long liquid hydrogen target (~ 4 kW)
  - Precision collimation (minimizes backgrounds)
  - Full azimuthal coverage
  - Foreseen particle rate is ~ 135 GHz
  - Radiation hard, segmented detector array

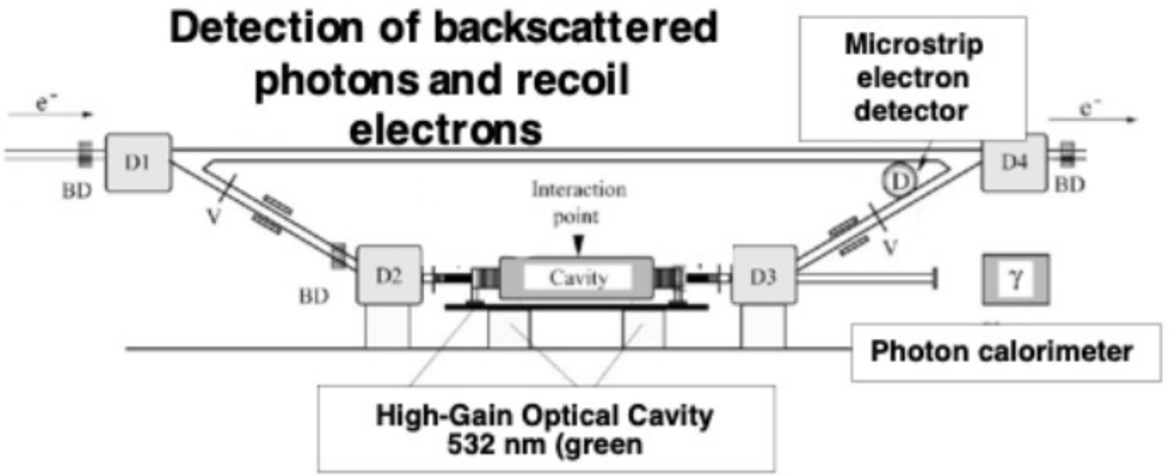


Picture courtesy: MOLLER TDR

Polarized beam monitoring



Reference design of the MOLLER beam line



Electron beam polarimetry

Electron Beam Polarimetry

- Two independent measurements
- Compton: continuous monitor
- Møller: invasive at low beam current

Beamline and Beam Monitoring

- Redundant position, angle & intensity monitoring
- Intensity, position monitor & resolution requirements

Beam Property	Defining Equation	Required 960Hz pair random fluctuations	Cumulative Helicity Correlation (full data set)
Intensity	$A_q \equiv \frac{I_0 - I_1}{I_0 + I_1}$	< 1000 ppm	< 10 ppb
Energy	$A_E \equiv \frac{E_0 - E_1}{(E_0 + E_1)} = \frac{\Delta E}{2E}$	< 110 ppm	< 1.4 ppb
Position	$D_x = \Delta x \equiv x_0 - x_1$	$< 50 \times 10^{-6}$ m	$< 0.6 \times 10^{-9}$ m
Angle	$\Delta\theta \equiv \theta_0 - \theta_1$	$< 10 \times 10^{-6}$ radian	$< 0.12 \times 10^{-9}$ radian
Spot-size	$\Delta\sigma/\sigma \equiv \frac{\sigma_0 - \sigma_1}{\frac{1}{2}(\sigma_0 + \sigma_1)}$	-	$< 10^{-5}$

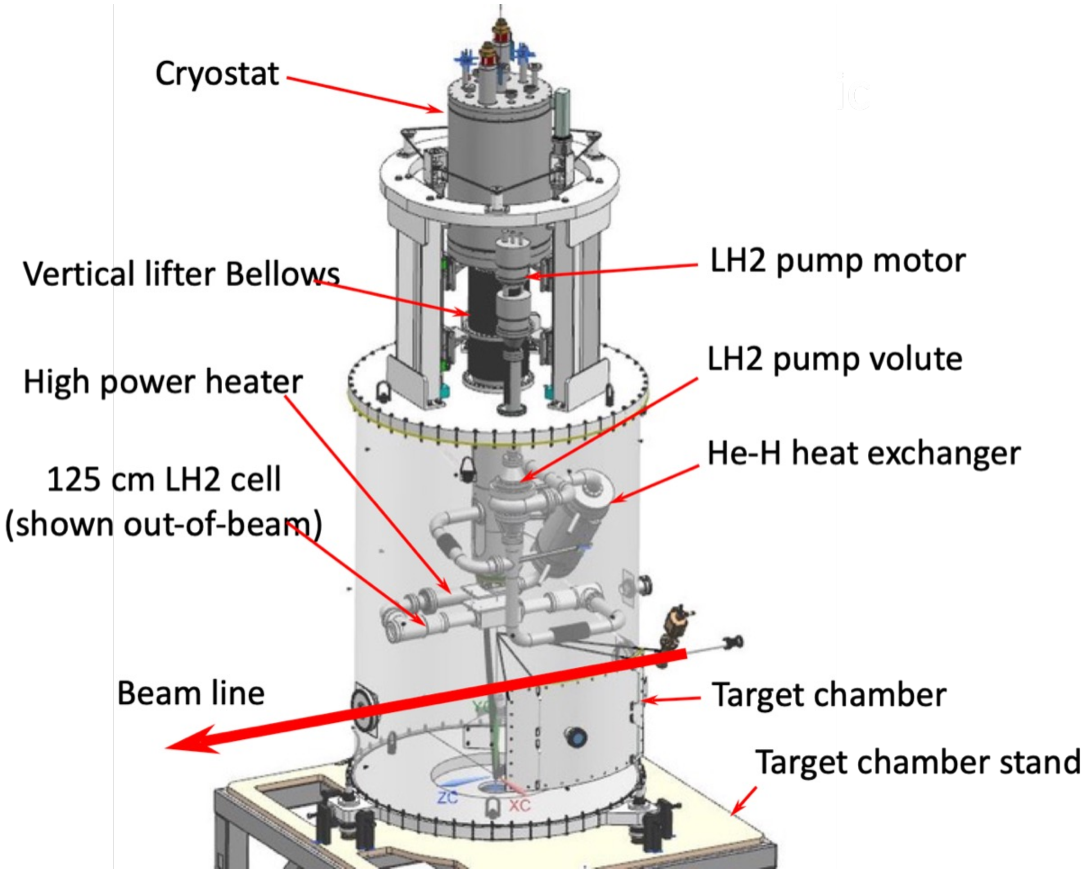
Parity quality beam performance goals for MOLLER

Picture & table courtesy: MOLLER TDR

Liquid Hydrogen (LH_2) target

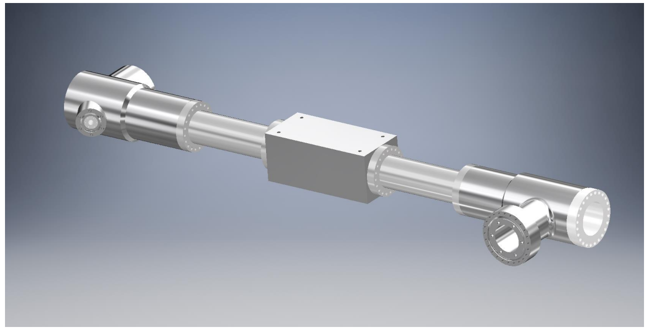
- Largest electron thickness for least radiation length
- No complex nucleus to scatter from
- Easy to assure that the target is unpolarized

Target parameters	
Cell length	125 cm
Cell thickness	8.9 g/cm^2
Cell acceptance (**θ**,**Φ**)	12 mrad, 2**Π**
Pressure & temperature	35 psia & 20K
LH_2 pump rate	< 25 l/s
Target power	4.5 kW
LH_2 density fluctuation	< 30 ppm (70 **μ**A; 1920 Hz)



The target chamber

Extensive Computational Fluid Dynamics (CFD) simulations are being performed to finalize the target cell design

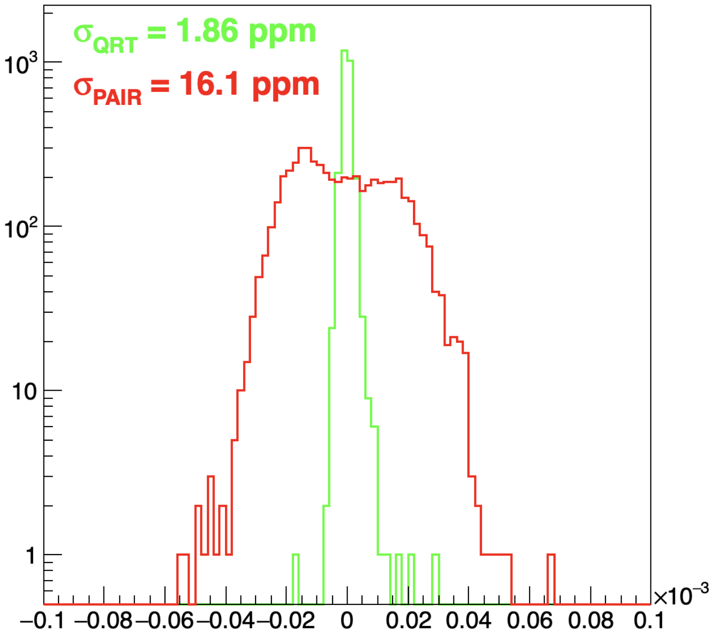


The target cell

Picture courtesy: MOLLER TDR

Target chamber continued…

- The Q_{weak} target satisfies all its design requirements and thus validates the use of CFD calculations
- Realistic CFD simulation with the latest design of the target cell gives the target noise at 1920 Hz to be ~ 16 ppm for pair asymmetries
- **Solid targets will be available for ancillary, background and optics study**



LH_2 density asymmetry comparison between pair and quartet asymmetries at 1920 Hz

Brief status of target chamber

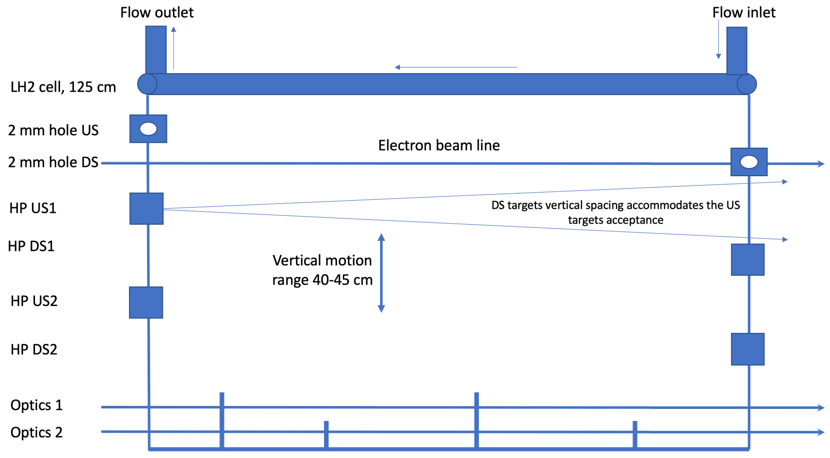
Vacuum System: Design and engineering complete

Hydrogen Gas Service: Mostly ready

Helium Gas Service: Work in progress for the distribution system and cryostat

Target Loop: Design complete, some engineering of the LH_2 pump and solid targets ladder are ongoing

Target Motion, controls and instrumentation: Mostly completed



Sketch of solid targets ladder with the optics foils tray

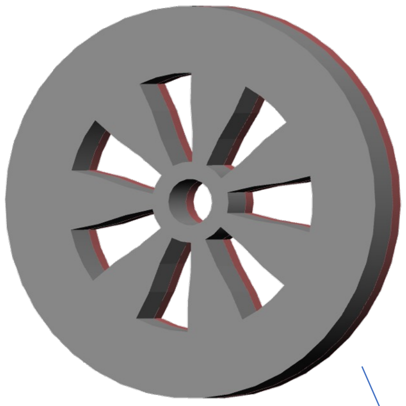
Plot & Picture courtesy: MOLLER TDR

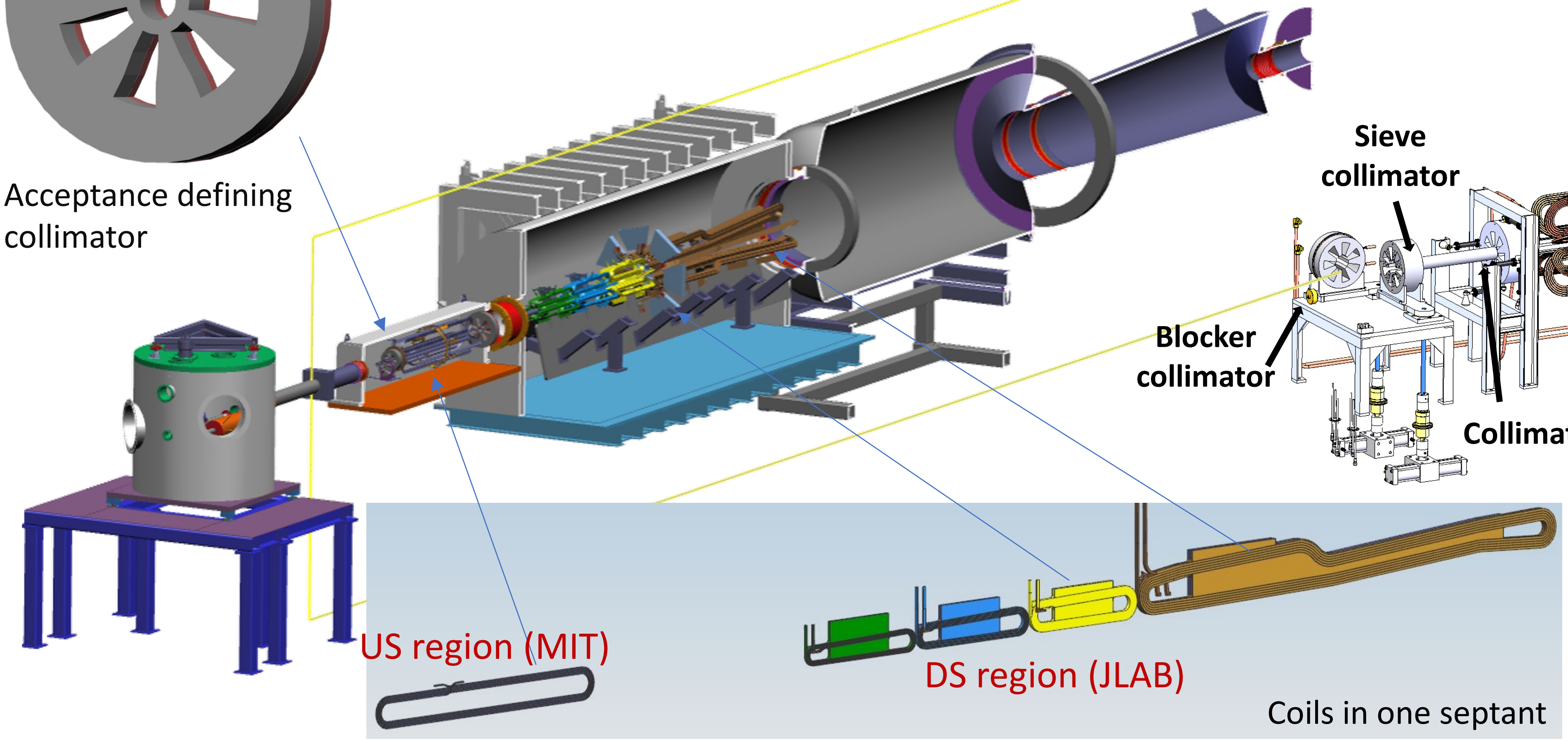
S. C. Dusa's talk at MOLLER collaboration meeting 2023

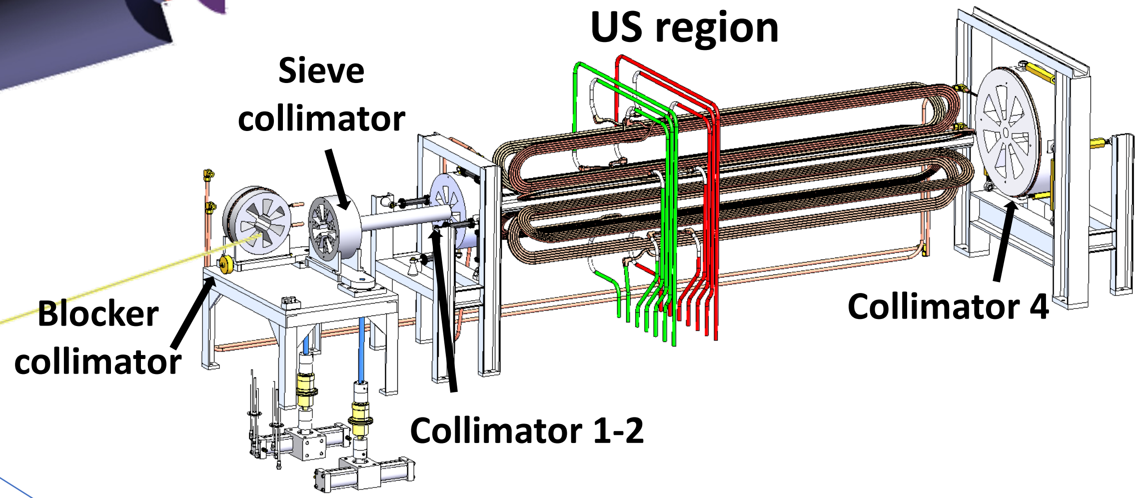
Spectrometer

Elements

- Set of resistive toroidal magnets (US and DS)
- 2 collimators to define the acceptance of the signal and that of the un-scattered beam





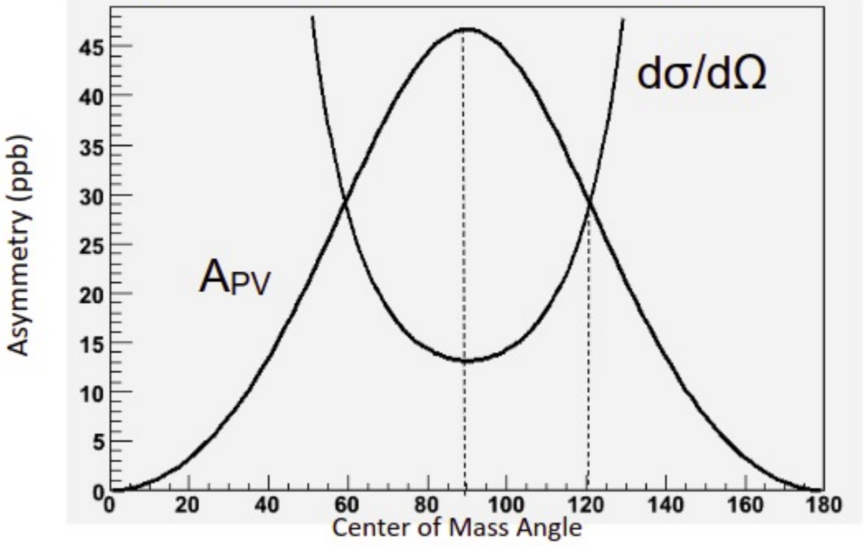


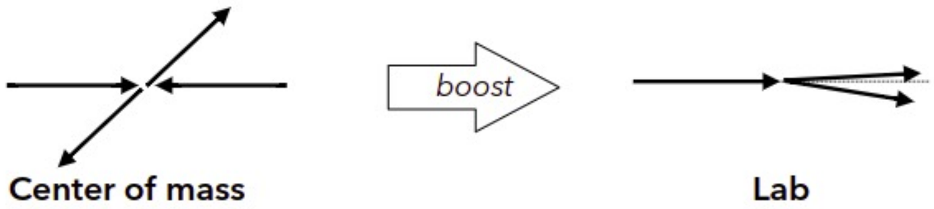
Picture courtesy: MOLLER TDR

Figure of merit

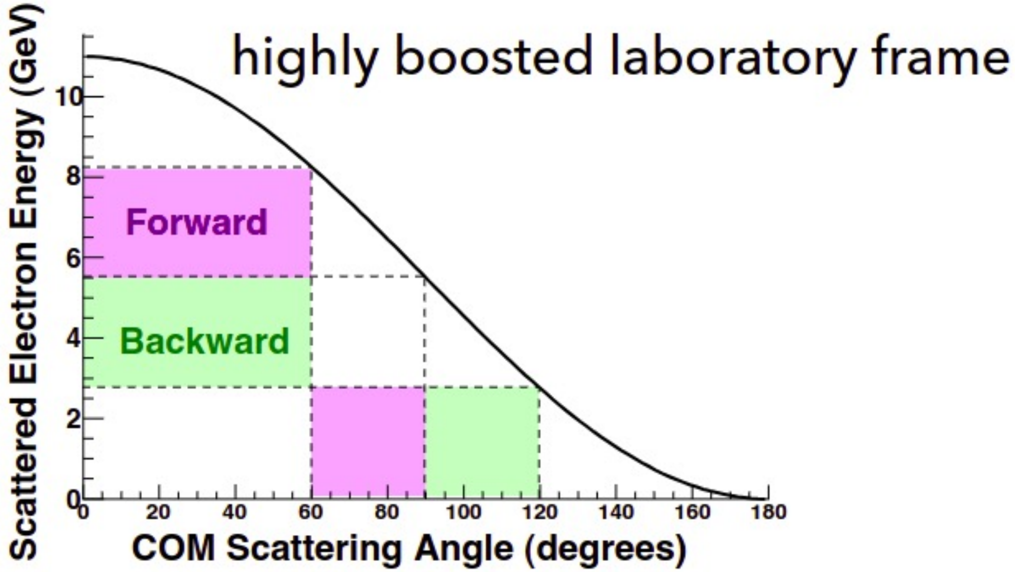
$$A_{PV} = \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L} = mE\frac{G_F}{\sqrt{2}\pi\alpha}\frac{4\sin^2\theta}{(3+\cos^2\theta)^2}Q_W^e$$

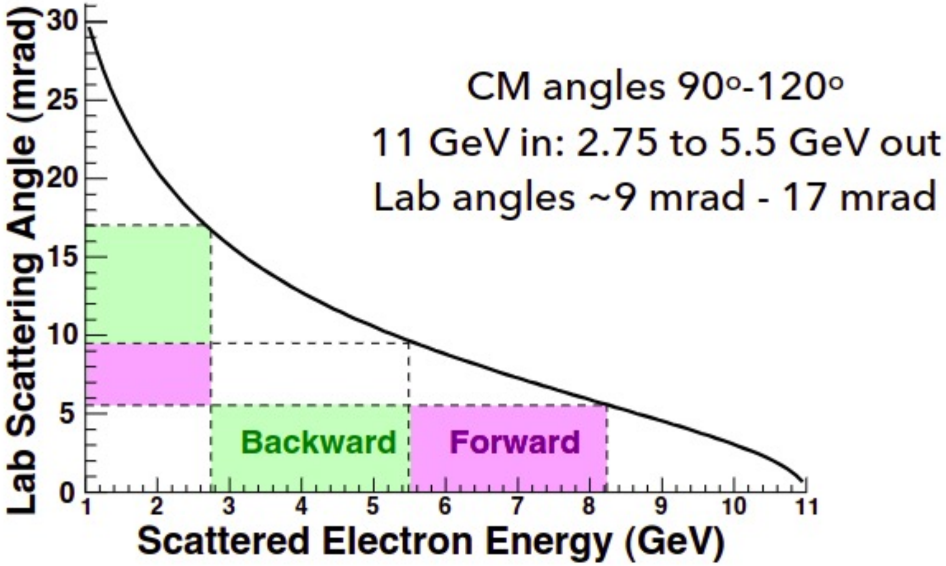
Highest figure of merit at θ_{CM} = 90°





Identical particles.
Measure either forward or backward scattering.





Identical particles

Since we only need either the forward or the backward scatter, accept forward+backward for half the azimuth