MOLLER Experiment at Jefferson Lab
VT Responsibilities

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Virginia Tech

CNP Research Day

<u>VT manpower:</u>
Mark Pitt
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Andrew Gunsch
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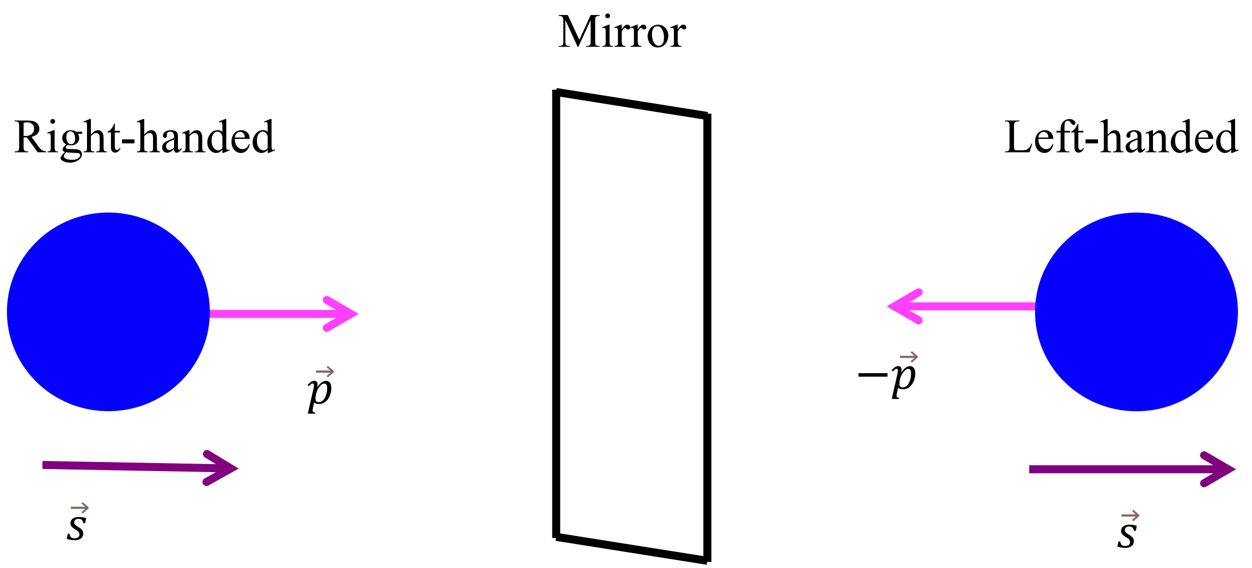
Outline

- Parity operation and its non-conservation in weak interaction
- Parity-violating electron scattering (PVeS) introduction
- MOLLER experiment overview
- Current status of the project
- Involvement and responsibilities of VT
- Conclusion

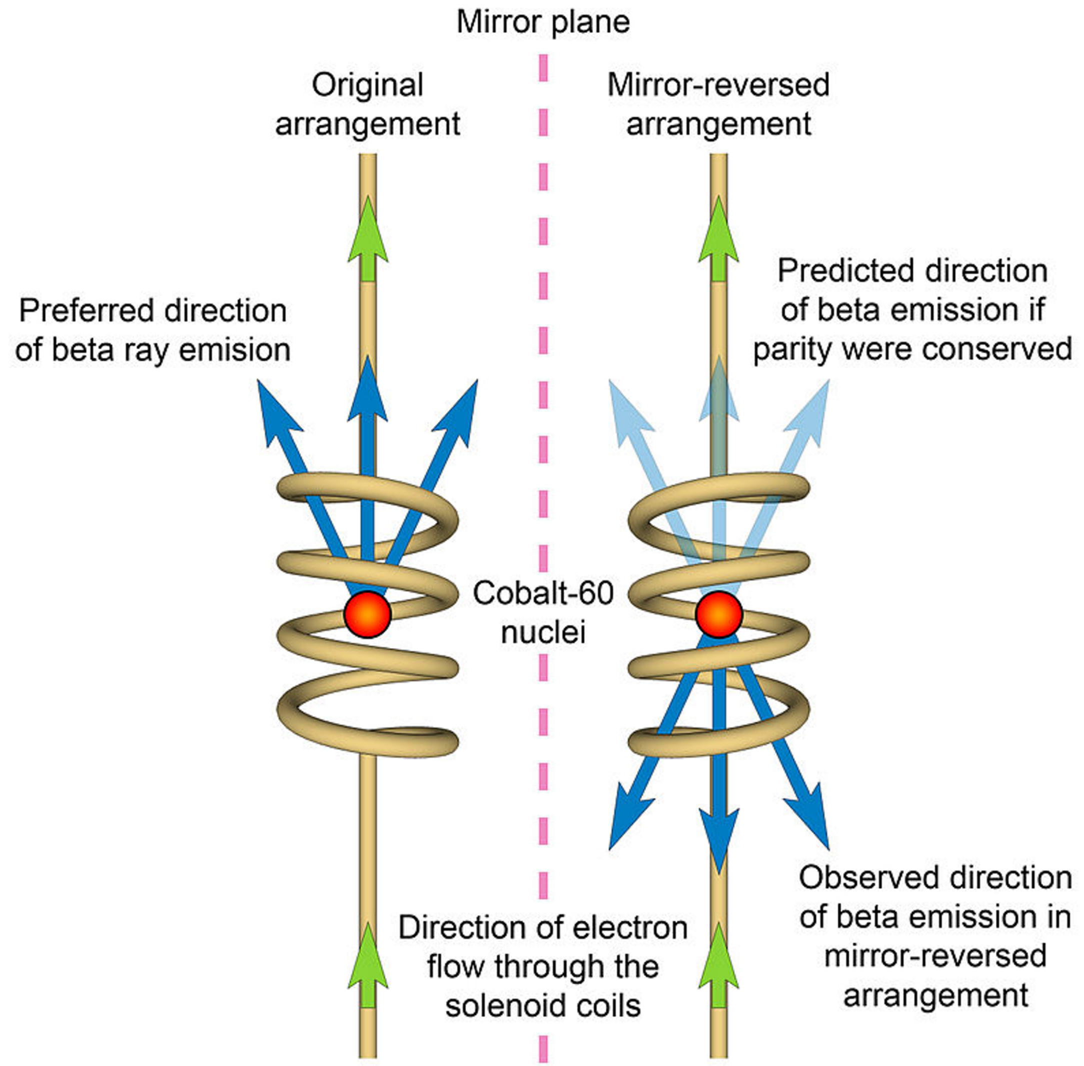
Parity Operation

- It is a mirror symmetry → inversion of spatial coordinates:

  $P(x, y, z) \Longrightarrow P(-x, -y, -z).$
- It is not conserved in weak interactions.
- Parity operation is same as changing helicity.
- **We change electron's helicity to mimic parity operation.**
- **Parity-violation creates tiny asymmetry (A_{PV}) in the detected flux.**



$h = \vec{s} \cdot \hat{p} \ = +s$ Parity operation $h = \vec{s} \cdot (-\hat{p}) \ = -s$



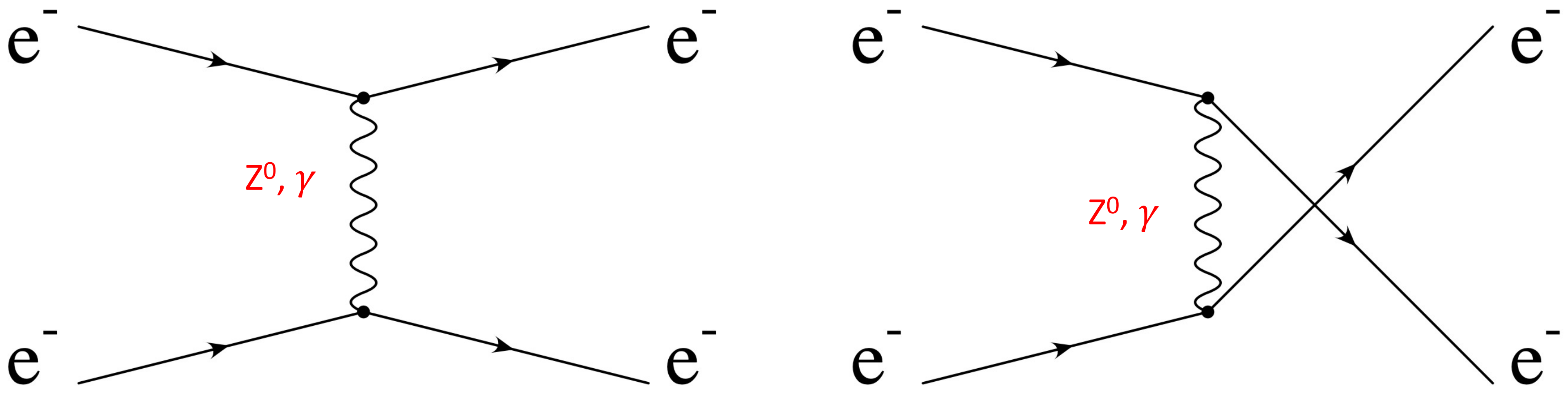
Wu Experiment (1956)

Parity Violation in Electron Scattering

- Scattering of longitudinally polarized electrons from unpolarized targets.
- **We change electron's helicity to mimic parity operation.**
- **Asymmetry (A_{PV}) of the detected rates between the beam's opposite helicity states.**

$$A_{PV} = \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L} \quad \text{where } \sigma \sim |\mathcal{M}_\gamma + \mathcal{M}_{Z^0}|^2 \quad \rightarrow A_{PV} \approx \frac{2\mathcal{M}_\gamma (\mathcal{M}_{Z^0})^*}{|\mathcal{M}_\gamma|^2}$$

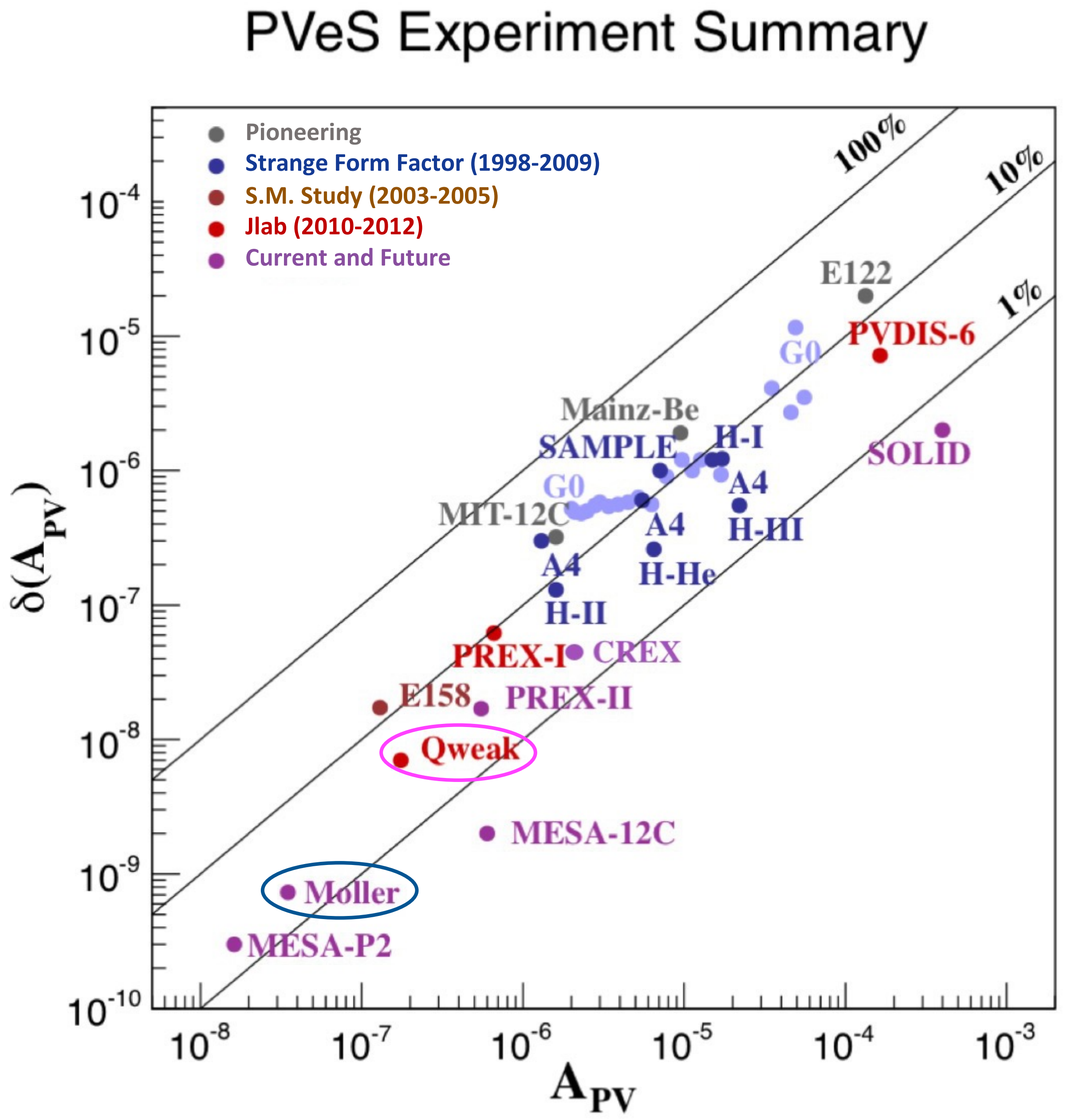
- At $Q^2 \ll (M_{Z^0})^2$ A_{PV} is dominated by the interference between the weak and electromagnetic amplitudes.



Feynman diagrams for Møller scattering at tree level

PVeS Experiments Summary

- E122 – 1st PVeS exp. (late 70's) at SLAC
- Jlab program launched in 90's
- E158 – measured PV in Møller scattering at SLAC (2007)
- Significant improvement in experimental components over time:
  - ➢ Photocathodes
  - ➢ Polarimetry
  - ➢ Cryotargets
  - ➢ Beam stability to nanometer level
  - ➢ Low noise electronics
  - ➢ Radiation-hard detectors

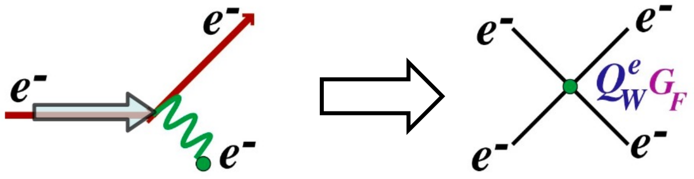


MOLLER Experiment Overview

- MOLLER: Measurement Of Lepton Lepton Electroweak Reaction
  - ➢ will have a factor of 5 improvement over E158 measurement

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

$$Q_W^e = 1 - 4\sin^2\theta_W \approx 0.075$$

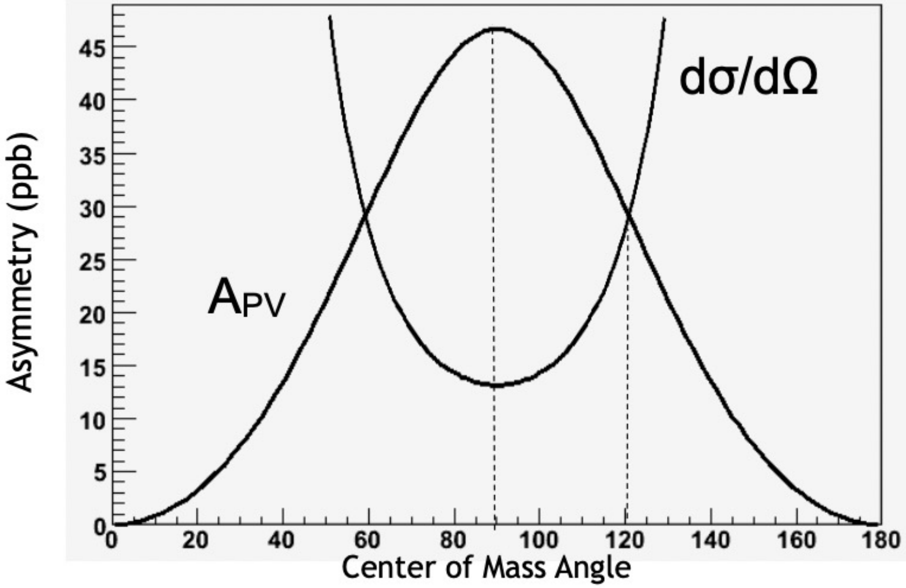


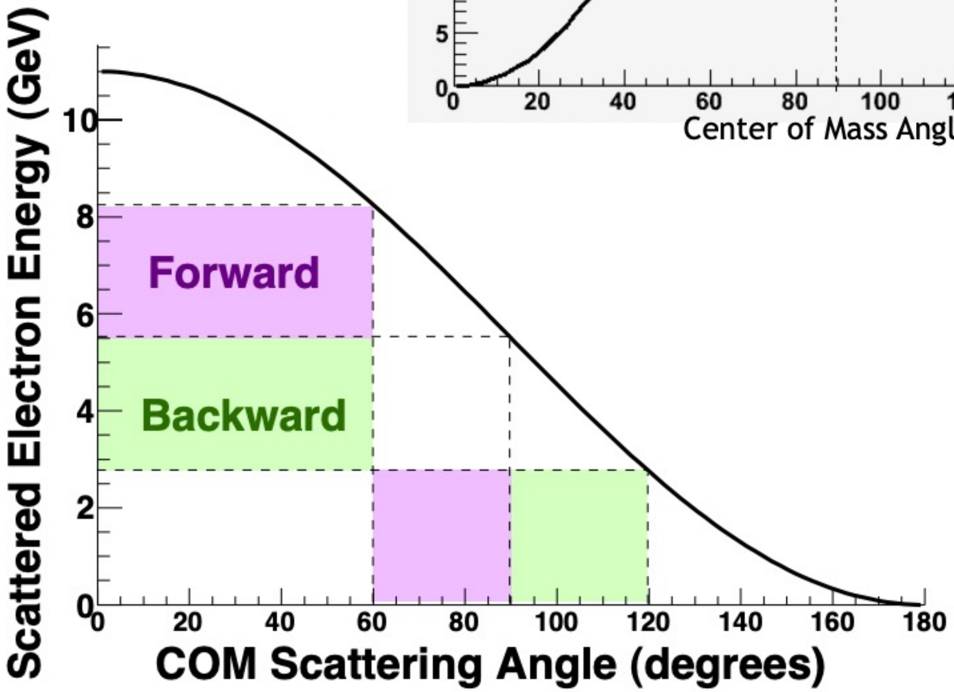
- MOLLER precision:

$$\delta(\sin^2\theta_W) = \pm 0.00023\ (\text{stat.}) \pm 0.00012\ (\text{syst.}) \Longrightarrow 0.1\ \%$$

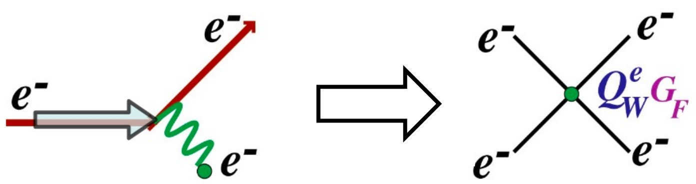
Parameter	Value
E	11 GeV
E'	2 – 9 GeV
θ_{CM}	60° – 90°
Target	120 cm long LH_2
Max. Luminosity	2.4×10^{39} cm^{-2} sec^{-1}
Moller Rate @ 65 µA beam current	134 GHz
Run Time	344 PAC-days
Polarization	≈ 90 %
$< A_{PV} >$	33 ppb

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





MOLLER Experiment Overview (contd.)



$$\mathcal{L}_{e_1 e_2} = \sum_{i,j=L,R} \frac{g_{ij}^2}{2\,\Lambda^2} \bar{e}_i \gamma_\mu e_i \bar{e}_j \gamma^\mu e_j$$

Sensitive to $\frac{\Lambda}{g}$ up to 7.5 TeV

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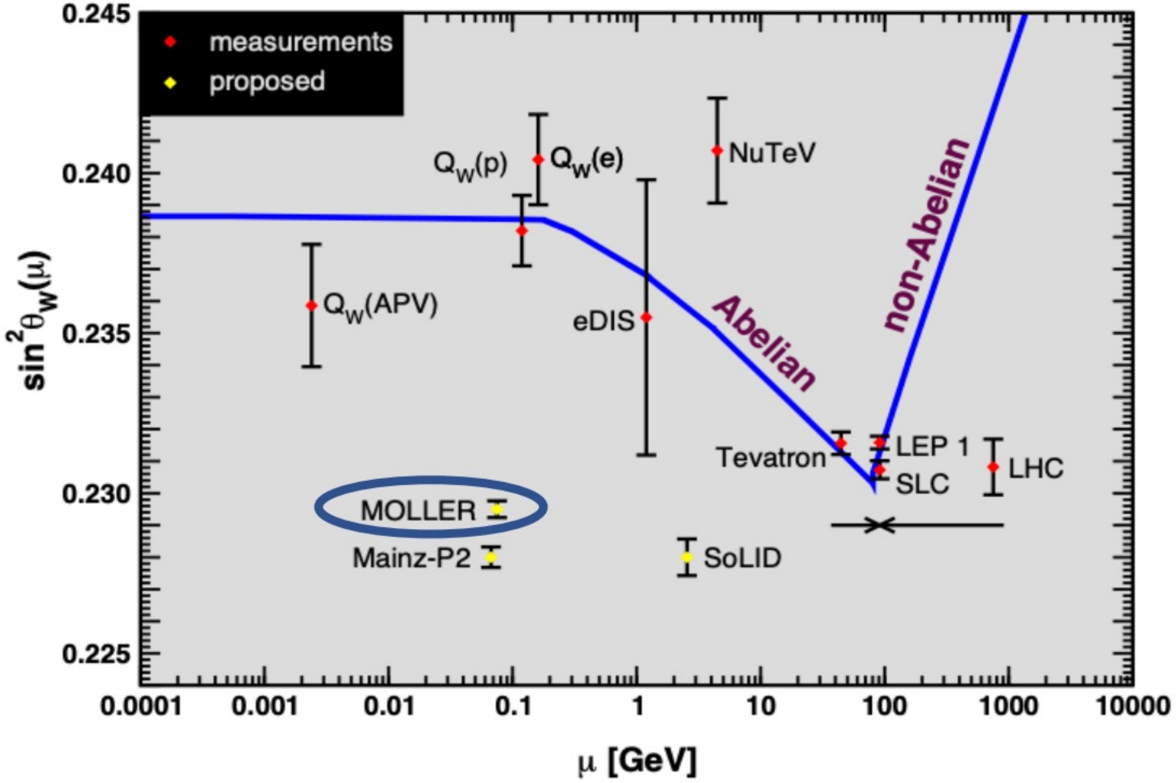
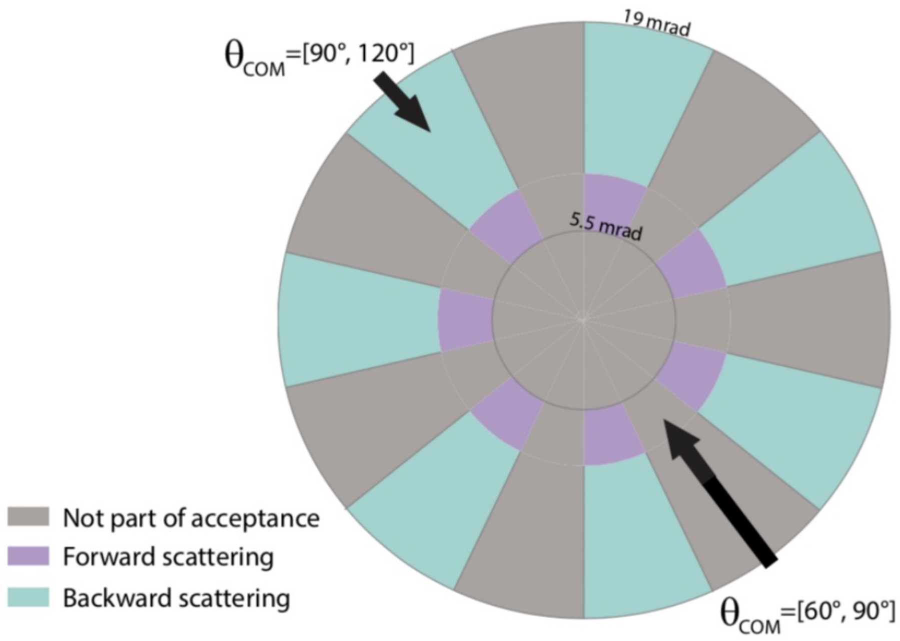
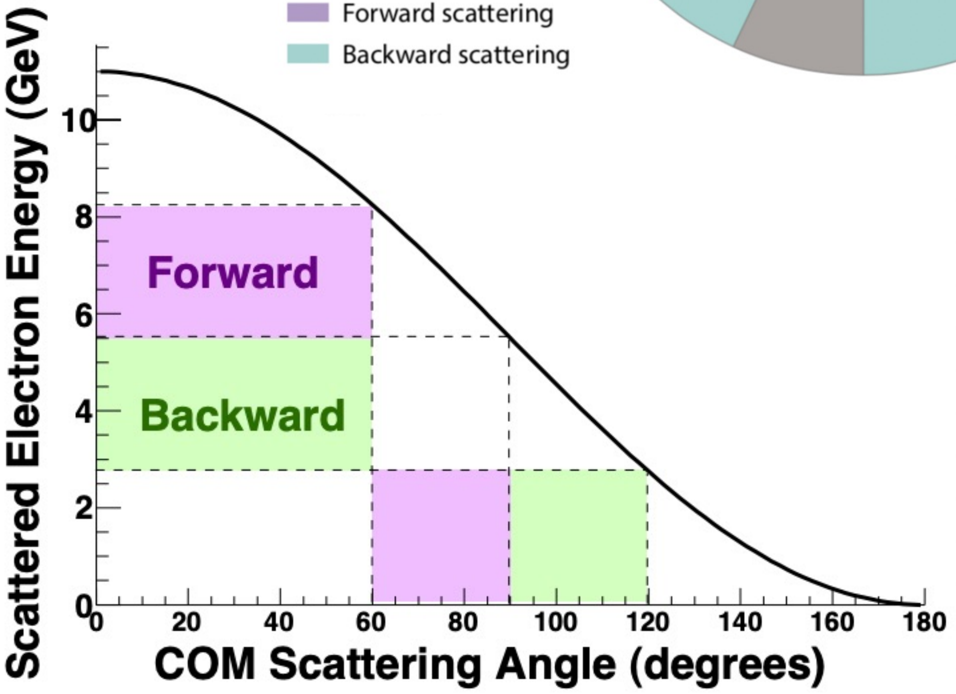




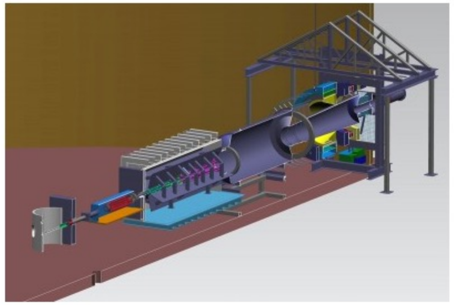


MOLLER Experiment History and Current Status

MOLLER collaboration: ~ 160 authors, 37 institutions, 6 countries; Spokesperson: K. Kumar, U. Mass, Amherst

- JLab PAC approval Jan. 2009, JLab Director's review Jan. 2010
- JLab PAC37 Ranking/Beam Allocation Jan. 2011 (A rating, 344 PAC days)
- Strong endorsement from DOE Science Review in Sept. 2014
- Second Director's Review in Dec. 2016
- DOE CD-0 status achieved in Dec. 2016; paused in Jan. 2017
- Project team formed in Jan. 2019
- Director's Review in April 2019 – Technical Readiness, Risk, Cost
- Director's Review in January 2020
- CD-1 Director's Review in August 2020
- DOE MOLLER CD-1 Independent Project Review, October 2020
- MOLLER-NSF Midscale Technical and Cost Review, October 2020
- MOLLER-NSF Midscale Funding Awarded, February 2021, VT lead institution
- MOLLER CD-1 approved
- DOE OPA IPR Annual Review, November 2021
- Next goal is CD-2 approval in calendar 2022

PARTNERSHIP CONTRIBUTES TOWARD SHARP EYES FOR MOLLER EXPERIMENT



The MOLLER experiment has received additional grants totaling $9 million

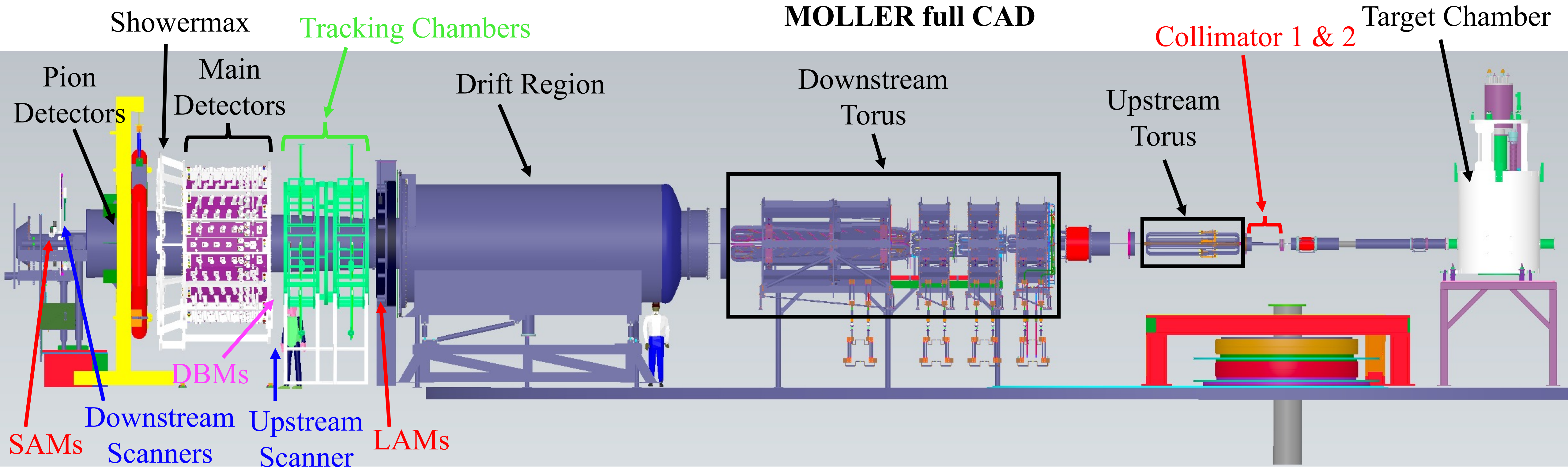
NEWPORT NEWS – Thirteen universities working on a new experiment to be carried out at the U.S. Department of Energy's Thomas Jefferson National Accelerator Facility have recently been awarded new grants totaling more than $9 million. The grants come from the National Science Foundation and the Canadian Foundation for Innovation, with a matching award for the CFI grant from Research Manitoba. The grants benefit the Measurement of a Lepton-Lepton Electroweak Reaction Experiment, called MOLLER.

MOLLER is an experiment designed to precisely measure the electron's weak charge, a gauge of how much influence the weak force exerts on the electron. MOLLER's precision measurement will test the theory that describes the particles and interactions that make up everyday matter.

The NSF Midscale Physics Projects program grant includes individual grants totaling $5.7 million to researchers at nine institutions. These include Idaho State University, Louisiana Tech University, Muskingum University, Ohio University, Syracuse University, the University of Massachusetts Amherst, the University of Virginia, Virginia Tech, and William & Mary.

The lead principal investigator on the NSF collaborative grant for MOLLER is Mark Pitt. Pitt is a professor and chair of the Department of Physics at Virginia Tech.

MOLLER Equipment and VT Responsibilities



Scattered beam monitors (SBMs):

- Seven Large Angle Monitors (LAMs)
- Eight Small Angle Monitors (SAMs)
- Integrating Cherenkov detectors
- Sensitive to potential false asymmetry from rescattered background

Diffuse Beam Monitors (DBMs):

- Fourteen DBMs (seven bare PMTs and 7 PMTs plus quartz)

Scanner Detectors (SDs)

- One Upstream Scanner
  - ❖ Scans in two dimensions
  - ❖ Counting and integrating mode Cherenkov detectors
- Four Downstream Scanners
  - ❖ Each scanner scans radially in one dimension
  - ❖ Integrating Cherenkov detectors

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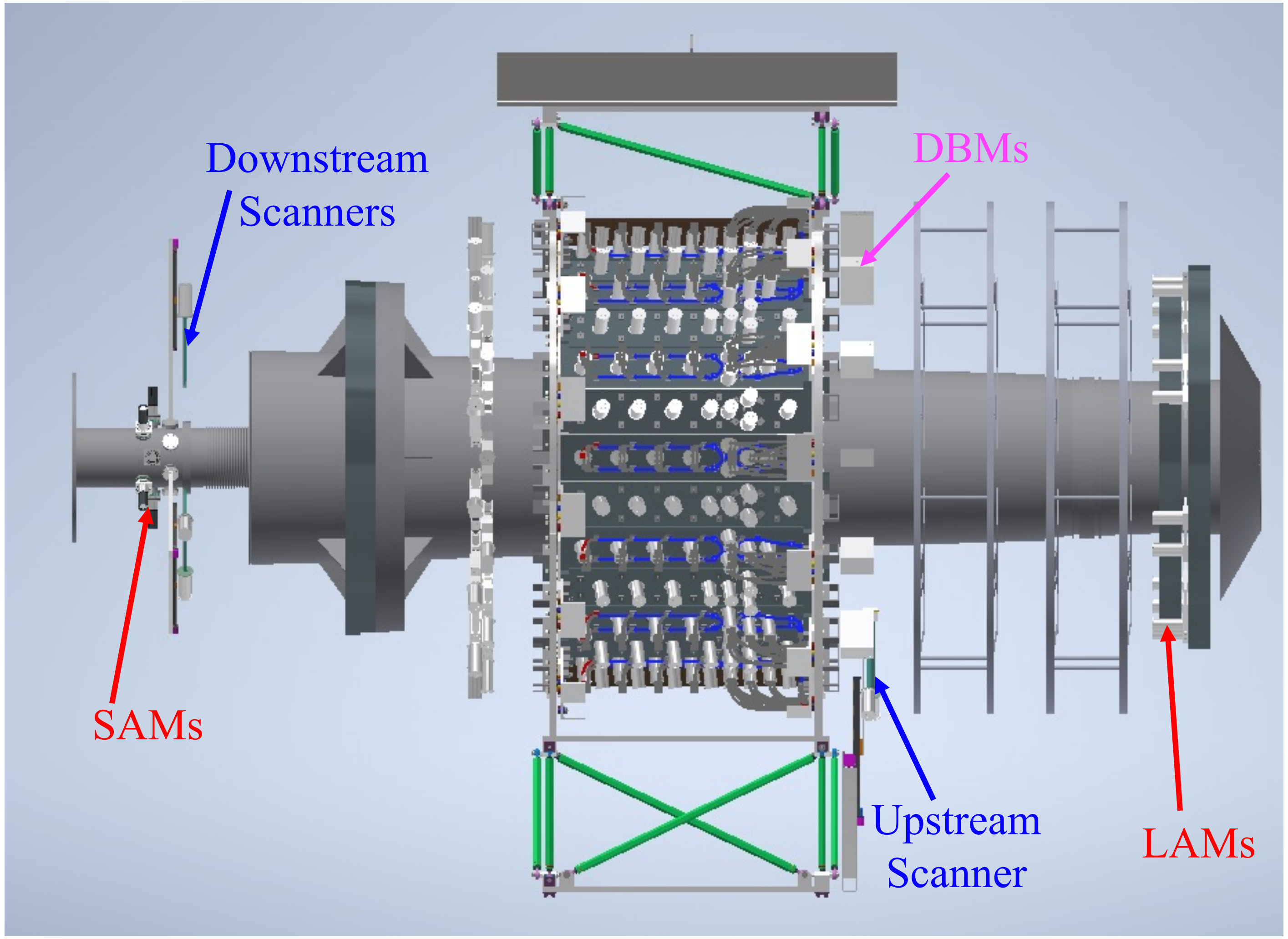
MOLLER detector CAD

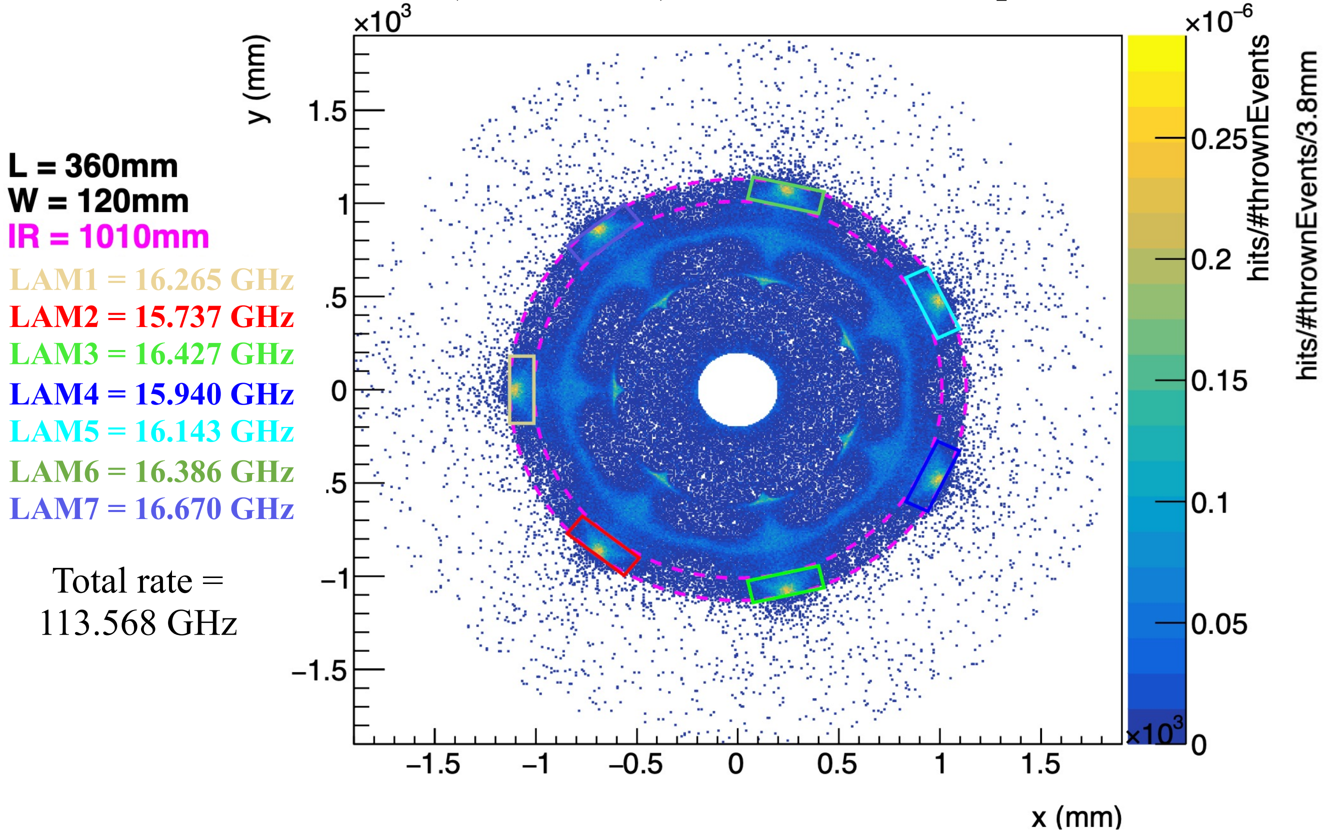


Large Angle Monitors (LAMs) Requirements

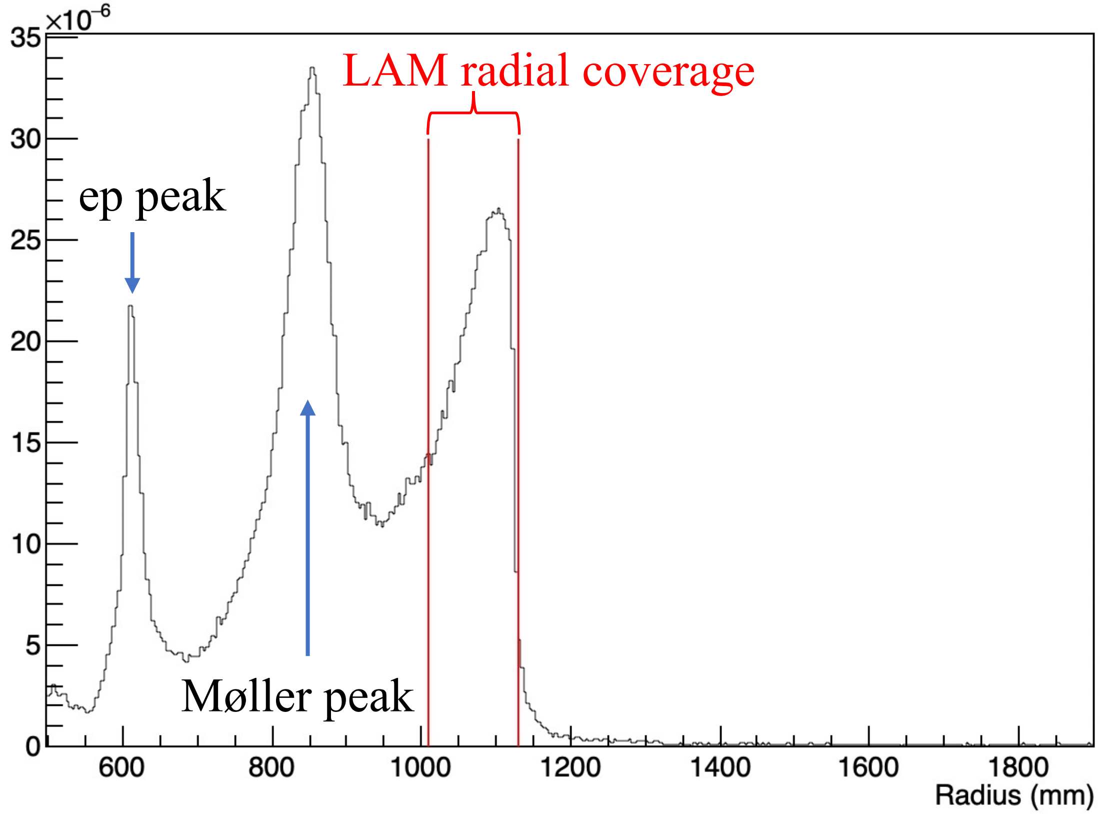
- Large angle, high rate, and small asymmetry
- "Null" asymmetry monitors as a check of helicity-correlated beam correction procedure
- Monitor for potential false asymmetries from rescattered backgrounds
- Accepted flux is dominated by e-p elastic radiative tail
- Total rate gives stat. width ~ 1.8 x Ring 5 (main physics); smaller (6 vs. 32 ppb) asymmetry

Process	Rate (GHz)	<A> (ppb)	<E> (GeV)
Møller	23	10	1.8
Elastic ep	90	4	1.4
Inelastic ep	0.2	332	
Total	**134**	**6**	

e-/π- (KE>1 MeV) XY dist. on LAM plane

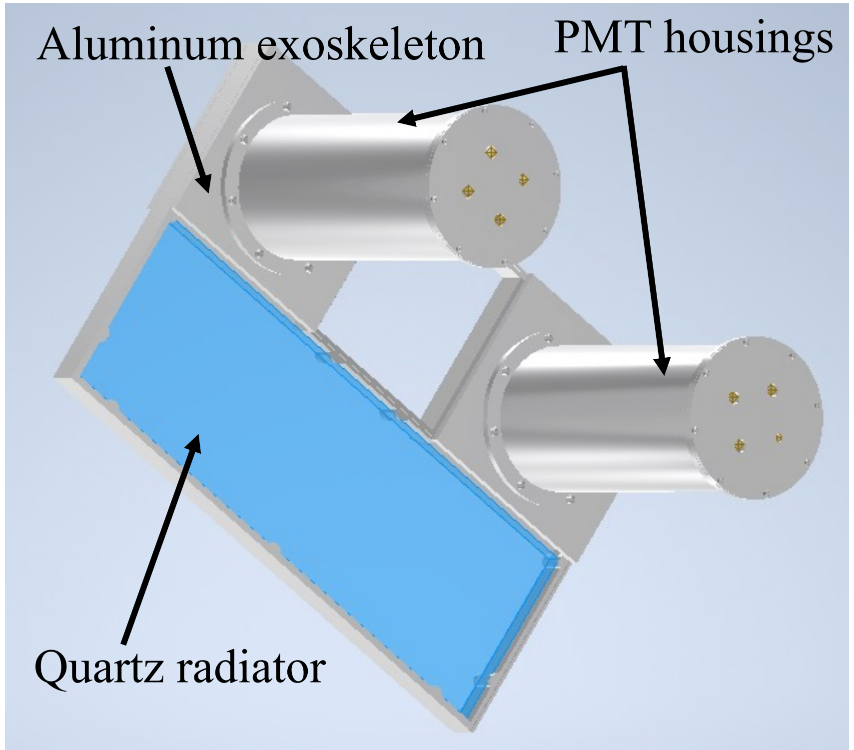


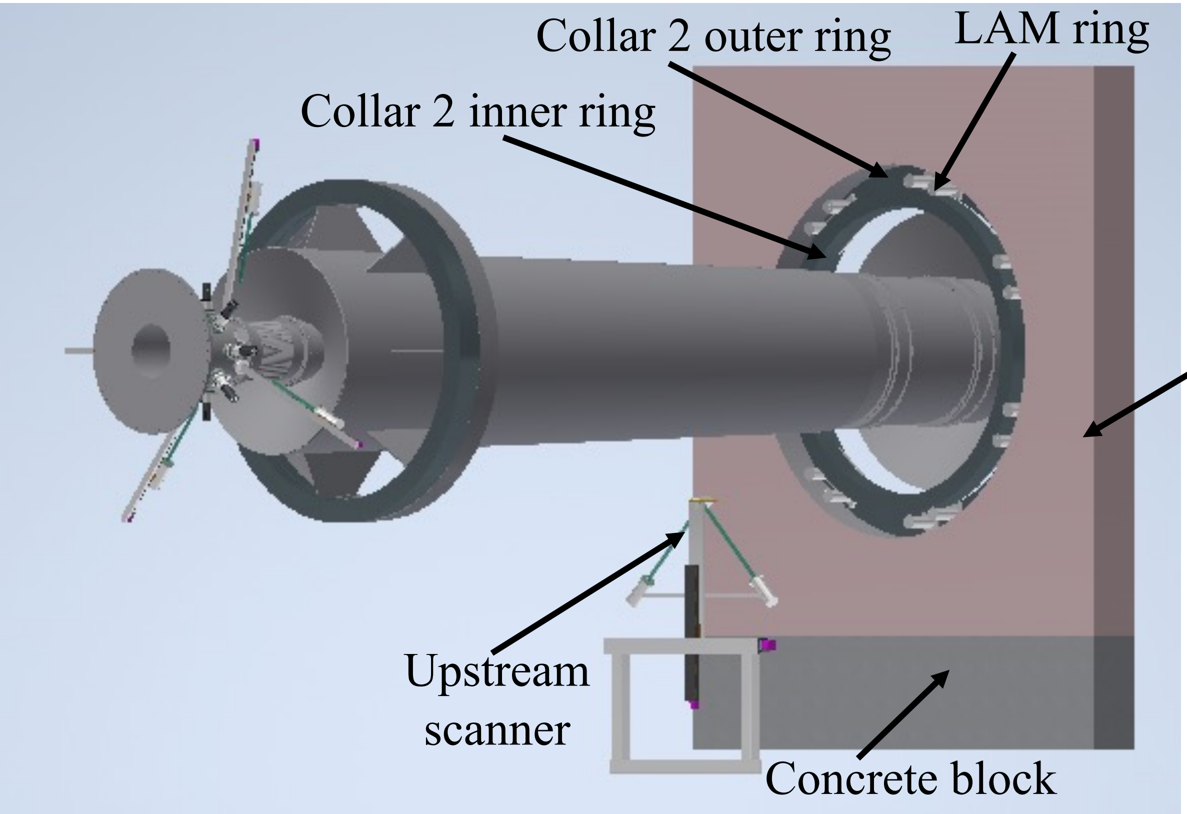
e-/π- (KE>1 MeV) radial dist. on LAM plane



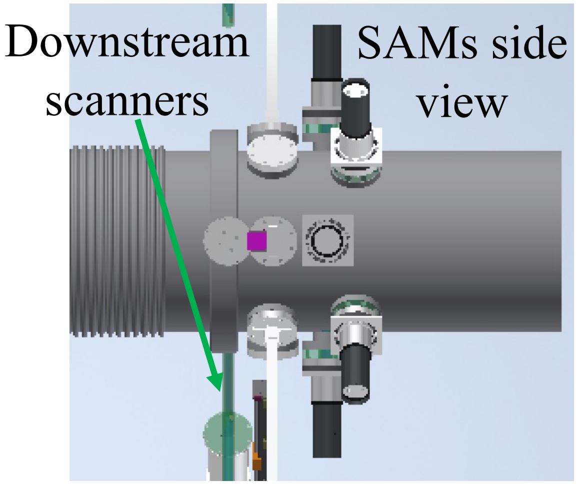
Large Angle Monitors (LAMs) Design

- Collar 2 blocks particles scattered (mostly secondaries) at large angles, has two rings made of lead
- Quartz radiator → $36\times12\times1$ cm^3, two quartz lightguides → $12\times12\times1$ cm^3
- LAM quartz sits just upstream of the collar 2 inner ring
- PMTs and light guide part will be behind the shadow of collar 2 outer ring
- PMTs will be glued on the downstream face of quartz (light guide)
- Can use the optical glue, same as in Qweak MAIN detectors
- The glue was tested for radiation damage for doses up to 1 MRad at a ^{60}Co facility during Qweak exp.



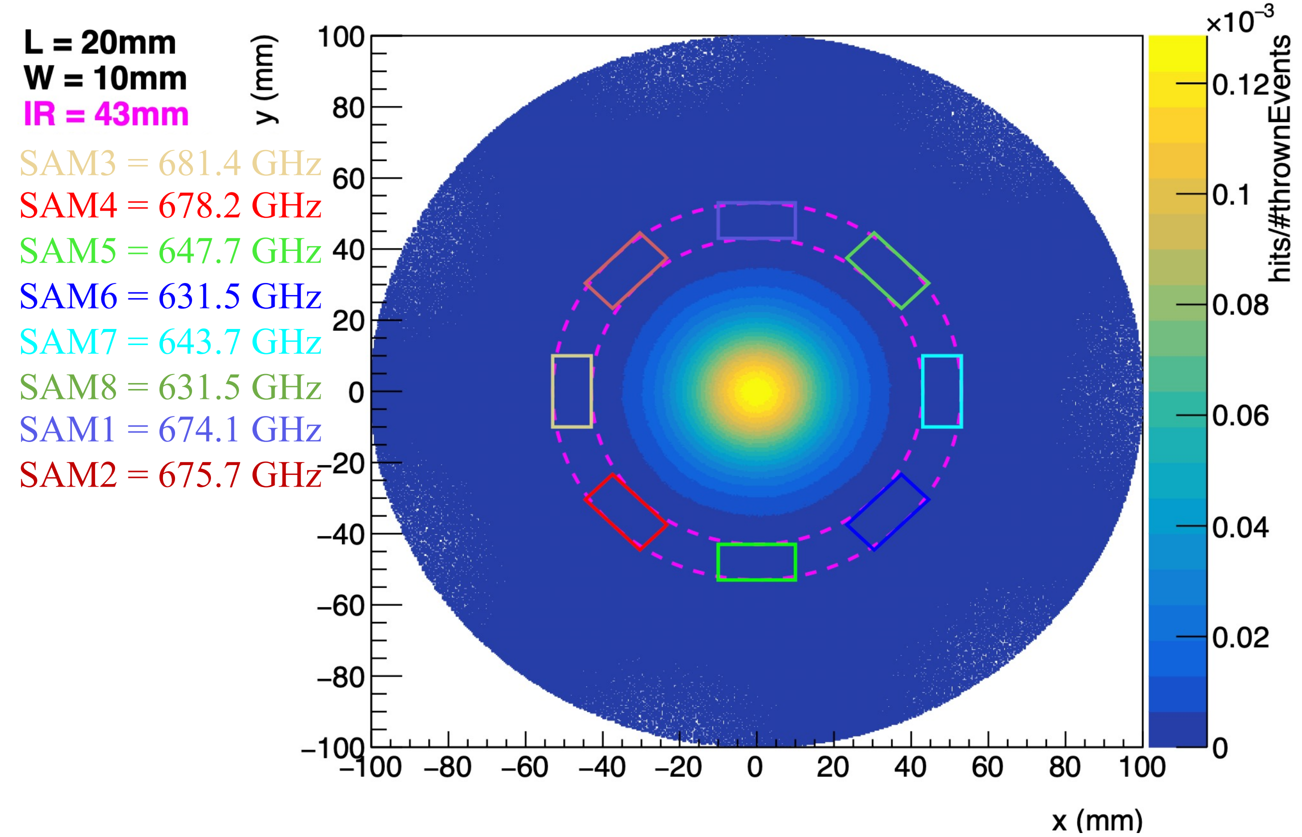


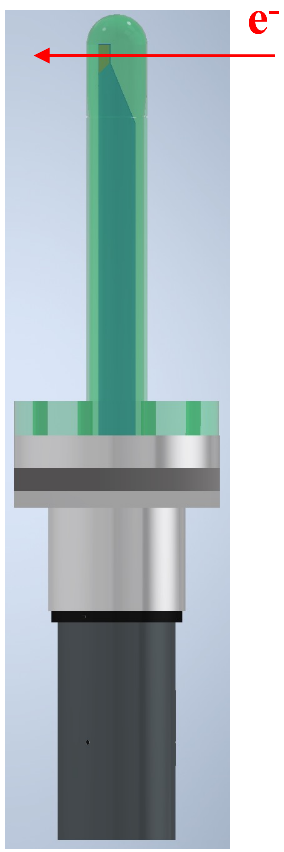
Small Angle Monitors (SAMs) Requirements and Goals

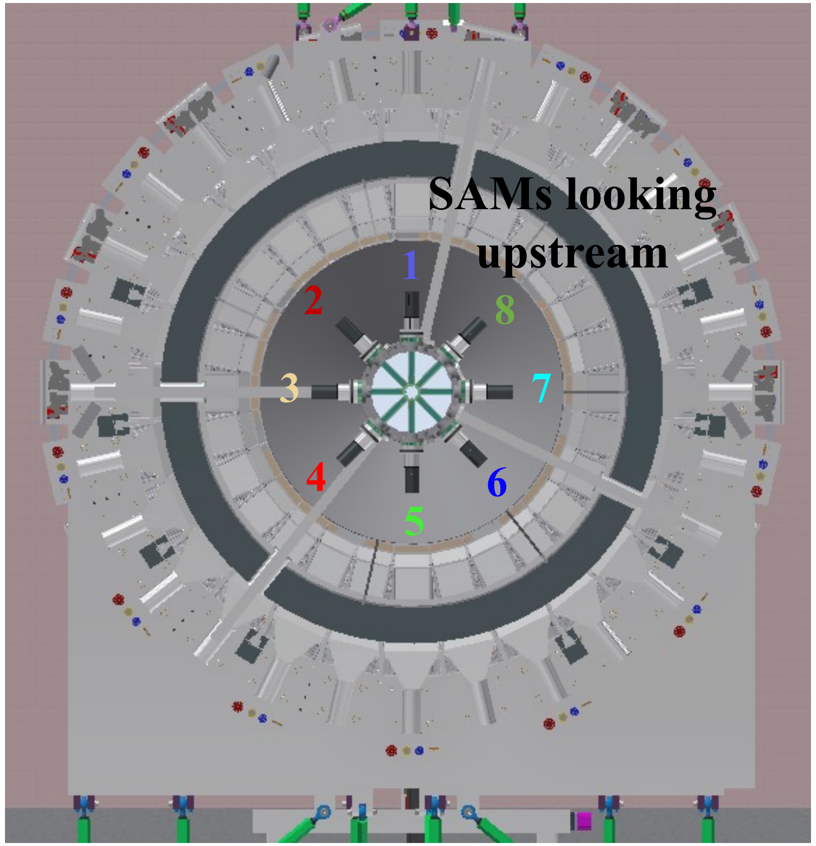


- Small lab scattering angle ~ 0.1^0 (43 mm – 53 mm radial distance)
- Small quartz block (1.0 x 2.0 x 0.6 cm^3), air light guide, and PMT
- High rate ~650 GHz per SAM, rate depends on at with azimuth the SAM is
- Small asymmetry ~3 ppb, order of magnitude smaller than main Møller asymmetry
- “Null” asymmetry monitors as a check of helicity-correlated beam correction procedure
- Monitor for potential false asymmetries from rescattered backgrounds

e-/π- (KE>1 MeV) XY dist. on SAM plane

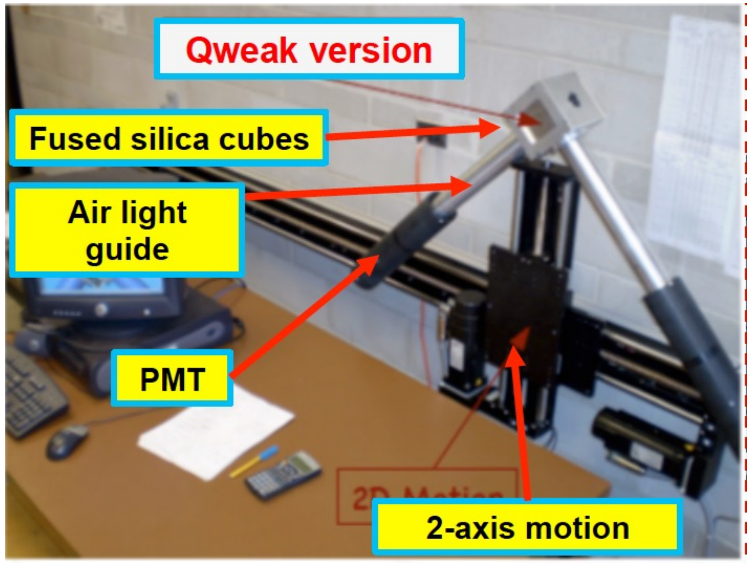


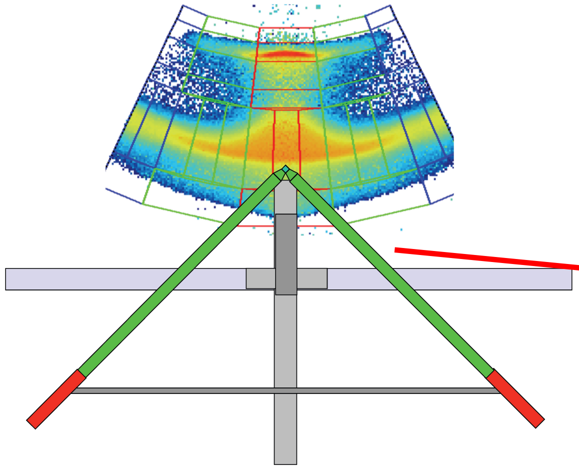


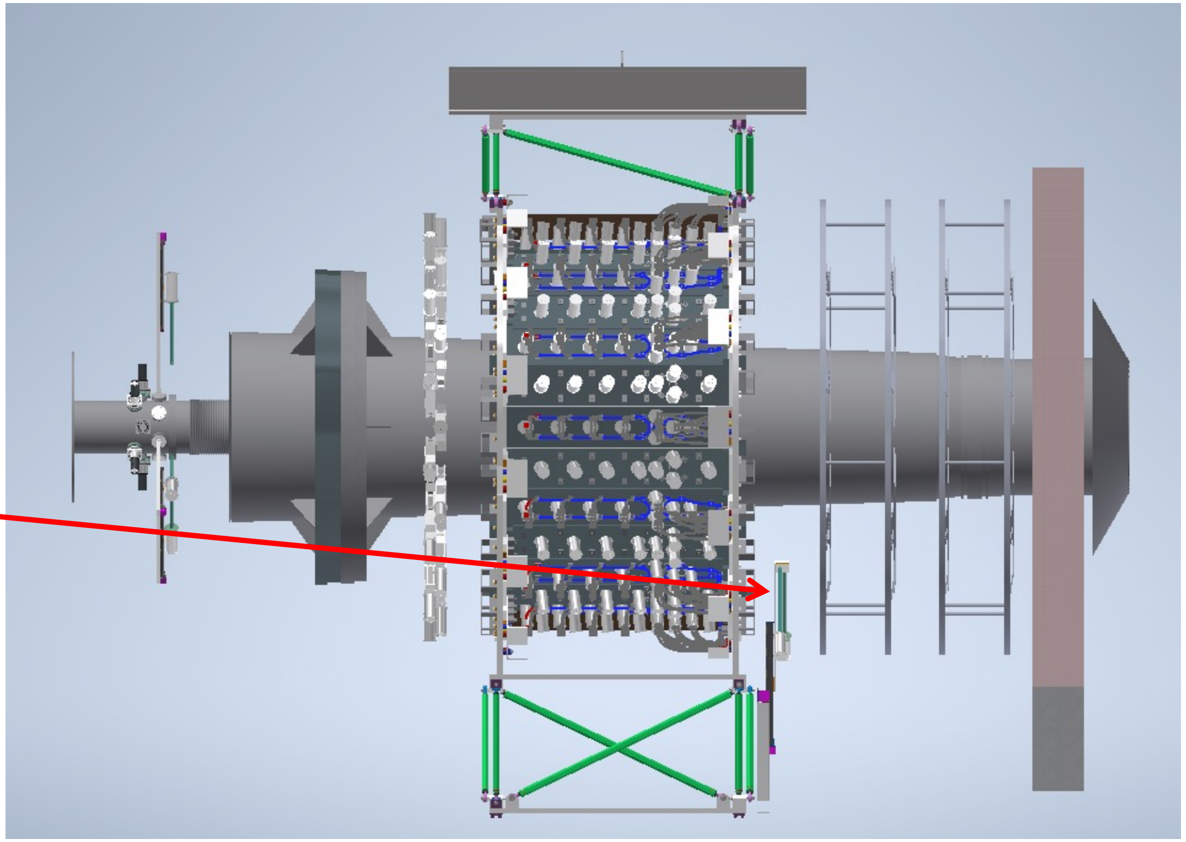


Upstream 2D Scanner Requirements and Goals

- Measured the scattered rate distribution in a sector (or combination of two sectors to make a complete one) at low and high beam currents; verify they are the same; monitor stability of kinematics and backgrounds
- Operates in counting and integrating modes
- Full scan in < 1 hour
- Can monitor for shifts ~ 0.5 mm in the profile, which could happen from a drift of 10^{-3} in the B*dl of the spectrometer field
- Can provide a more regular (if needed) monitor of the stability of the profile than the full tracking system which will only be deployed every few weeks

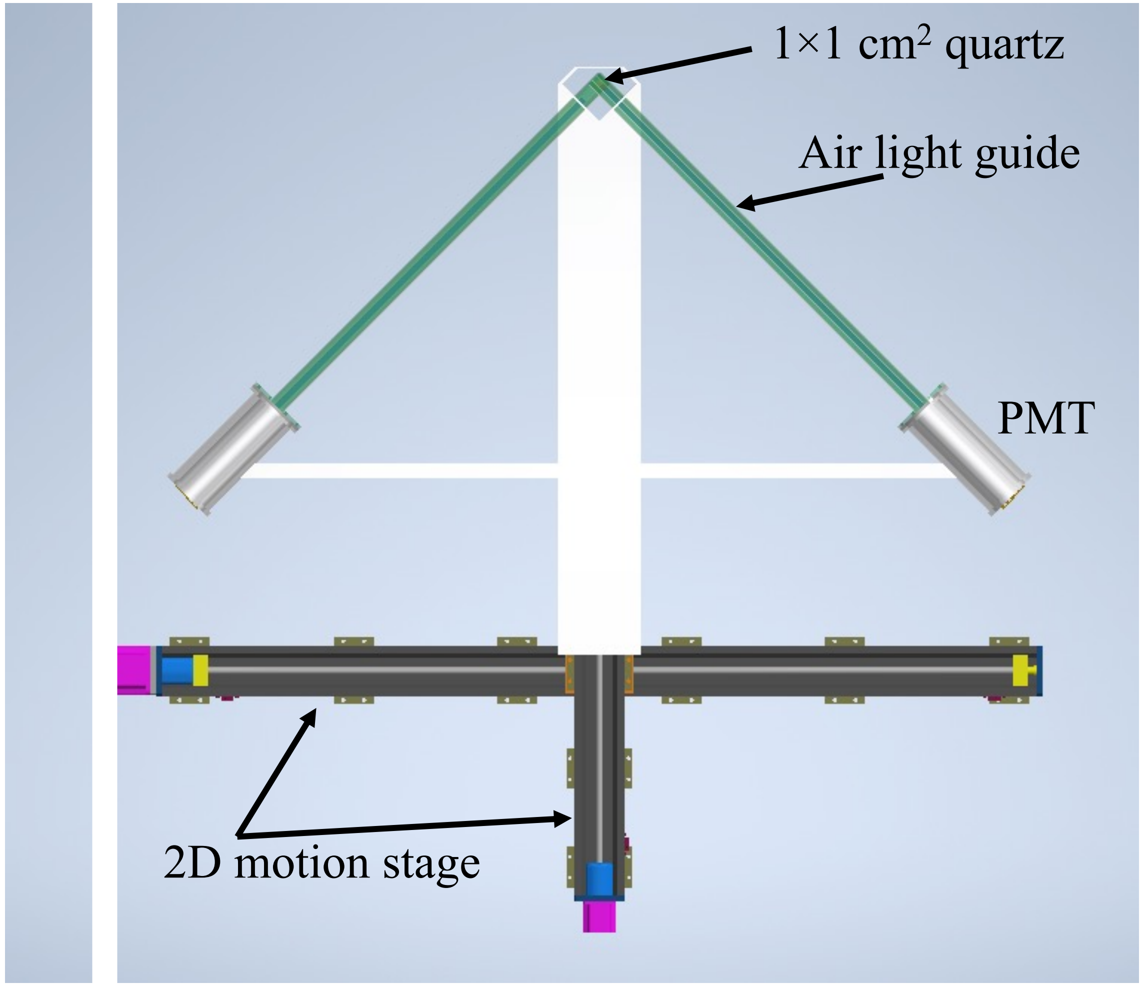


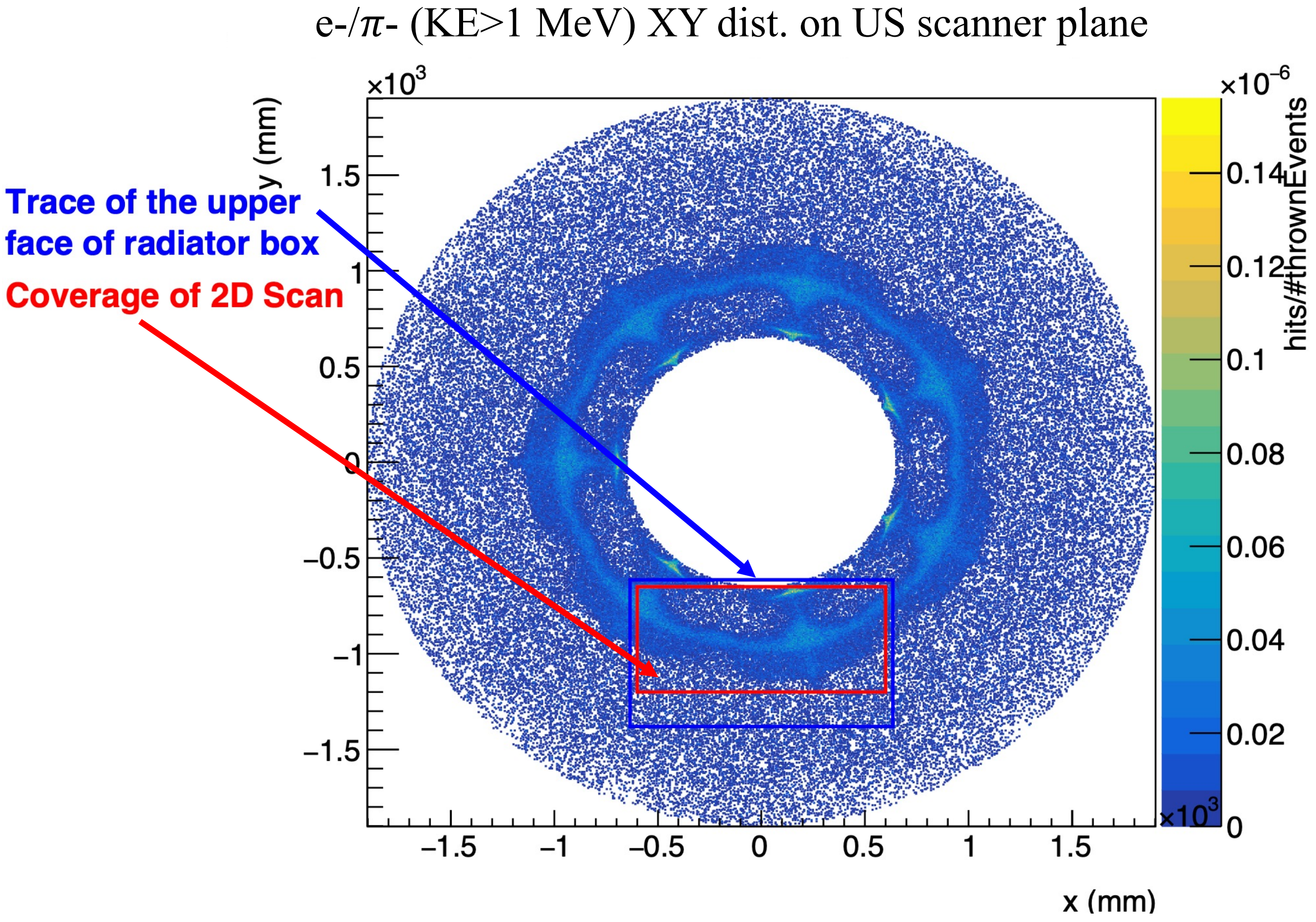




Upstream 2D Scanner Design and Expected Rate

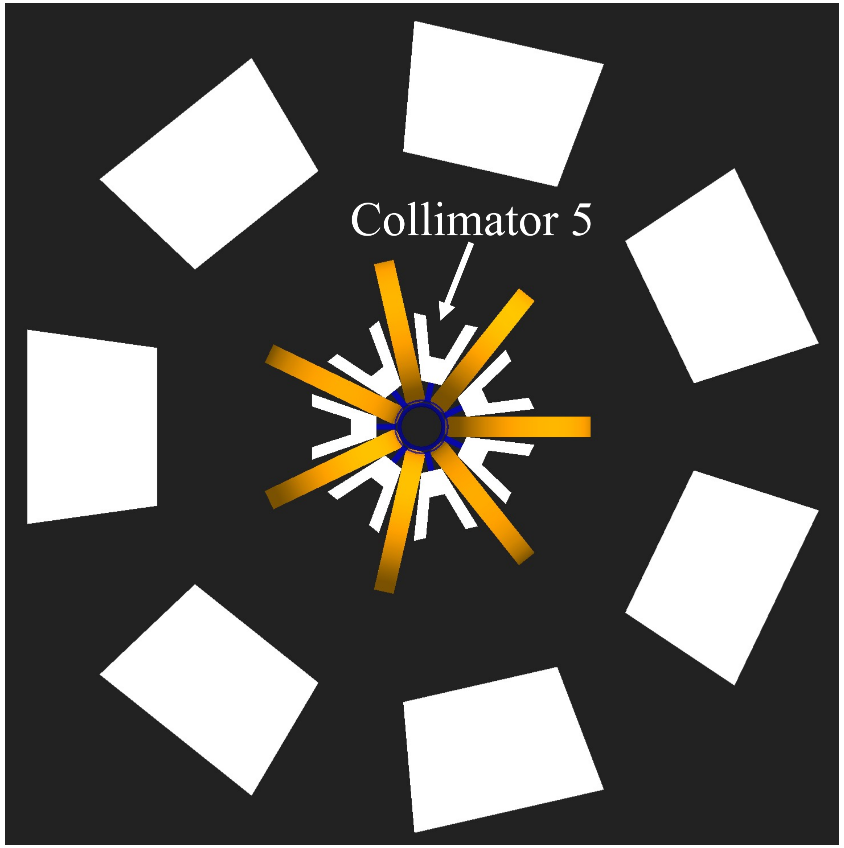
- A preliminary design uses the concept from Qweak (1×1 cm^2 quartz tile)
- Monitor scattered rate distribution for combination of two sectors at low and high beam currents
- Will see a rate up to ~2.62 MHz/μA



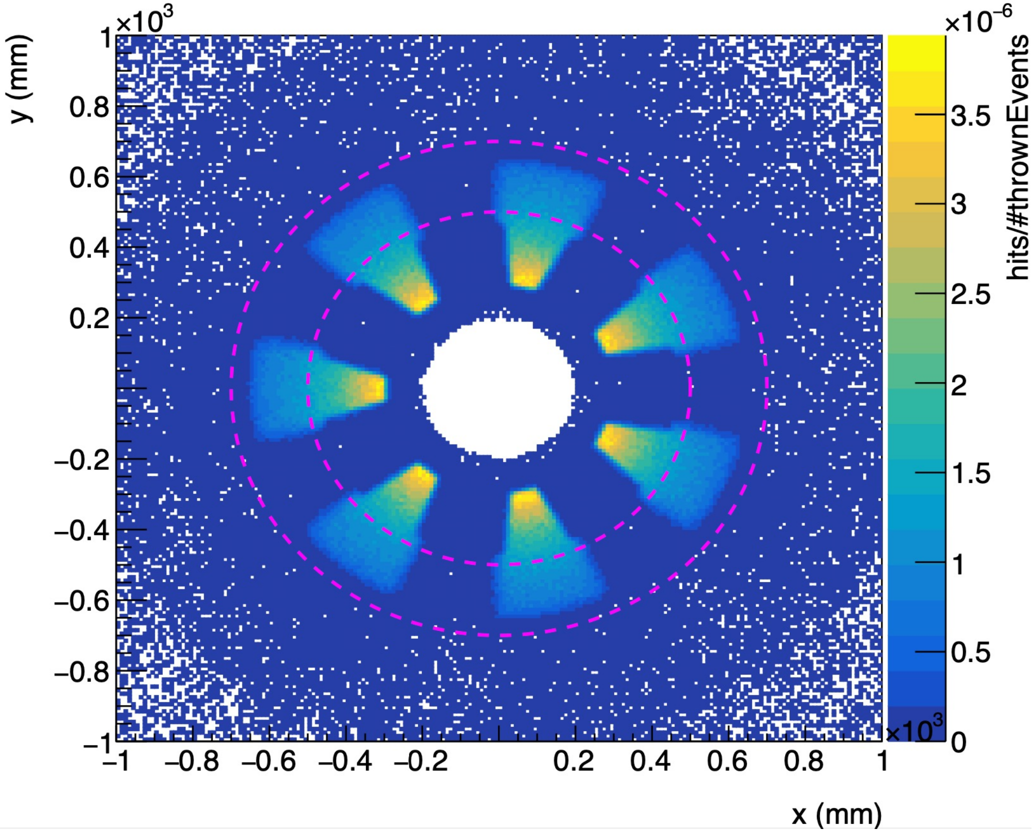


Downstream Linear Scanner Requirements and Goals

- Four 1-D scanners scan radially 55 – 75 cm at four azimuthal locations (just upstream SAM Z-location)
- Use magnet off spectrometer with thick (4 cm) carbon target
- Expected to pick off the outer edge of collimator 2 (acceptance defining collimator)
- We can also use them for collimator 5 alignment check if we increase the range to 25 – 75 cm
  - ❖ This needs more study and design concept
- Expect a sharp transition in charged particle rate at outer radius of acceptance defining collimator

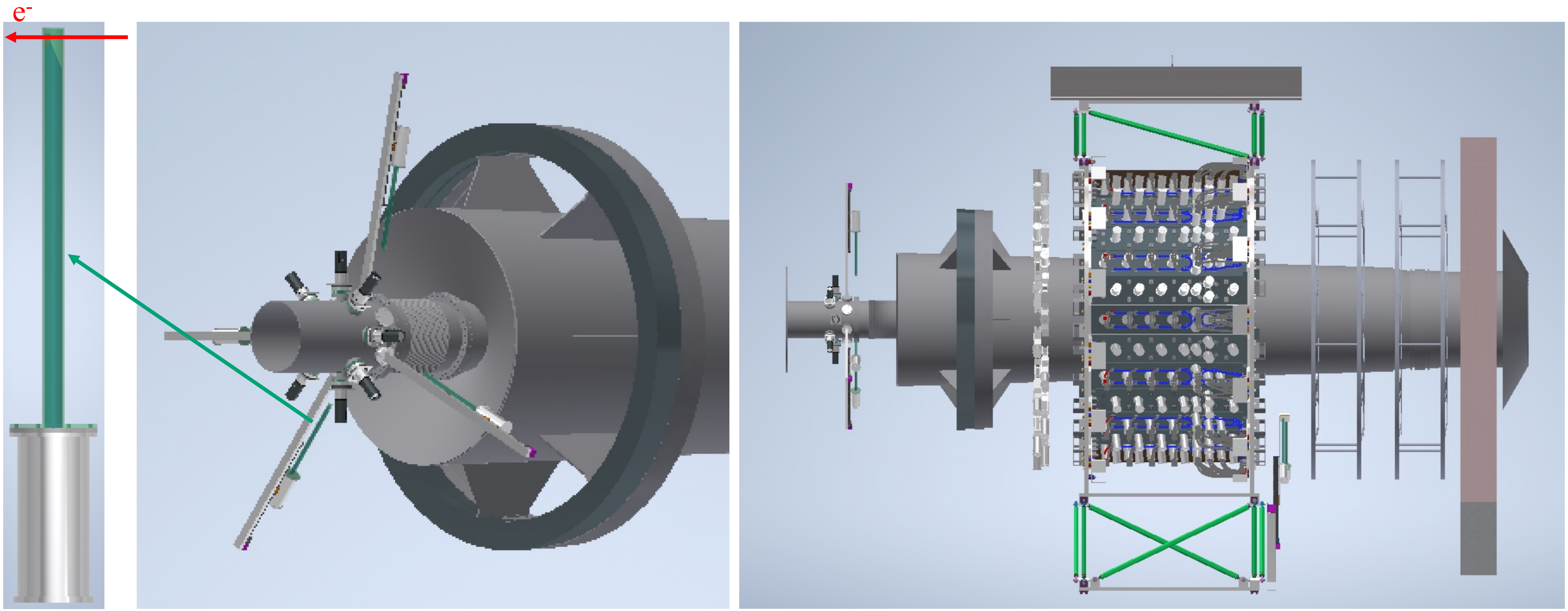


e-/π- (KE>1 MeV) XY dist. on DS scanner plane



Downstream Linear Scanner Design

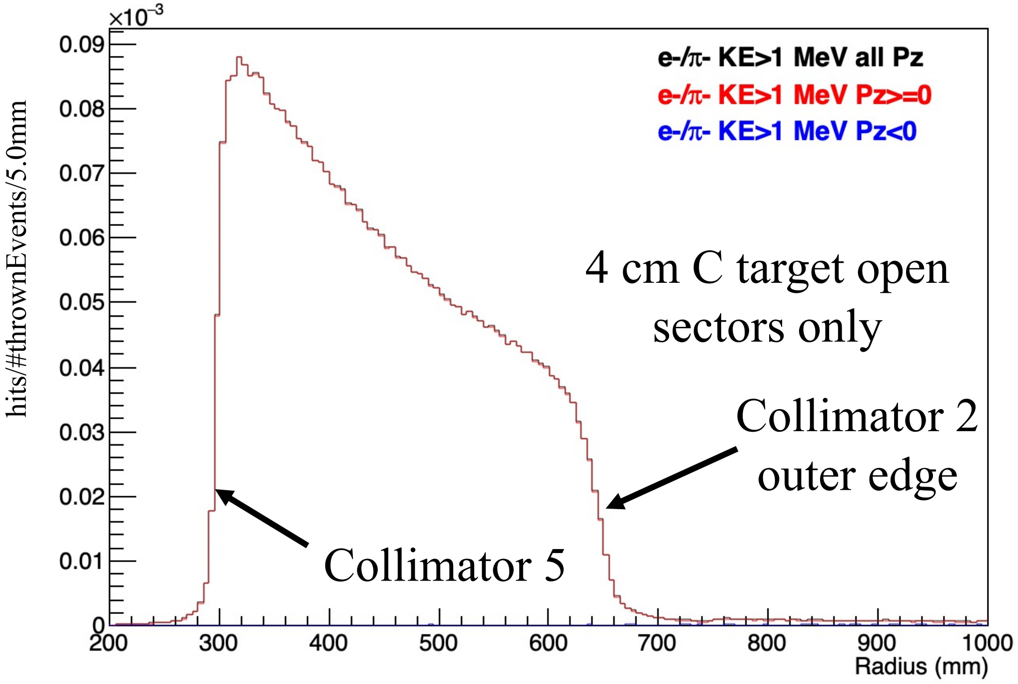
- A preliminary design uses 1×1 cm^2 quartz tile
- Each scanner uses air core lightguide and a 3-inch diameter PMT window
- Current plan is to use Velmex sliding motion stage for linear motion
- Will be parked at larger radii when not in use



Rate Profile in Downstream Linear Scanners

- Left: with 4 cm thick carbon target
- Right: ratio of forward to backward particle's rate
- Thicker target helps suppress backscattered particles

e-/π- (KE>1 MeV) radial dist. on DS scanner plane



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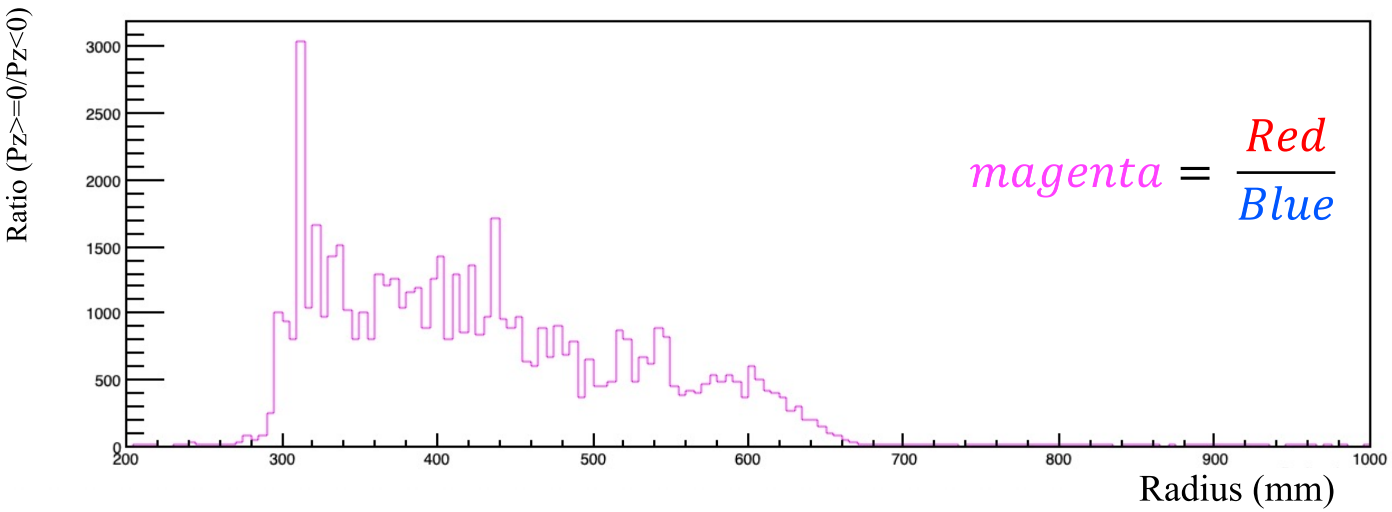

$$magenta = \frac{Red}{Blue}$$

Summary

- The MOLLER experiment will use PVeS to search new dynamics
  - ➢ 0.1% precision on $\sin^2_{\theta_W}$
- MOLLER is currently working on final design of all subsystems and anticipates DOE CD-2 near the end of 2022
- VT is responsible for design, construction, and operation of variou scattered beam monitors and scanners
  - ➢ Detector prototype construction will begin this summer