MOLLER Overview

Brynne Blaikie

University of Manitoba

on behalf of the MOLLER Collaboration

Hall A Winter Collaboration Meeting

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Overview

Møller Scattering

Weak Mixing Angle

MOLLER Apparatus

MOLLER Subsystems

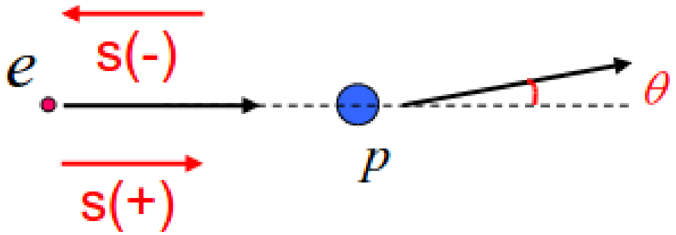
- Target
- Spectrometers & Collimation
- Detectors

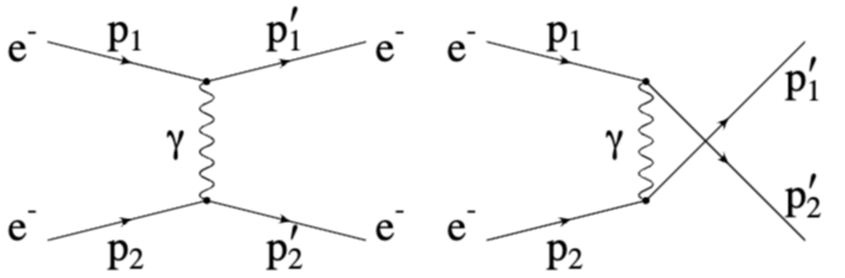
Obtaining A_{PV}

Future Impact

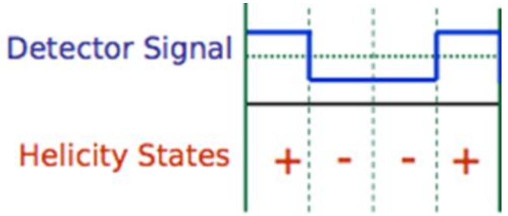
Møller Scattering

- longitudinally polarized electrons incident on unpolarized target electrons
- Parity-Violating Electron Scattering (PVES)
- measure fractional rate difference in Møller scattering

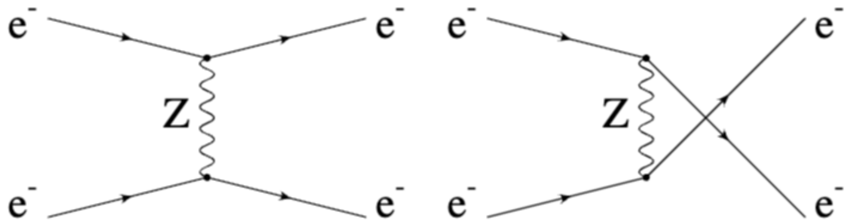




Electromagnetic Interaction: conserves parity



$$A_{PV} = \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L}$$



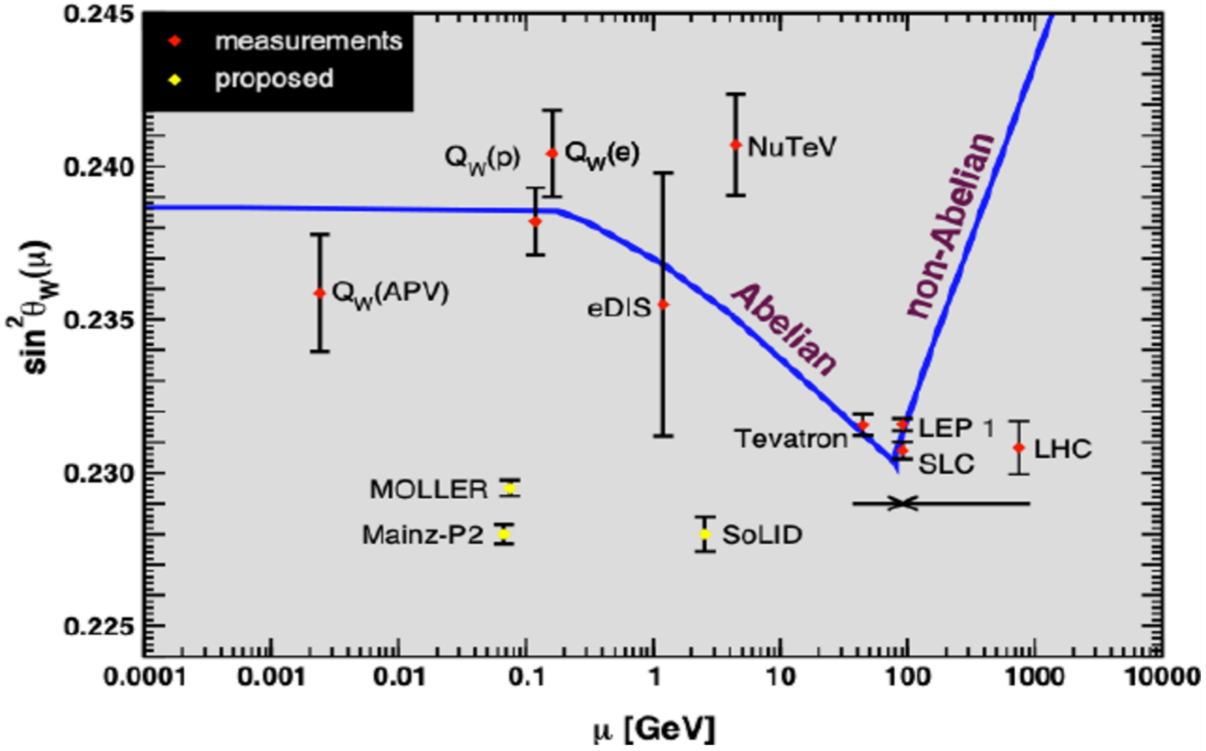
Weak Interaction: does not conserve parity

Challenges:

- PVES asymmetries are ~10^{-6} to 10^{-9}
- Requires high luminosity and high precision

A_{PV} predicted to be ≈ 33 ppb

Weak Mixing Angle



- "running" with interaction energy due to varying radiative corrections
- low Q^2 indirect probing new physics at multi-TeV
- **MOLLER** will determine $\sin^2\theta_W$ at average $Q^2 = 0.0056\ \mathrm{GeV}^2$ using **parity violating electron scattering**:

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

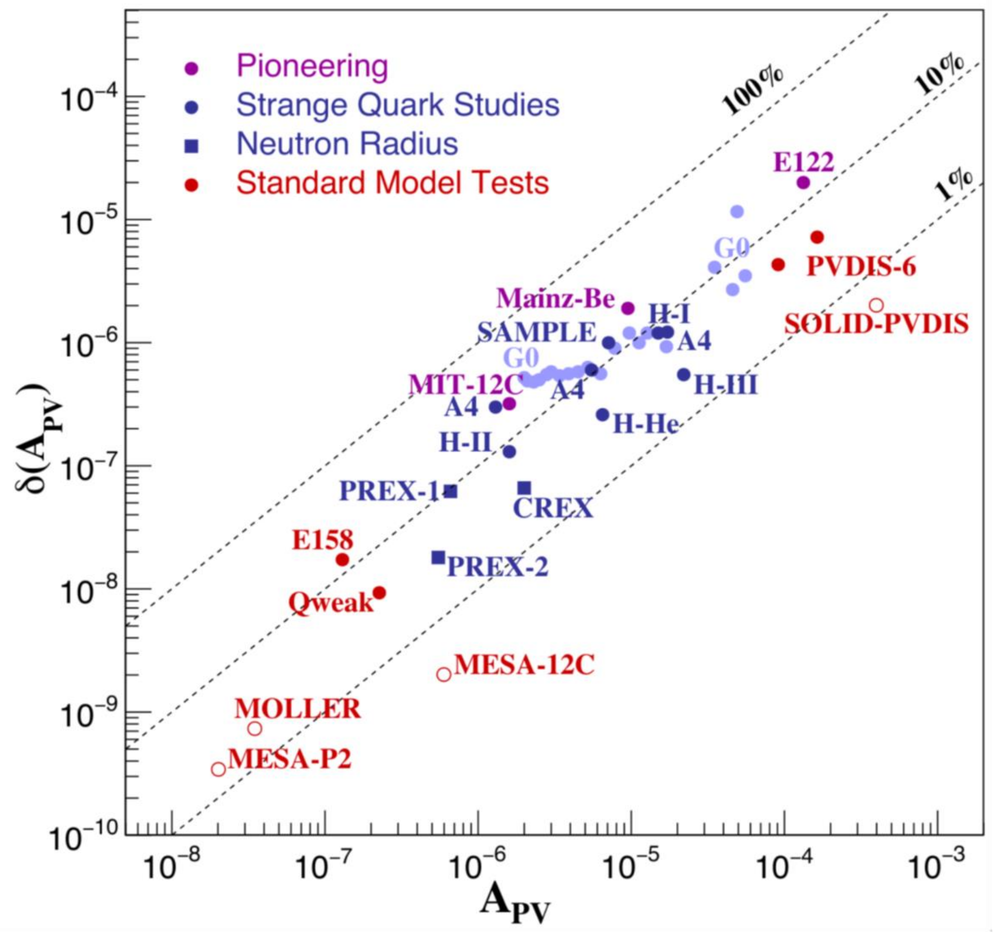
with $Q_W^e = 1 - 4\sin^2\theta_W \sim 0.0435$

MOLLER Nominal Parameters

Measurement Of a Lepton Lepton Electroweak Reaction

Key Features:

- $\mathcal{L} = 3 \times 10^{39}\ cm^{-2} \cdot s^{-1}$ $E_{beam} = 11\ GeV$
- $P_{beam} \geq 90 \pm 0.5\ \%$ $I_{beam} = 65\ \mu A$
- rapid helicity flip (1.92 kHz), high beam stability
- high precision polarimetry
- high power LH_2 target
- large acceptance
- systematic uncertainty control
- 344 PAC days = 8256 hours = 3 - 4 calendar years



A_{PV} predicted to be ≈ 33 ppb

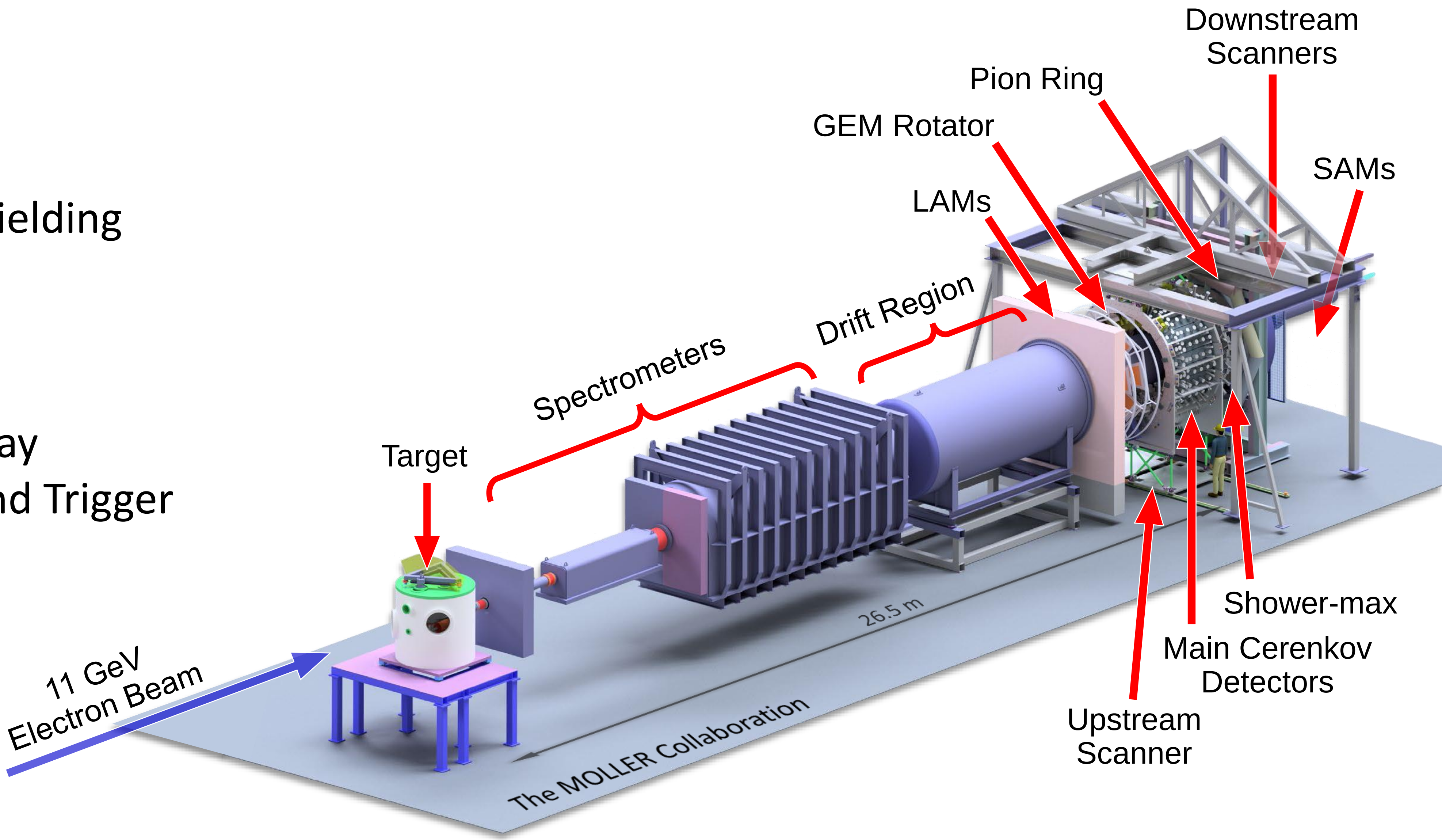
MOLLER Goal:

$$\delta A_{PV} = 0.8 \text{ ppb} \quad \Rightarrow \Delta Q_W^e = 2.4\% \quad \Rightarrow \Delta \sin^2\theta_W = 0.1\%$$

MOLLER Subsystems and Apparatus

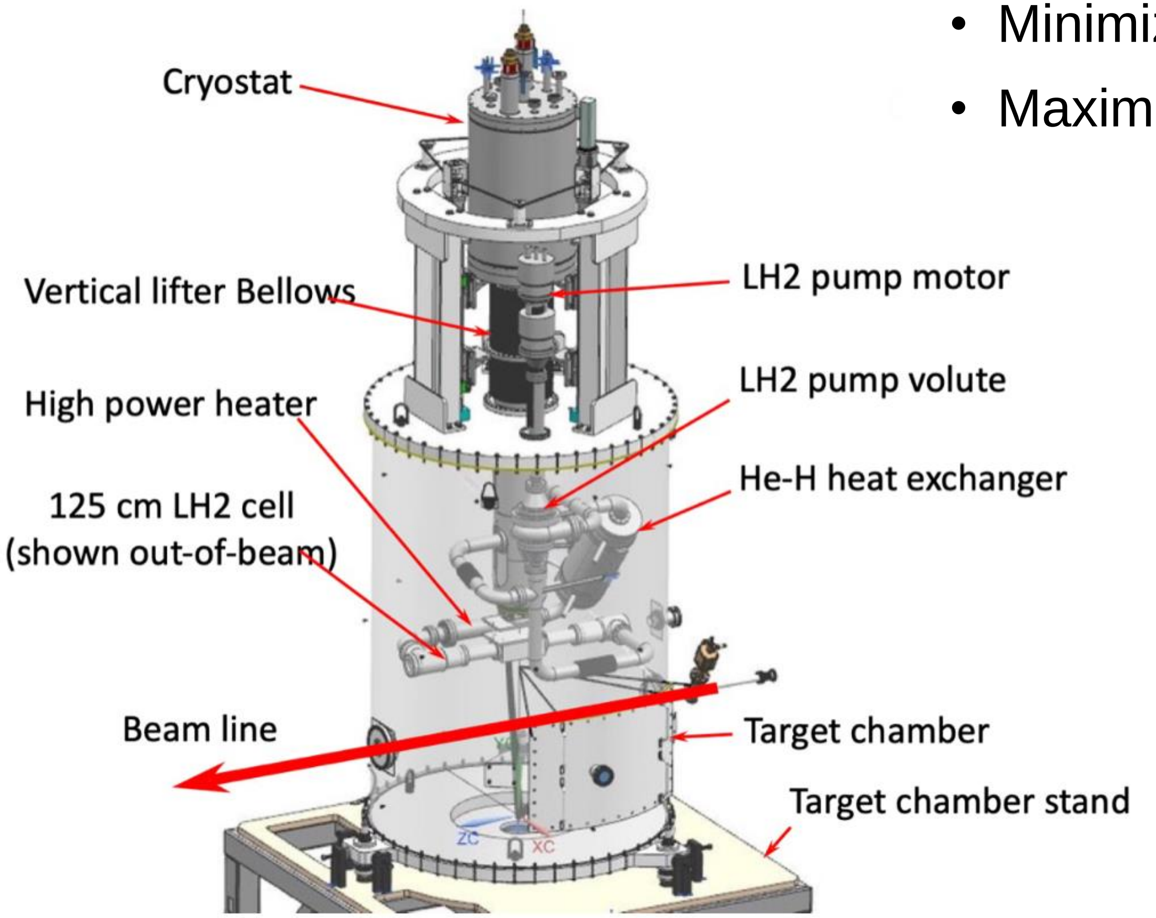
Subsystems:

Polarized Beam
Polarimetry
Target System
Collimation and Shielding
Spectrometers
Auxiliary Detectors
Tracking Detectors
Main Cerenkov Array
Data Acquisition and Trigger

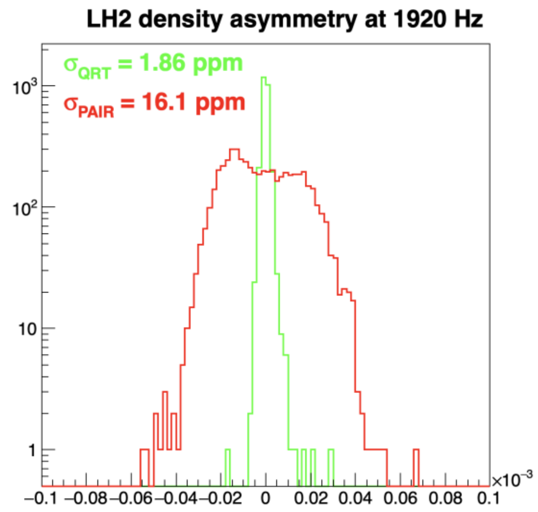


Target System

- **Requirements:**
- Minimize target density fluctuations < 30 ppm for 70 μA beam
- Maximize luminosity



- 125 cm long LH_2 target
- 4 kW total power
- 5 x 5 mm^2 raster
- designed using CFD (computational fluid dynamics)

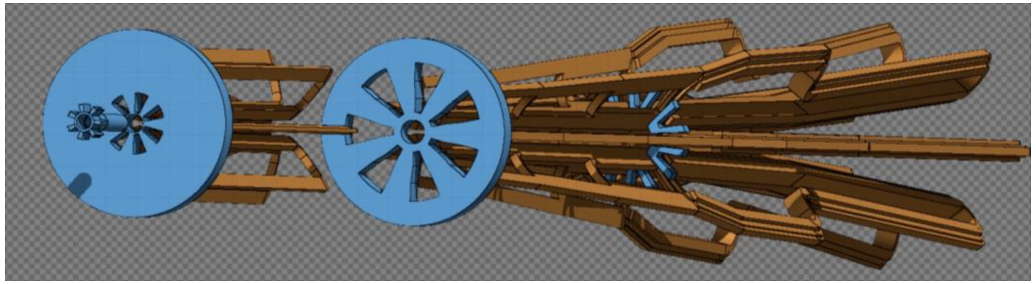


Spectrometer, Precision Collimation, and Shielding

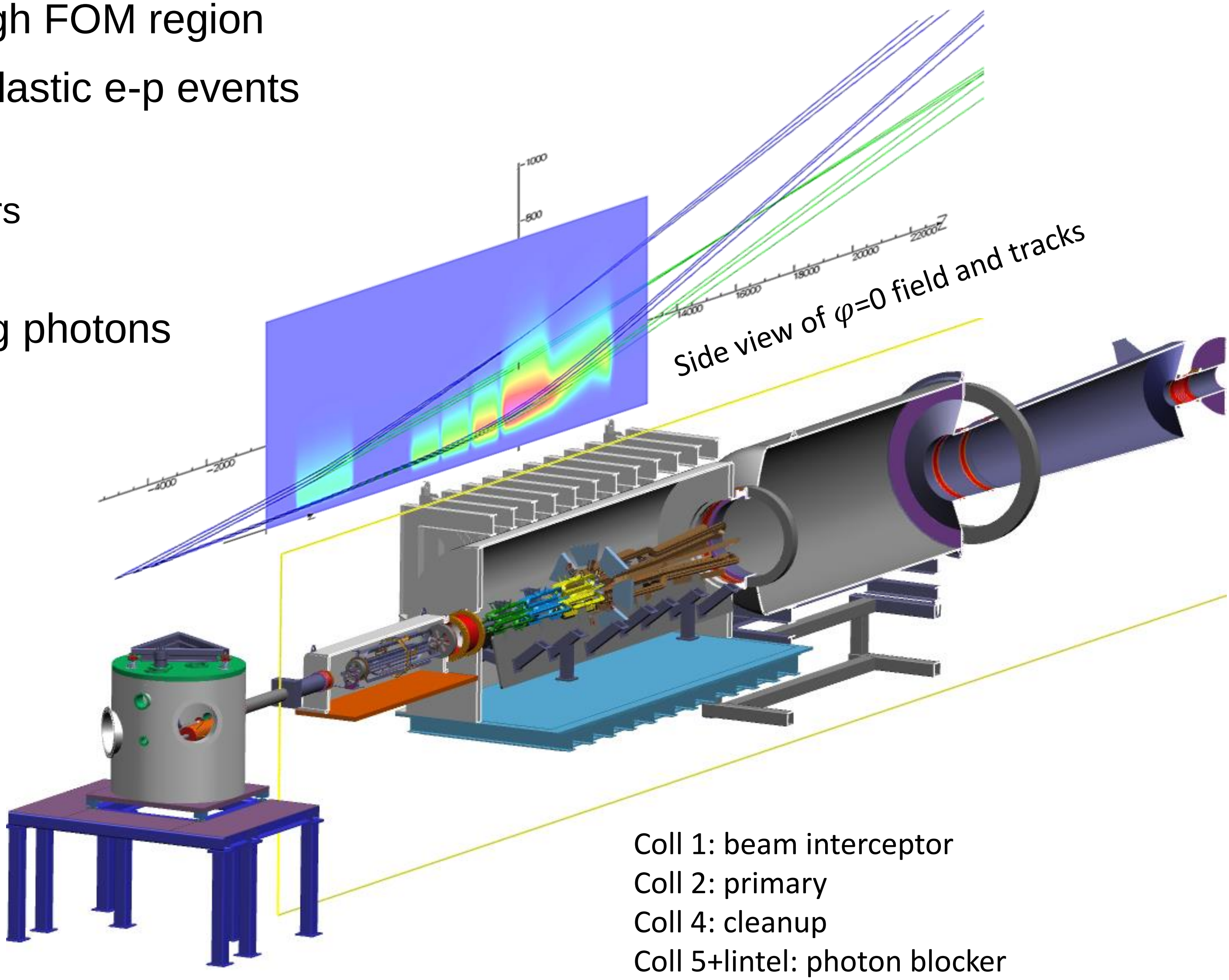
Requirements:

- full azimuthal acceptance of Møller events in high FOM region
- separation of Møller events from elastic and inelastic e-p events
- precise collimation
  - remove line-of-sight between target and detectors
  - “2-bounce” to minimize backgrounds
- channel for degraded beam and bremsstrahlung photons to beam dump
- shielding toroidal coils

5 toroidal magnets with 7-fold symmetry



1 2 4 5

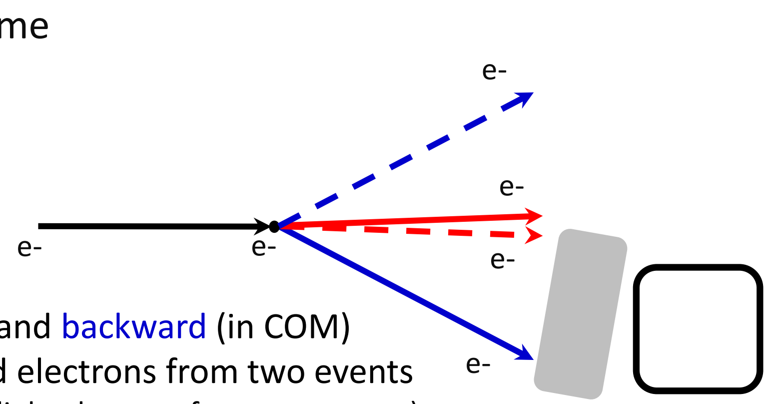


Coll 1: beam interceptor
Coll 2: primary
Coll 4: cleanup
Coll 5+lintel: photon blocker

100% Azimuthal Acceptance

MOLLER

Lab Frame



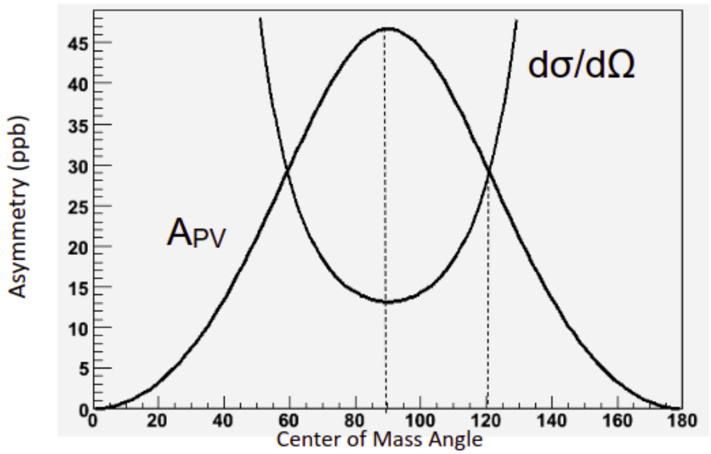
Detectors in open sectors

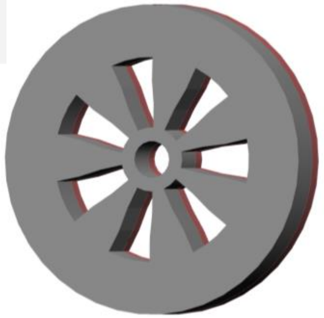
Coils in closed sectors

forward and backward (in COM) scattered electrons from two events
(line type links electrons from same event)

Any odd number of coils will allow for 100% φ acceptance

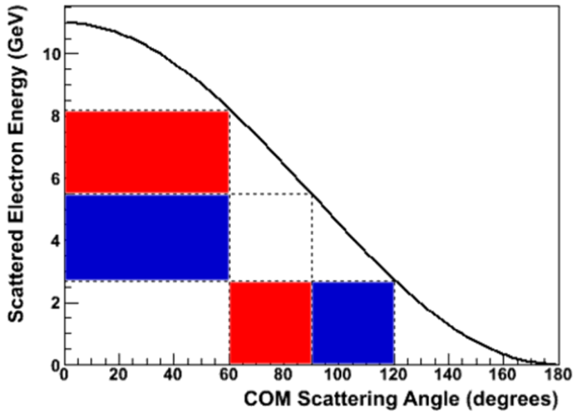
Highest figure of merit at $\theta_{CM} = 90^{o}$

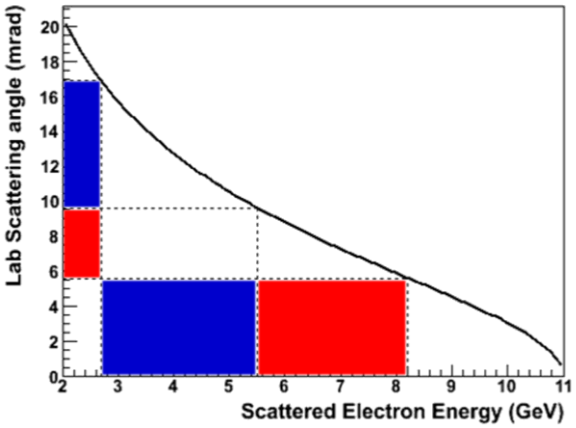


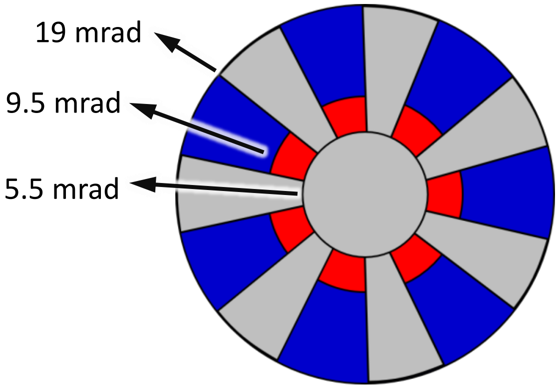


$$60^{\circ} \leq \theta_{COM} \leq 120^{\circ}$$

$$2.75 \leq E_{scat} \leq 8.25\ GeV$$







acceptance defining Coll.2
5 m downstream of target

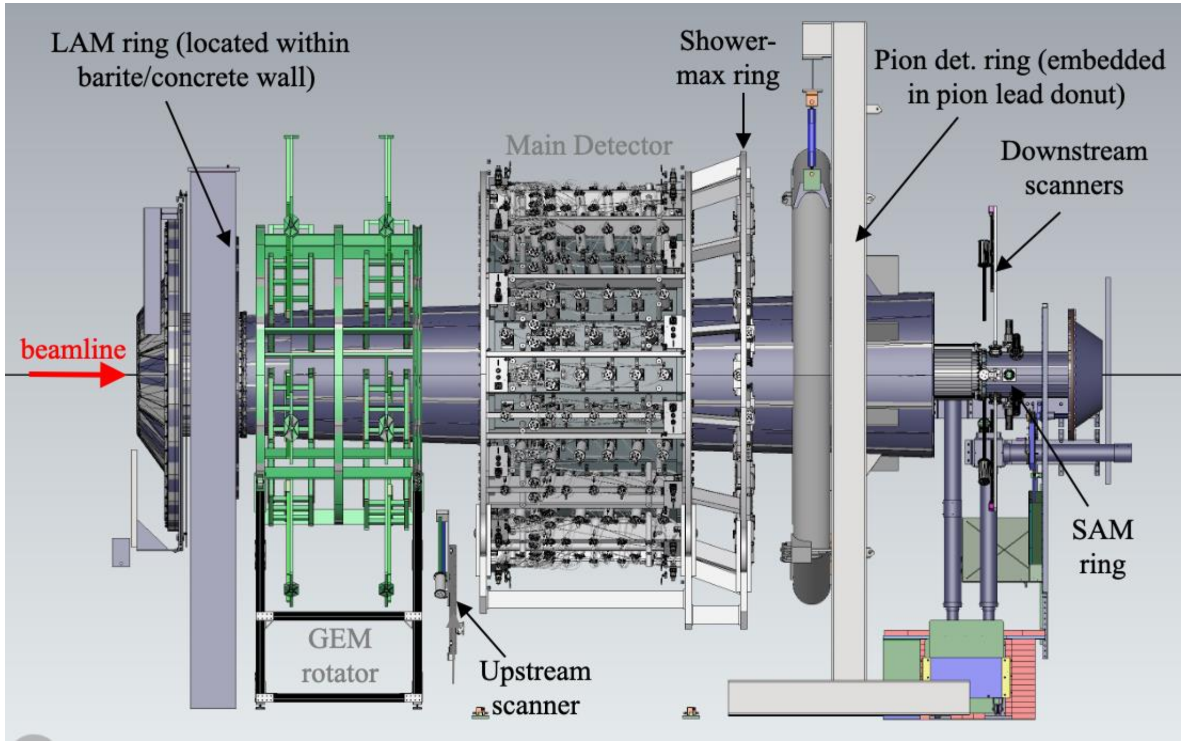
- Forward Scattering
- Backward Scattering
- Not in Acceptance

Detector Overview

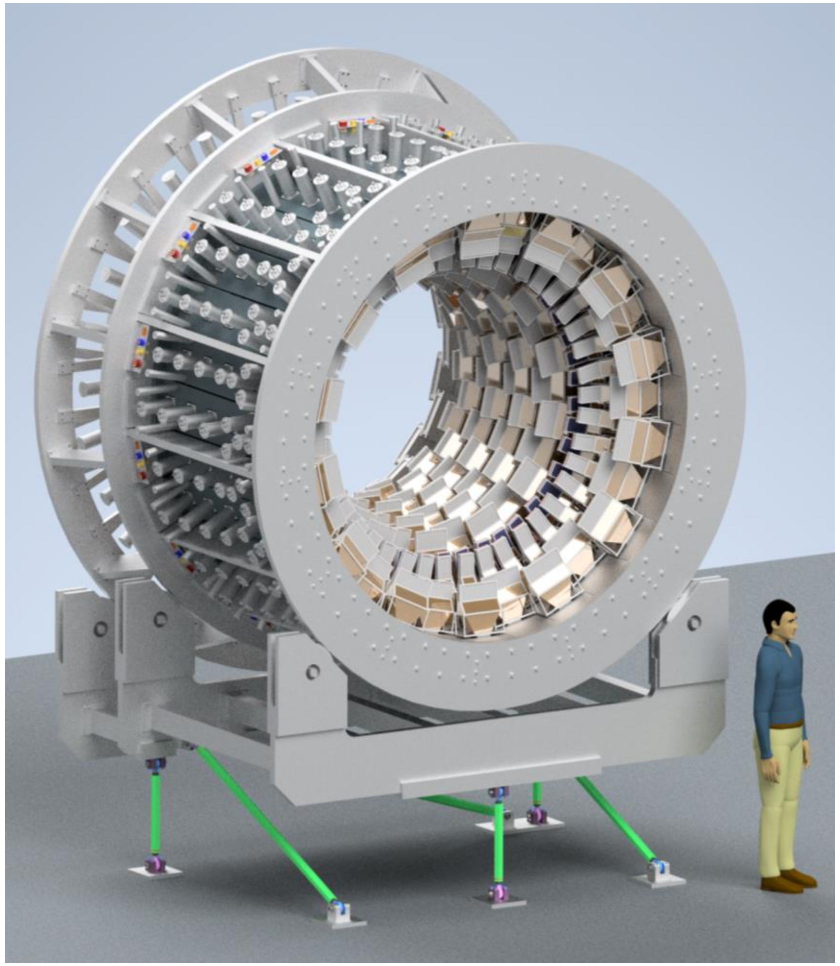
Integrating (current mode) detectors: asymmetry measurements in both signal and background, beam and target monitoring

Tracking (counting mode) detectors: spectrometer calibration, electron scattering angle distribution and background measurements

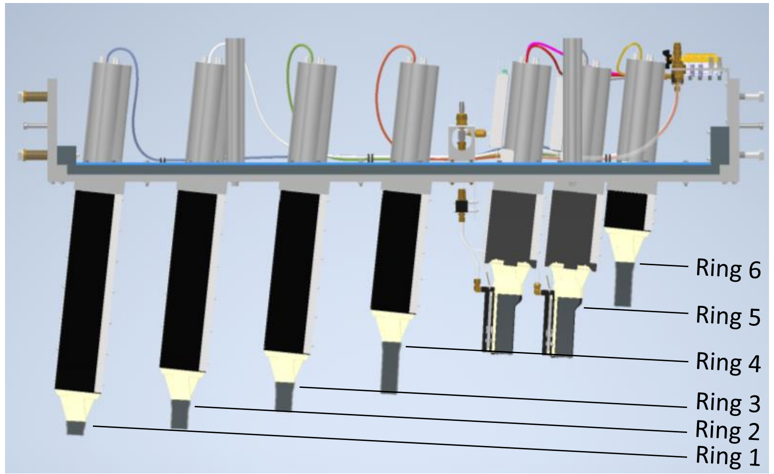
- GEMs and Scintillators
- Shower-max
- Pion Detectors
- Scattered Beam Monitors
  - Large Angle Monitors
  - Small Angle Monitors
  - Diffuse Beam Monitors
  - Upstream Scanners
  - Downstream Scanners
- HVMAPS
- Main Cerenkov Detectors

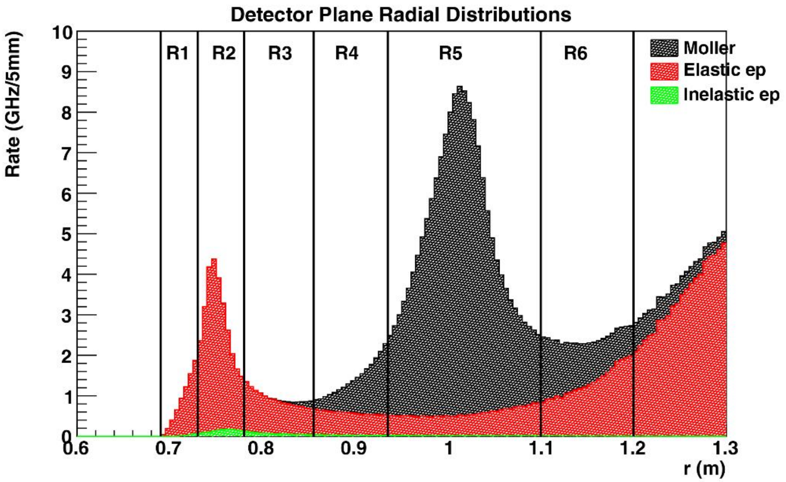


Main Detector Segmentation

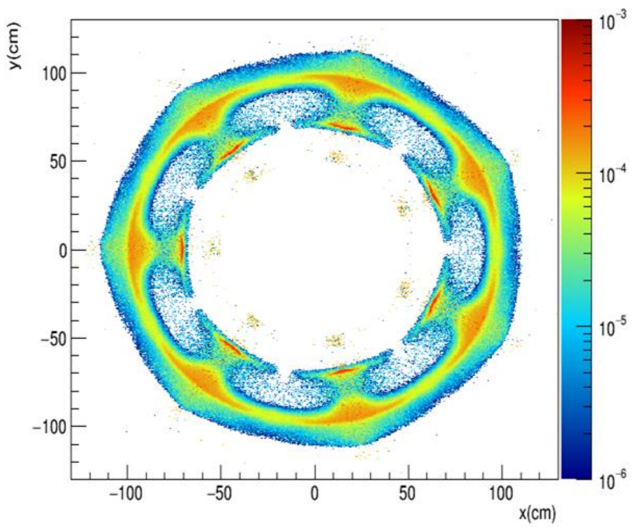


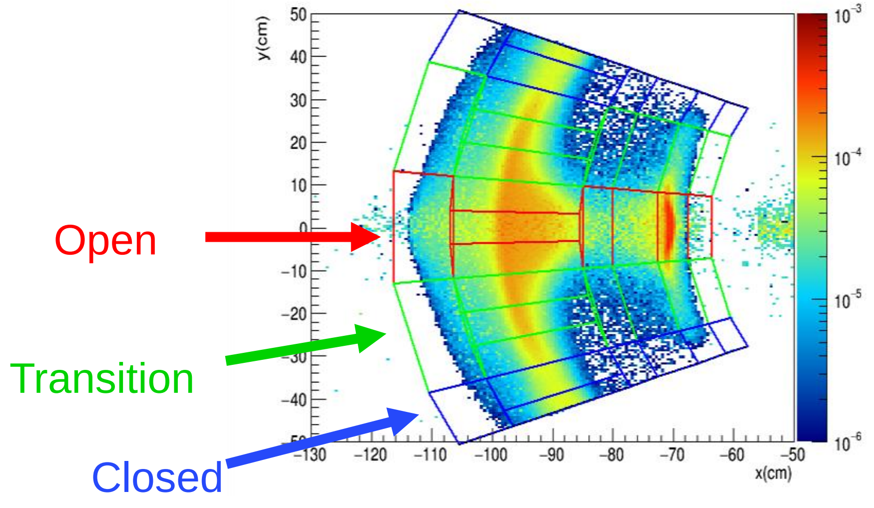
- 224 Detectors
  - Radially split into 6 Rings
  - Azimuthally split into 28 Segments
- Located 26.5 m downstream from target
  - Sufficient space for spectrometers to separate e-e and e-p peaks
- Full coverage of Møller events
- Integration and event mode data collection





Main Detector Segmentation





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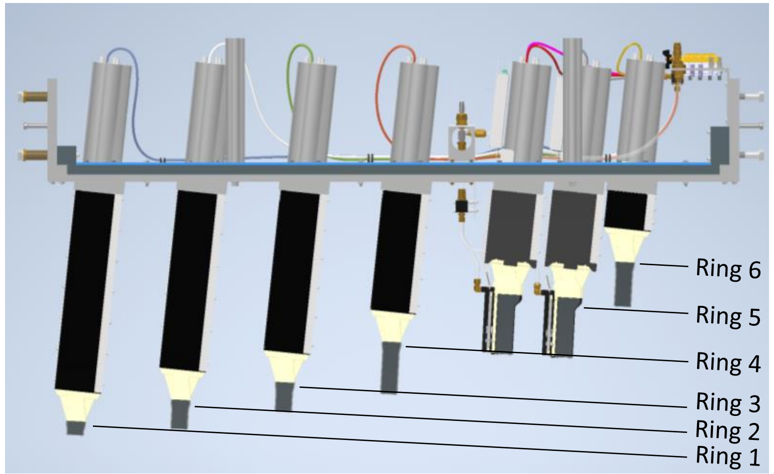
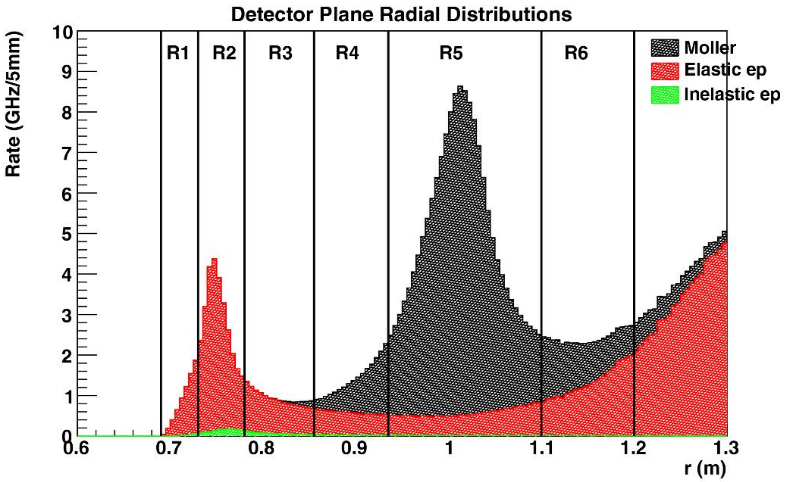
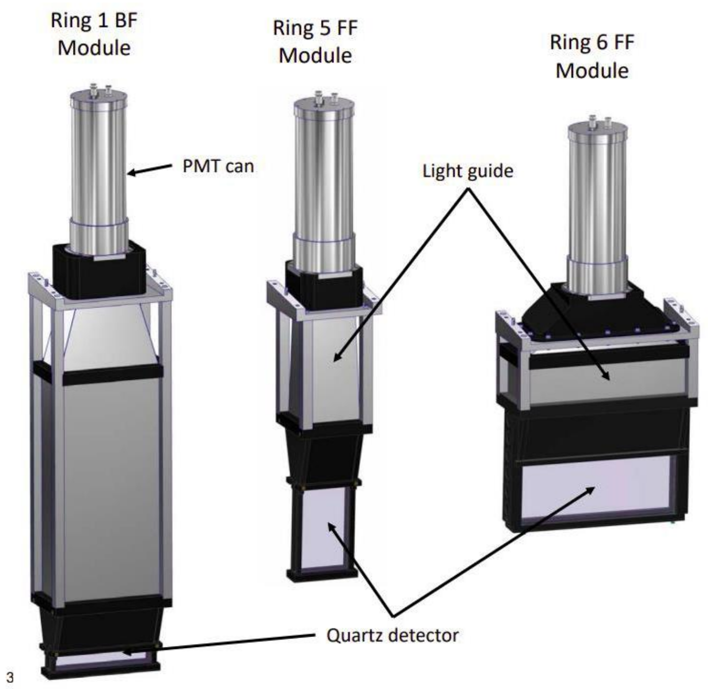
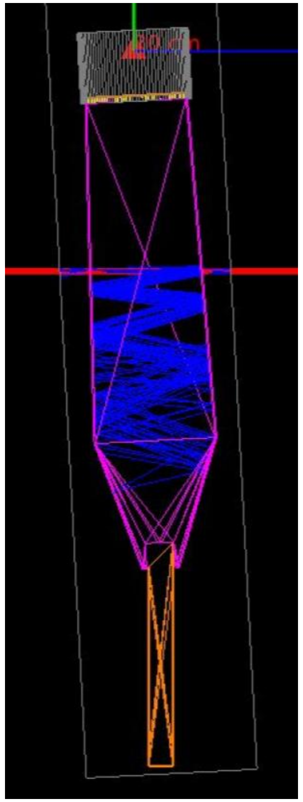




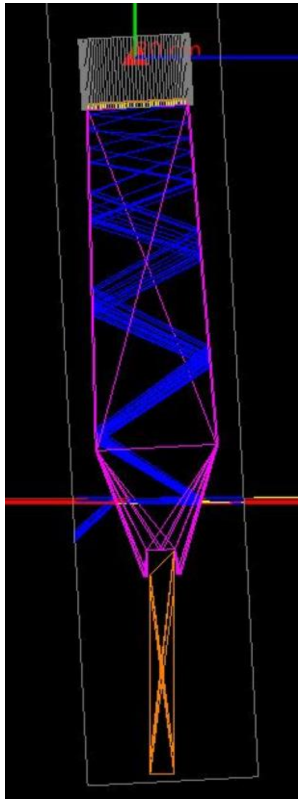
Main Detector Elements



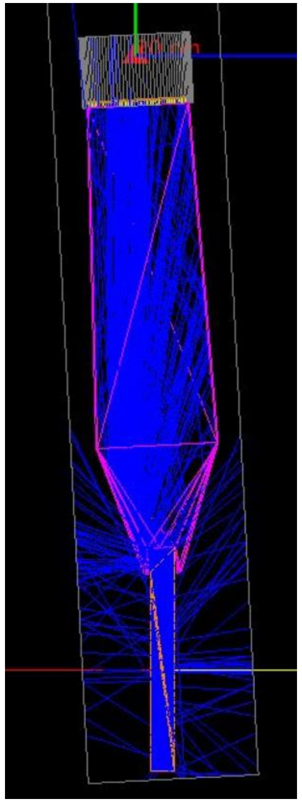
Scattered Electrons



Upper guide events



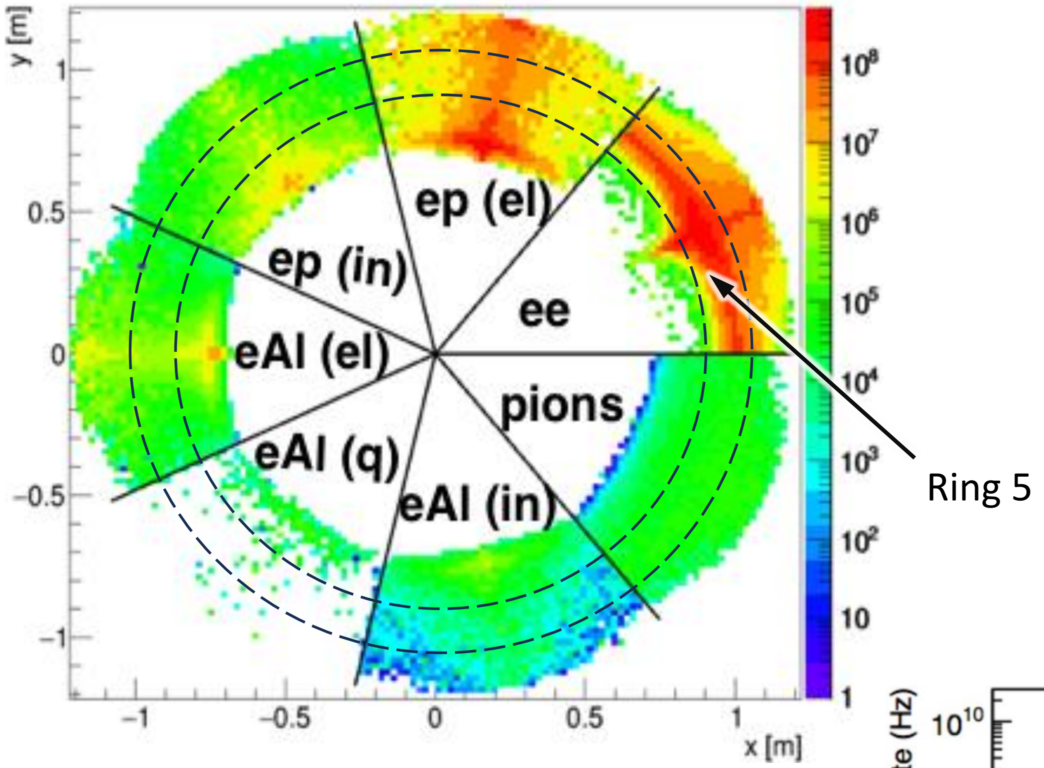
Lower guide events



Quartz events

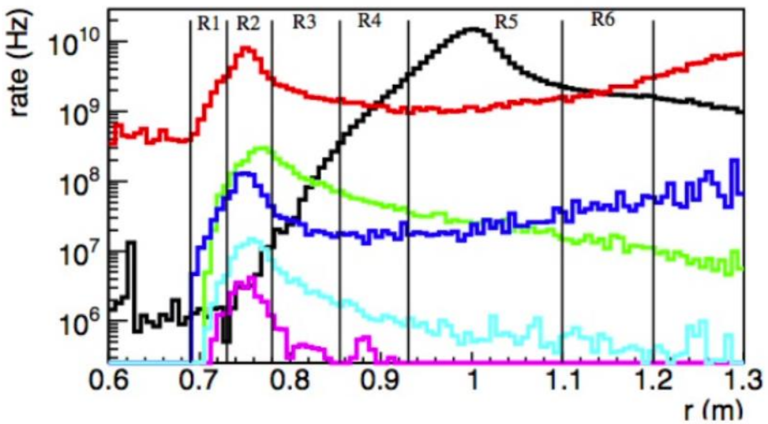
Irreducible Backgrounds

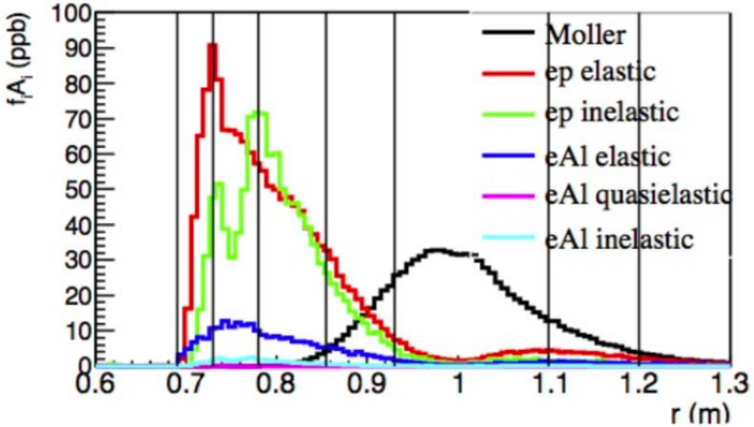
Signal and Background Distributions



- combination radial + azimuthal binning measures distribution of backgrounds for deconvolution from Møller signal

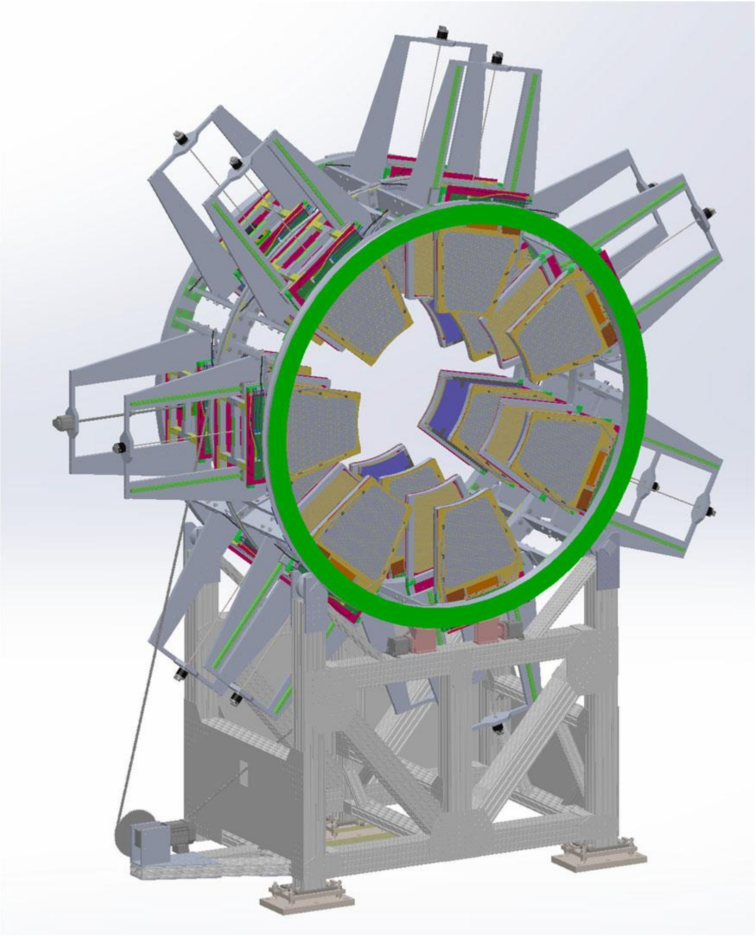
- background scattering processes may match energy-angle of Møller scattering

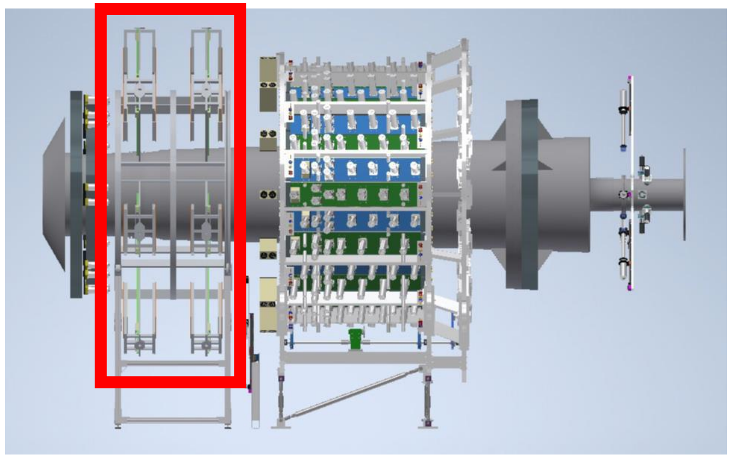




Tracking – GEM Rotator

Counting Mode Measurements: backgrounds, kinematics, spectrometer diagnostics, calibration





- 28 identical GEM modules
  - 4 layers of 7 GEM modules
- 14 identical trigger scintillators
  - 2 layers of 7 scintillators

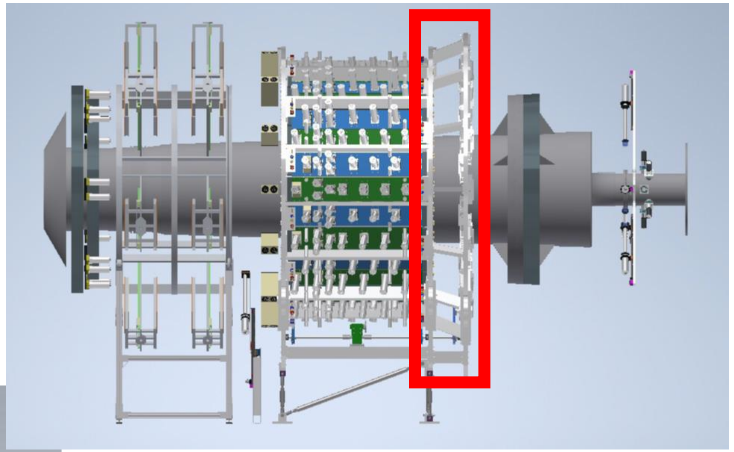
Requirements:

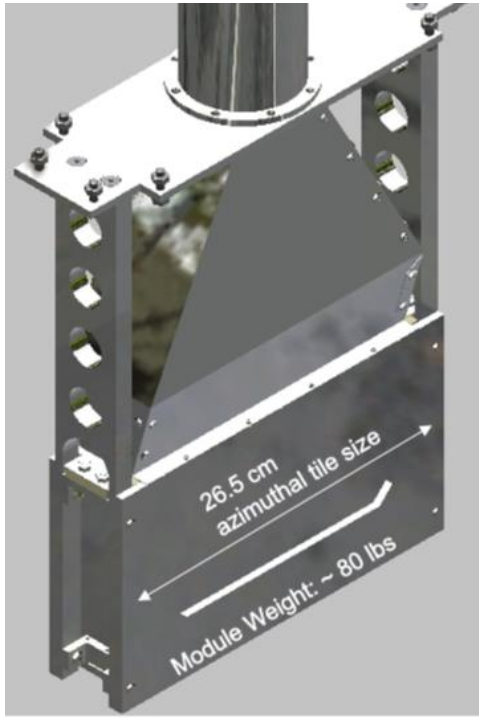
- stand capable of rotating 51.4° (full 360° coverage) with minimum 3 stopping positions
- radial extraction of GEMs and scintillators during high current beam
- minimize mass in scattered electron path
- structure primarily manufactured with aluminium

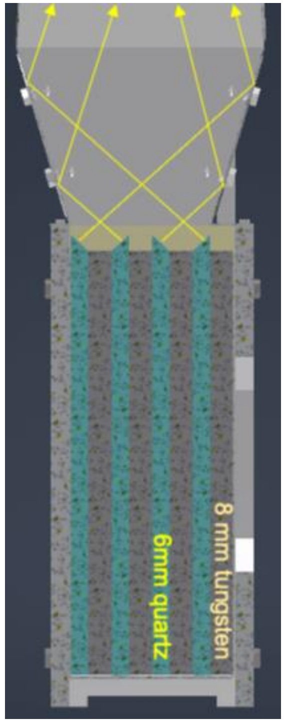
Shower-max

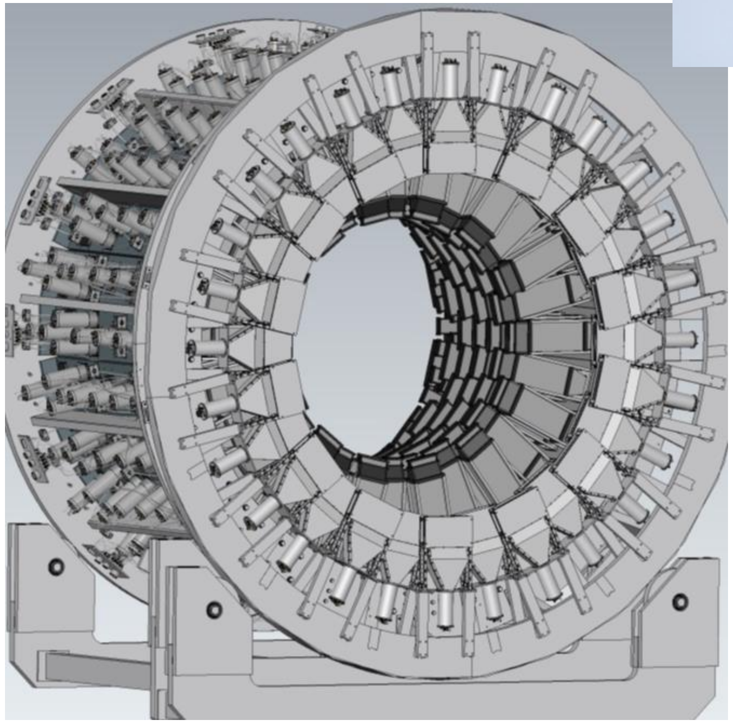
Goal: second, independent measurement of Møller peak

- electromagnetic sampling calorimeter
  - higher E – samples more, lower E – samples less
- 28 modules downstream of Ring 5
- layered quartz and tungsten





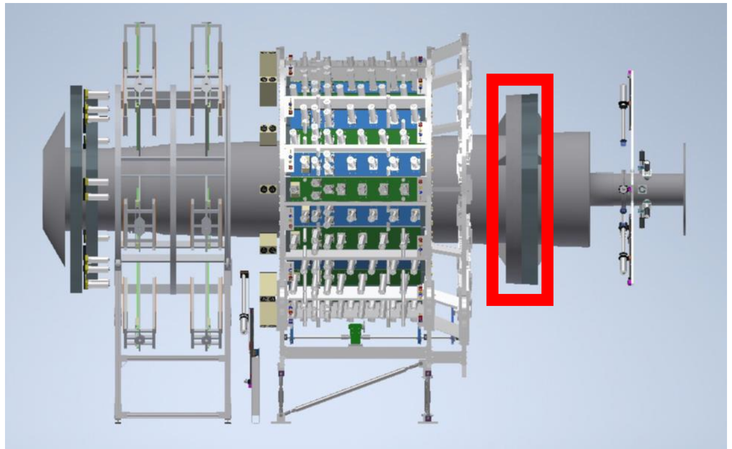


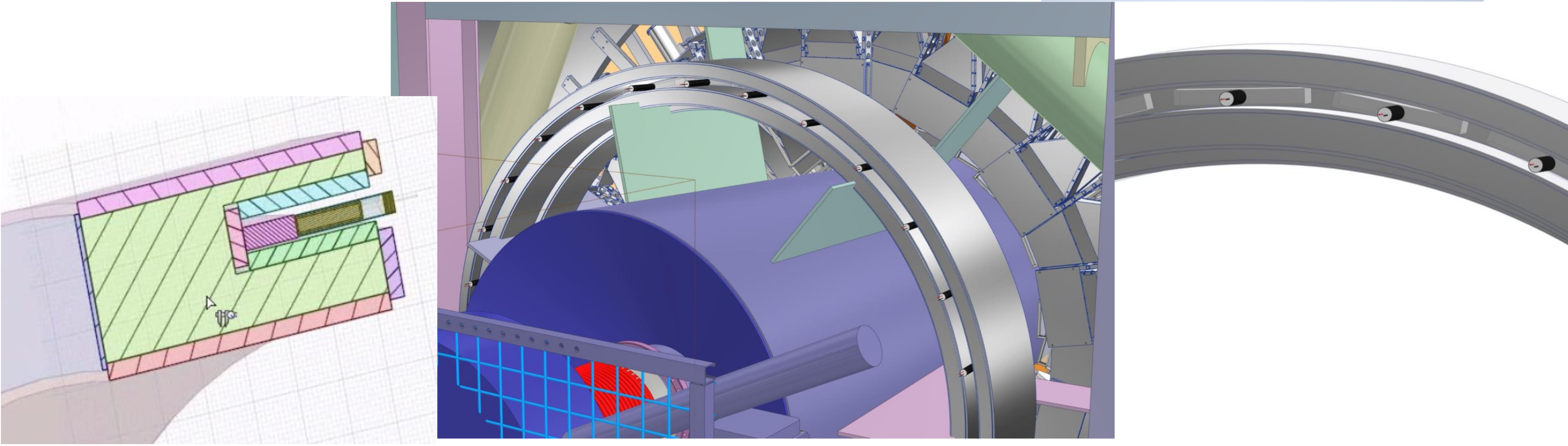


Pion Detectors

Goal: Quantify pion background contamination in Møller signal asymmetries

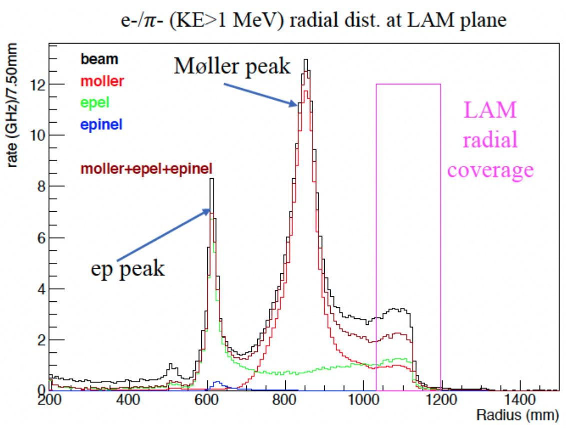
- 28 identical acrylic Cerenkov detectors
  - 7 cm deep x 21 cm wide x 1” thick
- encased in Pb donut, downstream of shower-max detectors to suppress Møller electrons by > 10^3

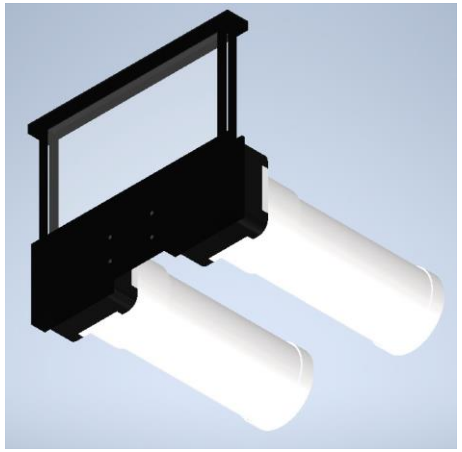


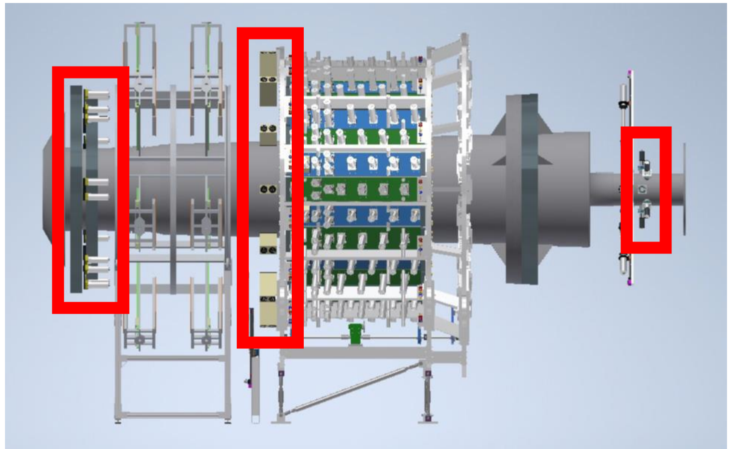


Scattered Beam Monitors

- 7 Large Angle Monitors (LAMs)
  - rate dominated by e-p elastic tail

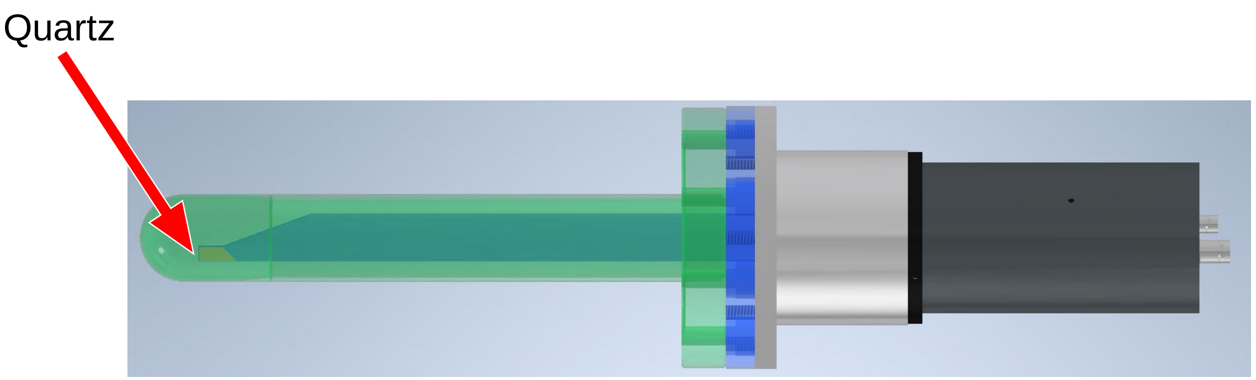






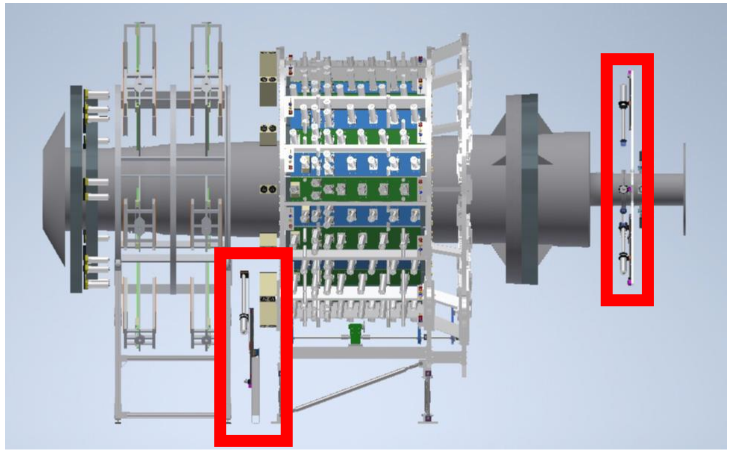
- 14 Diffuse Beam Monitors (DBMs)
  - monitor for large false asymmetries

- 8 Small Angle Monitors (SAMs)
  - monitor for target density fluctuations, false asymmetries

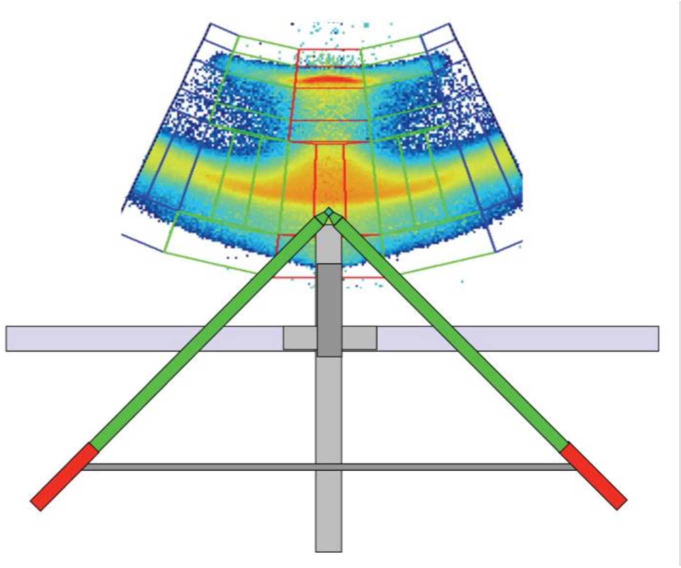


Scanner Detectors

- 1 Upstream Scanner
  - scattered rate distribution for one sector
  - 2D scanning for integration and counting mode
  - verify both currents same distribution
  - monitor stability of kinematics and backgrounds
  - full scan complete in < 1 hour
  - 1 x 1 cm^2 quartz tile

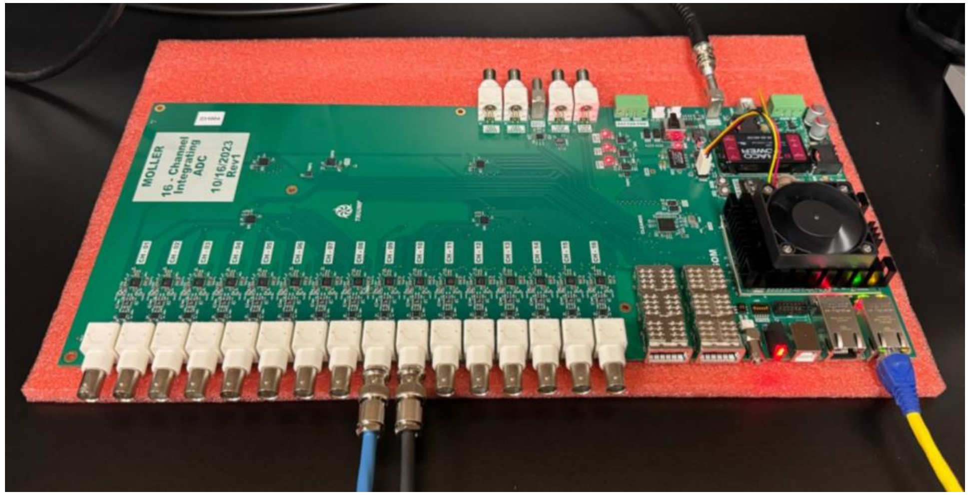


- 4 Downstream Scanners
  - 1D radial scanning for integration mode
  - 50 – 70 cm radial scanning at 4 azimuthal locations
  - located by SAMs for the outer edge of Coll. 2
  - magnet off, 4 cm carbon target



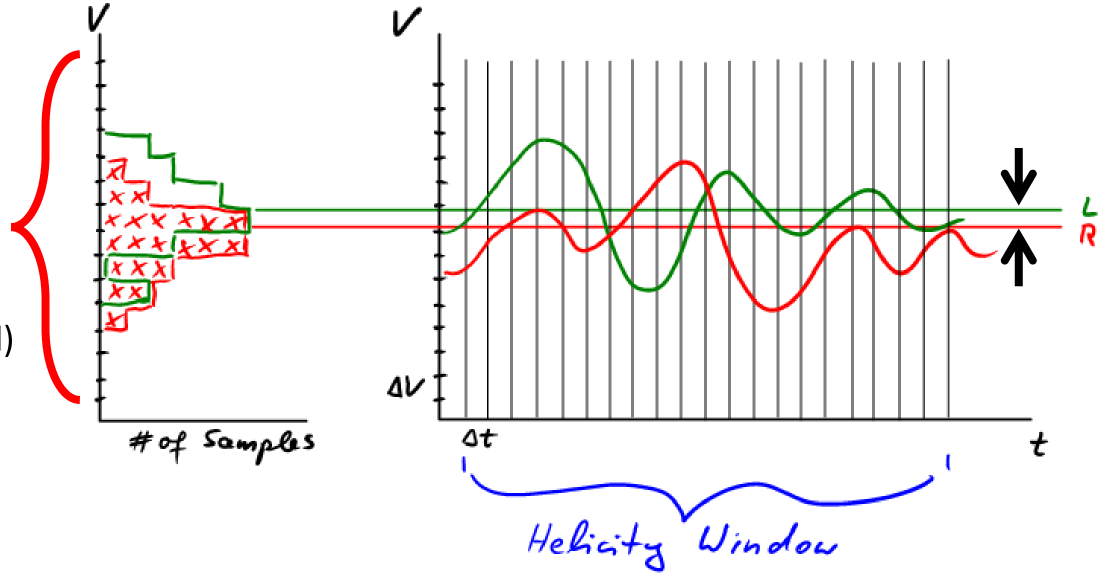
Integrating MOLLER ADC

- Trying to measure a 33 ppb asymmetry $\simeq 0.12\ \mu V\ @\ 2V$
- Optimize parameters: PMT signal, ADC range, resolution (timing and amplitude)
- Selected ADC: 18 bit, 15 Msps (~14 705 882 Hz actual)
- Dynamic range: $\pm 4.096\ V$
- Amplitude resolution: $\simeq 4V/2^{17} \simeq 32\ \mu V$
- Massively over-sample within each helicity window

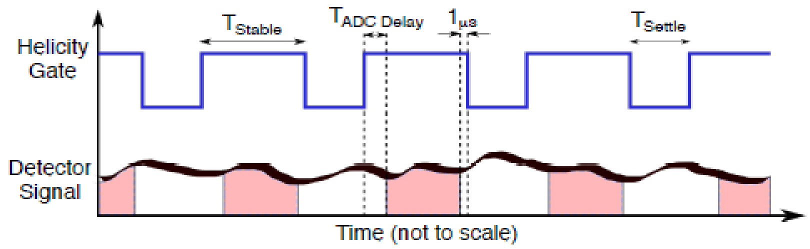


Digitization:

ADC range and resolution (0 suppressed)

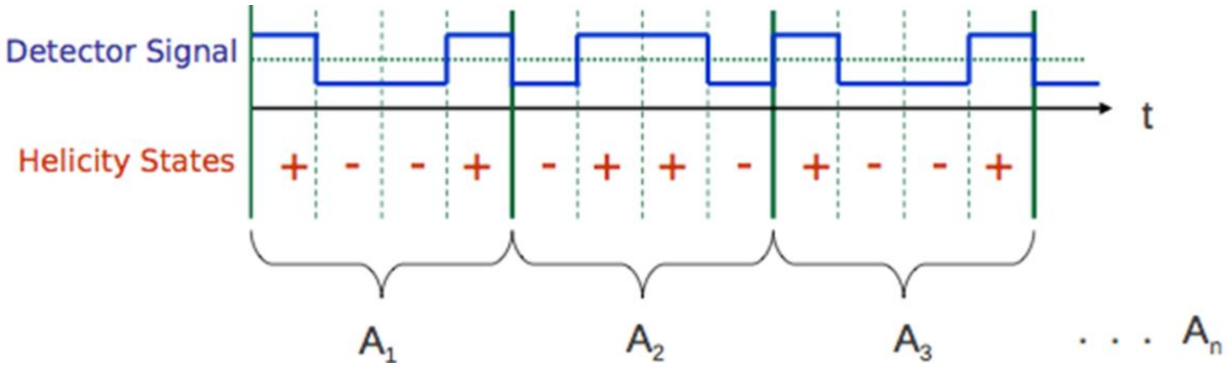


$\simeq 0.12\ \mu V\ @\ 2V$



Measuring A_{PV}

Flux Integration from light collected in Cerenkov detectors



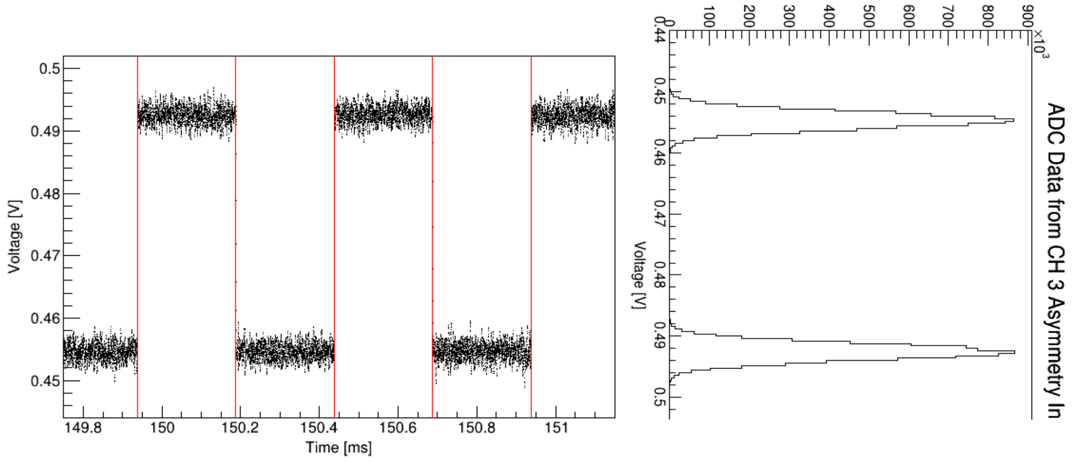
Calculate Asymmetry from adjacent data window pairs

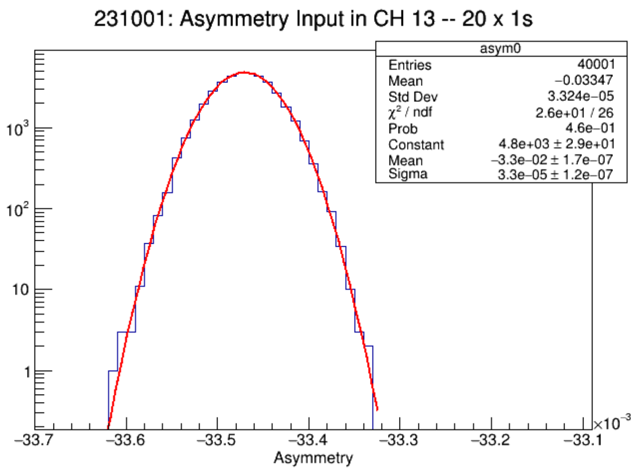
$$A_i = \left(\frac{F_R - F_L}{F_R + F_L}\right)_i \cong \left(\frac{\Delta F}{2F}\right)_i$$

Remove Correlations due to beam intensity, position, angle, energy fluctuations, etc.

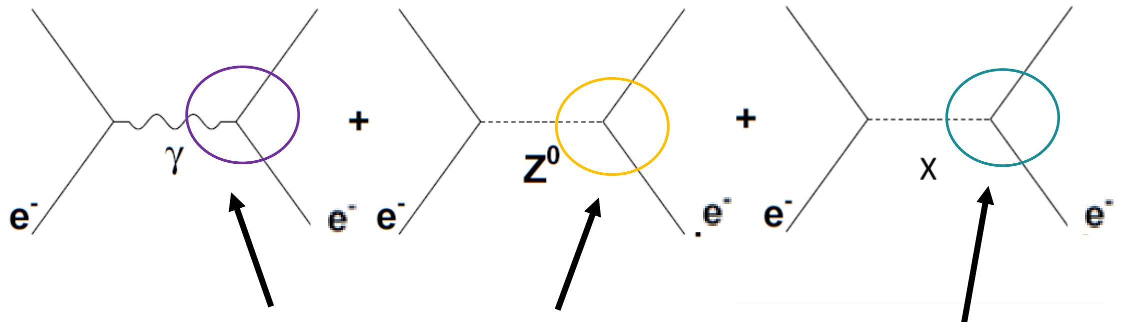
$$\left(A_{exp}\right)_i = \left(\frac{\Delta F}{2F} - \frac{\Delta I}{2I}\right)_i - \sum_j \left(\alpha_j \left(\Delta X_j\right)_i\right)$$

A_{PV} predicted to be ≈ 33 ppb





Future Impact: BSM or High Energy Constraints



Standard Model processes

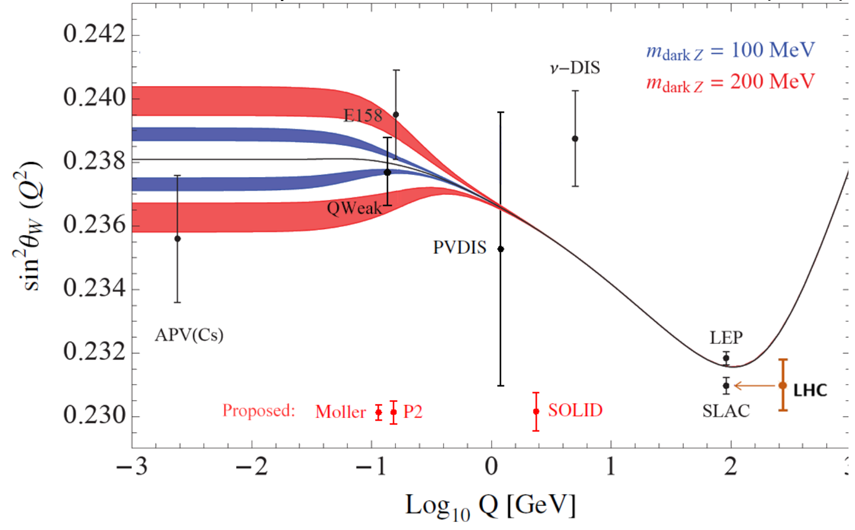
Standard Model Test
possible new exchange particle X

$Q^2 \rightarrow 0$
measure coupling of new physics to electrons

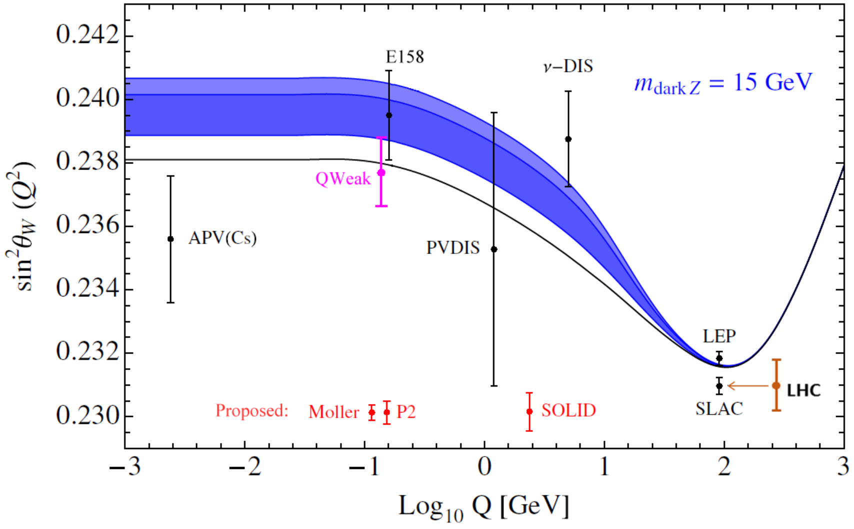
Possible BSM sensitivities:

- massive $\boldsymbol{Z'}$ boson interactions
- dark photon / $\boldsymbol{MeV}$ level $\boldsymbol{Z}$
- new parity violating interactions
- lepton compositeness ($\boldsymbol{47\ TeV}$)

Adapted from Marciano, Davoudiasl, Lee (2014)



Adapted from Davoudiasl et al. PRD 92, 055005 (2015)



- observe dark Z as shift in $\sin^2\theta_W$
- effect dependent on mass of dark Z

Thank You

Appendix

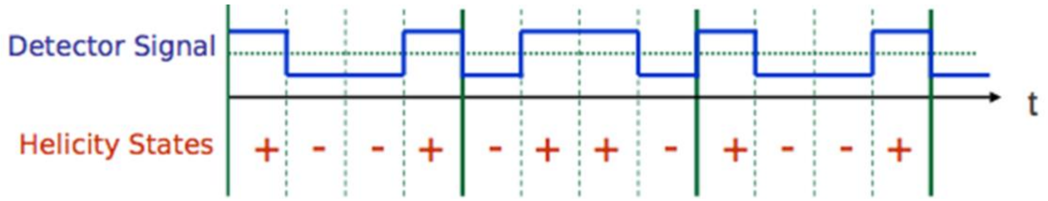
Nominal Parameters

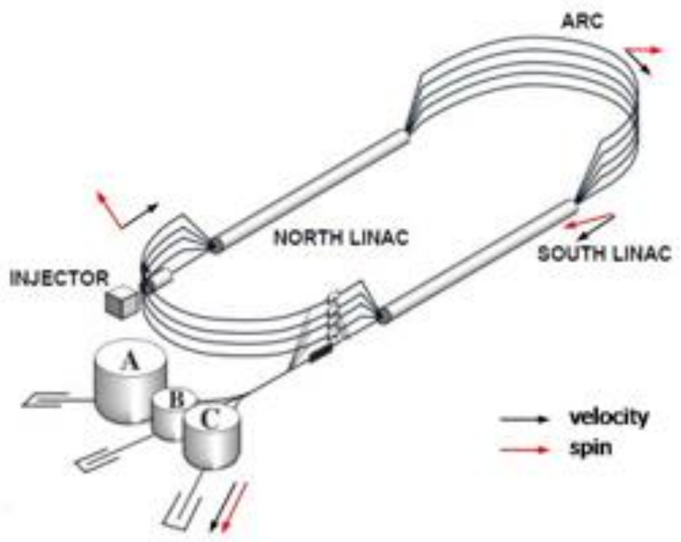
Parameter	Value
E [GeV]	≈ 11.0
E' [GeV]	2.0 - 9.0
$\theta_{\rm CM}$	50°-130°
$\theta_{\rm lab}$	0.26°-1.2°
$\langle Q^2 \rangle$ [GeV^2]	0.0058
Maximum Current [μA]	70
Target Length (cm)	125
ρ_{tgt} [g/cm^3] (T= 20K, P = 35 psia)	0.0715
Max. Luminosity [cm^{-2} sec^{-1}]	$2.4{\cdot}10^{39}$
σ [μbarn]	≈ 60
Møller Rate @ 65 μA [GHz]	≈ 134
Statistical Width(1.92 kHz flip) [ppm/pair]	≈ 91
Target Raster Size [mm $\times$ mm]	5×5
Production running time	344 PAC-days = 8256 hours
ΔA_{raw} [ppb]	≈ 0.54
Background Fraction	≈ 0.10
$P_{\rm B}$	$\approx 90\%$
$\langle A_{PV} \rangle$ [ppb]	≈ 32
$\Delta A_{stat}/\langle A_{expt} \rangle$	2.1%
$\delta(\sin^2\theta_W)_{stat}$	0.00023

Error Source	Fractional Error (%)
Statistical	**2.1**
Absolute Norm. of the Kinematic Factor	0.5
Beam (second moment)	0.4
Beam polarization	0.4
$e + p(+\gamma) \rightarrow e + X(+\gamma)$	0.4
Beam (position, angle, energy)	0.4
Beam (intensity)	0.3
$e + p(+\gamma) \rightarrow e + p(+\gamma)$	0.3
$\gamma^{(*)} + p \rightarrow (\pi, \mu, K) + X$	0.3
$e + Al(+\gamma) \rightarrow e + Al(+\gamma)$	0.15
Transverse polarization	0.2
Neutral background (soft photons, neutrons)	0.1
Linearity	0.1
Total systematic	**1.1**

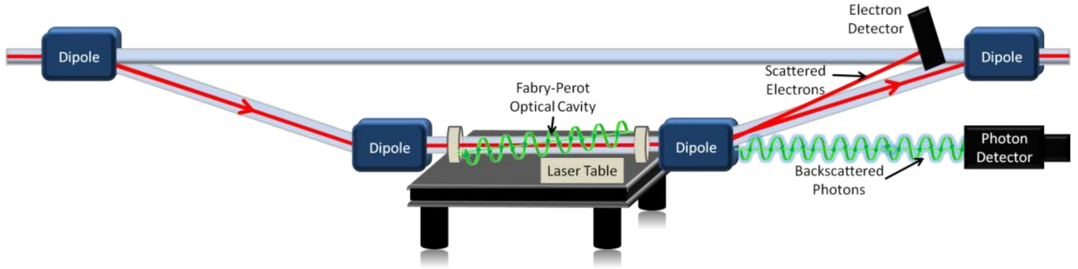
Electron Beam and Polarimetry

- 11 GeV longitudinally polarized $P_{beam} \geq 90 \pm 0.5\ \%$
- 1920 Hz fast helicity reversal rate
  - pseudo-random pattern

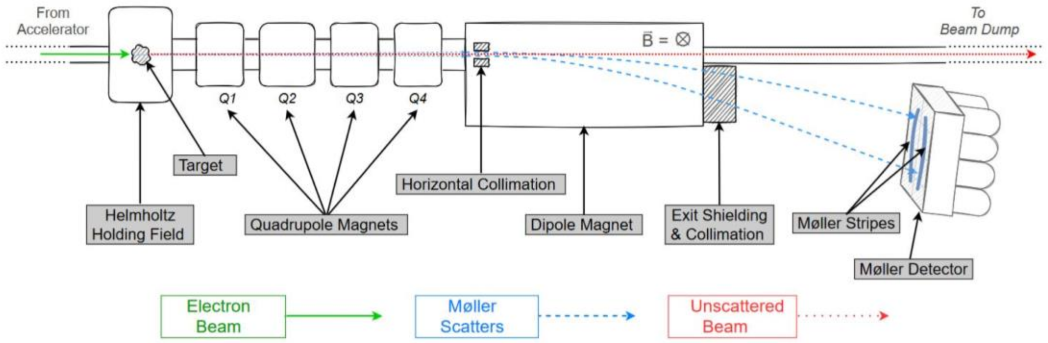




Compton Polarimeter: continuous at production beam current



Møller Polarimeter: invasive at low beam current

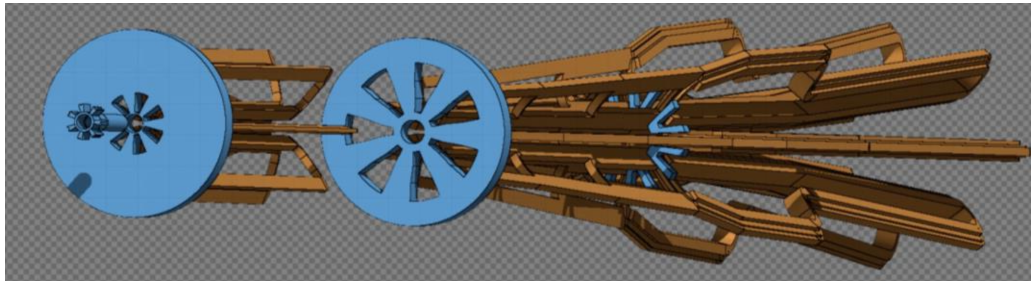


Spectrometer, Precision Collimation, and Shielding

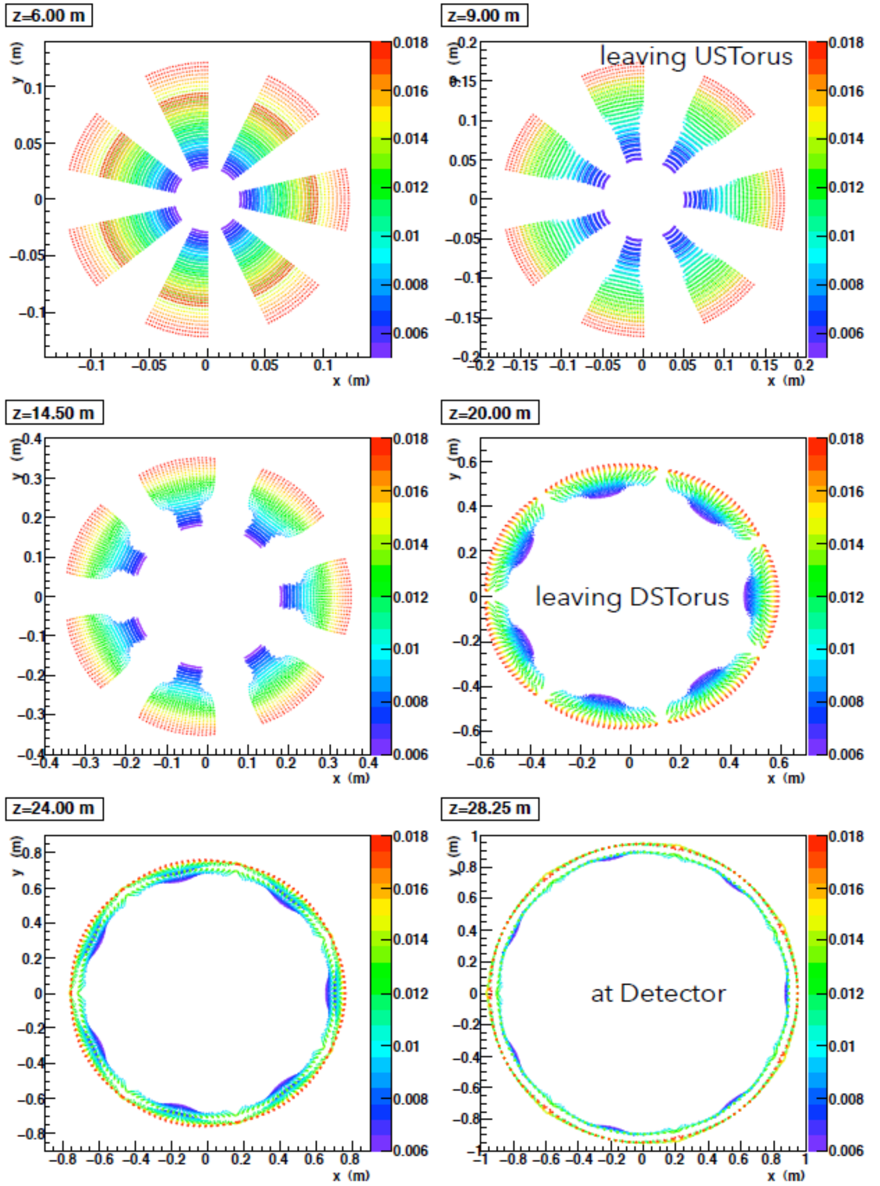
Requirements:

- full azimuthal acceptance of Møller events in high FOM region
- separation of Møller events from elastic and inelastic e-p events
- precise collimation
  - remove line-of-sight between target and detectors
  - “2-bounce” to minimize backgrounds
- channel for degraded beam and bremsstrahlung photons to beam dump
- shielding toroidal coils

5 toroidal magnets with 7-fold symmetry



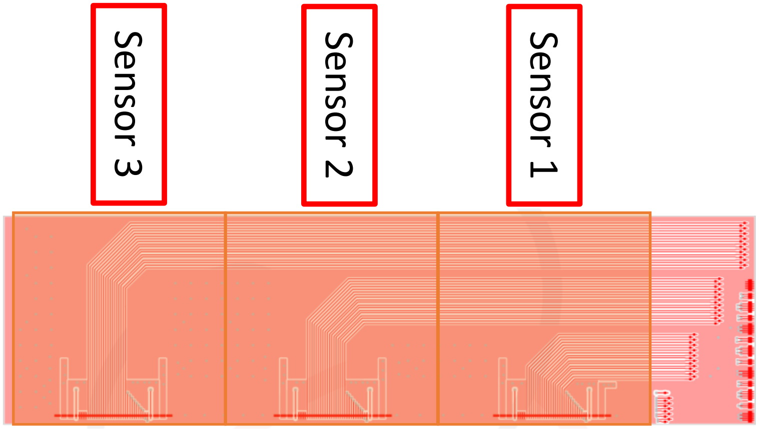
1 2 4 5

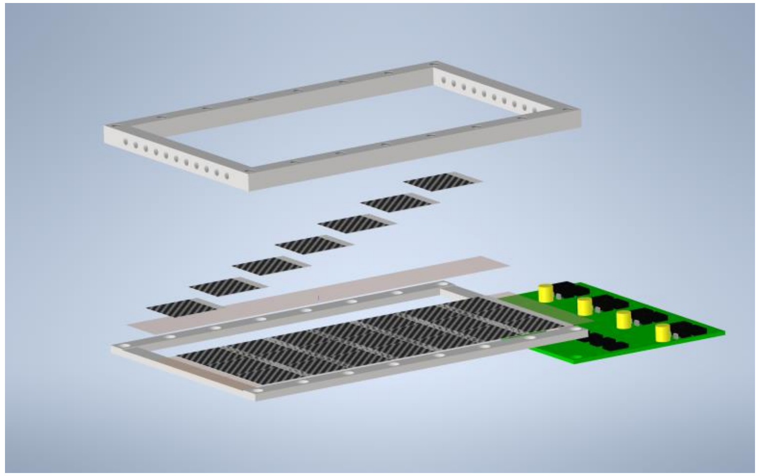


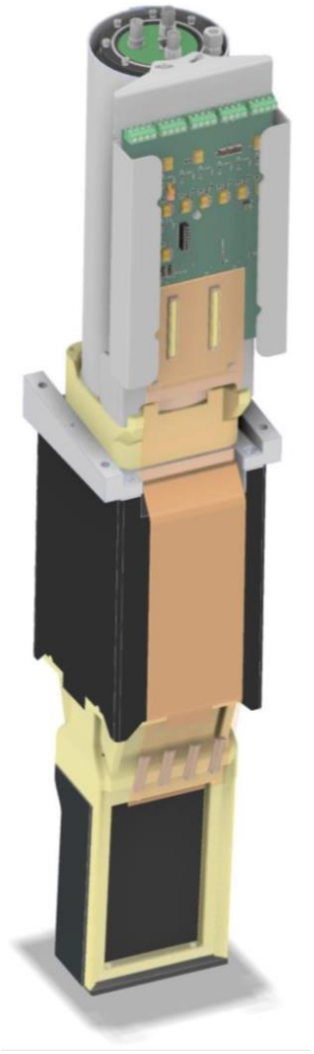
HVMAPS

High Voltage Monolithic Active Pixel Sensors

- active pixel size: 80 x 80 um^2
  - readout electronics, filters, amplifiers all integrated into chip
- overall detectable region size: 2 x 2 cm^2
- timing resolutions: 16 ns
- peak detection rate: 30 MHz







Ring 5

- 7 chips bonded to a flex-print
- 4 strips per quartz tile
- 28 HVMAPS placed behind
- map scattered electron profile
- diagnostic purposes
- HVMAPS glued & wire-bonded to Kapton flex-print w signal and power traces

$$R = 2.2 \times 10^{-4} \times 70/25 \simeq 600\ kHz/mm^2 \quad \Longrightarrow \quad \simeq 4\ kHz/pixel$$