MOLLER Experiment

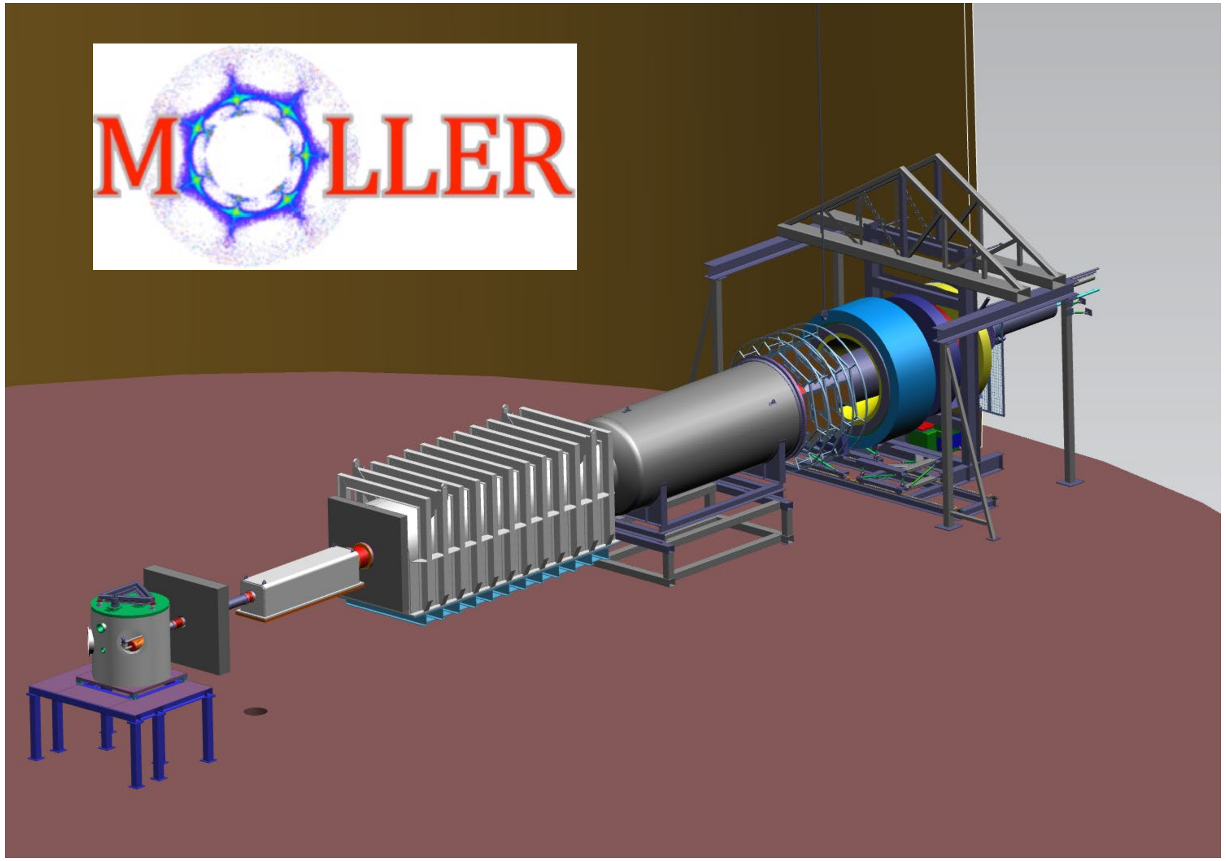
Hall A/C summer collaboration meeting

9 July 2021

OHIO UNIVERSITY

Paul M. King – Ohio University

For the MOLLER Collaboration



MOLLER Overview

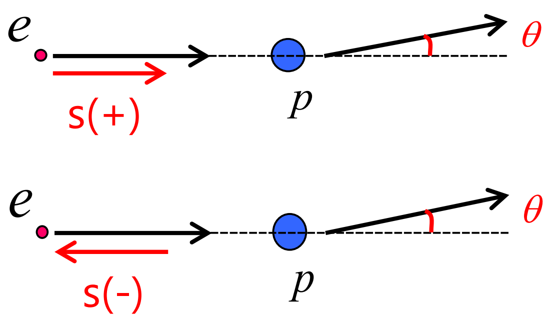
- Parity-violating asymmetry in electron-electron (Møller) scattering
  - Arises from interference between the electromagnetic and neutral weak amplitudes
  - Proportional to Q_W^e (and $\sin^2\theta_W$)

- A_{PV} predicted to be 33 ppb at our kinematics; uncertainty goal is 0.8 ppb
  - Would extract Q_W^e to a fractional uncertainty of 2.4%; $\sin^2\theta_W$ to 0.12%
  - Sensitive to physics beyond the Standard Model

- Principal funding for the apparatus is via a DOE Major Item of Equipment (MIE) project, now past CD-1
- Two other major sources of funding also in place: NSF Physics Midscale Award, and a Canadian Foundation for Innovation (CFI) Award.

- Project planning calls for achieving CD-2 status in late 2022 and completion of construction by mid-2024 to be ready for installation when Hall A is available.

Parity-Violating Electron Scattering



Electromagnetic (PC) + Neutral-weak (PV)

$$\mathcal{M}^{EM} \propto \frac{1}{Q^2} \qquad \mathcal{M}^{NC}_{PV} \propto \frac{1}{M_Z^2 + Q^2}$$

$$\sigma \propto |\mathcal{M}^{EM}|^2 + 2\mathcal{M}^{EM}\mathcal{M}^{NC}_{PV} + |\mathcal{M}^{NC}_{PV}|^2$$

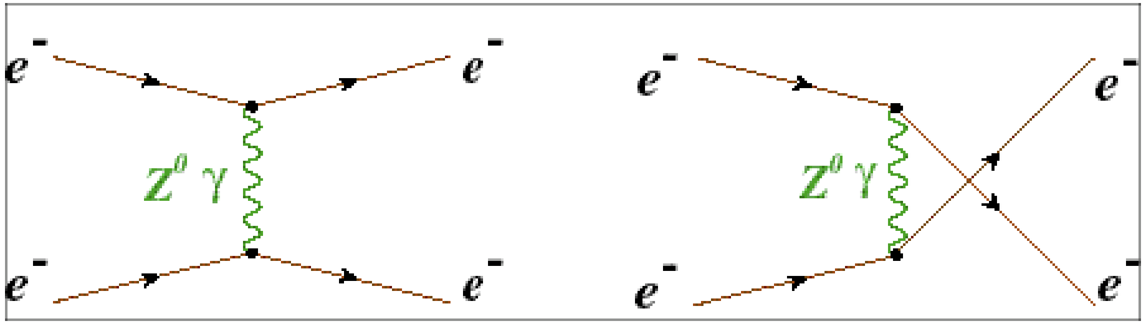
$$A_{PV}(p) = \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L} \propto \frac{\mathcal{M}^{NC}_{PV}}{\mathcal{M}^{EM}} \propto \frac{Q^2}{M_Z^2} \quad \text{when } Q^2 \ll M_Z^2$$

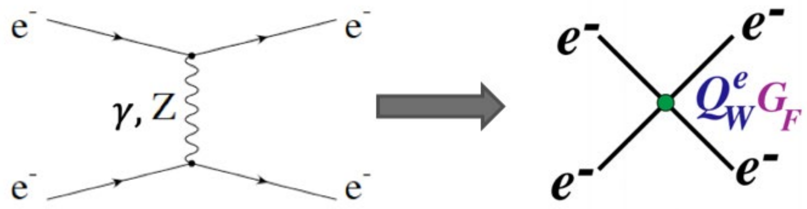
PV in Møller Scattering

$$A_{PV} = \frac{G_F}{\sqrt{2}\,\pi\alpha} \frac{m\,E\,4\sin^2\theta_{CM}}{(3+\cos^2\theta_{CM})^2} Q_W^e$$

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

with 1-loop
EW corrections



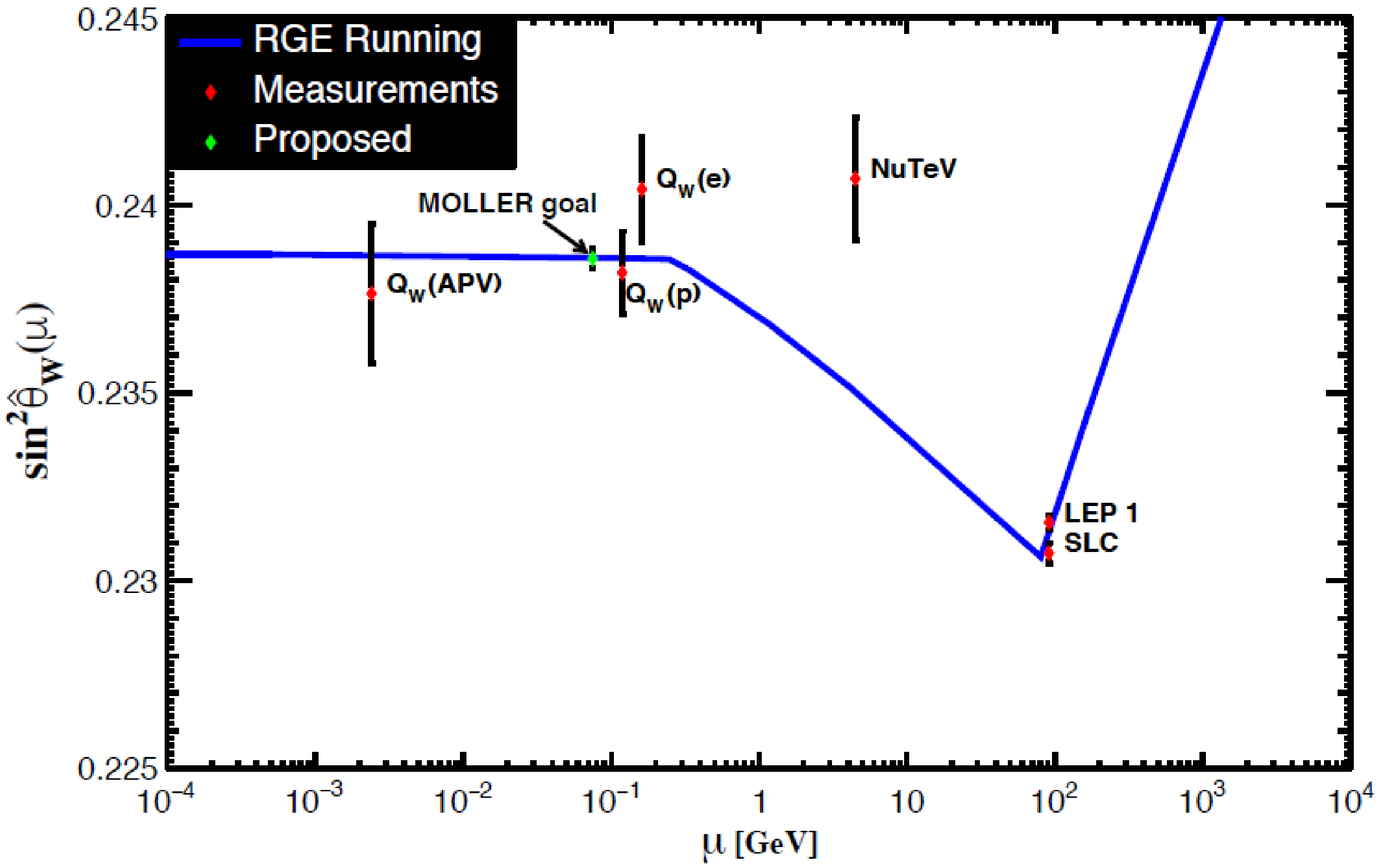


Can be most generally expressed in terms of a new contact interaction described by the strength (g) and scale (Λ) of the new dynamics

A 2.4% measurement of Q_W^e would be sensitive to interaction amplitudes as small as $1.5 \times 10^{-3} G_F$, corresponding to a sensitivity of $\Lambda/g = 7.5$ TeV; a 5σ discovery potential in the space allowed within the existing most stringent low and high energy constraints.

- $g \sim 1$ probes the TeV scale with new and unique sensitivity
- $\Lambda \sim 100$ MeV, there is extraordinary new sensitivity approaching $1.5 \times 10^{-3} \alpha_{QED}$

Running of the Weak Mixing Angle



- $\sin^2\theta_W$ is precisely given by Standard Model and anchored by the Z-pole measurements, LEP1 & SLC
- LEP1 and SLC differ at 3σ
  - Average is consistent with a SM Higgs Boson mass of 126 GeV
  - Choosing one or the other ruins this consistency and implies very different high-energy dynamics
- MOLLER's proposed sensitivity on $\sin^2\theta_W$ of 0.00028 has the same level of precision and interpretability

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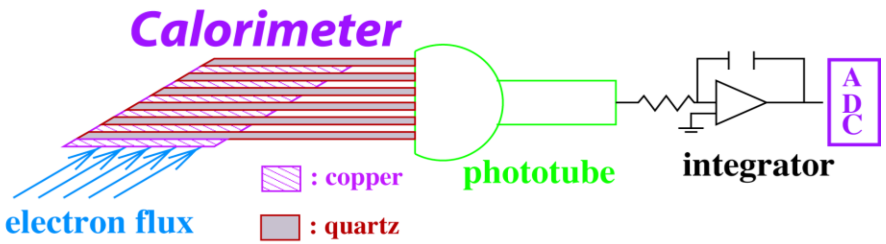
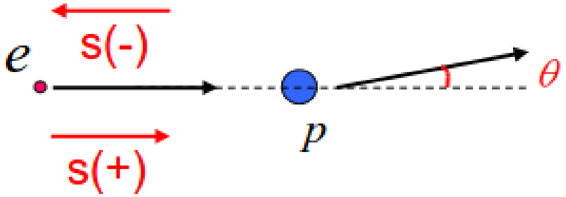
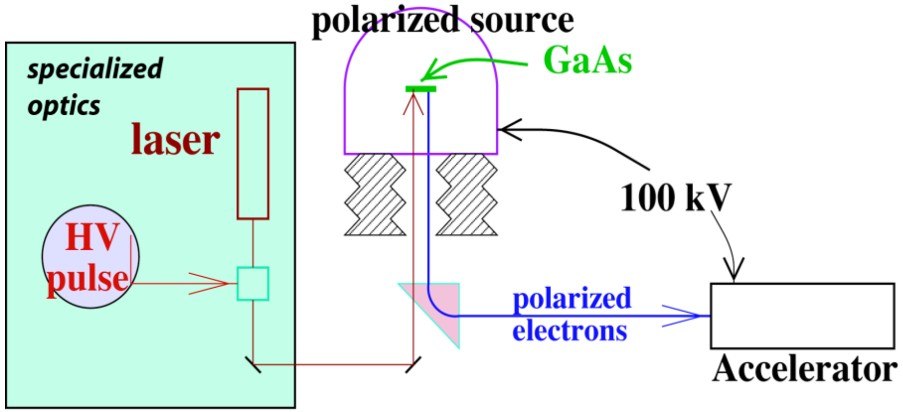
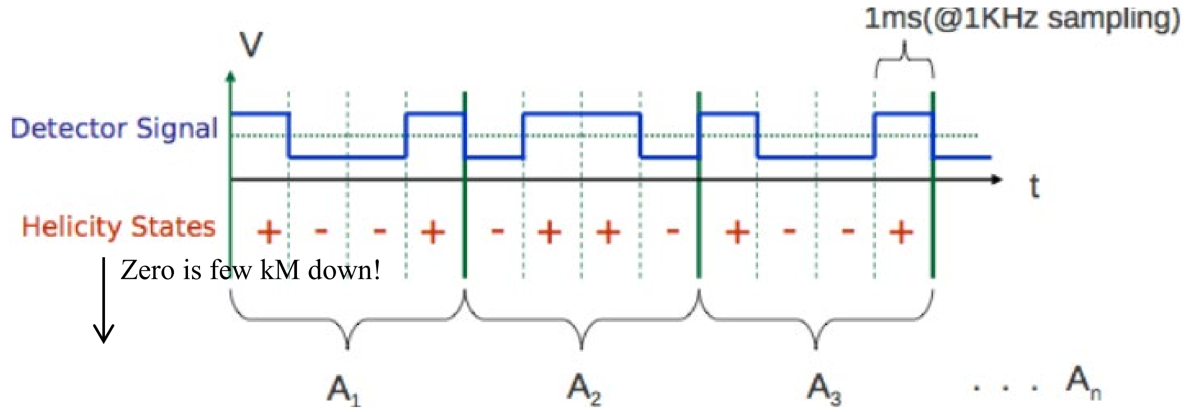
How to Do A PVES Experiment









rapid, random, helicity flipping

Helicity of electron beam flipped periodically, delayed helicity reporting to prevent direct electrical pick up of reversal signal by detectors

Detector signal integrated for each helicity window and asymmetry formed from helicity patterns

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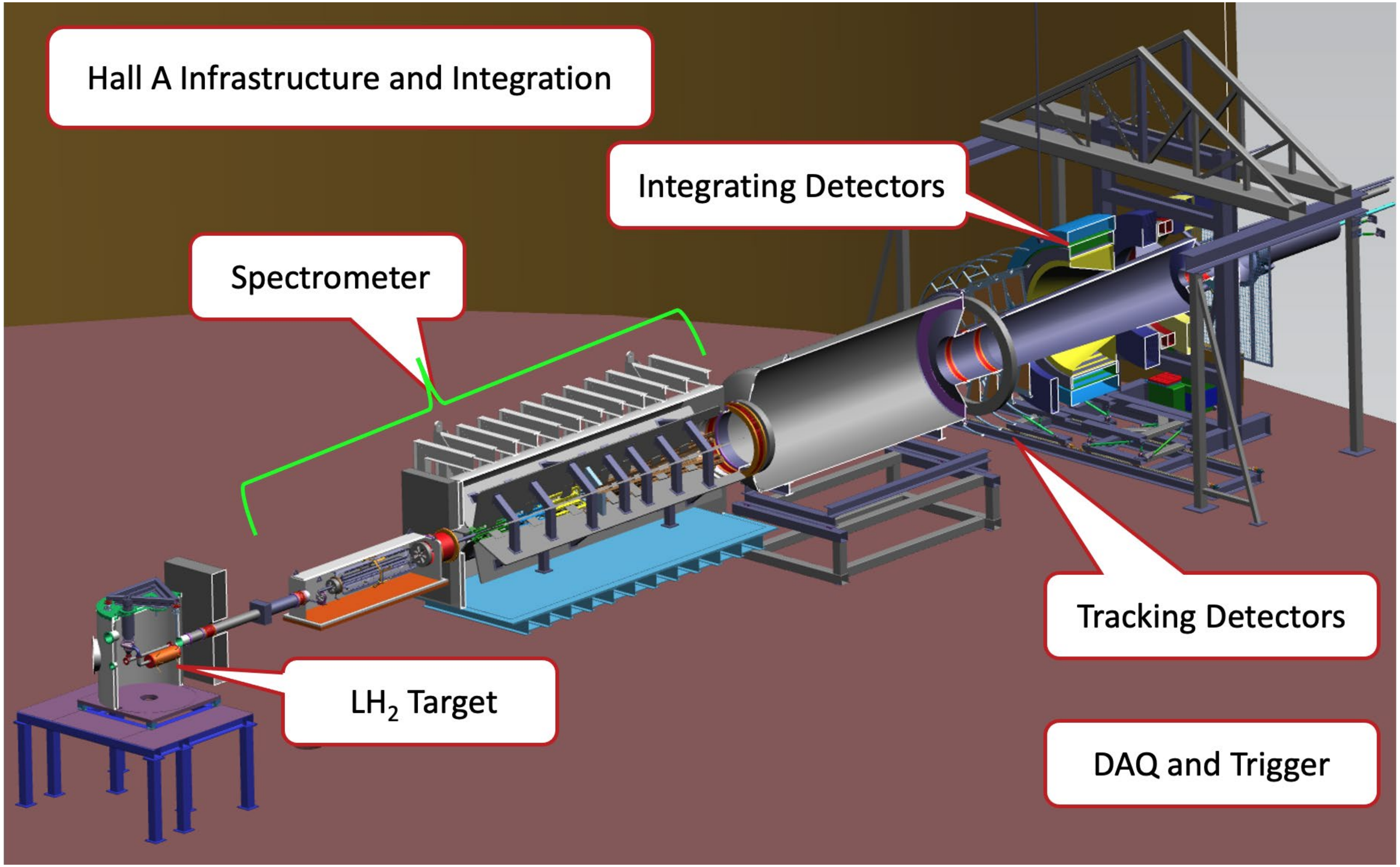
Apparatus overview

- 11 GeV beam
- 1.25 m LH2 target
- Full azimuth acceptance, $5 \leq \theta \leq 21$ mrad
- 70 μA max current
- Møller rate ~2 GHz/ μA
- 344 PAC days → 8256 hours spread over 3 running periods



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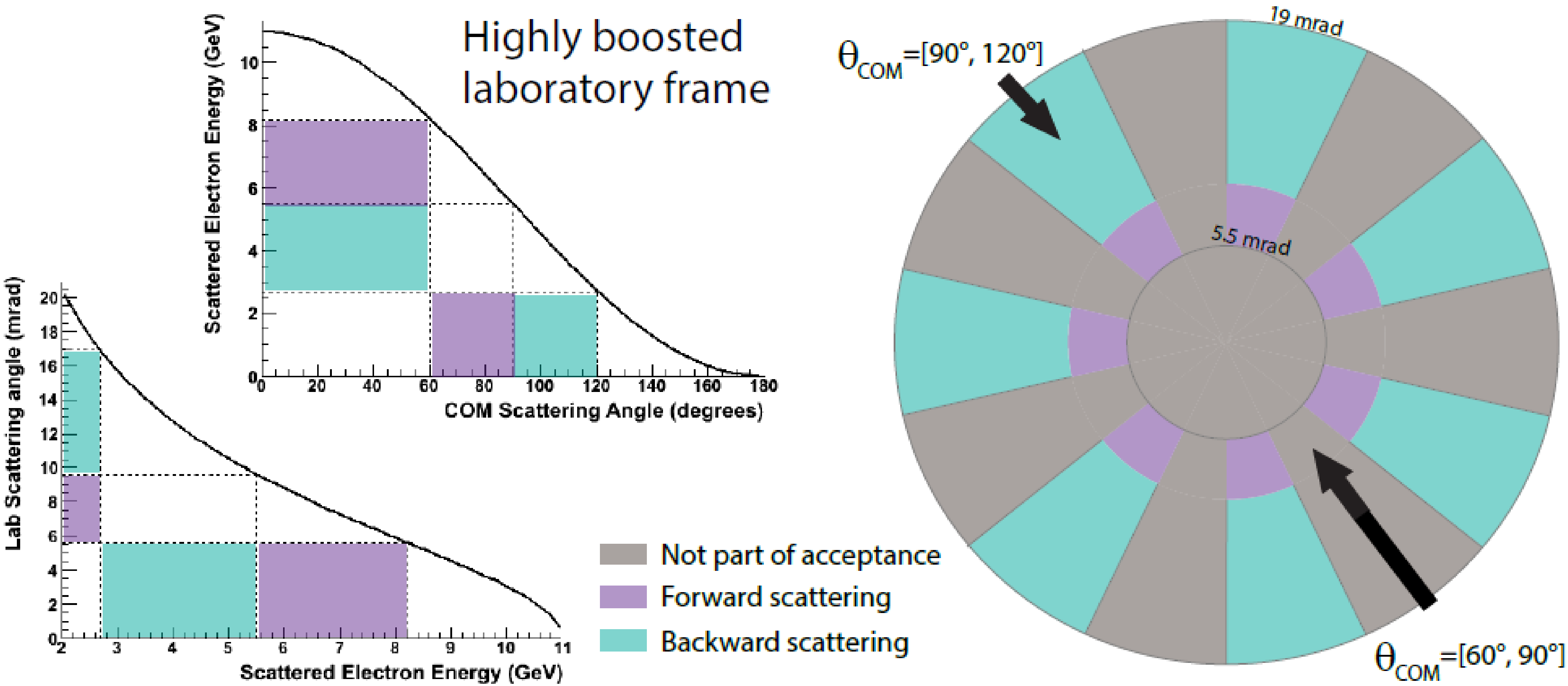
MOLLER Kinematics and Acceptance

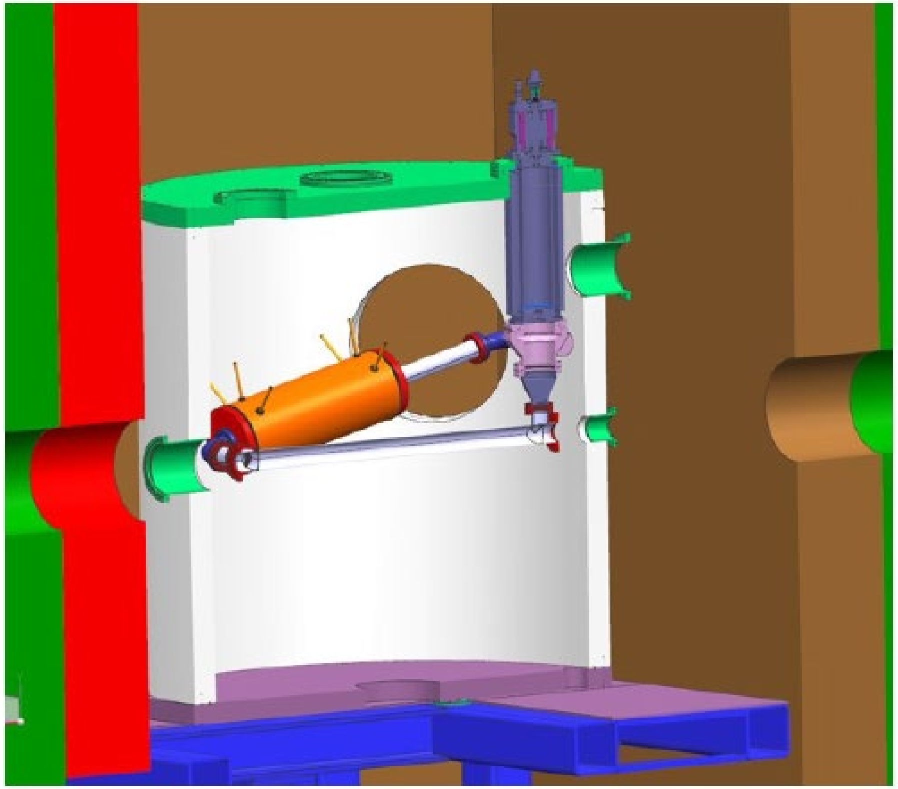
Møller scattering produces identical particles → can measure either forward or backward scattering in CM frame



Liquid Hydrogen Target

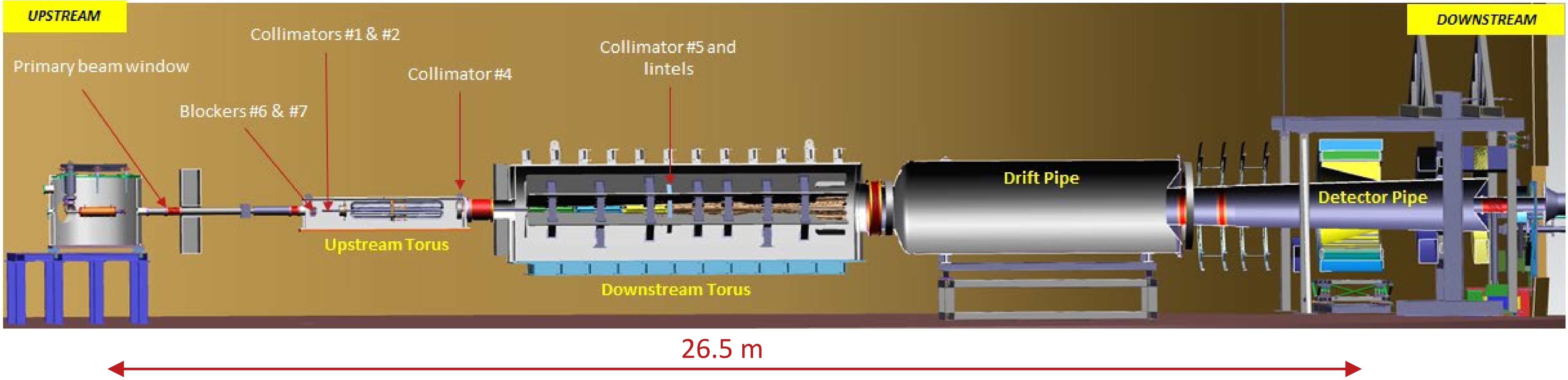
- Need as much thickness as technically possible with least radiative losses; trade-off between counting statistics and systematic effects
- Base design will be from the previous generation MOLLER experiment (E158), with developments based on the experiences with the QWEAK target, and CFD modeling

cell length	125 cm
cell thickness	8.93 g/cm2
radiation length	14.6%
p, T	35 psia, 20 K
target power	4000 W

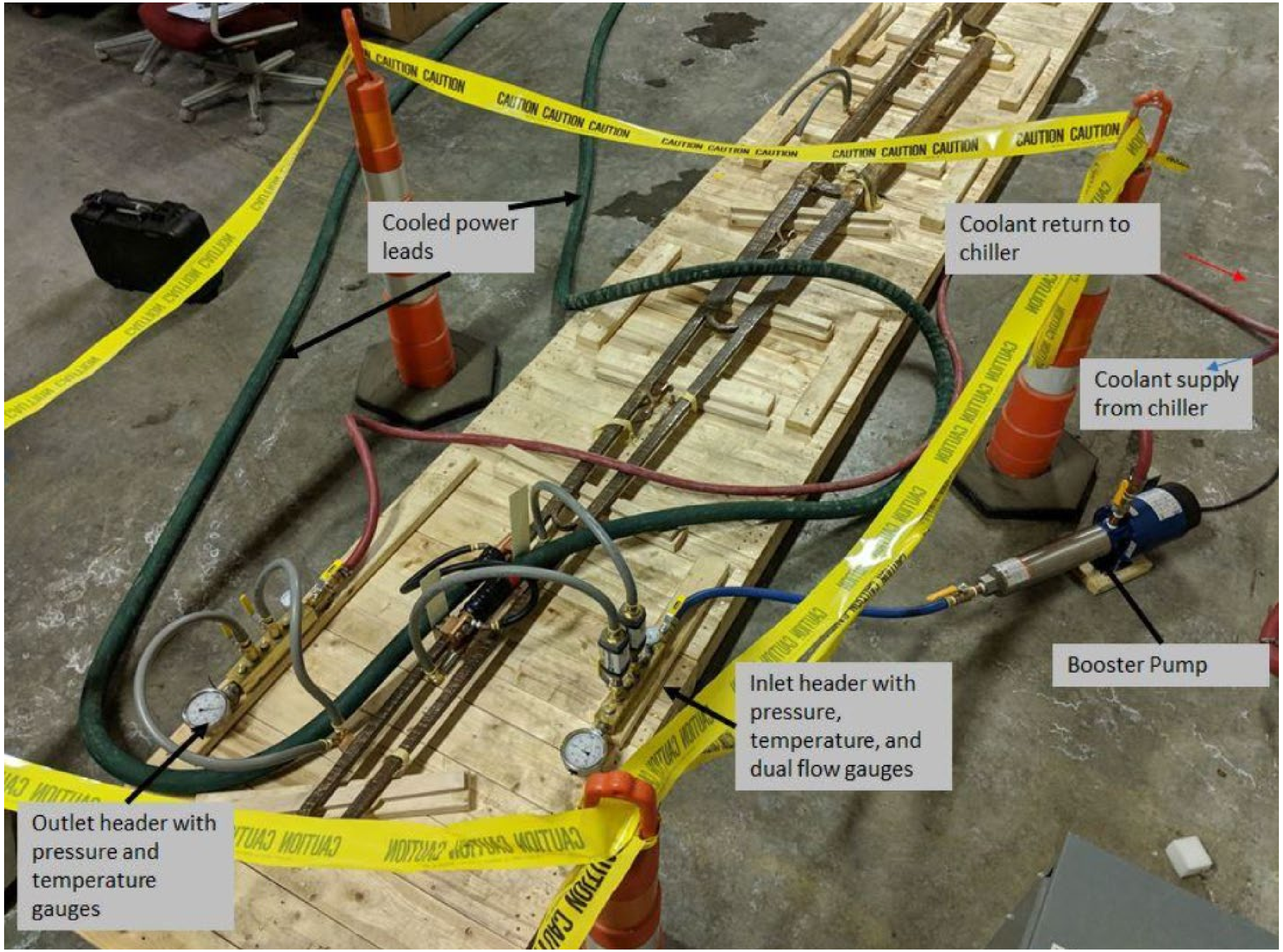


Toroidal Spectrometer

- Provides full azimuthal acceptance
- Have water-cooled warm copper coils
- The collimators define the acceptance of the experiment
- Strategic placement of collimators will minimize soft photon backgrounds by achieving a two-bounce system



MIT-Bates Prototype coil during testing



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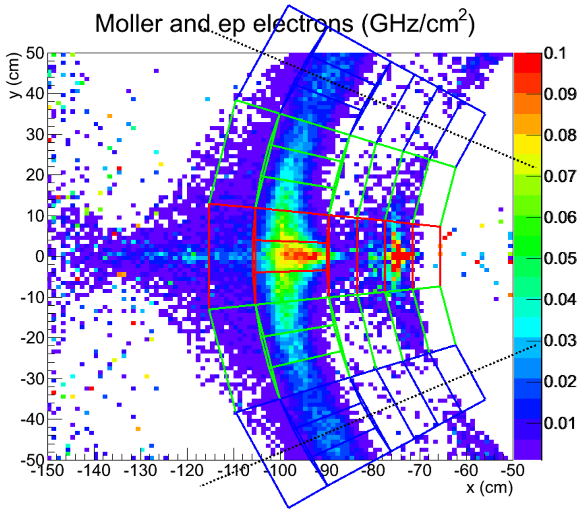
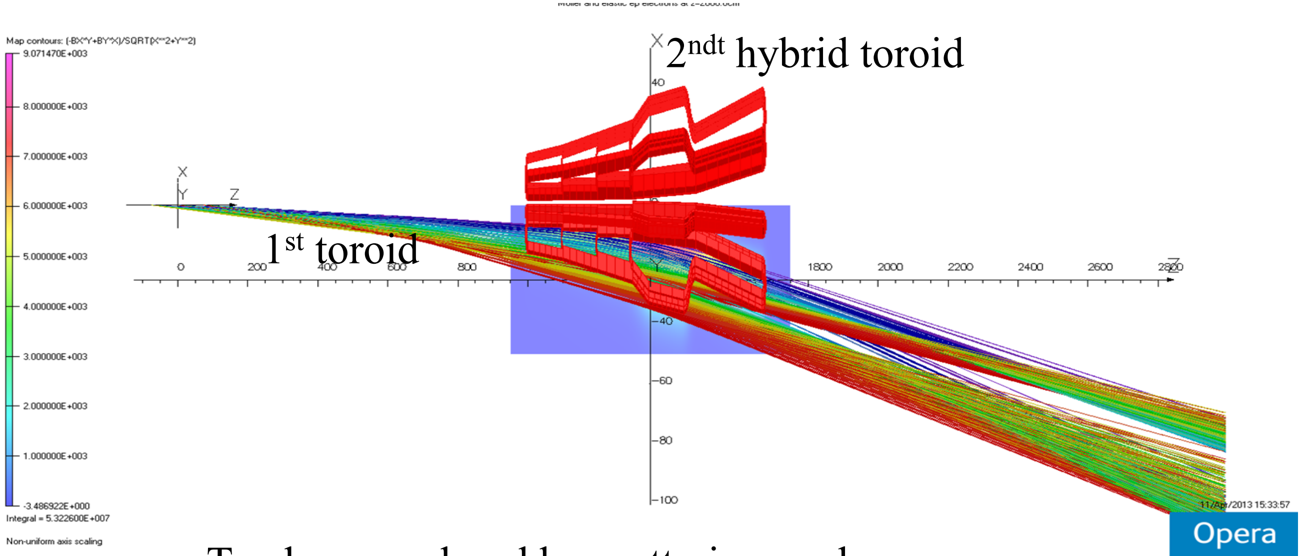
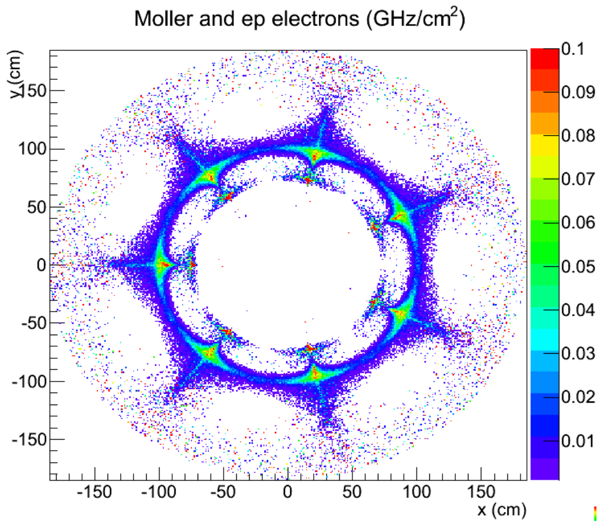
Toroidal Spectrometer and Detectors

- Møller and ep scattering signals are separated at the detector plane
- Optics are still being fine tuned
  - Reduce backgrounds
  - Optimize the asymmetry
  - Improve symmetric forward/backward





Tracks are colored by scattering angle from purple to red (low to high)



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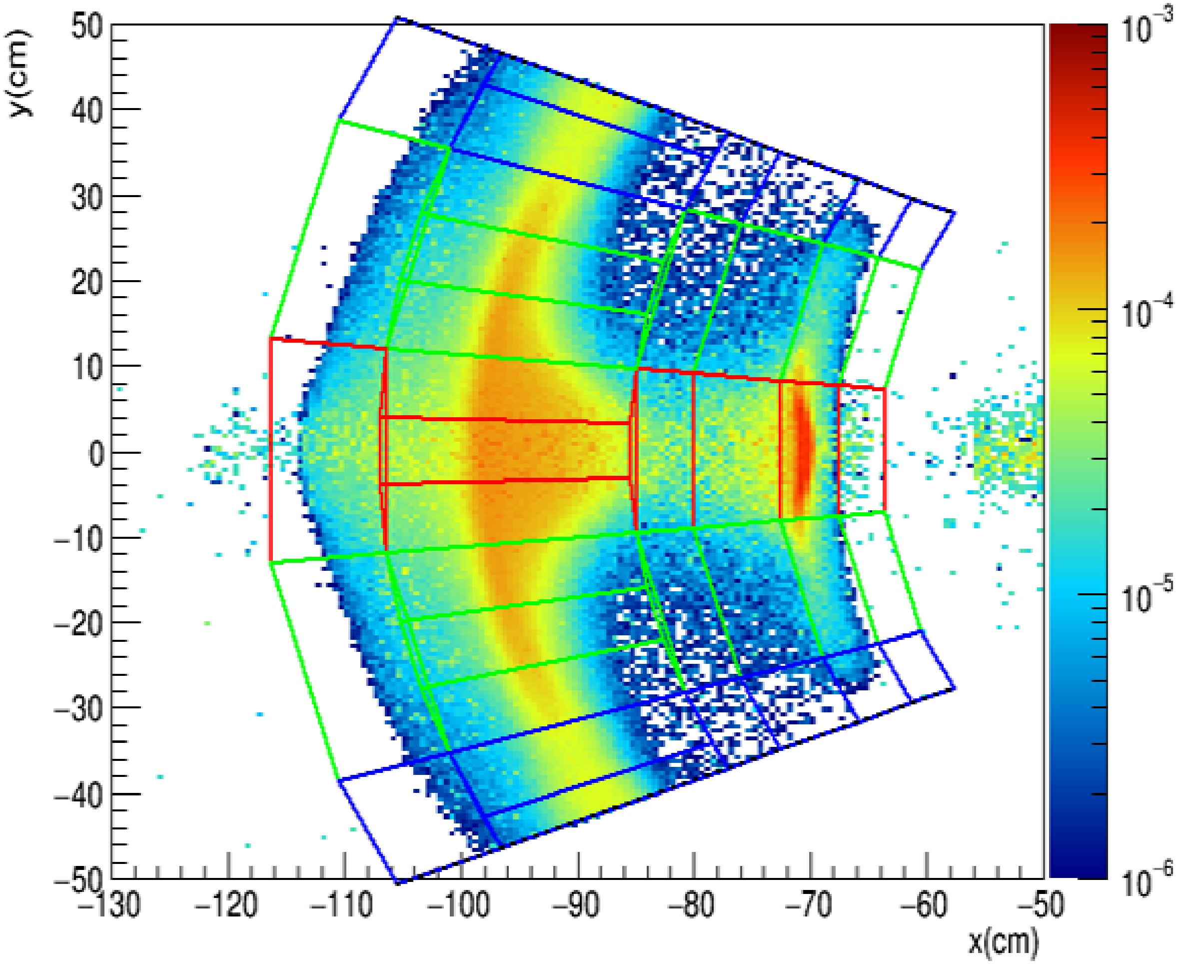
Detector segmentation and particle rates



Møller and e-p electron rates in units of GHz/μA/0.5 cm^2

- Main detector elements are quartz tiles coupled to air light-guides
  - The six rings of one sector are shown with electron rate distribution
  - Each sector has an "open" tile, two "transition" tiles, and shares a "closed" tile
  - Ring 5 largely contains the Møller events, and has further 3-fold segmentation

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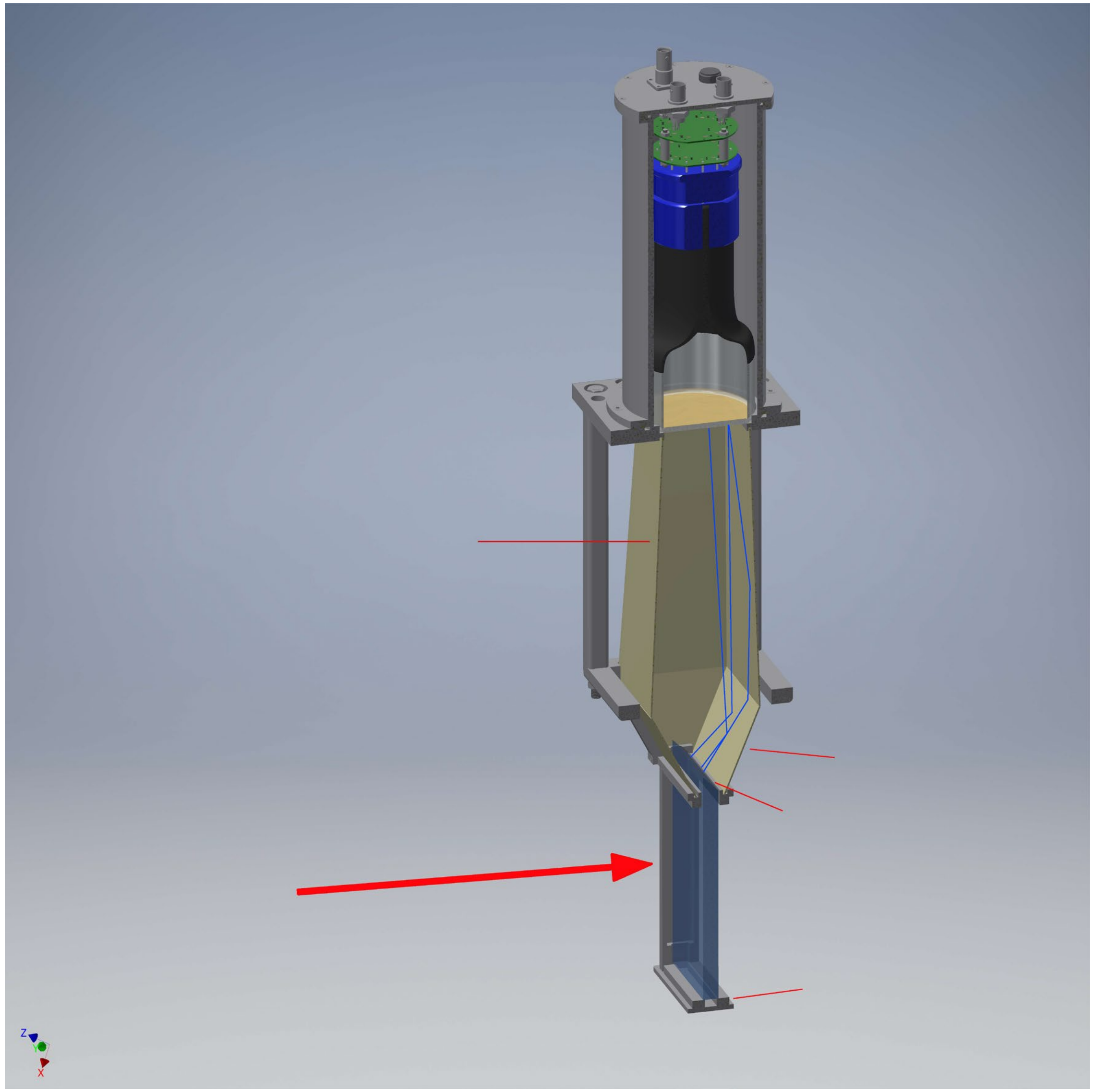
Detector segmentation and particle rates



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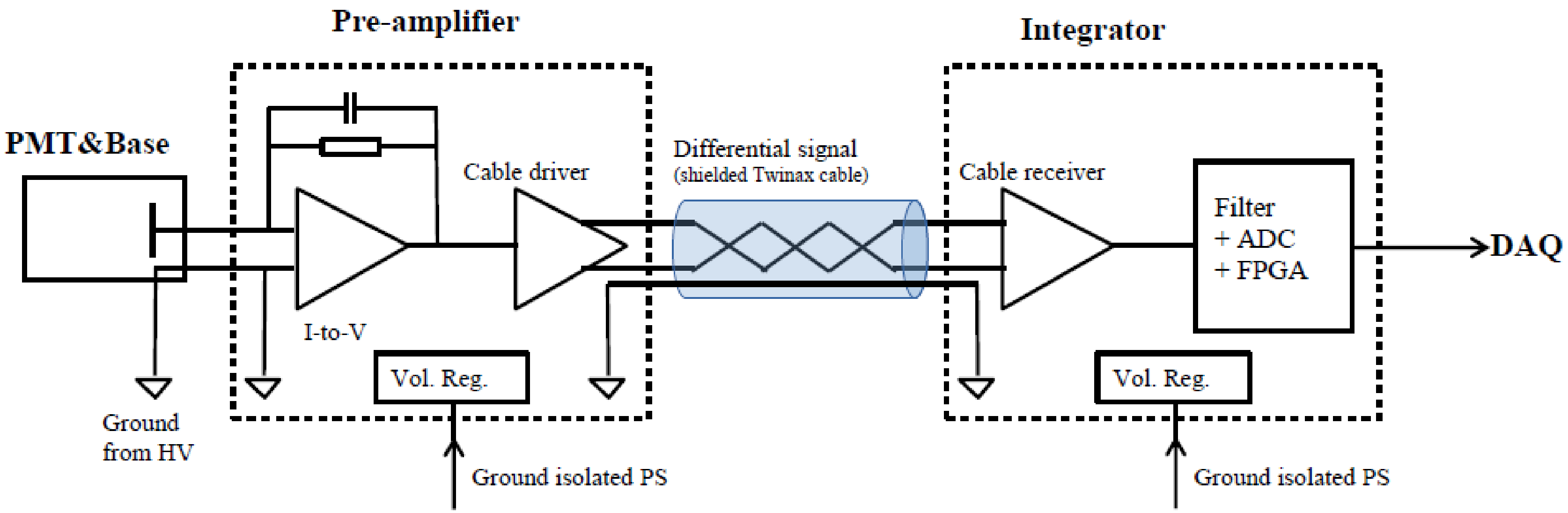
Integration-mode Detector Readout Concept



Preamplifiers located near detectors (in the PMT base)

- Preamp gain: 10's to 100's kΩ
- Bandwidth: ~1 MHz

Fully differential signal between preamp and integrators

Integrators located in shielded bunker far from detectors

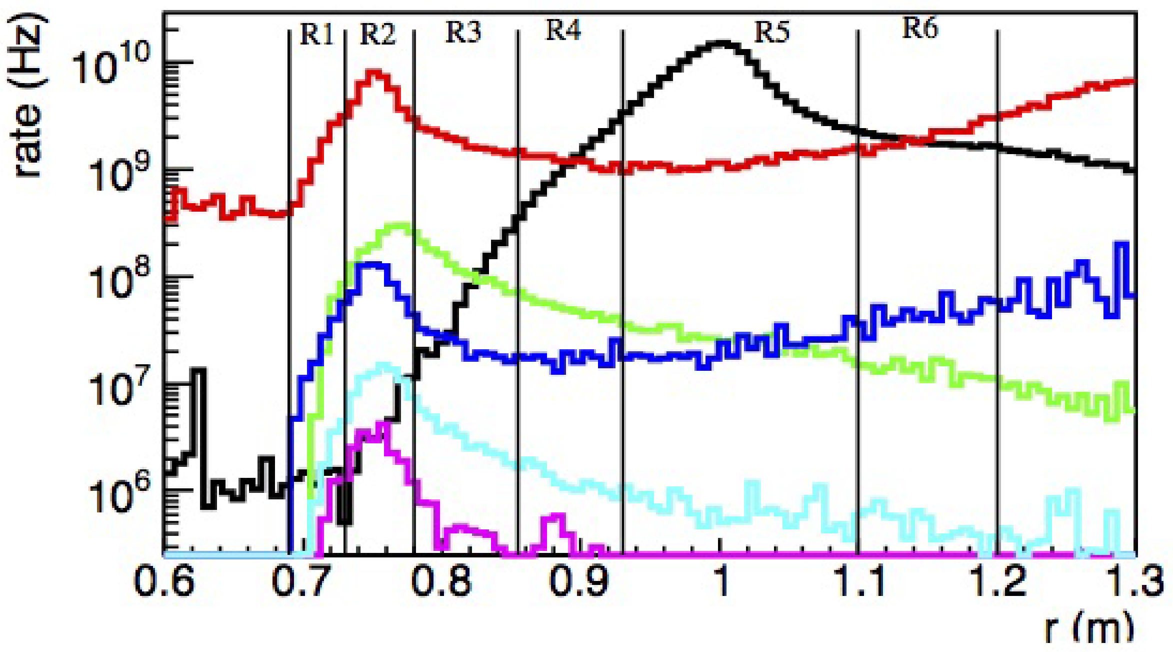
Integrator: Input and ADC

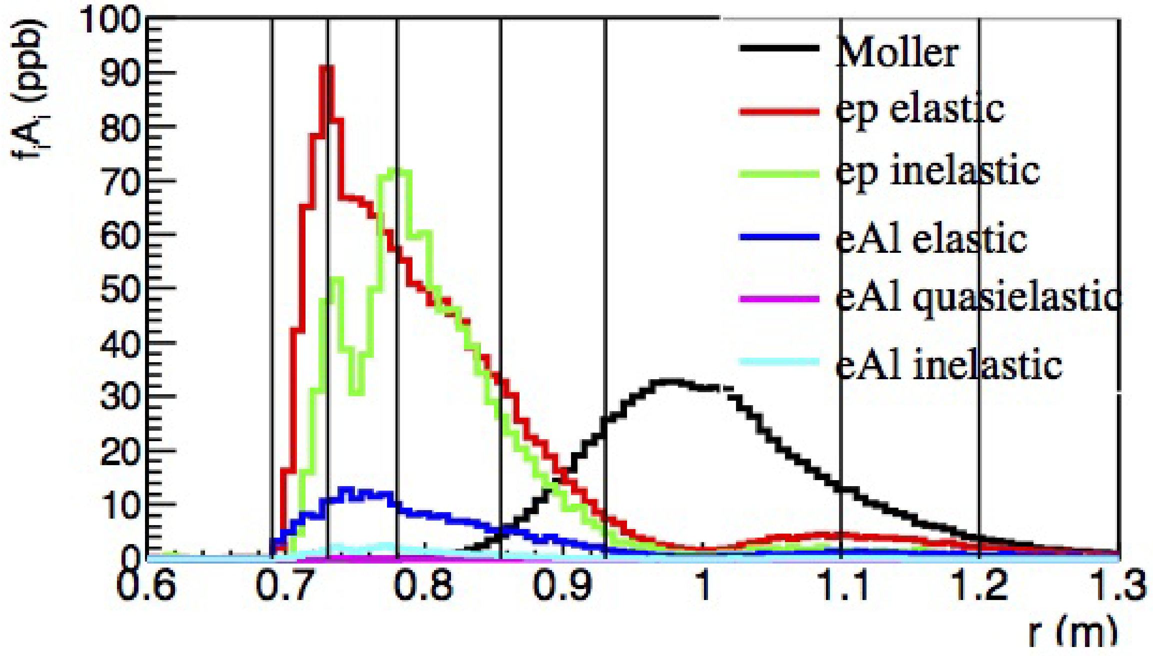
- Input bandwidth: ~1 MHz
- ADC resolution: 18 bit
- ADC sampling rate: 15 Msps

Integrator: FPGA

- Takes external clock and gate
- Sums 15 Msps down to helicity window data items
- Buffers the data and controls data transfer

MOLLER Backgrounds





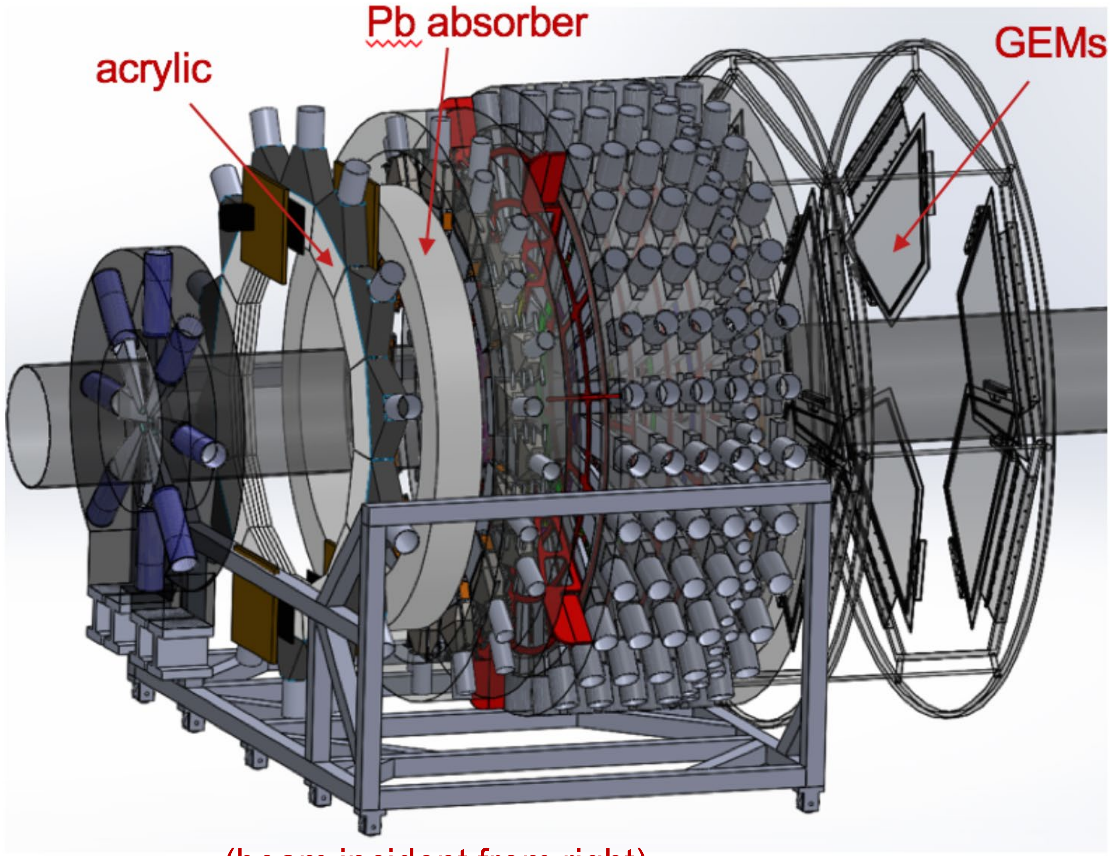
- The primary irreducible backgrounds : ep elastic and inelastic scattering
- Other background sources
  - Photons and neutrons from 2 bounce collimation system
  - Pions and muons : photo-production and DIS

Tracking-Mode and Pion Detectors

Track individual particles at very low beam currents

- Tracking System:
  - 4 layers of “coordinate” triple GEM detectors, in all 7 sectors
  - Each sector with pair of plastic trigger scintillators
  - Mounted on rotator to allow full azimuthal measurement

- Pion Detector:
  - Mounted downstream of Pb absorber to range-out electrons
  - 14 acrylic Cerenkov detectors, full azimuthal coverage
  - In two sectors, added trigger scintillators and GEMs for dilution determination



(beam incident from right)

Recent MOLLER Project Activity

- August 2020: Jefferson Lab Director’s review to assess the readiness of the MOLLER project for the anticipated DOE CD-1 review
- October 2020: DOE OPA CD-1 review - review to determine if the project had fulfilled the requirements for CD-1;
- December 2020: **DOE CD-1 (Alternative Selection and Cost Range) approval** was awarded
- March 2021: **NSF Physics Division Midscale award** was made to provide the apparatus for the Normalization and Systematic Control needed to achieve the systematic error goals. **Canadian Foundation for Innovation (CFI) and Research Manitoba (RM) award** was made to provide the fused silica detectors and electronics to measure the raw Møller flux asymmetry and achieve the requisite statistical error.

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Summary

- MOLLER builds on JLab’s prior successes in PVES, most recently PREX-2 and CREX
- MOLLER has a Jeopardy presentation at PAC 49 on July 22
- We anticipate achieving CD-2 status in late 2022 and completion of construction by mid-2024 to be ready for installation when Hall A is available.