MOLLER

Status Update

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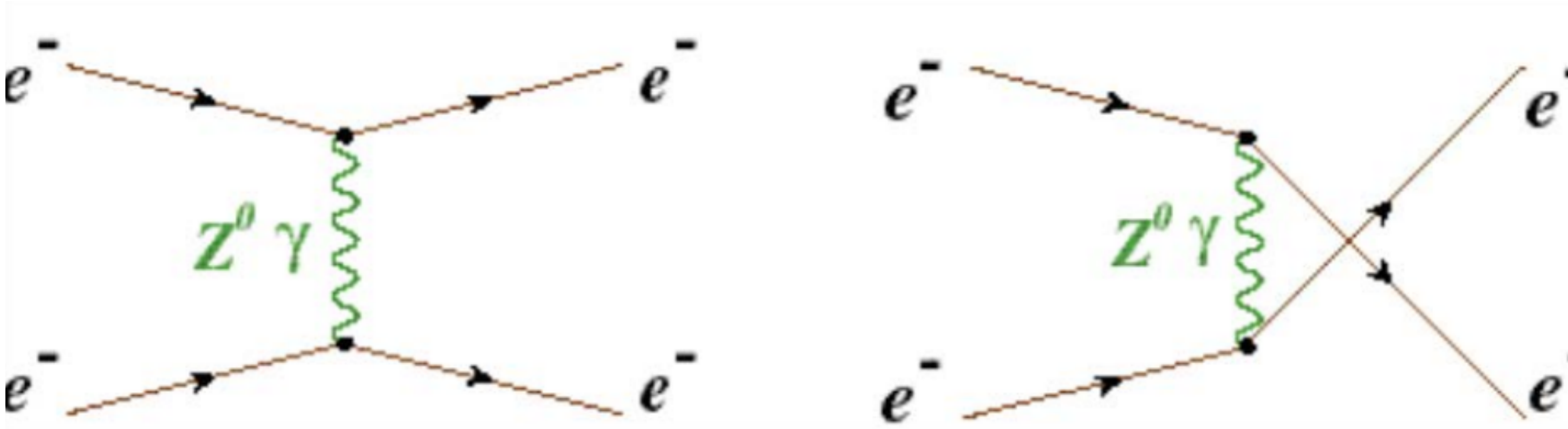
MOLLER experiment in a nutshell



$$A_{PV} = \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L} \propto \frac{\mathcal{M}_\gamma \mathcal{M}_Z}{\mathcal{M}_\gamma^2} \propto E_{lab} \frac{4\sin^2\theta}{(3+\cos^2\theta)^2} Q_W^e$$

Tree level: $Q_W^e = -(1 - 4\sin^2\theta_W)$

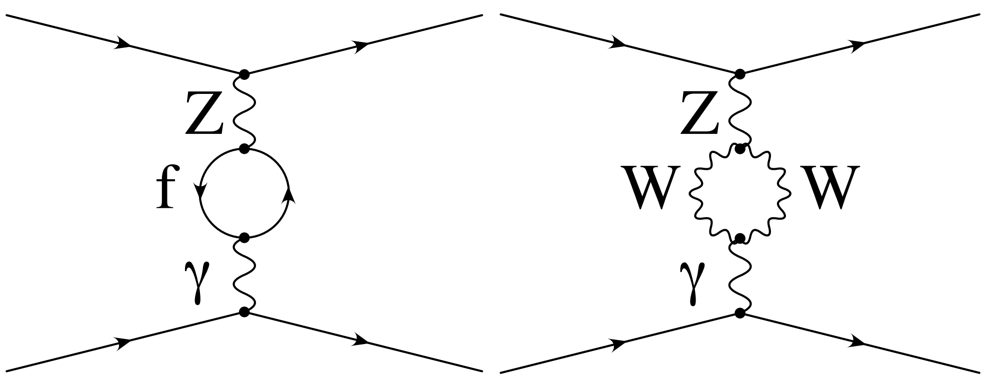
- MOLLER will be a high precision measurement of the weak charge of the electron

- The parity violating asymmetry in longitudinally polarized electron-electron scattering is directly proportional to the electron weak charge

High precision means considering loops

$$A_{PV}(ee) \propto \rho G_F \left[1 - 4\kappa(0)\sin^2\theta_W(m_Z)_{\overline{\mathrm{MS}}}\right] + \cdots$$

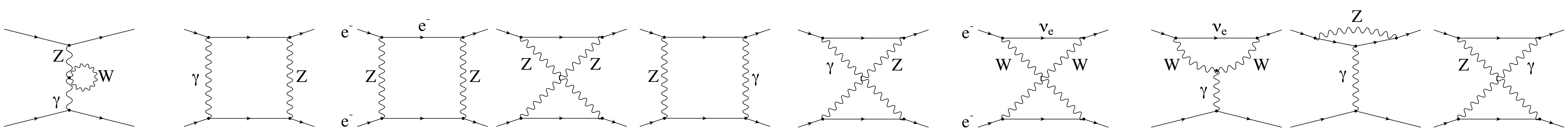
Dominant Contribution at 1-loop



κ(0) known better than 1% of itself

Erler and Ramsey-Musolf (2003)

Erler and Ferro-Hernandez (2018)



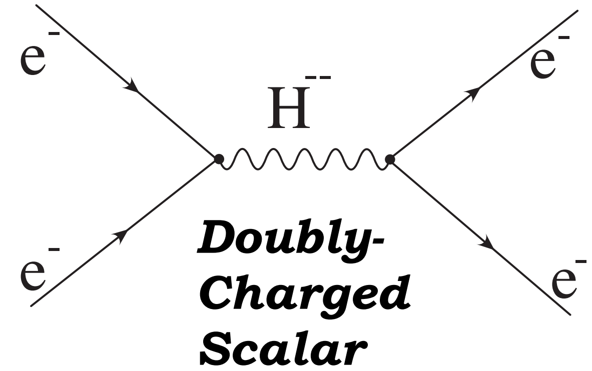
δ(Q^e_W) (theory) = 0.6%, another factor of 2 improvement with full two-loop calculation

MOLLER **δ(Q^e_W) goal = ± 2.1 % (stat.) ± 1.1 % (syst.)**

Unique BSM physics access

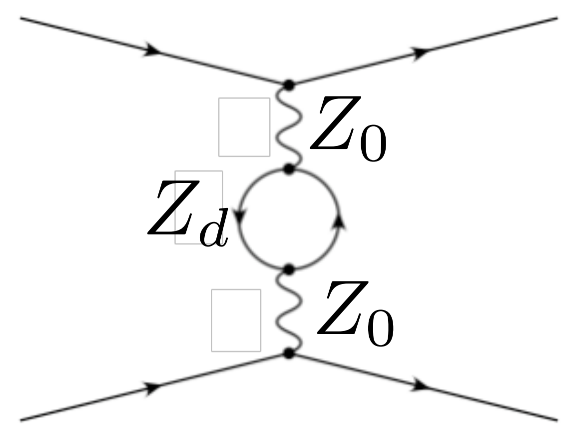
- Through a precise measurement of electron weak charge we can detect deviations from the SM calculations
- Possible deviations include doubly charged scalar that would lead to lepton number violations
- A dark Z which would only mix with the regular Z boson (would not be visible at colliders)
- Heavy Z's with mass in the TeV range
- Models where Lorentz Invariance could be violated show that our measurement could be sensitive to such effects

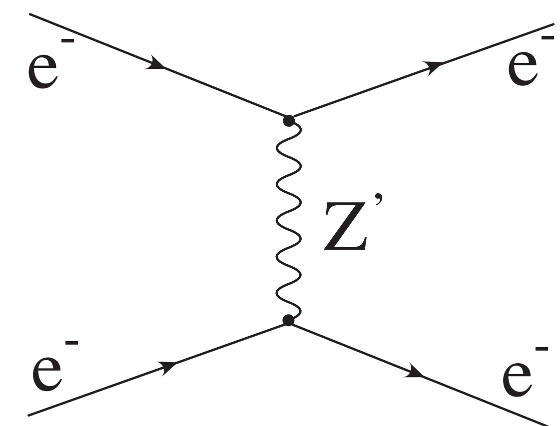
Lepton Number Violation



$$\left|\frac{\Delta Q_W^e}{Q_W^e}\right| = 0.14\frac{|h_{ee}|^2}{(M_\Delta/1\ \mathrm{TeV})^2}$$

5 σ for h_{ee} ~ 1 and M_Δ ~ 1 TeV





H. Davoudiasl, H-S. Lee and W. Marciano

Constraining Lorentz Invariance

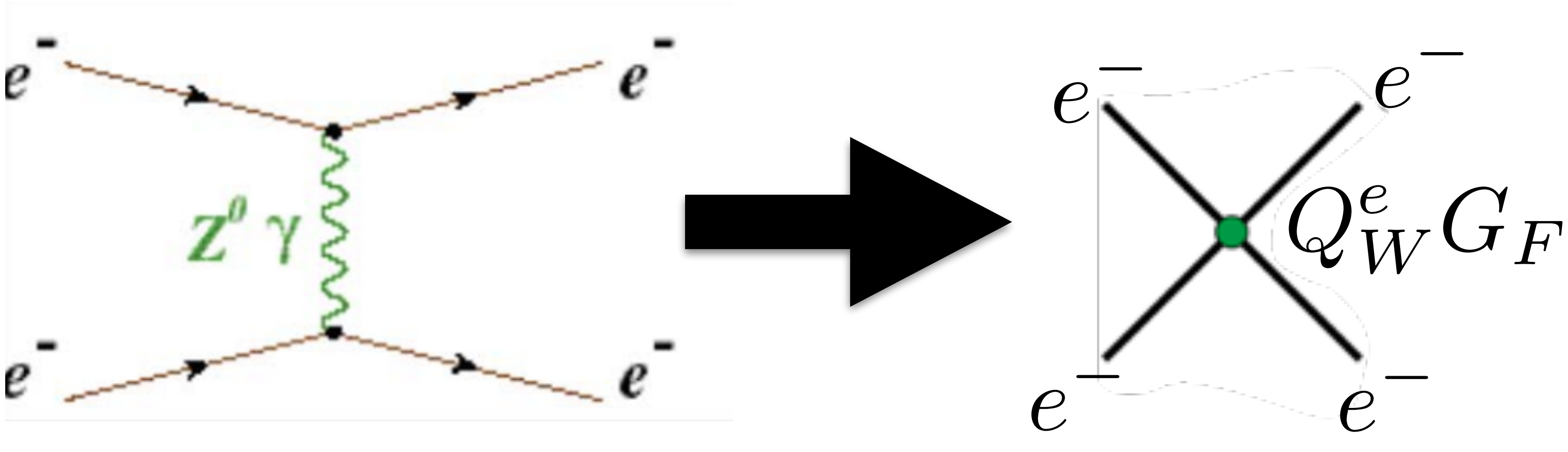
$$\delta A(t) = \frac{G_F}{\sqrt{2}\pi\alpha}\frac{E_k\, y\,(1-y)\sin^2\theta_W}{(y^2-y+1)^2}\vec{k}(t)\cdot\vec{\xi}$$

$$= \frac{G_F}{\sqrt{2}\pi\alpha}\frac{E_k^2\, y\,(1-y)\sin^2\theta_W}{(y^2-y+1)^2}\times$$

$$\left[\sqrt{\xi_X^2+\xi_Y^2}\sqrt{1-\cos^2\alpha\sin^2\chi}\,\cos\Omega_\oplus t + c_0\right]$$

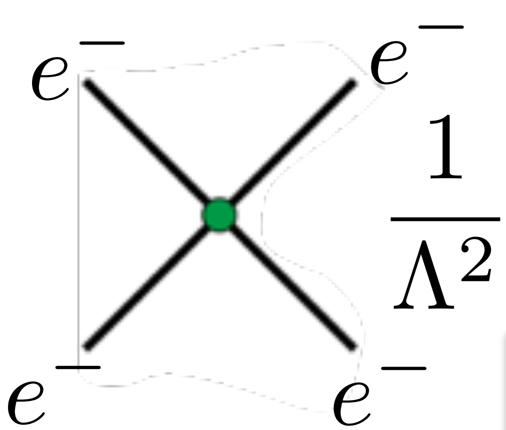
Ralf Lehnert, J. Phys.: Conf. Ser. **952** (2018) 012008

Effective Lagrangian



- At low $Q^2(<<M_Z^2)$ the interaction can be modeled as an effective 4-fermion contact interaction

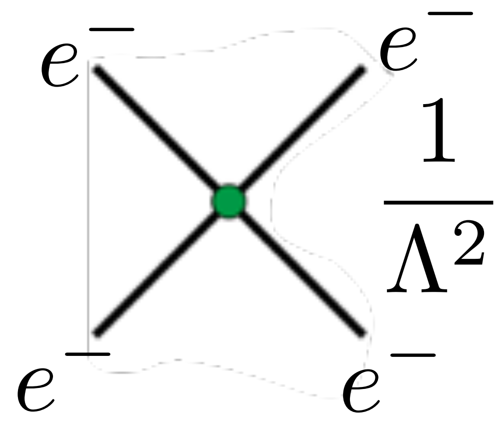
- Standard HEP way to introduce new physics through additional contact interactions



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

$$\frac{\delta Q_W^e}{Q_W^e} = 2.4\% \rightarrow \frac{\Lambda}{\|\sqrt{g_{RR}^2 - g_{LL}^2}\|} = 7.5 \text{ TeV}$$

Setting limits



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

$$g_{ij} = 4\pi\eta_{ij}$$

Model	η_{LL}^f	η_{RR}^f	η_{LR}^f	η_{RL}^f
$LL^\pm$	± 1	0	0	0
$RR^\pm$	0	± 1	0	0
$VV^\pm$	± 1	± 1	± 1	± 1

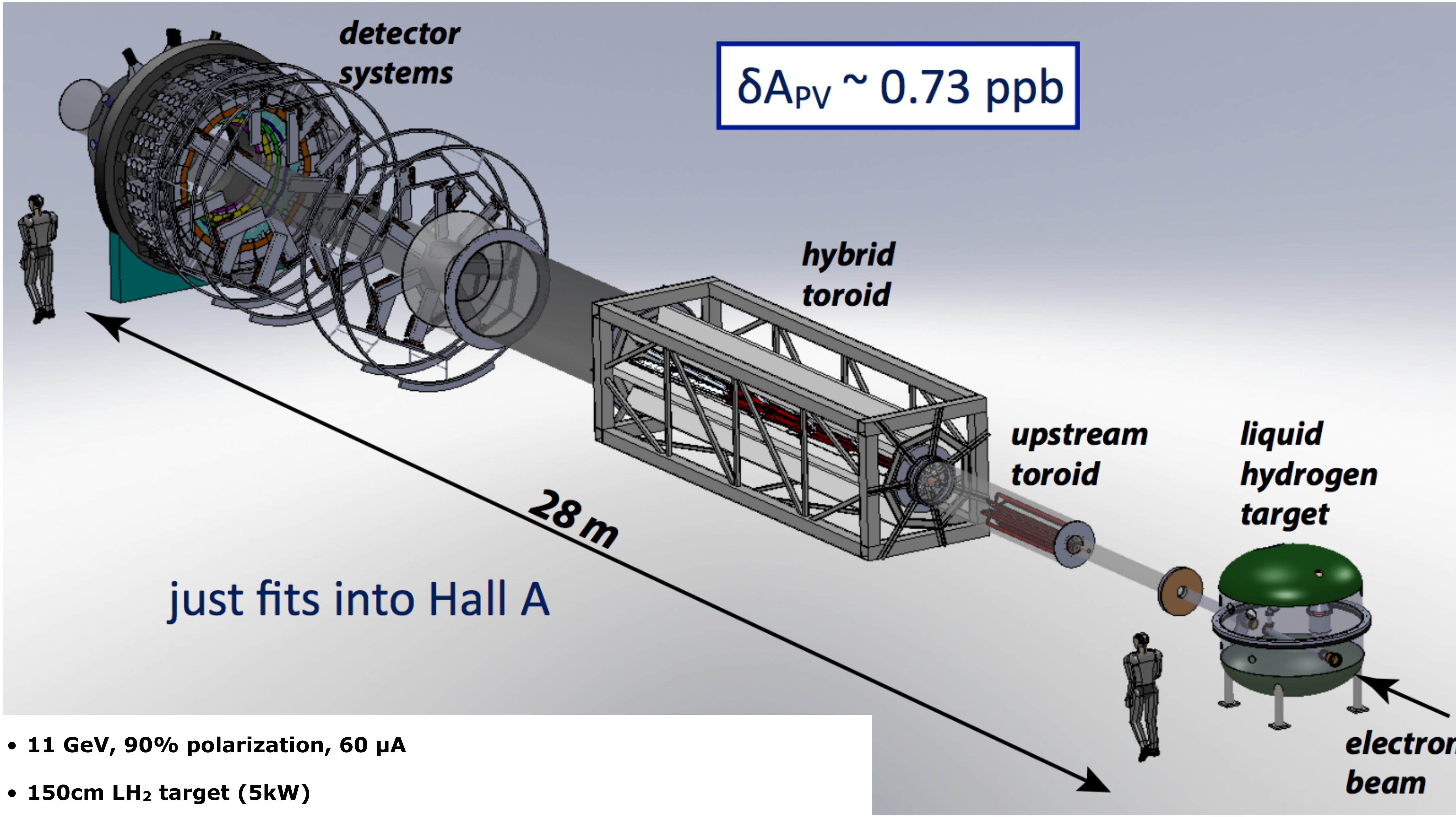
LEP200 Reach $\Lambda_{LL}^{ee} \sim 8.3$ TeV

E158 Reach $\Lambda_{LL}^{ee} \sim 12$ TeV

MOLLER Reach $\Lambda_{LL}^{ee} \sim 27$ TeV

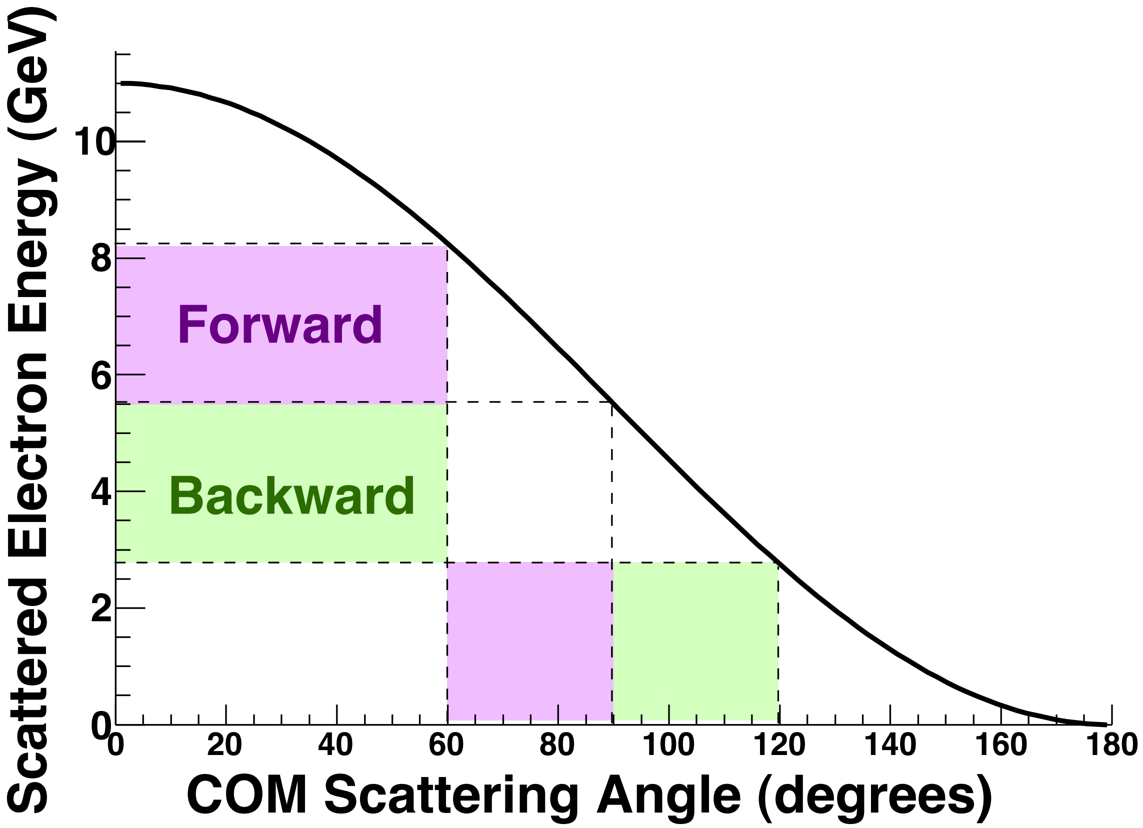
- Like E158 before it MOLLER will be able to set limits on leptonic BSM physics that will not be improved without the construction of a new lepton collider or neutrino factory

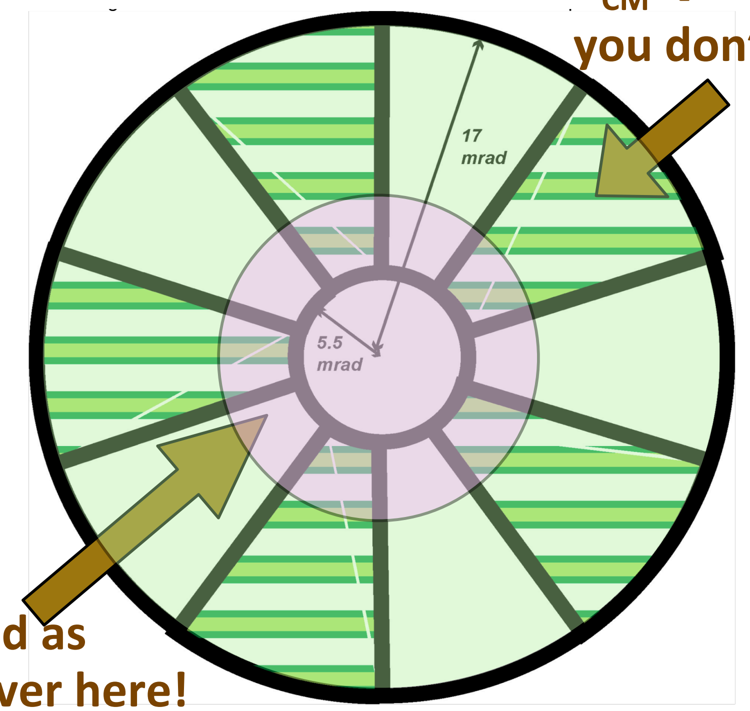
MOLLER experiment in a nutshell



- **11 GeV, 90% polarization, 60 μA**
- **150cm LH_2 target (5kW)**
- **Novel toroidal spectrometer**
- **Segmented integrating detectors + counting detectors (for background)**

Kinematics



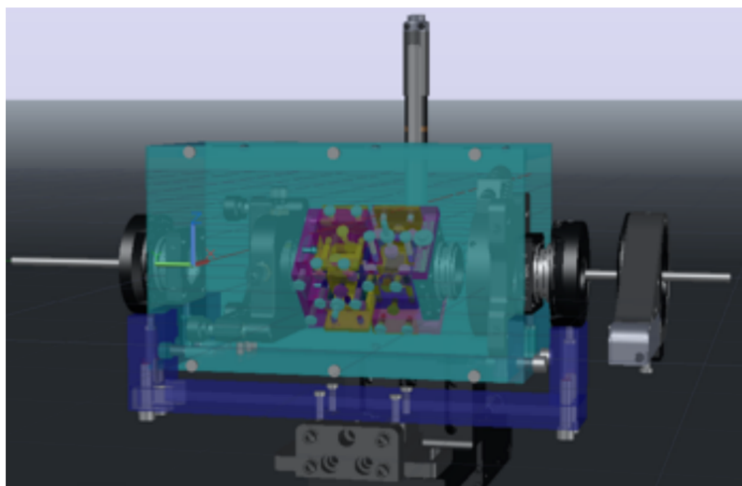


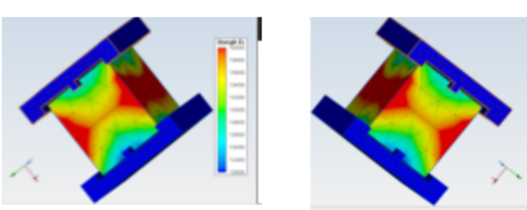
- The spectrometer design with an odd number of coils affords us the possibility to detector both forward and backward Moeller electrons in the same phi-bite

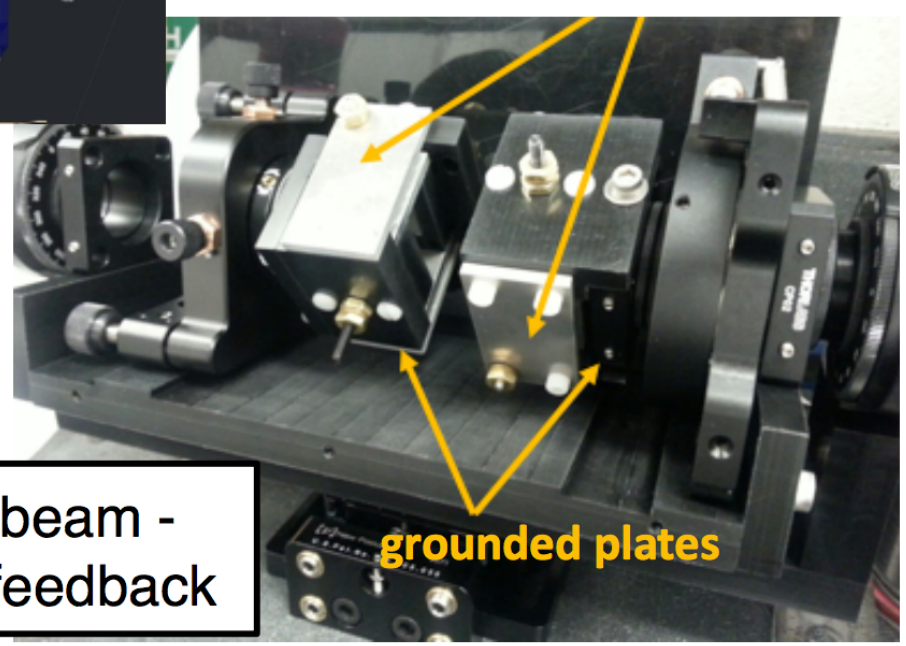
Polarized Source

MOLLER requires a 2kHz helicity flip with a 10 μs settle time (Qweak: 1kHz, 60 μs)

RTP upgrade (UVa):





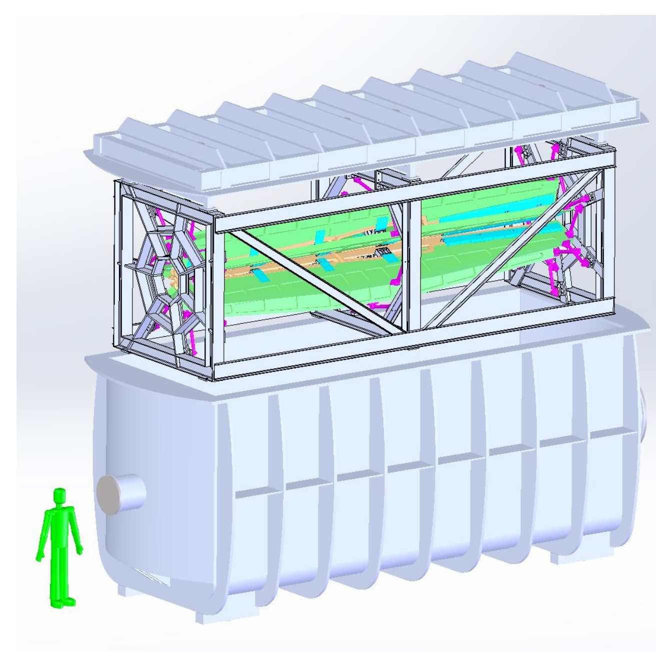


E-field gradient steers beam - use effect for position feedback

- The beam requirements for MOLLER will need a polarized source upgrade
- Caryn, Amali and Kent at UVa have conducted several successful beam tests replacing the KD*P cell with a RTP cell
    - electron beam helicity correlated position differences on the order of 100 nm were reached, with clear path towards improvement
- Further studies are scheduled for 2018 to characterize the properties of this new setup

Spectrometer update

- A test coil has been constructed
- Tests plan is in place to characterize and stress the coil
- Series of simulation studies needed to evaluate radiation load on coils is underway
- TOSCA field simulations are being produced to evaluate spectrometer construction tolerances, fringe fields and effects from environmental variations

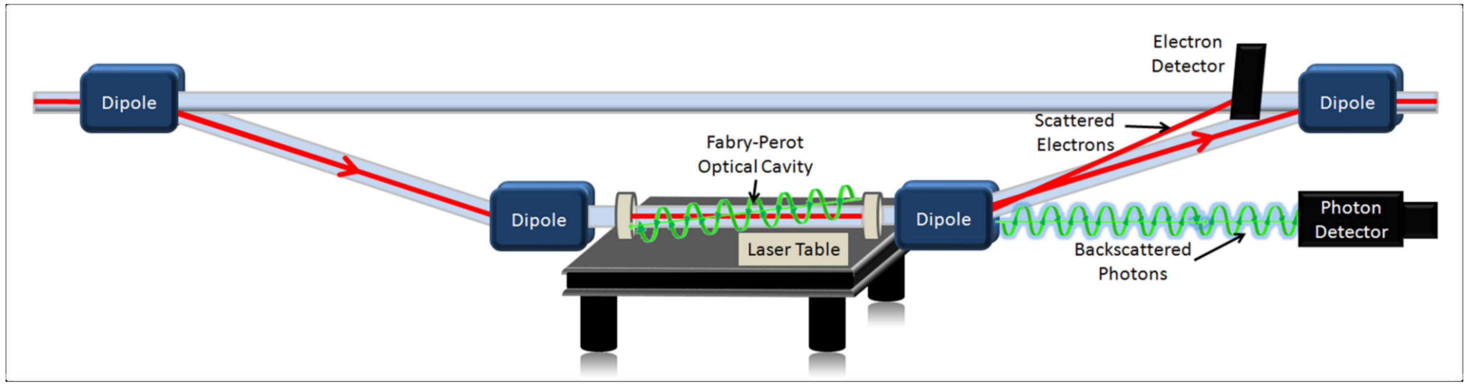


Vacuum Tank Concept

Polarimetry

Compton:

- The Compton was last successfully used during the DVCS Fall 2016 run
- Currently more work is needed for the laser table in order to get the system locking
- The photon detector works, with plans to upgrade the DAQ system
- Plans under way to recover functionality or replace electron detector



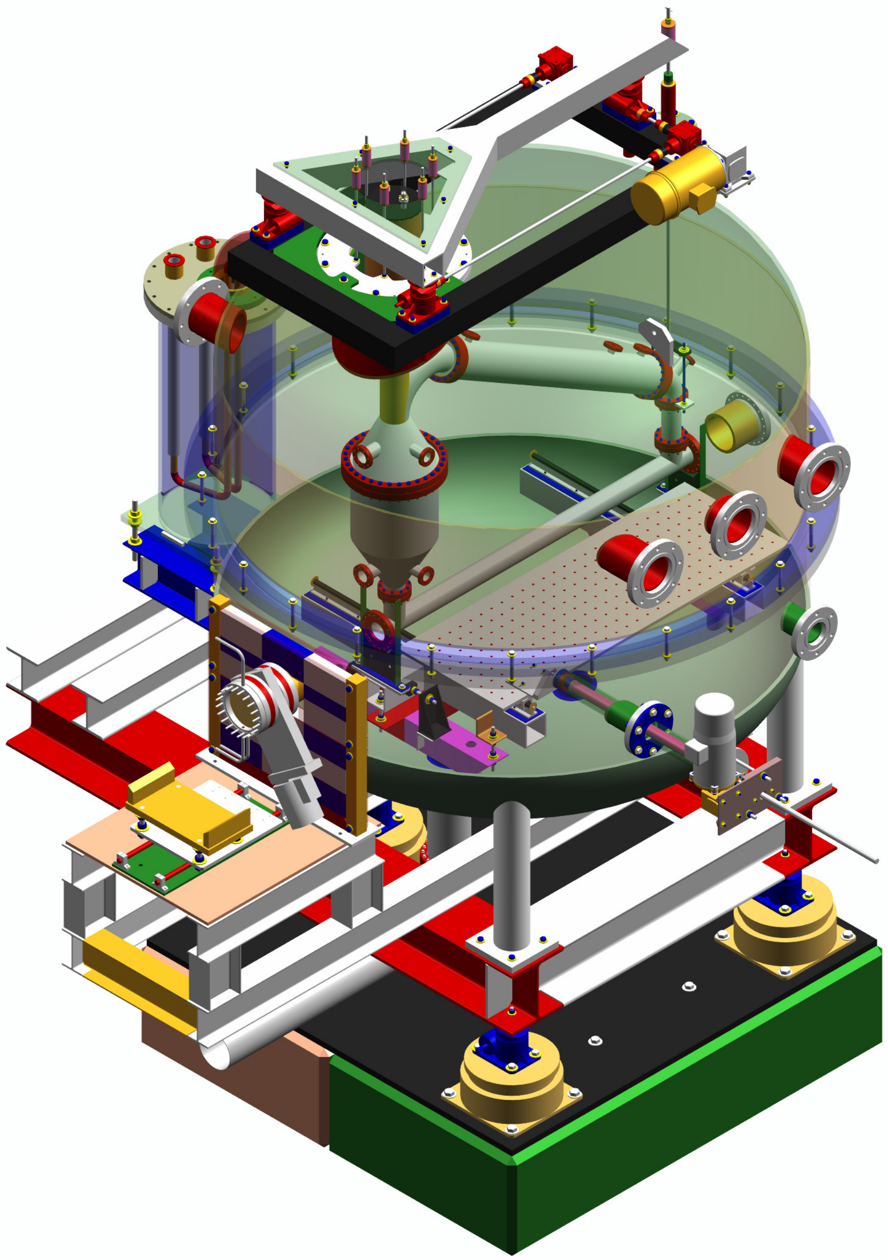
MOLLER:

- The new target ladder designed and built at Temple has been extensively tested and is on track to provide fine angle controls
- Kerr effect studies are under way lead by Stony Brook

- A Geant4 based simulation is being developed and tested against old Geant3 simulation package
- The Quads are being modeled in TOSCA and implemented in the new simulation

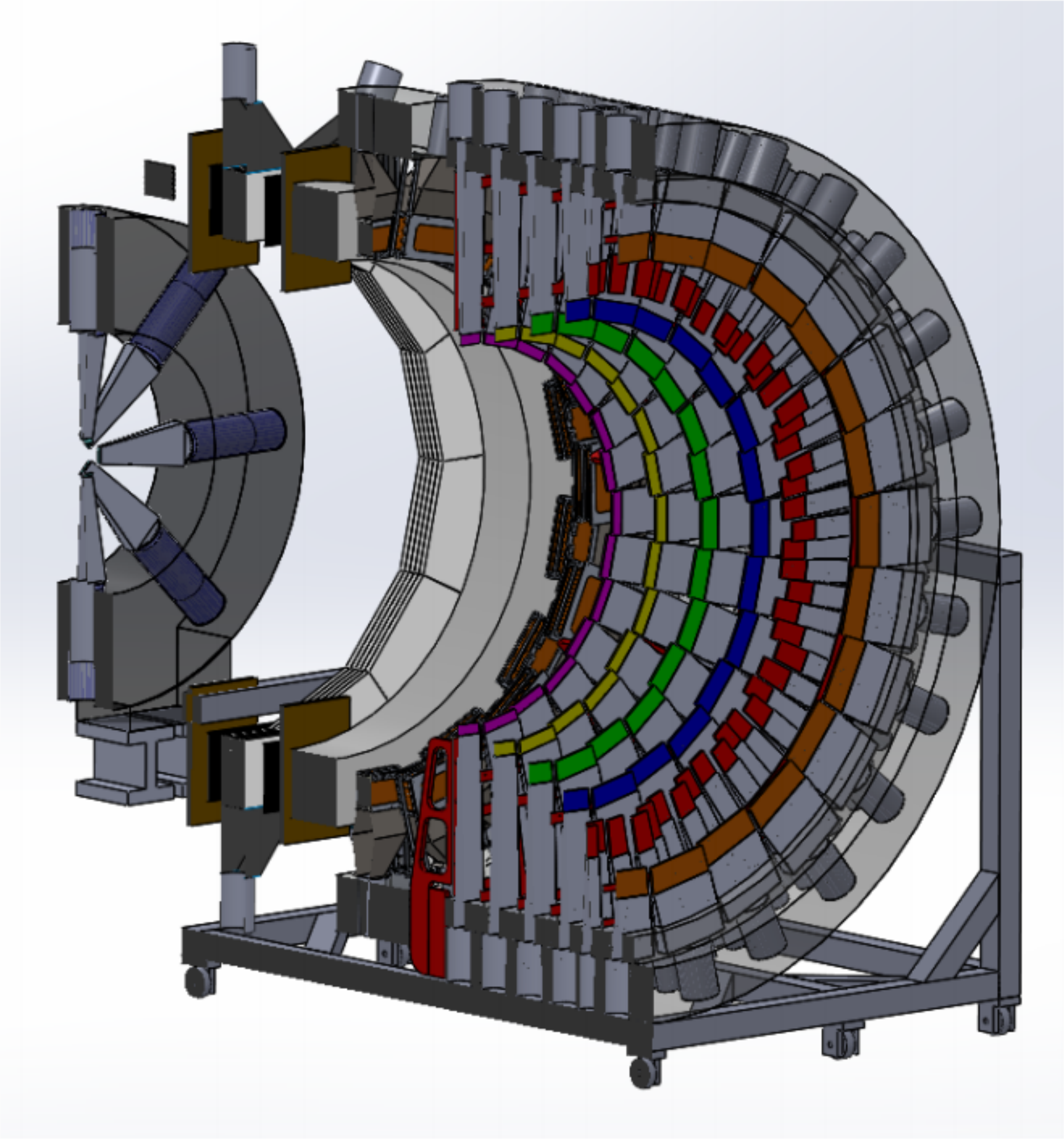
Target

- Long 150 cm liquid hydrogen target makes use of the experience garnered from other PVES experiments (most recently Qweak)
- The starting point is the E158 target geometry
- Will take ~5kW of power (Qweak target was 3kW)

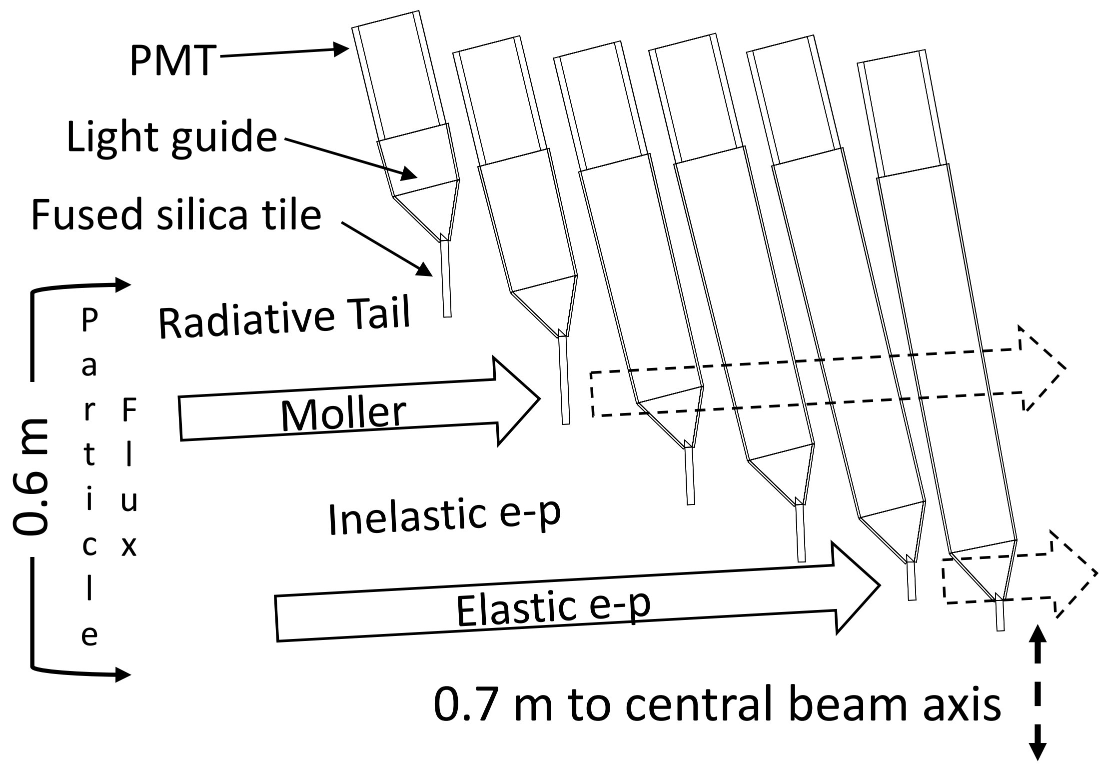


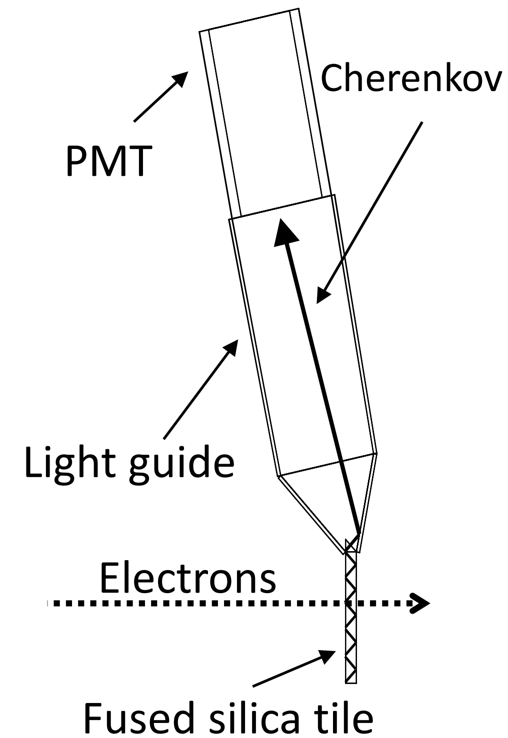
Detectors

- We have a pretty well established detector geometry and mechanical design (SBU)
  - several beam tests have been performed to ensure we will have the necessary quality
  - working on mechanical supports and assembly
- Shower max detectors have already been prototyped (including mechanical assembly) and tested with the Mainz beam (ISU)
- Radiation exposure and hardness tests have been started (ISU)
- Pion detectors are being developed to directly measure this contribution to our experiment (W&M)

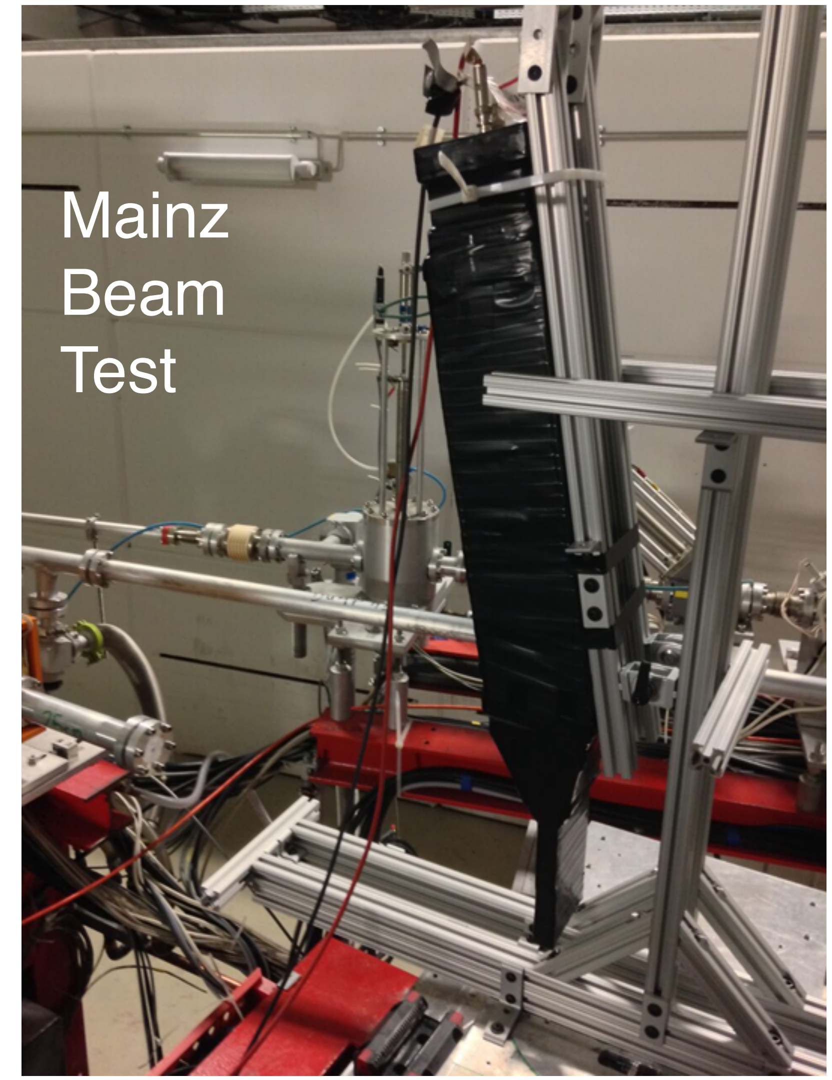


Detectors: First publication



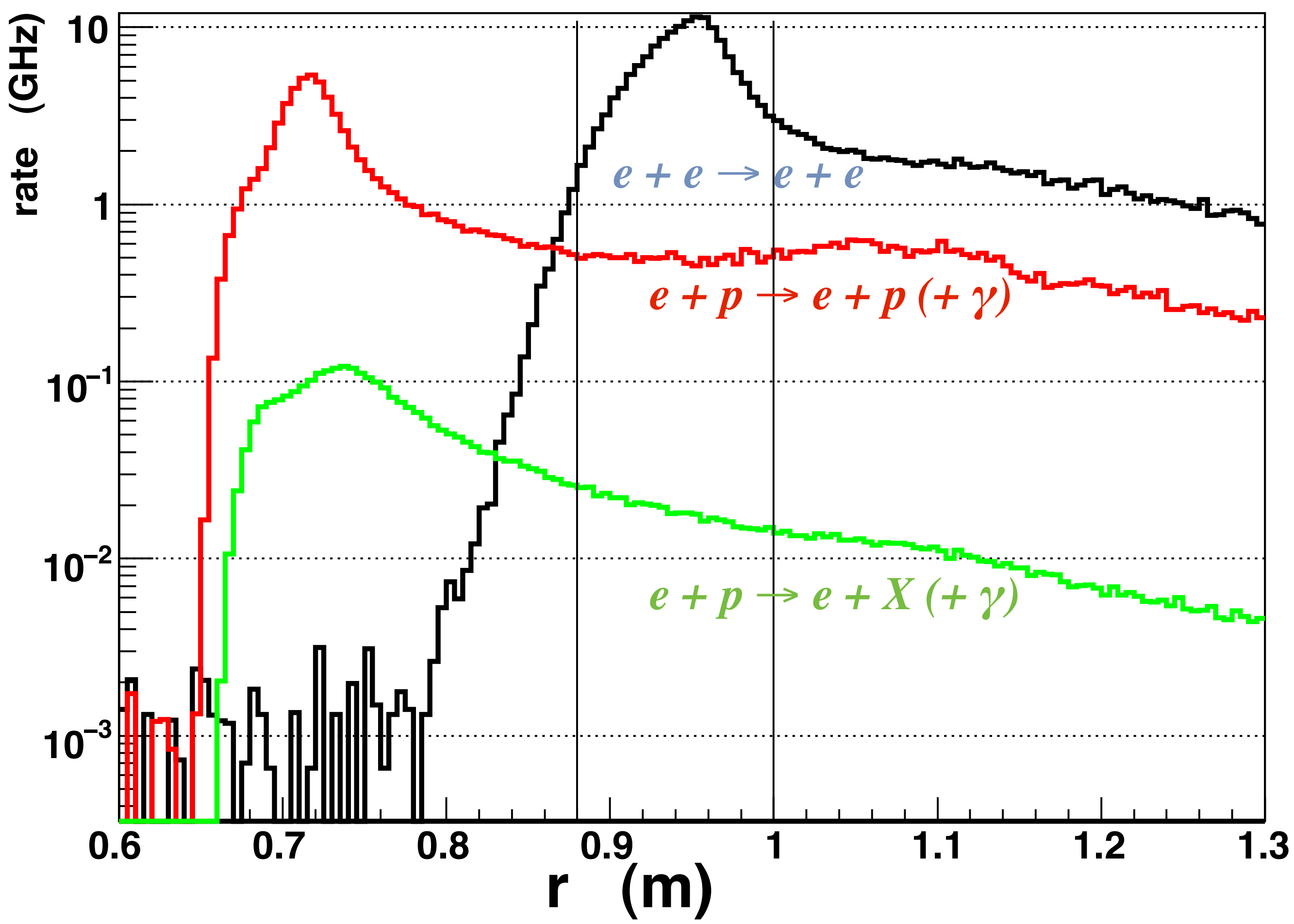


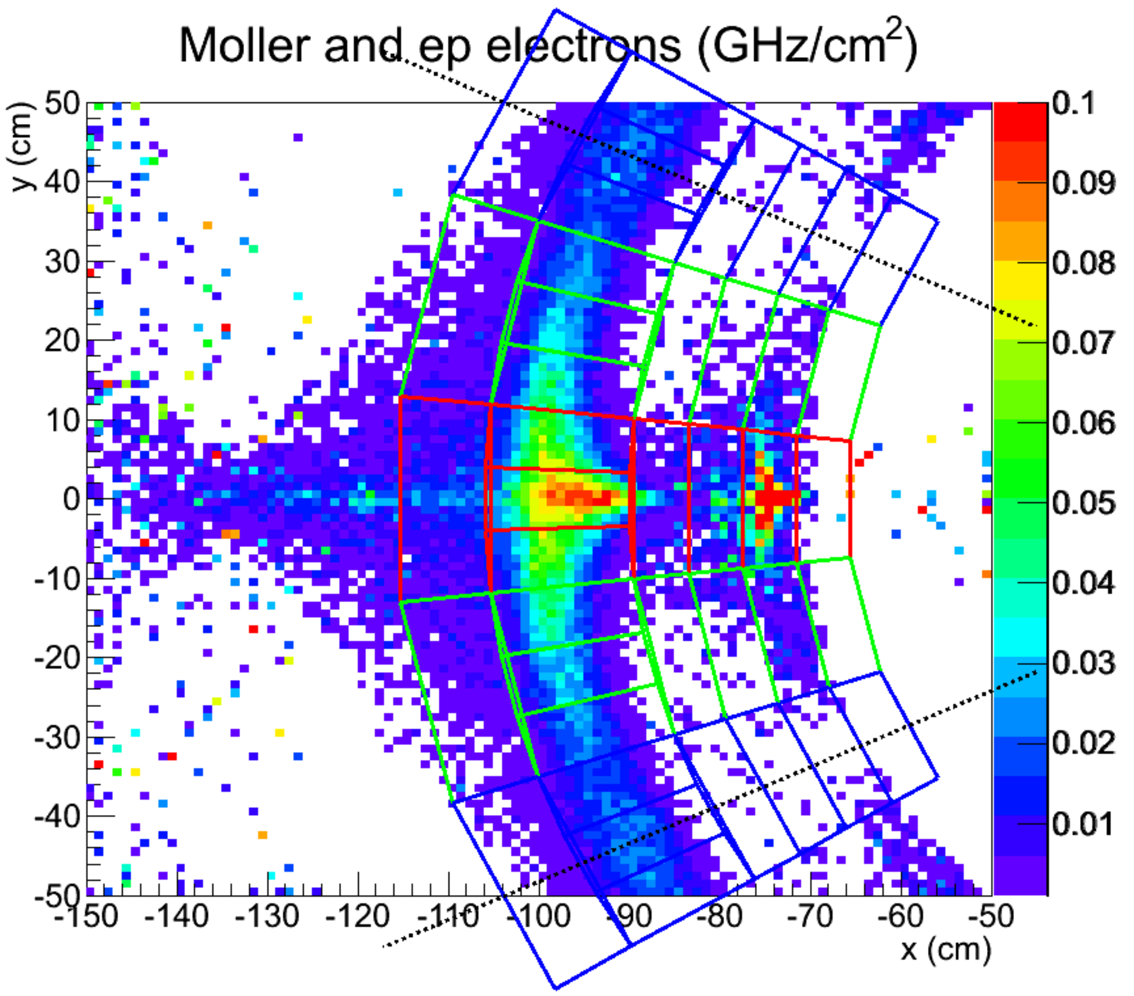
NIM A 896 (2018) 96–102



- We used the MAMI facility in Maintz to test different light guide and quartz design
- The air filled light guide produced manageable backgrounds
  - several gases were tested
- Varying the incidence angle of the electrons and light guide blackening produced sizable improvements

Physics signal and background rates

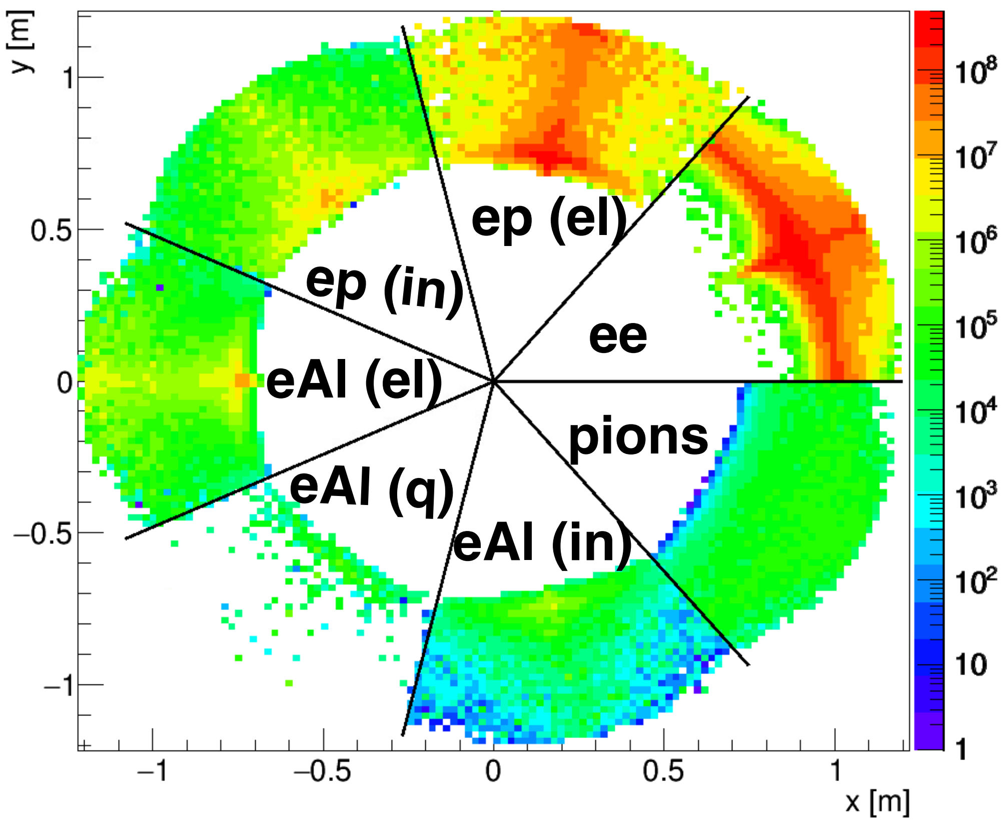


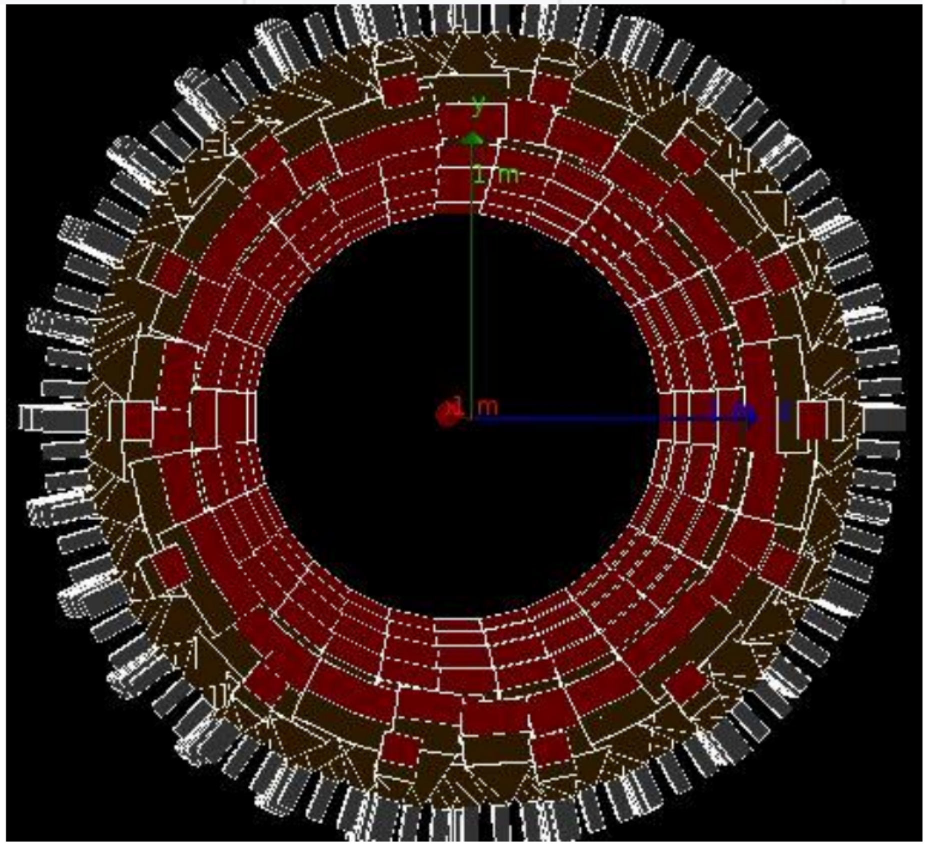


- Radial segmentation will enable for direct measurement of backgrounds
- Azimuthal segmentation will improve our asymmetry extraction

Simulations

- Using already developed background and signal extraction methods we are optimizing the geometrical coverage of our quartz detectors (UVa)
- We are evaluating contributions from non-standard background (re-scattering, slit-scattering etc.) (Manitoba)
- We are investigating possible transverse analyzing power effects to evaluate systematics offsets (UVa)
- More and more detailed geometry is introduced in the simulation package and effect on other components is being evaluated





Status

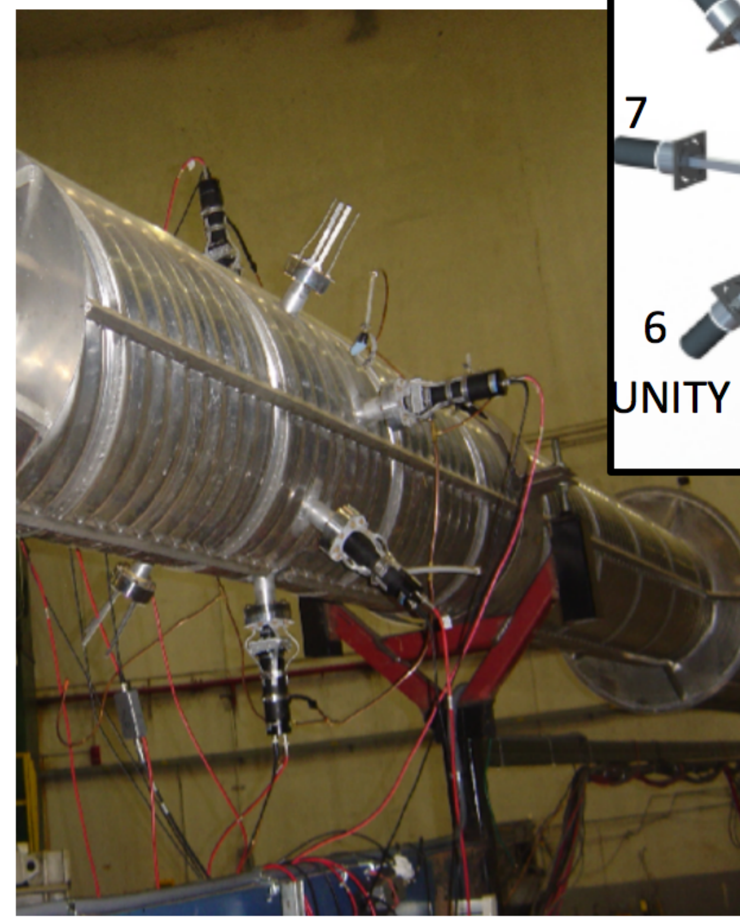
- We have ~120 collaborators from 30 institutions and 5 countries
  - lots of PVES experience from E158, SAMPLE, A4, HAPPEX, G0, PREX, Qweak
- After successful CD-0 review the project is still in a “paused” state
- The collaboration is hard at work improving the design of the detector, shielding, spectrometer, and target
- Our main working groups are very active with an emphasis on dealing with recommendations from previous reviews
- We will have a collaboration meeting later this summer to assess progress and plot course forward

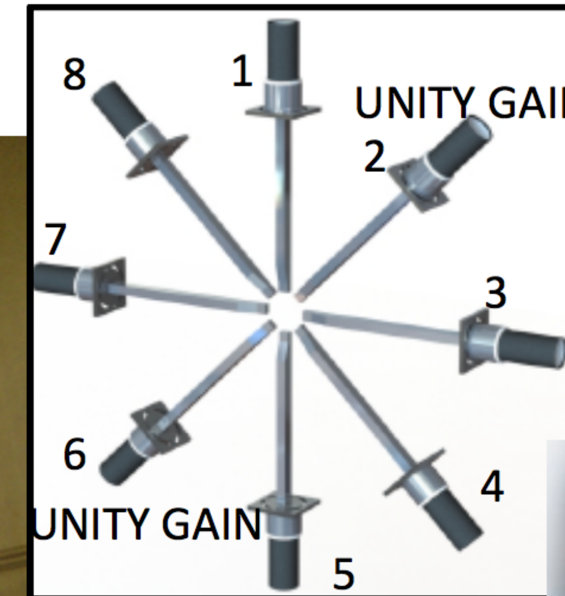
Summary

- The MOLLER experiment will have the largest reach for BSM physics in the foreseeable future
- Our collaboration is making good progress on all fronts towards realization of the technical aspects needed to stage this experiment

Beam monitoring

- Dustin McNulty (Idaho State) constructed and installed Small Angle Monitors in the Hall A beam line
- These detectors were used parasitically during the DVCS/Gmp run to test and characterize our current beam charge monitors
  - Analysis is underway
- Further characterization will need specific conditions (solid target) and higher currents and helicity flip rates
- Plans are being developed to implement new beam monitoring techniques at LBNL (Yury Kolomensky)





- 8 quartz detectors with light guides placed around beam line downstream of pivot
- Symmetric design helps disentangle beam position and angle HCBP’s
- For large dynamic range, mix ‘n matched

Uncertainty table

Beam Property	Assumed Sensitivity	Accuracy of Correction	Required 2 kHz random fluctuations	Required cumulative helicity-correlation	Systematic contribution
Intensity	1 ppb / ppb	$\sim$1%	$<$ 1000 ppm	$<$ 10 ppb	$\sim$ 0.1 ppb
Energy	-1.4 ppb / ppb	$\sim$10%	$<$ 108 ppm	$<$ 0.7 ppb	$\sim$ 0.05 ppb
Position	0.85 ppb / nm	$\sim$10%	$<$ 47 μm	$<$ 1.2 nm	$\sim$ 0.05 ppb
Angle	8.5 ppb / nrad	$\sim$10%	$<$ 4.7 μrad	$<$ 0.12 nrad	$\sim$ 0.05 ppb

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

All systematics required at sub-1% level