MOLLER

Measurement Of a Lepton Lepton Electroweak Reaction using Parity Violating Electron-Electron Scattering

A proposed 2.4% measurement of the electron weak charge:

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

A test for physics beyond the Standard Model

TRIUMF Science Week, July 2017

Willem van Oers

On behalf of the Canadian MOLLER group

MOLLER

Measurement Of a Lepton Lepton Electroweak Reaction

Currently 128 Collaborators from 38 Institutions from the US, Canada, Germany, Italy, France, and Mexico

Collaborating Institutions within Canada:
Acadia U., U. of Manitoba, Memorial U., TRIUMF, UNBC, U. of Winnipeg

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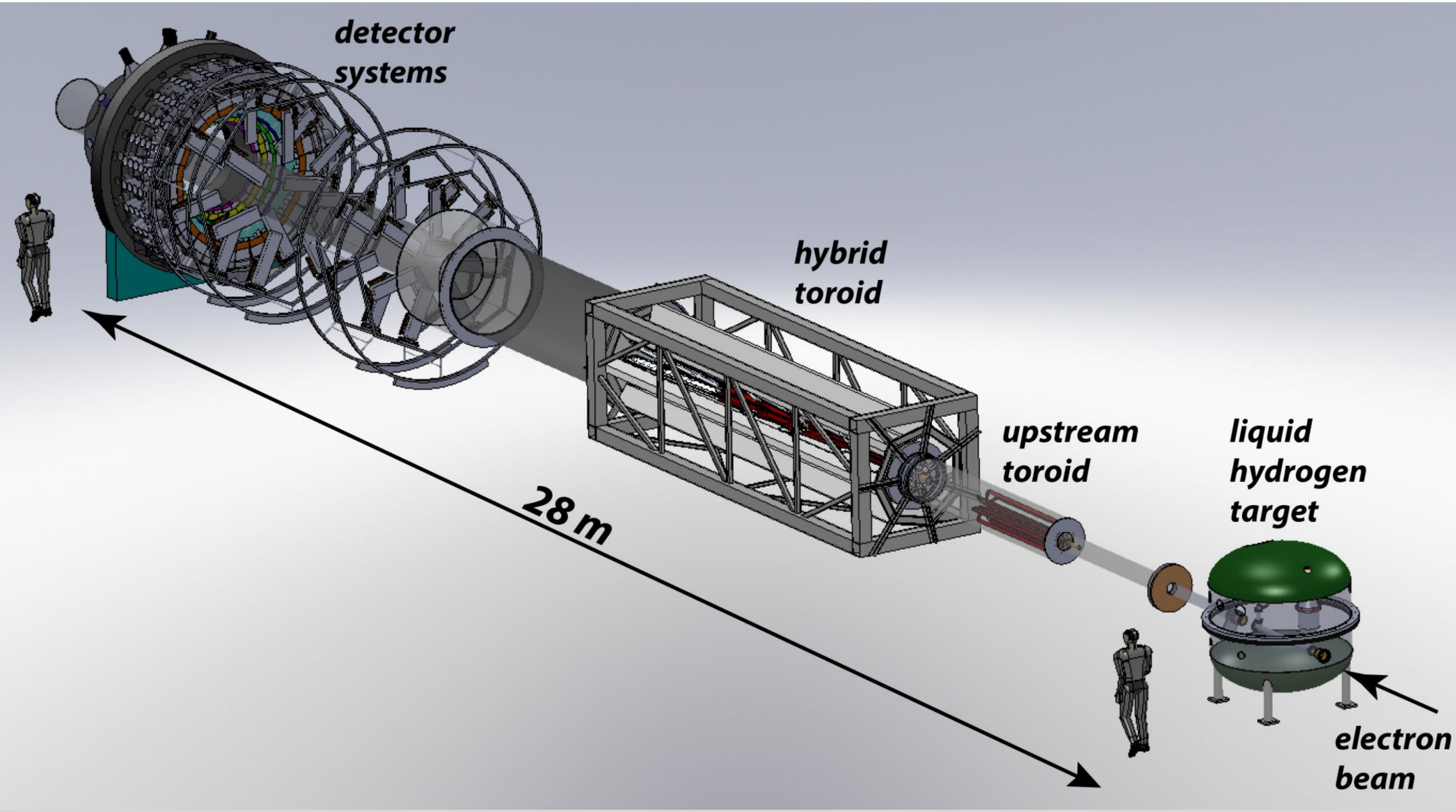
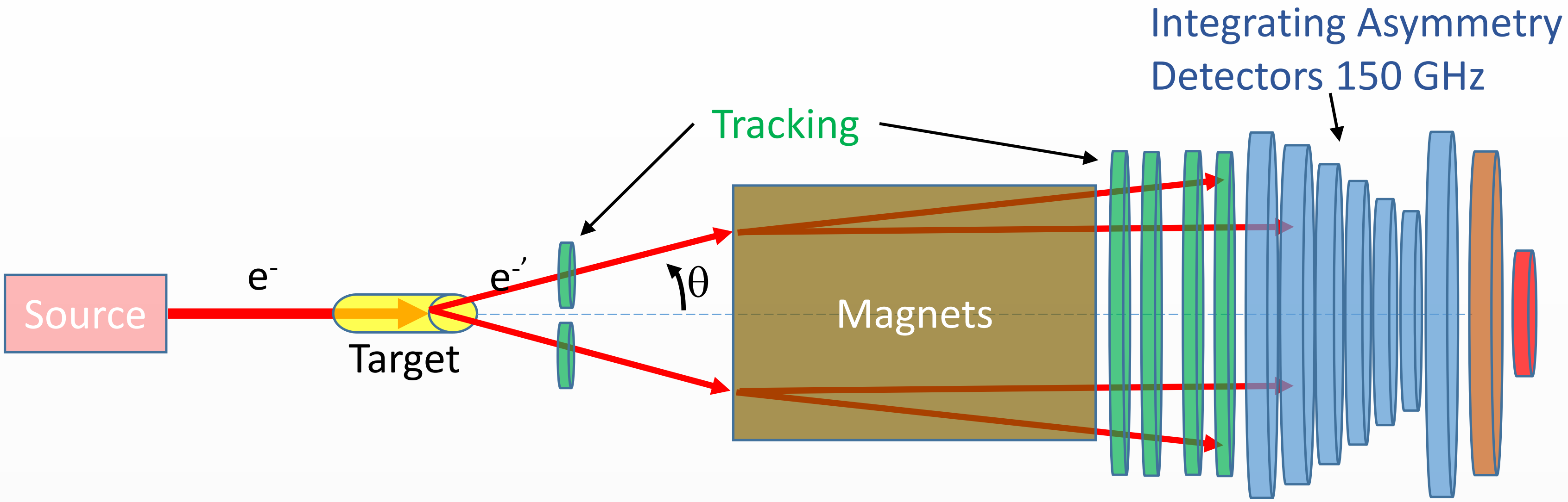
The MOLLER Experiment



The MOLLER Experiment



- Beam: $E = 11\ GeV$ $I = 85\ \mu A$ $P_e \geq 80\ \%$
- LH2 Target: $\ell = 150\ cm$ $L = 3 \times 10^{39}\ cm^{-2} \cdot s^{-1}$
- Scattering range: $0.3 \leq \theta \leq 1.1$ deg $2.75 \leq E' \leq 8.25\ GeV$
- Separate into e-e , e-p , and inelastic bins using two toroidal spectrometers
- Measure scattering angle with tracking detectors

The MOLLER Experiment

Main Technical Challenges:

- ❑ 150 GHz scattered electron rate
  - 2 kHz beam helicity reversal
  - 80 ppm pulse-to-pulse statistical fluctuations
- ❑ 1 nm control of beam centroid on target
  - Improved methods of "slow helicity reversal"
- ❑ Liquid hydrogen target with $\rho > 10$ gm/cm^2
  - 1.5 m: ~ 5 kW @ 85 μA
- ❑ Full Azimuthal acceptance with θ_{lab} ~ 5 milliradians
  - novel two-toroid spectrometer
  - radiation hard, highly segmented integrating detectors
- ❑ Robust and Redundant 0.4% beam polarimetry
  - use both, Compton and Møller polarimeters

The Facility

Parity Violating Electron Scattering (PVeS) at JLAB

A 4th generation JLab PVeS Experiment, with expertise from:

MIT Bates, SLAC E158, JLab G0 HAPPEX, PREX and QWeak.

There is a lot of expertise within the JLab user community, but …

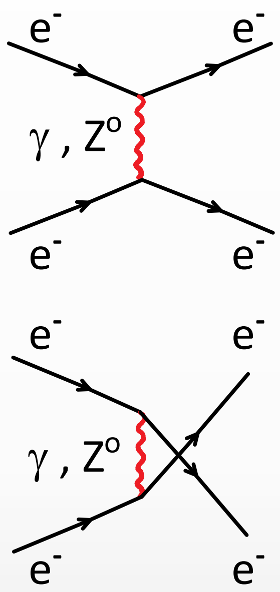
MOLLER is more challenging than previous PVeS experiments and would greatly benefit from new collaborators …

Hall A

The MOLLER Observable

The flux (N±) of scattered electrons will be measured as a function of initial electron helicity (±) and an asymmetry is formed:

$$A_{msr} = \frac{N^+ - N^-}{N^+ + N^-} = P_e\left(f_p A_p + \sum_b A_b f_b\right) + A_i$$



P_e = electron polarization
f_p = flux fraction from desired physics signal
f_b = flux fraction from background signal
A_p = physics asymmetry
A_b = background asymmetries
A_i = instrumental (false) asymmetries

SM predicted asymmetry 35 ppb - directly related to the weak charge of the electron:

$$A_p = mE\frac{G_F}{\sqrt{2}\pi\alpha}\frac{4\sin^2\theta}{\left(3+\cos^2\theta\right)^2}Q_W^e$$

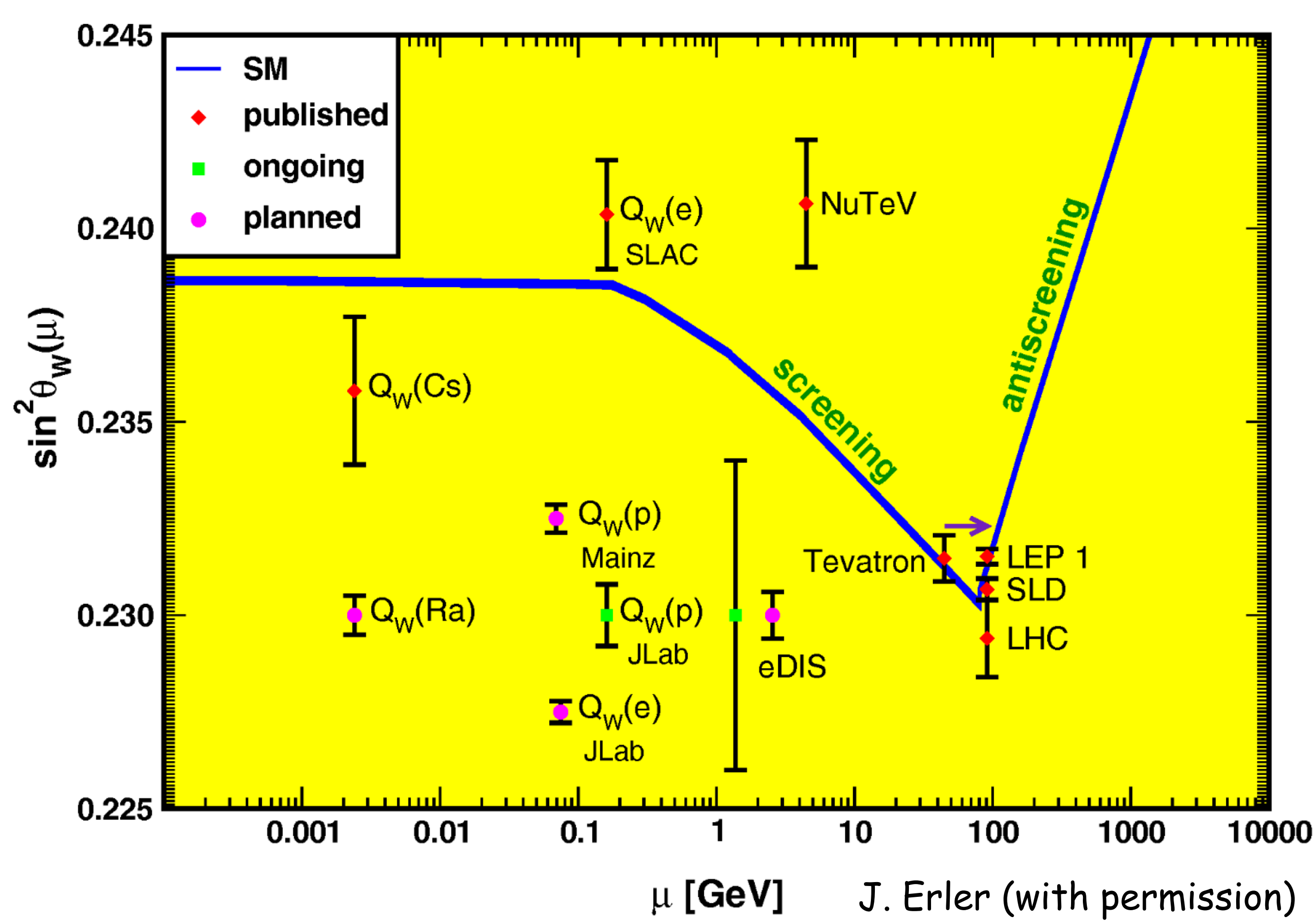
$$Q_W^e = (1 - 4\sin^2\theta_W)$$

At tree level, with no new physics

The MOLLER Physics

Propose to measure A_p to 2% (0.7 ppb)

$$\frac{\delta \sin^2\theta_W}{\sin^2\theta_W} \simeq .05\,\frac{\delta A_P}{A_P}$$



J. Erler (with permission)

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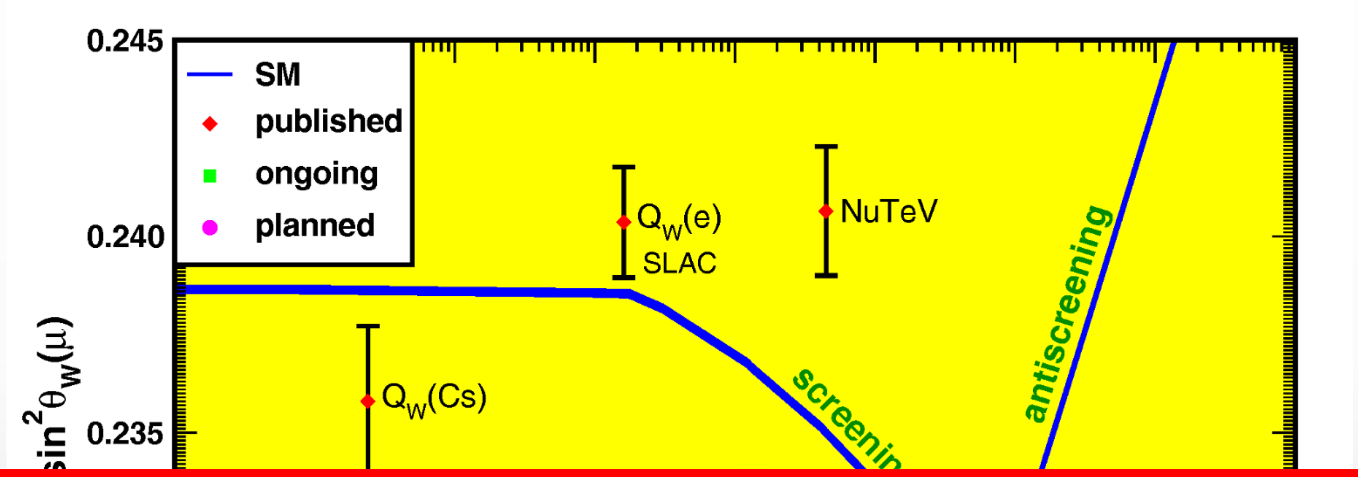


$$\delta\left(\sin^2\theta_W\right) = \pm 0.00026(stat.) \pm 0.00012(syst.) \quad \Rightarrow \quad \sim 0.1\%$$

Would match best collider (Z-pole) measurements.
Best contact interaction reach for leptons at low OR high energy.

To do better for a 4-lepton contact interaction would require:
Giga-Z factory, linear collider, neutrino factory or muon collider

Merit of the Project

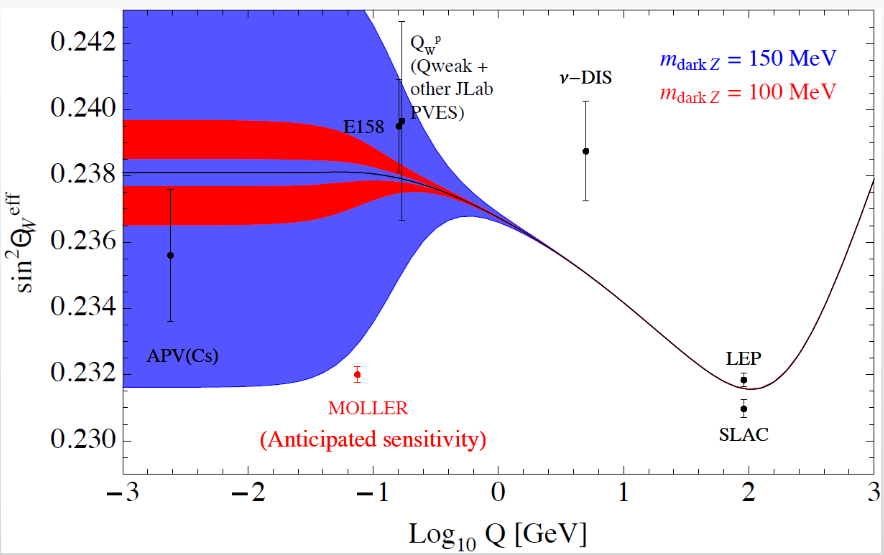
New physics sensitivity:

Induced by a range of new physics scenarios:

$$L_{eff} = \frac{g^2}{\Lambda^2} \sum_{i,j=L,R} n_{ij}^f \bar{e}_i \gamma_\mu e_i \bar{e}_j \gamma_\mu e_j$$

- low scale quantum gravity with large extra dimensions
- composite fermions,
- leptoquarks,
- heavy Z_0 bosons
- Dark photon (light dark Z)

$$\frac{\Lambda}{\sqrt{\left|g_{RR}^2 - g_{LL}^2\right|}} = \frac{1}{\sqrt{\sqrt{2}G_F \left|\delta Q_W^e\right|}} \simeq 7.5\ TeV$$



Electron compositeness

$$\sqrt{\left|g_{RR}^2 - g_{LL}^2\right|} = 2\pi \rightarrow \Lambda \simeq 47\ TeV$$

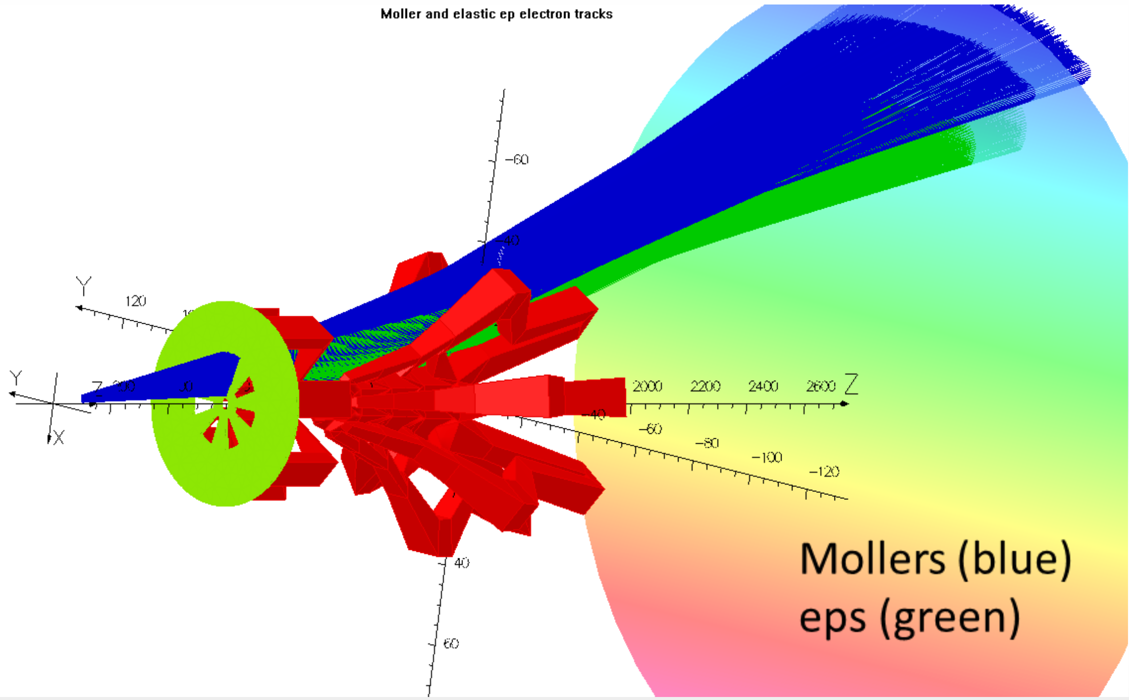
→ Study electron structure down to $4 \times 10^{-21}\ m$

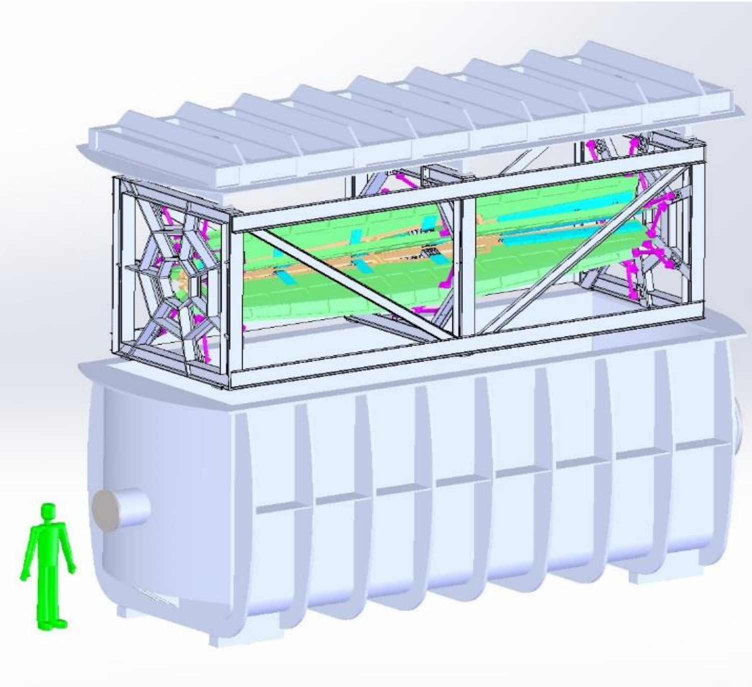
Very brief look at equipment associated with Canadian contributions:

- Integrating Detectors and Electronics
- Spectrometers
- Compton Polarimetry

The Spectrometer / Collimator

Separate events into e-e , e-p , and inelastic bins, using two spectrometers.



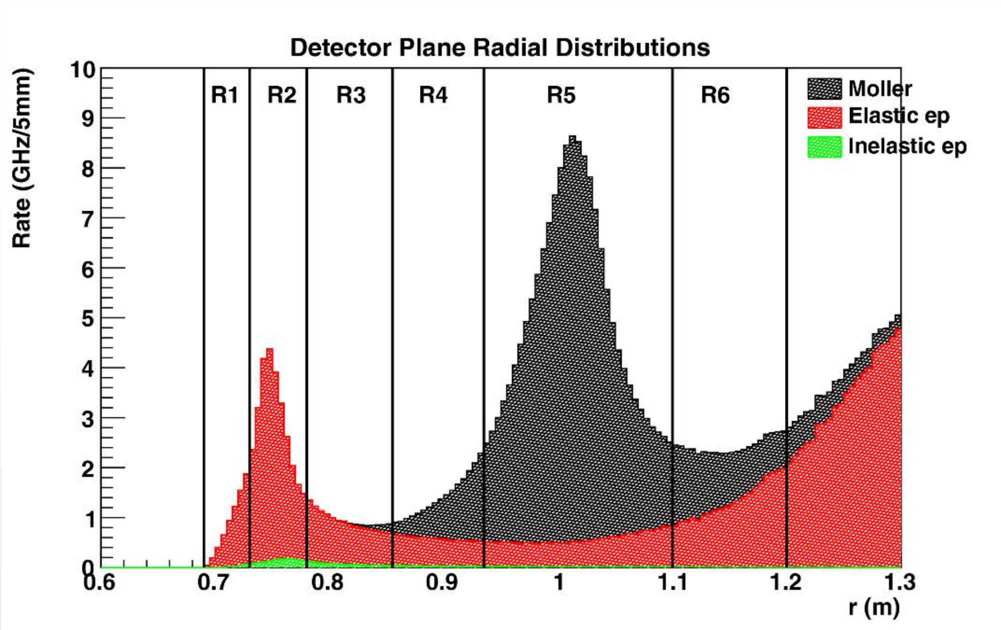


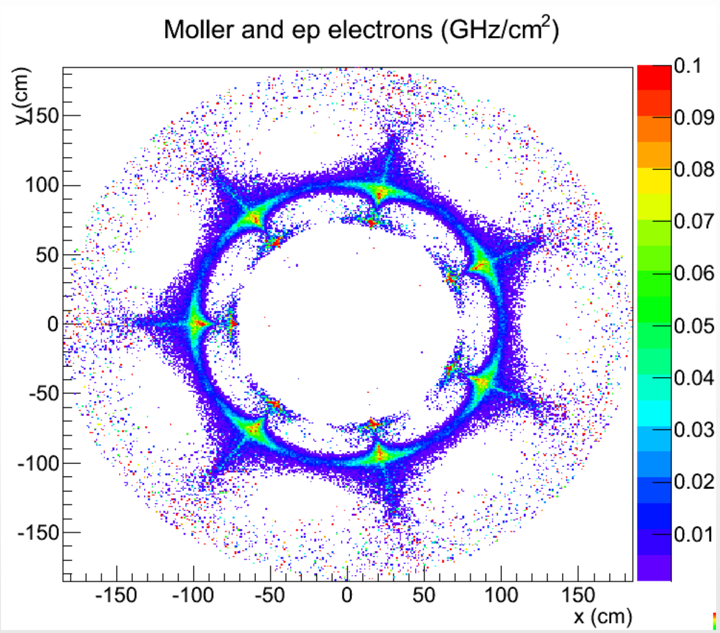
- Accept all (forward and backward) Møllers in the range $60 \leq \theta_{COM} \leq 120$ deg
- Clean separation of elastic and inelastic electron-proton scattering events
- Placement of detectors out of the line-of-sight of the target
- Clean channel for the degraded beam and the bremsstrahlung photons to beam dump
- Minimization of soft photon backgrounds by designing a “two-bounce” system

Event Distribution

In the "focal plane":

Simulated radial distribution, as a function of distance from the center of the beam line:

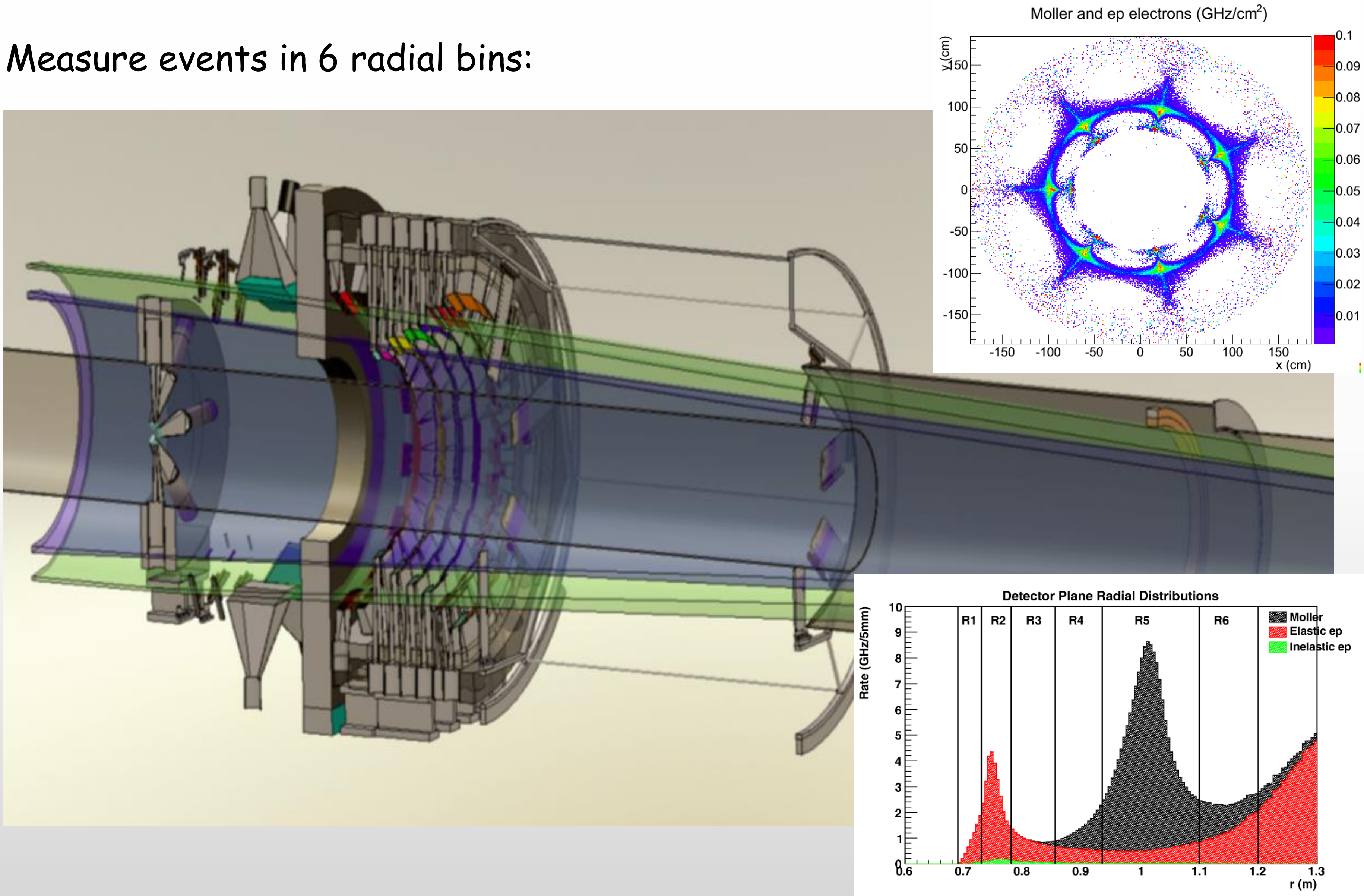




Proper separation of e-e , e-p , and inelastic events requires radial and azimuthal detector segmentation …

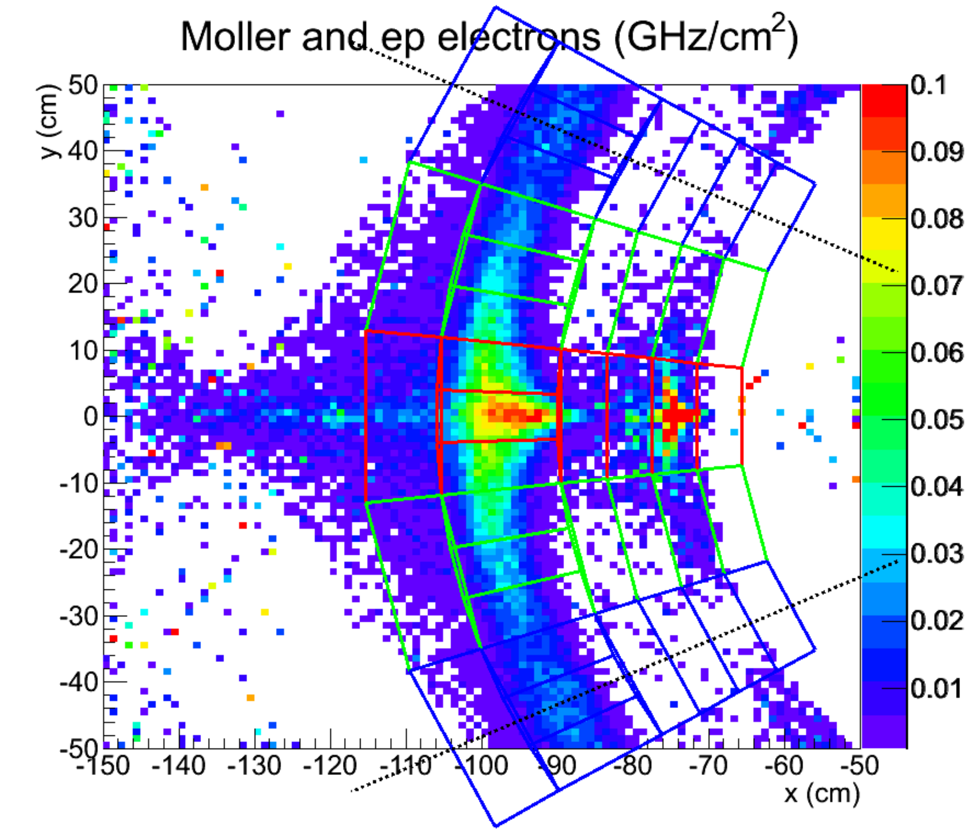
The Detectors

Measure events in 6 radial bins:



The Detectors

Divide each ring into azimuthal sectors:



Current design calls for 224 channels

Rate per channel: ~ few MHz to GHz

Acquisition mode: Flux Integrating

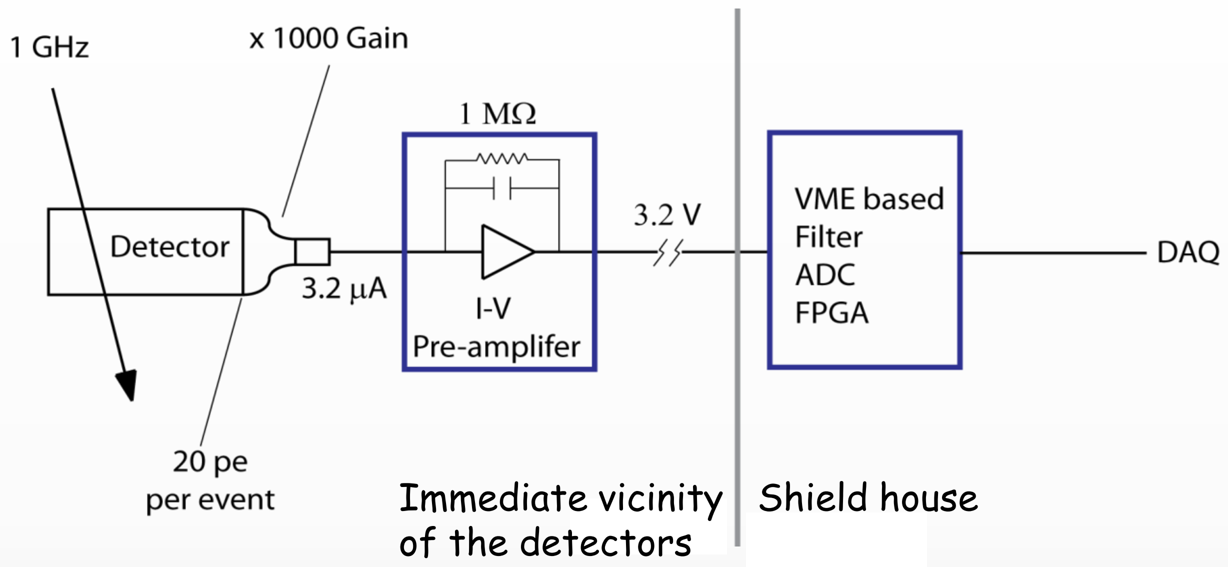
→ No event cuts possible

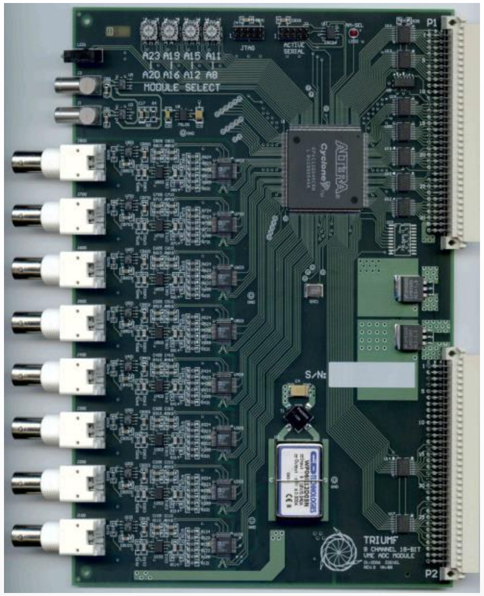
→ Low background by design

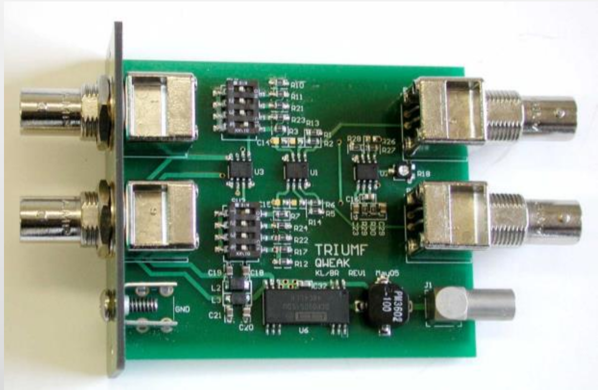
Radiation dose: 15 to 50 Mrad

→ Quartz DIRC + Air-Core light guide with PMT

Integrating Detectors Signal Chain





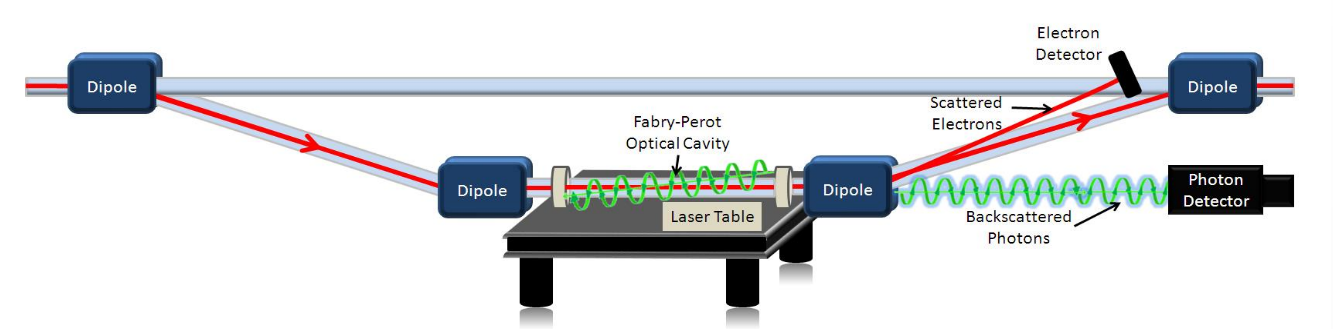


Preamplifier and ADC boards for the Qweak experiment produced at TRIUMF.

Development of similar electronics for the MOLLER experiment is will also take place at TRIUMF (Gate 2 stage).

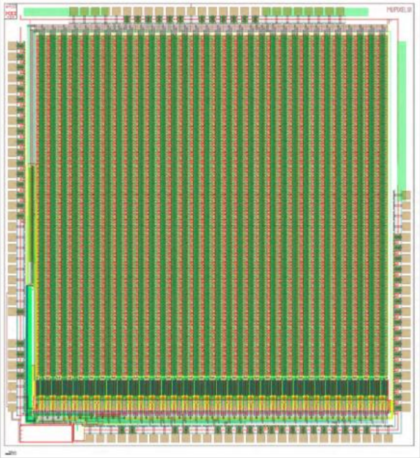
Polarimetry

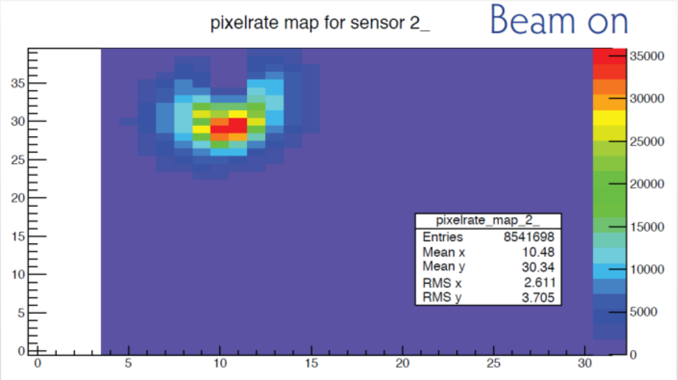
Compton polarimeter (also Mϕller, not shown here):



Stable beam polarization at Jefferson Lab has been measured to be up to 89%.
The experimental requirement for relative accuracy in beam polarization is 0.4%

Needed electron detector upgrades (HVMAP option collaboration between Manitoba, Mainz, Karlsruhe, and Heidelberg):





Status and Outlook

- Experiment approved at Jefferson Laboratory with highest rating
- High priority in the US NSAC LRP
- $25M Scale ($20M from DOE MIE)
- US groups have R&D funding from NSF and DOE
- Successful DOE review in December 2016
- DOE CD0 achieved in December 2016
- Projected date for start of installation: 2019-2020 (2-3 years running)
- Canadian group is NSERC funded
- R&D in full swing on spectrometer and detectors
- Work on HVMAPS for Compton polarimeter is NSERC (RTI) funded