The MOLLER Experiment

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(for the MOLLER Collaboration)

MIT

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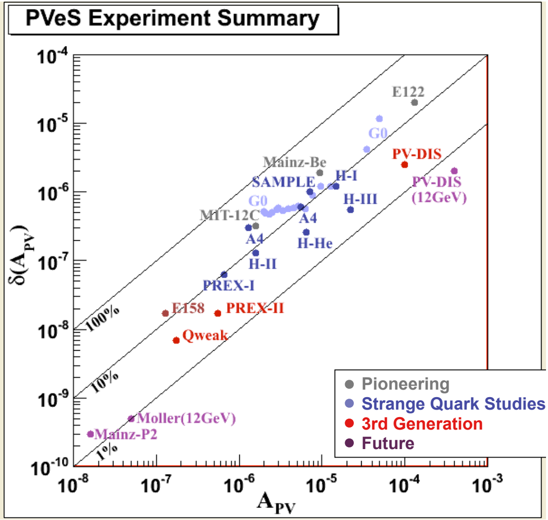
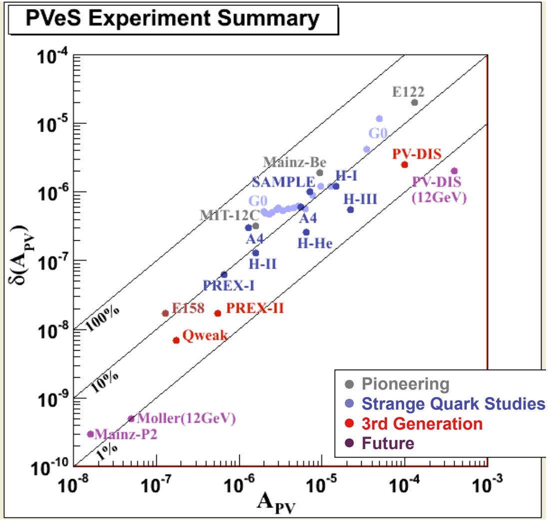
Hall A Collaboration Meeting

Overview



PVeS Experiment Summary
E122
G0
PV-DIS
Mainz-Be
H-I
SAMPLE
PV-DIS
(12GeV)
G0
H-III
MIT-12C
A4
A4
H-He
H-II
PREX-I
E158
PREX-II
Qweak
100%
10%
1%
Moller(12GeV)
Mainz-P2
$\delta(A_{PV})$
A_{PV}
Pioneering
Strange Quark Studies
3rd Generation
Future

Overview



- MOLLER proposes to measure the parity-violating asymmetry, A_{PV}, in polarized electron-electron (Møller) scattering to 0.73 parts-per-billion (ppb) at an average Q^2 of 0.0058 GeV^2.

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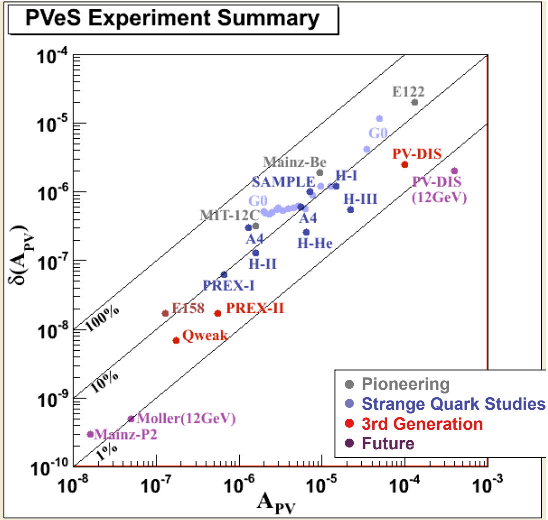

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- This is about 2% measurement of A_{PV}, which would yield a measurement of the weak charge of the electron, Q^e_W, to a fractional accuracy of $\sim$ 2.3% $\Rightarrow$ determination of $\sin^2\theta_w$ to $\sim$ 0.1%

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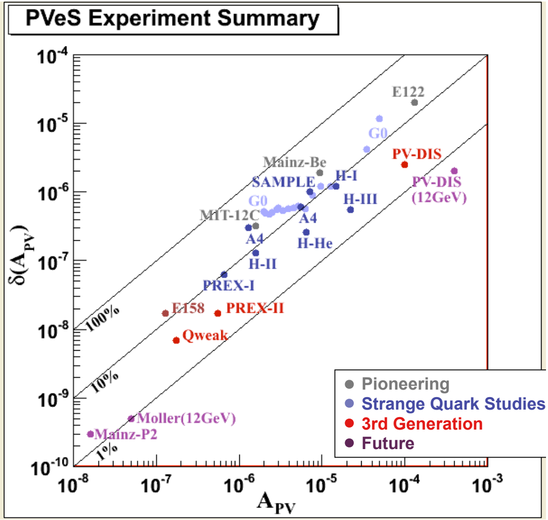

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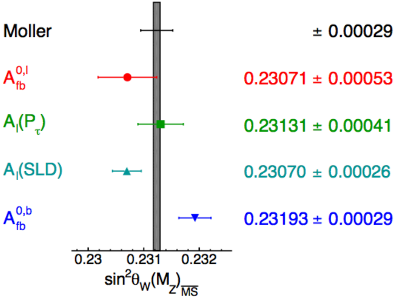
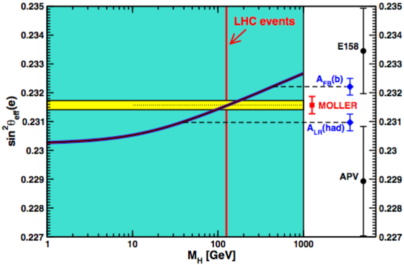
- This is about 2% measurement of A_{PV}, which would yield a measurement of the weak charge of the electron, Q_W^e, to a fractional accuracy of $\sim$ 2.3% $\Rightarrow$ determination of $\sin^2\theta_w$ to $\sim$ 0.1%
- The electron beam energy, luminosity and stability at JLab are uniquely suited to carry out such a measurement

The Weak Mixing Angle $\sin^2\theta_w$





The black band is SM prediction for $m_H = 126$ GeV

- Grand average of the four measurements is consistent with the theoretical expectation
- Each of the two measurements taken independently implies very different BSM dynamics

- Yellow band is world average
- Blue data points are the two best high energy measurements
- Black points are the two most precise measurements at $Q^2 \ll M_Z^2$

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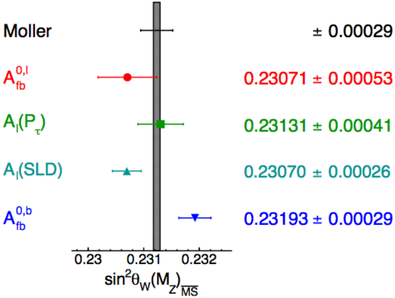

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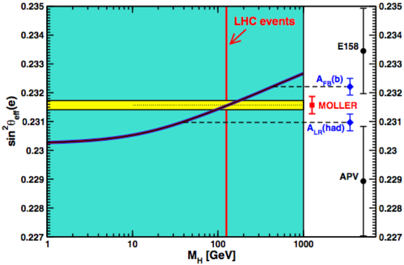

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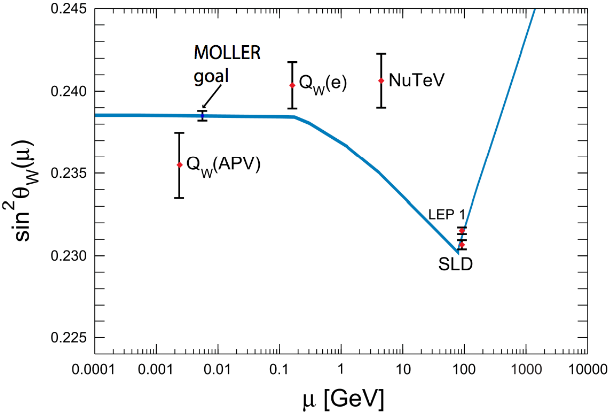
Therefore, it would be very useful to have new measurements such as MOLLER A_{PV} with comparable precision.

The Weak Mixing Angle $\sin^2\theta_w$ at $Q^2 \ll M_Z^2$



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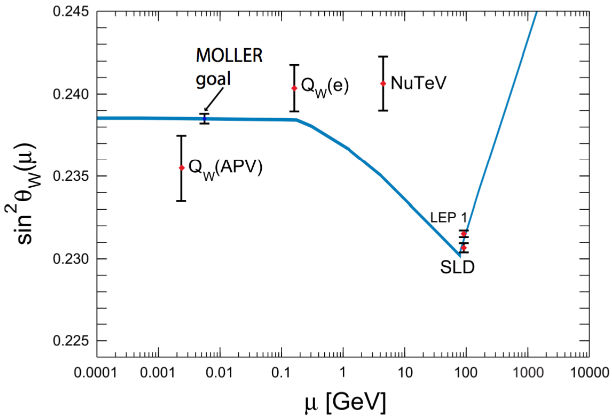

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Thus, there is plenty of new physics effects to be discovered at low energy with proposed MOLLER A_{PV} uncertainty.

Beyond Standard Model Physics

With the discovery of the Higgs boson, there is a definite prediction for the value of MOLLER A_{PV}, and any deviation at the level of measurement error is a signature of new dynamics beyond the Standard Model (BSM)

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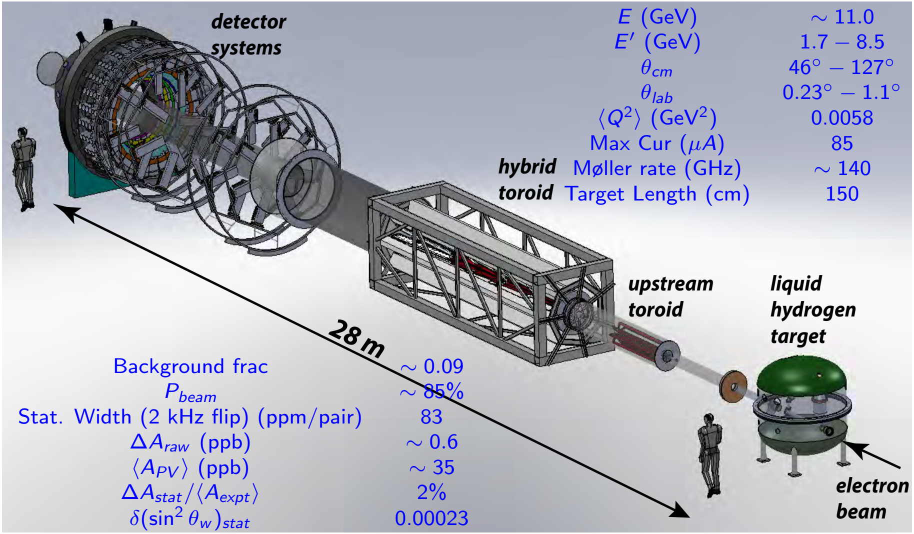
- Because MOLLER is performed at $Q^2 \ll M_Z^2$, it probes a very interesting region of discovery space of new low energy flavor-conserving effective amplitudes that might be induced for example by "dark" photons with a tiny admixture of the Standard Model Z^0 boson.

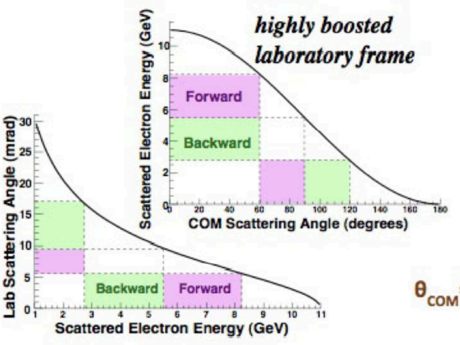
Experimental Design

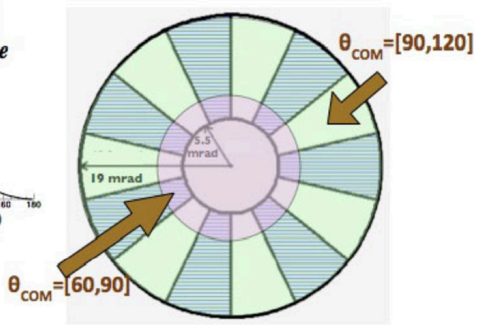


E (GeV)	~ 11.0
E' (GeV)	$1.7 - 8.5$
θ_{cm}	$46^\circ - 127^\circ$
θ_{lab}	$0.23^\circ - 1.1^\circ$
$\langle Q^2 \rangle$ (GeV^2)	0.0058
Max Cur (μA)	85
Møller rate (GHz)	~ 140
Target Length (cm)	150

Background frac	~ 0.09
P_{beam}	$\sim 85\%$
Stat. Width (2 kHz flip) (ppm/pair)	83
ΔA_{raw} (ppb)	~ 0.6
$\langle A_{PV} \rangle$ (ppb)	~ 35
$\Delta A_{stat}/\langle A_{expt} \rangle$	2%
$\delta(\sin^2 \theta_w)_{stat}$	0.00023

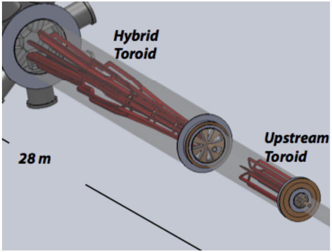
MOLLER Kinematics

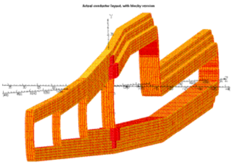




- In the COM frame, the maximum asymmetry, the minimum differential cross-section and the maximum figure-of-merit occurs at $\theta_{COM} = 90^{\circ}$
- Spectrometers & Collimators designed to accept *all* (forward and backward) Møller -scattered electrons in the range $\sim 60^{\circ} \leq \theta_{COM} \leq \sim 120^{\circ}$, with 100% azimuthal acceptance
- Collimate opposing sectors: eliminates double counting & plenty of space for toriodal coils

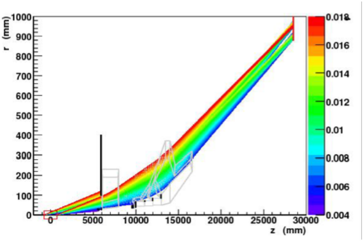
Toroidal Spectrometers



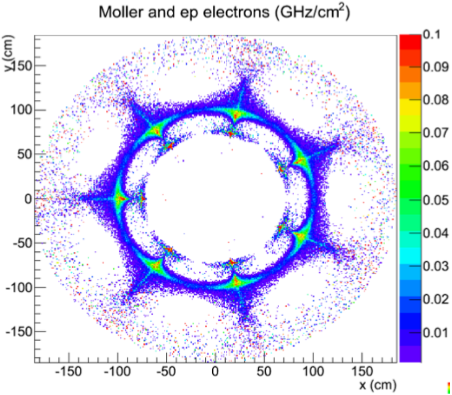


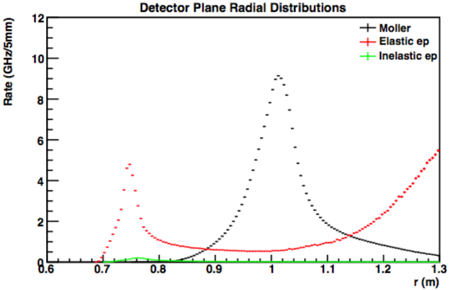
Single hybrid coil with 1/10 scale in z-direction.

Spectrometer employs two back-to-back toroid magnets and collimation:
– Upstream toroid has conventional geometry
– Downstream "hybrid" toroid novel design inspired by the need to focus Møller electrons with a wide momentum range while separating them from e-p (Mott) scattering background



Møller , ep and inelastic events

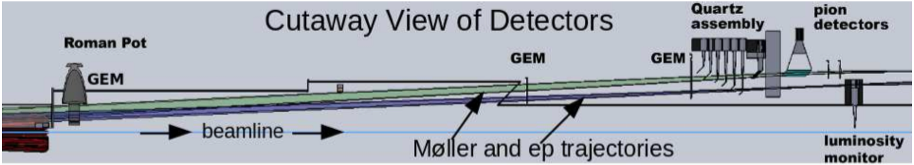




In the azimuthal dimension, the lower energy electrons are strongly defocussed by radial fields in the hybrid toroid and bend around into the regions behind the blocked portions of the primary acceptance collimator.

Clean separation from the primary background of elastic and inelastic electron-proton scattering.

Detectors



- Integrating (current mode) detectors: asymmetry measurements of both signal and background, and beam and target monitoring.
- Tracking (counting mode) detectors: spectrometer calibration, electron momentum distribution and background measurements.

Quartz A_{PV} measurements for Møller , elastic and inelastic electron-proton scattering events

Lumis monitor window-to-window fluctuations in the scattered flux for diagnostic purposes

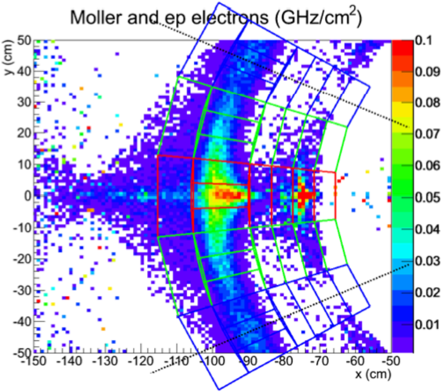
GEMs determine backgrounds, kinematics & light-weighted yield, perform spectrometer diagnostics

Pb-glass together with GEMs, measure hadronic background dilutions and asymmetries

Quartz/tungsten provide a second independent measurement of the flux in the main Møller "peak"

Detector Segmentation

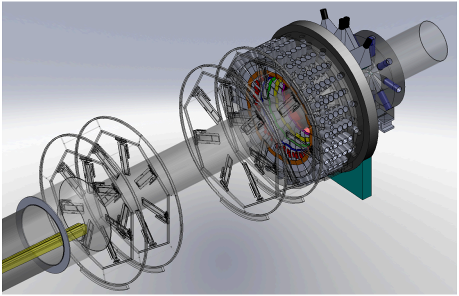
Detailed understanding of the signal, background fraction, and spectrometer optics requires high detector segmentation, both in the radial and azimuthal dimensions.



- six radial bins
- each azimuthal sector is further divided into 4 sub-sectors
  $\rightarrow$ 28 total azimuthal channels at each radial bin
  – the exception to this is the Møller radial bin, which is further divided into 3 additional bins, resulting in a total of 84 channels

Tracking

Tracking system required for determination of backgrounds, kinematics & light-weighted yield, and performing spectrometer diagnostics.



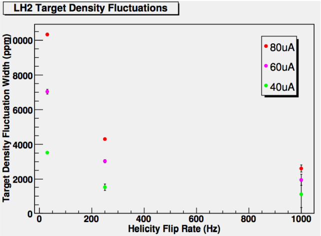
- GEMs: four locations + 1 behing the pion detector
- $\sim 250\ \mu m$ resolution at $\sim 200\ Hz/cm^2$ with 100 pA beam
- cover 25% of cross-sectional area traversed by beam
- rotatable, so can cover full azimuthal acceptance with several measurements
- system removable for asymmetry measurement
- $4(x, y, z)$ points per track: 3 to give a χ^2 criterion, one for inefficiency

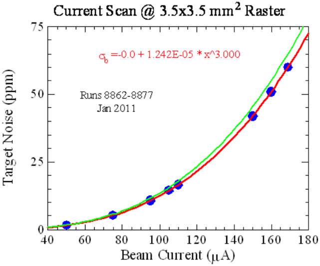
Target

Nominal Cell Length (cm)	150
Target Thickness ($\mathrm{gm/cm^2}$)	10.72
Radiation length (%)	17.5
Pressure (psia)	35
Temperature (K)	20
Target Power (kW)	5

Beam: 11 GeV, 85 μA, 5x5 mm

- Plenty of operational experience at JLab with 1 kW LH2 targets.
- QWEAK target commissioned and successfully operated at 2.9 kW, higher than its design power of 2.5 kW.
- Preliminary assesment is that the E158 target is a good starting point for the design of the high power target for MOLLER.





Goal:: Keep target density variation to $\leq$ 26 ppm at 1.92 kHz, corresponding to 5 % excess noise.

Technical Challenges

MOLLER precision is an order-of-magnitude better than present best precision measurement.

- 140 GHz total detected Møller event rate
  – Must flip Pockels cell at $\sim$ 2 KHz
  – 80ppm pulse-to-pulse statistical fluctuations
  — Electronic noise and target density fluctuations $< 10^{-5}$
  — Pulse-to-pulse beam monitoring resolution of a few microns at 1 KHz
- 0.5 nm/0.05 nrad control of beam on target
  – Requires improvement on control of polarized source laser transport
  – Improved methods of "slow helicity reversal" (double wien)
- Target requires $\sim$ 5 KW of cooling power at 85μA beam
- Full azimuthal acceptance with θ_{lab} between 5 and 17 mrad
  – Aggressive spectrometer design
  – Complex collimation and shielding issues
- Robust and redundant 0.4% beam polarimetry
  – Plan to pursue both Compton and atomic Hydrogen techniques

Research & Development

Polarized Beam Fast helicity flip goal of stable polarization in $10\mu s$, beam charge measurement to 10 ppm for 1 KHz window pairs, beam halo

Target Design Simulation with CFD programs, review of E158 target cell

Simulations and Software “2-bounce” collimation system for photon background, additional physics generators, energy deposition in collimators, radiation shielding, tracking

Spectrometer Design Optimization of spectrometer optics, conceptual designs of support structure, electrical and water-cooling connections of spectrometers, optimization of collimators

Detector Design Optimization of quartz shape, dimensions and surface quality, shape and material of air light guide, mechanical assembly for detector

Polarimetry Infrared Compton laser, short-pulse mode-locked Compton laser, high-field Møller , hydrogen Møller

Collaboration/Subsystems

- Polarized source
- Hydrogen Target
- Spectrometer
- Focal Plane Detectors
- Luminosity Monitors
- Pion Detectors
- Tracking Detectors
- Electronics
- Beamline Instrumentation
- Polarimetry
- Data Acquisition
- Simulations

- 30 institutions and about 100 collaborators
- Many institutions have signed up for projects
- Plenty of room for more collaborators

Status and Future Plans

- JLab PAC 34 - full approval - strong endorsement
- This endeavor represents 4^{th} generation JLab parity violation experiment with collaboration consisting of $\sim$ 100 physicists from 30 institutions
- MOLLER MIE proposal submitted by JLab to DOE Nuclear Physics last September requesting to initiate CD process
- Expecting to start CD process early next year
- 3 - 4 years for Construction/Installation
- 2- 3 years Commissioning/Running
- Approved request of 344 PAC days for production running and 13 commissioning weeks over 3 running periods

Conclusions

- MOLLER aims to measure the parity-violation in electron-electron scattering to unprecedented precision using the 11 GeV beam in Hall A at JLab.
- Unique opportunity to probe physics beyond the SM at the TeV-scale, probing contact interactiosn in a manner complementary to the LHC
- Most sensitive low energy measurement of a flavor-conserving purely leptonic interaction
- Sensitivity goal for A_{PV} in Møller scattering can only be achieved at JLab
- Experienced and motivated collaborators, who have been involved in several precision parity-violating experiments in the past.

Thank you!