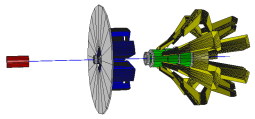


# **The MOLLER experiment - testing the Standard Model at Jefferson Lab**

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for the MOLLER Collaboration

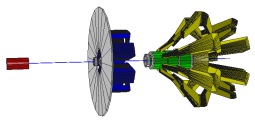
May 30, 2012



## The MOLLER experiment - testing the Standard Model at Jefferson Lab

### Outline

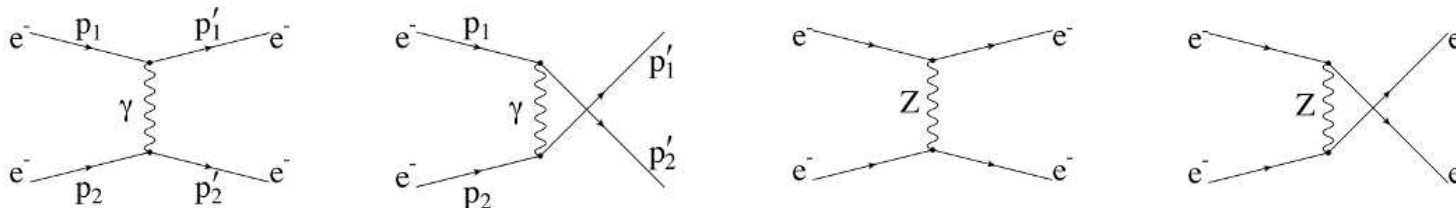
- Introduction
- Motivation (Indirect search for new physics)
  - Search for new contact interactions
  - Sensitivity to SUSY radiative effects, super-massive  $Z'$ , and light “dark”  $Z$  bosons
  - Precision electroweak test of  $\sin^2\theta_W$
  - Higgs Mass Constraints
- Update to Experimental Design
  - Layout of target, spectrometer, and detectors
  - Hybrid torus coil design
  - Tracking and integrating detectors
- Status and Future Plans



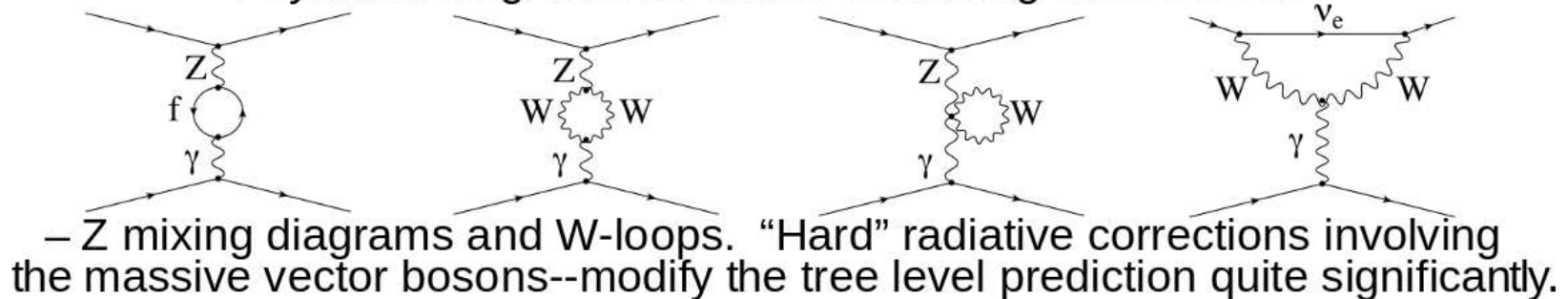
## Møller Scattering, $A_{PV}$ Measurement

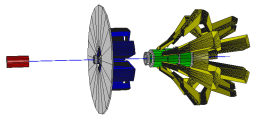
- MOLLER aimed at precision measurement of parity-violating asymmetry  $A_{PV}$  in polarized electron-electron scattering.
- According to SM,  $A_{PV}$  results from interference between electromagnetic and weak neutral current amplitudes.

$$A_{PV} = \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L} = \frac{A_\gamma A_Z}{A_\gamma^2} = m_e E_{lab} \frac{G_F}{\sqrt{2}\pi\alpha} \frac{4\sin^2\theta}{(3 + \cos^2\theta)^2} Q_W^e, \quad (1)$$



Feynman diagrams for Møller scattering at tree level.



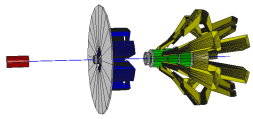


## Møller Scattering, $A_{PV}$ Measurement

- At proposed kinematics: 11 GeV  $e_{\text{beam}}^-$  (75  $\mu\text{A}$ , 80% polarization), and  $5\text{mrad} < \theta_{\text{lab}} < 20\text{mrad}$ :
  - Predicted  $\langle A_{PV} \rangle = 36\text{ppb}$  at  $\langle Q^2 \rangle = 0.0056 (\text{GeV}/c)^2$
- For 49 (PAC) week run:  $\delta(A_{PV}) = 0.74\text{ppb}$ :
  - $\delta(Q_W^e)/Q_W^e = \pm 2.1\%(\text{stat}) \pm 1.0\%(\text{syst})$
  - $\delta(\theta_W) = \pm 0.00026(\text{stat}) \pm 0.00012(\text{syst}) \sim 0.1\%$  precision!

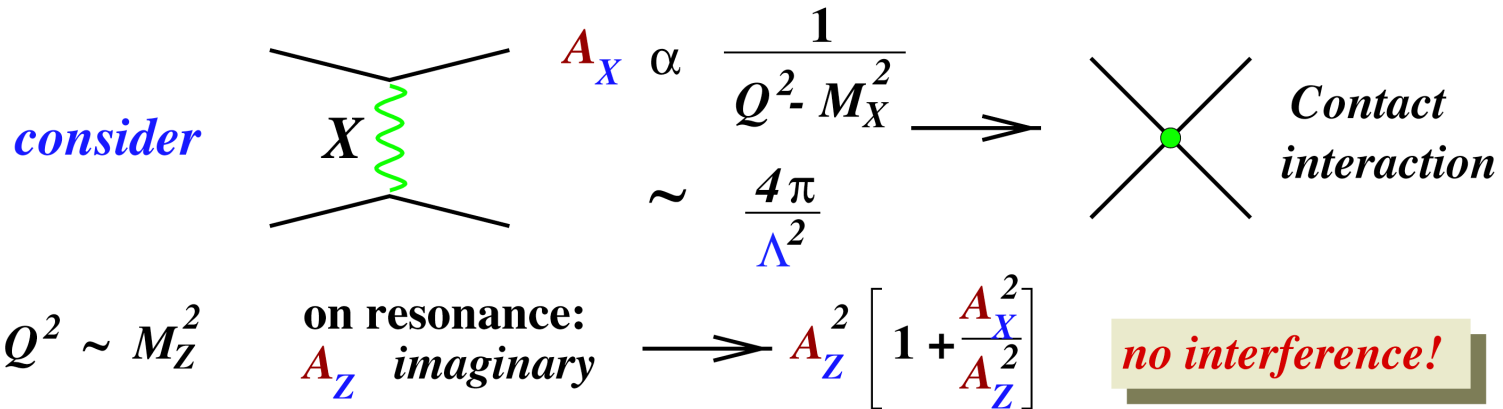
Very challenging measurement requiring:

- Unprecedented precision matching of electron beam characteristics for Left versus Right helicity states
- Precision non-invasive, redundant continuous beam polarimetry
- Precision knowledge of luminosity, spectrometer acceptance ( $Q^2$ ) and backgrounds
- **There have already been 3 generations of parity experiments at Jlab with progressively challenging experimental designs.**

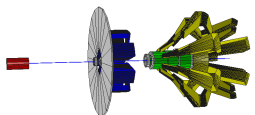


## Establishing Limits for New Contact Interactions (Off the Z Resonance)

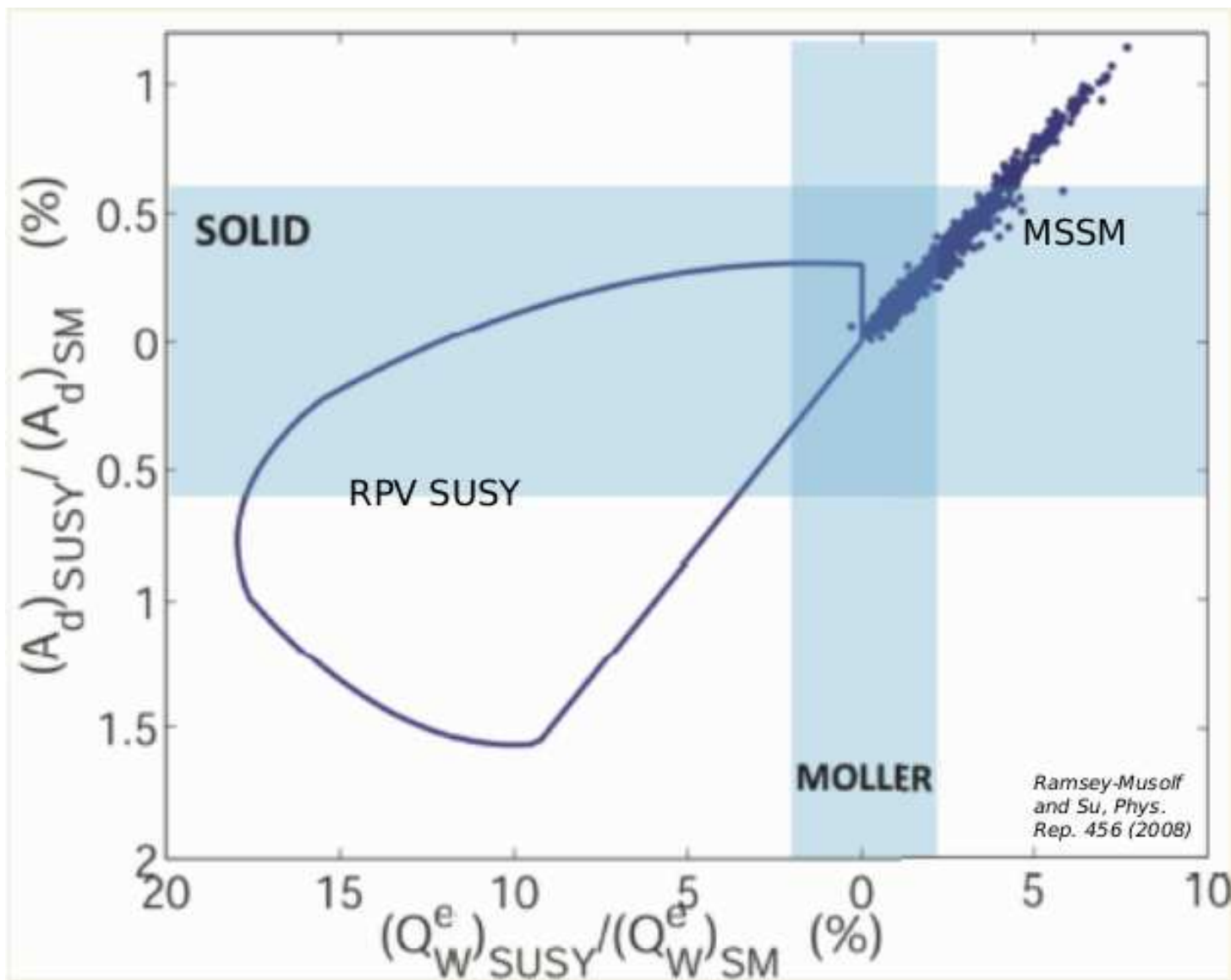
Important component of indirect signatures for "new physics"

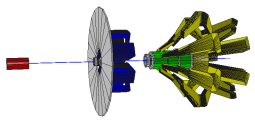


- Proposed meas. sensitive to new neutral current amp. as weak as  $\sim 10^{-3} \cdot G_F$  from undiscovered high energy dynamics ( $\Lambda_{new} \sim 7.5\text{TeV}$ )
- Current best limits on  $4e^-$  contact interac. come from LEP, LEP II: Probed  $\Lambda_{new} \sim 5\text{TeV}$ , but was insensitive to  $|g_{RR}^2 - g_{LL}^2|$
- Near the Z resonance, new physics interactions (e.g.  $Z'_X$  exchange) don't visibly mix with standard model  $A_Z$  (Collider Experiments)
- This underscores importance of low energy measurements of  $Q_W$ : E158, Qweak, PVDIS, MOLLER, and Mainz P2

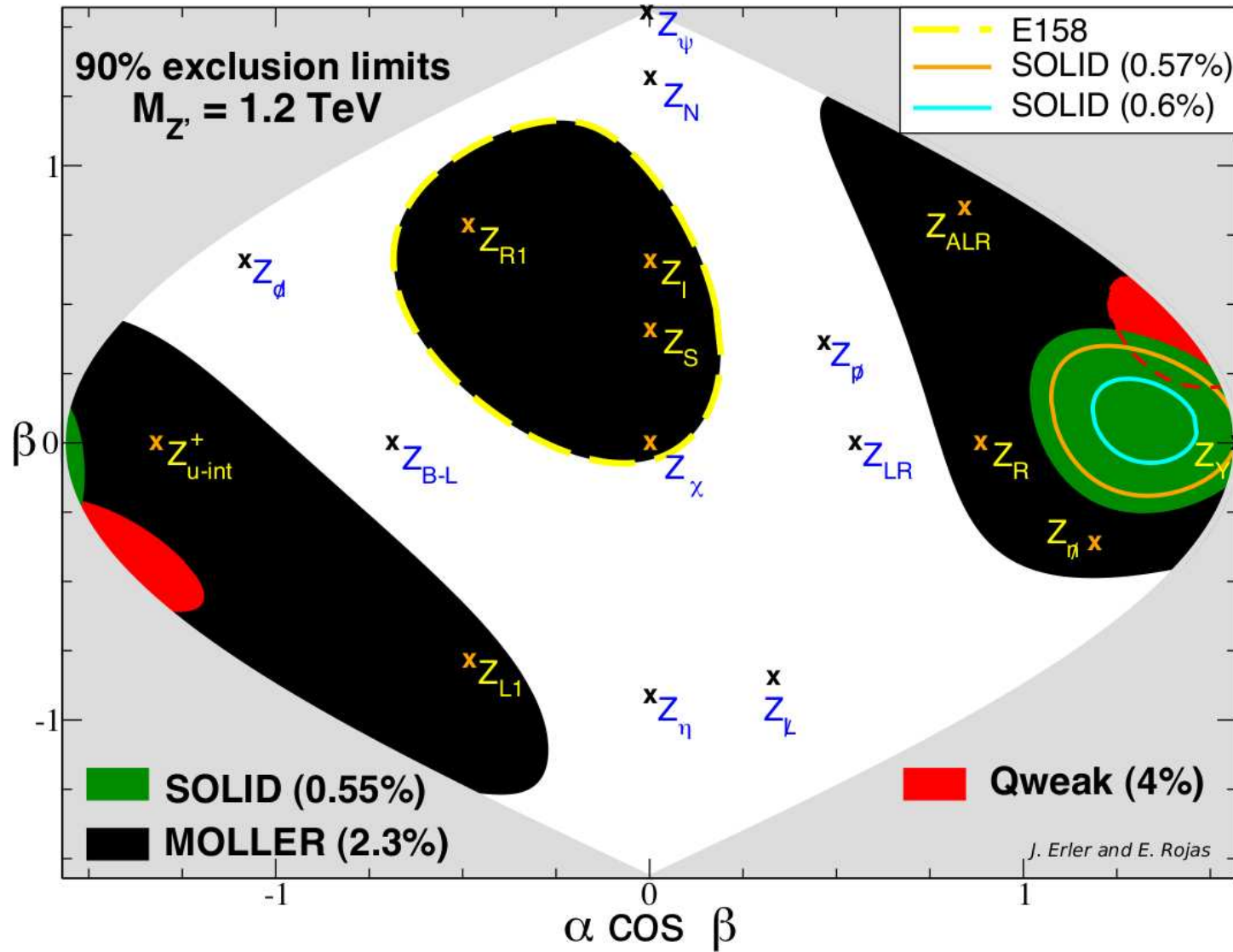


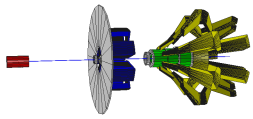
## Sensitivity to SUSY particle radiative loop effects



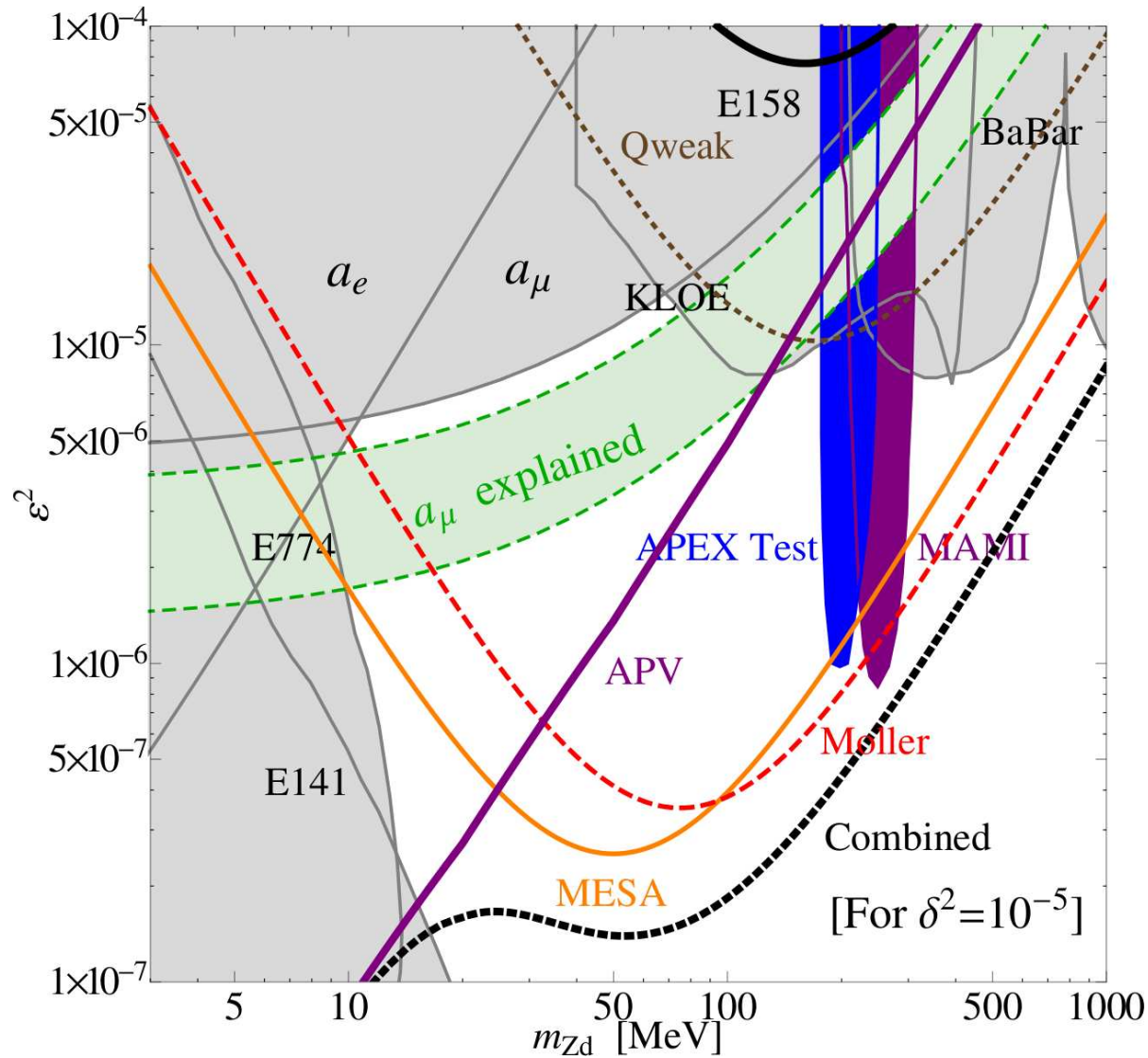


### Complimentary Measurement to LHC

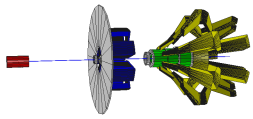




## Sensitivities for “Dark” Z Coupling to explain $a_\mu$ (from Davoudiast, Lee, and Marciano, arXiv:1205.2709v1)

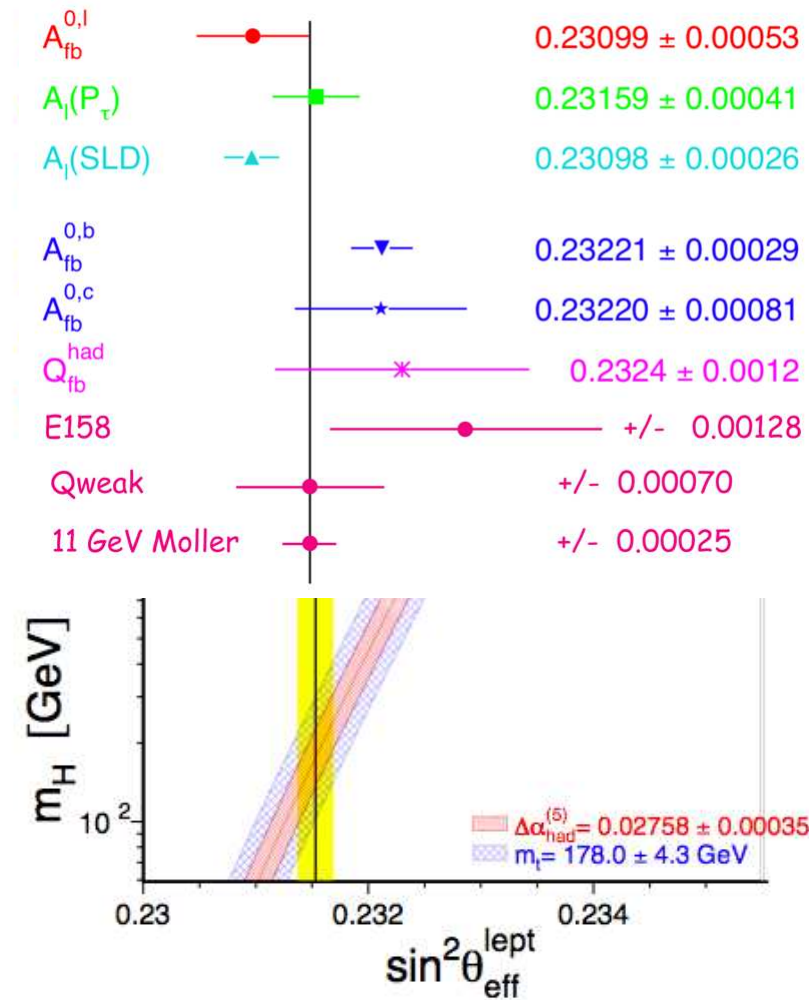


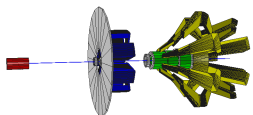




## Precision Electroweak Tests of $\sin^2\theta_W$ and the Higgs Mass

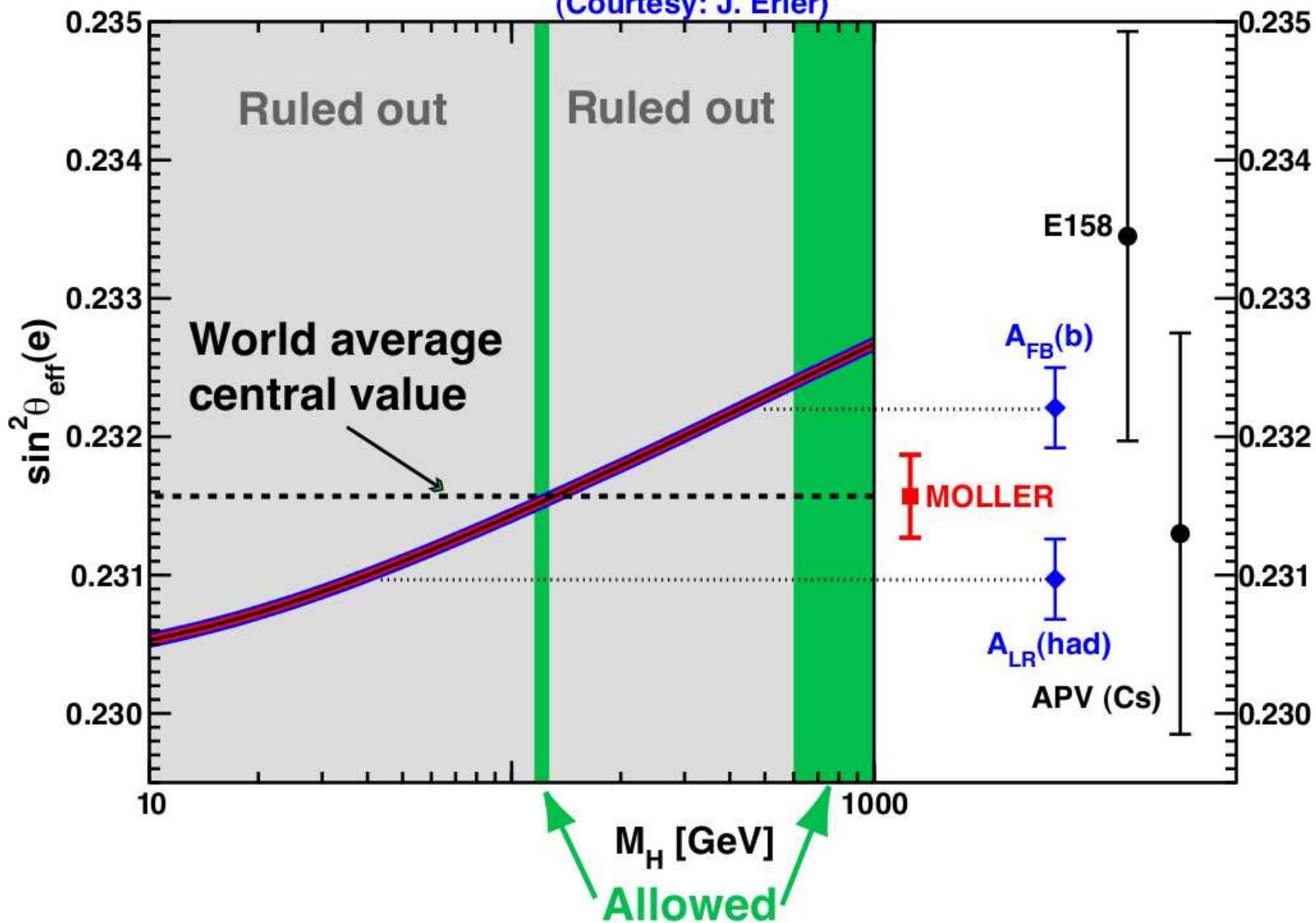
- World data avg:  $\sin^2\theta_W = 0.23122(17)$   
 $\Rightarrow m_H = 89_{-28}^{+38}$  GeV  
 (favors SUSY, rules out Technicolor)
- Avg dominated by two measurements separated by  $3\sigma$ :  
 $\rightarrow A_1(\text{SLD}) : 0.2310(3), \Rightarrow m_H = 35_{-17}^{+26}$  GeV  
 rules out SM!  
 $\rightarrow A_{fb}^{0,1} : 0.2322(3), \Rightarrow m_H = 480_{-230}^{+350}$  GeV  
 rules out SUSY, favors Technicolor
- Proposed measurement precise enough to effect the central value of  $\sin^2\theta_W$  and provide new indirect evidence for the range of allowed  $m_H$  values

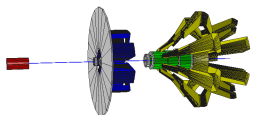




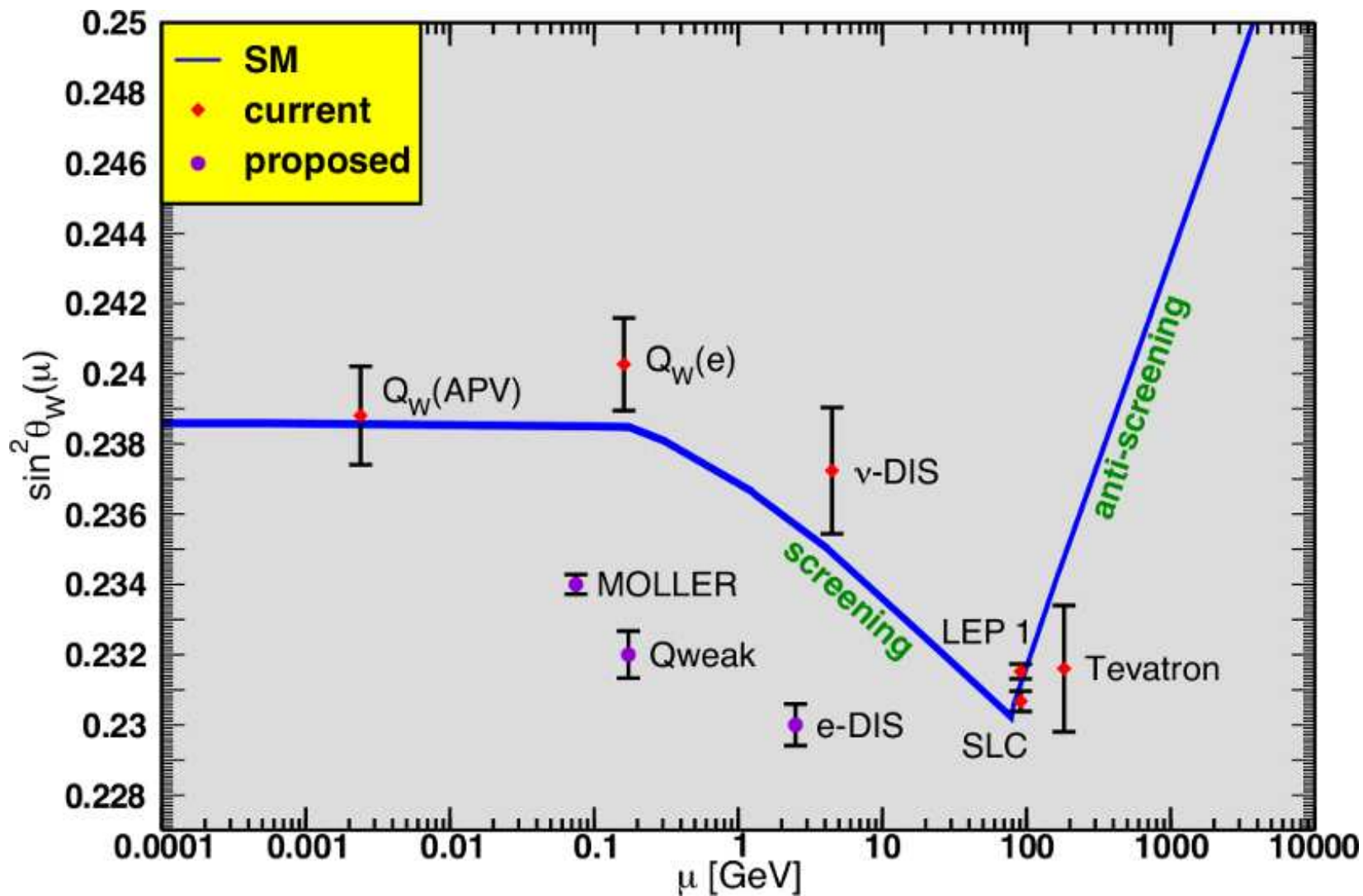
# Higgs Mass Constraints

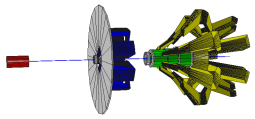
(Courtesy: J. Erler)



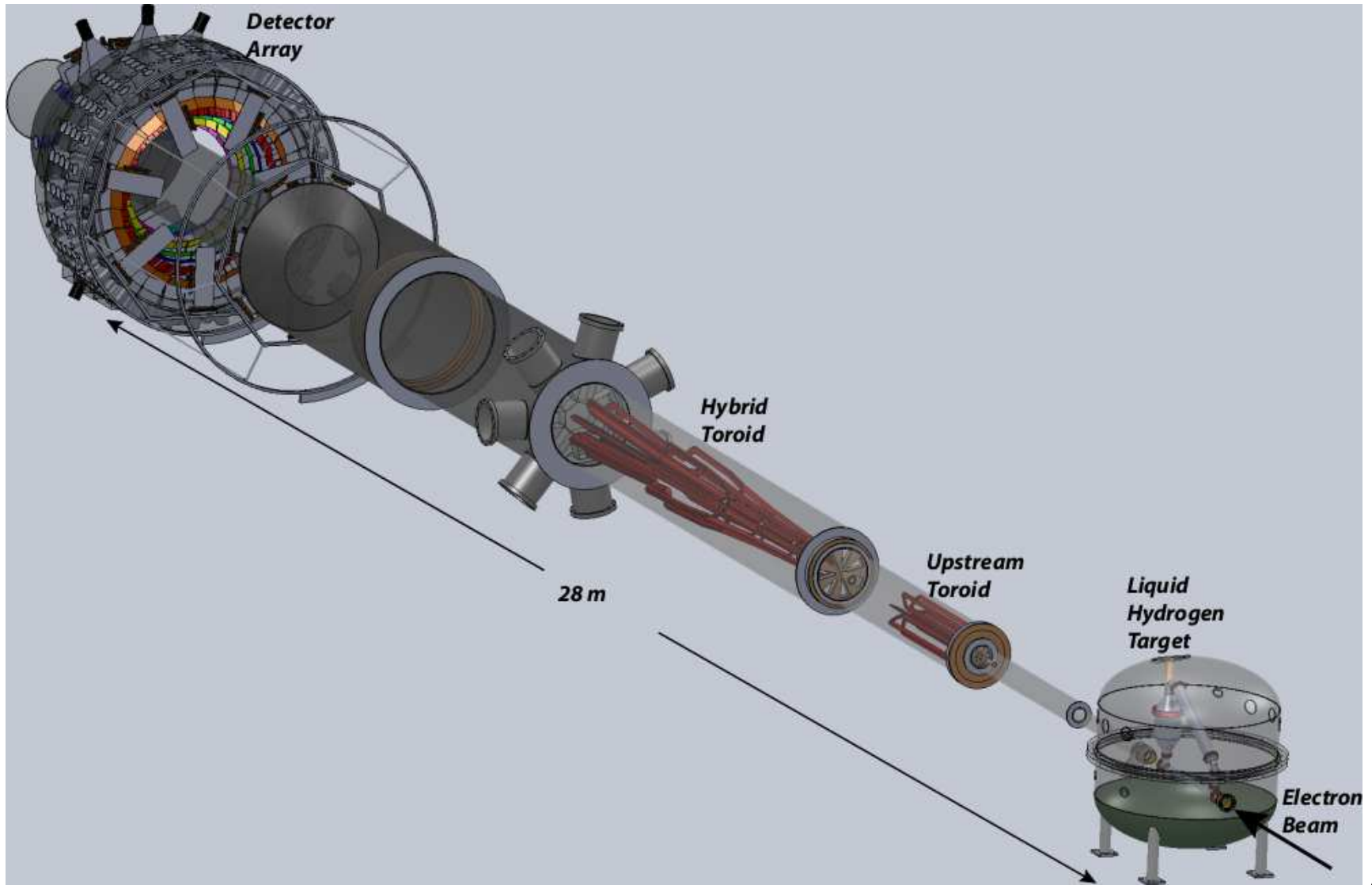


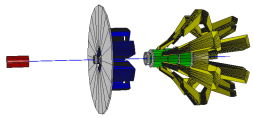
## Current and Future $\sin^2\theta_W$ Measurements



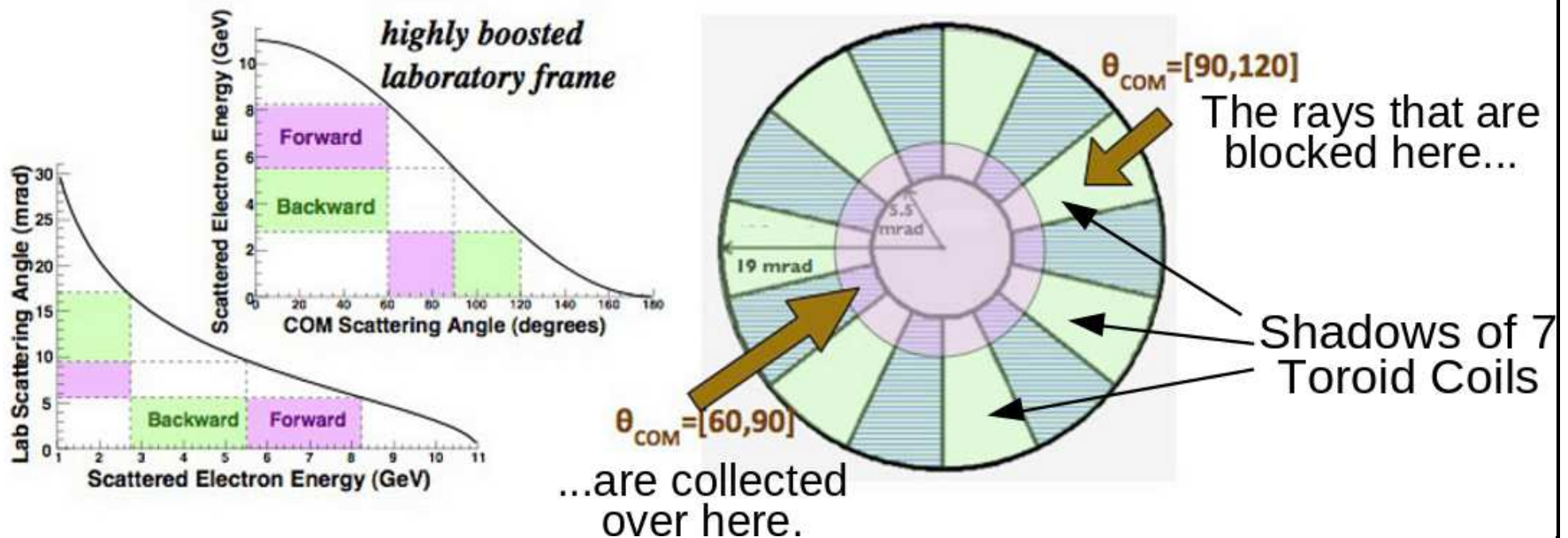


## Experimental Design Update

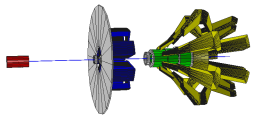




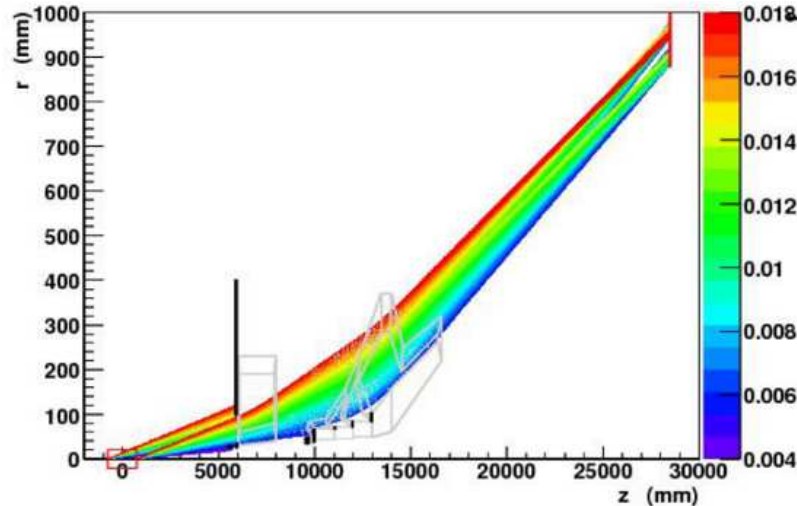
## Optimized Spectrometer ( $\sim 100\%$ Acceptance)



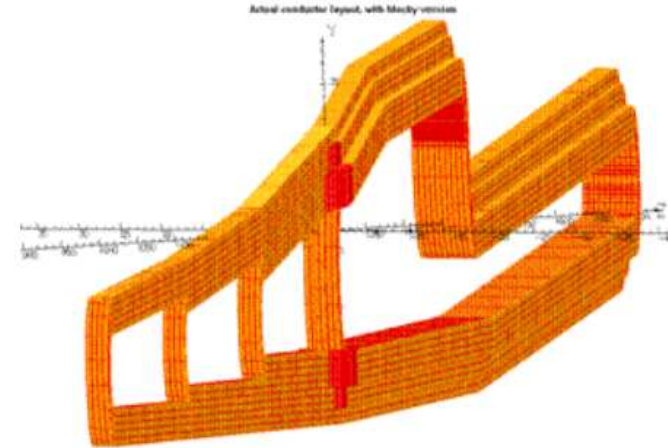
- The combination of a toroidal magnetic system with an odd number of coils together with the symmetric, identical particle scattering nature of the Møller process allows for  $\sim 100\%$  azimuthal acceptance



## Toroid Design Concept

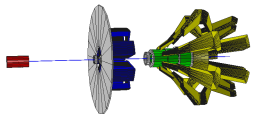


Projected radial coordinate of scattered Møller electron trajectories. Colors represent  $\theta_{lab}$  (rad). Magnet coils (grey) and collimators (black) are overlaid.

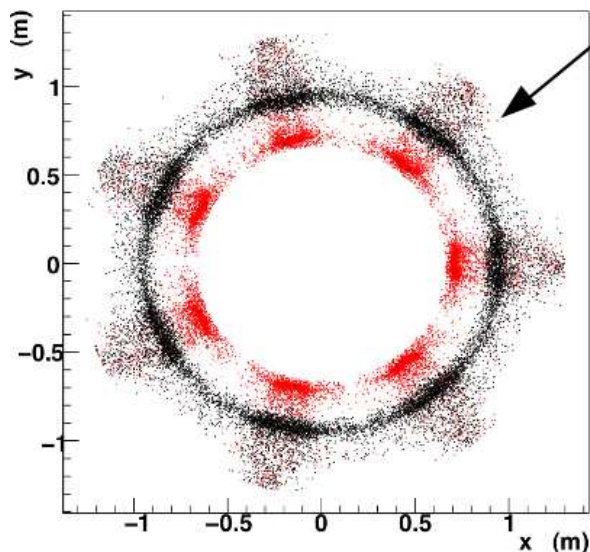
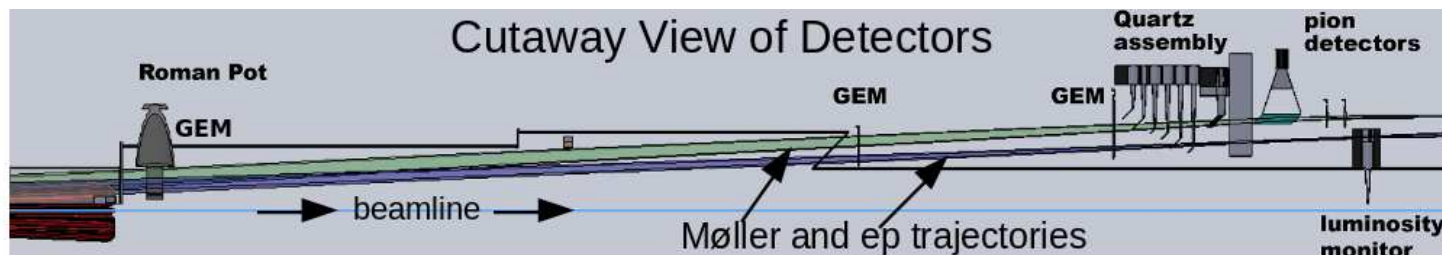


Single Hybrid coil shown with 1/10 scale in z direction. Note the 4 current returns give successively higher downstream fields.

- Spec. employs two back-to-back toroid magnets and prec. 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

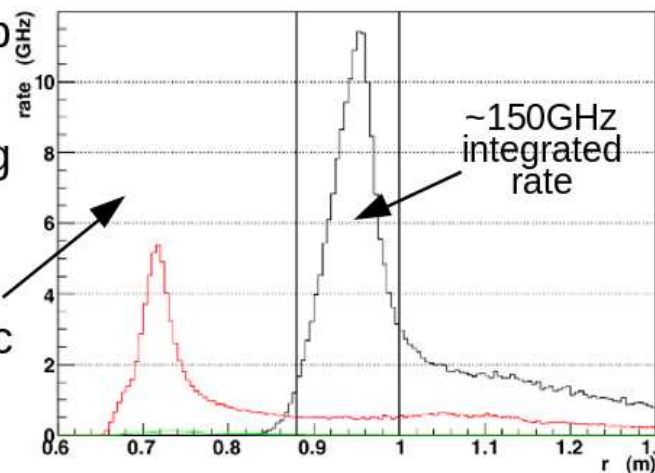


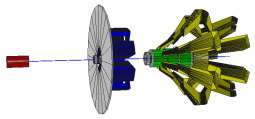
## Tracking and Integrating Detectors



Transverse distribution of Møller (black) and ep (red) electrons 28.5 m downstream of target. Note the phi defocusing of spectrometer optics.

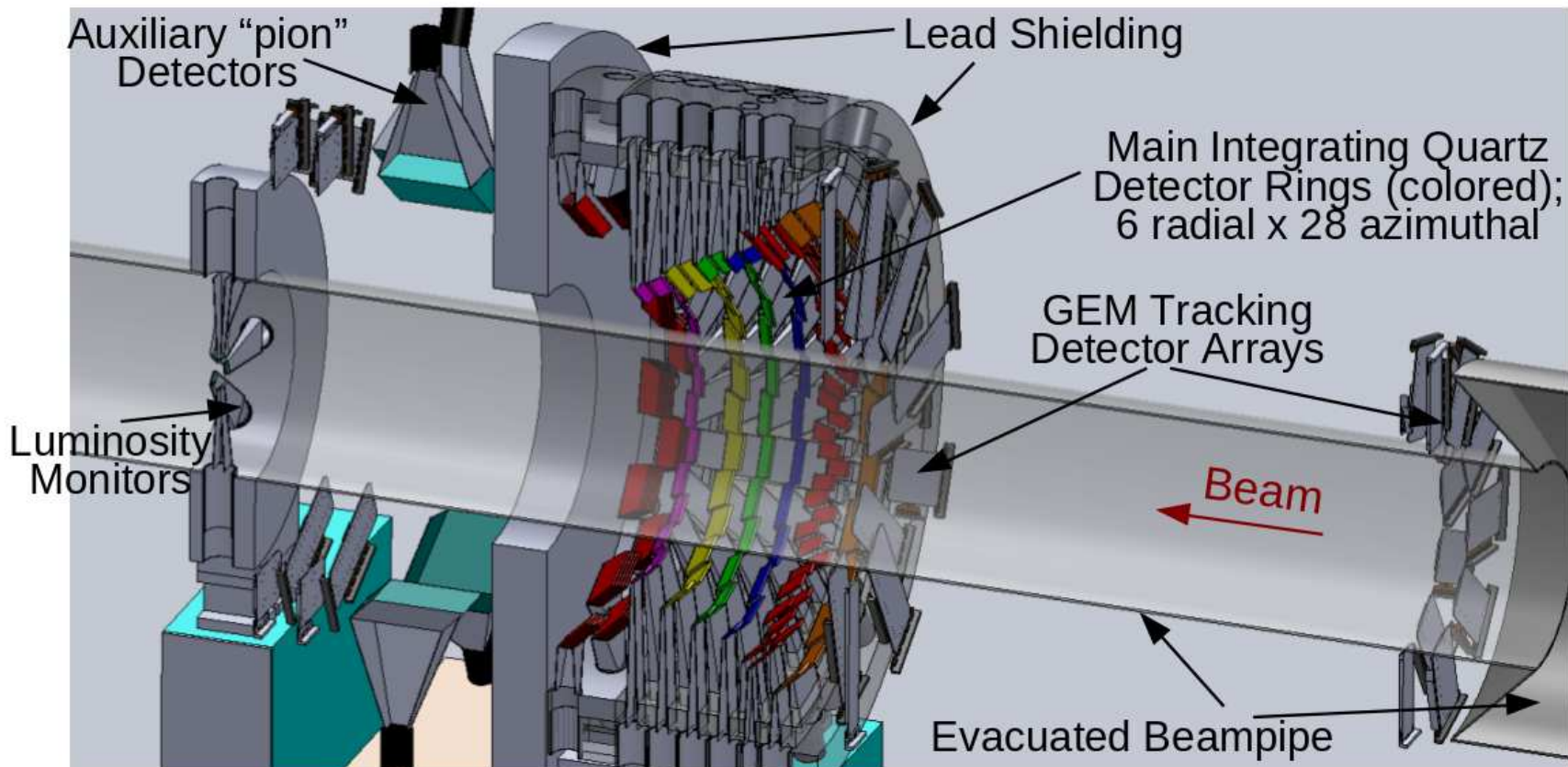
Radial rate distribution of Møller (black), elastic ep (red), and inelastic ep (green) electrons at main detector location.



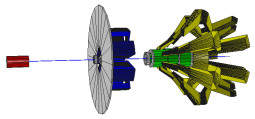


## Tracking and Integrating Detectors

### Perspective view of integrating detector assembly

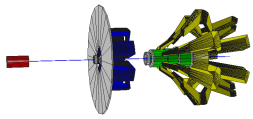






## Status and Future Plans

- JLab PAC 34 - full approval - strong endorsement
- This endeavor represents 4<sup>th</sup> 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 following DOE's NP retrenchment
- 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



## Status and Future Plans

- List of key subsystems and institutions interested in their design, construction, and implementation:
  - Polarized Source: UVa, JLab, Miss St.
  - Hydrogen Target: JLab, VaTech, Miss St.
  - Spectrometer: Canada, ANL, MIT, Umass, UVa
  - Focal Plane Detectors: Syracuse, Canada, JLab, UNC A&T, VaTech
  - Luminosity Monitors: VaTech, Ohio
  - Pion Detectors: Umass, LATech, UNC A&T
  - Tracking Detectors: W&M, Canada, Umass, UVa, INFN Roma
  - Electronics: Canada, JLab
  - Beamline instrumentation: Umass, JLab, VaTech
  - Polarimetry: UVa, Syracuse, JLab, CMU, ANL, Miss St.,  
Clermont-Ferrand, Mainz, W&M
  - Data Acquisition: Ohio, Rutgers
  - Simulations: ISU, Umass/Smith, Berkeley, LATech, UVa