Measurement of Lepton-Lepton Electroweak Reaction
MOLLER

Introduction

Agenda Overview & MOLLER Goals

Krishna Kumar

Stony Brook U.

DOE Nuclear Physics MOLLER Science Review, UMass, Amherst, September 10, 2014

Outline

- ✦ Comments on the Agenda
- ✦ Introduction to Møller Scattering
- ✦ SLAC E158 Result
- ✦ Introduction to MOLLER
  - ★ Precision and Accuracy Goals
  - ★ The Collaboration

Thanks

- Thanks to the panel members for taking the time and agreeing to participate in this review
- Thanks to the DOE Office of Nuclear Physics for scheduling this review and providing the opportunity to present the physics case for MOLLER
- Thanks to Michael Ramsey-Musolf and the Amherst Center for Fundamental Interactions (ACFI) for hosting this review at UMass, Amherst

Talk Titles and Speakers

- Parity-Violating Møller Scattering: Global Context (45): Michael Ramsey-Musolf
- Weak Mixing Angle, Radiative Corrections and New Vector Bosons (45): Bill Marciano
- Experimental Context and Overview of Technique (45): Krishna Kumar
- Overview of MOLLER Subsystems (45): Mark Pitt
- Statistics, Systematics and Run Phases (30): Kent Paschke
- Impact on JLab Science Program (20): Cynthia Keppel

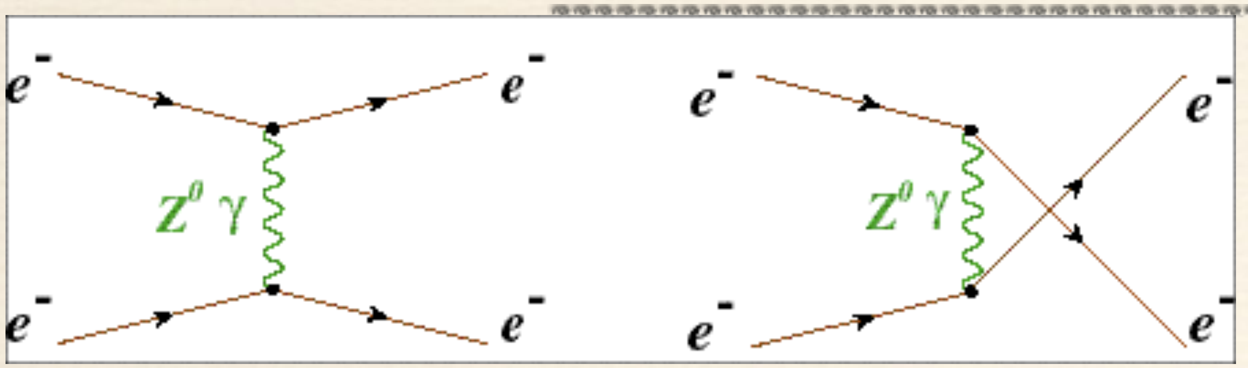
Flow of Talks

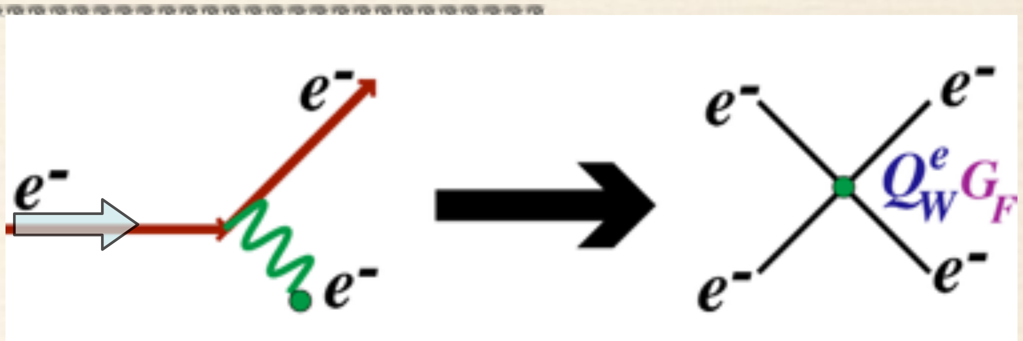
- **Morning Talks:**
  - **M. Ramsey-Musolf:** Context for ultra-precise low Q^2 measurements
  - **W. Marciano:** robust theoretical prediction and unique discovery reach of low Q^2 weak neutral current measurements
- **Afternoon Talks:**
  - **K. Kumar:** Phenomenological perspective and experimental technique overview
  - **M. Pitt:** Description of Main MOLLER Subsystems
  - **K. Paschke:** Systematic Control and Progressive Run Phases
  - **C. Keppel:** The JLab Hall A Program Science Impact

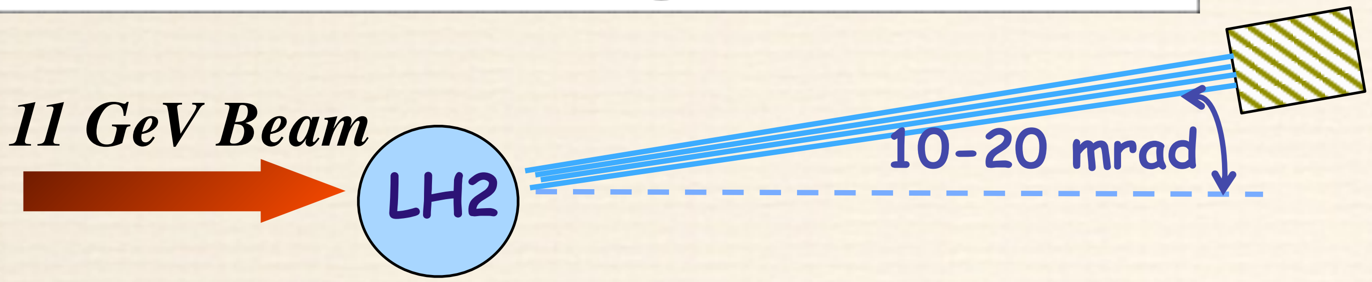
Charge Elements

- ✦ **Scientific Significance**
  - ★ Morning talks + first part of K.Kumar talk
- ✦ **Impact on Advancement of Nuclear Physics**
  - ★ Morning talks + K.Kumar talk
- ✦ **Research Effort Needed**
  - ★ W. Marciano talk (theory), K.Kumar and JLab talks (experiment)
- ✦ **Feasibility and First Three Year Impact**
  - ★ Afternoon talks, especially K. Paschke talk
- ✦ **Impact of Implementation on JLab Program**
  - ★ Afternoon talk by C. Keppel

APV in Møller Scattering



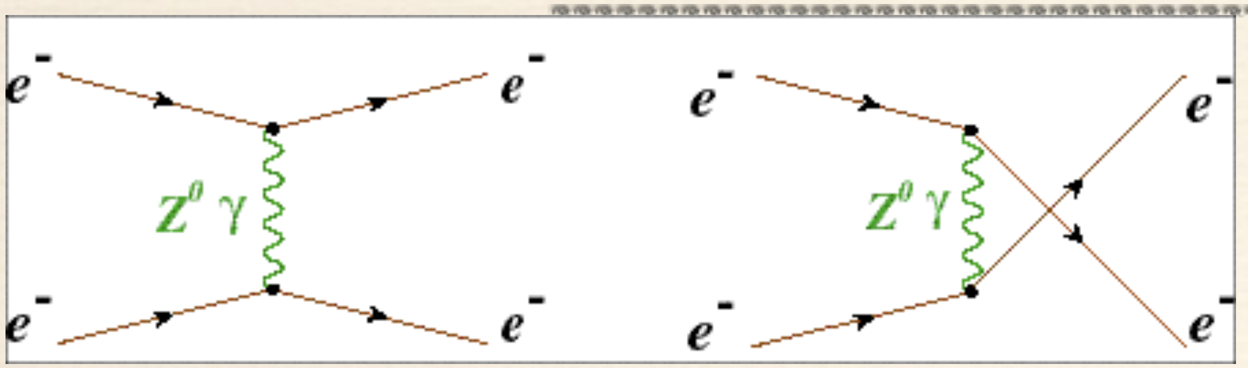


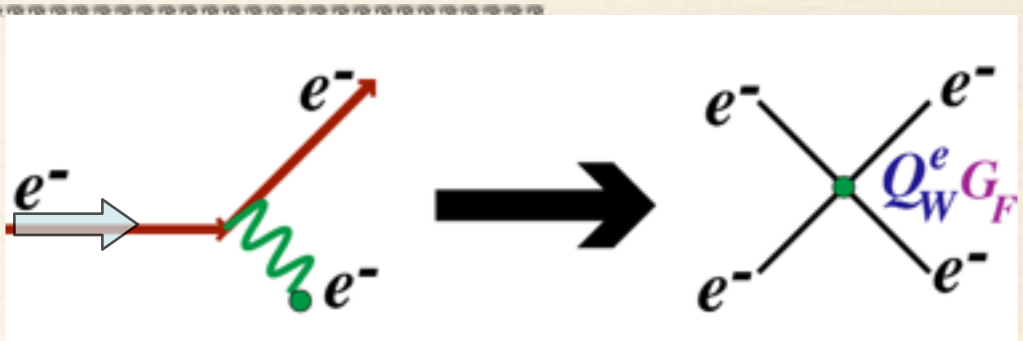


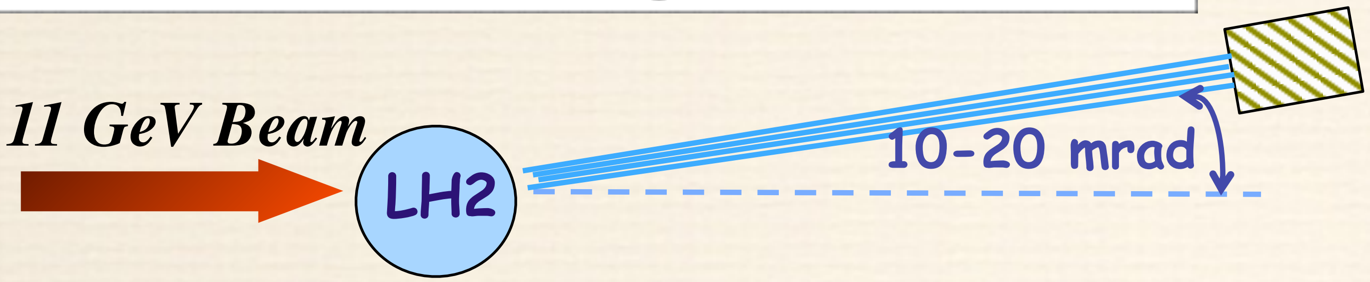
$$A_{PV} = \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L}$$

Fixed Target Electron Scattering

A_{PV} in Møller Scattering







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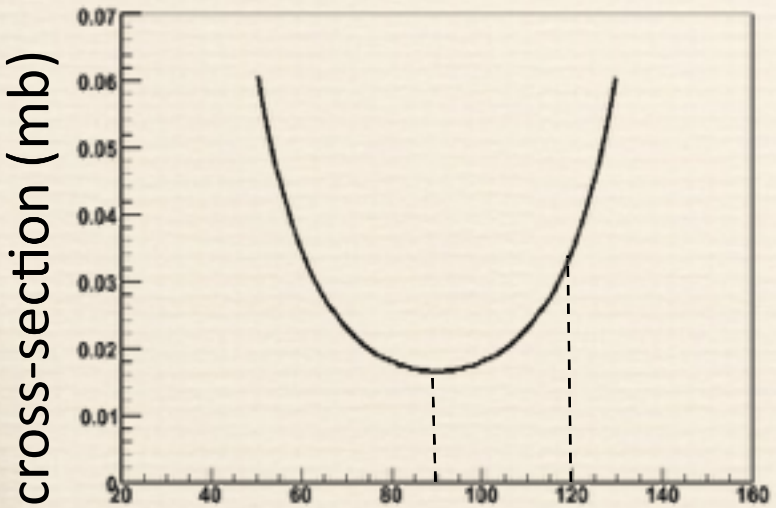
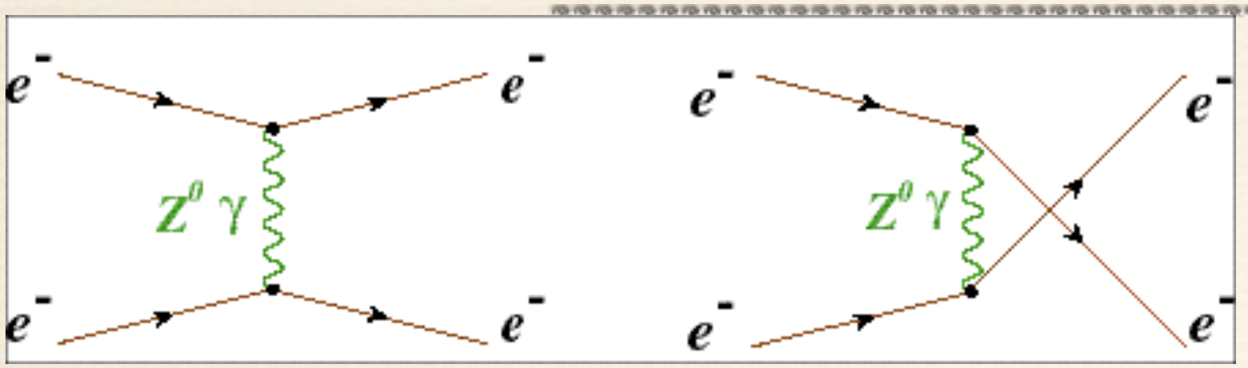
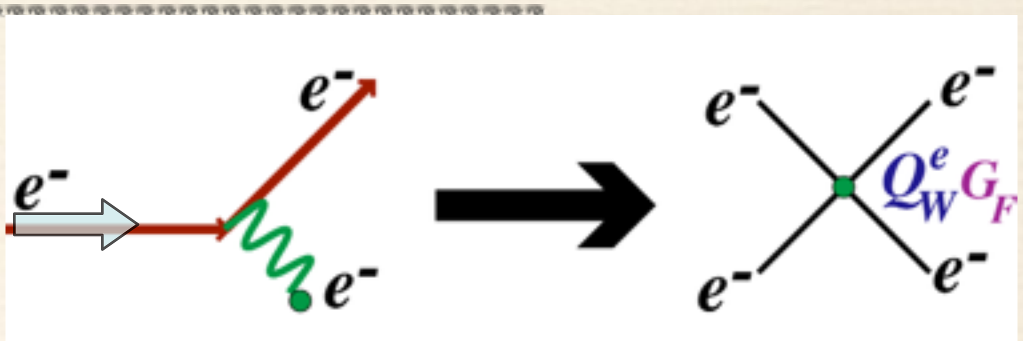
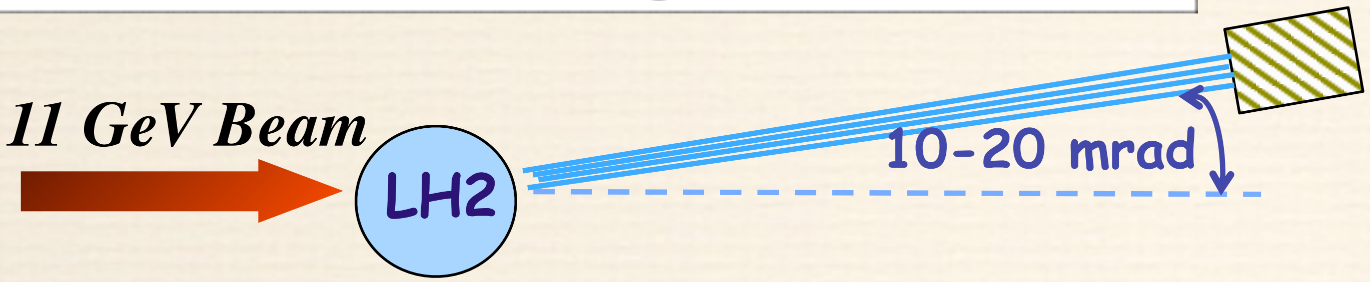
$$\frac{d\sigma}{d\Omega} = \frac{\alpha^2}{2mE}\frac{(3+\cos^2\Theta)^2}{\sin^4\Theta}$$



A_{PV} in Møller Scattering







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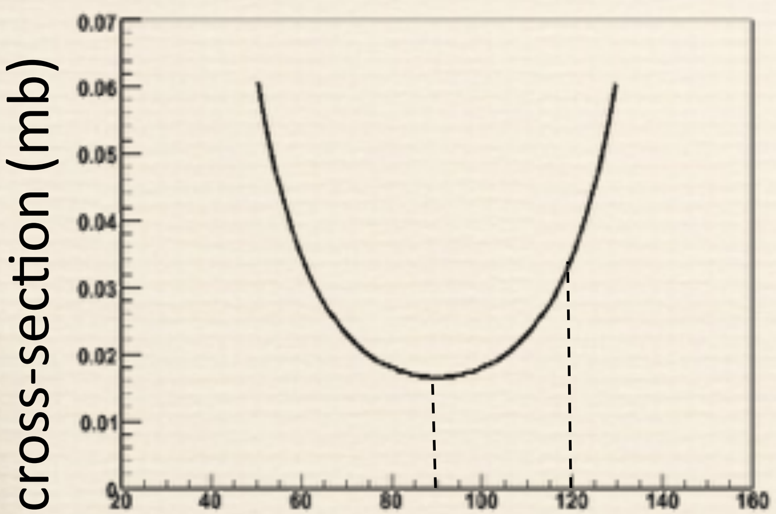
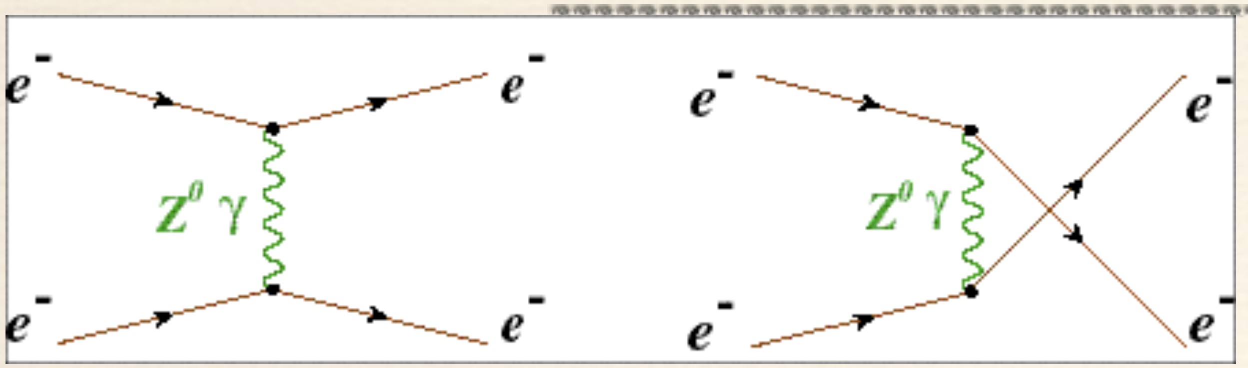
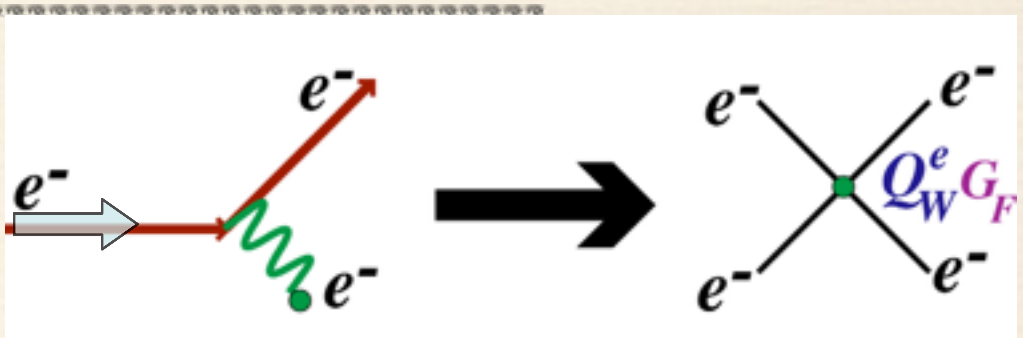
$$Q^e_W = 1 - 4\sin^2\theta_W \sim 0.075$$



Fixed Target Electron Scattering

A_{PV} in Møller Scattering





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A_{PV} varies from roughly 68 to 45 ppb

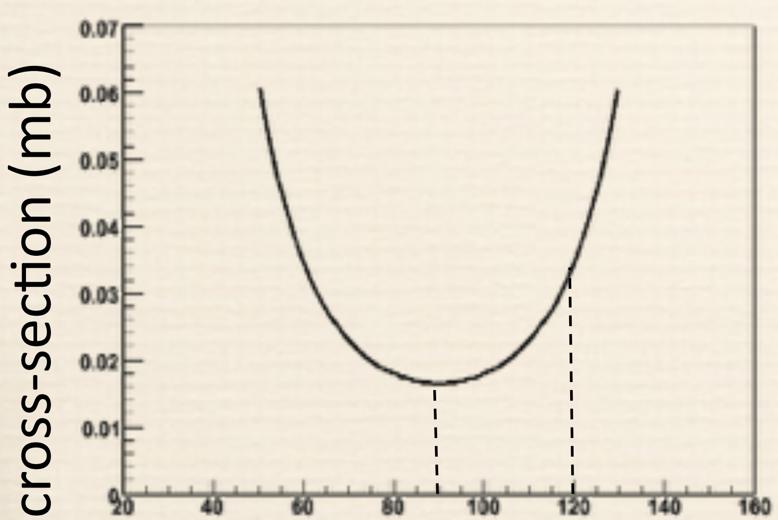
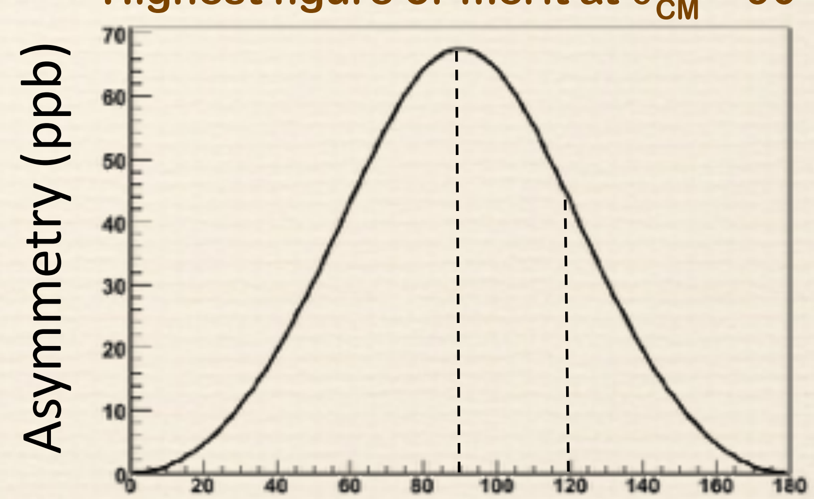


Figure of merit slowly decreases as COM scattering angle moves away from 90 degrees

Highest figure of merit at θ_{CM} = 90°



The Standard Model Prediction: Remarkably Well-Known

Radiative Corrections

$$A_{PV} = \frac{\rho G_F Q^2}{\sqrt{2}\pi\alpha} \frac{1-y}{1+y^4+(1-y)^4} \{1 - 4\kappa(0)\sin^2\theta_W(m_Z)_{\overline{\rm MS}}$$
$$+ \frac{\alpha(m_Z)}{4\pi\hat{s}^2} - \frac{3\alpha(m_Z)}{32\pi\hat{s}^2\hat{c}^2}(1-4\hat{s}^2)[1+(1-4\hat{s}^2)^2]$$
$$+ F_1(y,Q^2) + F_2(y,Q^2)\}$$

$$\mathbf{Q^e_W = 1 - 4\sin^2\theta_W \sim 0.075 \Longrightarrow 0.045}$$

The small size of the coupling, further reduced by radiative corrections, will be a recurring theme: it eases the pressure on "normalization" errors

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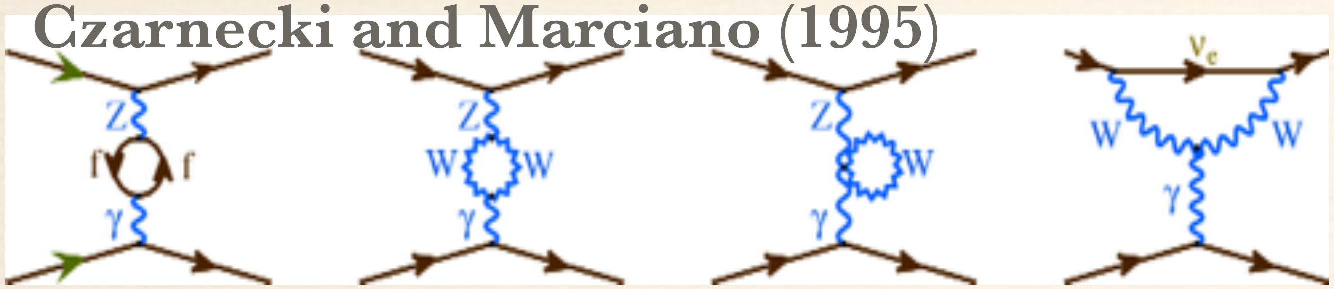
Czarnecki and Marciano (1995)



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$$\frac{\delta(Q_W)}{Q_W} \sim 10\% \Longrightarrow \frac{\delta(\sin^2\theta_W)}{\sin^2\theta_W} \sim 0.5\%$$

Czarnecki and Marciano (1995)

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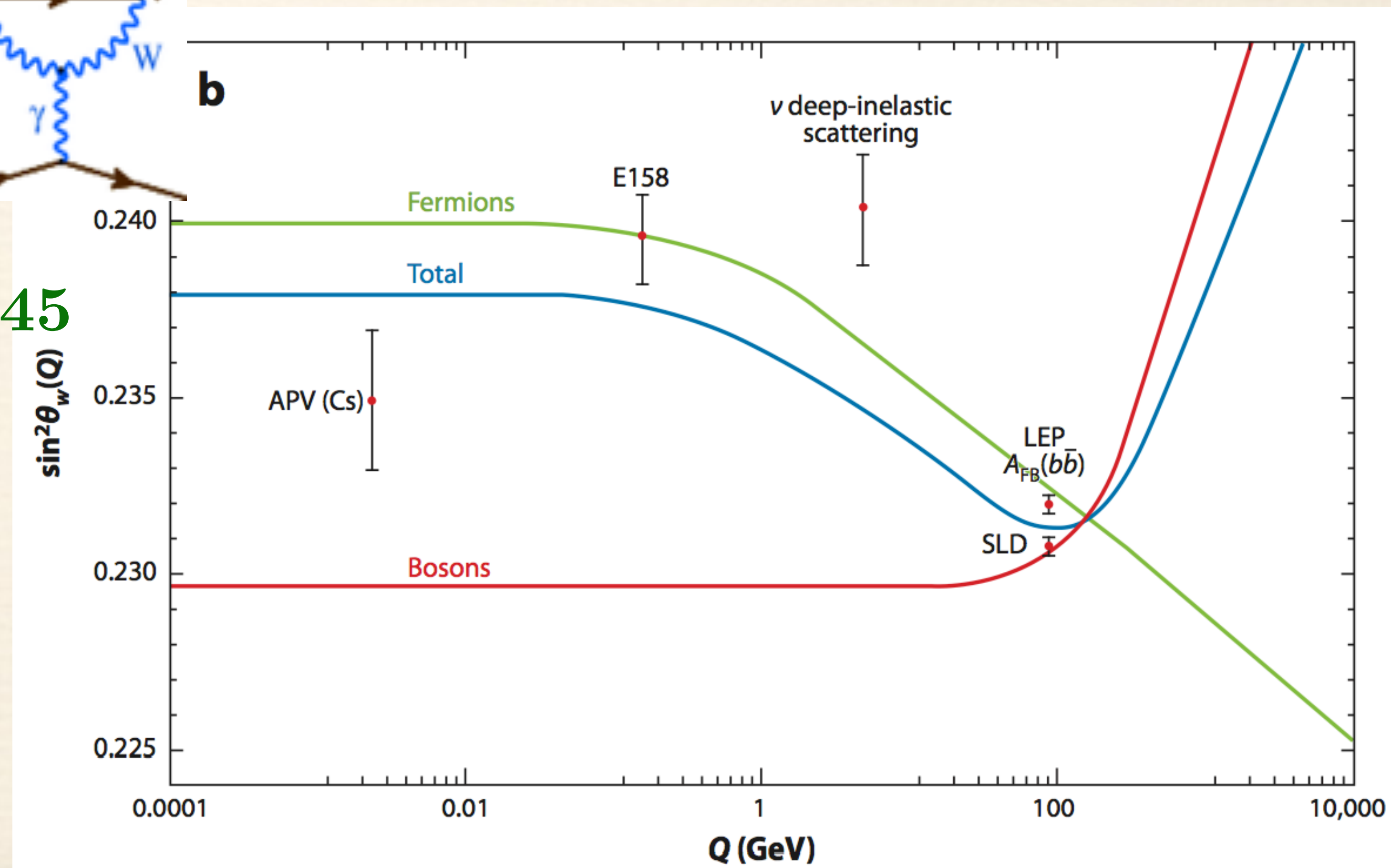
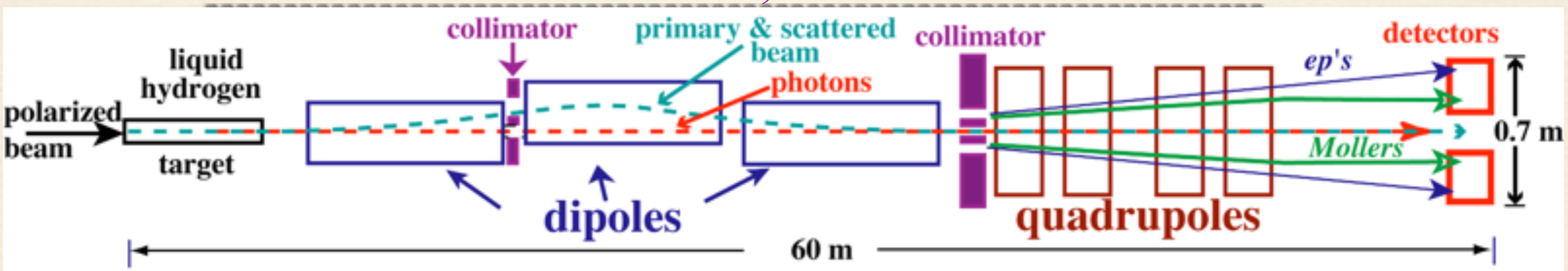
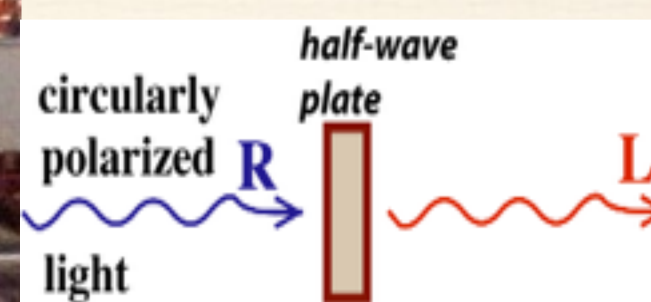


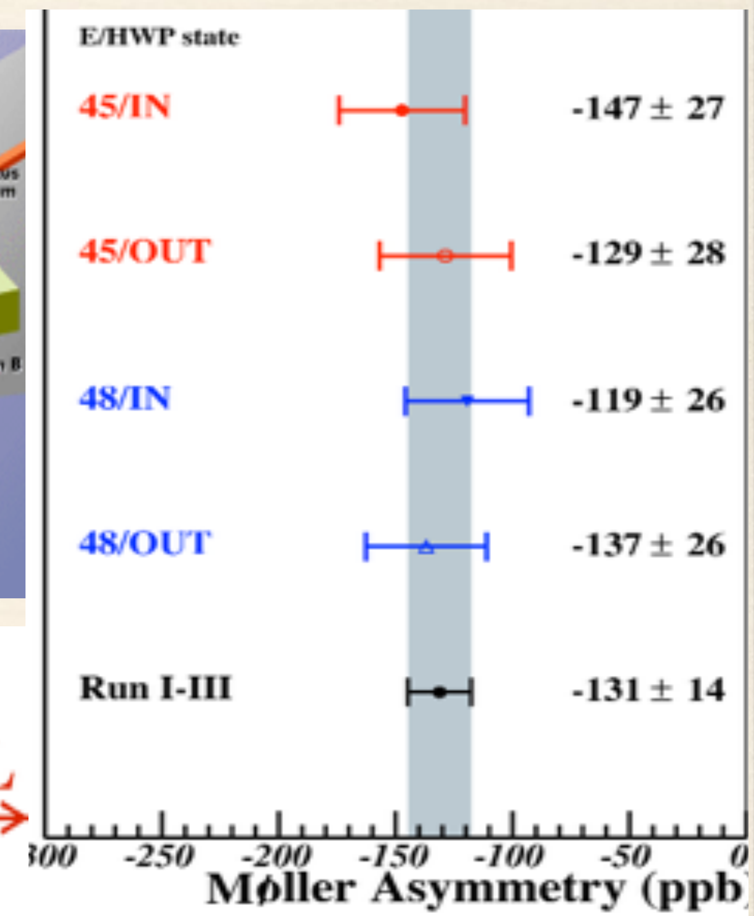
First PVES Measurement with TeV-scale sensitivity 1997-2004

Previous Result: SLAC E158

~ 10 ppb raw sensitivity at highest E_{beam}, ~ 0.5% error on weak mixing angle







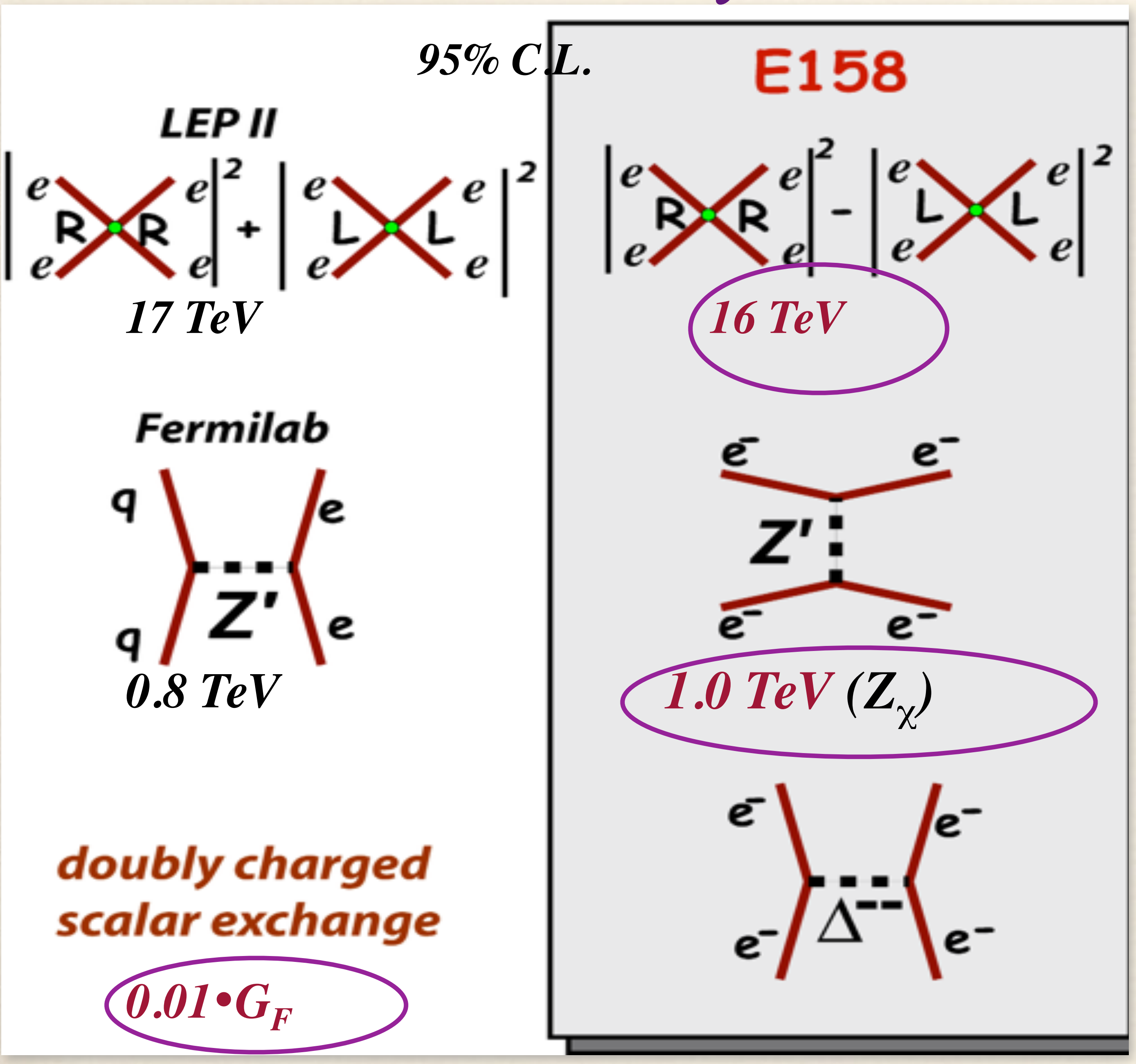
$A_{PV} = (-131 \pm 14 \pm 10) \times 10^{-9}$

Phys. Rev. Lett. **95** 081601 (2005)

E158 Physics Implications
2003

Unique discovery space probed: Complementary to Colliders

Limits on "New" Physics



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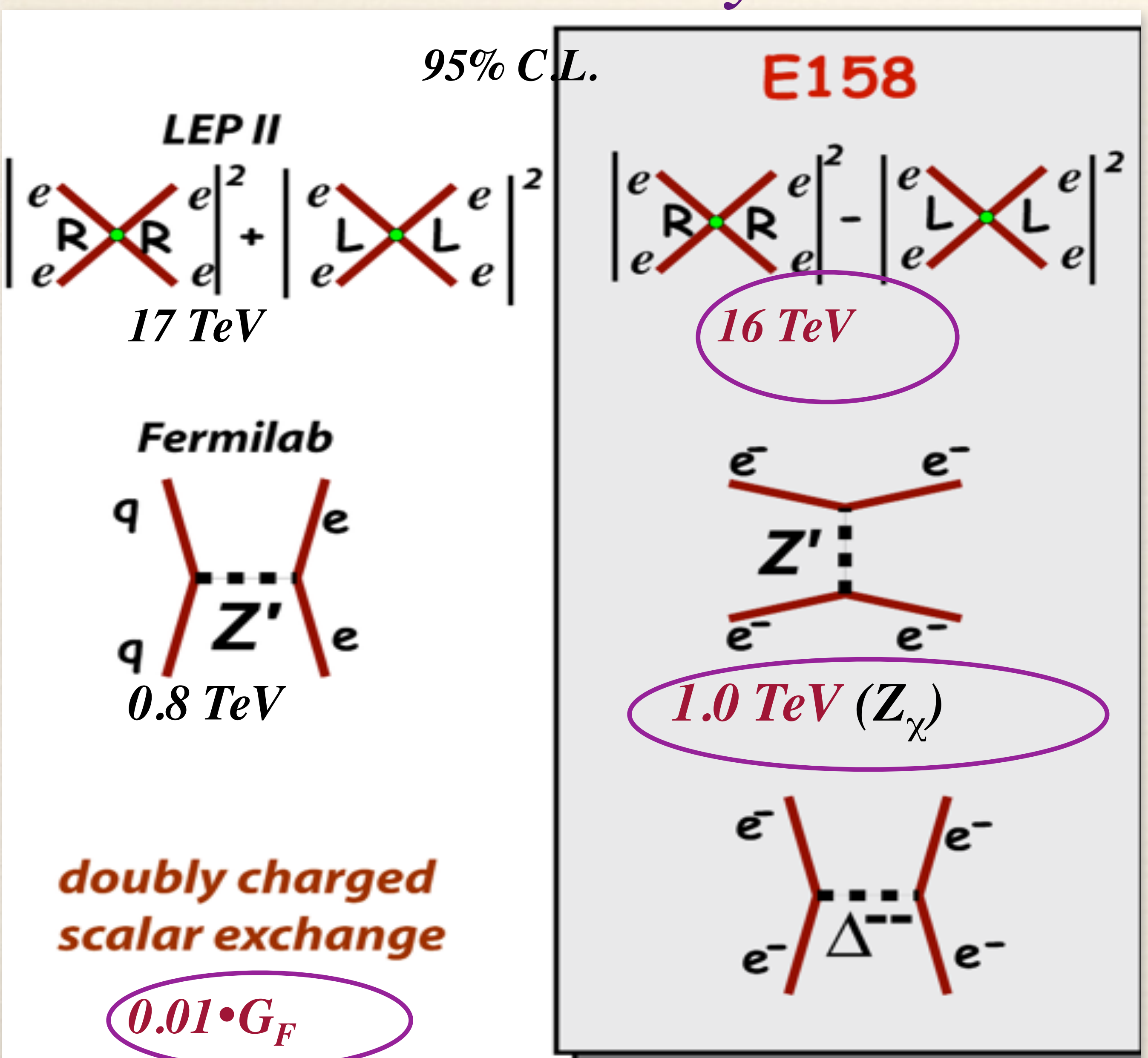

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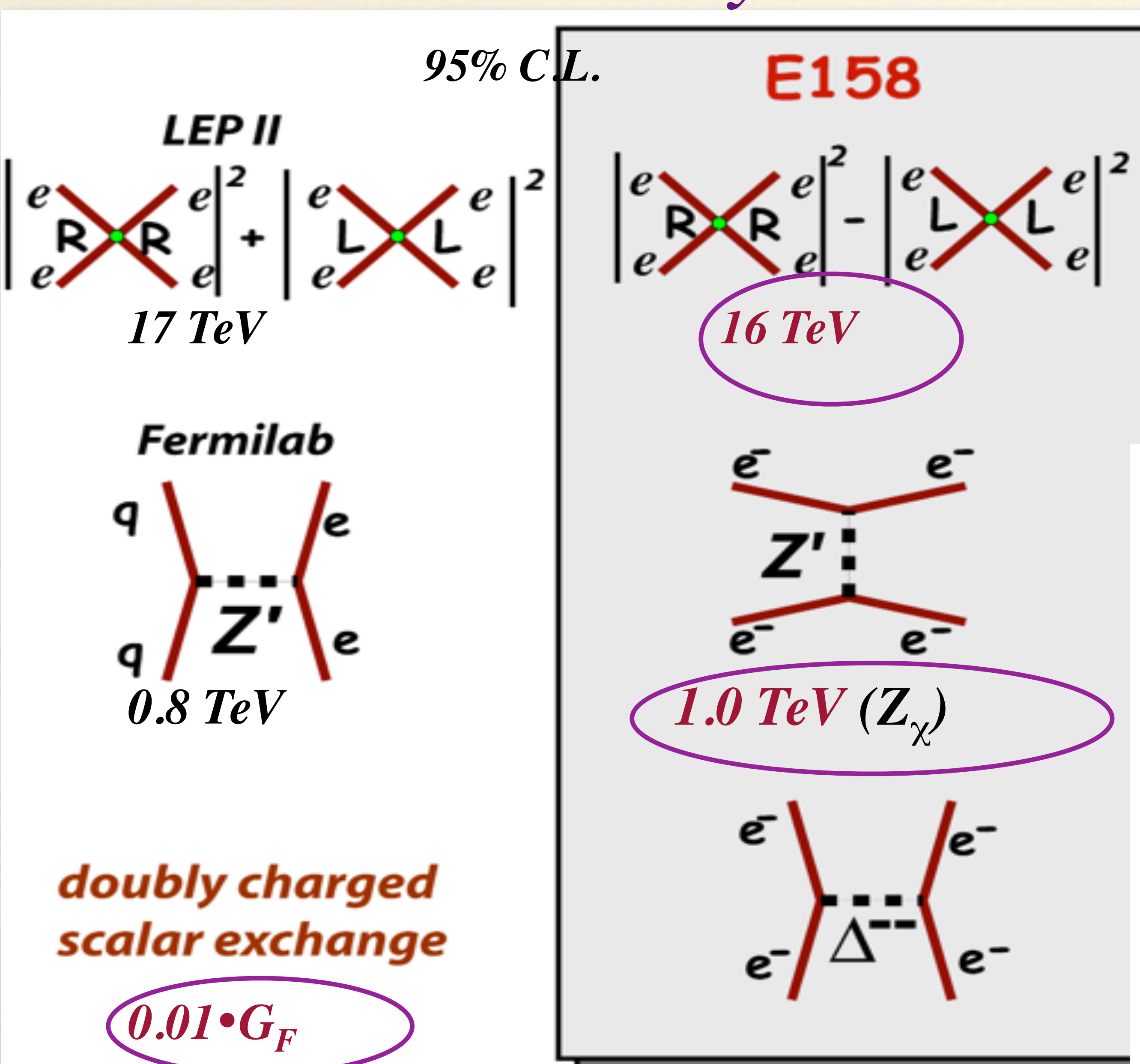

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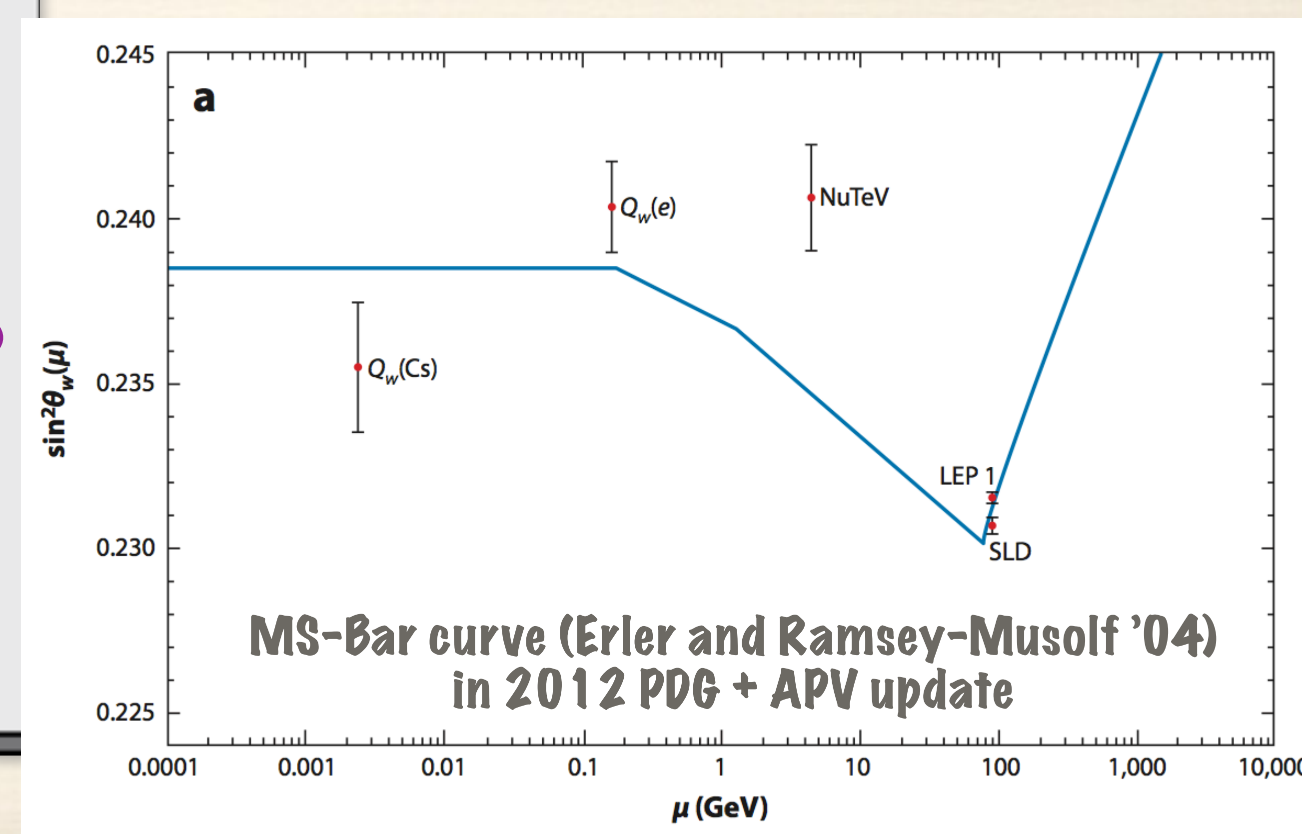


An ultra-precise measurement of the weak mixing angle using Møller scattering

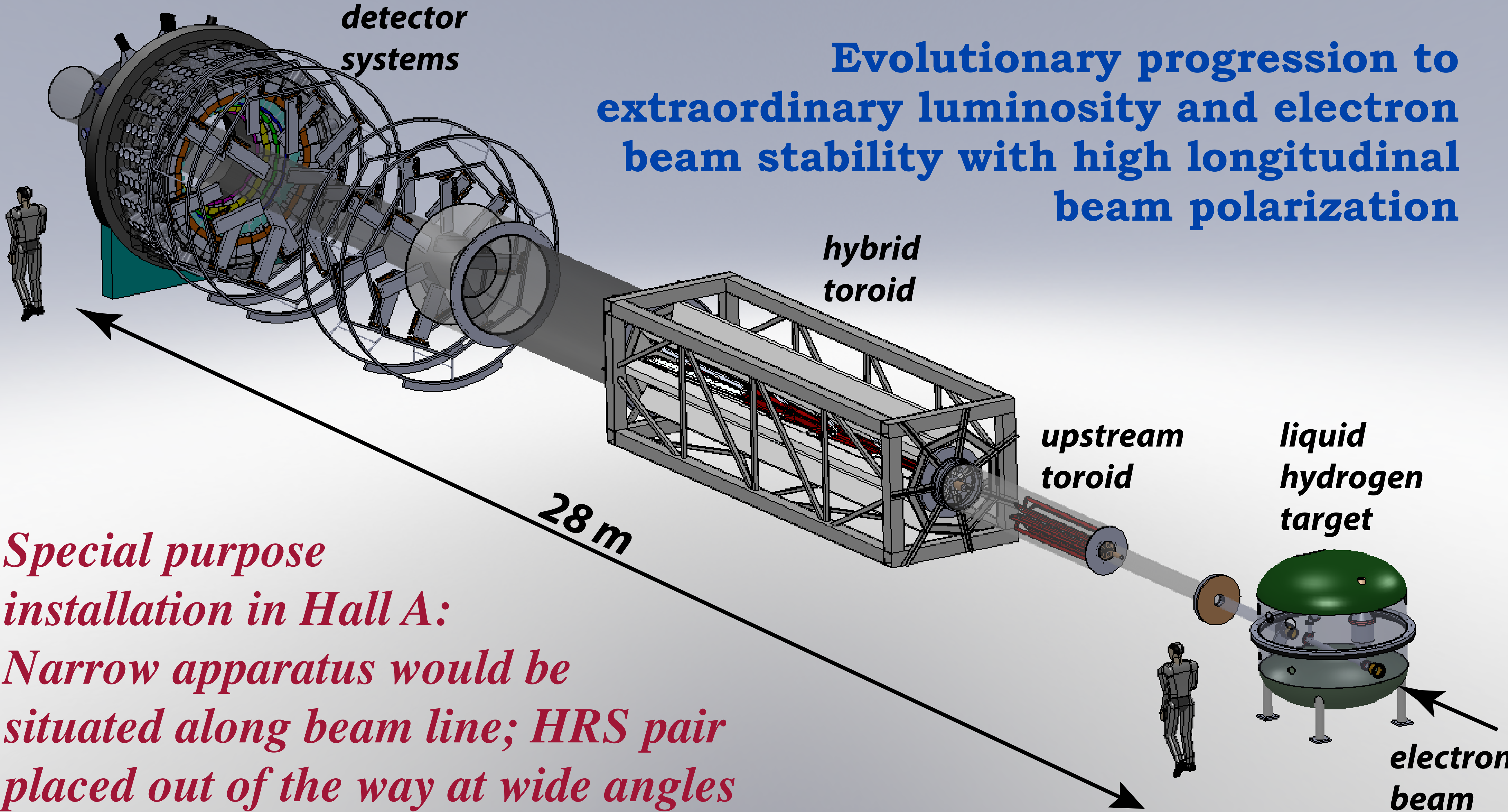
11 GeV Møller scattering

MOLLER at JLab

Measurement Of Lepton Lepton Electroweak Reaction

Unique opportunity leveraging the 12 GeV Upgrade investment

Evolutionary progression to extraordinary luminosity and electron beam stability with high longitudinal beam polarization



Special purpose installation in Hall A: Narrow apparatus would be situated along beam line; HRS pair placed out of the way at wide angles

Projected Uncertainty

A_{PV} = 35 ppb ***Luminosity: 3×10^{39} cm^2/s***

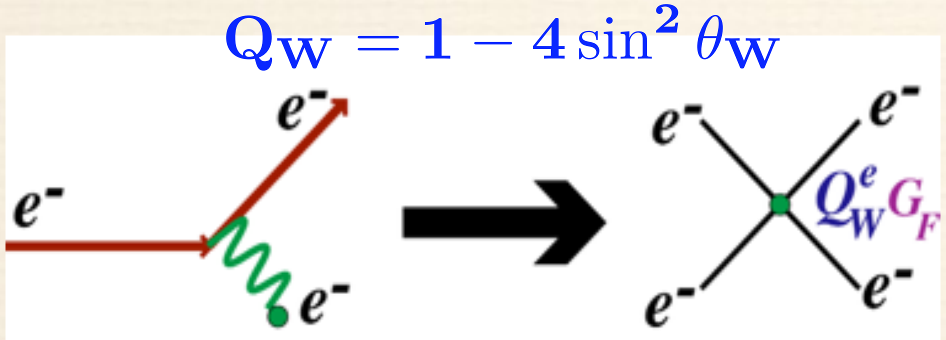
75 μA *80% polarized*

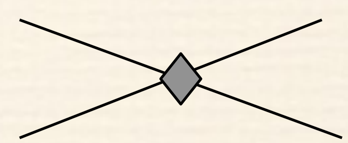
δ(A_{PV}) = 0.73 parts per billion

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

δ($\sin^2\theta_W$) = ± 0.00024 (stat.) ± 0.00013 (syst.) → ***~ 0.1%***

$\mathbf{Q_W = 1 - 4\sin^2\theta_W}$



$+$  $\dfrac{1}{\Lambda^2}\mathcal{L}_6$

$$\mathcal{L}_{e_1 e_2} = \sum_{\mathbf{i,j=L,R}} \frac{\mathbf{g_{ij}^2}}{\mathbf{2\Lambda^2}} \mathbf{\bar{e}_i \gamma_\mu e_i \bar{e}_j \gamma^\mu e_j} \Rightarrow \frac{\mathbf{\Lambda}}{\sqrt{|\mathbf{g^2_{RR}} - \mathbf{g^2_{LL}}|}} = \mathbf{7.5}\ \text{TeV}$$

MOLLER Collaboration

~120 Collaborators, 30 institutions, 6 countries

Expertise from several generations of successful parity experiments

Spokesperson: K. Kumar, Stony Brook U.

Executive Board Chair and Deputy Spokesperson: M. Pitt, Virginia Tech

Other Executive Board Members

Dave Armstrong (William and Mary)
Javier Gomez (JLab)
Cynthia Keppel (JLab)
Frank Maas (U. Mainz)
Juliette Mammei (U. Manitoba)
Kent Paschke (U. Virginia)
Paul Souder (Syracuse U.)

MOLLER Subsystem Leaders

Polarized Source: G. Cates (U. Virginia)
Beam Instrumentation: M. Pitt (Virginia Tech)
Hydrogen Target: S. Covrig (JLab)
Spectrometer: J. Mammei (Manitoba)
Integrating Detectors: M. Gericke (Manitoba)
Tracking Detectors, D. Armstrong (William and Mary)
Polarimetry: K. Paschke (U. Virginia)
Electronics/DAQ: R. Michaels (JLab) and P. King (Ohio)
Simulations: S. Riordan (UMass) and D. McNulty (Idaho State)

If/when MOLLER is ready to move forward as a funded project, the governance structure will be appropriately expanded.

Collaborators Present at Review

- D. Armstrong (College of William and Mary)
- G. Cates (U. Virginia)
- M. Gericke (U. Manitoba)
- E. Ihloff (MIT)
- K. Kumar (Stony Brook)
- K. Paschke (U. Virginia)
- M. Pitt (Virginia Tech)
- S. Riordan (UMass)
- P. Souder (Syracuse U.)