MOLLER: Ultra precise measurement of the weak mixing angle

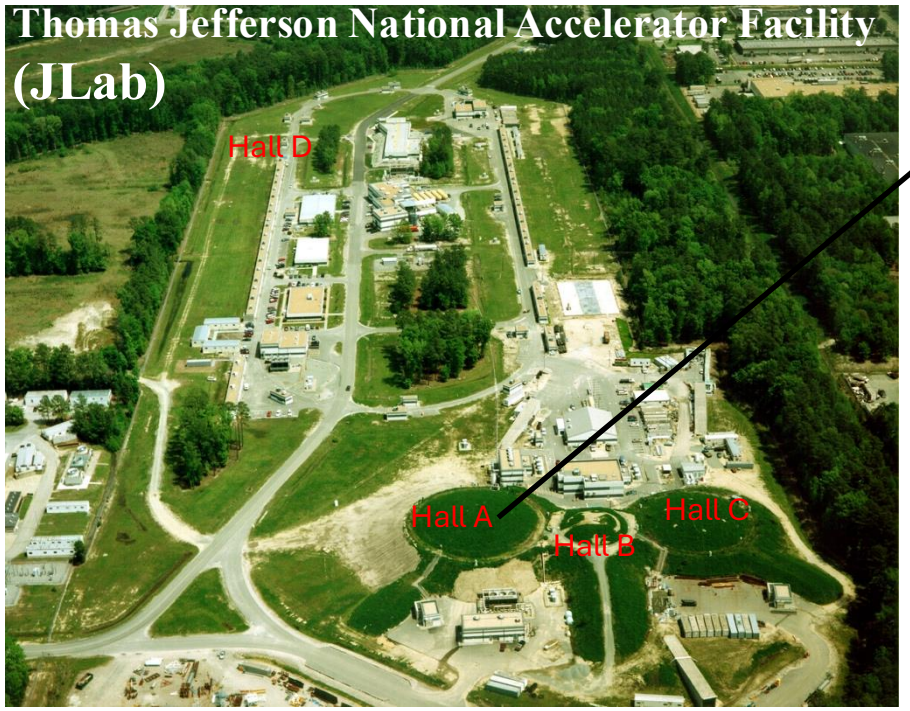
Sayak Chatterjee

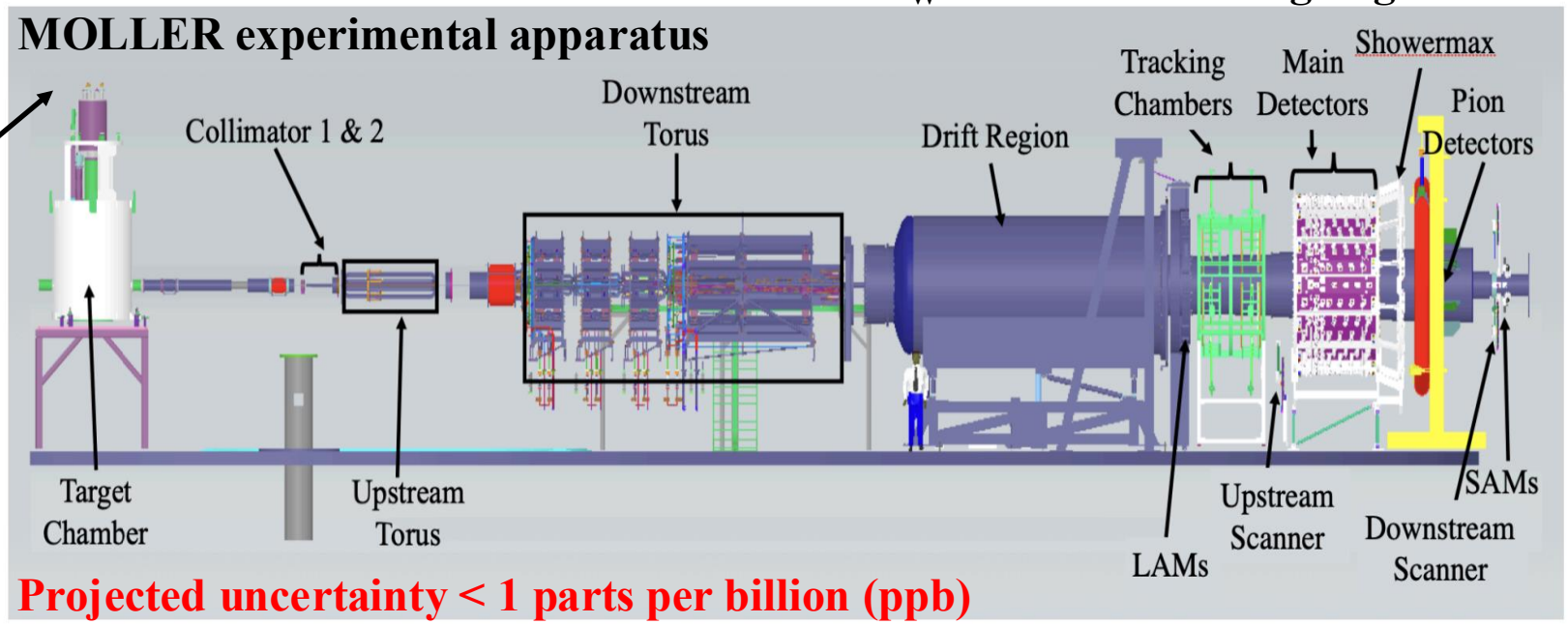
Department of Physics

University of Massachusetts, Amherst

$Q^{e}_{W} \sim 1 - 4 \sin^2\theta_W$ (at the tree level)

θ_W is the weak mixing angle



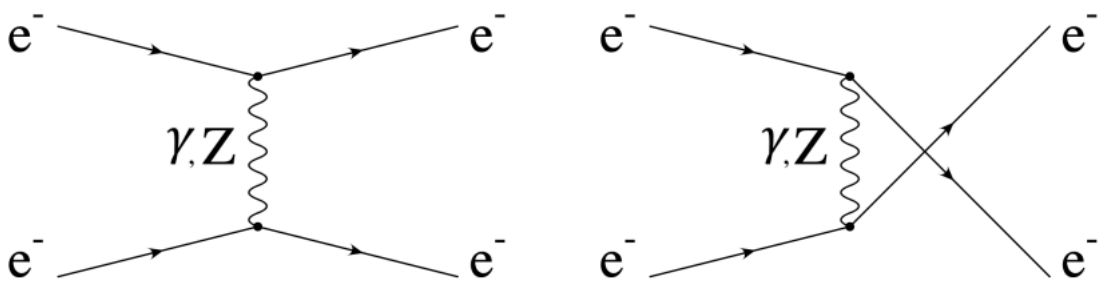


Projected uncertainty < 1 parts per billion (ppb)

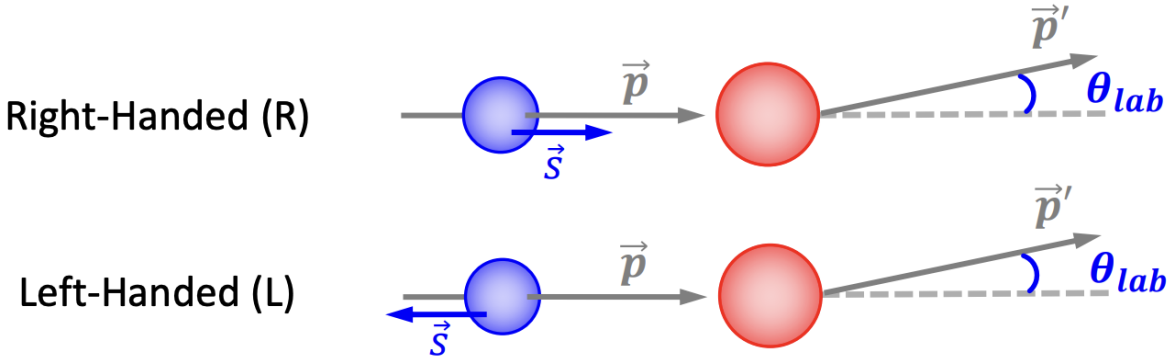
MOLLER : Measurement Of Lepton Lepton Electroweak Reaction

U.S. DEPARTMENT OF ENERGY | Office of Science | NSF U.S. National Science Foundation

Why Møller scattering???



The weak component (Z) does not conserve parity

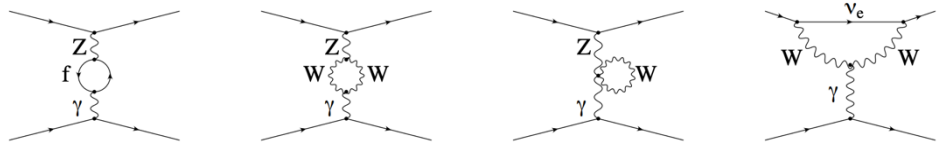


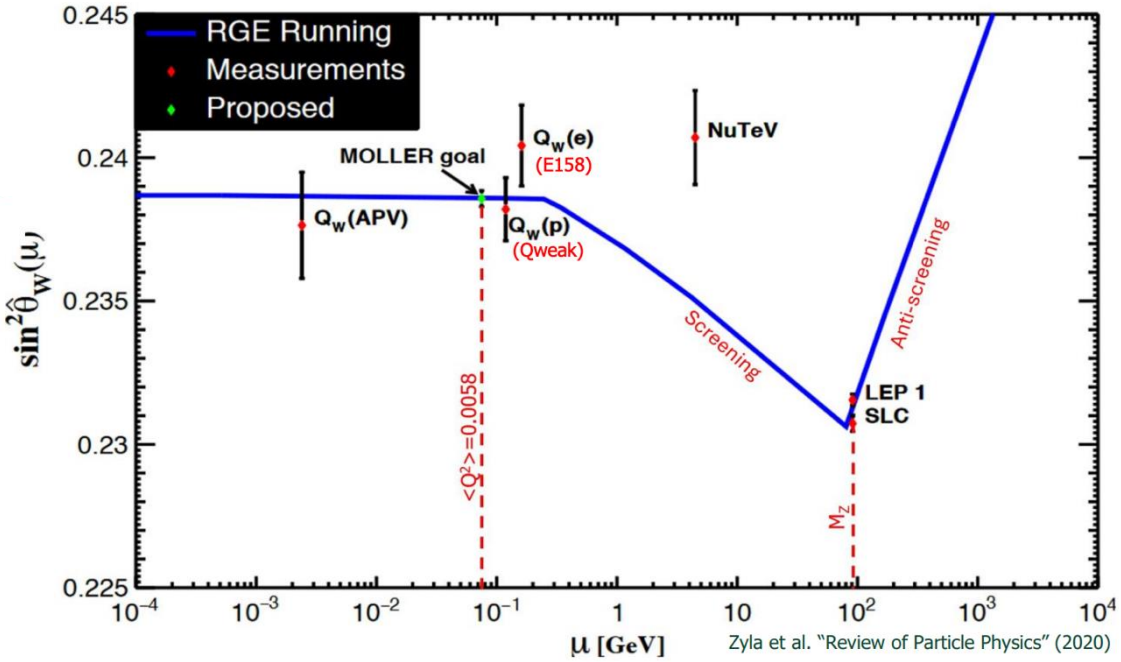
Parity Violating Electron Scattering (PVES)

The A_{PV} can be expressed (at the tree level) as

$$A_{PV} = \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L} \propto Q_W^e = (1 - 4\sin^2\theta_W)$$

- Purely leptonic process → small theoretical uncertainty
- Very well predicted by the SM
- **Any observed deviation from the prediction could indicate potential new physics beyond SM**





At MOLLER kinematics : A_{PV} = 32 (± 0.8) ppb → $\delta(\sin^2\theta_w) = \pm 0.00028$

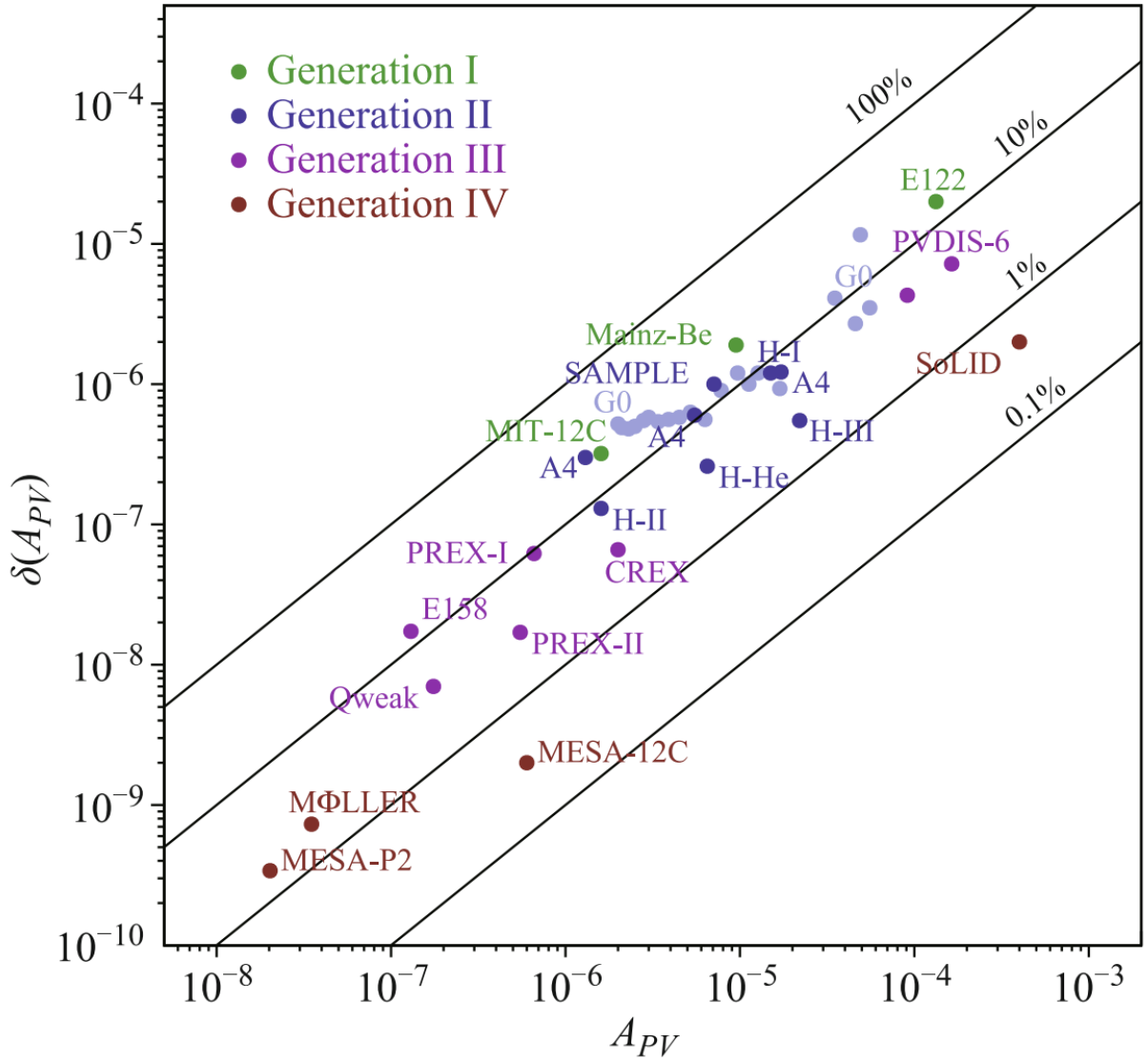
Parity Violating Electron Scattering (PVES)

- **Incident beam is longitudinally polarized**
- **Change sign of longitudinal polarization**
- **Measure fractional rate difference**
  - Takes care of the systematic uncertainties

PVES has become a precision tool

- ➢ **Beyond Standard Model Searches**
- ➢ **Strange quark form factors**
- ➢ **Neutron skin of a heavy nucleus**
- ➢ **QCD structure of the nucleon**

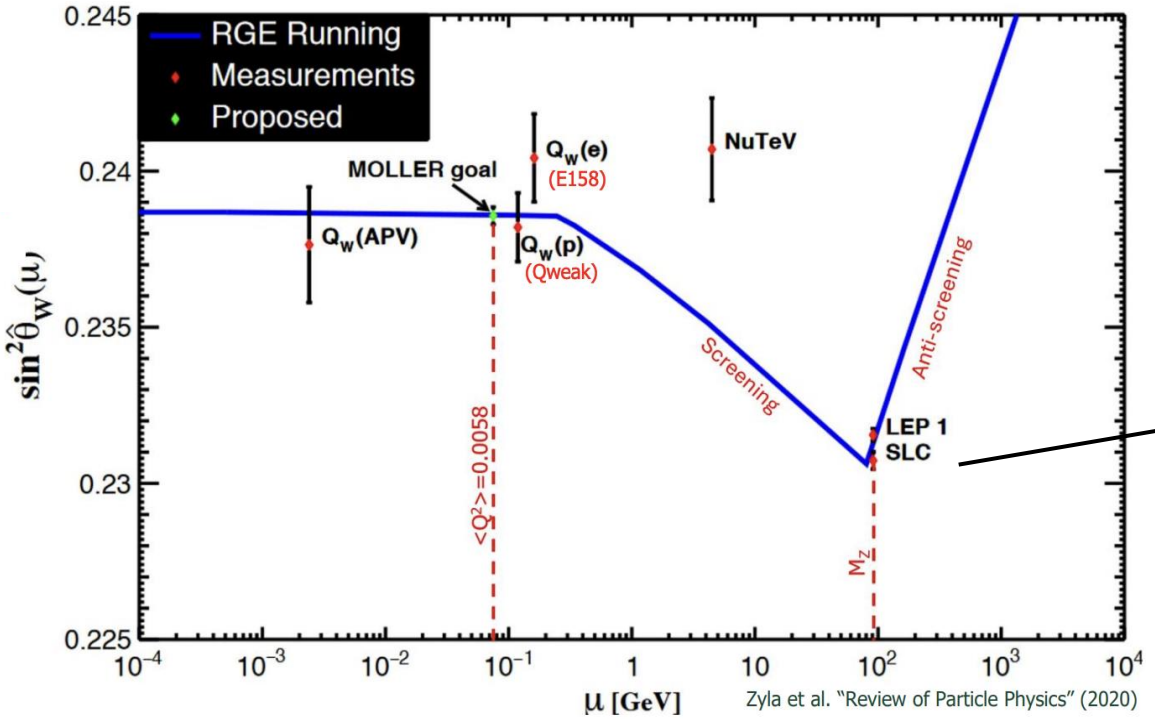
P. Souder, K. D. Paschke, Front. Phys. 11, 111301 (2016)

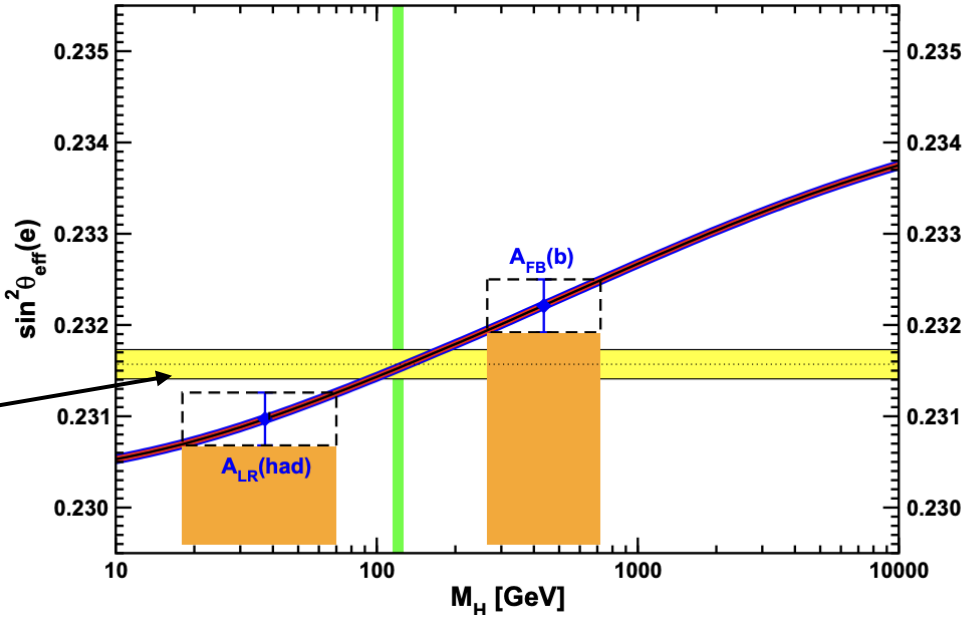


Improving the precision of the measurement so that we can challenge the existing prediction from the SM !!!

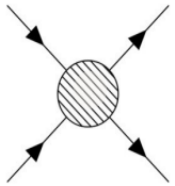
Physics impact

The most precise Z-pole measurements differ from each other by ~ 3σ



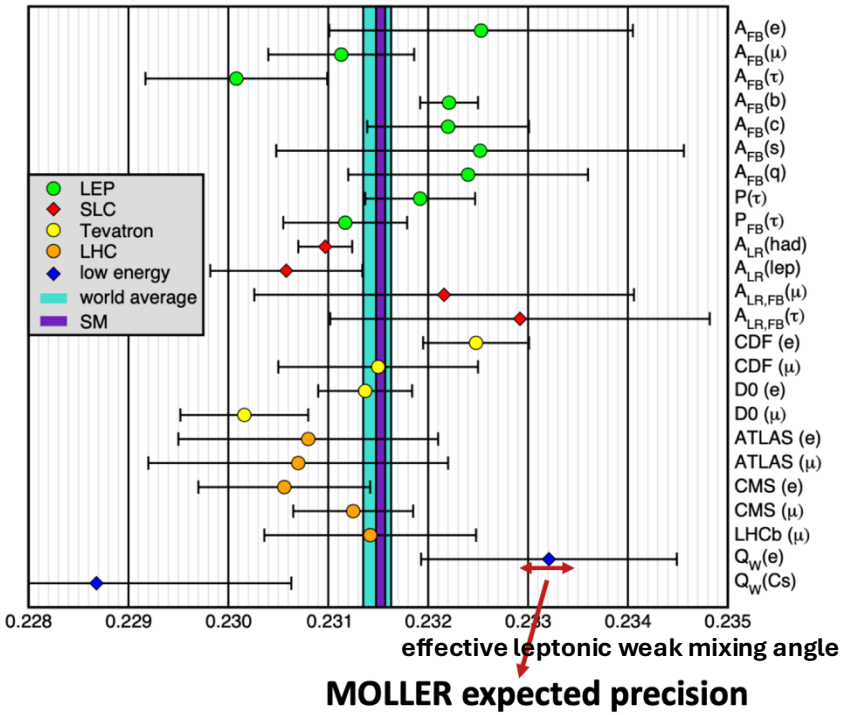


MOLLER experiment ($Q^2 << M_Z^2$) is very complementary to other precision low energy experiments and direct searches at high energy colliders



$$= \frac{\Lambda}{\sqrt{|g_{RR}^2 - g_{LL}^2|}} = \frac{1}{\sqrt{\sqrt{2}G_F|\delta Q_W^e|}} = 7.5\,[\text{Tev}]$$

$$\text{if } \sqrt{g_{RR}^2 - g_{LL}^2} = 2\pi \implies \Lambda \approx 47\,[\text{TeV}]$$



MOLLER has the potential for accessing the discovery space that cannot be reached until the advent of a new lepton collider or neutrino factory

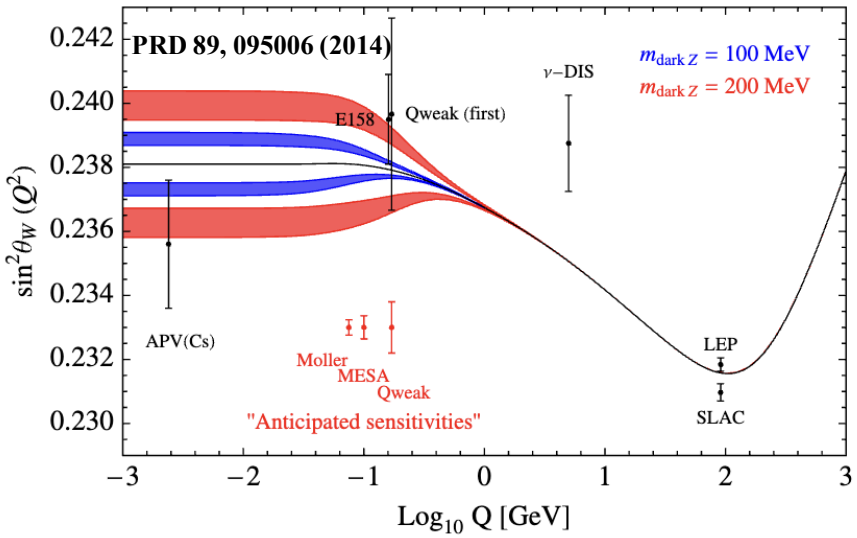
New dynamics beyond standard model

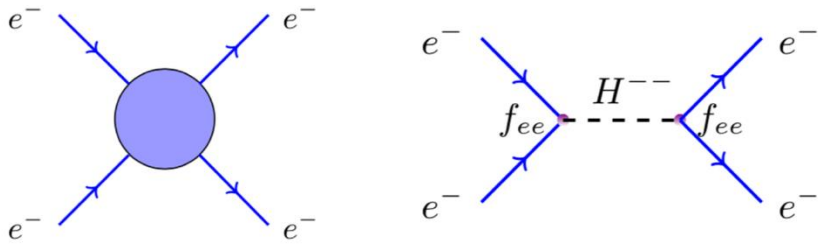
- MOLLER provides a unique window to new physics at MeV and multi-TeV scales, complementary to direct searches at high energy colliders

- Very sensitive probe of new flavor and CP-conserving neutral current interactions

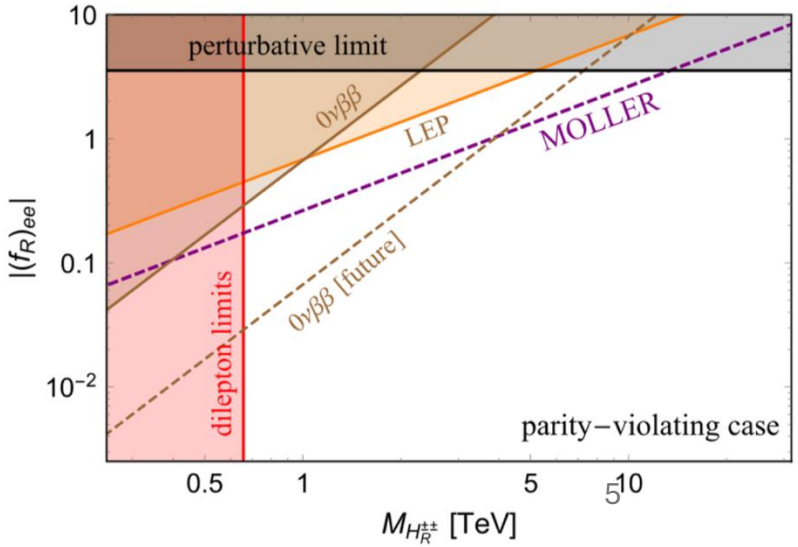
  - Weakly coupled MeV scaled mediators (dark Z → parity violating effect visible in low energy experiments ($Q2 \lesssim m_{Z_d}^2$))

  - High energy (multi-TeV) scale dynamics (Z', electron compositeness, supersymmetry, doubly charged scalars,…)





P. S. B. Dev, M. J. Ramsey-Musolf, Y. Zhang
PHYSICAL REVIEW D 98, 055013 (2018)

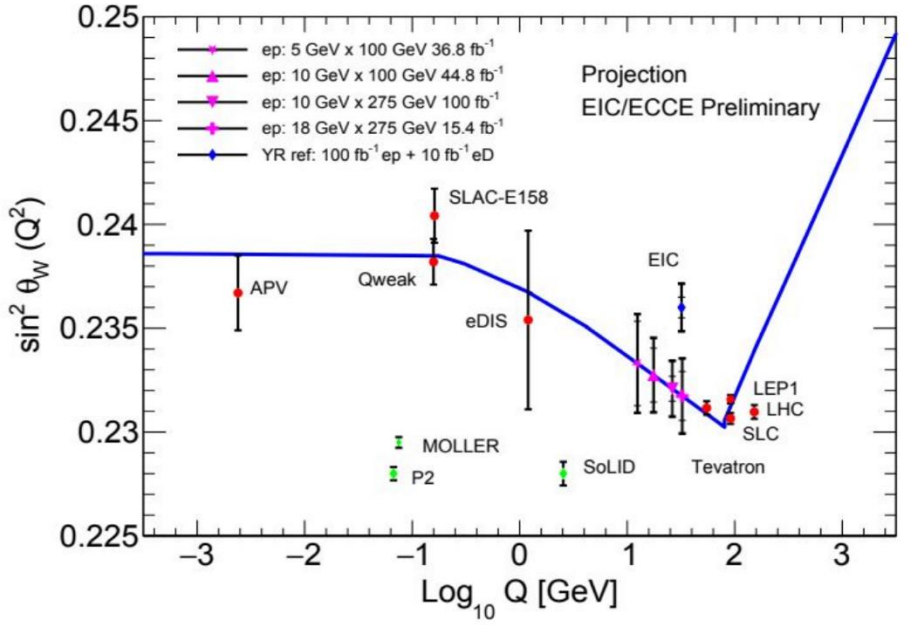


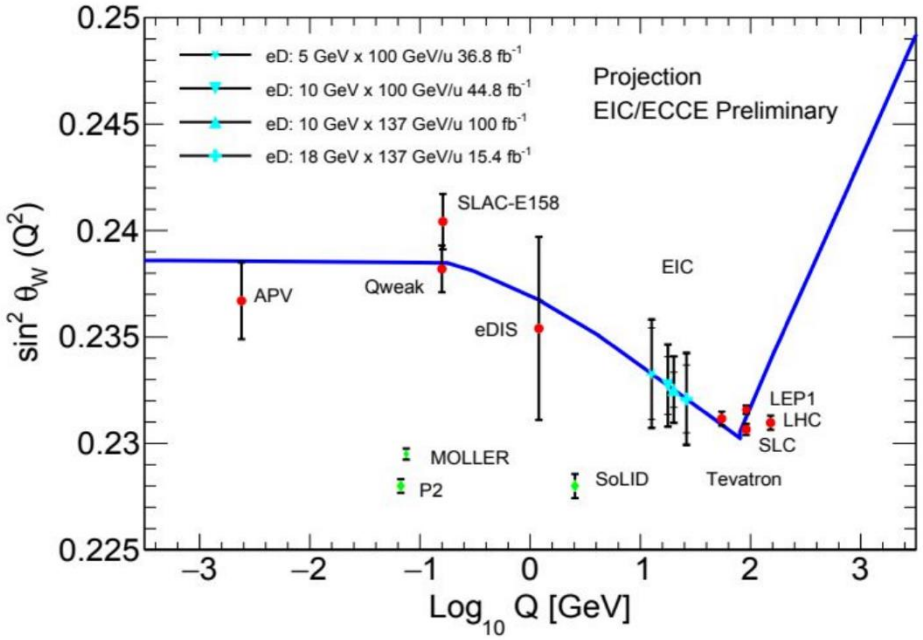
And many others …

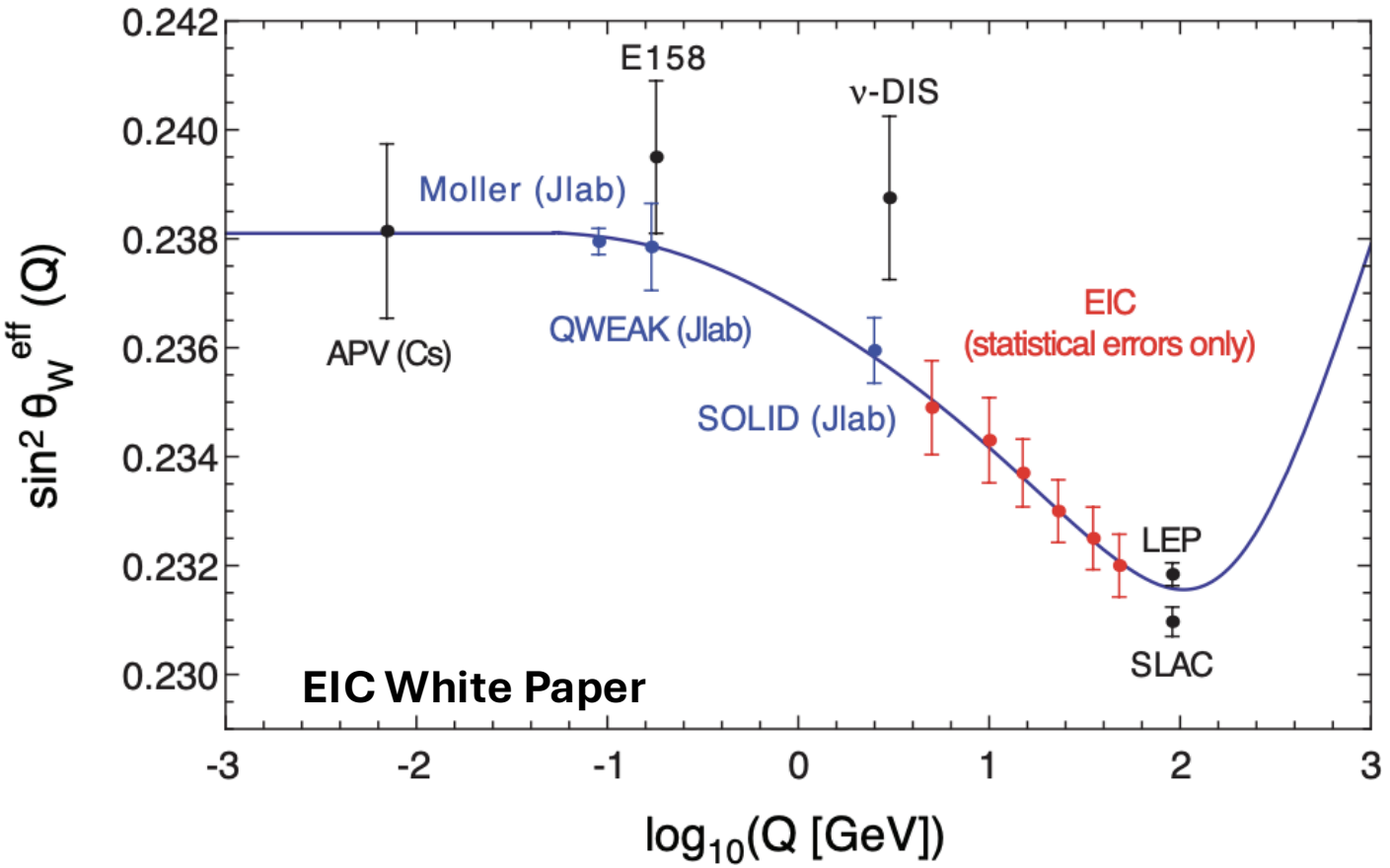
MOLLER physics motivation

- **Leptonic weak neutral current interaction; search for new flavor diagonal neutral currents**
- **Low Q^2 measurement; serves as the complimentary measurements of the direct searchers at high Q^2**
- **Potential for accessing discovery space that cannot be reached until the advent of a new lepton collider or neutrino factory**
- **Purely leptonic process;**
  - Robust theoretical predictions
  - Electroweak physics
  - New “low” energy physics
- **Potential to explore the beyond SM dynamics**

Can we measure something similar at EIC?



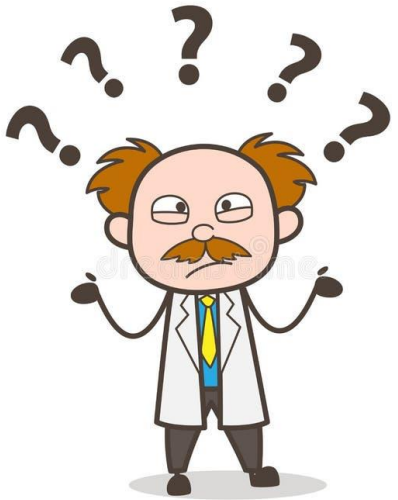




Statistical and beam polarimetry uncertainties dominate but offers moderate precision in an unmeasured energy region

R. Boughezal et al., PRD 106, 016006 (2022)

Well … but how are we planning to do it for MOLLER ?!!!



Well … but how are we planning to do it for MOLLER ?!!!

Listen to Sudip …

Thank you for your attention!!!