# The MOLLER Experiment

## **M**easurement **o**f a **L**epton **L**epton **E**lectroweak **R**eaction

An Ultra-precise measurement of the weak mixing angle using Møller Scattering


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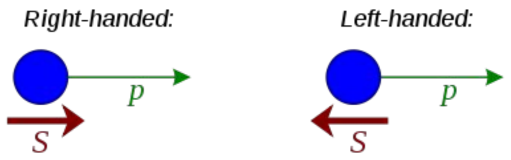
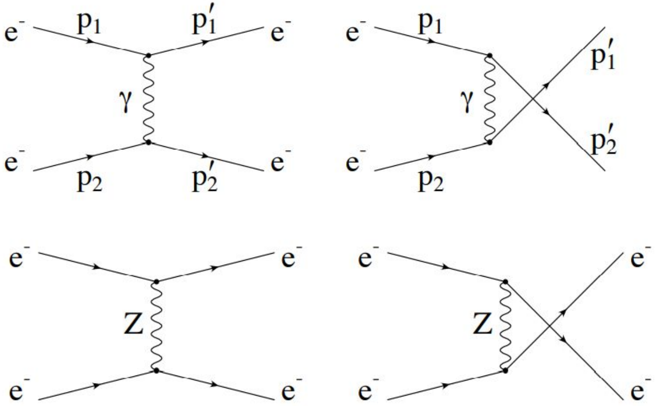
# History

- Lee and Yang in 1956 discovered that there is no experimental evidence for parity conservation in weak interactions. They proposed a test which was carried out later that year by C.S.Wu with radioactive Co-60. The experiment established parity violation in weak interactions.

- Another evidence of parity violation in weak interactions is revealed in the behaviour of neutrino. It was discovered that all neutrinos are left handed and all anti-neutrinos are right handed.



# Parity Violating Asymmetry ($A_{PV}$)




Tree-level Feynman diagrams for Moller Scattering

The Moller Experiment will measure an asymmetry defined by

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

The experiment proposes to measure this asymmetry in the scattering of longitudinally polarized electrons off unpolarized electrons, using the upgraded 11 GeV beam in Hall A at Jefferson Laboratory.

The electroweak theory prediction at tree level

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

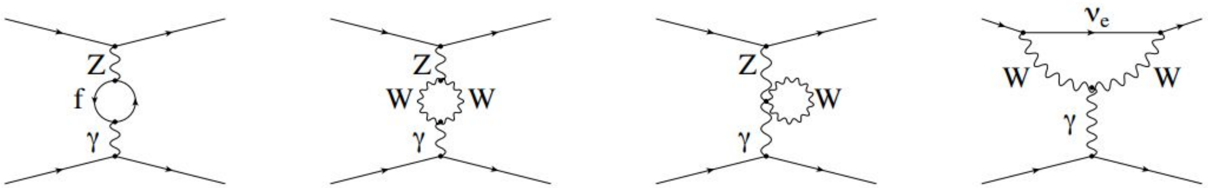
where $$Q_W^e = 1 - 4\sin^2\theta_W$$

θ is the scattering angle in the COM frame.

# Parity Violating Asymmetry ($A_{PV}$) (Cont.)

- The goal of the experiment is to have a precision measurement of the weak mixing angle ($\theta_W$).

- An important point to note here is that the higher order radiative corrections modify the tree-level prediction quite significantly. Even at 1-loop level, $\theta_W$ becomes dependent on the energy scale at which the measurement is carried out.




Higher order Feynman diagrams for Moller Scattering. The dominant effect comes from γ-Z mixing diagrams.

The $A_{PV}$ prediction with the proposed experimental design is ≈ 35 ppb and the goal is to measure this quantity with a statistical precision of 0.73 ppb.

# What is the weak mixing angle?

- It is a parameter in the standard electroweak theory given by Sheldon Glashow, Abdus Salam and Steven Weinberg for which they were awarded the Nobel Prize in 1979.

- The gauge group for the theory is SU(2) X U(1). To ensure the local gauge invariance we need to introduce 4 gauge bosons $A_\mu^1$, $A_\mu^2$, $A_\mu^3$ and $B_\mu$ in the theory.

$$D_\mu = \partial_\mu - igA_\mu^a T^a - ig'YB_\mu$$

- Spontaneous Symmetry Breaking → Massive $W_\mu^+$, $W_\mu^-$ and $Z^0_\mu$ and a massless $A_\mu$.

$$W_\mu^\pm = \frac{1}{\sqrt{2}}(A_\mu^1 \mp iA_\mu^2)$$

$$Z_\mu^0 = \frac{1}{\sqrt{g^2+g'^2}}(gA_\mu^3 - g'B_\mu)$$

$$A_\mu = \frac{1}{\sqrt{g^2+g'^2}}(g'A_\mu^3 + gB_\mu)$$

$$\begin{pmatrix} Z^0 \\ A \end{pmatrix} = \begin{pmatrix} \cos\theta_w & -\sin\theta_w \\ \sin\theta_w & \cos\theta_w \end{pmatrix} \begin{pmatrix} A^3 \\ B \end{pmatrix}$$

$$\cos\theta_w = \frac{g}{\sqrt{g^2+g'^2}}, \qquad \sin\theta_w = \frac{g'}{\sqrt{g^2+g'^2}}.$$

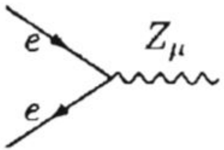
g and $g'$ are the SU(2) and U(1) gauge coupling constants respectively.

# Fermions in the theory and parity violation

- At the time of the formulation of the theory it was known that parity is violated in weak interactions.

- In the GWS Model, all the left handed fields transform as doublets under the SU(2) gauge group and all the right handed fields are singlets.

The interaction of fermions with these gauge bosons gives rise to the following Feynman rule for the Z interaction of the electron

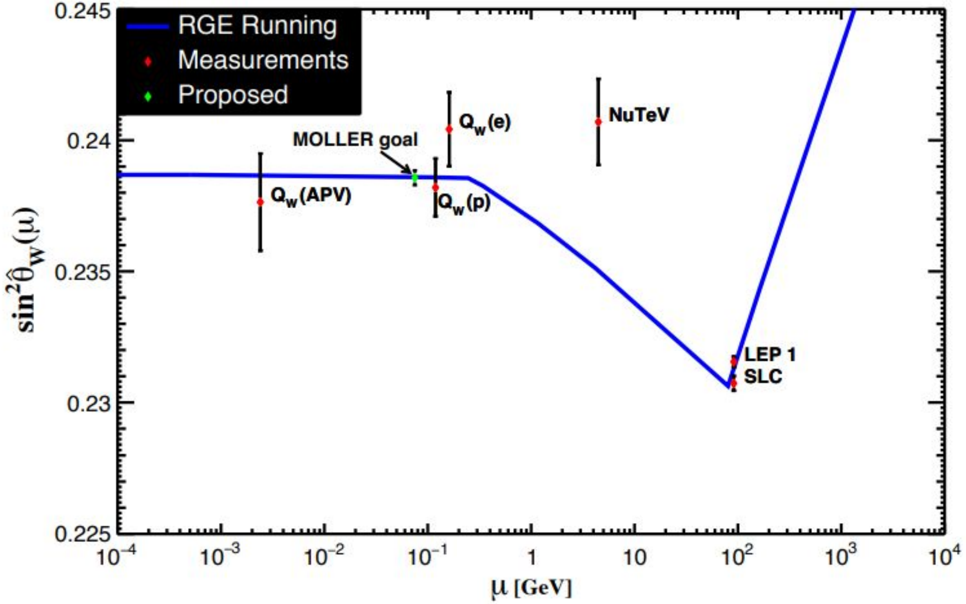



With the vertex factor $\frac{\iota g}{cos\theta_w}\gamma^\mu(t_3 L - Q sin^2\theta_w)$

with $L = (1-\gamma_5)/2$

The interaction of Z boson is different for different helicity states of the electron.

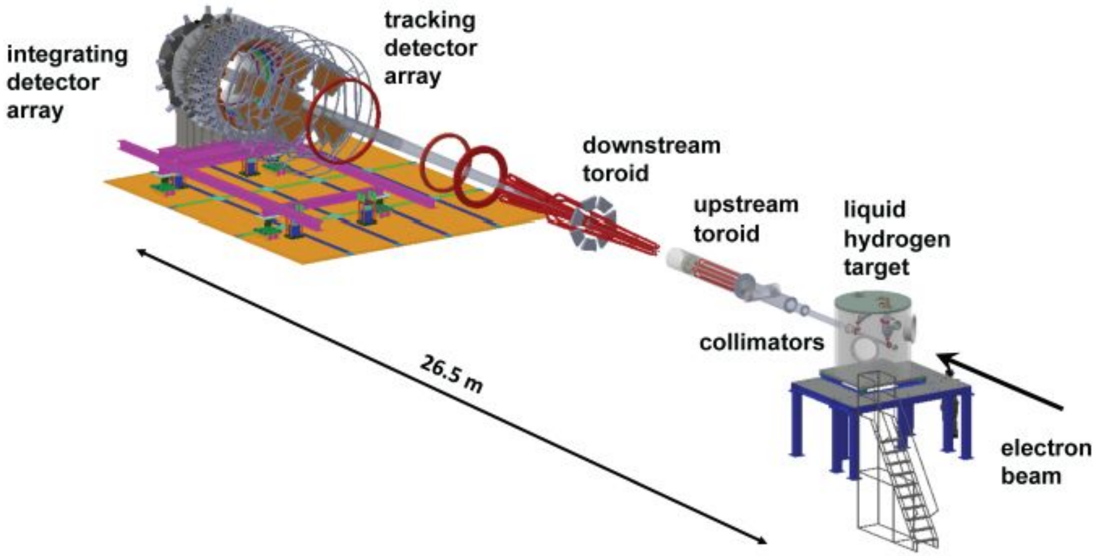
# Current and Proposed Measurements




- $Q_W(e)$ is the E158 result.
- $Q_W(p)$ is the $Q_{weak}$ result.
- $Q_w(APV)$ is the atomic parity violation experiment result using Cesium
- NuTeV - neutrino-nucleon DIS

**The vertical location of the proposed MOLLER point is arbitrary.**

# The MOLLER Experiment



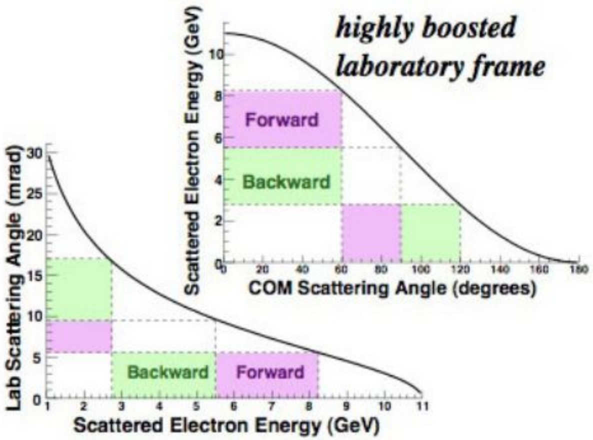
# 100% Azimuthal Acceptance possible!

- In order to achieve the stated precision on the parity-violating asymmetry the measurement needs as much rate as possible and we must therefore accept scattered electrons over the full range of the azimuthal angle φ, which would make the rate of more than 150 GHz available.

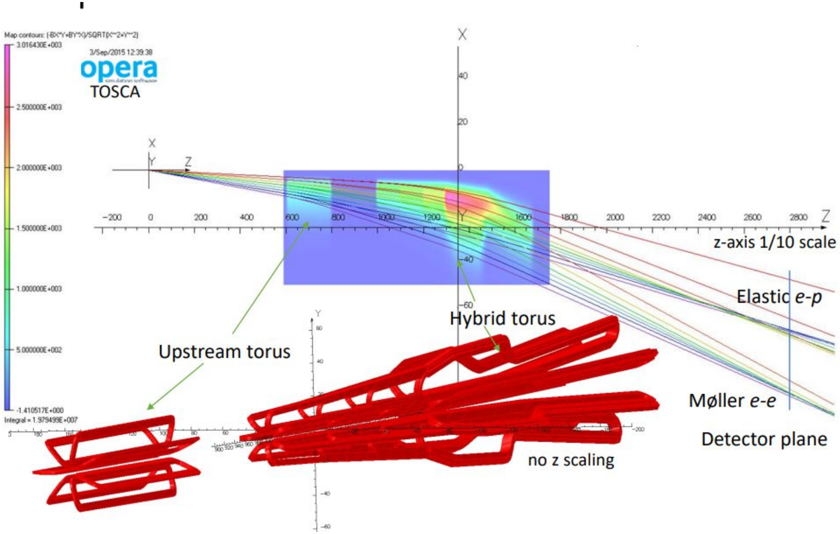
- To achieve this there are two back to back toroids in the setup.

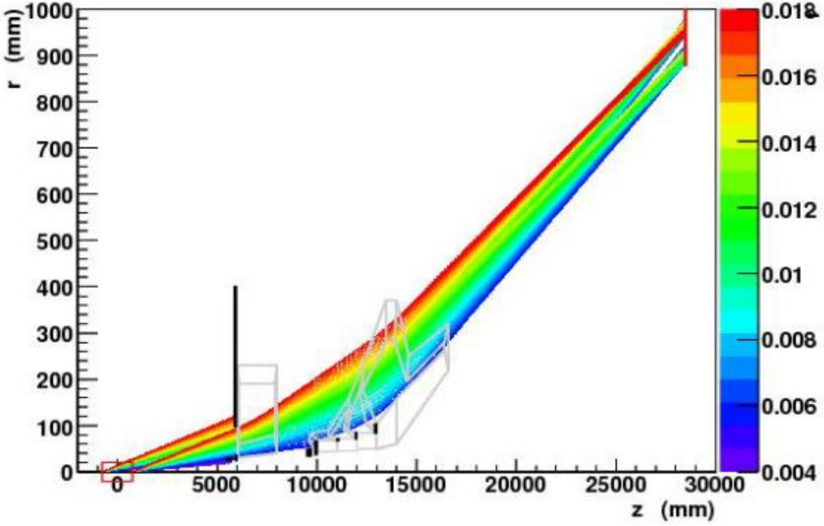
- The first is a conventional toroid placed 6 m downstream of the target and the second, a novel hybrid toroid placed between 10 and 16 m downstream of the target.

$$5.5 \leq \theta_{lab} \leq 17 \text{ mrad.}$$



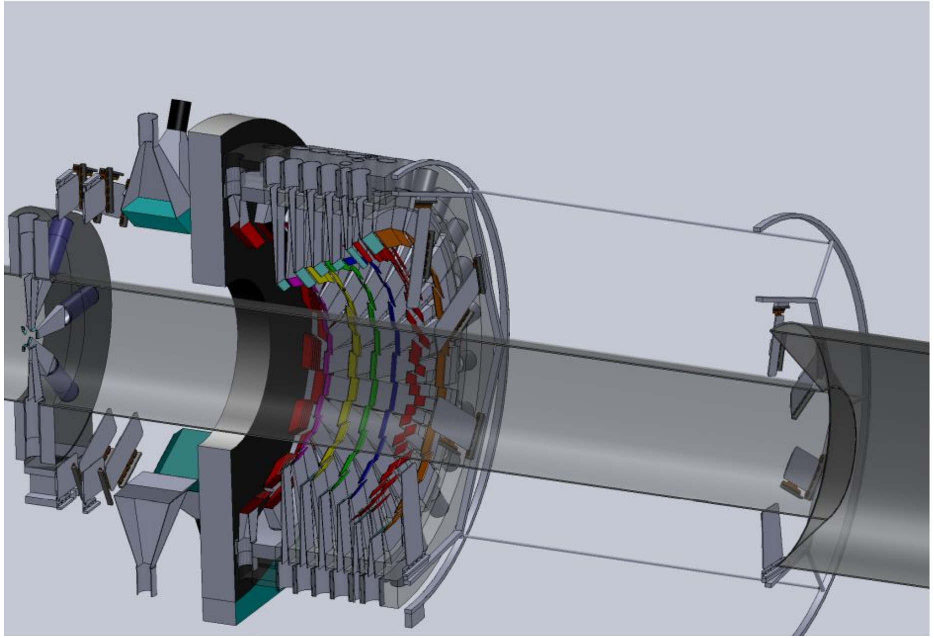
The hybrid toroid is in some sense the heart of the spectrometer concept. It is designed so that particles at different radial distances from the beam feel very different integral Bdl



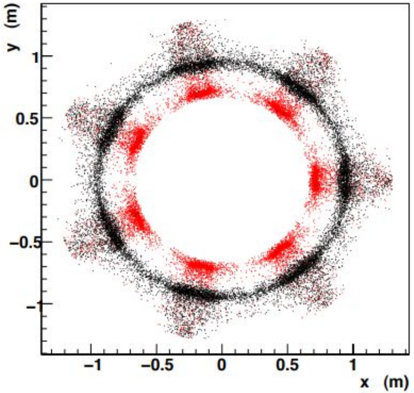




Projected radial coordinate of scattered Møller electron trajectories. Colors represent $\theta_{lab}$ (rad). The spectrometer coils (grey) and collimators (black) are overlaid.

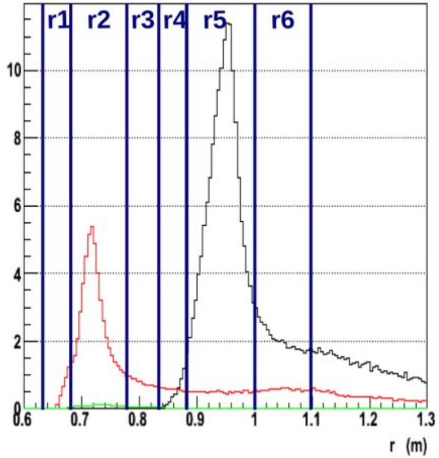
# Main Integrating Detector



The scattered electrons will be intercepted, after they exit the vacuum, by a set of thin quartz plates arranged radially.




Transverse distribution of Møller (black) and ep (red) electrons 28.5 m downstream of target




Radial distribution of Møller (black) and ep (red) electrons 28.5 m downstream of target. Green points are the ep inelastic electrons.

# Possibility for New Physics

- Comparison of a precise measurement of $A_{PV}$ with the standard model prediction can provide a sensitive probe of “new physics”.
- It requires, of course, a “new physics” contribution to the parity violating ee → ee amplitude.