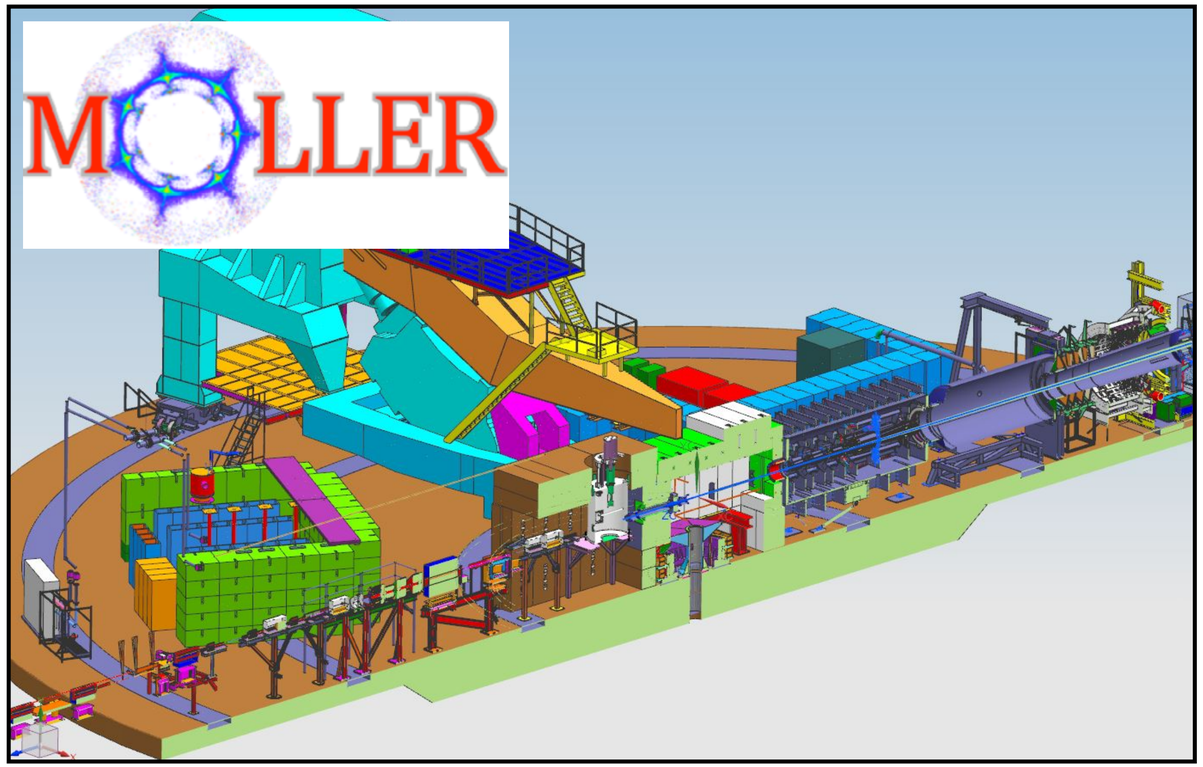
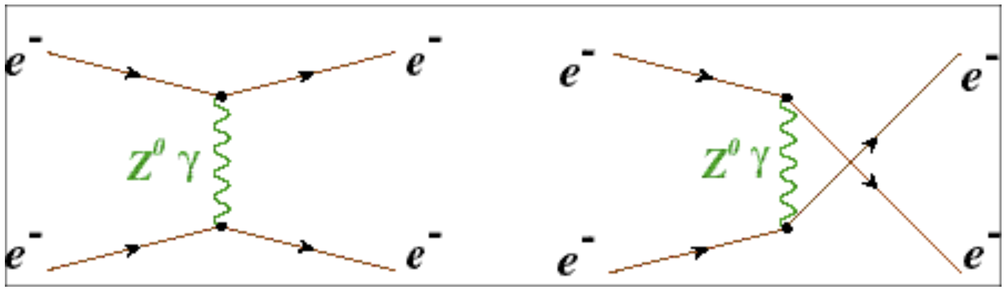
MOLLER Overview



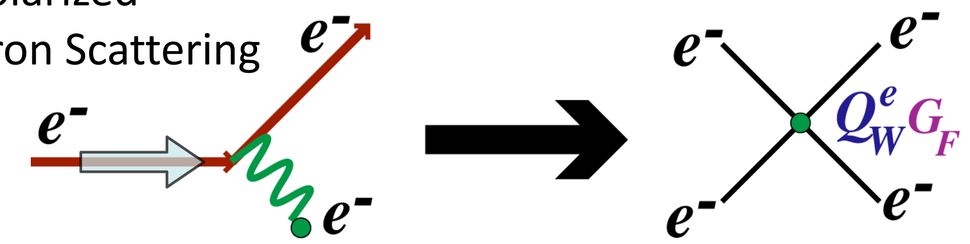
Kent Paschke
University of Virginia

August 1, 2025

The Observable: PV Asymmetry in Møller Scattering



Fixed Target Polarized
Electron-Electron Scattering



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

$$= -mE \frac{G_F}{\sqrt{2}\pi\alpha} \frac{16 \sin^2 \Theta}{(3 + \cos^2 \Theta)^2} Q^e_W$$

COM Scattering Angle

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

The Weak Charge of the Electron

$\delta(Q^e_W) = \pm 2.1\ \%\ (stat.) \pm 1.1\ \%\ (syst.)$

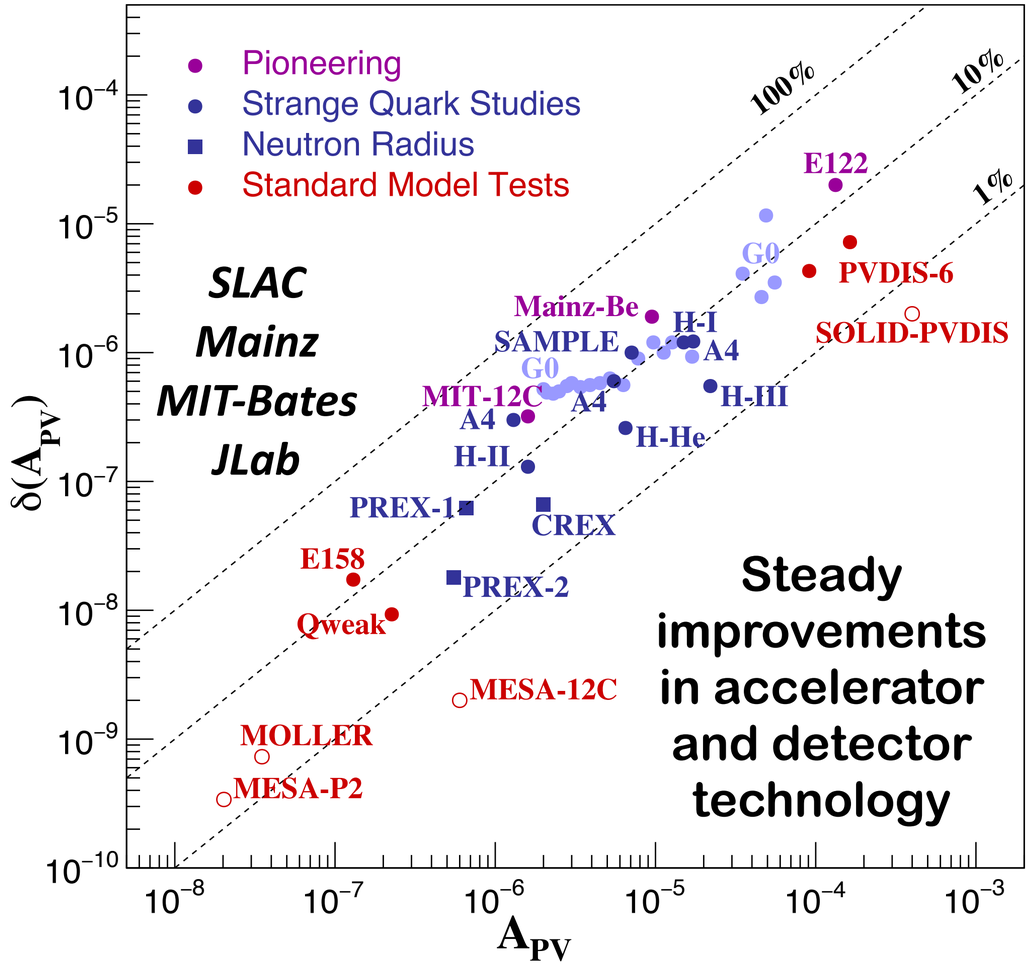
Jefferson Lab polarized electron beam

11 GeV, 65 μA 90% beam polarization

$A_{PV} \sim 32$ ppb $\delta(A_{PV}) \sim 0.8$ ppb

- **Unique sensitivity to TeV scale physics coupling more to leptons than to quarks**
- **Purely leptonic low Q^2 reaction: theory prediction accurately calculable with negligible hadronic physics uncertainty**

4th Generation Parity-Violating Electron Scattering Experiment at JLab



State of the Art

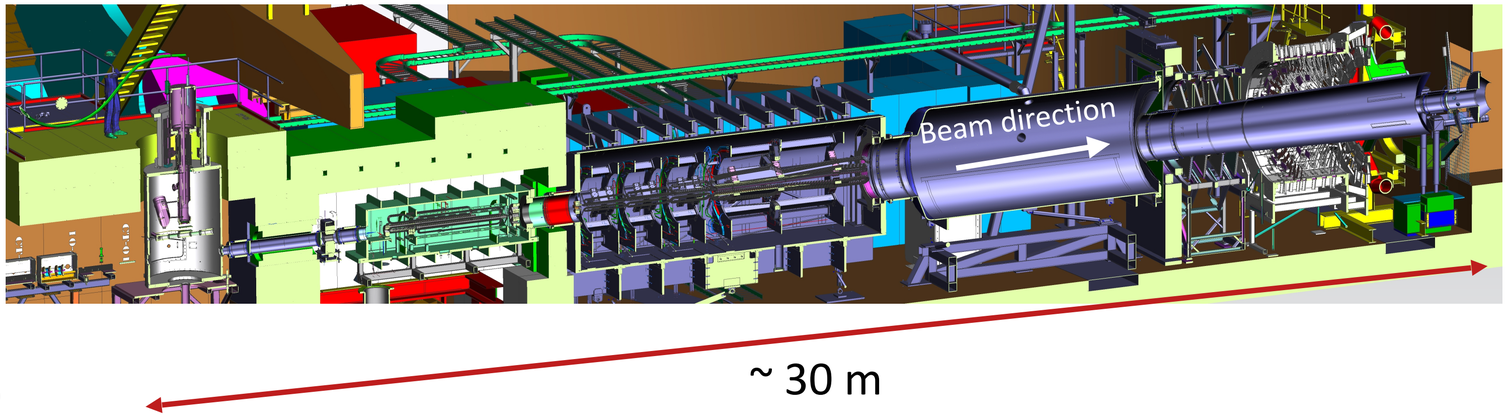
- **sub-part per billion statistical reach and systematic control**
- **sub-1% normalization control**

Unique opportunity leveraging 12 GeV Upgrade investment

Variety of Physics Topics:

continuous interplay between hadron physics and electroweak physics

MOLLER: *Special purpose installation in Hall A*



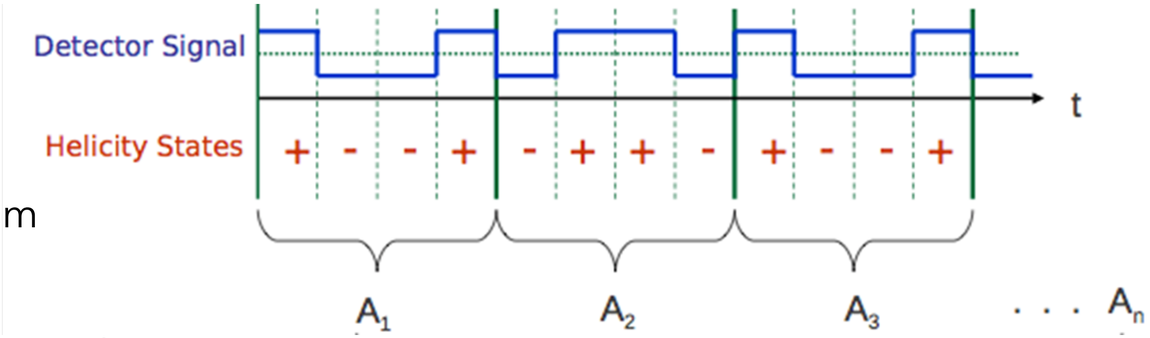
High Precision Measurement

Precise measurement of parity-violation in electron-electron scattering to search for new physics

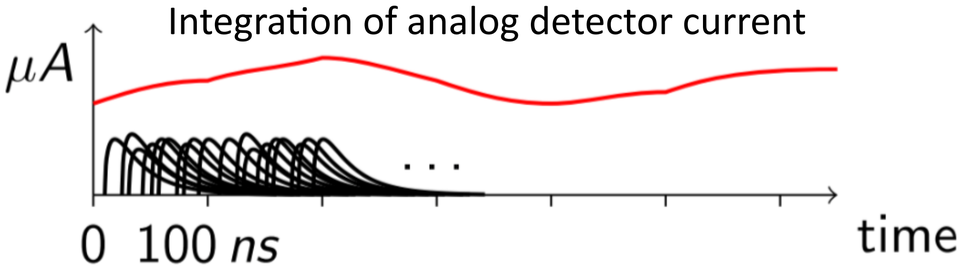
Difference in cross-section in scattering of left-handed vs right-handed electrons

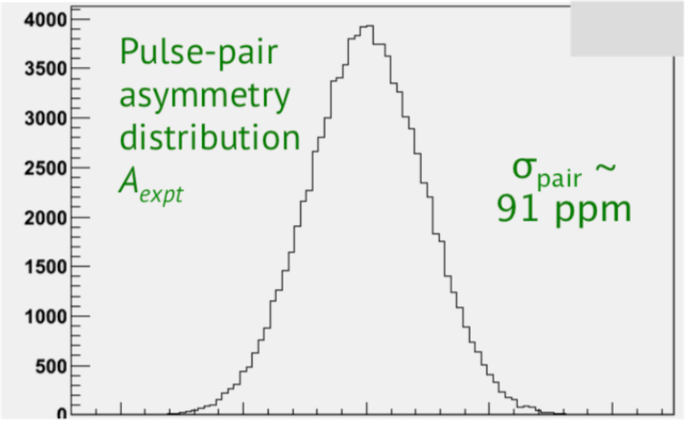
$$\mathbf{A_{PV}} = \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L}$$

Rapid (1kHz) measurement over helicity reversals to cancel noise



- Asymmetry measurements at 960Hz, each with precision 91 ppm
- Requires ~130 GHz signal rate
- magnetic spectrometer to spatially separate signal from background
- collect scattered particles in range 0.3° – 1.1°, 2.5 GeV - 8 GeV
- high luminosity (65uA, 1.25m LH2 target)

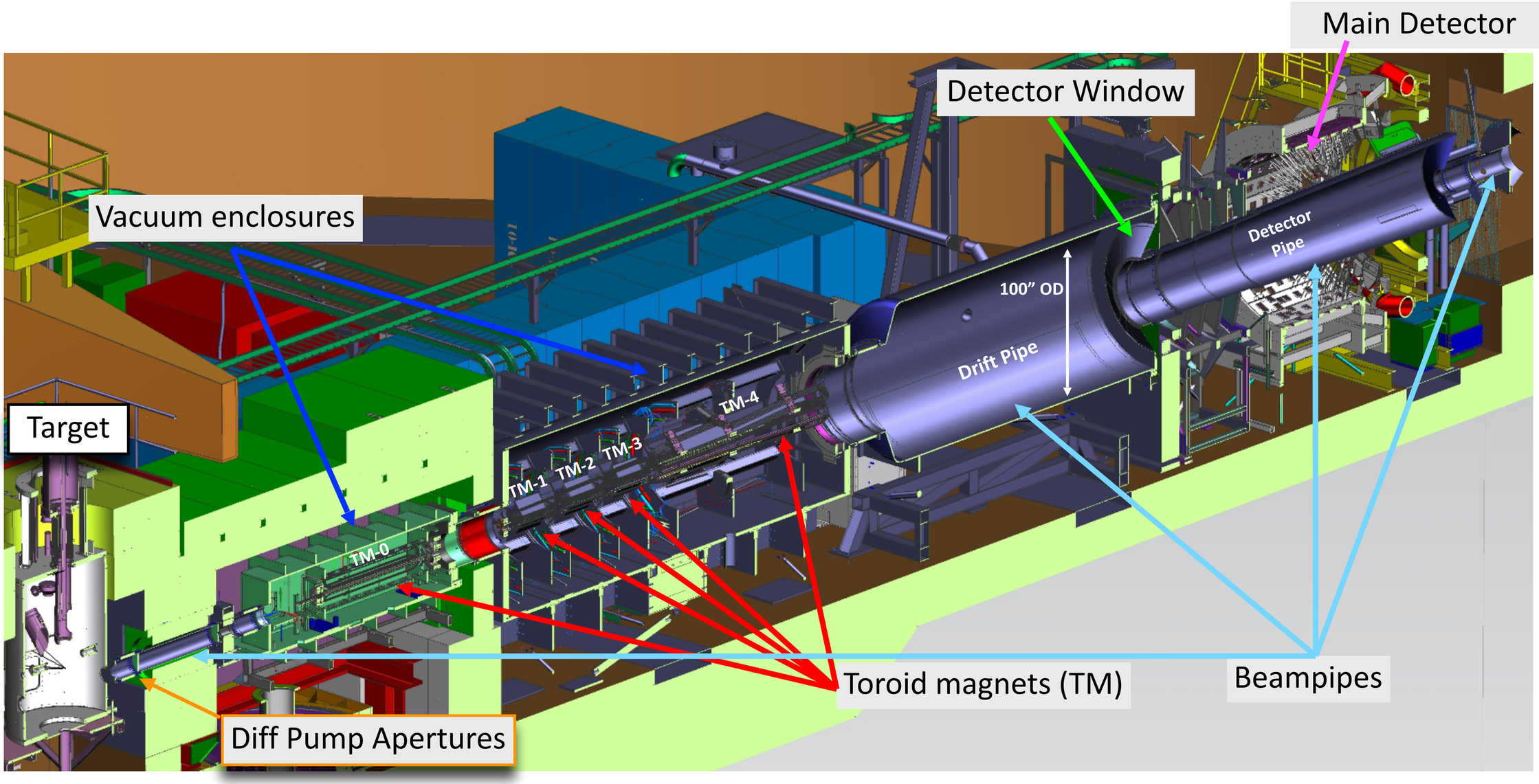




$$\sigma_{A_{cxpt}} = \frac{\sigma_{pair}}{\sqrt{N_{pair}}} = \frac{91\,\text{ppm}}{\sqrt{30\times10^9}} = 0.5\,\text{ppb}$$

Pulse-pair "width" σ_{pair} is the parameter that determines the statistical error

MOLLER Apparatus Overview



target: 5 m upstream of hall pivot, apparatus > 30 m

Getting to high precision

0.5 ppb error bar requires strict control of noise and systematic errors (false asymmetries)

Target

- high power - ~3kW beam power for high luminosity
- stability - density fluctuation will introduce noise (<30 ppm at 960Hz comparison)
- average density loss: could introduce non-linearity with beam current (<1% at 65uA)
- all ferromagnetic components must be qualified
- Thin Aluminum windows
- Alignment

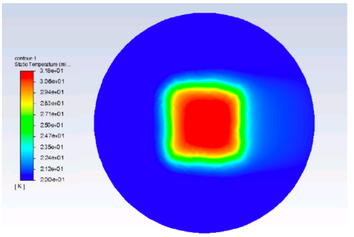
Parameter	Random Noise (65 μA)
Statistical width (0.5 ms)	$\sim$ **82 ppm**
Target Density Fluctuation	30 ppm
Beam Intensity Resolution	10 ppm
Beam Position Noise	7 ppm
Detector Resolution (25%)	21 ppm (3.1%)
Electronics noise	10 ppm
Measured Width (σ_{pair})	**91 ppm**

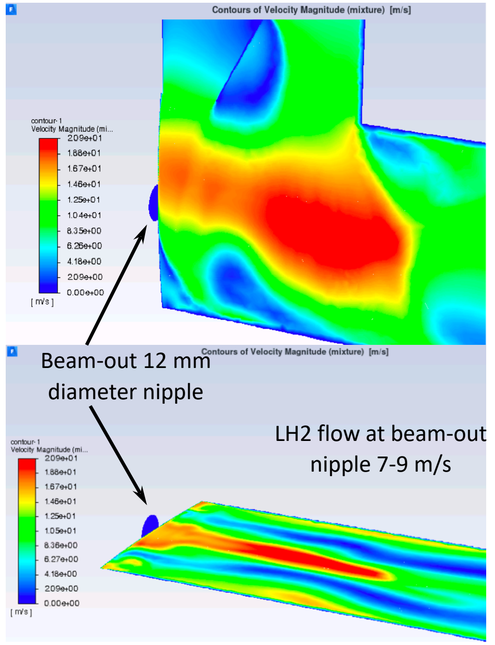
Error Source	Fractional Error (%)	
	Run 1	Ultimate
Statistical	**11.4**	**2.1**
Absolute Norm. of the Kinematic Factor	3	0.5
Beam (second moment)	2	0.4
Beam polarization	1	0.4
$e + p(+\gamma) \rightarrow e + X(+\gamma)$	2	0.4
Beam (position, angle, energy)	2	0.4
Beam (intensity)	1	0.3
$e + p(+\gamma) \rightarrow e + p(+\gamma)$	0.6	0.3
$\gamma^{(*)} + p \rightarrow (\pi, \mu, K) + X$	1.5	0.3
$e + Al(+\gamma) \rightarrow e + Al(+\gamma)$	0.3	0.15
Transverse polarization	2	0.2
Neutral background (soft photons, neutrons)	0.5	0.1
Linearity	0.1	0.1
Total systematic	**5.5**	**1.1**

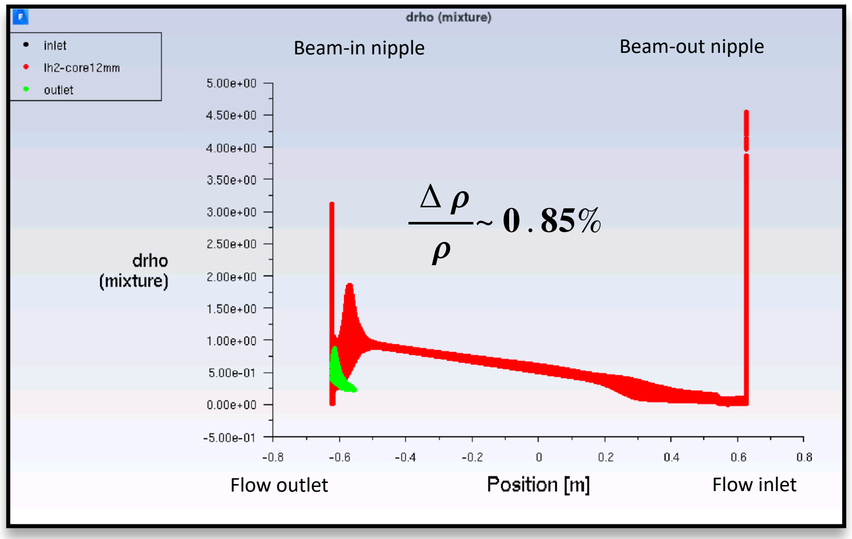
Achieving Specification

- Design informed by Qweak experience
- CFD simulations (S. Covrig Dusa)
- Jet at each window to cool dominant heat surface
- Qweak data shows noise dominated by lower frequencies, results reproduced in time-dependent CFD simulations
- CFD demonstrates design meets requirements

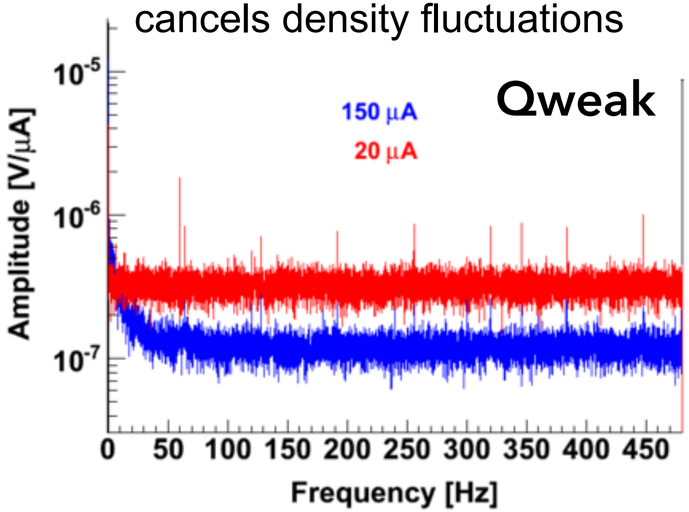
4x4 mm² raster area







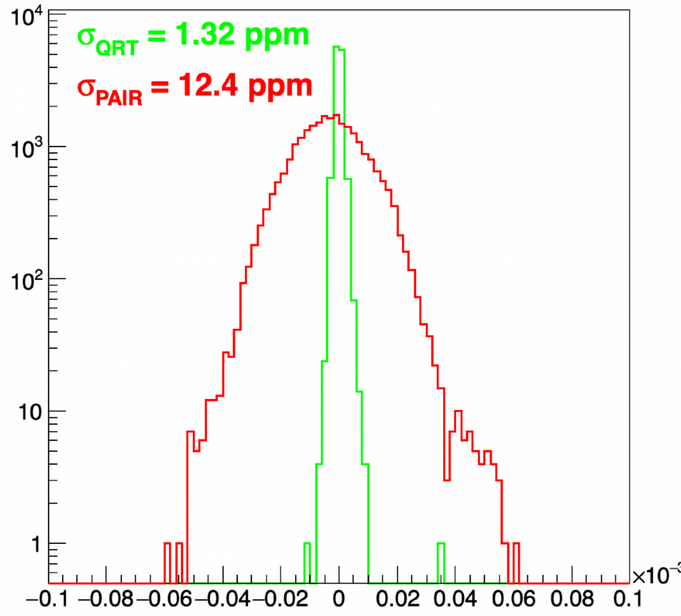
Fast helicity reversal (1 ms) cancels density fluctuations



Requirements:
- $\Delta\rho/\rho$ (%) < 1%
- σ_b < 30 ppm

CFD simulation result:
- $\Delta\rho/\rho$ (%) ~ 0.85%
- σ_b < 13 ppm

LH2 density asymmetry at 1920 Hz



Summary

- MOLLER is a high precision electroweak measurement with unique sensitivity to new physics
- The experiment requires careful control of noise and systematic errors, including target density fluctuations, target density loss, and aluminum background
- Current target design has been evaulated in time dependent CFD calculation, is expected to meet physics requirements