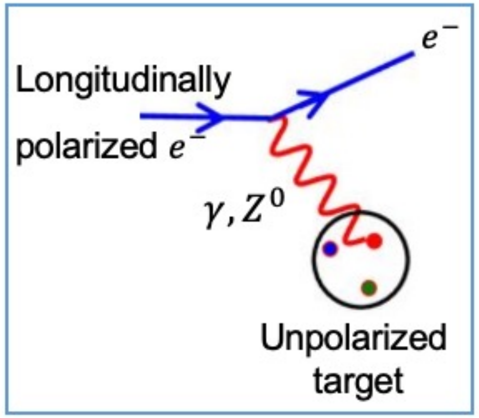
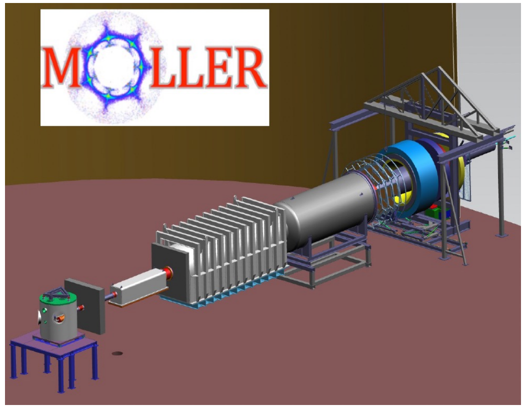
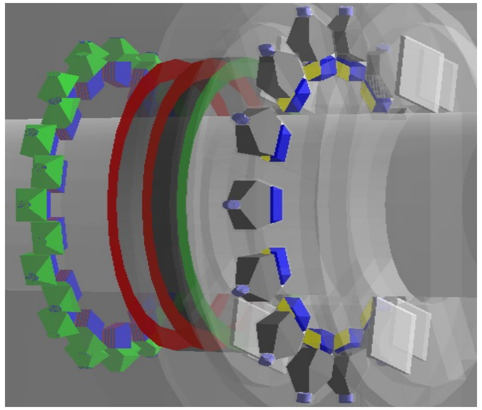
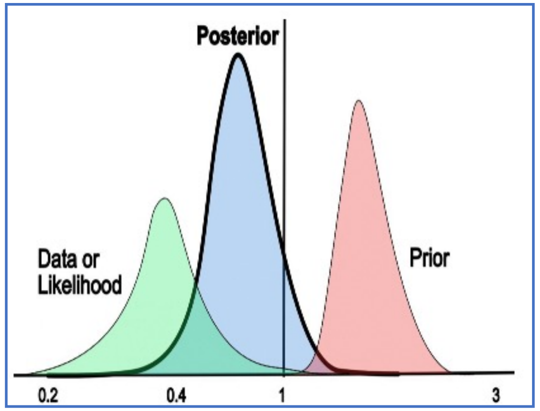
Contribution of the Pion's Parity-Violating Asymmetry in the MOLLER Experiment









Elham Gorgannejad

University of Manitoba

Department of Physics and Astronomy

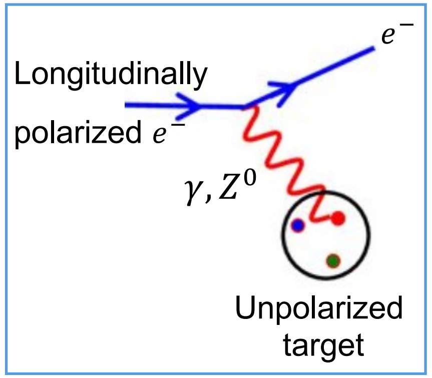
June 2022

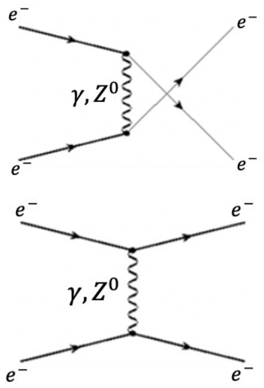
University of Manitoba

Canadian Association of Physicists

MOLLER

Parity violating electron scattering (PVES)





$$\sigma_{R(L)} = |A_\gamma + A_{Z^0}|^2 = |A_\gamma|^2 + 2|A_\gamma||A_{Z^0}| + |A_{Z^0}|^2$$

Interference of electromagnetic and weak neutral current amplitude

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

Helicity flipping to measure an asymmetry in MOLLER

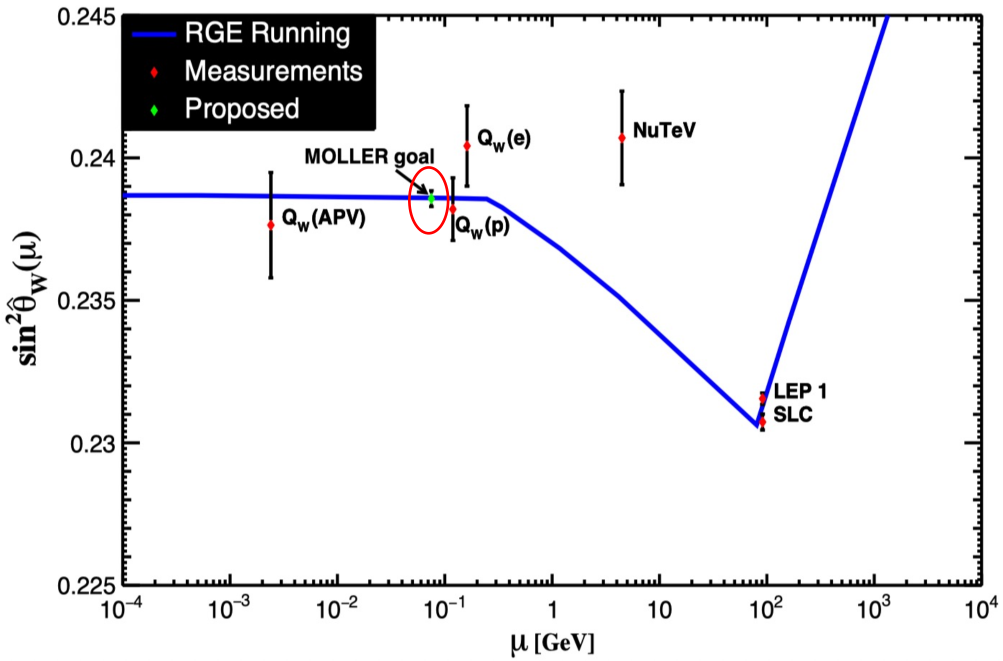
$$A_{PV} \propto Q_W^e = 1 - 4\sin^2\theta_W$$

weak charge of electron

weak mixing angle

Comparison of the weak mixing angle in terms of energy scale for some A_{PV} experiments

Reprinted from P. A. Zyla and the Particle Data Group



$Q_W(APV)$: Atomic parity violation
$Q_W(p)$: Qweak experiment
$Q_W(e)$: SLAC E-158
NuTev: Neutrino-Nucleon Scattering experiment
LEP+SLC: Z^0 pole asymmetries

MOLLER Apv would be the first low Q^2 measurement comparable to the single best measurement at Z^0-pole

MOLLER experiment at Jlab

Measurement Of a Lepton Lepton Electroweak Reaction (MOLLER)

The experiment will take place at Hall A at Thomas Jefferson National Accelerator Facility (JLab) in Newport News, Virginia (USA)

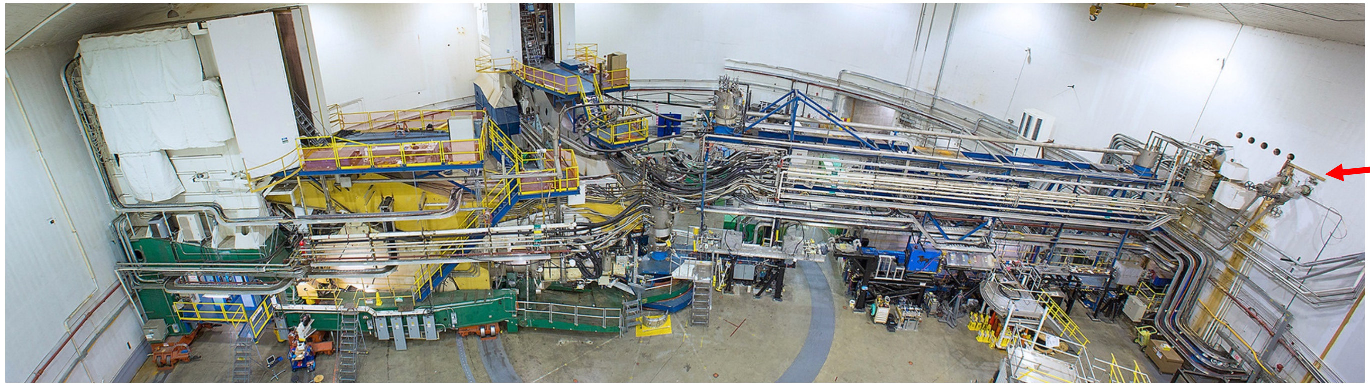
Collaboration:

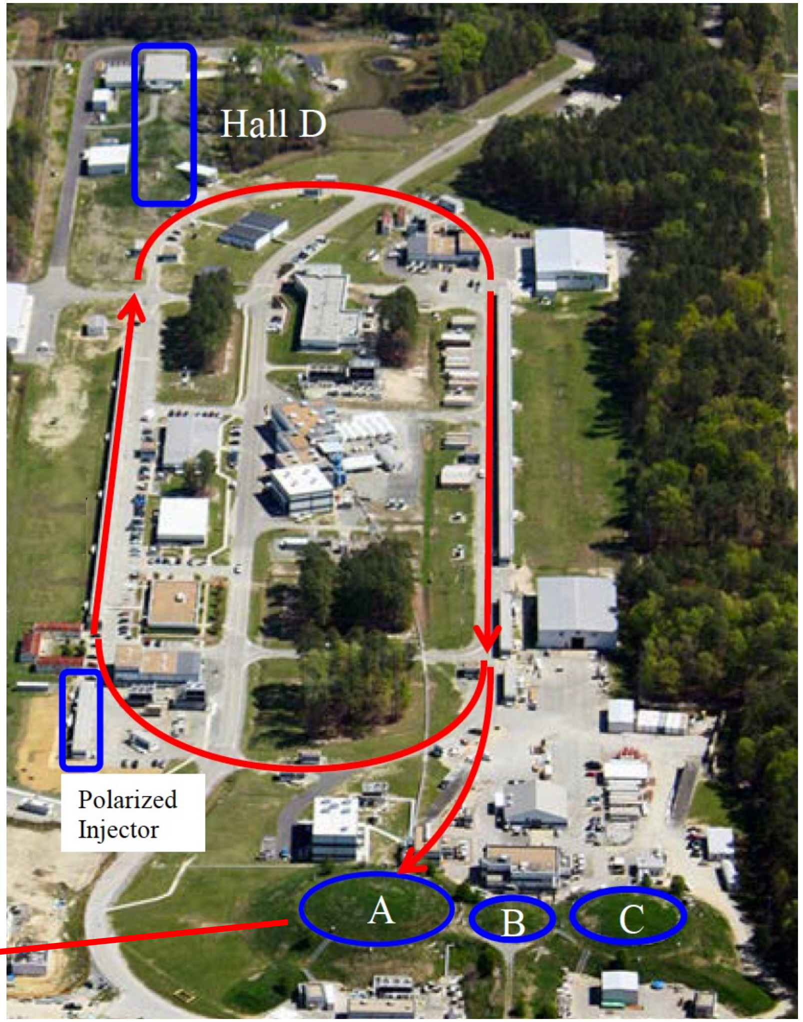
- ~ 120 authors,
- 30 institutions,
- 5 countries
- Currently in the design phase
- Physics run 2025-2027

MOLLER kinematics:

- Energy beam: 11 GeV
- Average Q^2: 0.0056 GeV^2
- Polarization: ~90%
- Beam Current: 65 (μA)
- Precision Goal: 0.7 ppb on A_{PV},

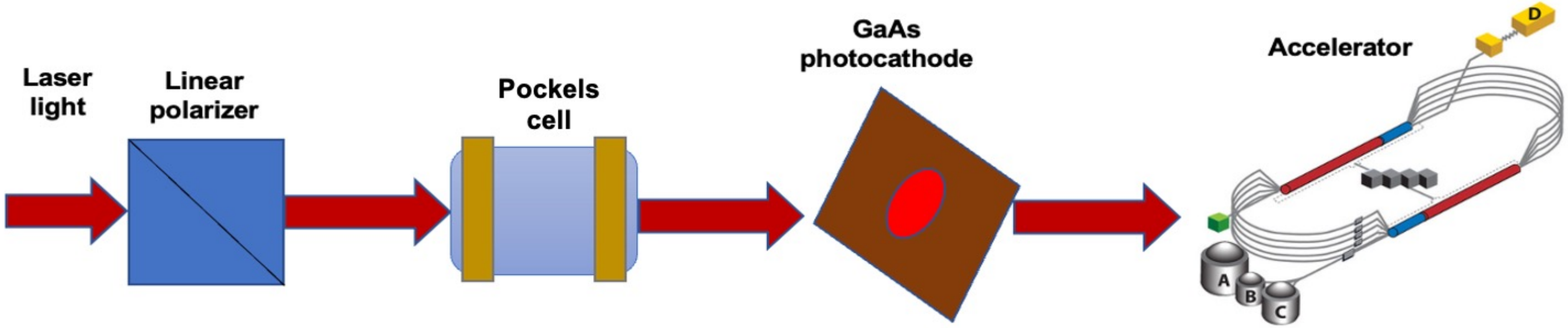
2.4% on electron weak charge

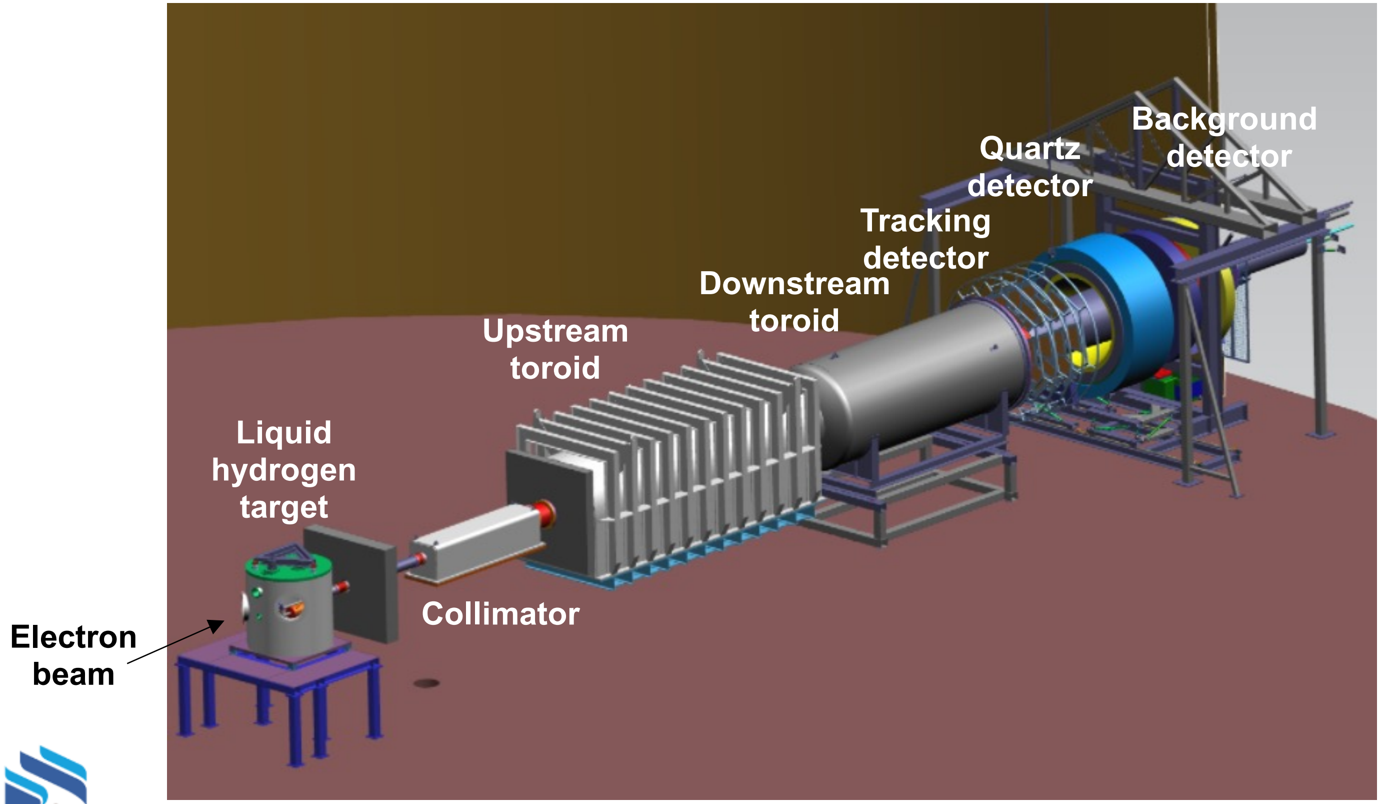




Thomas Jefferson National Accelerator Facility (JLab)

MOLLER experiment: Conceptual Design Overview





- 11 GeV, 90% polarized, 65 µA electron beam
- 125 cm long, 4 kW LH2 target
- Precision collimation
- Novel two toroid spectrometer
- Tracking detectors for background measurements
- Integrating detectors for asymmetry measurements
- Background detectors for background measurements

MOLLER experiment: Detector Overview

✓ **Tracking (counting mode) detectors:**

calibration

measure electron scattering angle

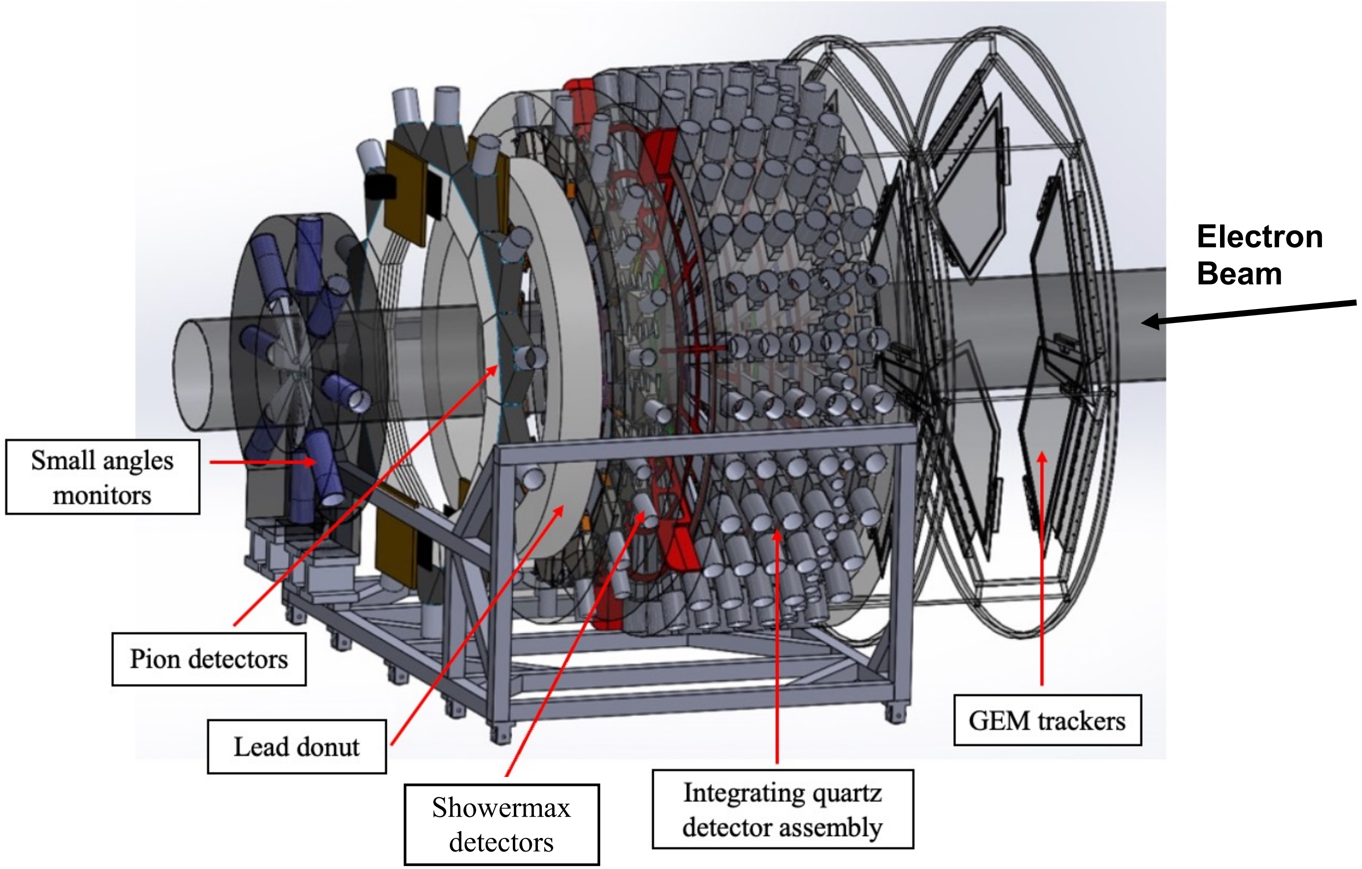
distribution, and background

✓ **Integrating (current mode) detectors:**

measure the asymmetry of both

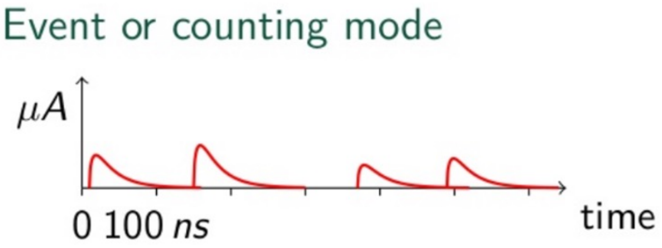
signal and background

beam and target monitoring



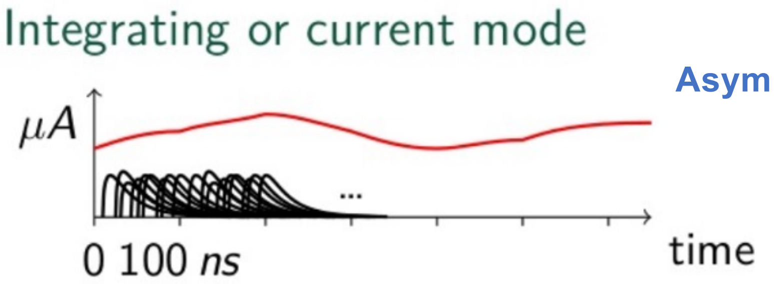
MOLLER experiment: Data acquisition

- ✓ Event data taking mode:



Background measurements (f_i^{bkgd}) →

- ✓ Integrating data taking mode :



Asymmetry measurements (A_{expt}, , A_i^{bkgd}) →

$$A_{PV} = R_{tot} \frac{\frac{A_{expt}}{P_b} - \sum_i f_i^{bkgd} A_i^{bkgd}}{1 - \sum_i f_i^{bkgd}}$$

R_{tot}: overall normalization factor,

P_b: beam polarization

A_{expt}: experimentally measured asymmetry

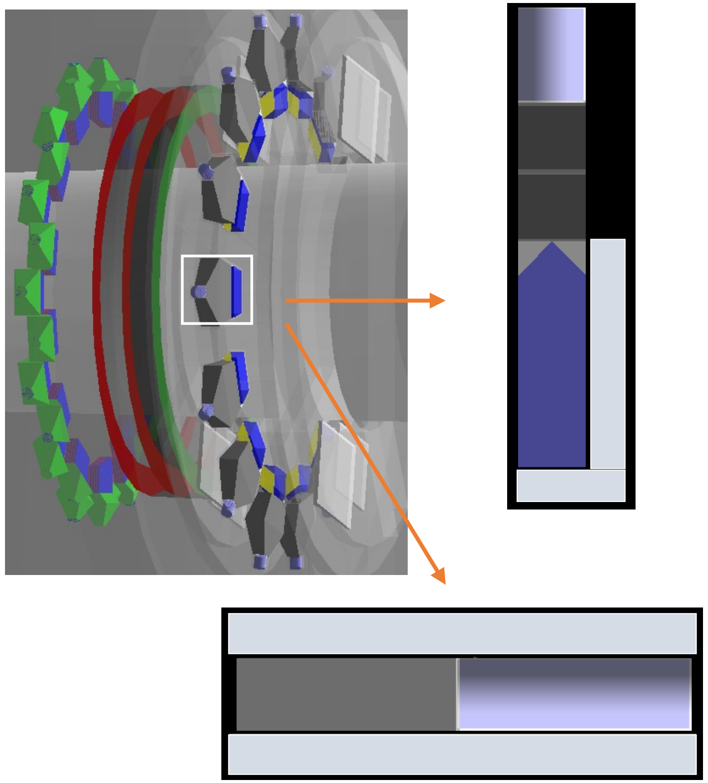
f_i^{bkgd}: fractional dilution factors

A_i^{bkgd}: asymmetries

MOLLER experiment: Objective of the Pion Detector

- Correction of A_{expt} for pion background $f^{\pi}A^{\pi}$

Suppress the Møller electrons by more than a factor of 10^3



2020 improvement:

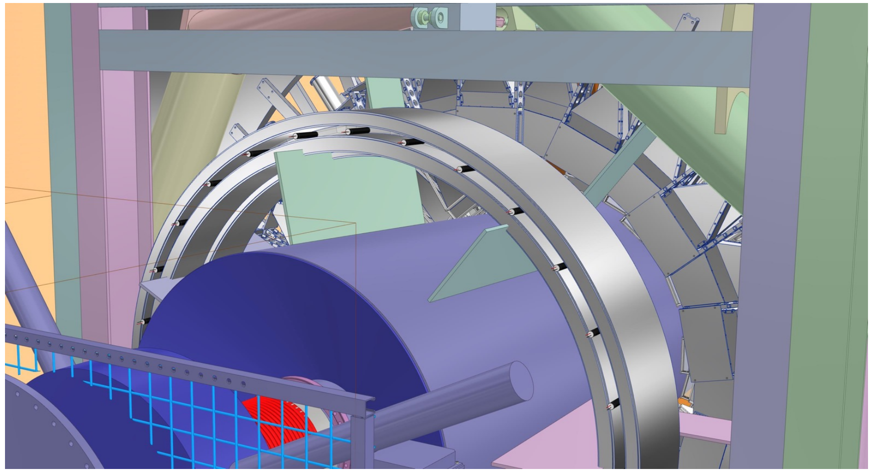
- Optimize geometry
- Reduce Lucite thickness
- Shielding

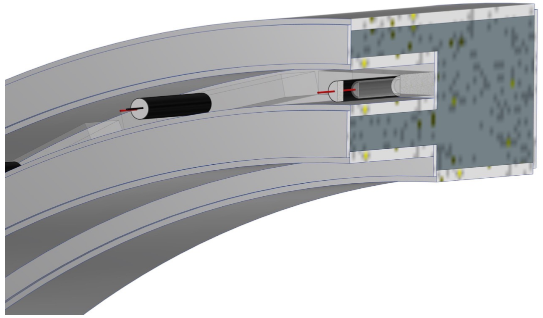
2021 improvement:

- Rotate detector 90 degrees
- Read out Lucite with directly-coupled PMT (no lightguide)
- Optimize optical design of Lucite

Results:

π/e photo-electron ratio:
0.1% ⇨ > 50% (meets design goal)



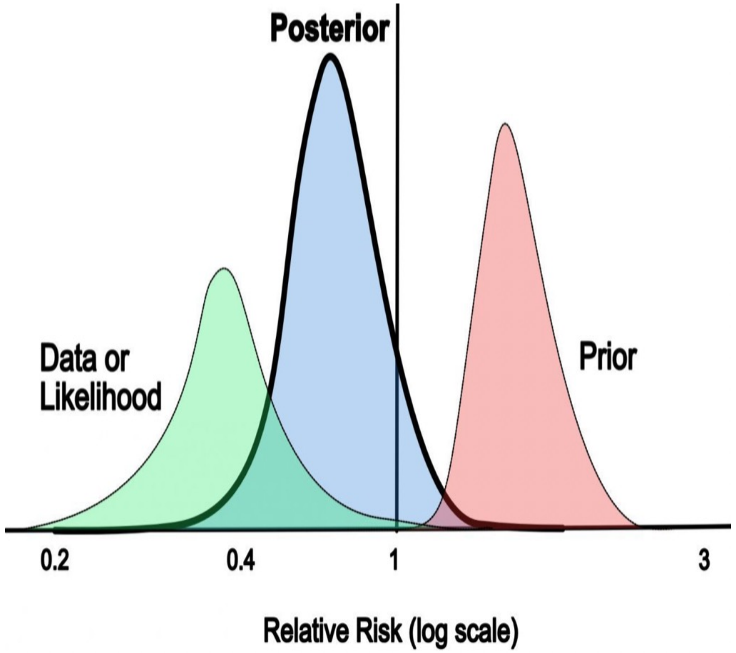


Final design (2022)

- Integrating pion detector with Pb donut
- 28 segments instead of 14
- One PMT/segment
- Maintain rectangular shape for Lucite

Bayesian analysis

Bayes rule: $p(a|d,I) = \dfrac{p(d|a,I)\,p(a|I)}{p(d|I)}$



- ✓ Infer the parameters **a** of a model M, based on data **d**
- ✓ Use Bayes rule, which gives the posterior: p(**a**|**d**,M,I) ∝ p(**d**|**a**,M,I) p(**a**|M,I).

Model:

Priors

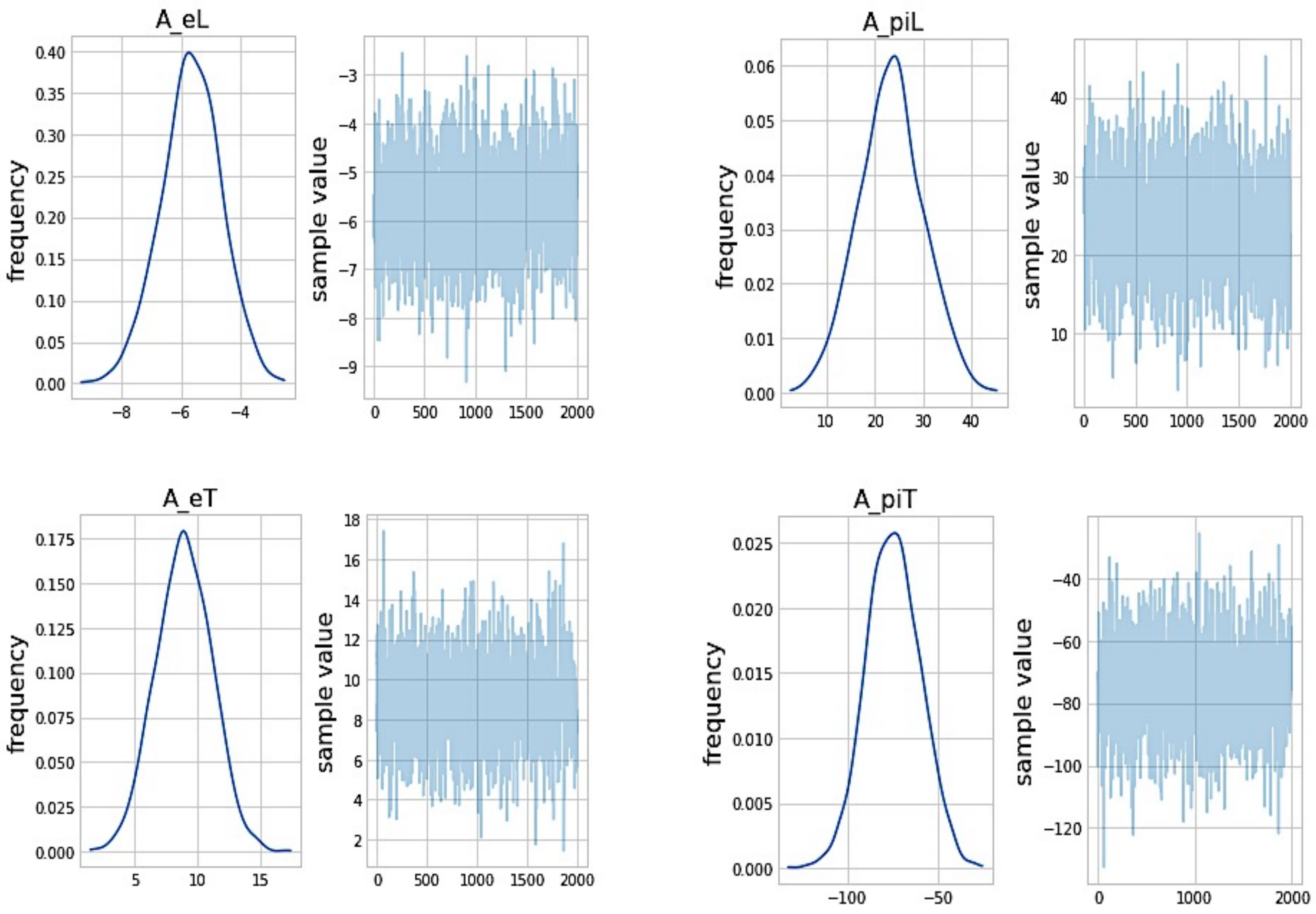
$$A^{ij}_{calc} = (1 - f^i_{NB})\left[(1 - f^i_\pi)(A^L_e \cos\theta^j_P + A^T_e \cos\theta^j_P \sin\phi^i) + f^i_\pi(A^L_\pi \cos\theta^j_P + A^T_\pi \cos\theta^j_P \sin\phi^i)\right]$$

Input:
$\mathbf{f^i_{bkgd}}$
θ
ϕ

→

Output:
A_{calc}
Updated priors

Component asymmetry distributions



- Generating data points
- Normal distribution about the mean and standard deviation
- Obtain samples from the distribution
- Test different priors
- Using Pystan
- Looping over parameters
- Calculating likelihood
- Obtain Posterior

Conclusion & Acknowledgement

Conclusion

- High precision detector system in the MOLLER experiment
- Background corrections with background detectors
- Pion detector for pion correction ($f_\pi A_\pi$)
- Pion detector design has reached > 50% (in π/e p.e. ratio)
- Integrating pion detector with Pb donut

Team Members:

Dr. Wouter Deconinck (U. Manitoba)

Dr. David Armstrong (William & Mary)

Elham Gorgannejad (U. Manitoba)

Raj Seehra (U. Manitoba, undergrad)

Julia Cornejo (U. Manitoba, undergrad)

This project is funded by:

Natural Sciences and Engineering Research Council of Canada (NSERC)

Canada Foundations for Innovation (CFI)

National Science Foundation (NSF)

Canadian Institute of Nuclear Physics (CINP) graduate fellowship

NSERC CRSNG

INNOVATION Canada Foundation for Innovation Fondation canadienne pour l'innovation

NSF National Science Foundation

CINP ICPN

MOLLER