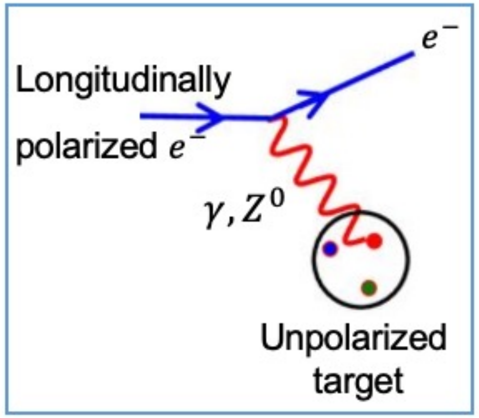
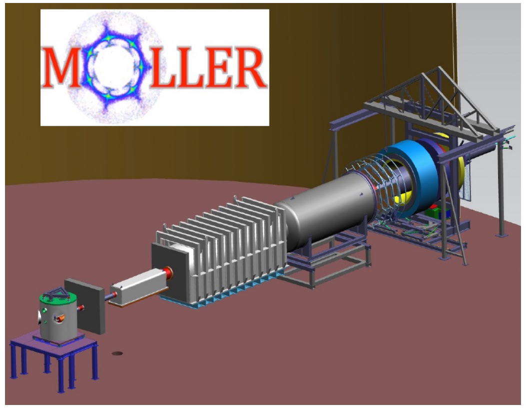
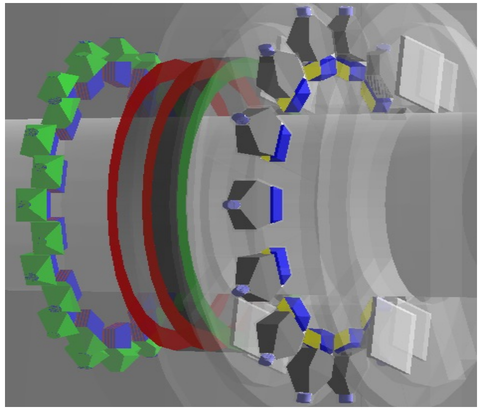
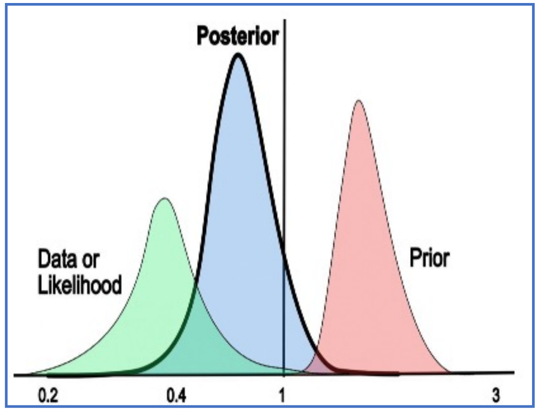
Contribution of the Pion's Parity-Violating Asymmetry in the MOLLER Experiment









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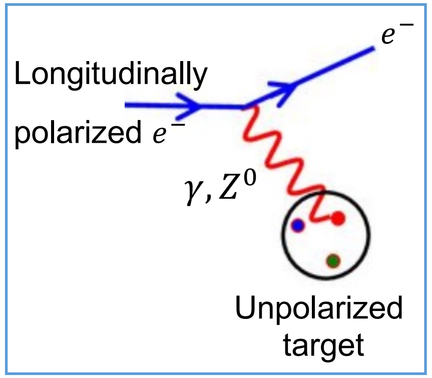
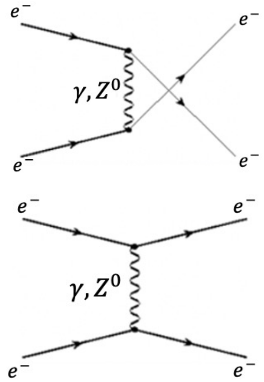
Canadian Association of Physicists

MOLLER

Parity violating electron scattering (PVES)





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

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

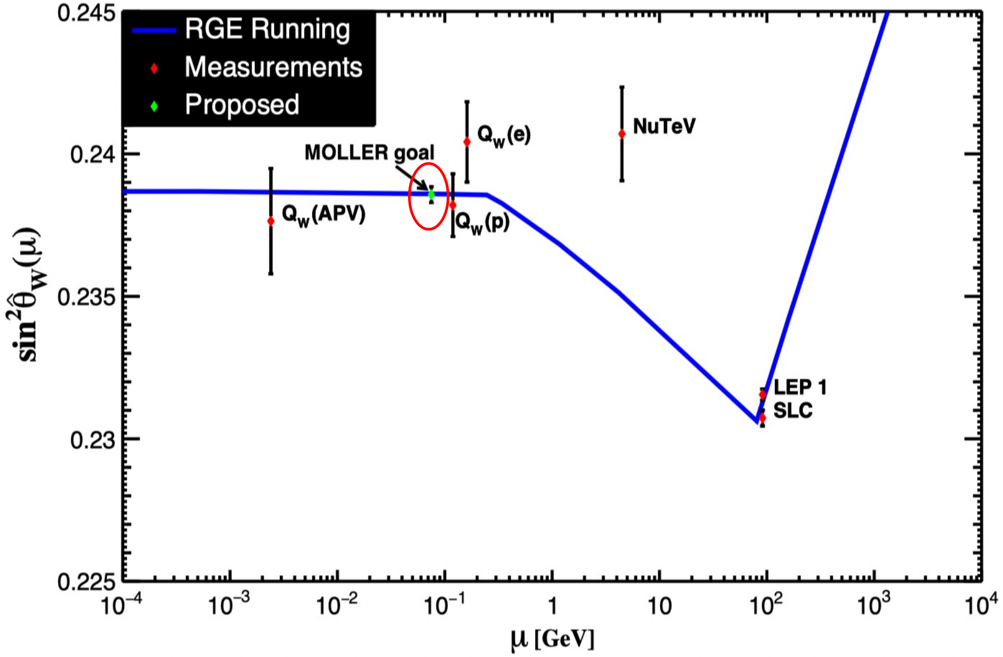
$$A_{PV} \propto Q_W^e = 1 - 4\sin^2\theta_W$$

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)

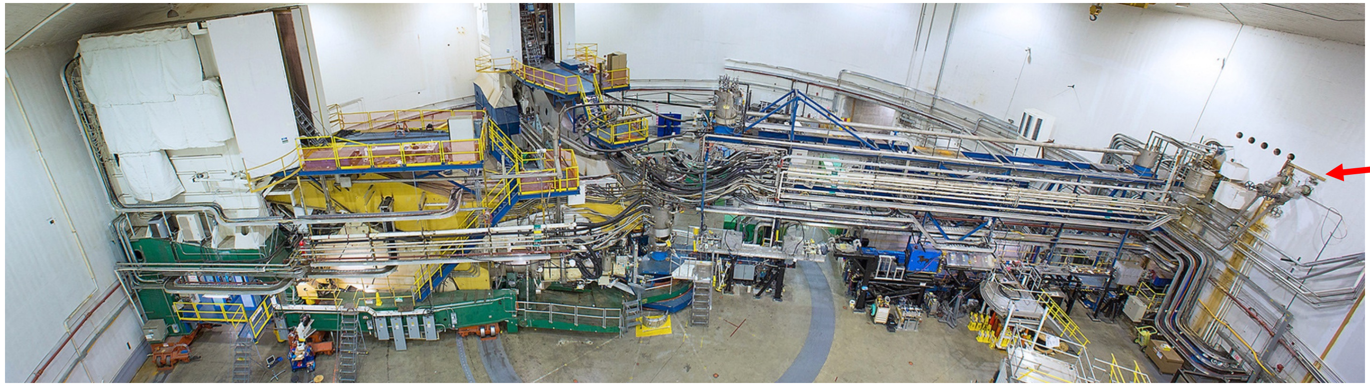
Collaboration:

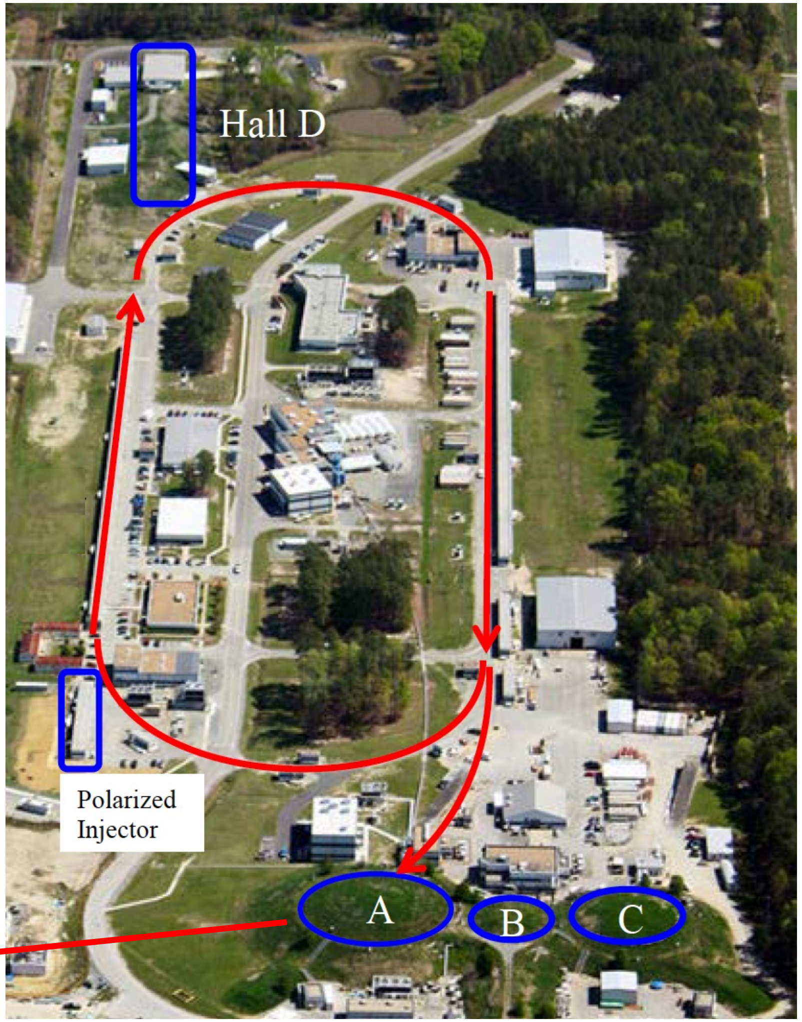
- ~ 120 authors,
- 30 institutions,
- 5 countries
- Currently in the design phase
- Physics run 2025-2027

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},

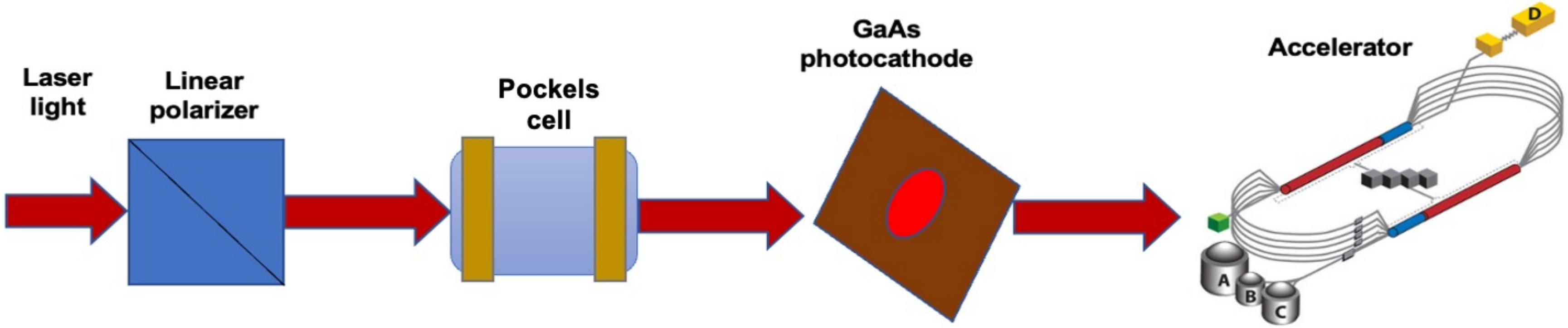
2.4% on electron weak charge

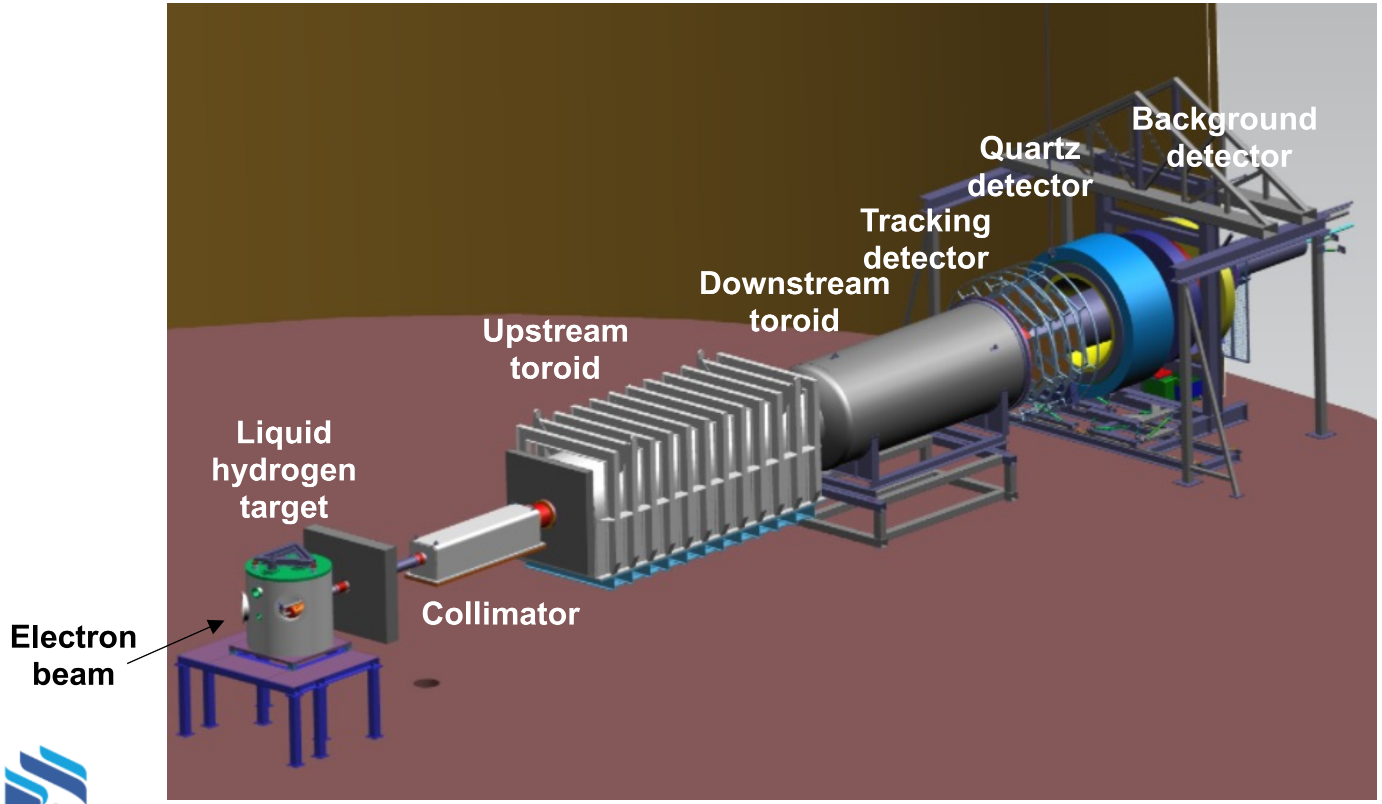




Thomas Jefferson National Accelerator Facility (JLab)

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:**

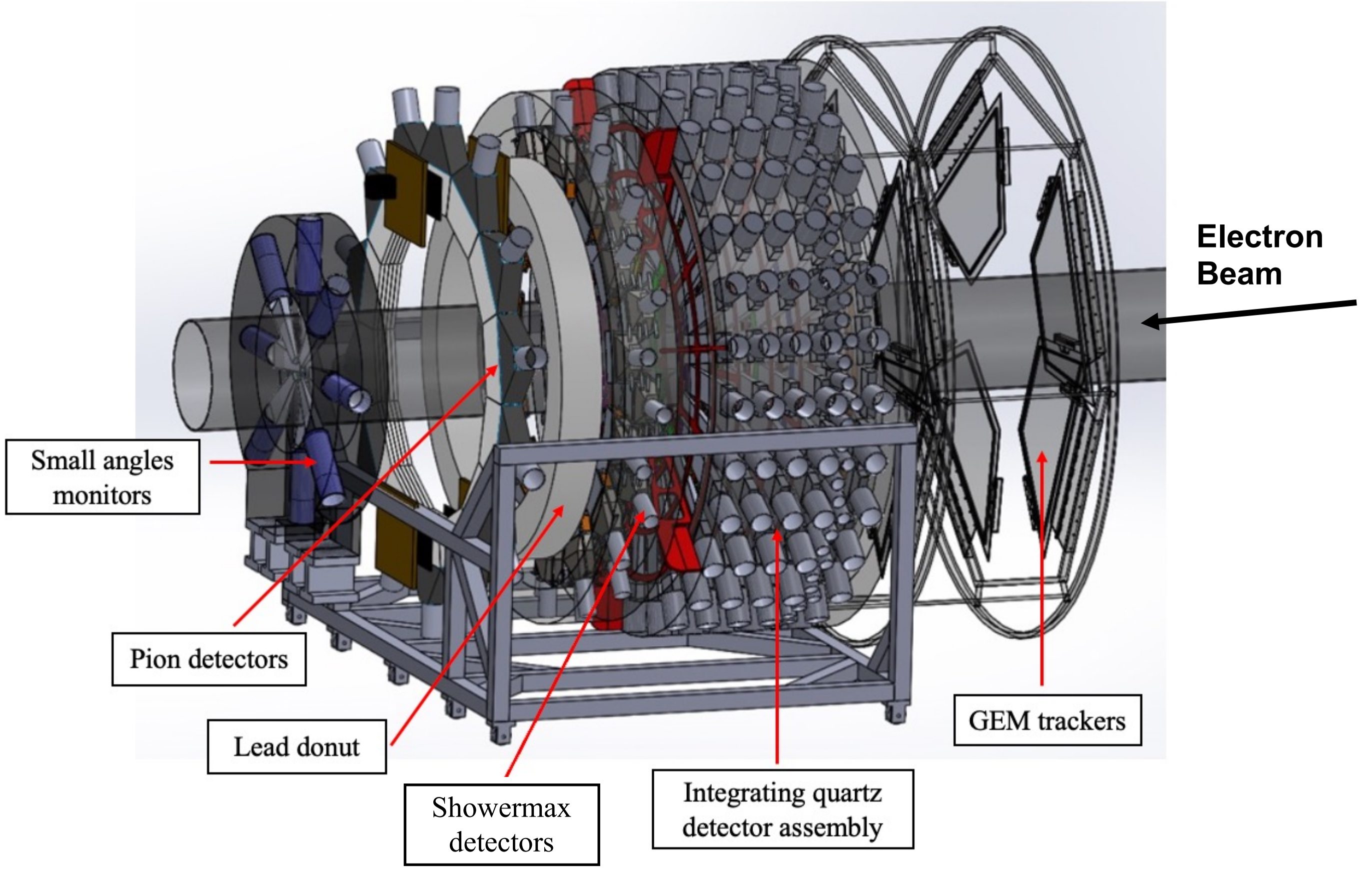
calibration

measure electron scattering angle distribution, and background

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

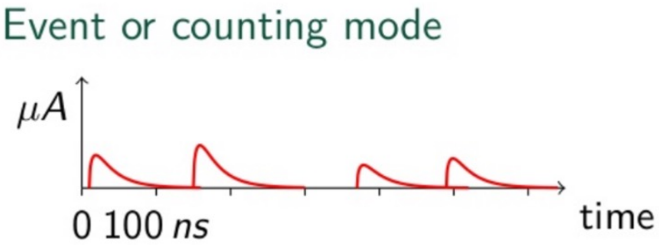
measure the asymmetry of both signal and background

beam and target monitoring



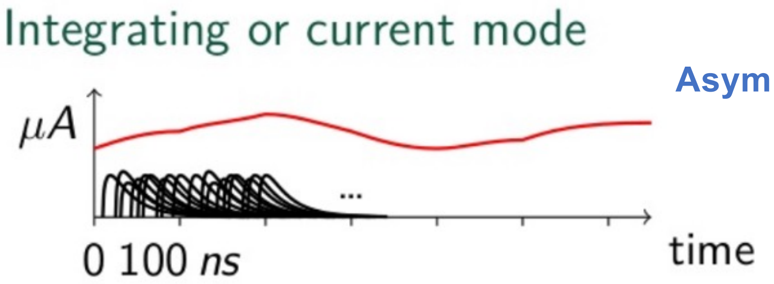
MOLLER experiment: Data acquisition

✓ 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

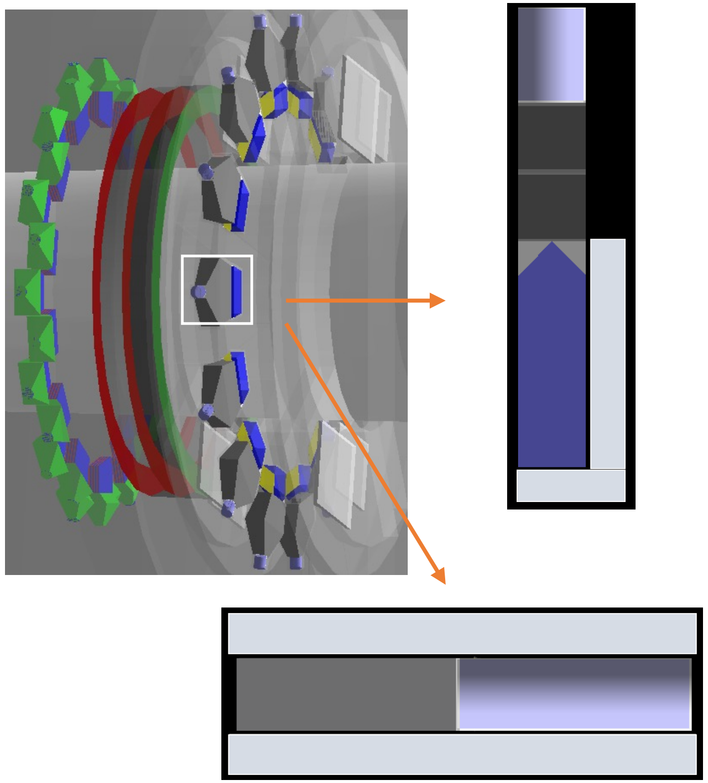
f_i^{bkgd}: fractional dilution factors

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:

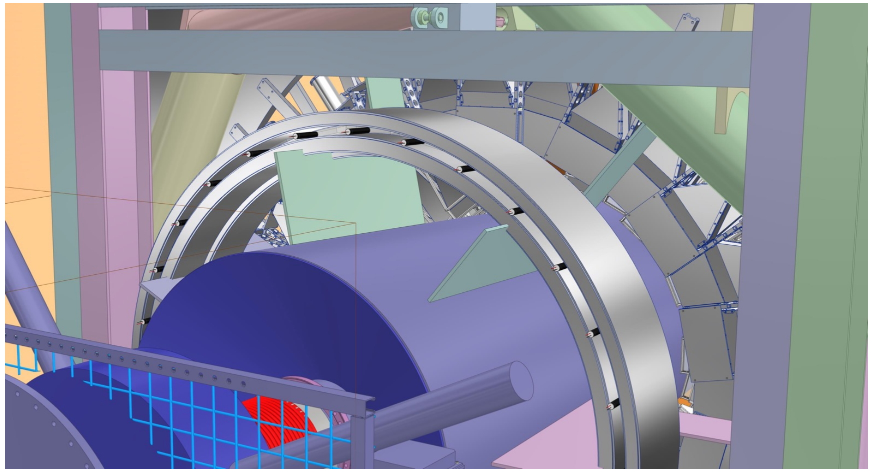
- Optimize geometry
- Reduce Lucite thickness
- Shielding

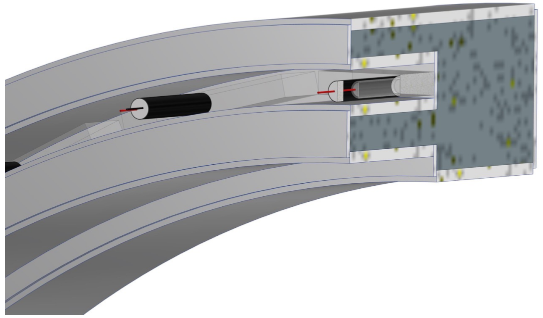
2021 improvement:

- 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)





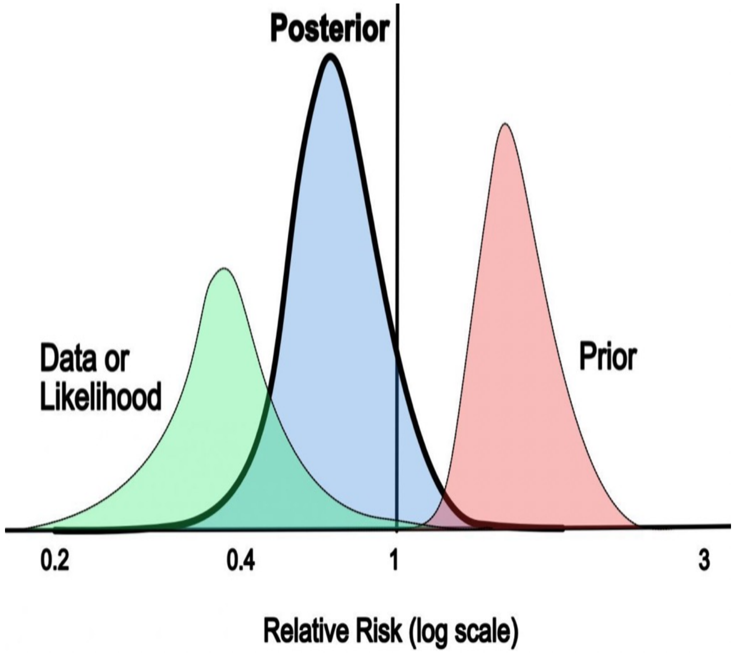
Final design (2022)

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

Bayesian analysis

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

- ✓ 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

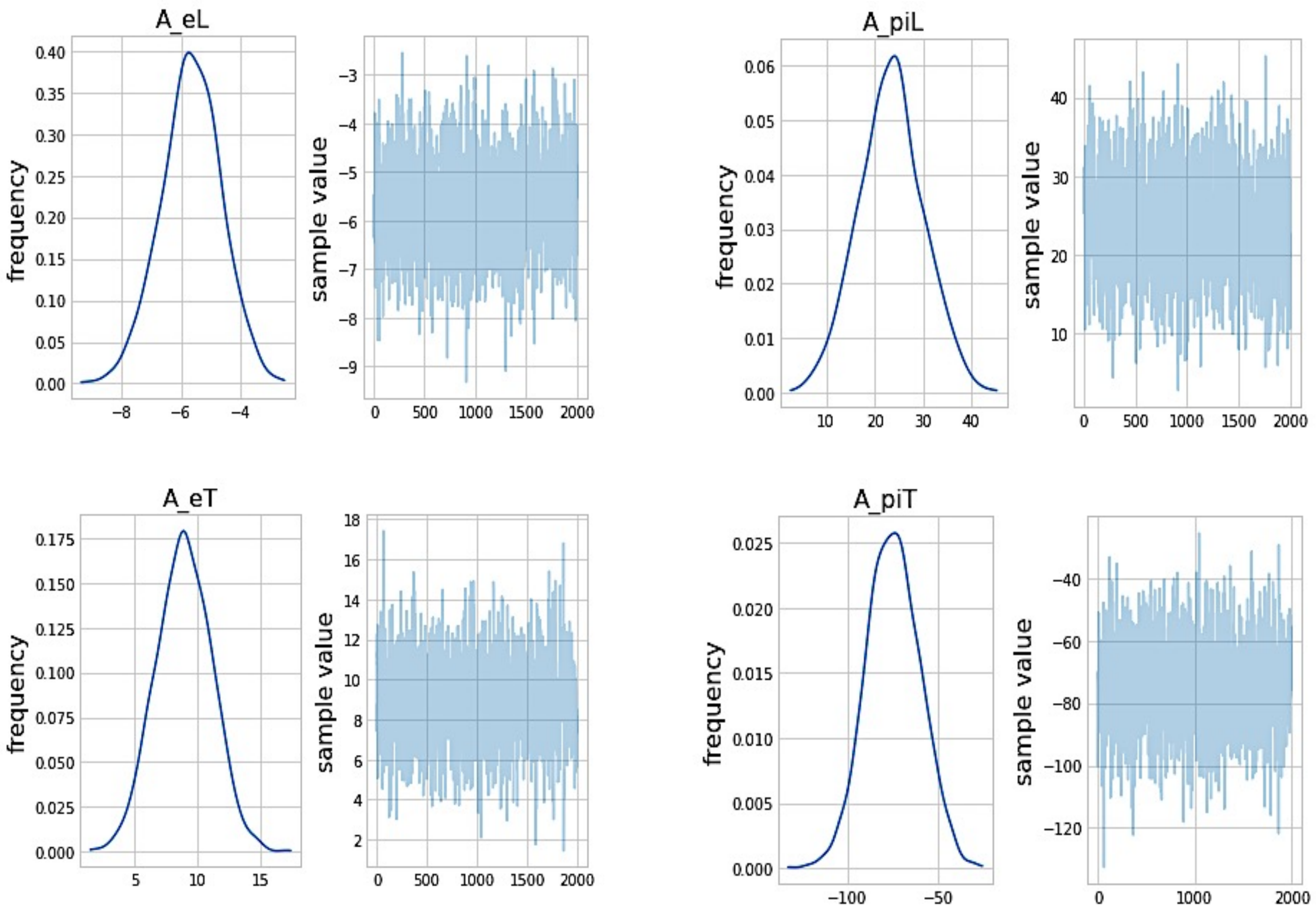
$$A^{ij}_{calc} = (1 - f^i_{NB})\left[(1 - f^i_\pi)(A^L_e \cos\theta^j_P + A^T_e \cos\theta^j_P \sin\phi^i) + f^i_\pi(A^L_\pi \cos\theta^j_P + A^T_\pi \cos\theta^j_P \sin\phi^i)\right]$$

Input:
$\mathbf{f^i_{bkgd}}$
θ
ϕ

Output:
A_{calc}
Updated priors

Bayesian analysis: Generating data based on model

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

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