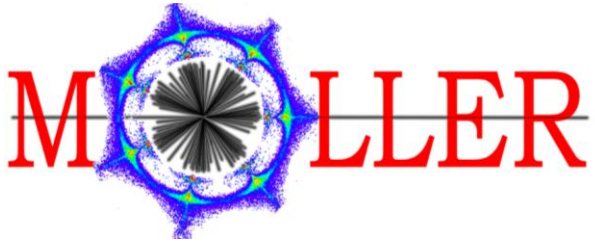
Overview of the



Experiment

Hall A Collaboration Winter Meeting

Ryan Conaway

Jan. 21, 2026

At a Glance

MOLLER =

Measurement

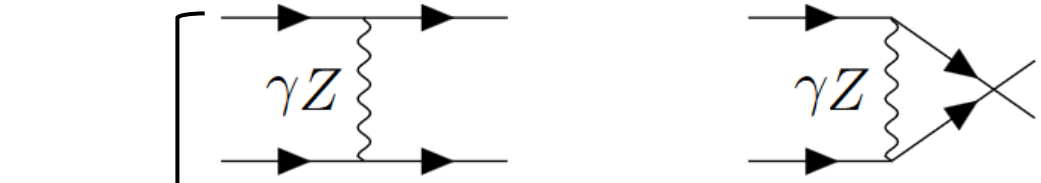
Of a

Lepton-

Lepton

Electroweak

Reaction



$$Q_{\mathrm{w}}^{\mathrm{e}} \begin{cases} A_{\mathrm{PV}} = \dfrac{\sigma_{\mathrm{R}} - \sigma_{\mathrm{L}}}{\sigma_{\mathrm{R}} + \sigma_{\mathrm{L}}} = 32\,\mathrm{ppb} \\ \qquad\qquad \langle Q^2 \rangle = 0.0058\,[\mathrm{GEV}] \\ \dfrac{\Delta(A_{\mathrm{PV}})}{A_{\mathrm{PV}}} = 2.4\% \end{cases}$$

Run Period	1 kHz Width	PAC Days (prod)	Stat Error σ (A_{meas})	Stat Error σ (A_{PV})	Calendar Weeks (prod)	Calendar Weeks (calib)
I	101	14	2.96 ppm	11.4%	5	6
II	96	95	1.08 ppm	4.2%	27	3
III	91	235	0.65 ppm	2.5%	56	4
Total		344	0.55	2.1	88	13

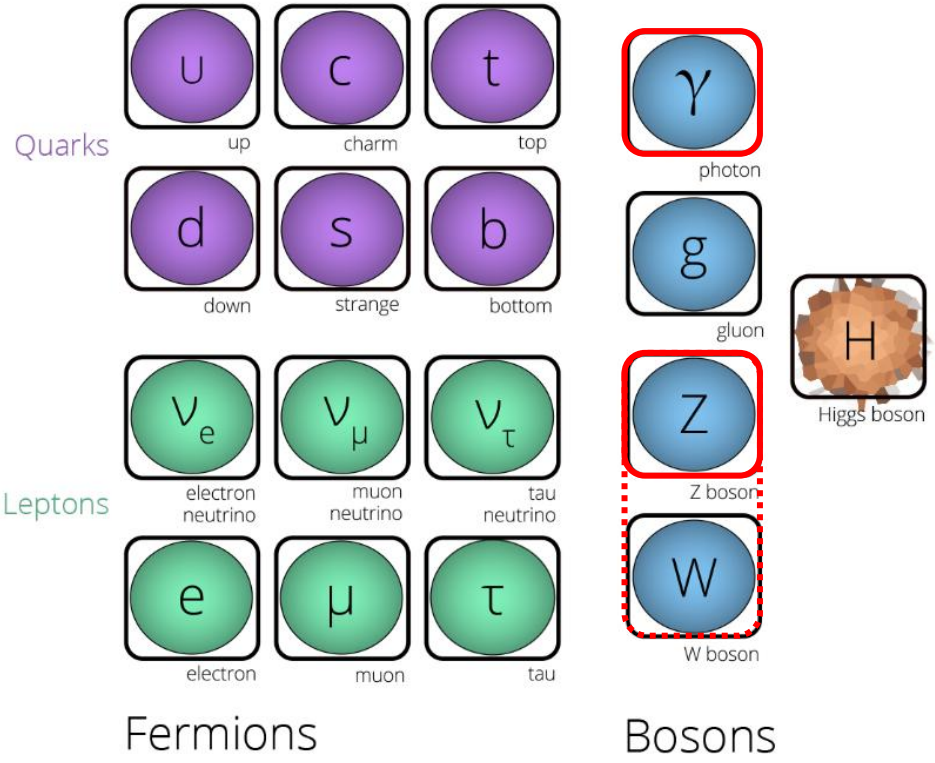
Equiv. to E158

+3 Years

Physics Overview

Motivation – The Standard Model

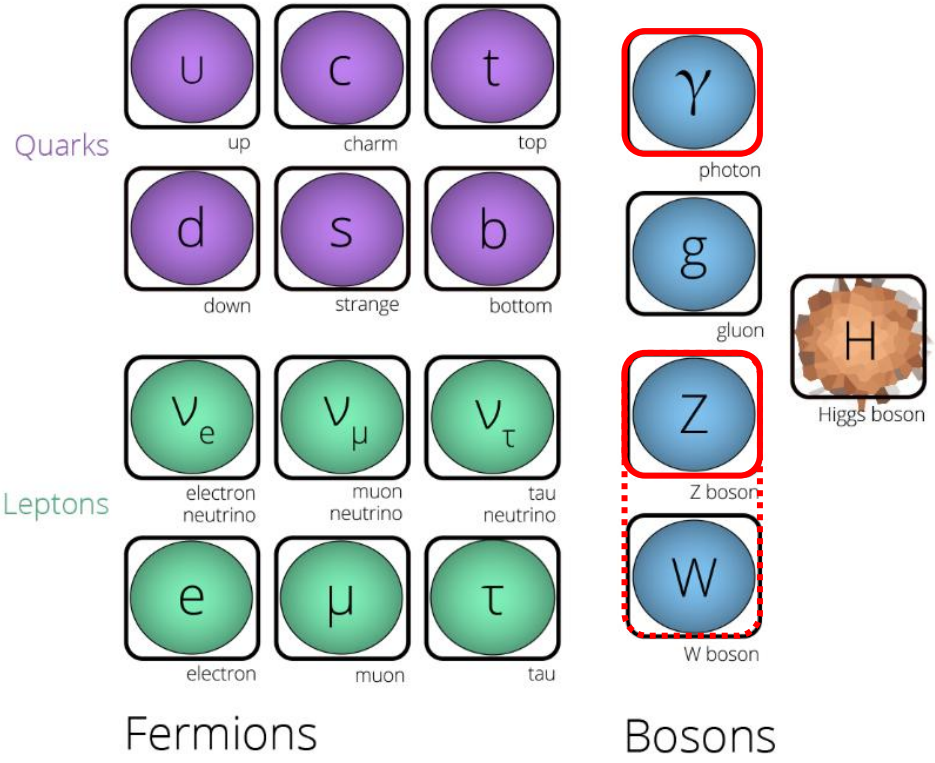
$SU(3)_{Strong}$ x $SU(2)_{Weak}$ x $U(1)_{EM}$



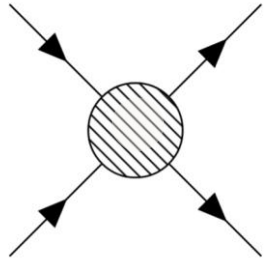
$$\begin{bmatrix} \gamma \\ Z \end{bmatrix} = \begin{bmatrix} \cos\theta_w & \sin\theta_w \\ -\sin\theta_w & \cos\theta_w \end{bmatrix} \begin{bmatrix} B^0 \\ W^0 \end{bmatrix}$$

Motivation – Beyond the Standard Model

$SU(3)_{Strong}$ x $SU(2)_{Weak}$ x $U(1)_{EM}$



- Neutrino Oscillations?
- Dark Matter?
- Dark Energy?
- Quantized Gravity?
- Fractional Q_{EM}?



Electroweak sector provides a clean probe into potential BSM physics

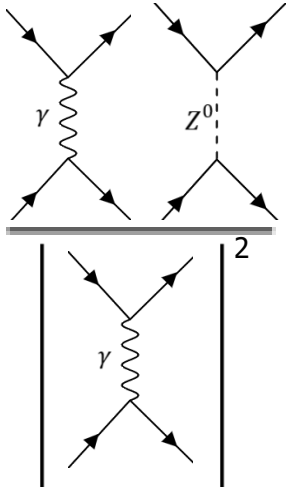
$SU(5) \supseteq SU(3)_{Strong} \times SU(2)_{Weak} \times U(1)_{EM}$?

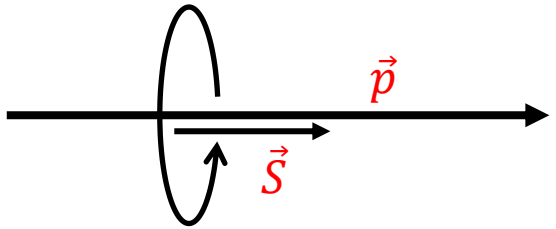
Motivation – Parity Violation

Violates Parity

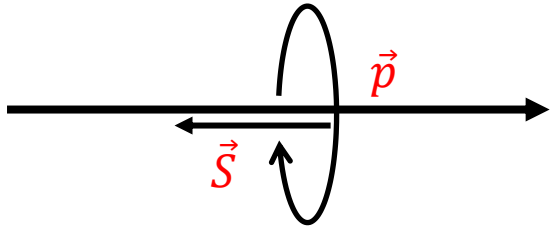
Conserves Parity

$$A_{PV} = \frac{}{}^{2} \longrightarrow \text{ppb}$$





Right-Handed



Left-Handed

MOLLER's GOAL:

$32\ ppb \pm 0.8\ ppb\ (2.4\%)$

$\delta(\sin^2\theta_w) = \pm 0.00028$

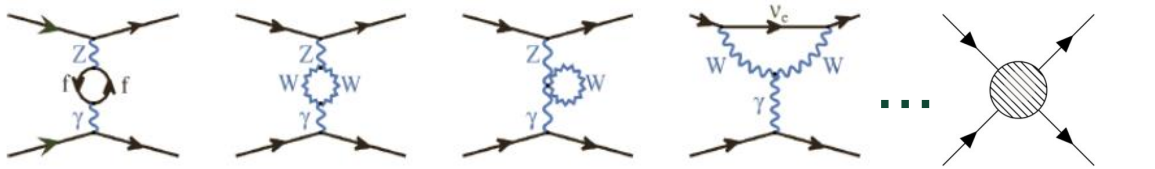
PVES – Theory

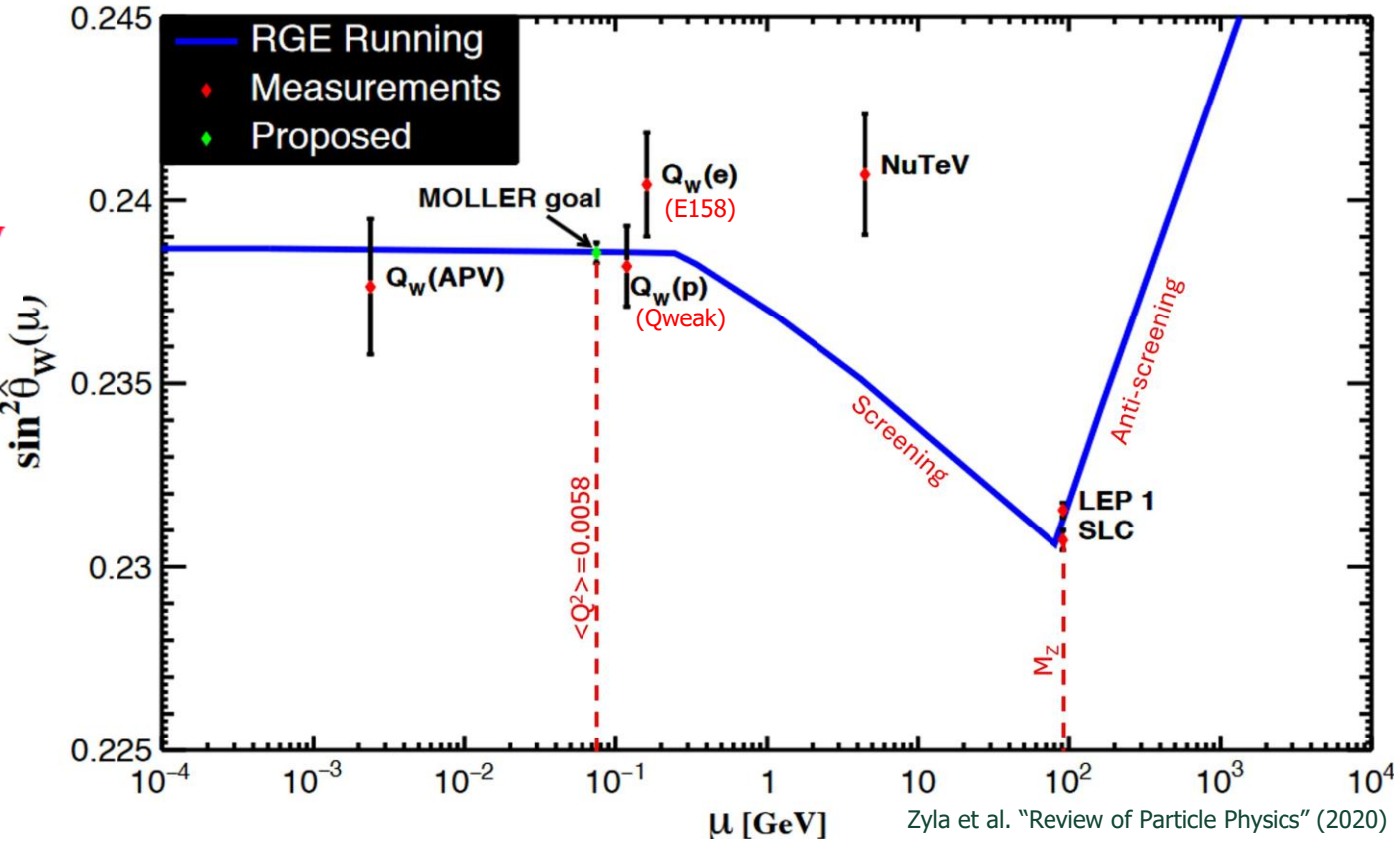
$$A_{PV} = \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L}$$

$$A_{PV} = mE_b \frac{G_F}{\sqrt{2}\pi\alpha} \frac{4\sin^2\theta_{cm}}{(2 + cos^2\theta_{cm})^2} Q_w^e$$

Particle	Q_{EM}	Q_W
u, c, t	$\frac{-2}{3}$	$1 - \frac{8}{3}\sin^2\theta_W$
d, s, b	$\frac{1}{3}$	$-1 + \frac{4}{3}\sin^2\theta_W$
e, μ, τ	-1	$-1 + 4\sin^2\theta_W$
p	+1	$1 - 4\sin^2\theta_W$
n	0	-1

(Tree-level) $\sin^2\theta_w \sim \frac{1}{4}$

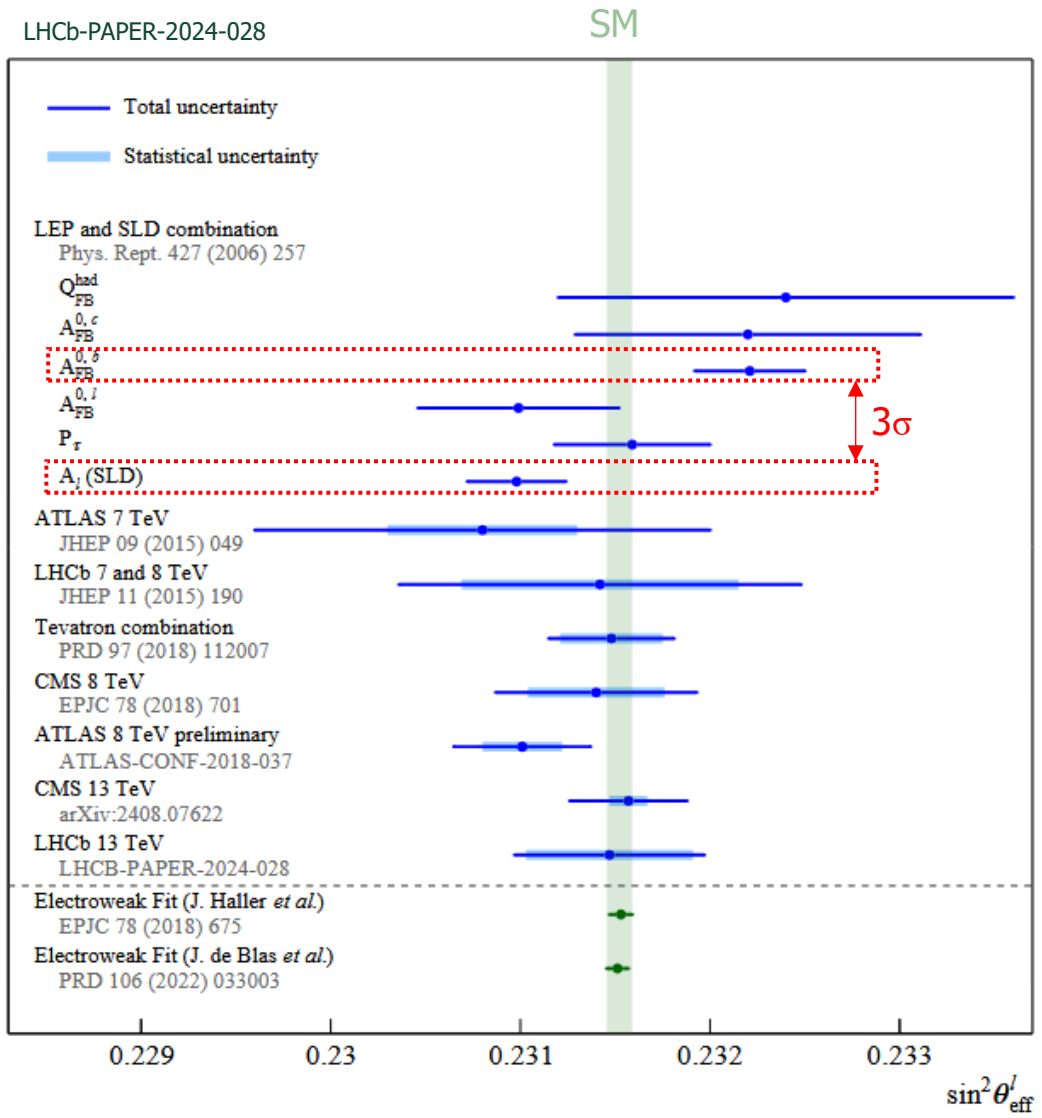




Zyla et al. "Review of Particle Physics" (2020)

Physics Impact

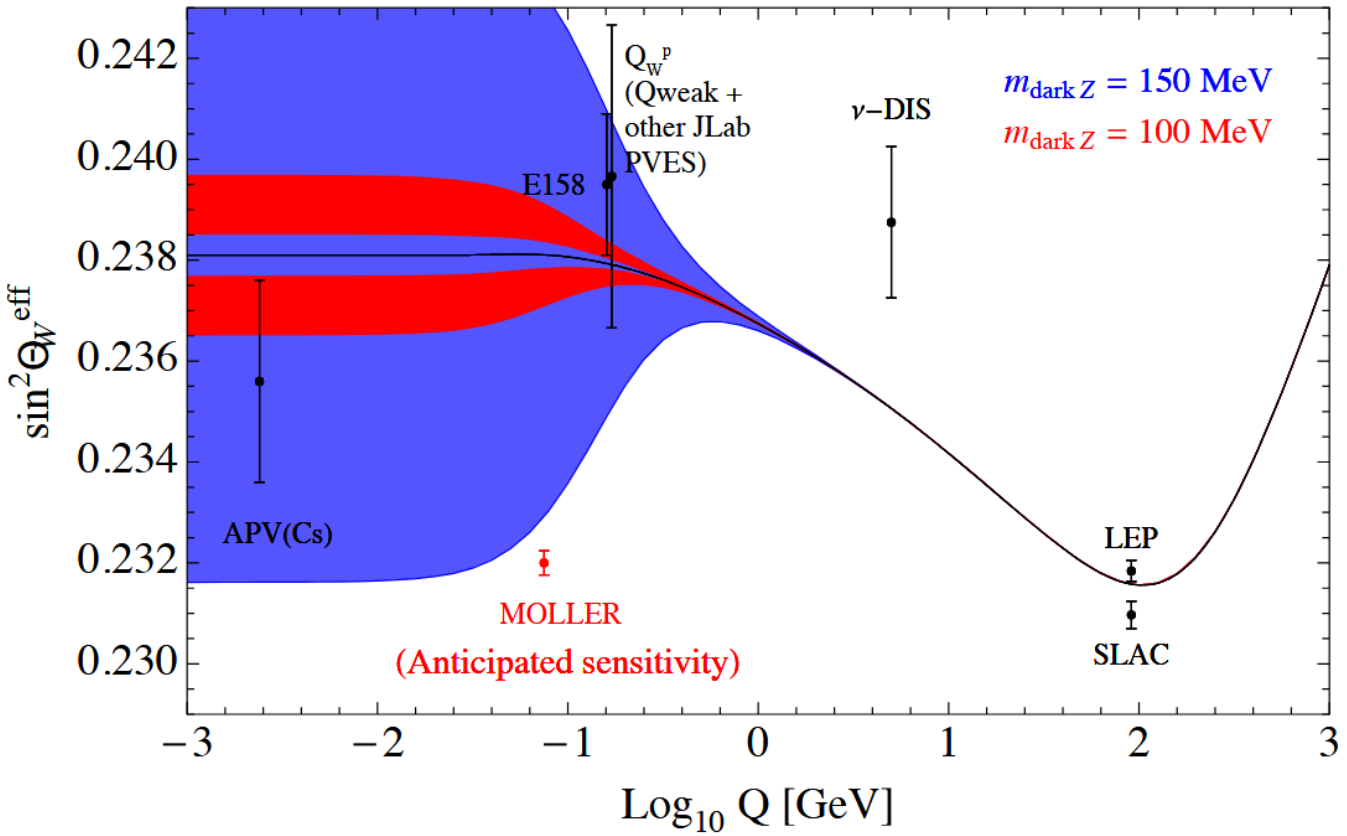
LHCb-PAPER-2024-028

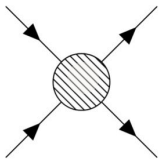


Hooman Davoudiasl et al. "Dark Z implications for Parity Violation, Rare Meson Decays, and Higgs Physics" (2012)

MOLLER's GOAL:

$$32\ ppb \pm 0.8\ ppb\ (2.4\%)$$
$$\delta(\sin^2\theta_w) = \pm 0.00028$$





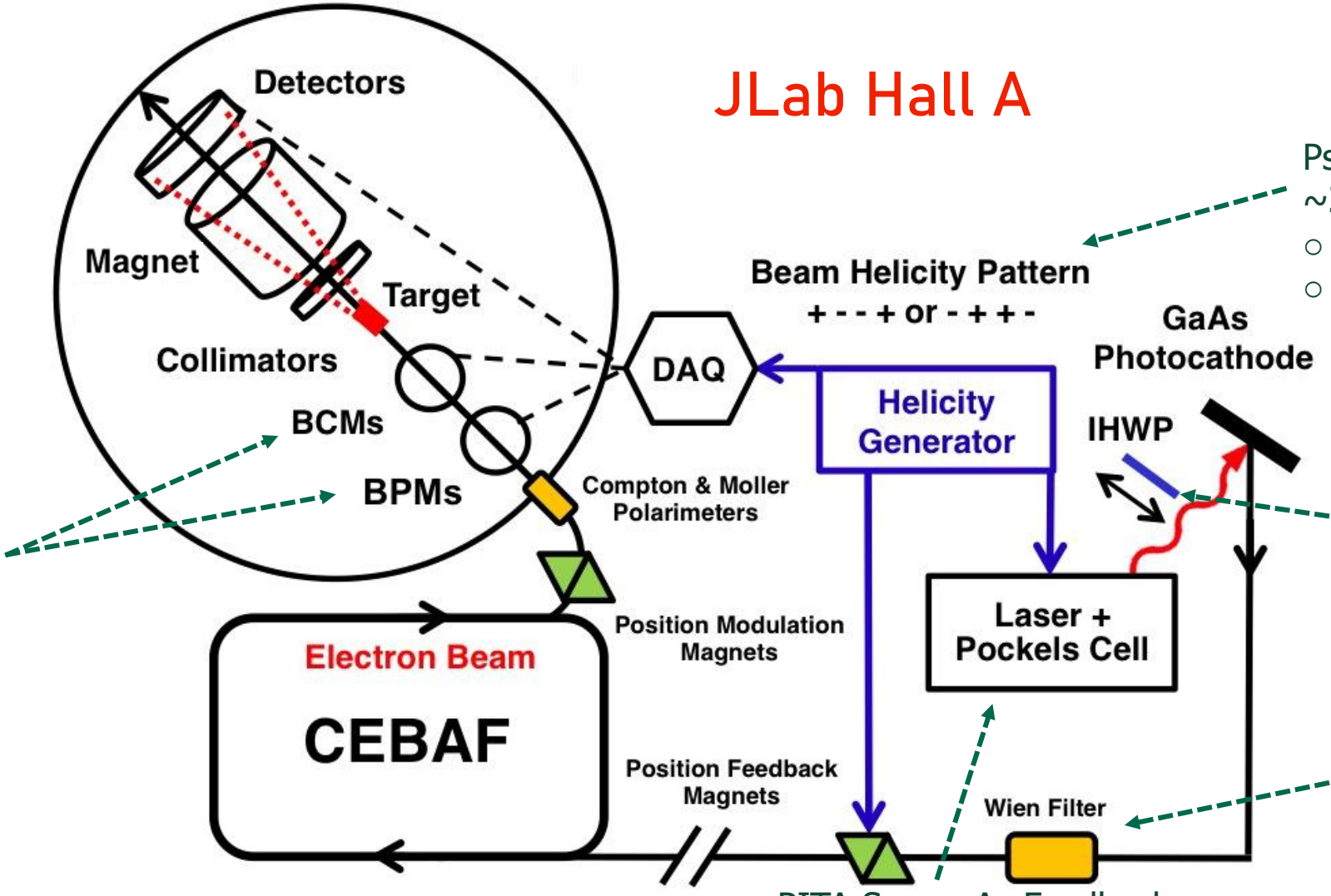
$$= \frac{\Lambda}{\sqrt{|g_{RR}^2 - g_{LL}^2|}} = \frac{1}{\sqrt{\sqrt{2}G_F|\delta Q_W^e|}} = 7.5\,[\text{Tev}]$$

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

Experimental Overview

Starts in the Injector

- The injector is critical to PVES!
- Heavy focus on minimizing Beam Correlated Asymmetries



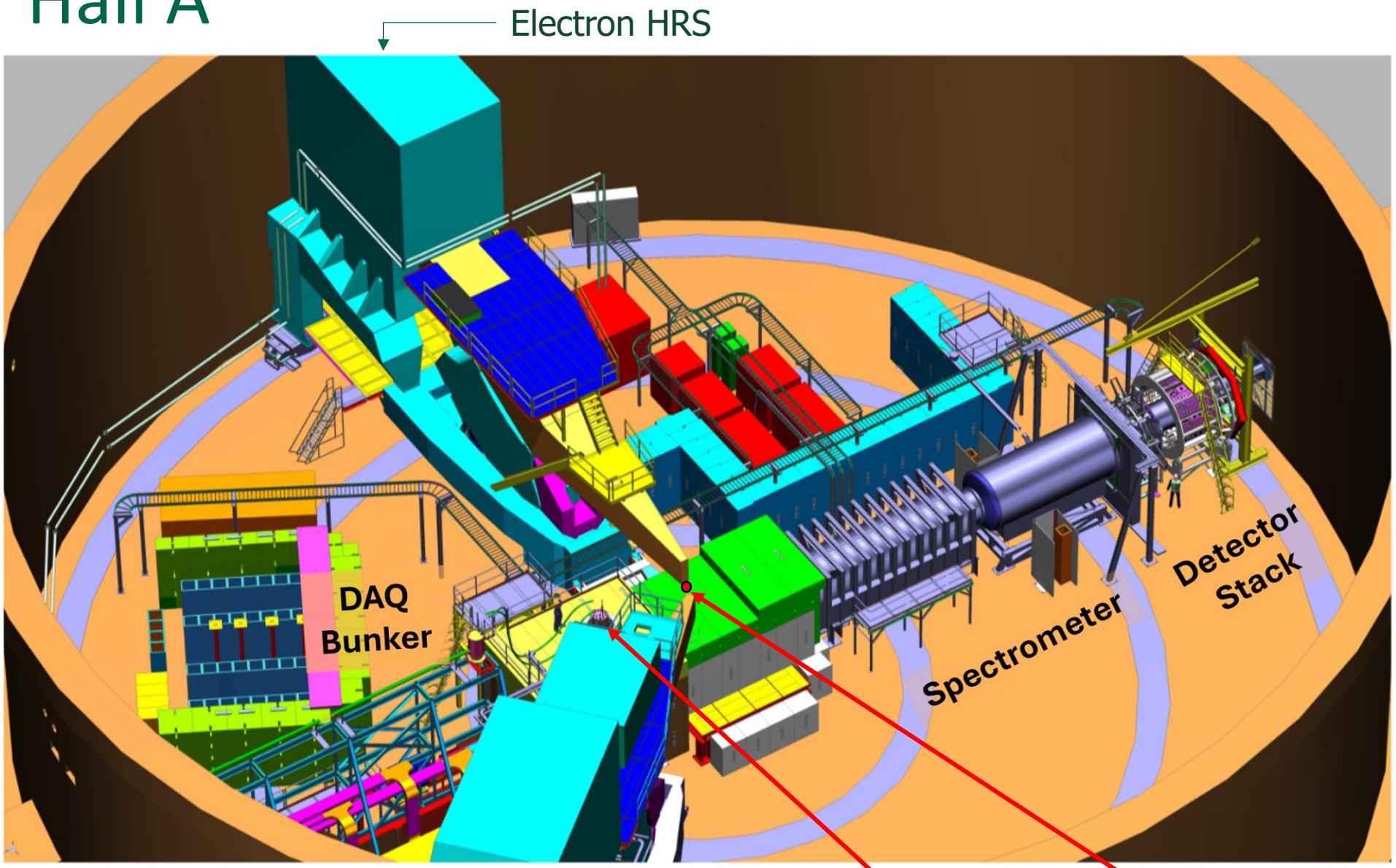
Pseudorandom ~2 kHz helicity flip
- Rejects 60 Hz noise
- Samples equivalent expt. conditions

Daily IHWP Insertion / Removal
- Cancels electronic corr. Asym.

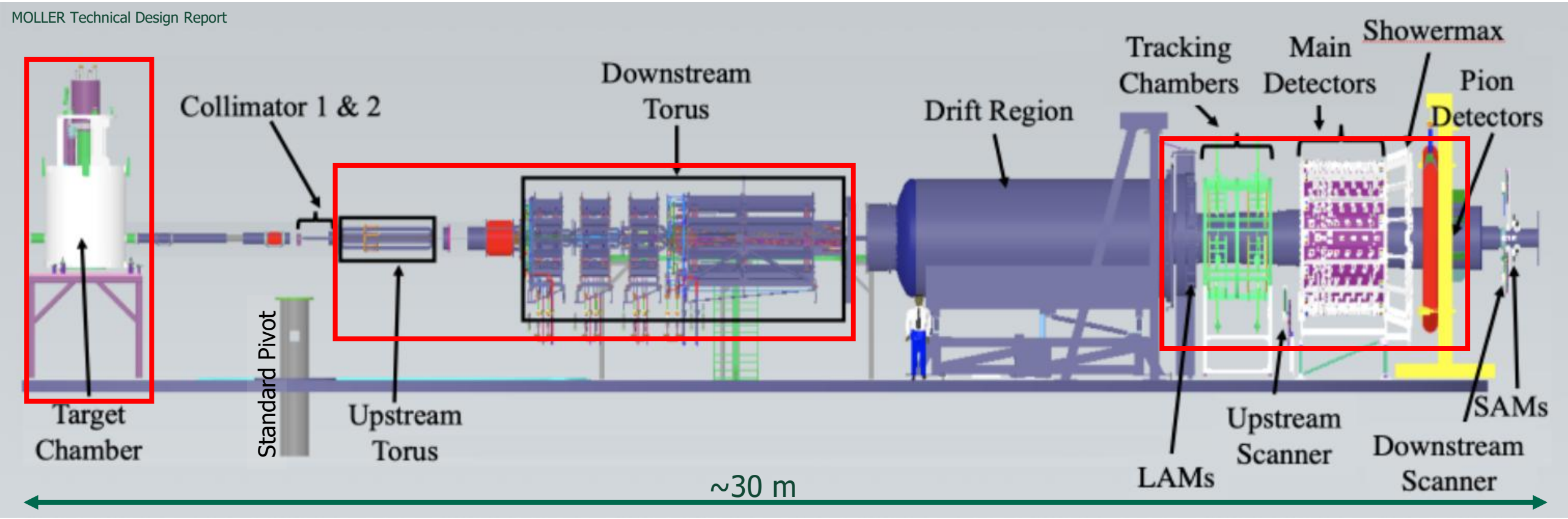
Weekly / Monthly Wien Reversals
- Cancels beam profile Asym

See R. Suleiman's talk

Hall A


Electron HRS
DAQ Bunker
Spectrometer
Detector Stack
Hadron HRS
Target Chamber
Standard Pivot

Expt. Sideview



Cryo-Target

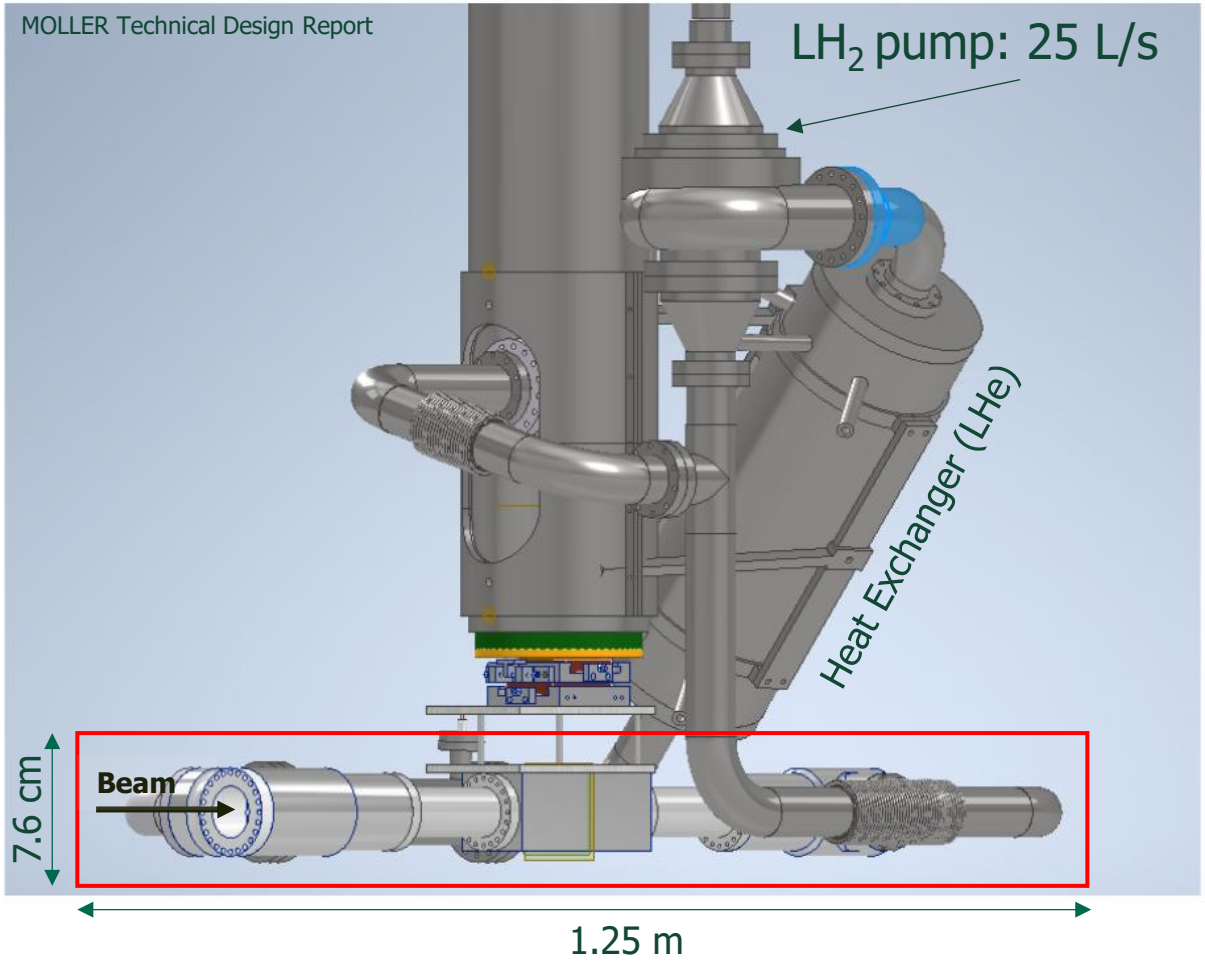
- 1.25 m long
- Target Type = LH_2
- Target Power = 4.5 kW

Highest power LH_2 target ever constructed

LH_2 offers an excellent balance of rad. length & electron density

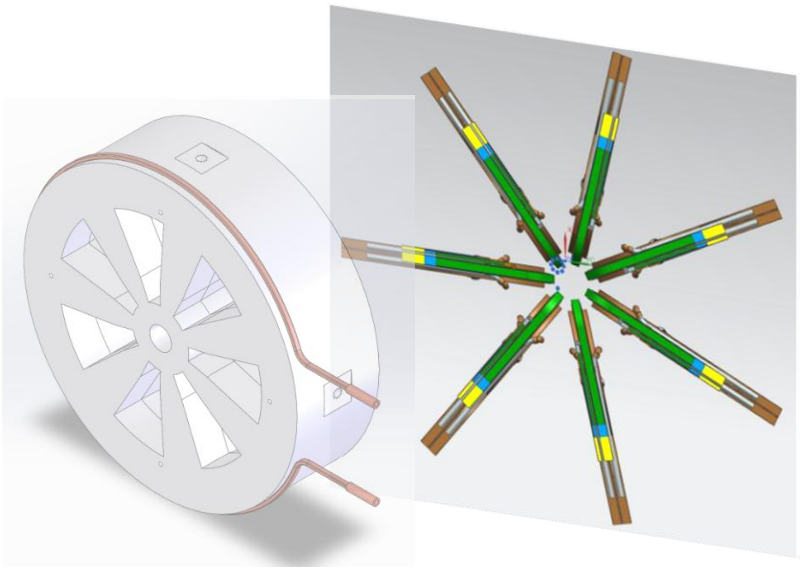
Primary Reactions:

- Møller Scattering
- Mott scattering



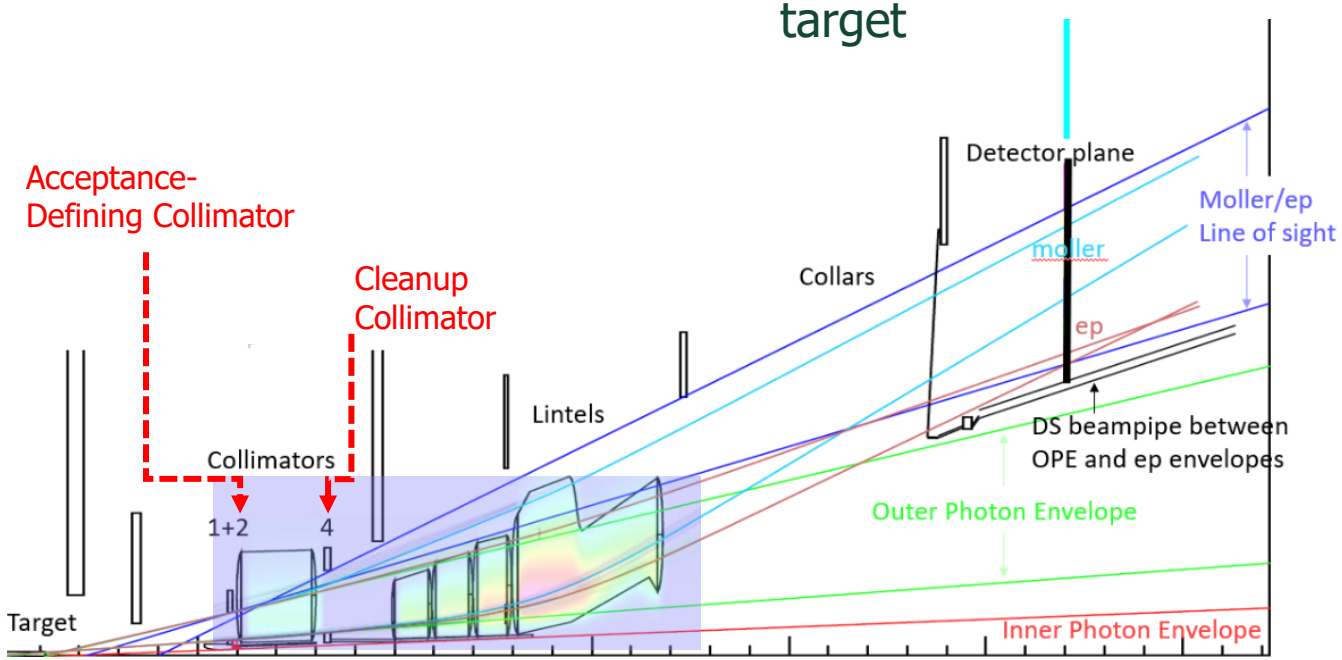
See S. Dusa's talk

Spectrometer



- 7-Fold Symmetry

- Detector systems do not have Line of Sight of the target

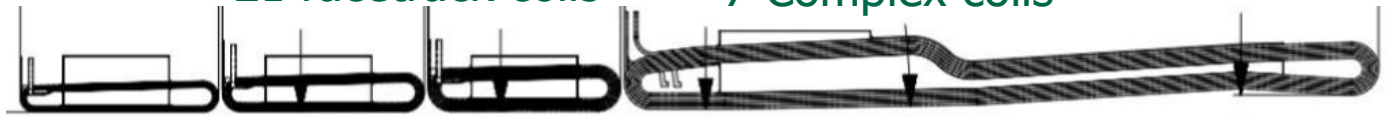


Upstream: 1 Toroidal Magnet

- 7 racetrack coils

Downstream: 4 Toroidal Magnet

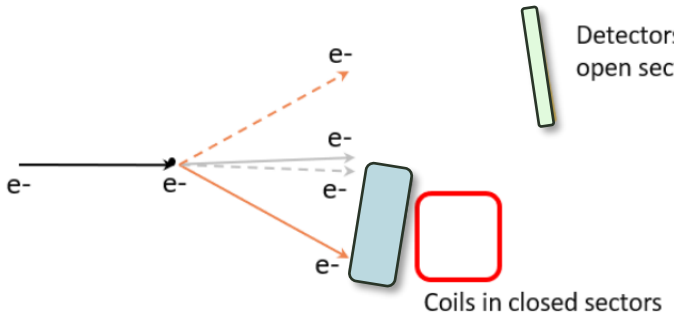
- 21 racetrack coils
- 7 Complex coils

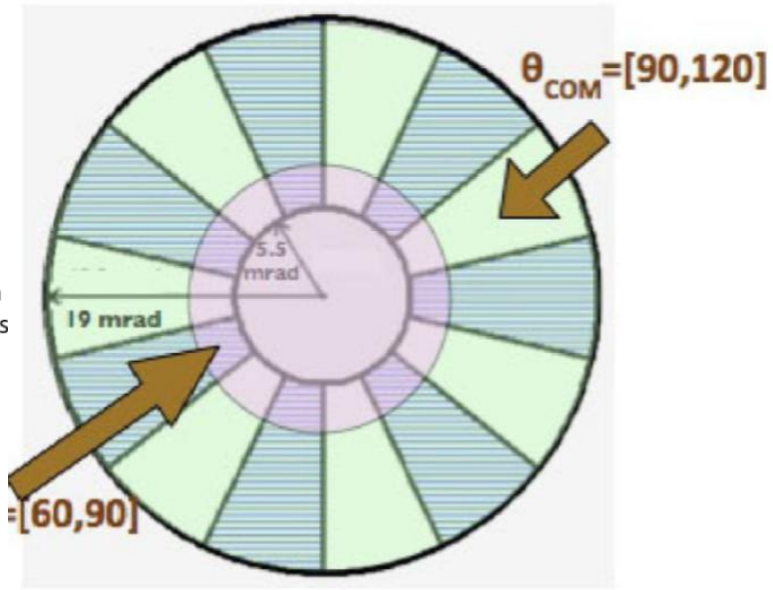


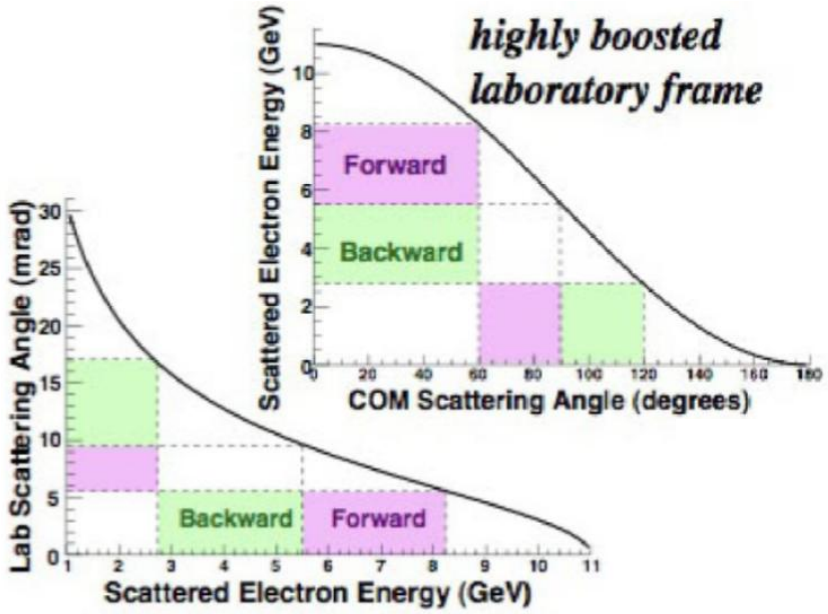
Target ← Beam

Angular Acceptance

- Odd # of coils
  - Effective 2π Acceptance







$$60^\circ \leq \theta_{\mathrm{CM}} \leq 120^\circ$$
$$2 \leq E' \leq 8.5 \qquad [\mathrm{GEV}]$$

MOLLER Technical Design Report

J. Benesch et al., "The moller experiment: An ultra-precise measurement of the weak mixing angle using Moller scattering" (2014)

Detectors

Main Detector:

- Thin Quartz Array
- Shower Max

See S. Bhattarai's talk

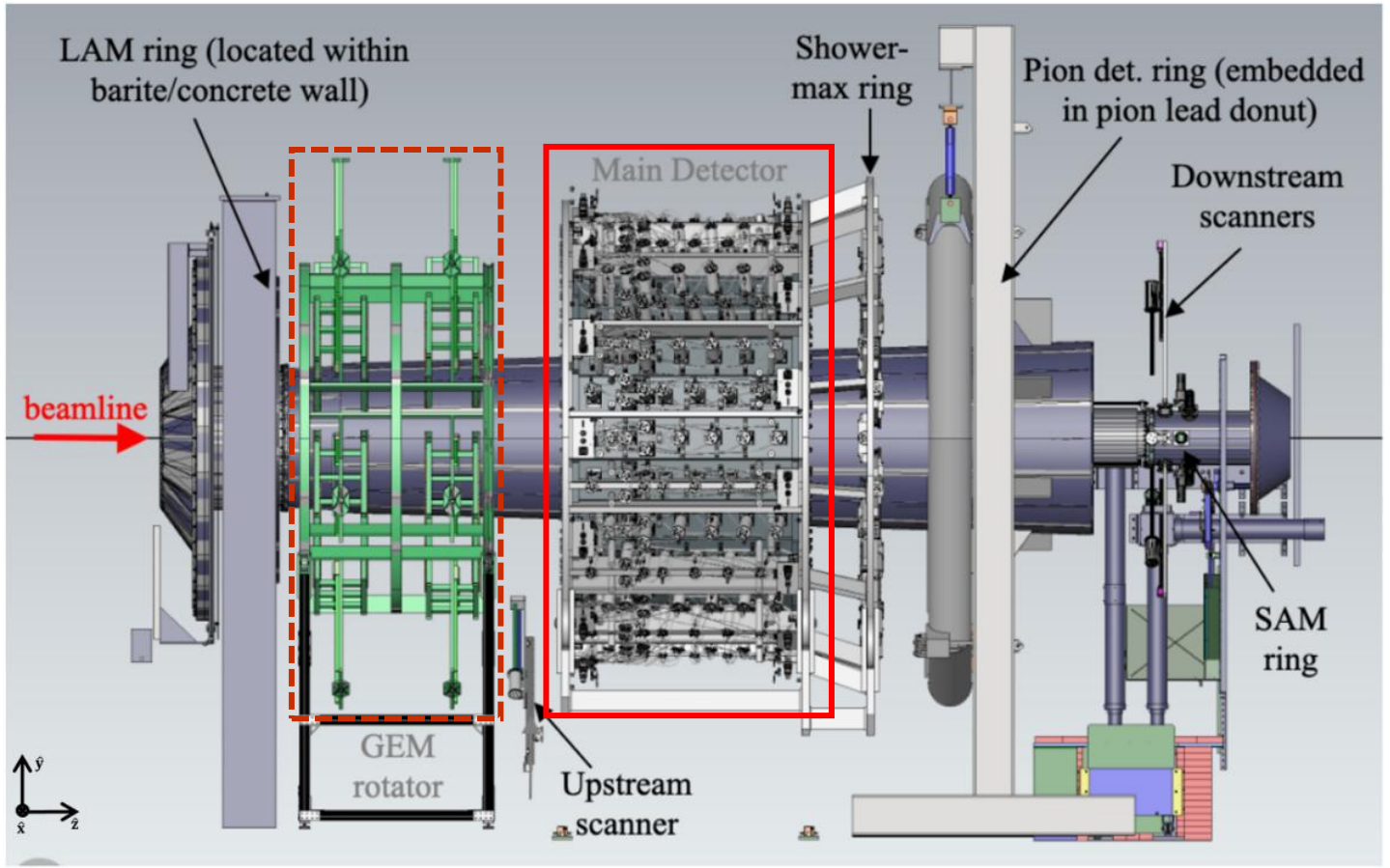
Tracking Detectors:

- GEMs

Auxiliary Detectors:

- Large Angle Monitors (LAMs)
- Small Angle Monitors (SAMs)
- U/D Scanners
- Pion Det (Ring)

See A. Gunsch's talk

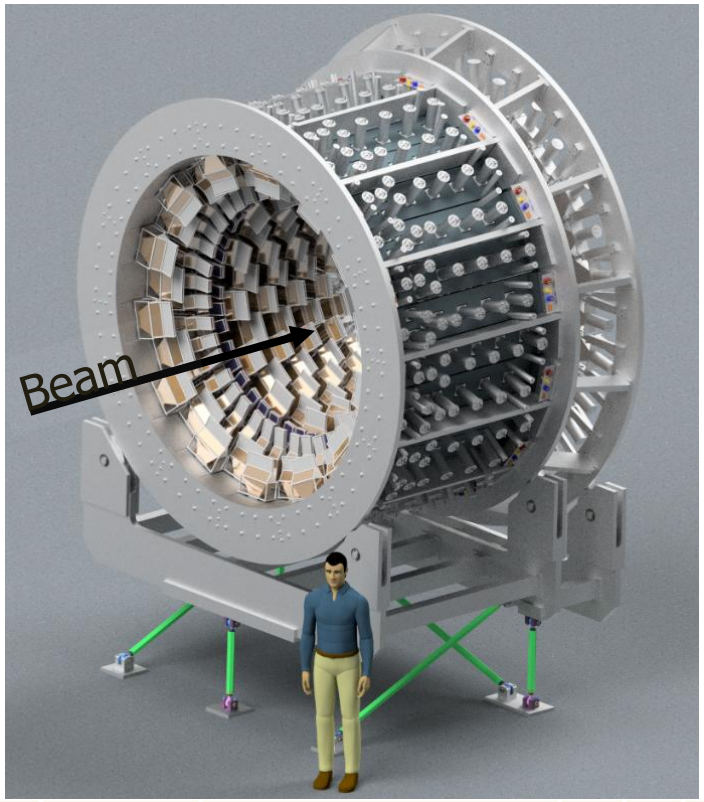


MOLLER Technical Design Report

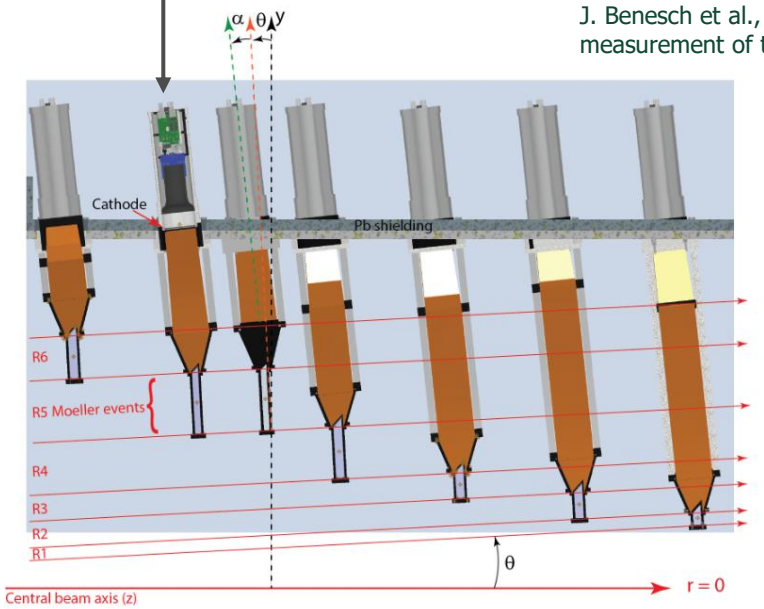
Main Detector – Thin Quartz Array

- 224 thin quartz elements
- 6 radial rings
- 28 azimuthal segments

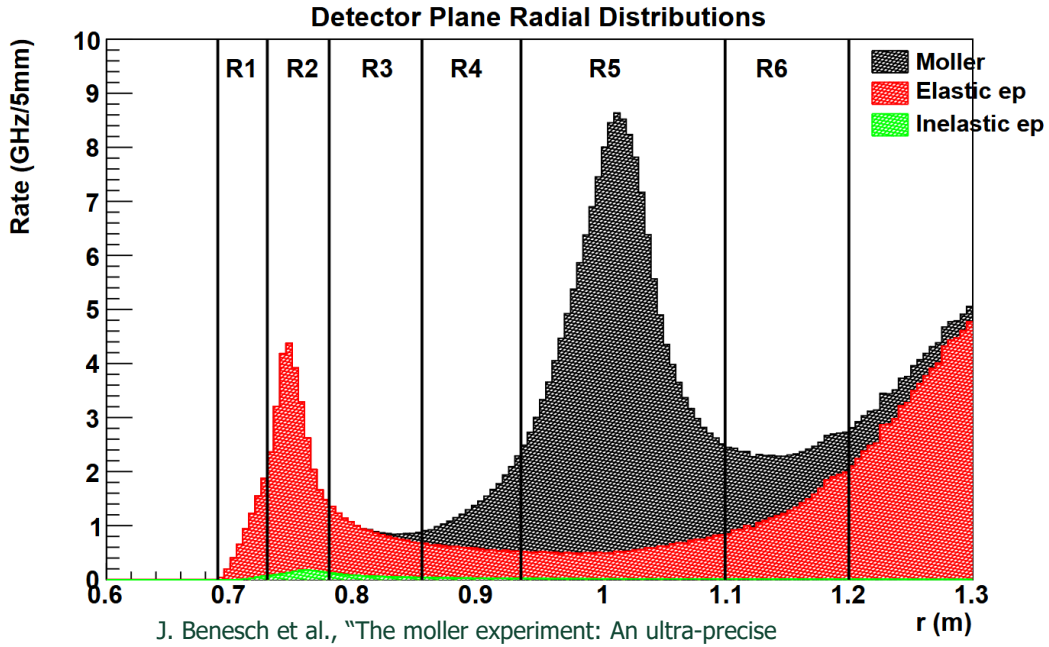
See S. Chatterjee's talk



Further divided into 84 elements



MOLLER Technical Design Report

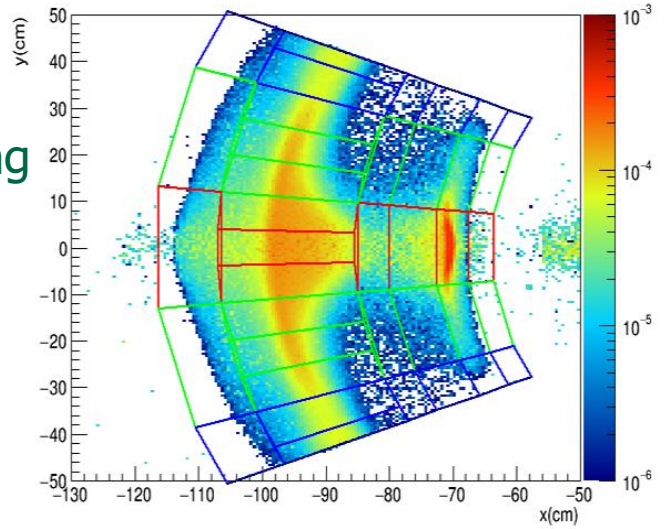


J. Benesch et al., "The moller experiment: An ultra-precise measurement of the weak mixing angle using Moller scattering," 2014

Fused Silica "thin quartz"

Tracking Detector -- GEMs

The Main Detector cannot discern individual scattering events!



Avg Rate: 50 kHz / mm^2

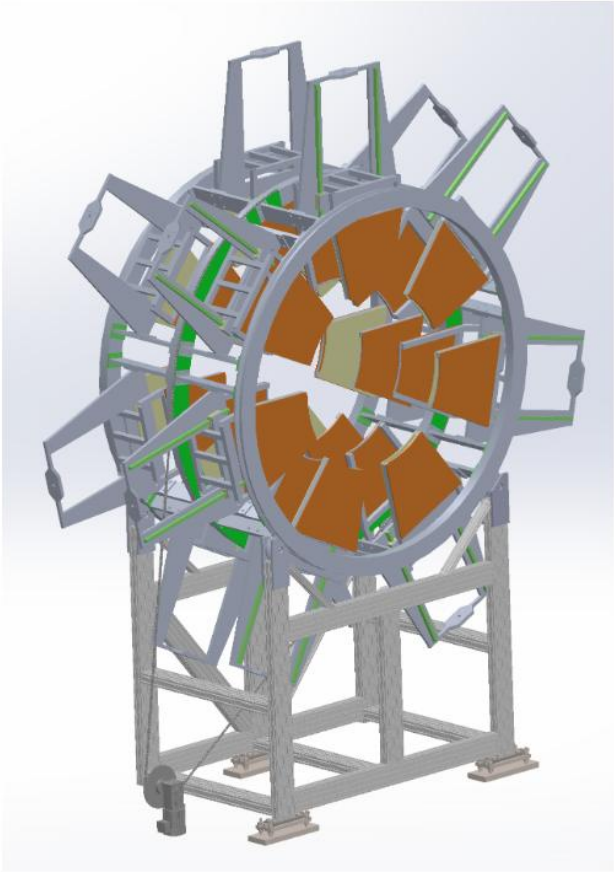
GEM =

Gaseous

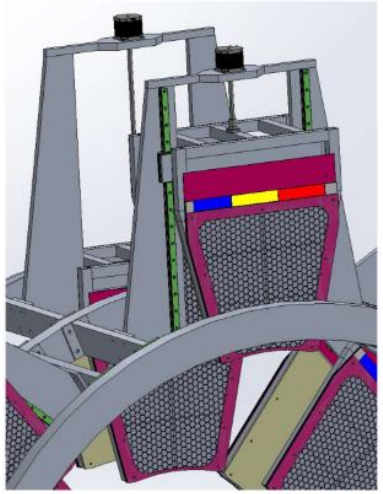
Electron

Multiplier

- Used for Track Reconstruction and dilution measurements
- Cannot be used during high flux (Production Running)
- Used during low flux "Counting Mode"
  - ~ 5% of total runtime



(a) *GEM Rotator and stand.*

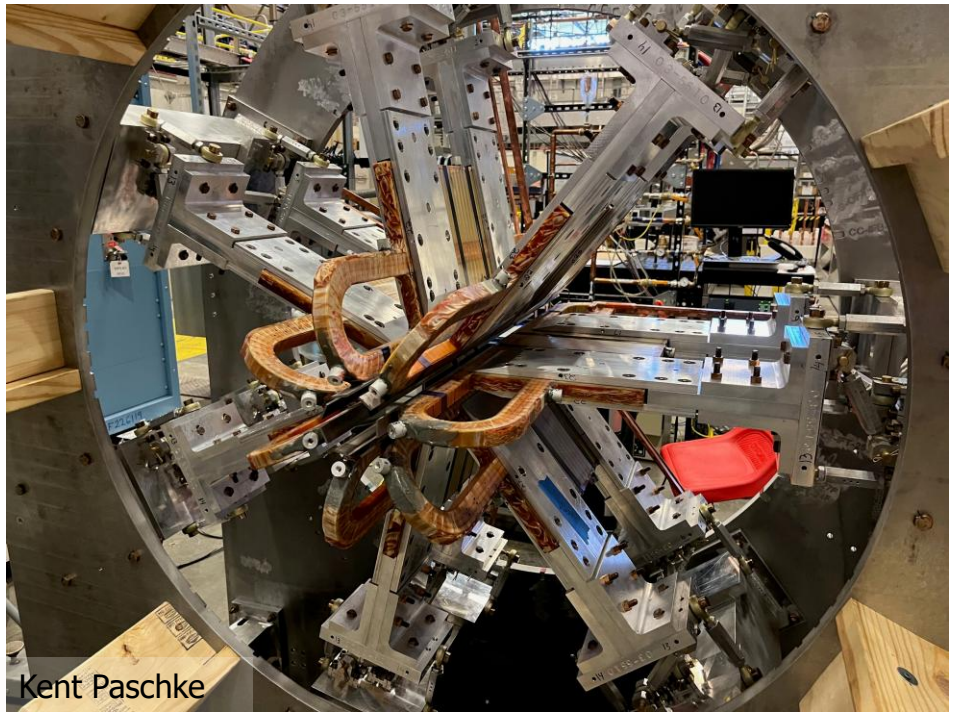


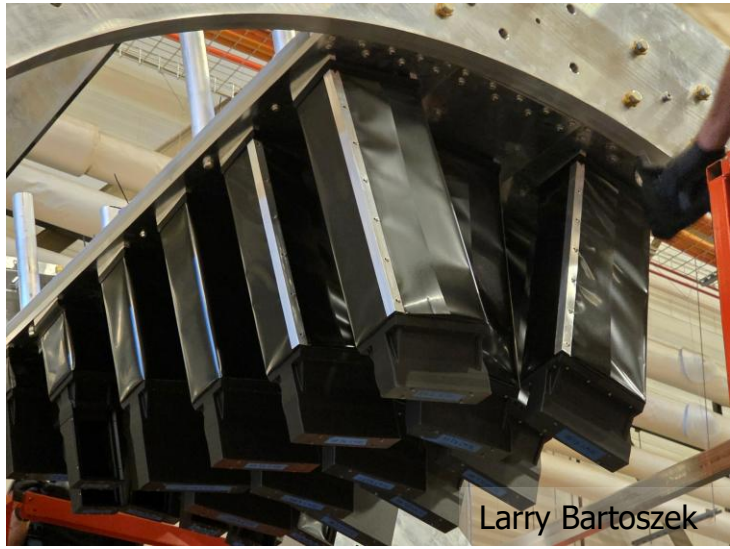
(b) *GEM Radial Motion.*

MOLLER Technical Design Report

See J. Shirk's talk

Assembly Photos





See C. Gal's talk

Timeline

- Fall 2025:
  - Assembly starts
- Fall 2026:
  - Installation ends
  - Commissioning starts
- Spring 2027:
  - Full Physics starts
- Spring 2029
  - Conclude MOLLER Expt.

Collaboration

Spokesperson: Krishna Kumar

Project Manager: Klaus Dehmelt

- Institutions: 37
- Authors: ~160
- Graduate Students: 25

Experimental Parameters

Parameter	Value
E [GeV]	11.0
E′ [GeV]	2.0-9.0
θ_{CM}	50°-130°
θ_{lab}	0.26°-1.2°
$\langle Q^2 \rangle$ [GeV^2]	0.0058
Maximum Current [μA]	70
Target Length [m]	1.25
$\rho_{targ.}$	0.0715
Max Luminosity [cm^{-2} sec^{-1}]	$2.4 \cdot 10^{39}$
σ [μb]	60
Møller Rate (65μA) [GHz]	134
Stat. Width [ppm/pair]	91
Raster Size [mm×mm]	5×5
Production Time	344 PAC-days (8256 hours)
ΔA_{raw} [ppb]	0.54
Background Fraction	0.10
P_{beam}	90%
$\langle A_{PV} \rangle$ [ppb]	32
$\Delta A_{stat.}/\langle A_{expt.} \rangle$	2.1%
$\delta \left(\sin^2 \theta_W\right)_{stat.}$	0.00023