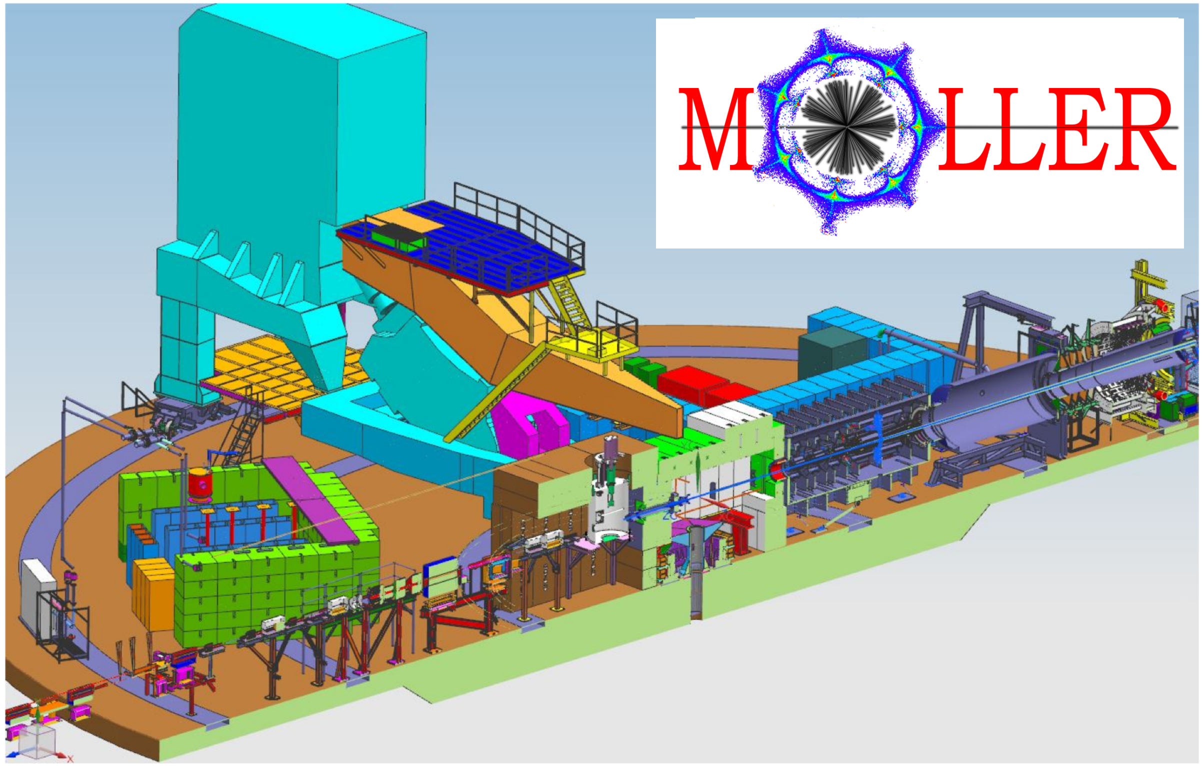
The MOLLER Experiment
An Ultra-Precise Measurement of the Weak Mixing Angle Using Møller Scattering

Measurement **O**f a **L**epton **L**epton **E**lectroweak **R**eaction



The 25th International Spin Symposium

SPIN 2023

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on behalf of the MOLLER Collaboration

Jefferson Lab

Stony Brook University

Center for Frontiers in Nuclear Science

U.S. DEPARTMENT OF ENERGY | Office of Science

JSA

Outline

- **MOLLER Physics Motivation**
  - Parity Violating Asymmetry in Møller Scattering
  - Weak Mixing Angle Measurements
  - Physics Impact
- **MOLLER Experimental Overview**
  - Introduction to the MOLLER Apparatus
  - The Projected Statistical and Systematic Uncertainties
- **Timeline**
- **Summary**
- **MOLLER Collaboration**

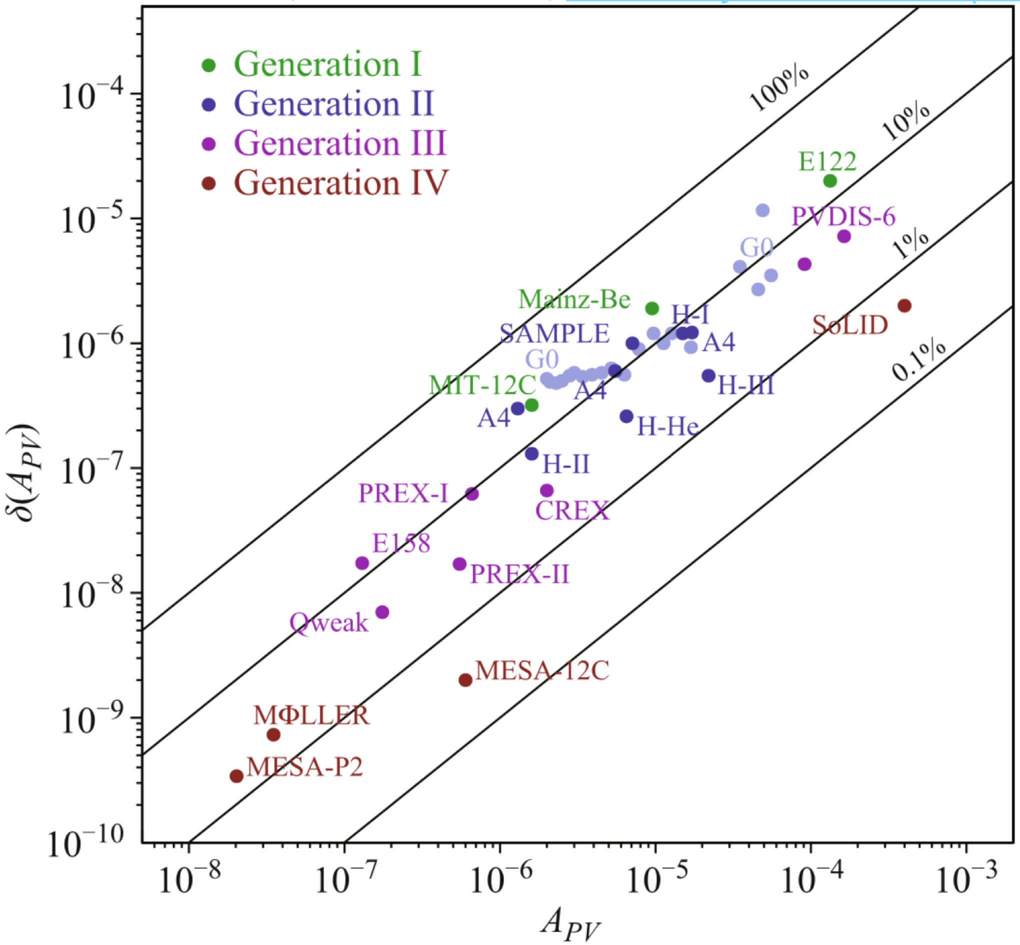
Parity Violating Asymmetry in Møller Scattering

- Ultra-precise measurement of parity-violating asymmetry A_{PV} in polarized electron-electron scattering.
  - A_{PV} results from interference between electromagnetic and weak neutral current amplitudes.
  - Proportional to the Q_W^e.

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

- A_{PV} is predicted to be ≈ 33 ppb at our kinematics.
  - Measure A_{PV} to an uncertainty of 0.8 ppb.
  - Achieve a 2.4% measurement of Q_W^e.

P. Souder, K. D. Paschke, Front. Phys. 11, 111301 (2016)

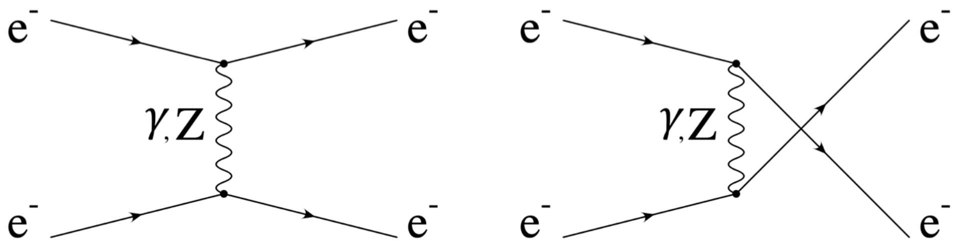


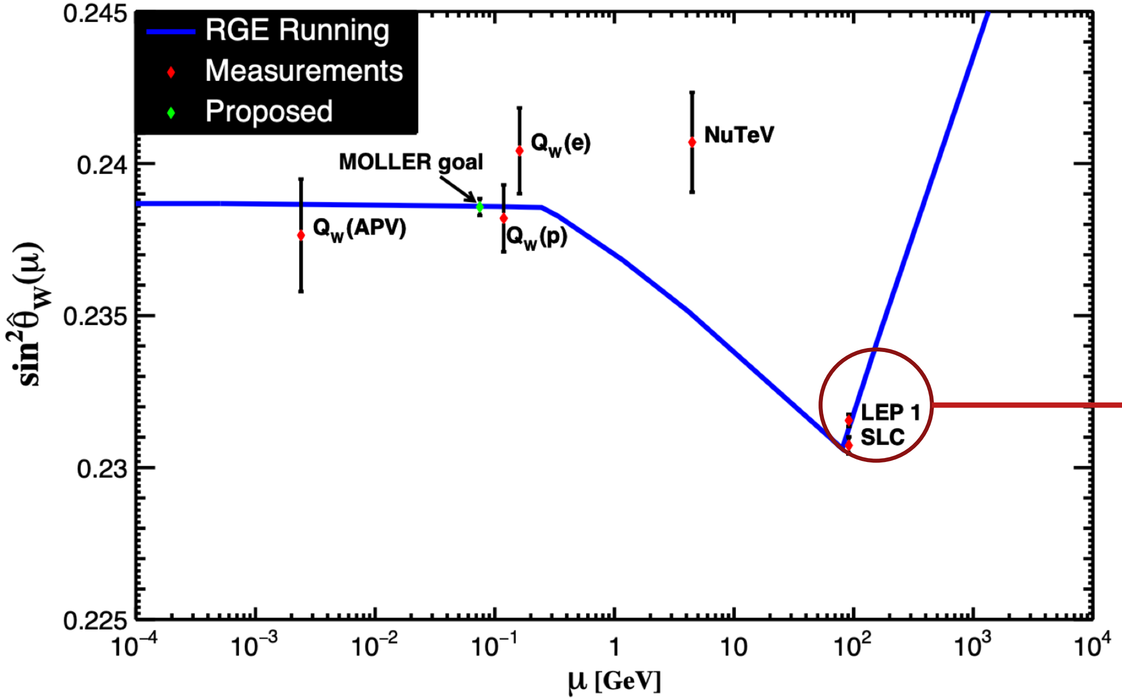
The precision of the measured/predicted value of the asymmetry in various PVES experiments

Weak Mixing Angle Measurements

- Electron's weak charge at tree level in term of the weak mixing angle is given by

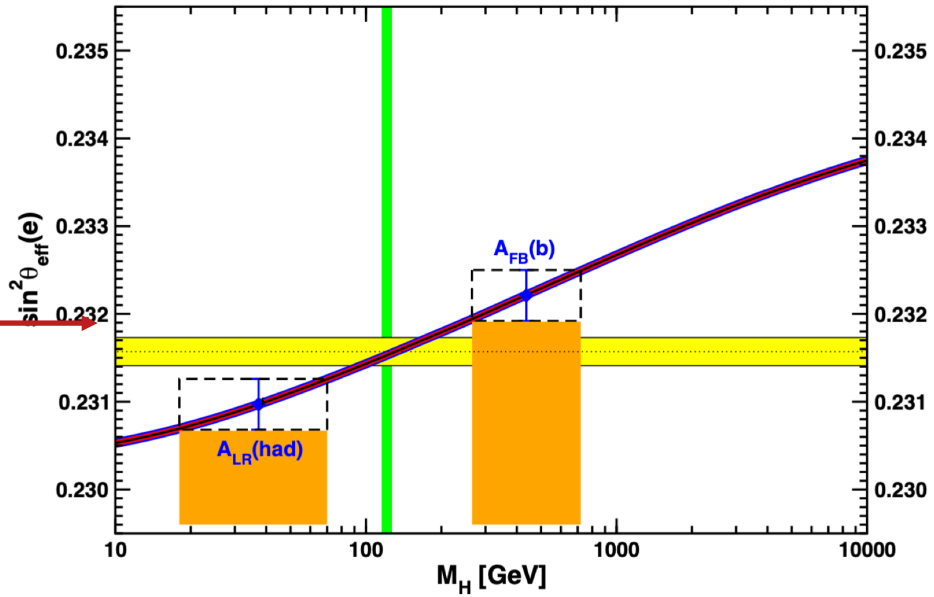
$$Q_W^e = 1 - 4\sin^2\theta_W \sim 0.075$$





The measurement of the weak mixing angle as a function of the energy scale μ

J. Erler, arXiv:1710.06503



The most precise Z-pole measurements of $\sin^2\theta_W$ differ from each other by $\sim 3\sigma$

Weak Mixing Angle Measurements at Low Energy

- Effective weak mixing angle:

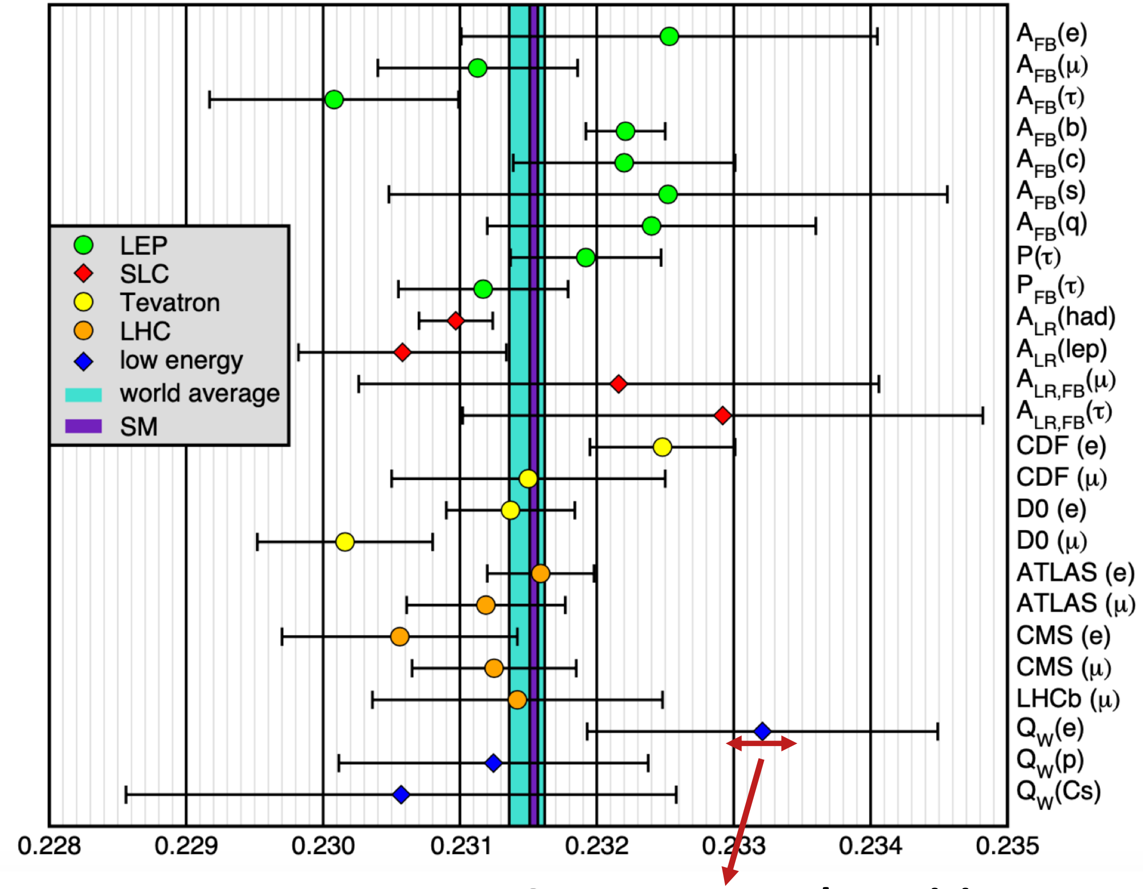
$$\sin^2\theta^l_{eff} \equiv \frac{1}{4}\left(1 - \frac{v_l}{a_l}\right)$$

- MOLLER A_{PV} would be the first low Q^2 measurement to match the precision of the single best high energy measurement at the Z^0 resonance.

- MOLLER projection:

$$\delta(\sin^2\theta_W) = \pm 0.00023(stat) \pm 0.00012(syst)$$
$$\rightarrow \sim 0.1\%$$

J. Erler, arXiv:1908.07346v1



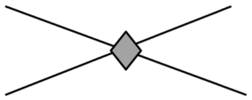
MOLLER expected precision

All measurements of the effective leptonic weak mixing angle.

Comparison with High Energy Colliders

Krishna Kumar

- MOLLER experiment is very complementary to other precision low energy experiments and direct searches at high energy colliders.



$$\frac{1}{\Lambda^2}\mathcal{L}_6 \qquad \frac{\Lambda}{\sqrt{|g_{RR}^2 - g_{LL}^2|}} \simeq 7.5\text{ TeV}$$

- Search for new physics by looking for deviations from Standard Model predictions.

e+e- Collisions

$\Lambda_{LL}^{ee} \sim 8.3\ TeV$ (LEP200 reach)

Fixed Target

$\Lambda_{LL}^{ee} \sim 12\ TeV$ (E158 reach)

$\Lambda_{LL}^{ee} \sim 27\ TeV$ (MOLLER reach)

LEP200: Lepton-Lepton interactions

E158: PV Møller Scattering

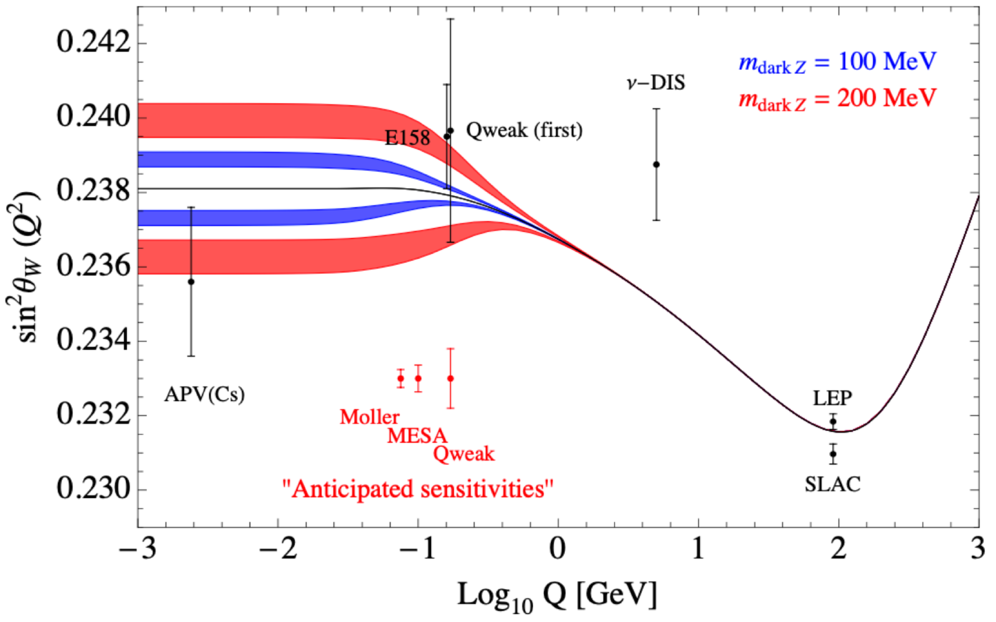
- **MOLLER is accessing discovery space that cannot be reached until the advent of a new lepton collider or neutrino factory.**

New Physics Beyond the Standard Model

✓ MOLLER provides a unique window to new physics at MeV and multi-TeV scales, complementary to direct searches at high energy colliders.

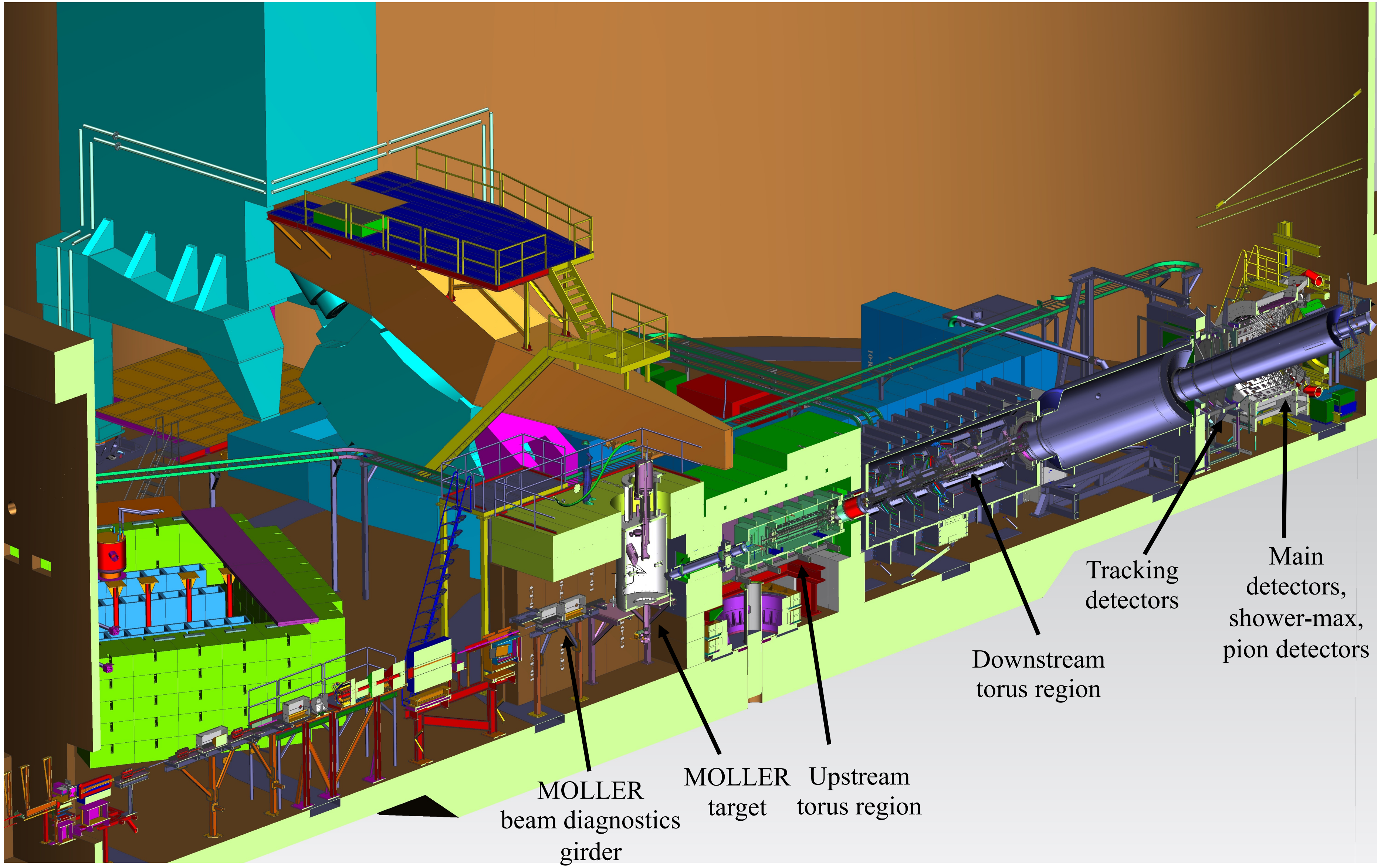
- Most sensitive probe of new flavor and CP-conserving neutral current interactions over next decade.
  - weakly coupled MeV scaled mediators (**dark *Z*** → parity violating effect visible in low energy experiments (if $Q^2 \lesssim m_{Z_d}^2$))

H. Davoudiasl, H.-S. Lee, W. J. Marciano, arXiv:1402.3620



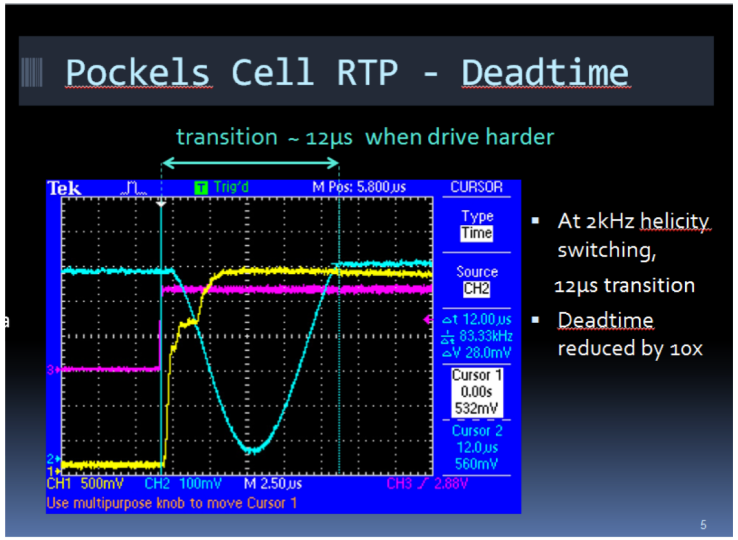
Running of the effective weak mixing angle, $\sin^2\theta_W(Q^2)$ with energy scale Q.

The MOLLER Experiment

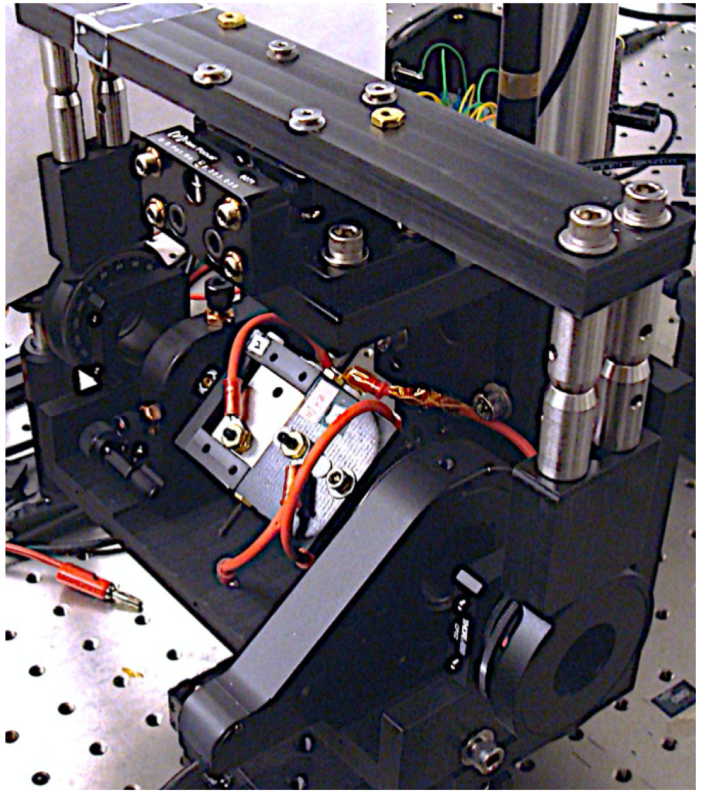


- 11 GeV beam (90% beam polarization)
- 1.25m LH_2 target
- Run time: 344 PAC days → 8256 h
- Full azimuth acceptance: 5-21mrad
- Møller rate at 65 μA ~ 134 GHz
- $A_{PV} \approx$ 33ppb
- Max Luminosity: $2.4\times10^{39}cm^{-2}s^{-1}$
- $\langle Q^2 \rangle$: 0.0056 GeV^2

Polarized Electron Source



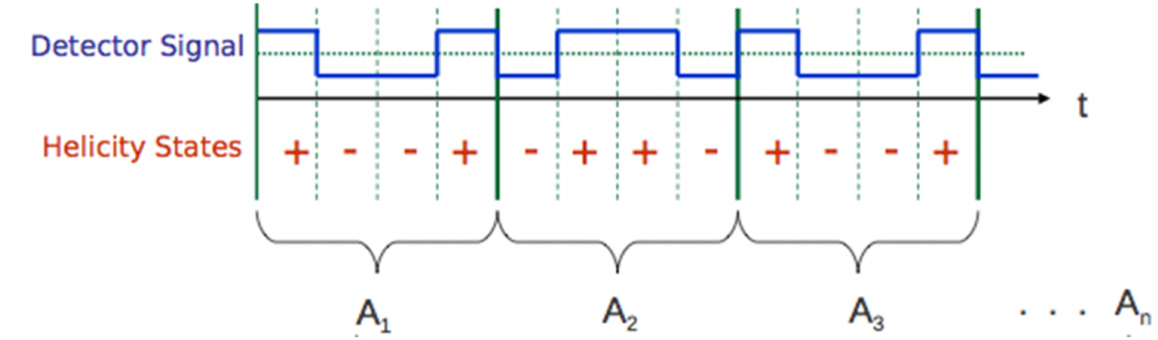
- Generated with a circularly polarized laser beam.
  - Pockels cell controls the spin of the electron beam.
- New technology needed: RTP (Rubidium Titanyl Phosphate) cell
  - Requiring high ~2kHz flip rates, ~11μs transitions
  - Two crystals, transverse field
  - No piezo-electric ringing artifacts
  - Much faster and more stable



The requirements for helicity-correlated beam asymmetries during MOLLER

	HAPPEX-II (achieved)	Q_{weak} (achieved)	PREX-2 (achieved)	CREX (achieved)	MOLLER (required)
Intensity asymmetry	400 ppb	30 ppb	25 ppb	-88 ppb	10 ppb
Energy asymmetry	0.1 ppb	0.4 ppb	0.8 ± 1 ppb	0.1 ± 1.0ppb	< 1.4 ppb
position differences	1.7 nm	4.4 nm	2.2 ± 4 nm	-5.2 ± 3.6nm	0.6 nm
angle differences	0.2 nrad	0.1 nrad	$< 0.6 \pm 0.6$ nrad	-0.26 ± 0.16nrad	0.12 nrad
size asymmetry (quoted)	–	$< 10^{-4}$	$< 3 \times 10^{-5}$	$< 3 \times 10^{-5}$	$< 10^{-5}$

How Do We Take the Bulk of Our Data?



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**

MOLLER specification is 10 ppm resolution for relative beam intensity measurement for 1 kHz window pairs.

- The raw signal from the detectors integrated for each helicity window (0.52 ms) and asymmetry formed from in a single helicity patterns.
  - MOLLER is designing around a helicity flip rate of 1.92 kHz.

$$A_i = \left(\frac{F_R - F_L}{F_R + F_L}\right)_i \cong \left(\frac{\Delta F}{2F}\right)_i ; \; A_{raw} = \langle A_i \rangle$$

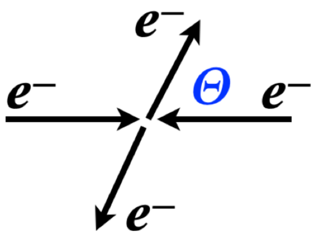
- Remove the correlations of flux to beam intensity, position, angle, and energy fluctuations:

$$A_i = \left(\frac{\Delta F}{2F} - \frac{\Delta I}{2I}\right)_i - \sum \left(\alpha_j (\Delta X_j)_i\right)$$

- Repeat 30 billion times to get desired statistical error.

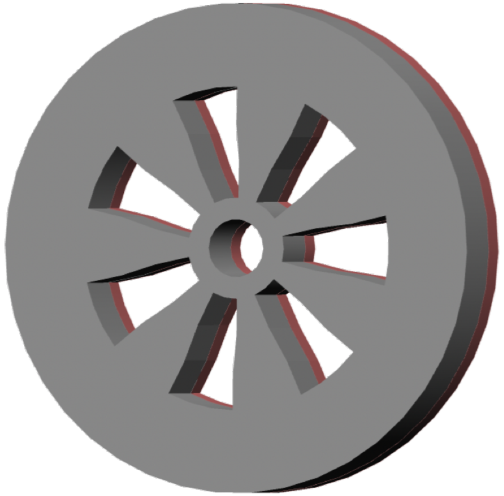
MOLLER Kinematics and Acceptance

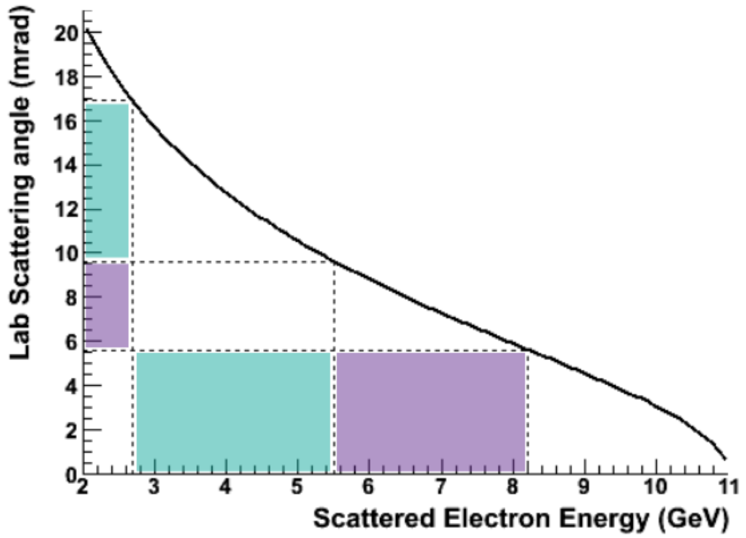
- Identical particles.

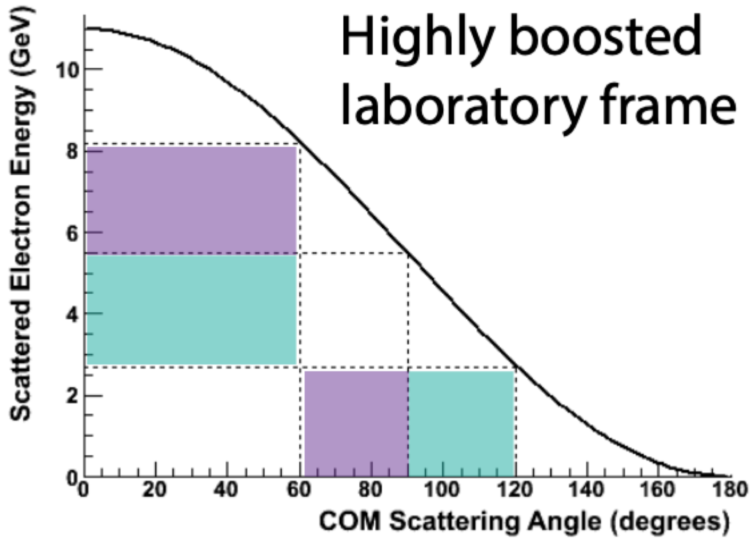


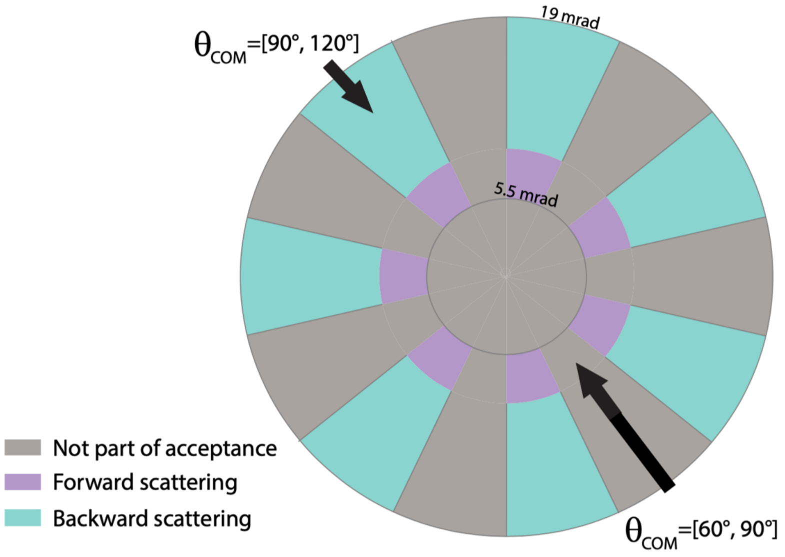
- Measure either forward or backward scattering in CM frame.
- Full azimuthal acceptance for Møller scatters from 6 <θ_{lab}< 20 mrad

Acceptance defining collimator
7-fold symmetry

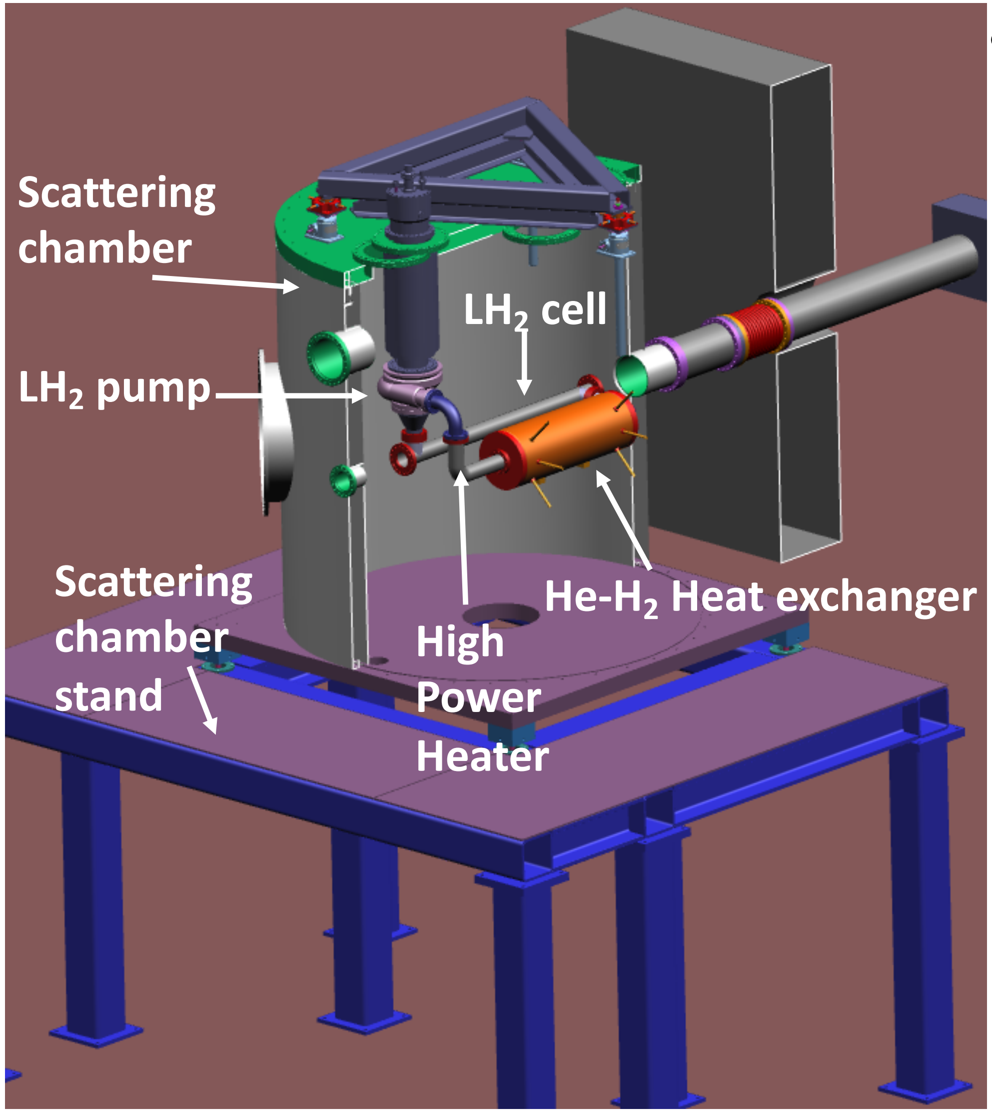






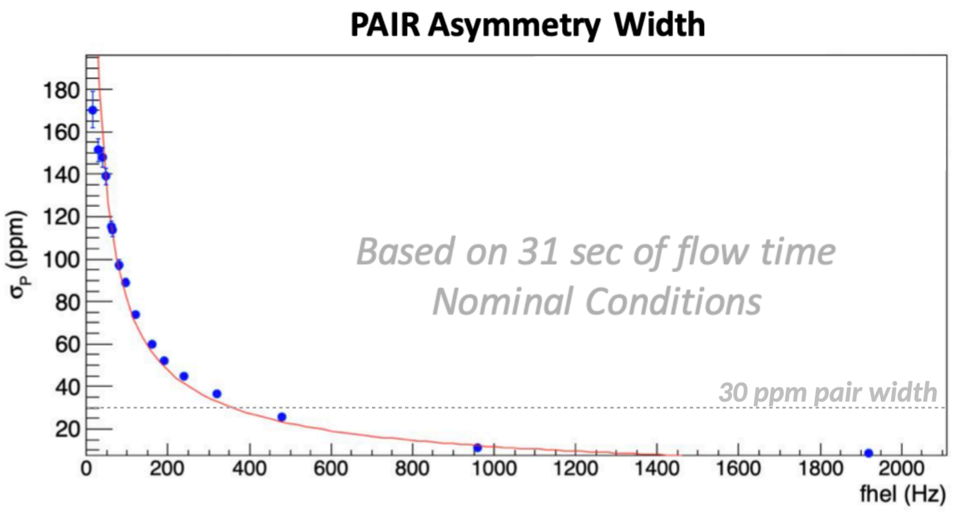


Liquid Hydrogen Target

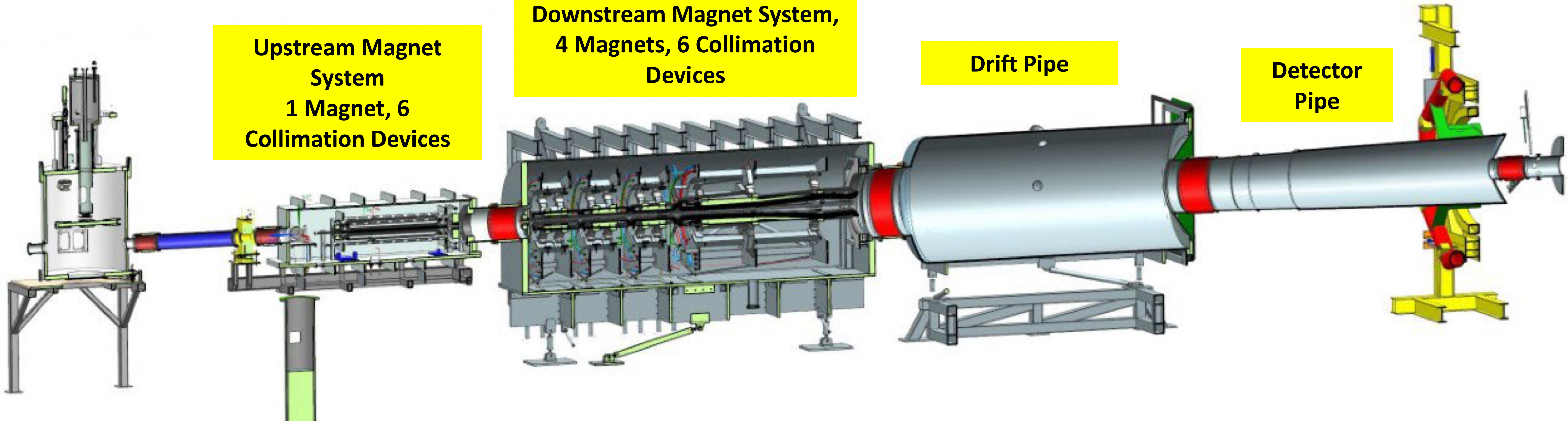


- The MOLLER target is designed using CFD to meet the demanding requirements:
  - Target power: 4 kW, Target flow: 25 l/s, Density fluctuation: <30 ppm
  - The Q_{weak} target (3kW, 17 l/s) demonstrated the capability of high-power, high-stability targets and CFD design tools.

Target Parameters	
Cell length	125 cm
Cell thickness	8.93 g/cm^2
Radiation length	14.6%
p, T	35 psia, 20K
ϕ acceptance	5 mrad (0.3°)
Target power	4000 W



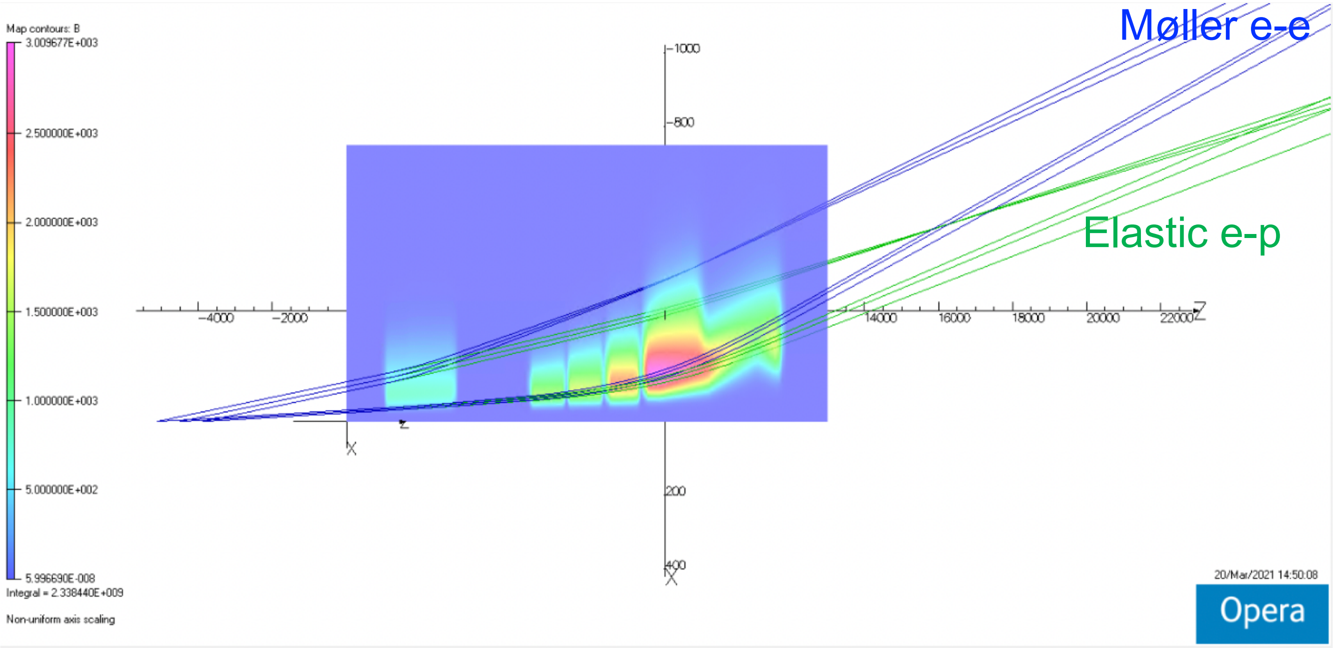
MOLLER Spectrometer



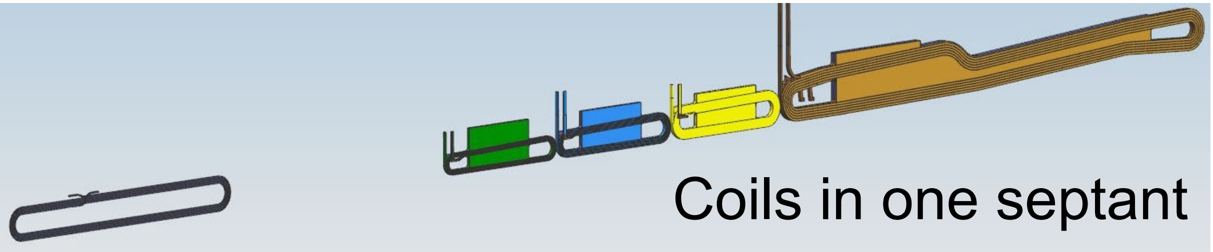
- Extent of spectrometer scope is 26.5 m.
- Defines the acceptance of the experiment.
- Consists of a pair of 7-fold symmetry toroidal magnets.
  - The odd-fold symmetry provides ~100% acceptance for the identical-particle Møller scattering process.
  - The toroidal magnets use a conventional resistive copper coil design.
- The collimation system will protect the magnet coils from the high rate, sculpt the signal shape and remove the backgrounds.

Open Spectrometer System Separates Signal from Backgrounds

Side view of φ=0 field and tracks (center of open septant)



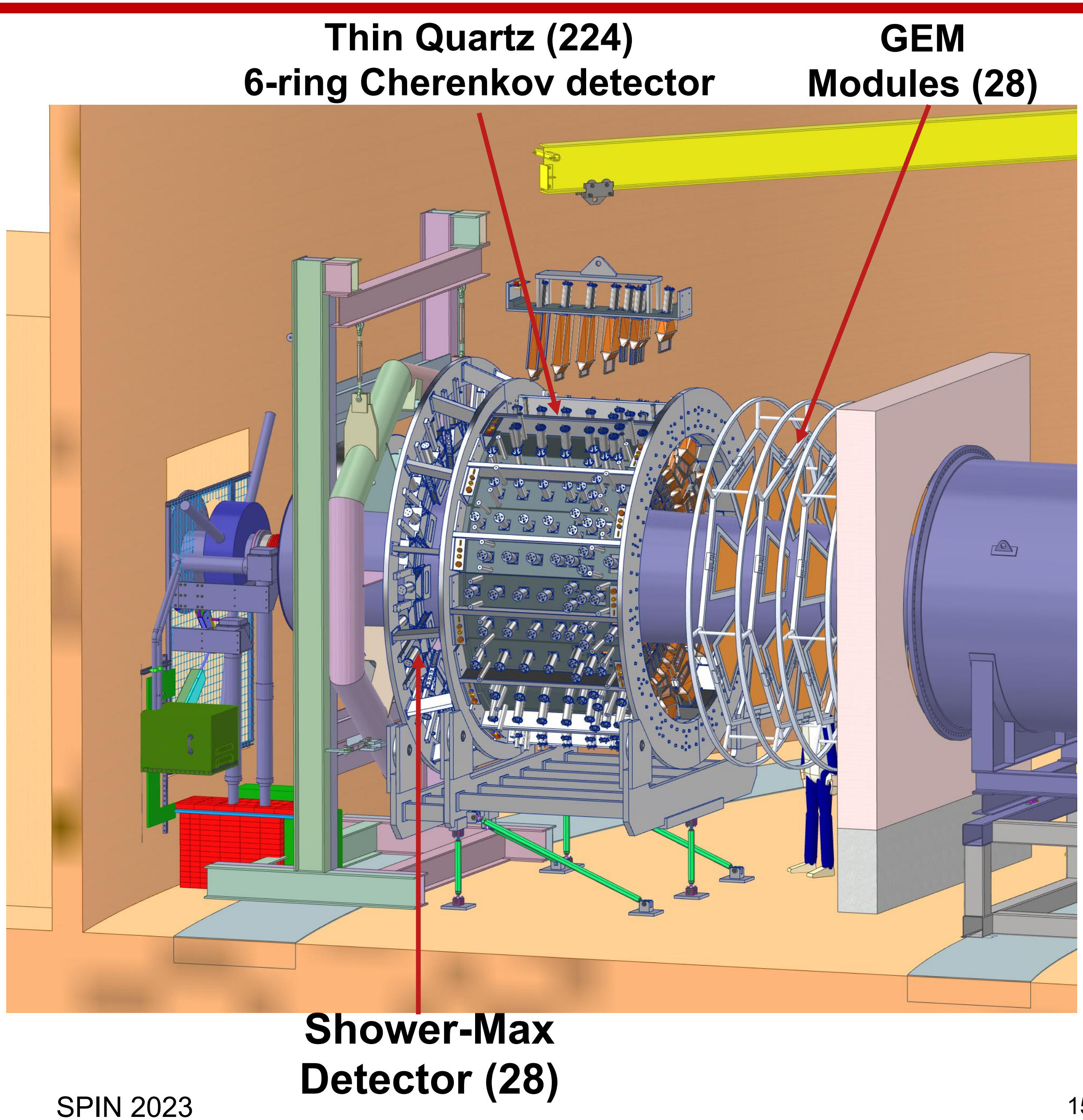
- The spectrometer allows us to separate the Møller electrons from the different backgrounds.



Coils in one septant

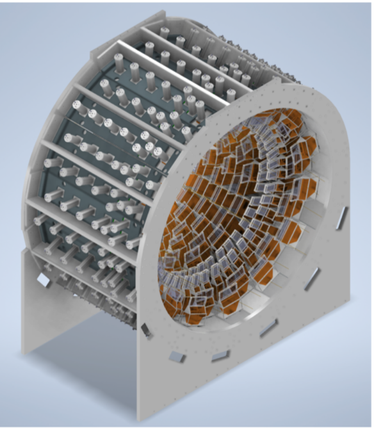
A prototype coil at JLab as setup for Survey

Integrating and Tracking Detectors Overview



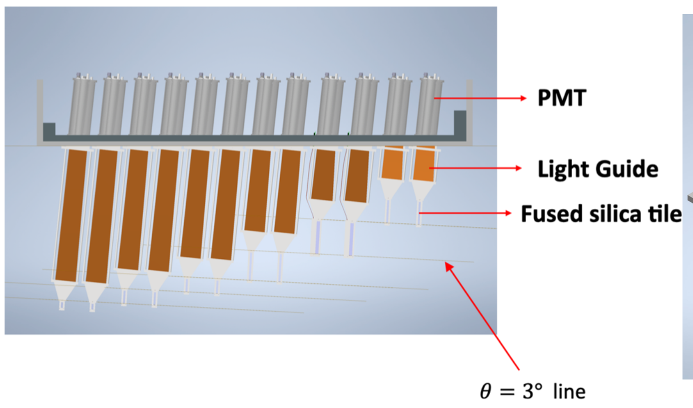
- **Integrating detectors:**
  - Asymmetry measurements of both signal and background, and beam and target monitoring.
  - 6 concentric rings. Ring 5 primarily capturing the Møller electron signal.
- **Shower-Max detector:**
  - Provides additional measurement of Ring 5 integrated flux $\Longrightarrow$ less sensitive to low energy and hadronic backgrounds.
- **Pion detector**
  - Hadronic dilution/asymmetries.
- **Integrating monitors:**
  - looking for a variety of anomalous helicity correlations.
- **GEMs**
  - Spectrometer calibration, electron scattering angle distribution and background measurements.

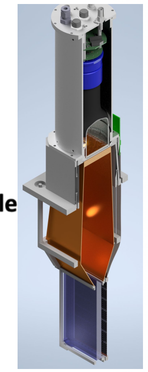
Detector Plane Segmentation

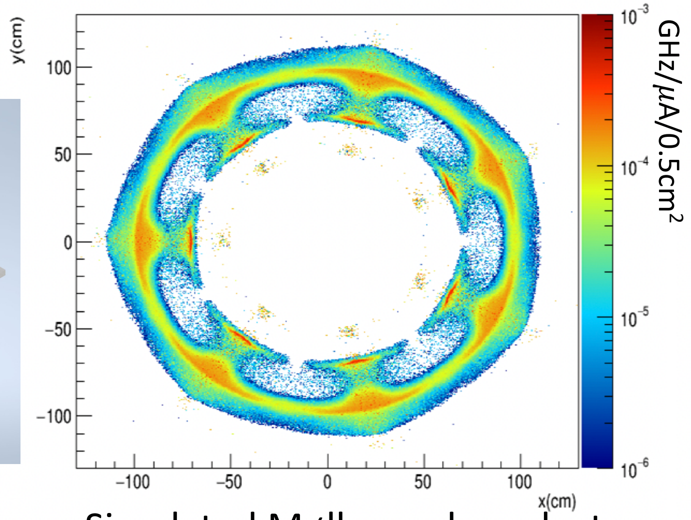


Detector assembly

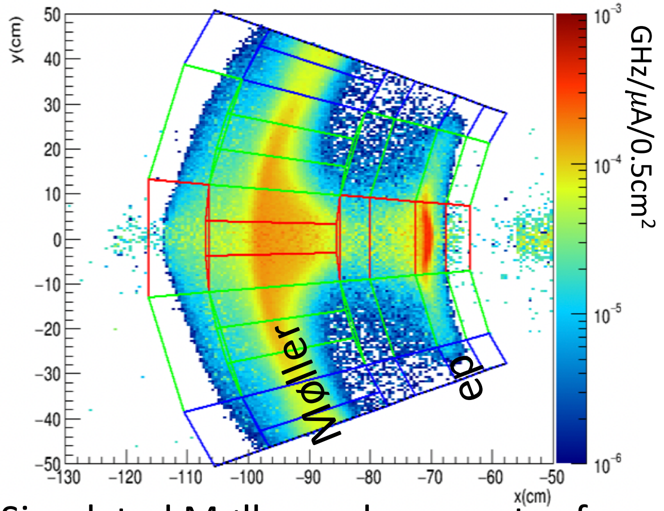
Beam left view





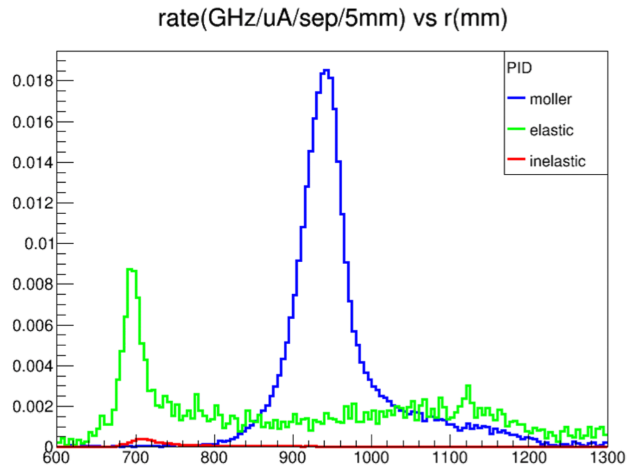


Simulated Møller and ep electron rates



Simulated Møller and ep e- rates for superimposed azimuthal and radial bins in one toroidal sector.

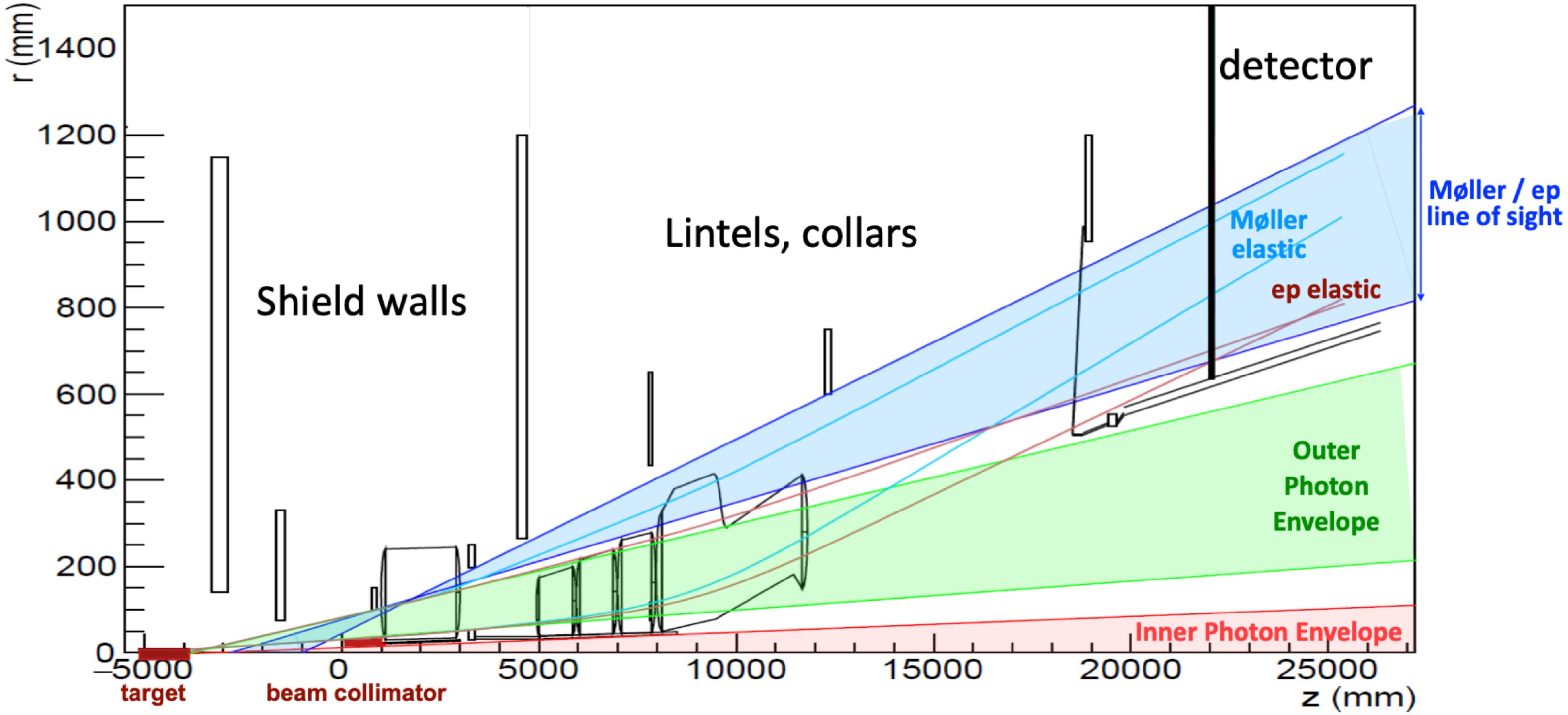
- The thin detector array consist of 6 rings and 224 detectors.
  - 28 segments around the annulus
  - Each segment has a total of 8 detector modules
  - 84 detectors in Ring 5 and 28 in each of the other rings
  - Each detector module consists of a quartz, tile, an air-core light guide, and a PMT.
- High level of segmentation separates irreducible backgrounds from Møller signal.
  - The modules must overlap slightly, to cover the azimuth so that the rings need to staggered along the beam direction. They also need to be spaced such that assembly and access to quartz tiles is possible.



Radial dist. at detector plane 26.5m from target, all φ includes rad. eff.

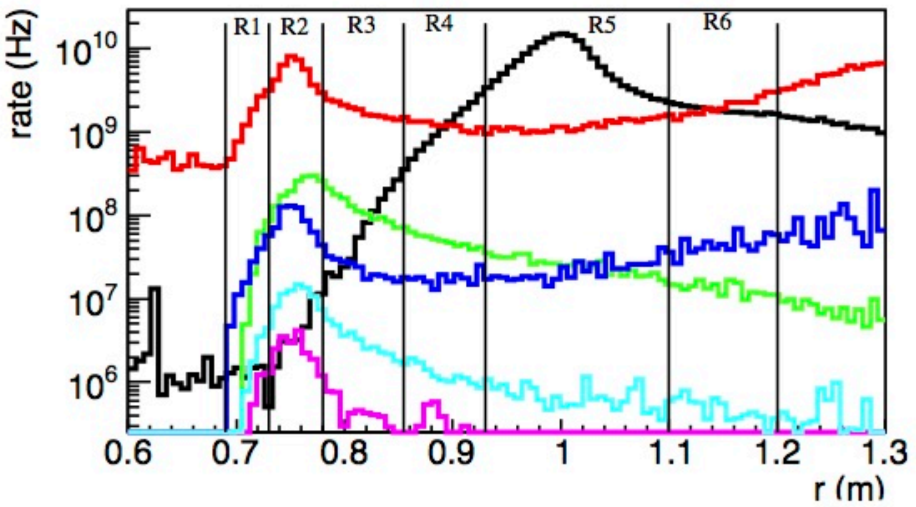
MOLLER Backgrounds

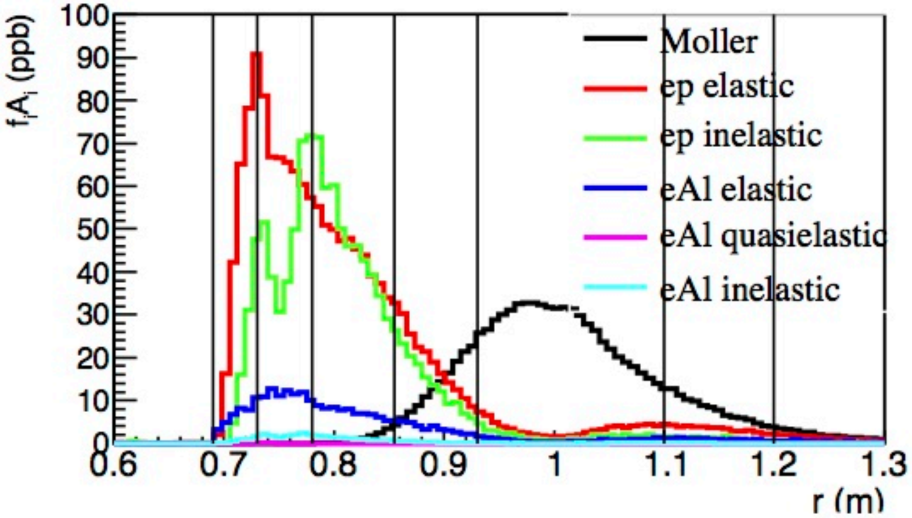
- Irreducible backgrounds arise from scattering off the target material that will pass through the spectrometer and arrive at the detector plane.
  - The principal irreducible background under the Møller "peak" is radiative elastic ep scattering.
- Other background sources
  - Photons and neutrons from 2 bounce collimation system.
  - Pions and muons: photo-production and DIS



Background Deconvolution

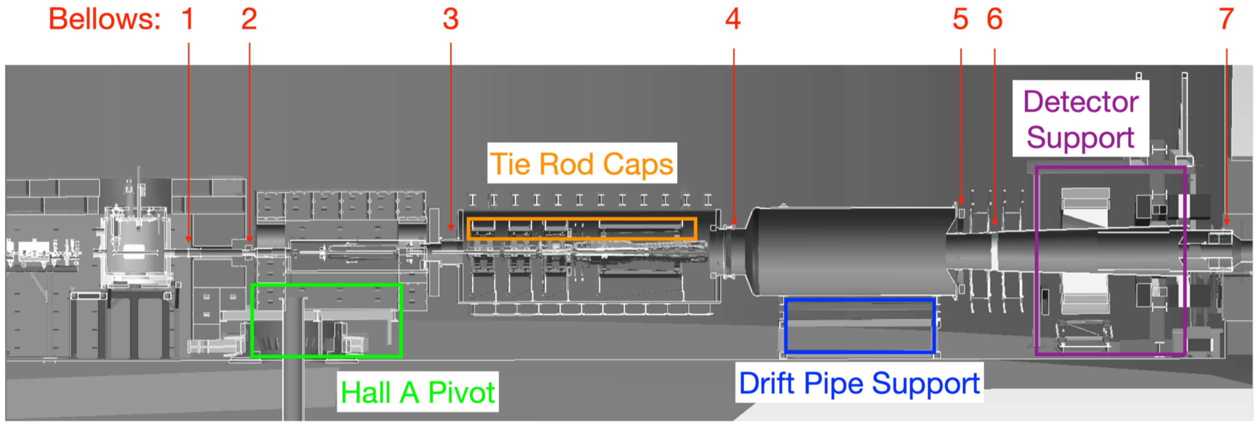
Kent Paschke





- Deconvolute the signal from the background using the segmented detector plane.
- Elastic ep: ~10% of the signal, asymmetry is well known.
- Inelastic ep: <0.3% of the signal but asymmetry is ~20x larger, not well known.
- The inelastic contribution is prominent in Rings 2 and 3, will be measured there.

Potential Background Asymmetries from Ferrous Materials



Elevation view of the MOLLER spectrometer, marked up from JLab CAD drawings.
The locations of potentially ferromagnetic materials are indicated.

Bellows: Inconel 625
Hall A Pivot, Tie Rod ends,
Detector support: mild steel
Drift pipe and downstream torus support: mild steel

- Potential backgrounds to the Møller scattering asymmetry due to scattering from polarized materials along the beam line or elsewhere in the Hall. → polarized materials are most likely due to ferromagnetic materials/components.
- Estimate false asymmetry A_f as;

$$A_f = f_r P_e P_s A_n$$

f_r: rate fraction of process
P_e: incident electron polarization
P_s: material electron polarization
A_n: analyzing power

- Goal: $A_f < 10^{-11}$
- In ~1G ambient field:

  Mild steel: $P_s \sim 10^{-2}$
  Stainless steel: $P_s \sim 10^{-5} \sim 10^{-7}$
  Inconel 625: $P_s \sim 10^{-8}$
  Aluminum (paramagnetic): $P_s < 10^{-9}$
  Conservative estimate: $P_e A_n \sim 10^{-3}$

The Projected Statistical and Systematic Uncertainties

Error Source	Fractional Error (%)	
	Run1	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**

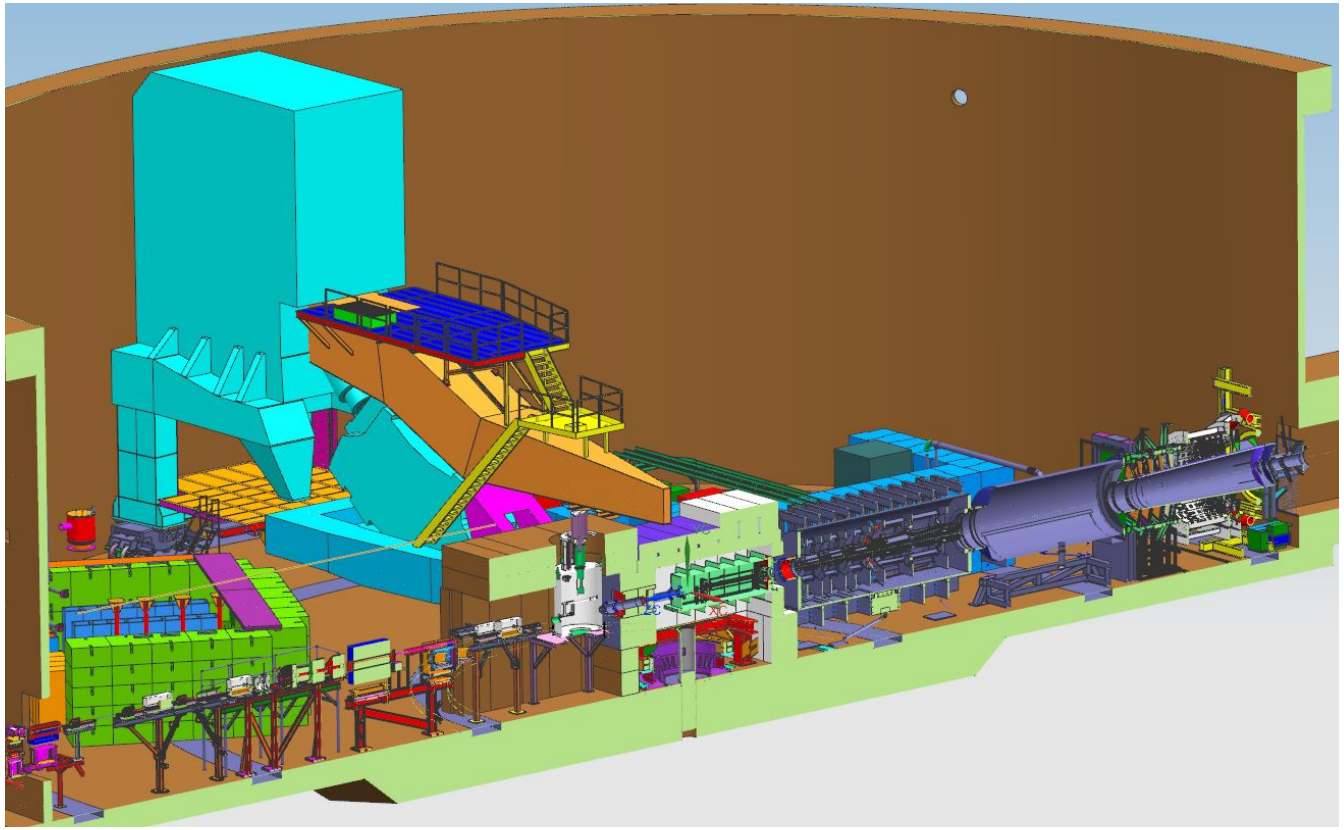
$$A_{PV} = \frac{\frac{A_{expt}}{P_b} - f_b A_b}{1 - f_b}$$

Run	PAC Days	Stat Error		Efficiency
Period	(prod)	$\sigma(A_{meas})$	$\sigma(A_{PV})$	
I	14	2.96ppm	11.4%	40%
II	95	1.08ppm	4.2%	50%
III	235	0.65ppm	2.5%	60%

Summary of notional run phases, with production and calibration estimates used for collaboration planning, to achieve the ultimate precision goals of the MOLLER experiment.

Timeline

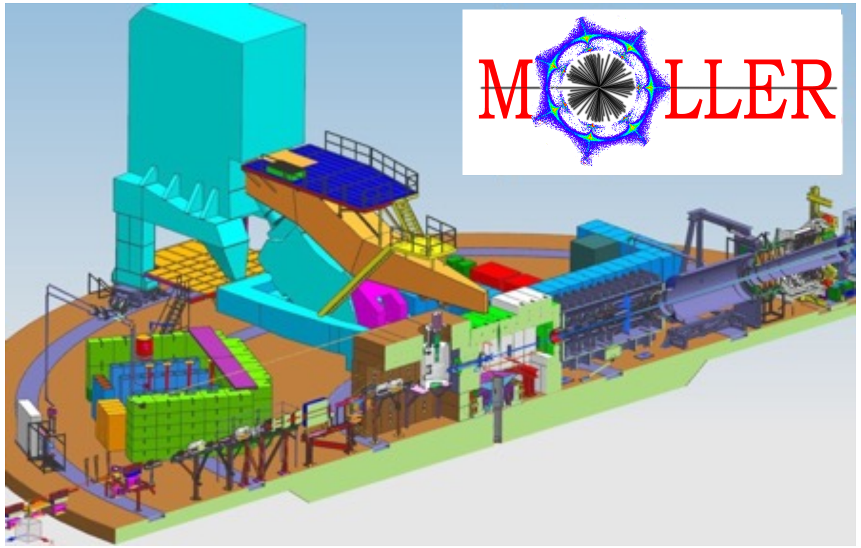
- 2023: CD-2/CD-3
  - Had a successful CD-2/3 Director's Review in August 2023.
  - MOLLER CD-2/3 Independent Project Review will take place in early October 2023.
- 2024: Construction
  - We must sufficiently advance all subsystem acquisition/construction by mid-2024
- 2025: Installation
  - The end of 2024 to end of 2025 installation.
- 2026: Physics
  - 2026 – 2028 data taking.



Construction funding: DOE (MIE), NSF, CFI/RM
Research funding: DOE, NSF, NSERC

Summary

- MOLLER represents a compelling opportunity to take advantage of the 11 GeV JLab beam at the upgraded facility.
  - Most sensitive probe of new flavor and CP-conserving neutral current interactions.
- The unique discovery capability in MOLLER will be very important.
  - If LHC sees any anomaly in high luminosity phases of 14 TeV.
  - MOLLER provides excellent sensitivity to Beyond Standard Model physics.
- We had a successful CD-2/3 Director's Review in August 2023.
  - things in very good shape headed into the CD-2/3 Review.
- Will have the MOLLER CD-2/3 Independent Project Review in early October 2023.



Thank You!

MOLLER Collaboration

Krishna Kumar

- 180 authors, 34 institutions, 4 countries.
- **Spokesperson:** Krishna Kumar (UMass, Amherst)
- **Executive Board Chair and Deputy Spokesperson:** Mark Pitt (Virginia Tech)
- **Other Executive Board Members**
  - David Armstrong (William & Mary), James Fast/Ruben Fair (JLab), Michael Gericke (Manitoba), Mark Jones (JLab), Juliette Mammei (Manitoba), Kent Paschke (UVa), Paul Souder (Syracuse U.)

MOLLER Working Groups

Polarized Source
Beam Instrumentation
Hydrogen Target
Spectrometer
Integrating Detectors
Tracking Detectors
Hall Integration
Polarimetry
Electronics/DAQ/Offline
Simulations
Physics Extraction

Technical Board

MOLLER Project Personnel

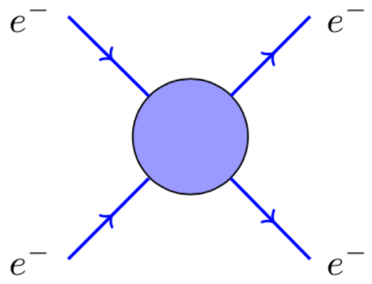
James Fast (Emeritus) / Ruben Fair (Incoming), MOLLER Project Manager

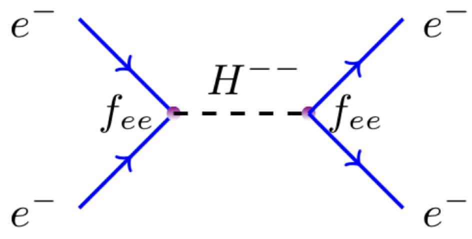
Project Leads
Control Account Manager
Technical Leads

Backup

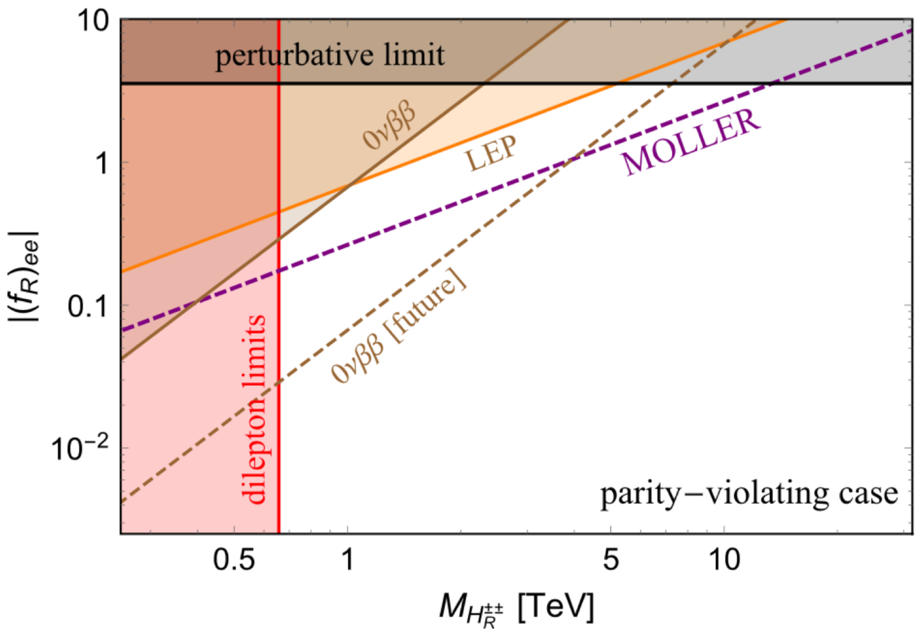
New Physics Beyond the Standard Model

- Most sensitive probe of new flavor and CP-conserving neutral current interactions over next decade.
  - high energy (multi-TeV) scale dynamics (Z', electron compositeness, supersymmetry, **doubly charged scalars**,…)





P. S. B. Dev, M. J. Ramsey-Musolf, Y. Zhang
PHYSICAL REVIEW D 98, 055013 (2018)

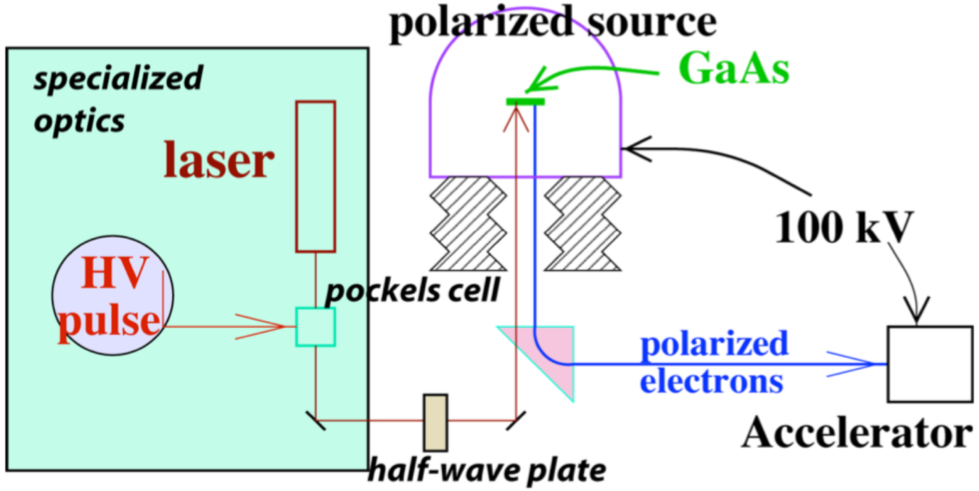


MOLLER prospect for the RH doubly-charged scalar mass $M_{H_R^{\pm\pm}}$ in the parity-violating LRSM and the coupling $|(f_R)_{ee}|$

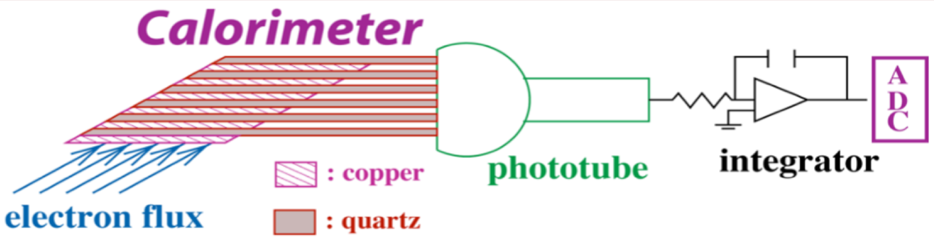
- $M_{H_R^{\pm\pm}}$ could be probed up to ≃10 TeV for a $\mathcal{O}(1)$ Yukawa coupling by MOLLER → This is far beyond the direct search capability of LHC or even future 100 TeV colliders.

Conceptual Overview of the Experimental Technique

Krishna Kumar



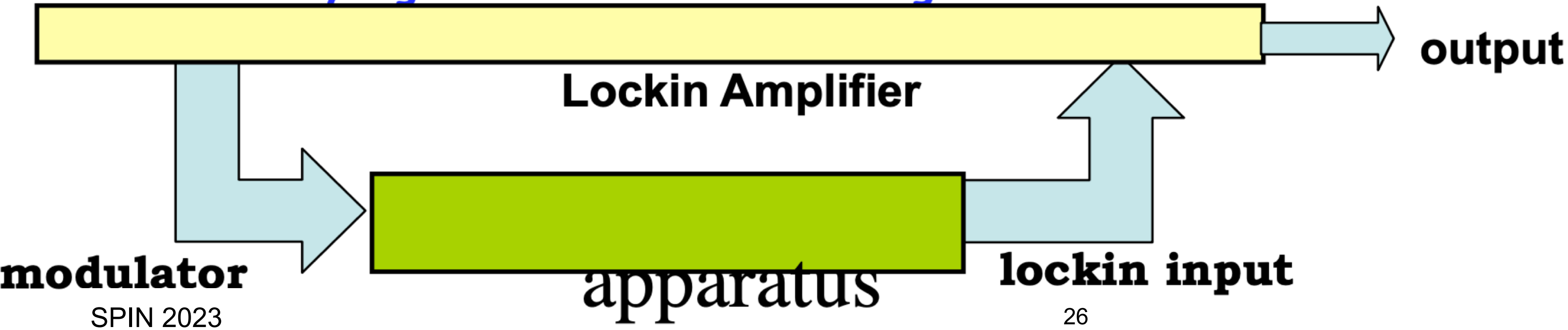
- **Optical pumping of a GaAs wafer: "black magic" chemical treatment to boost quantum efficiency**
- **Rapid helicity reversal: polarization sign flips > 100 Hz to minimize the impact of drifts**
- **Helicity-correlated beam motion: under sign flip, beam stability at the sub-micron level**



"Flux Integration": very high rates

direct scattered flux to background-free region

Tiny signal buried in known background



Apparatus:

beam, target, spectrometer, detectors and accelerator all interconnected!

Beam Corrections

Remove correlations to beam intensity, position, angle, and energy fluctuations:

$$\left(A_{cxpt}\right)_i = \left(\frac{\Delta F}{2F} - \frac{\Delta I}{2I}\right)_i - \sum_j \left(\alpha_j \left(\Delta X_j\right)_i\right)$$

Creates noise and also a systematic false asymmetry from average difference

Monitor resolution
Calibration imprecision

Parameter	Noise (65 μA)
Statistical Width	**~82 ppm**
Beam Intensity Resolution	10 ppm
Beam Position Noise	7 ppm

Error Source	Fractional Error (%)
Beam (position, angle, energy)	0.4
Beam (intensity)	0.3

Keep beam asymmetries small

- Special techniques with the polarized source laser optics
- Beam transport configuration to avoid exacerbating differences
- “slow reversals” that flip the sign of beam asymmetries
- feedback

Beam correction analysis

Two calibration techniques
- beam modulation for calibration
- linear regression

Combined, for precision and accuracy in the PREX-2 analysis
- Removed >90% noise
- 4% precision on total correction

Beam Property	Assumed Sensitivity	Accuracy of Correction	Required 1 kHz random fluctuations	Required cumulative helicity-correlation	Systematic contribution
Intensity	1 ppb / ppb	$\sim$1%	$<$ 1000 ppm	$<$ 10 ppb	$\sim$ 0.1 ppb
Energy	-0.7 ppb / ppb	$\sim$5%	$<$ 108 ppm	$<$ 1.4 ppb	$\sim$ 0.05 ppb
Position	1.7 ppb / nm	$\sim$5%	$<$ 47 μm	$<$ 0.6 nm	$\sim$ 0.05 ppb
Angle	8.5 ppb / nrad	$\sim$5%	$<$ 4.7 μrad	$<$ 0.12 nrad	$\sim$ 0.05 ppb
Spot Size	0.012 ppb / ppm	-	-	$<$ 10 ppm	$\sim$ 0.1 ppb

BCM Resolution

Parameter	Noise (65 μA)
Statistical Width (1016 μs)	**~82 ppm**
Target Density Fluctuation	30 ppm
Beam Intensity Resolution	10 ppm
Beam Position Noise	7 ppm
Detector Resolution (25%)	21 ppm
Electronics Noise	10 ppm
Measured Width	**91 ppm**

Existing BCM receivers

- Bench tests with well known receivers = 42 ppm
- Seven monitors (for MOLLER), average to get ~ 16 ppm resolution
- Would imply 92ppm ultimate pair width (instead of 91ppm) if not improved

Would prefer to do better, to enable systematic studies with better resolution

Two strategies for improvement

- New version of JLab electronics has been fielded
  - Expect 2x better (~22 ppm) resolution for single monitor
  - Bench tests suggest further improvements by improving local oscillator
- LBNL digital processor prototype (Kolomensky and group)
  - Uses fast sampling ADC's capable of direct RF sampling
  - Eliminates need for local oscillator
  - Initial bench studies give ~ 10 ppm resolution for 960 Hz window pairs

LBNL prototype receiver

Readout

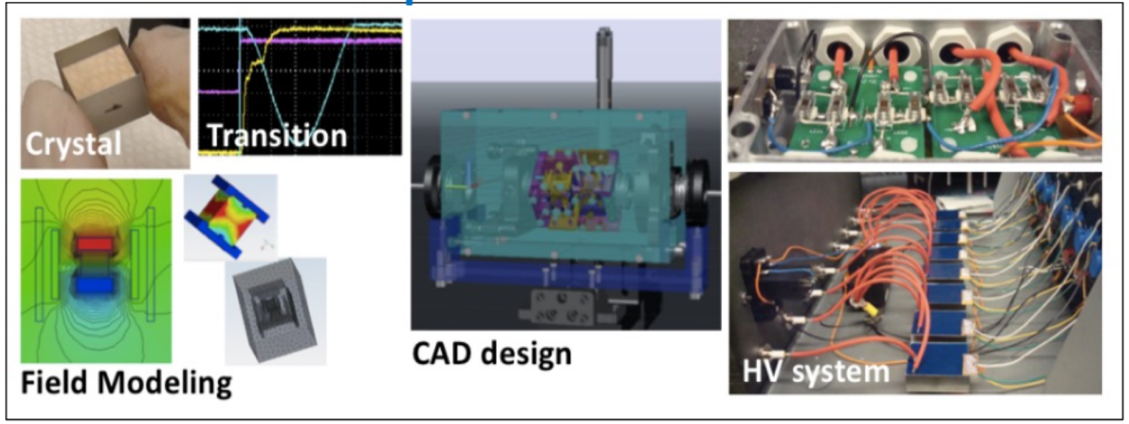
- Existing receivers use Digital-to-Analog Convertor → Integrators, matching detector readout chain
- Option to use digital readout favored, still being explored

Technical and Operational Experience from 3rd Generation PV Experiments

MOLLER
Kent Paschke

Careful configuration of the polarized source kept beam difference averages very small during PREX-2

RTP Pockels Cell: Improved control of beam fluctuations

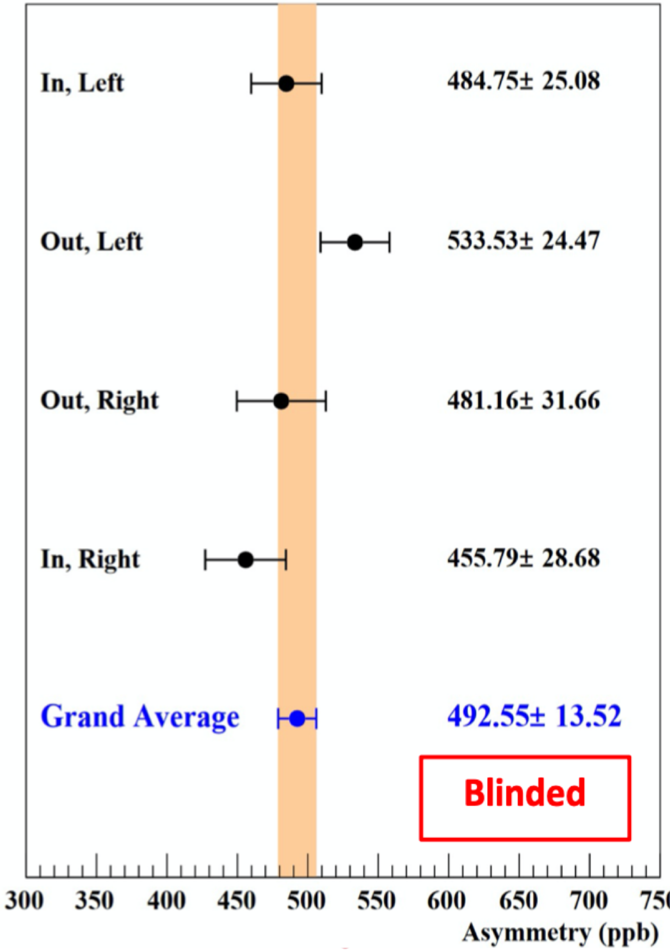


	MOLLER (344 PAC days)	MOLLER Run 1 (25 PAC days)	PREX-2 achieved (19 PAC days)
Intensity	<10 ppb	<30 ppb	25 ppb
Energy Asymmetry	<1.4 ppb	<7 ppb	0.8 ppb
Position Difference	<0.6 nm	<3 nrad	2.2 ppb
Angle Difference	<0.13 nrad	<0.6 nrad	0.6 nrad

Beam correction calibration, analysis and cross-checks

type	Mean(ppb)
X1	-22.33
Y1	22.5
E	-70.44
Y2	-2.84
X2	9.7
	1.27
	-0.01
	1.06
	0.26
	0.24
	0.18
	0.06
	-60.38

Total beam corrections:
(60.4 ± 2.5) ppb

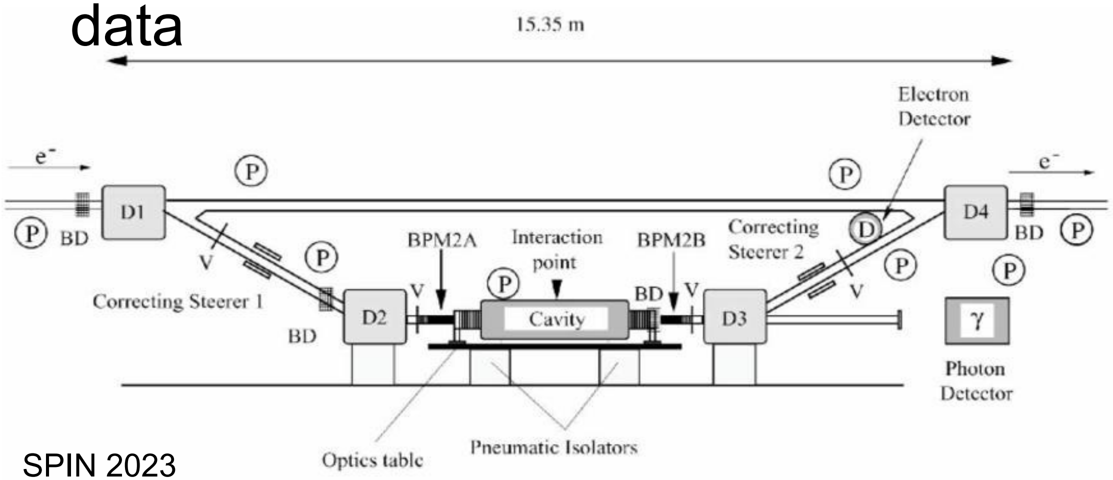


Polarimetry in the Experimental Hall

- Two independent measurements which can be cross checked.
- Continuous monitoring during production (protects against drifts, precession)
- Statistical power to facilitate cross normalization (get to systematic limit in about 1 hour)

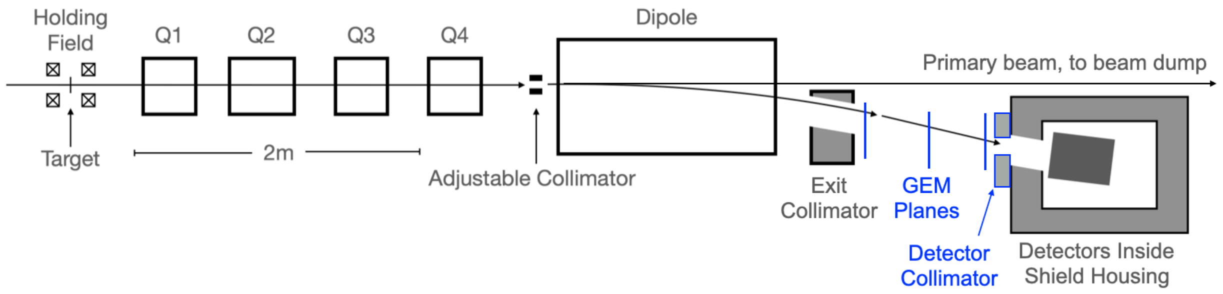
Compton Polarimetry

- Continuous, non-invasive measurement
- Utilized integrating technique with photon detector
- Polarimeter runs will be taken continuously alongside the main detector data



Moller Polarimetry

- Low-current, invasive measurement
- 0.5% instrumental precision for Hall C polarimeter
- Polarimeter runs will be taken approximately every week



Meeting MOLLER beam differences

Source configuration

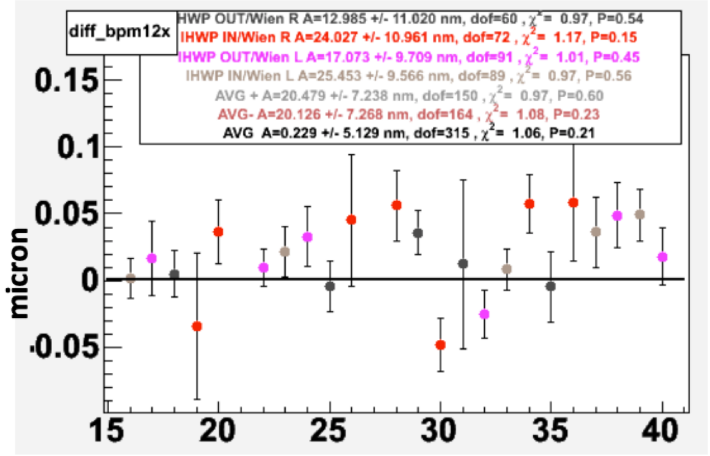
Adiabatic Damping

- Good beam match keeps variation small

Slow Reversals

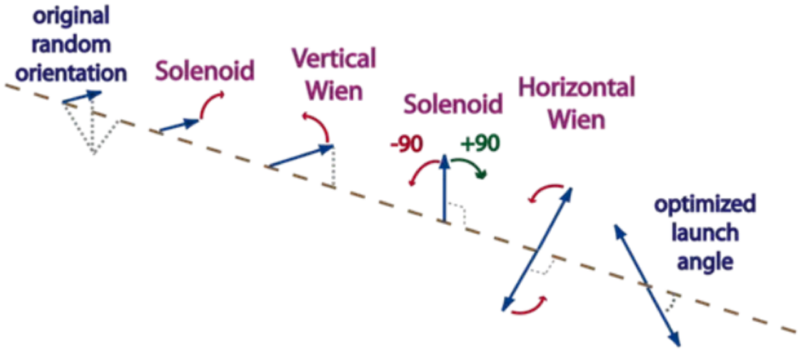
- Laser optics reversals (e.g. IHWP)
- Injector Spin Manipulation (“Wien” rotators)
- g-2 precession
- Net factor ~10 suppression of beam asymmetries

PREX-II showed ISM cancellation of position differences



Injector Spin Manipulation

- Solenoids + 2 Wien rotations
- ~80 reversals during run phase 2&3 (weekly)



g-2 rotation

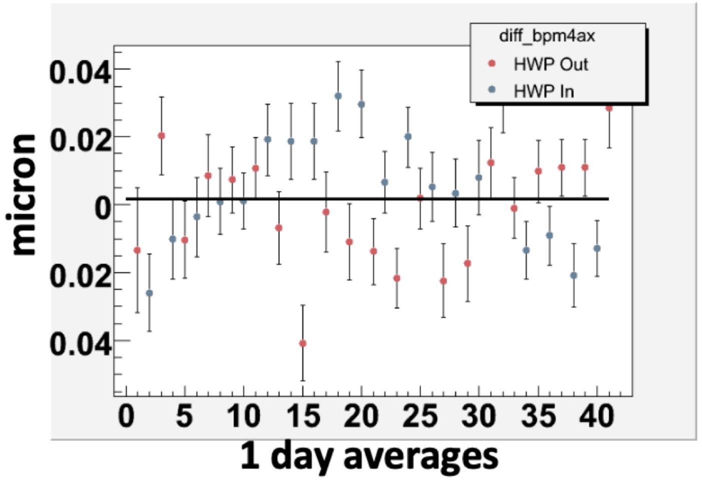
- Beam energy (ΔE~100 MeV)
- ~few reversals during run phases 2 and 3

Meeting MOLLER beam differences

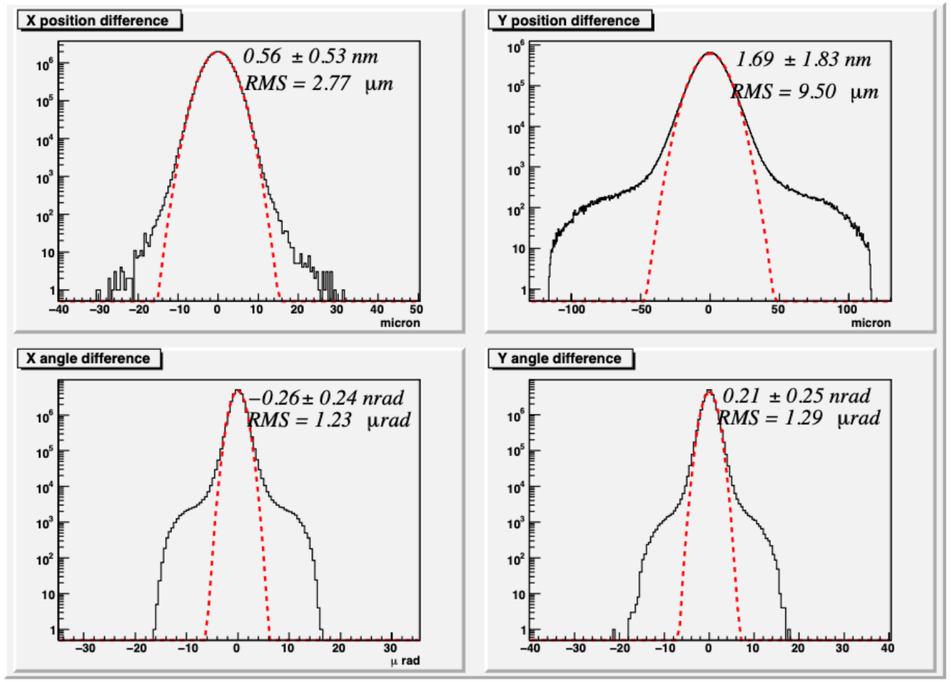
Kent Paschke

- Injector source laser — 20-50 nm in 5MeV injector
- e- beam delivery (adiabatic damping) — factor of 10-100 from adiabatic damping
- cancellation with "slow" reversals — factor of 2-10
- detector symmetry — Factor >10 in sensitivity
- correction calibration (beam modulation) — 10% precision

HAPPEX-II: position difference convergence



HAPPEX-II: Zero position differences



Factor of two in beam position asymmetry would be a small hit on total error bar

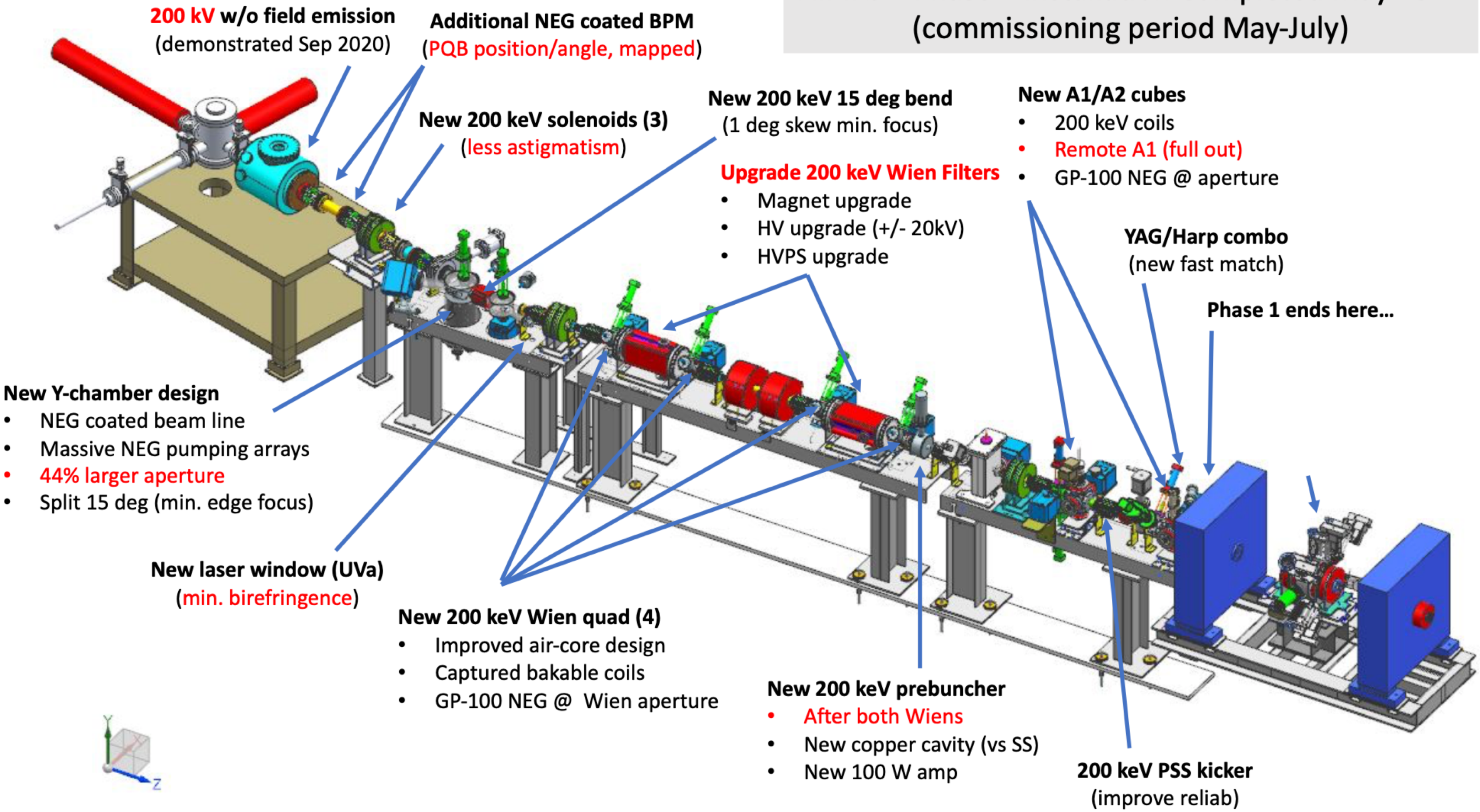
uncertainty		
statistical	2.1%	
systematic (total)	1.1%	
beam (position, angle, E)		0.4%
beam(intensity)		0.3%
beam (2nd moment)		0.4%

→ if doubled, total syst ~1.3%

Phase 1 Injector Upgrade

Kent Paschke

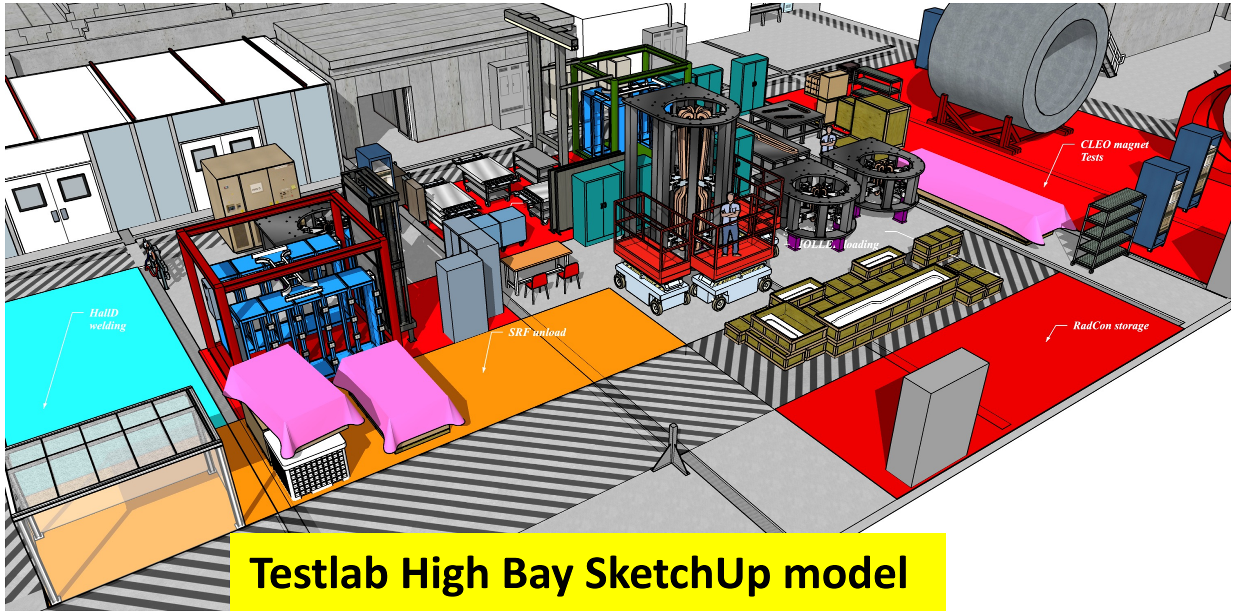
AIPINJ – Phase 1 Installation Completed May 2021
(commissioning period May-July)



MOLLER installation planning scope

Vladimir V. Berdnikov

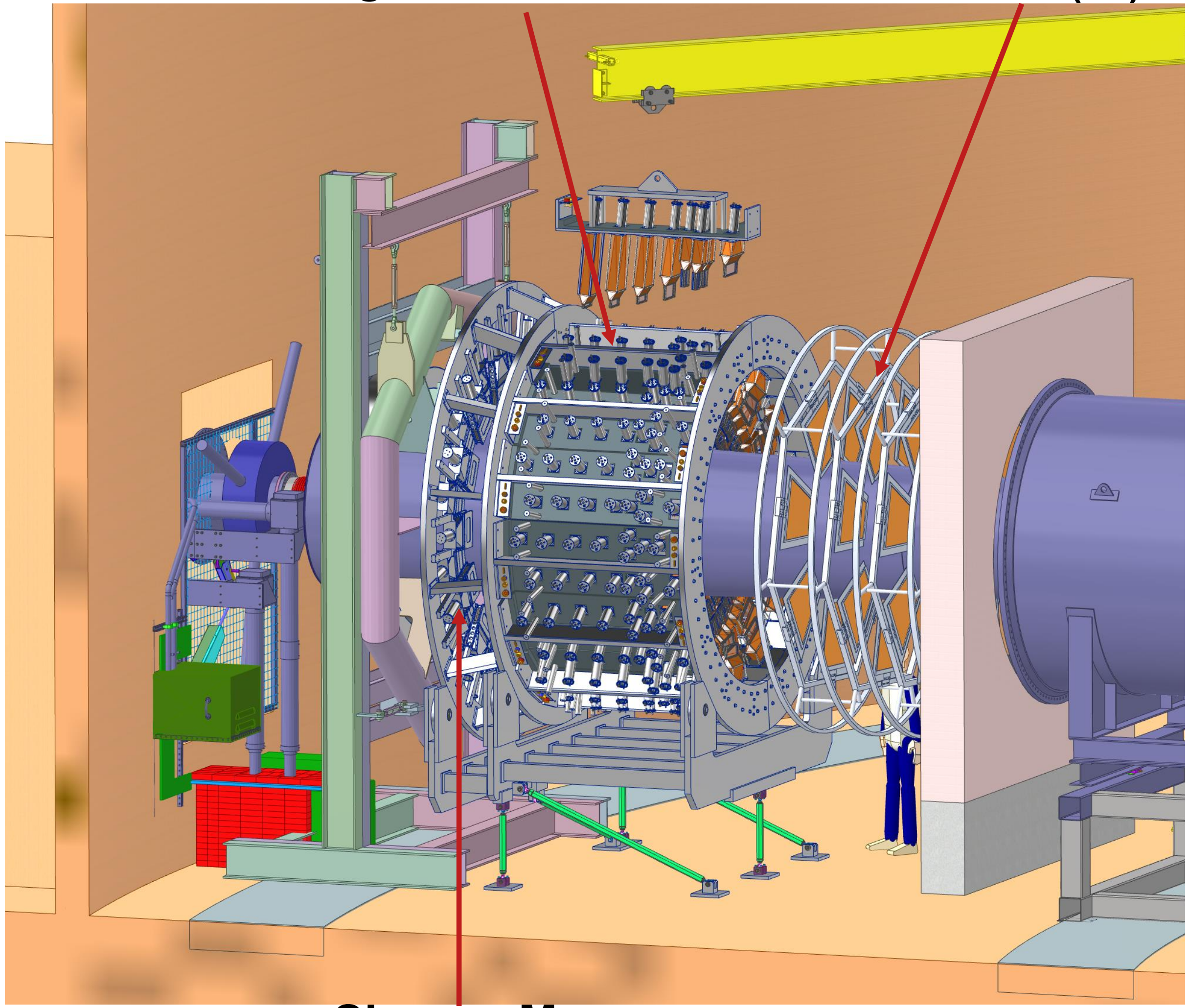
- MOLLER is a challenging, large-scale installation that will take >1 year.
- W&M Physics High Bay lab will facilitate most detector subsystems preinstallation, alignment, and tests prior to moving into experimental Hall A.
- The target will be preassembled at the EEL building.
- The downstream torus magnets will be preassembled and tested at the Testlab High Bay area FY(23-24)



Testlab High Bay SketchUp model

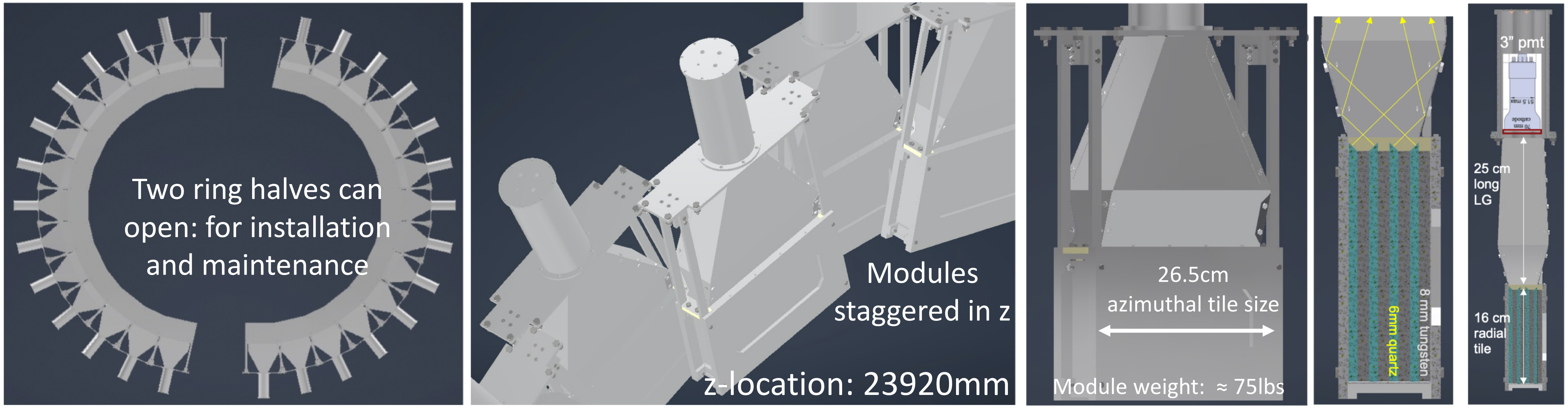

W&M High Bay

Integrating and Tracking Detectors Overview



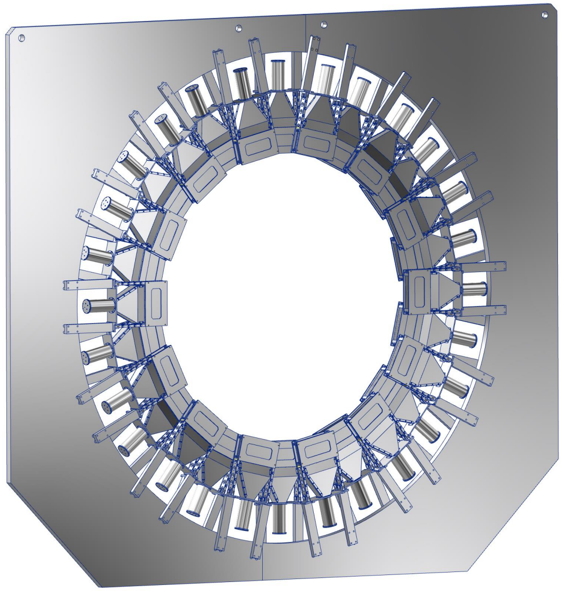
- **Integrating detectors** are an array of detectors based on quartz as the active element.
  - Asymmetry measurements of both signal and background, and beam and target monitoring.
  - 6 concentric rings. Ring 5 primarily capturing the Møller electron signal.
- **Shower-Max detector** concept uses a layered "stack" of tungsten and fused silica (quartz) to induce EM showering and produce Cherenkov light
  - Provides additional measurement of Ring 5 integrated flux $\Rightarrow$ less sensitive to low energy and hadronic backgrounds.
  - Will also operate in tracking mode to give additional handle on background pion identification.
  - Will have good resolution over full energy range ($\lesssim$ 25%), radiation hard with long term stability and good linearity.
- **Pion detector**
  - Hadronic dilution/asymmetries
- **Integrating monitors** are "canaries", looking for a variety of anomalous helicity correlations
  - Small Angle (SAMs); Large Angle (LAMs); Diffuse Background (DBMs); Scanners (remotely controllable)
- **GEMs**
  - Spectrometer calibration, electron scattering angle distribution and background measurements.

Shower-Max Detector



Dustin McNulty

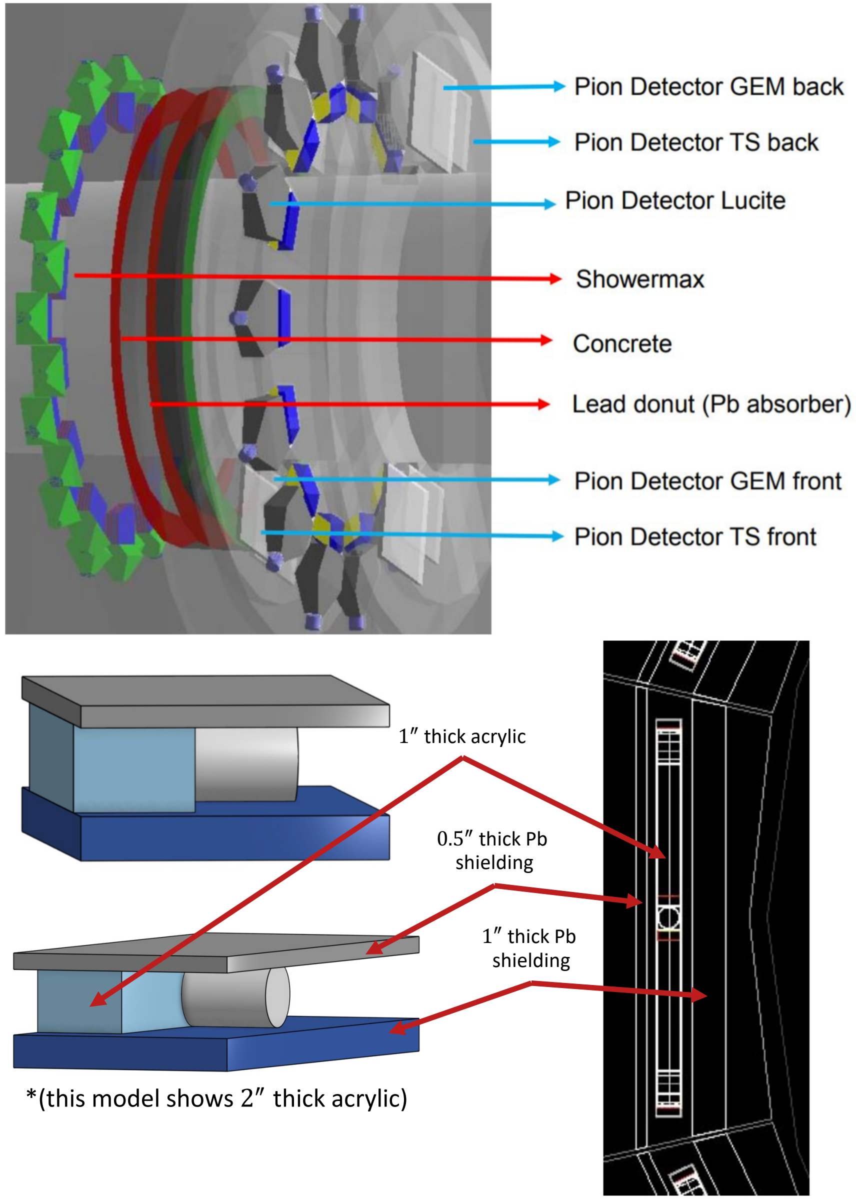
- ShowerMax detector: ring of 28 sampling calorimeters intercepting physics signal flux 1.7 m downstream of Ring 5
- Detector *z*-location and radial acceptance near finalized.
- New (final) quartz and tungsten tile sizes determined.
- CAD model updated and passed to engineer (Larry M Bartoszek) for FEA and external ring support structure design.
- Simulations of expected radiation loads in each quartz layer have been performed.



Larry M Bartoszek

Jefferson Lab

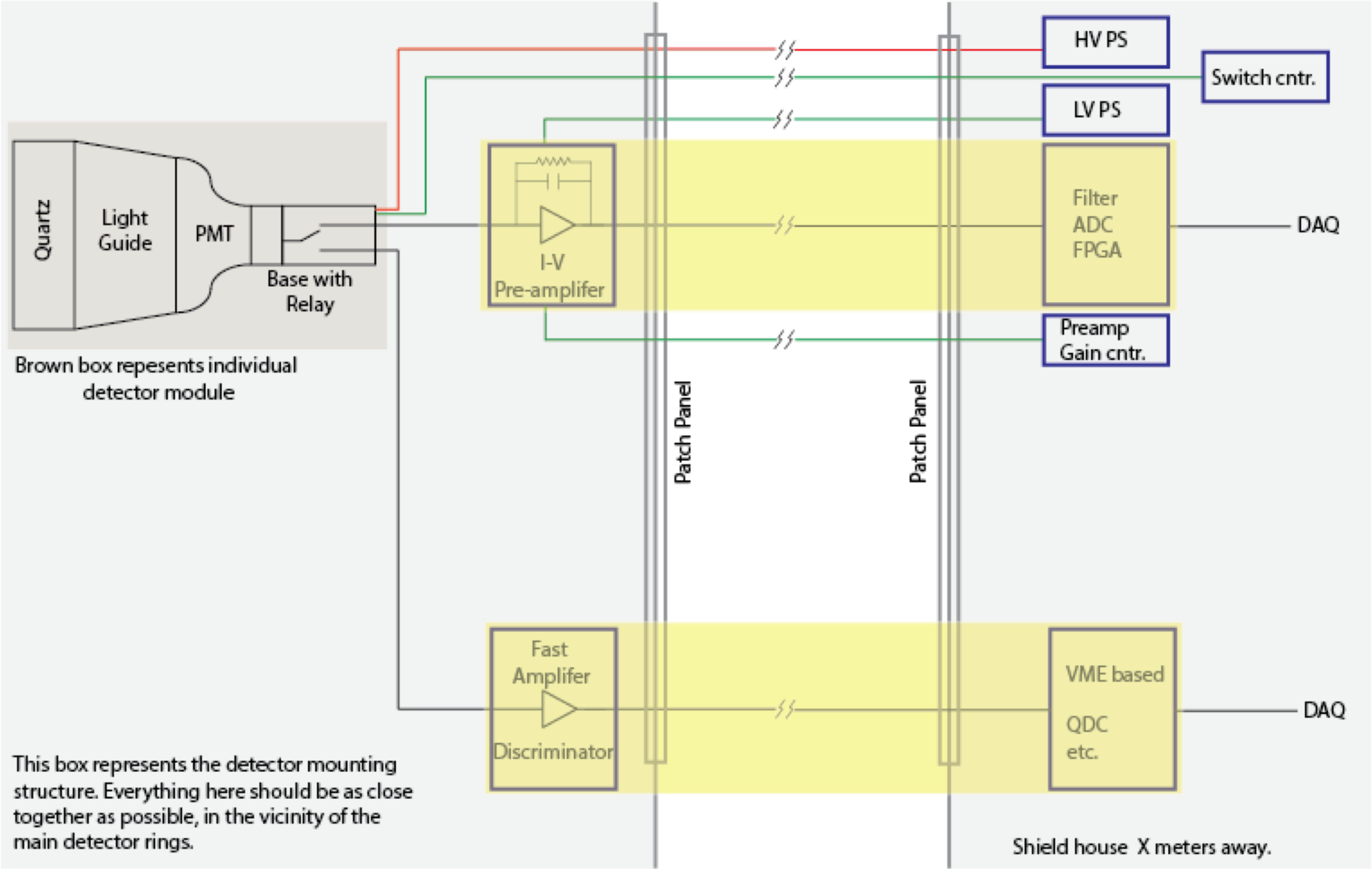
Pion Detector



David Armstrong Wouter Deconinck

- Original design had to be modified because of ShowerMax spray.
  - π/e photoelectron ratio ~10^{-3} due to ShowerMax secondaries producing copious flux of soft electrons (< 5 MeV) at pion detector
    - optimize optical design of lucite to maximize π/e ratio by using pion directionality, and allow for shielding at outer radial side
- New design is essentially a stack of lead-lucite-lead slabs [90° rotated design]:
  - $1''$ lucite layers (one or multiple)
  - PMT downstream, direct coupling to lucite
  - No more wedge, no more lightguide
  - Shielding on all sides, including outer radial side
- Rotated design indicates performance of up to 60% π/e photoelectron ratio
- Planned studies of rotated design:
  - Improved modeling of coupling to PMT
  - Optimization of length/thickness of lucite/shielding
  - Radiation at PMT (shielded from all sides)

Integrating Detector Signal Chain



Michael Gericke

- Separate readout chain for integration and counting mode
- In integration mode, chain goes from base to I-V preamp to ADC board (fully differential)
- Counting mode chain starts from base via separate cable
- Base is switched between the two modes via reed relay with a simple 5 V switching voltage.
- The highest rate in a single quartz detector will be ~5 GHz, while the lowest rate will be a few hundred MHz.