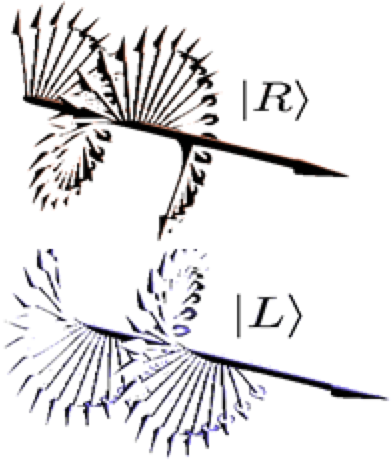
Parity Quality Beam

Caryn Palatchi

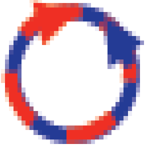
MOLLER ERR 7/2025

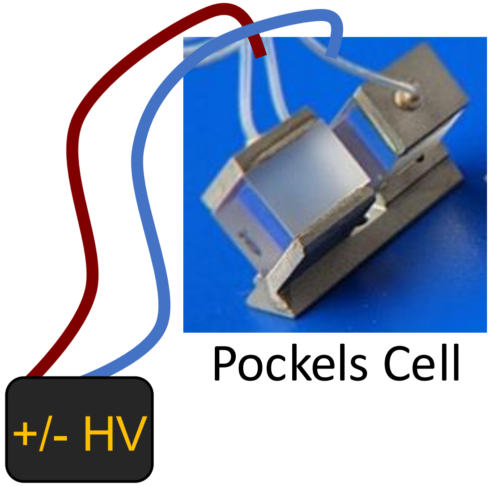
Beam from source to target

Laser Beam



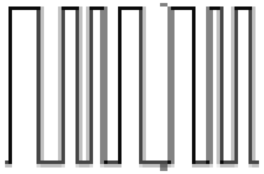
Circularly polarized light



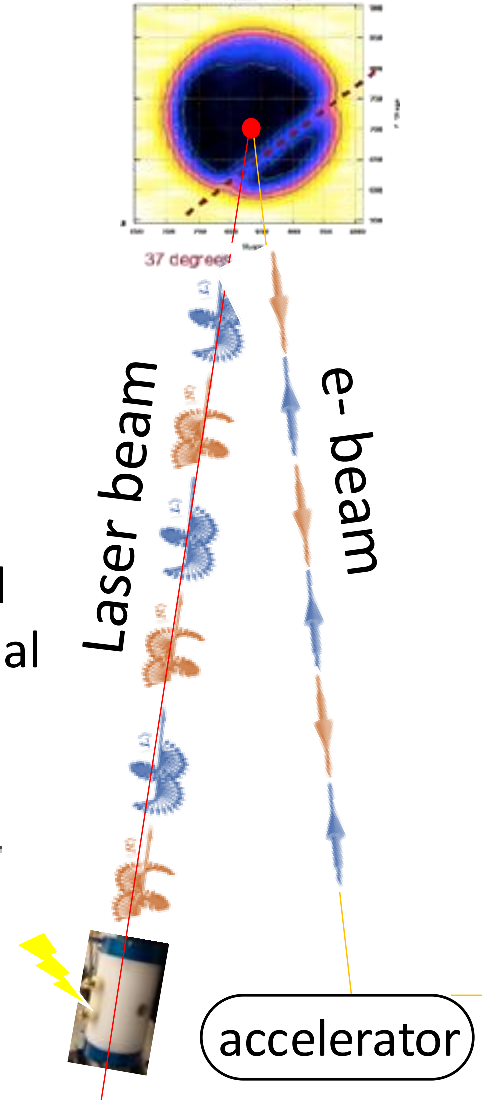


Pockels Cell

Randomized Helicity Signal

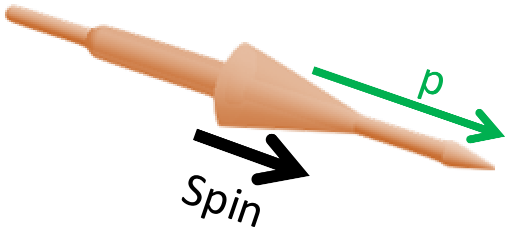


GaAs photocathode

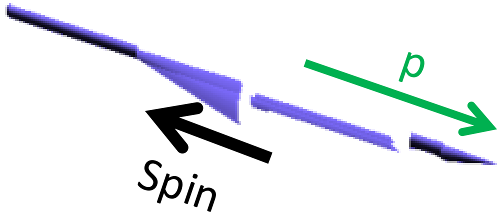


Electron Beam

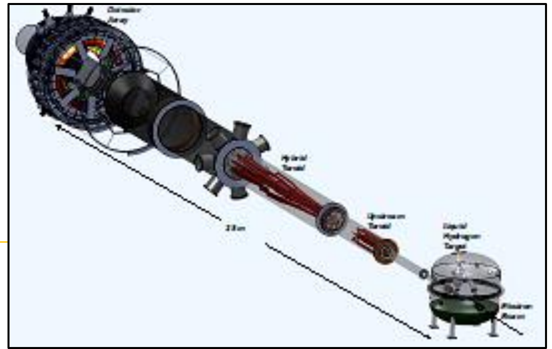
e- : Right handed



e- : Left handed



Experimental Hall

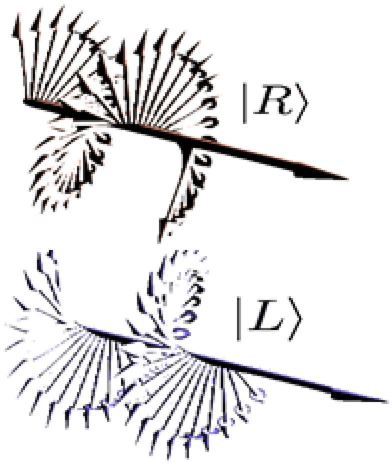


Ref: Silwal Thesis, Fig 6.7.2

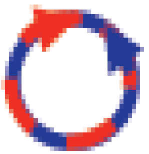
Beam from source to target

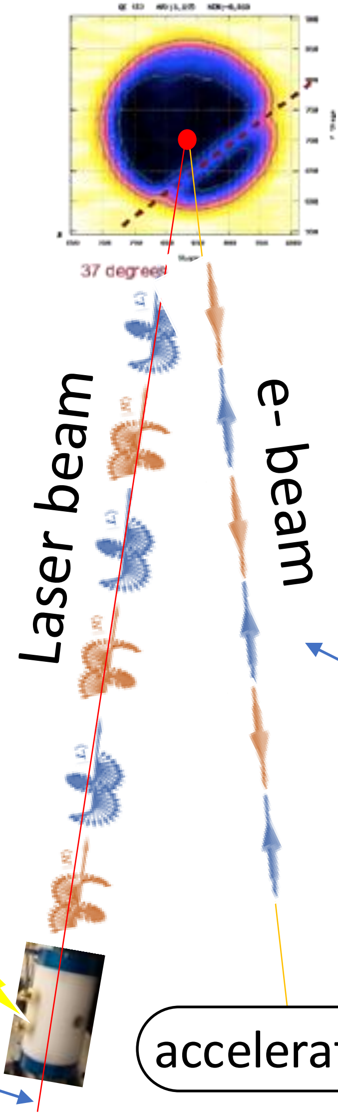
Both fast and slow reversals
8 reversal combinations
Helicity: HV +/-, IHWP out/in

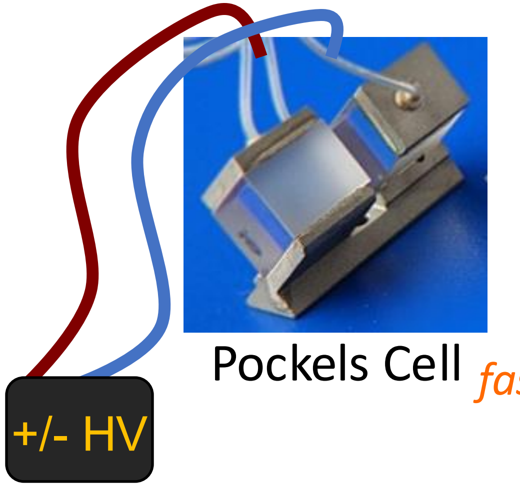
Laser Beam



Circularly polarized light



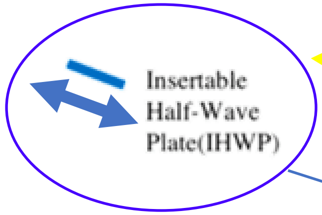




Pockels Cell *fast*

Randomized Helicity Signal

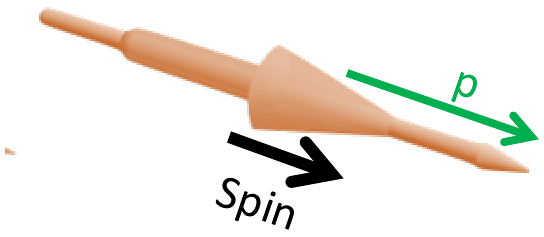
slow



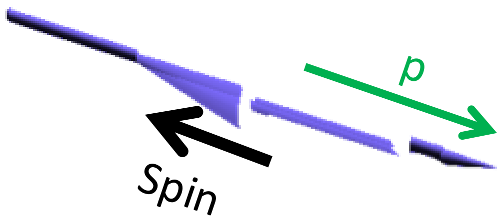
accelerator

Electron Beam

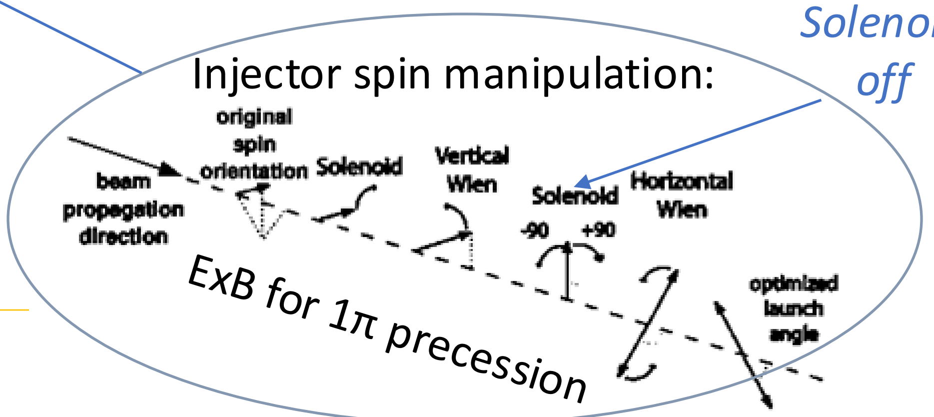
e- : Right handed



e- : Left handed



Solenoid off

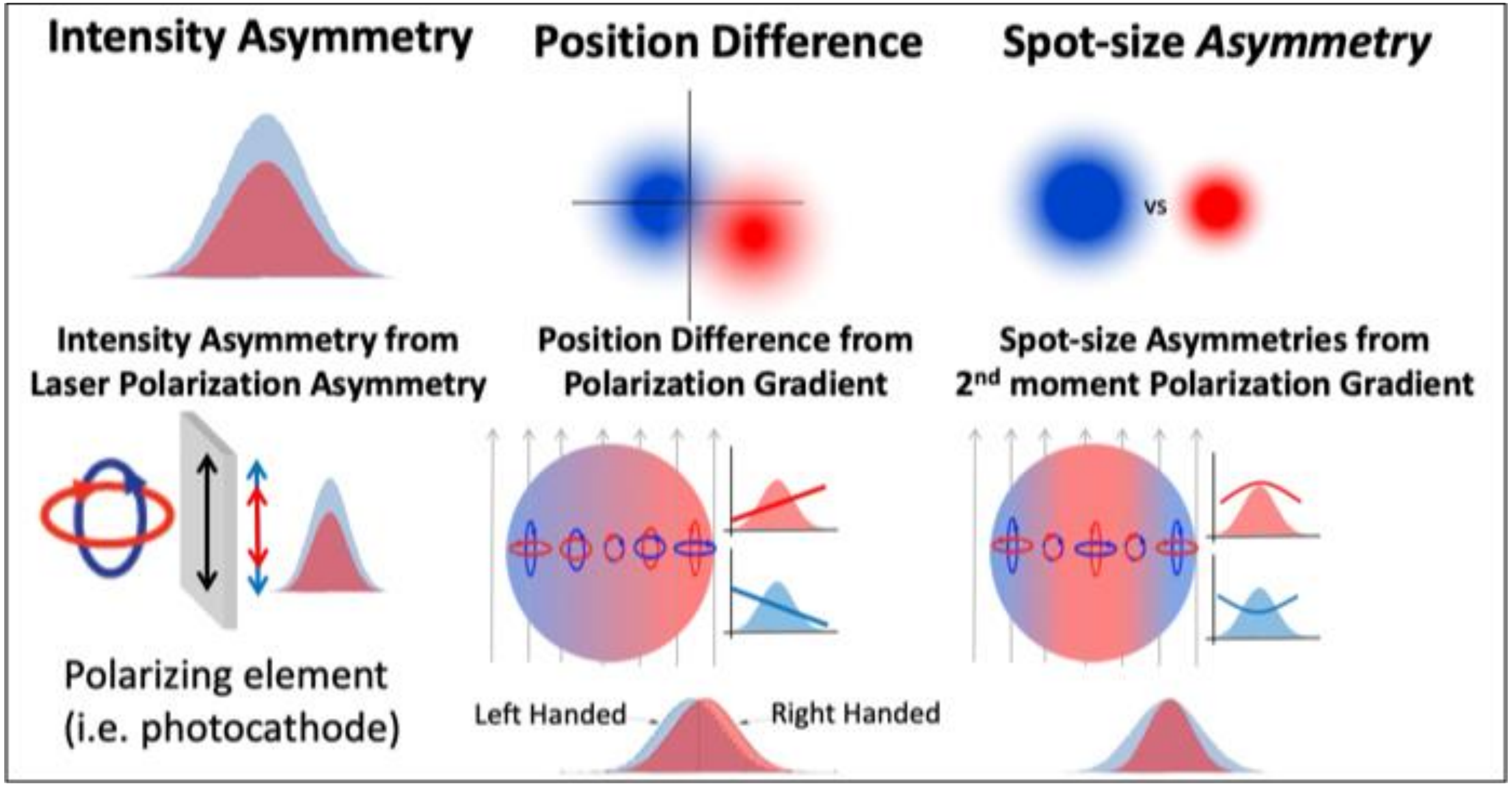


Ref: Silwal Thesis, Fig 6.7.2

Helicity Correlated Beam Asymmetries

Any change in the polarized beam, correlated to helicity reversal, can be a potential source for a false asymmetry

$$A_{raw} = A_{det} - A_Q + \alpha\Delta_E + \Sigma\beta_i\Delta x_i$$



MOLLER HCBA Goals, Polarization, and P_T

Any change in the polarized beam, correlated to helicity reversal, can be a potential source for a false asymmetry

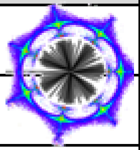
$$A_{raw} = A_{det} - A_Q + \alpha\Delta_E + \Sigma\beta_i\Delta x_i$$

HCBA's are expected to contribute ~0.14 ppb uncertainty for Moller *(~10ppb for PREXII)*

(Helicity Correlated Beam Asymmetries)

HCBA Contributors

	MOLLER (344 PAC days)	**MOLLER Run 1 (25 PAC days)**
Intensity	<10ppb	<40ppb
Energy Asymmetry	<1.4ppb	<6ppb
Position Difference	<0.6nm	<4nm
Angle Difference	<0.12nrad	<0.5nrad
Size Differences	<10ppb	<50ppb



Constrained at nm, nrad, ppb level

Suppressing HCBA

- *Slow Reversals*
- *Feedback*
- *Adiabatic Damping*

- P_B goal: ~90% polarization
- P_T goal: average 0.06ppb uncertainty contribution to A_{PV}

Achieving these goals begins with the laser and Pockels Cell

Previous Experimental Results

		~20PAC days PREX-2 (achieved)	~40PAC days CREX (achieved)	344PAC days MOLLER (required)	14PAC days Cumulative Helicity Correlation (Run1)
Aq	Intensity asymmetry	25 ppb	-88 ppb	10 ppb	< 40 ppb
ΔE/E	Energy asymmetry	0.8 ± 1 ppb	0.1 ± 1.0ppb	< 1.4 ppb	< 6 ppb
Dx	position differences	2.2 ± 4 nm	-5.2 ± 3.6nm	0.6 nm	$< 4 \times 10^{-9}$ m
Δθ	angle differences	$< 0.6 \pm 0.6$ nrad	-0.26 ± 0.16nrad	0.12 nrad	$< 0.5 \times 10^{-9}$ radian
A_σ	size asymmetry (quoted)	$< 3 \times 10^{-5}$	$< 3 \times 10^{-5}$	$< 10^{-5}$	$< 10^{-5}$

- Aq: PREX-II achieved 25ppb (+-25ppb) Aq, met the MOLLER Run1 goal and came within a factor of 2X of the MOLLER goal
- ΔE/E : PREX-II and CREX met both the MOLLER Run1 goal and the MOLLER goal
- Δθ : PREX-II met the MOLLER Run1 goal, and CREX achieved 0.26+-0.16nrad, coming within a factor of 2X of the MOLLER goal (statistics limited)
- Dx: PREX-II and CREX met the MOLLER Run1 goal.
  - Plan to do feedback (the longer we run, the better we measure position differences, and the closer to zero we can drive them). Plan for getting individual suppression factors as good as we can.
- A_σ Spot Size asymmetry: PREX-II and CREX came within a factor of 3 of the MOLLER goal
  - Plan for achieving better cell alignment and getting individual suppression factors as good as we can.

Dx

-(#X)=estimated, not measured

		slow reversals												
		injector	IHWP	wien	g-2	inj damping	acc damping	feedback	hall	sensitivity	avg det sens.	sensitivity avg	correction uncertainty	Unc. total sys.
Dx	goal	20nm	10X	10X	10X	10X	10X	10X	<0.6nm	17ppb/nm	10X	1.7 ppb/nm	5%	0.05ppb
	Run1 goal	20nm	10X	10X	10X	10X	10X	10X	<4nm	17ppb/nm	10X	1.7 ppb/nm	5%	0.34ppb
	past	30nm	2X	10X	-	30X	~5X	10X	<2nm+-4nm	*17ppb/nm*	*10X*	*1.7 ppb/nm*	*5%*	0.14ppb
	now	60nm	-(2X)	5X (1-12X)	- (5X)	5X (1-20X)	-(1X)- ~12X	-(10X)	Estimated: 0.025nm (0.003-0.6nm)	*17ppb/nm*	*10X*	*1.7 ppb/nm*	*5%*	Estimated: -<0.05ppb

- PREX-II achieved (2+-4nm) Dx over ~20PAC days, meeting the MOLLER Run1 (14PAC days) goal and coming within a factor of 4X of the MOLLER (344PAC days) goal
- Plan for getting individual factors as good as we can. Conservative estimates of present performance get us where we ultimately need to be. Just need to make sure this performance of individual factors happens again: tie down slow reversals like Wien flip and g-2 flip, do pockels cell alignment, try to achieve some damping, do feedback
- Feedback
  - During PREX-II and CREX , used infrequent feedback on position differences to drive average central values towards zero
  - During MOLLER running, to beat $1/\sqrt{N}$ statistics, plan to use active feedback using RTP cell (or Helicity Magnets depending on adiabatic damping) on a time scale to be determined (depending on noise/damping levels - minirun/run/slug level time-scales)
  - During running, plan to include sensitivity scans of RTP/Helicity magnets as part of beam-mod cycle (every minirun/~5-10min)
  - Helicity magnets (with fast <10us response) not yet installed. Plan to install helicity magnets Fa25 (next SAM)

Spot size A_σ

-(#X)=estimated, not measured

		laser table	window	cathode	injector	clipping	chopper	IHWP	wien	g-2	inj damping	acc damping	synch rad	hall	sensitivity avg	Unc.
A_σ	goal	<5e-5 analyzing like, <10ppm steering like	<2ppm	15X analyzing 0.1X non-anal.	<10ppm	change <1ppm	change <1ppm	10X	10X	10X	10X	10X	10X	<10ppm	0.012ppb/ppm	0.1ppb
	past	<3e-4 analyzing like, 5-30ppm steering like	-	15X-100X anal, -	<30ppm est	-	-	-	10X	-	30X	~5X	-	<30ppm	*0.012ppb/ppm*	0.36ppb
	now	-	>12ppm	30X anal, -	>12ppm	-	<1ppm	-	5X(1-12X)	-	5X(1-20X)	~12X	-(10X)	>12ppm	*0.012ppb/ppm*	>0.14ppb
	example	(<3e-4 anal, 30ppm steer)	(1e-4)	(100X anal, 0.1X)	(350ppm)	(<1ppm)	(<1ppm)	-(2X)	-(1.5X)	-(1X)	-(1X)	-(1X)	-(10X)	(11ppm)	*0.012ppb/ppm*	(0.11ppb)

- During PREX-II , got within 3X of MOLLER goal estimated in the injector
  - Plan: Using Quick-align pockels cell with spot size asymmetry control via voltages we expect to have easier time with laser table alignment and hope to achieve even smaller laser-table spot-size asymmetries
- All slow reversals, damping, are incredibly important for minimizing spot size asymmetry – especially Wien Flip, g-2 flip
  - Plan: Perform Wien Flip every few days during experimental running. Perform g-2 flip every few weeks. Study Wien flip stability over several days during upcoming SAMs
- Synch radiation Injects incoherent noise that dilutes A_σ (measured emittance implies a factor of 10X)
- At present, A_σ has possible contributions from suspicious window (or steering lens) birefringence level observed
  - Presently, the new vacuum Window (or steering lens) birefringence is observed to be possibly larger than previously measured (>2% instead of <1%) and therefore possible larger birefringence gradients. Additional birefringence may come from window (stress) or steering lens on laser table
  - Plan: investigate window (or steering lens) matter further with an inj. PQB cathode rot. study at START of Fa2025 (START of next SAM). Do cathode rotation during expeimental running. Accelerator to measure lens birefringence with spinning LP
  - Possible outcomes: (1) fine: do nothing – just modestly changes expected precision needed on cathode rotation [10deg->5deg] (2) not fine due to lens: replace lens or reduce stress on lens (3) not fine due to window: replace window, reduce stress on window, tighten expected precision needed on cathode rotation back to PREX-II/CREX level (~1deg)
- Transmission level is at present not meeting TDR spec. Need good transmission to be sure of maintaining painstakingly achieved small spot size asymmetry.

RMS noise Aq, Dx, ΔE/E, Δθ

Specifications on jitter on beam while we run MOLLER. Present beam performance at 11GeV meets specifications

		injector	clipping	hall
Aq RMS			>95% T (>99%?)	
	goal	<1000ppm	change <50ppm	<1000ppm
	now	<750ppm	60-175ppm	560-1400ppm (tails)
Dx RMS	goal	-	-	<50um
	now	<22um (<120um 0R's)	-	<12-56um
ΔE/E RMS	goal	-	-	<110ppm
	now	-	-	<22ppm
Δθ RMS	goal			<10urad
	now			<3.4urad

Aq RMS

- Present noise at 960Hz/1920Hz at 10GeV in HallA is fine for MOLLER (except for 60Hz tails which can be suppressed with mega-multiplets)
  - Plan: Run experiment at either 960Hz or 1920Hz depending on target boiling and beam noise observation
  - Updating settings on hel.gen.board for 960Hz *(Thue-morse pattern with Tstables for Tsettles 10,15,20us)*
- However, clipping in the injector in the region of A3/A4 leads to Aq RMS change not meeting TDR goals(175ppm instead of 50ppm).
  - Plan: Accelerator installs a lens system to reduce beam size (or enlarges A3/A4) during Fa2025 (next SAM) and PQB Transmission test is performed towards end of next SAM
  - Make high transmission for MOLLER a priority during exp. running

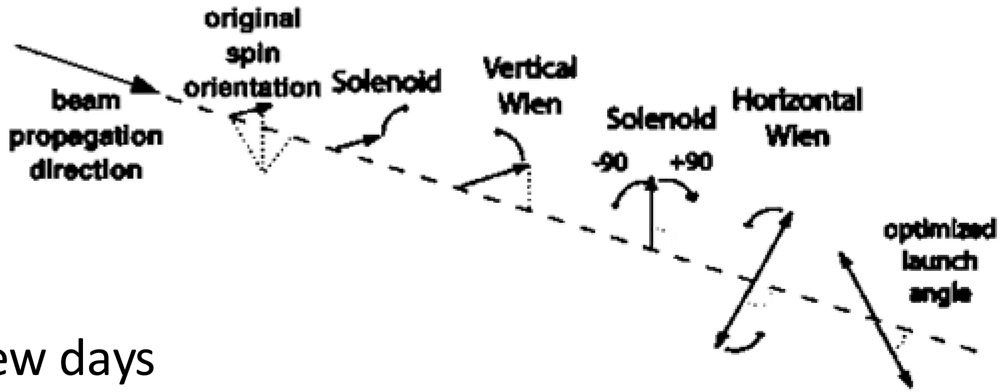
Dx RMS

- Present noise at 960Hz/1920Hz at 10GeV in HallA is fine for MOLLER (as long as beam is acceptable to the Compton system)
  - FFB behavior non-optimal, but typical. FFB increases Y noise at nominal settings (seen before during CREX), but still an OK width. FFB gain settings changes helped as might reducing noise upstream. In the past, selecting a different set of magnet/BPMs to feedback on helped. Acceptable for MOLLER as long as Compton backgrounds and radiation levels acceptable.
  - Plan: Measure Compton Polarimeter background rates during this summer

ΔE/E RMS and Δθ RMS

- Present noise at 960Hz/1920Hz at 10GeV in HallA is fine for MOLLER

Wien



Wien Flips

- During MOLLER Running, will need to do a Wien flip once every few days
- Important note: Presently (Sp 2025), was not able to perform a true Vertical Wien Flip, due to arcing at high voltages
  - Plan: Accelerator finds a solution to the arcing issue so Wiens can be set to 90deg as they are designed to do. To be installed at end of SAM after next, just before Run1
  - Essential to MOLLER experimental goals: Unnerving. We would prefer to have this tested before Run1.

P_T

- During MOLLER Running, will need feedback on polarization orientation ~ every shift
  - Plan: Corrections for drifts envisioned to occur each shift during regular running, or in a shorter time scale after any significant linac energy rebalancing. The changes are expected to be about 1-2° and applied to the nominal Injector Wiens angles.
  - Measurements being feedback on come from the main detector – high precision fast
  - 2025 studies show Wien adjustments of several degrees (3-5°) do not impact beam delivery to ILD or to Hall A significantly (small alignment tweaks, 5min)

Damping

		inj damping	acc damping
Dx	goal	10X	10X
	Run1 goal	10X	10X
	past	1-30X (best)	~5X
	now	5X (1-20X)	~12X

Damping in the Injector

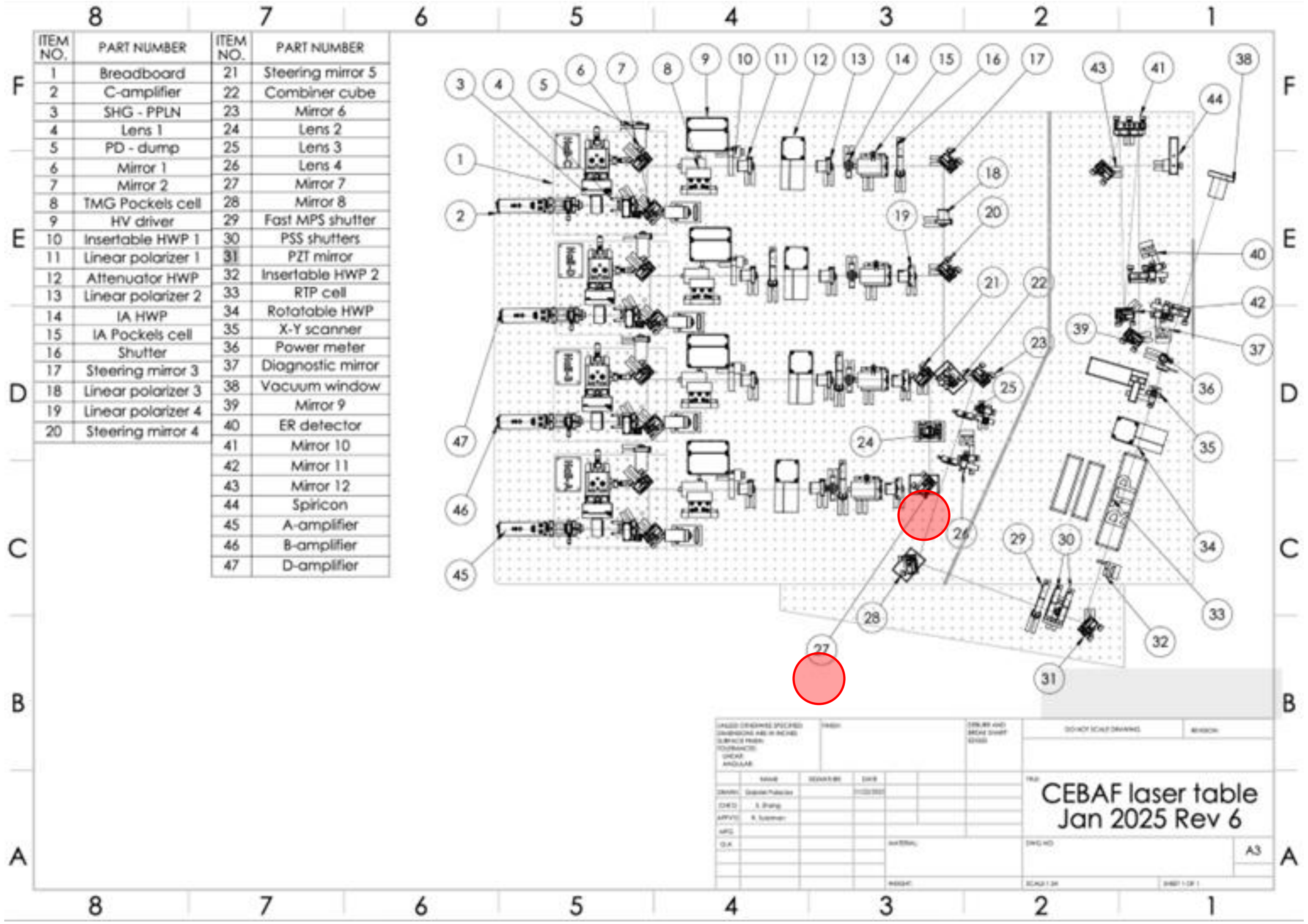
- Difficult to measure
- Presently (Sp25) did not observe significant degree of damping after boost region in injector compared with 2019 despite upgraded injector
- Plan: During Fa25 (next SAM), perform iterative injector damping optimization, accelerator scanning optics, while PQB measures damping

Damping in HallA

- Raytrace was revived and is the right tool to measure damping. HallA 10GeV test have been done. But damping is unquantified, unoptimized presently.
- Plan: Accelerator uses Raytrace to optimize and monitor adiabatic damping before MOLLER
- Helicity magnets can also be used to assess damping, but are not yet installed
- Plan: Accelerator installs Helicity Magnets during Fa25 (next SAM)

Laser Steering Mirrors

- New System- Activated motion-feedback Steering Mirrors on laser source are incompatible with MOLLER goals and should be disabled during MOLLER (and PQB studies)



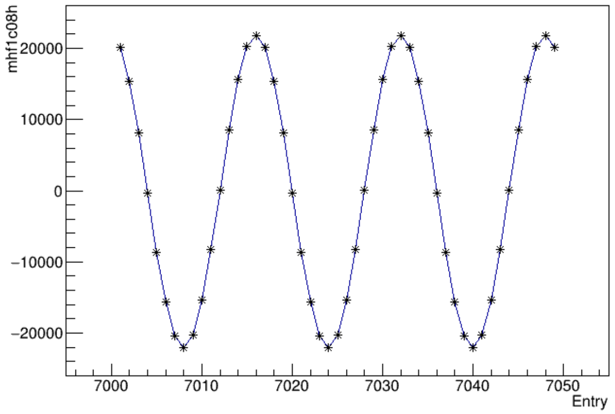
ITEM NO.	PART NUMBER	ITEM NO.	PART NUMBER
1	Breadboard	21	Steering mirror 5
2	C-amplifier	22	Combiner cube
3	SHG - PPLN	23	Mirror 6
4	Lens 1	24	Lens 2
5	PD - dump	25	Lens 3
6	Mirror 1	26	Lens 4
7	Mirror 2	27	Mirror 7
8	TMG Pockels cell	28	Mirror 8
9	HV driver	29	Fast MPS shutter
10	Insertable HWP 1	30	PSS shutters
11	Linear polarizer 1	31	PZT mirror
12	Attenuator HWP	32	Insertable HWP 2
13	Linear polarizer 2	33	RTP cell
14	IA HWP	34	Rotatable HWP
15	IA Pockels cell	35	X-Y scanner
16	Shutter	36	Power meter
17	Steering mirror 3	37	Diagnostic mirror
18	Linear polarizer 3	38	Vacuum window
19	Linear polarizer 4	39	Mirror 9
20	Steering mirror 4	40	ER detector
		41	Mirror 10
		42	Mirror 11
		43	Mirror 12
		44	Spiricon
		45	A-amplifier
		46	B-amplifier
		47	D-amplifier

•Turn off laser steering mirrors (500 Hz motion) - maybe generated by turbo-pumps on cryomodules (30,000 rpm)

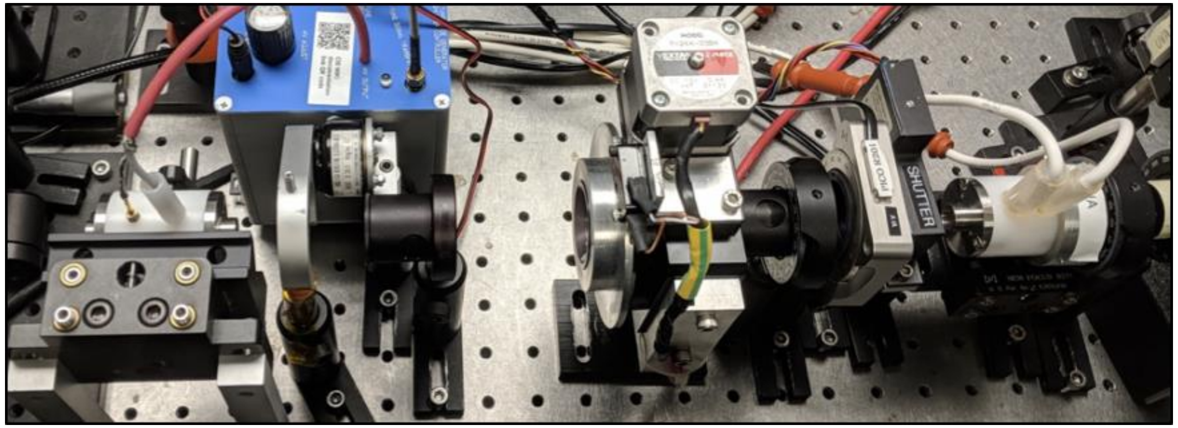
New hardware:

- Modulating HallA IA (Intensity Attenuator) cell with beam modulation driver (small sine-wave small amplitude modulation on beam intensity)
- Essential for measuring detector linearity and intensity/Position monitor coupling
- Plan: Install HallA IA cell with beam mod driver before MOLLER
- Standard IA (Intensity Asymmetry) drivers for other Halls – to be tested for ~10us transition times (test stand ready at UVA since December 2024)

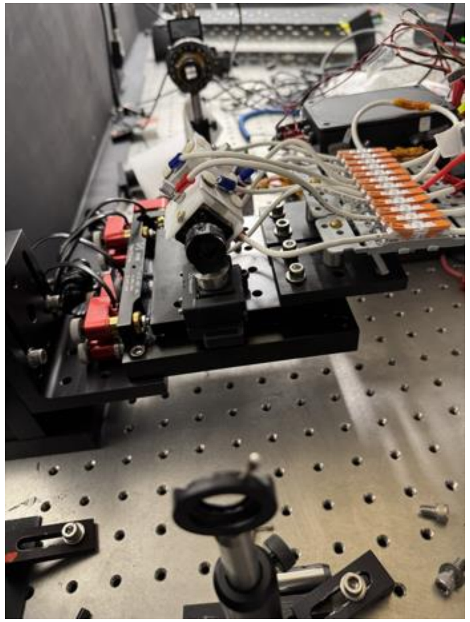
Modulation



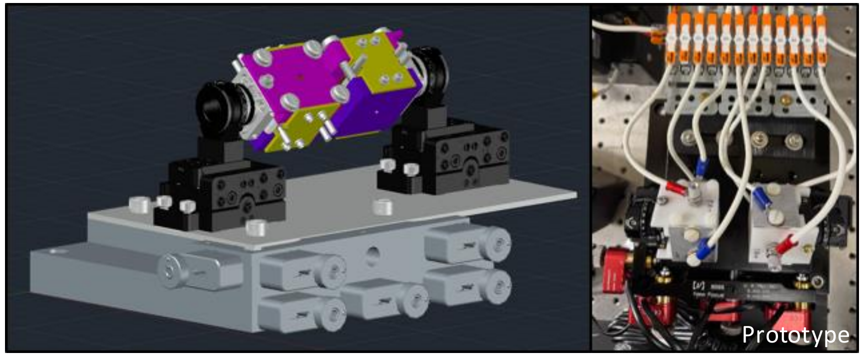
IA cell



UVa test stand

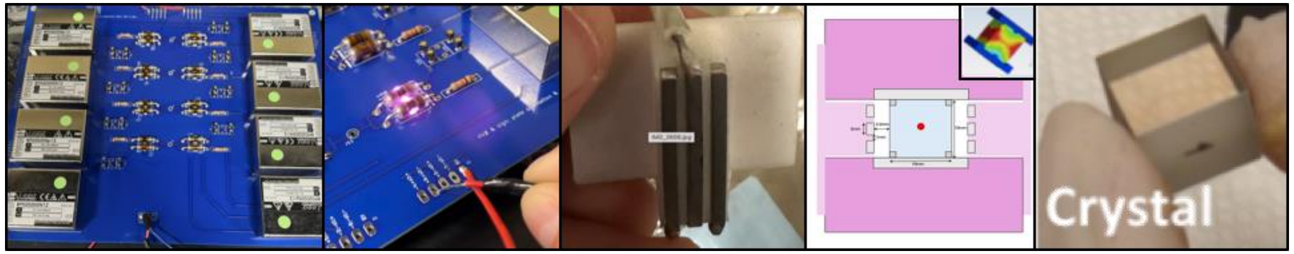


Expected Upgrade: Quick-Align Cell



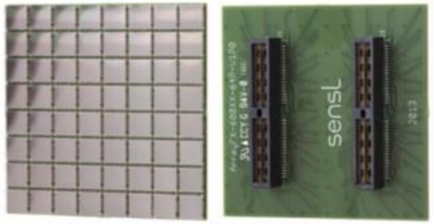
Purpose

- Typically alignment relative to laser beam setup can take over 1 week
- In the event cell became misaligned relative to beam during MOLLER running (for example Hall A laser needs adjustment of some kind, changing optics), would be a long downtime to realign the cell
- So, designed and built (NSF funded) quick-align cell for MOLLER which could be swapped in faster if needed
- Since quicker to align than existing large cell mount, in principle, advantageous to already have it installed before MOLLER Run 1
- Plan: Install Quick-Align (16Voltage cell) before MOLLER



Properties

- 16Voltages instead of 8Voltages
- Controls both position differences and spot-size asymmetry
- Motorized angle/position control
- Compact Design



Diagnostics

- 2D photodiode array for faster diagnostics (instead of 10 measurement configurations with quad-photodiode and linear array, only 2 configurations)

- *Jlab wants to change the HV system and control system and grounding isolation system. Untested. If tests fail, we have a functional system that we will use.*

Accelerator Support

Selection of MOLLER related accelerator studies organized by <u>Riad Suleiman (MOLLER Liason)</u>

- **Support from Bteam and Electron Gun Group**
- **Accelerator Parity-Quality-Beam Liaison:** Riad Suleiman
- **Accelerator Physicist Experimental Liaison:** Yves Roblin
- **Instrumentation and Controls (I&C):** Jim Kortze, John Musson, Nate Rider
- **Yan and Reza Injector Experts**

Selection of Beam Studies in Hall A - 10.720 GeV, 18 μA

- FFB BSList 115369 (Ryan Bodenstein)- 6 hours
- RayTrace and Adiabatic Damping - Setup, troubleshooting, and tests (Ryan Bodenstein and Dennis Turner) BSList 116768 - 4 hours
- Test Polarization Feedback (Riad Suleiman, Yan): BSList 116272 - 4 hours
- Measure Compton Polarimeter background rates (Dave Gaskell, Yves Roblin, K Paschke): BSList 116468 - 8 hours
- Hall A Beam Modulation Test at 5 Pass (Ciprian Gal, Paul King, and Arindam Sen) BSList 116856- Completed

Collaboration Personnel: PARITY QUALITY BEAM TEAM

Members
•Xiang Zhang (UVA)
•Jon Mott (UMass)
•Arindam Sen (OU)
•Ryan Conaway (OU)
•Devi Adhikari (VT)
•Prakash Gautam (UVA)
•Danielle Schaper (IU)
•Chandan Ghosh (Jlab)
•Paul King (IU)
•Kent Paschke (UVA)
•Caryn Palatchi (UVA)

2025 PQB Studies Done
Injector (~3 shifts)
- Chopper scan
- RHWP scan
- Wien Flip characterizations
- Small Hwien changes 2-5deg
- 960Hz noise measurements
- Aq noise and transmission checks
- Position Difference reduction

HallA (~ 2+ shifts)
- FFB tests at various frequencies (including 960Hz) and settings
- Aq noise measurements
- Beam modulation tests

THANK YOU!

Prior Beam Studies to check the upgrade
2024: ~1 ½ HallA shifts (May 2024)
2023: ~3 ½ injector shifts (OWL week of 8/14/23-8/27/23)

Always challenges to schedule beam studies but future PQB beam studies needed during next SAMs

Appendix

Conclusions

Remove impediments to:

- Scheduling future PQB beam studies during next SAMs
- Window/lens inj. PQB cathode rot. study at START of Fa2025 (START of next SAM) and rot. during running
- **Installation and alignment of quick-align 16voltage cell and 2D photodiode array diagnostics before MOLLER**
- Performing Compton Polarimeter background rates test during this summer
- Study to perform iterative injector damping optimization During Fa25 (next SAM)
- **Request to turn steering mirror(s) off during MOLLER running and PQB tests.**
- Performing extensive battery/helicity pickup tests post-installation of cell system
- Installing a HallA IA cell with beam mod driver

Ensure

- Accelerator measures lens birefringence with spinning LP at start of Fa25(next SAM)
- **Increasing transmission with hardware installation(s) remains on accelerator Fa2025 (next SAM) plans**. Remove impediments to transmission PQB beam study towards end next SAM.
- Make high transmission for MOLLER a priority during exp. running
- Hel Mag install remains on accelerator Fa2025(next SAM) plans
- **That finding a solution to the arcing issue so the Wiens can be set to 90deg (via hardware installation(s)/repairs/burn-ins) remains a high priority on accelerator Fa2025 (next SAM) plans.**
- Keeping FFB on for HallA is a priority during running for energy stability
- Helicity Magnet installation remains on accelerator Fa2025 (next SAM) plans.
- Existing PQB laser room hardware not be removed without collaboration working group convener approval. Collaboration working group conveners have go/no-go decision on what hardware is working best and what PQB hardware is ultimately used during MOLLER Run1 and 2,3.
- **Vertical Wein Flip PQB beam study before MOLLER during upcoming SAMs**
- PQB studies of Wien flip stability during upcoming SAMs

Facilitate

- Support for further Raytrace tests in HallA this summer so accelerator can learn/figure out how to quantify and maximize adiabatic damping in the machine (this summer is the last chance in HallA before MOLLER starts)
- Uninterrupted time in laser room (1-2 weeks) without disturbances. Remove impediments to installation of "Captain Expando" in Hall A laser beamline and possible steering lens change to achieve optimized laser optics at cell and cathode.
- Making Wien and g-2 flips priority during running
- Software support for updating settings on hel.gen.board for 960Hz: Thue-morse pattern with Tstables for Tsettles 10,15,20us
- Ops-Inj and CIS should provide the optimal protocol to apply the required changes. Might also find out if the feedback can be done by the beam energy instead as an alternate option.
- Software support for copy/pasting RTP 8 voltage gui and making a 2nd identical gui with another label.
- Software support for making beam mod gui to turn on/off HallA IA cell charge amplitude modulation and to vary the amplitude.
- Software support for updating settings on hel.gen.board for 960Hz: Thue-morse pattern with Tstables for Tsettles 10,15,20us

Plan

Appendix

Su2025
- Measure Compton Polarimeter background rates
- Accelerator uses Raytrace to measure and optimize adiabatic damping

Fa2025 (next SAM)
- Investigate window (or steering lens) with an injector PQB cathode rotation study at START of Fa2025 (START of next SAM) (RHWP/cathode-rotation/QE scan/spot-move)
- Accelerator measures lens birefringence with spinning LP
- Turn off laser steering mirrors (500 Hz motion) [maybe generated by turbo-pumps on cryomodules (30,000 rpm)] during PQB studies during SAMs
- Accelerator installs a lens system to reduce beam size (or enlarges A3/A4) to reduce clipping
- Accelerator installs Helicity Magnets
- PQB Transmission test is performed towards end of next SAM
- Perform position difference feedback at various time scales to (1) examine our ability to beat $1/\sqrt{N}$ statistics (2) examine if we can drive down position differences back down to 30nm
- Iterative injector damping optimization

Sp2026 (SAM after next)
- Accelerator finds a solution to the arcing issue so Wiens can be set to 90deg as they are designed to do
- Optimize laser optics (spot size on cell/cathode, divergence, lens installation of “Captain Expando” in Hall A laser beamline, possible steering lens change)
- Install/Align Quick-Align (16Voltage cell)
- Install 2D array for fast diagnostics and faster alignment.
- Using Quick-align pockels cell with spot size asymmetry control via voltages we expect to have easier time with laser table alignment and hope to achieve even smaller laser-table spot-size asymmetries
- Install HallA IA cell with beam mod driver before MOLLER
- Vertical Wein Flip PQB test is performed towards end of SAM
- Study Wien flip stability over several days

Before MOLLER
- Perform all usual injector PQB measurements and perform position difference feedback
- Accelerator uses Raytrace to optimize adiabatic damping

During MOLLER
- To beat $1/\sqrt{N}$ statistics, plan to use active feedback using RTP cell (or Helicity Magnets depending on adiabatic damping) on a time scale to be determined (depending on noise/damping levels - minirun/run/slug level time-scales)
- Include sensitivity scans of RTP/Helicity magnets as part of beam-mod cycle (every minirun/~5-10min)
- Do cathode rotations after each cathode reheating to a precision to-be-determined by Fa2025 PQB studies (expected 10deg, could be 5deg, used to be 1deg with old window)
- Perform Wien Flip every few days during experimental running. Perform g-2 flip every few weeks.
- Run experiment at either 960Hz or 1920Hz depending on target boiling and beam noise observation
- Wien corrections for P_T drifts envisioned to occur each shift during regular running, or in a shorter time scale after any significant linac energy rebalancing. The changes are expected to be about 1-2° and applied to the nominal Injector Wiens angles.
- Keep FFB on to maintain energy stability for precession stability
- Accelerator uses Raytrace to optimize and monitor adiabatic damping
- Turn off laser steering mirrors (500 Hz motion) [maybe generated by turbo-pumps on cryomodules (30,000 rpm)] during MOLLER

References

- TDR https://moller-docdb.physics.sunysb.edu/DocDB/0009/000998/003/MOLLER_TDR-24-02-15.pdf
- Moller Beam Studies List https://moller-docdb.physics.sunysb.edu/cgi-bin/DocDBTest/private/ShowDocument?docid=1144
- Accelerator Beam Tasks for Moller https://moller-docdb.physics.sunysb.edu/cgi-bin/DocDBTest/private/ShowDocument?docid=1046
- Moller Beam Requirements https://moller-docdb.physics.sunysb.edu/cgi-bin/DocDBTest/private/ShowDocument?docid=984
- Summary of Beam Requirements https://moller-docdb.physics.sunysb.edu/cgi-bin/DocDBTest/private/ShowDocument?docid=403

Backup Slides

Backup

Aq

Aq		laser table	window	cathode	injector	clipping	feedback	hall	sensitivity avg	correction uncertainty	Unc.
						>95% T (>99%)					total sys.
	Goal TDR	<5% DoLP	<1%DoLP	<7% analyzer	20ppm	change <20ppm	2000X	<10ppb	1ppb/ppb	1%	0.1ppb
	Run1 goal	<5% DoLP	<1%DoLP	<7% analyzer	20ppm	change <20ppm	2000X	<40ppb	1ppb/ppb	1%	0.4ppb
	past	<5% DoLP	<1%DoLP	3% analyzer	-	-	-	25+-25ppb	*1ppb/ppb*	*1%*	0.25ppb
	now	<5% DoLP	>2% DoLP	3.3%	20-75ppm	change 20-75ppm	-	-	-	-	-

- PREX-II achieved 25ppb (+-25ppb) Aq over ~20PAC days, meeting the MOLLER Run1 (14PAC days) goal and coming within a factor of 2X of the MOLLER (344PAC days) goal.
  - Note: PREX-II, CREX non-zero values of Aq was largely due to offline analysis choice to include post-beam trip Aq-feedback-disabled data.
  - Aq feedback was observed to beat $1/\sqrt{N}$ statistics during PREX-II and CREX when enabled
- Presently (Sp 2025), clipping in the injector in the region of A3/A4 leads to Aq change not meeting TDR goals (up to 75ppm instead of 20ppm).

Dx

-(#X)=estimated, not measured

Dx						slow reversals											
		cathode	injector	clipping	chopper	IHWP	wien	g-2	inj damping	acc damping	feedback	hall	sensitivity	avg det sens.	sensitivity avg	correction uncertainty	Unc. total sys.
	goal	15X analyzing	20nm	<5nm	<5nm	10X	10X	10X	10X	10X	10X	<0.6nm	17ppb/nm	10X	1.7 ppb/nm	5%	0.05ppb
	Run1 goal	15X anal.	20nm	<5nm	<5nm	10X	10X	10X	10X	10X	10X	<4nm	17ppb/nm	10X	1.7 ppb/nm	5%	0.34ppb
	past	15-100X	30nm	-	<4nm	2X	10X	-	30X	~5X	10X	<2nm+-4nm	*17ppb/nm*	*10X*	*1.7 ppb/nm*	*5%*	0.14ppb
	now	30X analyzing	60nm	-	<4nm	-(2X)	5X (1-12X)	- (5X)	5X (1-20X)	-(1X)- ~12X	-(10X)	Estimated: 0.025nm (0.003-0.6nm)	*17ppb/nm*	*10X*	*1.7 ppb/nm*	*5%*	Estimated: -<0.05ppb

- PREX-II achieved (2+-4nm) Dx over ~20PAC days, meeting the MOLLER Run1 (14PAC days) goal and coming within a factor of 4X of the MOLLER (344PAC days) goal
  - During PREX-II and CREX , used infrequent feedback on position differences to drive average central values towards zero
  - During MOLLER running, to beat $1/\sqrt{N}$ statistics, plan to use active feedback using RTP cell (or Helicity Magnets depending on adiabatic damping) on a time scale to be determined (depending on noise/damping levels - minirun/run/slug level time-scales)
  - During running, plan to include sensitivity scans of RTP/Helicity magnets as part of beam-mod cycle (every minirun/~5-10min)
  - Helicity magnets (with fast <10us response) not yet installed.
- Presently (Sp 2025), only achieved 60nm in the injector as opposed to 30nm in the past, but cell is unaligned and hours-long position difference feedback wasn't performed. Raytrace was revived and is the right tool to measure damping, but damping is unquantified presently.
  - Plan: During Fa2025 (next SAM), perforcm position difference feedback at various time scales to (1) examine our ability to beat $1/\sqrt{N}$ statistics (2) examine if we can drive down position differences back down to 30nm
  - Plan: During Sp 2026 (SAM after next): Optimize laser optics (spot size on cell/cathode, divergence, lens installation of "Captain Expando" in Hall A laser beamline, possible steering lens change), Install/Align quick-align 16voltage cell, Install 2D array for fast diagnostics and faster alignment.
  - Ask: Facilitate uninterrupted time in laser room (1-2 weeks) without disturbances. Remove impediments to installation of "Captain Expando" in Hall A laser beamline and possible steering lens change to achieve optimized laser optics at cell and cathode. Remove impediments to installation and alignment of quick-align 16voltage cell and 2D photodiode array diagnostics.

Backup

ΔE/E

		hall	sensitivity avg	correction uncertainty	Unc.
					total sys.
dE/E	goal	<1.4ppb	-0.7ppb/ppb	5%	0.05ppb
	Run 1 goal	<6ppb	-0.7ppb/ppb	5%	0.21ppb
	past	<1ppb	*-0.7ppb/ppb*	*5%*	0.035ppb

- PREX-II achieved 0.8+-1ppb ΔE/E over ~20PAC days, and CREX achieved 0.1+-1ppb ΔE/E over ~40PAC days, meeting both the MOLLER Run1 (14PAC days) goal and the MOLLER (344PAC days) goal

Δθ

		slow reversals											
		IHWP	wien	g-2	inj damping	acc damping	feedback	hall	sensitivity	avg det sens.	sensitivity avg	correction uncertainty	Unc.
													total sys.
Angle	goal	10X	10X	10X	10X	10X	10X	<0.12nrad	85ppb/nrad	10X	8.5ppb/nrad	5%	0.05ppb
	Run 1 goal							<0.5nrad					
	past	2X	10X	-	30X	~5X	10X	<0.26nrad+-0.16	*85ppb/nrad*	*10X*	*8.5ppb/nrad*	*5%*	0.1+-0.05ppb
	now	-	5X(1-12X)	-	5X(1-20X)	~12X	-		-	-	-	-	

- PREX-II achieved 0.6+-0.6nrad Δθ over ~20PAC days, meeting both the MOLLER Run1 (14PAC days) goal, and CREX achieved 0.26+-0.16ppb Δθ over ~40PAC days, coming within a factor of 2X of the MOLLER (344PAC days) goal.
    - Considering the # PAC days [as well as the damping] and feedback capability, we

Backup

RMS noise Aq, Dx, ΔE/E, Δθ

		injector	clipping	hall	sensitivity	avg det sens.	sensitivity avg	correction uncertainty	Unc. RMS
			>95% T (>99%?)						total sys.
Aq RMS	goal	<1000ppm	change <50ppm	<1000ppm	1ppb/ppb	-	1ppb/ppb	1%	<10ppm
	now	<750ppm	60-175ppm	560-1400ppm (tails)	*1ppb/ppb*	-	*1ppb/ppb*	1%	6-14ppm(tails)
Dx RMS	goal	-	-	<50um	17ppb/nm	10X	1.7 ppb/nm	5%	<4ppm
	now	<22um (<120um 0R's)	-	<12-56um	*17ppb/nm*	*10X*	*1.7 ppb/nm*	*5%*	<1-<4.8ppm
ΔE/E RMS	goal	-	-	<110ppm	-0.7ppb/ppb	-	-0.7ppb/ppb	5%	<4ppm
	now	-	-	<22ppm	*-0.7ppb/ppb*	-	*-0.7ppb/ppb*	*5%*	<0.8ppm
Δθ RMS	goal			<10urad	85ppb/nrad	10X	8.5ppb/nrad	5%	<4ppm
	now			<3.4urad	*85ppb/nrad*	*10X*	*8.5ppb/nrad*	*5%*	<1.4ppm

Aq RMS **Specifications on jitter on beam while we run MOLLER. Present beam performance at 11GeV meets specifications**

- Present noise at 960Hz/1920Hz at 10GeV in HallA is fine for MOLLER – except for 60Hz tails which can be suppressed with mega-multiplets
  - Plan: Run experiment at either 960Hz or 1920Hz depending on target boiling and beam noise observation
  - Updating settings on hel.gen.board for 960Hz *(Thue-morse pattern with Tstables for Tsettles 10,15,20us)*
- However, clipping in the injector in the region of A3/A4 leads to Aq RMS change not meeting TDR goals(175ppm instead of 50ppm).
  - Plan: Accelerator installs a lens system to reduce beam size (or enlarges A3/A4) during Fa2025 (next SAM) and PQB Transmission test is performed towards end of next SAM
  - Ensure increasing transmission with hardware installation(s) remains on accelerator Fa2025 (next SAM) plans. Remove impediments to transmission PQB beam study towards end next SAM. Make high transmission for MOLLER a <u>priority</u> during exp. running

Dx RMS

- Present noise at 960Hz/1920Hz at 10GeV in HallA is fine for MOLLER (as long as beam is acceptable to the Compton system)
  - FFB behavior non-optimal, but typical. FFB increases Y noise at nominal settings (seen before during CREX), but still an OK width. FFB gain settings changes helped as might reducing noise upstream. In the past, selecting a different set of magnet/BPMs to feedback on helped. Acceptable for MOLLER as long as Compton backgrounds and radiation levels acceptable.
  - Plan: Measure Compton Polarimeter background rates during this summer

ΔE/E RMS and Δθ RMS

- Present noise at 960Hz/1920Hz at 10GeV in HallA is fine for MOLLER

Backup

Comprehensive Overview

		laser table	window	cathode	injector	clipping	chopper	IHWP (slow reversals)	wien	g-2	inj damping	acc damping	synch rad	feedback	hall	sensitivity	avg det sens.	sensitivity avg	correction uncertainty	Unc. total sys.
Aq	goal	<5% DoLP	<1%DoLP	<7% analyzer	20ppm	>95% T (>99%?) change <20ppm	-	-	-	-	-	-	-	2000X	<10ppb	1ppb/ppb	-	1ppb/ppb	1%	0.1ppb
	past	_____	<1%DoLP	3% analyzer	---	_____	-	-	-	-	-	-	-	_____	25ppb	1ppb/ppb	-	1ppb/ppb	1%	0.25ppb
	now	-	>2% DoLP?	3.3%	20-75ppm	20-75ppm	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dx	goal	-	_____	15X analyzing	20nm	<5nm	<5nm	10X	10X	10 X	10X	10X	-	10X	<0.6nm	17ppb/nm	10X	1.7 ppb/nm	5%	0.05ppb
	past	_____	_____	15-100X anal.	30nm	-	<4nm	2X	10X	-	30X	~5X	-	10X	<2nm	17ppb/nm	10X	1.7 ppb/nm	5%	0.14ppb
	now	Est. 10um analyzing-like, 0.5um steering-like	_____	30X analyzing	60nm	_____	<4nm	-	5X(1-12X)	-	5X(1-20X)	~12X	-	-	-	-	-	-	-	-
Asigma	goal	<5e-5 analyzing like, <10ppm steering like	<2ppm	15X analyzing 0.1X non-anal.	<10ppm	change <1ppm	change <1ppm	10X	10X	10 X	10X	10X	10X	-	<10ppm	0.012ppb/ppm	-	0.012ppb/ppm	-	0.1ppb
	past	<3e-4 analyzing like, 5-30ppm steering like	-	15X-100X anal, -	<30ppm est	-	-	-	10X	-	30X	~5X	-	-	<30ppm	0.012ppb/ppm	-	0.012ppb/ppm	-	0.36ppb
	now	-	>12ppm	30X analyzing, -	>12ppm	-	<1ppm	-	5X(1-12X)	-	5X(1-20X)	~12X	-	-	>12ppm	0.012ppb/ppm	-	0.012ppb/ppm	-	>0.14ppb
Aq RMS	goal	<15 kppm	-	<7% analyzer	<1000ppm	change <50ppm	-	-	-	-	-	-	-	-	<1000ppm	1ppb/ppb	-	1ppb/ppb	1%	<10ppm
	past	_____	_____	3% analyzer	_____	_____	-	-	-	-	-	-	-	-	_____	1ppb/ppb	-	1ppb/ppb	1%	_____
	now	-	-	3.3%	<750ppm	60-175ppm	-	-	-	-	-	-	-	-	560-1400ppm (tails)	1ppb/ppb	-	1ppb/ppb	-	6-14ppm(tails)
Dx RMS	goal	-	-	-	-	-	-	-	-	-	-	-	_____	-	<50um	17ppb/nm	10X	1.7 ppb/nm	5%	<4ppm
	past	_____	-	-	_____	-	-	-	-	-	-	-	-	-	_____	17ppb/nm	10X	1.7 ppb/nm	5%	_____
	now	-	-	-	<22um (<120um 0R's)	-	-	-	-	-	-	-	-	-	<12-56um	17ppb/nm	10X	1.7 ppb/nm	5%	<1-<4.8ppm
dE/E	goal	-	-	-	-	-	-	-	-	-	-	-	-	-	<1.4ppb	-0.7ppb/ppb	-	-0.7ppb/ppb	5%	0.05ppb
	past	-	-	-	-	-	-	-	-	-	-	-	-	-	<1ppb	-0.7ppb/ppb	-	-0.7ppb/ppb	5%	0.035ppb
Angle	goal	-	-	-	-	-	-	10X	10X	10 X	10X	10X	-	10X	<0.12nrad	85ppb/nrad	10X	8.5ppb/nrad	5%	0.05ppb
	past	-	-	-	-	-	-	2X	10X	-	30X	~5X	-	10X	<0.26nrad	85ppb/nrad	10X	8.5ppb/nrad	5%	0.1ppb
	now	-	-	-	-	-	-	-	5X(1-12X)	-	5X(1-20X)	~12X	-	-	-	-	-	-	-	-
dE/E RMS	goal	-	-	-	-	-	-	-	-	-	-	-	_____	-	<110ppm	-0.7ppb/ppb	-	-0.7ppb/ppb	5%	<4ppm
	past	-	-	-	-	-	-	-	-	-	-	-	-	-	_____	-0.7ppb/ppb	-	-0.7ppb/ppb	5%	_____
	now	-	-	-	-	-	-	-	-	-	-	-	-	-	<22ppm	-0.7ppb/ppb	-	-0.7ppb/ppb	5%	<0.8ppm
Angle RMS	goal	-	-	-	-	-	-	-	-	-	-	-	_____	-	<10urad	85ppb/nrad	10X	8.5ppb/nrad	5%	<4ppm
	past	-	-	-	-	-	-	-	-	-	-	-	-	-	_____	85ppb/nrad	10X	8.5ppb/nrad	5%	_____
	now	-	-	-	-	-	-	-	-	-	-	-	-	-	<3.4urad	85ppb/nrad	10X	8.5ppb/nrad	5%	<1.4ppm

Note: **TDR** has widths in **1920Hz window pairs** == “960Hz” pair-width is a phrase used synonymously - confusingly

Backup

Coupling

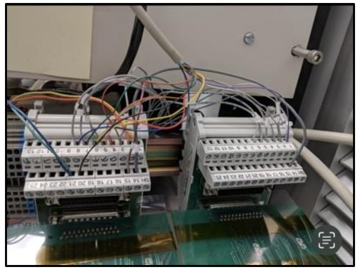
- Beam Current Monitors (BCM) don’t just measure beam current. They can be sensitive to beam position.
- Beam Position Monitors (BPM) don’t just measure beam position. They can be sensitive to beam current.
- The amount of potential coupling between BCMs and beam position can lead to an effective degradation of BCM resolution (since it contains beam position noise) …
- The amount of potential coupling between BPMs and beam current can lead to…
- Disentangling various monitor and detector sensitivities to beam position has been done in the past successfully using beam-modulation (which varies beam position and energy, spanning the phase space X,X’,Y,Y’,E)
- However, there is currently no beam-modulation of beam current
- To disentangle BPMs coupling to beam current, a HallA IA cell with beam-modulation driver could be used to produce a small amplitude sine-wave in beam current at the sub-% level (smaller than usual current noise level)

Backup

Hardware Available

Low risk hardware options in bold text

- Crystals – need 1 pair (+ spare)
    - Existing crystal pair 12x12mm – installed and run for past 7 years (UVA xtal, at JLab) [low risk spare]
    - 10x10mm crystal pair (IU xtal, at UVA at present)
    - **10x10mm crystal pair (IU xtal, to be specially AR coated) [low risk]**
- Mounts – need 1 mount
    - Existing big mount + 1 spare (with position difference control, 8Voltages) [low risk spare]
    - 1 compact mount (with position difference control, 8Voltages)
    - **1 compact quick-align mount (with both position difference control and spot size asymmetry control, 16Voltages) [low risk]**
- Drivers – need 1 driver (+spare)
    - Existing LED 8Voltage driver + 2 spares (at IU/UVA) - tested
    - **2 LED 16Voltage drivers - same design as existing, just 2 pulses like KD*P driver used to be – to be tested [low risk + spare]**
    - 2 new solid state 8Voltage drivers – to be tested
- Switches – need 1 switch (+spare)
    - Existing LED 8Voltage switch – tested
    - Partially build 8Voltage LED spare switch (Jlab 2020)
    - **4 LED 8Voltages switches (aka 2 LED 16Voltage switches) - same design as existing, just compact housing [low risk + spare]**
    - 2 solid state 8Voltage switches (aka 1 solid state 16Voltage switch) – to be tested
- Ground Isolation Systems – need 1 ground isolation system
    - **Existing isolation system – tested [low risk]**
    - New isolation system – to be tested
- Setting Control Systems – need 16 control channels
    - **Existing EPICS control system (> 16 channels available for RTP) – tested [low risk]**
    - New FPGA control system – to be tested



Ask: Existing hardware not be removed without collaboration working group convener approval. Collaboration working group conveners have go/no-go decision on what hardware is working best and what PQB hardware is ultimately used during MOLLER Run1 and 2,3. Remove impediments to performing extensive battery/helicity pickup tests post-installation.

Backup

Previous Experimental Results (Included for Posterity)

	HAPPEX-II [29] (achieved)	Q_{weak} [12] (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)	–	$< 10^{-4}$	$< 3 \times 10^{-5}$	$< 3 \times 10^{-5}$	$< 10^{-5}$

Table 6: MOLLER beam asymmetry requirements compared to the approximate magnitude of run-averaged asymmetries achieved in previous experiments. The values for position and angle differences are modified from those reported by the experiments in accordance with definitions used as indicated in the table. The quoted Q_{weak} results are from run 2. The uncertainties quoted for PREX-2 and CREX represent a "radius of convergence" of random beam jitter, showing that the trajectory differences are consistent with convergence of random noise with zero systematic offset. The spot size asymmetry estimate for PREX-2 is shown without factoring in slow reversal cancellations.

Backup

PREX-II Aq

BEAM CURRENT MONITOR DOUBLE DIFFERENCES

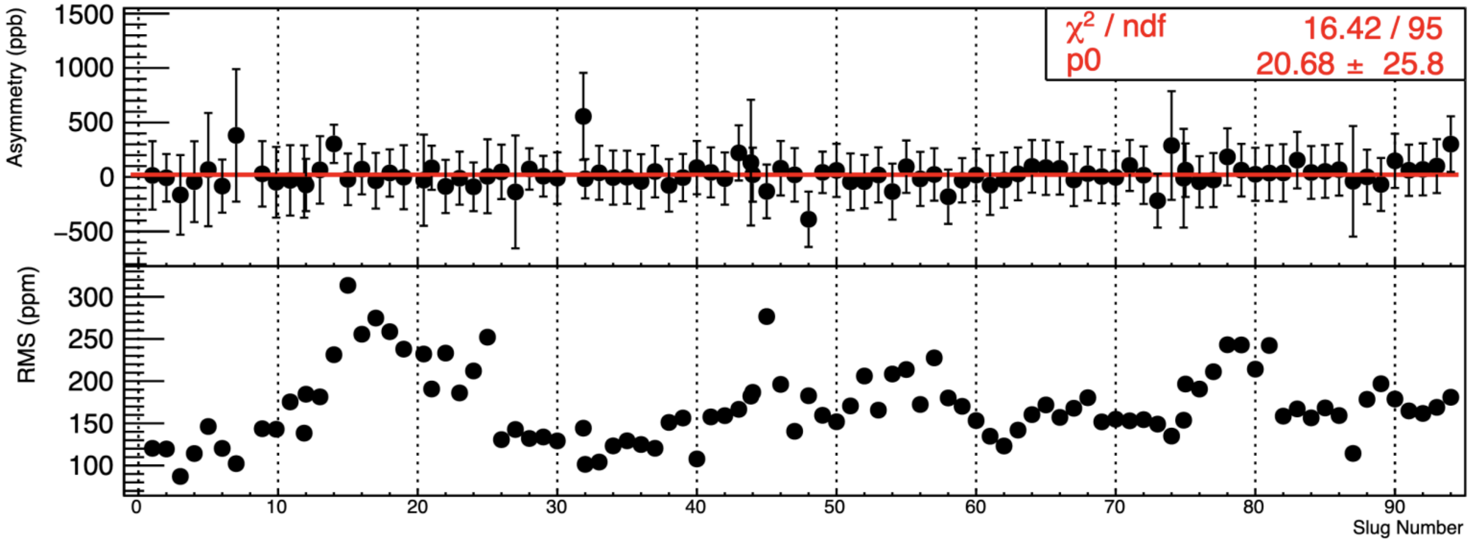


FIGURE 1. Aq of normalizing BCM detector-weighted, sign-corrected, calculated slug-wise.

PREX docdb https://prex.jlab.org/cgi-bin/DocDB/private/ShowDocument?docid=483

Backup

Run 1 Goals
(2022 document)

There are 4 tables being checked here Tab 1 , Tab 3, Tab 2 and Tab 5. Values which have been changed from the CDR values are in red. Values which are potentially concerning are in blue.Tab 4 shows the corrections made to Tab 3.

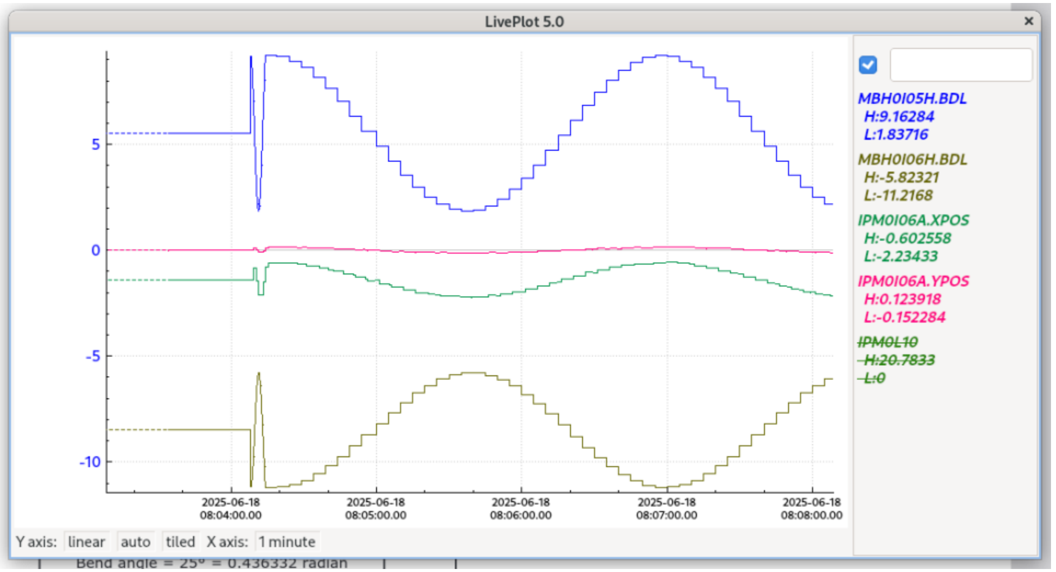
Beam Property	Defining Equation	Required 960Hz pair random fluctuations	Cumulative Helicity Correlation (Run1)	Cumulative Helicity Correlation (full data set)
Intensity	$A_q \equiv \frac{I_0 - I_1}{I_0 + I_1}$	< 1000 ppm	< 40 ppb	< 10 ppb
Energy	$A_E \equiv \frac{E_0 - E_1}{(E_0 + E_1)} = \frac{\Delta E}{2E}$	< 108 ppm	< 6 ppb	< 1.4 ppb
Position	$D_x = \Delta x \equiv x_0 - x_1$	$< 47 \times 10^{-6}$ m	$< 4 \times 10^{-9}$ m	$< 0.6 \times 10^{-9}$ m
Angle	$\Delta\theta \equiv \theta_0 - \theta_1$	$< 4.7 \times 10^{-6}$ radian	$< 0.5 \times 10^{-9}$ radian	$< 0.12 \times 10^{-9}$ radian
Spot-size	$\Delta\sigma/\sigma \equiv \frac{\sigma_0 - \sigma_1}{\frac{1}{2}(\sigma_0 + \sigma_1)}$	-	$< 10^{-5}$	$< 10^{-5}$

Table 1: *Parity quality beam performance goals for MOLLER*

Moller Document 984-v4
https://moller-docdb.physics.sunysb.edu/cgi-bin/DocDBTest/private/ShowDocument?docid=984

Backup

RayTrace Damping Test



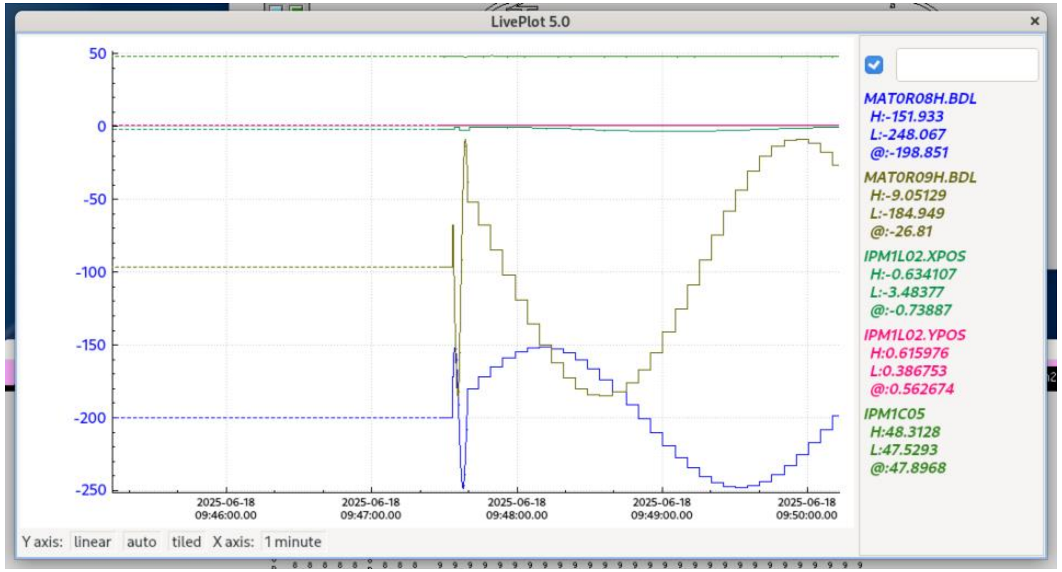
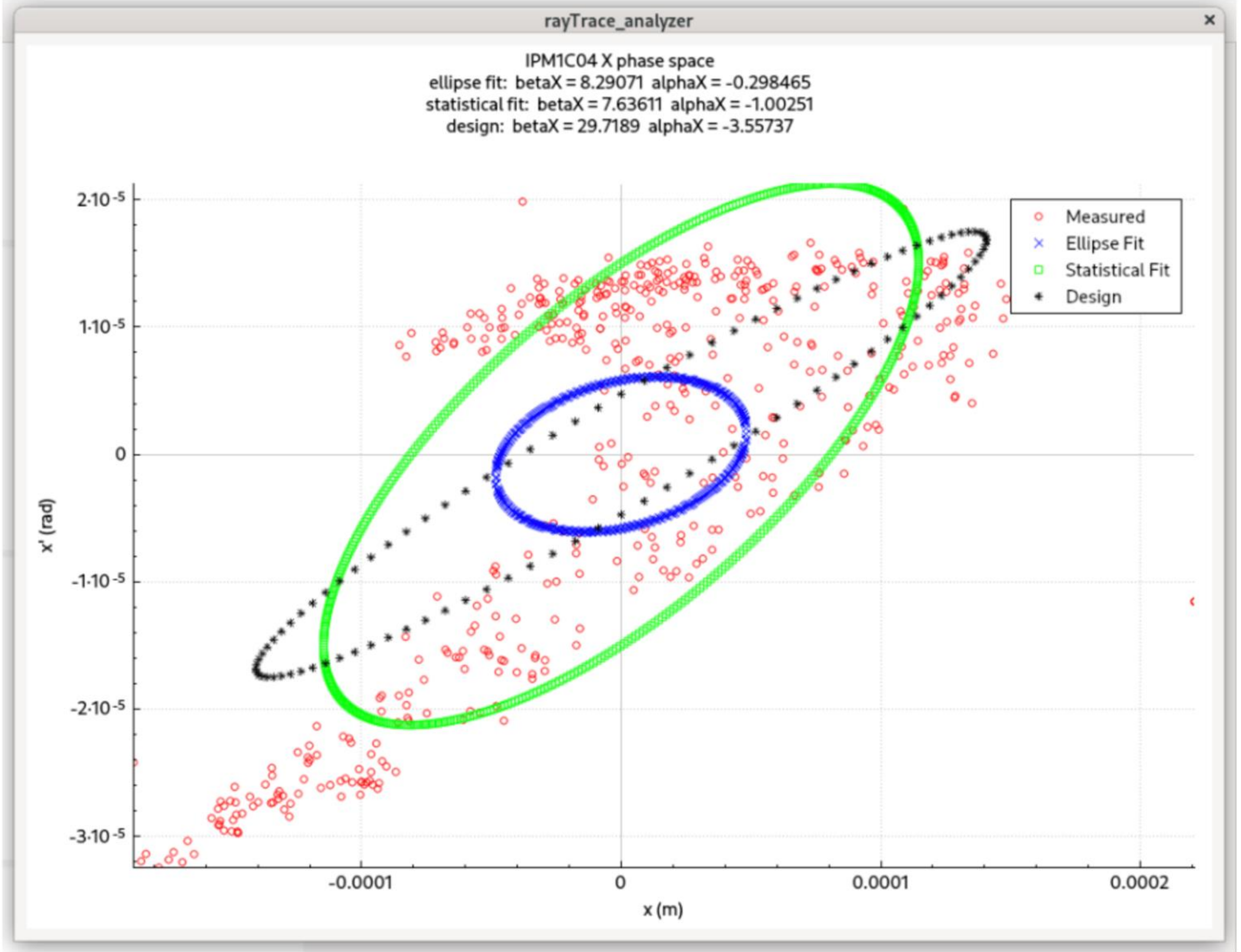


Fig. 11 See horizontal scale - this is too small for resolution [06/18/2025 10:03:26]



"Analysis forthcoming. May repeat later, but will re-submit at the appropriate time."

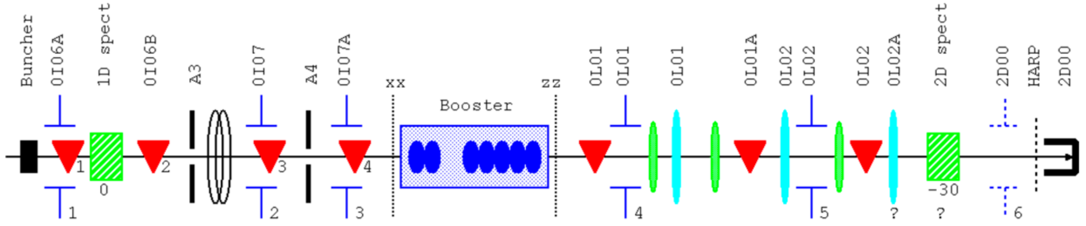
[RayTrace - Emittance Damping Tests](https://logbooks.jlab.org/entry/4400405) https://logbooks.jlab.org/entry/4400405

The data was messy. When more time is available, will try larger values.

Backup

Adiabatic damping in the Booster

Max Bruker, Volker Ziemann, JLab



- Data recorded on 250723
- Use upstream correctors to make 5 x 5 grid scan
- Reconstruct phase space xx from upstream BPM
- Reconstruct phase space zz from downstream BPM
- (Linear) fit transfer matrix of booster from 5 x 5 x 8 that's 200 recorded orbits (JLAB-TN-25-014)

RayTrace - Emittance Damping Tests
https://logbooks.jlab.org/entry/4400405

https://wiki.jlab.org/ciswiki/index.php/MOLLER_PQB_Meeting_July_29,_2025

What do we expect?

- Transfer matrix will exhibit focusing due to RF.
- and adiabatic damping
  - magnitude = p/p_2 = 494/6792 = 0.073
  - 4 x 4 TM: detTM= 0.073^2 = 0.0053

~14X @ 7GeV

What did we find?

- TM =

0.8397	0.4334	0.0945	0.0023
-0.4592	-0.1311	-0.0364	-0.0011
0.0088	0.0185	0.8627	0.4465
0.0058	-0.0076	-0.4522	-0.1261

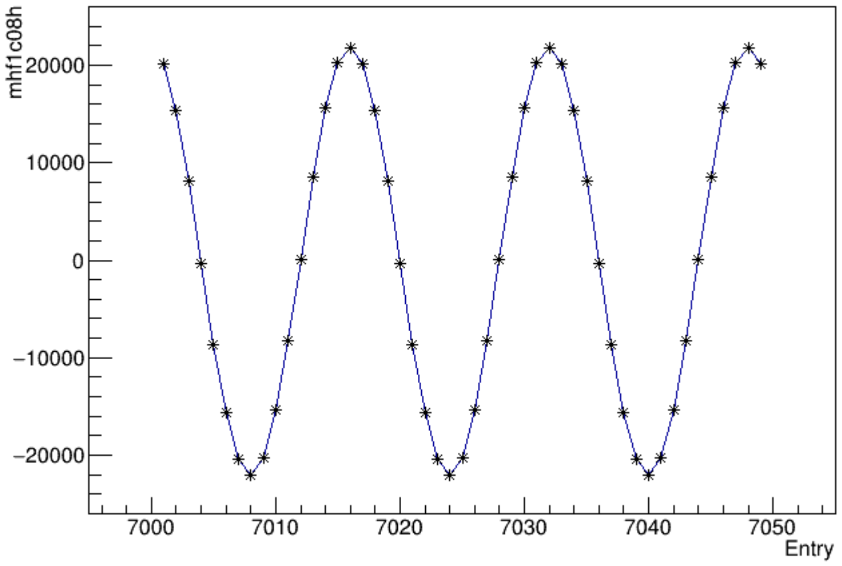
measured!

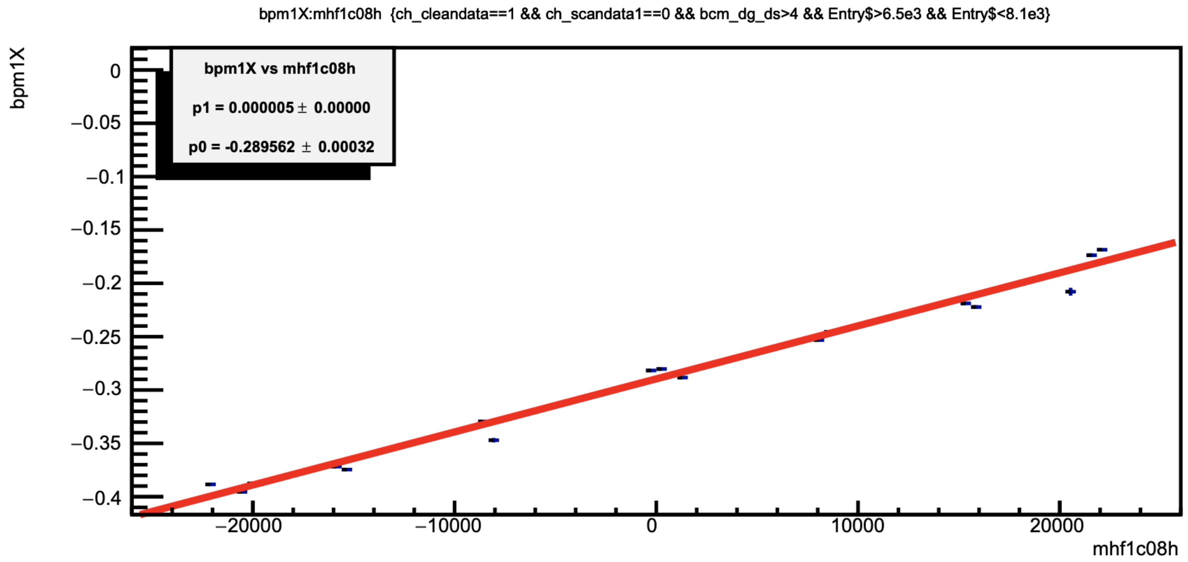
- det(TM) = 0.0083 (and not 0.0053)
- Factorize transfer matrix
  - TM = (L/2)*Q*SQ*D*(L/2)
  - with D=diag(1,α,1,α) with $\alpha = p/p_2$
- Result: $f_x \approx f_y \approx 2.3$ m, $f_s \approx 162$ m
  - and α = 0.085 (instead of 0.073)

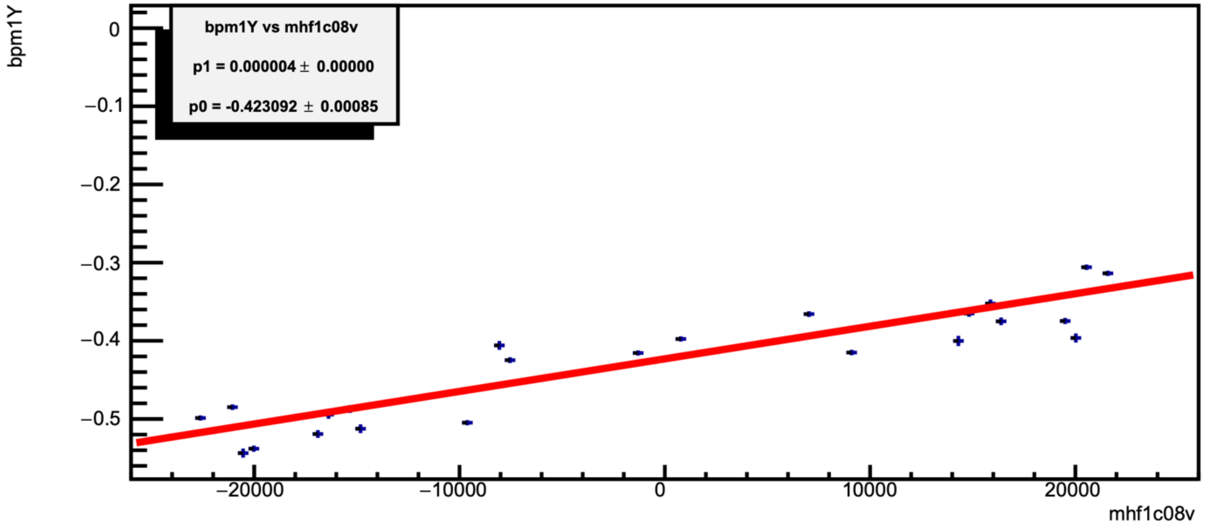
~12X @ 7GeV

Backup

Hall A Beam Modulation Test at 5 PASS







https://logbooks.jlab.org/entry/4400440 https://tasklists.jlab.org/bslist/tasks/116856

Backup

Main results March 2025

- Significant clipping observed on A3, A4 – attributed to beam size and aperture size [OPS can see this on their own 1-2uA] – reduced after rematch
- Significant clipping observed on Master Slit - attribute to longer pulse duration [OPS can see this on their own 1-2uA] – reduced after rematch
- Mixed H/V Wien flip – qualitatively symmetrical (better than pre-upgrade solenoid flip was) , quantitatively not quite as symmetrical on average (not as good as pure Vwien flip has been previously)
- Large 600ppm Aq offset term in RHWP scans, larger than have ever seen since replacing the vacuum window– attribute to either (1) birefringent element besides vacuum window (<1% birefringence) like lens (2) cathode being 45deg away from ideal rotation angle (MOLLER will need to be within 10deg for ideal angle to bound spot size asymmetries) (3) beam passing though edge of the window, very not centered [This can be done by Jlab staff]
- Significant damping not observed after boost in injector : up to 20, but more like ~5X on average, similar to 2023, in 2019 saw maybe up to >30
- Chopper scan indicates larger phase/position coupling than previously [OPS can see this on their own with chopper scans and strip chart with bpm0i05 or step’n’graph, don’t need parity DAQ]
- After 24 hours and 48 hours Wien flip setup appear stable enough that Yan could restore it in 15-20min
- Scanning HWien angle by 2deg and by 5deg did not cause issues with BLM trips or injector issues, Yan could do it in 3min to the ILD

Backup

Action Items March 2025

- Replace A3 and A4 (possibly also A1, A2) with larger apertures (or remove them?) or put a focusing optic before them [Even though recent match obtained better transmission, A3/A4 were NEVER an issue we had to contend with pre-upgrade and experiments were still **terribly** difficult to maintain good transmission…and these constraints are best loosened when running MOLLER since non-ideal conditions are very likely to occur through drift and compromise with other Hall's setups]
- Reduce the pulse duration for higher currents at the master slit to reduce clipping [OPS can see this on their own with chopper scans, don't need parity DAQ]
- Get Wien to be able to flip Vwein by 90deg (note: was able to do this in 2023 at 180keV…no sparking then at whatever voltages on the Wien were required…worth investigating if sparks now at those same voltages…if so, and if the wien is the same as it was in 2023, there could be something else going on…)
- (1) Measure DoLP on the laser table before steering lens and after steering lens to make sure it does not cause >1% extra DoLP with its birefringence (2) check where the beam is passing through the window and document how off center it is on the window (if quite off center could lead to higher birefringence) (3) Plan for cathode rotations during MOLLER to get within 10deg of ideal [This can be done by Jlab staff]
- (1) Do chopper scan at low beam current (with HallA beam on HallA slit with gang phase) to measure the laser pulse duration and make doing this a part of standard startup procedure checkout again – or if it was done recently with another slit, compare to previous years scans (2) turn up the current to 20 or 65uA and work on the prebunching to reduce the pulse duration and reduce clipping on the master slit (3) train operators in chopper scans [OPS can see this on their own with chopper scans, don't need parity DAQ]
- Study chopper scan gang phase/position coupling (with HallA beam on HallA slit with gang phase) with bpm 0i05X,Y on strip chart or with step'n'graph and try to work on reducing phase-position coupling it if that's even possible
- (1) Practice Wien flip restoration after longer time intervals: 3 days, 4 days, 1 week. (2) Train operators in Wien flips
- Remeasure cathode analyzing power and confirm it's only 3% as opposed to 6-7% seen in more recent years.
- Plan to restore Helicity magnets
- Plan pure OPS beam study to measure damping with their methodology and for Yves to try to optimize damping in HallA as a beam test this spring with just OPS tools
- Restore Linesync Mode for 240Hz
- Fix BPM0L03 XM channel

Backup

Timeline

- 2018-2019 : Preparations for PVES Experiments
  - Laser Beam RTP cell setup, alignment, characterization on injector laser table
  - Electron Beam characterization and alignment studies
- 2019 – 2020 : PREX & CREX
  - Lessons Learned: Digital BCM Mystery, Mystery of Charge Feedback, IHWP in/out Polarization Difference
  - 2020: IHWP in/out Polarization Difference Solved – Vacuum Window birefringence high, new better window found, characterized, now has been installed
- 2021- 2023 SAD : Injector Upgrade Phase I, Ib & Beam Studies to check the upgrade
  - Gun voltage increased up to 180keV (from 130keV), Solenoids replaced with "Counter-wound solenoids" (but design mistake, so need to re-replace in SAD 24), Wein upgrade to perform at 200keV, BPMs added after gun and elsewhere, apertures changed, 1497 MHz "BCM-style" cavity to be installed in the Prebuncher location as part of the Injector Upgrade, new booster, new helicity generator boards for 2kHz.
  - Beam studies found a bad power supply for the Wein, found new vacuum window is indeed better
- 2023-2024 : PREX & CREX Mysteries Solved
  - Digital BCM Mystery Solved – Caused by Local Non-linearities in BCM response function – solution to be found to fix it…
  - Mystery of Charge Fedback Solved – Fa23 HallA Exp Observed Aq deviations after long beam down periods, indicate RTP cell thermally sensitive to beam on/off or overall temperature – fine if Aq feedback cuts same as data cuts
- 2023-2024 : Beam Studies to check the upgrade
  - ~$3^1/_2$ injector shifts (OWL week of 8/14-8/27) & ~$1^1/_2$ HallA shifts (May 2024) – found clipping on apertures & in boost region, found a couple broken BPMS, "damping" in injector not better, FFB operational but made noise worse in Y direction (though this is not atypical prior to optimization from prior experience) FF not yet, digital cavity receivers not 'fixed' by gain change or beam noise, 1^o Wein changes for A_T feedback "ok" downstream OPS-wise, everything else looked fine
- 2024 SAD : Injector Upgrade Phase Ic/II
  - Install new 200keV Gun (with corrected focal length), replace "Counter-wound solenoids" with corrected ones, Install new switch for JLAB cell "solid state" driver, (change laser table layout, install new Hall A seed laser … eventually[?])
- 2024 -2025: Beam Studies to check the upgrade, Adiabatic Damping, + new Helicity Magnets, + new IA cells/drivers,

Backup

2023

PQB hardware on Accelerator Tasks List formed by PQB group

We can flip fast with the Pockels cell now, everything else need to flip fast too.

•Helicity Generator Board – currently debugging, will be able to produce mega-multiplets and have delay option of 10-20us. 8 boards (out of 13 total) will be available for MOLLER for detector and data acquisition development

•Helicity Magnets – needed to be required to transition in <10us and field maps examined to verify position/lensing coupling is negligibly small.

•IA cells – needed to be tested to ensure transition time is <10us and plan to update the IA cells driver circuit to ensure fast transition and ..... (so Helicity signal isn't carried by a BNC cable!)

•Pockels cell driver circuit - IU reverse engineering circuit so John H's circuit is properly documented, Electronics group to make a spare, exploring solid-state switch development (UVA)

•Helicity Decoder Boards: Newly designed board to prevent mis-identification of real helicity events in counting mode for the 2 kHz MOLLER helicity reversal. 20 boards needs to be fabricated and installed in data acquisition systems of four Halls and for all helicity or polarimeter data acquisition systems

Backup

Wein

- Explore ideal frequency of Wein flips 1/week 1/3days? How long for things to drift?

Backup

Spot-size Asymmetry Laser Bounds

$A_\sigma = \Delta\sigma/2\sigma \sim (\sigma_0 - \sigma_1)/(\sigma_0+\sigma_1)$

- Analyzing like $<3\times10^{-7}$ (near S2)
  - 3×10^{-4}
  - Analyzing power 6-7% -> 2×10^{-5}
  - RHWP angle was chosen 1-2deg from S2 (0.1%), further bounding Arms $<\sim10^{-6}$
- Non-analyzing-like - $<5\times10^{-6} – 3\times10^{-5}$
- Measured at 120Hz, 240Hz, 30Hz

https://logbooks.jlab.org/entry/3731868

Backup

PT and AT

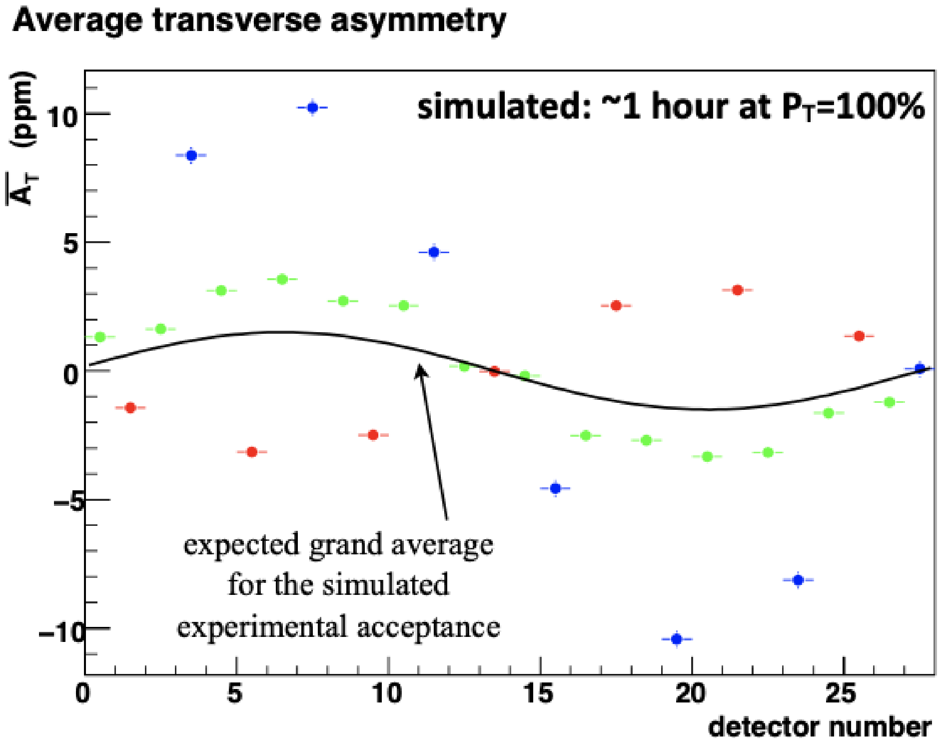


Figure 131: *Simulated values of the transverse asymmetries for* 100% *transverse polarization for the three different types of azimuthal detectors in the Møller ring - open (red), transition (green), and closed (blue). Even with the expected production transverse polarization of* $< 1-2\%$*, the expected transverse modulation is large enough that it can be measured within a few hours of production running, allowing for a "manual" feedback technique to minimize the transverse beam polarization.*

- A_T ~10ppm MAX
- P_T initially 1-2%
- 1/N suppression, 1 correction/shift ~ 1°
- 25X suppression in 1 week
- 10X suppression averaged over detectors
- 10ppm * 2% * 1/25 * 1/10 = 0.8ppb in 1 week
- Goal: average 0.06ppb after 344 PAC days

The statistical error on the inferred transverse polarization angle from a few hours of data will be well below 1°. It should therefore be possible to devise a "manual" feedback loop that would make small tweaks to the launch angle of the electron beam polarization at the low energy end of the machine based on the measured A_T every few hours. While the statistical "noise" in the inferred transverse polarization will be inserted into the launch angle set point, this algorithm should nevertheless lead to a rapid convergence of the total data set to zero average transverse polarization over a series of setpoint adjustments.

Ideally, the suppression of the initial launch angle (averaged over all the data) is expected go like $1/N$, where N is the number of adjustments. In principle, we should gain a factor of about 25 below the setup accuracy of 1° in a week. If one now further conservatively assumes a factor of 10 suppression in the grand average of A_{PV} over the full range of detectors, then the total correction to A_{PV} will be less than 0.06 ppb. Therefore, with the implementation of the manual launch angle feedback, it is our expectation that no correction for the transverse polarization will need to be made. We have assumed the entire value of the anticipated correction to be the systematic error in our projections. As a final control measure, if the aforementioned level of suppression is difficult to achieve in practice, some of it can be recovered by a slightly different re-weighting of the data from the various different azimuthal detectors with only a small loss in the statistical error in the extracted A_{PV}.

Backup

Precision & Systematic Error Goals

Any change in the polarized beam, correlated to helicity reversal, can be a potential source for a false asymmetry

$$A_{raw} = A_{det} - A_Q + \alpha\Delta_E + \Sigma\beta_i\Delta x_i$$

HCBA's are expected to contribute ~10ppb uncertainty for PREXII (~*0.14 ppb for Moller)*

HCBA Contributors

	MOLLER	previously achieved	PREXII
Intensity	10 ppb	~ 30 ppb (Qweak)	1-20ppb
Energy Asymmetry	<0.7 ppb	0.2 ppb (H-II)	0.8-1ppb
Position Difference	<1.2 nm	2 nm (H-II)	1.5-2nm
Angle Differences	<0.12 nrad	0.25 nrad (H-II)	0.15-0.4nrad
Size Differences	$< 1x10^{-5}$	$<1x10^{-4}$ (PREX-I,	$5x10^{-6}$ -$3x10^{-5}$

OBSOLETE

Suppressing HCBA
- *Slow Reversal*
- *Feedback*
- *Damping*

	Source	Adiabatic Damping	Slow Reversals	Feedback
Intensity	<10 ppm (inj)	-	$\sim 10\times$	$100\times$
Position/angle (Past)	~ 20 nm (inj) (50 – 200 nm)	$\sim 100\times$ ($30\times$, max $95\times$)	$\sim 10\times$ ($\sim 10\times$ IHWP, ISM)	$\sim 10\times$, control jitter ($\sim 10\times$, unused)
Spot-size (Past)	$< 10^{-5}$ (laser) ($< 10^{-4}$)	(synch light dilution)	$\sim 10\times$ (IHWP, g-2, ISM) ($\sim 10\times$ from ISM)	- -

Achieving these goals begins with the laser and Pockels Cell

Backup

HCBA goals, Polarization, and P_T

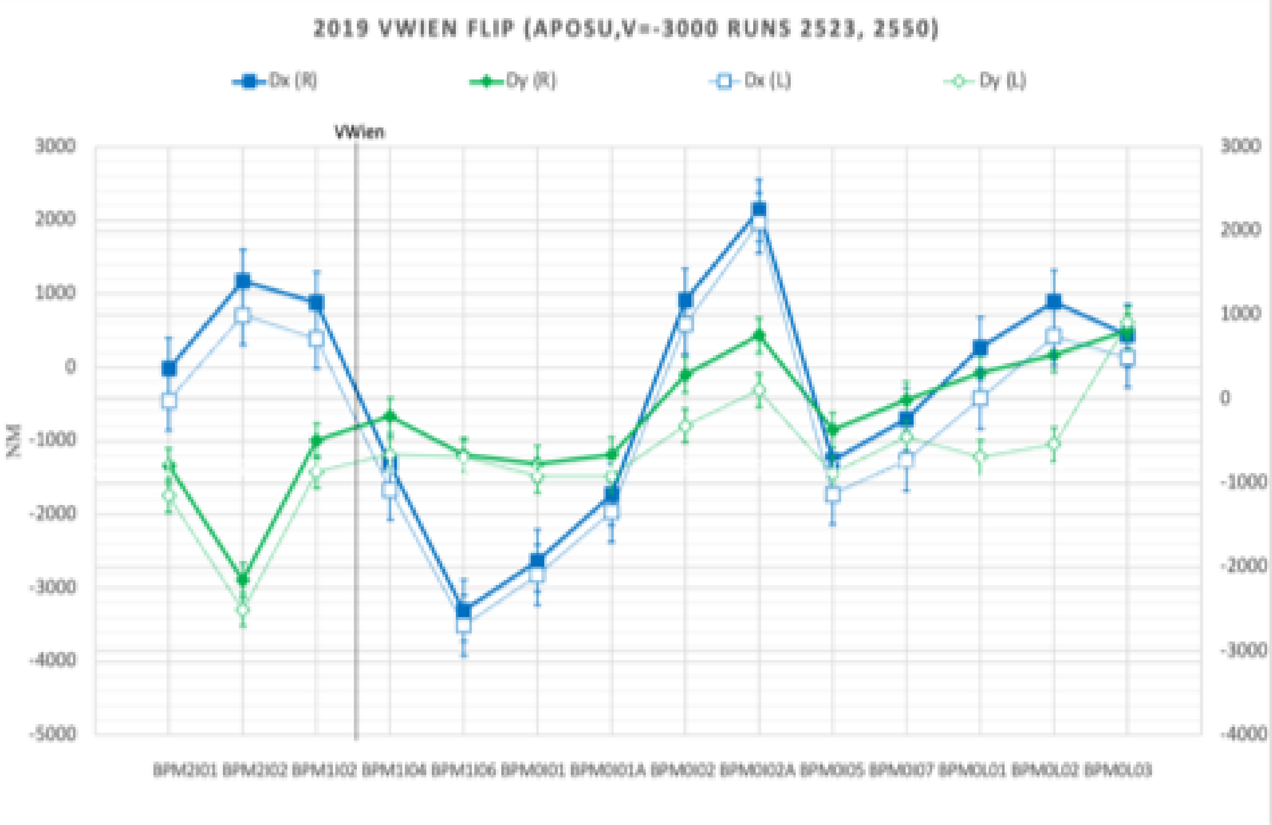
- HCBA goals: Run1 and Full Data Set

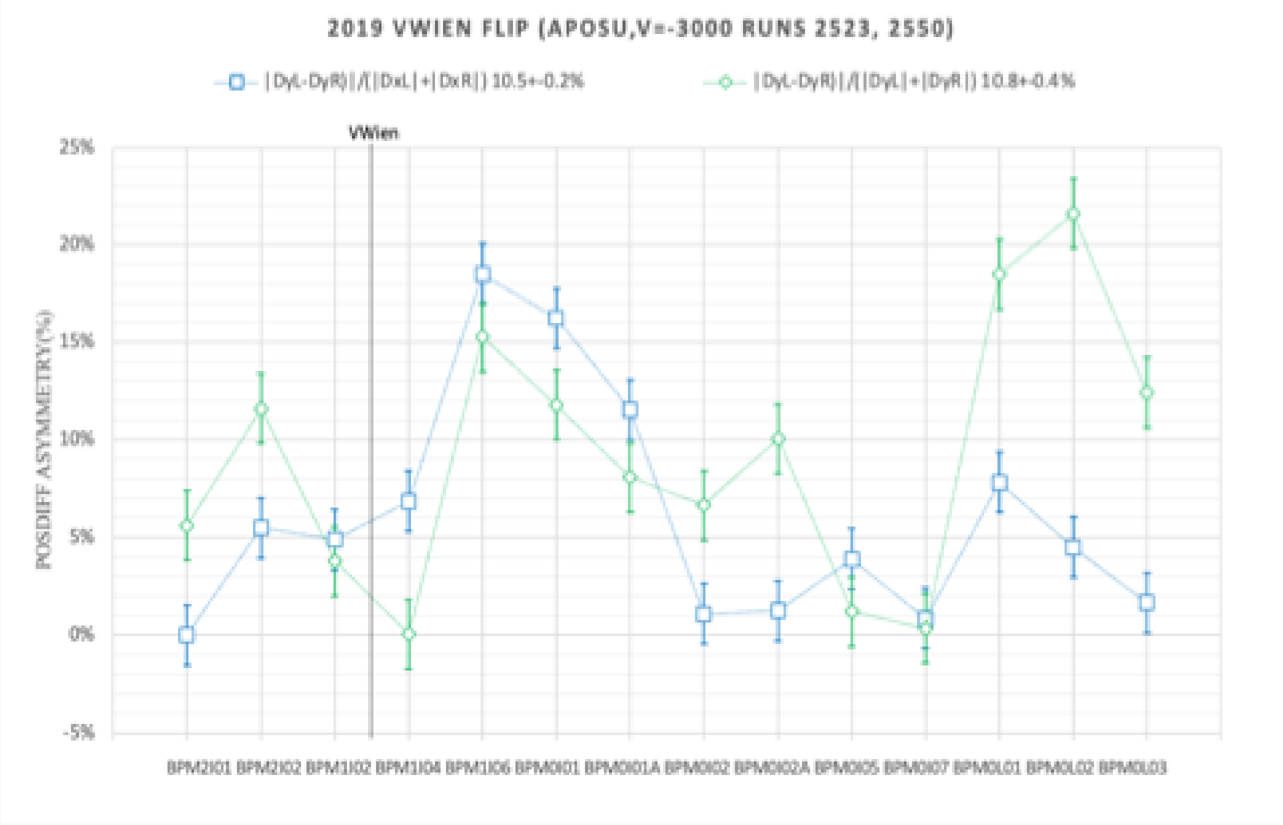
Beam Property	Defining Equation	Required 960Hz pair random fluctuations	Cumulative Helicity Correlation (Run1)	Cumulative Helicity Correlation (full data set)
Intensity	$A_q \equiv \frac{I_0-I_1}{I_0+I_1}$	< 1000 ppm	< 40 ppb	< 10 ppb
Energy	$A_E \equiv \frac{E_0-E_1}{(E_0+E_1)} = \frac{\Delta E}{2E}$	< 108 ppm	< 6 ppb	< 1.4 ppb
Position	$D_x = \Delta x \equiv x_0 - x_1$	$< 47 \times 10^{-6}$ m	$< 4 \times 10^{-9}$ m	$< 0.6 \times 10^{-9}$ m
Angle	$\Delta\theta \equiv \theta_0 - \theta_1$	$< 4.7 \times 10^{-6}$ radian	$< 0.5 \times 10^{-9}$ radian	$< 0.12 \times 10^{-9}$ radian
Spot-size	$\Delta\sigma/\sigma \equiv \frac{\sigma_0-\sigma_1}{\frac{1}{2}(\sigma_0+\sigma_1)}$	-	$< 10^{-5}$	$< 10^{-5}$

- P_B goal: ~90% polarization
- P_T goal: average 0.06ppb uncertainty contribution to A_{PV} after 344 PAC days

Backup

2019 VWIEN FLIP





Backup

OLD DAMPING 2019

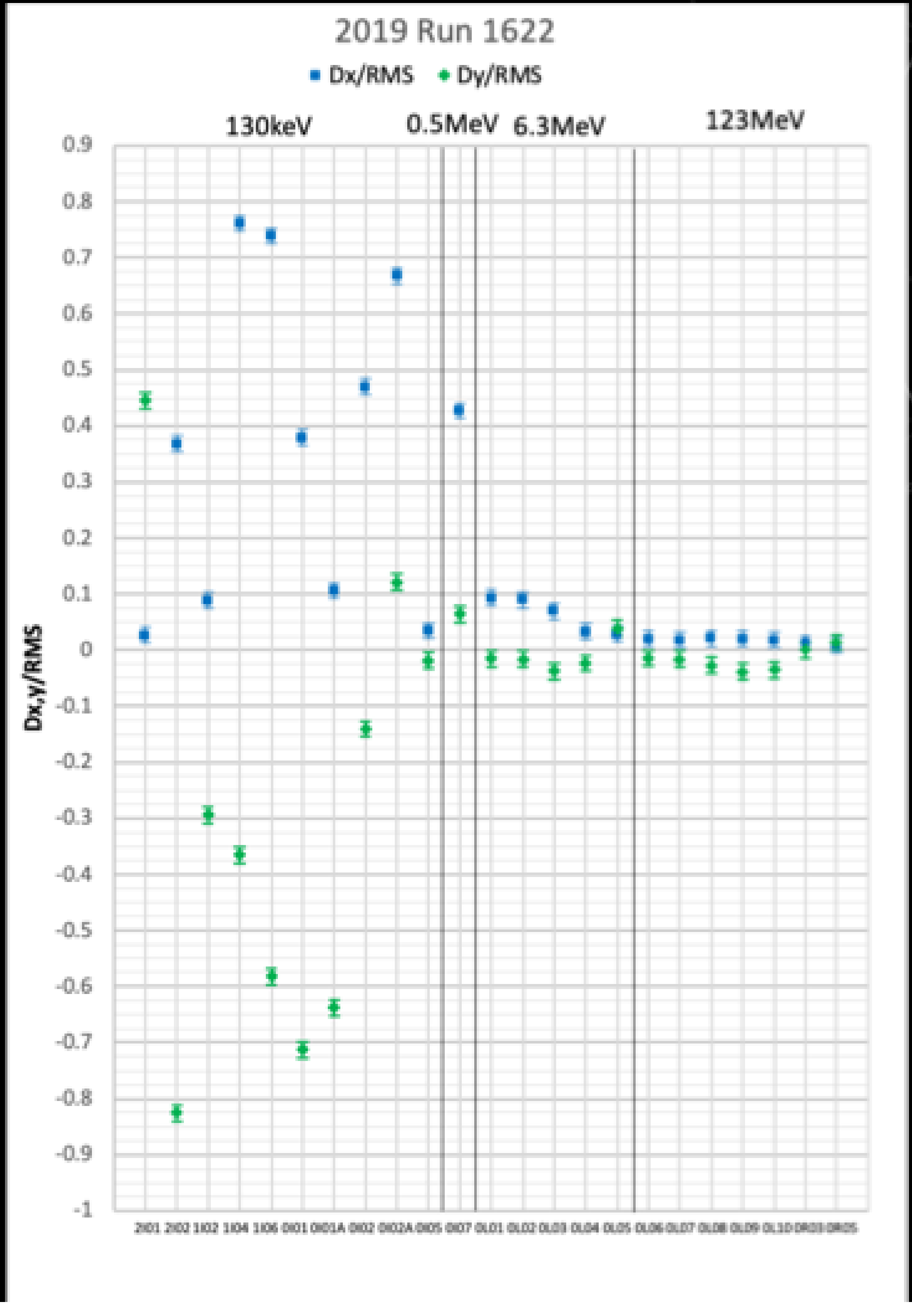
Damping from Vwien Flip in 2019 seemed better

Take Dx,y/RMS to approximate damping

		Dx/RMS MAX	damping
0L06-0R05	123MeV	0.02	35.81
0L01-0L05	6.3MeV	0.09	8.13
2i01-0i05	130keV	0.76	

		Dy/RMS MAX	damping
0L06-0R05	123MeV	0.04	21.67
0L01-0L05	6.3MeV	0.04	21.32
2i01-0i05	130keV	0.83	

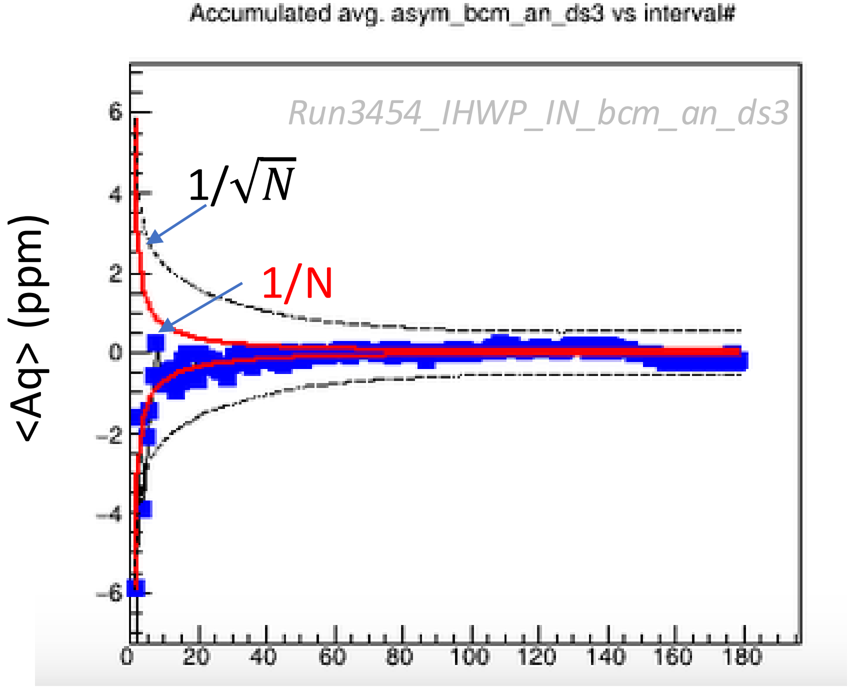
Note: didn't really see damping when using helicity magnets, here using RTP cell



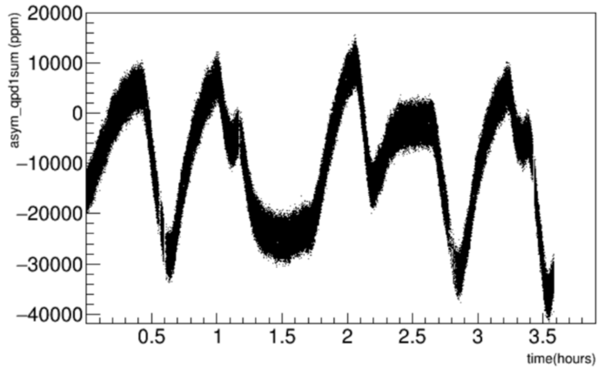
Backup

Aq Suppression – Feedback & Slow reversals

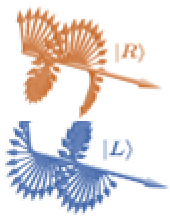
Feedback: Interval (sub-10sec, 120Hz)



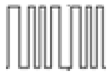
- Counteract Slow Thermal Fluctuations



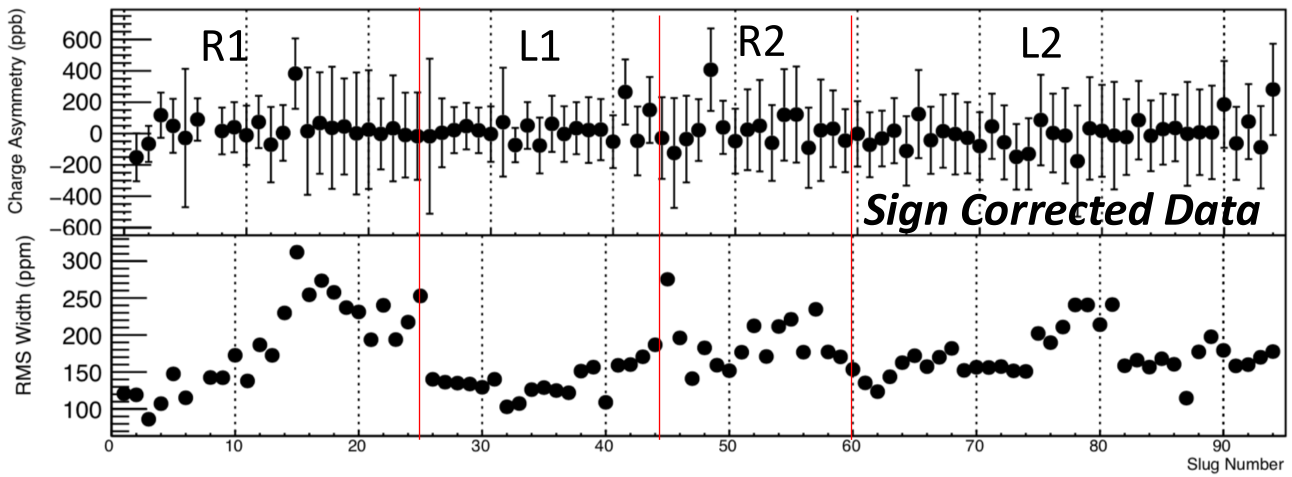
***Helicity:** HV +/-, IHWP out/in, Wein L/R*



	Wien R1	Wien L1	Wien R2	Wien L2
A+	IHWPin	IHWPout	IHWPin	IHWPout
A-	IHWPout	IHWPin	IHWPout	IHWPin

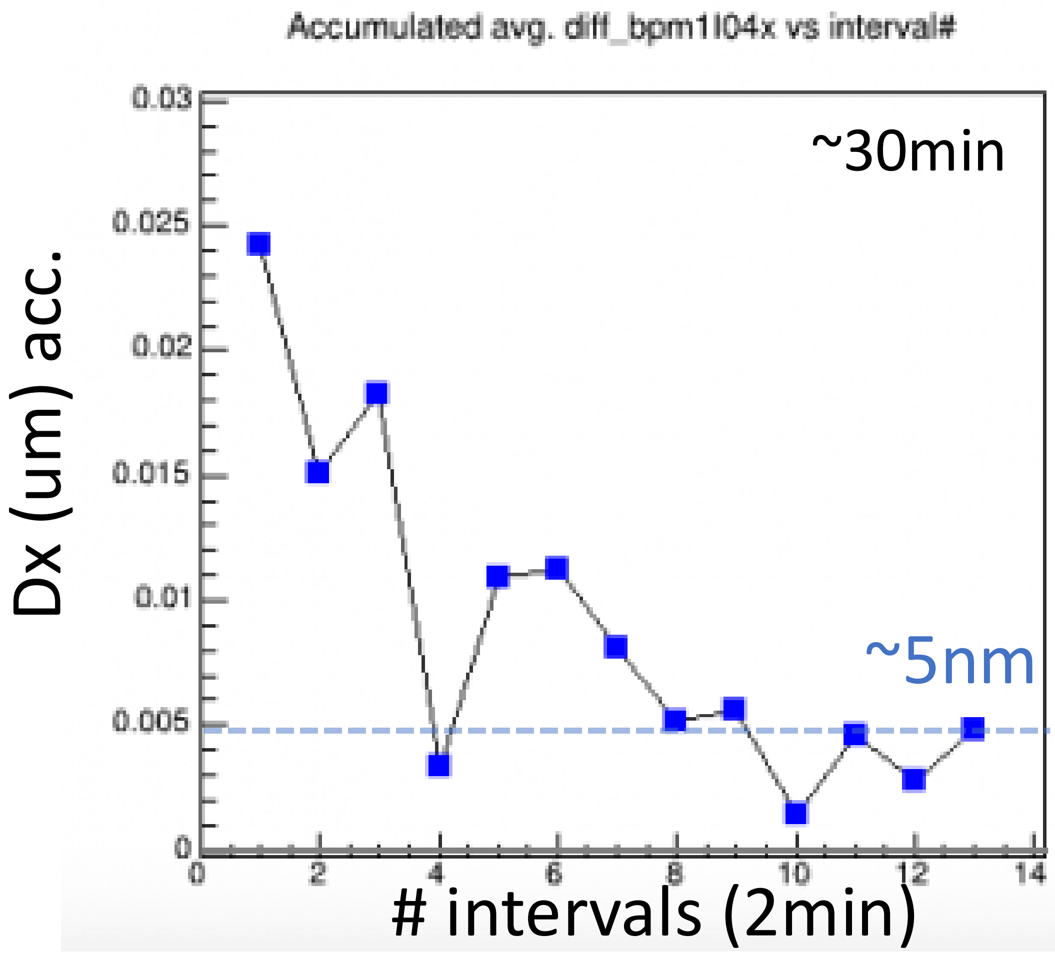


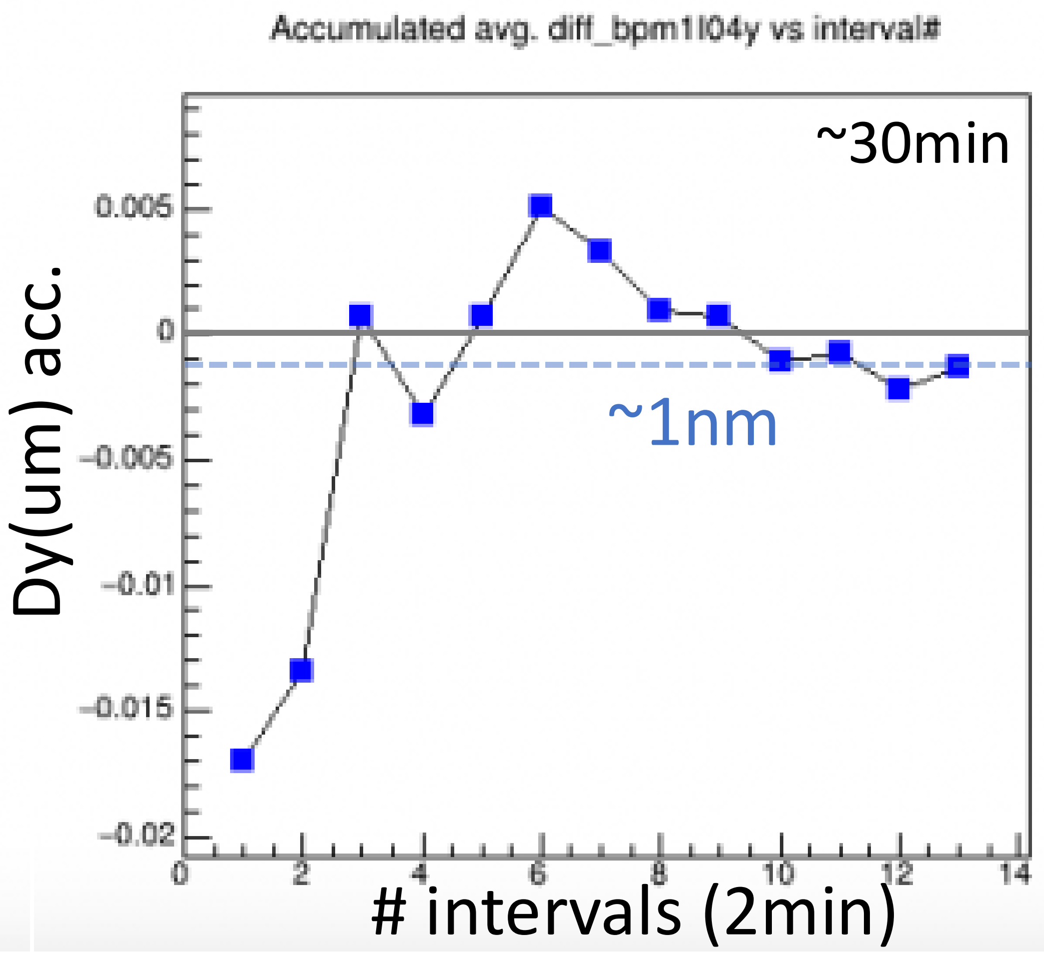
***Reversals:** 4 Wein flips, 94 IHWP flips, 300 x10^6 Pockels cell HV flips*



PREXII: <Aq> ~ 20ppb

Position Difference feedback – near S2

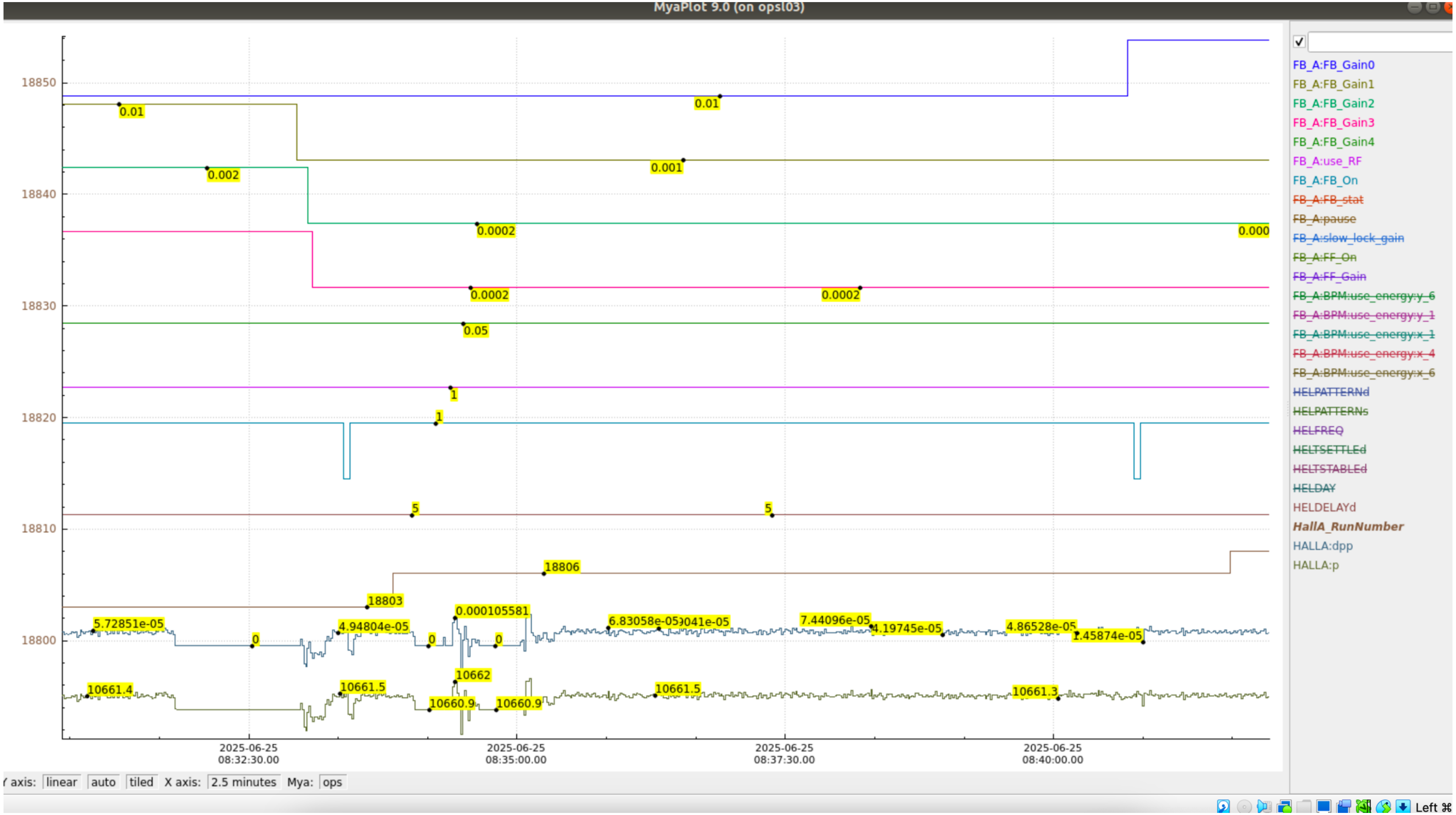




Run4017_RHWP1000_IHWPout_1I04feedback_Dxconverge.png
Run4017_RHWP1000_IHWPout_1I04feedback_Dyconverge.png

BPM1I04

Recent Energy changes: dpp during FFB



seconds time scale

FFB on 18806 (after it got 'started')

dpp

7.44E-05 high

1.45E-05 low

5.99E-05 diff

FFB off 18812

dpp

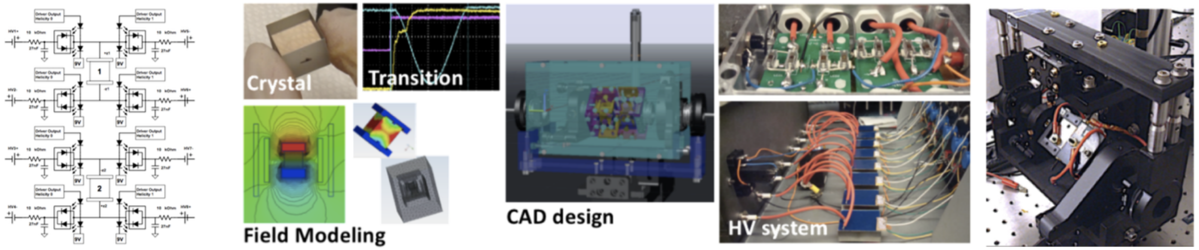
2.60E-05 low

0.0001055 high

7.95E-05 diff

Run this <1e-4 dpp is clearly gonna average to a smaller number over **minutes time scale**

PQB hardware on Accelerator Tasks List formed by PQB group



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