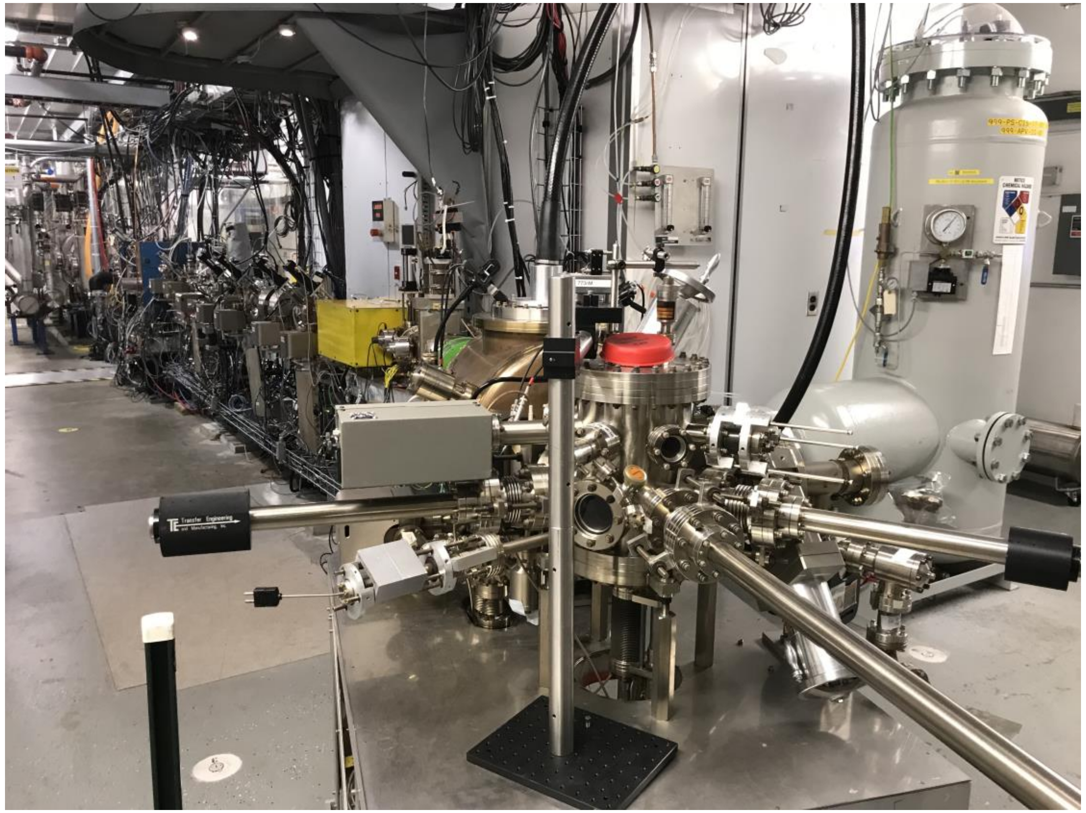
Injector Status and Upgrades for MOLLER

Hall A Collaboration Winter Meeting

January 15 – 16, 2025



Riad Suleiman

Monday, February 17, 2025

Outline

- Parity Violation Experiments at CEBAF
- MOLLER Requirements
- Injector Status and Upgrades for MOLLER:

  1. Source: 200 kV Gun, Polarized Photocathodes
  2. Beamline: Solenoid Magnets, 200 keV Wien Filters, SRF Booster
  3. Helicity Controls: Helicity Generator Board, Helicity Decoder Board
  4. Parity-Quality Beam : RTP HV Driver, IA HV Driver, Helicity Magnets Control

- Future Plans

Parity-Violating Experiments at CEBAF

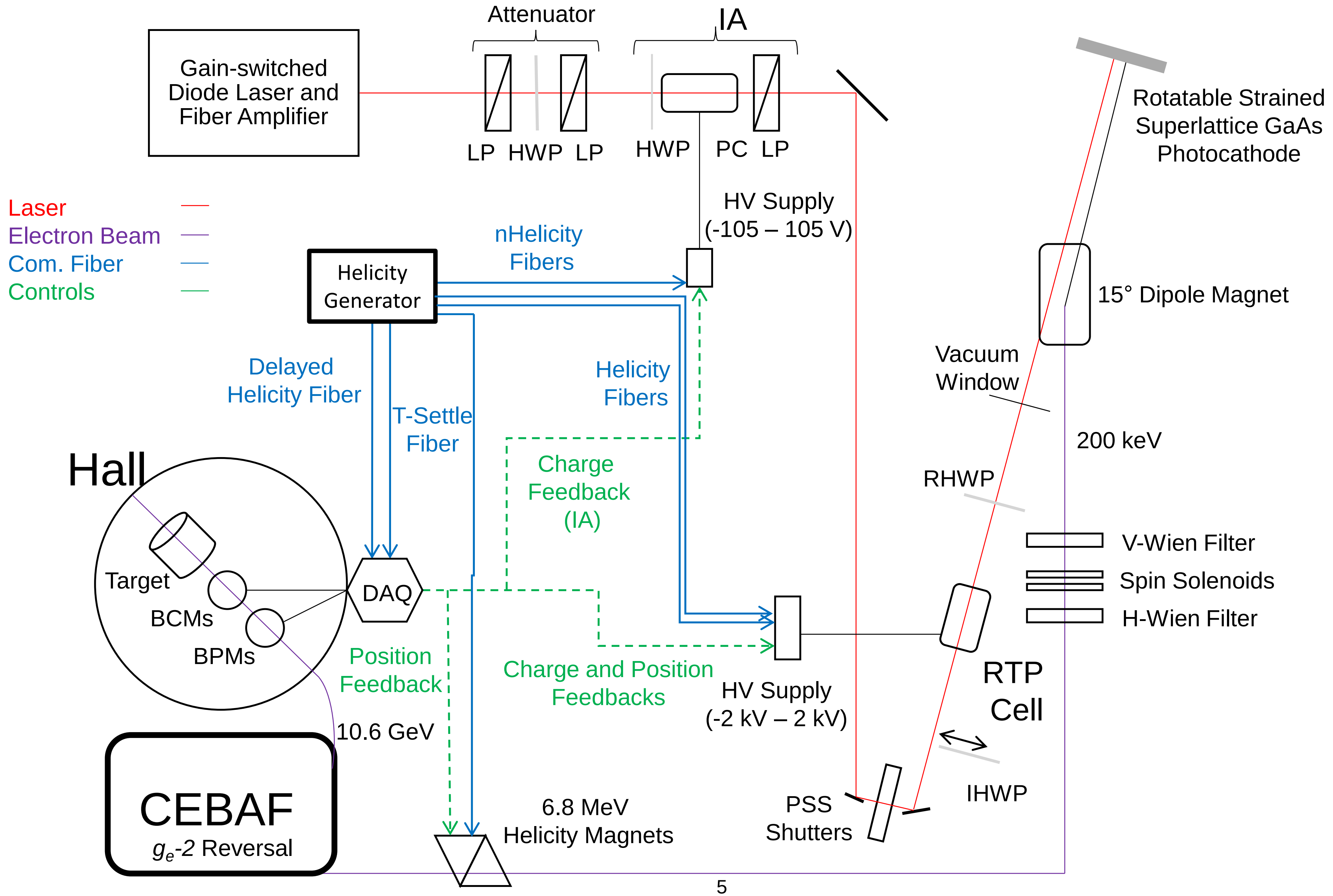
PV Experiment	Energy (GeV)	Pol (%)	I (μA)	Target	A_{pv} (ppb)	Charge Asym (ppb)	Position Diff (nm)	Angle Diff (nrad)	Size Asym(δσ/σ)
HAPPEx-I 1998 – 1999	3.3	38.8 68.8	100 40	^{1}H (15 cm)	15,050	200	12	3	$<10^{-3}$
G0-Forward 2003 – 2004	3.0	73.7	40	^{1}H (20 cm)	3,000-40,000	300±300	7±4	3±1	$<10^{-3}$
HAPPEx-II 2004 – 2005	3.03	87.1	55	^{1}H, ^{4}He (20 cm)	1,580	400	2	0.25	$<10^{-3}$
G0-Backward 2006 – 2007	0.359, 0.688	85.8	60	^{1}H, ^{2}H (20 cm)	9,700-37,400	-30±300	47±9	1.2±0.5	$<10^{-3}$
HAPPEx-III 2009	3.484	89.4	100	^{1}H (25 cm)	23,800	200±10	3	0.5±0.1	$<10^{-3}$
PVDIS 2009	6.067	89.0	105	^{2}H (20 cm)	60,000-160,000	100	100	40	$<10^{-3}$
PREx-I 2010	1.056	89.2	70	^{208}Pb (0.5 mm)	657±60	85±1	4	1	$<10^{-4}$
QWeak 2010 – 2012	1.162	88.7	180	^{1}H (34 cm)	226.5±9.3	20.5±1.7	-4.6±0.2	-0.07±0.01	$<10^{-4}$
PREx-II 2019	0.953	89.7	70	^{208}Pb (0.5 mm)	550±18	20.7±0.2	2.2±4	0.3±0.3	$<6\times10^{-5}$
CREx 2019-2020	2.18	87.1	150	^{48}Ca (5 mm)	2668±113	-88±26	-5.2±3.6	-0.13±0.08	$<6\times10^{-5}$
MOLLER 2027-2029	**10.6**	**90**	**65**	**^{1}H (125 cm)**	**35.6±0.74**	**<10**	**<0.6**	**<0.12**	**$<10^{-5}$**

An overview of how parity-violating electron scattering experiments are performed at CEBAF, P.A. Adderley *et al.*, Nuclear Inst. and Methods in Physics Research, A 1046 (2023) 167710 https://doi.org/10.1016/j.nima.2022.167710

MOLLER Requirements

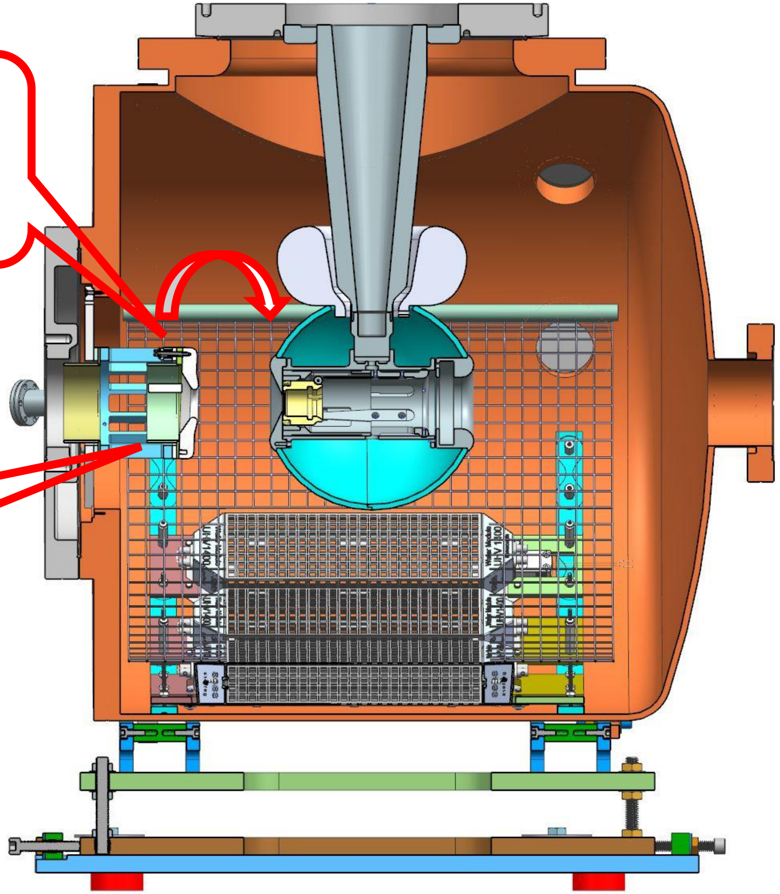
1. MOLLER Apparatus is designed for nominal beam energy: 10.6 ± 0.2 GeV with low RF trip rate (<6/hour)
2. 65 µA with 90% polarization (max 70 µA for target studies)
3. Fast helicity reversal:
   I. 1920 Hz, 10 µs settle time, 64-window pattern, 128-window delay
4. Slow helicity reversals:
   I. Insertable half-wave plate (IHWP)
   II. Wien Filters
   III. g_e-2 ($\Delta E \sim 0.10$ GeV)
5. Feedbacks on:
   I. Helicity-correlated beam charge
   II. Helicity-correlated position and angle
   III. Polarization orientation
6. Small helicity-correlated beam asymmetries
7. Adequate adiabatic damping of transverse phase-space (for both xx' and yy') – a factor of 100 is desired, a factor of 10 is required. Ideally, $\sqrt{P_f/P_{gun}} = \sqrt{10800/0.494} = 148$
8. Acceptable beam halo (MOLLER Halo Monitor: to be specified, Compton Polarimeter: <100 Hz/µA)

From Beginning-to-End



200 kV Gun – Spherical Electrode and 18" Chamber

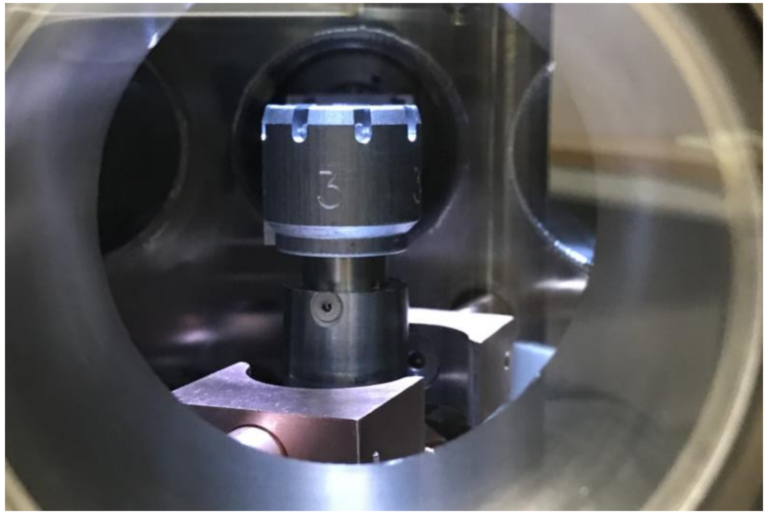
- Upgraded from 130 kV to 200 kV: less space-charge forces → higher transmission
- Optimized beam optics and longer charge lifetime
- Commissioned and delivering beam right now



https://doi.org/10.1103/PhysRevAccelBeams.27.123401

Polarized Photocathodes

- Now running from Puck #3 (QWeak sibling)
- Have extra two SLSP photocathodes in Preparation Chamber

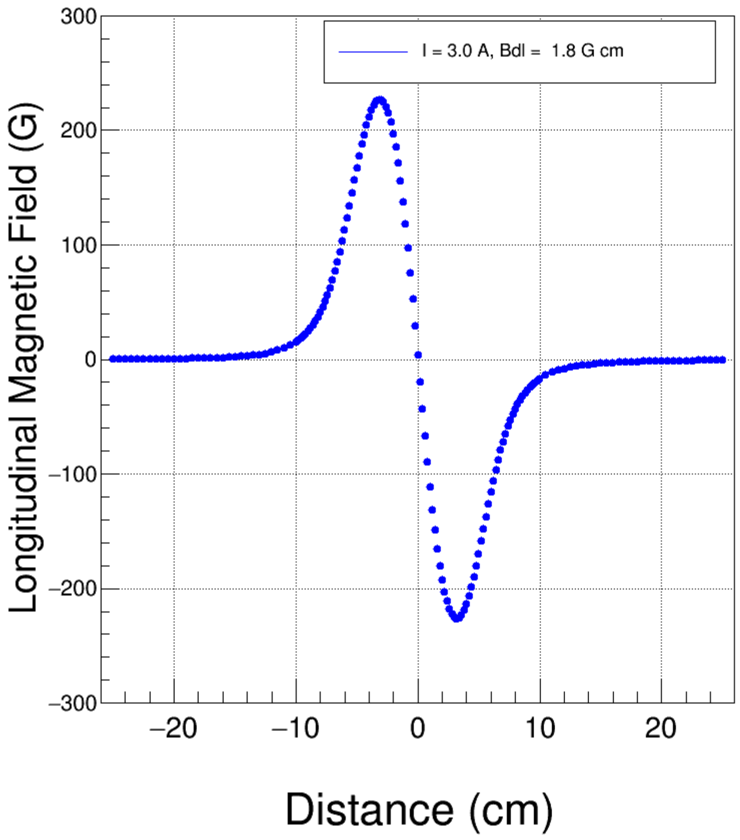


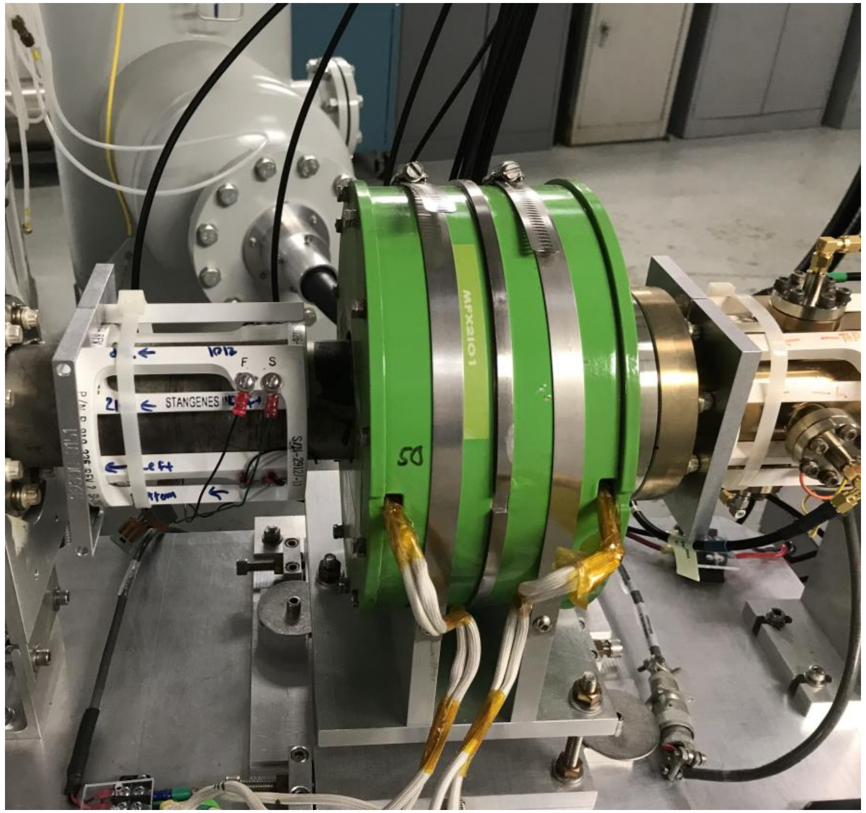
Puck #	Photocathode Material	Note
8	SLSP-5247-1	PREx-I, QWeak (July 2009 - January 2015)
9	SLSP-5756-4	PREx-II and CREx (January 2015 – July 2023)
3	**SLSP-5247-4**	**(December 2023 – present)**
10	SLSP-5757-3	Sibling of 5756 wafer
31	SLSP-75104-1	Measured 0.7% QE and 90% polarization in micro-Mott

- Jefferson Lab, ODU, and UCSB collaborations are successfully prototyping new high-polarization high-QE photocathodes:
  - https://doi.org/10.1063/5.0170106
  - https://pos.sissa.it/456/215/pdf

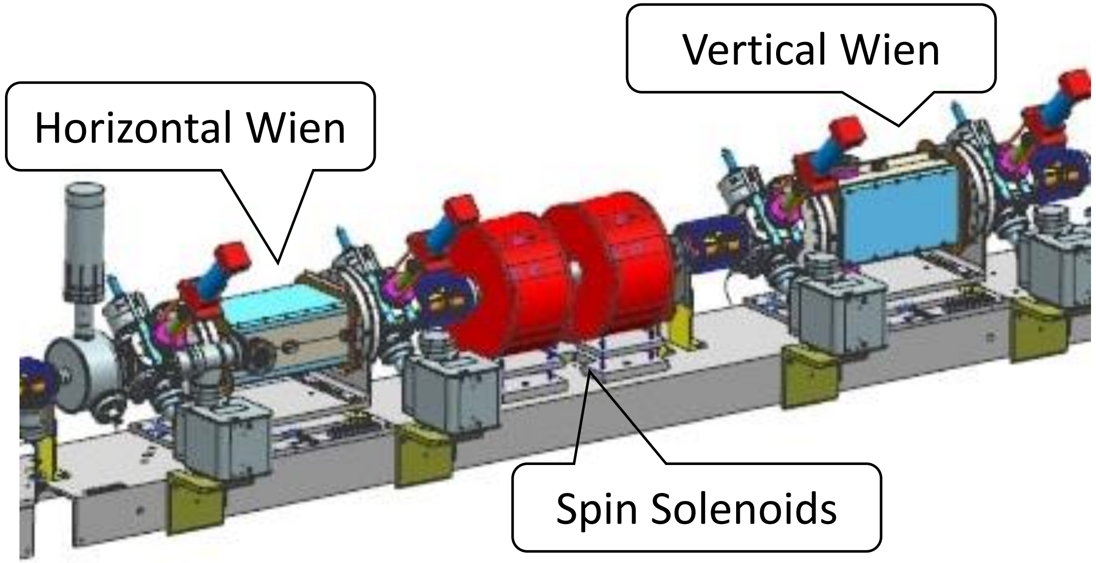
Solenoid Magnets

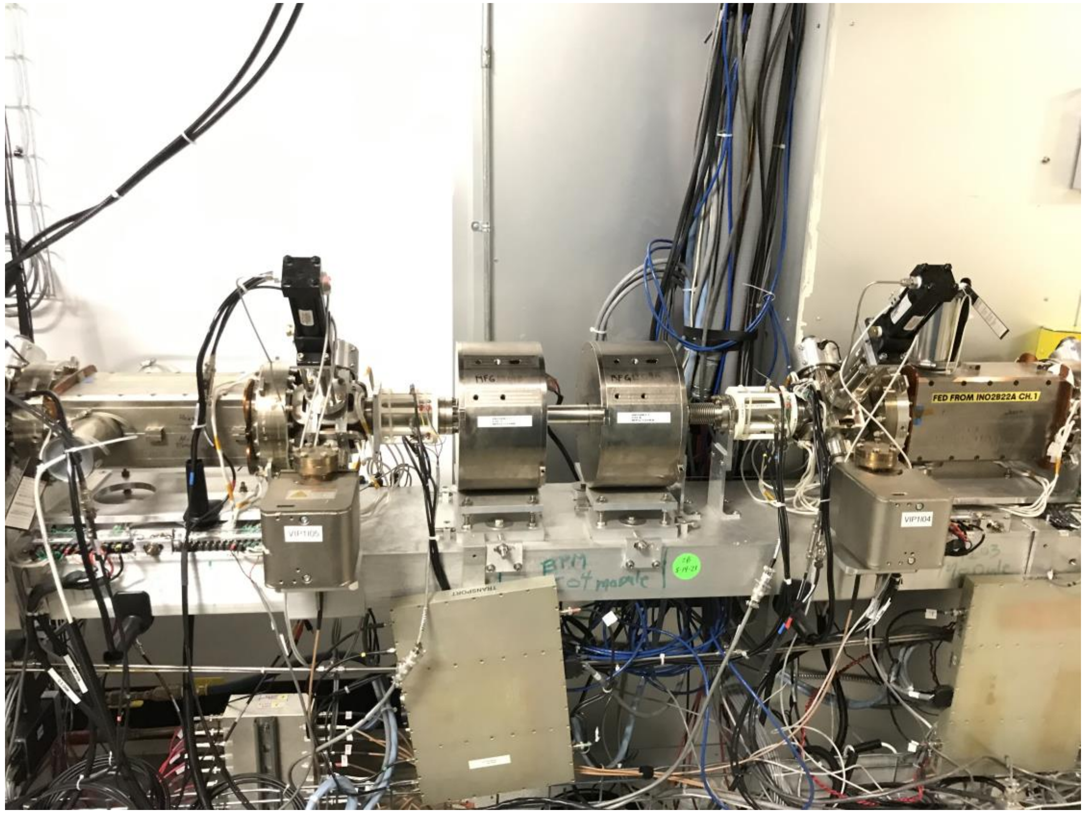
- Six new solenoids in keV region: uniform field at center – less aberrations
- All powered counter-wound: no x/y coupling or spin rotation ($\int Bdl \equiv 0$), only focusing ($\int B^2 dl$)



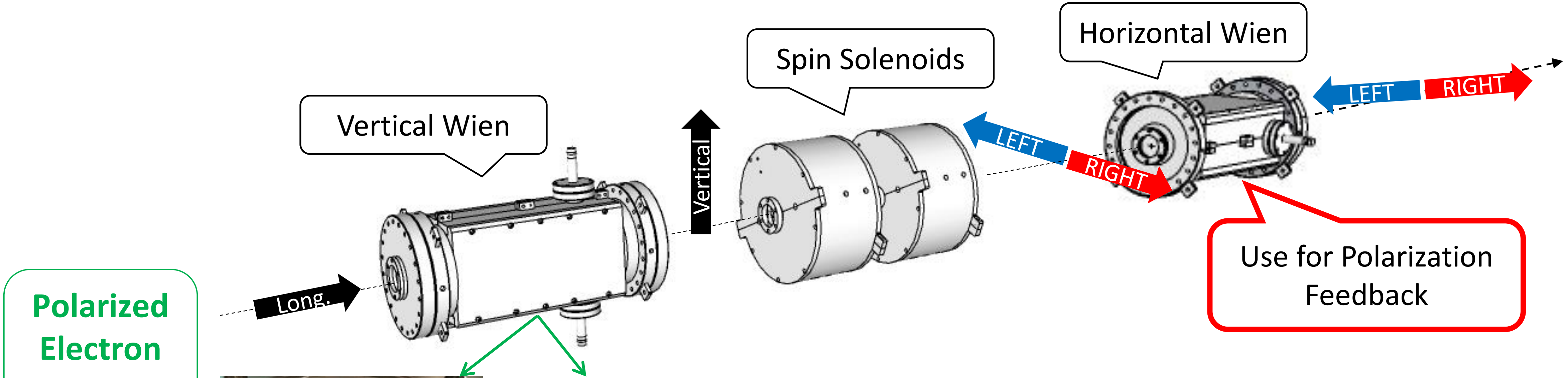


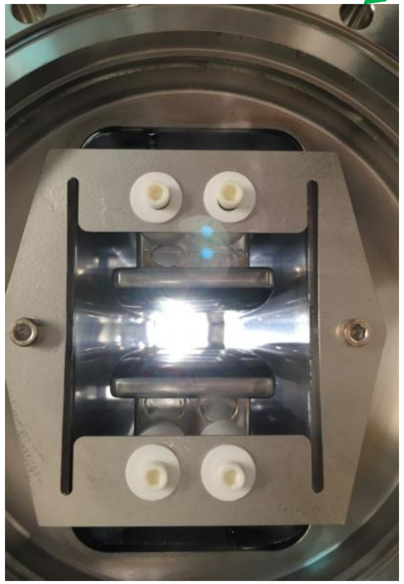
200 keV Wien Filters

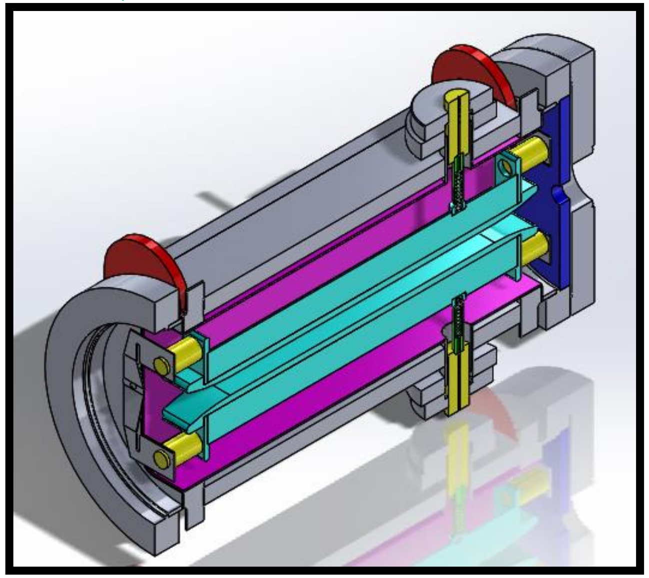




200 keV Electron Beam Spin Manipulation



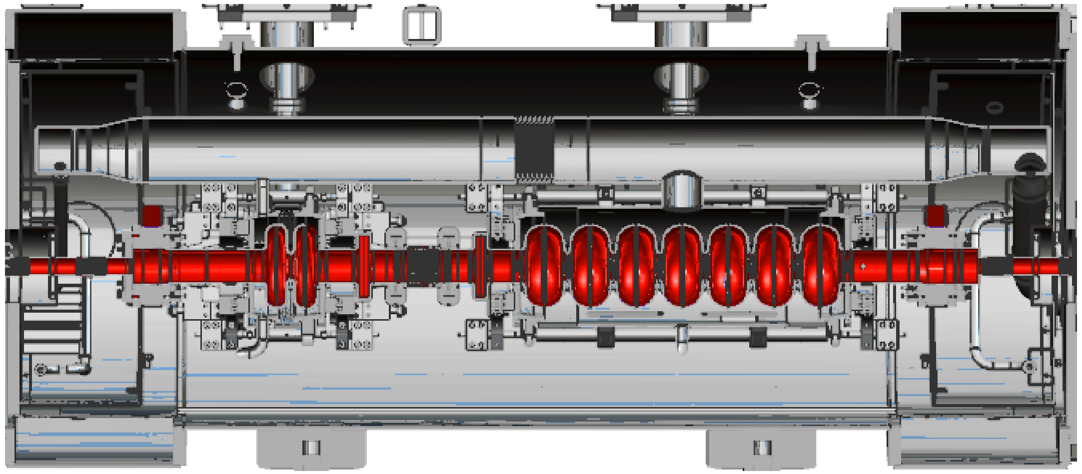




- HV conditioned to 22 kV
- Will be able to rotate spin to 110 degrees

https://jacow.org/napac2022/papers/wepa20.pdf

SRF Booster



Booster replaced warm RF Capture and ¼ Cryo-unit:

- Parity-quality beam (MOLLER)
- Matched to 200 keV gun energy
- Resolves x/y coupling
- Mitigate emittance growth

Quantity	Booster	¼ Cryo-unit
Kinetic Energy	$\leq$ 8 MeV	$\leq$ 9 MeV
$\epsilon_{n,x}$	0.3 µm rad	0.5 µm rad
$\epsilon_{n,y}$	0.2 µm rad	0.5 µm rad
x/y Coupling Angle	$\leq 0.6°$	$5°$
x/y Deflection	$\leq 1.0°$	$\leq 1.0°$

For more data:

- JLAB-TN-23-005
- [https://doi.org/10.18429/ JACoW- NAPAC2022- WEPA12](https://doi.org/10.18429/JACoW-NAPAC2022-WEPA12)

Helicity Generator Board

- **Built 13 boards and distributed to MOLLER**

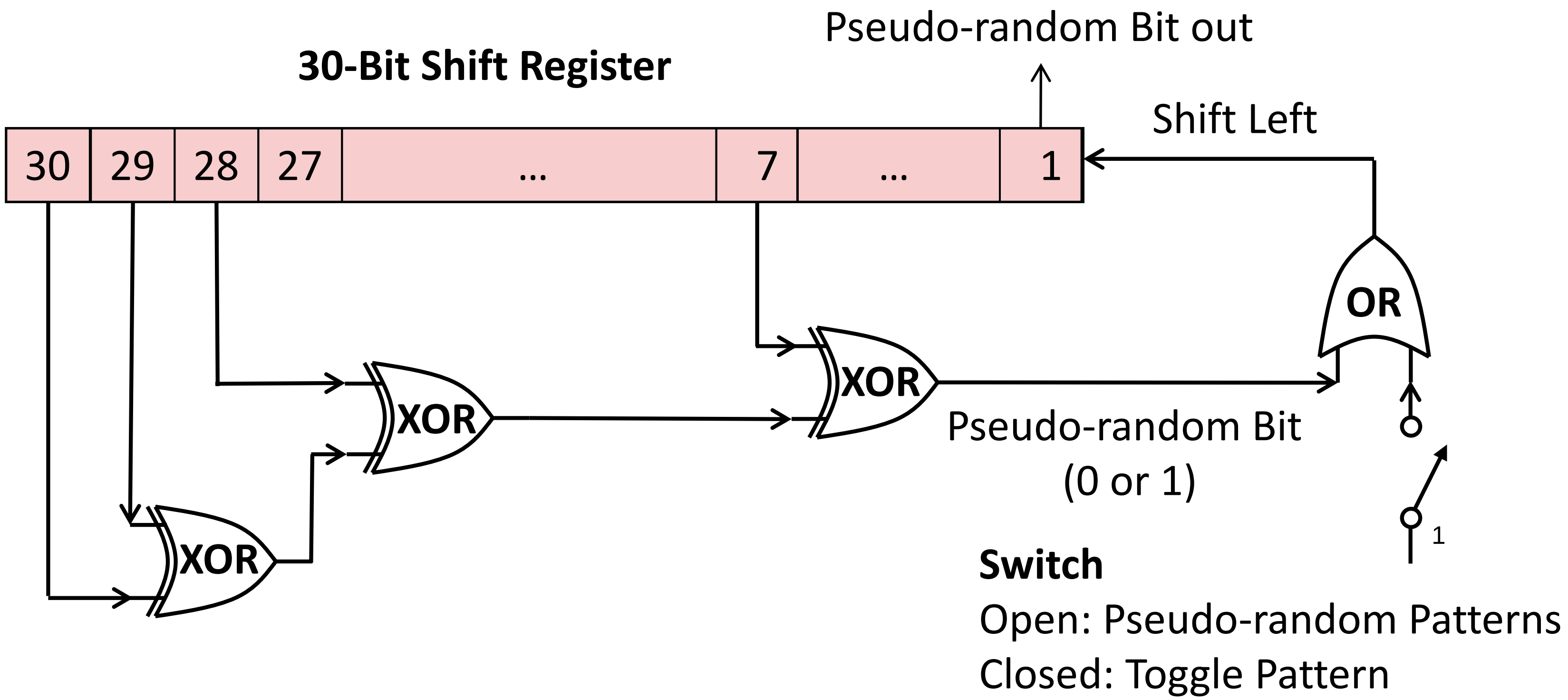
Board is supported by Jefferson Lab Fast Electronics Group

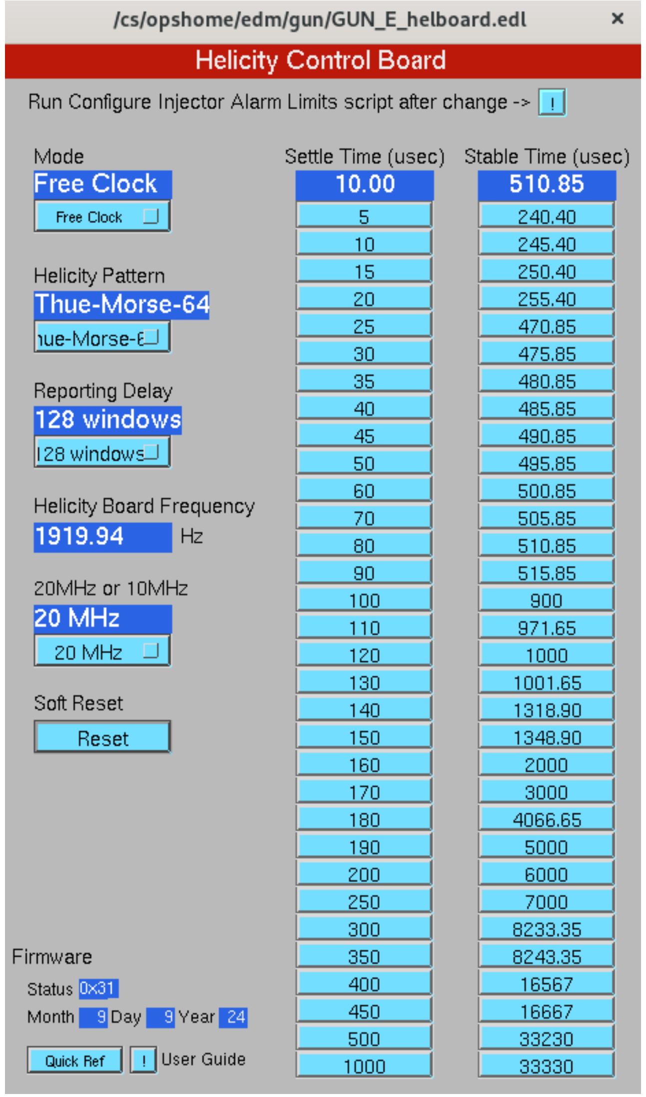
- **Recent firmware additions:**
  - New Helicity settings for MOLLER:
    I. Free Clock Mode at 1920 Hz, 10 µs T_Settle, 510.85 µs T_Stable
    II. 64-window patterns: Thue-Morse-64, 16-Quad, 32-Pair
  - Fixed Line-Sync Mode
  - Added Soft Reset functionality

- **Recent hardware changes:**
  - Changed IA0 and IA1 fiber outputs to Helicity Flip and nHelicity Flip

Jefferson Lab

Helicity Generator Settings





Helicity Decoder Board

- MOLLER fast helicity reversal **with delay reporting** could cause mis-identification of real helicity of some of events in counting mode (these are random events), diluting measured asymmetry
- Board developed by: MOLLER Collaboration (Ohio University), Jefferson Lab Fast Electronics Group and Accelerator Division
- **Will be used by all data acquisition systems using helicity signals**
- **Board will not reconstruct real helicity or real 30-Bit Shift Register**
- Board has four input signals: T_Settle, Delayed Helicity, Helicity Pattern, and Pair Sync
- For each counting event:
  - Now: Delayed Helicity and Pattern are recorded in Rings of helicity-gated SIS3801 Scaler. Offline analysis then attempts to construct real helicity, a complicated process due to delay and randomness of events.
  - New Board: board will keep records of helicities spanning last 30 patterns – to be able to construct 30-bit shift register seed of pseudo-random helicity generator – and position within pattern. And for each event, these records are read along with event. Offline analysis (anytime>n-patterns) will calculate real helicity using helicity predictor. Will be able to correctly identify helicity of every event.

Electron Beam Travel Time

- With 10 µs T_Settle time, travel time from photocathode (Pockels Cell) to Hall target becomes relevant. Also, time it takes for helicity board signals to propagate to Laser Hut and to Halls.

- It takes electron beam about 4.3 µs per pass to reach Hall.
- Total distance at 5 passes is about 6.5 km
- Fiber length from Injector Service Building (ISB) IN01B05 to Counting House was measured to be 1705 ft. With n=1.45, it takes 2.5 µs for helicity signals to travel in fibers to Hall DAQ

  - ➢ All these travel times will be accounted for in this new Helicity Decoder Board such that recorded events have correct helicity at Physics Interaction Time

- Built 20 Production Boards, tested and ready for distribution:
  - Five in use: 2 MOLLER, 1 Hall B, 1 Hall D, 1 Injector Mott Polarimeter
  - **Contact Chris Cuevas to get your board**

Decoder Board I/O and Features

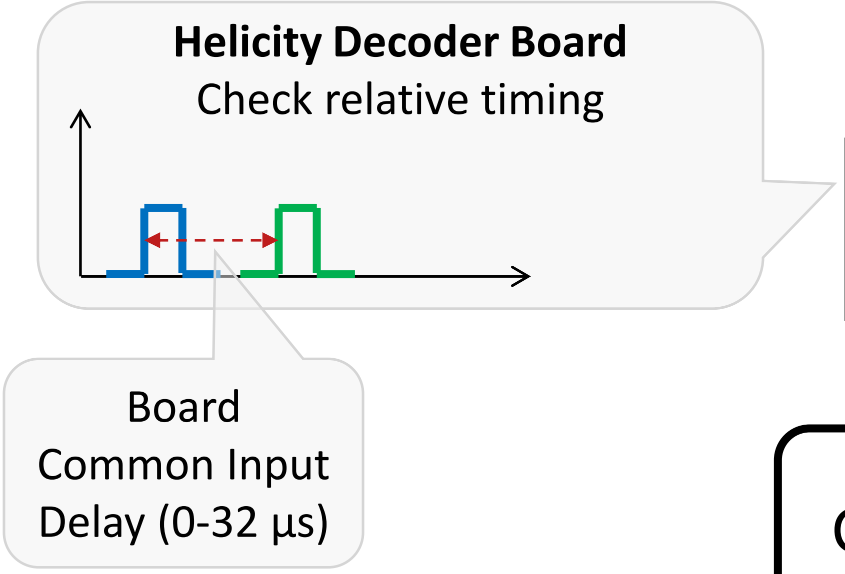
- Input:
  1. T_Settle
  2. Delayed Helicity
  3. Helicity Pattern
  4. Pair Sync

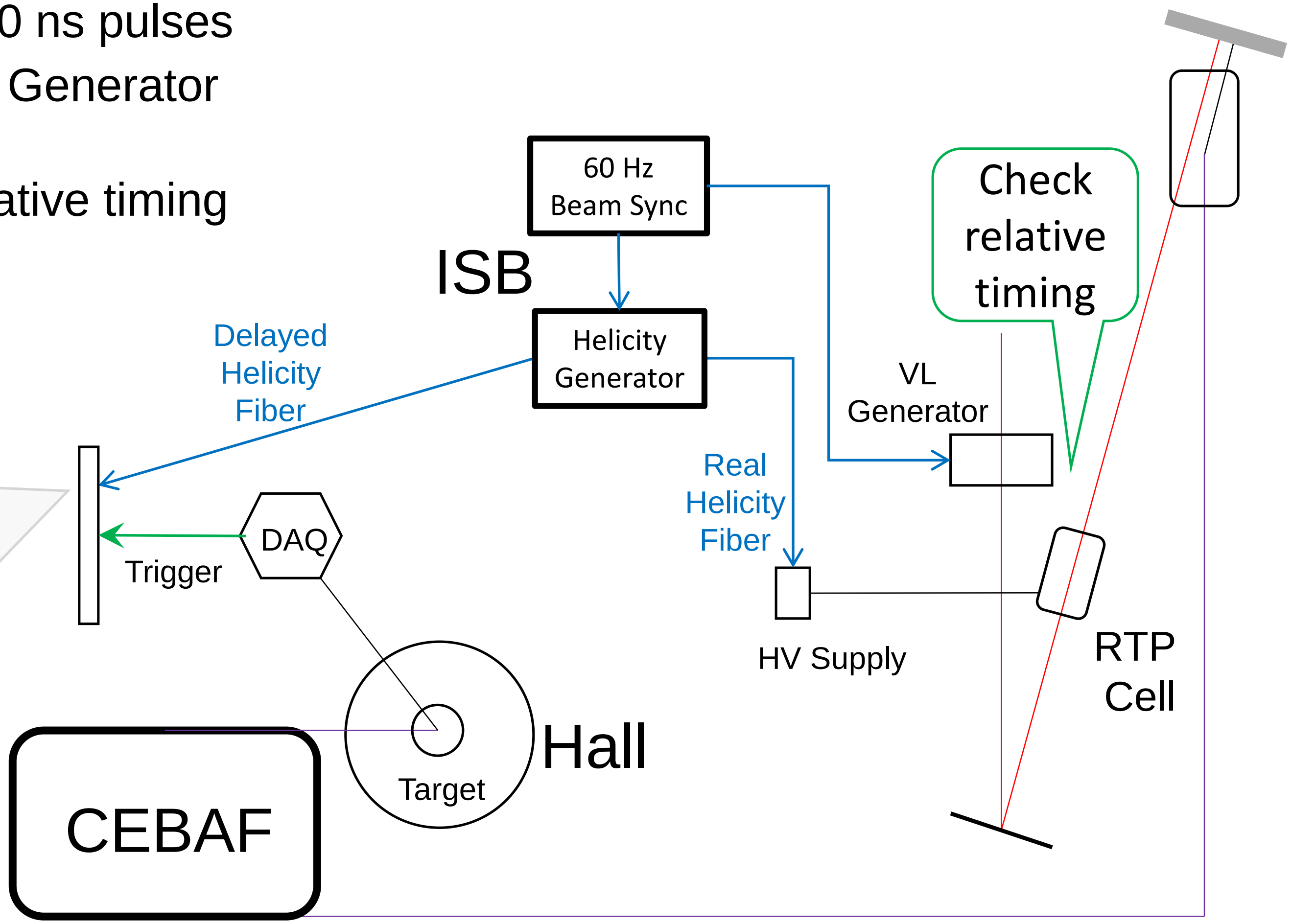
  (1–4: NIM or Fiber, programmable)

  5. External 250 MHz FADC Clock (ECL) – Board has 250 MHz internal clock
  6. Trigger and Sync Signals
- Output:
  1. Four NIM helicity outputs: T_Settle, Delayed, Pattern and Pair Sync
  2. Data words for each trigger event
- Add programable common delay (0-32 μs) for input helicity signals:
  - To fix time delays due to beam travel time and helicity signal distribution to Hall
  - Will be measured for each board in a specific DAQ
  - Will sync helicity of beam at Physics Interaction Time in Hall

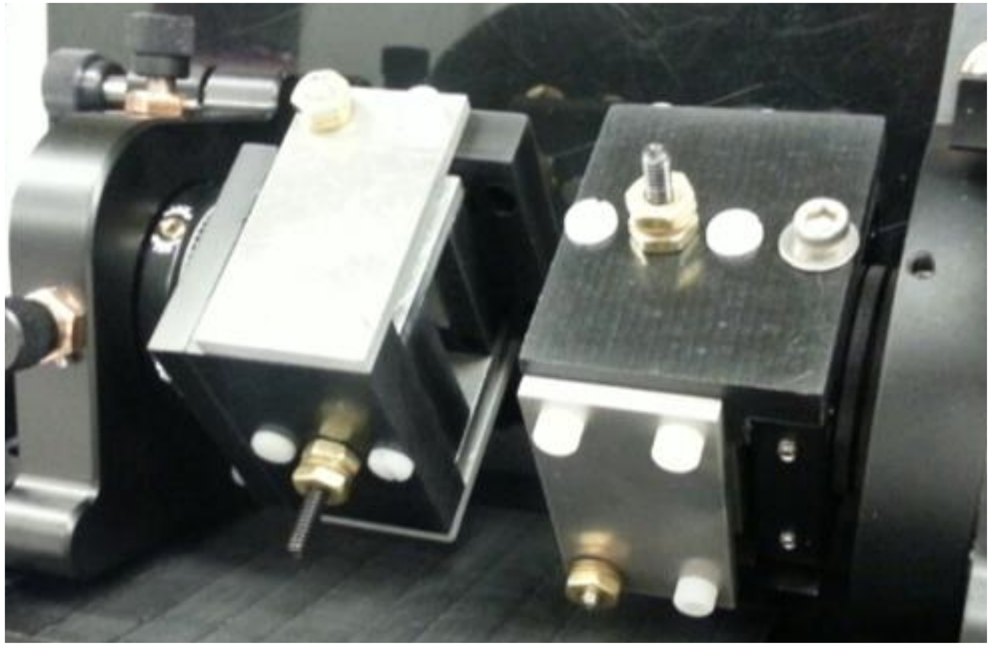
Board Programmable Common Delay

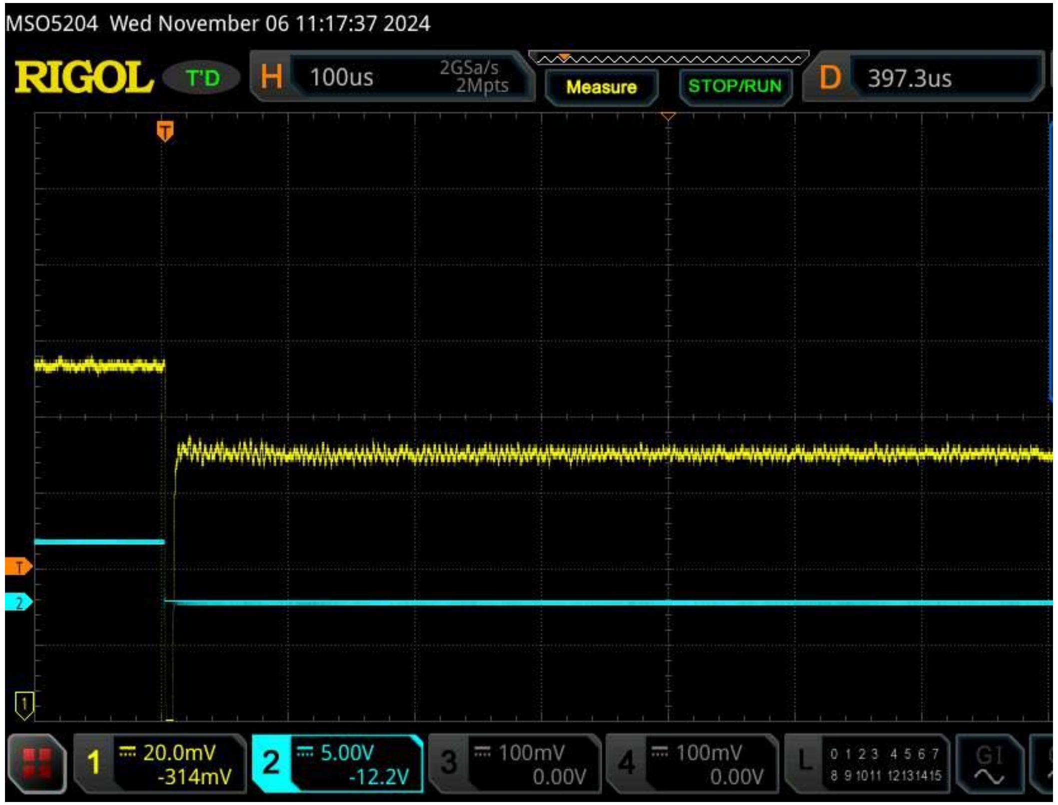
- How to set input common time delay:
  - Helicity Board: 60 Hz Beam Sync (354 μs)
  - Electron Beam: VL, 60 Hz Beam Sync, 50 ns pulses
  - First, check relative timing of electron VL Generator and Helicity signal on laser table
  - Adjust board common delay to match relative timing at laser table





UVA Prototype RTP HV Driver

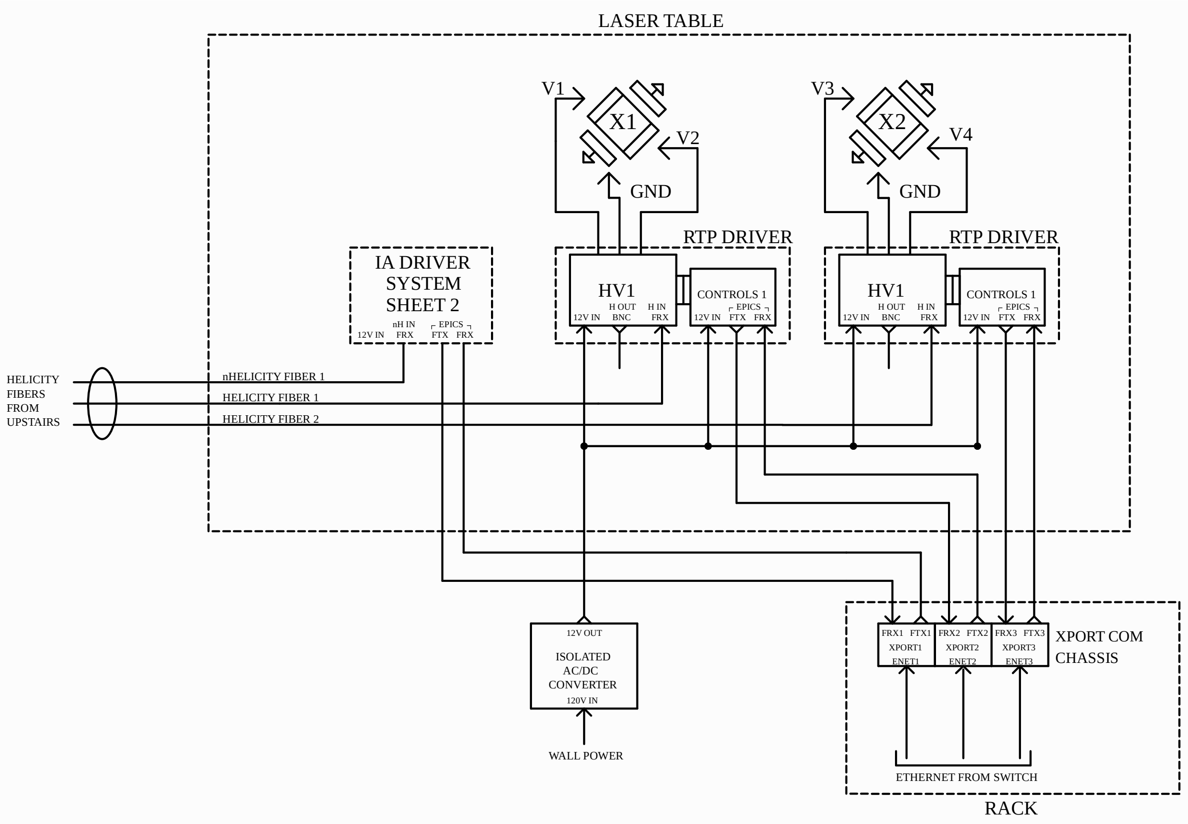


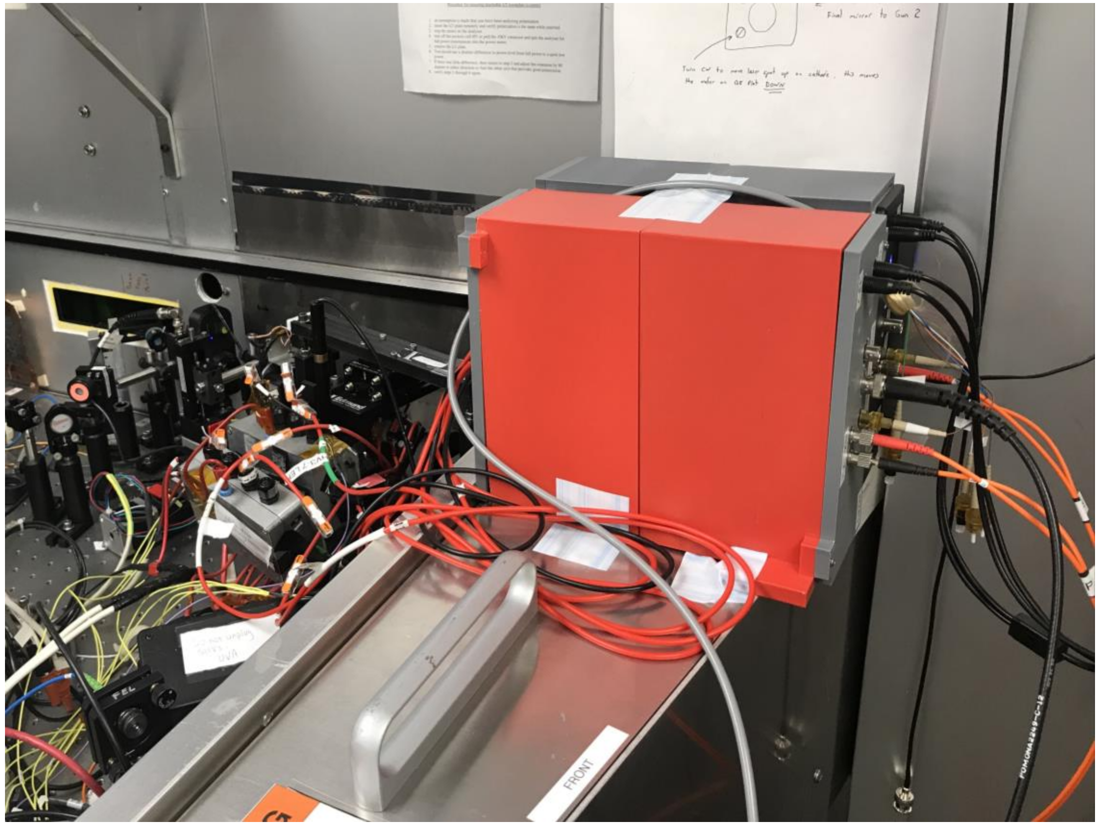


- Use Rubidium-Titanyl-Phosphate (RTP) Pockels cell to produce Right-handed and Left-handed circularly-polarized laser light
- Use an opto-diode HV to switch between ±800 V
- Switching time ≤ 10 µs and ringing amplitude $< 1\%$

https://doi.org/10.48550/arXiv.2106.09546

New JLab RTP HV Driver



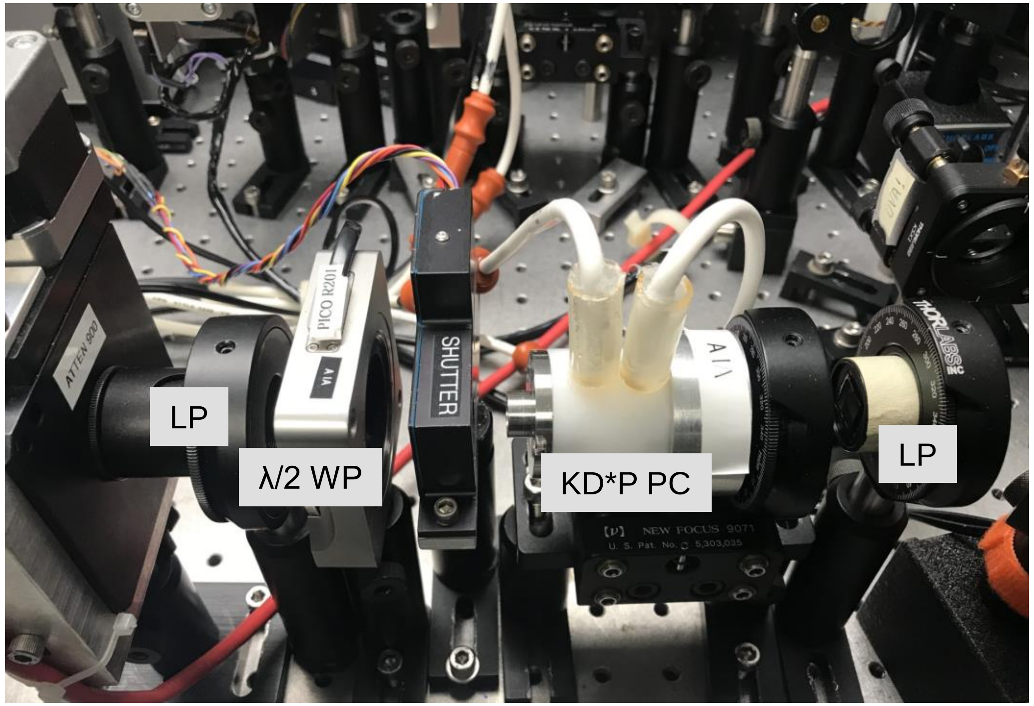


- Use solid-state switch – MOSFET
- Prototype under development and testing

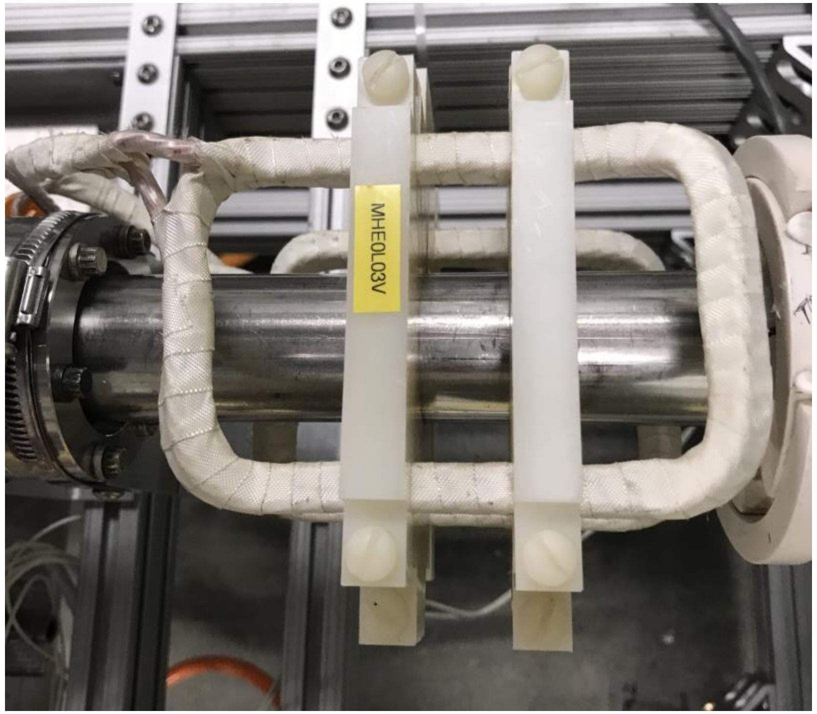
Designed and built by Steven Covert and Jim Kortze

IA HV Driver and Helicity Magnets Control

- New Intensity Attenuator (IA) HV Driver is planned in FY2025
- Use ±105 V precision Operational Amplifier
- Switching time $\leq 10\ \mu s$
- IA system for each Hall (A, B, C, and D)



- New Helicity Magnets controller is planned in FY2025
- Switching time $\leq 10\ \mu s$
- Four air-core magnets made of Litz wire are installed in Injector MeV region



Jefferson Lab

Future Plans

- This Run Period:
  - Parity-quality beam studies in Injector and Hall A
  - Install RTP HV Driver

- This coming Scheduled Accelerator Maintenance:
  - Install IA HV Driver
  - Install Helicity Magnets Control
  - Upgrade Isolated Rack of Helicity Generator
  - Laser Room Cleanup

- Possibility of new 6.8 MeV Wien Filter for polarization feedback