Compton Polarimeter

1. System overview
2. Performance in previous experiments
3. Improvements for MOLLER
4. Status and plans

MOLLER ERR

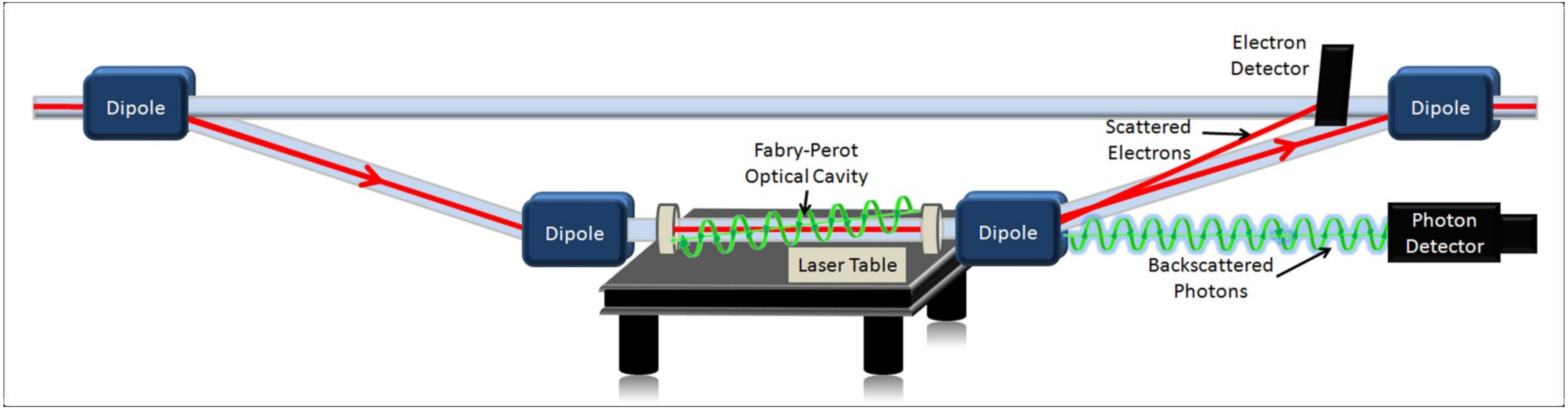
July 29-31, 2025

Jefferson Lab

U.S. DEPARTMENT OF ENERGY | Office of Science

JSA

Compton Polarimeter Overview



Key Components:

1. 4-dipole chicane: Deflects beam by 22 cm to interact with laser system
2. Laser system: High finesse/high-gain Fabry-Perot cavity. Pumped by narrow linewidth 1064 nm laser, frequency doubled to 532 nm
3. Photon calorimeter: $PbWO_4$ calorimeter. May be operated in energy-integrating or differential mode.
4. Electron detector: Position sensitive detector between dipoles 3 and 4. Diamond strips, HVMAPS
5. DAQ: Upgrading to fast counting DAQ with integrating capabilities

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Polarimetry Requirements

Error Source	Fractional Error (%)	
	Run 1	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**

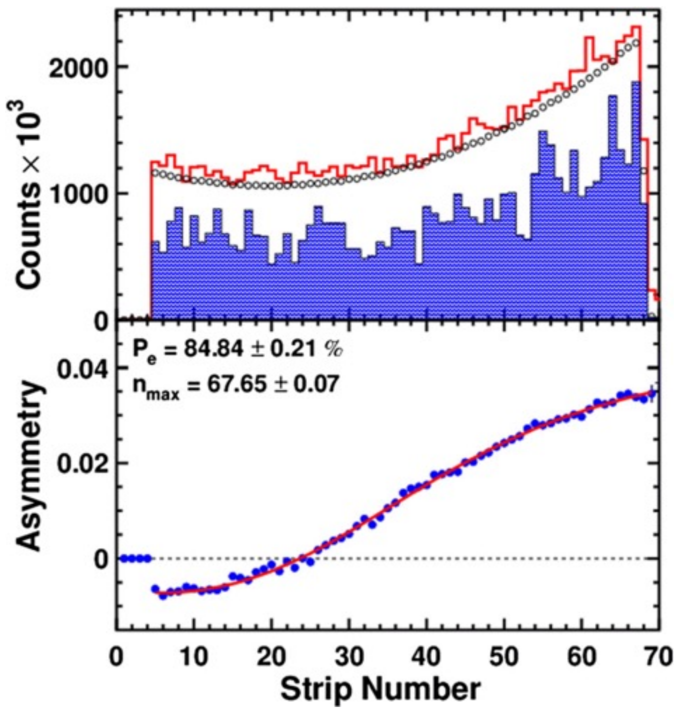
Systematic uncertainty:

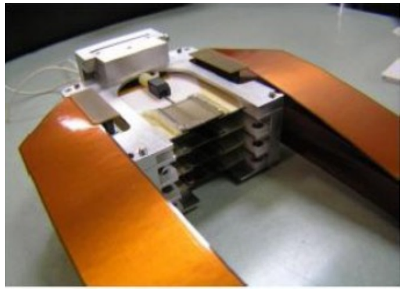
dP/P = 1% (Run 1)

dP/P = 0.4% (Run 2)

Compton Polarimeter Performance

Electron detection



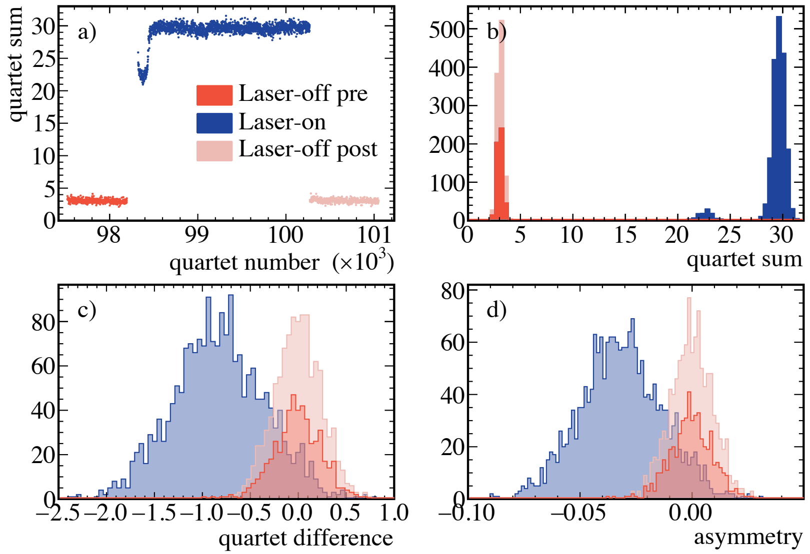


Hall C diamond strip detector

Highest precision achieved during Q-Weak experiment using diamond strip detectors:
dP/P = 0.59% → largest contribution due to DAQ (configuration issue)

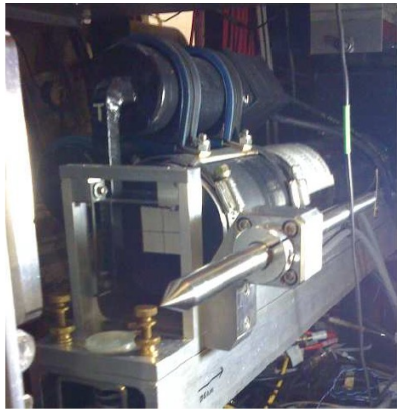
A. Narayan et al, Phys.Rev.X 6 (2016) 1, 011013

Photon detection



Threshold-less integrating technique has yielded improved uncertainty

Highest precision achieved during CREX experiment:
dP/P = 0.36% → largest contributions from collimation, gain shift



A. Zec et al, Phys.Rev.C 109 (2024) 2, 024323

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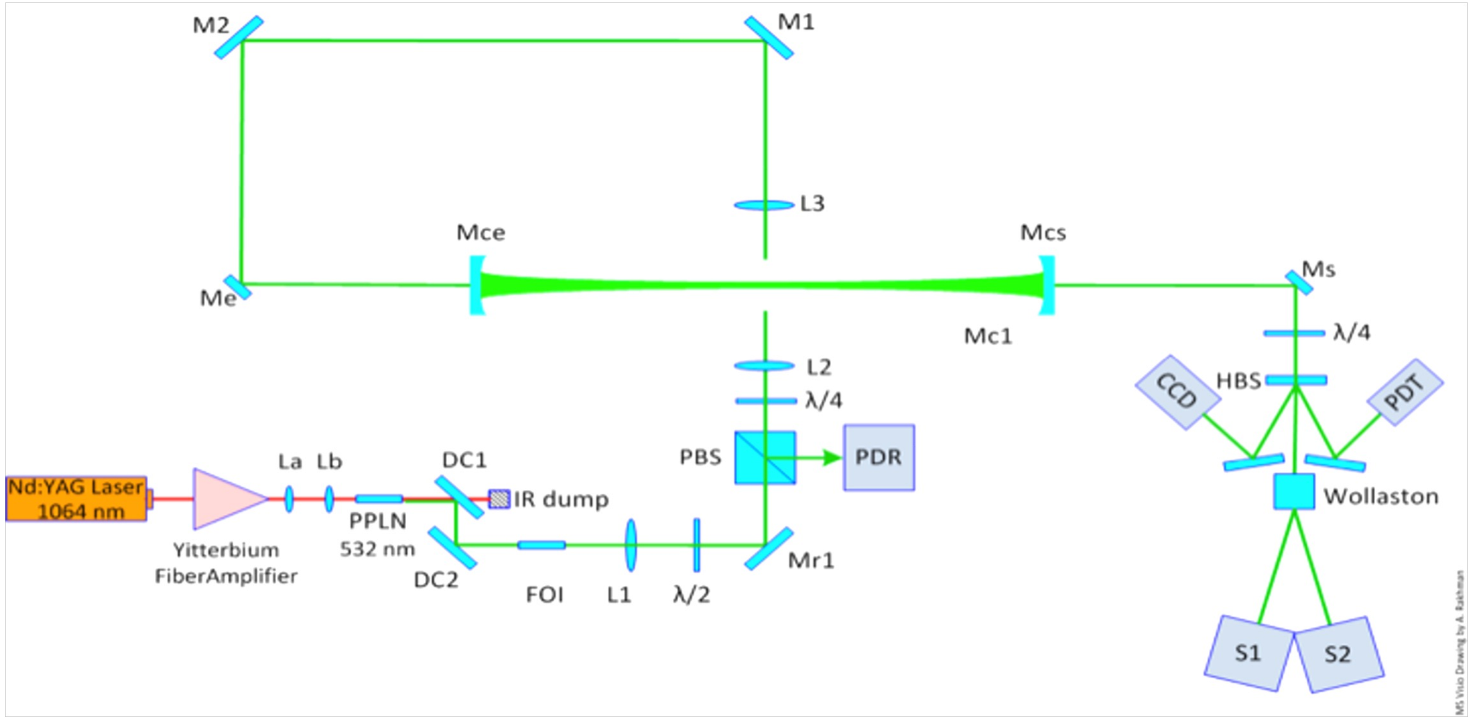
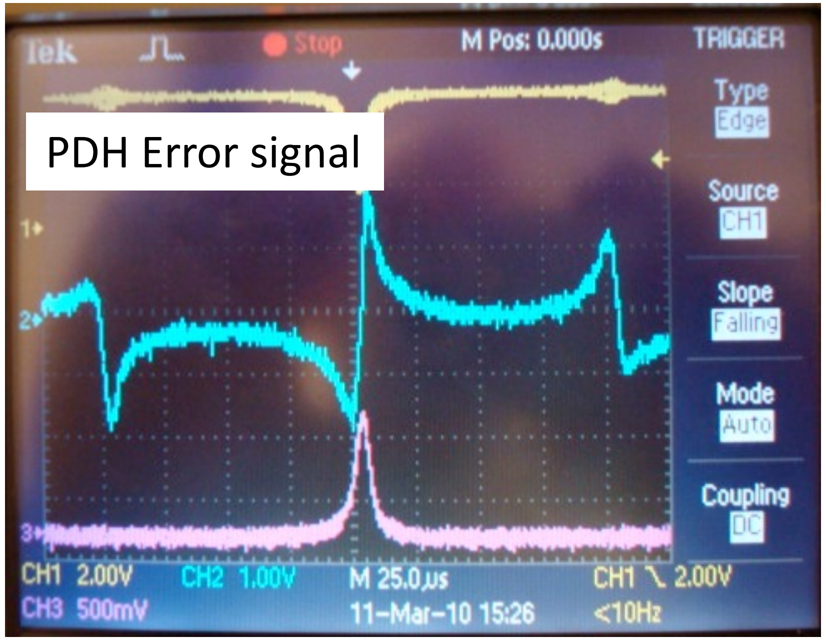
Improvements and Upgrades for MOLLER

- Systematic uncertainty requirements
  - Run 1: dP/P = 1%
  - Run 2: dP/P = 0.4 %
- Previous high precision Compton results
  - CREX (2020, 2 GeV, Hall A): Achieved dP/P=0.36% using integrating technique with high resolution photon calorimeter (GSO)
  - Q-Weak (2012, 1 GeV, Hall C): Achieved dP/P=0.59% using electron detection
- MOLLER (11 GeV) will use both electron and photon detection
- Compton upgrades and changes:
  - PbWO4 calorimeter → Has been used during 12 GeV DVCS running. Ultimate performance to be demonstrate
  - New electron detector for Hall A
  - New DAQ for photon detector – will include integrating and fast counting
  - Additional development of laser system for robust operation and improved laser polarization determination
  - Protection against synchrotron radiation in chicane → crucial challenge at 11 GeV
  - Improvement in beam optics configuration → new harp

Laser System Overview





System uses high Finesse Fabry-Perot cavity (locked using Pound-Drever-Hall method), pumped by narrow linewidth (<5 KHz) green laser

→ Laser system components: 1064 nm seed + 5-10 W fiber amplifier + PPLN doubling system → generates ~ 1 W green power

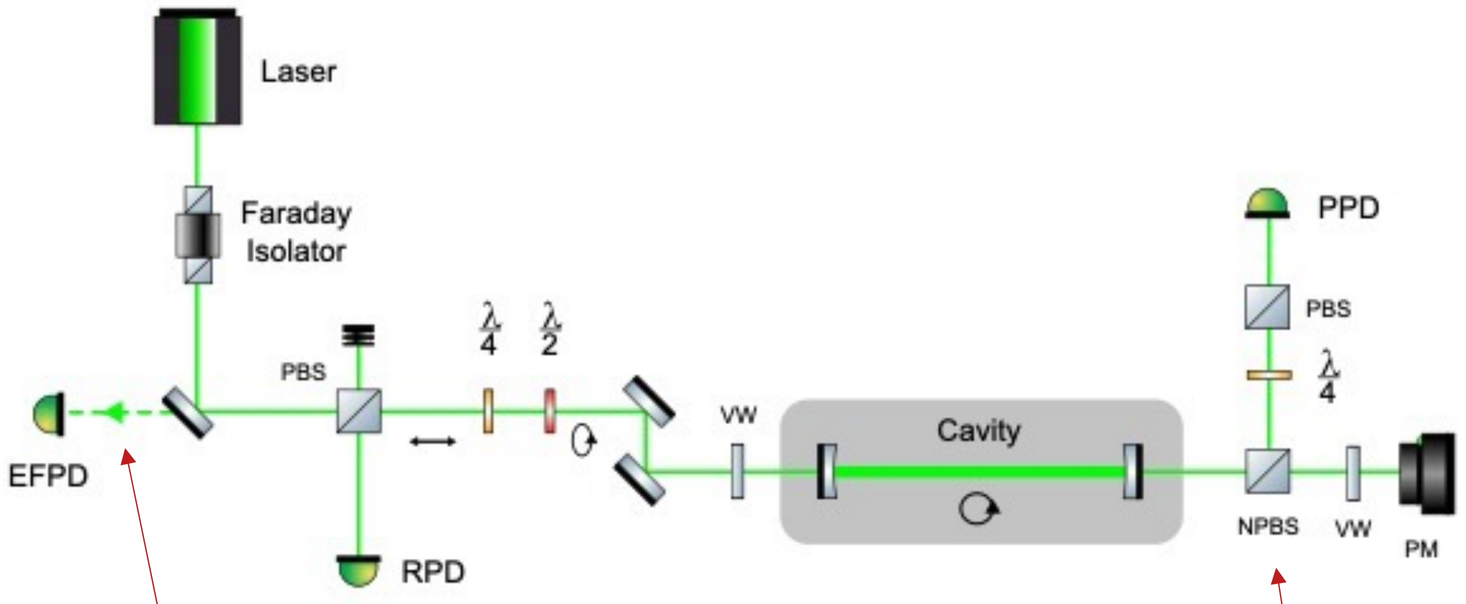
→ Have spare seed lasers, fiber amplifier, doubling crystals on hand

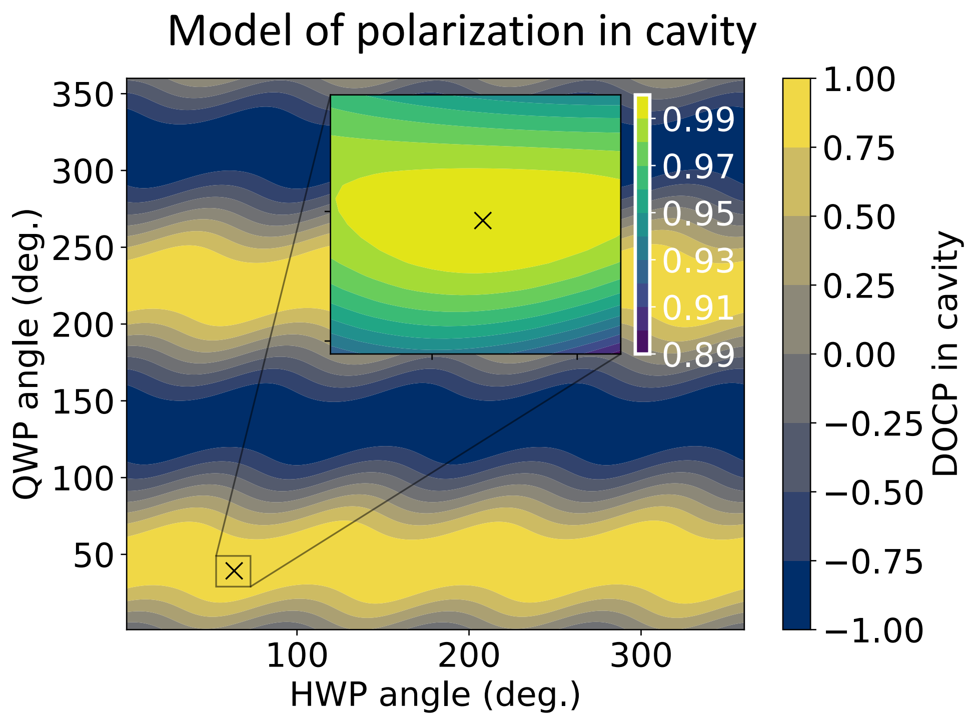
→ Locking electronics custom-built in 1990s, already using spare modules. Key concern is failure of these electronics

Tested alternate electronics (Digilock) with high finesse cavity – successfully locked cavity with similar performance

Laser Polarization Determination

Polarization of laser light stored in cavity determined in 2 major steps:





1. Use light reflected back from cavity w/cavity unlocked to determine entrance function

2. Measure polarization of light transmitted through cavity with cavity locked to determine mirror birefringence

Determined laser polarization to 0.25% for CREX – working to improve system and technique

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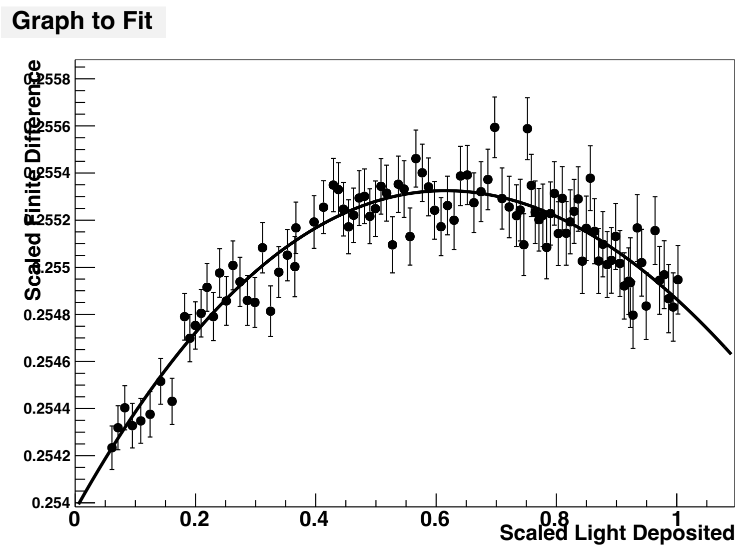
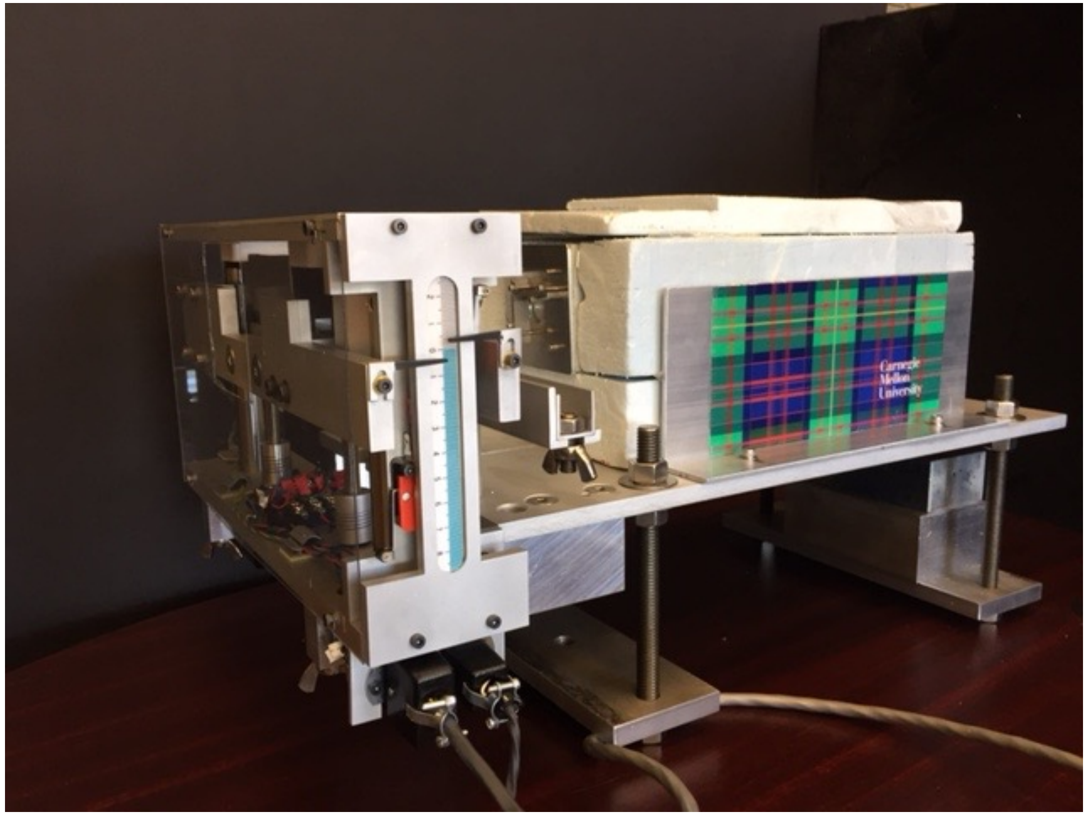
Photon Detector Status

Existing “high energy” photon detector → 4 blocks of lead-tungstate recycled from Hall C + PMT w/base optimized by Brian Quinn (CMU) for high linearity
→ Used successfully during 12 GeV DVCS run in Hall A



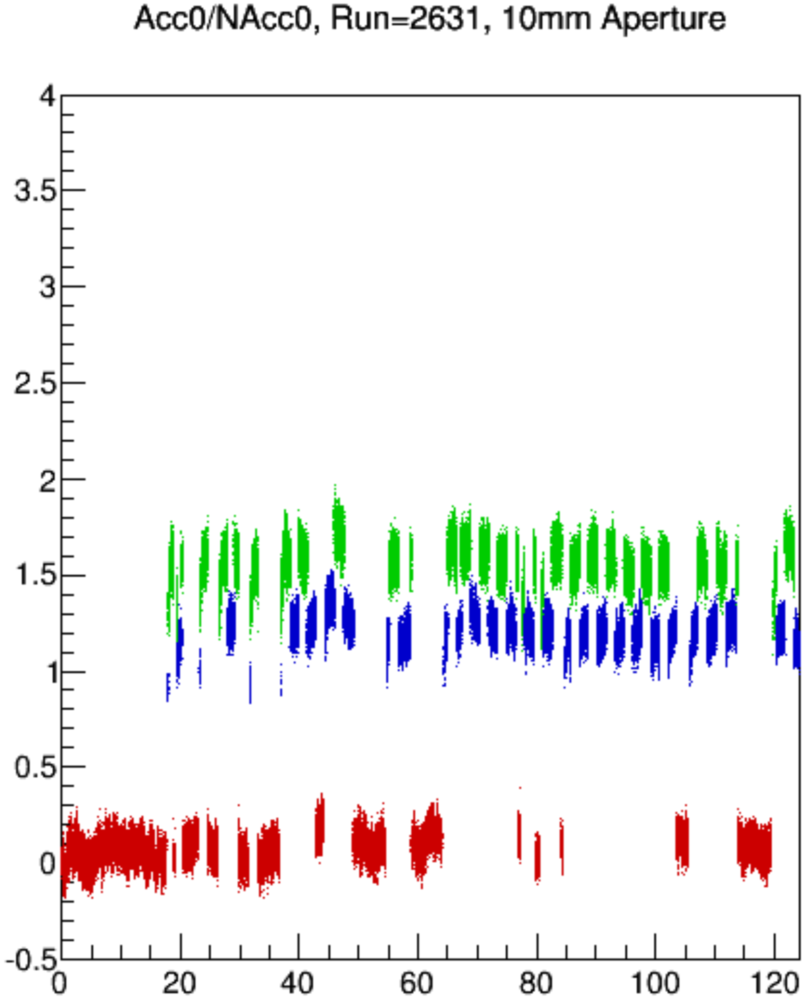
Key property of the photon detector is the linearity
→ Some non-linearity is ok, but it must be known
→ Measured using existing LED system – updated measurements will be made before start of MOLLER

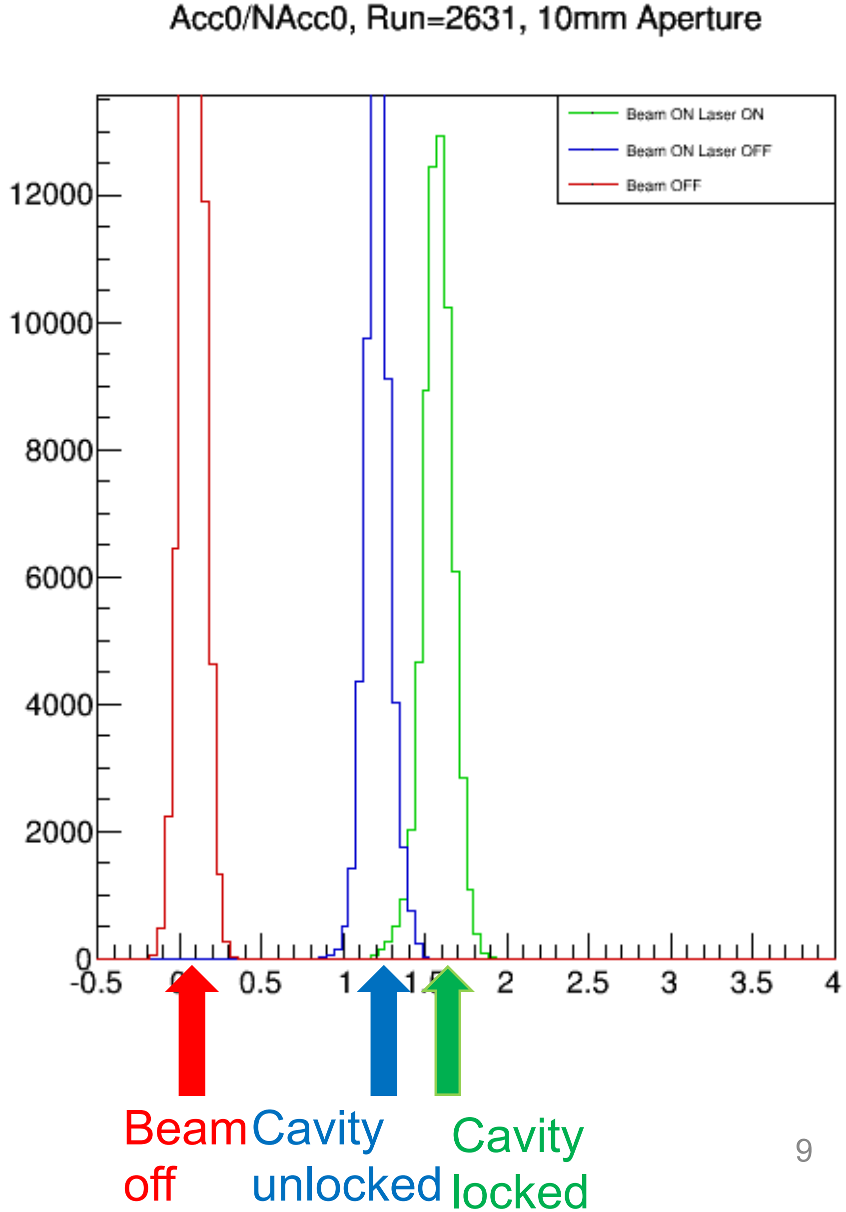


At higher energies, will have increased synchrotron radiation
→ Remotely adjustable collimators were successfully used during DVCS to mitigate synchrotron

Synchrotron Radiation

Hall A: 4 pass





Laser-off shows large signal due to synchrotron

Brian Quinn: March 2017 PREX/CREX meeting

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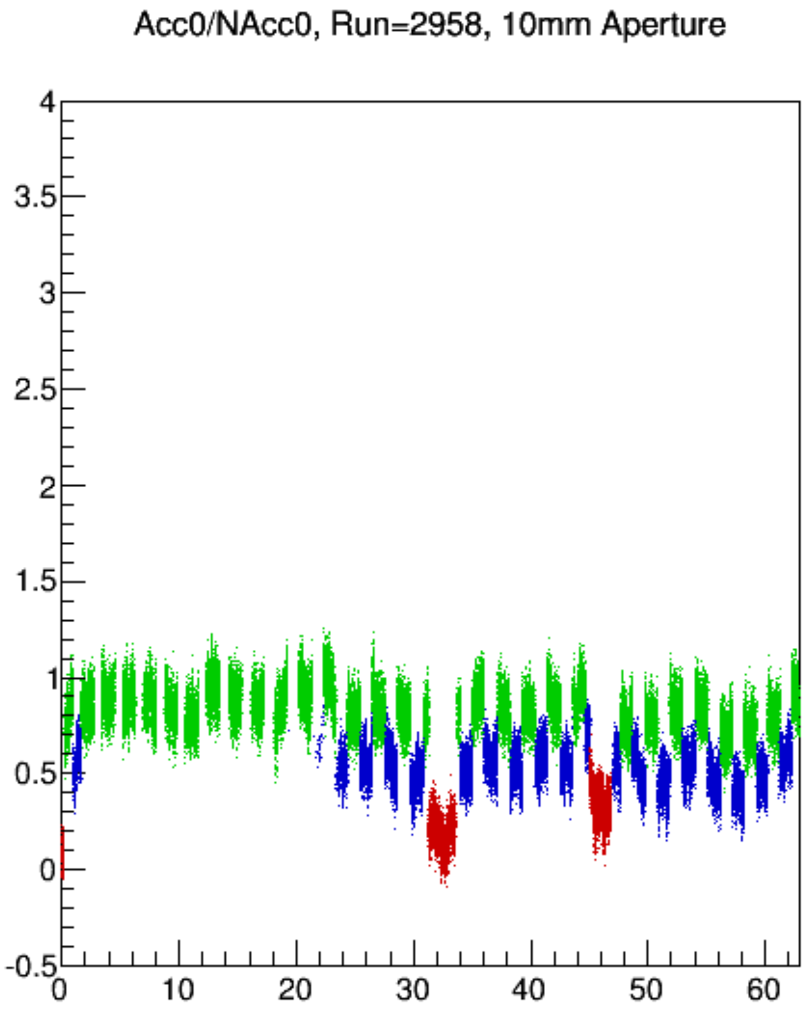
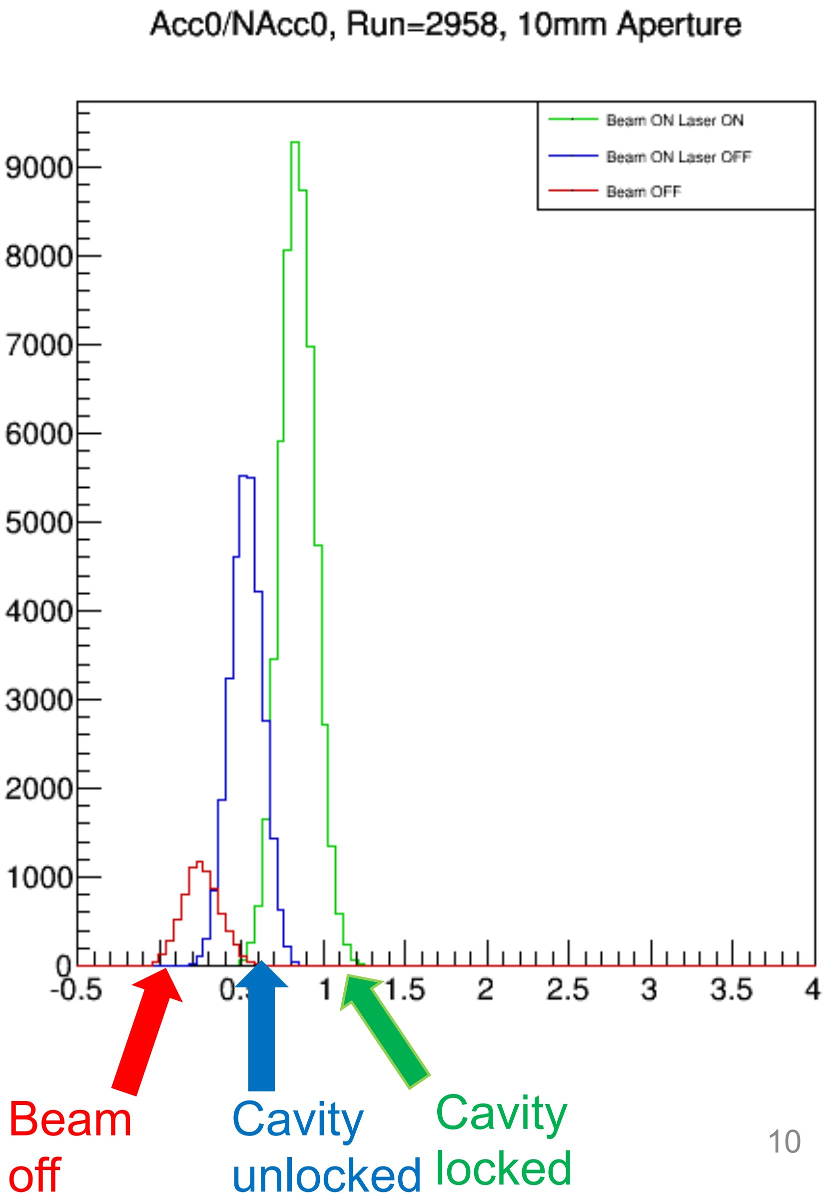
Synchrotron Radiation

Hall A: 4 pass





Synchrotron greatly reduced with addition of “JAWS”

Electron Detector

Diamond Strip Detector (HIPPOL Capital Project)

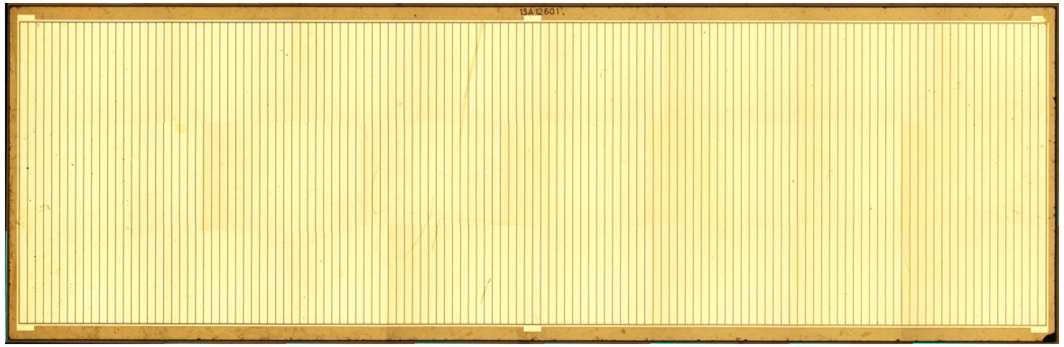


Figure 3: Photo of the strip side of JLab 13A12601 after final processing.

New diamond strip detector being built with help from Harris Kagan (Ohio State) and SenseICs → Also developed new ASIC to improved signal to noise

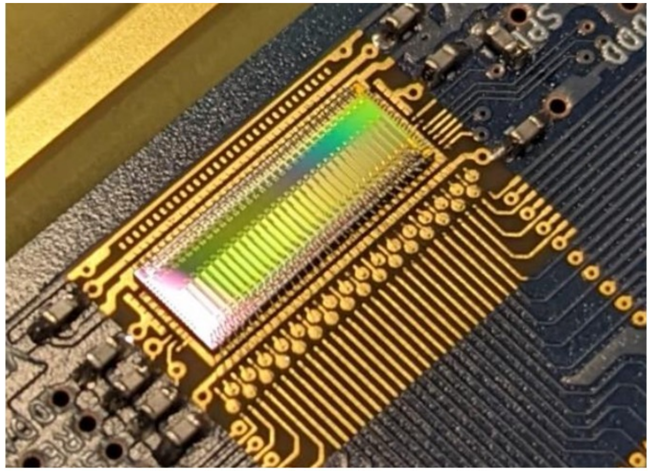
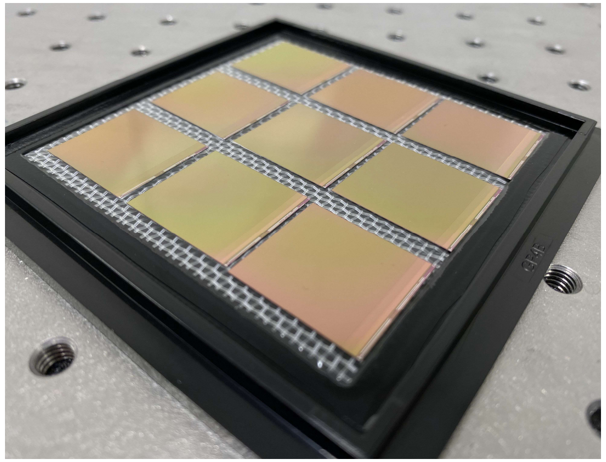


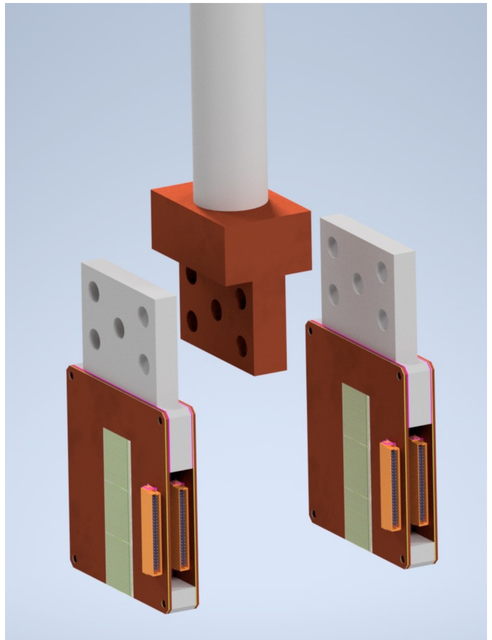
Figure 2: Wire bonded FLAT-32 on the test PCB.

Diamond sensors nearly complete, FLAT-32 complete
→ **Detector boards expected in spring of 2026**

HVMAPS (U. Manitoba)

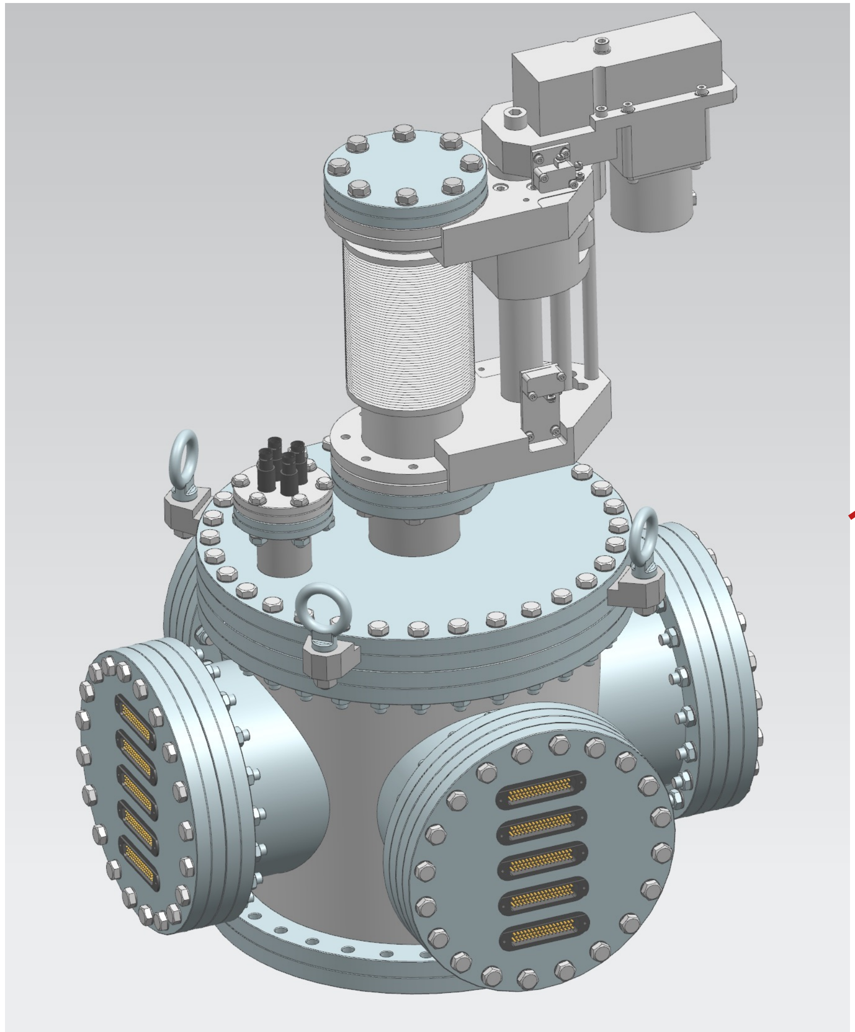
Manitoba building HVMAPS detectors for main experiment → also building several planes for possible use on Compton polarimeter



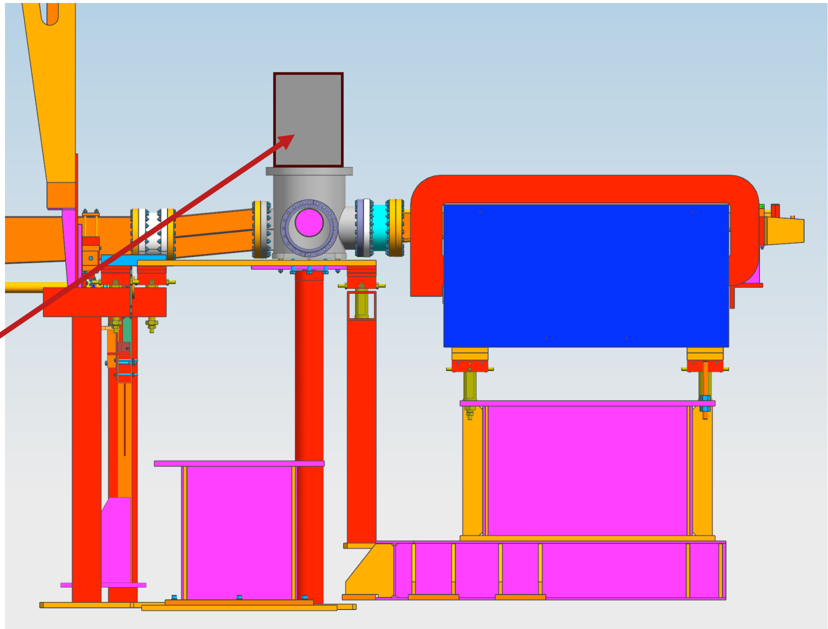


Timescale similar to diamond boards
→ Plan to start with 2 planes of diamond and 2 planes of HVMAPS

Electron Detector Chamber



Design: Chris Soova



New detector can will sit on top of existing vacuum chamber
→ 4, 10-inch flanges with 5, 50-pin feedthroughs
→ 4 HV feedthroughs
→ Linear actuator with 10 cm travel

Will accommodate diamond and/or HVMAPS detectors

PO awarded to Lesker – delivery expected October 2025

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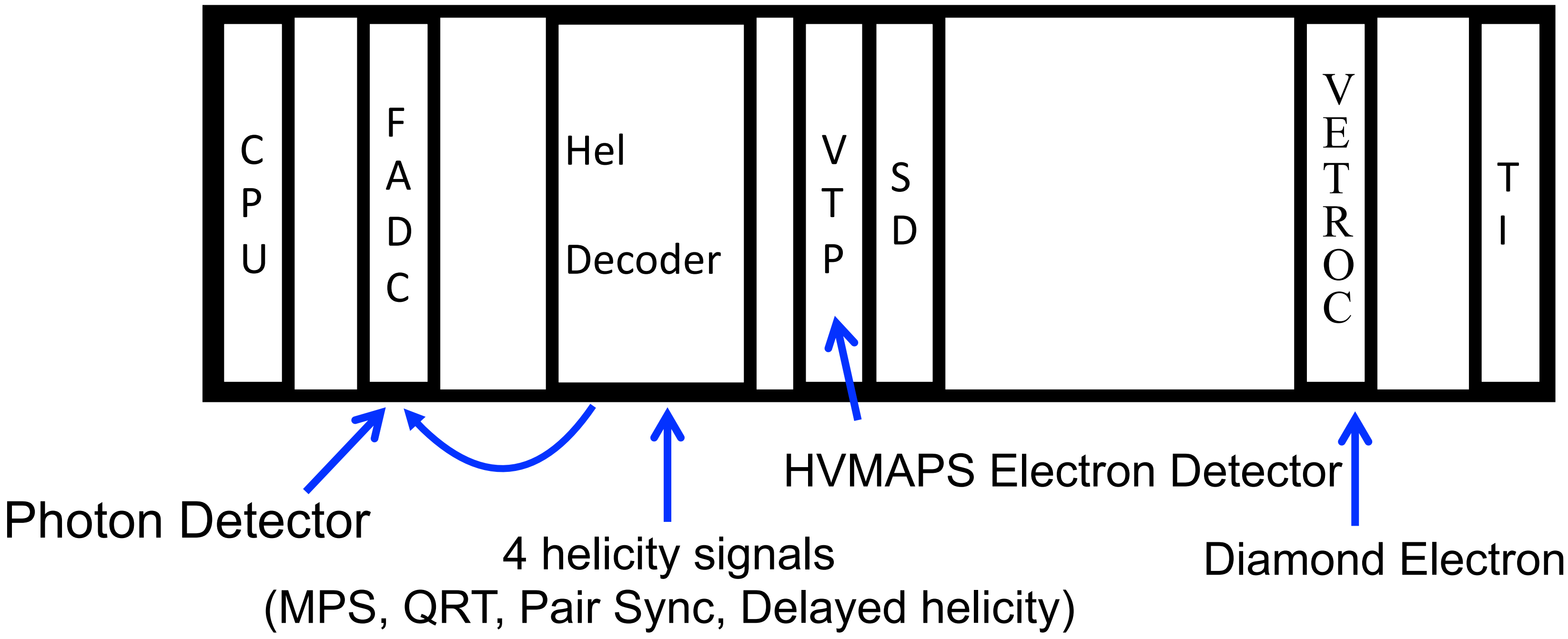
Compton DAQ



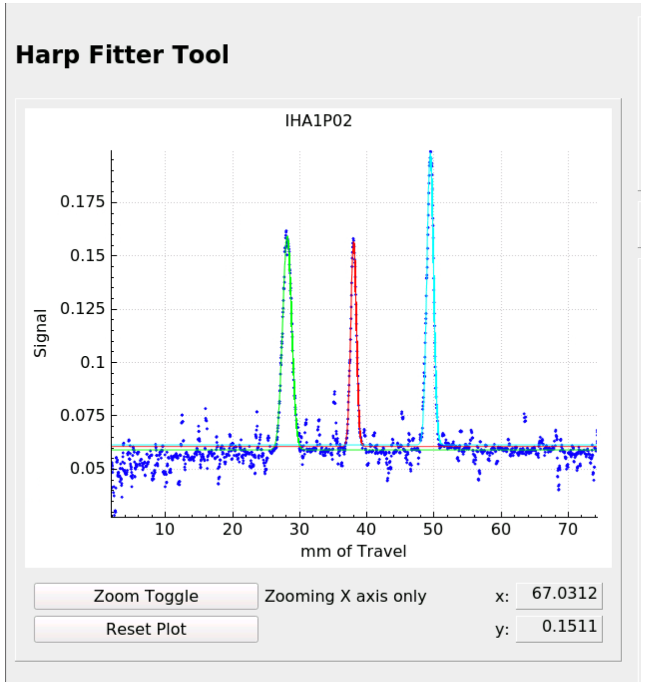
Courtesy Hanjie Liu

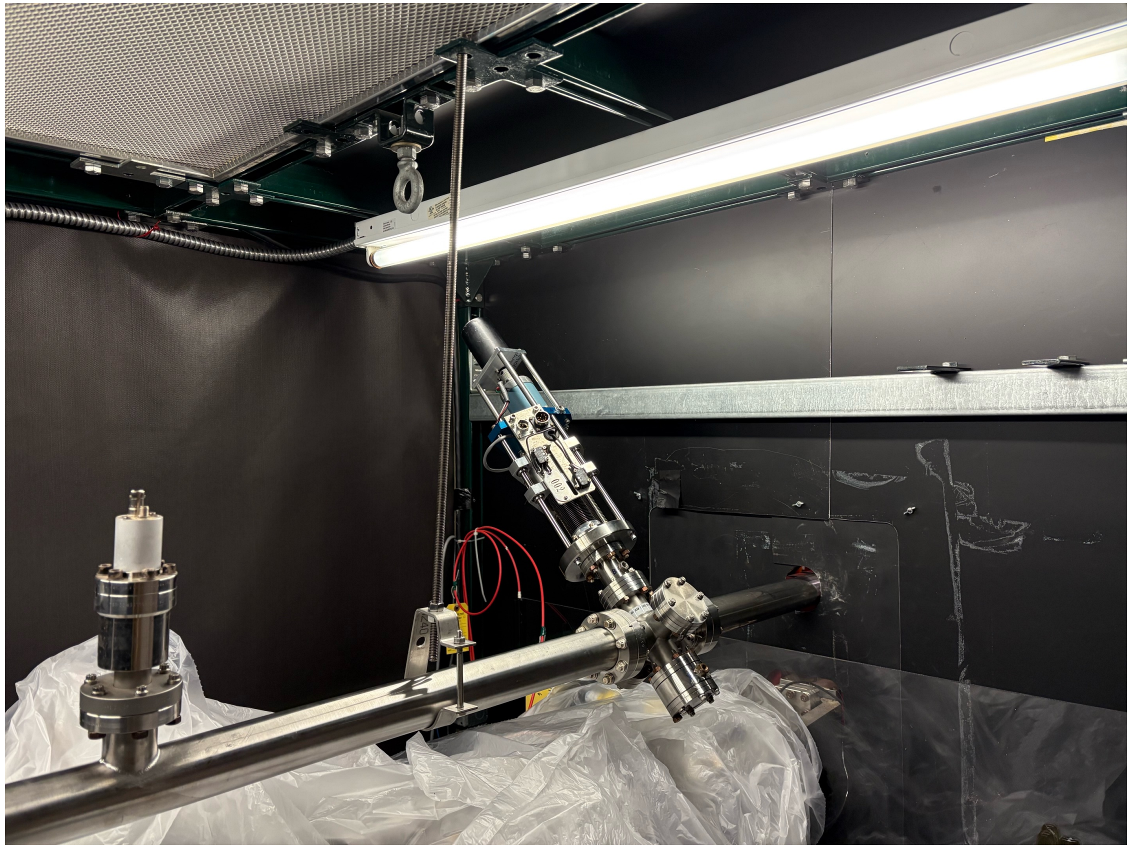
- Photon detector → customized FADC firmware including: accumulators, counting, snapshots of waveforms; The firmware design ongoing, expected completion September 2025
- Diamond Electron Detector → VETORC TDC module. TDC readout design when test board available (spring 2026)
- HVMAPS Electron Detector signals serialized by lpGBT, sent to the VTP. Will build test stands in Jlab and U. of Manitoba
- VTP collects data from the FADC, VETROC, and lpGBT via the VXS backplane and front panel optic link
- Electron-photon coincidences, and other advanced processing algorithms will be implemented in the VTP firmware.

Compton Chicane: New harp

New harp installed above Compton laser table during previous SAM

→ During previous runs, setting up the Compton has been very challenging due to lack of diagnostics near laser table
→ Difficult to infer beam size
→ New harp will speed up setup, verify optics





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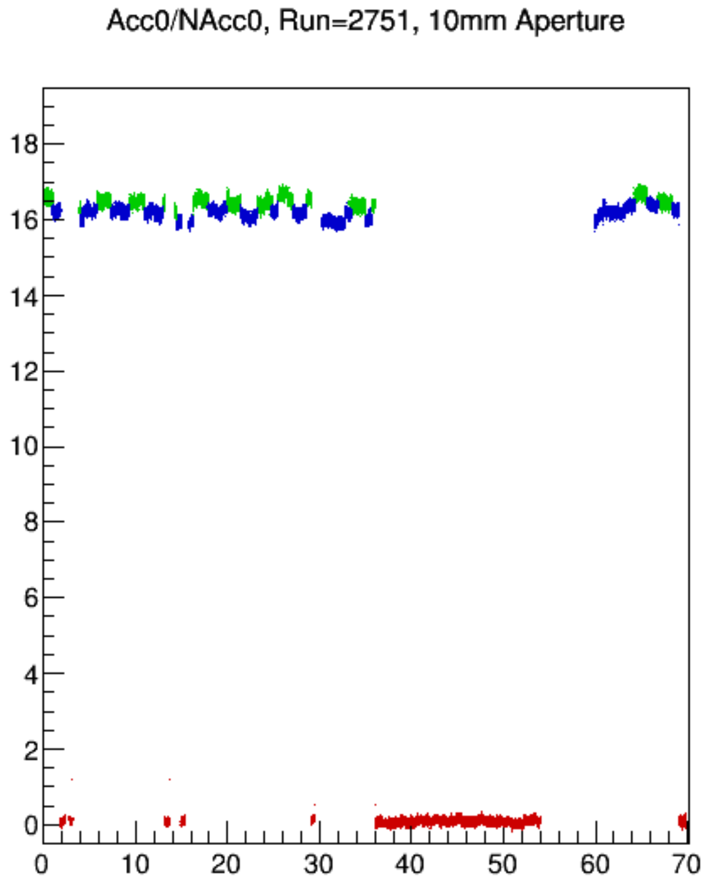
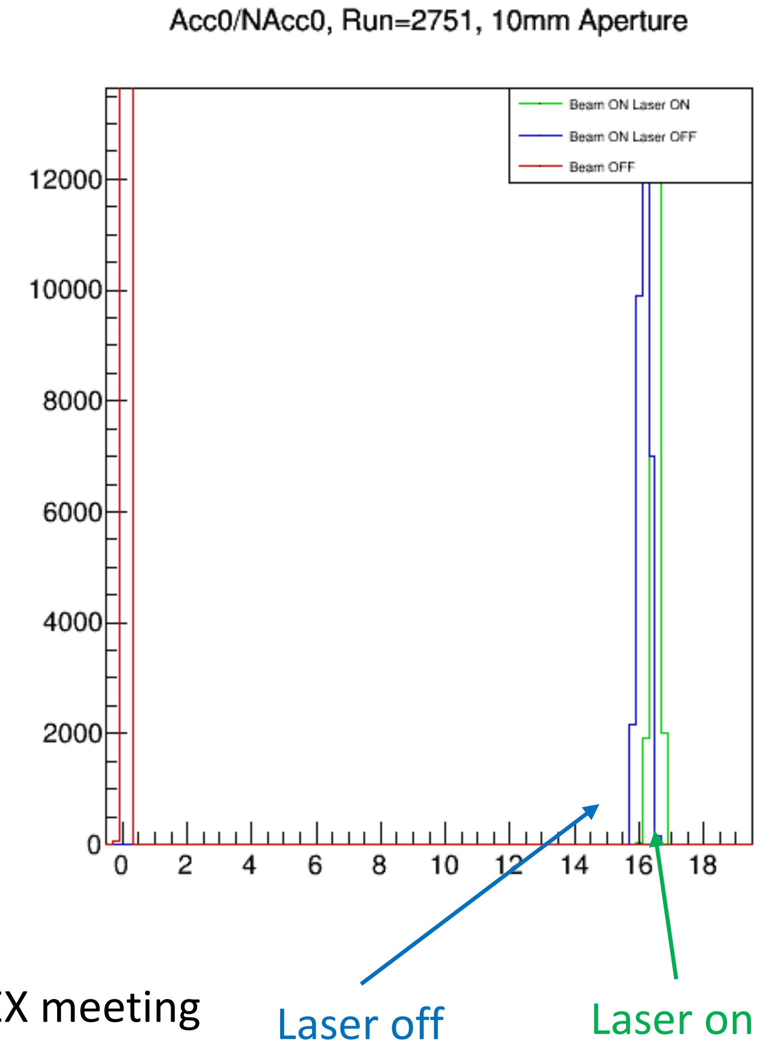
Beam Test During GeP-V

Plan to perform beam test during GeP-V

→ Limited experience at 5 pass
→ "JAWS" were effective at 4 pass during DVCS - need to check at 5 pass

Beam test expected to run early August





Brian Quinn: March 2017 PREX/CREX meeting

Compton Polarimeter Workforce

- Jefferson Lab Hall A/C
  - Dave Gaskell → coordination, laser system
  - Ciprian Gal → laser system
  - Hanjie Lu → DAQ
  - Sanghwa Park → Diamond electron detector
  - Ben Raydo → DAQ, firmware
  - Hai Dong → DAQ, firmware
  - William Gu → Electron detector testing, flex cable design
  - Alexandre Camsonne → DAQ consulting
  - Chris Soova → Electron detector chamber design
- University of Virginia
  - Kent Paschke → coordination, laser system, photon detector
  - Xiang Zhang → laser system, photon detector, analysis
  - Prakash Gautam → Polarimeter simulations
- University of Manitoba
  - Michael Gericke → HVMAPS coordination
  - Nafis Niloy → HVMAPS testing, prototyping, motion/support design
  - Kristofer Isaak → HVMAPS engineering support
  - Shefali → HVAMPS cooling simulations and verification

Summary

- Hall A Compton Polarimeter has been successfully for several experiments in the 6 GeV and 12 GeV era
  - Most recently during PREX/CREX running
- CREX results have already achieved precision needed for MOLLER using photon detection
- New electron detector will provide precise, quasi-independent measurements
  - Based on successful Hall C electron detector
- Laser polarization a key systematic uncertainty
  - Techniques developed during CREX will be improved and practiced prior to and during MOLLER installation
- All new components will be at JLab before summer 2026

Backup

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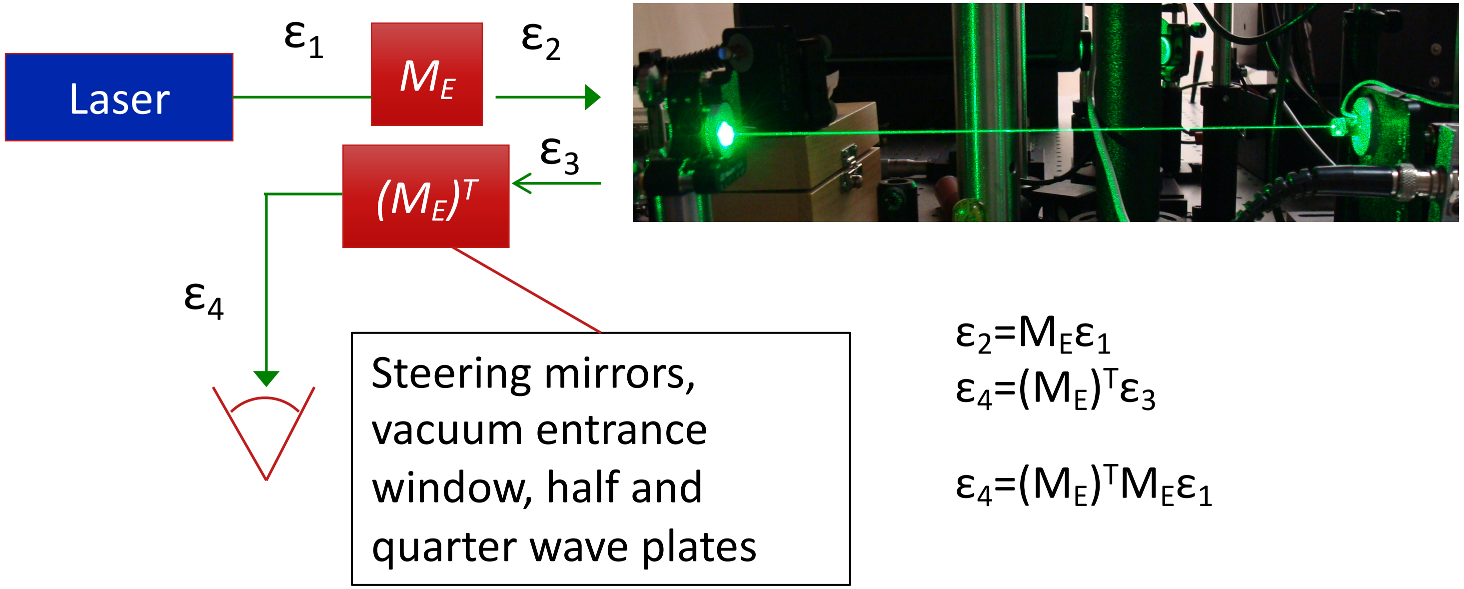
Laser Polarization at Cavity Entrance

"If input polarization (ε_1) linear, polarization at cavity (ε_2) circular only if polarization of reflected light (ε_4) linear and orthogonal to input"

→ Consequence of optical reversibility theorem, see J. Opt. Soc. Am. A/Vol. 10, No. 10/October 1993

→ In the context of the Hall A system, this means that the circular polarization at cavity entrances is maximized when retro-reflected light is minimized

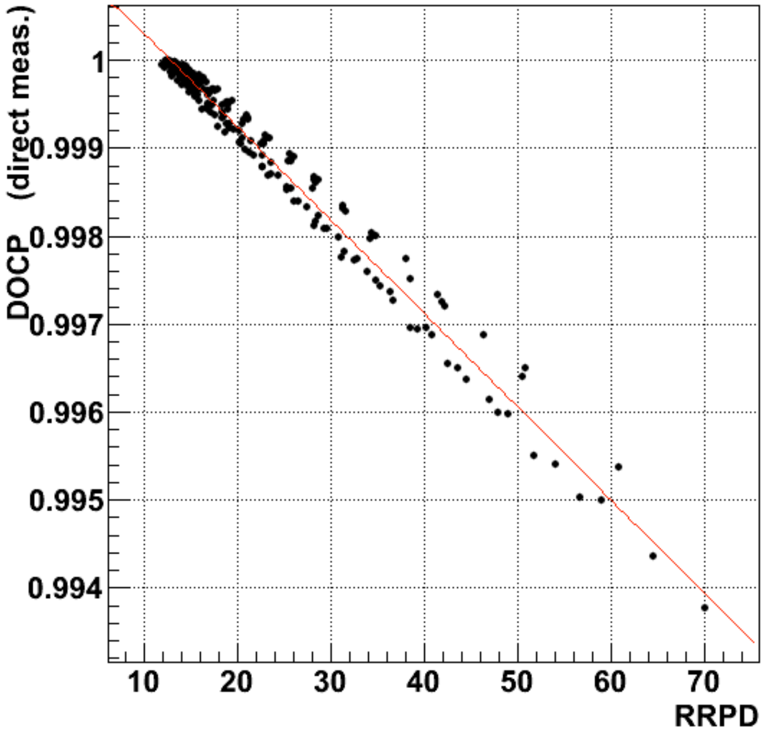


$\varepsilon_2 = M_E \varepsilon_1$

$\varepsilon_4 = (M_E)^T \varepsilon_3$

$\varepsilon_4 = (M_E)^T M_E \varepsilon_1$

Circular polarization at cavity entrance



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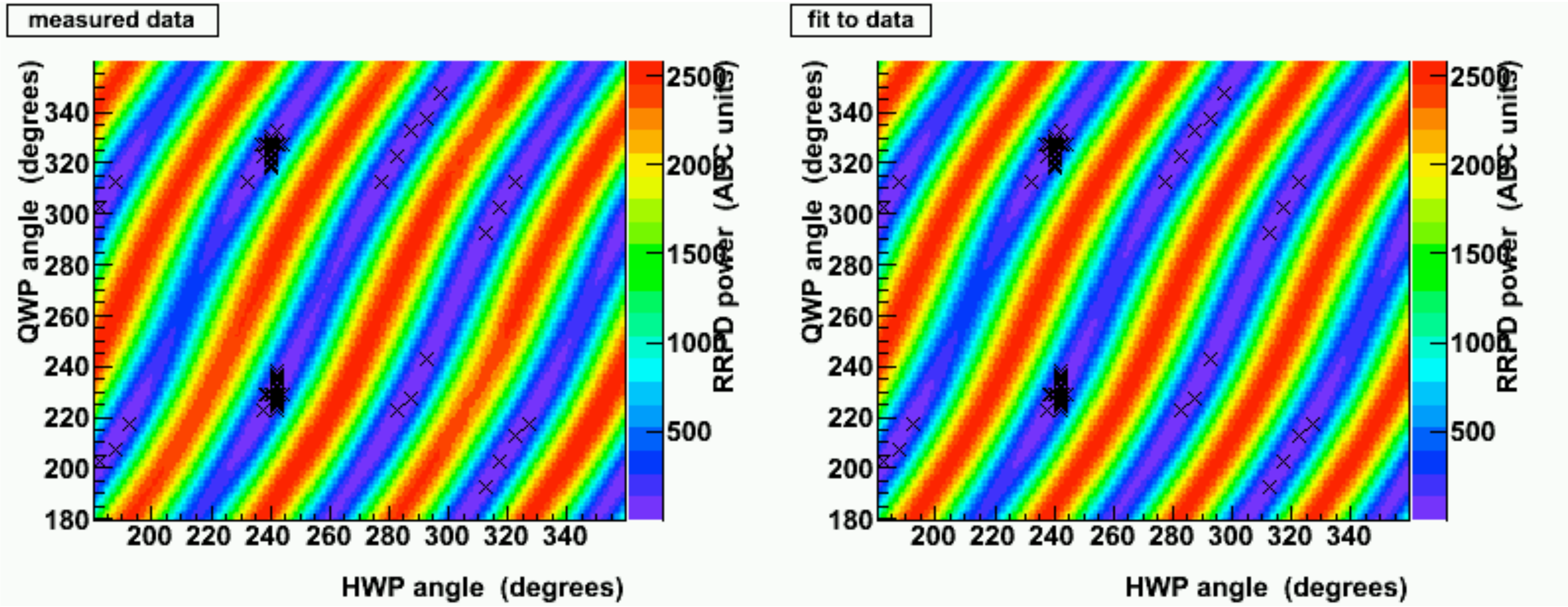
Reflected Power Scans

Using a combination of half and quarter wave plates, we can build an arbitrary polarization state

→ Scanning this polarization phase space and monitoring the retro-reflected power, we can build a model for the entrance function, M_E

→ Free parameters include variations to HWP and QWP thicknesses, arbitrary element with non-zero birefringence



Using this entrance function, we can determine the laser polarization at the cavity entrance for an arbitrary input state

Diamond Strip Electron Detector

Diamond detectors being developed/fabricated under JLab HIPPOL Project – Jim Fast working with Shane Smith (SenseICs) and Harris Kagan (Ohio State university)
→ Fabrication of sensors underway at SenseICs

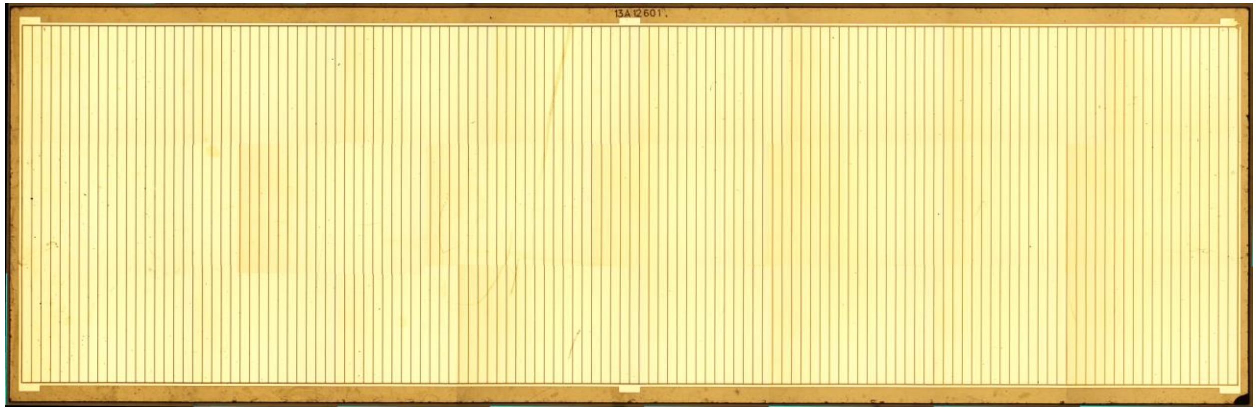
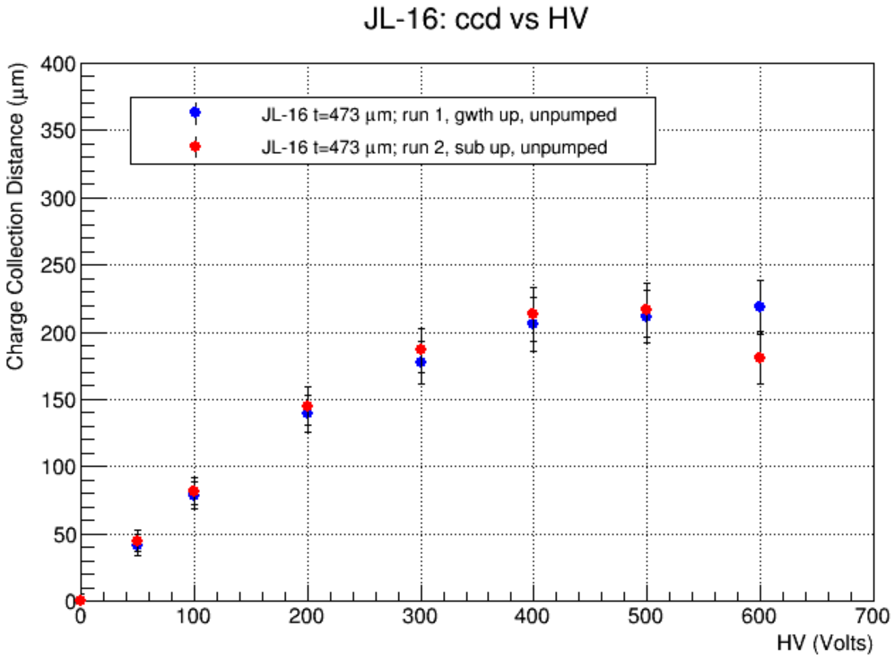


Figure 3: Photo of the strip side of JLab 13A12601 after final processing.



Sensors will be complete this summer

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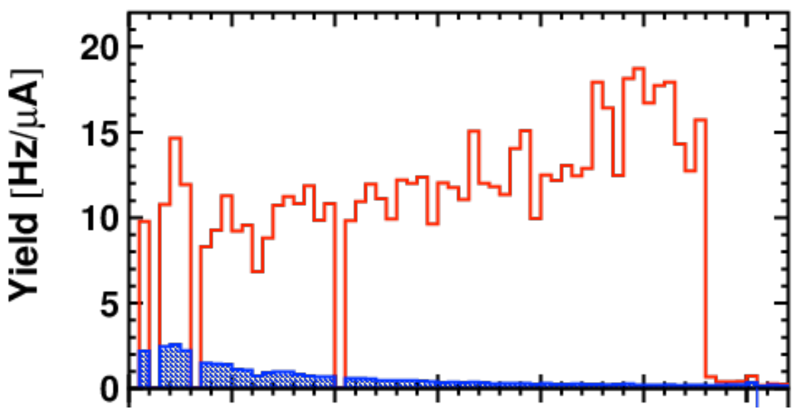
FLAT-32 Electronics

Primary drawback of Hall C diamond detector was strip-to-strip variation in efficiency → needed high thresholds to suppress noise

→ Diamond signals were not large, signals propagated to electronics outside the vacuum chamber

→ New Hall A diamond detector will have amplifier-discriminator electronics mounted on carrier board → FLAT-32



Strip number

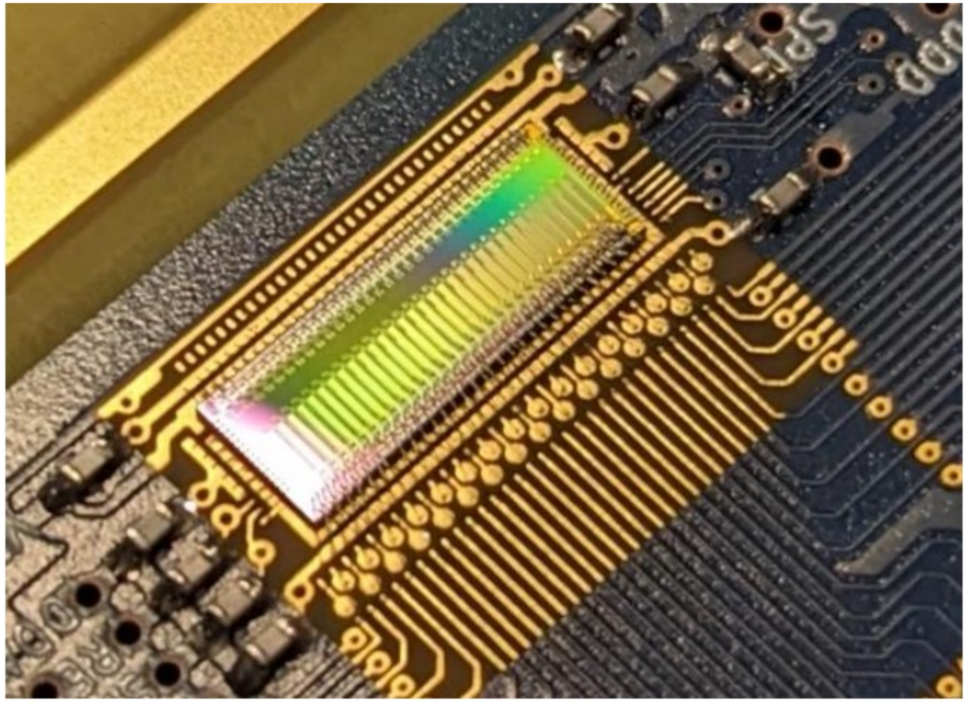


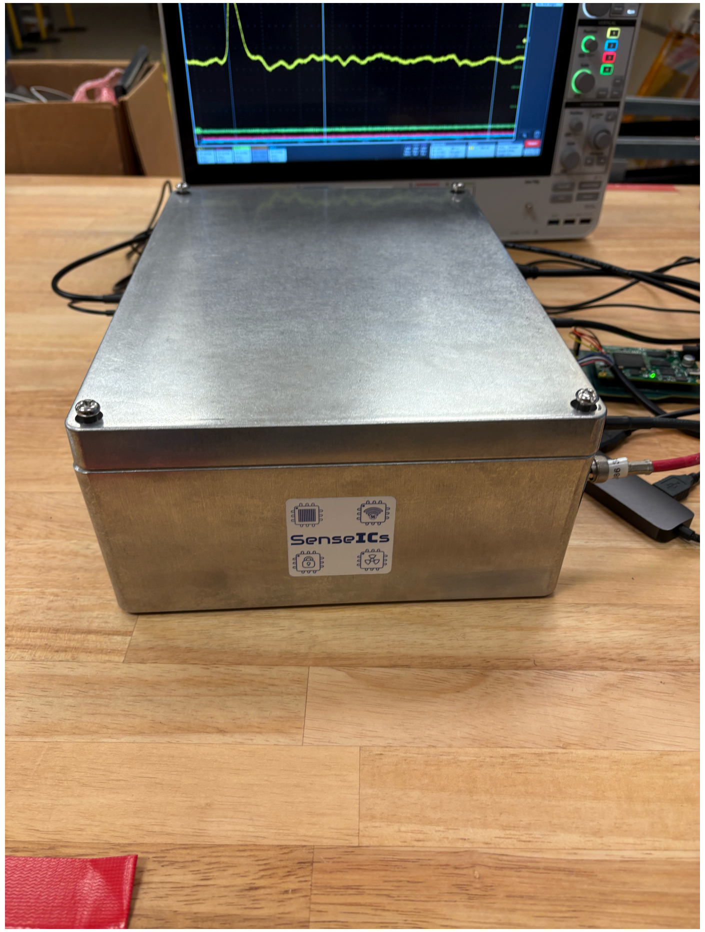
Figure 2: Wire bonded FLAT-32 on the test PCB.

Development of FLAT-32 by SenseICs
→ 32 channel version of CALYPSO electronics
→ Low noise, fast
→ Choice of analog or LVDS output

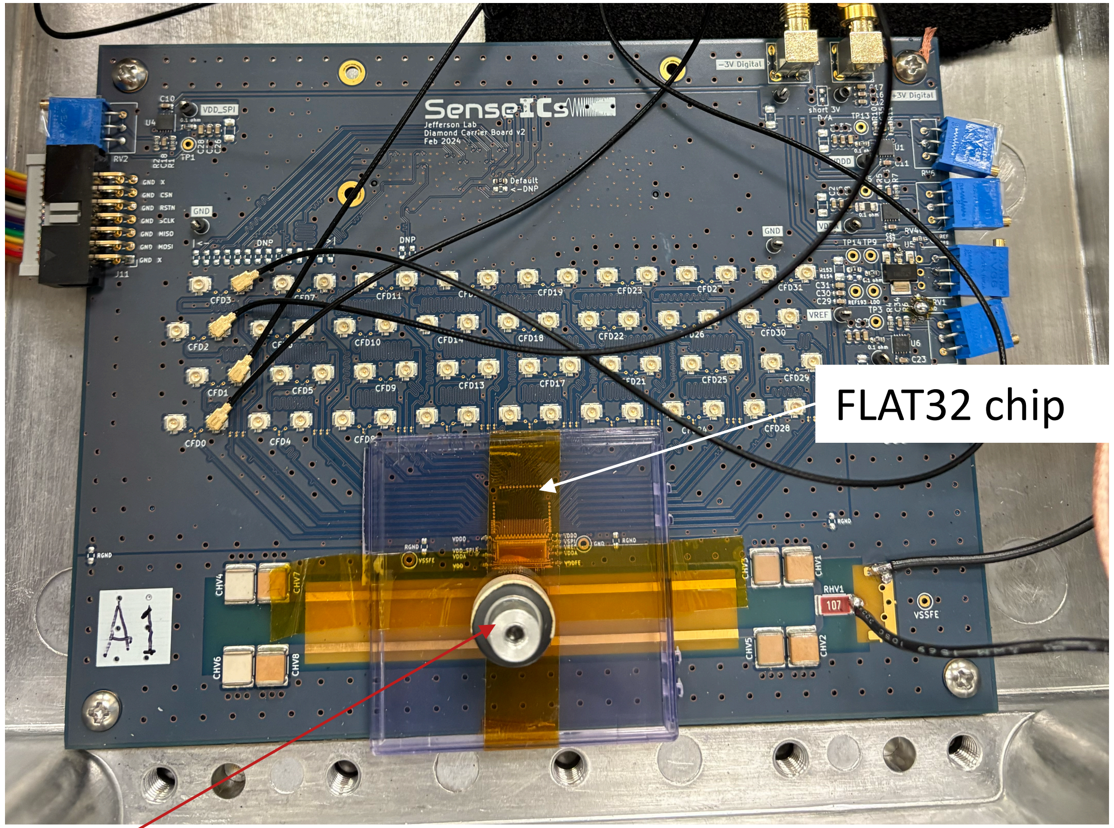
Development complete – SenseICs visited in February to demonstrate

SenseICs Site Visit

Test box



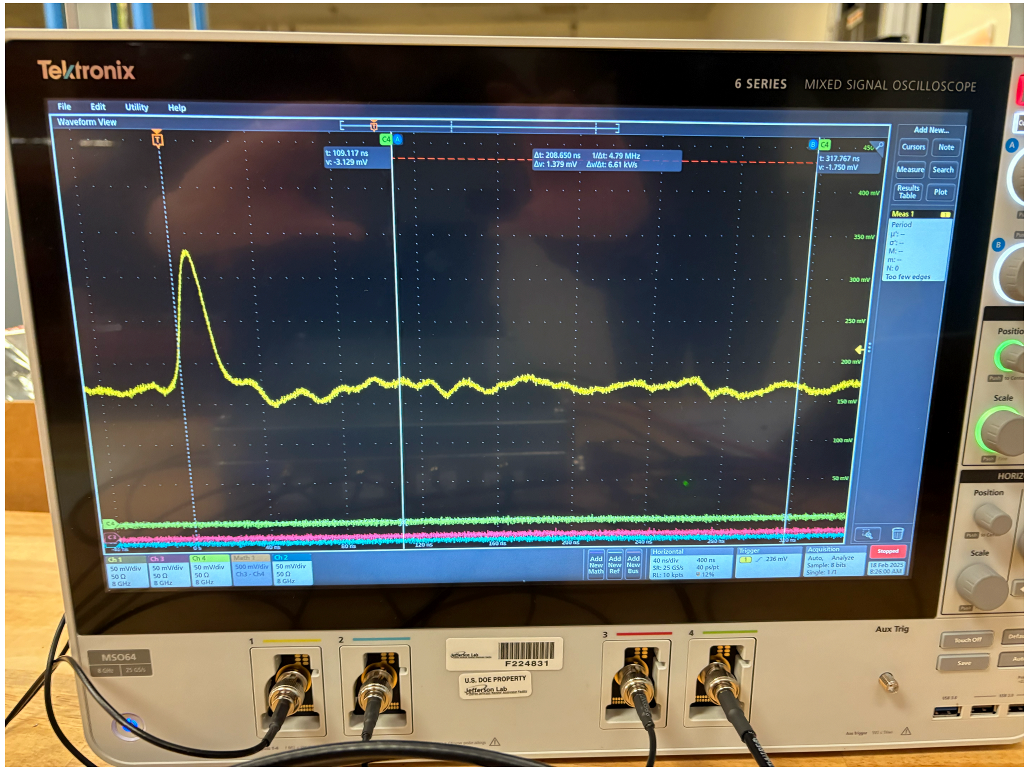
Test board



Source – hiding diamond detector

SenseICs Site Visit

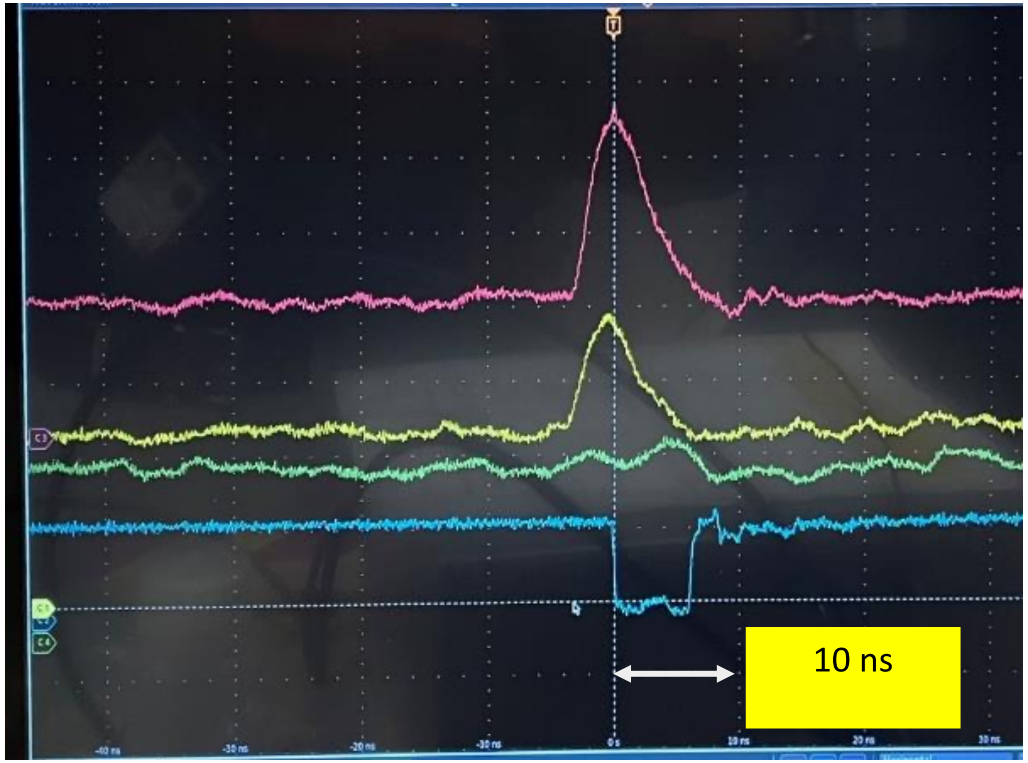
Analog output



Has 3 optional response times: “fast” → 10 ns, “medium” → 10s of ns, “slow” → 100 ns

Medium/slow and fast have to be selected using output pads

Analog and LVDS output



Picture from earlier visit

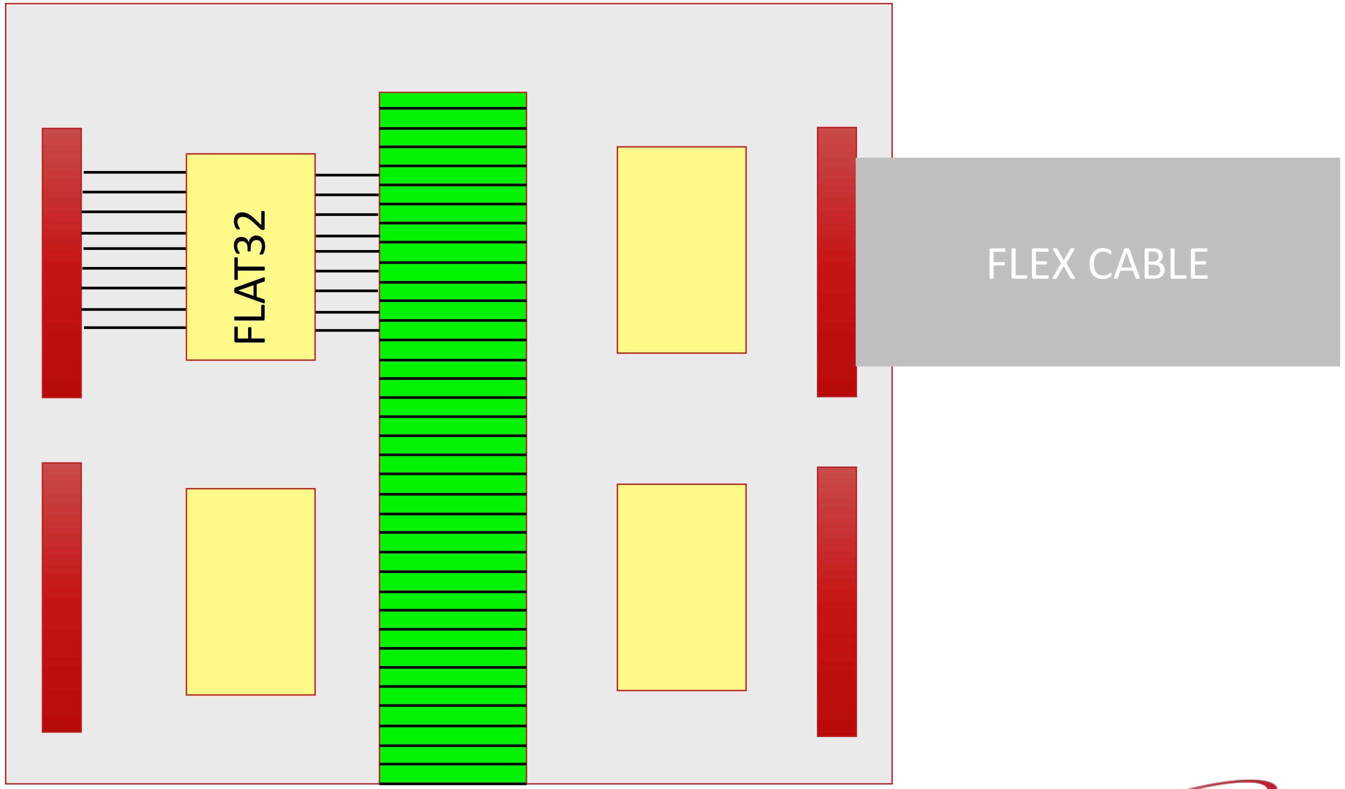
Bonus: FLAT-32 meets requirements for EIC as well

Diamond Carrier Board

Need to cover ~ 6 cm at 11 GeV → will use 2 x 3 cm tall, 1 cm wide diamond detectors (up to 4 planes)
→ Strip pitch = 0.248 mm → 120 x 2 strips for each plane
→ Up to 960 channels total

Once diamond sensors and FLAT32 chips are complete, need to mount both on carrier board

→ PR for design and fabrication of final detector board awarded in early July



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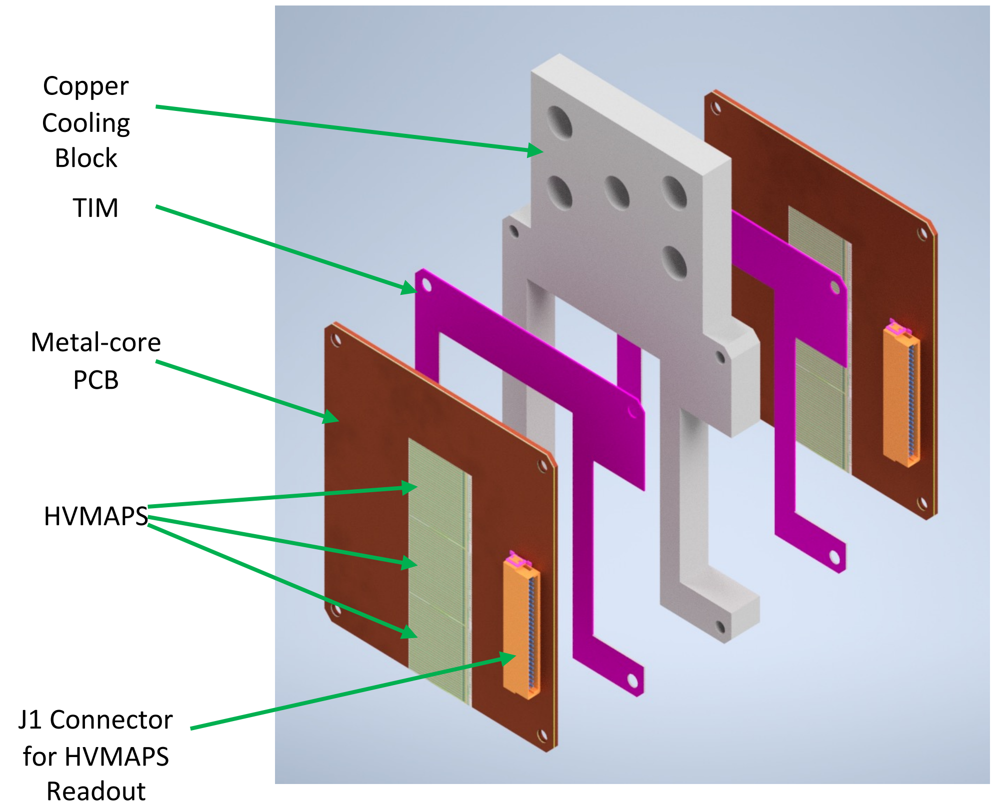
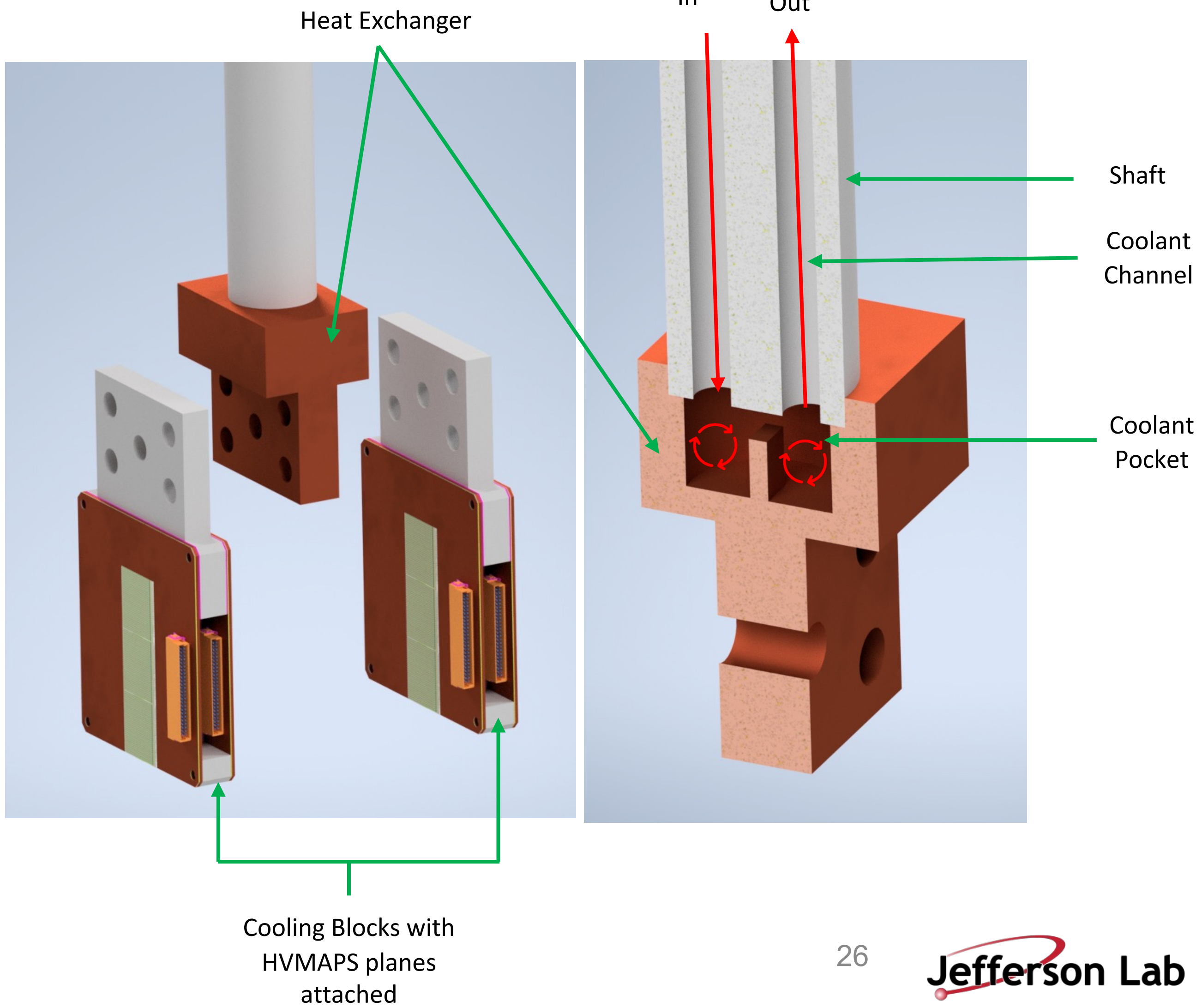
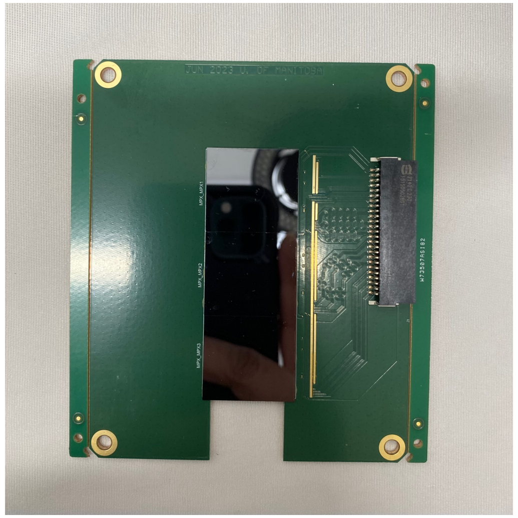
HVMAPS electron detector

In parallel, U. Manitoba building HVMAPS electron detector
→ Significant work in design and prototyping, cooling

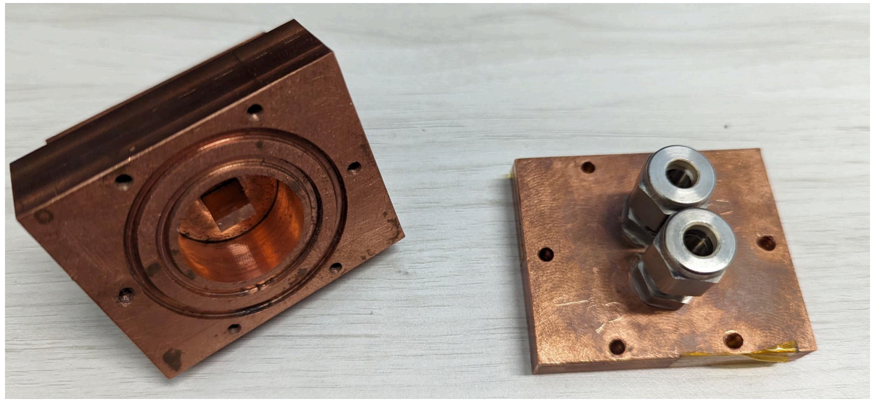




HVMAPS Prototyping

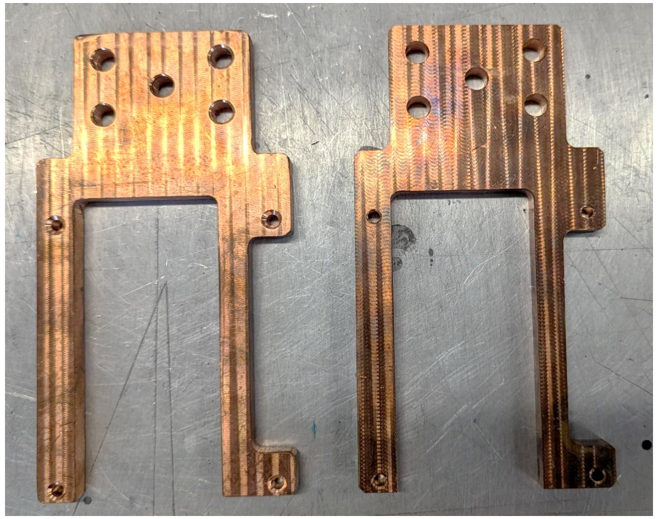


Copper-core PCB

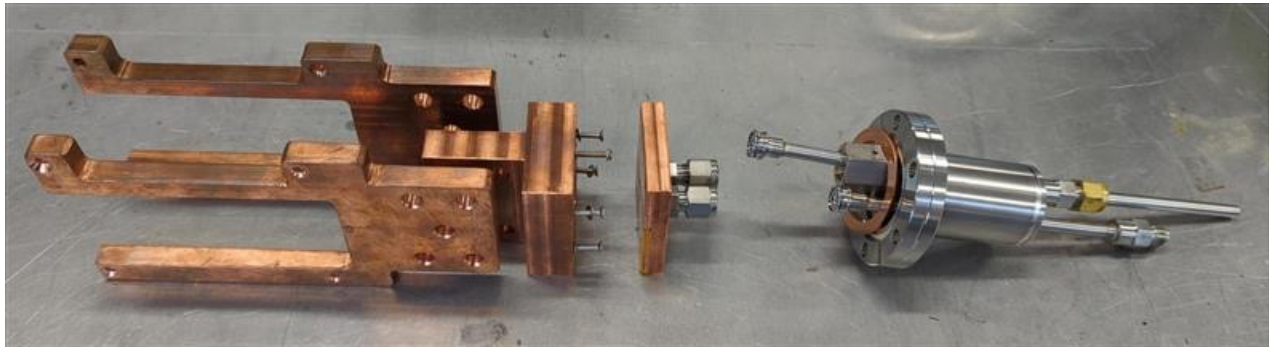


Heat Exchanger

Detector Mounting Bracket



Copper cooling blocks



Heat exchanger prototype, including chilled water feed-through

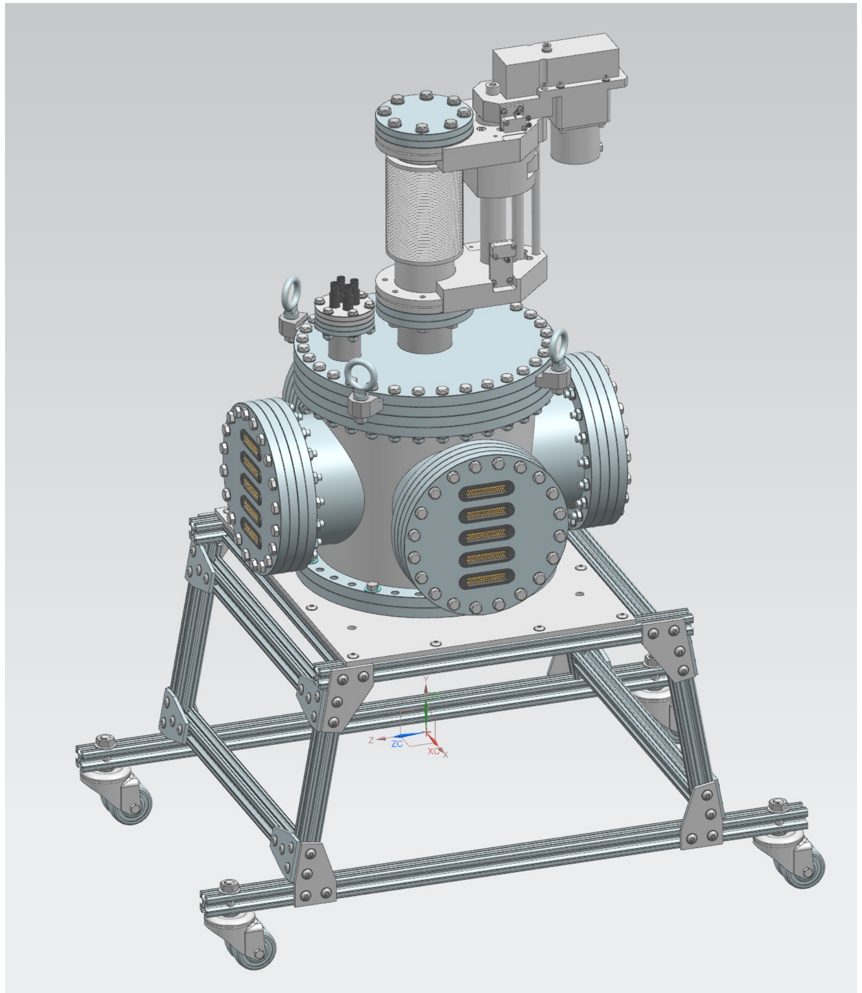
Nafis Niloy

Electron Detector Chamber

Stand for detector assembly
→ Detector will be installed with can on stand
→ Wheels to allow rolling from platform to detector location
→ Whole assembly lifted in place using lifting fixtures in ceiling

Stand and chamber assembly awarded

Electron detector to-do:
→ Diamond detector cooling calculations
→ LVDS repeater for diamond detectors (fast electronics)
→ Design and fabricate flex cables



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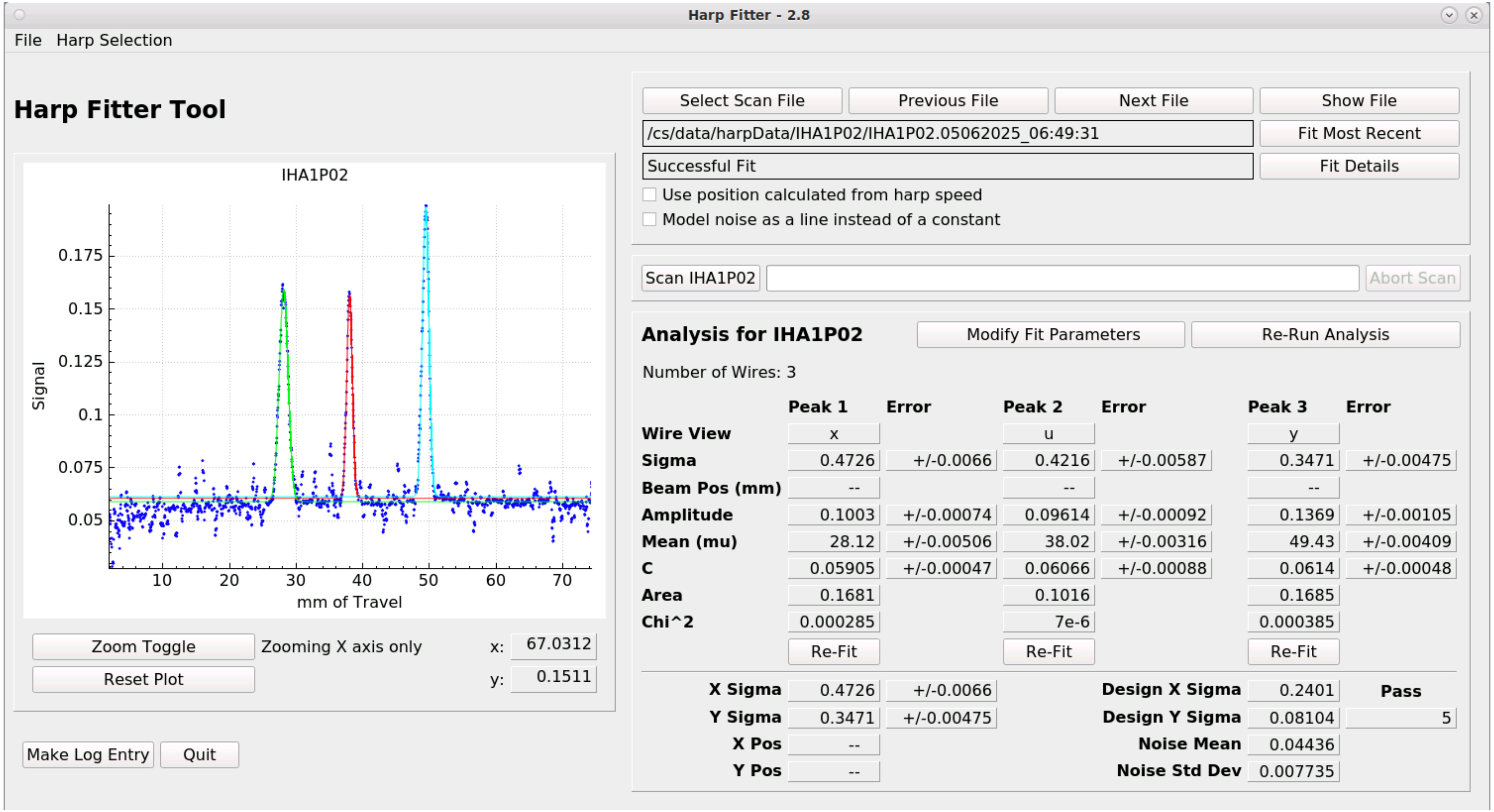
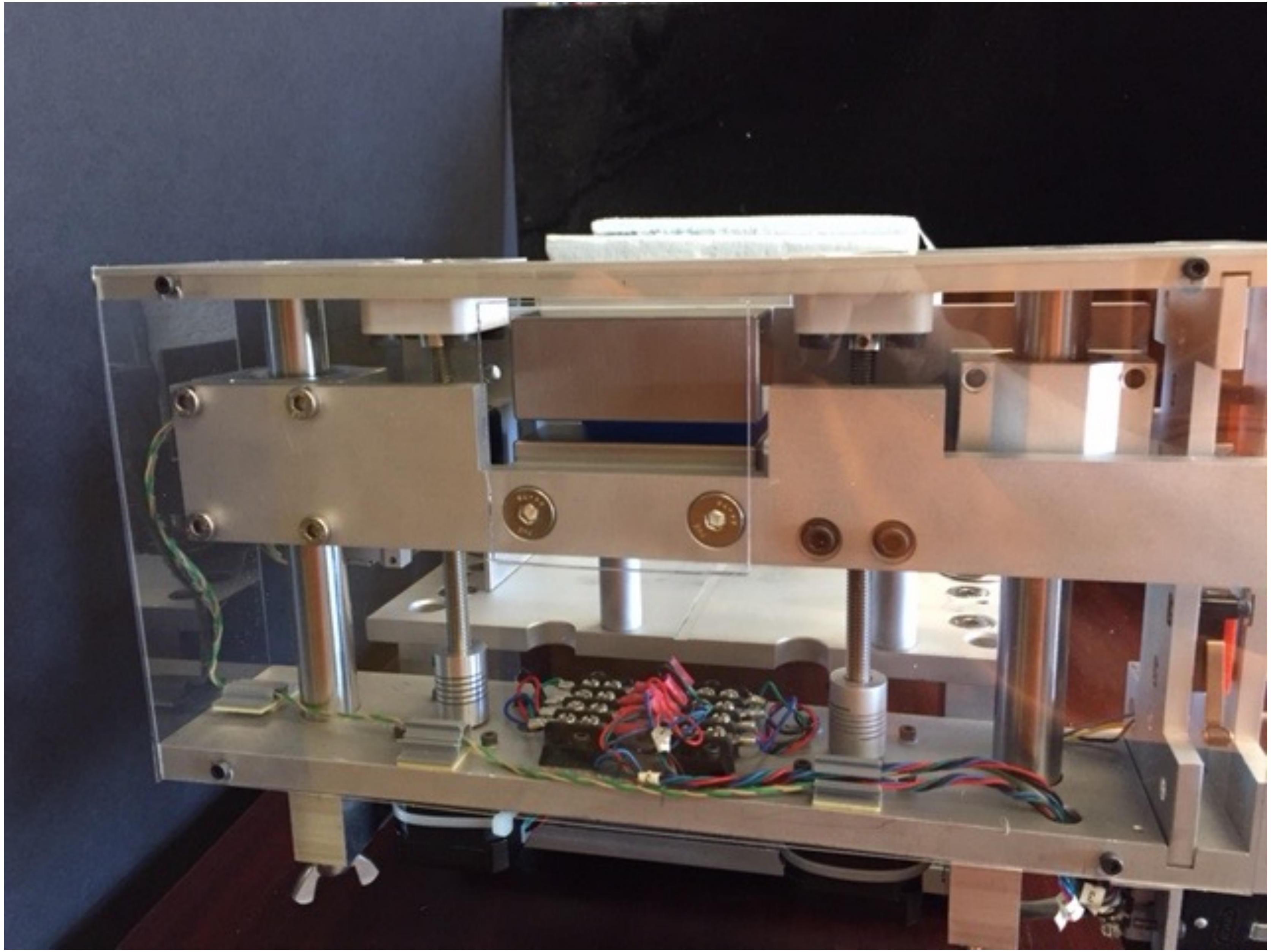
New harp



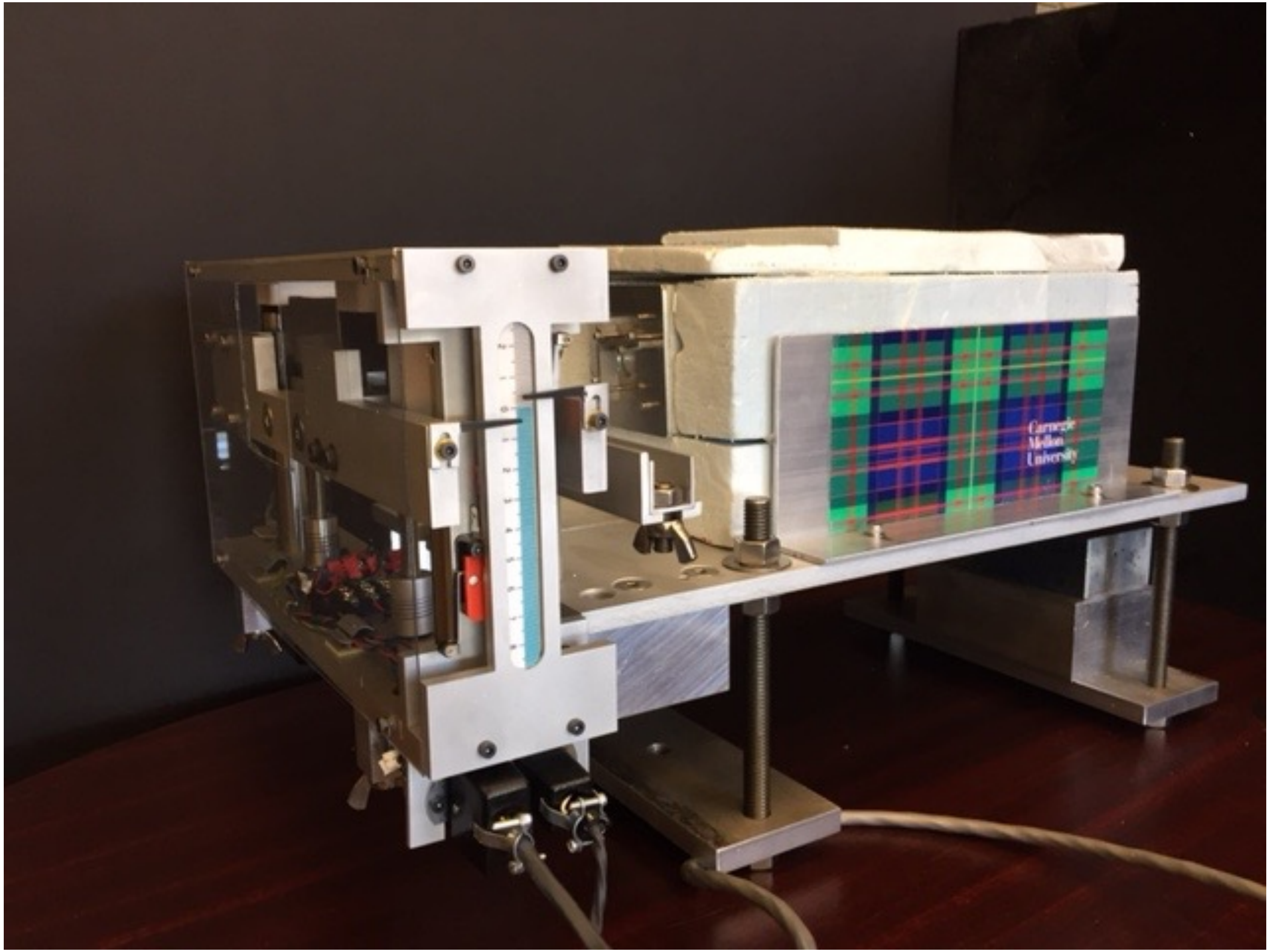
	Peak 1	Error	Peak 2	Error	Peak 3	Error
Wire View	x		u		y	
Sigma	0.4726	+/-0.0066	0.4216	+/-0.00587	0.3471	+/-0.00475
Beam Pos (mm)	--		--		--	
Amplitude	0.1003	+/-0.00074	0.09614	+/-0.00092	0.1369	+/-0.00105
Mean (mu)	28.12	+/-0.00506	38.02	+/-0.00316	49.43	+/-0.00409
C	0.05905	+/-0.00047	0.06066	+/-0.00088	0.0614	+/-0.00048
Area	0.1681		0.1016		0.1685	
Chi^2	0.000285		7e-6		0.000385	

Harp scan – May 6

JAWS



JAWS + Detector



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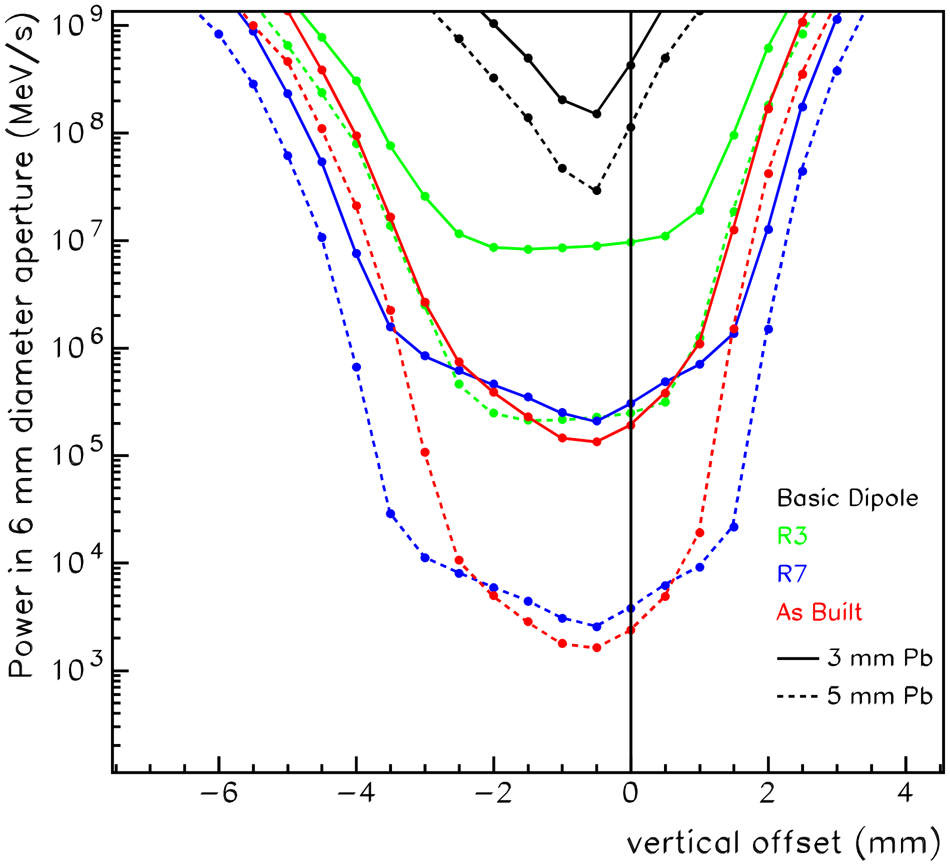
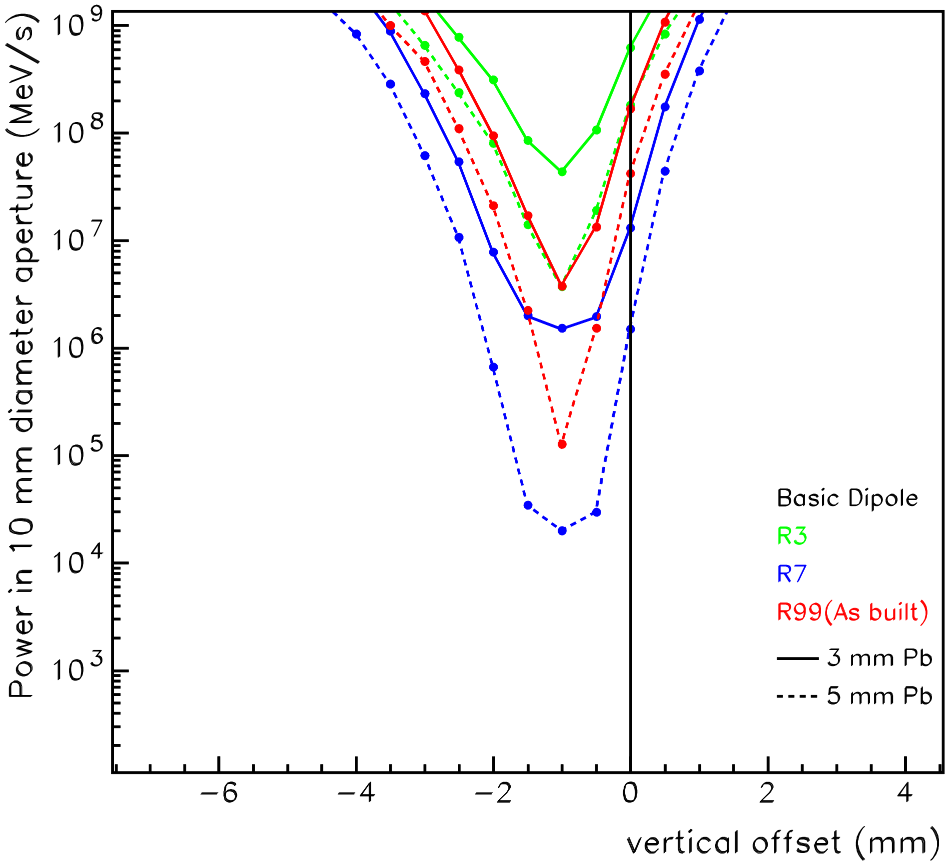
Synchrotron Radiation

6 mm aperture



10 mm aperture



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