Diamond Detectors for Accurate Compton Polarimetry

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Outline

- Motivation
- Design Overview
- Diamond Detectors

Motivation for Compton Polarimetry for Hall C, JLab

- Continuous, noninvasive measurement of polarization
- Complementary to pre-existing Moller Polarimeter (which is periodic, invasive)
- Systematic uncertainty to be similar to Moller (<1%)
  - required for high-precision experiments, e.g. Qweak.

Q-weak Experiment

- Measure parity-violating asymmetry in elastic electron scattering to isolate the "weak charge" of the proton.

$$A_{PV} = \frac{-G_F Q^2}{4\sqrt{2}\pi\alpha}\left(Q^p_{weak} + Q^2 B(Q^2)\right)$$

$$A_{meas} = P_e \times A_{PV}$$

$$Q^p_{weak} = 1 - 4\sin^2\theta_W$$

Source	$\Delta A_z / A_z$	$\Delta Q^p_{Weak} / Q^p_{Weak}$
Statistical	1.8%	2.9%
Hadronic structure	–	1.9%
Beam polarization	1.0%	1.6%
Q^2 determination	0.5%	1.1%

4% extraction of $Q_{weak}{}^p$ $\Rightarrow$ 0.3% determination of $\sin^2\theta_W$

Compton Polarimeter Design Goals

- $(\Delta P/P)_{\text{statistical}} < 1\%$ per hour
  - high laser power
  - high laser energy (green) increases Compton asym.
  - large acceptance for detectors (in energy)
- $(\Delta P/P)_{\text{systematic}} < 1\%$
  - stable beam, small spot in interaction region
  - low backgrounds
  - good energy resolution in detectors
  - high laser energy increases Compton edge

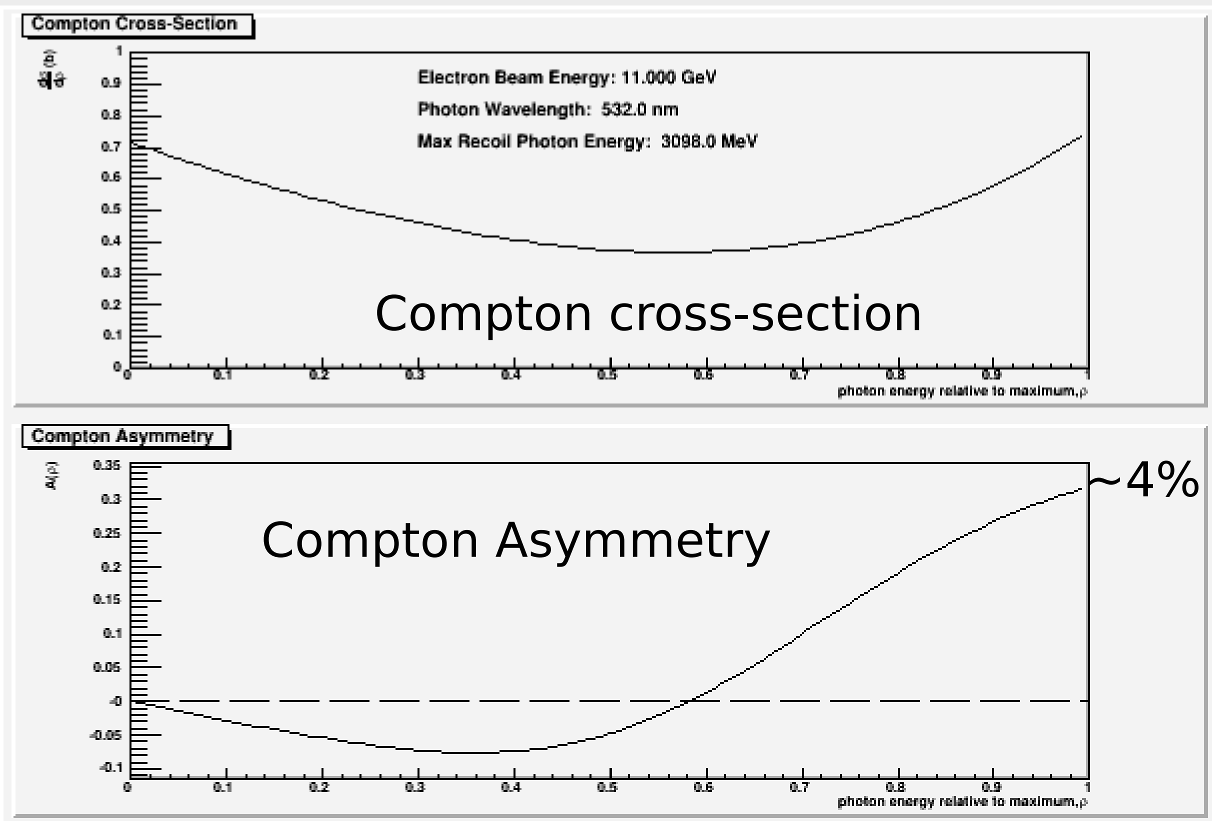
Design Goals Cont'd

- Operable for a variety of beam energies from 1.165 GeV – 11.0 GeV
  - chicane
  - must fit in Hall C

Most design studies currently focused on achieving 1% for Qweak experiment:
1.165 GeV @ 180 uA

Compton Polarimetry Principle

- Scatter the electrons from polarized laser light.



~4%

Photon Energy relative to Compton edge

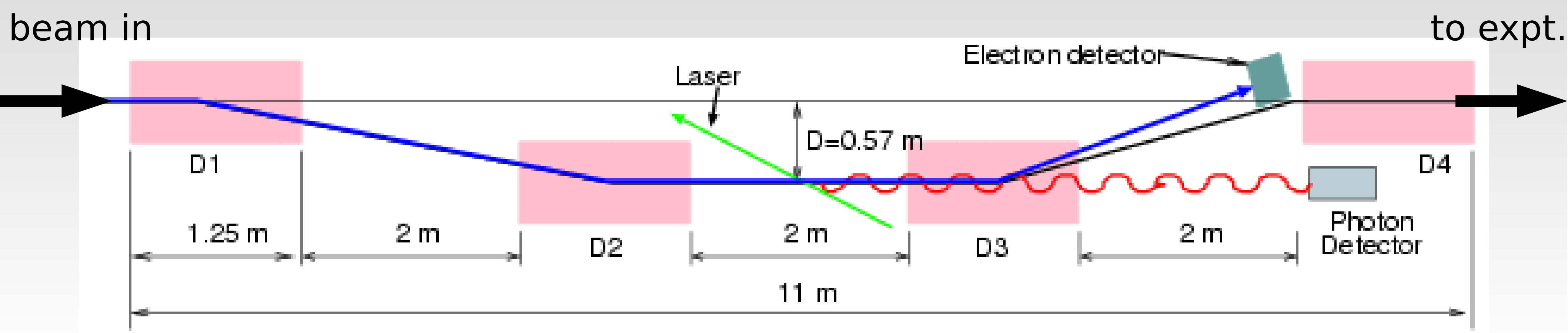
$$A_{meas} = P_e P_\gamma A_{Compton}$$

Measure:
- Compton asymmetry
- Energy dependence
- Laser polarization

Theory:
- Compton asymmetry

Extract:
- P_e

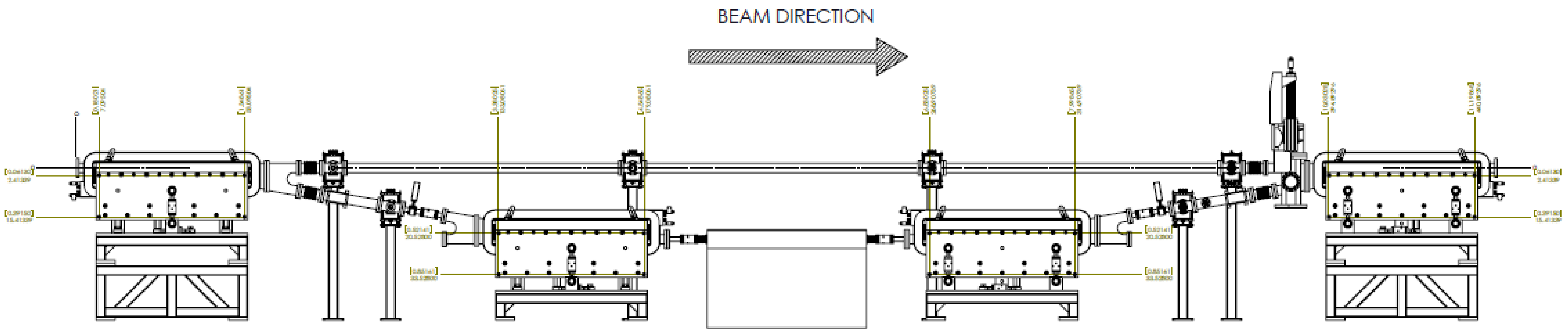
Hall C Compton Overview



- Chicane
- Laser
- Detectors

Parameter	Symbol	Value
Beam Energy	E_{beam}	1.165 GeV
Laser wavelength	λ	532 nm
Photon Compton edge	k'_{max}	46.4 MeV
Asymmetry @ edge	A_{max}	0.041
Chicane bend angle	θ_{bend}	10 deg
Electron free drift	d_{drift}	3.3 m
e- displacement @ edge	X_{max}	23 mm

Chicane



- Chicane in final design stages / out for bid.

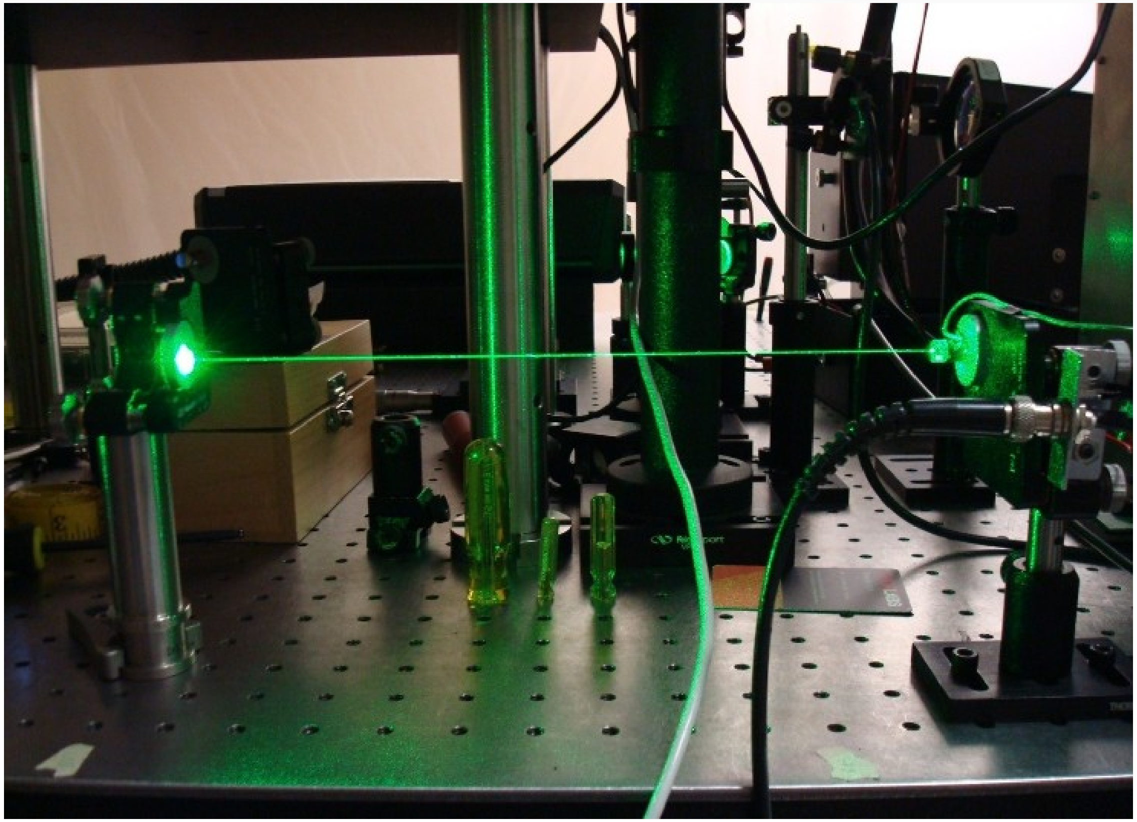
Chicane will be reconfigured for 12 GeV upgrade

E_e (GeV)	θ_{bend}	B (Tesla)	D_{vert} (cm)	Δx_e (cm)
1.165	**10**	**0.67**	**57**	**2.4**
2.0	10	1.16	57	4.1
2.5	10	1.45	57	5.0
2.5	4.3	0.625	25	2.2
3.0	4.3	0.75	25	2.6
6.0	4.3	1.50	25	4.9
4.0	2.3	0.54	13	1.8
11.0	2.3	1.47	13	4.5

- interplay of chicane parameters with electron displacement at Compton edge
- Photon/electron detectors probably look different at 12 GeV than at 1.165 GeV

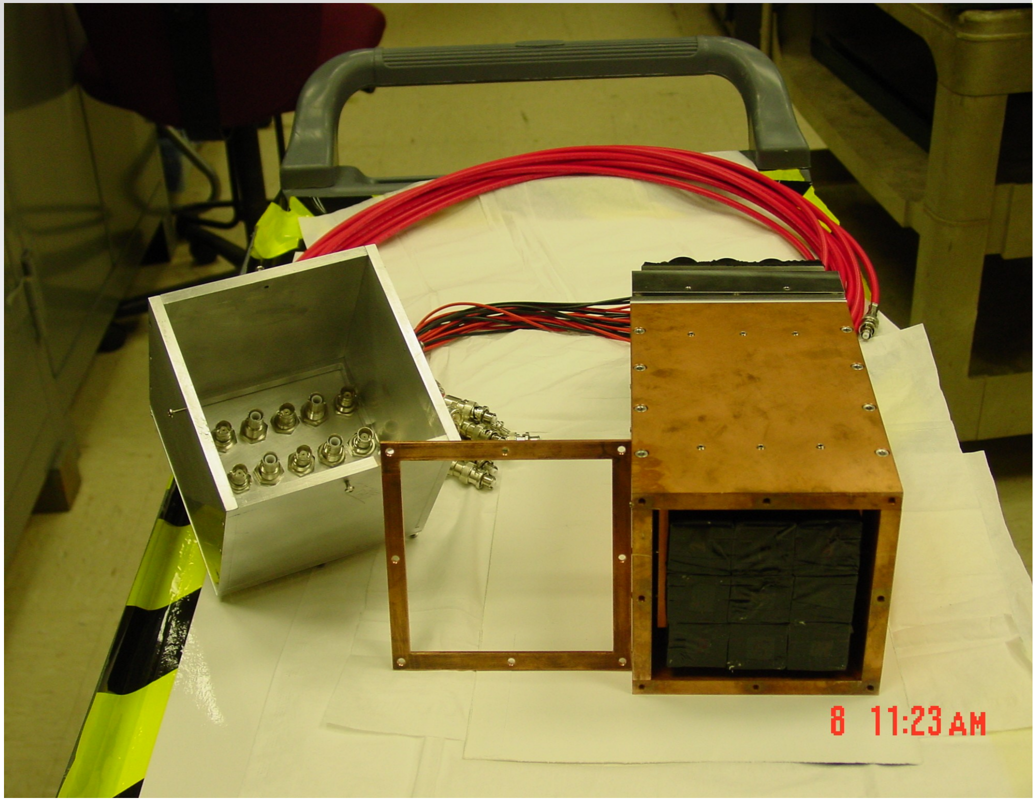
Laser

- External green laser, 10 W. (Coherent VERDI)
- Low gain (x 100) cavity in vacuo.
- Electron beam passes directly through the cavity.
- Cavity gains in excess of 100 recently demonstrated by UVa+JLab group



Detectors

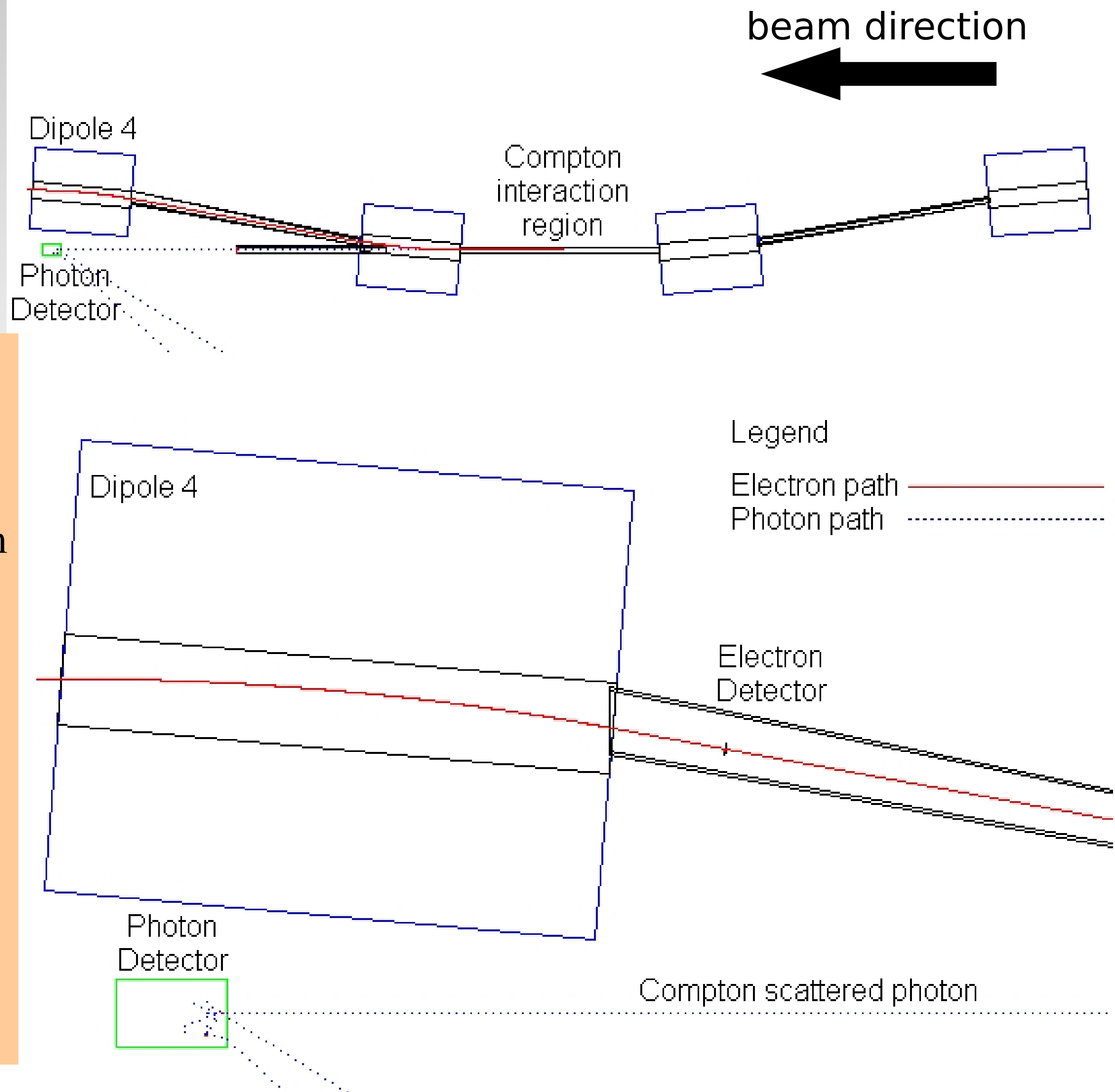
- Photon Detector options
  - 3x3 array of $PbWO_4$
  - Monolithic CsI (undoped)



- Electron Detector (what I'll mainly focus on)
  - diamond strip tracker

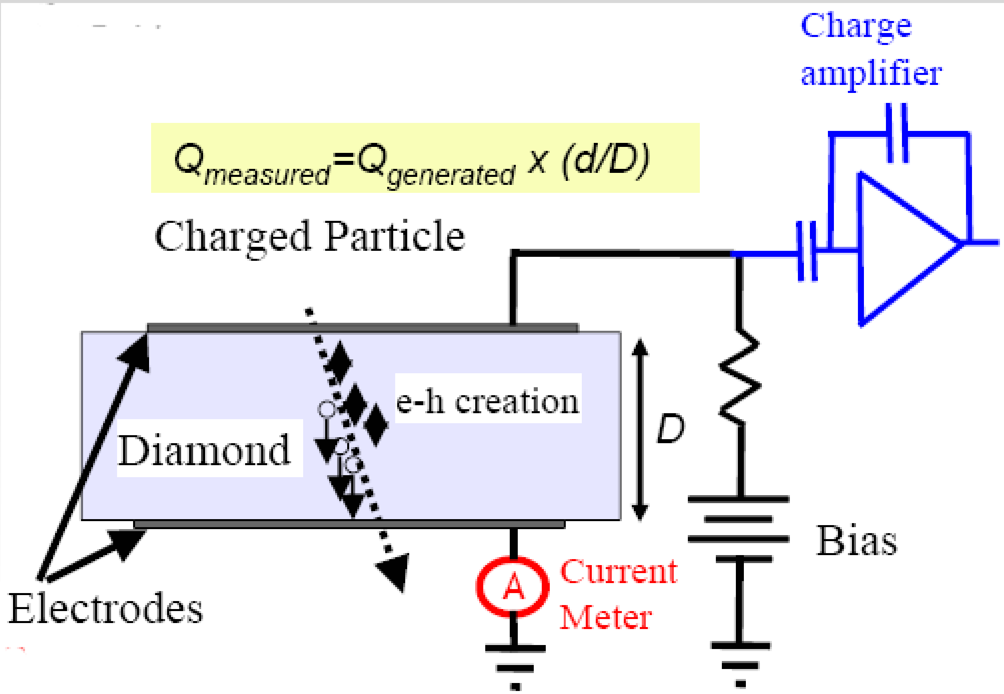
Motivation for Electron Detector

- Position resolution gives momentum of scattered electron.
  - Independent single-arm measurement of polarization
  - Calibration of photon detector (coincidence mode)
- Designing for 1% Polarization Determination for BOTH



Monte Carlo simulation from D. Storey, U. Wpg hons thesis

How a diamond detector works



- Signal limited by impurities and grain boundaries
- Increases with E-field up to ~1-2 V/μ **m**
- CCD ("charge collection distance") ~ 250 μ **m**

We use pc-CVD (polycrystalline chemical vapour deposition) diamond from Element Six, UK.

Why pc-CVD diamond?

	Silicon	Diamond
Band Gap (eV)	1.12	5.45
Electron/Hole mobility (cm^2/Vs)	1450/500	2200/1600
Saturation velocity (cm/s)	$0.8x10^7$	$2x10^7$
Breakdown field (V/m)	$3x10^5$	$2.2x10^7$
Dielectric Constant	11.9	5.7
Displacement energy (eV)	13-20	43
e-h creation energy (eV)	3.6	13
Av. e-h pairs per MIP per micron	89	36
Charge collection distance (micron)	full	~250

Low leakage current, shot noise

Fast signal collection

Low capacitance, noise

Rad hardness

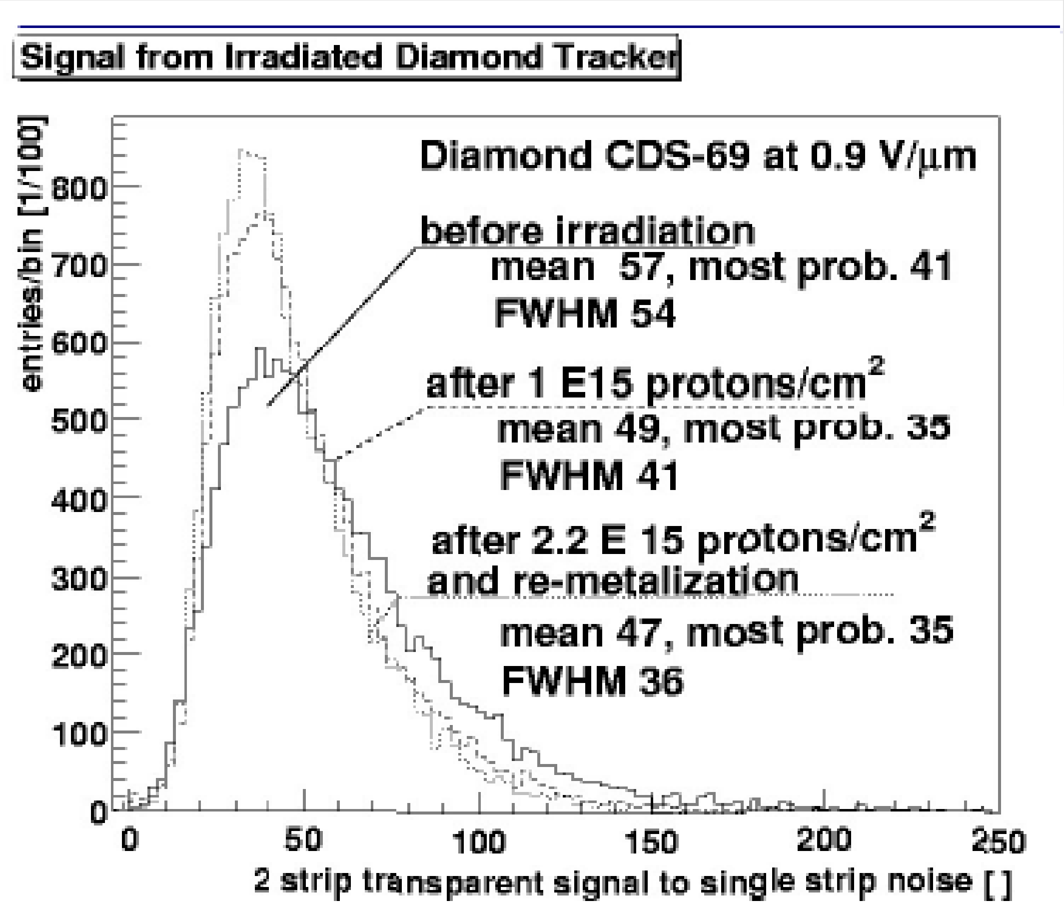
Smaller signal

from Wallny, UCLA

Advantages: lower leakage current, faster, lower noise, rad hard

At the expense of: smaller signal

Radiation Hardness of Diamond Detectors



Thanks R. Wallny (UCLA)

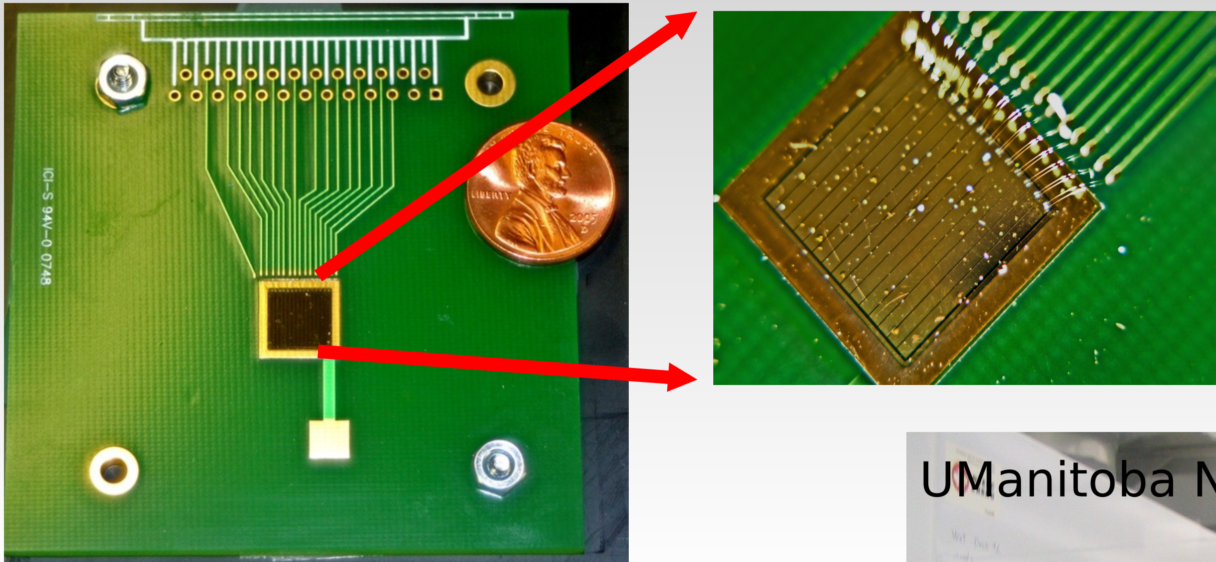
CERN RD-42: Performance after irradiation with protons

- Little change in S/N after exposure of ~5 Mrad
- 15% change in S/N after exposure of ~50 Mrad

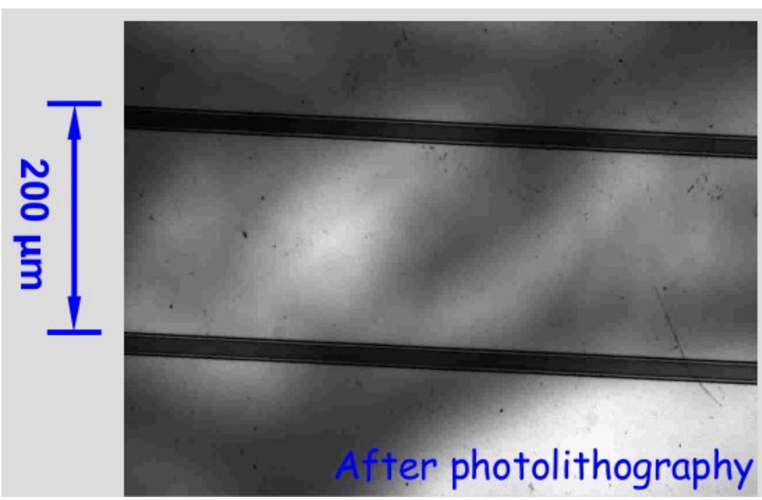
- Si 50% change in S/N after exposure of ~3 Mrad

Estimate for Q-weak alone: 3 Mrad

Prototypes We Fabricated

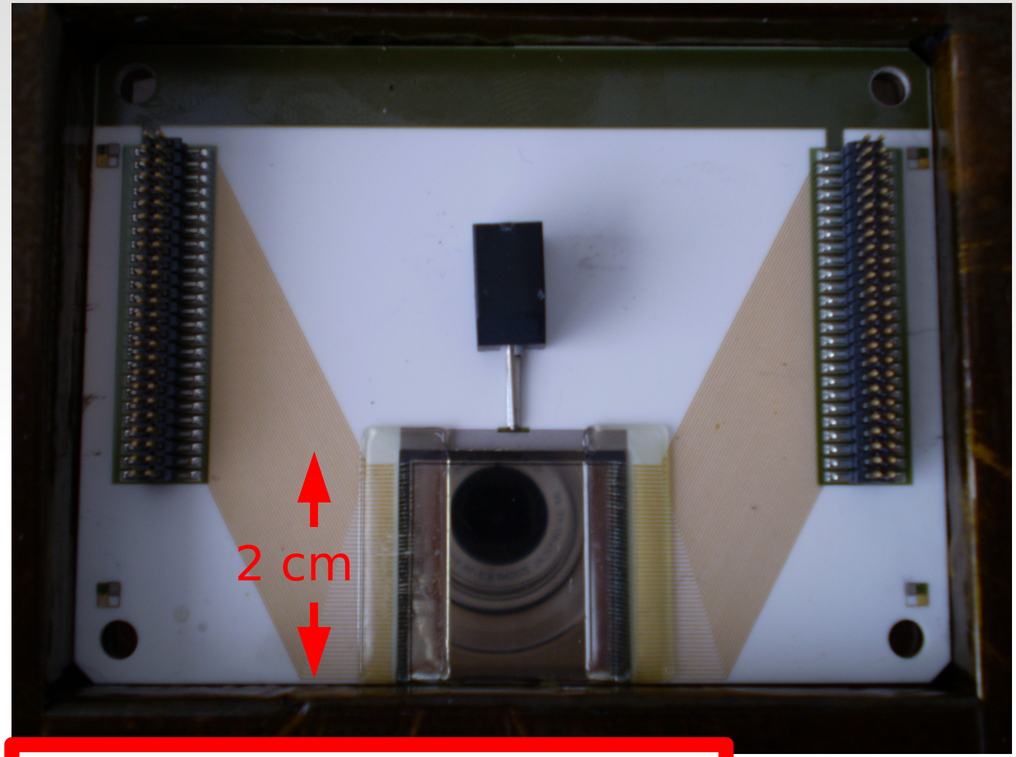


1. at OSU (H. Kagan et al)
2. in Winnipeg (ourselves)



Achieved: 9000 electrons signal (consistent with typical result from CERN RD-42)

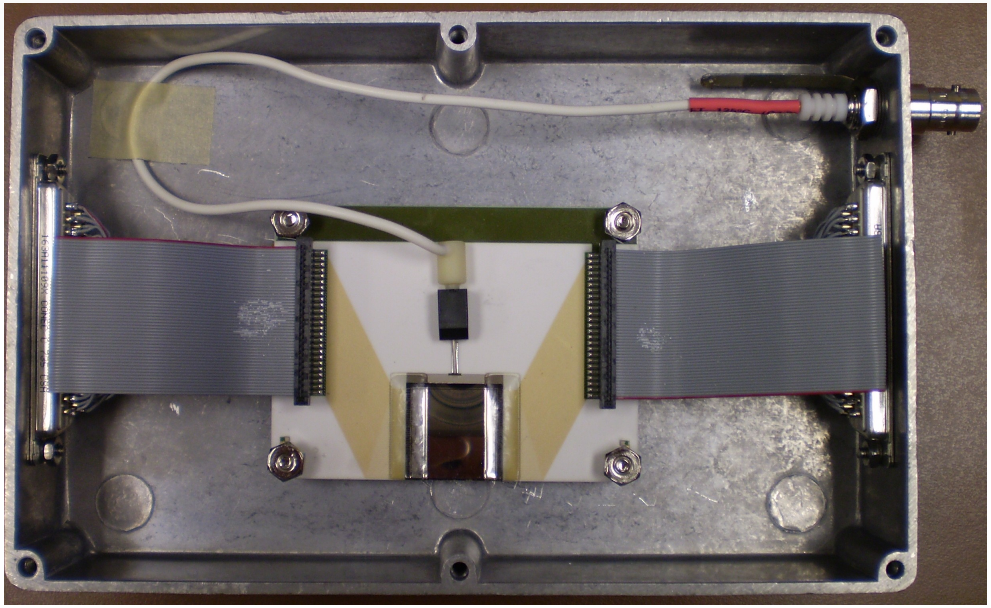
Final Detectors



Metallized diamond
on alumina carrier board

Purchased from Diamond Detectors Ltd.

- 96 strips = 48 + 48
- 200 um pitch
- 1 kV applied to opposite side

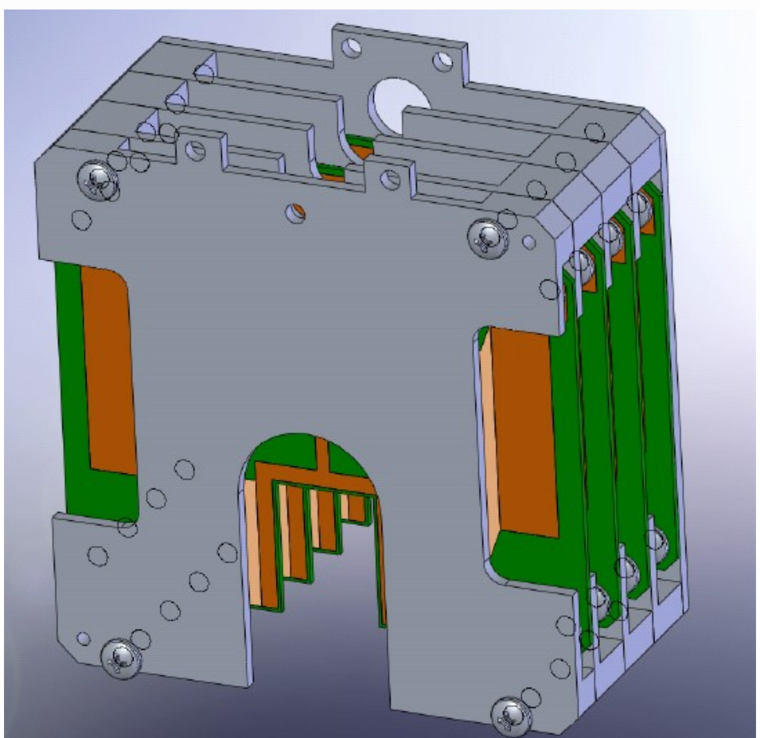


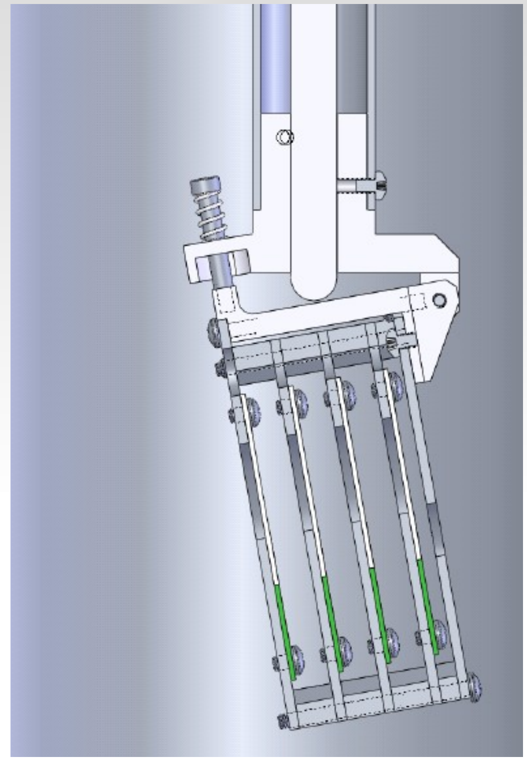
Test setup for radioactive sources

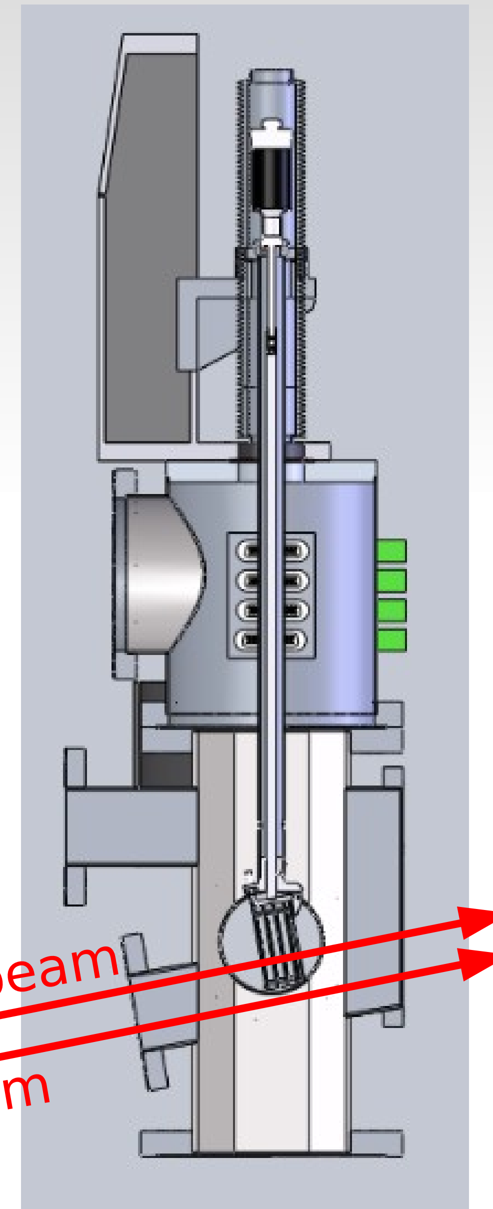
- All diamond now in hand – bench testing with sources

Layout of Diamond Planes

- Four planes for background rejection, track reconstruction with high efficiency

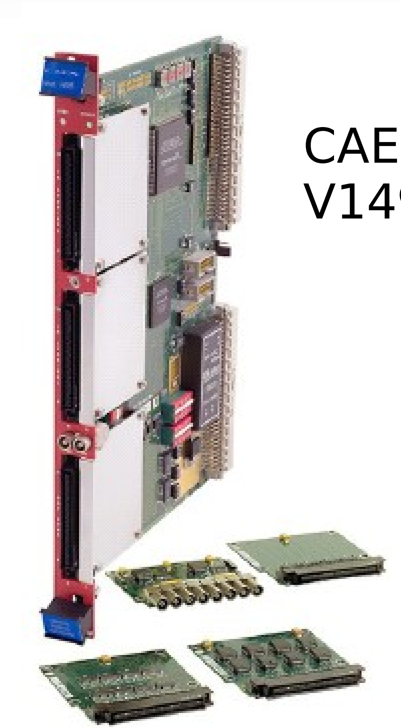






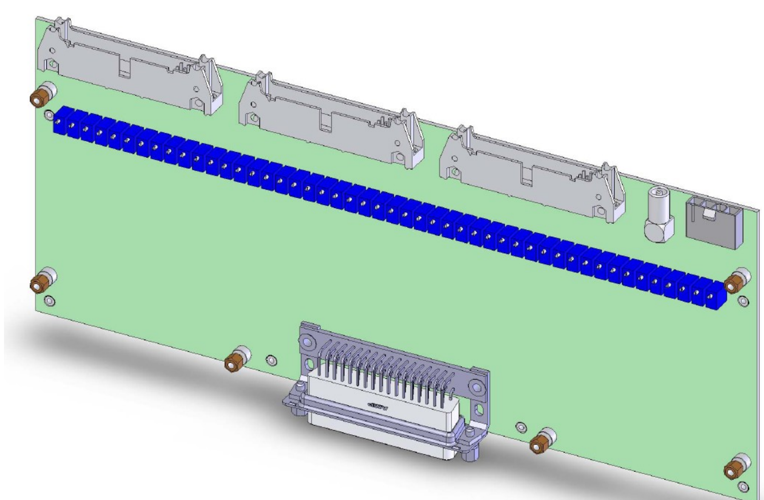
Electronics + DAQ

- Custom discrete preamp + discriminator based on previous TRIUMF design (for LiXe project).
- Multiple CAEN V1495's (commercial FPGA plus VME interface) for all trigger + readout.
- Trigger: ¾ planes, or track-finding, ...



CAEN V1495

Q-weak amplifier-discriminator board

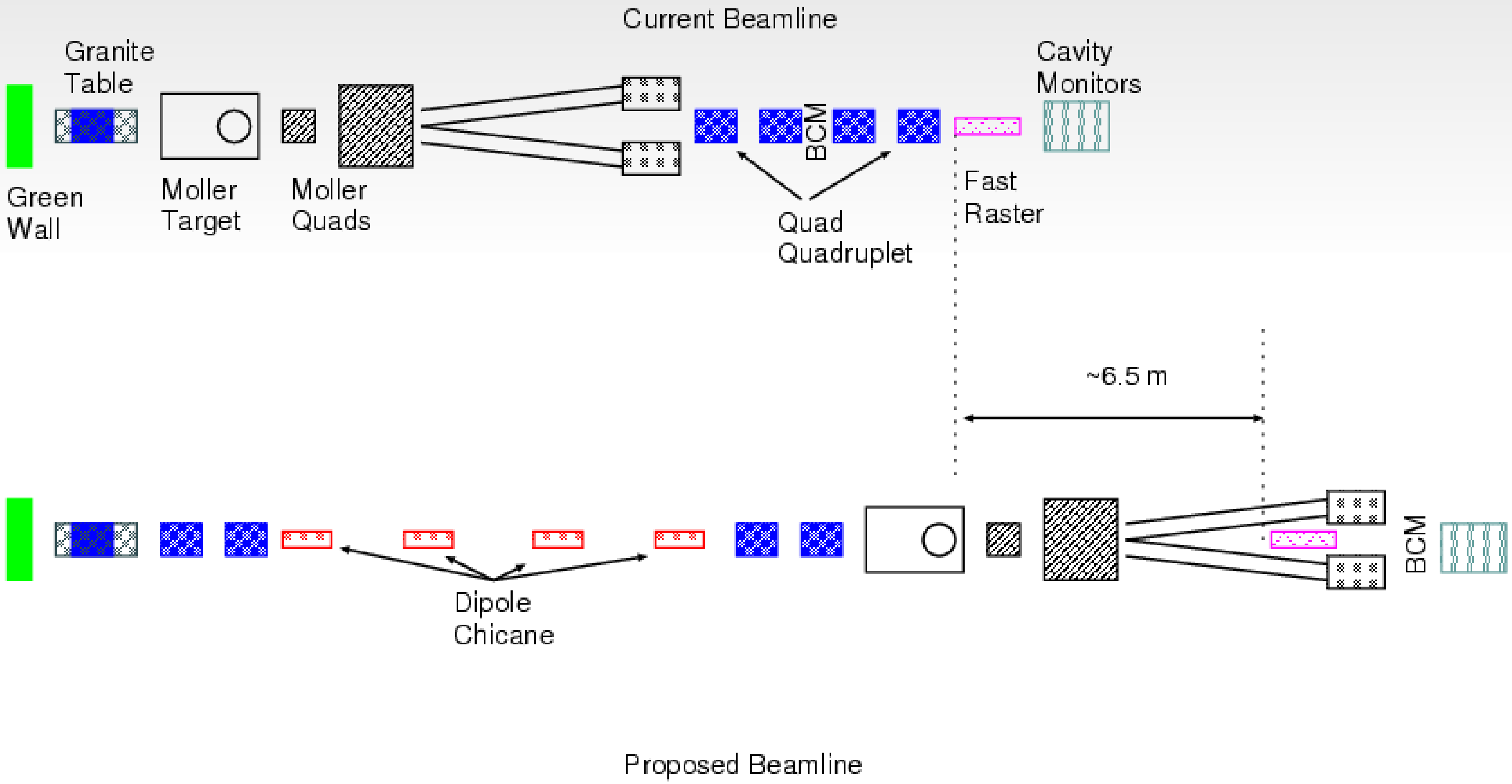


Summary/Timescale for Hall C Compton

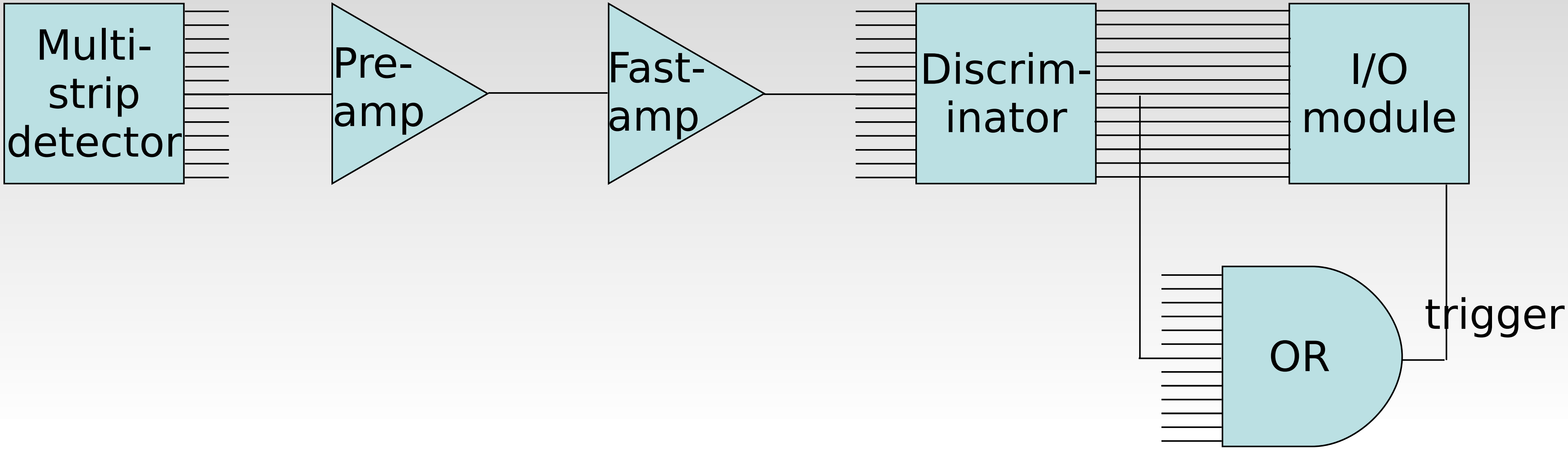
- New Compton Polarimeter is under development for JLab Hall C
- unique features compared to Hall A:
  - laser, chicane, electron detector
- Installation in Hall C for Q-weak early 2010.
- Commission May 2010.
- Reconfigure for 12 GeV during long shutdown after Q-weak

Extras

Cartoon of Hall C Beamline



Electronics/DAQ



Requirements:

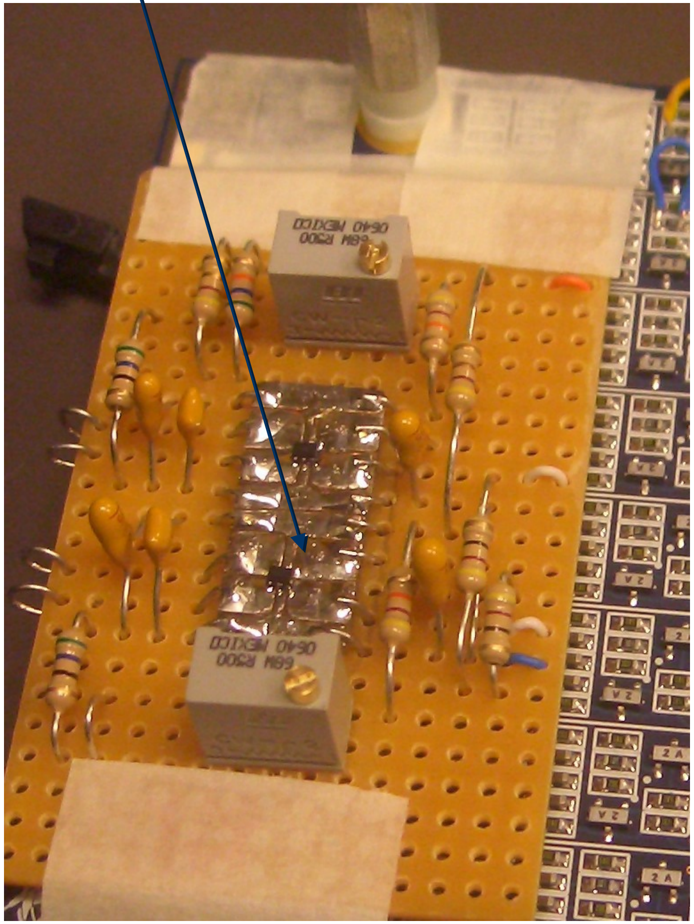
- 4*100 strips – for momentum analysis
- trigger: 3 out of 4 planes must fire (efficiency, background reduction)
- < 100 MHz rates expected from Compton Scattering + background
- High Amplification – small signal in diamond, ~ ½ silicon

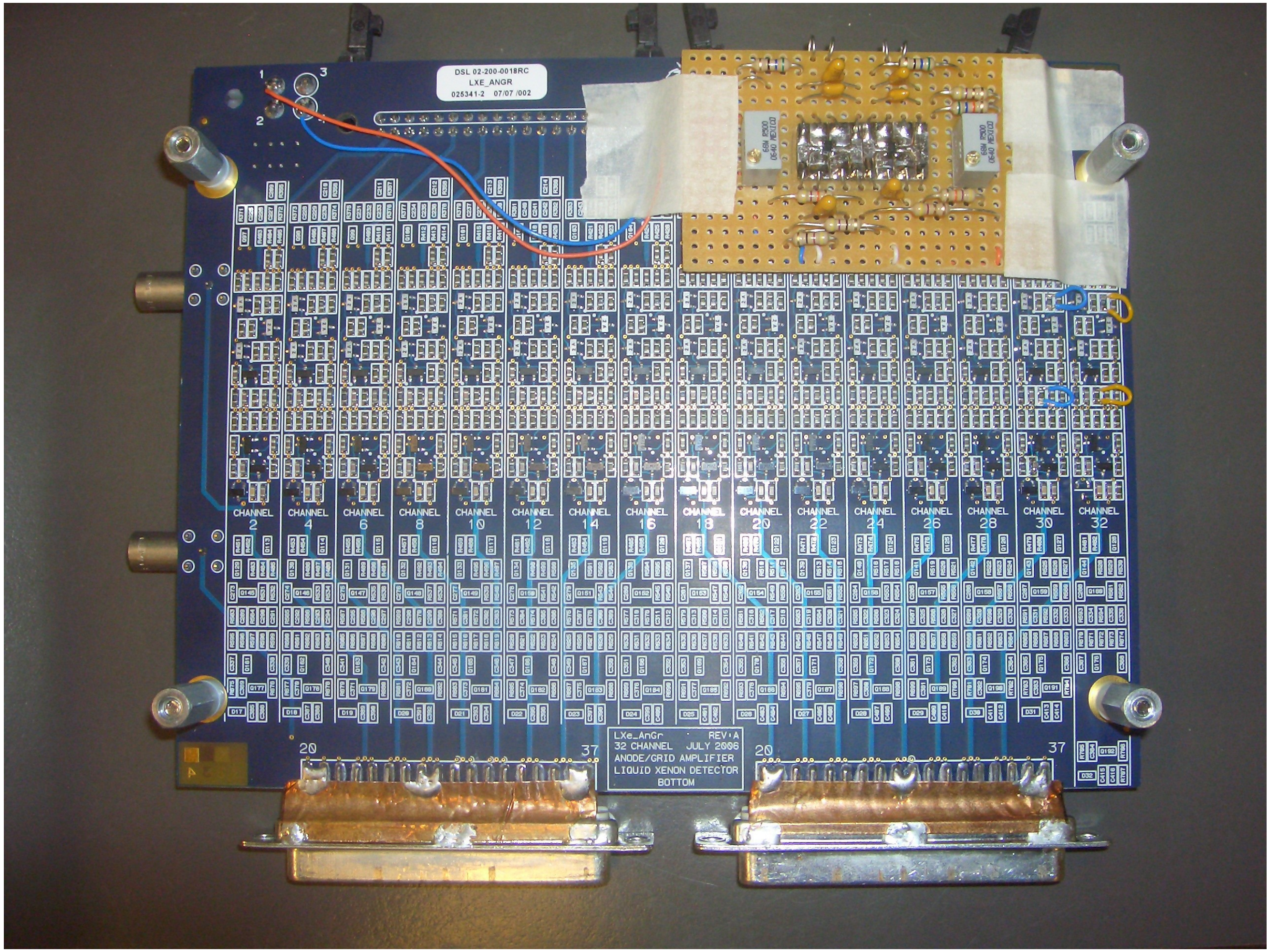
- similar rates for photon det, but need to additionally digitize pulse height
- waveform digitizer?

Readout Electronics

Peiqing Wang made these modifications @ Winnipeg

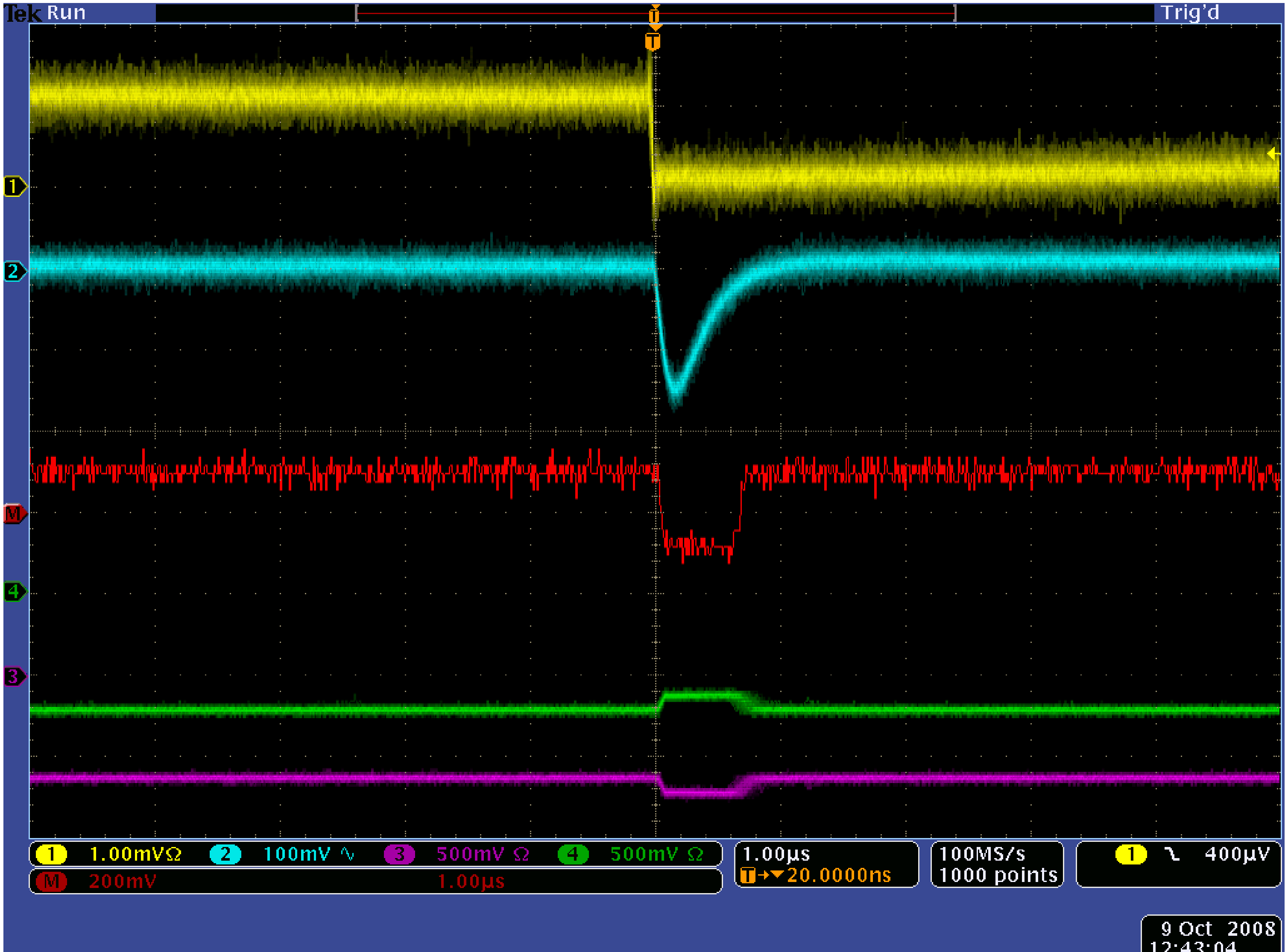
ADC MP604 Comparator





Increased gain on 2 channels and
add discriminators

Readout Electronics



Gain increased to 100mV/fC
Width ~ 0.6µ s

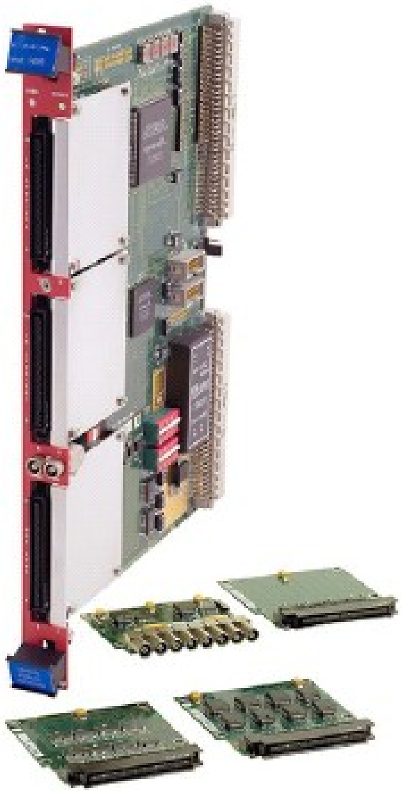
LVDS output from the discriminator

No oscillations
No increase in input capacitance

Need to retest with increased input capacitance to account for ~3ft of cable between detector and card.

Logic and I/O

CAEN Module V1495



- Commercially available
- General purpose VME board
- Can be directly customized by the user
- Field Programmable Gate Arrays (FPGA)

• 96 inputs with 32 outputs

Demonstrated by Tanja Horn:
Transaction time: 0.43 μs
Readout rate: 4.7 Mb/s

Conclusion: sufficient for our design rate of 100 kHz – might need two of them

Experience and help available from the JLab DAQ group