A Diamond Micro-strip Electron Detector for Compton Polarimetry

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on behalf of Hall – C Compton Team

Outline

- Qweak Polarimetry requirements
- Hall – C Compton Overview
- Electron detector
- Data Acquisition
- Analysis approach
- Preliminary results

Qweak and Polarimetry

The Qweak experiment aims to measure the weak charge of the proton with a precision of 4.1%, by measuring the parity violating asymmetry in polarized e-p elastic scattering with a precision of 2.5%

Qweak Error Budget		
Uncertainty	δAPV/APV	δQw/Qw
Statistical (~2500 hours at 150 μA)	2.1%	3.2%
Systematic:		2.6%
Hadronic structure uncertainties		1.5%
Beam polarimetry	1.0%	1.5%
Effective Q^2 determination	0.5%	1.0%
Backgrounds	0.5%	0.7%
Helicity-correlated beam properties	0.5%	0.7%
Total:	**2.5%**	**4.1%**

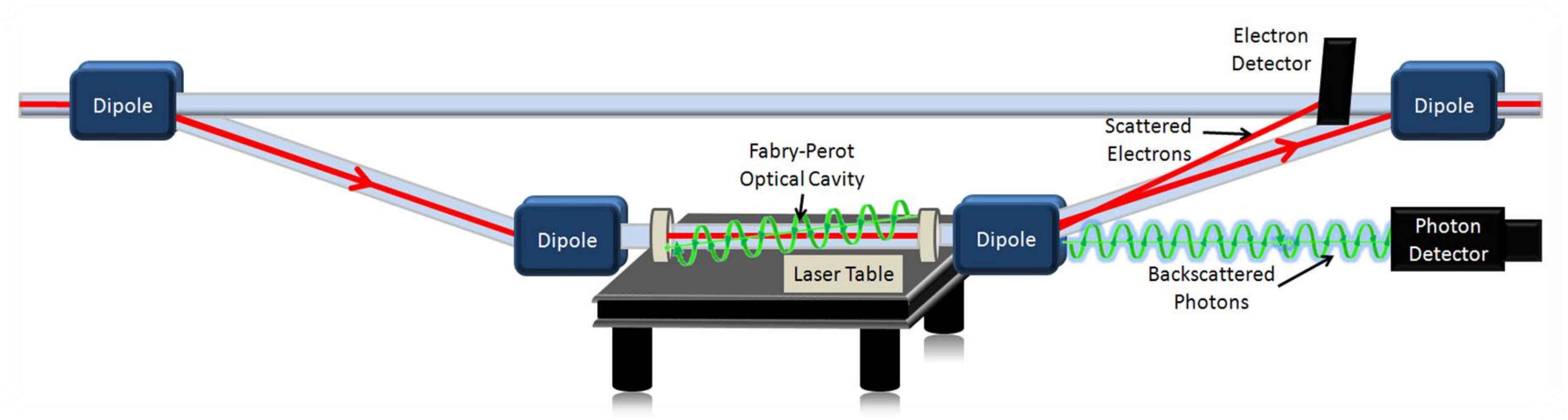
Qweak talk: *Katherine Myers, Sept 8*

one of the largest experimental contribution to the error budget

The Hall-C Moller polarimeter is the highest precision polarimeter at JLab, however it is periodic, invasive and operates only at low currents..

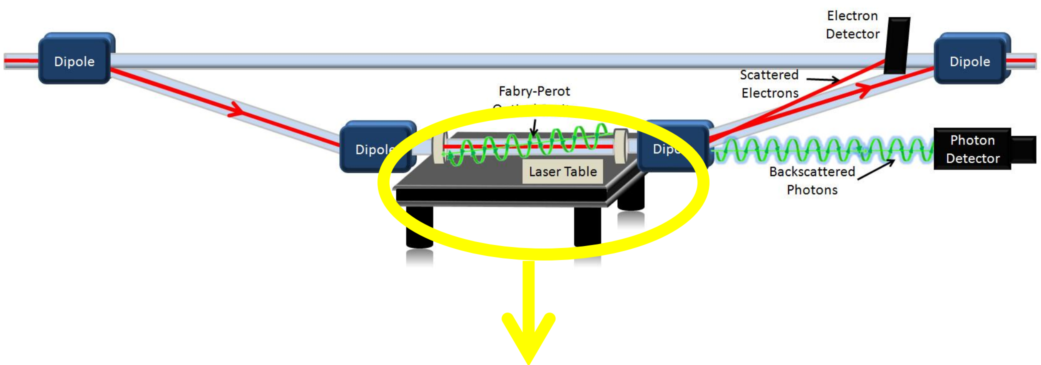
The new Compton polarimeter is **continuous**, **non invasive** and can operate at **high currents**.

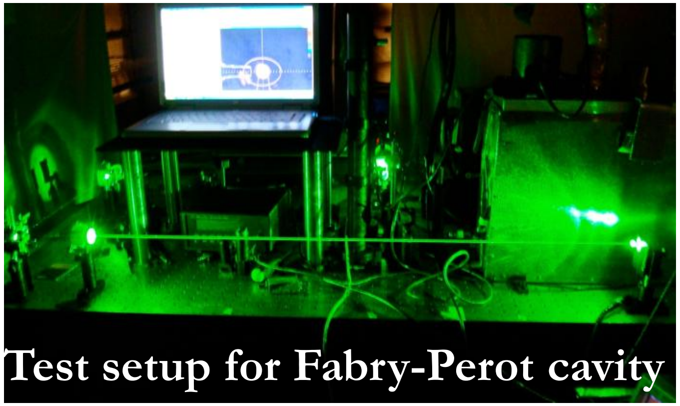
Overview: Compton Layout

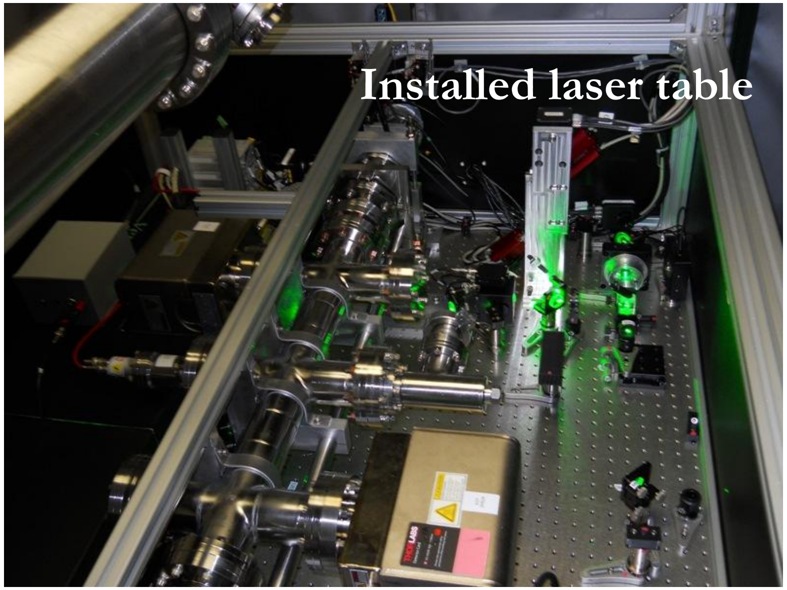


Parameter	Value
Beam Energy	1.16 GeV
Laser Wavelength	532 nm
Chicane bend angle	10.1 deg
Electron free drift distance	1.6 m
Max. Electron Displacement	17 mm
Compton edge energy	46 MeV

Overview: Laser Table




Test setup for Fabry-Perot cavity

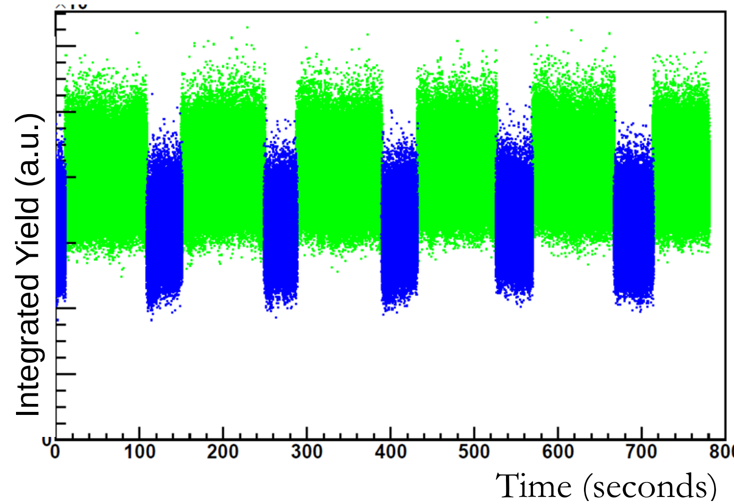

Installed laser table

- Photon target at center of chicane is Coherent Verdi 10W laser locked to low gain Fabry-Perot cavity
- Power in the cavity is ~ 1kW
- laser polarization > 99%
- low reflectivity mirror in Fabry-Perot cavity allows robust measurement of laser polarization

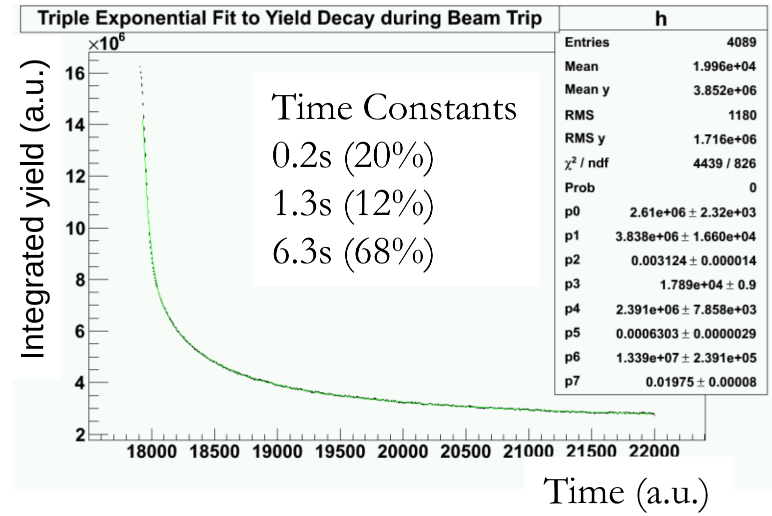
courtesy: Donald Jones, University of Virginia

Overview: γ−Detector

- Laser cycled on and off with a period of ~ 140 s
- γ - detector signal is integrated with no threshold to eliminate sensitivity to gain drift
- Tried CsI crystal at first but found that phosphorescence with ms to second timescales diluted our measurement
- Currently using PbW crystal detector. Less energy resolution but for signal integration this is not an issue.
- Achieving <1% statistical uncertainty in a few hours.

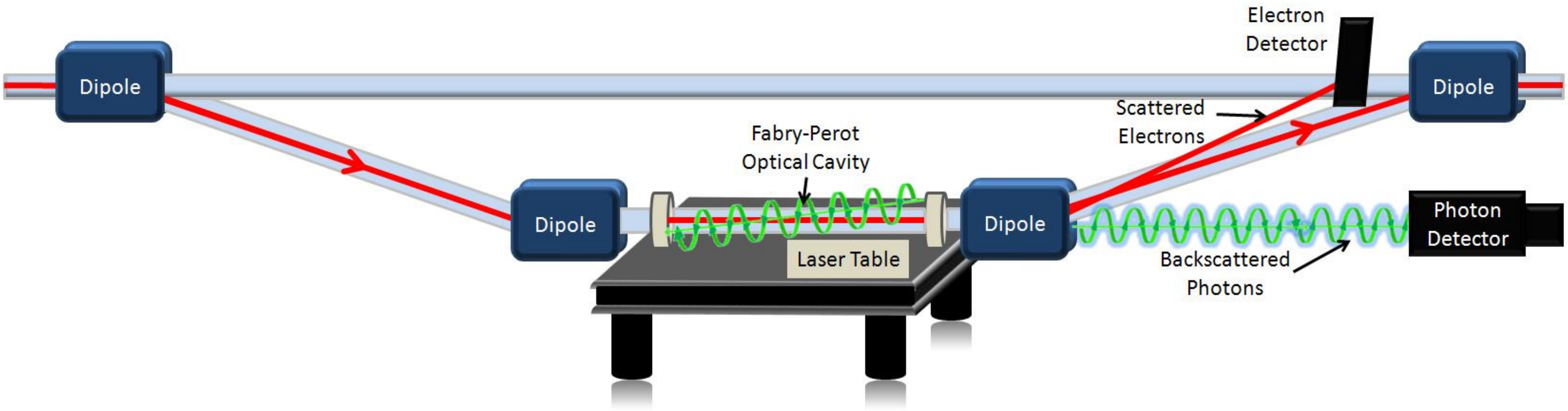


Fit to Yield from CsI during Beam Trip



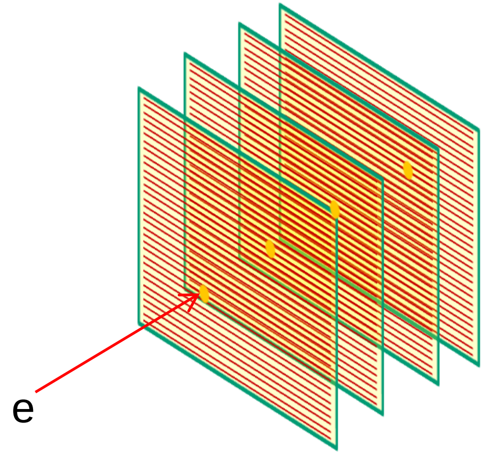
courtesy: Donald Jones, University of Virginia

Overview: e-detector



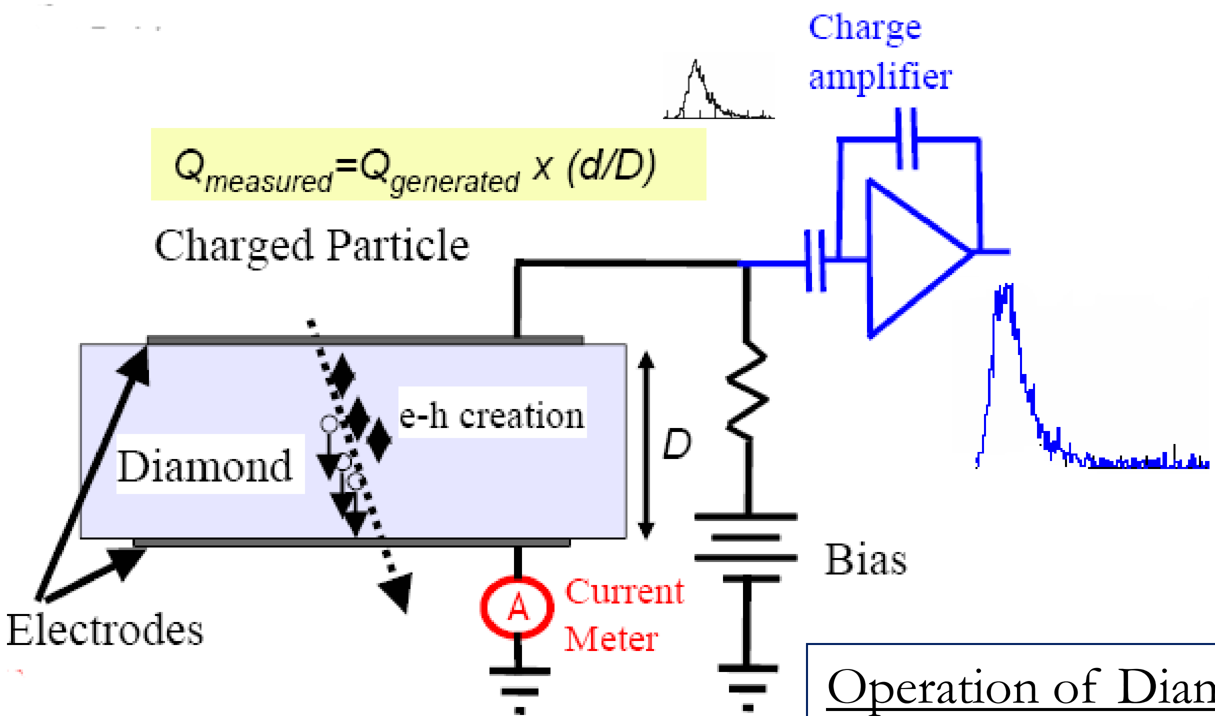
Through the γ-detector and e-detector we have two independent measurements having different uncertainties hence being a good cross-check on each other

- We use diamond micro-strip detector for detecting the Compton scattered electrons
- We have 4 planes of the detector to allow coincidence measurements



e-detector: working

The detector uses Diamond which is artificially grown using Chemical Vapor Deposition

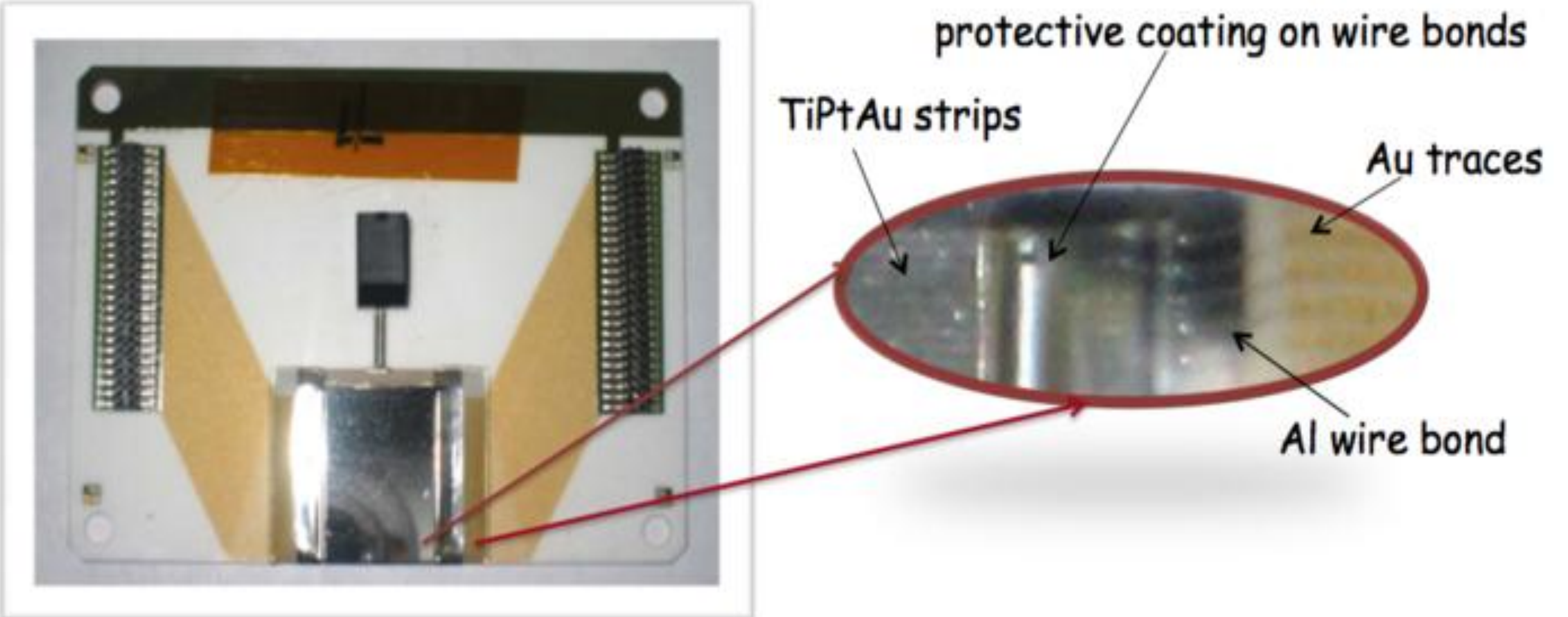


How does it work as a detector ?

<u>Operation of Diamond Detectors</u>

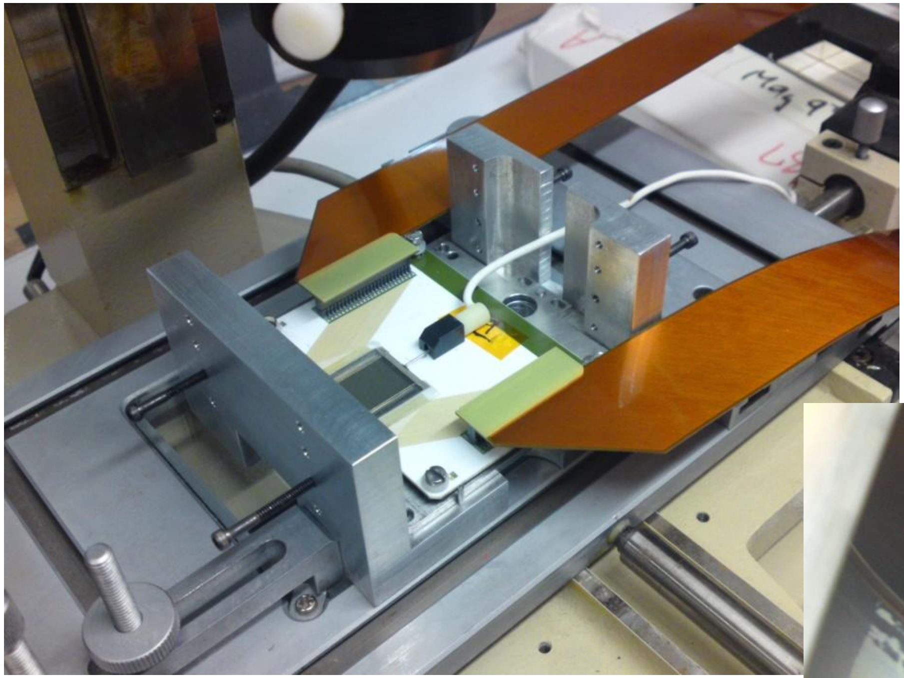
- Bias voltage ~ 1000 V,
- Charge collection distance (d) ~ 250 μm

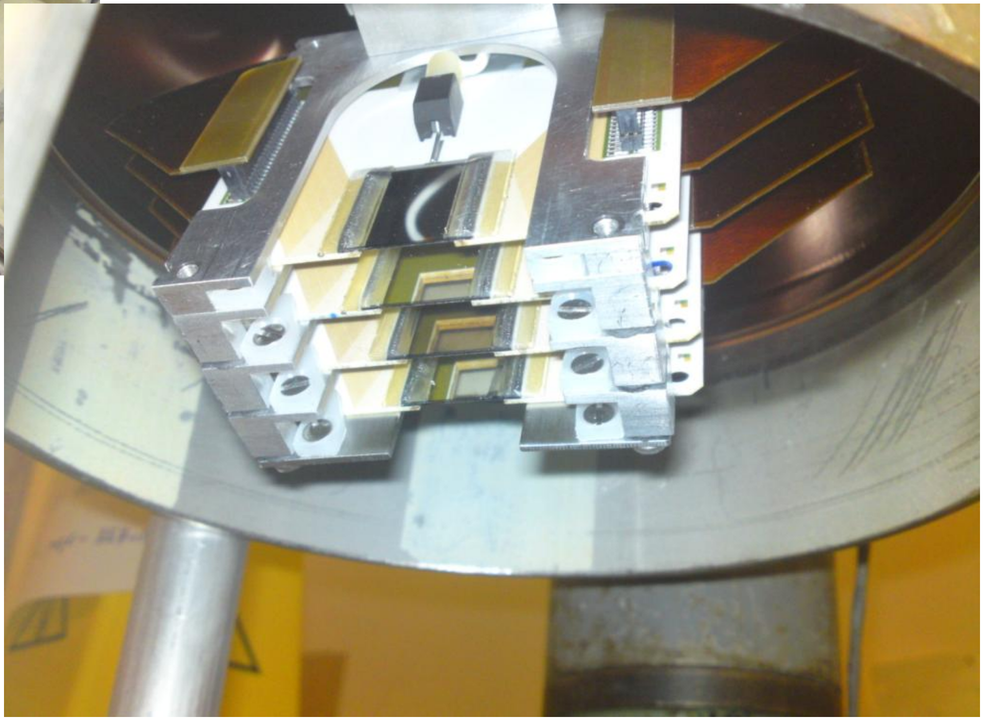
Diamond micro-strip detectors



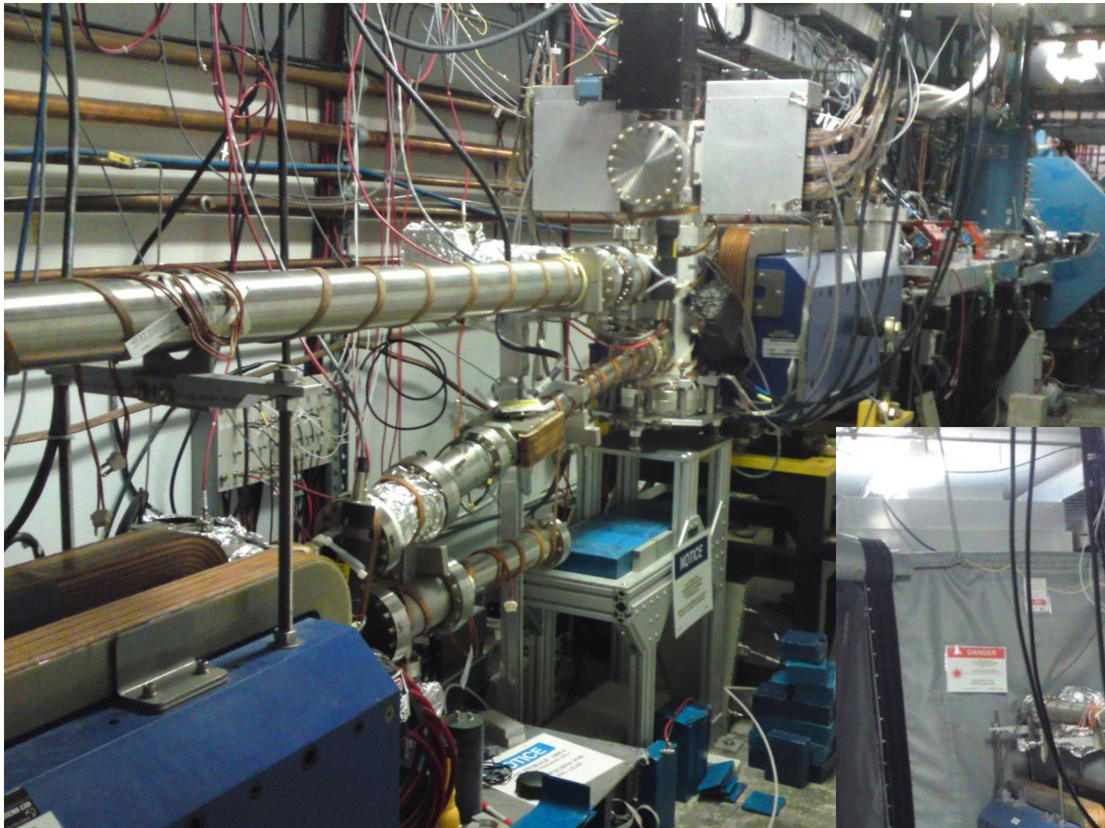
- alumina (ceramic) used for carrier board
- metallization (on diamond) done with TiPtAu
- detector dimensions : 21 mm x 21 mm
- detector thickness: 500 μm
- each detector plate has 96 strips
- strip pitch is 200 μm.

e-detector: installation





e-detector: installed



downstream view

upstream view

e-detector DAQ

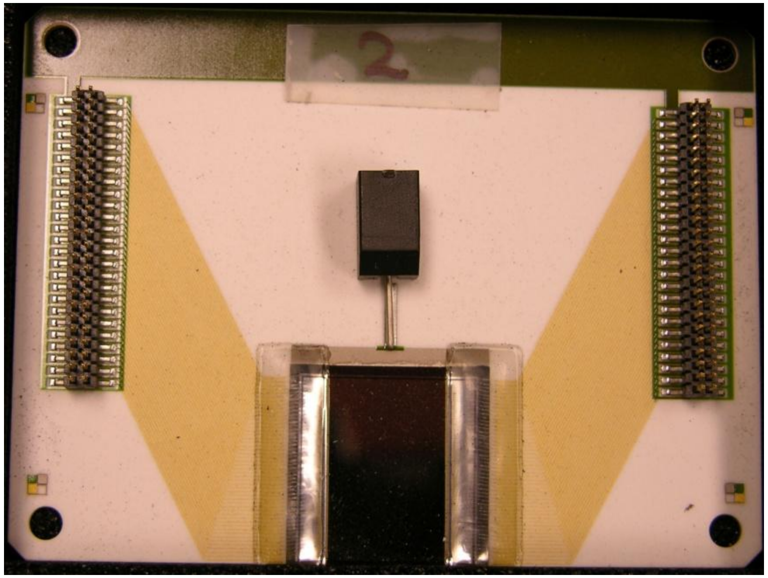
Diamond micro - strip detectors

↓

Amplification, shaping and digitization of the signal

↓

Trigger processed using FPGA based v1495



This is the **first** Diamond micro-strip detector to be used as a tracking device in an experiment

e-detector DAQ

Diamond micro - strip detectors

↓

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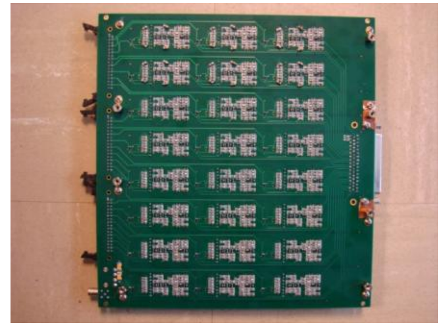


QWAD boards custom made by TRIUMF

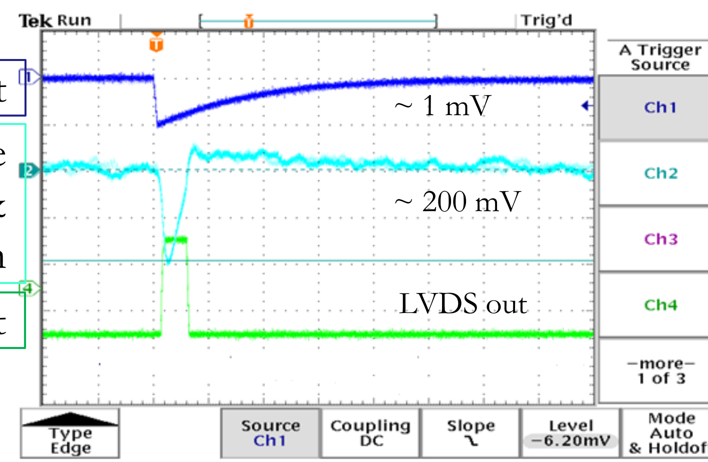
Gain : $\dfrac{200\text{ mV}}{(10\text{x}10^{3})\text{ x }(1.6\text{x}10^{-19})}$

$= 120\text{ mV / fC}$

test input

after charge integration & amplification

digital output



e-detector DAQ

Diamond micro - strip detectors

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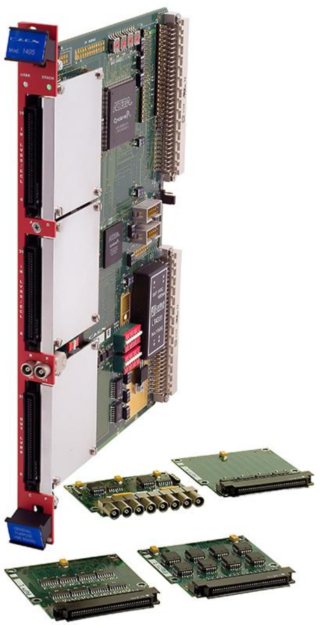
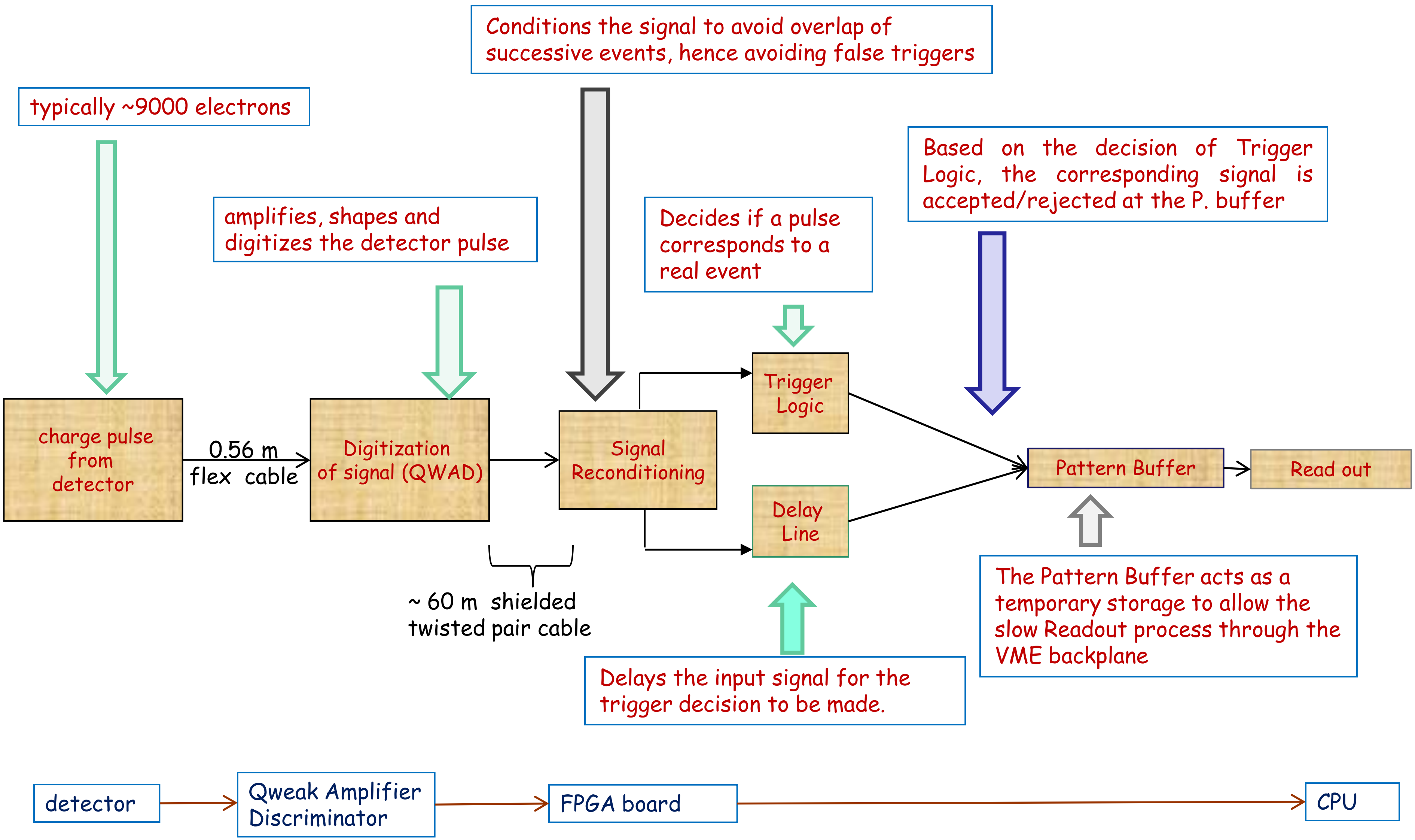


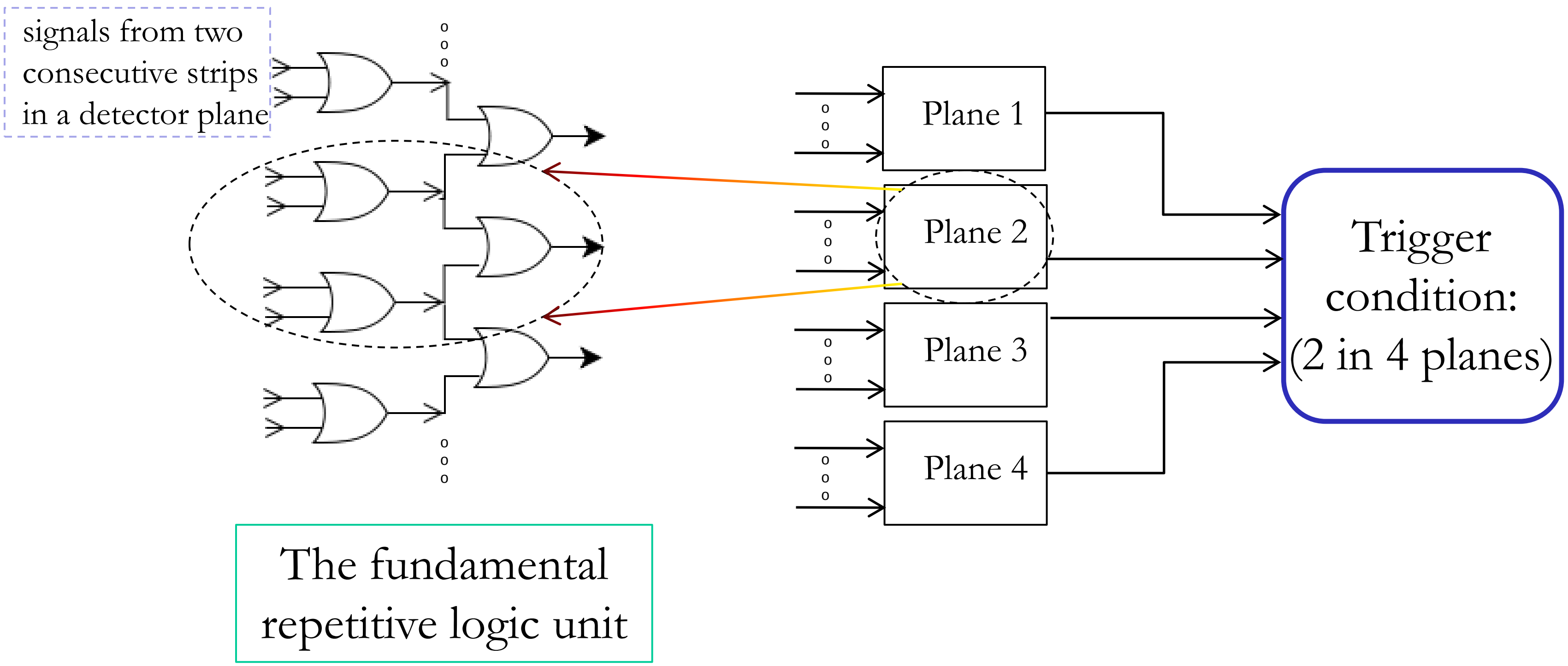
v1495 : CAEN general purpose logic modules. The module was programmed for trigger generation and data readout using VHDL

* Field Programmable Gate Array

e-detector DAQ : schematic

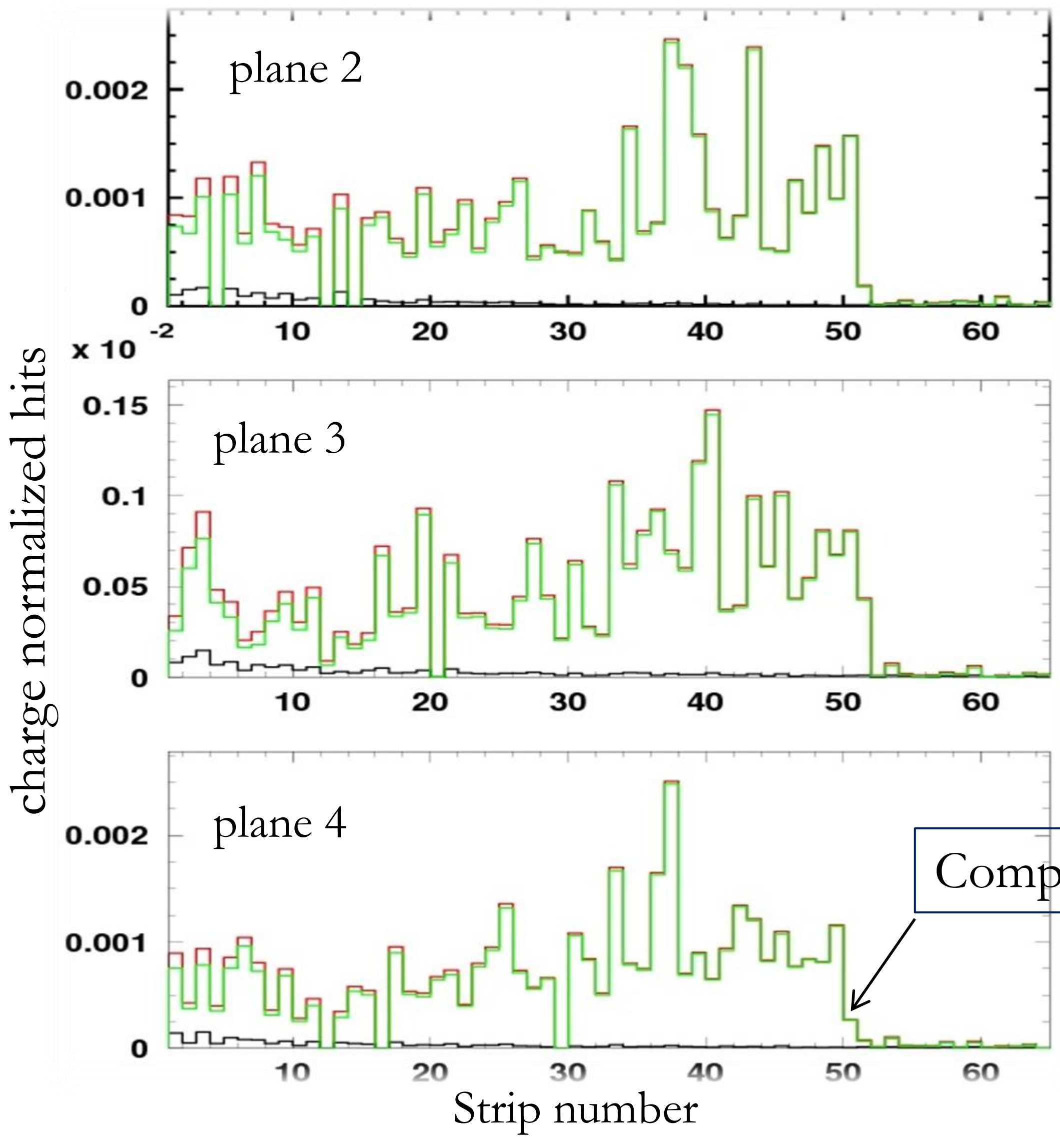


e-detector DAQ: Trigger



- to suppress background, we require a coincidence between multiple planes
- default trigger is hits on 2 out of 4 planes
- we localize the trigger in a single detector plane to 4 consecutive strips

Charge normalized strip hit



Beam Current: 150 μA

Red: Laser On

Black: Laser Off

Green: Background subtracted

we had 3 active planes during Qweak Run 1

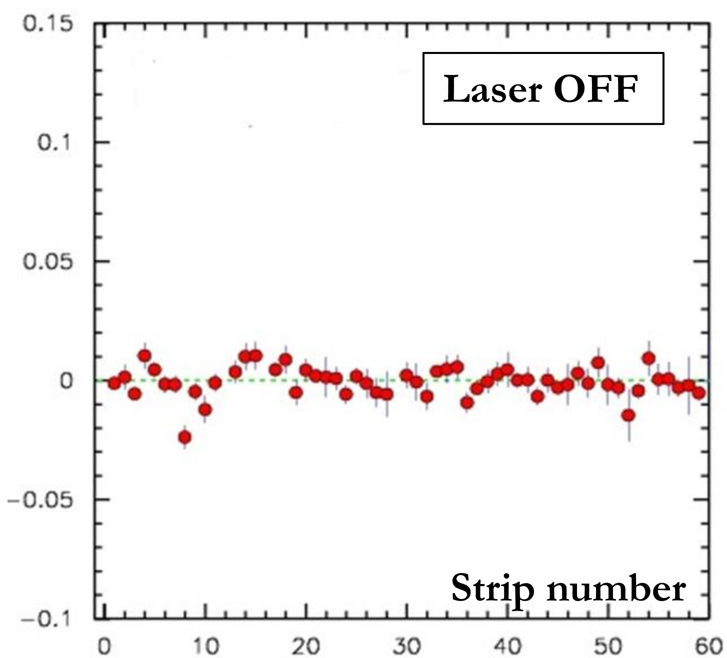
Compton edge at Strip 50

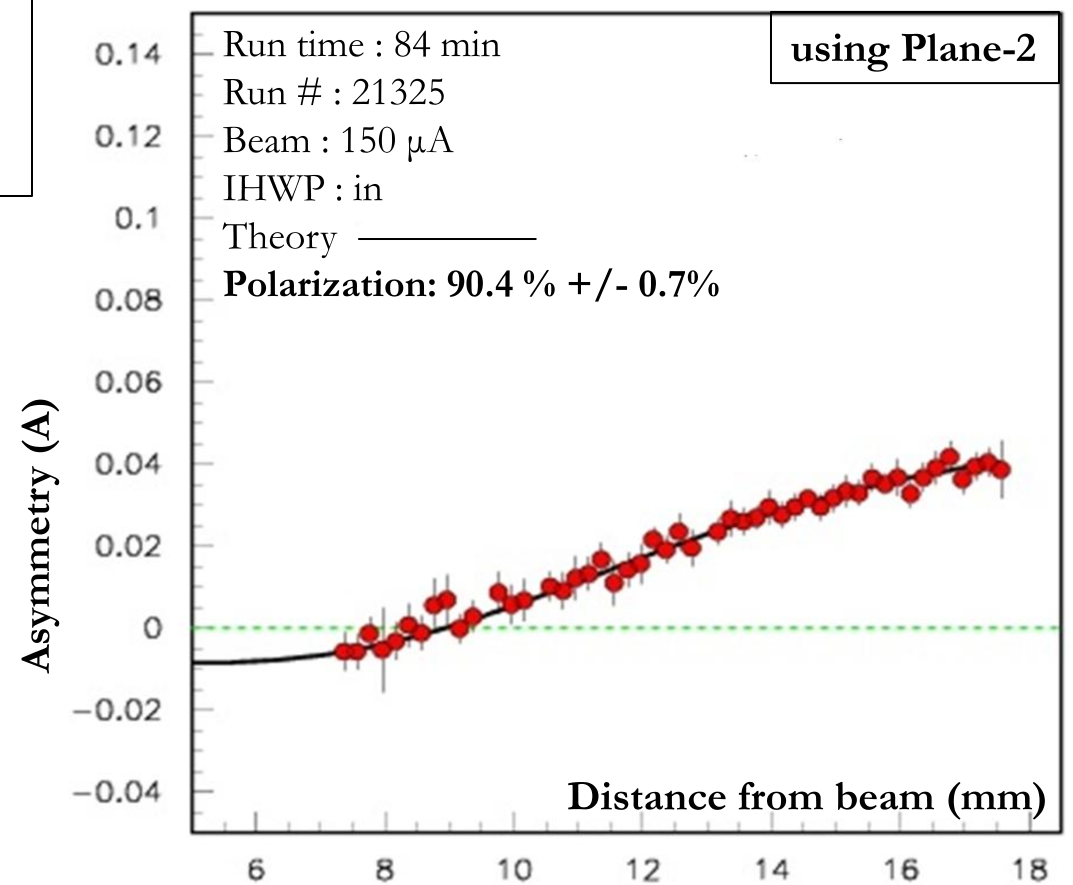
Asymmetry

$$A = \frac{(N^{+}_{on} - r^{+}N^{+}_{off}) - (N^{-}_{on} - r^{-}N^{-}_{off})}{(N^{+}_{on} - r^{+}N^{+}_{off}) + (N^{-}_{on} - r^{-}N^{-}_{off})}$$

where $r^{+} = \frac{Q^{+}_{on}}{Q^{+}_{off}}$ and $r^{-} = \frac{Q^{-}_{on}}{Q^{-}_{off}}$

Laser on : Laser off :: 2 : 1





Calculating Polarization

we know:

- ✓ e-beam energy,
- ✓ magnet field map,
- ✓ detector location & geometry

⇩

deviation from nominal e-beam

↓

momentum of Compton recoil e^-

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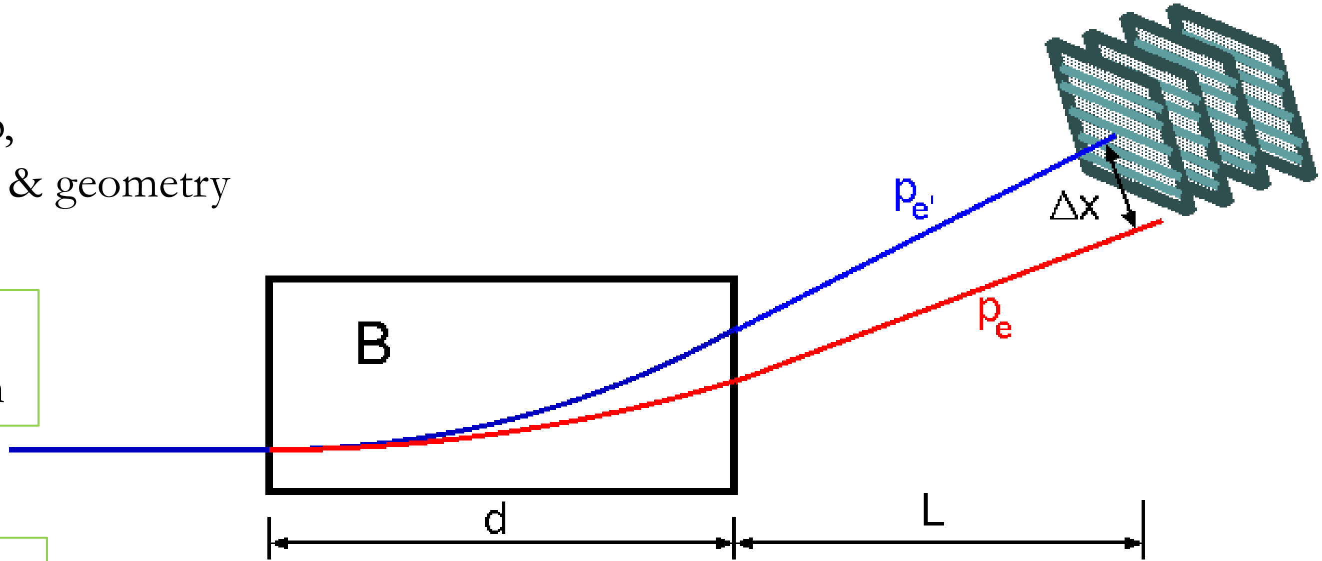
Compton asymmetry is precisely known from QED as a function of momentum



$$\Delta x_{measured} \xrightarrow{(p_e,\ B_{map},\ L)} p_{e'} \longrightarrow \rho = k'/k$$

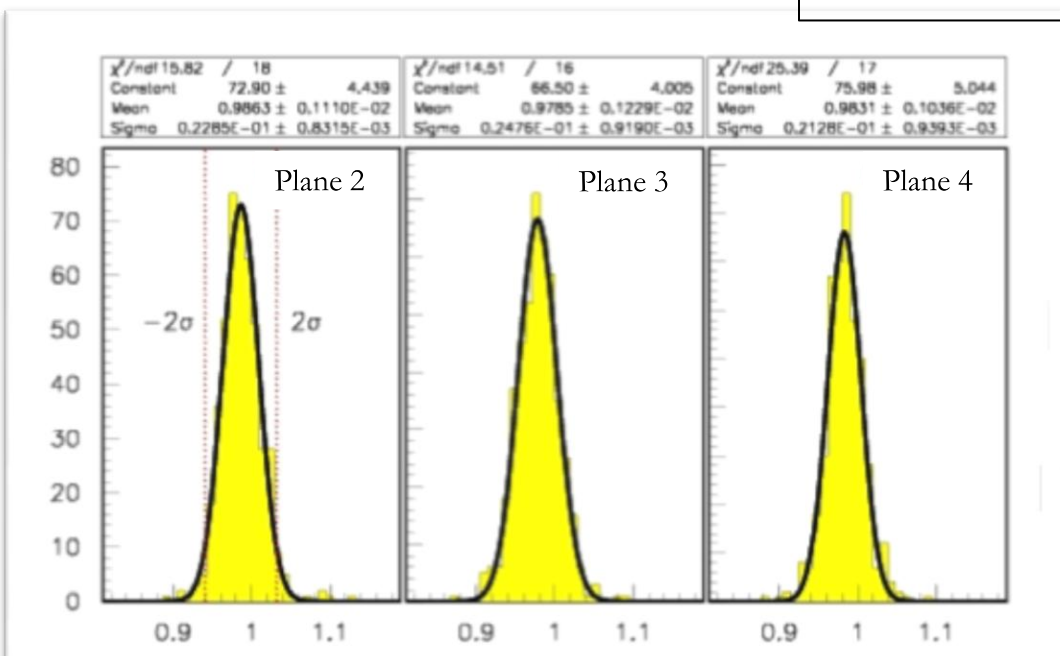
$$A(\rho)_{Theory} \longrightarrow A(\Delta x)_{Theory}$$

Fitting this theoretical asymmetry to the measured asymmetry gives us the beam polarization

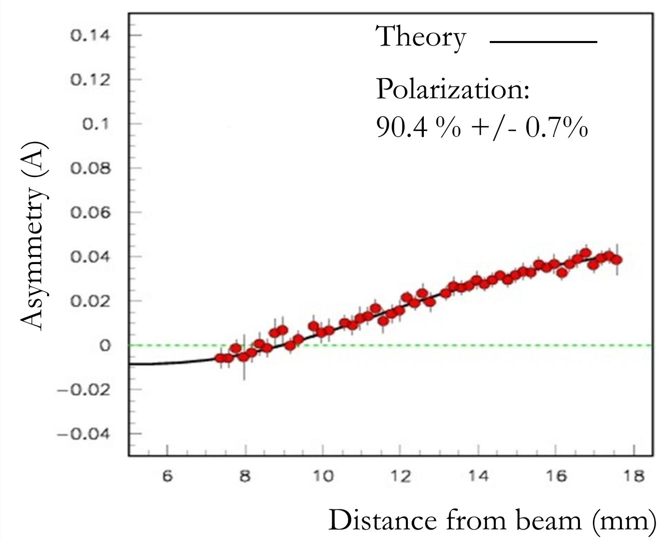
Calculating Polarization

- The Compton edge for the theoretical Compton asymmetry is fixed at 17.6 mm from the beam (based on known beam parameters and detector geometry)
- Polarization is obtained by performing a two parameter fit with **polarization** and **effective pitch**

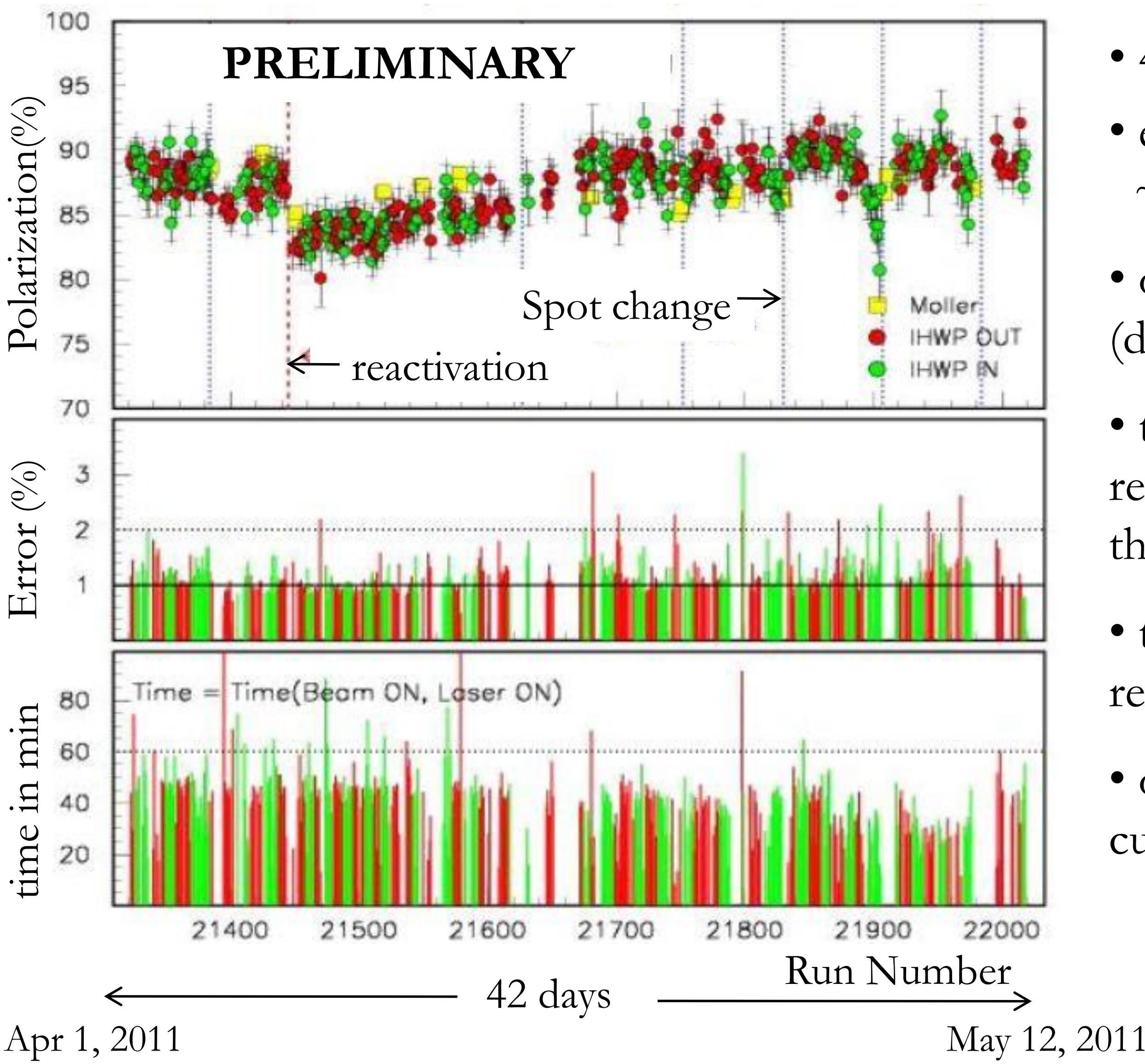
$$A_{exp} = \frac{N^+ - N^-}{N^+ + N^-} = P_e P_\gamma A_{th} \quad \text{where } P_e = \frac{A_{exp}}{P_\gamma A_{th}}$$



effective pitch parameter fit



Preliminary Polarization

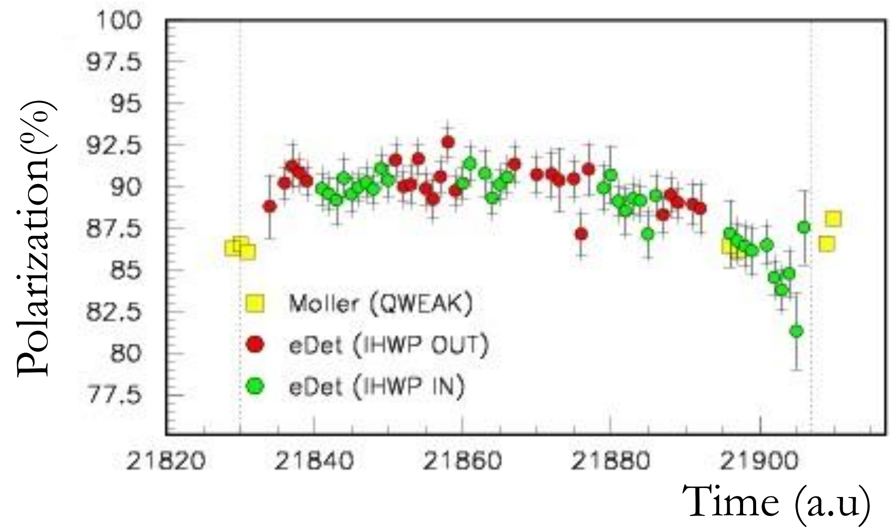


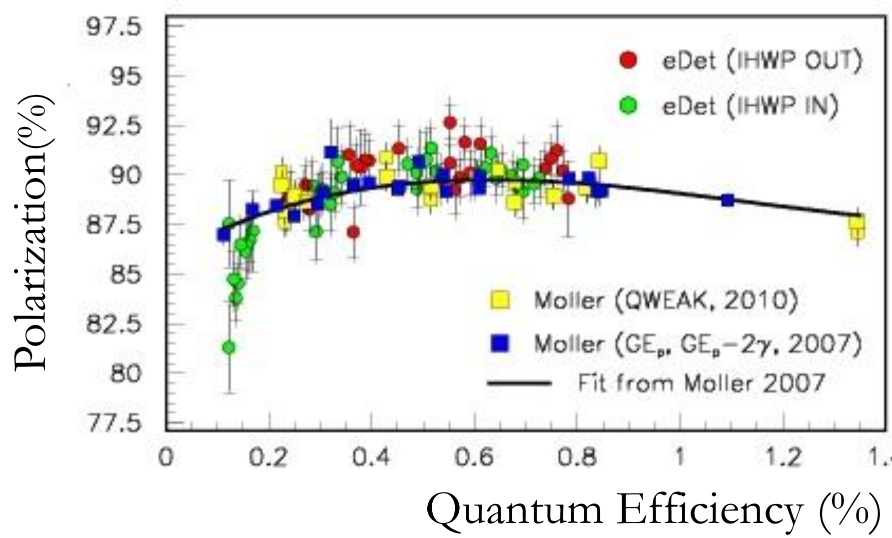
- 42 days of Compton data
- each point represents a ~ 1 hr run
- only Partial systematic error (due to strip – pitch) included
- the dotted vertical lines represent spot changes on the photocathode
- the dashed vertical line represents Re-activation
- on an average the beam current was ~ 160 μA

Quantum efficiency

Zooming into a region of consecutive spot changes:

Polarization was found to drop significantly before the spot move





Systematic errors

Error Contribution	(~)Value
Due to detector strip size	0.2 %
Detector geometry	0.15 %
Difference between planes	0.2 %
Magnetic field	?
Beam & Laser Position	?
Dead time	?
TBD	?
Laser Polarization	99.5 +/- 0.4% (overall)
Total	0.50 %

We don't expect the unknown in the above table to be very large

Summary

Accomplished:

- ✓ This is the first Diamond micro-strip detector to be used as a tracking device in an experiment
- ✓ Despite several challenges posed by the electronic noise environment, leading to strict trigger condition, we achieved the design goal of < 1% statistical uncertainty and projected low systematic

Next:

- ✓ In our preparation for Qweak run-2, We have 4 active planes (already installed)
- ✓ Adapting from experiences of run-1, we are using more noise-robust electronics, with a better control over signal correlations in adjacent channels.
- ✓ All set to provide an independent absolute polarization measurement for Hall-C beam

Compton Team

<u>Institutions involved:</u>

1. College of William and Mary (γ - detector)
2. Jefferson Lab (all subsystems)
3. Mississippi State University (e - detector)
4. MIT Bates (magnets, vacuum – can, detector holder, previous CsI crystal for γ - detector)
5. TRIUMF (Qweak Amplifier Discriminator boards)
6. University of Manitoba (e - detector)
7. University of Virginia (laser and γ - detector)
8. University of Winnipeg (e - detector)
9. Yerevan Physics Institute (γ - detector and help with e - detector)

Alphabetical order

This work was supported by U.S. DoE, Grant Number: DE-FG02-07ER41528

Thanks

This presentation was made possible due to significant contribution from Dipangkar Dutta, Vladas Tvaskis and Donald Jones

The author can be contacted at narayan@jlab.org

Extras

Background subtraction

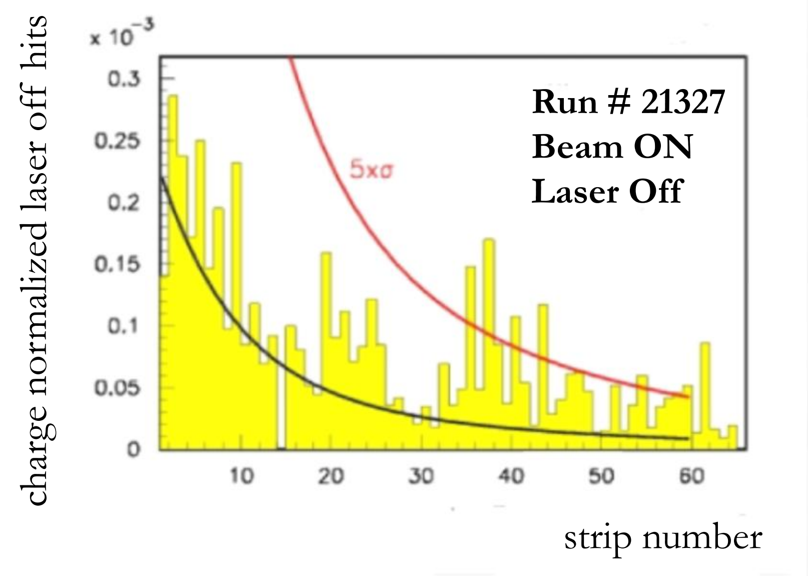
$$N^{+}_{Laser\ On} = N^{+}_{Laser\ On} - Time^{+}_{Laser\ On} / Time_{Beam\ Off} \times N_{Beam\ Off}$$

$$N^{+}_{Laser\ Off} = N^{+}_{Laser\ Off} - Time^{+}_{Laser\ Off} / Time_{Beam\ Off} \times N_{Beam\ Off}$$

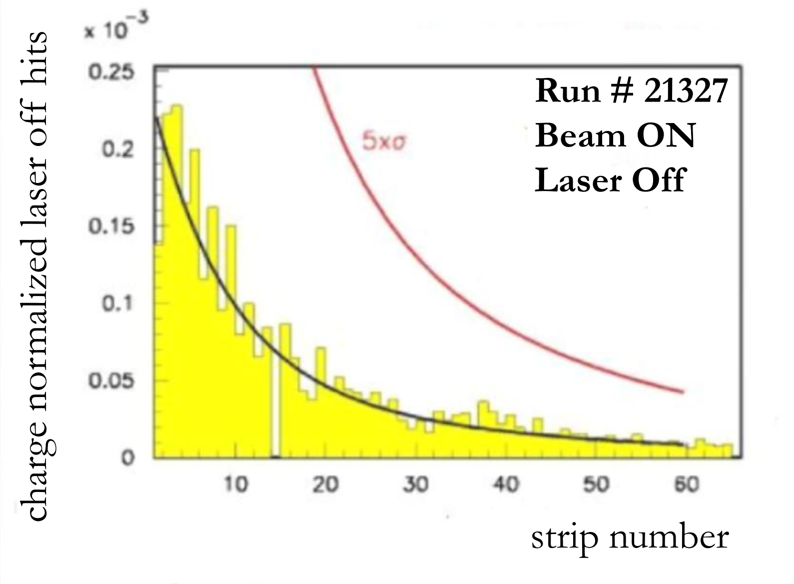
$$N^{-}_{Laser\ On} = N^{-}_{Laser\ On} - Time^{-}_{Laser\ On} / Time_{Beam\ Off} \times N_{Beam\ Off}$$

$$N^{-}_{Laser\ Off} = N^{-}_{Laser\ Off} - Time^{-}_{Laser\ Off} / Time_{Beam\ Off} \times N_{Beam\ Off}$$

before electronic noise subtraction



After electronic noise subtraction



why diamond ?

Property	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, short noise

Fast signal collection

Low capacitance, noise

Radiation hardness

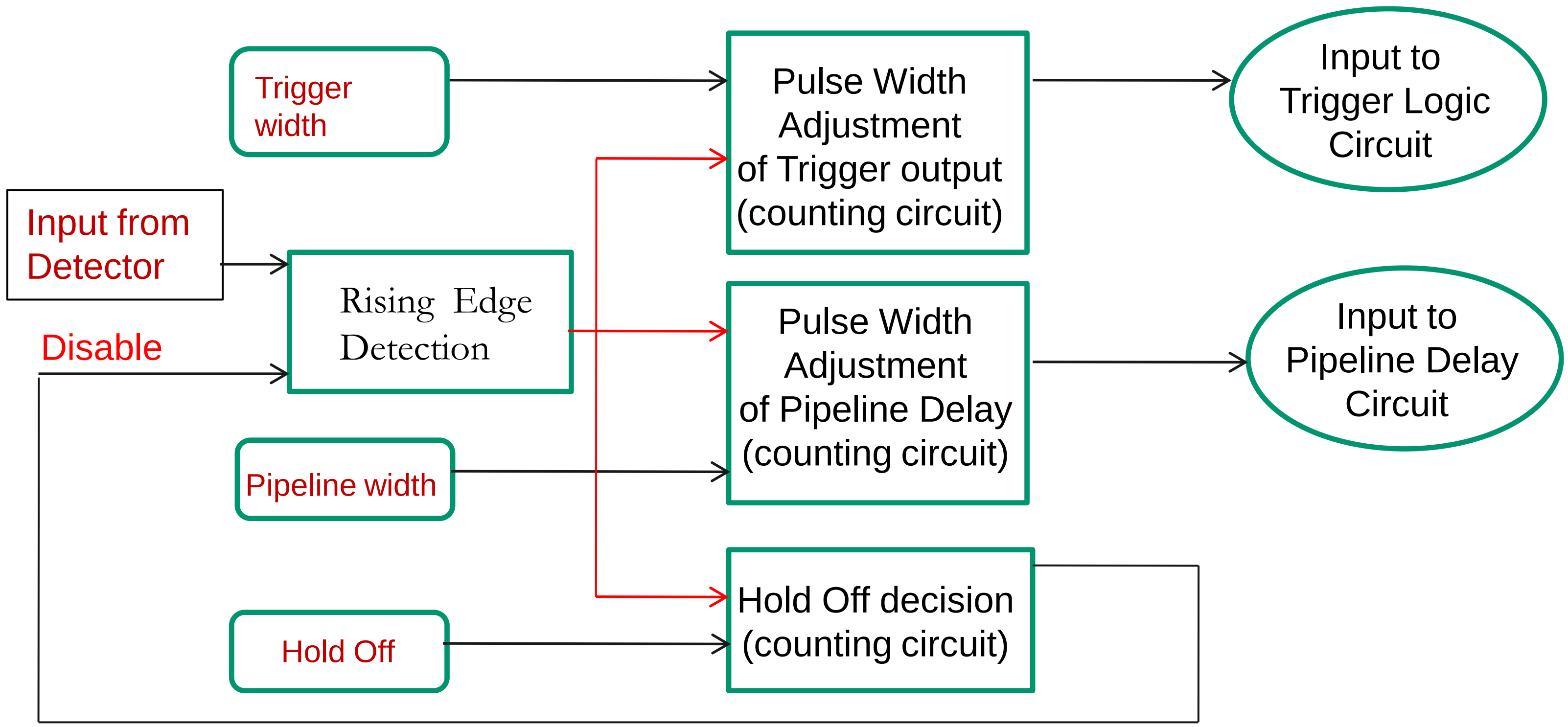
Smaller signal

2 parameter fit

x = 17.6 - (strip # of edge - strip # of histogrammed bin)*strip_pitch

x = 17.6 - (strip # of edge - strip # of histogrammed bin)*strip_pitch * P2

Input Reconditioning Stage



DAQ

- We accumulate the counts in the detector over a given Helicity window and read it out at the end of the Helicity window
- Our Helicity reversal rate is ~ 960 Hz
- wait time for Helicity stabilization ~ 76 μs