Hall C Compton Polarimeter: A new Compton for JLab

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EIC Electron Polarimetry Workshop
University of Michigan, August 23-24, 2007

Outline

- Project Overview
- Progress in Design and Prototyping
  - focusing on laser, and on electron detector
- Monte Carlo
- Some comments for EIC

Motivation for Compton Polarimetry for Hall C

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

Design Goals

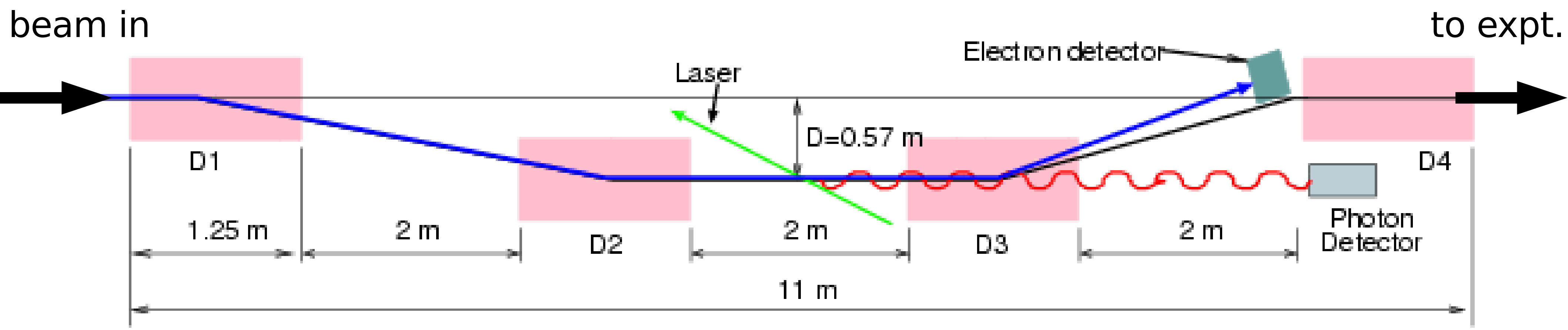
- $\left(\Delta P/P\right)_{\text{statistical}}$ < 1% per hour
  - high laser power
  - high laser energy (green) increases Compton asym.
  - large acceptance for detectors (in energy)
- $\left(\Delta P/P\right)_{\text{systematic}}$ < 1%
  - stable beam, small spot in interaction region
  - low backgrounds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

Hall C Compton Overview



- Laser
- Chicane
- Detectors

Some Design Parameters at 1.165 GeV

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

major design goal at low beam energy is to maximize Compton edge

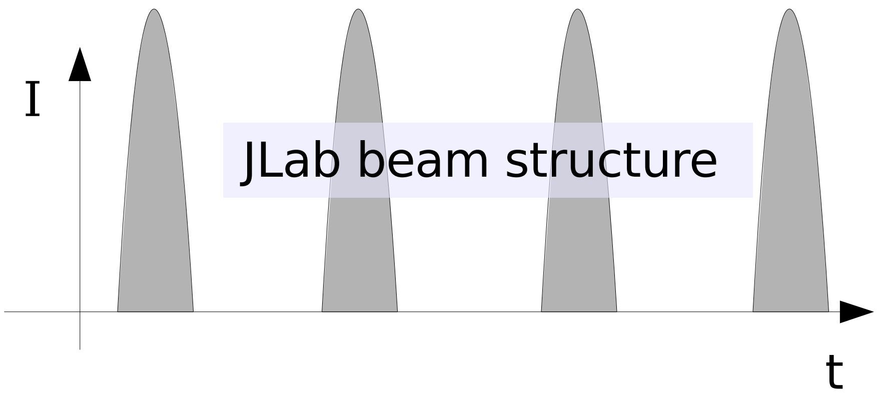
Laser Options Considered for Hall C

Energy-weighted asymmetry

laser option	λ (nm)	P (W)	E_{max} (MeV)	rate (KHz)	<A> (%)	t (1%) (min)
Hall A	1064	1500	23.7	480	1.03	5
UV ArF	193	32	119.8	0.8	5.42	100
UV KrF	**248**	**65**	**95.4**	**2.2**	**4.27**	**58**
Ar-Ion (IC)	514	100	48.1	10.4	2.10	51
DPSS	**532**	**100**	**46.5**	**10.8**	**2.03**	**54**
Fiber laser	**532**	**20**	**46.5**	**20.1**	**2.03**	**30**
Fiber laser (counting mode)	**532**	**20**	**46.5**	**20.1**	**1.33**	**74**

based on this, and on other factors, we have selected the “Fiber laser” solution

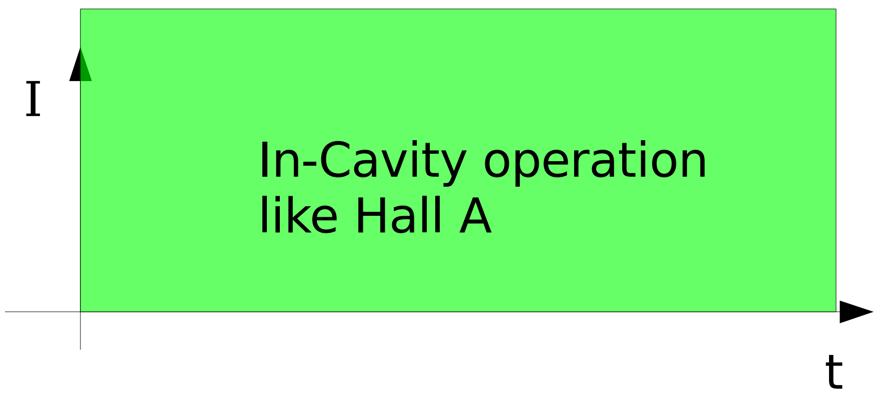
Electron Beam

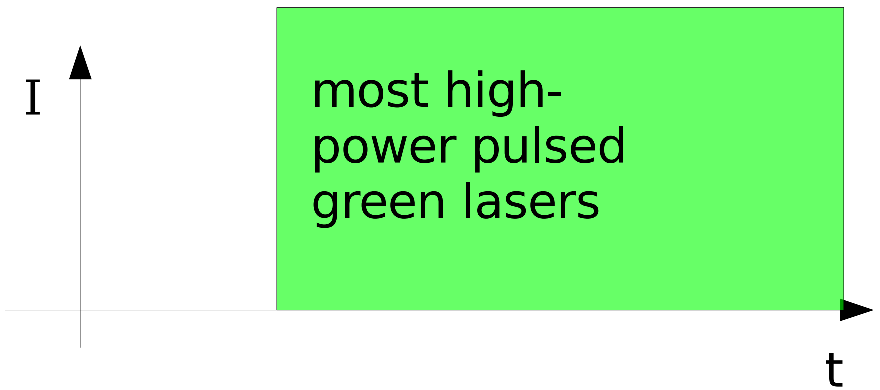


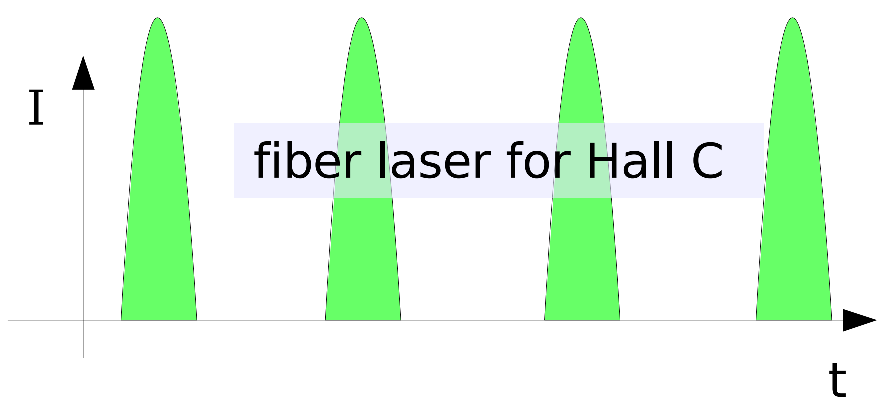
Despite lower average power, fiber laser would achieve higher luminosity than higher power pulsed green lasers on the market.

Other advantages:
- lower instantaneous rates for counting

Laser Beam





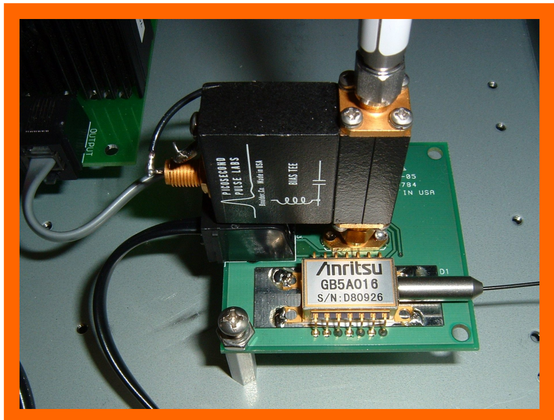


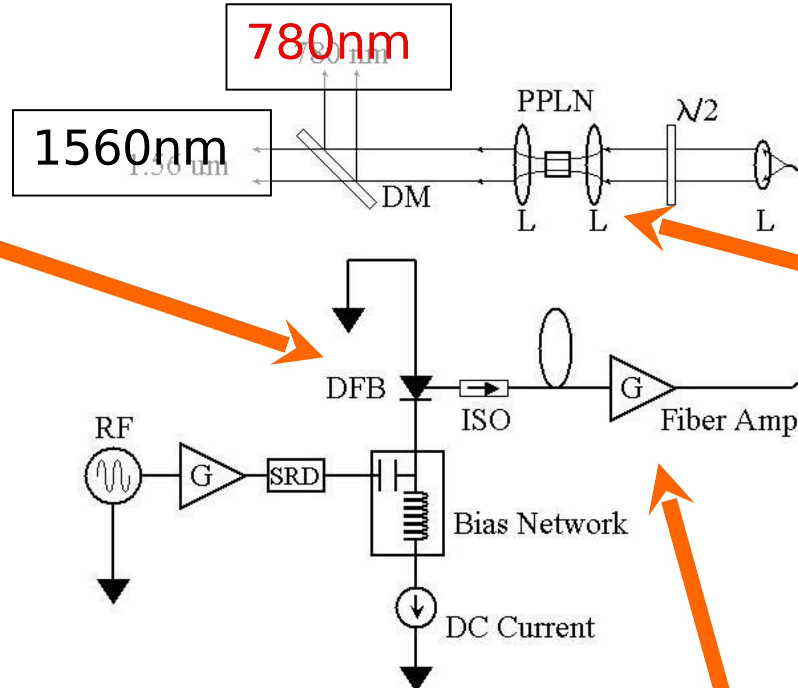
Fiber Laser Advantages

- External to beamline vacuum (unlike Hall A cavity)
  - easy access
- Pulse at JLab microstructure rate (499 MHz)
  - huge luminosity boost when phase locked!
- In-house expertise
  - M. Poelker and JLab source group demonstrated few Watts operation at 780 nm for CEBAF source.
  - excellent stability, low maintenance, straightforward implementation
  - almost ideal optical properties $M^2 = 1.33$

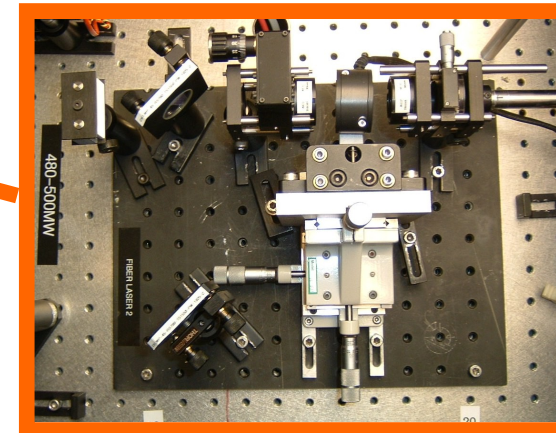
“CEBAF's Last Laser” - demonstrated at polarized source

Gain-switched seed





Frequency-doubler



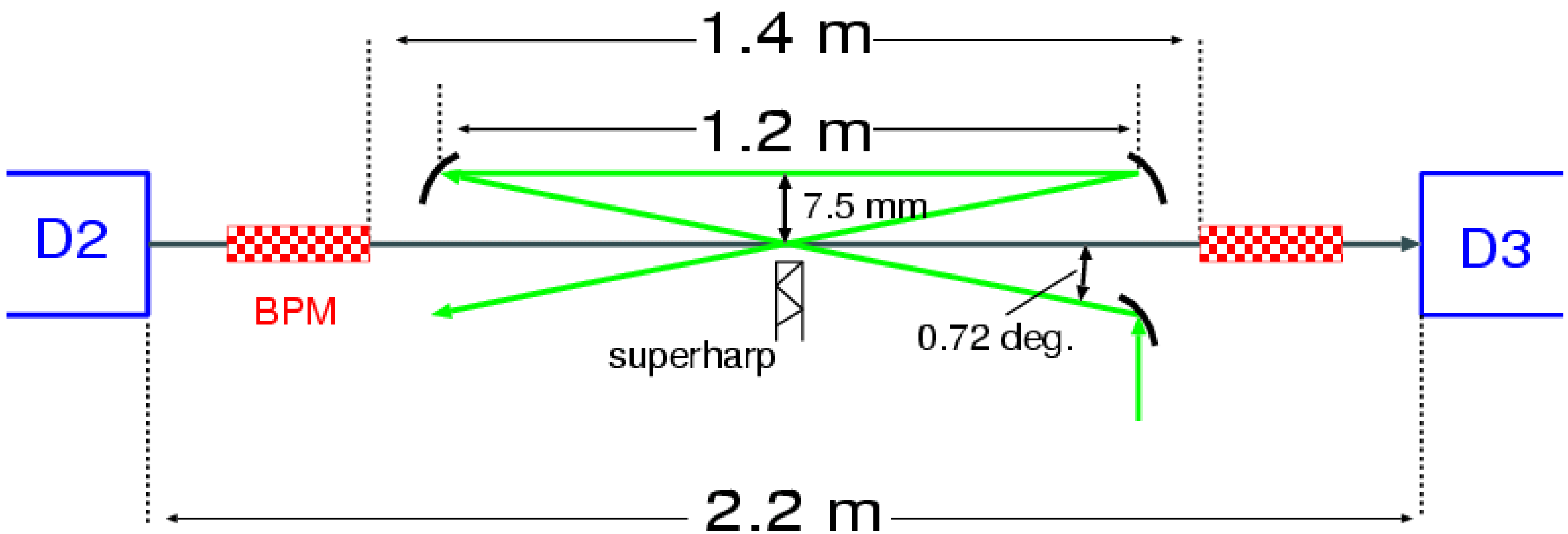
ErYb-doped fiber amplifier

Fiber Laser for Hall C Compton

- Seed laser @ 1064 nm
- Fiber amplifier (50 W output at 1064 nm)
- Frequency doubling cavity
- Result: 25 W, 532 nm, 30 ps pulses at 499 MHz
- In-house expertise helps us even more
  - Polarized source group is willing to build our laser (with help from Shukui Zhang from FEL for the frequency doubling)
  - New ideas: low gain cavity x10-100.

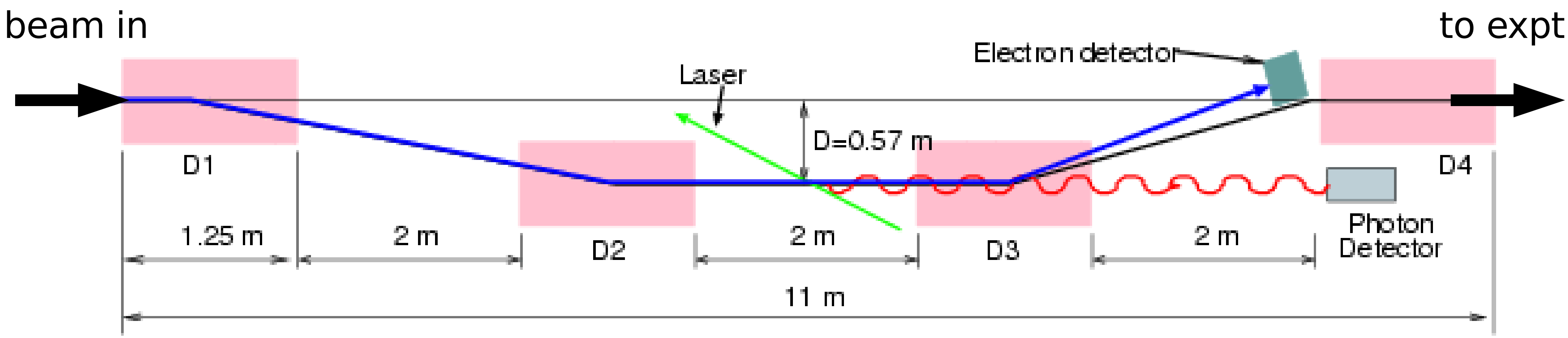
We need more than a laser

- Optics table design
  - e.g. Need to know P_{circ} = 100%
- Potential x2 gain in power if mirrors internal to beamline can be implemented.



a possible interaction region layout

Chicane



- Optics design exists
- Physical layout underway (fit in Hall C)
- Dipole design underway

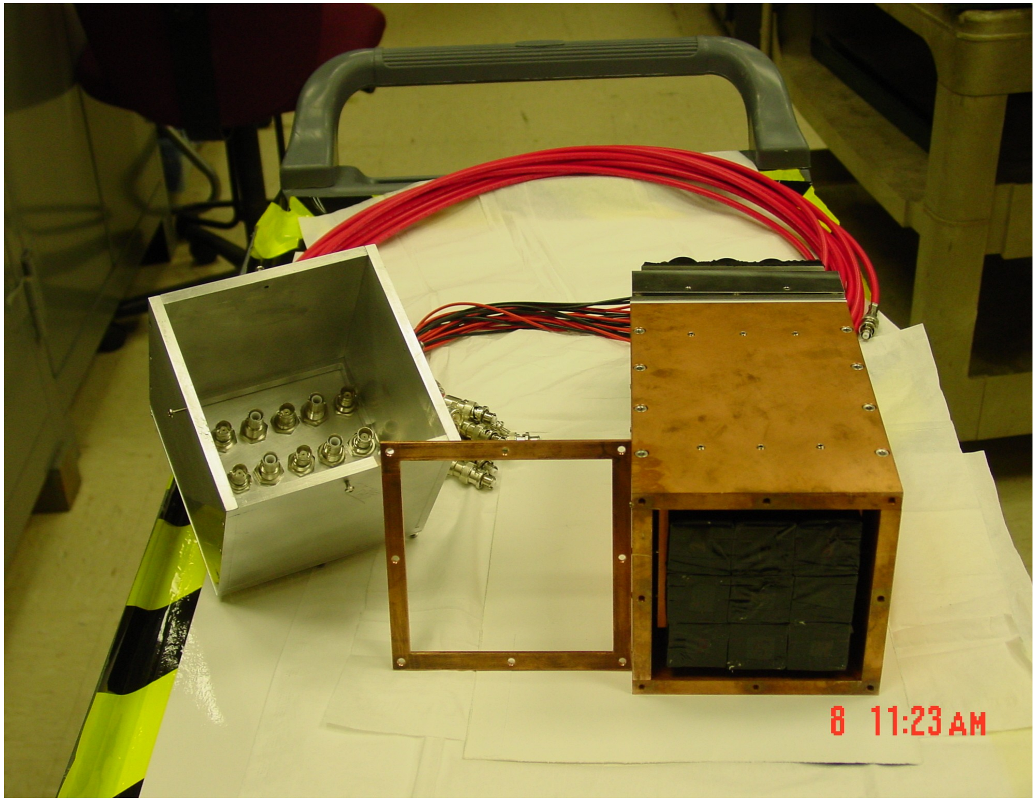
Chicane will be reconfigured for 12 GeV upgrade

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

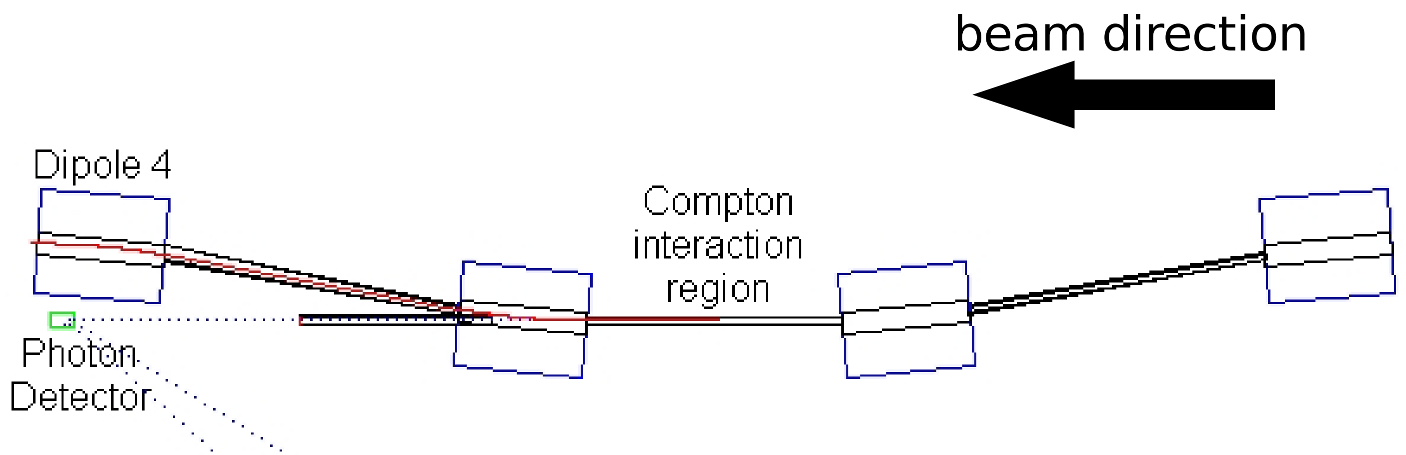
Detectors

- Photon Detector
  - 3x3 array of $PbWO_4$
  - working prototype
  - calibration and testing underway
  - different from Hall A plan for low beam energy

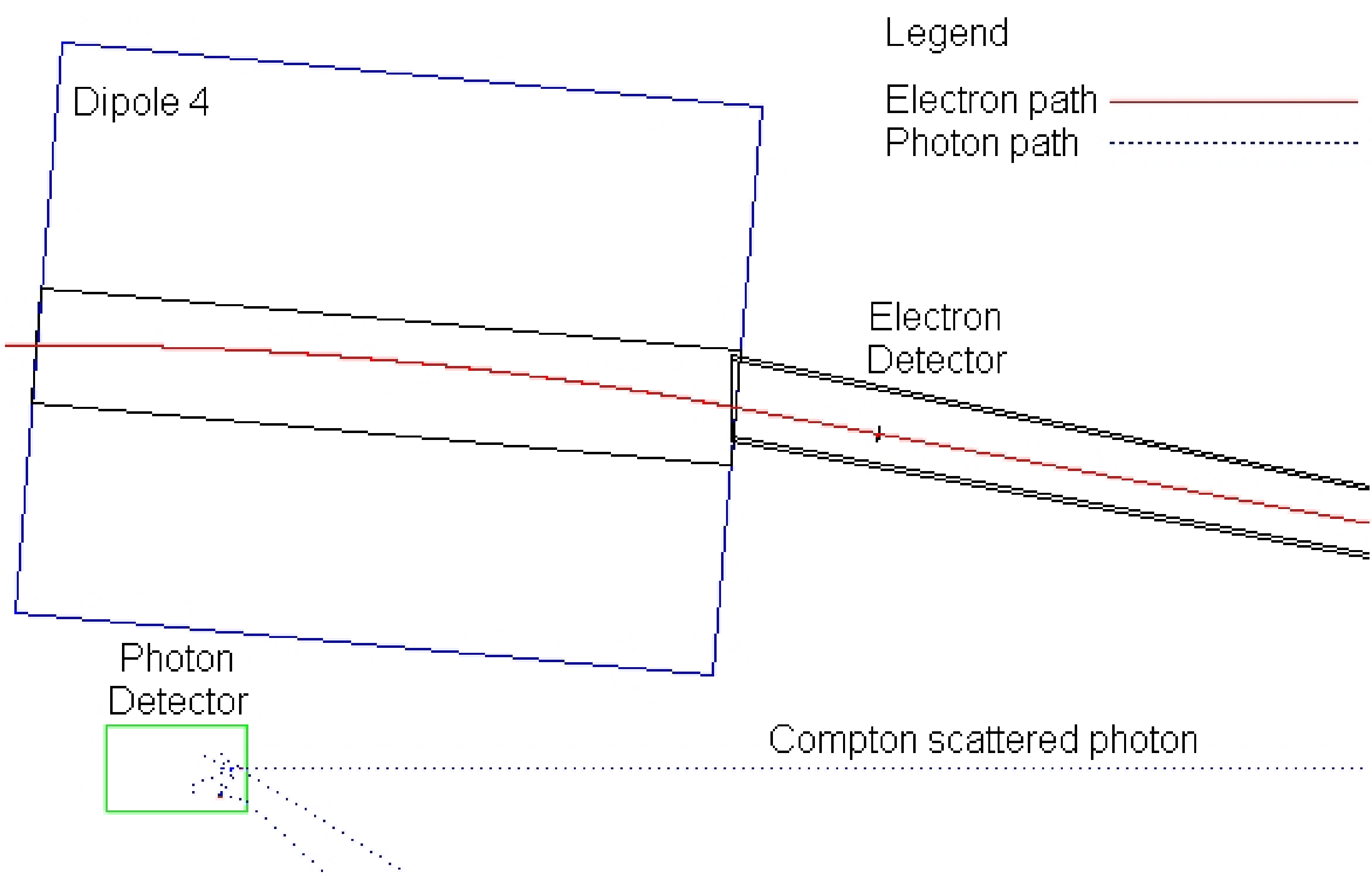


- Electron Detector (what I'll mainly focus on)
  - diamond strip tracker
  - monolithic diamond prototyping nearly complete
  - prototyping of strips on diamond underway

Motivation for Electron Detector

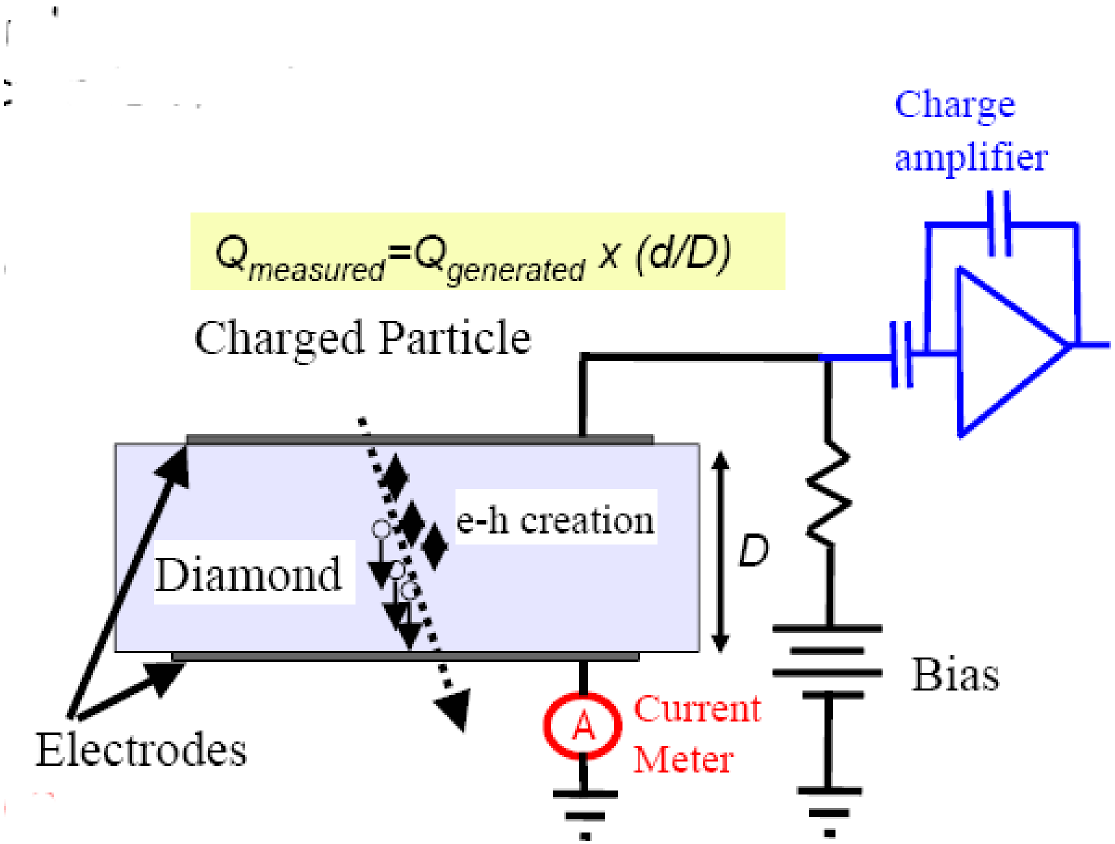


- Position resolution gives momentum of scattered electron.
  - Independent single-arm measurement of polarization
  - Calibration of photon detector (coincidence mode)
- Designing for 1% Polarization Determination for BOTH



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/μm
- CCD ("charge collection distance") ~ 250 μm

Why pc-CVD diamond?

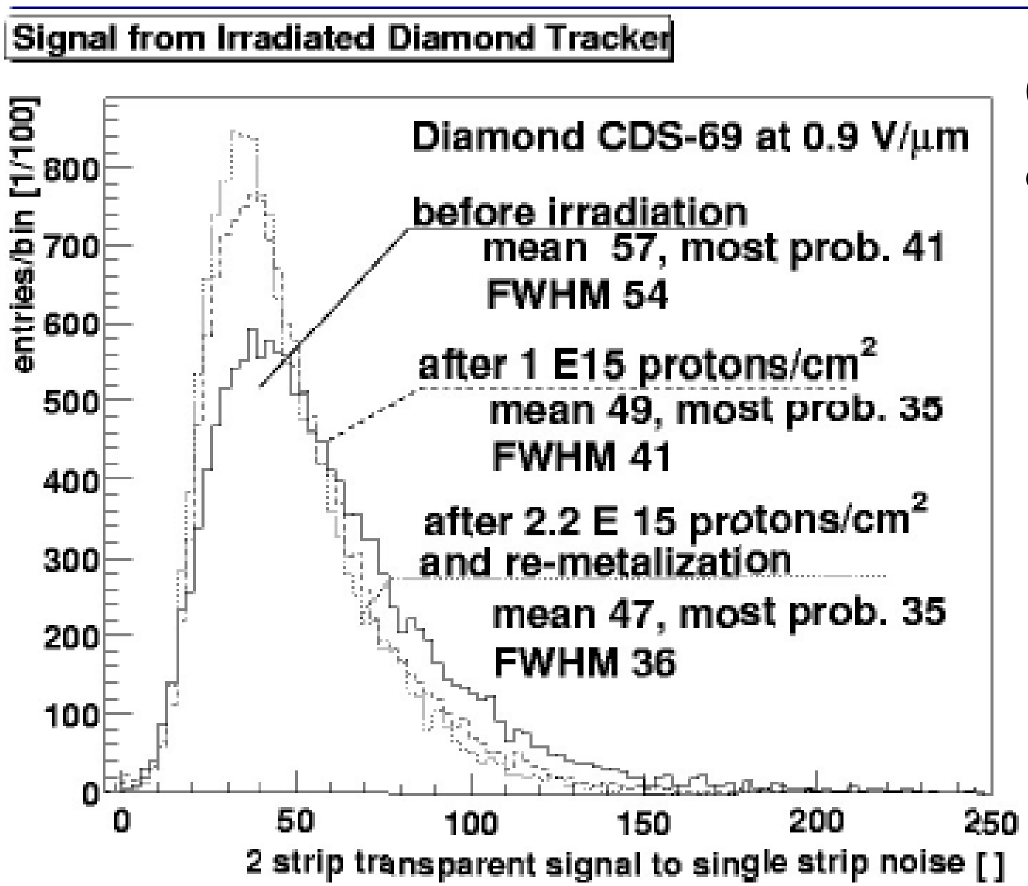
	Silicon	Diamond	
Band Gap (eV)	1.12	5.45	Low leakage current, shot noise
Electron/Hole mobility (cm^2/Vs)	1450/500	2200/1600	Fast signal collection
Saturation velocity (cm/s)	0.8×10^7	2×10^7	
Breakdown field (V/m)	3×10^5	2.2×10^7	
Dielectric Constant	11.9	5.7	Low capacitance, noise
Displacement energy (eV)	13-20	43	Rad hardness
e-h creation energy (eV)	3.6	13	Smaller signal
Av. e-h pairs per MIP per micron	89	36	
Charge collection distance (micron)	full	~250	

from Wallny, UCLA

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

At the expense of: smaller signal

Radiation Hardness of Diamond Detectors



CERN R&D: Performance after irradiation with protons

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

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

Thanks R. Wallny (UCLA)

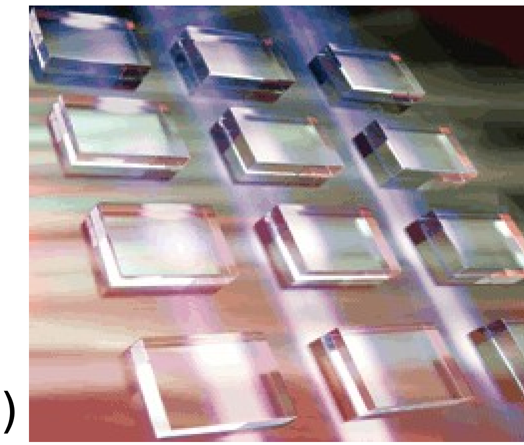
Estimate for Qweak alone: 3 Mrad

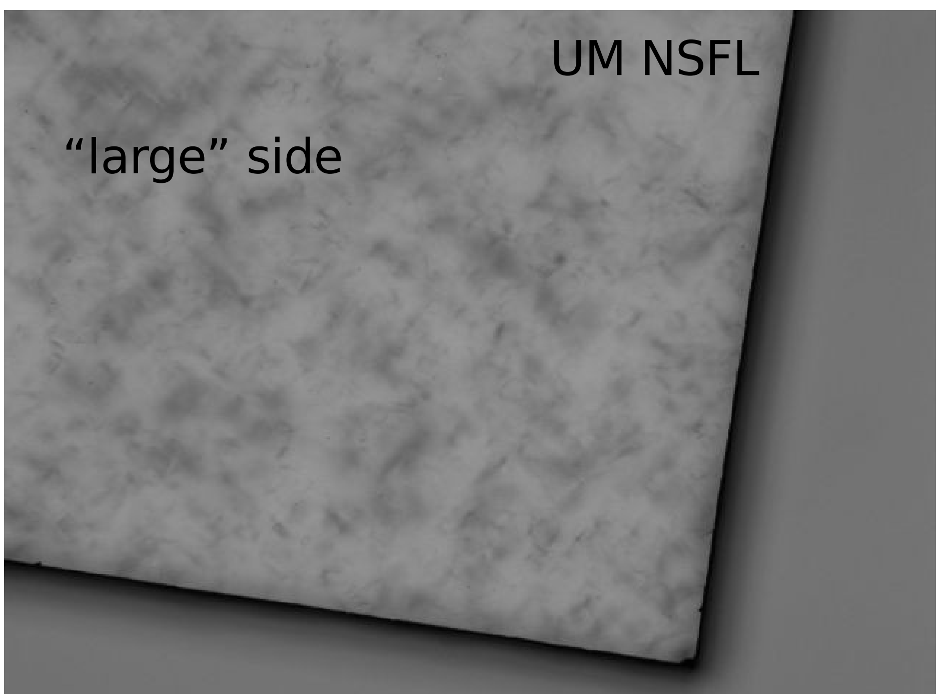
Interlude
How we make diamond detectors

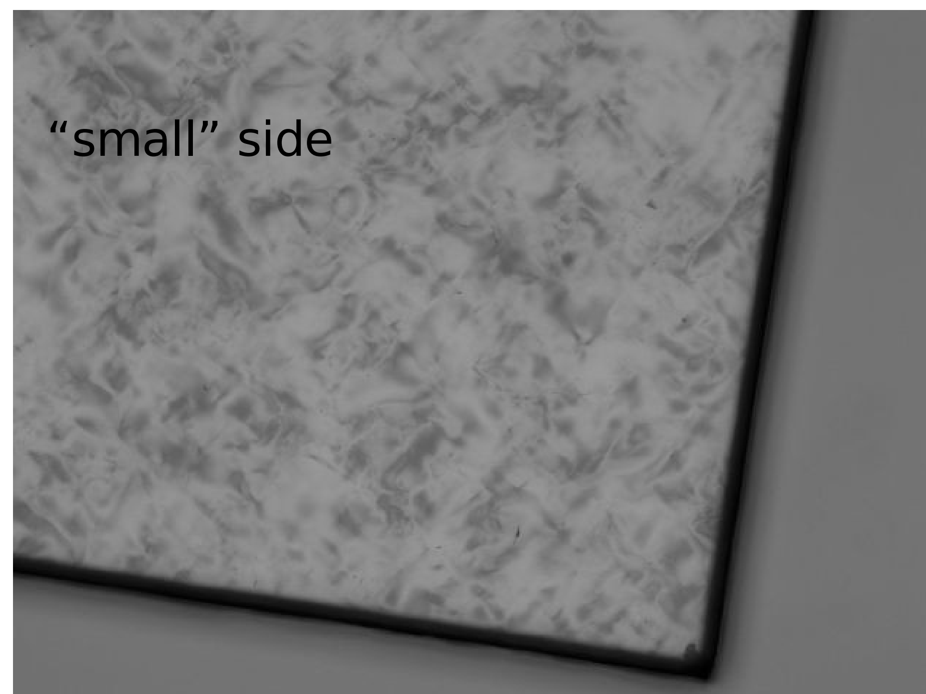
1. Get a “CERN grade” diamond from elementsix

ADVANCING DIAMOND

- Pictures below of Hall C prototypes (two exist):
  - 1 cm x 1 cm x 500 um
  - pc-CVD (polycrystalline-chemical vapor deposition)





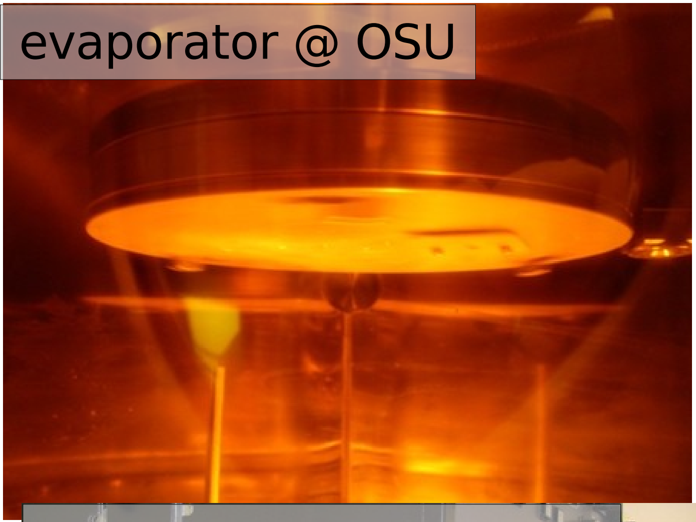


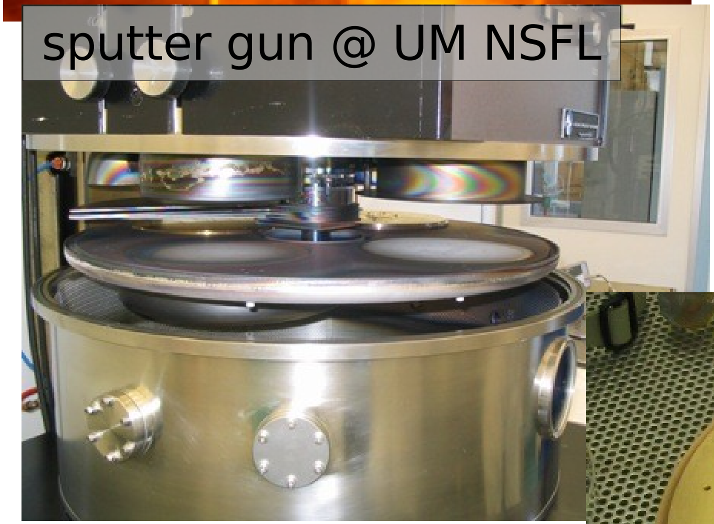
2. Boil in various acids/bases.

- cleans off the surface
- attempt to replace H-terminated surface with O-terminated (oxidizing agents like H_2O_2)
- follow with low-power plasma etch in O_2 environment

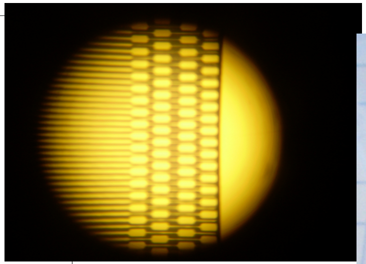
3. Lay down some metal

- sputter or evaporate
- test detectors usually done with Cr (50 nm) / Au (200 nm)
- shadow mask used for “dots”
- photolithography (“lift-off”) used for strips.
- OSU procedure: dots, then strips, for <u>every</u> diamond.

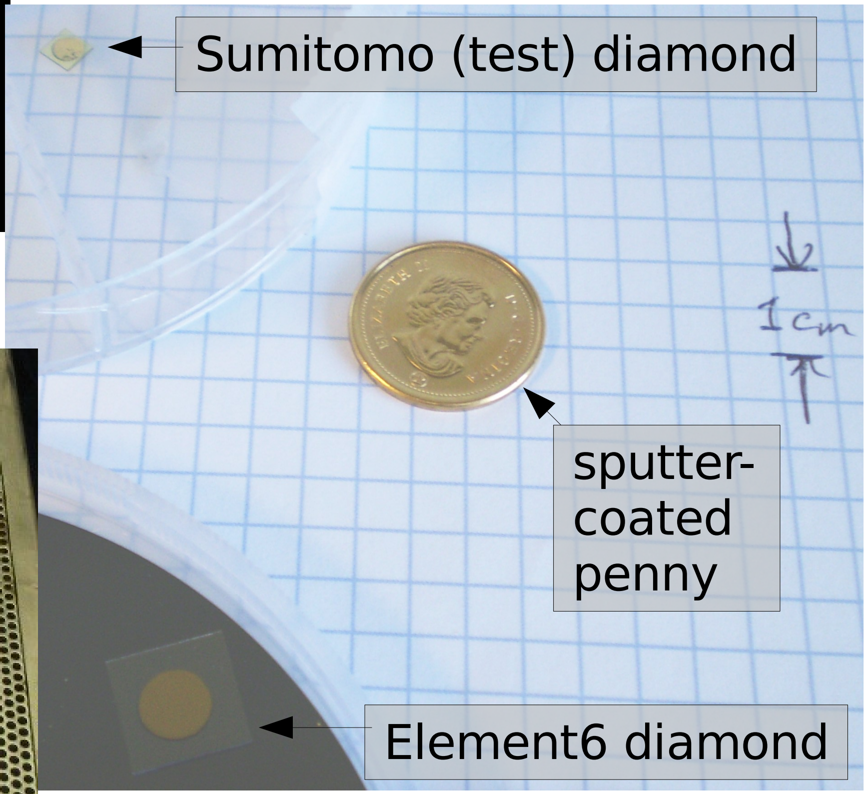

evaporator @ OSU


sputter gun @ UM NSFL

strips on glass @ OSU 50 um pitch




gold coated diamond @ UM

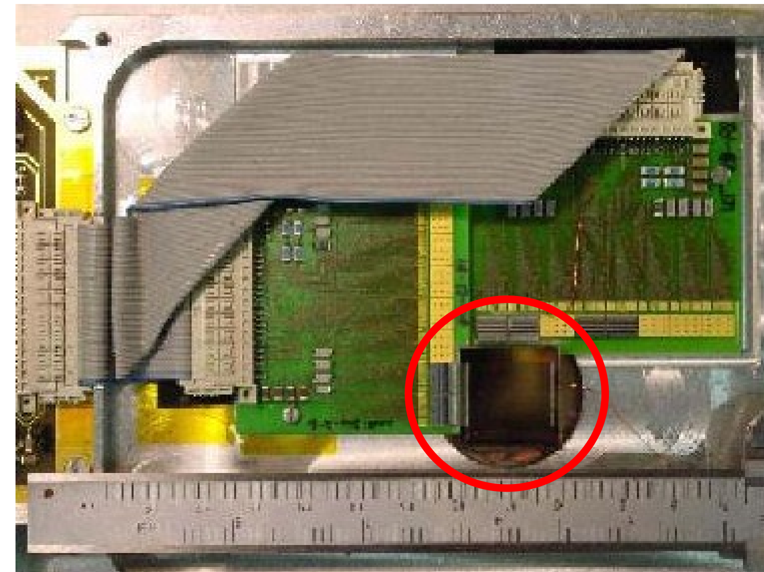


Sumitomo (test) diamond

sputter-coated penny

Element6 diamond

4. Test / mount in package

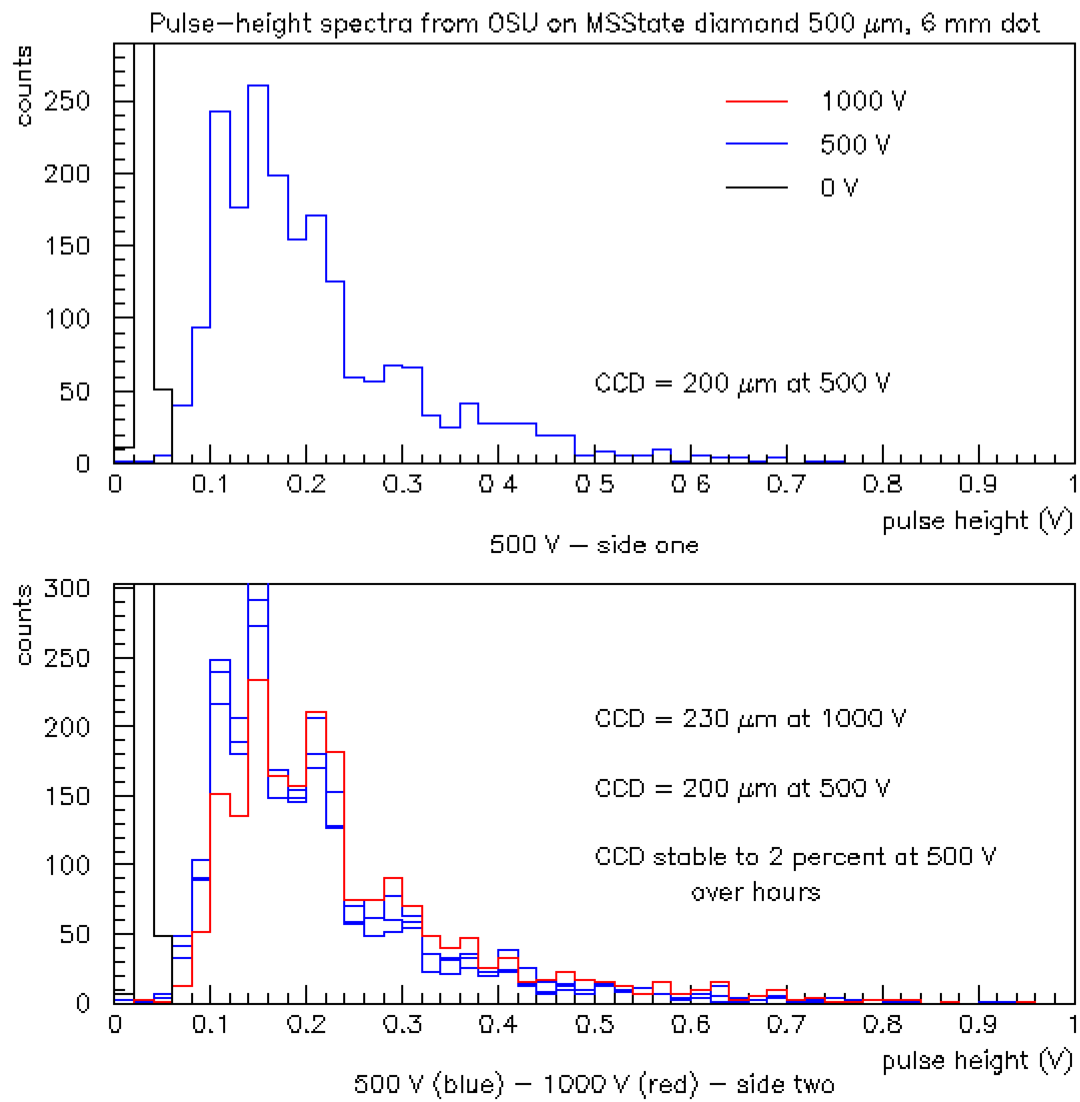


RD42-owned diamond strip tracker with seven planes, 50 um strip pitch.

- Hall C will use four planes of 2 cm x 2 cm x 0.5 mm square pc-CVD diamond
- 100 strips per plane => 200 um strip pitch
- stagger the planes to achieve 100 um position resolution in bend plane of chicane

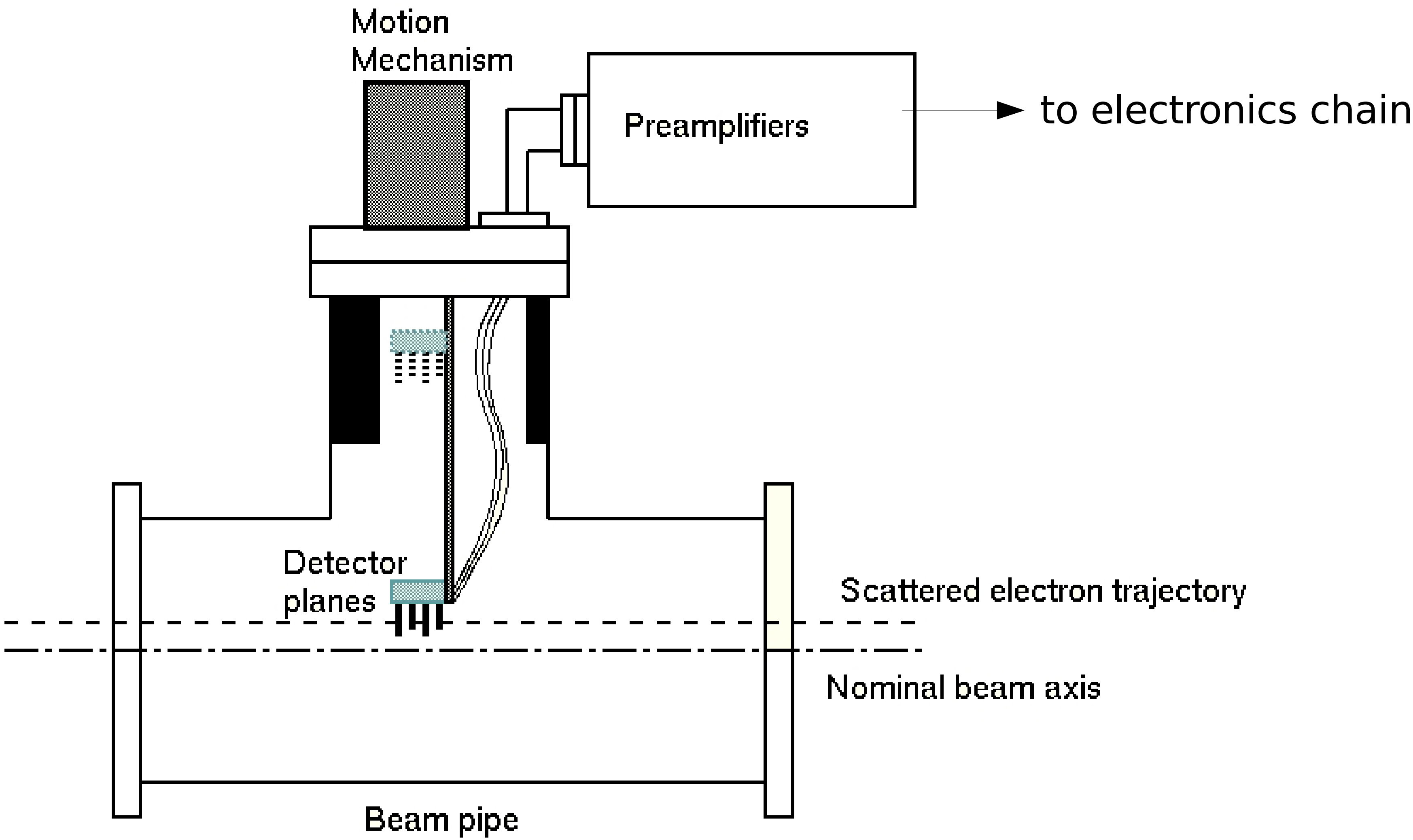
CCD Results for our prototype diamond @ OSU

- Good results for our first dot!
- CCD "typical"
- Next steps:
  - replicate OSU dot process at UWpg, UManitoba (done)
  - design multistrip prototype (in progress)



Eventual Apparatus for Hall C

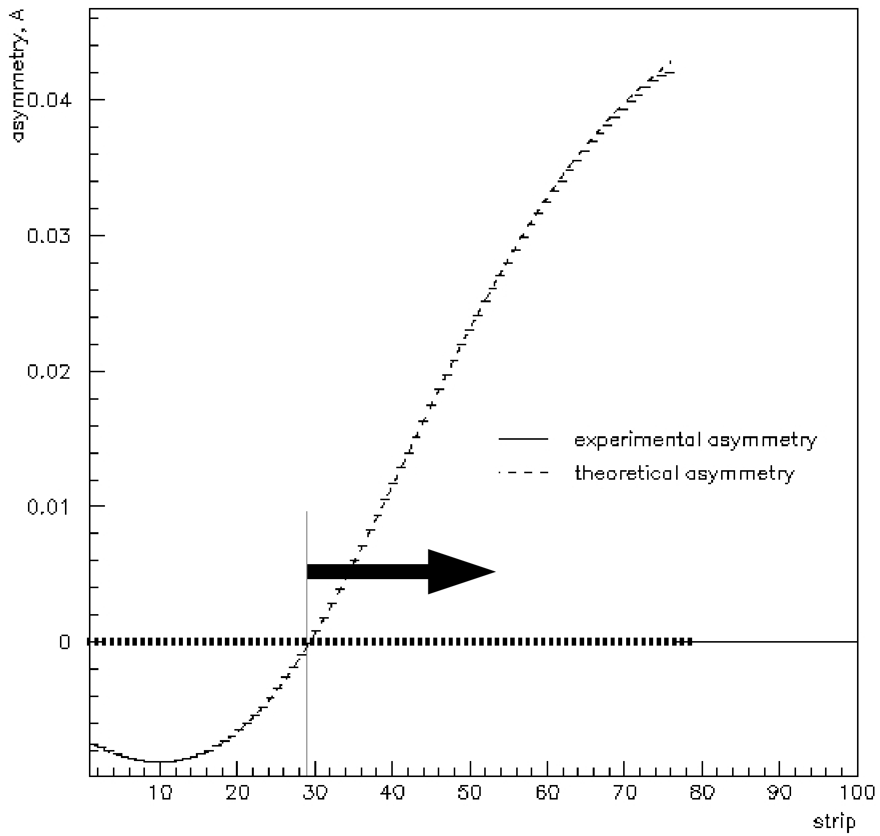
- Diamond Detector (4 planes, with 100 strips each)
- Electronics (preamp, discriminator, input module chain)



Monte Carlo Electron Detector Simulation

- D. Storey, U.Wpg honours thesis

Asymmetry vs strip number



Polarization extracted by two methods:
· fit method
· integration above asymmetry zero

Fit method susceptible to imperfect beam optics, nonlinearities in strip vs momentum.

Integration method robust against such problems.

For current Hall C design, complementary approaches give similar ultimate systematic uncertainty < 1%.

Summary/Timescale for Hall C Compton

- New Compton Polarimeter is under development for Hall C (EIC collaborators always welcome!!!)
- unique features compared to Hall A:
  - laser, chicane, electron detector
- Installation in Hall C for Qweak mid-2009.
- Commissioning early 2010.
- Reconfigure for 12 GeV, and pursue any upgrades, during long shutdown.

My own random thoughts and comments on EIC Compton Project (geared towards electron det.)

- Dual photon/electron detection critical for < 1%
- Current belief at JLab seems to be electron detector is more critical to achieve systematic uncertainty (consistent with SLAC?)
- basic kinematics consistent with Hall C at 11 GeV.
  - see next couple of slides
- You are welcome to a copy of our Geant3 Compton MC for more detailed questions.

Hall C Parameters at 11 GeV

Parameter	Symbol	Value
Beam Energy	E_{beam}	11 GeV
Laser wavelength	λ	532 nm
Photon Compton edge	k'_{max}	3.1 GeV
Max. asymmetry	A_{max}	0.32
Chicane angle	θ_{bend}	2.3 deg
Electron free drift distance	d_{drift}	3.3 m
Electron displacement at Compton edge	X_{max}	37 mm

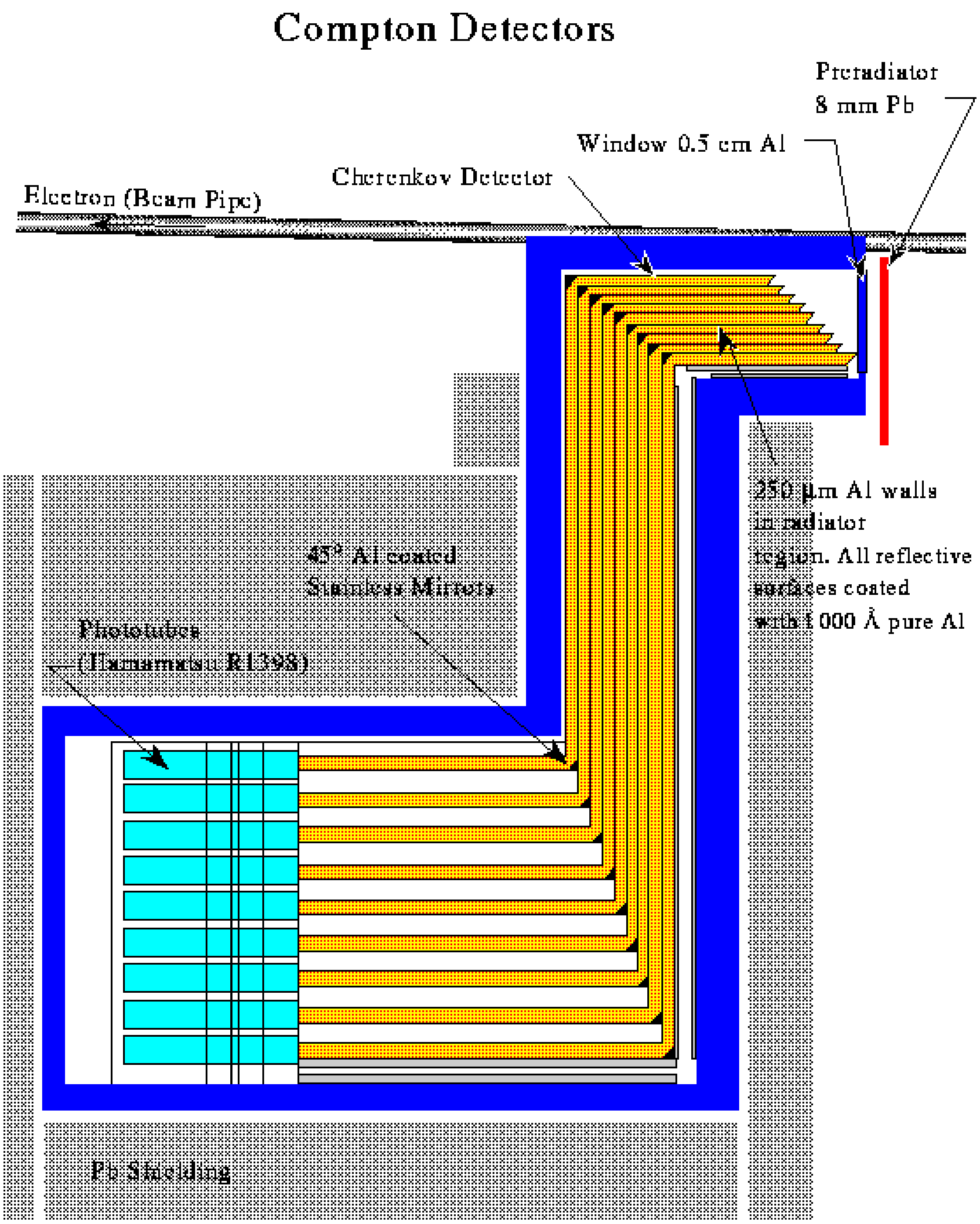
still have to put the electron detector within ~ cm of the beam

Increase Bend Angle, Electron Drift Distance

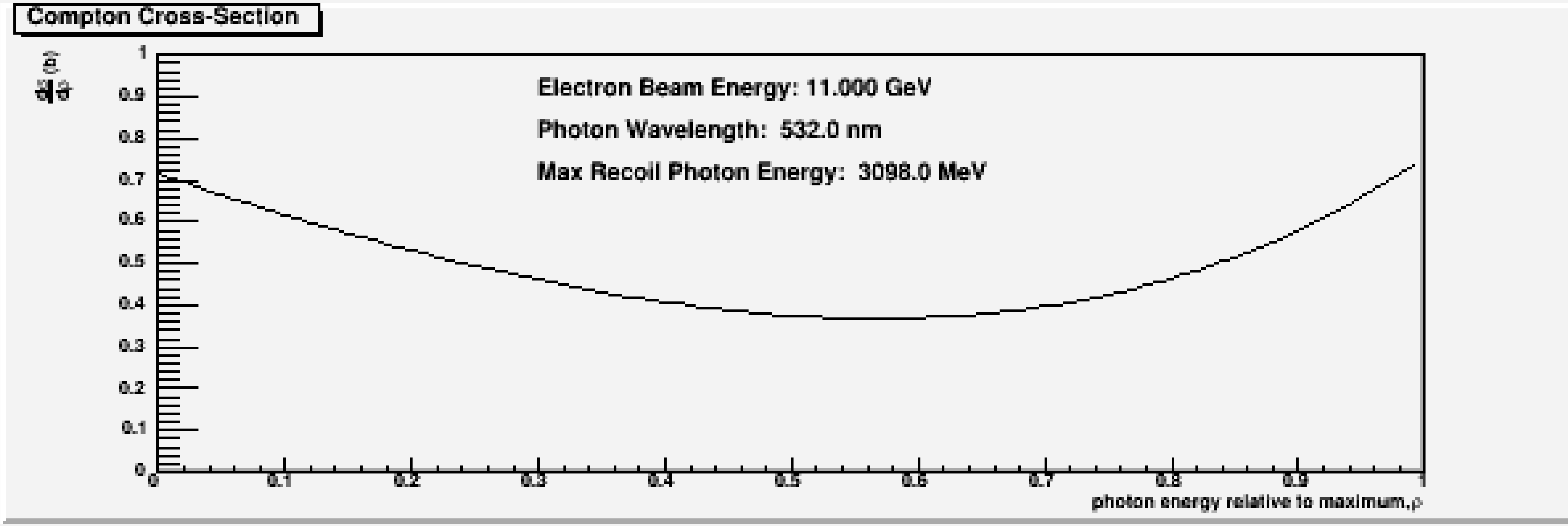
Parameter	Symbol	Value
Beam Energy	E_{beam}	11 GeV
Laser wavelength	λ	532 nm
Photon Compton edge	k'_{max}	3.1 GeV
Max. asymmetry	A_{max}	0.32
Chicane angle	θ_{bend}	5.2 deg
Electron free drift distance	d_{drift}	10 m
Electron displacement at Compton edge	X_{max}	25 cm

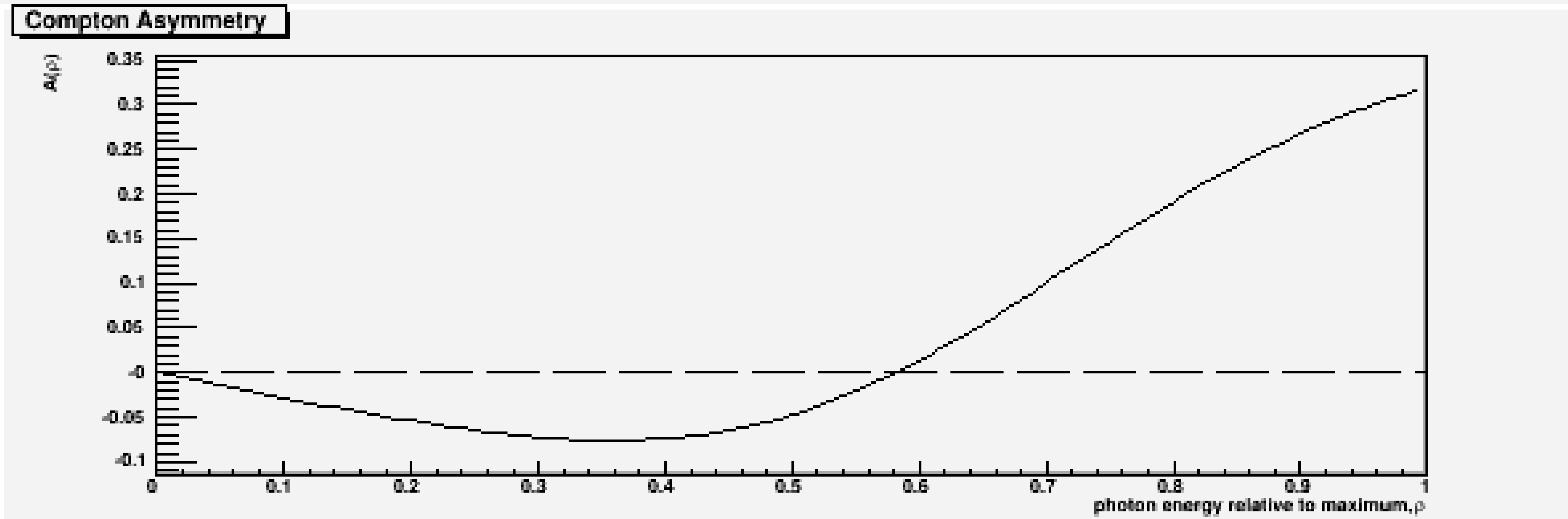
- constraints more consistent with SLD polarimeter (Compton edge at 18 cm)
- but electron detector would be much bigger.
- this is no longer a chicane.

Extras

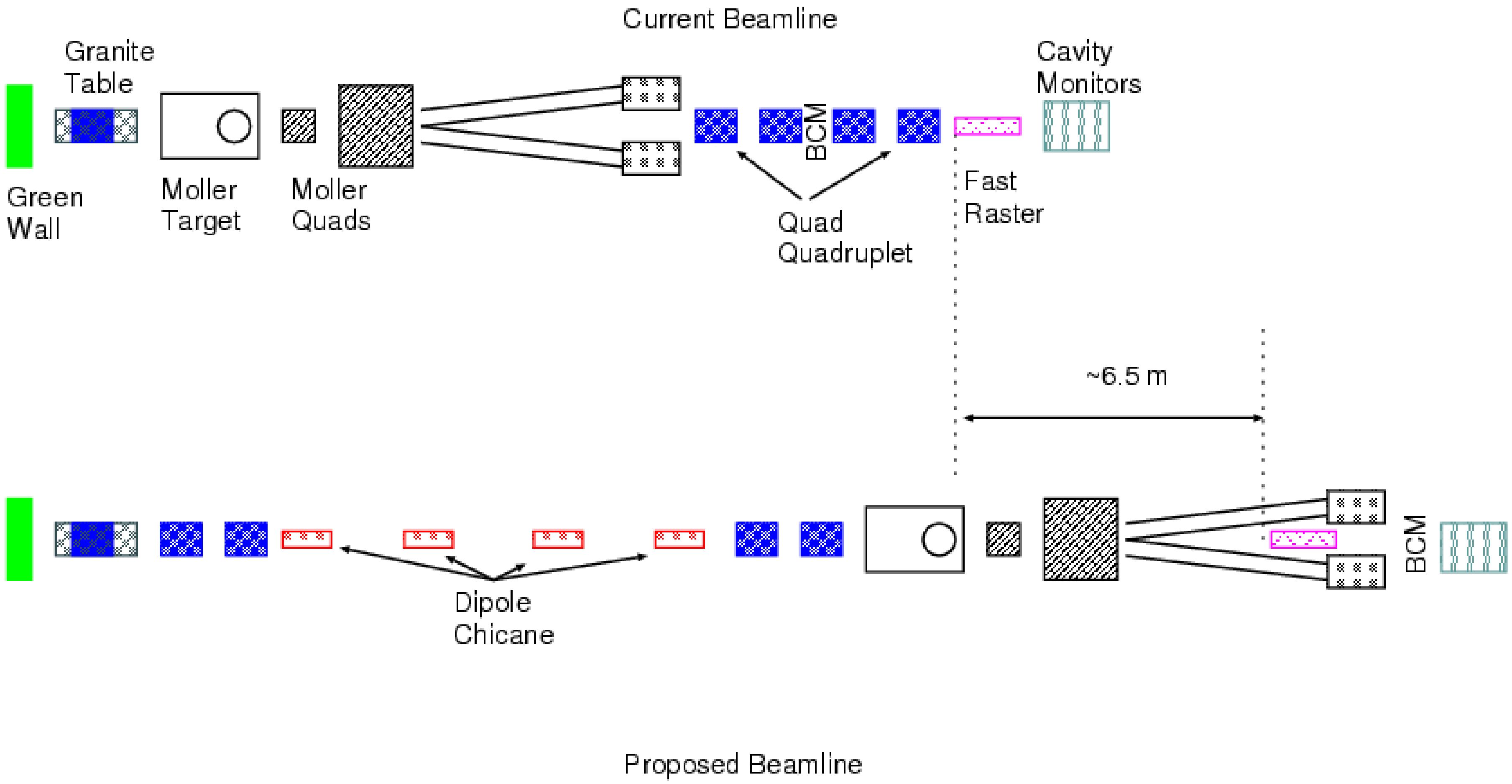


from SLD Compton Pol site.


Compton Cross-Section
Electron Beam Energy: 11.000 GeV
Photon Wavelength: 532.0 nm
Max Recoil Photon Energy: 3098.0 MeV
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
photon energy relative to maximum,ρ


Compton Asymmetry
A(ρ)
0.35
0.3
0.25
0.2
0.15
0.1
0.05
-0
-0.05
-0.1
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
photon energy relative to maximum,ρ

Cartoon of Hall C Beamline



Luminosity from Fiber Laser

- Average power from fiber laser modest (20 W) does this equal factor of 5 reduction in luminosity compared to 100 W laser?
- No – we can actually get about a factor of 4 improvement
  - For laser pulsed at electron beam repetition rate (499 MHz) and comparable pulse width (on the order of ps), the luminosity is increased by a factor:

$$\frac{L_{pulsed}}{L_{CW}} \approx \frac{c}{f\sqrt{2\pi}} \left(\sqrt{\sigma^2_{c\tau,laser} + \sigma^2_{c\tau,e} + \frac{1}{\sin^2(\alpha/2)} \left(\sigma^2_e + \sigma^2_{laser} \right)} \right)^{-1}$$

- For typical JLab parameters, this yields about a factor of 20 improvement in luminosity for α = 20 mrad

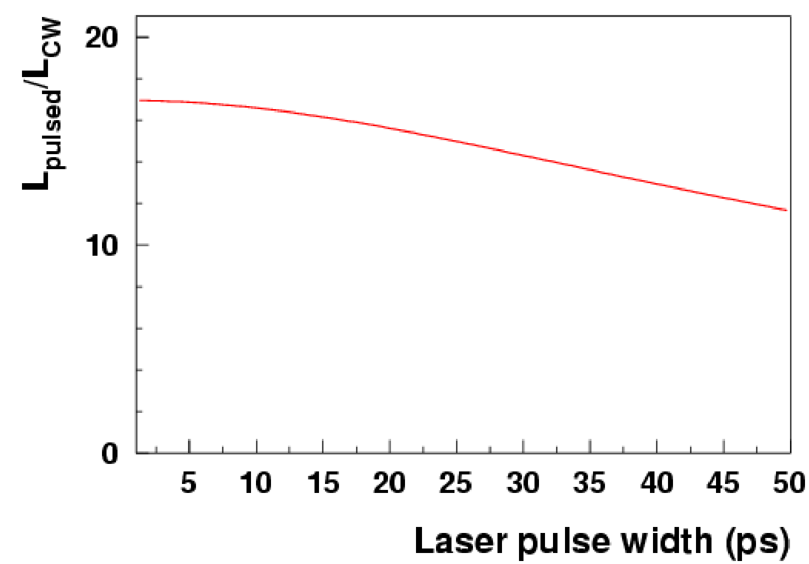
Luminosity from Fiber Laser

Fiber laser pulse-width about 15 times larger than electron beam – no problem!

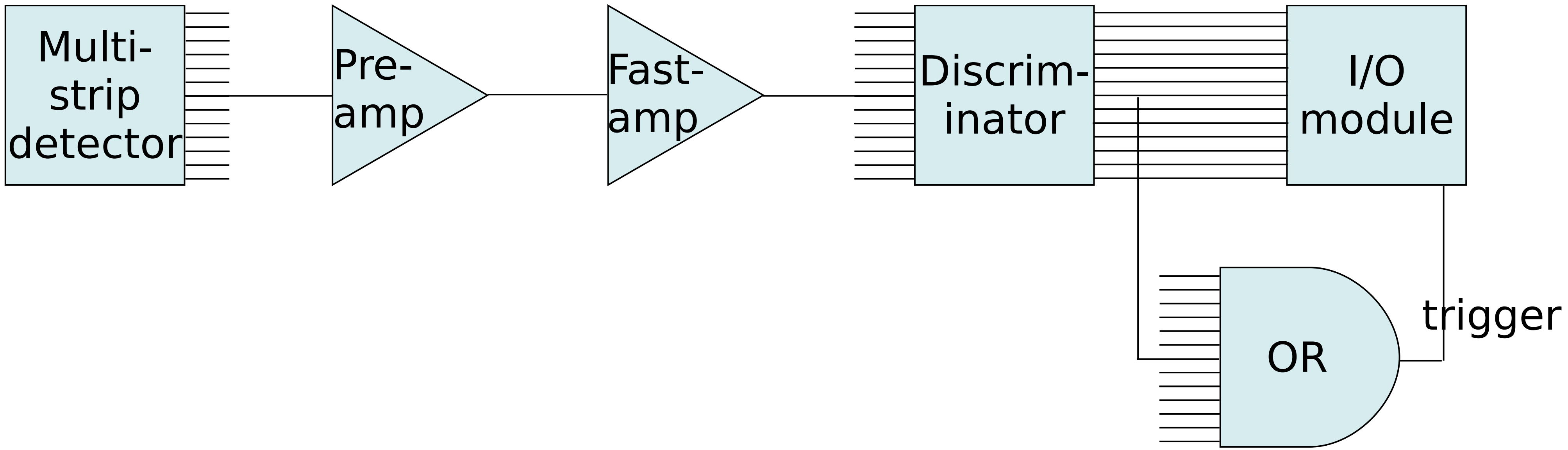
$$\frac{L_{pulsed}}{L_{CW}} \approx \frac{c}{f\sqrt{2\pi}}\left(\sqrt{\underbrace{\sigma^2_{c\tau,laser}}_{1\ \mathrm{cm}^2}+\sigma^2_{c\tau,e}+\underbrace{\frac{1}{\sin^2(\alpha/2)}\left(\sigma_e^2+\sigma_{laser}^2\right)}_{2.0\ \mathrm{cm}^2}}\right)^{-1}$$

$\sigma_e = \sigma_{laser} = 100\ \mu\mathrm{m}$, $\alpha = 20$ mrad

Luminosity gain only weakly dependent on laser pulse width
→ for laser pulses ~ 10's of ps



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?