Introduction to High Precision Polarimetry working group

Kent Paschke

University of Virginia

Outline

Goals:

- Establish common view of goals, challenges, and expected capabilities
- Identify possible pitfalls
- Flag areas requiring near-term activity

Outline:

- Plan for high precision polarimetry
- Moller, general issues
- Compton, general issues.
- Comparison between polarimeters

Credibility for 0.4% accuracy

- **Two independent measurements which can be cross-checked**
- Continuous monitoring **during production (protects against drifts, precession...)**
- **Statistical power to facilitate** cross-normalization **(get to systematics limit in about 1 hour)**

Schedule for high precision:
- PREX2/CREX Fall 2018: 1% at 1 GeV and 2 GeV
- MOLLER 2020: 0.5% at 11 GeV (for phases 2 & 3)
- SOLID 2024(?): 0.4% at 11 GeV and 6.6 GeV

Møller

Upgraded “high field” polarimeter

JLab, Temple, SBU, Kharkov/UVa

Atomic hydrogen gas target polarimeter
- expected accuracy to better than 0.4%
- non-invasive, continuous measurement
- Requires significant R&D
- backup plan, if needed

Mainz, W&M

Mott

Upgraded for precise asymmetry measurement

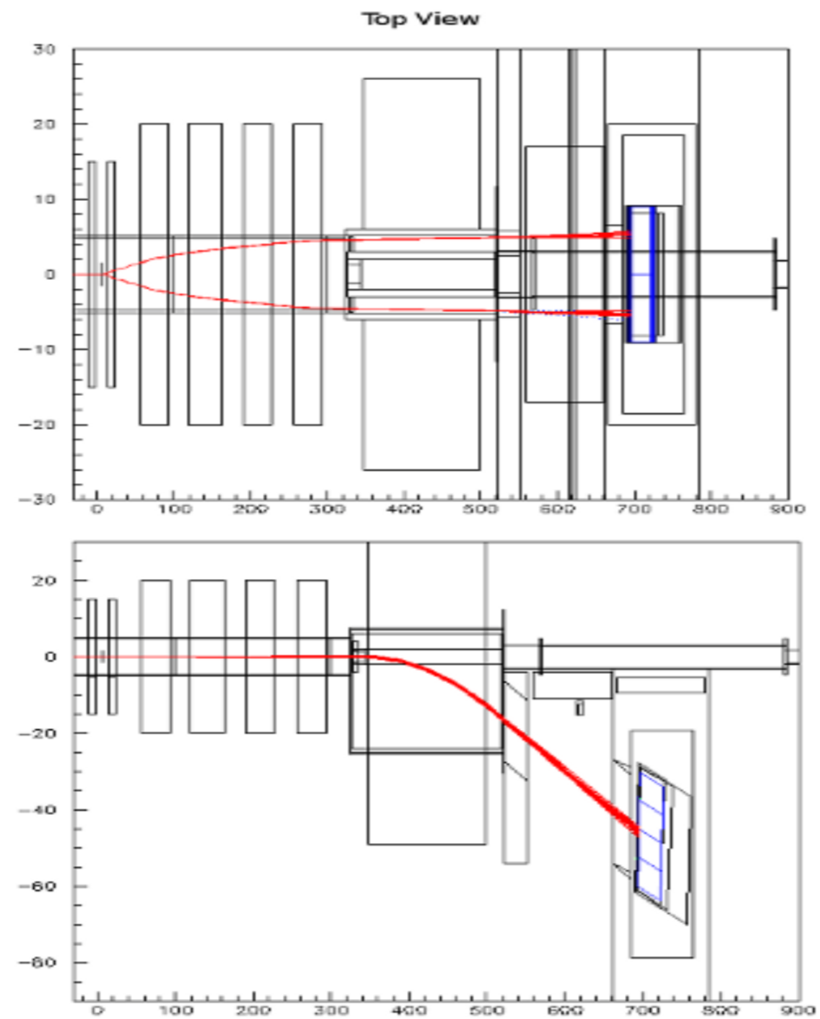
Techniques for limiting Sherman function uncertainty

Compton

11 GeV baseline may meet goals
- significant independence in photon vs electron measurements
- continuous measurement with high precision

JLab, CMU, UVa, Manitoba, MSU, SBU

Moller Polarimetry Goals



- "high field" iron target
  - well-known magnetization at saturation
  - ultimately rests on empirical spin polarization from force/torque measurements
- QQQQD spectrometer
  - Open acceptance minimizes Levchuk correction
- Detect coincidence of identical particles
  - low background measurement

Can be (in principle) well understood:
spectrometer acceptance, magnetic saturation, target heating, radiative corrections, dead time, backgrounds…

Same techniques in Hall C ~ 0.7% polarimetry

Rebuilt for 12 GeV and high field.

- Commissioned at high energy
- Needs low energy commissioning
- Target apparatus being improved

After DVCS

- move target system to test lab for development
- Reinstall, commission for PREX in 2018

Potential Moller Polarimetry Challenges

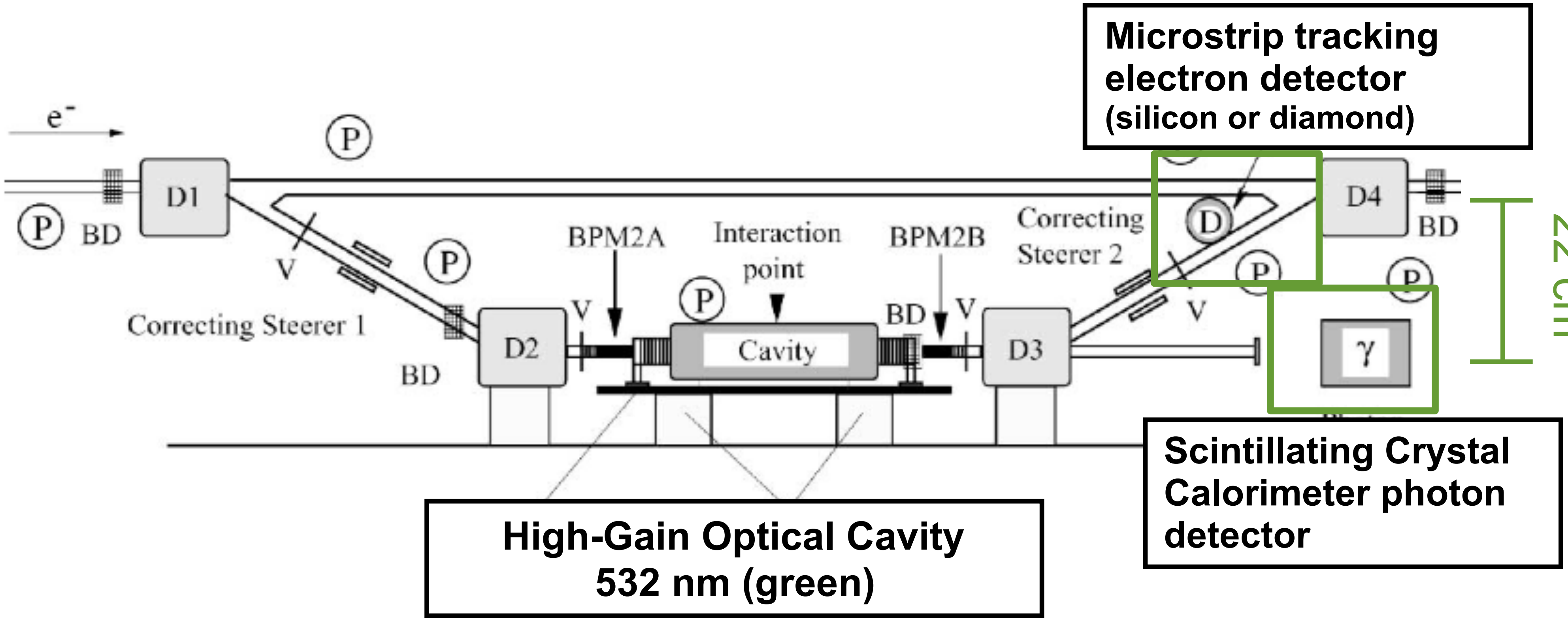
Accuracy of Asymmetry Measurement
- Rate dependence / deadtime
- Background - dilution?
- Background asymmetry - iron pipe and new beam optics quadrupole

Analyzing power normalization
- Optics / acceptance (distorted by target field?)
- Levchuk correction
- Quality of saturation
- Target heating
- Electron spin polarization in magnetized material

Extrapolation to running conditions
- Polarization vs. Cathode current
- Polarization vs. slit width, etc…

Other issues?

Hall A Compton Polarimeter

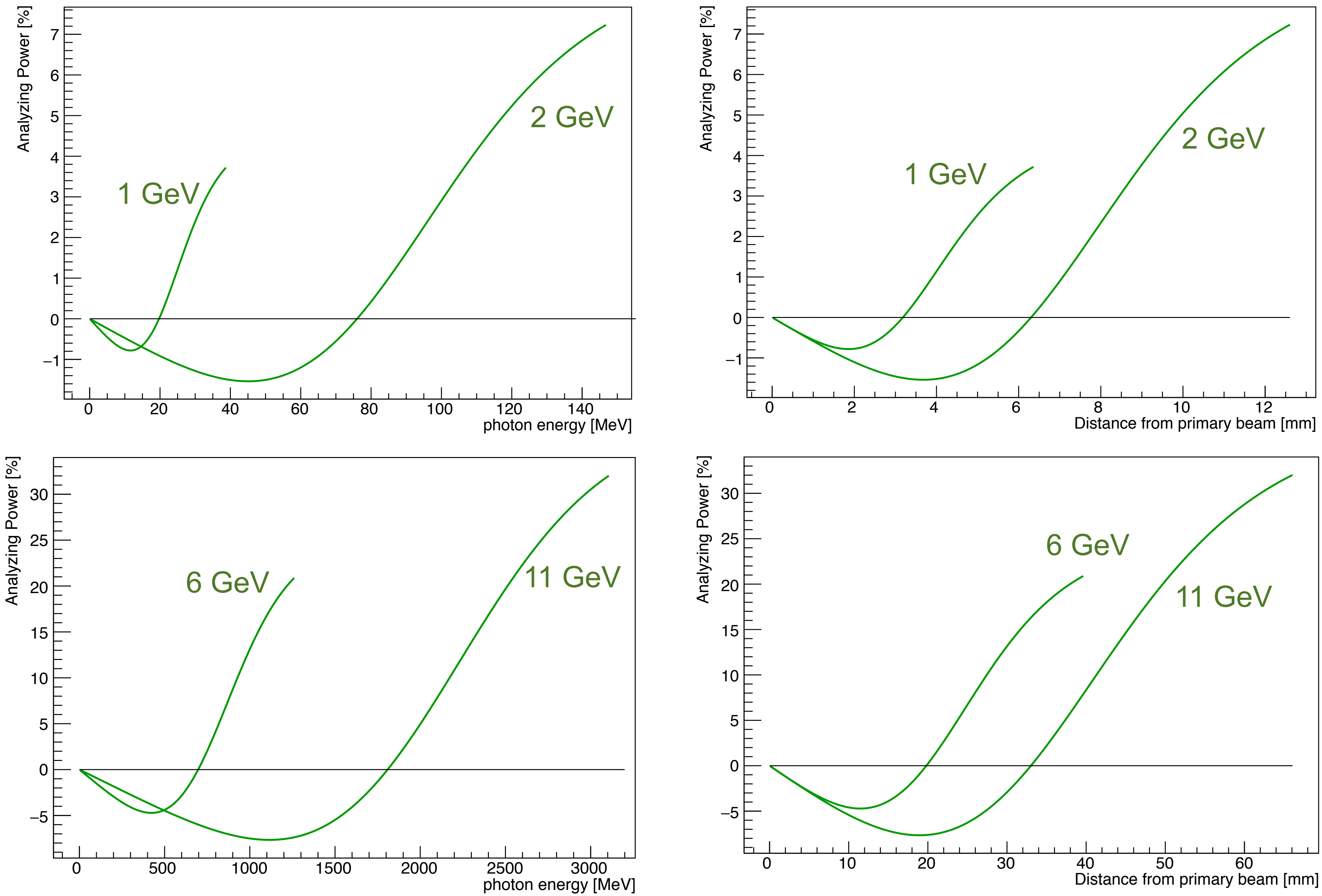


Operation at lower energy (1-2 GeV) is a very different set of challenges
<1% at 1 GeV is important proving ground for 0.4% at 11 GeV

Past Achievement

- HAPPEX-3 (2009): 0.8% at 3 GeV
- PREX-2 (2010): 1.0% at 1.06 GeV
- Qweak (2012): 0.8% at 1 GeV

PREX / CREX vs. MOLLER/SOLID



Potential Compton Polarimetry Challenges

Photon

Accuracy of Asymmetry Measurement

- Detector baseline shifts (integration)
- Detector rate linearity (integration, counting)
- Synchrotron radiation
- background magnitude / stability
- electronics noise (integrating)

Analyzing power normalization

- Energy calibration (counting)
- Response function linearity (integrating)
- Laser polarization

Electron

Detector

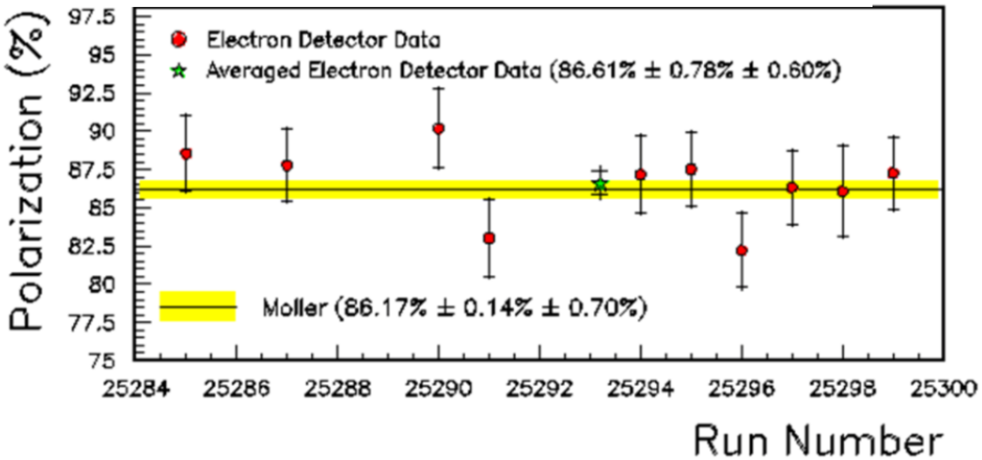
- no Hall A detector since 2007
- Efficiency? Geometry? Radiation resistance? Light sensitivity? Thickness?
- DAQ
- Most useful at high-E. At 2 GeV (CREX in 2018) probably would be useful

Analysis

- Qweak-style fit - well defined set of possible errors, cross-checks
- Cross-checks ("zero-slope")

Spin Dance / Cross-Comparison

Qweak Moller-Compton-Moller (2012)

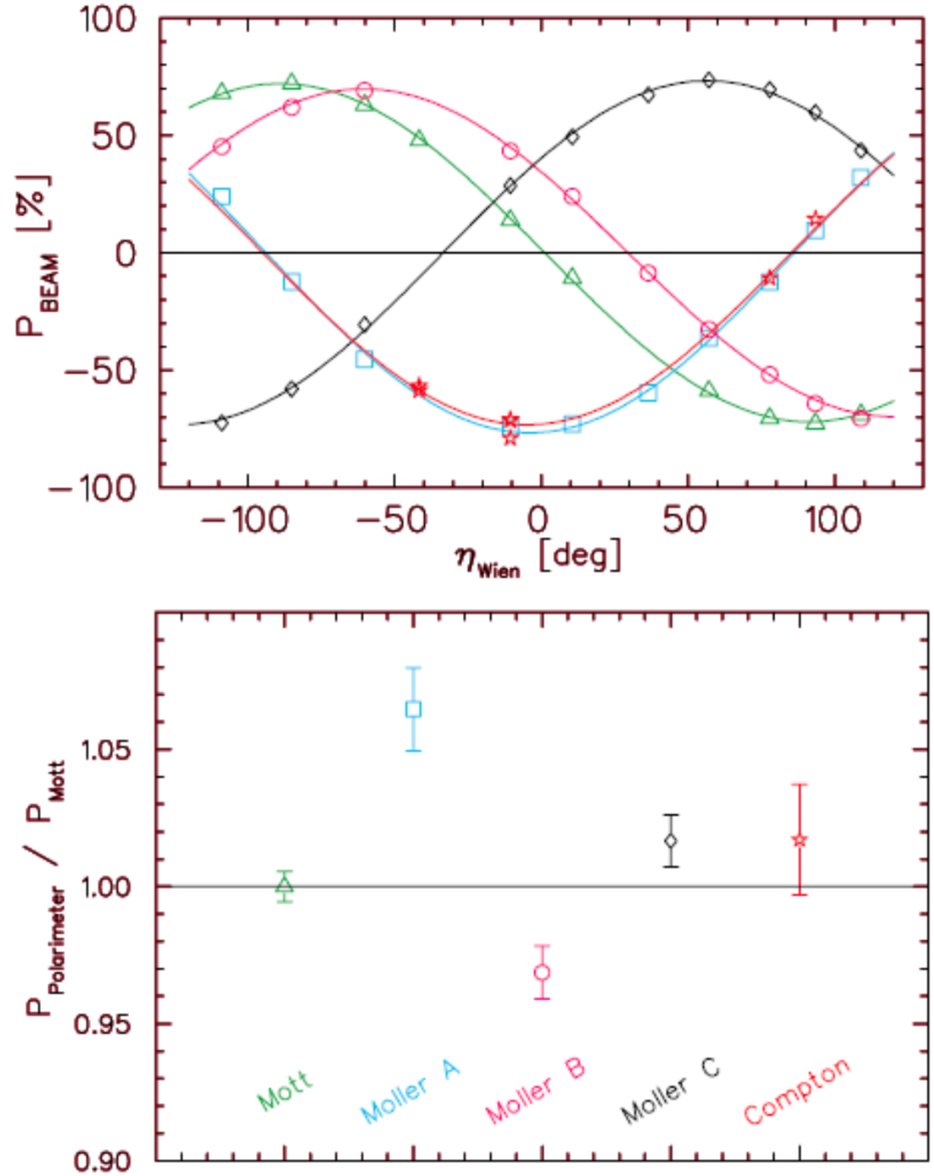


Direct Comparison between polarimeters is crucial benchmark

PREX should have
- high precision Moller and Compton in Hall A
- maybe can be compared to Moller in Hall C?
- Mott in injector?

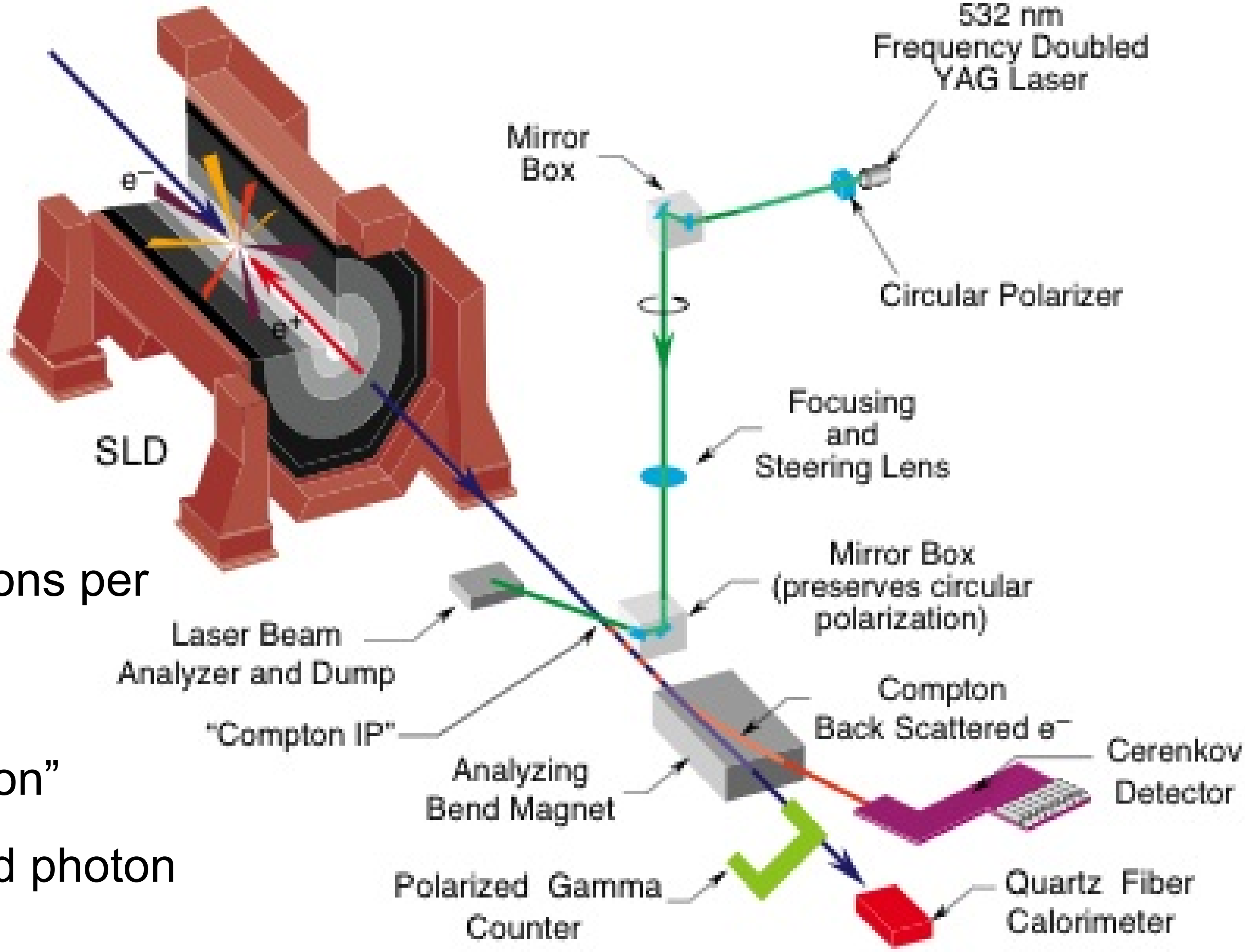
Will Hall C Compton be ready for high precision again (no Hall C physics driver)?

JLab Spin Dance (2000)



SLD Compton Polarimeter

"The scanning Compton polarimeter for the SLD experiment" (SLAC-PUB-7319)



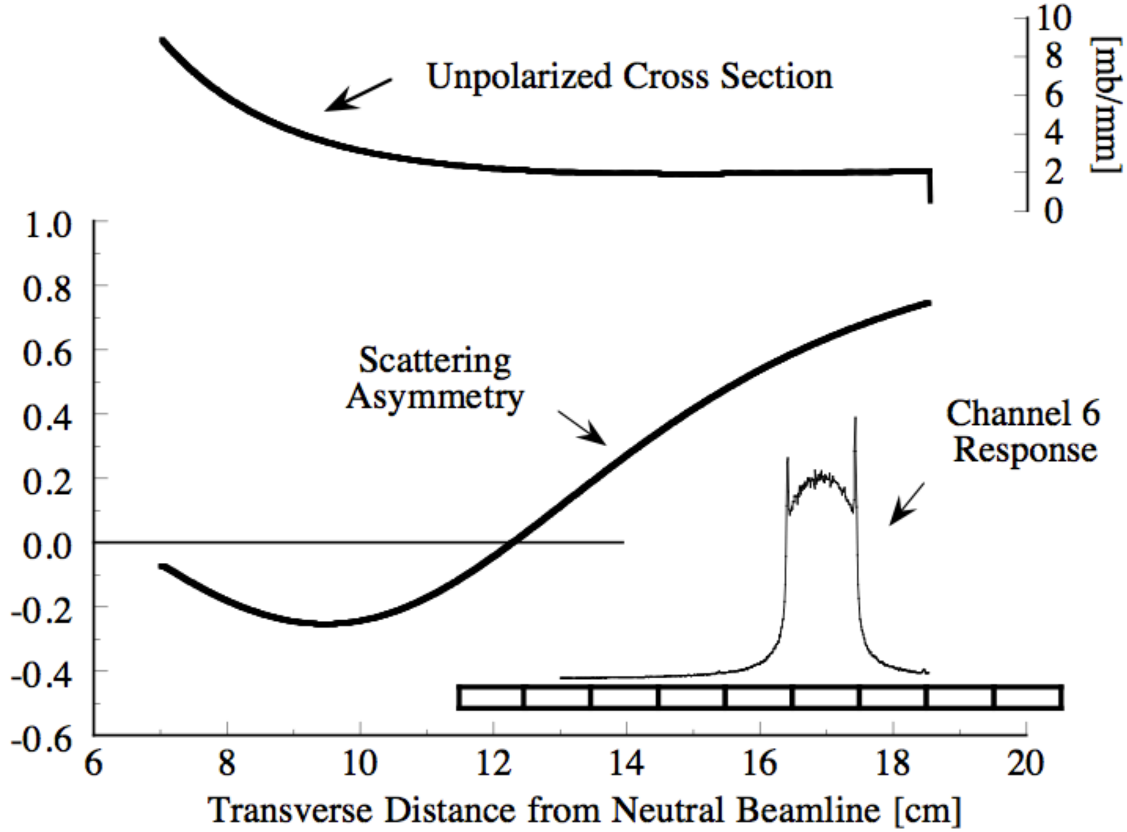
- Pulsed laser
- ~1000 scattered electrons per pulse
- 2/3 operating time was calibration, not "production"
- Integrating electron and photon detectors
- Published results $\delta P/P \sim 0.5\%$

Collider Compton Polarimetery

Electron detector was corrected for energy calibration, response function

Detector element at the Compton edge was least sensitive to corrections, and so most precise

$\sin^2\theta_W$ rests on a single electron detector channel !

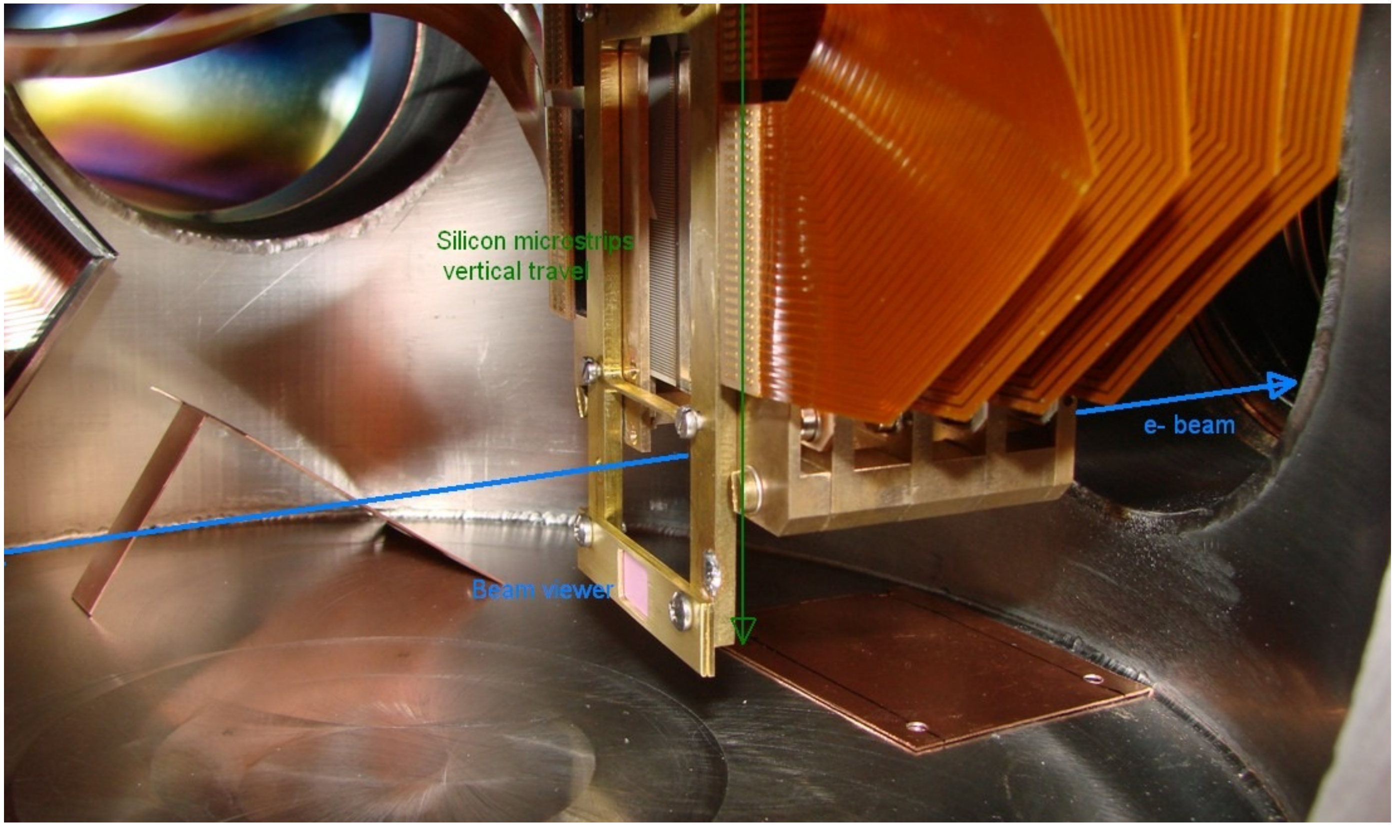


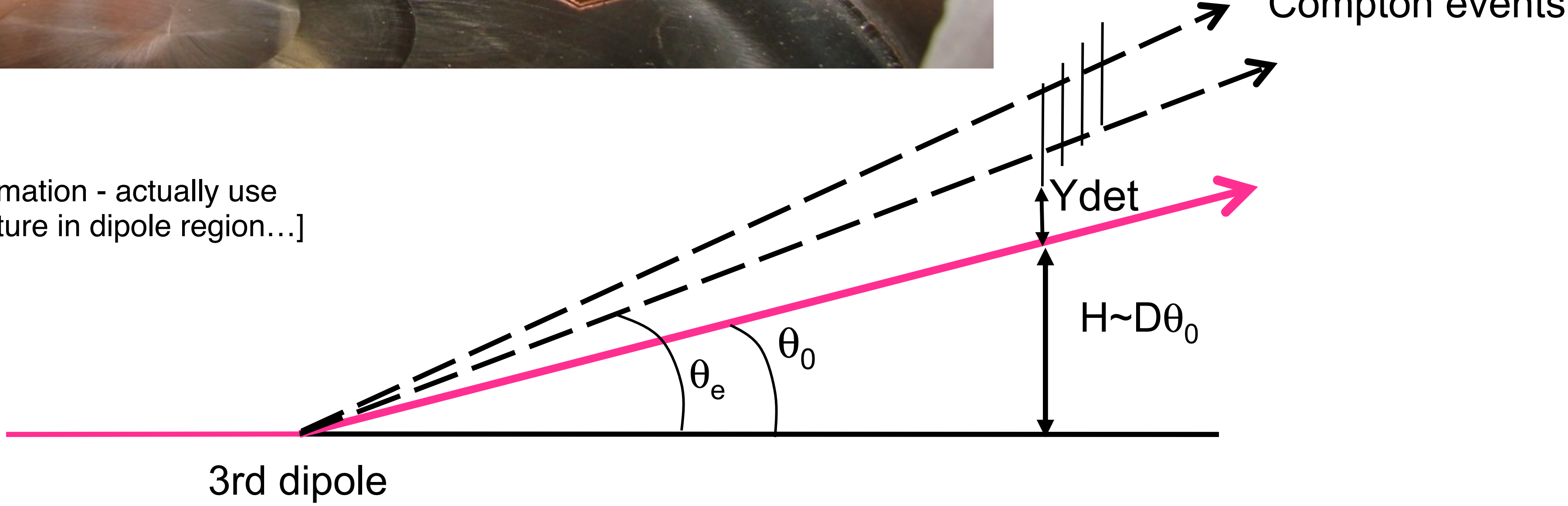
Electron Detector

SLD vs. Hall A

- SLD near interaction region: no photon calorimeter for production
- SLD is only pulsed mode
  - Hall A has single-photon / single-electron mode (CW)
    - Efficiency/resolution studies
    - Tagged photon beam
    - Measured spectrum vs. simulation
- SLD had crude electron detector resolution
  - Hall A: greater resolution resolution, more precise calibration
- SLD didn’t cover all of Compton-scattered spectrum
  - Hall A: calibrate features of spectrum
- SLD required chromaticity correction

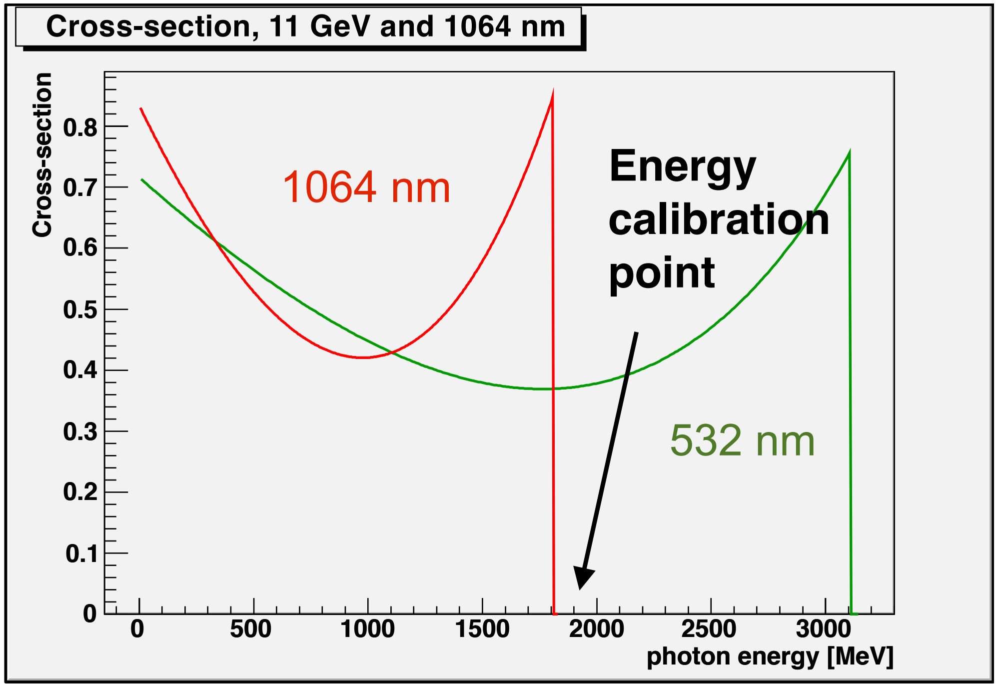
Electron Detector

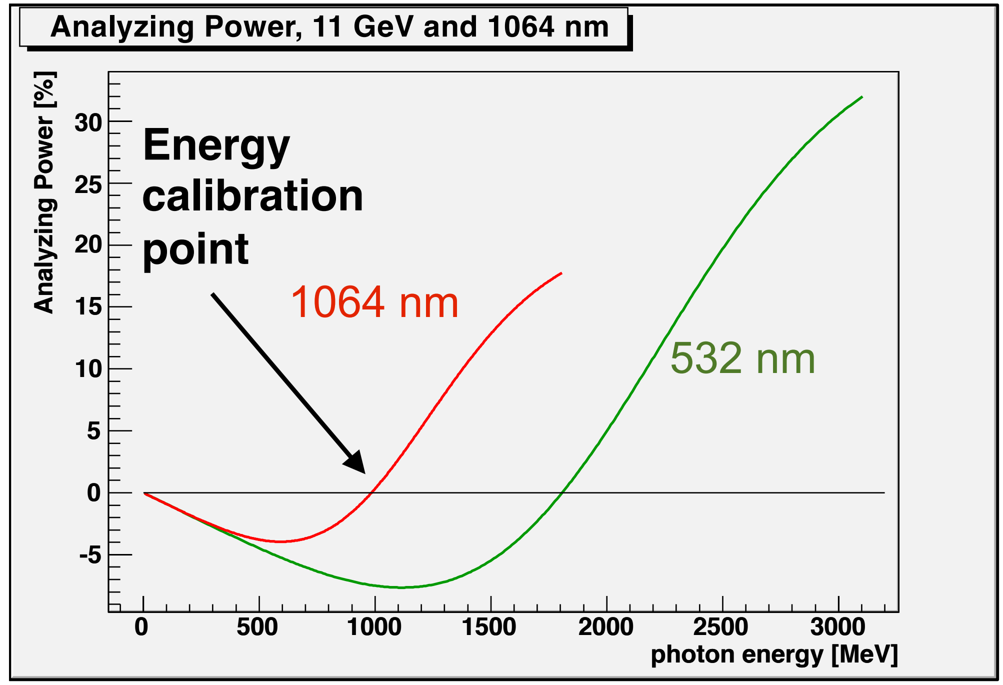




[Crude approximation - actually use radius of curvature in dipole region…]

Calibrating the Analyzing Power





Major challenge for **electron counting** is knowing kinematics seen by each strip, so the expected analyzing power for each strip. Calibrate the Compton edge, asymmetry zero-crossing, slope in region between, at minimum asymmetry .

Major challenge for **photon counting** is averaging over the response function to find analyzing power for bins of detector response. Cleaner response function at higher energy helps!

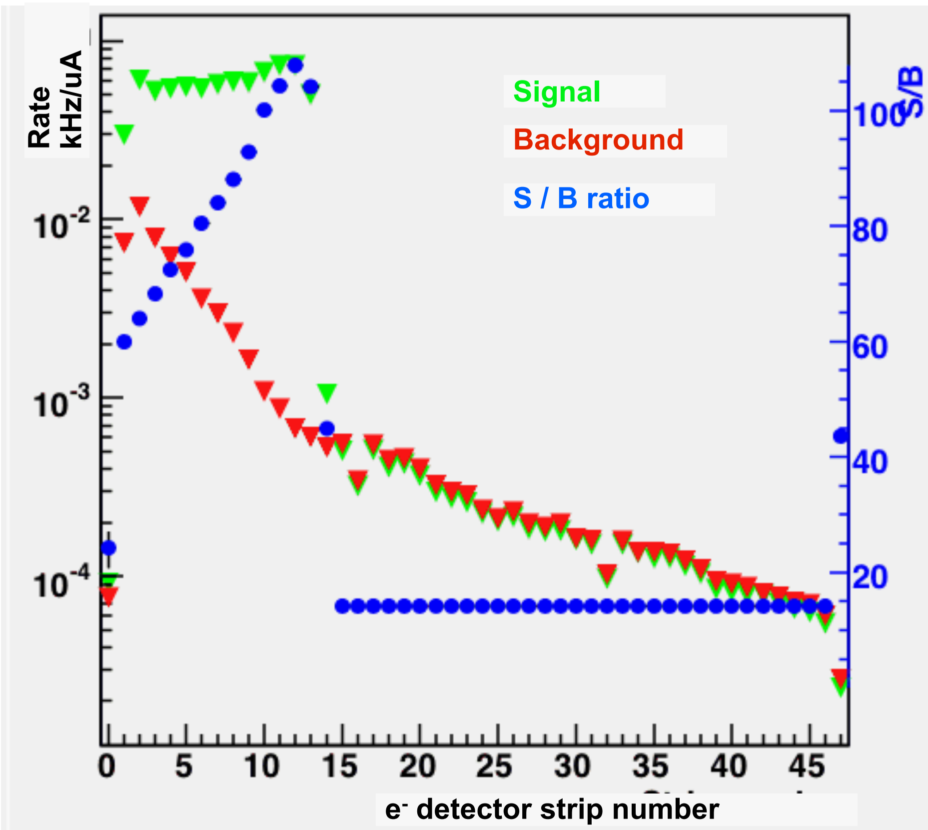
HIGH ENERGY

Major challenge for **photon integration** is linearity, and perhaps noise.

LOW ENERGY

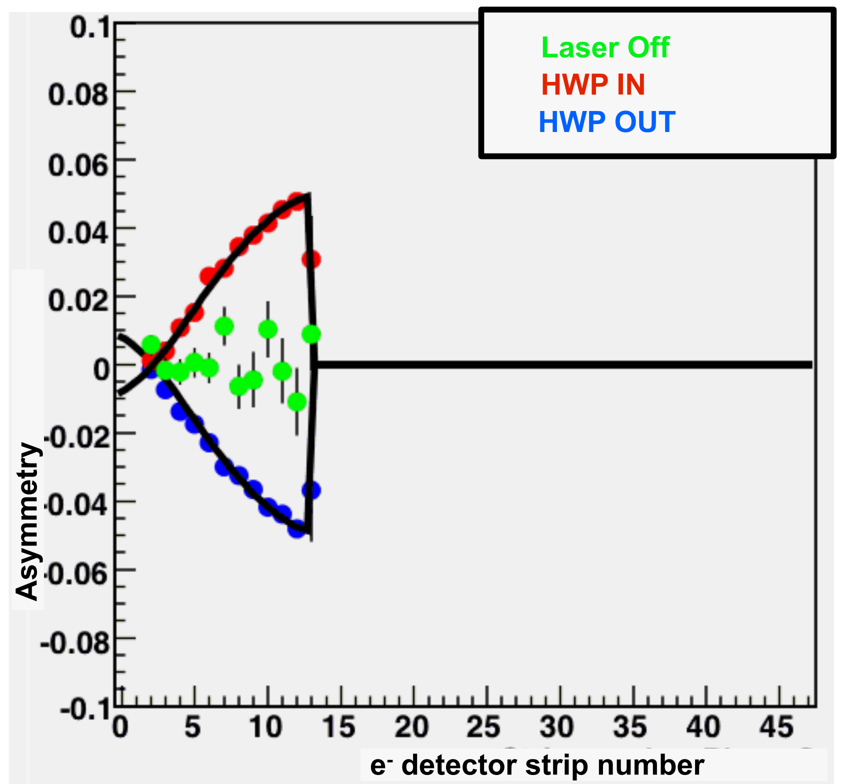
Electron counting and photon integration have been successful at 1 GeV for <1% precision!

Electron Detector in Hall A



data from HAPPEX-II (2005)
E_{beam}~3 GeV, 45 uA,
P_{cavity} < 1000 W

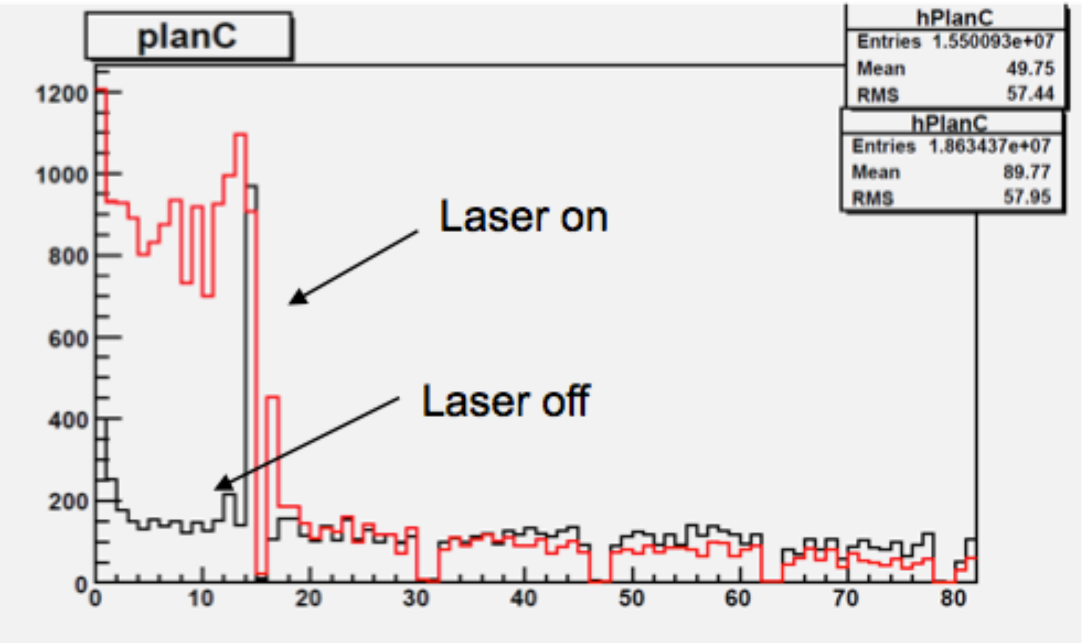
Background ~ 100 Hz / uA at Y_{det} ~ 5mm



Current Electron μstrip Detectors

Noise vs. signal, especially in Hall, makes high efficiency hard

Existing Hall A Si strip system



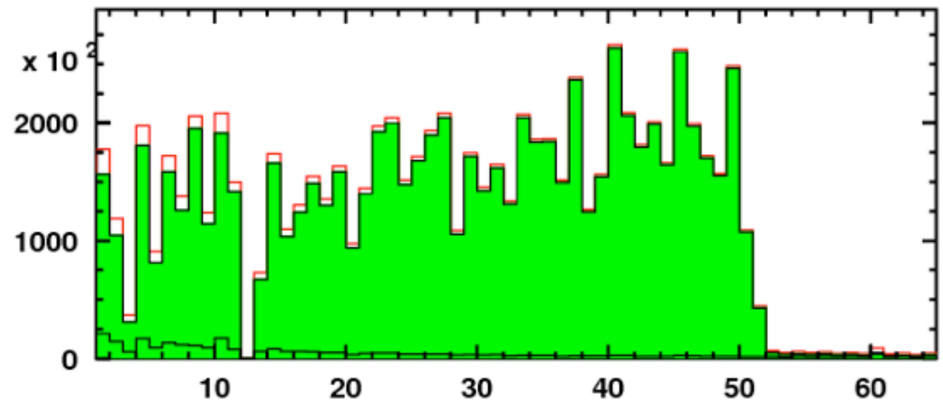
Thicker Si strips with existing electronics? (is rescattering from Si substrate an important systematic correction?)

New electronics for Si ustrips?

Cons: radiation hardness and synch light sensitivity

Hall C Diamond strips

Rough guess: 65% efficient?

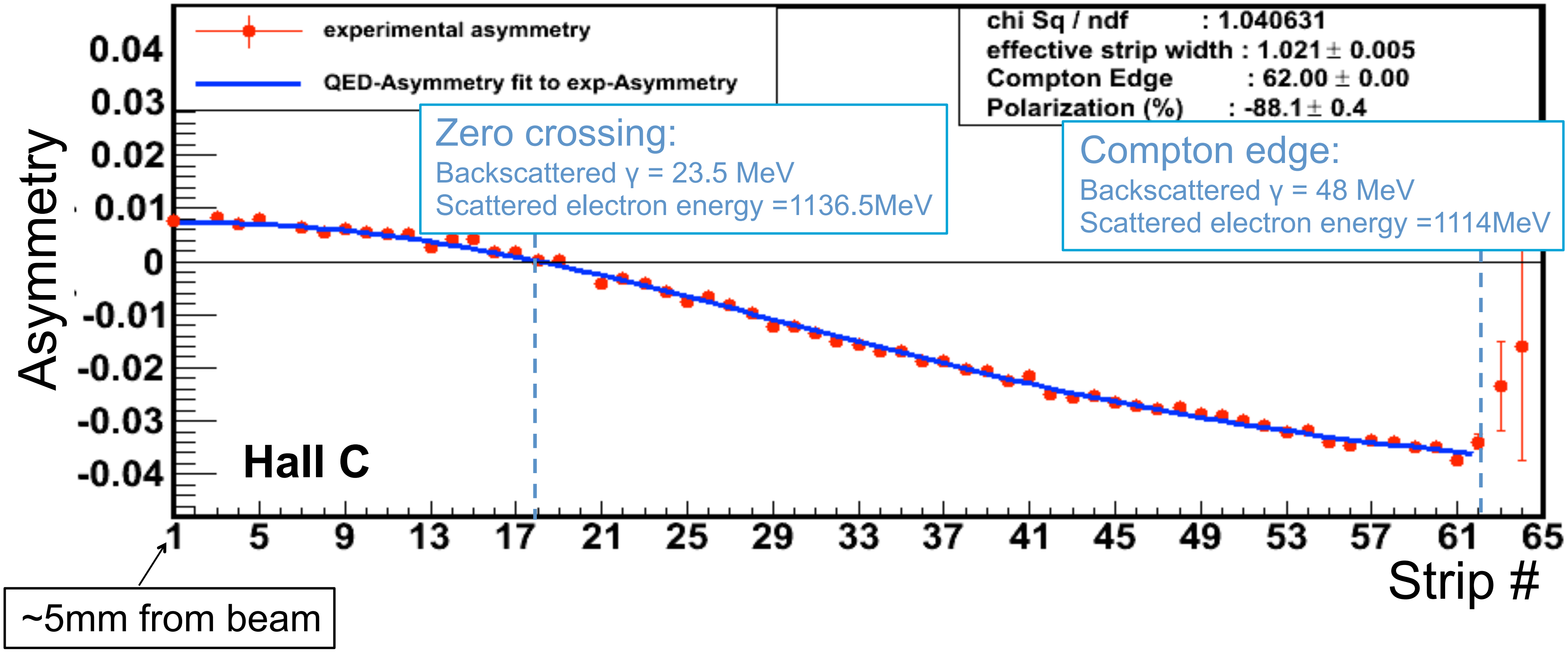


Hall C style diamond strips?

Improved electronics? (compton edge from hit pattern is an important calibration point: high efficiency needed!)

Improved radiation hardness & synch light sensitivity

Electron Detector, Hall C



- Fit to the asymmetry spectrum shape to theoretical asymmetry distribution.
- Shape (including zero crossing) provides calibration, to absolute asymmetry.
- Check with Compton edge in the rate spectrum, and known BdL.

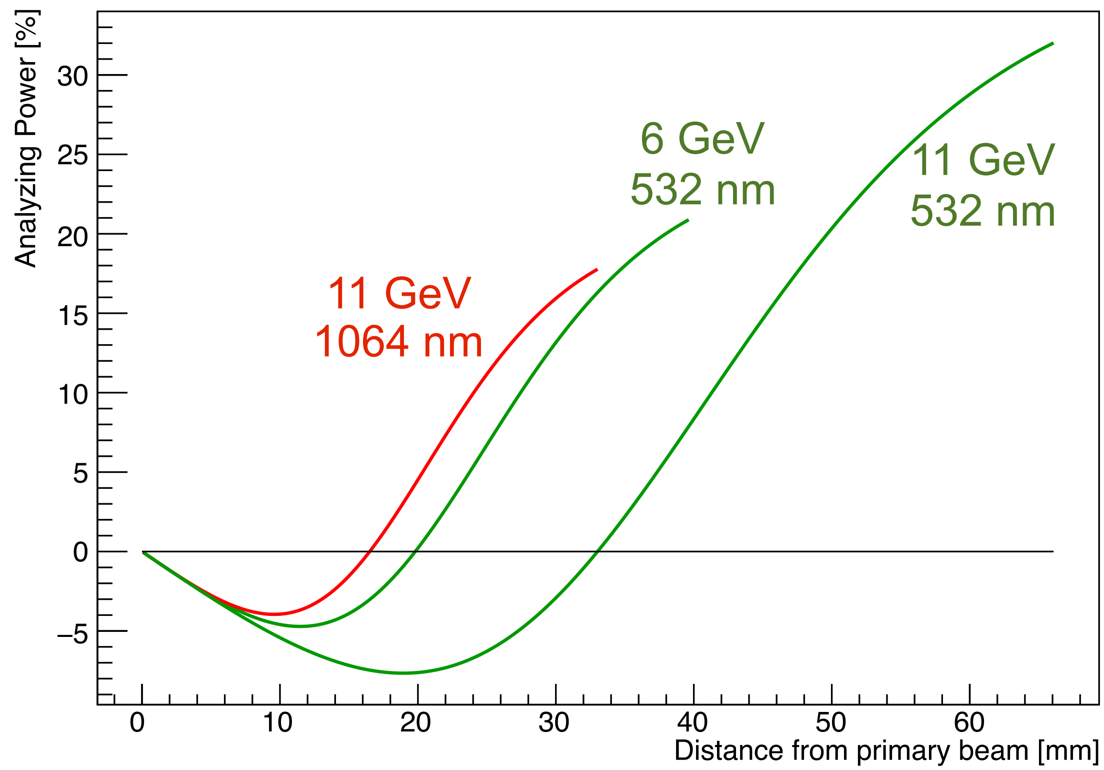
Electron analysis at 11 GeV

Multiple analysis techniques to calibrate analyzing power

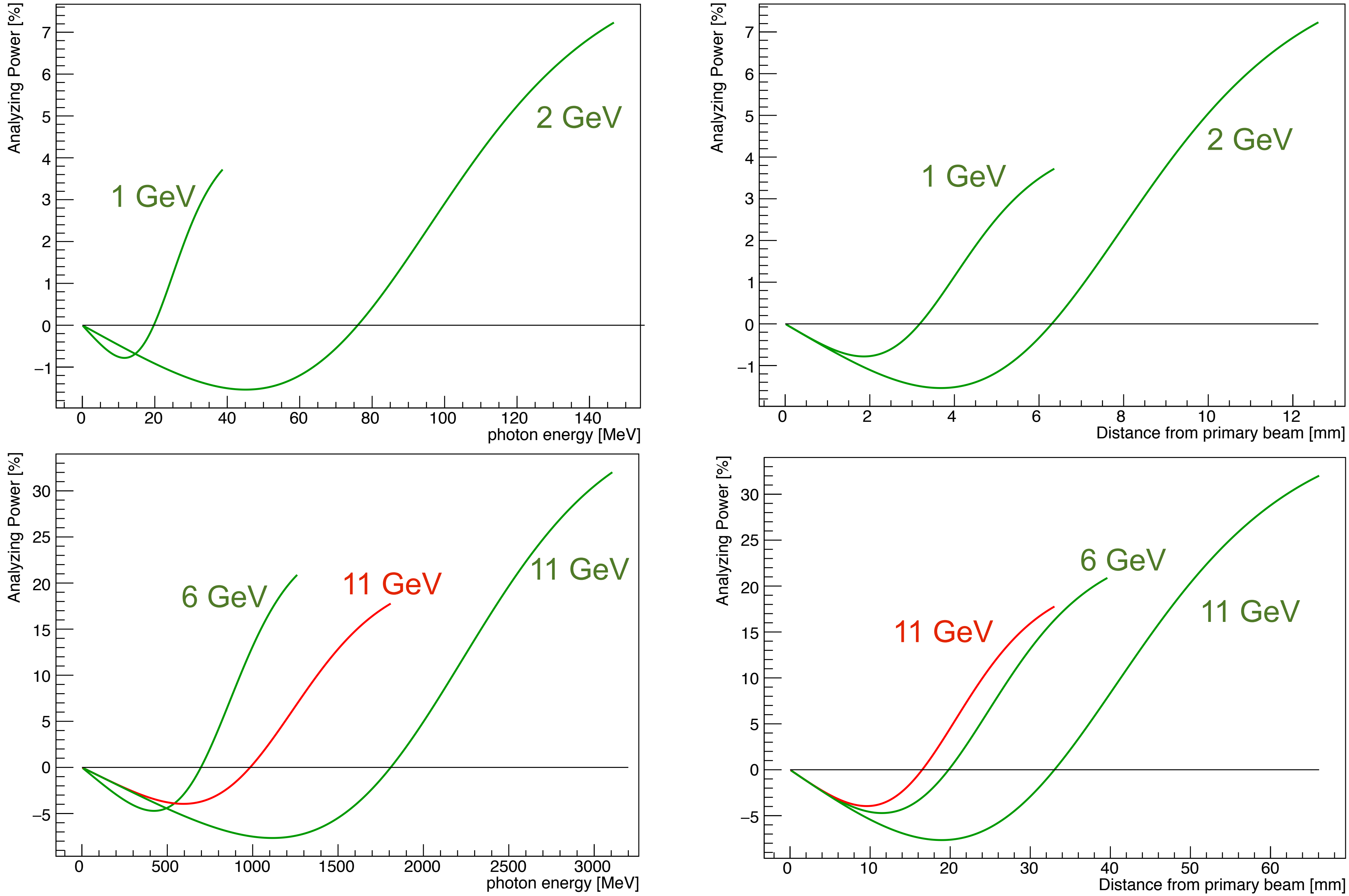
- **Asymmetry Fit:** using Compton edge and 0xing to calibrate
- **Edge "single strip"**- a single microstrip, 250 micron pitch, right at the compton edge. (~1 hour to 0.4%)
- **Minimum single strip**- a single microstrip, at the asymmetry minimum (~1 day to 0.4%)

Other possible complications

- Compton Edge location (efficiency, noise)
- δ-ray / rescattered Compton e^-
- Deadtime (noise, background)



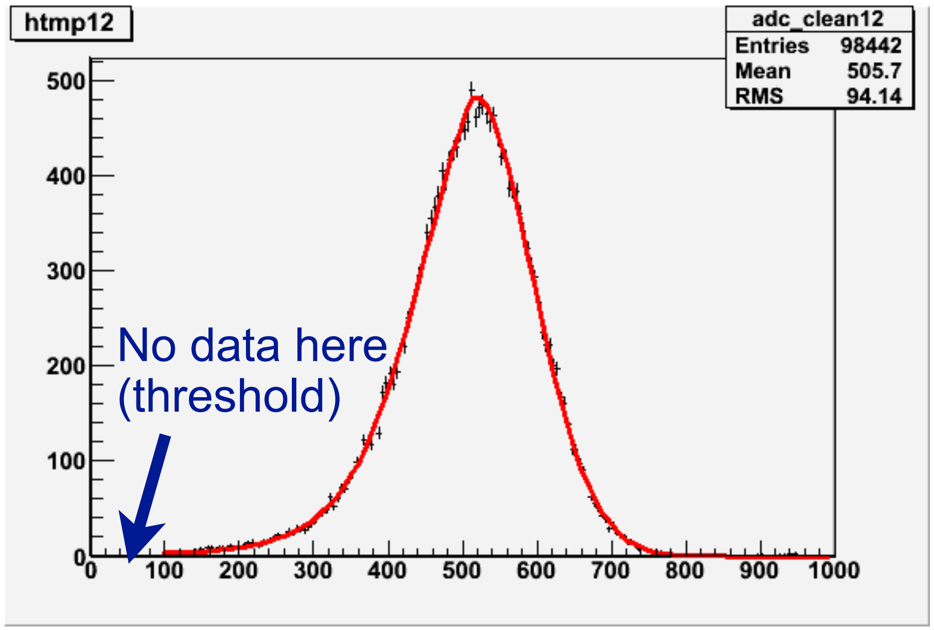
PREX / CREX vs. MOLLER/SOLID



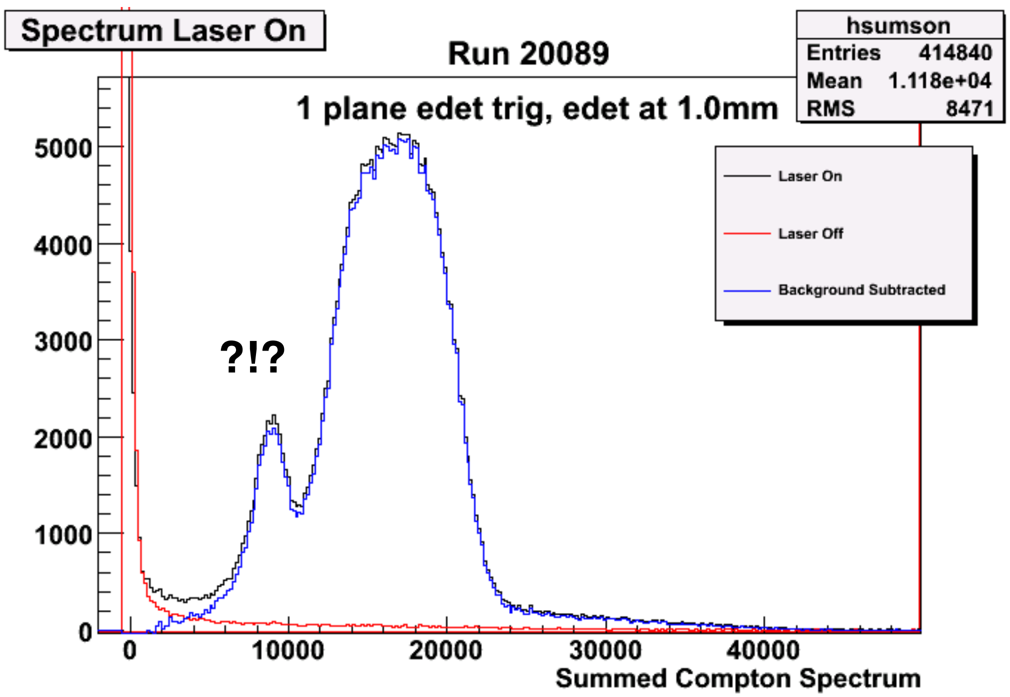
e-γ coincidence: response function calibration

- Electron-photon coincidence
- low-rate trigger (prescaled)
- Photon discriminator threshold and minimum e^- detector approach leaves some portion of the response function unmeasured....

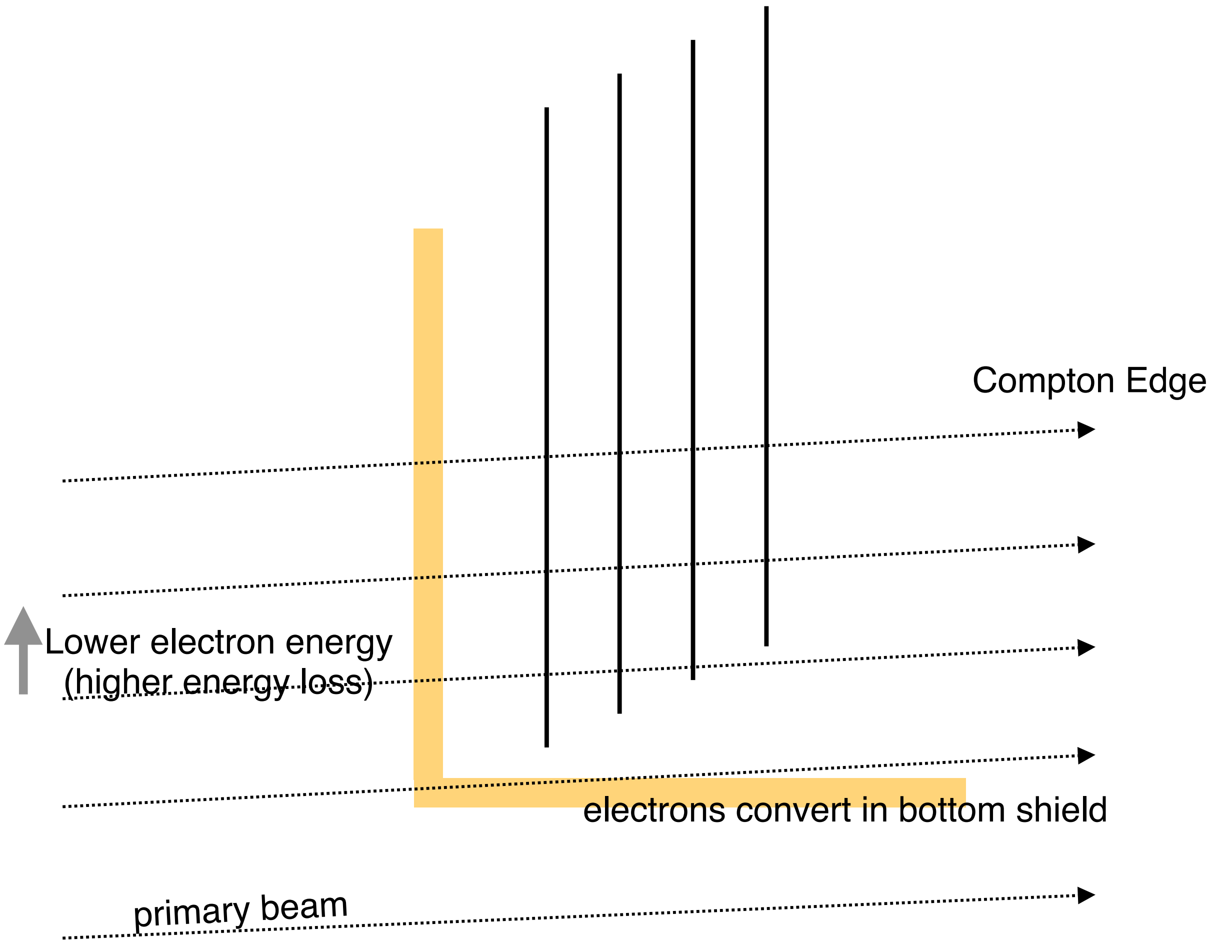
Photon detector response in coincidence with single e-det strip

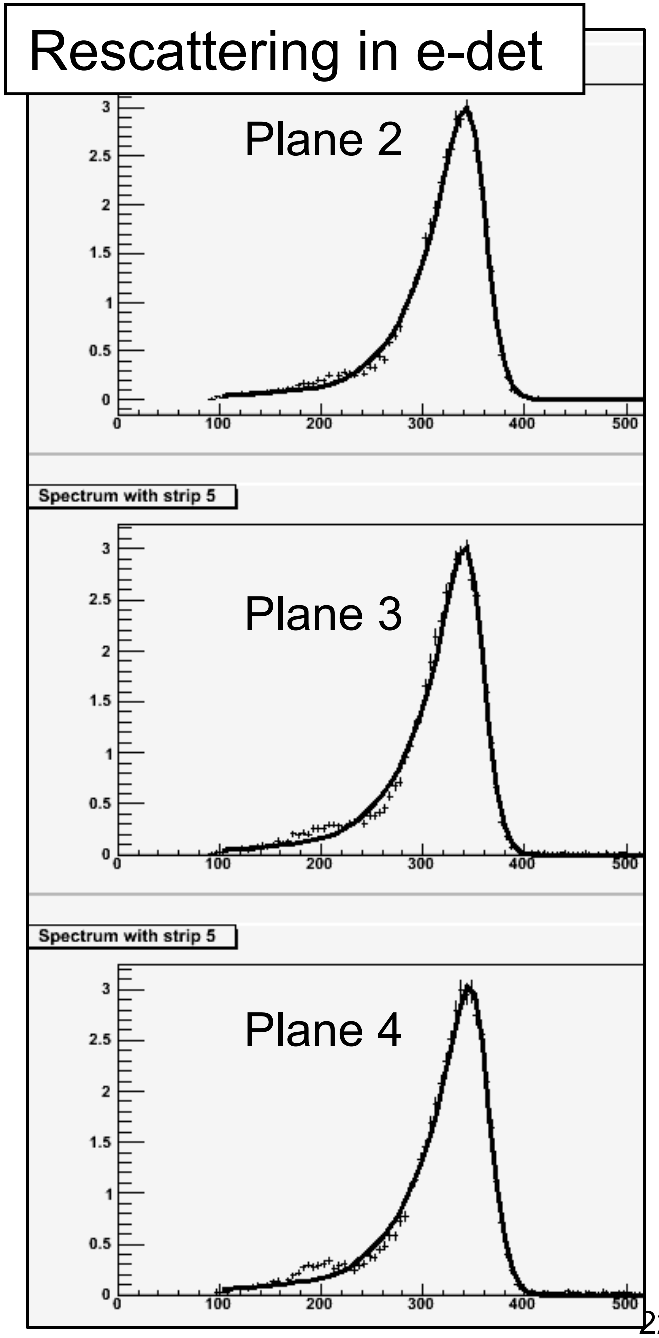


HAPPEX-3 2009 (3 GeV)



HAPPEX-3 “bump”





Summary

Relative Error (%)	electron	photon
Position Asymmetries	-	-
E_{beam} and λ_{laser}	0.03	0.03
Radiative Corrections	0.05	0.05
Laser Polarization	0.2	0.2
Background/Deadtime/Pileup	0.2	0.2
Analyzing Power Calibration / Detector Linearity	0.25	0.35
Total	0.38	0.45

correlated

uncorrelated

- **At high energy** there are more options for achieving high precision with edet
- **At low energies** electron detector calibration will be very difficult. Helpful cross-check?
- **Thin detector better than thick**

Backup

Beam Aperture

Collimators protect optics at small crossing angles... but at the cost of larger backgrounds?

Existing 1cm aperture (1.4° crossing)
10kW IR gives signal ~23 kHz/μA
(few minutes to 0.5% precision)

Typical “good” brem rate: ~ 100 Hz/uA
Residual gas should be about 10x less

How much larger will the halo and tail be, due to synchrotron blowup?

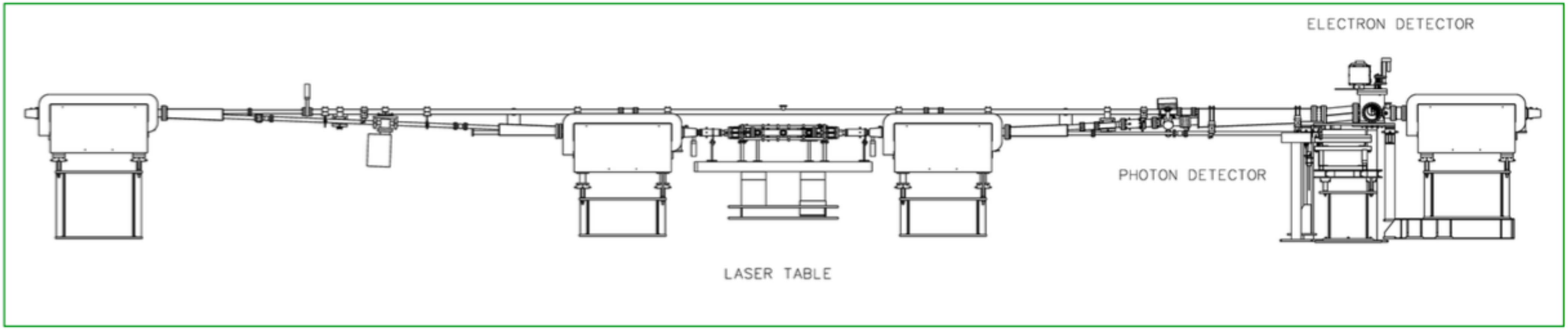
Full 0.5” aperture, signal ~9 kHz/μA. Still plenty of precision!
Uptime and precision may benefit from larger aperture, to be considered after tests with 11 GeV beam.

Hall A Compton, 11 GeV Update

11 GeV functionality required changing chicane deflection: 30 cm → 21.55 cm

As of January 2014, most of the infrastructure work had been completed
→ Dipole height adjusted
→ New vacuum chambers fabricated and installed
→ Laser table height adjusted (new legs)
→ New electron detector chamber fabricated

Recently completed
→ Modifications for photon detector stand and collimator holder
→ Photon tube



from D. Gaskell, PREX Collab Mtg, Dec 2014

Dipole Shims for Synch Light Background

At higher energies, synchrotron backgrounds in photon detector get uncomfortably large

→ This can be mitigated by adding relatively small shims at ends of dipole to "soften" the bend

→ Shims have been installed as part of the 12 GeV improvements

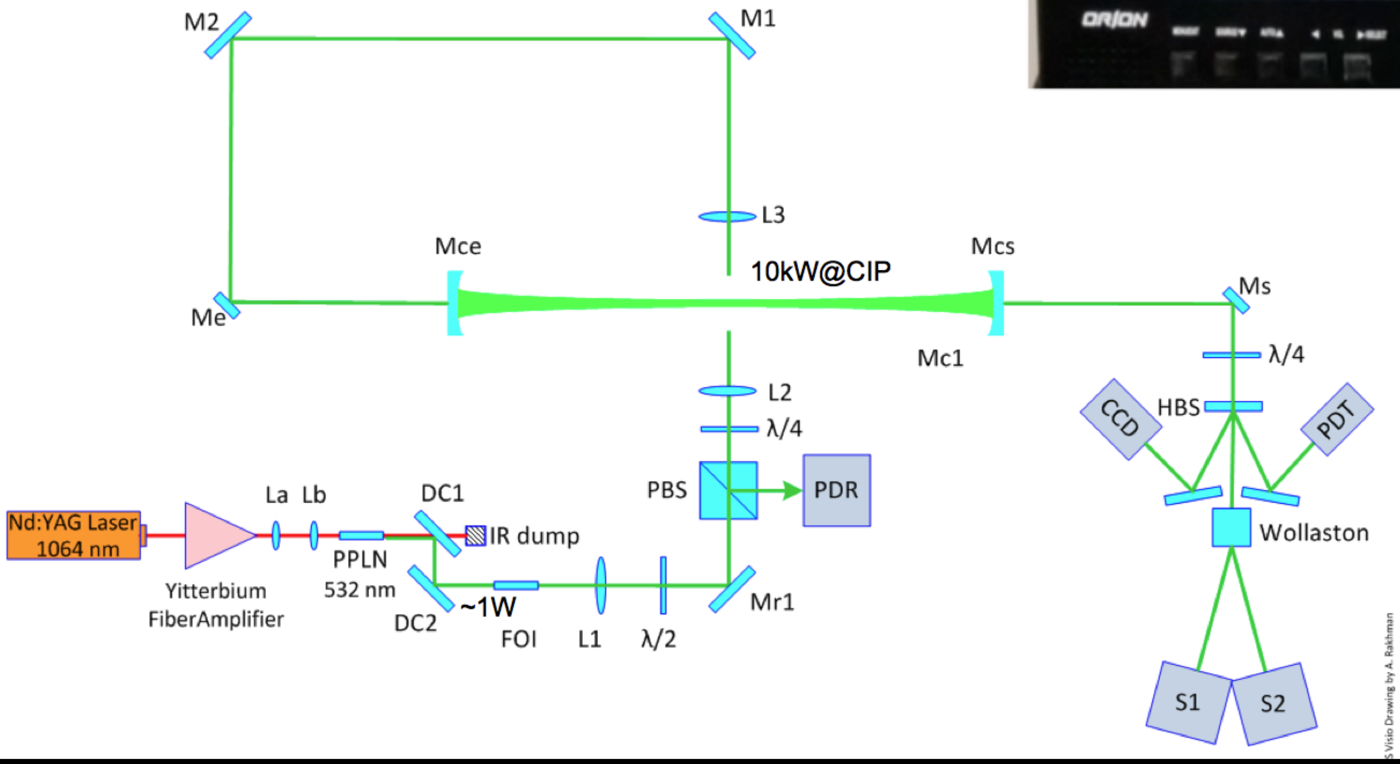
from D. Gaskell, PREX Collab Mtg, Dec 2014

A more optimal design for these shims has already been fabricated - to be installed in problems are evident in 11 GeV Commissioning (DVCS)

Laser

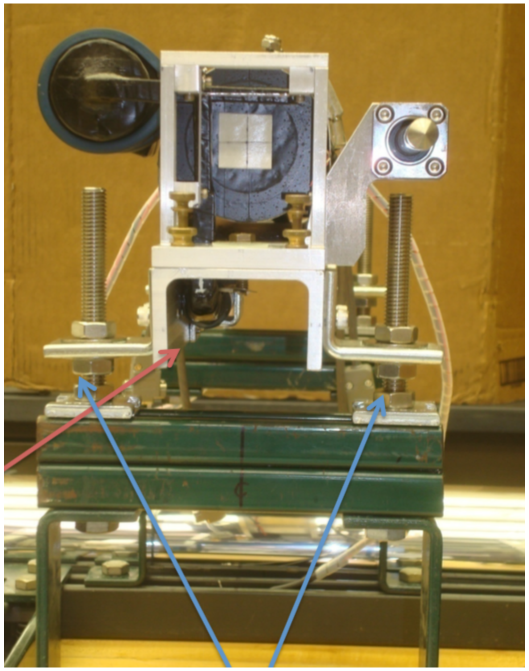
Laser System being revived

- ➡ Doubling to green, with good efficiency (20%, could be improved?)
- ➡ Slow control functionality restored
- ➡ Laser lock established, but low gain (500x expected, 100x achieved)
- ➡ state of the art was 10kW - provided overhead for larger crossing angle (if needed)



Photon Detector

New Photon Detector Mounting
for 11 GeV Configuration

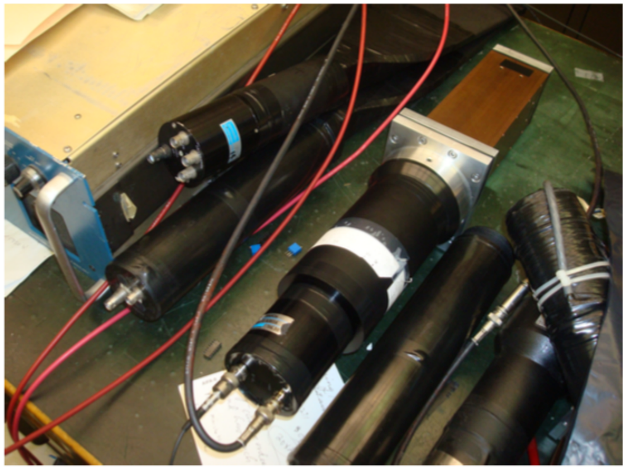


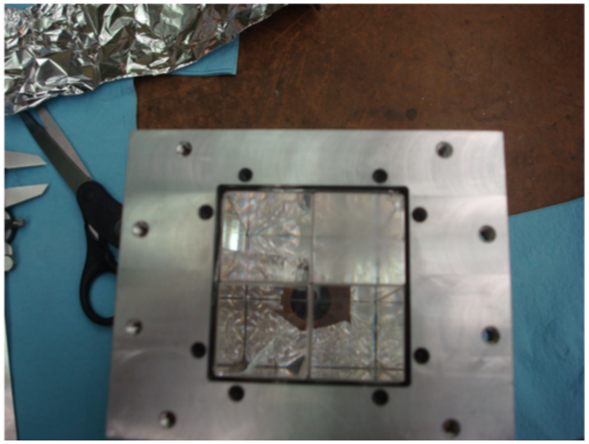
GSO Detector: testing/development underway at CMU. High-resolution for low-energy (PREX)

Tools for linearity/gain studies critical for both 1 GeV and 11 GeV operations

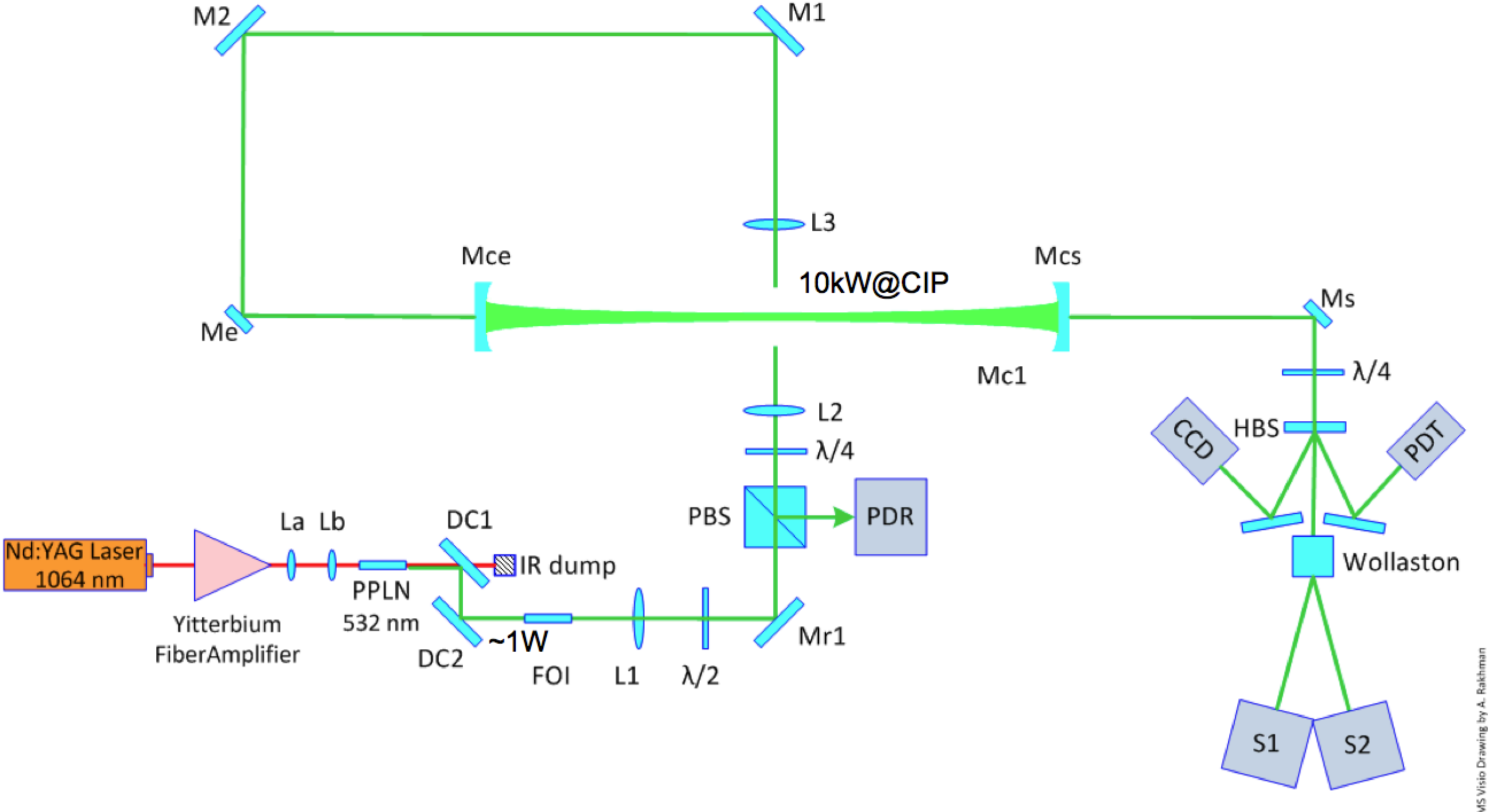
11 GeV needs detector optimized to higher energy (3 GeV vs. 30 MeV photon energy)

Lead-tungstate test detector (2x2 array of 3x3x10cm crystals) to be used during DVCS.



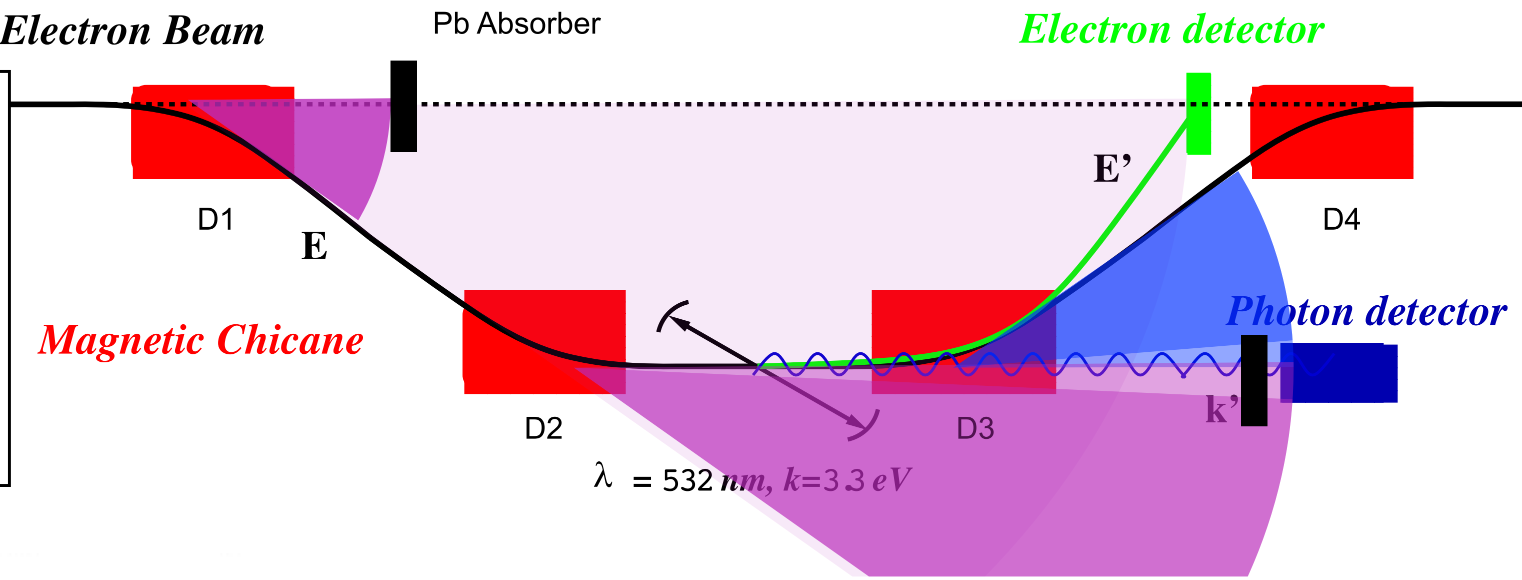


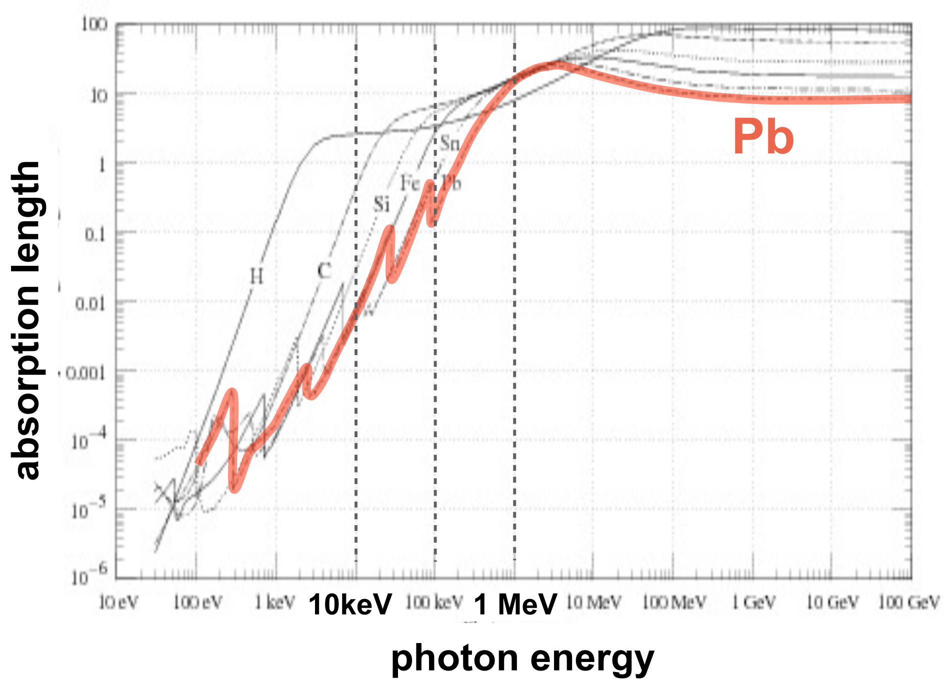
Optical Layout



Synchrotron Radiation

Synchrotron radiation will carry an order of magnitude more power than present 6 GeV running





SR intensity and hardness can be reduced with D2, D3 fringe field extensions

- Excessive SR power overwhelms Compton signal and may increase noise
- SR is blocked by *collimator* (1mrad) to photon detector, except for portion most aligned to interaction region trajectory
- *Shielding* helps, but distorts Compton spectrum, forcing larger corrections to analyzing power

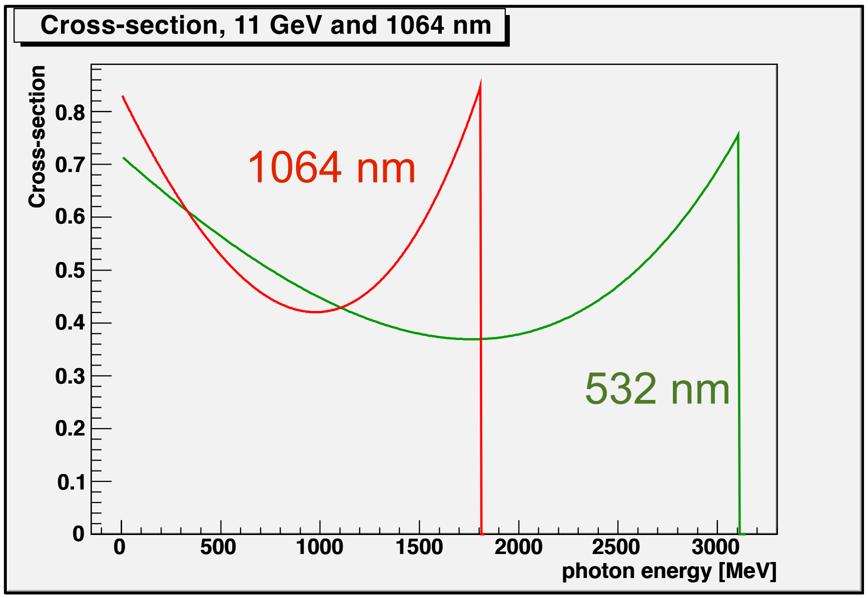
Qweak Electron Detector Analysis

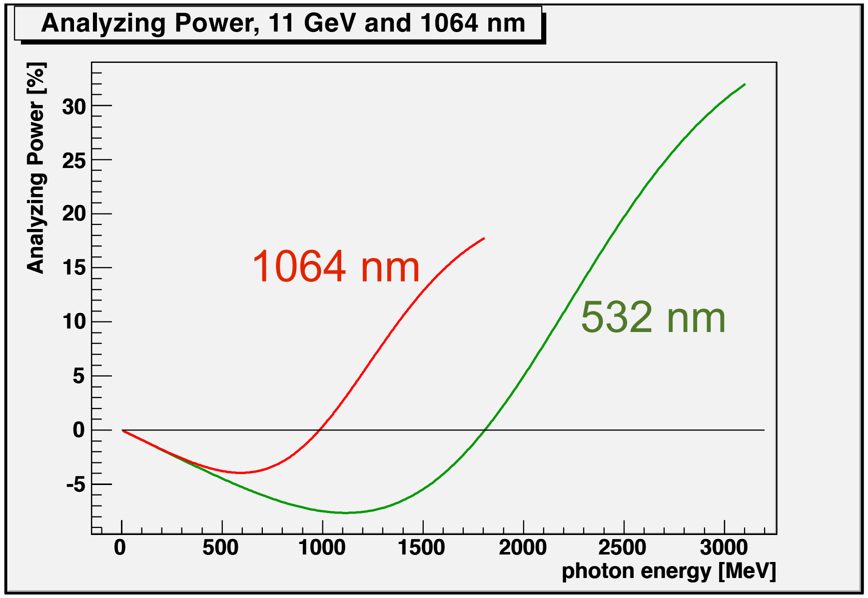
Parameter	Uncertainty	det.P/P%
Laser Polarization	0.18	0.18
Plane to Plane	secondaries	0.00
magnetic field	0.0011 T	0.13
beam energy	1 MeV	0.08
detector z position	1 mm	0.03
inter plane trigger	1-3 plane	0.19
trigger clustering	1-8 strips	0.01
detector tilt(w.r.t x)	1 degree	0.03
detector tilt(w.r.t y)	1 degree	0.02
detector tilt(w.r.t z)	1 degree	0.04
detector efficiency	0.0 - 1.0	0.1
detector noise	up to 0.2% of rate	0.1
fringe field	100%	0.05
radiative corrections	20%	0.05
DAQ inefficiency correction	100% (preliminary)	0.7
DAQ inefficiency pt.-to-pt.	(preliminary)	0.35
Total		0.85

Photon analysis

Energy Weighted Integration
Optimal strategy for low energies.
Uniformity of detector response function is important

Asymmetry Fit or Averaging, with Threshold.
calibration of response function with tagged photons





Detector Response Function -

- Resolution is less important for integrating technique.
  - Helps for e-det coincidence cross-calibration.
- Linearity is crucial in any case
  - large dynamic range in both average and peak current
- PMT and readout require care
- Effect of shielding on asymmetry spectrum