High Precision Polarimetry for SOLID

SOLID collaboration Meeting

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Strategy to meet required 0.4% accuracy

- **Unimpeachable credibility for 0.4% polarimetry**
- **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)**
- **High precision operation at 6.6 GeV - 11 GeV**

Compton

Plan: Upgrade beyond 11 GeV baseline will meet goals

- significant independence in photon vs electron measurements
- continuous monitor with high precision

Møller

Default: Upgraded “high field” polarimeter

- falls short of 0.4%
- invasive

Plan: Atomic hydrogen gas target polarimeter

- expected accuracy to better than 0.4%
- non-invasive, continuous monitor
- Requires significant R&D

Strategy for Moller polarimetry

High Field Moller: 4T to saturate iron foil magnetization

- Based on Hall C system
- 1st implementation in Hall A was less precise than these goals
- Levchuck effect and integration of analyzing power can be well controlled
- Is foil polarization so well understood?

	Hall C	High Field	Atomic H
Target Polarization	0.25%	0.50%	0.01%
Analyzing Power	0.24%	0.30%	0.10%
Levchuk	0.30%	0.20%	0.00%
Target Temp	0.05%	0.02%	0.00%
Dead Time	-	0.30%	0.10%
Background	-	0.30%	0.10%
others	0.10%	0.30%	0.30%
Total	0.47%	0.80%	0.35%

Atomic Hydrogen Polarimeter:

- Precise electron polarization (100%)
- No Levchuk effect
- Reduced radiation / kinematic uncertainty
- non-invasive, continuous monitor
- **R&D required**

Plans for Atomic Moller R&D

Mainz P2 experiment requires high precision polarimetry and, at low energies, has limited options.

Atomic Hydrogen Moller is ideal!

Plan:

- Build prototype using existing UVa (UMich) atomic trap
- Build a 2nd generation trap for P2
- Apply lessons to design and construction of a second trap for 6-11 GeV application at JLab

Status:

- UVa trap to be shipped to Mainz (any day now!)
- Postdoctoral researcher is hired, will start project mid-June
- Wouter Deconinck at W&M: funded for R&D, will start electrode design this summer with graduate student

More from Kurt Aulenbacher, in next talk

Compton Polarimetry

0.5% at the SLD Compton Polarimeter

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

- Published results δP/P~0.5%
- Integrating electron and photon detectors
- 2/3 operating time was calibration, not "production"

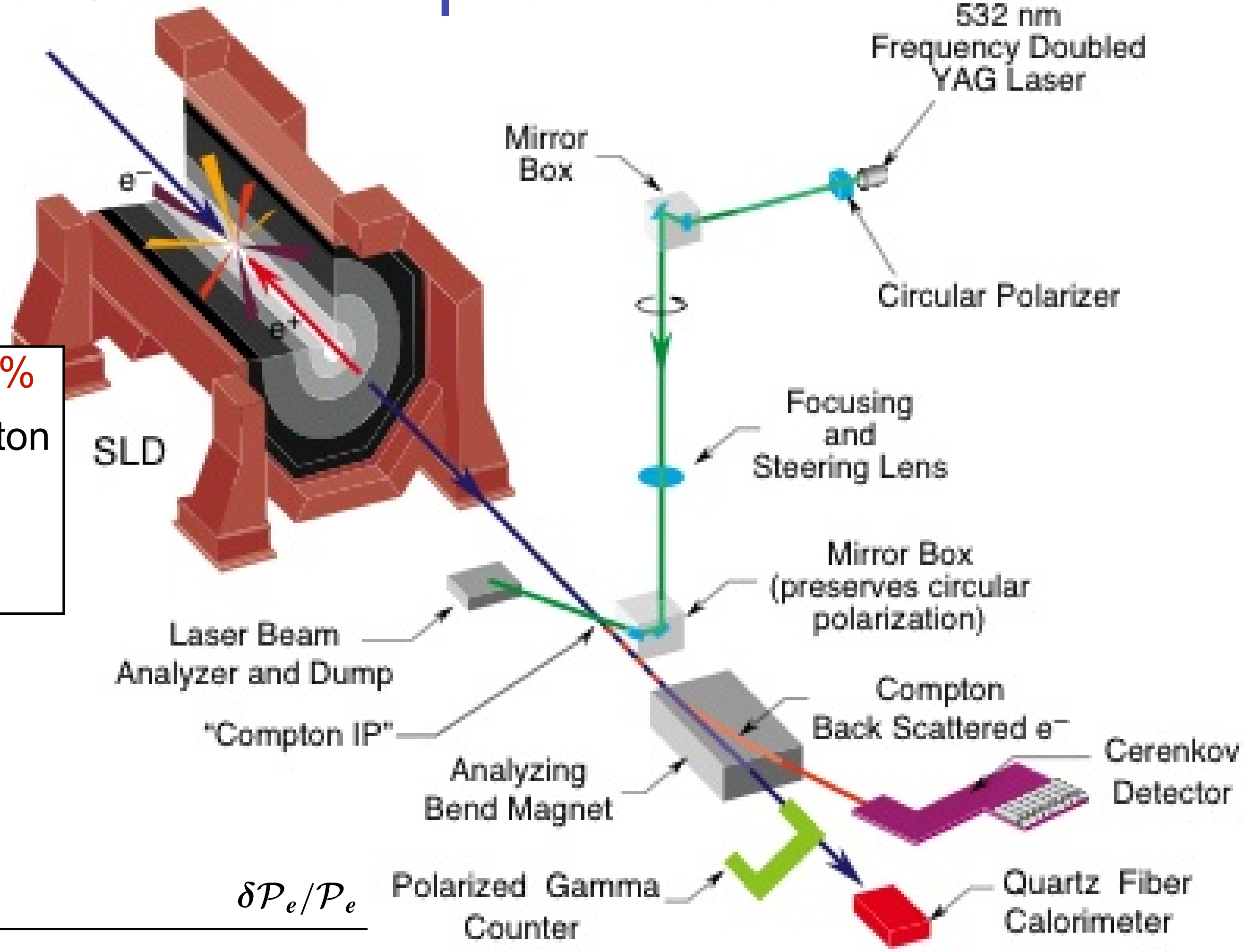


Table from:
Annu. Rev. Nucl. Part. Sci.
2001. 51:345–412

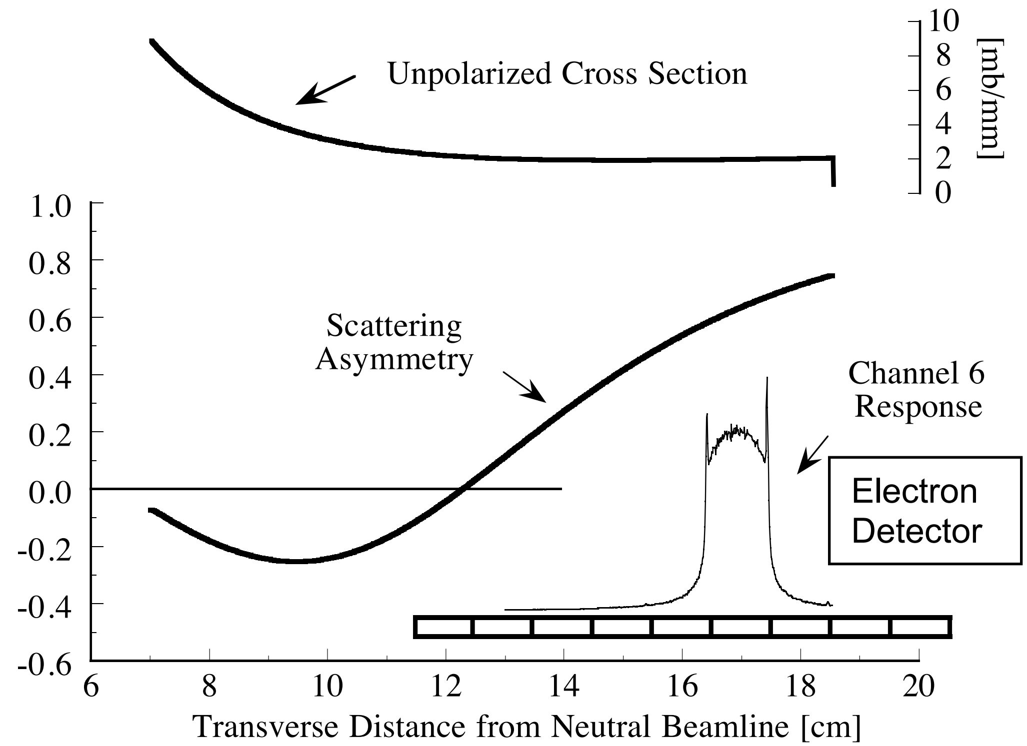
Uncertainty (%)	$\delta\mathcal{P}_e/\mathcal{P}_e$
Laser polarization	0.10
Detector linearity	0.20
Analyzing power calibration	0.40
Electronic noise	0.20
Total polarimeter uncertainty	0.50

Bounded by cross-calibration with photon detector

Collider Compton Polarimetery

Detector element at the Compton edge was least sensitive to energy calibration and response function, and so most precise

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



Why do we think we can do better?

- Independent electron/photon measurements
- Hall A has single-photon / single-electron mode (CW)
- Greater electron detector resolution
- Greater coverage of Compton-scattered spectrum

High Precision Goals

Relative Error (%)	electron	photon
Position Asymmetries	-	-
E_{beam} and λ_{laser}	0.03	0.03
Radiative Corrections	0.05	0.05
Laser Polarization	0.20	0.20
Background/Deadtime/Pileup	0.20	0.20
Analyzing Power Calibration / Detector Linearity	0.25	0.35
Total	0.38	0.45

correlated

uncorrelated

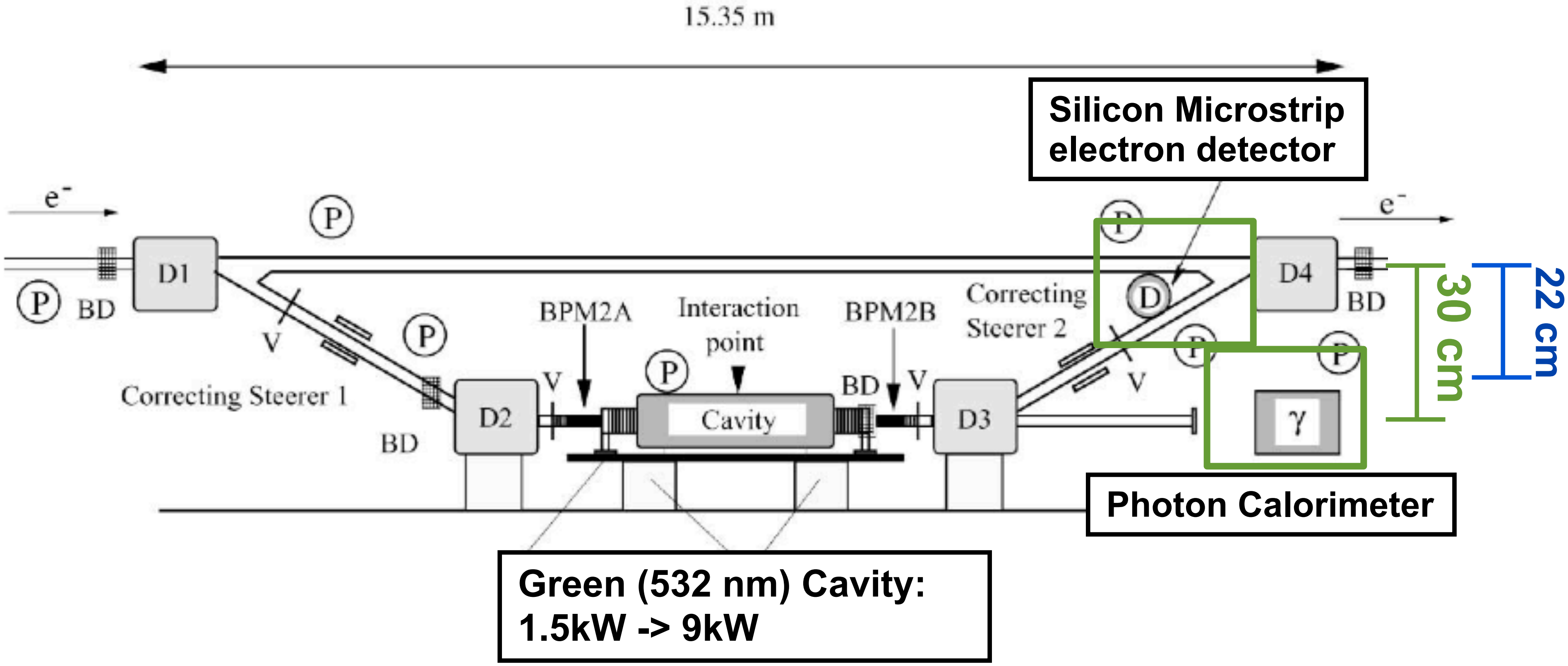
Independent detection of photons and electrons provides **two (nearly) independent polarization measurements**; **each should be better than 0.5%**

What's been achieved: ~1%
(HAPPEX-3, PREX, Qweak)

Primary Challenges:
- Laser Polarization
- Synchrotron Light
- Signal / Background

Participants from UVa, Syracuse, JLab, CMU, ANL, Miss. St., W&M

Hall A Compton Polarimeter



Standard Equipment upgrade plan for 11 GeV Operation:

- Reduce chicane bend angle
- Laser power will be ~9kW
- New e-det (Thicker silicon, new electronics)

Other likely changes not in upgrade scope:

- DAQ rebuild (replace aging, non-replaceable components)
- New (old?) photon calorimeter to contain high-E shower

Electron analysis at 11 GeV

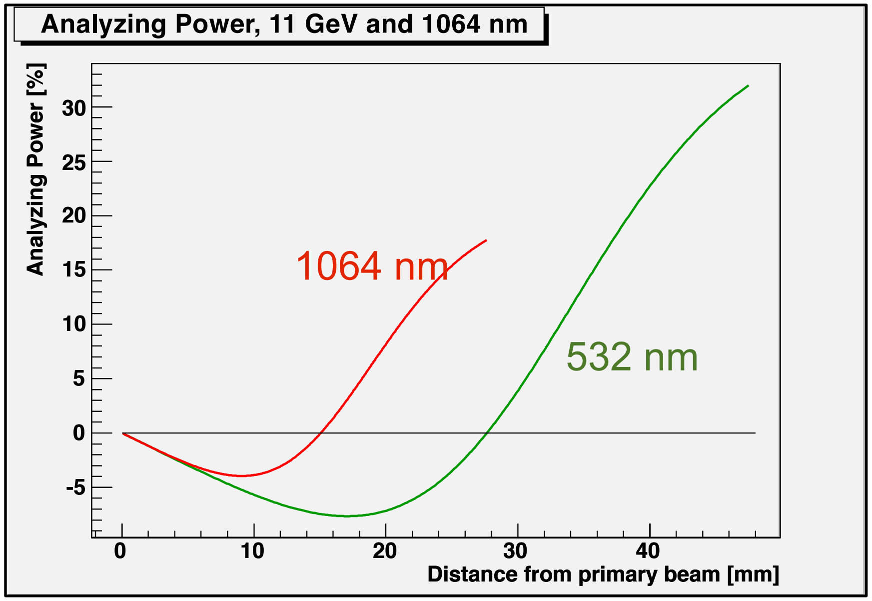
Analyzing power should be very well known,

- **Asymmetry Fit:** using Compton edge and 0xing to calibrate
- **Integration:** Compton edge to 0xing
- **Edge "single strip"**- a single microstrip, 250 micron pitch, right at the compton edge. (~30 minutes to 0.5%)
- **Minimum single strip**- a single microstrip, at the asymmetry minimum (~12 hours to 0.5%)

Other systematic effects must be treated carefully

- Compton Edge location
- Background sensitivity
- Deadtime
- Synch light
- Rescattered Compton Bkgrnd

Detector does not presently exist: upgrade is underway

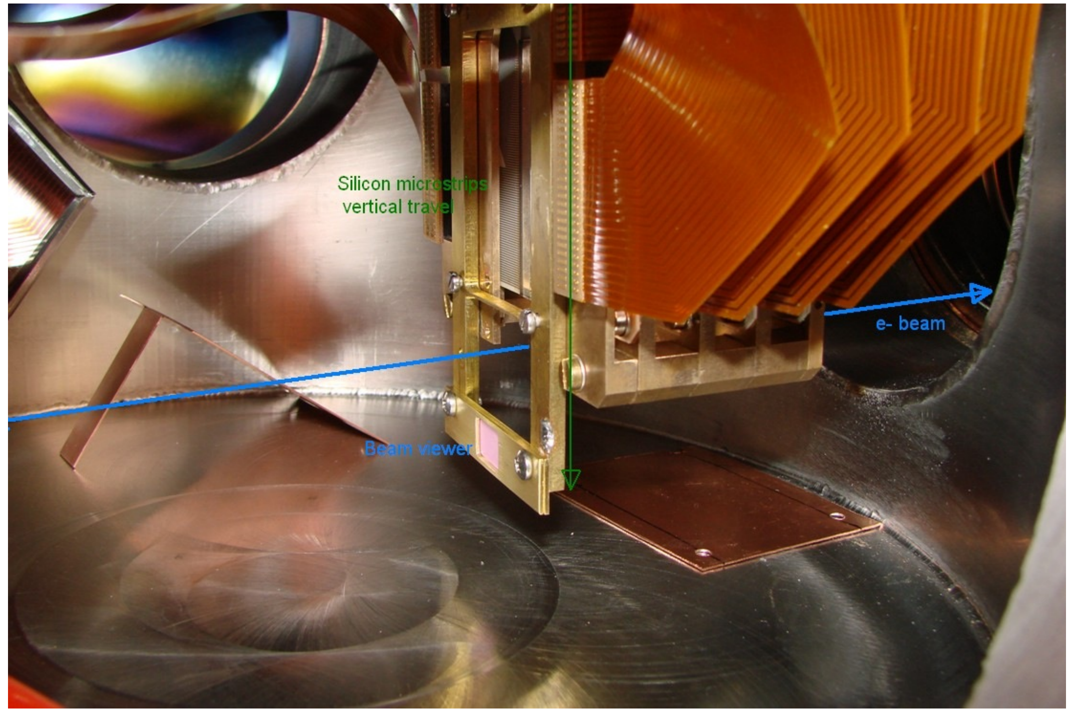


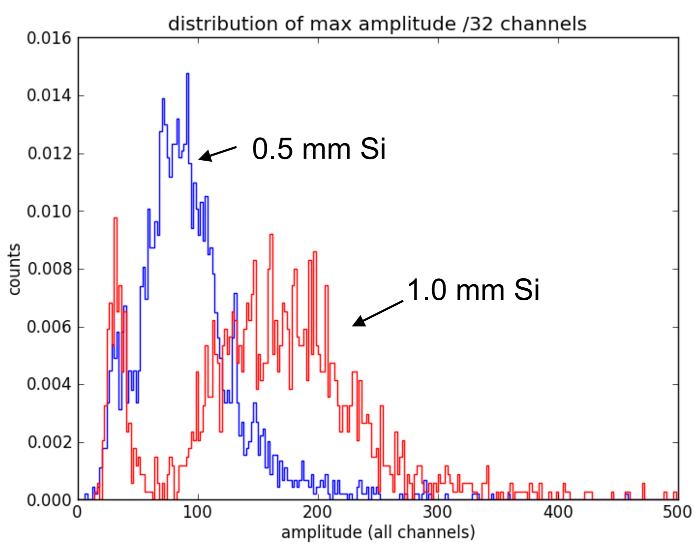
Electron Detector Replacement

Clermont-Ferrand

Silicon Microstrip Detectors

- 758 ch, 240 μm pitch
- 4 planes, 1cm spacing
- 192 strips/plane (~45mm)

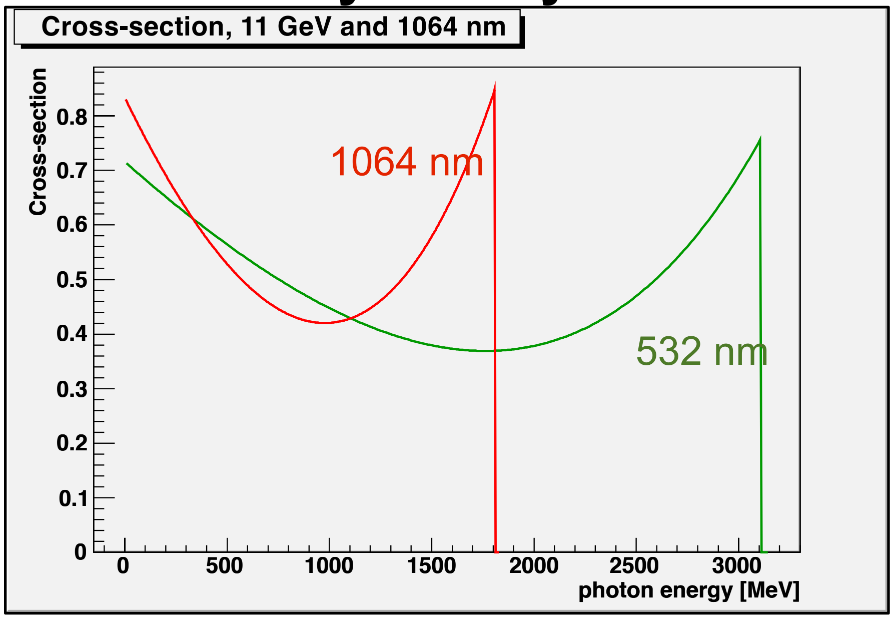


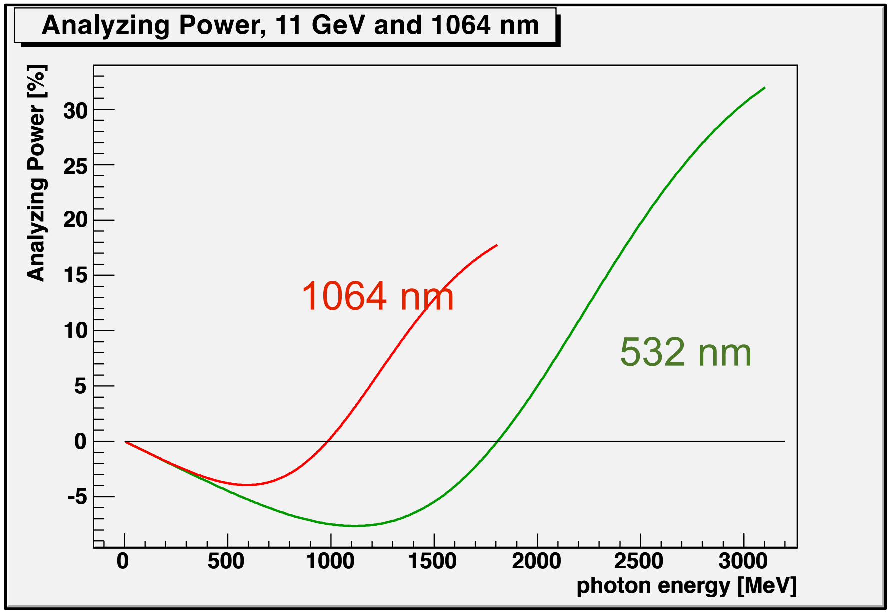


New installation 2009
- signal size insufficient for noise
- some improvements in electronics
- 1mm thickness gives better signal than 0.5mm. Cosmic tests underway.

Photon analysis with a “clean” spectrum

- **Energy Weighted Integration**
- **Asymmetry Fit:** using Compton edge and 0xing to calibrate
- **Cut in Asymmetry minimum**





Detector Response Function will be important. Resolution is less important for integrating technique, but linearity is crucial in any case.

Sensitivity to Synch light - and effect of shielding on analyzing power

- Existing calorimeter will probably need to be replaced.
- PMT will require careful preparation (assure and measure linearity)

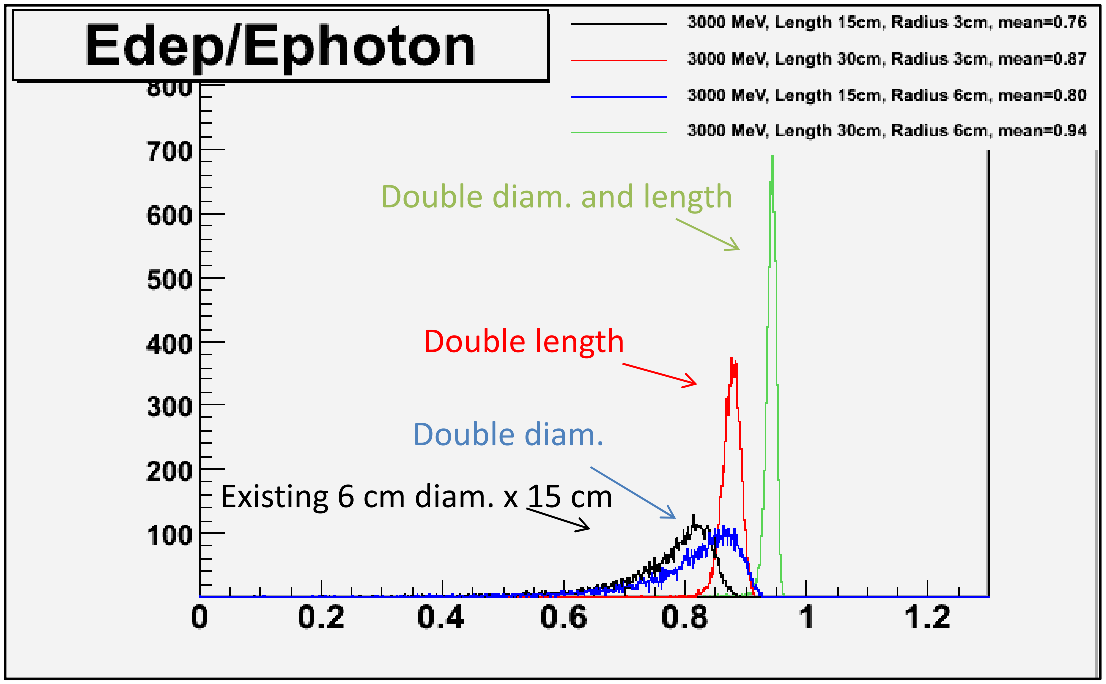
Photon Detector Options

Existing detector: GSO scintillating crystal,
15cm long, 6cm diameter
~60ns, ~150 photoelectron/MeV

but, small for high-energy photons

Something larger needed to contain showers at high energy,
(maybe 6”x6”x15”)

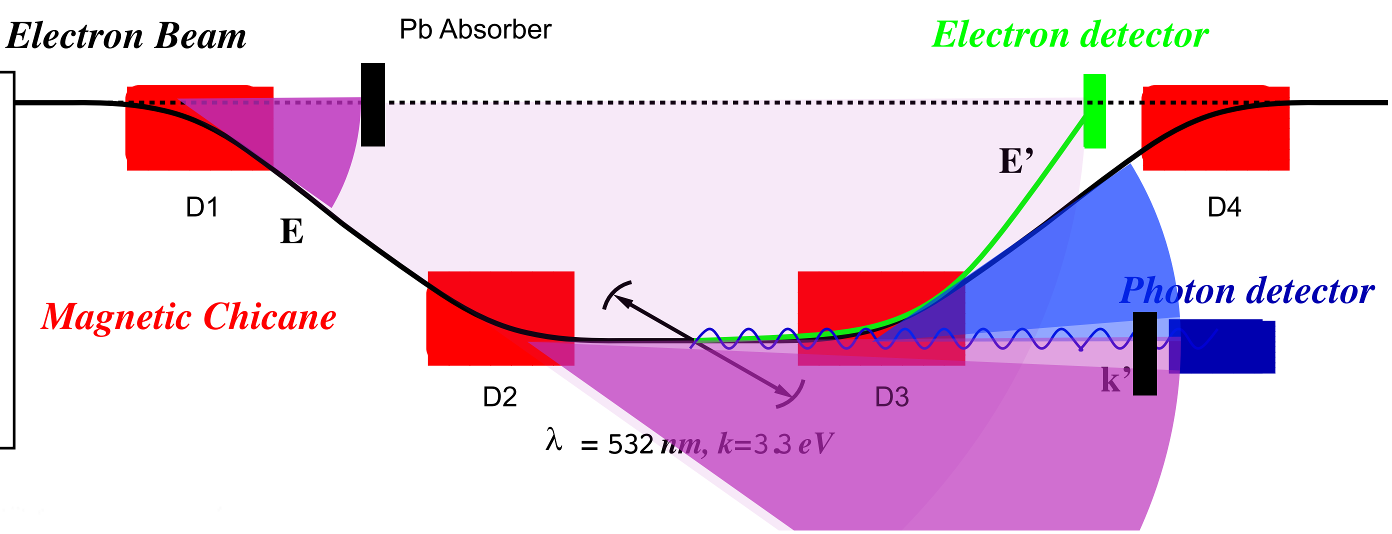
Must investigate lead glass, other Cerenkov or scintillating
detectors in simulation



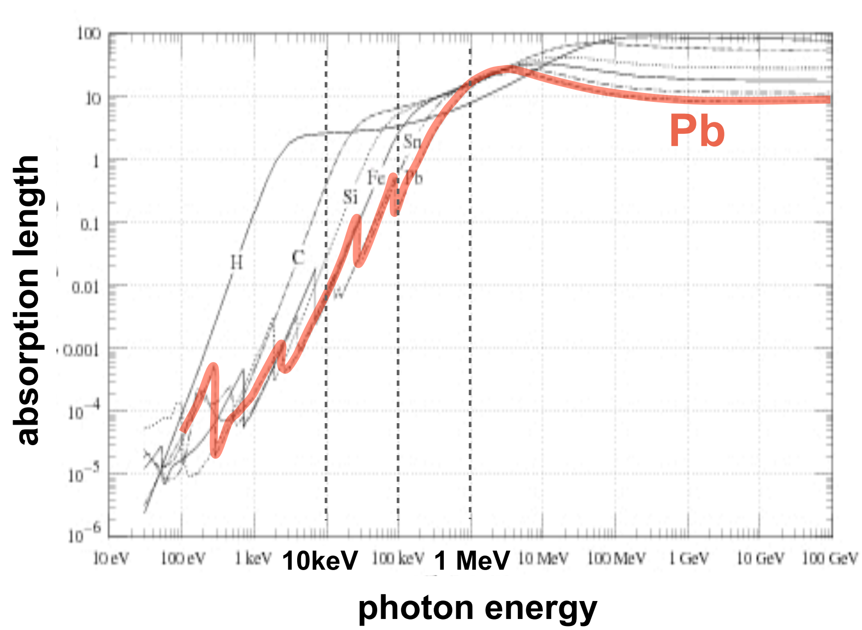
Synchrotron Radiation

Synchrotron Radiation

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



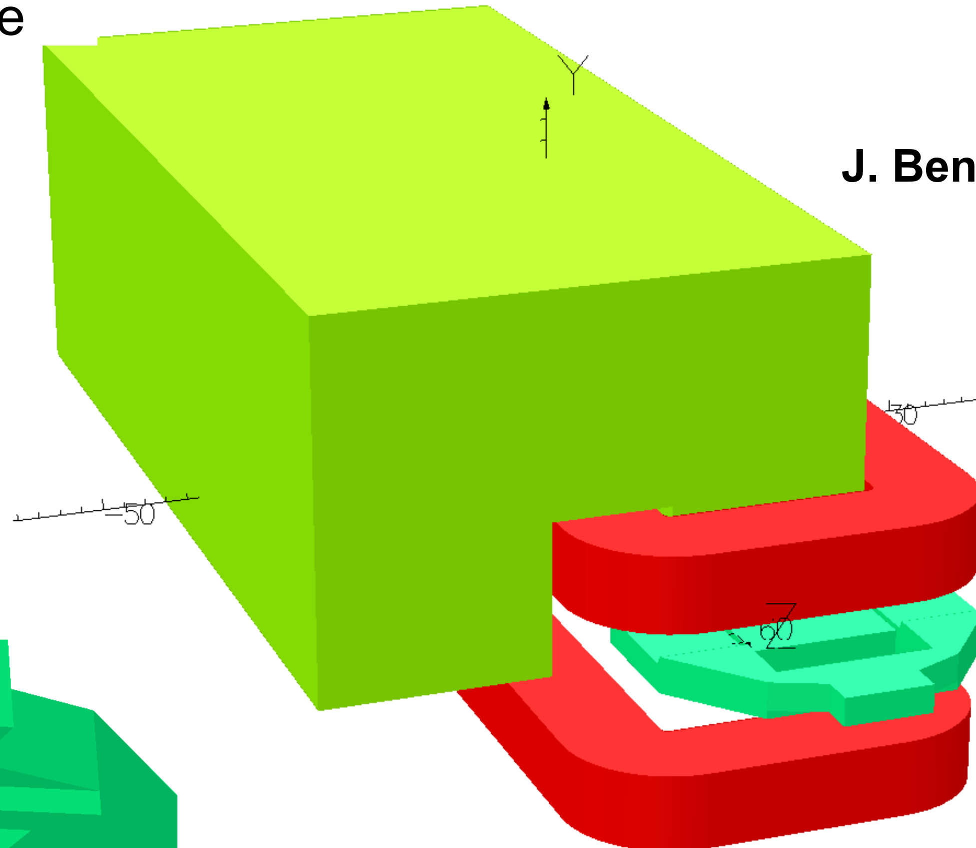
SR intensity and hardness can be reduced with D2, D3 fringe field extensions



- 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

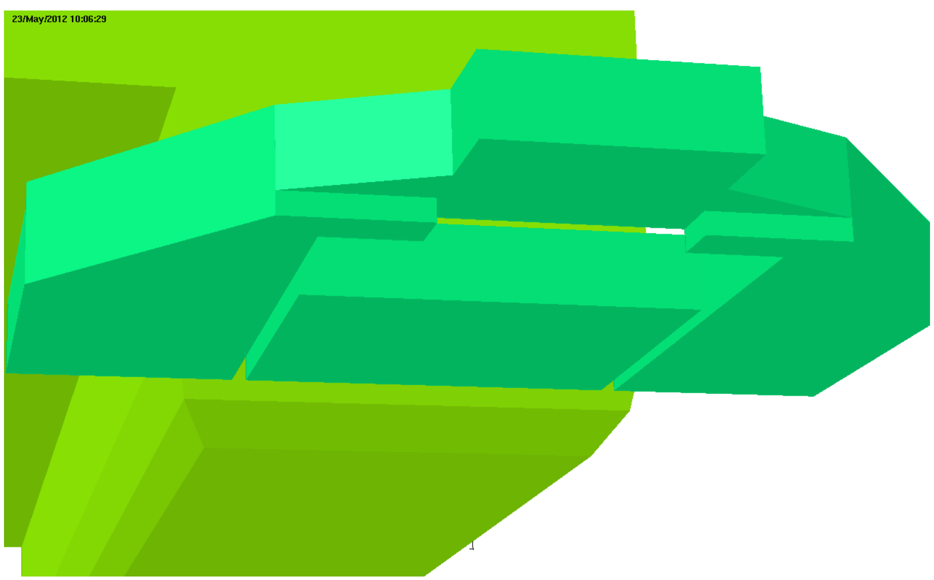
Modeling the Dipoles

Bolt-on shims, no cutting of iron yoke or modification of beamline



J. Benesch

All 4 dipoles will be shimmed in this way, to improve operability



- Do magnets require re-mapping?
- Design will be completed during 16mo down

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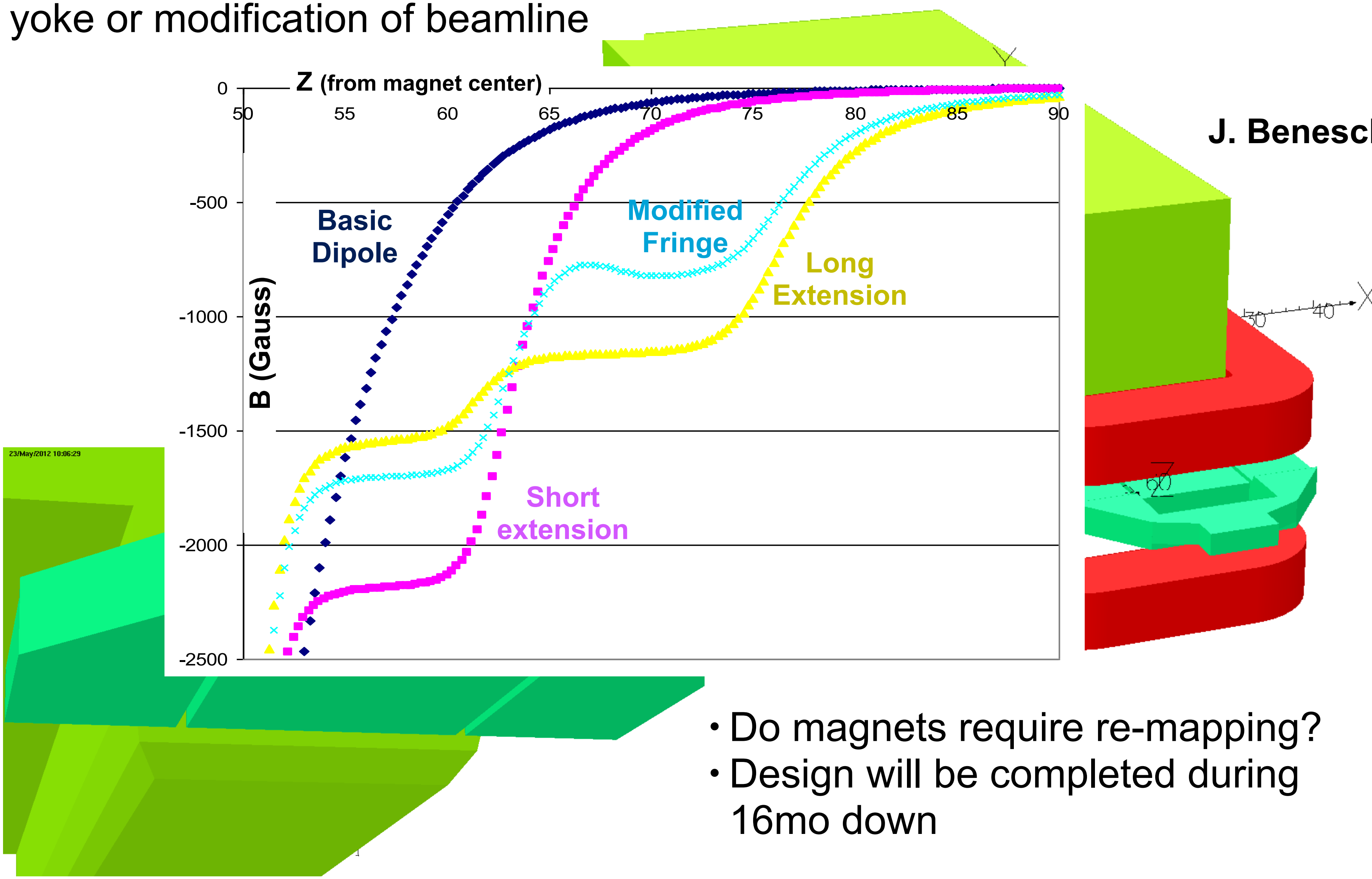

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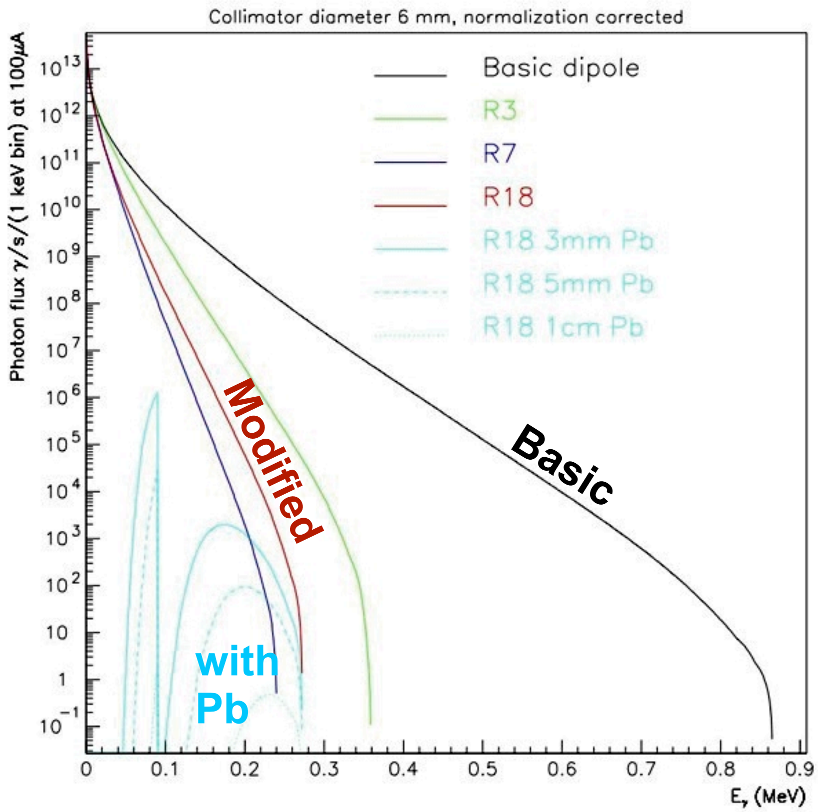
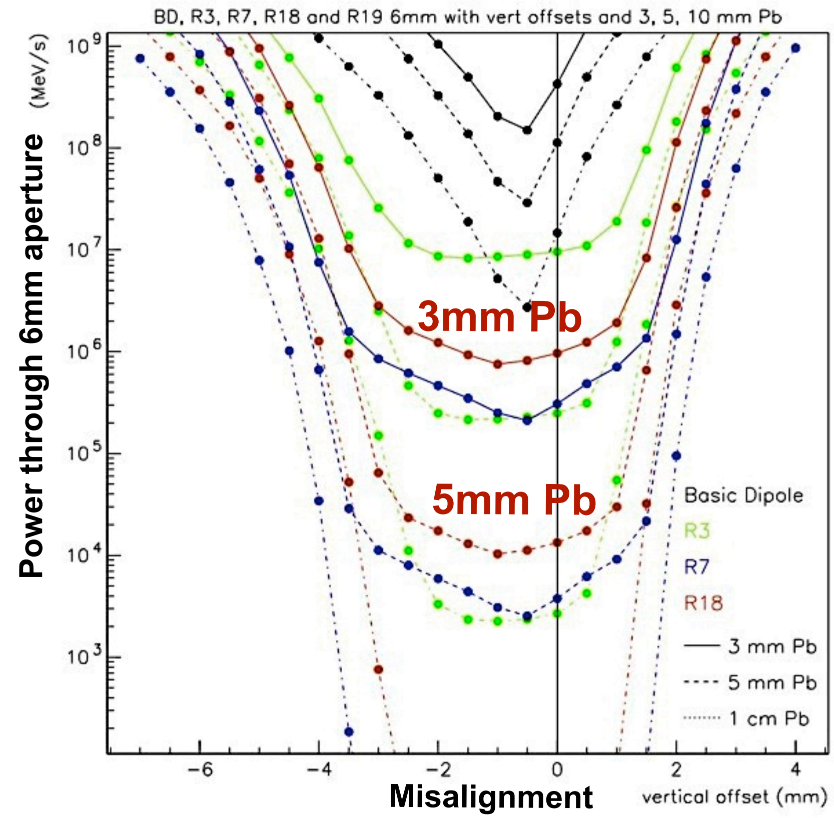
Reduced SR power, robust operation





Benesch, Quinn (CMU)

All 4 dipoles will be shimmed in this way, to improve operability

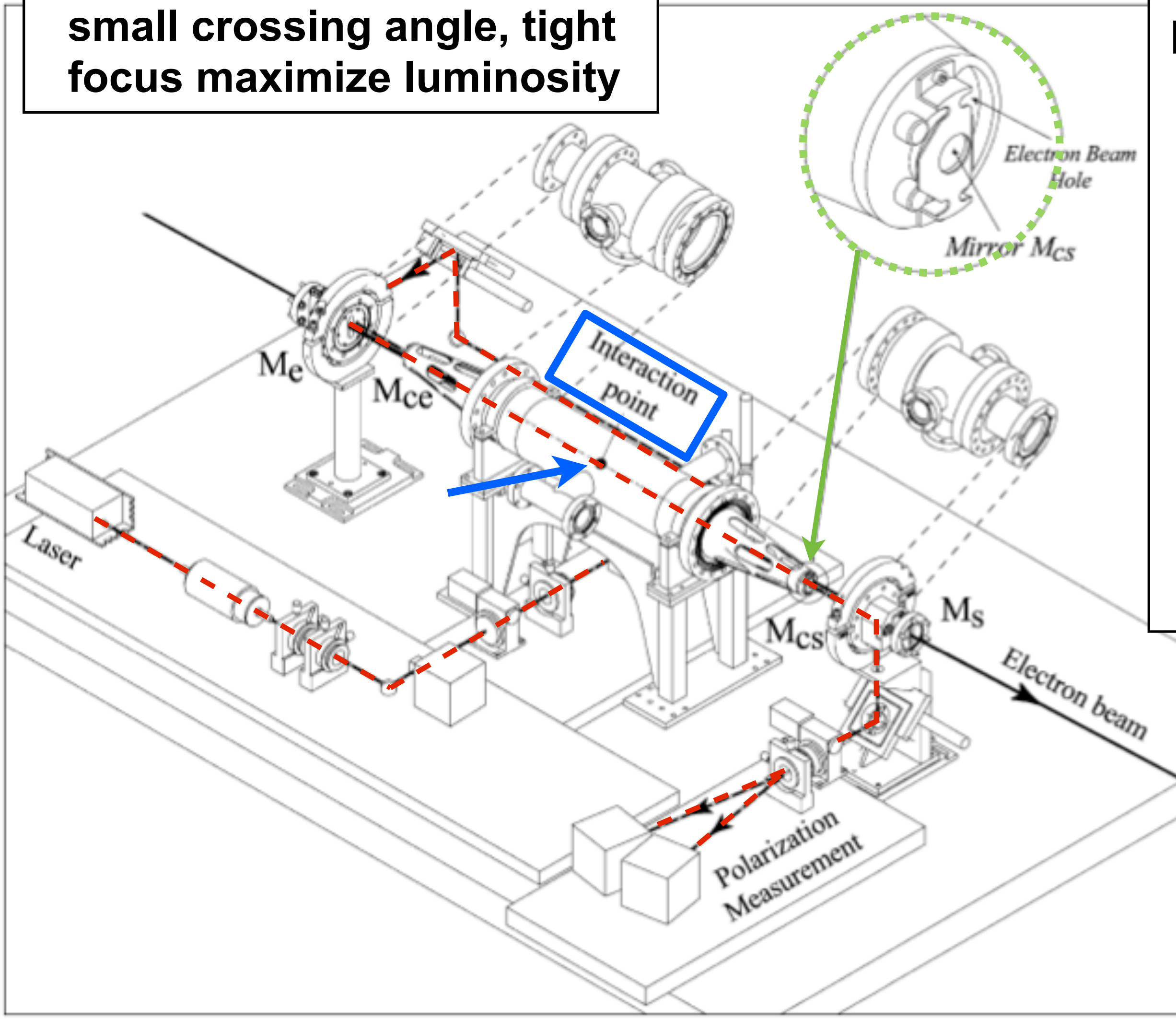
	3mm Pb	5mm Pb
Basic Dipole	450 TeV/s	120 TeV/s
Modified Dipole	1 TeV/s	0.01 TeV/s
Compton Signal	860 TeV/s	860 TeV/s

Laser Polarization

Hall A Compton Interaction Region

- 23 mrad crossing angle
- 1 cm e- beam aperture
- 125 µm laser spot
- 50-100 µm e^- beam spot

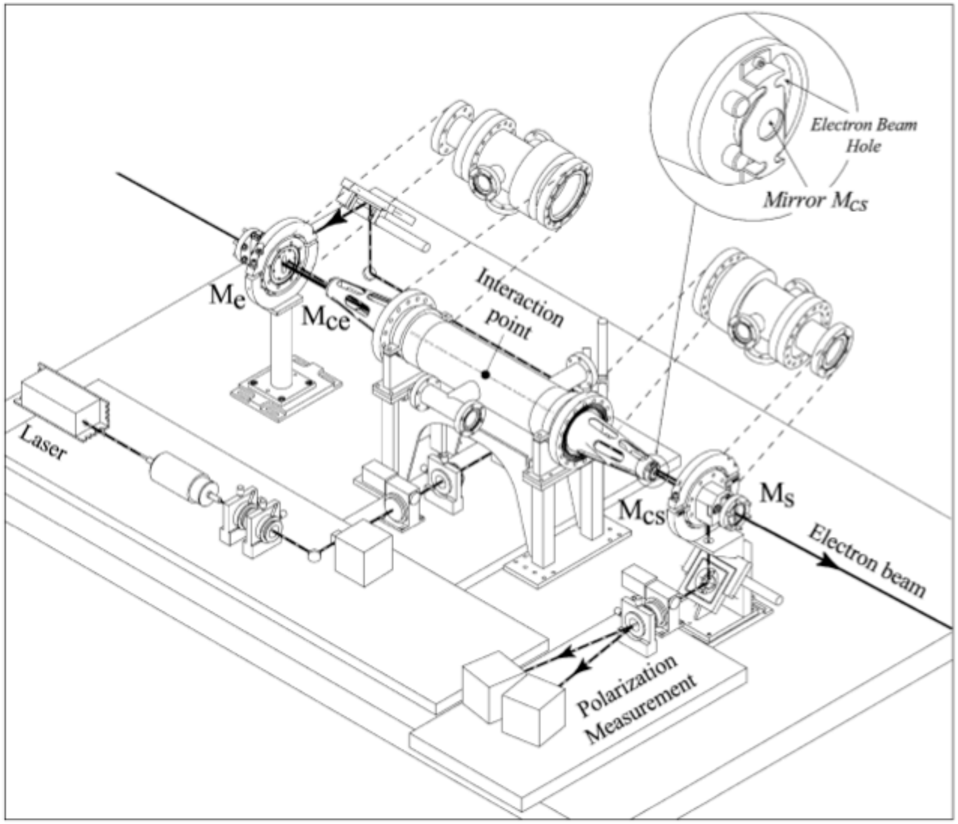
small crossing angle, tight focus maximize luminosity



532 nm (green) light in a Fabry-Perot resonant cavity

- Continuous wave
- 200 mW 1064nm source laser
- amplified (>5W), SHG doubled to 532nm (1-2W)
- Gain ~ 12000
- Finesse ~ 26000
- Waist radius ~125 micron
- 9 kW stored

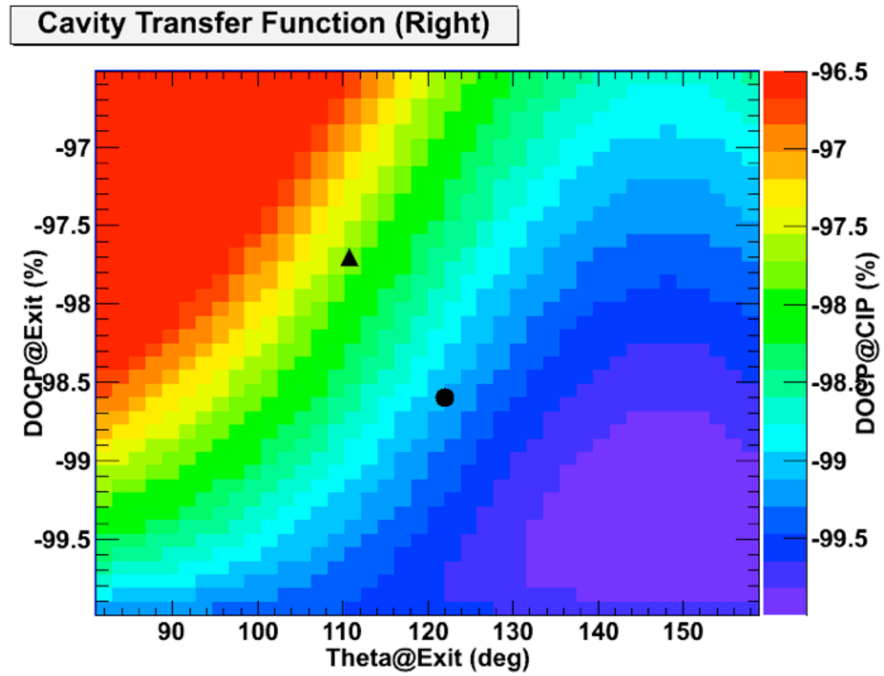
Determining Laser Polarization



Do we know the polarization inside the **cavity** by monitoring the transmitted light?

Current uncertainty: 0.35%-1%

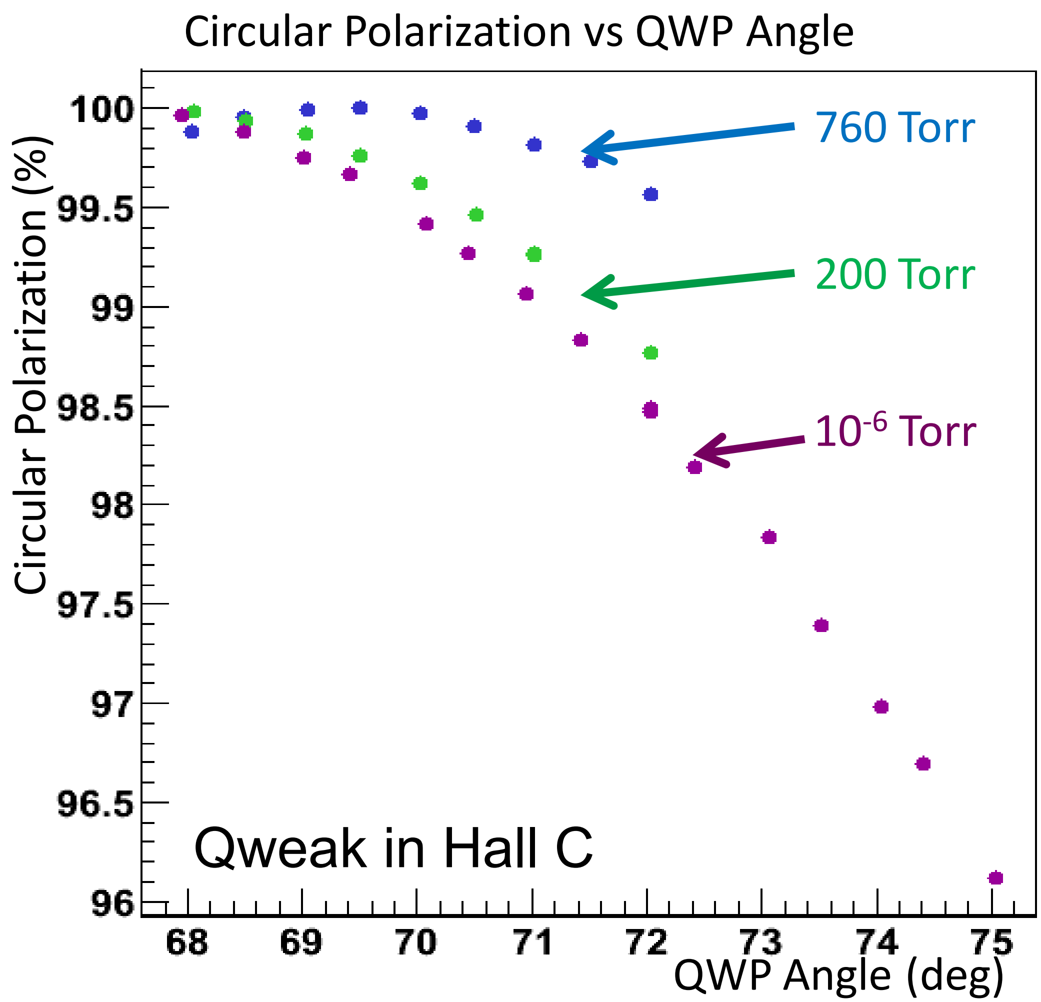
Transfer function translates measured transmitted polarization after cavity to the Compton Interaction Point



Are there effects from
- cavity mirrors?
- power level (heating)?
- alignment variations?
- model dependence of TF?

Very High Precision will require significant improvements. Goal = 0.2%

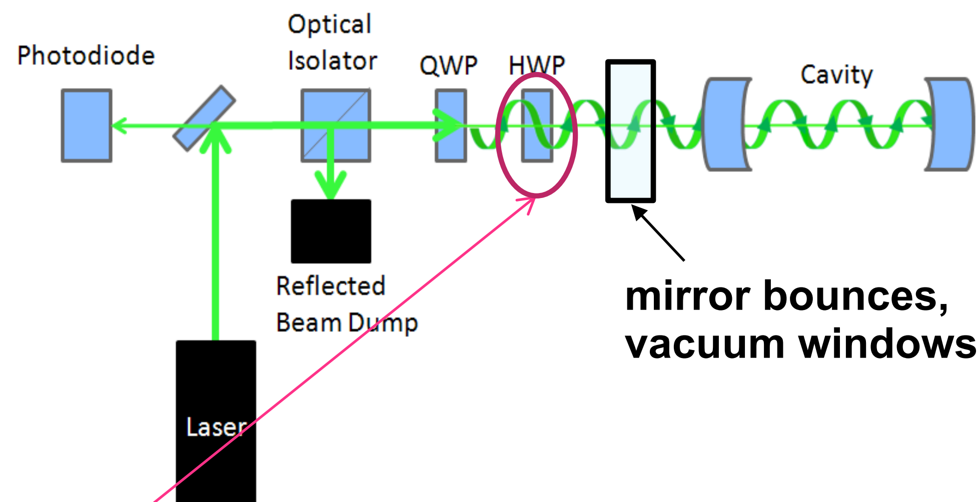
Vacuum / Assembly Stress Induced Birefringence



Measurement at exit changes with vacuum pressure.
Is it a change on input? Output? Who knows?

Optical Reversibility Theorem

Beam polarization is used for optical isolation: back-reflected circular light is opposite handedness, and is opposite to initial linear polarization after the QWP



This isolation fails, to the degree that light is not perfectly circular at the reflecting surface.

Mark Dalton

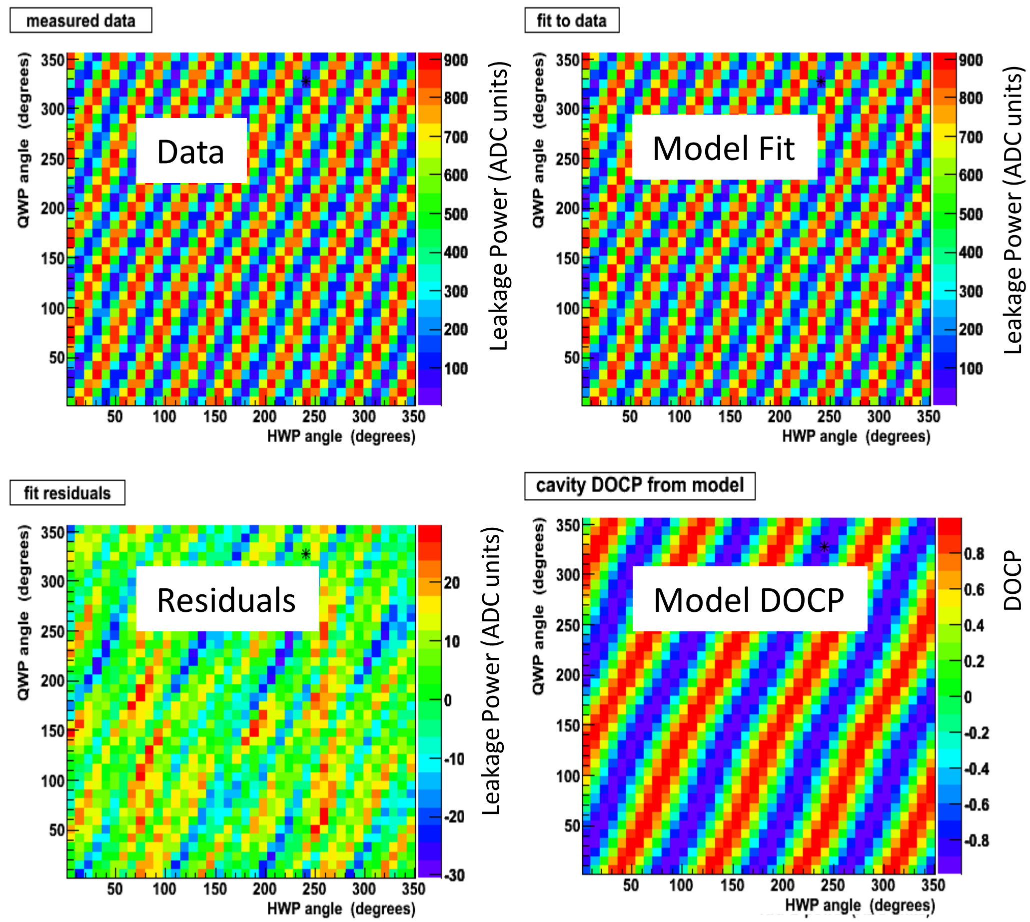
This provides a technique to repeatably maximize circular polarization, even in the case of changing intermediary birefringent elements (vacuum or thermal stress, etc.)

This technique appears in the literature as well, for similar configurations ("Remote control of polarization")

Preliminary Studies

Leakage power was measured while scanning over initial polarization set by QWP and HWP.

Fit demonstrates model is self-consistent, suggesting 100% polarization can be set at cavity entrance with <0.1% uncertainty

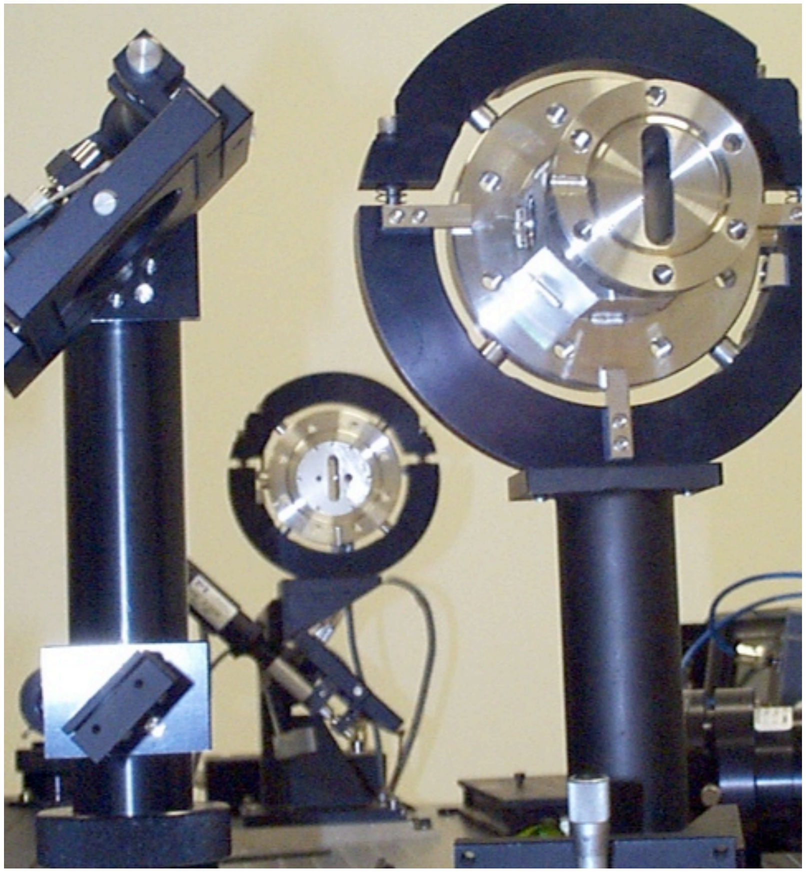


Mark Dalton

Further study is required to verify this technique, and bound the accuracy. Qweak decommissioning will include a significant study of this technique

Crossing Angle, Laser Options

Existing Compton Interaction Region



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

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 and the small CEBAF magnetic apertures?

UPTIME and PRECISION will go up if we use larger apertures
(and therefore larger crossing angles)

~3.6 degrees puts aperture at size of beampipe,
luminosity drops by a factor of 3
9kW should be sufficient. Which gives better accuracy?

Alternative: RF Pulsed Laser

RF pulsed laser, at 499 MHz (or close subharmonic)

High duty factor: still single-photon/electron mode

Such a laser is feasible:

- commercial IR 100MHz, 10ps at 45 W

RF IR Pulsed “1-pass”:

- 350 Hz/μA
- Fast on/off improves background subtraction

No cavity mirrors: does the “single-shot” laser path reduce uncertainty in the laser polarization measurement?

RF IR Pulsed cavity:

- proof of concept exists
- low gain = fairly robust
- statistical power matches CW cavity

New Problem: time-dependent polarization shift in 10ps pulse?

Given the progress on controlling laser polarization and the high power of the existing system, we do not expect (at this time) to pursue a pulsed laser option.

Status Summary

Moller polarimeter:

Work on atomic hydrogen Moller is starting now at Mainz, with the intention of running this polarimeter for the P2 measurement and bringing this technology to JLab

Compton polarimeter:

Baseline upgrade (chicane + electron detector) should create a functional polarimeter
High precision requires additional work:

- **Chicane magnet field extension** is essential for photon detector operation. Conceptual design is underway.
- Significant progress on crucial issue of **laser polarization** measurement, to be confirmed by bench studies staring with QWeak decommissioning.
- High power cavity should allow us to meet precision goals even with larger crossing angle, ***IF*** laser polarization is proved on the bench to be under control
- Alternative laser system is feasible, but presents its own optical polarization challenges
- New **photon detector**. Careful characterization needed**.**
- Work on-going, and significant technological development from recent Hall A and C measurements.
- Participants from UVa, Syracuse, JLab, CMU, ANL, Miss. St., W&M