High Precision Polarimetry for SOLID

SOLID collaboration Meeting

December 15, 2012

Kent Paschke

University of Virginia

Working Group: E. Chudakov, D. Gaskell, S. Nanda, M. Dalton, K. Aulenbacher, V. Tioukine, W. Deconinck, J. Singh, D. Dutta, G. Franklin, B. Quinn, J. Benesch

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

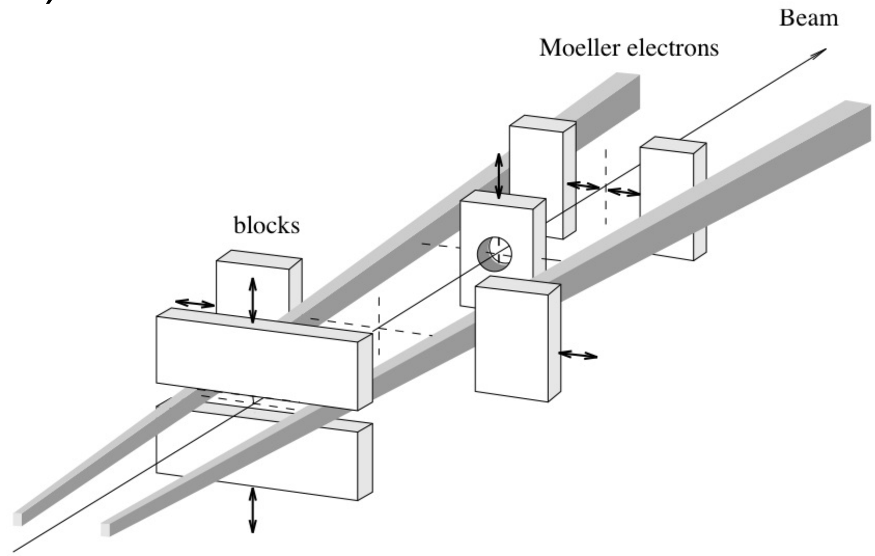
- falls short of 0.4%
- invasive

Plan: Atomic hydrogen gas target polarimeter

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

Hall C High-Field Møller Polarimeter

- Coincidence measurement of $e^- + e^- \rightarrow e^- + e^-$
- Iron foil in 4T field (saturated, low uncertainty in e- polarization)
- Precise collimation system: must be well simulated to control analyzing power and Levchuck effect (~3%)



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Target Polarization	0.25%
Analyzing Power	0.24%
Levchuk	0.30%
Target Temp	0.05%
Dead Time	-
Background	-
others	0.10%
Total	0.47%

- Analyzing power ~7/9 at $\theta_{CM} = 90^o$
- High cross-section
- Ferromagnetic target $P_T \sim 8\%$
- Invasive, 1-10 μm thick foil
- Low current only

High-Field Møller in Hall A

- Based on Hall C system
- 1st implementation in Hall A was less precise than these goals
- Not optimal implementation - uncertainties can be improved

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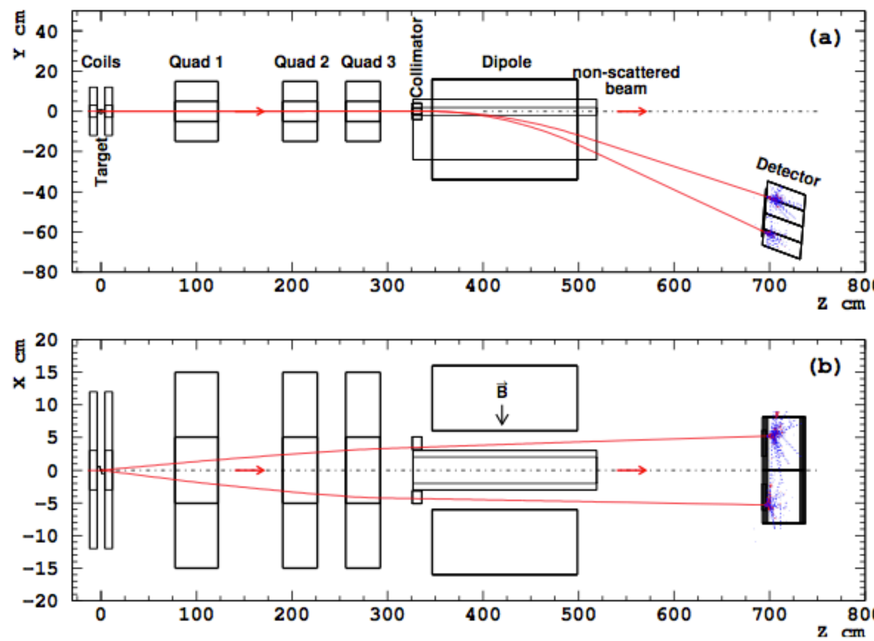

Large acceptance to integrate analyzing power, reduce Levchuck correction

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Known from measurements in bulk material, subtracting out orbital contribution (5% effect). Foil alignment and stability also critical

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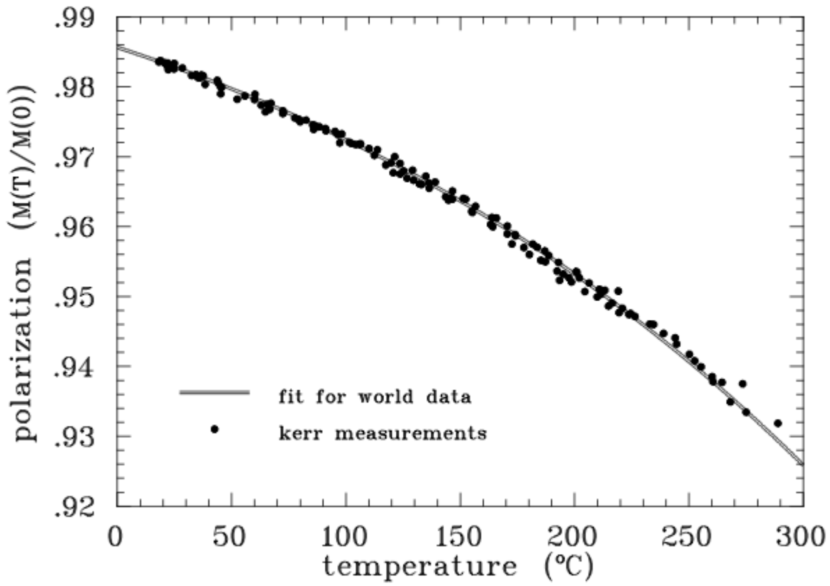
Can be improved, but not negligible at this level. Another reason to prefer low current

Target Polarization vs. Temperature

Trend of surface polarization vs. sample temperature
measured via Kerr effect on reflected light.



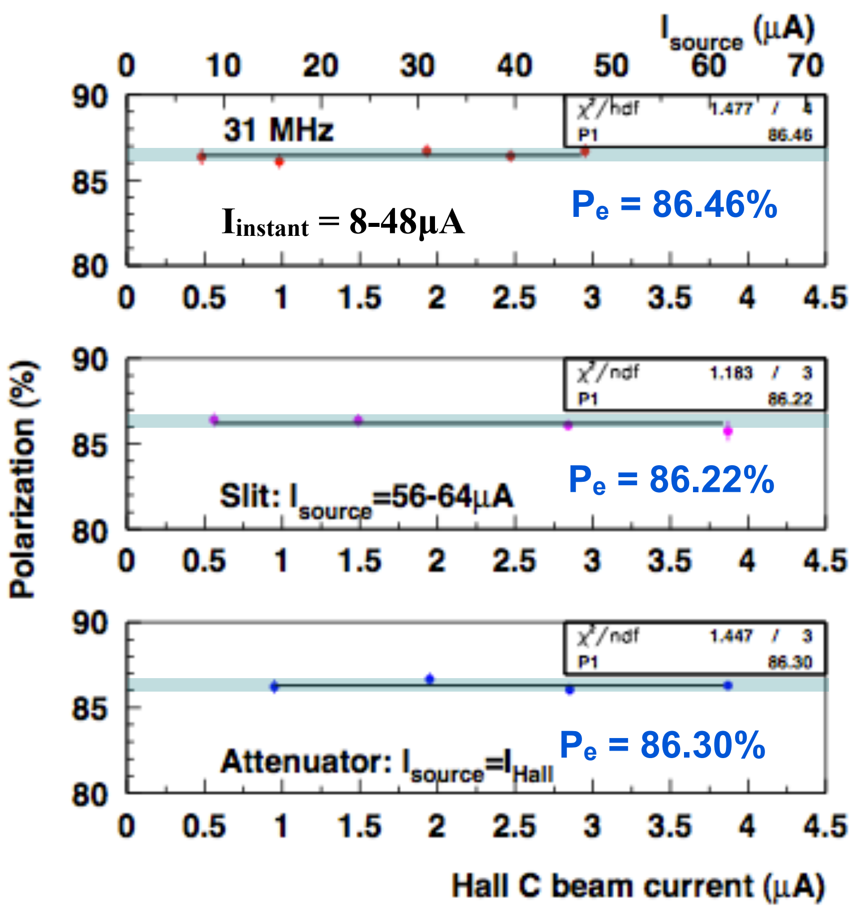
in situ Kerr relative monitoring is proposed, but challenging

One challenge: overlapping optical measurement with beam-heated region. Size must match, to maintain sensitivity.

This potentially complicates the question of whether Moller measurements at low currents provide a good measure of the polarization at high current

Beam Current vs Polarization

There is no convincing empirical evidence for a possible systematic variation of polarization with beam current, but existing evidence against is also limited



Beat frequency technique allows high instantaneous current

SOLID requires 0.4%
(bands show +/- 0.5%)

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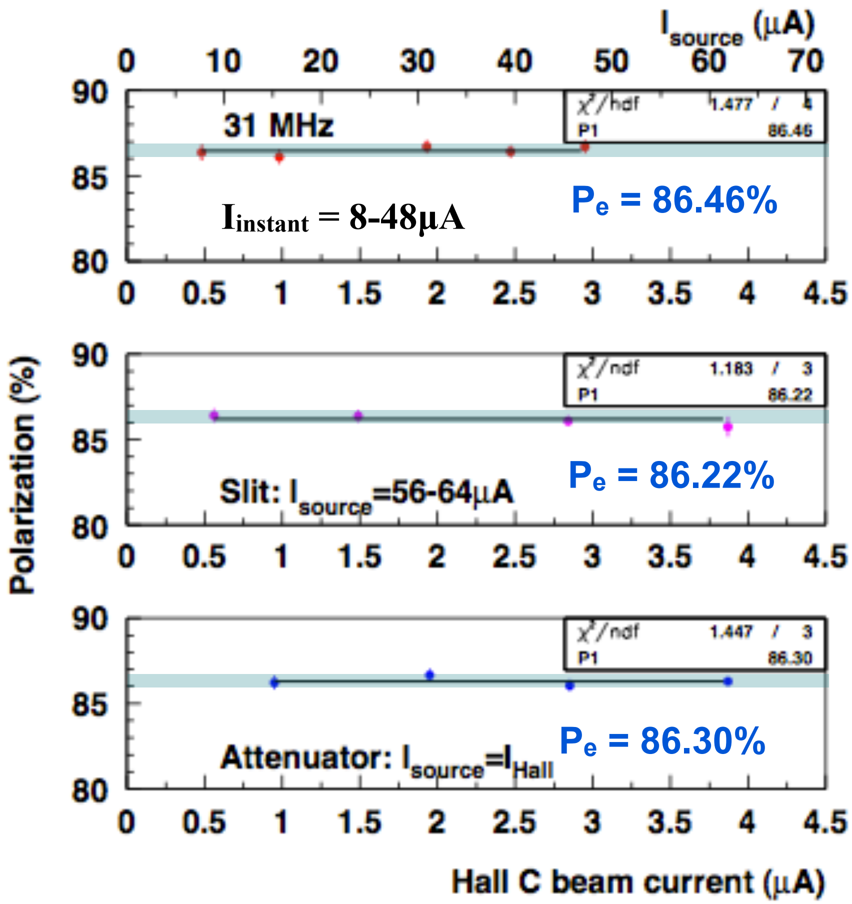

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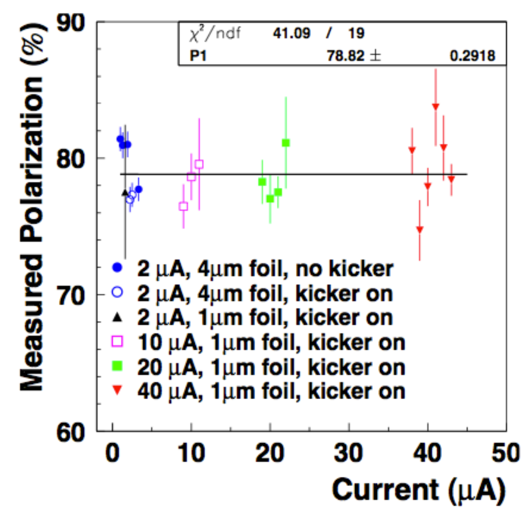
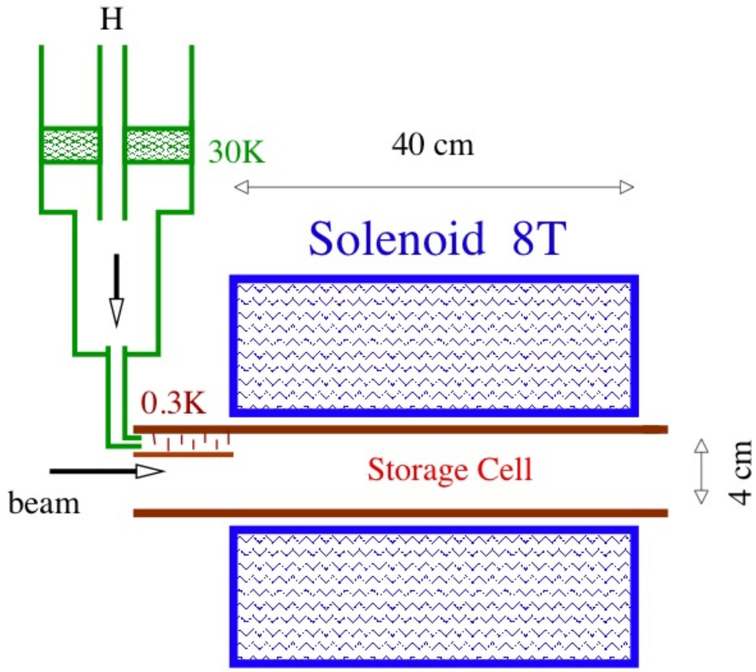
“Kicker” to move beam on Moller foil with low duty factor.



Atomic Hydrogen For Moller Target



10 cm, ρ = 3x10[15]/cm[3]
in B = 7 T at T=300 mK

$$\frac{n_+}{n_-} = e^{-2\mu B/kT} \approx 10^{-14}$$

Brute force polarization

Moller polarimetry from polarized atomic hydrogen gas, stored in an ultra-cold magnetic trap

- 100% electron polarization
- tiny error on polarization
- thin target (sufficient rates but low dead time)
- Non-invasive, high beam currents - continuous measurement over experiment
- no Levchuk effect

E. Chudakov and V. Luppov, IEEE Transactions on Nuclear Science, v 51, n 4, Aug. 2004, 1533-40

Significant technical challenges remain

Atomic Hydrogen Polarimeter in Hall A

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Precisely known, largely from first principles

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Lower density

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Lower density

Also requires improvements, but again not worse than other techniques

Catch all

Summary: High field vs. Atomic Hydrogen

If you applied the more aggressive goals on backgrounds and analyzing power to match the atomic hydrogen proposal...

... you could match the quoted atomic-hydrogen polarimeter.

...at low currents. You'd still need to find a way to convince yourself that measurements match production at the same level

~0.35% extrapolation error
= 0.5% polarimetry

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Target Temp	0.05%	0.00%
Dead Time	0.20%	0.10%
Background	0.10%	0.10%
others	0.1%	0.30%
Total	0.37%	0.35%

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

Summary

Need major effort to establish unimpeachable credibility for 0.4% polarimetry ➙ two separate measurements, with separate techniques, which can be cross-checked.

- Compton

- High-Field Moller
- Atomic Hydrogen Moller

High Field can be pushed down to be almost good enough
- atomic physics
- levchuk
- spot checks / extrapolation errors

Atomic Hydrogen Moller has the more robust systematic error (but also technical risk)

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 based on 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:

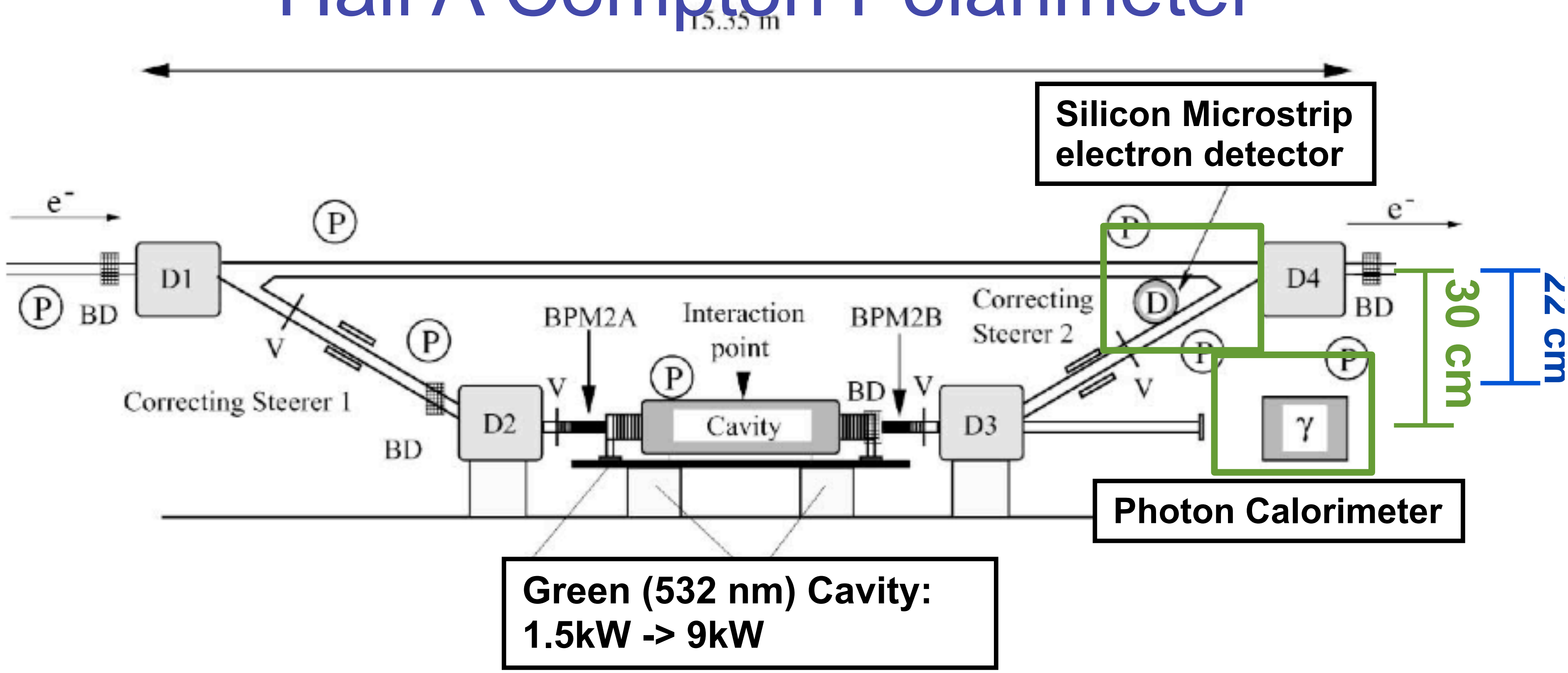
- Postdoctoral researcher has started project.
- Rebuild of refrigerator has started
- Wouter Deconinck at W&M: funded for R&D

Required for a funded experimental effort

Hydro Möller project staging

- UVA “prototype”-trap can be used at Mainz in spite of high helium consumption (Helium liquifier available at Mainz)
- Mainz will build ‘prototype‘ to characterize the Atomic trap under beam conditions
- study for instance ionic/molecular fractions…
- ….and depolarization induced by beam r.f.-fields
- Based on prototype experiments, Mainz will design polarimeters which are adapted for use at 0.2 GeV and multi GeV.
- Timeline: Prototype experiments until 2014, final designs 2015 making both types available for resp. experiments

Hall A Compton Polarimeter



Standard Equipment upgrade plan for 11 GeV Operation:

- Reduce chicane bend angle
- Laser power will be ~9kW
- New e-det (New microstrips, new electronics)
- synchroton light shiels

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

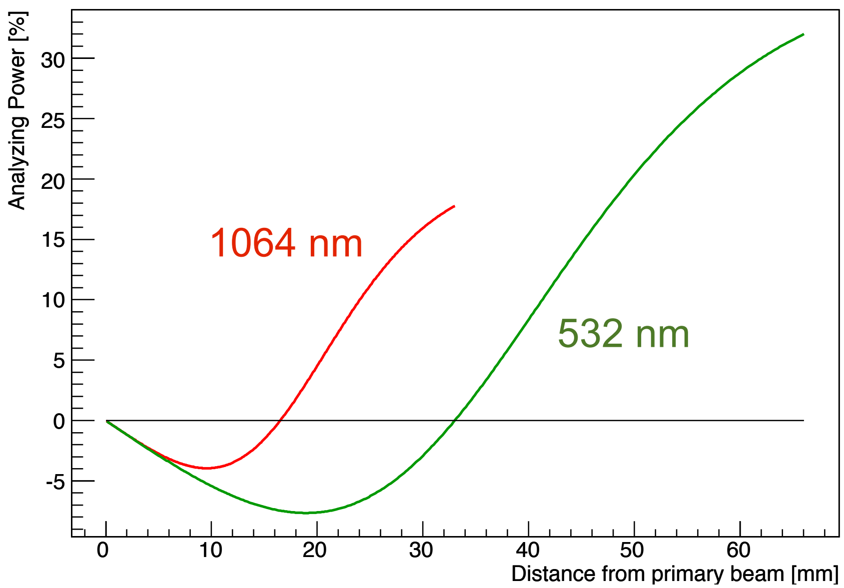
Analyzing power should be very well known,

- **Asymmetry Fit:** using Compton edge and 0xing to calibrate

Detector does not presently exist:
upgrade is under discussion

Other systematic effects must be treated carefully

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



Photon analysis with a "clean" spectrum

- **Energy Weighted Integration**

  HAPPEX+PVDIS+PREX experience
  (CMU, JLab, Syracuse, UVa)

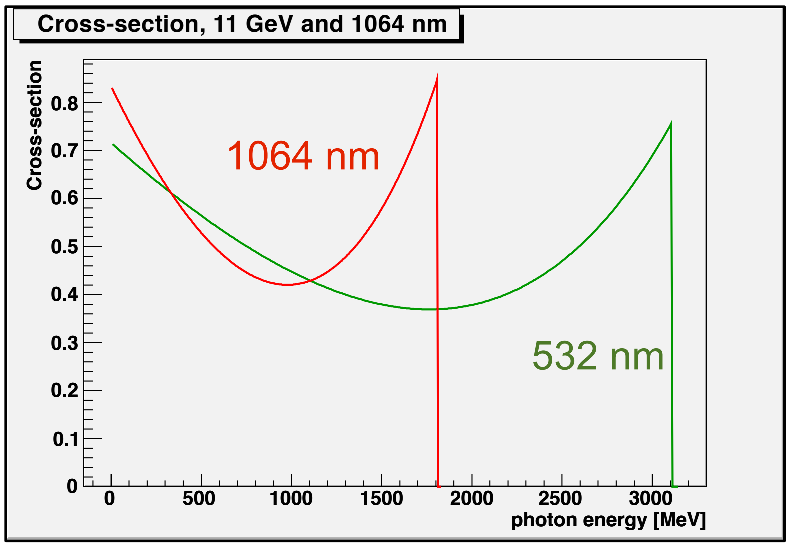
- **Asymmetry Fit / Integrate with Threshold.**
  Use Compton edge and 0xing to calibration?
  Cut in asymmetry minimum?

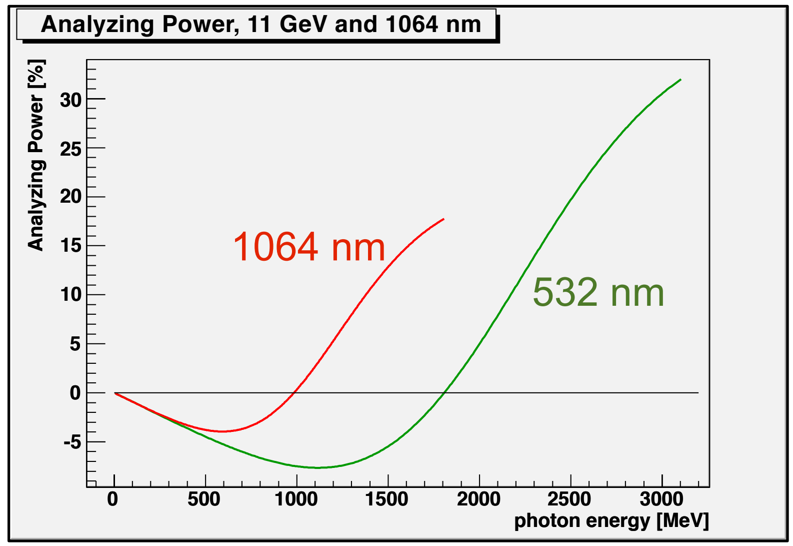
Preliminary Results from Integrating Compton Photon Polarimetry in Hall A of Jefferson Lab. , Parno *et al.*, J.Phys.Conf.Ser. 312 (2011) 052018.

Upgraded photon calorimeter with integrating readout for Hall A Compton Polarimeter at Jefferson Lab., Friend *et al.*, Nucl.Instrum.Meth. A676 (2012) 96-105.

An LED pulser for measuring photomultiplier linearity., Friend *et al.*, Nucl.Instrum.Meth. A676 (2012) 66-69.

Comparison of Modeled and Measured Performance of GSO Crystal as Gamma Detector, Parno *et al.*, in preparation.



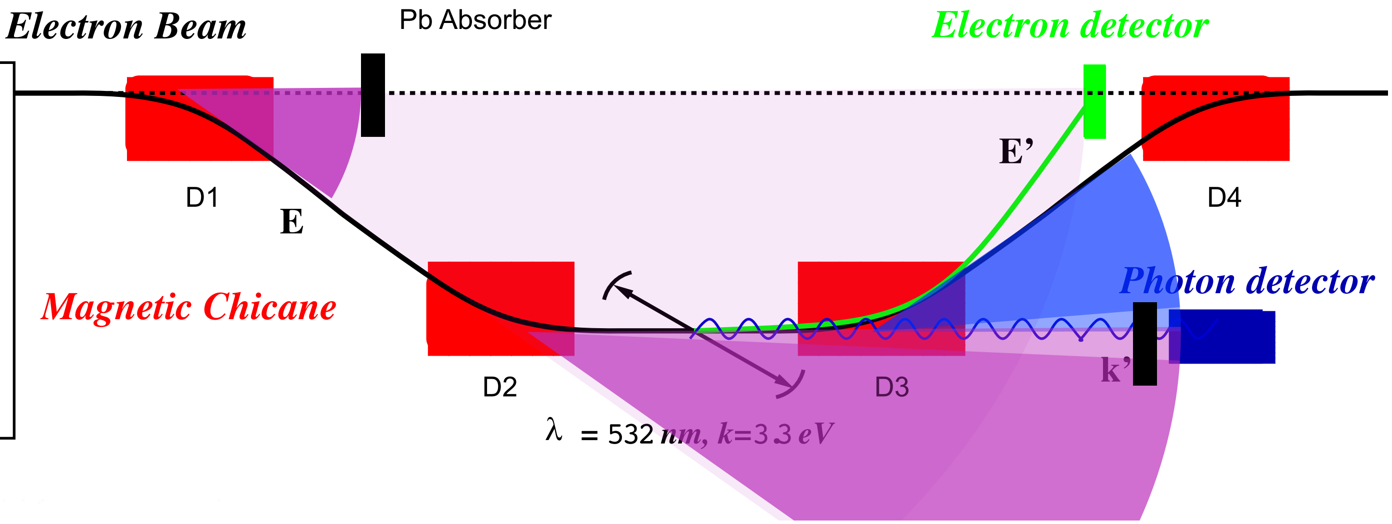


Detector Response Function -

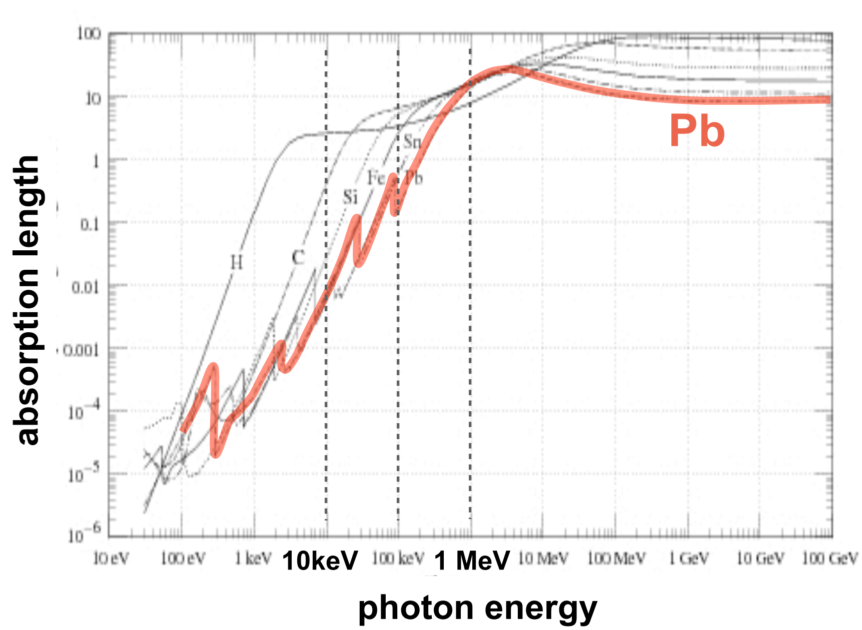
- Resolution is less important for integrating technique.
  - Helps for e-det coincidence cross-calibration.
- Linearity is crucial in any case
  - large dynamic range in both average and peak current
- PMT and readout require care (CMU expertise)
- Effect of shielding on asymmetry spectrum must be quantified

Synchrotron Radiation

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



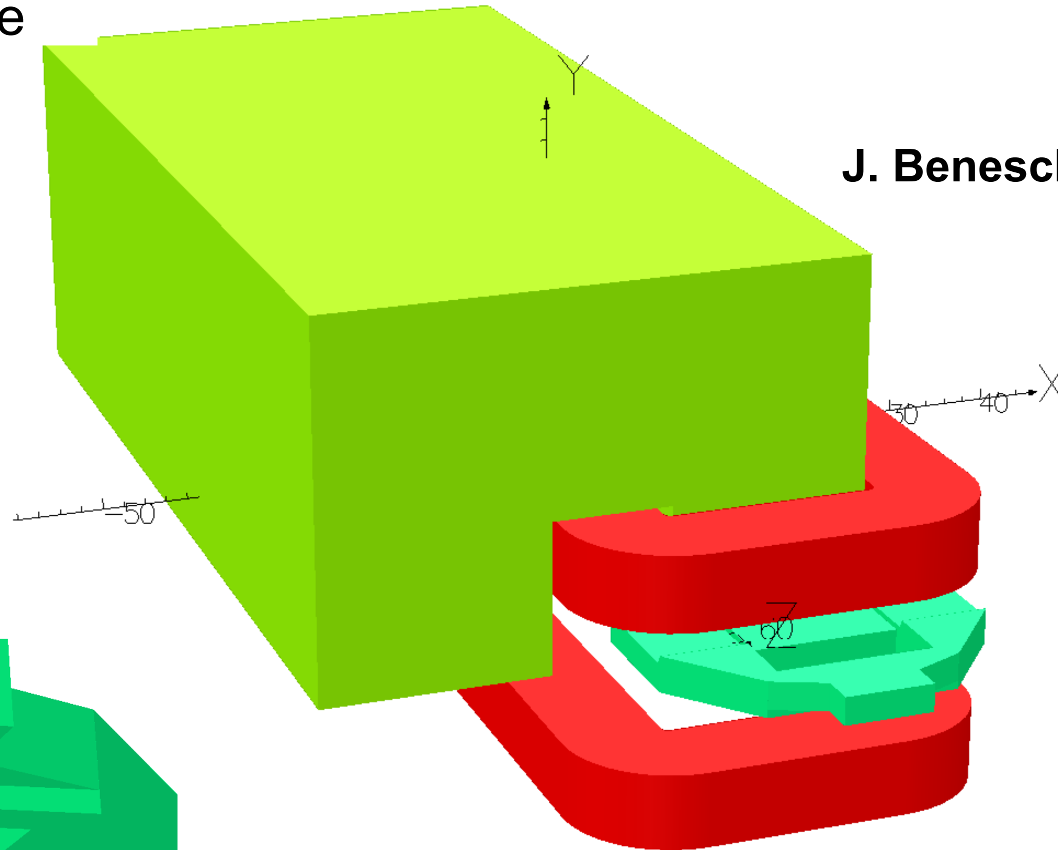
SR intensity and hardness can be reduced with D2, D3 fringe field extensions



- 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

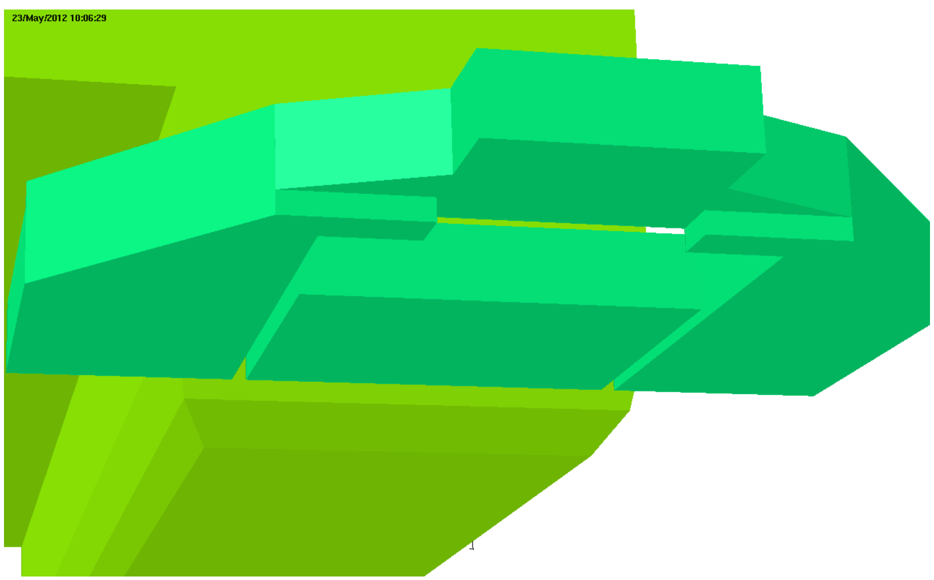
Modeling the Dipoles

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 (planned during Fall 2012)
- Parts fabricated and will be installed

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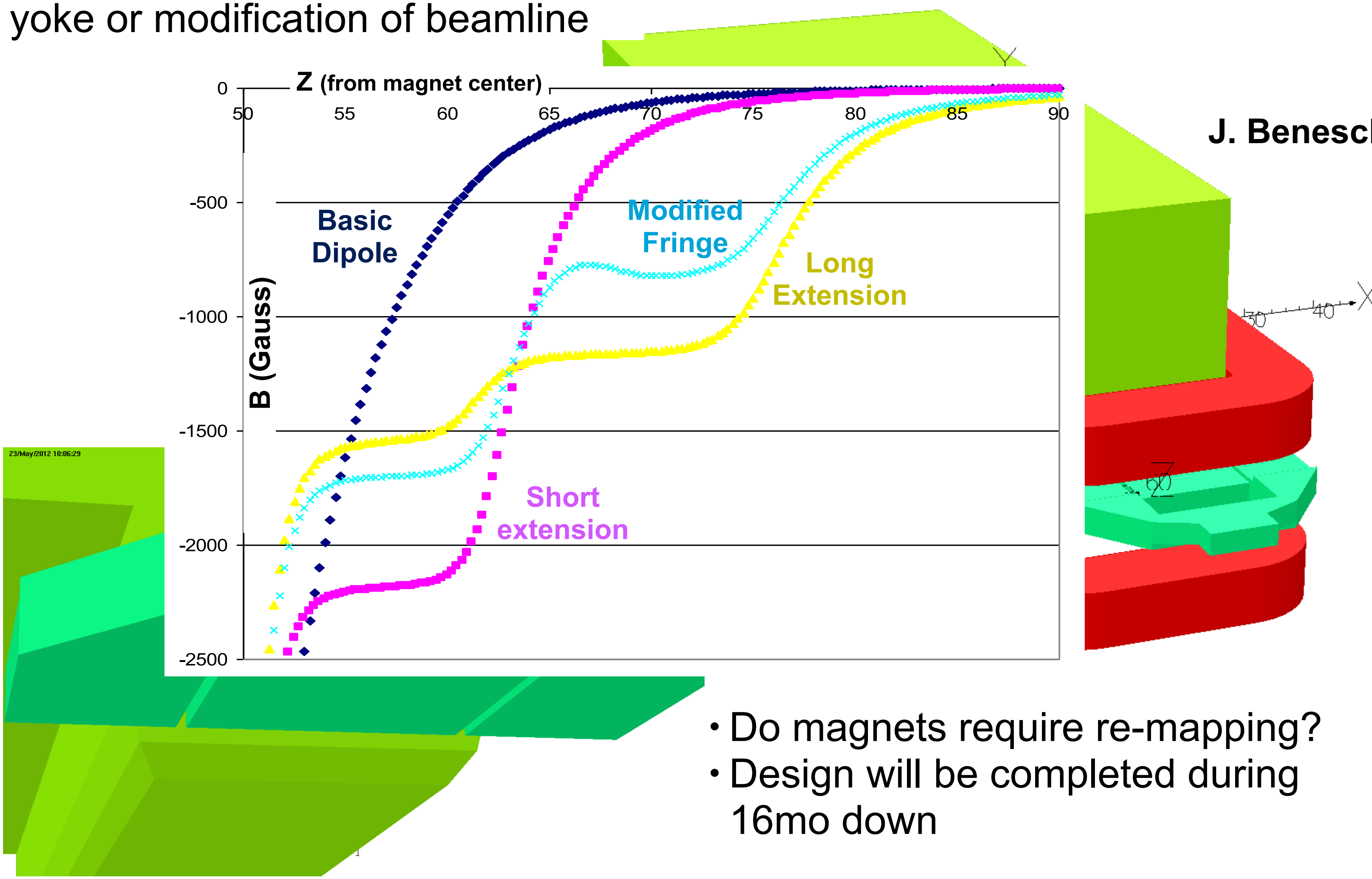
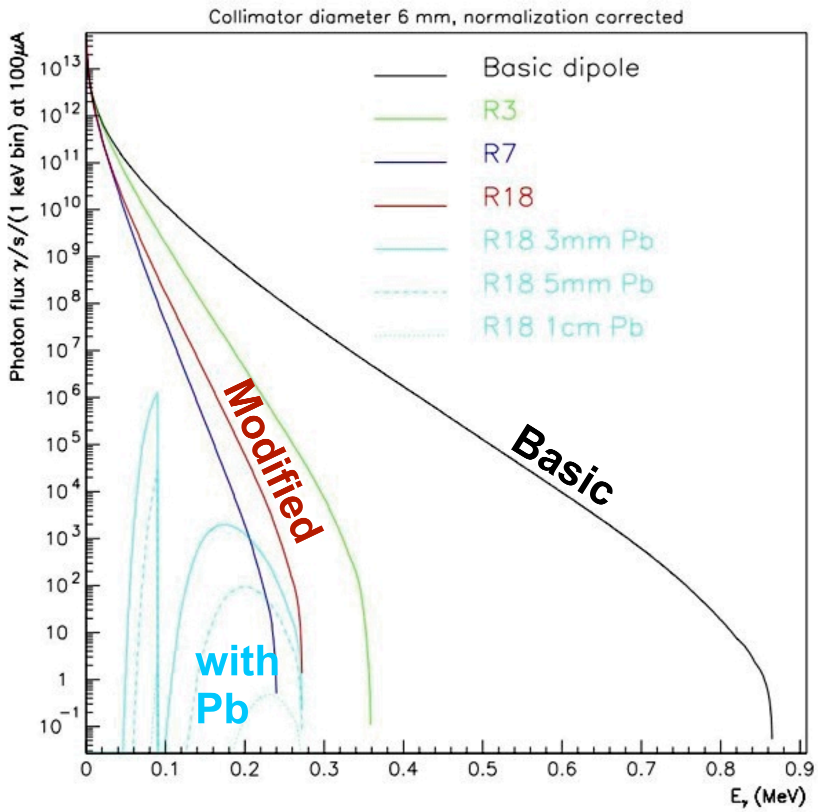
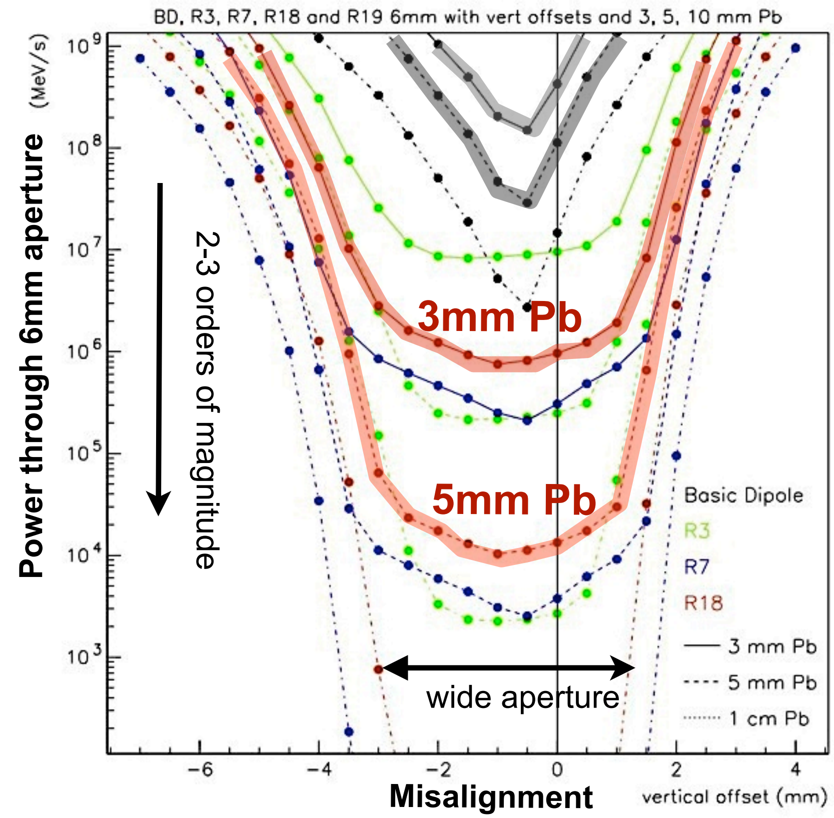


- Do magnets require re-mapping?
- Design will be completed during 16mo down

Reduced SR power, robust operation





Benesch, Quinn (CMU)

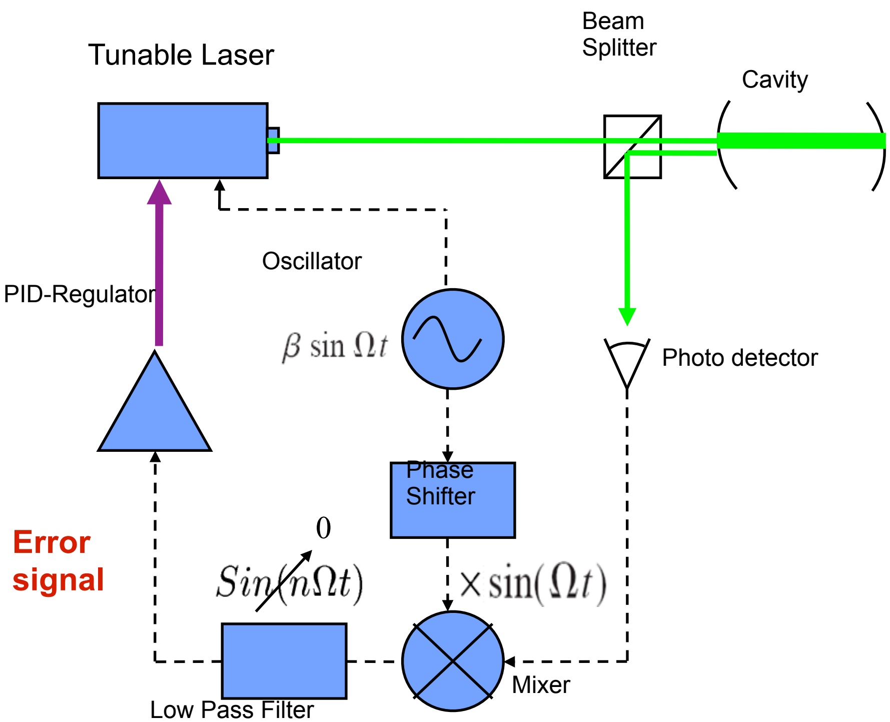
All 4 dipoles will be shimmed in this way, to improve operability

	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 System - Fabry-Perot Resonant Cavity

532 nm (green) upgrade

- Continuous wave
- amplified (>5W), SHG doubled to 532nm (1-2W)
- Gain ~ 10000
- up to 10kW(!) stored



Challenges

- Laser polarization
- Mirror lifetime (radiation damage)
- Operational stability at 10kW
- background due to beam apertures

R&D efforts

- Maintainable locking electronics
- Continued prototyping
- Intra-cavity Stokes polarimeter
- Improved mechanical design for improved vacuum load stability
- mirror tests (rad damage?)
- design for larger crossing angle

Alternative: RF pulsed single pass laser, no longer actively considered

Existing Compton Interaction Region

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

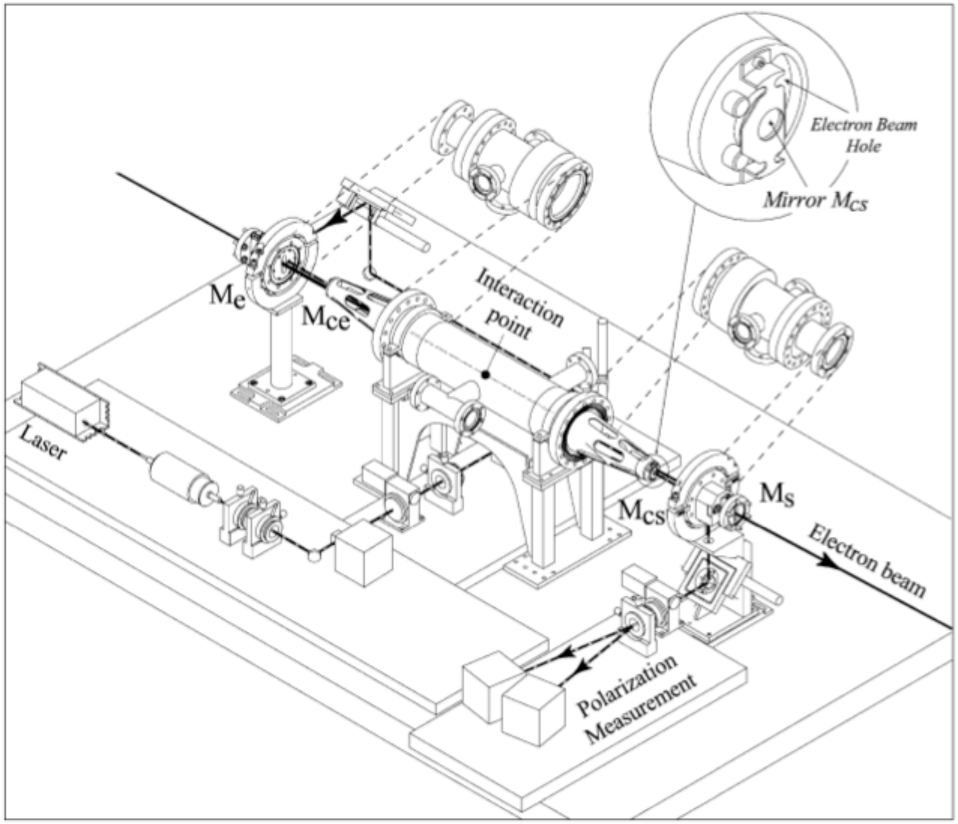
Typical “good” brem rate: ~ 100 Hz/uA
Residual gas should be about 10x less

How much larger will the halo and tail be, due to synchrotron blowup and the small CEBAF magnetic apertures?

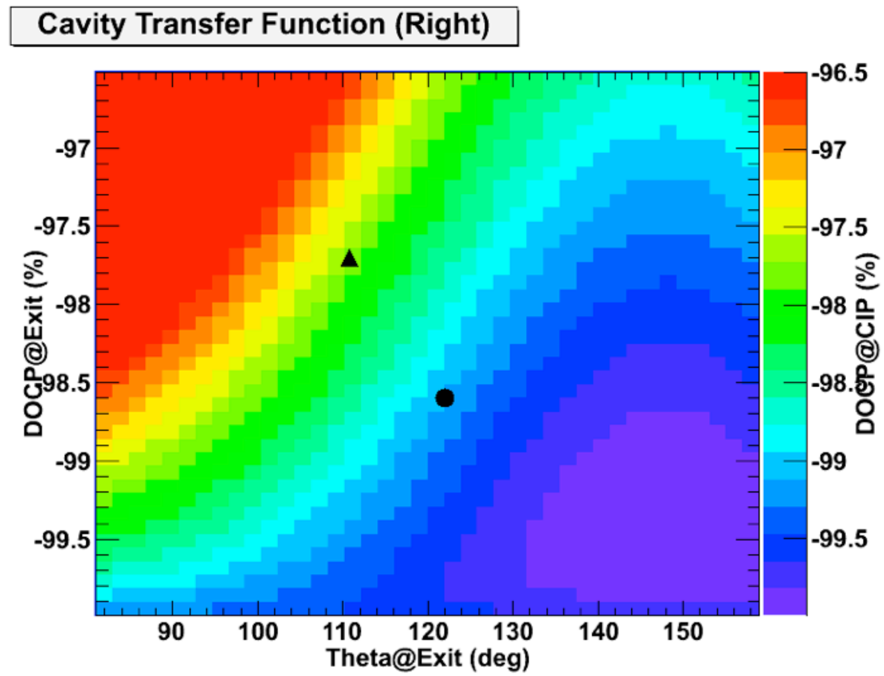
UPTIME and PRECISION will go up if we use larger apertures (and therefore larger crossing angles)

~3.6 degrees puts aperture at size of beampipe,
Laser luminosity drops by a factor of 3, but with
10kW this should still be sufficient. Which gives better accuracy?

Determining Laser Polarization



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



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

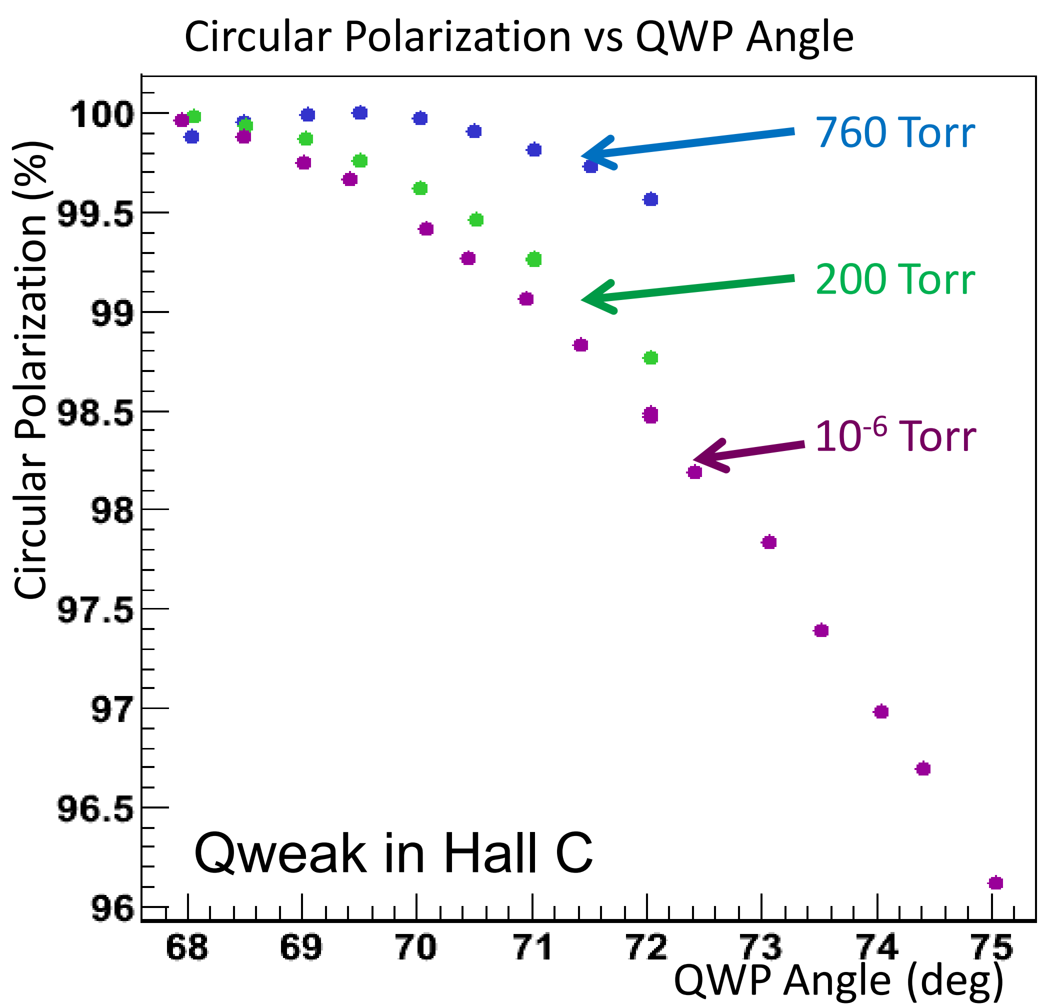
Current uncertainty: 0.35%-1%

Are there effects from

✓vacuum stress
✓resonant depolarization
✓power level (heating)
✓alignment variations?
✓model dependence of TF?

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

Vacuum / Assembly Stress Induced Birefringence

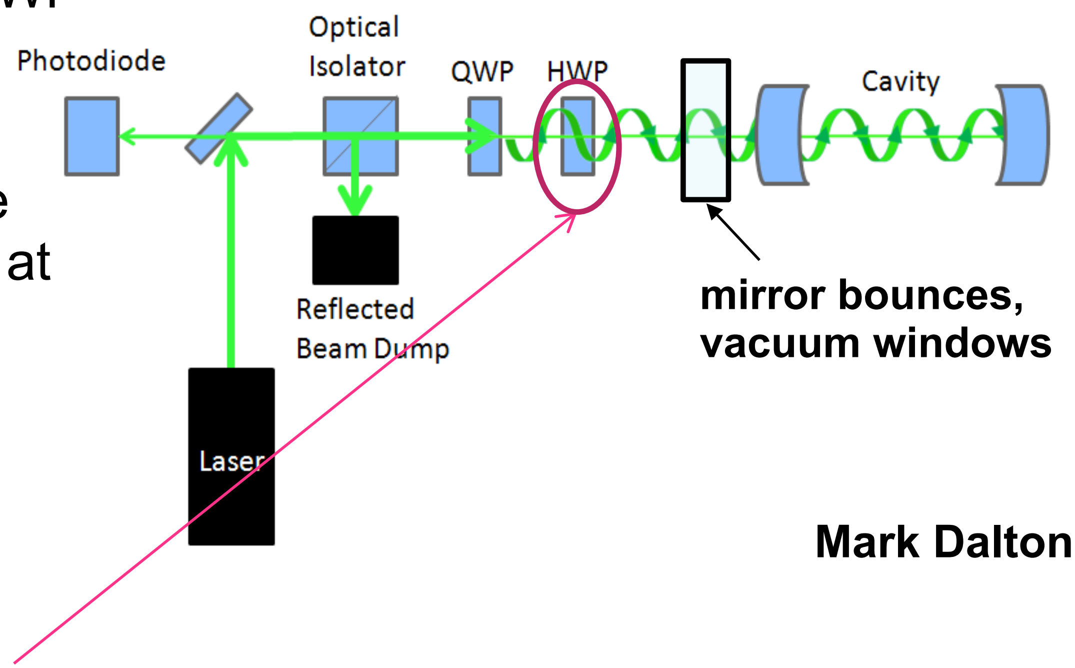


Measurement at exit changes with vacuum pressure.
Is it a change on input? Output? Who knows?

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

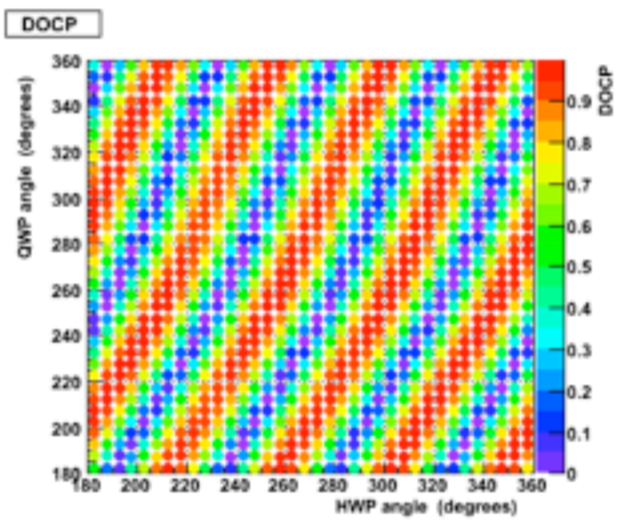
This provides a technique to repeatably maximize circular polarization, even in the case of changing intermediary birefringent elements (vacuum or thermal stress, etc.)

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

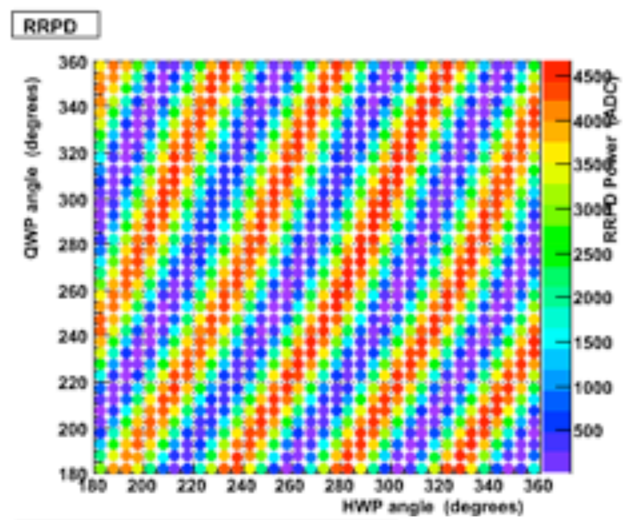
Direct Test of Optimizing Circular Polarization

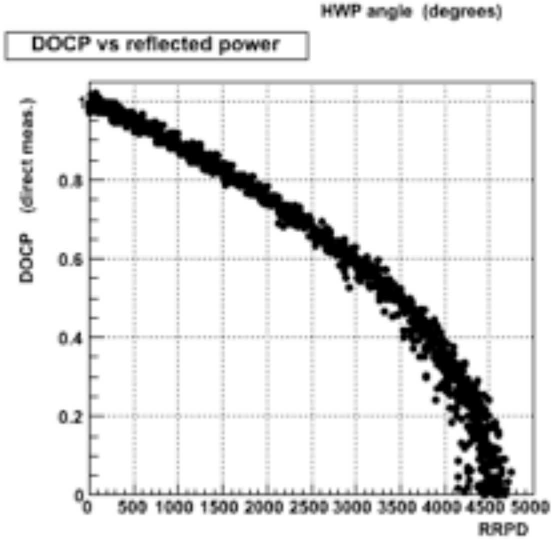
Measurements while scanning over initial polarization set by QWP and HWP.

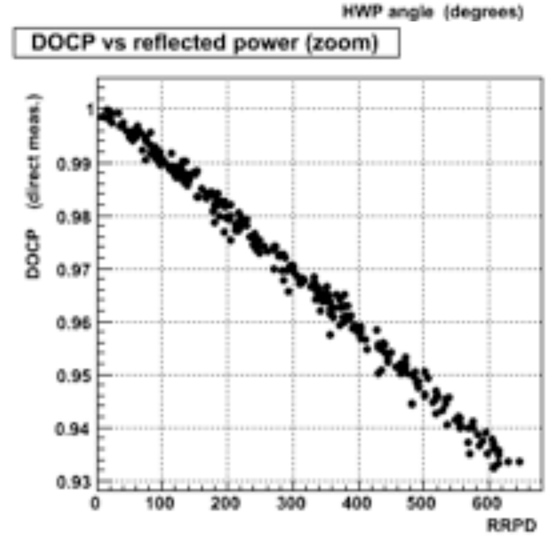
DoCP in (open) cavity



Return power (through isolator)







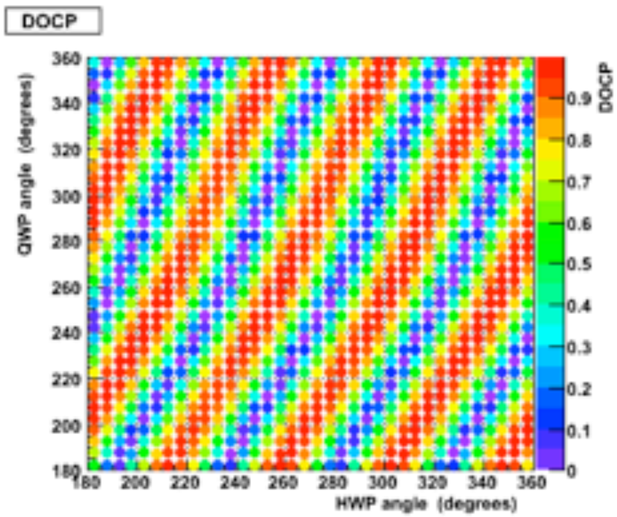
Excellent agreement

If minimizing return power, maximizing DoCP at 99.9%+*

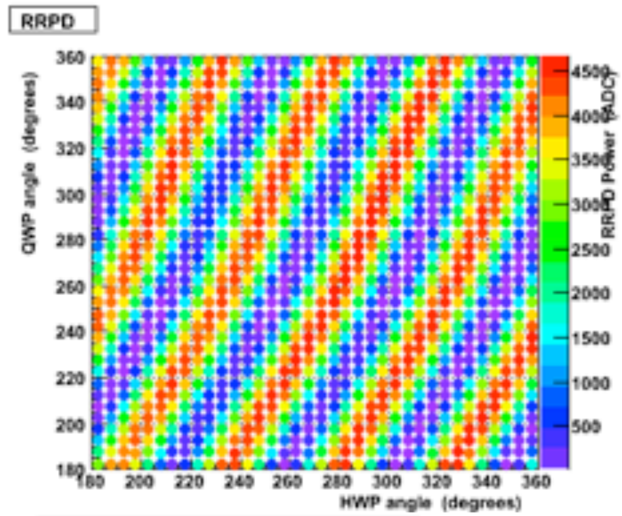
Direct Test of Optimizing Circular Polarization

Measurements while scanning over initial polarization set by QWP and HWP.

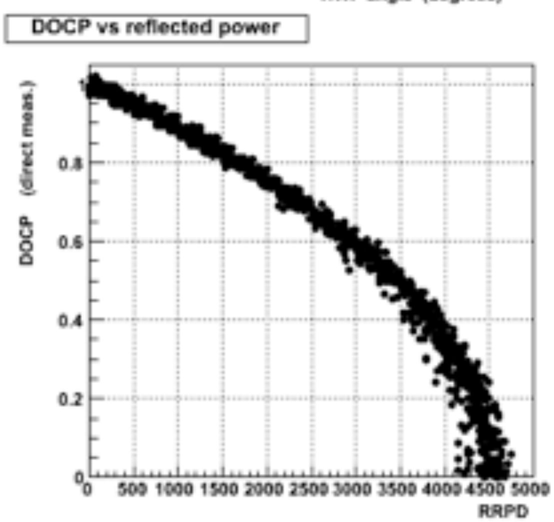
DoCP in (open) cavity

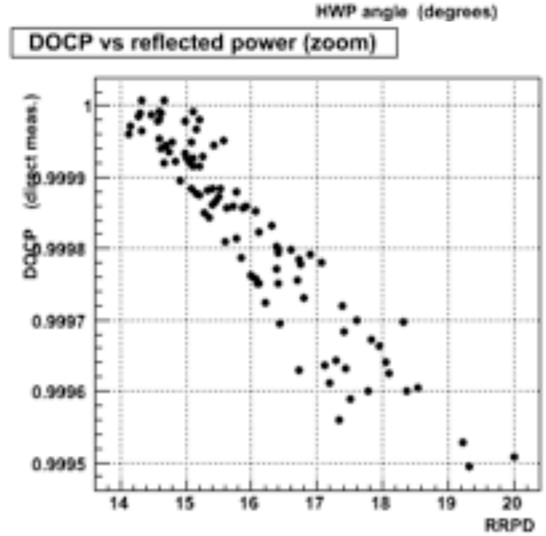


Return power (through isolator)



Excellent agreement

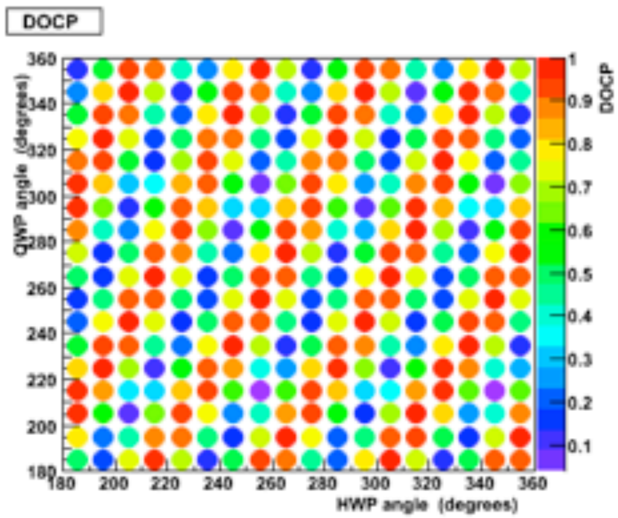


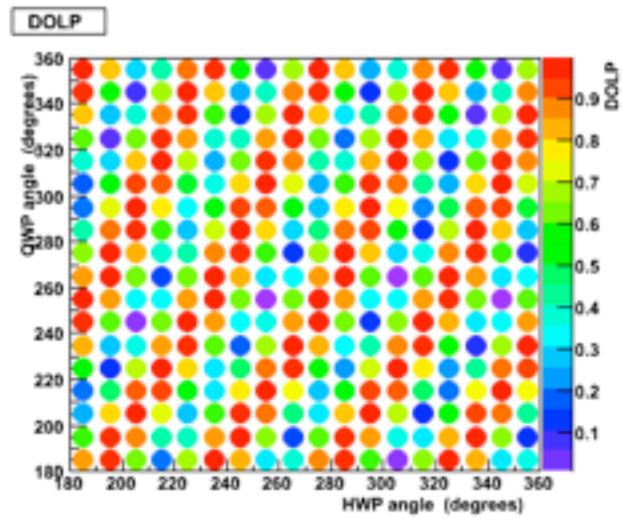


If minimizing return power, maximizing DoCP at 99.9%+*

Fitting Entrance Function

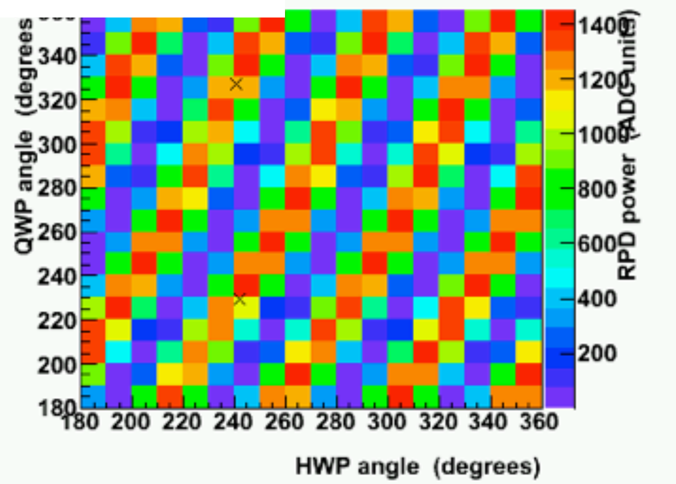
Measurements while scanning over initial polarization set by QWP and HWP.



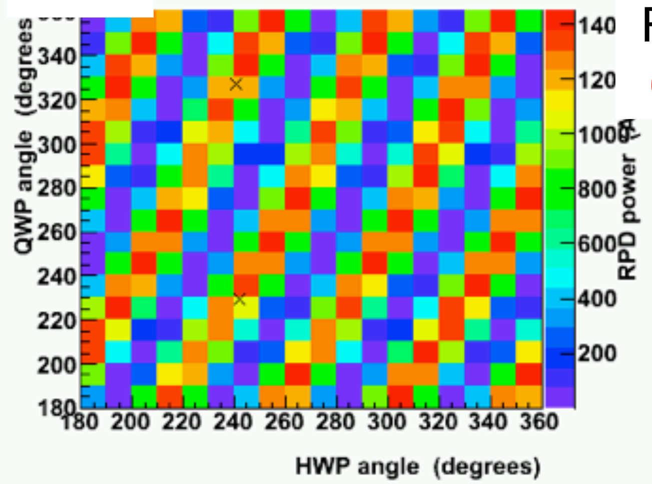


DoCP in (open) cavity

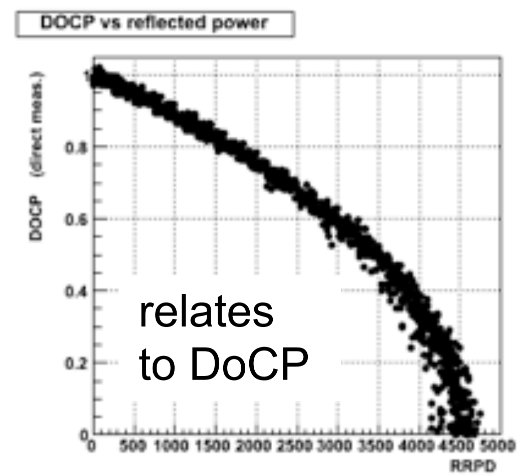
Measured



Fit

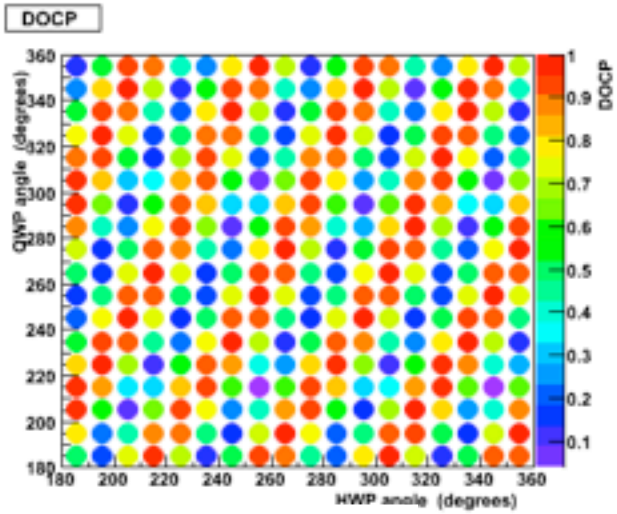


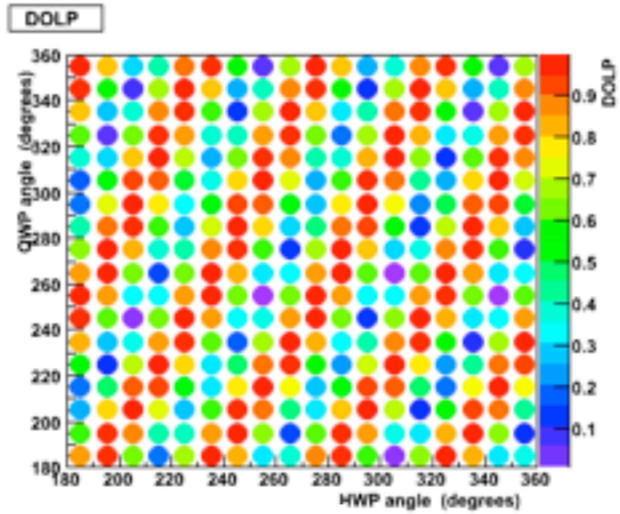
Return power, then **fit to (simple) optical model**



Fitting Entrance Function

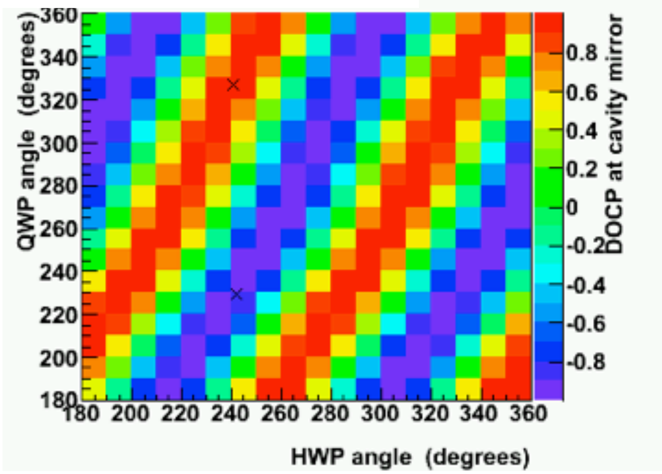
Measurements while scanning over initial polarization set by QWP and HWP.



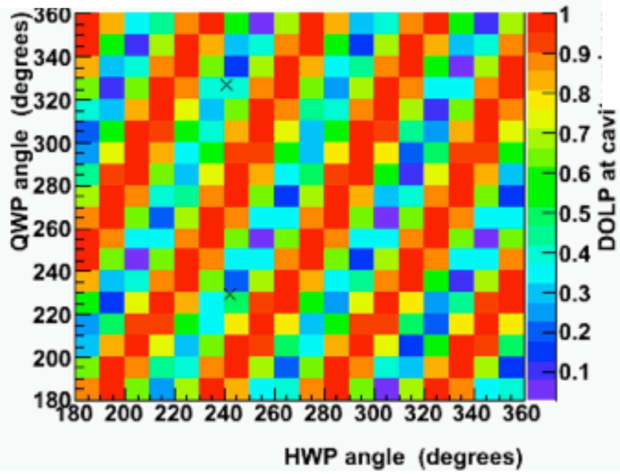


DoCP in (open) cavity

Fit DoCP



Fit DoLP

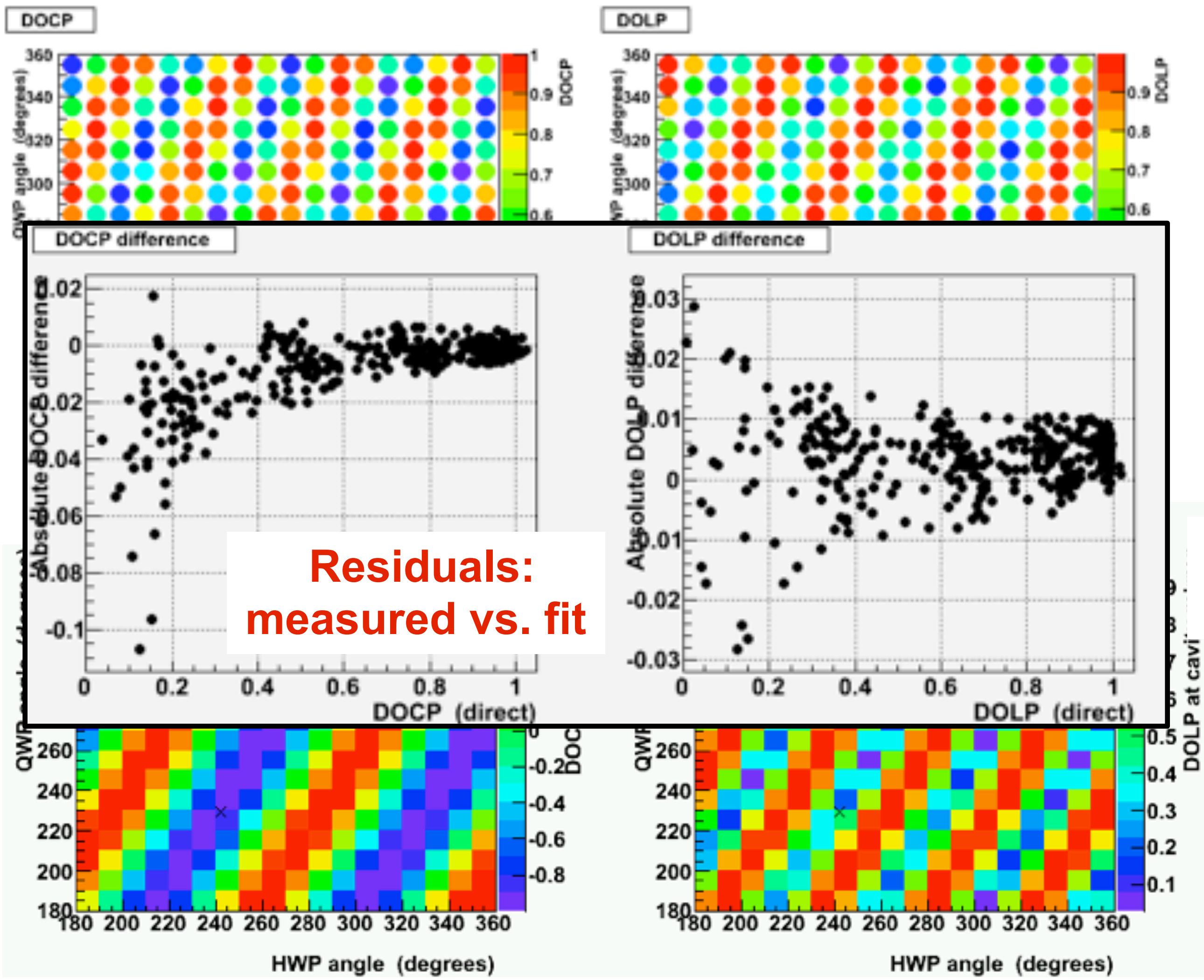


DoCP from fit to (simple) optical model

Measurement at 0.1% level in DoCP from external measurements

Fitting Entrance Function

Measurements while scanning over initial polarization set by QWP and HWP.



DoCP in (open) cavity

DoCP from fit to (simple) optical model

Measurement at 0.1% level in DoCP from external measurements

High Precision Compton Polarimetry

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%**

UVa, Syracuse, JLab, CMU, ANL, Miss. St., W&M, Manitoba/UW

Primary Challenges:
- Laser Polarization ✓
- Synchrotron Light ✓
- Signal / Background
- New eDet

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 (Qweak).
- High power cavity: power for precision goals with larger crossing angle
- New **photon detector**. Careful characterization needed.
- Participants from UVa, Syracuse, JLab, CMU, ANL, Miss. St., W&M, Manitoba

Hall C Moller Polarimeter

Systematic uncertainties

source	uncertainty	effect on A
beam position x	0.5mm	0.15%
beam position y	0.5mm	0.03%
beam direction x	0.15mr	0.04%
beam direction y	0.15mr	0.04%
current Q1	2%	0.10%
current Q2	1%	0.07%
position Q2	1mm	0.02%
multiple scattering	10%	0.12%
Levchuk effect	10%	0.30%
position collimator	0.5mm	0.06%
target temperature	50%	0.05%
direction B-field	2°	0.06%
value B-field	5%	0.03%
spin polarization in Fe		0.25%
total		0.47%

Result

get *very low* systematic uncertainties, 0.5%,
without doing precise measurements!

For future

could push to 0.25% without much effort
then limited by knowledge of spin polarization

Approaches δP_B ~0.5%

Samples (<2hr / measurement) can control drifts of polarization

Some accounted errors?
(no showstoppers)
+ dead-time?
+ radiative corrections?

LOW CURRENT ONLY

"Pulsed" Moller might sample from high current beam, but
- larger systematics
- not full current
- less time-efficient and not continuous

Ingo Sick,

JLab Workshop on Precision Electron Beam Polarimetry

Jefferson Lab, June 9-10, 2003

Atomic Hydrogen Trap Operation

$H + H \rightarrow H^2$ recombination

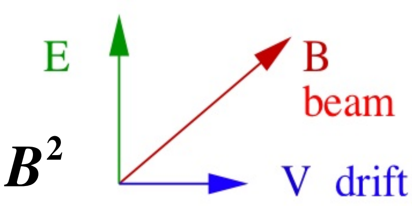
- suppressed for polarized gas
- surface must be coated (~50nm of superfluid ^4He)
- H_2 freezes to walls

Gas lifetime > 1 hour

Beam + RF ➞ 10^{-4}/sec ionizations (~20%/sec in beam)

- Ions purged by transverse electric field ~1 V/cm
- Cleaning (~20 μs) + diffusion ➞ $<10^{-5}$ contamination

$$v = \vec{E} \times \vec{B} / B^2$$



Polarimeter with Atomic Hydrogen

Replace existing Hall A Moller Target (keep spectrometer)

Expected depolarization → <2e-4

Expected contamination (residual gas + He, H_2, excited states, hyperfine states) → < 1%

Dominant systematic errors **total <0.5%**

- Analyzing power → <0.2%
- Background → <0.3%
- He dilution → <0.1%

Statistical error 1% in ~30 min (30 μA)

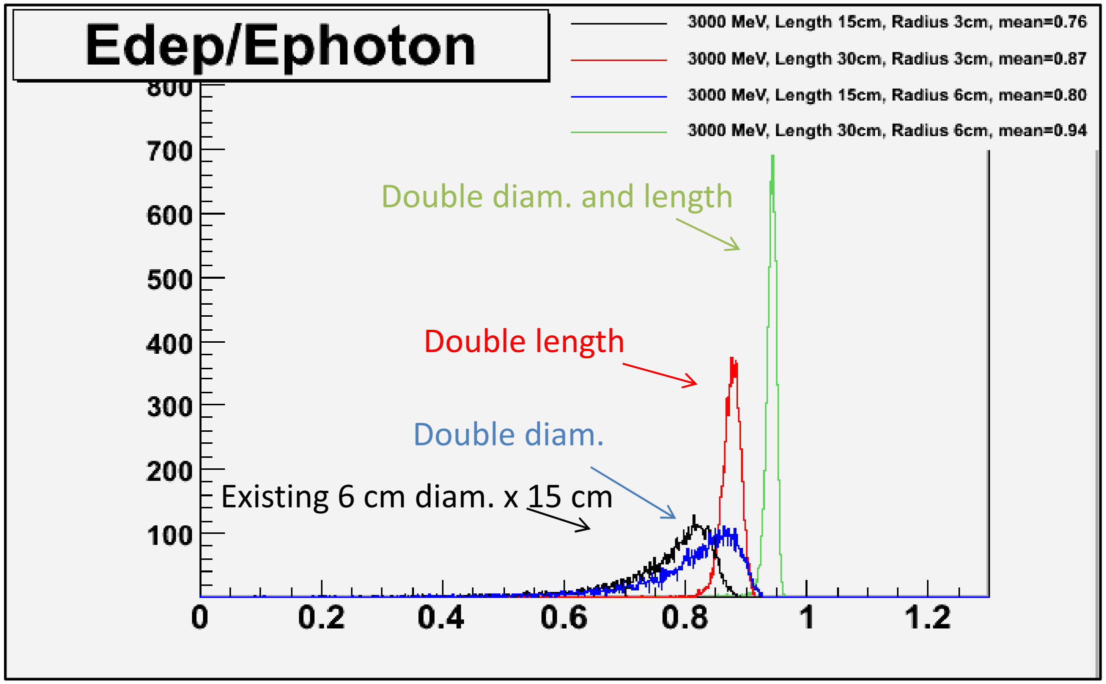
Photon Detector Options

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

but, small for high-energy photons

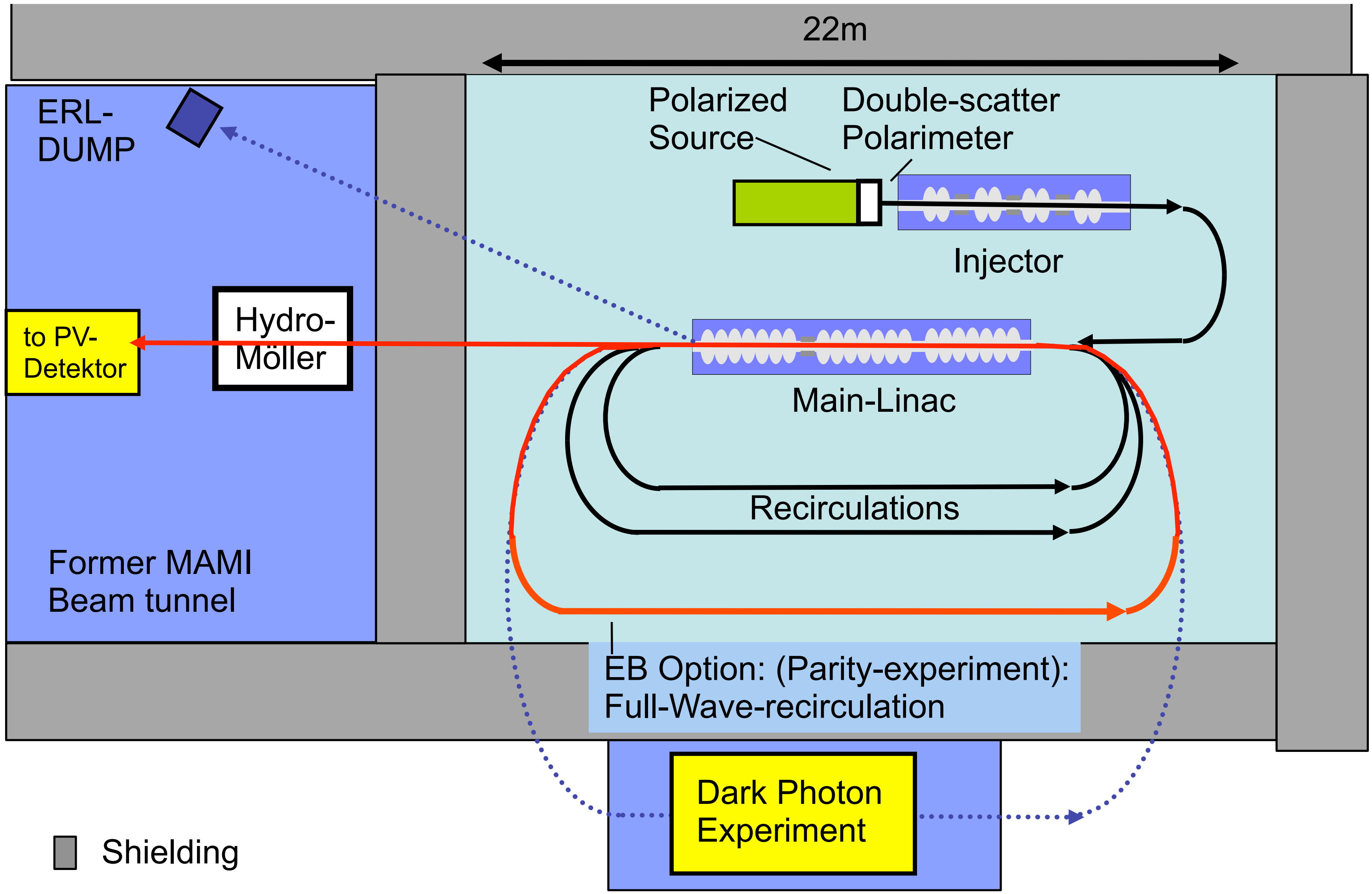
Something larger needed to contain showers at high energy,
(maybe 6”x6”x15”)

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



Hydro-Möller-Project rationale for Mainz university

- P2 experiment at U-Mainz requires $\Delta P/P \leq 0.5\%$
- Laser Compton not applicable due to 200 MeV beam energy
- Two independent polarimeters envisaged : Double scattering Mott at source
  energy, 'Hydro-Möller' at 200MeV.
- → Mainz will design Hydro-Möller also for SOLID needs
- Next transparency: Sketch of proposed P2-experiment with new proposed
  'MESA'-accelerator



“Unimpeachable” polarization measurement: two independent polarimeters with $\Delta P/P < 0.5\%$ each.

Machine could be in operation in 2017→ start polarimeter tests NOW!

Location of Set-up in Mainz

Shutdown of A4 experiments in 2012 makes space for polarimeter tests available. Experiments with MAMI beam (0.18-1.6 GeV) still possible.