

High Precision Polarimetry for SOLID

SOLID Collaboration Meeting

October 14, 2011

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University of Virginia

Route to precision polarimetry

Compton

Baseline Compton polarimeter upgrade for operation at 11 GeV

Additional upgrade plan required for high precision

Independent detection of photons and electrons provides two (nearly) independent polarization measurements at high precision

Møller

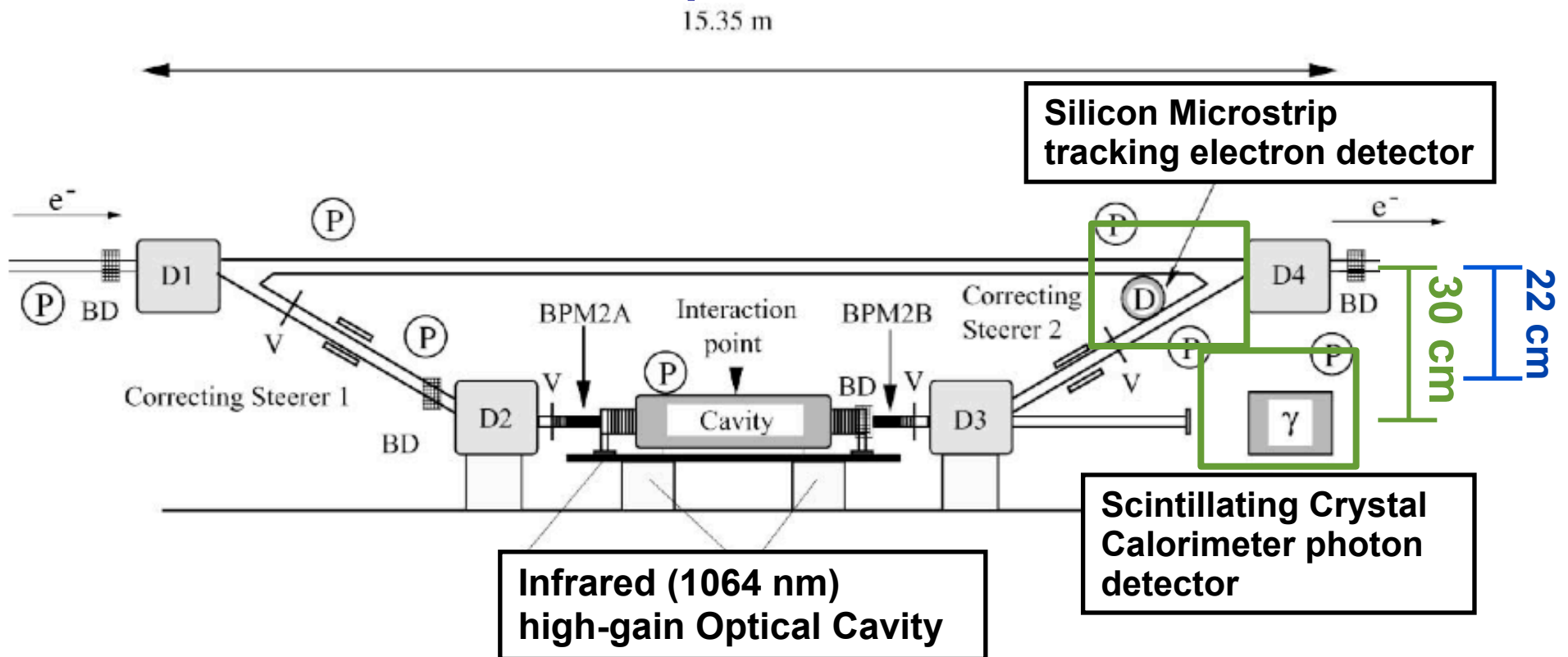
Upgraded “high field” Møller polarimeter would be compatible with 11 GeV

- high field to saturate iron foil limits target polarization error $\sim 1\%$, total error $\sim 1.1\%$
- low-duty cycle can be used to measure at high current
- invasive, used to test Compton polarimetry normalization

Atomic Hydrogen gas target for Møller polarimetry: would provide non-invasive, high-precision monitor at high current

Compton Polarimetry

Hall A Compton Polarimeter



- Detection of backscattered photons and recoil electrons
- new green (532 nm) laser cavity

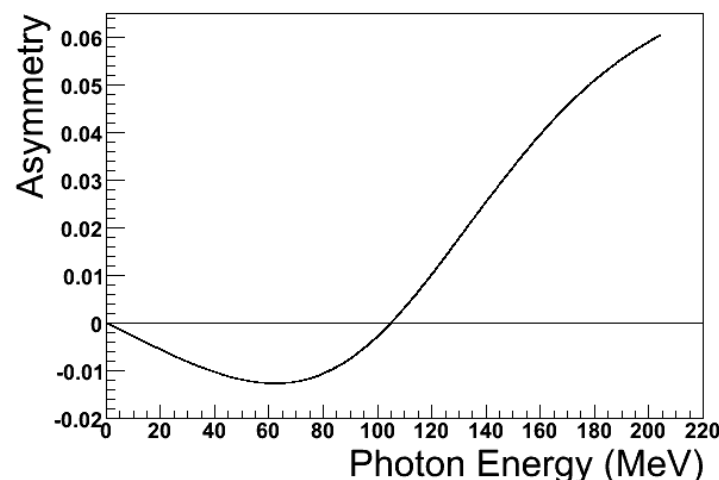
Standard Equipment upgrade plan for 11 GeV Operation

- Reduce chicane bend angle
- New e-det (Thicker silicon, new electronics)
- New (old?) photon calorimeter to contain high-E shower

HAPPEX-3 Analysis

Energy-weighted integration of Compton signal
reduces errors due to calibration of analyzing power

Systematic Errors	
Laser Polarization	0.80%
Analyzing Power	0.33%
Asymmetry Measurement	0.37%
Interpolation	0.20%
Statistical	0.06%
Total	0.96%



M. Friend *et al.*, “Upgraded photon calorimeter with integrating readout for Hall A Compton Polarimeter at Jefferson Lab,” Submitted to Nucl. Instr. and Meth. A (2011) , arXiv:1108.3116.

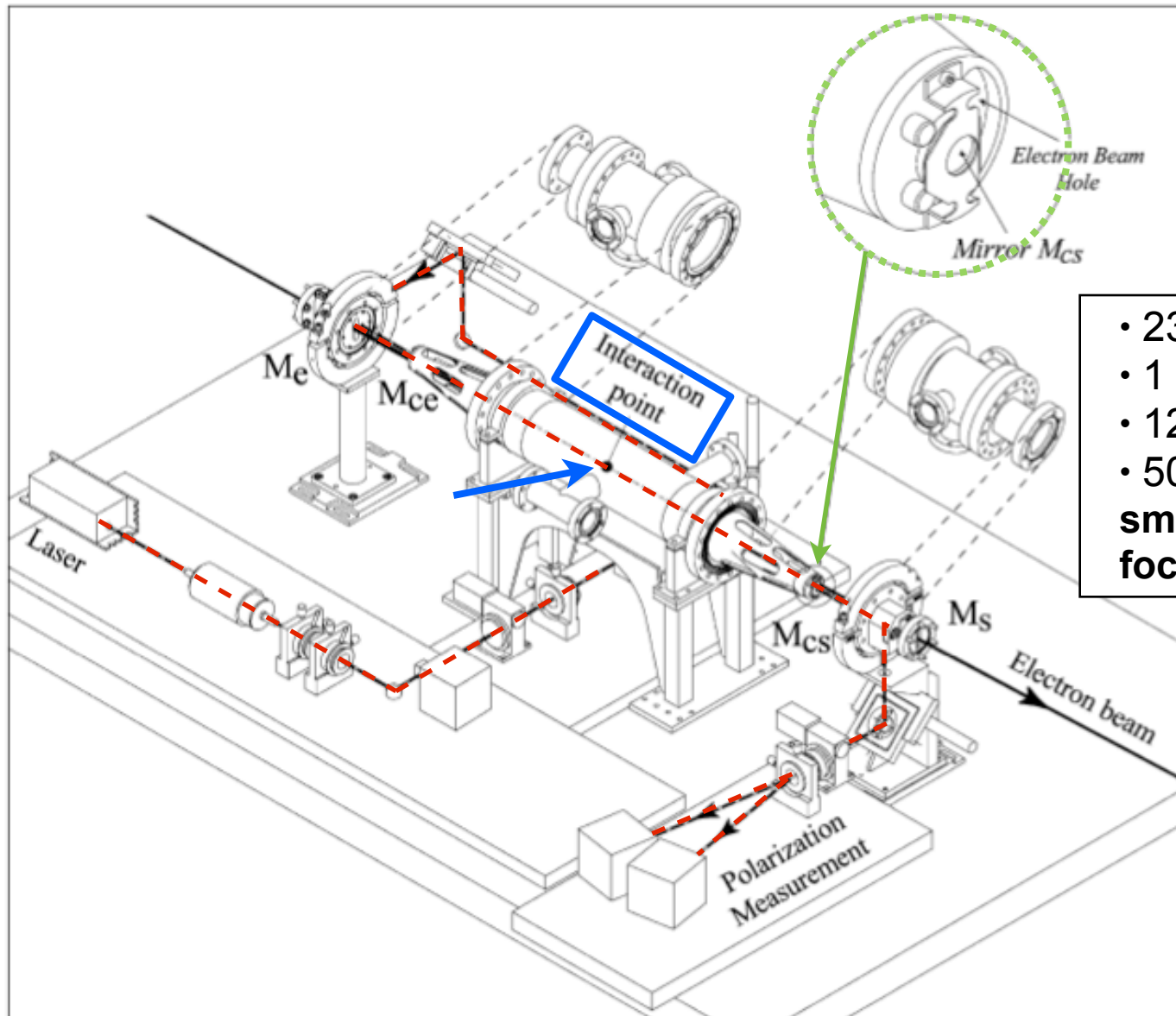
- Uniformity of detector response
- Laser polarization

Certain things get easier at 11 GeV (favorable kinematics and larger asymmetry)...

... but some things will also get harder, and 0.4% is very demanding

Photon Target

Hall A Compton Interaction Region

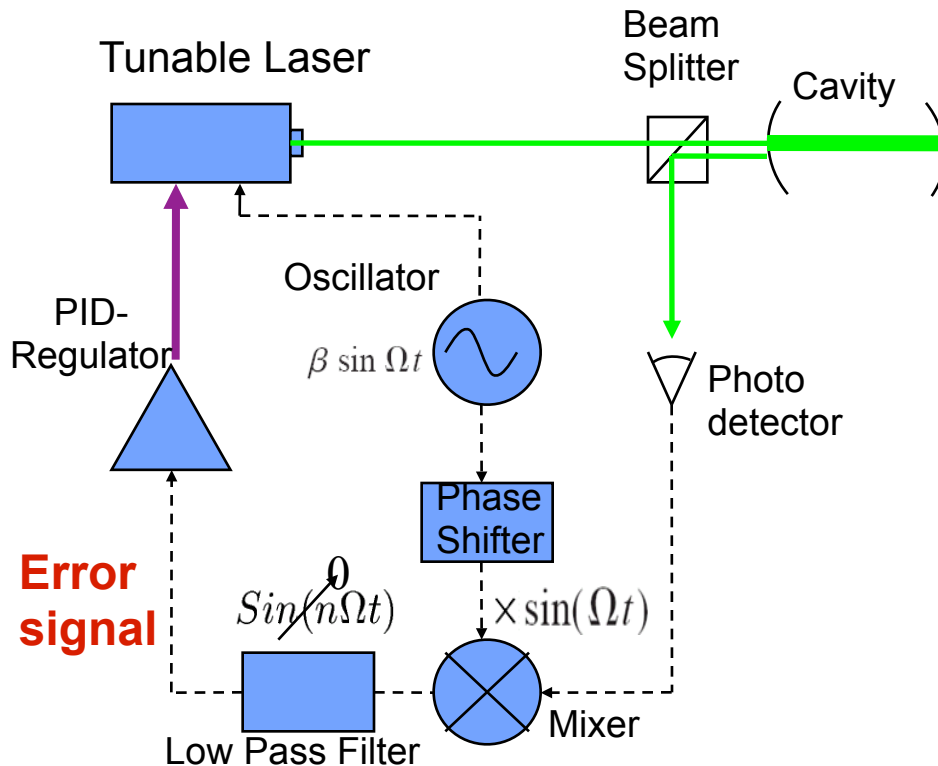


- 23 mrad crossing angle
 - 1 cm e- beam aperture
 - 125 μm laser spot
 - 50-100 μm e- beam spot
- small crossing angle, tight focus maximize luminosity**

Fabry-Perot Laser Cavity

Detect phase of the resonance from reflected light

Feedback to tunable element to stay “locked” to resonance



1064 nm (IR) light in a Fabry-Perot resonant cavity

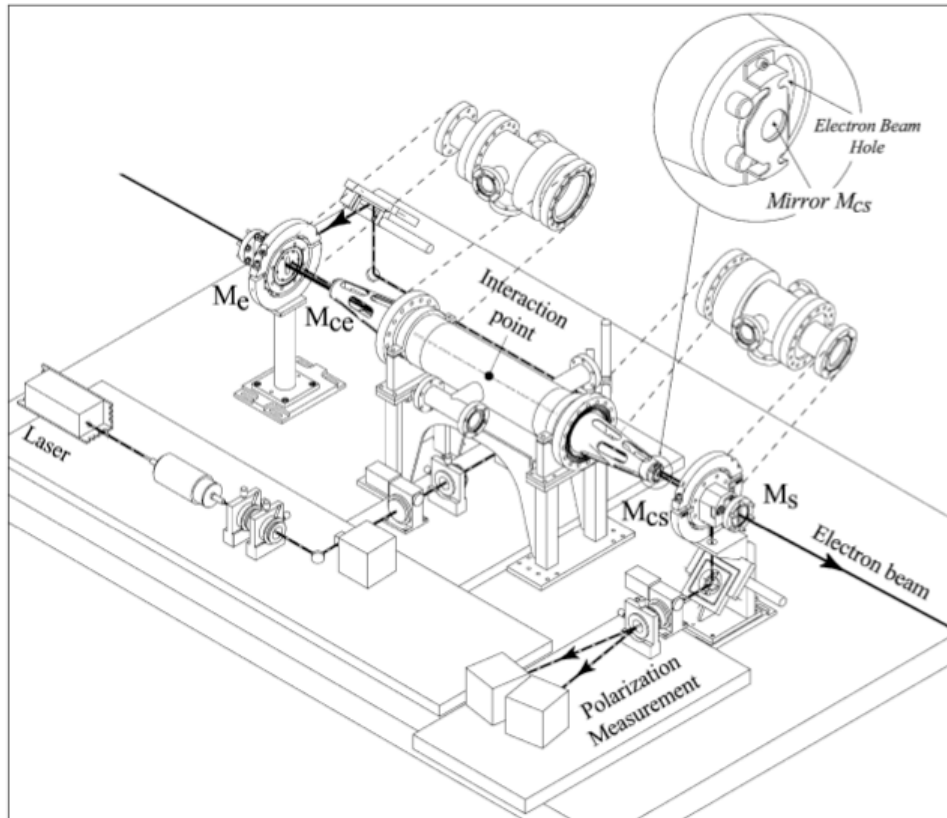
- Continuous wave
- 200-300 mW source laser
- 800-2000 W
- Gain $\sim 4000-7000$
- Finesse ~ 25000
- Waist radius ~ 125 micron

532 nm (green) upgrade

- Continuous wave
- same seed laser (1064nm)
- amplified ($>5W$), SHG doubled to 532nm (1-2W)
- Gain $\sim 2000-5000$
- up to 5kW stored
- Waist radius ~ 125 micron

- double maximum photon energy
- higher asymmetry
- similar rate

Photon Polarization

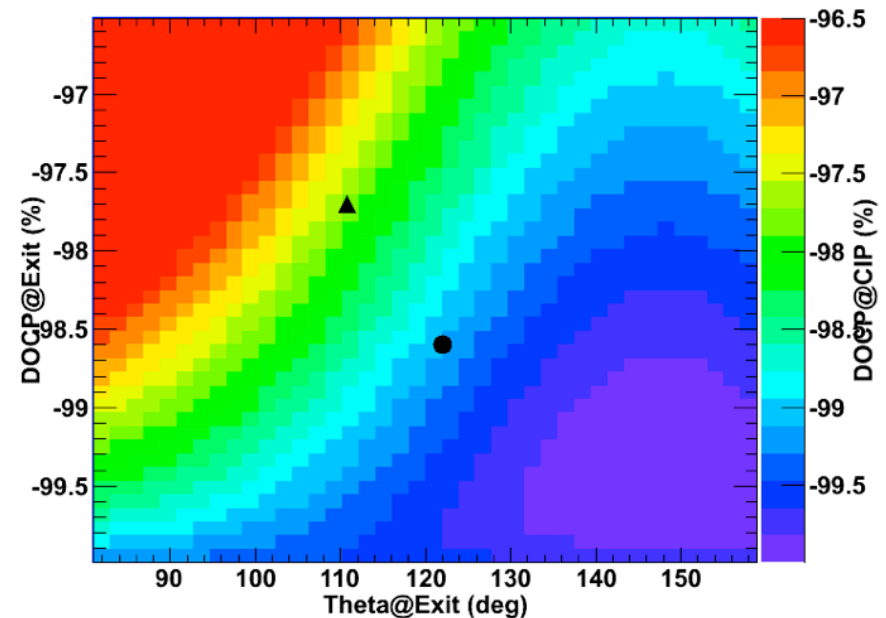


Do we know the polarization inside the **cavity** by monitoring the transmitted light?

Current uncertainty: 0.35%-1%

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

Cavity Transfer Function (Right)

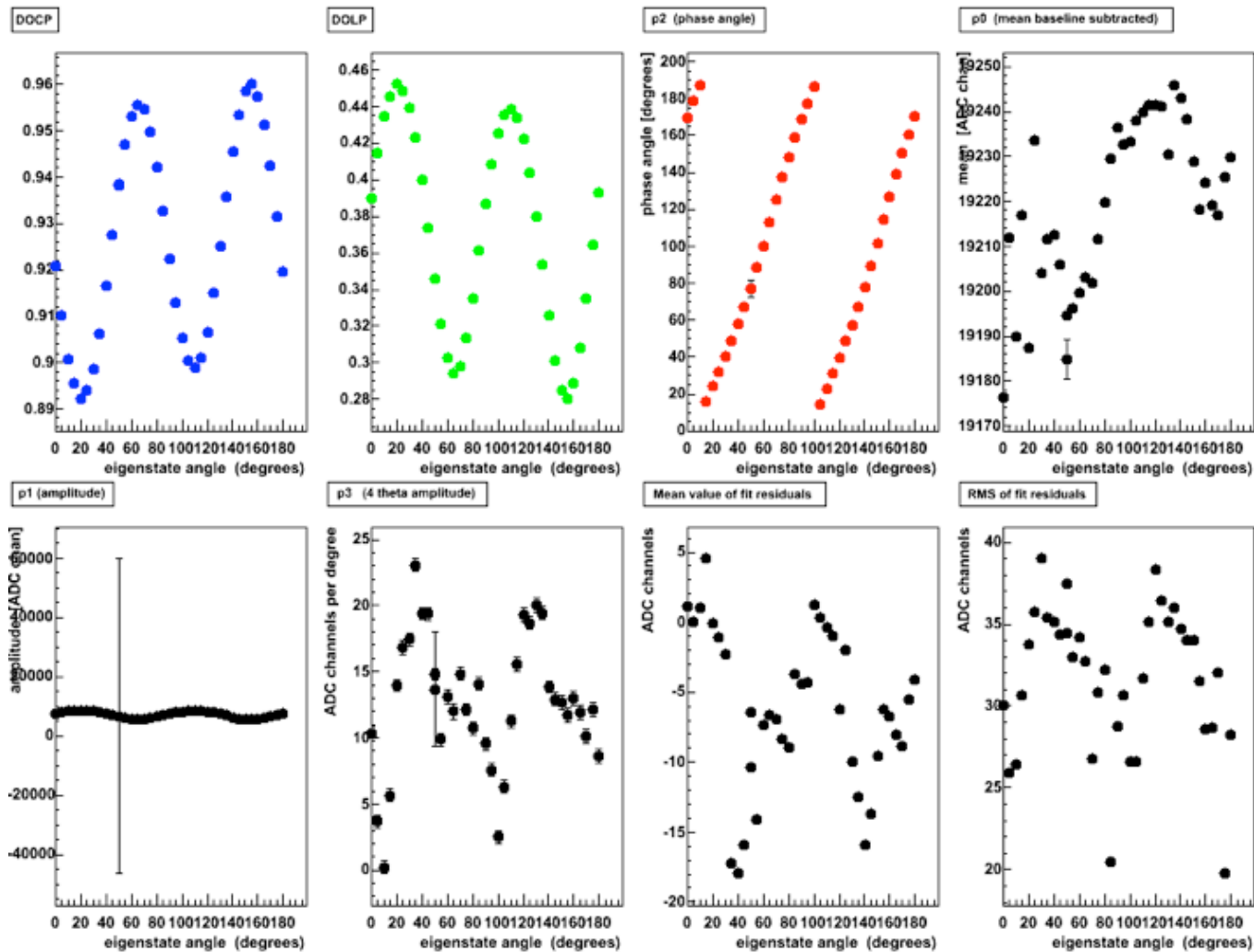


Are there effects from

- cavity mirrors?
- power level (heating)?
- alignment variations?
- model dependence of TF?

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

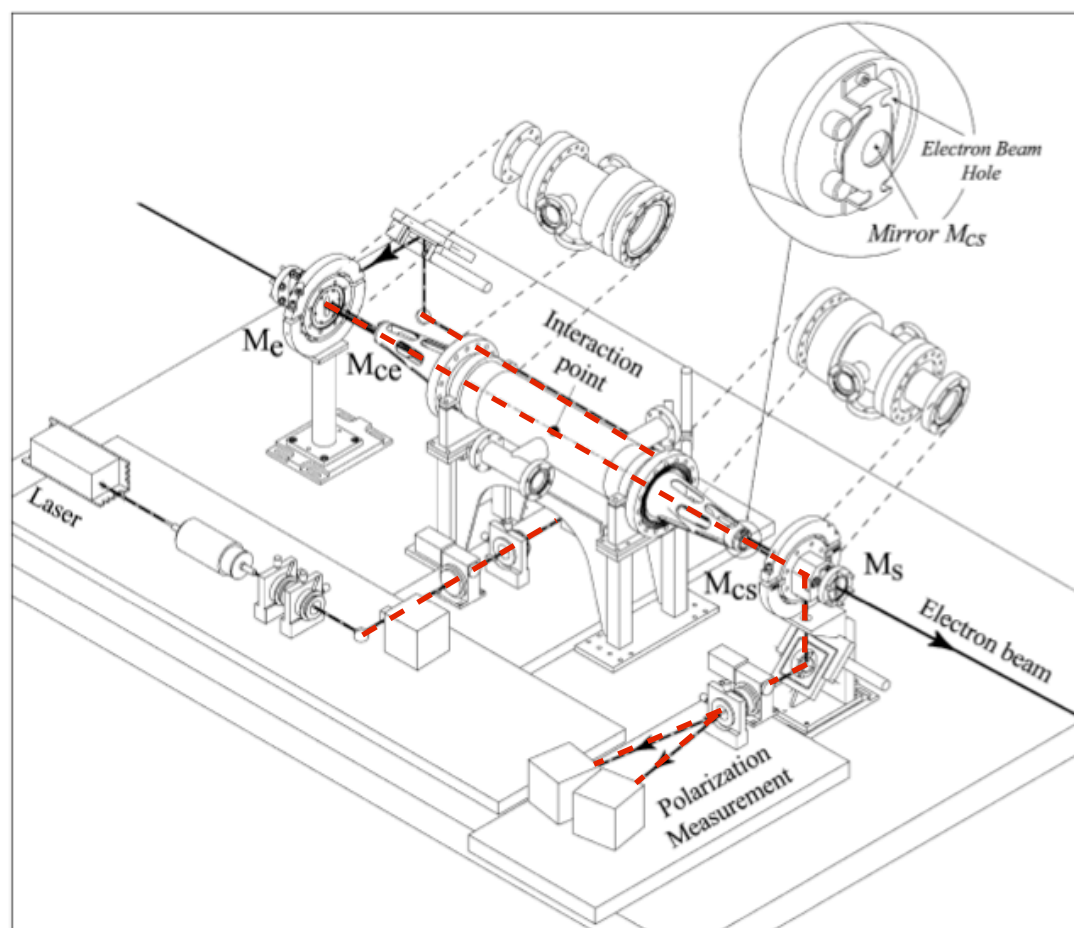
Hall C - Automation and improved mechanics for TF measurement



Cavity Polarization

Polarization of pump beam leakage must be measured *in situ* (but this is not sufficient)

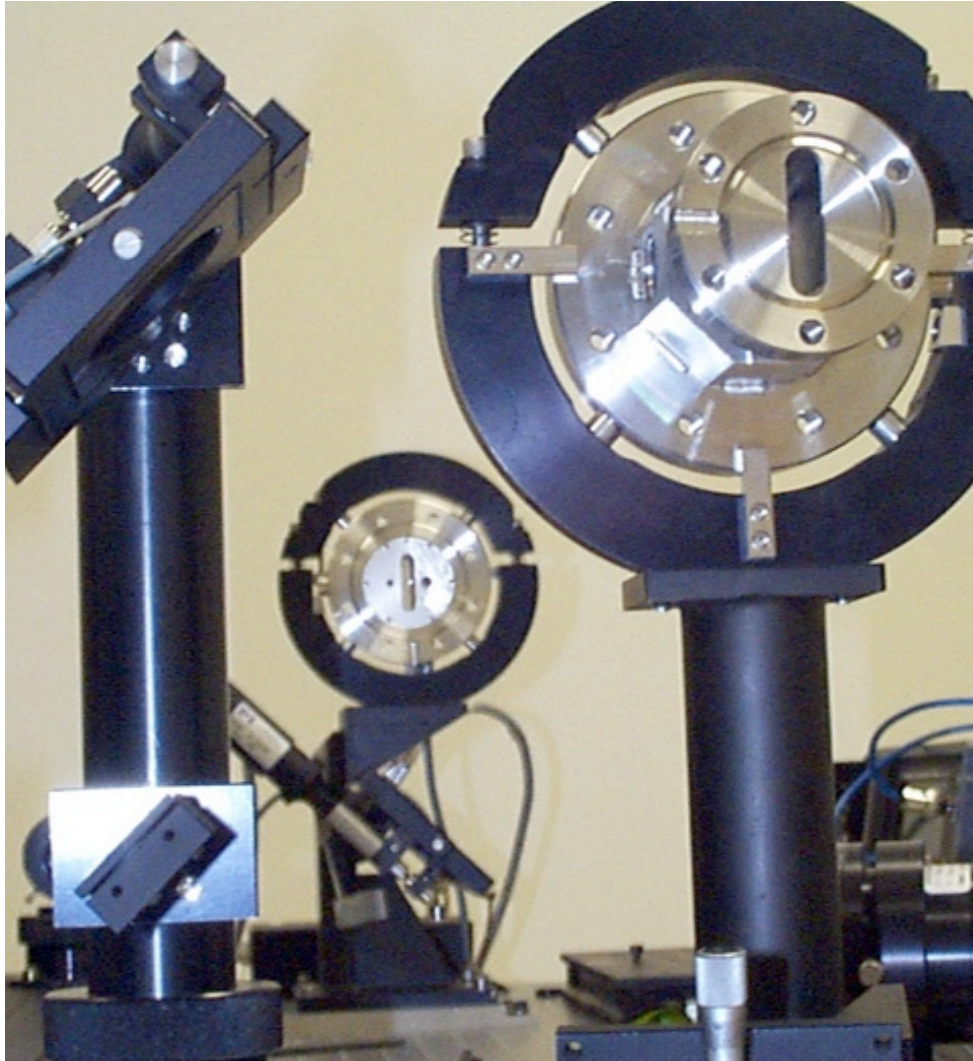
Transfer function must be well studied and used to provide confirmation for polarization of locked state



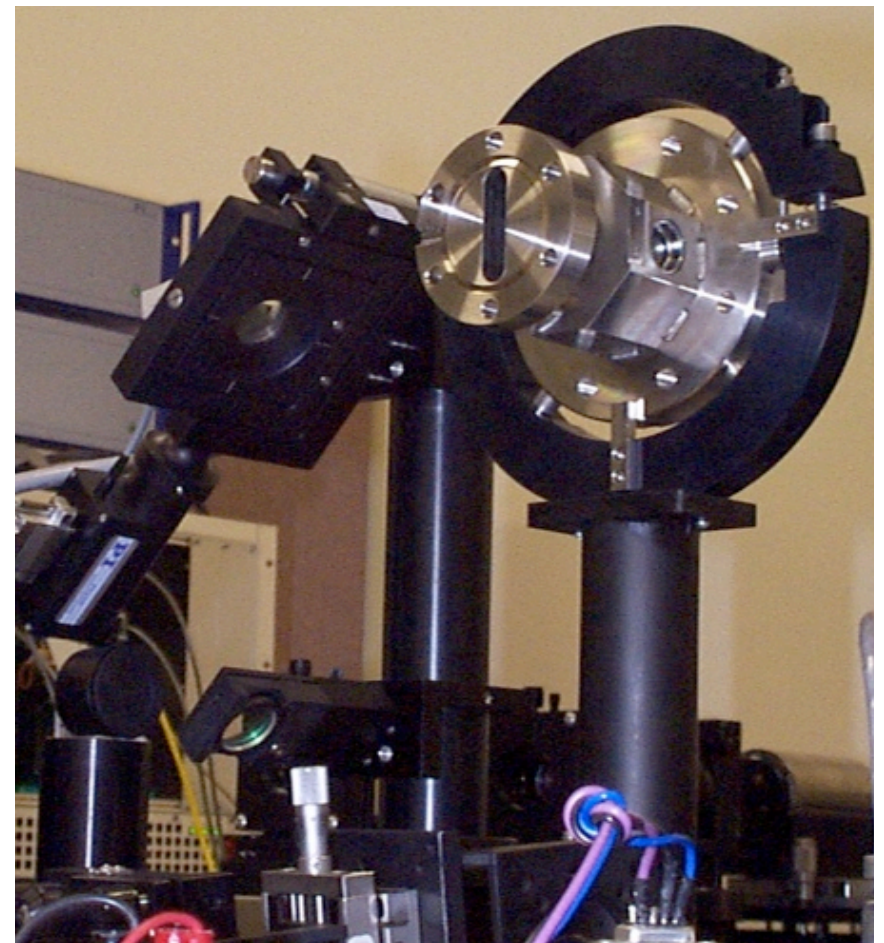
Cavity vacuum enclosure and mechanics not presently optimized for polarization determination

- simplify mirror insertion
- in situ cavity polarization analysis station
- **HARD WORK** is required for high precision

Existing Compton Interaction Region



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



Typical “good” brems rate: $\sim 100 \text{ Hz/uA}$
Residual gas should be about 10x less?

New Concern at 11 GeV

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

Can we get rid of the small apertures in the interaction region?
What will be backgrounds be, as a function of aperture?

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
(Cavity redesign not part of baseline)

Do we have enough photon power to keep statistical
precision? to keep signal over background?

Laser options

- Signal over background
 - how much improvement from crossing angle?
- Transfer function
- Reliable, robust, technical risks

Baseline upgrade - CW Green cavity:

- green exists @ 3kW (5kW possible? 15?)
- transfer function is hard
- at 3.6° , 700 Hz/ μ A.

at 11 GeV:
 $A_p = 32\%$
 $k_{\max} = 3 \text{ GeV}$

IR cavity

- Factor of 5 in photons over baseline with previous cavity
- at 3.6° , 3.5 kHz/ μ A.

at 11 GeV:
 $A_p = 17\%$
 $k_{\max} = 1.8 \text{ GeV}$

For 11 GeV: IR system is (probably) best candidate
For 6.6 GeV: green would be beneficial

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/ μ A
- Fast on/off improves background subtraction

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

RF IR Pulsed cavity:

- proof of concept exists
- low gain = fairly robust
- statistical power matches 10kW CW cavity

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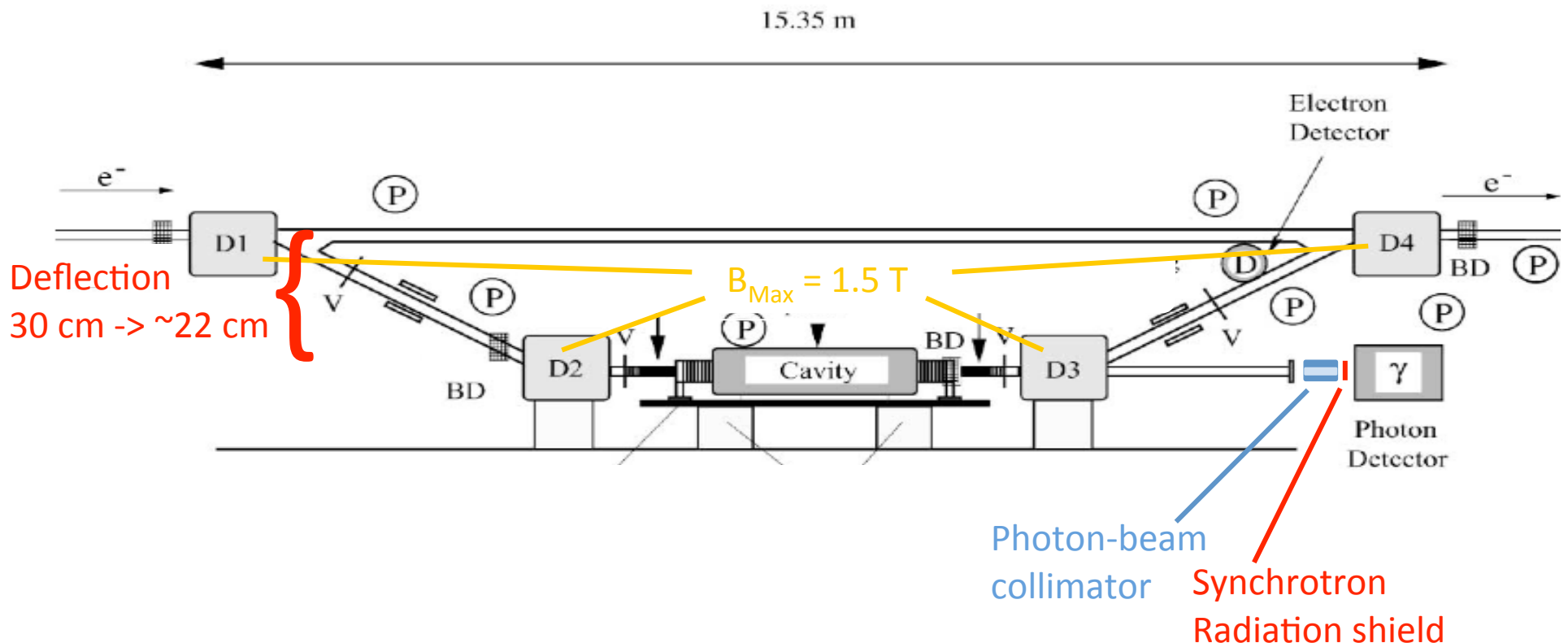
New Problem: time-dependent polarization shift in 10ps pulse?

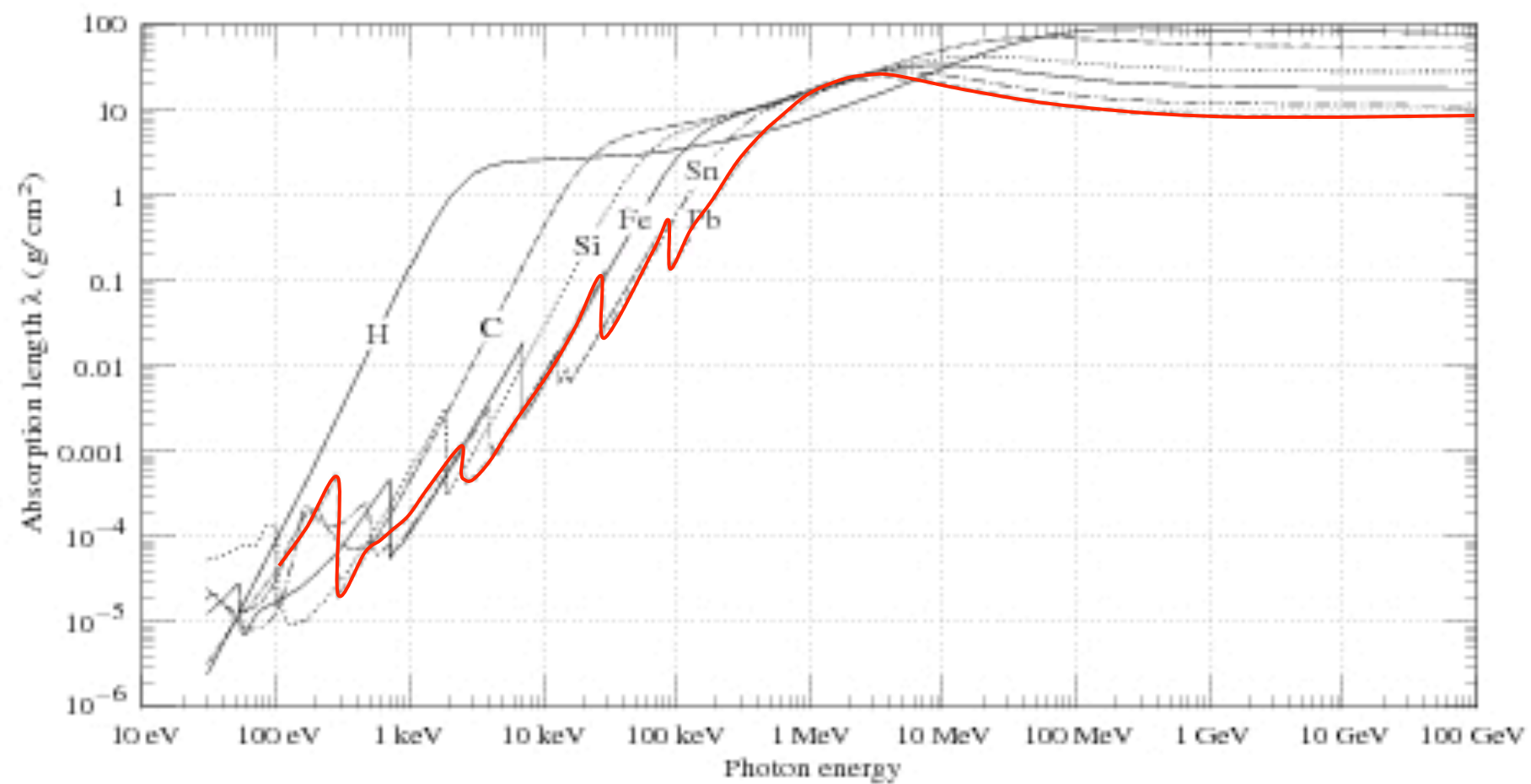
Synchrotron Radiation

New Concern at 11 GeV

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

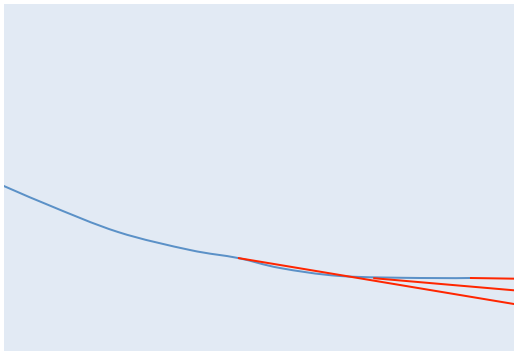
- Understand effects of shielding through simulation studies
- Detector sensitivity to synch light must be considered
- Model synch light from realistic magnets: can chicane be designed to lessen synch light power into photon aperture?



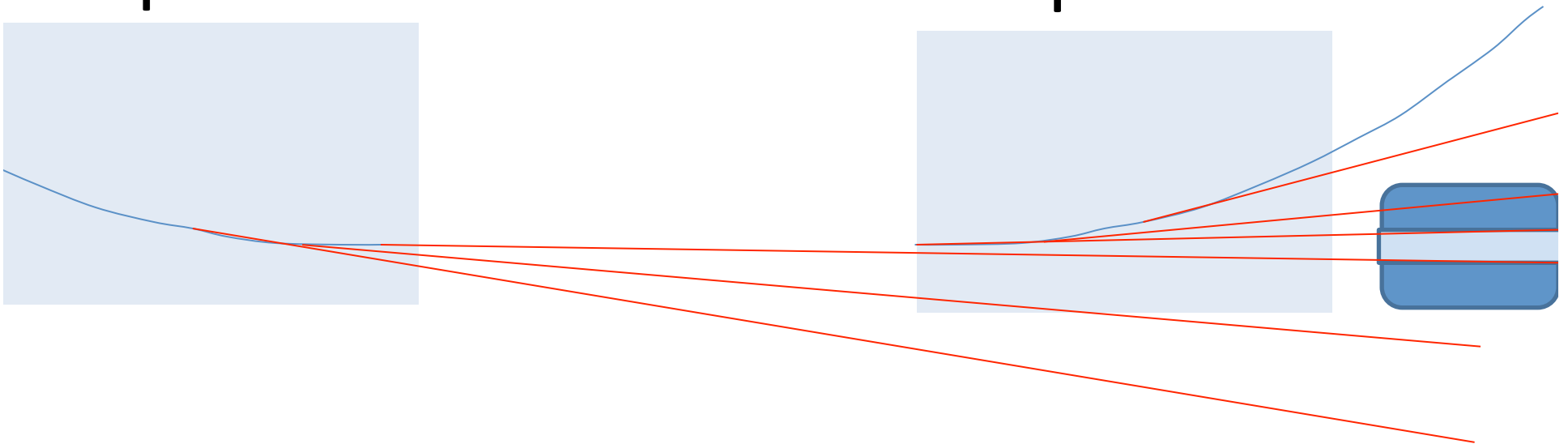
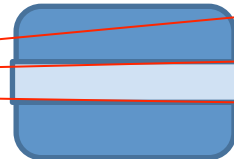
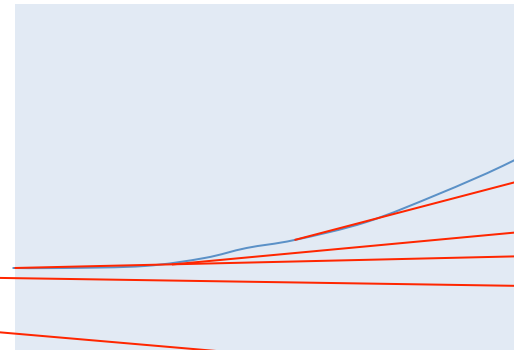


Synch light in calorimeter from interaction region

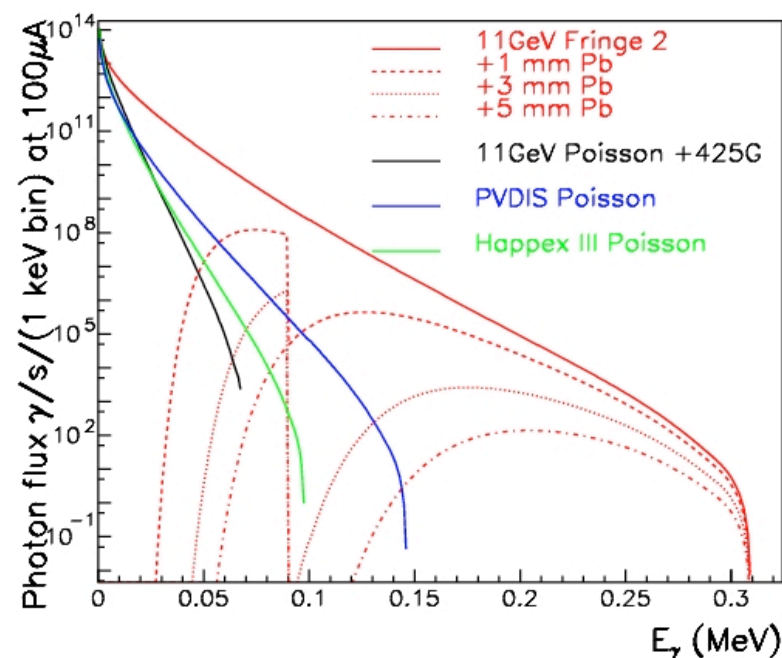
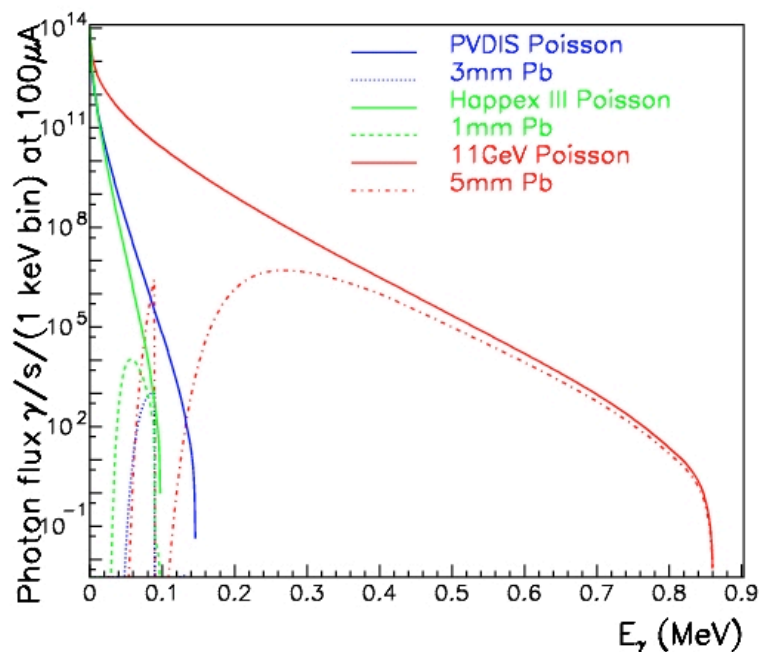
Dipole 2



Dipole 3

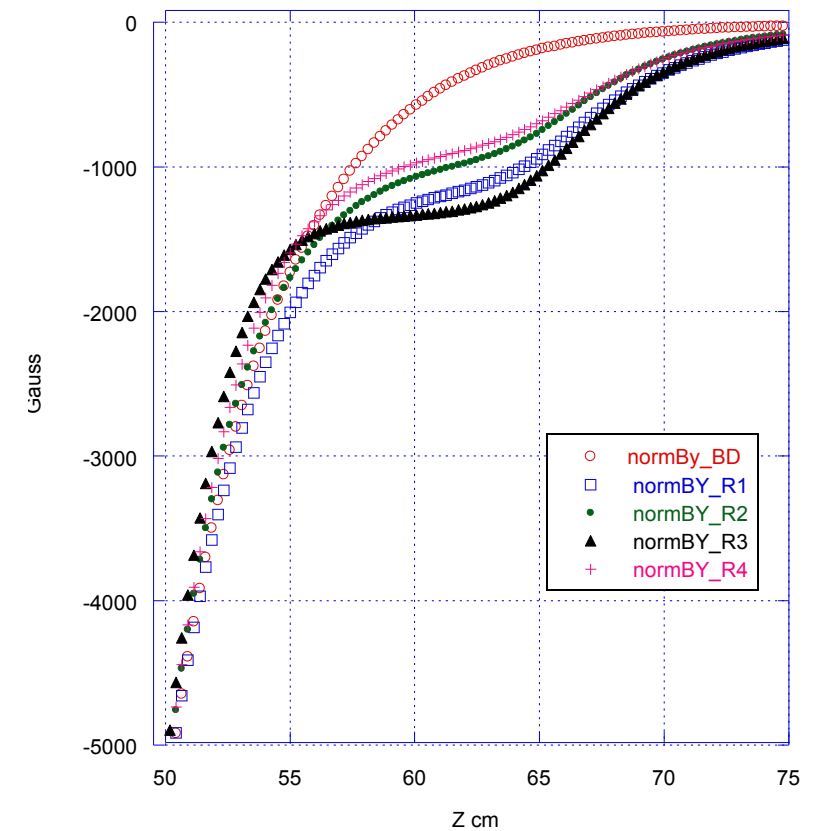
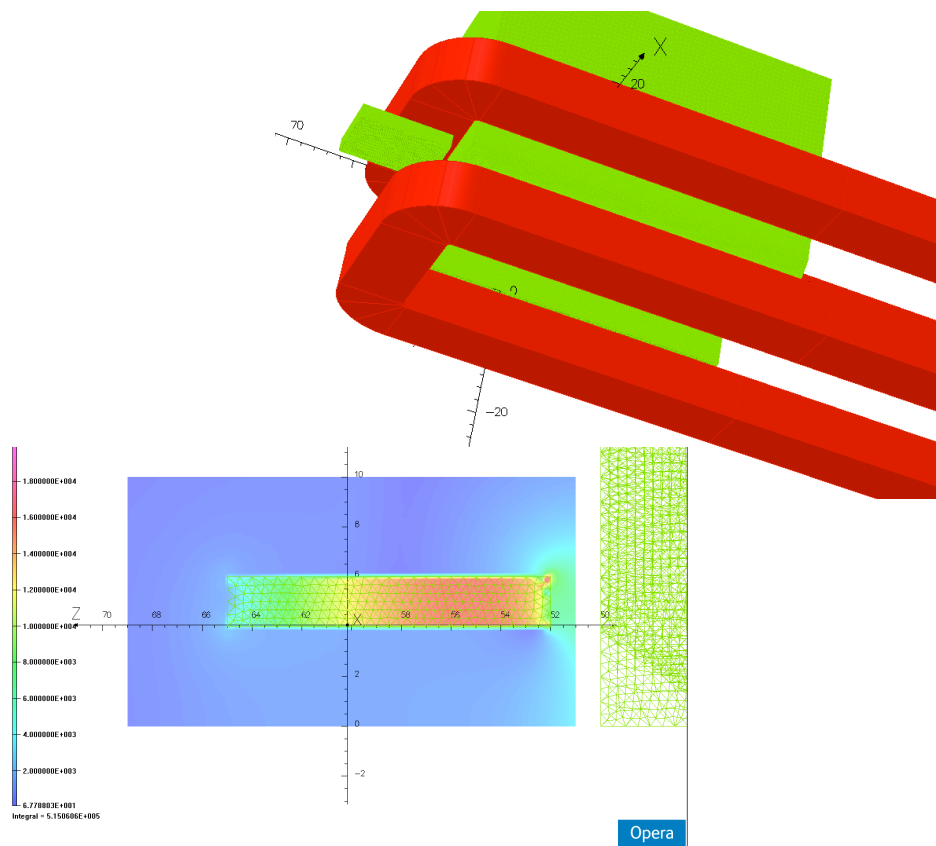
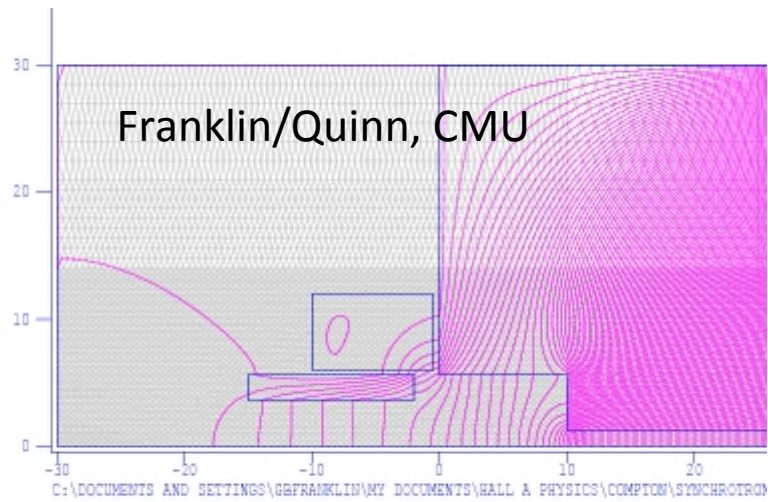


Softening the dipole fringing softens the spectrum, reduces the power



Franklin/Quinn, CMU

Modeling of Fringe Field Underway



Benesch, JLab

Detection and Analysis

Electron analysis at 11 GeV

- **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. IR: 20 minutes to 0.5%. (125micron calibration = 0.5% error in A_p)
- **Minimum single strip-** a single microstrip, at the asymmetry minimum (12 hours to 0.5%)

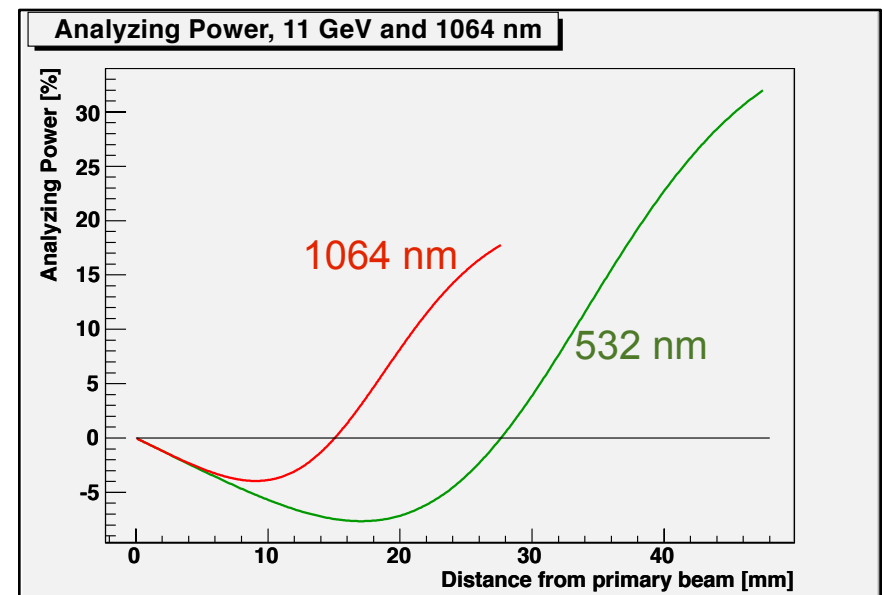
Analyzing power should be very well known, but other systematic effects must be treated carefully

Detector resolution?

Background sensitivity?

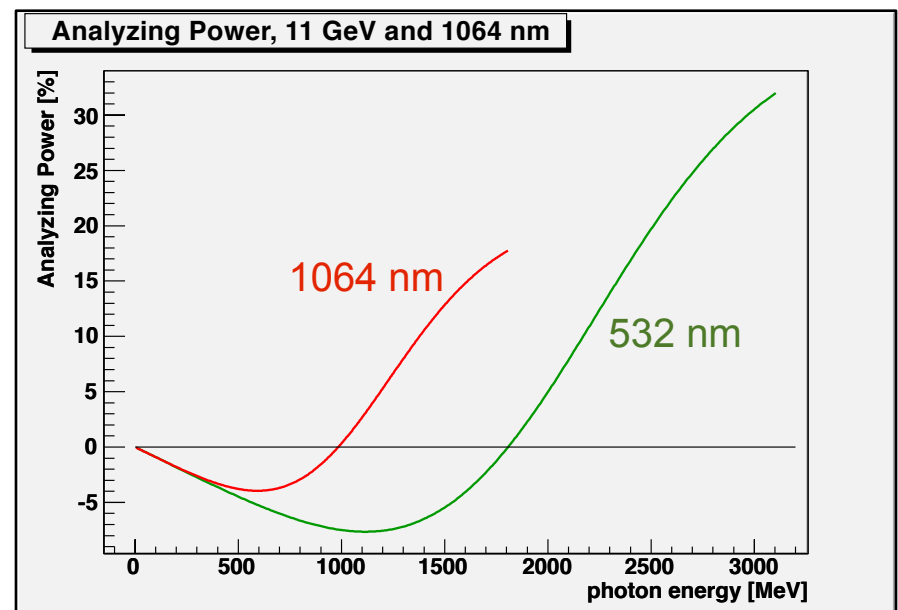
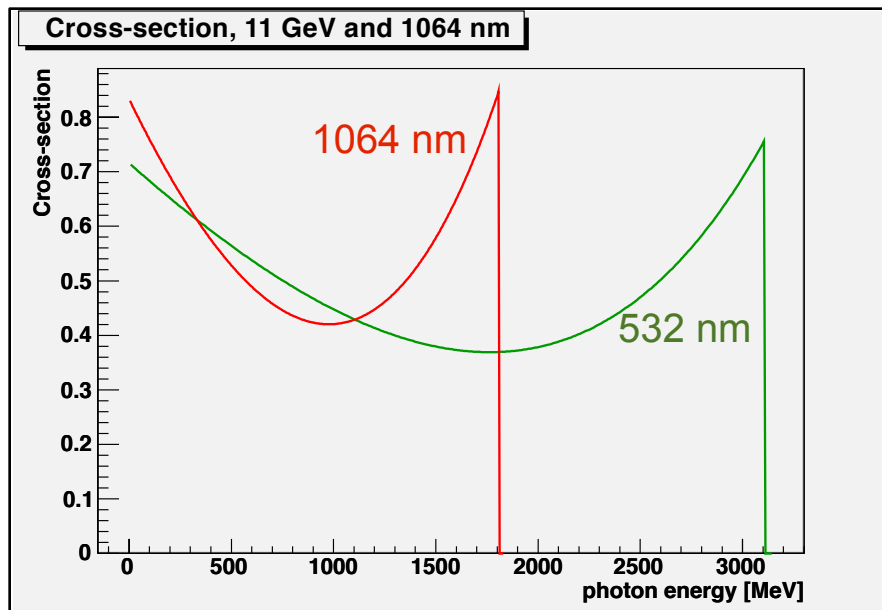
Synch light?

Detector does not presently exist:
upgrade is underway



Photon analysis with a “clean” spectrum

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



Detector resolution - less important for integrating technique

Background subtraction - and pile up, less important for integration

Sensitivity to Synch light

Synch light shielding - effect on analyzing power

Existing calorimeter will probably need to be replaced.

PMT will require careful preparation.

Summary of Compton Uncertainties

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

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

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

R&D Studies

Laser System Studies

- study of laser polarization transfer through cavity mirrors
- RF pulsed laser development to reduce backgrounds and improve knowledge of laser polarization

Chicane Magnet Study

- field uniformity vs. synch light power, optimize concept
- design, installation?

started

Simulations

- synch light
- 11 GeV backgrounds
- calorimeter: analyzing power
- e-det: backgrounds and A_p calibration

Detection

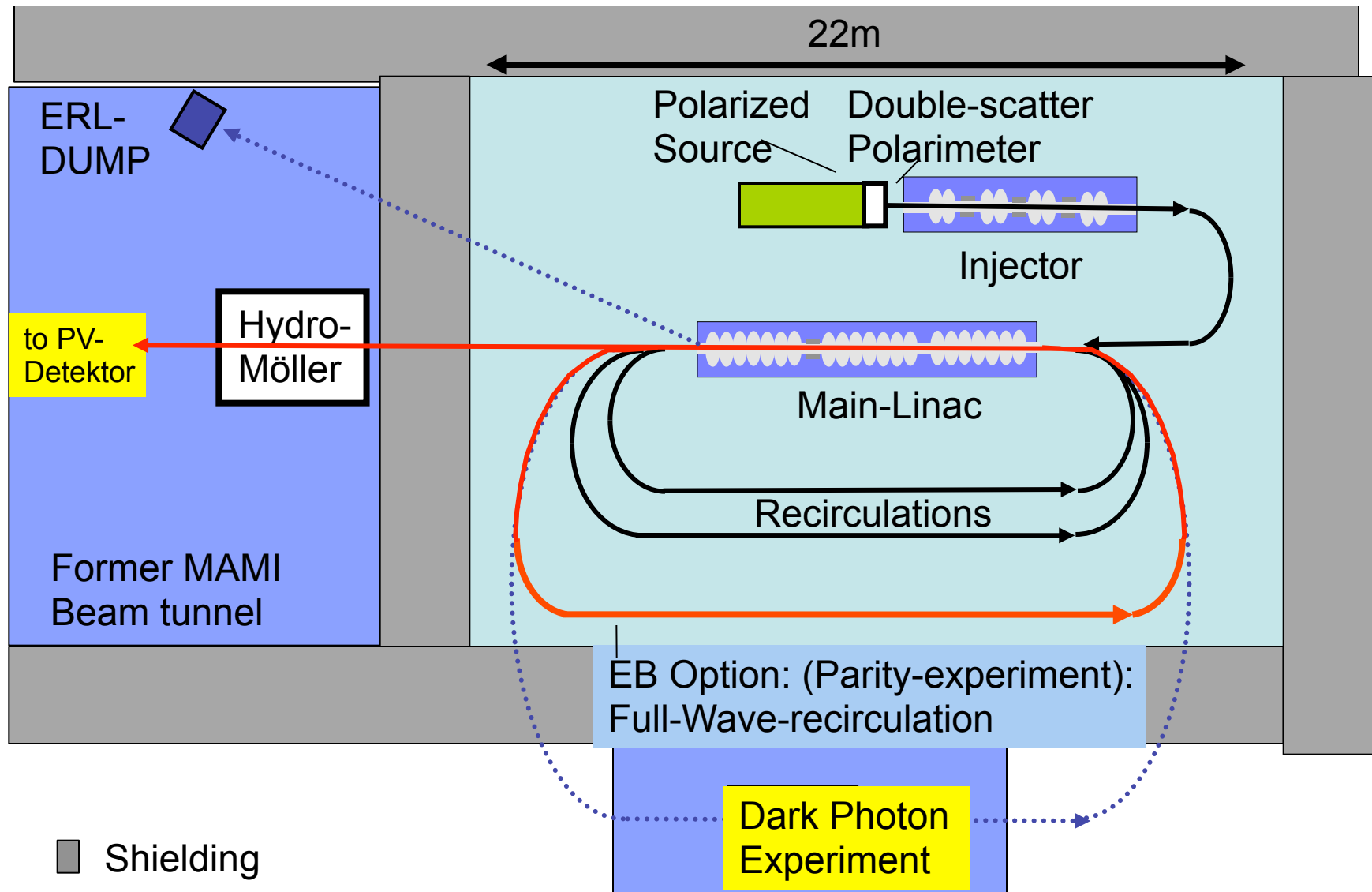
- Trade light for speed in photon calorimeter?
- photon detector linearity
- DAQ: required. Needs collaborators.

also, “training” on Qweak, PREX, HAPPEX-3

Moller

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

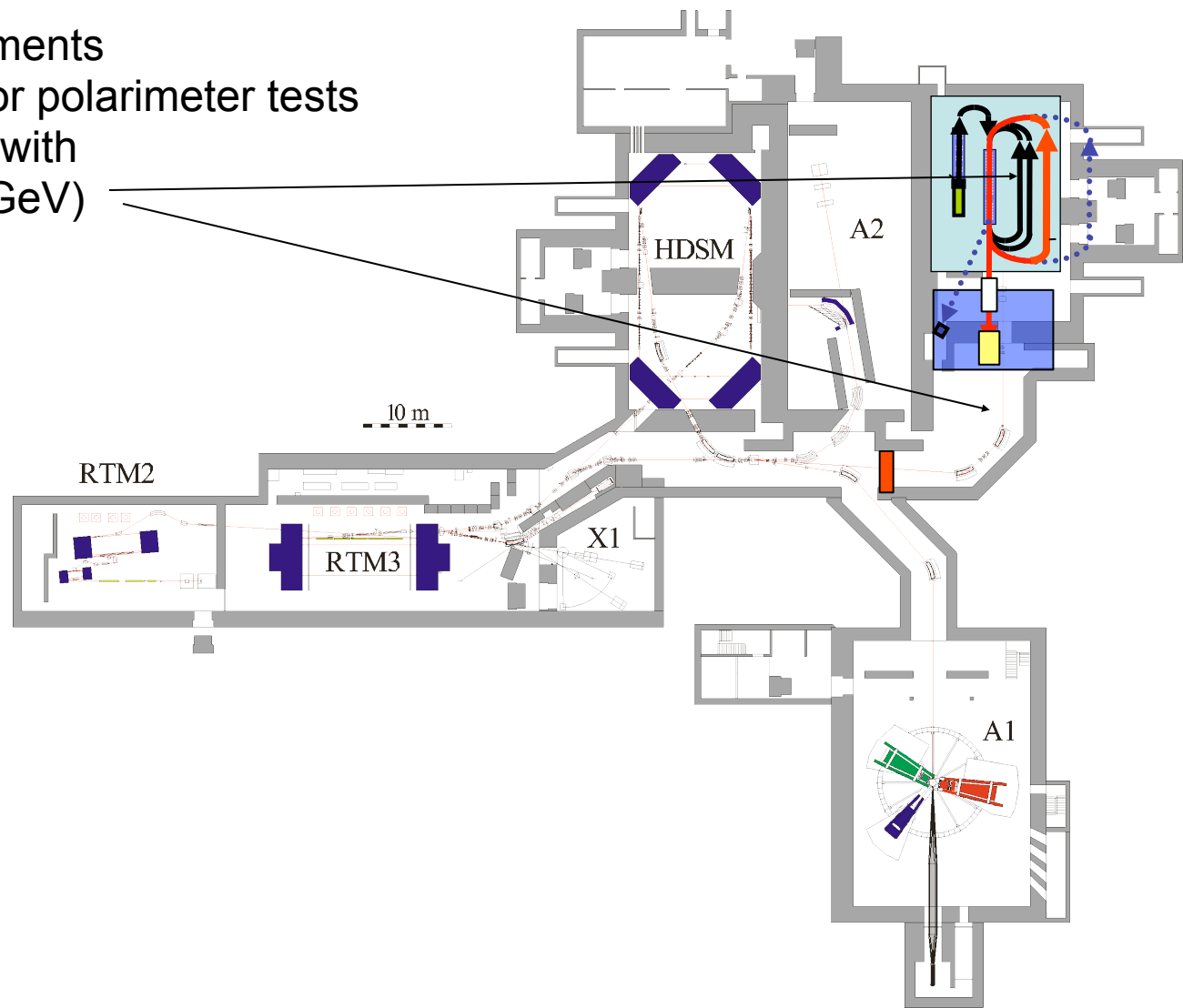


“Unimpeachable” polarization measurement: two independent polarimeters with $\Delta P/P < 0.5\%$ each.

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

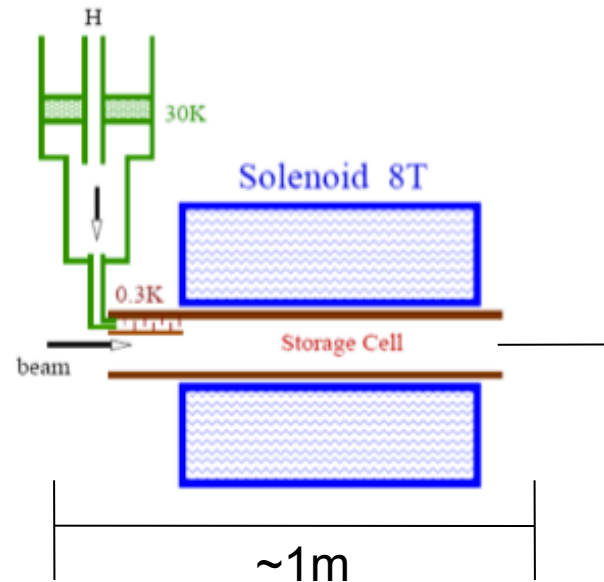
Location of Set-up in Mainz

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



Hydro-Möller

Chudakov&Luppov, Proceedings IEEE Trans. Nucl. Sc. **51**, 1533 (2004)



Solenoid traps pure $H\uparrow$ which has a long lifetime due to He-coating of storage cell. All other species are removed quickly from the trap.

- 1- ϵ Polarization can be reasonably well estimated, but not measured. No experience I with high intensity electron beam so far...
- Test experiments with existing UVA trap (D. Crabb) will demonstrate feasibility of concept!

Hydro Möller project staging

- UVA “prototype”-trap can be used at Mainz in spite of high helium consumption (Helium liquifier available at Mainz)
- Mainz can use UVA-‘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

Mainz group: K. Aulenbacher, S. Baunack, F. Maas, V. Tioukine

Status Summary

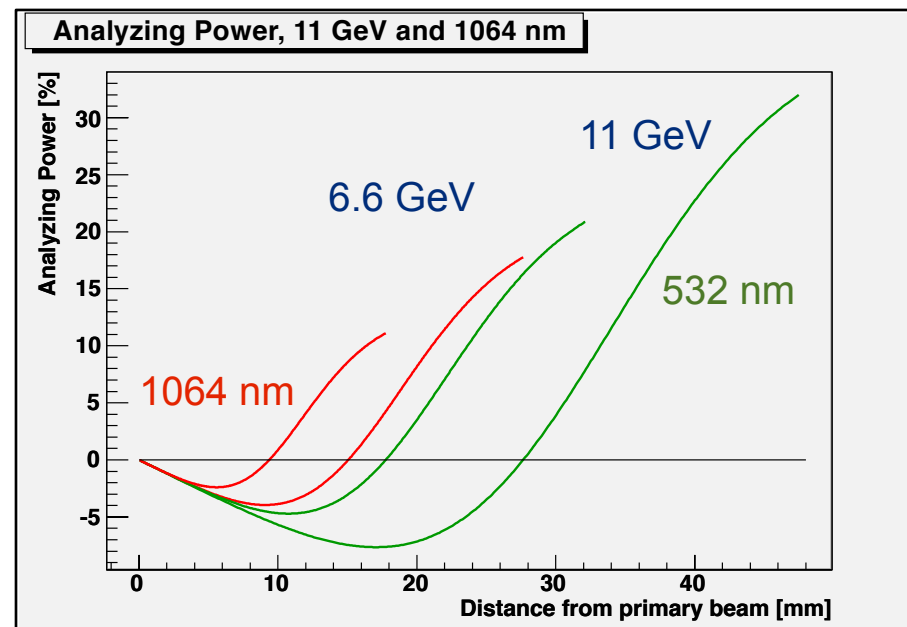
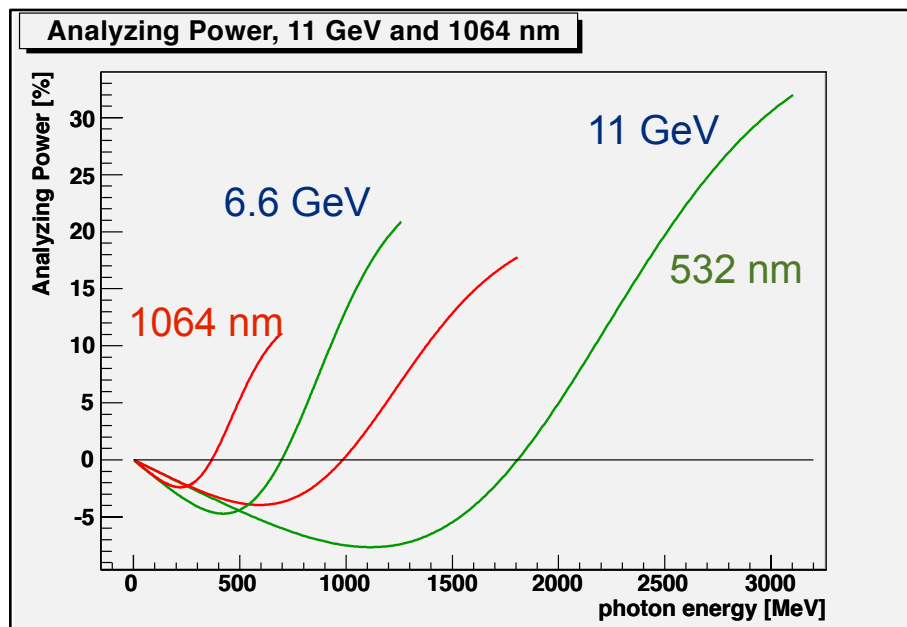
Moller polarimeter:

Work on atomic hydrogen Moller is starting now at Mainz, with the intention of bringing this to JLab

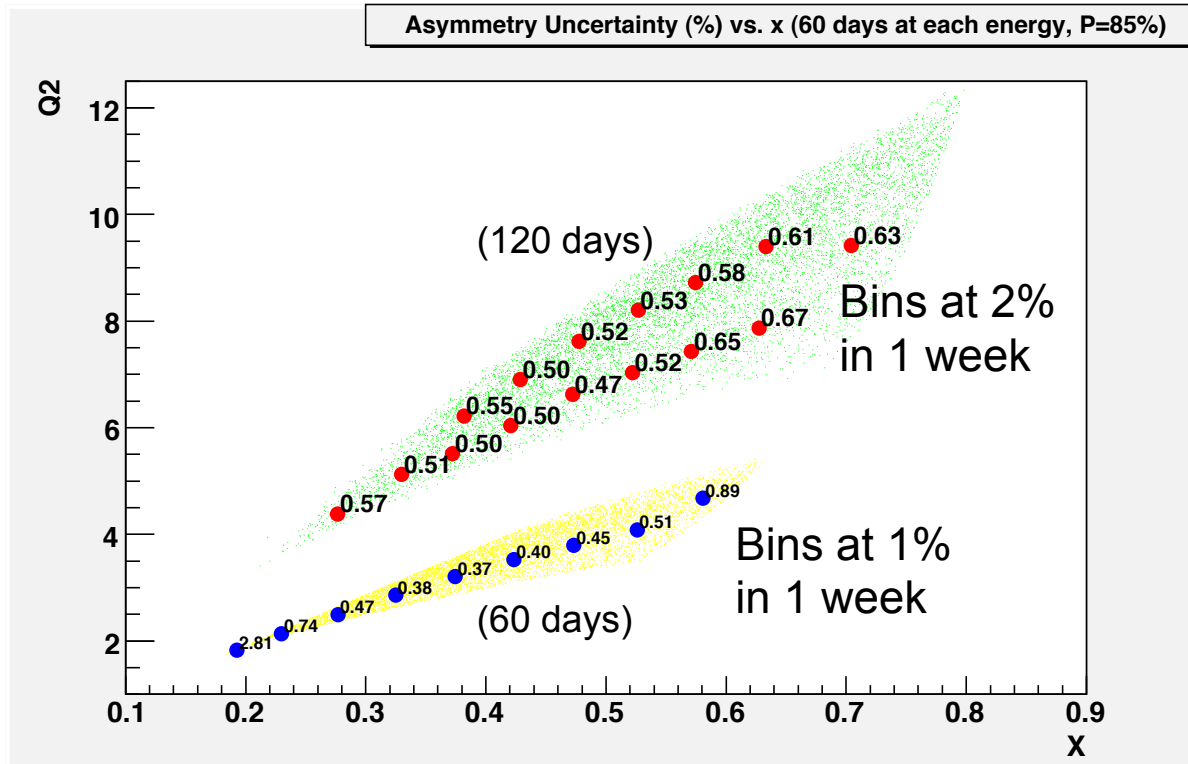
- start with studies of existing cell (via UVa), new designs by 2015
- beam tests possible at Mainz facility

Compton polarimeter:

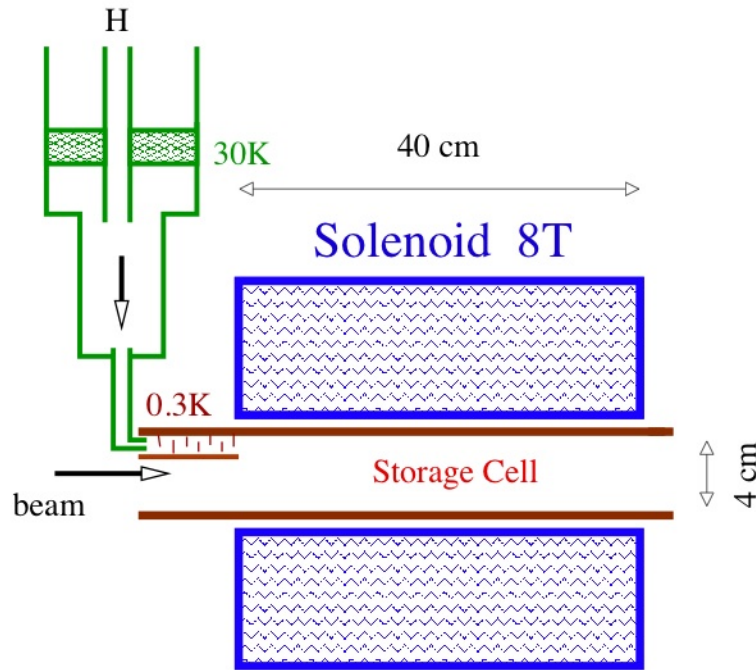
- Laser polarization measurement is key. Work on laser polarization determination must start to demonstrate feasibility of cavity solution
- Alternative laser system is feasible, but presents its own optical polarization challenges
- Chicane magnet modification conceptual design underway. Installation plan must move quickly (12 mo. down?)
- new electron detector (baseline upgrade)
- new photon detector? careful characterization needed.
- Participants from UVa, Syracuse, JLab, CMU, ANL, Miss. St., W&M



High Precision Polarimetry Needed



Atomic Hydrogen For Moller Target



10 cm, $\rho = 3 \times 10^{15} / \text{cm}^3$
in $B = 7 \text{ T}$ at $T = 300 \text{ mK}$

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

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 no dead time)
- Non-invasive
- high beam currents allowed
- no Levchuk effect

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

Atomic Hydrogen Trap Operation

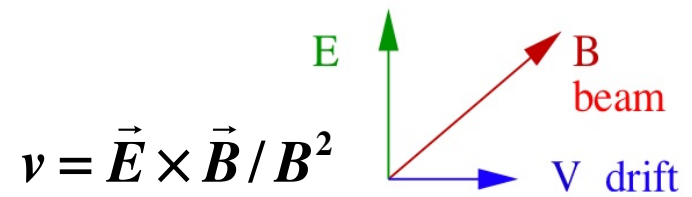
$H + H \rightarrow H^2$ recombination

- suppressed for polarized gas
- surface must be coated ($\sim 50\text{nm}$ of superfluid ^4He)
- H_2 freezes to walls

Gas lifetime > 1 hour

Beam + RF $\rightarrow 10^{-4}/\text{sec}$ ionizations ($\sim 20\%/\text{sec}$ in beam)

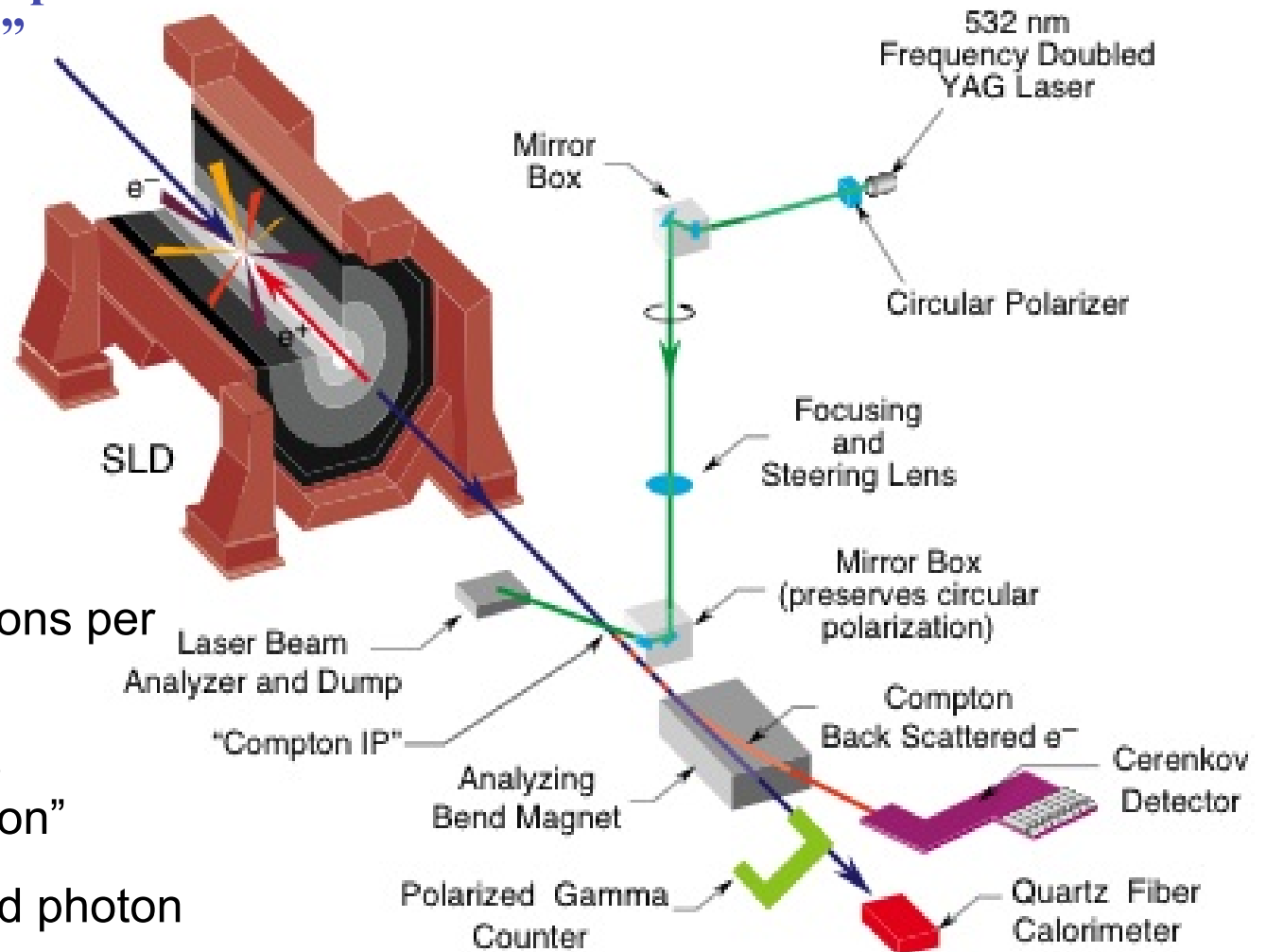
- Ions purged by transverse electric field ~ 1 V/cm
- Cleaning ($\sim 20 \mu\text{s}$) + diffusion $\rightarrow < 10^{-5}$ contamination



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 $\delta P/P \sim 0.5\%$



Photon detectors were not
used for production running

Collider Compton Polarimetry

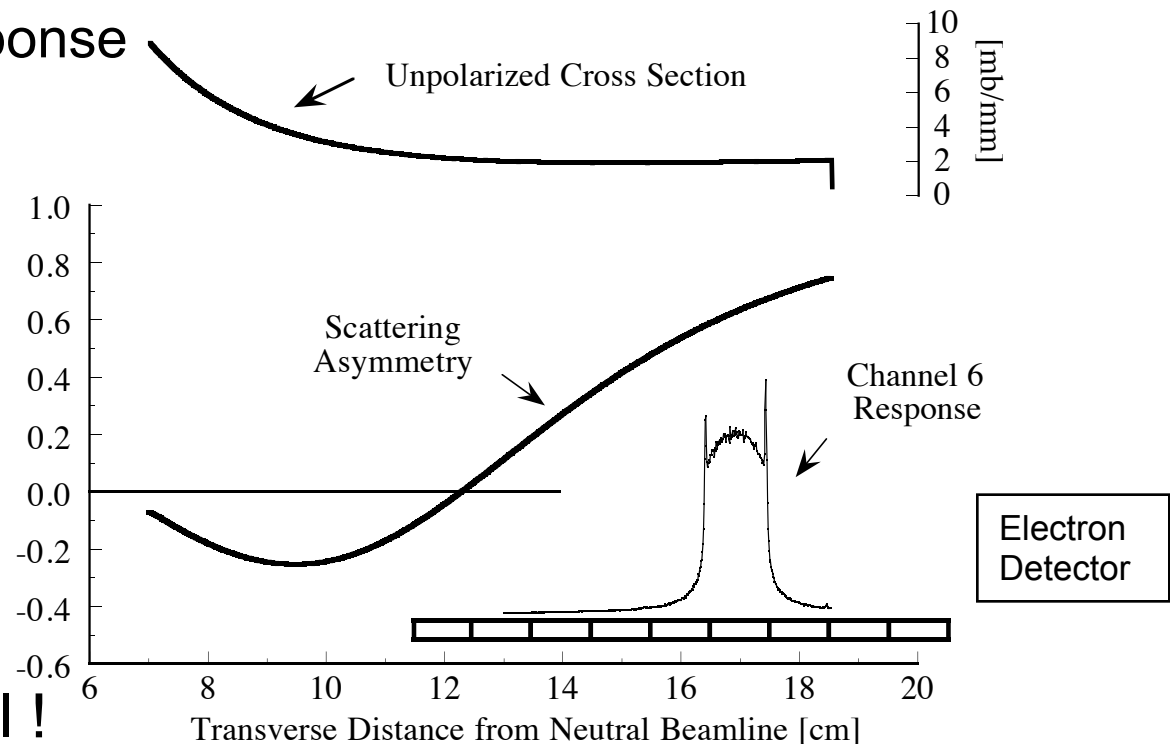
Uncertainty (%)	$\delta\mathcal{P}_e/\mathcal{P}_e$	
Laser polarization	0.10	
Detector linearity	0.20	
Analyzing power calibration	0.40	← Bounded by cross-calibration with photon detector
Electronic noise	0.20	
Total polarimeter uncertainty	0.50	
<i>Chromaticity and interaction point corrections</i>	0.15	← collider specific

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

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 !



High Precision Compton

At higher energies, SLD achieved 0.5%.

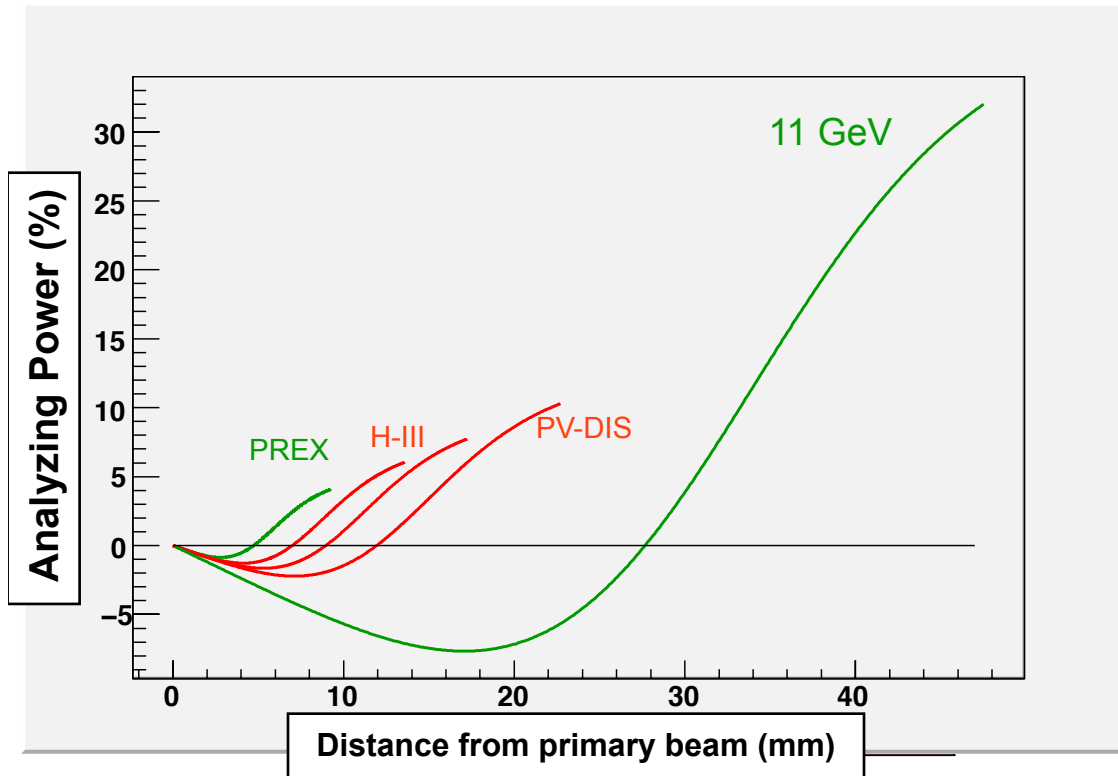
Why do we think we can do better?

- SLD polarimeter near interaction region
 - No photon calorimeter for production
- Hall A has single-photon / single-electron mode (CW)
 - Efficiency studies
 - Tagged photon beam
- Greater electron detector resolution
 - less resolution correction
- Greater coverage of Compton-scattered spectrum
- No “luminosity-weighted” polarization correction (chromatic aberrations at collider IP)

- Crystal Properties

	PbWO ₄	BGO	GSO	CeF ₃	BriLanCe 380	PreLude 420
Density (g/cm ³)	8.30	7.13	6.70	6.16	5.29	7.1
Rad Length (cm)	0.90	1.12	1.39	1.68	~1.9	1.2
Moliere Radius (cm)	2.0	2.3	2.4	2.6	?	?
Decay time (ns)	50	300	56:600	30	16	41
Light output (% NaI)	0.4%	9%	45%	6.6%	165%	84%
photoelectrons (# / MeV)	8	170	850	125	3150	1600
					\$\$\$ 4 in max	Natural decay

Existing electron detector



Silicon Microstrip Detectors

4 planes of 192 μ strips

(240 μ m pitch)