High Precision Polarimetry for SOLID

January 6, 2012

High Precision Polarimetry Needed

“Unimpeachable” result requires redundant polarization measurement

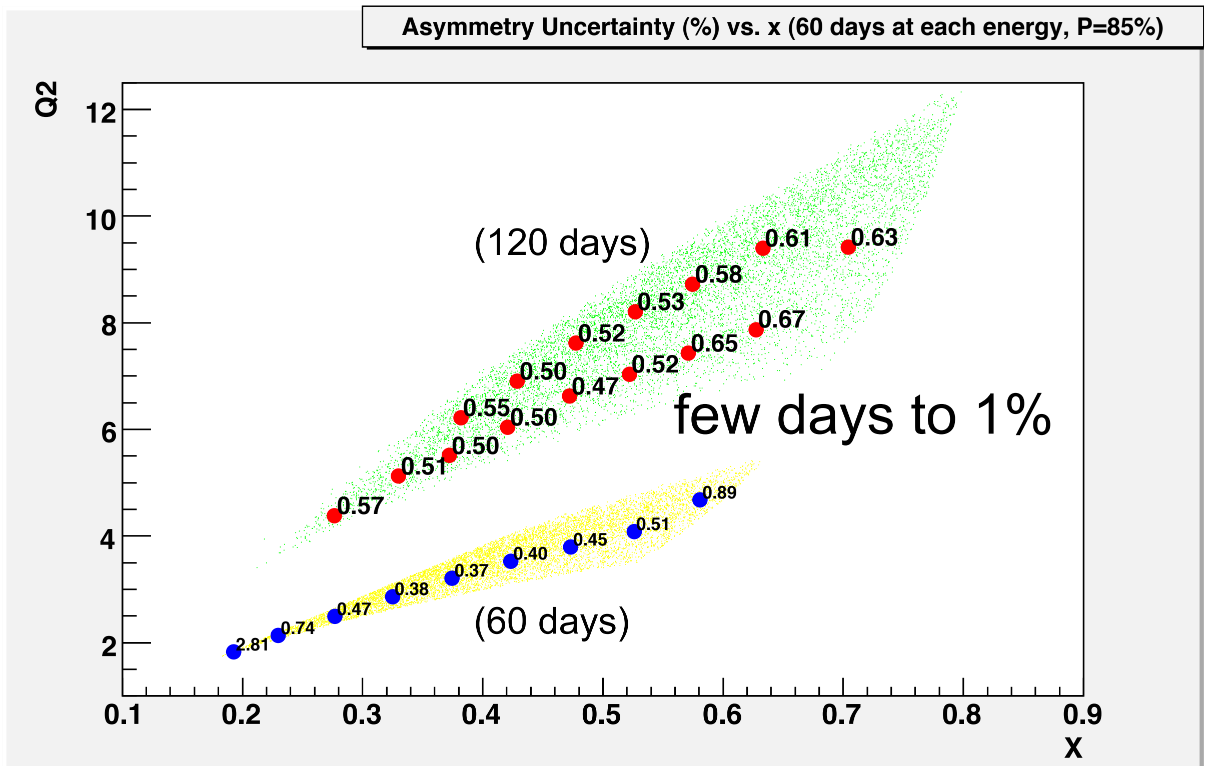


Table 2.2: Error budget in A_{PV}^{EW} at $x = 0.4$ for the test of the Standard Model

Source	Uncertainty in %
Statistics	0.3
Polarimetry	0.4
Q^2	0.2
Radiative Corrections	0.3
Total	0.6

Precision at both 11 GeV and 6.6 GeV, potentially leading systematic error

Route to precision polarimetry

Compton

Baseline Compton polarimeter upgrade for operation at 11 GeV

Additional upgrade plan <u>required</u> for high precision

Independent detection of photons and electrons provides two (nearly) independent polarization measurements at high precision (never been done before)

Møller

Upgraded "high field" foil Møller polarimeter

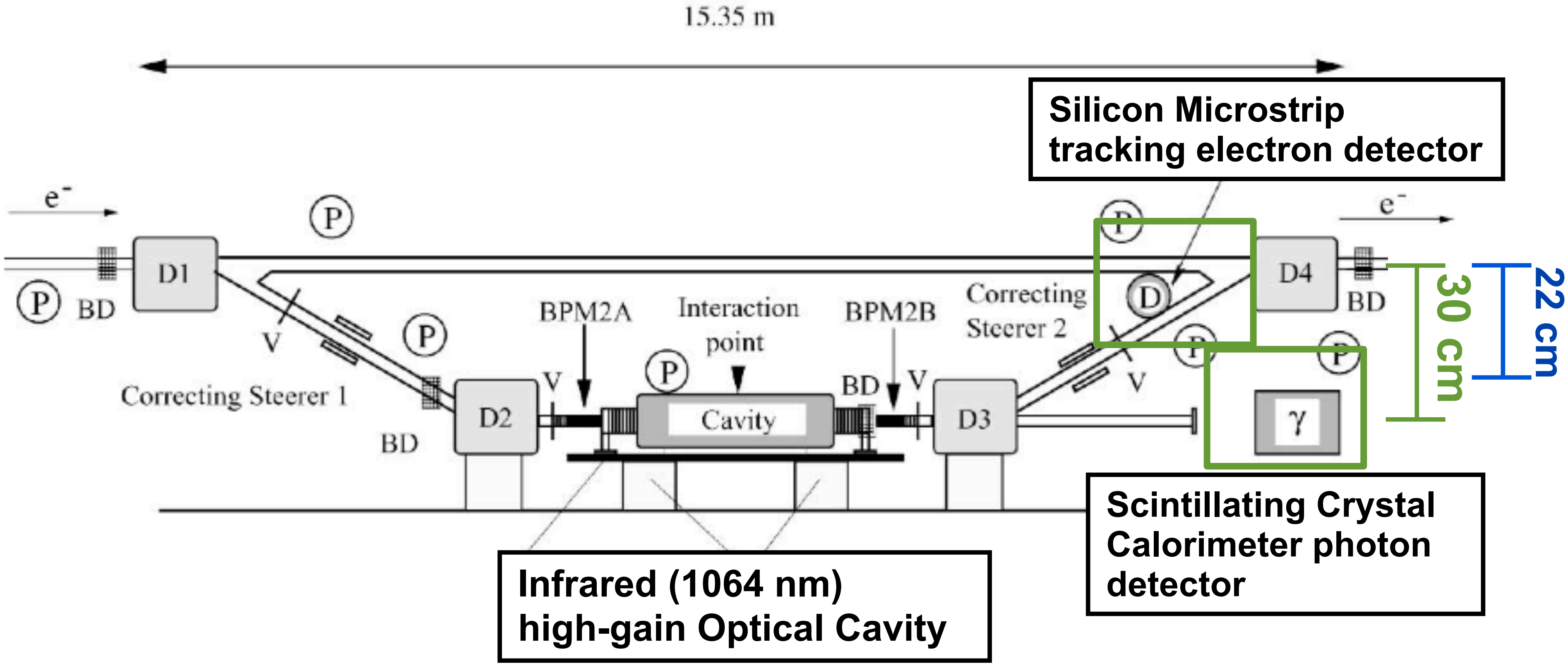
- saturated iron foil limits target polarization error ~1%
- invasive, used to test Compton polarimetry normalization?

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

Shared requirements (and strategy) with MOLLER

Compton

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

Compton Precision Upgrade

Laser System - Push cavity development to store 5-15kW green
- could use IR with higher power, but at 6.6 GeV may be challenging
- increase crossing angle to get larger aperture
- study of laser polarization transfer through cavity mirrors
- Develop in situ polarization measurement techniques
- RF pulsed laser development to reduce backgrounds and improve knowledge of laser polarization (alternative)

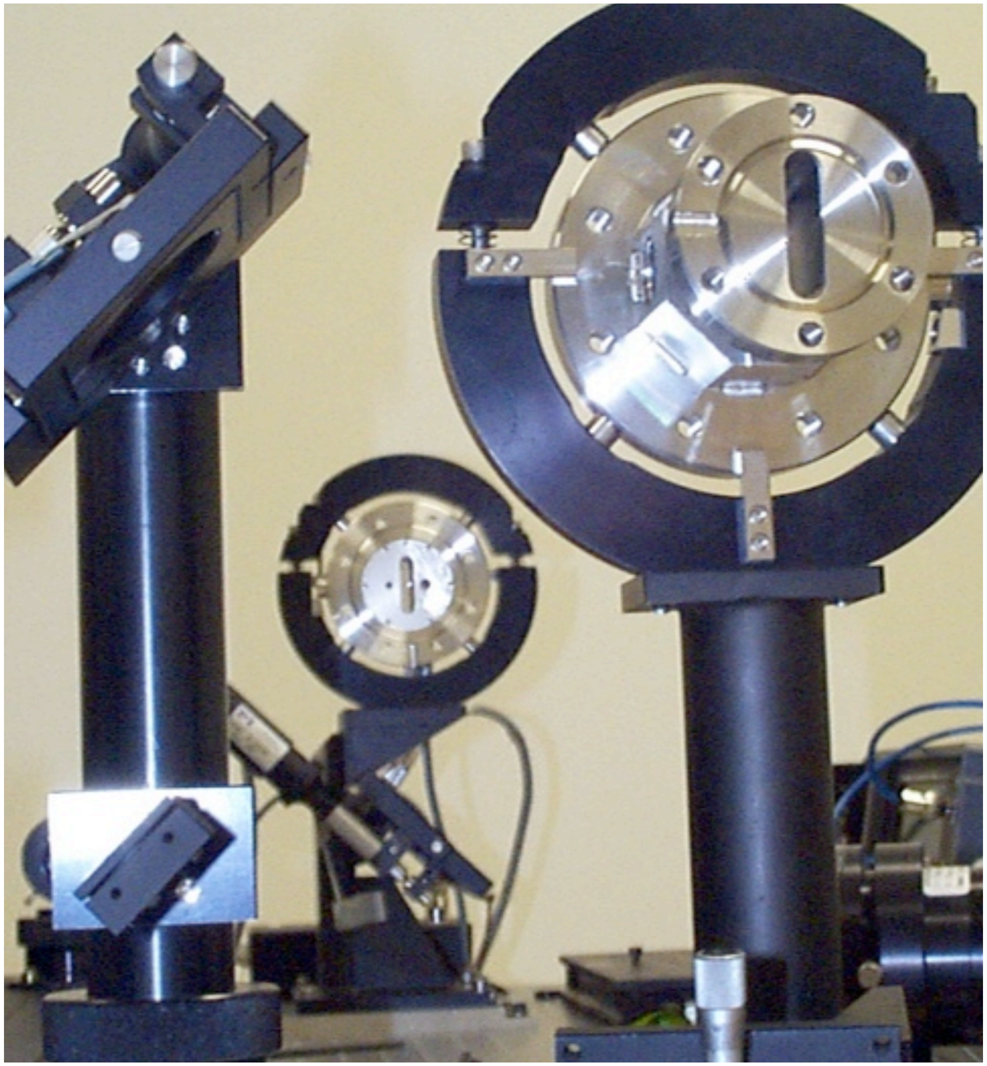
Chicane Magnet Modification - low-field pre-bend to cut synchrotron power

Photon Detection
- Trade light for speed in photon calorimeter. Not expecting major new investment.
- Linearity/characterization tools

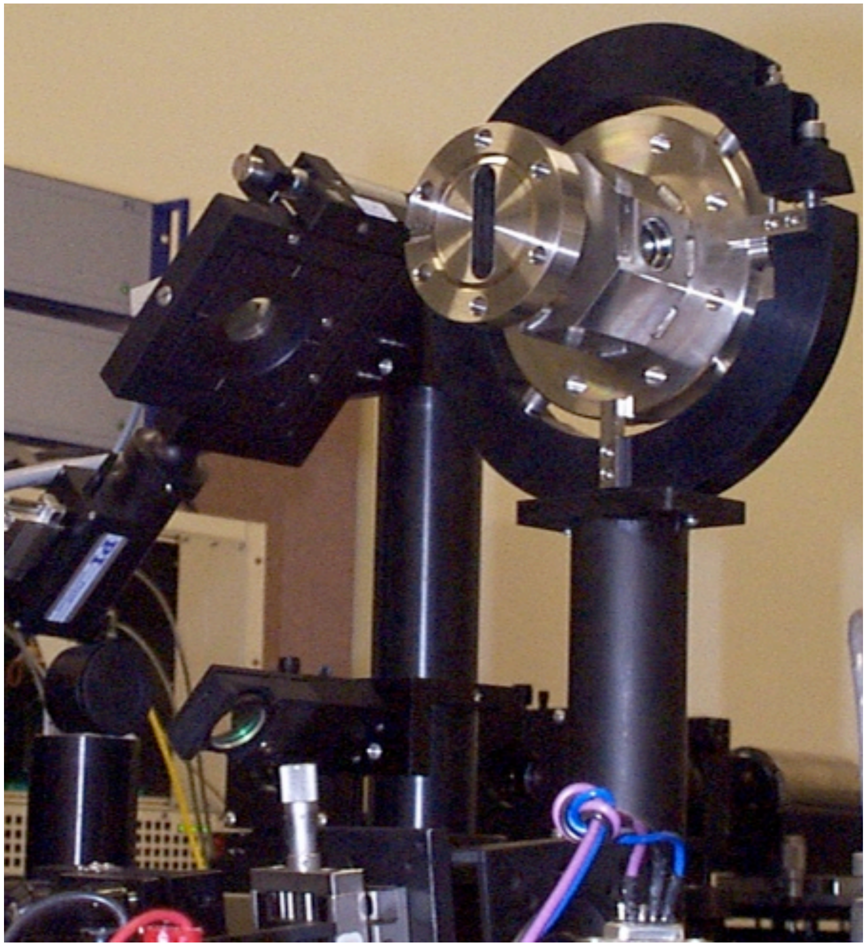
Electron Detection
- baseline should leave us with a functioning detector.

DAQ - integrating photon (exists). Counting photon(?) and electron readout.

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?

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/μA.

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

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

at 11 GeV:
A_p = 17%
k_{max} = 1.8 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/µA
- 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

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

Summary of Compton Uncertainties

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%

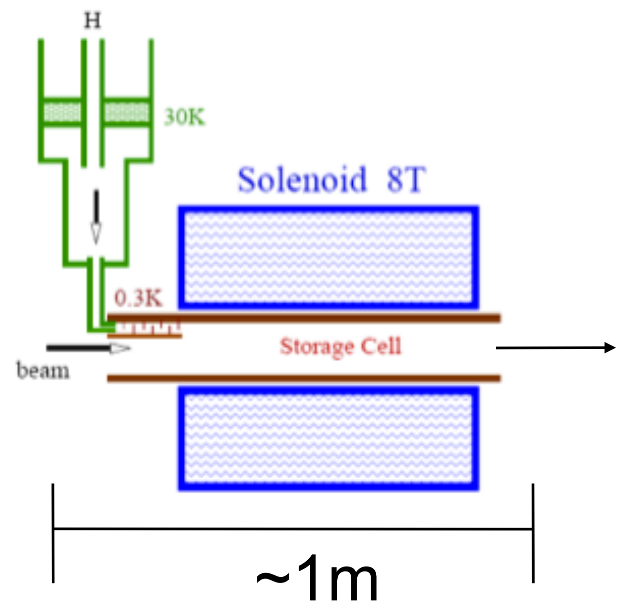
(Never been done before)

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

Moller

Hydro-Möller

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



Solenoid traps pure H↑ 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 (ε near 0)

→ technical questions: beam RF depolarization? cell superfluid He coating, E field

→ expertise must be developed

→ Development at Mainz: experiments with existing UVA trap (D. Crabb) will demonstrate feasibility of concept!

Precision at 0.5%, continuous measurement.

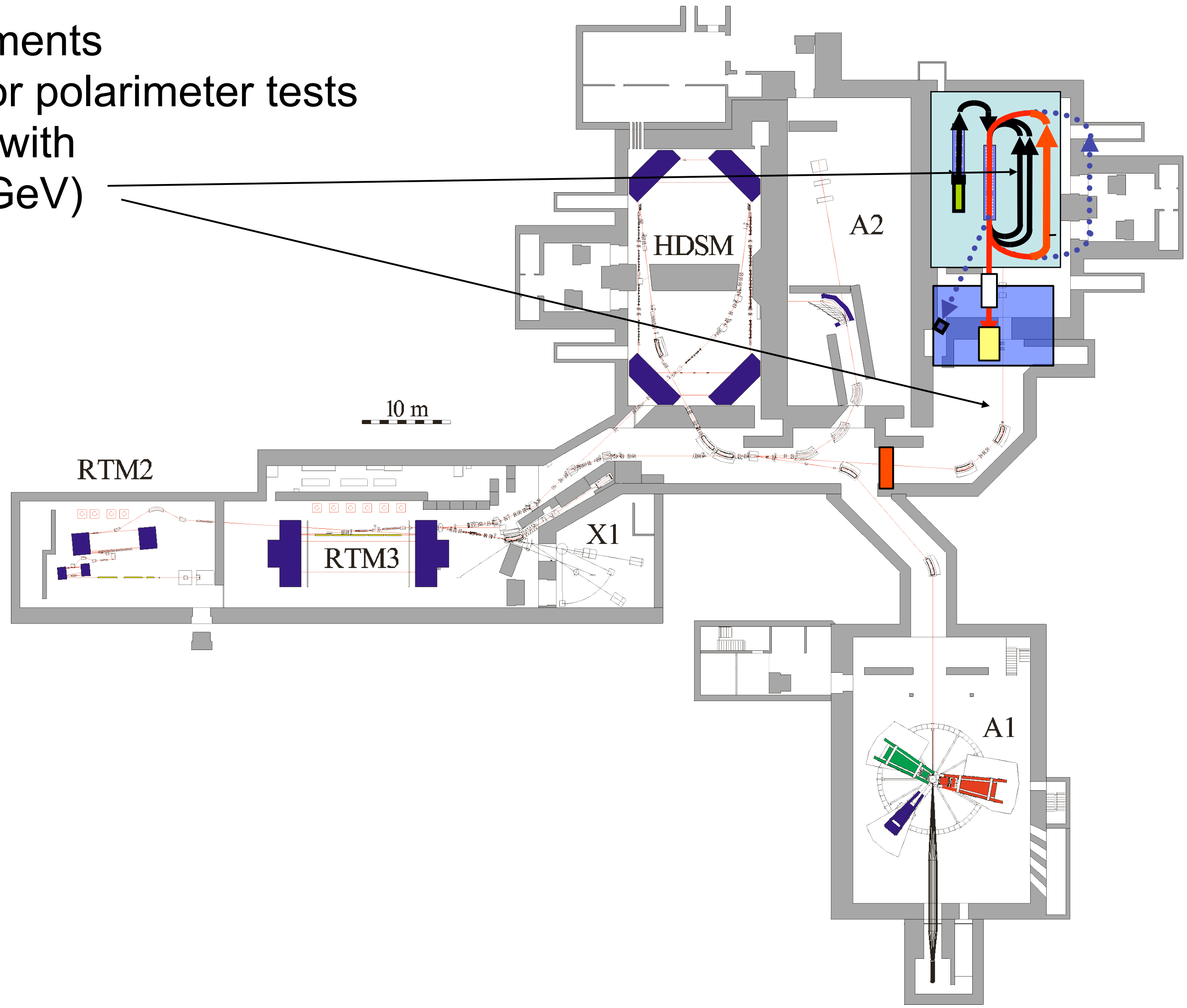
Hydro-Möller-Project rationale for Mainz university

- 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

"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 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
- 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 experiments

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

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
- Push laser power, robust locking electronics
- 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)
- DAQ rebuild
- new photon detector? careful characterization needed.

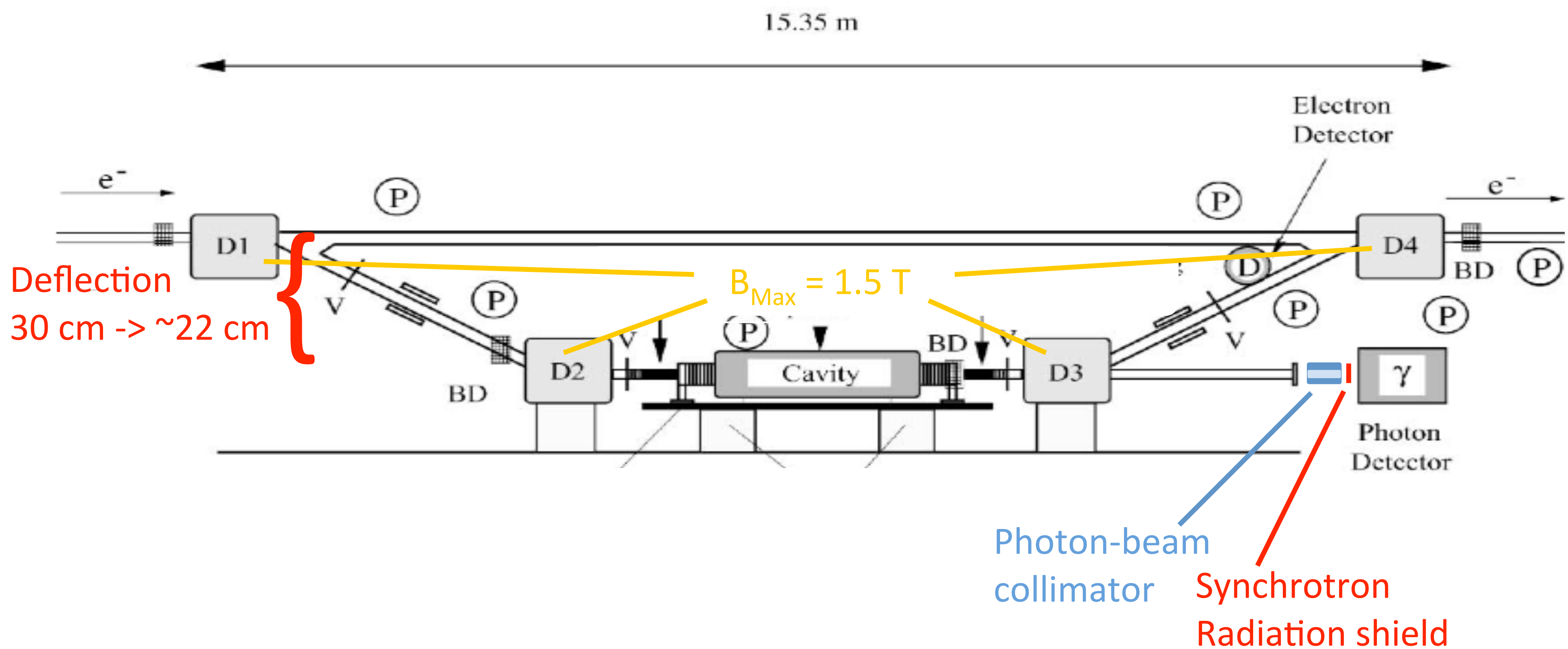
backup

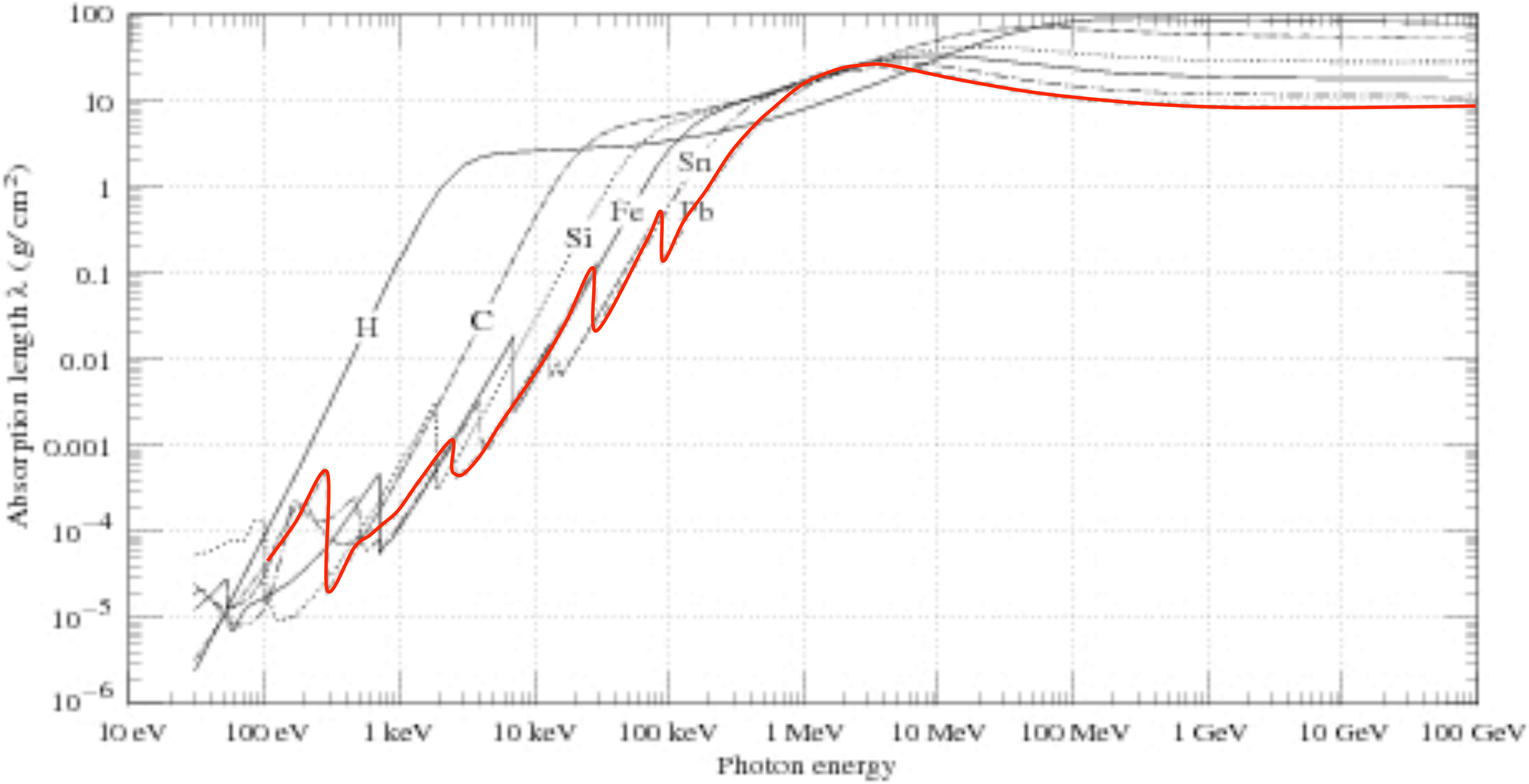
Synchrotron Radiation

New Concern at 11 GeV

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

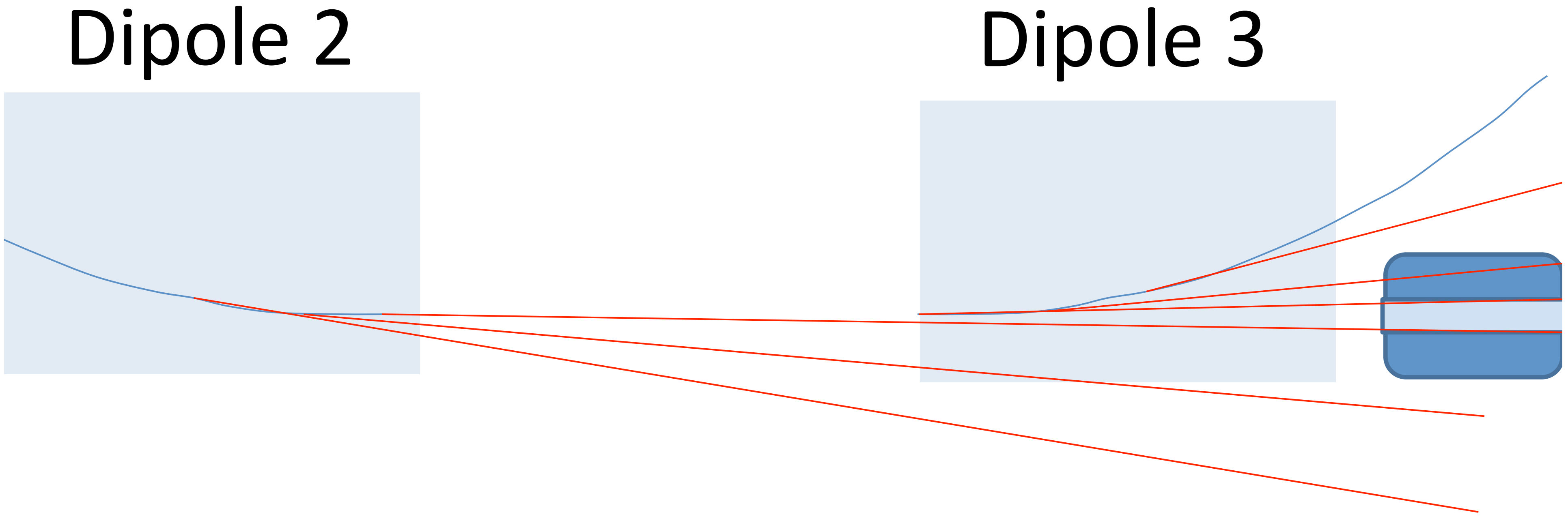
- Understand effects of shielding through simulation studies
- Detector sensitivity to synch light must be considered
- Model synch light from realistic magnets: can chicane be designed to lessen synch light power into photon aperture?



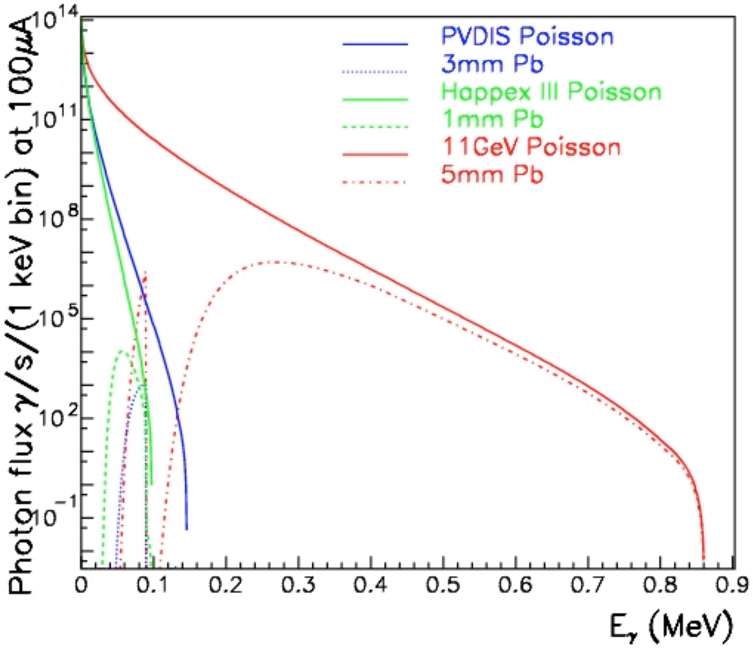


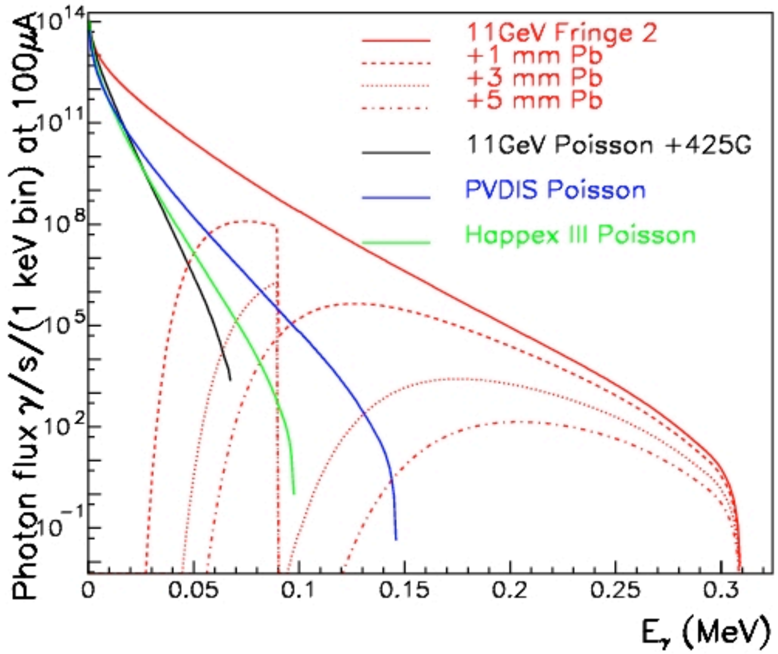
100
10
1
0.1
0.01
0.001
10^{-4}
10^{-5}
10^{-6}
Absorption length λ (g/cm^2)
H
C
Si
Fe
Sn
Pb
10 eV
100 eV
1 keV
10 keV
100 keV
1 MeV
10 MeV
100 MeV
1 GeV
10 GeV
100 GeV
Photon energy

Synch light in calorimeter from interaction region



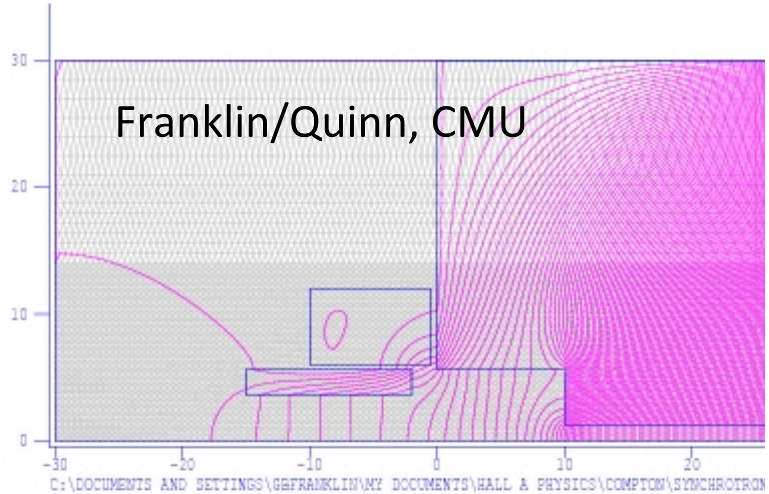
Softening the dipole fringing softens the spectrum, reduces the power

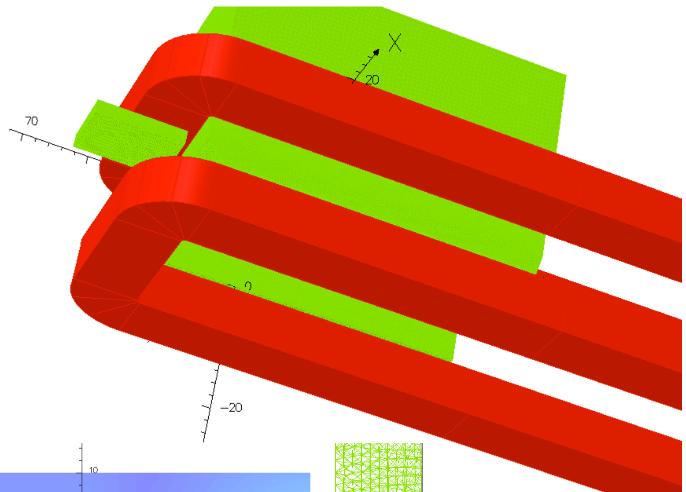


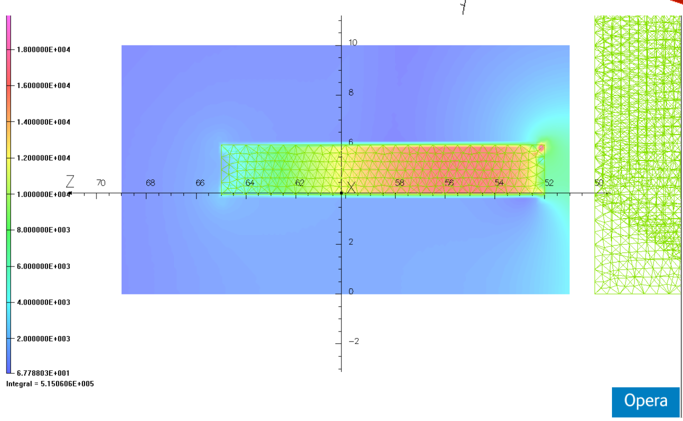


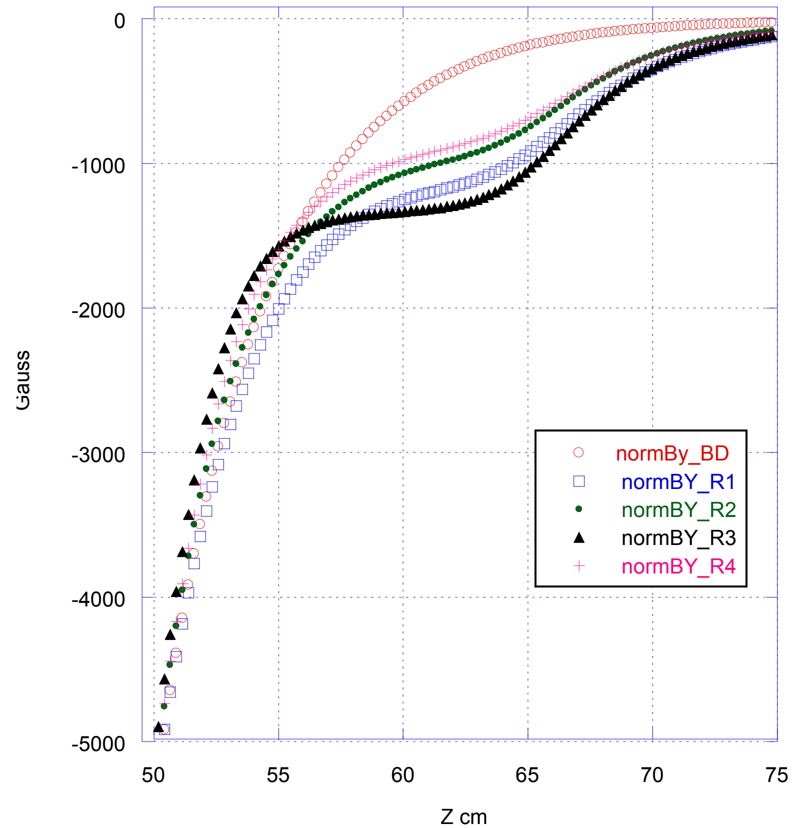
Franklin/Quinn, CMU

Modeling of Fringe Field Underway





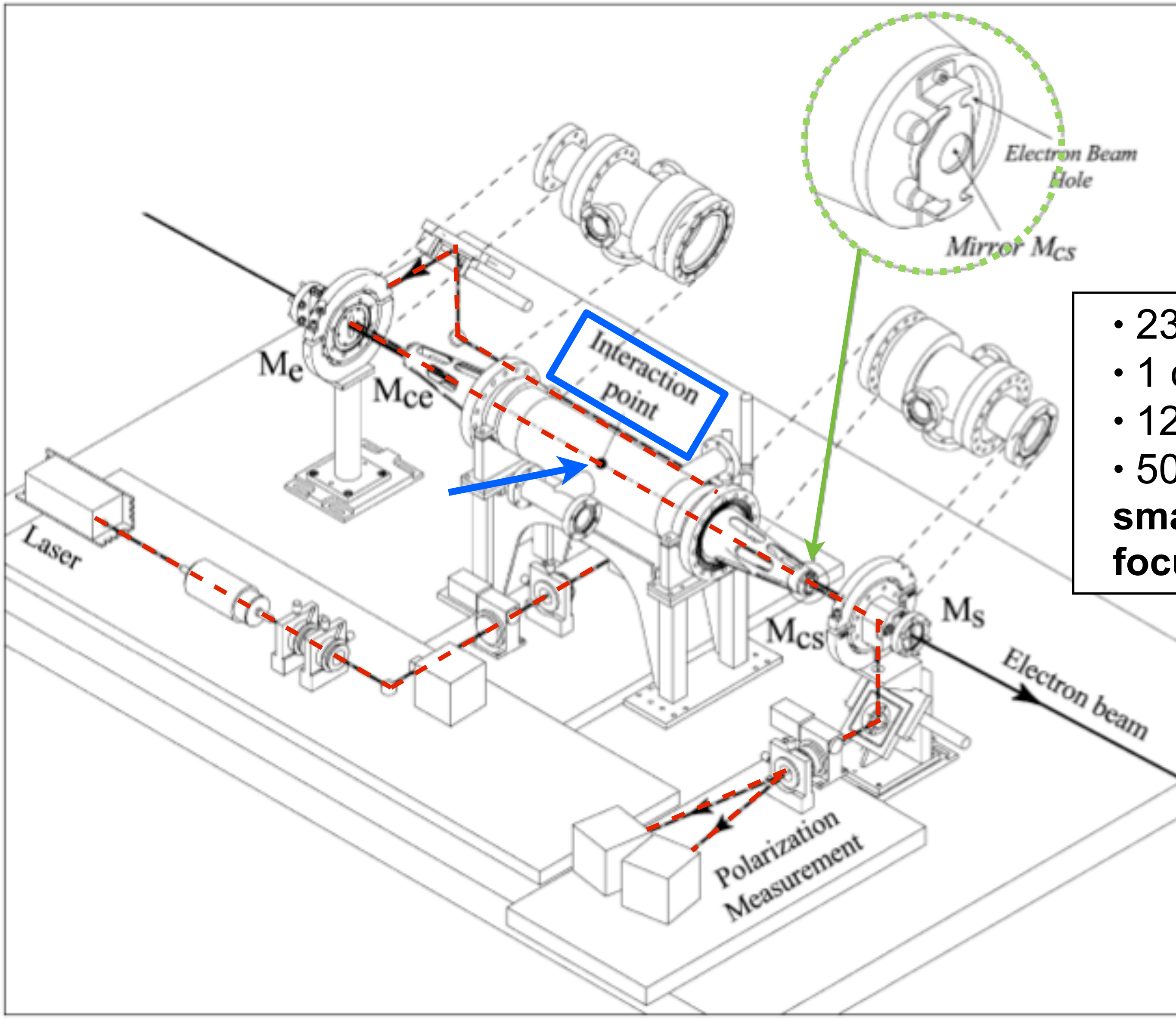




Benesch, JLab

Photon Target

Hall A Compton Interaction Region



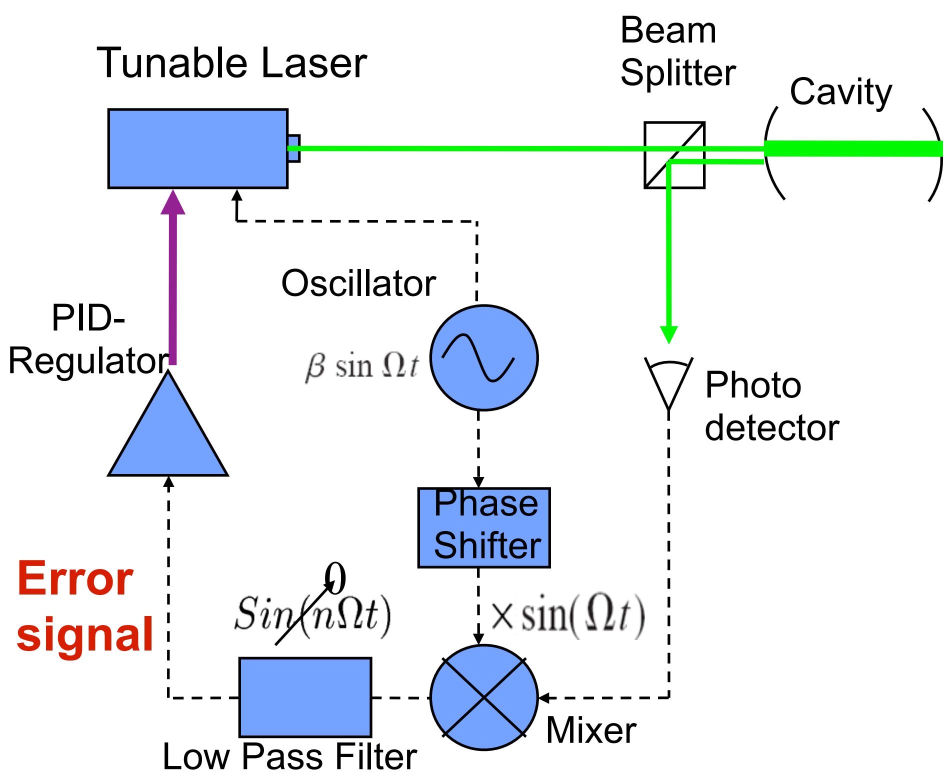
- 23 mrad crossing angle
- 1 cm e- beam aperture
- 125 μm laser spot
- 50-100 μm e^- beam spot

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

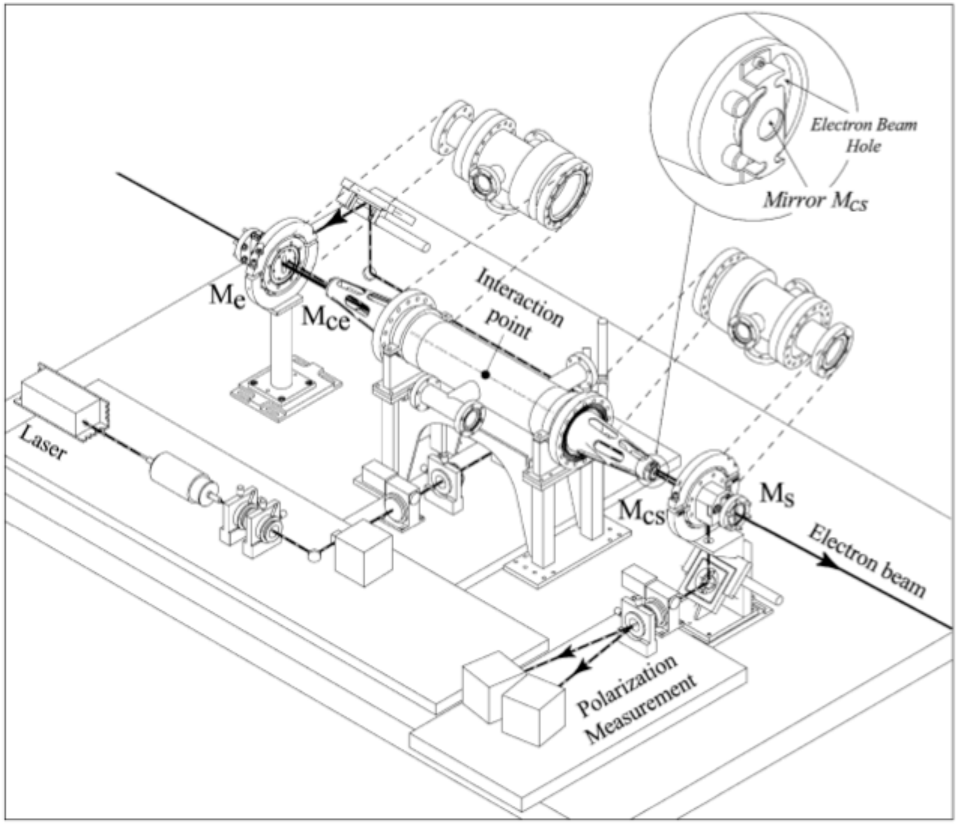
- Continuous wave
- 200-300 mW source laser
- 800-2000 W
- Gain ~ 4000-7000
- Finesse ~ 25000
- Waist radius ~125 micron

532 nm (green) upgrade

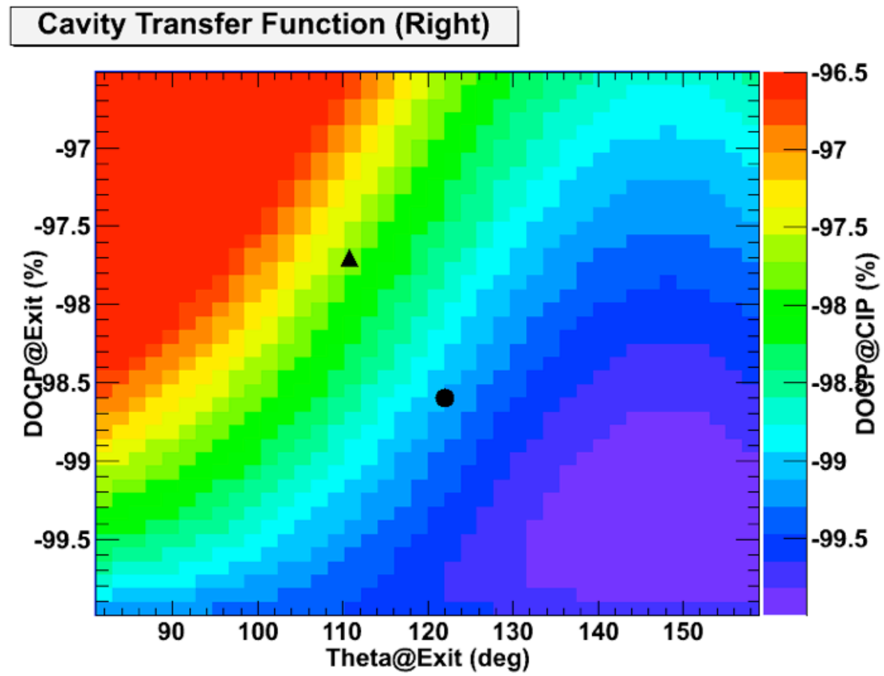
- Continuous wave
- same seed laser (1064nm)
- amplified (>5W), SHG doubled to 532nm (1-2W)
- Gain ~ 2000-5000
- up to 5kW stored
- Waist radius ~125 micron

- double maximum photon energy
- higher asymmetry
- similar rate

Photon Polarization



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



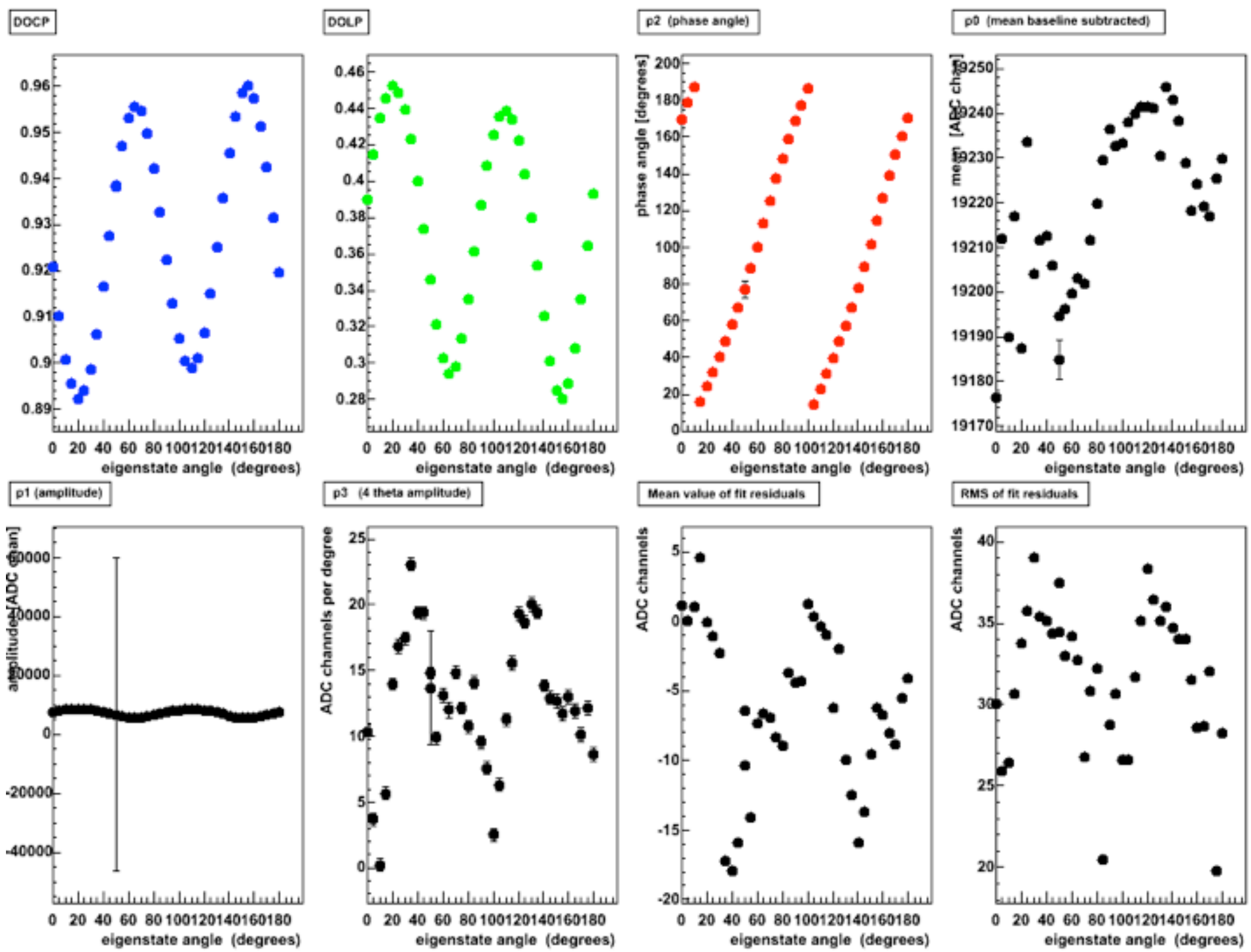
Do we know the polarization inside the **cavity** by monitoring the transmitted light?

Current uncertainty: 0.35%-1%

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

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

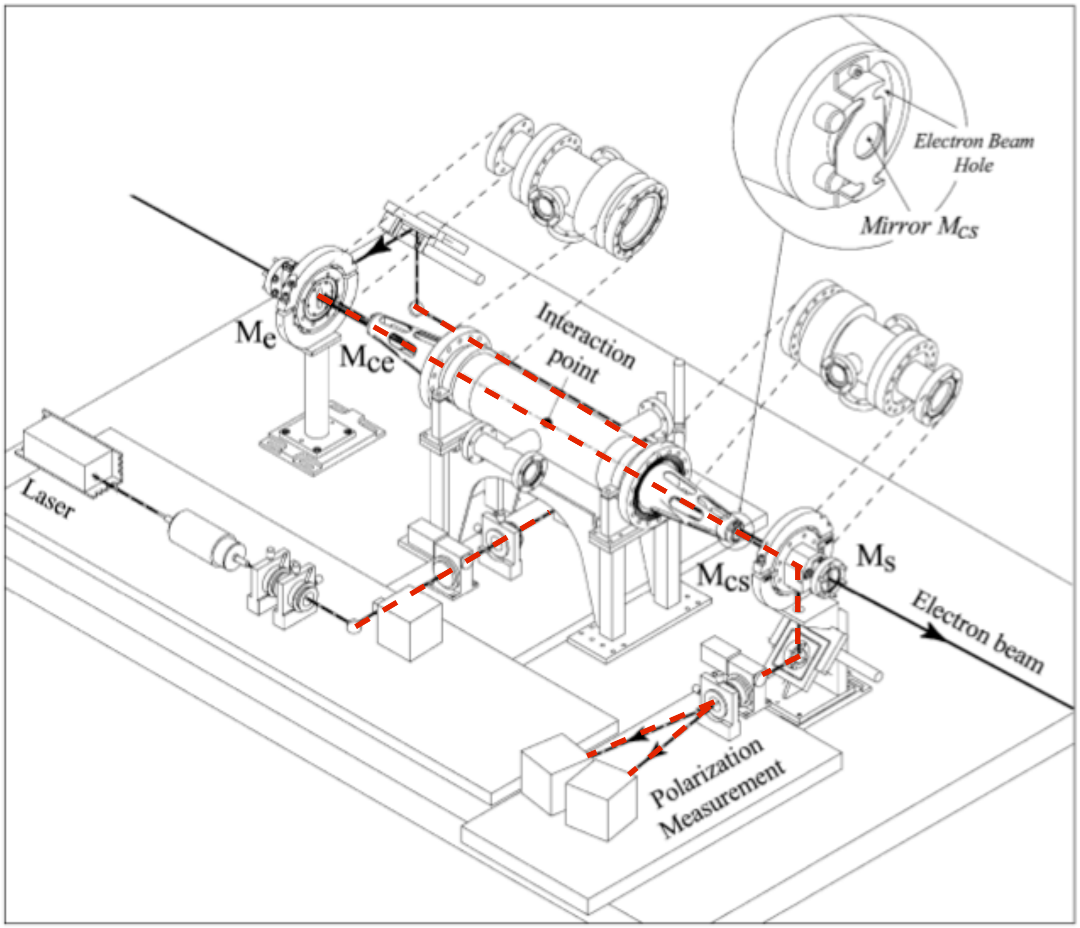
Hall C - Automation and improved mechanics for TF measurement



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

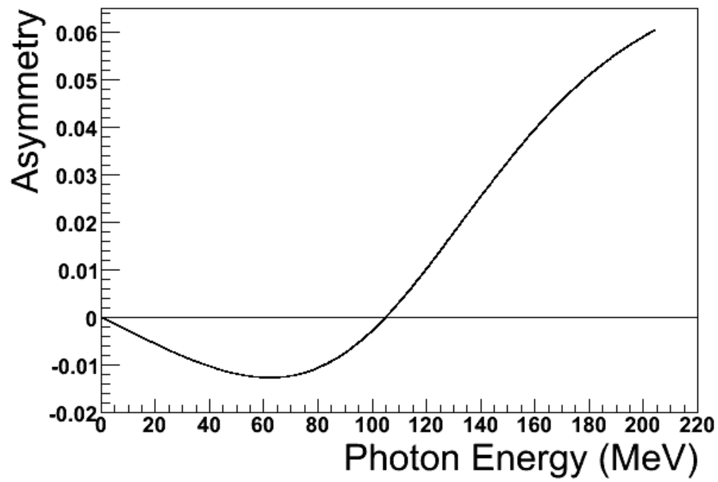
- simplify mirror insertion
- in situ cavity polarization analysis station
- HARD WORK is required for high precision

Detection and Analysis

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

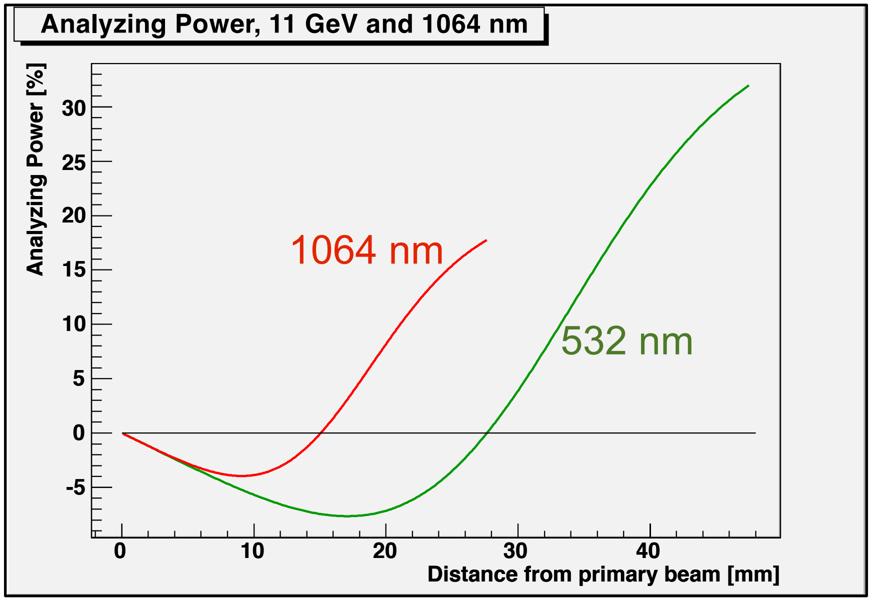
Electron analysis at 11 GeV

- **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

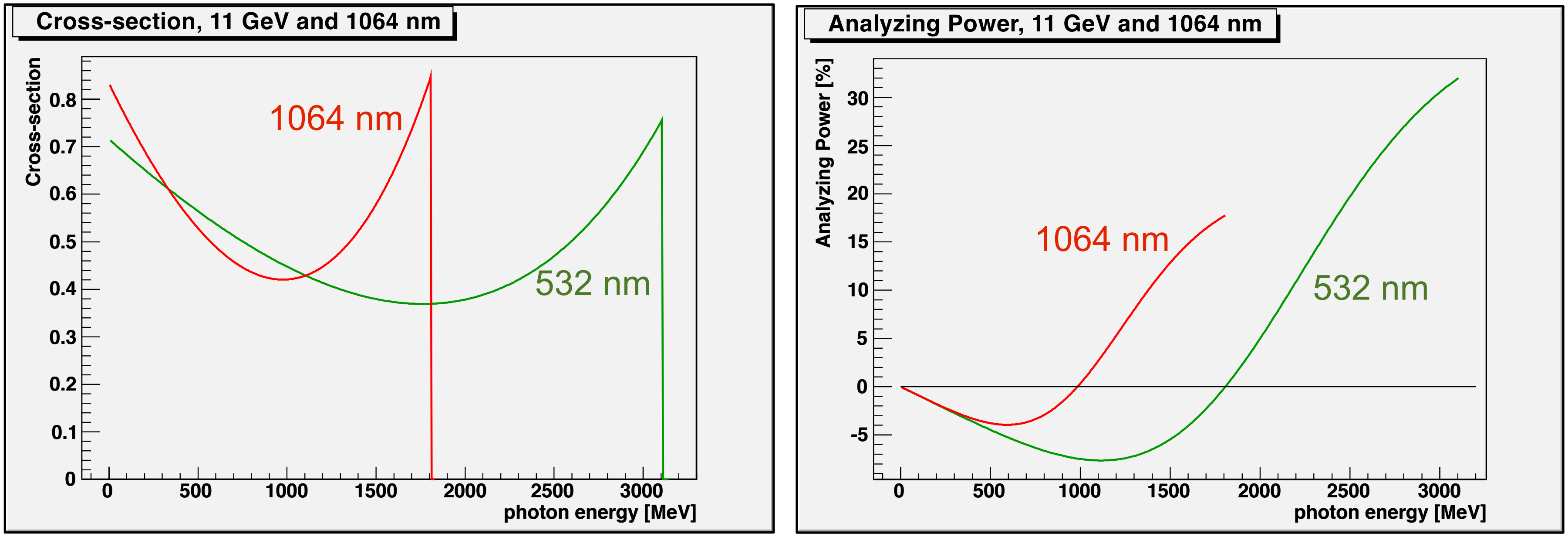
Detector resolution?
Background sensitivity?
Synch light?

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.

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

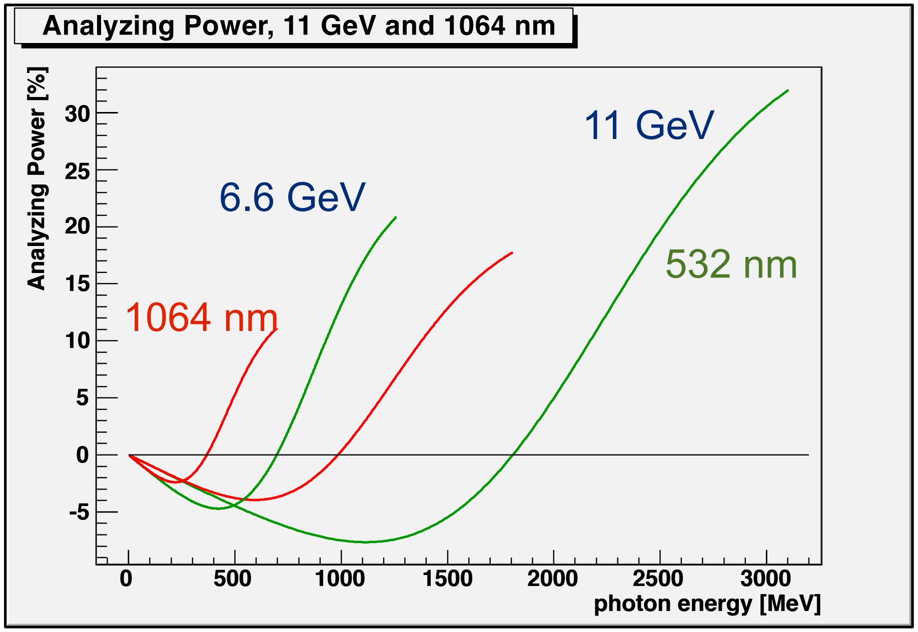
Chicane Magnet Study
- field uniformity vs. synch light power, optimize concept
- design, installation?

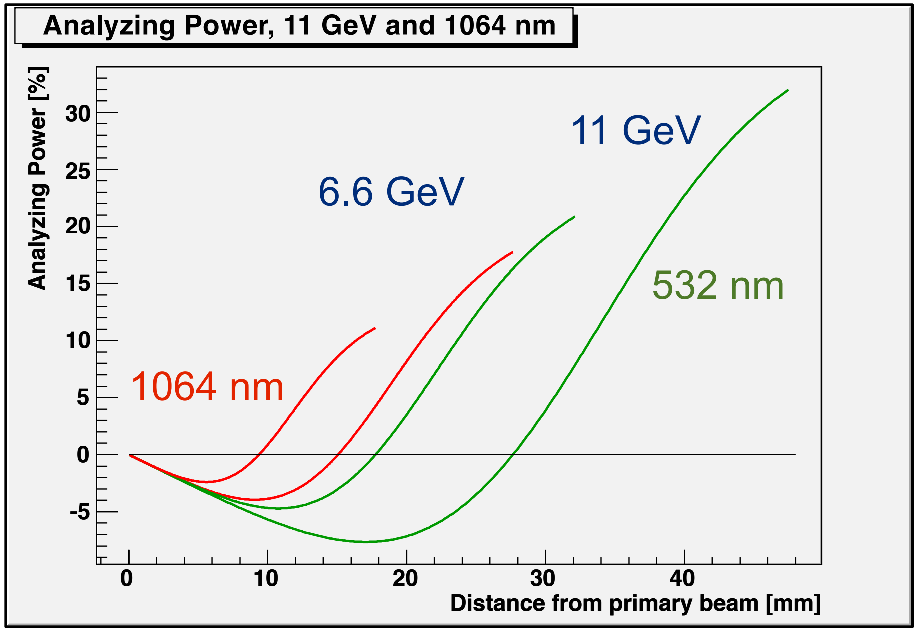
started

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

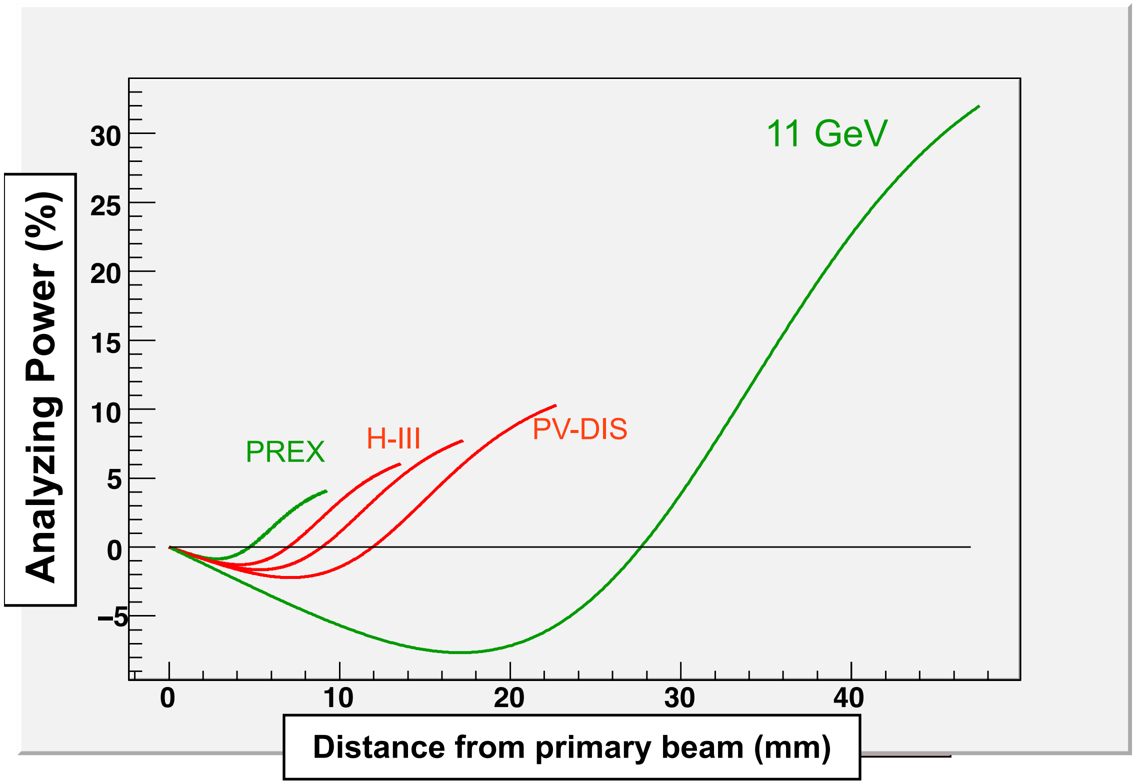
Detection
- Trade light for speed in photon calorimeter?
- photon detector linearity
- DAQ: required. Needs collaborators.

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


Analyzing Power, 11 GeV and 1064 nm
Analyzing Power [%]
photon energy [MeV]
11 GeV
6.6 GeV
532 nm
1064 nm


Analyzing Power, 11 GeV and 1064 nm
Analyzing Power [%]
Distance from primary beam [mm]
11 GeV
6.6 GeV
532 nm
1064 nm

Existing electron detector



Silicon Microstrip Detectors

4 planes of 192 μstrips

(240 μm pitch)

• Crystal Properties

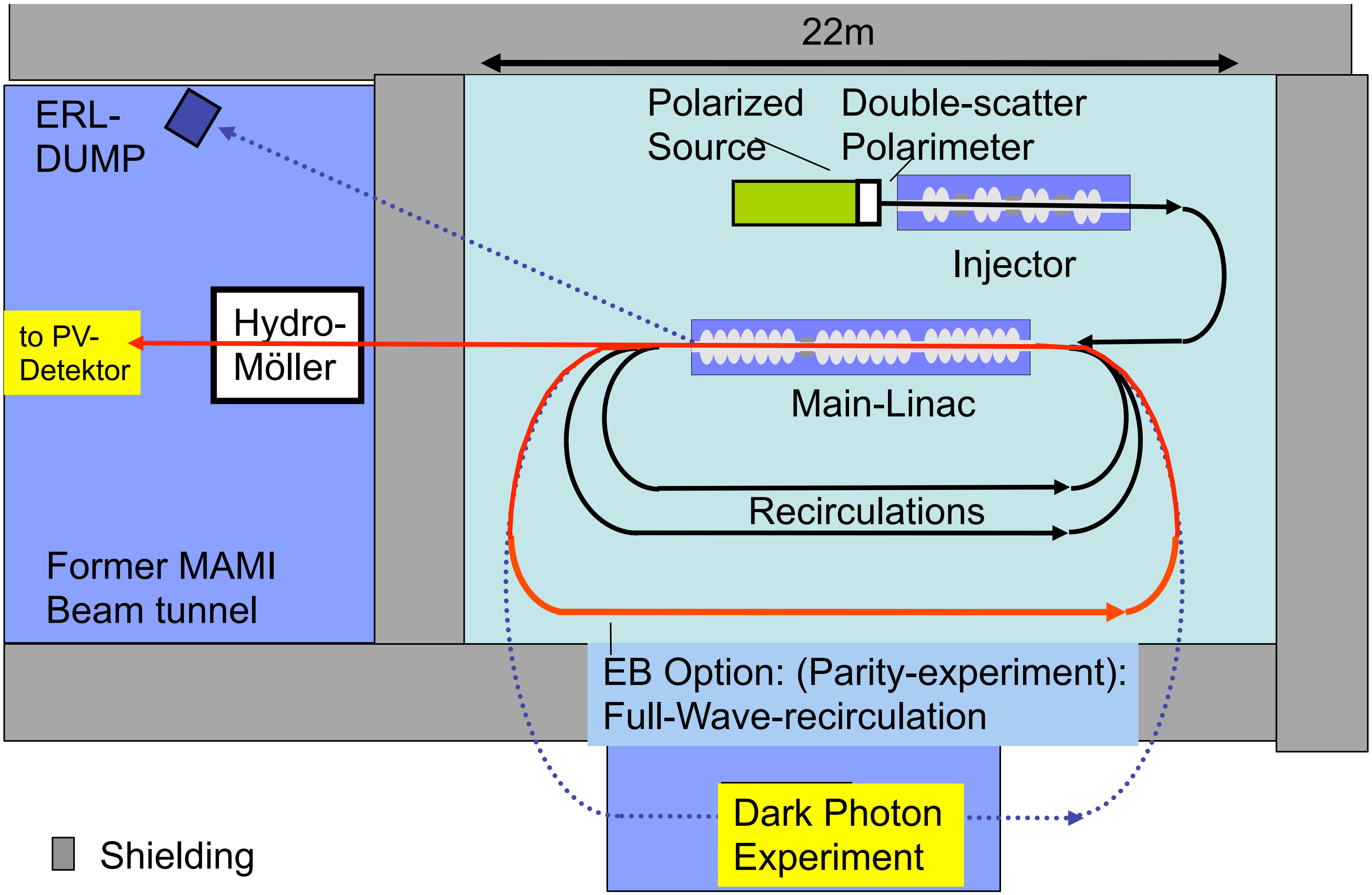
	PbWO4	BGO	GSO	CeF_3	BriLanCe 380	PreLude 420
Density (6/cm³)	8.30	7.13	6.70	6.16	5.29	7.1
Rad Length (cm)	0.90	1.12	1.39	1.68	~1.9	1.2
Moliere Radius (cm)	2.0	2.3	2.4	2.6	?	?
Decay time (ns)	50	300	56:600	30	16	41
Light output (% NaI)	0.4%	9%	45%	6.6%	165%	84%
photoelectrons (# / MeV)	8	170	850	125	3150	1600
					$$$ 4 in max	Natural decay

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

Slides from Kurt Aulenbacher

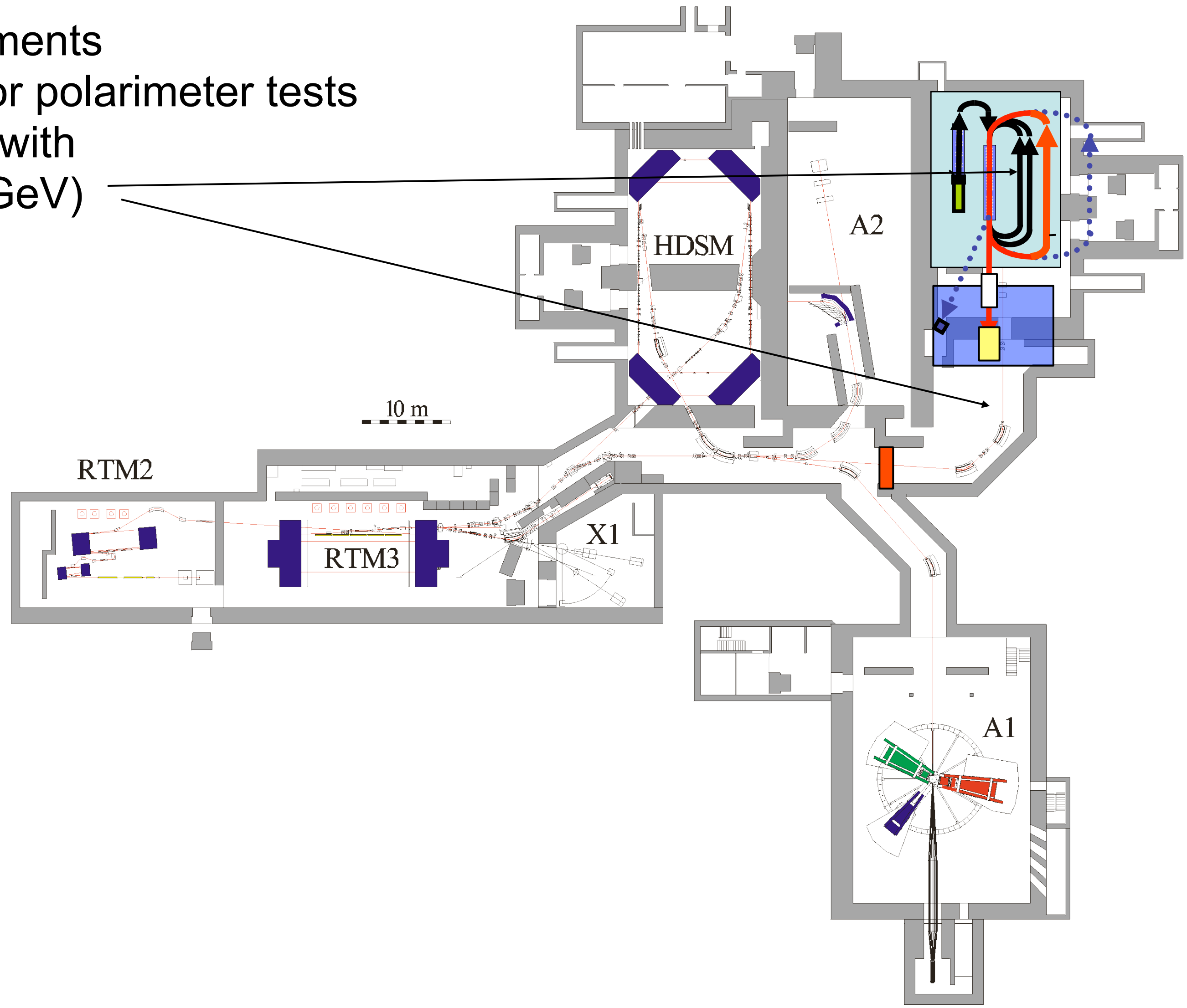


"Unimpeachable" polarization measurement: two independent polarimeters with ΔP/P <0.5% each.

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

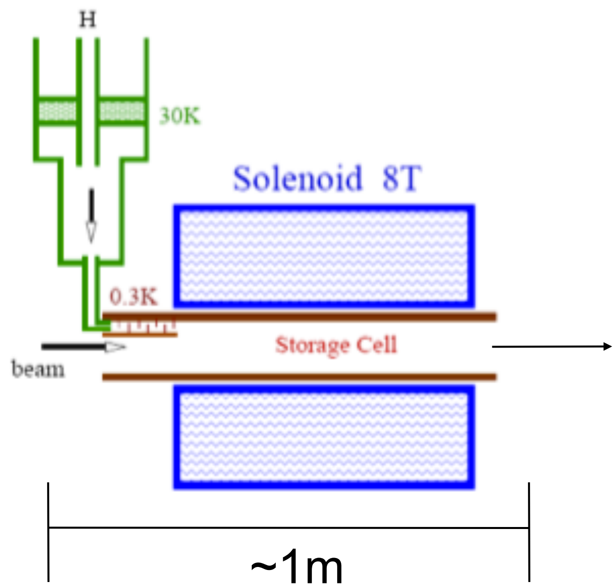
Location of Set-up in Mainz

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↑ 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 l with high intensity electron beam so far…

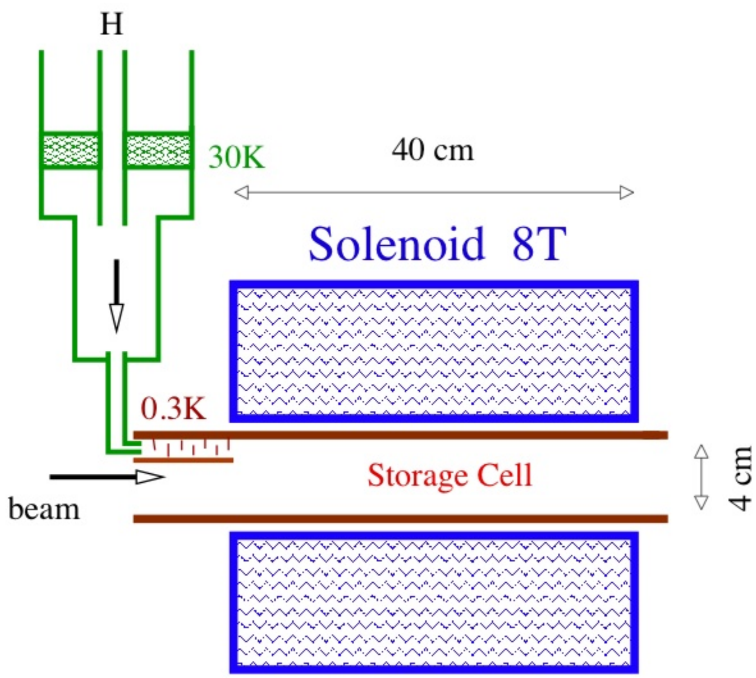
→ Test experiments with existing UVA trap (D. Crabb) will demonstrate feasibility of concept!

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

Atomic Hydrogen For Moller Target



10 cm, ρ = $3\times10^{15}/cm^3$

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 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 (~50nm of superfluid ^{4}He)
- 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

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