Polarisation Summary of the EPWS'08 in Zeuthen

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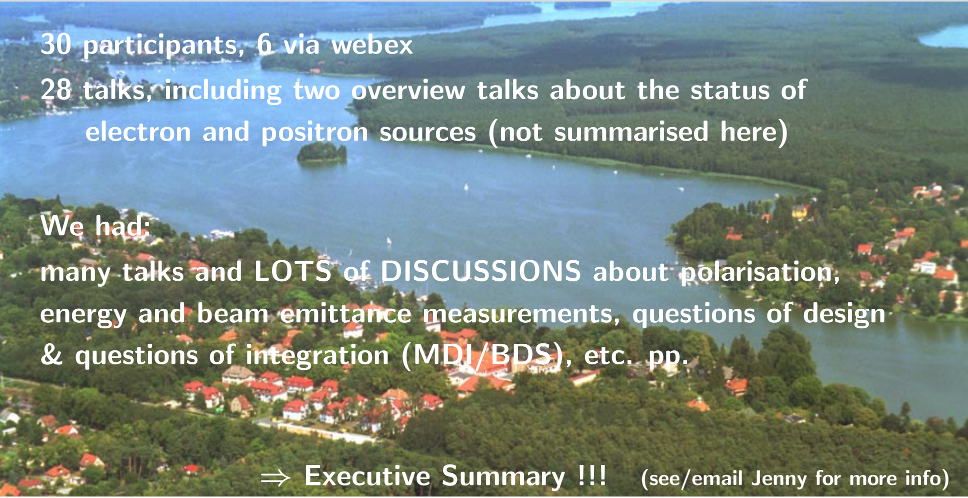
ECFA Workshop
Warsaw, June 9-12, 2008

WS on Polarization and Energy measurements at t



30 participants, 6 via webex

28 talks, including two overview talks about the status of electron and positron sources (not summarised here)

We had:

many talks and LOTS of DISCUSSIONS about polarisation, energy and beam emittance measurements, questions of design & questions of integration (MDI/BDS), etc. pp.

⇒ Executive Summary !!! **(see/email Jenny for more info)**

. . . and we even had two referees:

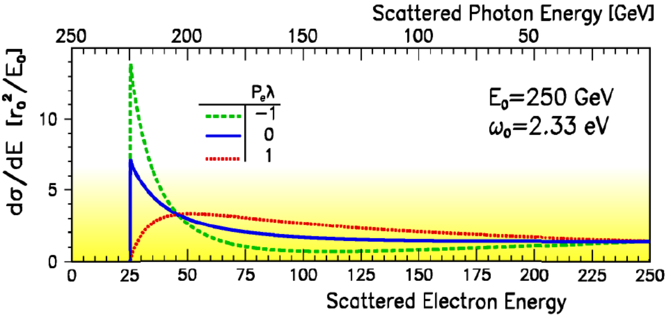
Klaus Mönig & Wolfgang Lorenzon (U. Michigan, non-ILC related)

Polarisation Basics

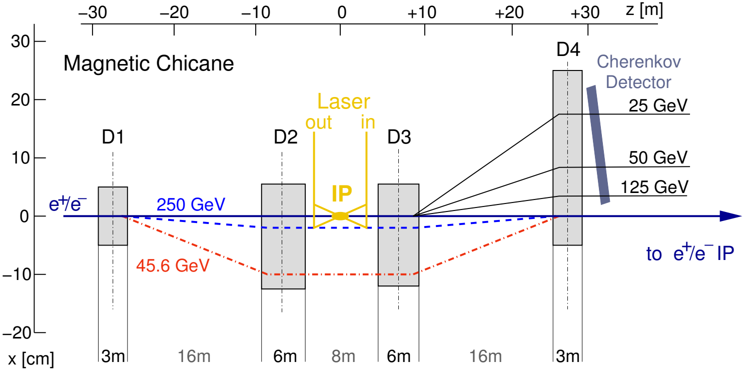
Compton Polarimetry Basics

- Compton scattering of laser photons on beam electrons (positrons)
- $^{d\sigma}/_{dE}$ depends on two things:
  - circular laser polarisation: λ (left / right)
  - longitudinal electron (positron) polarisation: P_{e^-}, P_{e^+}
- Asymmetry ($\mathcal{A}$): $P \approx \left(d\sigma^{\mathrm{R}} - d\sigma^{\mathrm{L}}\right) / \left(d\sigma^{\mathrm{R}} + d\sigma^{\mathrm{L}}\right)$

  Analyzing Power ($\mathcal{AP}$) is Asymmetry for P = 100%



Upstream Pol.: Original Design

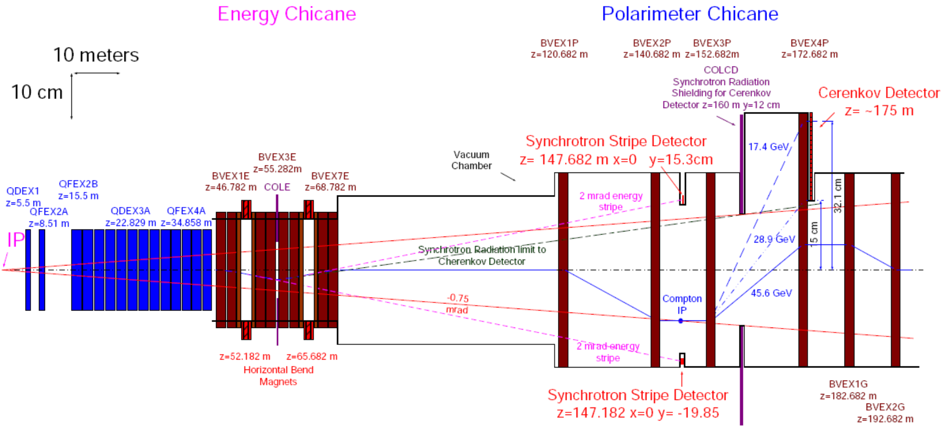


- fast: $\mathcal{O}(10^3)$ Compton scatterings / bunch: cannot measure energy distribution directly, use spectrometry: energy → position
- Constant B-field: Compton edge position is independent of E_b
- Laser (same frequency for all E_b) moves horiz. by ≈ 10 cm with E_b

  ⇒ Vacuum chamber & laser optics had been designed accordingly !

Downstream Polarimeter: Design (K. Moffeit)

- same principle as upstream polarisation measurement, but measures luminosity weighted polarisation
- more difficult due to disrupted beam & SR (large background) → need high-power laser (smaller repetition rate)



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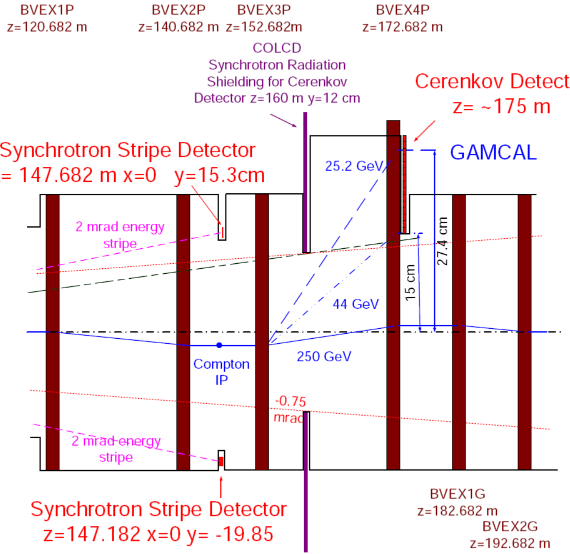
zoom:



Up- vs. Downstream GDE Plans. . . ?

Upstream vs. Downstream Pol. Measurement

Upstream measurement (pros & cons):

- polarisation before interaction → depol. (≈0.3% @ 500 GeV) needs to be calculated (unavoidable uncert. due to unknown beam parameters)
- clean environment → high time granularity since it allows to measure every bunch individually (stat. error $\ll 1\%/\mathrm{s}$)
- large variation in $\mathcal{AP}$ allows internal cross checks

Downstream measurement (pros & cons):

- gives access to depol. in collision → luminosity-weighted polarisation (polarisation of non-interacting beams can be measured outside collisions)
- larger background → measure only one (three) bunches per train
- depol. of disrupted beam about twice the depol. of interacting beams (need correct transfer matrix to adjust to depol. of interacting beams; BMT-effect)
- absolute value of transfer matrix is easily adjusted, but: sign is more difficult & important if collision is not exactly head-on and spins not perfectly aligned
- variation in $\mathcal{AP}$ is small, but should be sufficient for internal cross checks

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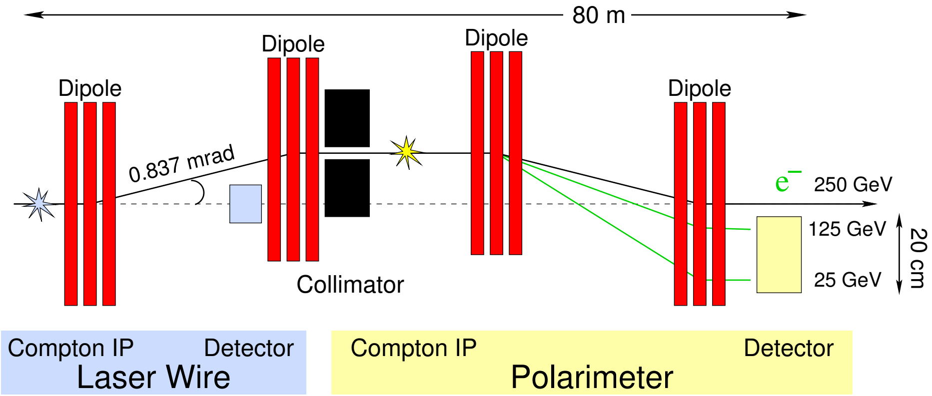
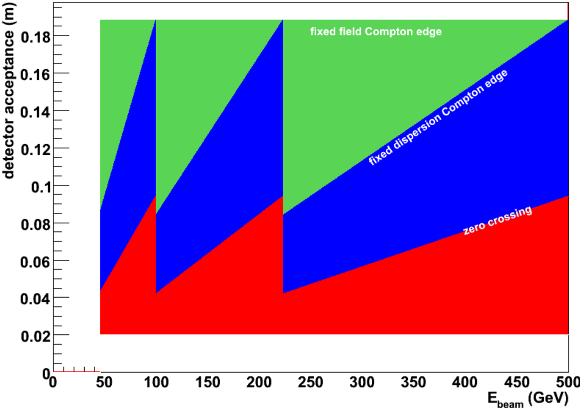
Upstream Pol.: GDE Design & Plans

Can the polarimeter chicane host other instrumentation? (cost savings)
e.g. laserwire emittance diagnostics, or an MPS collimator . . . ?



Upstream Pol.: GDE Design & Plans

GDE question: Can the chicane B-field be scaled with E_b, such that the dispersion is constant?



⇒ uniform acceptance & uniform precision for all E_b go down the drain!

SLD-pol reminder:

its precision was limited by the calibration of the Analyzing Power !

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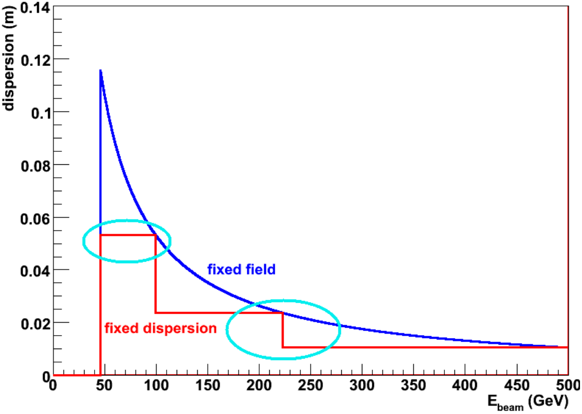

$\Rightarrow$ problems with emittance blow-ups @ high-E_b

$\Rightarrow$ laserwire detector will be in serious trouble for all $E_b > 220$ GeV

$\Rightarrow$ @ low-E_b the dispersion will be too large for it

Downstream Polarimeter: Open Issues

- Large backgrounds (disrupted beam, SR)
  modified extraction line with 2 add. magnets improves acceptance of Compton scattered electrons → detection over a larger part of Compton energy spectrum possible
- Large, expensive, power-hungry(!) magnets
- Claim to not need additional tunnel lengths(?), since the way to dump needs to be of a certain length anyway . . .
- But: cannot measure zero-crossing of the asymmetry
  → Consequences for precision?
  - ▷ variations in det. position must be known precisely
  - ▷ accurate knowledge of (non-)linearity is crucial
  - ▷ need to calibrate the spectrometer very precisely, i.e.: dispersion characteristics must be known

Precision Goals
& AP Calibration

Precision & Systematic Error Goals (J. List)

- Laser polarisation readily known: $\approx 0.1\%$
- Chicane magnets: negligible ?

- Analyzing Power knowledge / calibration (limiting factor for SLD-pol.)
  - ▷ absolute scale w.r.t. SLD → no preradiator needed
  - ▷ relative position of: beam ↔ detector:
    determine this from data to $\mathcal{O}(0.5\text{ mm}) \rightarrow < 0.1\%$ on $\mathcal{AP}$

- Detector linearity → goal: 0.1 – 0.2%
  - ▷ cross channel calibration via table scans !
  - ▷ need laser/LED calibration system to monitor single channel response

Thus, in total: $\approx 0.25\%$ – but tight !

⇒ High redundancy & complementarity will be crucial for a precise calibration of the detector and the Analyzing Power ($\mathcal{AP}$)!

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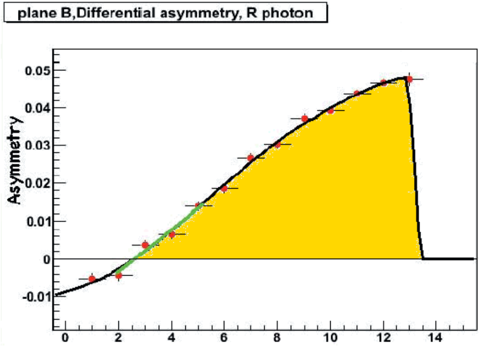
How to Calibrate the Analyzing Power? (J. List)

How well can the $\mathcal{AP}$ be determined under various conditions?

- Compare: perfect nominal detector, then start adding non-linearities and/or different detector coverages (for diff. E_b)
- Parameters to determine:
  - ▷ Detector alignment w.r.t. the beam: shift, tilt, ...
  - ▷ $\mathcal{AP}$-shape: stretch/squeeze spectra ↔ deformation due to non-lin.
- First need to know:
  How do the parameter errors translate into $\mathcal{AP}$ or $\mathcal{P}$ uncertainty?
- Use fast simultion & start with simple things ...
  first results (very preliminary!) and a rather long “to do” list!

What is special about Zero-Crossing? (W. Lorenzon)

Zero-Crossing e$^-$ Analysis: use two points of well-defined energy
⇒ the asymmetry zero-crossing & the Compton edge



- linear fit of the zero-crossing of the Compton asymmetry
- **integrate** the asymmetry from there up to the Compton edge
- absolute calibration:
  only "input" is QED (small corr. due to finite strip size & resolution)
- only weak dependence on energy resolution, or variations in detector position; no assumption on dispersion characteristics
- no need to carfully calibrate the entire spectrometer !

Global Scheme
“3 ways to measure”

Pol. Measurement: Global Scheme (K. Mönig)

Polarimetry from GigaZ to high energy; with or without e$^+$ polarisation

aim for a polarisation uncertainty of: $\frac{\Delta P}{P} = 0.25\%$

no e$^+$-polarisation:

$$\sigma = \sigma_0 \left[1 + P_e - A_{LR}\right]$$

- pol.error $\frac{\Delta A_{LR}}{A_{LR}} = \frac{\Delta P_{e-}}{P_{e-}}$
- only average pol. relevant!

with e$^+$-polarisation:

$$\sigma = \sigma_0 \left[1 - P_{e^+} P_{e^-} + (P_{e^+} - P_{e^-}) A_{LR}\right]$$

- observables dep. on P and on $P_{e+} \cdot P_{e-}$
  (time-)corr. between e$^-$/e$^+$ pol. matter
- effective pol. enters in observables
  (pol.error reduces by a factor of up to three)

$$P_{eff} = \frac{P_{e+} + P_{e-}}{1 + P_{e+} P_{e-}} \quad \text{for } A_{LR}$$

Use up- & downstream polarisation measurement for correlations (cross checks, redundancy and to control systematics) and polarisation measurement from annihilation data for absolute calibration !

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Polarisation from Annihilation Data (K. Mönig)

no e^+ pol.: $\sigma = \sigma_0 \left[1 + P_{e^-} A_{LR}\right]$

$\Rightarrow$ 3 unknowns, 2 measurements → no model-indep. meas. possible

But, the W-pair production in forward direction is dominated by t-channel ν-exchange.

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$\Rightarrow$ 4 unknowns & 4 measurements → model-independent polarisation measurement via the Blondel scheme (see: LEP)

However, in both cases:

- Annihilation data measurement has potential for smaller error when corrections are known from polarimeters
- Measurement needs high statistics → takes months
- Polarimeters needed for left/right differences & time dependencies (e^+-pol)
- Threshold scans: might not be sufficient statistics for each scan point
- Pol. extraction from data requires always some data with all states (i.e. also the "uninteresting" settings: $++$, $--$)

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A Word on Variations . . . (K. Mönig)

Where can variations in P_{e^+} and/or P_{e^-} come from?

- variations inside a bunch train
- daily variations from outside temperatures, etc.
- long term improvements
- variations from beam-beam interactions
- trains, airplanes, football results, . . . (see LEP energy measurements)

For a quantitative assessment we need a detailed model on possible (correlated) polarisation variations! (needs still to be found/defined)

Much work is ongoing: CAIN, GuineaPig++, SLICKTRACK . . .
see summary from WS on Spin Dynamics (Daresbury, 27-28 March'08)
http://ilcagenda.linearcollider.org/conferenceDisplay.py?confId=2599

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Global Scheme of Polarimetry (K. Mönig)

- Some processes can have up to 10^6 events (@ high-E)

  (@ GigaZ: with 10^9 events → polarisation can be obtained solely from annihil. data)
- For e^- pol. only & 0.25% precision error, physics measurements might be limited by polarisation uncertainty
- Need all possible cross checks & redundancy!

  hunt down & control systematic uncertainties
- Complimentarity:
  - upstream: cleanest measurement with highest time granularity gives main input for correlations & left-right difference
  - downstream: measures depolarisation effects from collisions, providing access to the luminosity weighted polarisation
  - annihil. data: provides the absolute calibration & has potential for smaller errors when corr. are known from polarimeters

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Conclusions of the Workshop

Summaries: W. Lorenzon & K. Mönig

- Impressive group of people & lots of experience
- Big challenge: $\Delta P/P = 0.25\%$ → no fundamental show stoppers!
- Use multiple devices/techniques to control the systematics

  all three ways to measure polarization are needed
- extensive modeling needed (A_Z, depolarisation, BMT, etc.)
- much work done, much still ahead to optimize design

- Polarimetry is an essential part of the ILC
- Polarimetry may be THE limiting precision for some measurements
- We should make every effort to get the error down

- Only a comb. of the schemes (up-, downstream, annihil.) can give the cross checks & redundancy to achieve this goal !

Available Documents

⇒ Executive Summary (soon to be finished)

⇒ Proceedings of the entire Workshop (in progress, ≈ 1-2 months)

⇒ Comprehensive overview: POWER Report
see: hep-ph/0507011 (in press as Physics Reports)
see also: `www.ippp.dur.ac.uk/~gudrid/source/`

⇒ Proposal to the Research Director Sakue Yamada to include polarisation measurement @ Z-pole energy during calibration runs
(. . . might include a small add-on for GigaZ-running)

Thank you!

BACKUP

The “Spin Dance” Experiment (W. Lorenzon)

- performed at JLab in July 2000…
- Purpose: Perform a cross-normalisation of the relative analyzing power of the five employed electron polarimeters (1 Mott, 3 Møller, 1 Compton pol.) to reveal possible systematic differences that had not yet been accounted for.
- The exp. showed significant discrepancies between the polarimeter results even if the previously – for each polarimeter individually – evaluated systematic uncertainties were included.

⇒ It is all but trivial to provide or even prove an analyzing power precision at the 1% level. The ILC polarimeters want to go to a precision of $\frac{\Delta P}{P} = 0.25\%$.

The “Spin Dance” Experiment (2000)

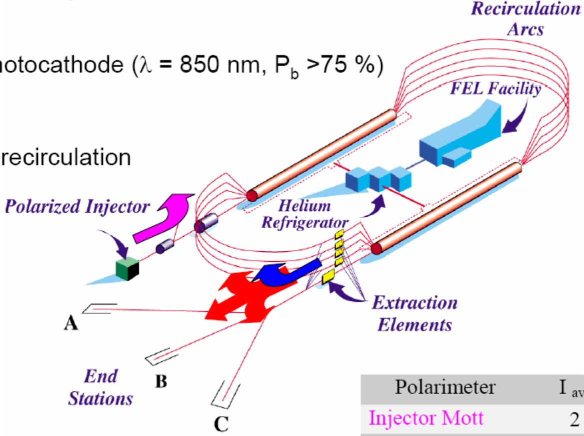
Phys. Rev. ST Accel. Beams **7**, *042802 (2004)*

Source

Strained GaAs photocathode (λ = 850 nm, P_b >75 %)

Accelerator

5.7 GeV, 5 pass recirculation



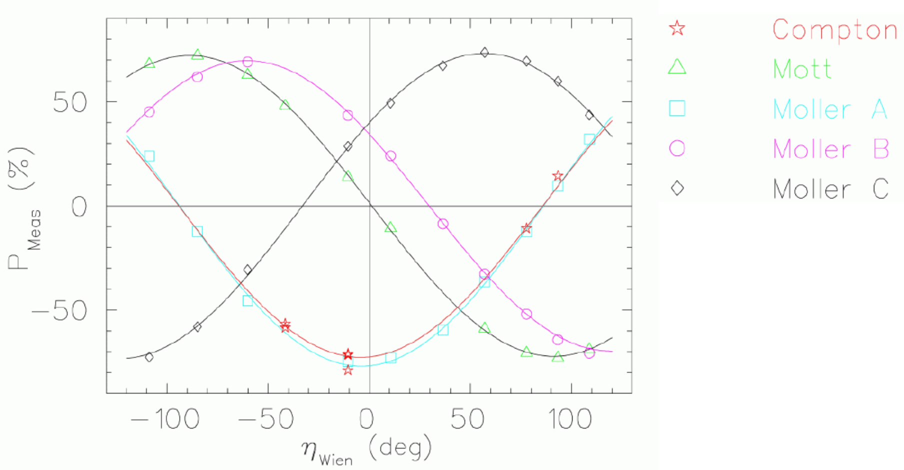
Wien filter in injector was varied from -110° to 110° to vary degree of longitudinal polarization in each hall

→ precise cross-comparison of JLab polarimeters

Polarimeter	I_{ave}	P_x	P_y	P_z
Injector Mott	2 µA	x	x	
Hall A Compton	70 µA			x
Hall A Moller	1 µA	x		x
Hall B Moller	10 nA		x	x
Hall C Moller	1 µA			x

"Spin Dance" 2000 Data

$P_{meas} \cos(\eta_{Wien} + \phi)$



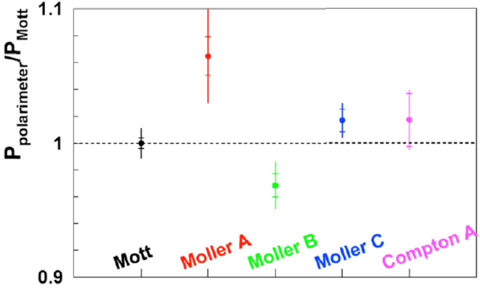
Polarization Results

Results shown include statistical errors only
→ some amplification to account for non-sinusoidal behavior

Statistically significant disagreement

Systematics shown:

Mott
Møller C } 1%
Compton
Møller B 1.6%
Møller A 3%

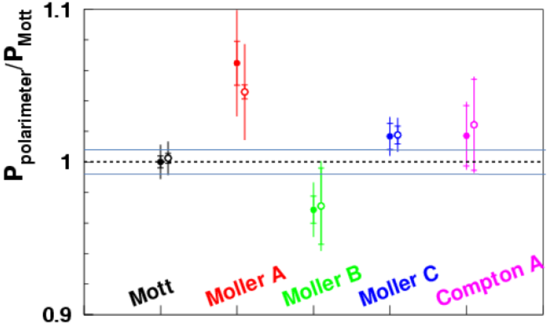


Even including systematic errors, discrepancy still significant

Polarization Results- Reduced Data Set

Hall A, B Møllers sensitive to transverse components of beam polarization

Normally – these components eliminated via measurements with foil tilt reversed, but some systematic effects may remain



closed circles = full data set
open circles = reduced data set

Agreement improves, but still statistically significant deviations
→ when systematics included, discrepancy less significant

Lessons Learned

- Providing/proving precision at 1% level challenging
- Including polarization diagnostics and monitoring in beam lattice design is crucial
- Measure polarization at (or close to) IP
- Measure beam polarization continuously
  - protects against drifts or systematic current-dependence to polarization
- Flip electron and laser polarization
  - fast enough to protect against drifts
- Multiple devices/techniques to measure polarization
  - cross-comparisons of individual polarimeters are crucial for testing systematics of each device
  - at least one polarimeter needs to measure absolute polarization, others might do relative measurements
  - absolute measurement does not have to be fast