# High-precision polarimetry at the LHeC

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- Introduction
  - Why ?
  - Compton back-scattering polarimetry
- State of the art
  - SLC
  - HERA
  - Preliminary conclusion
- On-going developments
  - ILC
  - Laser technology
- Conclusion : towards very high precision polarimetry

# Introduction



Electroweak physics sensitive to polarization
Informations on structure functions ratios

Polarisation Asymmetry and R=NC/CC

$$\frac{2}{P_L - P_R} \cdot A^{\pm} \simeq \mp\kappa_Z a_e \frac{F_2^{\gamma Z}}{(F_2 + \kappa_Z a_e Y_- x F_3^{\gamma Z}/Y_+)} \simeq \mp\kappa_Z a_e \frac{F_2^{\gamma Z}}{F_2}$$

$$\frac{2}{P_L - P_R} \cdot A^{\pm} \simeq \pm\kappa \frac{1 + d_v/u_v}{4 + d_v/u_v}.$$

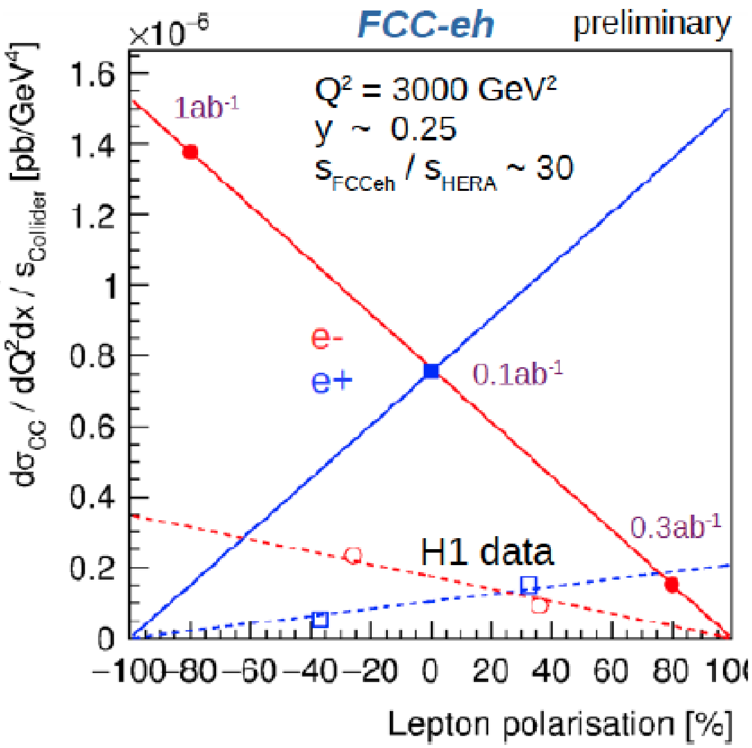
Classic asymmetry (Prescott et al, 1978) accesses weak interaction, $F_2^{\gamma Z}$ is a new, direct measure of valence quarks at high x

$$R^{\pm} = \frac{\sigma_{NC}^{\pm}}{\sigma_{CC}^{\pm}} = \frac{2}{(1 \pm P)\kappa_W^2} \cdot \frac{\sigma_{r,NC}^{\pm}}{\sigma_{r,CC}^{\pm}}$$

$$R^{\pm} \simeq \frac{2a_e^2}{(1 \pm P)\cos^2\Theta} \cdot \frac{Y_+ F_2^Z - Y_- P x F_3^Z}{Y_+ W_2^{\pm} + Y_- x W_3^{\pm}}$$

R accesses weak interaction and the pure weak structure functions which are best measured at the LHeC/FCC-eh

Note that in experiment you would measure the cross sections and determine all correlations which is still more informative than A or R but contains their physics.




Precise Compton polarimetry is required to reach physics goals

# Compton back-scattering polarimetry

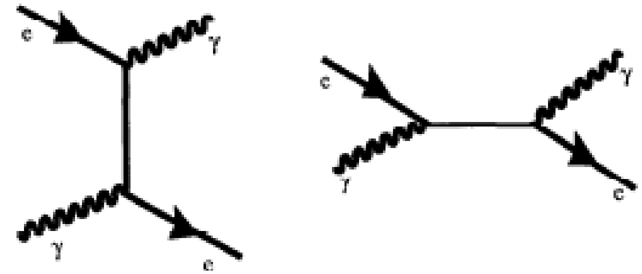
Barber et al., NIMA329 (1993) 79
Lath SLAC PhD thesis (1994), Woods SLAC-PUB-7319

## Start in '90s at HERA and SLC

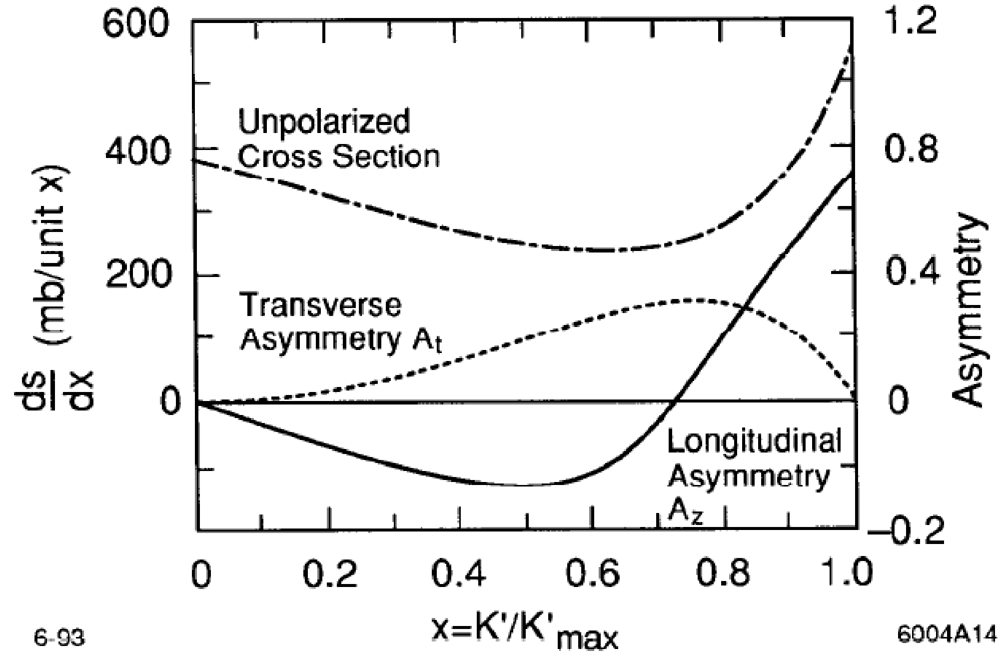
$$\left(\frac{d^2\sigma}{dx\,d\phi}\right)_{Comp} = \left(\frac{d^2\sigma}{dx\,d\phi}\right)_{unpol} \cdot \{1 - \mathcal{P}_\gamma\,[\mathcal{P}_z A_z^{e\gamma}(x) + \mathcal{P}_t \cos\phi\, A_t^{e\gamma}(x)]\},$$

$$A_z^{e\gamma} \equiv r_0^2\, y[1 - x(1+y)]\left\{1 - \frac{1}{[1 - x(1-y)]^2}\right\} \cdot \left(\frac{d^2\sigma}{dx\,d\phi}\right)^{-1}_{unpol}$$

$$A_t^{e\gamma} \equiv r_0^2\, yx(1-y)\frac{\sqrt{4xy(1-x)}}{1 - x(1-y)} \cdot \left(\frac{d^2\sigma}{dx\,d\phi}\right)^{-1}_{unpol}.$$




Measure scattered photons and/or electrons
→ Larger sensitivity expected at the threshold energy
→ e- counters (SLC/ILC)
→ γ calorimeter (HERA)

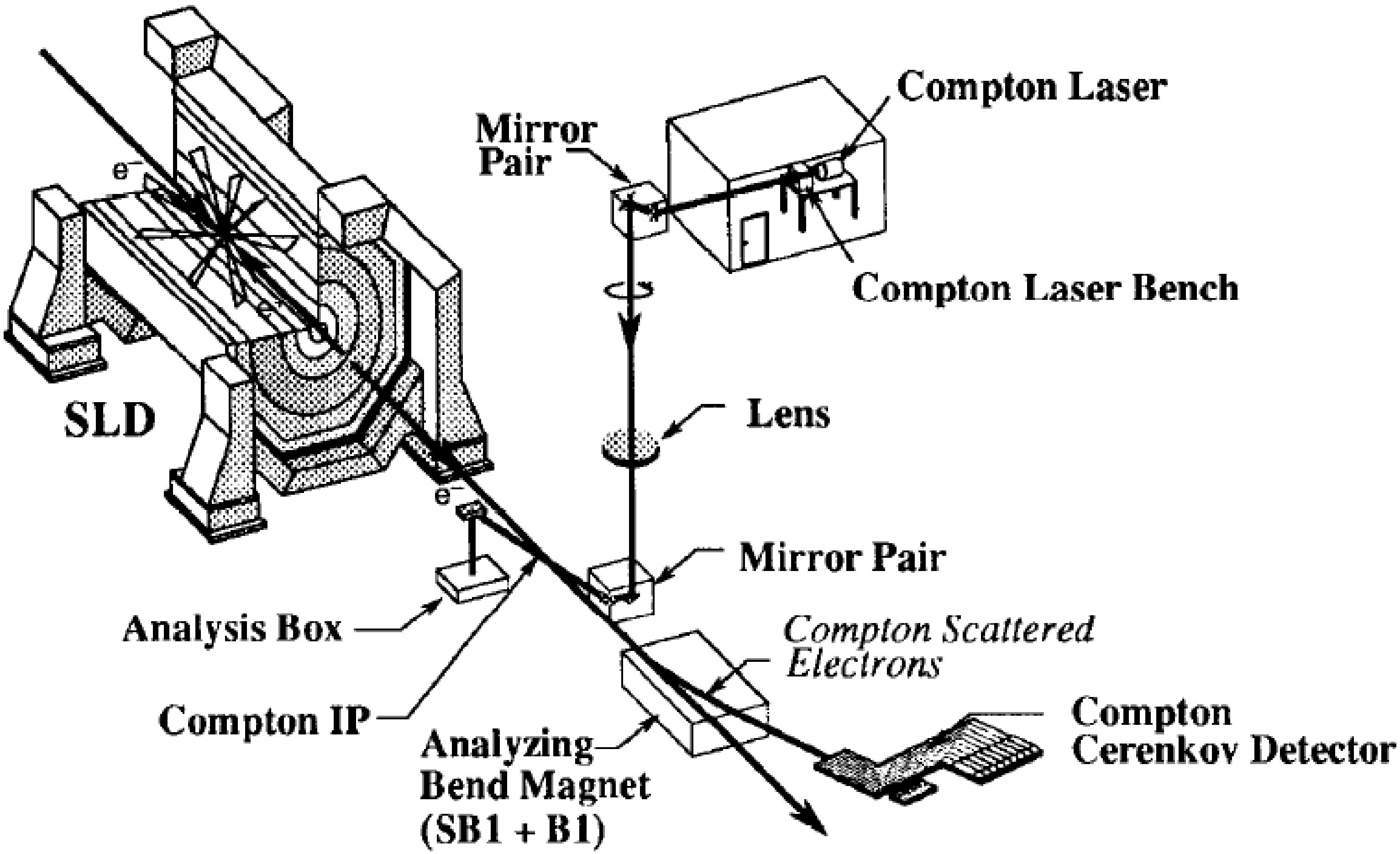


Review of the state of the art:

- Usual design ?
- Detector choice ?
- Systematics ?

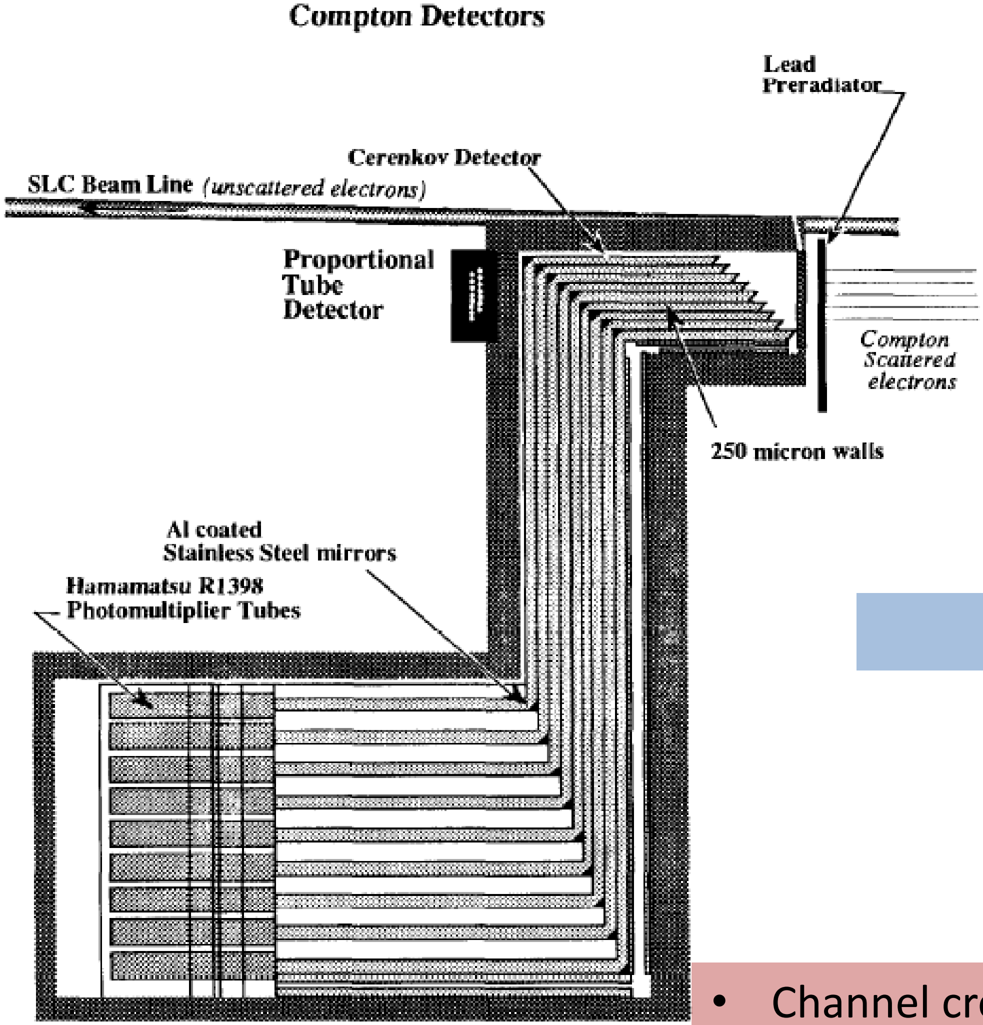
# SLC design: detection of electrons

Lath SLAC PhD thesis (1994), Woods SLAC-PUB-7319



# SLC design: Cherenkov counters

Lath SLAC PhD thesis (1994), Woods SLAC-PUB-7319




Systematics :

- Laser Polarization: 1.0%
- Photomultiplier Linearity: 0.6%
- Detector Position Calibration (and EGS simulation): 0.4%
- Electronic Noise and crosstalk: 0.2%
- Inter-channel consistency: 0.5%

'or a total of $\delta\mathcal{P}/\mathcal{P} = \delta A_{LR}/A_{LR} = 1.3\%$.

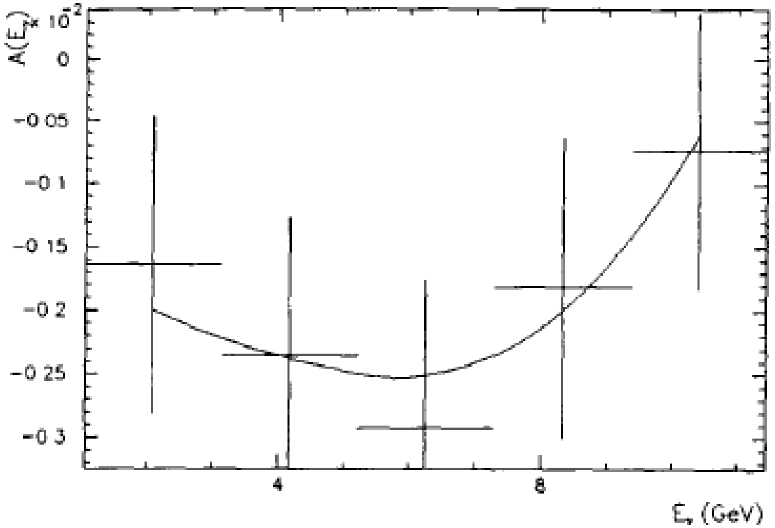
About 1000 scatters per crossing

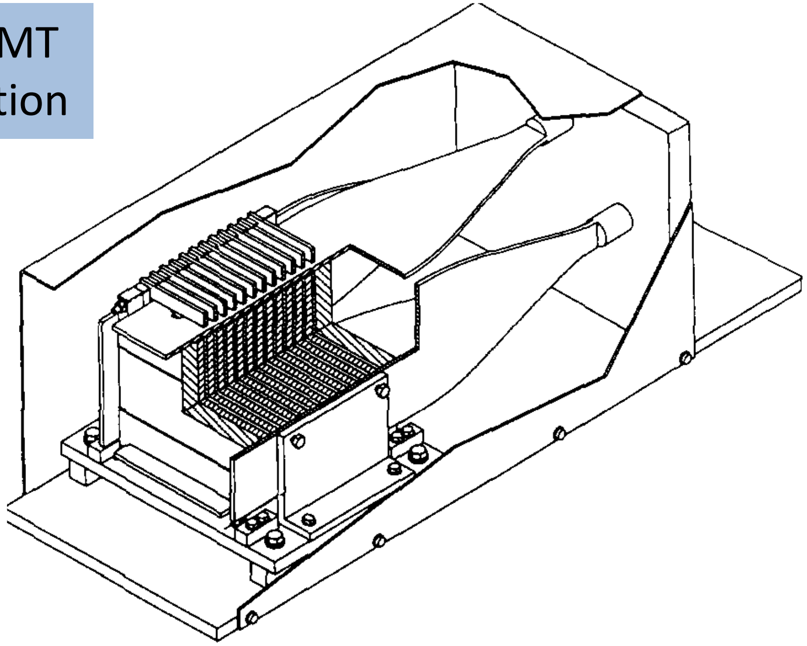
- Channel cross-calibration and linearity is critical
- Position sensitivity of the detector
- Laser polarization can be improved → see next slides

# HERA T-POL

Barber et al., NIMA329 (1993) 79

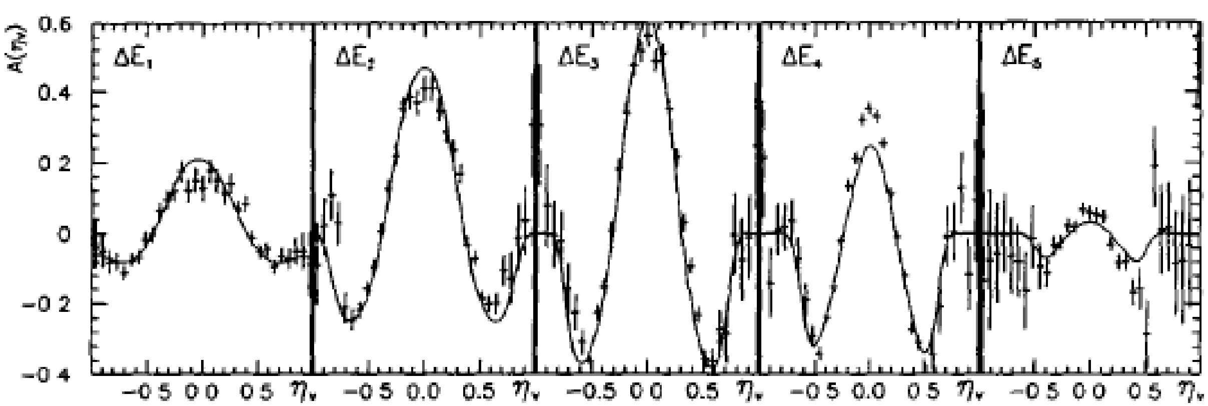
2 channel W-scintillator (up/down) w/ WLS+PMT
+ 2 additionnal readouts (left/right) for calibration



Small number (<<1) of scatters per crossing

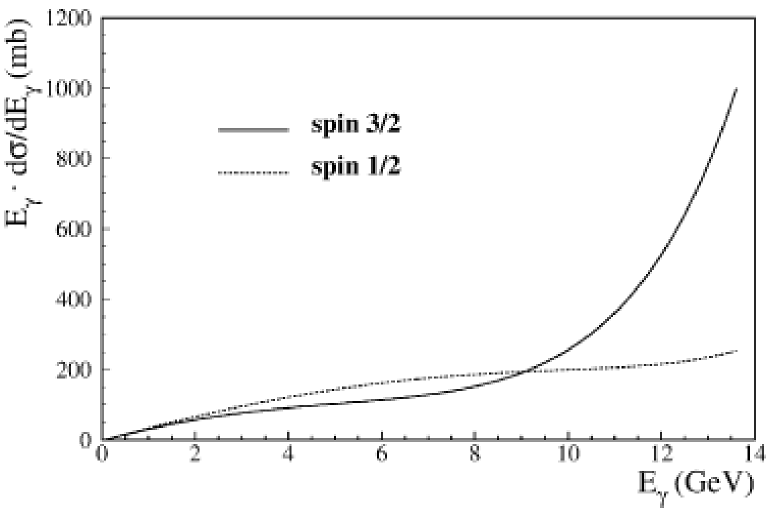
Fit of energy and vertical asymmetries
→ Longitudinal and transverse polarisations




→ % level precision

# HERA LPOL 1

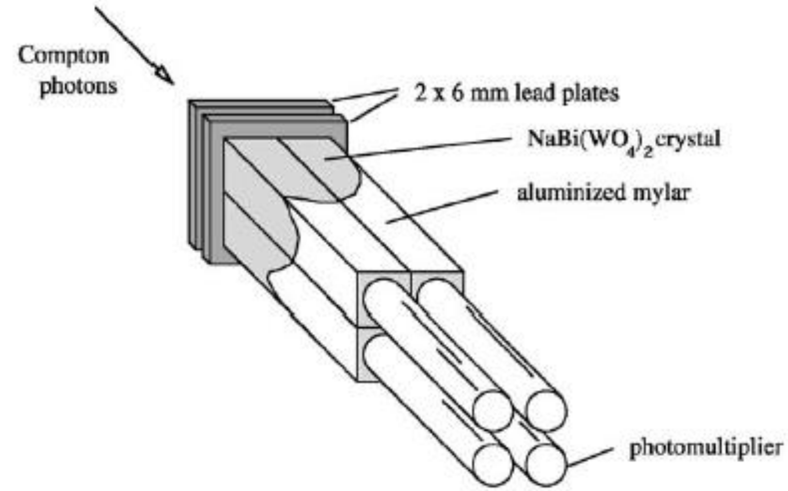
Beckmann et al., NIMA479 (2002) 334

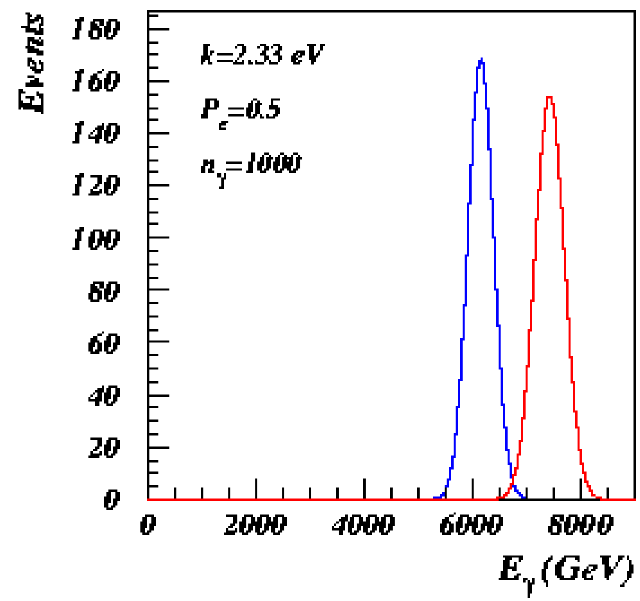



Low sensitivity to threshold & backgrounds

| Source of systematic uncertainty | $\Delta P_e/P_e$ (%) |
|---|---|
| Analyzing power | $\pm 1.2$ |
| Analyzing power long-term instability | $\pm 0.5$ |
| Gain mismatching | $\pm 0.3$ |
| Laser light polarization | $\pm 0.2$ |
| Pockels cell misalignment | $\pm 0.4$ |
| Electron beam instability | $\pm 0.8$ |
| Total | $\pm 1.6$ |

Extrapolation of calibration ?
Data driven control channel ?

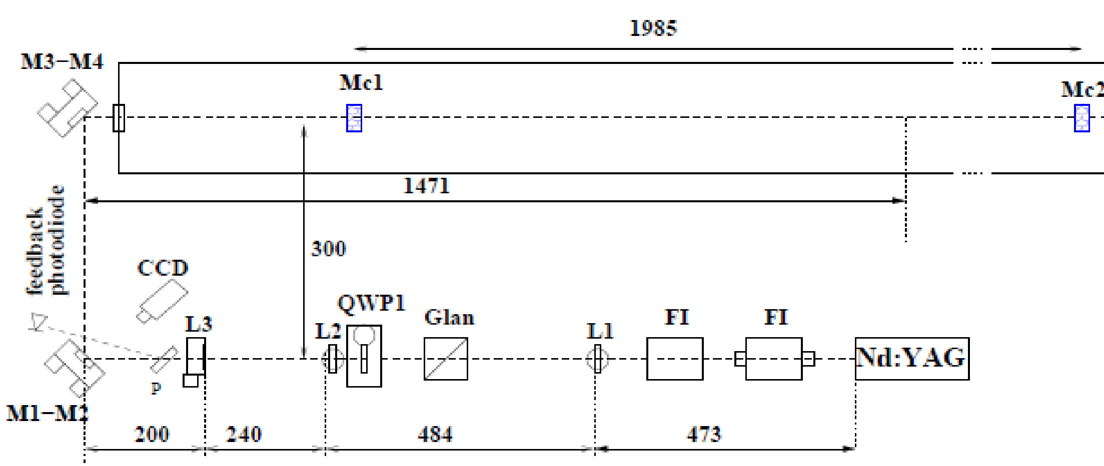


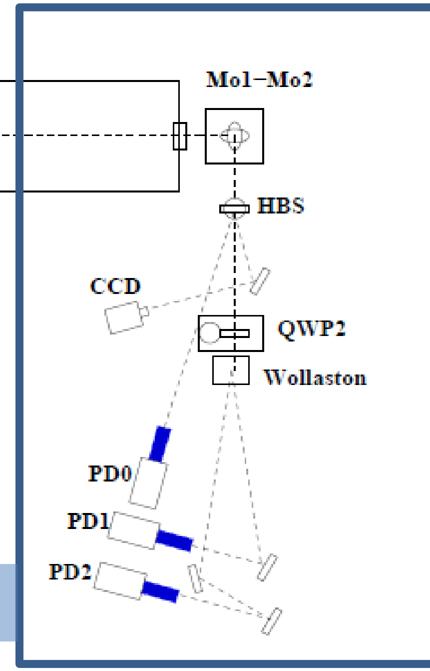




Thousand of scatters per crossing

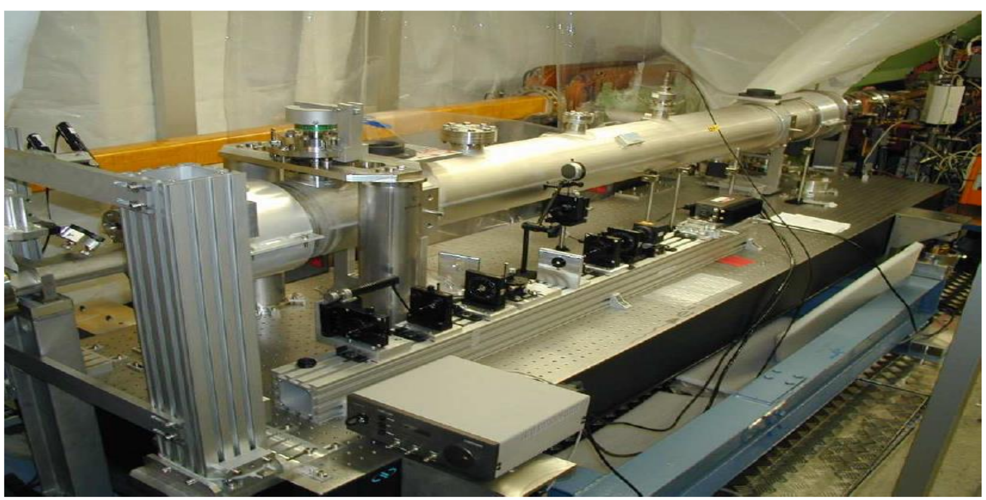
# HERA LPOL 2

Baudrand et al., JINST 5 P06005 (2010), Brisson et al., JINST 5 P06006 (2010),
Escoffier et al., Nucl. Instrum. Meth. A 551 (2005) 563



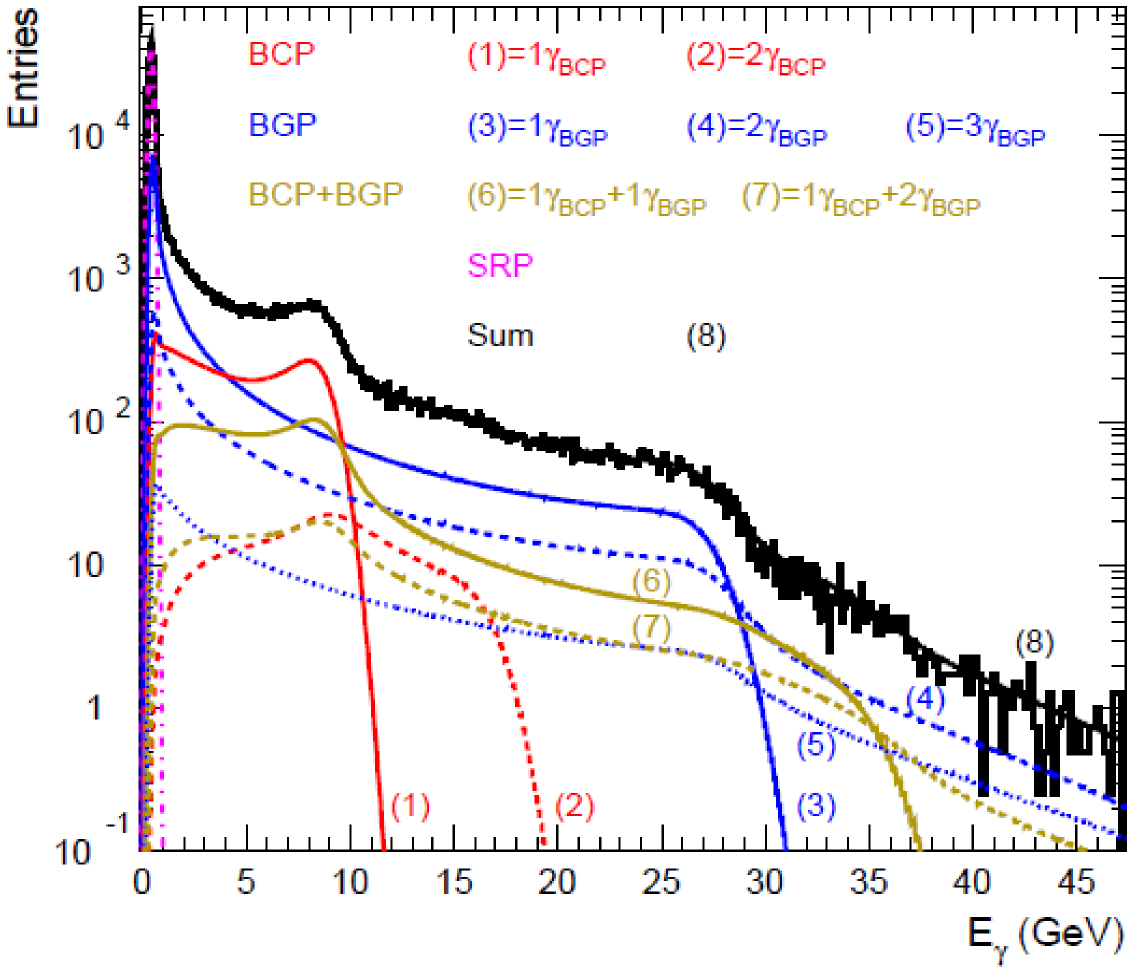




Careful design of ellipsometer <0.3% systematics

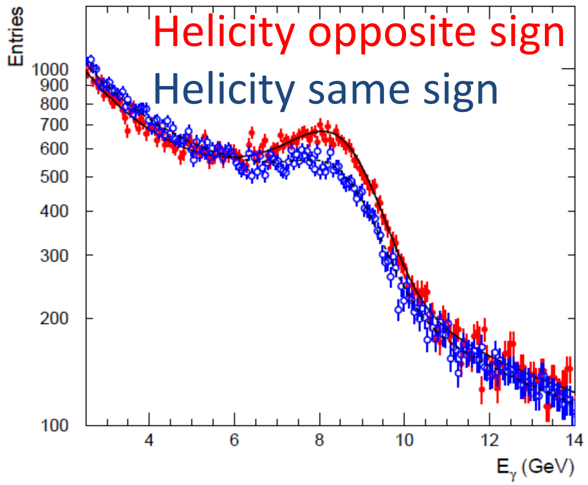


# HERA L-POL 2: results

Baudrand et al., JINST 5 P06005 (2010)




intermediate number (~1) of scatters per crossing

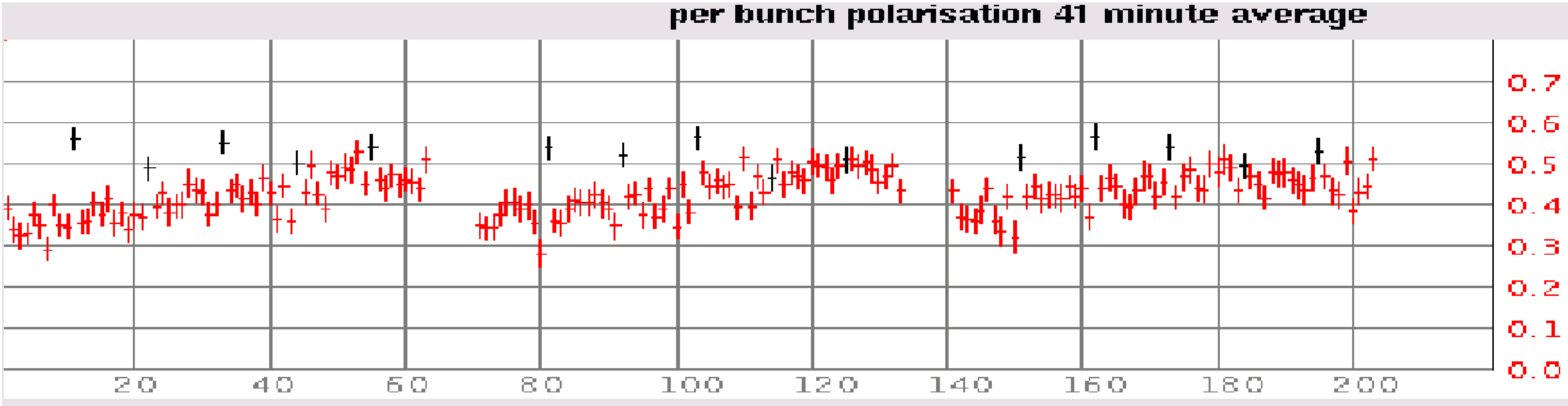



Multi-parameter fit of Beam-gas contribution, synchroton radiation, Compton scattering
Bunch per bunch measurement cumulated over 400k turns in HERA ring

# HERA: bunch/bunch measurements

Baudrand et al., JINST 5 P06005 (2010)

Bunch per bunch measurement required




- Detector knowledge and performance
- Position sensitivity of the detector (too small?)
- Synchrotron radiation treatment

| Source | $\Delta P/P(\%)$ |
|---|---|
| Uncorrelated errors | |
| HERA beam variations | 0.4 |
| Detector parameters | 0.5 |
| Correlated errors | |
| BGP and BBP cross-sections | negligible |
| Calorimeter resolution and ADC to energy conversion | 0.4 |
| Merging of the SRP peak | 0.4 |
| Laser polarisation circularity | 0.3 |
| Electronic sampling subtraction | 0.4 |
| Calorimeter position scan (horizontal) | 0.4 |
| Calorimeter position scan (vertical) | 0.4 |

# Preliminary conclusion

% level polarimetry achieved at SLC and HERA with Compton polarimetry, systematics limited

- Careful optical design and ellipticity control at 0.3% was obtained at HERA
- Bunch per bunch measurements are of interest to control single bunch polarization
- Two technologies have been tested:
  - electron counting
    - Direct xsec measurement
  - photon calorimetry
    - Infer polarization from energy spectra and/or energy dependent geometrical asymmetries
    - Low/medium/high yield options (driven by background level)

Systematics :

- All measurements limited, among other effects, by alignment of detectors
- Detector performance calibration also a critical contribution
  - PMT response
  - Electronic noise
  - Energy dependent efficiencies (calorimetric measurements only)

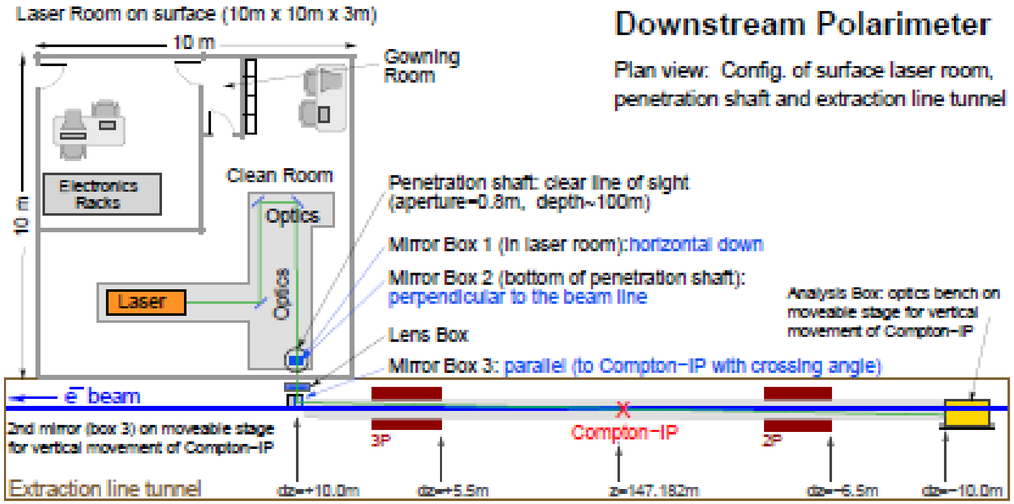
Cherenkov detector can be integrated in LHeC environment ?
Radiation hard and fast (25ns) detector ?

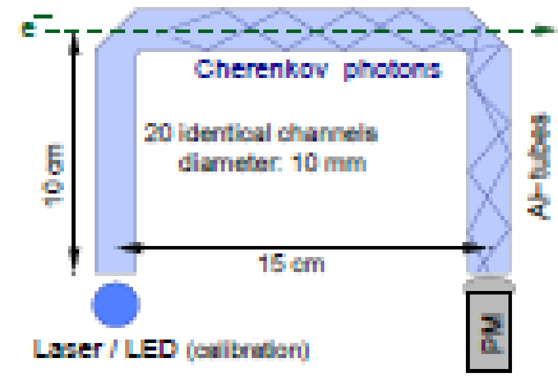
The path towards per-mille level polarimetry @ LHeC:

- on going developments for ILC
- available laser source

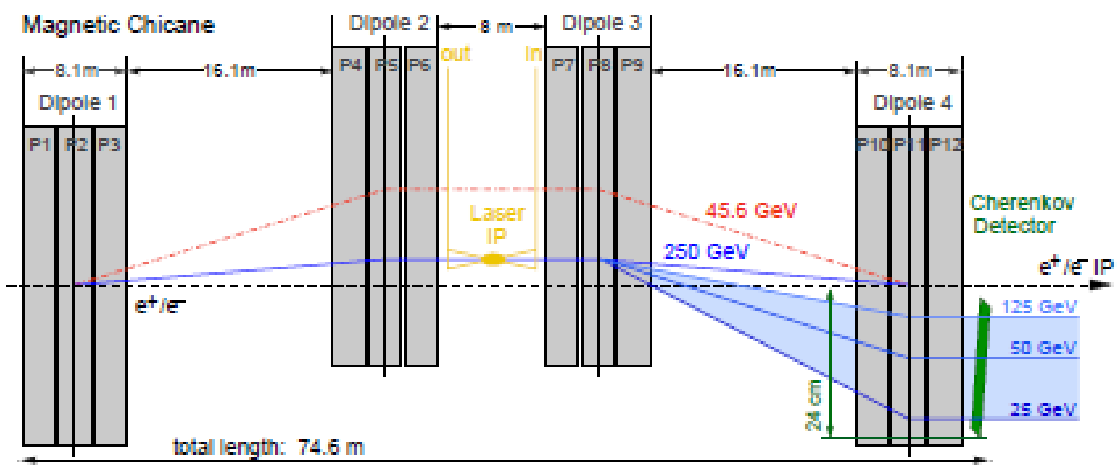
# ILC design in a nutshell

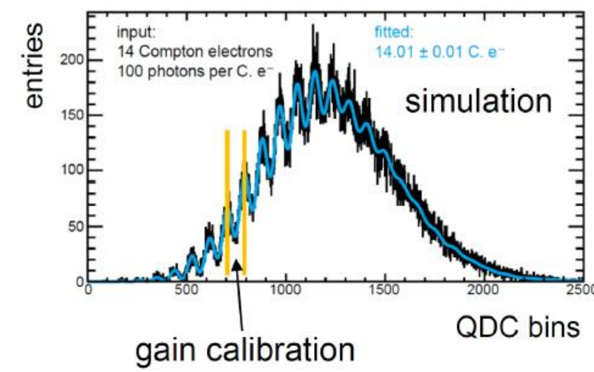
Bartels et al., JINST 7 P01019 (2012), Boogert JINST 4 P10015 (2009), Vauth
PhD thesis *DESY-THESIS-2014-022*, List @ALCW 2015,...




In situ LED calibration



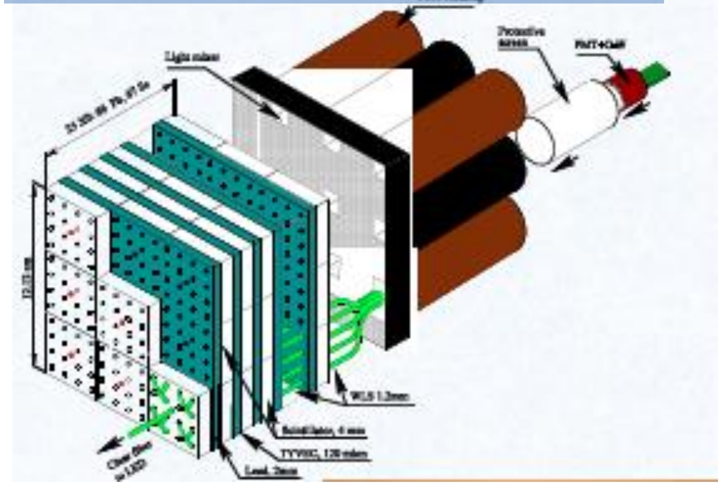

Radiation hardness to integrate it in LHeC tunnel ?

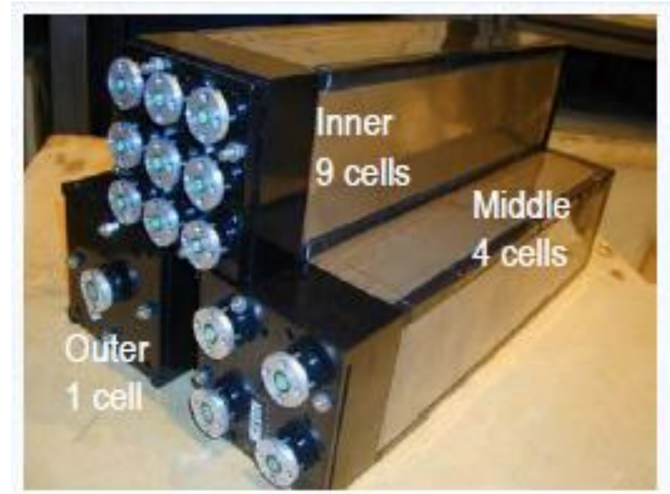
Quartz cherenkov counters ?
→ Data driven calibration
→ Signal collection time ?

# Possible calorimetric detector

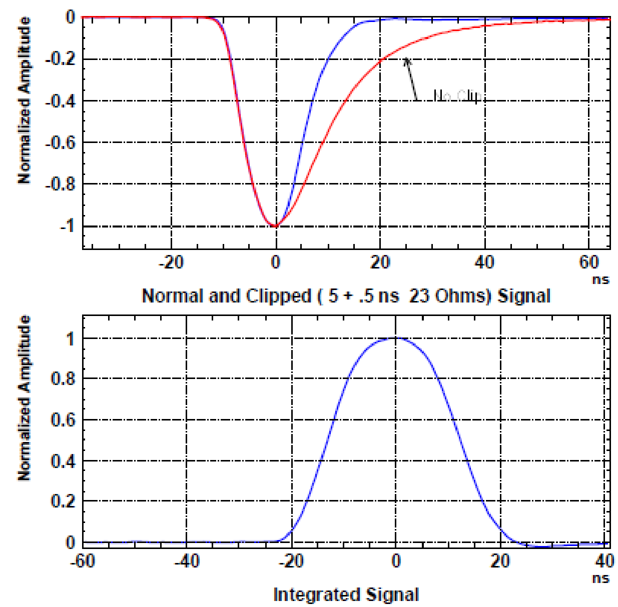
LHCb Calorimter TDR LHCC/2000-0036,LHCb upgrade PID TDR LHCC 2013-022
Zhu @ Mu2e-II Workshop at ANL

Scintllator : plastic (PSM-115)






Relatively fast calorimeter
Different use-case: probability of 2 successive events in a given calorimeter cell is low in LHCb




R&D is required
Prefer CsI ? BaF2:Y (Mu2e-II developments)
Radiation hardness level required ?

# Possible Laser design : industrial table-top laser

http://www.amplitude-systemes.com, Laser-Technik Journal (2/2016) 56

## Laser specifications

Possible solution if 1-10 scatters per crossing

| | TANGOR | TANGOR HP |
|---|---|---|
| Average power | > 50 W | > 100 W |
| Pulse energy | > 300 µJ | > 500 µJ |
| Pulse duration | < 500 fs to 10 ps | |
| Repetition rate | Single shot to 40 MHz | |
| Wavelength | 1030 nm | |
| Beam quality | Beam $M^2 < 1.3$ | |
| Spatial mode | $TEM_{00}$ | |
| Dimensions | 68 cm x 48 cm x 16 cm | |

versatile

Specifications are subject to change without notice | © 03-2018 | 876

Ultra compact ! → integrate close to Compton IP ?

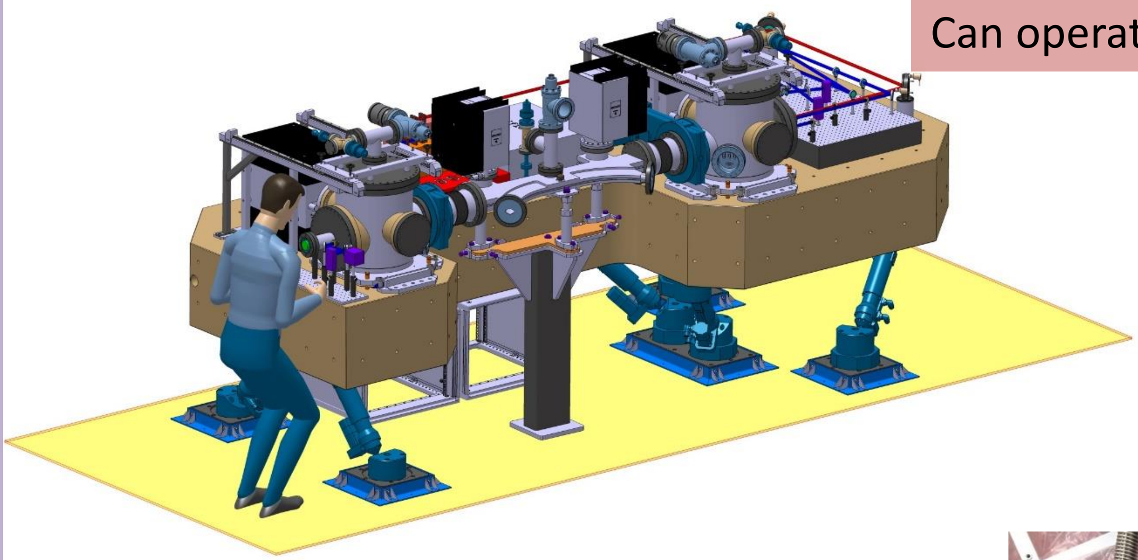
## Applications


Demanding industrial sector: routinely operating systems

NB: Also TRUMPF GmBH producing similar systems (but lower repetition rate advertised)

# Possible Laser design : Fabry-Perot cavity

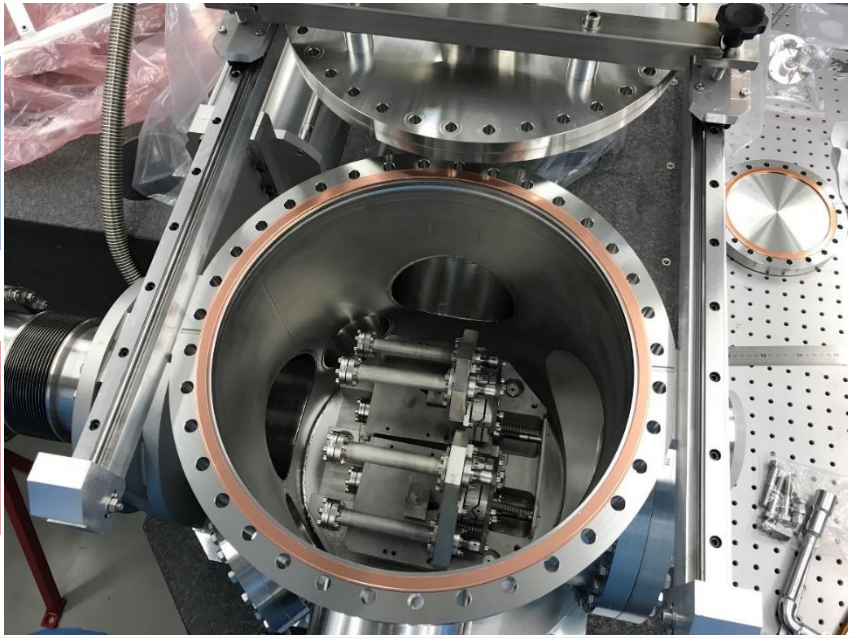
Chaikovska et al., Scientific Reports 6 (2016) 36569, ThomX TDR



Possible solution if > 10 scatters per crossing
Can operate at lower power

ThomX : High gain Fabry-Perot cavity (10k)
33MHz operation with >100kW stored power under routine operations

LHeC is less demanding : about 1.2kW
→ lower cavity gain, helicity may be switched within 90µs



# Conclusion and open points for discussion

% level polarimetry achieved at SLC and HERA with Compton polarimetry, systematics limited
Studies have been continued for ILC where precision is required to be about 0.25%

- Careful optical design and ellipticity control at 0.3% was obtained at HERA
- Bunch per bunch measurements are required to control single bunch polarization
- Two technologies have been tested: electron counting vs photon calorimetery
- Laser system can be shrinked using nowadays industrial systems or non planar FP cavity

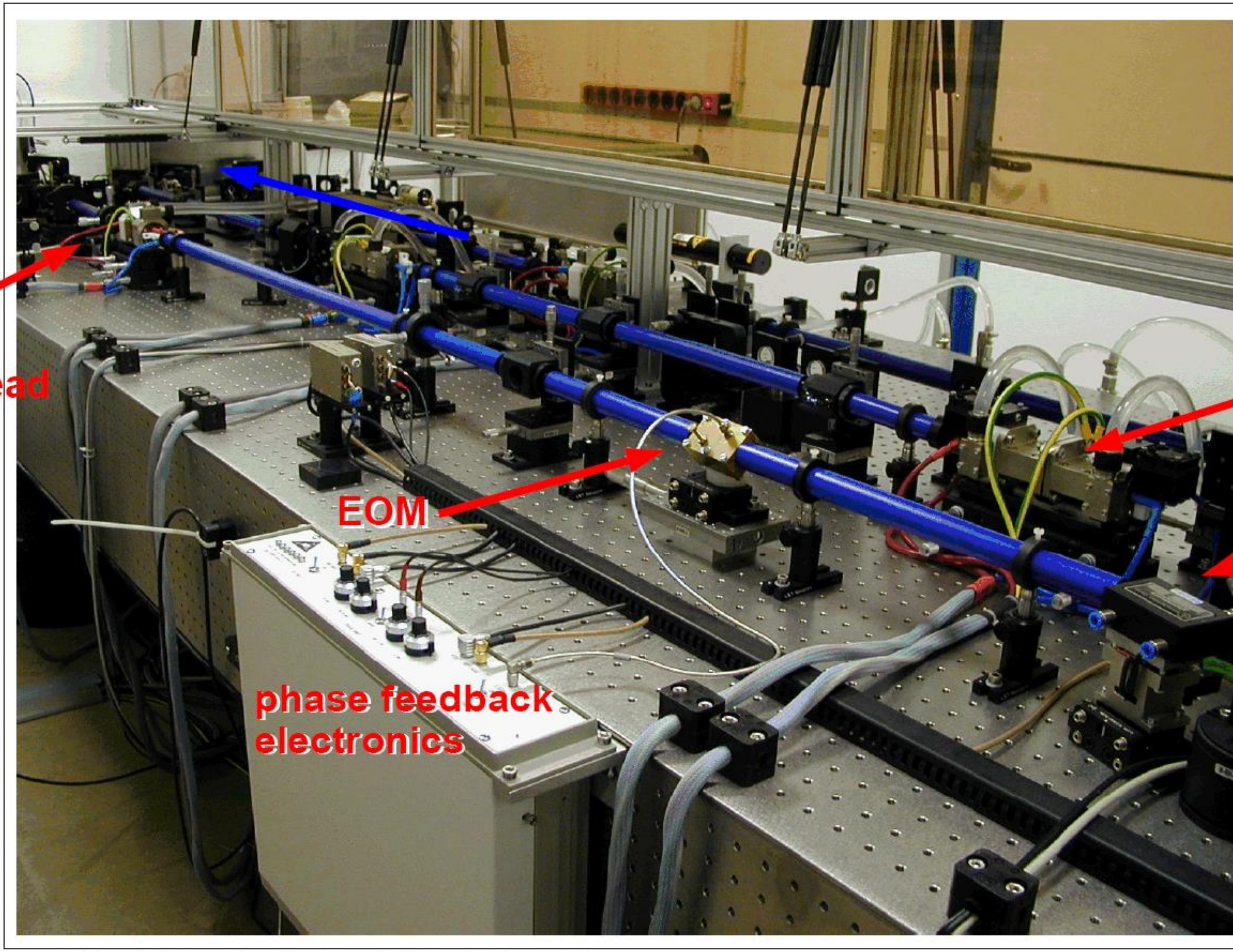
Systematics :

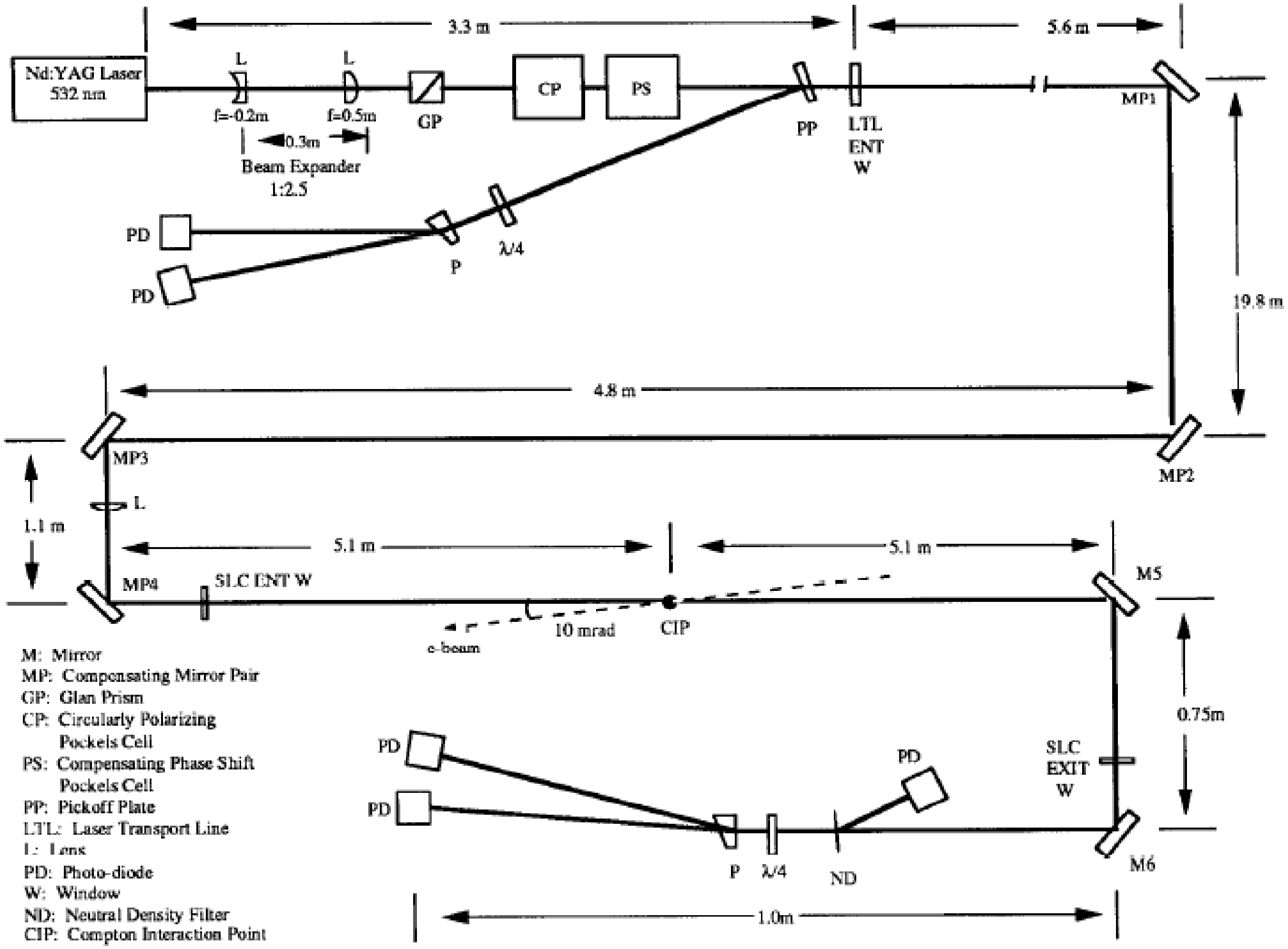
- Laser ellipticity can be improved with synchronous measurement techniques ?
- Alignment of detectors is critical : review detector design
- In situ/data driven detector performance calibration
- Redundant measurements ? With different technologies ?
- Play with laser parameters : energy, 2-color laser system ?

Detailed simulations needed, use more recent technologies, keep in mind:

- Systematics
- Radiation hardness
- Time response of detectors
- Background levels

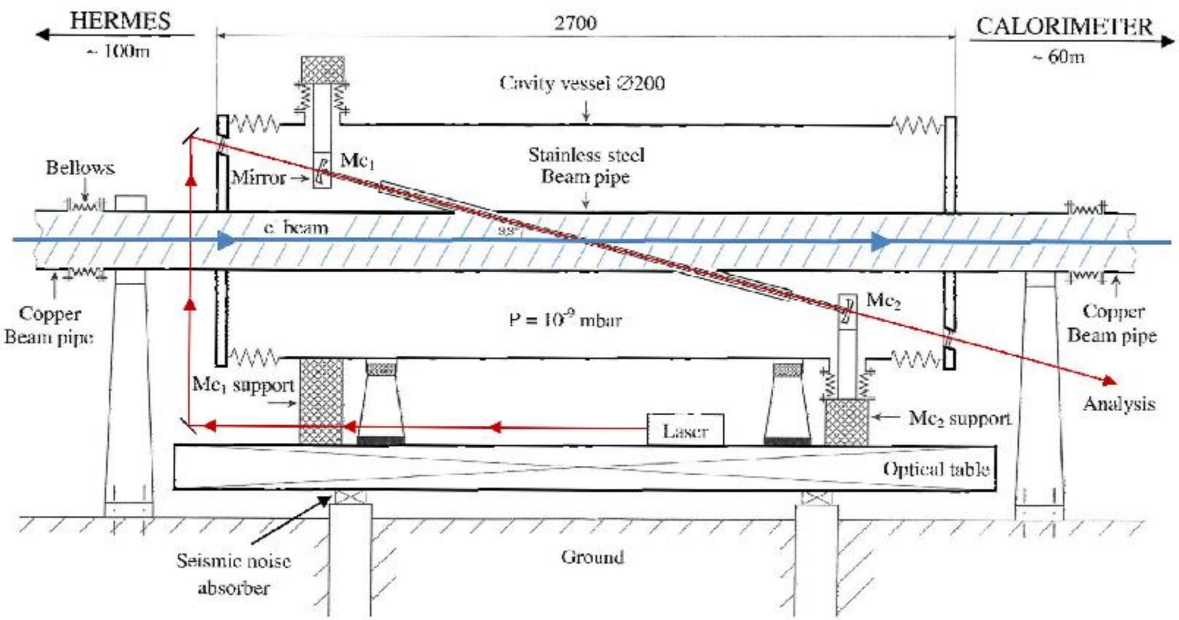
# TTF1 laser system





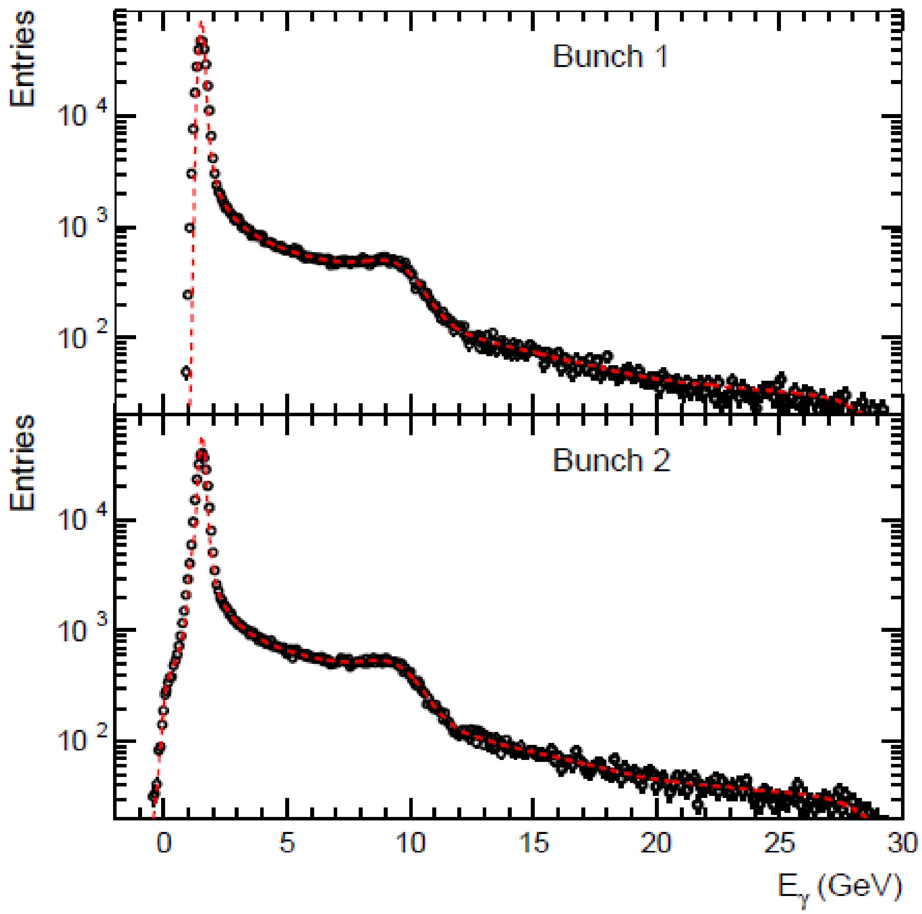

M: Mirror
MP: Compensating Mirror Pair
GP: Glan Prism
CP: Circularly Polarizing Pockels Cell
PS: Compensating Phase Shift Pockels Cell
PP: Pickoff Plate
LTL: Laser Transport Line
L: Lens
PD: Photo-diode
W: Window
ND: Neutral Density Filter
CIP: Compton Interaction Point
P: Calcite Prism

**Figure 3-9: Compton Polarimeter Laser Transport System.**


HERMES
~ 100m
2700
CALORIMETER
~ 60m
Cavity vessel Ø200
Bellows
Mirror
Me1
Stainless steel
Beam pipe
e beam
Copper
Beam pipe
P = 10^-9 mbar
Me2
Copper
Beam pipe
Me1 support
Laser
Me2 support
Analysis
Optical table
Seismic noise
absorber
Ground

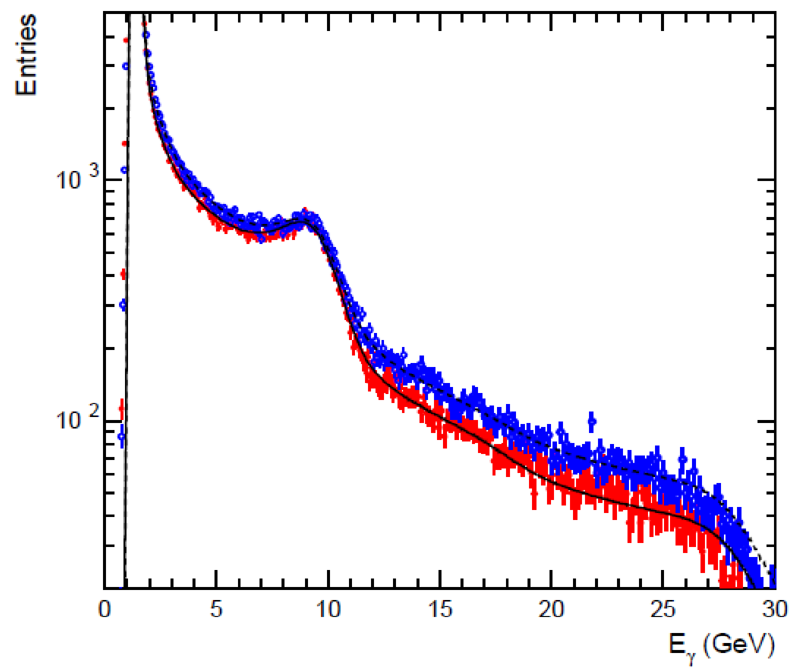
# HERA L-POL 2: tiny effects

Baudrand et al., JINST 5 P06005 (2010)



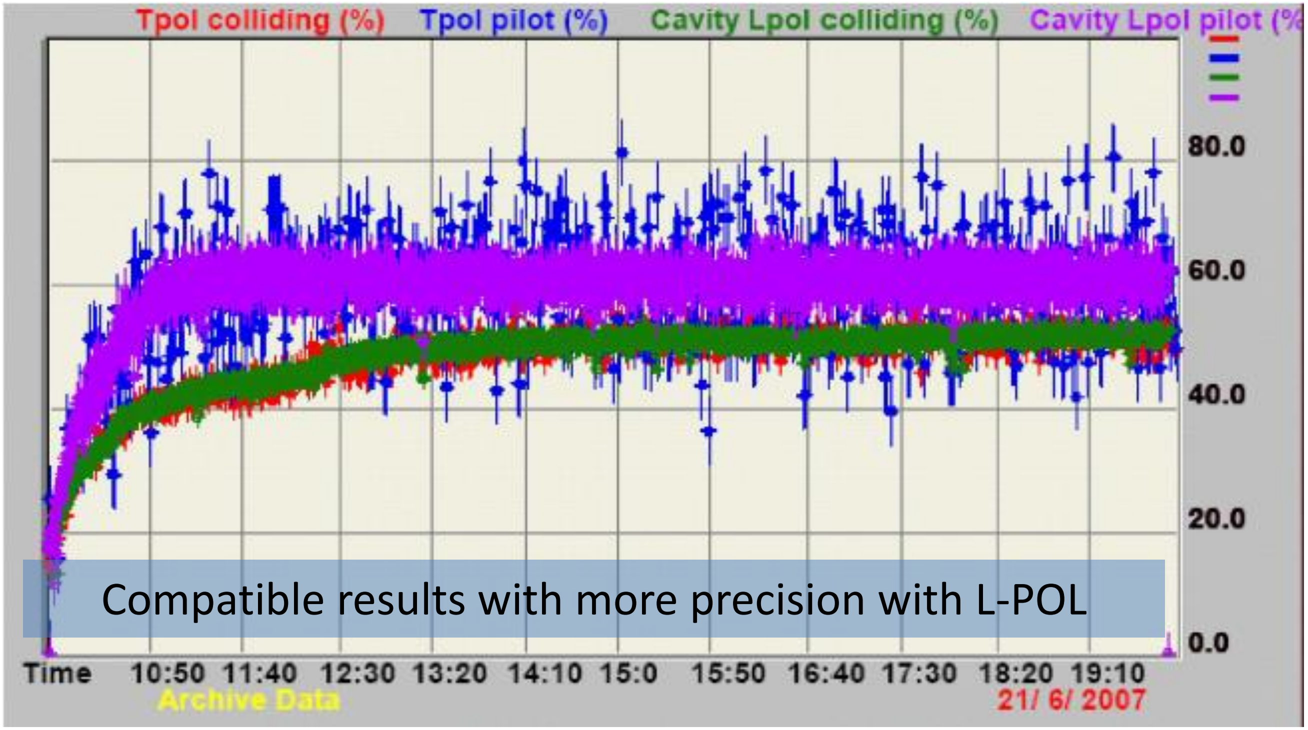

Pile-up effects are included

Background fluctuations in between changes of laser helicity



# HERA L-POL 2/T-POL comparison

Baudrand et al., JINST 5 P06005 (2010)




Compatible results with more precision with L-POL

One measurement every 10s

- Detector knowledge and performance
- Position sensitivity of the detector
- Synchrotron radiation treatment

| Source | $\Delta P/P(\%)$ |
|---|---|
| Uncorrelated errors | |
| HERA beam variations | 0.4 |
| Detector parameters | 0.5 |
| Correlated errors | |
| BGP and BBP cross-sections | negligible |
| Calorimeter resolution and ADC to energy conversion | 0.4 |
| Merging of the SRP peak | 0.4 |
| Laser polarisation circularity | 0.3 |
| Electronic sampling subtraction | 0.4 |
| Calorimeter position scan (horizontal) | 0.4 |
| Calorimeter position scan (vertical) | 0.4 |

# Introduction



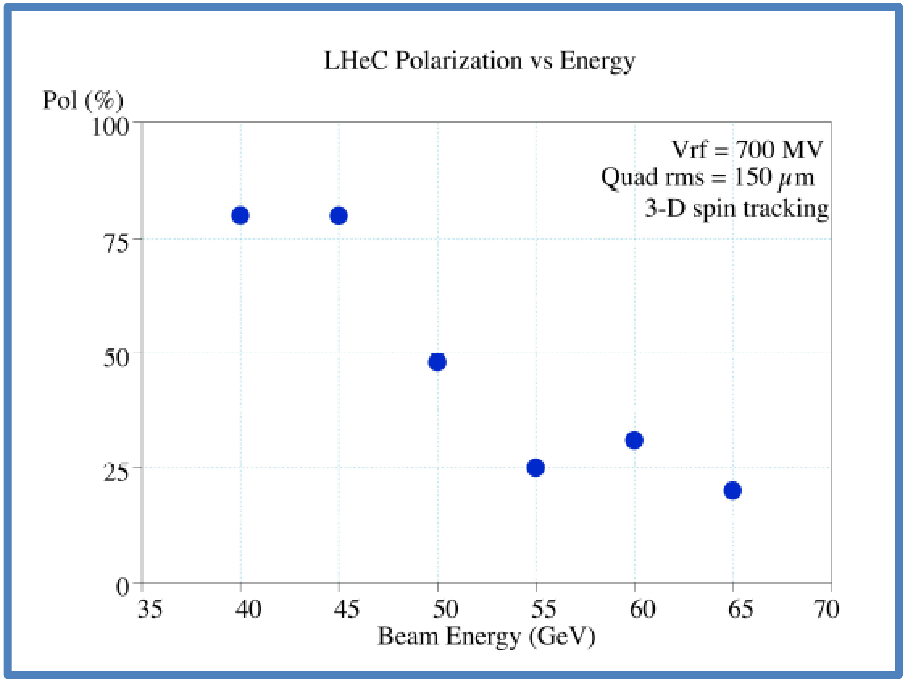
Spin (longitudinal) polarization of e- beams at LHeC is an involved subject

Ring-ring option:

- Spin tends to (anti-)align with B field due to synchrotron radiation (ST, BK)
- Spin precess (T-BMT equation) quickly (large 'spin tune')

→ Depolarization arise due to vertical betatron motion, skew quads, spin rotators, solenoids

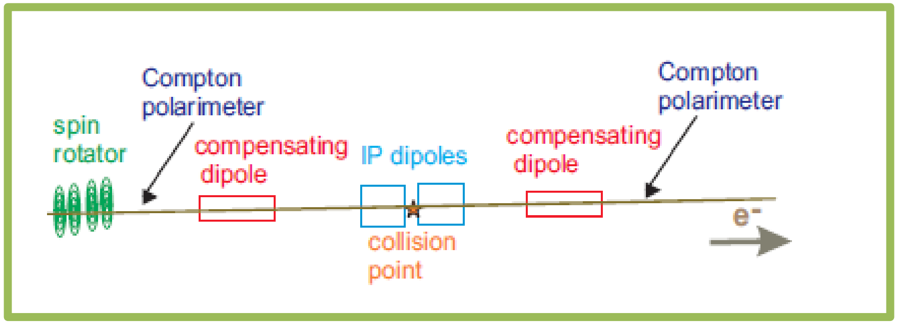
→ Depolarization increases with energy




LINAC-ring option:

→ Depolarization can be small

→ chromatic effects in spin rotators




Precise Compton polarimetry is required to reach physics goals