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# Introduction to polarimetry at HERA

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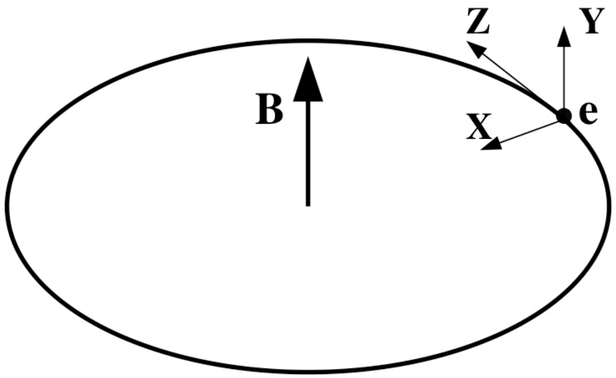
- Electron polarisation at HERA
- The LPOL
- The TPOL
- The LPOL cavity

# Electron polarisation in storage rings

- Electron beam deflected around a ring with B field in the y axis radiates photons




- Flip of the projection of electron spin along y can occur

- Spin flip probabilities per unit time

$$\omega_{\uparrow\downarrow} = \frac{5\sqrt{3}}{16}\left(1 + \frac{8}{5\sqrt{3}}\right)\frac{c\lambda_c r_0 \gamma^5}{\rho^3} \qquad \omega_{\downarrow\uparrow} = \frac{5\sqrt{3}}{16}\left(1 - \frac{8}{5\sqrt{3}}\right)\frac{c\lambda_c r_0 \gamma^5}{\rho^3}$$

$\gamma \equiv$Lorentz factor ($E_e/m_e$) $\rho \equiv$bending radius of B field $\lambda_c \equiv$Compton wavelength $r_0 \equiv$electron radius

- Since $\omega_{\uparrow\downarrow} \neq \omega_{\downarrow\uparrow}$ starting from an unpolarised beam, synchrotron radiation induces a transverse polarisation
  - Sokolov-Ternov effect

# Polarisation in storage rings

The asymptotic polarisation limit is given by

$$P_{ST} = \frac{\omega_{\uparrow\downarrow} - \omega_{\downarrow\uparrow}}{\omega_{\uparrow\downarrow} + \omega_{\downarrow\uparrow}} = \frac{8}{5\sqrt{3}} \approx 92.4\%$$

With time evolution given by

$$P_Y(t) = -P_{ST}(1 - e^{-t/\tau_{ST}})$$

where

$$\tau_{ST} = \frac{1}{\omega_{\uparrow\downarrow} + \omega_{\downarrow\uparrow}} = \frac{8\rho^3}{5\sqrt{3}c\lambda_c r_0 \gamma^5}$$

is the build up time.

# Polarisation in storage rings

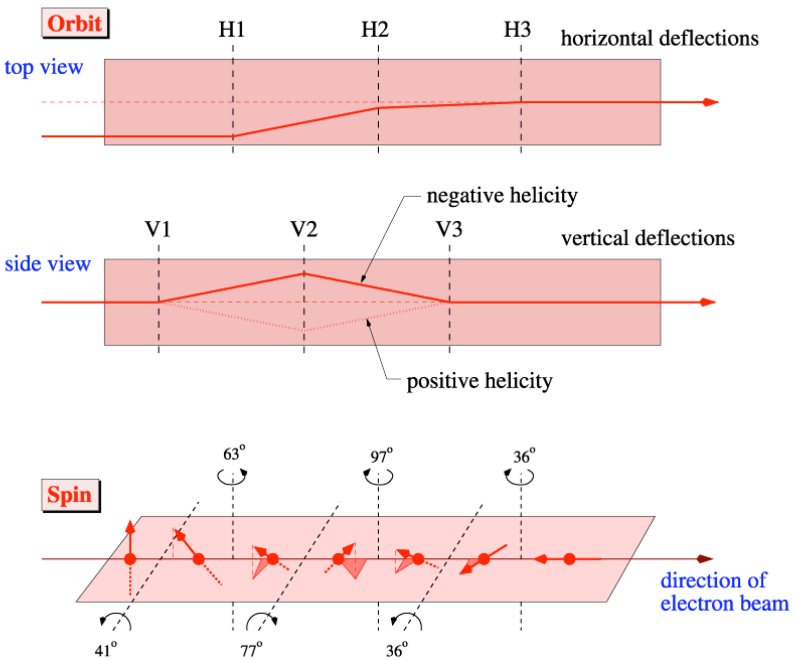
So what should we note about this?

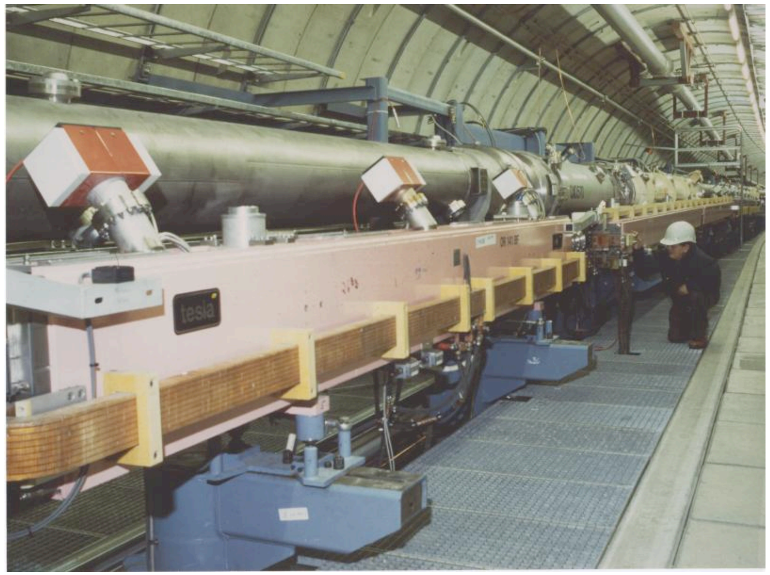
- $P_{ST}$ is a constant and $P_{ST}<1$
- $P_{ST}$ antiparallel to the B field (parallel for positron beam with same field)
- At HERA $E_e$=27.5 GeV $\tau_{ST}\approx$40 mins
- Long timescale reflects small size of asymmetry. Compare to $\tau\approx10^{-8}$ s for photon emission.
- Long timescale also means same all around ring
- $\tau_{ST}$ highly energy dependent $\propto 1/E^5$
- $P_{ST}$ and $\tau_{ST}$ calculable from first principles
  - Measurement of rise-time $\tau$ provides absolute P calibration

# Depolarising effects

- Of course all the previous stuff assumes
  - a perfect planar storage ring (i.e. only perfectly vertical homogenous B field)
  - After photon emission the electron stays on the perfect orbit
- In a real storage ring
  - Horizontal and longitudinal fields (mis-aligned magnets etc.)
  - Electrons oscillate around the central orbit
  - Stochastic depolarisation through synchrotron radiation
  - Interactions with the proton beam
- Depolarising effects lead to $P_{MAX} < P_{ST}$
- Have to correct orbit to keep spin aligned
  - Empirically done using "harmonic bumps"

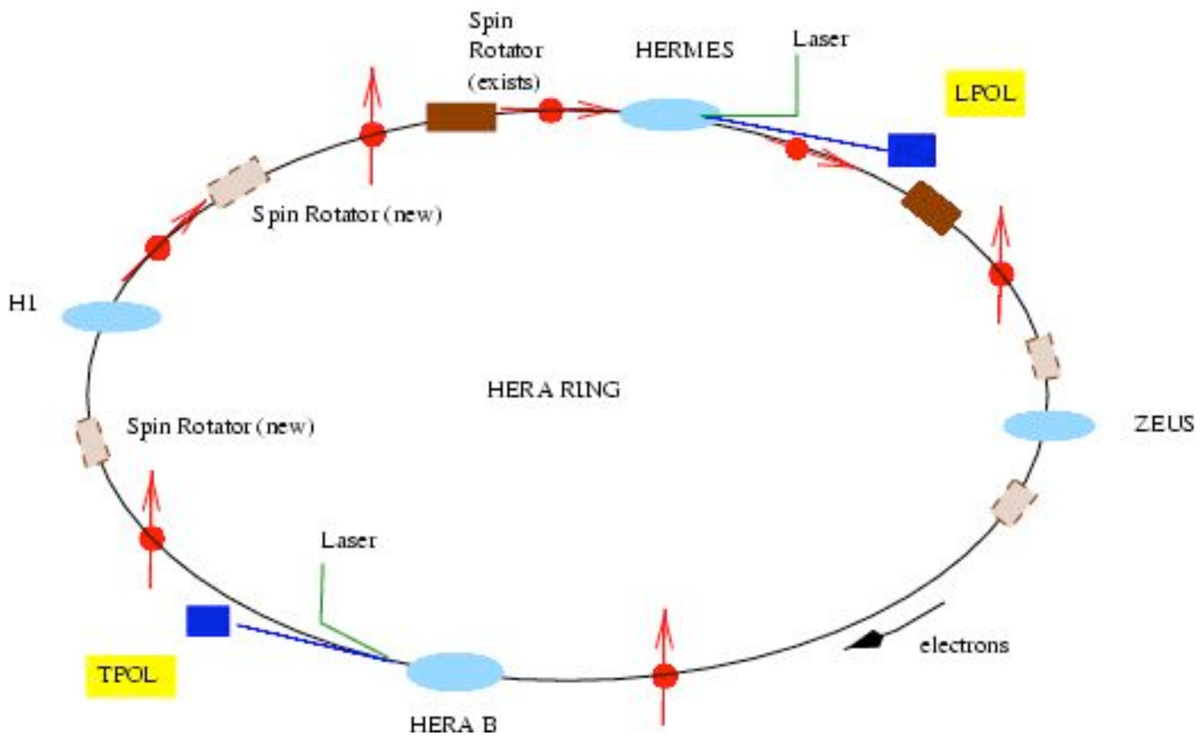
# Spin rotators



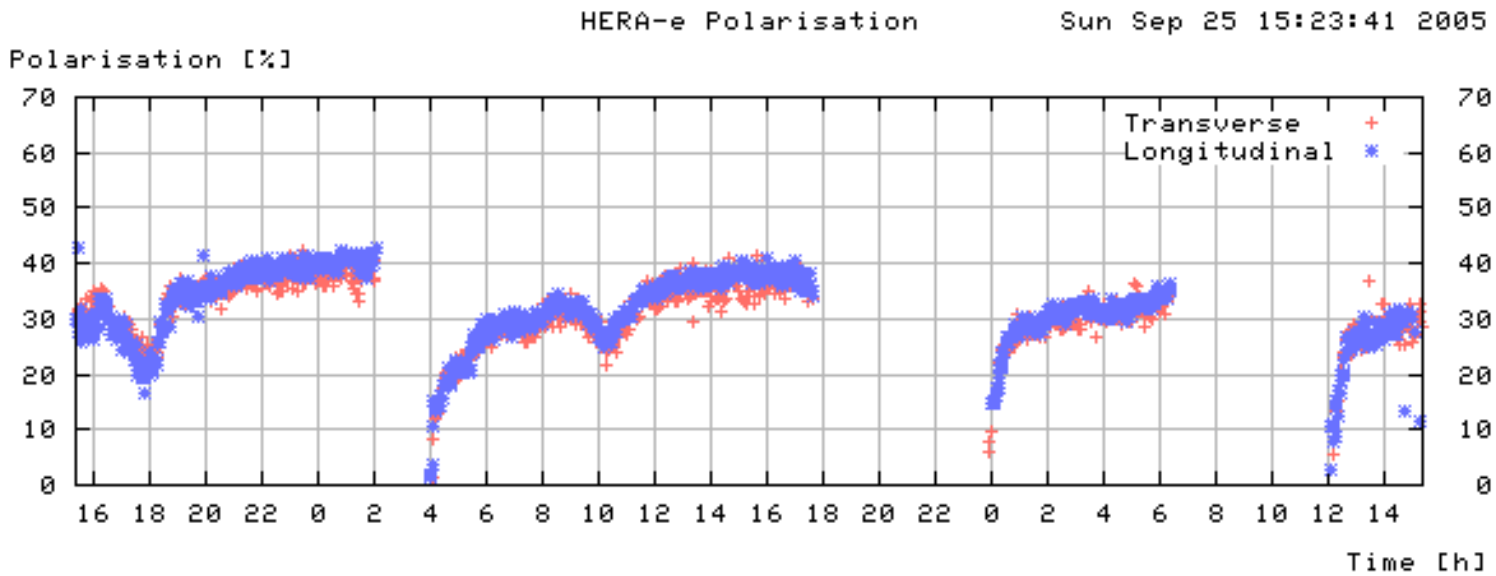
- Make use of spin precession ($\Delta\phi_{SPIN}=62.5\Delta\phi_{ORBIT} \rightarrow \Delta\phi_{ORBIT} \sim$mrad)
- Use series of transverse magnetic fields to change $P_Y$ into $P_Z$
- Move section vertically during access days to change helicity
- So called “mini-rotator” only 56m long!

# Polarisation at HERA



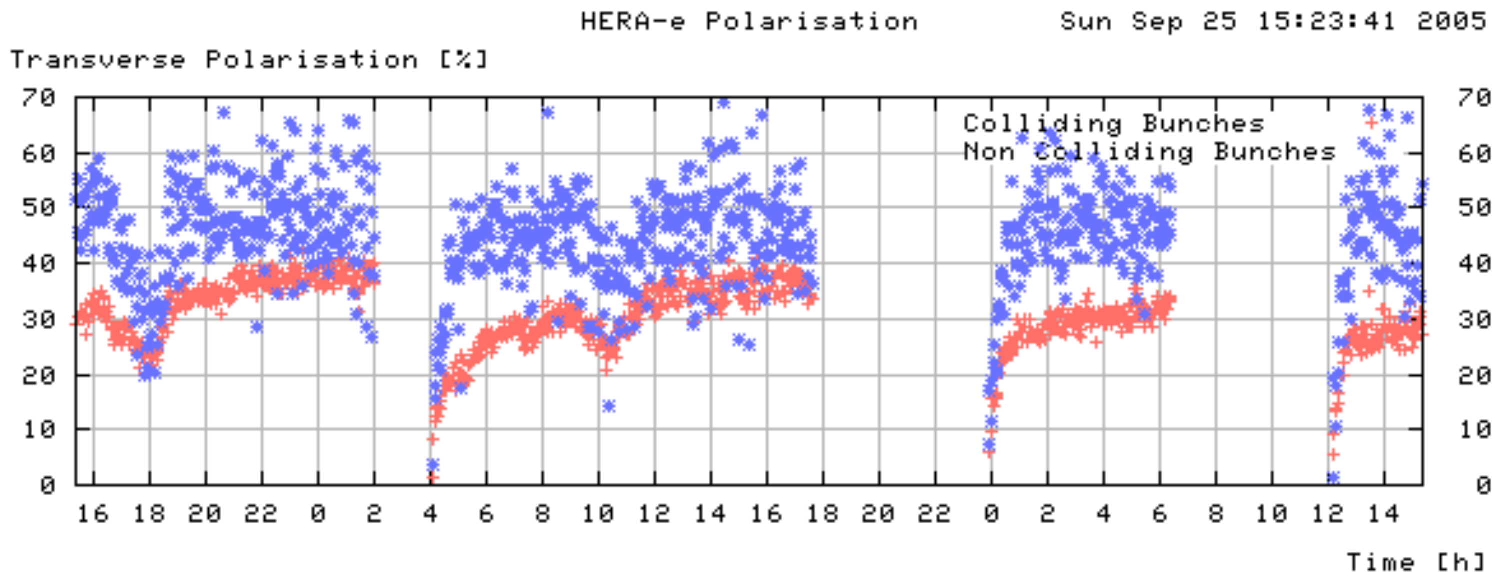

- Spin rotators around H1, HERMES and ZEUS
- Two independent polarimeters
  - Longitudinal polarimeter (LPOL) near HERMES
  - Transverse polarimeter (TPOL) near HERA-B hall

# Polarisation at HERA




- Fills from yesterday
- Rise of polarisation, some tuning and rise towards the end of the fill

# Polarisation at HERA




- Fills from yesterday
- Non-colliding bunches higher P than colliding
- Far fewer non-colliding hence larger error

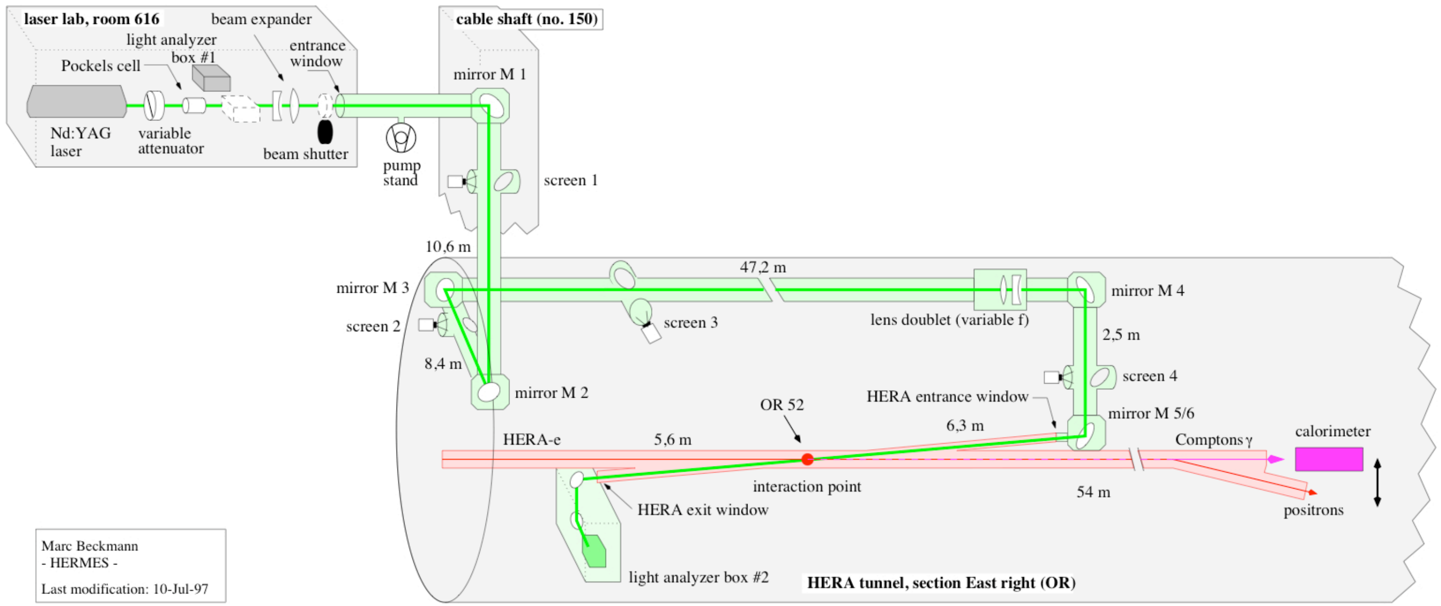
# Compton scattering

- Spin-dependent cross section for $\gamma$-e scattering

$$\frac{d^2\sigma}{dEd\phi} = \Sigma_0(E) + S_1\Sigma_1(E)\cos 2\phi + S_3\left[P_Y\Sigma_{2Y}(E)\sin\phi + P_Z\Sigma_{2Z}(E)\right]$$

- $S_1$,$S_3$ linear and circular components of laser beam
- $P_Y$,$P_Z$ transverse and longitudinal components of lepton beam polarisation
- Use asymmetry between $S_3$=+1 and $S_3$=-1 states

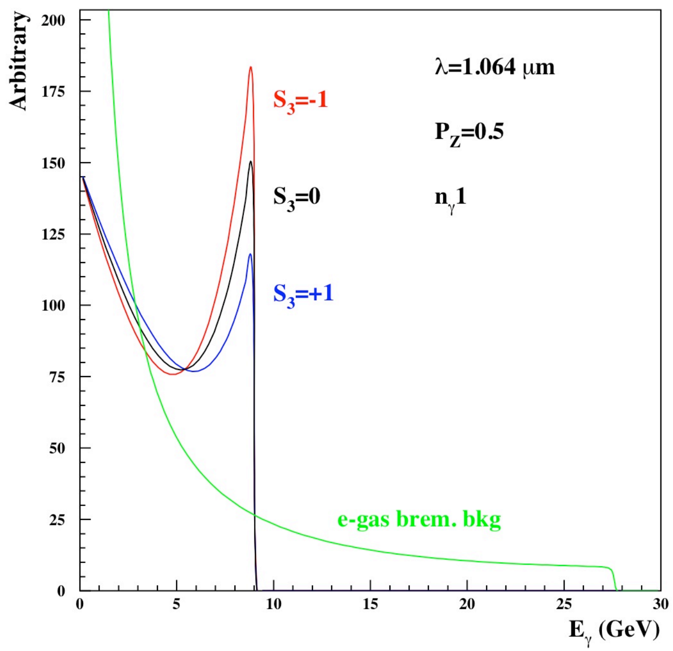
# LPOL




- Nd:YAG laser - 3ns x 100 mJ @ 100 Hz
- Pockels cell converts linear (>99%) light to circularly polarised light
- Transported to tunnel and collided with electron beam
- Detect backscattered photons in calorimeter downstream
- Laser polarisation monitored in tunnel and ctrl room

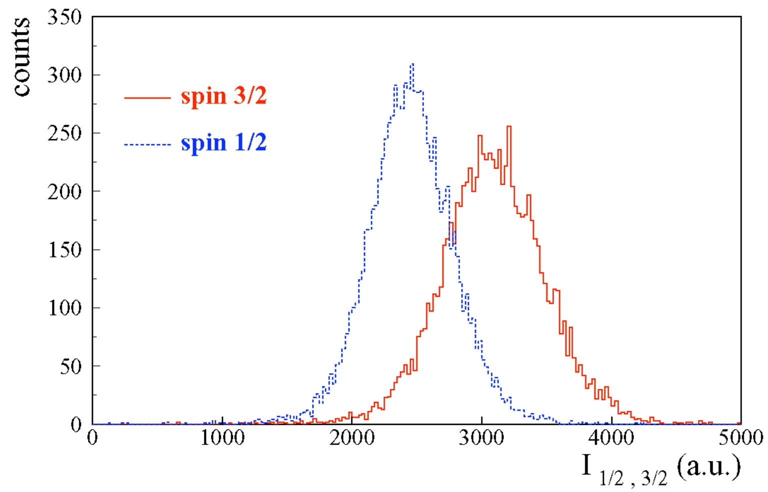
# LPOL single-photon mode

- $n_\gamma \approx 0.001$ per bunch crossing
- Can use single-photon cross section. Calculate $\sigma$ from QED
- Compton edge gives energy calibration
- Large separation of LH and RH states (up to 0.6)
- But at LPOL location Bremsstrahlung background is too high
- $s/b \approx 0.2$ gives too large a statistical error ($\delta P/P = 0.01$ takes 2.5 hours)
- Use for systematic studies



# LPOL multi-photon mode

- $n_\gamma \approx 1000$ per bunch crossing
- No background problems
- No easy way to monitor calorimeter energy response (E>5 TeV!)
- High power pulsed laser but only at 100 Hz compared to HERA 10 MHz
- $\delta P/P=0.01$ in 1 minute

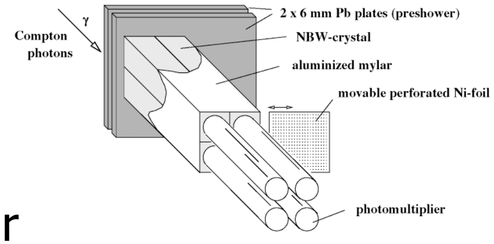


# LPOL

- $NaBi(WO_4)_2$ crystal calorimeter
- Tungsten-scintillator calorimeter for systematic studies
- In multi-photon mode asymmetry given by:

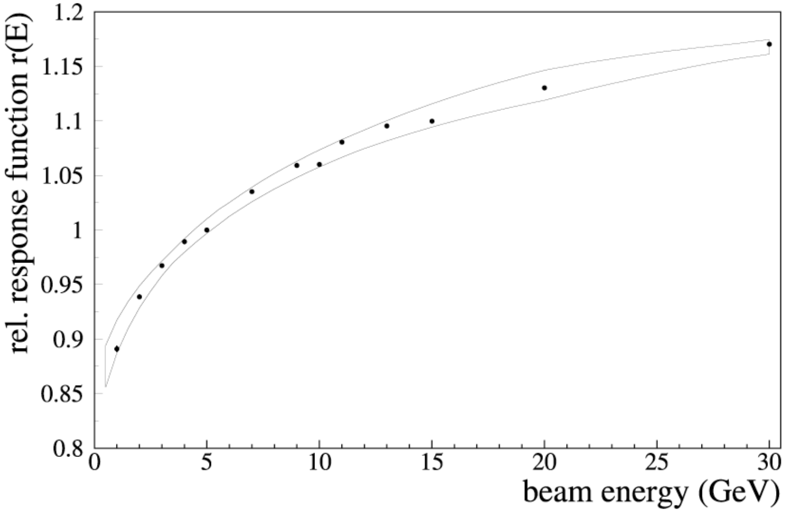
  $A_m = (I_{3/2}-I_{1/2})/(I_{3/2}+I_{1/2}) = P_c P_e A_p$

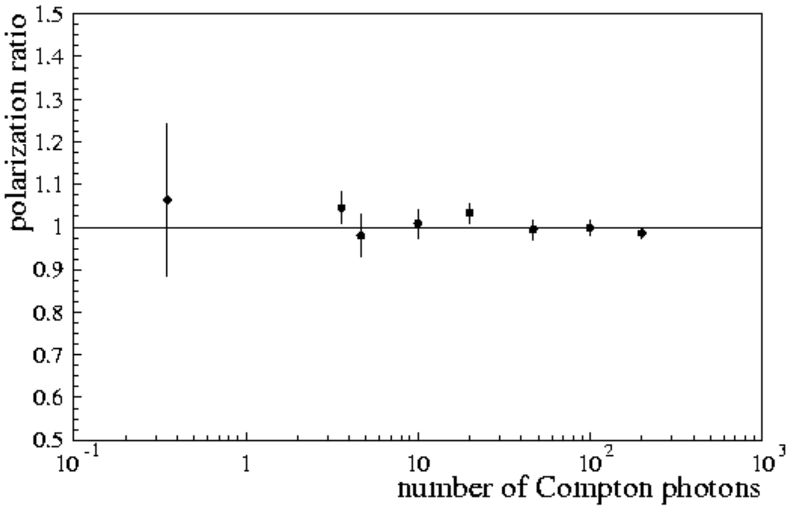
  $A_p=(\Sigma_{3/2}- \Sigma_{1/2})/(\Sigma_{3/2}+ \Sigma_{1/2}) = 0.184$ if detector is linear




- Get $A_p$ from test-beam response

$$\Sigma_i = \int_{E_{min}}^{E_{max}} (d\sigma / dE)_i E \cdot r(E) dE$$



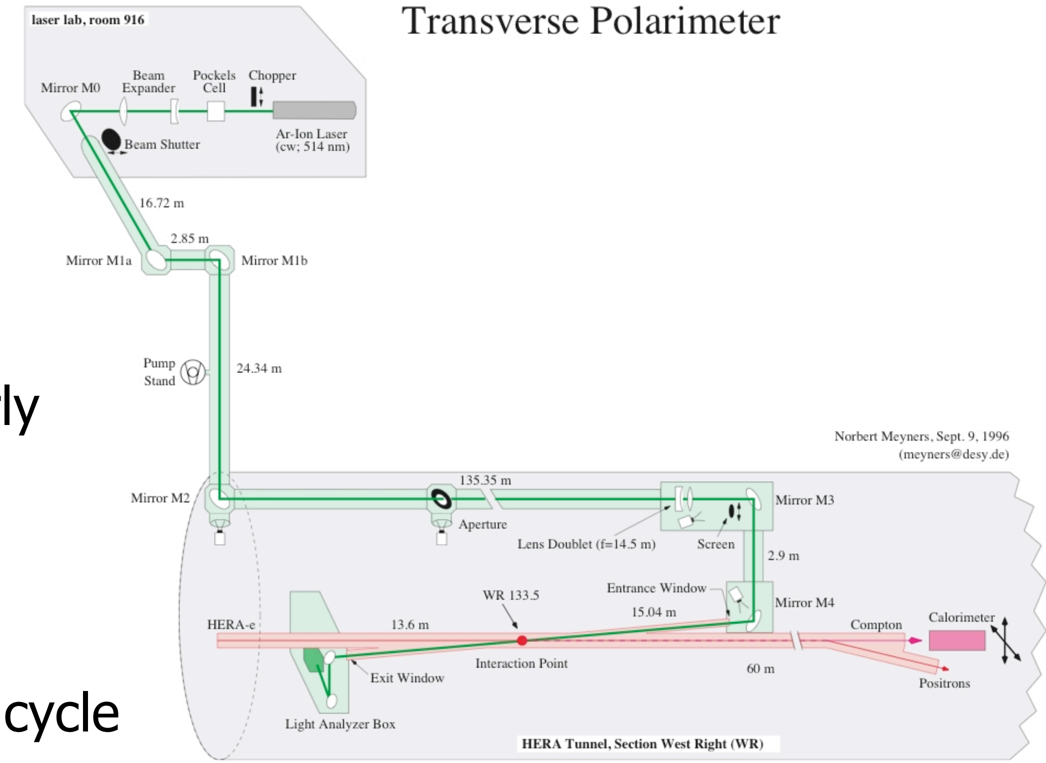
# LPOL

- Linearity dominates systematic uncertainties for LPOL
- Contributions from the measured response function and the extrapolation to multi-photon mode

| Systematic source | δP/P (%) |
|---|---|
| Analysing Power $A_p$ | ±1.2 |
| - response function | (± 0.9) |
| - single to multi photon transition | (± 0.8) |
| $A_p$ long-term stability | ± 0.5 |
| Gain mismatching | ± 0.3 |
| Laser light polarization | ± 0.2 |
| Pockels cell misalignment | ± 0.4 |
| Electron beam instability | ± 0.8 |
| **Total** | ± **1.6** |

# TPOL

- Ar-ion 10W cw laser
- Linear polarisation >99%
- Pockels cell converts to circularly polarised
- Helicity swapped at 90 Hz
- One measurement cycle 40 secs of laser on - 20 secs laser off for background measurement
- Laser power and polarisation monitored in tunnel and ctrl room
- DAQ rate 100 kHz

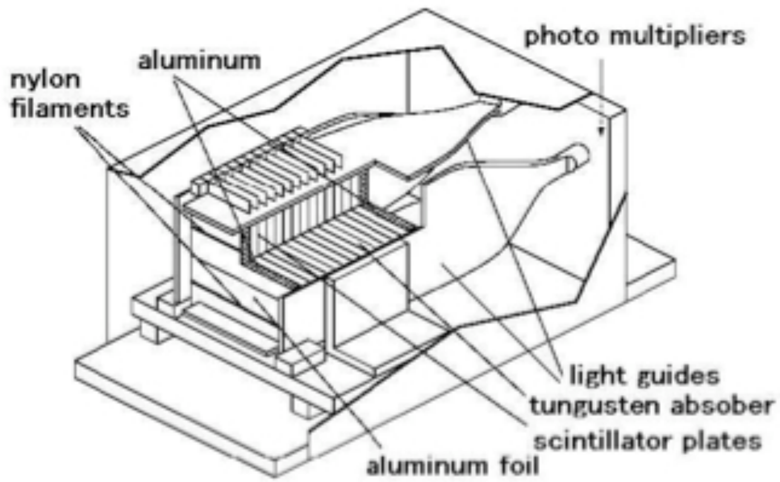


# TPOL

- Have to measure $E_\gamma$ and spatial asymmetry
- Use single-photon mode and Compton edge for energy calibration online
- Tungsten-scintillator sampling calorimeter
- Calorimeter has upper and lower halves
- Measured energy $E_\gamma = E_U + E_D$
- Energy asymmetry $\eta = (E_U - E_D)/(E_U + E_D)$
- Gives up-dn spatial asymmetry….

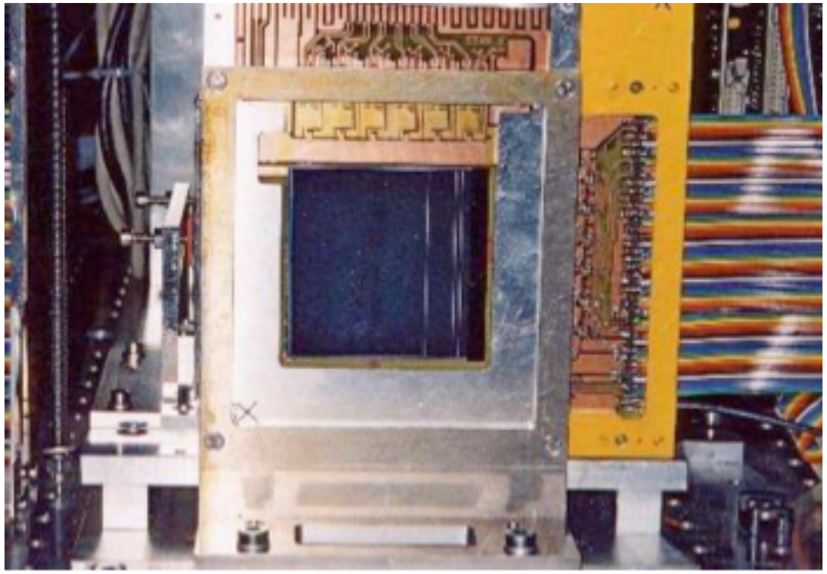
…but have to transform to y

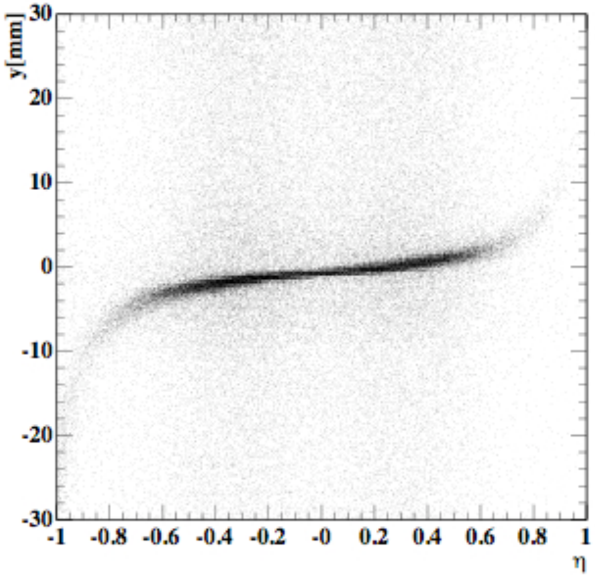
- Known only from test-beam
- Depends on transverse shower shape in calorimeter
- Main uncertainty $\eta$-y transformation



# TPOL - silicon detector

- Measure y position of Compton beam accurately at the face of the CAL
- Provide in-situ $\eta$-y calibration

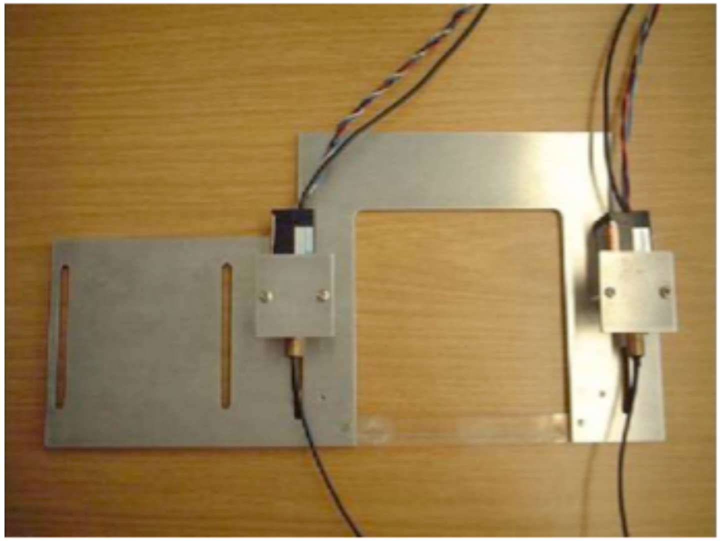





- 6cm x 6cm silicon sensors
- Two planes: x and y
- Pitch 80(240) $\mu$m in y(x)
- Readout < 1 kHz - much slower than CAL
- No fast online measurement

# TPOL - fibre detector

- TPOL is a high radiation area
  - Estimated to be ~2MRad/year
  - Expect some degradation of the silicon response
  - Especially concentrated at the centre of the beam



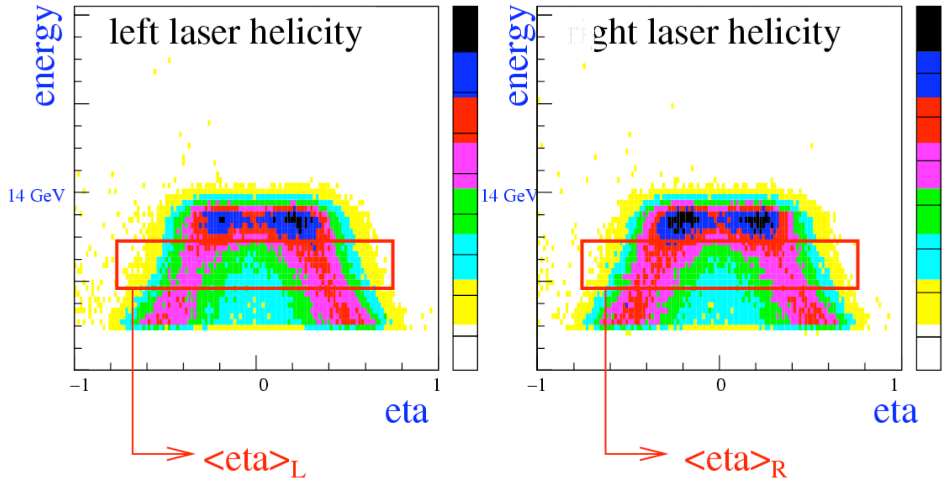
- Installed scintillating fibre detector upstream of silicon
- Can be scanned vertically over the face of the silicon detector using a stepping motor
- Periodic scans can monitor the silicon response at different y coordinates
- If necessary avoid bias by correcting silicon response

# TPOL online analysis

- Integrate $d^2\sigma/dE_\gamma d\eta$ over sensitive region in $E_\gamma$ and $\eta$

- Consider asymmetry between laser beam helicities

$$\langle \eta_L \rangle - \langle \eta_R \rangle = 2|S_3|P_Y\Pi$$




- $\prod$ is the analysing power from rise-time calibration and MC
- $S_3$ is measured between HERA fills to be 1 with error ±0.5%

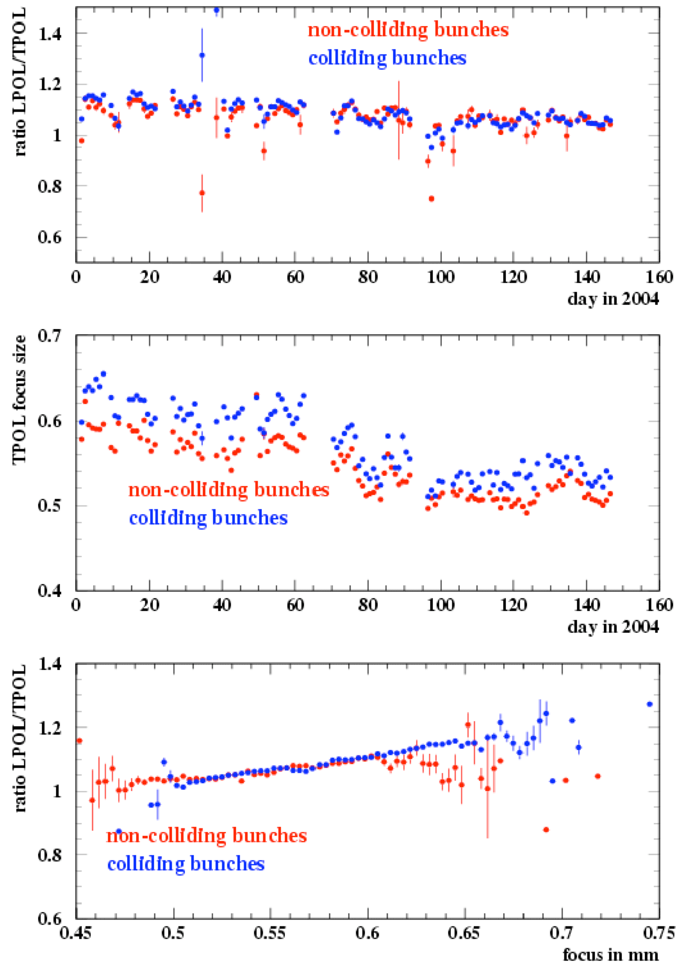
- Fast and simple method using only CAL
- This is what you see on TPOL monitor in the control room and actually what we've used in physics analyses so far

# TPOL online analysis

Implicitly assumes that the following are constant:

- Vertical size of lepton beam at the IP
- Position of the Compton beam on the CAL
- Vertical size of the Compton beam at the CAL (focus)
- Energy resolution of the CAL
- $\eta$-y transformation
- Linear component of laser light $S_1$

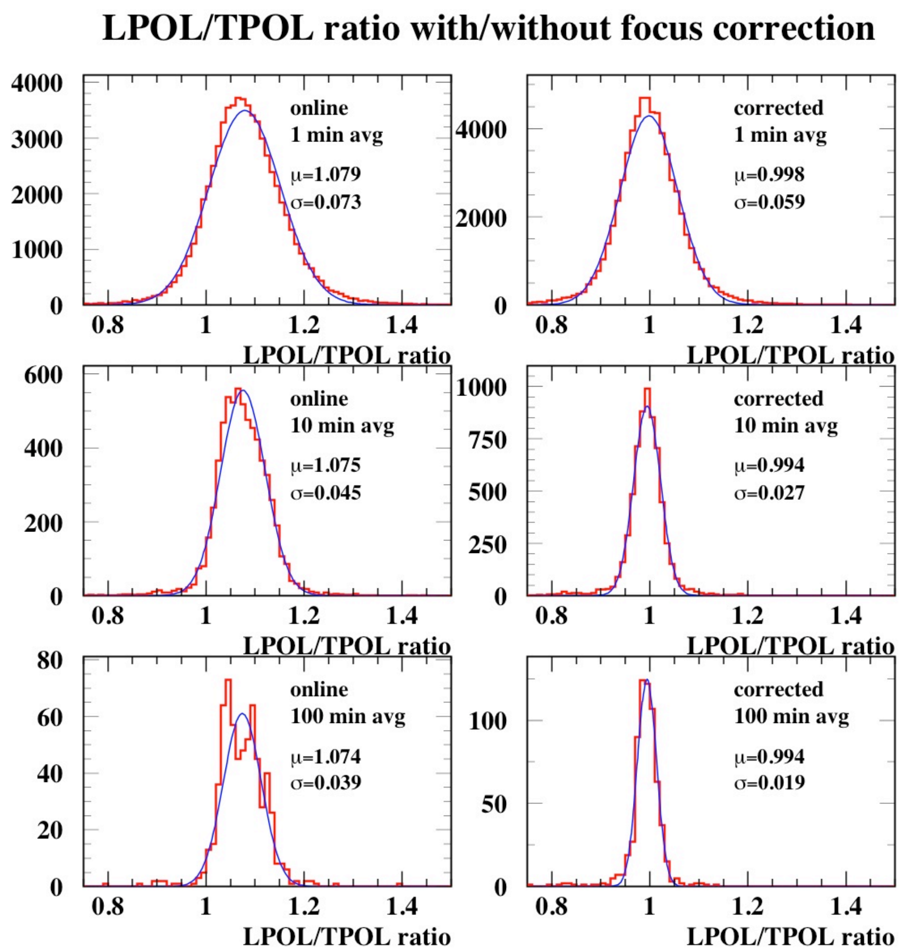
One example of drawback is the focus which changes significantly over time and causes bias in the measurement



# TPOL online analysis

- Focus has a correction derived from MC to remove bias
- Gives nice agreement between LPOL and TPOL measurements

- Still other parameters are assumed to be stable
- Does not exploit the full sensitivity of the data
- Develop more complex offline analysis →

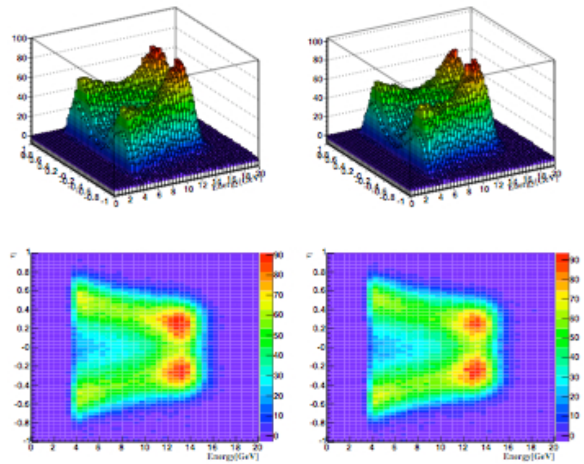


# TPOL offline analysis

- Develop new analysis
  - More robust to changes in conditions
  - More precise polarisation measurement
  - Better control of systematics

- Exploit full 2D information from CAL and new position sensitive detectors

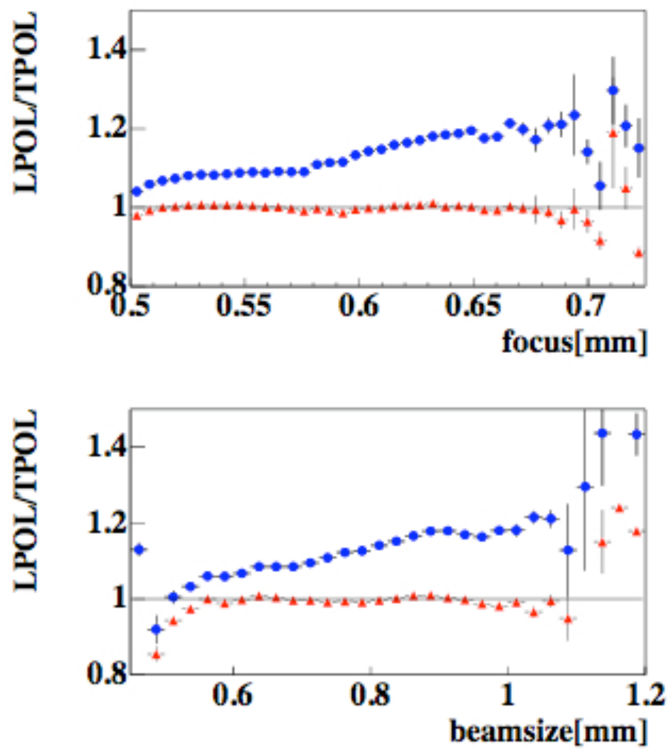
- Multi-parameter fit to include
  - Beam conditions
  - CAL response
  - $\eta$-y transformation



# TPOL offline analysis

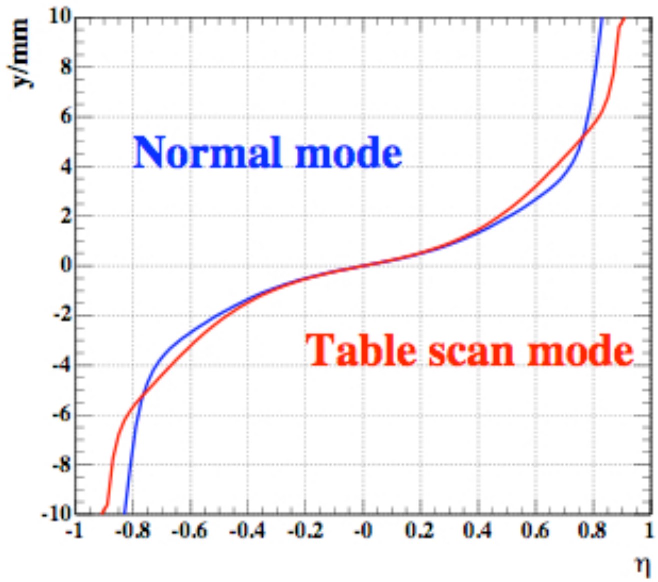
- After considerable study end up with 5 free input parameters
  - 2 to define the vertical size and position of the beam
  - 2 for the CAL calibration
  - 1 for the CAL energy resolution

- Good fit to all the data
- $\chi$/ndf = 1.2
- Consistent with LPOL
- Robust to changes in beam size and focus



# TPOL offline analysis

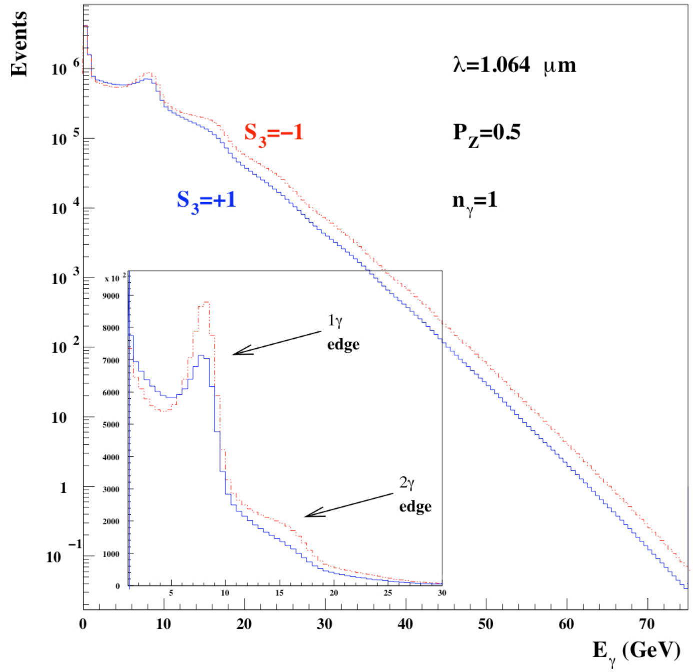
| Systematic source | δP/P (%) |
|---|---|
| Distance | ±0.78 |
| Beam offset | ±0.02 |
| η-y curve | ±0.87 |
| Fitting range | ±1.99 |
| Calibration | ±1.97 |
| Resolution | ±1.16 |
| **Total** | **±3.247** |




- First estimate of systematic uncertainty ~3.2%
- Largest contributions from η-y transformation
  - This is where most of the work continues
  - Understand systematic differences in η-y curve
- Still need work on CAL response too

# LPOL cavity

- Consider "few photon mode"
  That's $n_\gamma \approx 1$ per bunch crossing

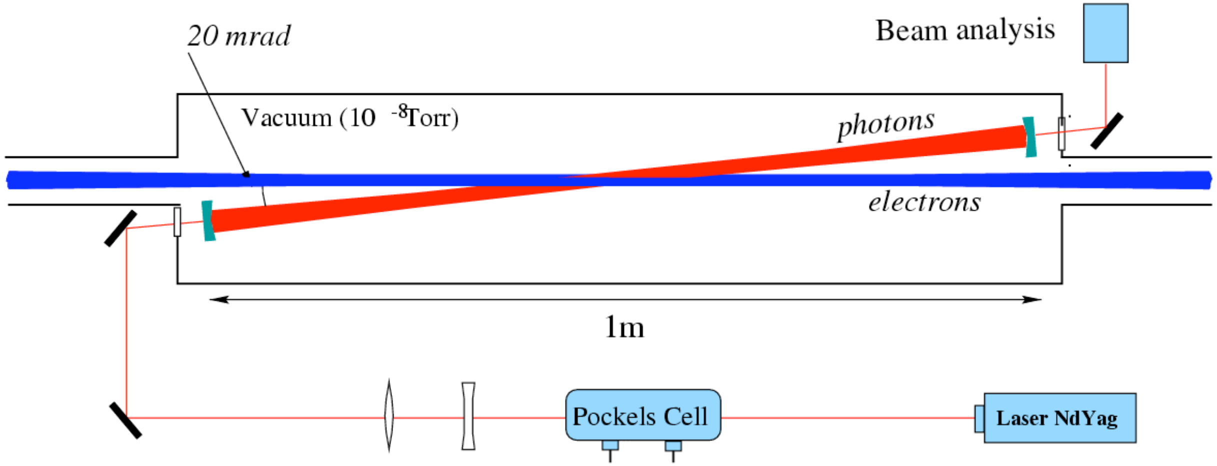



- ✓ Can still use single-photon cross section
- ✓ Compton edge energy calibration
- ✓ Good systematic precision
- ✓ Enough statistics to overcome the background

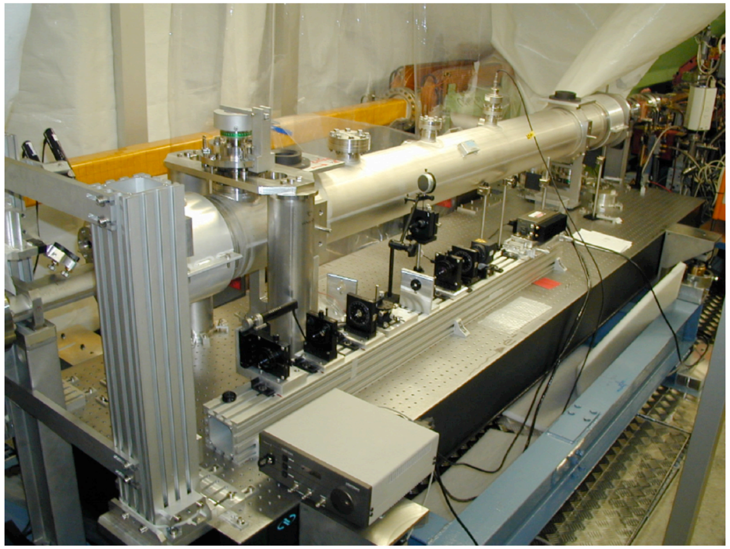
- ✗ Need a 10kW cw laser!

- ✓ Use a 1W cw laser and a Fabry-Perot cavity with Q≈10000

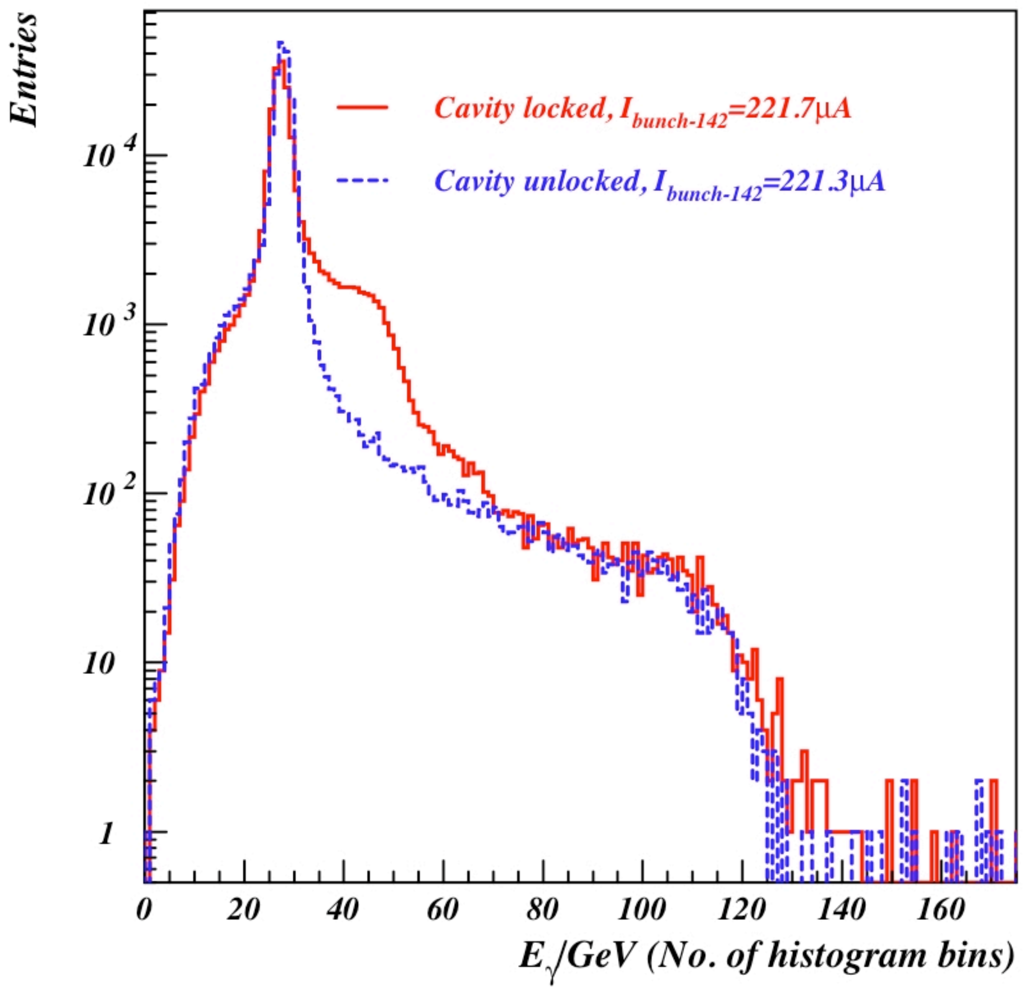
# LPOL cavity




- Installed in the tunnel
- Initially laser electronics damaged by radiation but shielding improved and now able to run

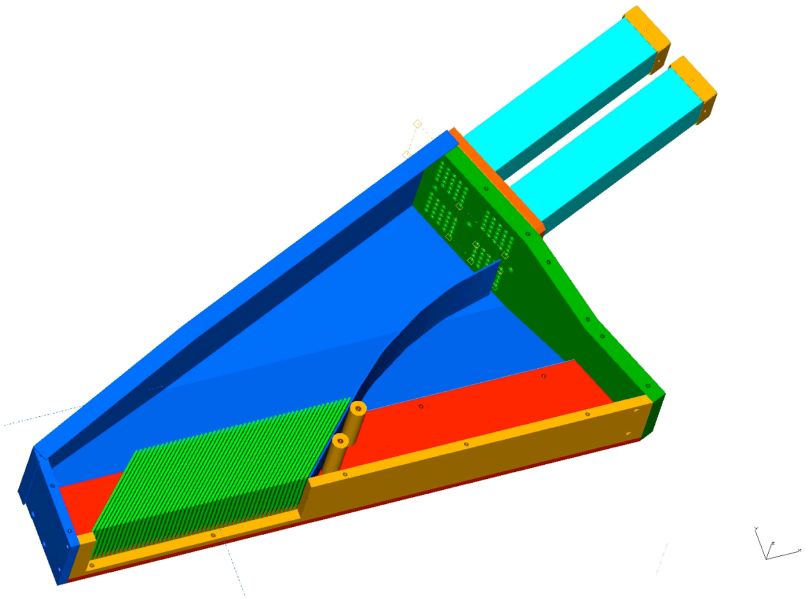


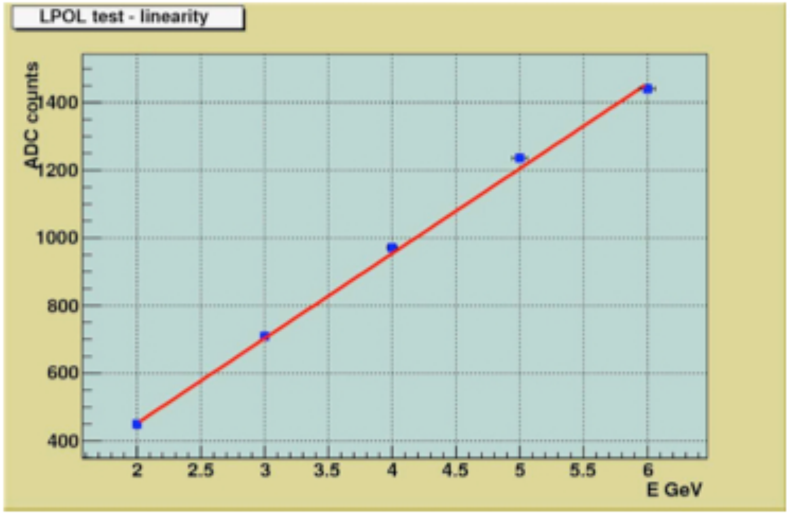
# LPOL cavity




- First Compton beam observation March 2005
- Signal with $n_\gamma \approx 0.1$ per bunch crossing
- Histograms are of one bunch and correspond to ~4 secs of data

# LPOL cavity






- Neither exisiting LPOL calorimeter suitable for cavity
  - New calorimeter necessary
- Tungsten quartz-fibre sampling calorimeter
- Similar design to H1 luminosity monitor
- Cerenkov signal from quartz fibres
- Short calibration in DESY test beam then installed in tunnel

# LPOL cavity status

- Cavity and calorimeter both installed in tunnel
- Calorimeter being commissioned
  - First signals seen
- Cavity has seen Compton signal
  - Commissioning of DAQ etc. ongoing
- Promised first polarisation measurement before the shutdown and routine operation afterwards
- Promised $\delta P/P=0.001$ and $\delta P/P=0.01$ /min/bunch
- Very fast measurement should aid HERA in tuning

# Bibliography


Polarisation

- http://www.desy.de/~mpybar

LPOL

- M. Beckmann et. al., NIM A479 (2002)

TPOL

- D. Barber et. al., NIM A329 (1993); A338 (1994)
- O. Ota, ZEUS 05-012

Cavity

- F. Zomer, Habilitation Thesis, Orsay, LAL 03-12



Thanks to Kunihiro and Uta for suggestions.