Imperial College London

Introduction to polarimetry at HERA

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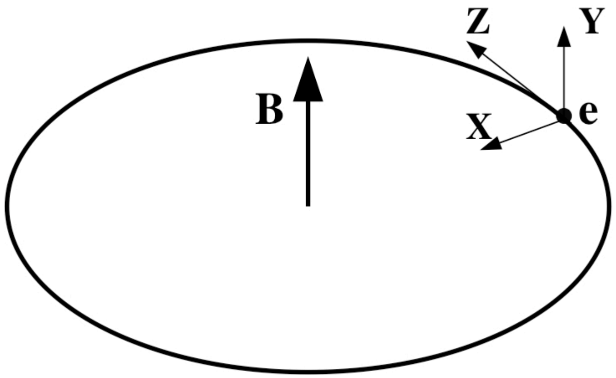
- Electron polarisation at HERA
- The LPOL
- The TPOL
- The LPOL cavity

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
- τ_{ST} highly energy dependent $\propto 1/E^5$
  - Use to measure beam energy cf. LEP
- P_{ST} and τ_{ST} calculable from first principles
  - Measurement of rise-time τ provides absolute P calibration

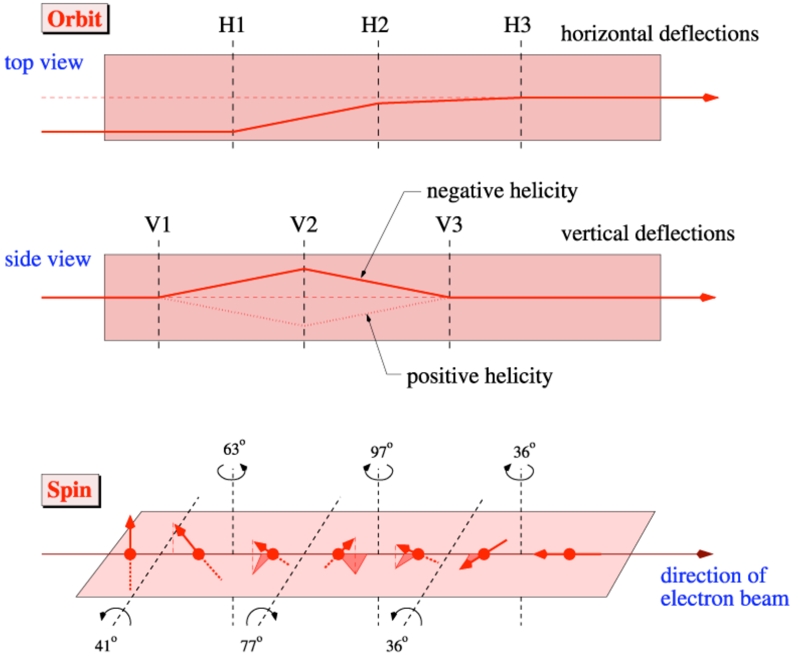
Depolarising effects

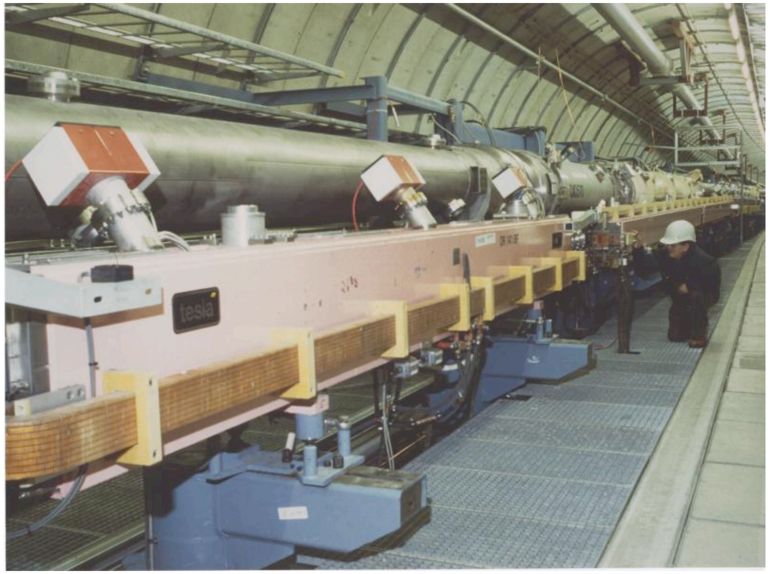
- Of course all the previous stuff assumes
  - a perfect planar storage ring (i.e. only perfectly vertical homogenous B field)
  - After photon emission the electron stays on the perfect orbit

- 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"

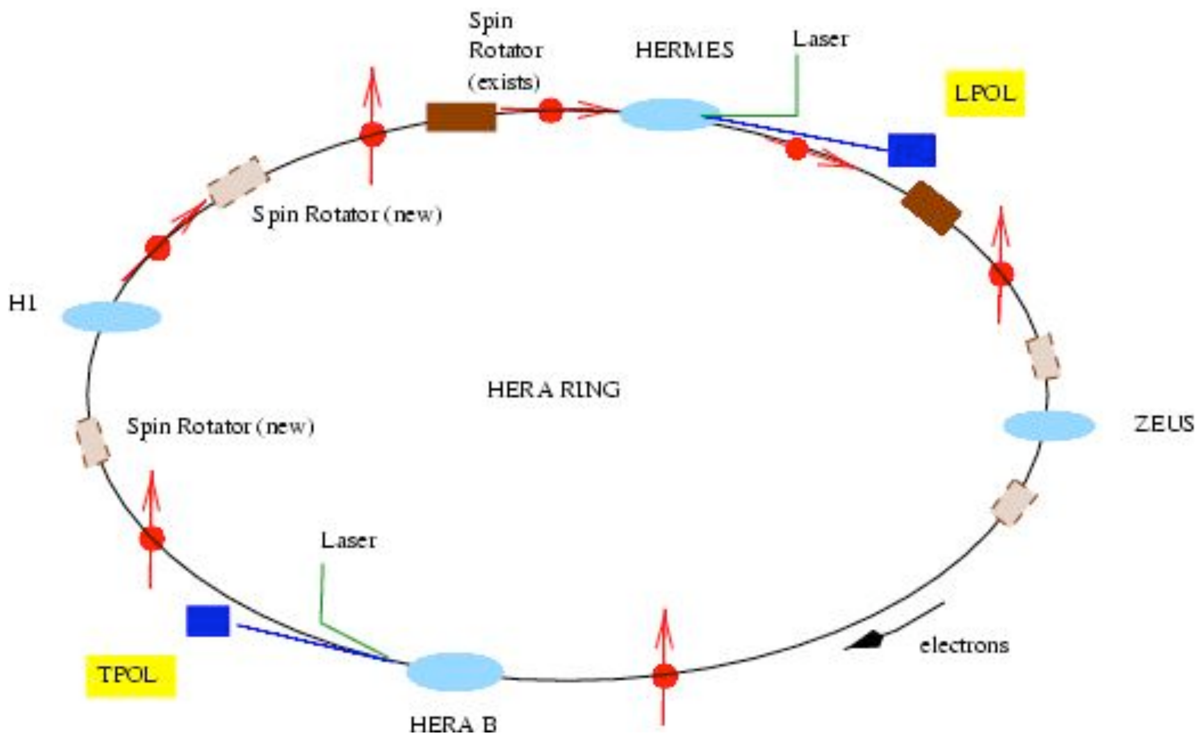
Spin rotators





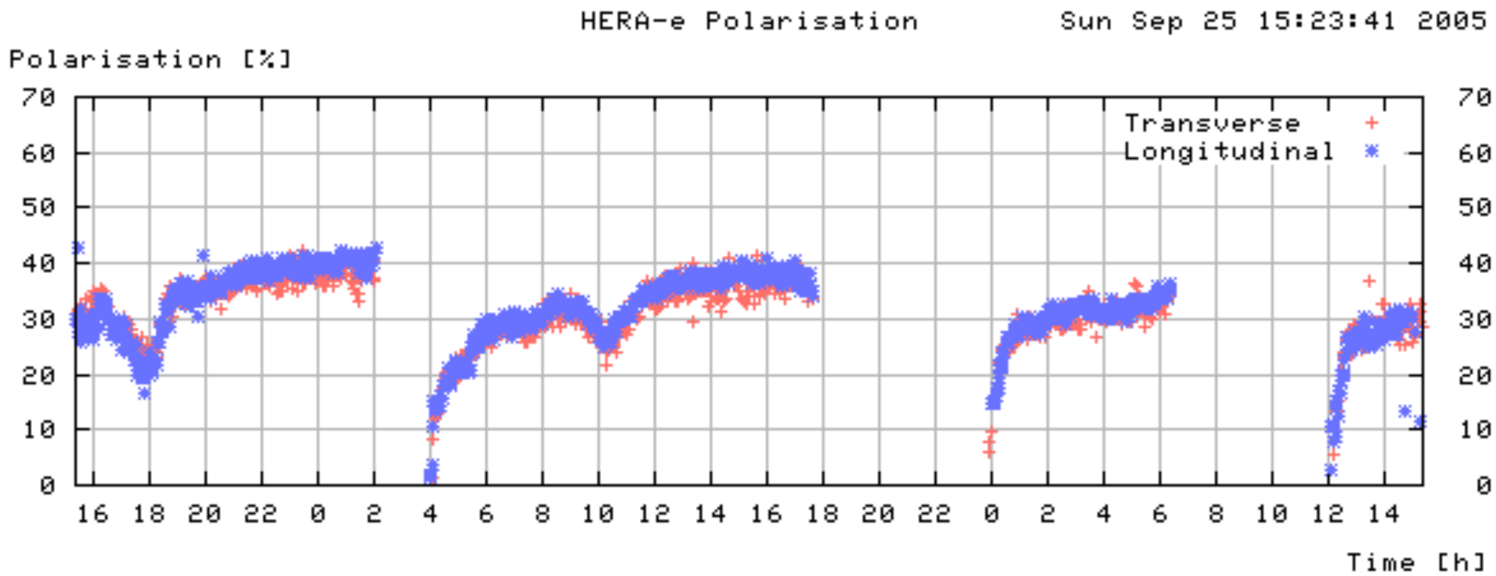
- Make use of spin precession ($\Delta\phi_{SPIN}=62.5\Delta\phi_{ORBIT} \rightarrow \Delta\phi_{ORBIT} \sim$mrad)
- Use series of transverse magnetic fields to change P_Y into P_Z
- Move section vertically during access days to change helicity
- So called "mini-rotator" only 56m long!

Polarisation at HERA



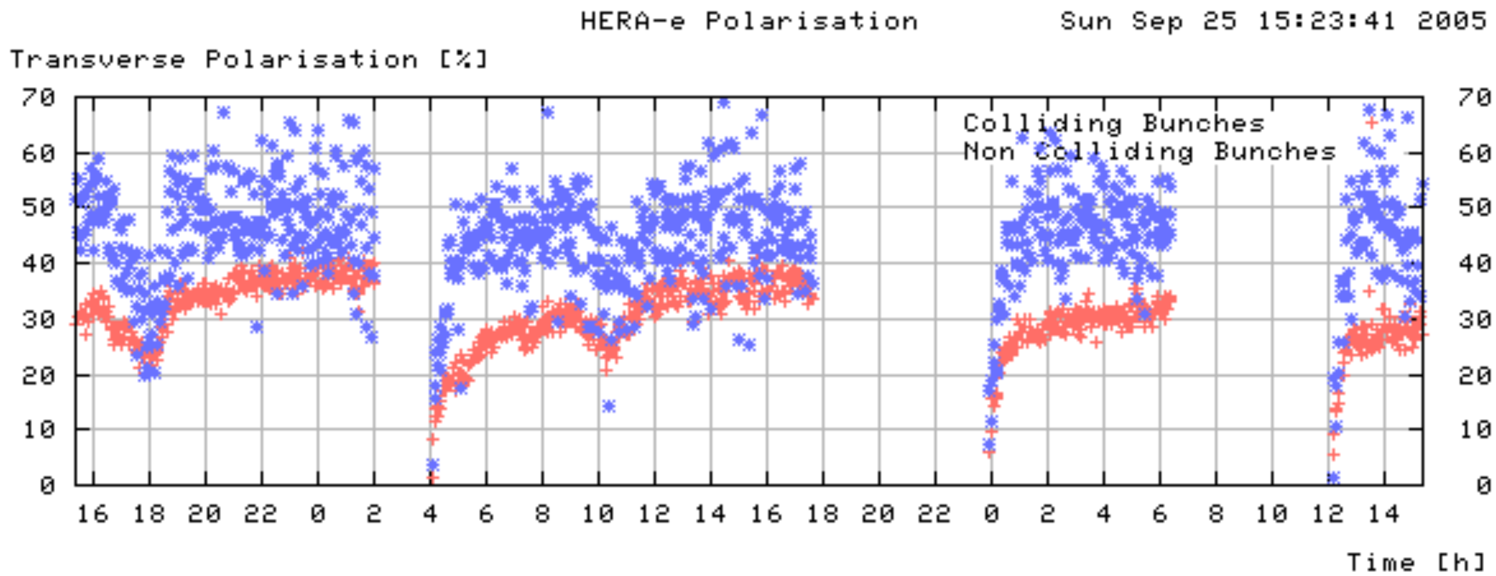
- Spin rotators around H1, HERMES and ZEUS
- Two independent polarimeters
  - Longitudinal polarimeter (LPOL) near HERMES
  - Transverse polarimeter (TPOL) near HERA-B hall

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

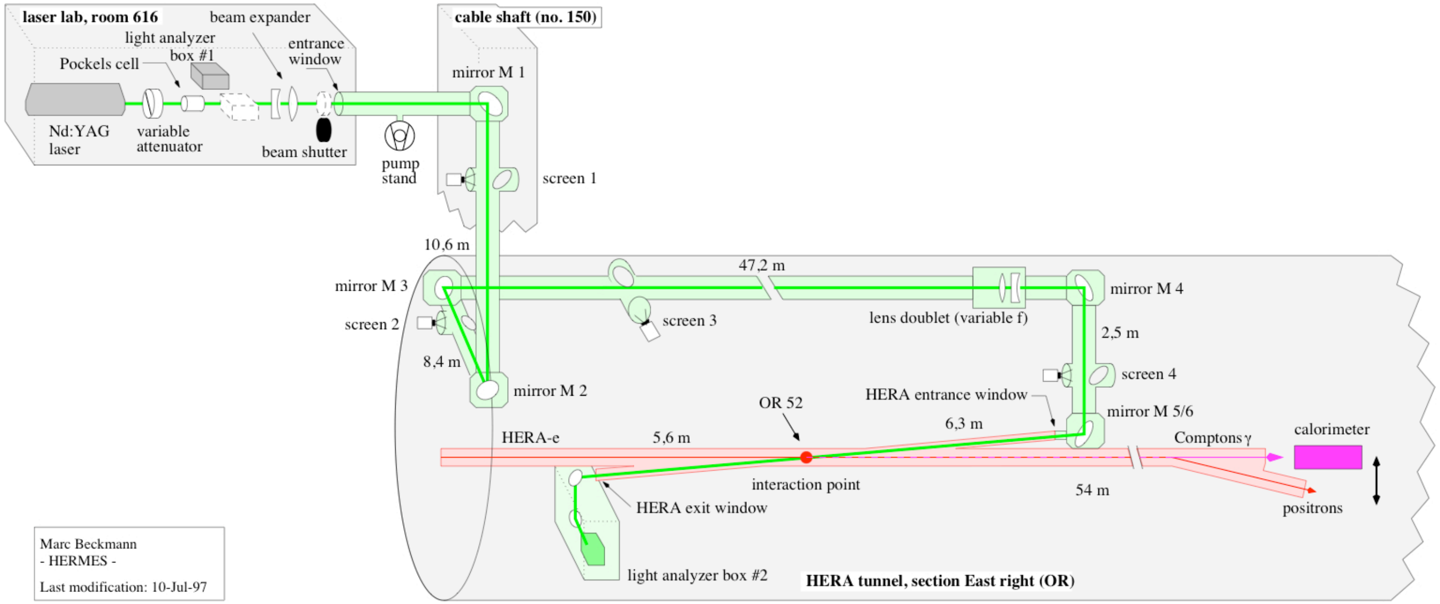
Compton scattering

- Spin-dependent cross section for γ-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

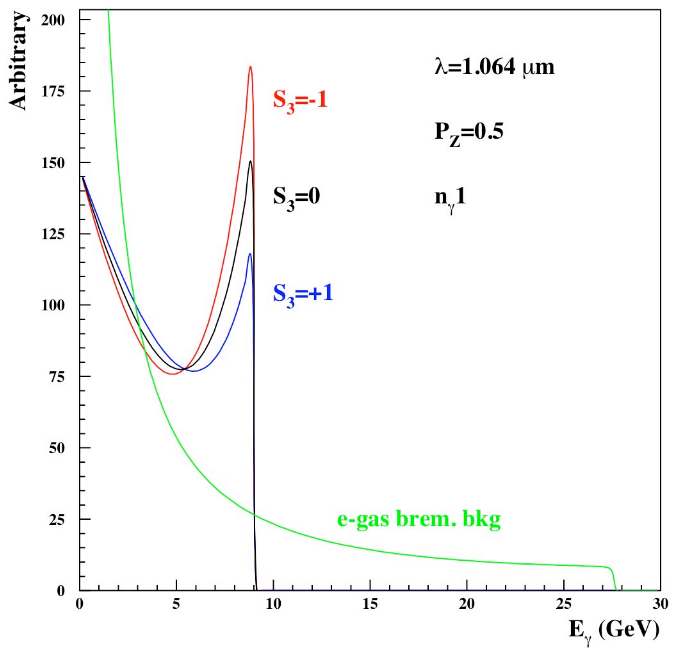
LPOL



- 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

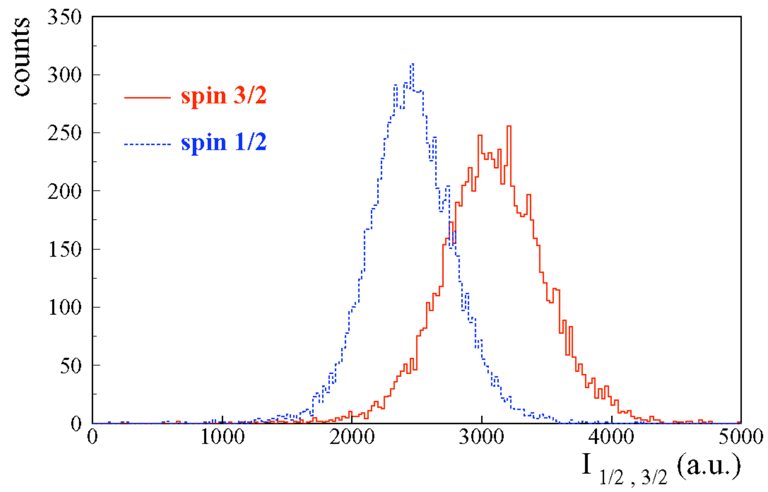
LPOL single-photon mode

- $n_\gamma \approx 0.001$ per bunch crossing
- Can use single-photon cross section. Calculate σ 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

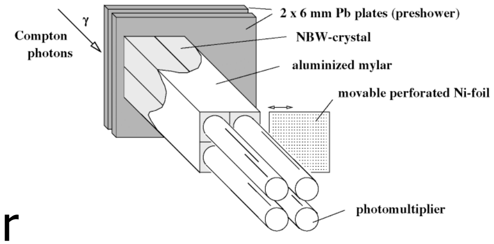


LPOL

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

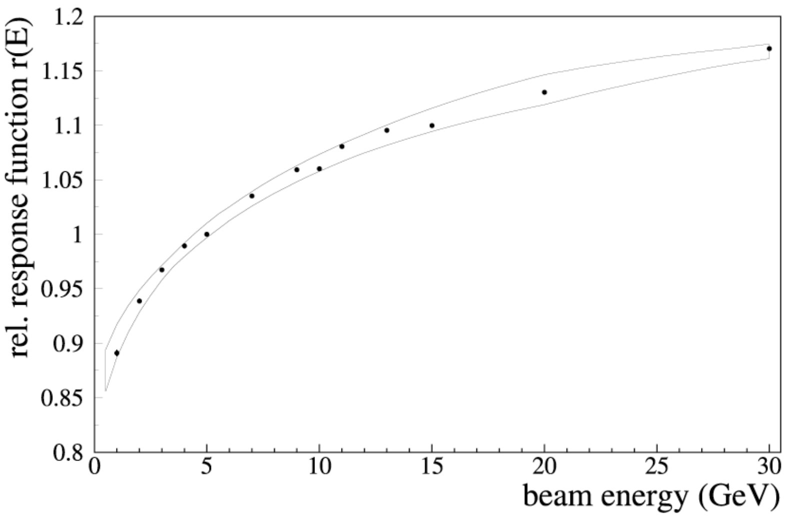
  $A_m = (I_{3/2}-I_{1/2})/(I_{3/2}+I_{1/2}) = P_c P_e A_p$

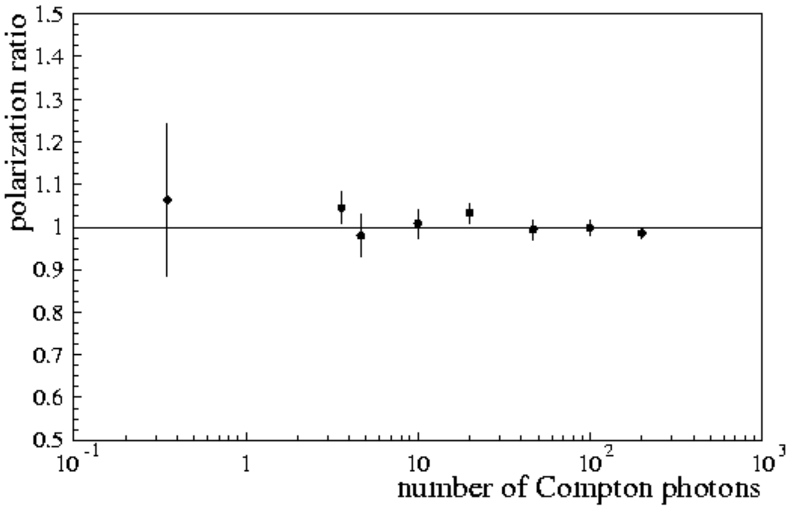
  $A_p=(\Sigma_{3/2}- \Sigma_{1/2})/(\Sigma_{3/2}+ \Sigma_{1/2}) = 0.184$ if detector is linear



- Get A_p from test-beam response

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





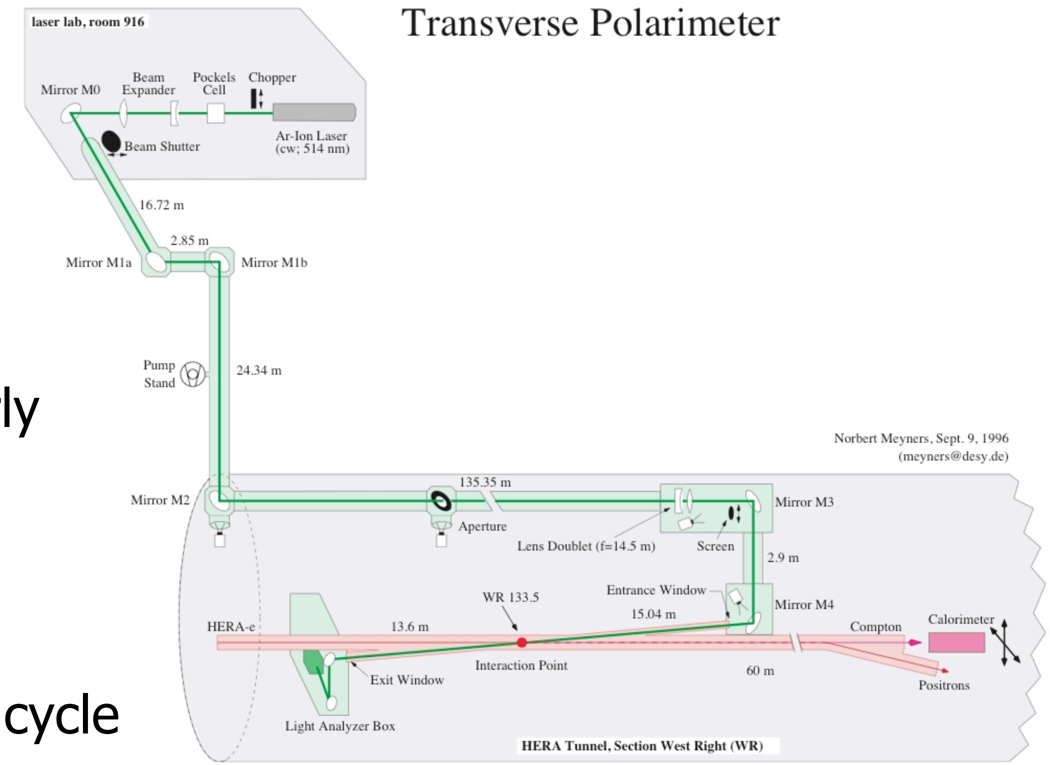
LPOL

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

Systematic source	$\delta P/P$ (%)
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



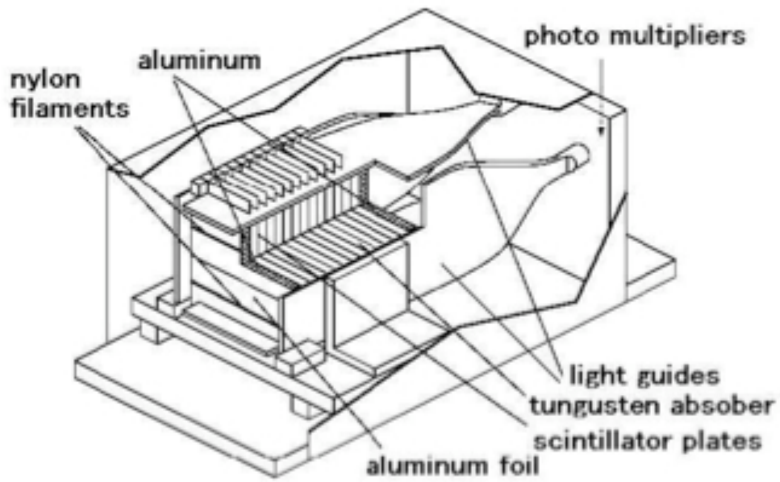
- Laser power and polarisation monitored in tunnel and ctrl room
- DAQ rate 100 kHz

TPOL

- Have to measure E_γ 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….

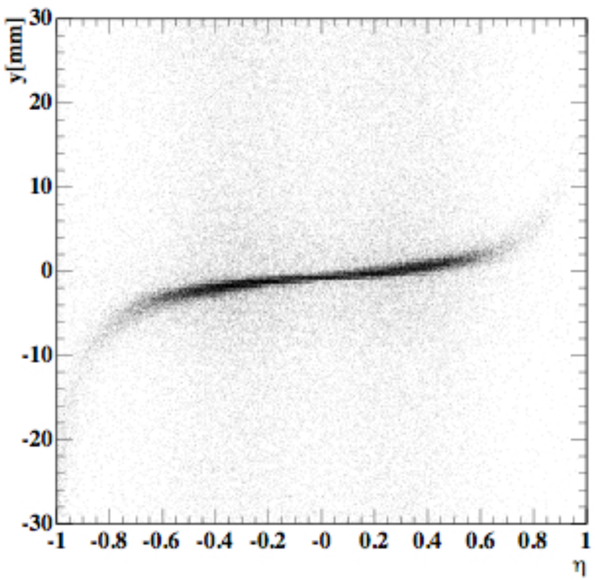
…but have to transform to y

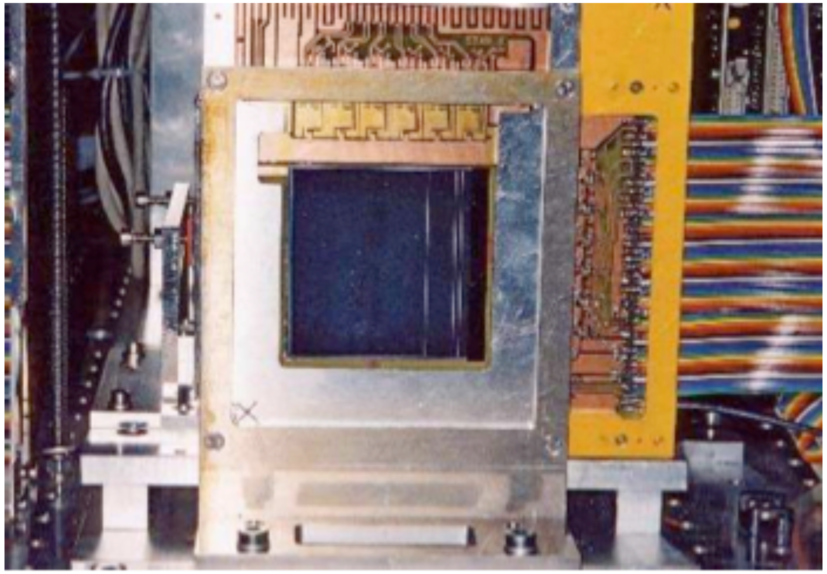
- Known only from test-beam
- Depends on transverse shower shape in calorimeter
- Main uncertainty η-y transformation



TPOL - silicon detector

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

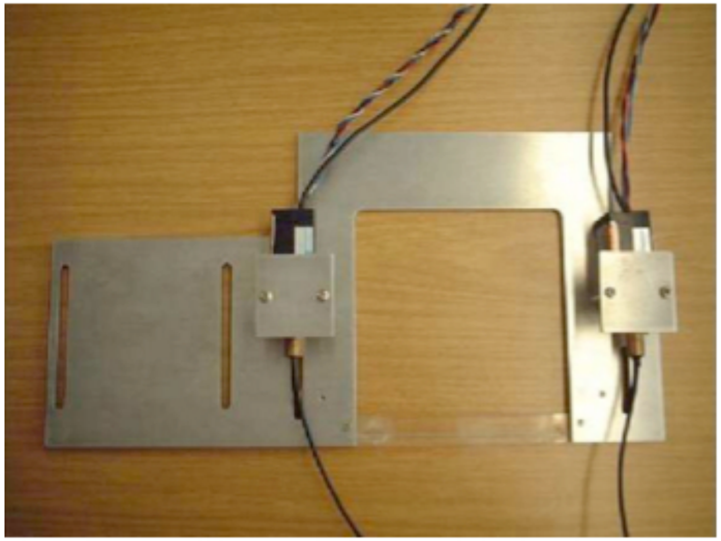




- 6cm x 6cm silicon sensors
- Two planes: x and y
- Pitch 80(240) μm in y(x)
- Readout < 1 kHz - much slower than CAL
- No fast online measurement

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



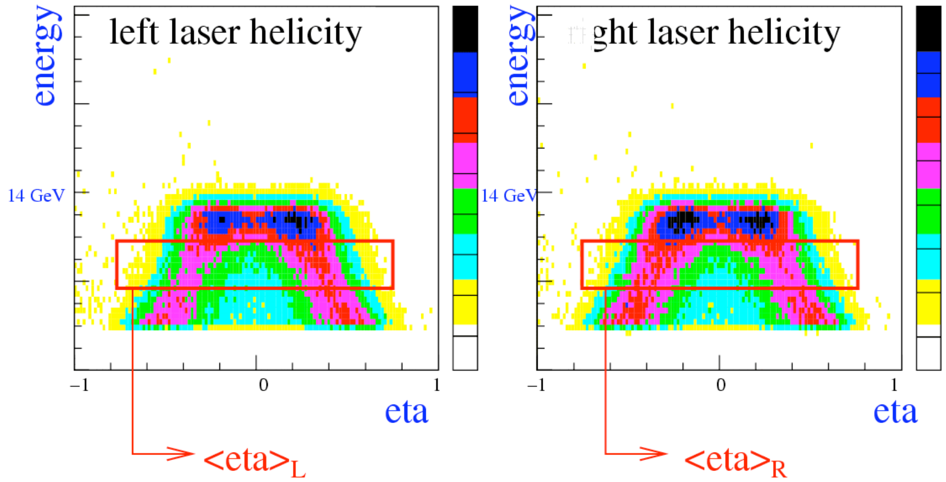
- Installed scintillating fibre detector upstream of silicon
- Can be scanned vertically over the face of the silicon detector using a stepping motor
- Periodic scans can monitor the silicon response at different y coordinates
- If necessary avoid bias by correcting silicon response

TPOL online analysis

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

- Consider asymmetry between laser beam helicities

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



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

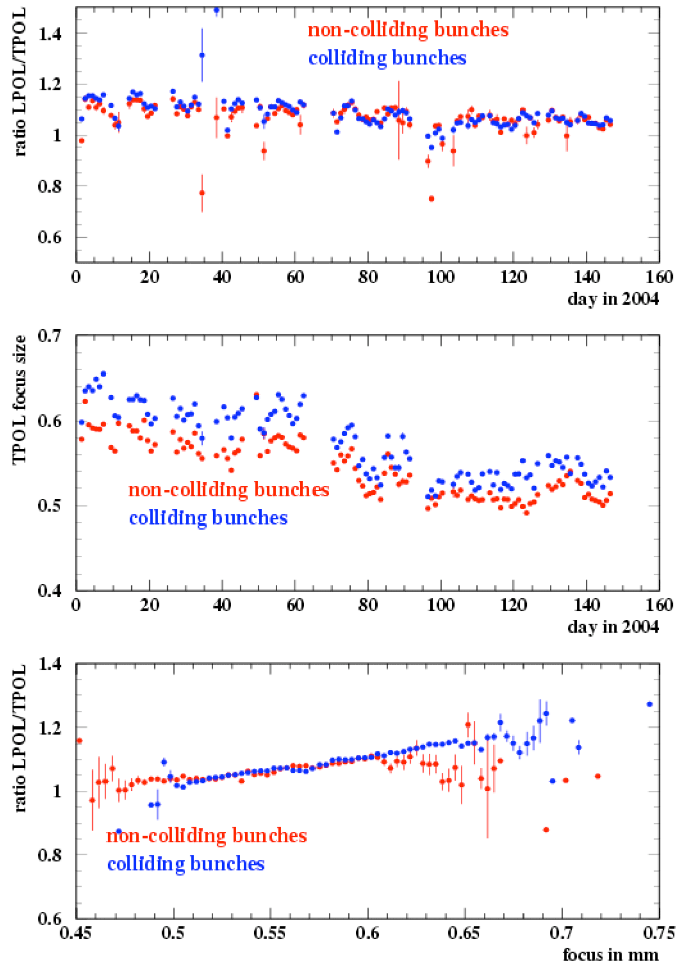
- Fast and simple method using only CAL
- This is what you see on TPOL monitor in the control room and actually what we've used in physics analyses so far

TPOL online analysis

Implicitly assumes that the following are constant:

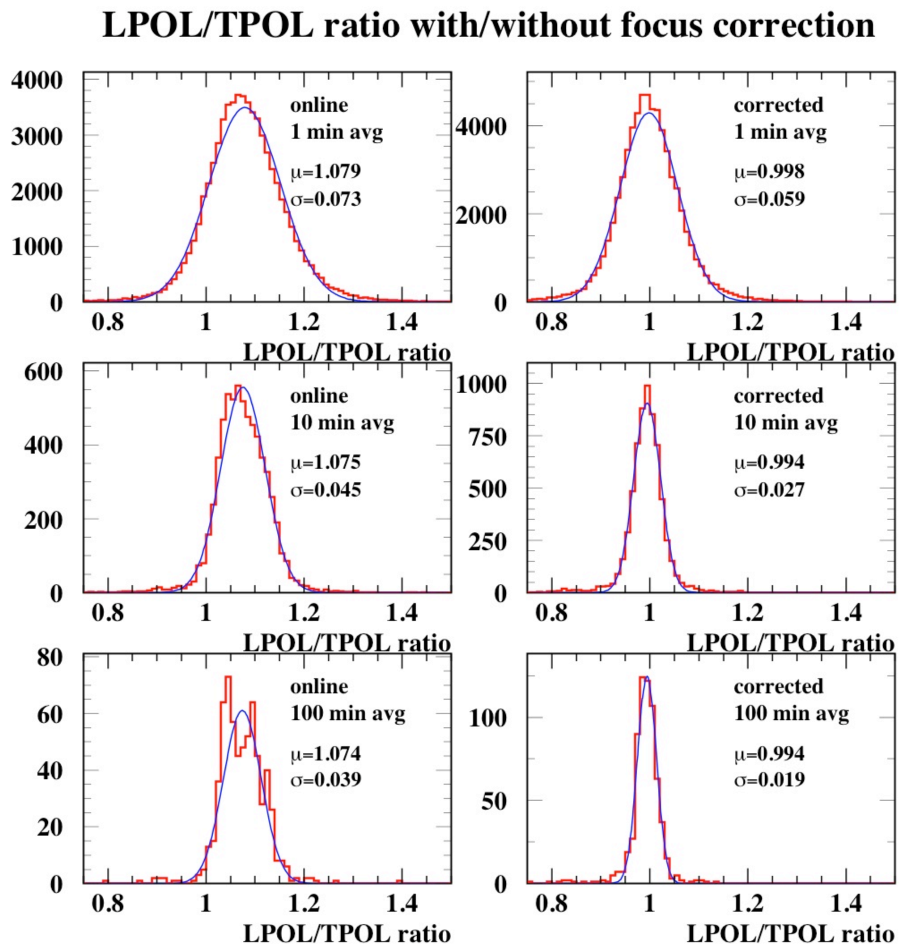
- Vertical size of lepton beam at the IP
- Position of the Compton beam on the CAL
- Vertical size of the Compton beam at the CAL (focus)
- Energy resolution of the CAL
- η-y transformation
- Linear component of laser light S_1

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 →

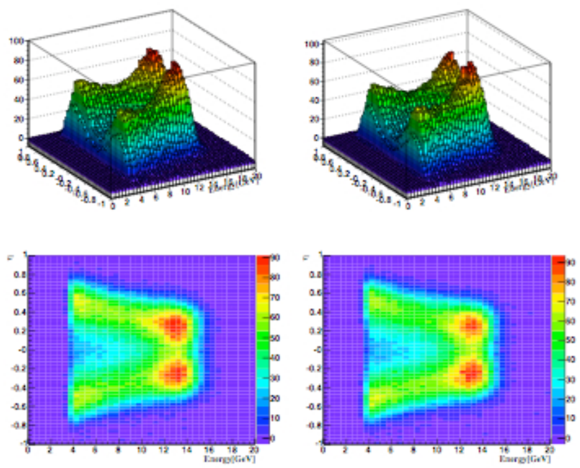


TPOL offline analysis

- 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
  - η-y transformation

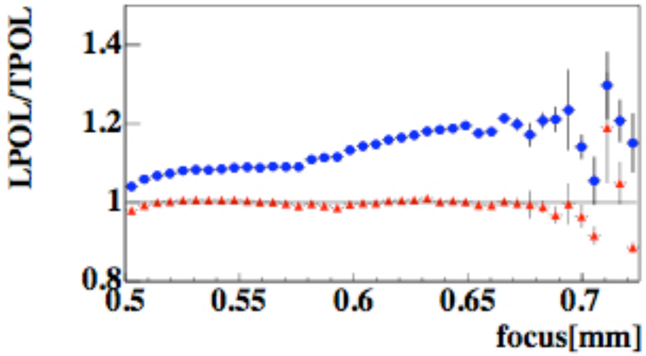


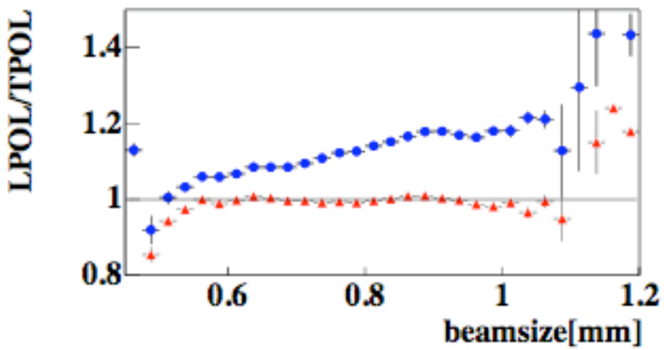
TPOL offline analysis

- 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

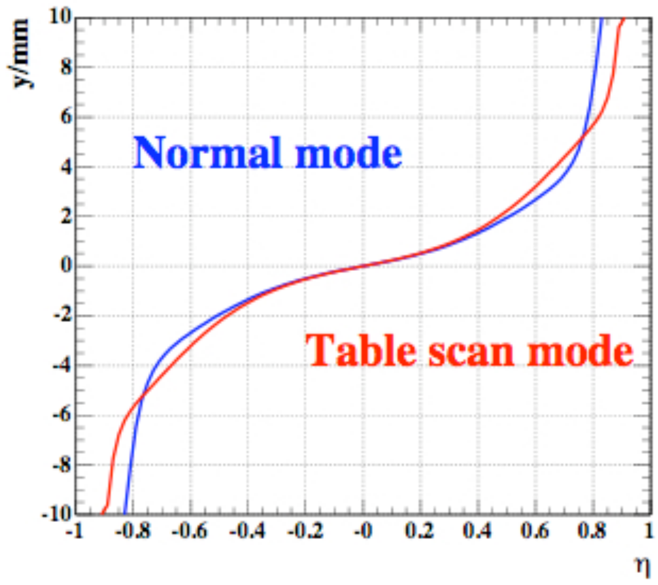
- Good fit to all the data
- χ/ndf = 1.2
- Consistent with LPOL
- Robust to changes in beam size and focus





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

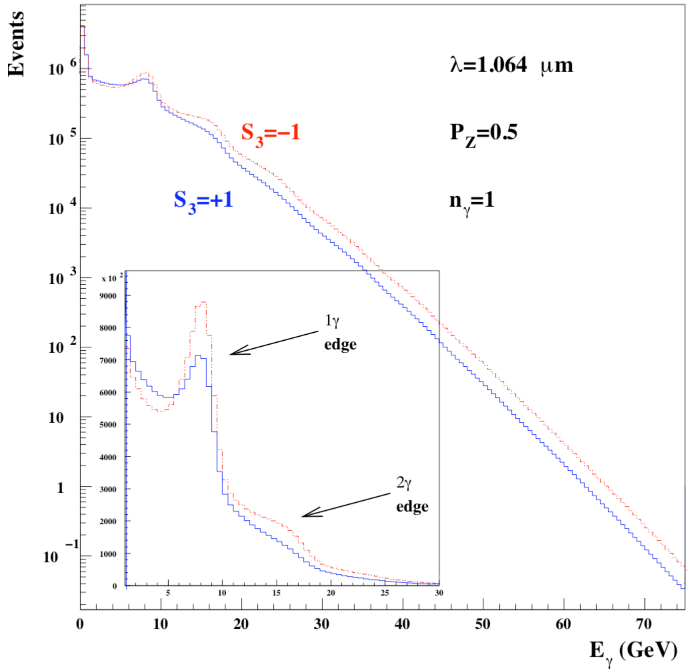
LPOL cavity

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

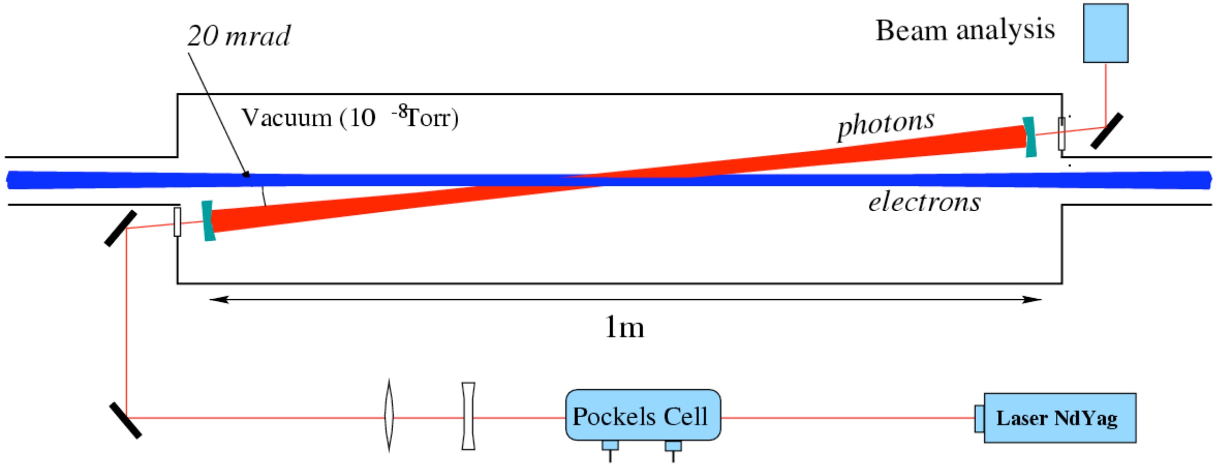
- ✓ Can still use single-photon cross section
- ✓ Compton edge energy calibration
- ✓ Good systematic precision
- ✓ Enough statistics to overcome the background

- ✗ Need a 10kW cw laser!

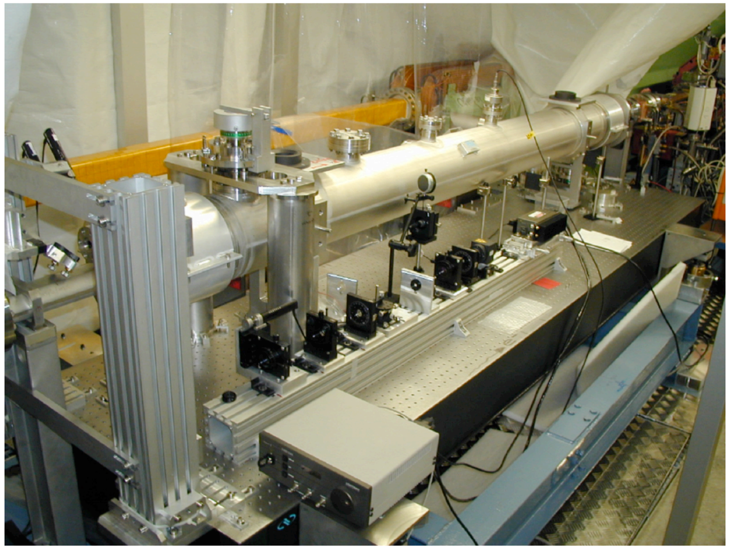
- ✓ Use a 1W cw laser and a Fabry-Perot cavity with $Q \approx 10000$



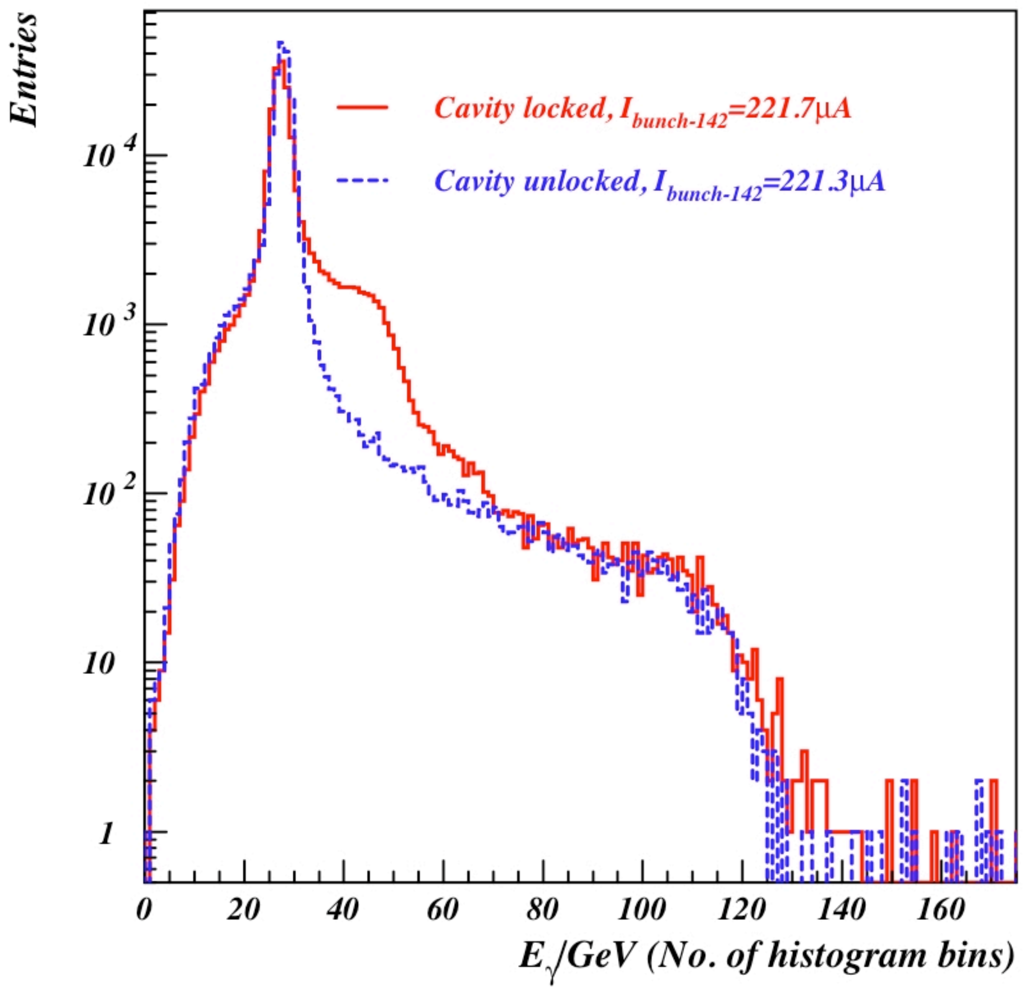
LPOL cavity



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

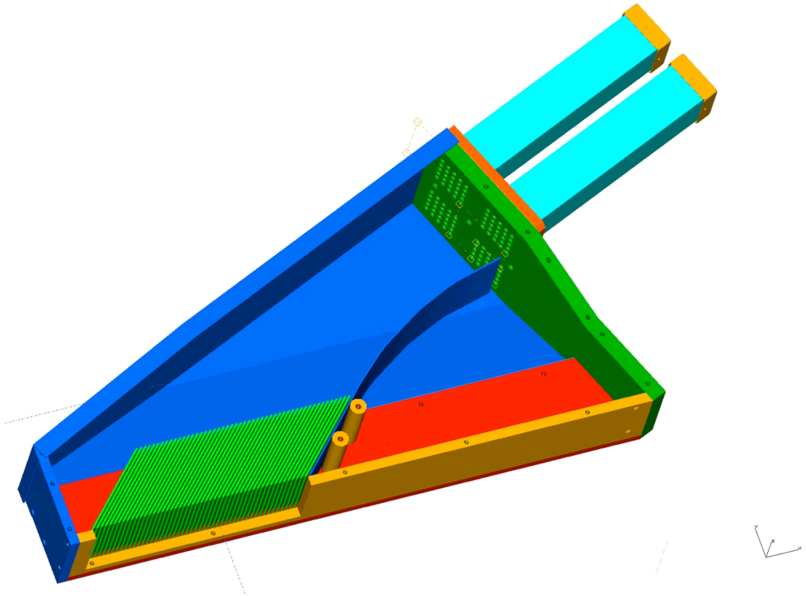


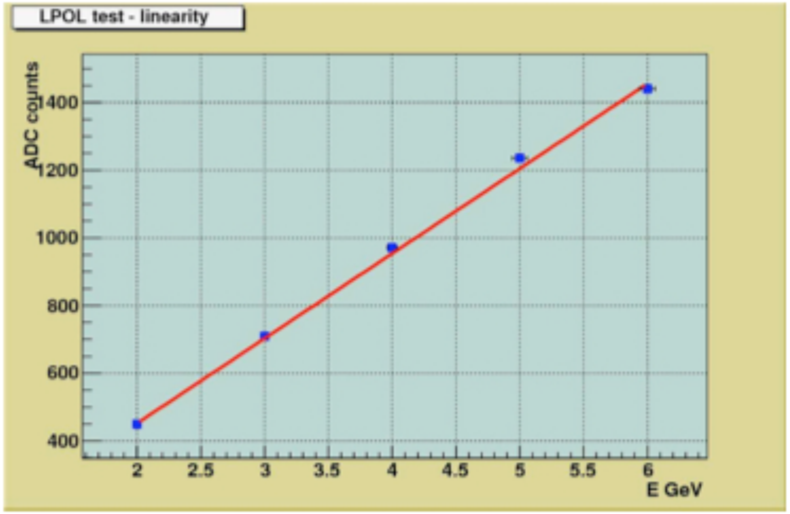
LPOL cavity



- 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.