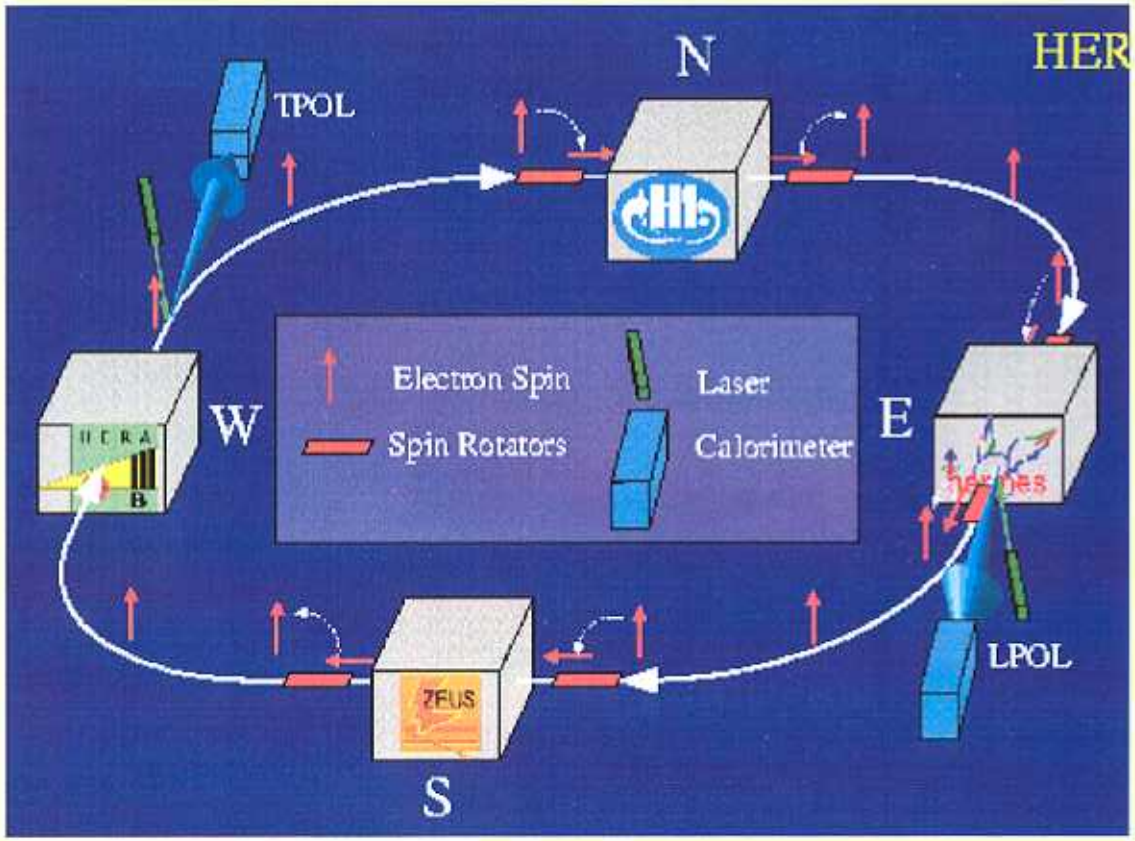
HERA Transverse Polarimeter

- **Polarized e± at HERA**
- **Physics Motivation**
- **Compton Polarimetry**
  - General Features
  - Transverse Polarimetry: this talk
  - Longitudinal Polarimetry: next talk
- **HERA Transverse Polarimeter**
  - basic layout
  - performance
  - recent upgrades & plans

Polarized e± at HERA

HERA I : (→ 2000)

- **HERMES:** longitudinally polarized e± beam (27.5 GeV), polarized gas targets
- **H1 & ZEUS:** transversely polarized ("unpolarized") e±, colliding with unpolarized proton beam (920 GeV)



HERA II: (2002 → 2005)

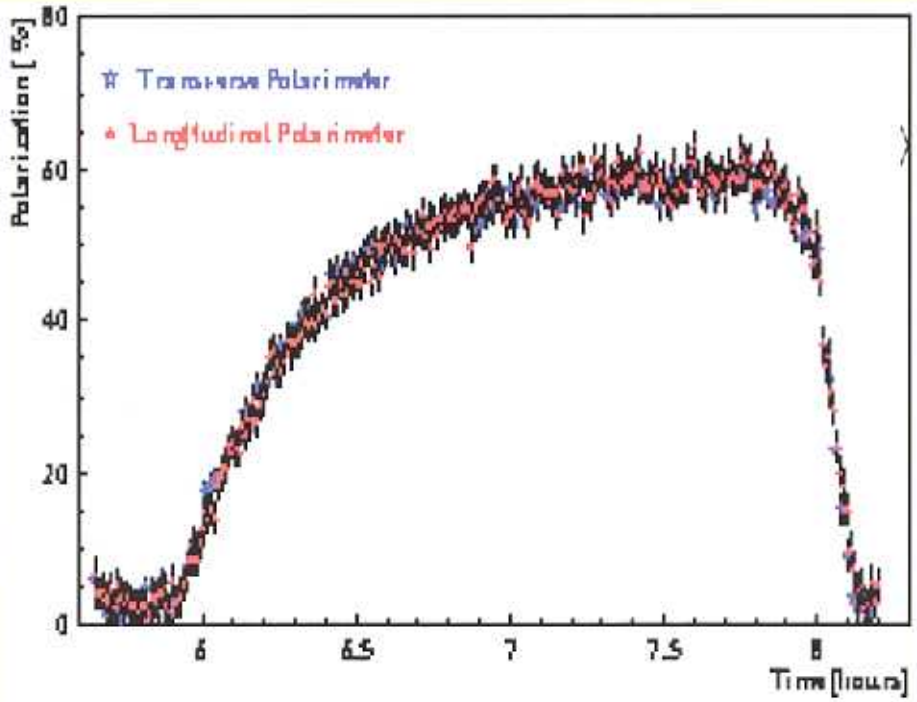
- **HERMES cont'd**
- **H1 & ZEUS :** long. pol. e±, unpol. proton beam

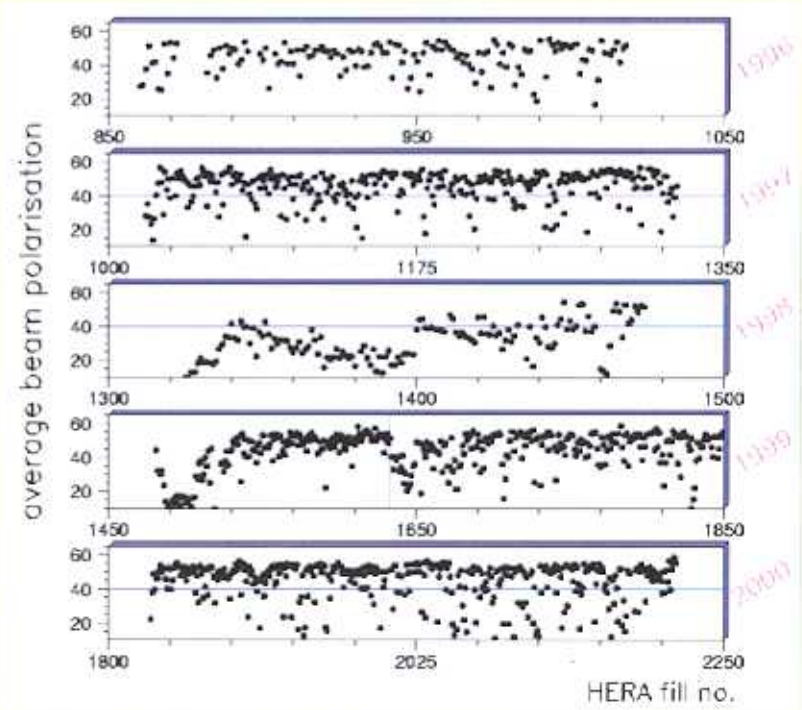
Polarized e± at HERA

- **Self-Polarization by Emission of Synchroton Radiation: Socholov-Ternov Effect ($\tau \sim 30$ min.)**
- **Longitudinal Polarization with Buon-Steffens Type Spin-Rotators at Experiments**

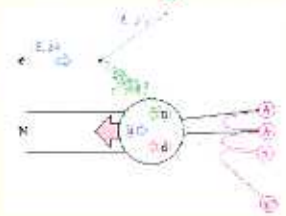
$$P(t) = P^{\infty}\left[1 - \exp\left(t/\tau\right)\right]$$

$$\left\langle P \right\rangle_{average} \approx 55\%$$

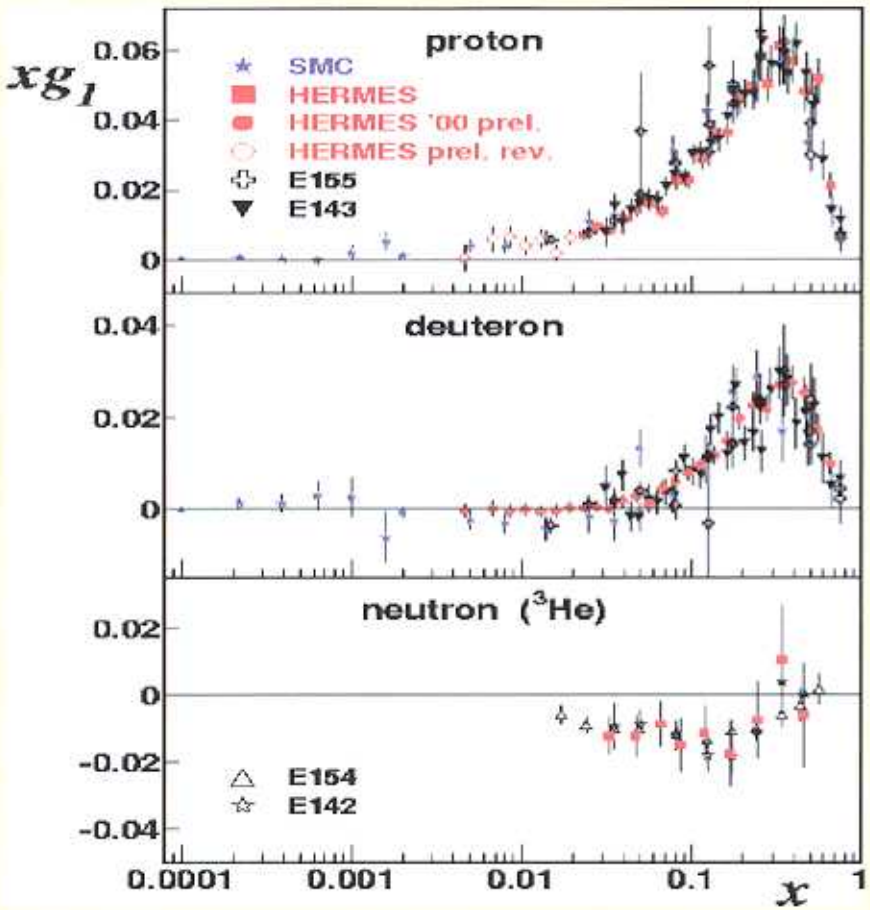


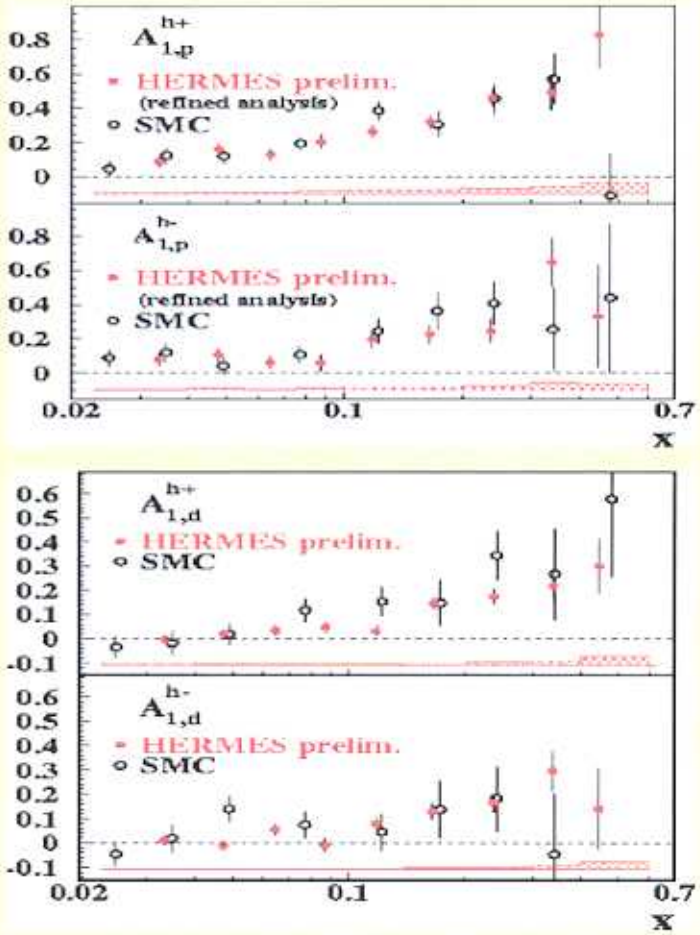


Physics Motivation: HERMES



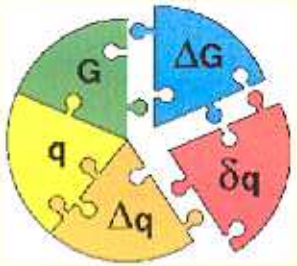
Inclusive & Semi-Inclusive
Spin-Dependent DIS Data





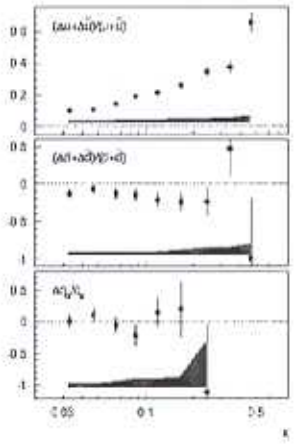
Physics Motivation: HERMES

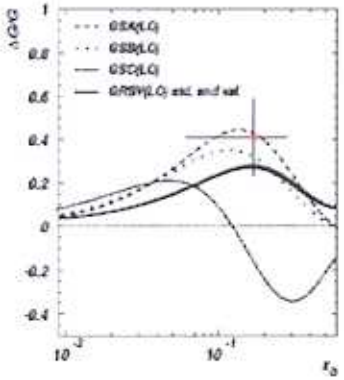
Spin Structure of the Nucleon: Δu, Δd, ..., ΔG, ...

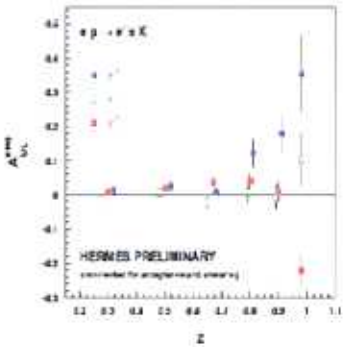


$$\frac{1}{2} = \frac{1}{2}\underbrace{(\Delta u + \Delta d + \Delta s)}_{\downarrow} + \underbrace{\Delta G}_{\downarrow} + \underbrace{L_q + L_g}_{\downarrow\ ?}$$

inclusive: g_p^1, $g_n^1 \rightarrow \Delta\Sigma$	PGF	exclusive: π, γ
semi-incl.: flavor separation	high-p_t hadron pairs	Production
	Open Charm	



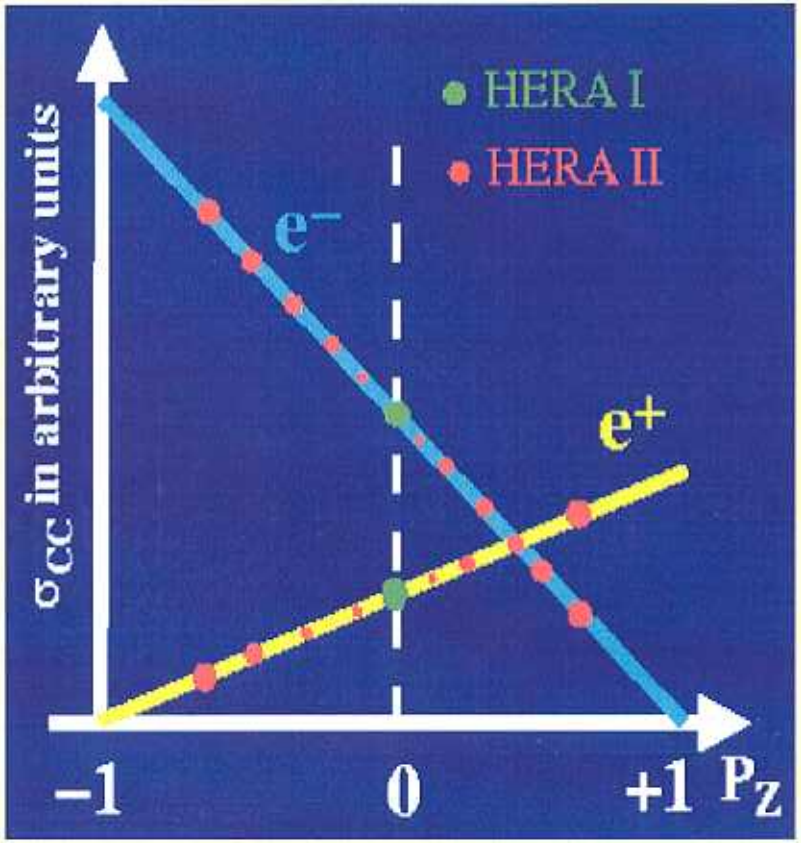




recent and new topics: DVCS, transversity, ...

Physics Motivation: H1 & ZEUS

Charged & Neutral Current Cross-Sections:
depend strongly on e± polarization



$$\sigma_{CC}^{e^+P} = (1+\mathcal{P})\,\frac{G_\mu^2}{2\pi}\left(\frac{M_W^2}{Q^2+M_W^2}\right)^2\left(\bar{u}+\bar{c}+(1-y)^2(d+s+b)\right)$$

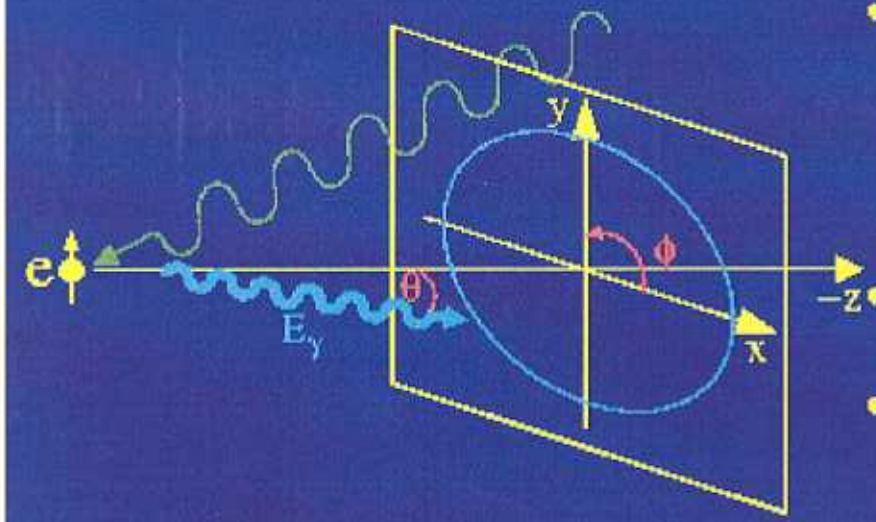
$$\sigma_{CC}^{e^-P} = (1-P)\,\frac{G_\mu^2}{2\pi}\left(\frac{M_W^2}{Q^2+M_W^2}\right)^2\left(u+c+(1-y)^2(\bar{d}+\bar{s}+\bar{b})\right)$$

precise knowledge of polarization:
as important as
luminosity & detector response
in order to

- **test SM cross-section**
- **extrapolate to $P = \pm 1$**
- **search for right-handed CC**

$\Rightarrow$ need $\Delta P/P < 1\%$

Compton Polarimetry



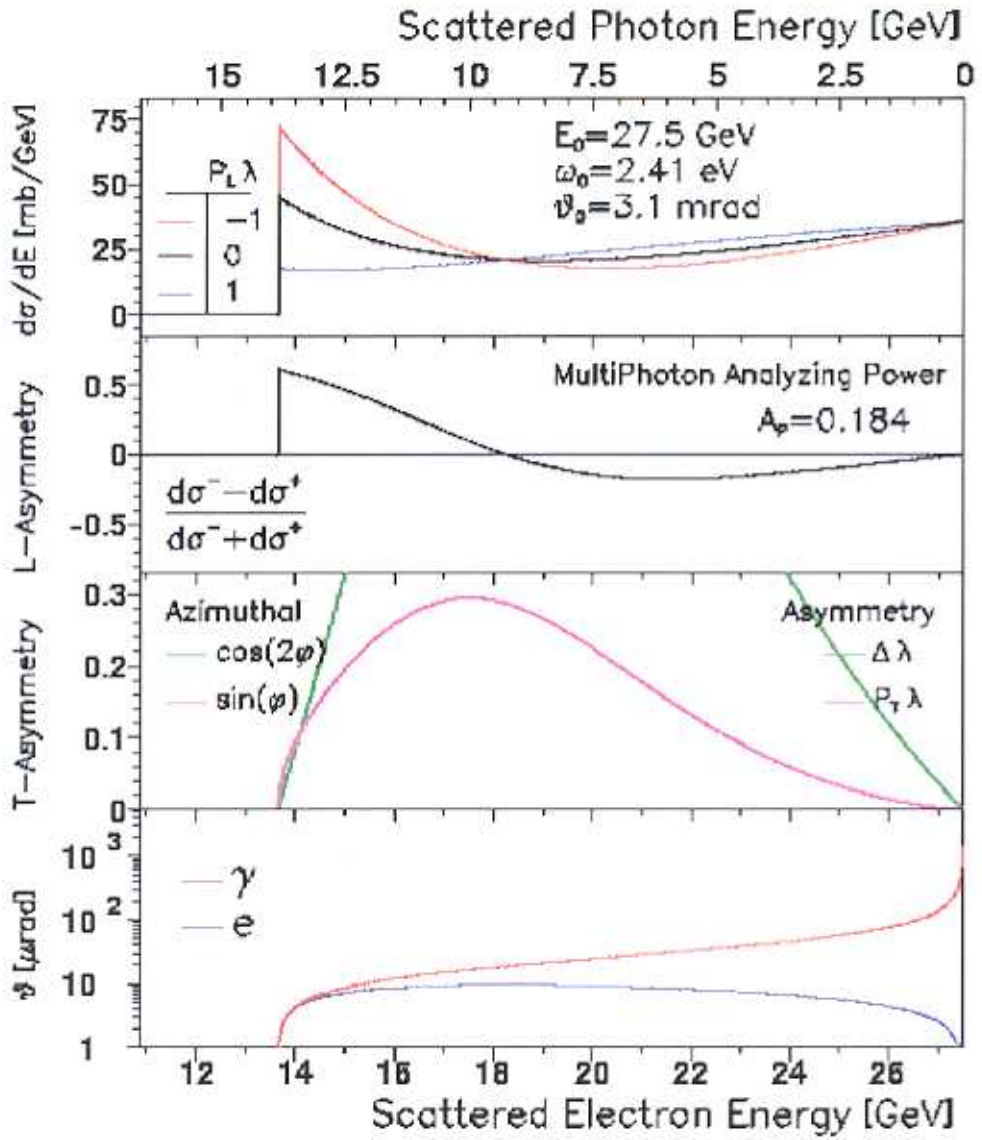
- Kinematics described by 2 variables:
  - polar angle θ <=> E_γ (photon energy)
  - azimutal angle ϕ => y (vert. coordinate)
- S1, S3: lin. & circ. laser polarisation
- P_Y,P_Z: transv. & long. e polarisation

$$\frac{d^2\sigma}{dE\,d\phi} = \Sigma_0(E) + S_1\,\Sigma_1(E)\cos 2\phi + S_3\,(P_Y\Sigma_{2Y}(E)\sin\phi + P_Z\Sigma_{2Z}(E))$$

- LPOL: needs only energy dependence
- TPOL: needs energy and y, i.e. full 2D cross section

Important: use asymmetry between $S_3 = +1$ and $S_3 = -1$

Compton Polarimetry



$$x = \frac{4E_0\omega_0}{m^2}\cos^2(\theta_0/2) \simeq \frac{4E_0\omega_0}{m^2}$$

$E_0 = 27.5\,GeV$

$\omega_0 = 2.41\,eV$ $\qquad x = 1.015$

$\theta_0 = 3.1\,mrad$

$$\omega + E = \omega_0 + E_0 \simeq E_0$$

$$\omega_{max} = E_0\frac{x}{1+x} = 13.854\,GeV$$

$$E_{min} = E_0\frac{1}{1+x} = 13.646\,GeV$$

$$\theta_\gamma = \frac{m}{E_0}\sqrt{\frac{x}{y} - (x+1)}$$

$$\theta_e = \frac{y}{1-y}\theta_\gamma$$

$$y = 1 - \frac{E}{E_0} = \frac{\omega}{E_0}$$

HERA Compton Polarimeters

Operating Modes and Principles

Laser Compton scattering off HERA electrons

TPOL

CW Laser - Single Photon

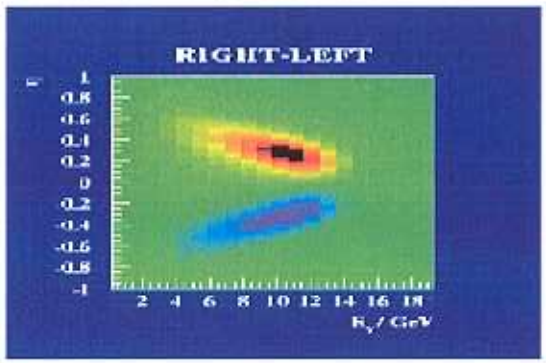
LPOL

Pulsing Laser - Multiphoton

Flip laser helicity and measure scattered photons

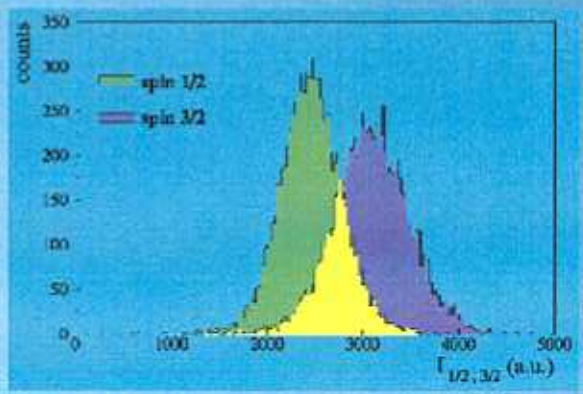
P_y =0.59

Spatial Asymmetry



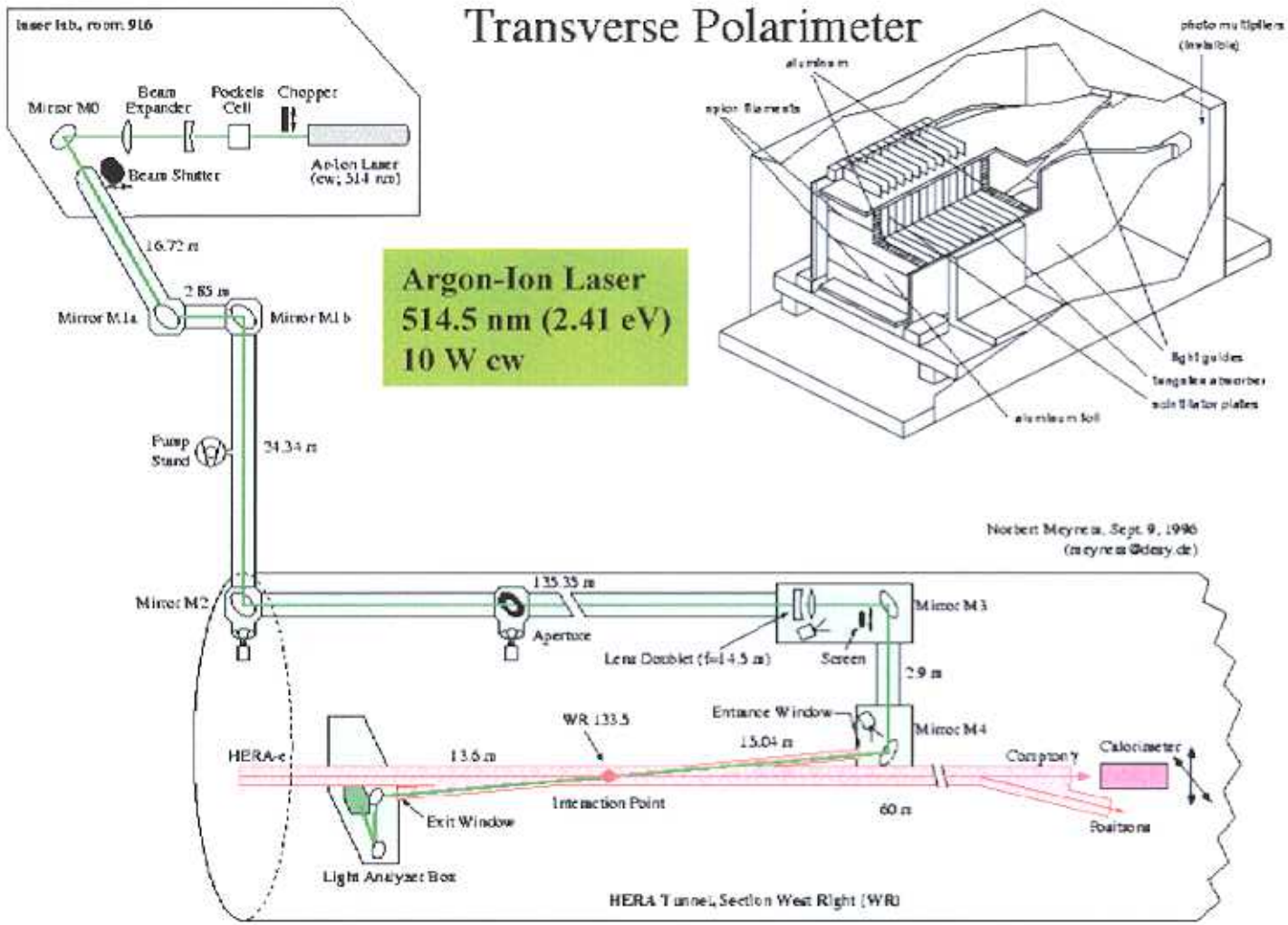
P_z =0.59

Helicity Dependent γ Spectra

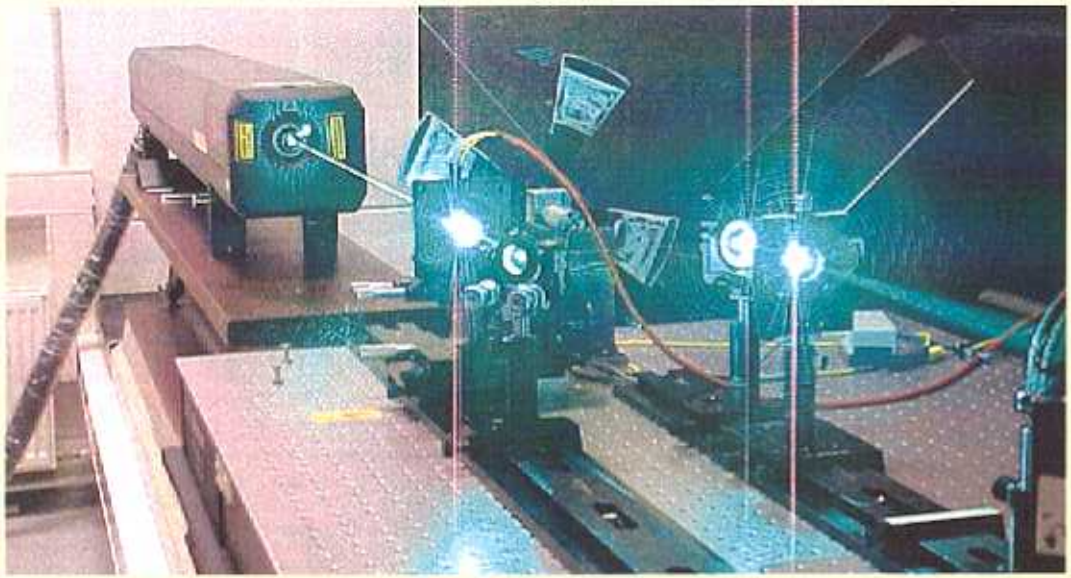


Statistical Error ΔP=1% per minute @ HERA average currents

TPOL: Experimental Layout

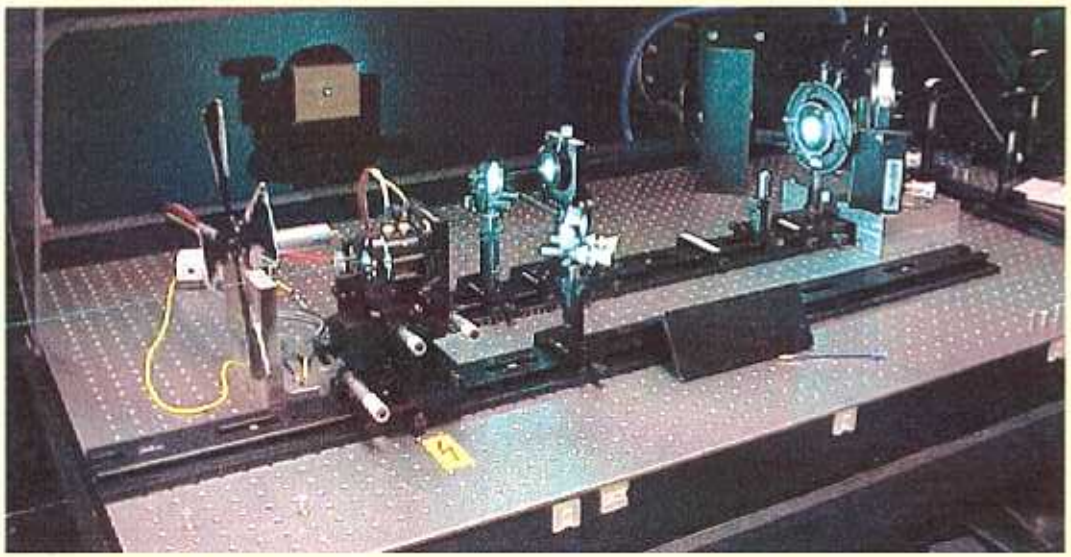


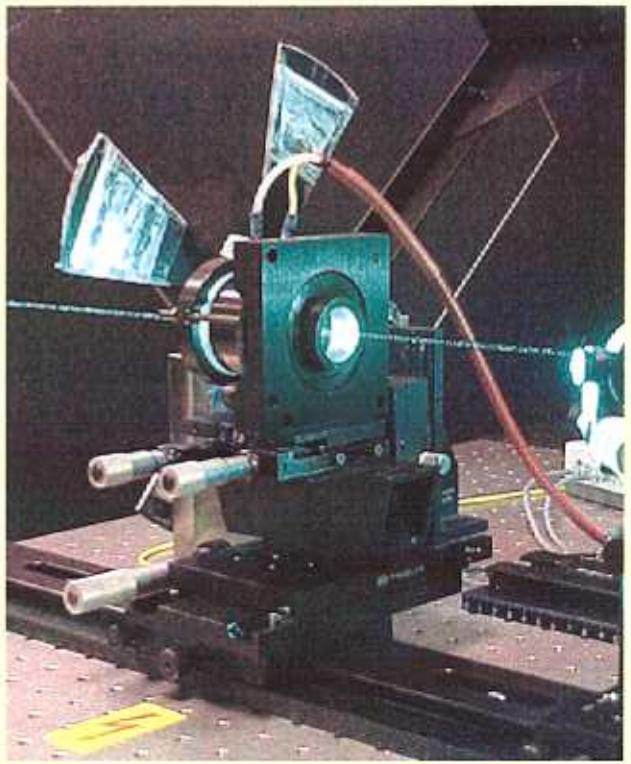
Laser Optics



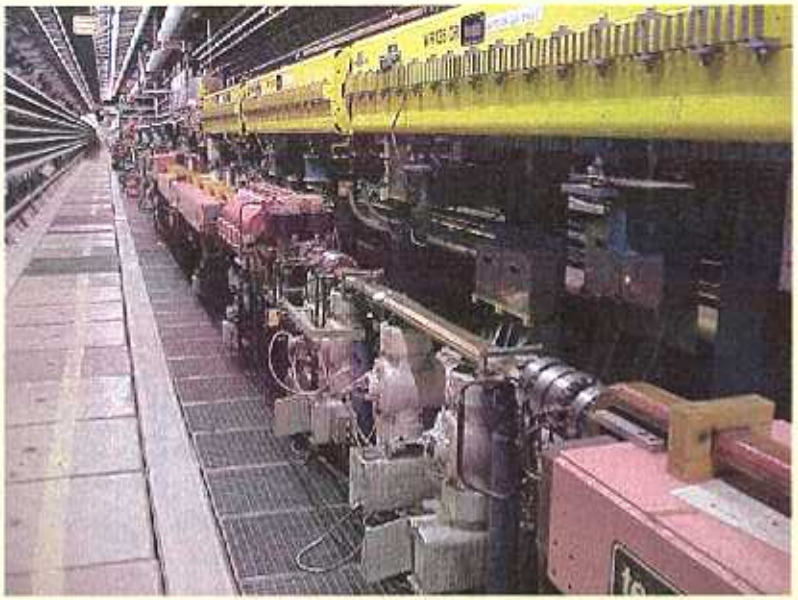
Argon-Ion Laser
514.5 nm (2.41 eV) 10 W cw

optics table with beam chopper,
Pockels cell & beam expander



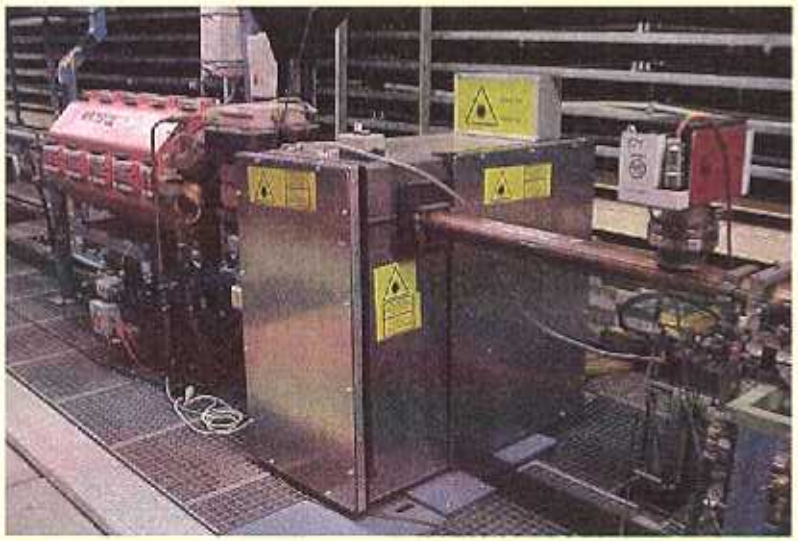


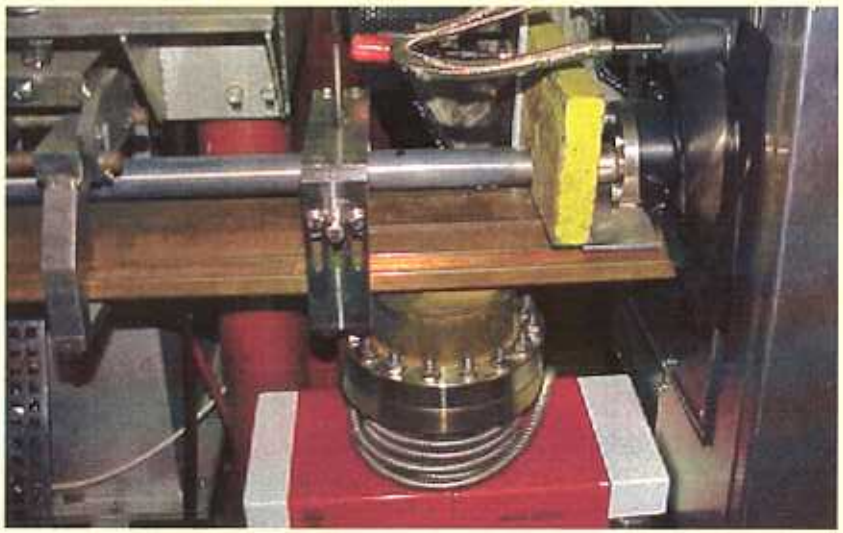
HERA Tunnel



laser and e± beam crossing
at 3.1 mrad

laser analyzer box

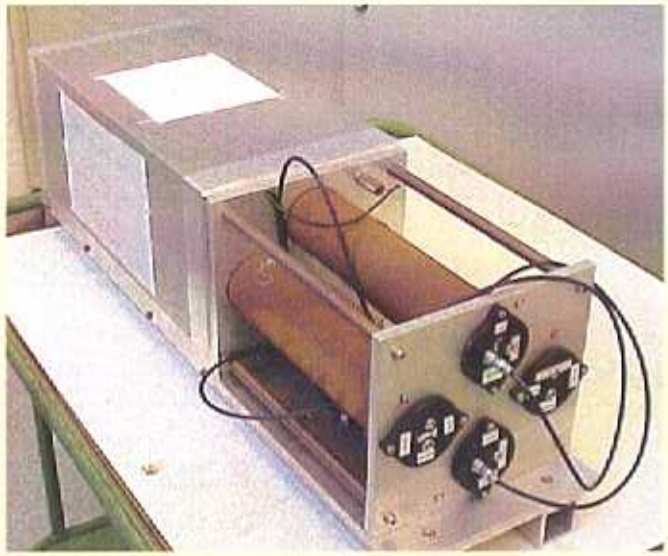




HERA Tunnel

Compton Gamma Beamline
and
Detector House

Calorimeter Photon Detector

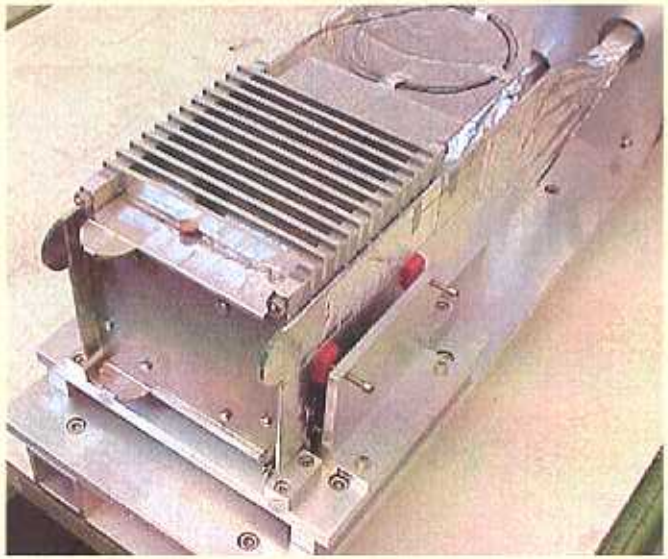


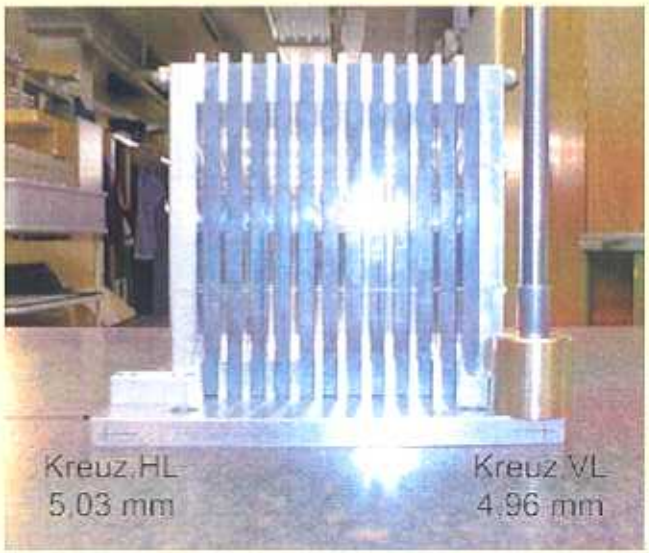
Tungsten-Scintillator Sandwich (12 layers)

Absorber: 12 x 6.22 mm
Densimet-17 (90.5% W, 6.5% Ni, 3% Fe/Cu)
19.6 rad. Lengths, Moliere radius: 1 cm

Scintillator plates: 12 x 2.6 mm (SCSN-38)
120 mm x (2 x 50 mm)
optically isolated upper & lower half

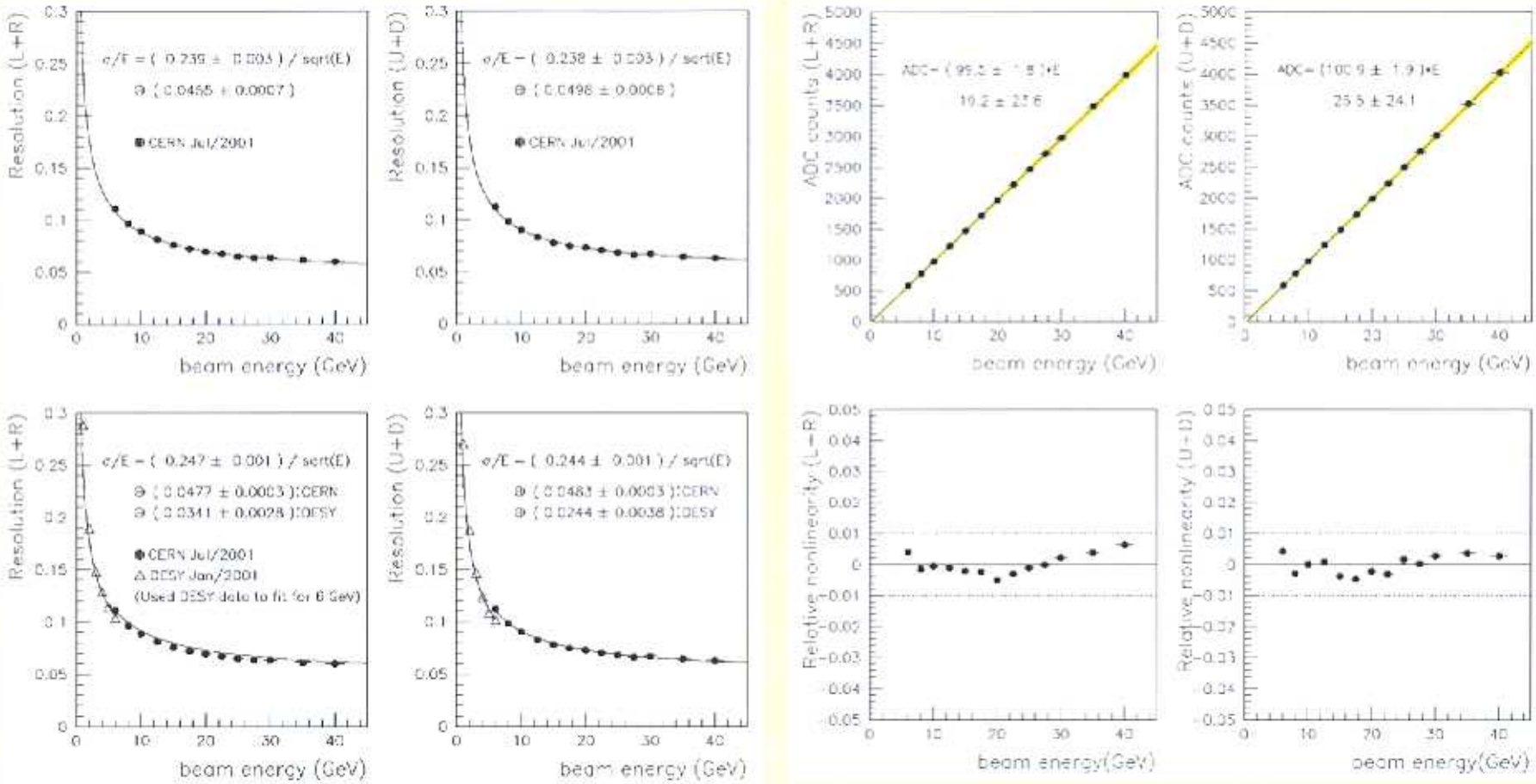
Readout: PMMA & Y7 WLS material,
Hamamatsu R580 Photomultipliers (4x)



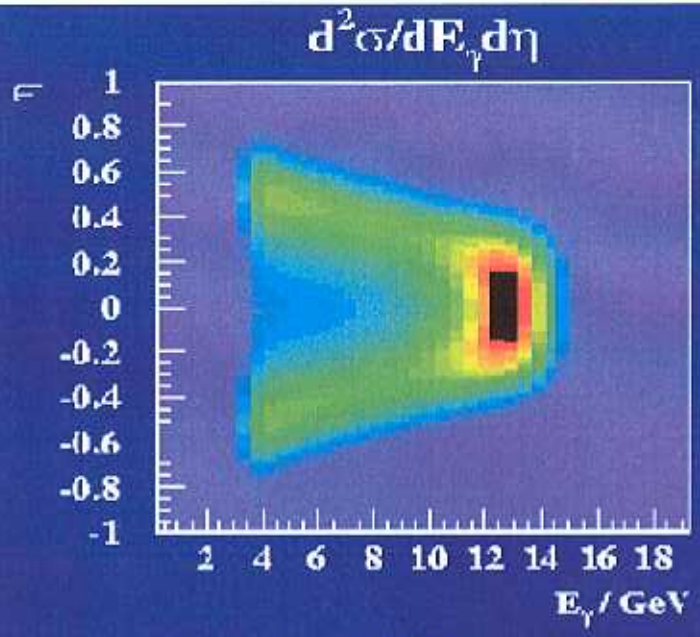


Calorimeter Calibration

Energy Resolution and Linearity from test beam measurements

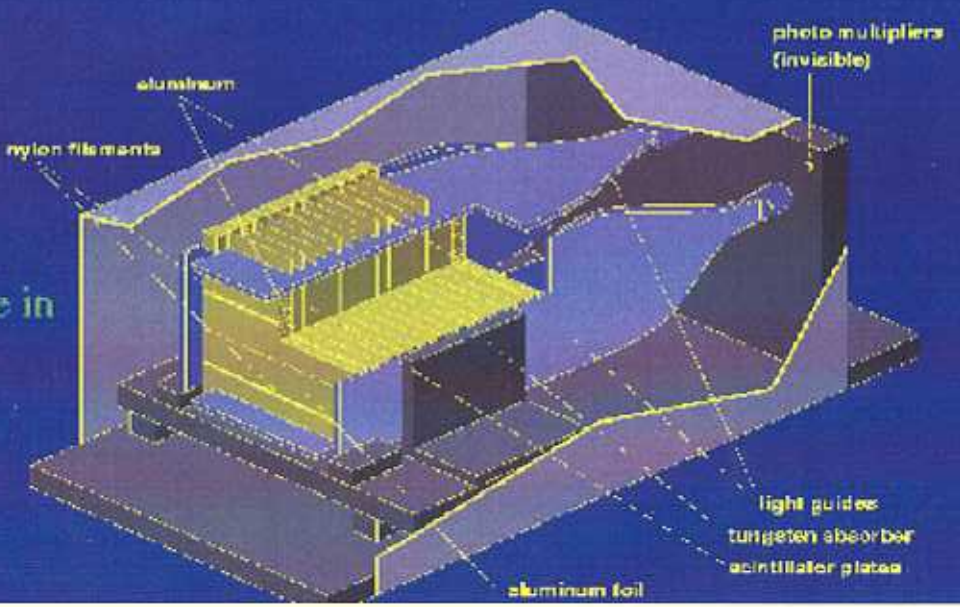


TPOL: Principle of Measurement

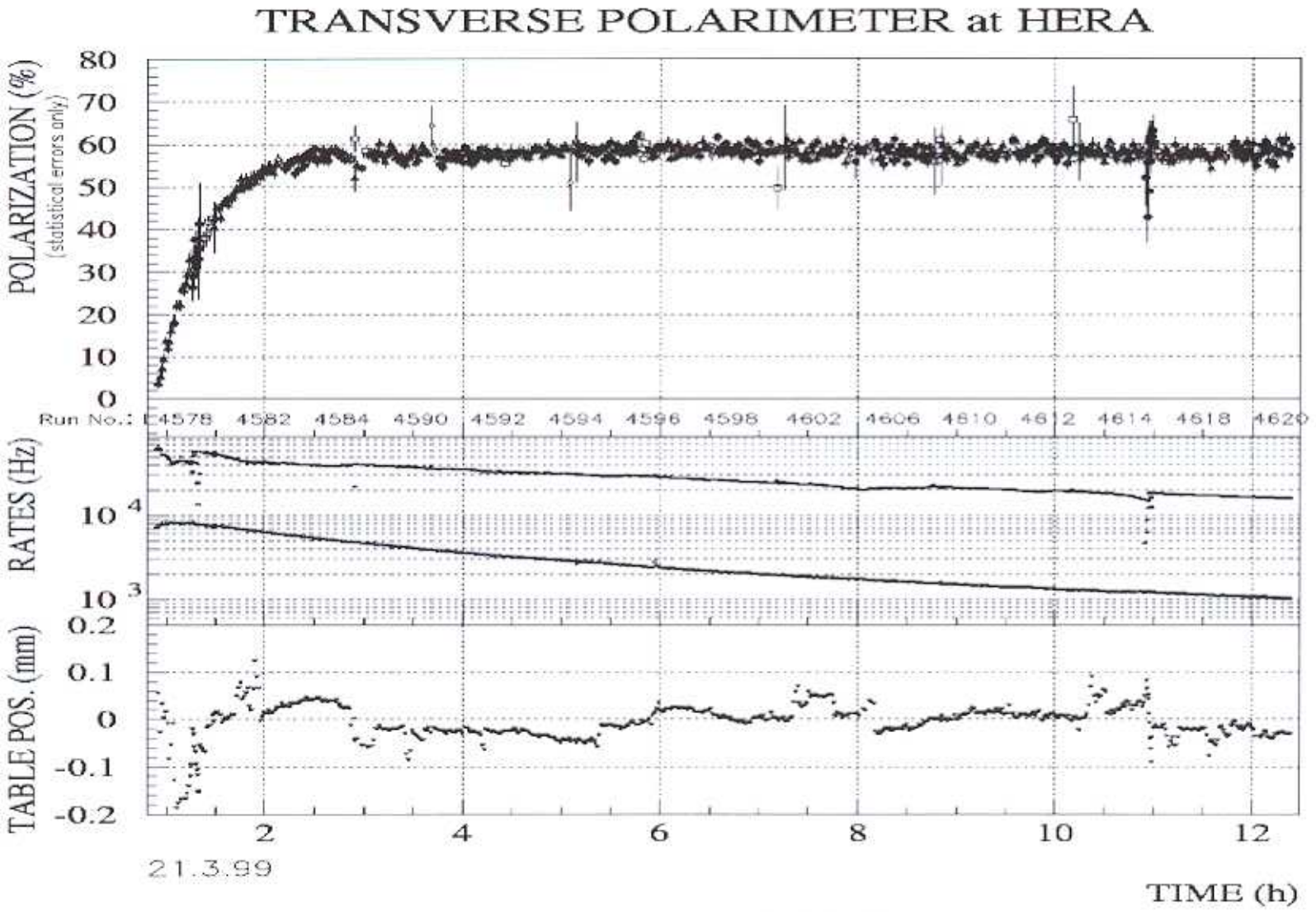


- have to measure E_γ and y!
- Calorimeter has upper and lower half:
  - $E_\gamma = E_{up} + E_{down}$
  - $y = y(\eta)$, $\eta = (E_{up} - E_{down})/(E_{up} + E_{down})$
- use asymmetry w.r.t. laser helicity
  => less sensitive to systematics

- main uncertainty:
  η-y-transformation
  - depends on transverse shower shape in calorimeter
  - up to now:
    known from testbeam only....



some old plots



more old plots

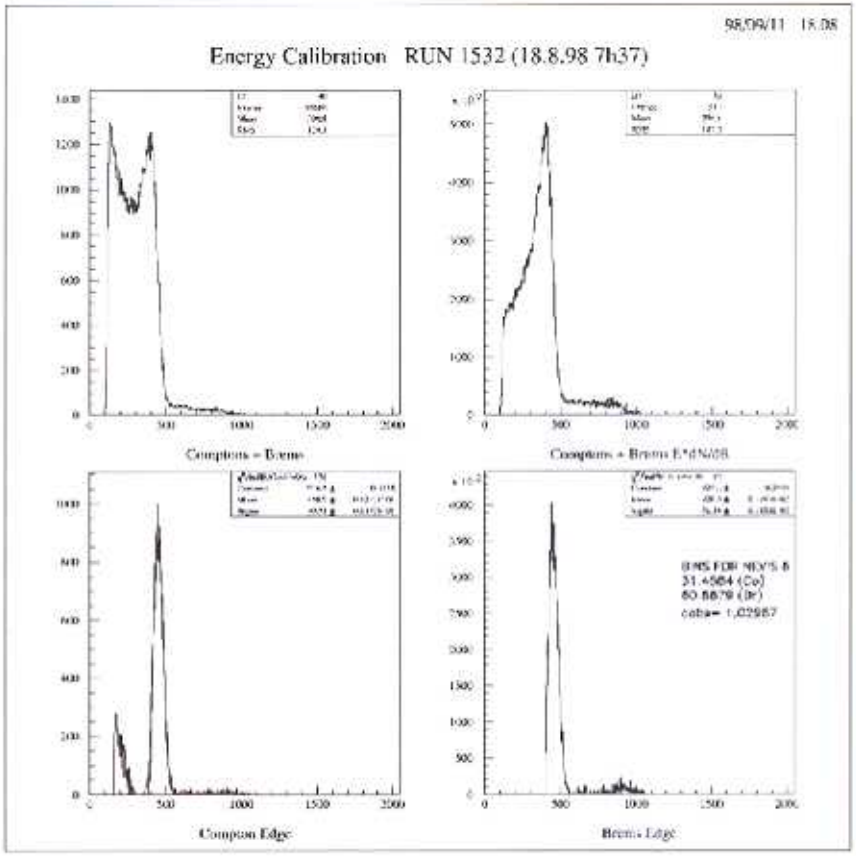


Figure 3: The absolute energy calibration with comptons and bremsstrahlung.

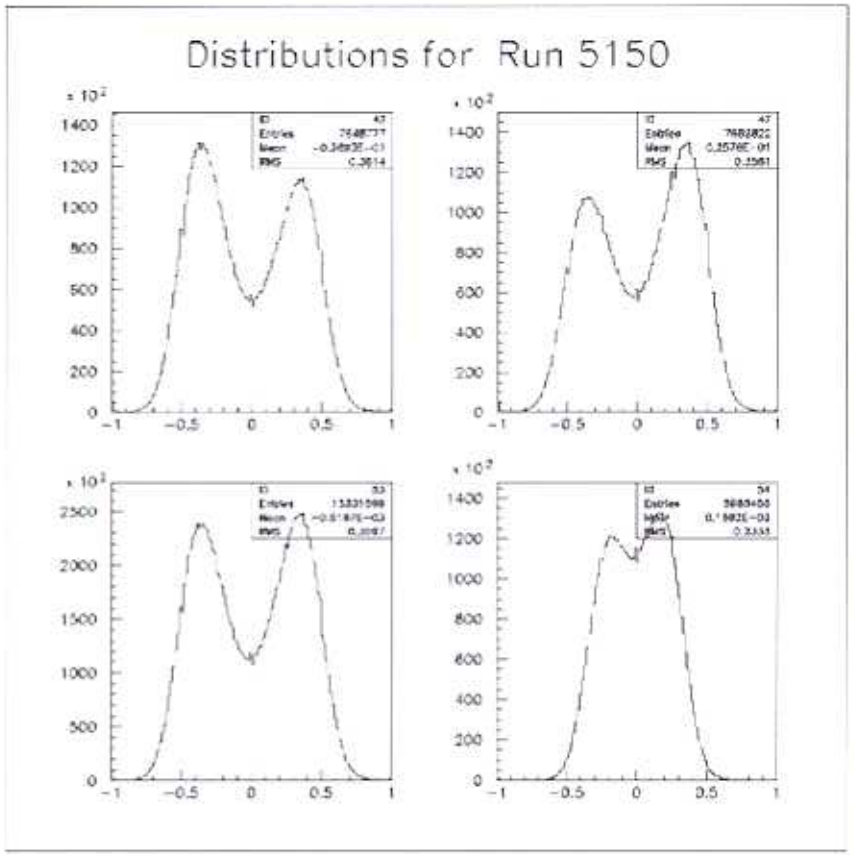


Figure 5: The Compton distributions.

Energy Spectra

Compton Distributions

TPOL Upgrade Goals

Measure bunch by bunch and Reduce systematic error

Systematics @ HERA I

Input Parameter Nominal Value	Max. and Min. Values	Resulting change in Polarisation (%)
Calorimeter Centering nominal: 0.00mm	0.03mm −0.03mm	+0.14 −0.19
Light Polarisation ΔS_1 nominal: 9%	12%	−0.34
Pedestal Position nominal: 0 ADC ch	23 ADC ch	+0.33
Electron Spot $\sigma_{e,y}$ nominal: 0.50mm	0.45mm 0.55mm	+1.10 −1.16
$\eta - y$ Transformation nominal: CERN 8 GeV	CERN 5 GeV CERN 11 GeV	+0.69 −0.69

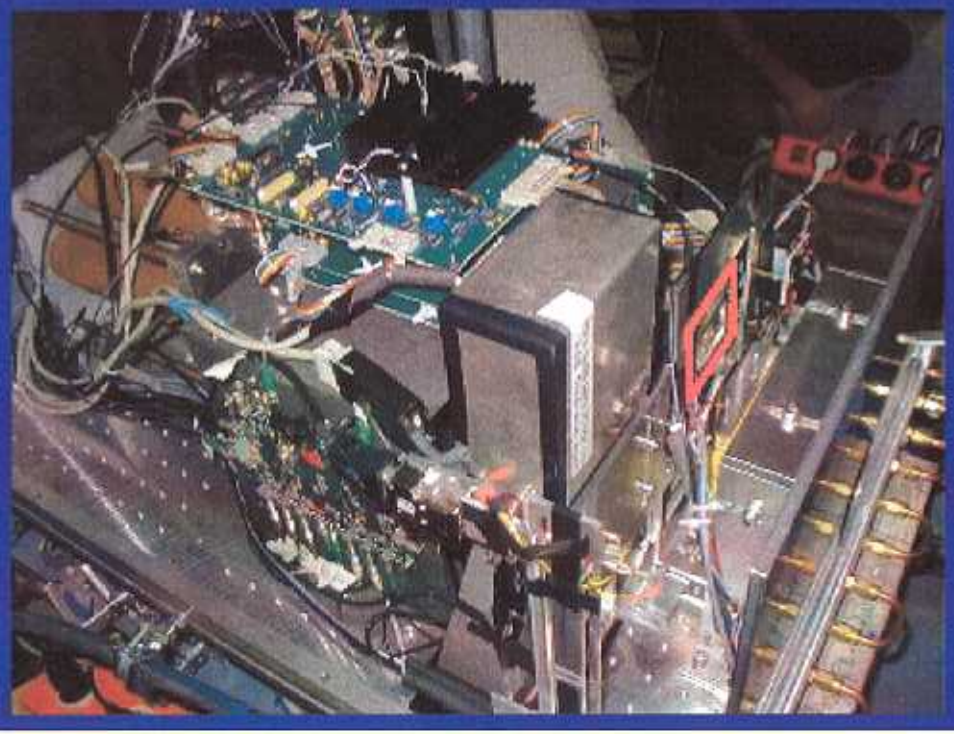
	Rise-Time Measurement Rotators Off	Rise-Time Measurement Rotators On	Monte-Carlo Calculation
Analysing Power (%)	9.608	9.308	8.930
Systematic Error (%)	3.4	1.8	1.95

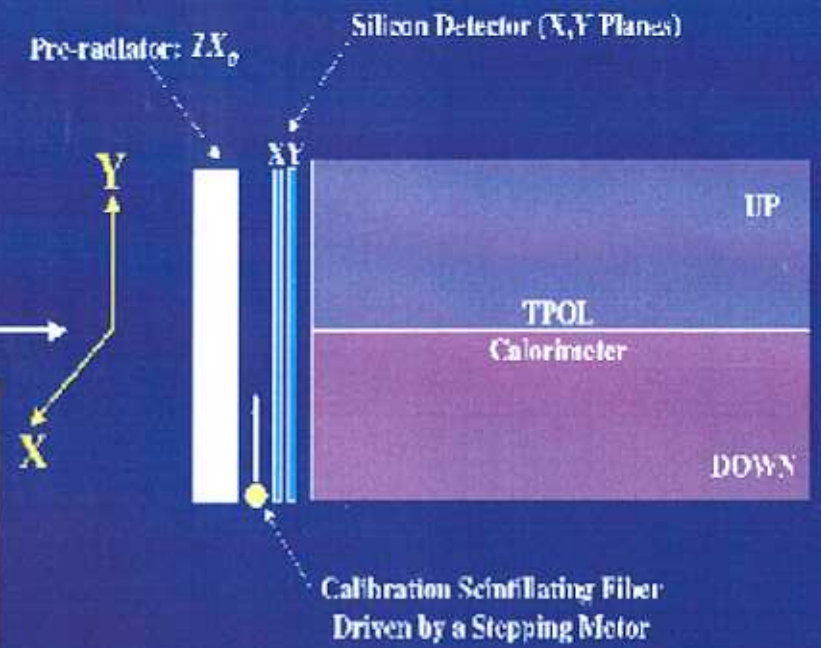
Improvements @ HERA II

Online η-y ⇒Converge better	Silicon
Frequent Optimization with light calorimetry	SLOW Ctr Optics
Event by event pedestals	DAQ
2D fit	Analysis
Online η-y	Silicon Sci-Fiber
0.891 ≤ 1%	Analysis ALL

TPOL Upgrade: Silicon Strip Det.

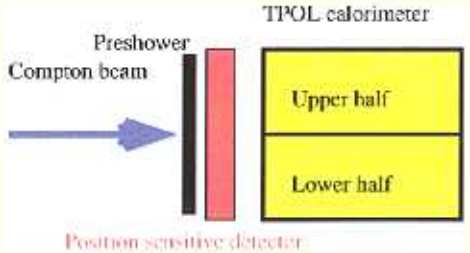
- new SI strip detector in y and x in front of calo as calibration device





- first in–situ measurements of η-y-transformation with new SI tracker done
- Studies in progress!

Silicon Detector

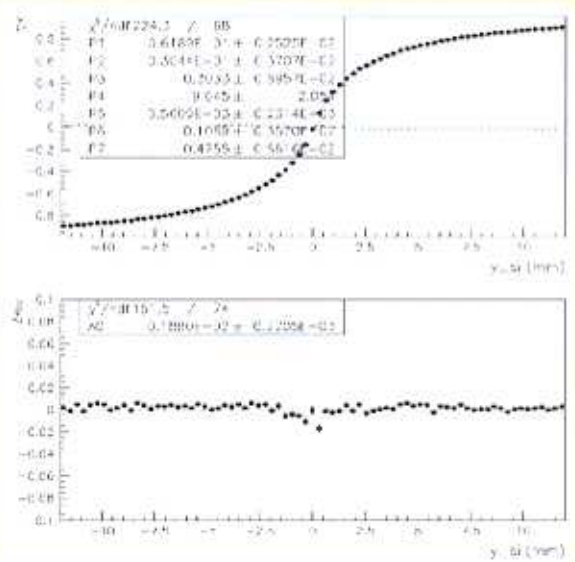


energy asymmetry $\eta = (U - D) / (U + D)$
measured by calorimeter

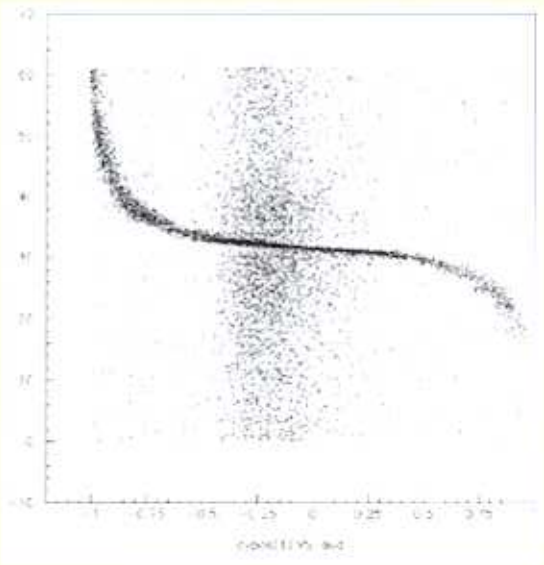
position y (mm)

measured by Silicon detector

CERN test beam results



first results from HERA

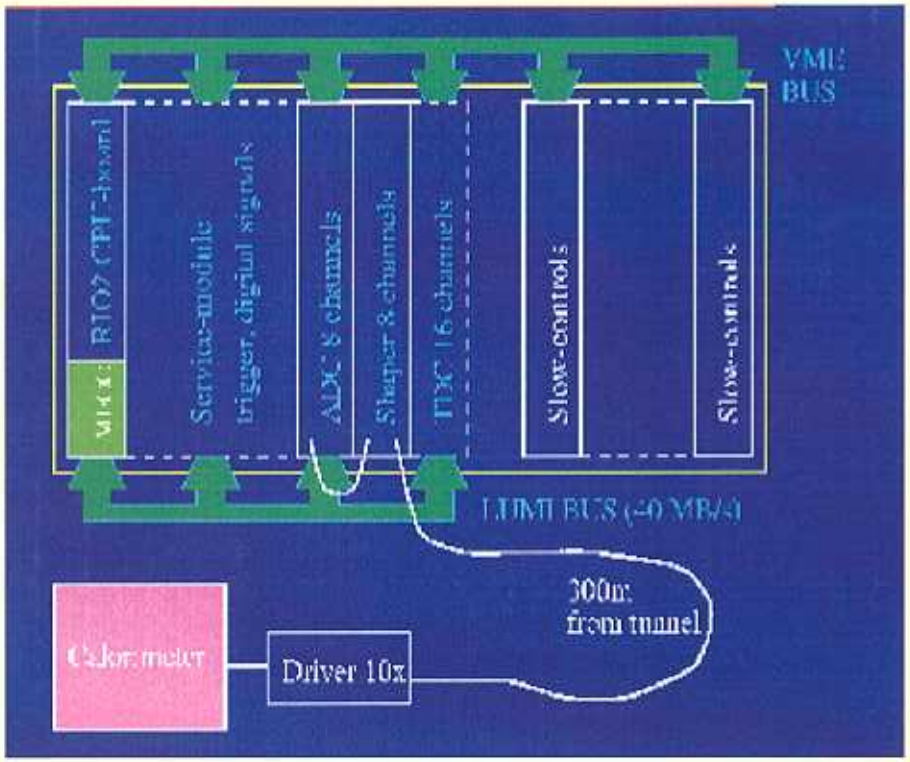


analyzing power: new = old /1.078
(preshower effect)

1 kHz calibration data

⇒ input for offline polarization extraction

TPOL Upgrade: Data Acquisition

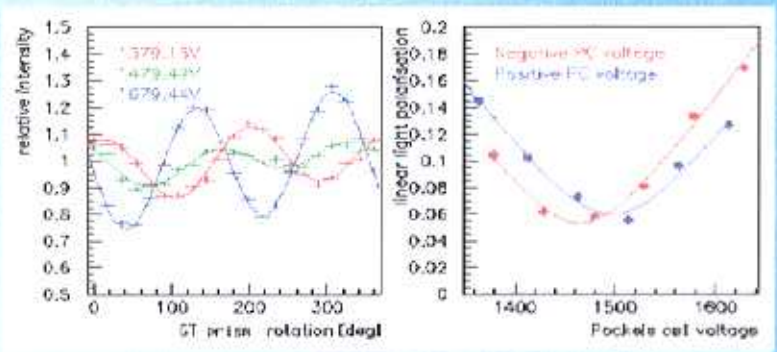


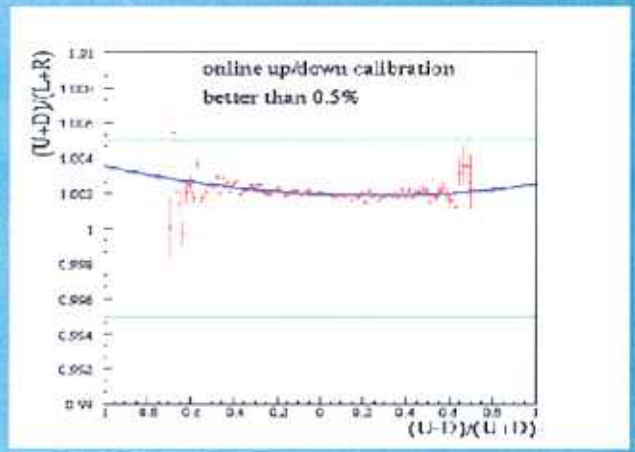
completely new DAQ:

- hardware, software, slow controls
- pedestals measured event by event
- polarization measurement for individual HERA bunches

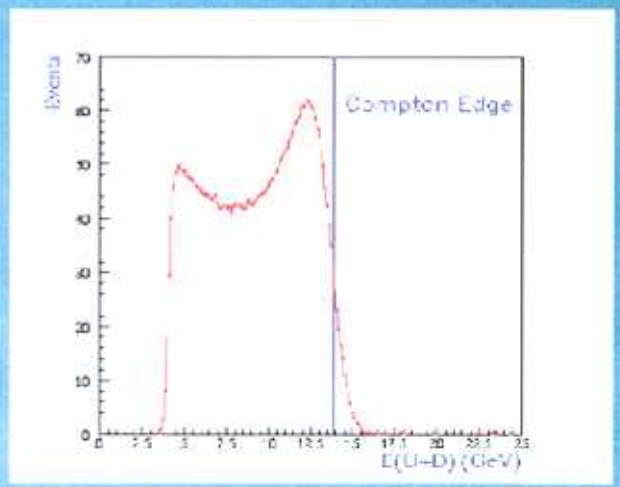
Calibrations

Light Pol. Optimization





Calorimeter Gain matching
abs. Energy scale by Compton edge



Controlled per minute<0.5% =>

Contribution to beam polarization <0.1%

TPOL Online Analysis

- integrate $d^2\sigma/dE_\gamma d\eta$ over most sensitive E_γ and η range
- form asymmetry w.r.t. to laser helicity:

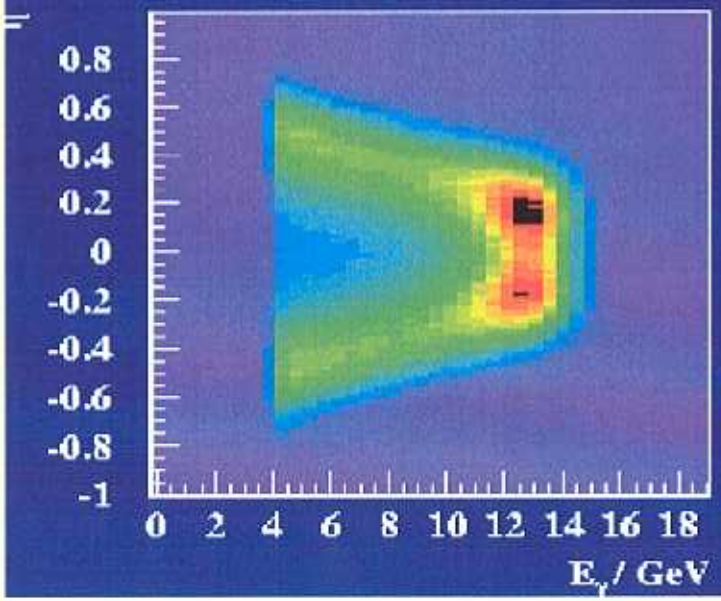
$$\frac{(\sigma_R - \sigma_L)}{(\sigma_R + \sigma_L)} \equiv 2\,|S_3|\,P_Y \frac{\iint \Sigma_{2Y}\, dE_\gamma d\eta}{\iint \Sigma_0 dE_\gamma d\eta} =: 2\,|S_3|\,P_Y\,\Pi$$

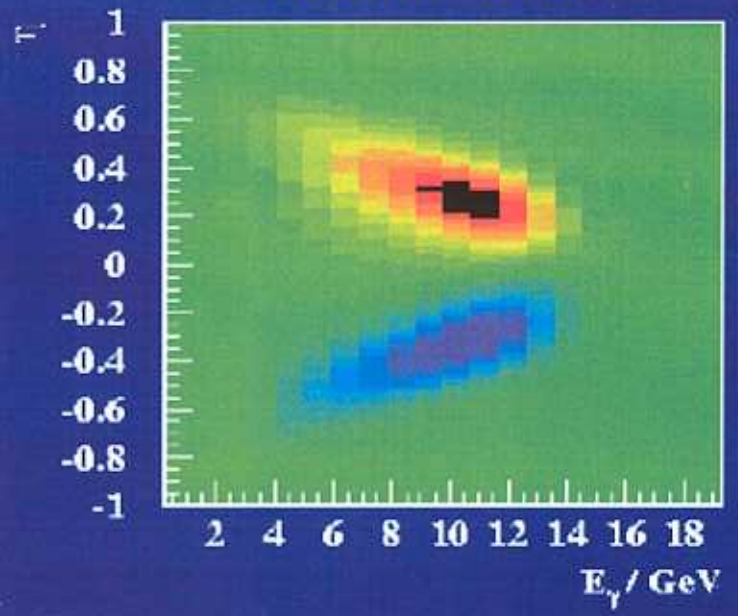
  Π: "analysing power" taken from risetime calibration &MC

- fast & simple method
- BUT: only valid if ALL parameters are:
  - **equal to default values**
  - **and constant over time.**
  - especially: η–y–transformation has to be "known" a priori!
- o.k. within ~3.4%...
  ... probably not true down to subpercent level!

New Offline Analysis

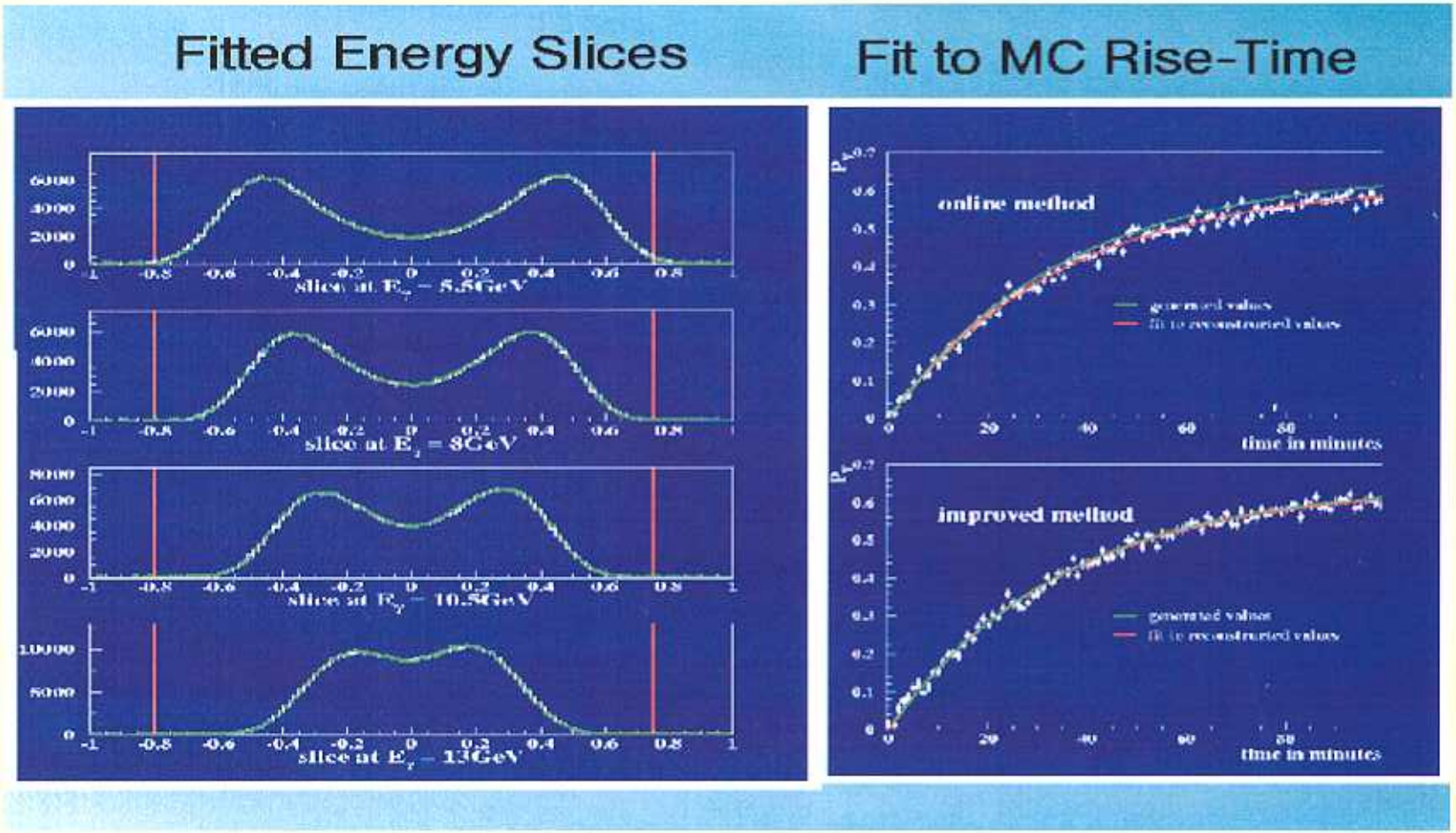
- Idea: fit double differential x–section
  => no assumptions about:
  - linear laser polarisation
  - η–y–transformation
  - calibration, alignment, resolution ...





- First step : fit sum of spectra for both laser helicities => calibration
- Second step: fit difference => polarisation
- analysis not final yet
- no final systematic error yet

New Offline Analysis



can adjust analyzing power dynamically to changing operating conditions

HERA I → HERA II

Polarization Machine Aspects

New Spin Rotators for H1 and Zeus =>

less polarization by ~ 5%

estimate for 0.7mm orbit flatness

No anti-Solenoids =>

new compensation scheme

still to be demonstrated

Orbit Flatness Control: 1.2 → 0.7mm (RMS)

will require implementation of
Beam Based Alignment

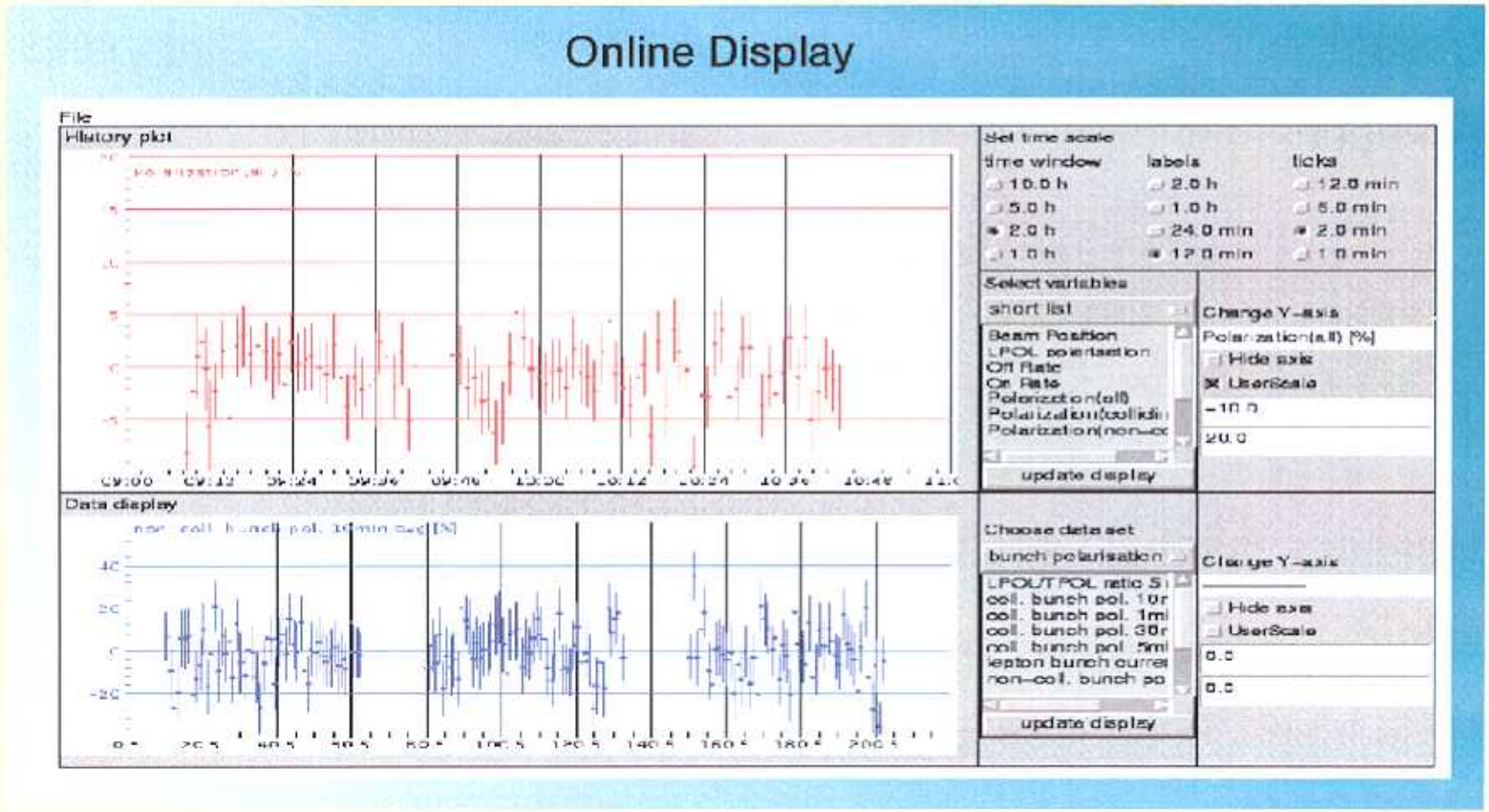
Harmonic Bump Control

Complex Amplitudes 4 → 8 → 16

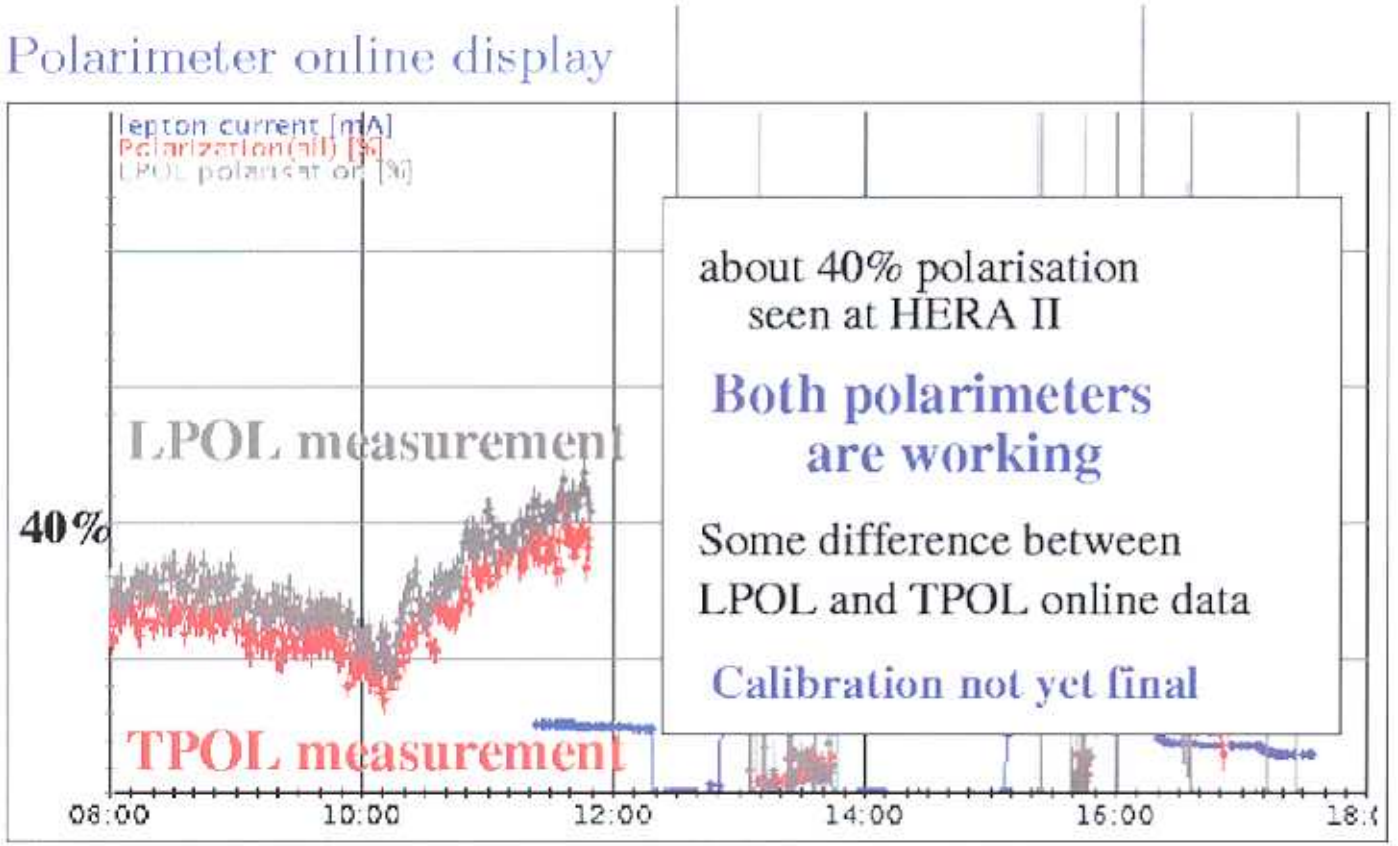
Expected Average Polarization 55% (Hera I) → 50% (HERA II)

TPOL Online Display

routine operation (3 May 2002)
at low beam current ($I_{e^+} = 3.5\ mA$)
(HERA not yet tuned for polarization)



first beam polarization tune-up at HERA II



Summary

- **TPOL operational since 1992, for HERMES physics since 1995**
- **Systematic Error $\Delta P/P = 1.8\%$ from 1996/97 rise-time calibrations**

- **TPOL successfully upgraded in 2001-2002**
- **measures now bunch by bunch polarization**
- **new Silicon and Fiber detector providing data to reduce systematic uncertainties**
- **ongoing analysis to prove sub percent precision**