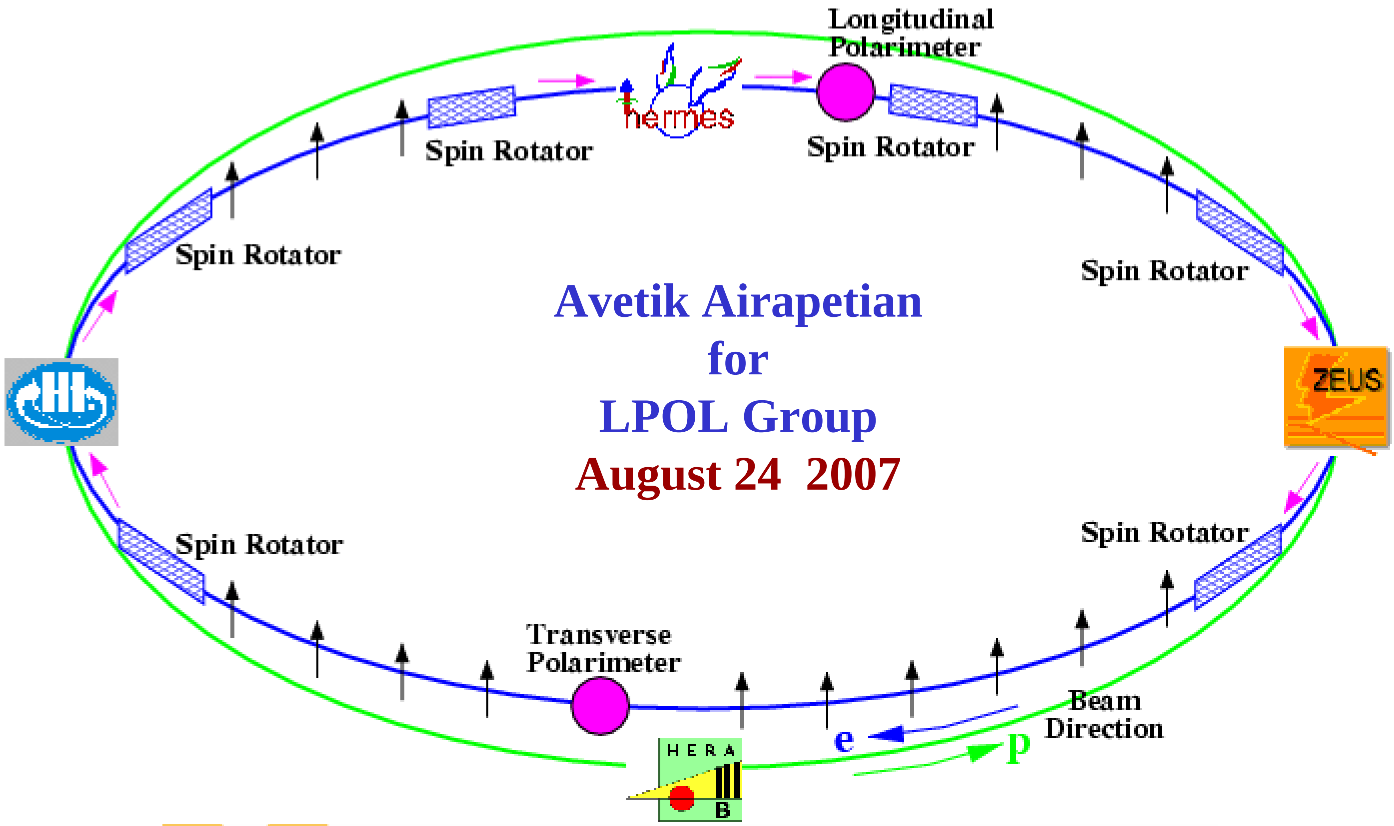
Compton Polarimetery at HERA, more than 10 years of operation



Avetik Airapetian
for
LPOL Group
August 24 2007

UNIVERSITY OF MICHIGAN

Outline

- Demand for electron polarization measurements: from HERMES to H1/ZEUS
- Polarimeters at HERA (TPOL ,LPOL, Cavity)
- LPOL under detailed look
- Conclusions & Suggestions for EIC

HERMES: Main Customer untill 2000

- **SPIN “crisis”**

1987: EMC/CERN (μ p)

$\Delta\Sigma$ = 0,12 ± 0,09 ± 0,14

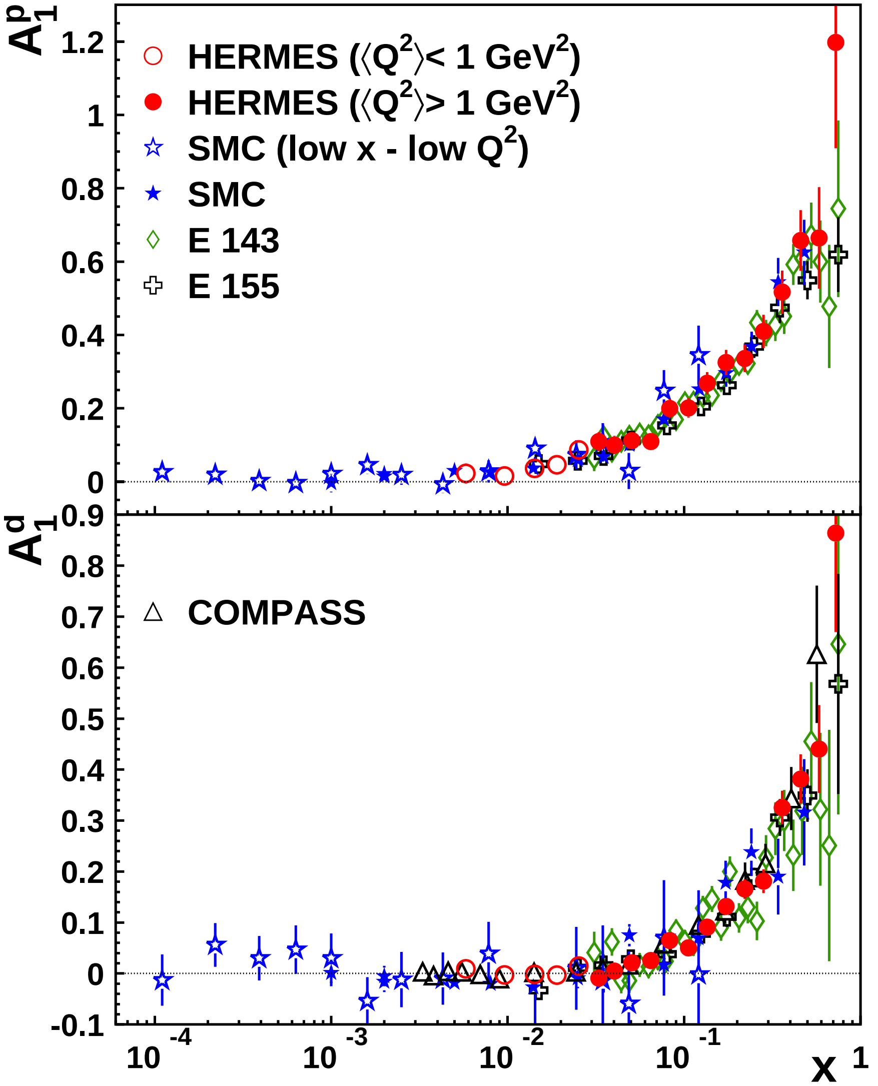
Contribution of quark spins

to nucleon spin is very small

Most precise determination of $\Delta\Sigma$

$\Delta\Sigma$ = 0.330 ± 0.025 ± 0.011 ± 0.028

HERMES: P. R. D 75 (2007) 012007



HERMES: Main Customer untill 2000

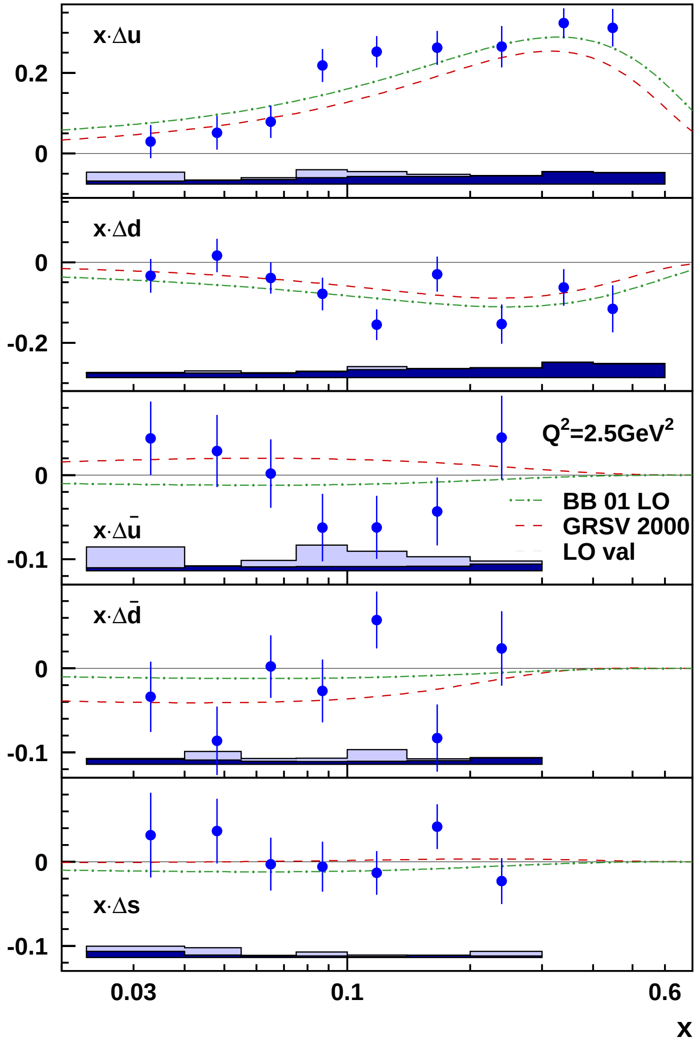
Using hadron asymmetries:

$h = \pi^{\pm}, K^{\pm}, p$

Targets: $\vec{H}$, $\vec{D}$

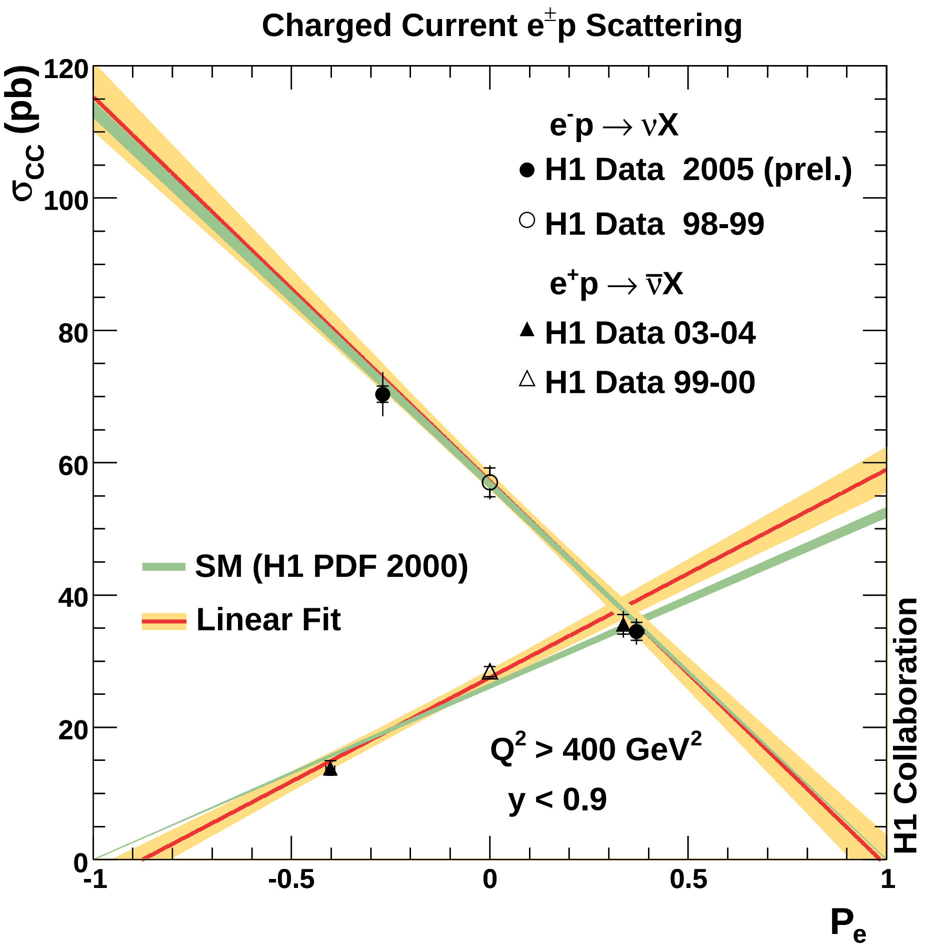
First determination of sea quark polarisation:

consistent with zero.



HERMES: PRL 92 (2004) 012005, PRD 71 (2005) 012003

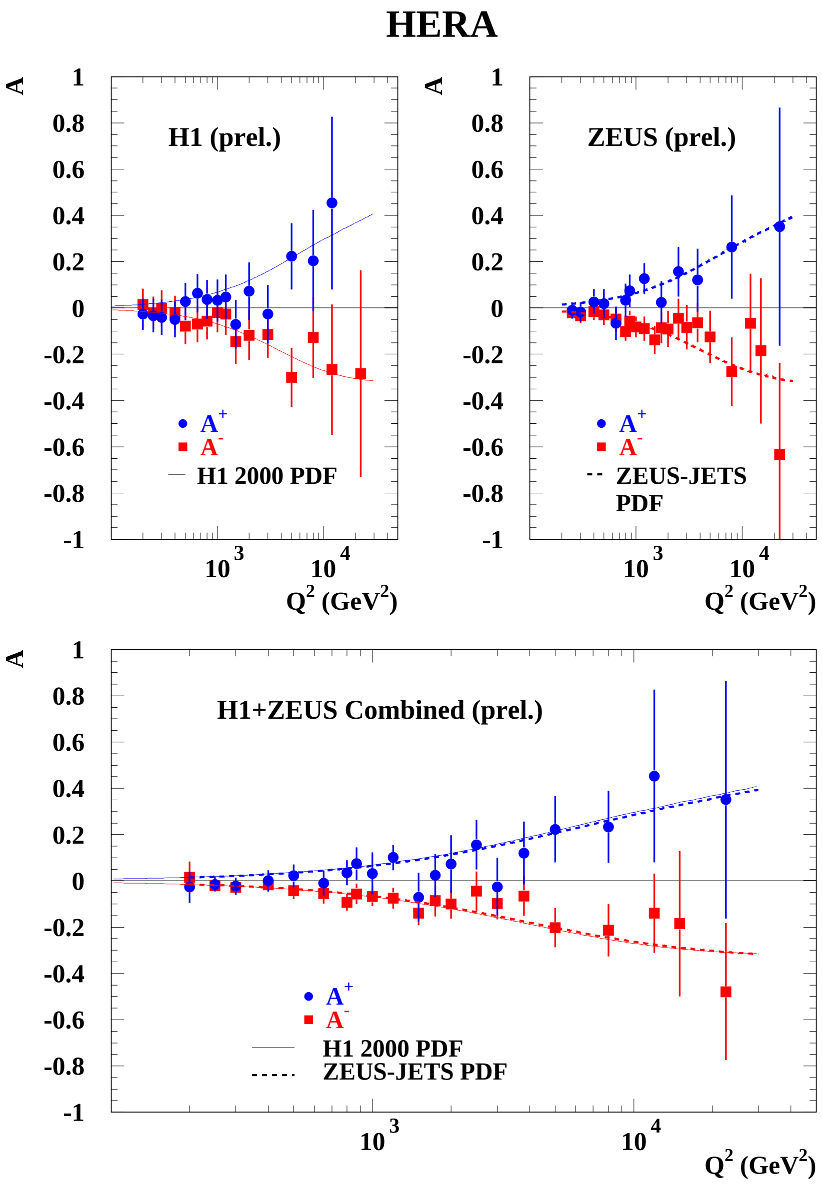
After 2000: HERMES, H1 and ZEUS



$$\sigma^{CC}(e^{\pm}p) = (1 \pm P_e) * \sigma^{CC}{}_{P_e=0}(e^{\pm}p)$$

- Linear dependence of σ^{CC} P_e confirmed
- Extrapolation to $P_e = \pm 1$,
- No sign of right-handed charged currents

H1 and ZEUS



- Asymmetry of two helicity states:

$$A^{+-} = \frac{2}{P_L - P_R}\,\frac{\sigma^{+-}_{P_R} - \sigma^{+-}_{P_L}}{\sigma^{+-}_{P_R} + \sigma^{+-}_{P_L}}$$

A≠0 at highest Q^2:

Evidence for parity violation in neutral currents

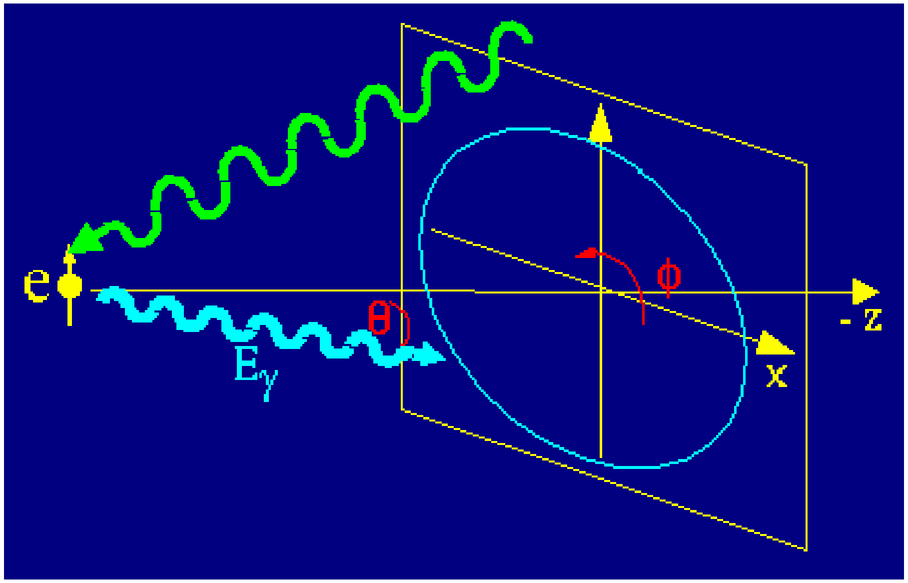
At small distances 10^{-18} m

Expect $A^+ = -A^-$ in standard model

$$A = \frac{\sum_q e_q v_q (q + \bar{q})}{\sum_q e_q^2 (q + \bar{q})}$$

- Sensitivity to quark vector coupling v_q

West Hall (TPOL): Principle of Measurement: Compton-Scattering



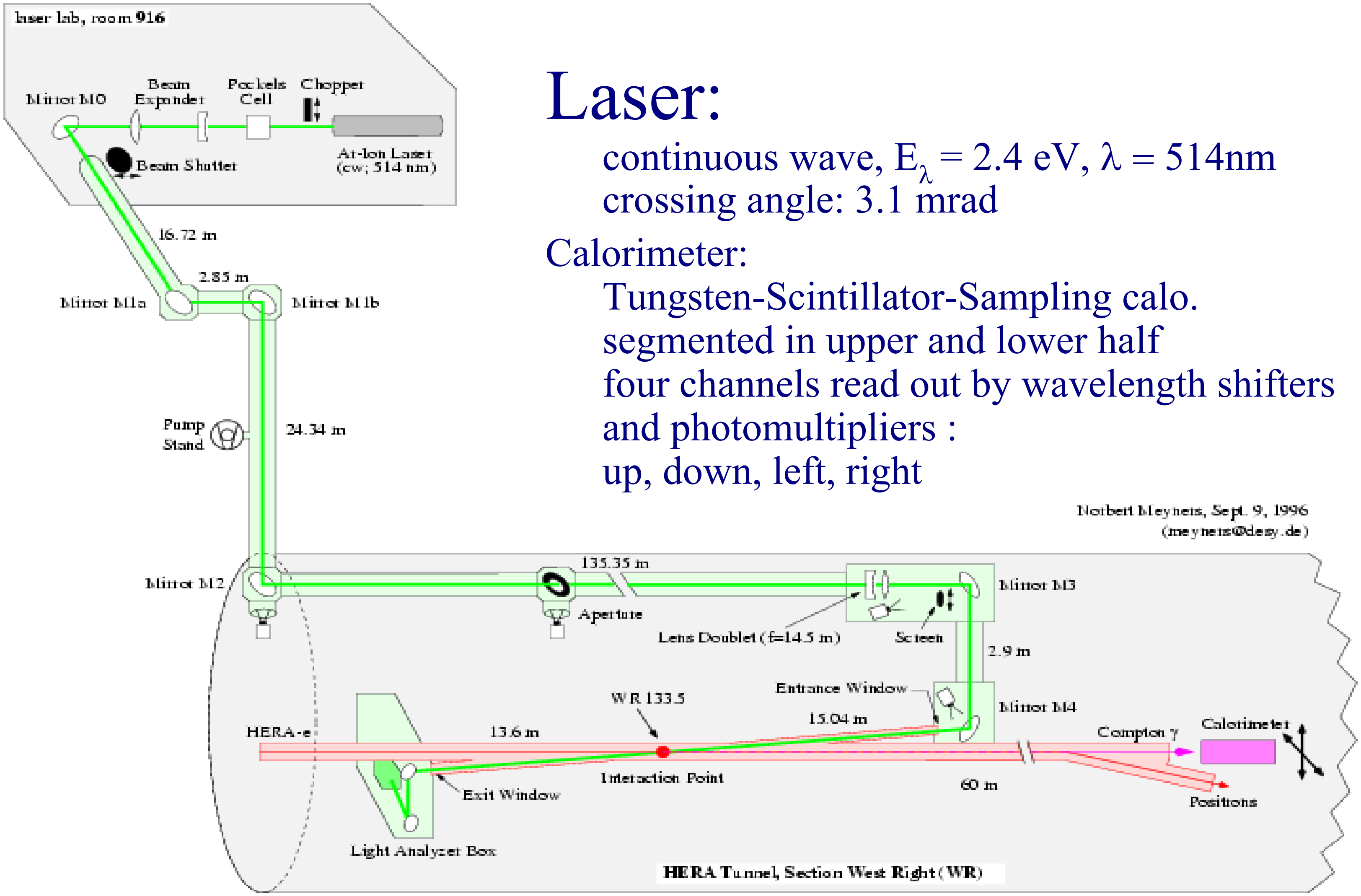
- kinematics described by 2 variables:
  - polar angle θ <=> E_γ (photon energy)
  - azimutal angle φ => y (vert. position)
- S1, S3: lin. & circ. polarisation of laser
- P_Y,P_Z: transv. & long. beam polarisation

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

TPOL: measure (energy dependent) angular asymmetry

- up-down asymmetry very small (even at 65m!)
- need very precise position measurement (better than 10µm)
- distance from IP also has to be measured very precisely (not trivial)

Transverse Polarimeter (I)



Norbert Meyners, Sept. 9, 1996
(meyners@desy.de)

Laser:

continuous wave, $E_\lambda = 2.4$ eV, $\lambda = 514$nm
crossing angle: 3.1 mrad

Calorimeter:

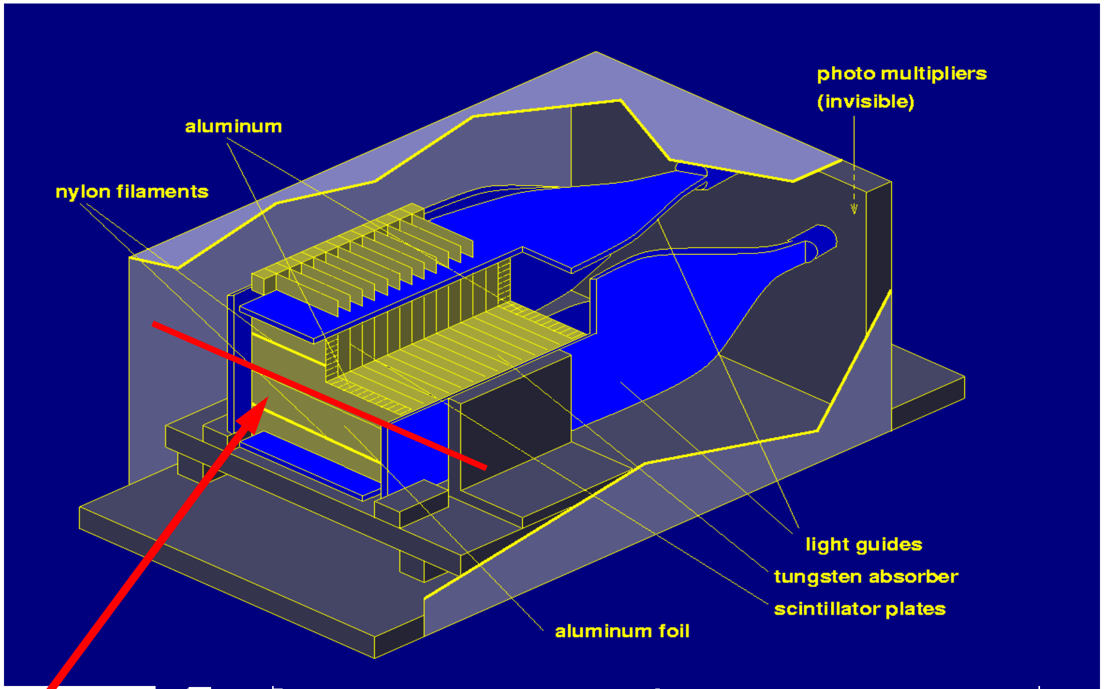
Tungsten-Scintillator-Sampling calo.
segmented in upper and lower half
four channels read out by wavelength shifters
and photomultipliers :
up, down, left, right

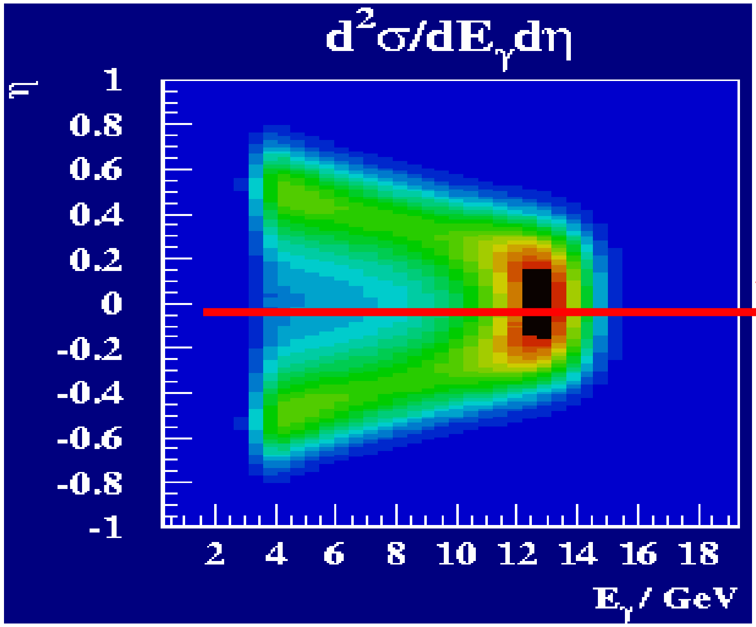
Transverse Polarimeter (II)

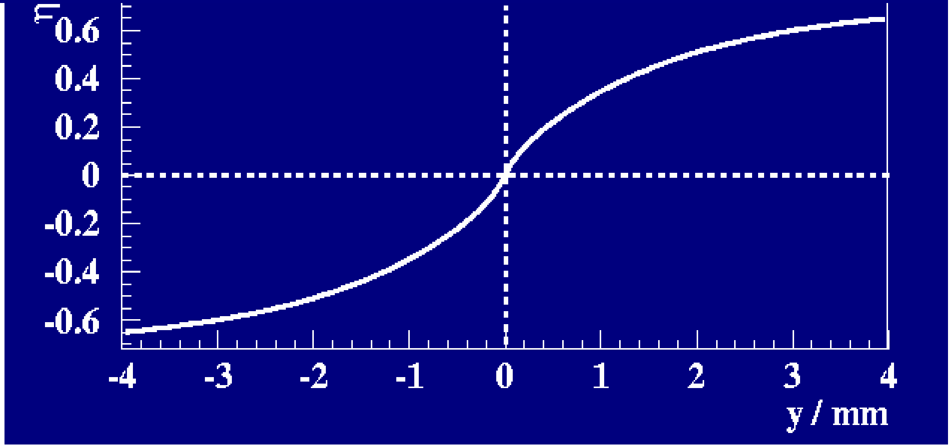
- measured quantities:

$E_\gamma = E_{up} + E_{down}$

$\eta = (E_{up} - E_{down})/(E_{up} + E_{down})$,
$y = y(\eta)$ <= main uncertainty!

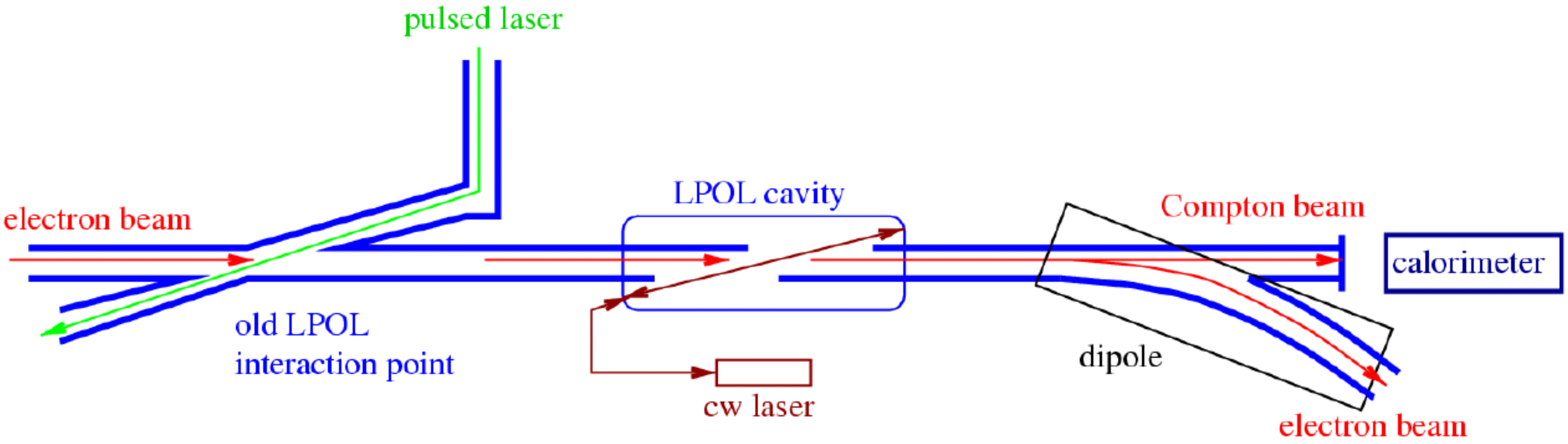




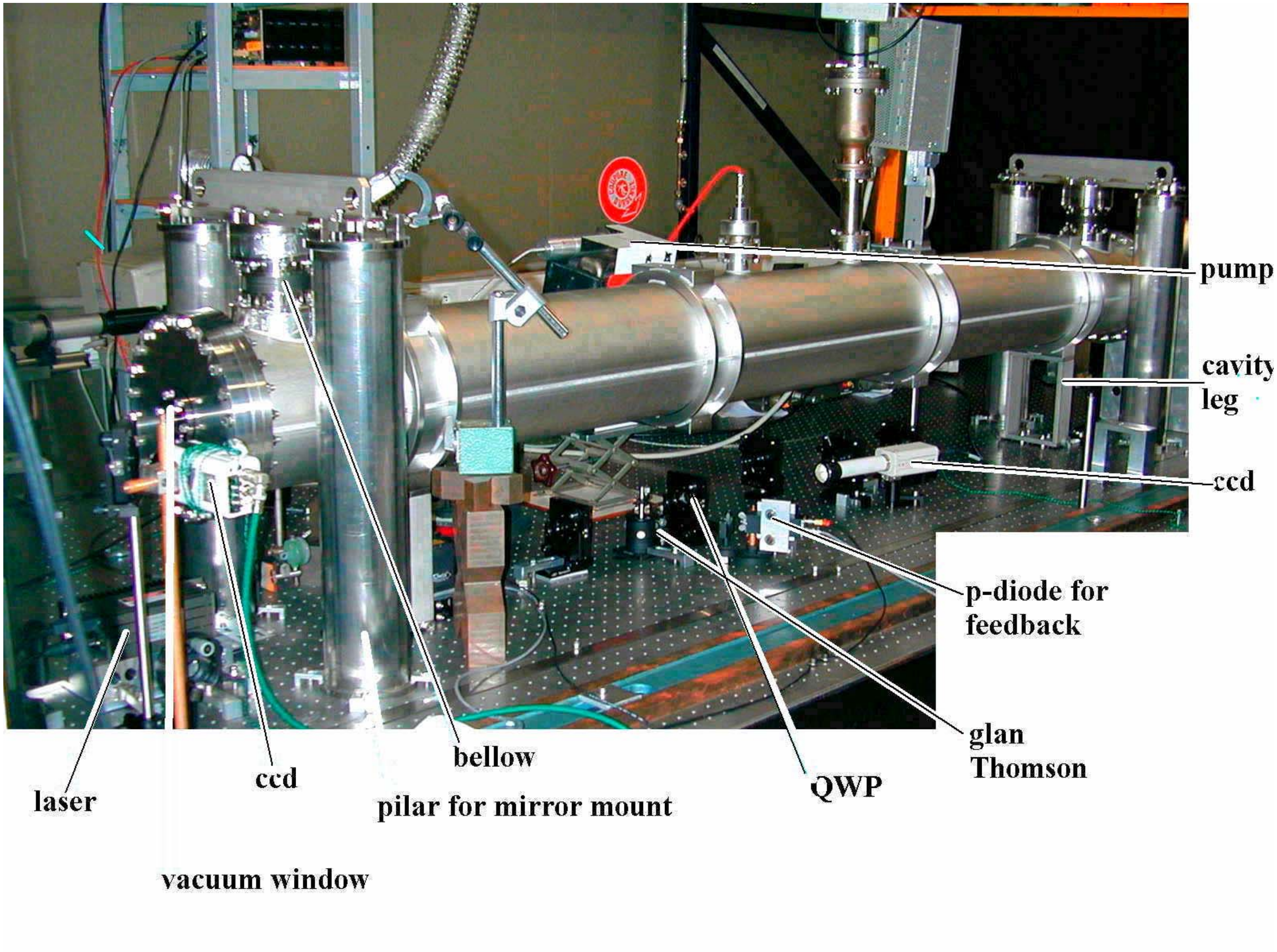


East Hall (Cavity-LPOL, LPOL): Principle of Measurement:

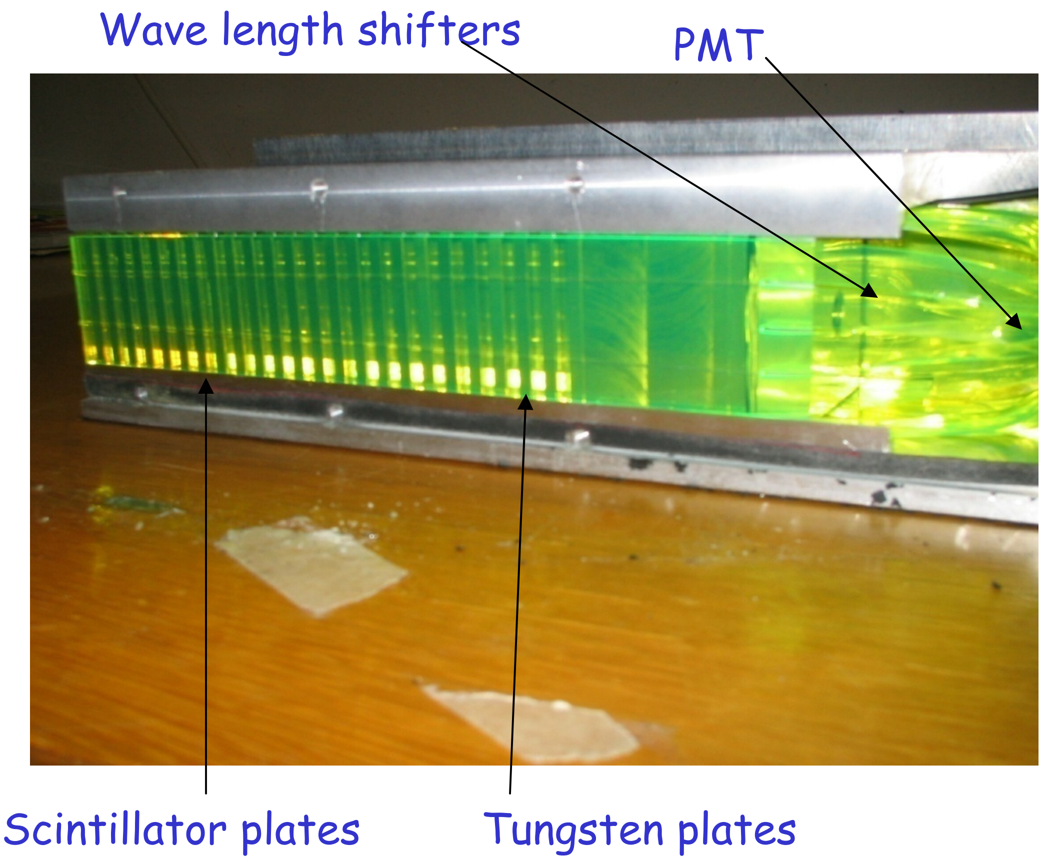
$$d\sigma/dE_\gamma = d\sigma_0/dE_\gamma[1+ P_e P_\lambda A_z(E_\gamma)]$$



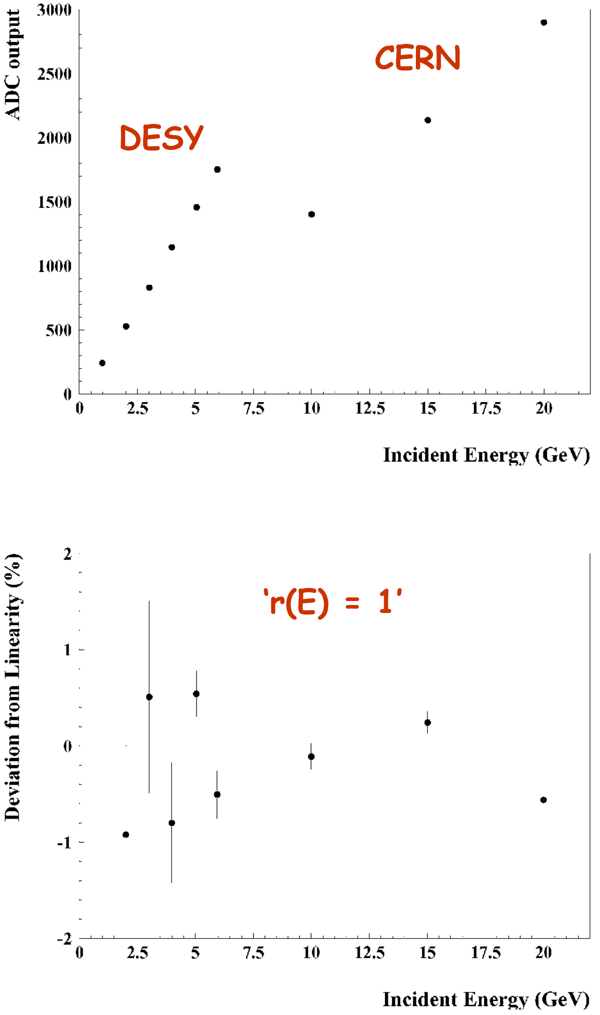
Cavity Polarimeter: Setup



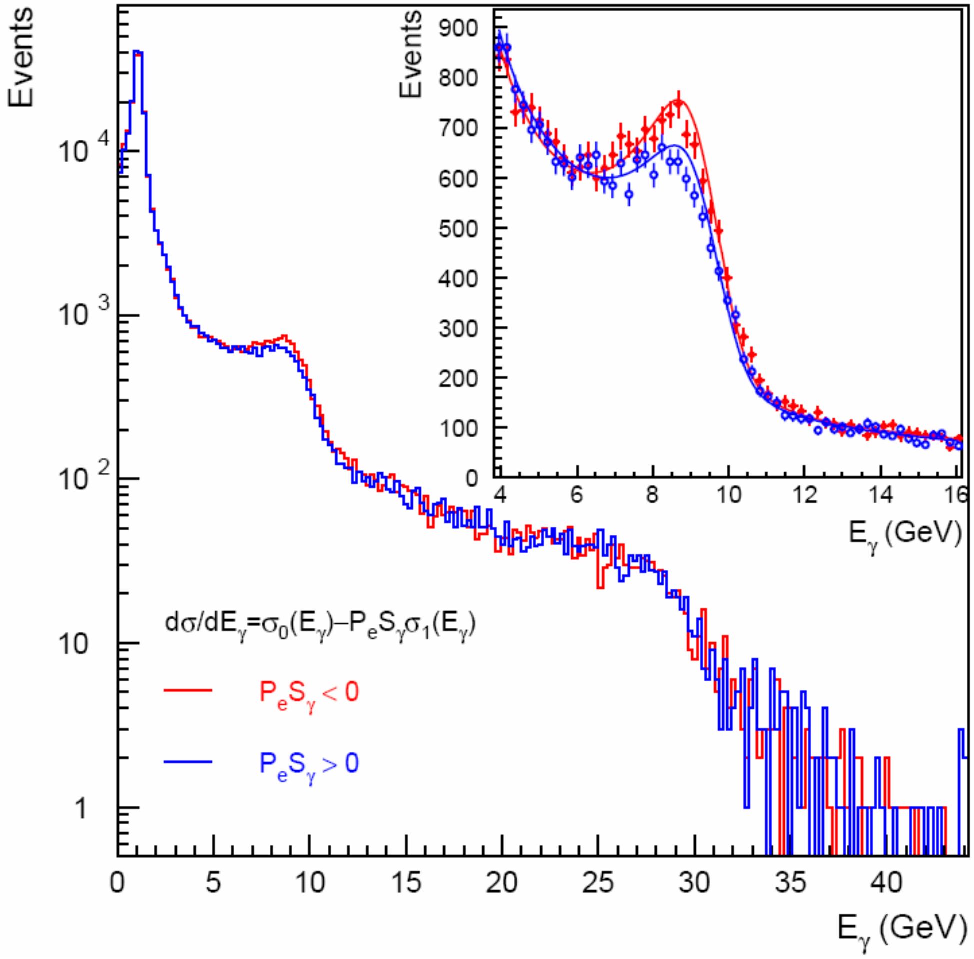
Cavity uses LPOL Calorimeter



Test beam results



Cavity: Method of Measurement



An example for one single bunch
(taken in 4 + 4 seconds)

Cavity: fitting procedure

- **Step 1: Fit laser-off (brem.) spectrum**

  to fix calorimeter related parameters

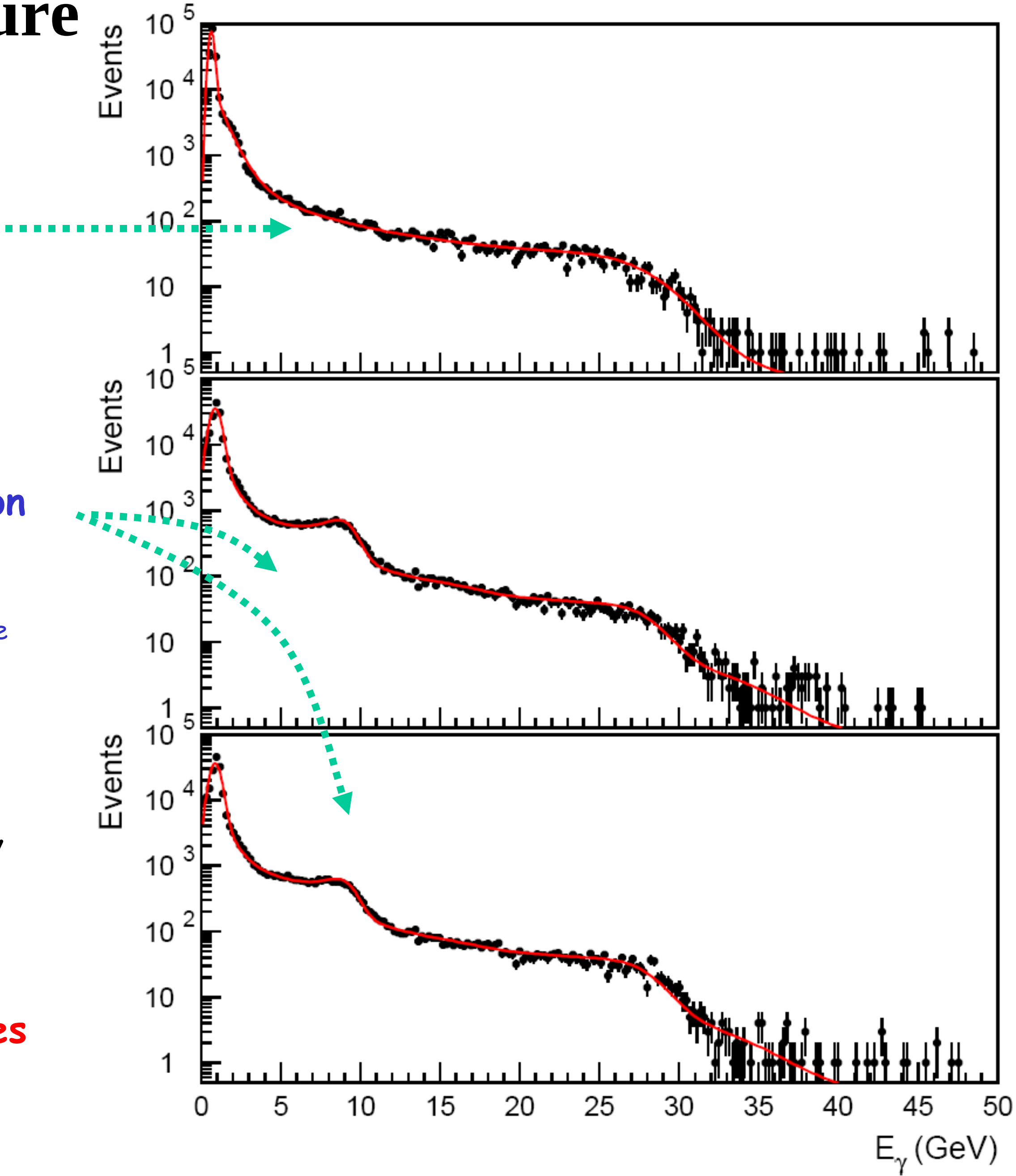
- **Step 2: Fit laser-on spectra in two laser polarization states**

  to get the beam polarization P_e & other beam/background related parameters

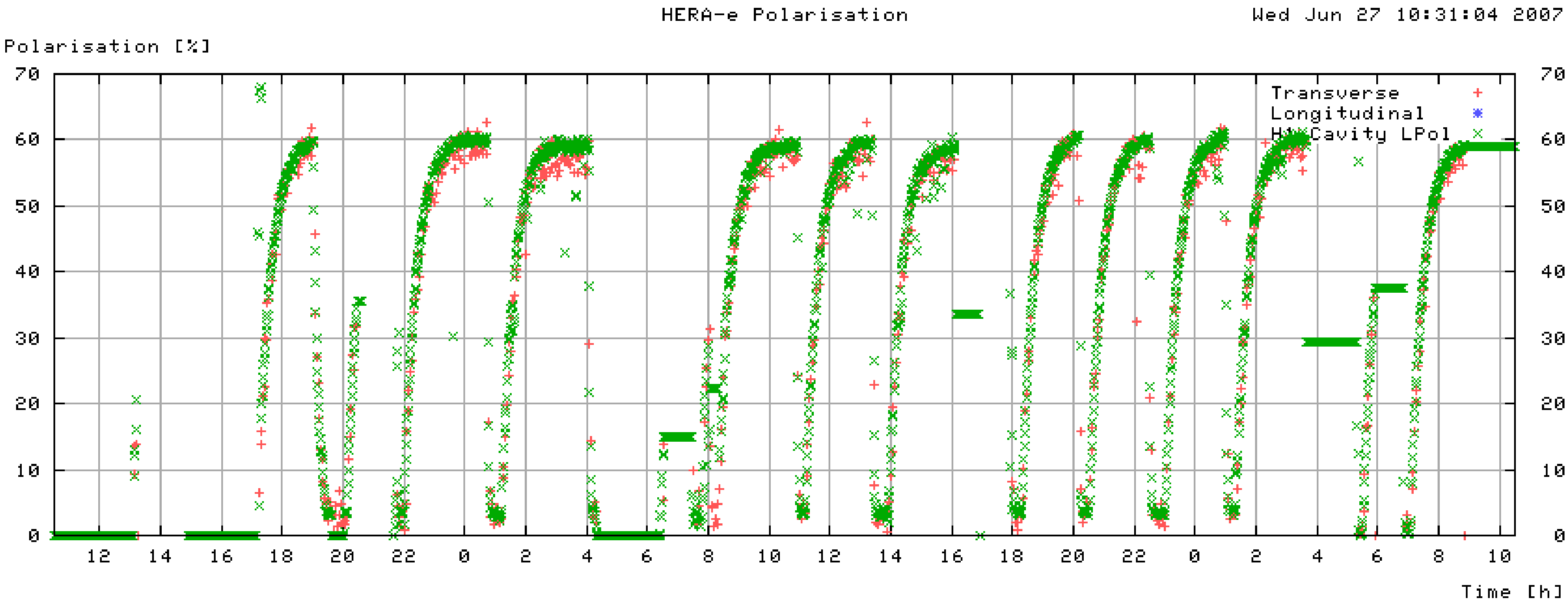
Caveat:

Brem. spectrum taken at slightly different beam conditions than the laser-on spectra

➔ To be improved in further data taking, **NOW OFFLINE analyses**

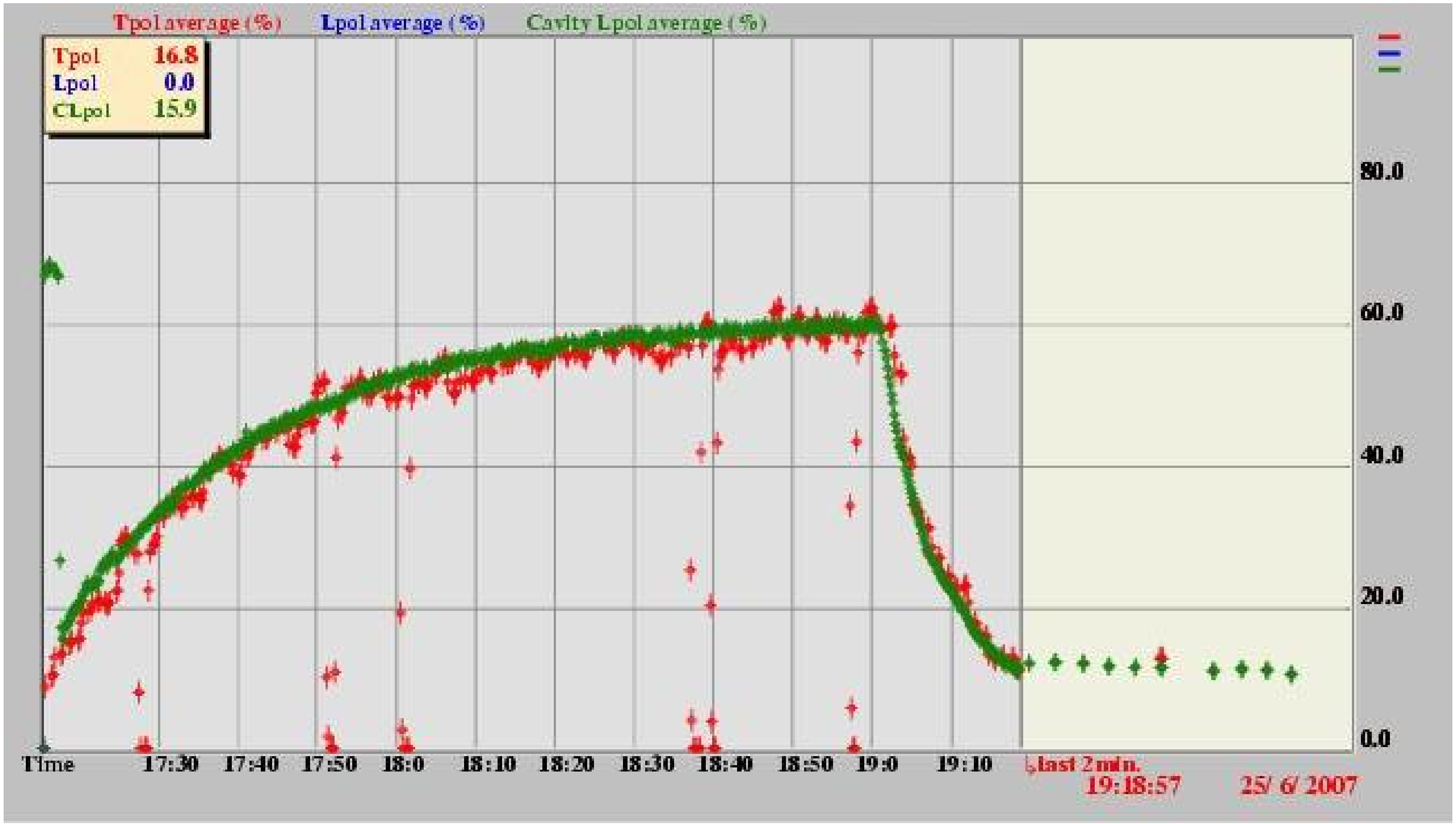


TPOL and Cavity: Rise-Time Measurements



- Rise-Time measurements by Cavity-LPOL and TPOL during last week of HERA operations

TPOL and Cavity: Rise-Time Measurement



- Note: 5 times increase of frequency of measurement by Cavity-LPOL

Physics of LPOL P_e Measurement: Compton Scattering

Compton Scattering:

$e+\lambda \rightarrow e'+\gamma$

Cross Section:

$d\sigma/dE_\gamma = d\sigma_0/dE_\gamma[1+ P_e P_\lambda A_z(E_\gamma)]$ $d\sigma_0$, A_z: known (QED)

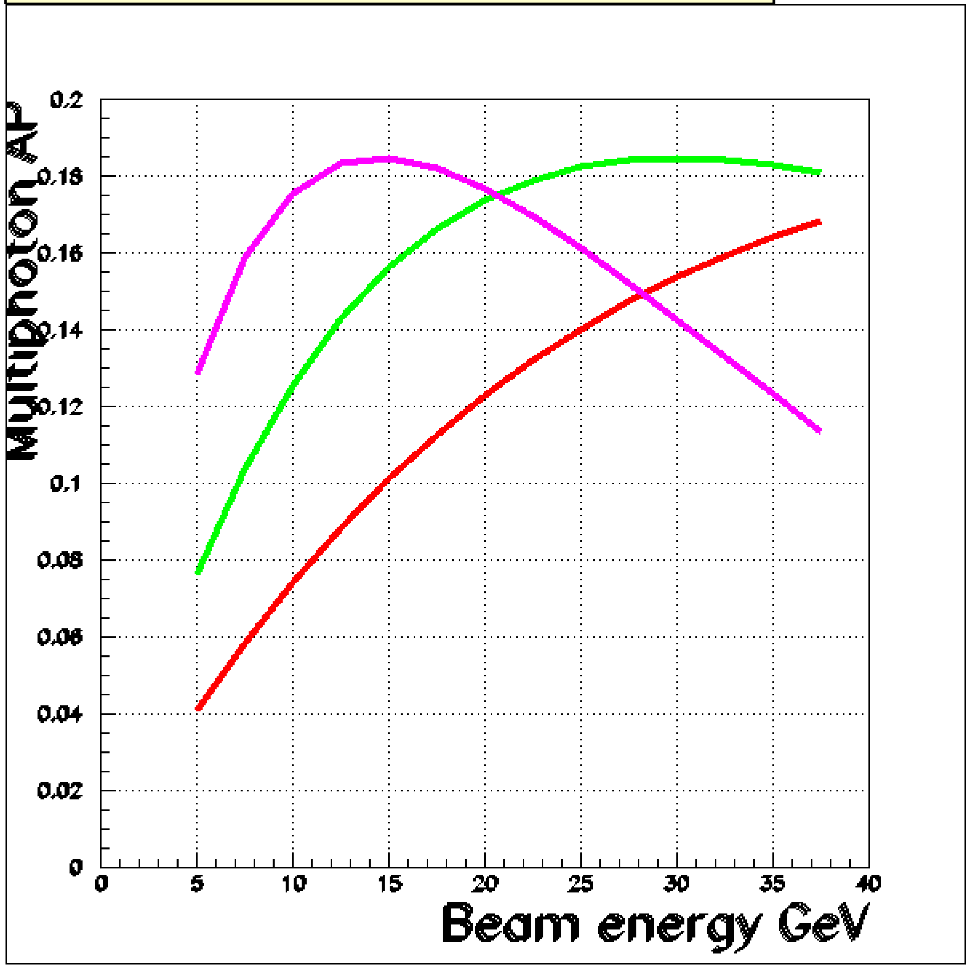
P_e: longitudinal polarization of **e beam**

P_λ: circular polarization (±1) of **laser beam**

Multi-Photon Mode

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

$A_p = (\Sigma_{3/2} - \Sigma_{1/2}) / (\Sigma_{3/2} + \Sigma_{1/2})$



Advantages:

- eff. independent of brems. bkg
- dP/P = 0.01 in 1 min
- in first approximation, independent from absolute energy calibration

Disadvantage:

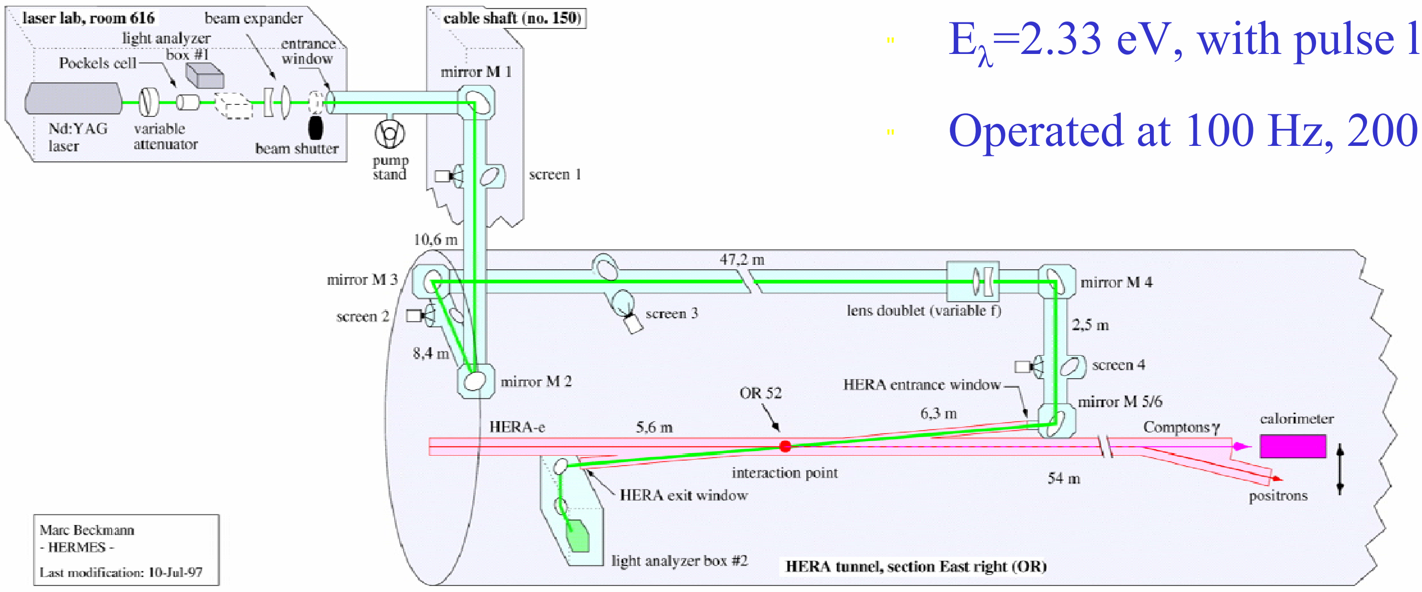
- no easy monitoring of calorimeter performance

LPOL, LIVE

- A. Most
- S. Borissov
- A. Simon
- M. Beckman
- B. Zihlmann
- R. Fabbri
- W. Lorenzon
- W. Deconinck
- J.Seibert
- A. Airapetian

Longitudinal Polarimeter

(M.Beckmann et al. NIM A479 (2002) 334-348)



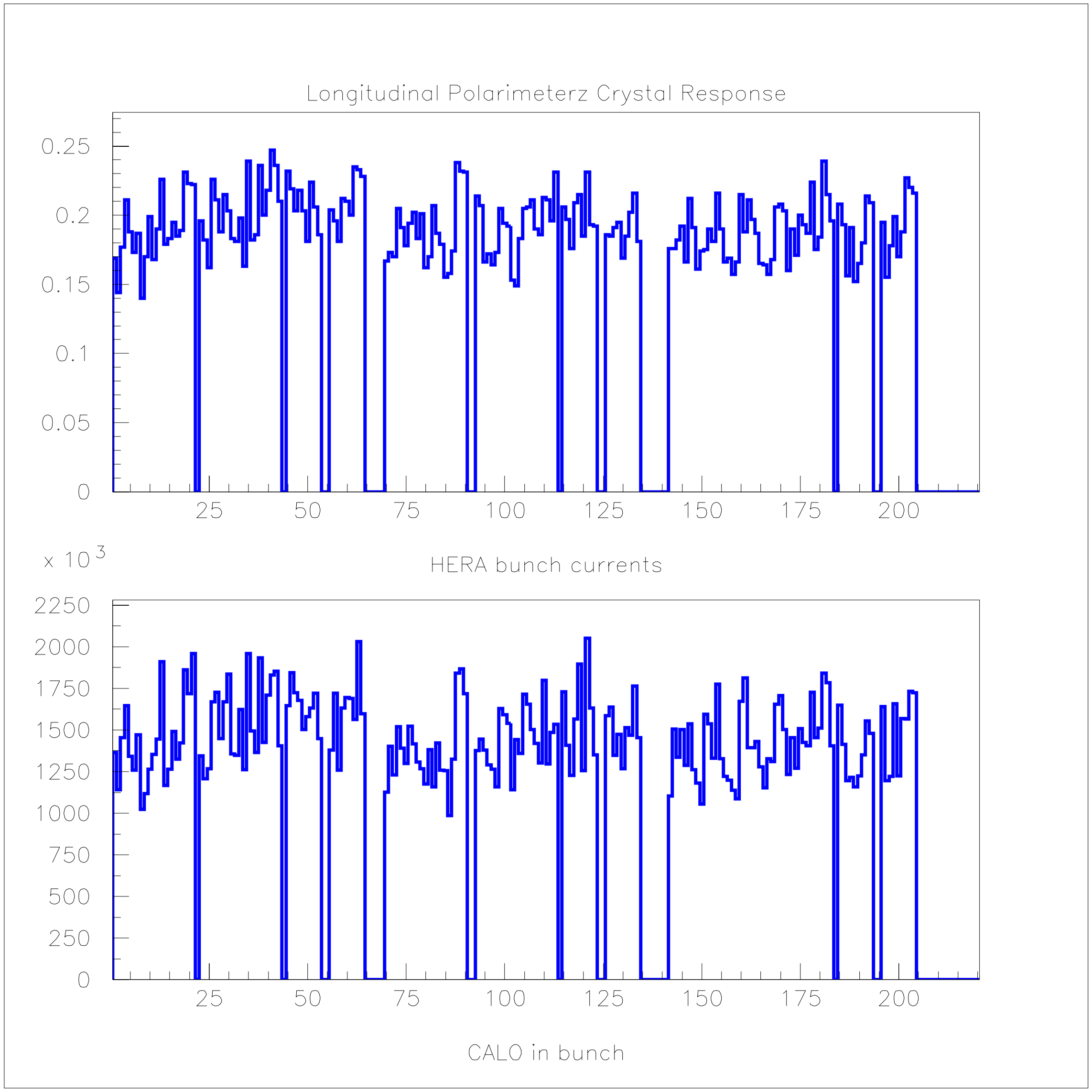
- Laser frequency doubled Nd:YAG
- E_λ=2.33 eV, with pulse length 3 ns
- Operated at 100 Hz, 200 mJ/pulse

LPOL: Details I

- Use HERA Clock and bunch structure to generate an appropriate trigger
- Depending on the type of trigger (Laser ON, OFF, BEAM ON, OFF)
  fire (don't fire) the laser
- Produce right (left) circularly polarized laser pulse using a Pockels Cell (depending on trigger)
- Send to IP and get Compton photons (background signal) to calorimeter
- Open the GATE and read all information you need to calculate bunch polarization
- Analyze laser pulse after IP to monitor S3

LPOL: Details II

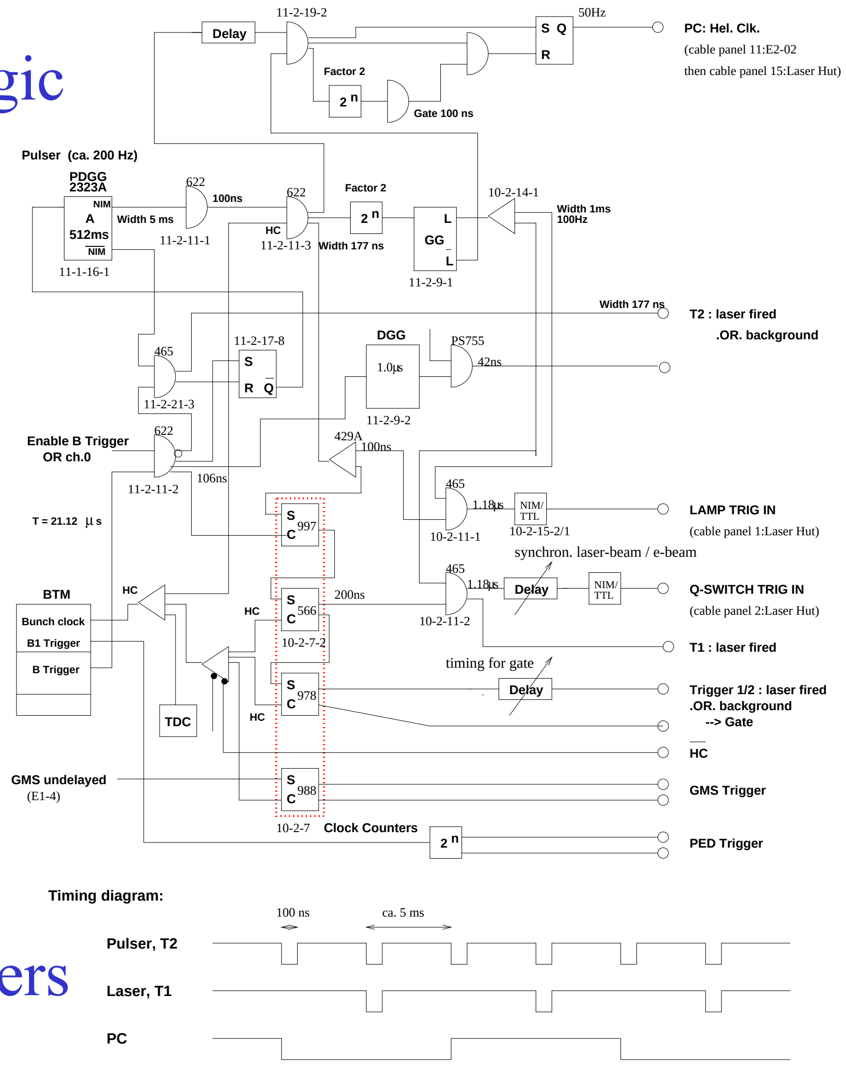
- Use HERA Clock and bunch structure to generate an appropriate trigger
- HERA electron bunches are separated by 96 ns. Depending on the fill there might be up to 180/220 bunches filled



LPOL: Details III

Trigger logic

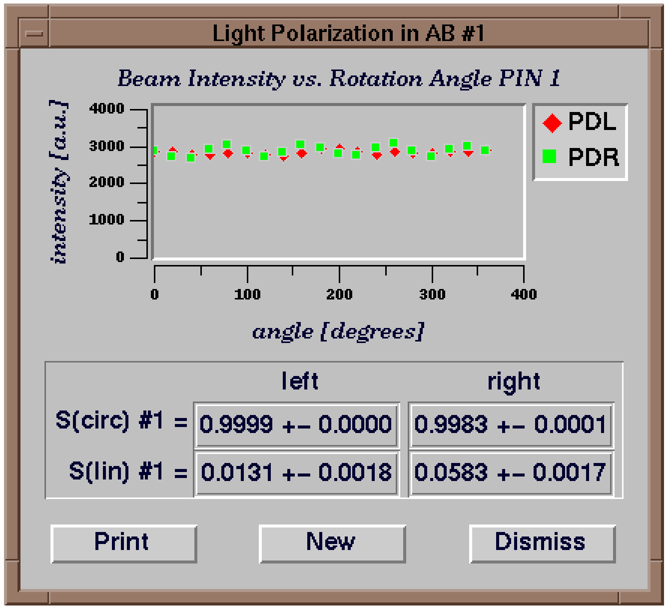
- Depending on the type of trigger (Laser ON, OFF, BEAM ON, OFF), laser is fired (or not)



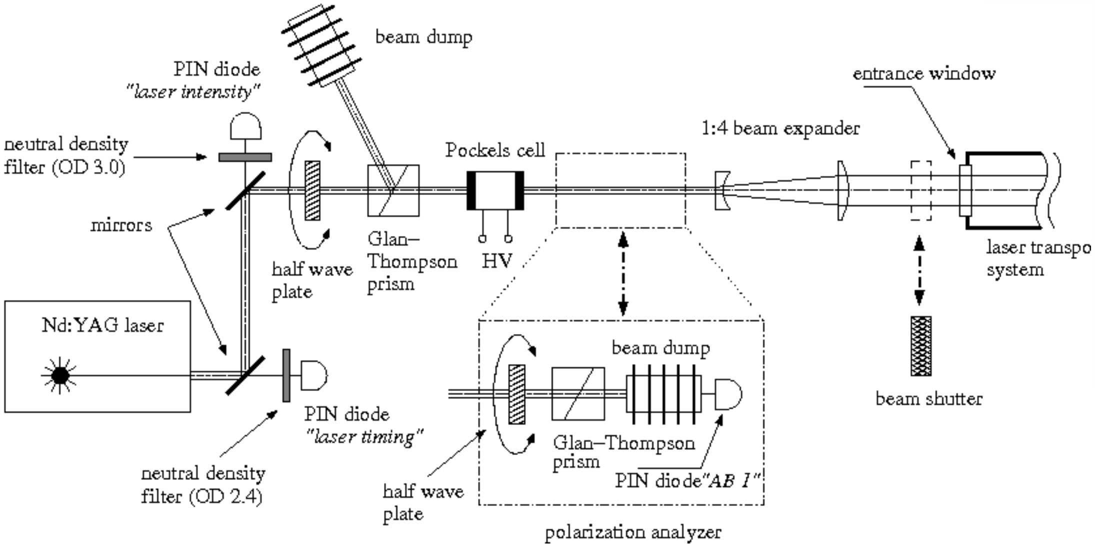
- LPOL startup, Triggers

LPOL: Details IV

- Produce right (left) circularly polarized laser pulse using a Pockels Cell

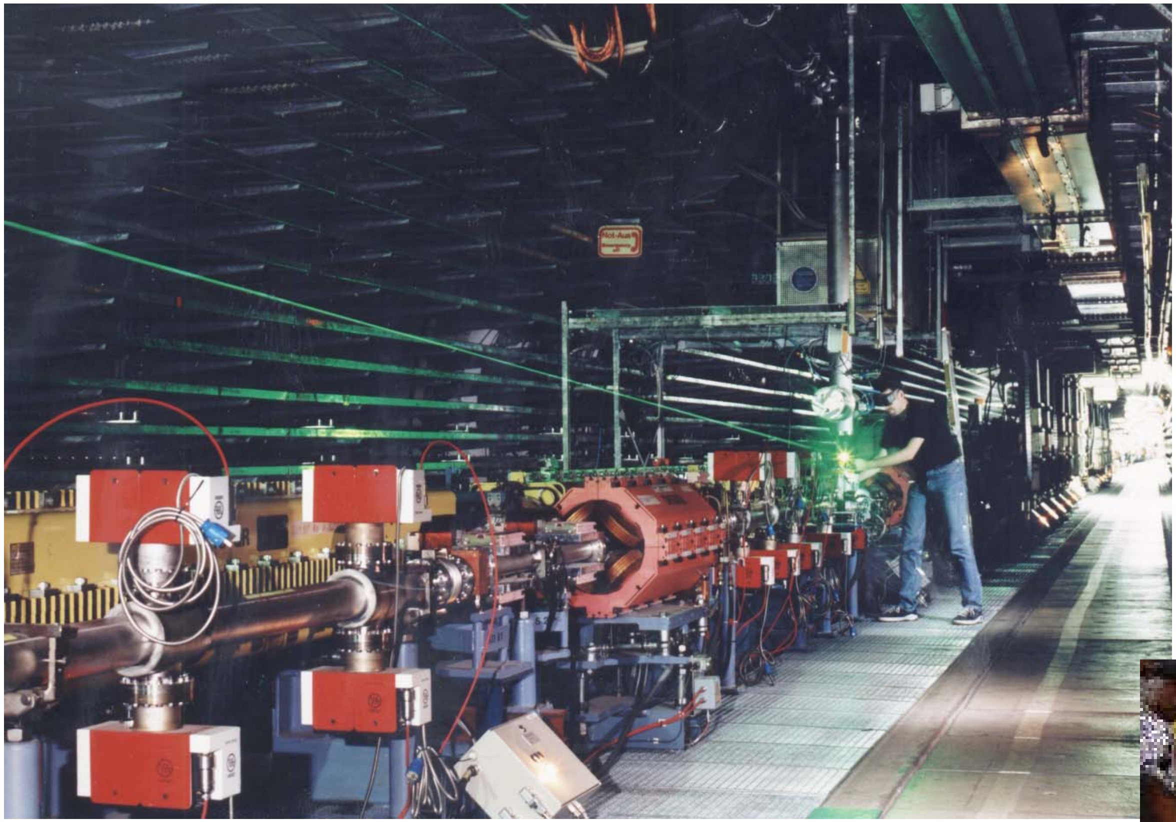


	left	right
S(circ) #1 =	0.9999 +- 0.0000	0.9983 +- 0.0001
S(lin) #1 =	0.0131 +- 0.0018	0.0583 +- 0.0017

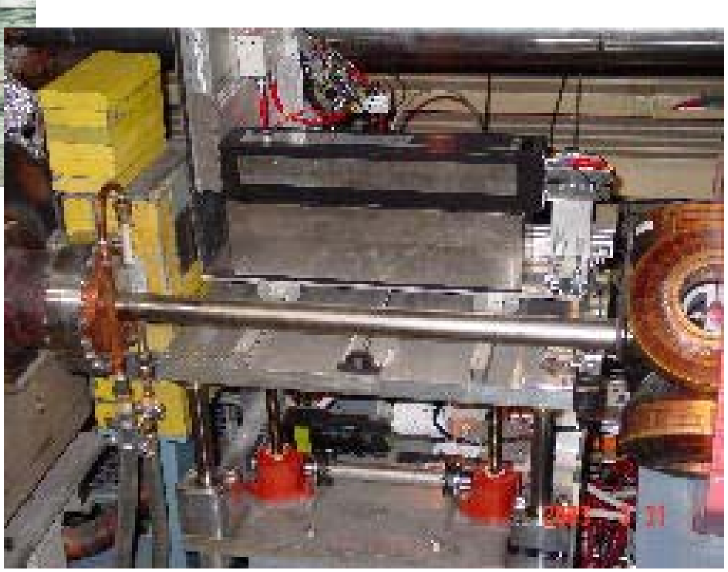


Laser travels ~80 m to IP

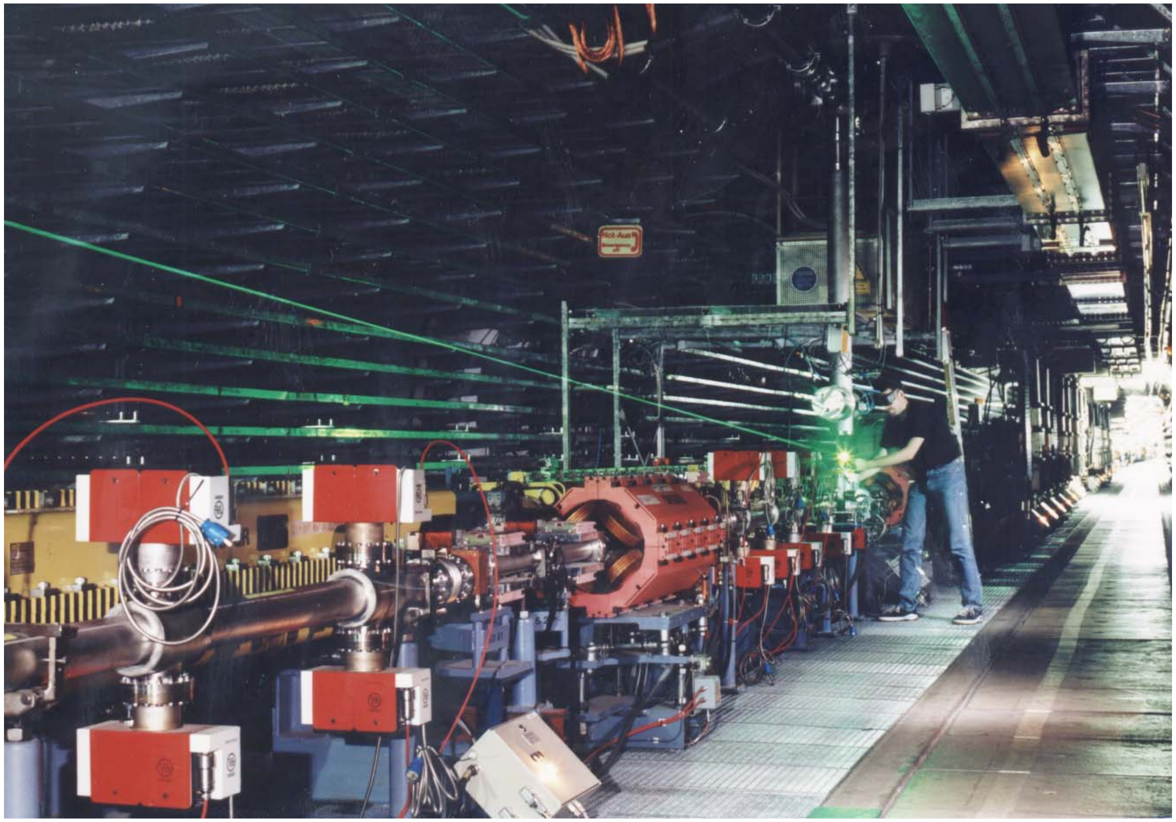
LPOL: Details V



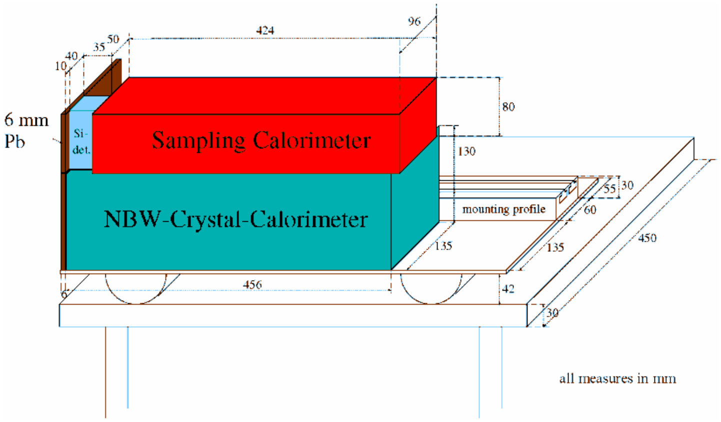
- Send laser pulse to IP and get Compton photons (background signal) to calorimeter



LPOL: Details V

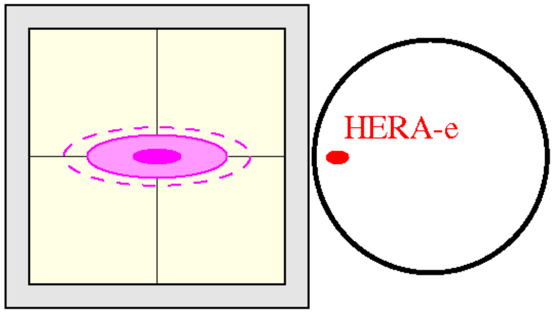


- Send laser pulse to IP and get Compton photons (background signal) to calorimeter

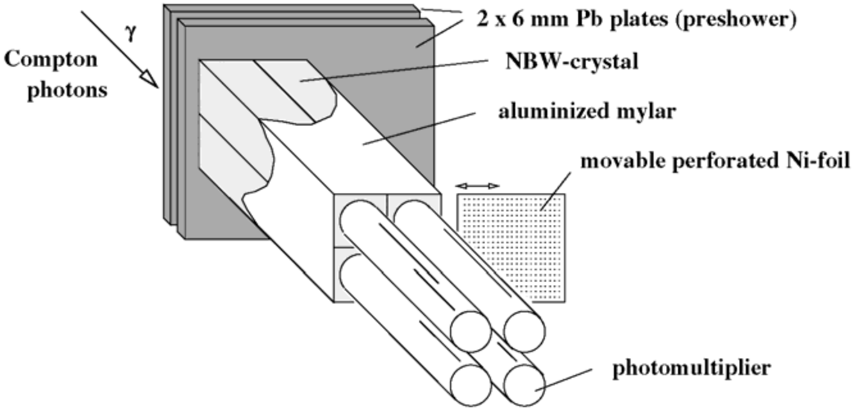


LPOL: Main Calorimeter

Calorimeter position



$NaBi(WO_4)_2$ crystal calorimeter



segmentation → position detection of Compton photons

$NaBi(WO_4)_2$ crystals: 22 x 22 x 200 mm^3

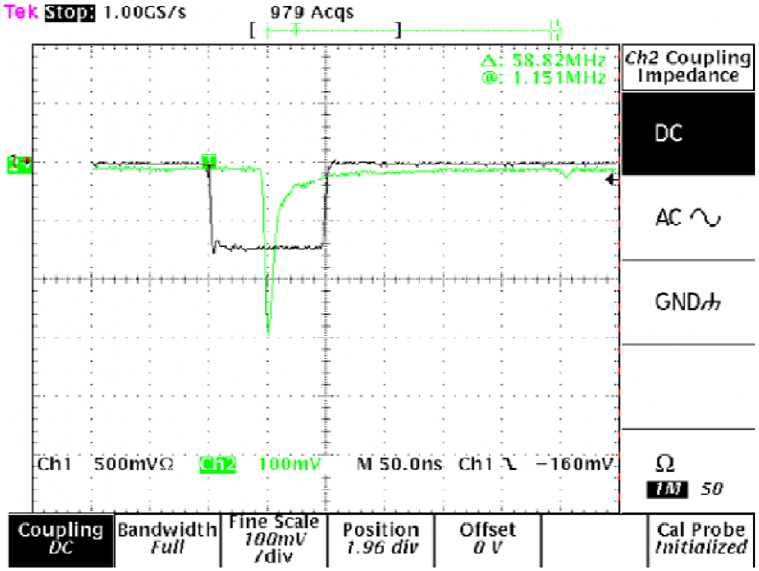
ρ : 7.57 g cm^{-2} X_0 : 1.03 cm

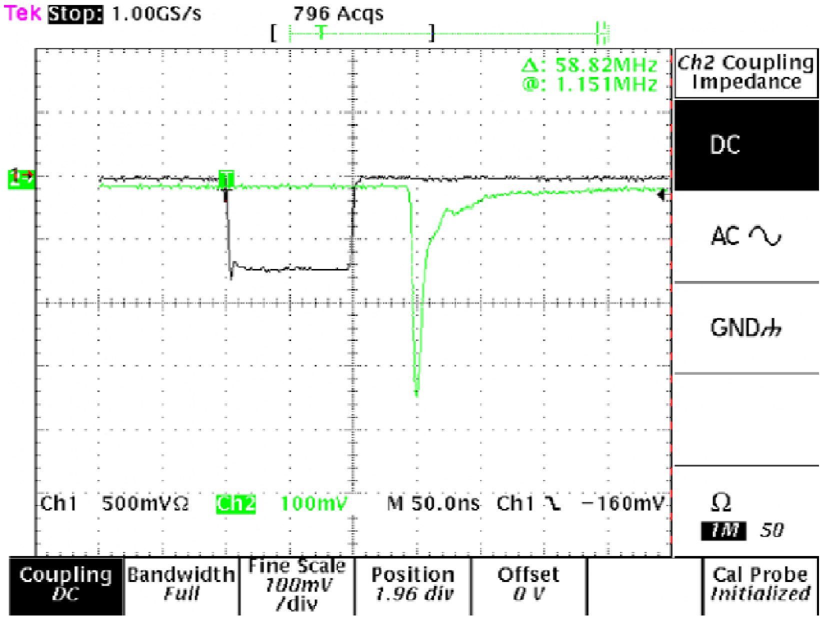
R_M : 2.38 cm rad. hard. : < 7 x 10^7 rad

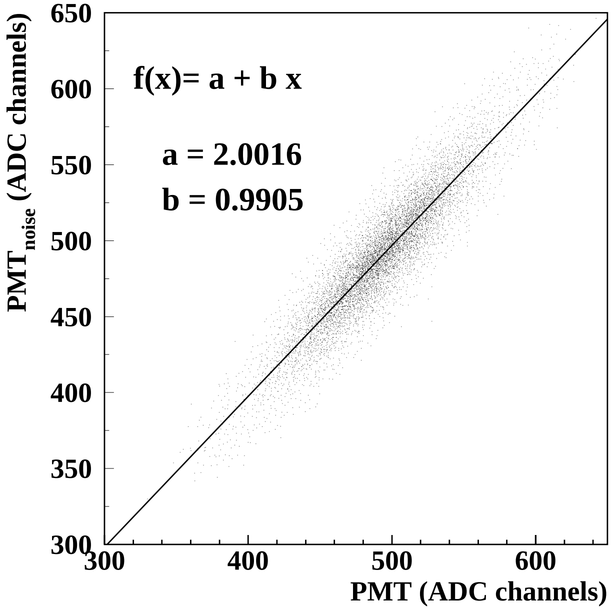
σ_t : 12 ns n : 2.15

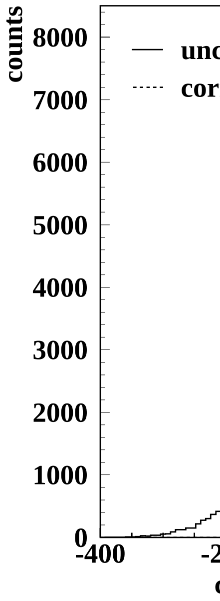
LPOL: Details VI

- Open the GATE and read every information you need to calculate bunch Polarization



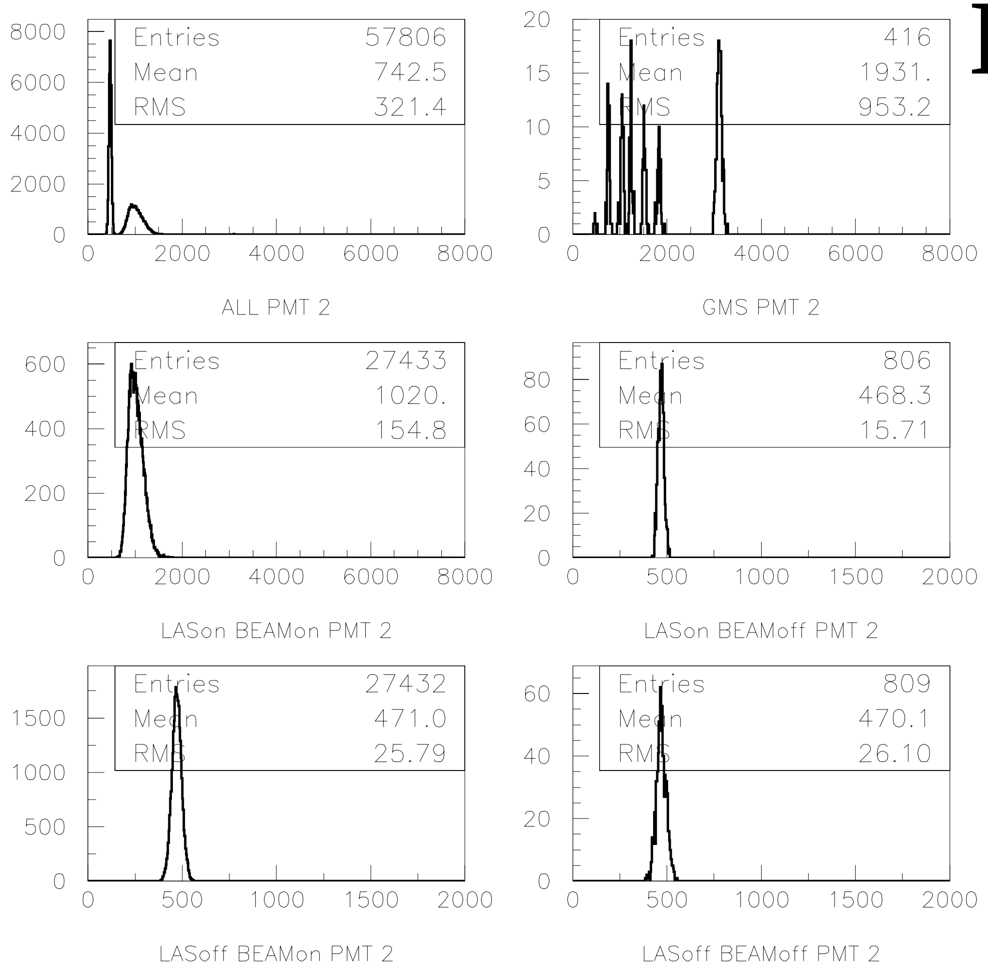






An elegant way to estimate Pedestal

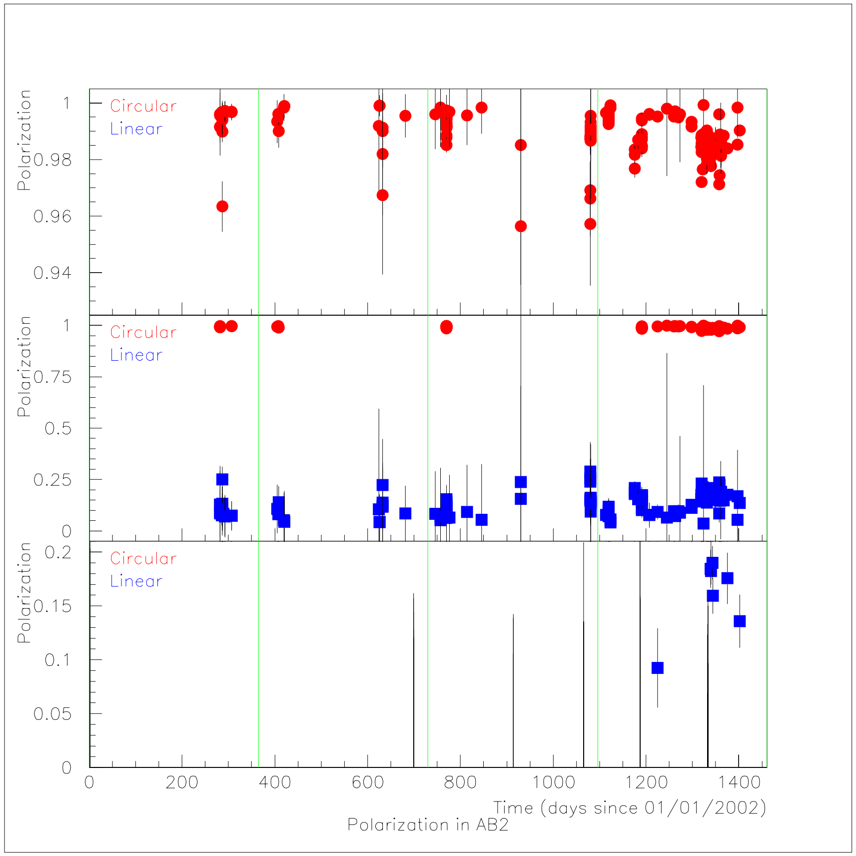
LPOL: Details VII



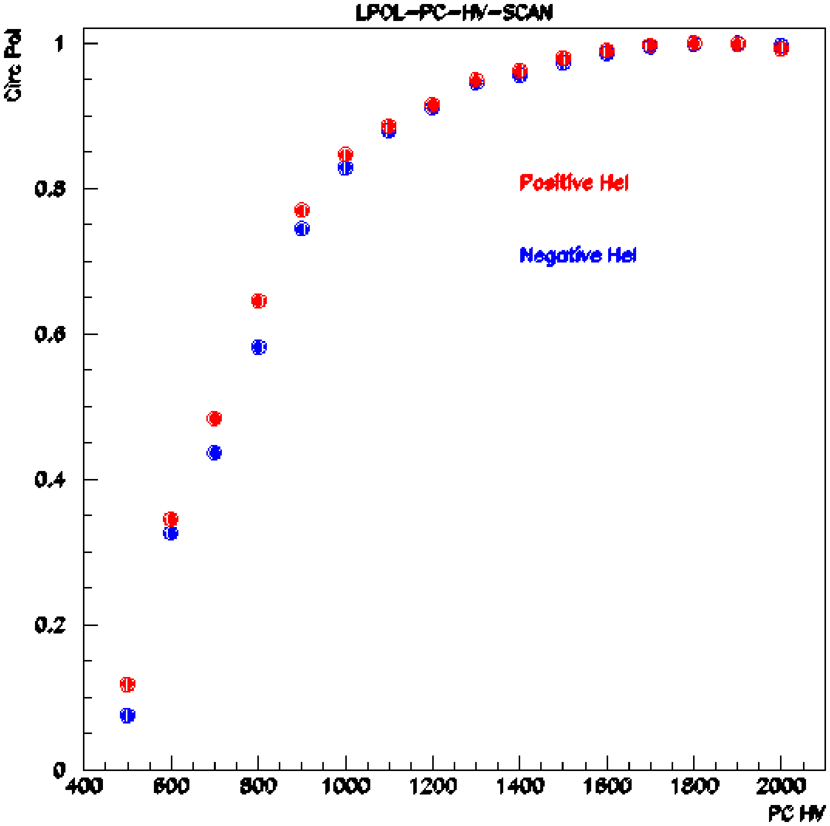
- Histogram for every event type and trigger

Correct for Pedestal, laser jitter, and gain matching . Then group in 220•2 histograms and calculate polarization for each bunch

LPOL: Details VIII

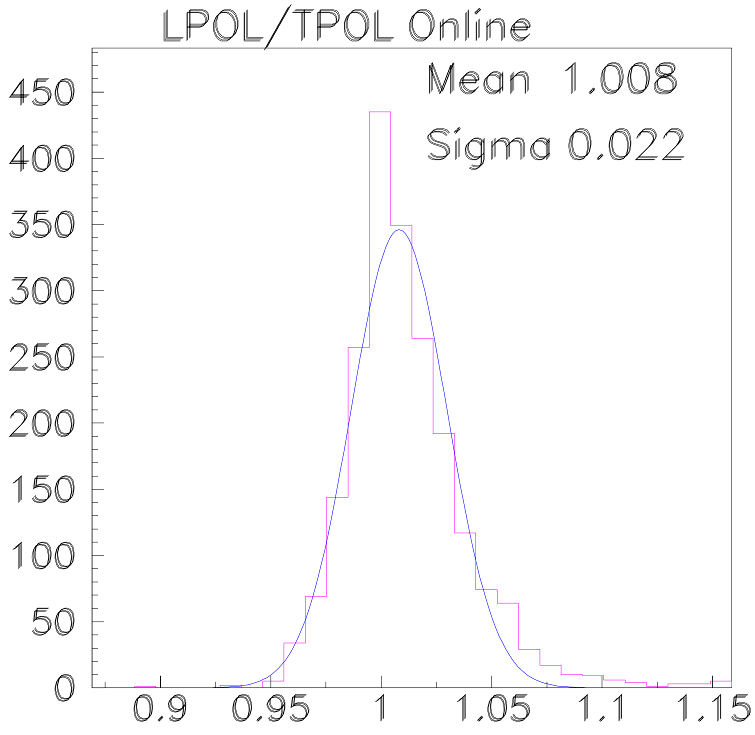


Analyze laser pulse after IP to monitor S3



Perform regular PC HV scans to ensure maximum and symmetric S3 at working voltage

LPOL error budget (1996-2000)



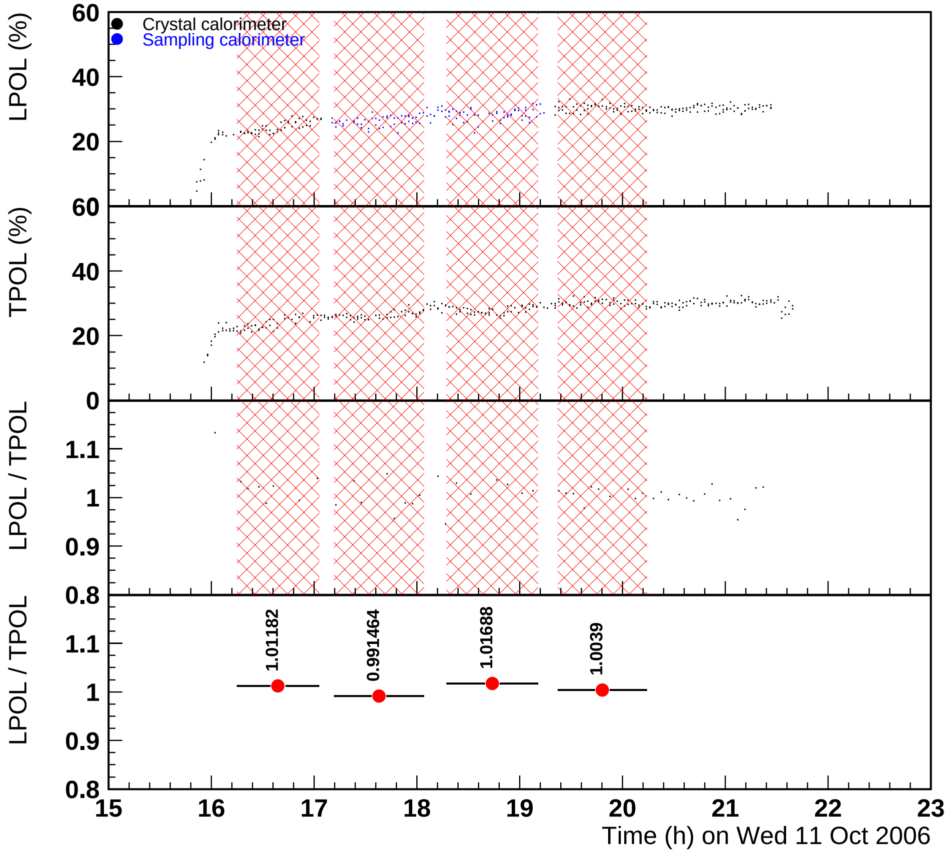
- comparison between LPOL and TPOL (1999)

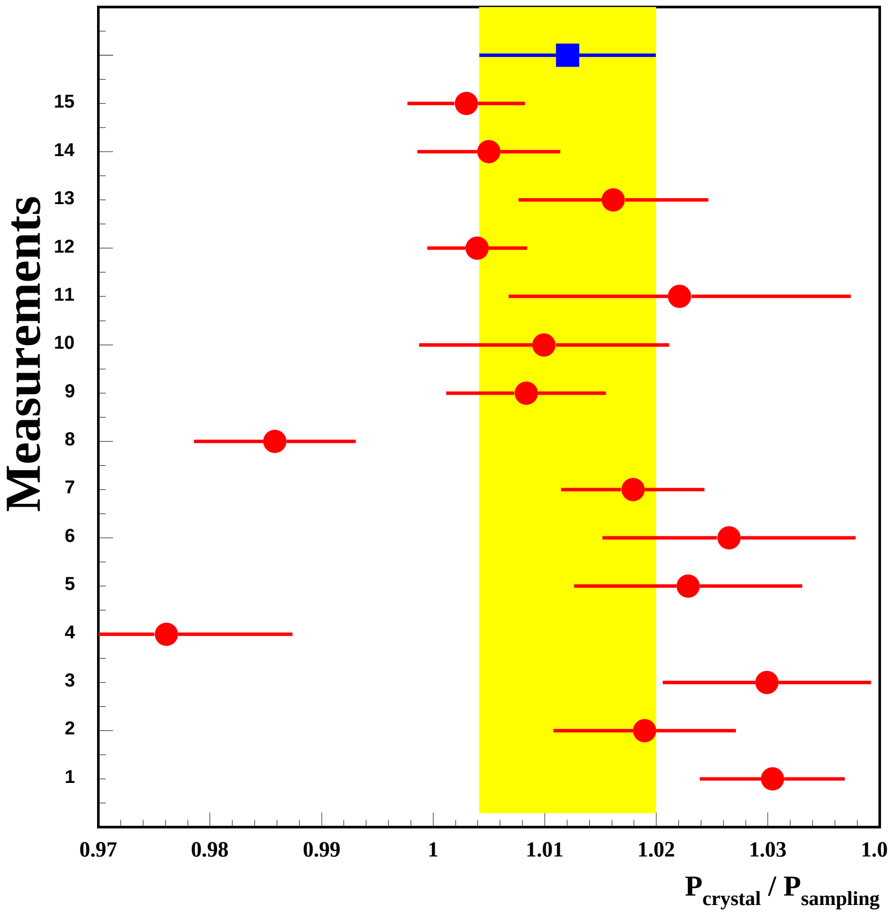
Source	$\Delta P_e/P_e$ (%) (2000)
Analyzing Power A_p	± 1.2
- response function	(±0.9)
- single to multi photon transition	(±0.8)
A_p long-term instability	± 0.5
- PMT linearity (GMS system checked)	(±0.4)
Gain mismatching	± 0.3
Laser light polarization	± 0.2
Pockels cell misalignment	± 0.4
- $\lambda/2$ plate (helicity dep. beam shifts)	(±0.3)
- laser-electron beam overlap	(±0.3)
Electron beam instability	± 0.8
- electron beam position changes	(±0.6)
- electron beam slope changes	(±0.5)
Total	**± 1.6**

LPOL error budget (2002-2007)

- Regularly check for possible false asymmetries with both sampling and crystal calorimeters
- Constantly monitor with GMS gain of both calorimeters (relative)
- Perform coordinate scans to check gain mismatching
- After every Pockels Cell change (they are subject of laser radiation damage) perform Pockels Cell HV scan to verify alignment
- Perform table offset scans to center Compton photons on calorimeter
- Vary laser power and check calorimeter response and measurement stability
- Alternate regularly between sampling and crystal calorimeters

LPOL error budget (2002-2007)

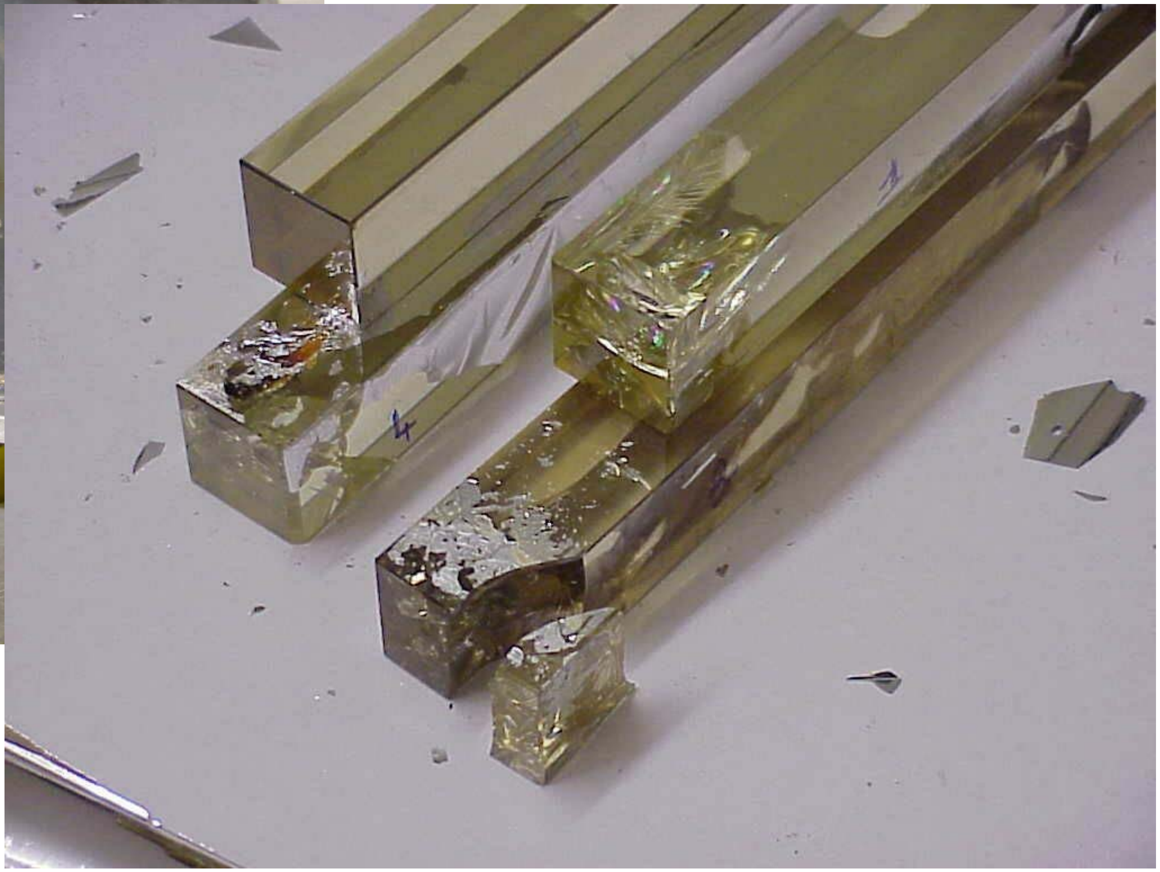




Have to supply OFFline LPOL measurements to Physics Analysers,but for preliminary results and numbers LPOL Group recommendation is used 2% as an upper limit for the LPOL systematic uncertainty

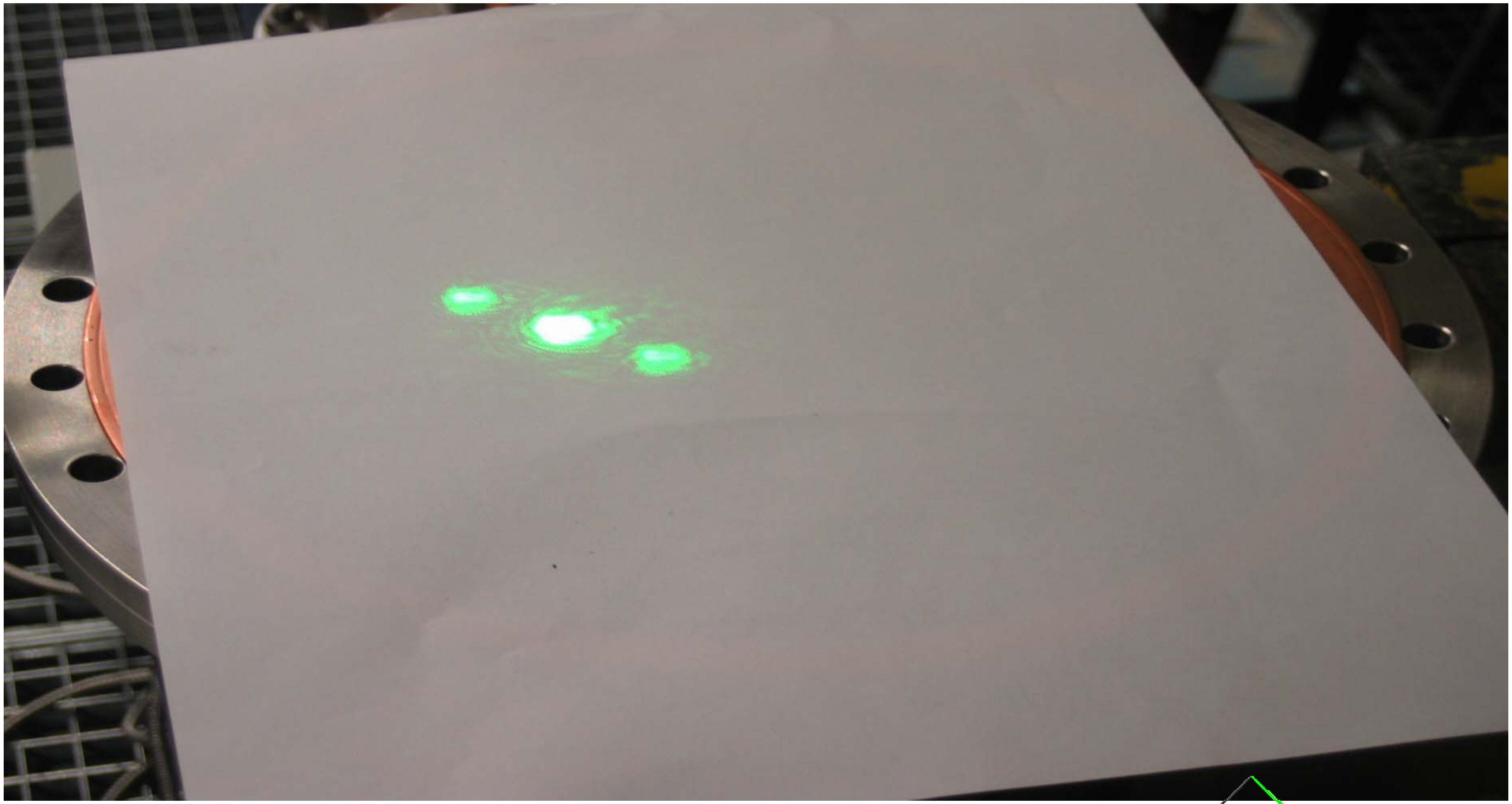
LPOL: Accidents

- **Sep 2003**, 1 rad length Pb was not enough!
- To withstand synchrotron radiation from HERMES Transverse Magnet: replaced Pb with1 rad length W, and monitored temperature

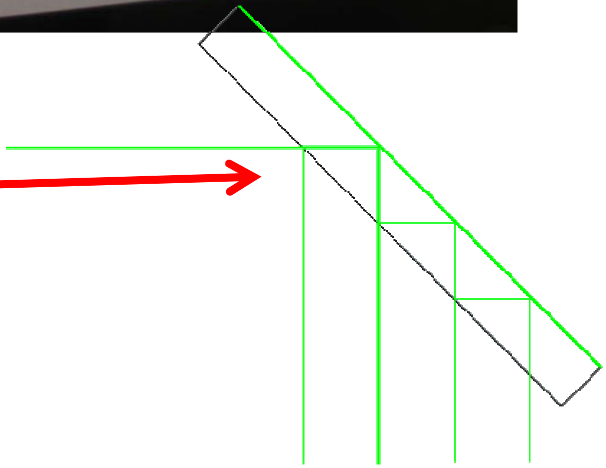


- **June 2004**, beam lost in LPOL area resulted in broken crystals!

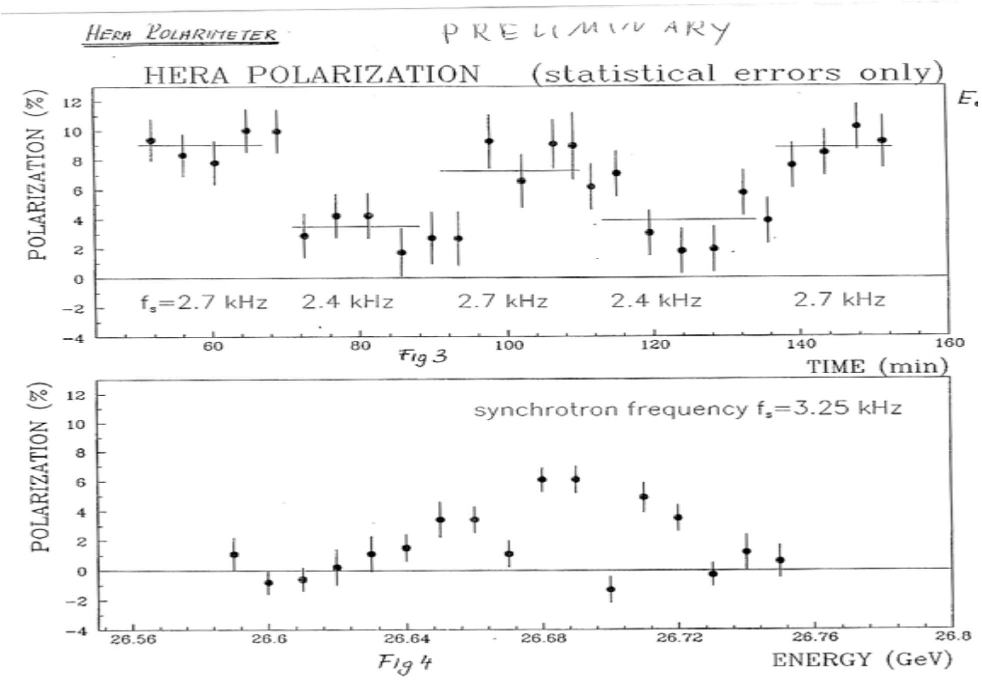
LPOL: Our own Mistakes

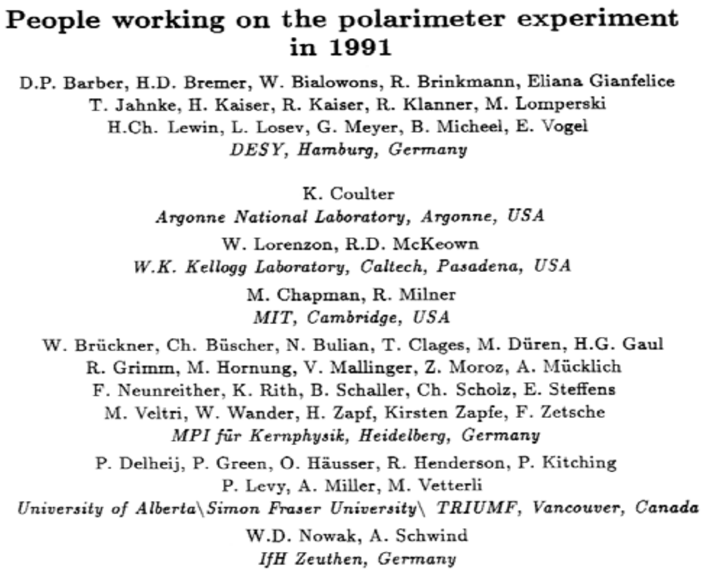


- In **Jan 2005** when rad damaged mirror was replaced , new mirror was mounted incorrectly (coating on wrong side): 3 spots instead of one!



Achievements:TPOL





People working on the polarimeter experiment in 1991

D.P. Barber, H.D. Bremer, W. Bialowons, R. Brinkmann, Eliana Gianfelice
T. Jahnke, H. Kaiser, R. Kaiser, R. Klanner, M. Lomperski
H.Ch. Lewin, L. Losev, G. Meyer, B. Micheel, E. Vogel
DESY, Hamburg, Germany

K. Coulter
Argonne National Laboratory, Argonne, USA

W. Lorenzon, R.D. McKeown
W.K. Kellogg Laboratory, Caltech, Pasadena, USA

M. Chapman, R. Milner
MIT, Cambridge, USA

W. Brückner, Ch. Büscher, N. Bulian, T. Clages, M. Düren, H.G. Gaul
R. Grimm, M. Hornung, V. Mallinger, Z. Moroz, A. Mücklich
F. Neunreither, K. Rith, B. Schaller, Ch. Scholz, E. Steffens
M. Veltri, W. Wander, H. Zapf, Kirsten Zapfe, F. Zetsche
MPI für Kernphysik, Heidelberg, Germany

P. Delheij, P. Green, O. Häusser, R. Henderson, P. Kitching
P. Levy, A. Miller, M. Vetterli
University of Alberta\Simon Fraser University\ TRIUMF, Vancouver, Canada

W.D. Nowak, A. Schwind
IfH Zeuthen, Germany

GREEN light to SPIN physics at HERA (1991)

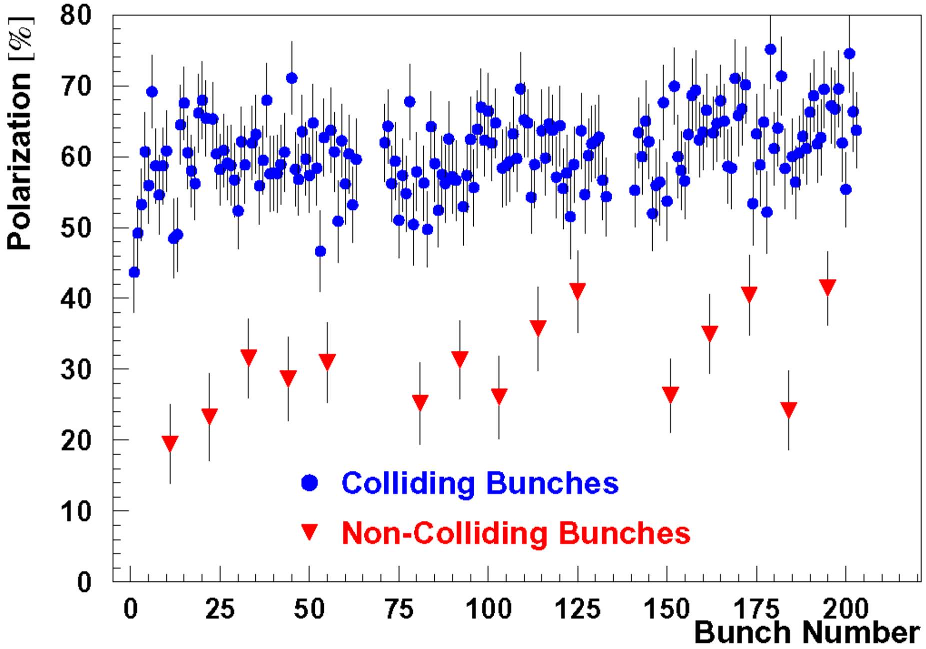
Achievements: LPOL

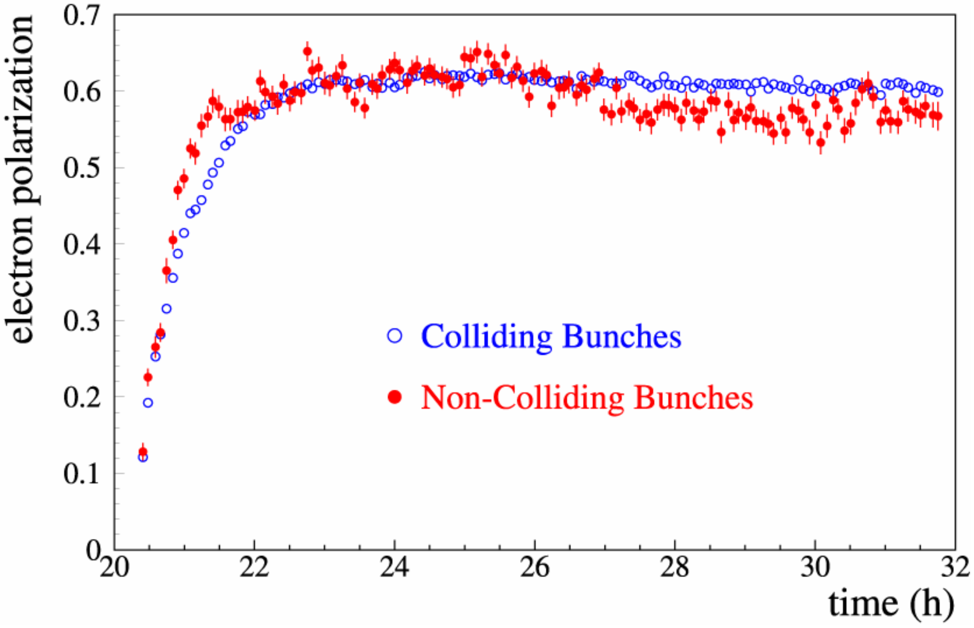
20 min measurement

dP/P = 0.03 in each bunch

time dependence:

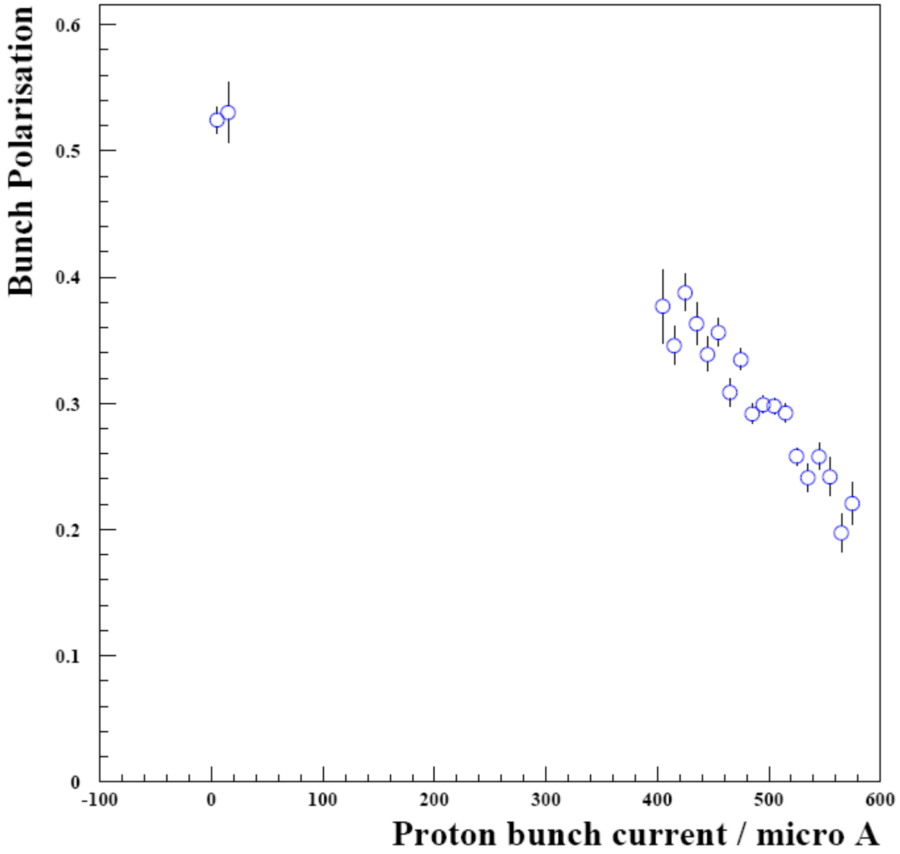
helpful tool for tuning





First measurement of BUNCH polarization:
New tool for tuning for high polarization!

Achievements: Cavity LPOL



Data of Sept. 14, 2005

➔ The observation with cavity of the anti-correlation between the P_e values and the p-beam current

This effect has to be taken into account in the physics analyses

- Maybe will help for HERA Machine Monte Carlo simulations to pin down polarization ristetime scale

Thanks to the People from whom I borrowed slides & graphs

- K.Rith HERA END of DATA Taking Symposium
- S.Schmitt H1&ZEUS talk at Moriond 2007
- W.Lorenzon various talks
- Beautiful, MultyTalent LPOL Group, who designed, built, and maintained LPOL at high level for more than 10 Years

Conclusions

- Compton MultiPhoton mode proved to be very robust in measuring electron/positron beam polarization in a high energy collider
- Polarisation (Polarimetry) is a tool to significantly enhance Physics Programs at many Research centers, therefore:
- It has to be included into design of the new machines and gain appropriate attention (see W. Deconinck’s presentation)