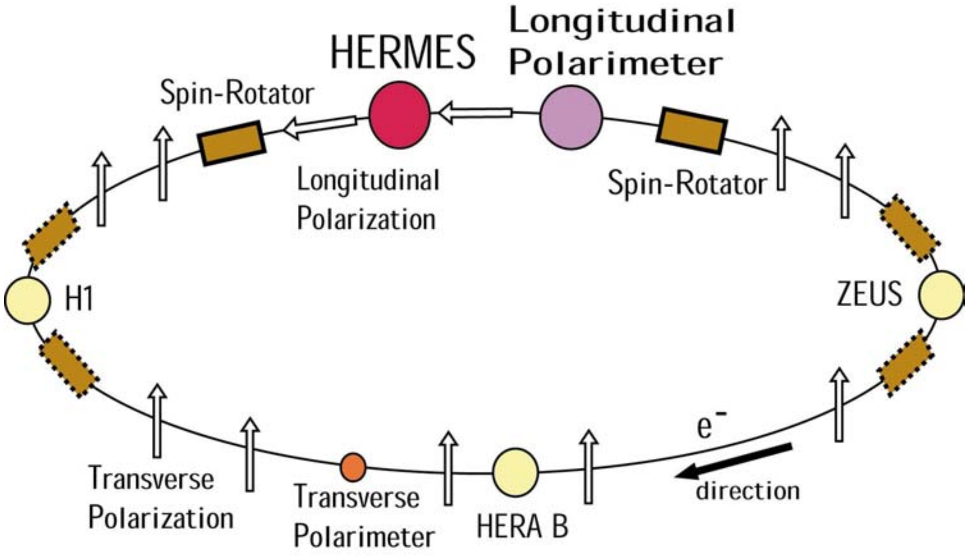
The Longitudinal Polarimeter at HERA

W. Lorenzon (Michigan)
Precision Electron Polarimetry at Jlab

(10 June 2003)

- Electron Polarization at HERA
- Laser System & Calorimeter
- Statistical and Systematic Precision
- Laser Cavity Project
- Summary and Outlook

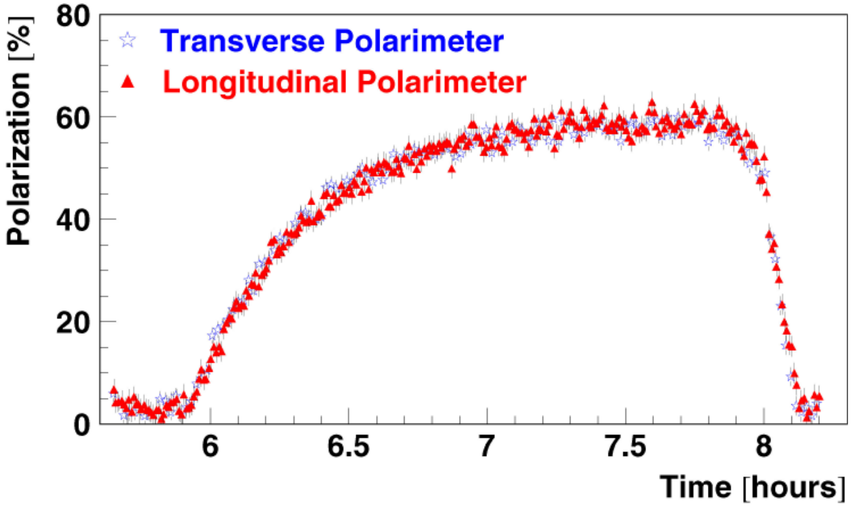
Electron Polarization at HERA



Self polarization of electrons by Synchrotron radiation emission in curved sections:

Sokolov-Ternov effect ($\tau \sim 30$ min.)

$$P(t) = P_{\infty} \cdot (1 - e^{-t/\tau})$$



Sokolov Ternov Effect

- $P_{ST} = 0.924$ for an ideal, flat machine, independent of any machine parameter
- $\tau_{ST} = 37$ min for HERA @ 27.5 GeV (prop. $1/\gamma^5$, R^3)
- depolarization effects (τ_D) in a real machine
  → can substantially reduce P_{max}:

$$P_{\max} = P_{ST} \frac{\tau_D}{\tau_{ST} + \tau_D}$$

  → and effective build-up time constant τ:

$$\tau = \tau_{ST} \frac{\tau_D}{\tau_{ST} + \tau_D}$$

- P_{ST} and τ_{ST} calculable from first principles
  → a simultaneous measurement of P_{max} and τ provides a calibration method:

$$P_{\max} = \tau \left(\frac{P_{ST}}{\tau_{ST}} \right) = k \cdot P_{meas}$$

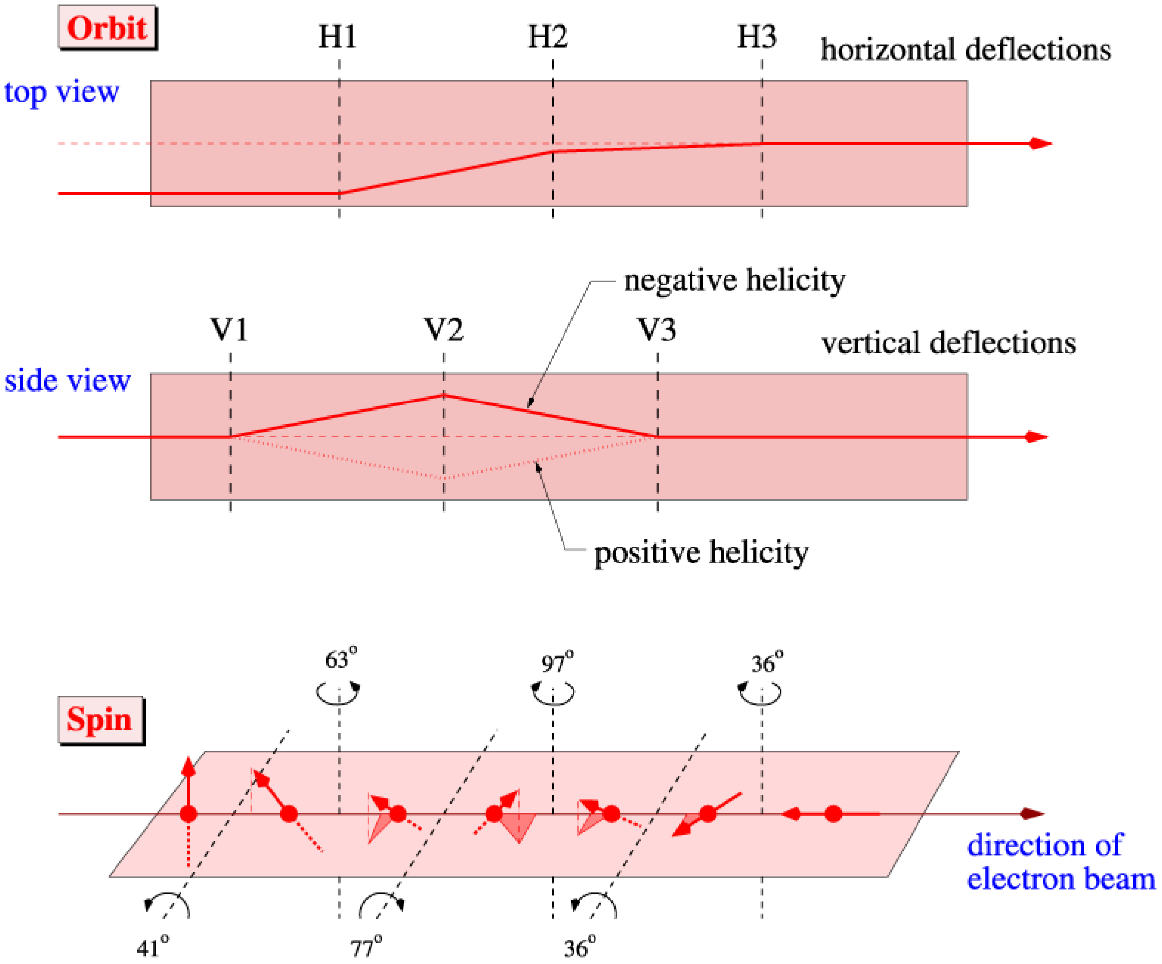
HERMES Spin Rotators

$$\Delta\phi_{spin} = G\gamma\Delta\phi_{orbit}$$

Spin Tune at 27.5 GeV

$G\gamma = E/(0.440\ \text{GeV}) = 62.5$

$\Delta\phi_{spin}$	$\Delta\phi_{orbit}$ (mrad)
45^0	12.5
90^0	25
180^0	50



Principle of the P_e Measurement with the Longitudinal Polarimeter

e (27.5 GeV)

λ (2.33 eV)

α

back scattered Compton photon

E_γ

Calorimeter

Compton Scattering:

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

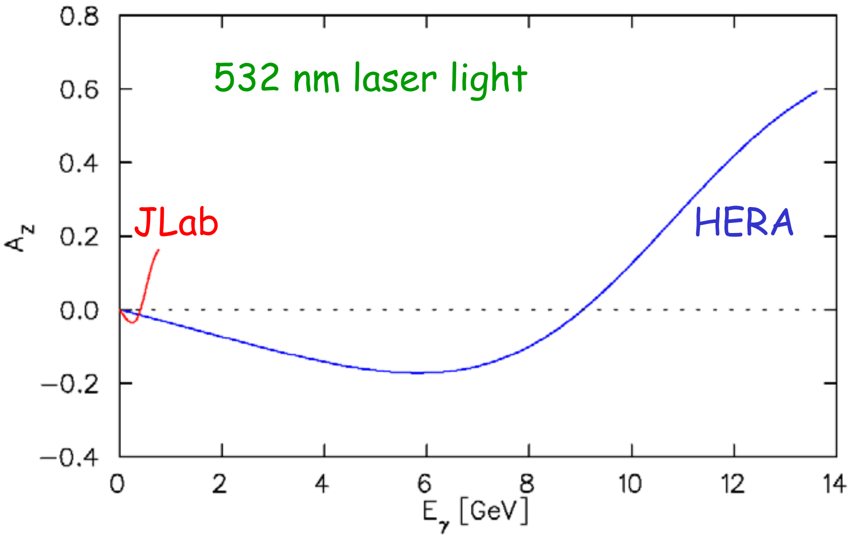
Cross Section:

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

$d\sigma_0$, A_z: known (QED)

P_e: longitudinal polarization **of e beam**

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



Compton edge: $E_\gamma^{max} \propto E_e^2 E_\lambda$

Asymmetry: $A \propto E_e E_\lambda$

Compton Polarimetry at HERA

Operating Modes and Principles

Laser Compton scattering off HERA electrons

TPol

CW Laser – Single Photon

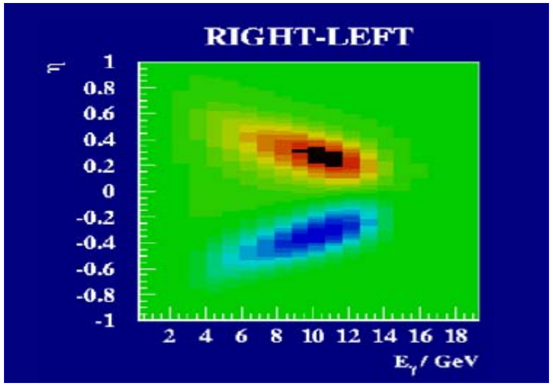
LPol

Pulsed Laser – Multi Photon

Flip laser helicity and measure scattered photons

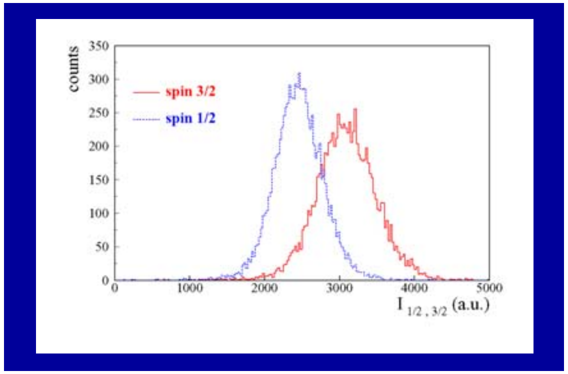
$P_y = 0.59$

Spatial Asymmetry



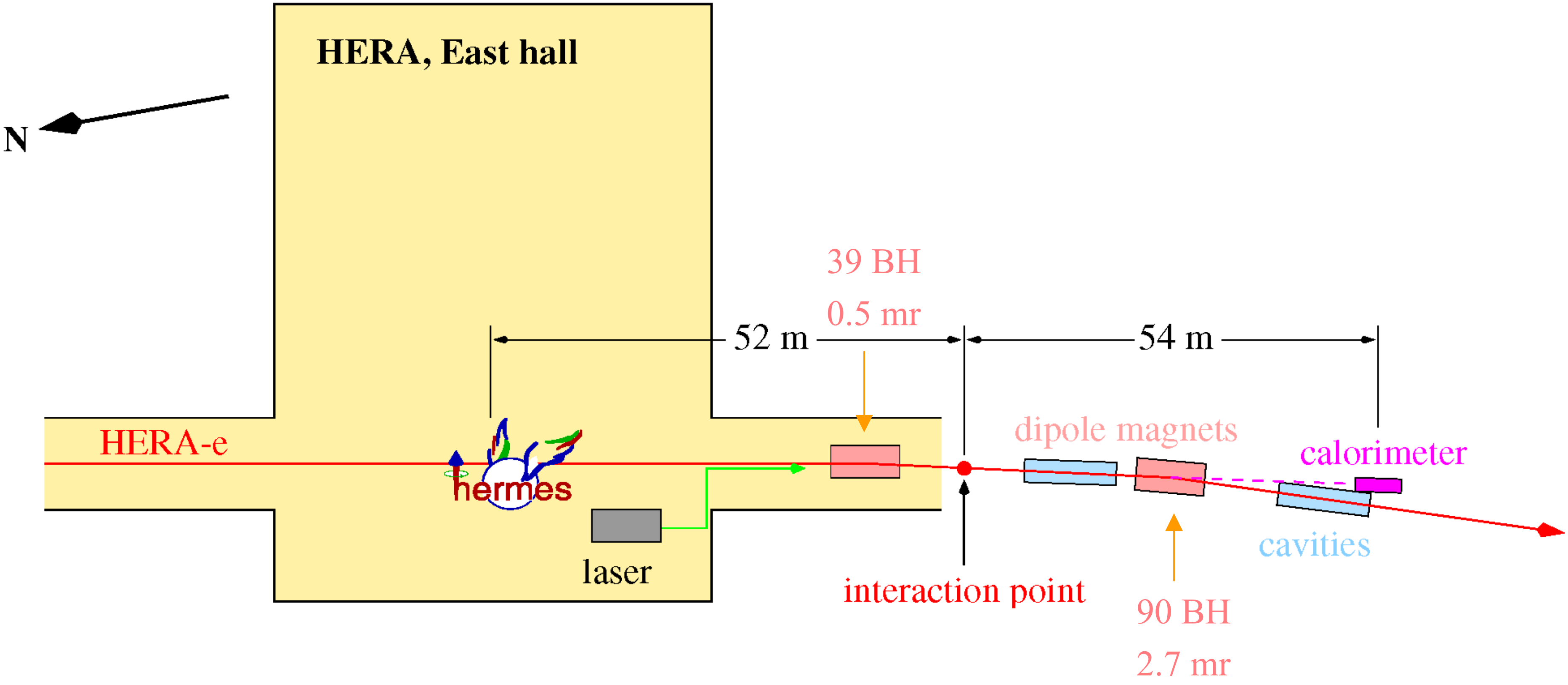
$P_z = 0.59$

Rate or energy Asymmetry



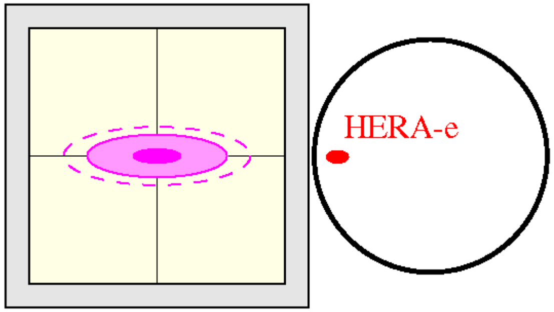
Statistical Error $\Delta P = 1\%$ per minute @ HERA average currents

Experimental Setup - Overview

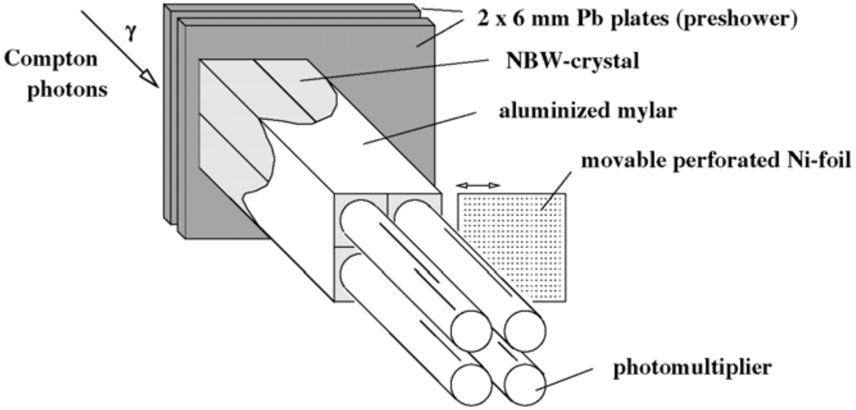


Experimental Setup - Calorimeter

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

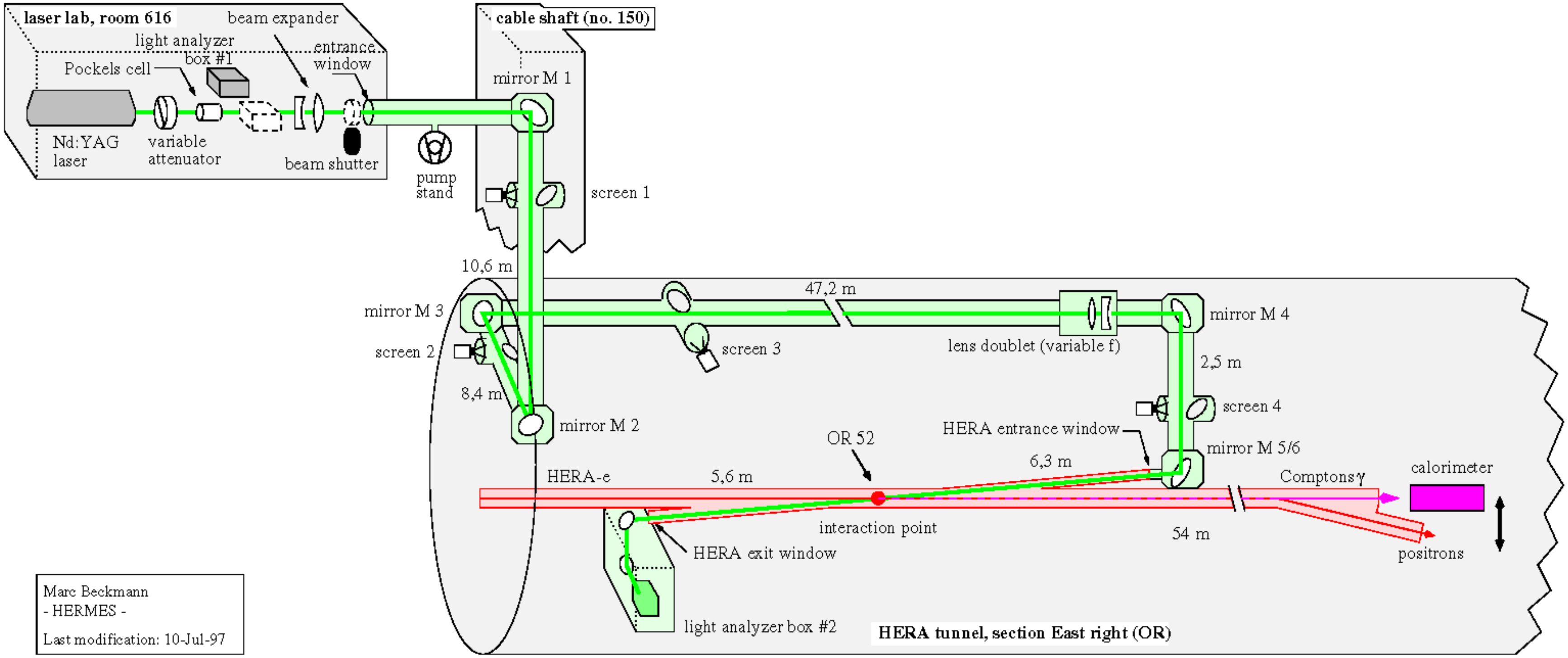
R_M : 2.38 cm

rad. hard. : < 7 x 10^7 rad

σ_t : 12 ns

n : 2.15

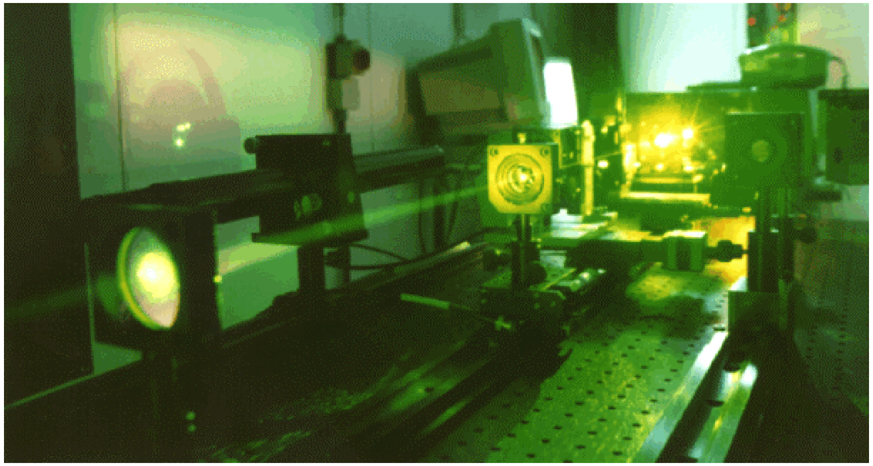
Experimental Setup – Laser System



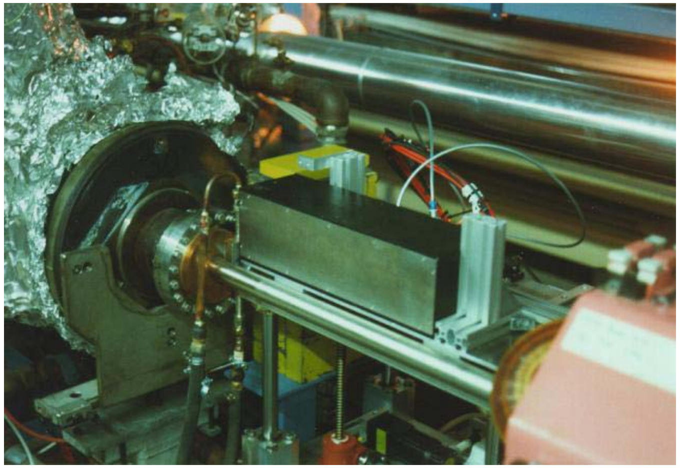
- M1/2 M3/4 M5/6: phase-compensated mirrors
- laser light polarization measured continuously in box #2

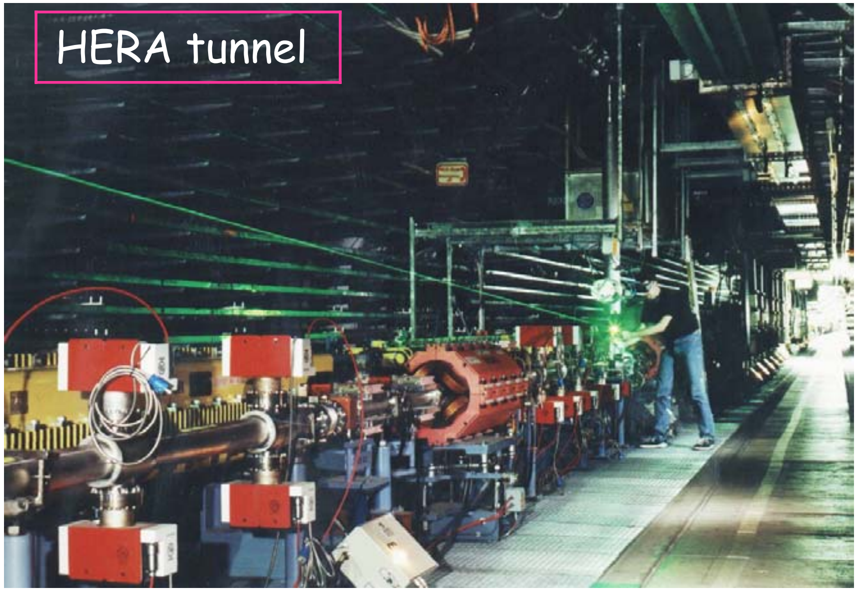
Experimental Setup - Details

beam expander

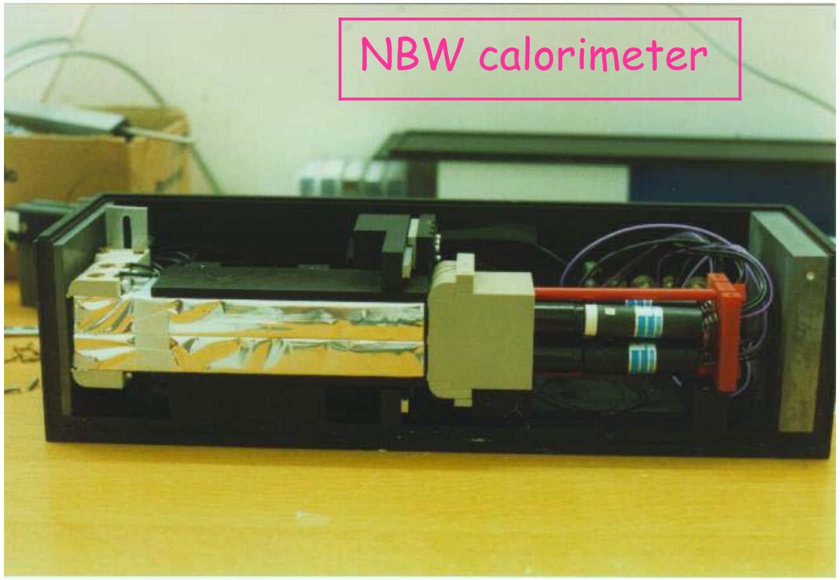


calorimeter position



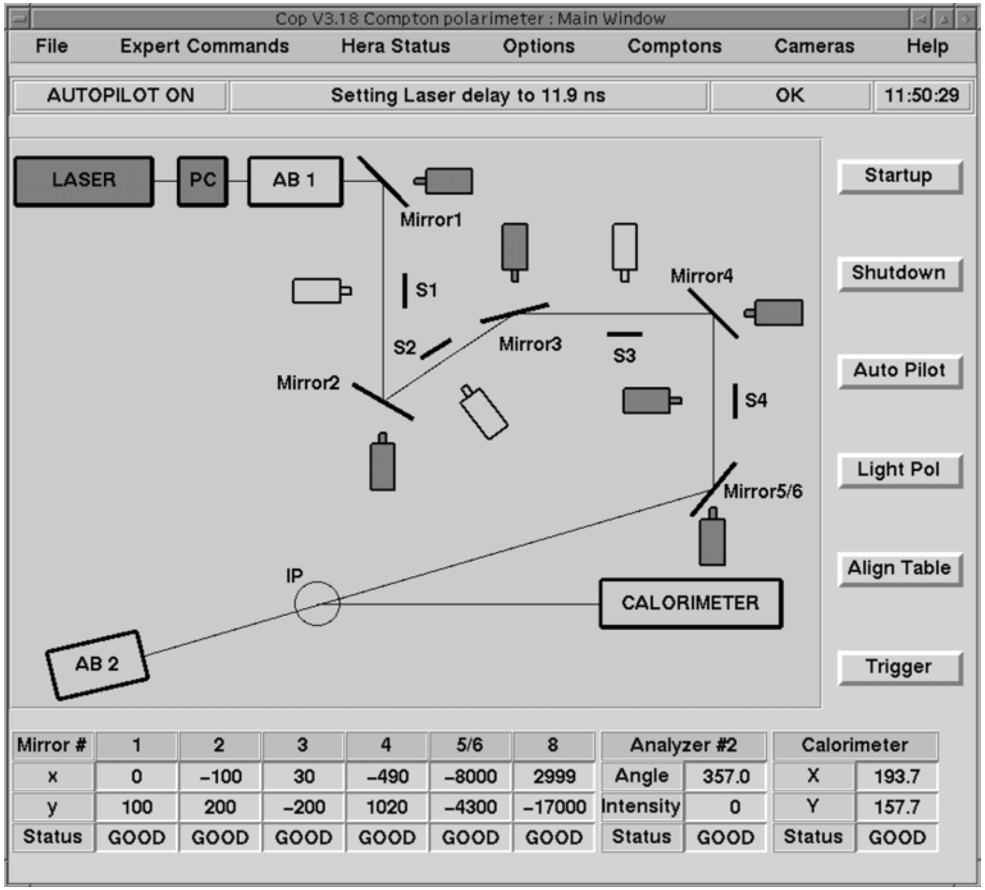


HERA tunnel



NBW calorimeter

Laser Control - COP



AUTOPILOT ON | Setting Laser delay to 11.9 ns | OK | 11:50:29

Mirror #	1	2	3	4	5/6	8
x	0	-100	30	-490	-8000	2999
y	100	200	-200	1020	-4300	-17000
Status	GOOD	GOOD	GOOD	GOOD	GOOD	GOOD

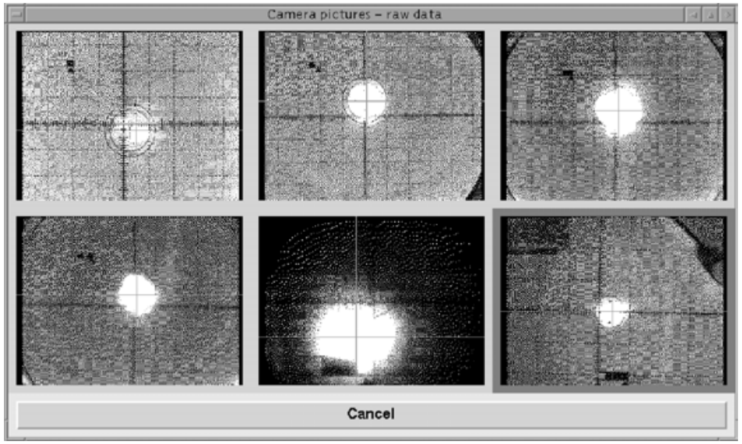
Analyzer #2	
Angle	357.0
Intensity	0
Status	GOOD

Calorimeter	
X	193.7
Y	157.7
Status	GOOD

Automatic Control

- Synchronizing laser and electron beam
- optimize luminosity
- optimize λ polarization
- center γ beam on calorimeter
- control & readjust all parameters: …

  laser spots on all mirrors using CCD cameras



Polarimeter Operation I

Single-Photon Mode

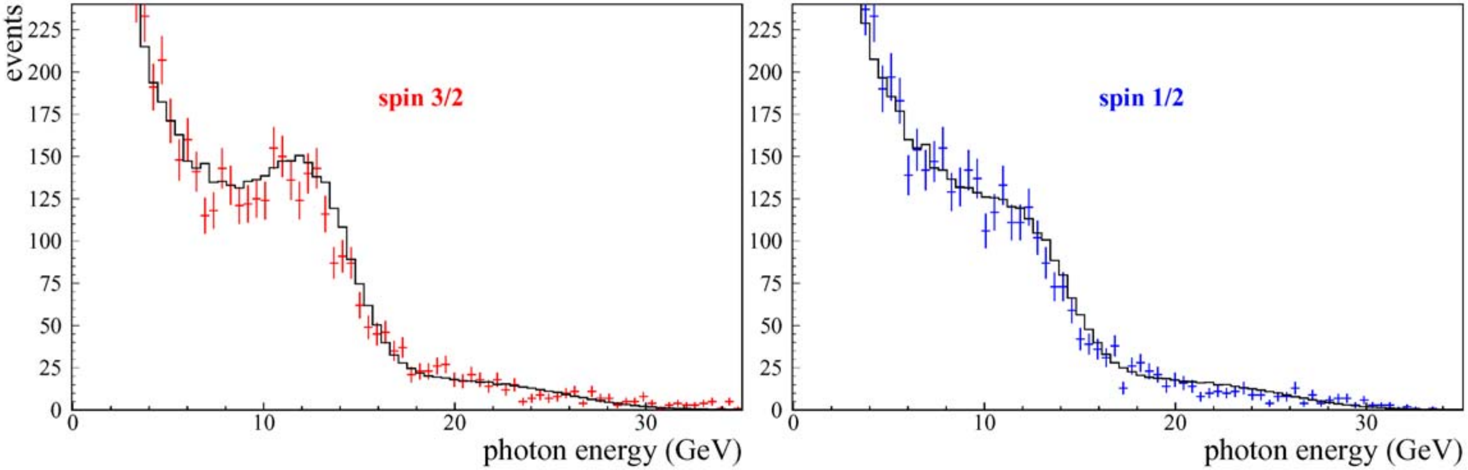
Advantages:

- large asymmetry: 0.60 (max)
- easy comparison to dσ/dE

Disadvantage:

- dP/P = 0.01 in 2.5 h (too long)

$$A_s(E_\gamma) = (\sigma_{3/2} - \sigma_{1/2}) / (\sigma_{3/2} + \sigma_{1/2})$$
$$= P_e \, P_\lambda \, A_z(E_\gamma)$$



Polarimeter Operation II

Multi-Photon Mode

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

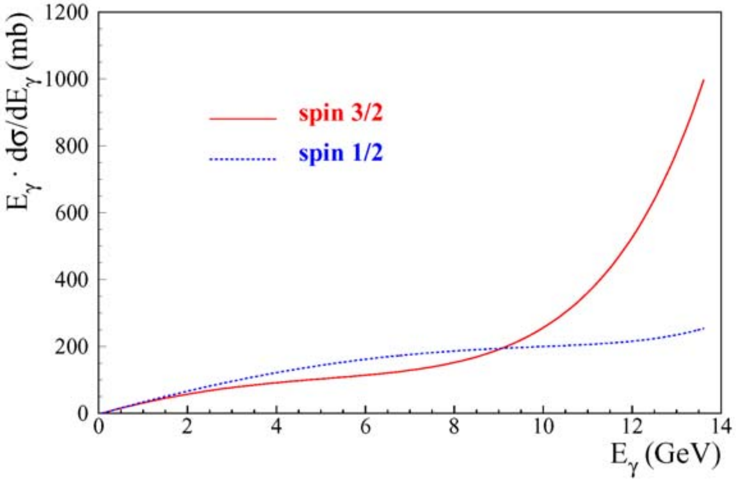
Advantages:

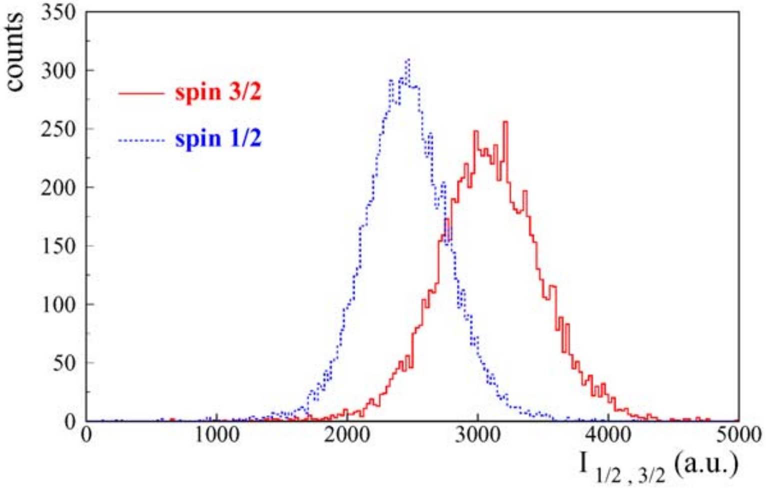
- eff. independent of brems. bkg and photon energy cutoff
- dP/P = 0.01 in 1 min

Disadvantage:

- no easy monitoring of calorimeter performance

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





Polarization Determination

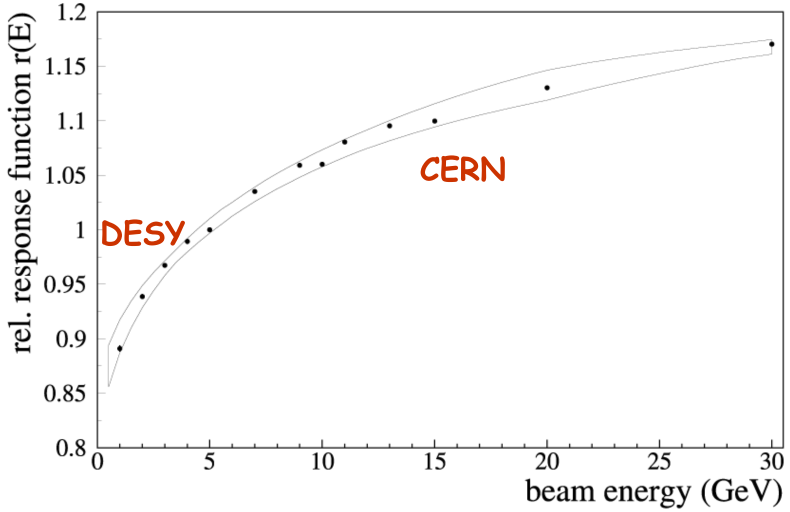
$$A_p = (\Sigma_{3/2} - \Sigma_{1/2}) / (\Sigma_{3/2} + \Sigma_{1/2})$$
$$= 0.193 \quad \text{(for crystal calorimeter)}$$

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

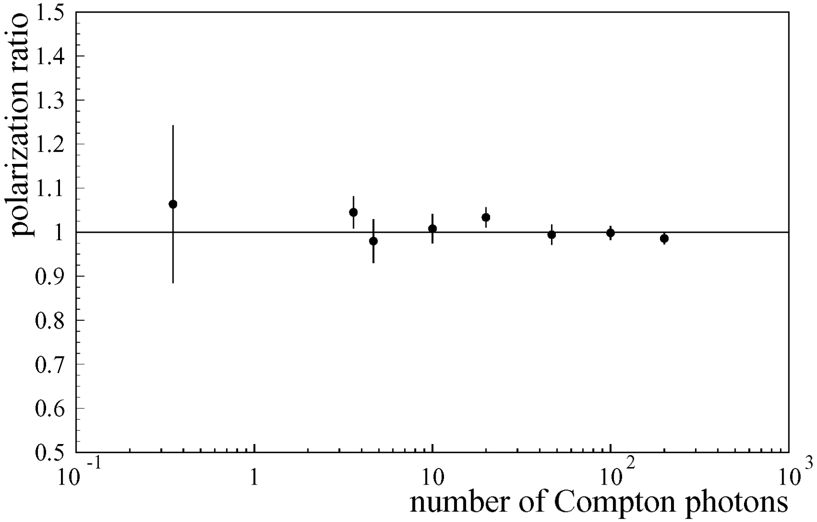
Question:

Is response function linear over full single to multi-photon range?

Test beam results



0.9% syst. uncertainty



0.8% syst. uncertainty

Polarization Performance

HERA: 220 bunches separated by 96 ns

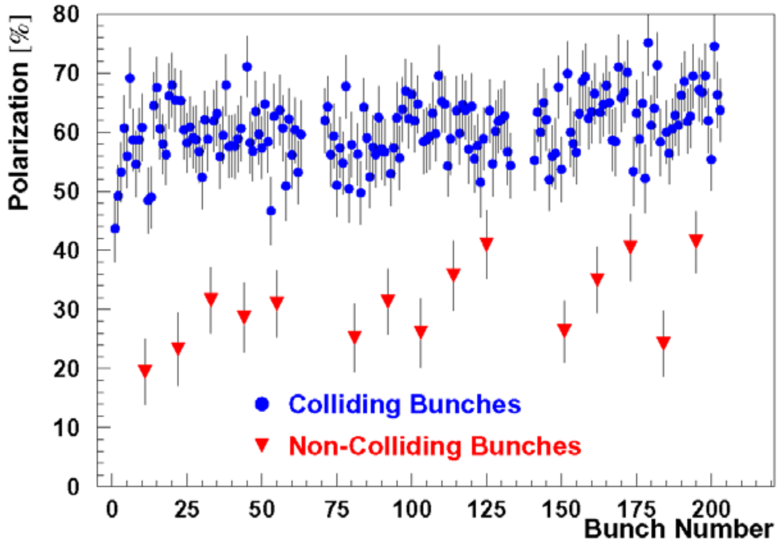
174 colliding + 15 non-colliding = 189 filled bunches

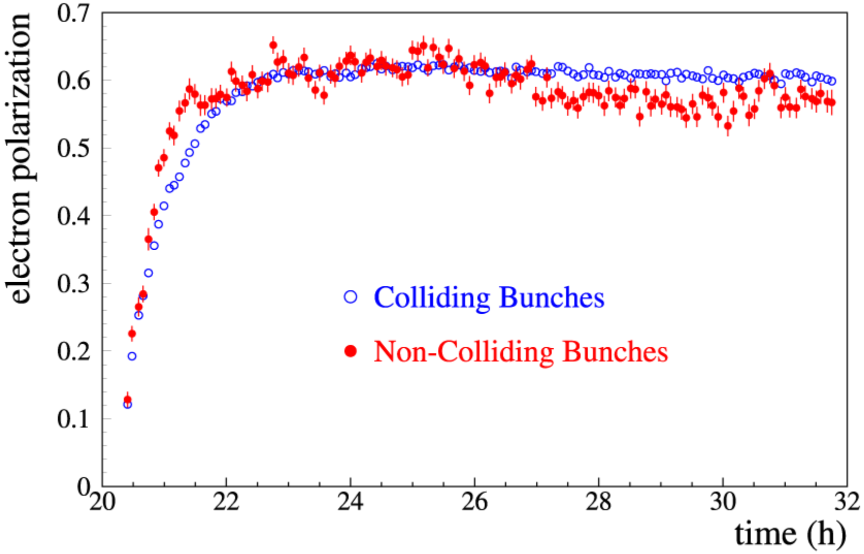
20 min measurement

dP/P = 0.03 in each bunch

time dependence:

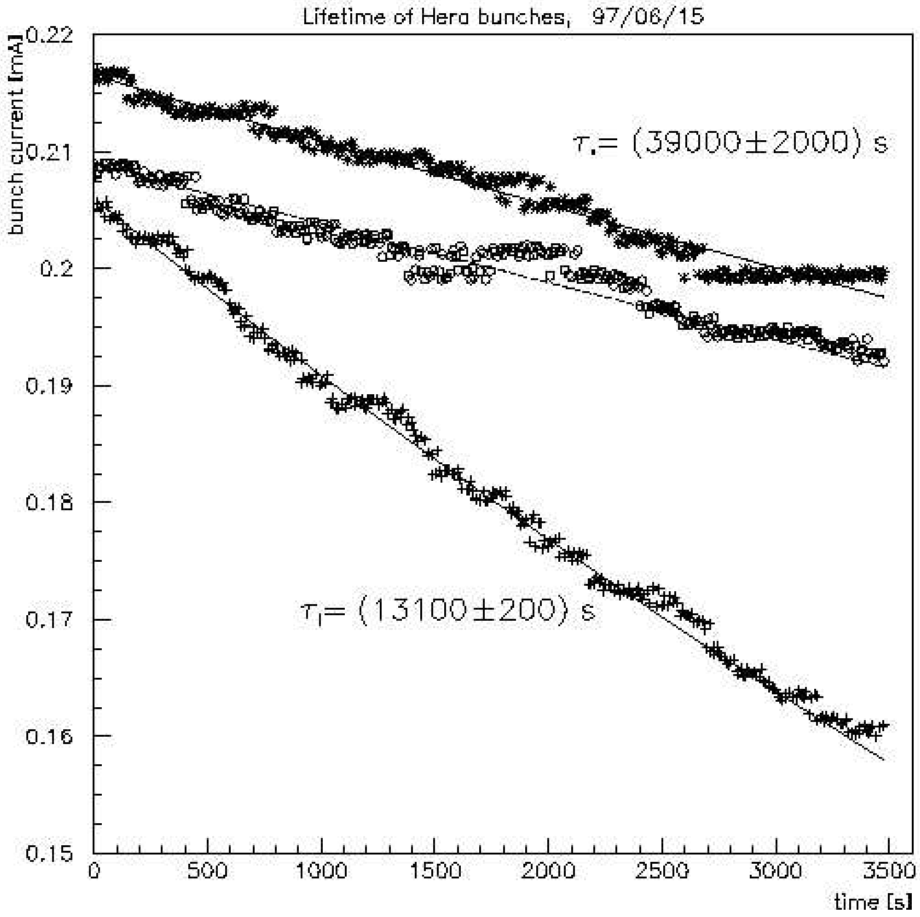
helpful tool for tuning





"Non-Invasive" Method

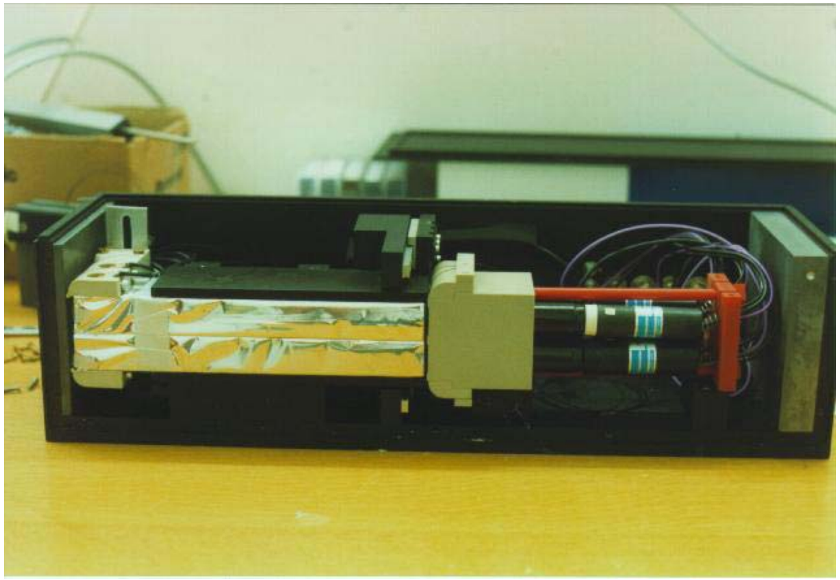
Possible to 'empty' an electron bunch with a powerful laser beam at HERA



A large Systematic Effect - Solved

In multi-photon mode:

1000 γ's → 6.8 TeV in detector



Protect PMT's from saturation

→ insert Ni foil in 3mm air gap

Problem:

NBW crystals are 19 X_0

→ small shower leakage
with large analyzing power

A_p(w/ foil) = 1.25 x A_p(w/o foil)

No light attenuators are used since early 1999

Systematic Uncertainties

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

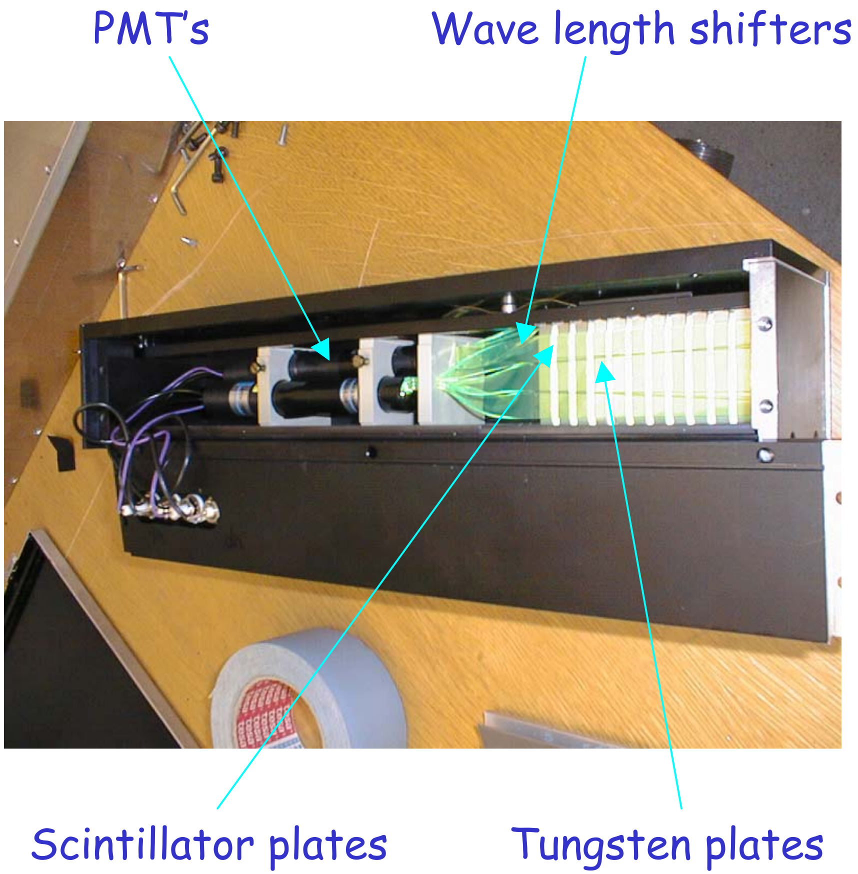
[α] new sampling calorimeter built and tested at DESY and CERN

[β] from comparison with prototype sampling calorimeter

[γ] statistics limited

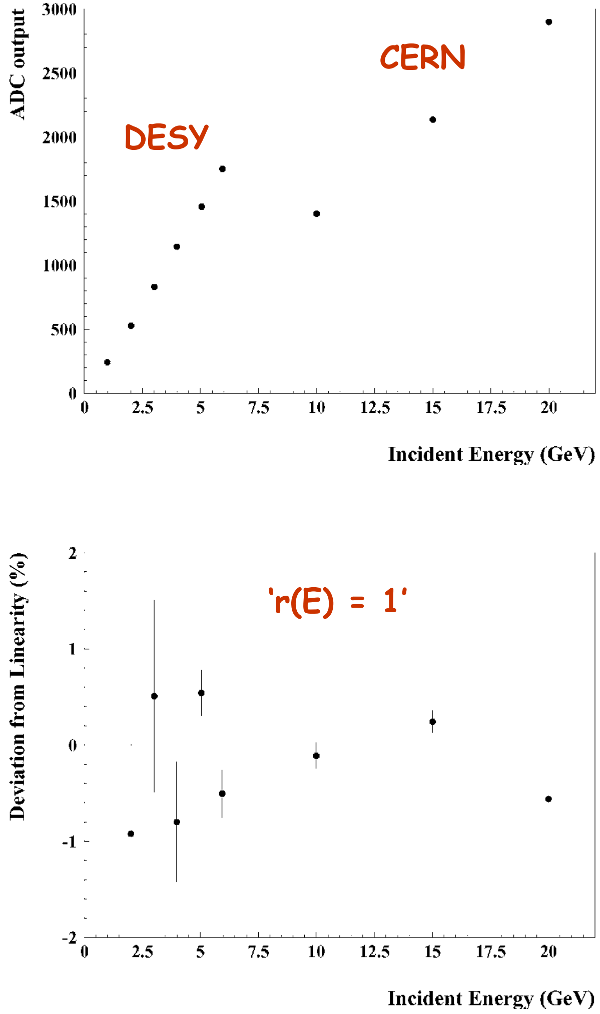
[δ] published in NIM A 479, 334 (2002)

New Sampling Calorimeter



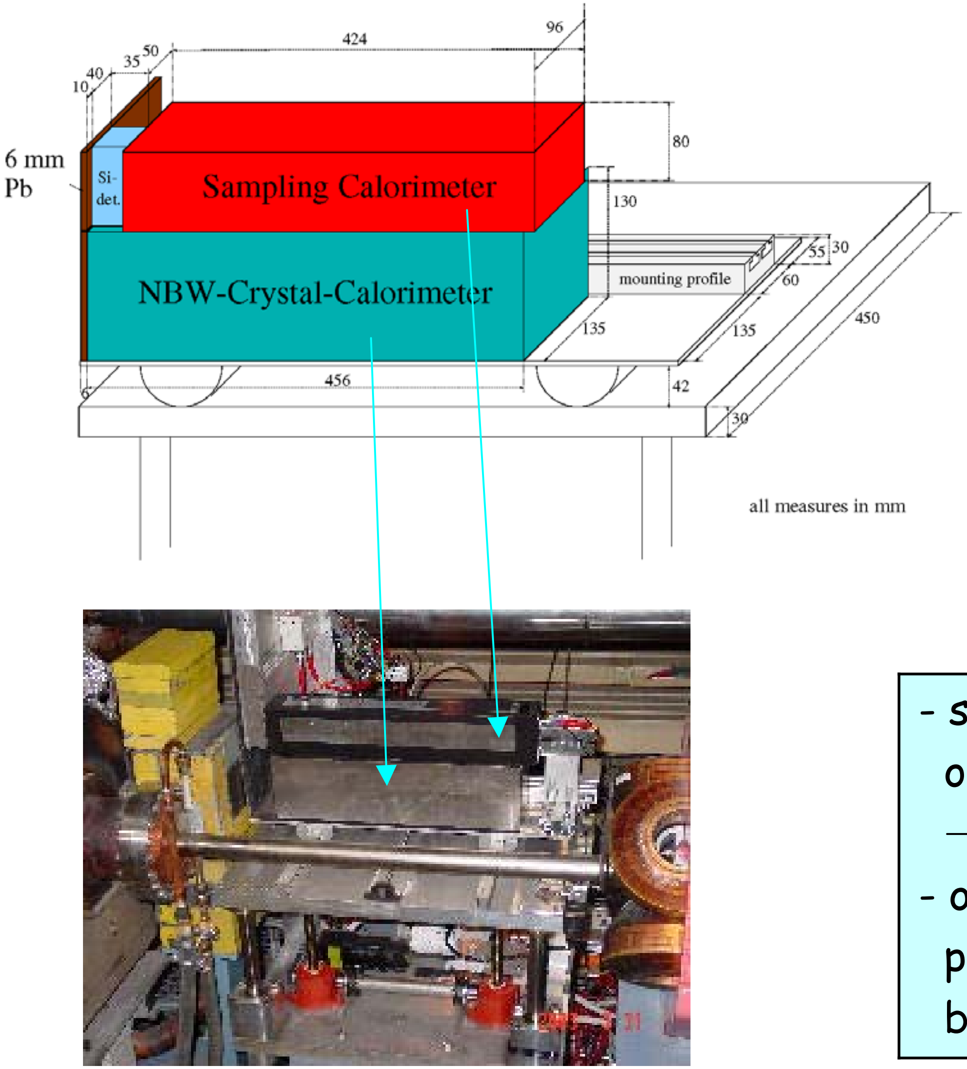
better energy resolution & linearity than NBW calorimeter

Test beam results

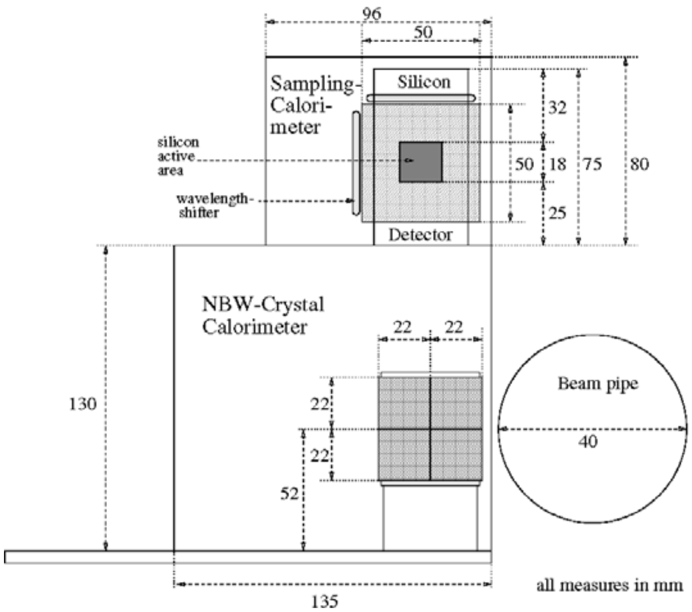


New Sampling Calorimeter - Details

side view



beam view



- sampling & NBW calorimeters sit on movable table (x-y)

  ⟶ fast switching possible
- one calorimeter is always protected from synchrotron and bremsstrahlung radiation

Systematic Uncertainties

Source	$\Delta P_e/P_e$ (%) (2000)	$\Delta P_e/P_e$ (%) (>2002)
Analyzing Power A_p	± 1.2[α]	± 0.8
- response function	(0.9)	(+-0.2)[α]
- single to multi photon transition	(0.8)	(+-0.8)
A_p long-term instability	± 0.5	± 0.5
Gain mismatching	± 0.3[β]	± 0.2
Laser light polarization	± 0.2	± 0.2
Pockels cell misalignment	± 0.4[β]	± 0.2
Electron beam instability	± 0.8[β]	± 0.4
Total	**± 1.6**	**± 1.1**

[α] new sampling calorimeter built and tested at DESY and CERN

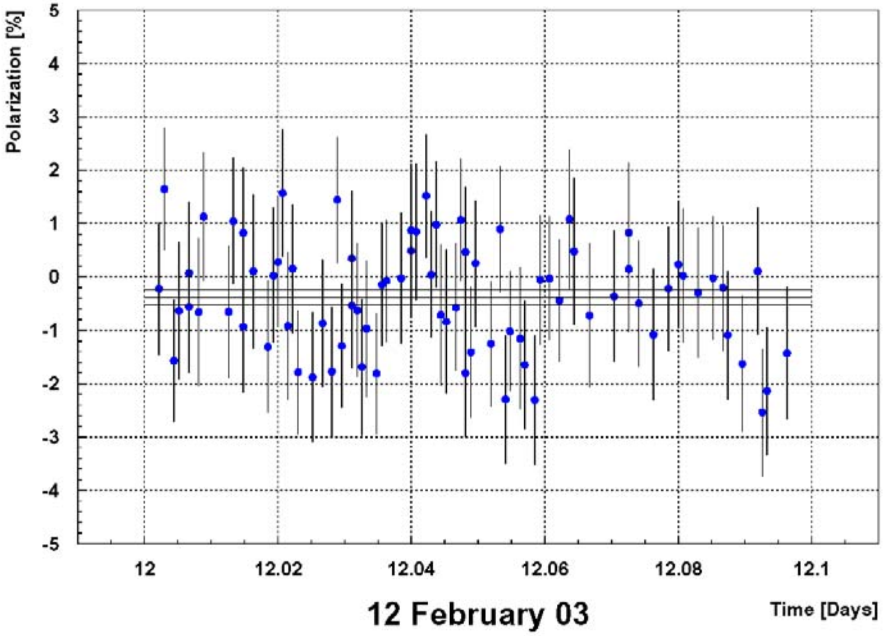
[β] statistics limited

expected precision: (multi-photon mode)

Systematic Uncertainties - II

Longitudinal polarization with unpolarized electron beam (27.6 GeV)

→ measure false asymmetries (IP not optimal, HERA clock unstable)



$\langle P_e \rangle$ = -0.38% ± 0.14%

$\langle I_e \rangle$ = 14 mA

χ^2/df = 55.3/78

Gain mismatching (± 0.2%)

Pockels cell misalignment (± 0.2%)

Electron beam instability (± 0.4%)

} estimate consistent with data

↑ estimated (2002)

Polarization-2000

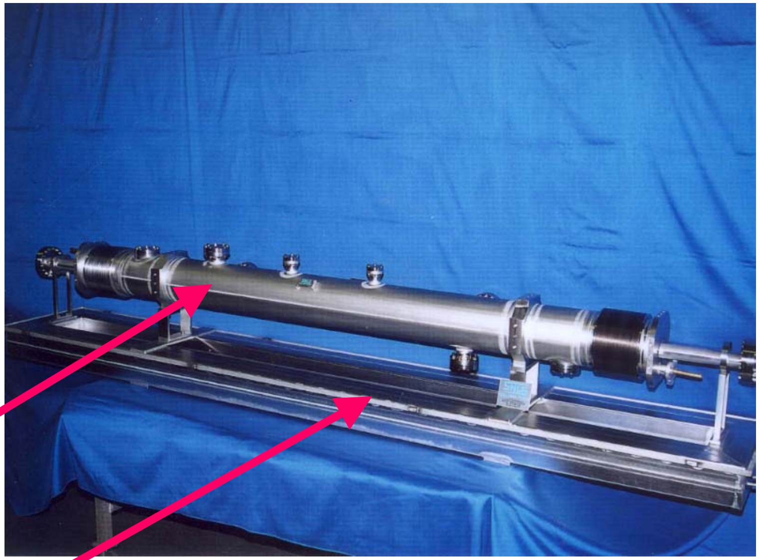
HERMES, H1, ZEUS and Machine Group

Goal: Fast and precise polarization measurements of each electron bunch

Task: major upgrade to Transverse Polarimeter (done)
upgrade laser system for Longitudinal Polarimeter (in progress)

Fabry-Perot laser cavity

[$(\delta P_e)_{stat}$ =1%/min/bunch]

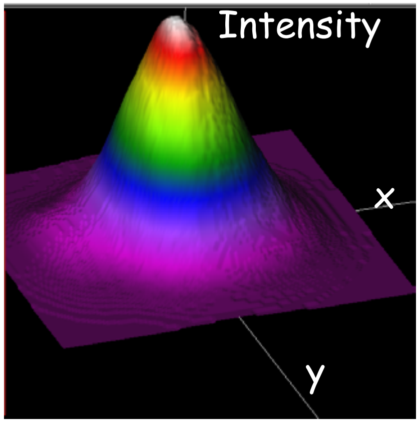


Final Cavity

Mount for travel

(courtesy F. Zomer)

beam intensity after cavity



A Comparison of Different Polarimeters

	P_L	e-γ rate	γ rate (n_γ)	$(\delta P_e)_{stat}$	$(\delta P_e)_{syst}$
LPOL:	33MW	0.1kHz pulse laser	1000 γ/pulse multi-γ mode i.e. 0.01 γ/bc (bc=bunch crossing)	1%/min (all bunches) 1%/(>30min) (single bunch)	~2%
TPOL:	10W	10MHz cw laser (cw=continuous wave)	0.01 γ/bc single-γ mode	1-2%/min (all bunches)	~4% → <2% (upgrade)
New LPOL:	5kW	10MHz cw laser	1 γ/bc few-γ mode	0.1%/6s (all bunches) 1%/min (single bunch)	per mill

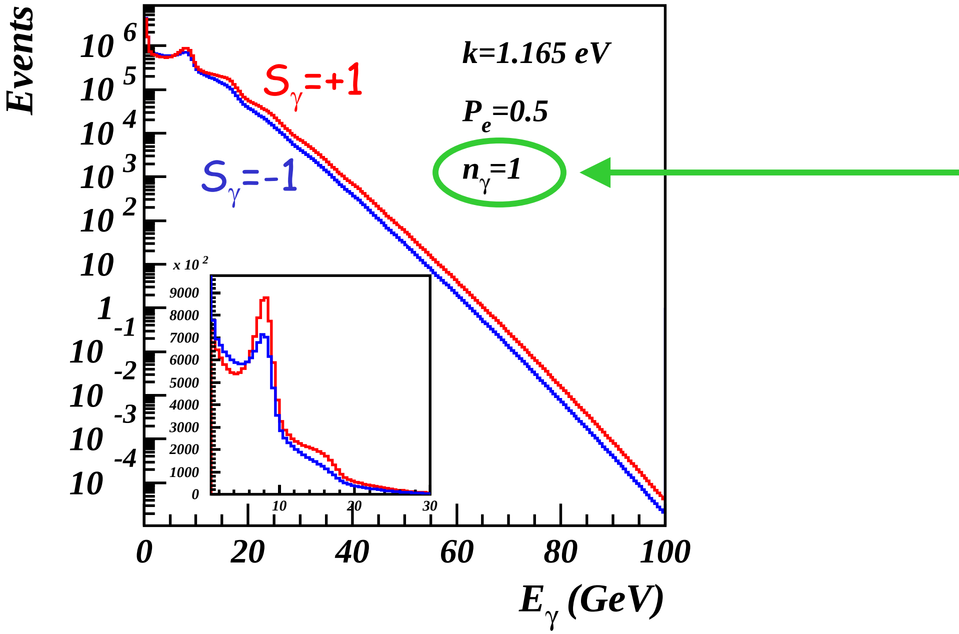
0.7W ↑ **Fabry-Perot Cavity** ↑ 5kW

Expected precision

(courtesy F. Zomer)

Photon Detection and Systematic Uncertainty of P_e

New LPOL (few-photon mode):

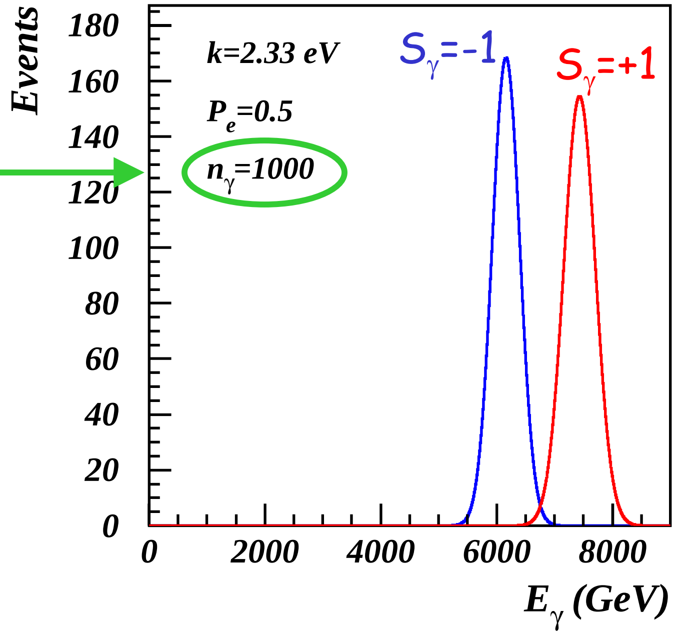


Compton and Bremsstrahlung edges clearly visible

Background determination and Calibration easy

$(\delta P_e)_{syst}$: per mill level expected

Existing LPOL (multi-photon mode):



Up to 1000 γ produced per pulse

Signal/background ratio improved

> 5TeV measured in the detector!

Calibration difficult

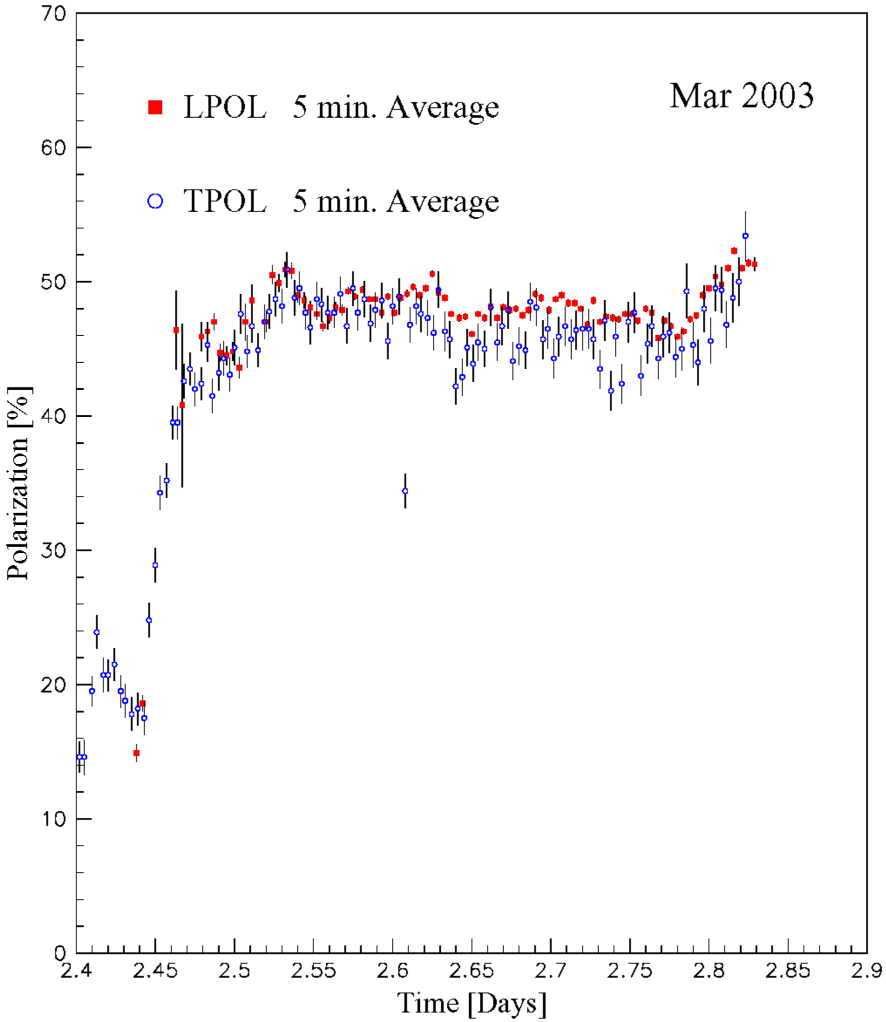
Non-linearity → main syst. error

(courtesy F. Zomer)

Polarization after Lumi Upgrade

All three spin rotators turned on

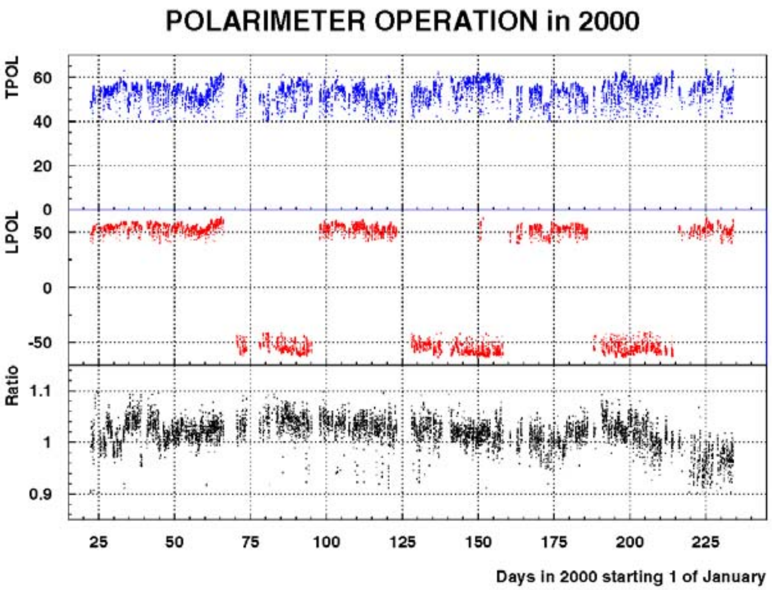
$P_e > 50\%$



TPOL/LPOL Ratio

Still under investigation

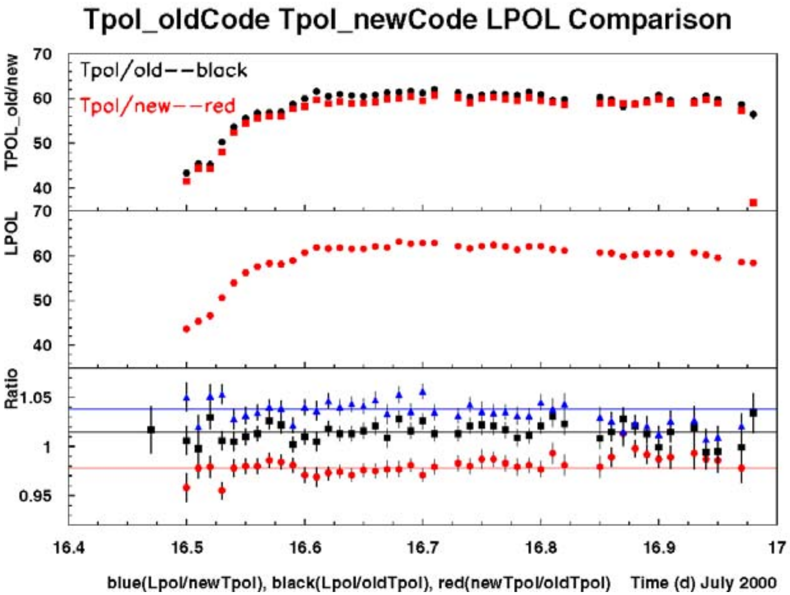
LPOL:



TPOL:

various analysis codes give different answers!

good fill



Strategy:

investigate ratio for good and bad fills and look for any dependencies

Conclusions

- Longitudinal Polarization is currently measured with
  - 1% statistical uncertainty per minute (for all bunches)
  - 1.6% systematic uncertainty (with NBW calorimeter)
  - ~1% systematic uncertainty (with new Sampling calorimeter)

- After upgrade to optical cavity is finished,
  - systematic uncertainty: 1% or less.
  - statistical uncertainty: 1-2% for each individual bunch

- Longitudinal Polarimeter measures rate (energy) differences

- Compton Scattering is possible for $E_{beam} \gtrsim 1$ GeV
  - large asymmetries: $A \sim E_e E_\lambda$
  - polarization measured/monitored continuously