# HERA Compton polarimeter

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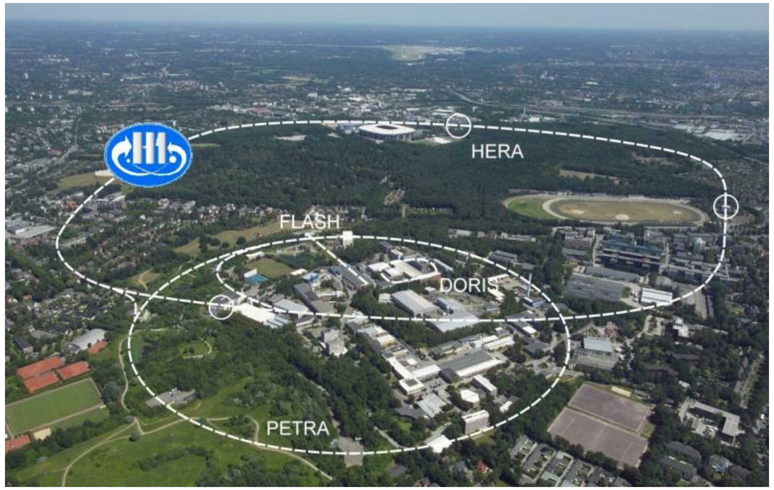
2021-12-07

# Outline

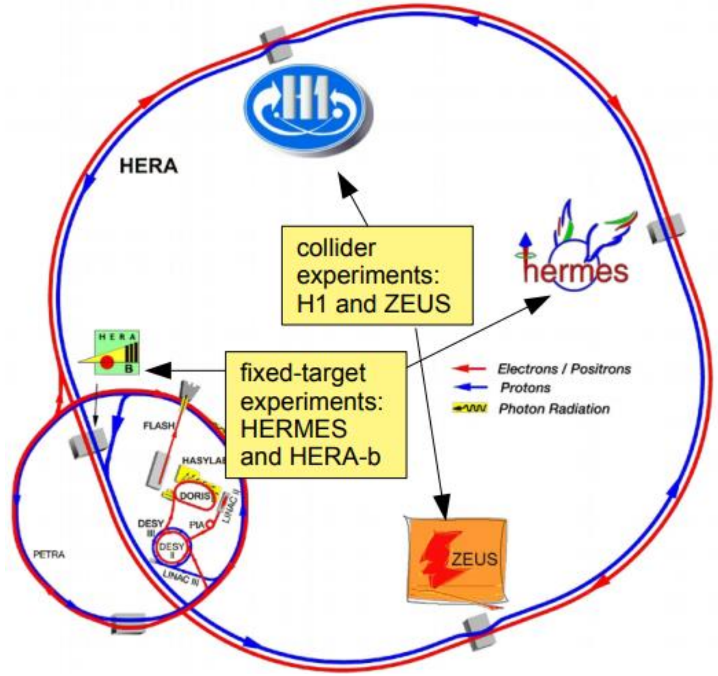
- Introduction of HERA
- HERA polarimeter
- Polarization during HERA operation
- Cross section (1st principle )
- TPOL/LPOL in HERA
- Discussion & Conclusion

# HERA

- HERA was the largest particle accelerator and research project in Germany. During 1992-2007, high energy **electron (27 GeV)** and **proton (920 GeV)** beams circulated in a **6.3 km** long tunnel with experiments, known as HERA-B, HERMES, H1 and ZEUS, at four stations around the ring. Even today, HERA has been **the only electron-proton collider** in the world and allowed the most precise measurements of the **structure of the proton** to be made as well as **the investigation of a wide range of other phenomena**. The data from the experiments is still being analyzed and high-profile papers being published in international scientific journals.



汉堡地下隧道里的HERA加速器

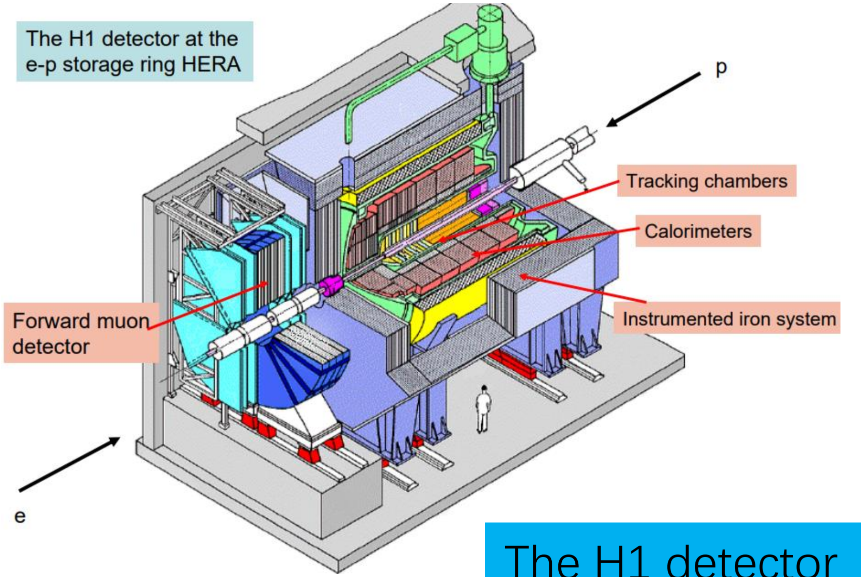



[1] https://www.desy.de/index_eng.html
[2] http://www.ihep.cas.cn/kxcb/zmsys/DESY/201009/t20100916_2964676.html

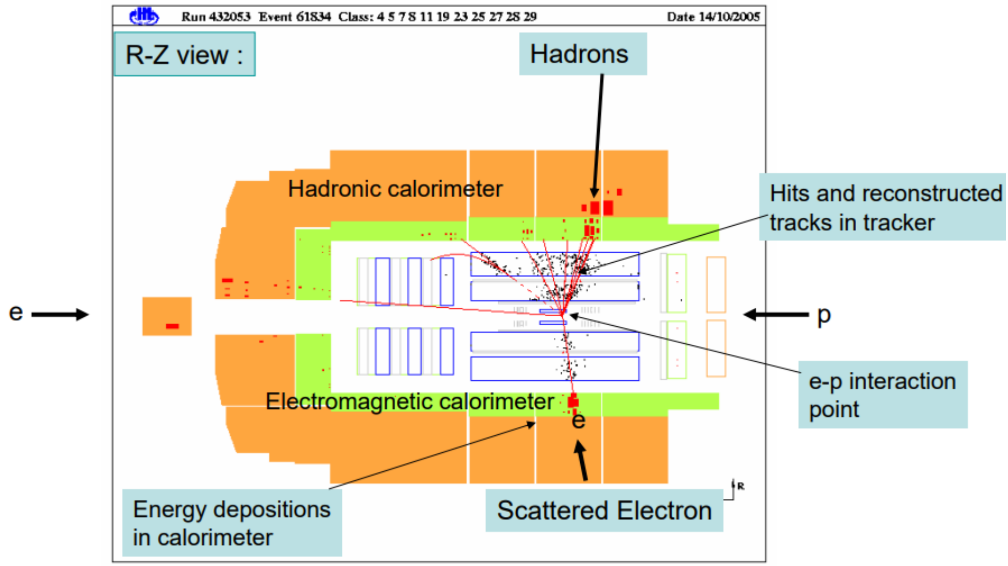
# HERA detectors

## ◆ The H1 and ZEUS experiments

- The H1 and ZEUS experiments (crosscheck) collected data from the collisions of high energy electrons and protons using general-purpose detectors which, although measuring the same physical processes, were very different constructions.
- Physics goal:
  - map the structure of the proton over a wide kinematic range,
  - demonstration of the unification of the electromagnetic and weak forces,
  - determination of the strong coupling constant, investigating the hadronic final state
  - searches for new particles and physics signatures.




The H1 detector




The H1 physical event

Ref: [1] https://h1.desy.de/
[2] https://www.desy.de/~jmeyer/H1-event.tutorial.pdf

# HERA detectors

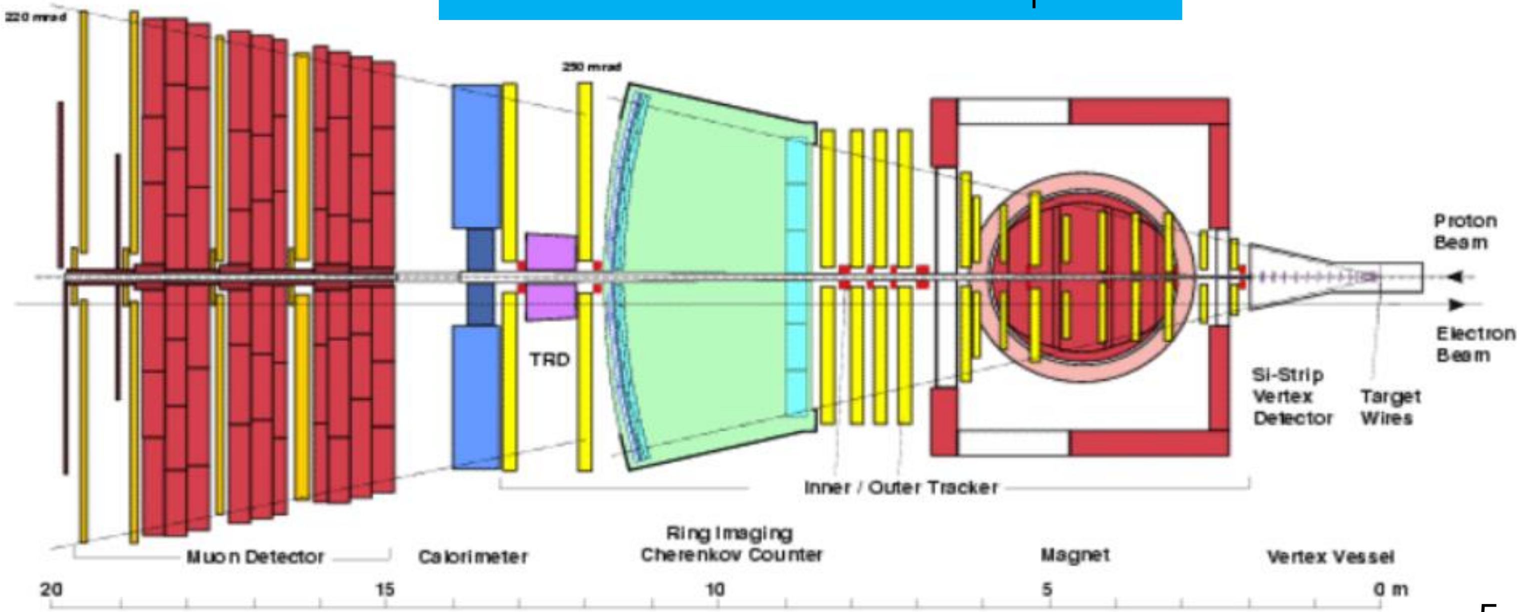
## ◆ The HERMES experiments

- The <u>HERMES</u> experiment collected data from scattering of **longitudinally polarized electrons** on various polarized gas targets such as hydrogen, deuterium, or helium.
- Physical goal : map out the spin structure of the nucleon, i.e. protons and neutrons.
    - These nucleons are made up of quarks with spin-1/2, bound together by gluons with spin-1.
    - HERMES is trying to answer how the constituents make up a nucleon, which has spin-1/2.
    - delving deeper into the spin structure of the building blocks of matter.

## ◆ The HERA-B experiments

- HERA-B collected data during 1999-2003 from collisions of the **proton beam** on a **stationary target of wires** of **different nuclei**.
- A large-aperture, high-rate **spectrometer detector** was designed to measure the properties of the heavy quarks, bottom and charm.

HERA-B Subdetector Descriptions



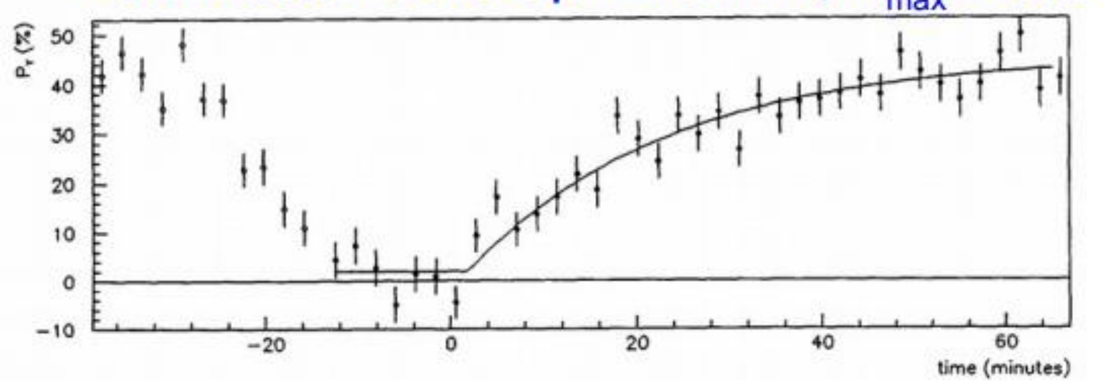

[1] *http://www-hera-b.desy.de/general/info/*
[2] *http://www-hera-b.desy.de/*

# HERA polarimeter

## Transverse polarization for experiments

- Proton-beam: unpolarized
- Lepton beam: unpolarized at injection energy (12 GeV)
- Lepton beam acquires transverse polarization at collision energy (27.5 GeV): Sokolov-Ternov effect
- rise-time ~40 minutes
  (cf. duration of a fill: ~10 hours)

Polarization build-up τ=43 min, $P_{max}$=45%




## Longitudinal polarization for experiments

- First experiment making use of HERA beam polarization: HERMES (start in 1995)
- Spin rotators: longitudinal polarization in the HERMES straight section, transverse polarization in the arcs
- Luminosity upgrade 2000-2002
  – Install spin-rotator pairs around H1 and ZEUS
  – Remove compensating coils

➢ Motivation

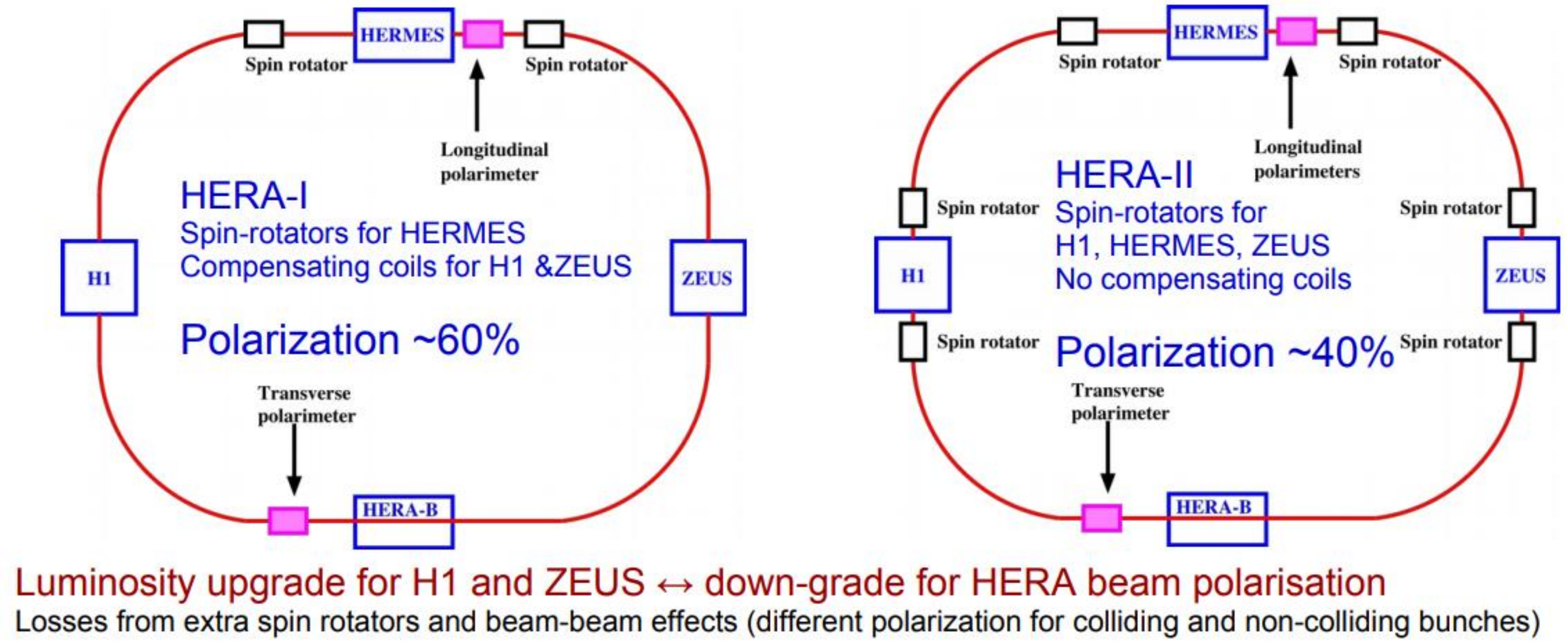
Longitudinally polarized electrons are perfect probes in two basic fields in high energy physics:

- the study of the spin structure of the proton and neutron as in the HERMES
- the study of weak interactions by the H1 and ZEUS

*Ref: [1]https://desy.de/~sschmitt/talks/2020-07-01_eic-pol2000.pdf*

# Polarization during HERA operation

➢ Compare the HERA Ⅰ and HERAⅡ

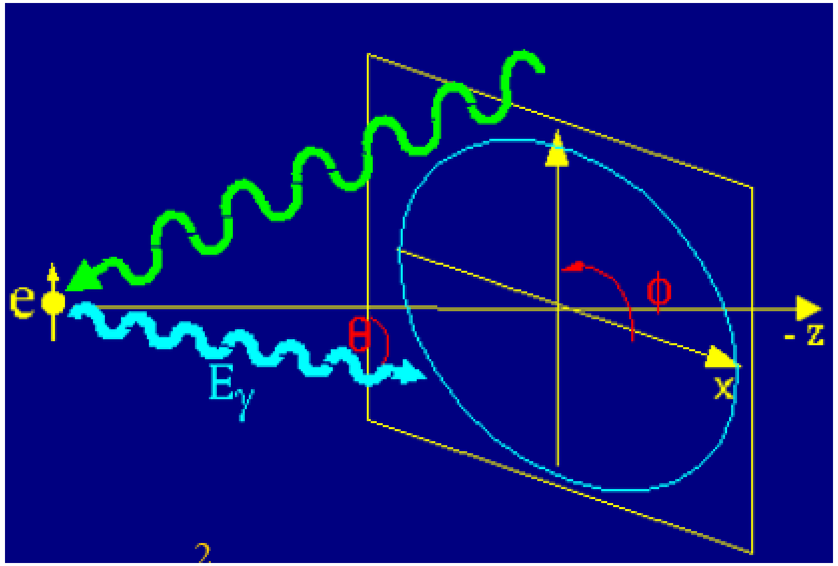



**Polarimetry requirement:**

- Fast and reliable monitoring of polarization during data taking
  - Colliding bunches (H1,ZEUS) and all bunches (HERMES)
  - Absolute scale uncertainty better than 2%

*Ref: [1]https://desy.de/~sschmitt/talks/2020-07-01_eic-pol2000.pdf*

# 1st principle




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

- kinematics described by 2 variables:
  - polar angle $\theta$ => $E_\gamma$ (photon energy)
  - azimuthal angle $\varphi$ => y (vert. position)
- S1, S3: linear & circular polarization of laser
- $P_Y$,$P_Z$: transverse & longitudinal beam polarisation

TPOL: measure (energy dependent) angular asymmetry

LPOL: measure scattered energy of photons asymmetry

# Transverse polarimeter setup

◆ An overview of the HERA polarimeter

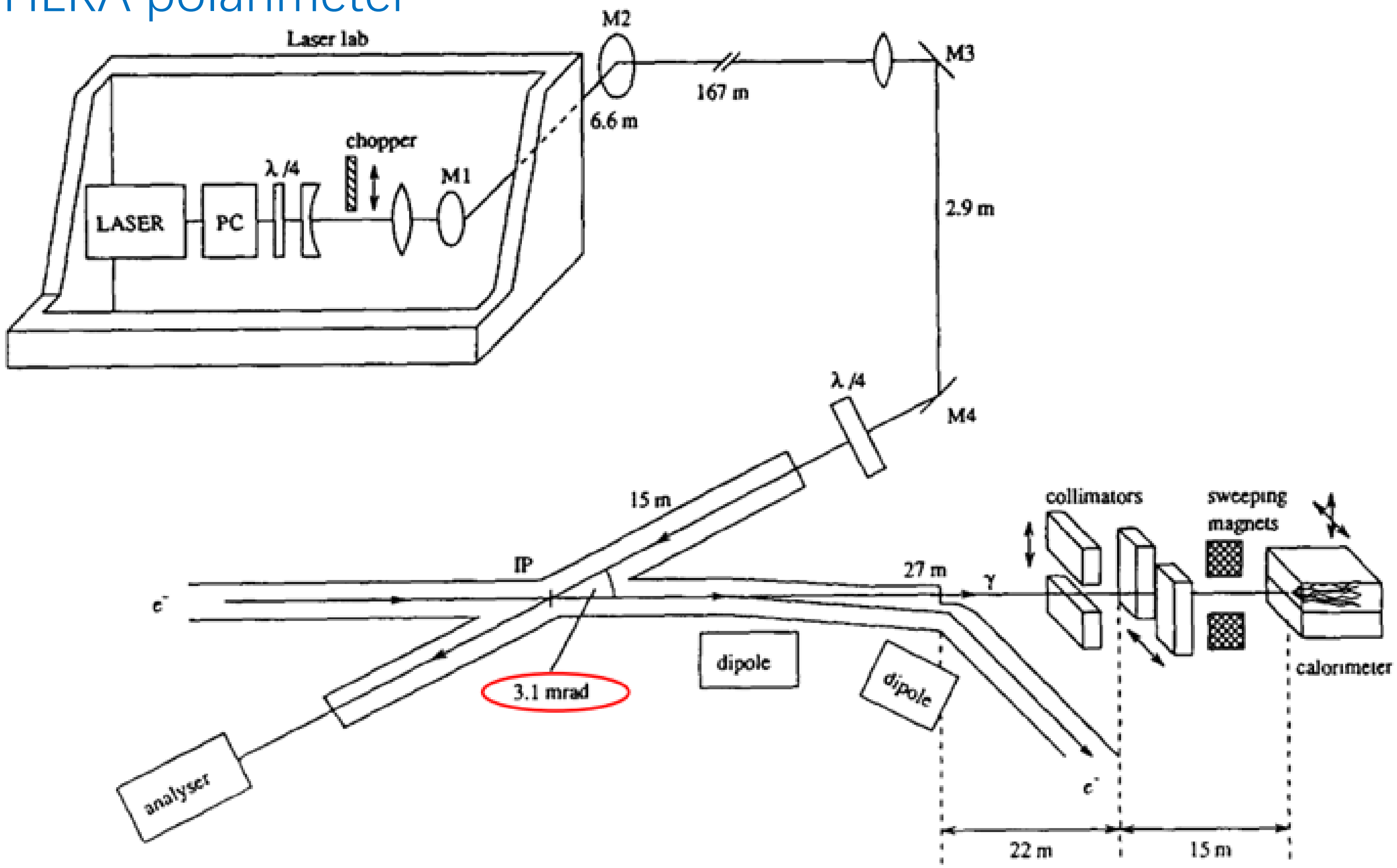



Fig. 9. An overview of the HERA polarimeter.

IP 位于直线节的末尾，进入ARC以前；
Calorimeter 探测器距离IP点65米；
The detector must measure the energy and the vertical position of high energy photons

# Transverse polarimeter setup

◆ Laser Optics

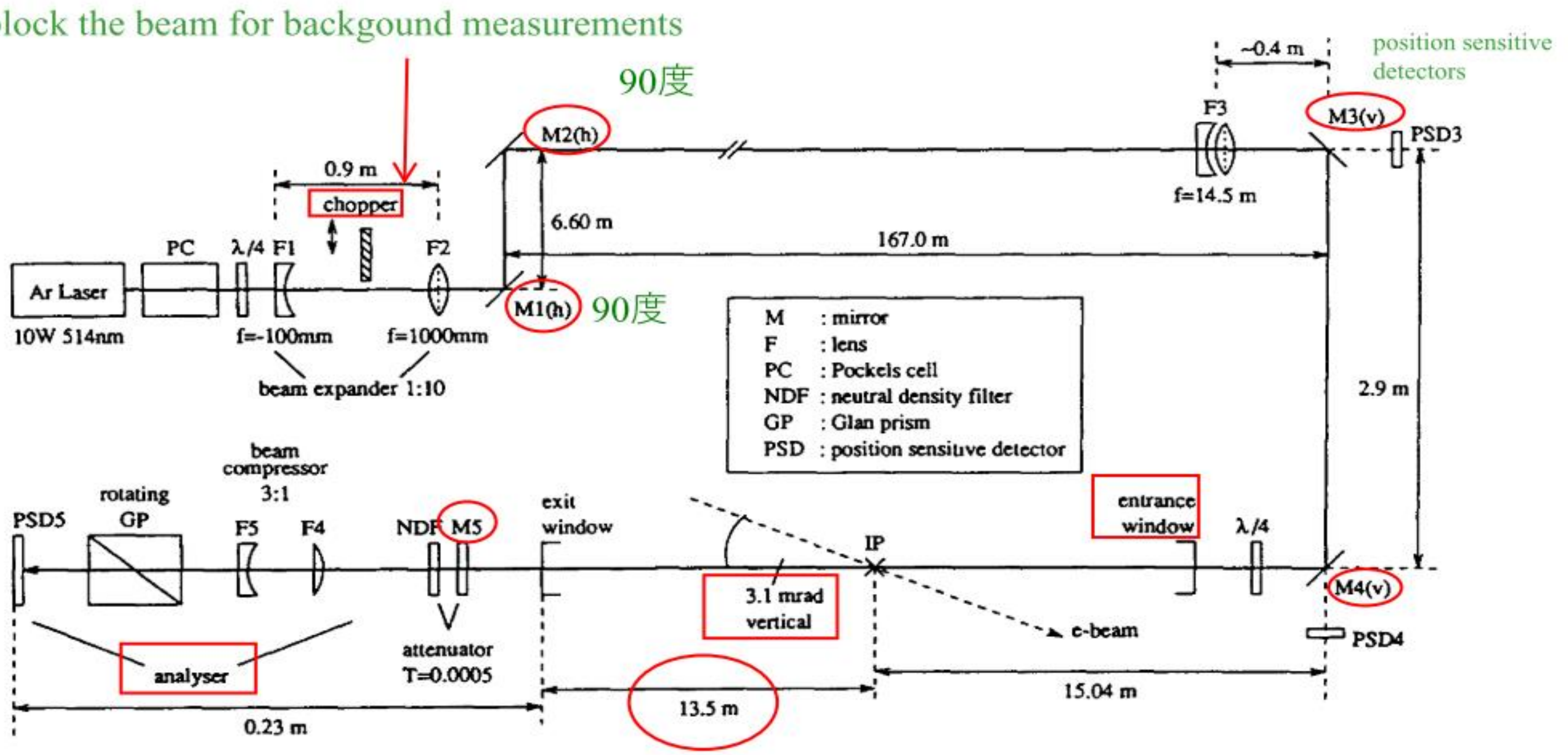



Fig. 11. An overview of the optical system.

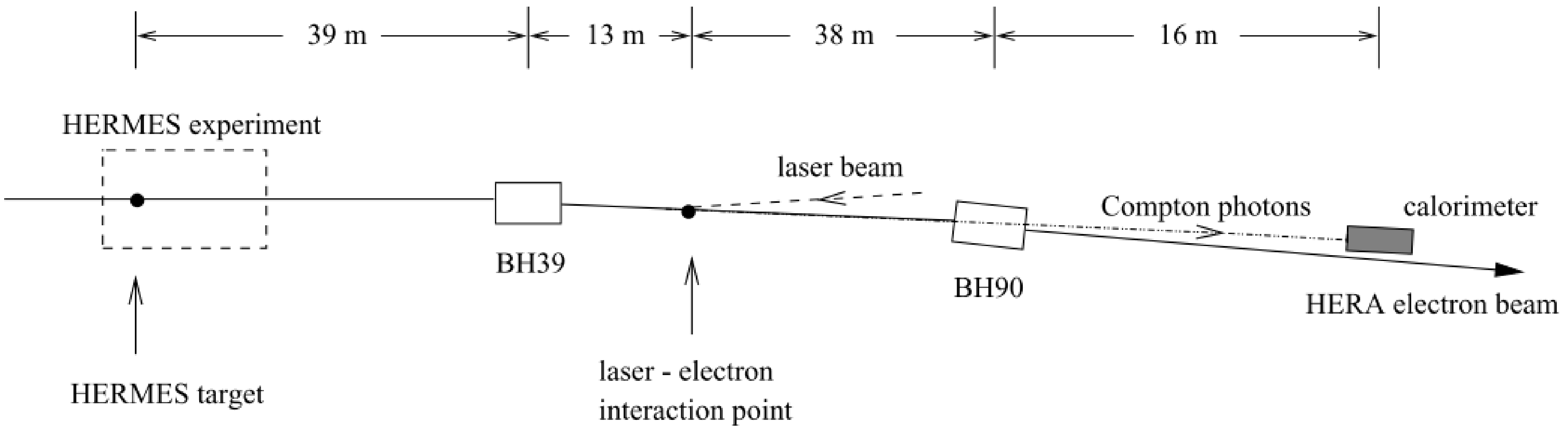
- Laser 通过4个mirror转向与电子束对撞;
- 电子真空中的光学元件容易受到电子束和同步辐射的损坏。通常使用金属反射镜，这些反射镜的光学质量较差。因此，决定将镜M4安装在真空外部，并在此位置使用高反射率介质镜。
- M5：偏转激光出去用于极化测量。

Laser的相关参数:

| Photon wavelength | Argon ion laser |
|---|---|
| Photon energy | 2.41eV |
| Photon wavelength | 514.5nm(green) |

# Longitudinal polarimeter setup

- Layout




The second polarimeter (LPOL) measured the longitudinal lepton beam polarization within the HERMES spin rotator pair, downstream of the HERMES gas target

Compton IP位于BH39和BH90之间。

# Longitudinal polarimeter setup

## ◆ Laser Optics

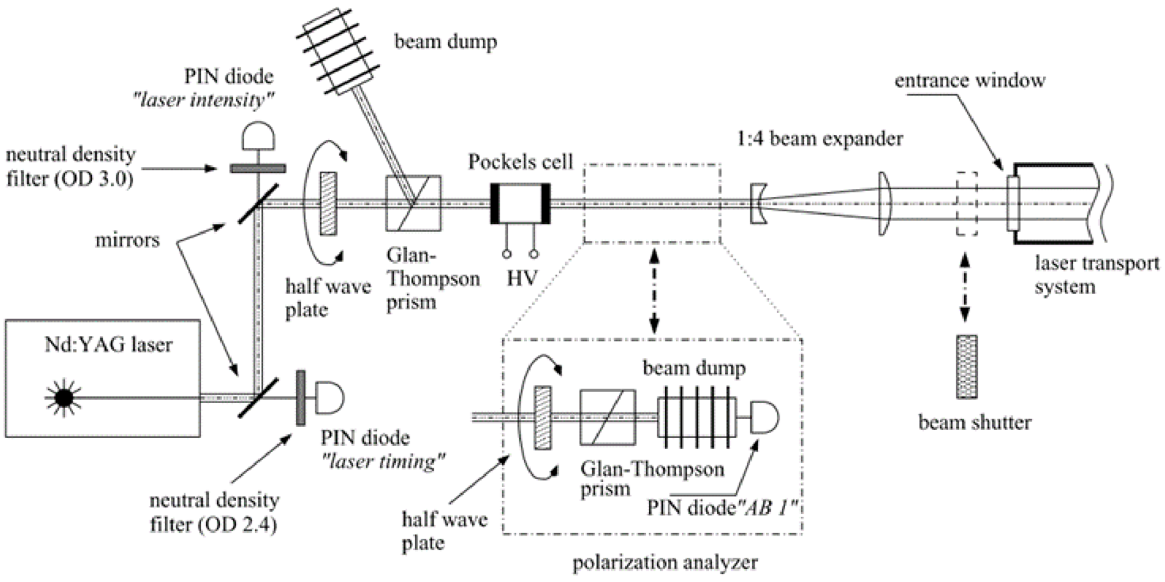



Fig. 3. Arrangement of the optical system in the laser room.

Laser的相关参数:

| | |
|---|---|
| Laser | Frequency-doubled, pulsed Nd:YAG laser |
| Photon energy | 2.33eV |
| Photon wavelength | 532nm |
| pulse | 3ns |
| Repetition rate | Continuously variable: from single shot to 100Hz |
| Pulse energies | 100mJ per pulse |
| (with electron) triggered | 100Hz |
| Laser spot | 0.5mm |

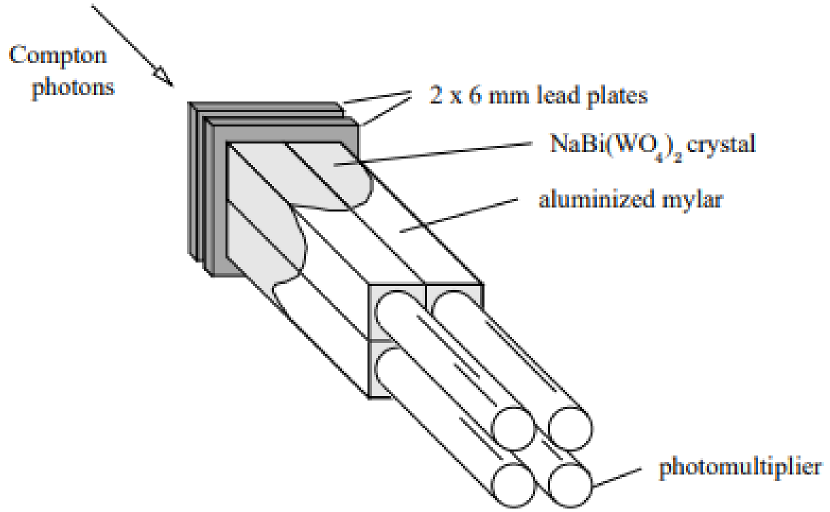
光学装置:

- half wave plate: （可旋转的）激光强度保持
- Glan-Thompson prism: （固定的）激光强度保持
- Pockels cell: 电可逆折射池，使得线偏振转变成圆偏振，调节成四分之一波的相移，每一个脉冲相移一次
- Polarization analyzer: 定期测laser的极化
- 1：4 beam expander: 扩束器，光束直径通过一组平凹透镜和平凸透镜扩大四倍。扩束器减少了激光束的发散，使其能够穿过80 m长的光路到达激光-电子相互作用区域，并减少了相互作用点处产生的束腰。此外，它将对激光束发散变化的敏感性降至最低，并降低激光束的能量密度，以防止损坏光路中的光学元件。

# detector

- The backscattered Compton photons were detected 65m downstream of the Compton interaction point in calorimeter

- scintillator plates were optically decoupled along the central horizontal plane, thus dividing the calorimeter effectively into independent upper and lower halves. Information about the energy and the vertical impact position y of an incident photon is then obtained from the sum of the two halves $E = E_{up} + E_{down}$ and the energy asymmetry η between them:




$$\eta := \frac{E_{\text{up}} - E_{\text{down}}}{E_{\text{up}} + E_{\text{down}}}$$

# Longitudinal polarimetry

LPOL is operated **multi-photon mode:**

- a pulsed high power laser to produce thousands of backscattered photons on each collision with electron bunch.
- This mode allows a better separation of the ADC spectra with left and right circular laser polarization.
- the contribution from bremsstrahlung to the energy deposition integral becomes negligible.

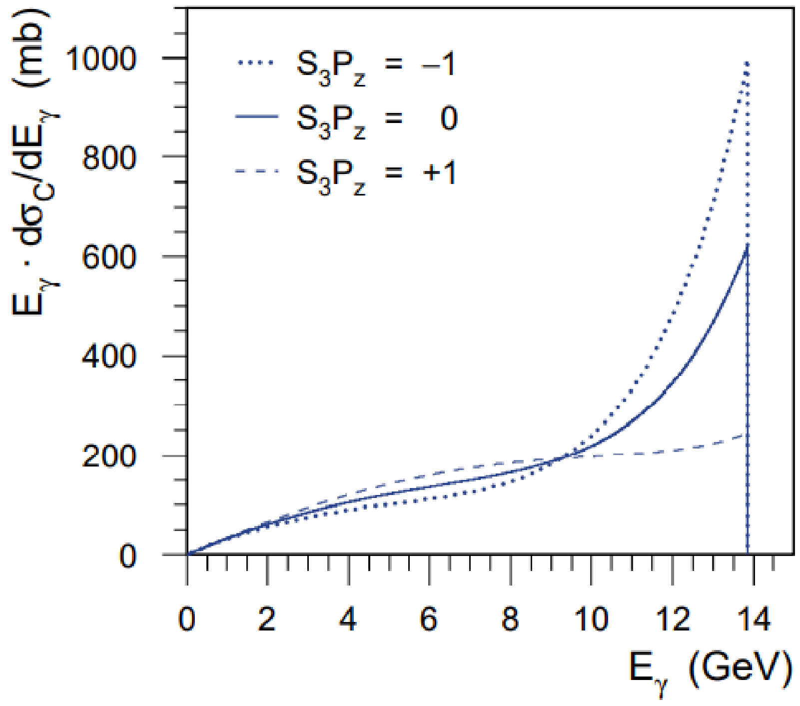
TPOL is operated **single-photon mode**:

- apply at the system that the time between electron bunch is short
- only one photon will be detected.
- While this requires relatively low photon rates of < 100 kHz, it allows to use Compton edge, for the absolute calibration of the detector.
- The main background is bremsstrahlung generated along the 7.3m short straight section which is in the line of sight of the detector.
- The measurement of the backscattered photon distributions separately for the two laser helicity states was interspersed regularly with measurements where the laser was blocked off. (measure the background)

# Longitudinal polarimetry

$$\mathcal{A} := \frac{I_{S_3P_z<0} - I_{S_3P_z>0}}{I_{S_3P_z<0} + I_{S_3P_z>0}} = \Delta S_3 P_z \Pi_z$$

- The statistical uncertainty of the measurement is about 1 − 2 % per minute and
- about 6 % per 5 minutes measurement, clearly limited by the repetition rate of the laser.

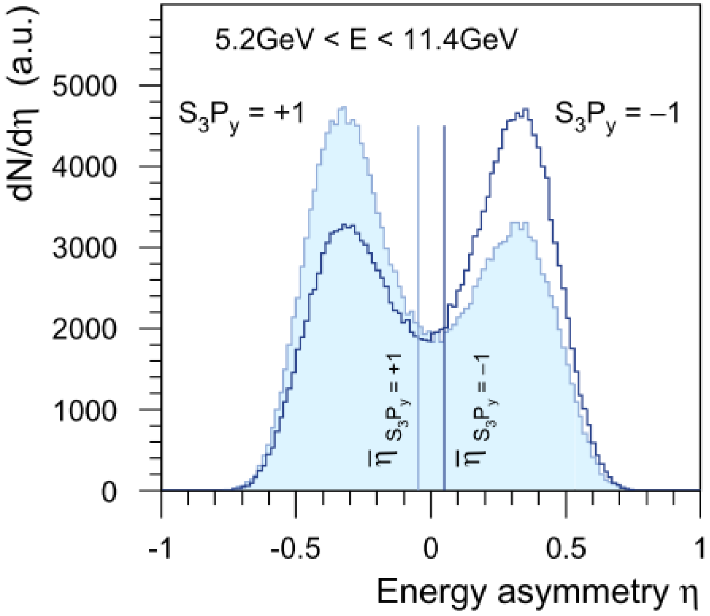



| Systematic uncertainty | $\Delta P/P$ |
|---|---|
| Analysing power | $\pm 1.2\,\%$ |
| long-term stability | $\pm 0.5\,\%$ |
| Gain matching | $\pm 0.3\,\%$ |
| Laser light polarisation | $\pm 0.2\,\%$ |
| Helicity dep. luminosity | $\pm 0.4\,\%$ |
| Interaction region stability | $\pm 0.8\,\%$ |
| Total (HERA I) | $\pm 1.6\,\%$ |
| Extra (new calorimeter) | $\leq \pm 1.2\,\%$ |
| Total (HERA II) | $\pm 2.0\,\%$ |

# Transverse polarimetry

The polarisation is then calculated from the shift of the mean energy asymmetry distributions for left and right laser helicity states using an analysing power Π:

$$\bar{\eta}_{\mathrm{L}} - \bar{\eta}_{\mathrm{R}} := \Delta S_3 P_y \Pi \tag{5}$$




| Systematic uncertainty | $\Delta P/P$ |
|---|---|
| Electronic noise | $< \pm 0.1\,\%$ |
| Calorimeter calibration | $< \pm 0.1\,\%$ |
| Background subtraction | $< \pm 0.1\,\%$ |
| Laser light polarisation | $\pm 0.1\,\%$ |
| Compton beam centering | $\pm 0.4\,\%$ |
| Focus correction | $\pm 1.0\,\%$ |
| Interaction point region | $\pm 0.3\,\%$ |
| Interaction point distance | $\pm 2.1\,\%$ |
| Absolute scale | $\pm 1.7\,\%$ |
| Total syst. uncertainty | $\pm 2.9\,\%$ |

Figure 2: Illustration of the polarisation dependent shift of the mean energy asymmetry distributions (left) and the preliminary list of contributions to the fractional systematic uncertainty of the TPOL measurement (right).

# Discussion & Summary

- dP/P ≤ 1% required by physics programme of H1 & ZEUS
- Transverse polarimeter: spatial asymmetry in single-photon mode [2%]
- Longitudinal polarimeter: integral energy asymmetry multi-photon mode [2%]