Lepton beam polarisation for the HERA experiments ZEUS and H1

- Polarisation at collider machines
- The HERA storage ring
- The HERA polarimeters
- The collider experiments ZEUS and H1
- The HERA II upgrade
- Data taking in 2003

Polarisation at collider machines

Polarized beams are produced in several colliders world-wide, e.g.

- RHIC (pp collisions)
- SLAC (e^+e^-, one beam polarized)
- LEP (e^+e^-, polarisation for beam diagnostics only)
- HERA (ep, e beam polarized)

Techniques to obtain polarized beams

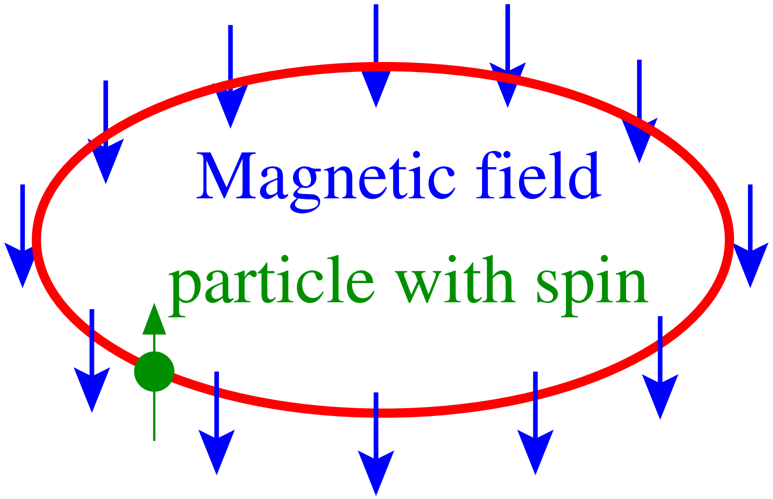
- p beam and linear colliders: start with polarized source
  p storage ring: avoid depolarizing resonances during acceleration
- e storage ring:
  Sokolov-Ternov effect
  slow built-up of polarisation at full energy

Physics analyses:

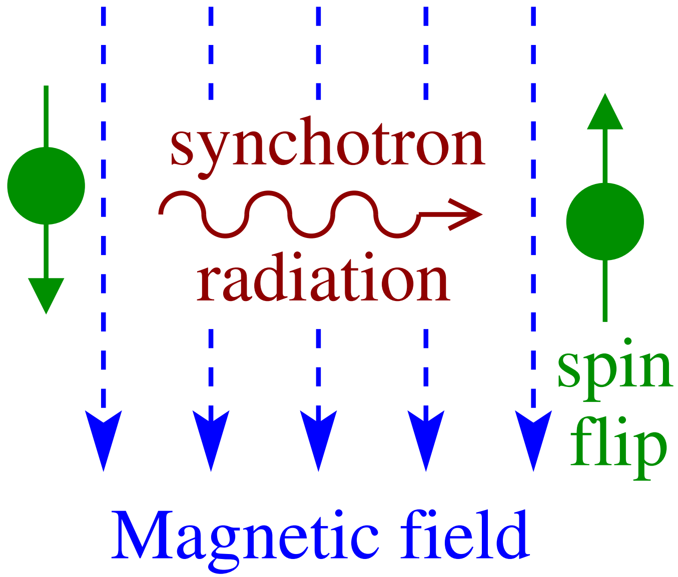
- polarized $p \rightarrow$ study origin of proton spin
- longitudinally polarized $e \rightarrow$ electroweak physics

The Sokolov-Ternov effect

- Particle motion in storage ring: perpendicular to B-field of bending dipoles
- Spins are aligned parallel or antiparalell to the magnetic field



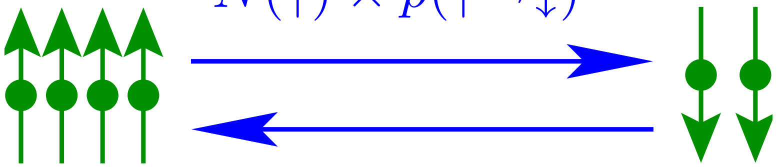
- Synchotron radiation may cause spin flip
- Probability for spin flip $p(\uparrow \to \downarrow)$ differs from $p(\downarrow \to \uparrow)$



The Sokolov-Ternov effect (cont'd)

Equilibrium: $N(\uparrow) \times p(\uparrow\rightarrow\downarrow) = N(\downarrow) \times p(\downarrow\rightarrow\uparrow)$

$N(\uparrow) \times p(\uparrow\rightarrow\downarrow)$



$N(\downarrow) \times p(\downarrow\rightarrow\uparrow)$

$$P = \frac{N(\uparrow)-N(\downarrow)}{N(\uparrow)+N(\downarrow)}$$

Theory:

$P = P_{\max} \times (1 - \exp(-\frac{t}{\tau}))$

$P_{\max} = \frac{8}{5\sqrt{3}} \approx 0.924$

$\tau \approx 100\mathrm{s}\frac{(R/\mathrm{m})^3}{(E/\mathrm{GeV})^5}$

Real machine: depolarizing effects:

non-uniform magnetic fields

quadrupoles, etc

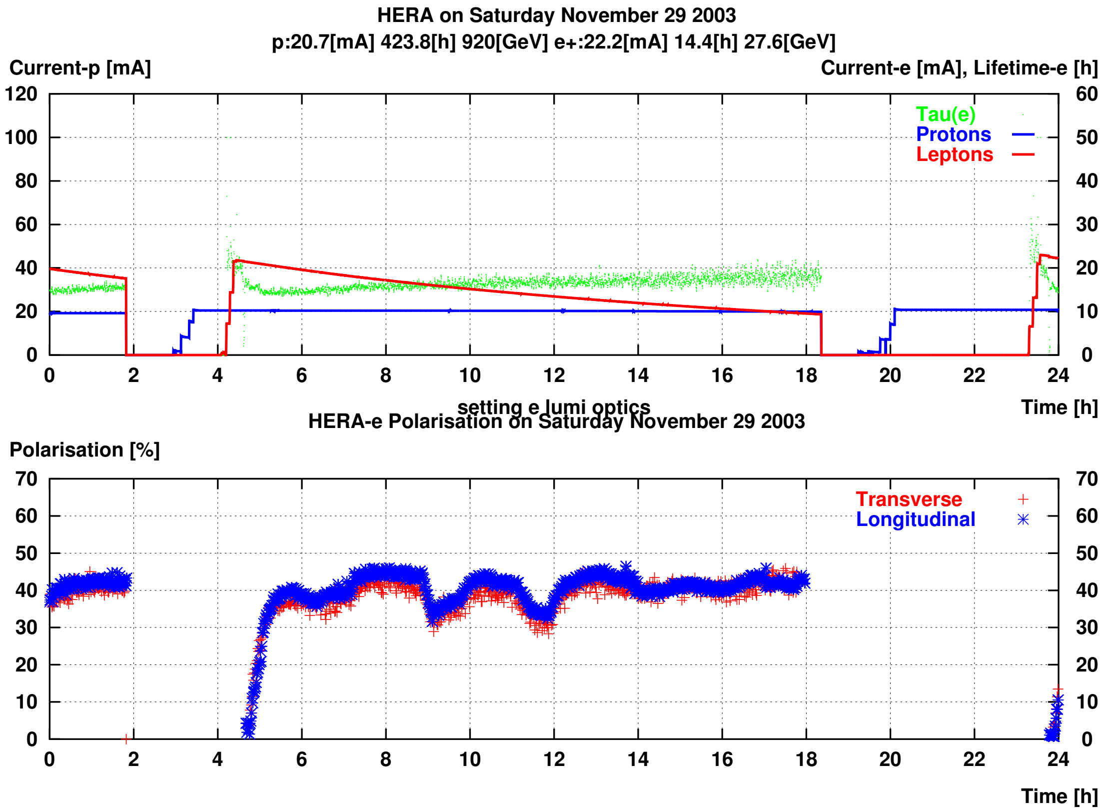
$\rightarrow$ smaller $P_{\max}$, smaller τ

Slow built-up of transverse polarisation

$\tau(\mathrm{LEP}) = \mathcal{O}(10\mathrm{h})$

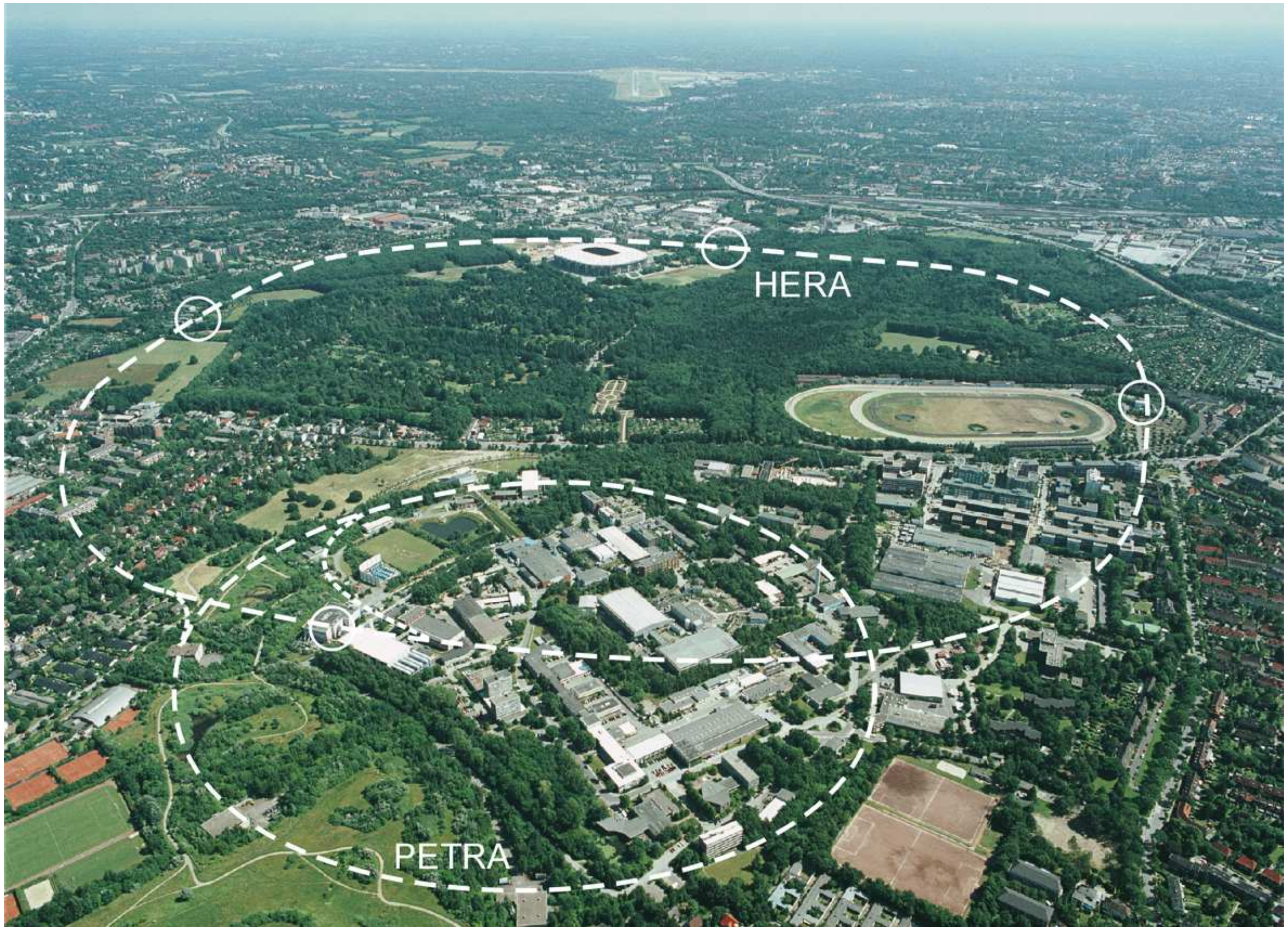
$\tau(\mathrm{HERA}) = \mathcal{O}(30\mathrm{min})$

Example: polarisation built-up at HERA



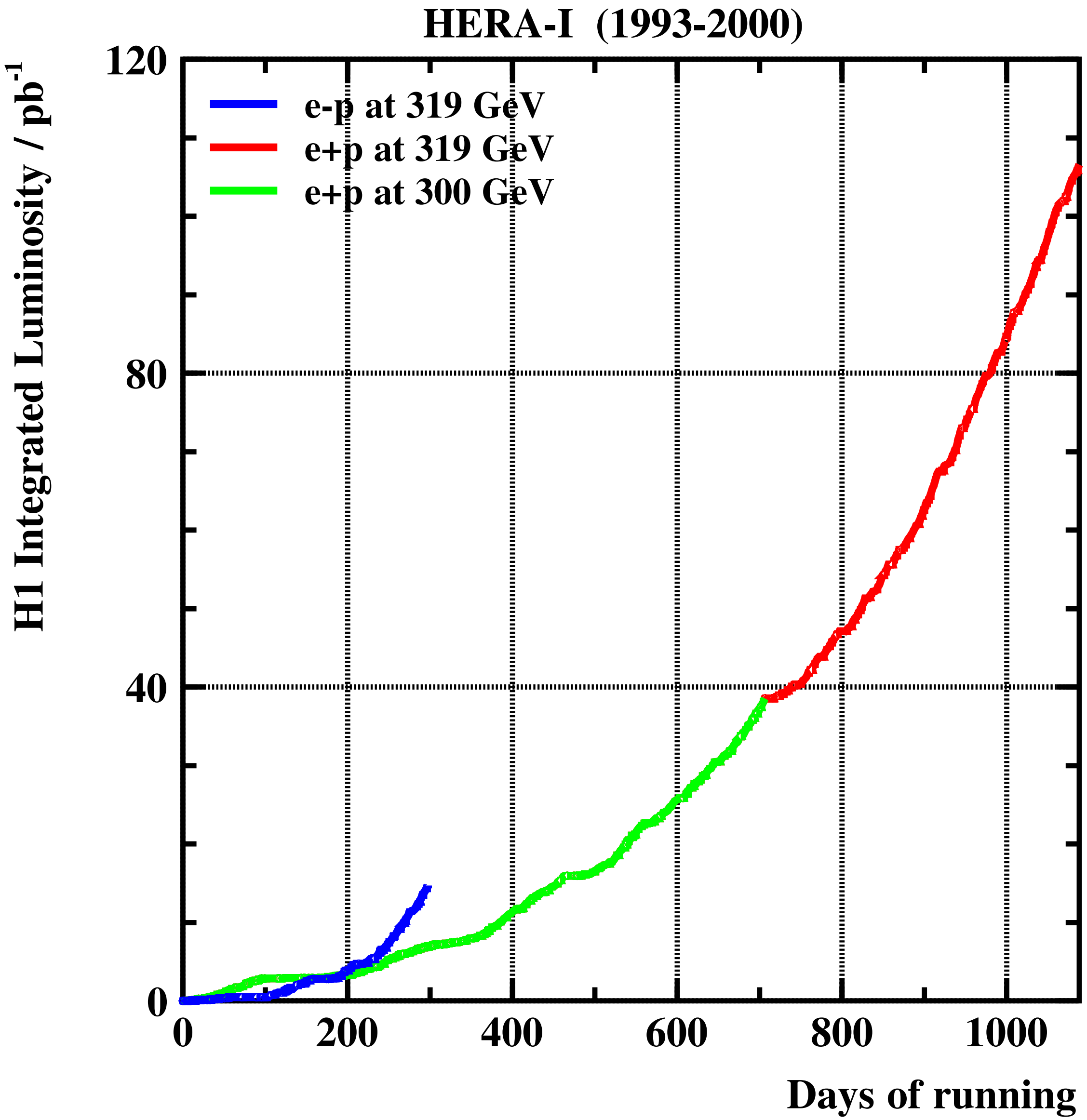
- Maximum polarisation $\approx 45\%$
- Rise-time $\approx 30\,\text{min}$
- Polarisation tuning: optimize orbits and other machine parameters
- Constant monitoring by two independent polarimeters

The HERA storage ring



- HERA: ep collider
- $E(e) = 27.6\,\mathrm{GeV}$
- $E(p) = 920\,\mathrm{GeV}$
- $E_{\mathrm{CM}} = 320\,\mathrm{GeV}$
- e beam polarized
- Collider experiments ZEUS, H1
- Fixed target exp. HERMES, HERA-b

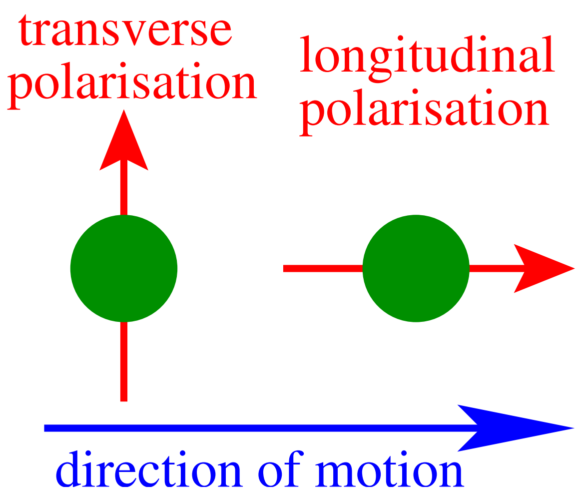
HERA I operation 1993-2000



- Integrated luminosity $120\,\mathrm{pb}^{-1}$ per collider experiment (ZEUS, H1), mostly in e^+p collisions
- Transverse e beam polarisation about 60%
- Transverse e polarisation: Not relevant for physics analyses
- Longitidinal e polarisation for HERMES since 1994/95 (spin rotators)

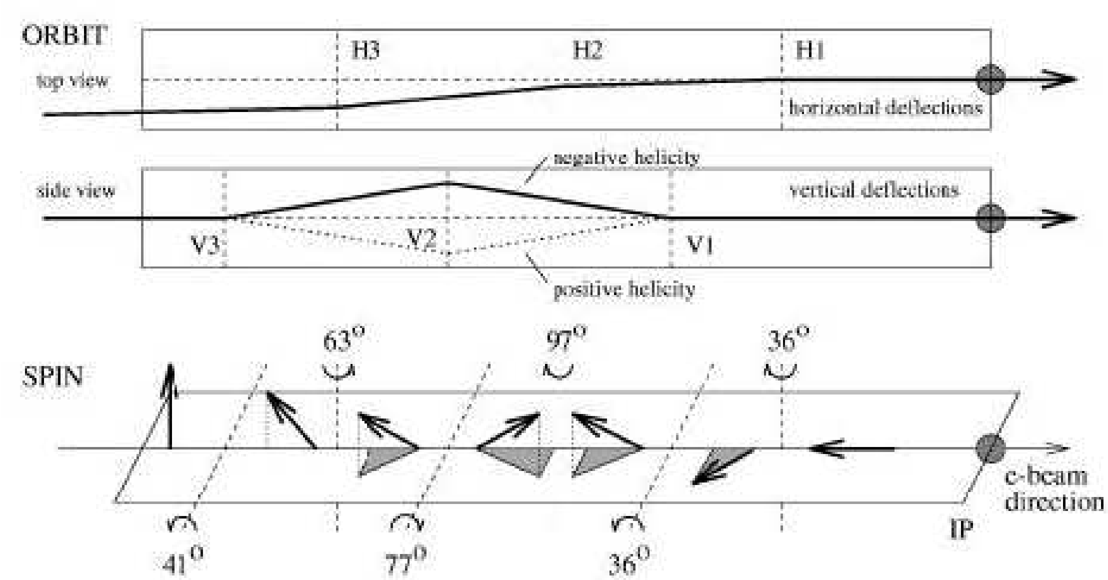
  Left-handed or right-handed electrons e_L, e_R for HERMES, **not** for H1, ZEUS

Spin rotators



- transv. pol.: spin aligned to B-field of bending dipoles
- long. pol.: well defined helicity

  e_L or e_R

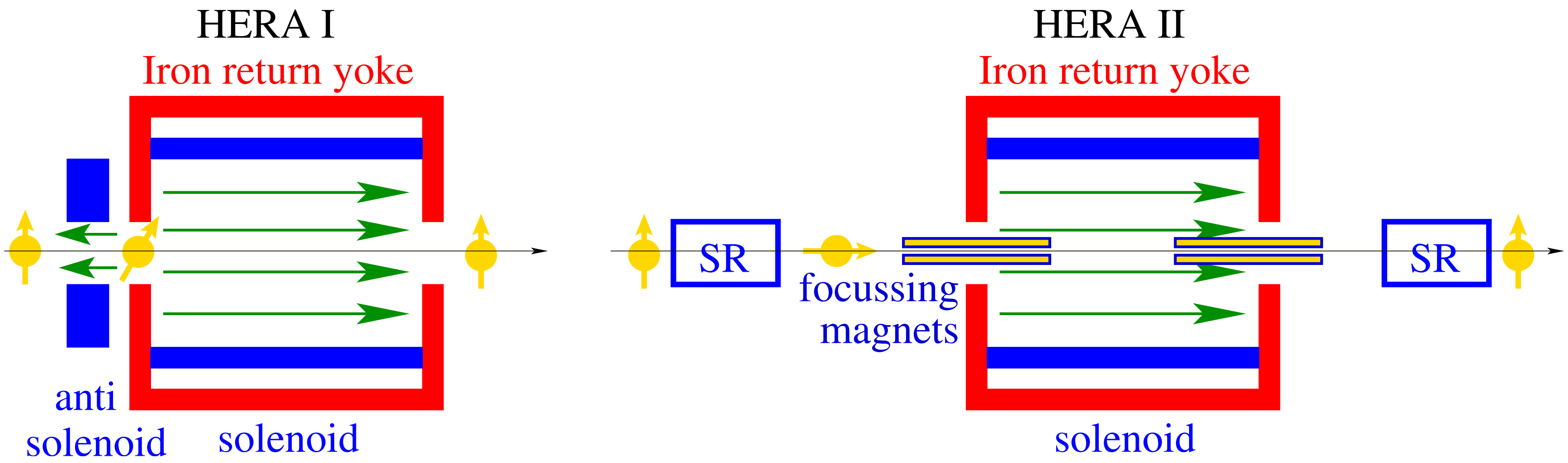


56 m (“short”) → no quads.

27 – 39 GeV, both helicities, variable geometry

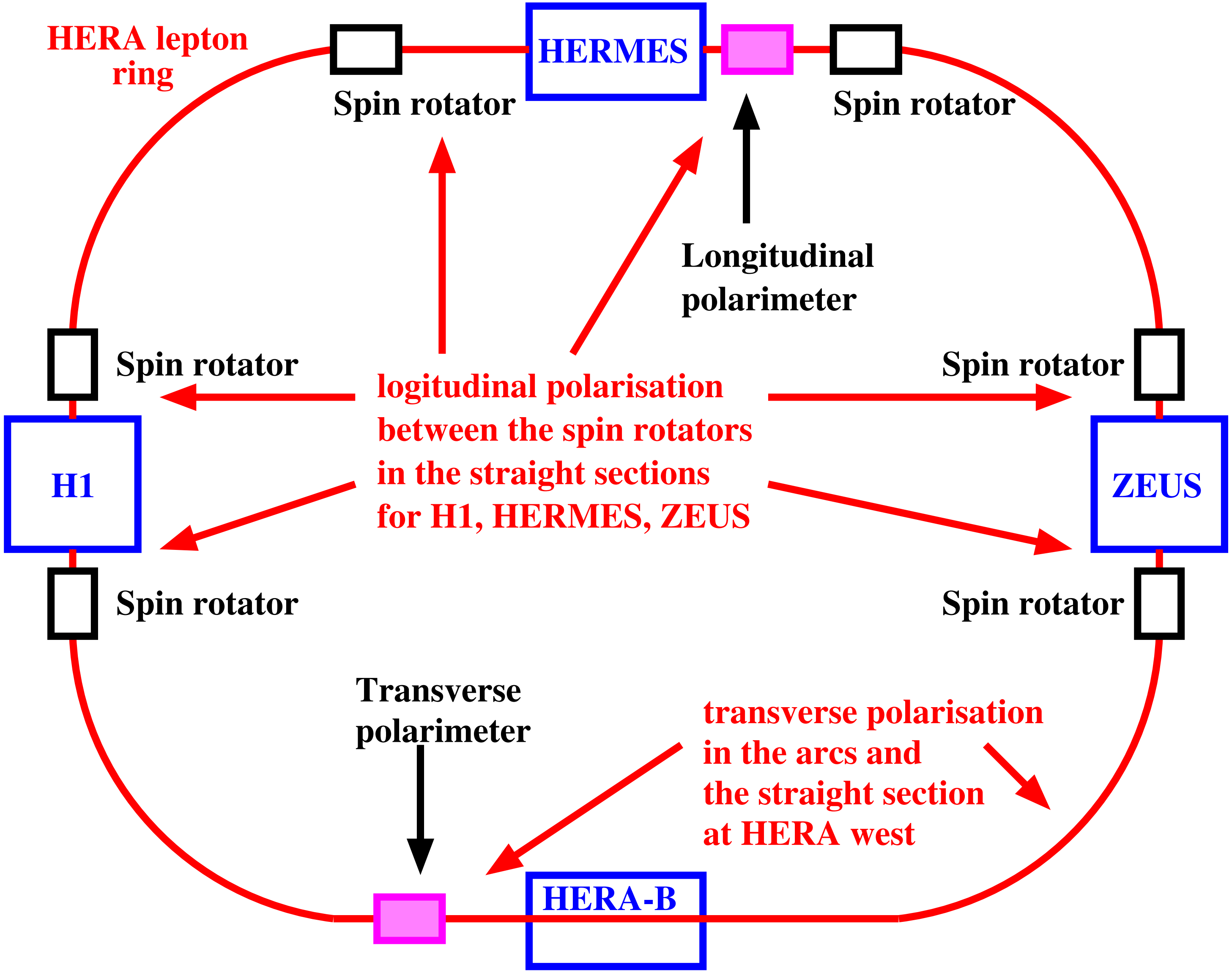
- Six dipole magnets
- Complex spin rotation and beam movement in 3D
- Beam direction after passing rotator is unchanged

The HERA upgrade (2000 – 2001)



- Add strong focussing magnets inside H1 and ZEUS
  + Increase specific luminosity
  – Synchrotron radiation sources close to interaction region, small aperture, beam steering "difficult"
- Remove compensating coils and add spin rotators
  + Longitudinal polarisation for H1 and ZEUS
  – Complex spin and beam orbit, delicate to tune

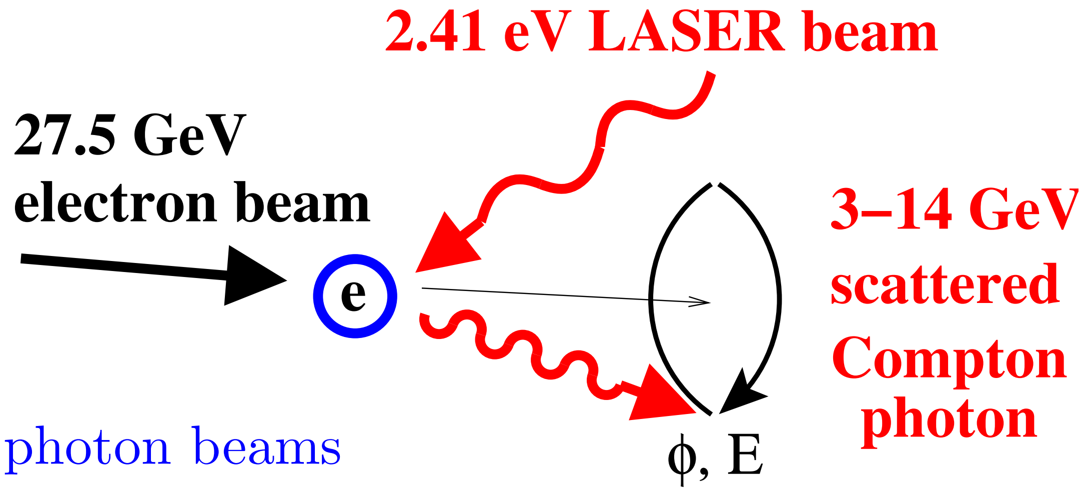
The HERA lepton ring



- two independent polarimeters
- TPOL measures transverse polarisation far from spin rotators $P = P_y$
- LPOL measures longitudinal polarisation between HERMES spin rotators $P = P_z$

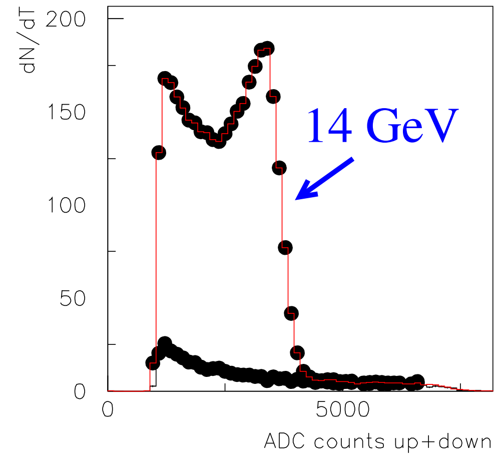
The HERA polarimeters

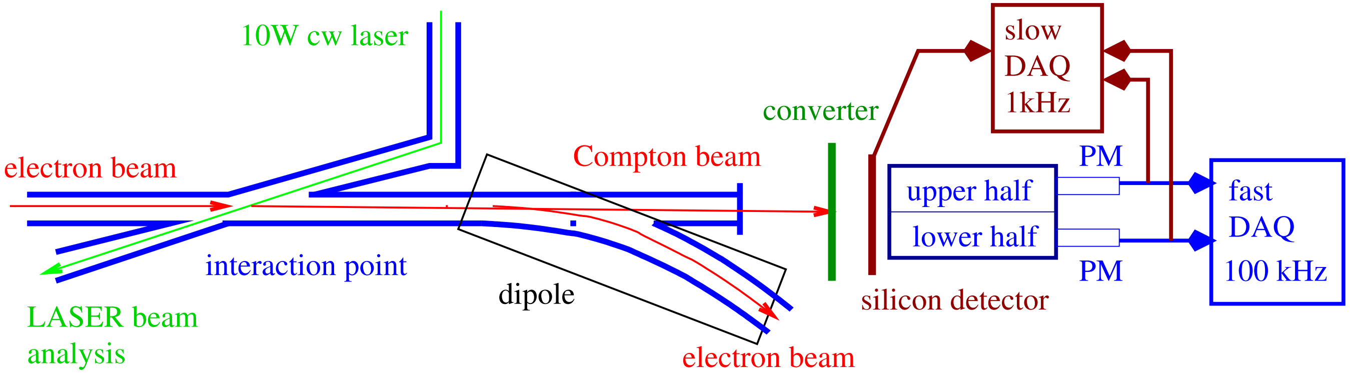
Compton scattering of high-energy electrons and LASER photons



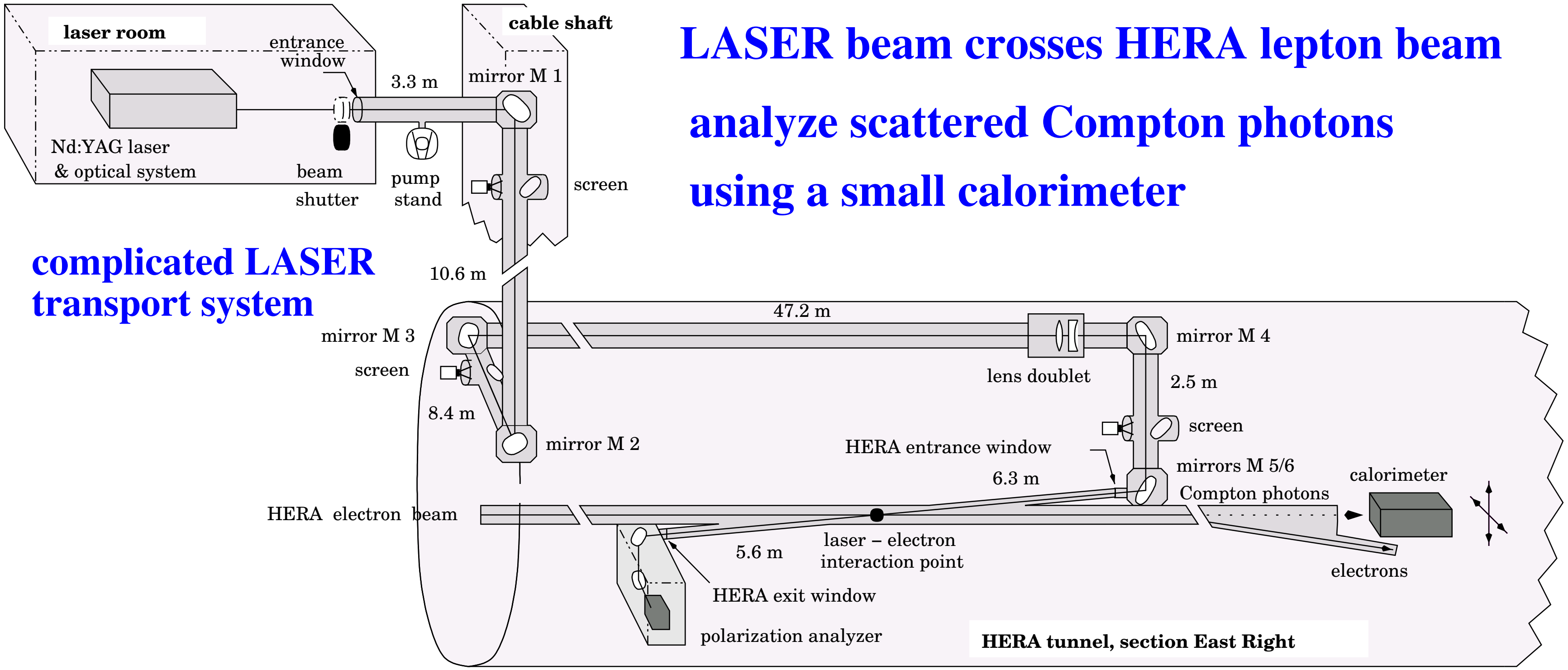
- Electron and scattered photon beams are seperated by bending magnets
- Detect scattered photons in a small calorimeter
- Cross-section is sensitive to beam polarisation

$$\sigma = \sigma_0(E) + P_x\sigma_x(E,\varphi) + P_y\sigma_y(E,\varphi) + P_z\sigma_z(E)$$





The HERA LPOL setup



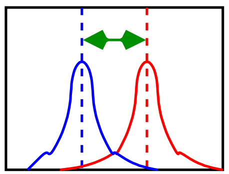
LASER beam crosses HERA lepton beam

analyze scattered Compton photons

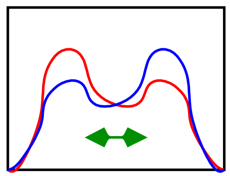
using a small calorimeter

complicated LASER transport system

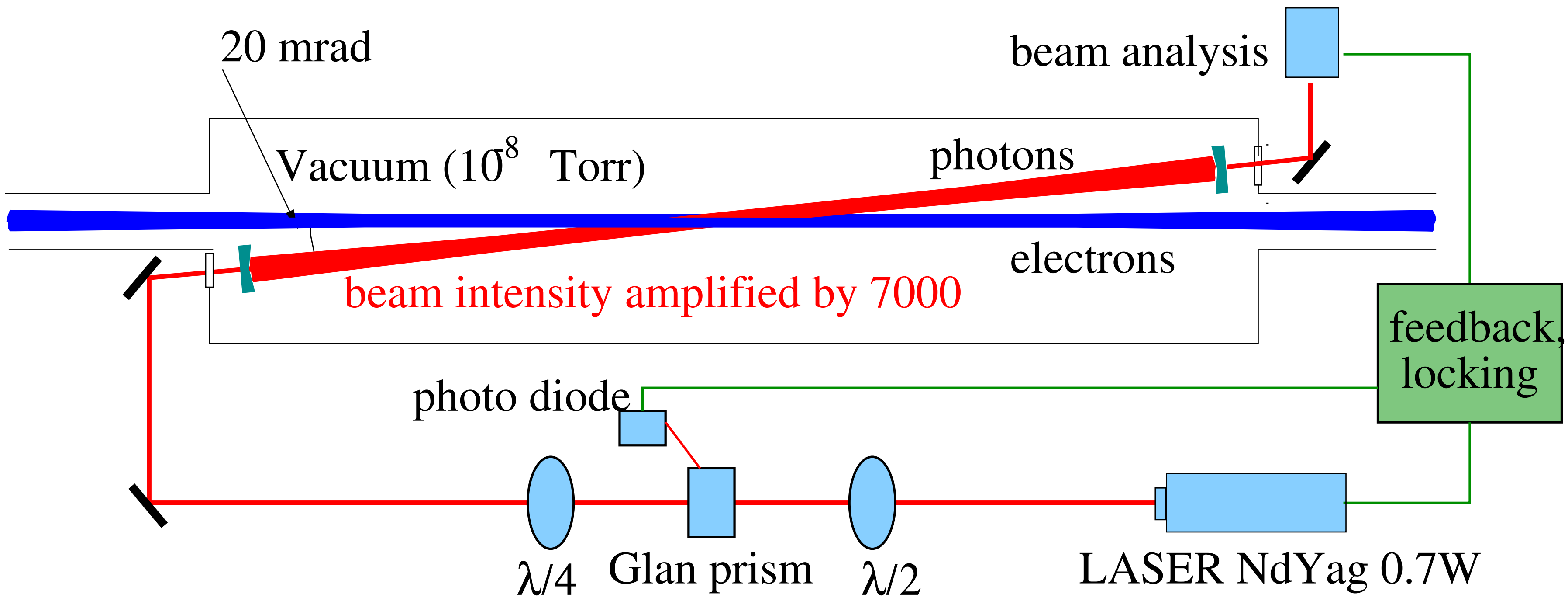
LPOL: measure
energy asymmetry
between left/right
circular LASER light
pulsed laser



TPOL: measure
spatial asymmetry
between left/right
circular LASER light
cw laser

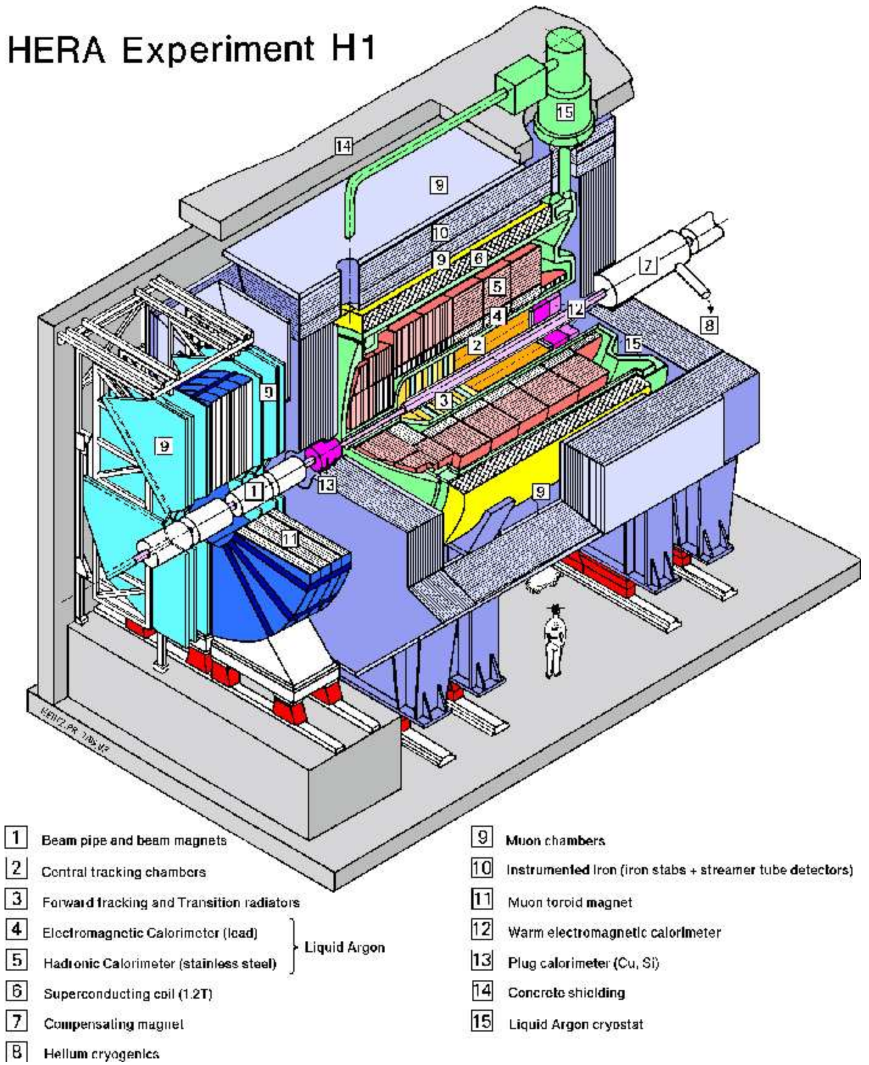


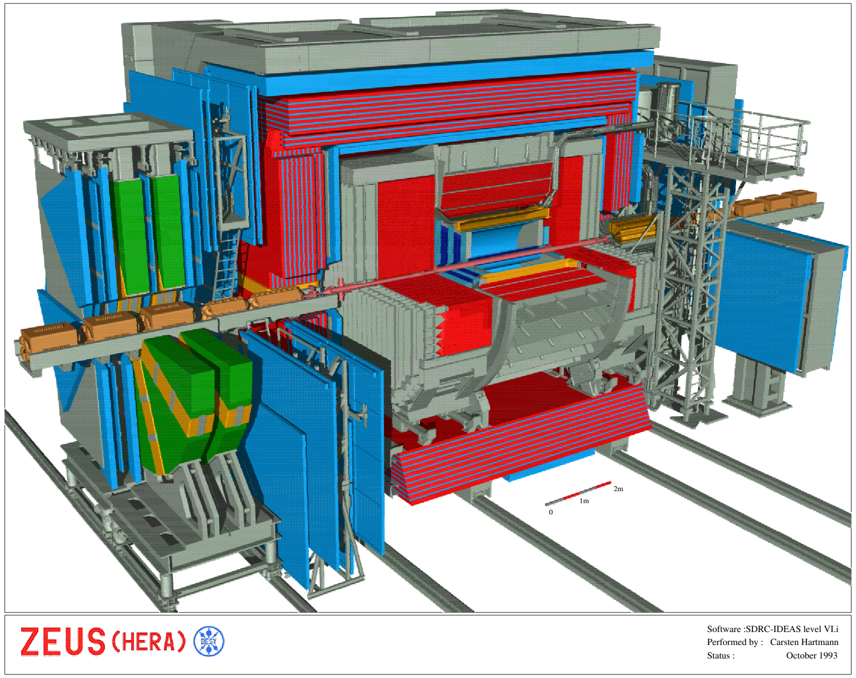
LPOL cavity upgrade



- LASER with 0.7 W intensity is amplified in a Fabry-Perot cavity
  Increase probability of Compton scattering (1 per bunch-crossing)
  High precision polarimetry
- Similar cavity is operational at CEBAF
- HERA cavity commisioning ongoing

The collider experiments ZEUS and H1





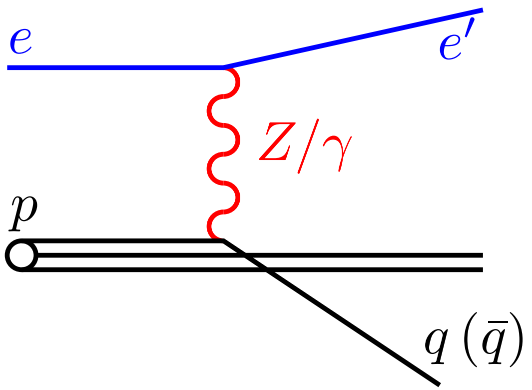
Typical HEP detectors: tracking, solenoid, calorimeter, muon chambers

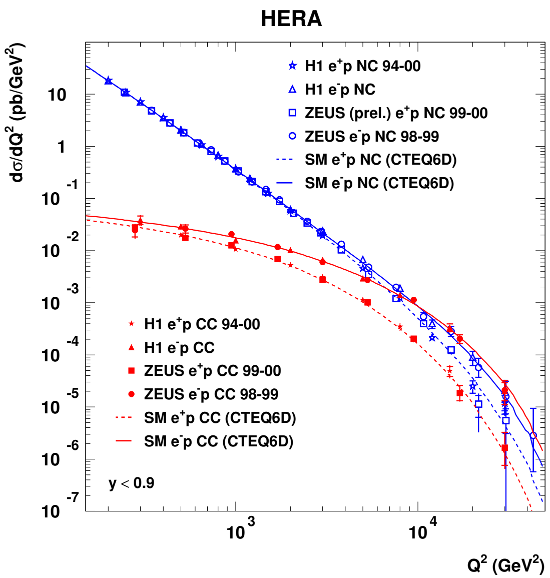
Detectors are asymmetric

($E_e = 27.5\,\mathrm{GeV}$ and $E_p = 920\,\mathrm{GeV}$)

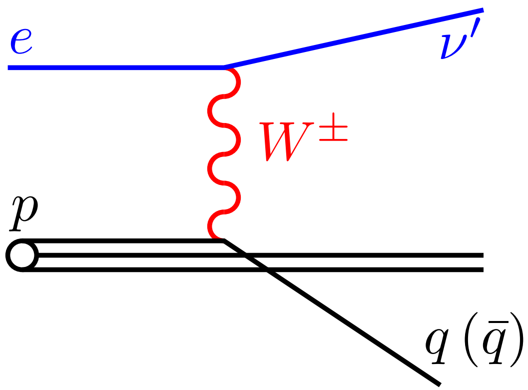
Deep inelastic scattering

Neutral current





Charged current



Kinematic variables

momentum transfer $Q^2 = -(e - e')^2$

center-of-mass energy of eq system: $E_{eq} = \sqrt{\hat{s}}$, $\hat{s} = sx$

At high Q^2: observe unification of electroweak forces

With longitudinally polarized electrons: study helicity dependence

Polarized Neutral current cross-section

Neutral current cross-section:

$$\sigma^{\pm}_{\rm NC} \propto \frac{1}{Q^4}\frac{1}{x} \quad \Big[Y_+ F_2^0(x,Q^2)$$
$$\mp Y_- xF_3^0(x,Q^2)$$
$$+P \times \big(Y_+ F_2^P(x,Q^2)$$
$$\mp Y_- xF_3^P(x,Q^2)\big)\Big]$$

Structure functions:

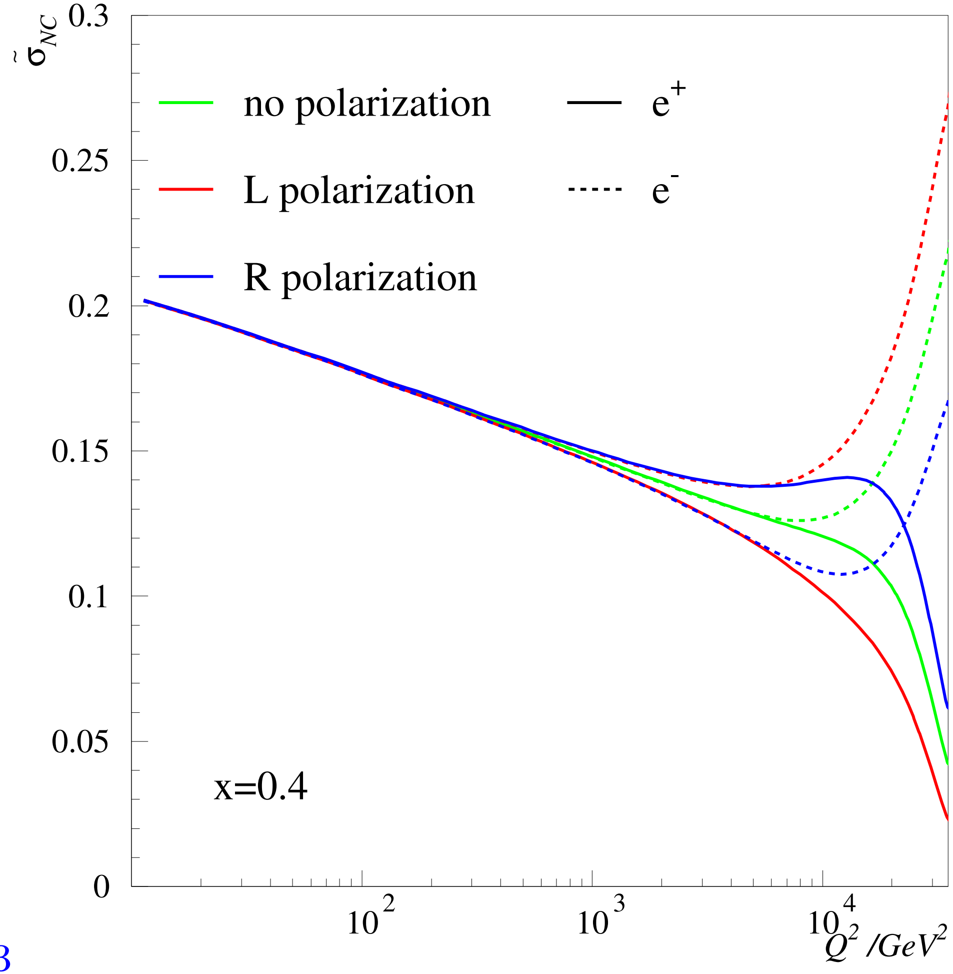
F_2^0 and xF_3^0

Polarized structure functions:

F_2^P and xF_3^P

e^+p and e^-p data: measure F_2, xF_3

$+P$ and $-P$: measure F_2^P, xF_3^P



Structure functions: HERA I and HERA II

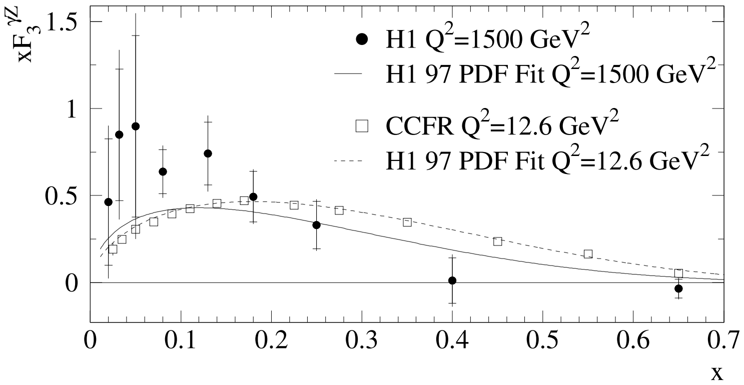
HERA I:

$\approx 100\,\text{pb}^{-}1$ in $e^{+}p$ data

$\approx 16\,\text{pb}^{-}1$ in $e^{-}p$ data

per experiment ($P = 0$)

$\rightarrow$ measurement of xF_3

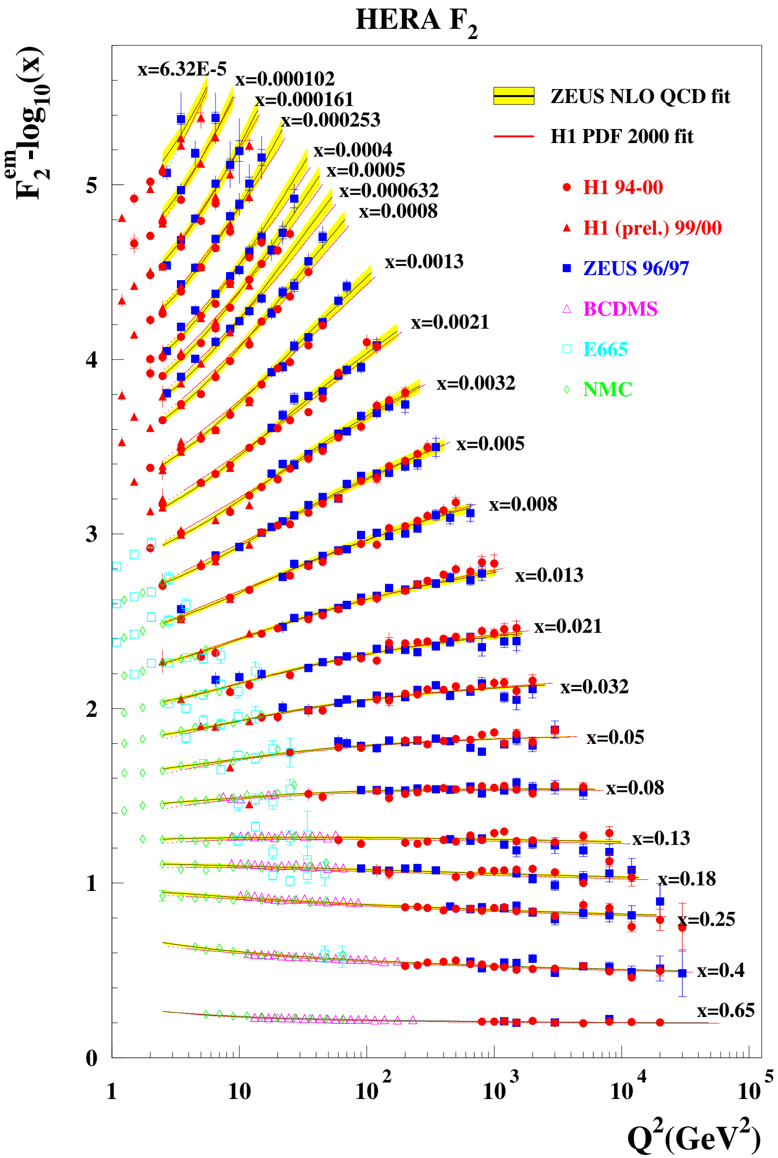


HERA II:

plan to have $4 \times 250\,\text{pb}^{-1}$

for each combination of $e^{\pm}p$ and $\pm P$

$\rightarrow$ measurement of F_2^P and F_3^P



Measurement of the electroweak couplings

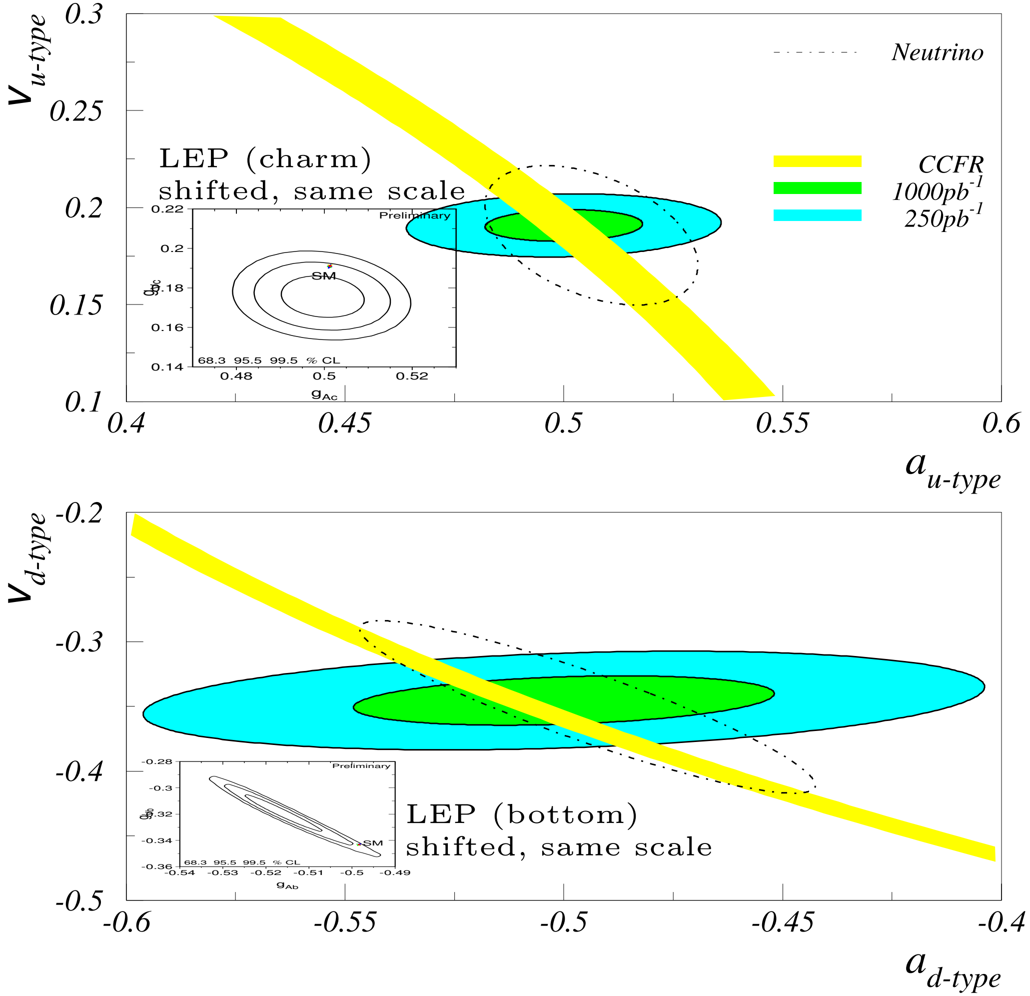
$$F_2^{0,P}(x,Q^2) = \sum_q A_q^{0,P} x(q+\bar{q})$$

$$A_q = f\left(v_q, a_q, \frac{1}{Q^2+M_{Z^0}^2}\right)$$

Simultaneous fit of v_u, a_u, v_d, a_d

Study for: $4 \times 250\,\mathrm{pb}^{-1}$

of $e^{\pm}p$ with $P = \pm 0.7$

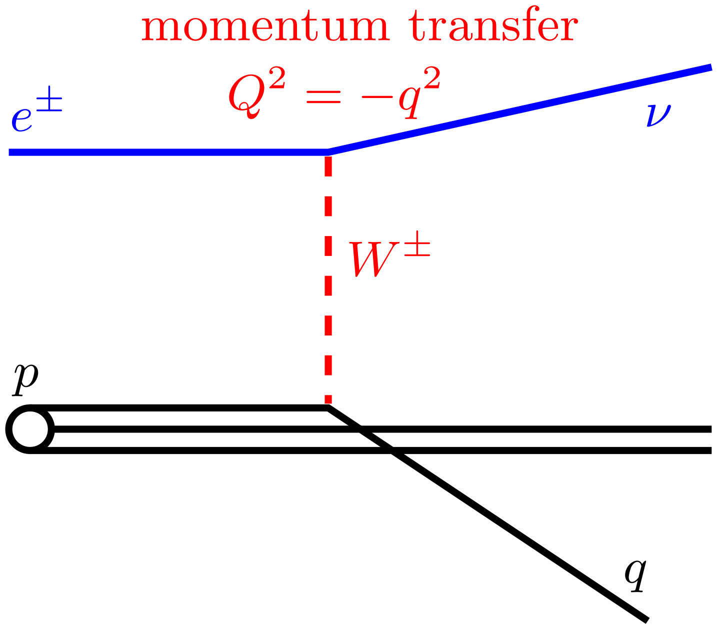


HERA measures light quarks

Complementary to

LEP measurements for heavy quarks

Charged current cross-section



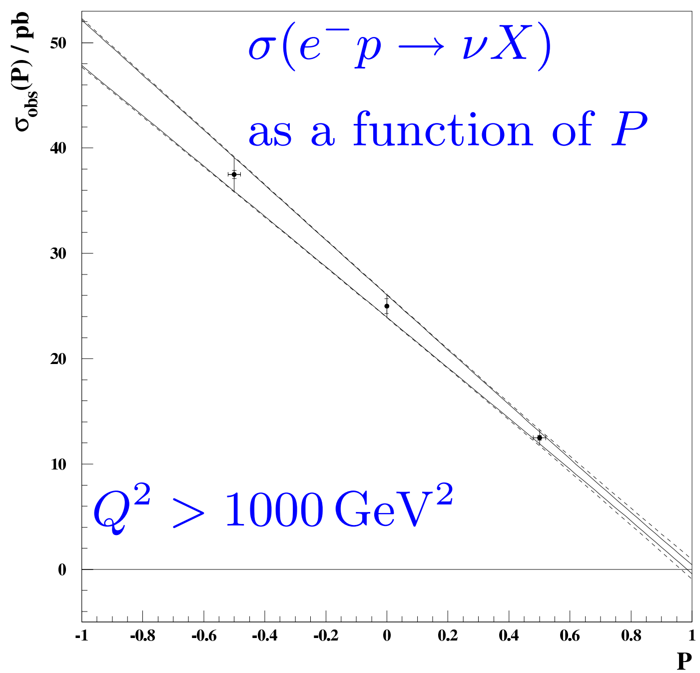
CC cross-section is a linear function of P:

$\sigma_{\mathrm{CC}}^{e^-} = \frac{1-P}{2}\sigma_{\mathrm{CC}}^{L} + \frac{1+P}{2}\sigma_{\mathrm{CC}}^{R}$

Right-handed cross-section is zero in the SM

$\rightarrow$ Look for new physics at P close to 1 (e.g. W_R)

Need to know P with accuracy 1%



SM differential cross-section

$\sigma_{\mathrm{CC}}^{L} \propto G_F^2 \left(\frac{m_W^2}{Q^2+m_W^2}\right)^2$

$\rightarrow$ measure W-mass

Highest cross-section for P close to -1

W mass measurement

HERA I:

Result from DIS2002 ($e^- p$)

$m_W = 79.9 \pm 2.2(\text{stat})$

$\pm 0.9(\text{syst}) \pm 2.1(\text{pdf})\ \text{GeV}$

HERA II:

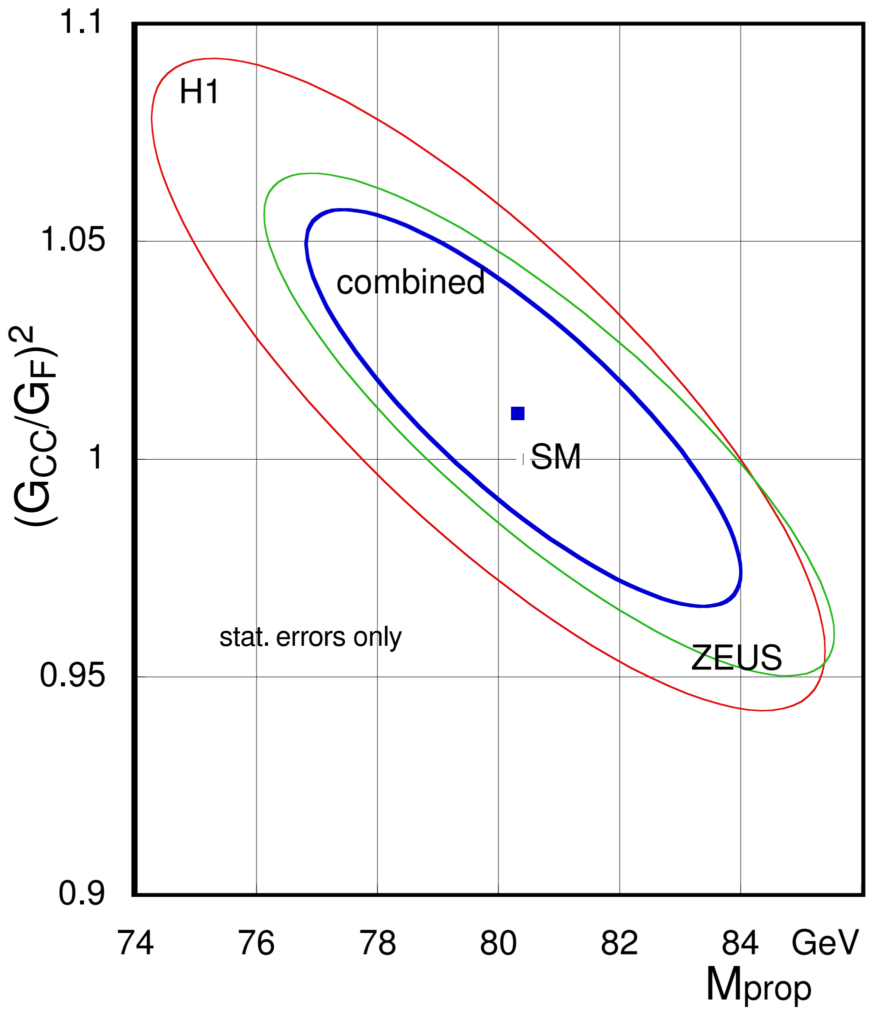
High degree of polarisation

increase $\sigma(\text{CC})$, keep $\sigma(\text{bgr})$ constant

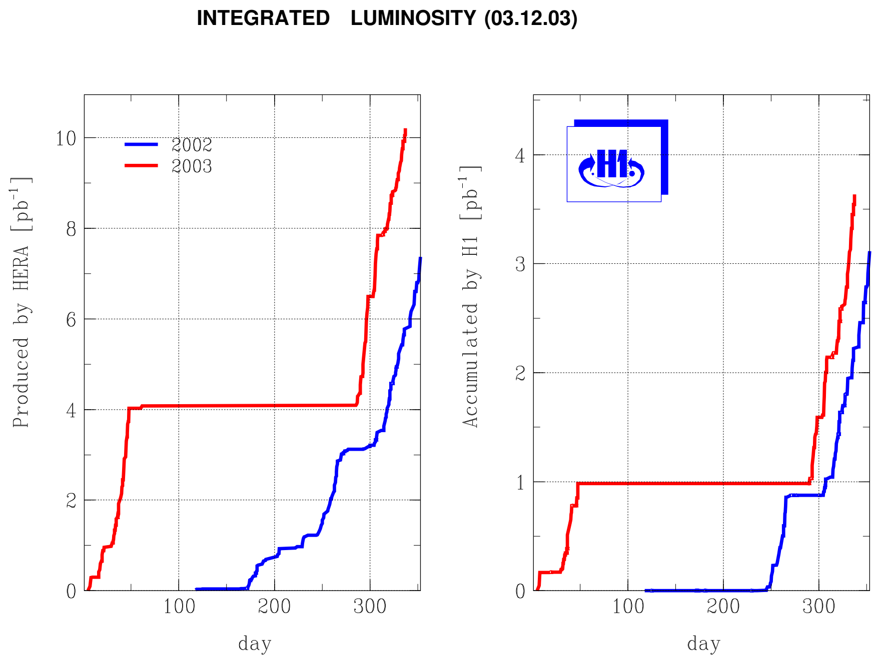
Accuracy for $1000\,\text{pb}^-1$

$\Delta m_W = 50\,\text{MeV}$

(constrained fit, use m_{top}, etc)



Conclusions: HERA II data taking has started



- HERA operation restarted this autumn
- Background conditions improved for H1 and ZEUS
- HERA currents slowly increasing towards design values
- Polarized e beam for H1 and ZEUS
  $\rightarrow$ electroweak physics, searches