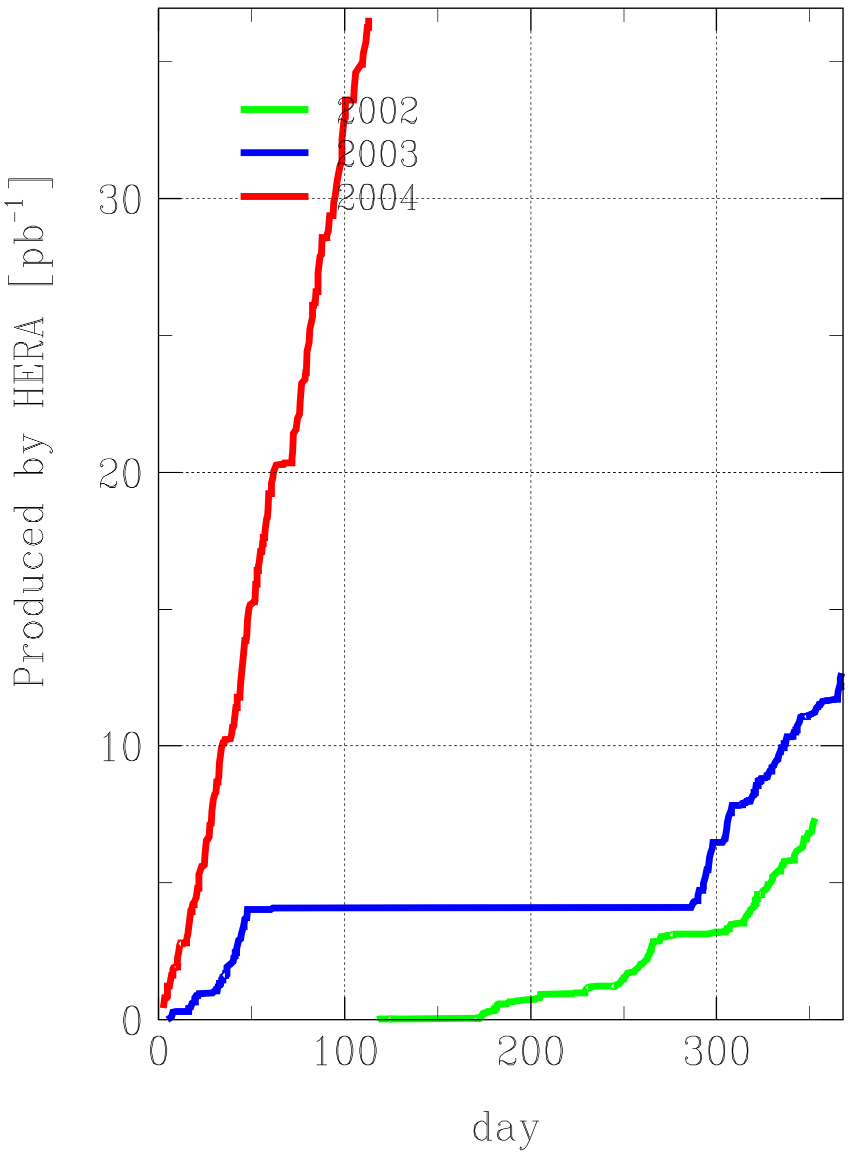
HERA II: from backgrounds to physics

Daniel Pitzl, DESY

DESY Wissenschaftlicher Ausschuss, 27.4.2004

- Luminosity running
- Background problems overcome
- First HERA II physics results
- Physics program and planning

Luminosity running



- In 2004 HERA delivered: 37.2 pb^{-1}.
  Slope is like in 2000, with much lower duty cycle – thanks to higher specific luminosity.

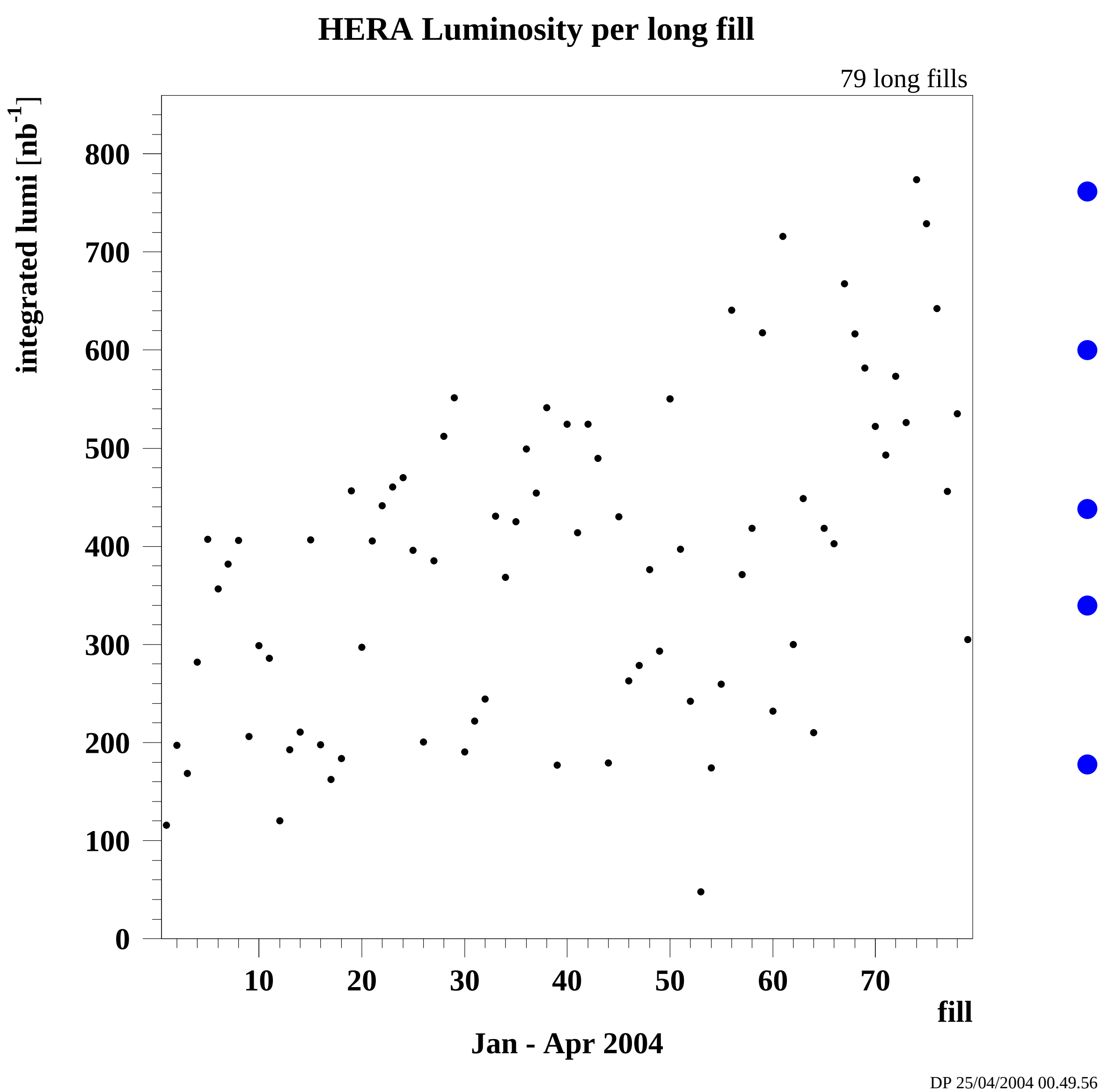
- Peak luminosity so far: $3.5 \cdot 10^{31}$ cm^2/s compared to $1.8 \cdot 10^{31}$ cm^2/s in 2000.

- H1 DAQ running: 35.5 pb^{-1}.
  95.5% average DAQ efficiency.

- DAQ · (1 - deadtime) 32.8 pb^{-1}.
  7.6% average deadtime by design.

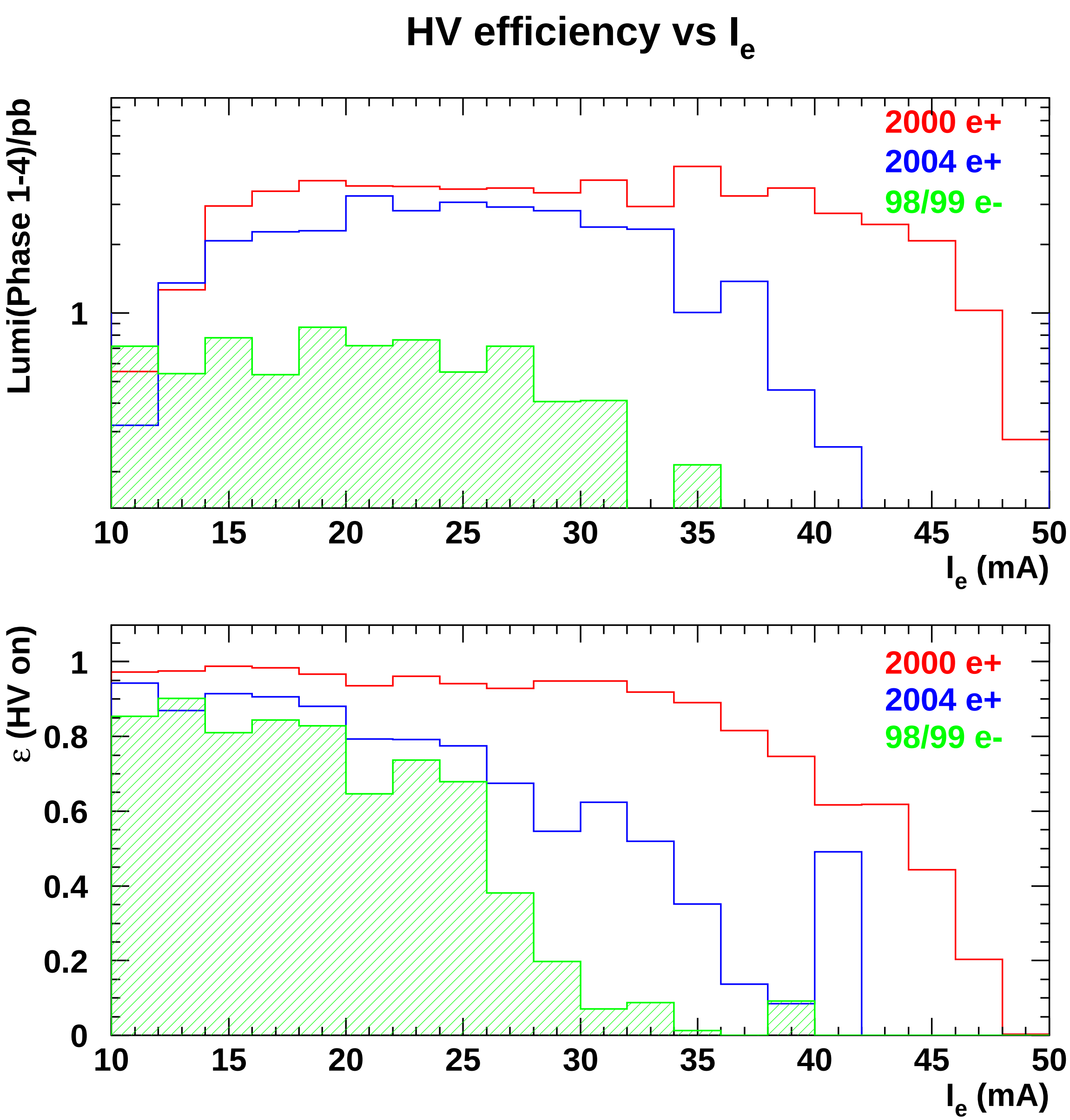
- CJC1,2 and CIP full HV: 22.1 pb^{-1}.
  67% average HV efficiency.

Luminosity development



- 'Long' fills last at least 5 h, and up to 15 h.
- Steady increase of the peak lumi from higher beam currents.
- Best so far: 785 nb^{-1} in one fill.
- Goal: 1200 nb^{-1} per day every day!
- Main challenge: increase duty cycle from 40% now to 55% like in 2000.

Past and present HV efficiency vs I_e for e^+ and e^-

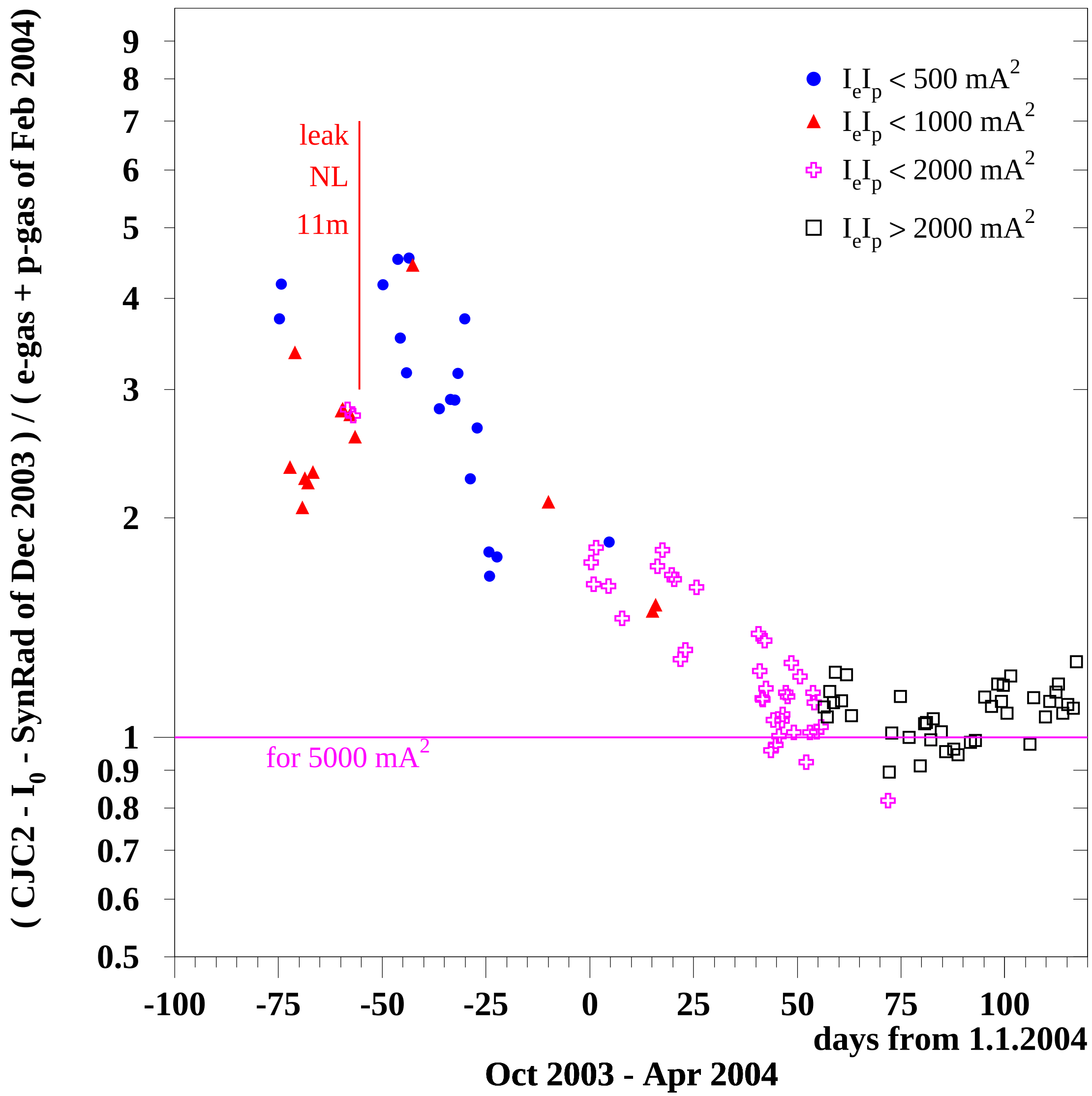


- HV turn-on procedure and initial steering period cause losses at highest I_e.
- H1 and especially ZEUS suffer from short background 'spikes', causing HV ramp-down, often several per hour.
- Stable conditions are required to profit from highest luminosity.
- In H1 e^-p operation in 1998/1999 was inefficient above 28 mA.

Overcoming the background problem

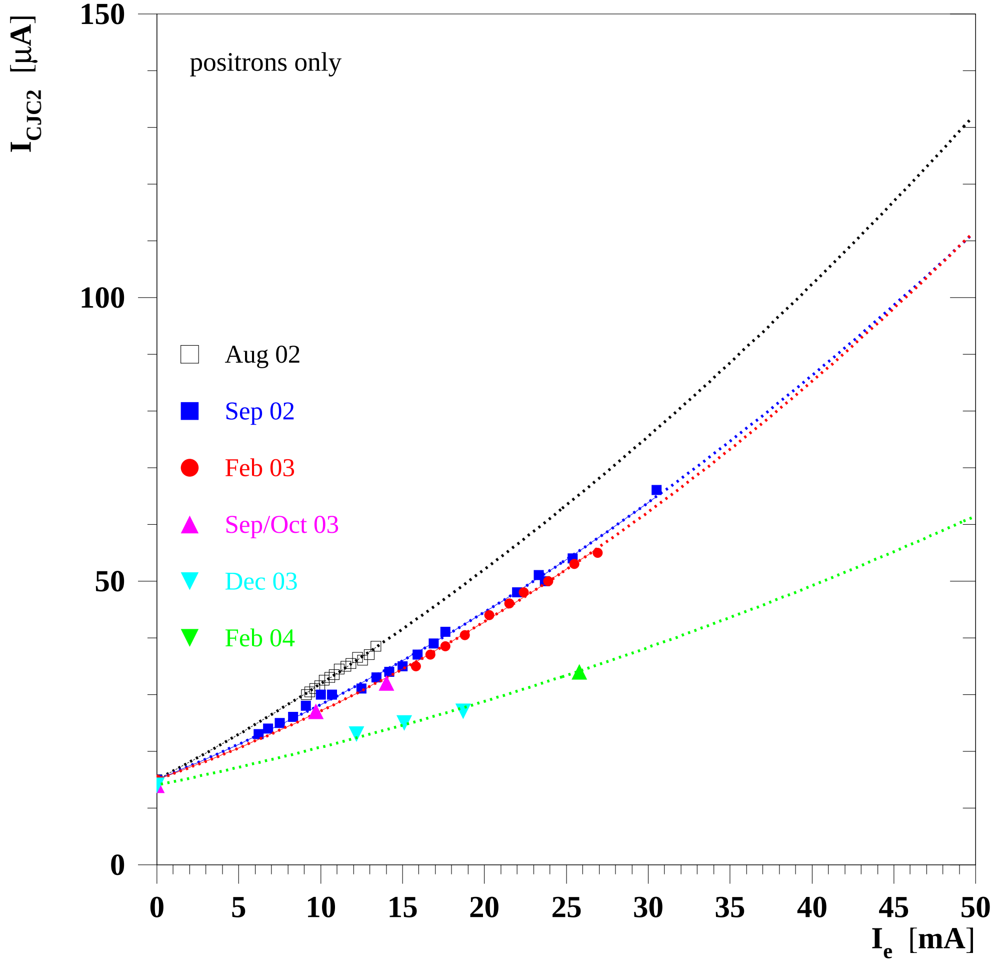
- Dec 2001: backscattered SynRad from 3.6 and 6.0 m.
- Feb 2002: opened aperture in ABS1, ABS2.
- May 2002: proton gas background in H1 and ZEUS, SynRad in ZEUS.
- Autumn 2002: dedicated background experiments and simulations.
- Sep '02 and Jan '03: background reviews with external advisors.
- ep is the worst of all worlds: SynRad causes beampipe outgassing, protons interact with large cross section.
- Mar–Jun 2003: shutdown to reduce backgrounds:
- Increased pumping power, extra getter pump, better SynRad shielding.
- Aug–Sep 2003: extended bakeout at 12 GeV: $\int I_e dt \approx 11$ Ah.
- Nov 4, 2003: last major vacuum leak around H1 (uncontrolled p loss after magnet power supply failure).
- Steady vacuum and background improvement since then.
- Feb 2004: H1 and ZEUS declare that they can operate at design beam currents!

H1 chamber current history Oct 2003 – Feb 2004



- Long-term improvement by factor ≈ 4 with $\tau \approx 70$ days after vacuum leak on 4.11.2003
- Chamber currents in Feb 2004 allow operation at design beam currents.
- HERA is no longer background limited!
- How can the time constant be understood?
- Have we reached the final level?

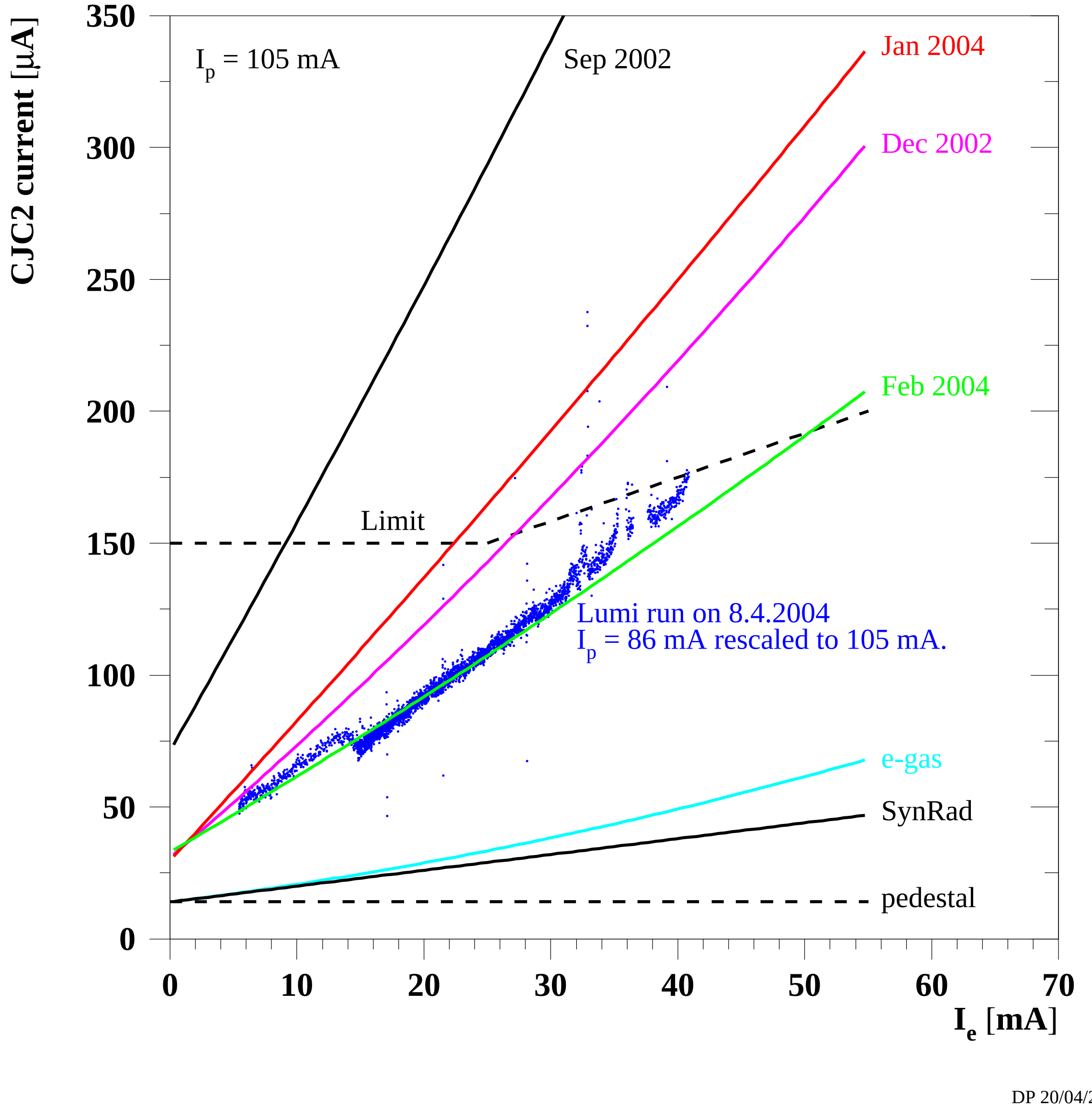
Synchrotron Radiation background reduction



- Synchrotron radiation background in the CJC is now a factor of 2 smaller than in 2002.
- Main effect due to better alignment of H1 beam pipe and better beam steering.
- Lead shielding in backward region also contributes.
- Further reduction factor 1.7 possible by installation of a coated absorber, but requires break of vacuum.

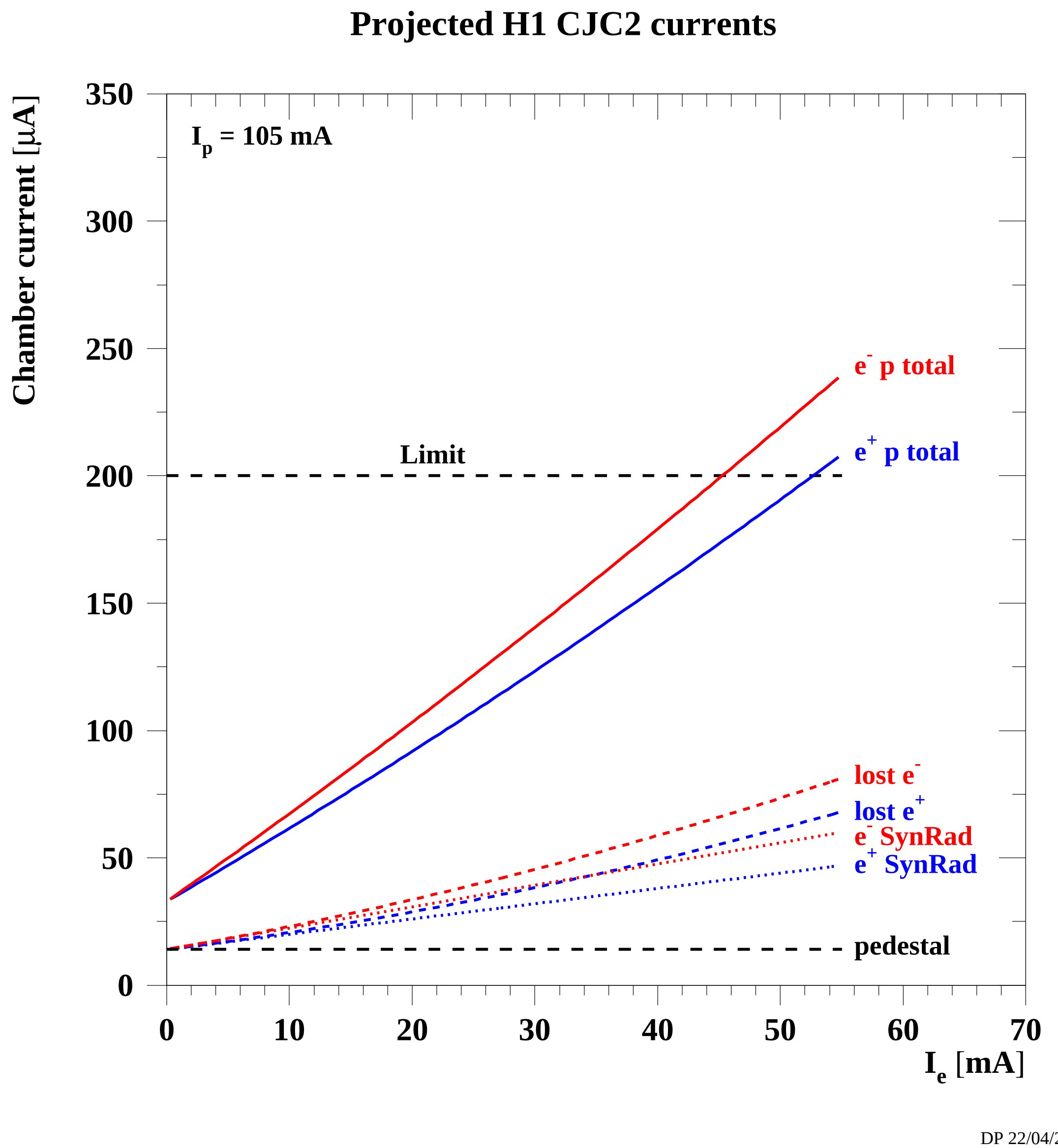
Chamber current

H1 Chamber current vs beam current



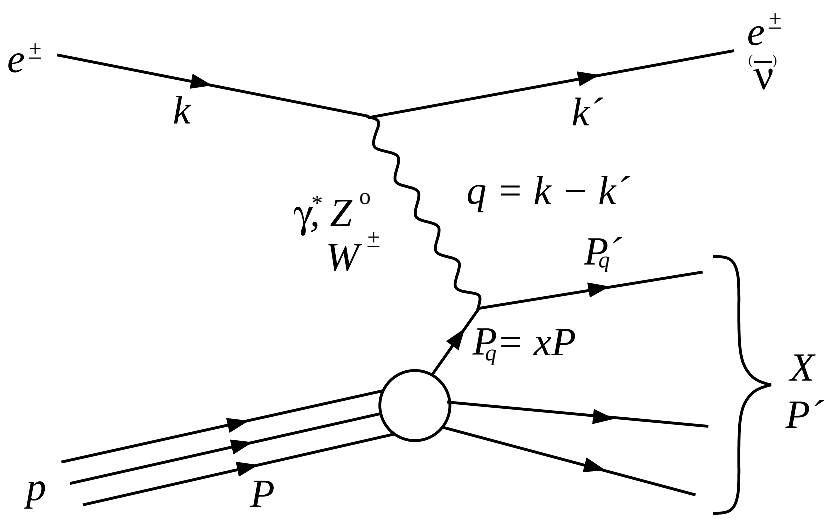
- Long-term aging effects set a limit at 200 μA.
- Background contributions parameterized as function of beam currents:
- p-gas (dominant)
- e-gas
- Synchrotron radiation
- Safe operation should now be possible at $I_e \cdot I_p = 52 \cdot 105\,\mathrm{mA}^2$.

Expected chamber current e^+p and e^-p



- Backscattered SynRad background in the CJC increases by 40% due to higher flux and harder spectrum.
  Coating of ABS4 would reduce by a factor 1.7.
- e-gas unchanged, with proper collimator setting.
- p-gas increases by 15% due to higher photon flux, causing photodesorption.
- The 200 μA limit is reached at $45 \cdot 105\,\mathrm{mA}^2$ with e^-p instead of at $52 \cdot 105\,\mathrm{mA}^2$ with e^+p

Deep inelastic scattering



Kinematic variables:

- $Q^2 = -q^2$ = momentum transfer
- $y = \frac{P\cdot q}{P\cdot k} = (1 + \cos\Theta^*_{eq})/2$ = inelasticity
- $s = (P + k)^2 = (320\,\mathrm{GeV})^2 = ep$ cms energy
- $x = \frac{Q^2}{ys}$ = momentum fraction

reconstructed from e and/or hadronic final state.

Neutral current:

$$\frac{d^2\sigma^{NC}}{dx\,dQ^2}(e^+_{L,R}) = \frac{2\pi\alpha^2}{xQ^4}\left[Y_+ F_2^{L,R} - Y_- xF_3^{L,R} - y^2 F_L\right]$$

$$Y_+ = 1 + (1-y)^2, \quad Y_- = 1 - (1-y)^2$$

$$F_2^{L,R} = \sum_q x \left[q(x,Q^2) + \bar{q}(x,Q^2)\right] A_q^{L,R}$$

$$xF_3^{L,R} = \sum_q x \left[q(x,Q^2) - \bar{q}(x,Q^2)\right] B_q^{L,R}$$

$$A_q^{L,R} = e_q^2 + 2e_e(v_e \pm a_e)e_q v_q \chi_Z + (v_e \pm a_e)^2(v_q^2 + a_q^2)\chi_Z^2$$

$$B_q^{L,R} = \pm 2e_e(v_e \pm a_e)e_q a_q \chi_Z \pm (2v_e a_e)v_q a_q \chi_Z^2$$

with $L = +$, $R = -$

$$\chi_Z = \frac{1}{4\sin^2\Theta_W \cos^2\Theta_W} \frac{Q^2}{Q^2 + M_Z^2}$$

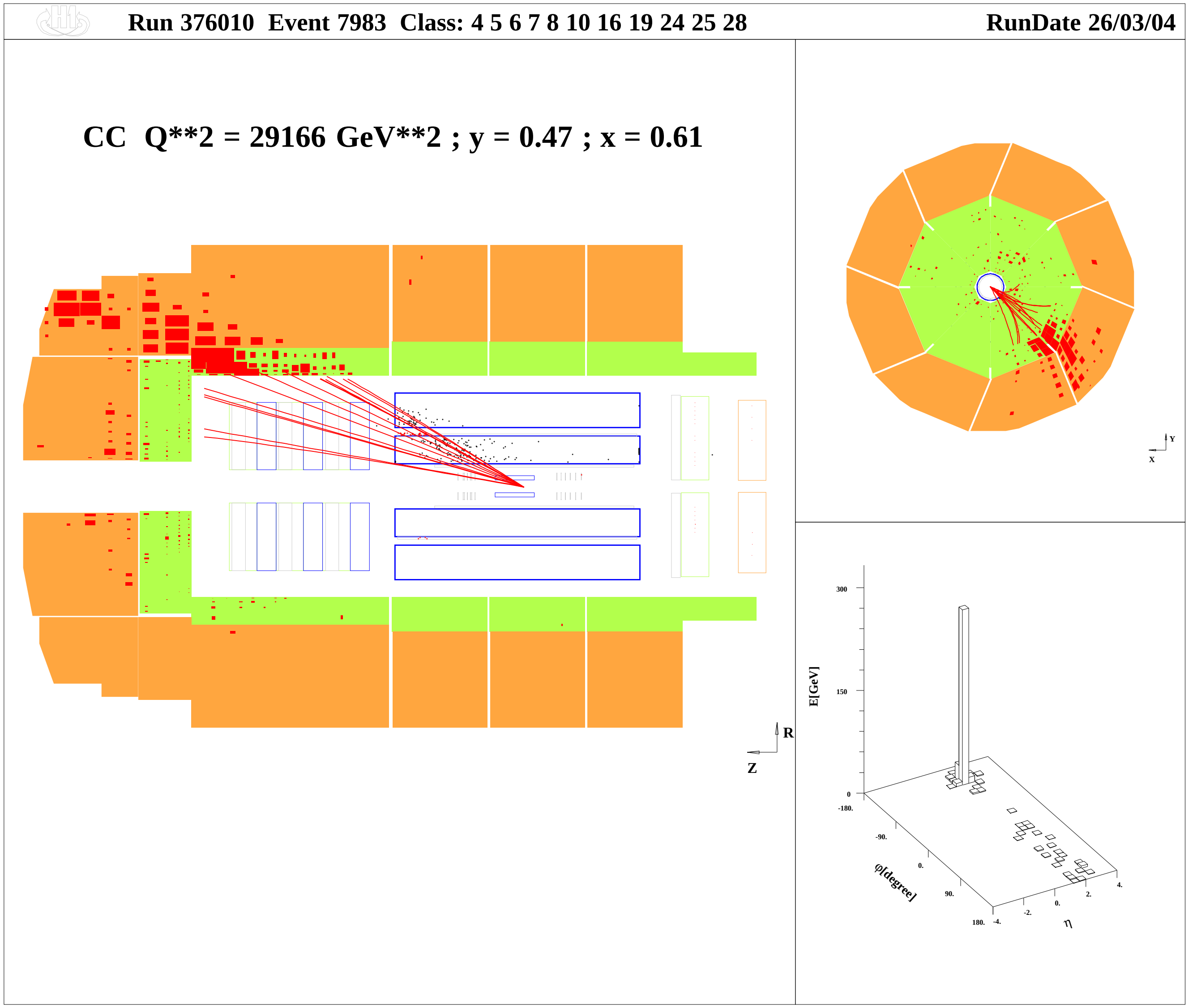
Charged current:

$$\frac{d^2\sigma^{CC}}{dx\,dQ^2}(e^+) = (1+P)\frac{G_F^2}{2\pi}\left[\frac{M_W^2}{Q^2+M_W^2}\right]^2 x\left[\bar{u} + \bar{c} + (1-y)^2(d+s+b)\right]$$

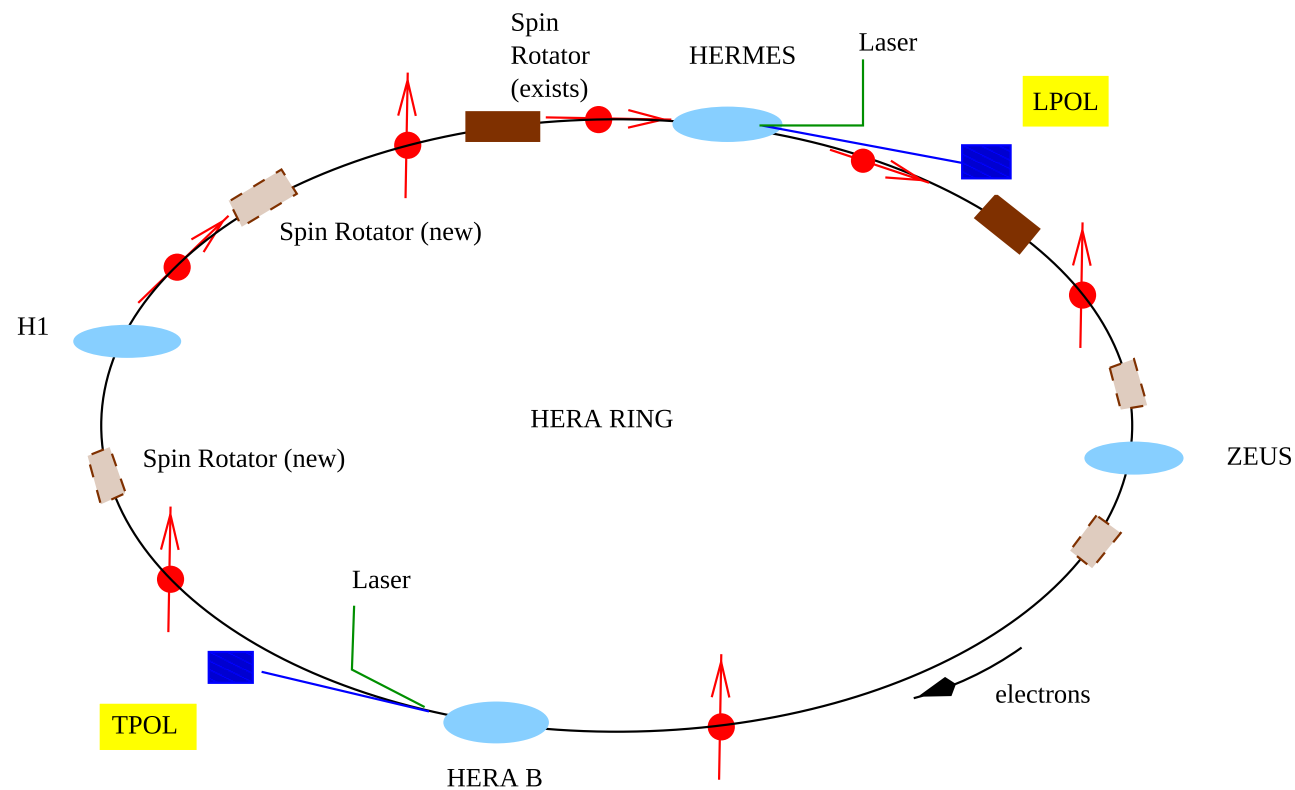
Longitudinal polarization:

$$P = \frac{N_R - N_L}{N_R + N_L}$$

A high Q^2 charged current event in H1

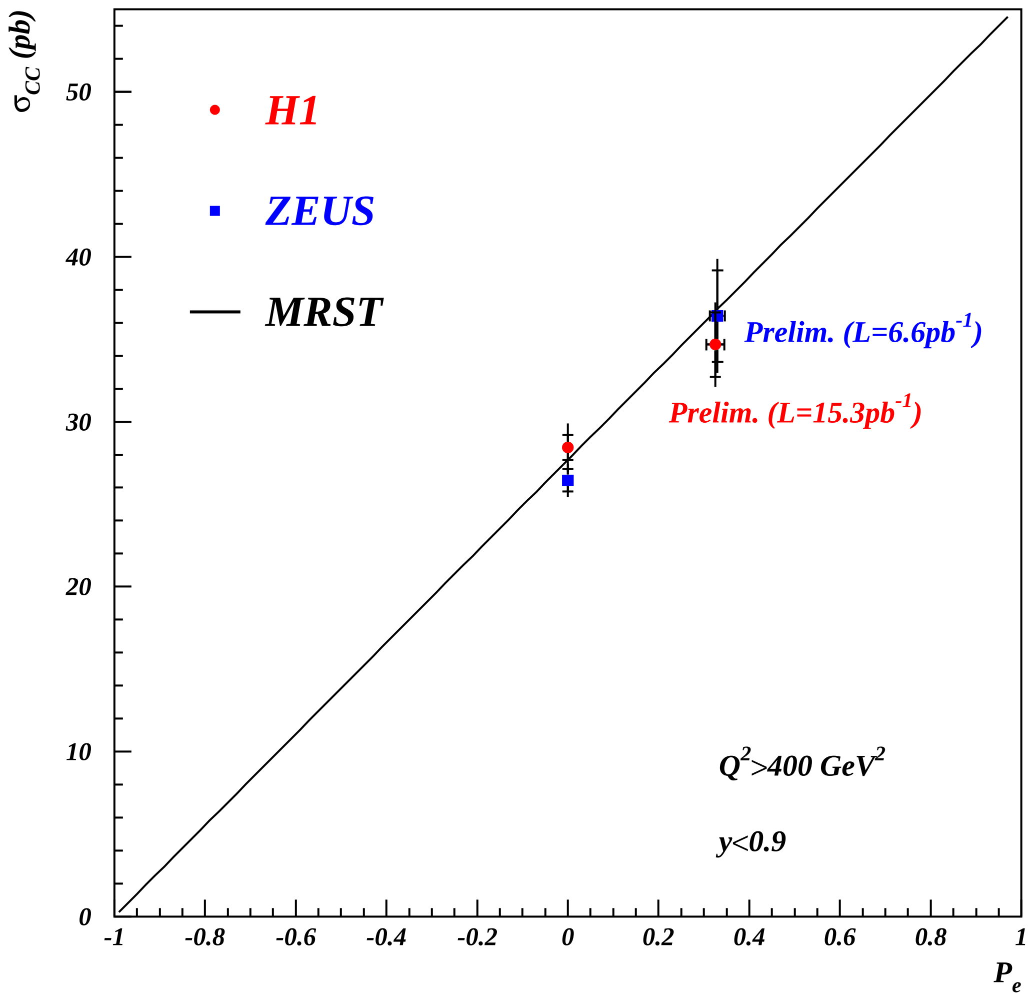


Positron beam polarization



- e^+ magnetic moment couples to storage ring dipole field. Sokolov-Ternov build-up of transverse polarization by synchrotron radiation: $\tau \approx 25\,\text{min}$. $P = 40\%$ reached.
- Spin Rotators use $g-2$ precession to get longitudinal polarization at the IPs.
- Polarimeters use asymmetries in Compton backscattered polarized laser light.

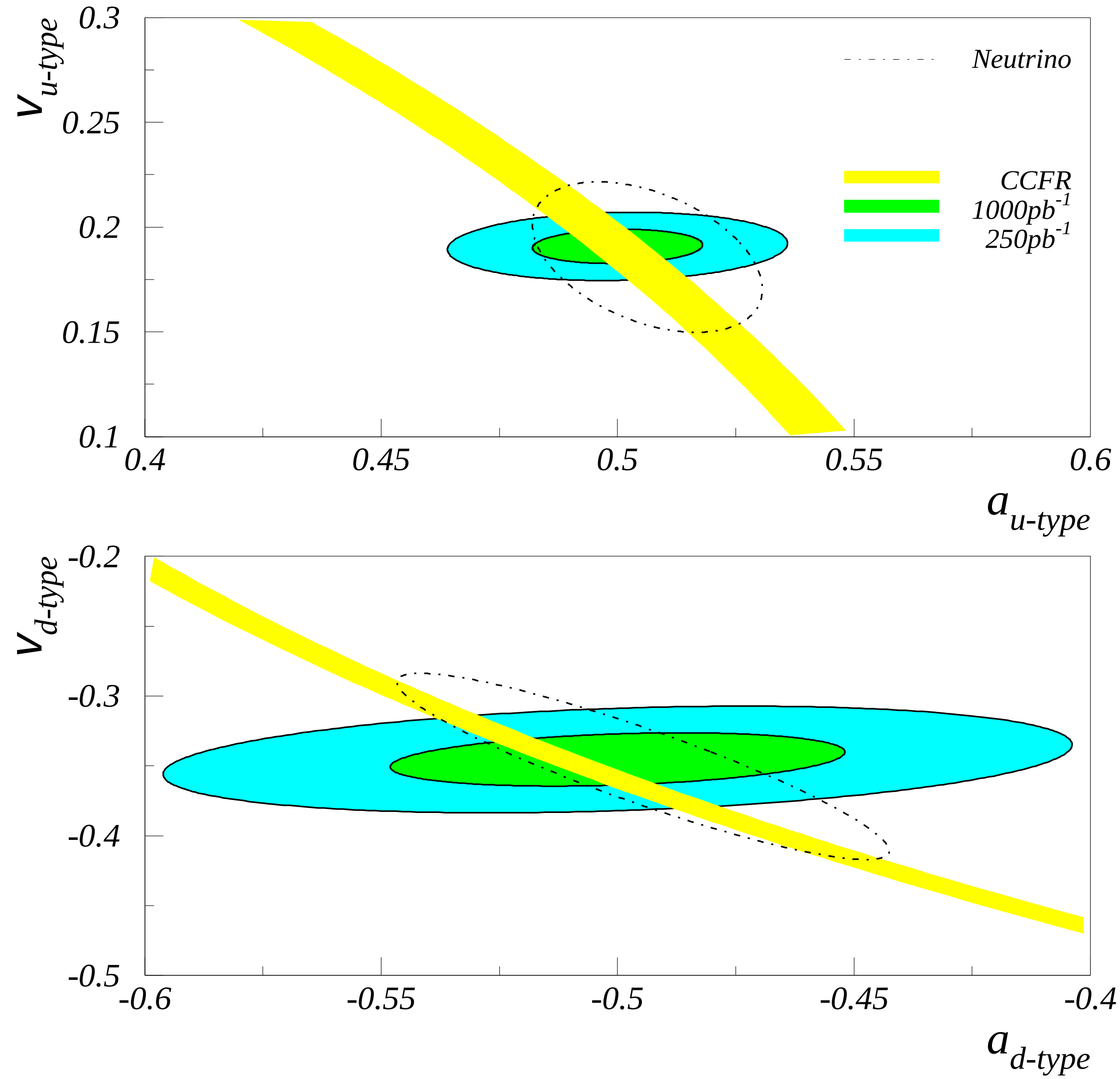
Polarised $e^{\pm}p$ charged current cross section



- H1 and ZEUS have measured the charged current $e^{+}p$ cross section at $+33 \pm 2\%$ average polarization from the Oct '03 – Mar '04 HERA II data.
- For $P = 0$ it has been measured at HERA I.
- The Standard Model expectation agrees with the data.
- We now take data with negative polarization.
- Extrapolation to $P = -1$ allows to set limits on right-handed currents.

u and d quark couplings to Z^0

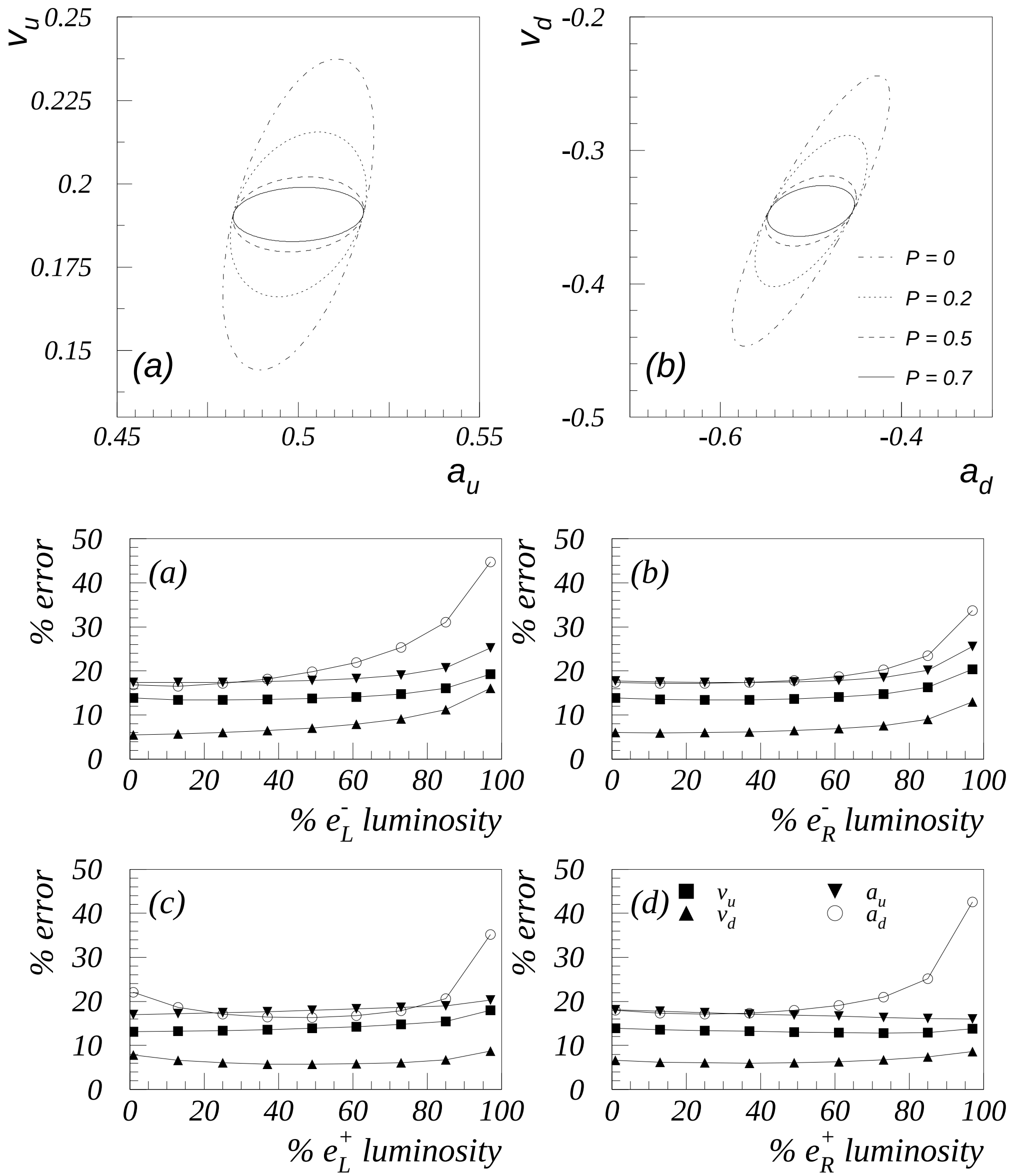
Simulation



- HERA simulation: 250 or 1000 pb^{-1} divided between $e^{\pm}_{L,R}$ with 70% polarization.
- High luminosity is essential!
- CCFR fixed target neutrino beam data from NC/CC ratio.
- LEP has measured a and v with slightly better precision for c and b quarks.

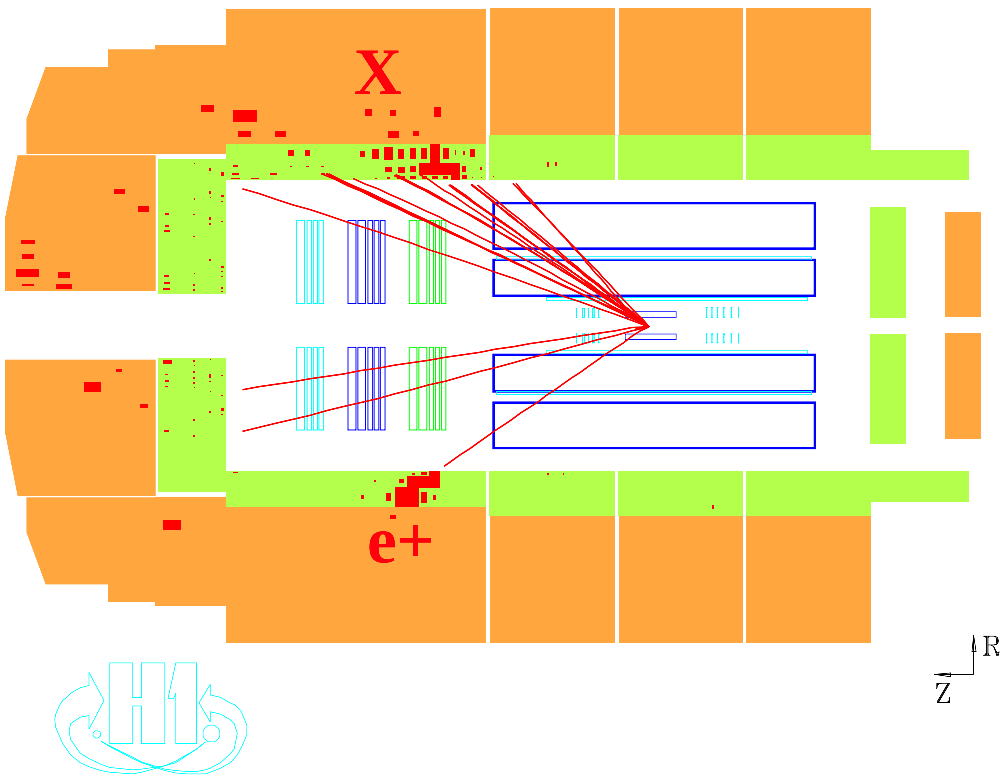
$\Rightarrow$ test flavour universality of Z^0 couplings.

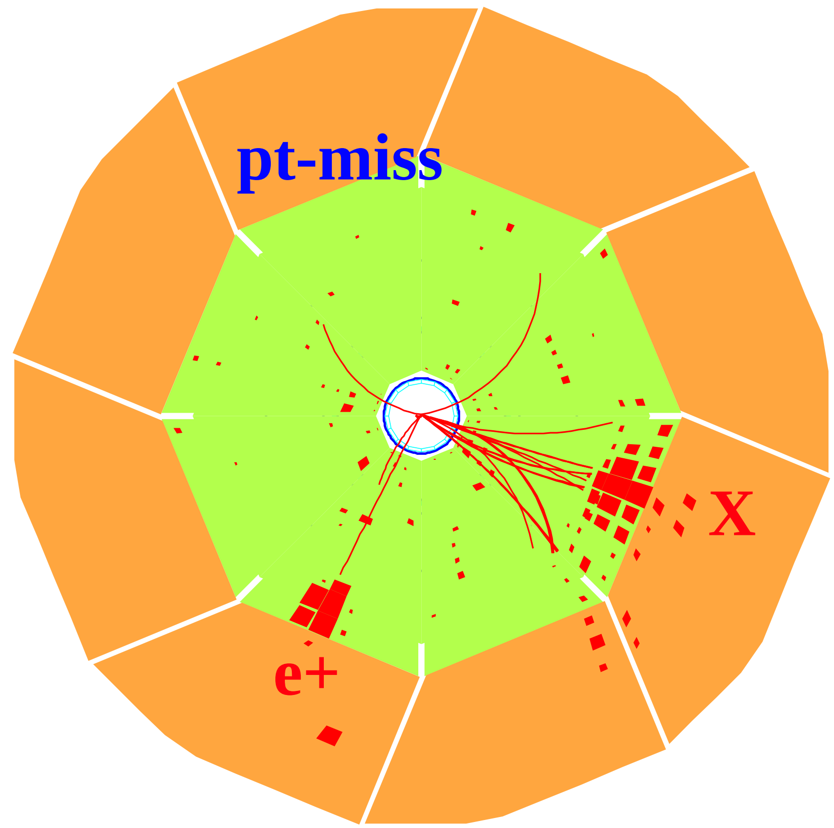
High Polarization required



- Simulation for 1000 pb^{-1}.
- Good precision on v_u and v_d requires $> 40\%$ polarization.
- Division of luminosity between $e^{\pm}_{L,R}$ is less critical.

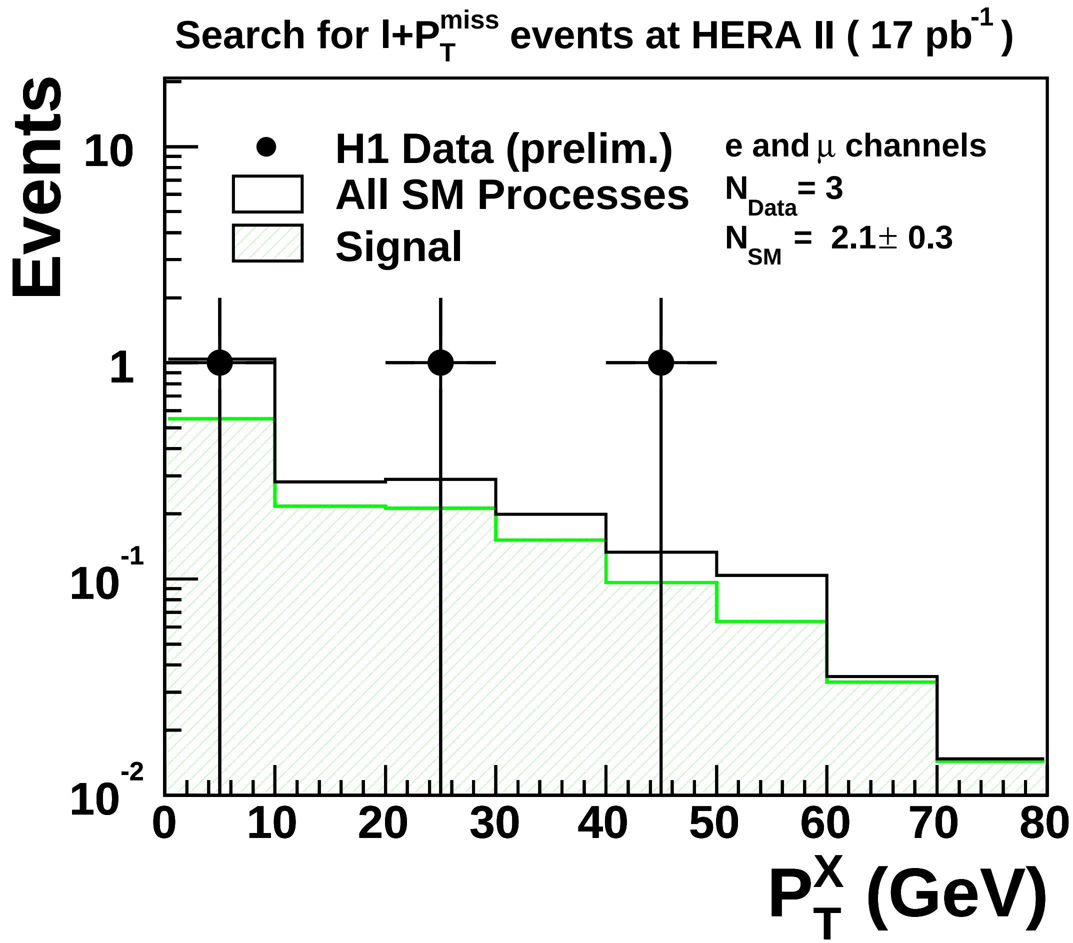
Events with isolated high p_T lepton and missing p_T from HERA II





$p_T^e = 37$ GeV, $p_T^{\mathrm{miss}} = 44$ GeV, $p_T^X = 29$ GeV.

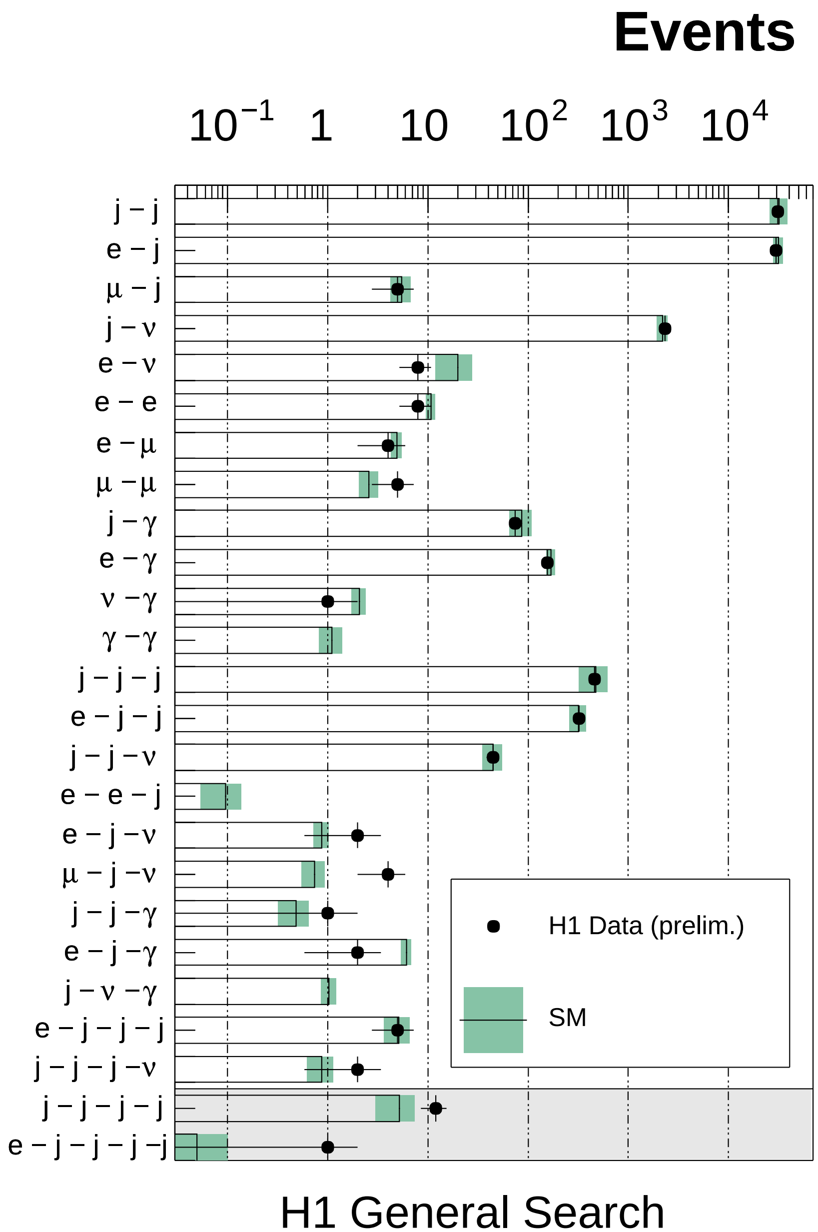
p_T^X distribution



SM Signal is mainly real W production.

- H1 observes 3 events in $e+\mu$ channels in 17 pb^{-1} of HERA II data, expecting 2 ± 0.3.
- H1 observes 2 events with $p_T^X >$ 25 GeV, expecting 0.6 ± 0.1.
- In 105 pb^{-1} e^+p data from 1994–2000 H1 observed 10 events with $p_T^X > 25$ GeV, expecting 2.9 ± 0.3.
- ZEUS observes 7 events with $p_T^X > 25$ GeV, expecting 5.6 ± 0.3 in 130 pb^{-1} HERA I data.
- This channel needs to be investigated with highest e^+p luminosity before the 'discovery window' closes.

General high-p_t search in HERA I data



- Require 2 well separated objects with $p_T > 20$ GeV per event: e, μ, γ, ν, or jet.
- Compare to Standard Model expectation using simulation.
- The most significant excess is in the $\mu - j - \nu$ channel: the isolated high p_T muons with missing p_T and large p_T^X.

High luminosity physics program

e^+p

- Clarify isolated high p_t leptons.
- Clarify multi-electrons.
- $F = 0$ leptoquarks.
- d density from charged current.
- Searches: RPV stop, SUSY with c, u.

e^+p and e^-p

- u and d couplings to Z^0.
- Valence density at 'low' x from xF_3.
- DVCS charge asymmetry.

Reduced E_p

- F_L.
- High x densities .

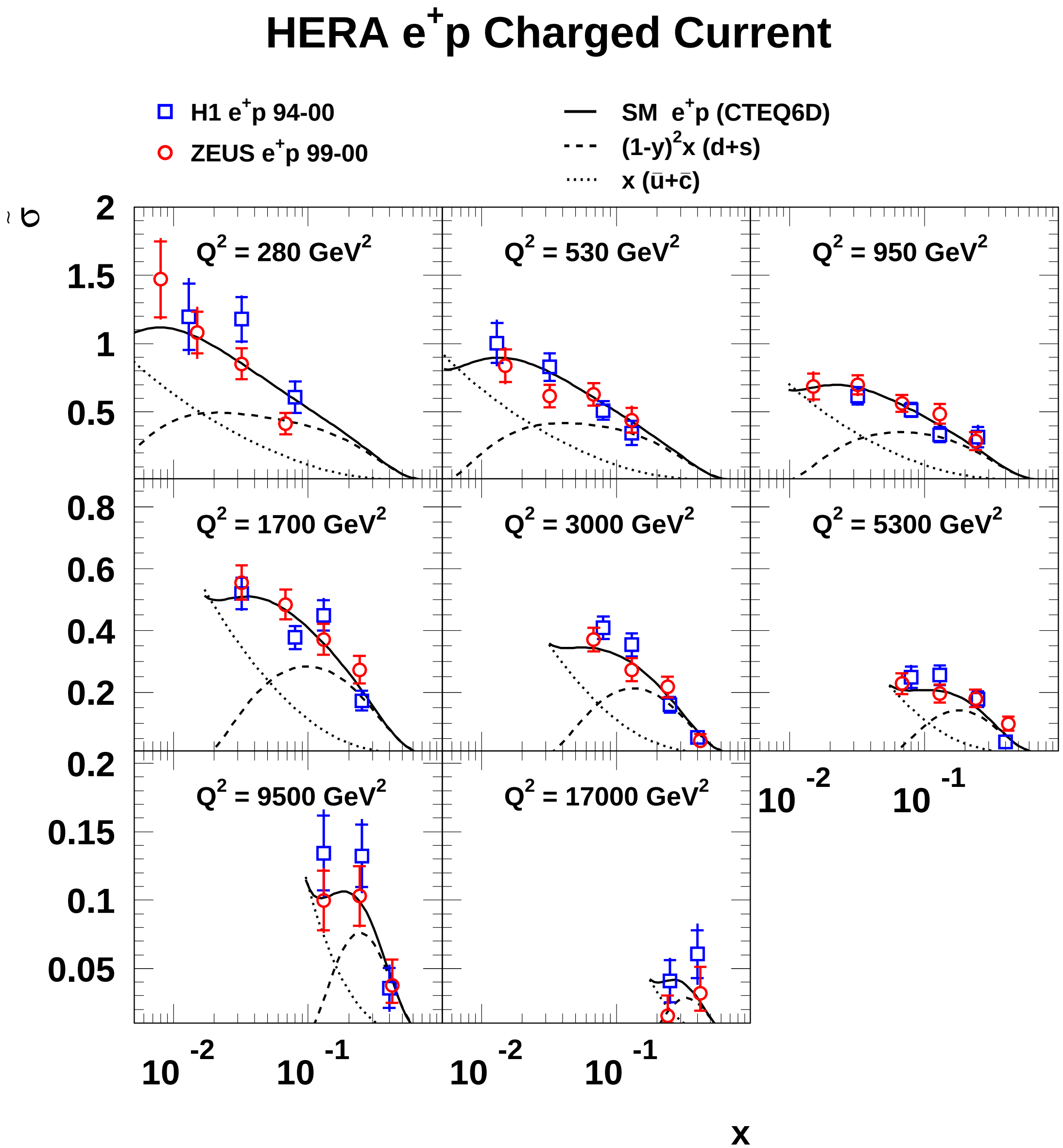
any ep

- Substructure, contact interactions.
- Large extra dimensions.
- Precision F_2, u density at high x.
- G_2, parity violation, d/u at high x.
- Pentaquark spectroscopy.
- QCD tests with jets, charm, beauty.
- Diffraction, DVCS, low x physics.

e^-p

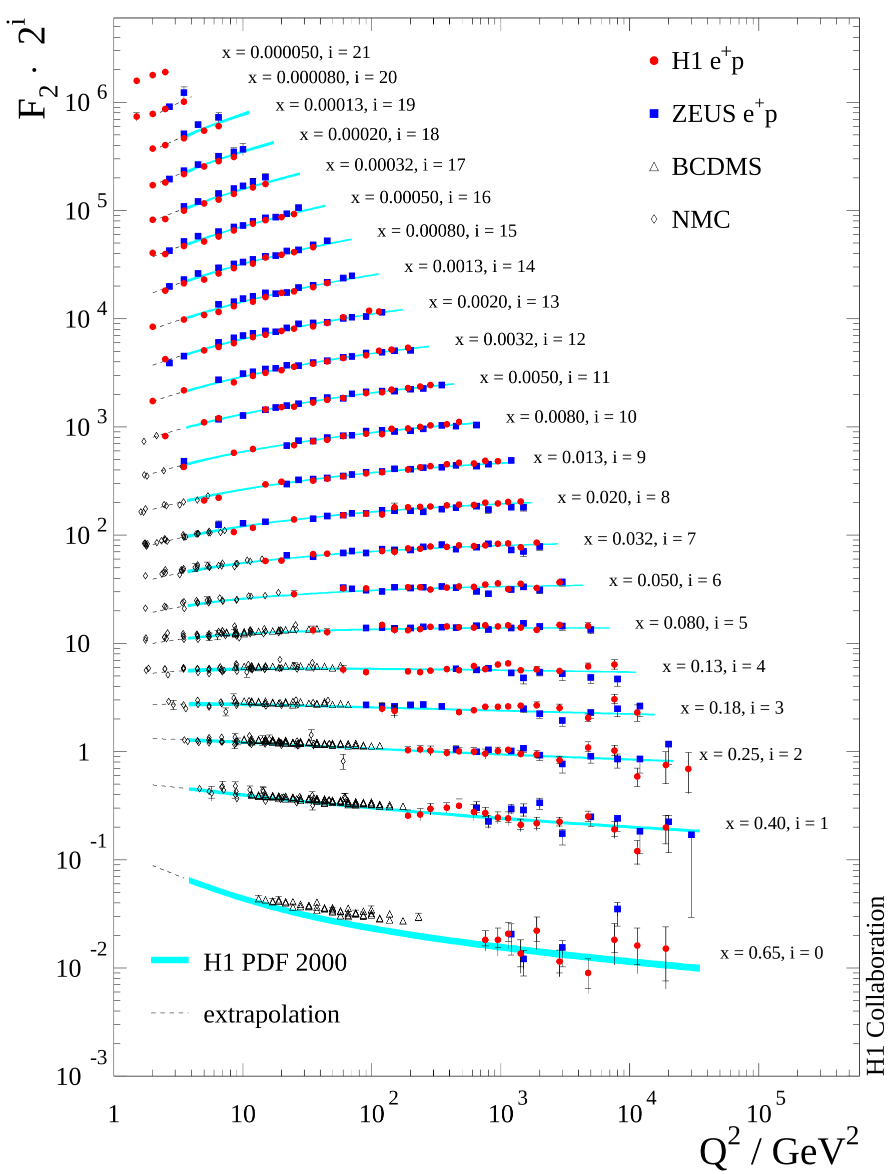
- $F = 2$ leptoquarks.
- Excited neutrinos.
- Susy with b,s,d.

$$\frac{d^2\sigma^{CC}}{dx\,dQ^2}(e^+) \sim x\left[\bar{u} + \bar{c} + (1-y)^2(d+s)\right]$$



- The double-differential charged current cross section has been measured at medium and high Q^2.
- It agrees with Standard Model expectation.
- It allows a flavour decomposition, giving access to $d+s$.
- More data are being collected at HERA II.

$\mathbf{F}_2$

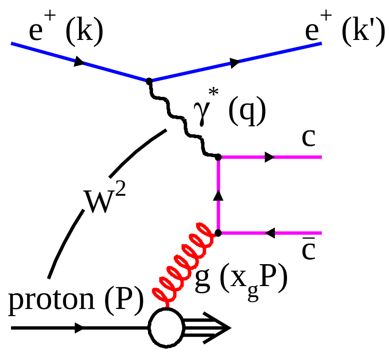


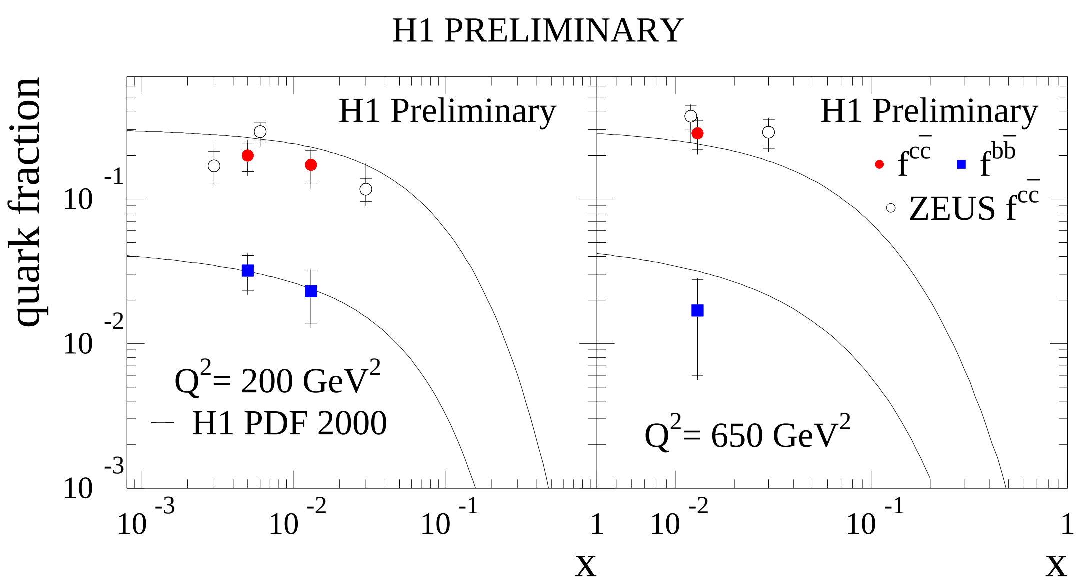
- HERA data cover 4 decades in x and Q^2. Good agreement between H1 and ZEUS.
- Experimental precision reaches 2–3% in the central region.
- Smooth transition to fixed target data, except at the highest x.
- Strong scaling violations: $\partial F_2/\partial Q^2$ varies with x.

$\Rightarrow$ Gluon density and α_S determination.

- Parton densities are parametrised in x at a starting scale $Q_o^2 = 4\,\mathrm{GeV}^2$.
- Good NLO QCD fit of Q^2 evolution using DGLAP equation.

Heavy flavour contribution $F_2^{c,b}/F_2$

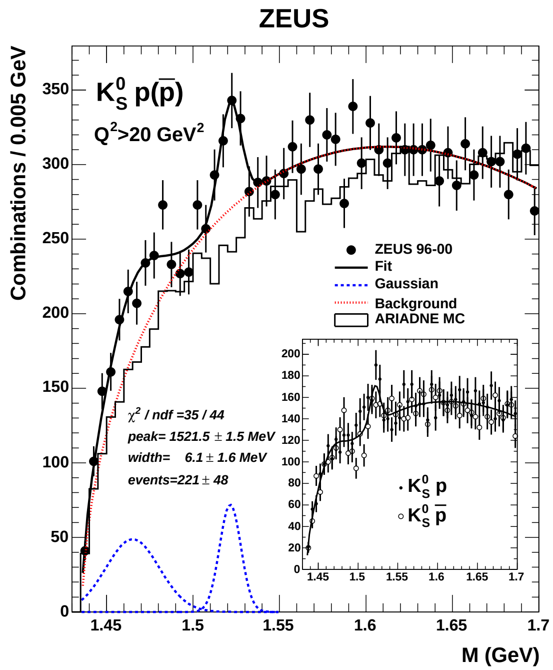




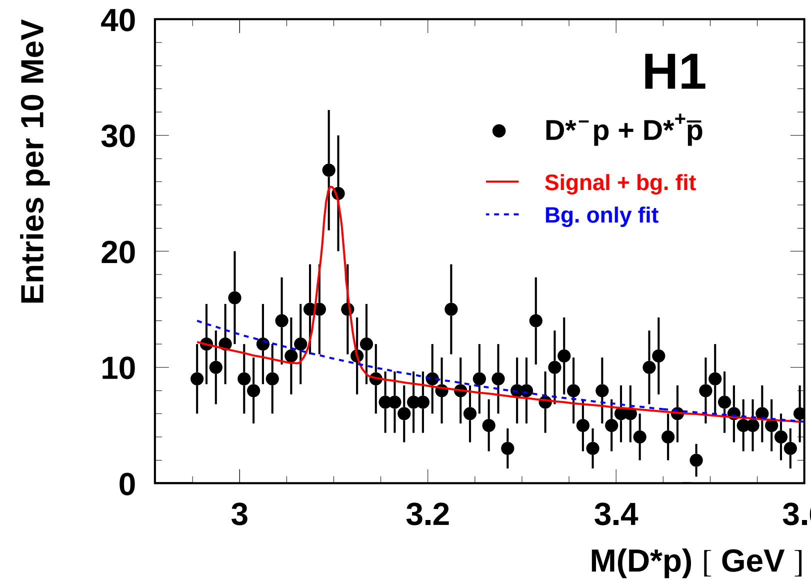
HERA I result.

- Charm and beauty measured at $Q^2 > 150\,\mathrm{GeV}^2$.
- H1 exploits long lifetime with its silicon vertex detector.
- f_2^c approaches flavour democracy limit from charge counting: 0.36.
- f_2^b is measured for the first time.
- ZEUS and H1 have extended silicon vertex detectors at HERA II.

Pentaquarks



- Peaks in $K^0_S p$ and $K^0_S \overline{p}$ at 1522 MeV.
- Interpreted as the isospin-rotated decay of the pentaquark candidate observed in K^+n by several low-energy γp experiments at 1540 MeV.
- First observation of this state at high energy, in the fragmentation region.



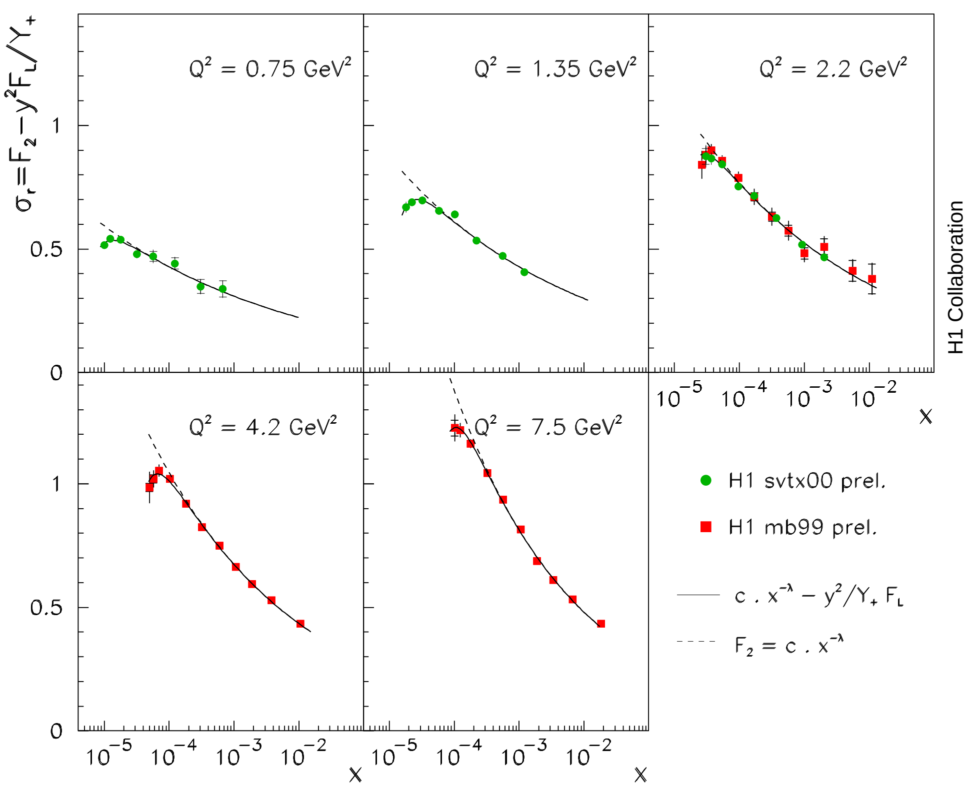
- H1 observes a peak in $D^{*-}p$ and $D^{*+}\overline{p}$ at 3099 MeV in DIS ($5.4\,\sigma$) and in photoproduction.
- An anti-charmed baryon is manifestly exotic. The minimal quark content is $uud\,d\overline{c}$
- This signal awaits confirmation by other experiments and more H1 data.

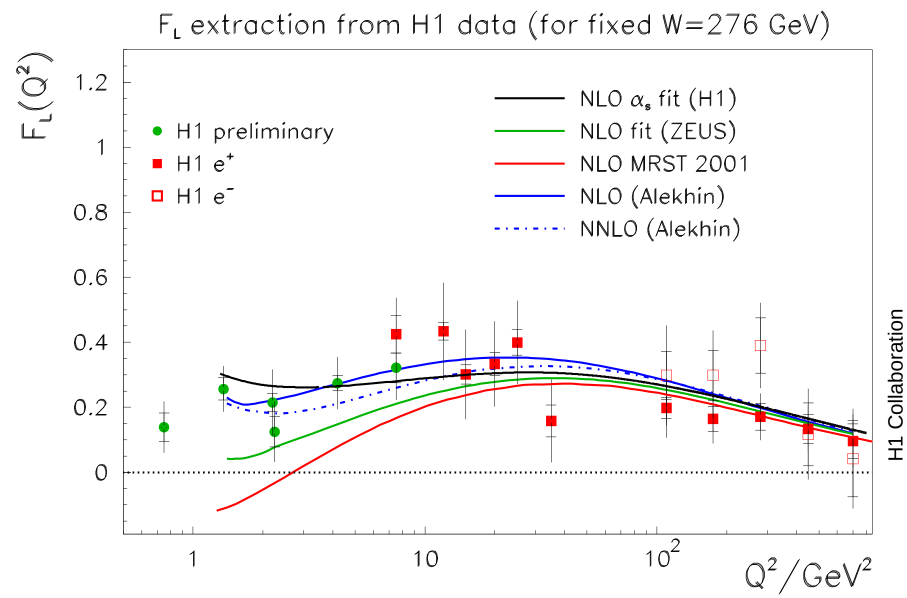
F_L extraction

$$\frac{xQ^4}{2\pi\alpha^2 Y_+}\frac{d^2\sigma^{NC}}{dx\,dQ^2} = F_2 - \frac{y^2}{Y_+}F_L$$

Exploit kinematic factor y^2/Y_+ at high y $=$ low x.

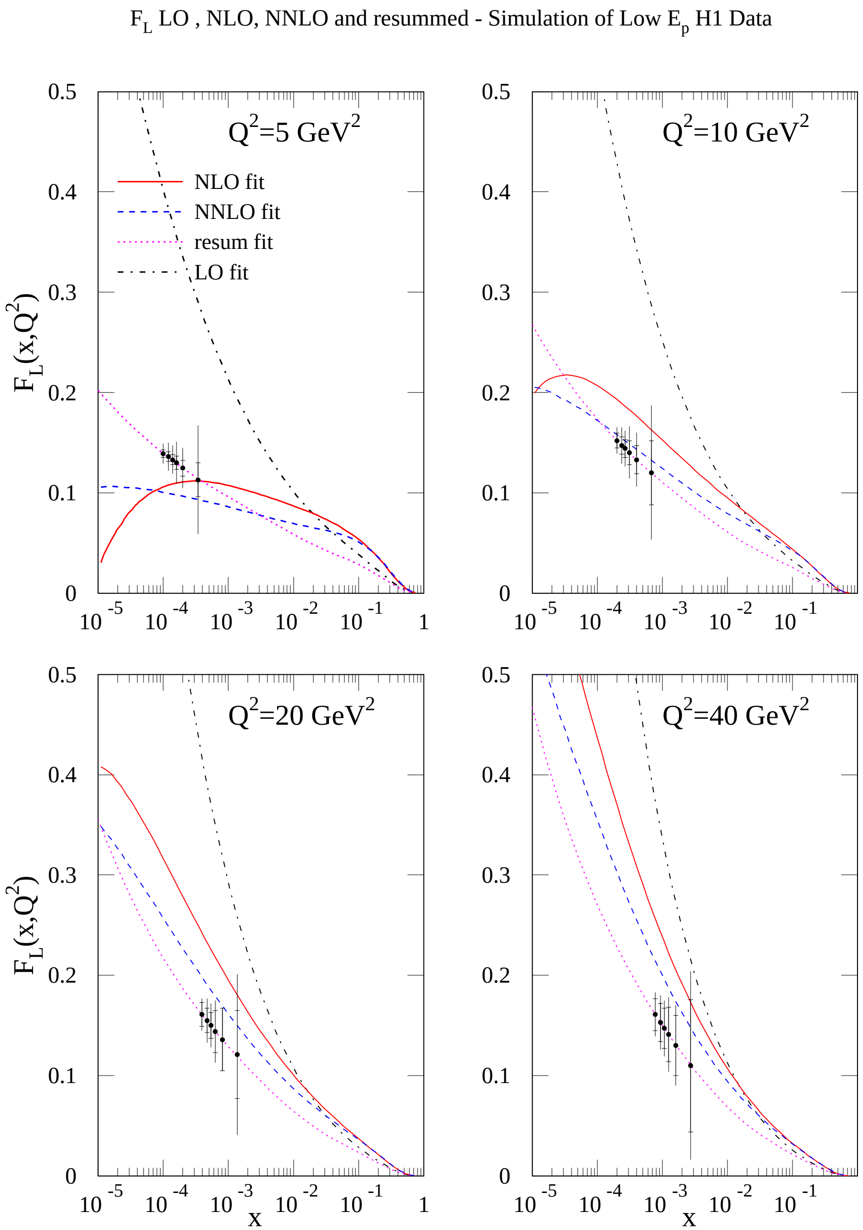
Fit $F_2 \sim x^{-\lambda}$ and extract F_L.





- $F_L = 0$ in the naive parton model.
- Off-mass-shell quarks after gluon radiation or splitting couple to longitudinal photons.
- QCD calculations differ at low Q^2.
- Need run at reduced proton beam energy for direct F_L measurement!

F_L measurement with reduced proton beam energy



- Simulation for $E_p = 400$, 465, and 575 GeV $\mathcal{L} = 3$, 5, and 10 pb^{-1}.
- $E_e = 27.5$ GeV.
- 6 points in x can be measured in each Q^2 bin.
- High discrimination power between QCD models.
- p beam emittance and divergence $\sim 1/E_P$ (adiabatic damping).

$\Rightarrow$ $\mathcal{L}_{\text{spec}} \sim E_p^2$

$\Rightarrow$ this run is equivalent to $\sim 50\,\text{pb}^{-1}$ at 920 GeV, plus setup time.

Running strategy autumn 2004 – mid 2007

- Expect 70 pb^{-1} e^+p until summer 2004.
- Assume running until mid 2007; needs Verwaltungsrat decision.
- Yearly summer shutdowns for mandatory interlock tests.
- Gradual lumi increase due to continuous improvement program.
- A: 1 more year e^+, 1 year e^-, 1 more year e^+: $70 + 200 + 165 + 260 = 695\,\mathrm{pb}^{-1}$
- B: 2 years e^-, 1 more year e^+: $70 + 120 + 180 + 260 = 630\,\mathrm{pb}^{-1}$
- ZEUS wants to establish e^- running soon and wants a balanced budget, like in B.
- Hermes wants to establish e^- running before the recoil detector is installed in summer 2005, and then needs both polarities for DVCS charge asymmetries (B).
- H1 wants to clarify the anomalies seen in HERA I data and aims for highest luminosity. H1 wants to collect 300 pb^{-1} before changing parameters.
- The original HERA II goal of 1 fb^{-1} and reduced E_p running cannot be reached in this time frame.

Summary

- HERA II has overcome the background problems and is in luminosity production mode.
- The main challenge now is the continuous improvement of the duty cycle and reliability of all components, in machine and experiments.
- First exciting physics results from HERA II have appeared.
- We are looking forward to efficient data taking in the following years, hope for a discovery, and expect to make precision measurements in all fields of HERA physics.
- The strategic planning takes place now.