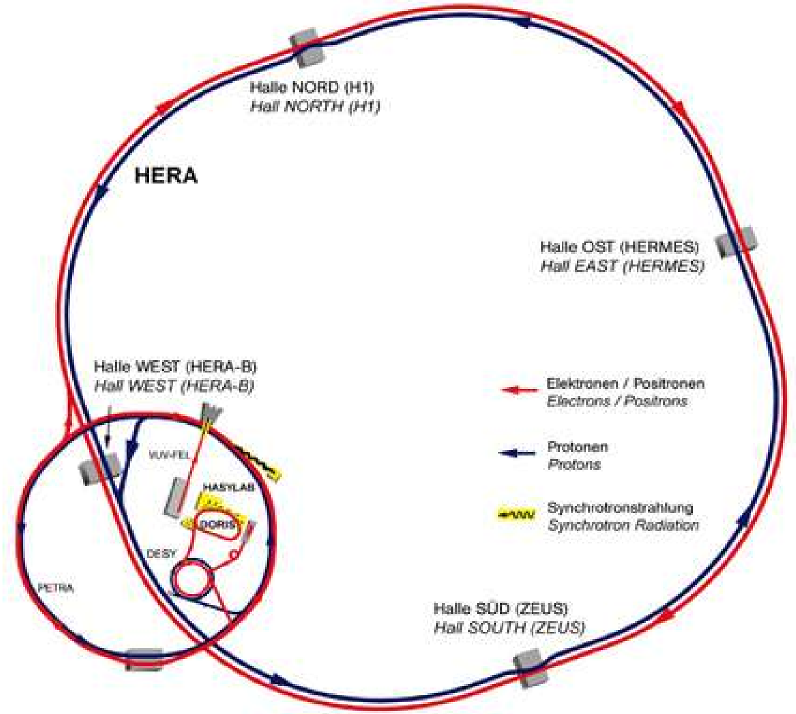
HERA

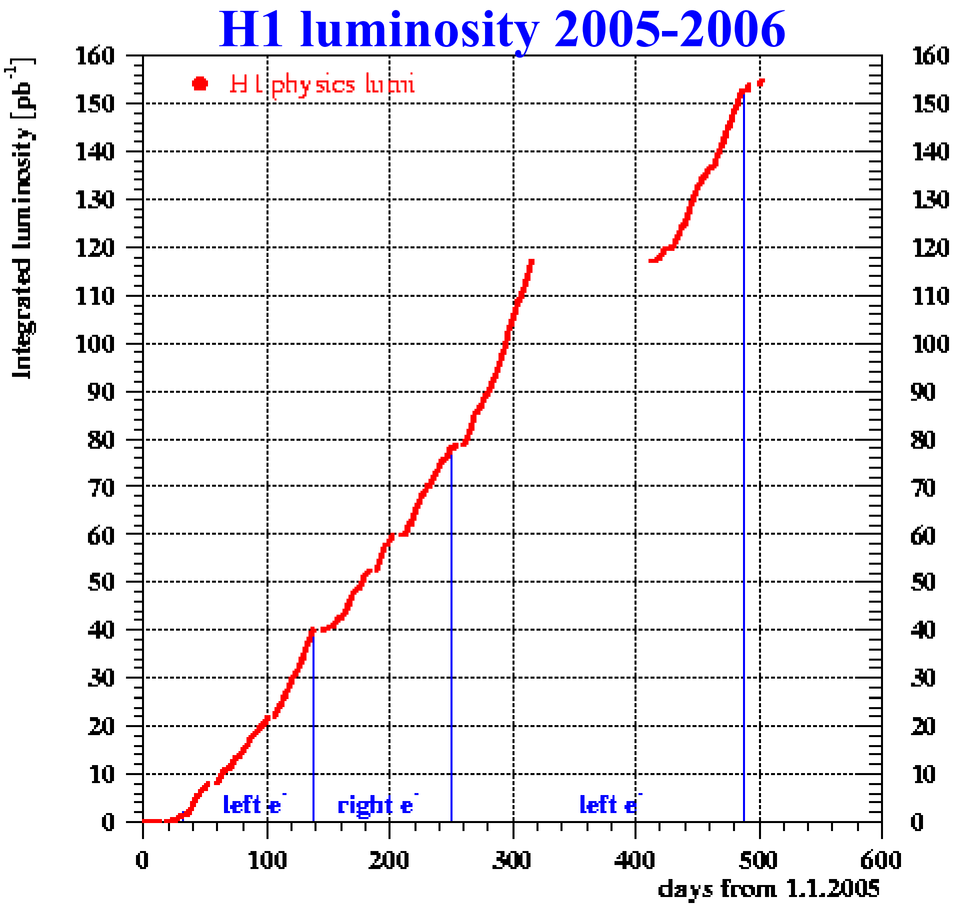
Daniel Pitzl, DESY FH1

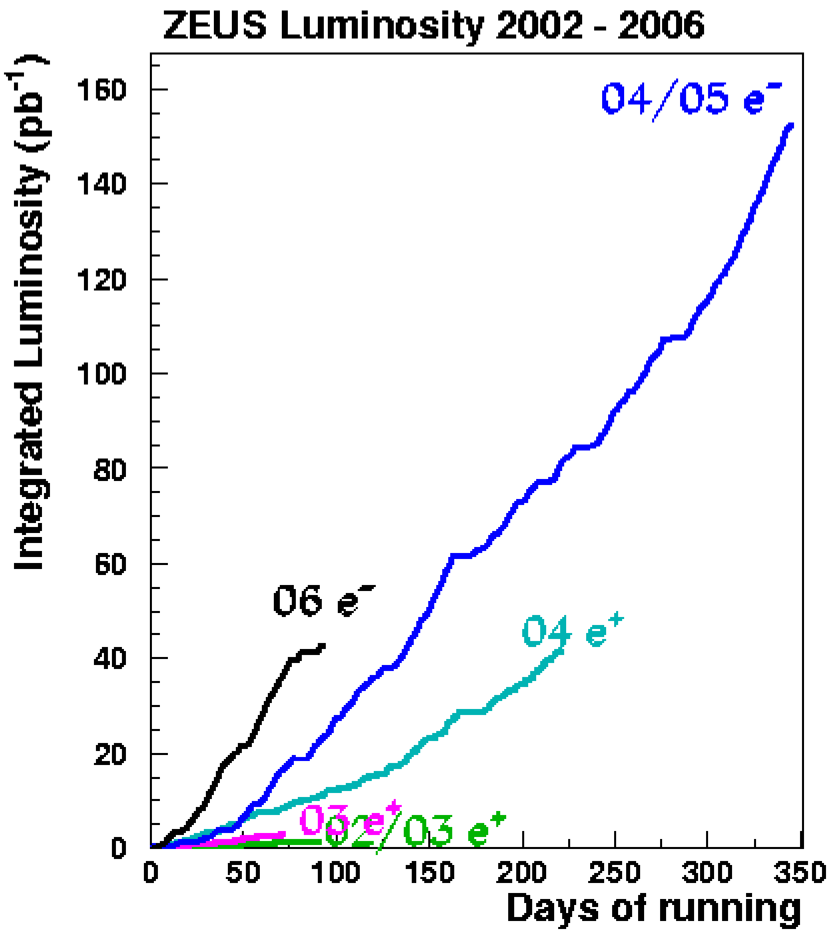
WA 23.5.2006



- HERA running
- Status of the experiments
- Selected physics results
- F_L
- HERA and LHC

Luminosity collection





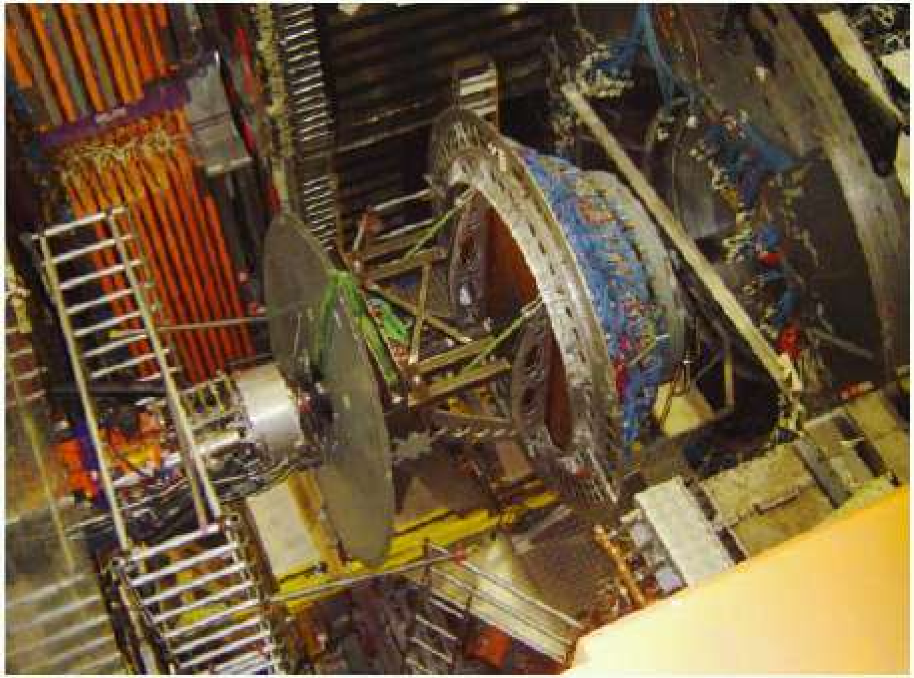
- 2005 was HERA's best year so far!
- 2006 started good, but the last 2 weeks had problems: Hermes target cell damaged, e-ring beam pipe leak.
- Switch to e^+ at the end of June '06.

ZEUS Straw Tube Tracker

STT cooling upgrade

- **During the shutdown Nov.05 to Jan.06, STT was once removed to upgrade its cooling system, and then was reinstalled**

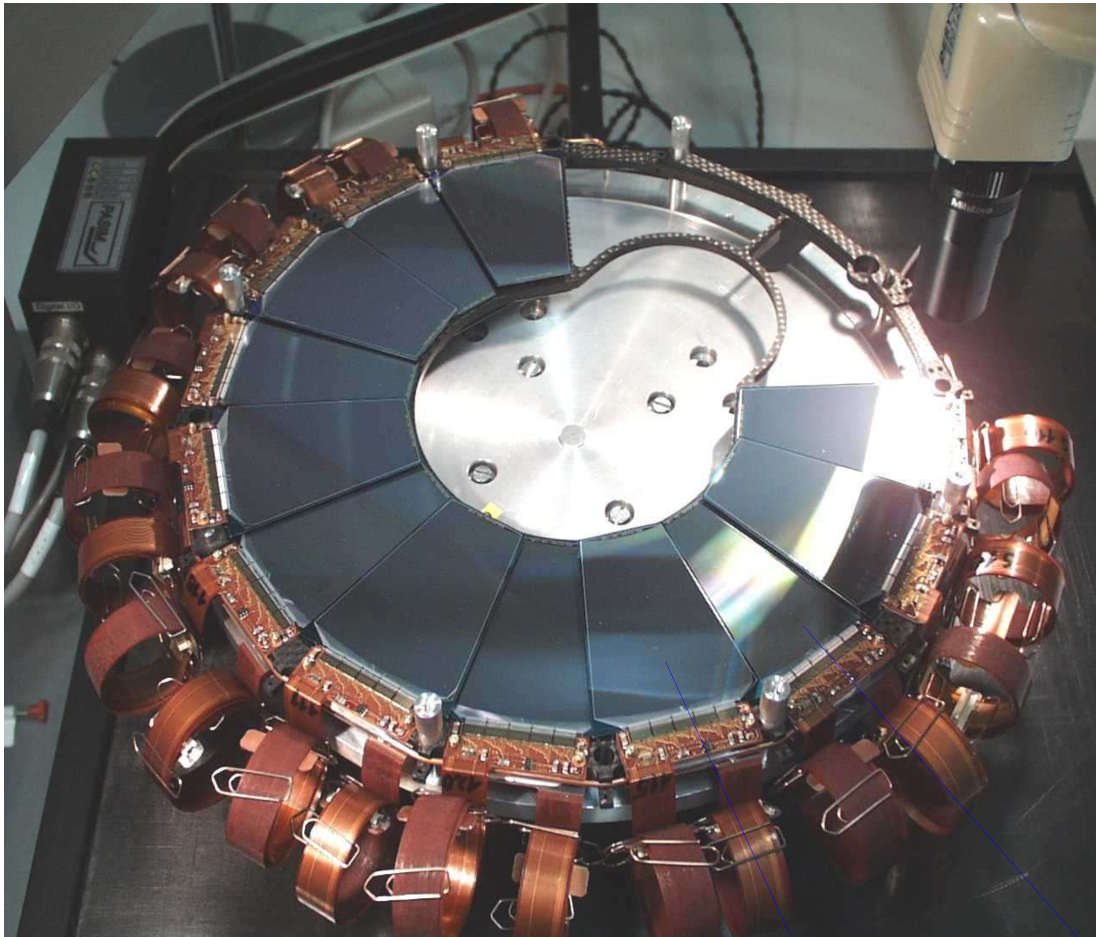
  -- Insufficient STT cooling interfered solenoid operation
  -- Thus, STT was off for 04-05 e- runs



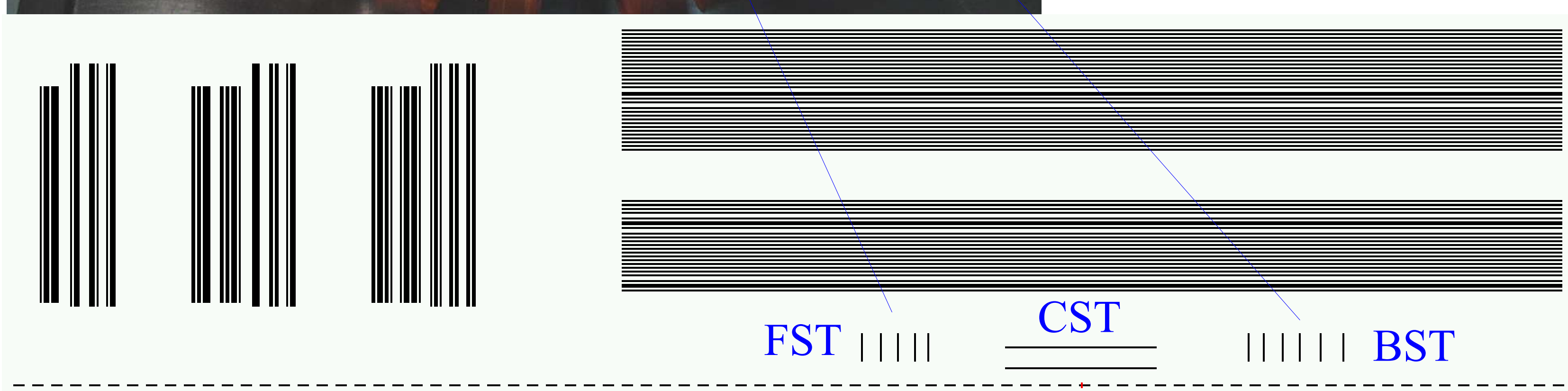
- Whole procedure was completed successfully.

→ No interference problem to solenoid operation observed.
→ STT is on for 06 e- runs, and is taking data.

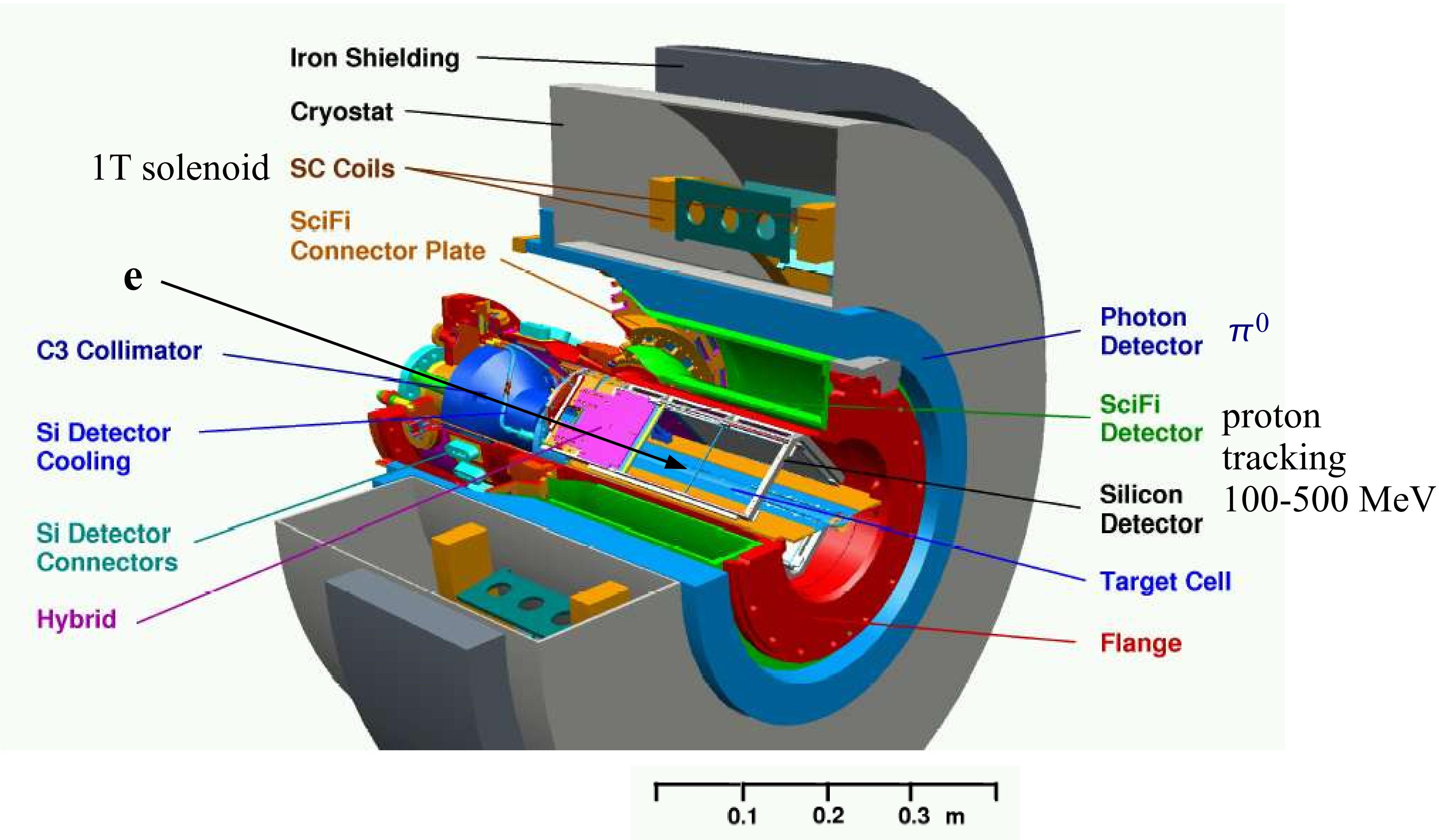
H1 silicon tracker



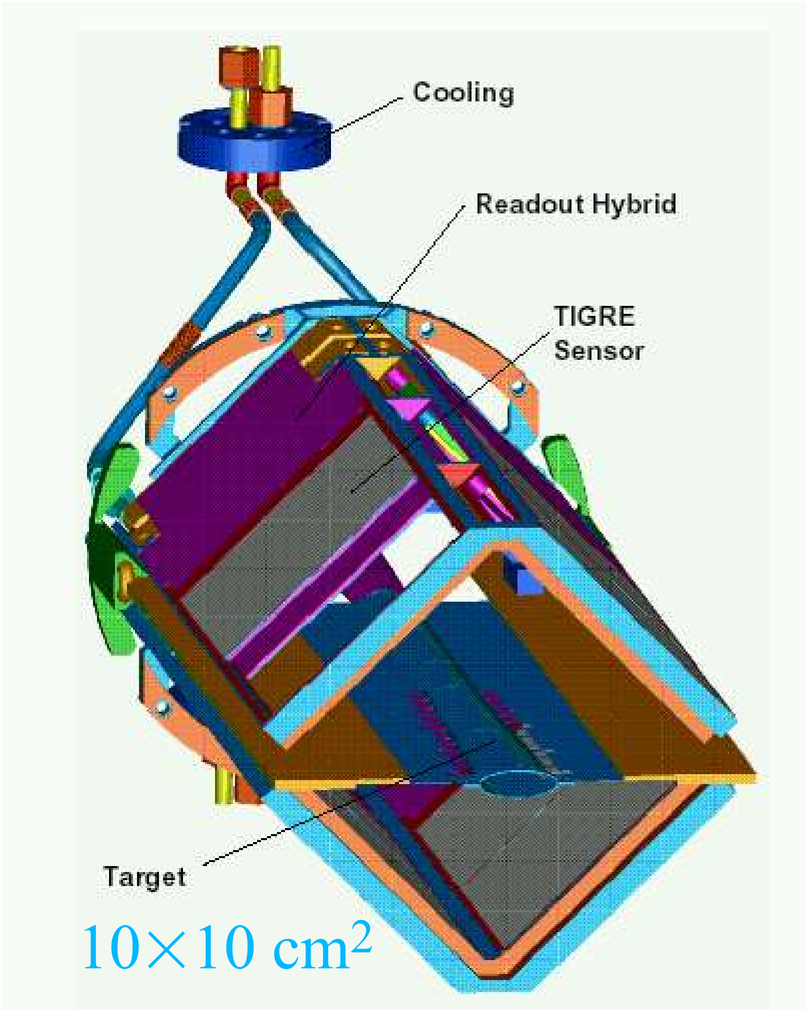
- 11 double-sided wheels of silicon strip detectors repaired in 2005.
- Complete silicon tracking for 2006/07.



Hermes recoil detector

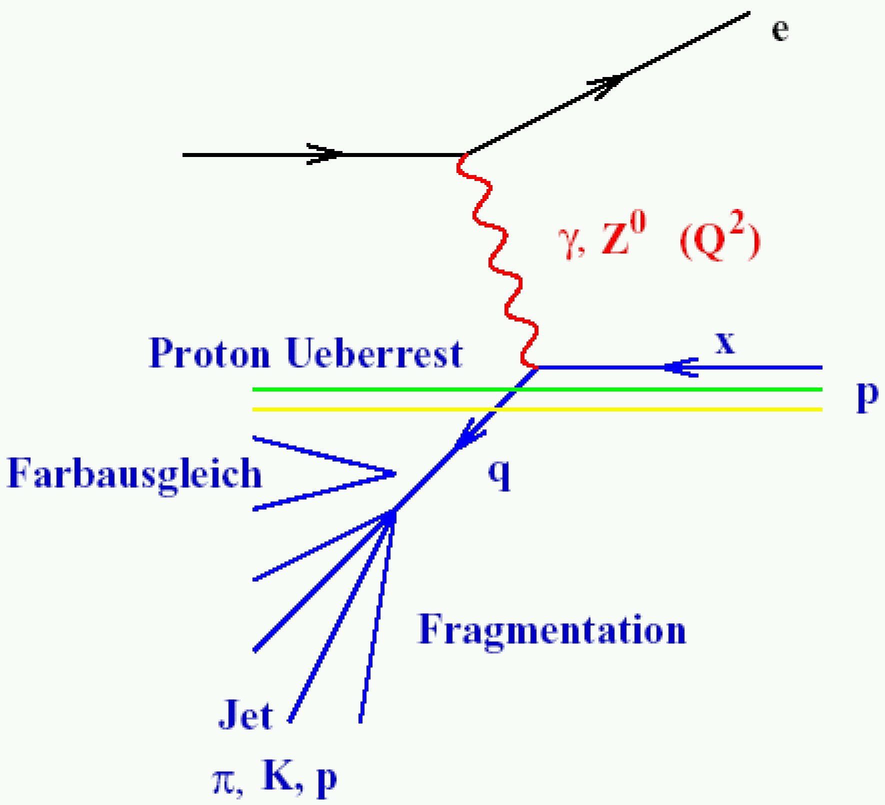


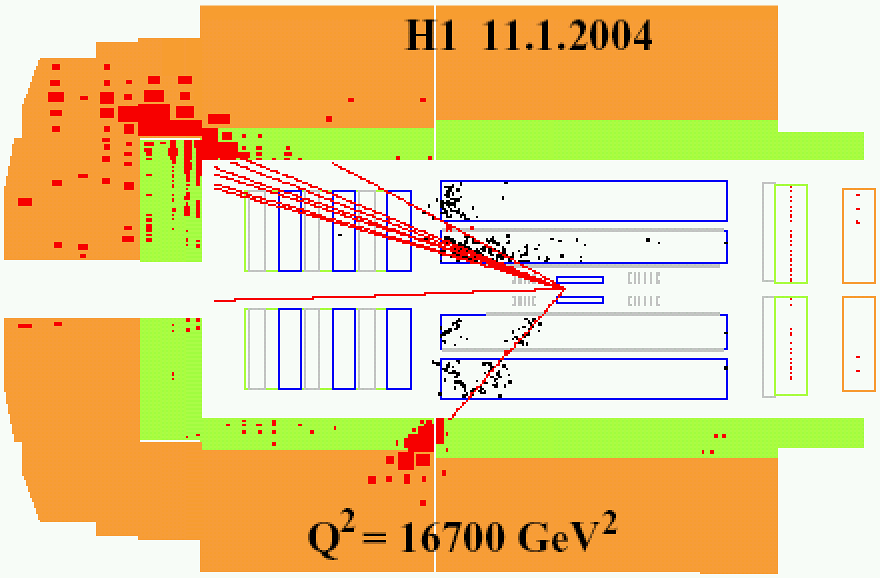
Hermes recoil silicon detector



- Installed in Jan '06.
- Target cell damaged with beam in Mar '06.
- Radiation damage: 80-100 krad in 3 days in May.
- Repair underway.
- Reinstall end of June '06.

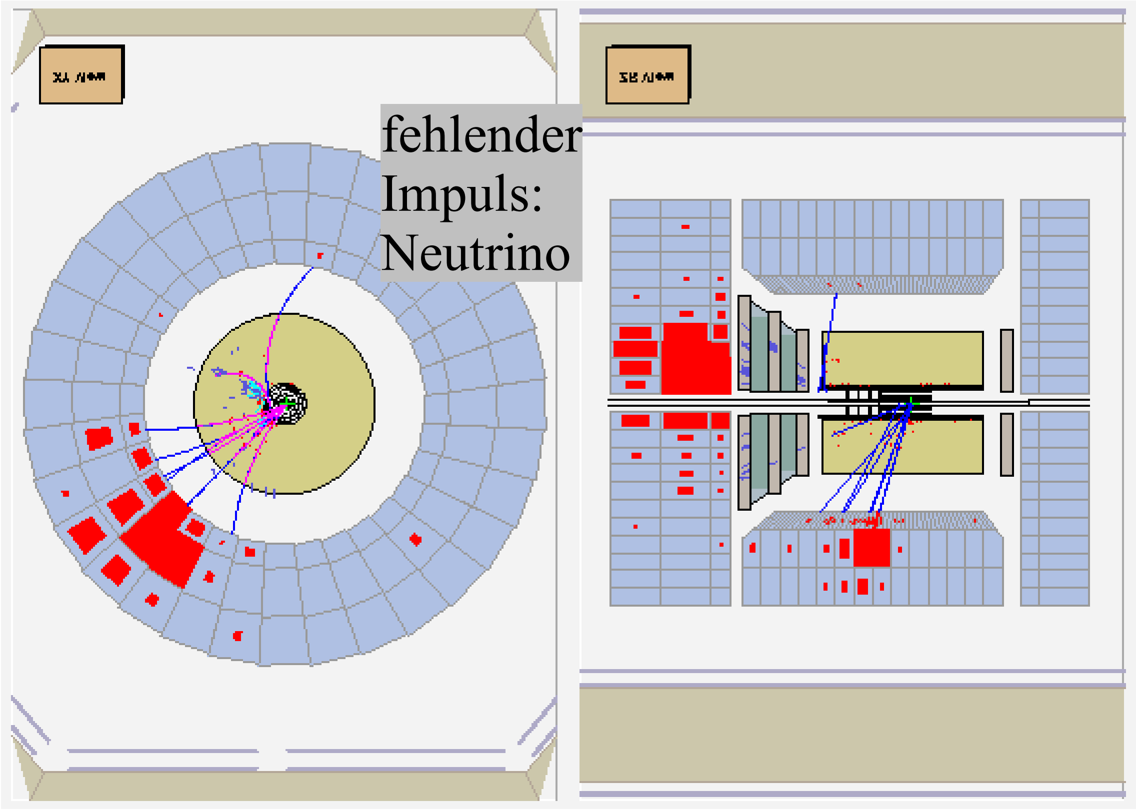
Tief-inelastische ep Streuung

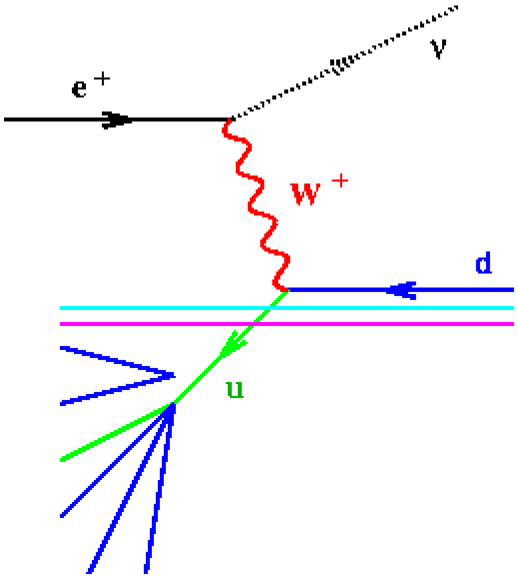




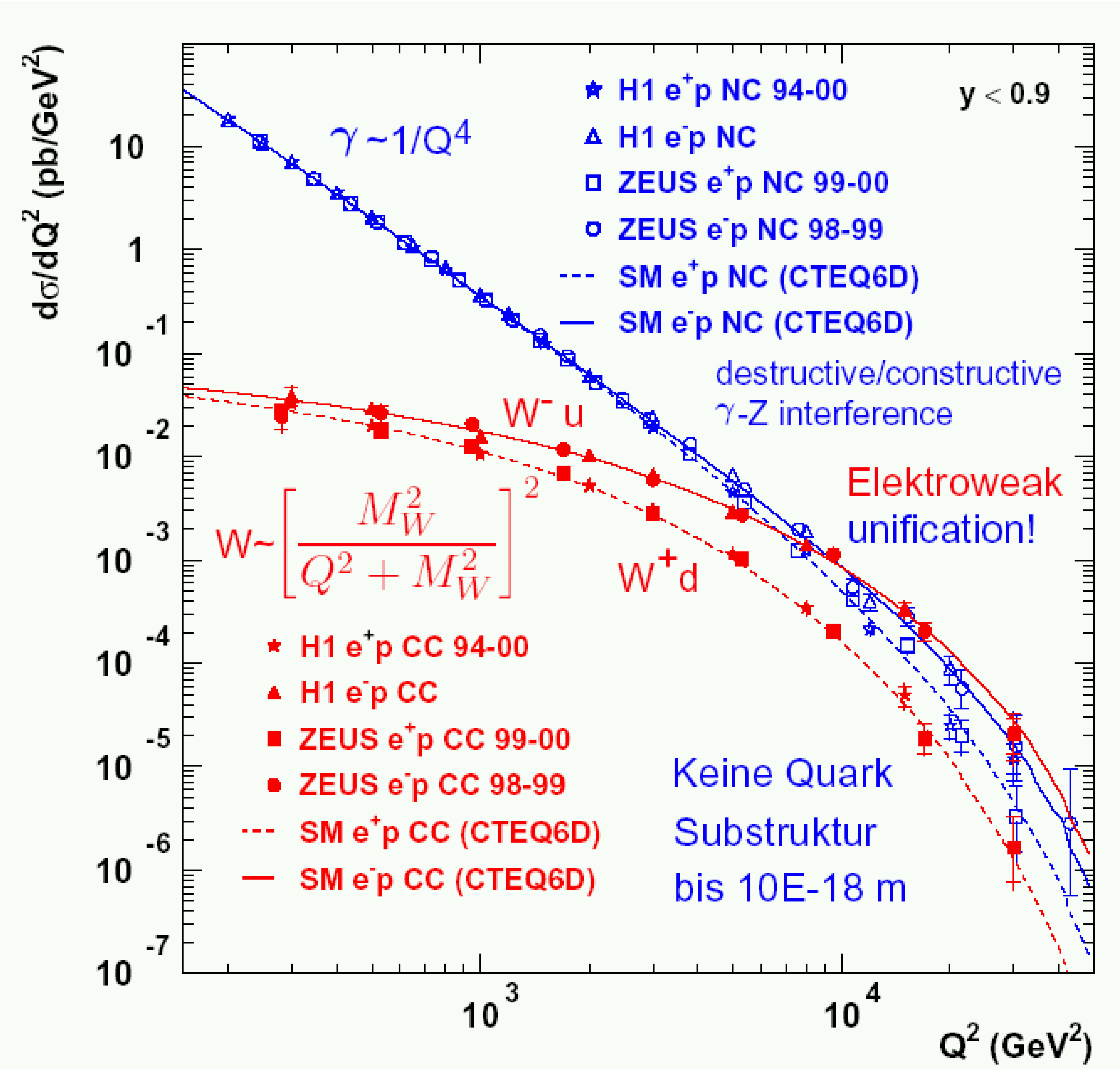
- HERA Schwerpunktenergie $\sqrt{s} = \sqrt{4E_pE_e} = 319\,\mathrm{GeV}$.
- $Q^2_{\max} = s = 10^5\,\mathrm{GeV}^2$.
- Auflösungsvermögen: $\lambda \approx \frac{hc}{Q} \rightarrow 4 \cdot 10^{-18}\,\mathrm{m}$.
- Zeitauflösung: $t = \frac{h}{Q} \rightarrow 1.3 \cdot 10^{-26}\,\mathrm{s}$.

Geladener Strom: W$^{\pm}$ Austausch





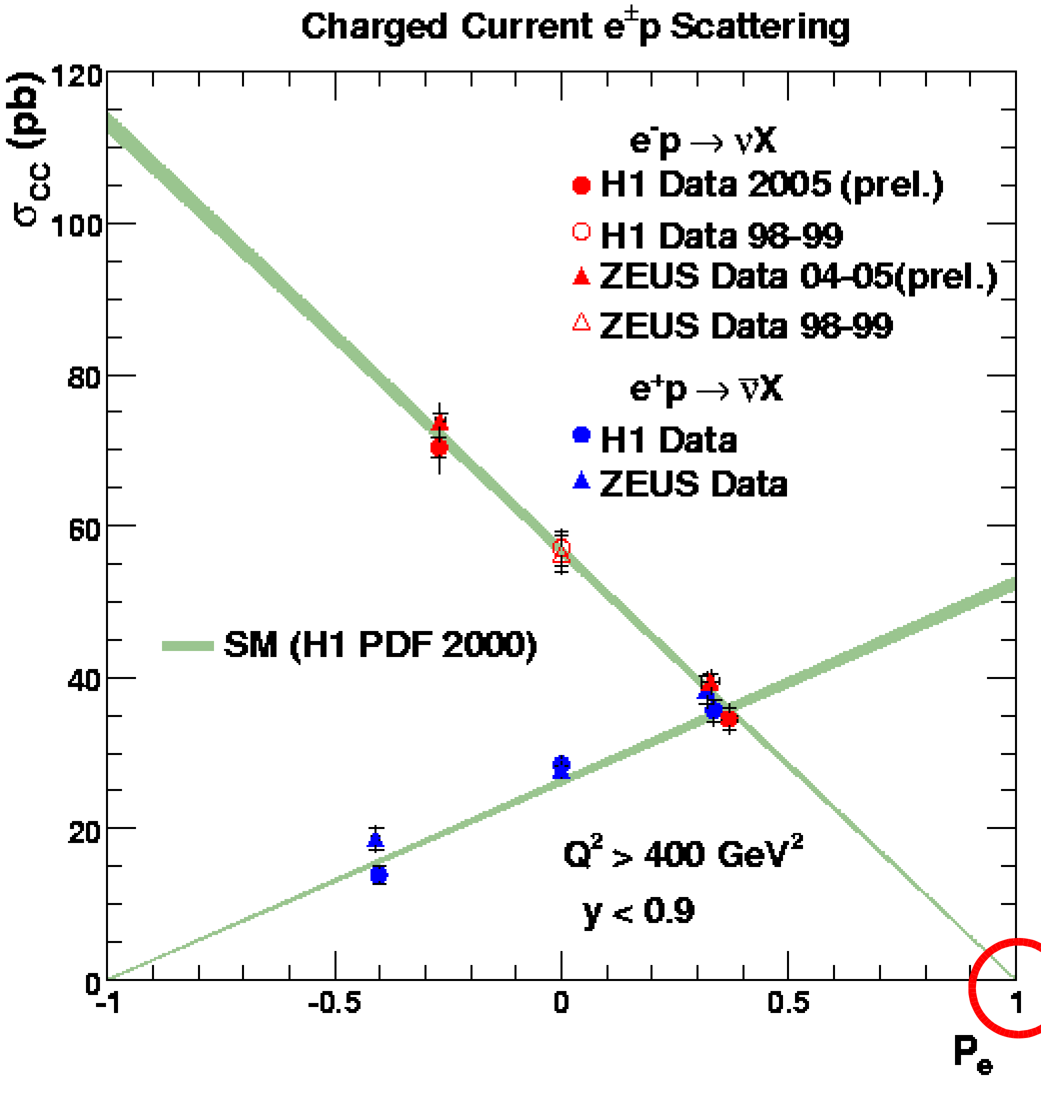
Wirkungsquerschnitte



- Textbook measurement from HERA I.

Geladener Strom mit polarisierten $e^{\pm}$

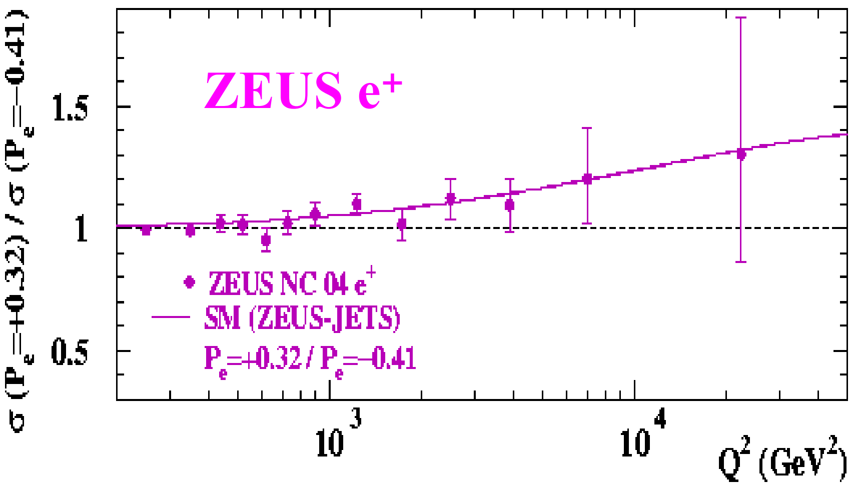
Standard Model: $\sigma(P) = (1\text{-}P)\sigma_0$

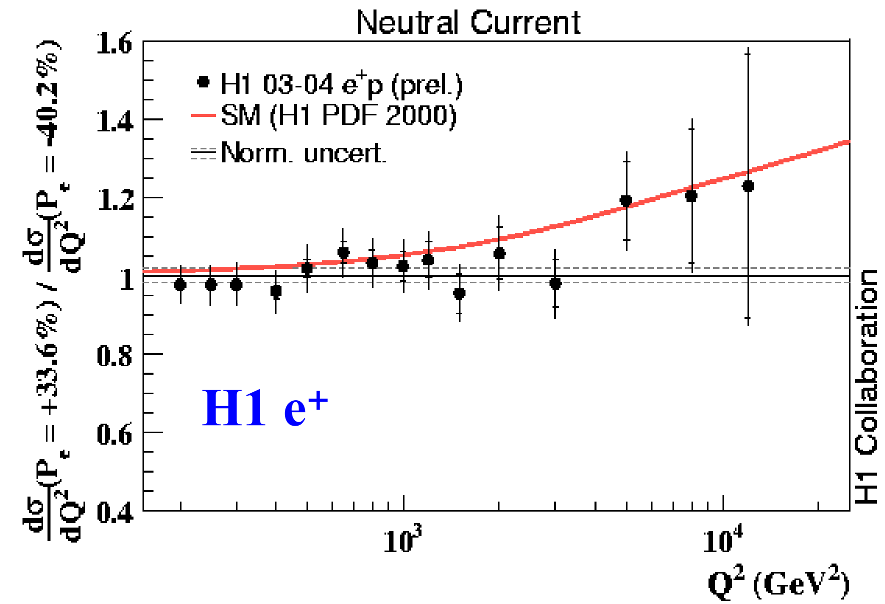


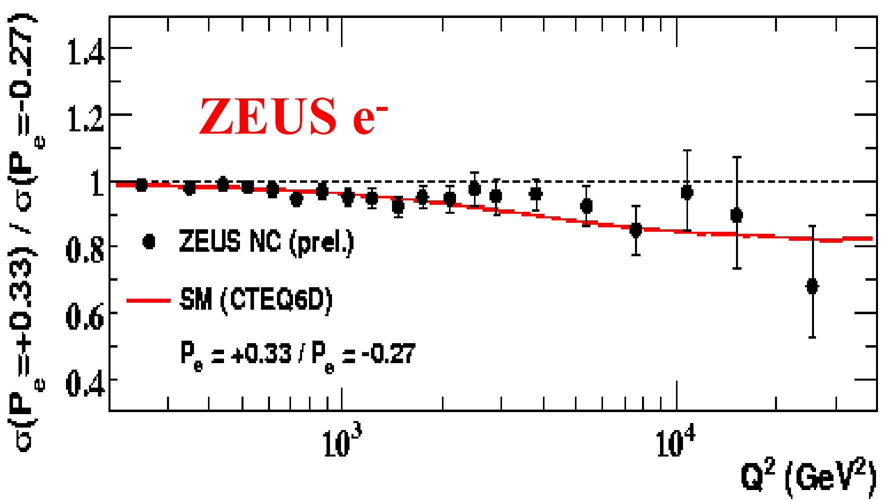
limit: $m(W_R) > 186$ GeV.

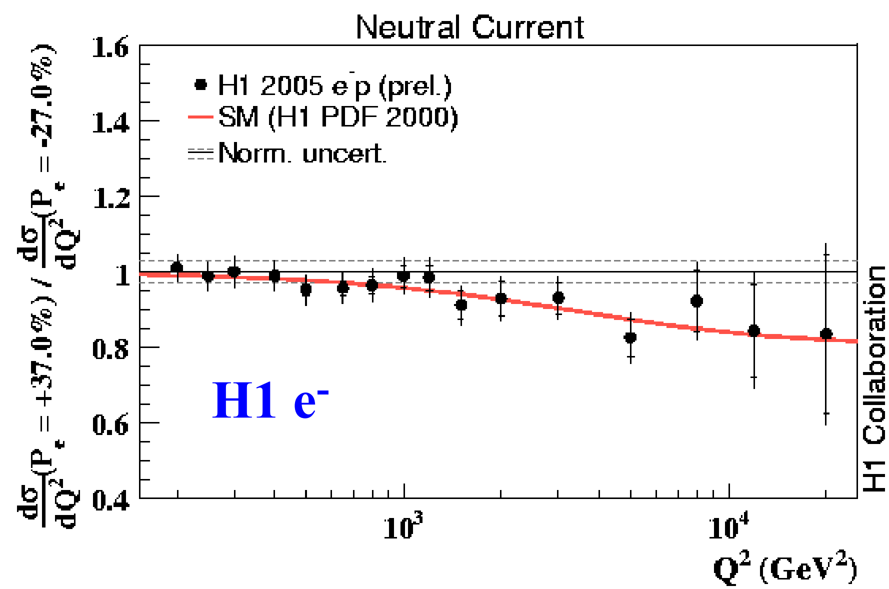
- Textbook measurement!

Neutraler Strom mit polarisierten $e^{\pm}$



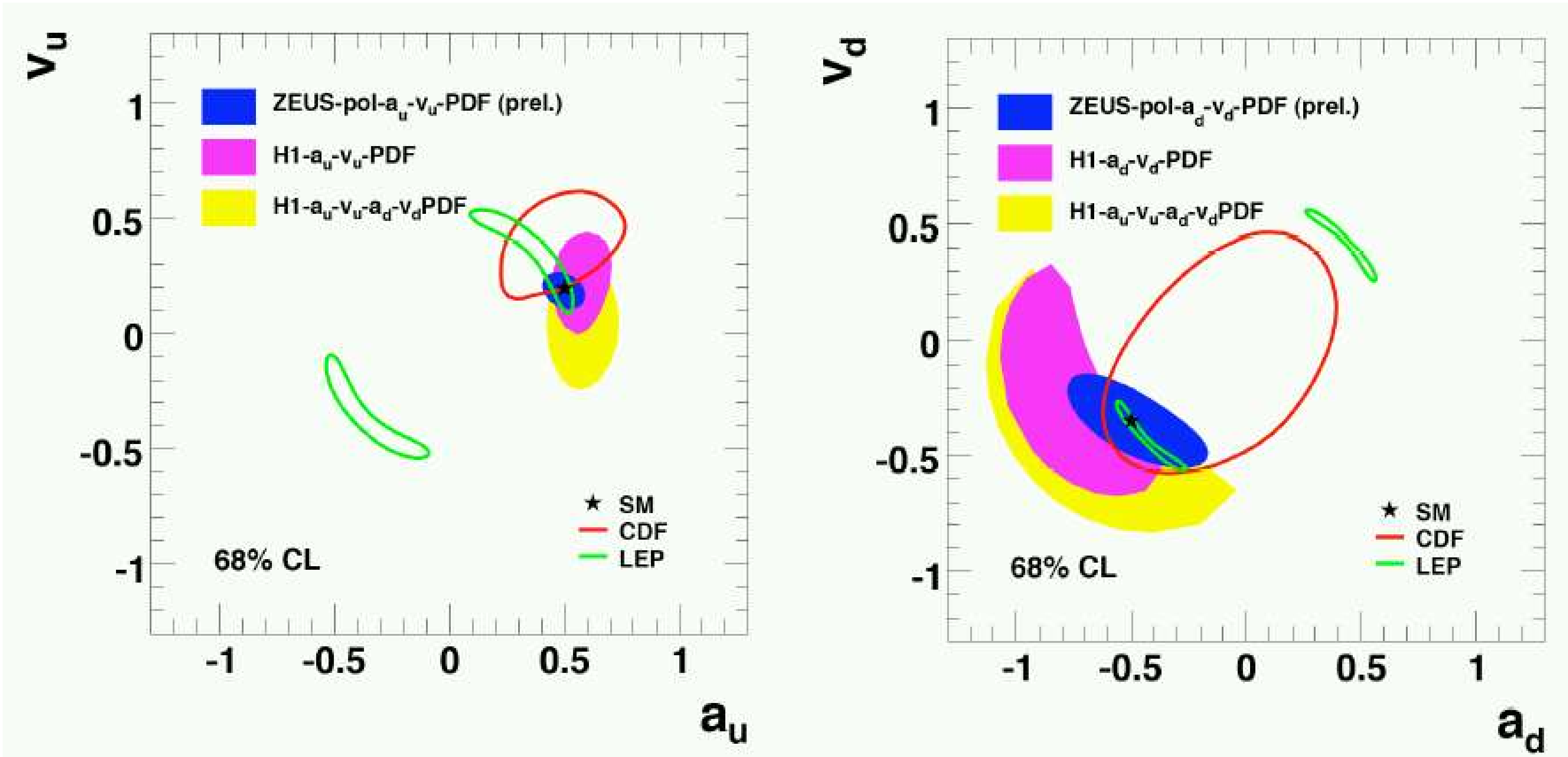






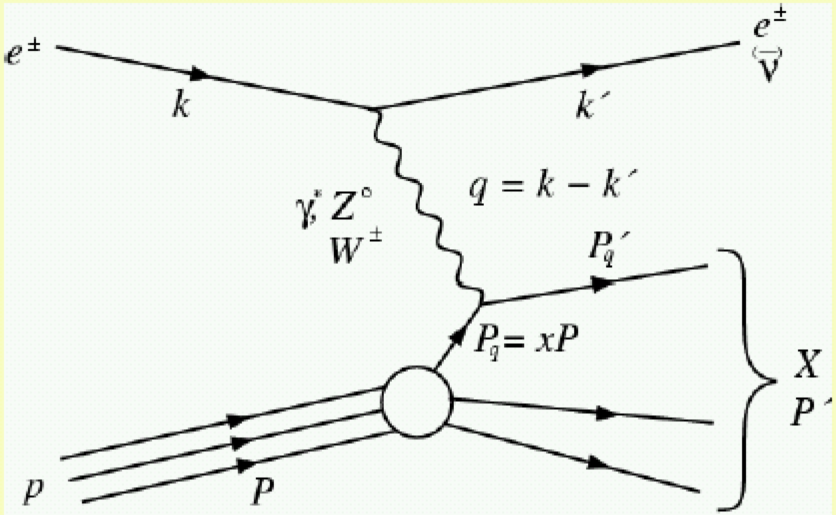
Clear observation of electro-weak effects in neutral current interactions.

Z0 couplings to u and d quarks



- ZEUS: with polarized HERA II data
- H1: unpolarized HERA I data.
- Ultimately: combine H1 and ZEUS!
- **Electroweak precision physics from HERA.**

Tief-inelastische Streuung

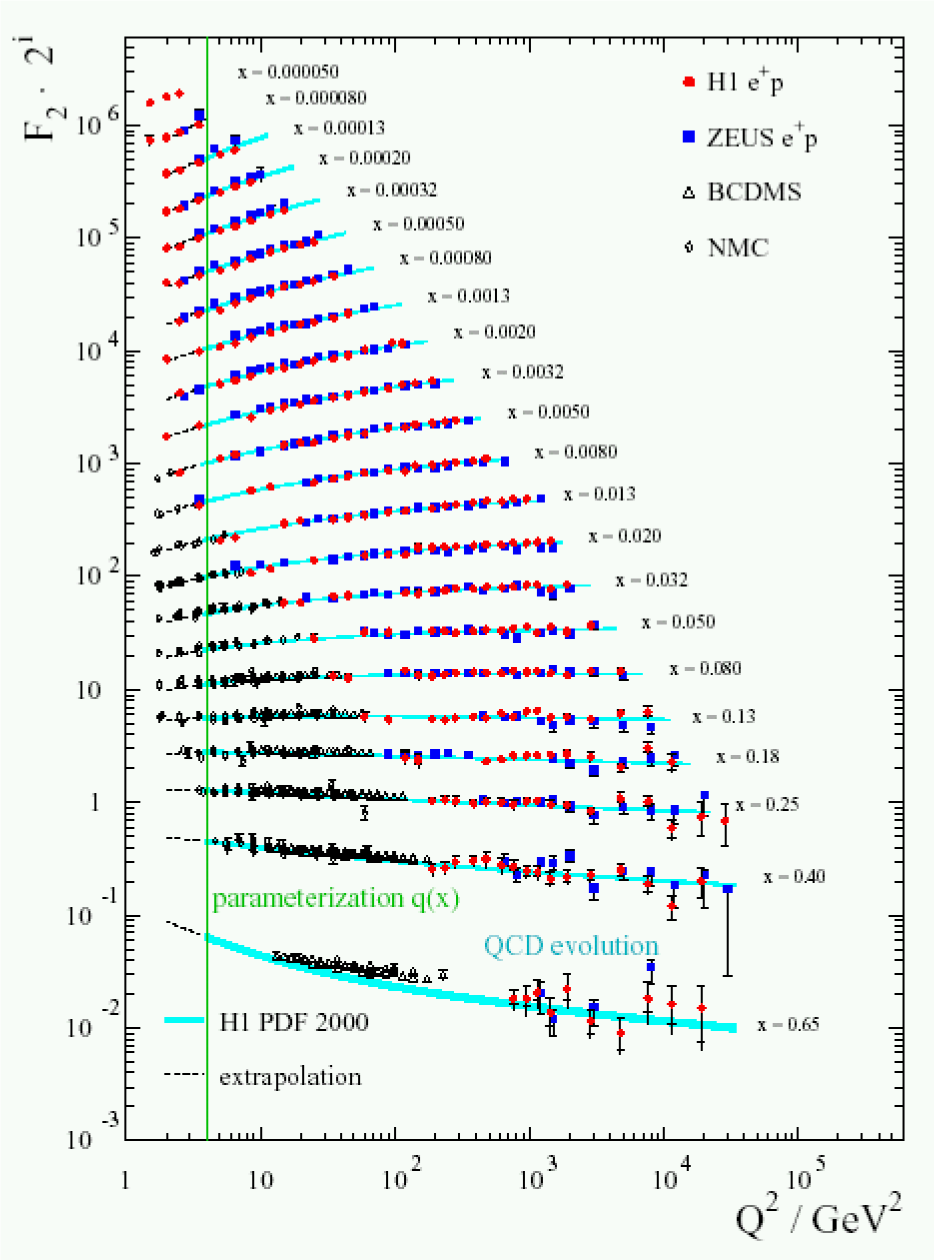


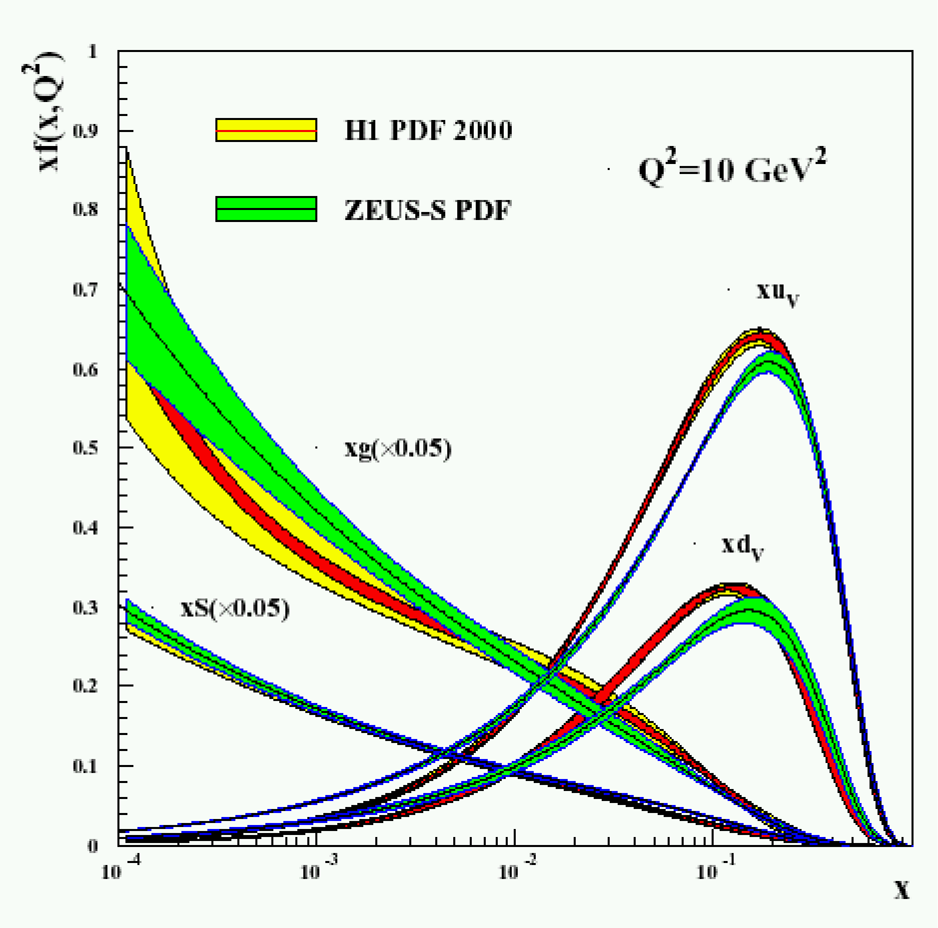
DIS cross section and
Structure Functions:

$$\frac{d^2\sigma_{NC}^{e^\pm p}}{dx dQ^2} = \frac{2\pi\alpha^2}{xQ^4}(1+(1-y)^2)\left[F_2 - \frac{y^2}{1+(1-y)^2}F_L\right]$$

$Q^2 = -q^2$	*virtuality of* $\gamma^*, Z^o, W^\pm$
$x = Q^2/2(pq)$	*Bjorken scaling variable*
$y = (Pq)/(pk)$	*inelasticity*

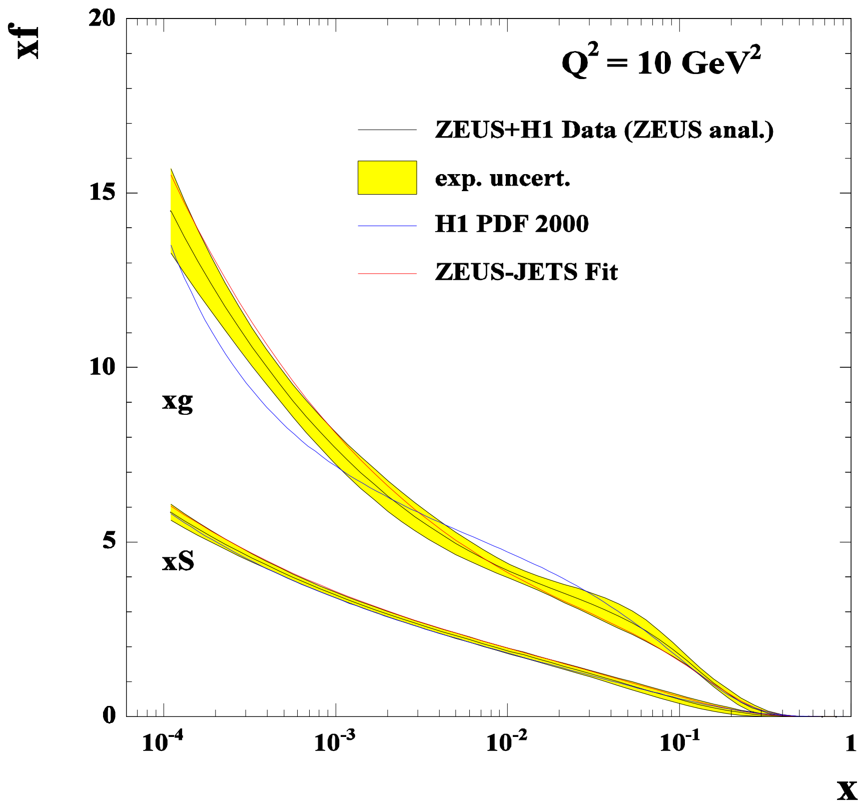
F2 and QCD analysis



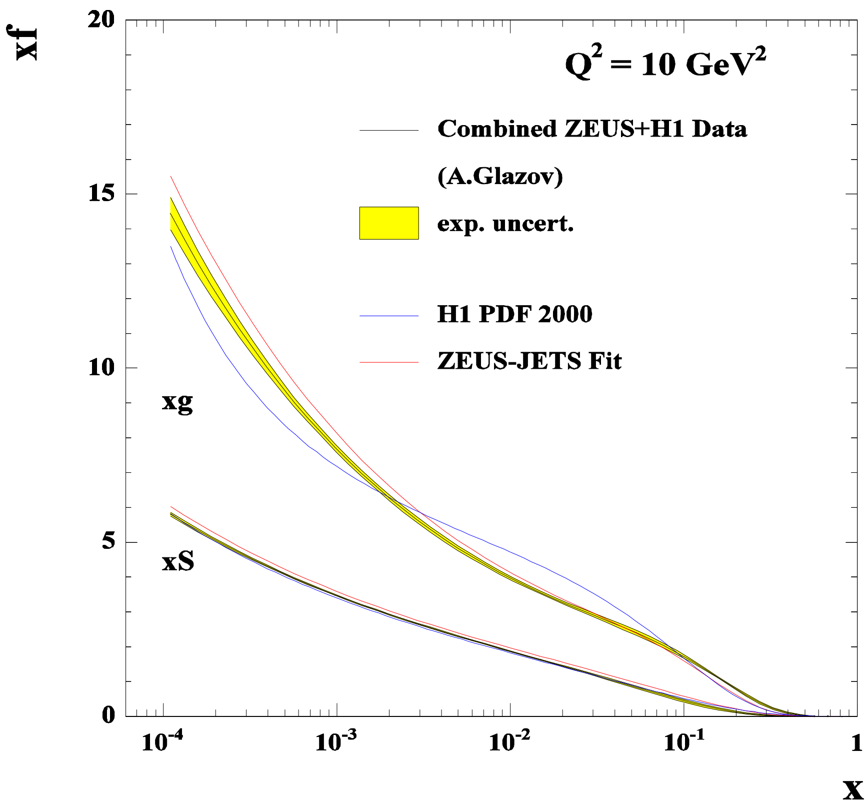


Average of HERA data

Fit PDF to H1& ZEUS:

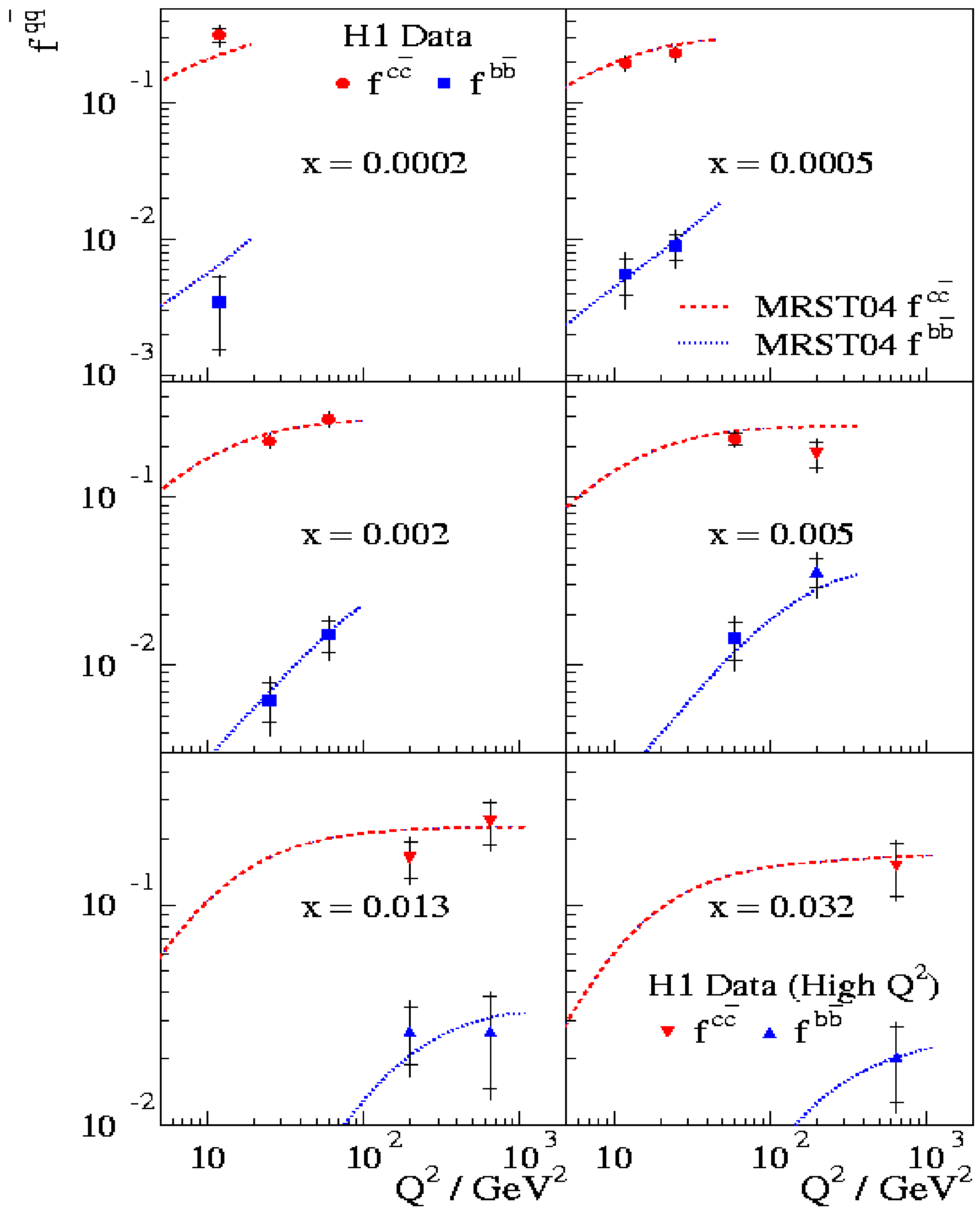


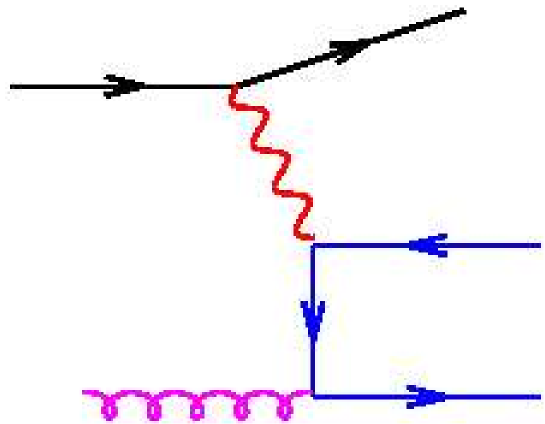
Average H1& ZEUS, then fit:



Averaging H1 and ZEUS leads to reduced uncertainties due to cross-determination of systematic errors.

Charm and beauty in the proton





- Charm contributes 10-30% to F2.
- Beauty contributes 0.5-3%
- More data to come with ZEUS and H1 silicon vertex detectors.

FL

$$\frac{d^2\sigma}{dx dQ^2} = \frac{2\pi\alpha^2 Y_+}{Q^4 x}\left[F_2(x,Q^2) - f(y).F_L(x,Q^2)\right] = \frac{2\pi\alpha^2 Y_+}{Q^4 x}\sigma_r$$

with $f(y) = \frac{y^2}{Y_+}$ and $Y_+ = \left[1+(1-y)^2\right]$

$Q^2 = sxy$, $s = 4E_eE_p \Rightarrow$ vary E_p to get f(y) at fixed x, Q2.

$F_L = \left(\frac{Q^2}{4\pi^2\alpha}\right)\sigma_L$ absorption of longitudal virtual photons.

Helicity conservation for on-shell quarks: $\sigma_L = 0$.

QCD: $F_L = \frac{\alpha_S}{4\pi}x^2\int_x^1 \frac{dz}{z^3}\left[\frac{16}{3}F_2 + 8\sum e_q^2(1-\frac{x}{z})zg\right]$

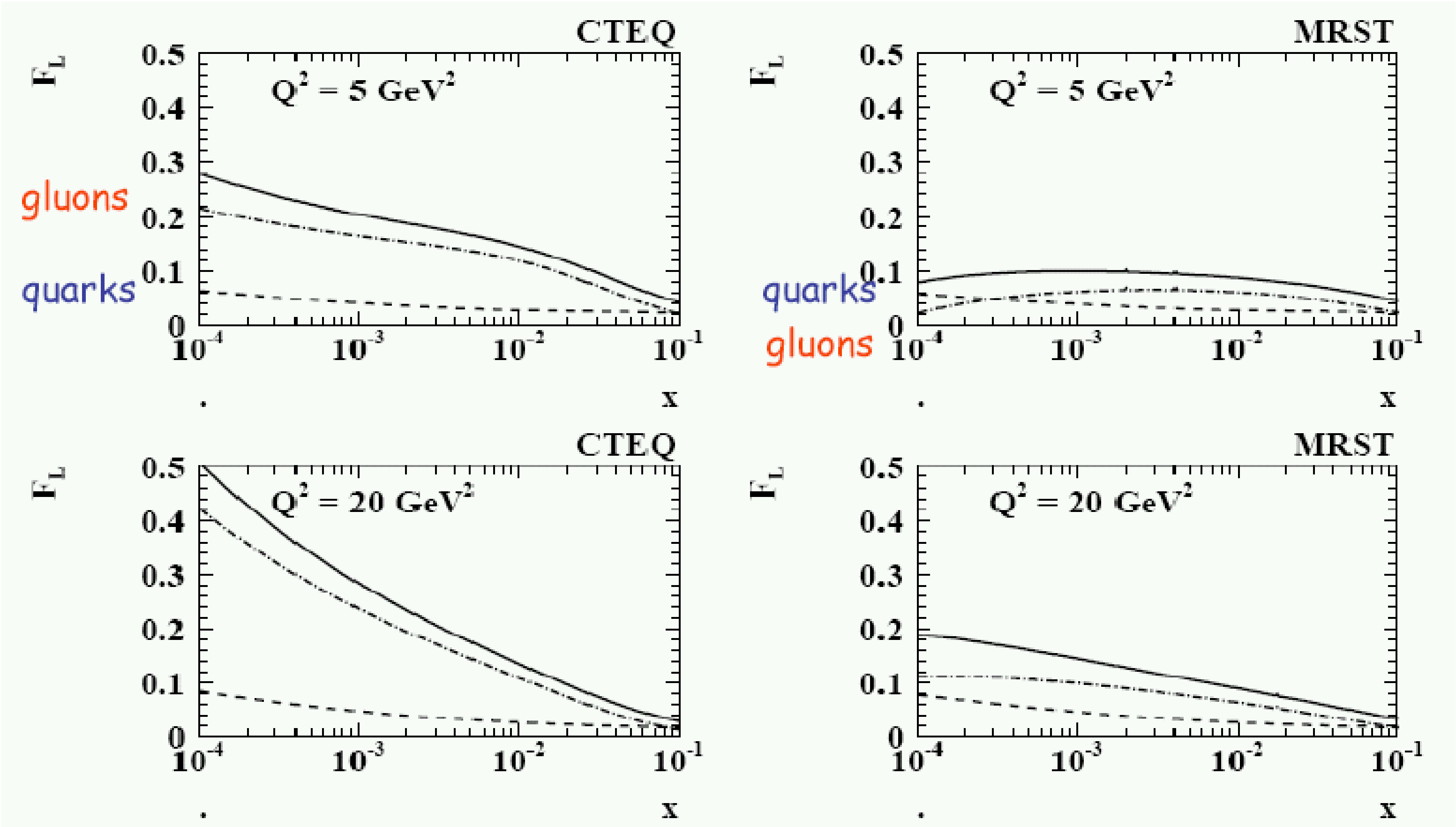
Altarelli, Martinelli 1978

$q \to qg$

$g \to q\bar{q}$ dominates

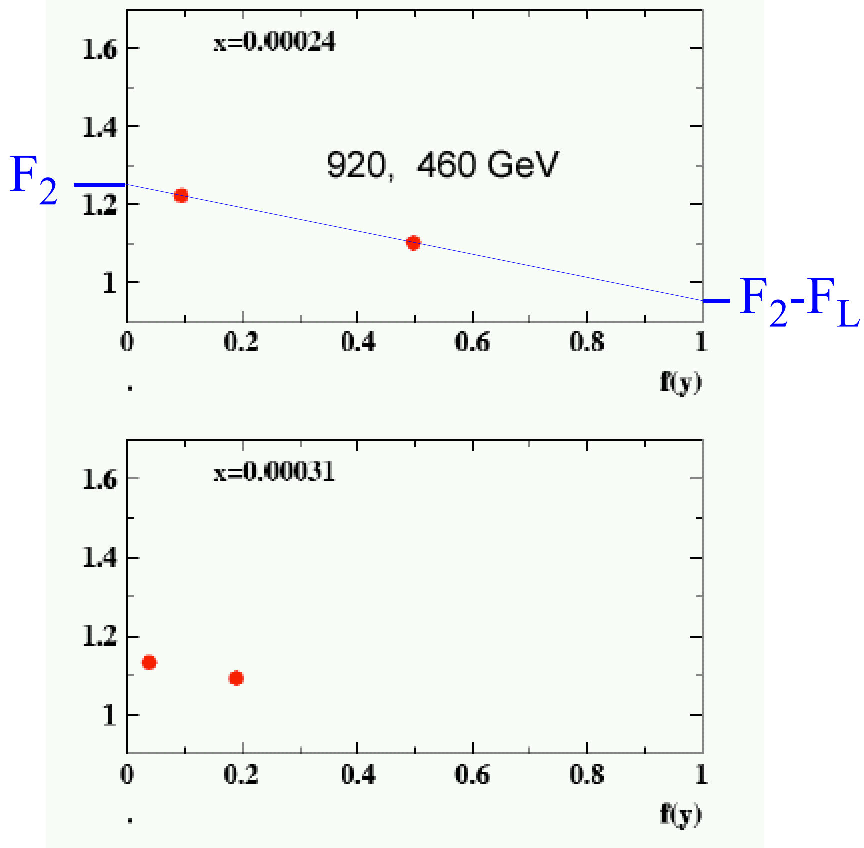
FL

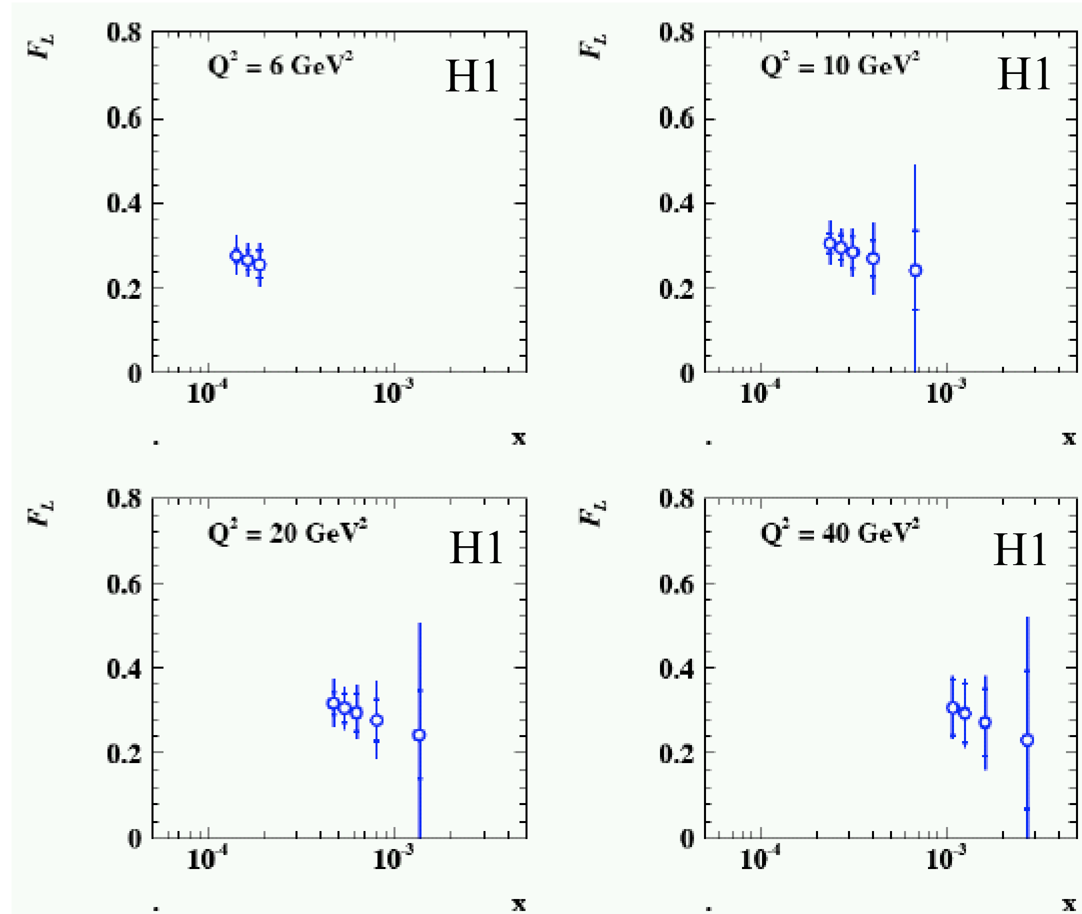
$$F_L = \frac{\alpha_S}{4\pi} x^2 \int_x^1 \frac{dz}{z^3} \left[\frac{16}{3} F_2 + 8 \sum e_q^2 (1 - \frac{x}{z}) zg \right]$$



FL simulation

$$\sigma_r = F_2 - f(y) \cdot F_L$$





10 pb^{-1} at 460 GeV: statistical and systemtic error are similar.

ZEUS: larger systematics at low Q^2: photo-production background.

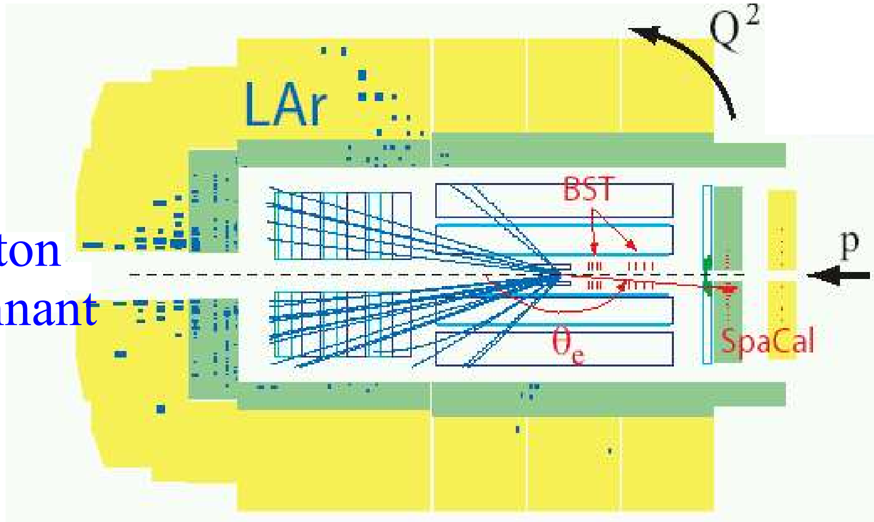
HERA: $\mathscr{L} = 1.5 \cdot 10^{31}/\text{cm}^2\text{s}$ at 460 GeV

Need 3 months for 10 pb^{-1}.

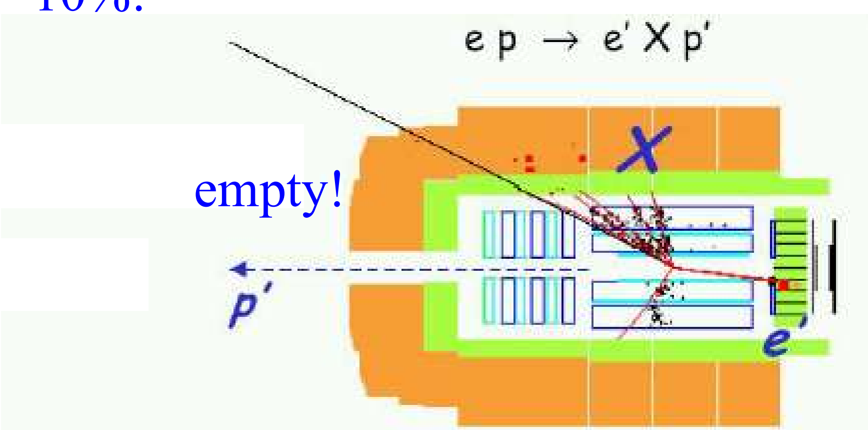
Diffraction

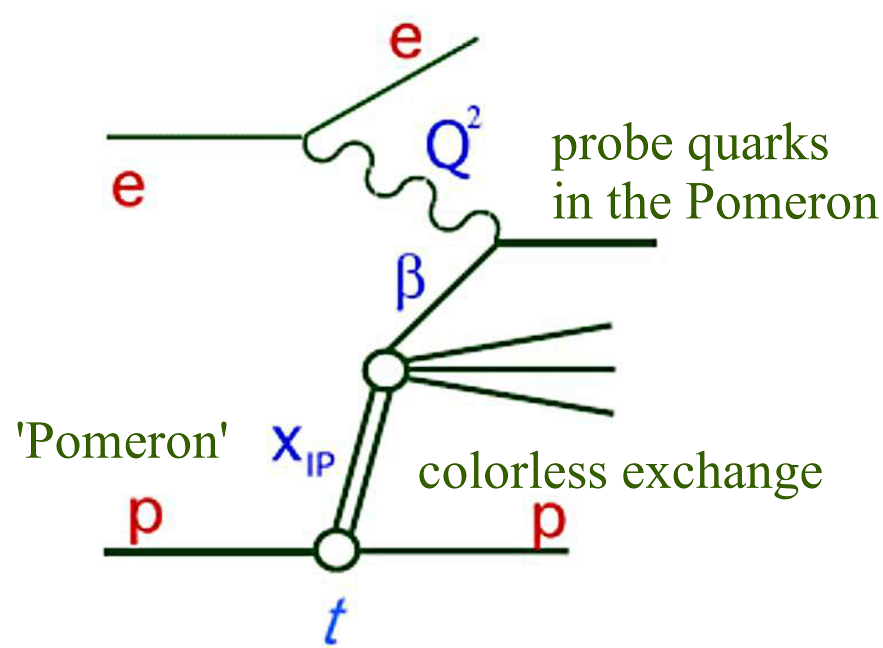
normal DIS:

proton
remnant

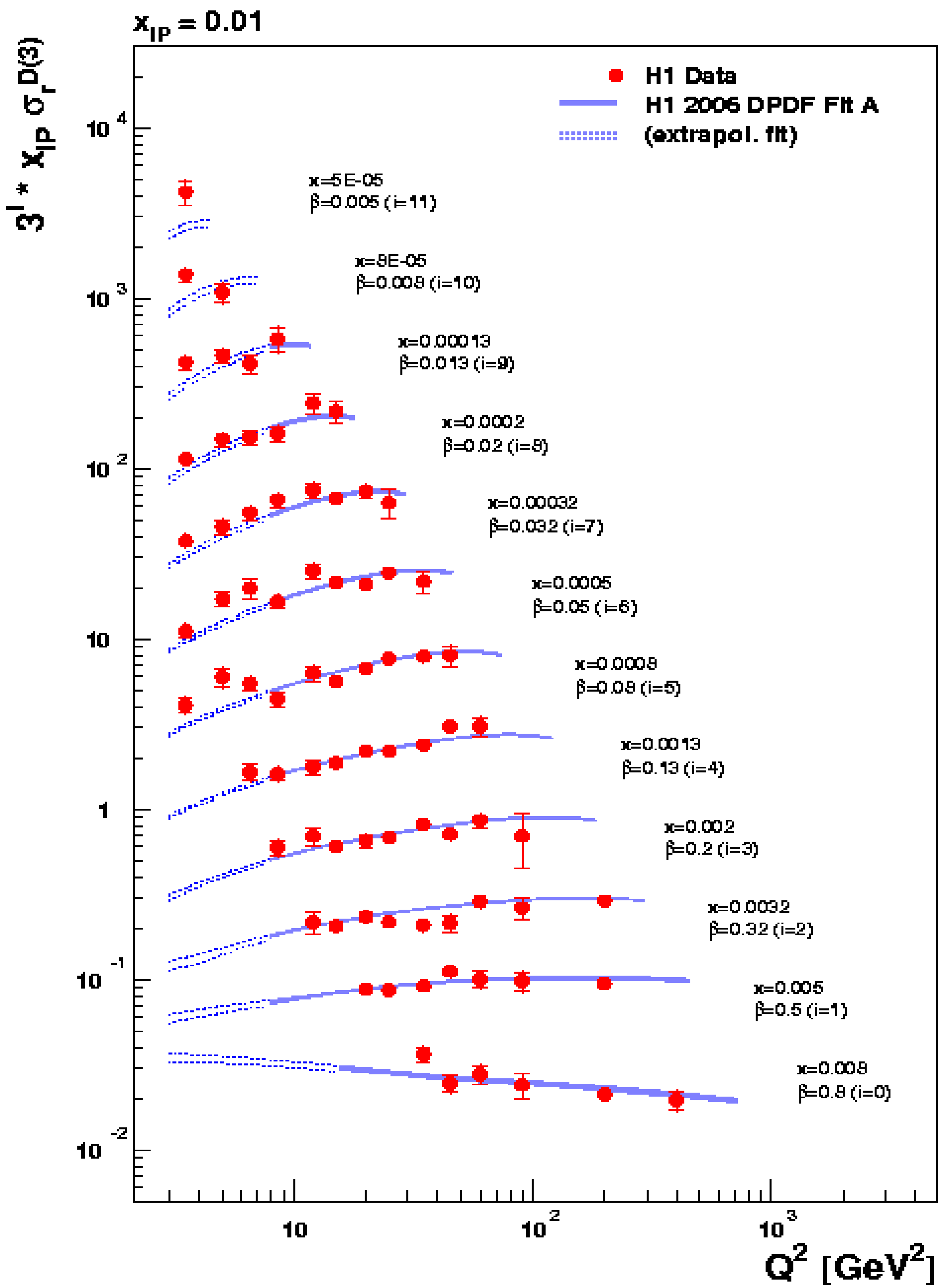


10%:

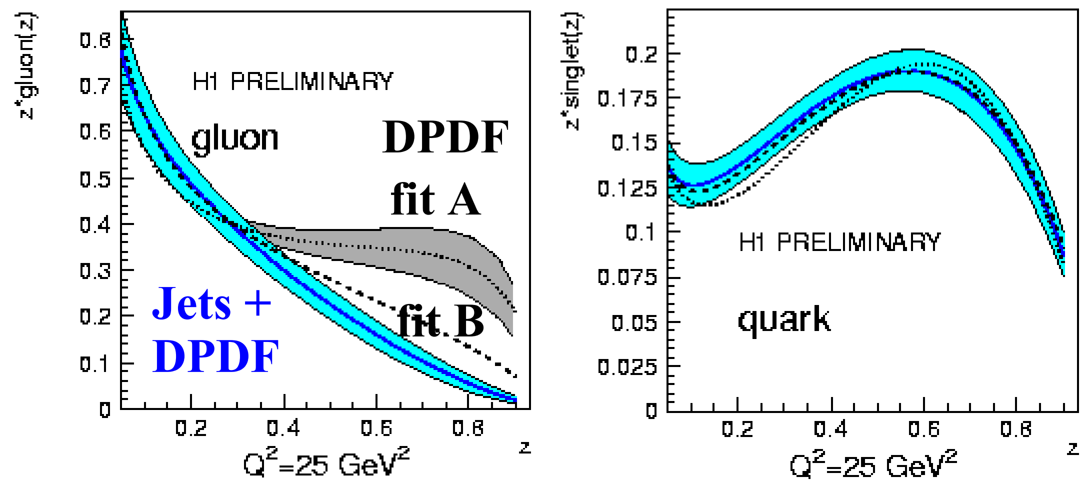




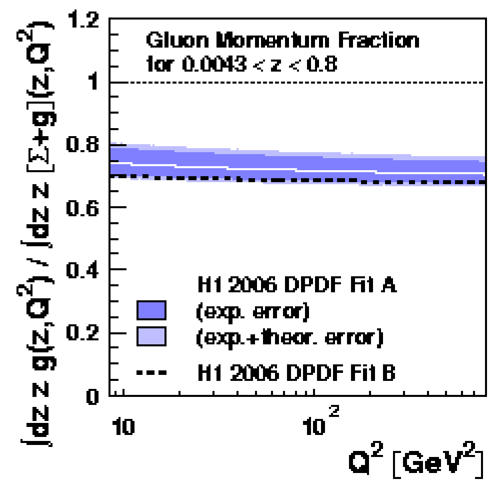
QCD analysis of Diffractive DIS



Pomeron parton extraction:

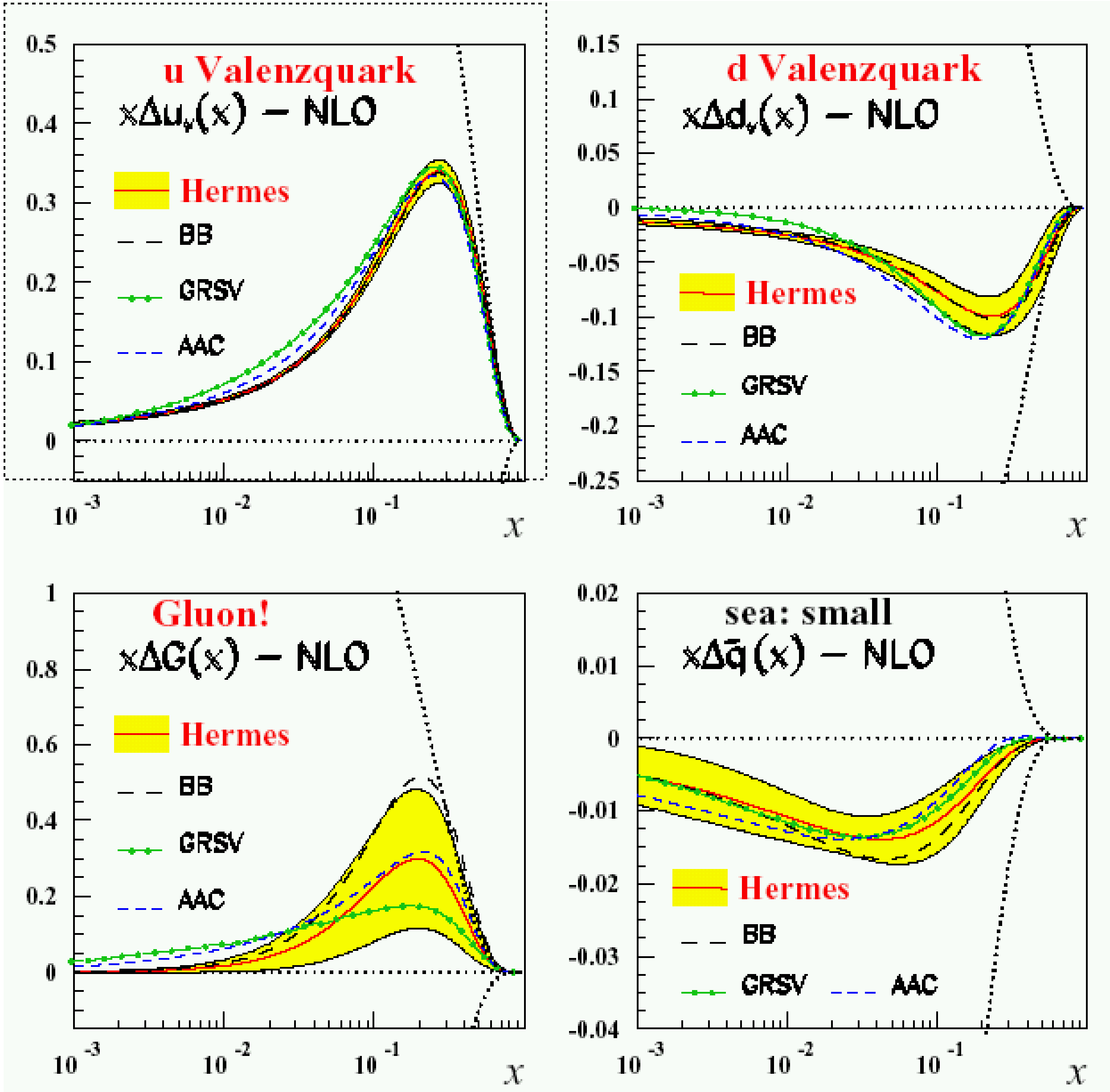


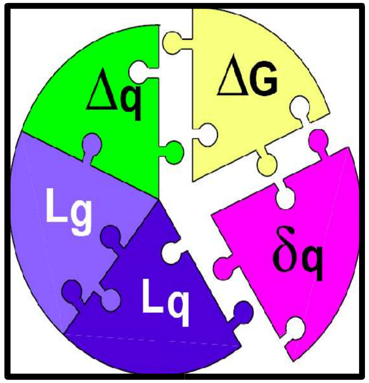
Gluons carry 70% of the Pomeron momentum:



Proton spin density

QCD analysis of the g_1 polarized structure function:





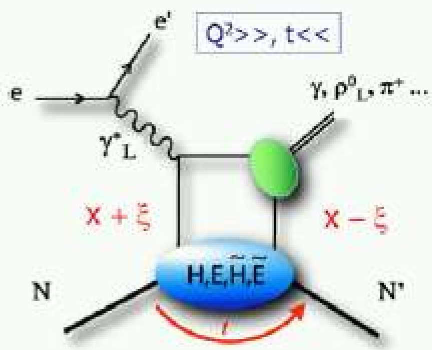
$$\frac{1}{2} = \underbrace{\frac{1}{2}\overbrace{(\Delta u + \Delta d + \Delta s)}^{\sim 30\%} + L_q}_{J_q} + \underbrace{\Delta G + L_g}_{J_g}$$

New Hermes result from
$K^{\pm}$ production in DIS:
$\Delta s \approx 0$

What about angular momentum?

Towards parton angular momentum

Generalised Parton Distributions (GPDs)



GPDs @twist-2:

$\boxed{H, E}$ $\boxed{\tilde{H}, \tilde{E}}$

quantum number of final state selects different GPDs:

→ DVCS ←

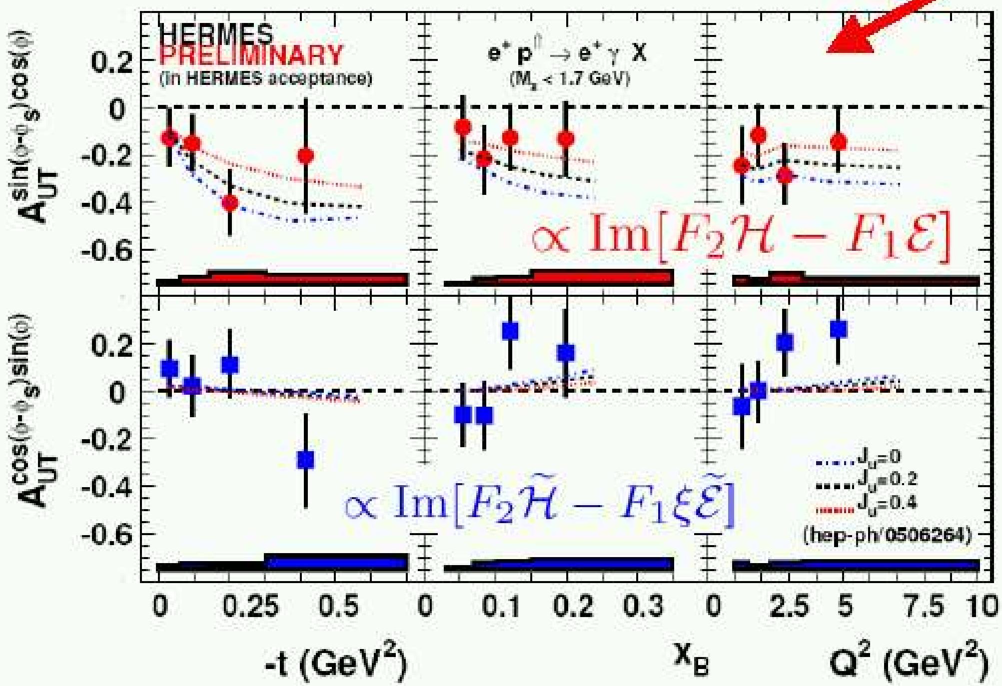
HERMES: interference between DVCS and Bethe-Heitler

DVCS asymmetries:

BCA (e^+,e^-) ~ $\mathrm{Re}\mathbf{H}\cdot\cos\phi$

BSA (P_{beam}^+,P_{beam}^-) ~ $\mathrm{Im}\mathbf{H}\cdot\sin\phi$

LTSA ($P_{targ.}^+$,$P_{targ.}^-$) ~ $\mathrm{Im}\tilde{\mathbf{H}}\cdot\sin\phi$



Transverse Target-Spin Asymmetry

will allow the first determination of J_u through certain GPD models

$$\frac{1}{2} = \underbrace{\frac{1}{2}\overbrace{(\Delta u + \Delta d + \Delta s)}^{\sim 30\%} + L_q}_{J_q} + \underbrace{\Delta G + L_g}_{J_g}$$

Ji's Sum Rule:

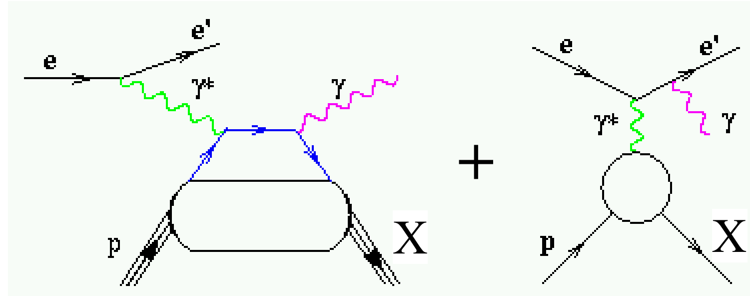
$$J_{q,g} = \frac{1}{2}\lim_{t\to 0}\int_{-1}^{1} dx \cdot x \cdot [H_{q,g}(x,\xi,t) + E_{q,g}(x,\xi,t)]$$

Recoil detector (2006/2007)

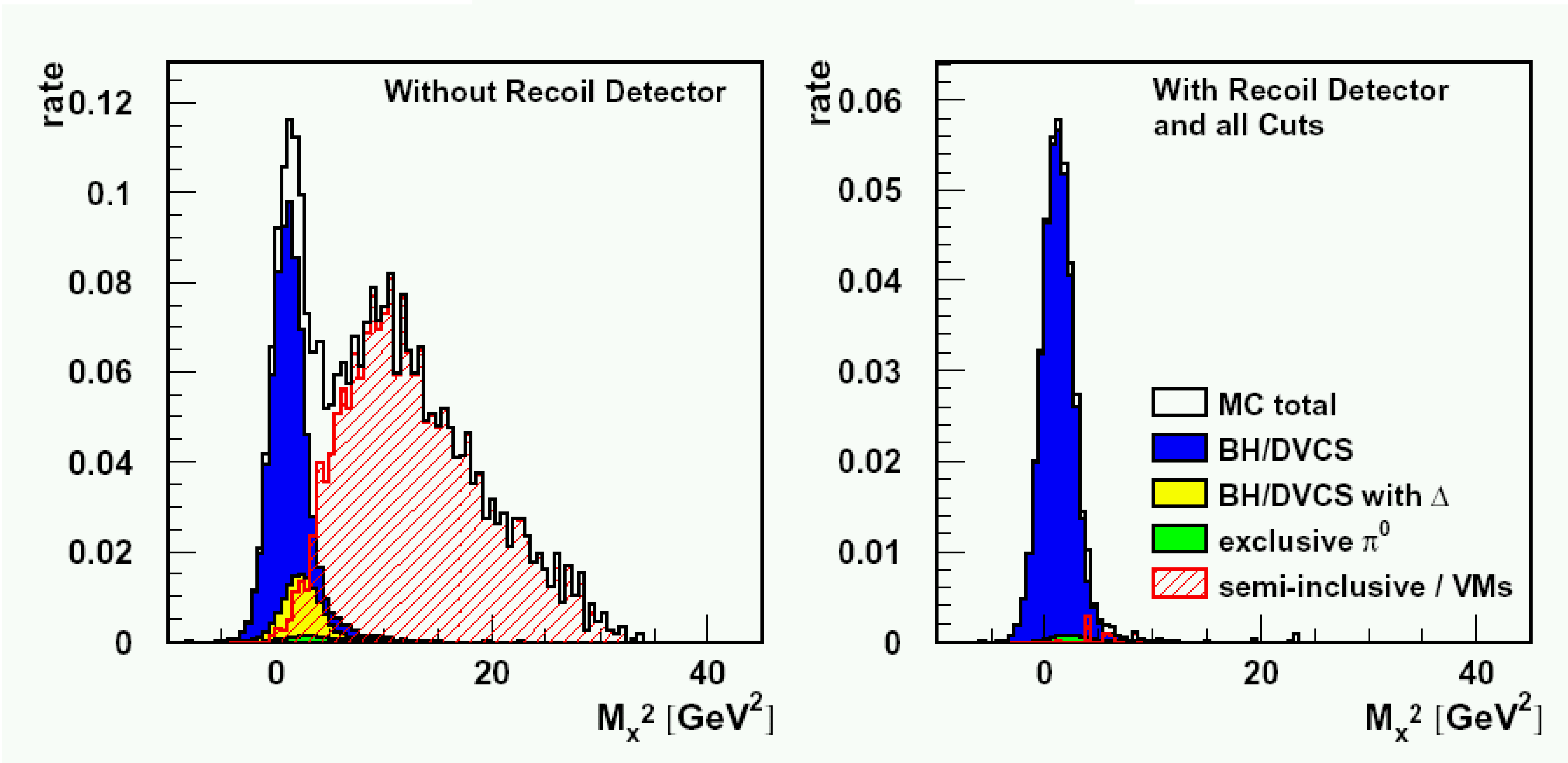
- detection of recoil proton
- background free DVCS (bkg ~5% -> < 1%)

DVCS recoil spectrum

Deeply-virtual Compton scattering



Bethe-Heitler Bremsstrahlung



Recoil detector gives 'exclusivity'.

HERA determinations of the strong coupling

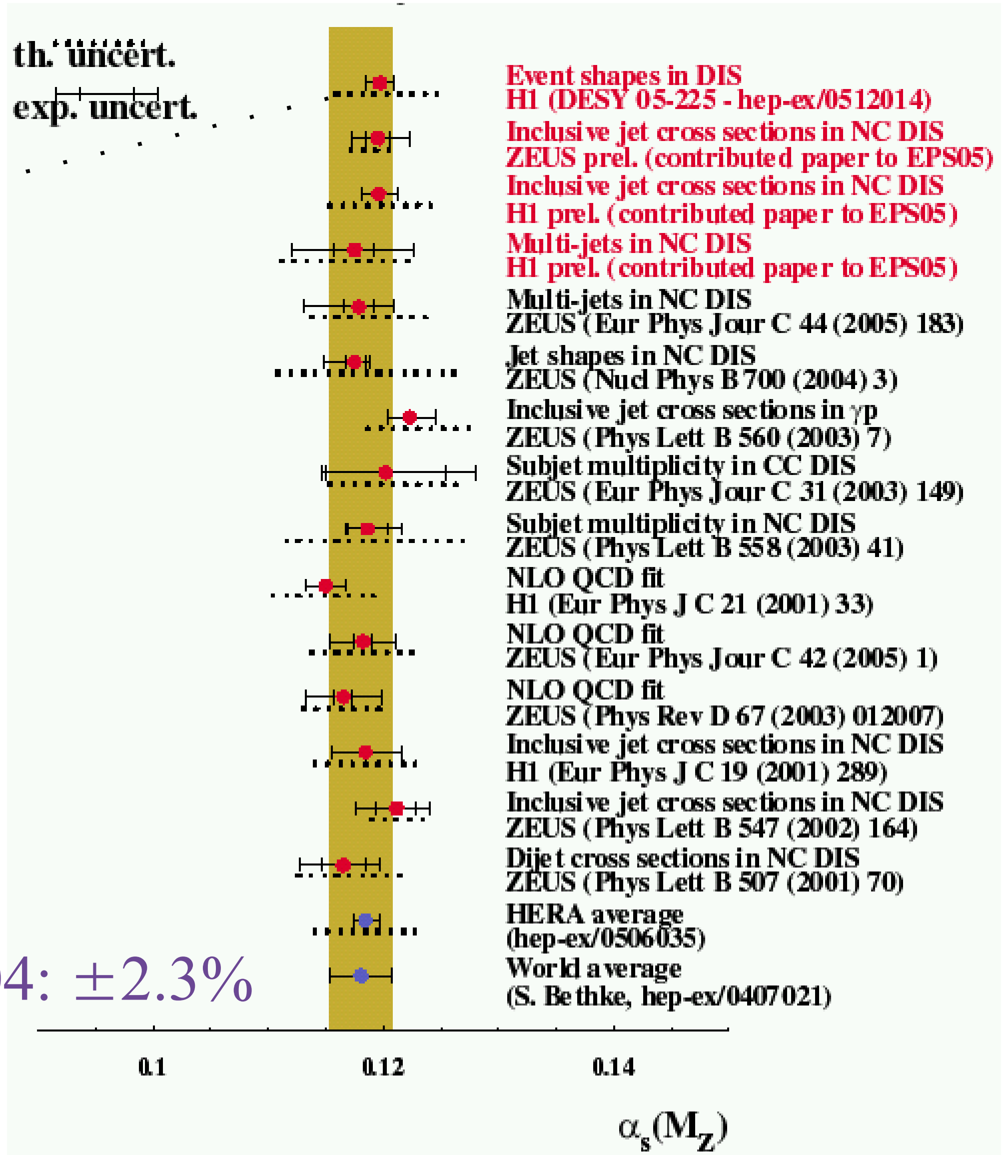
Theoretical uncertainty dominates: ±4%.

Need to use higher order (NNLO) QCD calculations.

Goal for HERA:

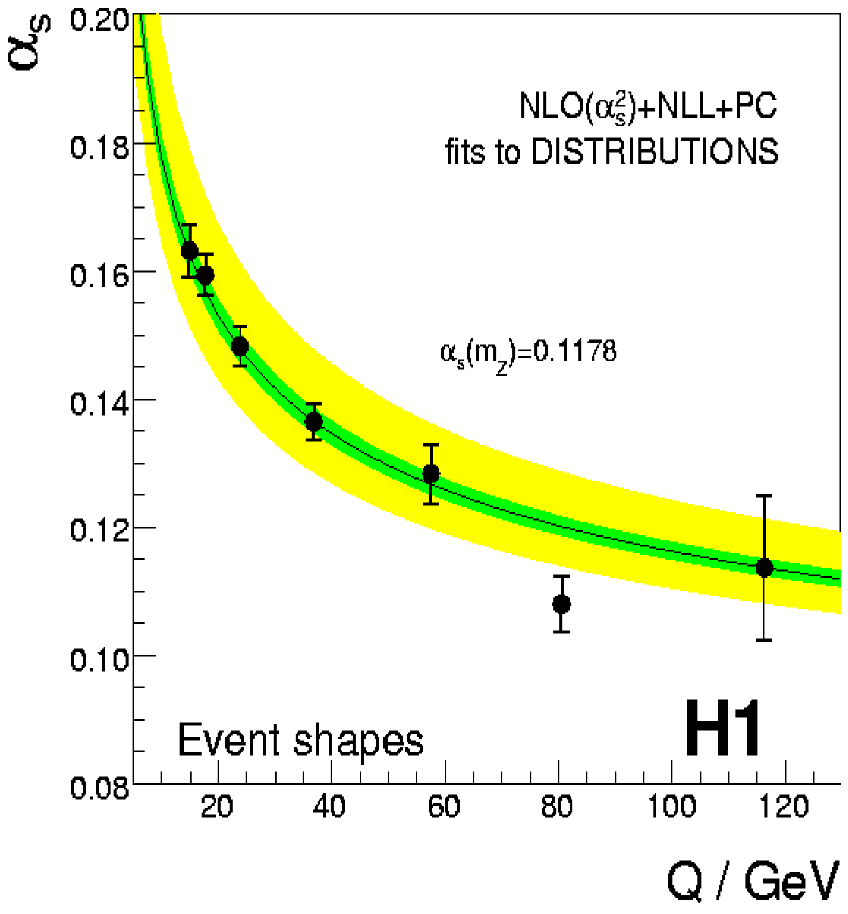
α_S to 1%

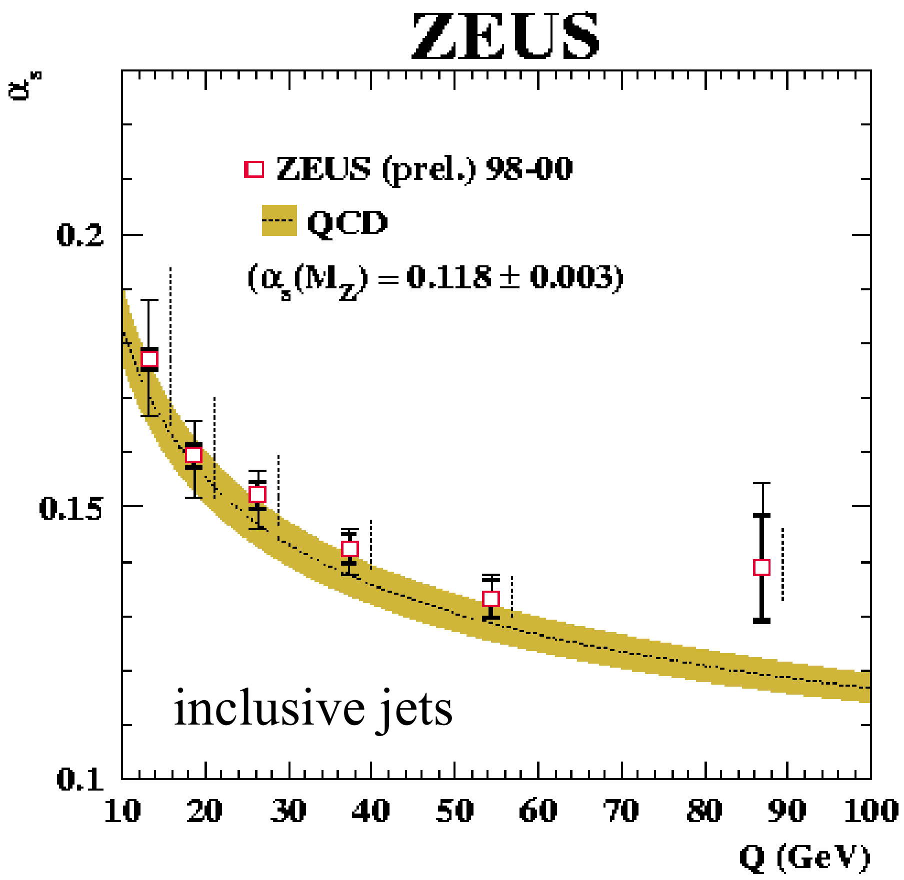
World average 2004: ±2.3%



Running coupling constant in QCD

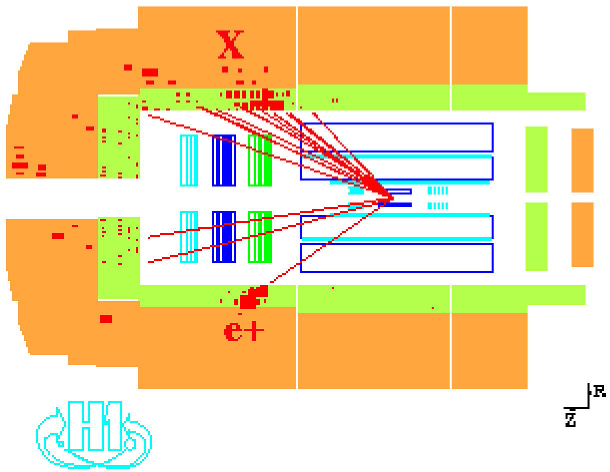
α_S measurements from HERA:

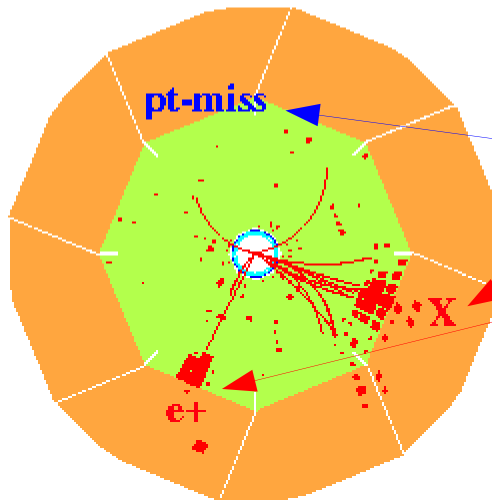




Nobel prize 2004 for Gross, Wilczek, Politzer for predicting this in 1973.

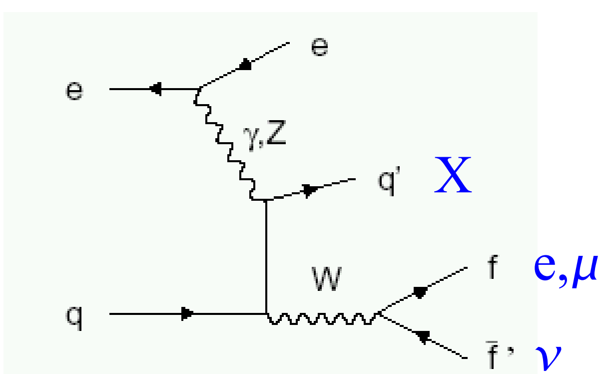
HERA isolated lepton events

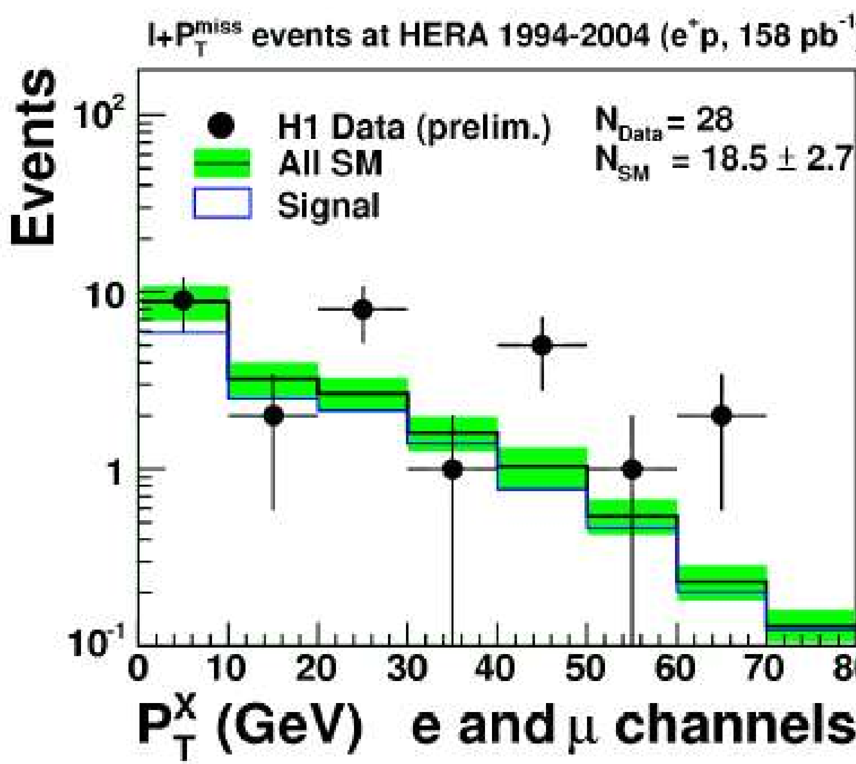




Missing momentum
Hadronic system X
Isolated high p_t e or μ

Standard model:
W production
but: expect small P_T^X



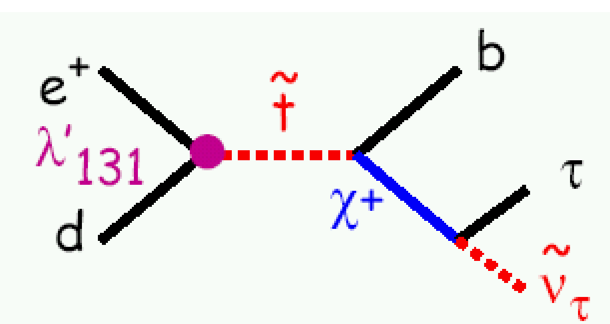


Isolated leptons with large P_T^X

$P_T^X > 25$ GeV	e channel obs. / exp. (signal)	μ channel obs. / exp. (signal)	τ-channel
H1 e^+p data 158 pb^{-1}	9 / 2.3 ± 0.4 (80%)	6 / 2.3 ± 0.4 (84%)	**0 / 0.40±0.10**
H1 e^-p data 121 pb^{-1}	2 / 2.4 ± 0.5 (62%)	0 / 2.0 ± 0.3 (76%)	**3 / 0.35±0.10**

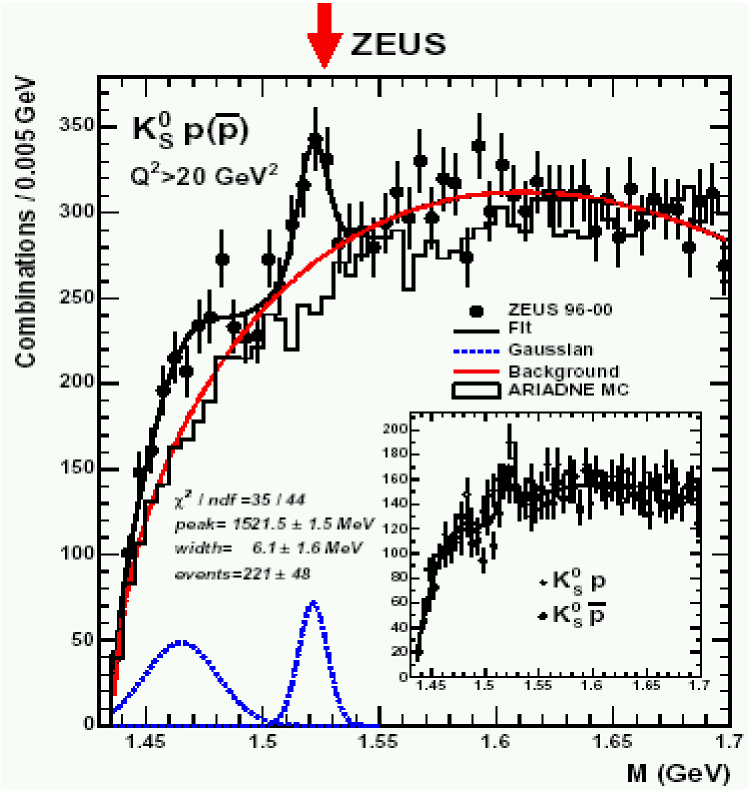
$P_T^X > 25$ GeV	**e-channel**	**μ-channel**	**τ-channel**
Z e^+ p 99-04 106 pb^{-1}	**1 / 1.50±0.13** (78%)		
Z e^+ p 94-00 130 pb^{-1}			**2 / 0.2±0.1**
Z e^- p 98-05 143 pb^{-1}	**3 / 2.86±0.46** (53%)		
Z e- p 04-05 126 pb^{-1}		**2 / 1.4±0.2** (86%)	

One possible explanation:
R-parity violating Susy:

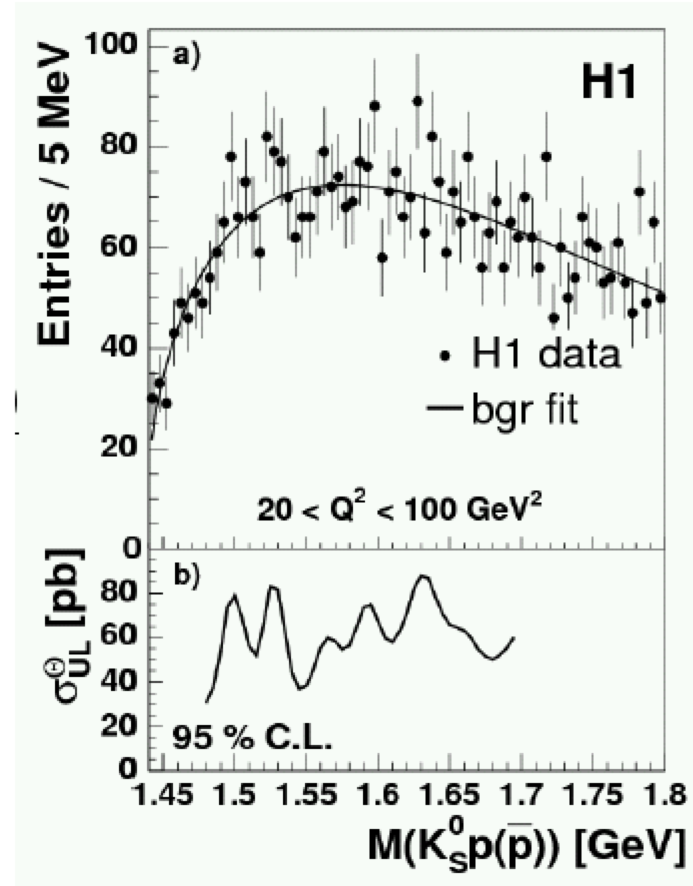


e^+ p: F = 0.
More e^+ data to come!

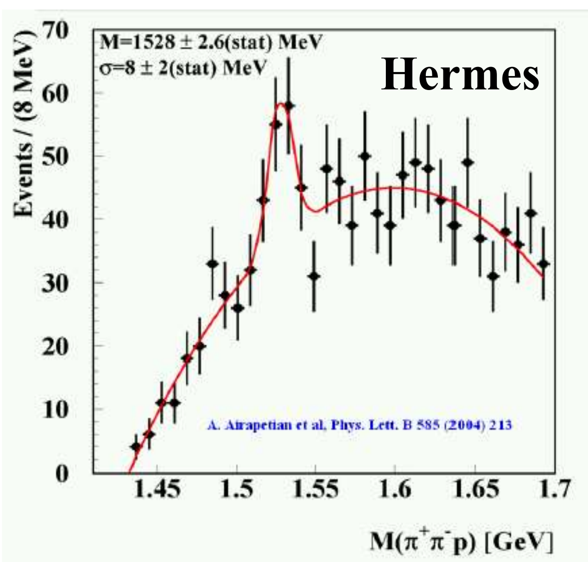
Strange Pentaquarks?



HERA I data.



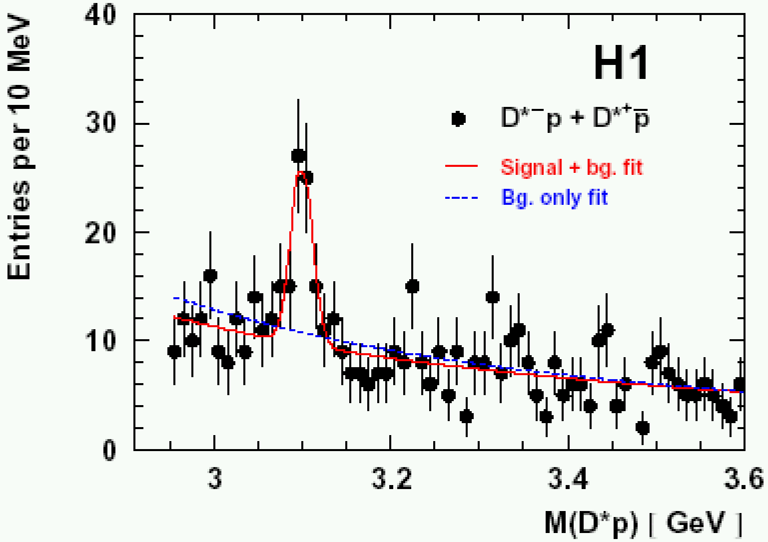
H1 does not confirm ZEUS signal, but upper limit is not yet in conflict.

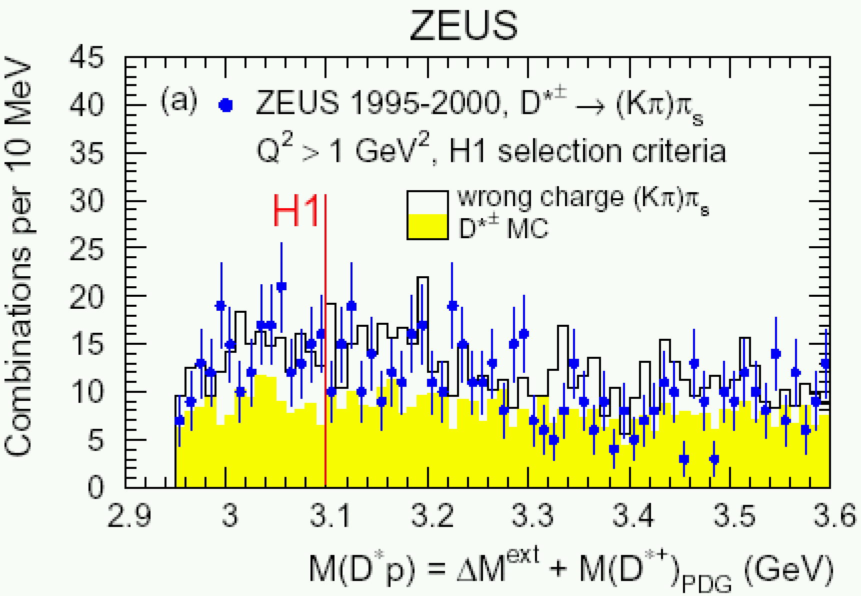


A high statistics run with CLAS at JLAB has not confirmed the Θ^+.

Charmed Pentaquark?

H1 Daten 1996–2000 (DIS):

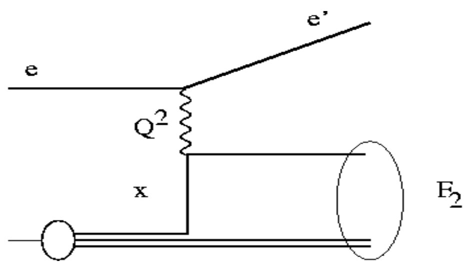


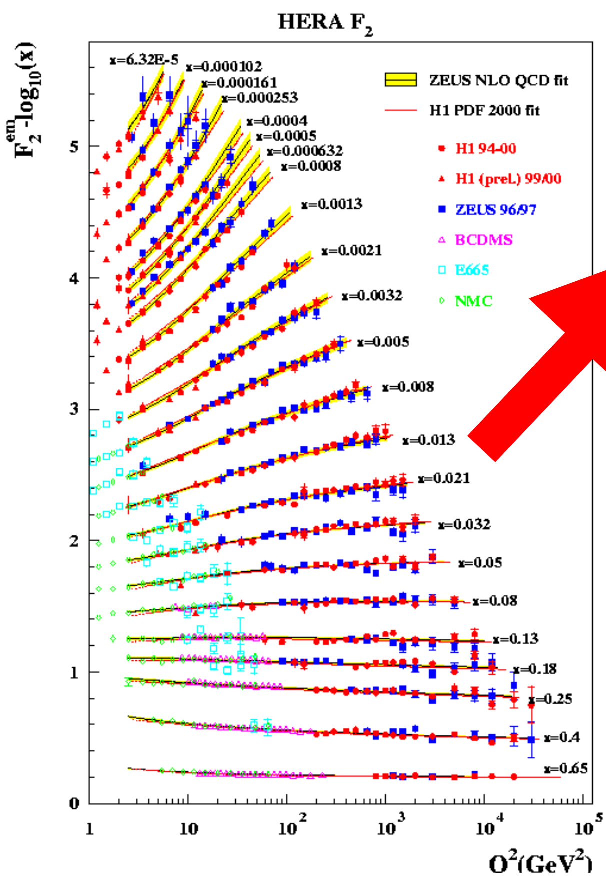


- H1 beobachtet ein signifikantes Signal ($5.4\,\sigma$) bei 3099 MeV im Kanal $D^{*-}p$ und $D^{*+}\overline{p}$.
- Ein Θ_c Anticharmbaryon wäre exotisch und müsste aus mindestens 5 Quarks bestehen: $uudd\overline{c}$.
- Etwa 1% aller D^* enstammen diesem Signal.

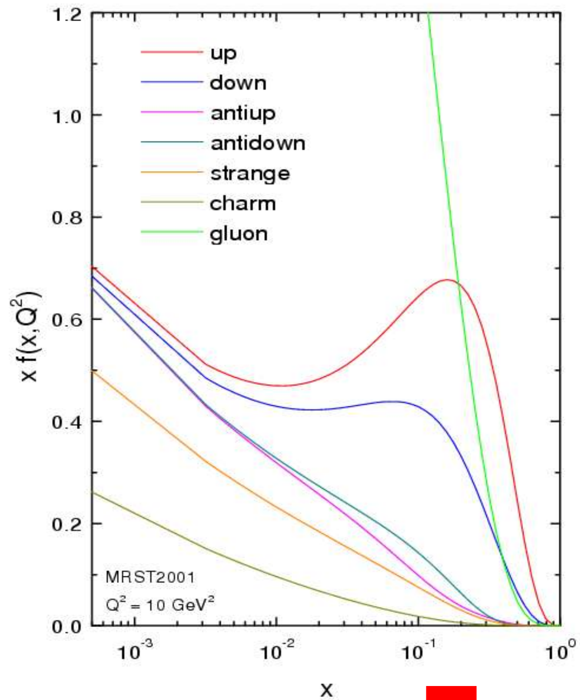
- Mit ähnlichen Selektionskriterien findet ZEUS kein Signal in diesem Kanal.
- Das Massenspektrum kann durch zufällige Kombinationen beschrieben werden.
- Höchstens 0.35% aller D^* könnten einem Θ_c entstammen.

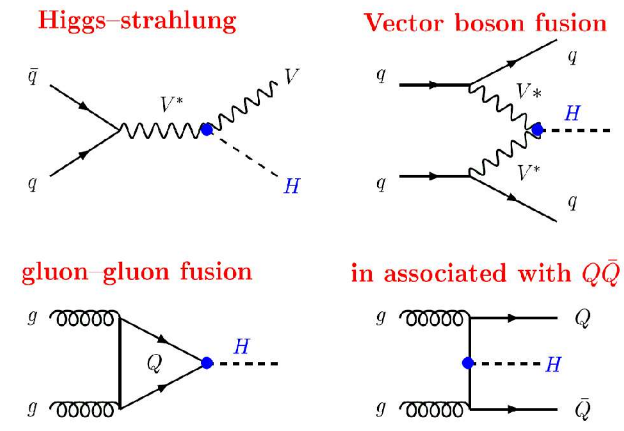
From HERA F_2 to the Higgs at LHC



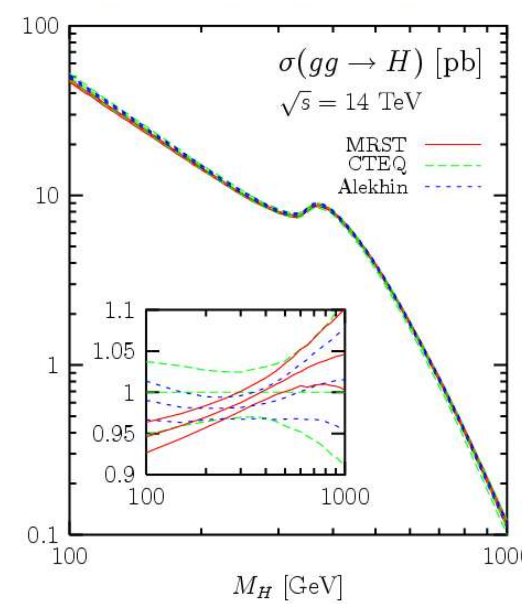


extract parton densities:





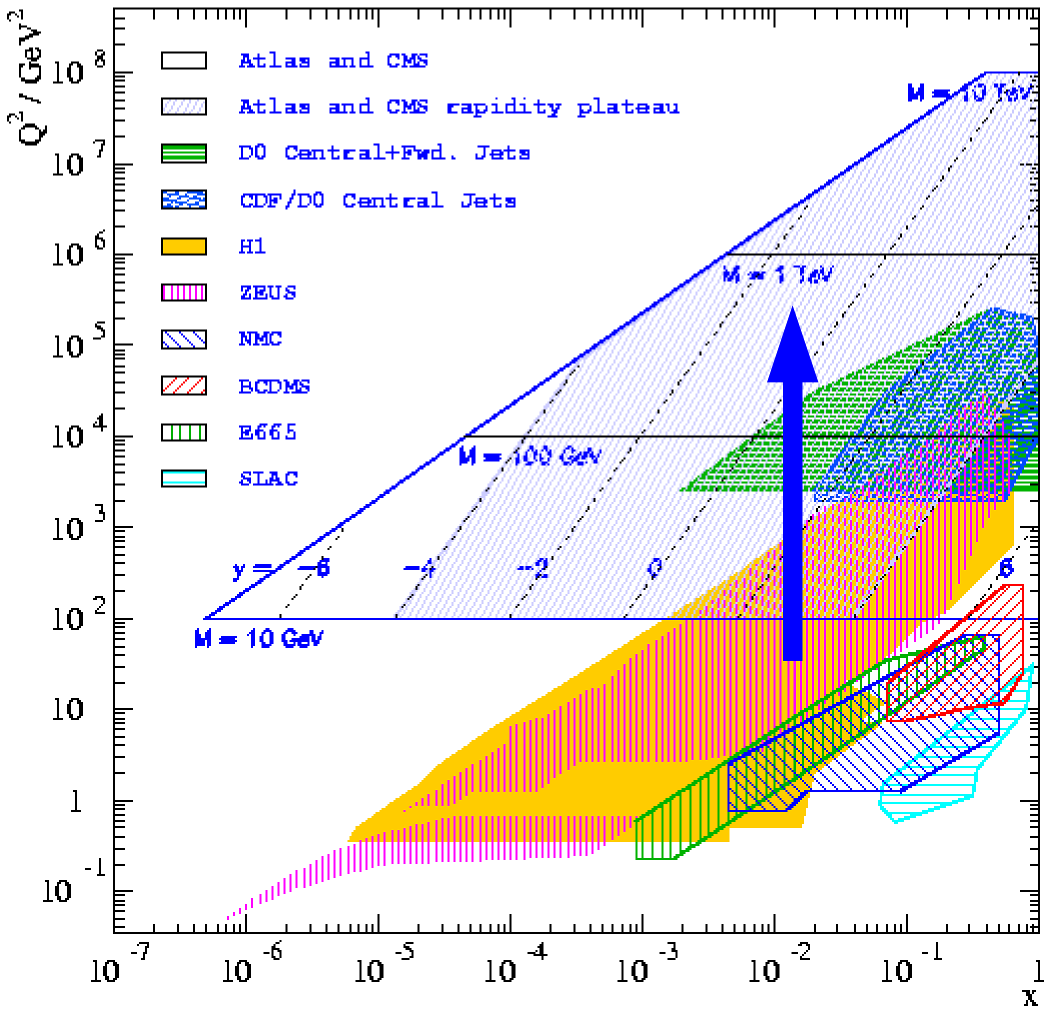
calculate Higgs production:



Structure function F_2

Up to 10% uncertainty

Kinematic reach of colliders



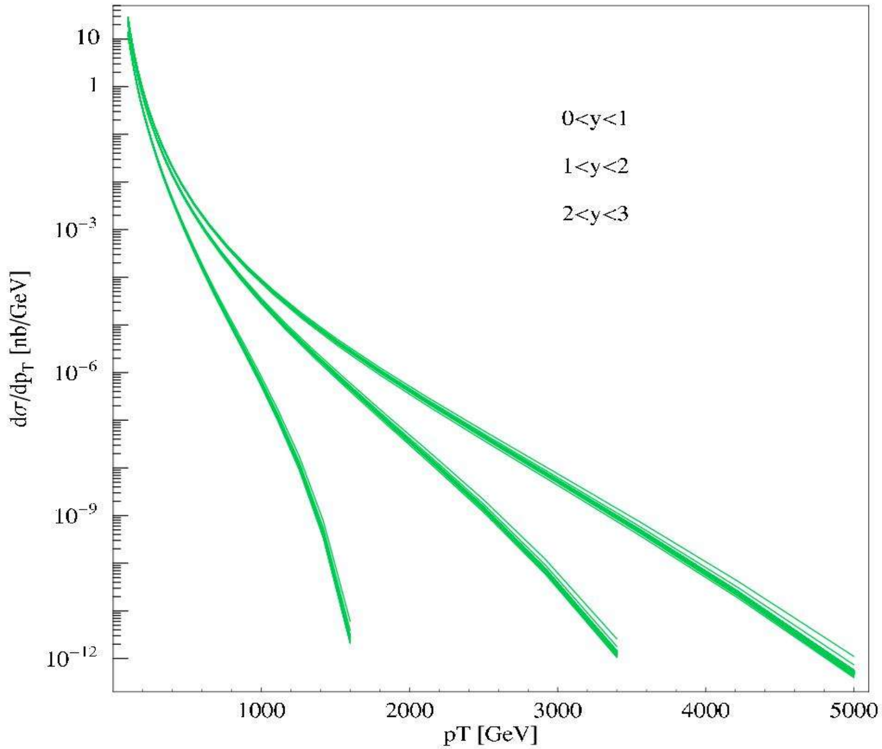
$$x_{1,2} = M/\sqrt{s} * \exp(\pm y)$$

QCD evolution
(DGLAP equation).

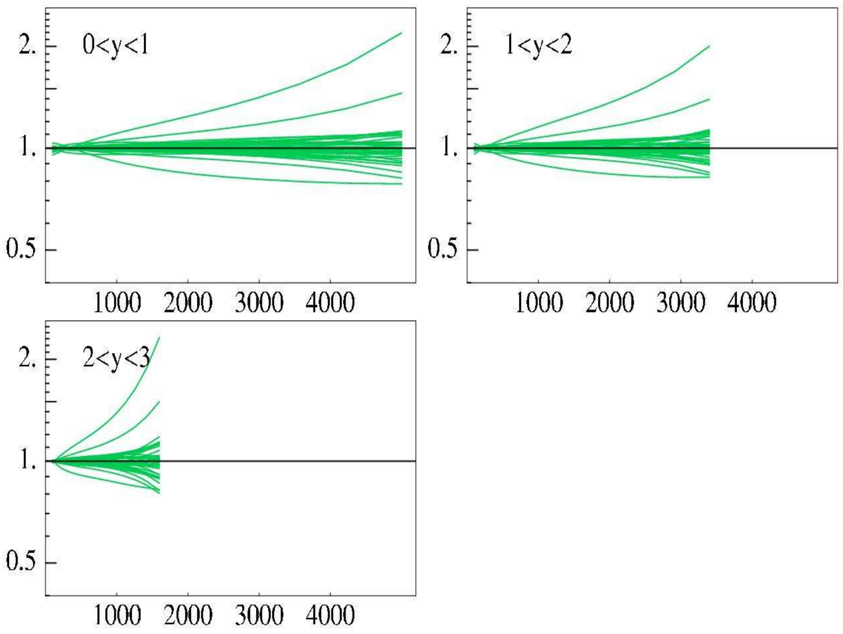
HERA covers the x-range for central production at the LHC.

Precise parton densities required

Signature for new physics:
jet cross-section vs p_T in rapidity bins:



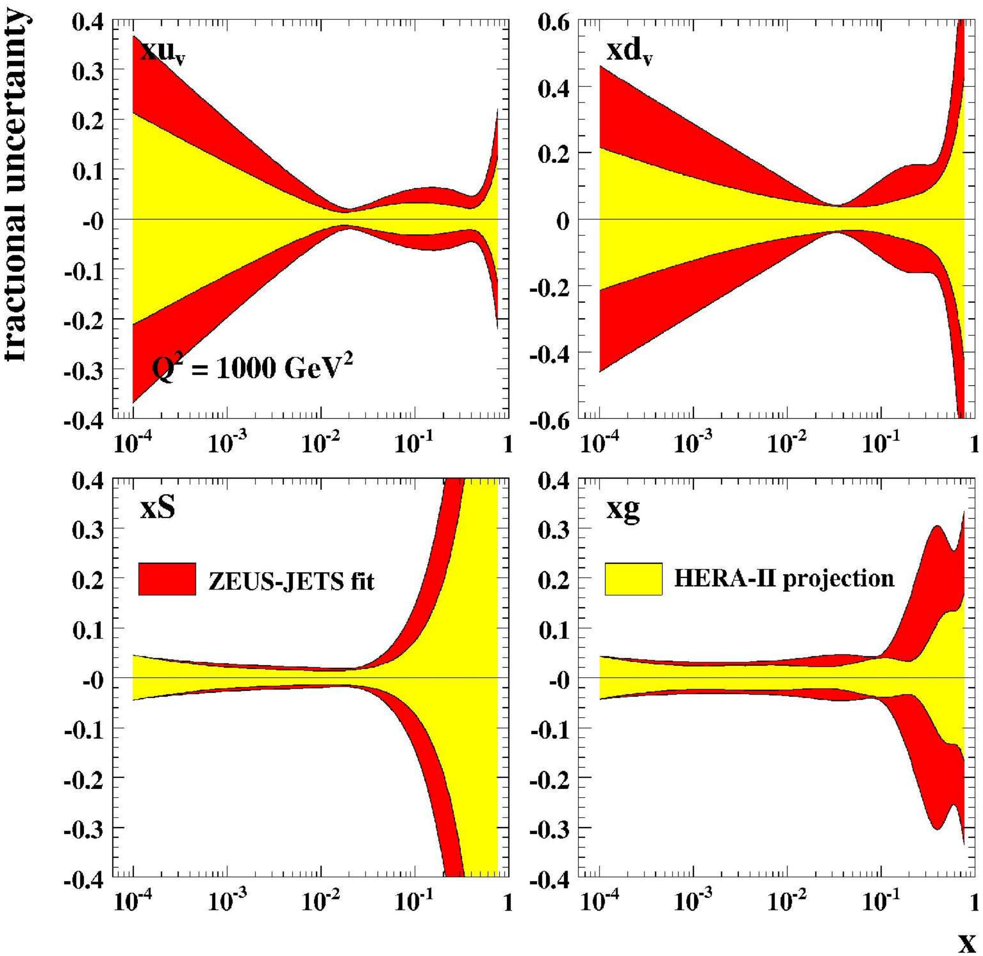
Discovery potential depends
on knowledge of parten densities:
ratios from different theorists:

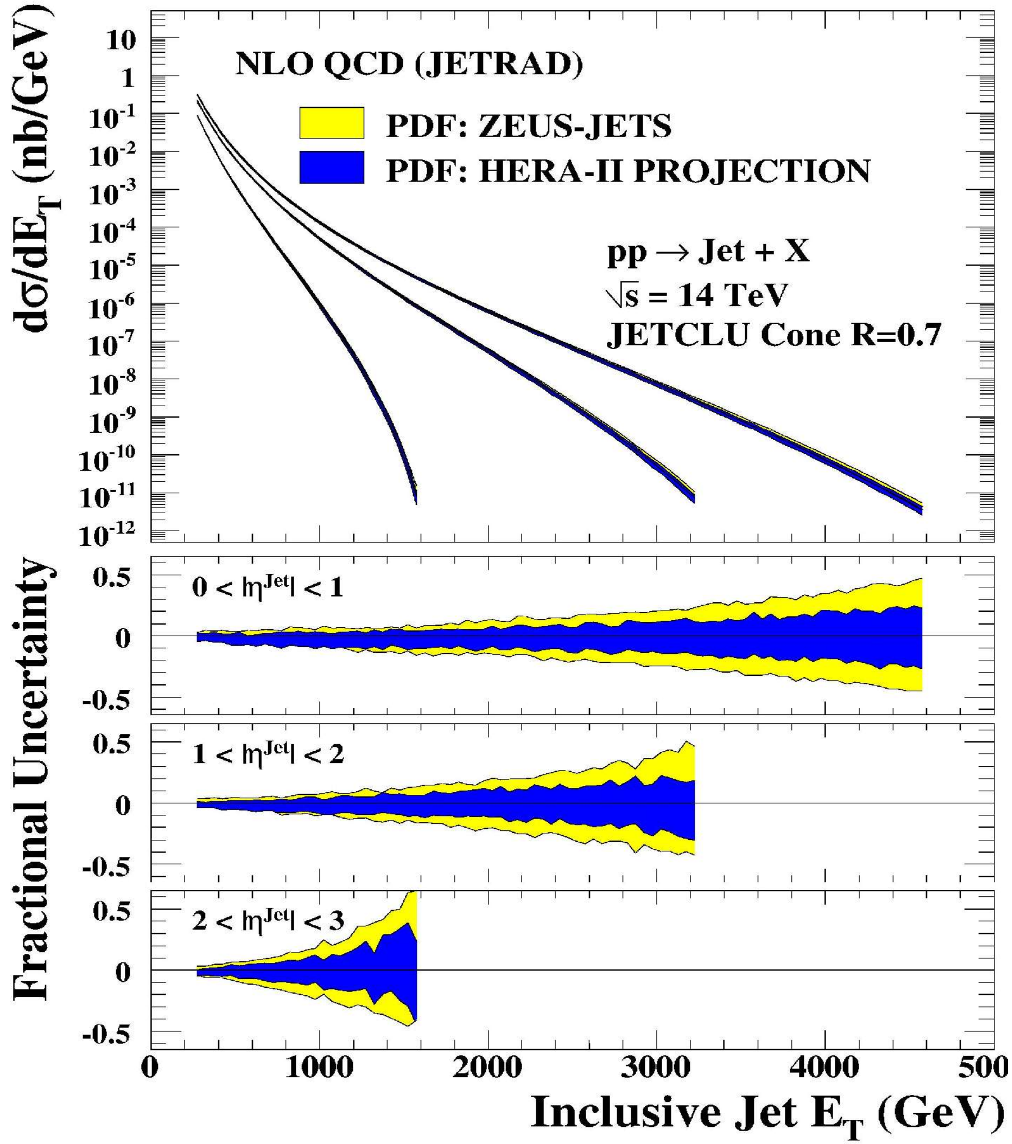


Improvements from HERA II

Using jets together with F_2 (at large Q^2)

quark and gluon uncertainties:

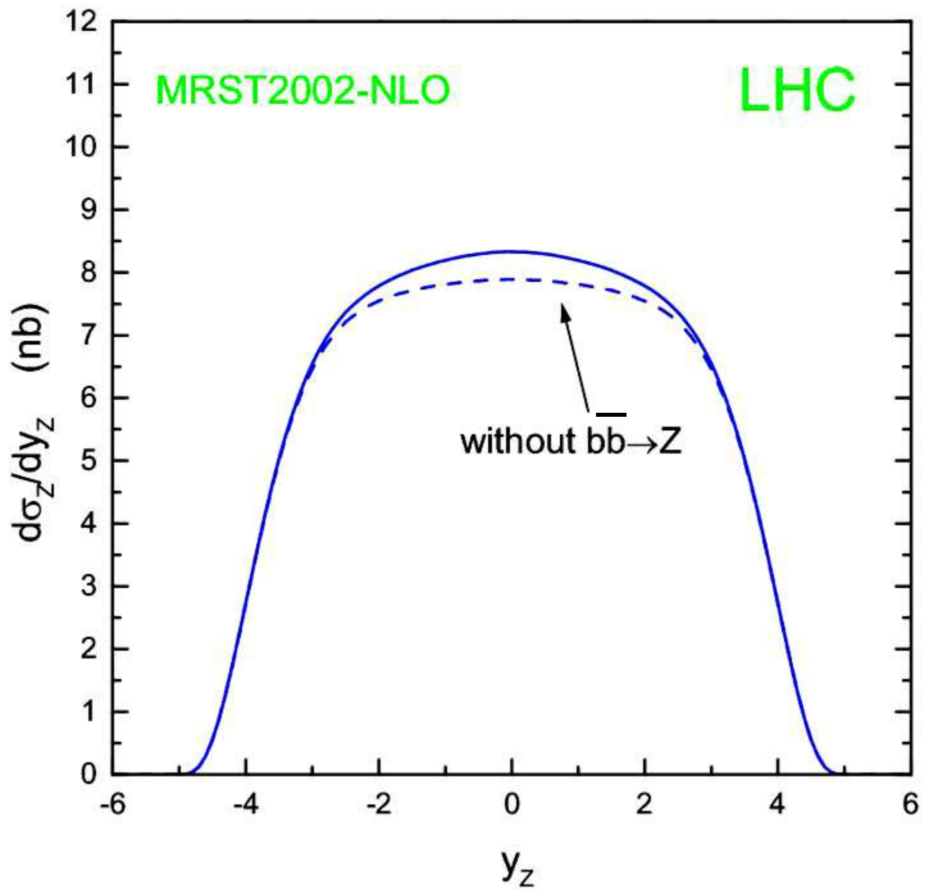


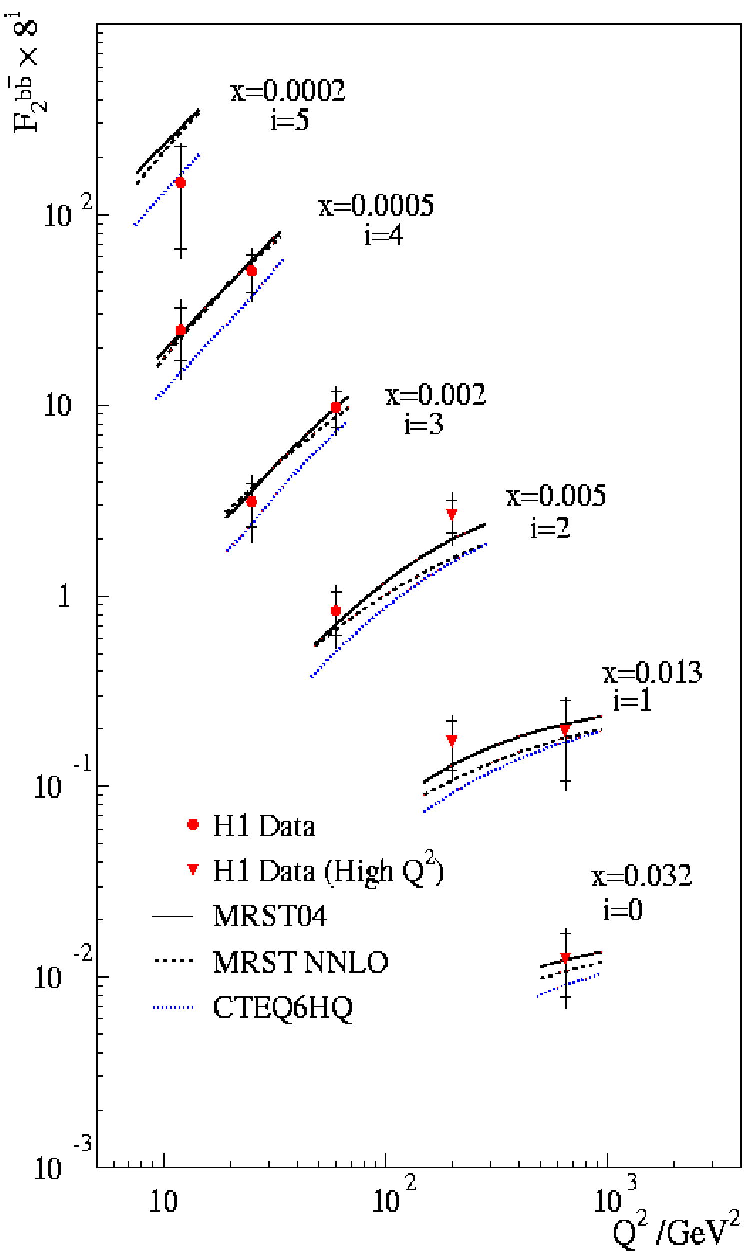


high statistics from HERA II is important (assumed 700 pb-1)

Error on LHC jet cross-section reduced

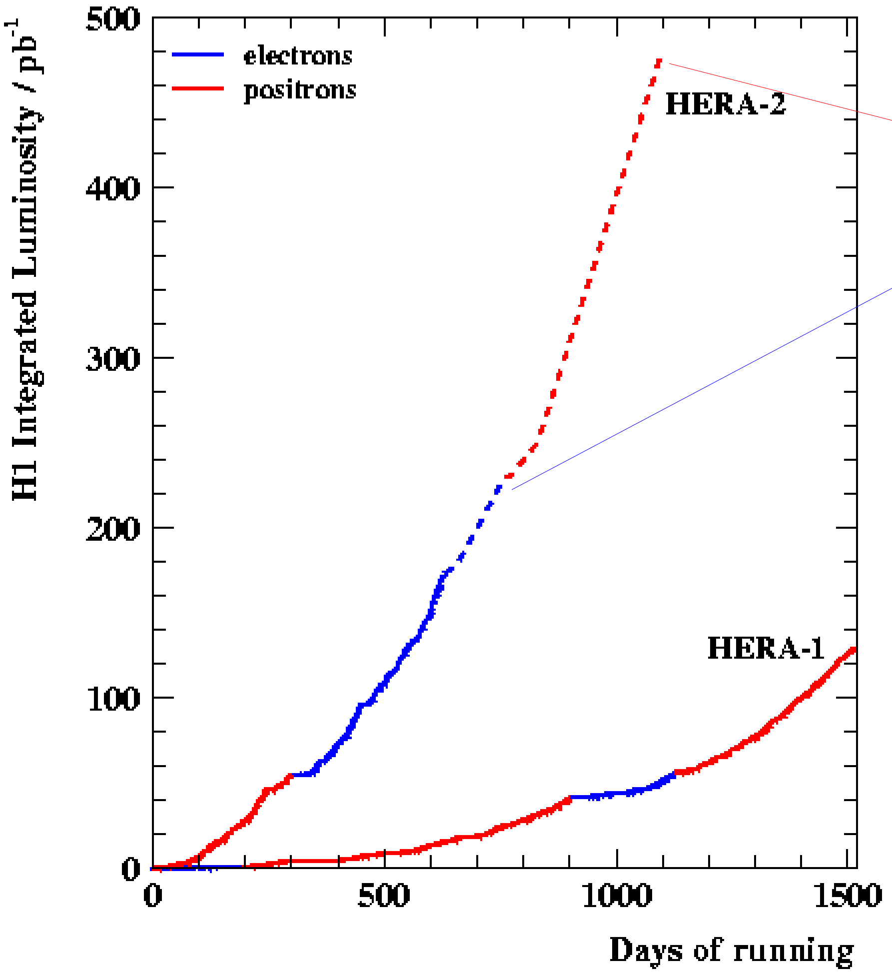
LHC needs beauty density in the proton





- $b\bar{b}$ is 5% contribution to Z production
- Need to know F_2^b to 20% accuracy to get Z production at 1% level.
- Reachable with ZEUS and H1 data at HERA II.

Luminosity outlook

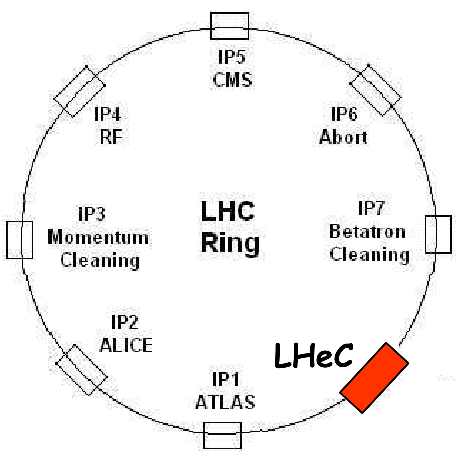


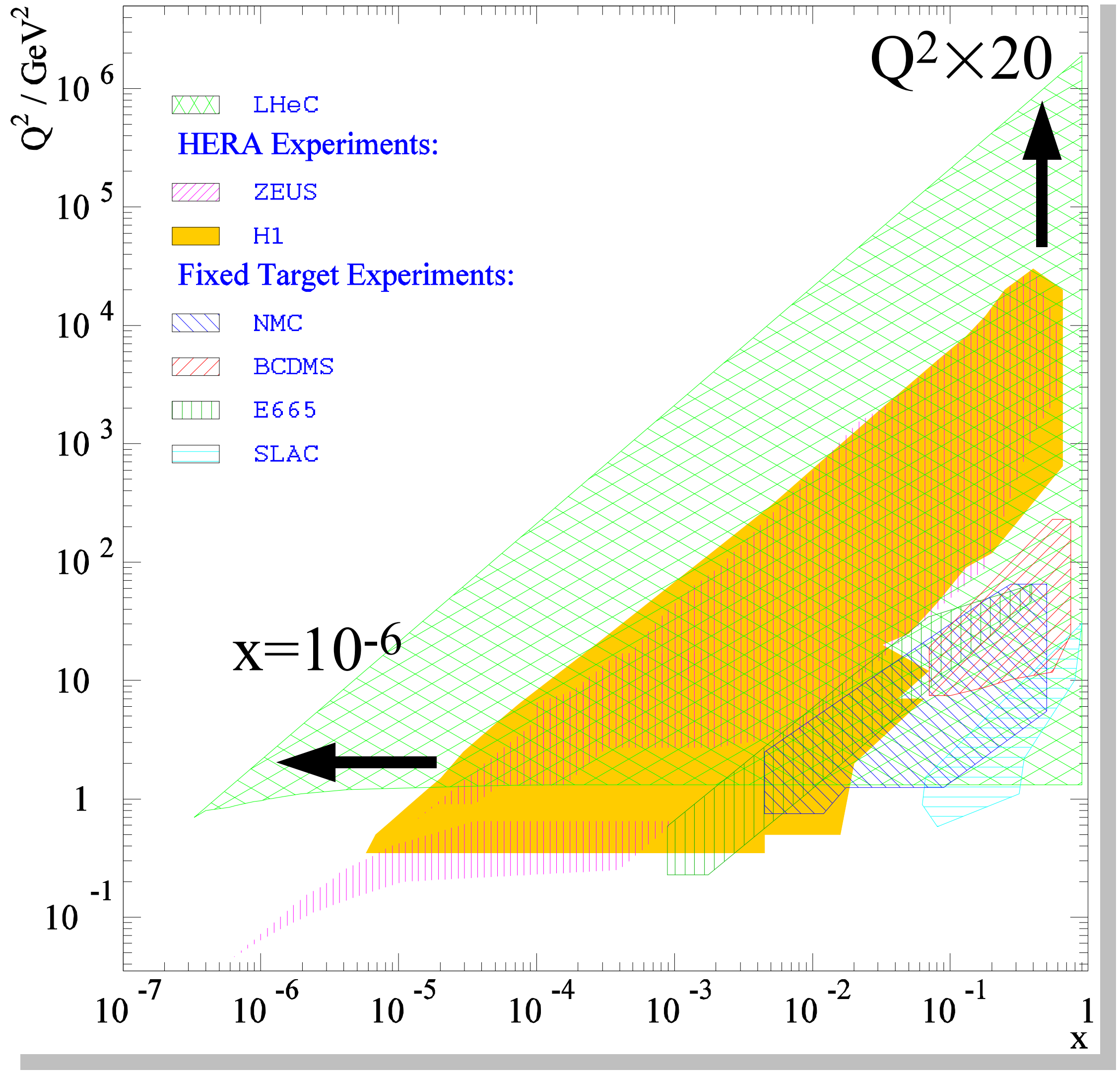
- Run until end of June 2007.
- Switch to e$^+$ end of June 2006.
- 3 months for the FL run (not shown).

⇒ expect 450 pb-1 of physics data per experiment from HERA II.

The future of DIS?

- **LHeC**: ep at CERN
- 7 TeV × 70 GeV.
- $\sqrt{s}$ = 1400 GeV.
- $\mathscr{L} = 10^{33}/\mathrm{cm}^2/\mathrm{s}$
- After LHCb.
- e bypass at Atlas, CMS.
- **Seminar by F. Willeke and M. Klein today!**





Summary

- HERA II has almost completed a successful e^-p run.

  We hope for a similarly successful e^+p run.

- The collider experiments are in their best shape ever.

  The Hermes recoil detector is being repaired for the e^+ run.

- Excellent physics results are being produced in all fields, increasingly using the HERA II data.

- Physics analysis will continue for many years beyond HERA running.

- H1 and ZEUS want to do a low E_p run to measure F_L.

  The physics case has been positively reviewed by the PRC.

Running HERA is hard – but it's worth it!

Thanks to all groups involved!