Physics Results and Future Plans of the ZEUS Experiment

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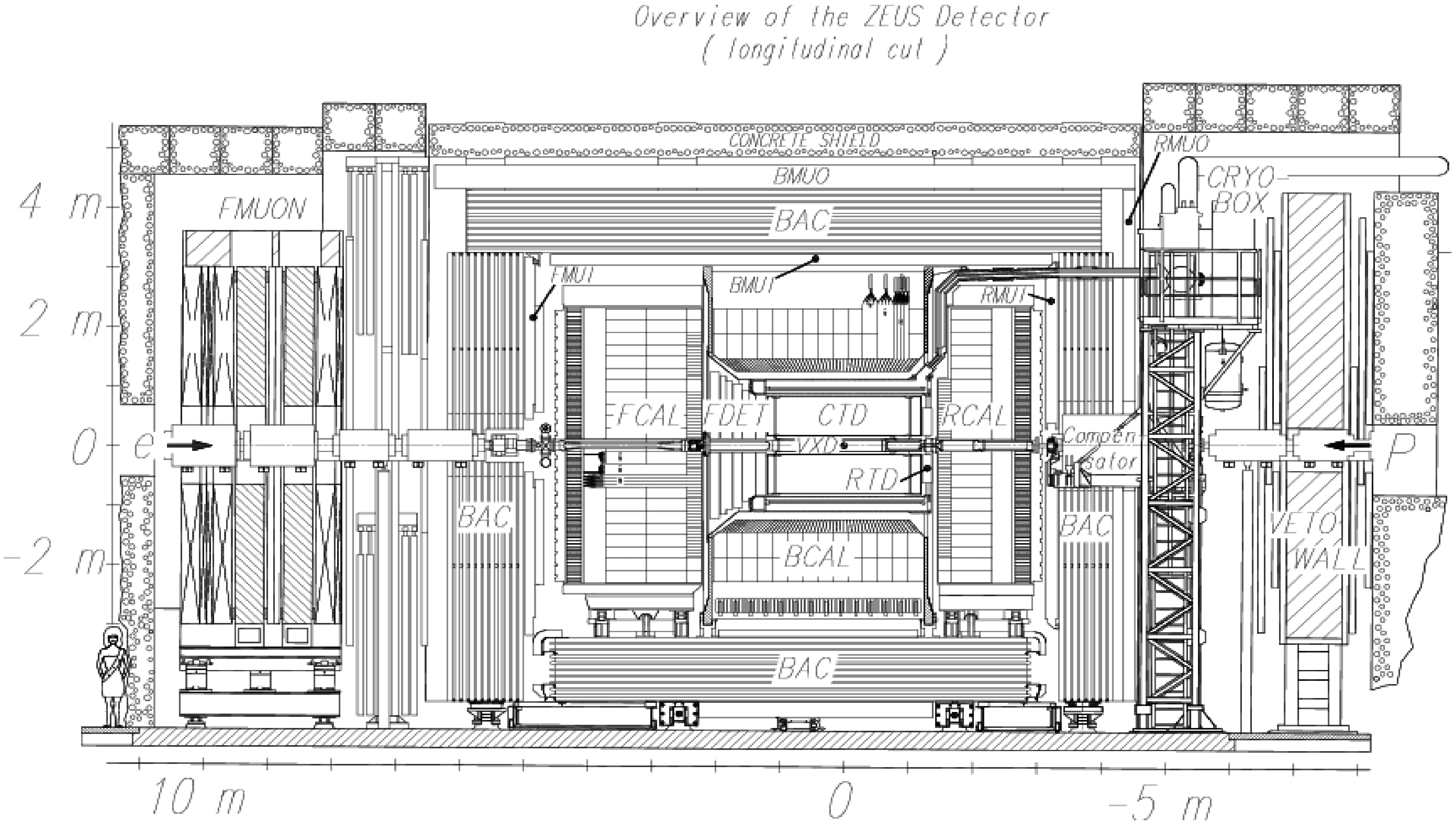
For the ZEUS Collaboration

- Proton Structure
- Photon Structure
- HERA II

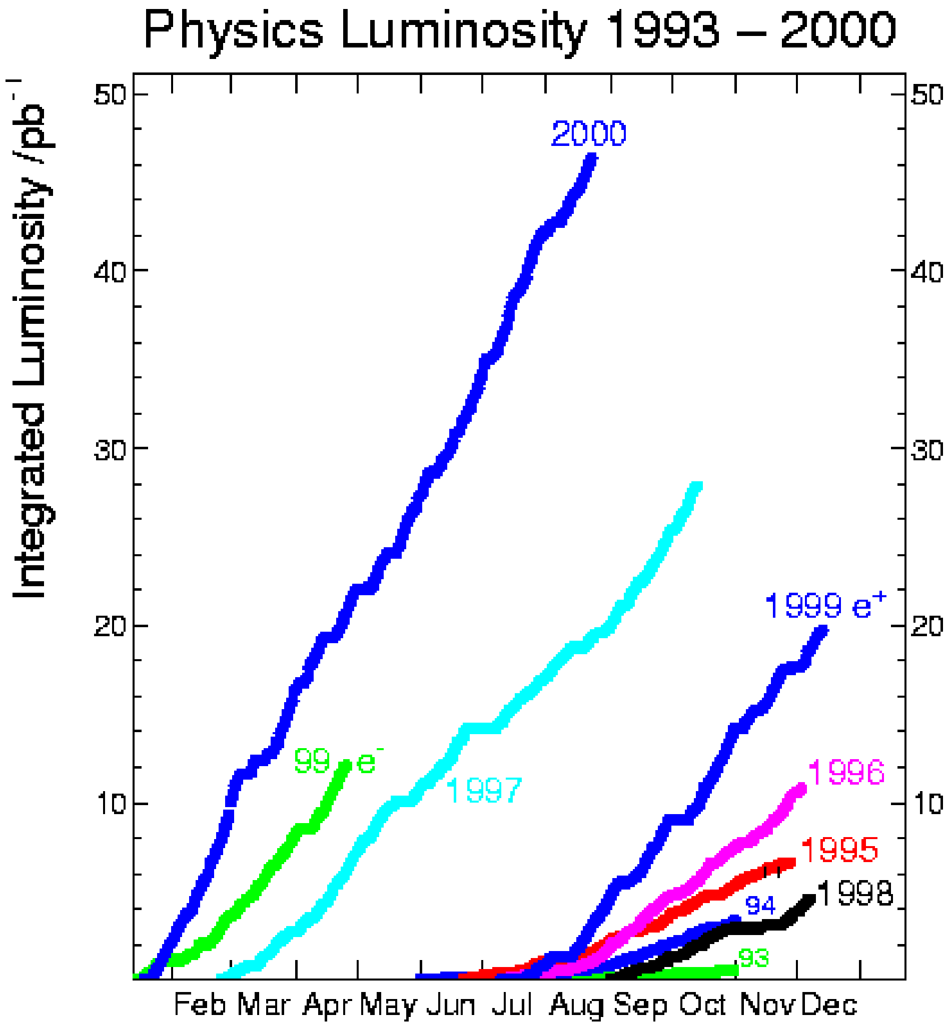
Quarks '2002
1 – 7 June 2002, Novgorod, Russia

Detector



Overview of the ZEUS Detector
(longitudinal cut)
CONCRETE SHIELD
BMUO
BAC
FMUON
RMUO
CRYO-
BOX
FMUI
BMUI
RMUI
FCAL
FDET
CTD
RCAL
VXD
RTD
Compen
sator
BAC
BAC
BCAL
VETO
WALL
BAC
4 m
2 m
0
e
-2 m
P
10 m
0
-5 m

Performance



Best machine values (2000):

$$I_p = 110\text{ mA}$$

$$I_e = 50\text{ mA}$$

$$\mathcal{L} = 2 \cdot 10^{31} sec^{-1} cm^{-2}$$

$$\mathcal{L}_{spec.} = 8 \cdot 10^{28} sec^{-1} cm^{-2}$$

Typical ZEUS detector efficiency well above 80%.

Collected 110 pb^{-1}.

Very successful data taking time.

Proton Structure

$$\frac{d\sigma}{dx dQ^2} = \frac{2\pi\alpha^2}{xQ^4}\left[Y_+ F_2^{ep}(x,Q^2) - y^2 F_L^{ep}(x,Q^2) - Y_- x F_3^{ep}(x,Q^2)\right]$$

$$Q^2 = -q^2 = -(k-k')^2$$

$$x = \frac{Q^2}{2P\cdot q}$$

$$y = \frac{q\cdot P}{k\cdot P}$$

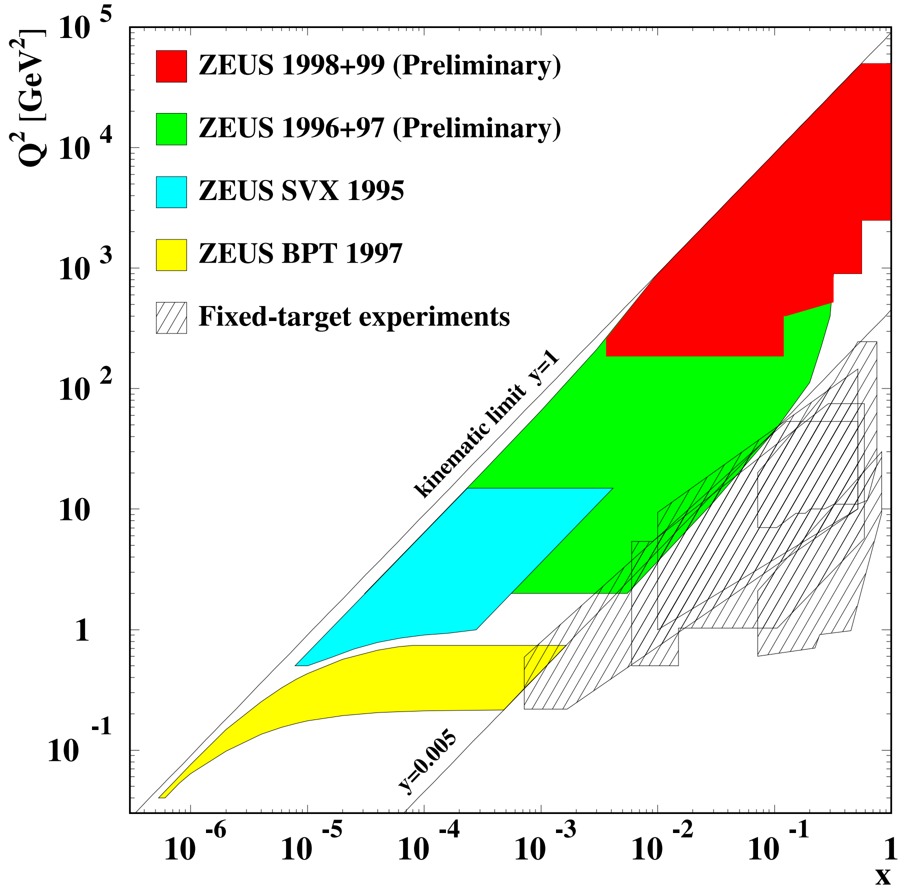
$$Q^2 = x\cdot y\cdot s$$

$$W^2 = (q+P)^2$$

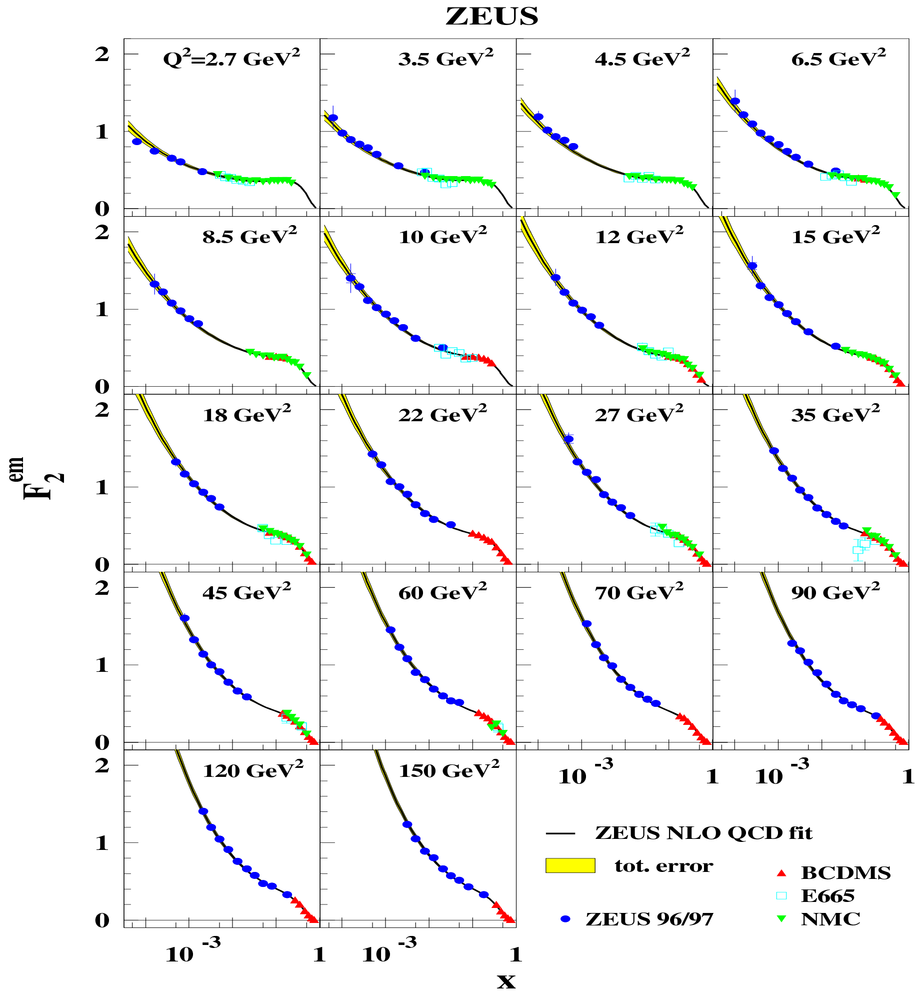
$$Y_\pm = 1 \pm (1-y)^2$$

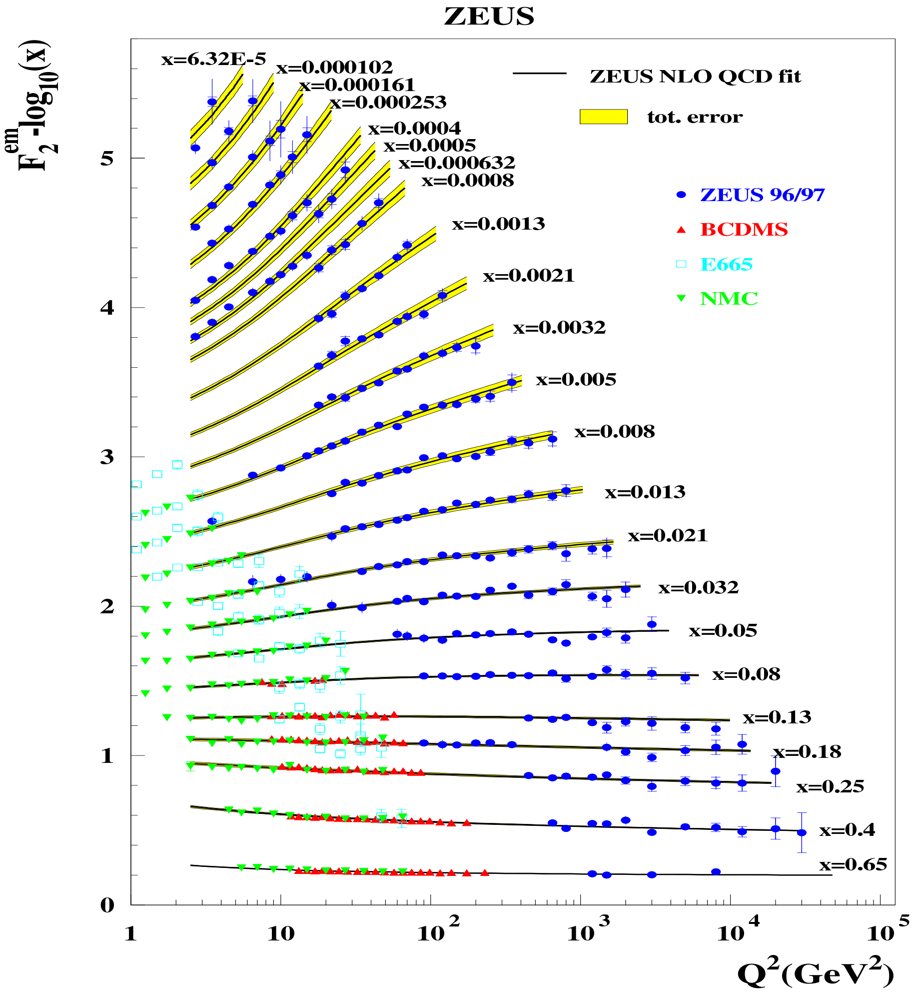
Reduced cross section:

$$\tilde{\sigma} = \frac{d\sigma}{dx dQ^2}\cdot\frac{xQ^4}{2\pi\alpha^2 Y_+}$$



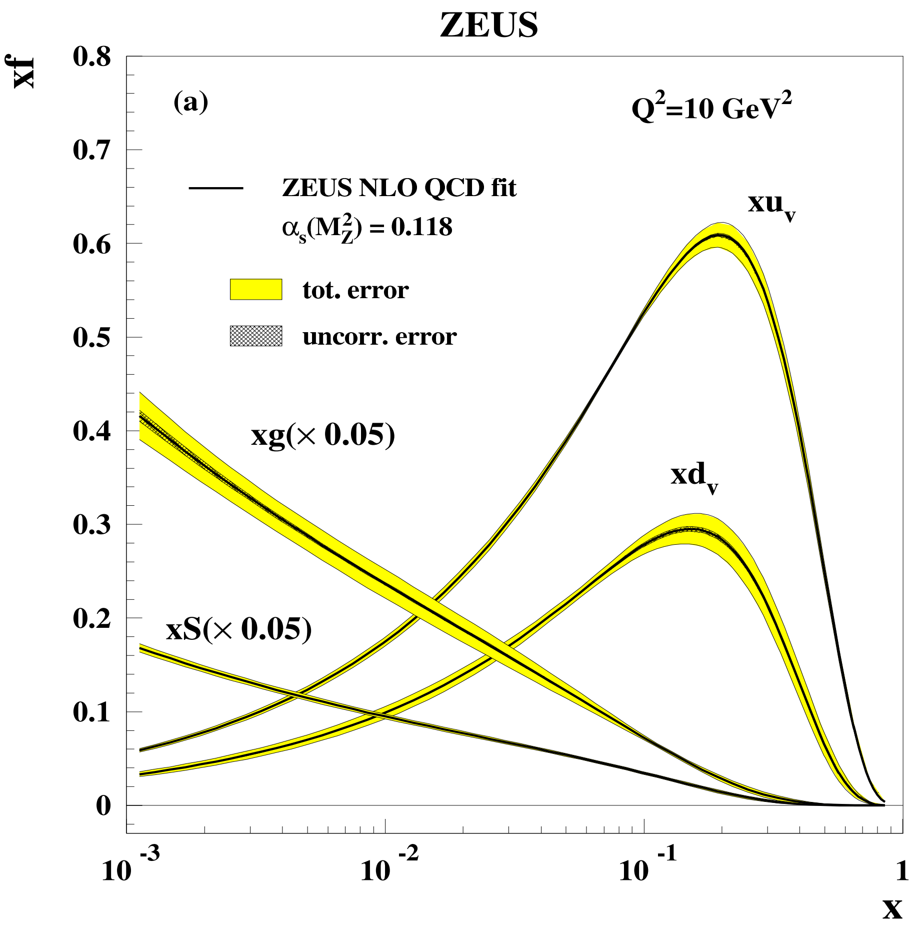
NLO Fits



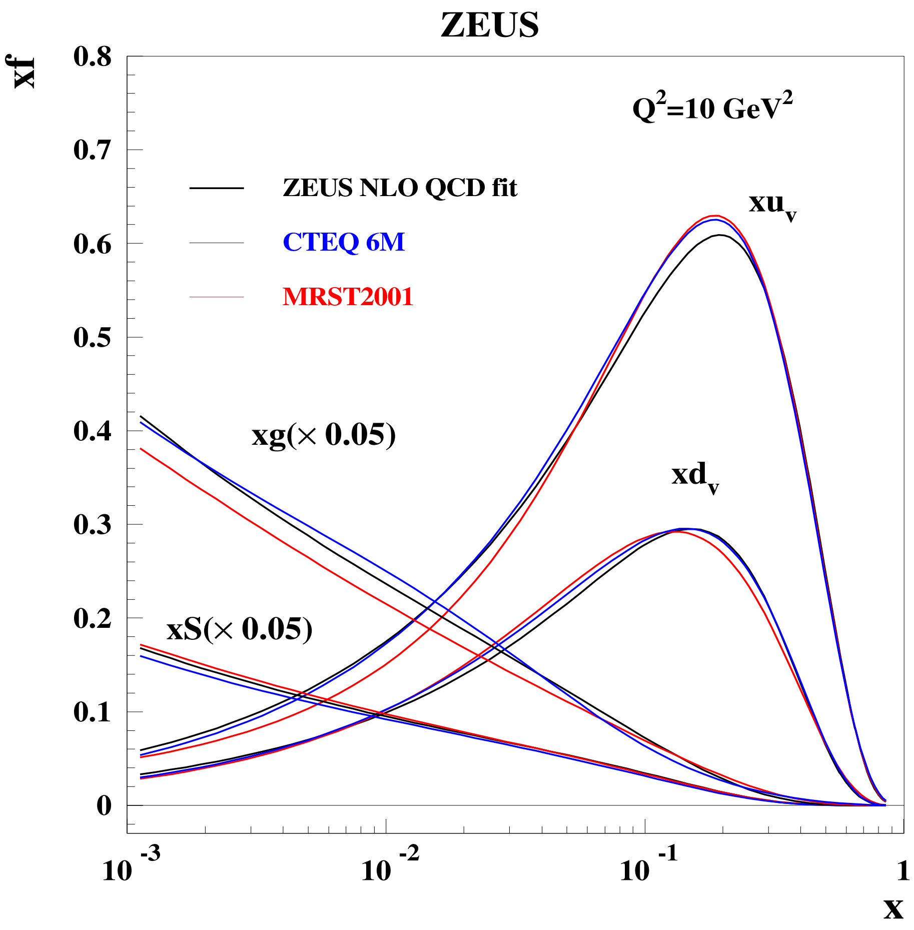


Data well described by the fit.

NLO Fits



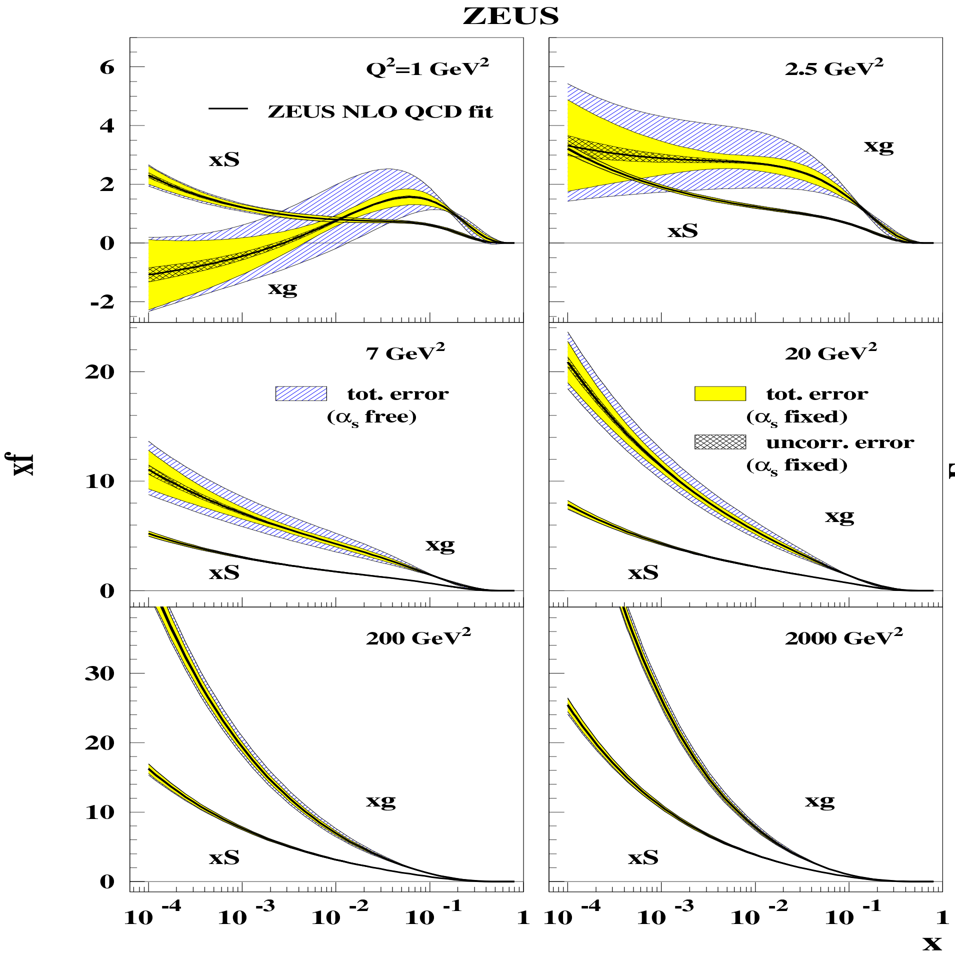
ZEUS PDF.



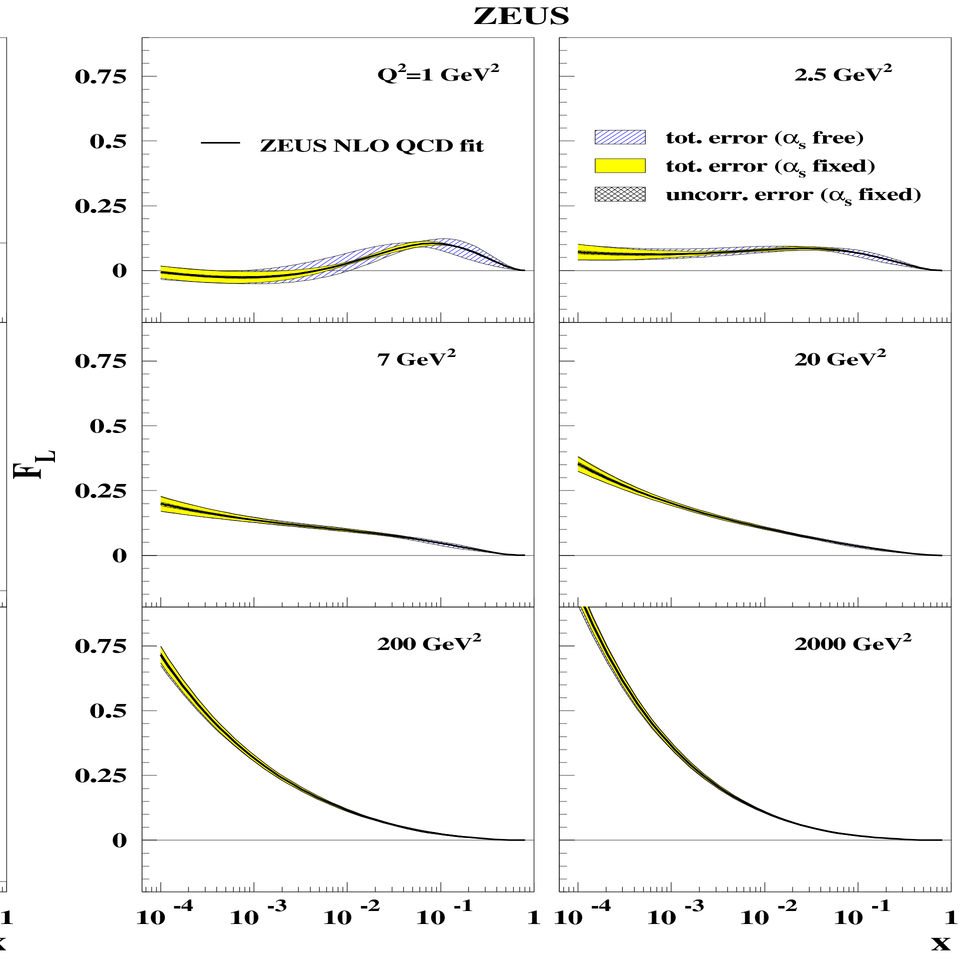
Comparison to others.

NLO Fits

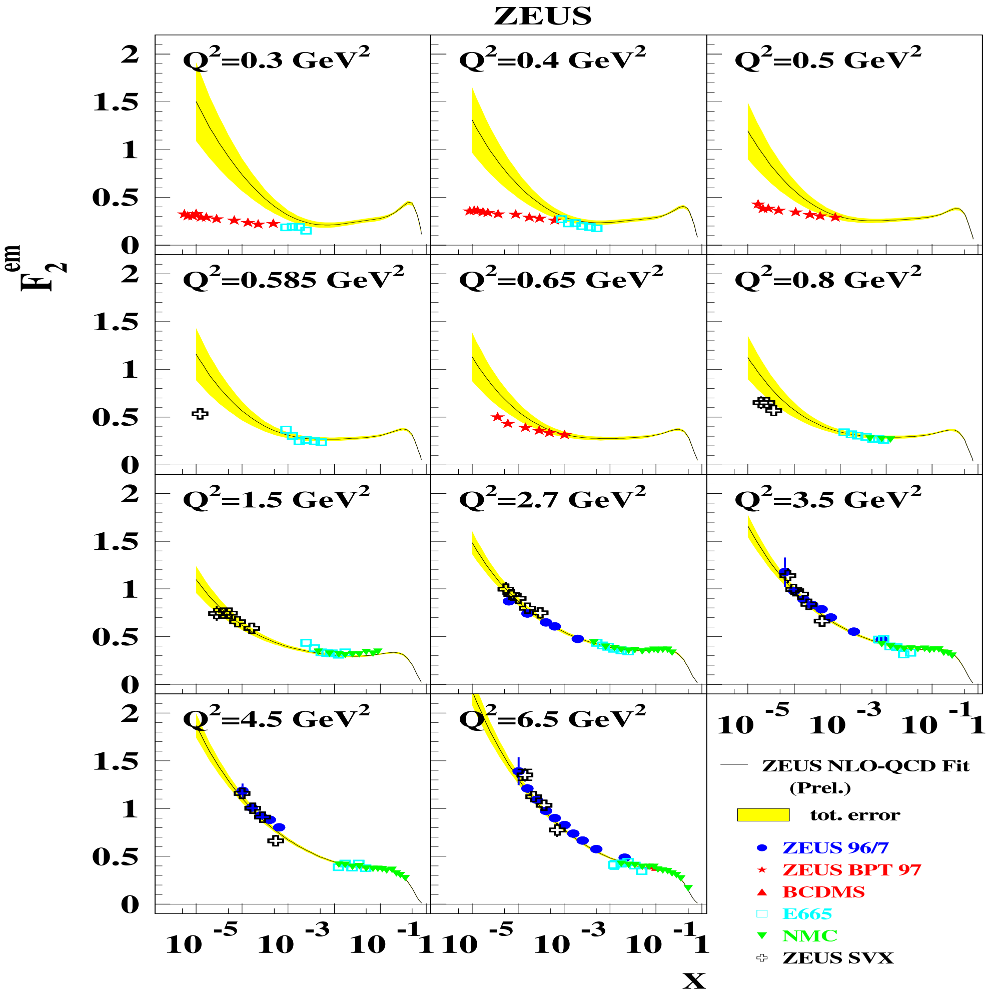
Sea and Glue

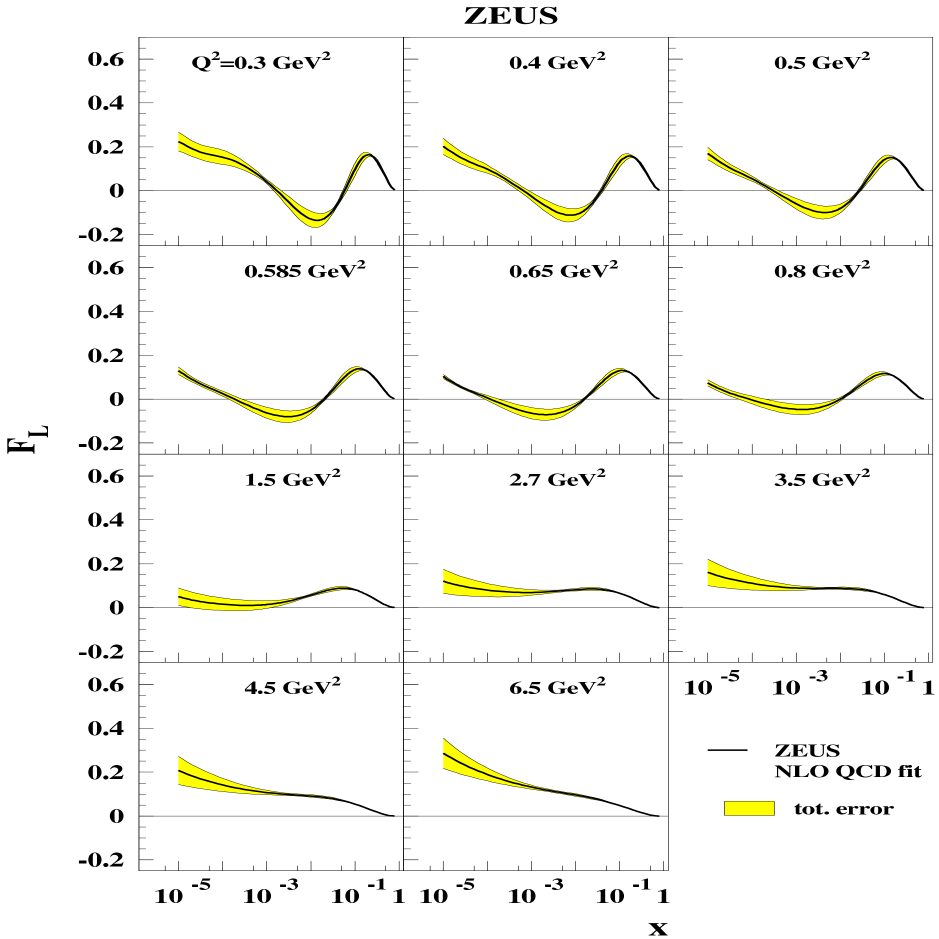


The F_L



NLO Fits





Large discrepancies $Q^2 < 1.5$ GeV^2. Limit of the DGLAP fit application.

High Q^2 Neutral Current Cross Section

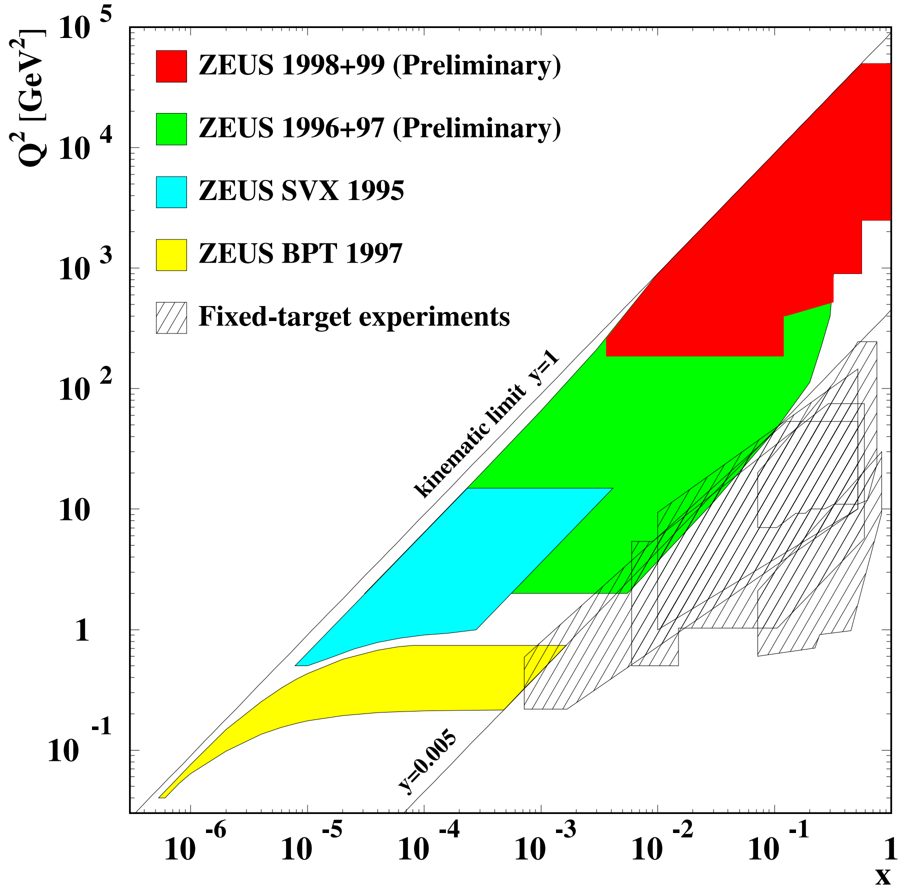
$$\frac{d\sigma^{e^\pm p}_{NC}}{dxdQ^2} = \frac{2\pi\alpha^2}{xQ^4}\left[Y_+F_2^{NC}(x,Q^2) - y^2F_L^{NC}(x,Q^2) \mp Y_- xF_3^{NC}(x,Q^2)\right]$$

$$\tilde{\sigma}^{e^\pm p}_{NC} = \frac{d\sigma}{dxdQ^2}\cdot\frac{xQ^4}{2\pi\alpha^2 Y_+}$$

$$\tilde{\sigma}^{e^\pm p}_{NC} = F_2^{NC} \mp \frac{Y_-}{Y_+}xF_3^{NC} - \frac{y^2}{Y_+}F_L^{NC}$$

Kinematic range:

185 GeV^2 < Q^2 < 50000 GeV^2



High Q^2 Neutral Current Cross Section

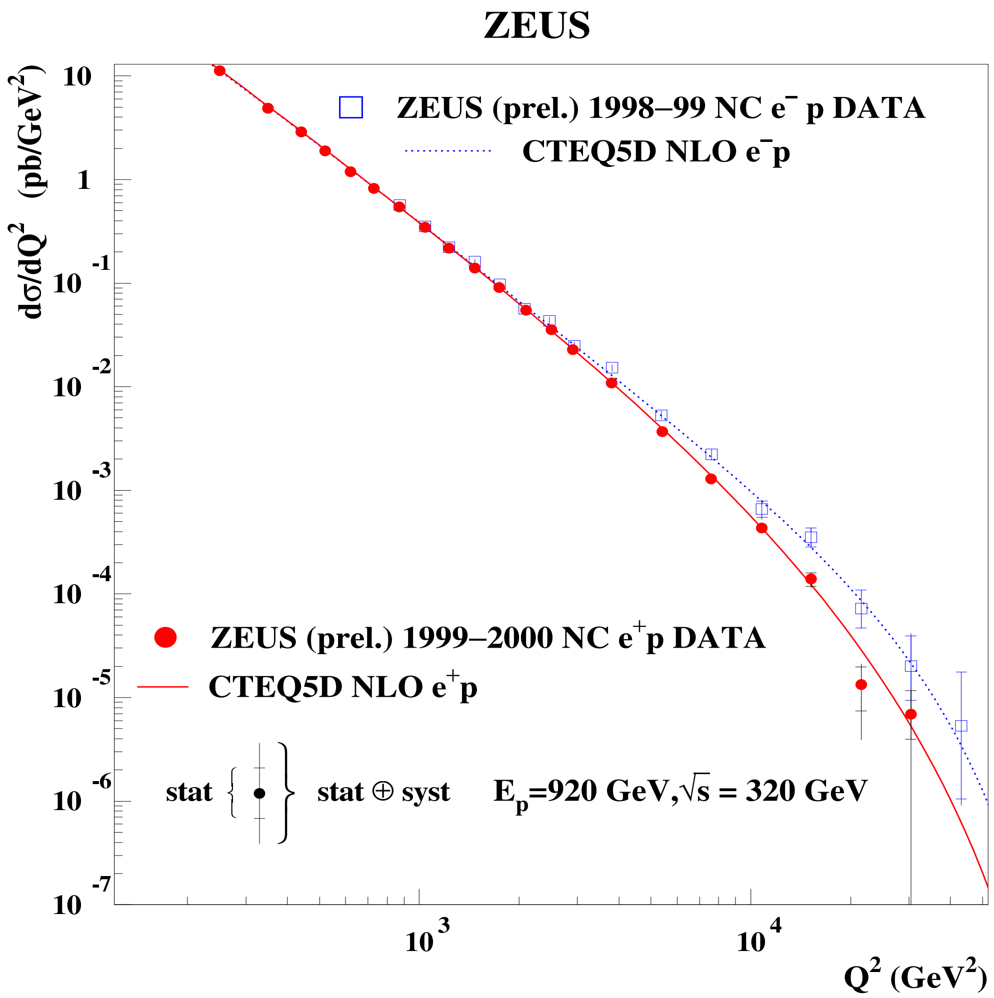
For $Q^2 < 3000$ GeV^2:

photon exchange dominates.

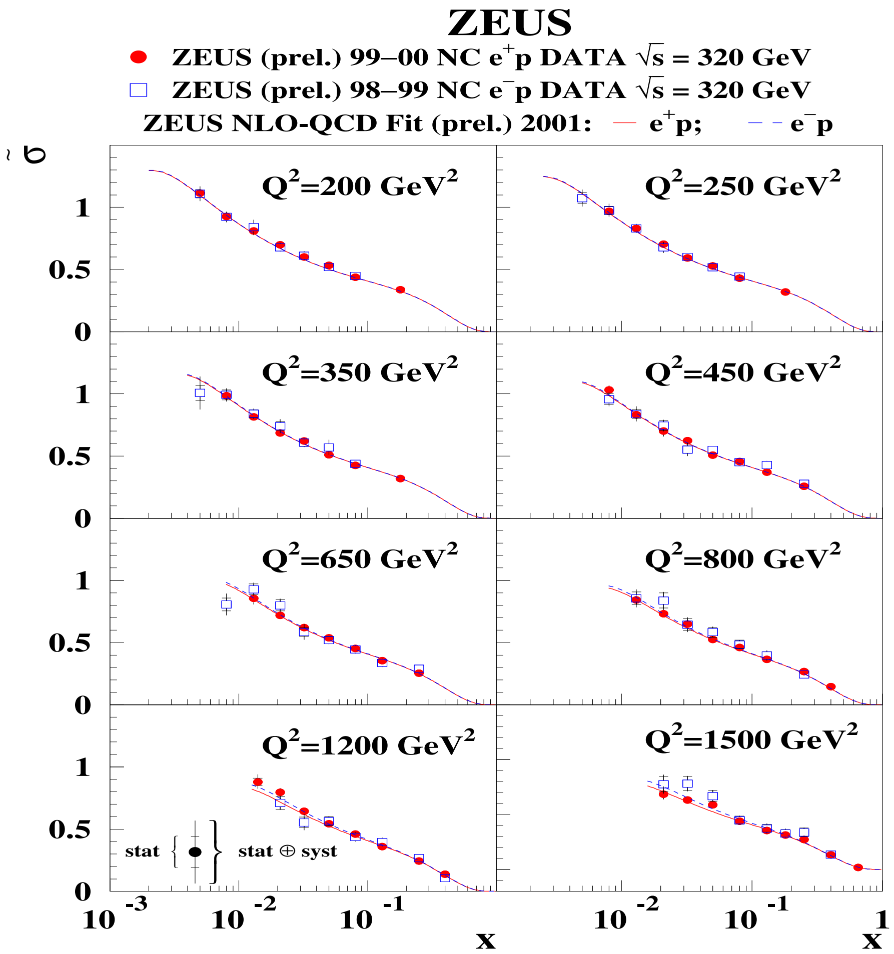
For larger Q^2:

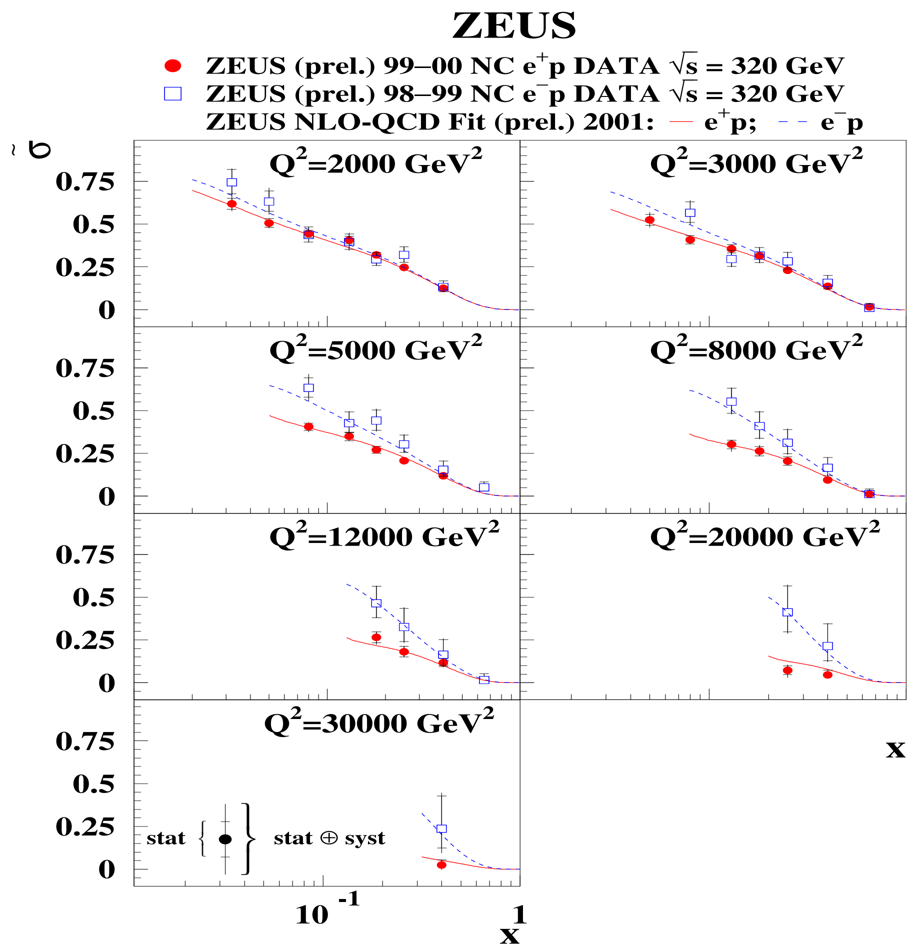
$\gamma - Z^0$ interference visible.

Good description by Standard Model over several orders of magnitude.



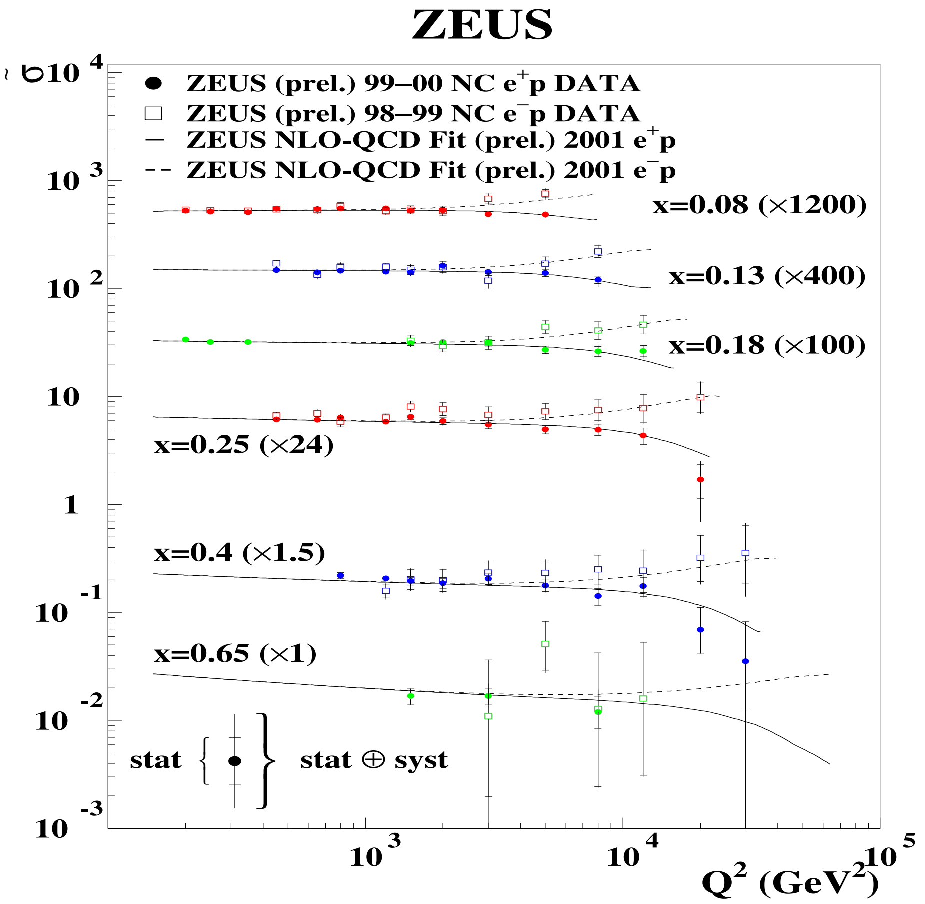
High Q^2 Neutral Current Cross Section





Reduced cross sections well described by ZEUS NLO fit.

High Q^2 Neutral Current Cross Section



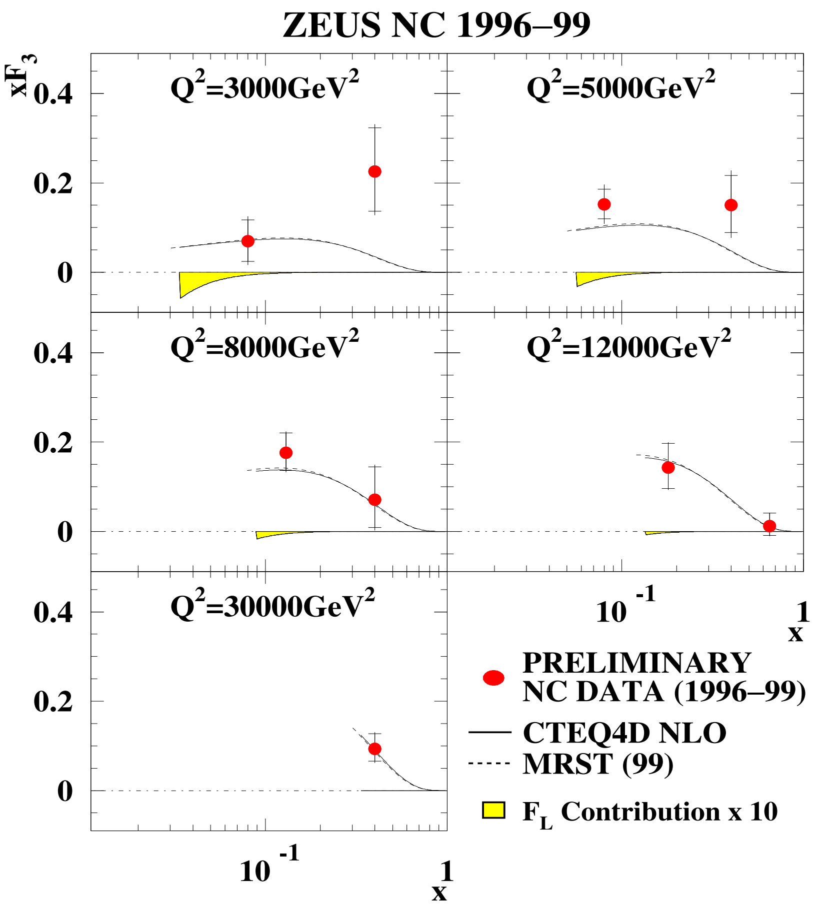
Similarity of e^+p and e^-p cross sections – photon exchange.

The $\gamma - Z^0$ interference visible above Q$^2 > 3000$ GeV^2.

Standard Model well describes the data.

The data sets can be used to extract xF_3.

High Q^2 Neutral Current Cross Section



Positron data taken at $E_P = 820$ GeV, electron data at 920 GeV.

Correct for different $\sqrt{s}$.

$$xF_3(x,Q^2) = \frac{xQ^2}{2\pi\alpha^2}\left(\frac{Y_-^{920}}{Y_+^{920}} + \frac{Y_-^{820}}{Y_+^{820}}\right)^{-1} \cdot \left(\frac{1}{Y_+^{920}}\frac{d\sigma^-}{dxdQ^2} - \frac{1}{Y_+^{820}}\frac{d\sigma^+}{dxdQ^2}\right) - \Delta F_L$$

and

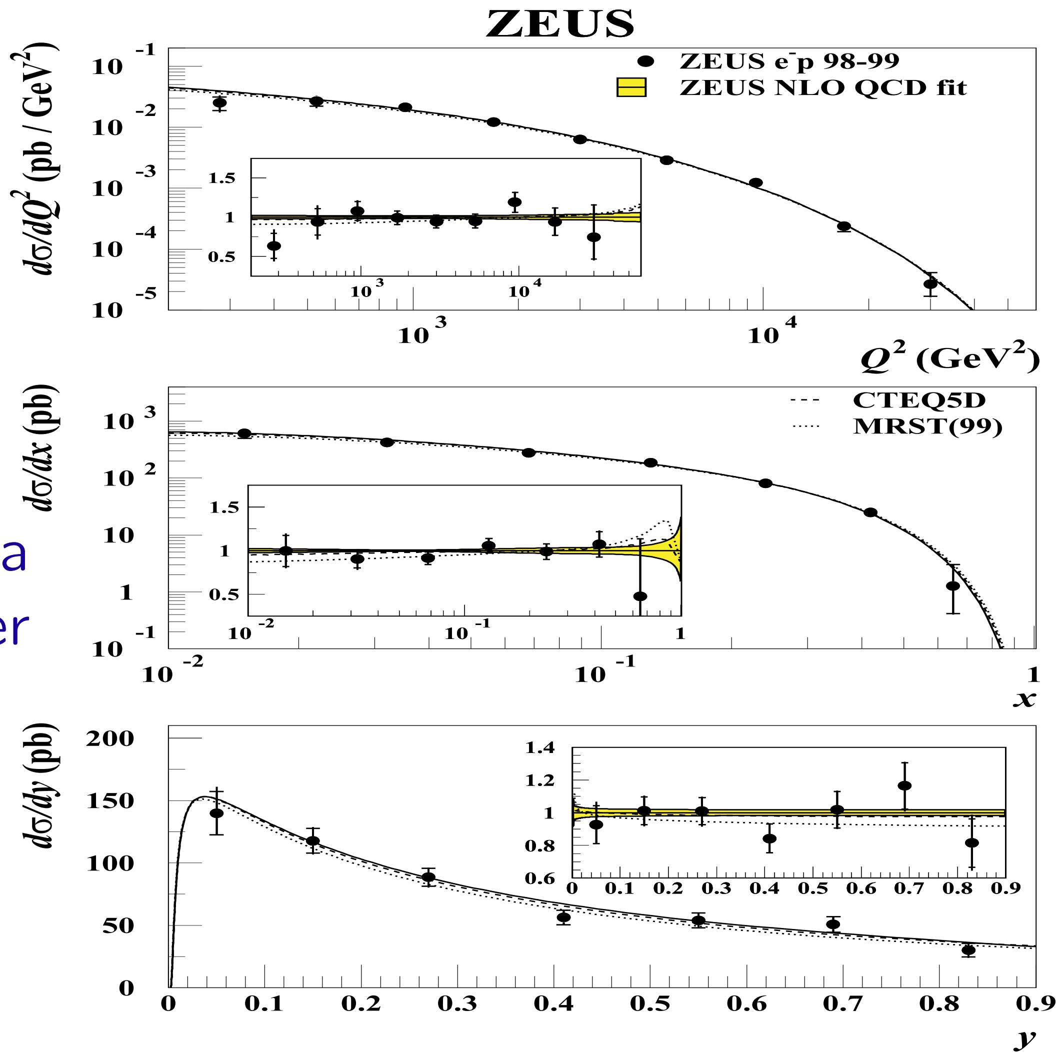
$$\Delta F_L = \frac{Y_+^{820}\cdot(y^{920})^2 - Y_+^{920}\cdot(y^{820})^2}{Y_-^{920}\cdot Y_+^{820} + Y_-^{820}\cdot Y_+^{920}} F_L(x,Q^2)$$

Data well described by Standard Model. Results statistically limited.

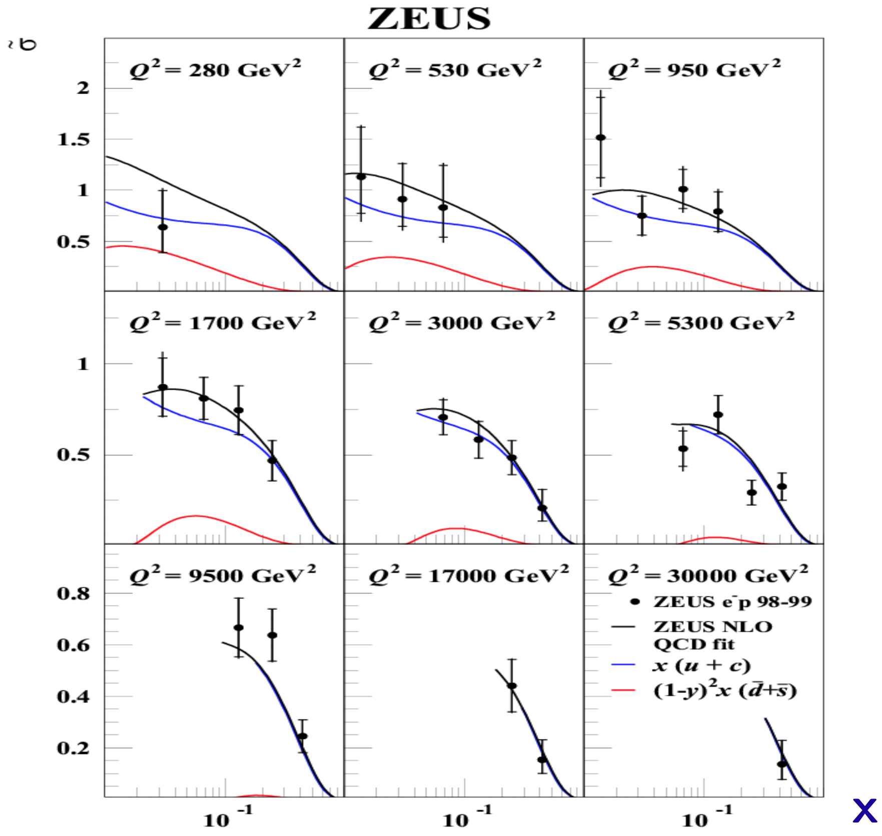
High Q^2 Charged Current Cross Section

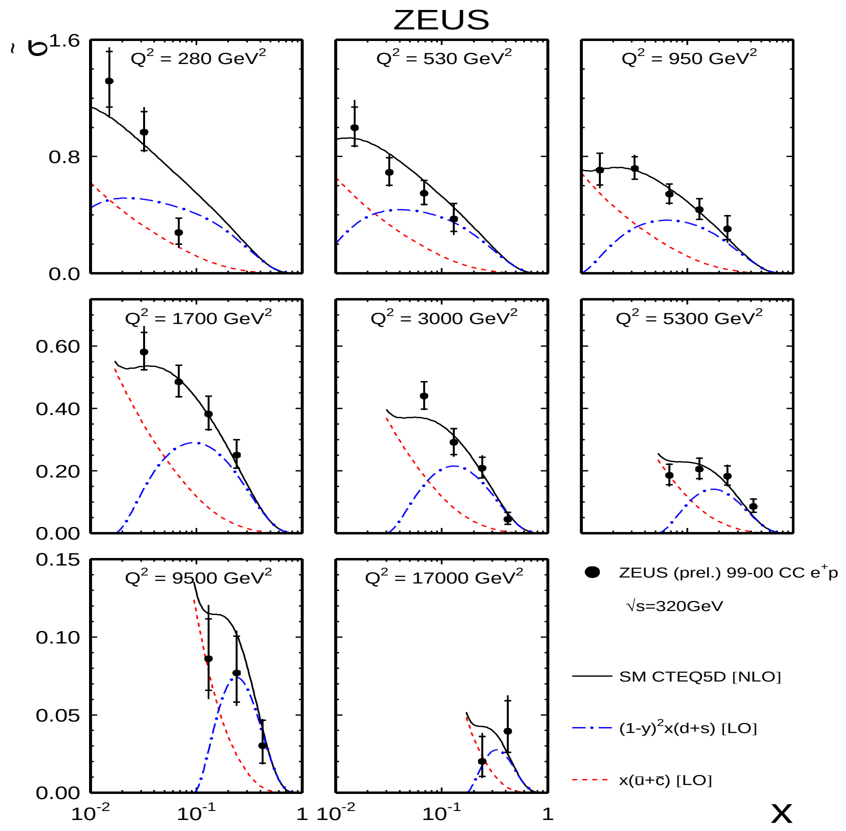
$$\frac{d\sigma_{CC}}{dQ^2} = \frac{G_F^2}{4\pi}\left(\frac{M_W^2}{M_W^2+Q^2}\right)^2 F(Q^2)$$

Good description of the data by ZEUS NLO fits and other parametrisations.



High Q^2 Charged Current Cross Section





$$\tilde{\sigma}_{CC}(e^-p) = x(u+c) + (1-y)^2 x(\bar{d}+\bar{s}) \qquad \tilde{\sigma}_{CC}(e^+p) = x(\bar{u}+\bar{c}) + (1-y)^2 x(d+s)$$

Data are well described by ZEUS and SM NLO fits.

High Q^2 Charged Current Cross Section

Fit shape of:

$$\frac{d\sigma_{CC}}{dQ^2} = \frac{G_F^2}{4\pi}\left(\frac{M_W^2}{M_W^2+Q^2}\right)^2 F(Q^2)$$

$G_F = 1.11639 \cdot 10^{-5}$ GeV^{-2}

fixed to PDG value.

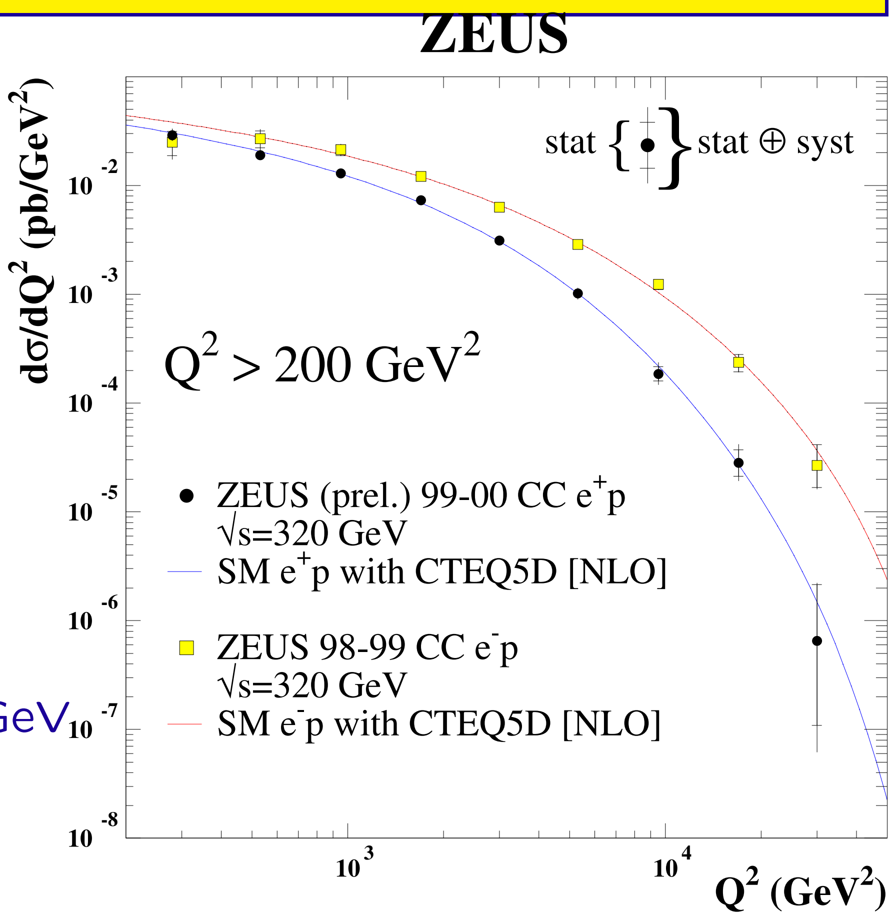
Electron data result:

$M_W = 80.3 \pm 2.1(stat.) \pm 1.2(syst.) \pm 1.0(pdf)$ GeV

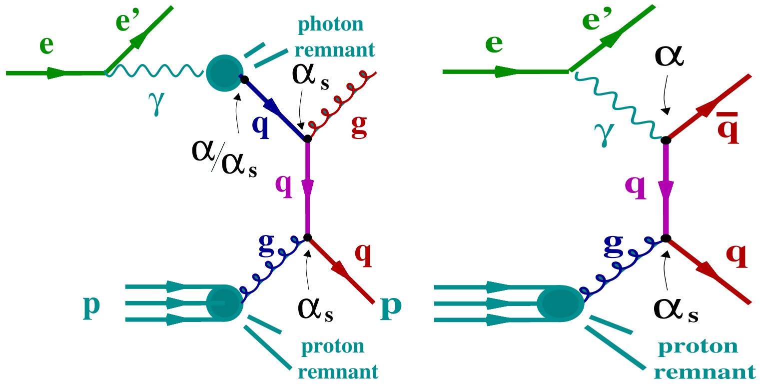
Compared to positron data result:

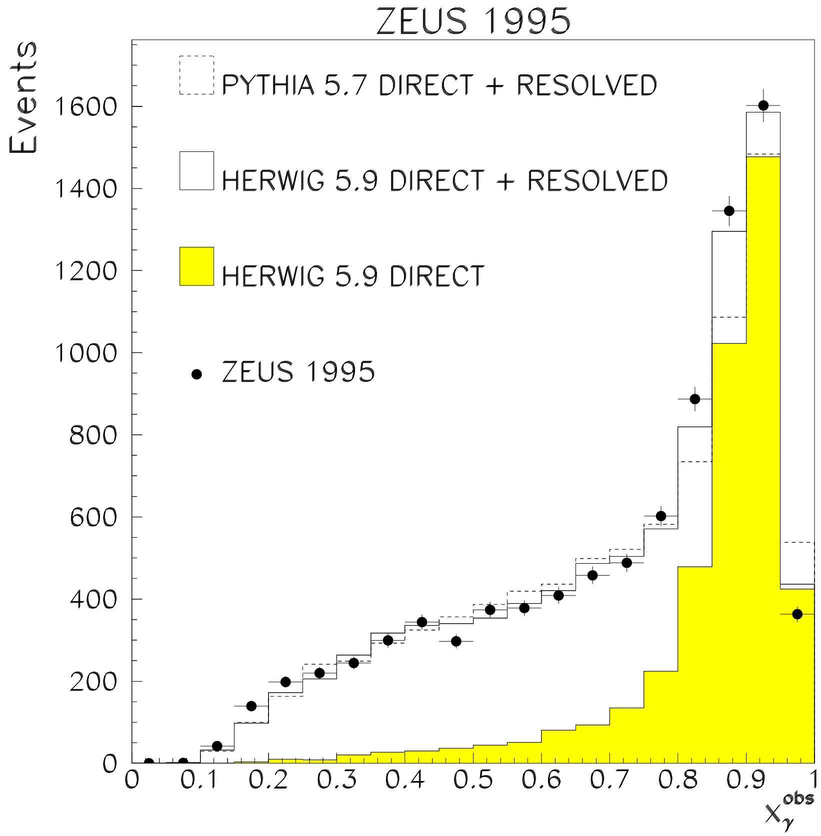
$M_W = 81.4^{+2.7}_{-2.6}(stat.) \pm 2.0(syst.)^{+3.3}_{-3.0}(pdf)$ GeV

and PDG value of: $M_W = 80.422 \pm 0.047$ GeV



Photon Structure – Dijets





In LO direct and resolved component.

$$x_\gamma^{obs} = \frac{E_T^{jet1} e^{-\eta^{jet1}} + E_T^{jet2} e^{-\eta^{jet2}}}{2 \cdot y \cdot E_e}$$

$x_\gamma^{obs} < 0.75$ – resolved dominated,

$x_\gamma^{obs} > 0.75$ – direct dominated.

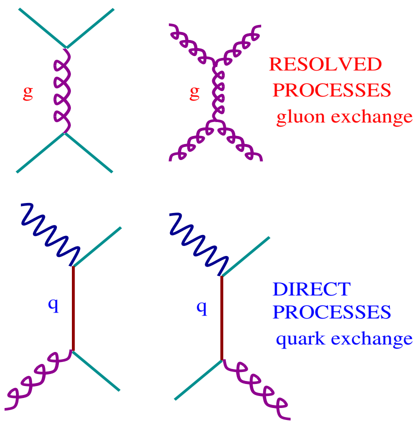
$$d\sigma_{ab} = \sum_{ab} \int_{x_\gamma} \int_{x_p} dx_p dx_\gamma f_P(x_p, \mu^2) f_\gamma(x_\gamma, \mu^2) d\hat{\sigma}_{ab}(x_p, x_\gamma, \mu^2) \cdot (1 + \delta_{had})$$

$\mu = \mu_R = \mu_F$ and δ_{had} – hadronisation corrections.

Photon Structure – Dijets

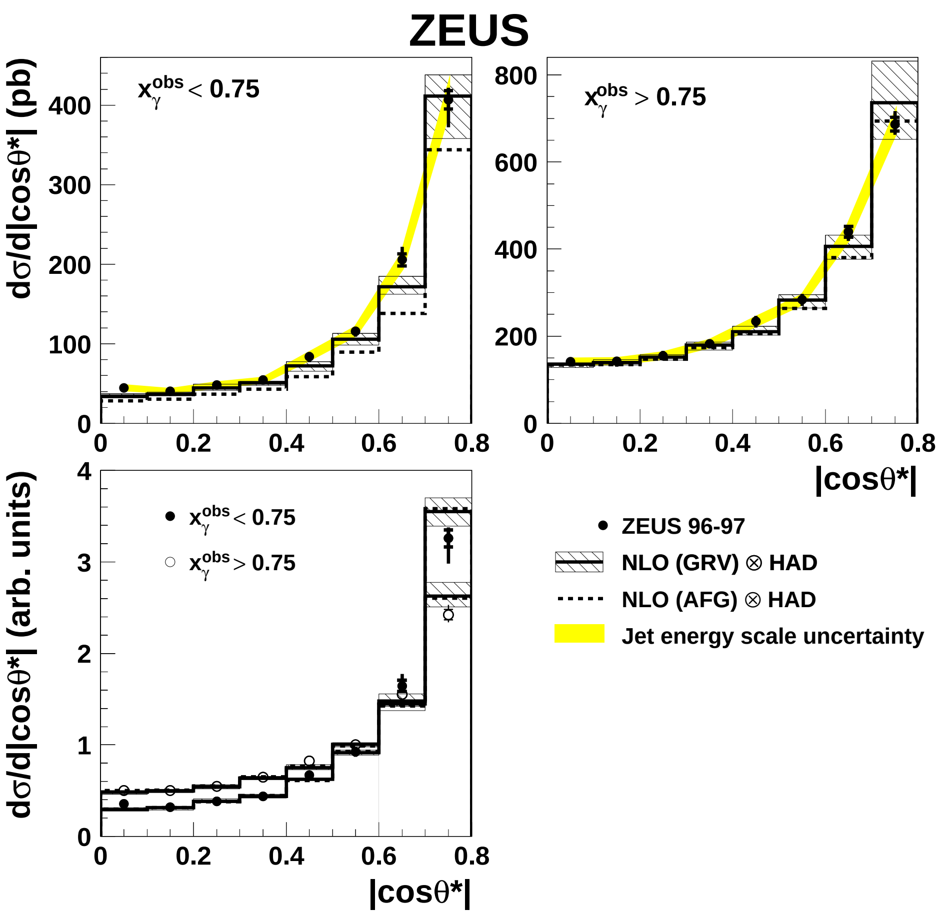
How to test dynamics ?

$$\cos\theta^* = tanh\left(\frac{\eta^{jet1} - \eta^{jet2}}{2}\right)$$



$\sim (1 - cos\theta^*)^{-2}$

$\sim (1 - cos\theta^*)^{-1}$



Reasonable description by the NLO parametrisations.

$x_\gamma^{obs} < 0.75$ data underestimated,

$x_\gamma^{obs} > 0.75$ data – O.K.

The resolved component dominated data increase faster with $|\cos\theta^*|$.

Photon Structure – Multijet

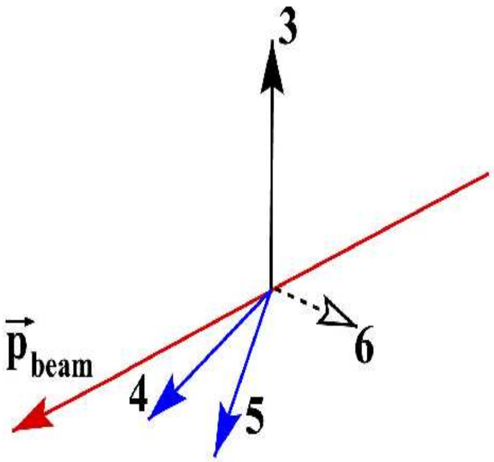
$$\gamma + p \rightarrow j_3 + j_4 + j_5 + j_6$$

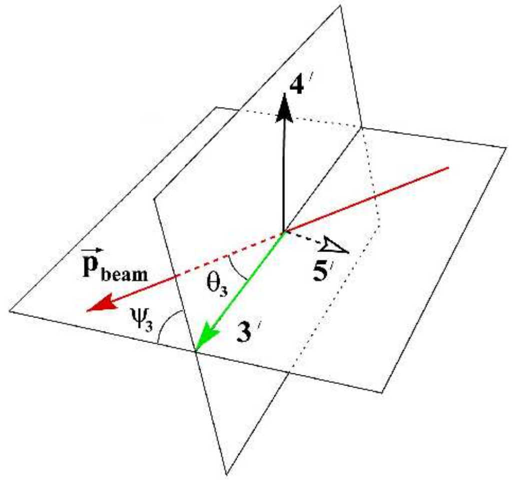
Sensitive to QCD at $\mathcal{O}(\alpha_S^3)$ and Multi-parton interactions.

Look at the angular distributions to study dynamics:

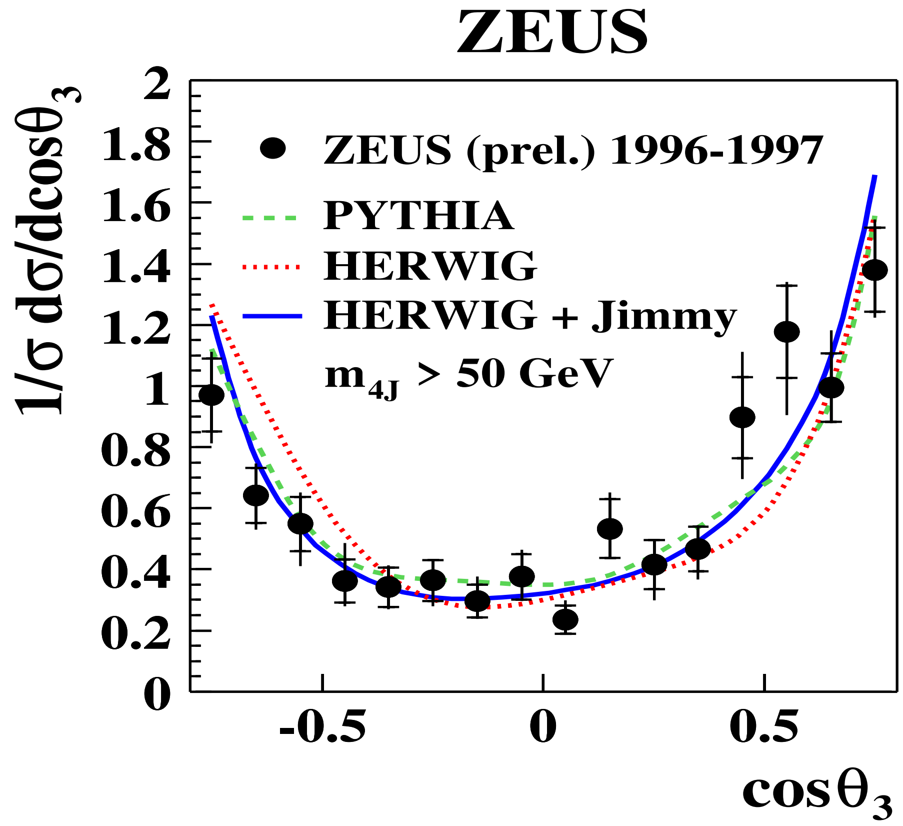
Out of four make three jets:

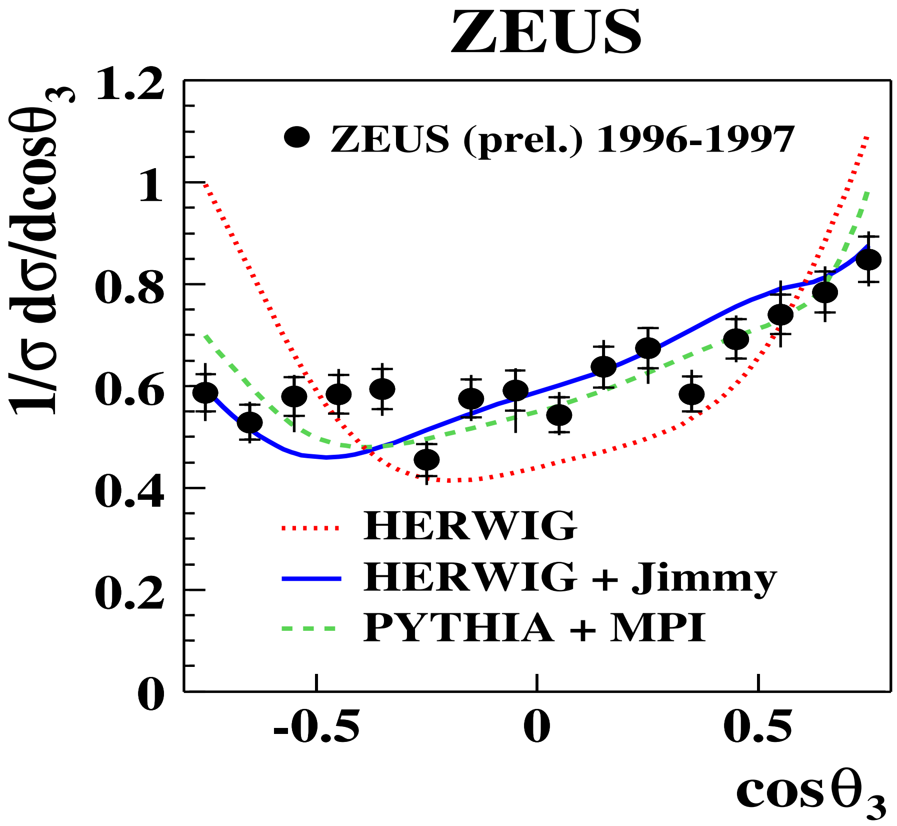
- merge two jets with lowest two-jet mass,
- re-order jets in energy,
- look at the $\cos\Theta_3$ distribution.





Photon Structure – Multijet





For large m_{4jet} shower MC (LO) well describes data.

MPI required to reproduce data.

Total Cross Section $\sigma^{\gamma\ p}_{ToT}$

$\sigma^{\gamma\ p}_{TOT} = 174 \pm 1(stat.) \pm 13(syst.)\ \mu b$

Regge motivated fit:

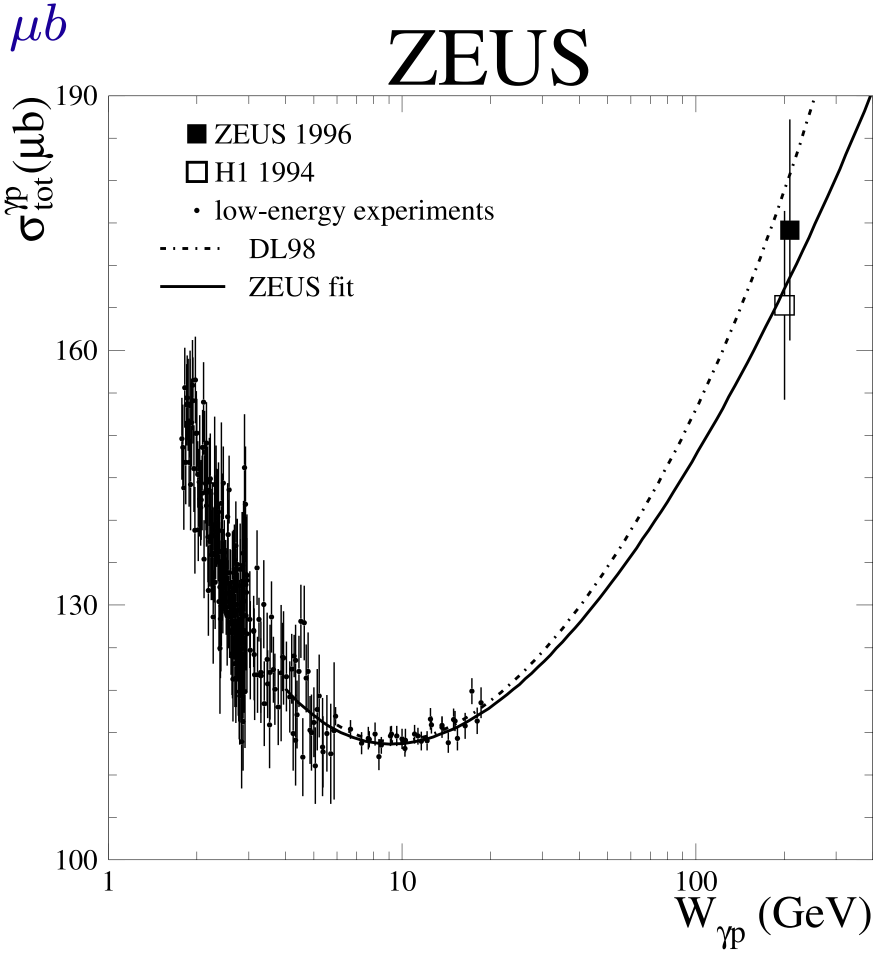
$$\sigma^{\gamma\ p}_{TOT} = A \cdot W^{2\epsilon}_{\gamma\ p} + B \cdot W^{2\eta}_{\gamma\ p}$$

$$\alpha_{I\!R} = 1 - \eta - \text{fixed}$$

$$\alpha_{I\!P} = 1 + \epsilon - \text{fitted}$$

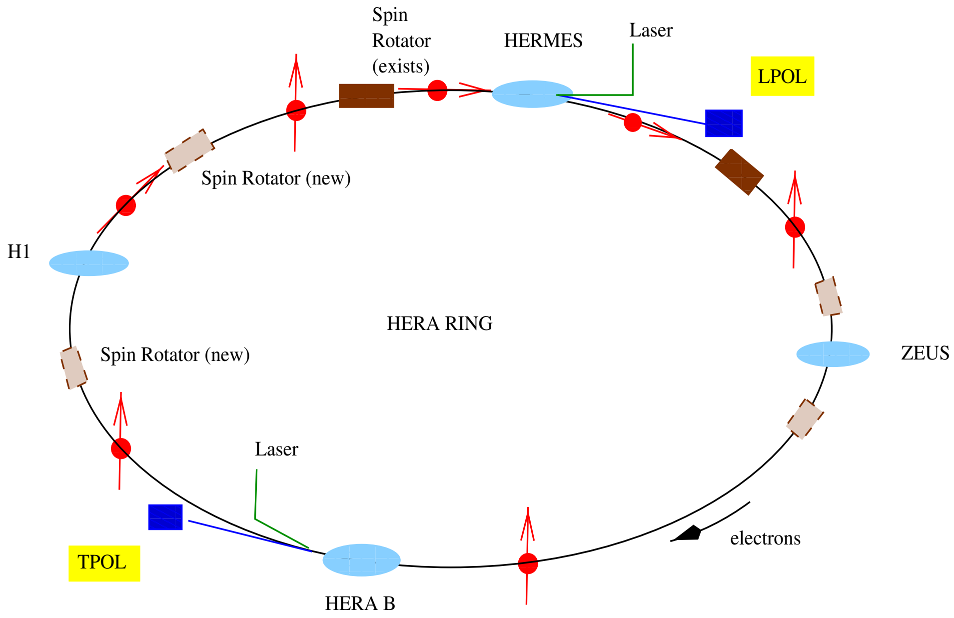
$$\epsilon = 0.100 \pm 0.012$$

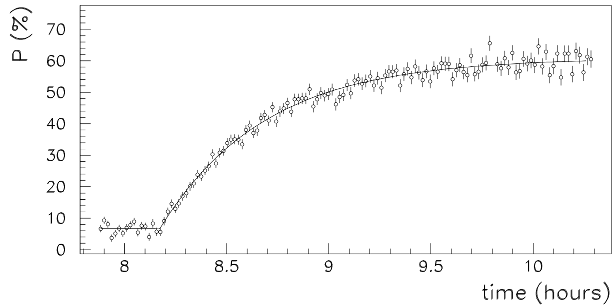
in good agreement with 0.093 ± 0.002 based on pp and $p\bar{p}$ data.



HERA II

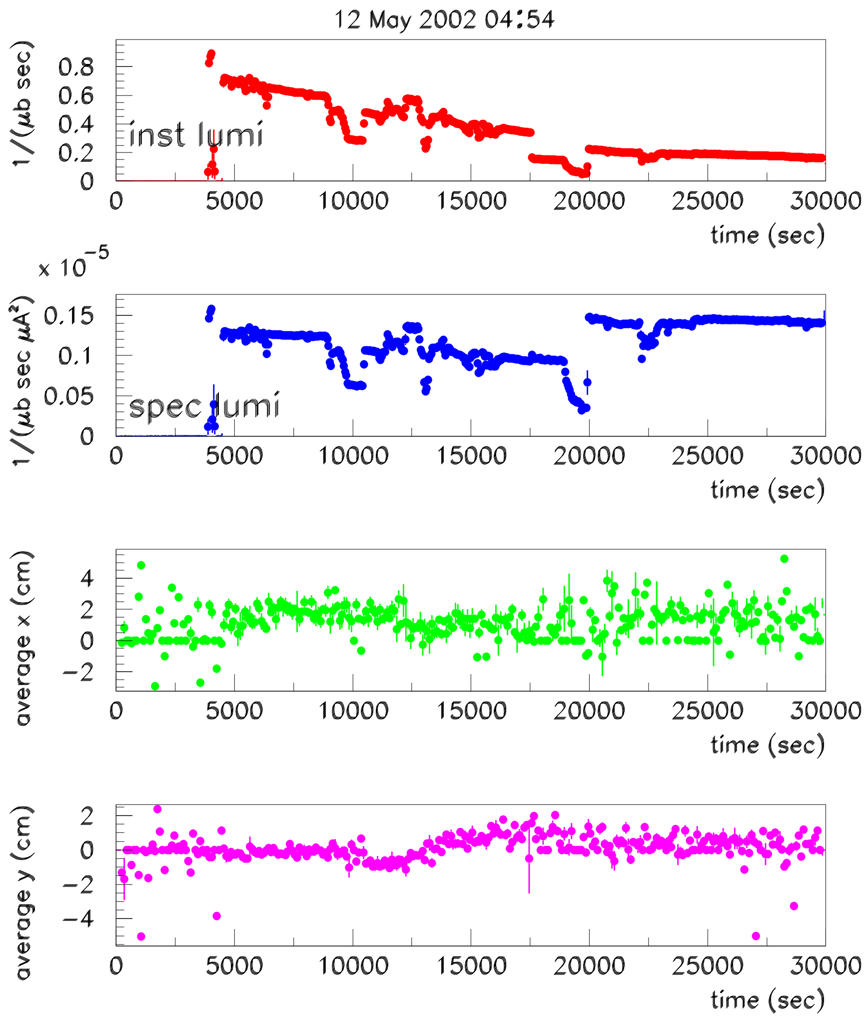
- major machine upgrade,
- final focusing magnets introduced into the detector,
- 3.5 times luminosity increase,
- longitudinal polarisation of the lepton beam – up to 70%,
- new spin rotators and polarimeters,
- expected 1000 pb^{-1} by 2006,
- luminosity shared equally between e^+p, e^-p, and L and R polarisations,
- lower CMS energy runs for high x and F_L measurements.





HERA II – Status

- Summer 2001 – machine began operations.
- Autumn – first ep collisions in HERA II,
  – designed specific luminosity reached,
- Currently – work on the currents increase and the background reduction.



HERA II

- Detailed physics program in “Future Physics at HERA”, 1996, eds. G. Ingelman, A. De Roeck, R. Klanner.

- Precision tests require 3-10 times increase in luminosity.

- Beam polarisation will help to pin down the problems.

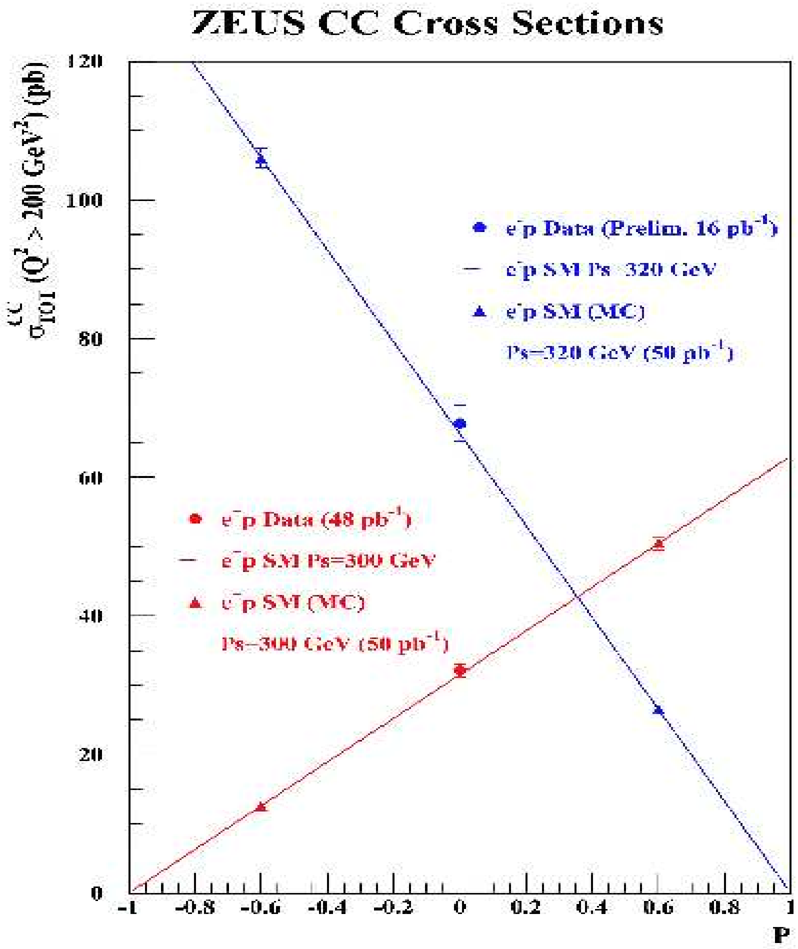
HERA II

Cross sections linearly dependent on the polarisation.

e^- is steeper which offers better sensitivity.

Standard Model tests.

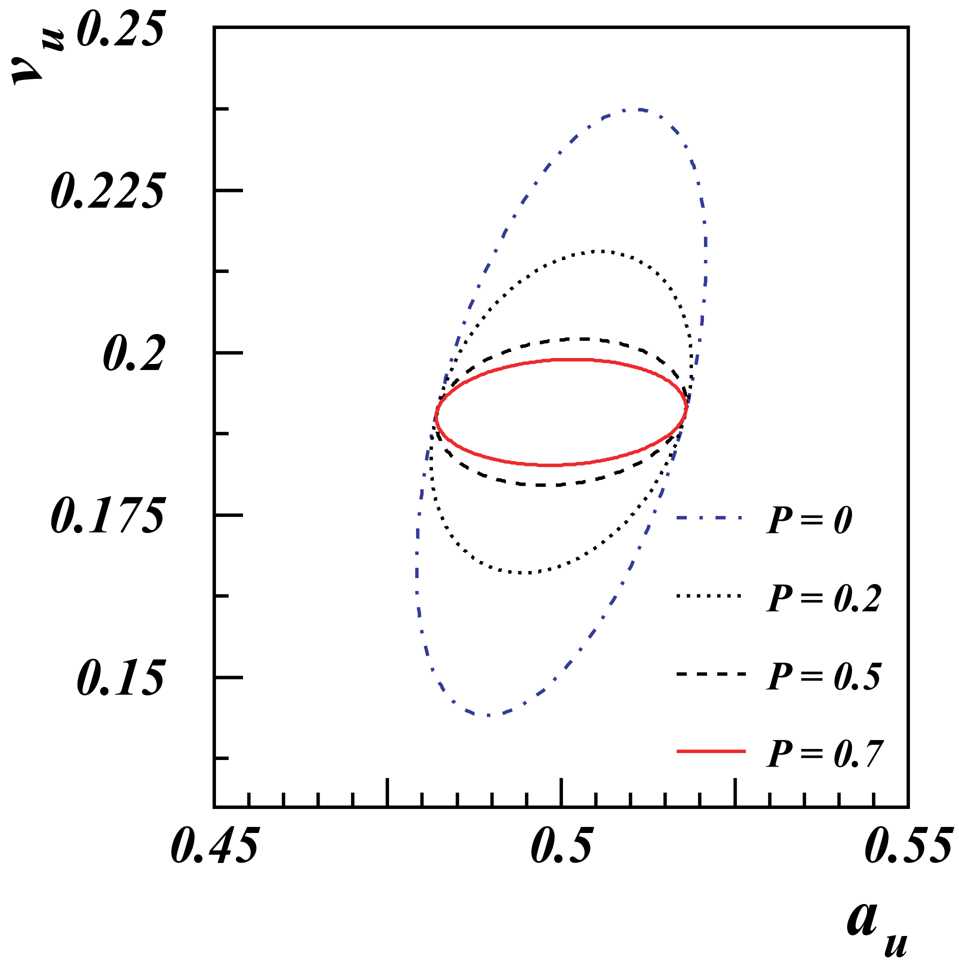
Large luminosity and both polarisations preferred.



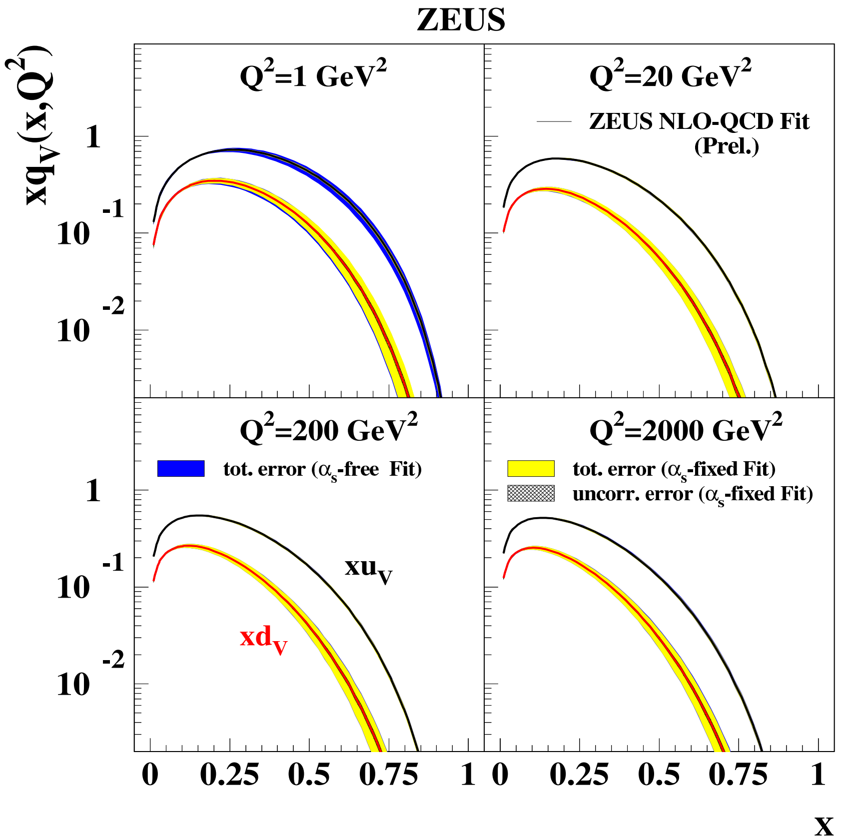
HERA II

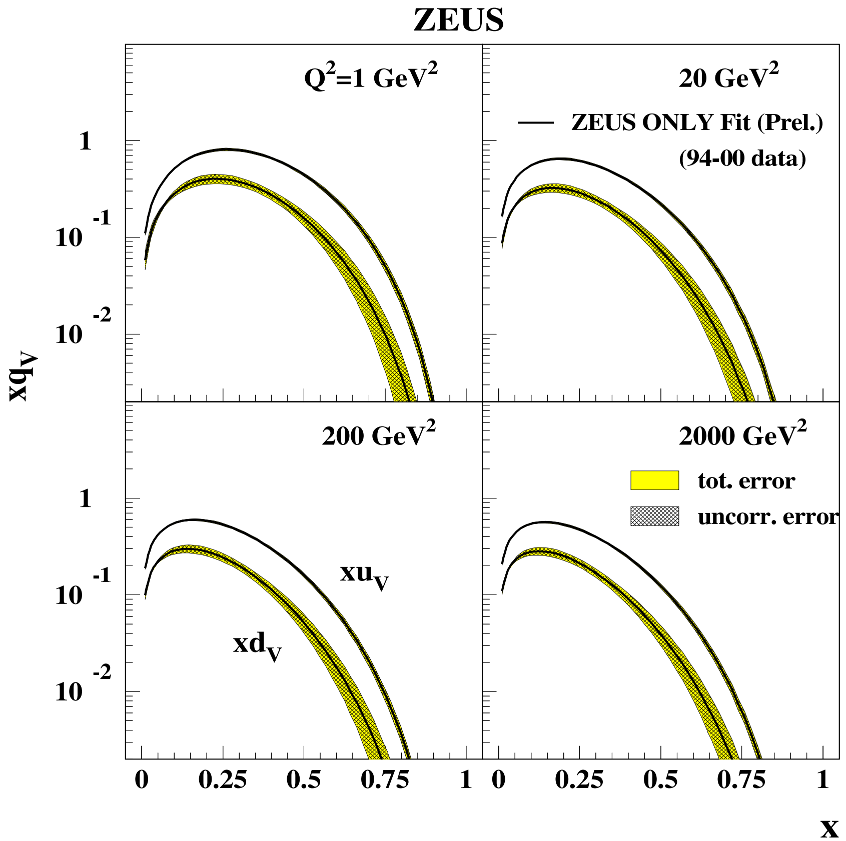
For $e^{\pm}_{L,R}$ and 70% polarisation and 250 pb^{-1} per beam light quark couplings know to several percent.

Clear improvement in sensitivity with increasing beam polarisation.



HERA II





HERA is able to deliver its "own" PDFs with well understood systematics. Good electron reconstruction at high x needed. At highest x and Q^2 statistically limited with 1000 pb^{-1}.

HERA II

$$\frac{d\sigma^{\pm(L,R)}}{dxdQ^2} = \frac{2\pi\alpha^2}{xQ^4}\left[Y_+F_2^0 \mp Y_-xF_3^0 + P\cdot(Y_+F_2^P \mp Y_-xF_3^P) - y^2F_L\right]$$

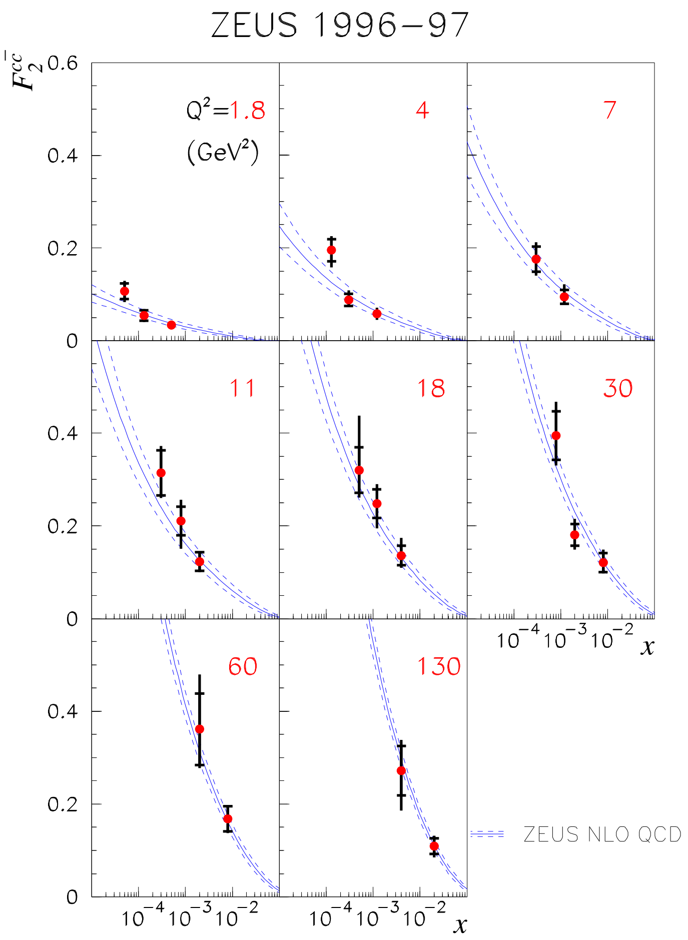
- F_2 from sum of: $\sigma^+(L,R) + \sigma^-(L,R)$ – large luminosity
- xF_3^0 from the difference of cross sections – equal number of positron and electron events.

HERA II

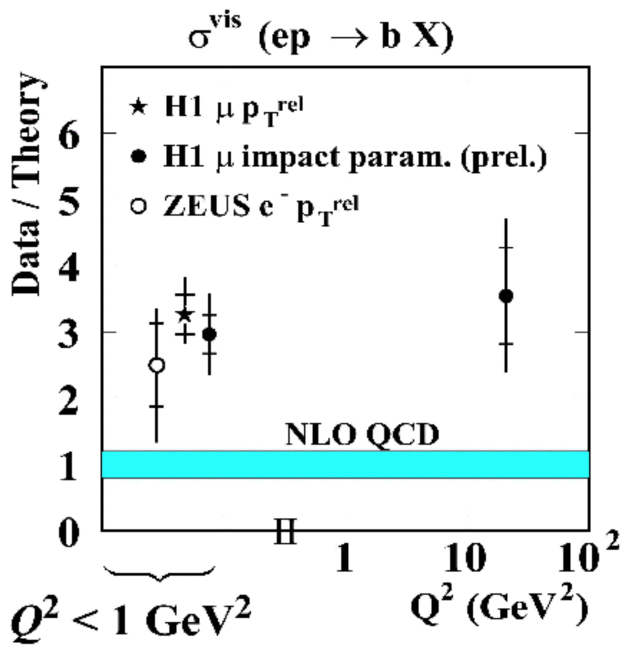
Present results are dominated by statistical errors.

High precision implies:

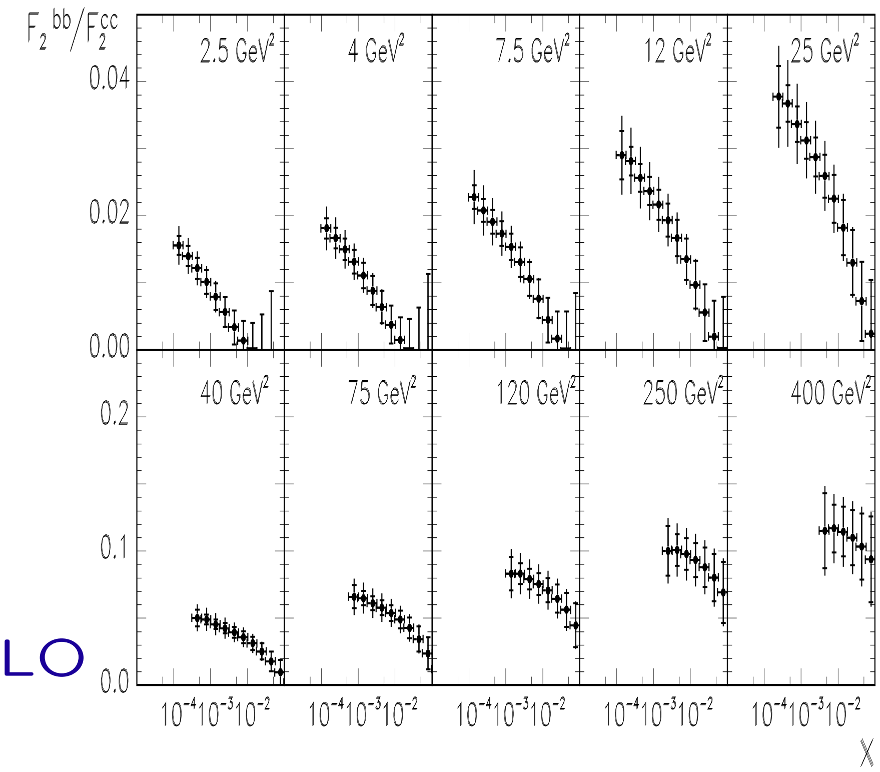
- highest possible luminosity,
- improved interaction vertex and tracks reconstruction.



HERA II



$500 pb^{-1}$



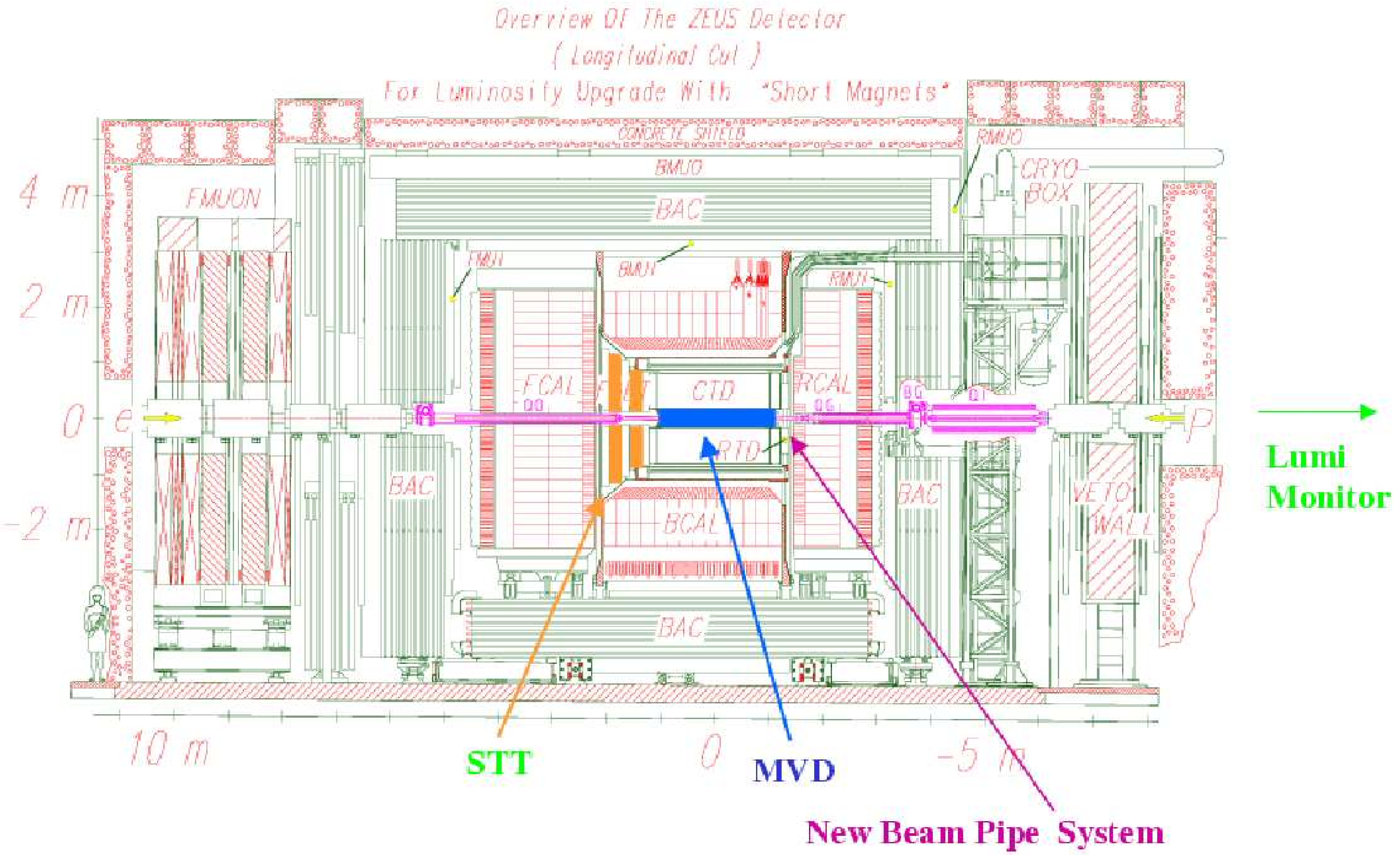
Data in contradiction to the NLO calculation.

Large luminosity and a good vertex reconstruction and forward tracking needed.

Upgraded Detector

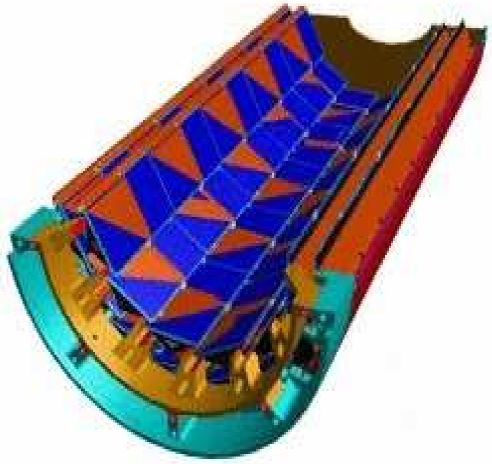
- New, mini beta optics
  - magnets introduces inside the detector
  - forward and backward regions rebuilt.
- major hardware upgrade:
  - silicon micro-vertex detector
  - forward silicon detector
  - forward Straw Tube Tracker
  - new lumi system.

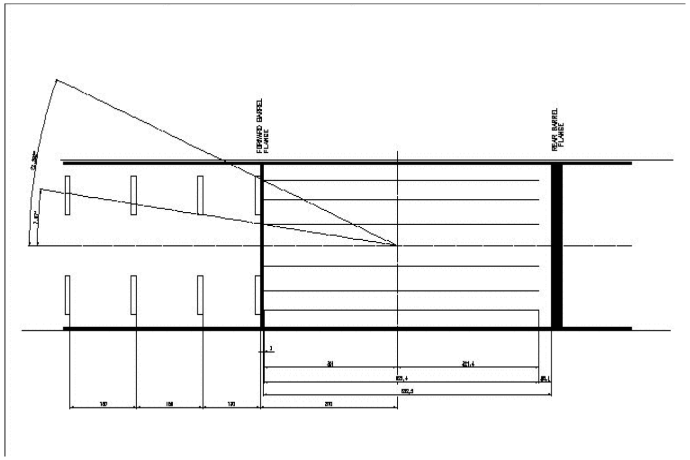
Upgraded Detector



The Micro Vertex Detector

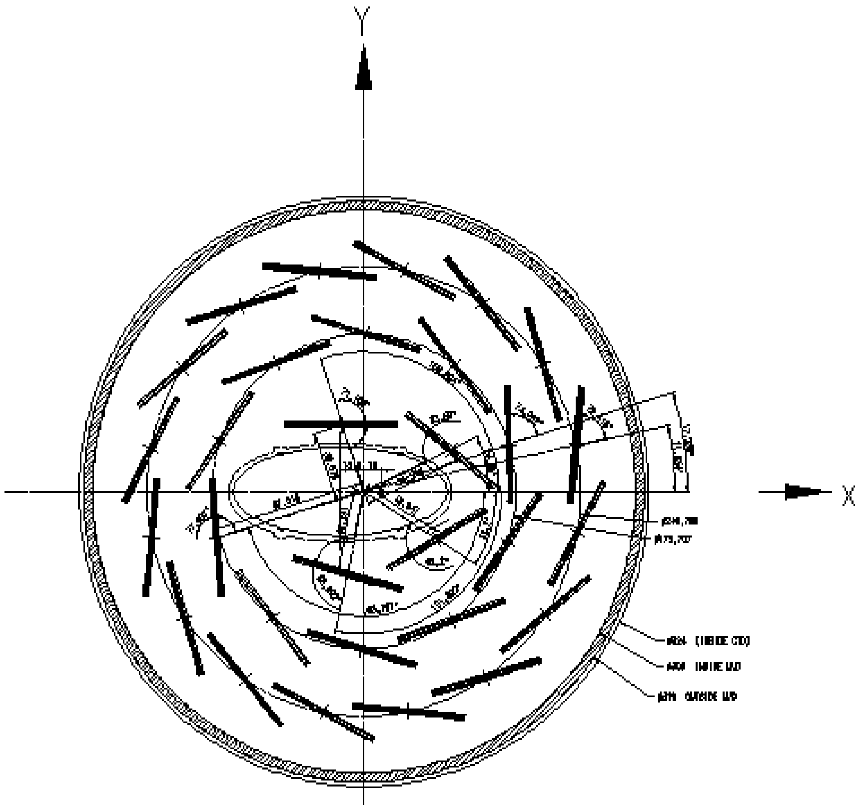
charm production peaked in the forward direction,
improved vertex reconstruction – heavy flavor physics,
improved charged current physics.





The Micro Vertex Detector

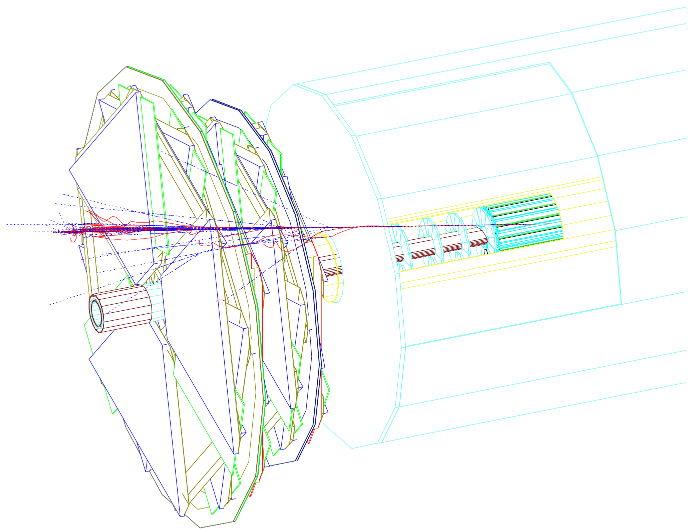
- angular coverage $10^\circ < \Theta < 160^\circ$,
- three points per track,
- $20\ \mu m$ intrinsic hit resolution,
- $200\ \mu m$ of two track separation.



$r - \phi$ view

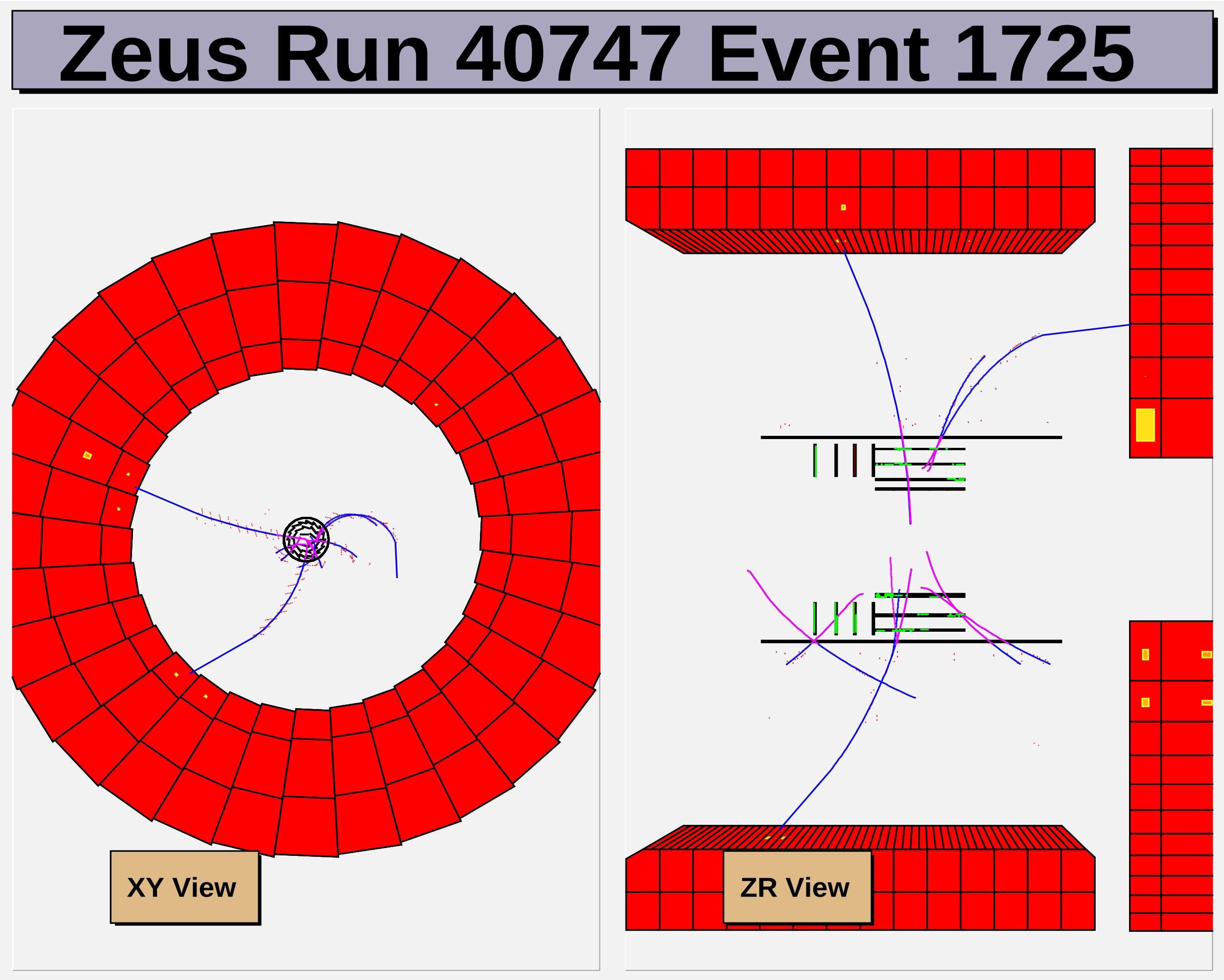
Straw Tubes Tracker

- ZEUS MEPHI group involved in similar projects in ATLAS and HERA-B
- four layers of straw tubes drift chambers
- high efficiency, low occupancy
- improved forward tracking for:
  - electroweak and exotics studies with high Q^2 events
  - charm production
  - bottom production
  - extension of W range for the vector meson and QCD studies



- coverage $5^\circ < \Theta < 25^\circ$,
- single wire spatial resolution $\sim 140\mu m$,
- efficiency/straw 98.5%.

Summary



Summary

- The Zeus NLO fits well describe the ZEUS DIS data.
- The DGLAP analysis is limited down to $Q^2 \approx 1.5$ GeV^2.
- High Q^2 charged and neutral cross sections have been measured and are also well described by the NLO fits and the Standard Model
- Study of the photon structure show:
  - the NLO calculations with GRV (HO) resonable well the data,
  - the angular distributions show evidence for the gluon exchange,
- The photoproduction total cross section has been measured
- Energy dependence is well described by the parametrisation based on the pp and $p\bar{p}$ data.

Summary

- Upgraded HERA at the "commissioning" phase.
- The work concentrated on the backgrounds reduction and the beams' currents increase.
- The physics program will focus on:
  - measurement of $F_2, xF_3, F_2^{ss}, F_2^{cc}$ and F_2^{bb},
  - determination of α_s, xg,
  - measurement of the polarisation dependent DIS for precision tests of SM and u, and d-quark NC couplings
  - search for new physics...
- The ZEUS detector, upgraded to match new challenges, waits for the data.