Diffractive PDF fits to the ZEUS Mx data

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Outline

- Very brief overview
- Experimental Data
- Regge Factorization tests
- Fits of Data
- Interpretation of the fit results
- Conclusion

Regge Theory and the Pomeron

- It is assumed that the diffractive interactions are due to the Pomeron exchange, where the Pomeron is a Regge trajectory and can be parameterized as,

$$\alpha_{IP}(t) = \alpha_{IP}(0) + \alpha'_{IP}\, t$$

- Then total hadron-hadron cross section is,

$$\sigma_{tot}(ab) \sim s^{\alpha_{IP}(0)-1}$$

- Results from hadron-hadron interactions by Donnachie and Landshoff

$$\alpha_{IP}(0) = 1.08 \qquad \alpha'_{IP} = 0.25\, GeV^{-2}$$

- In current study we set,
  - $\alpha_{IP}(0)$ – free parameter,
  - $\alpha'_{IP} = 0.25$

Regge Factorization

- **Using previous assumption we can write**

$$F_2^{D(4)} = \frac{N}{16\pi} \mid \beta_{p\,IP}(t) \mid^2 x_{IP}^{1-2\alpha_{IP}(0)} F_2^{IP}(x_{IP}, t, \beta, Q^2)$$

- **Here $\beta_{IP}(t)$ represents the Pomeron-proton coupling. It may be obtained from fits to elastic hadron-hadron cross section at small t ,**

$$\beta_{p\,IP}(t) = 4.6mb^{1/2} e^{1,9\,GeU^{-2} t}$$

- **Regge factorization states that**

$$F_2^{IP}(x_{IP}, t, \beta, Q^2) = F_2^{IP}(\beta, Q^2)$$

- **And so F_2^{IP} can be treated as the Pomeron structure function. To simplify expressions we can introduce the Pomeron flux factor,**

$$f_{IP/P}(x_{IP}, t,) = \frac{N}{16\pi}[\beta_{p\,IP}(t)]^2 x_{IP}^{1-2\alpha_{IP}(t)}$$

- **Then diffractive structure functions become,**

$$F_2^{D(4)}(x_{IP}, t, \beta, Q^2) = f_{IP/p}(x_{IP}, t) F_2^{IP}(\beta, Q^2)$$

$$F_1^{D(4)}(x_{IP}, t, \beta, Q^2) = f_{IP/p}(x_{IP}, t) \frac{1}{x_{IP}} F_1^{IP}(\beta, Q^2)$$

$$F_L^{D(4)}(x_{IP}, t, \beta, Q^2) = f_{IP/p}(x_{IP}, t) F_L^{IP}(\beta, Q^2)$$

Regge Factorization cont.

- $F_2^{D(3)}$ and $F_L^{D(3)}$ have the same x_{IP} dependence
- In the experiment, reduced crossection is measured.

$$x_{IP}\sigma_r^{D(3)} = x_{IP}F_2^{D(3)} - \frac{y^2}{2(1-y+y^2/2)} x_{IP}F_L^{D(3)}$$

- Its longitudinal part contains kinematic factor that is x_{IP} dependent.

$$y = \frac{Q^2}{x_{IP}\beta\, s}$$

- This factor is small for small y, thus longitudinal part is usually neglected for $y<0.45$. In the current study, $F_L^{D(3)}$ was included and no cut on y was done.

Pomeron parton distribution functions

- Within the Ingelman and Schlein model the Pomeron structure functions are defined in exactly the same way as the structure functions of the proton.
- Some constraints must be applied in order to get object with vacuum quantum numbers.
  - Self-charge-conjugation implies that

    $$f_{q/IP}(x) = f_{\bar{q}/IP}(x)$$

  - Isoscalar implies that

    $$f_{u/IP}(x) = f_{d/IP}(x) = f_{\bar{u}/IP}(x) = f_{\bar{d}/IP}(x) = f_{q/IP}(x)$$

- Evolution equations allows to obtain PDFs at any scale by providing PDF at some initial scale Q_{ini}.
- In the massless scheme, below mass threshold the PDF of corresponding quark is 0.

  $$f_{q/IP}(x,Q^2) = 0 \ \ if \ \ Q^2 < 4m_q^2$$

- For strange quark we make following assumption:

  $$f_{s/IP}(x) = sf_{u/IP}(x)$$

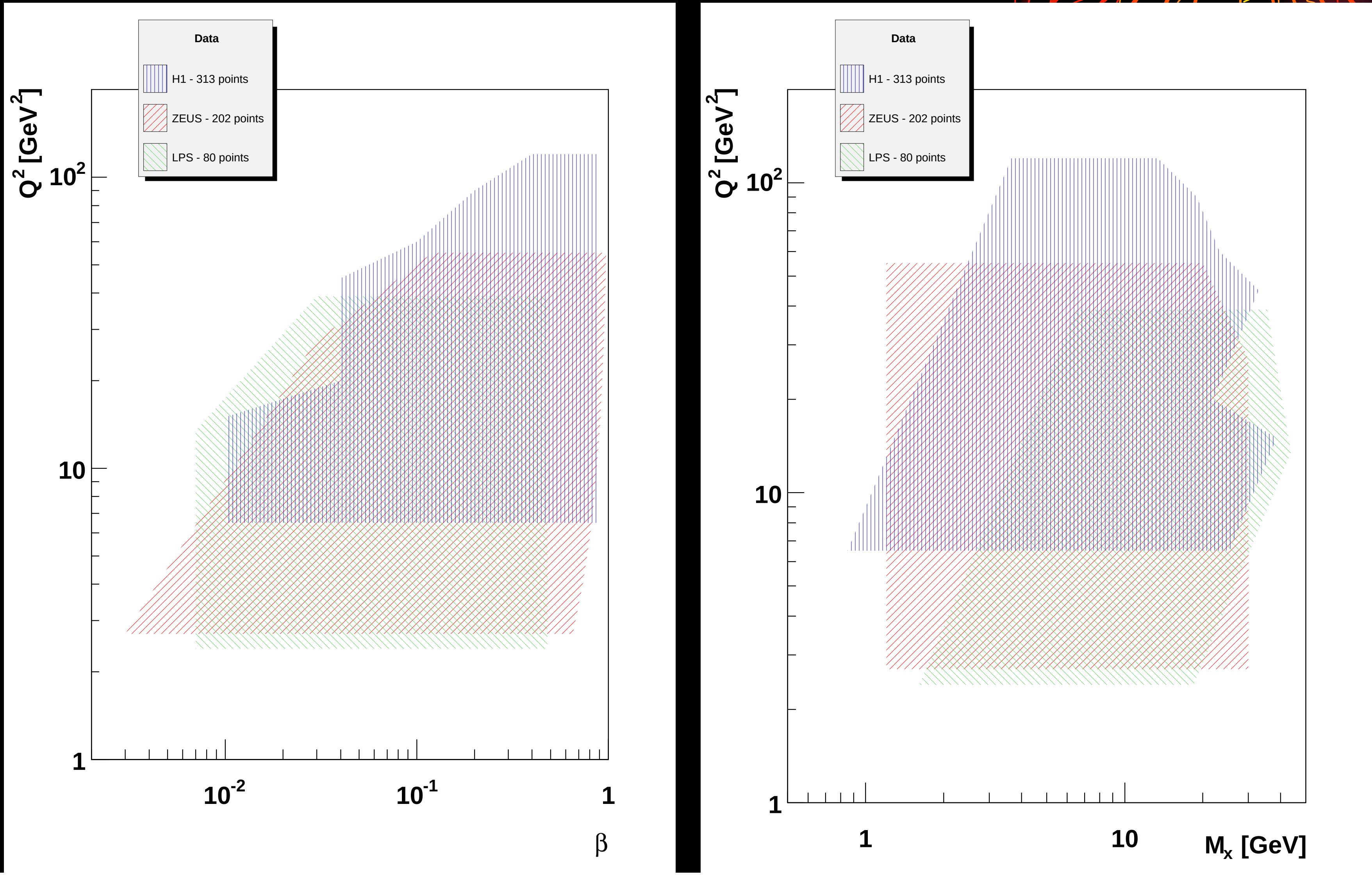
  - where $0 \leq s \leq 1$

Experimental Data

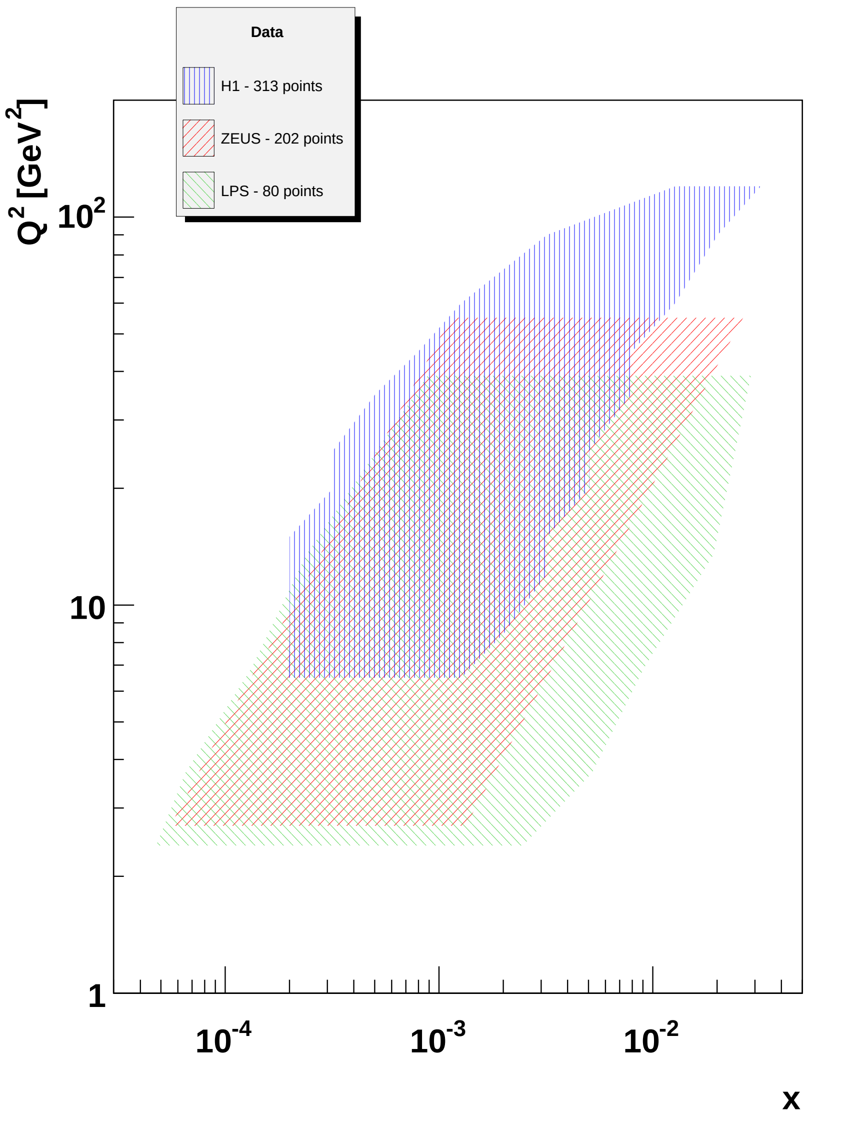
- **HERA collider**
  - **ZEUS experiment**
    - **FPC – forward plug calorimeter**
      - **Mx Method**
    - **LPS – leading proton spectrometer**
      - **Direct proton measurements**
  - **H1 experiment** (partial sample)
      - **Large Rapidity Gap**

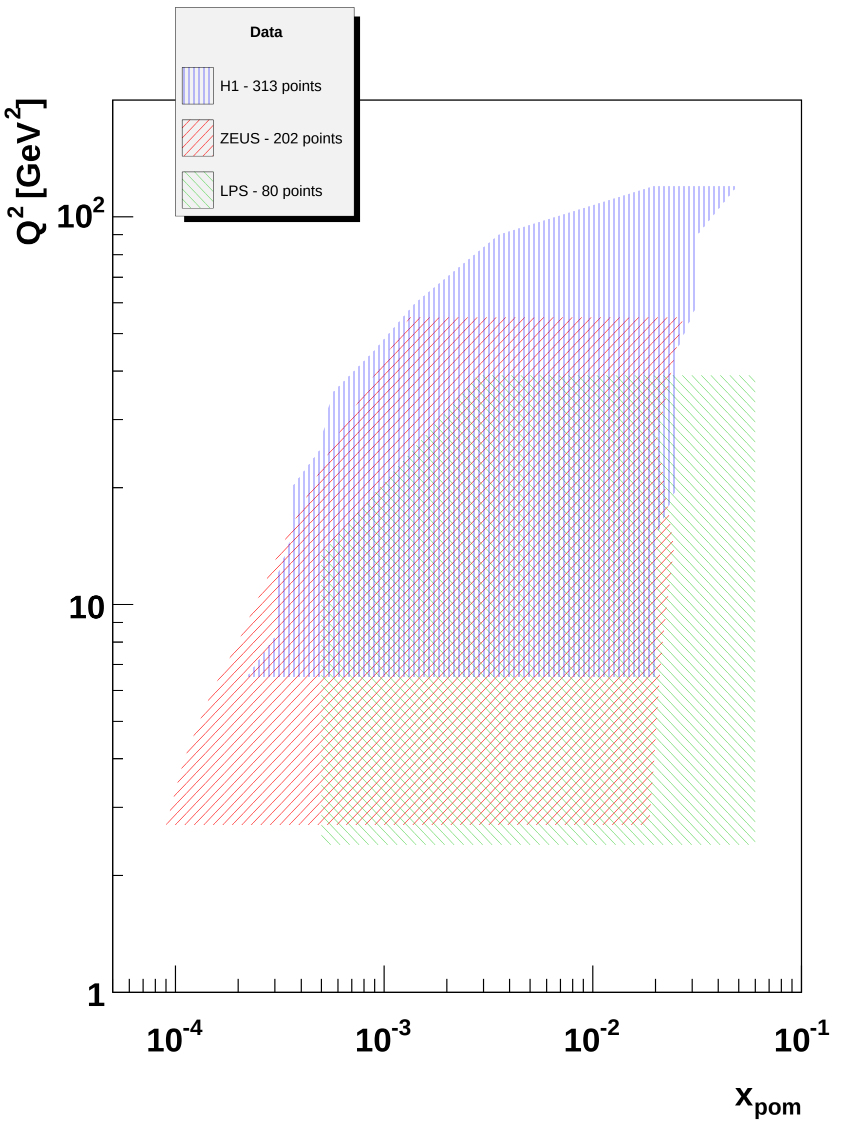
- **Values** $x_{IP}\sigma_r^{D(3)}$ **at different** β, Q^2 *and* x_{IP} .

Kinematical ranges



Kinematical ranges





Regge Factorization Test

- **Check only x_{IP} dependence.**
- **Fit with following function:**

$$x_{IP} F_2^{D(3)}(x_{IP}, \beta, Q^2) = N(\beta, Q^2)\, f(x_{IP})$$

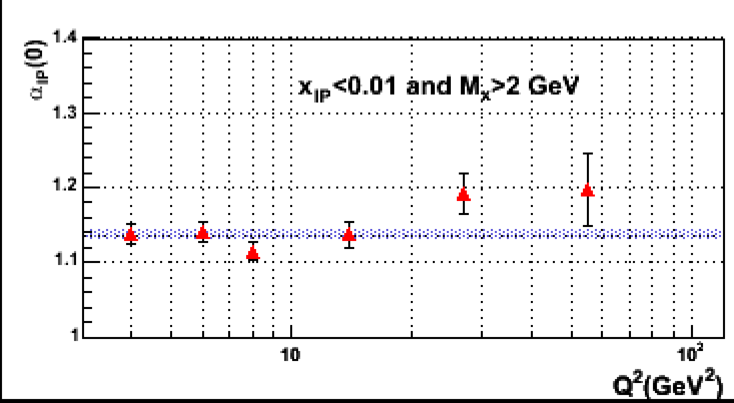
  - **where $N(\beta, Q^2)$ factor will incorporate β *and* Q^2 dependence and $f(x_{IP})$ represents x_{IP} dependence.**
- **Two types of $f(x_{IP})$ were checked**

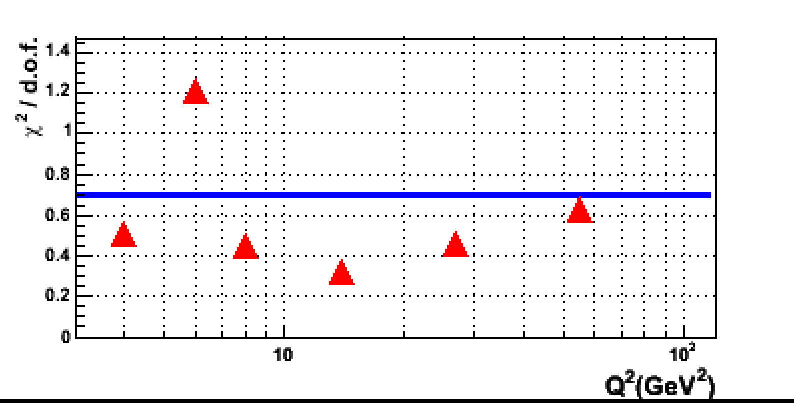
$$f(x_{IP}) = \frac{1}{x_{IP}^{A}}$$

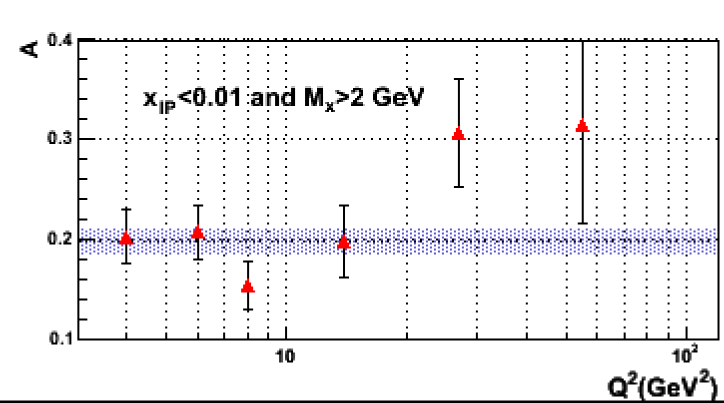
$$f(x_{IP}) = f_{IP}(x_{IP}; \alpha_{IP})$$

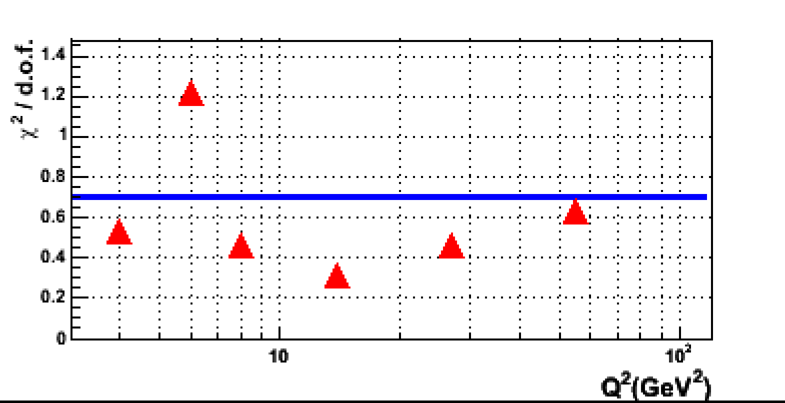
- **Values of $N(\beta, Q^2)$ were determined from the fit to each (β, Q^2) bin independently.**
- **The values of parameters A, α_{IP} are global.**
- **Two sets of fits were done:**
  - **Fits in different Q^2 bins independently with aim to find Q^2 dependence.**
  - **Fits in different β bins independently with aim to find β dependence.**

Q^2 dependency test of ZEUS FPC data

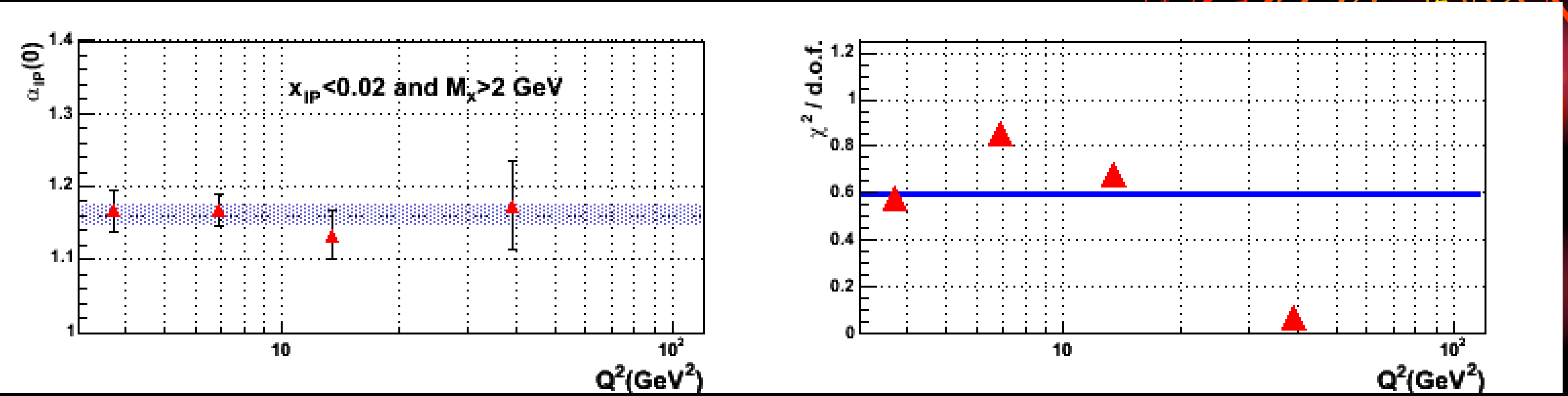


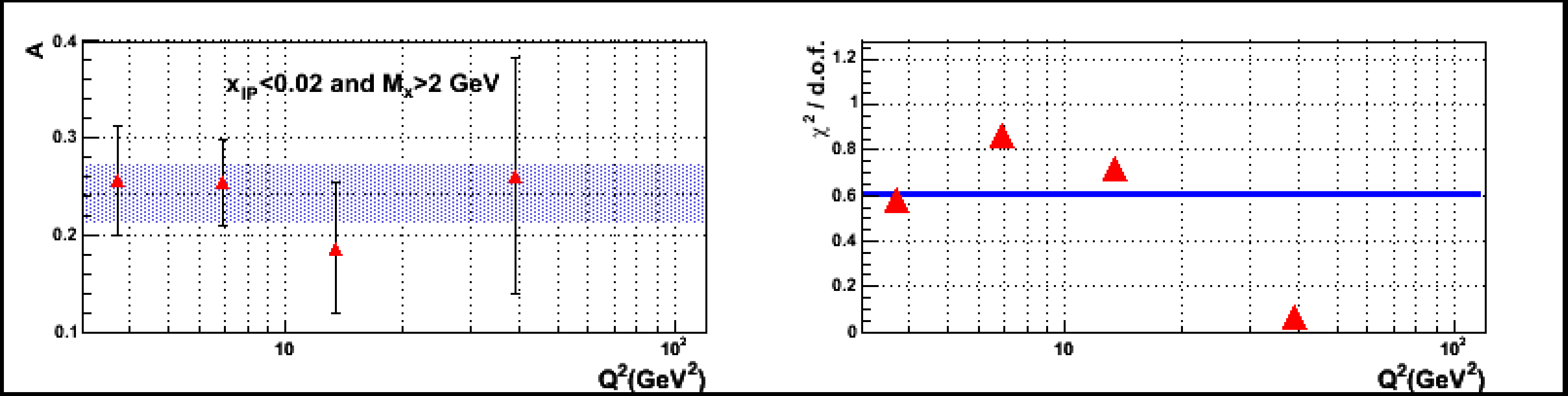




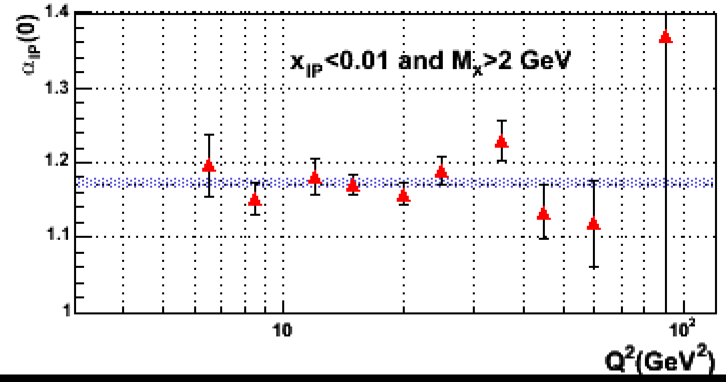


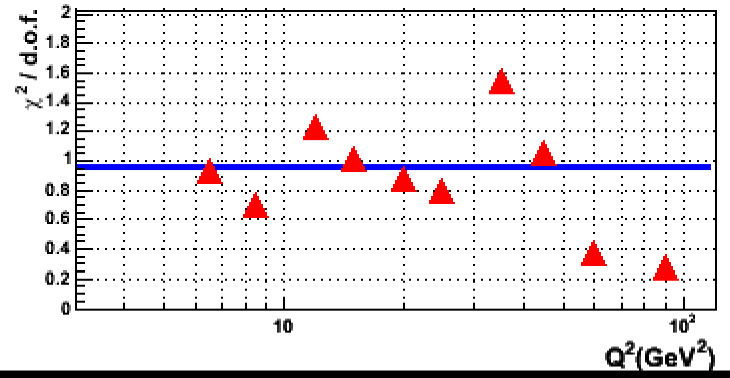
Q^2 dependency test of ZEUS LPS data

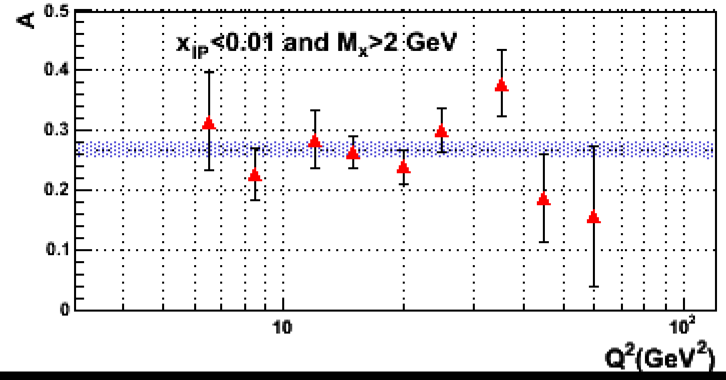


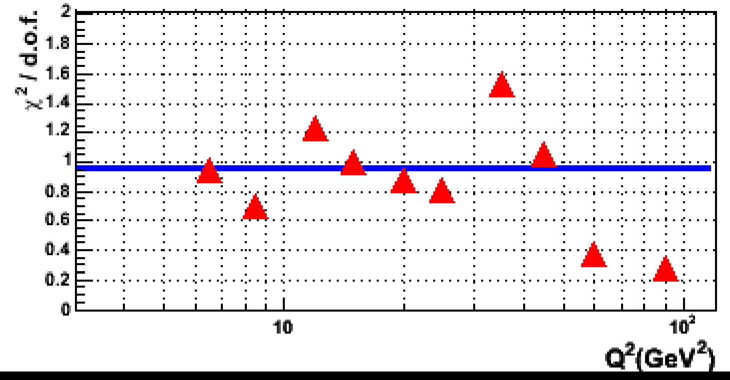


Q^2 dependency test of H1 data

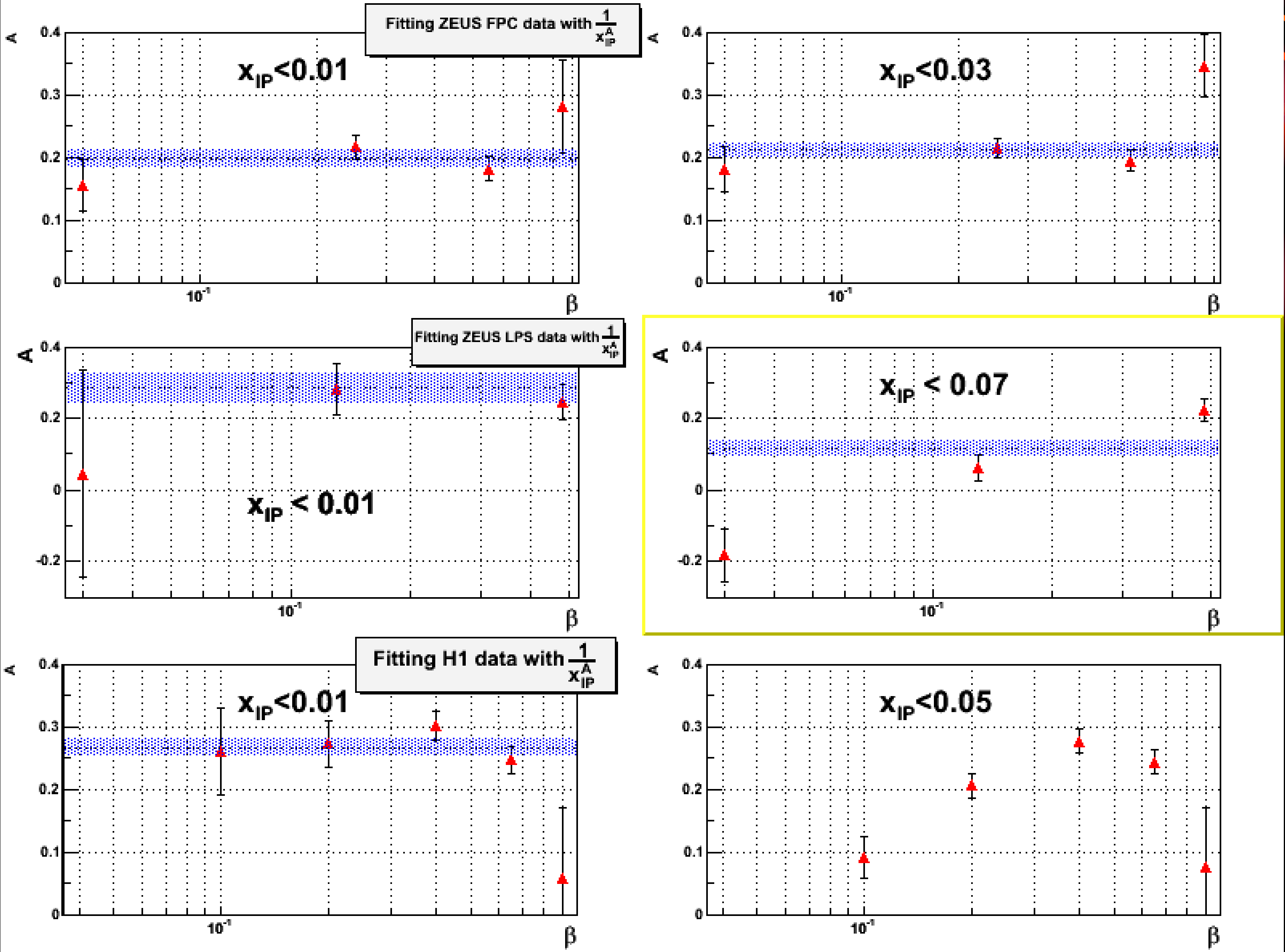








β dependency test of ZEUS FPC data



Fits of Data

Parameterization of Pomeron PDFs.

- Guess Pomeron parton distribution functions at initial scale.
- Following parameterization was chosen:

$$xq(x) = A_q x^{\alpha_q} (1-x)^{\beta_q}$$
$$xg(x) = A_g x^{\alpha_g} (1-x)^{\beta_g}$$
$$xs(x) = 0$$

- The constraints are,

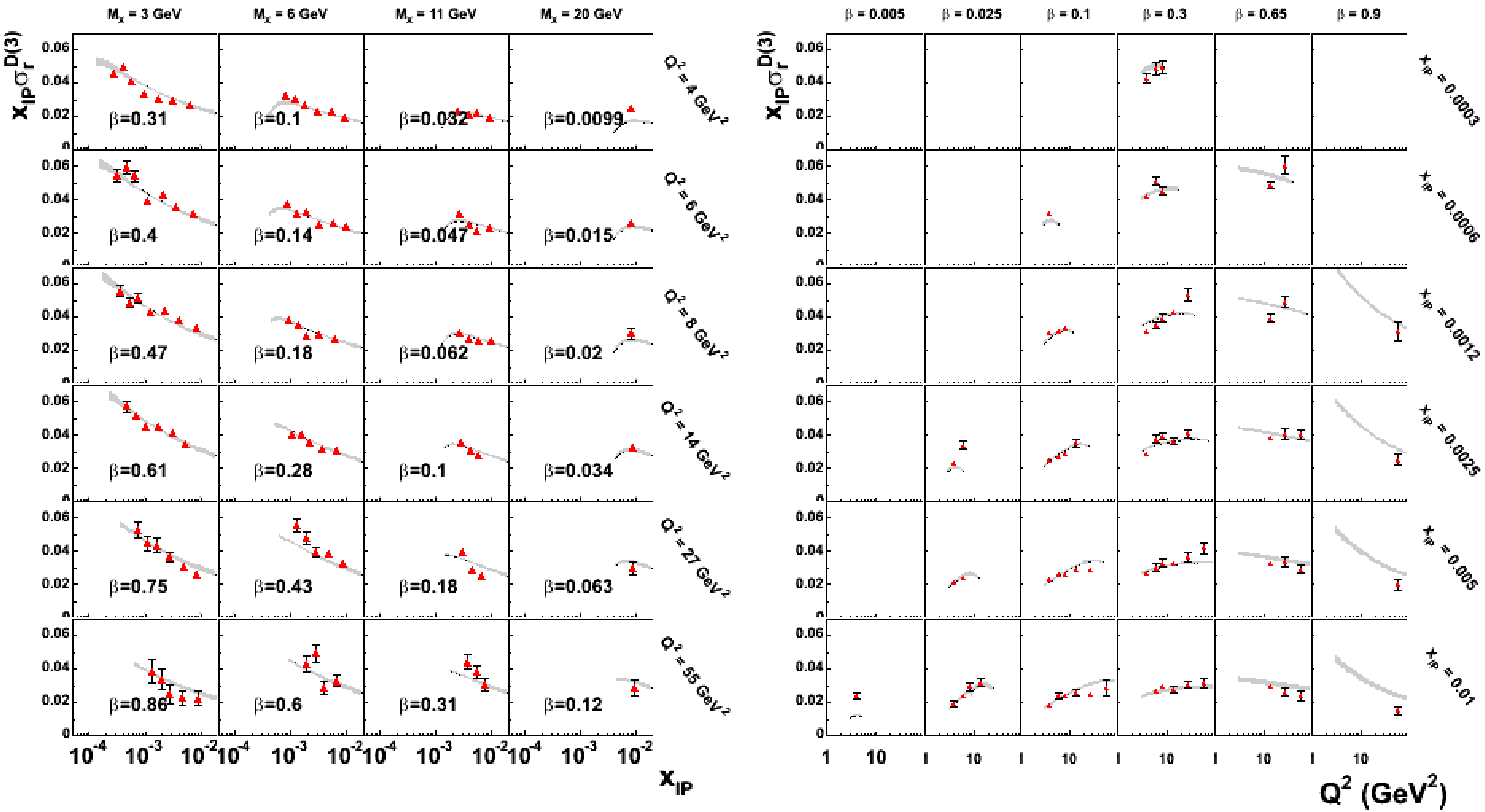
$$A_q, A_g > 0$$
$$\alpha_q, \alpha_g, \beta_q, \beta_g > -1$$

- Evolve using CTEQ package with massless scheme

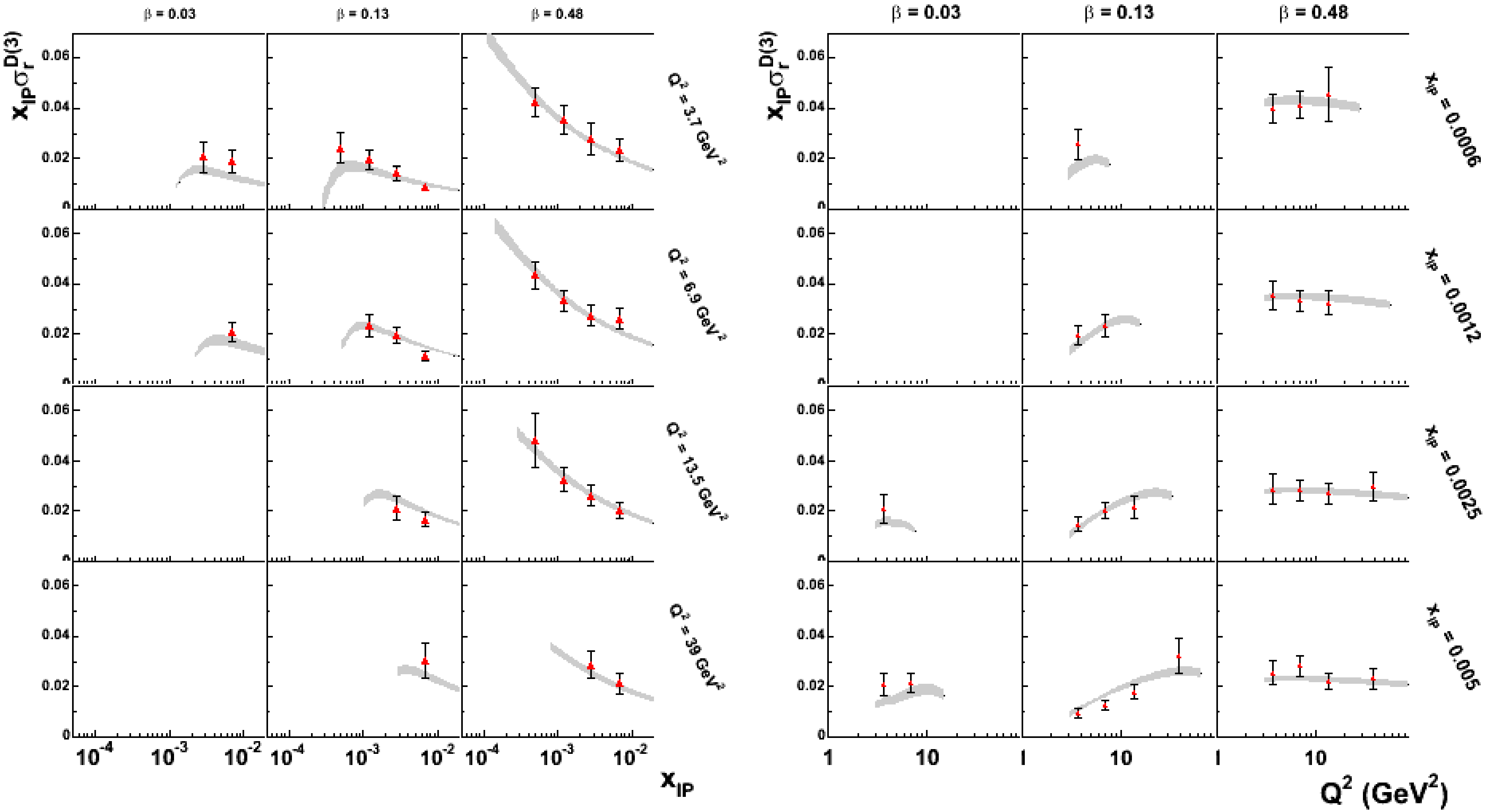
Data Selection

- $M_X > 2$ GeV
  - *Higher twist effects*
- $Q^2 > Q^2_{ini} = 3$ GeV^2
- $x_{IP} < 0.01$
  - *Single Pomeron exchange*

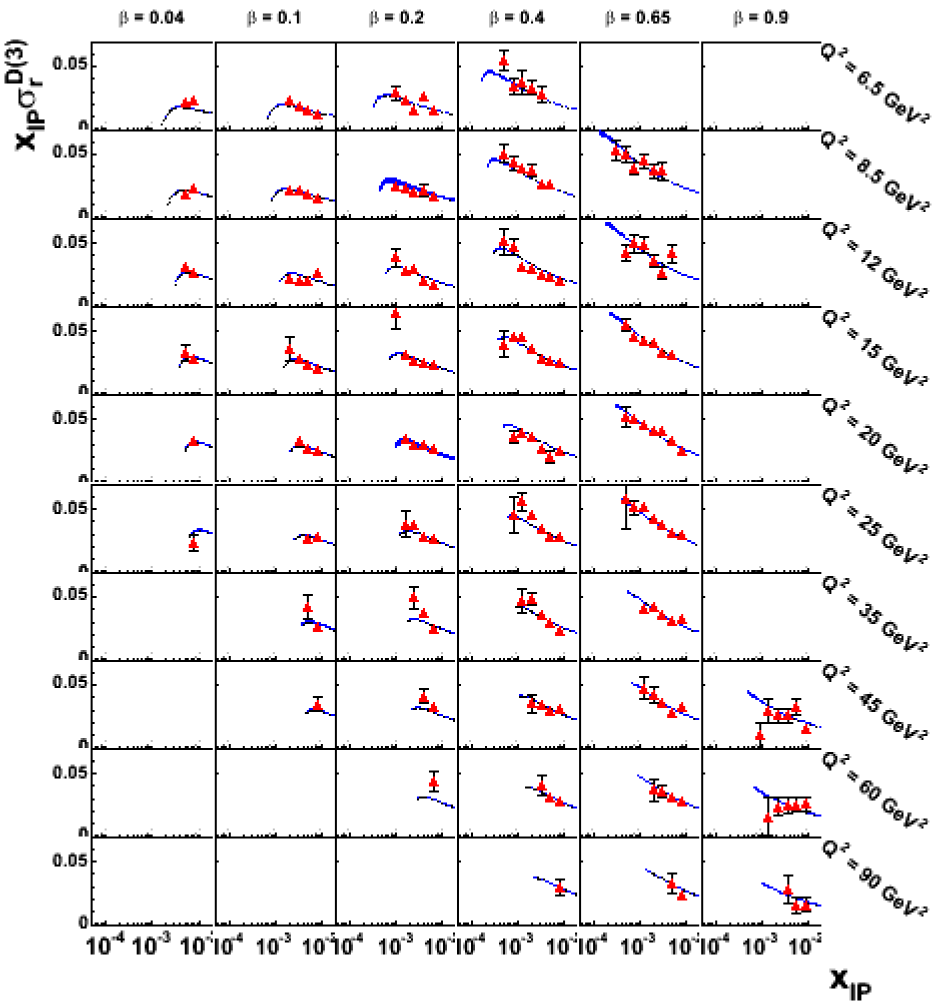
Fit results for ZEUS FPC data

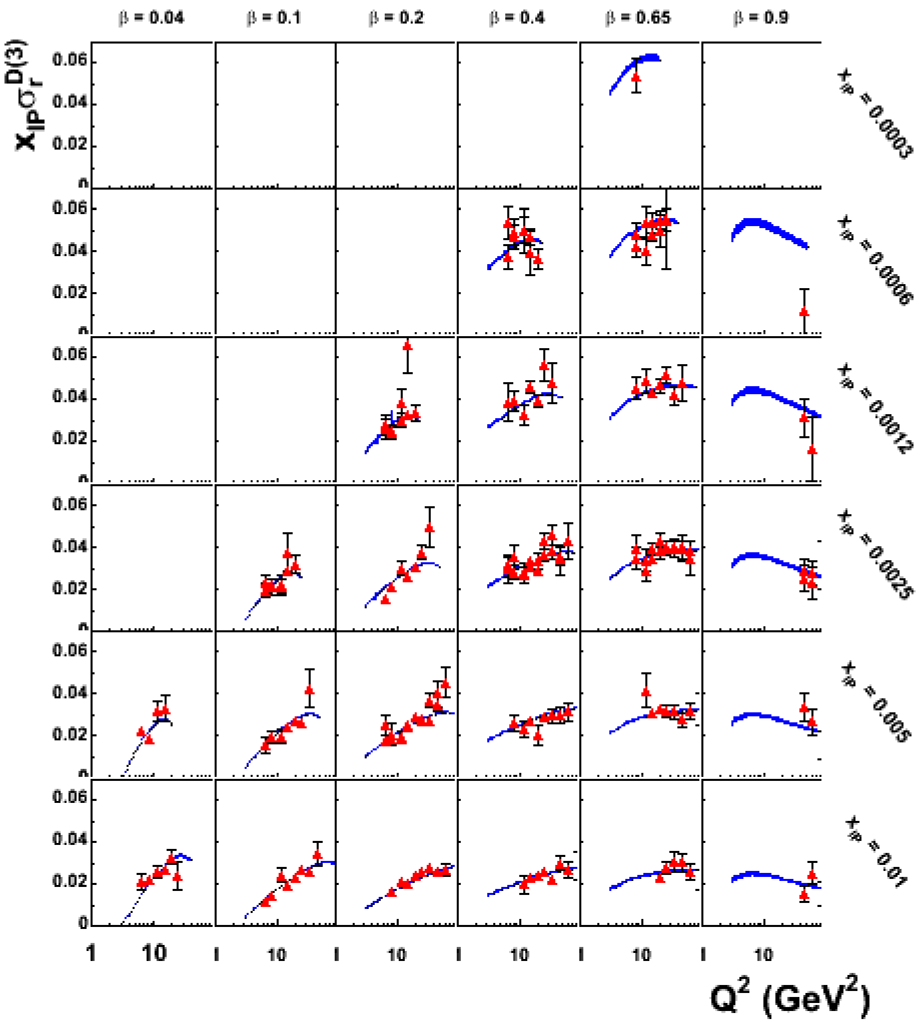


Fit results for ZEUS LPS data



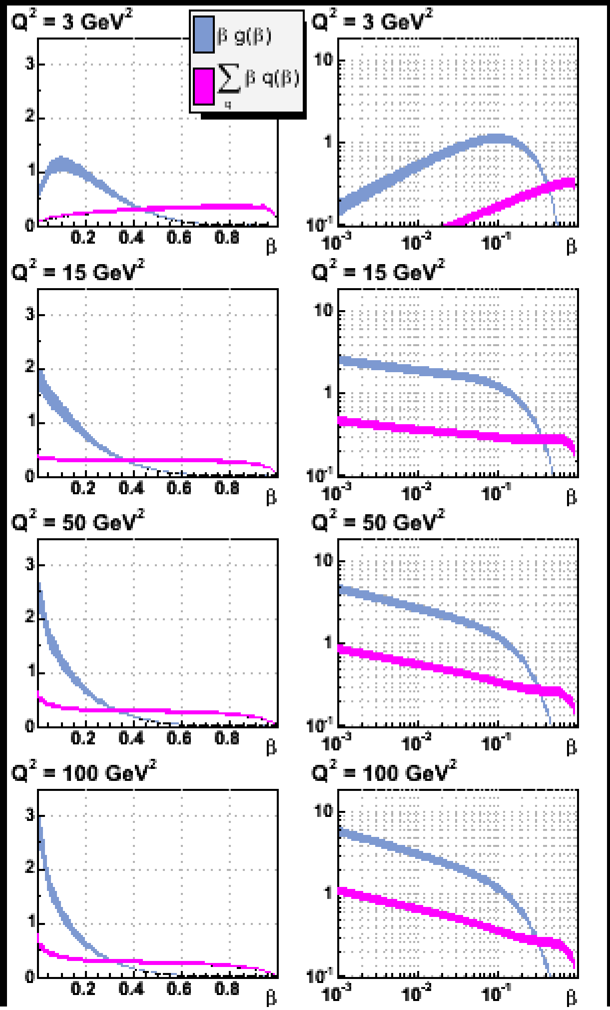
Fit results for H1 data



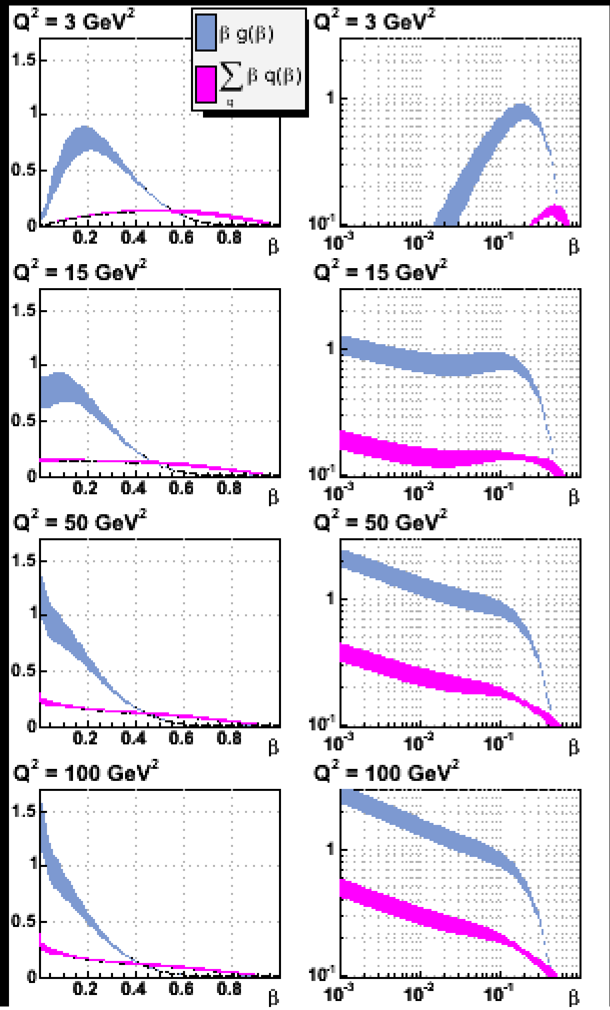


Parton Distribution functions

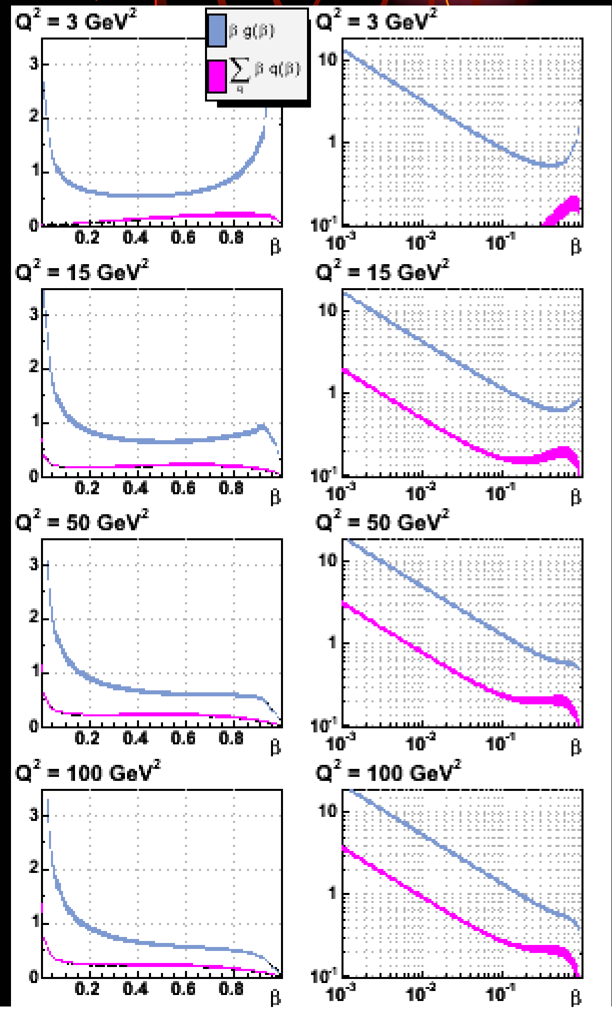
ZEUS FPC



ZEUS LPS

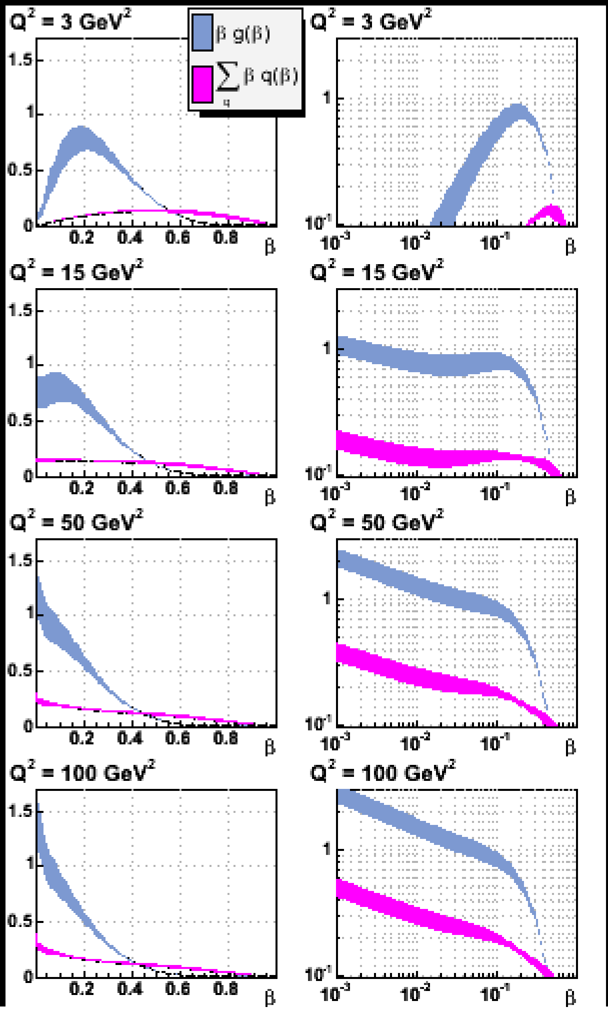


H1

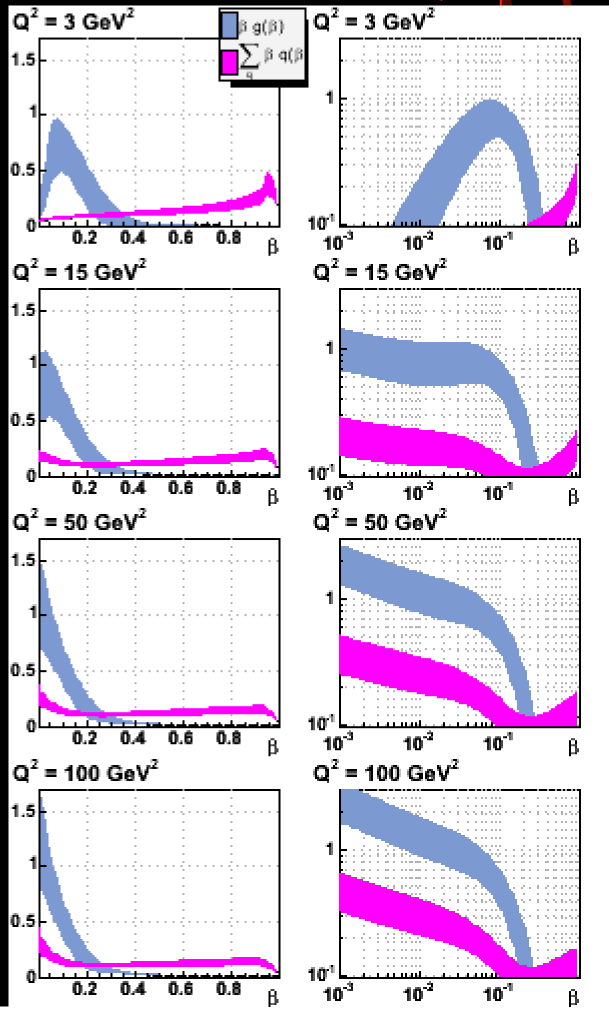


Two solutions of ZEUS LPS data

gluons >> quarks

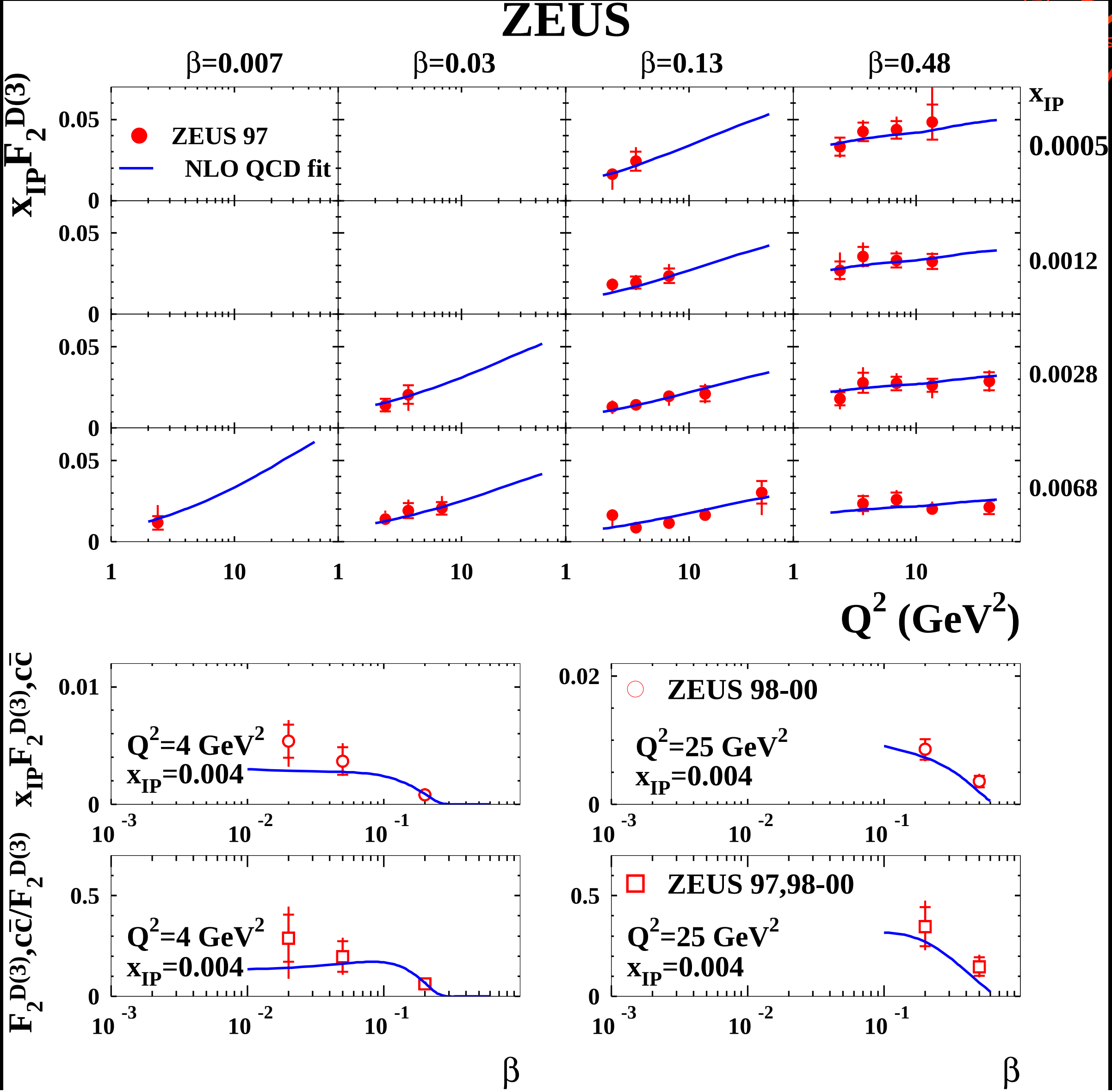


gluons ≈ quarks

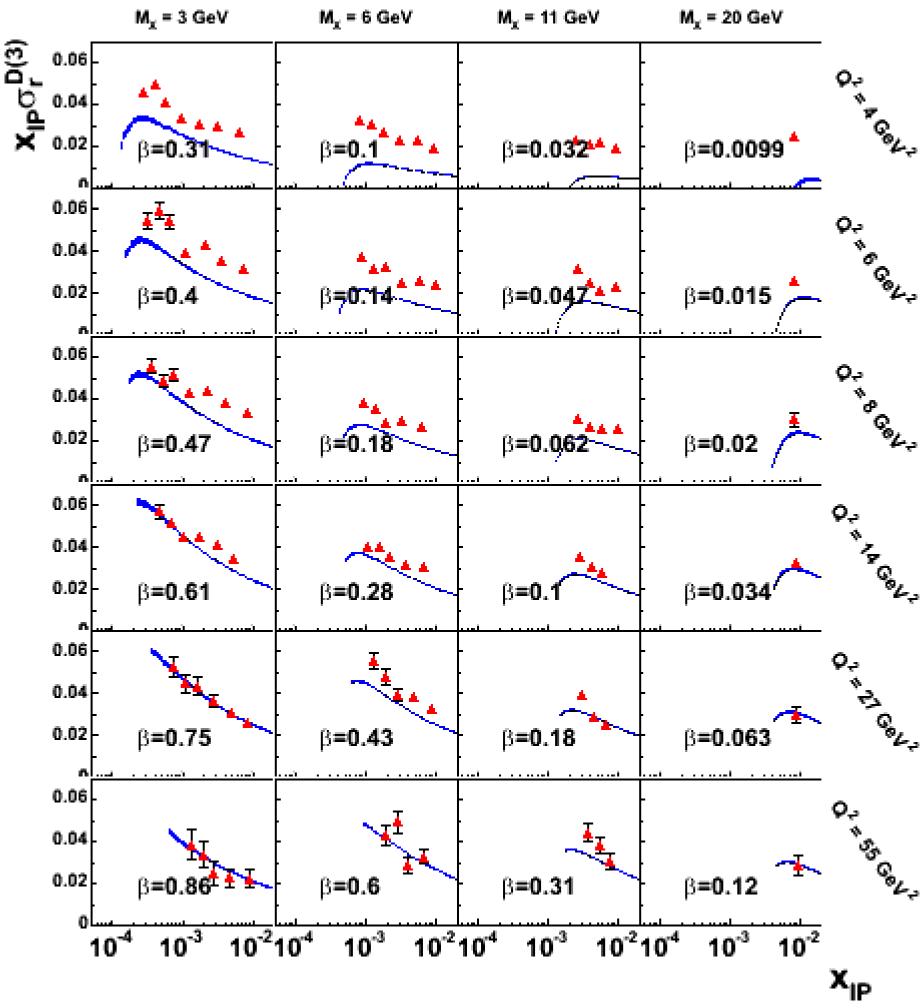


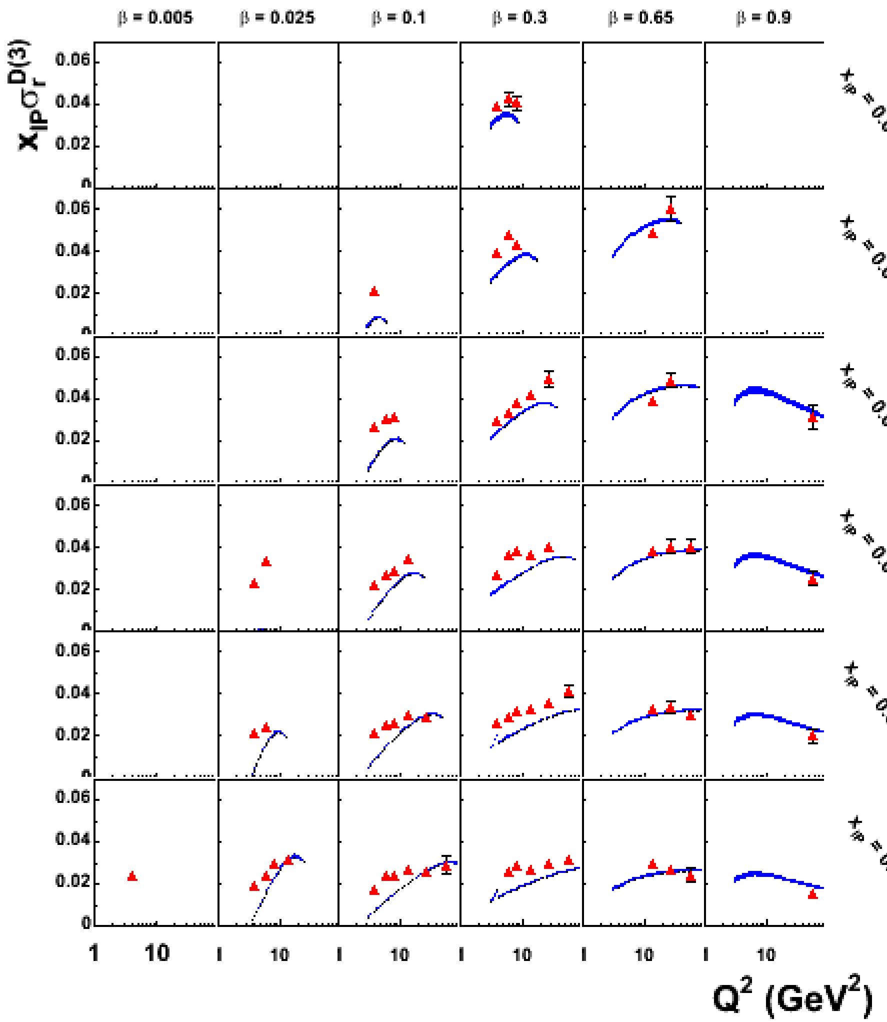
ZEUS LPS fit with charm data points

Alexander Proskuryakov

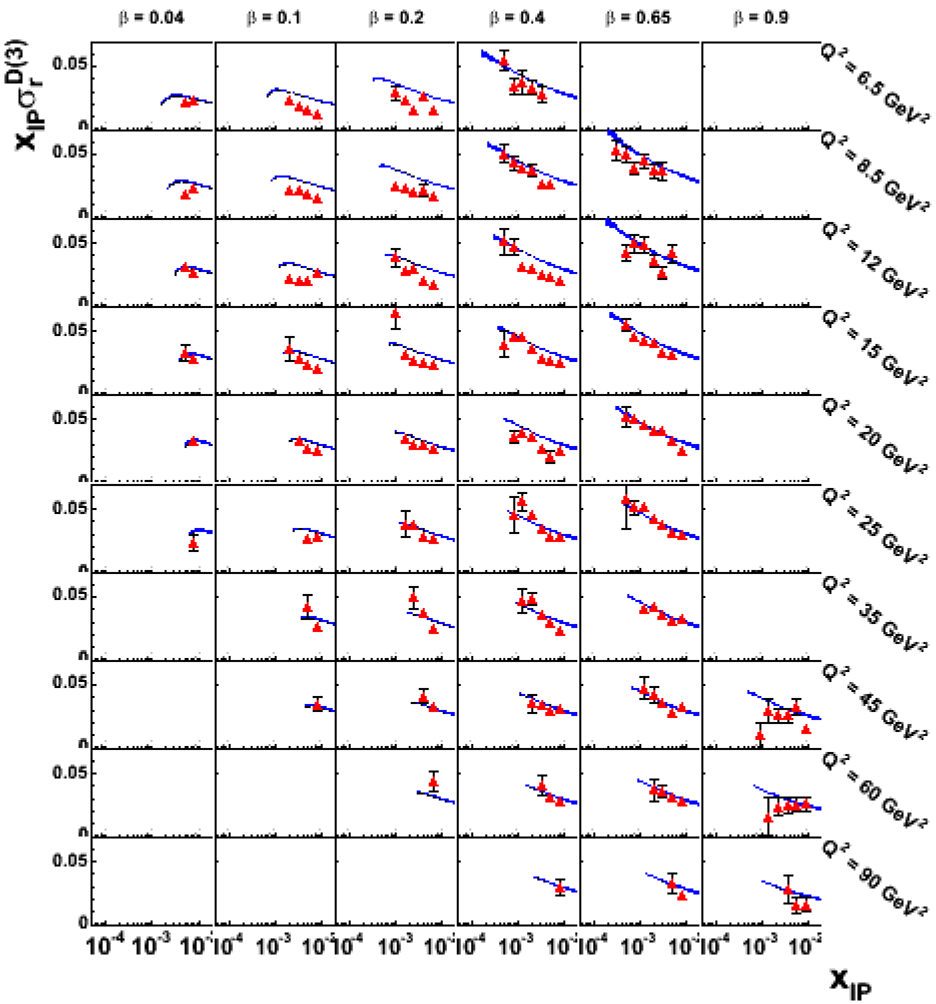


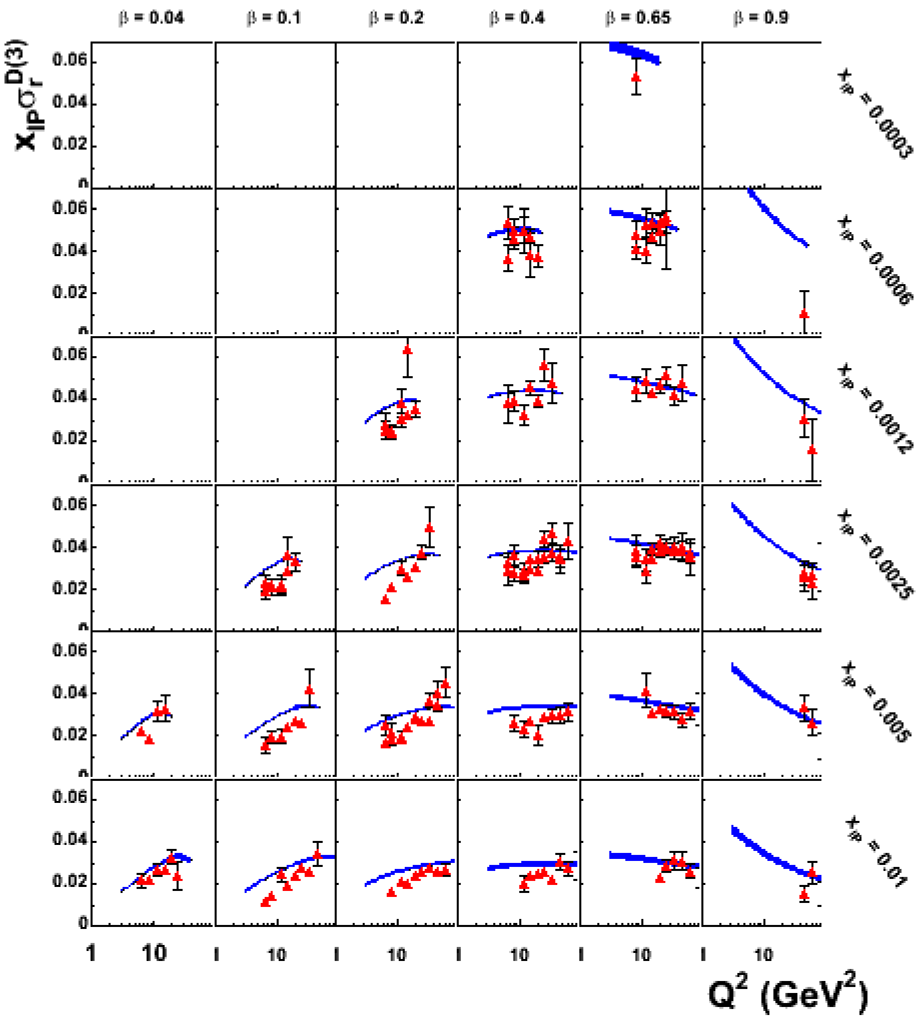
Comparison:
ZEUS FPC data vs. H1 fit





Comparison: H1 data vs. ZEUS FPC fit



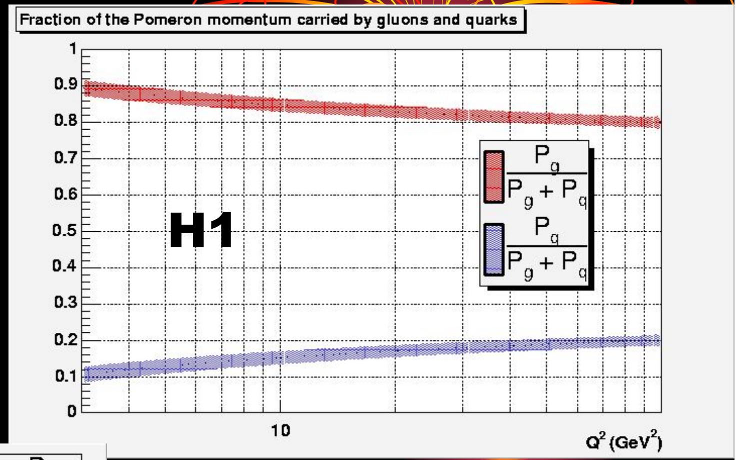


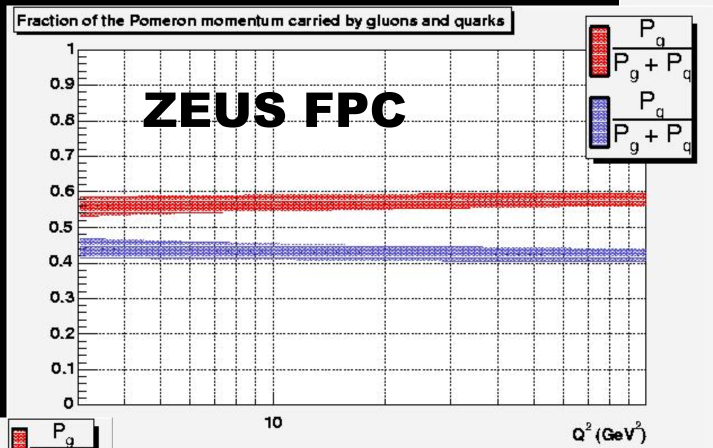
Interpretation of the fit results

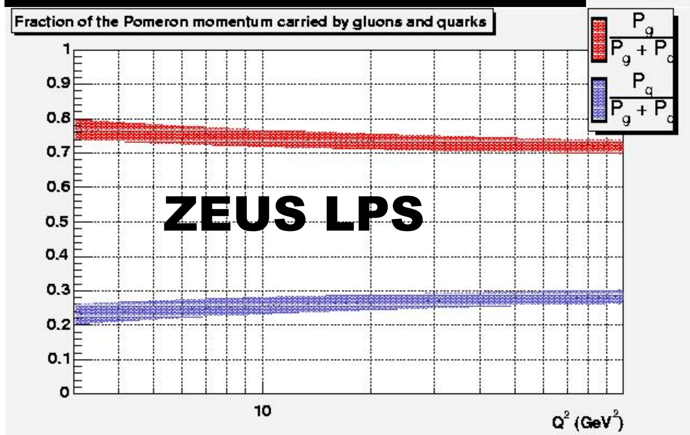
Fraction of Pomeron momentum carried by quarks/gluons

$$P_q(Q^2) = \sum_i \int_0^1 dx \;\; x q_i(x, Q^2)$$

$$P_g(Q^2) = \int_0^1 dx \;\, x g(x, Q^2)$$







$$\frac{P_g}{P_g + P_q}$$

$$\frac{P_q}{P_g + P_q}$$

Probability of diffraction

- **The probability of diffraction for the action of the hard probe which couples to quarks or gluons is:**

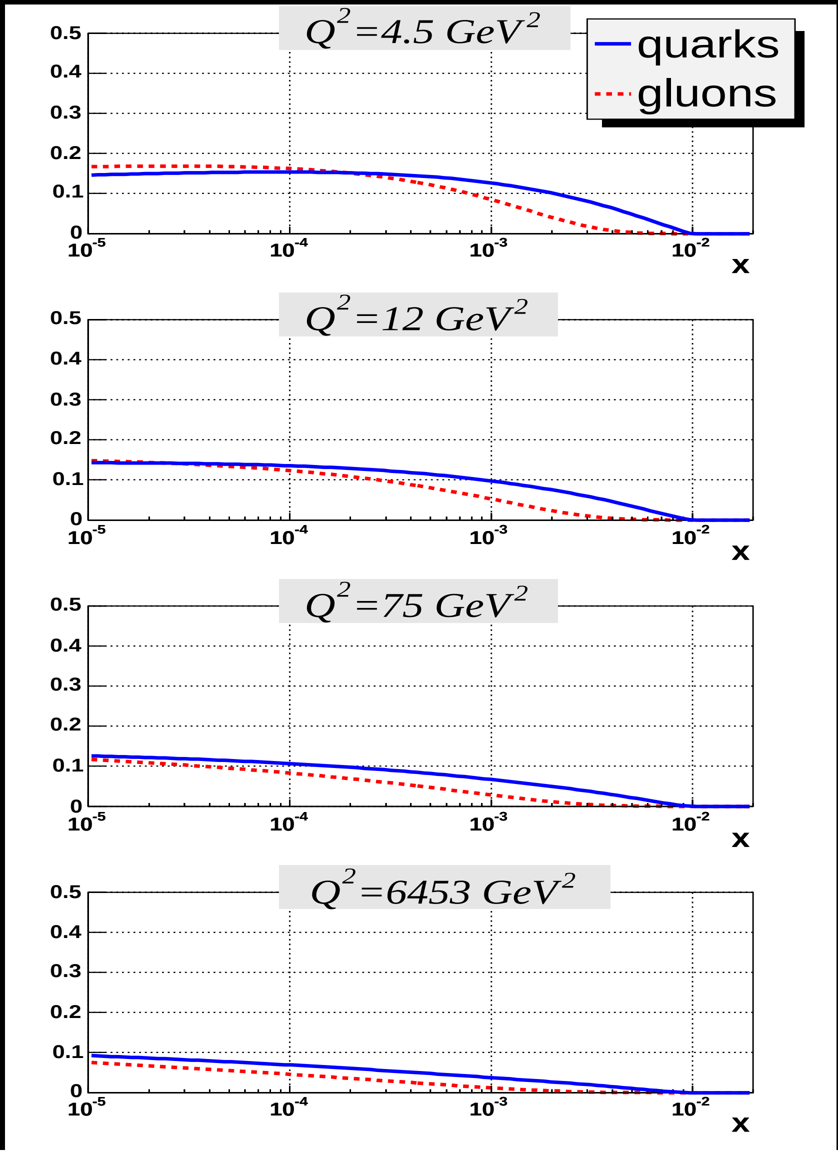
$$P_q^D(x,Q^2)=\frac{\sum_i \int dx_{IP}\,d\beta\,\delta(x-x_{IP}\beta)\,f_{IP}(x_{IP})\,q_i^{IP}(\beta,Q^2)}{\sum_i q_i^{IP}(x,Q^2)}$$

$$P_g^D(x,Q^2)=\frac{\int dx_{IP}\,d\beta\,\delta(x-x_{IP}\beta)\,f_{IP}(x_{IP})\,g_i^{IP}(\beta,Q^2)}{g_i^{IP}(x,Q^2)}$$

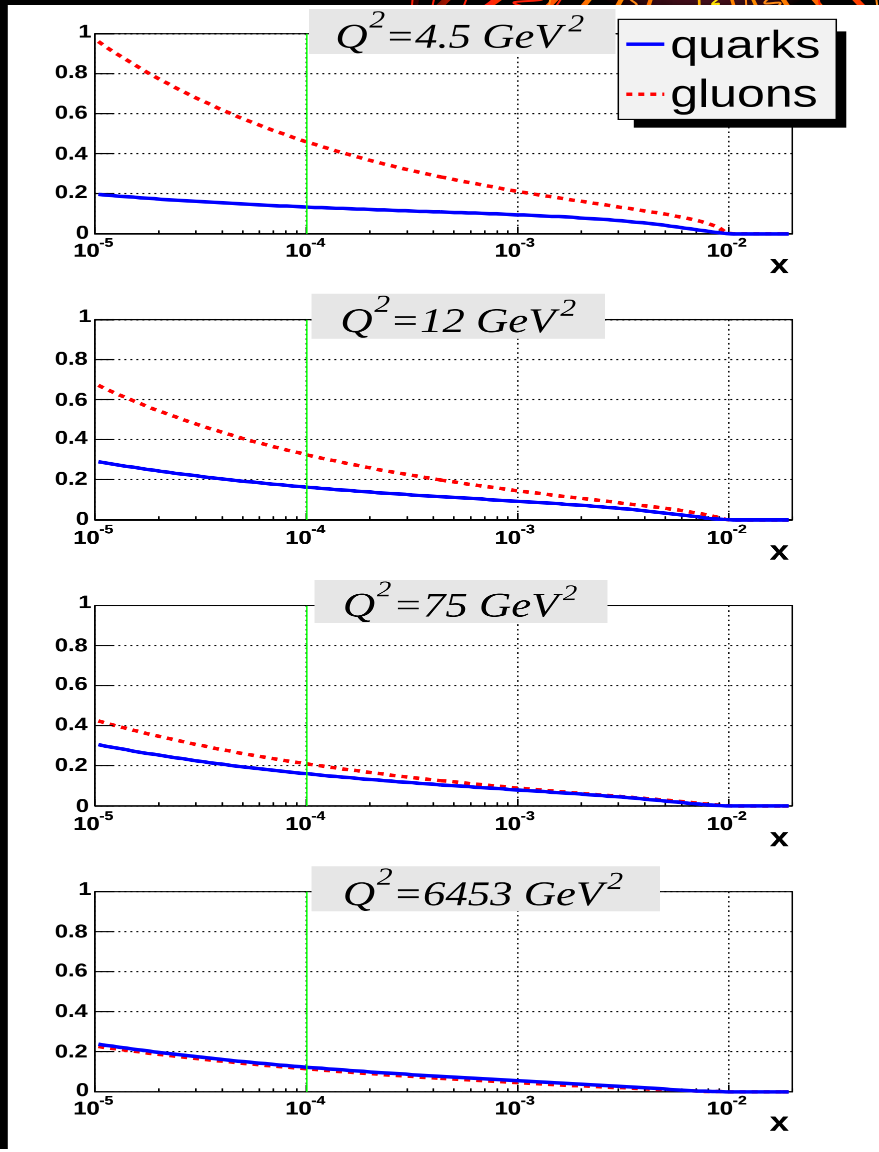
- **If the interaction in the gluon sector at small x reaches a strength close to the unitarity limit then P_g is expected to be close to ½ and be larger than P_q.**
- **L.Frankfurt and M.Strikman,** ***"Future Small x physics with ep and eA Colliders"***

Probability of Diffraction

ZEUS FPC fit



H1 fit



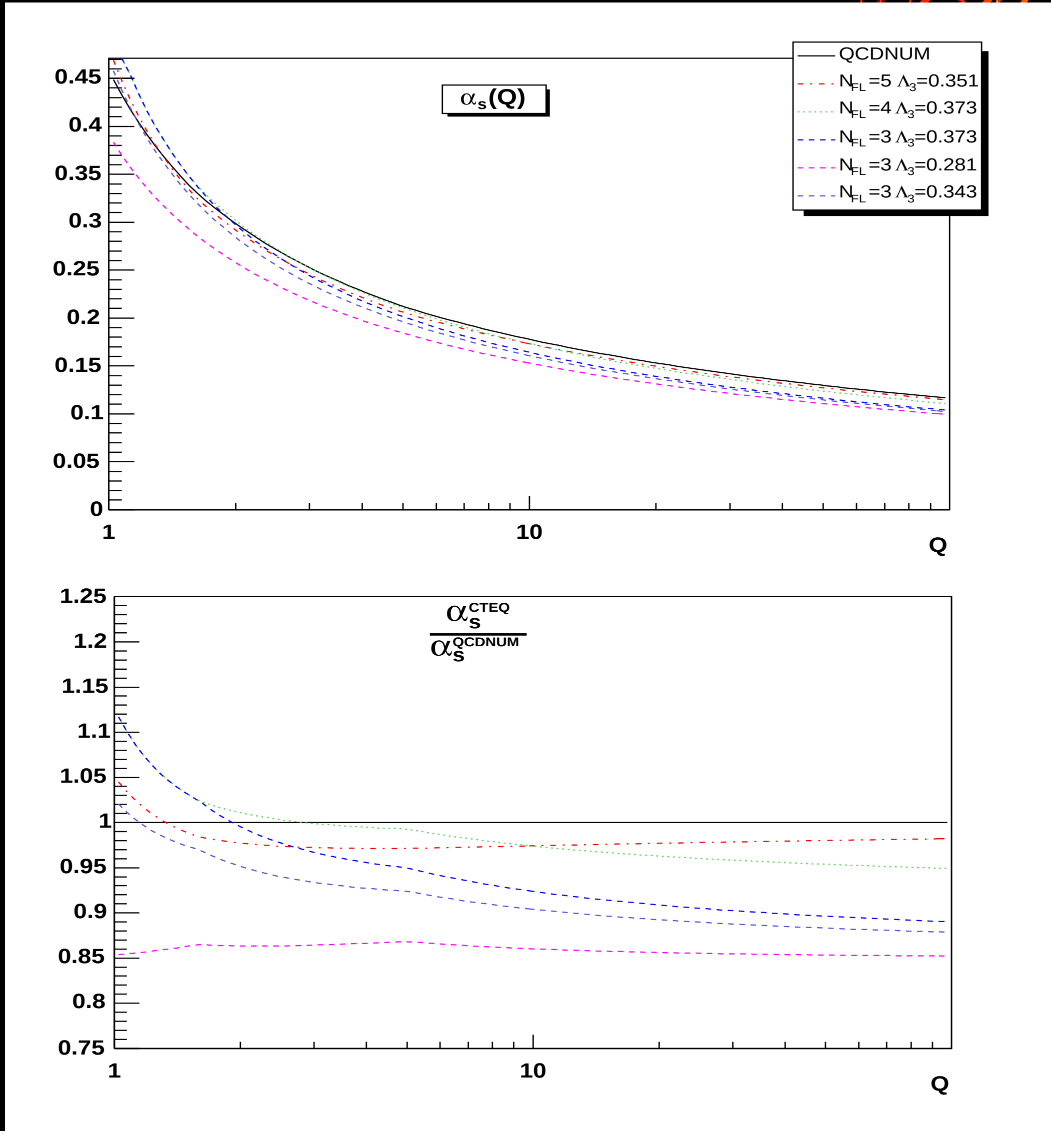
Conclusions

- Regge Factorization tests succeeded for $x_{IP} < 0.01$
- Simple parameterization of Pomeron parton distribution function allows to describe well existing data in selected kinematical range.
- We didn't succeed to fit ZEUS FPC and H1 data using the same parameterization even with introducing some overall normalization factor.
- The fraction of the Pomeron momentum carried by gluons was found to be *70-90%* for ZEUS LPS/H1 data and *55-65%* for ZEUS FPC data.
- Although the probability of diffraction can be calculated at any value of x, the results below 10^{-4} are unphysical. Possible reason is gluon saturation.

The End

Thank you

Computation of Strong coupling constant.



DIS Formalism

- **Cross section can be expressed as,**

$$\frac{d^2\sigma}{dxdy} = \frac{4\pi\alpha^2 s}{Q^4}\left(\frac{y^2}{2}2xF_1(x,Q^2) + (1-y)F_2(x,Q^2)\right)$$

  - The structure functions F_1 and F_2 are process dependent

- **At high Q^2 it can be represented as incoherent sum of lepton quark interactions**

$$\frac{d^2\sigma^{ep}}{dxdy} = \sum_q \frac{d^2\sigma^{eq}}{dxdy}$$

- **In the leading order the structure functions are,**

$$F_1(x) = \frac{1}{2}\sum_i q_i^2 f_i(x) \qquad F_2(x) = 2\sum_i xq_i^2 f_i(x)$$

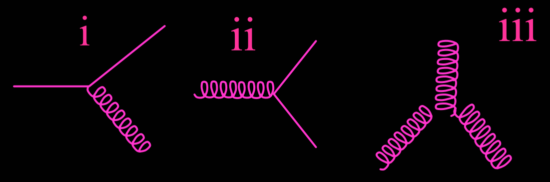
  - *f(x)* is a probability density of finding parton with momentum *x*

- **Then the Callan-Gross relation should hold,**

$$2xF_1 = F_2$$

Evolution Equations

- In QCD partons interacts one with another through the exchange of gluons and so the parton distribution functions become Q^2 dependent. The following processes must be considered:
    i. Gluon Bremsstrahlung,
    ii. Quark pair production by gluon,
    iii. *ggg* coupling.



- The DGLAP evolution equations describe the evolution of parton distribution functions with Q^2

$$\frac{dq_i(x,Q^2)}{d\log Q^2} = \frac{\alpha_s}{2\pi}\int_x^1 \frac{dy}{y}\left[q_i(y,Q^2)P_{qq}\left(\frac{x}{y}\right) + g(y,Q^2)P_{qg}\left(\frac{x}{y}\right)\right]$$

$$\frac{dg_i(x,Q^2)}{d\log Q^2} = \frac{\alpha_s}{2\pi}\int_x^1 \frac{dy}{y}\left[\sum_i q_i(y,Q^2)P_{gq}\left(\frac{x}{y}\right) + g(y,Q^2)P_{gg}\left(\frac{x}{y}\right)\right]$$

- The emission of non-collinear gluons by quarks will induce an appearance of non-vanishing σ_L. This leads to the violation of Callan-Gross relation which can be quantified by longitudinal structure function,

$$F_L = F_2 - 2xF_1$$

Diffractive DIS Formalism

- In an analog to the DIS, the diffractive cross section can be expressed as,

$$\frac{d^2\sigma^D}{dxdy} = \frac{4\pi\alpha^2 s}{Q^4}\left(\frac{y^2}{2}2xF_1^D(x,Q^2) + (1-y)F_2^D(x,Q^2)\right)$$

- Then the four-fold differential X sec. can be written as,

$$\frac{d^4\sigma^D}{dx_{IP}dtd\beta dQ^2} = \frac{4\pi\alpha^2}{\beta Q^2}\left(\left[1-y+\frac{y^2}{2}\right]F_2^{D(4)}(x,Q^2,x_{IP},t) - \frac{y^2}{2}F_L^{D(4)}(x,Q^2,x_{IP},t)\right)$$

- Let us introduce reduced X sec.,

$$\frac{d^4\sigma^D}{dx_{IP}dtdxdQ^2} = \frac{4\pi\alpha^2 s}{Q^4}\left(1-y+\frac{y^2}{2}\right)\sigma_r^{D(4)}(x_{IP},t,\beta,Q^2)$$

$$\sigma_r^{D(4)} = F_2^{D(4)} - \frac{y^2}{2(1-y+y^2/2)}F_L^{D(4)}$$

- Two quantitative conclusions can be made.

  i. F_L affects σ_R at high y.

  ii. If $F_L = 0$ then $\sigma_R = F_2$.

- Three-fold variables are defined in the following way:

$$X^{D(3)} = \int dt X^{D(4)}$$

Diffractive parton distributions

- **QCD Factorization holds for diffractive processes,**

$$d\sigma = \sum_i \int d\beta f_i^{(D)}(b,\ x/\beta\ , t; \mu)\ d\hat{\sigma}_i$$

  - **where,**
    - **the index i is the flavor of the struck parton,**
    - **the hard-scattering coefficients $d\hat{\sigma}$ are perturbatively calculable and are the same as for the corresponding fully inclusive cross section,**
    - **the renormalization/factorization scale should be of the order of Q,**
    - **the diffractive parton distribution function $f^{(D)}$ is the density of partons conditional on the observation of a diffractive proton in the final state.**

- **Then F_2^D can be represented in the following way:**

$$\frac{d^2 F_2^D(x, Q^2, x_{IP}, t)}{dx_{IP}dt} = \sum_i \int d\beta \frac{d^2 f_i^D(\beta, x_{IP}, t; \mu)}{dx_{IP}dt} \hat{F}_{2,i}(\beta, Q^2; \mu)$$

- **The probability of diffraction looks like,**

$$P_i(x, Q^2) = \frac{\int\ f_i^{(D)}(\beta, x_{IP}, t; \mu)\ \delta(x - x_{IP}\beta)\ dx_{IP}\, d\beta\ dt}{f_i(x, Q^2)}$$

Regge Theory

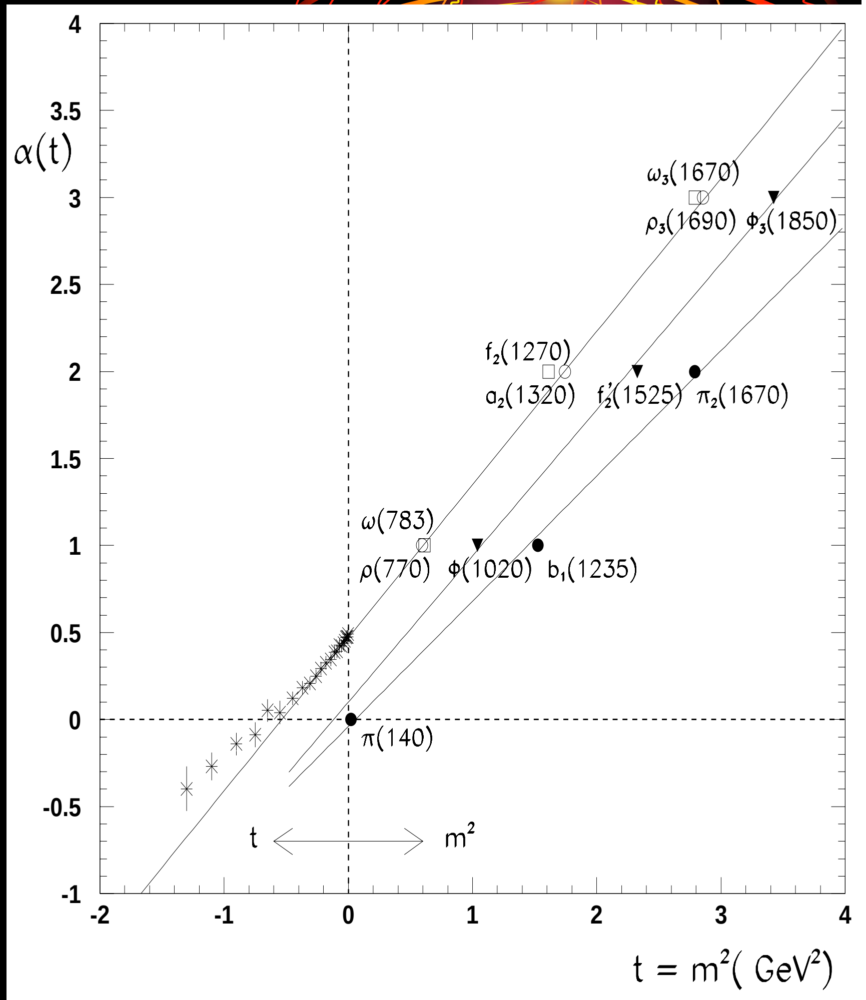
- **Hadrons with different spins but same other quantum numbers lie on *Regge Trajectories***

$l = \alpha(t)$ $\alpha(m_i^2) = J_i$ $\alpha(t) = \alpha_0 + \alpha' t$

- **In hadron-hadron interactions it is useful to consider the exchange of the whole trajectory and not of a single particle.**

- **Then the scattering amplitude is given by,**

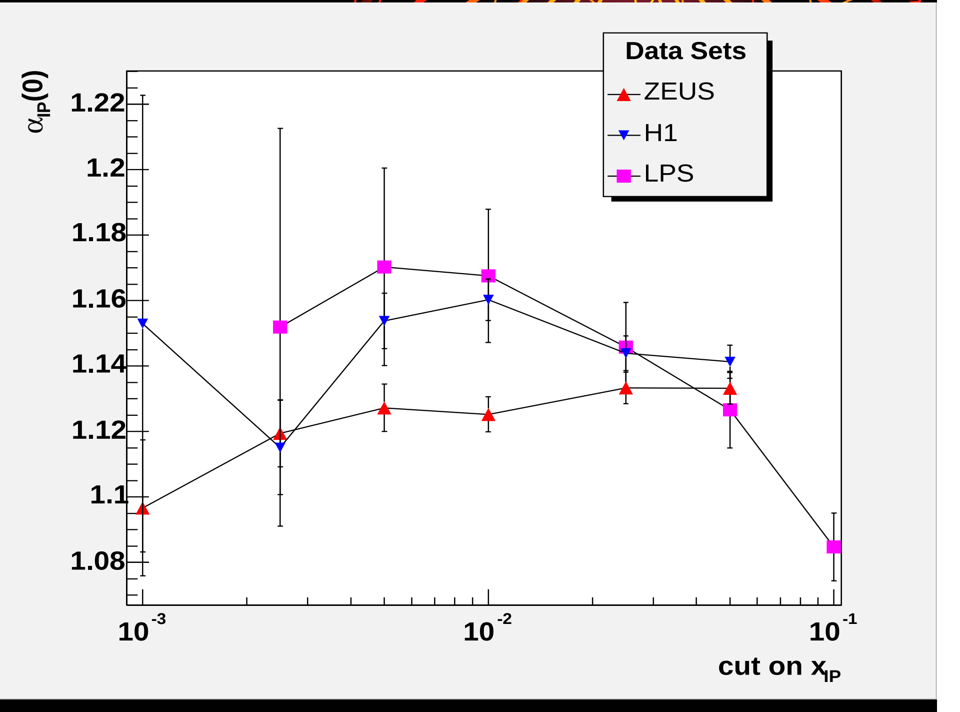
$$A(s,t) \sim s^{\alpha(t)}$$

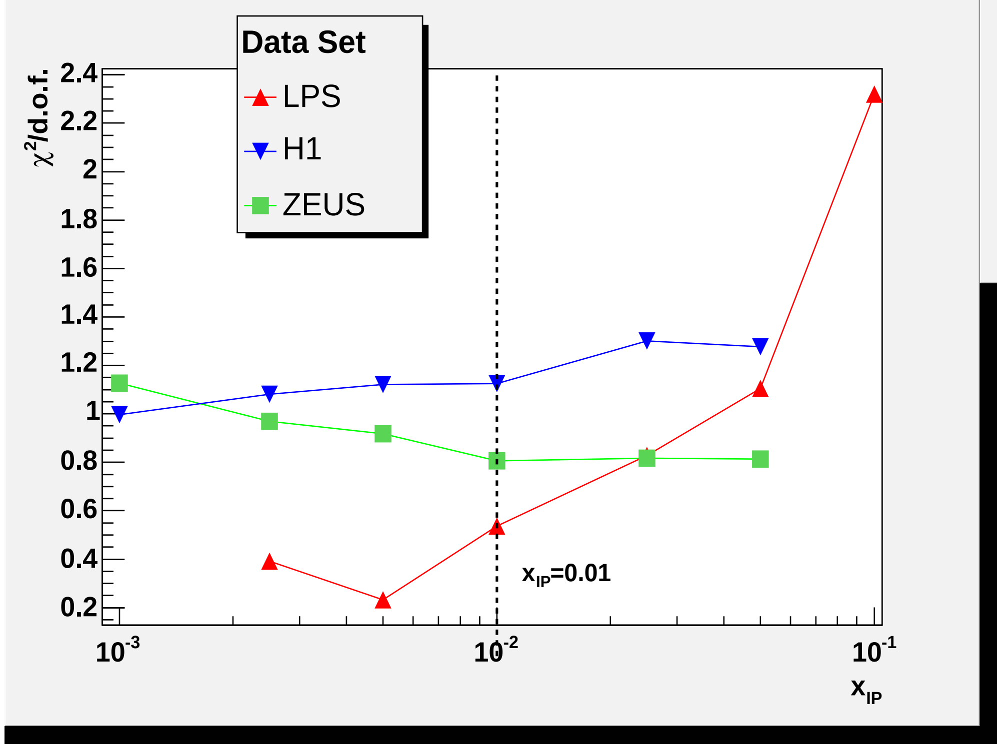


□ ω ▼ φ

○ ρ ● π

Cut on x_{IP} and Regge Factorization Test.



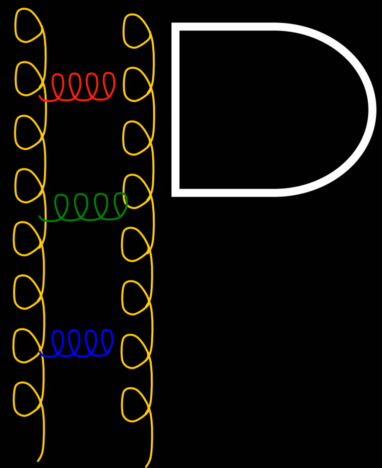


e P scattering

- Elastic Scattering
- Deep Inelastic Scattering (DIS)
- Diffractive DIS
  - Inclusive diffraction
  - Vector Meson production

What is Pomeron?

- Regge Trajectory
- Object with vacuum quantum numbers
  - Colorless
  - Self-charge-conjugate
  - Isoscalar
- Two gluon exchange
- Ladder structure develops
- Quark constituent may also exist.

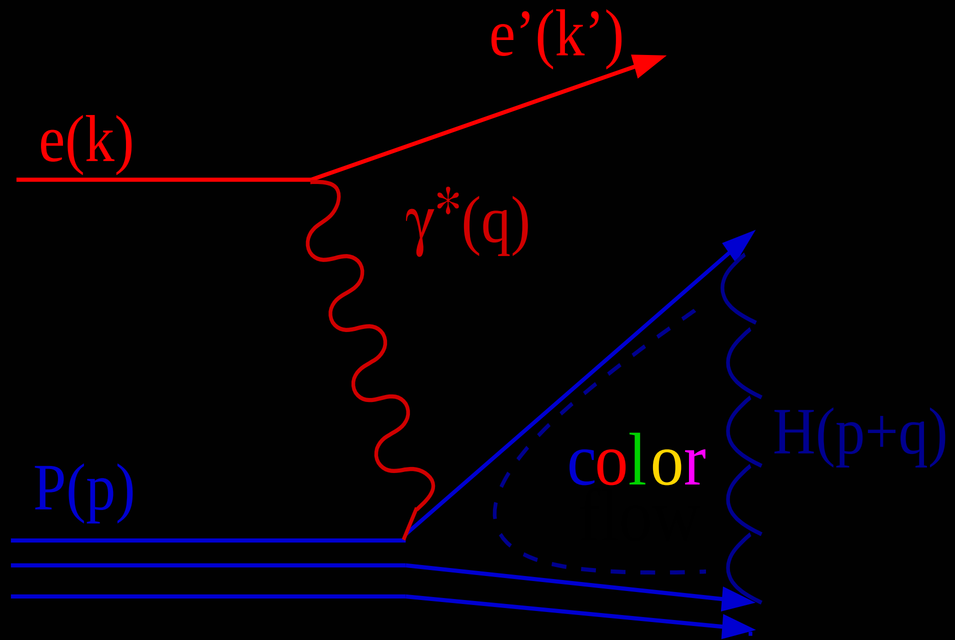


≡ IP

Theoretical Framework

Deep Inelastic Scattering

$$e(k) + P(p) \xrightarrow{\gamma^*} e(k') + H(p+q)$$



$$Q^2 \equiv -(k-k')^2$$

$$W^2 \equiv (p+q)^2$$

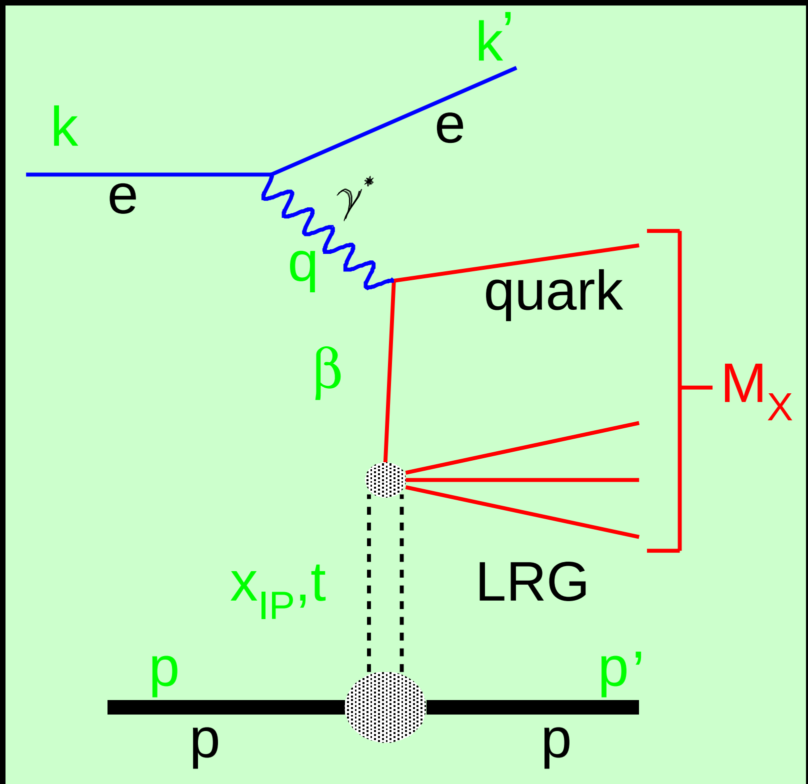
$$x \equiv \frac{Q^2}{2p \cdot q}$$

$$y \equiv \frac{p \cdot q}{p \cdot k} = \frac{Q^2}{sx}$$

Diffraction and the Pomeron

$$e(k) + P(p) \longrightarrow e(k') + P(p') + H$$

$$\gamma^*(q) + P(p) \xrightarrow{IP} P(p') + H$$



- **Ingelman and Schlein model of diffractive scattering**
- **If p' > 0.99 p - Pomeron exchange**
- **Pomeron has vacuum quantum numbers**
- **Large Rapidity Gap**

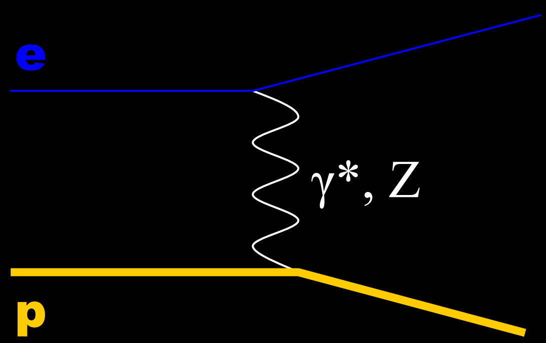
$$t \equiv (p - p')^2$$

$$x_{IP} \equiv \frac{q(p-p')}{q \cdot p} = \frac{M_X^2 + Q^2 - t}{W^2 + Q^2 - m_P^2} \approx \frac{M_X^2 + Q^2}{W^2 + Q^2}$$

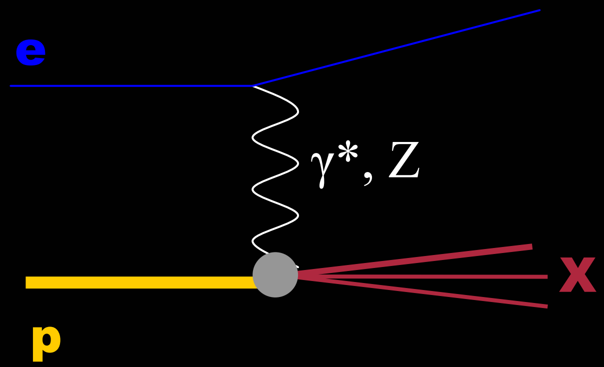
$$\beta \equiv \frac{Q^2}{2q \cdot (p - p')} \approx \frac{Q^2}{Q^2 + M_X^2}$$

$$x = x_{IP} \beta$$

Elastic Scattering

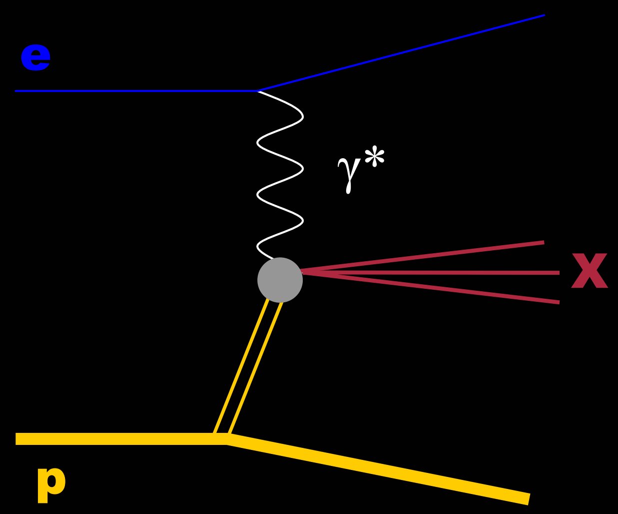


Deep Inelastic Scattering



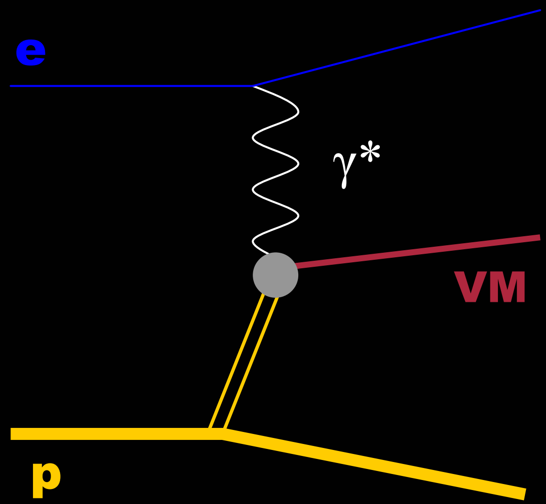
Diffractive Scattering

Inclusive Diffraction



Diffractive Scattering

Vector Meson production

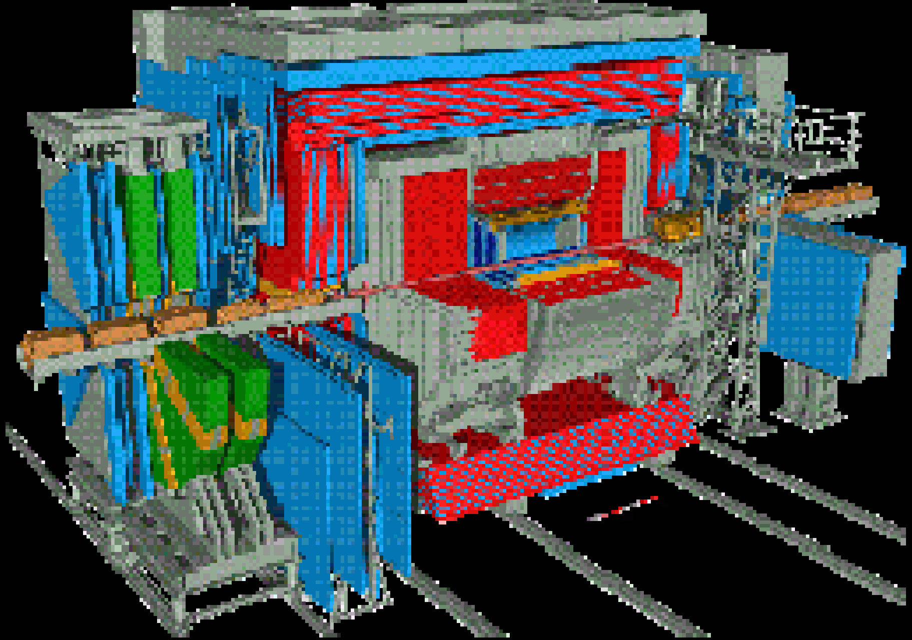


HERA accelerator at DESY

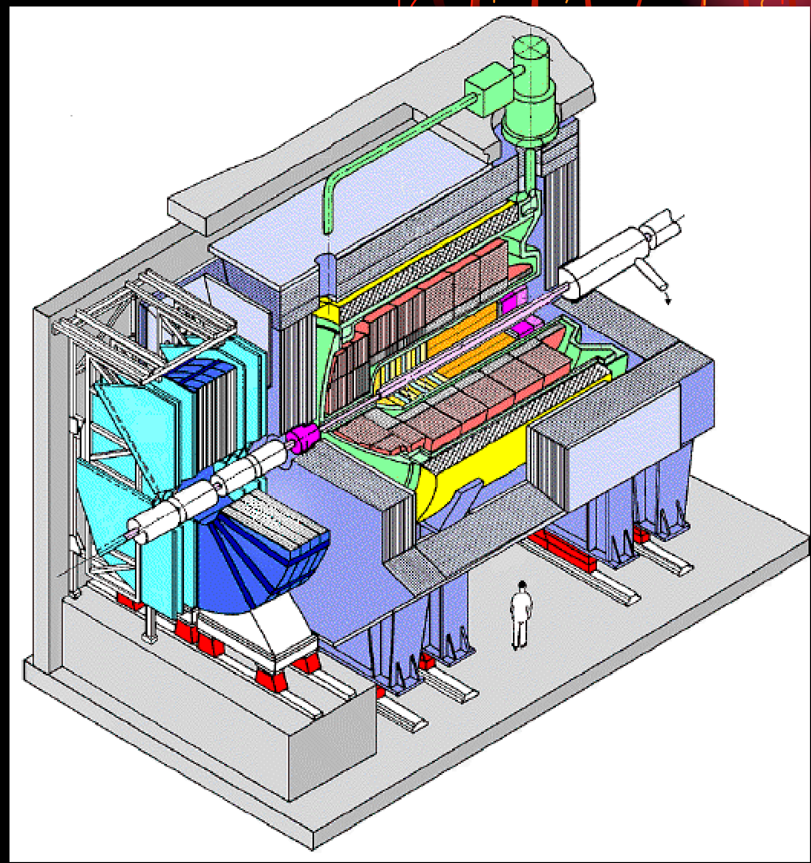
- **length – 6.5 km**
- **since – 1992**

$$E_P = 920\,GeV$$
$$E_e = 30\,GeV$$
$$\sqrt{s} = 330\,GeV$$

Detectors at HERA



ZEUS



H1

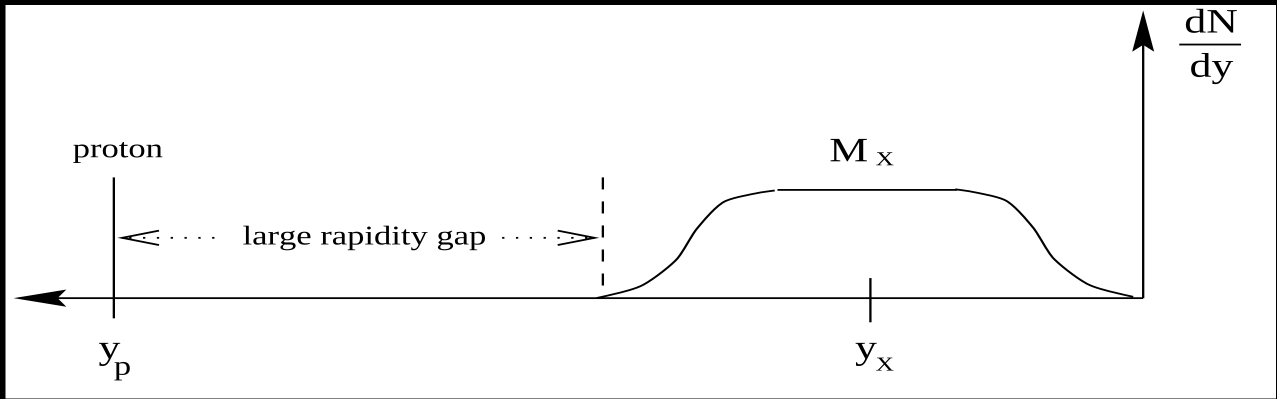
Experimental signatures of diffraction

- **Outgoing proton with high momentum. Unfortunately, very often proton goes down the beam pipe and thus can not be observed. Only ZEUS LPS detector allows to detect diffractive protons directly.**
- **Large Rapidity Gap.**

$$y_P = \frac{1}{2}\ln\frac{E_P + p_L}{E_P - p_L} \approx \frac{1}{2}\ln\frac{W^2}{m_P^2}$$

$$y_X = \frac{1}{2}\ln\frac{E_X + p_L}{E_X - p_L} \approx \frac{1}{2}\ln\frac{W^2}{M_X^2}$$

$$\Delta y = y_P - y_X \approx \ln\frac{W^2}{m_P M_X}$$

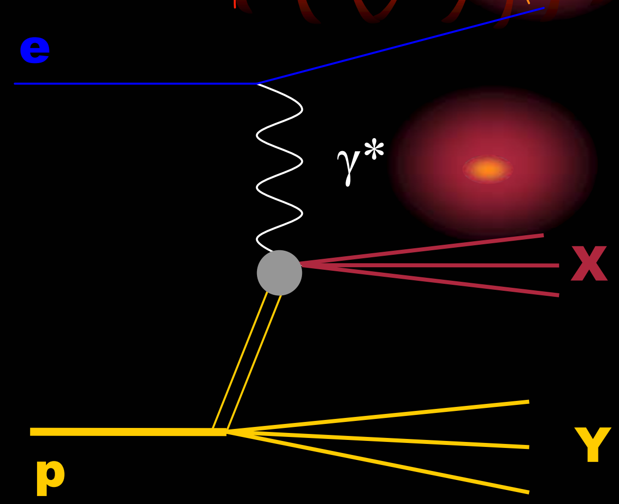


- **Problem: if proton is not seen then a selection on absolute value of rapidity must be done.**

Proton dissociation

- There are also processes where proton doesn't remain intact and also dissociates into some system Y. In this case the LRG can be still observed. This process is called *double diffractive dissociation*.

$$\gamma^* + P \xrightarrow{IP} X + Y$$

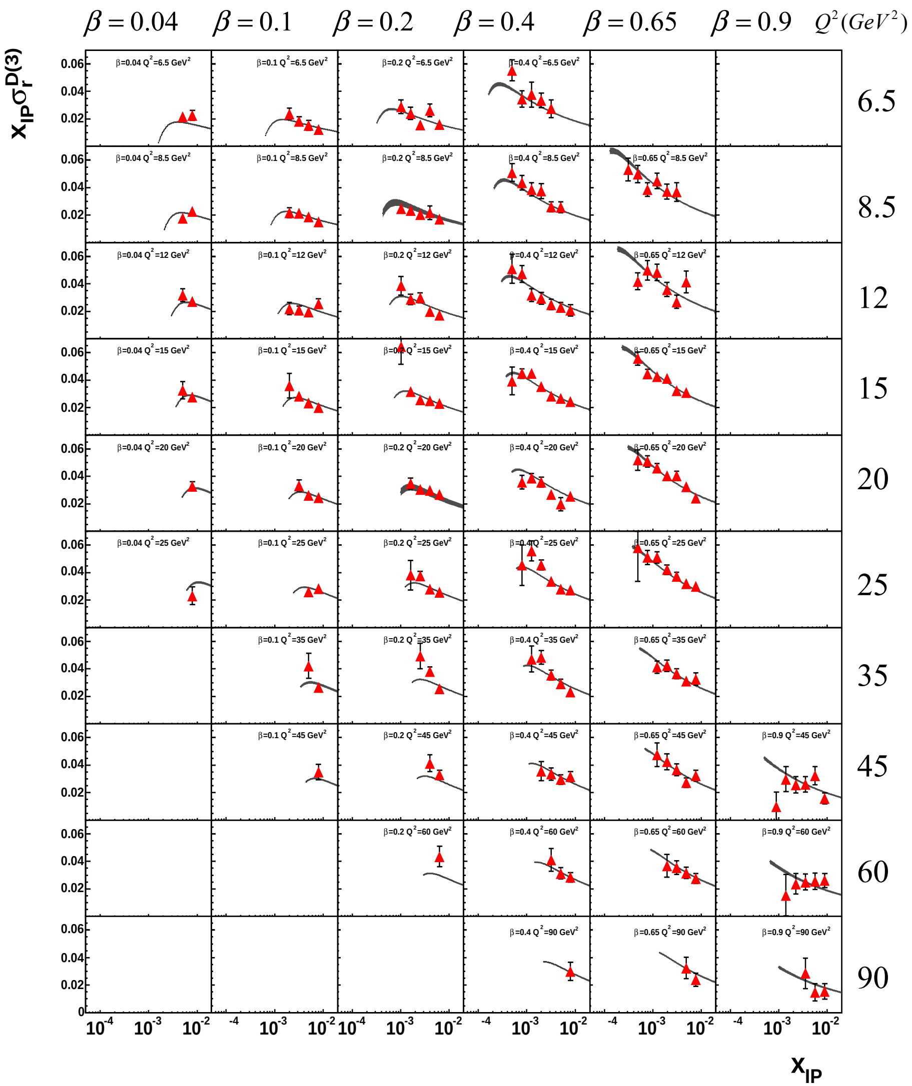


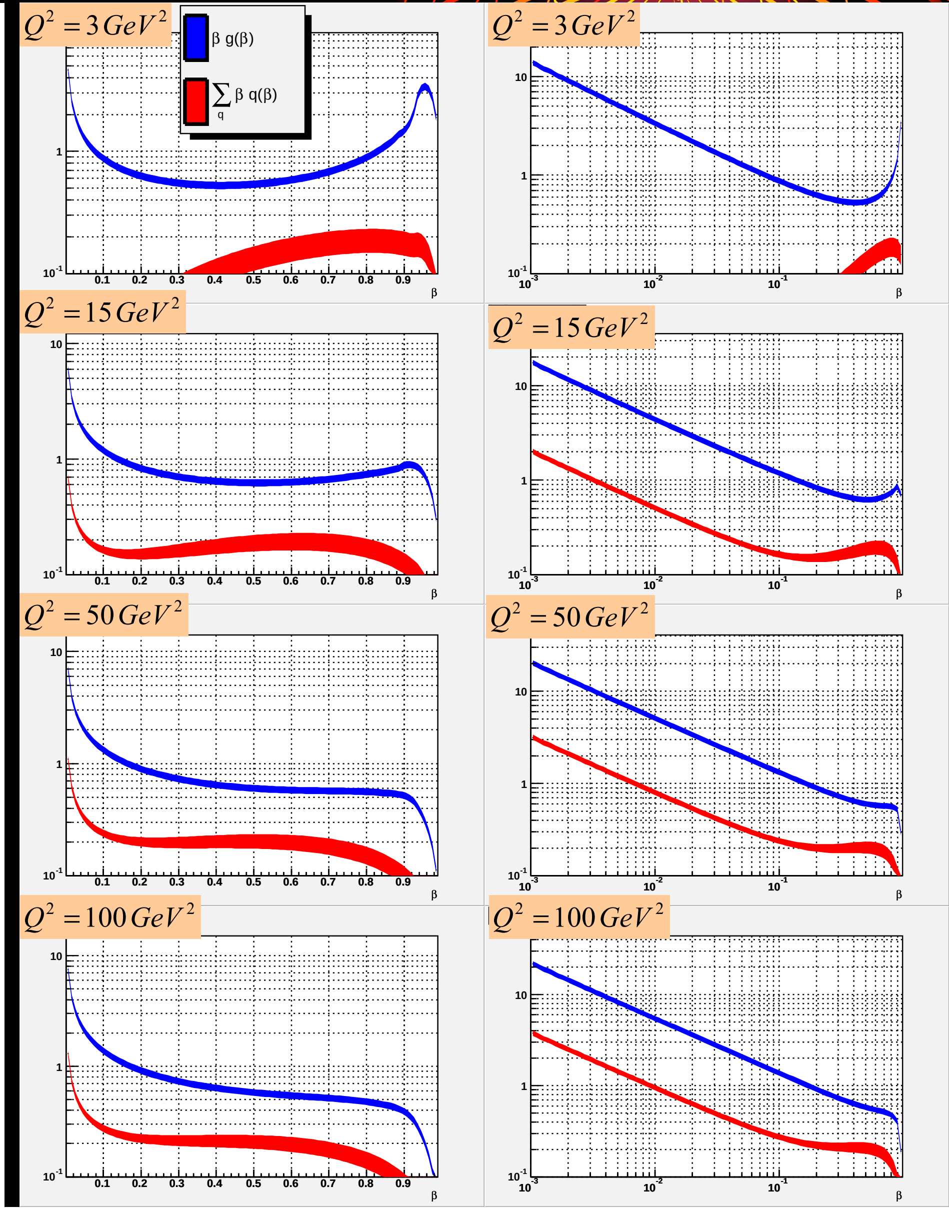
- If the proton breaks up one can not be sure that the exchanged object had vacuum quantum numbers. In addition the Pomeron proton coupling can change.
- In order to get *pure* sample it is necessary to exclude proton dissociation events. Unfortunately we often do not know whether dissociation occurred or not.

Differences between data sets

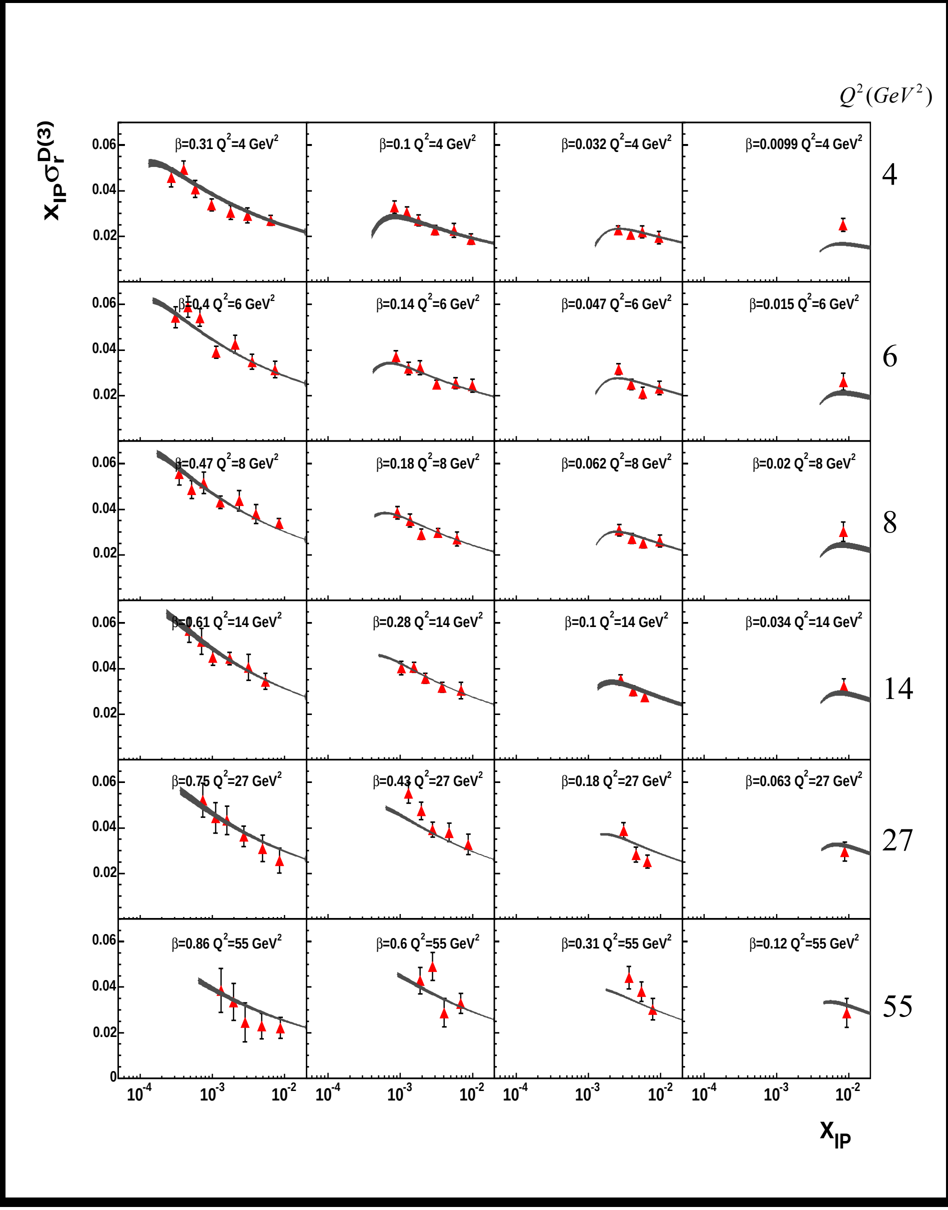
- **Background evaluation**
  - The LRG can be also observed for non-diffractive events. It is exponentially suppressed for small values of Mx, but becomes very important for high masses.
  - H1 group uses Monte-Carlo simulations in order to evaluate background, while ZEUS FPC group developed their own *Mass Decomposition Method*.
- **Proton dissociation**
  - It is often impossible to determine whether the proton indeed remained intact and hadn't dissociated. Detector structure and kinematics provide only an upper limit for mass of the object that went down the beam pipe. For H1 detector this value is $2GeV$ while for ZEUS detector it is $4GeV$. To overcome this problem appropriate corrections must be done.
- LPS part of the detector doesn't have such problems because it measures outgoing proton directly. Unfortunately it has low acceptance which leads to small statistics.

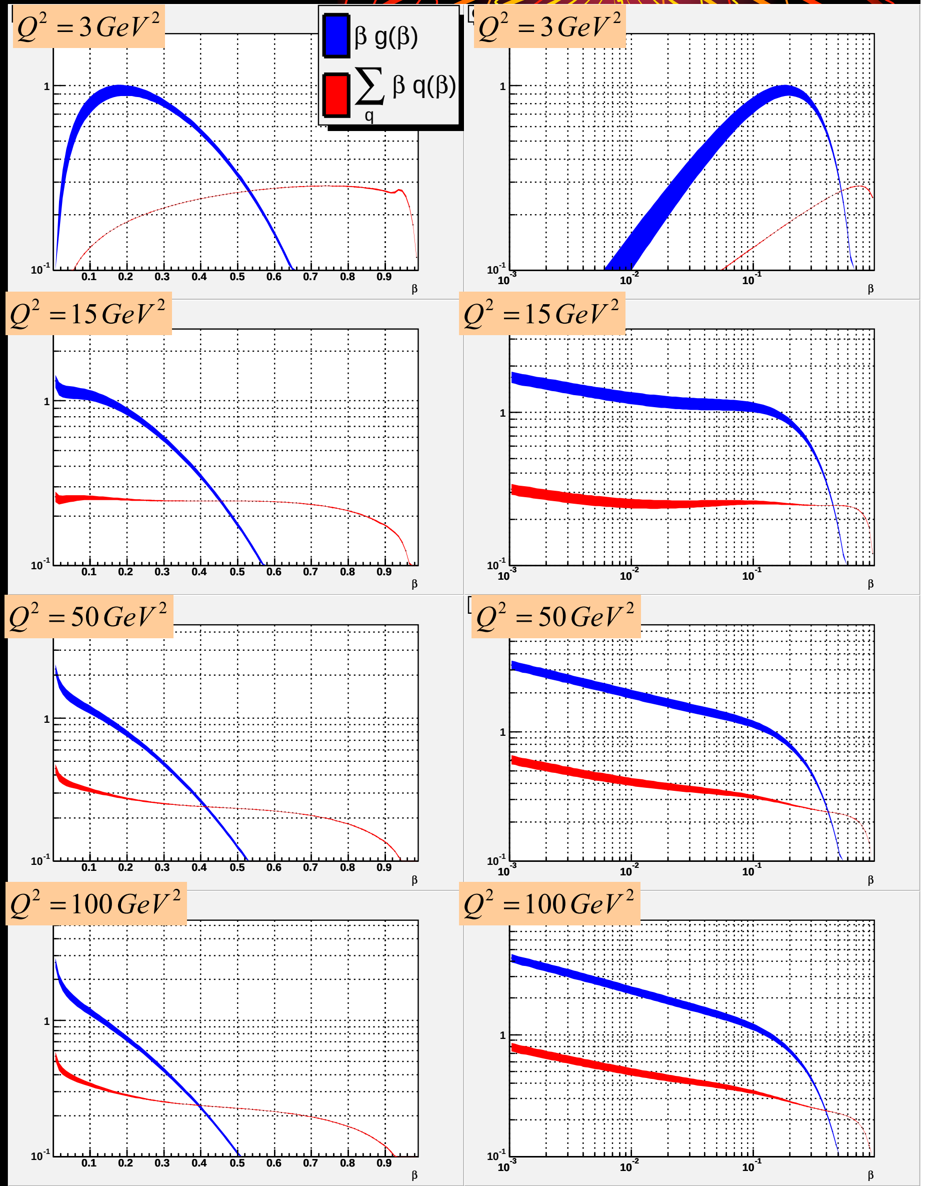
Fit results for H1 data



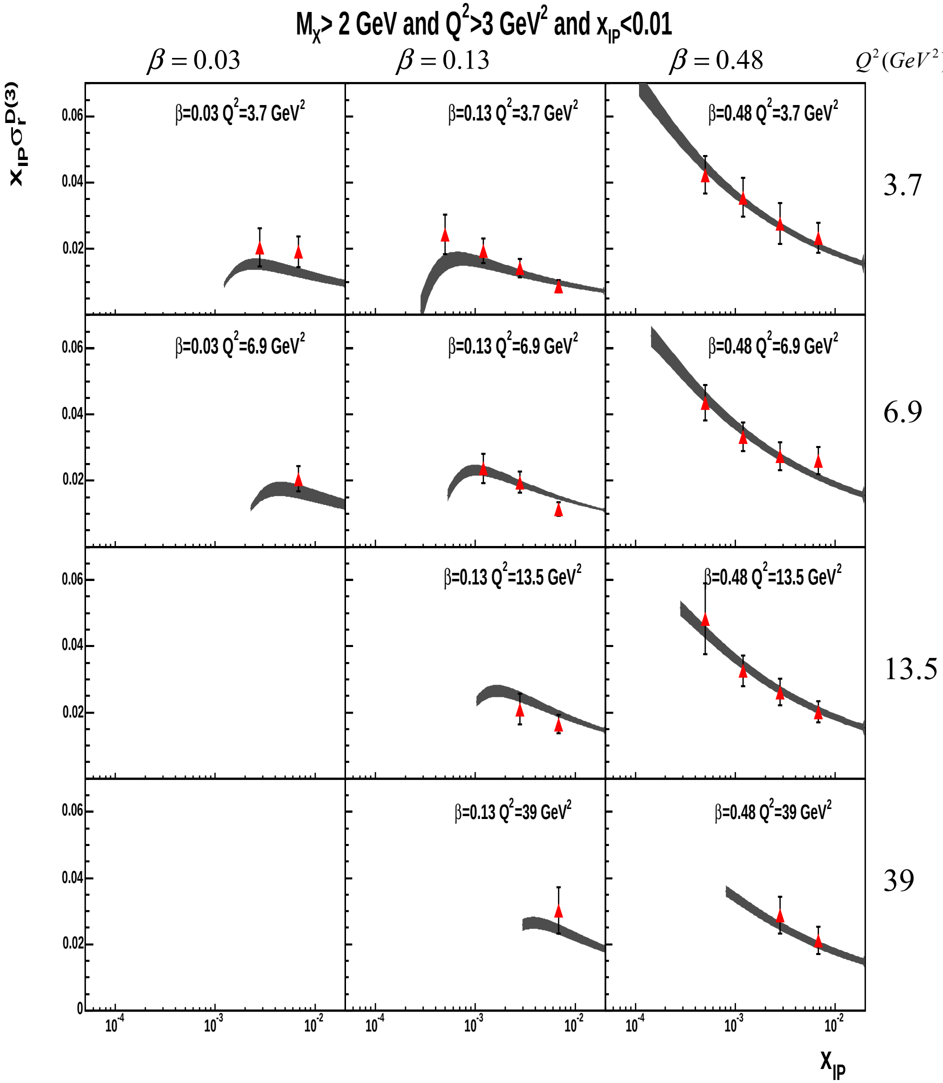


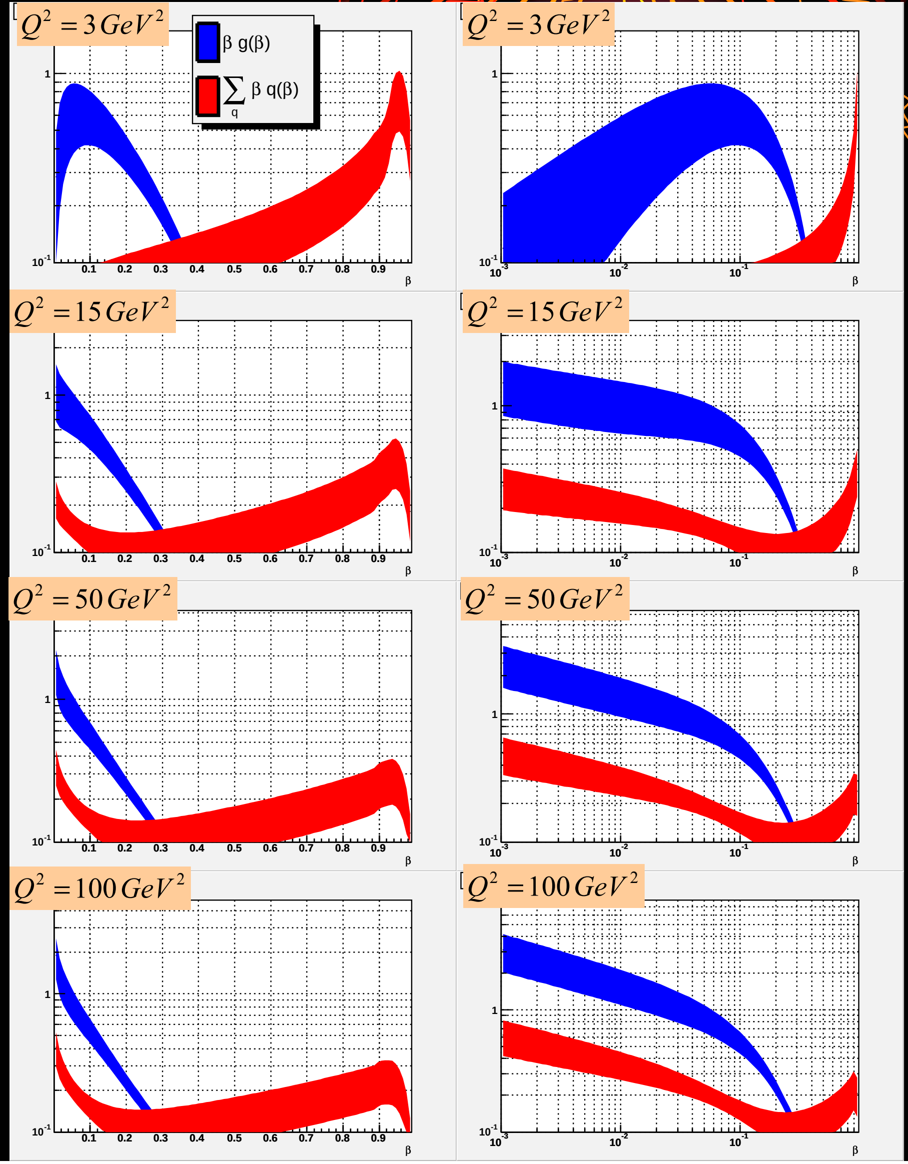
Fit results for ZEUS FPC data



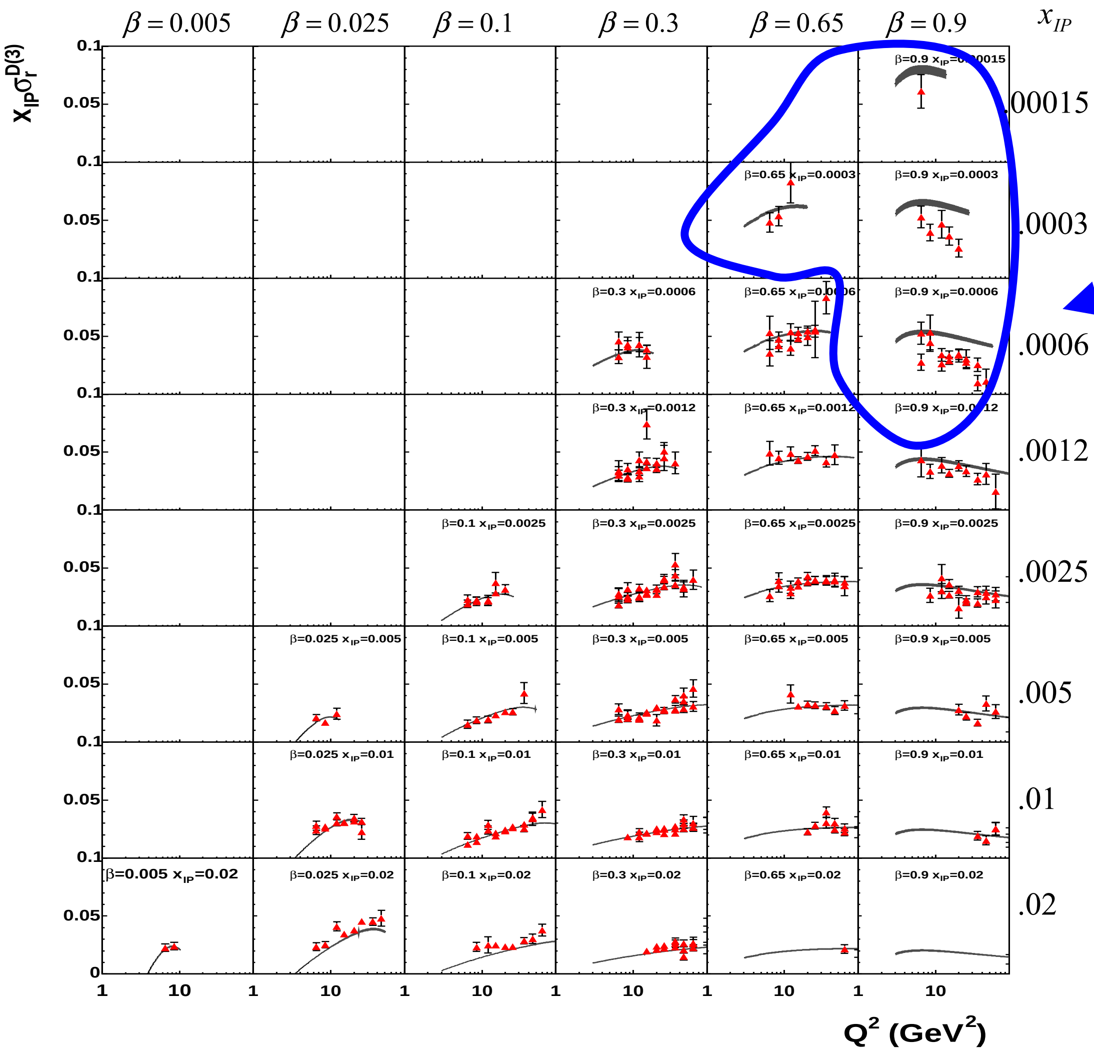


Fit results for ZEUS LPS data



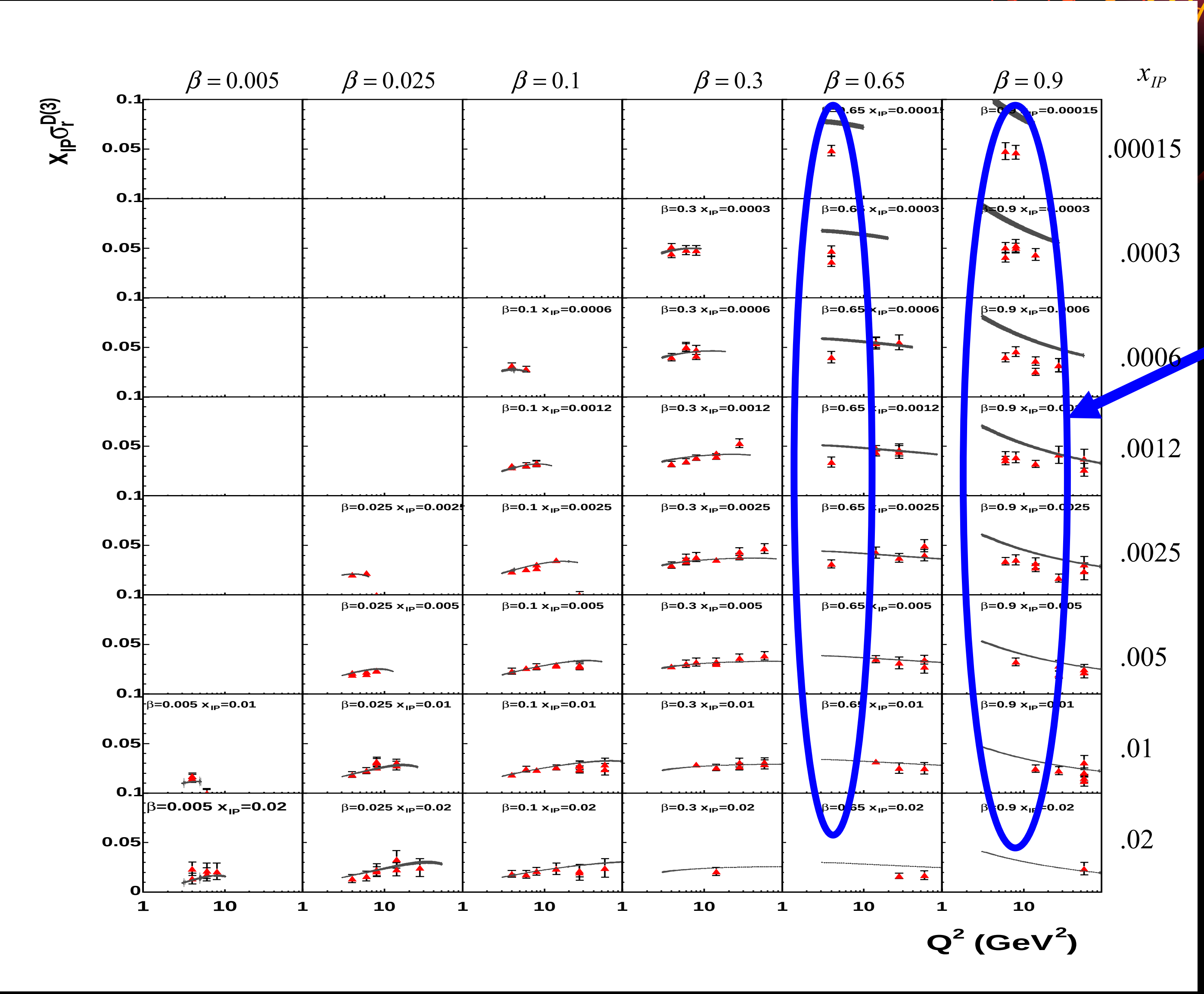


Q^2 Dependence of H1 data



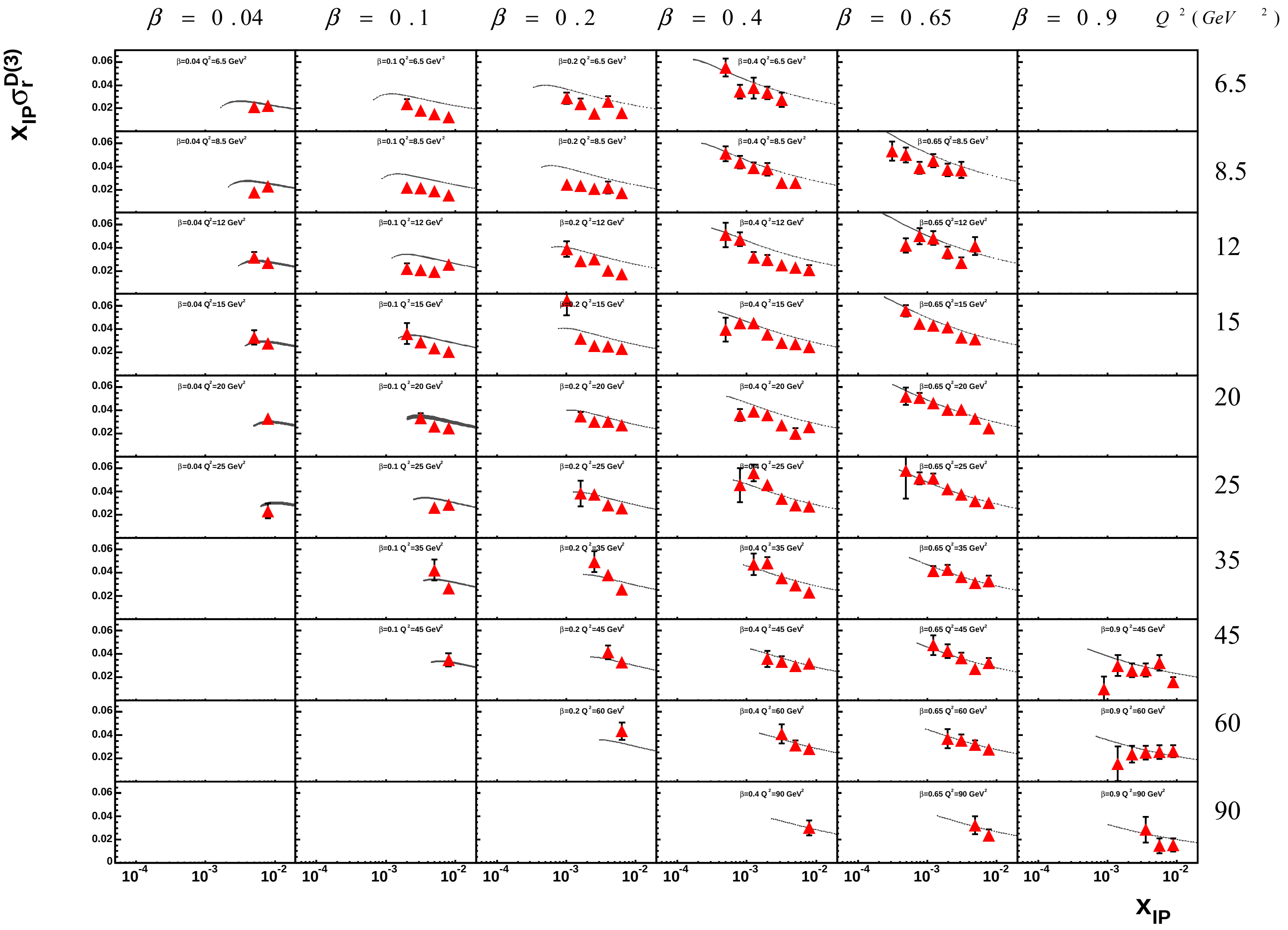
Data with $Mx<2$ GeV

Q^2 Dependence of ZEUS FPC data

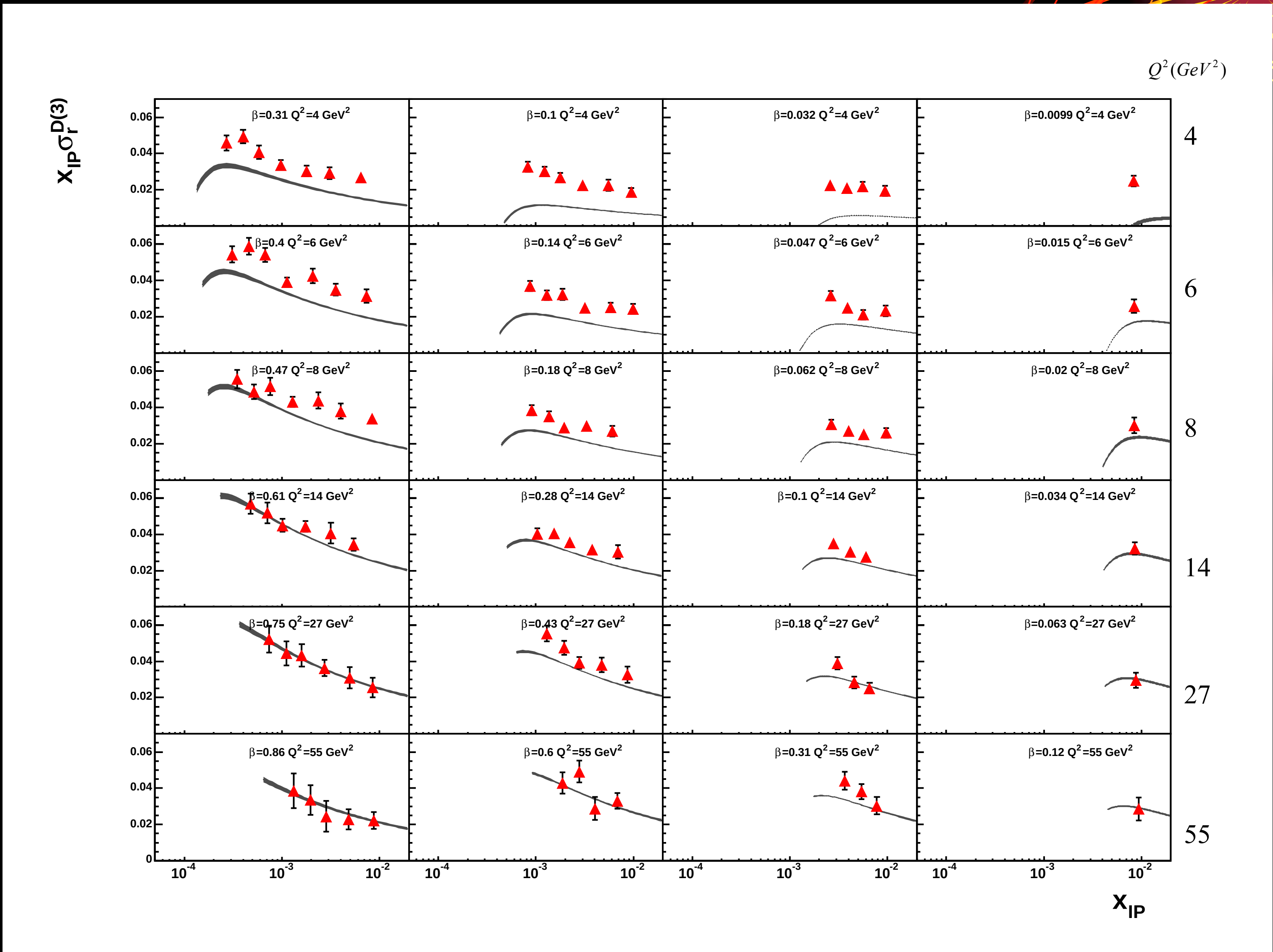


Data with *Mx<2* GeV

ZEUS FPC fit vs. H1 data



H1 fit vs. ZEUS FPC data



Overview

- Obtain experimental diffractive data
- Test validity and limitations of the Regge Factorization
- Fit the experimental data assuming the validity of the Regge factorization in the selected kinematic range
- Calculate some physical quantities using the fit results

Probability of Diffraction

H1 data

$$P_q^D(x,Q^2) = \frac{\sum_i \int dx_{IP}\, d\beta\, \delta(x - x_{IP}\beta)\, f_{IP}(x_{IP})\, q_i^{IP}(\beta,Q^2)}{\sum_i q_i^{IP}(x,Q^2)}$$

$$P_g^D(x,Q^2) = \frac{\int dx_{IP}\, d\beta\, \delta(x - x_{IP}\beta)\, f_{IP}(x_{IP})\, g_i^{IP}(\beta,Q^2)}{g_i^{IP}(x,Q^2)}$$