Measurement of the Longitudinal Proton Stucture Function in Diffraction

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HERA Accelerator

- the one and only *ep* accelerator in the world (since 1992)
- data taking ended on 02.07.2007
- recently, there is no other *ep* collider to be built

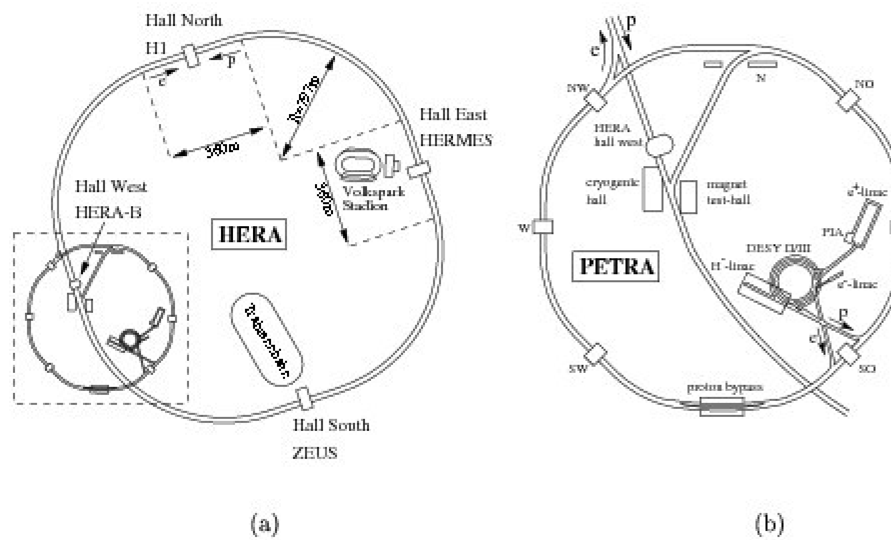


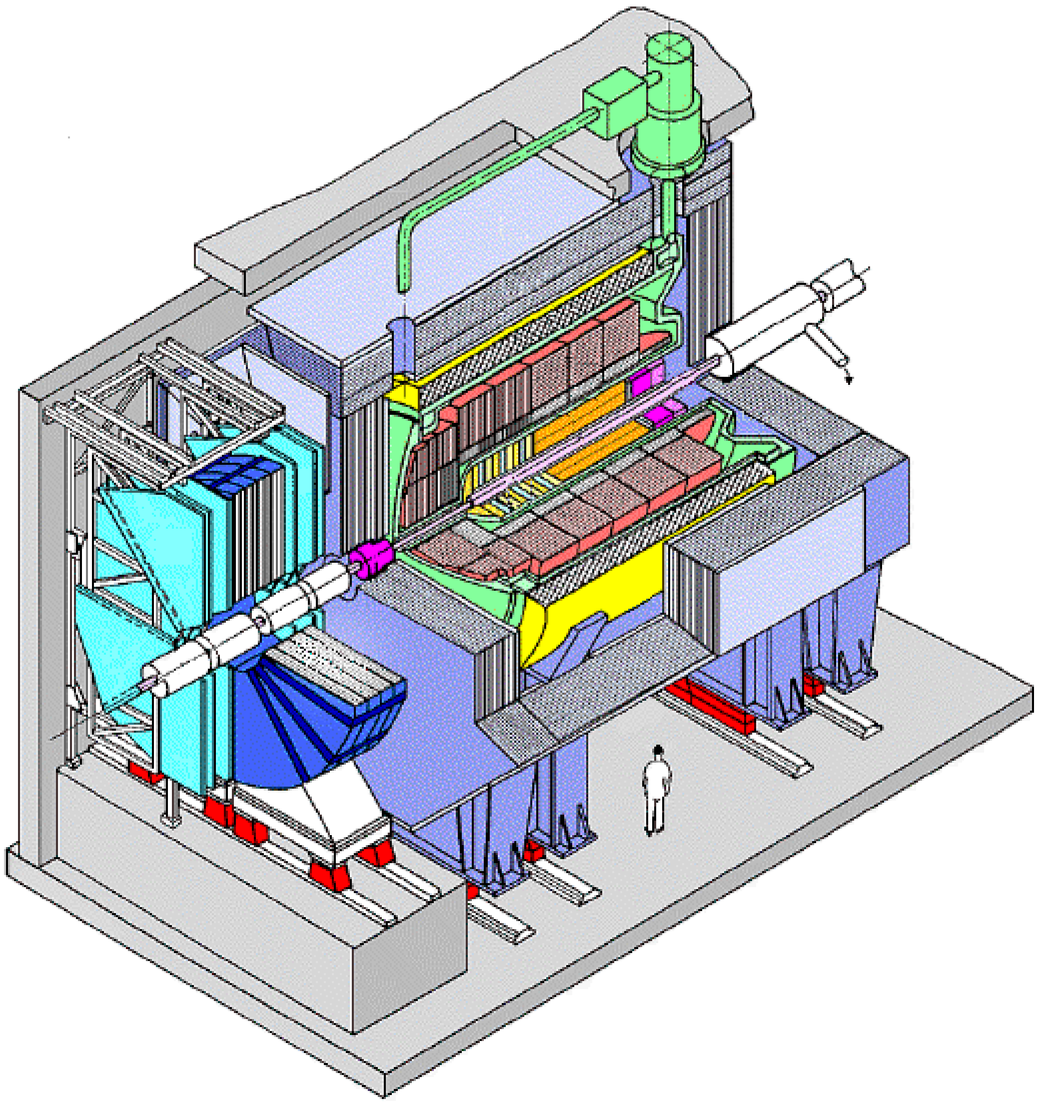
Fig. 3.1. *HERA (a) and its pre-accelerators (b).*

E_p = 920 GeV
E_e = 27.5 GeV

H1 Experiment

THE H1 EXPERIMENT AT HERA

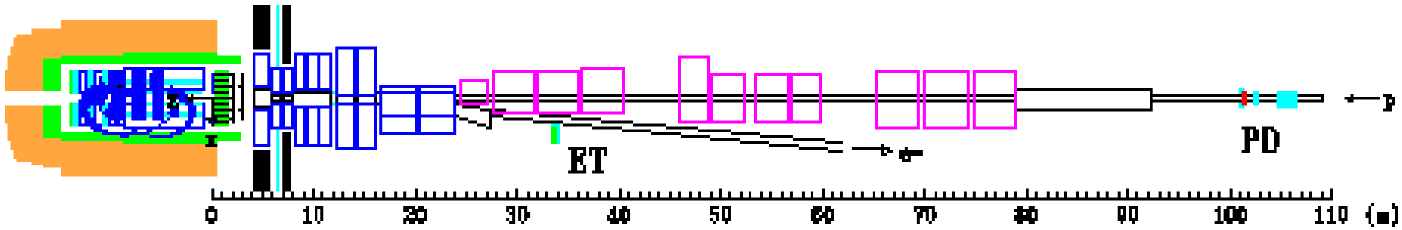
H1 Collaboration at DESY, Notkestr.85, D-22607 Hamburg, Germany



- tracking detectors
  - silicon detectors
  - drift chambers
- calorimeters
  - LAr, spagetti calorimeter
- muon chambers
- forward detectors
  - FMD, PRT
  - FPS, VFPS
- and others

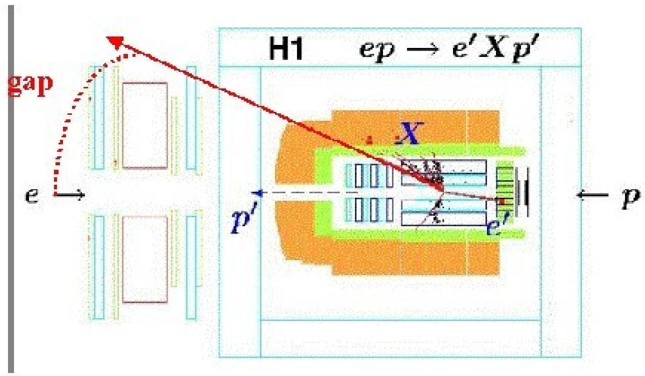
Cross Section Measurement

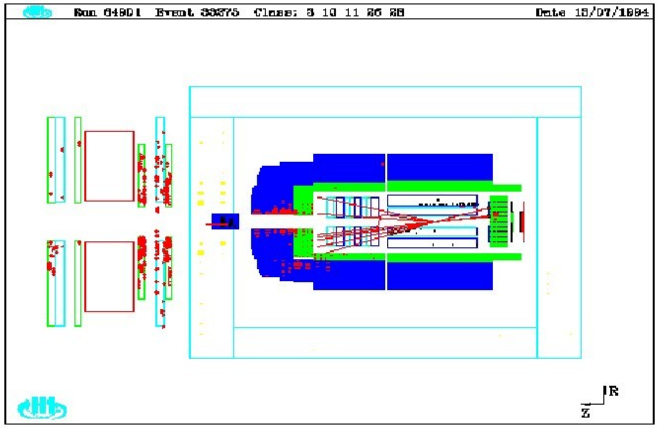
- number of events is proportional to luminosity $N=\sigma L$
- luminosity can be calculated out of the beam properties
- but it is more likely to be measured by some well known process
- Bethe-Heitler process $ep \longrightarrow ep\gamma$
  - calculable within QED
  - accuracy ~1%

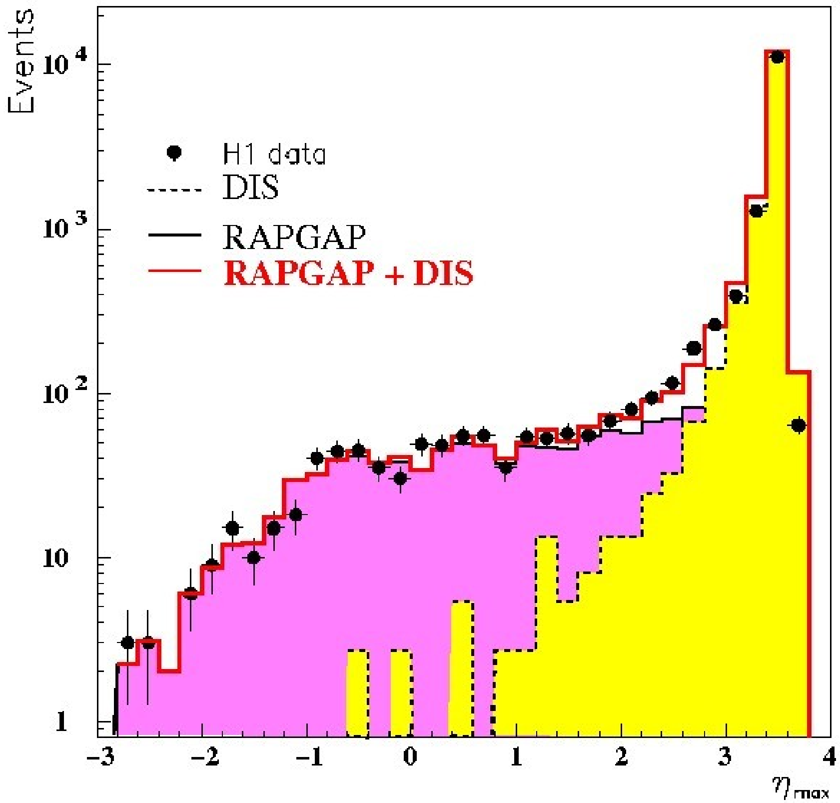


Rapidity Gap

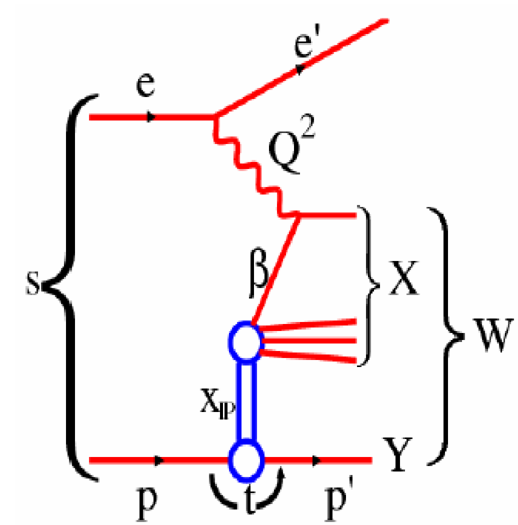
- rapidity $$y = \frac{1}{2}\log\frac{E+p_z}{E-p_z} = \frac{1}{2}\log\frac{(E+p_z)^2}{m^2+p_t^2}$$
- pseudorapidity $$\eta = y|_{m=0} = \log\frac{E+p_z}{p_t} = -\log\left(\tan\frac{\theta}{2}\right)$$







Diffraction



~ 10% of DIS events have a rapidity gap

$t = (p - p')^2$

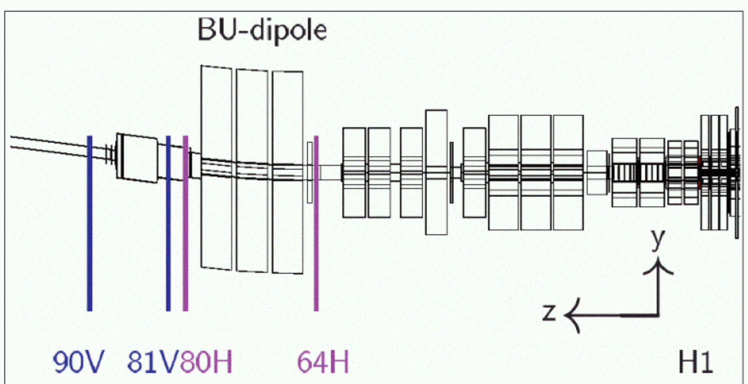
$\beta = x_{quark/IP}$

$x_{IP} = x_{IP/proton}$

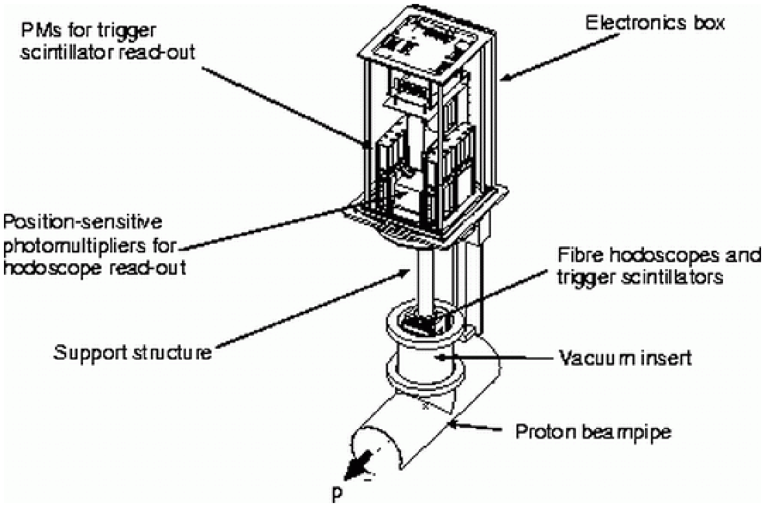
- inelastic process where the proton remains intact
  $ep \longrightarrow epX$
- rapidity gap reflects the exchange of colourless object with quantum numbers of vacuum (Pomeron)
- there is no colour flow between the final state *X* and the scattered proton *Y*

Forward Proton Detectors (FPS, VFPS)

- Roman pots detect scattered protons and measure their momenta
- an alternative to large rapidity gap cut to select diffractive data is to require a scattered proton in the Roman pots
- small acceptance makes the rapidity gap cut more favourable (for many analyses) as it is good to have larger statistics
- still, the Roman pots can be used to understand background better



Schematic view of the forward beam line with HERA magnets and all four FPS stations



Cross Section – Transversal and Longitudinal Component

$$\sigma = c\,\varepsilon^{\mu}\varepsilon^{\nu}W_{\mu\nu}$$

$$W_{\mu\nu} = -W_1(p,q)g_{\mu\nu} + W_2(p,q)\frac{p_\mu p_\nu}{M^2}$$

$$\varepsilon_L = \frac{1}{\sqrt{Q^2}}(q_3, 0, 0, q_0)$$

$$\varepsilon_L^2 = 1$$

$$q_3^2 - q_0^2 = Q^2$$

$$q_3^2 = \nu^2 + Q^2$$

$$\varepsilon_T = \frac{1}{\sqrt{2}}(0,1,0,0)$$

$$\varepsilon_T = \frac{1}{\sqrt{2}}(0,0,1,0)$$

$$\varepsilon_T^2 = -1$$

$$p = (M, 0, 0, 0)$$

$$\sigma = c\left(-W_1\varepsilon^2 + W_2\frac{(\varepsilon\cdot p)^2}{M^2}\right)$$

$$\sigma_T = c\,W_1$$

$$\sigma_L = c\left(-W_1 + W_2\frac{q_3^2}{Q^2}\right) = c\left(-W_1 + W_2\frac{Q^2+\nu^2}{Q^2}\right) \to_{Q^2 \ll \nu^2} c\left(-W_1 + W_2\frac{\nu^2}{Q^2}\right)$$

Measurement of the Longitudinal Proton Structure Function in DIS Using Two Different Centre-of-Mass Energies

$$\frac{d^2\sigma}{dx\,dQ^2}=\frac{4\pi\alpha^2}{Q^4 x}[F_2(1-y)+F_1 y^2 x]$$

$$F_2=\nu W_2$$

$$F_1=M W_1$$

$$R=\frac{F_2}{2\mathrm{xF}_1}-1=\frac{W_2\nu^2}{W_1 Q^2}-1=\frac{\sigma_L}{\sigma_T}$$

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

$$Y_+=1+(1-y)^2$$

$$\boxed{\frac{d^2\sigma}{dx\,dQ^2}=\Gamma(E,x,Q^2)[\sigma_T+\sigma_L\varepsilon(E,x,Q^2)]}$$

- x, Q^2 fixed
- y vary

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

- proton structure function F_2 is measured according to this formula
- structure functions F_2 and F_L cannot be separated unless you vary y
- without varying y the measurement of neither of the structure functions is not direct, it is based on some assumptions on one of them

Measurement of the Longitudinal Proton Structure Function in Diffraction

$$\frac{d^3\sigma^{ep\to eXY}}{dx_{IP}\,d\beta\,dQ^2}=\frac{2\pi\alpha^2}{\beta Q^4}Y_+\sigma_r^D(x_{IP},\beta,Q^2)$$

$$\sigma_r^D=F_2^D-\frac{y^2}{Y_+}F_L^D$$

$$Y_+=1+(1-y)^2$$

- the measurement will be performed in the same way as in case of F_L
- no direct measurement of F_L^D has been performed so far

$$\boxed{F_L^D=\frac{Y_+^{460}Y_+^{920}}{y_{460}^2Y_+^{920}-y_{920}^2Y_+^{460}}(\sigma_r^{D920}-\sigma_r^{D460})}$$

- x_{IP}, β, Q^2 fixed
- y vary $\qquad Q^2 = s\, x_{IP}\, \beta\, y$

Low Energy Runs at HERA

- last few weeks of HERA data taking were devoted to low energy runs that are necessary to measure the proton structure functions F_L and F_L^D
- at least 10 pb^{-1} of low energy data needed in order to perform a good F_L measurement
- $s = 4E_e E_p$
- 10 pb^{-1} of data with E_p = 460 GeV taken
- the low energy runnig was smooth, therefore the middle energy running had been proposed also
- 7 pb^{-1} of data with E_p = 575 GeV taken

Different Models

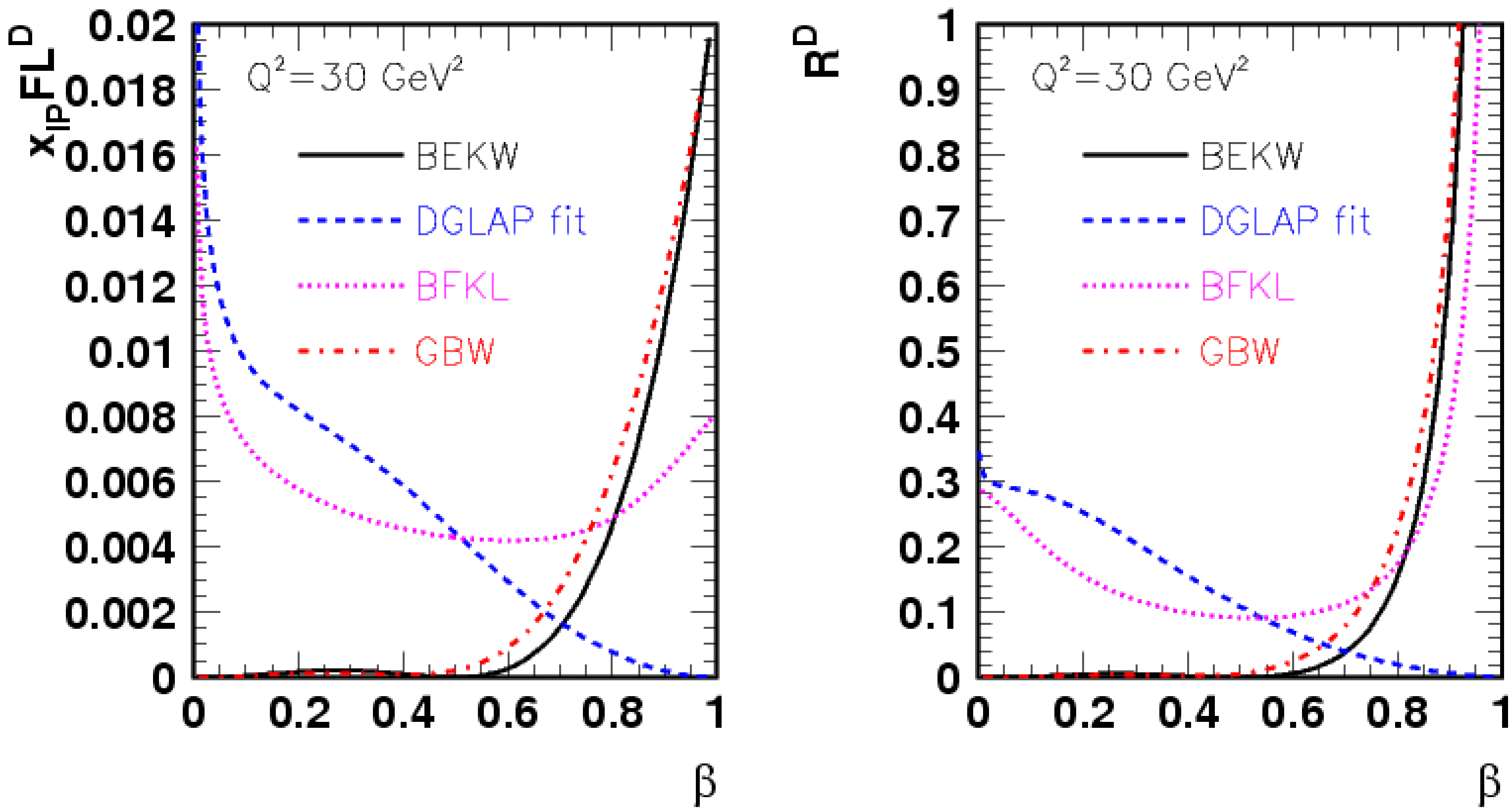
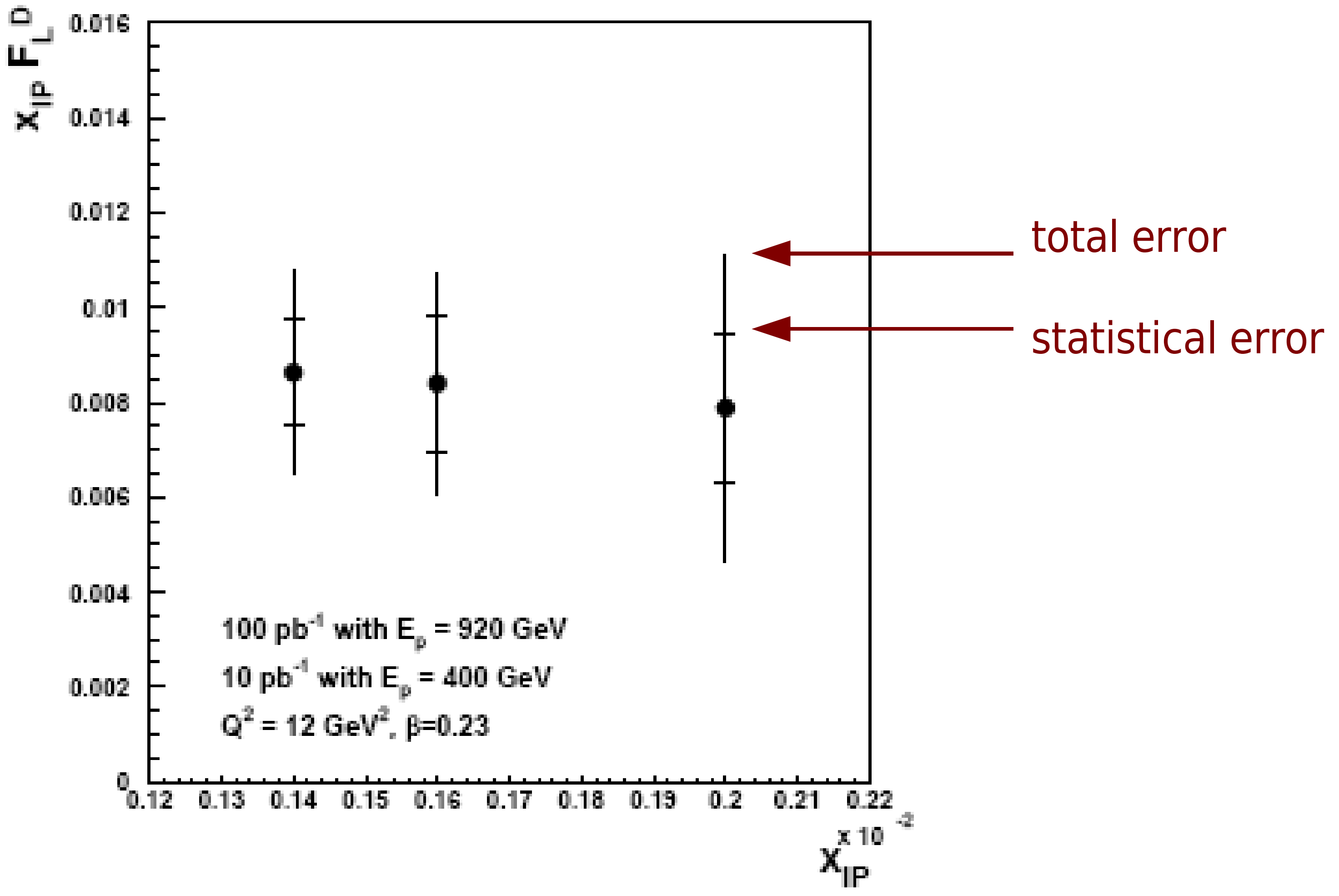


FIG. 9. Predictions for $x_{\mathbb{P}} F_L^D$ (left) and $R^D = \frac{F_L^D}{F_2^D - F_L^D}$ as a function of β at $Q^2 = 30\ \text{GeV}^2$ and $x_{\mathbb{P}} = 10^{-3}$. We present predictions for BEKW as a full line, DGLAP fit as a dashed line, BFKL as a dotted line and GBW as a dashed-dotted line.

Simulation



$x_{IP} F_L^D$
0.016
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
0.12
0.13
0.14
0.15
0.16
0.17
0.18
0.19
0.2
0.21
0.22
x 10^{-2}
x_{IP}
100 pb^{-1} with E_p = 920 GeV
10 pb^{-1} with E_p = 400 GeV
Q^2 = 12 GeV^2, β=0.23
total error
statistical error