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Session PA-02: Soft Interaction Processes

F_2^p at low Q^2 and total γp cross section

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representing

Outline

- Introduction: Three questions

- Photoproduction limit: $\sigma_{\text{tot}}^{\gamma p}$

(a) • DIS in pQCD domain: F_2, F_L and $xg(x)$

(b) • Transition region: **closing the gap ?**

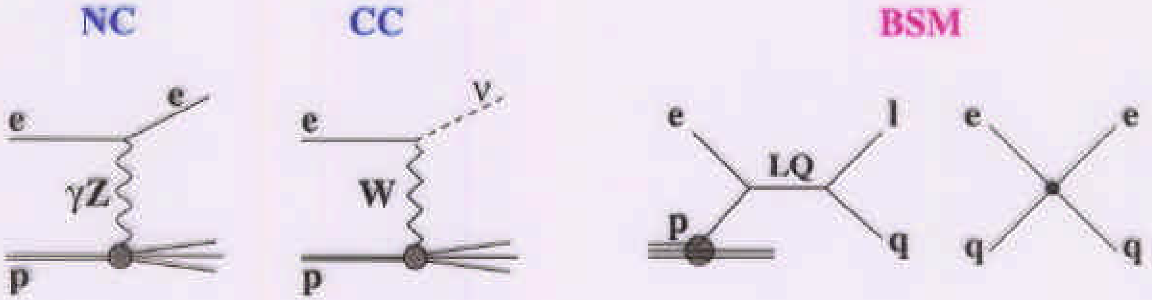
- Summary: Three answers

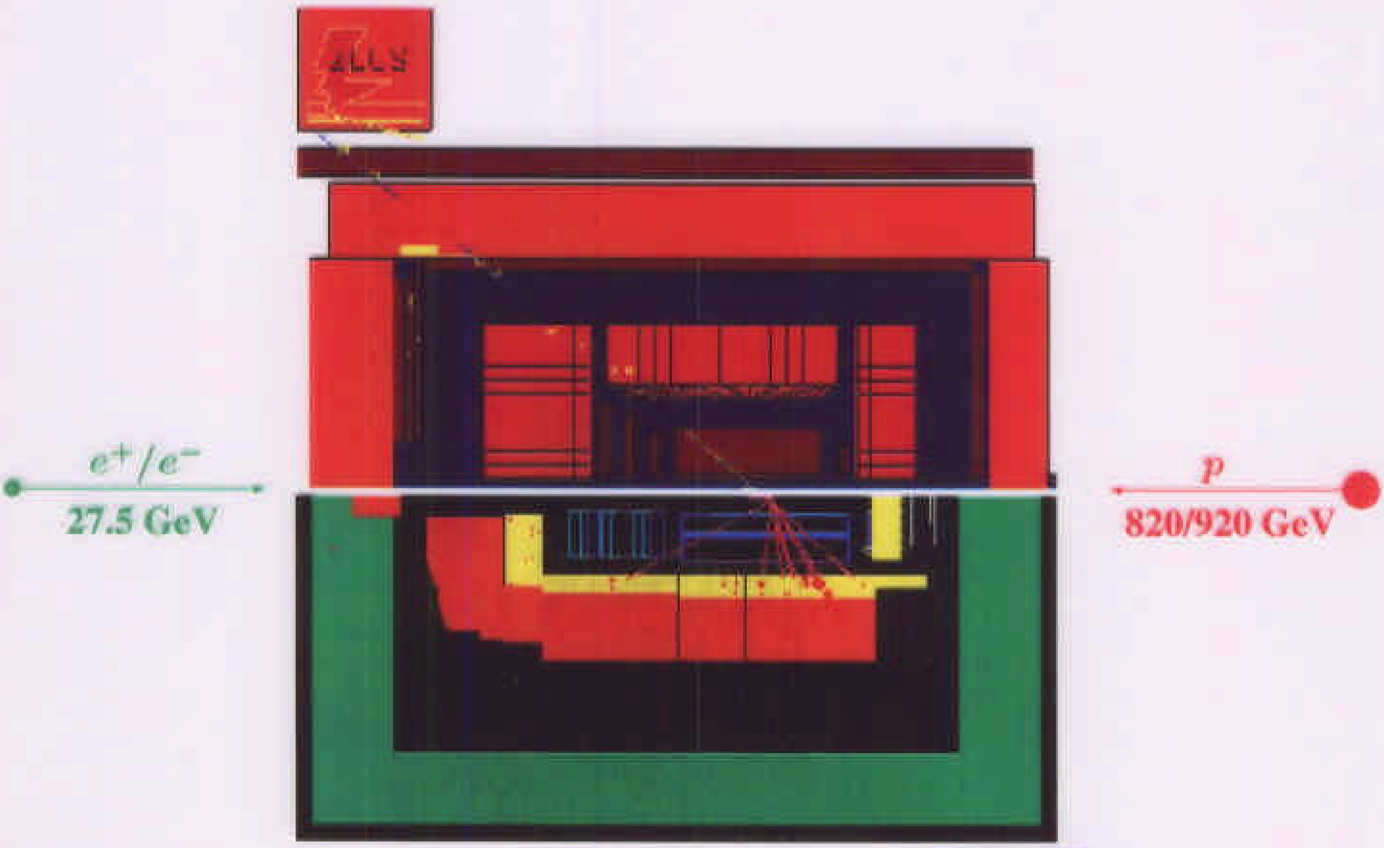
Ref. *Abstracts:* **944, 1046, 1047**

(a) See also the talk of F.Zomer in PA-03

(b) See also the talk of A.Pellegrino in PA-02

HERA collider





$\sqrt{s} = 300(319)$ GeV $\qquad \mathcal{L}$(HERA-I)$= \mathcal{O}(100)$ pb^{-1}

(in this talk – 96/97 data only – $\mathcal{L} \simeq 30$ pb^{-1})

★ Resolving structure of the matter at $10^{-16} \div 10^{-18}$ m

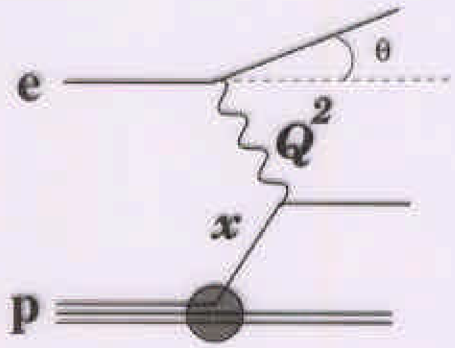
Motivation

What do we know about Strong Interaction?

- **RFT** works fine for soft peripheral processes at high energies ($s \to \infty,\ \ t/s \ll 1$), but there is no microscopic picture of underlying dynamics in it

- **QCD** is right theory of strong interactions, but has technical problems in non-perturbative regime. pQCD describes hard scattering only

What is so special in DIS at HERA?



$\sqrt{s} = 300(319)$ GeV → large

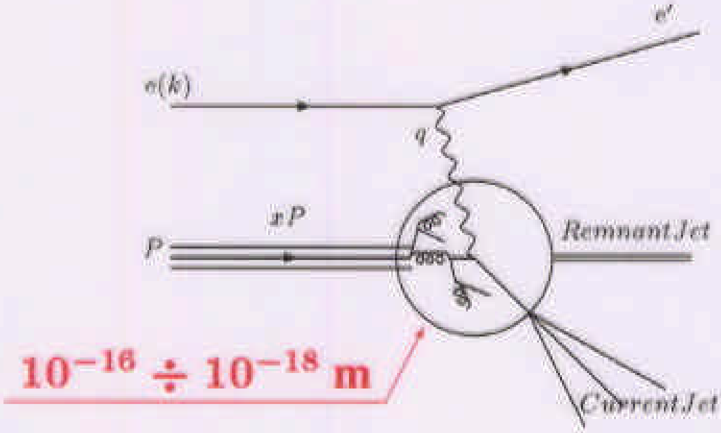
Q^2 – "key player" in the game →
can scan over complete range
from 0 to 10^5 GeV^2

Q1: How far up in Q^2 can we get with Regge theory starting from photoproduction ?

Q2: How far down in Q^2 can we go with pQCD ?

Q3: Where the transition region is? How to merge RFT and pQCD?

NC: Basic Definitions



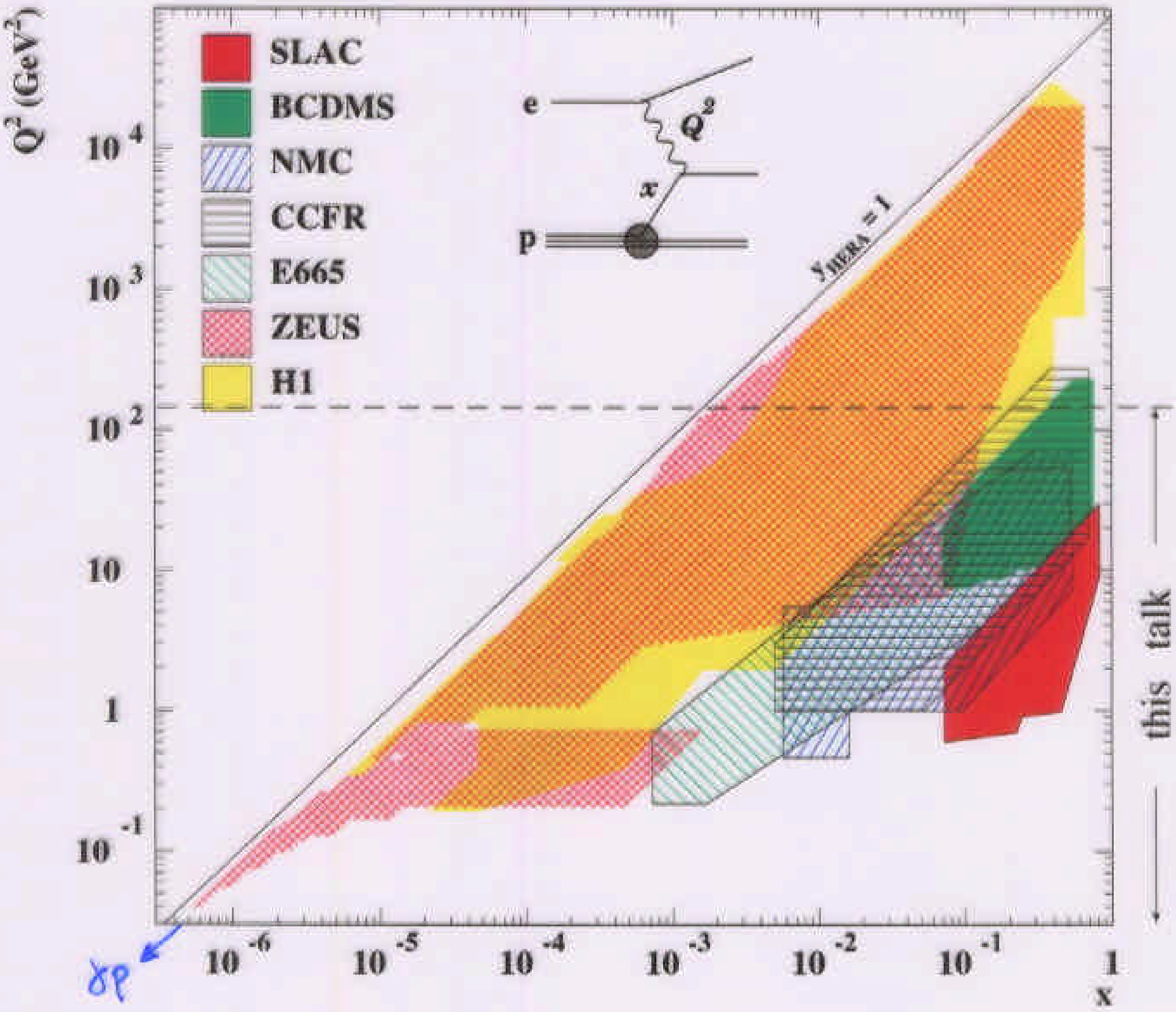
- $Q^2 = -q^2$ – 4-momentum transfer squared
- $x = \frac{-q^2}{2P\cdot q}$ – parton momentum fraction
- $y = \frac{P\cdot q}{P\cdot k}$ – inelasticity
- $W^2 = (q+P)^2$ – total hadronic energy squared
- $Q^2 = sxy$ $\quad W^2 = \frac{Q^2(1-x)}{x} + m_p^2 \rightarrow \frac{Q^2}{x}$ (at $x \rightarrow 0$)

$$\left.\frac{d^2\sigma^{NC}(ep)}{dxdQ^2}\right|^{\text{Born}}_{Q^2 \ll M_Z^2} = \frac{4\pi\alpha^2}{xQ^4}\left[y^2xF_1 + (1-y)F_2\right] = \Gamma_T\sigma_T^{\gamma^*p} + \Gamma_L\sigma_L^{\gamma^*p}$$

- $F_2 = \sum_f A_f[xq_f(x,Q^2) + x\bar{q}_f(x,Q^2)]$ (LO QCD)
- $F_L = F_2 - 2xF_1$ – longitudinal structure function (0 in QPM)

$$\sigma_{tot}^{\gamma^*p}(W,Q^2) = \sigma_T^{\gamma^*p} + \sigma_L^{\gamma^*p} \approx \frac{4\pi^2\alpha}{Q^2}F_2(x,Q^2)$$

HERA kinematic range



$x/Q^2 \rightarrow 10^{-5}$ $\Rightarrow$ low x limit of pQCD

$y \rightarrow 0.005$ $\Rightarrow$ overlap with fixed target experiments

$y \rightarrow 0.82$ $\Rightarrow$ sensitivity to F_L

$Q^2 \rightarrow 0.045$ GeV^2 $\Rightarrow$ transition to γp

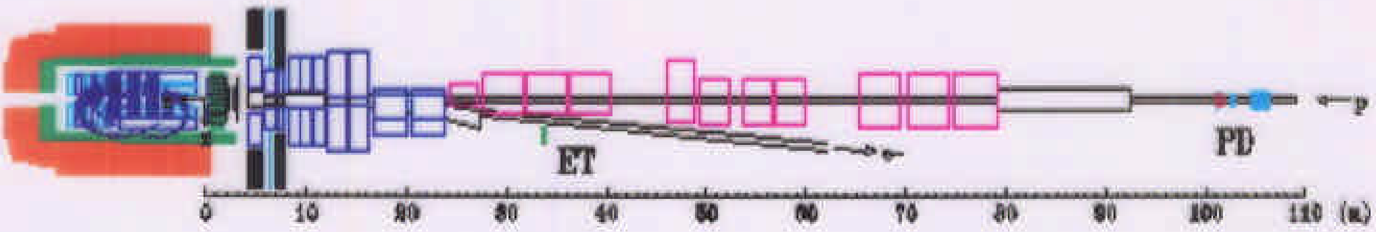
$Q^2 \rightarrow 50000$ GeV^2 $\Rightarrow$ EW sector, (new physics?)

Emphasized by the Upgrade-2000

Photoproduction limit: $\sigma_{\rm tot}^{\gamma p}$

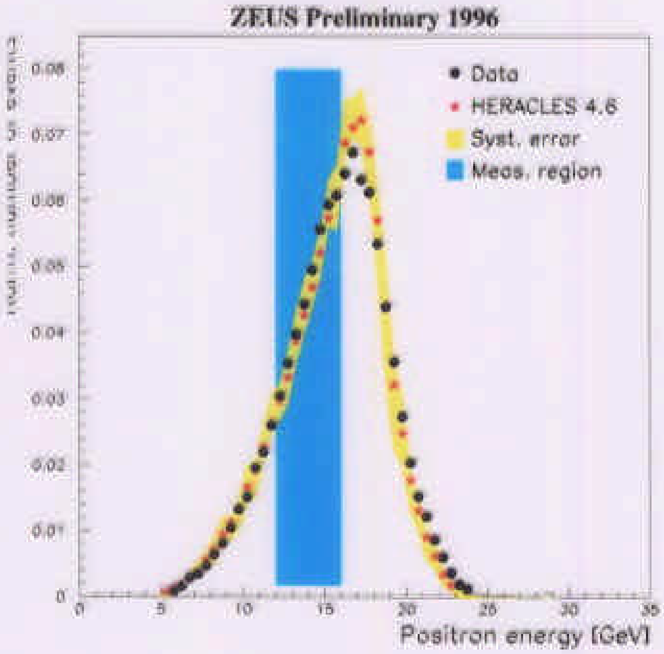
Using e tagger in the tunnel: $e^+ p \to e^+ X$ (H1-94, new: ZEUS-96)

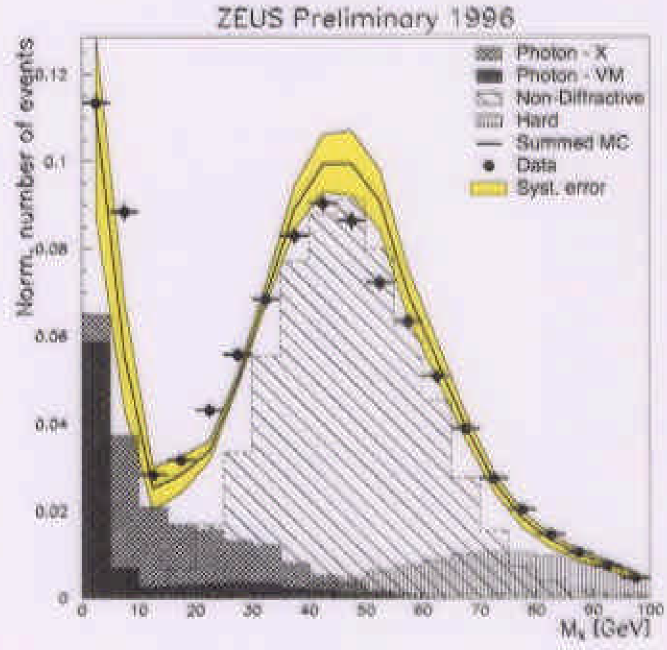
$$(\theta_e < 5\ \mathrm{mrad} \ \rightarrow \ <Q^2> \approx 10^{-4}\ \mathrm{GeV}^2)$$



$$\frac{d\sigma_{\rm tot}^{ep}(y)}{dy} = \mathcal{F}_\gamma(y, Q^2_{\rm min}, Q^2_{\rm max})\,\sigma_{\rm tot}^{\gamma p}$$

$$\sigma_{\rm tot}^{\gamma p} = \frac{N_{ep}}{\mathcal{L}} \cdot \frac{1}{\mathcal{F}_\gamma} \cdot \frac{\Delta_{corr}}{A_{etag} \cdot A_{main\_det}}$$

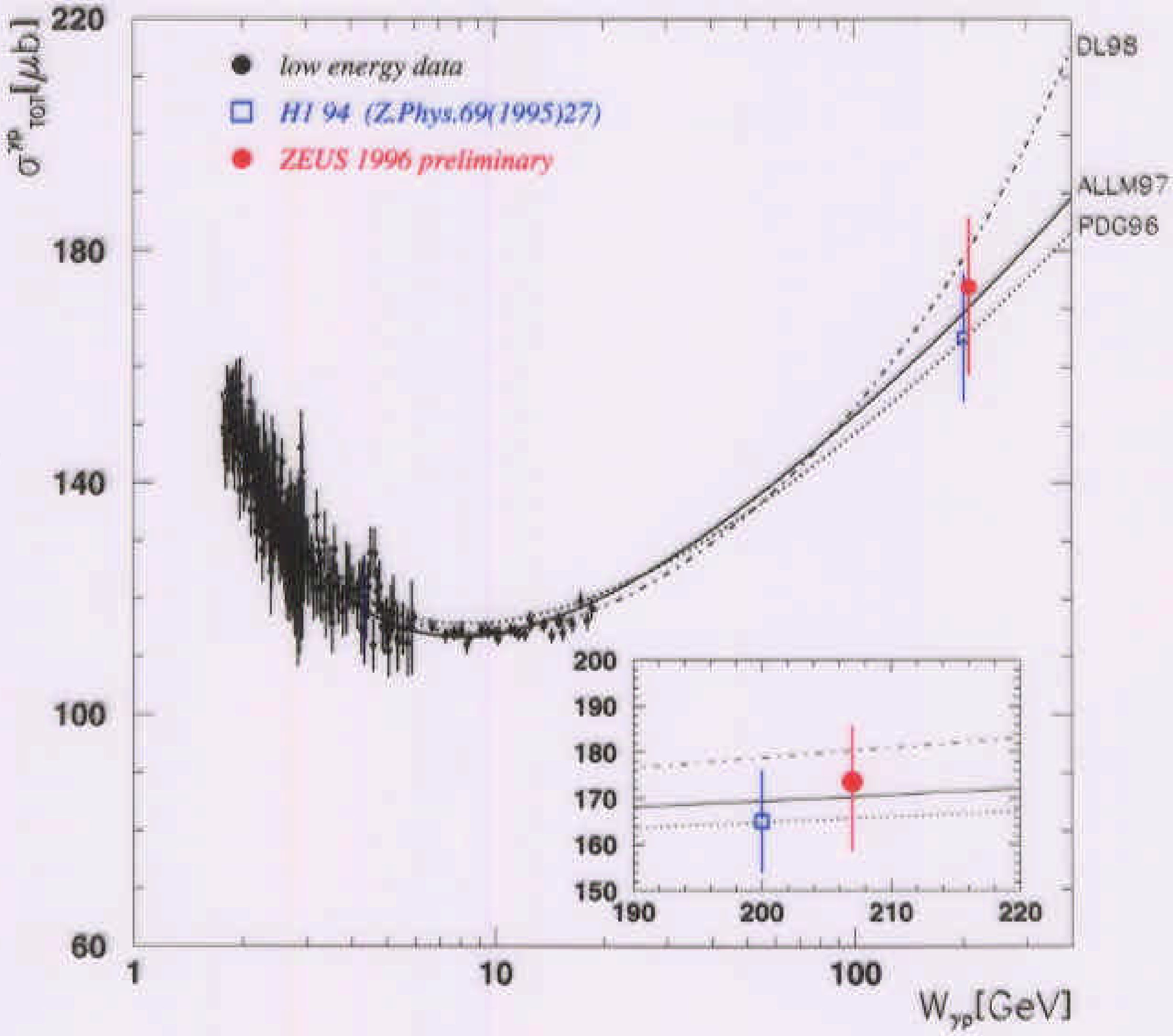




$\delta A_{etag} = 5 \div 6\%$ $\delta A_{main\_det} = 4 \div 5\%$

$\sigma_{\text{tot}}^{\gamma p}$ at HERA – Results

(Abs. PA02-1046)

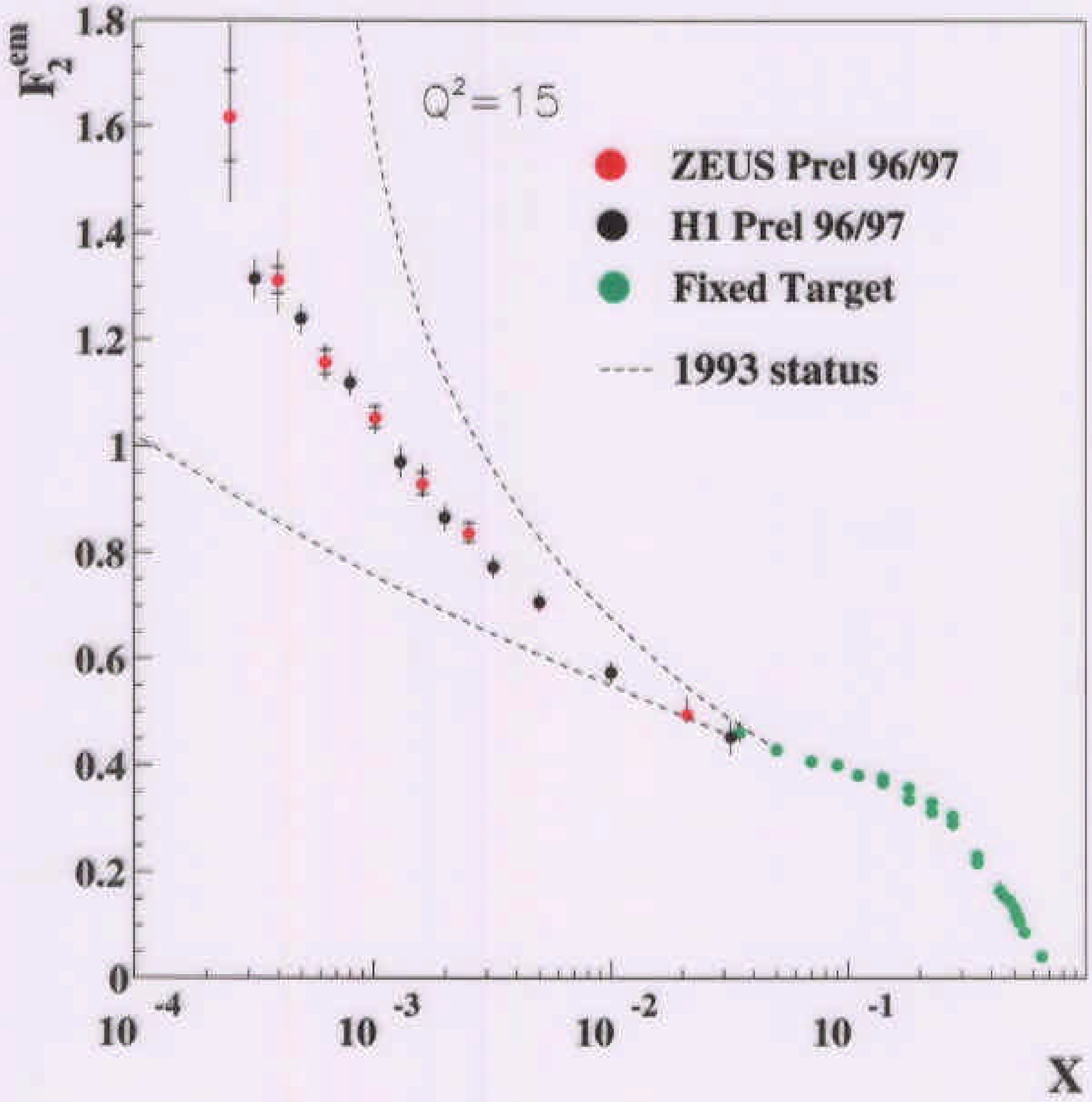


H1-94: $\sigma_{\text{tot}}^{\gamma p}(W_{\gamma p} = 200\ \text{GeV}) = 165 \pm 2 \pm 11\ \mu\text{b}$

ZEUS : $\sigma_{\text{tot}}^{\gamma p}(W_{\gamma p} = 207\ \text{GeV}) = 172 \pm 1^{+13}_{-15}\ \mu\text{b}$

★ $\gamma p \approx hh$. Universal soft $I\!P$ in full glory

HERA impact: F_2^p at low x



★ High precision: 1%(stat) $\oplus$ 2-3%(syst)

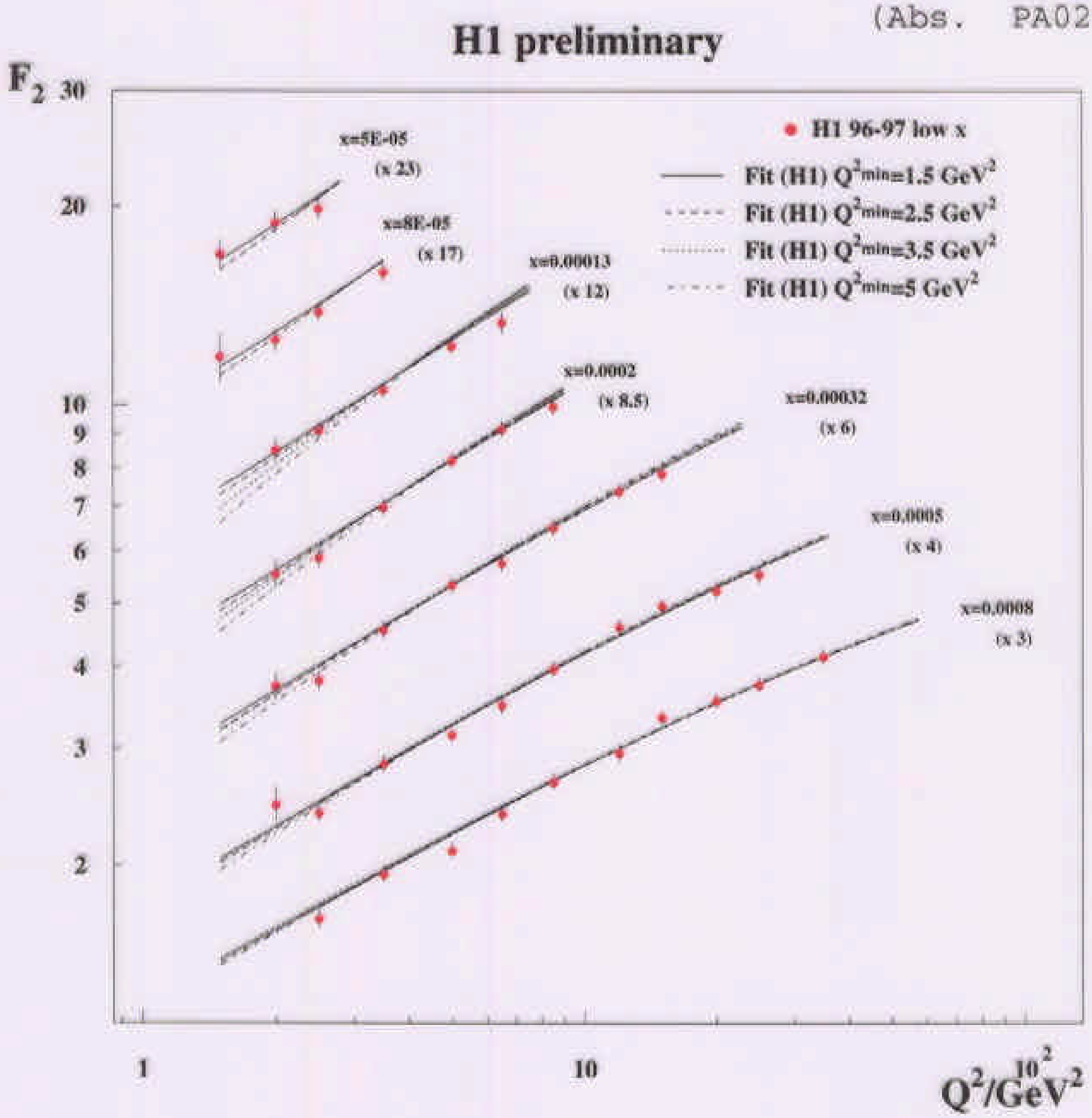
★ Good agreement between H1 and ZEUS

★ Overlap is achived with fixed target experiments

★ Enormous improvement wrt “1993 knowledge”

F_2 scaling violation

(Abs. PA02-944)



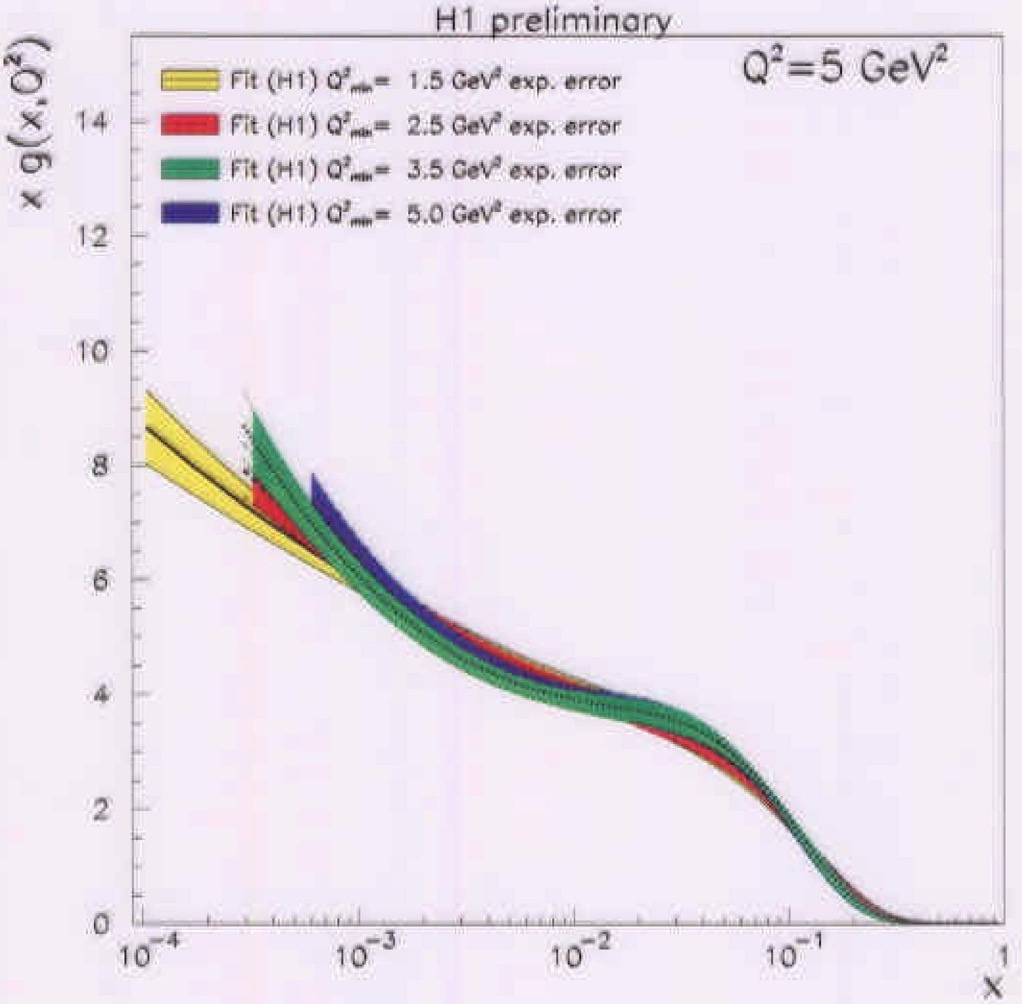
★ New precise measurements ($1.5 < Q^2 < 150$ GeV^2) allow to fit H1 data alone in the range $Q^2 < 3000$ GeV^2

★ **pQCD in glory:** NLO DGLAP describes the data all the way down to surprisingly low $Q^2 = 1.5$ GeV^2
(note however the effect of the $Q^2_{\rm min}$ choice...)

Gluon Density in the Proton

The scaling violation of F_2 at low x is dominated by the gluon density:

$$dF_2/d\log Q^2 \propto xg(x)\cdot\alpha_s$$



- Statistical errors are small. Systematics dominate (mainly $Q^2_{\rm min}$)
- At $Q^2 = 7$ GeV^2 the gluons carry $\mathbf{0.449 \pm 0.015}$ of the proton momentum (in agreement with previous results)

★ DGLAP QCD fit is too "flexible"? → Try more constraints...

Extraction of F_L

$\sigma_r = (F_2 - \frac{y^2}{Y_+} F_L) \quad \rightarrow \quad F_L$ gets important at high $y \quad (x = \frac{Q^2}{ys})$

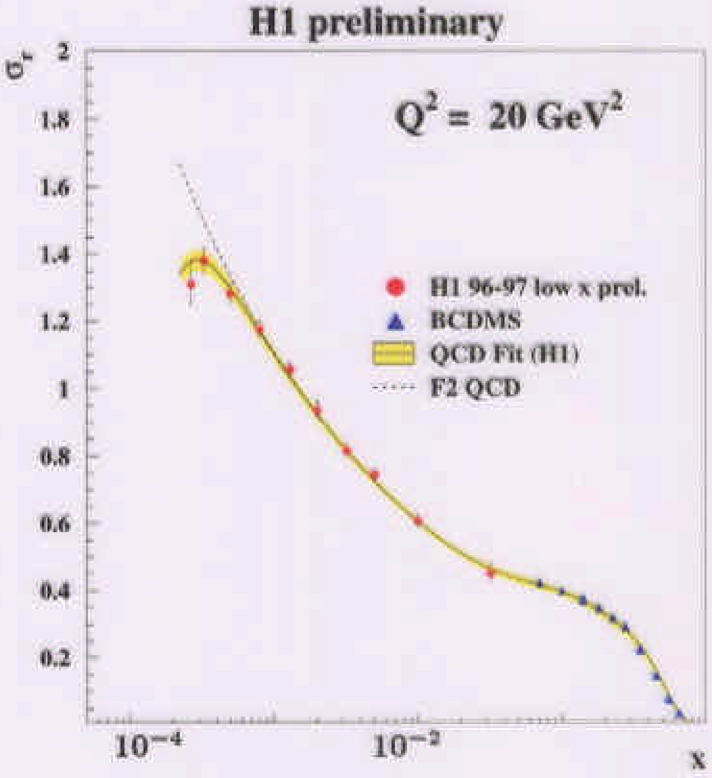
$\Downarrow$

$\frac{Q^4 x}{2\pi\alpha^2 Y_+} \cdot \frac{d^2\sigma_{ep}}{dx\,dQ^2}$

Methods

1. Subtraction method
   $(Q^2 > 10\ \mathrm{GeV}^2)$

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



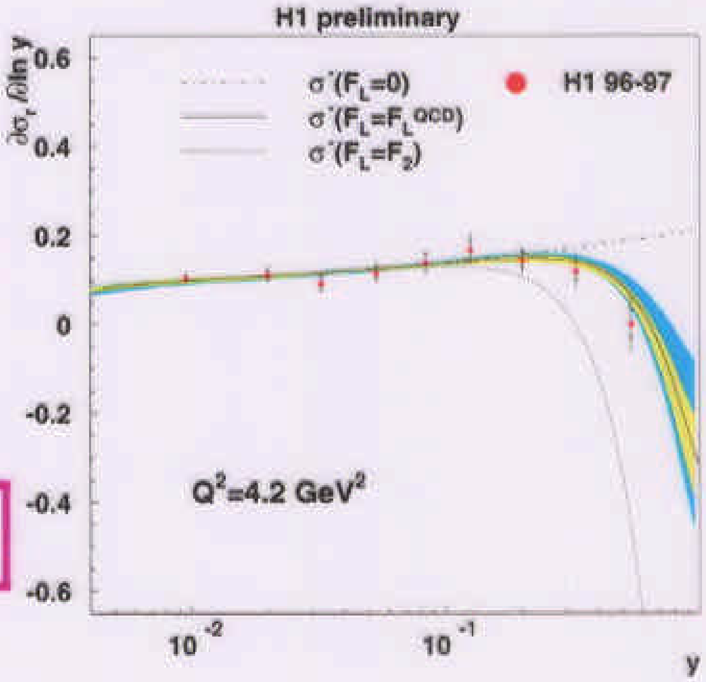
2. Derivative method
   $(Q^2 < 10\ \mathrm{GeV}^2)$

$$\frac{\partial \sigma_r}{\partial \log y} = \frac{\partial F_2}{\partial \log y} -$$

$$F_L 2y^2 \frac{(2-y)}{Y_+^2} - \frac{\partial F_L}{\partial \log y} \cdot \frac{y^2}{Y_+^2}$$

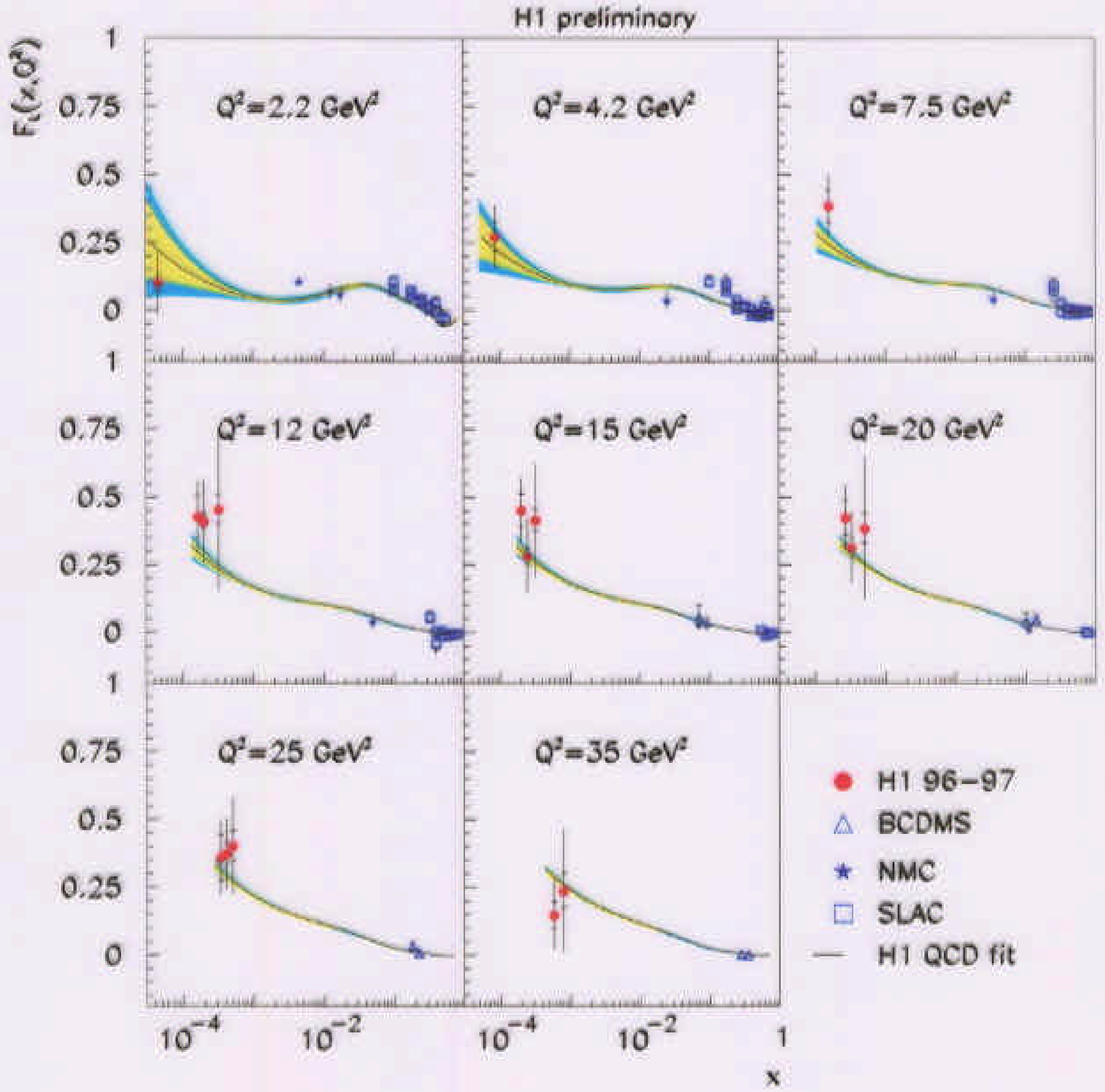
$F_2 \sim x^{-\lambda}$ $(x \sim 1/y)$ $\Rightarrow$

$$\boxed{\frac{\partial F_2}{\partial \log y} \sim \lambda + \lambda^2 \log y + \ldots}$$



F_L: HERA vs Fixed target

(Abs. PA02-944)



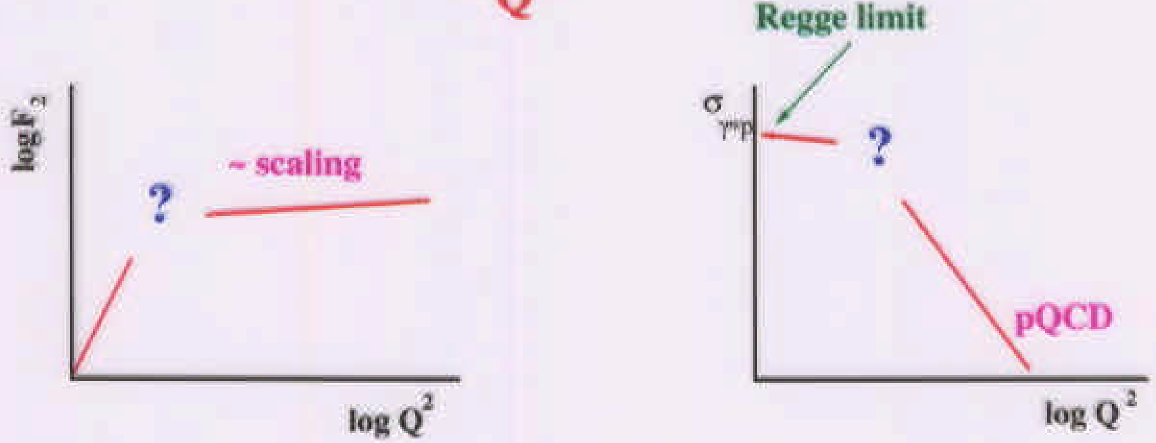
★ F_L is rising at low x in accord with pQCD

★ For better precision have to use "classical" method (varying collision energy) ⇒ After HERA upgrade

Pushing QCD to low Q^2 extreme

- We have verified that **Regge theory** works in photoproduction ($\sigma_{tot}^{\gamma p}$)
- We also demonstrated, that in DIS regime **pQCD** describes inclusive NC cross section (F_2, F_L)

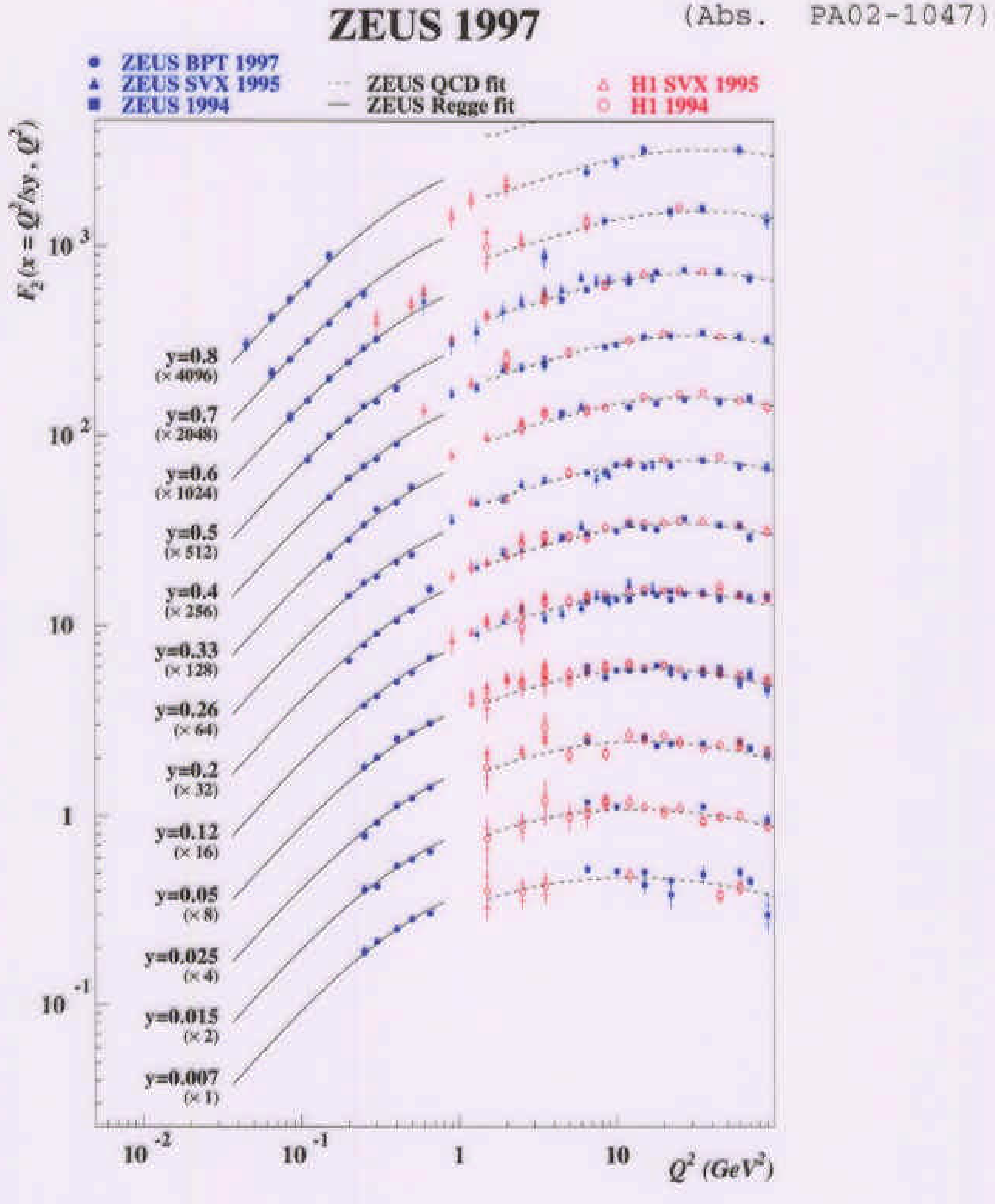
$$\sigma \sim \frac{1}{Q^2} F_2$$



But where the transition happens? And how it happens?

Since the theory is silent – see what the data tell us...

Transition pQCD → Regge



★ **Transition to non-perturbative regime, from partonic to hadronic degrees of freedom, at $Q^2 \simeq 1$ GeV^2 – still a challenge for QCD**

Summary

★ e^+p interactions have been studied at HERA in the extended kinematic range. High level of precision is achieved: in the bulk area NC cross section is measured with **1%** stat. and **3%** syst. error.

★ **(A1)** In photoproduction limit $\sigma_{tot}^{\gamma p}$ exhibits mild rise similar to that of hh scattering. It is well described by the conventional Regge theory with universal 'soft' Pomeron. Regge motivated parametrization also describes the data in low $Q^2 < 0.7$ GeV^2 region.

★ **(A2)** In DIS regime NLO QCD is able to describe F_2 data all way down to surprisingly low scale, $Q^2 \simeq 1.5$ GeV^2. For the first time gluon density has been extracted with high precision using HERA data alone.

★ **(A3)** A smooth transition from partonic to hadronic dergees of freedom occurs around $Q^2 \simeq 1$ GeV^2 The details of the underlying dynamics is still a challenge for the theory.