

*Plenary ECFA
DESY, July 18th 2008*

*Claude Vallée
for ZEUS and H1*

Building up the HERA Legacy



It all started with ECFA...



After further discussion, an amended recommendation was drawn up:

"As recommended at its meeting on 2 November 1979, ECFA puts first priority on the construction of the electron-positron collider LEP by CERN to keep Europe at the front line of sub-nuclear physics.

The Electron-Proton Working Group of ECFA has conclusively demonstrated the unique scientific interest of electron-proton collisions. Such investigations are complementary to the programme realizable by LEP and other projects elsewhere.

From a study of the Working Group on High-Energy Activities in the CERN Member States, it appears clearly that the scope of sub-nuclear physics in Europe will be greatly broadened with a facility for physics operational in the second half of the 1980s.

ECFA has considered at its meeting on 9 May 1980 the design of an electron-proton collider storage ring, HERA, that German physicists have proposed for DESY.

ECFA recommends strongly the construction of this machine at DESY and welcomes the possibility of its being used by the European community."

The recommendation was unanimously approved.



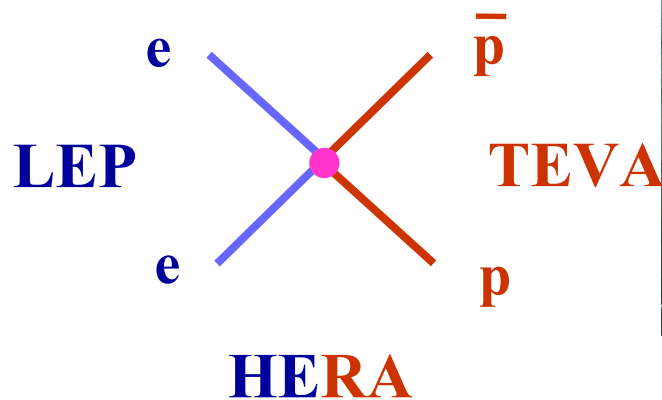
Quiz: was this photo taken in 1990 or 2008 ?

27th Plenary
ECFA, 9.5.1980

The High Energy Frontier Landscape in the 1990-2010's



0.21 TeV, $\sim 0.9 \text{ fb}^{-1}/\text{exp.}$



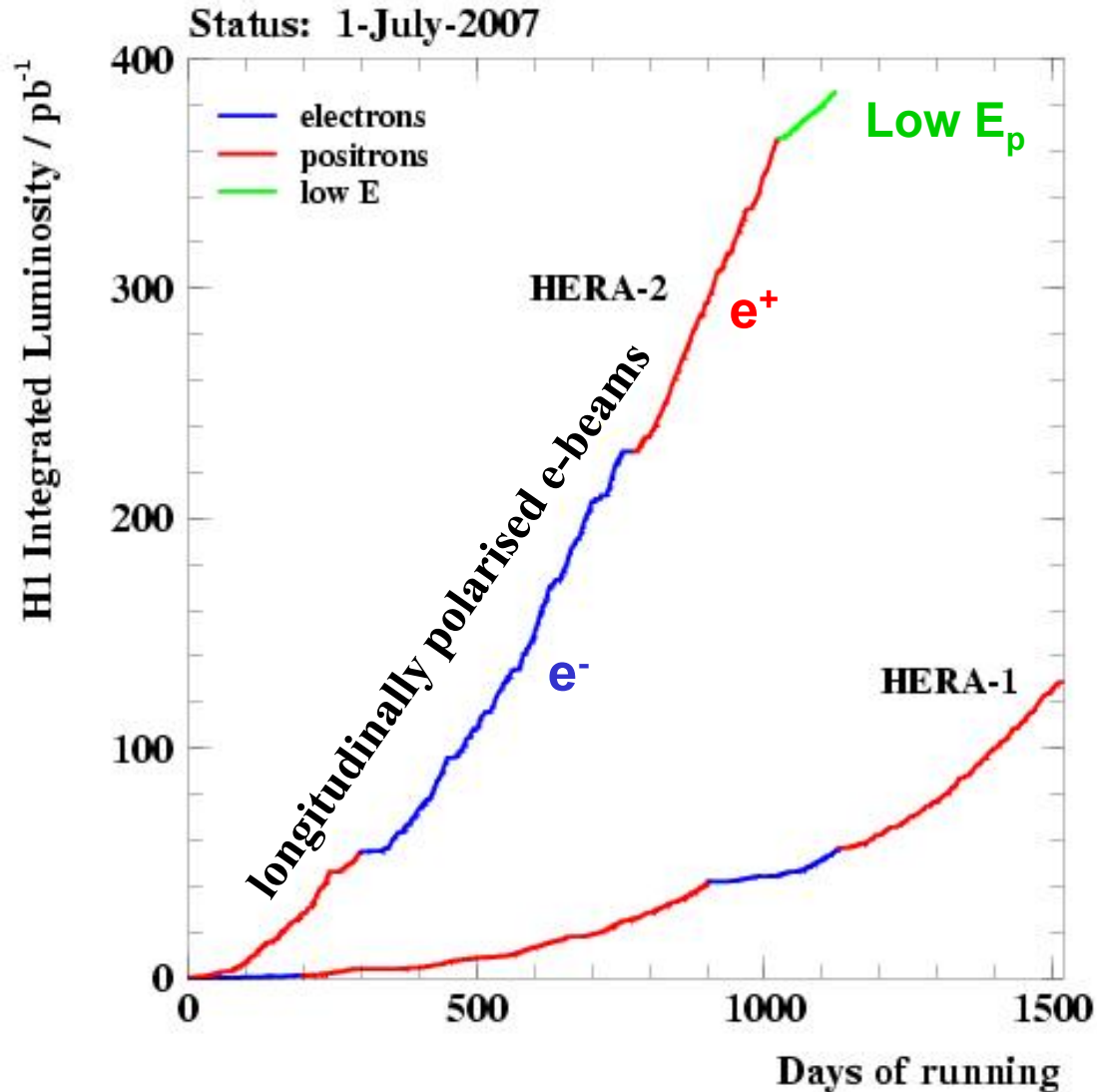
1.96 TeV, $\sim 4 \text{ fb}^{-1}/\text{exp.}$

\sim twice more expected
until 2010



0.32 TeV, $\sim 0.5 \text{ fb}^{-1}/\text{exp.}$

The final HERA data samples

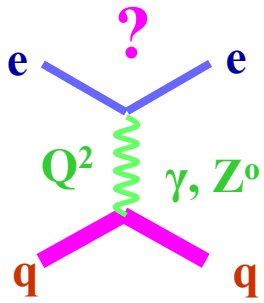


Building up the HERA legacy

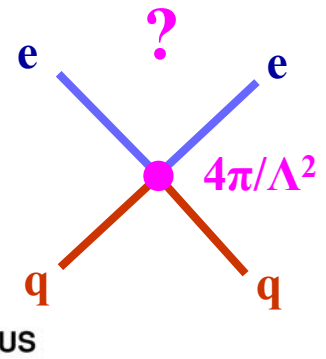
High-Energy Frontier
exploration close to completion

Proton structure//QCD dynamics
*final high precision results being derived with full HERA data
in close cooperation between H1 and ZEUS*

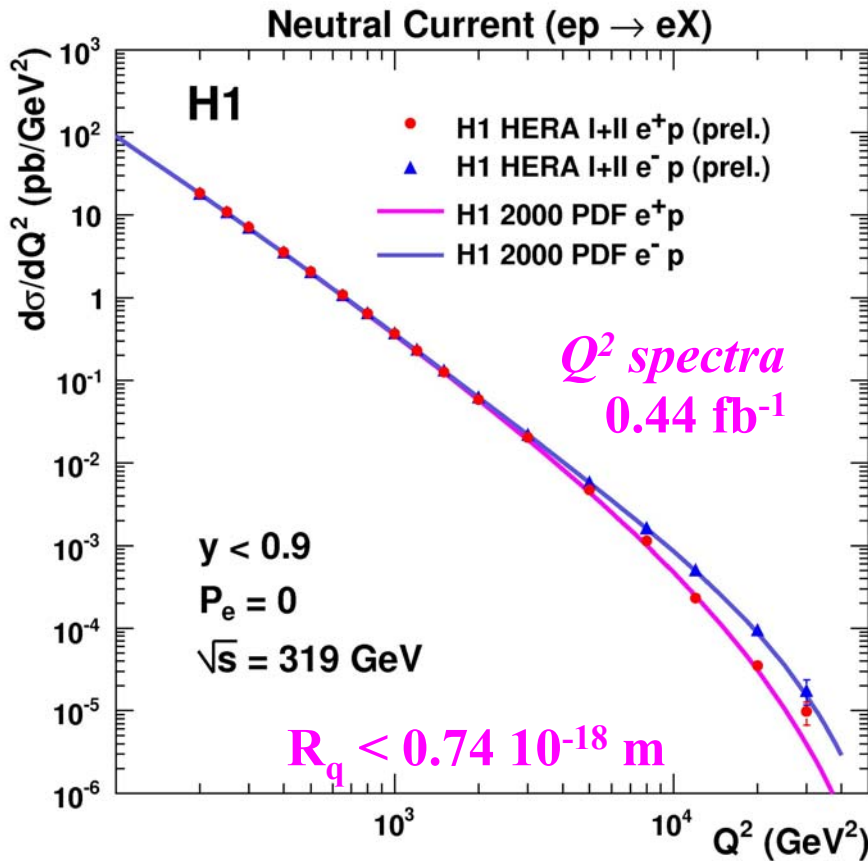
HIGH ENERGY FRONTIER: quark sub-structure



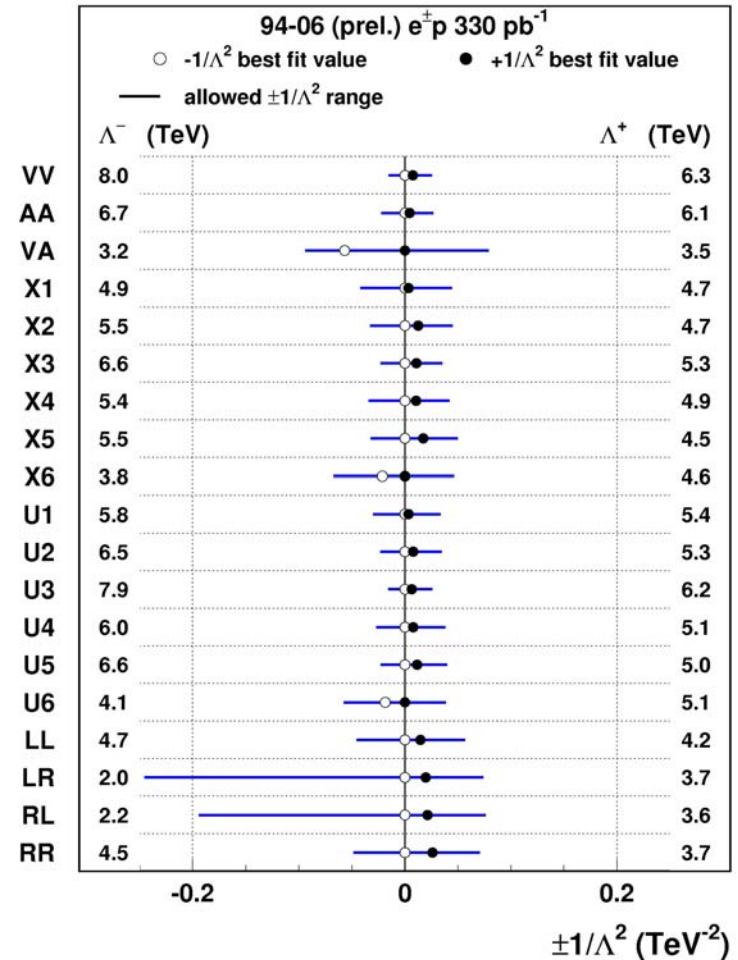
quark radius R_q
factor: $(1 - R_q^2 Q^2 / 6)$



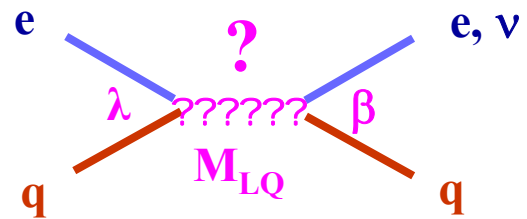
ZEUS



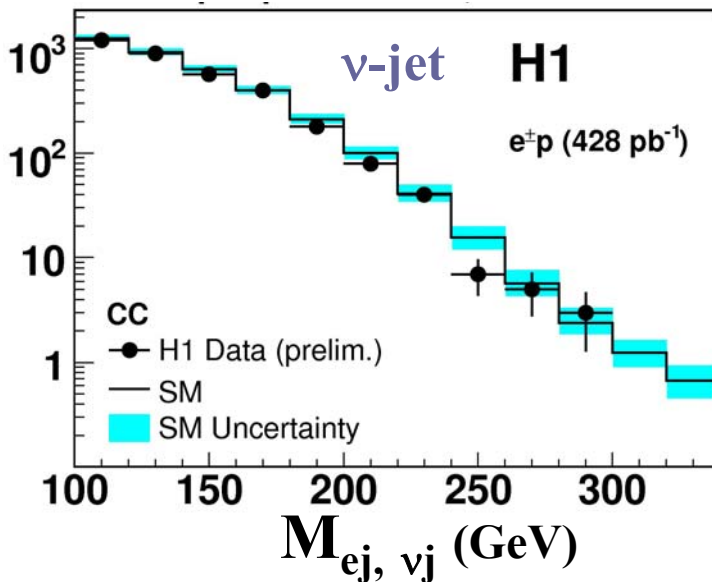
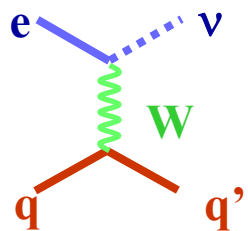
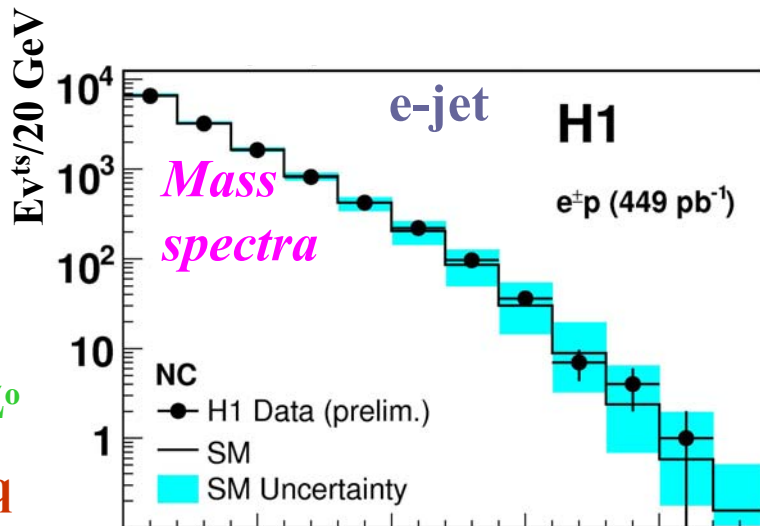
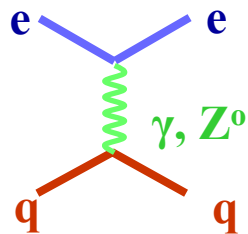
ZEUS 0.33 fb^{-1} : $R_q < 0.62 \cdot 10^{-18} \text{ m}$



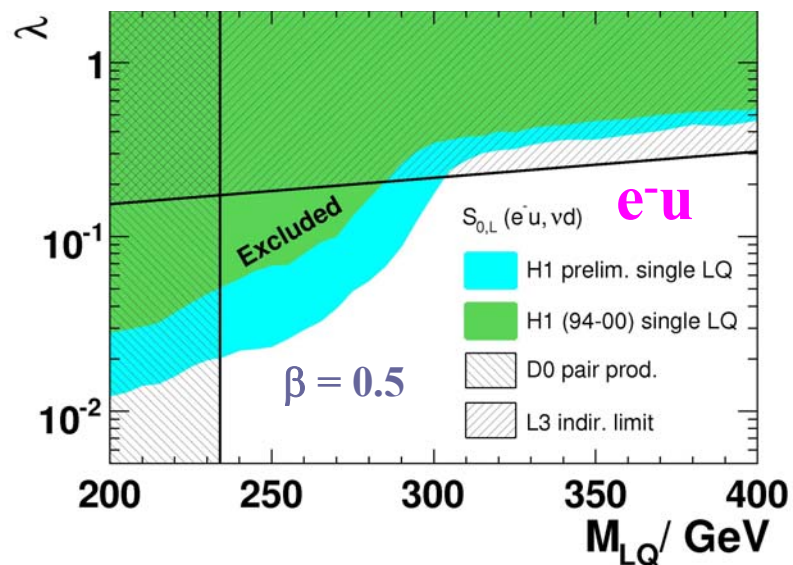
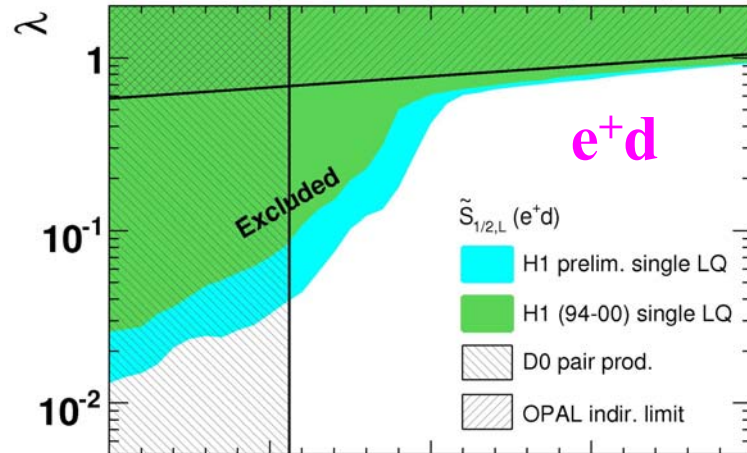
HIGH ENERGY FRONTIER: Leptoquarks



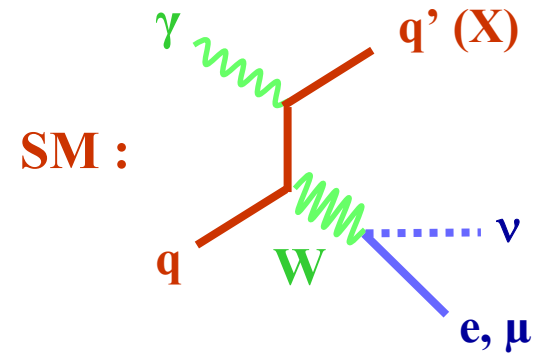
SM :



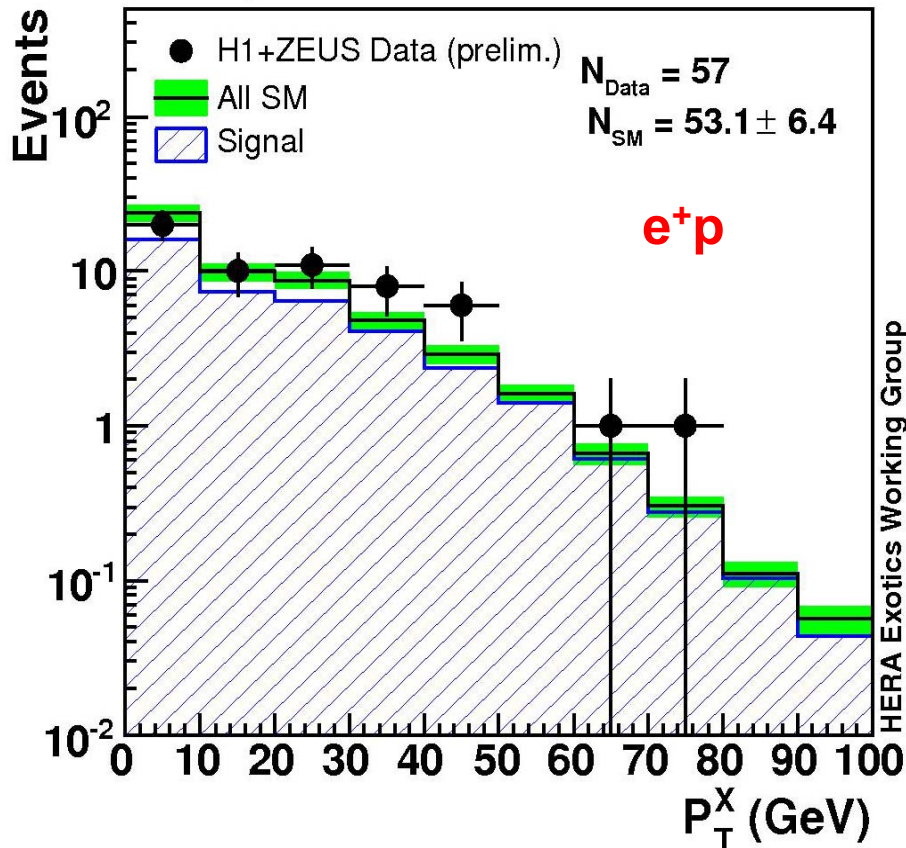
Leptoquark Search, HERA I+II (449 pb⁻¹)



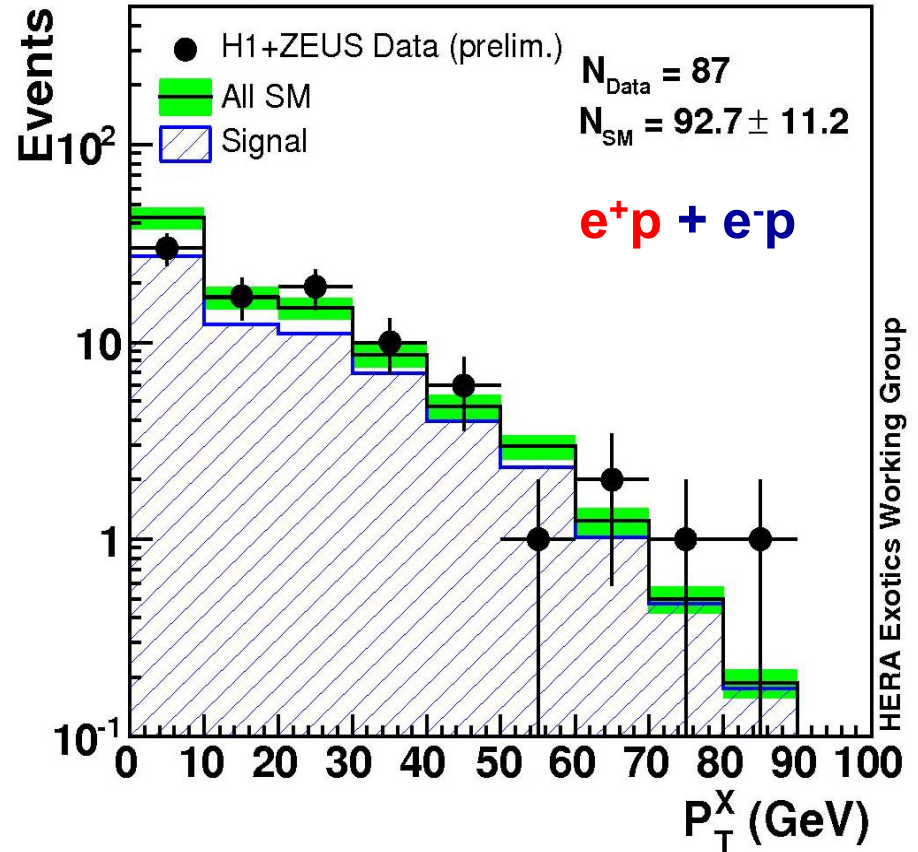
HIGH ENERGY FRONTIER: Isolated Leptons + Missing P_T



$e, \mu + P_T^{\text{miss}}$ events at HERA I+II (e^+p , 0.58 fb^{-1})

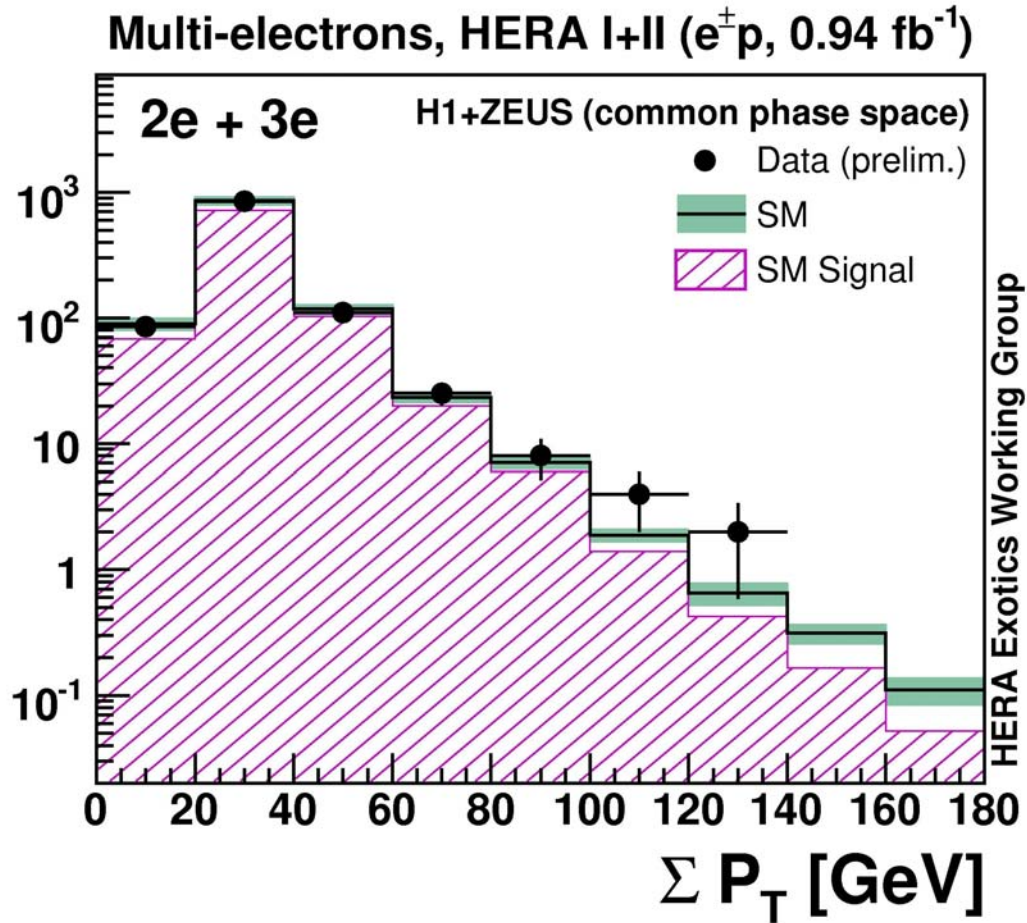
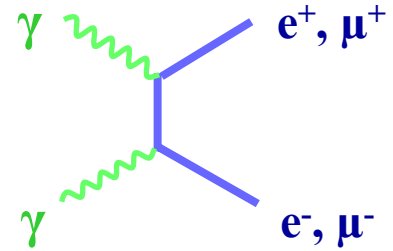


$e, \mu + P_T^{\text{miss}}$ events at HERA I+II ($e^\pm p$, 0.97 fb^{-1})



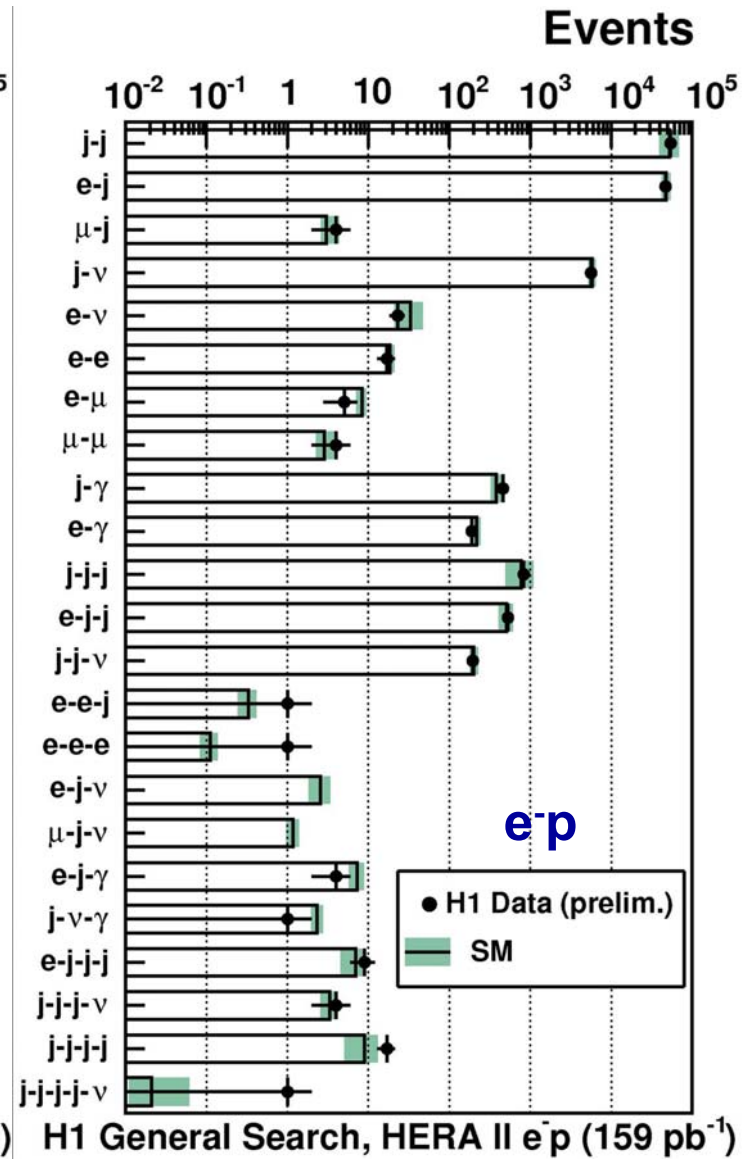
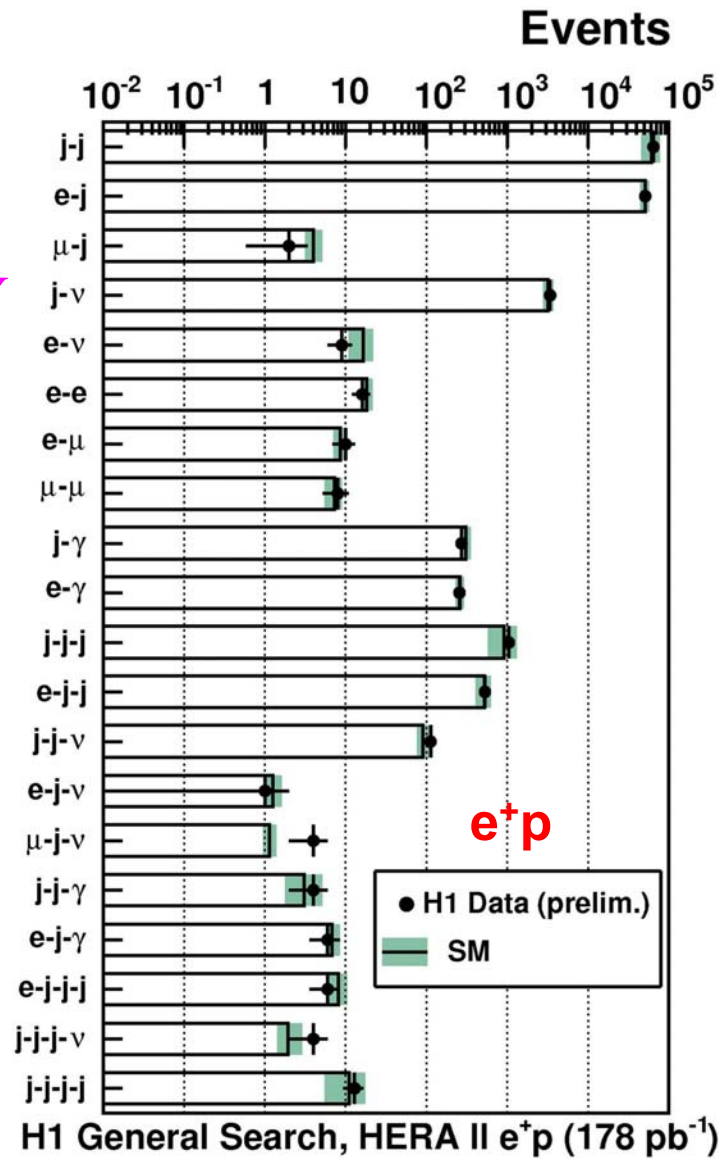
HIGH ENERGY FRONTIER: Multi-Leptons

SM :

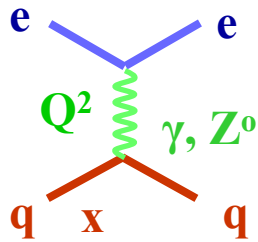


*HIGH ENERGY
FRONTIER:
Generic Search*

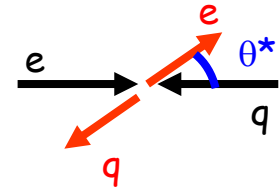
SM OK



PROTON STRUCTURE



$$\tilde{\sigma}_{NC}^{\pm} = \frac{d^2 \sigma_{NC}^{e^{\pm} p}}{dx dQ^2} \frac{x Q^4}{2\pi \alpha^2 Y_{\pm}}$$



$$y = Q^2/sx = (1 - \cos\theta^*)/2$$

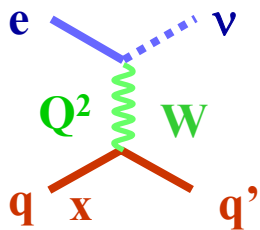
$$= \tilde{F}_2 - \frac{y^2}{Y_{\pm}} \tilde{F}_L \mp \frac{Y_{\mp}}{Y_{\pm}} x \tilde{F}_3$$

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

valence + sea quarks

gluon

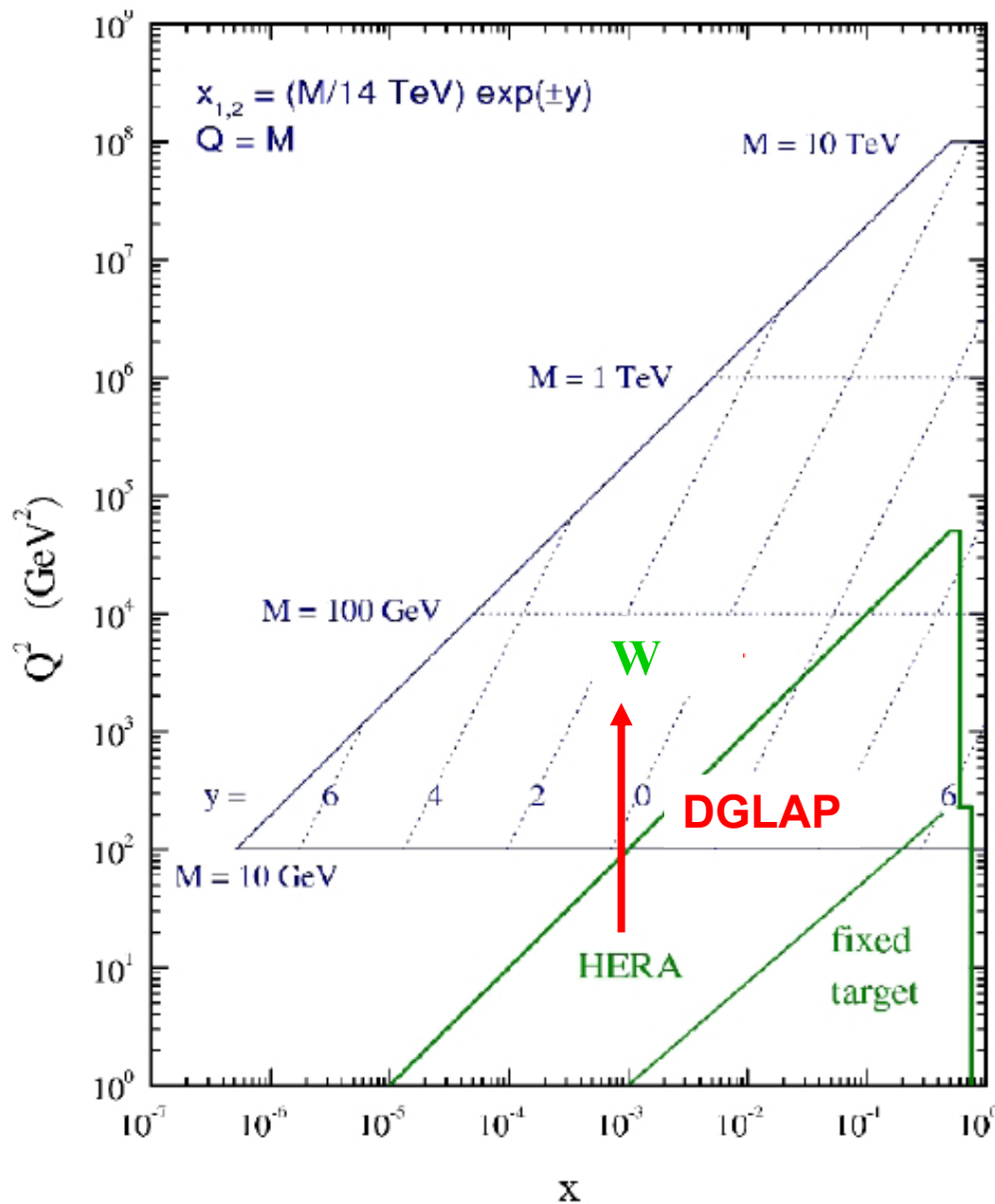
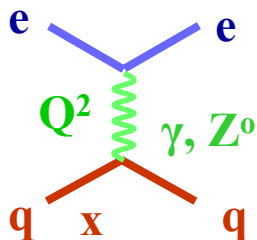
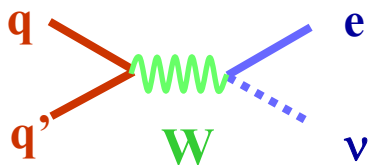
valence quarks

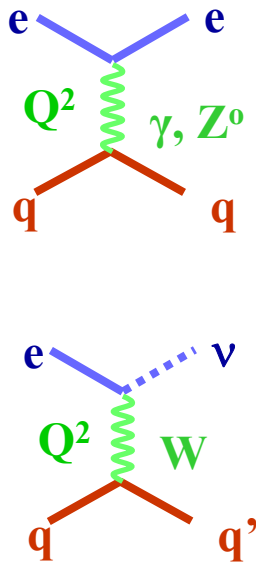


$$\sigma_{CC}(e^+ p) \propto x[(1 - y^2)(d + s) + (\bar{u} + \bar{c})] \quad \times (1 + P_e)$$

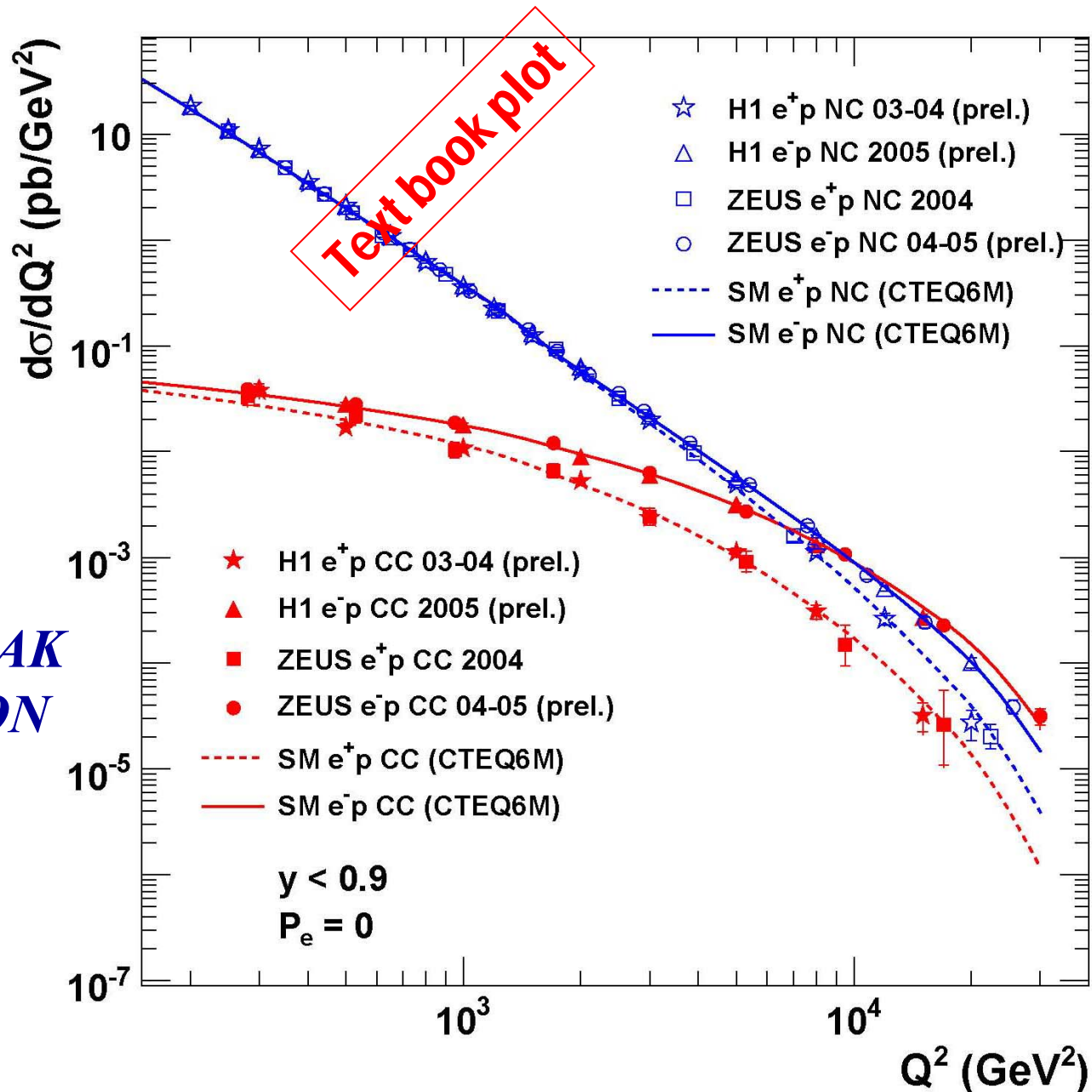
$$\sigma_{CC}(e^- p) \propto x[(u + c) + (1 - y^2)(\bar{d} + \bar{s})] \quad \times (1 - P_e)$$

KINEMATICS: HERA ↔ LHC

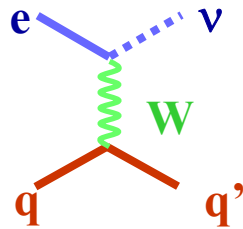




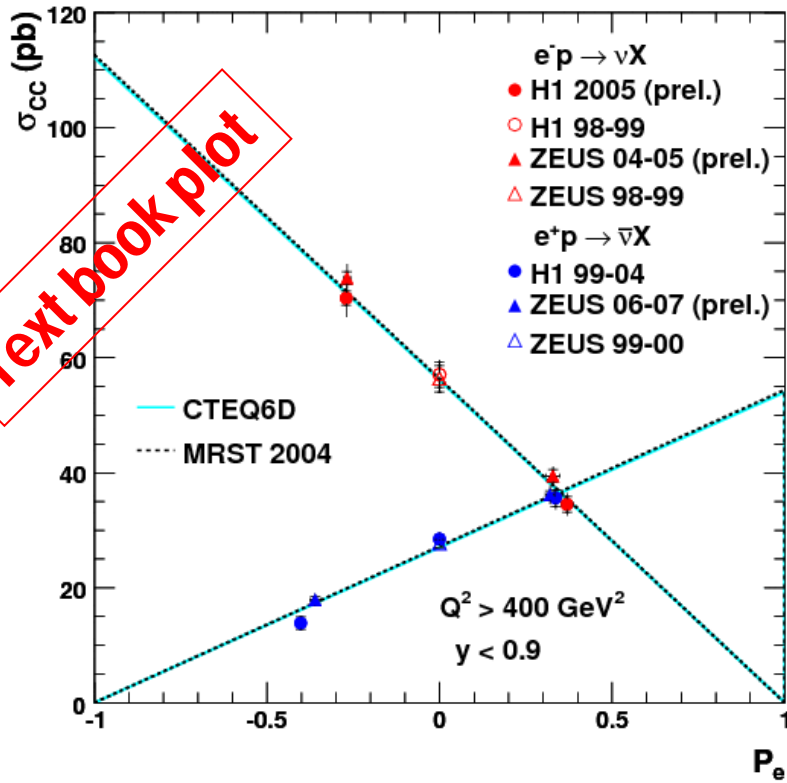
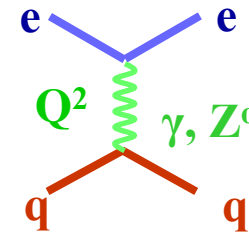
ELECTROWEAK UNIFICATION



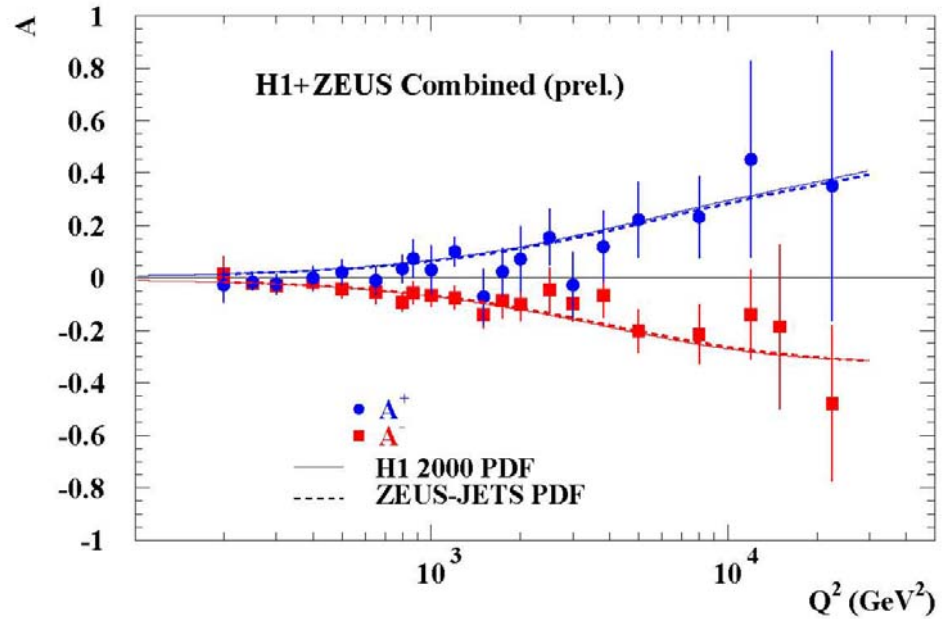
ELECTROWEAK POLARISATION ASYMMETRIES



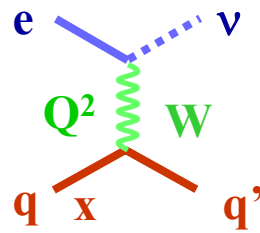
Charged Current e^+p Scattering



$$A^\pm = \frac{2}{P_R - P_L} \frac{\sigma^\pm(P_R) - \sigma^\pm(P_L)}{\sigma^\pm(P_R) + \sigma^\pm(P_L)}$$

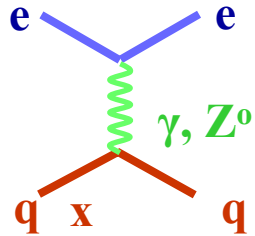


PROTON STRUCTURE: valence quarks

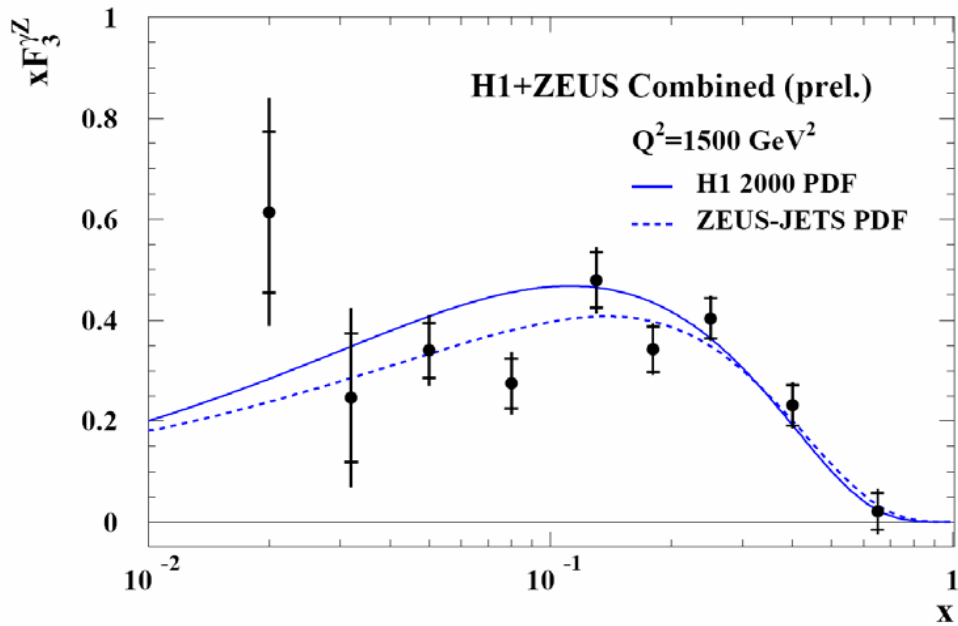


HERA Charged Current

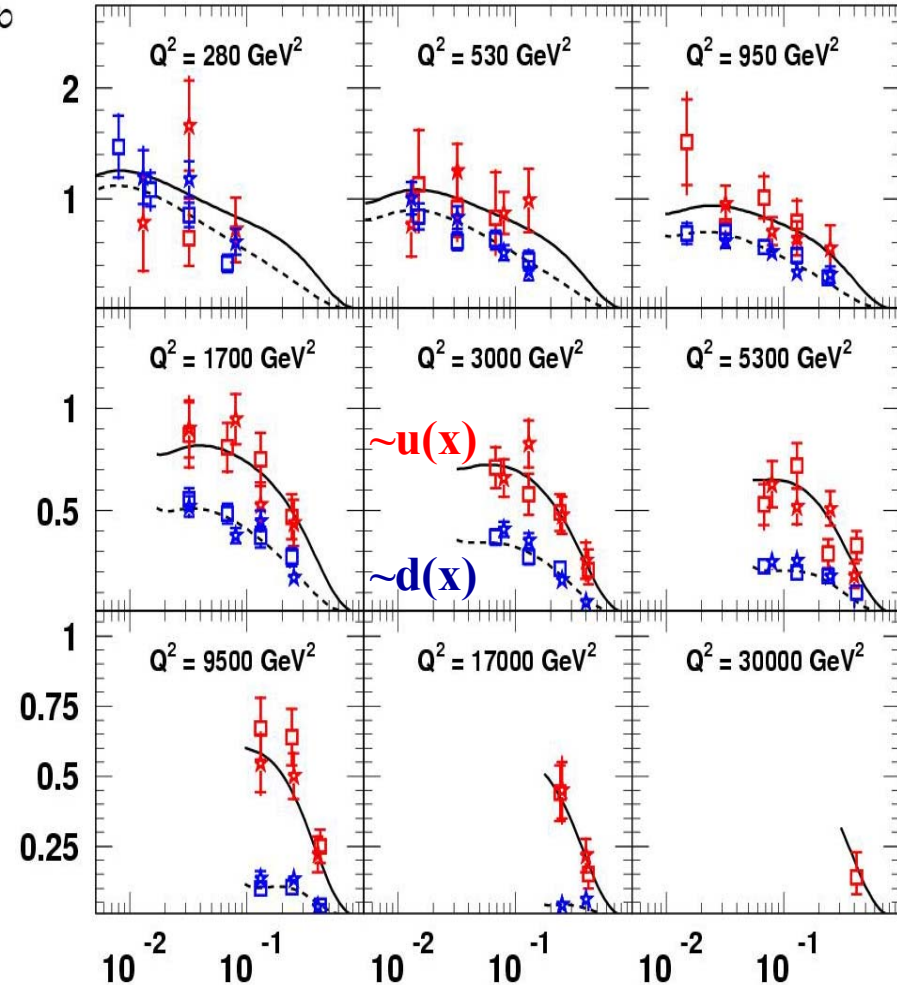
- ★ H1 e^-p
- ★ H1 e^+p 94-00
- SM e^-p (CTEQ6D)
- ZEUS e^-p 98-99
- ZEUS e^+p 99-00
- SM e^+p (CTEQ6D)



$$xF_3 \sim \sigma(e^-) - \sigma(e^+) \sim (2u_v + d_v)$$



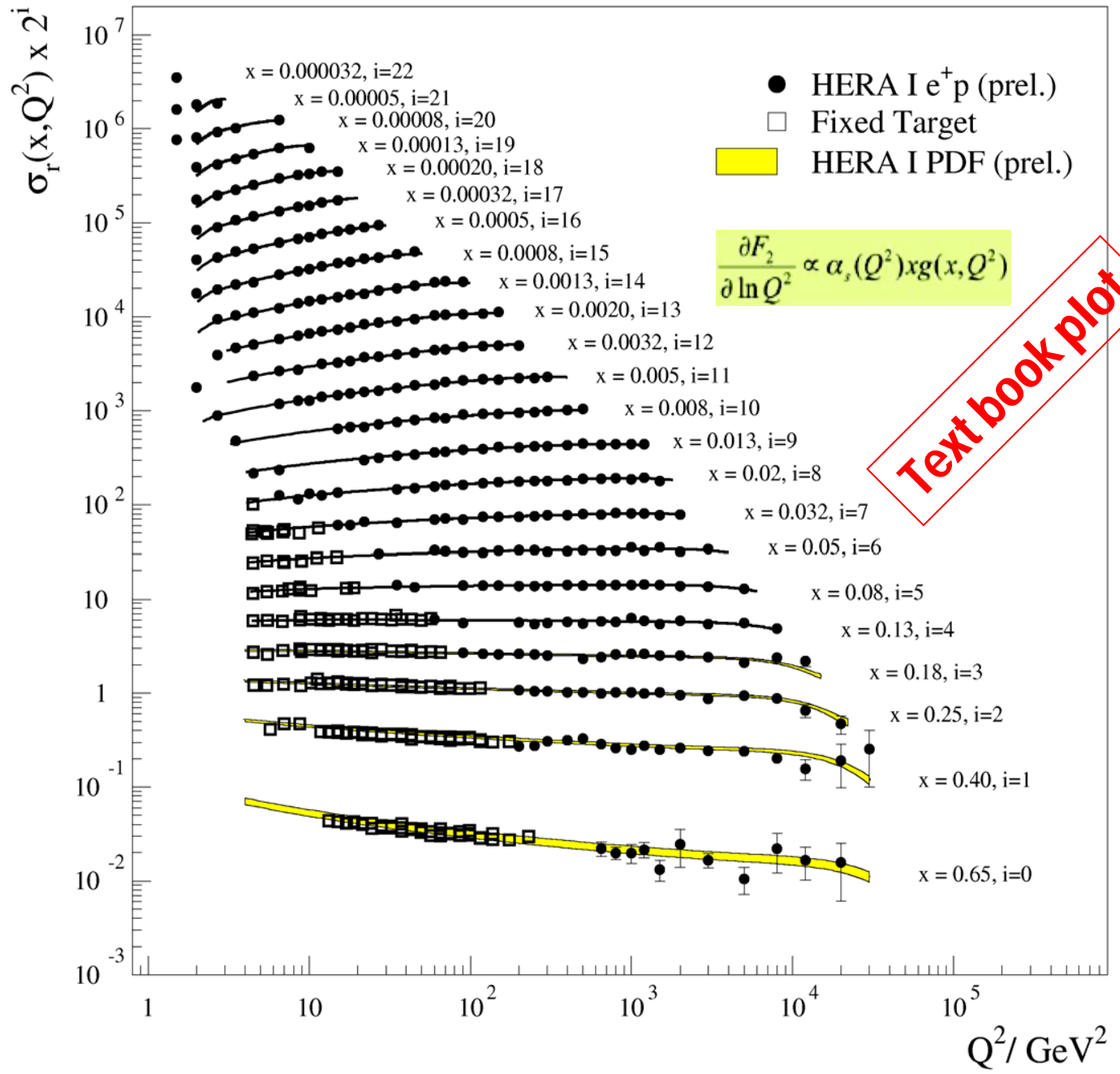
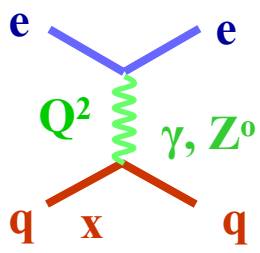
b



PROTON STRUCTURE:

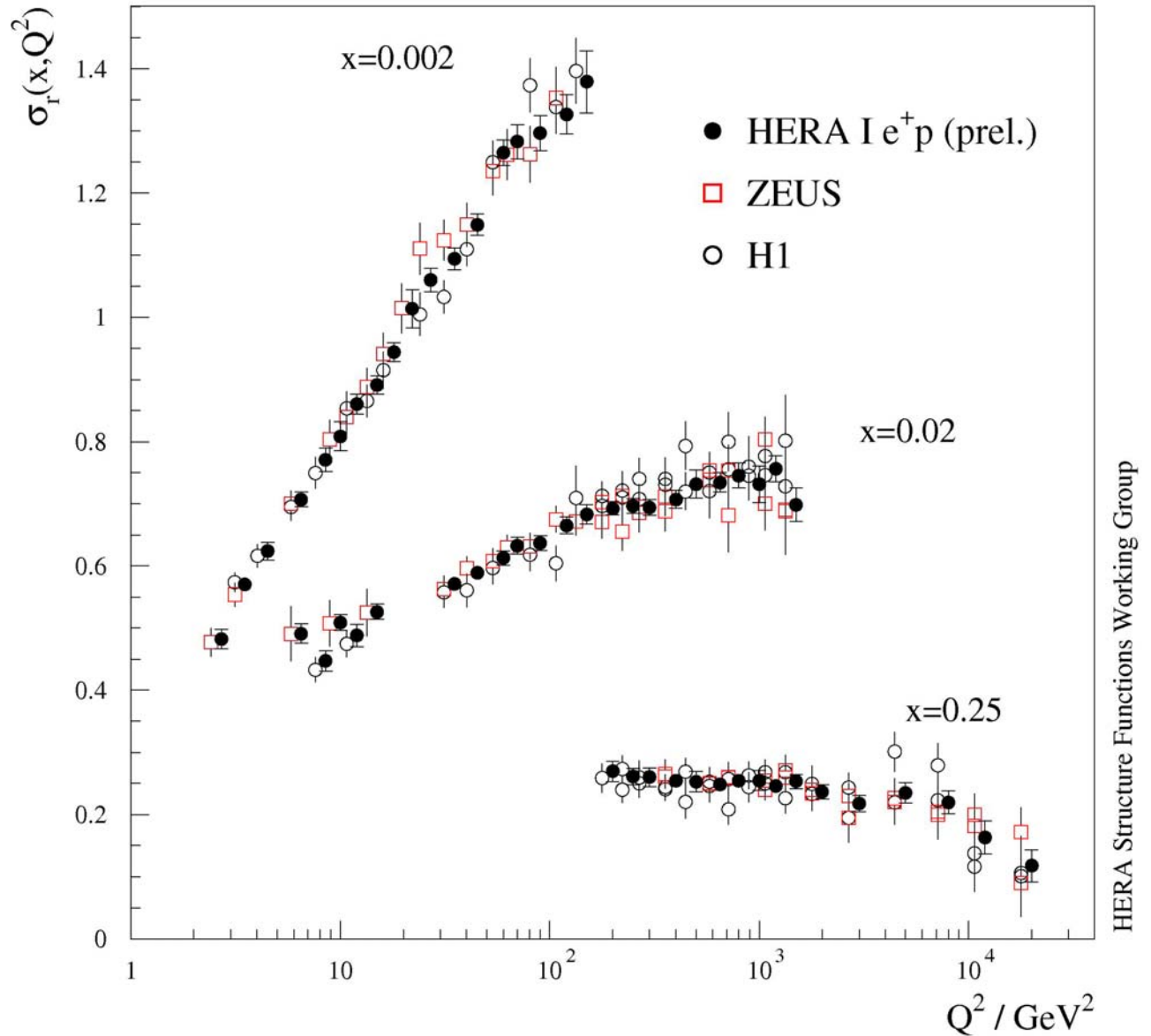
valence
+
sea quarks

$$F_2(x, Q^2)$$



HERA I e^+p Neutral Current Scattering - H1 and ZEUS

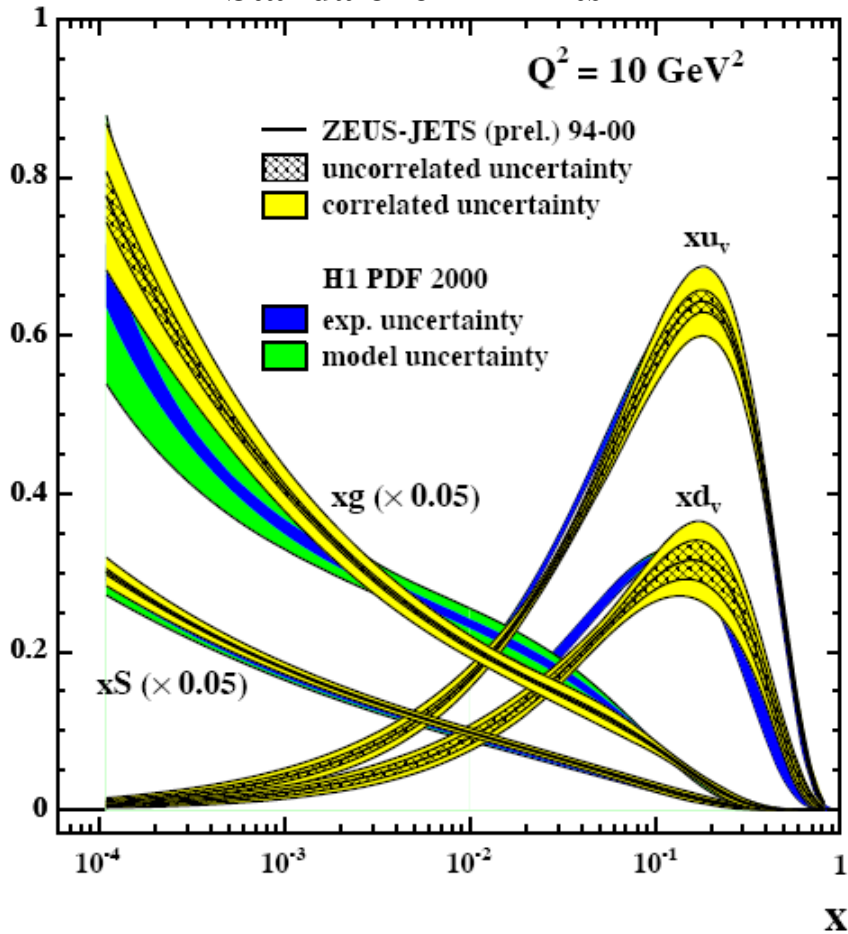
***PROTON
STRUCTURE:
the power of
combining***



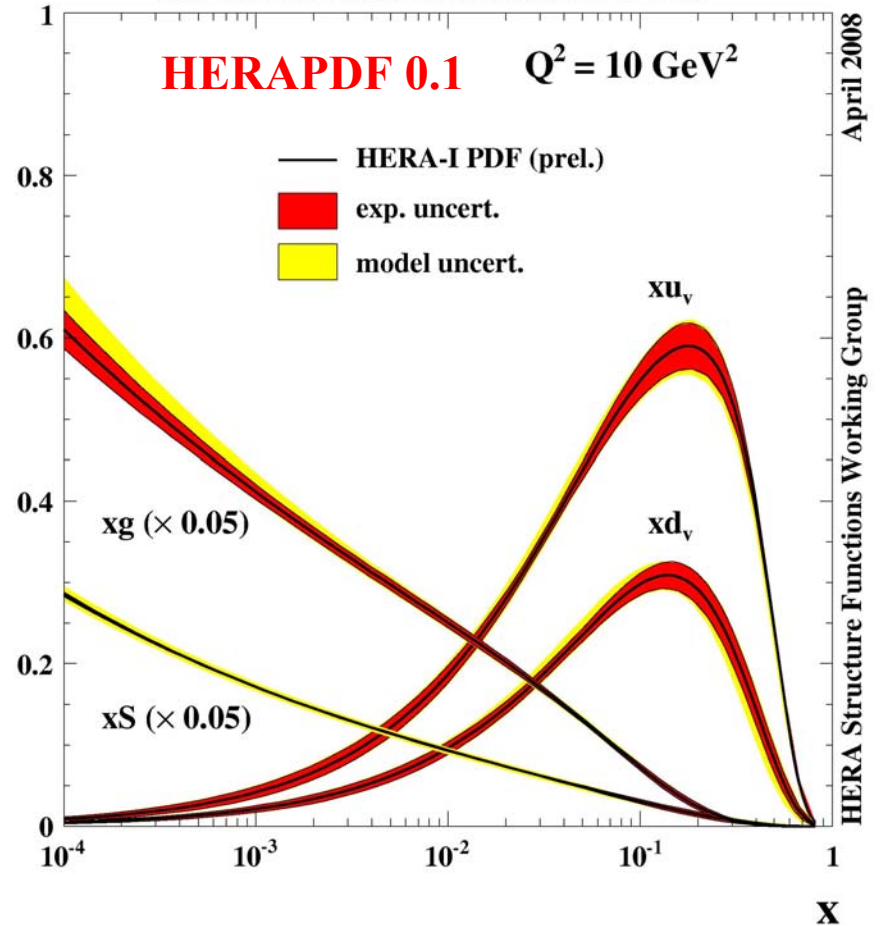
PROTON STRUCTURE:

Common PDF Fit on HERA I combined data

Standalone PDF Fits

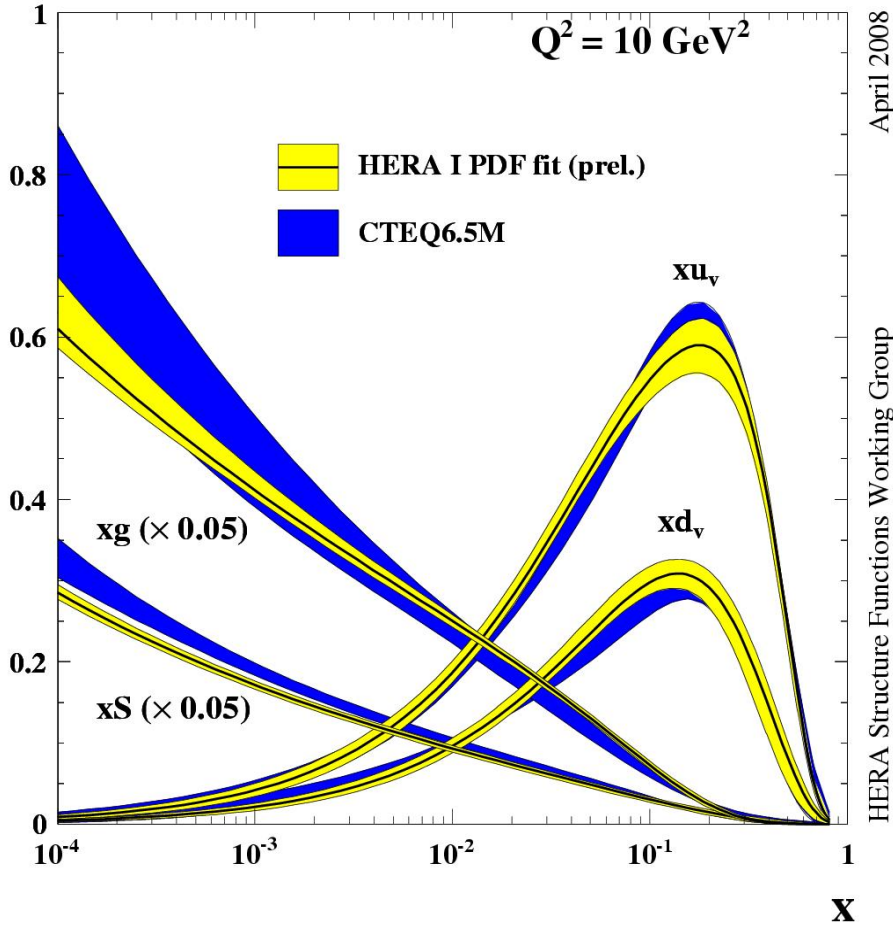


H1 and ZEUS Combined PDF Fit

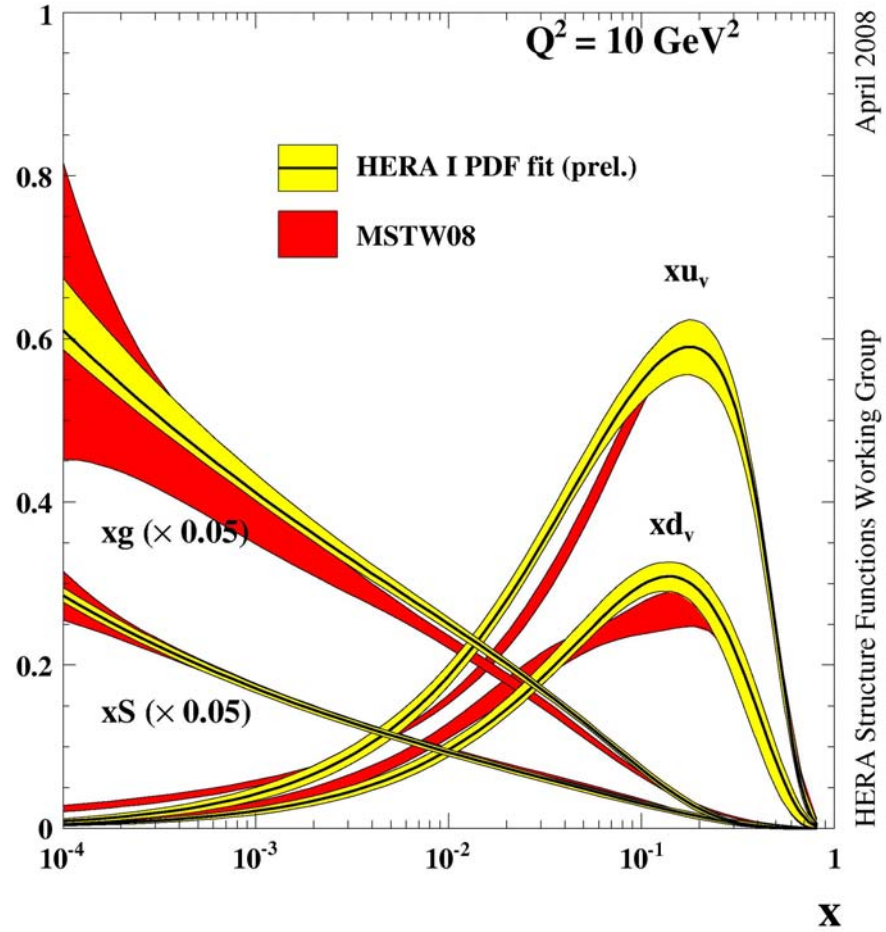


PROTON STRUCTURE: HERA I PDF Fit versus CTEQ and MSTW

H1 and ZEUS Combined PDF Fit

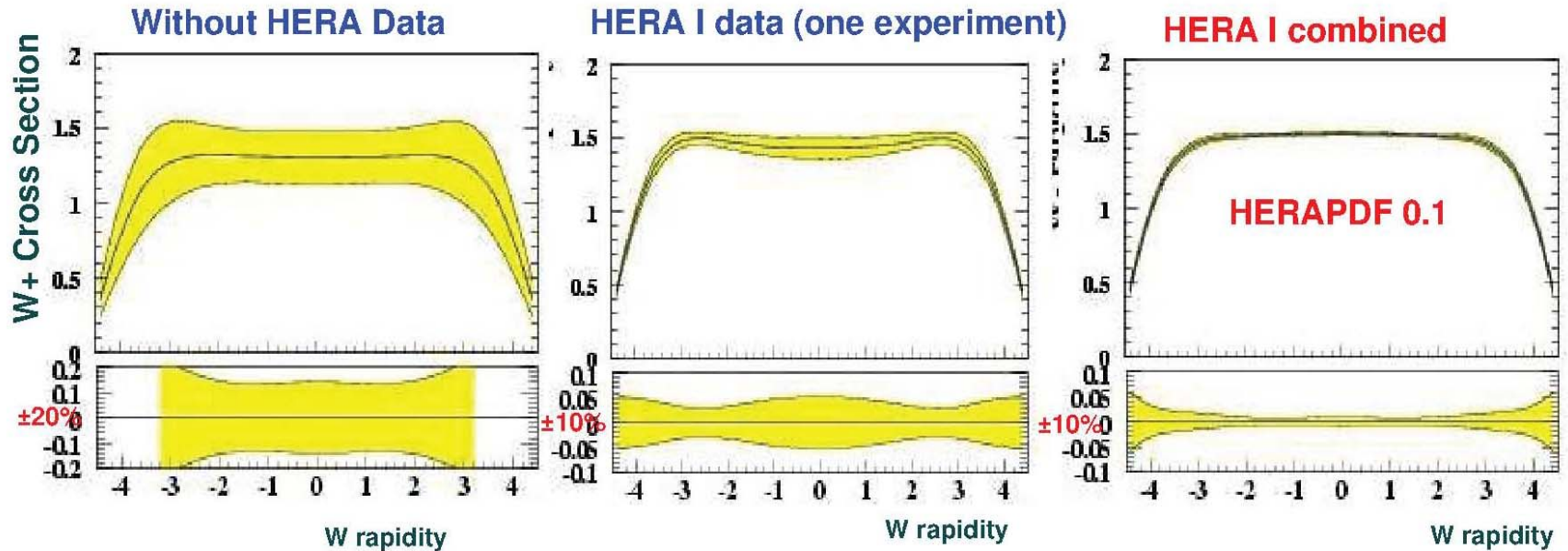


H1 and ZEUS Combined PDF Fit



PROTON STRUCTURE

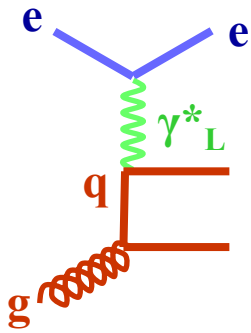
Impact on LHC: the example of W production



**HERA combined data and PDF's:
a crucial input for LHC predictions**

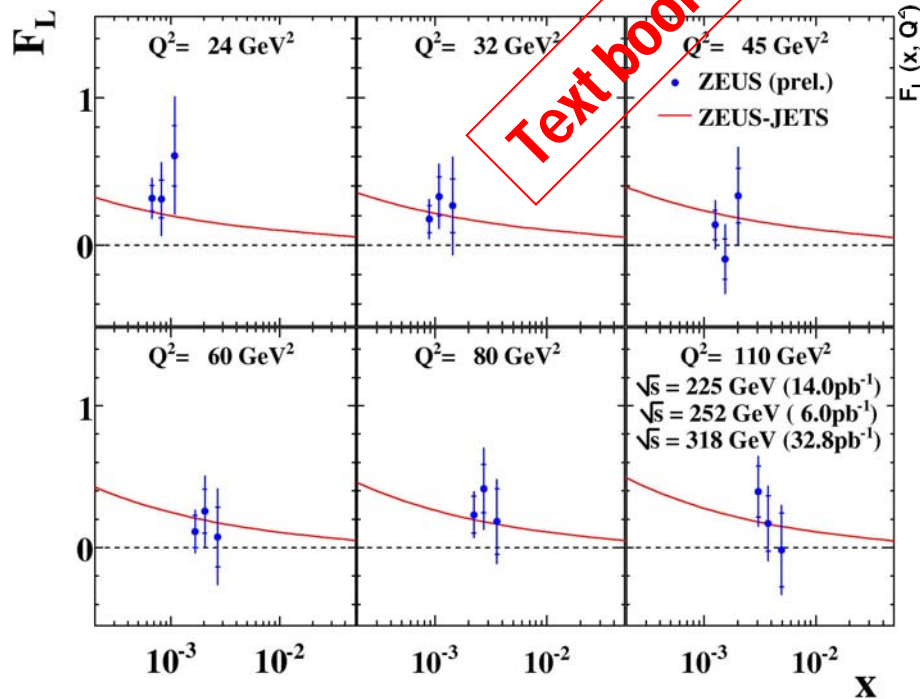
**An issue being closely followed
within the PDF4LHC workshop
(also a topic of the HGF Terascale Alliance)**

QCD Dynamics: probing the gluon directly with F_L

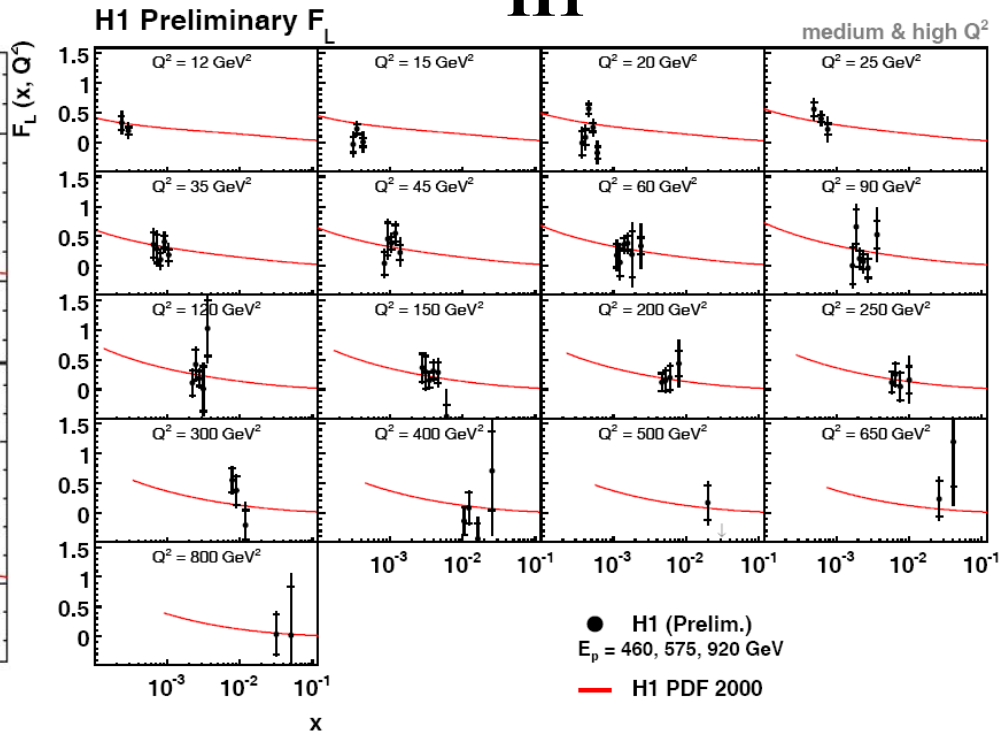


$$\tilde{\sigma}_{NC} = \frac{d^2\sigma_{NC}^{ep}}{dx dQ^2} / \left(\frac{2\pi\alpha^2}{xQ^4} Y_+ \right) = F_2 - \frac{y^2}{1+(1-y)^2} F_L \quad \mathbf{y = Q^2/sx}$$

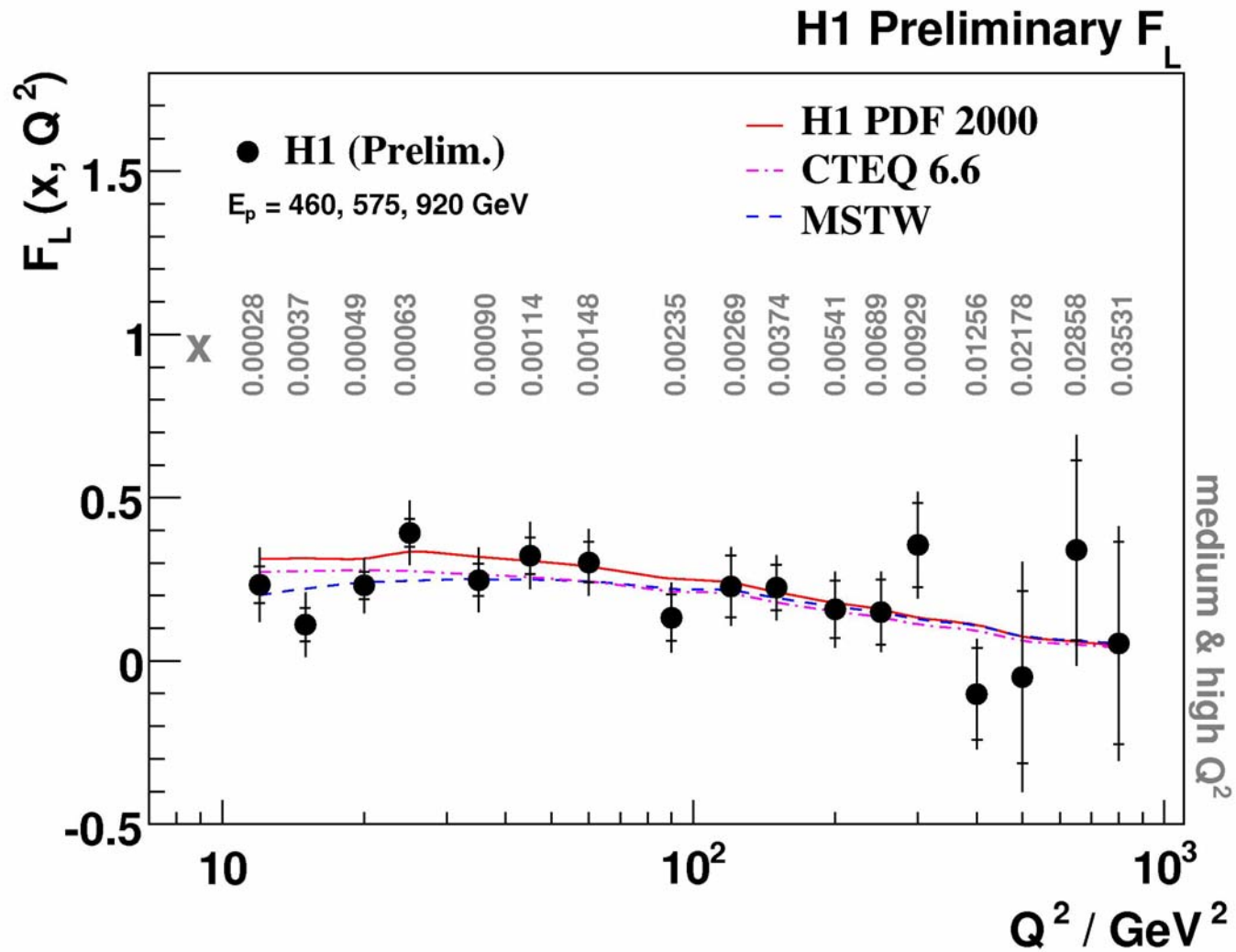
ZEUS



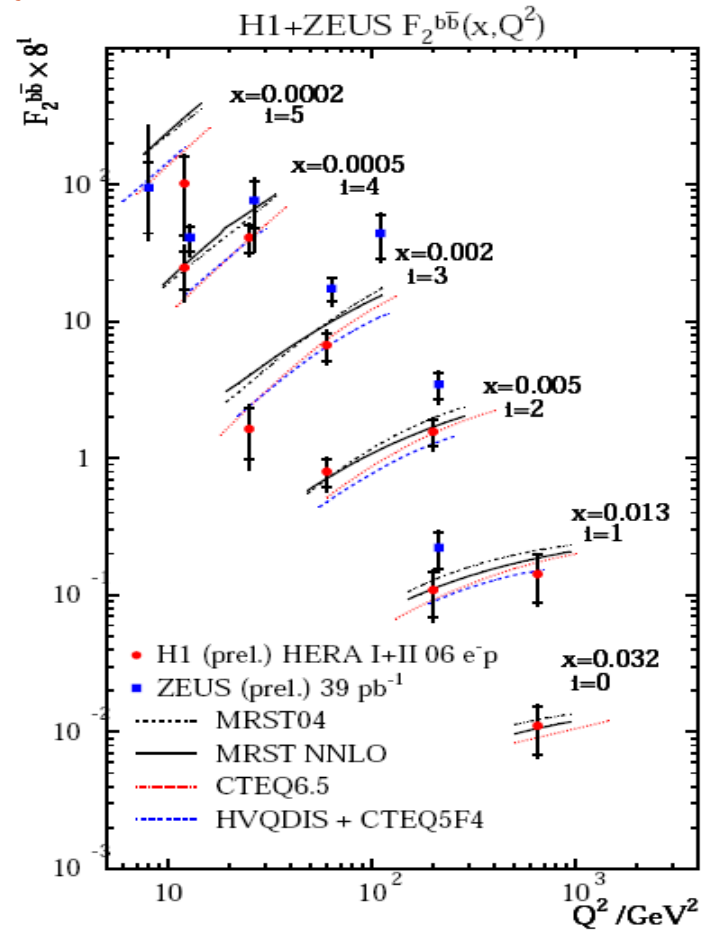
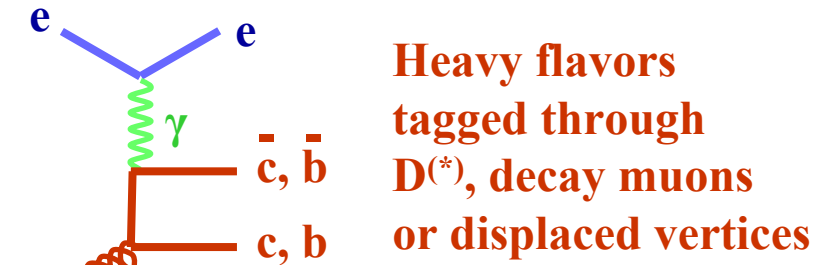
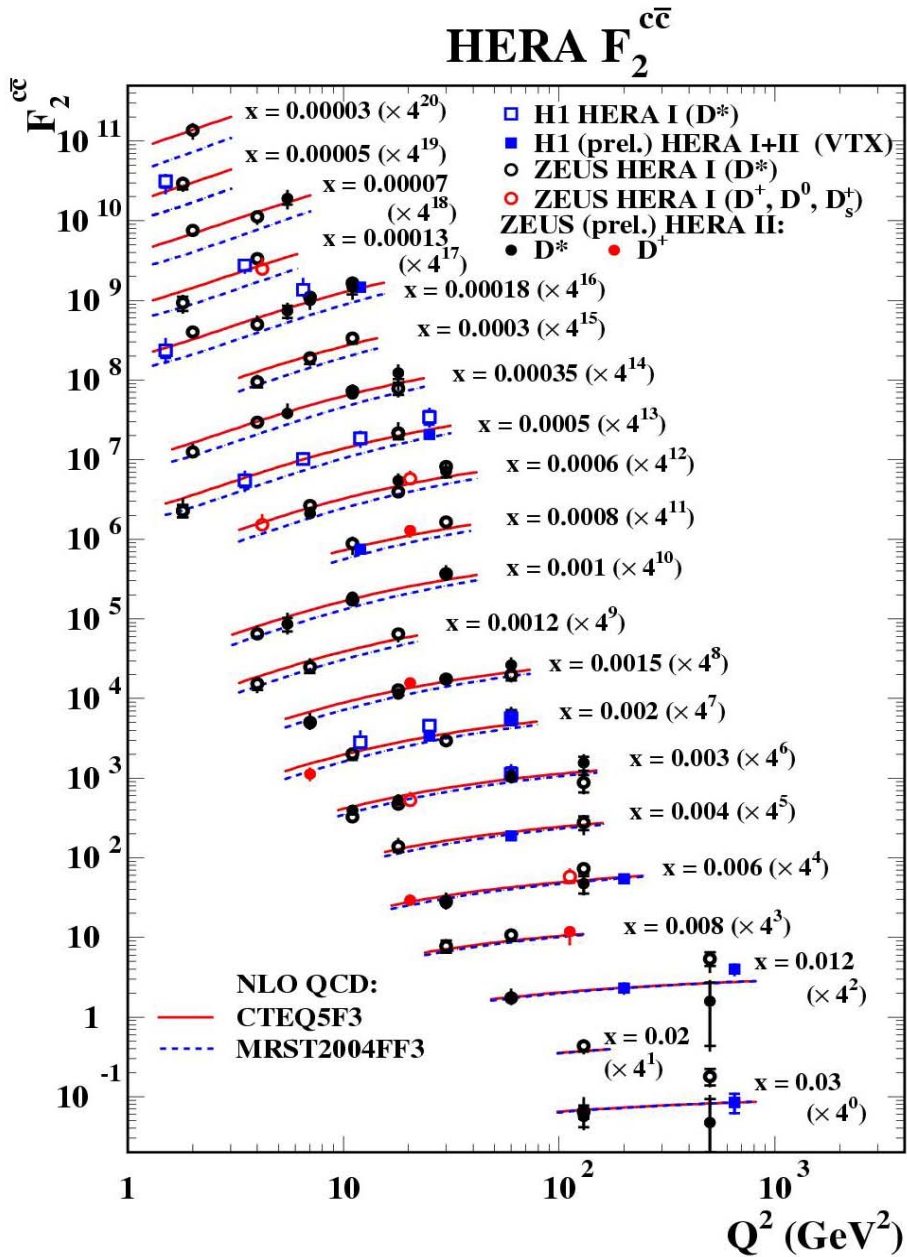
H1



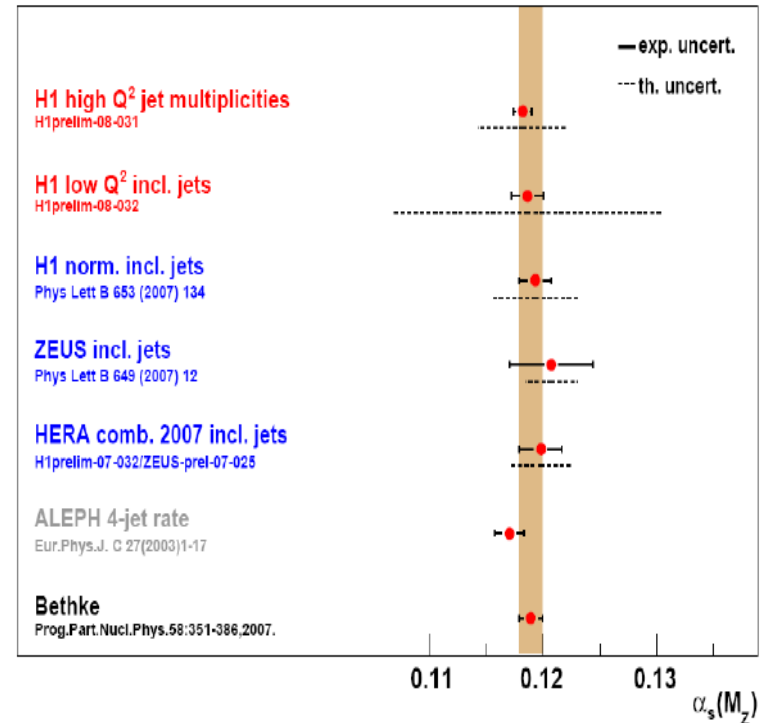
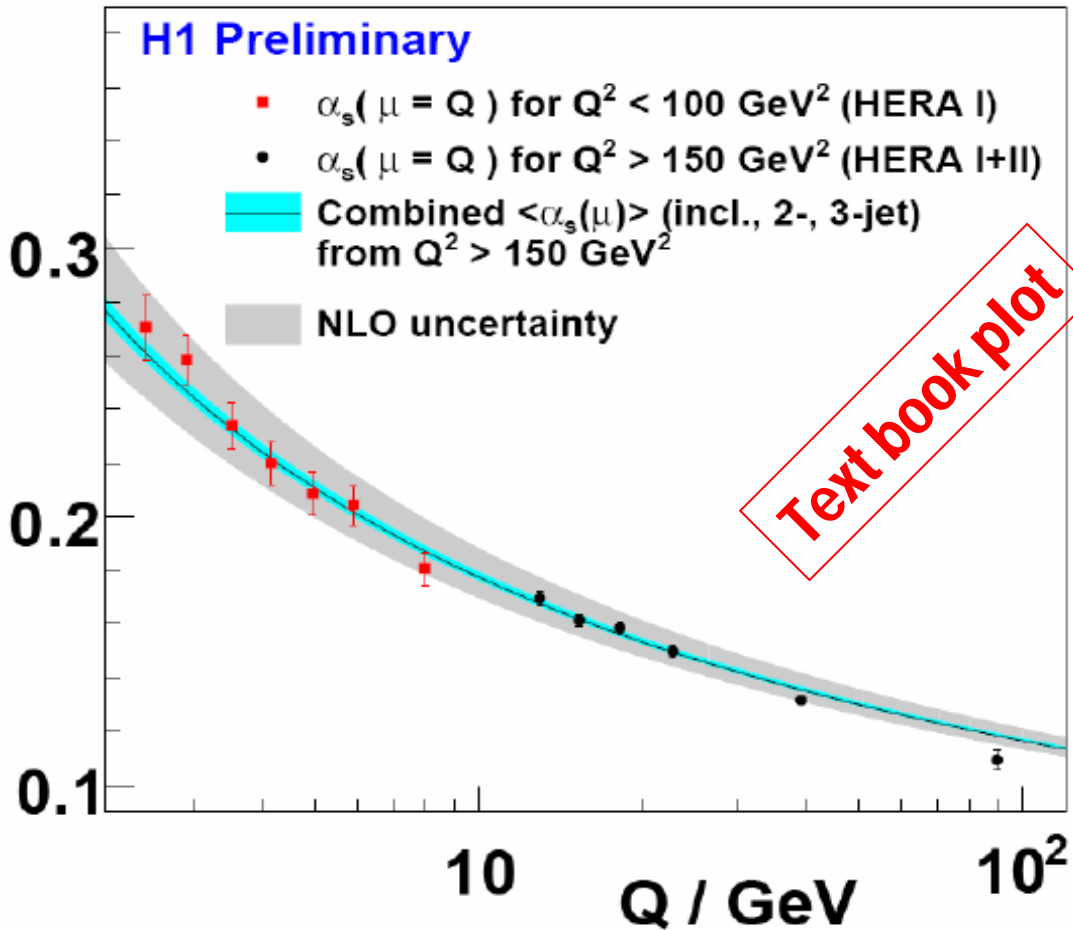
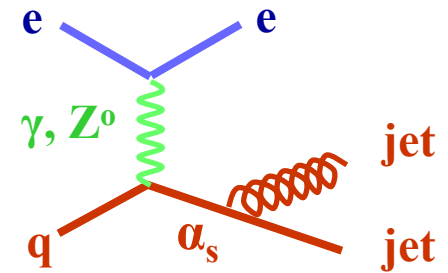
QCD Dynamics: comparing F_L with NLO DGLAP predictions



QCD Dynamics: Heavy Quark content of the proton

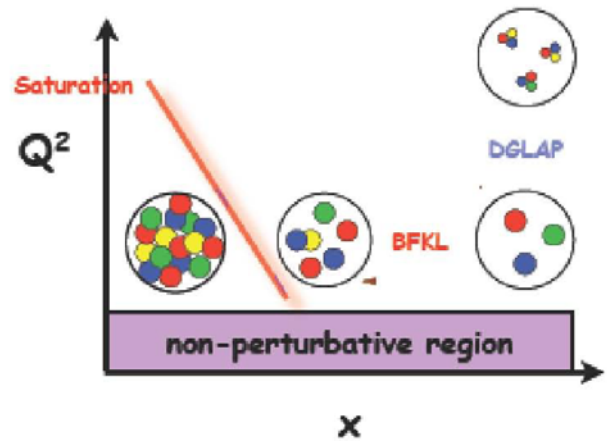


QCD Dynamics: the strong coupling α_s from multi-jet rates

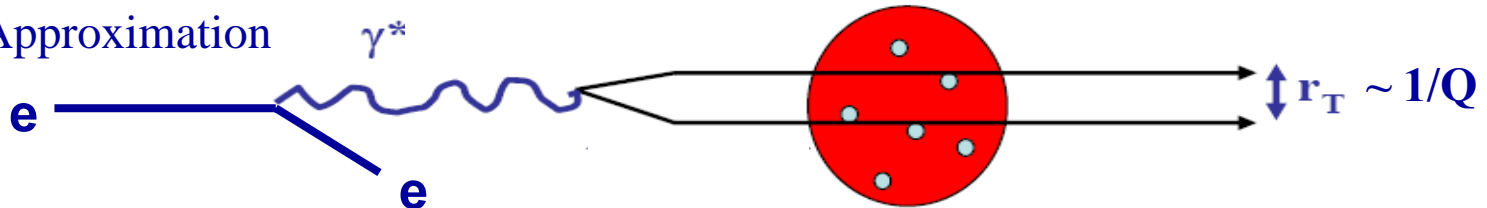


HERA exp. error $\sim 0.7\%$
a challenge for theory !

QCD Dynamics:
the very low x / low Q² limit



Williams-Weizsäcker
Approximation



$$d\sigma_{ep}/dydQ^2 \sim \Phi_{\gamma^*}(y, Q^2) \times \sigma_{\gamma^*p}(W^2, Q^2) \quad W^2 \sim Q^2/x$$

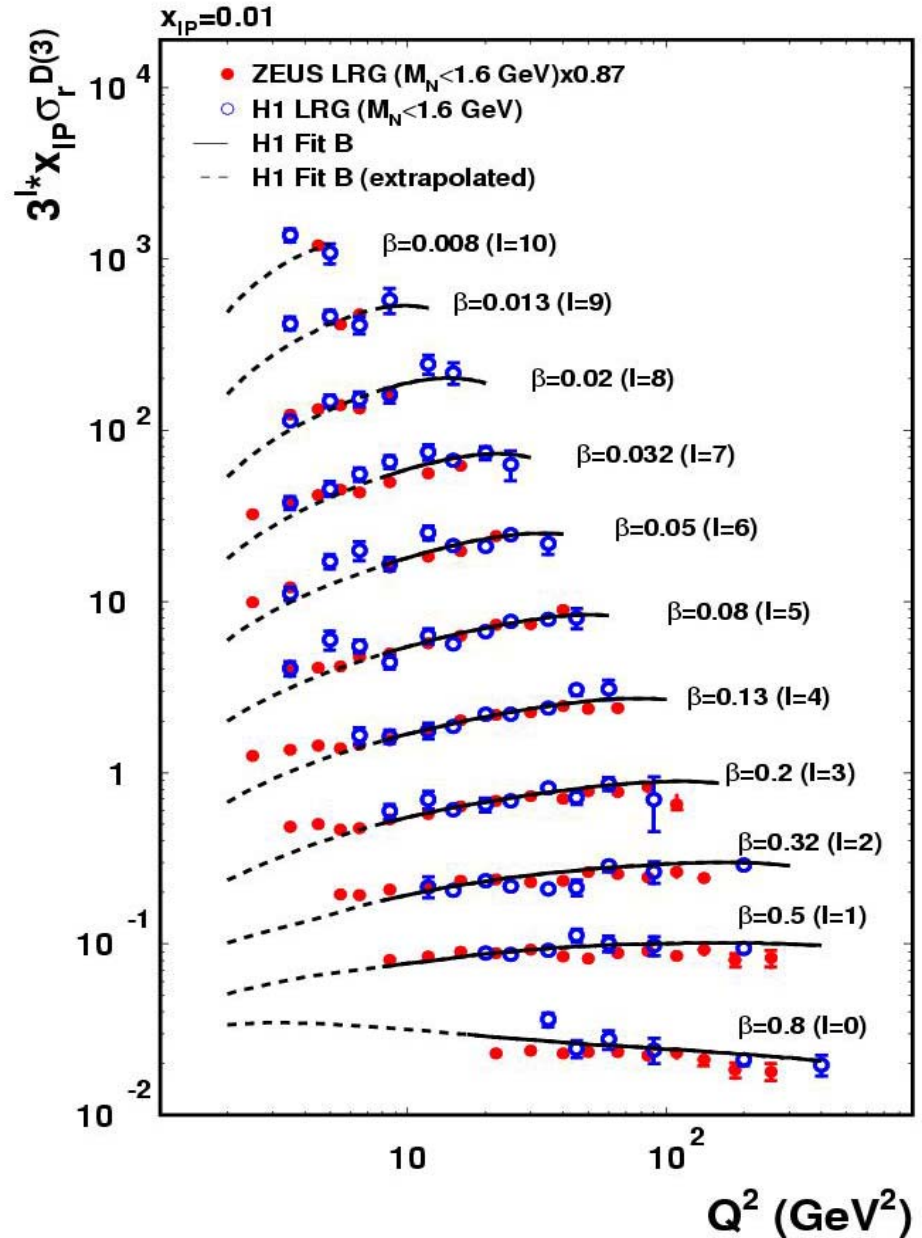
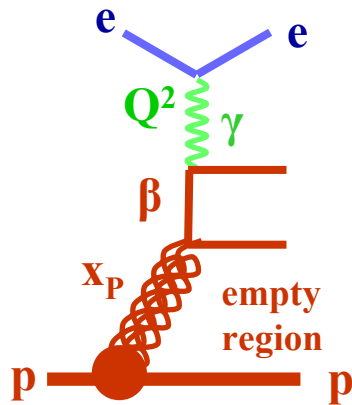
$$\alpha/Q^2 [1+(1-y)^2]/y \quad \alpha/Q^2 \times q(x)$$

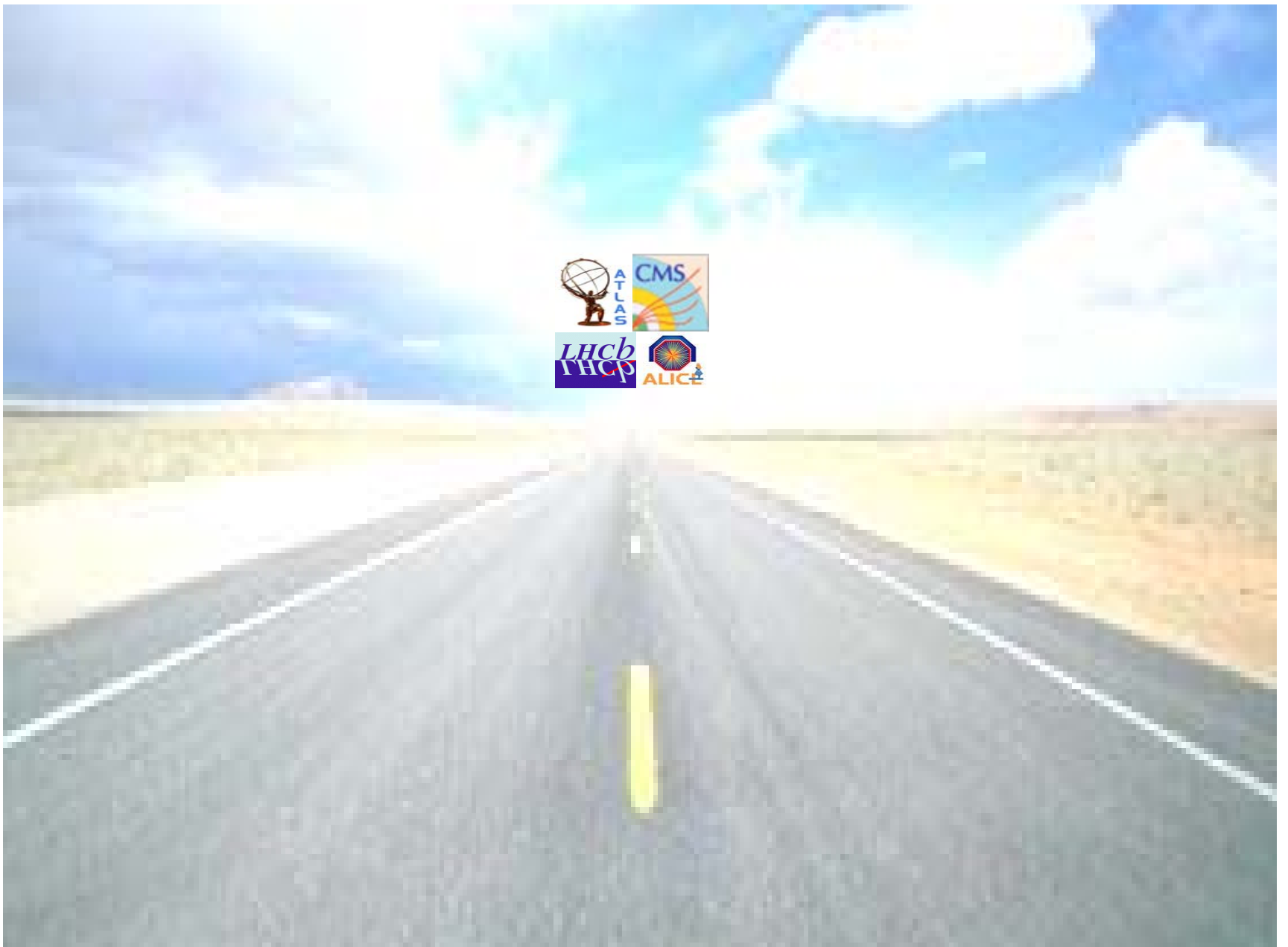
Allows to relate low-x dynamics, deep-inelastic scattering, photoproduction, diffraction and saturation

A wealth of HERA results with vector mesons, DVCS, exclusive and inclusive diffraction

HERA inclusive diffraction

*QCD Dynamics:
the perturbative structure
of Diffraction*







**long term repository of
HERA data to enable later revisiting**

structure and dynamics of diffraction

EM probe of exclusive QCD dynamics (jets, photons ...)

**quark/gluon mapping of the proton
with full HERA data**

