

GDR Terascale, Grenoble, April 1st 2009

*Claude Vallée
H1 experiment, CPPM-Marseille*

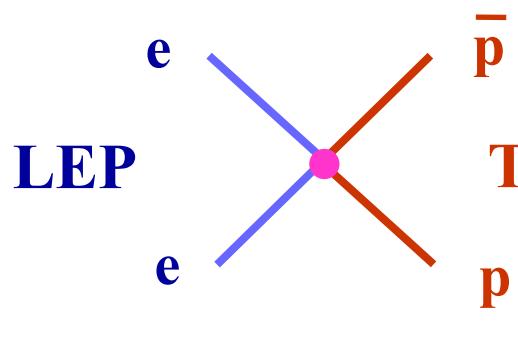
Implications of HERA Measurements on LHC Physics



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



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

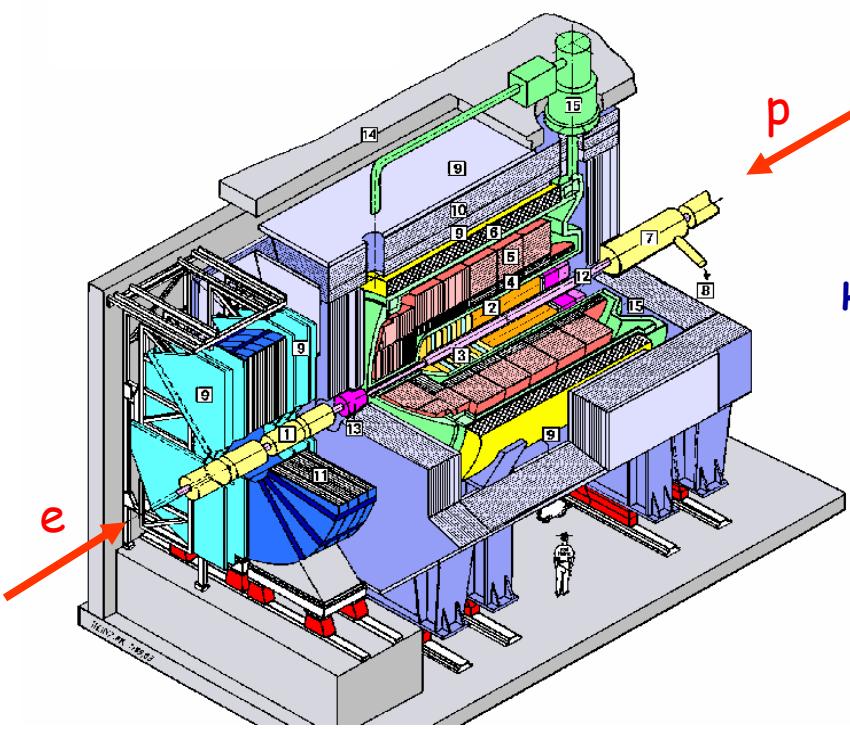


0.32 TeV, $\sim 0.5 \text{ fb}^{-1}/\text{exp.}$



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

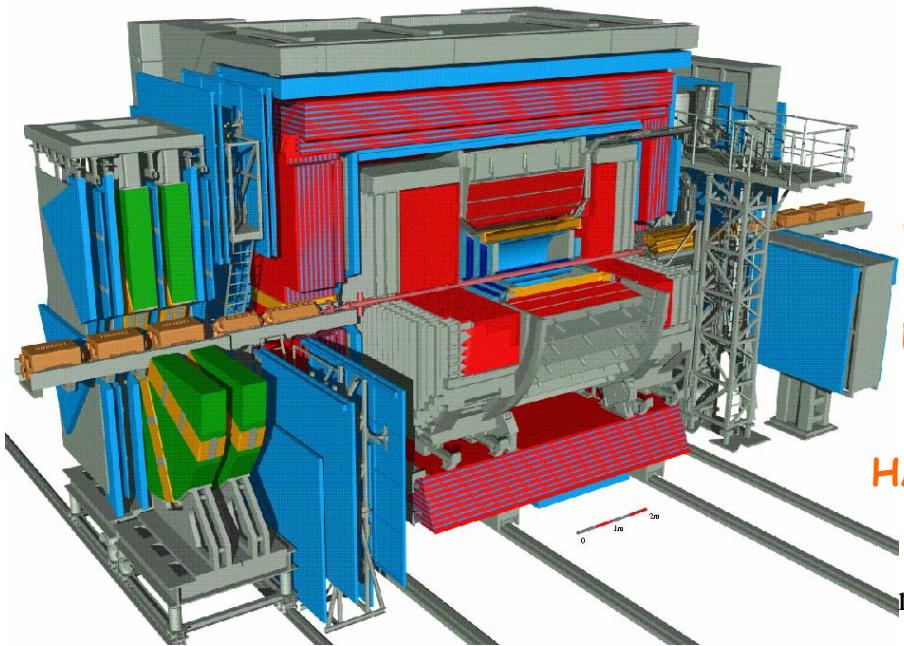
**~ twice more expected
until 2010**



EM: $\frac{\delta E}{E} = \frac{12\%}{\sqrt{E}}$

HAD: $\frac{\delta E}{E} = \frac{50\%}{\sqrt{E}}$

LAr
calorimeter

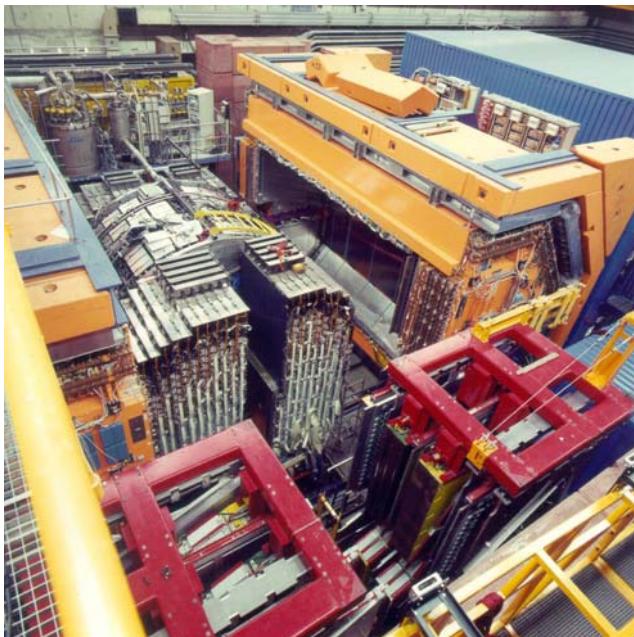
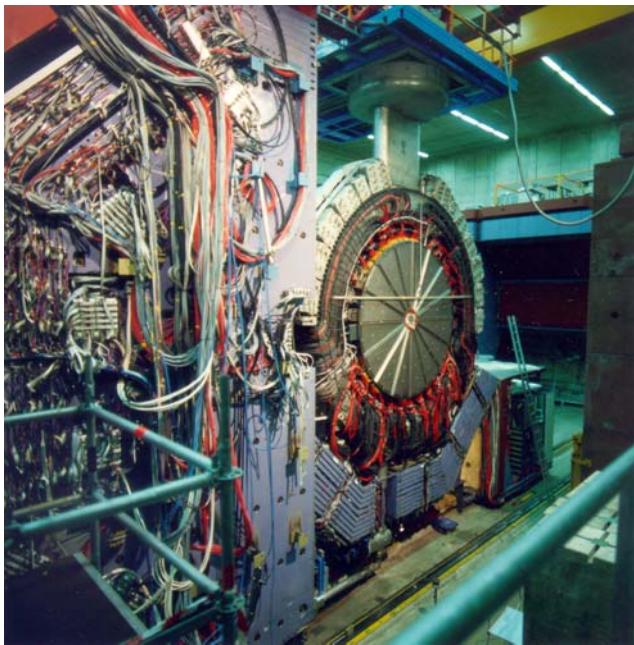


U-scint.
calorimeter

EM: $\frac{\delta E}{E} = \frac{18\%}{\sqrt{E}}$

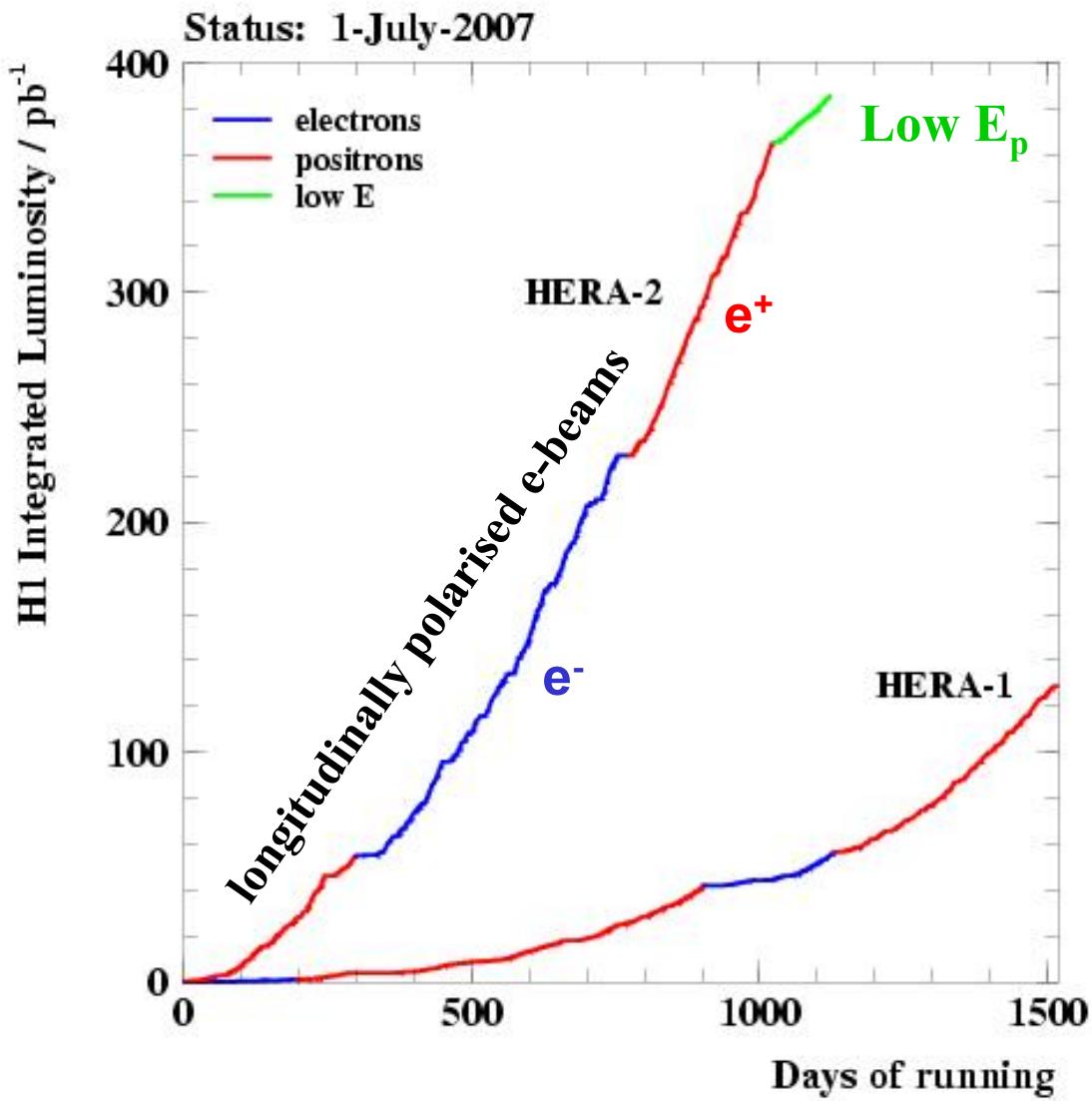
HAD: $\frac{\delta E}{E} = \frac{35\%}{\sqrt{E}}$

gements and LHC



All good things come to an end...





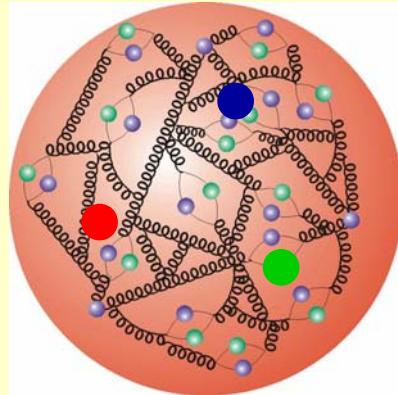
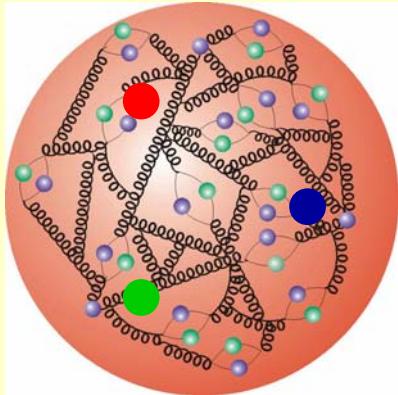
The final HERA data samples

$\sim 0.5 \text{ fb}^{-1} / \text{experiment}$

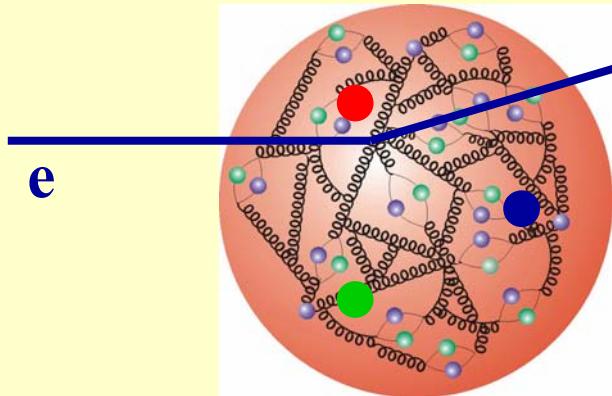
balanced e^+p and e^-p samples

$\sim 35\%$ polarised e at HERA II

Low- E_p runs for F_L

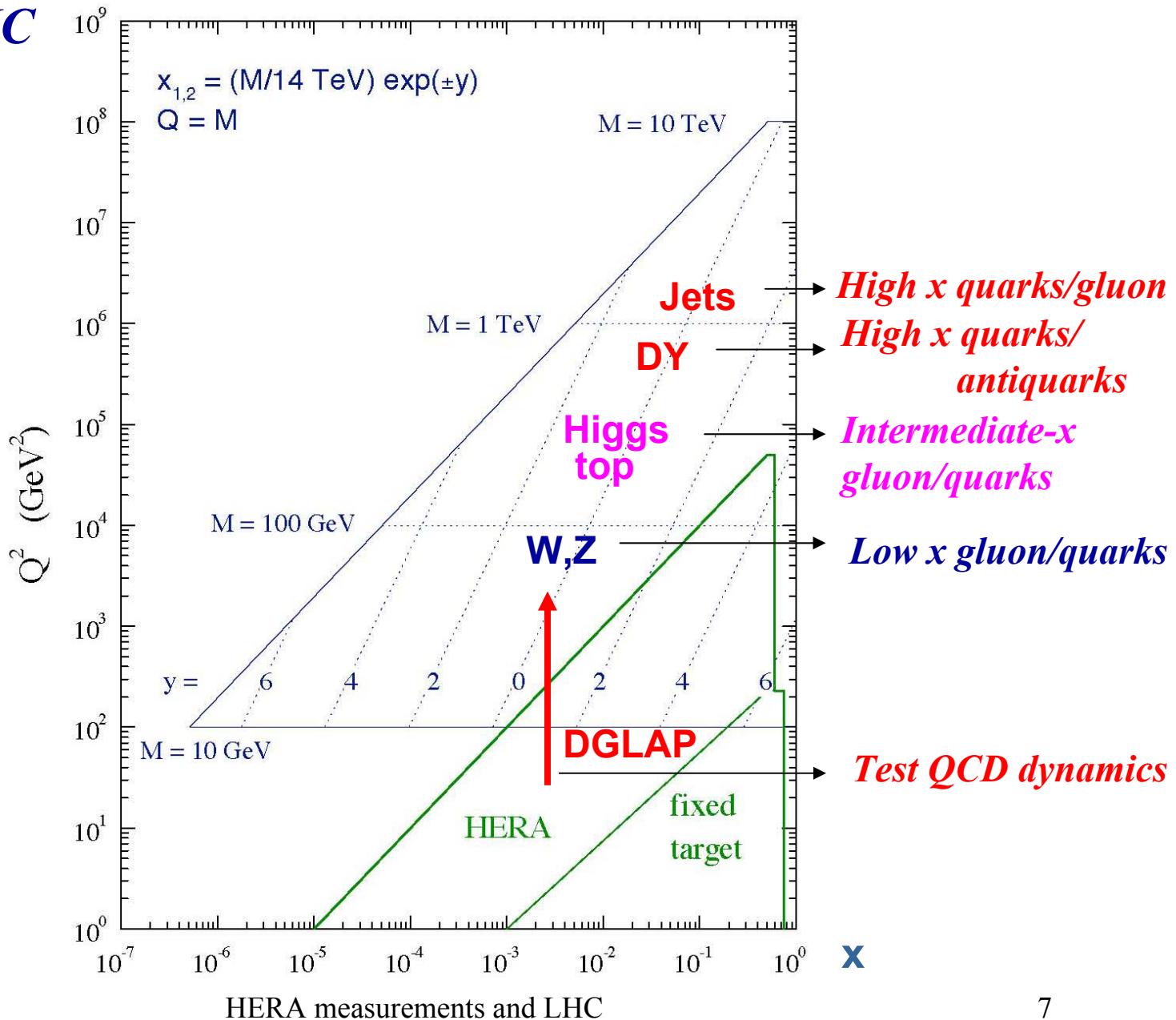
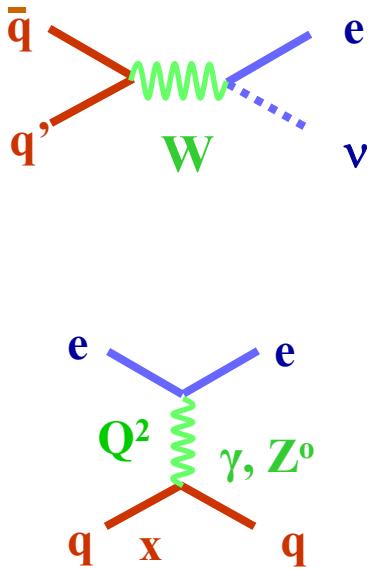


LHC needs
(plots from contributors to the PDF4LHC workshop)

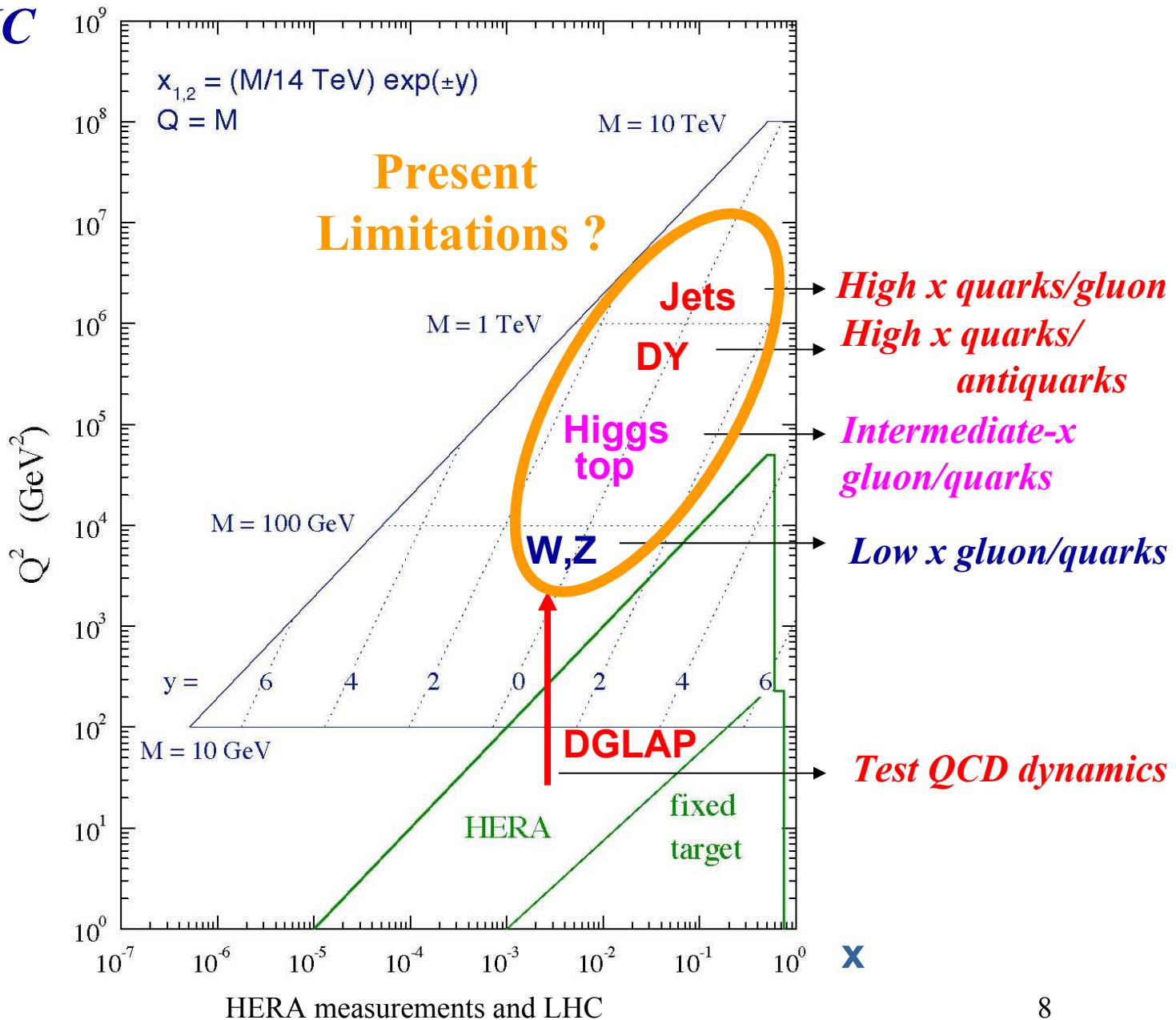
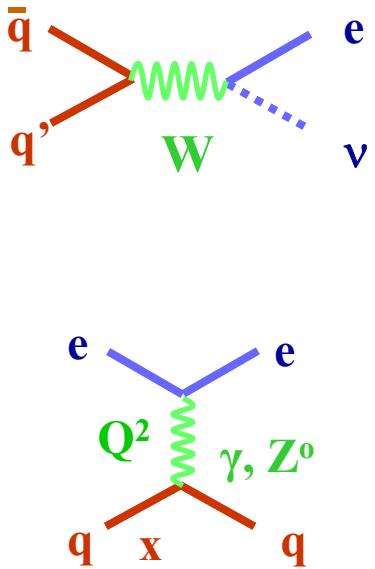


HERA MEASUREMENTS
*Proton structure and dynamics
Diffraction and the low-x limit*

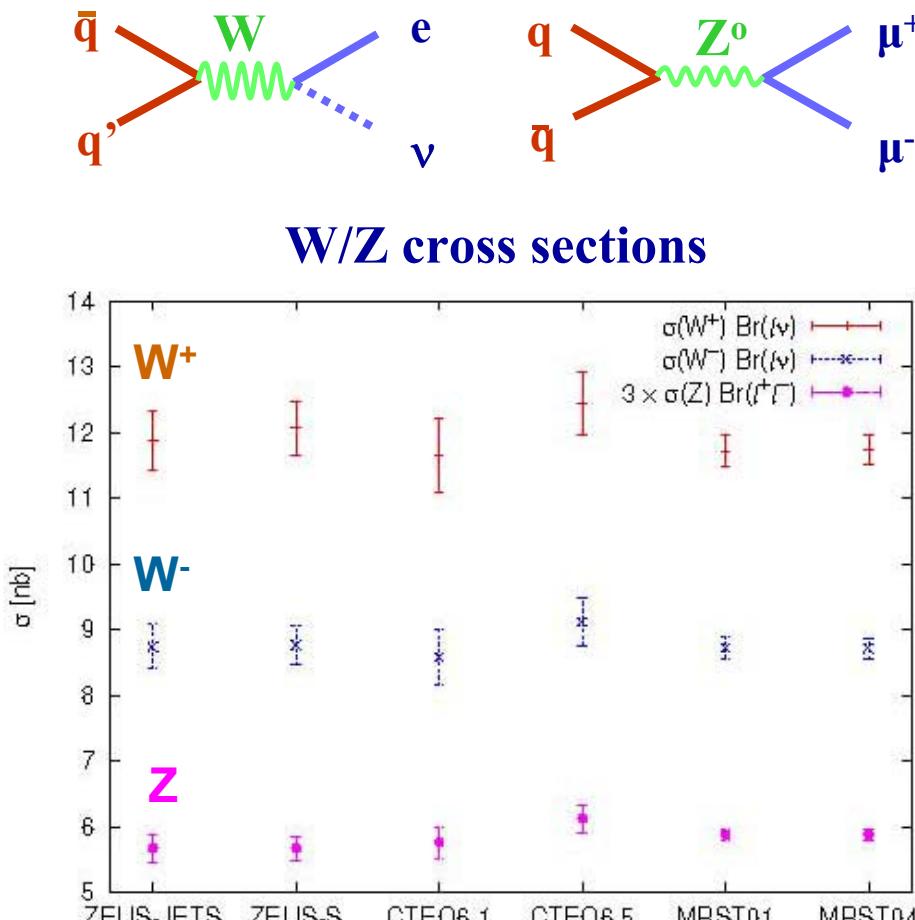
HERA \leftrightarrow LHC kinematics



HERA \leftrightarrow LHC kinematics

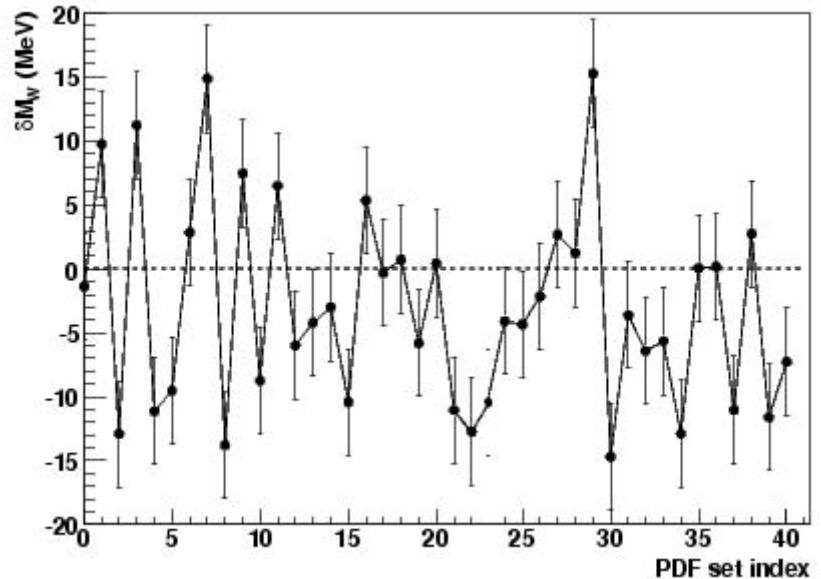


LHC needs: W/Z production



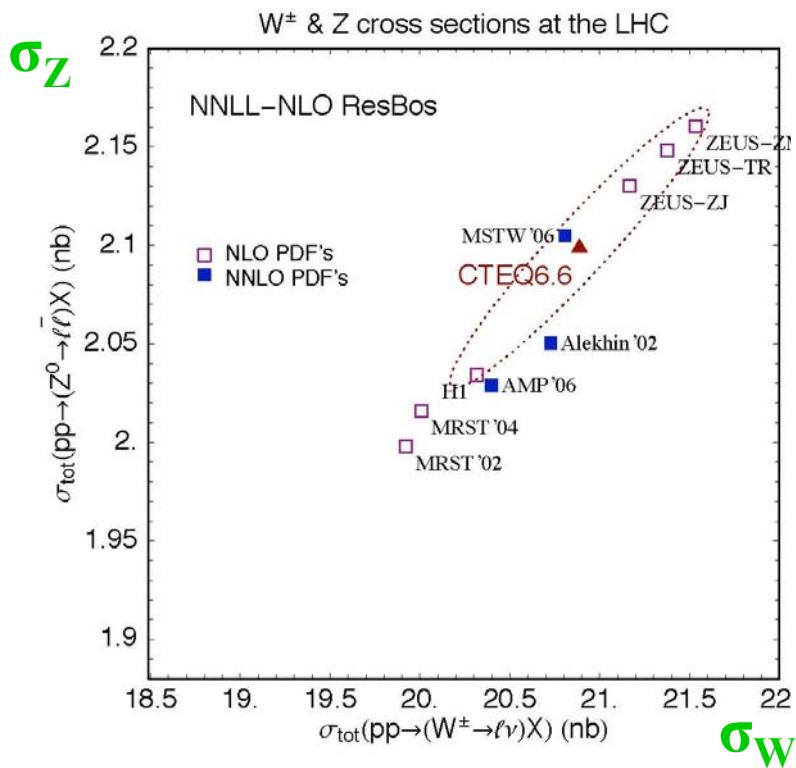
σ variations from PDF's at the level of $\sim 5\%$

W mass determination

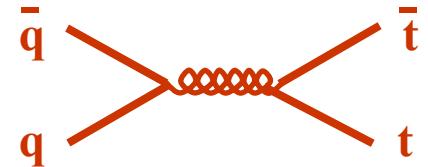


Spread of ~ 25 MeV
in M_T mass fit
due to PDF uncertainties
in rapidity distribution
(goal is ~ 1 MeV)

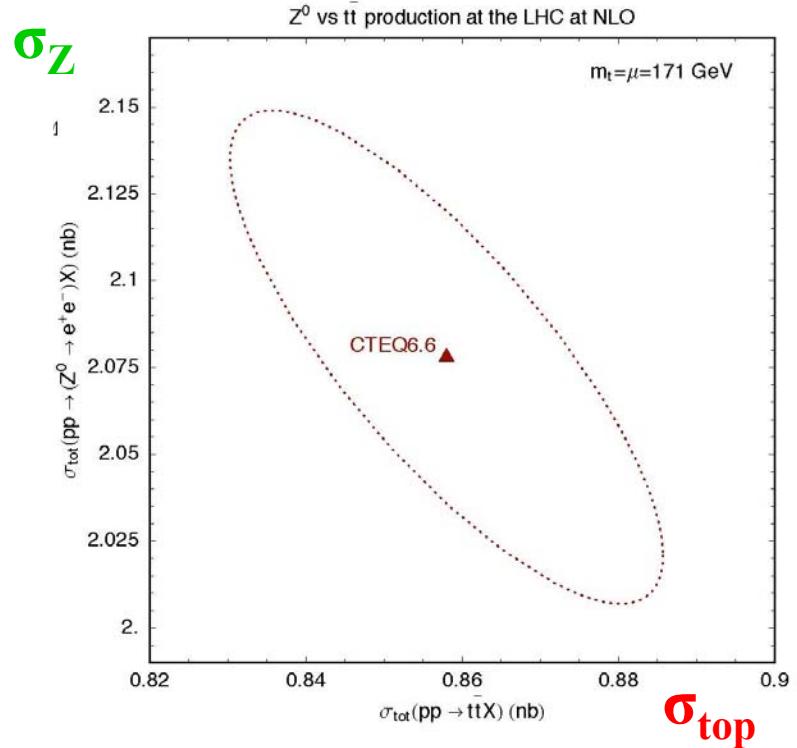
LHC needs: $W \leftrightarrow Z \leftrightarrow$ top PDF correlations



W and Z strongly correlated

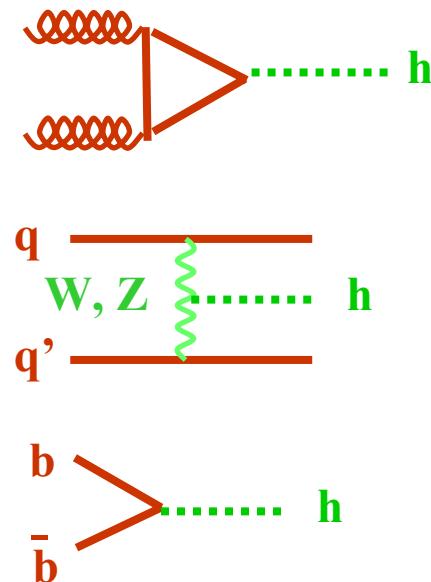
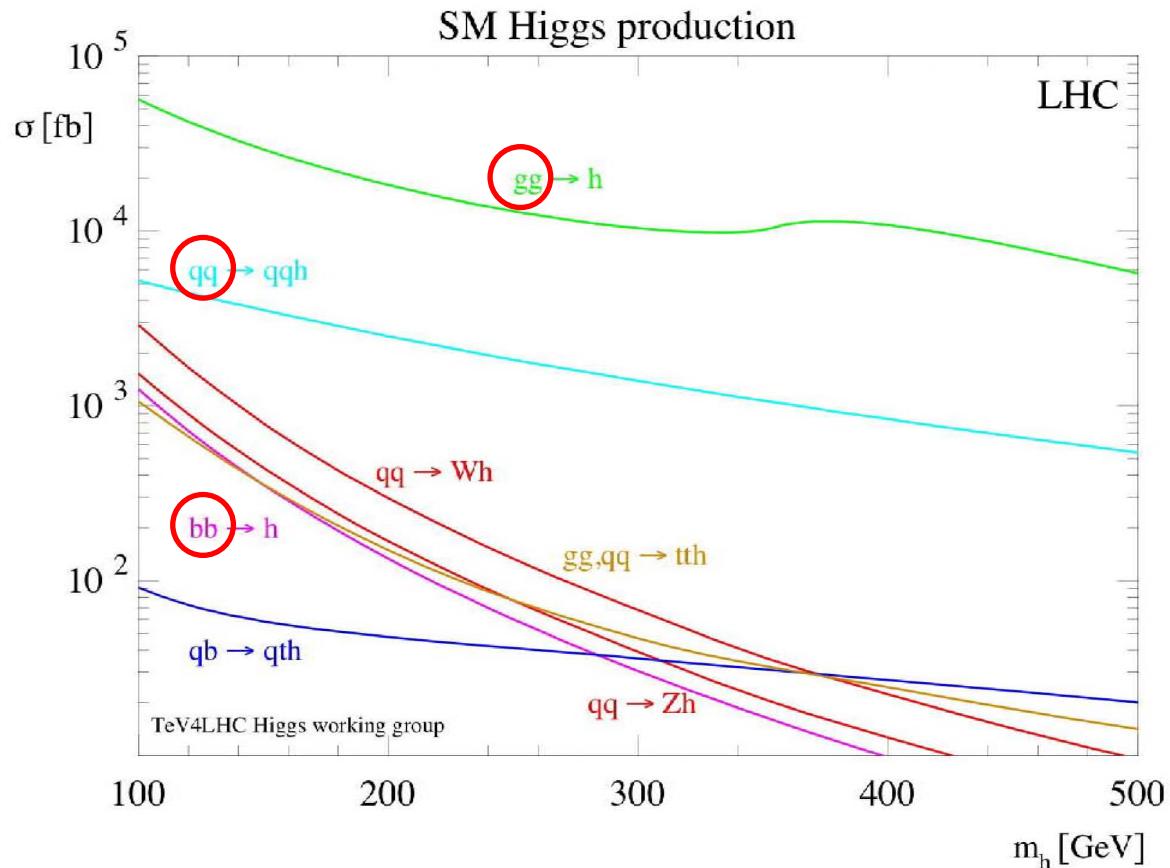


CTEQ6.5	$\sigma = 908^{+82(9.0\%)}_{-85(9.3\%)} (\text{scales})^{+30(3.3\%)}_{-29(3.2\%)} (\text{PDFs}) \text{ pb}$
MRSTW-06	$\sigma = 961^{+89(9.2\%)}_{-91(9.4\%)} (\text{scales})^{+11(1.1\%)}_{-12(1.2\%)} (\text{PDFs}) \text{ pb}$

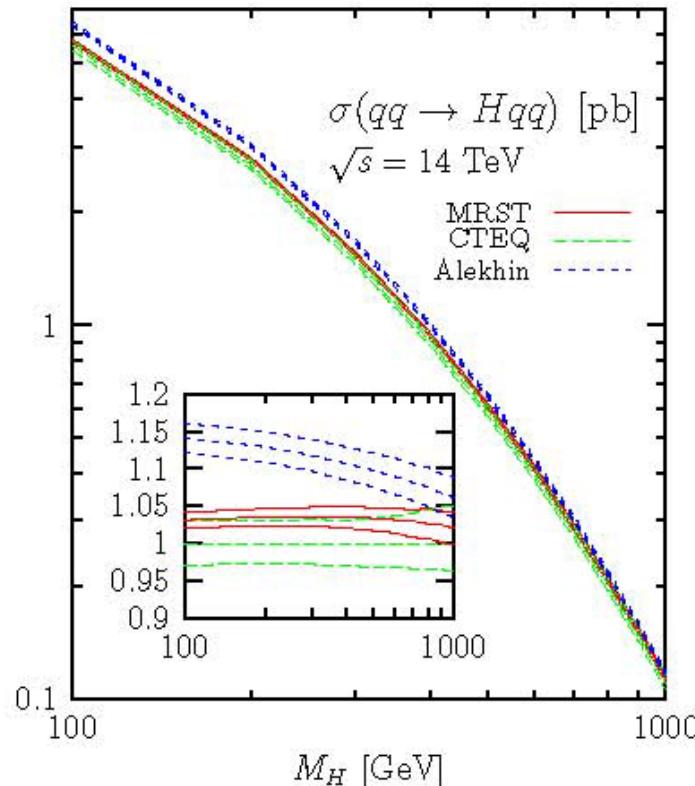
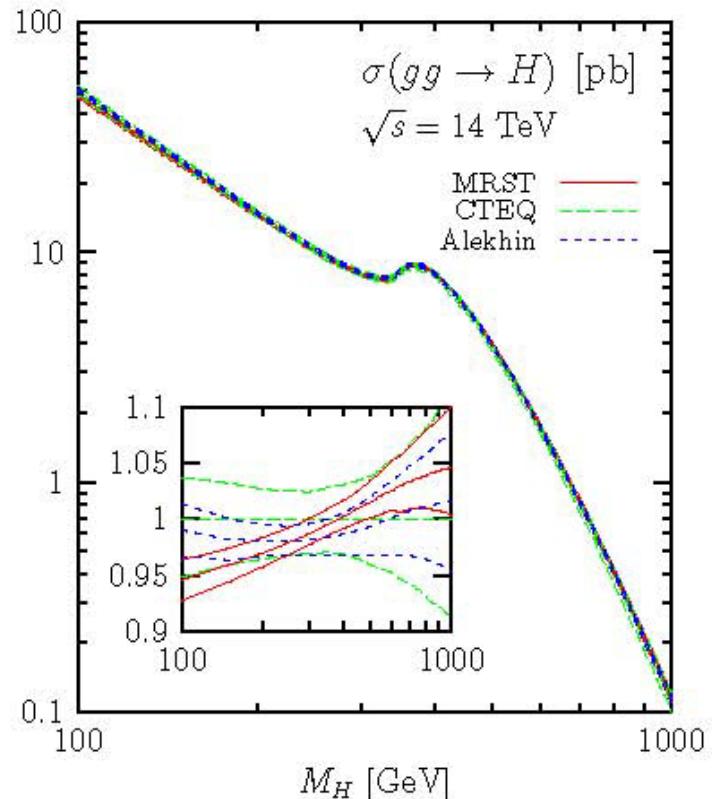
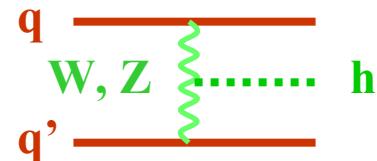
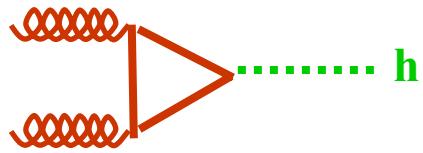


Top uncertainty ~5%
anti-correlated with Z

LHC needs: SM Higgs production



- Sensitive mainly to gluon and light quarks at low or intermediate x
- Beauty PDF contributes mainly at low mass for a SM Higgs



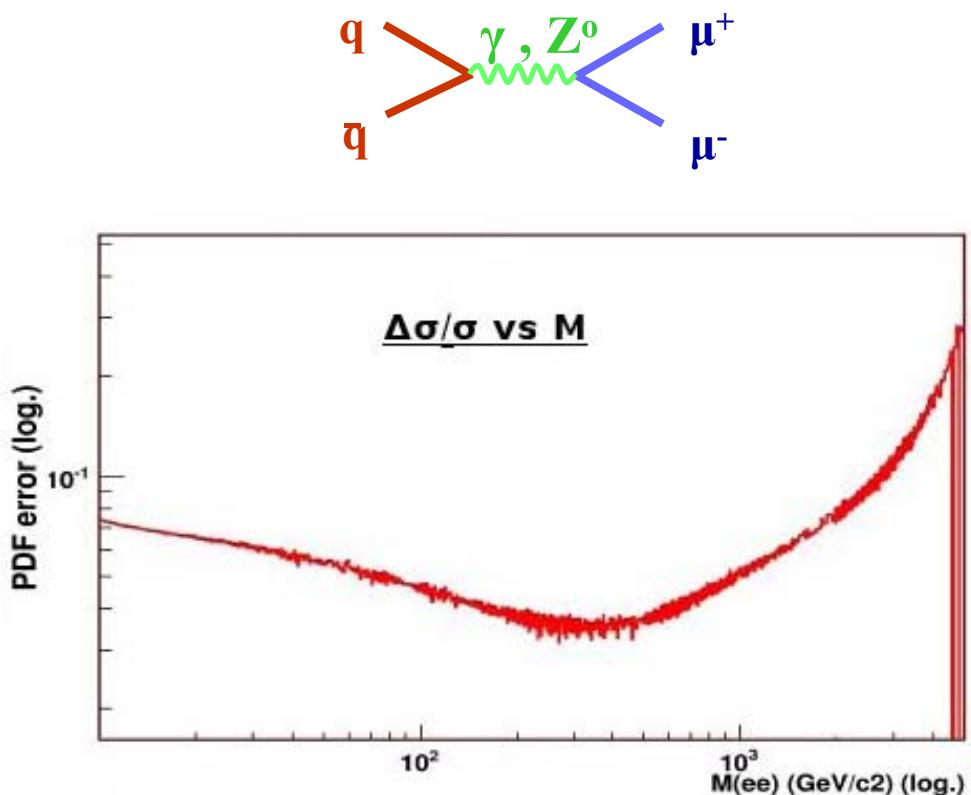
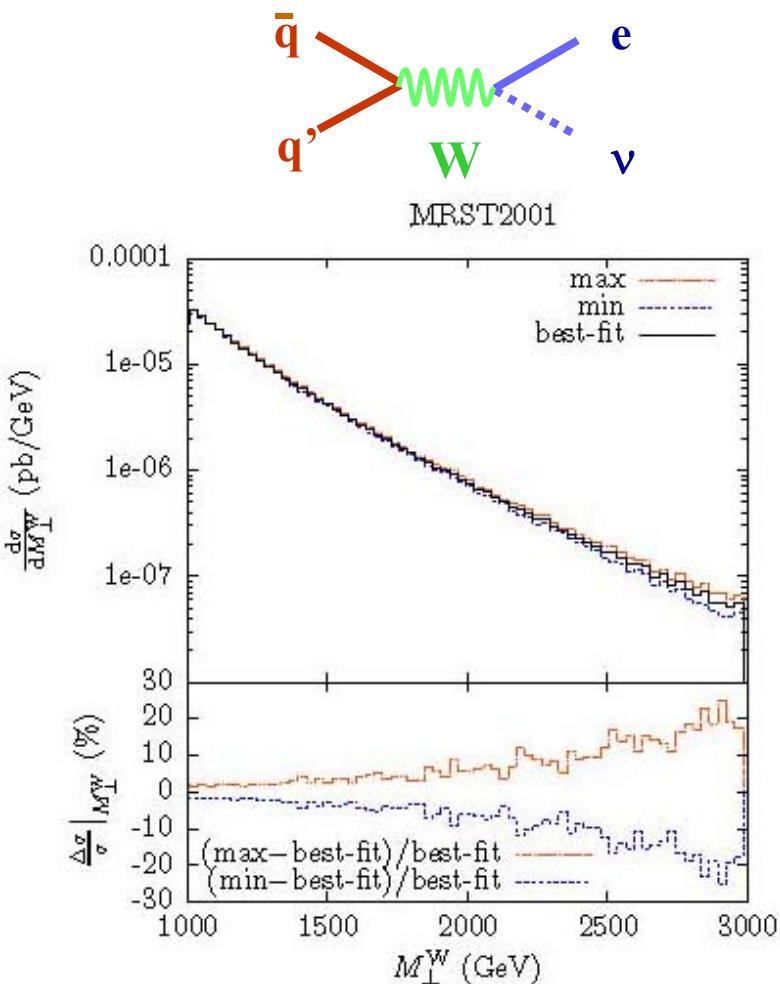
Higgs
cross-section

PDF
uncertainty
~5-10 %

- Light Higgs correlated to W/Z
- Heavy Higgs correlated to top

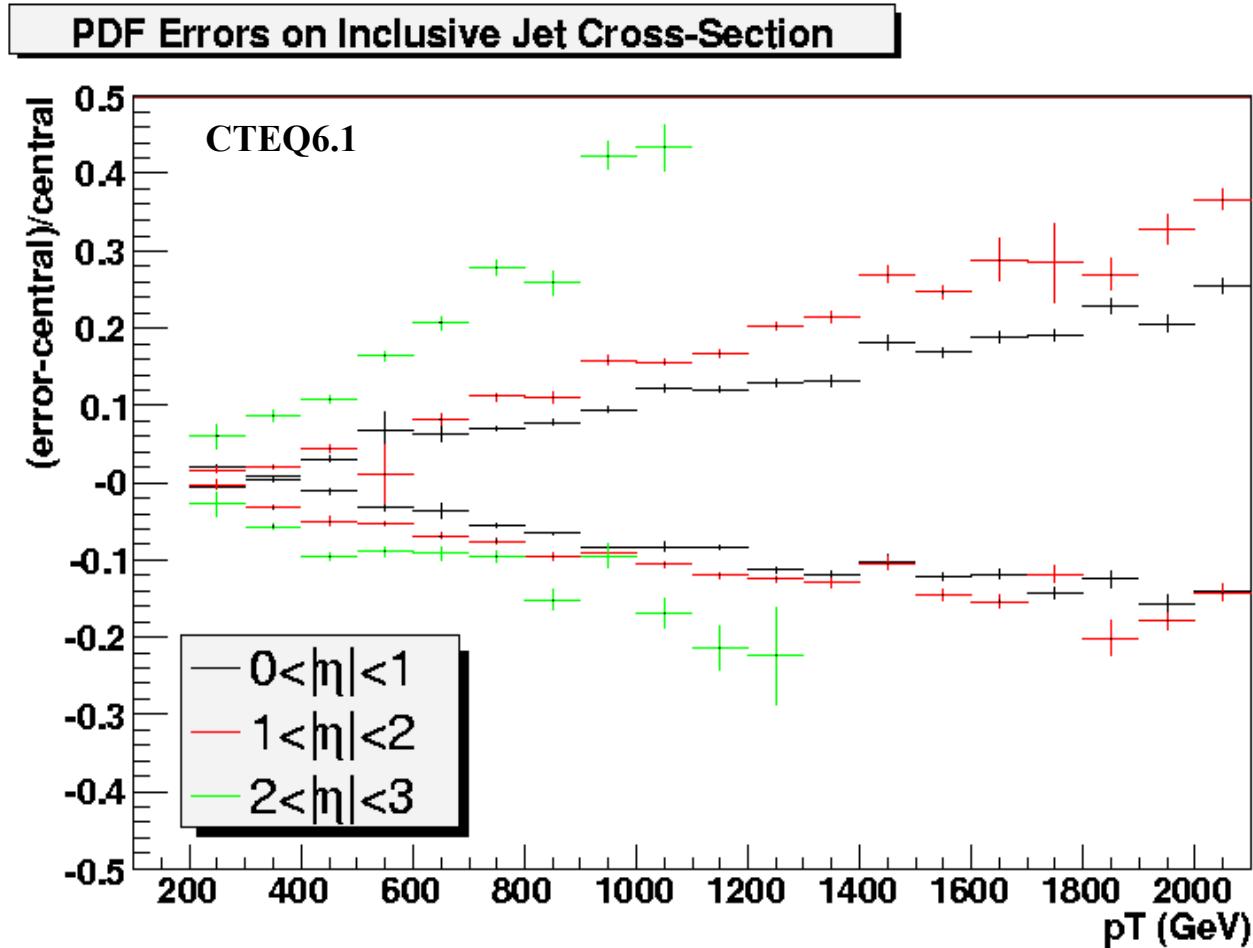
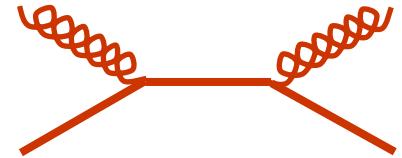
→ Best Standard Candle to which to renormalise may depend on mass

LHC needs: high-mass Drell-Yan cross-section



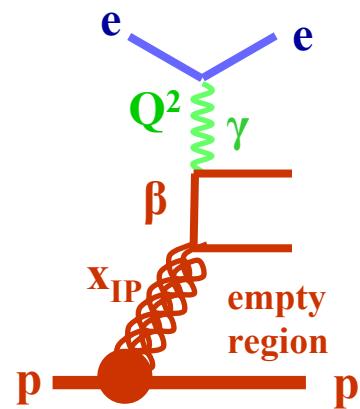
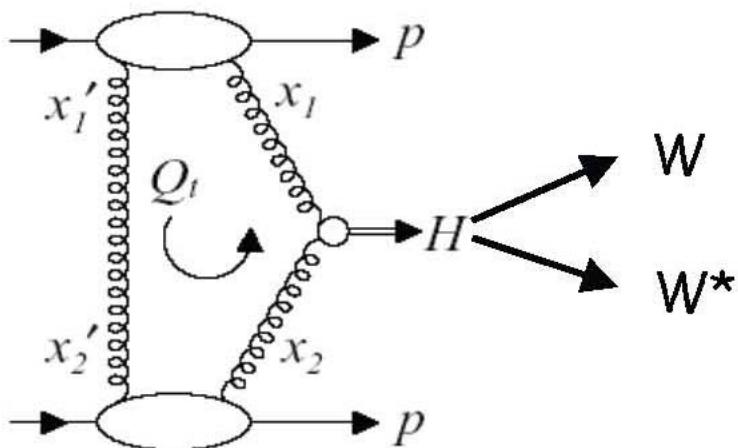
Uncertainty varies from ~5%
to ~20% at high mass

LHC needs: high- P_T jets cross-section



Uncertainty up
to ~30% at high P_T

LHC needs: Diffractive Higgs production



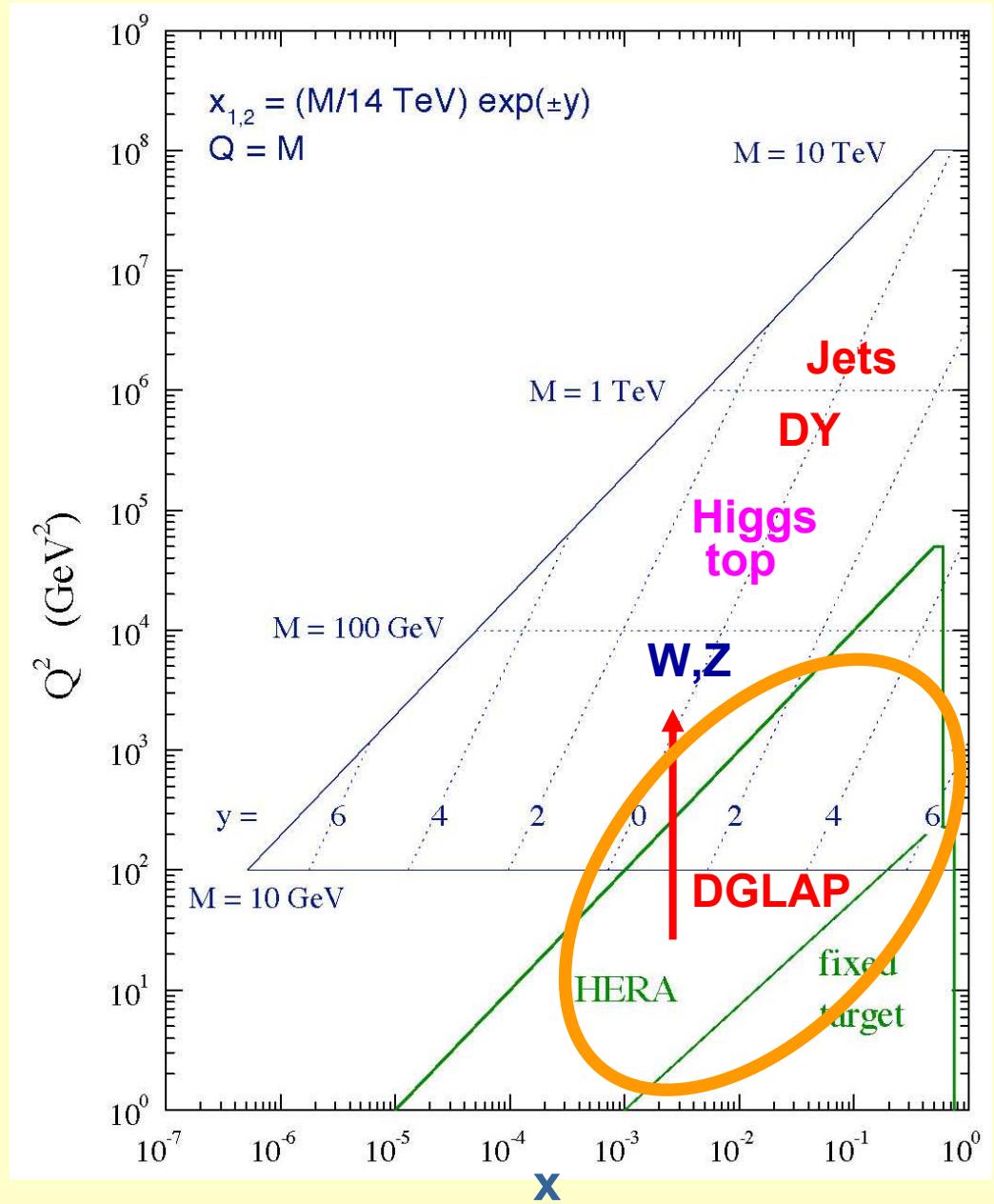
Cross-section depends
on 2-gluon GPD's

Structure of inclusive
colorless exchange
also necessary for
background (high β)

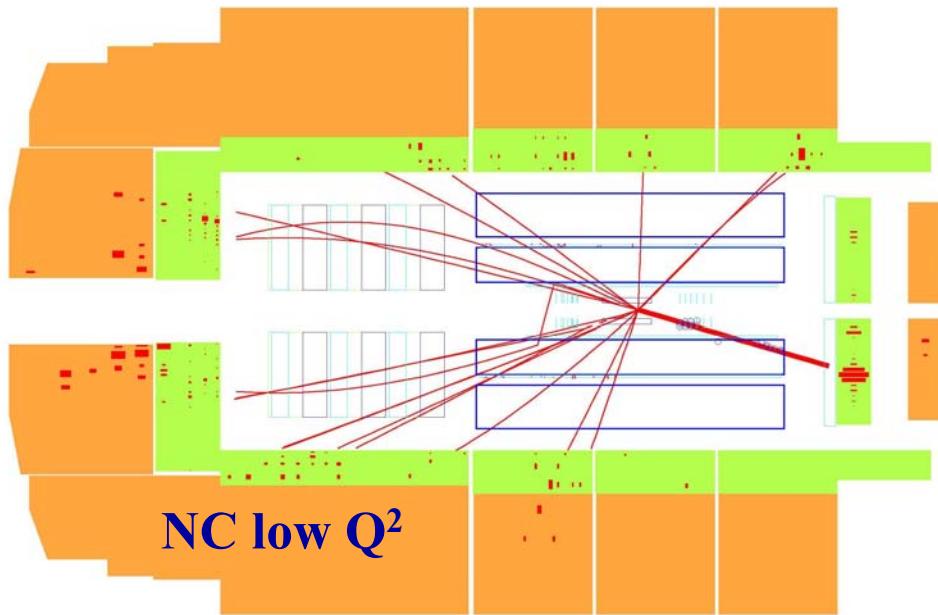
HERA PRECISION MEASUREMENTS

*Proton structure
and dynamics*

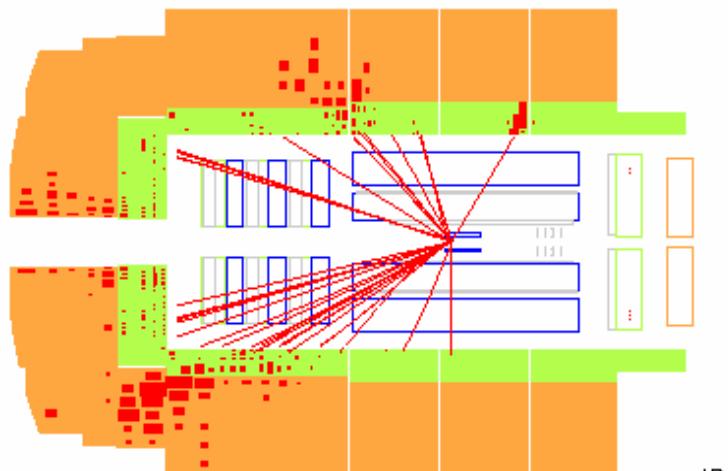
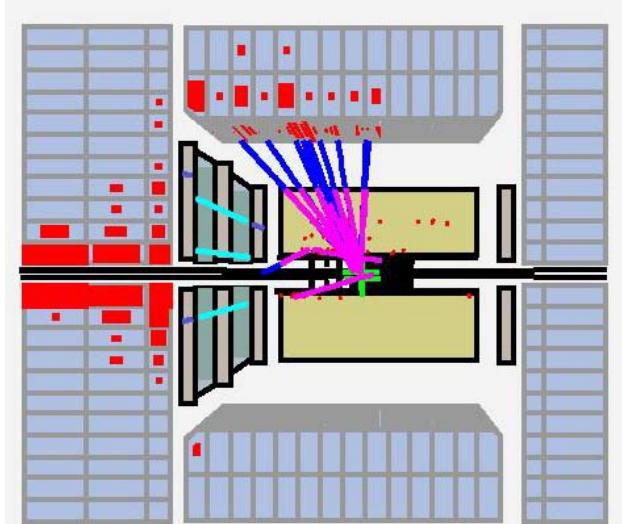
Latest HERA results



Typical interactions for HERA precision measurements



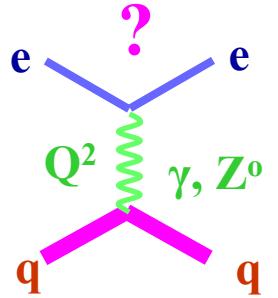
CC intermediate Q^2



NC intermediate Q^2

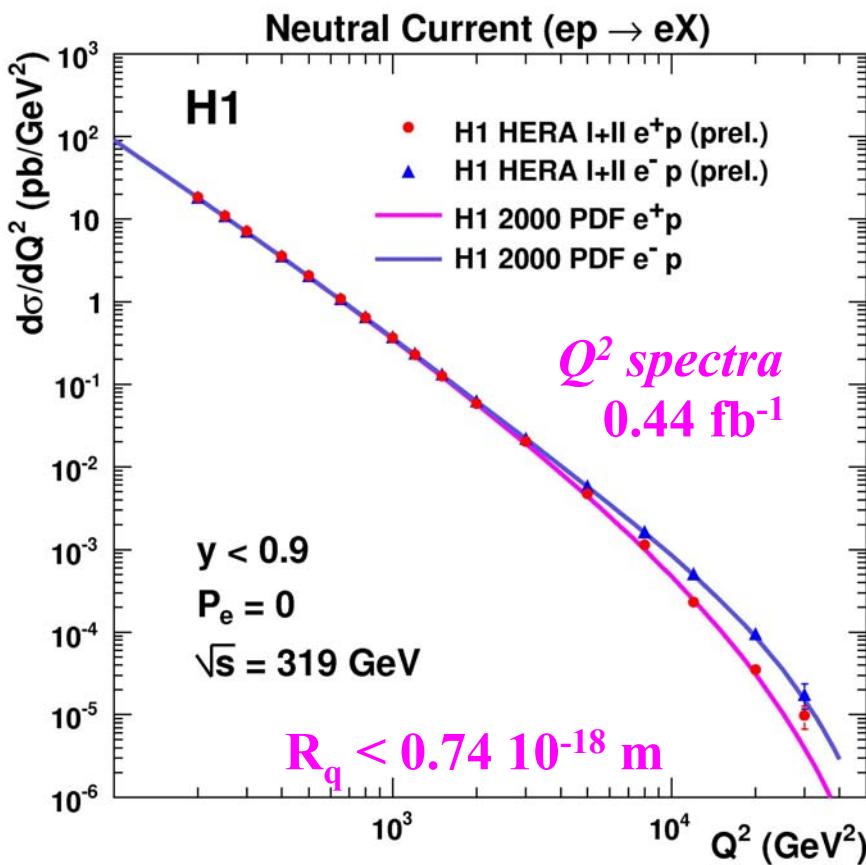
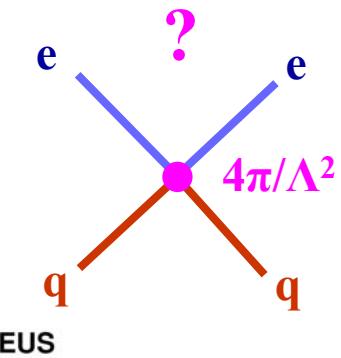
\vec{z}

HIGH ENERGY FRONTIER: are quarks point-like ?

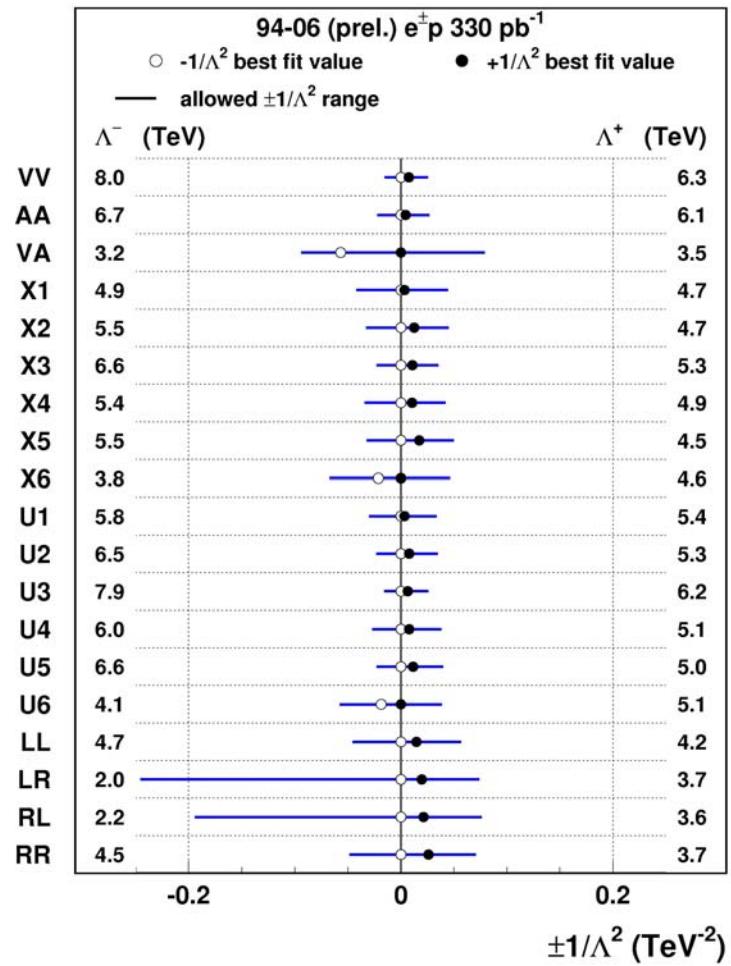


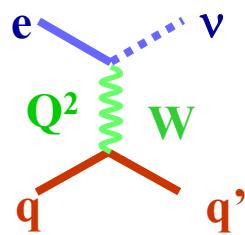
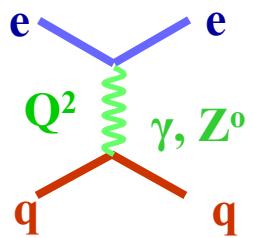
quark radius R_q
factor: $(1 - R_q^2 Q^2 / 6)$

Yes ! (at the HERA scale...)



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

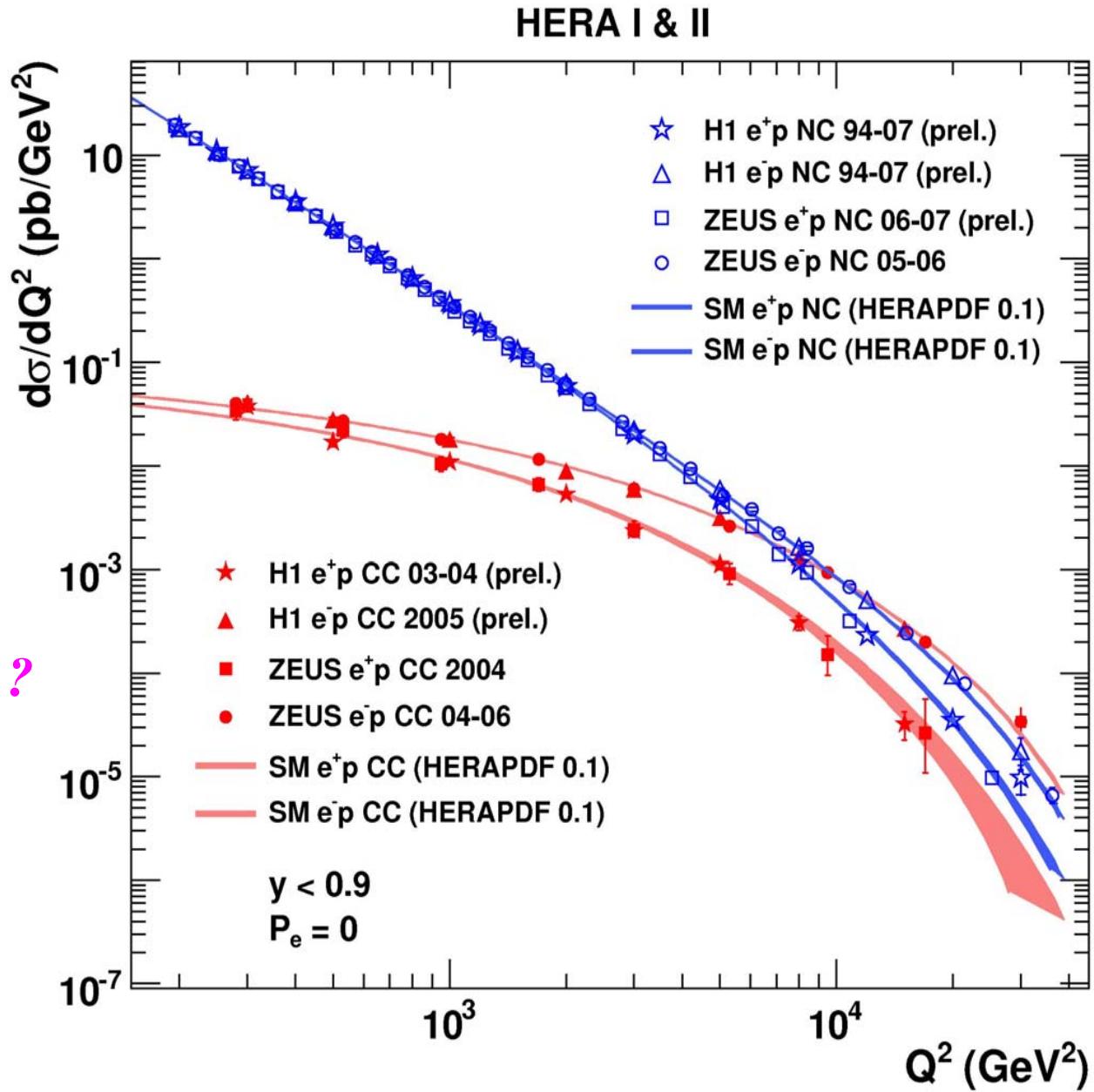




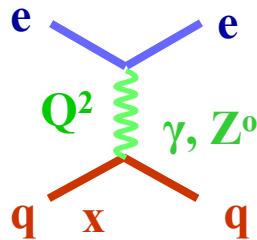
*Does the e-probe
behave as expected ?*

YES!

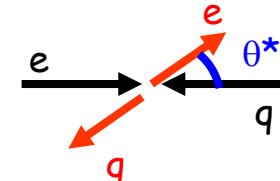
EW unification
in the t-channel
at the $M_{W,Z}$ scale



MEASURING THE PROTON STRUCTURE



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

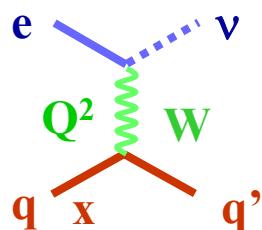


$$y = Q^2/sx = (1 - \cos\theta^*)/2$$

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

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

valence + sea quarks
gluon
valence quarks

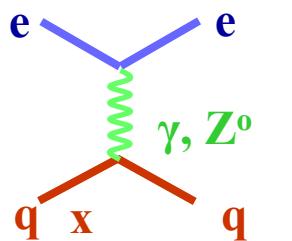


$$\sigma_{CC}(e^+ p) \sim x [(1-y)^2 (d + s) + (\bar{u} + \bar{c})] \ x (1 + P_e)$$

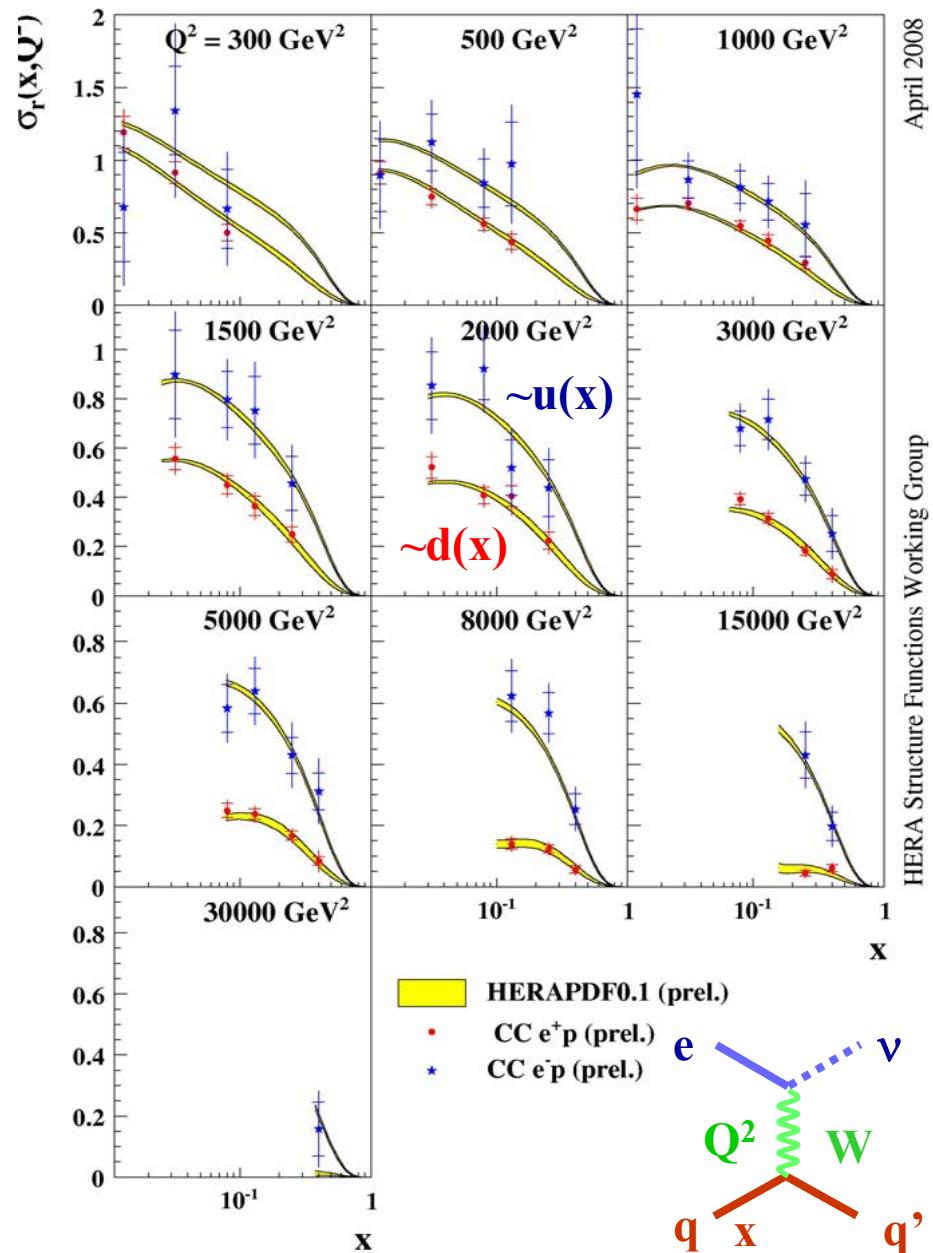
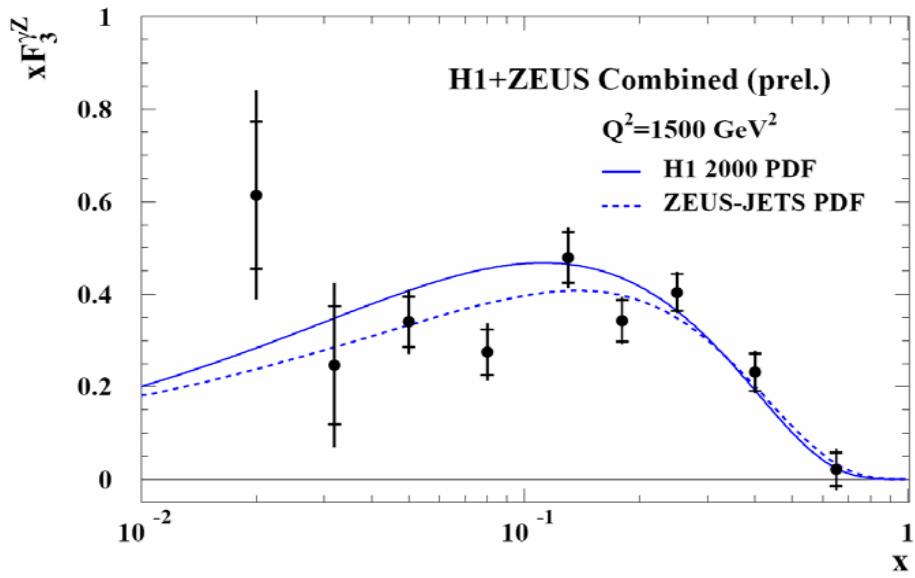
$$\sigma_{CC}(e^- p) \sim x [(u + c) + (1-y)^2 (\bar{d} + \bar{s})] \ x (1 - P_e)$$

PROTON STRUCTURE

valence quarks



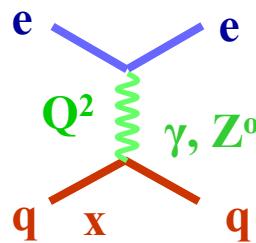
$$xF_3 \sim \sigma(e^-) - \sigma(e^+) \sim (2u_v + d_v)$$



PROTON STRUCTURE

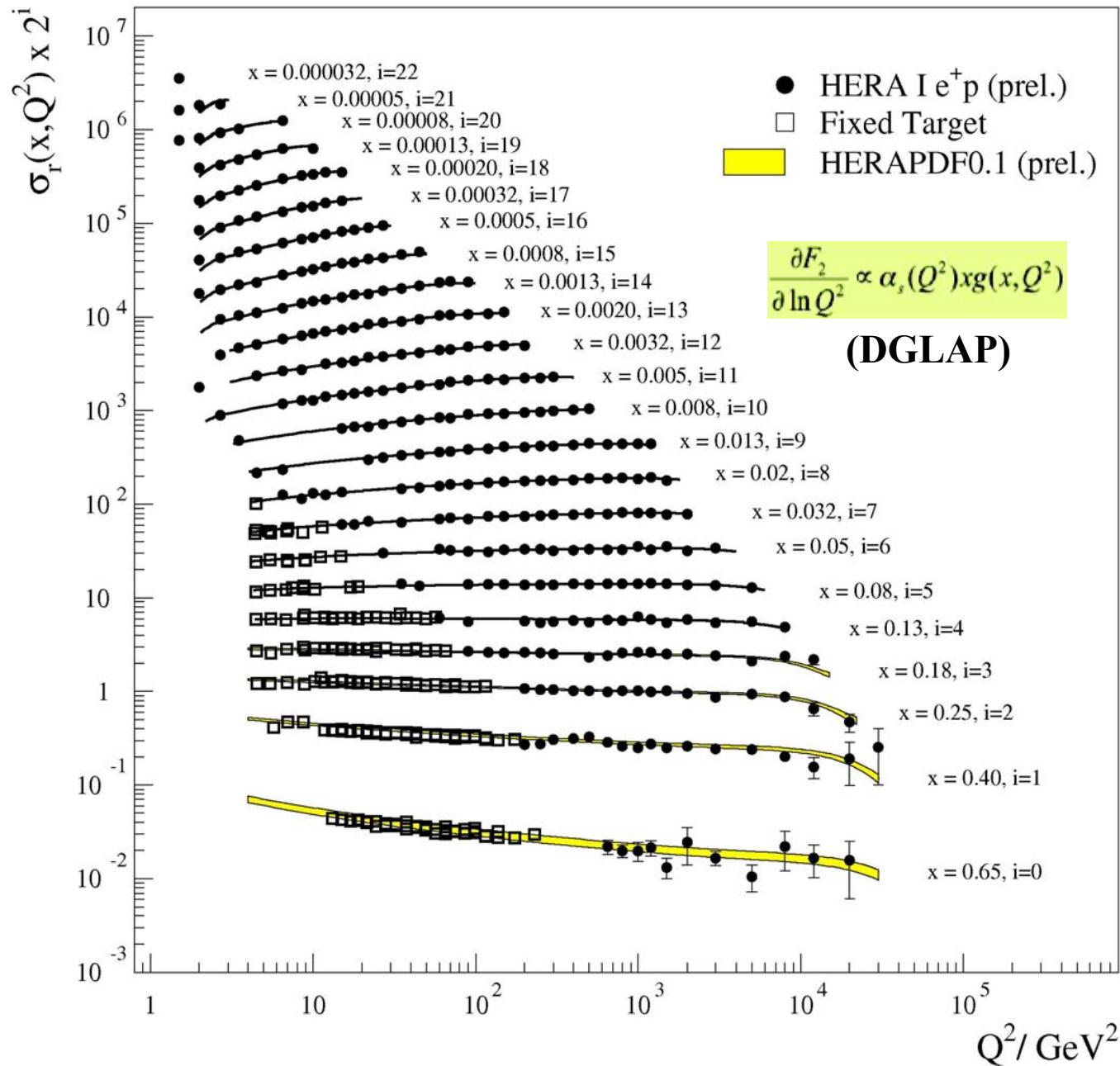
valence + sea
quarks

$F_2(x, Q^2)$



DGLAP works
on a very large
phase space !

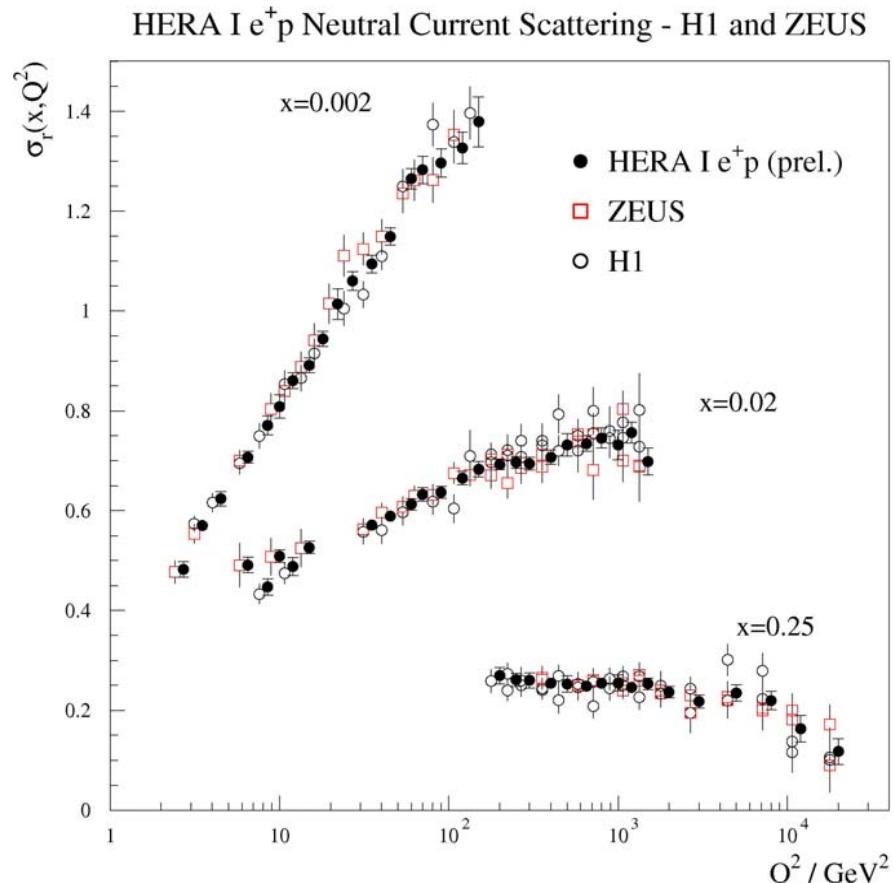
C. Vallee 1/04/09



PROTON STRUCTURE: the power of combining

$$\chi^2_{\text{exp}} \left(M^{i,\text{true}}, \Delta\alpha_j \right) = \sum_i \frac{\left[M^{i,\text{true}} - \left(M^i + \sum_j \frac{\partial M^i}{\partial \alpha_j} \Delta\alpha_j \right) \right]^2}{\sigma_i^2} + \sum_j \frac{\Delta\alpha_j}{\sigma_{\alpha_j}^2}$$

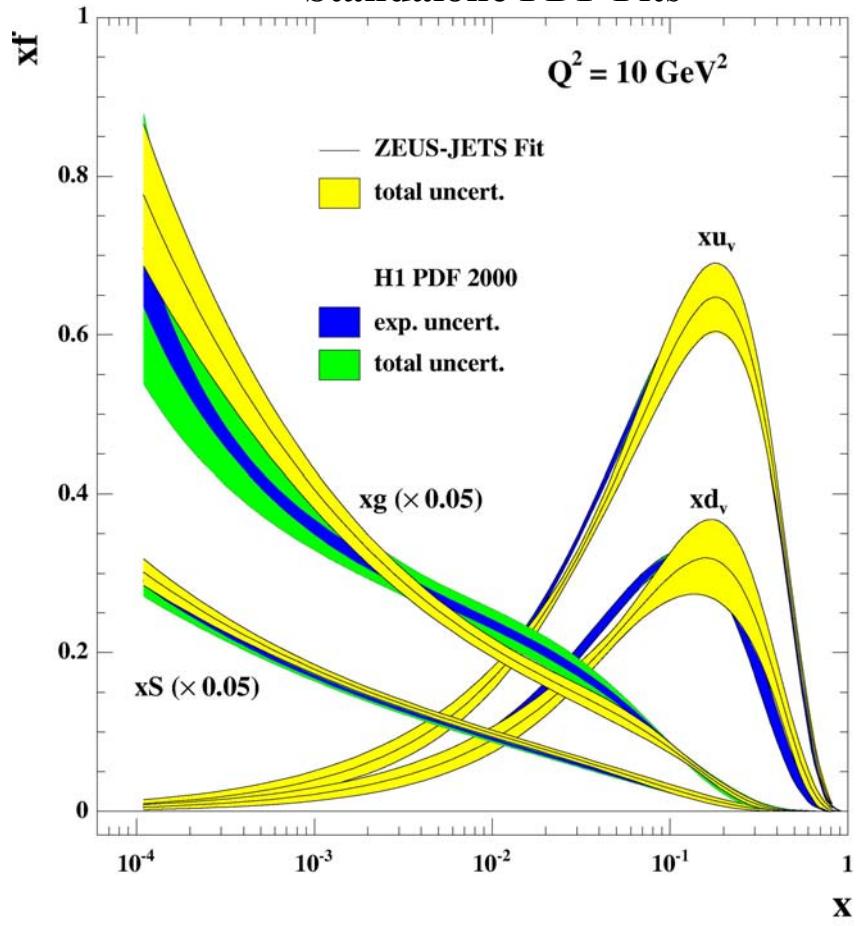
↗
**Cross-calibration
of both experiments**
 ↓
**systematic
uncertainties
reduced together
with statistical errors**



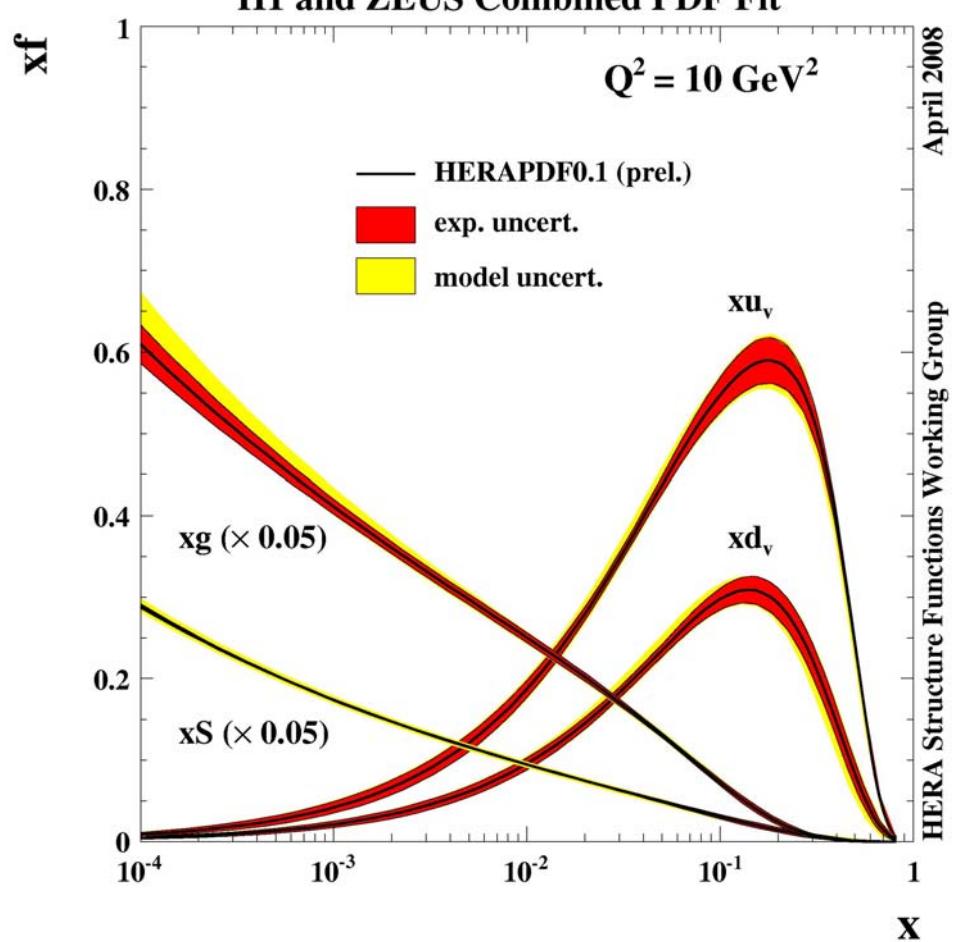
Extracting the essence of Structure Functions

common PDF Fit on HERA I combined data

Standalone PDF Fits

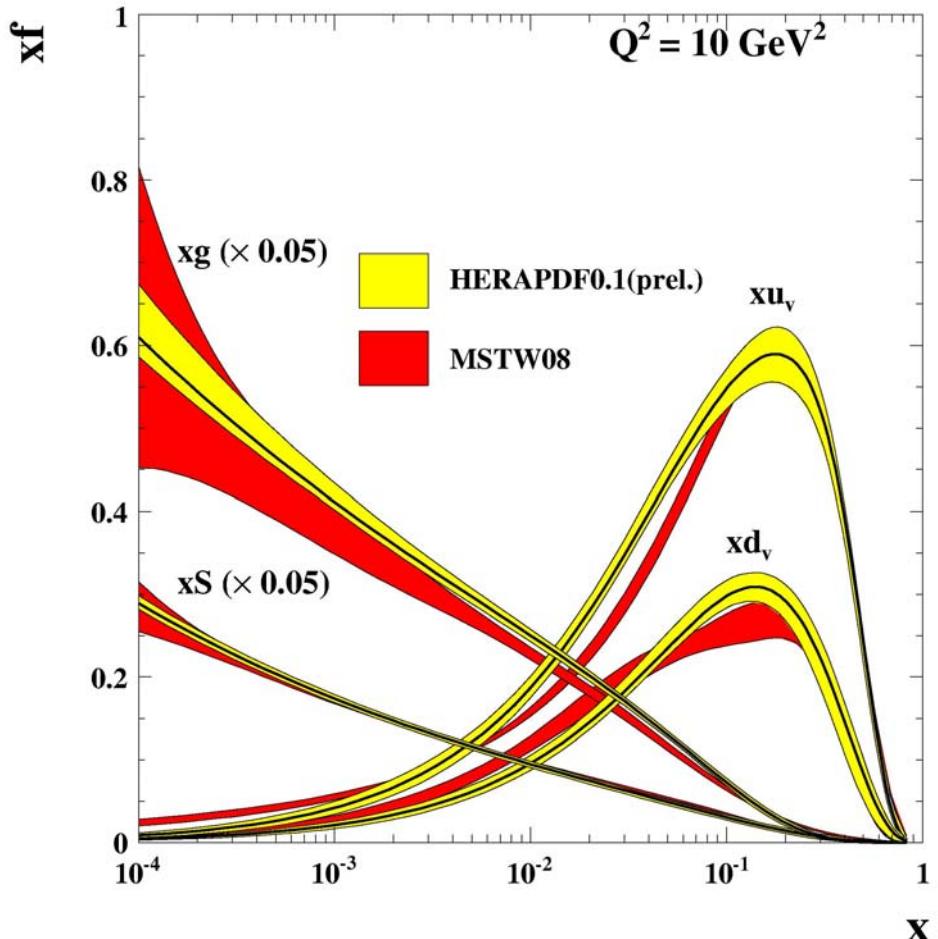
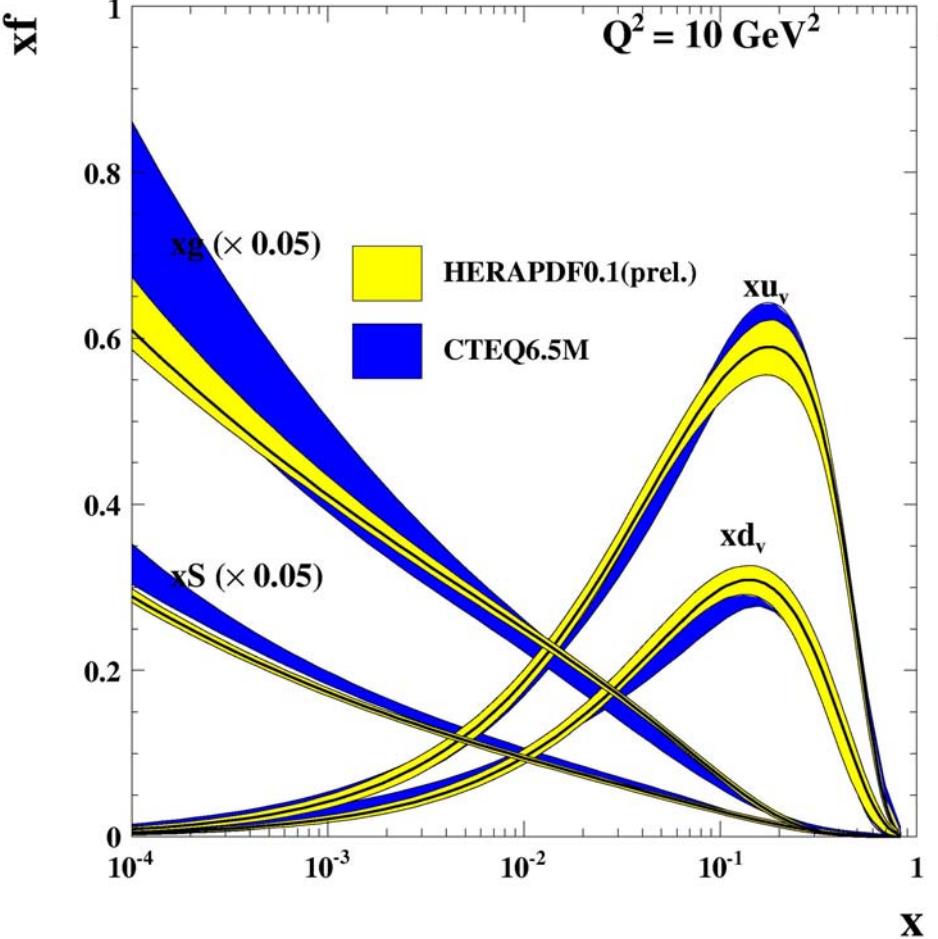


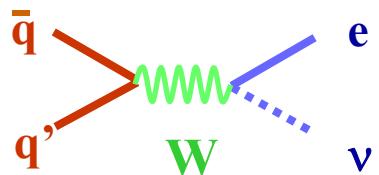
H1 and ZEUS Combined PDF Fit



HERAPDF0.1 *versus* CTEQ and MSTW

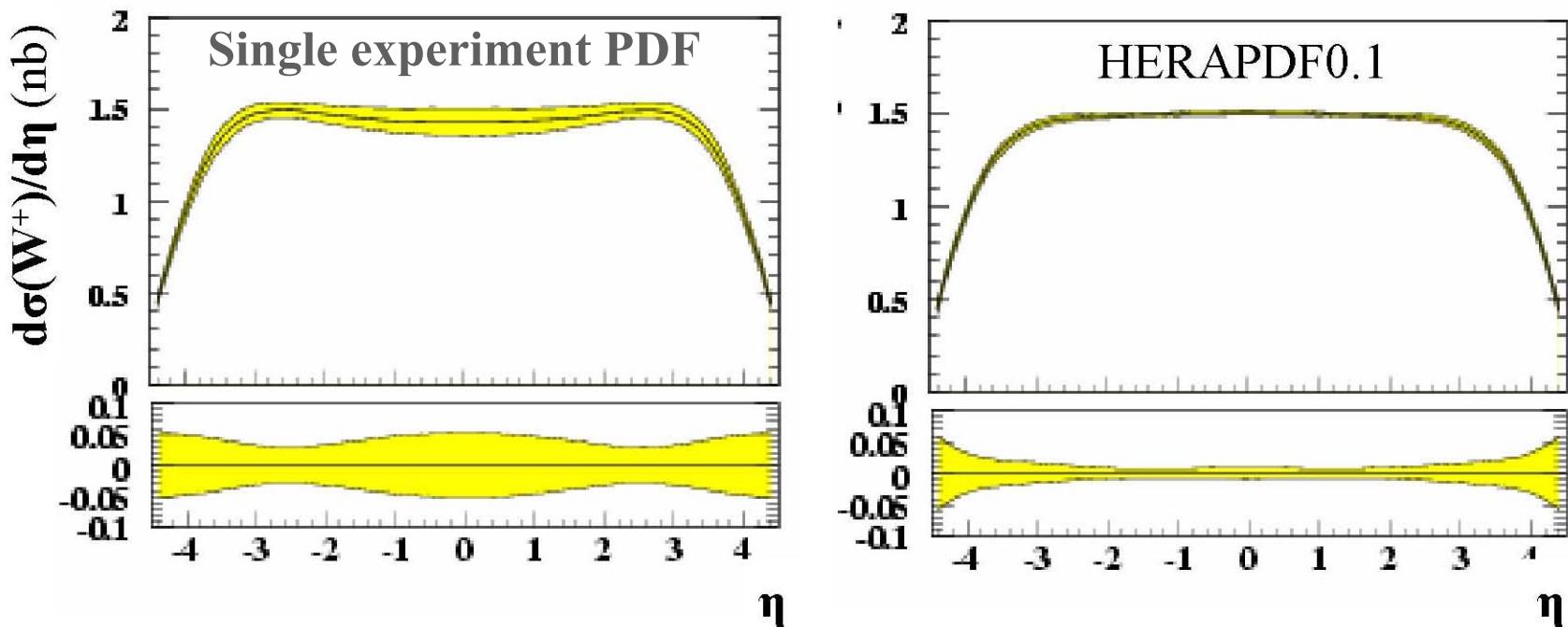
uncertainty on low- x gluon and sea strongly reduced





HERAPDF0.1 *impact on LHC* the example of W production

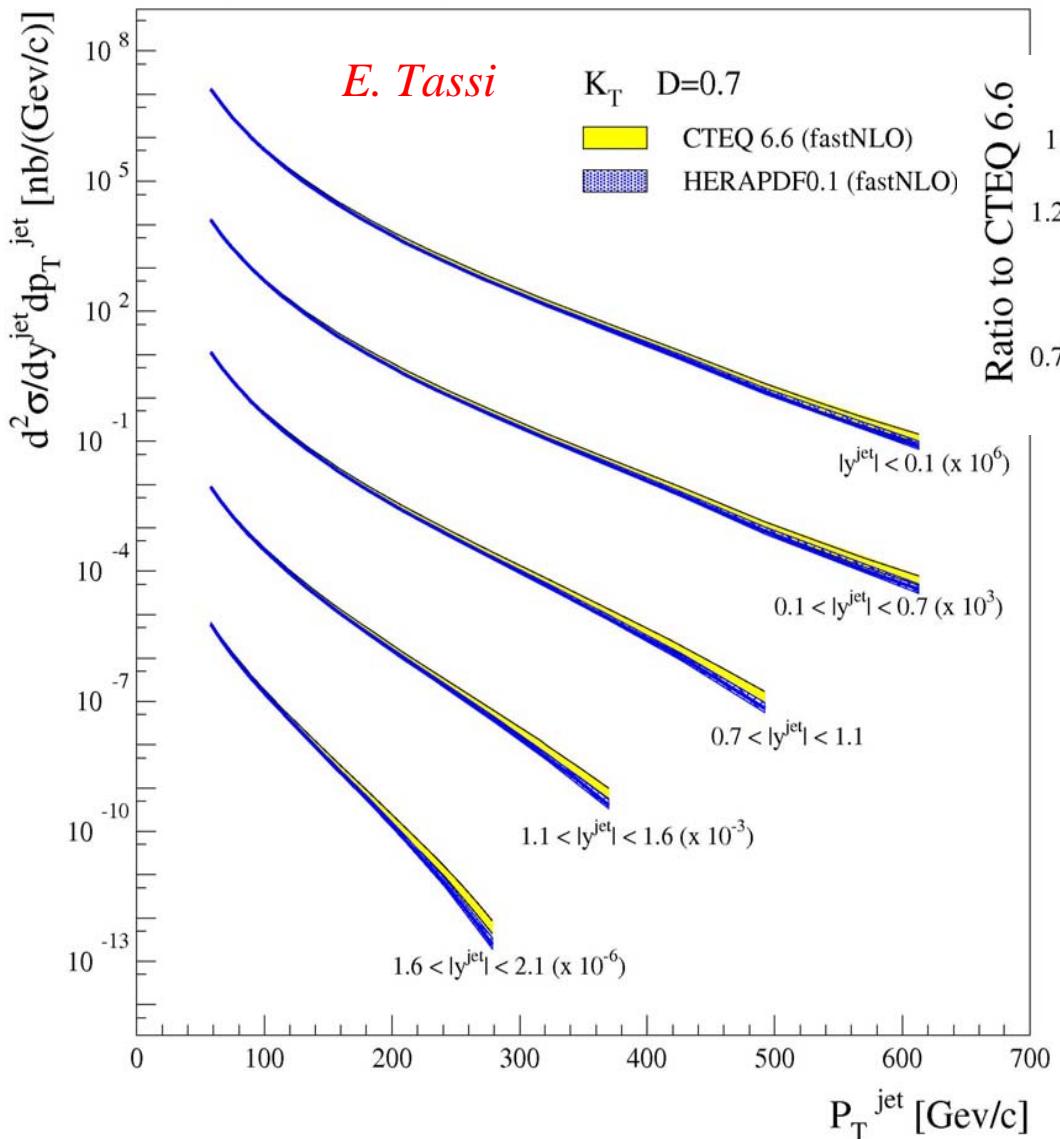
M. Cooper / E. Perez



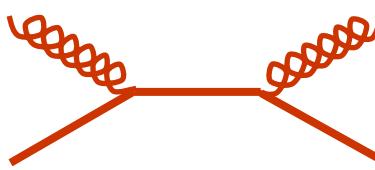
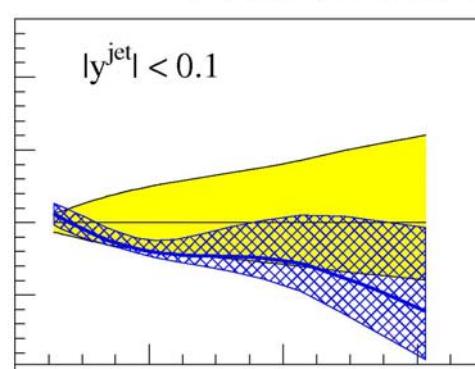
HERAPDF0.1 publicly released in LHAPDF (version 5.6.0)

...to be exercised by the LHC experiments !

Tevatron Jet Cross Sections

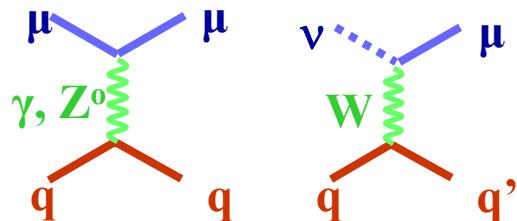


HERAPDF0.1 *impact on LHC* the gluon at high x



**Reasonable behaviour at high x
though no input from
Tevatron High- P_T jets in the fit**

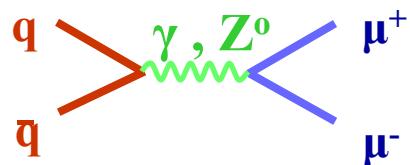
COMPLEMENTARY INPUTS to the PROTON PDF's



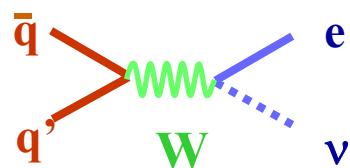
Fixed Target NC/CC
→ high-x quarks



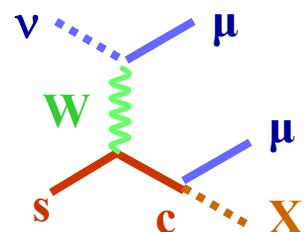
Tevatron High- P_T jets
→ high-x gluon



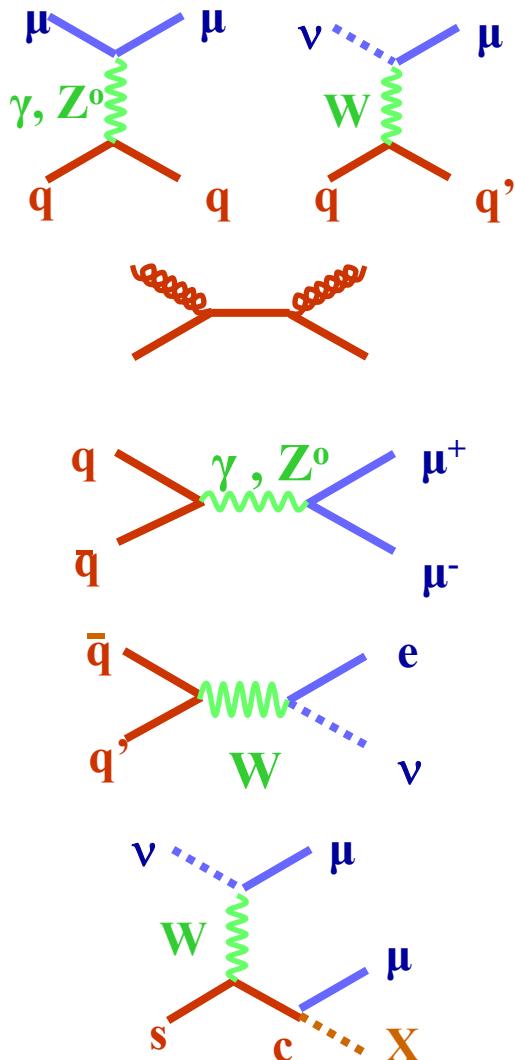
Fixed Target Drell-Yan
→ high-x antiquarks and \bar{u}/\bar{d} asymmetry



Tevatron W^+/W^-
→ u/d asymmetry at high x



Dimuons in Fixed Target CC
→ strange sea



TOWARDS OPTIMAL PROTON PDF's FOR LHC

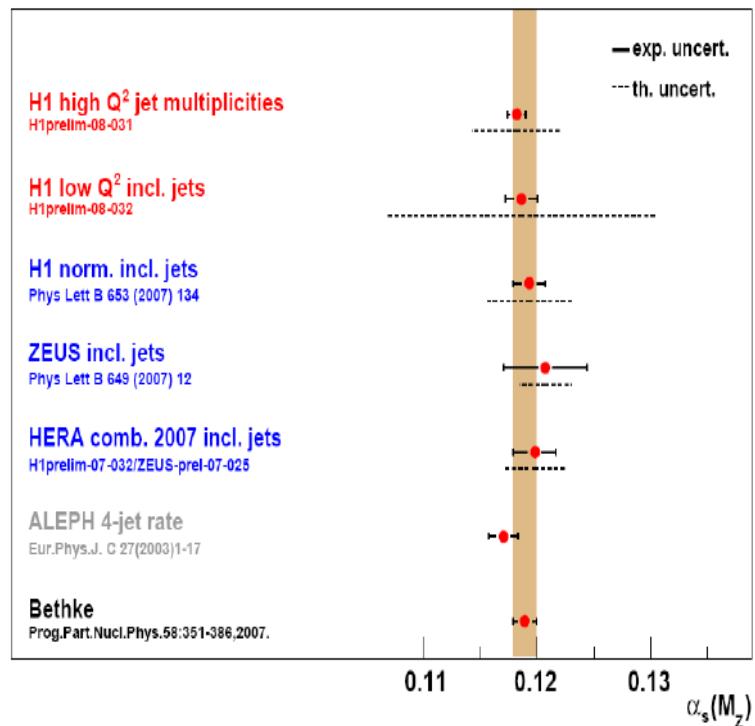
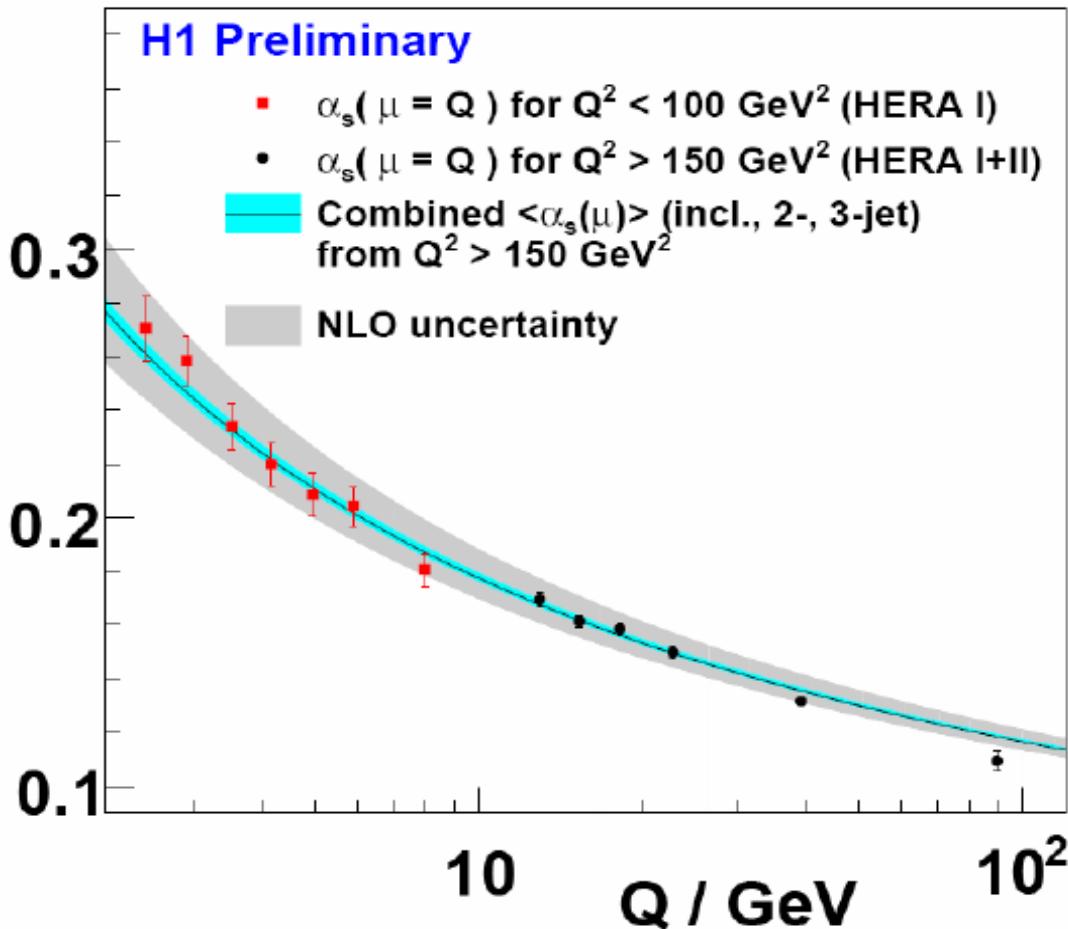
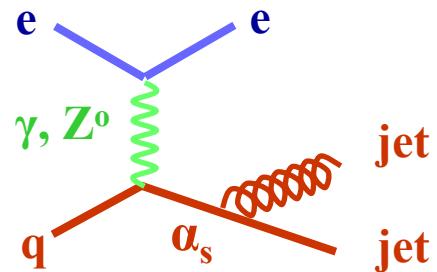
In the era of
high precision HERA results

*optimal inputs for LHC PDF's
and
PDF model uncertainties*

are essential questions
to be addressed by the
PDF4LHC workshop

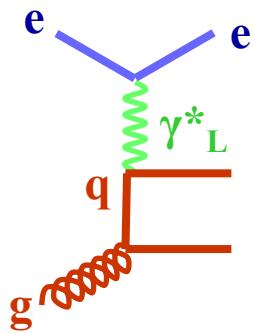
PROTON DYNAMICS

the strong coupling α_s from multi-jet rates



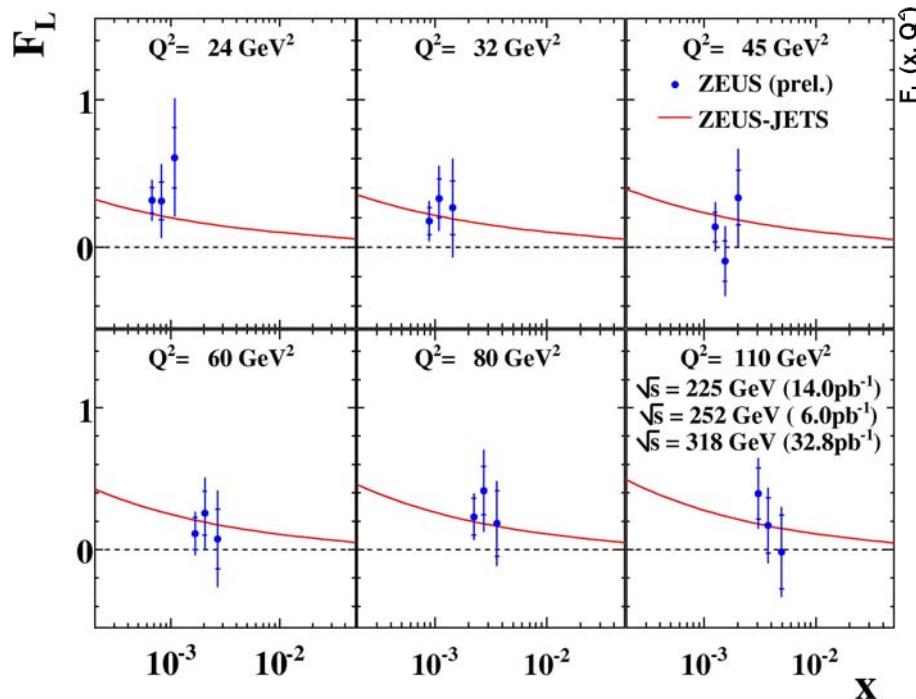
HERA exp. error $\sim 0.7\%$
a challenge for theory !

PROTON DYNAMICS: directly probing the gluon with F_L

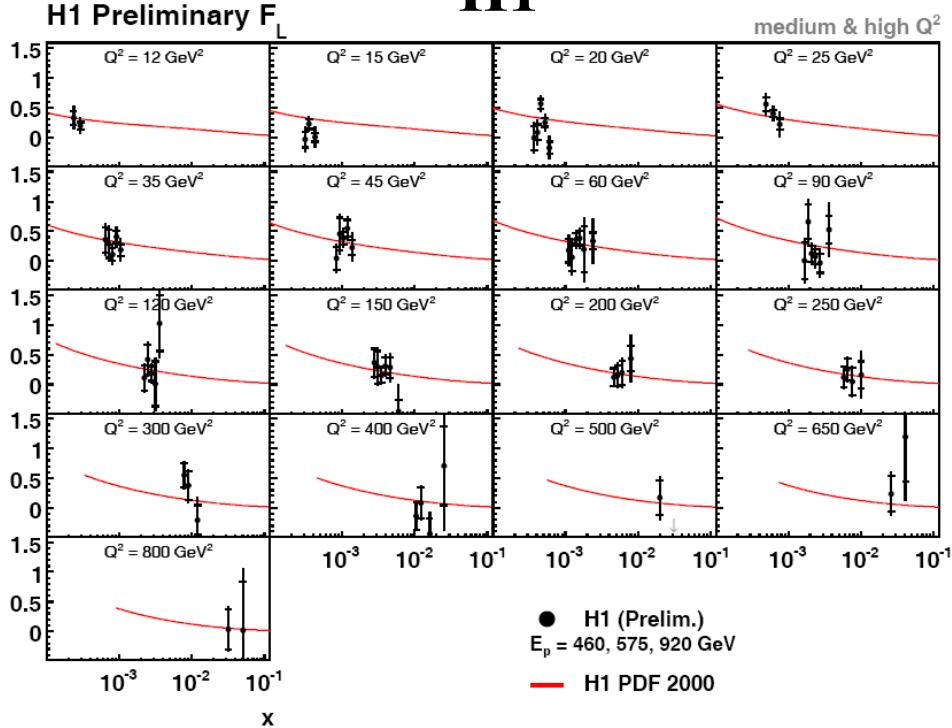


$$\tilde{\sigma}_{NC} = \frac{d^2\sigma_{NC}^{ep}}{dx dQ^2} / \left(\frac{2\pi\alpha^2}{xQ^4} Y_+ \right) = F_2 - \frac{y^2}{1+(1-y)^2} F_L \quad y = Q^2/sx$$

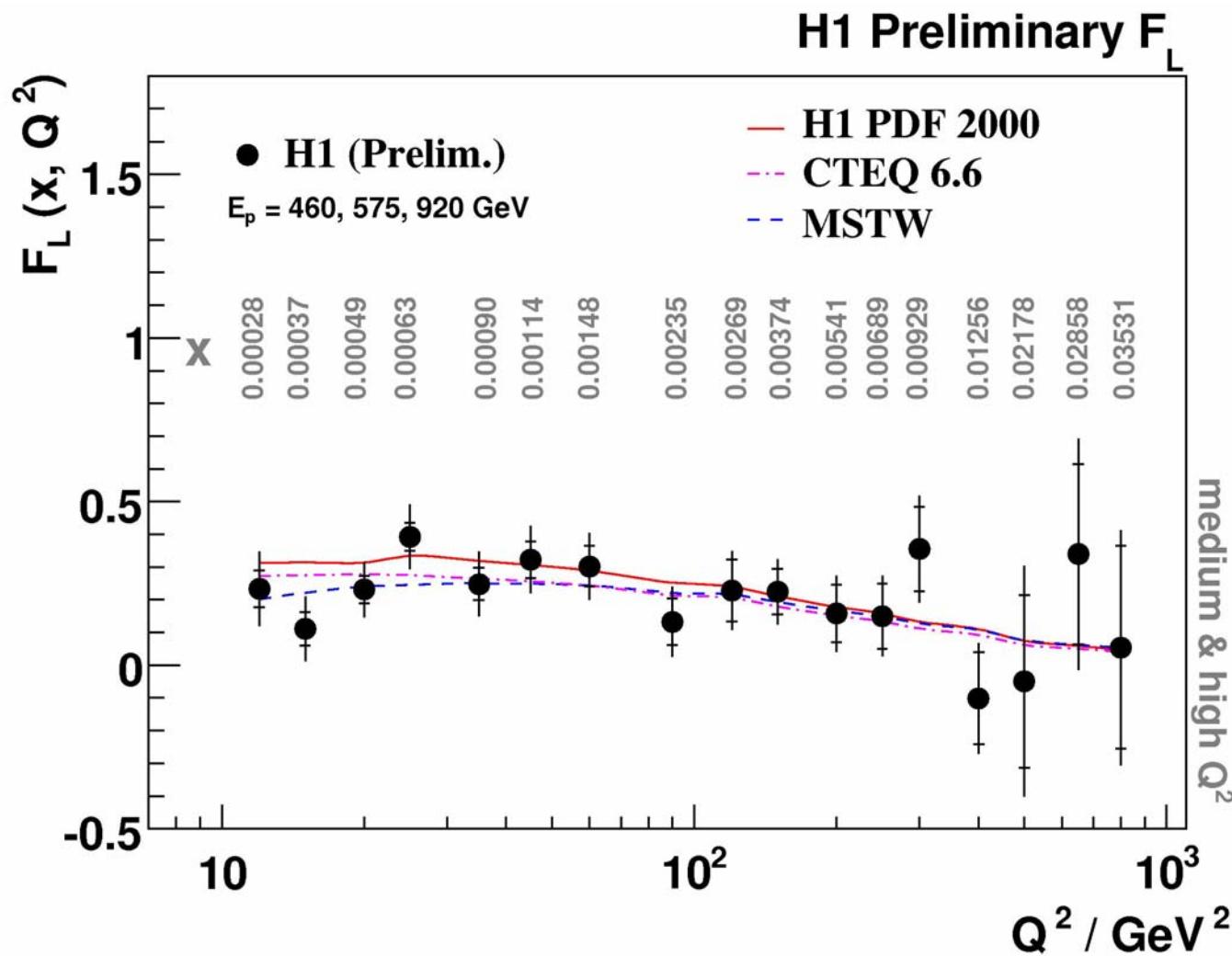
ZEUS



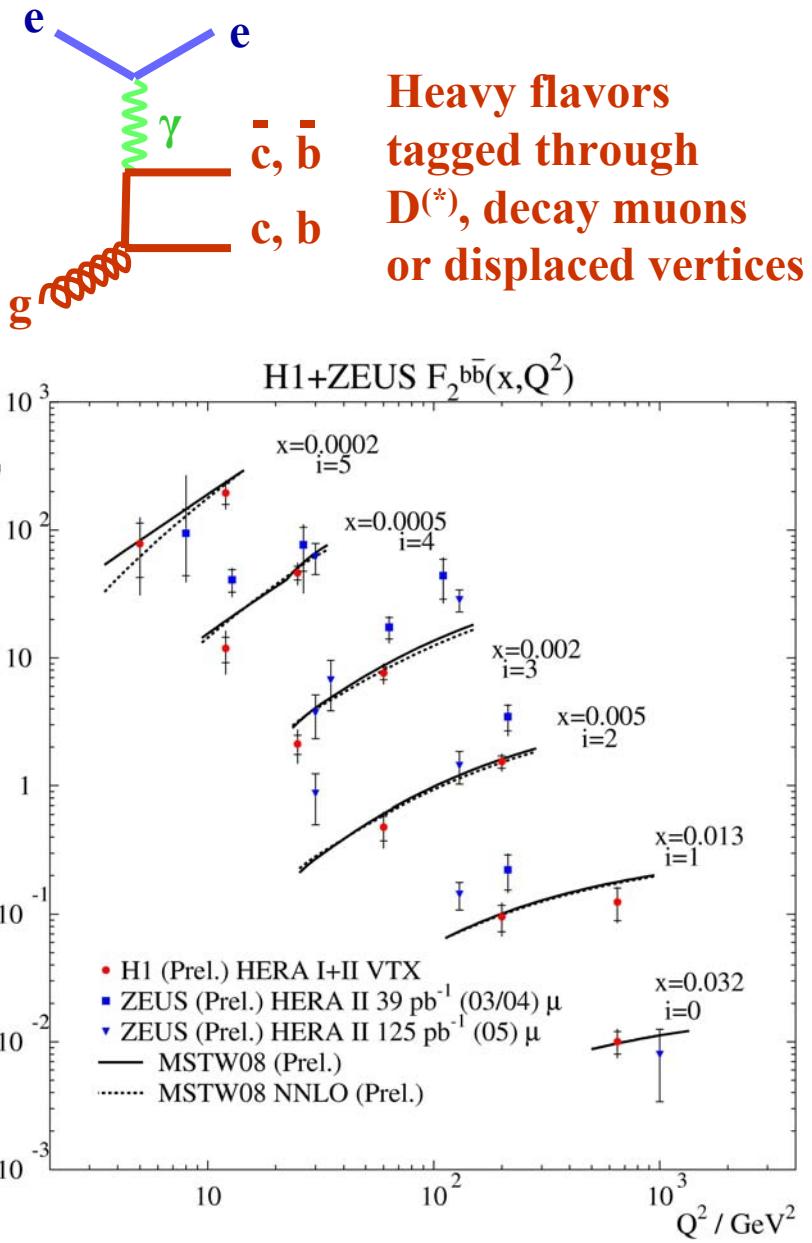
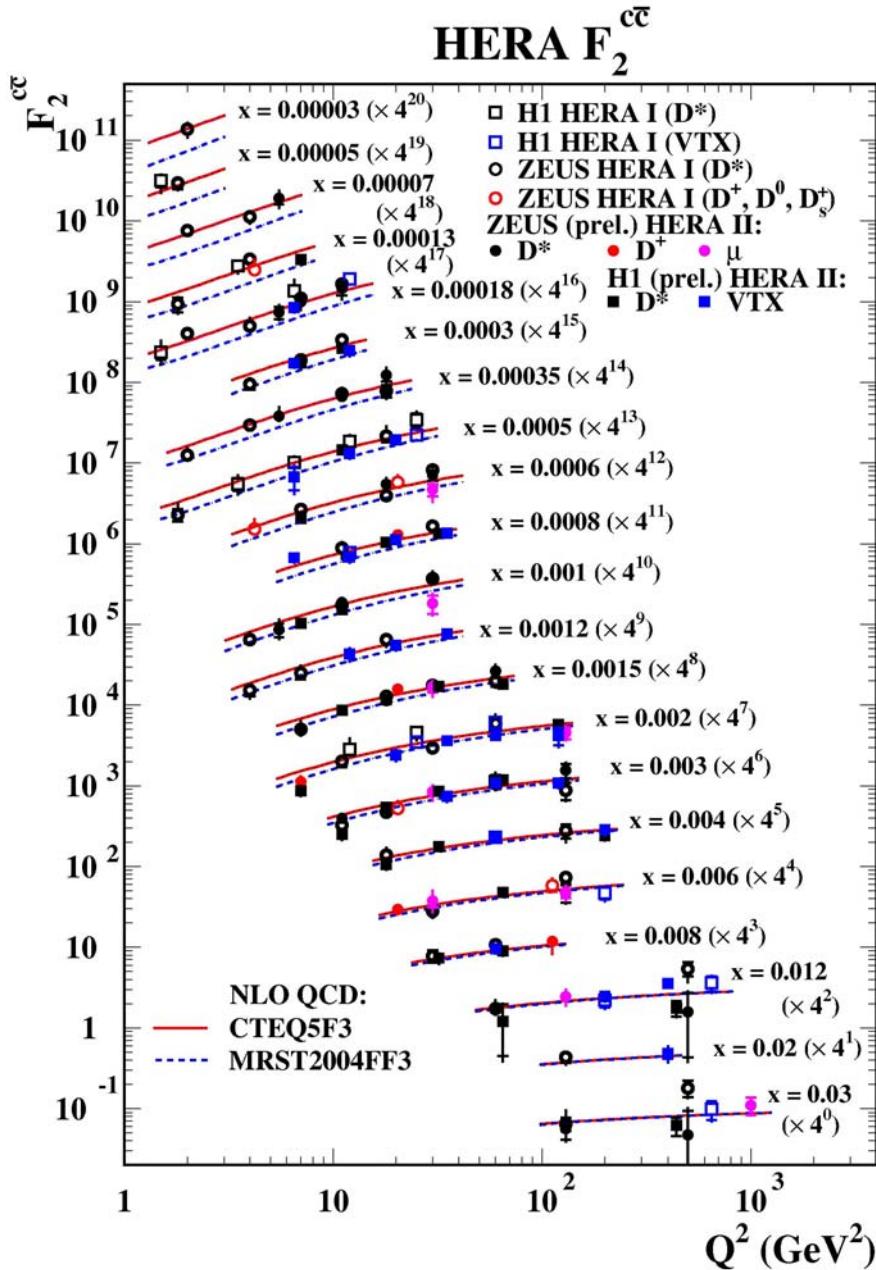
H1 Preliminary F_L



PROTON DYNAMICS: F_L compatible with NLO DGLAP predictions



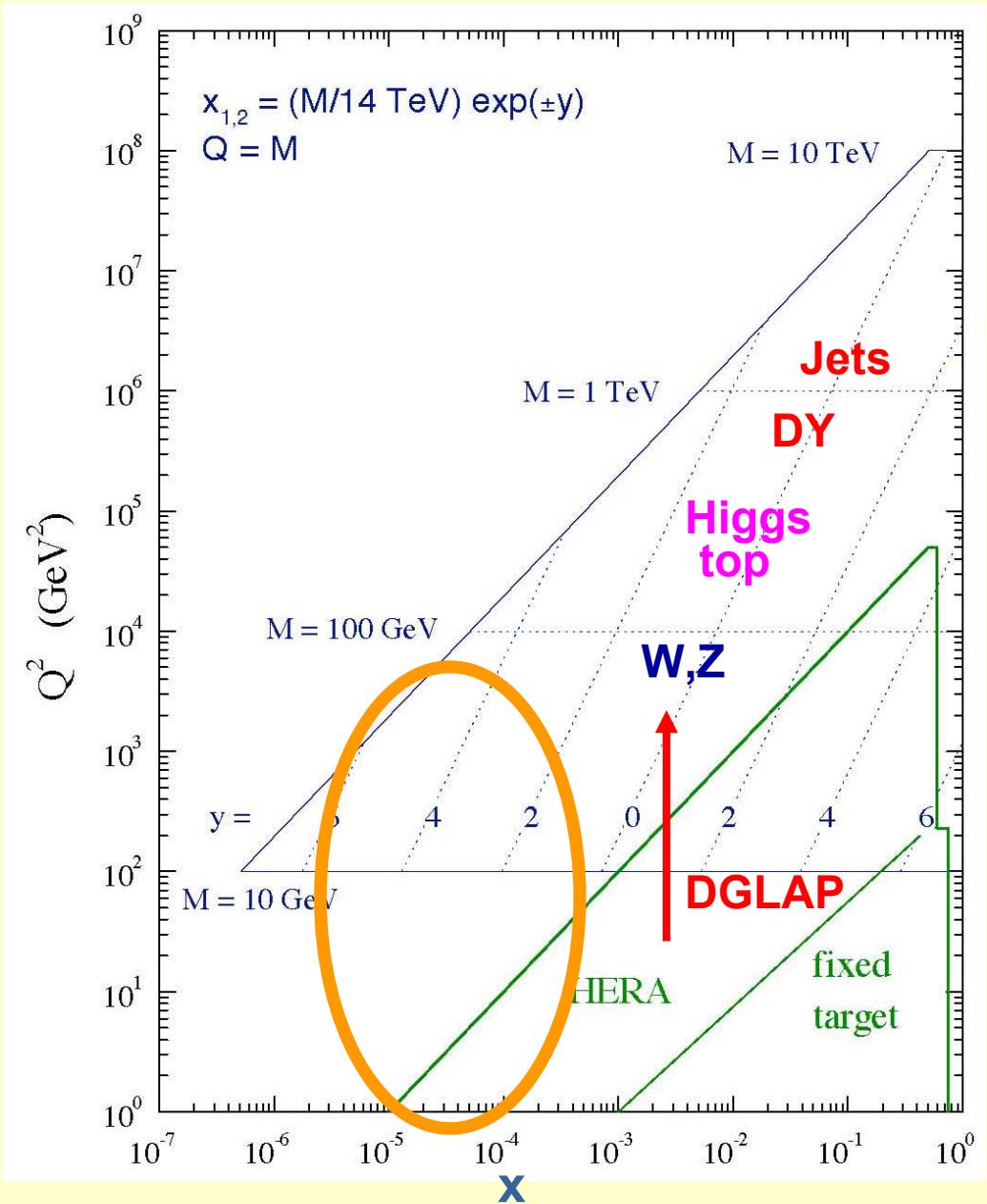
PROTON DYNAMICS: Heavy Quark generation well described by DGLAP



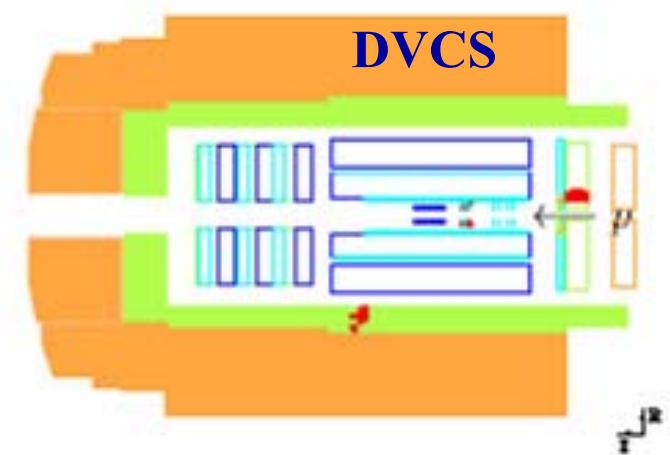
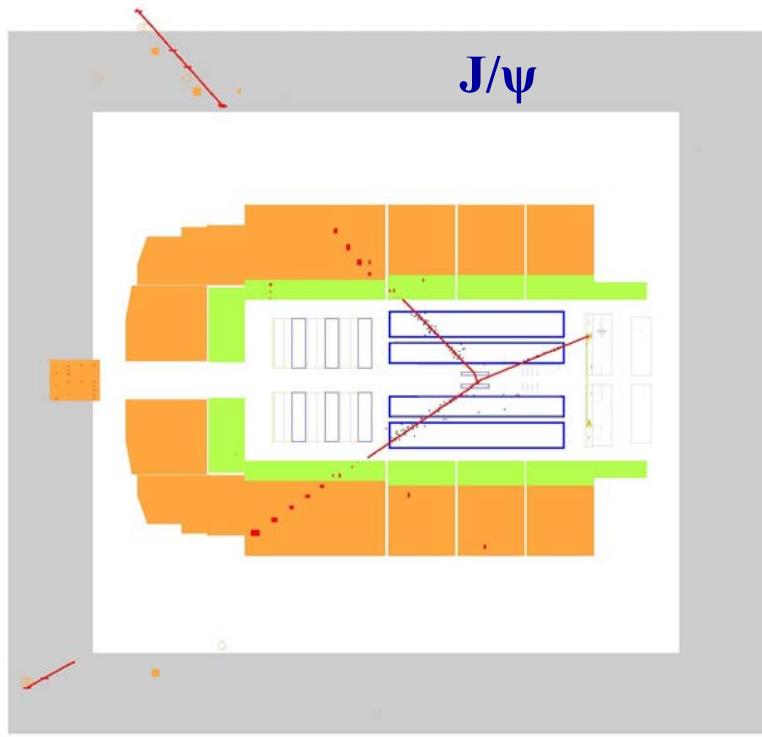
HERA PRECISION MEASUREMENTS

*Closer insights
from diffraction
in proton dynamics*

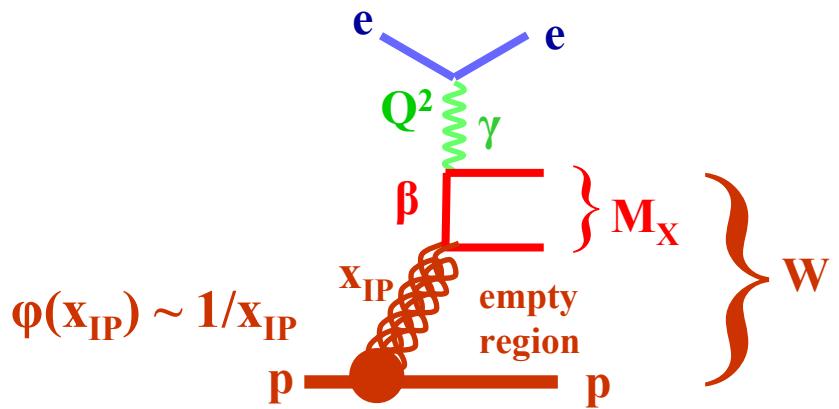
New effects at very low x ?



Typical diffractive interactions



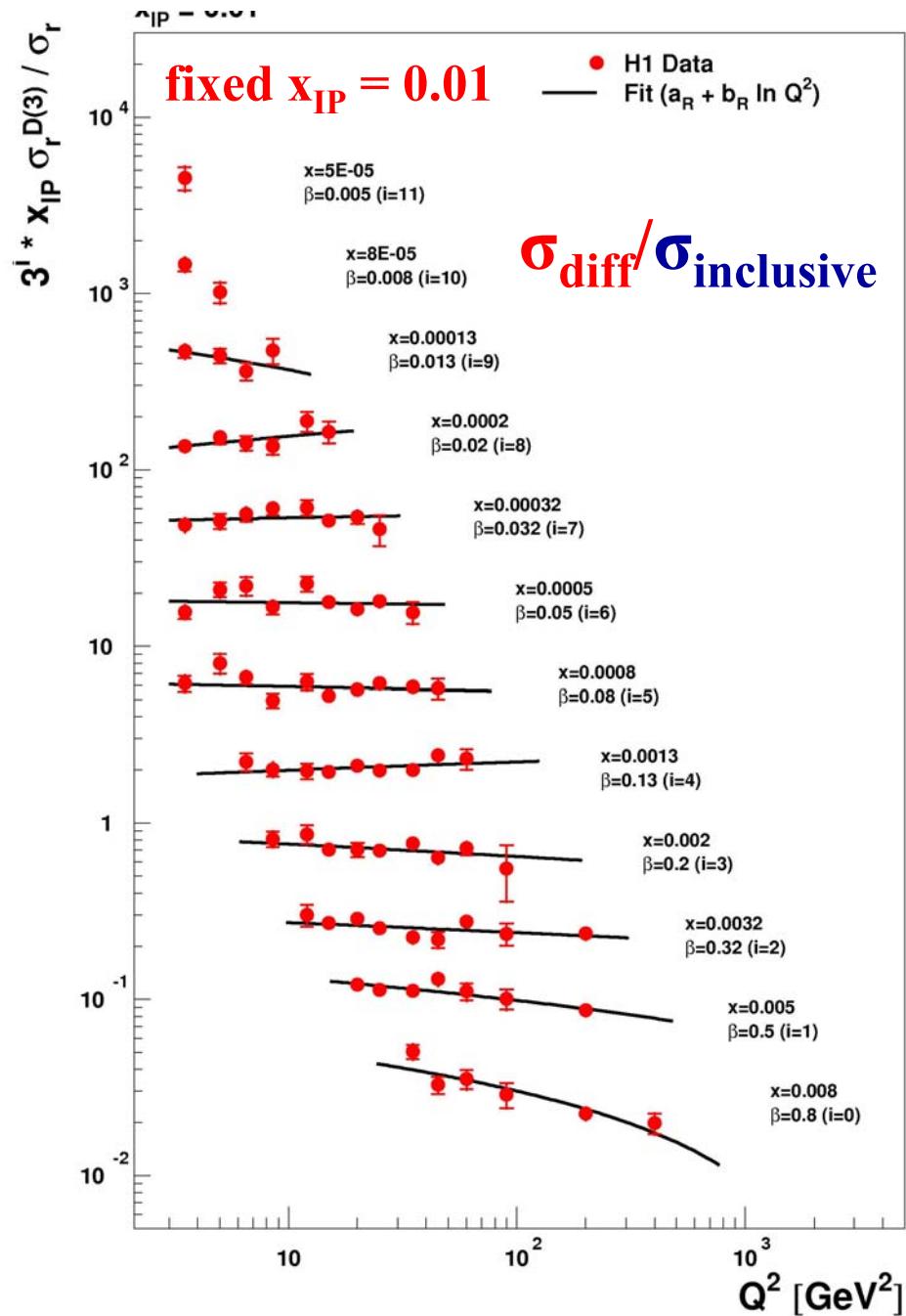
INCLUSIVE DIFFRACTION



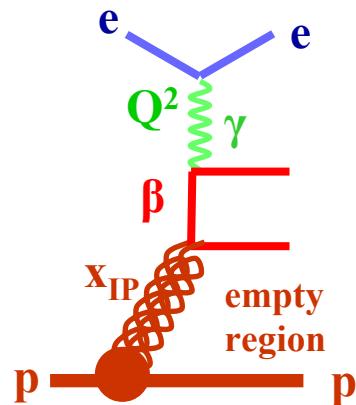
~10% of events are diffractive,
logarithmic variation with Q^2



diffraction is a leading-twist
intrinsic part of the proton structure



Perturbative structure of inclusive diffraction

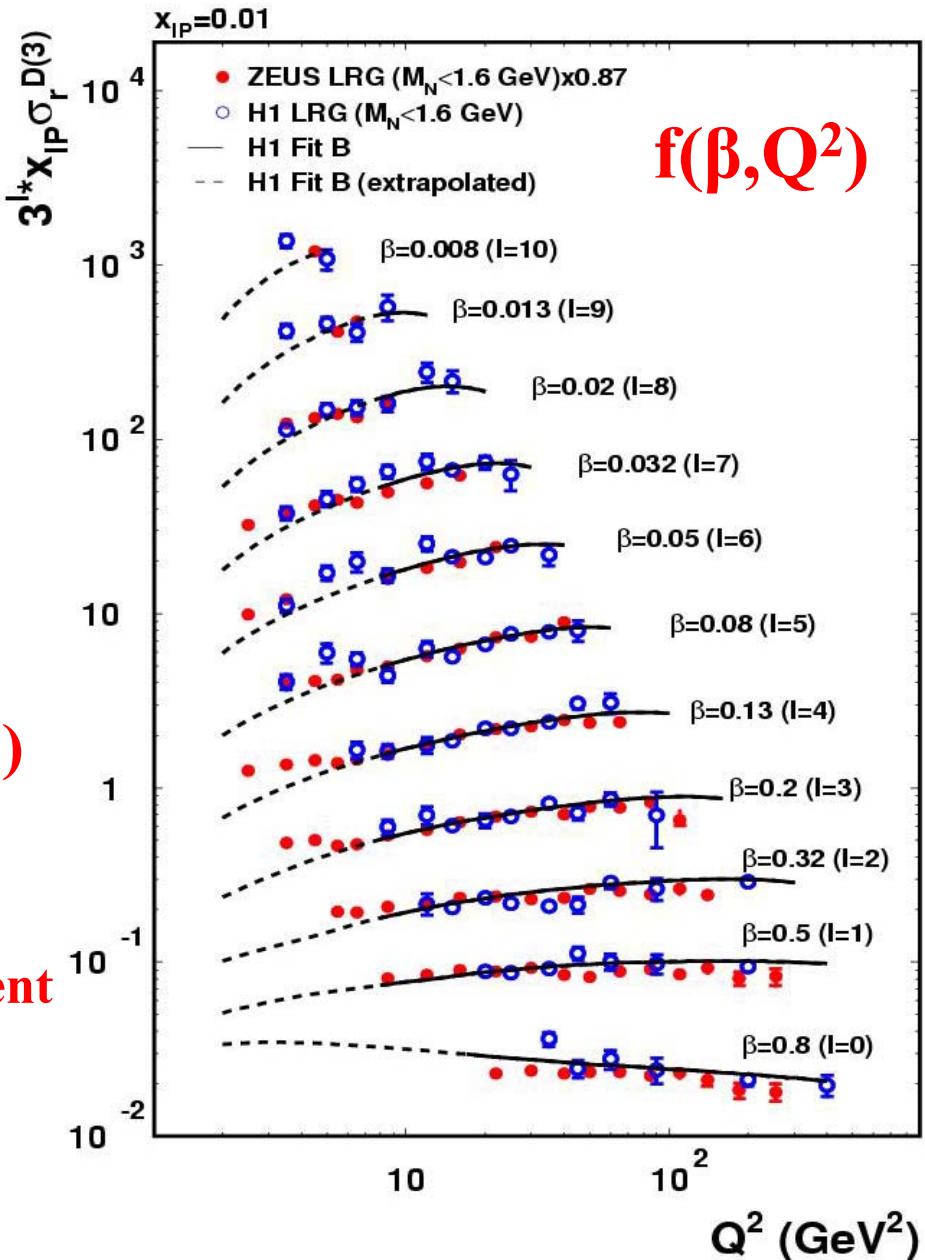


$$F_2^{D3}(x_{IP}, \beta, Q^2) \sim \varphi(x_{IP}) \cdot f(\beta, Q^2)$$

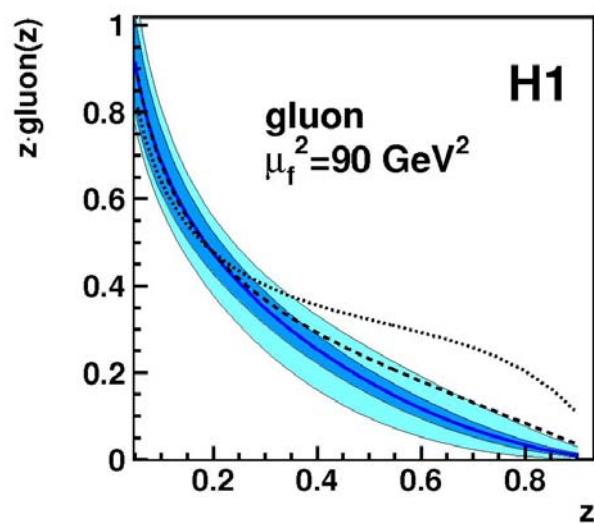
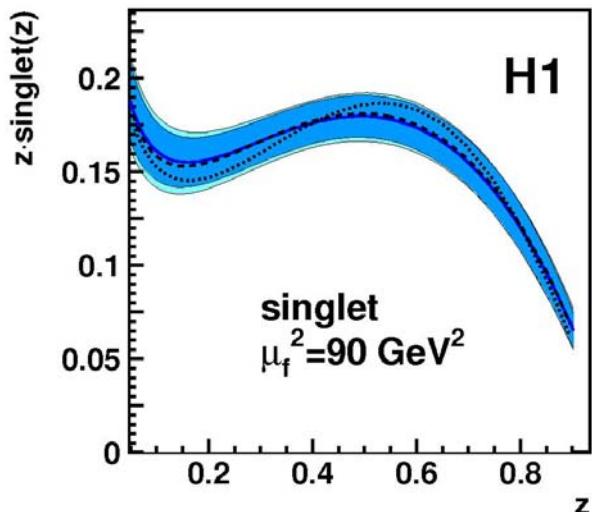
↑

**Strong positive scaling violations
indicate a dominant gluonic component
of the colorless exchange**

HERA inclusive diffraction

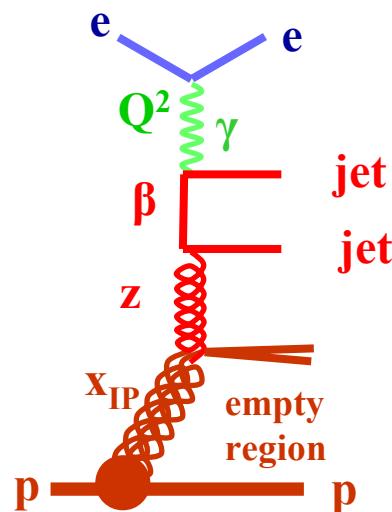


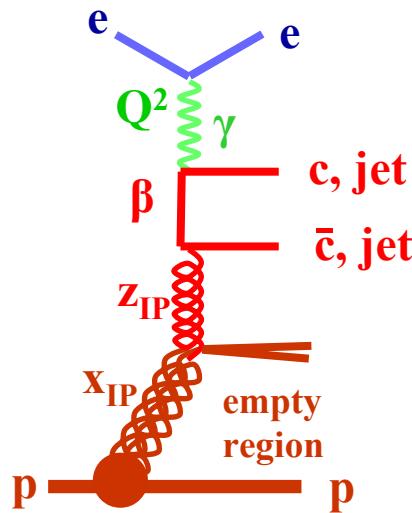
Diffractive PDF's



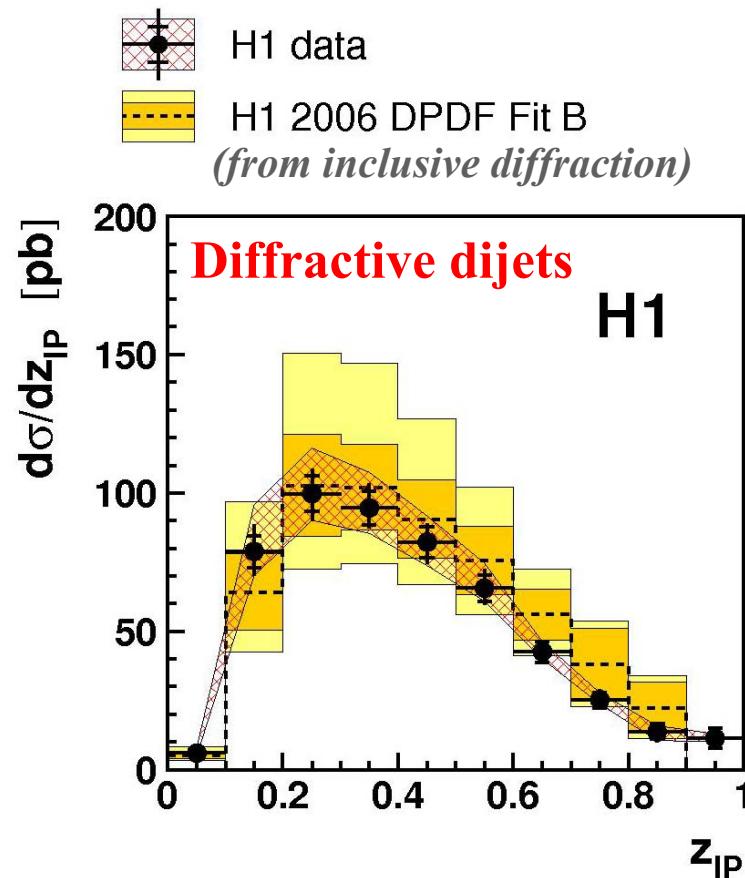
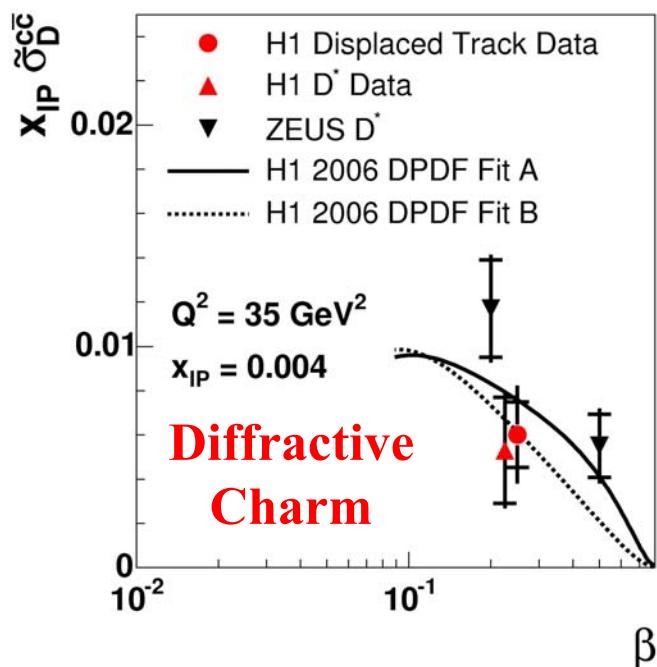
extracted from a common fit
to diffractive inclusive
and dijets cross-sections

- H1 2007 Jets DPDF
- exp. uncertainty
- exp. + theo. uncertainty
- H1 2006 DPDF fit A
- H1 2006 DPDF fit B

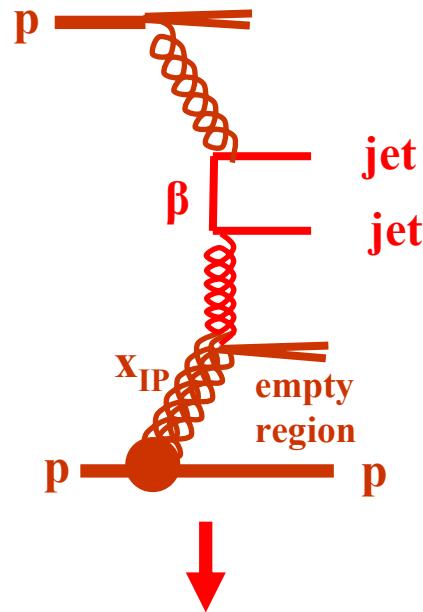




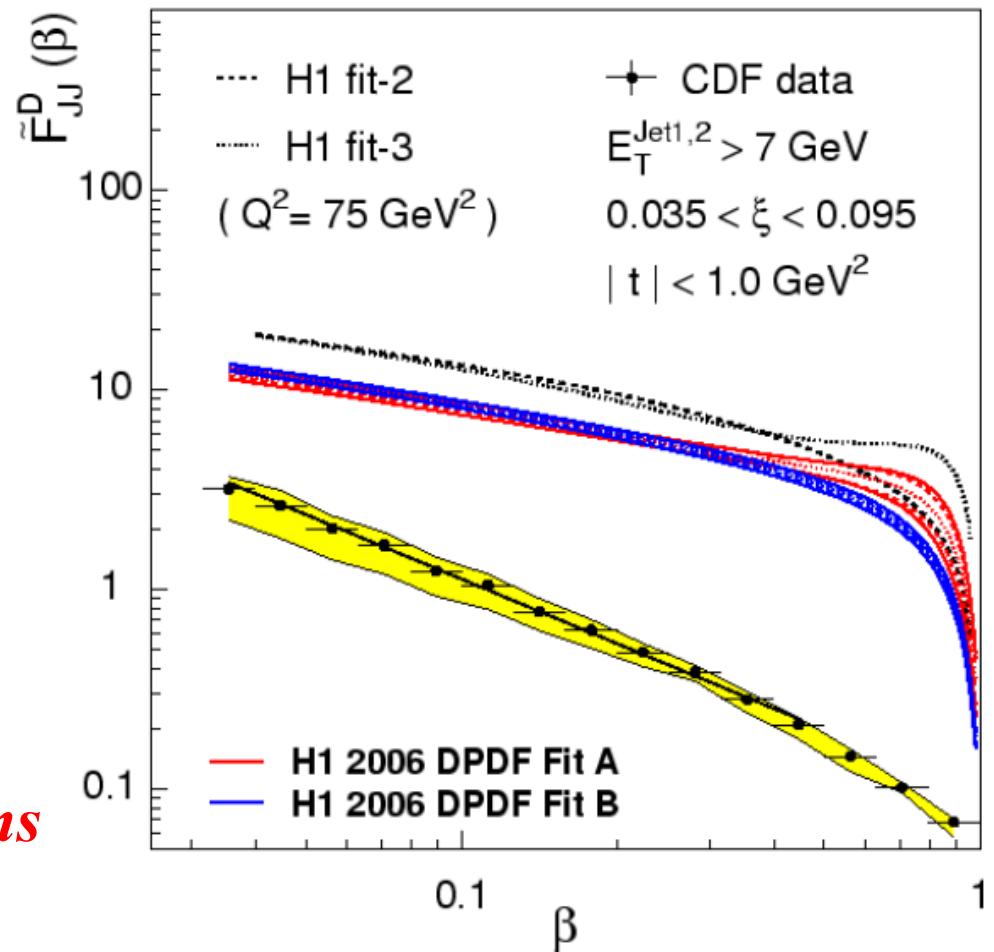
Factorisation of diffractive PDF's holds in DIS for charm and jets as predicted



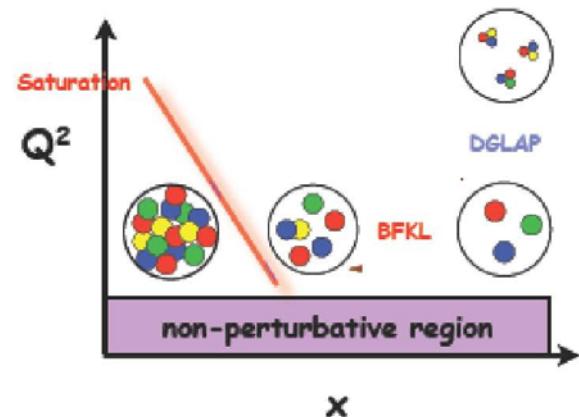
Factorisation of diffractive PDF's broken by a factor ~ 7 for diffractive dijets at Tevatron



*More studies on
rapidity gap survival
needed for LHC predictions*



Low x limit: is saturation observed ?



$$\sigma_{\gamma^* p}(x, Q^2) \sim \alpha_s/Q^2 x g(x)$$

diverges at low x



$$R_p^2 [1 - e^{-(\alpha_s/Q^2 R_p^2 x g(x))}]$$

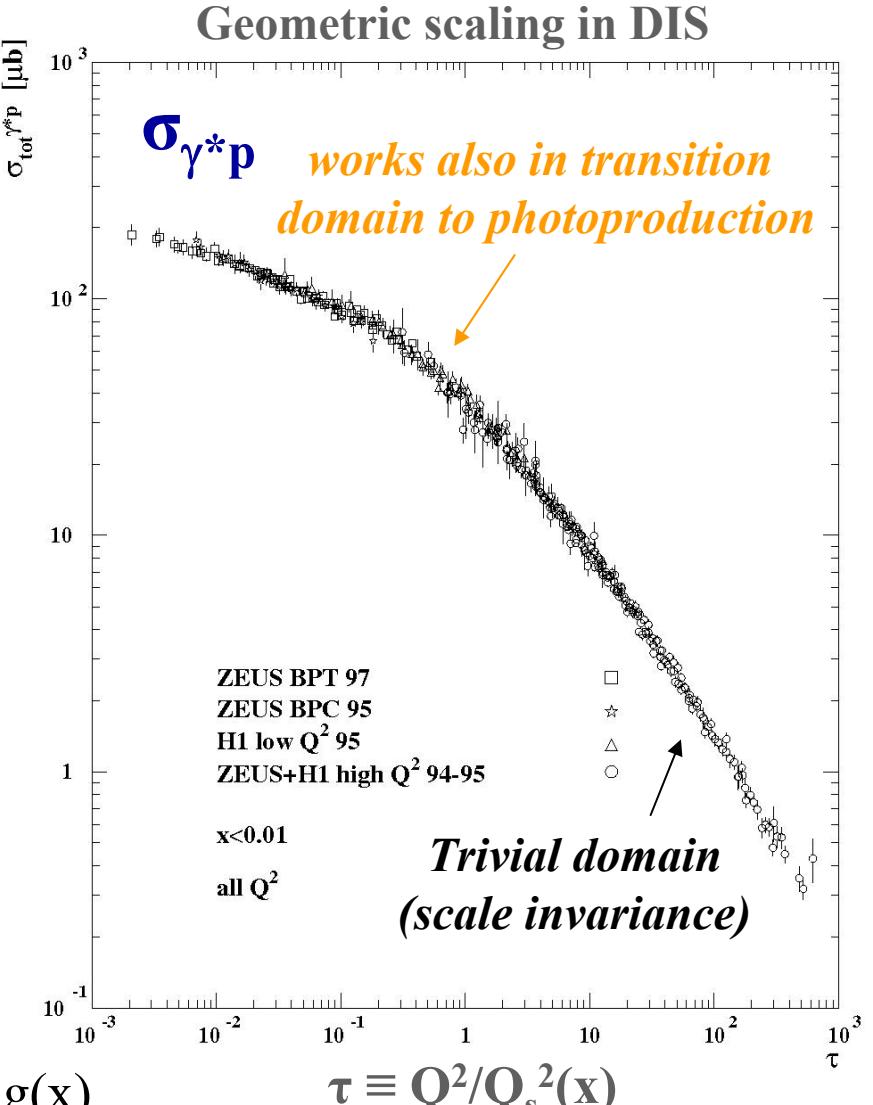
saturates to the proton surface R_p^2



Geometric scaling predicted:

$$\sigma(x, Q^2) \rightarrow \sigma(\tau \equiv Q^2/Q_s^2(x))$$

Universal saturation scale $Q_s^2(x) \sim \alpha_s/R_p^2 x g(x)$



Paving the way towards optimal LHC PDF's



New insights in
low-x dynamics from hard diffraction

DGLAP OK in the bulk phase space

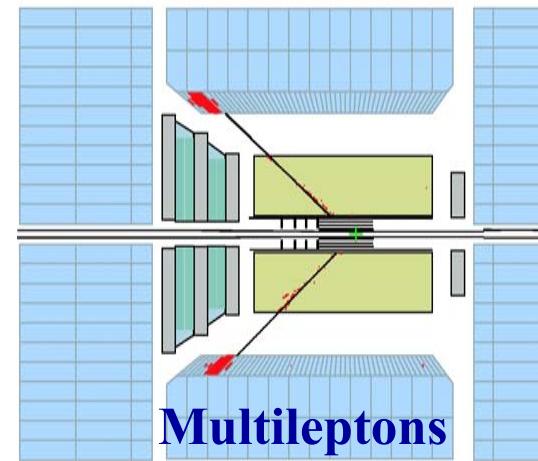
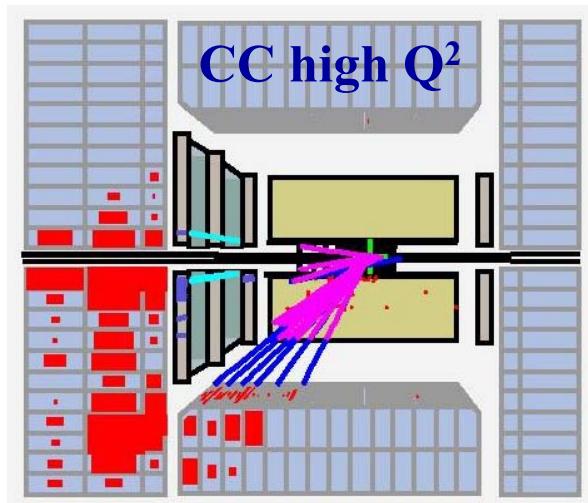
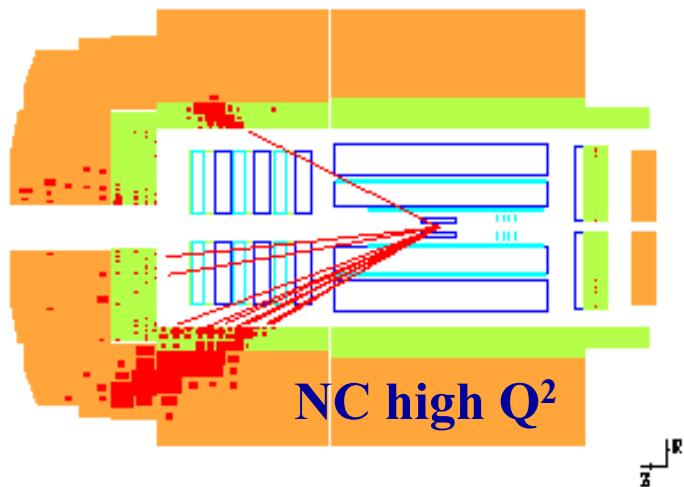
Recent breakthrough in precision at low x
from H1-ZEUS combinations

More to come at high x
with full HERA II data

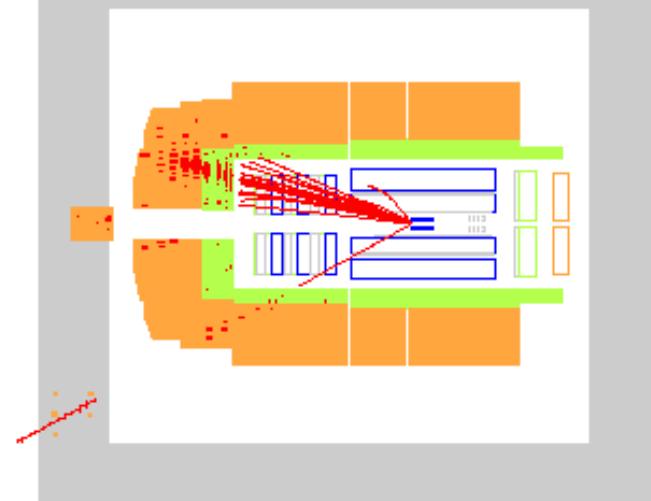


THE HIGH-ENERGY FRONTIER

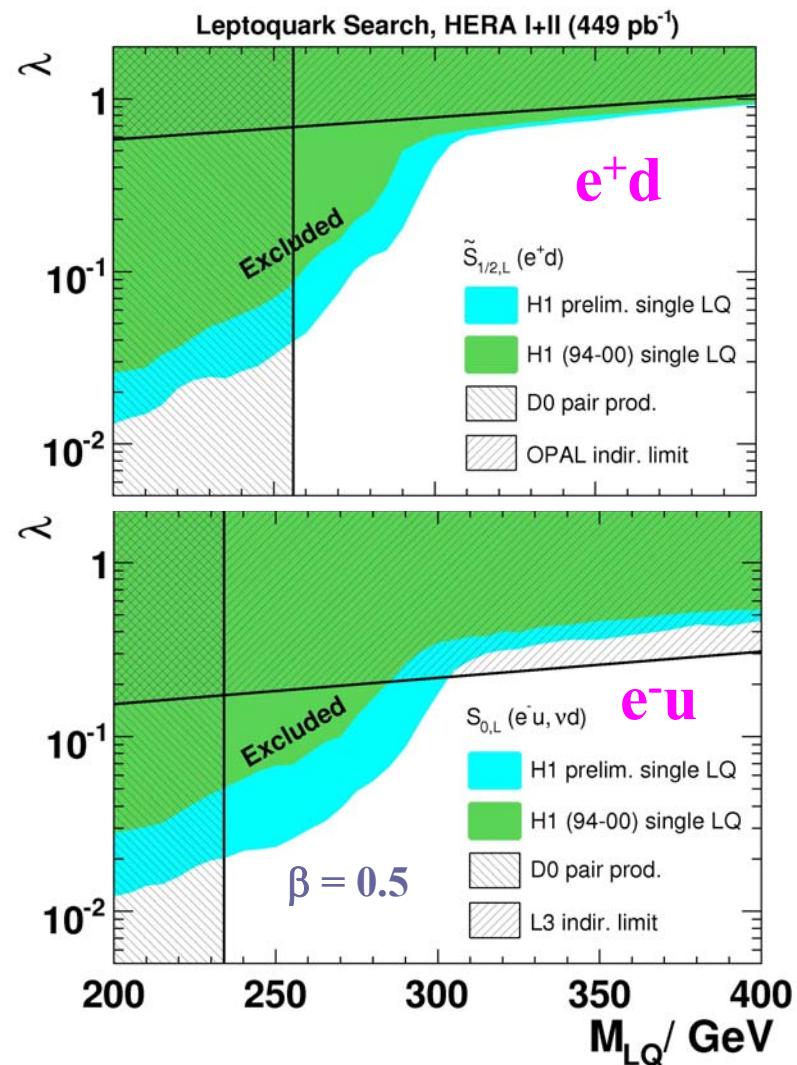
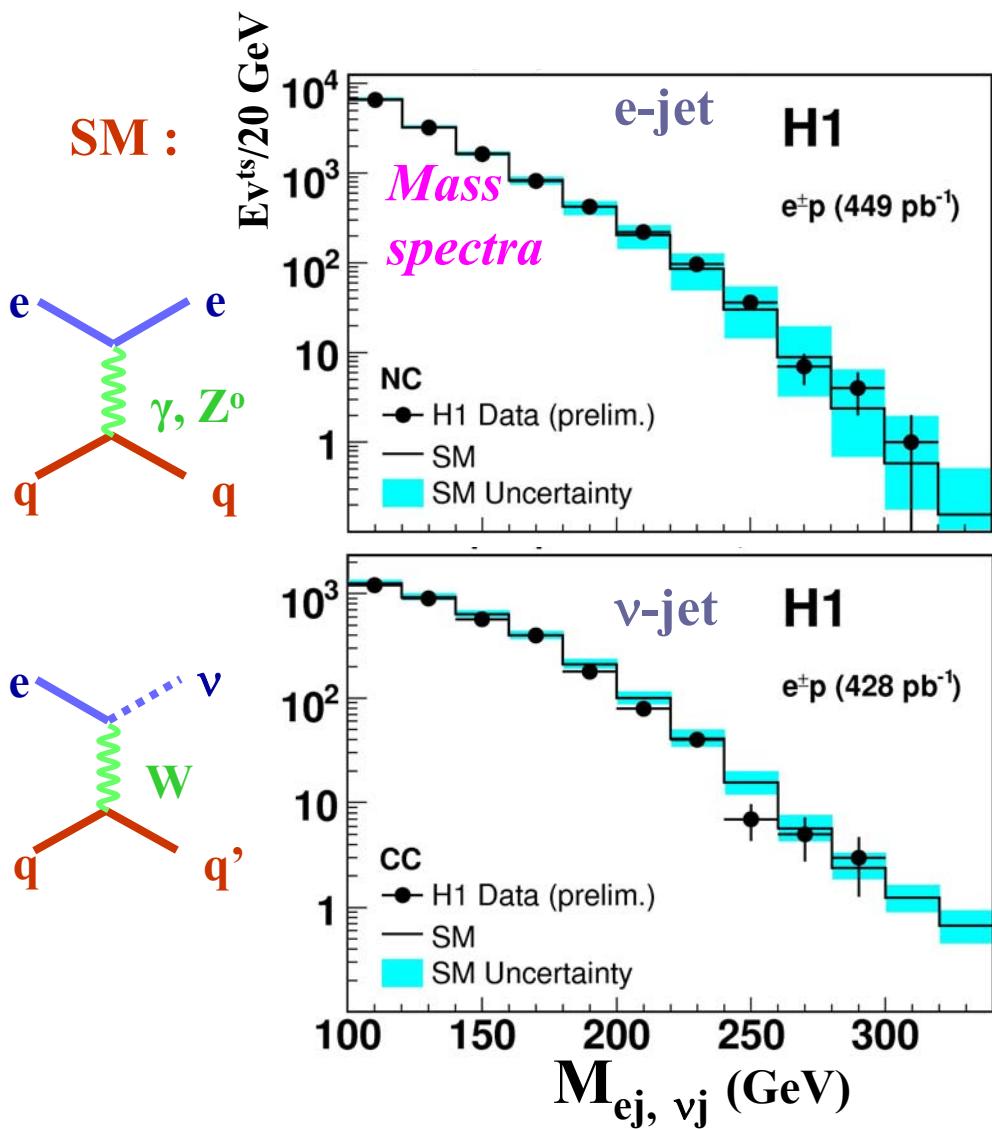
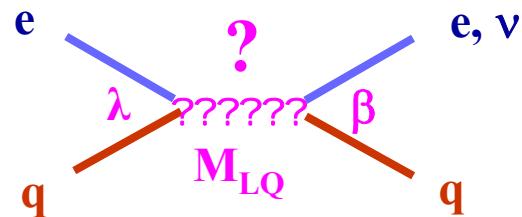
more results



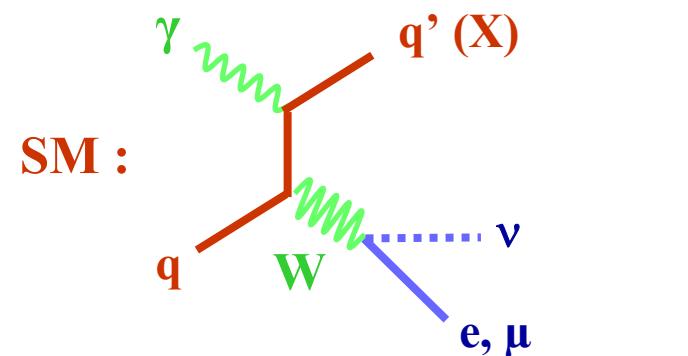
Isolated leptons and P_T^{miss}



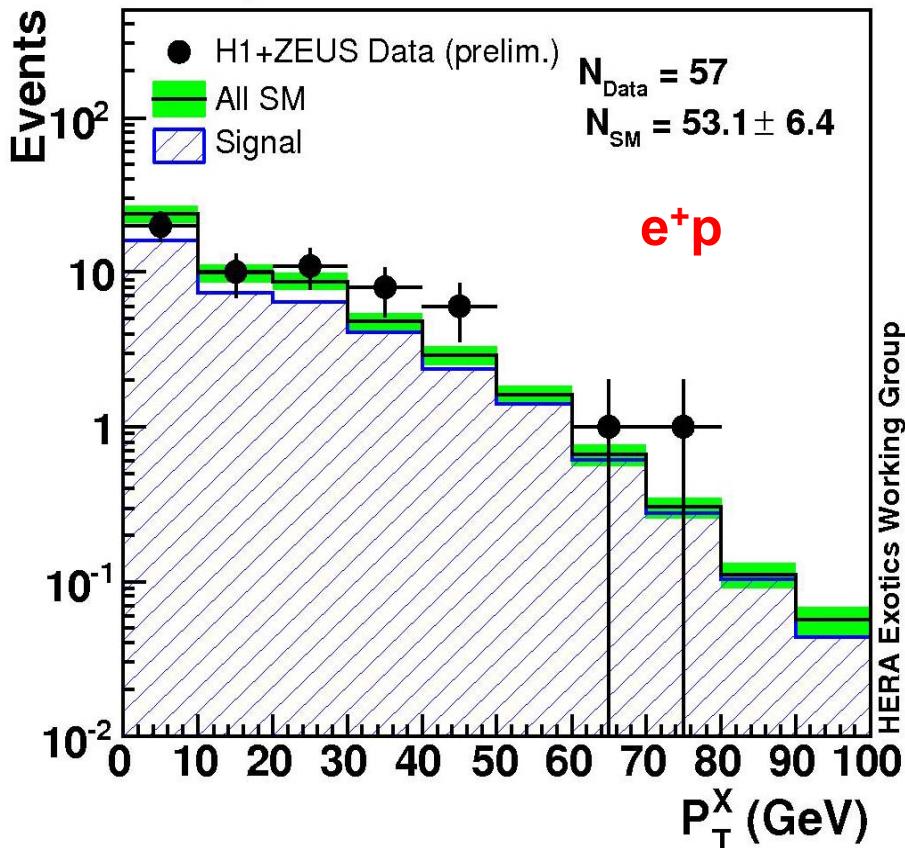
HIGH ENERGY FRONTIER: Leptoquarks



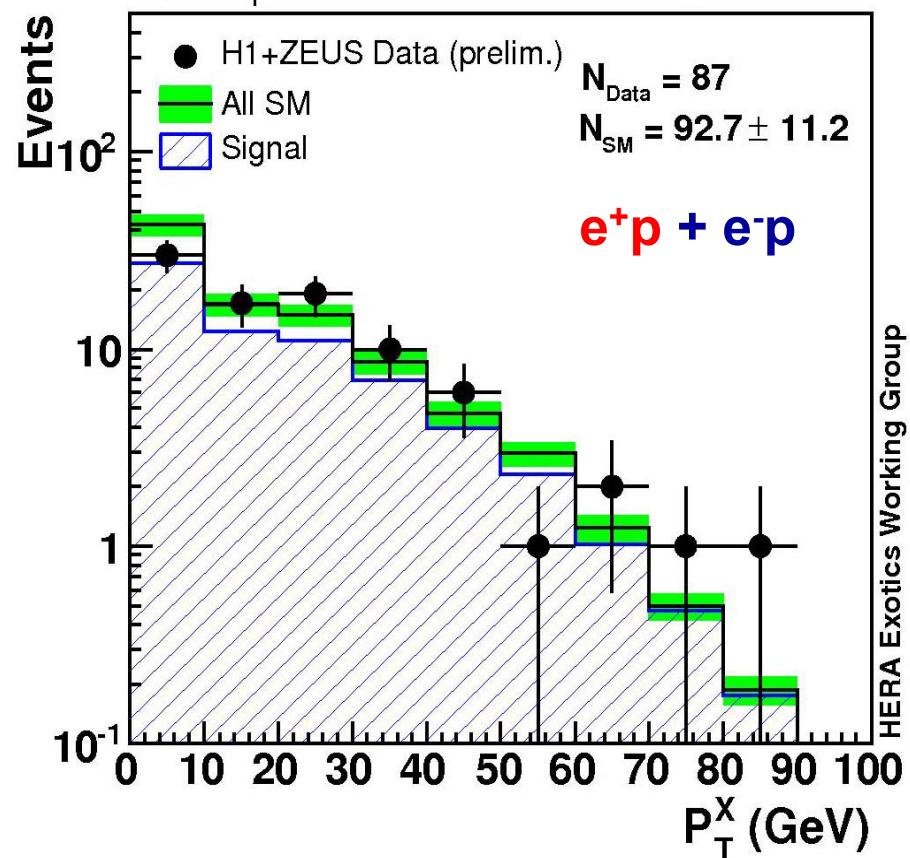
HIGH ENERGY FRONTIER: Isolated Leptons + Missing P_T



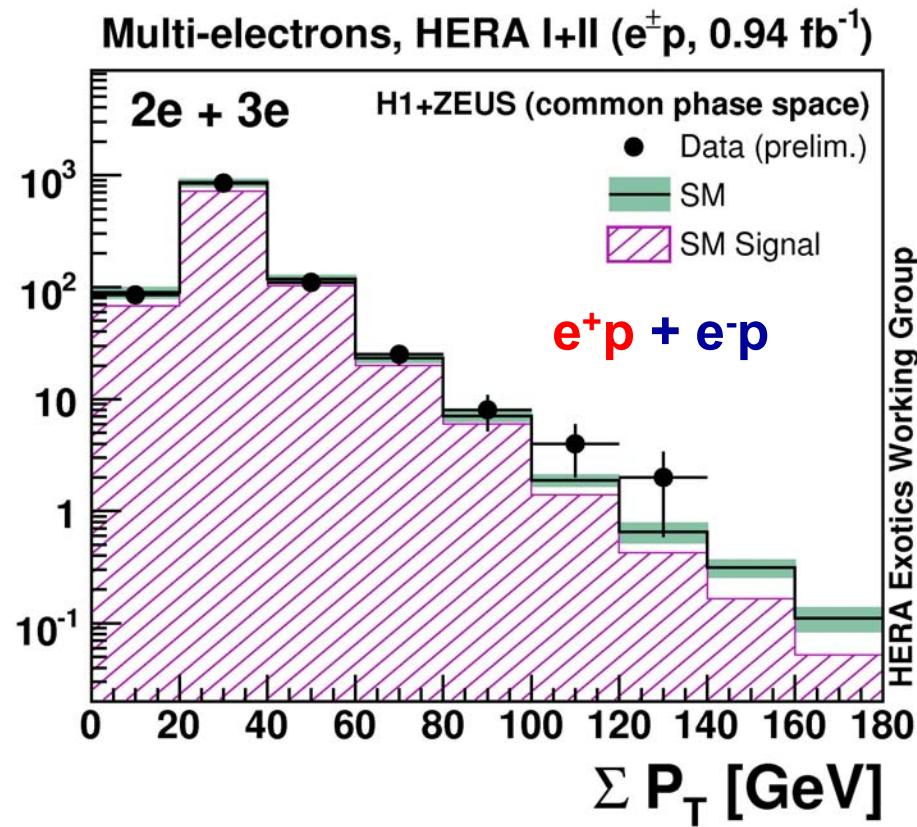
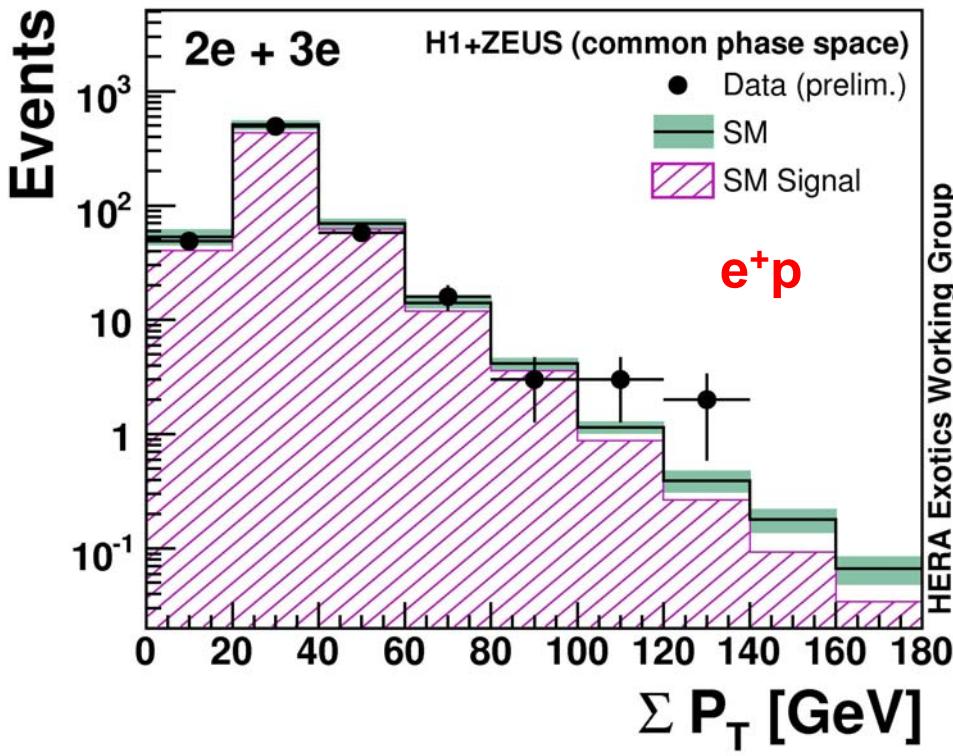
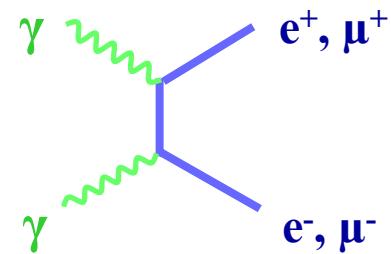
$e, \mu + P_T^{\text{miss}}$ events at HERA I+II ($e^+ p$, 0.58 fb^{-1})



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



HIGH ENERGY FRONTIER: Multi-Leptons



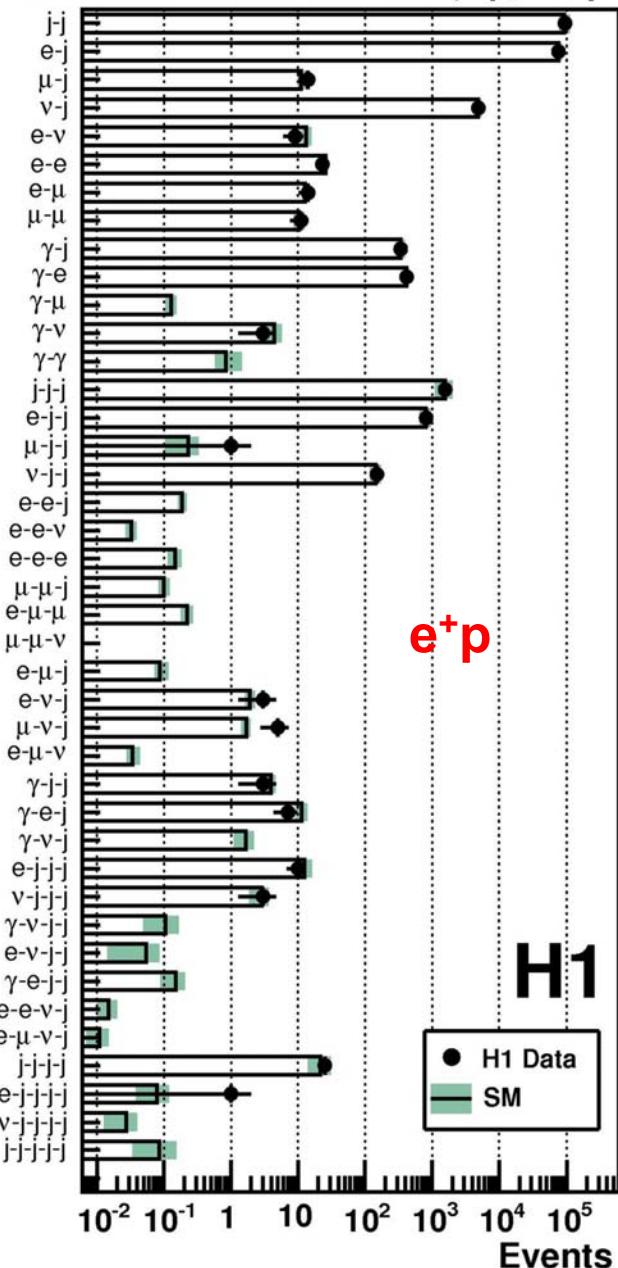
HIGH ENERGY FRONTIER: *Generic Search*

*Multi-body
topologies
 $P_T^i > 20 \text{ GeV}$*

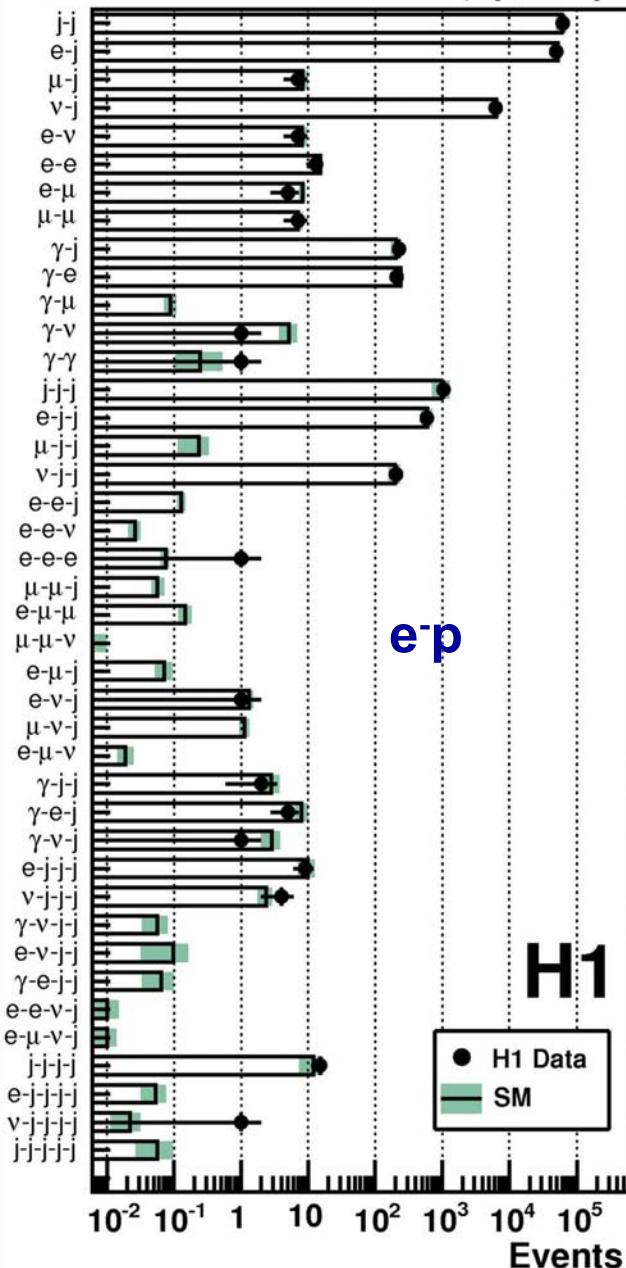
SM OK

C. Vallee 1/04/09

H1 General Search at HERA ($e^+p, 285 \text{ pb}^{-1}$)

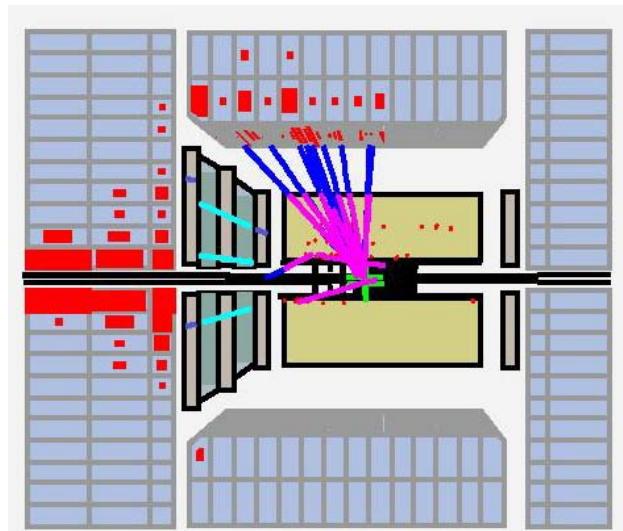
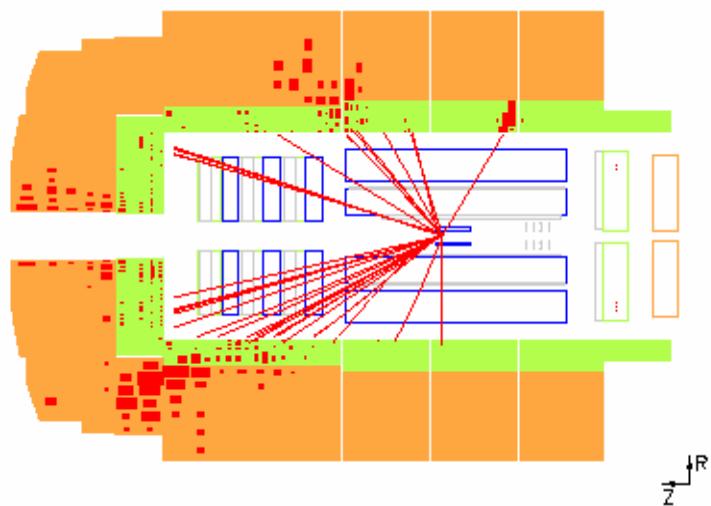


H1 General Search at HERA ($e^-p, 178 \text{ pb}^{-1}$)

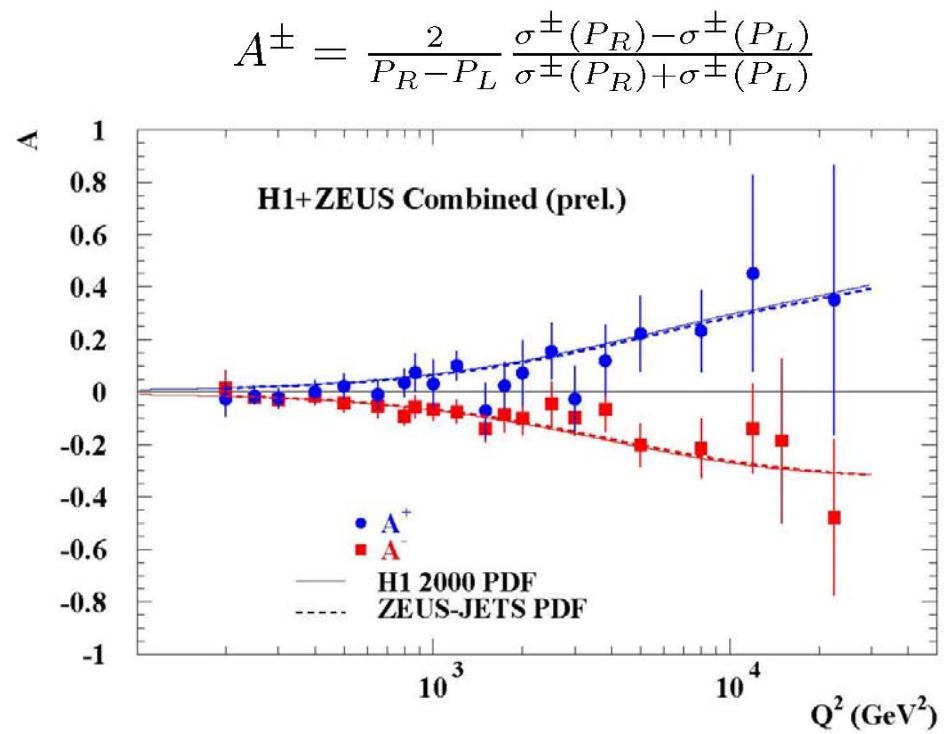
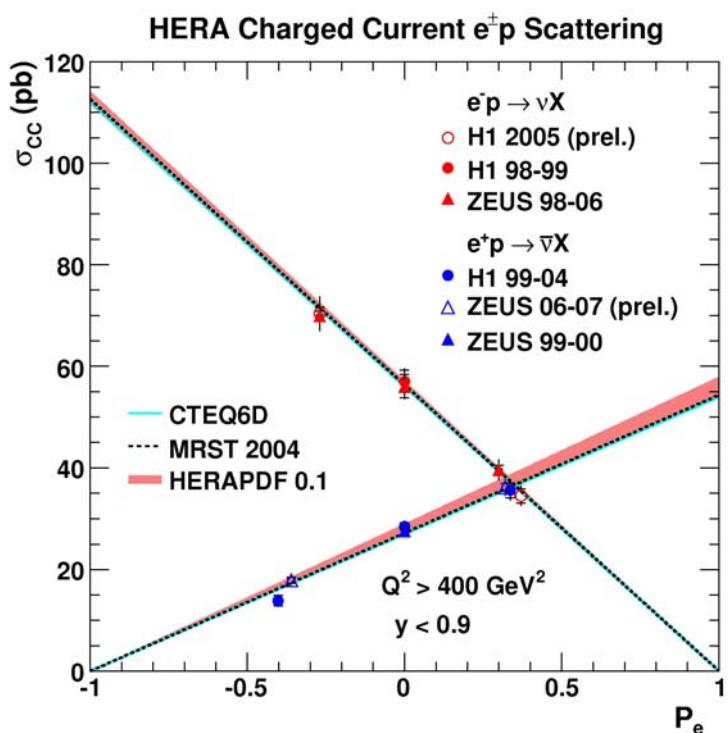
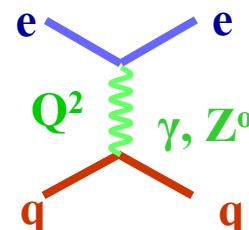
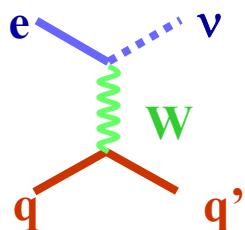


PRECISION MEASUREMENTS

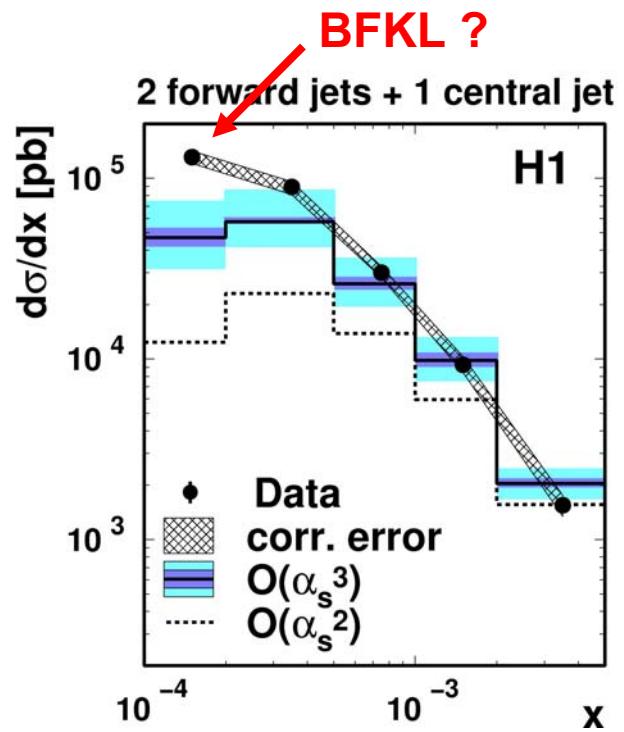
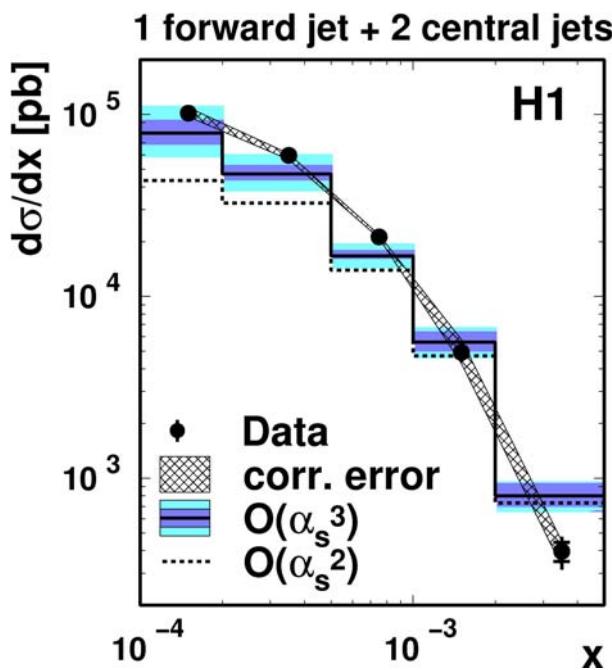
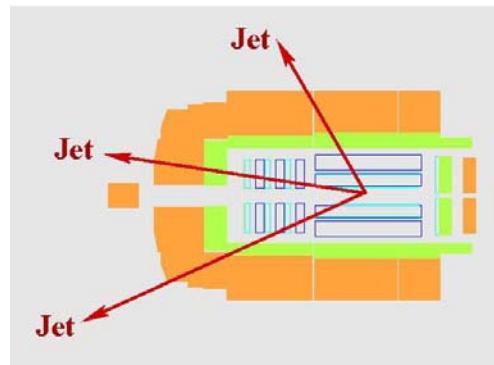
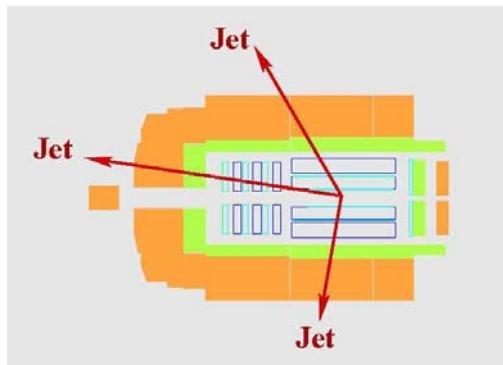
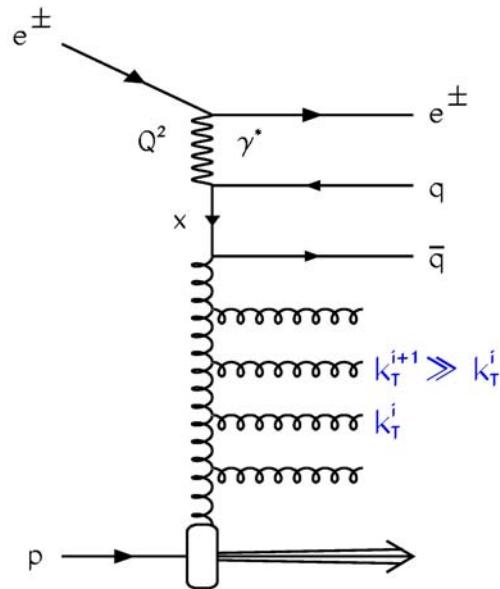
More results



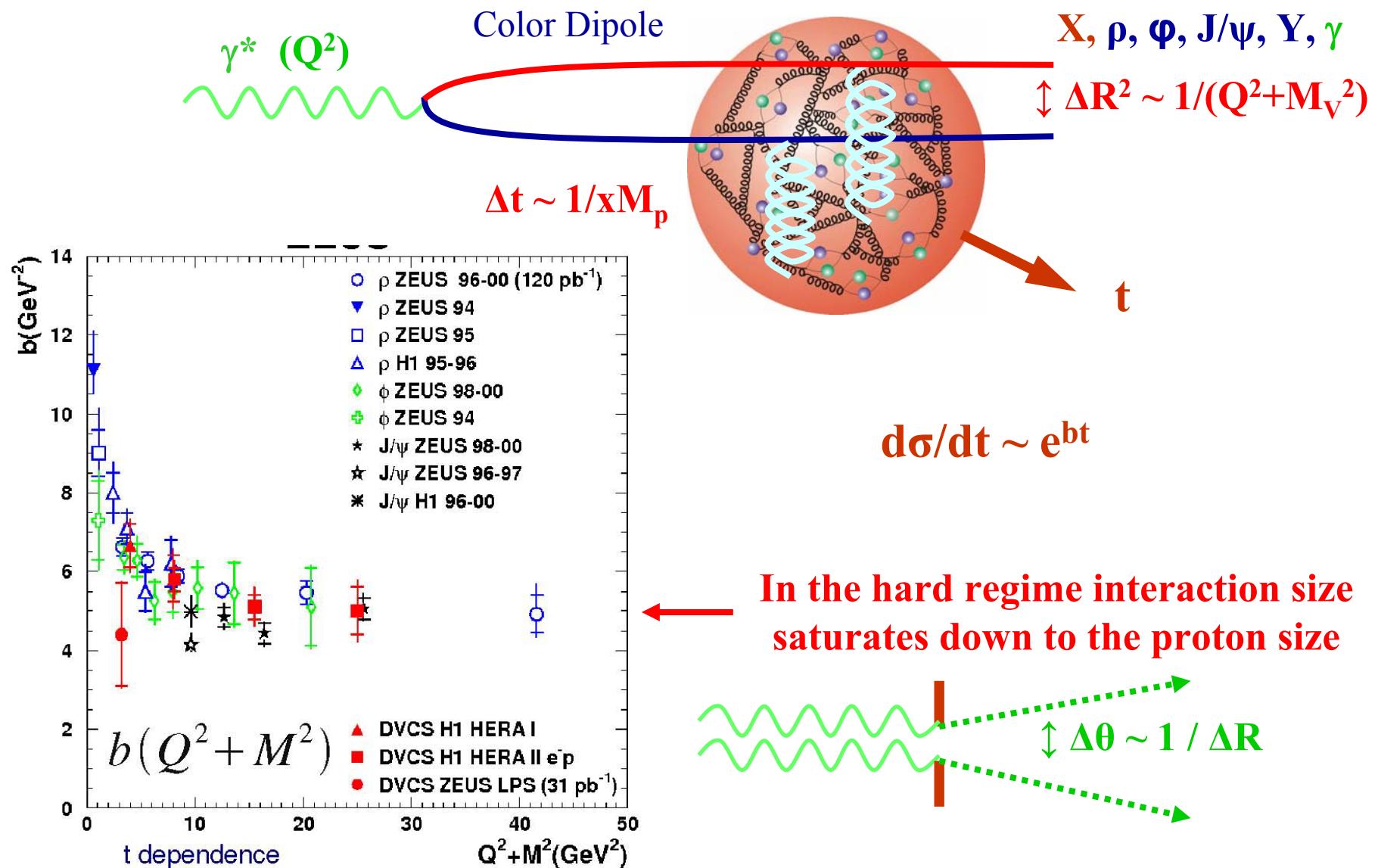
ELECTROWEAK POLARISATION ASYMMETRIES



QCD Dynamics: probing DGLAP with multijets at low x

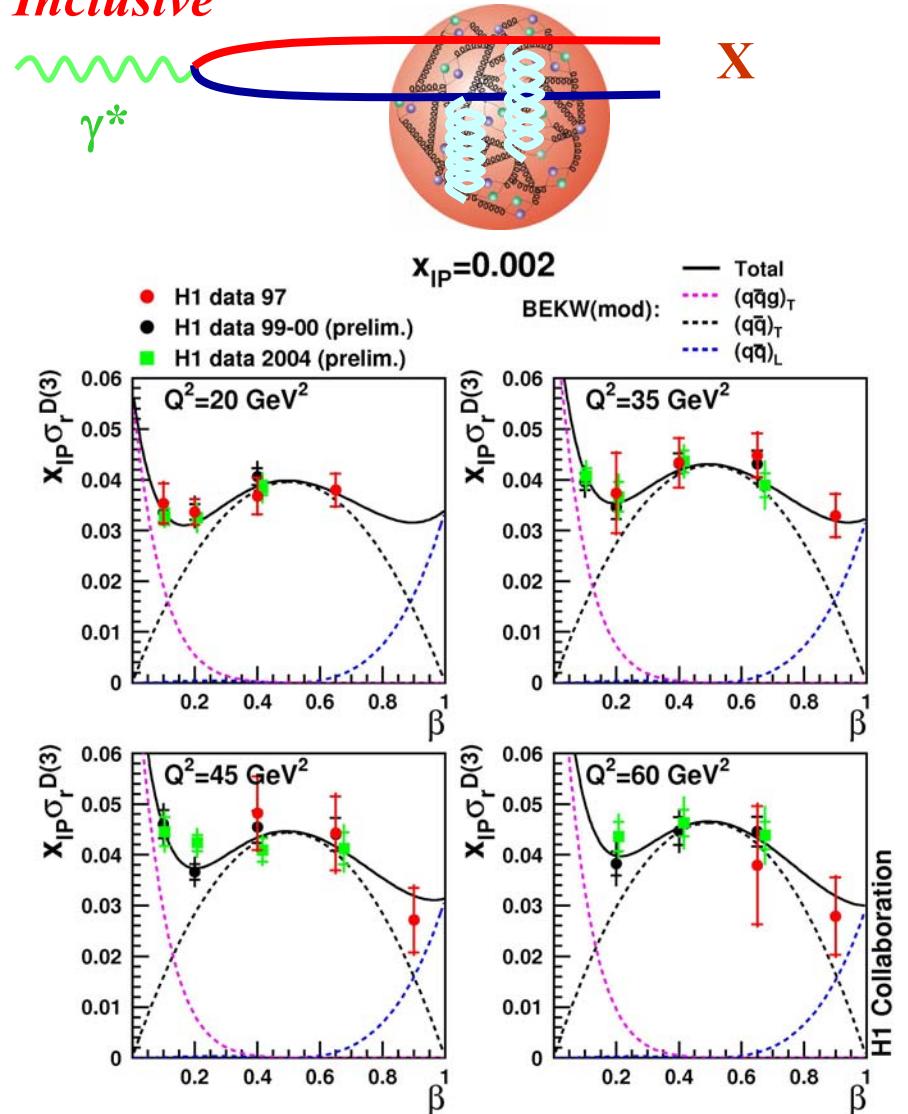


Diffractive processes: impact parameter



Perturbative QCD description of hard diffraction

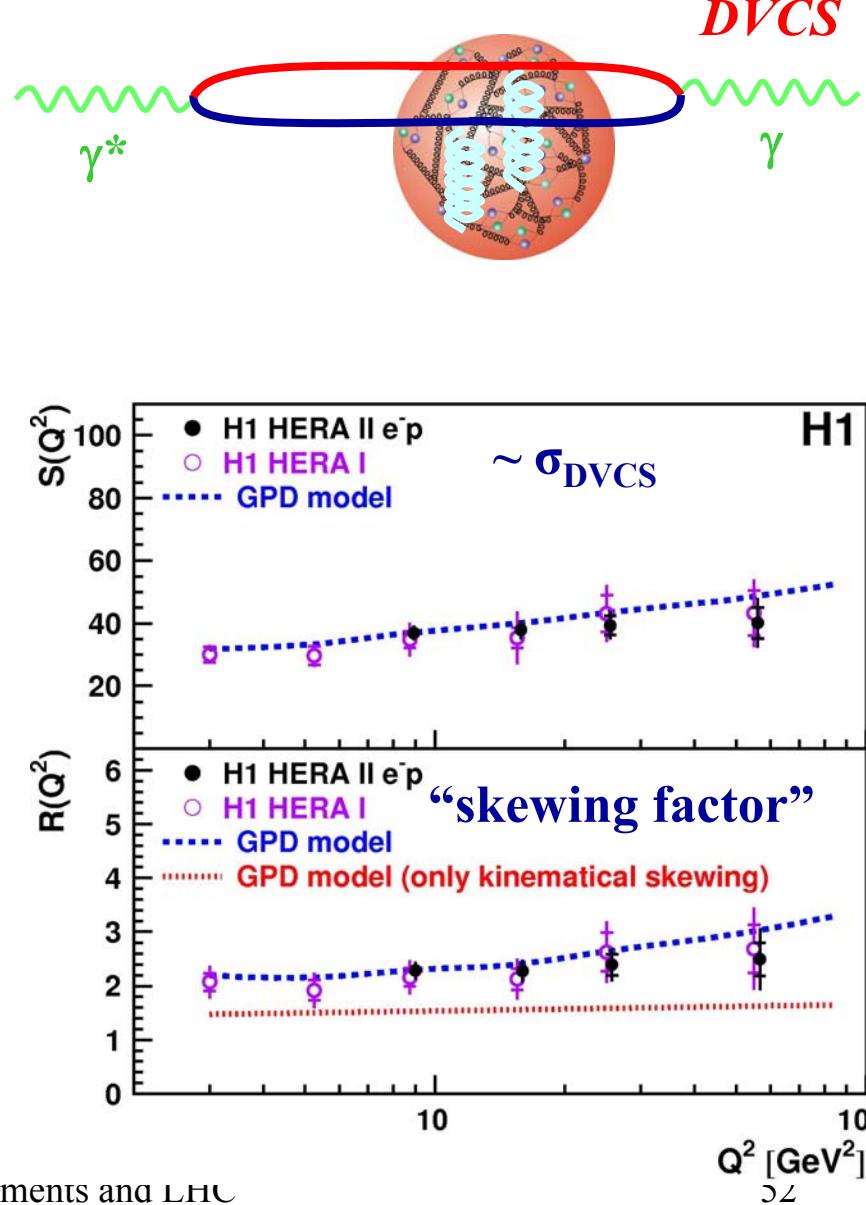
Inclusive



C. Vallee 1/04/09

HERA measurements and LHC

DVCS

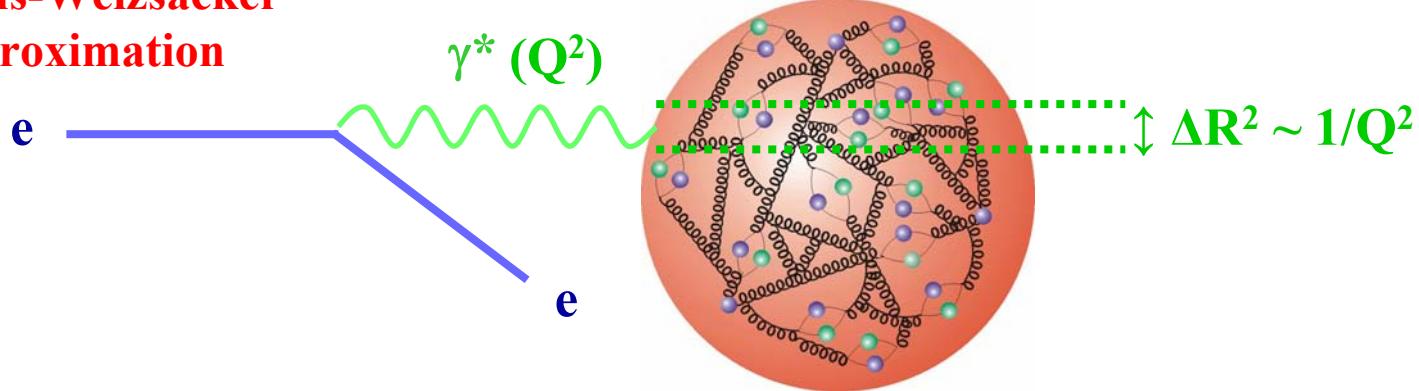


DIFFRACTION and LOW-X DYNAMICS

(experts please shut your eyes !)

Williams-Weizsäcker

Approximation

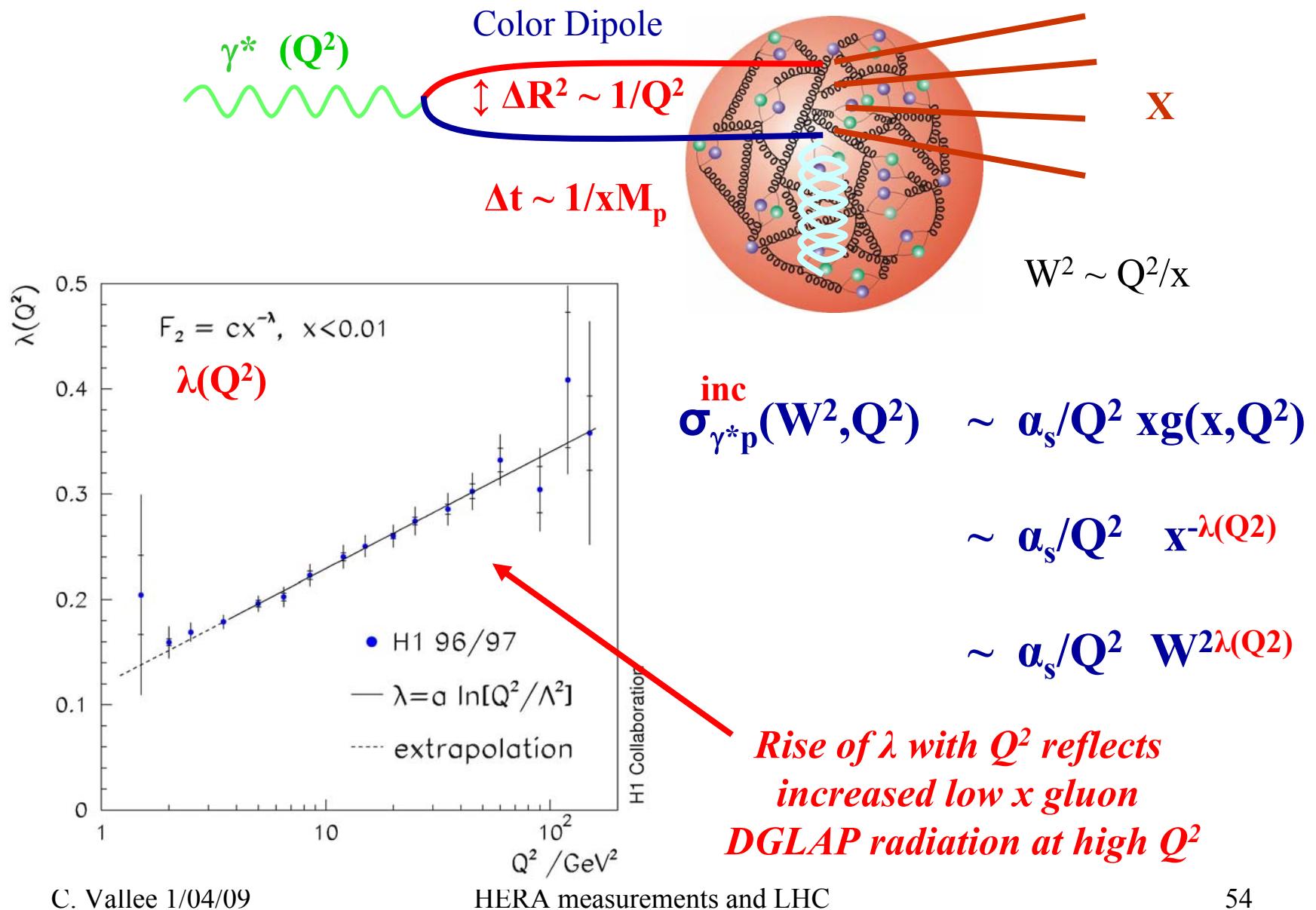


$$\frac{d\sigma_{ep}}{dy dQ^2} \sim \Phi_{\gamma^*}(y, Q^2) \quad x \quad \sigma_{\gamma^* p}(W^2, Q^2) \quad W^2 \equiv E_{cms}^2(\gamma^* p) \\ \sim Q^2(1-x)/x$$

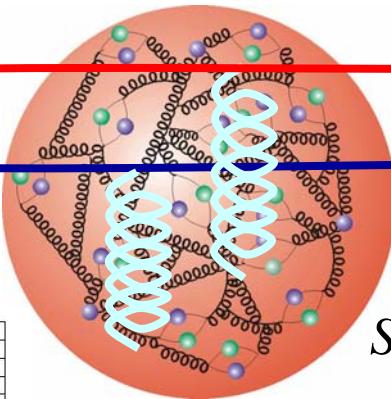
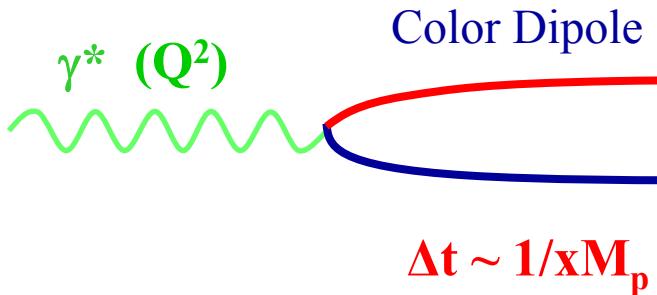
$$a/Q^2 [1+(1-y)^2]/y \quad x \quad a/Q^2 x q(x) \quad \text{scale invariance at high } x$$

*WWA allows to relate
diffraction, photoproduction and deep inelastic scattering
at low x in a unified frame.*

Low- x limit: inclusive cross-section



Low- x limit: diffractive cross-sections



$X, \rho, \varphi, J/\psi, Y, \gamma$
 $\updownarrow \Delta R^2 \sim 1/(Q^2 + M_V^2)$

$$W^2 \sim Q^2/x$$

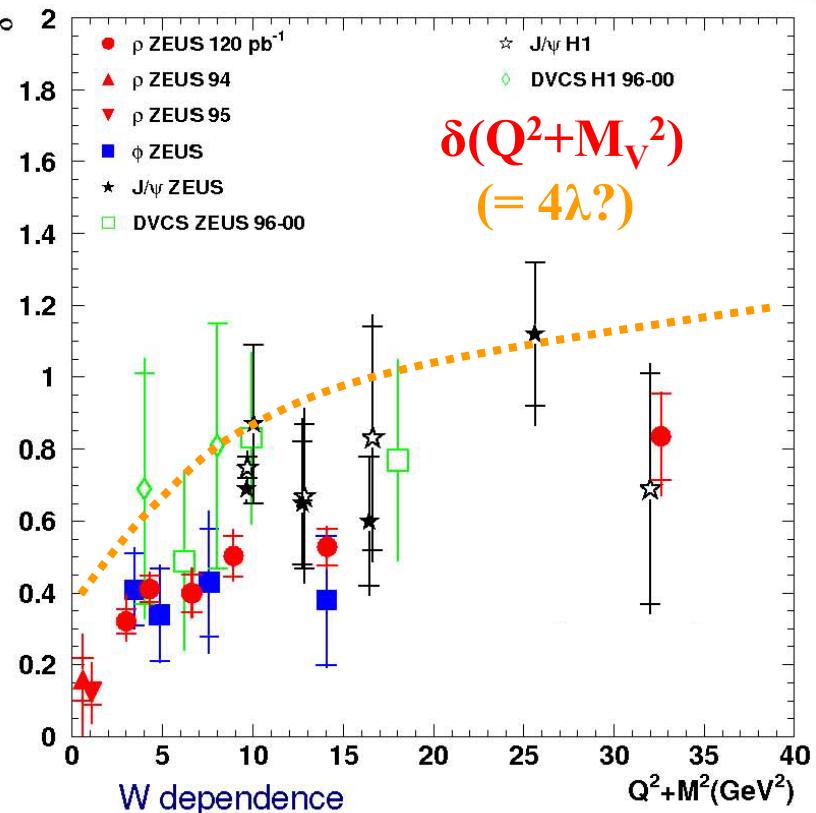
*Simplest colorless exchange
is from two gluons*

$$\sigma_{\gamma^* p}^{\text{diff}}(W^2, Q^2) \sim \alpha_s^2/Q^2 [x g(x, Q^2 + M_V^2)]^2$$

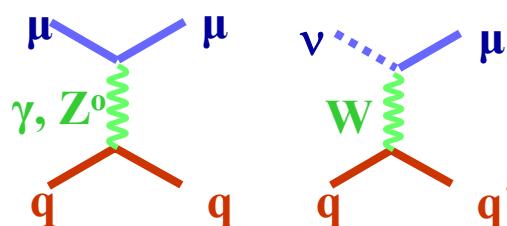
$$\sim \alpha_s^2/Q^2 \quad x^{-2\lambda(Q^2 + M_V^2)}$$

$$\sim \alpha_s^2/Q^2 \quad W^{\delta(Q^2 + M_V^2)}$$

*Rise of δ with $(Q^2 + M_V^2)$ reflects
entering the hard diffraction regime
with direct sensitivity to the gluon.
 $\delta \lesssim 4 \lambda$ hints to saturation*

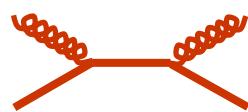


COMPLEMENTARY INPUTS to the PROTON PDF's (personal comments)



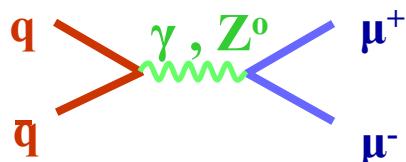
Fixed Target NC/CC
Nuclear corrections (CC) and possible Higher Twists (low Q^2)

Still needed with final HERA II high Q^2 NC/CC ?

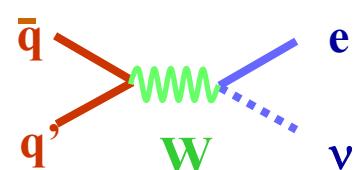


Tevatron High- P_T jets

Still needed with high precision HERA $F_2 + \text{jets}$?

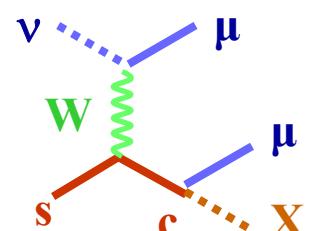


Fixed Target Drell-Yan
Nuclear corrections same as in DIS ?



Tevatron W^+/W^-

Special data will stay necessary for subtle asymmetry effects



Dimuons in Fixed Target CC

Increased tolerance needed in global fits
→ minimize number of experiments