

CEA-IRFU Saclay, January 26th 2009

Claude Vallée
H1 experiment, CPPM-Marseille

Building up the HERA Legacy

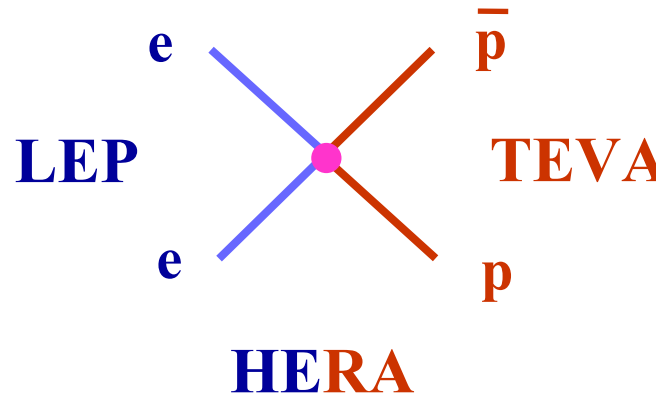
Impact on LHC



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



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

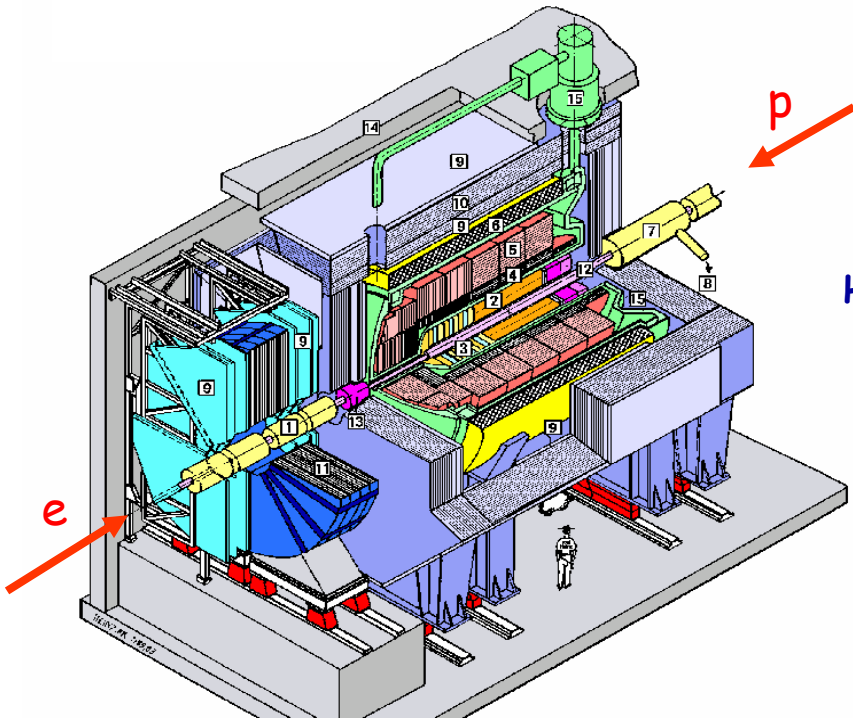


1.96 TeV, $\sim 4 \text{ fb}^{-1}/\text{exp.}$

\sim twice more expected
until 2010



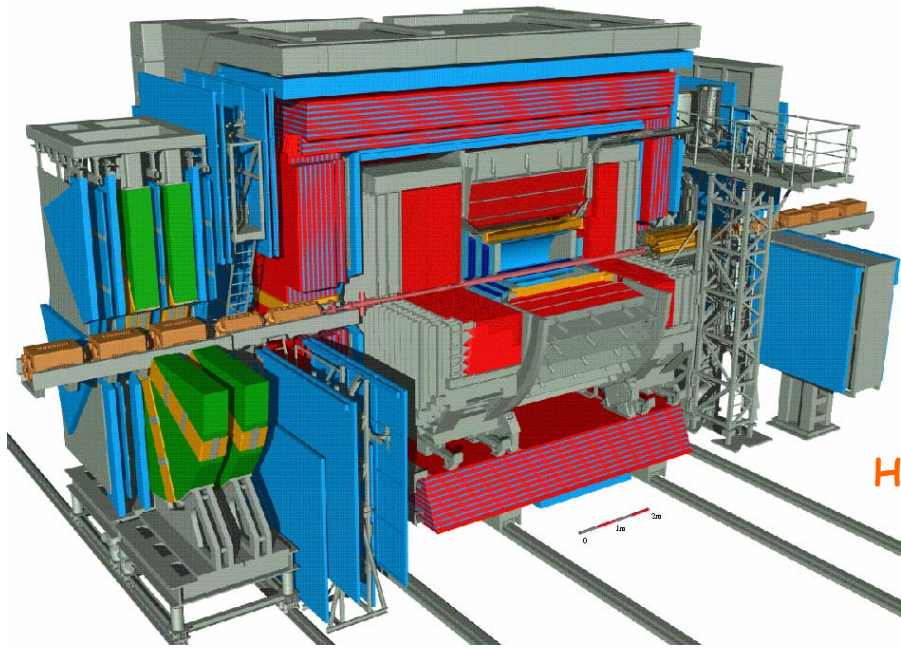
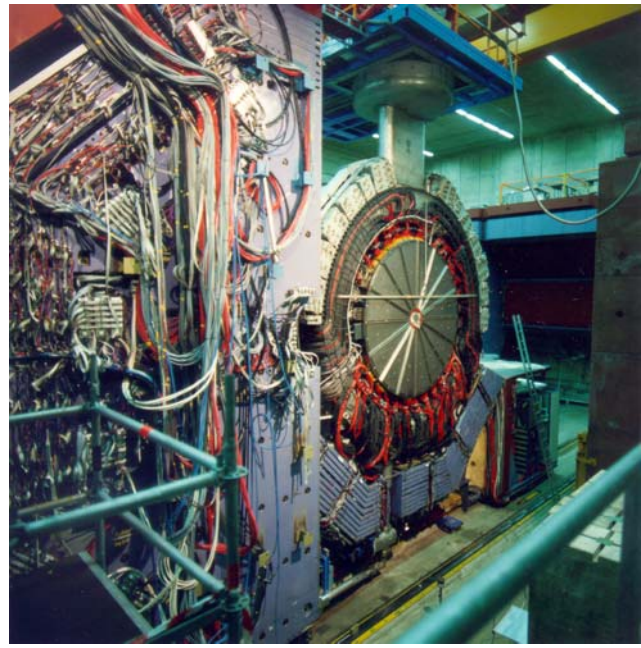
0.32 TeV, $\sim 0.5 \text{ fb}^{-1}/\text{exp.}$



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

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

LAr
calorimeter

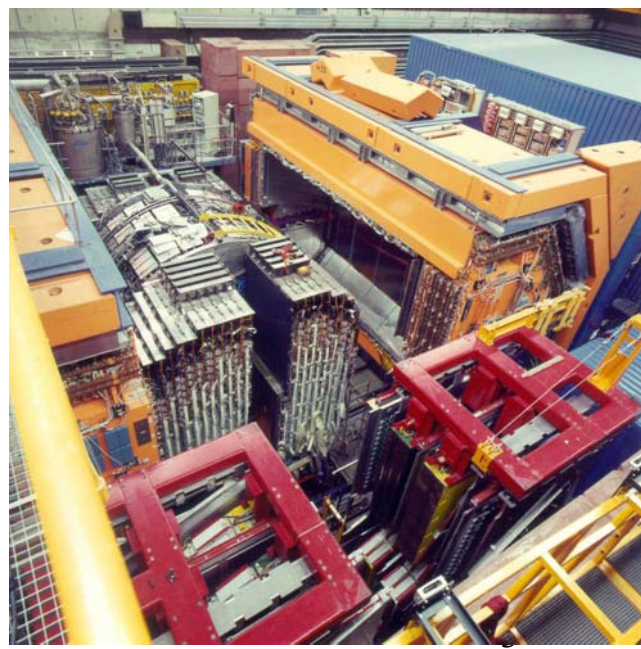


U-scint.
calorimeter

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

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

legacy and LHC



All good things come to an end...

HERA Fest 29/06/07



HERA Control Room 30/06/07 23H00



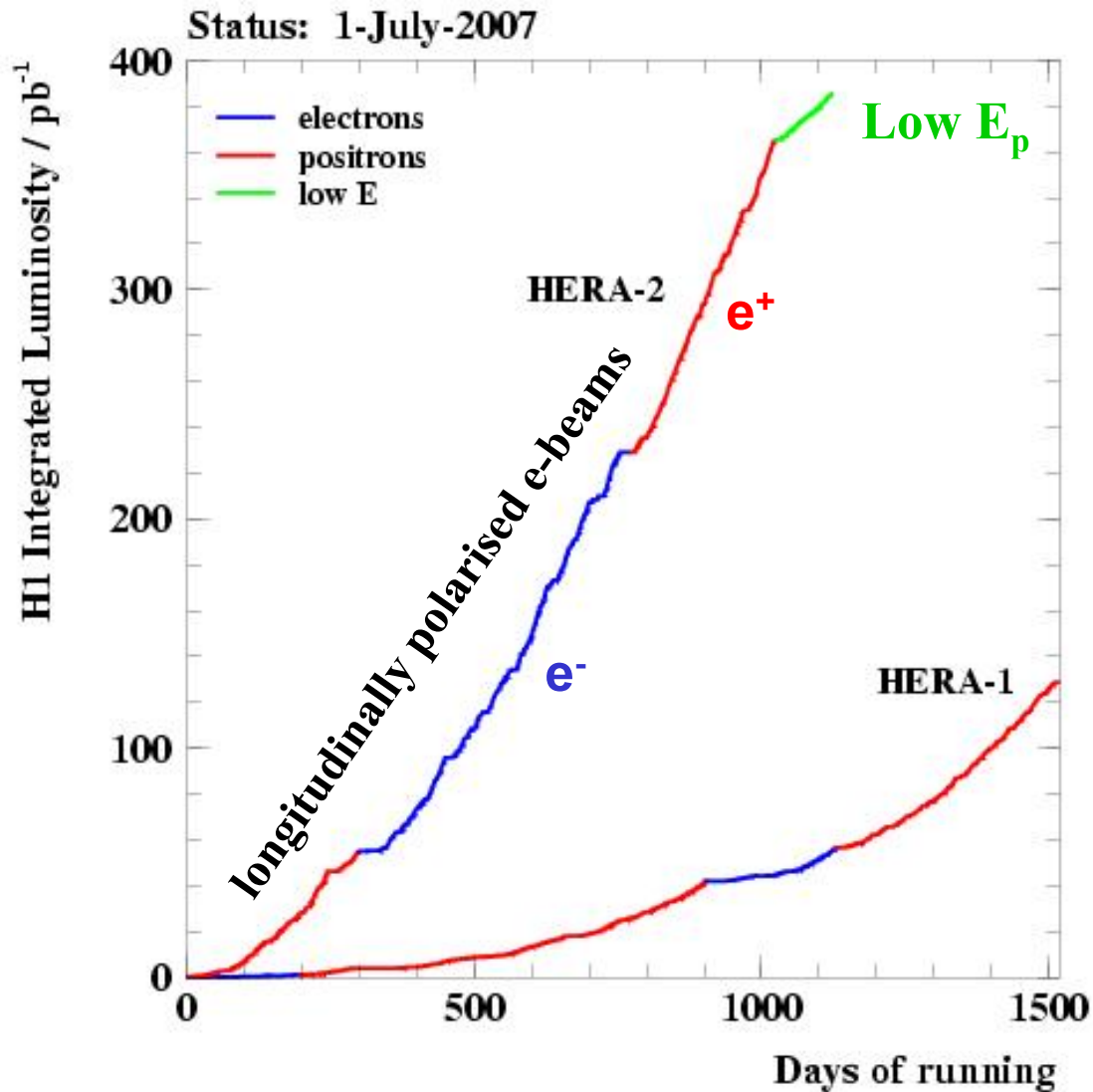
**Last Beam Dump
30/06/07 23H30**



ZEUS Run End Party 30/06-01/07/07



H1 Control Room 30/06/07 23H00



The final HERA data samples

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

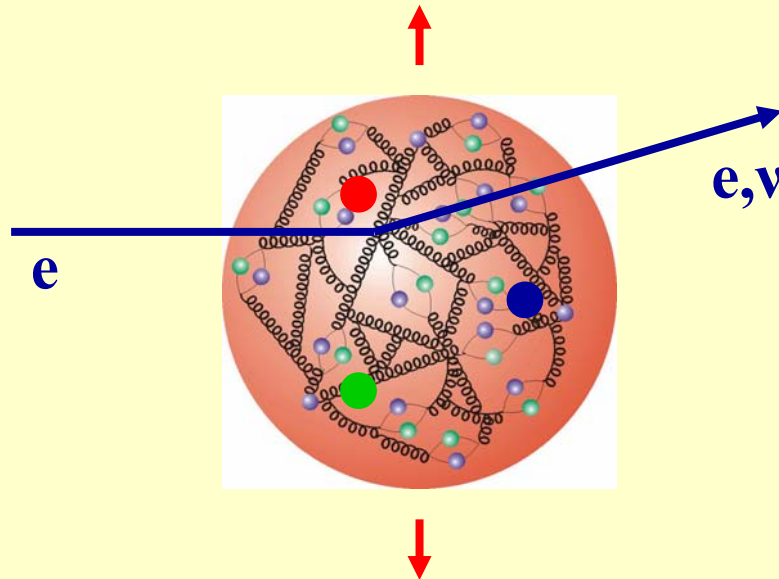
balanced e^+p and e^-p samples

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

Low- E_p runs for F_L

Building up the HERA legacy

THE HIGH-ENERGY FRONTIER



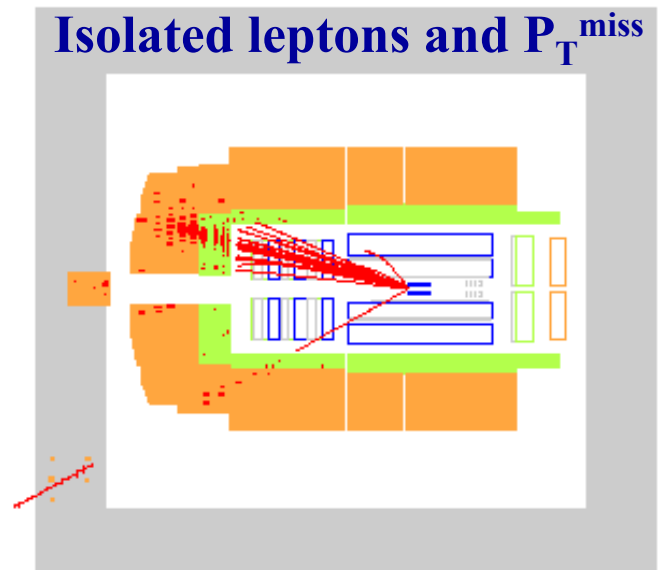
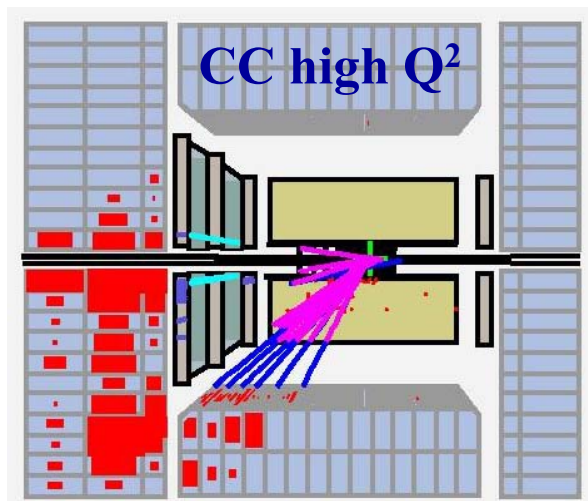
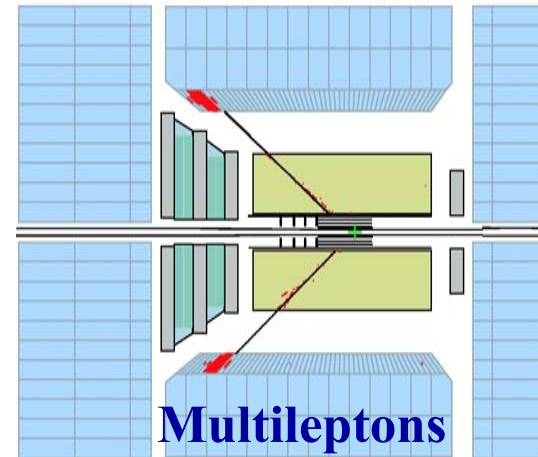
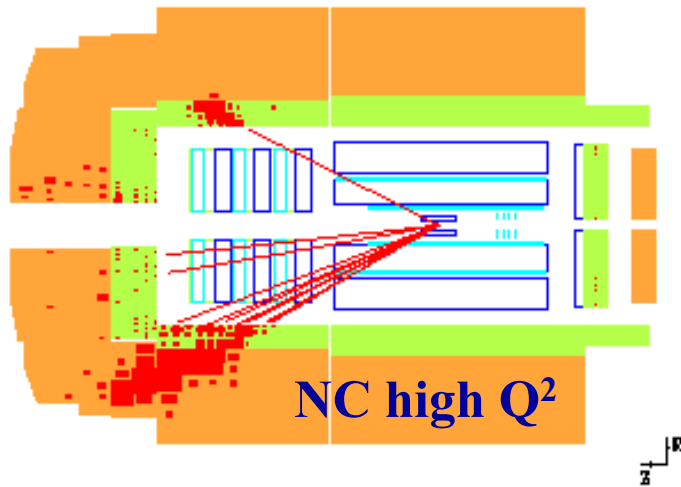
PRECISION MEASUREMENTS

LHC needs

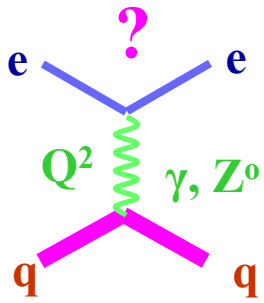
Proton structure and dynamics

Diffraction and the low- x limit

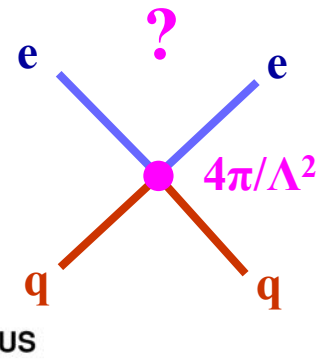
THE HIGH-ENERGY FRONTIER



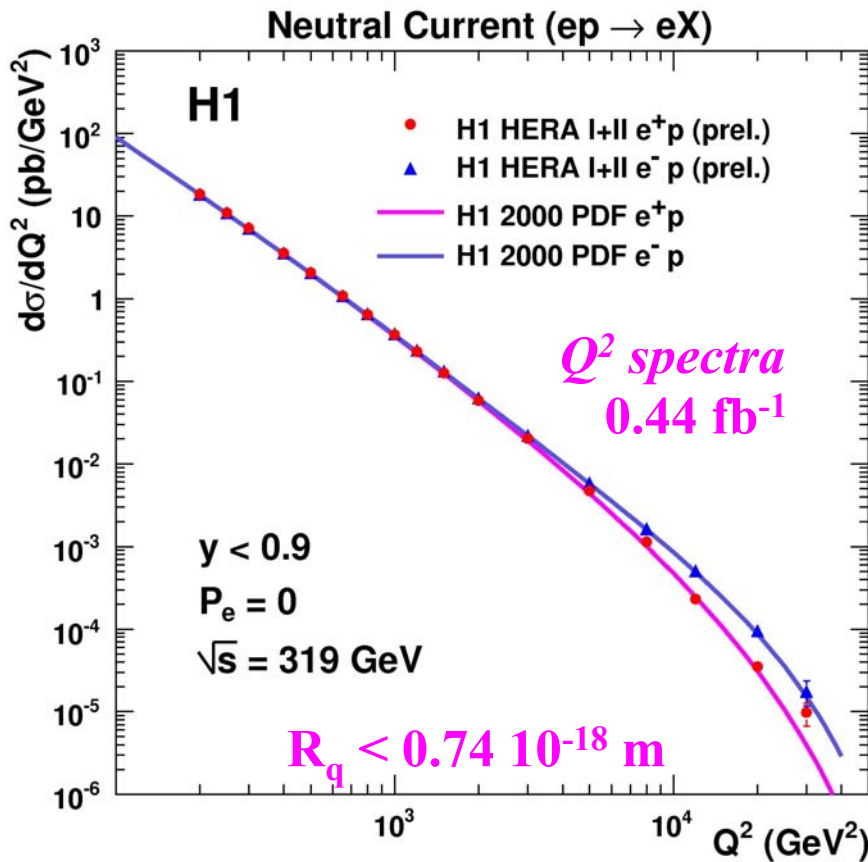
HIGH ENERGY FRONTIER: Quark sub-structure



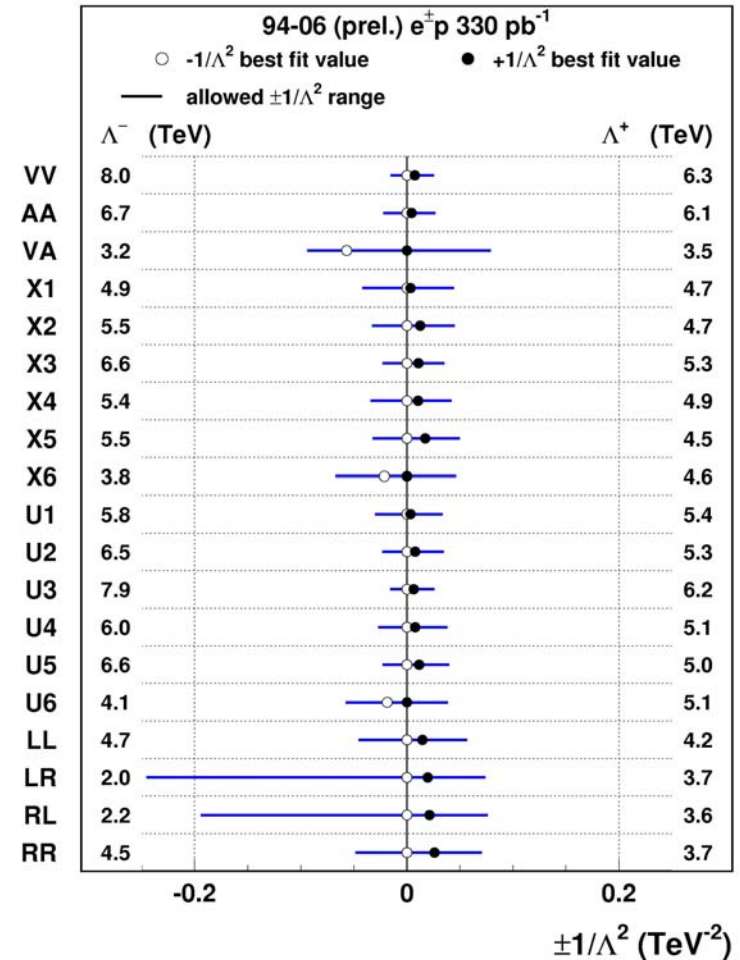
quark radius R_q
factor: $(1 - R_q^2 Q^2 / 6)$



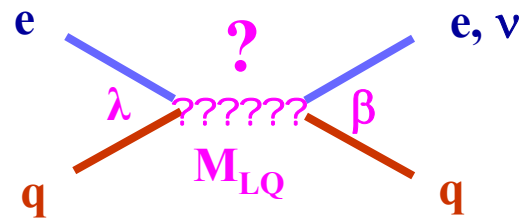
ZEUS



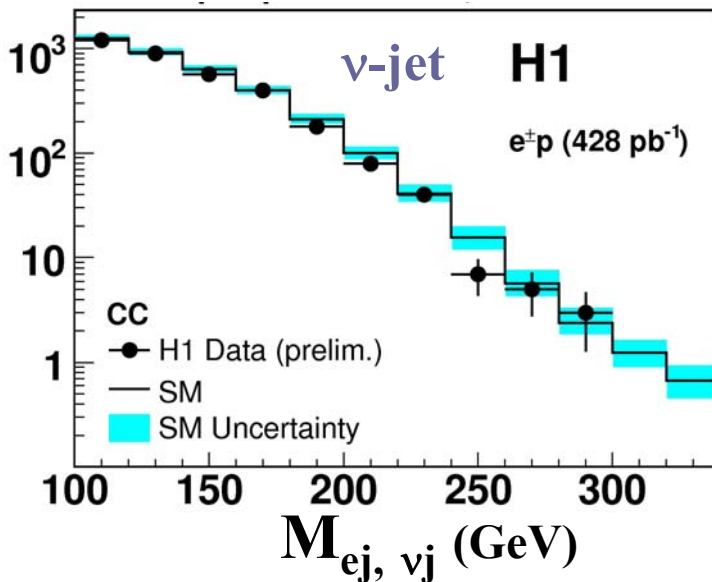
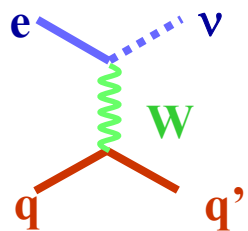
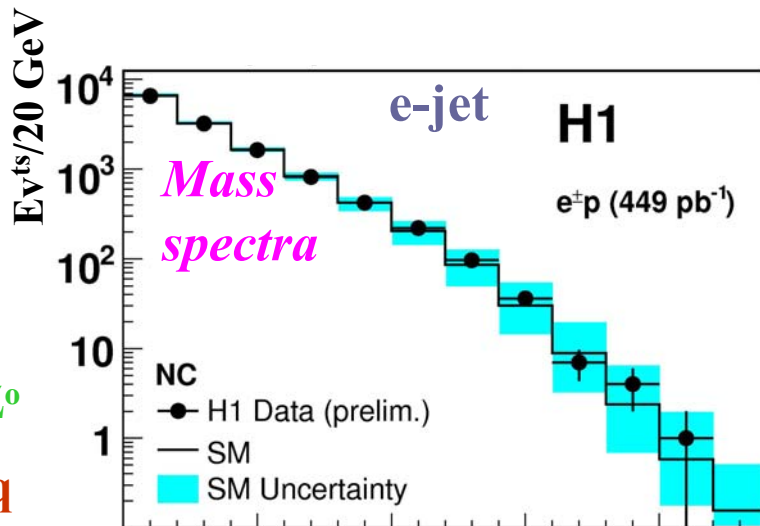
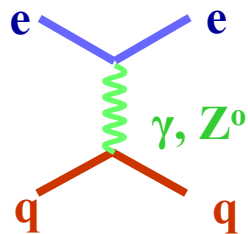
ZEUS 0.33 fb^{-1} : $R_q < 0.62 \cdot 10^{-18} \text{ m}$



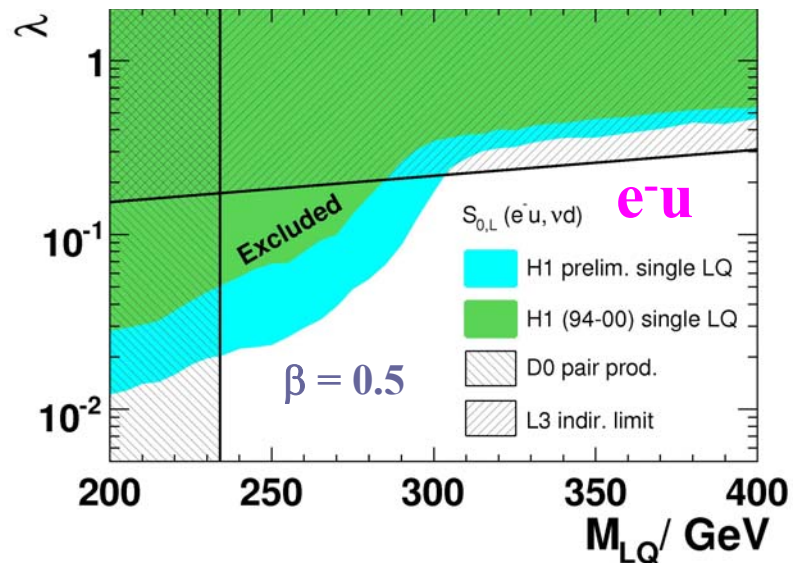
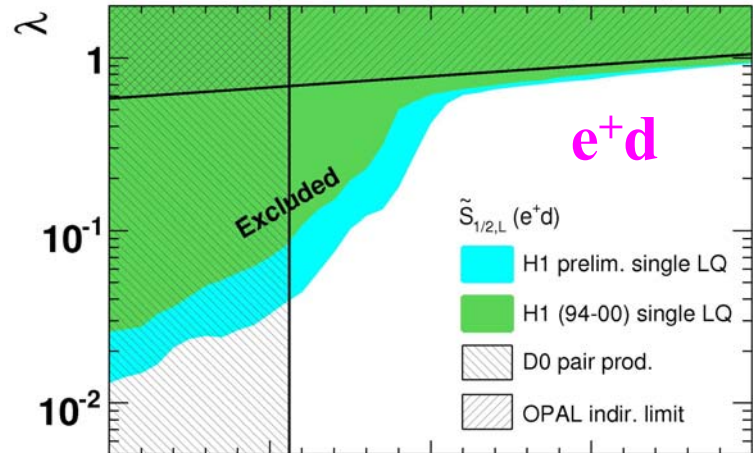
HIGH ENERGY FRONTIER: Leptoquarks



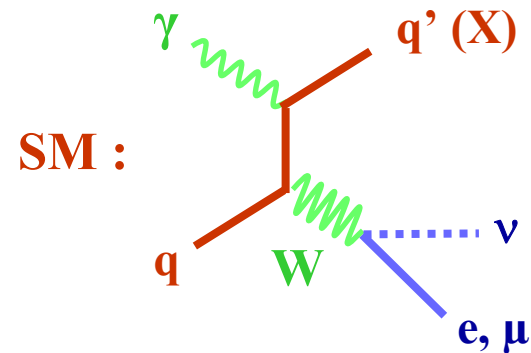
SM :



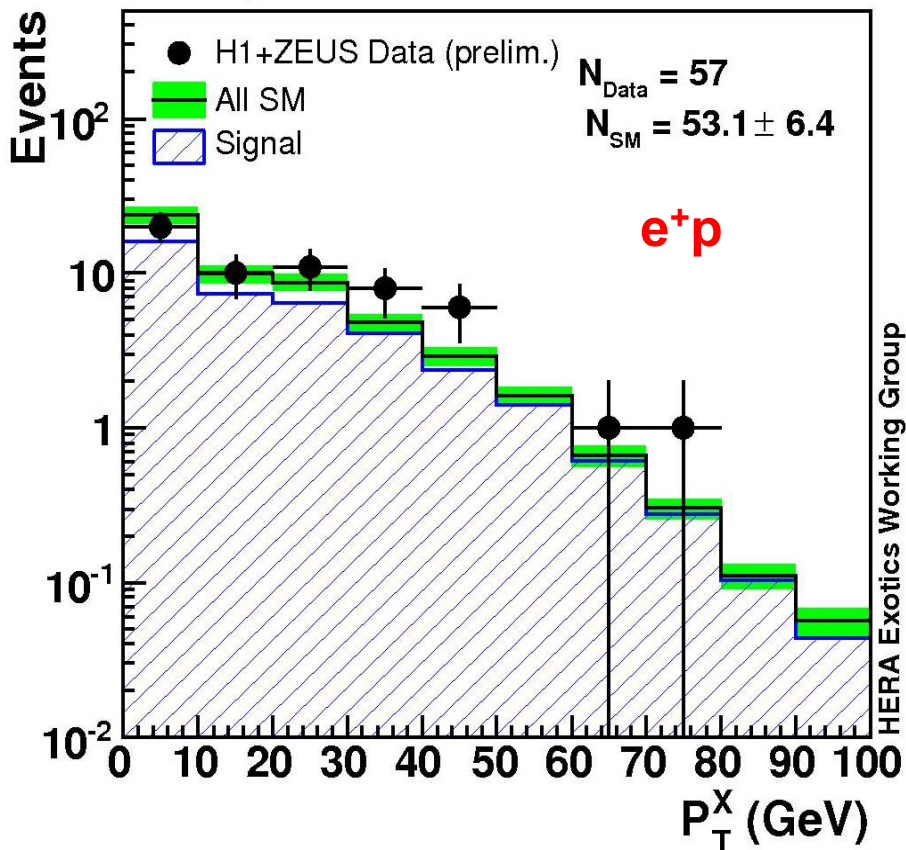
Leptoquark Search, HERA I+II (449 pb⁻¹)



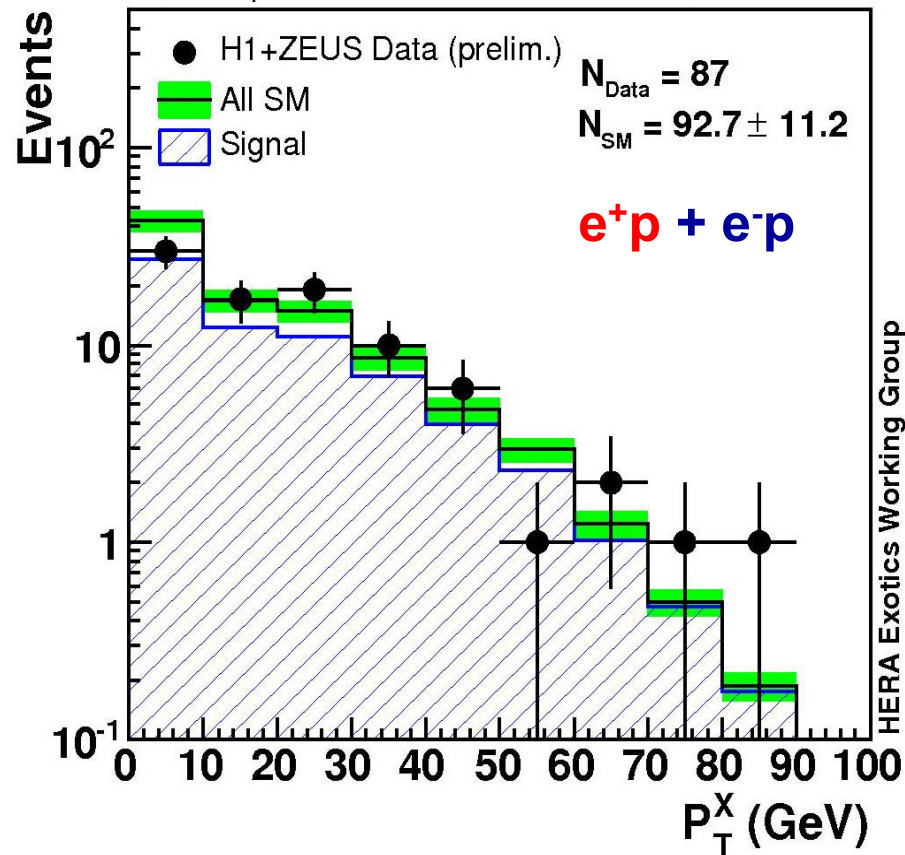
HIGH ENERGY FRONTIER: Isolated Leptons + Missing P_T



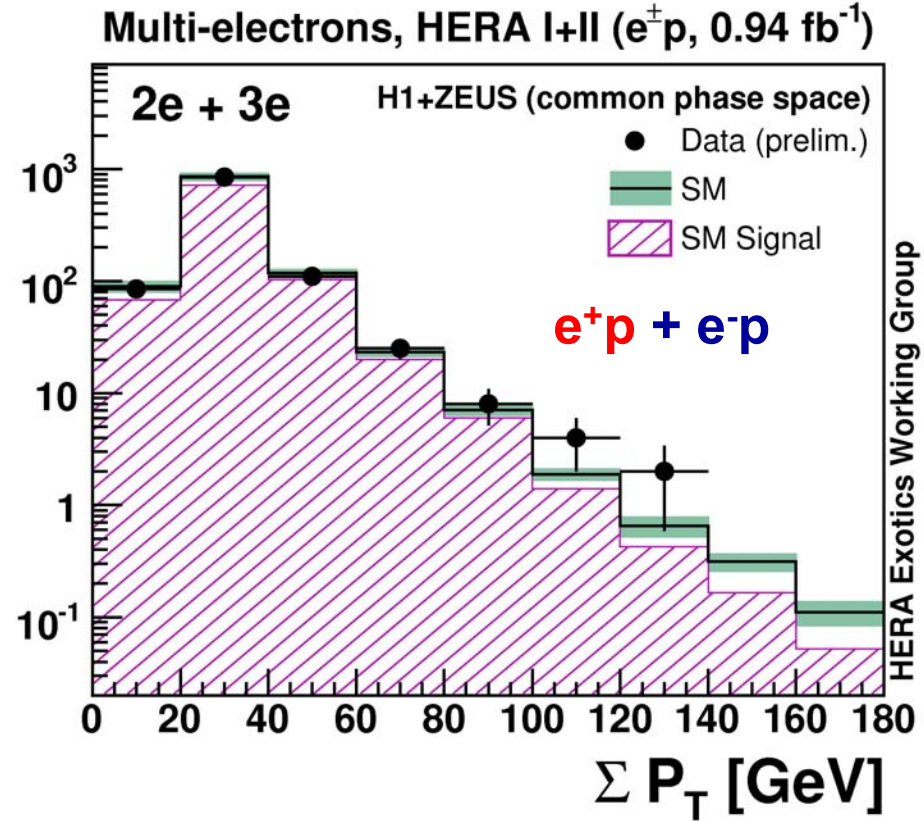
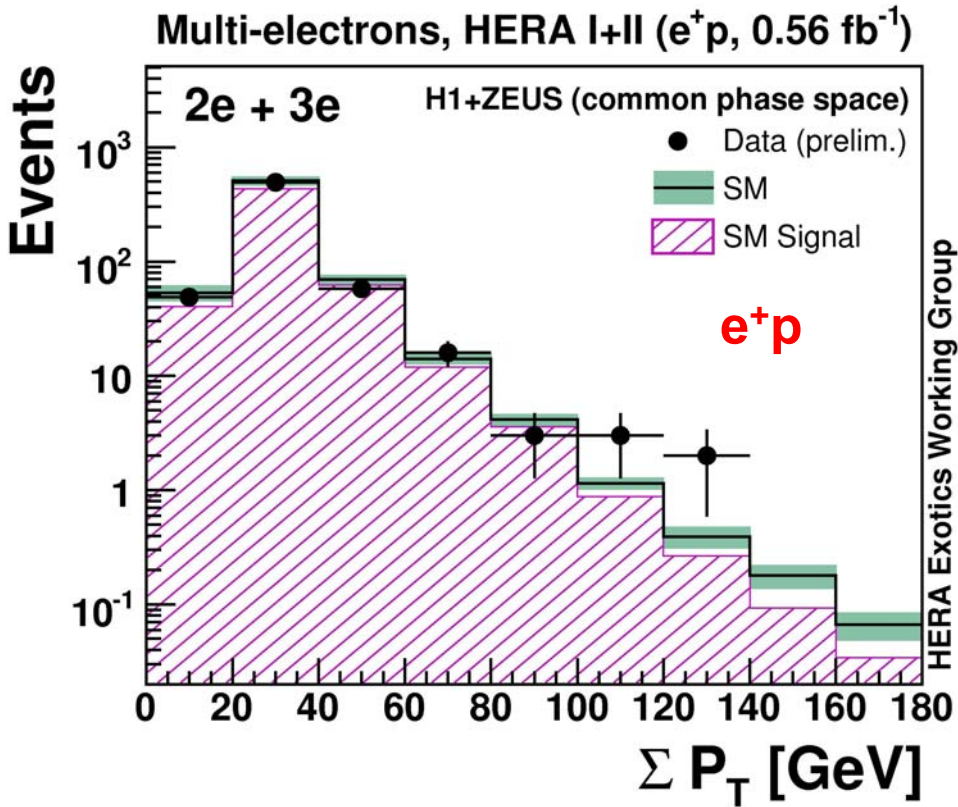
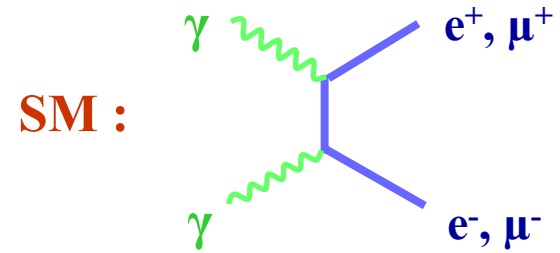
$e, \mu + P_T^{\text{miss}}$ events at HERA I+II (e^+p , 0.58 fb^{-1})



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



HIGH ENERGY FRONTIER: Multi-Leptons

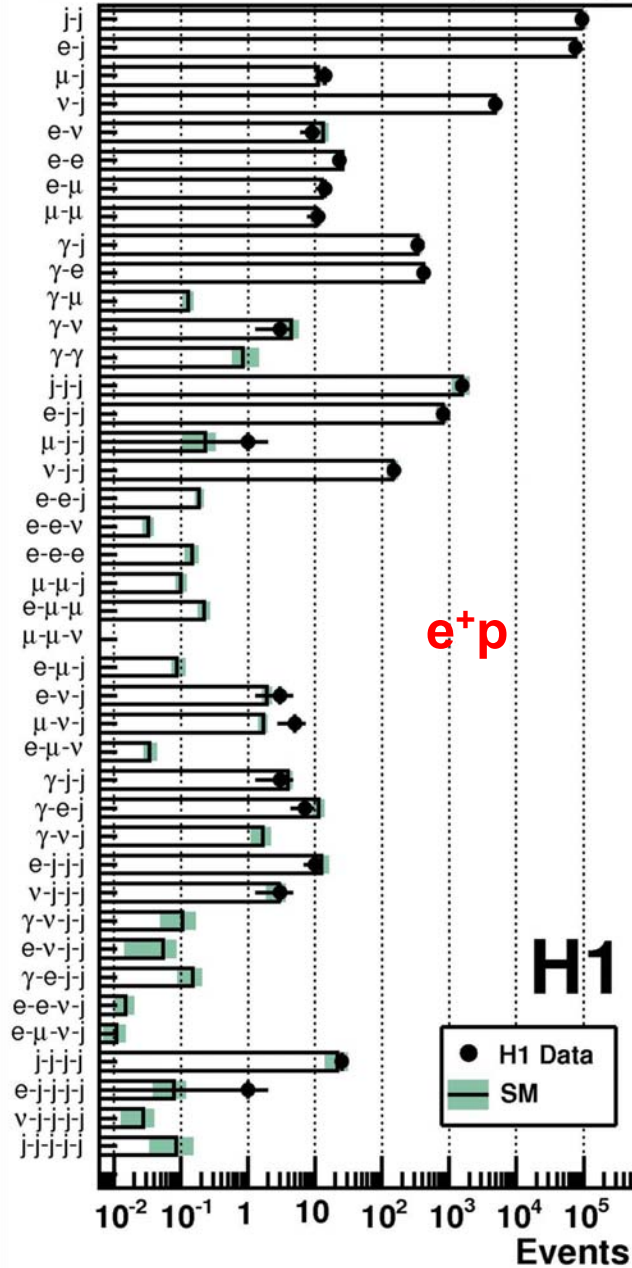


**HIGH ENERGY
FRONTIER:
Generic Search**

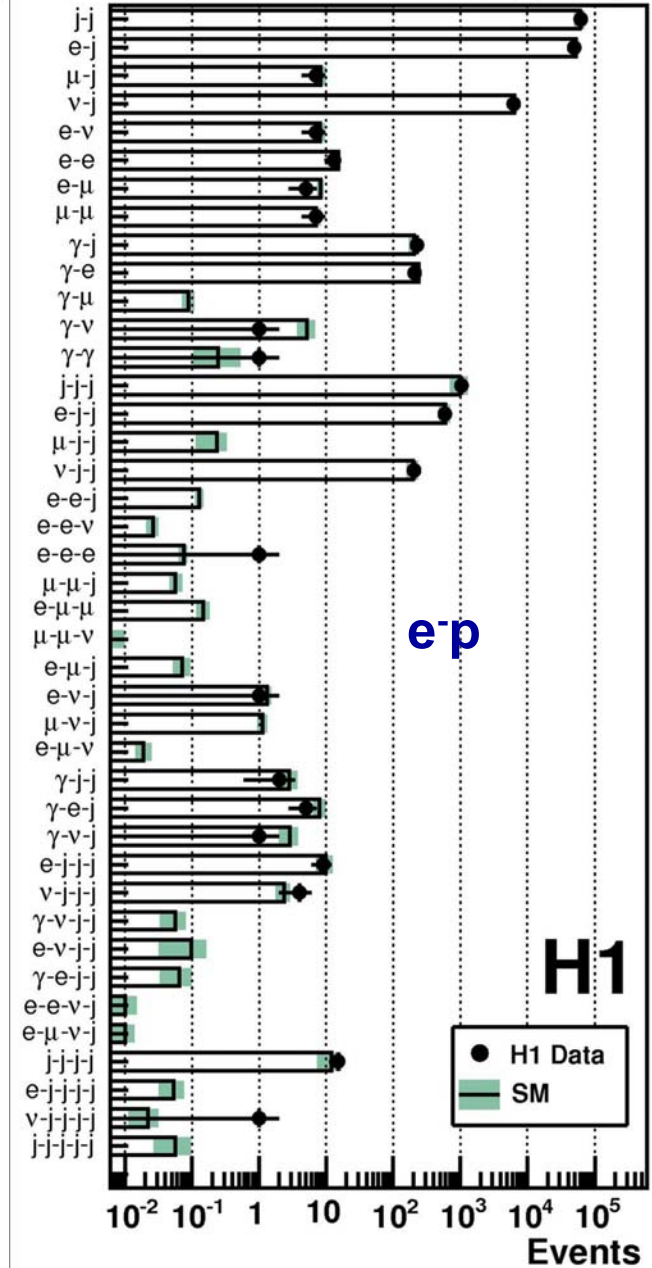
**Multi-body
topologies
 $P_T^i > 20 \text{ GeV}$**

SM OK

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

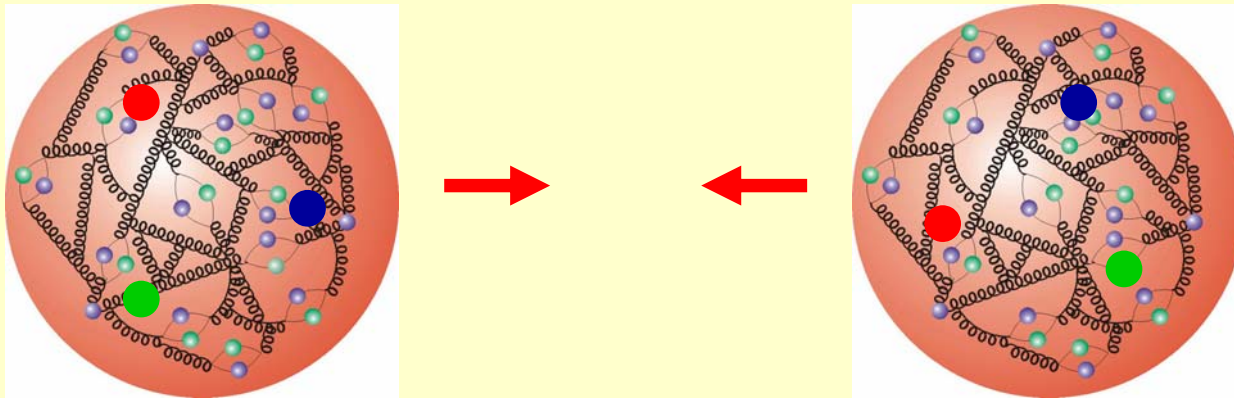


H1 General Search at HERA (e^-p , 178 pb^{-1})



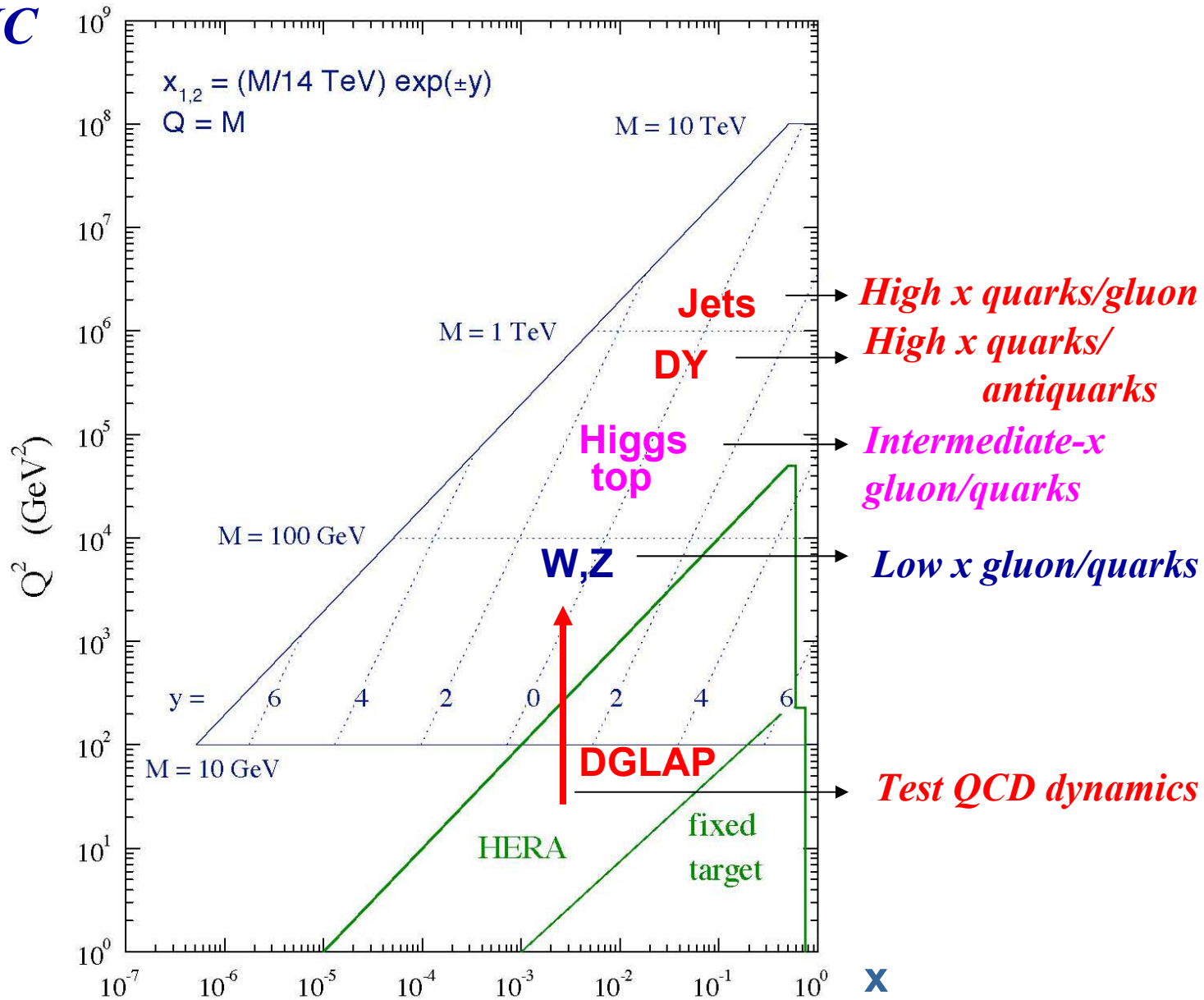
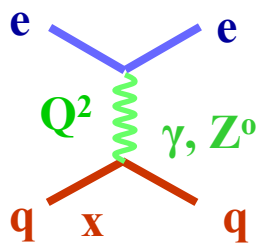
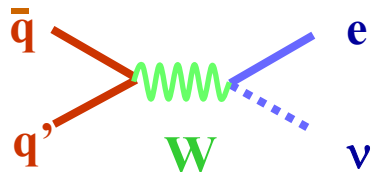
PRECISION MEASUREMENTS

LHC needs

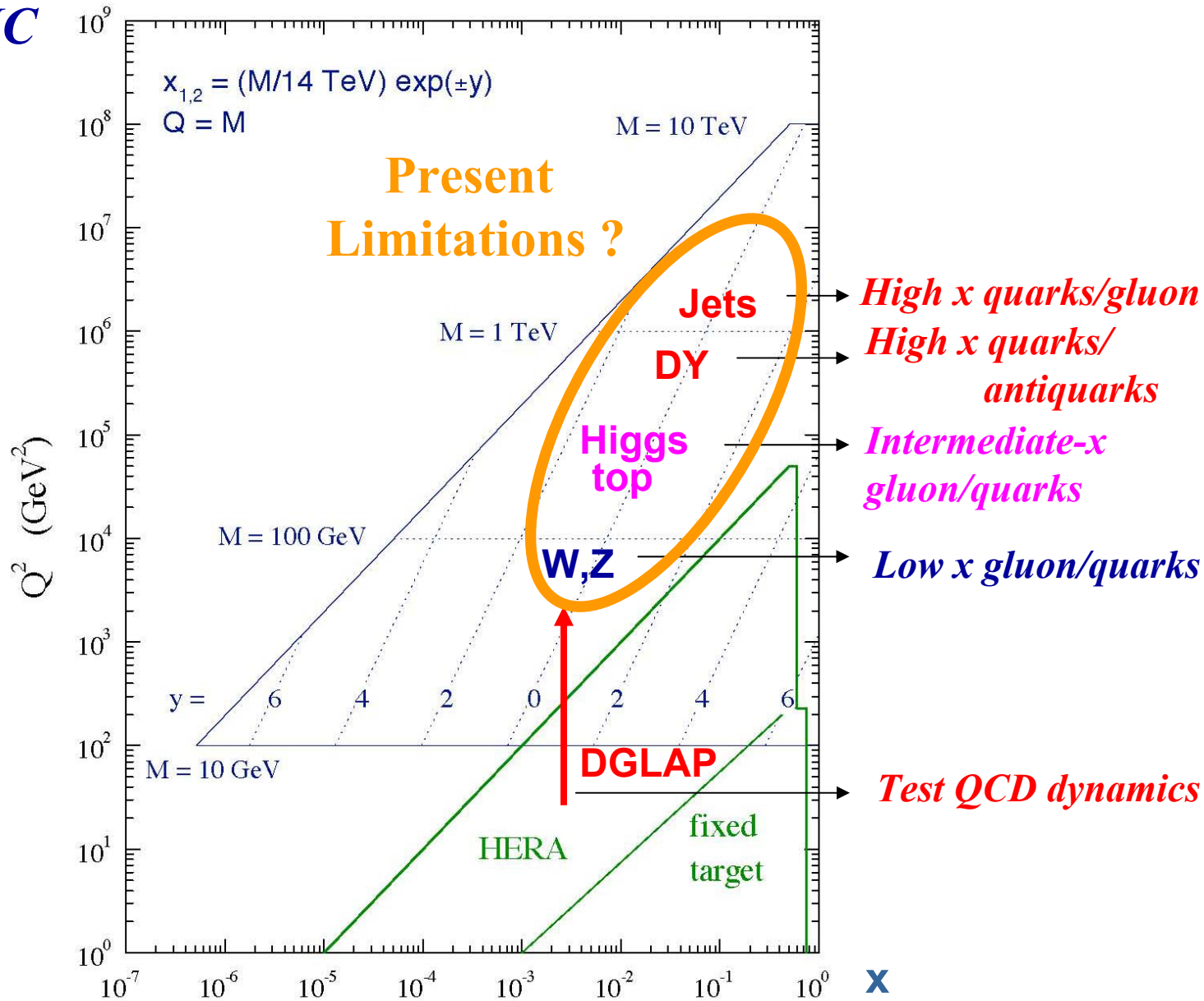
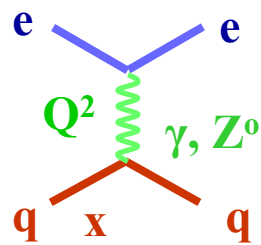
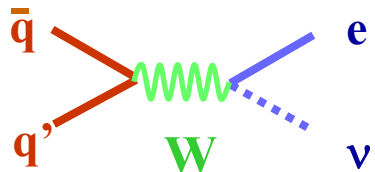


(plots from contributors to the PDF4LHC workshop)

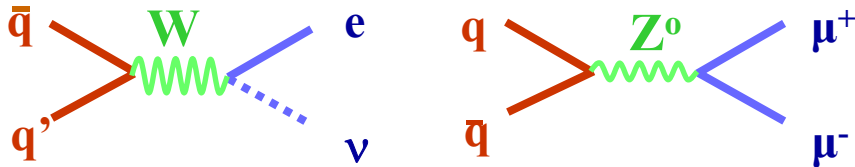
HERA ↔ LHC kinematics



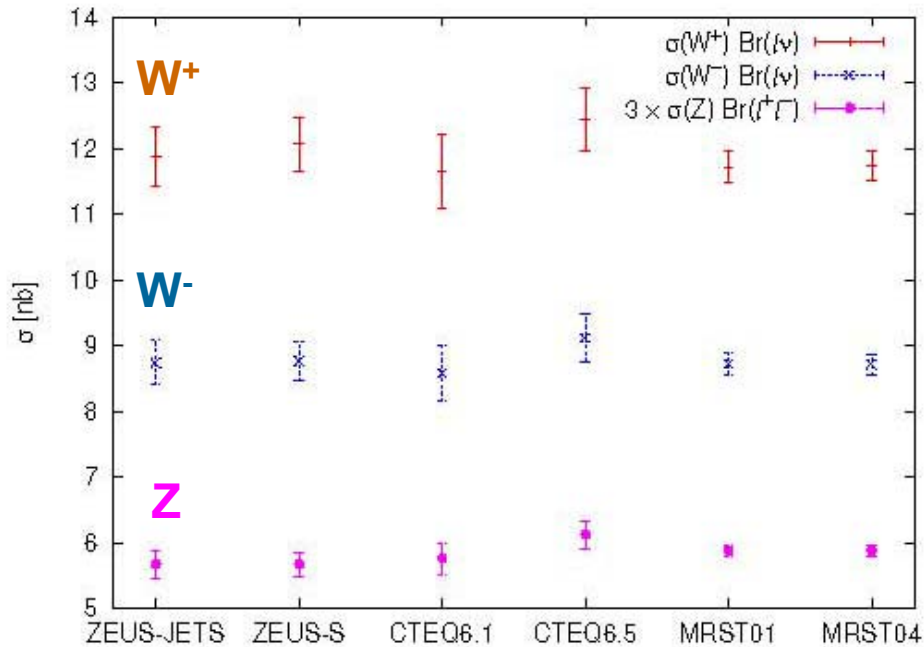
HERA ↔ LHC kinematics



LHC needs: W/Z production

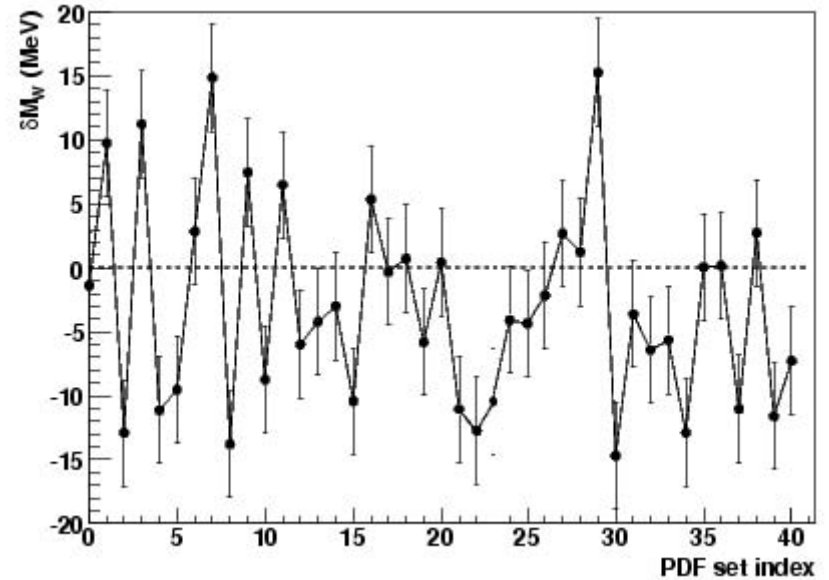


W/Z cross sections



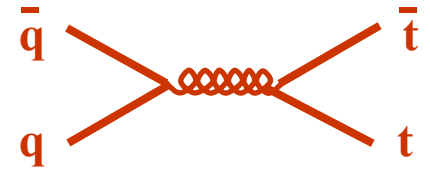
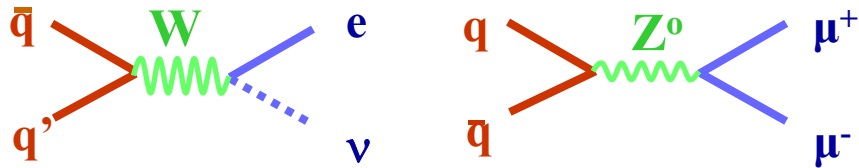
σ variations from PDF's at the level of ~5%

W mass determination

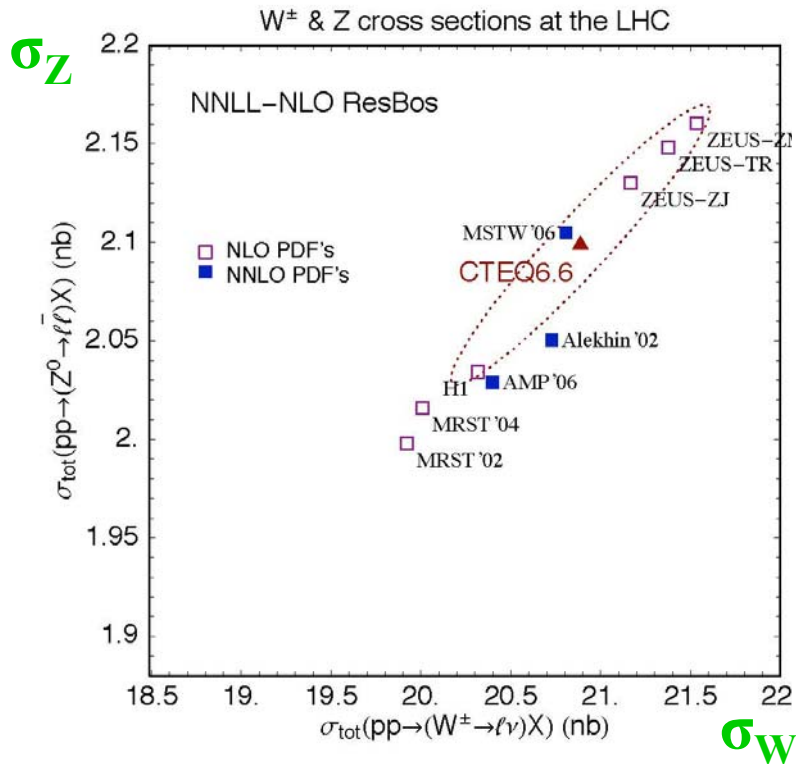


Spread of ~25 MeV
in M_T mass fit
due to PDF uncertainties
in rapidity distribution
(goal is ~1 MeV)

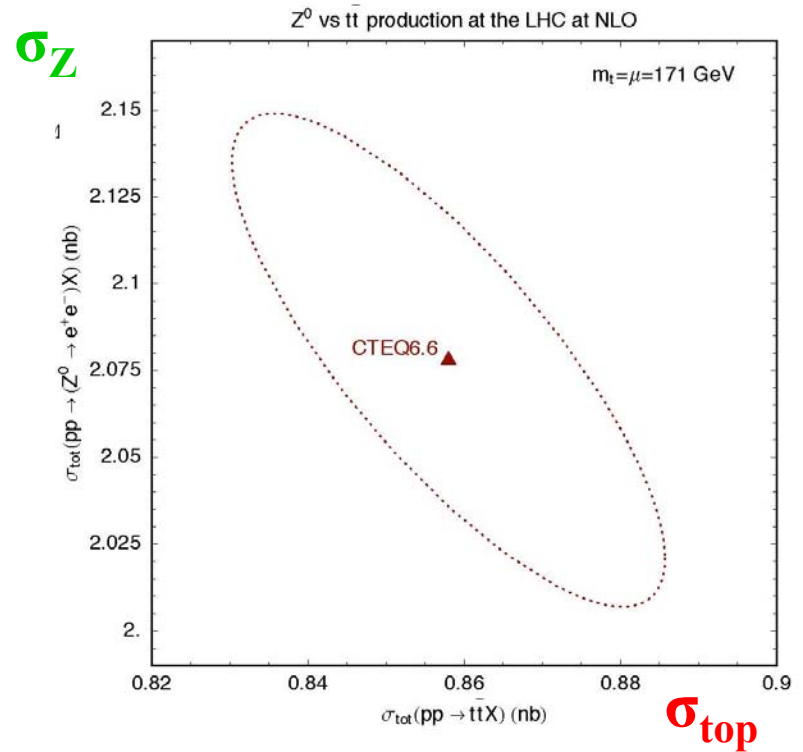
LHC needs: $W \leftrightarrow Z \leftrightarrow \text{top PDF correlations}$



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

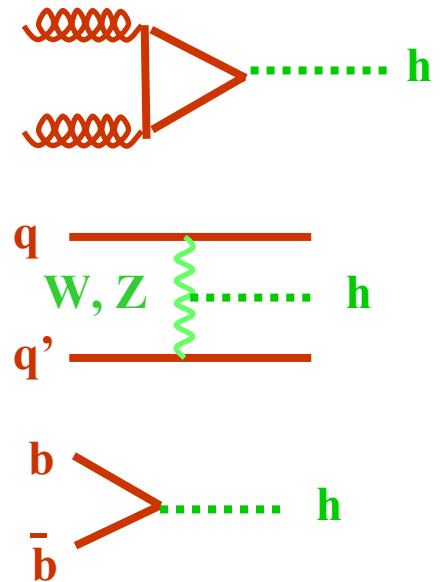
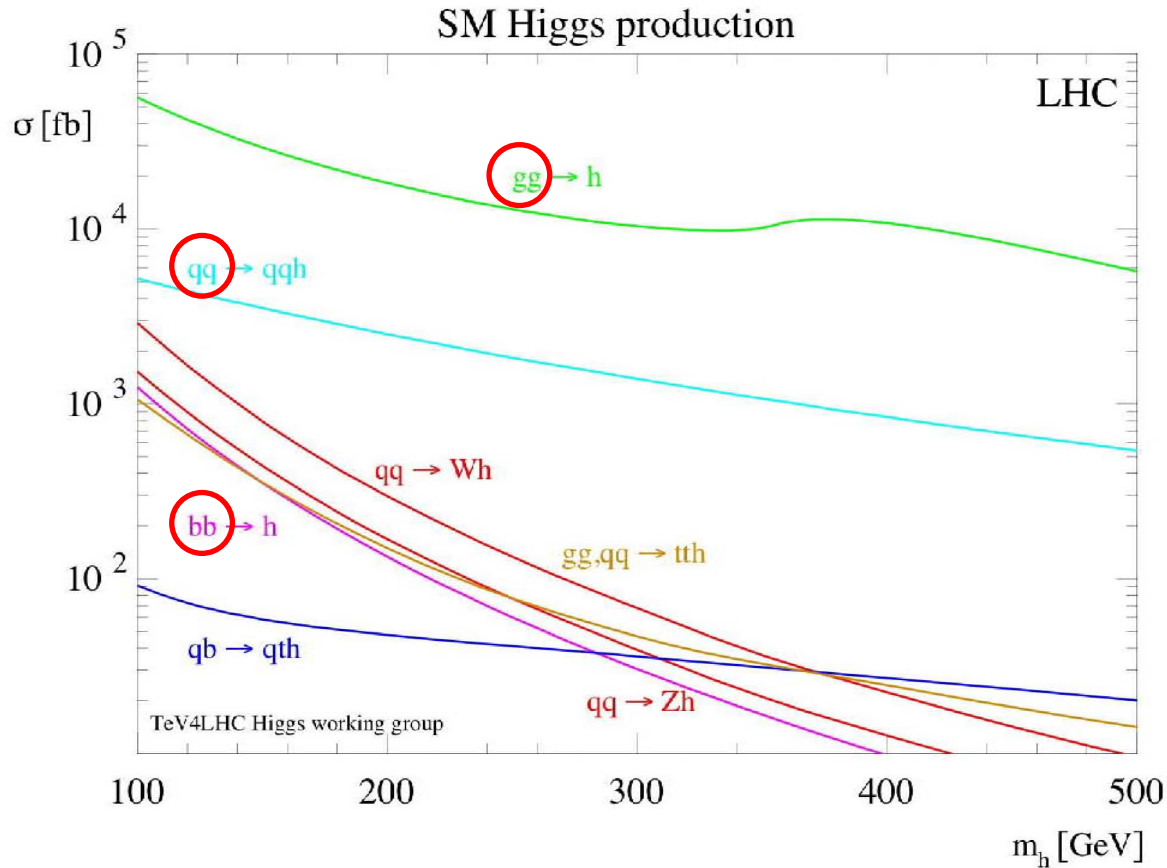


W and Z strongly correlated

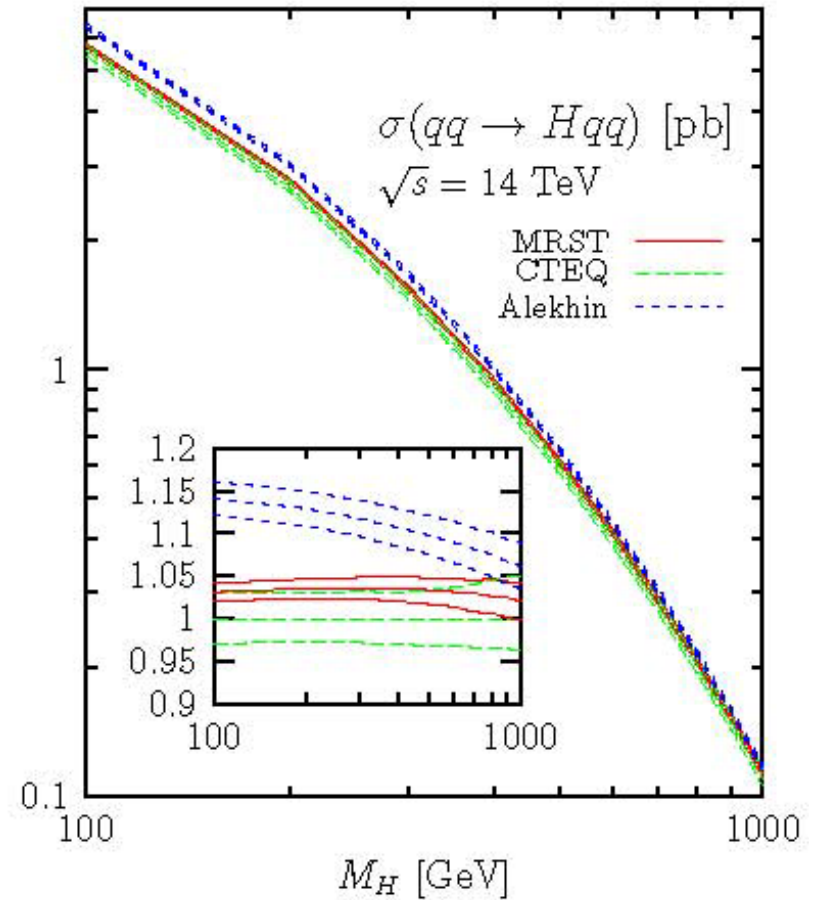
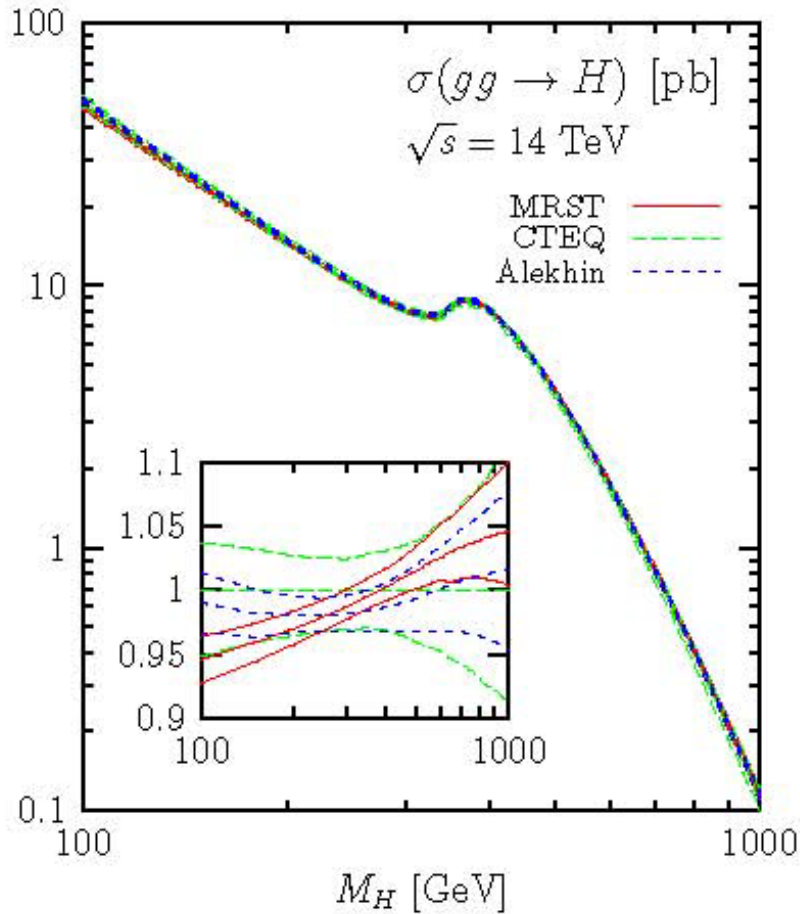
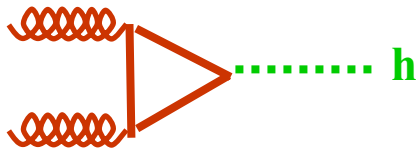


Top uncertainty ~5% anti-correlated with Z

LHC needs: SM Higgs production

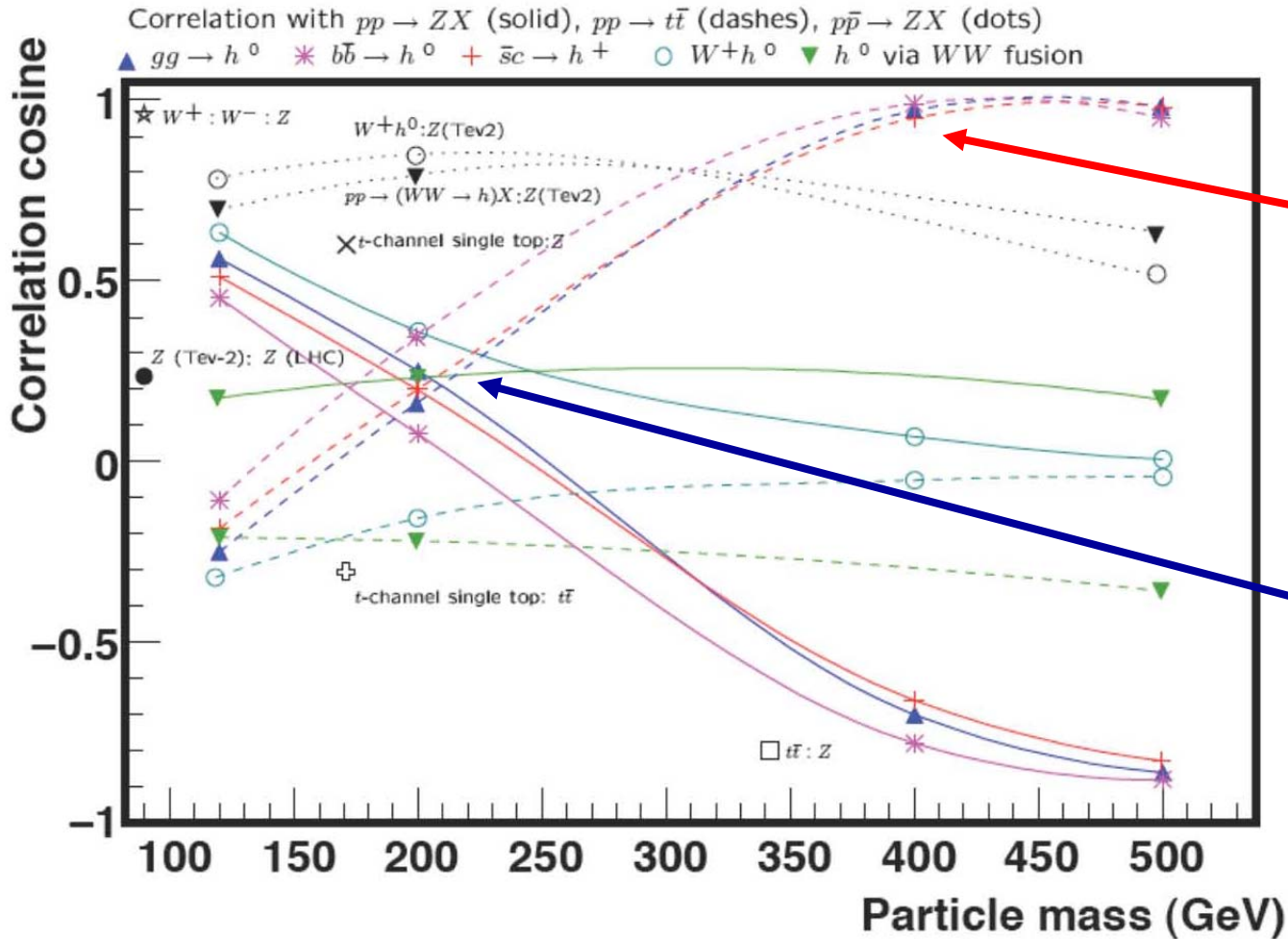


- Sensitive mainly to gluon and light quarks at low or intermediate x
- Beauty PDF contributes mainly at low mass for a SM Higgs



Higgs cross-section PDF uncertainty ~5-10 %

LHC needs: PDF cross-sections correlations

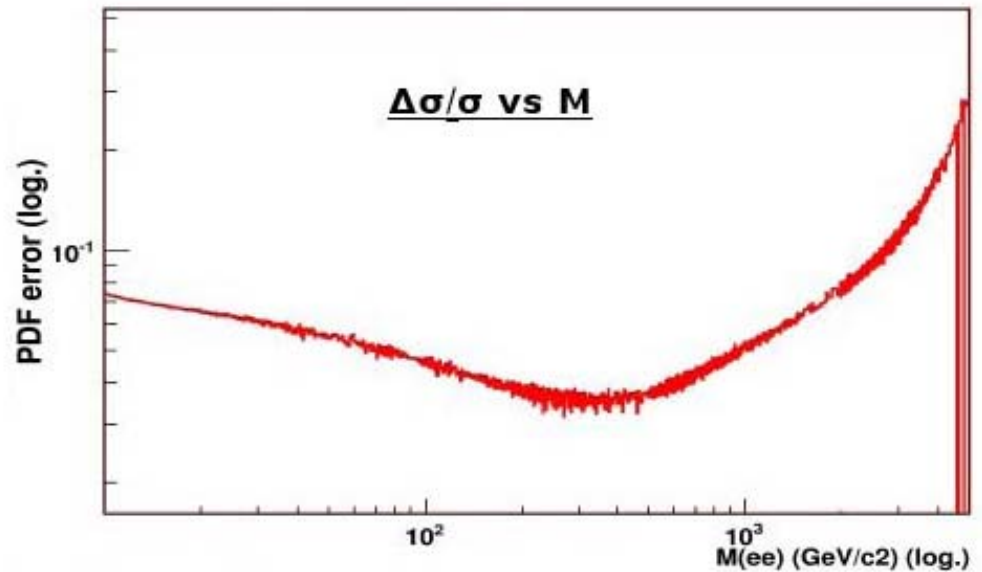
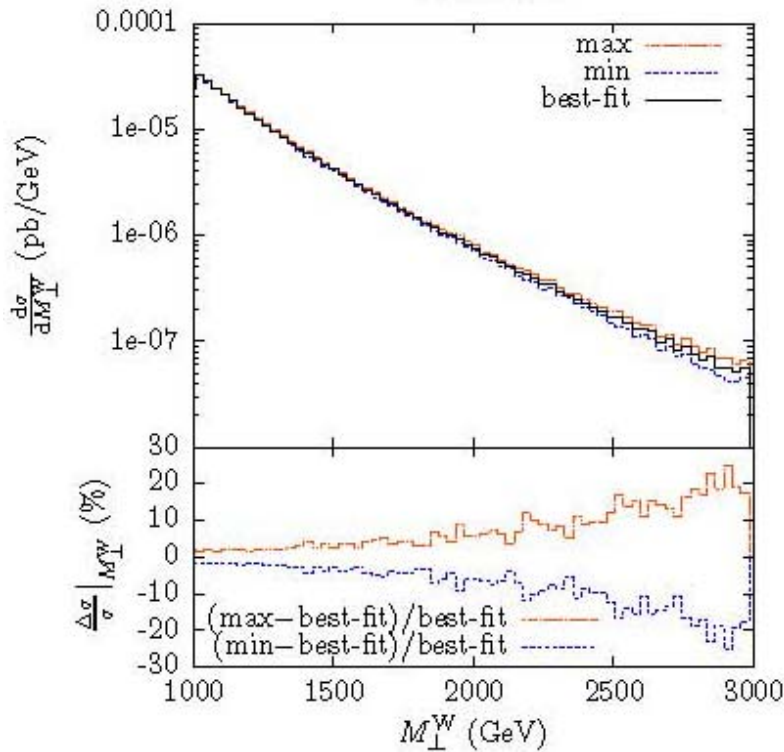
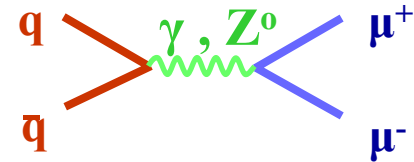
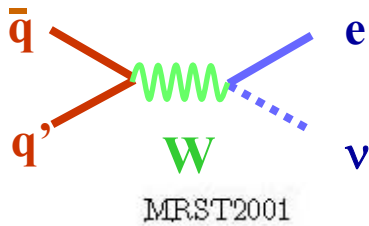


Heavy Higgs
correlated
with top

Light Higgs
correlated
with W/Z

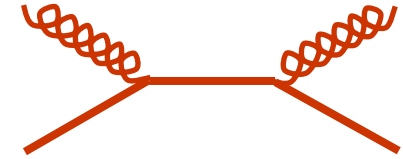
→ Best Standard Candle to which to renormalise may depend on mass

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

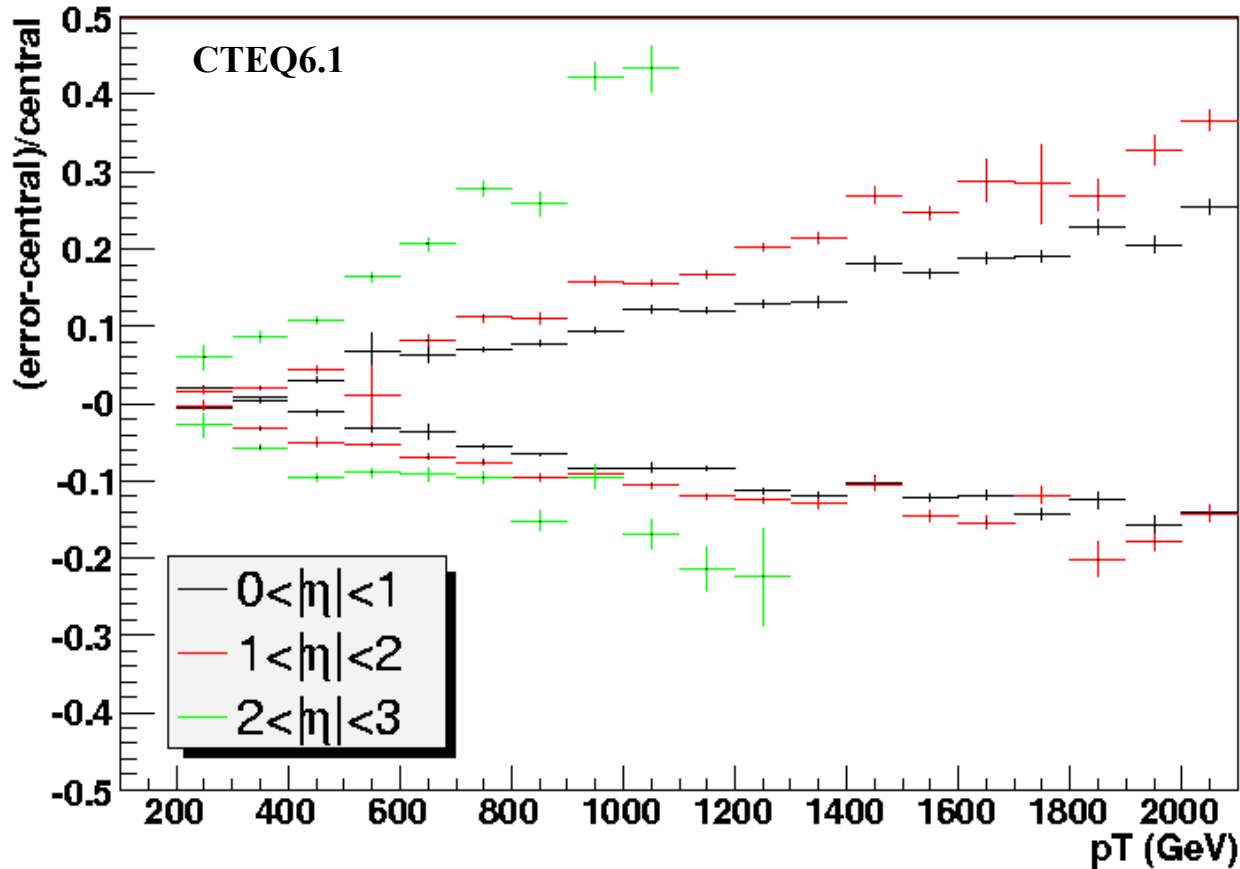


Uncertainty varies from ~5% to ~20% at high mass

LHC needs: high- P_T jets cross-section

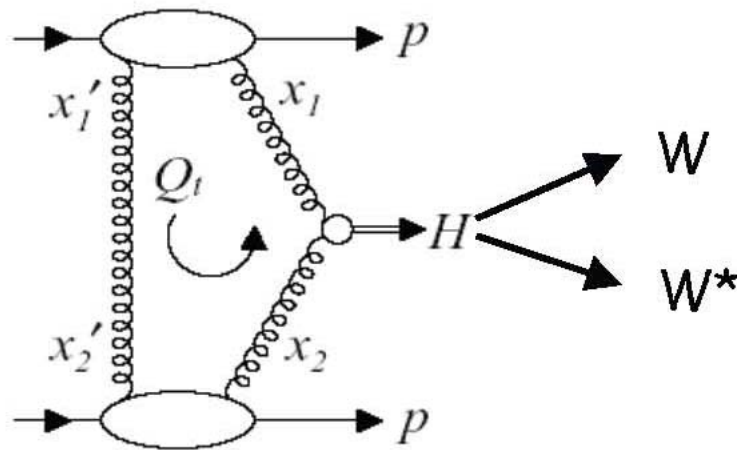


PDF Errors on Inclusive Jet Cross-Section

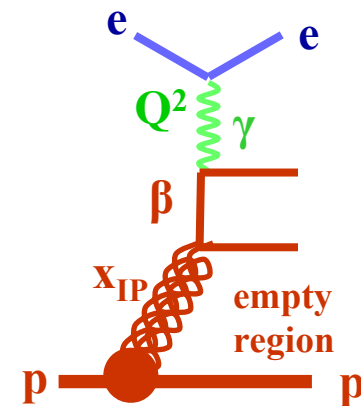


Uncertainty up to ~30% at high P_T

LHC needs: Diffractive Higgs production



**Cross-section depends
on 2-gluon GPD's**

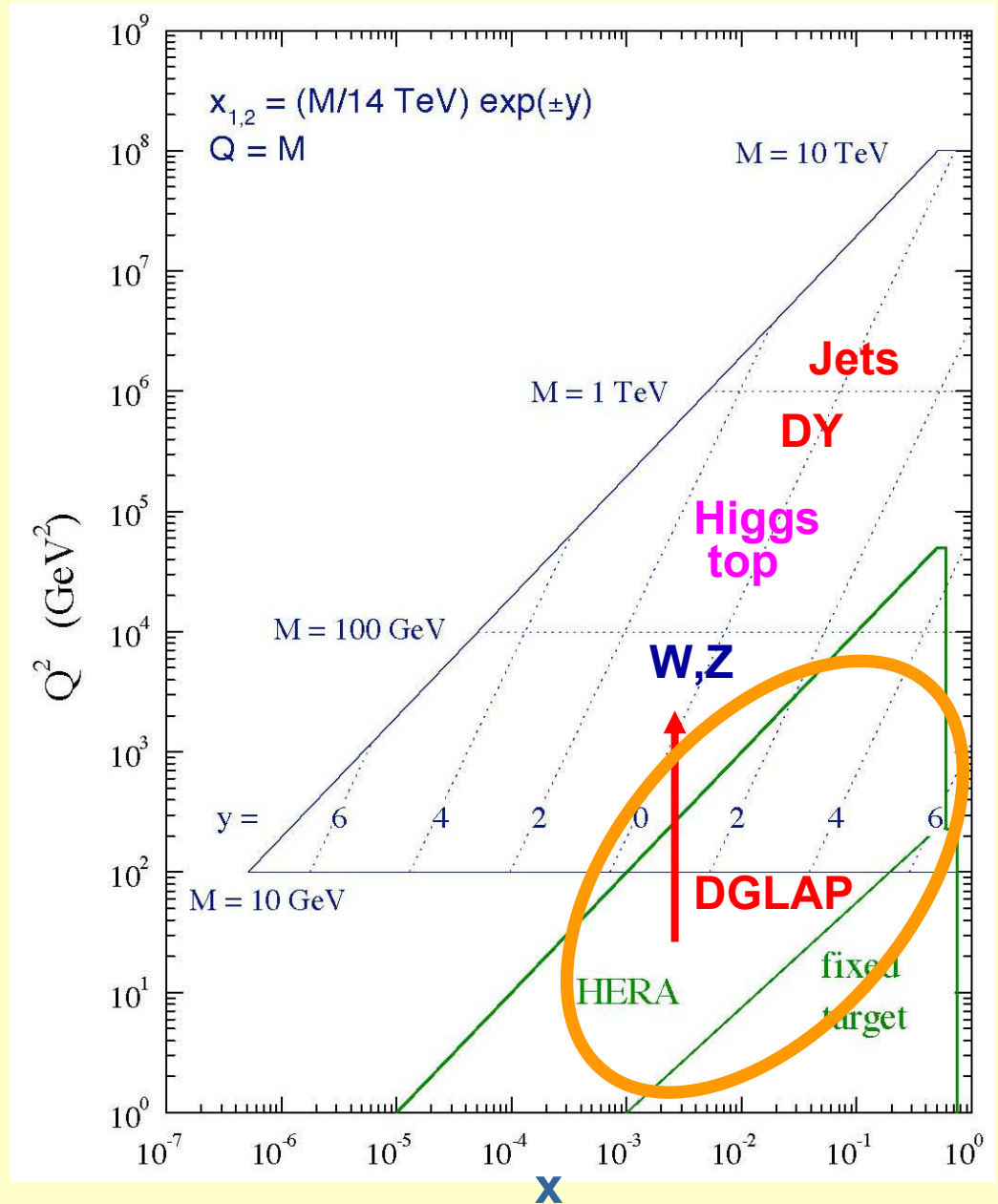


**Structure of inclusive
colorless exchange
also necessary for
background (high β)**

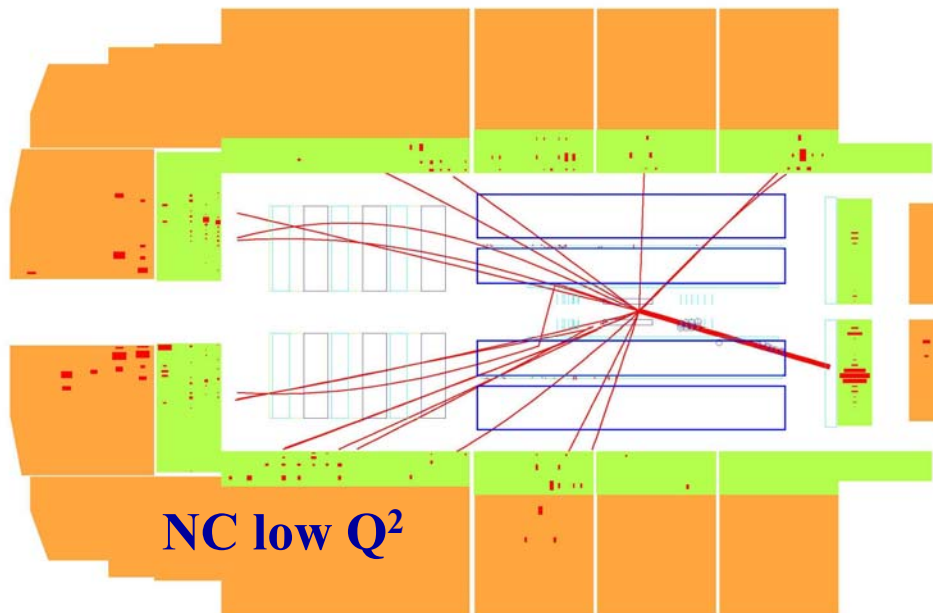
PRECISION MEASUREMENTS

Proton structure and dynamics

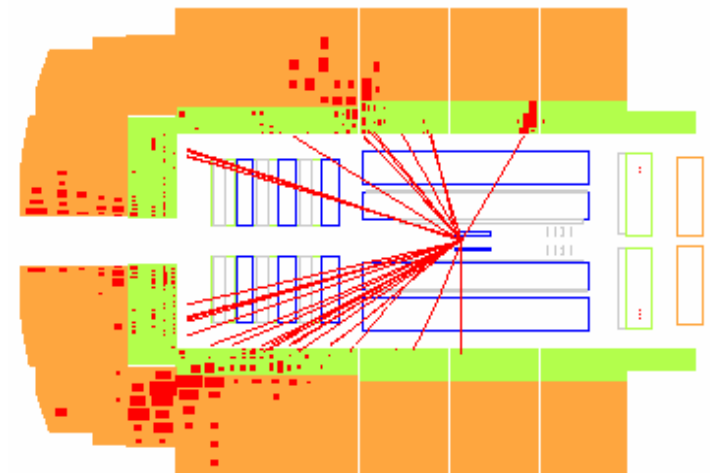
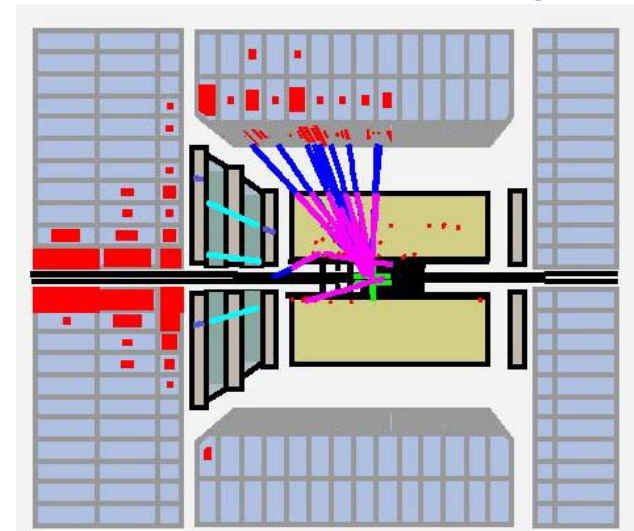
Latest HERA results



*Typical interactions
for
precision measurements*



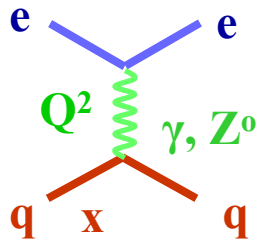
CC intermediate Q^2



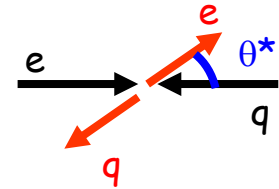
NC intermediate Q^2



MEASURING THE PROTON STRUCTURE



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



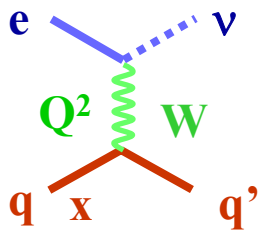
$$y = Q^2/sx = (1 - \cos\theta^*)/2$$

$$= \tilde{F}_2 - \frac{y^2}{Y_+} \tilde{F}_L \mp \frac{Y_-}{Y_+} x \tilde{F}_3 \quad Y_{\pm} = 1 \pm (1 - y)^2$$

valence + sea quarks

gluon

valence quarks

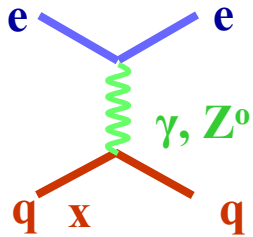


$$\sigma_{CC}(e^+ p) \propto x[(1 - y^2)(d + s) + (\bar{u} + \bar{c})] \quad \times (1 + P_e)$$

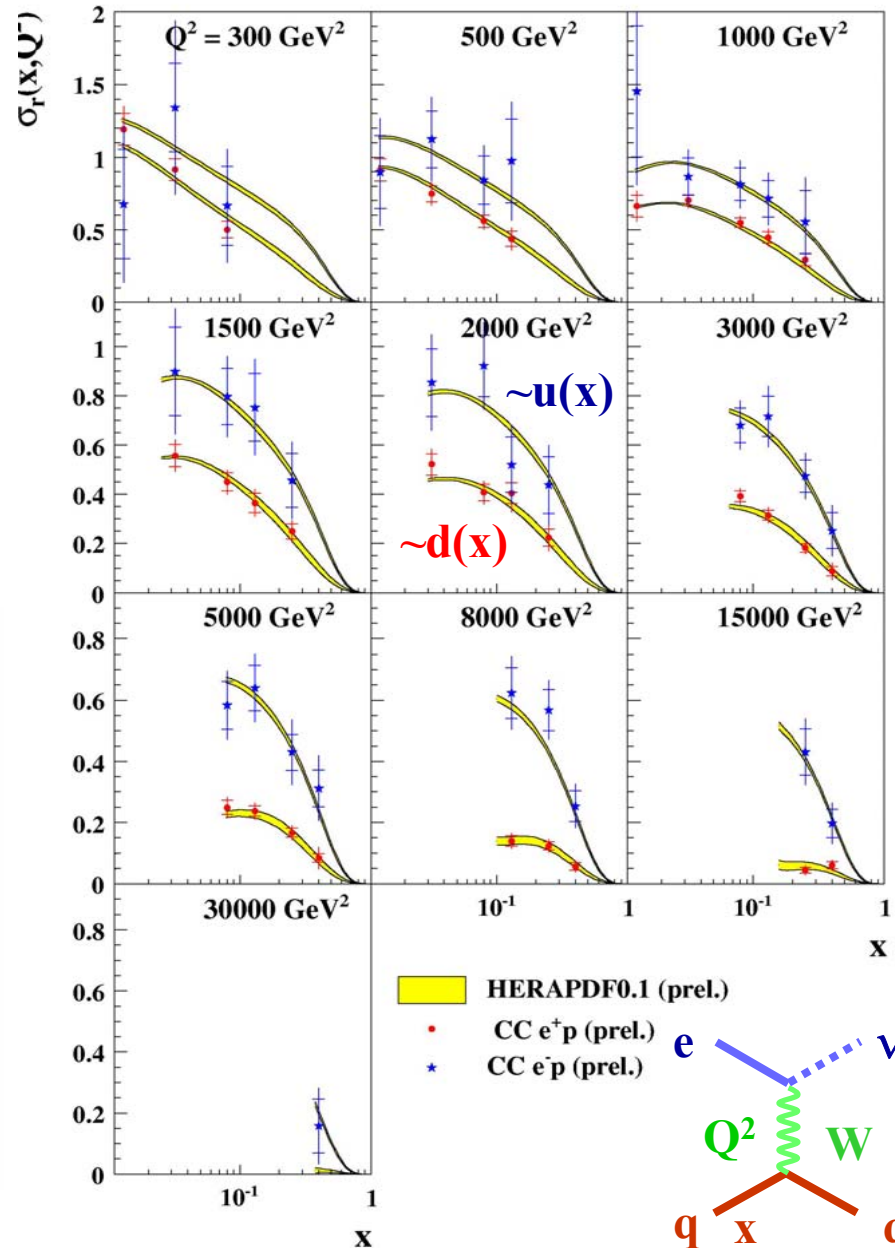
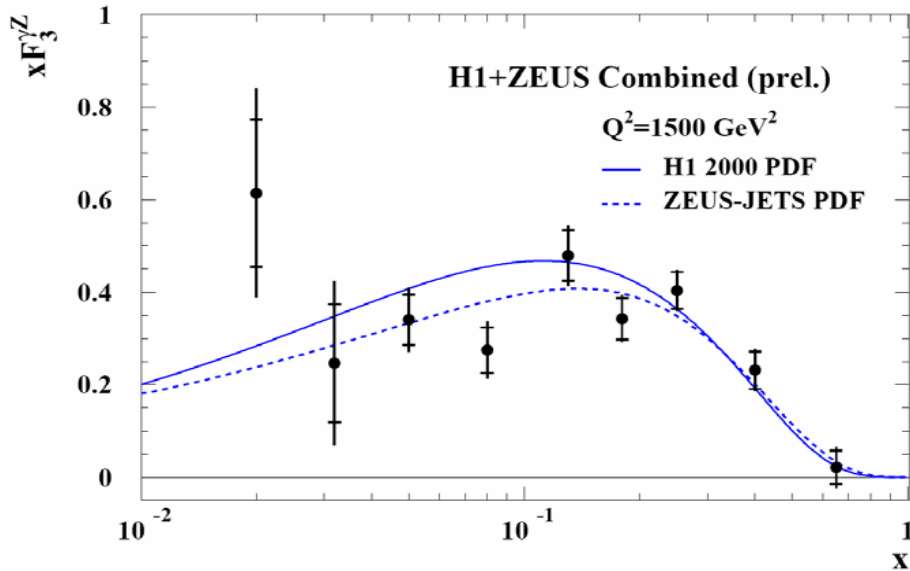
$$\sigma_{CC}(e^- p) \propto x[(u + c) + (1 - y^2)(\bar{d} + \bar{s})] \quad \times (1 - P_e)$$

PROTON STRUCTURE

valence quarks



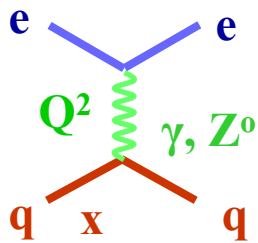
$$xF_3 \sim \sigma(e^-) - \sigma(e^+) \sim (2u_v + d_v)$$



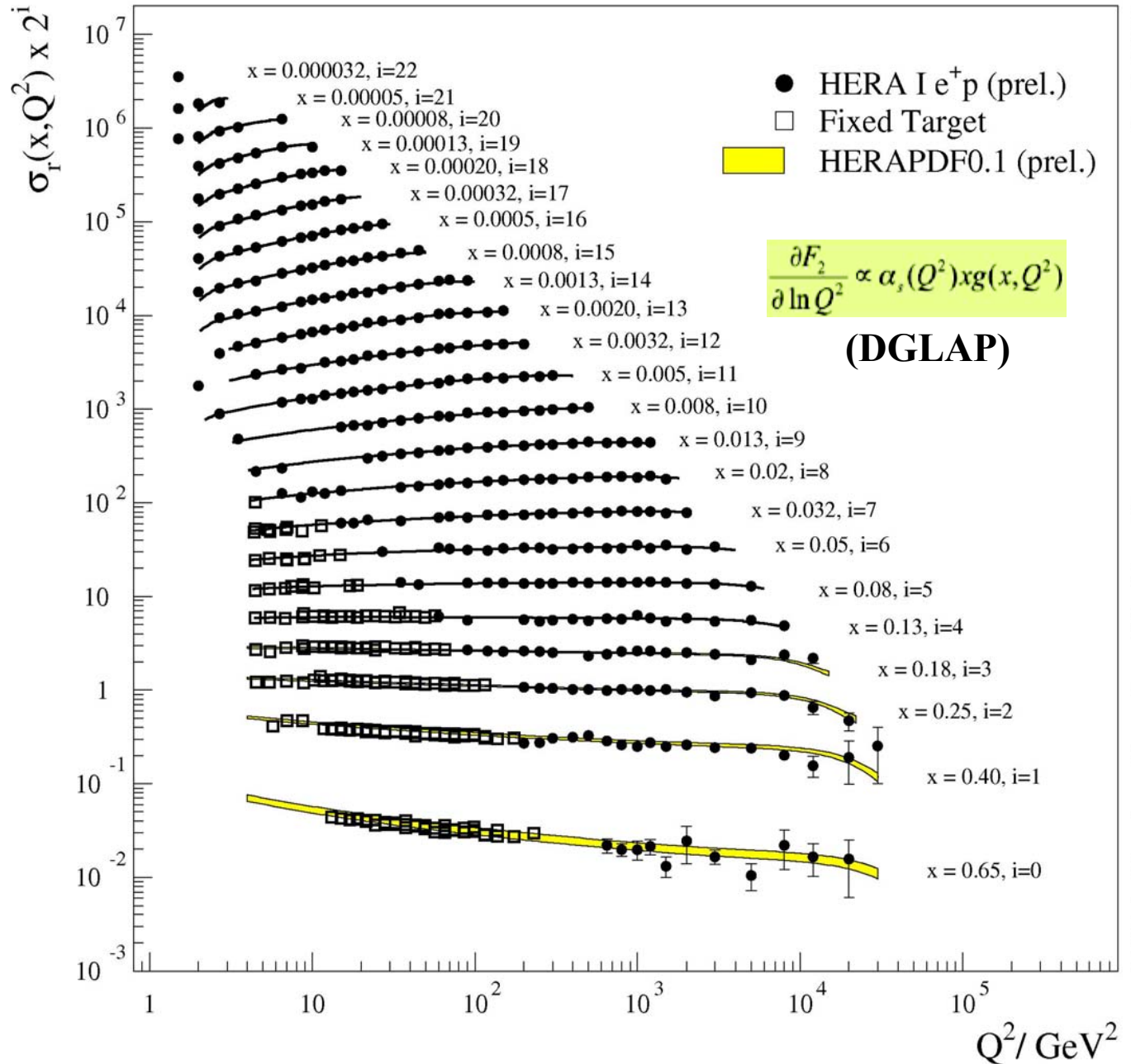
PROTON STRUCTURE

valence + sea
quarks

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



DGLAP works
on a very large
phase space !



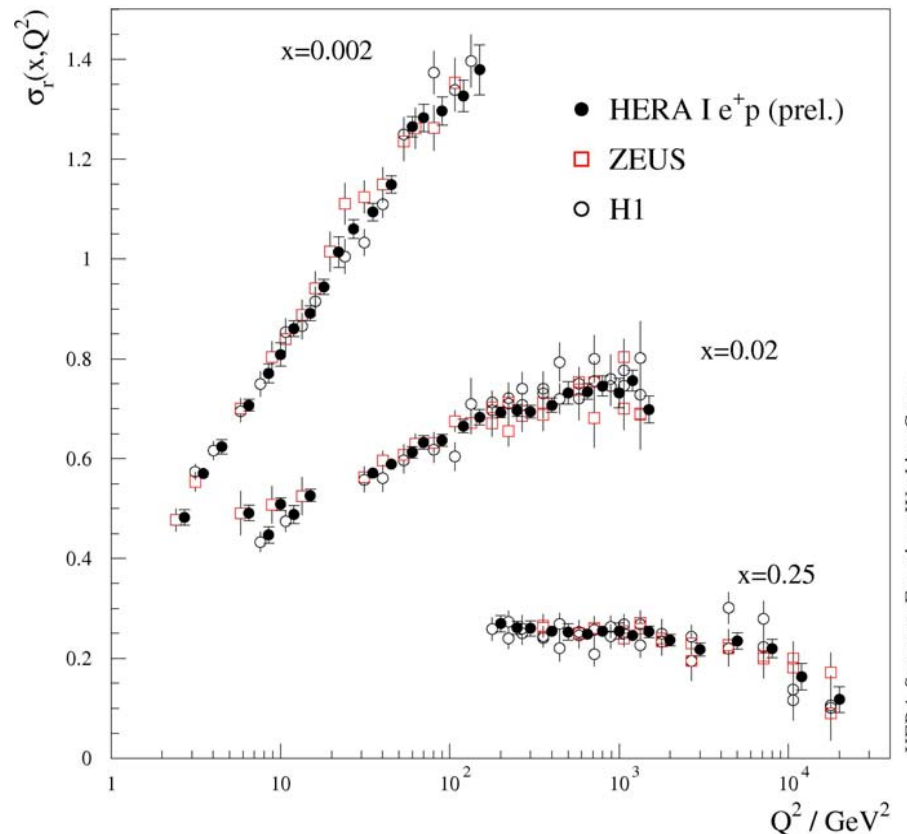
PROTON STRUCTURE: the power of combining

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

**Cross-calibration
of both experiments**

**systematic
uncertainties
reduced together
with statistical errors**

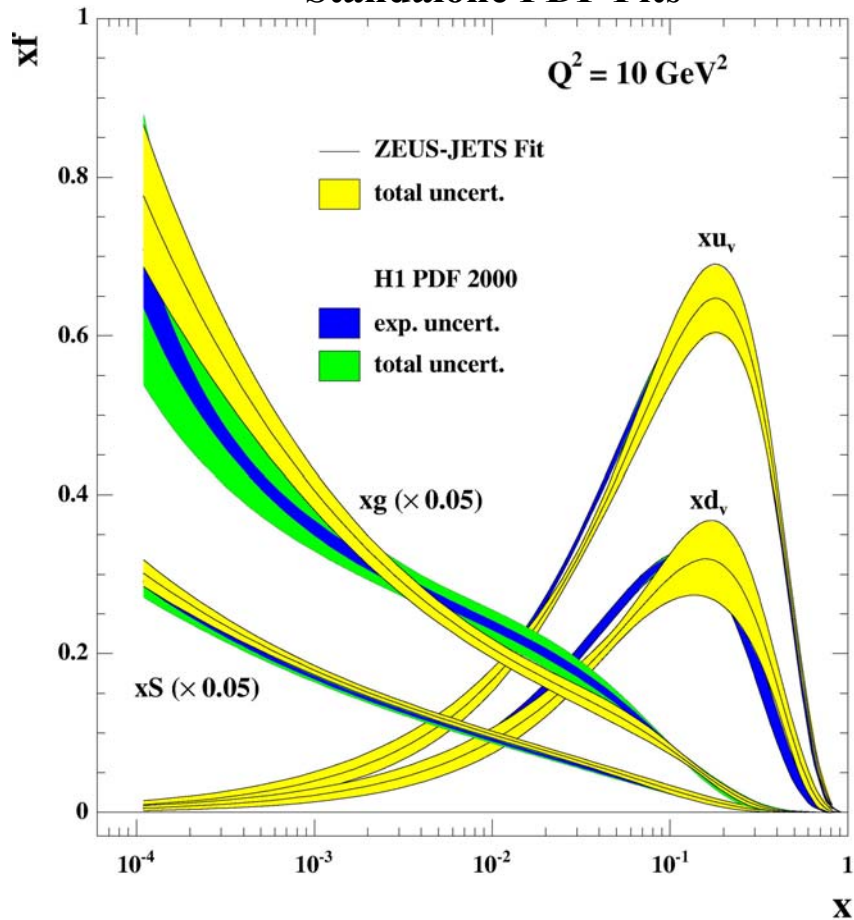
HERA I e^+p Neutral Current Scattering - H1 and ZEUS



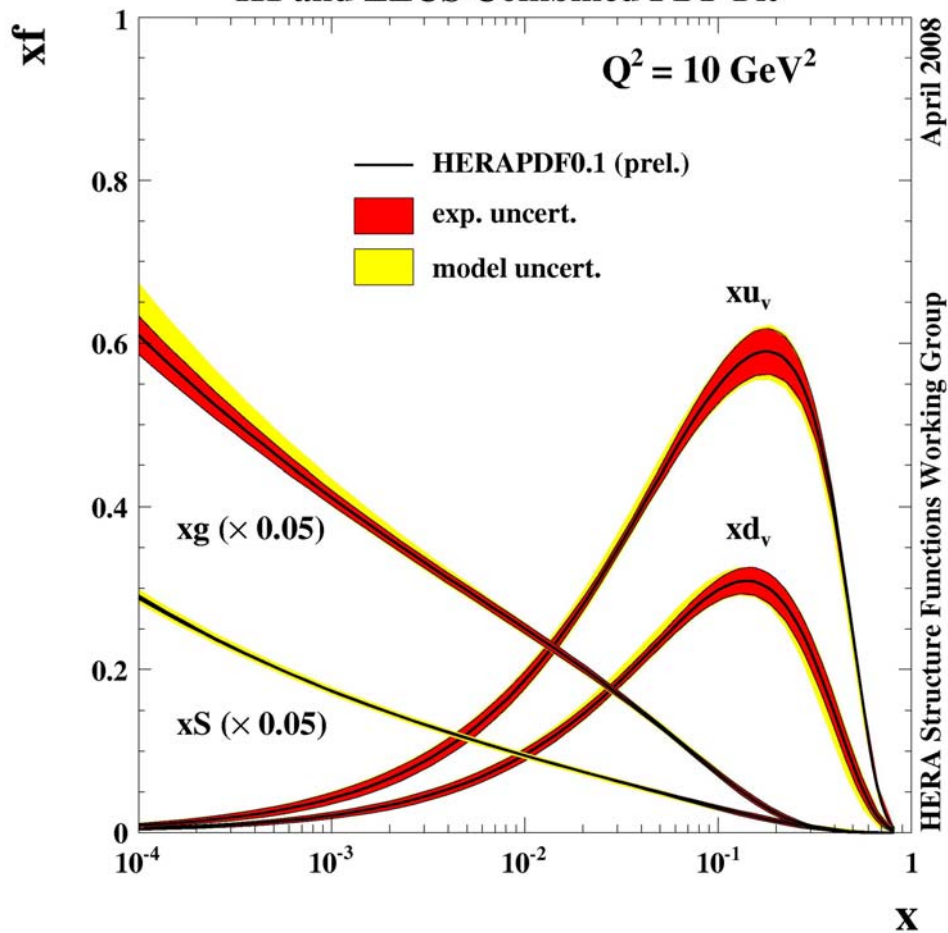
Extracting the essence of Structure Functions

common PDF Fit on HERA I combined data

Standalone PDF Fits

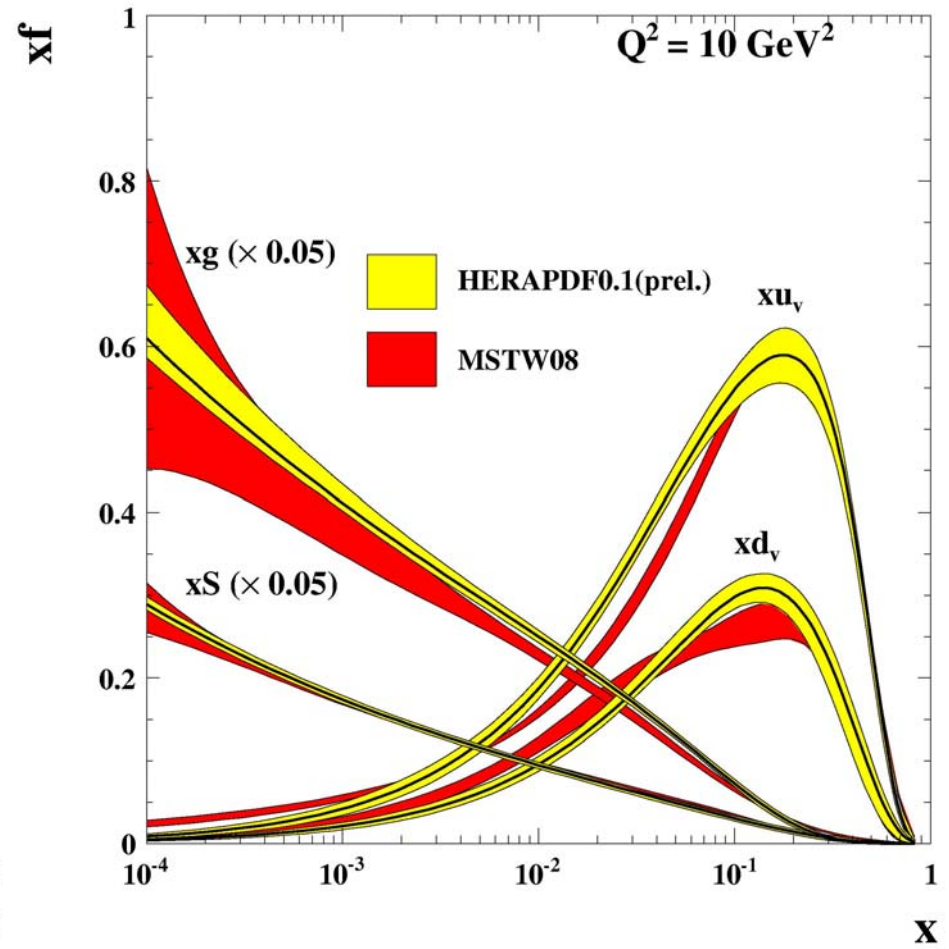
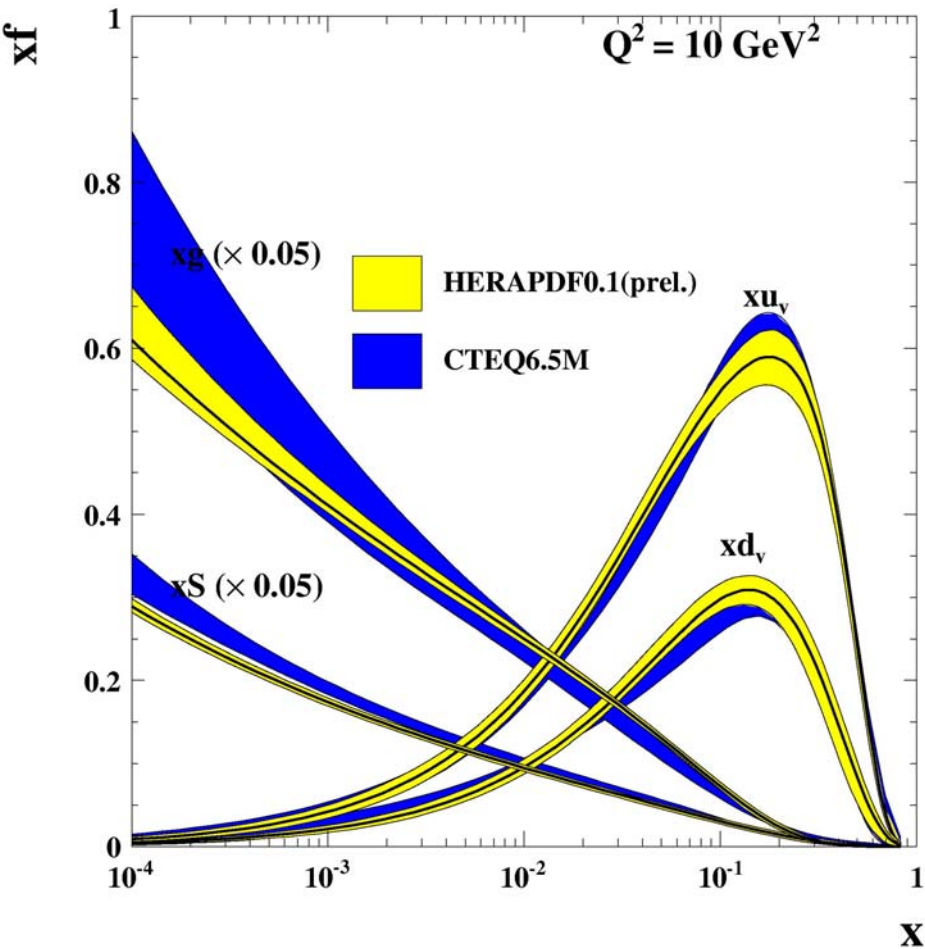


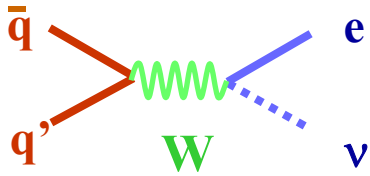
H1 and ZEUS Combined PDF Fit



HERAPDF0.1 *versus* CTEQ and MSTW

uncertainty on low-x gluon and sea strongly reduced

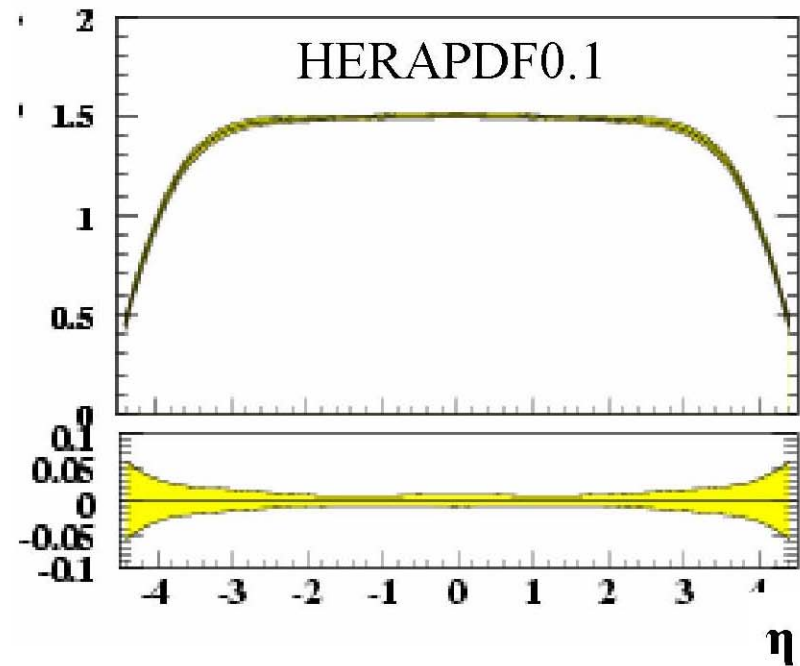
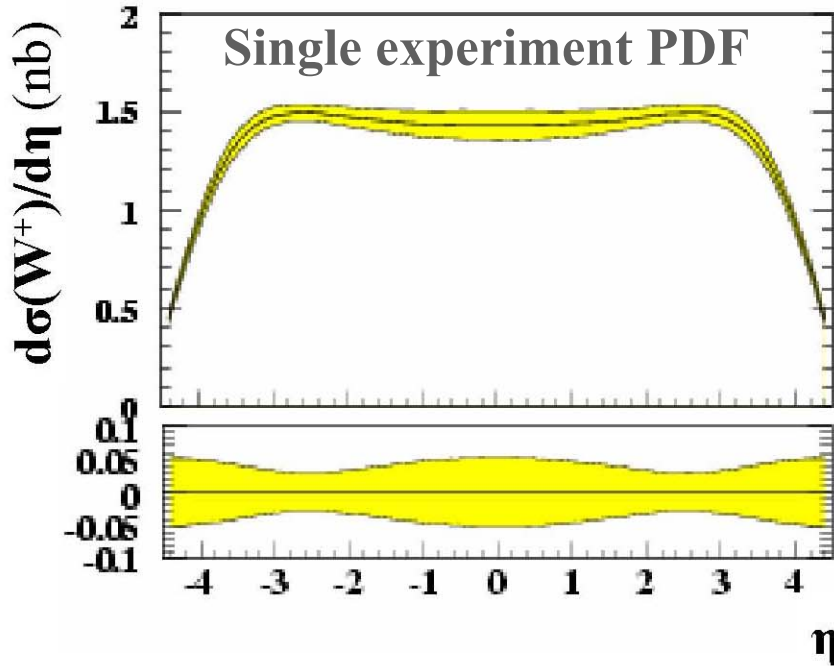




HERAPDF0.1 *impact on LHC*

the example of W production

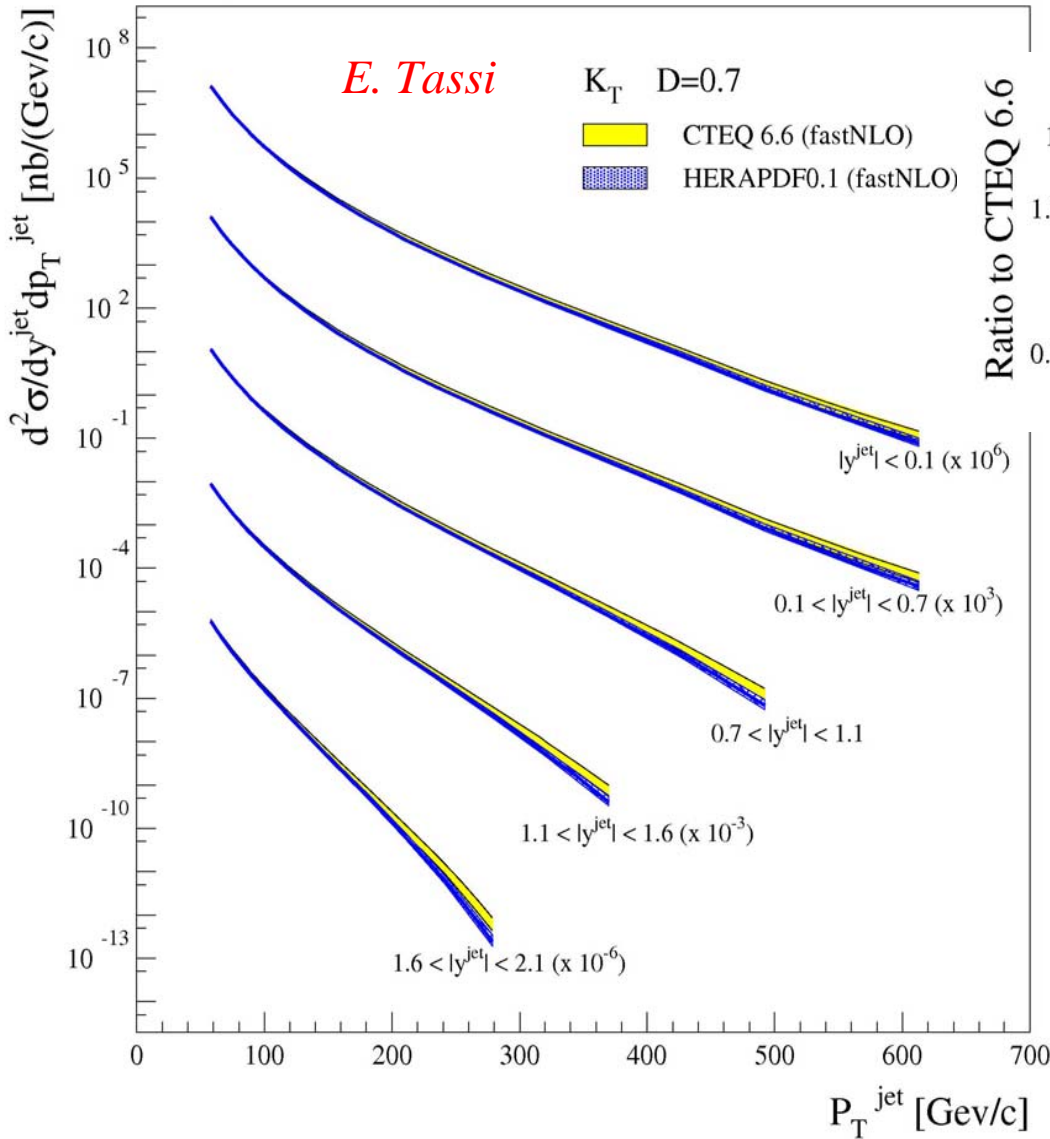
M. Cooper / E. Perez



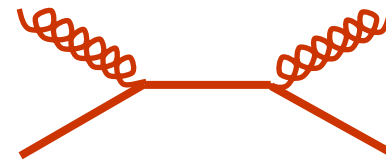
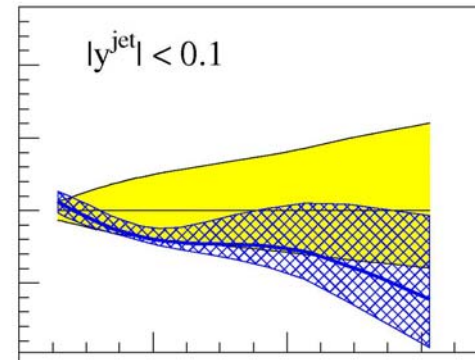
HERAPDF0.1 publicly released in LHAPDF (version 5.6.0)

...to be exercised by the LHC experiments !

Tevatron Jet Cross Sections

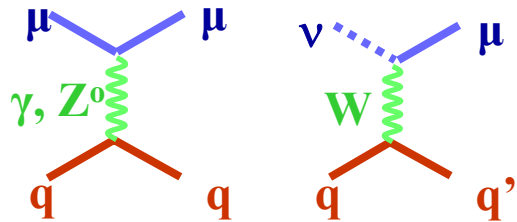


HERAPDF0.1 *impact on LHC* the gluon at high x

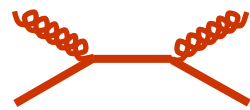


**Reasonable behaviour at high x
though no input from
Tevatron High- P_T jets in the fit**

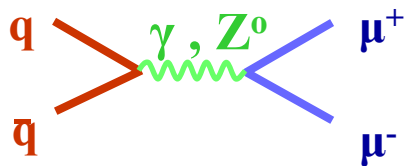
COMPLEMENTARY INPUTS to the PROTON PDF's



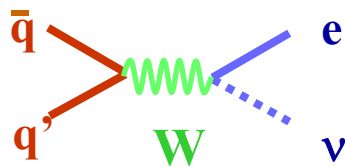
Fixed Target NC/CC
→ high-x quarks



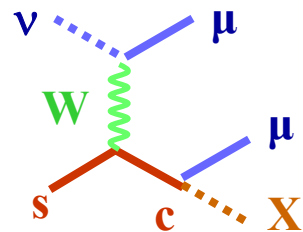
Tevatron High- P_T jets
→ high-x gluon



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

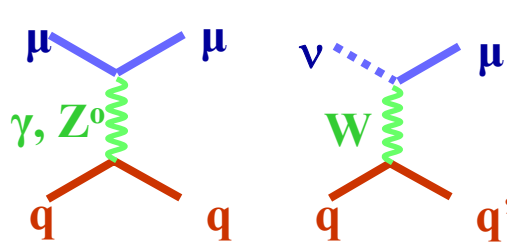


Tevatron W^+/W^-
→ u/d asymmetry at high x



Dimuons in Fixed Target CC
→ strange sea

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



Fixed Target NC/CC

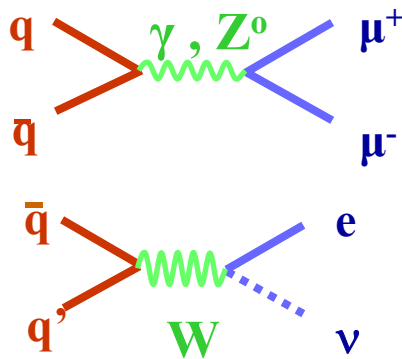
Nuclear corrections (CC) and possible Higher Twists (low Q^2)

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



Tevatron High- P_T jets

Still needed with high precision HERA F_2 + jets ?

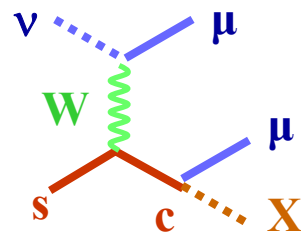


Fixed Target Drell-Yan

Nuclear corrections same as in DIS ?

Tevatron W^+/W^-

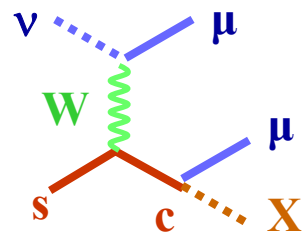
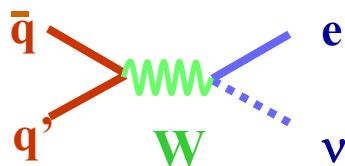
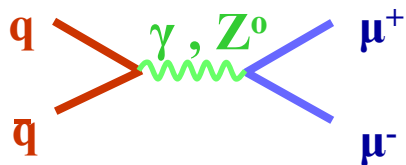
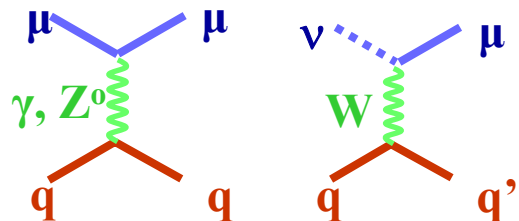
Special data will stay necessary for subtle asymmetry effects



Dimuons in Fixed Target CC

Increased tolerance needed in global fits

→ minimize number of experiments



TOWARDS OPTIMAL PROTON PDF's FOR LHC

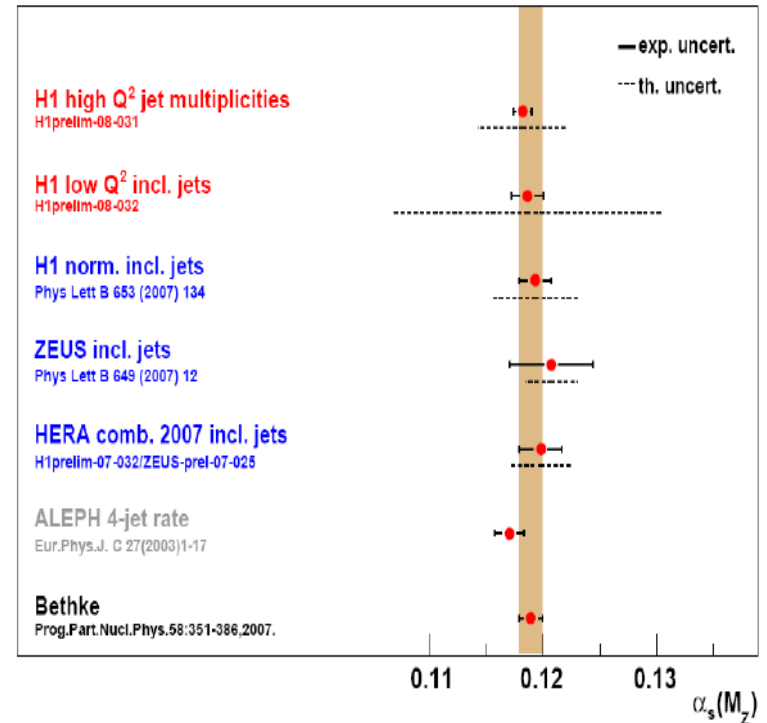
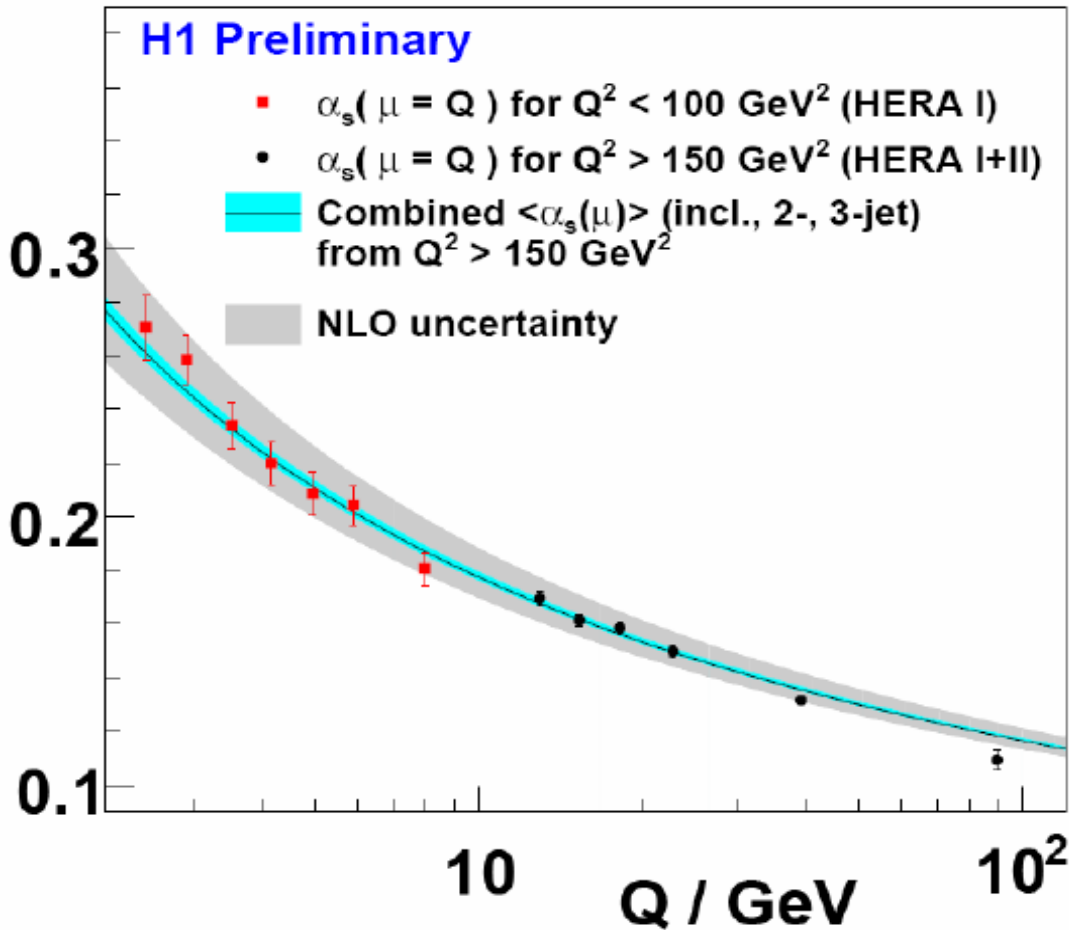
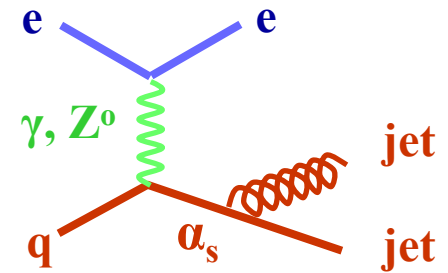
**In the era of
high precision HERA results**

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

**are essential questions
to be addressed by the
PDF4LHC workshop**

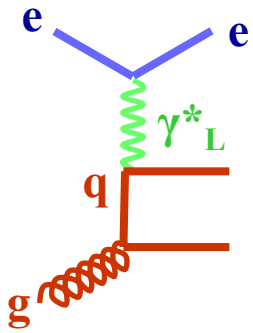
PROTON DYNAMICS

the strong coupling α_s from multi-jet rates



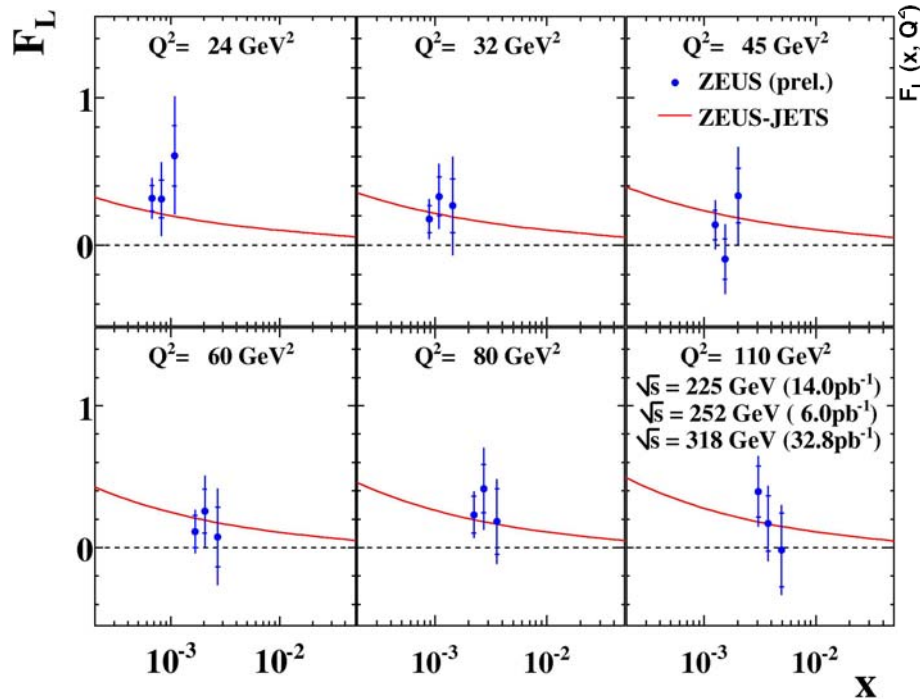
**HERA exp. error $\sim 0.7\%$
a challenge for theory !**

PROTON DYNAMICS: directly probing the gluon with F_L



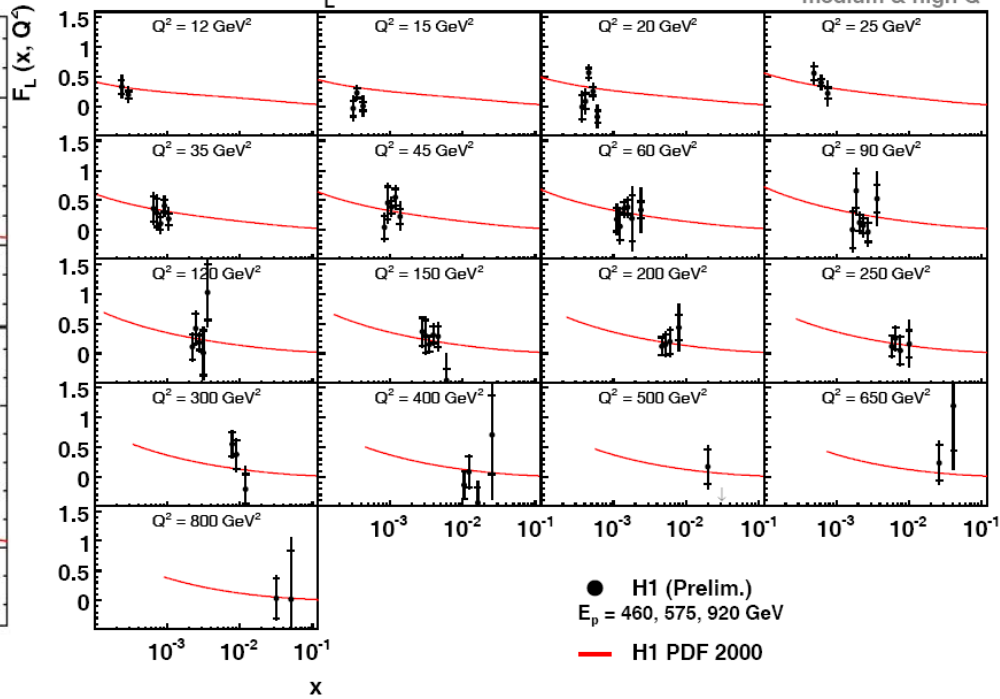
$$\tilde{\sigma}_{NC} = \frac{d^2\sigma_{NC}^{ep}}{dx dQ^2} / \left(\frac{2\pi\alpha^2}{xQ^4} Y_+ \right) = F_2 - \frac{y^2}{1+(1-y)^2} F_L \quad \mathbf{y = Q^2/sx}$$

ZEUS

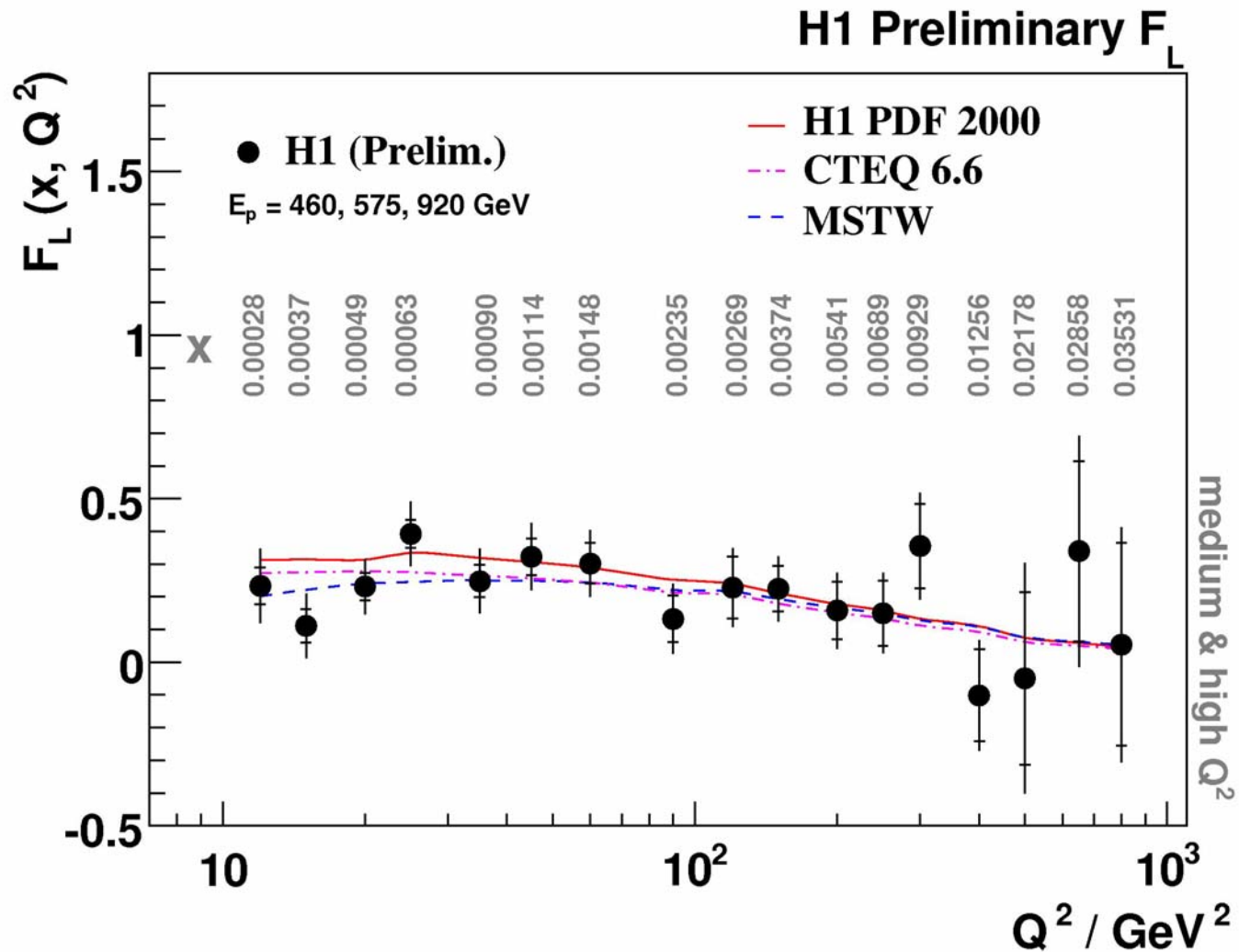


H1

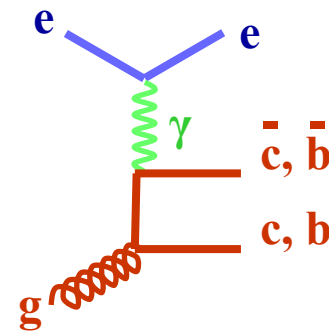
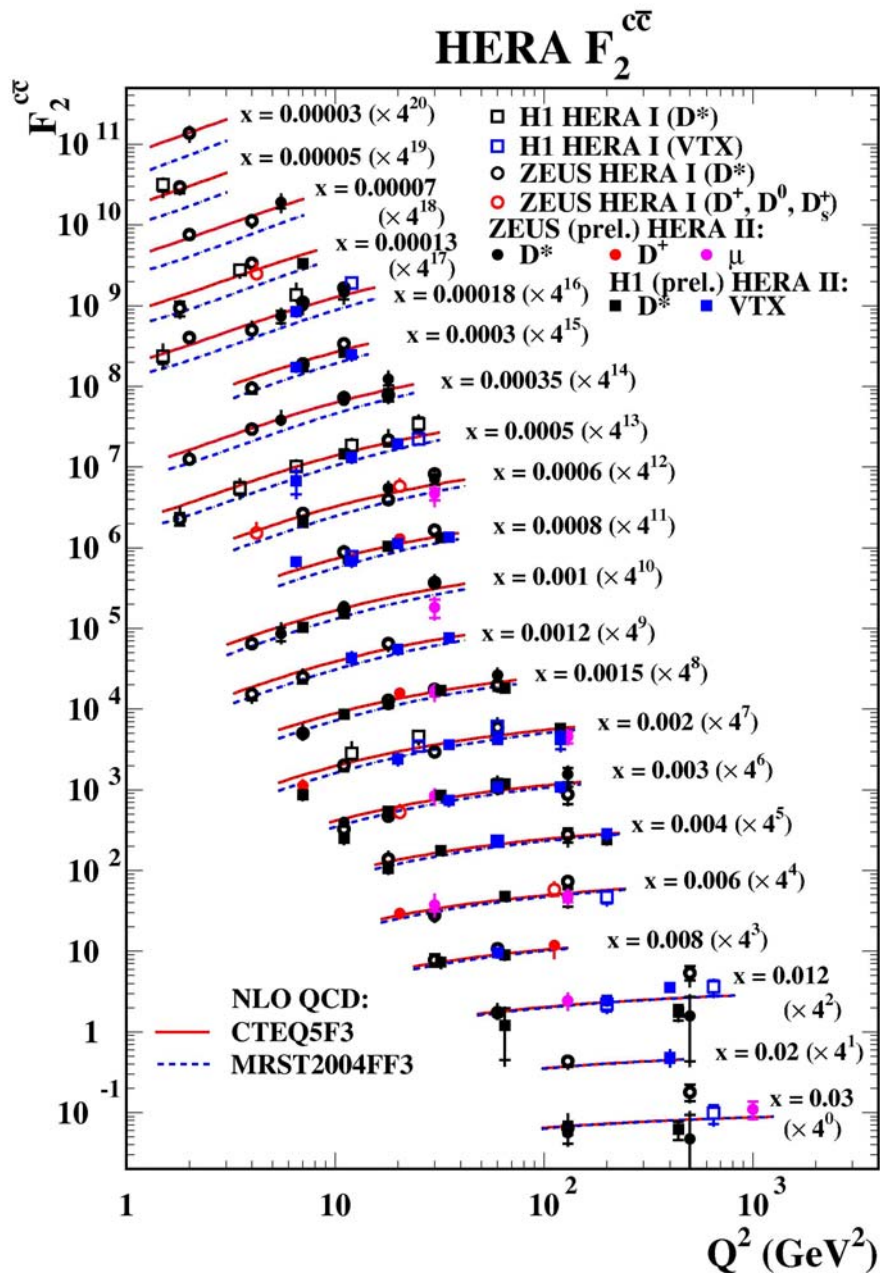
H1 Preliminary F_L



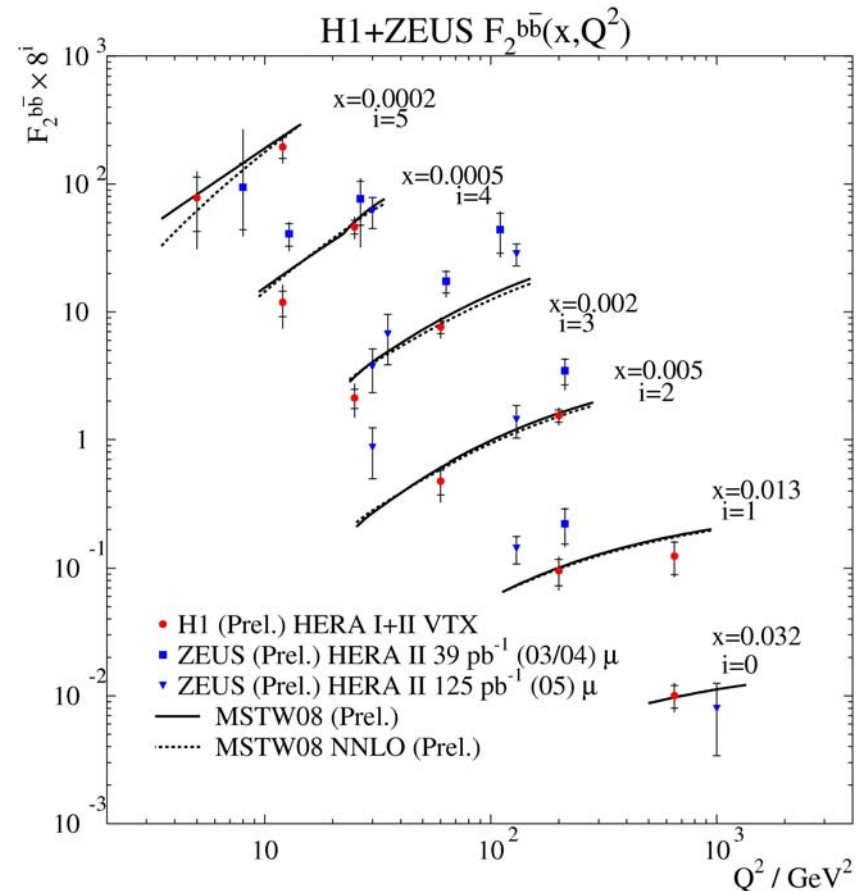
PROTON DYNAMICS: F_L compatible with NLO DGLAP predictions



PROTON DYNAMICS: Heavy Quark generation well described by DGLAP



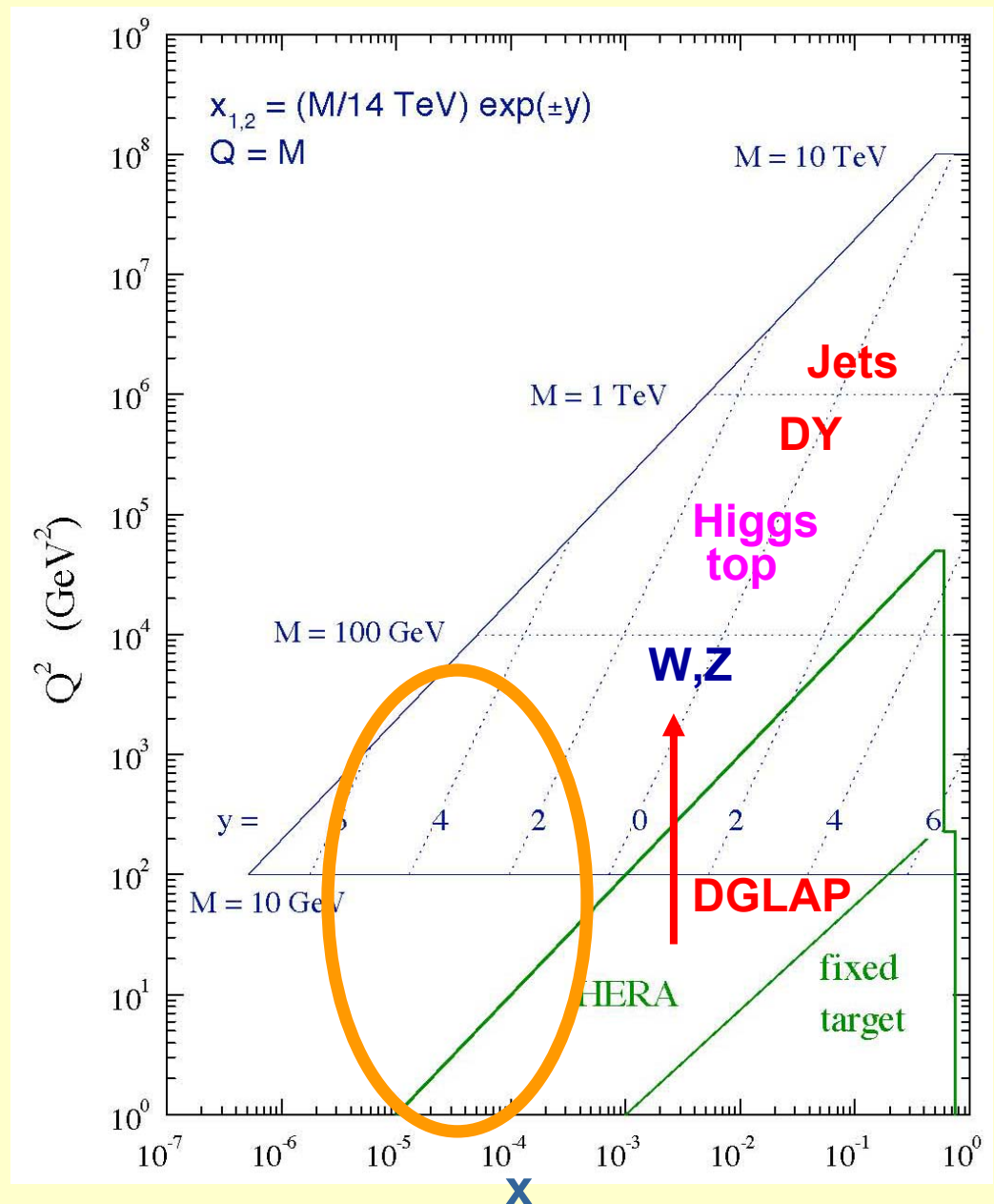
Heavy flavors tagged through $D^{(*)}$, decay muons or displaced vertices



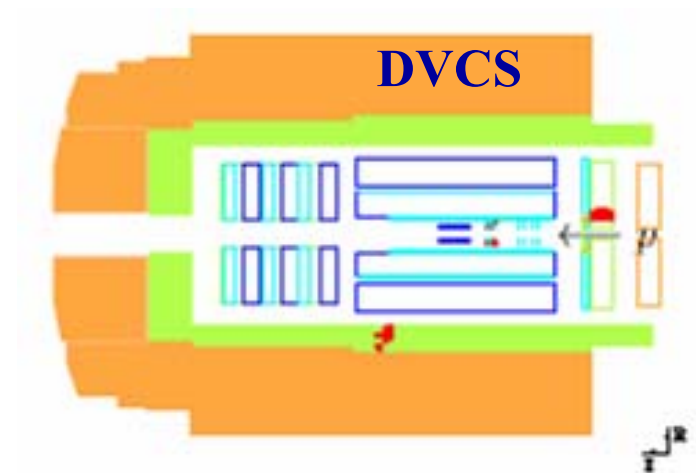
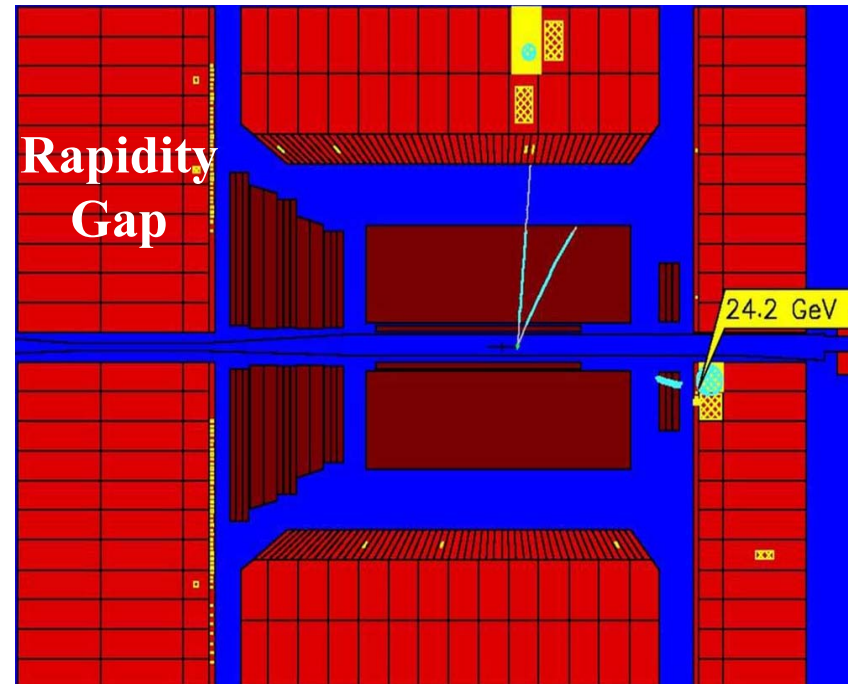
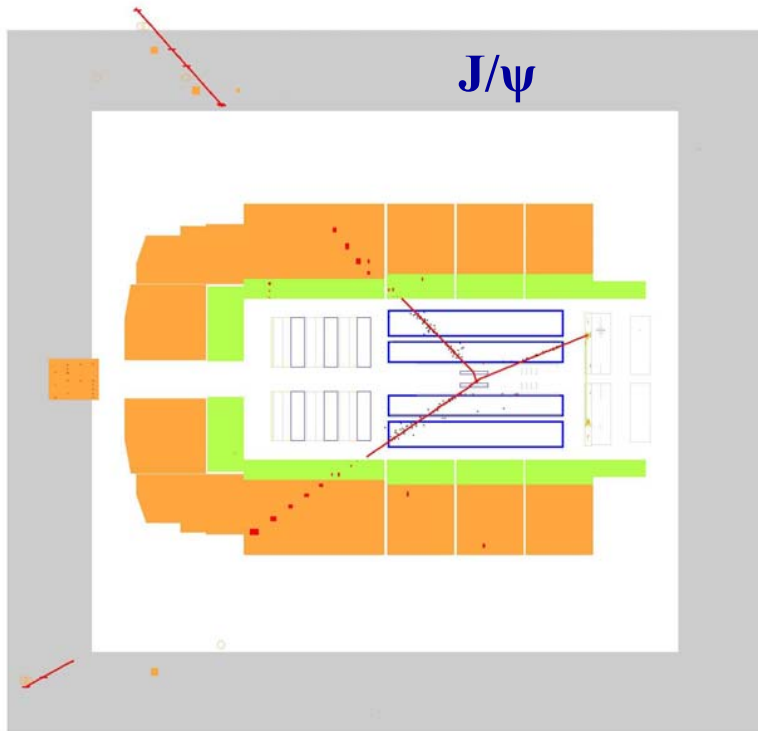
PRECISION MEASUREMENTS

Closer insights from diffraction in proton dynamics

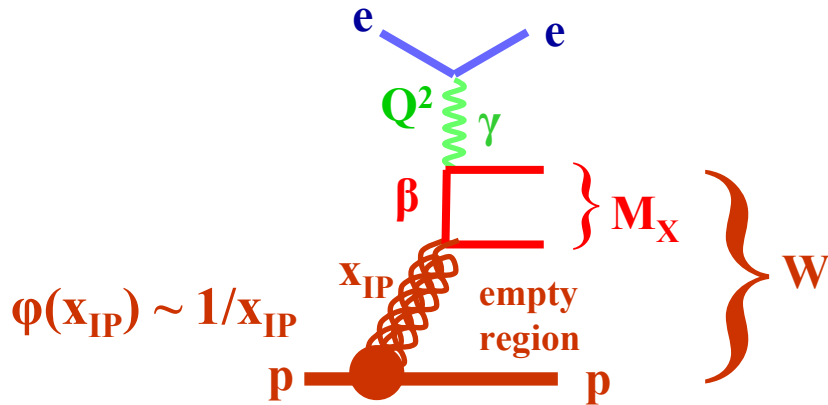
New effects at very low x ?



Typical diffractive interactions



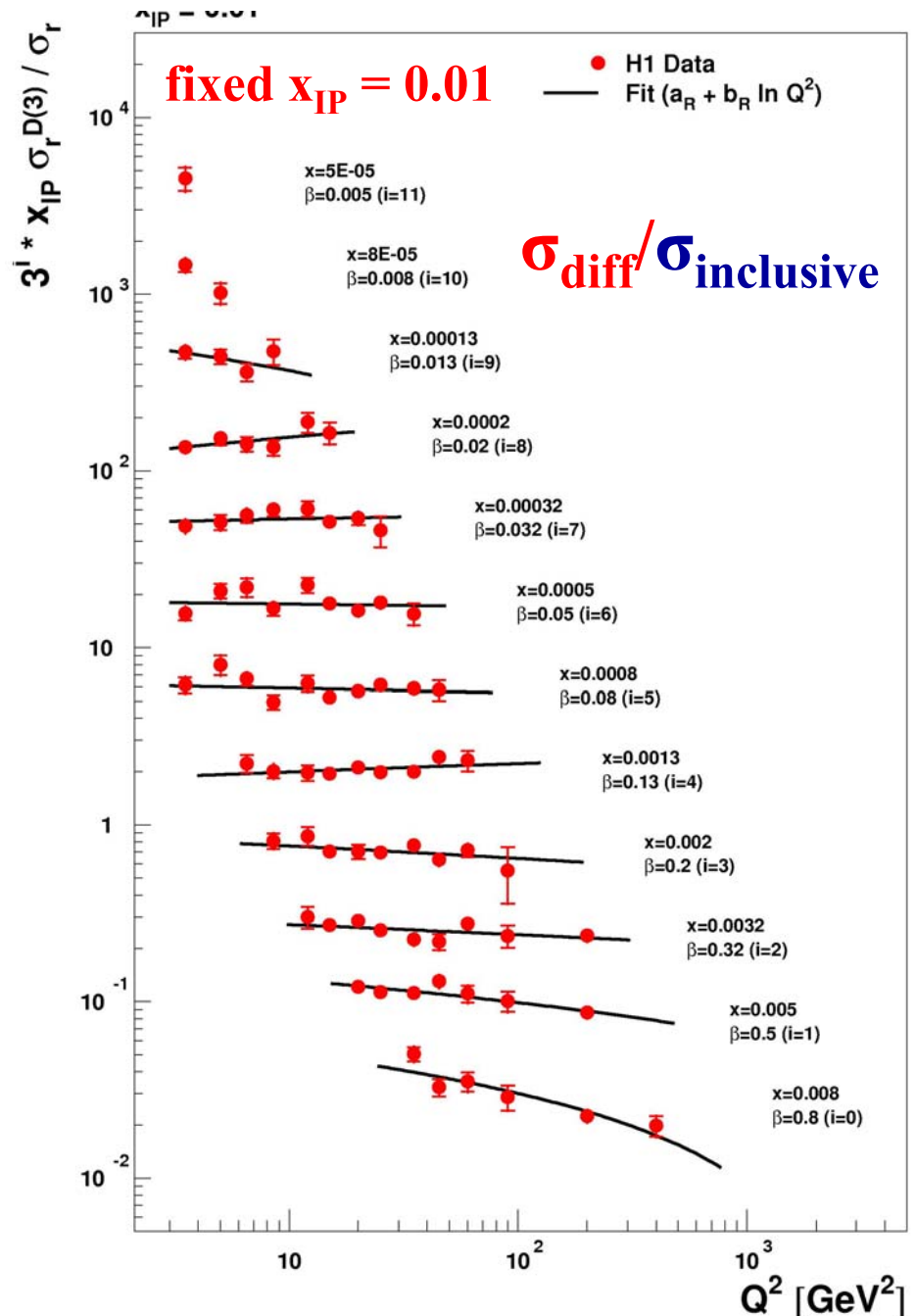
INCLUSIVE DIFFRACTION



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

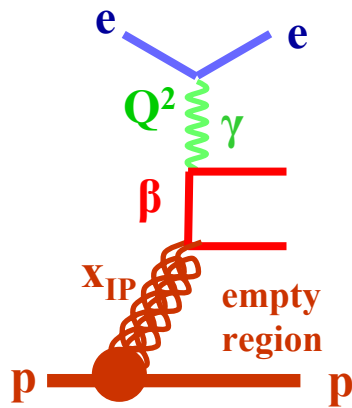


**diffraction is a leading-twist
intrinsic part of the proton structure**



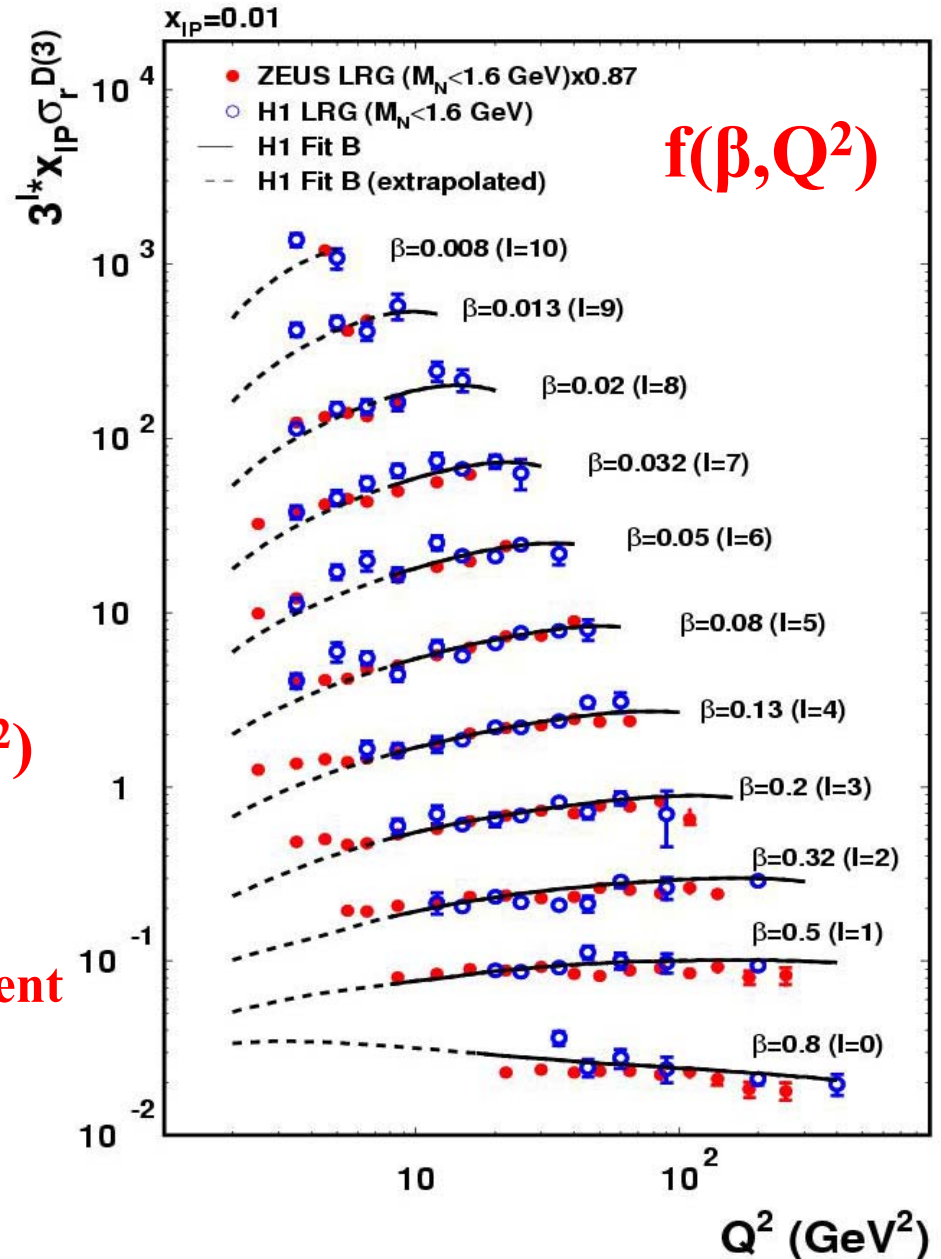
HERA inclusive diffraction

Perturbative structure of inclusive diffraction



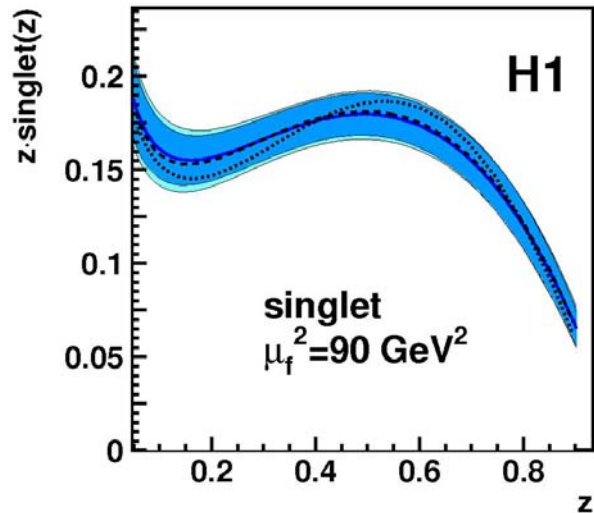
$$F_2^{D^3}(x_{IP}, \beta, Q^2) \sim \varphi(x_{IP}) \cdot f(\beta, Q^2)$$

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

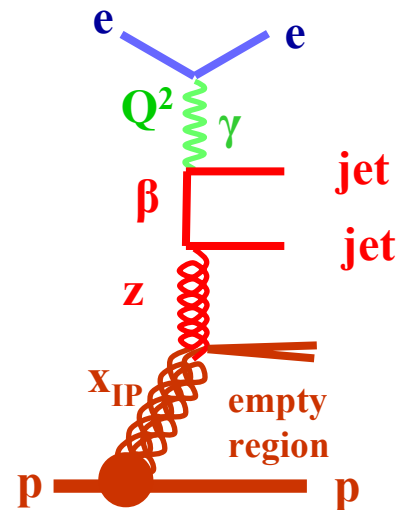
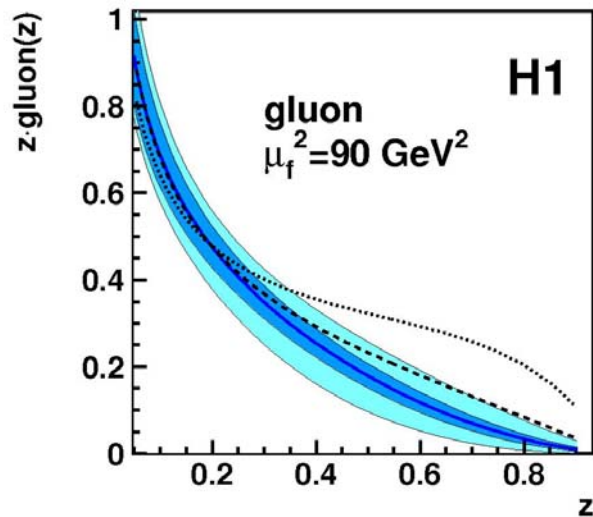


Diffractive PDF's

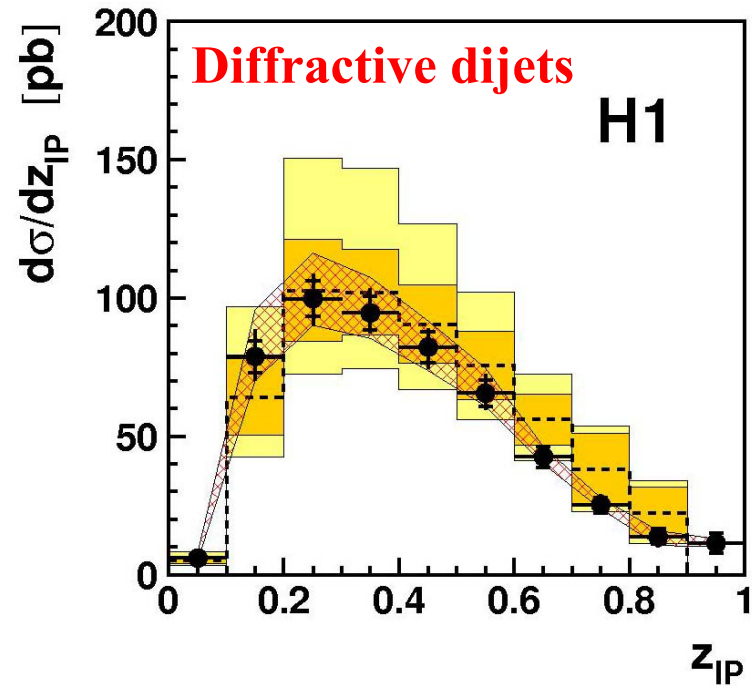
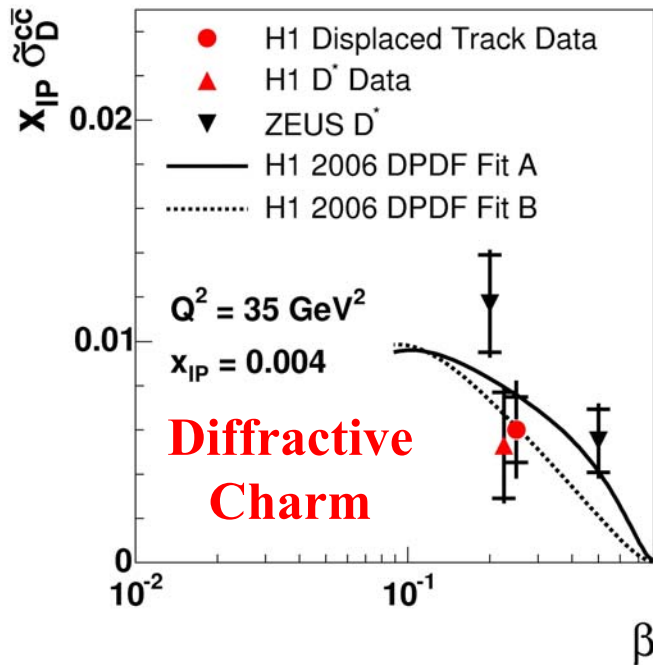
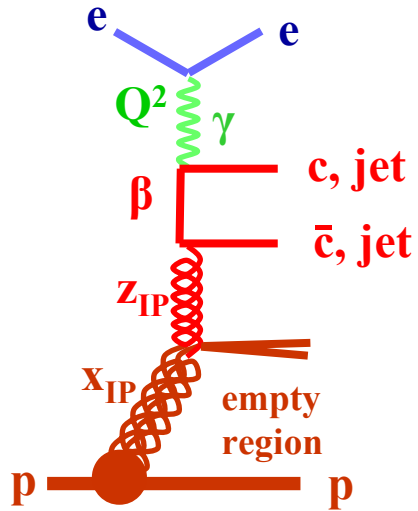
**extracted from a common fit
to diffractive inclusive
and dijets cross-sections**



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

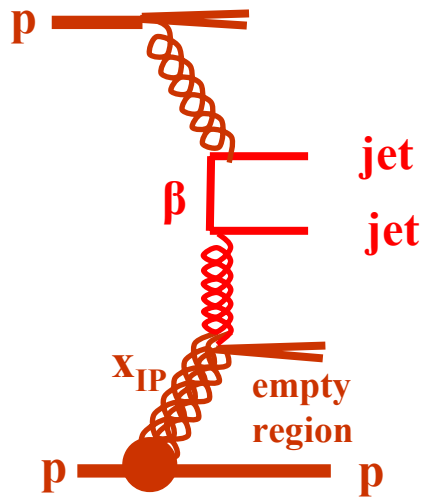


Factorisation of diffractive PDF's holds in DIS for charm and jets as predicted

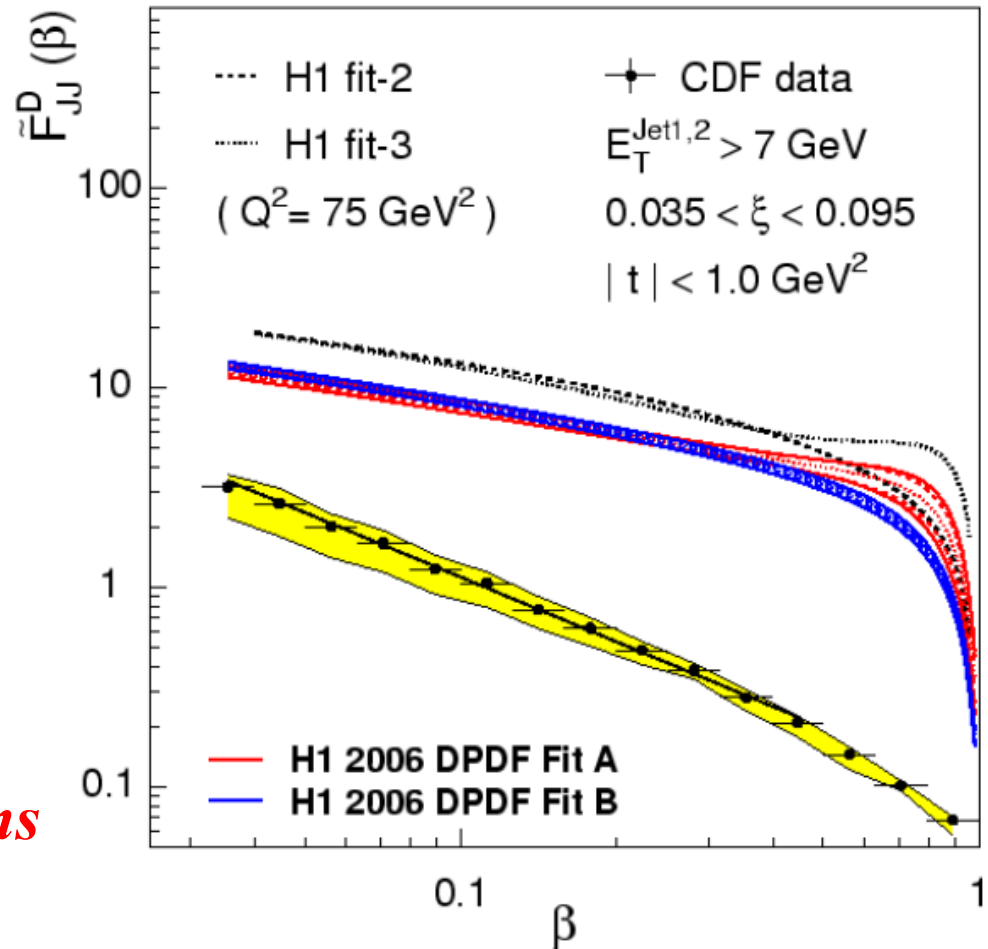


Factorisation of diffractive PDF's

broken by a factor ~ 7 for diffractive dijets at Tevatron



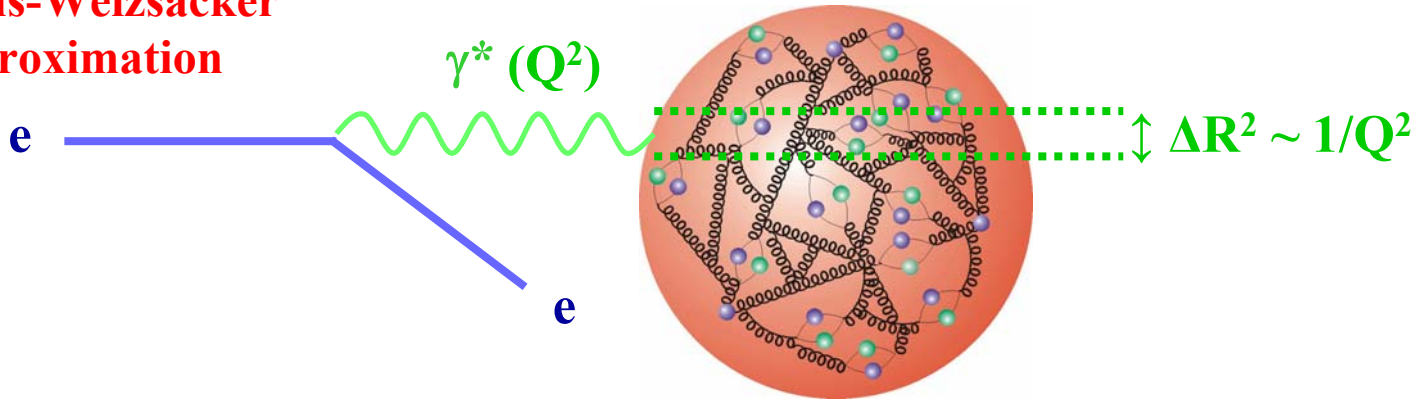
More studies on rapidity gap survival needed for LHC predictions



DIFFRACTION and LOW-X DYNAMICS

(experts please shut your eyes !)

Williams-Weizsäcker Approximation

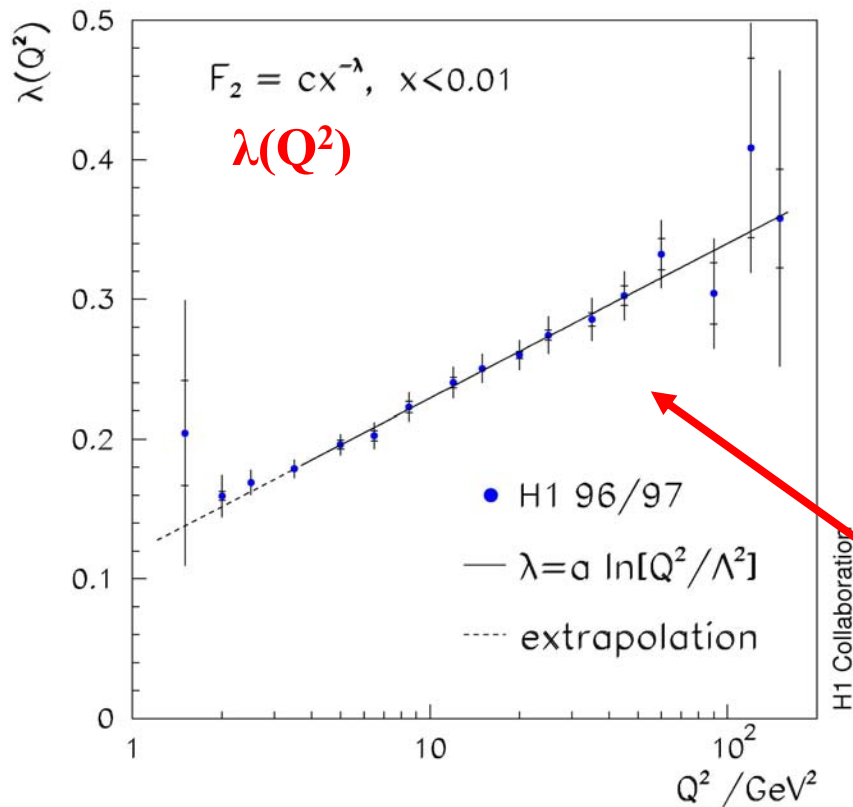
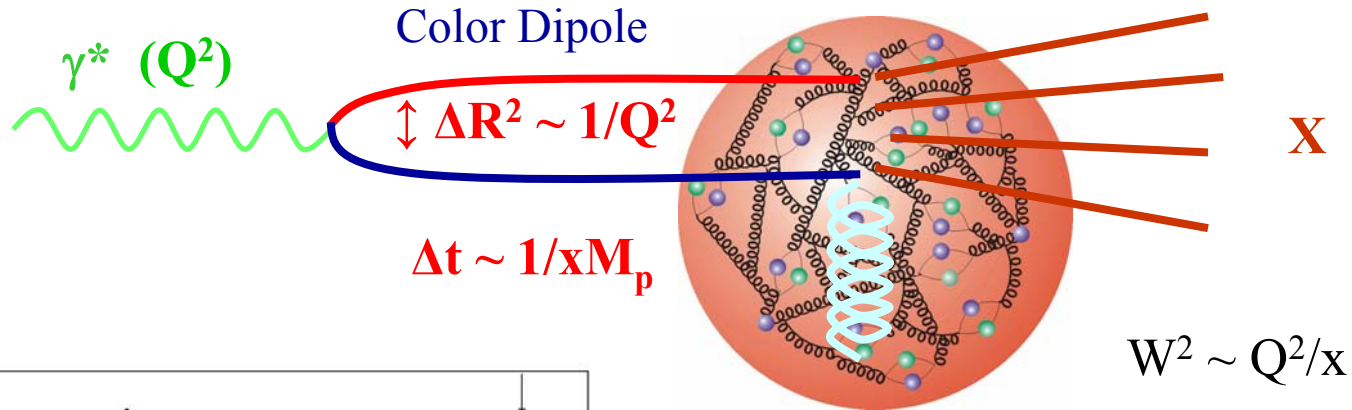


$$d\sigma_{ep}/dydQ^2 \sim \Phi_{\gamma^*}(y, Q^2) \times \sigma_{\gamma^*p}(W^2, Q^2) \quad W^2 \equiv E_{\text{cms}}^2(\gamma^*p) \sim Q^2(1-x)/x$$

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

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

Low-x limit: inclusive cross-section



inc

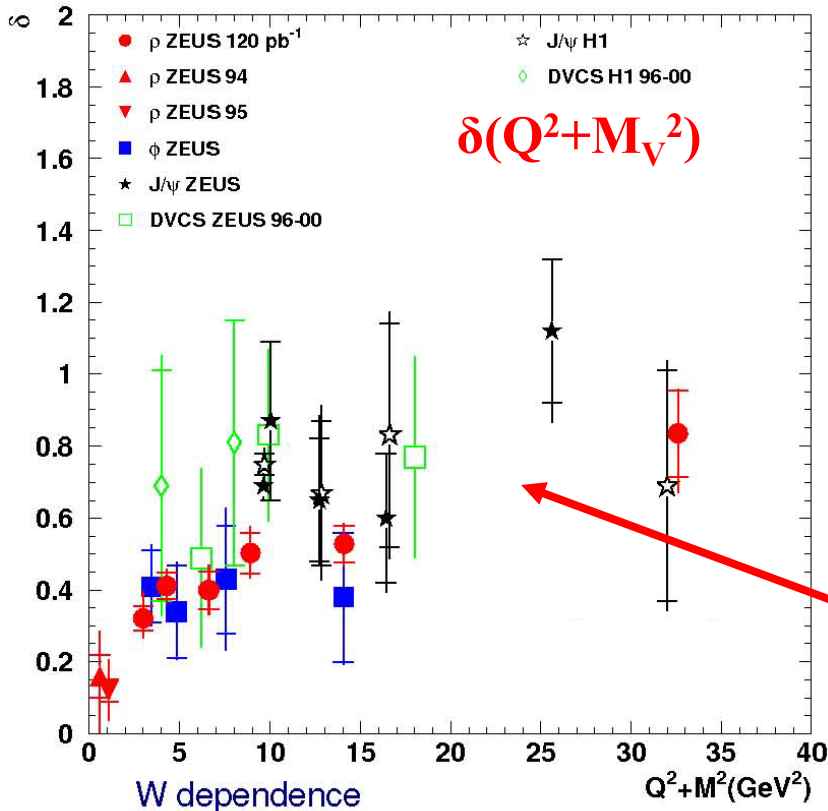
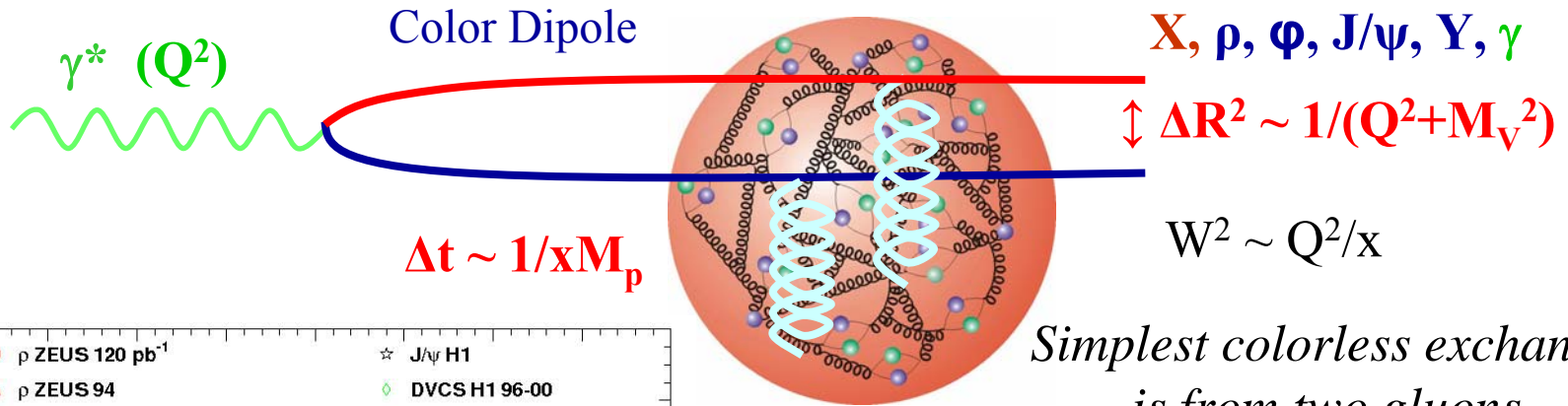
$$\sigma_{\gamma^*p}(W^2, Q^2) \sim \alpha_s/Q^2 xg(x, Q^2)$$

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

$$\sim \alpha_s/Q^2 W^{2\lambda(Q^2)}$$

Rise of λ with Q^2 reflects increased low x gluon DGLAP radiation at high Q^2

Low-x limit: diffractive cross-sections



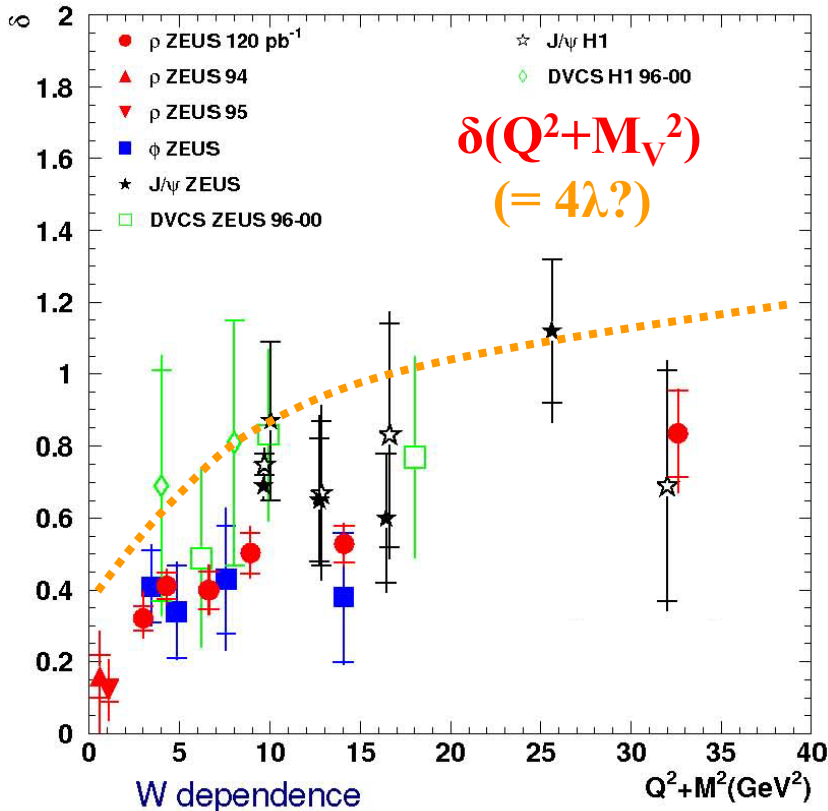
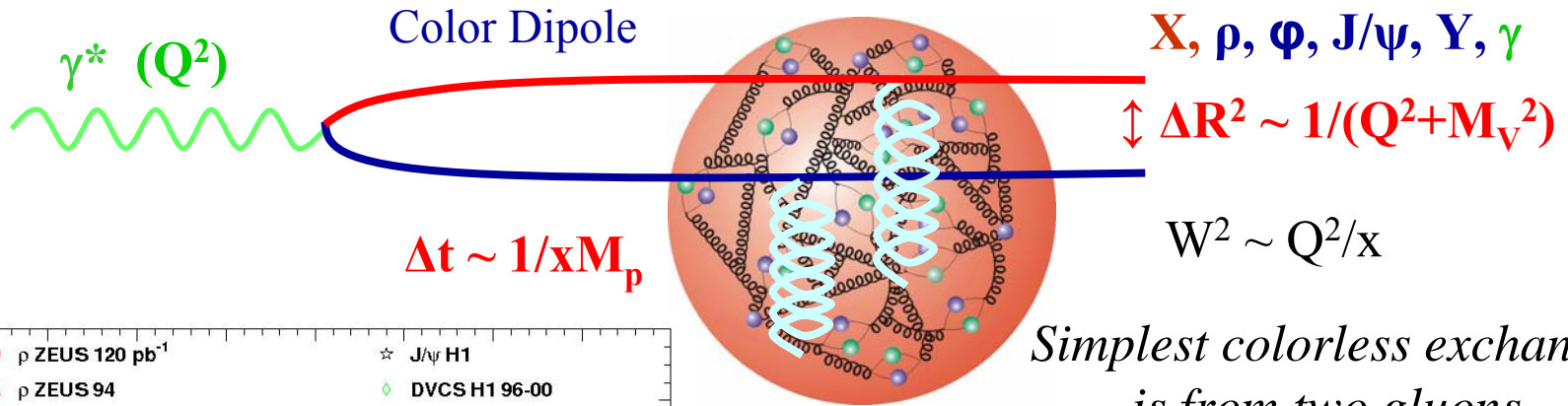
$$\sigma_{\gamma^*p}^{\text{diff}}(W^2, Q^2) \sim \alpha_s^2/Q^2 [xg(x, Q^2+M_V^2)]^2$$

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

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

Rise of δ with $(Q^2+M_V^2)$ reflects entering the hard diffraction regime with direct sensitivity to the gluon.

Low-x limit: diffractive cross-sections



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

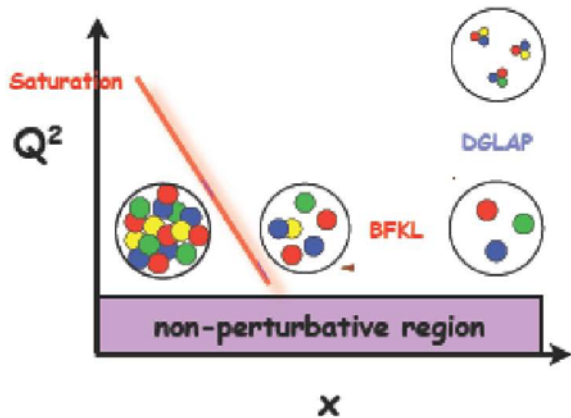
$$\sim \alpha_s^2/Q^2 \quad x^{-2\lambda} (Q^2+M_V^2)$$

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

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

Low x limit: is saturation observed ?



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

diverges at low x



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

saturates to the proton surface R_p^2

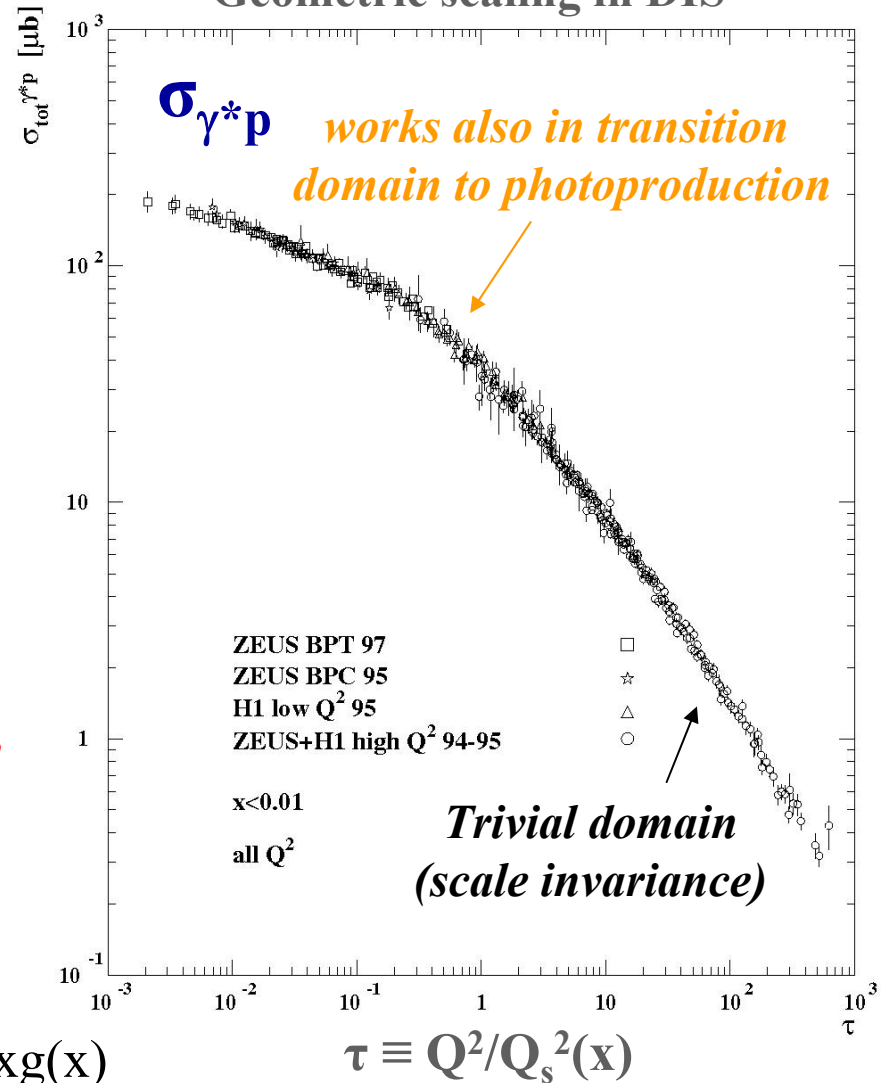


Geometric scaling predicted:

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

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

Geometric scaling in DIS



Paving the way towards optimal LHC PDF's



**New insights in
low-x dynamics from hard diffraction**

DGLAP OK in the bulk phase space

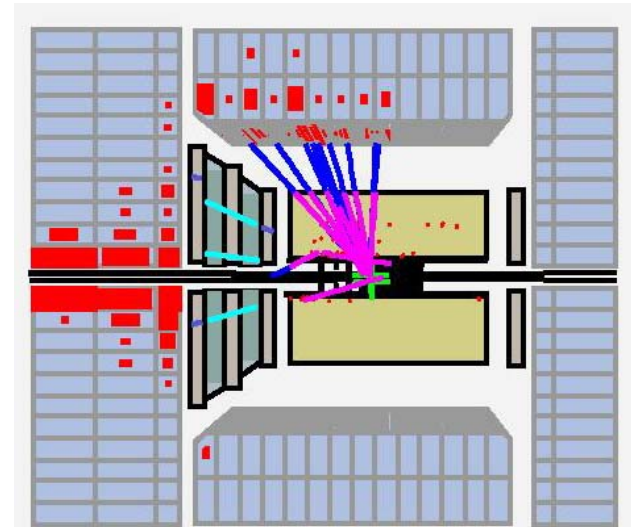
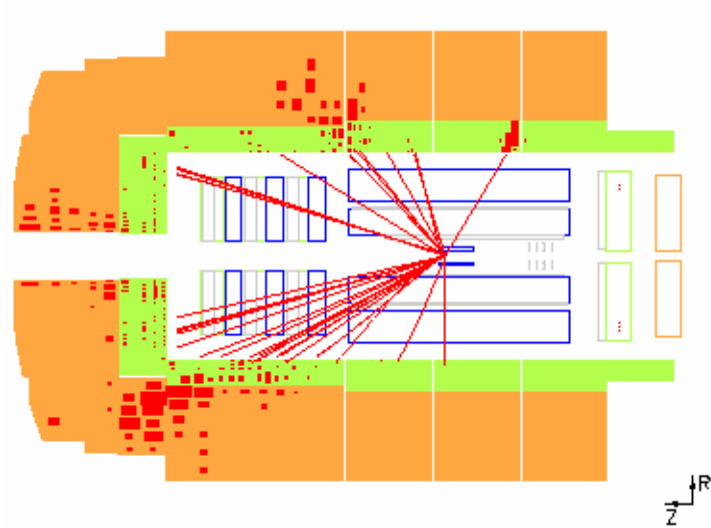
**Recent breakthrough in precision at low x
from H1-ZEUS combinations**

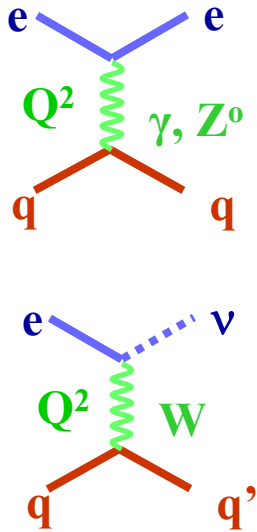
**More to come at high x
with full HERA II data**



PRECISION MEASUREMENTS

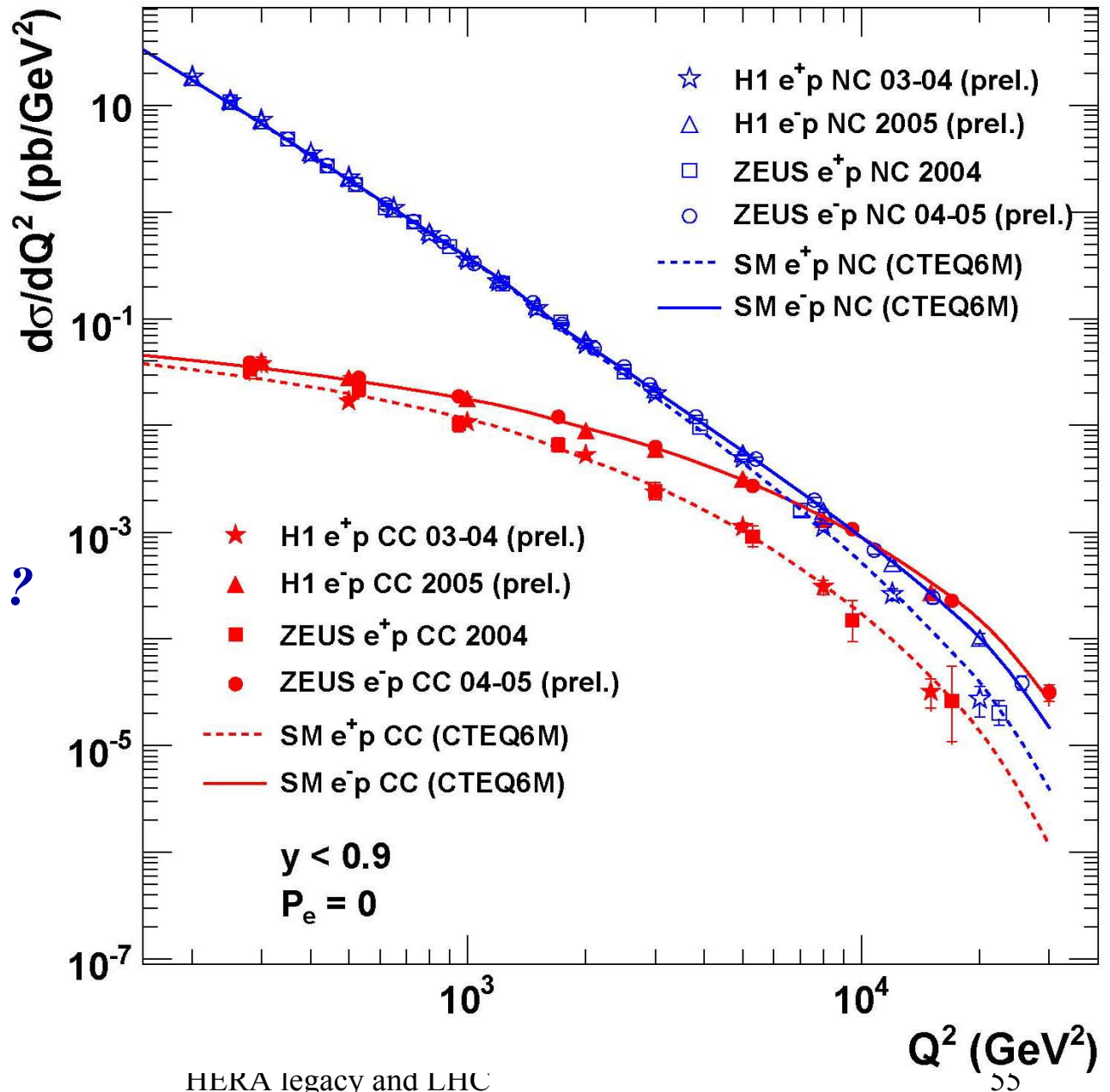
More results



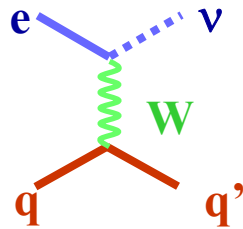


*Does the e-probe
behave as expected ?*

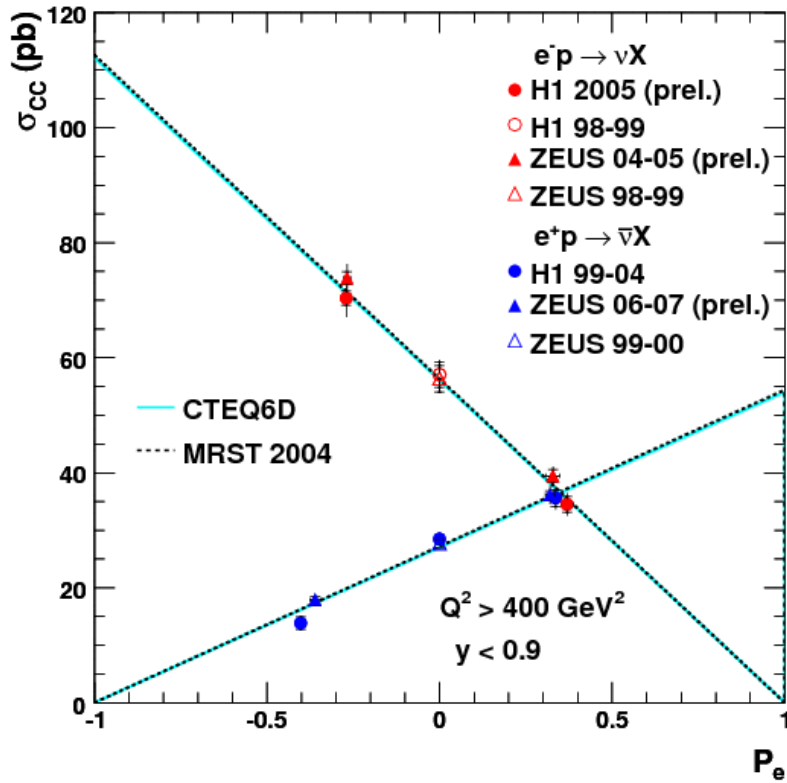
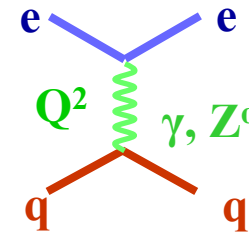
YES!
**EW unification
in the t-channel
at the $M_{W,Z}$ scale**



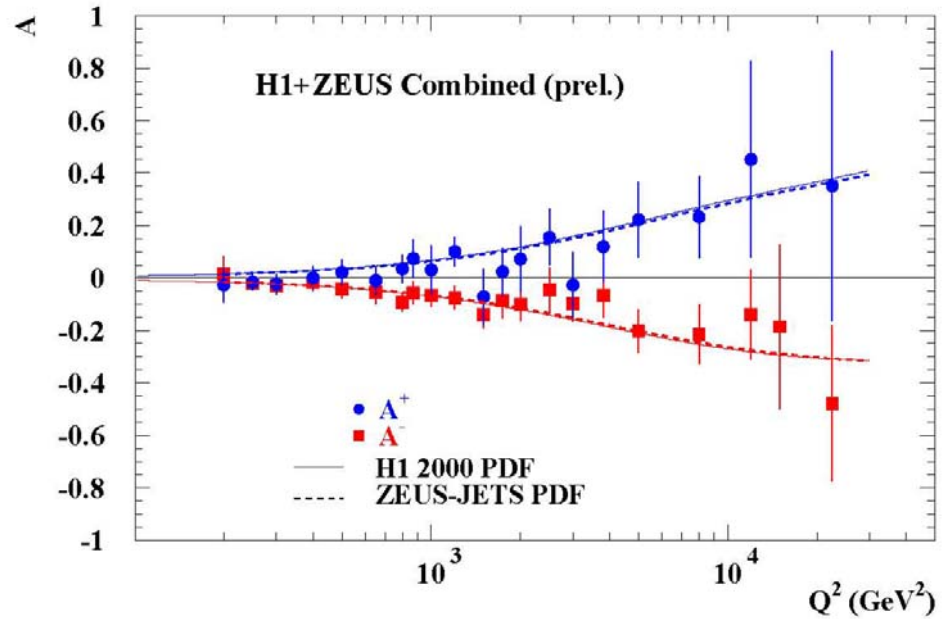
ELECTROWEAK POLARISATION ASYMMETRIES



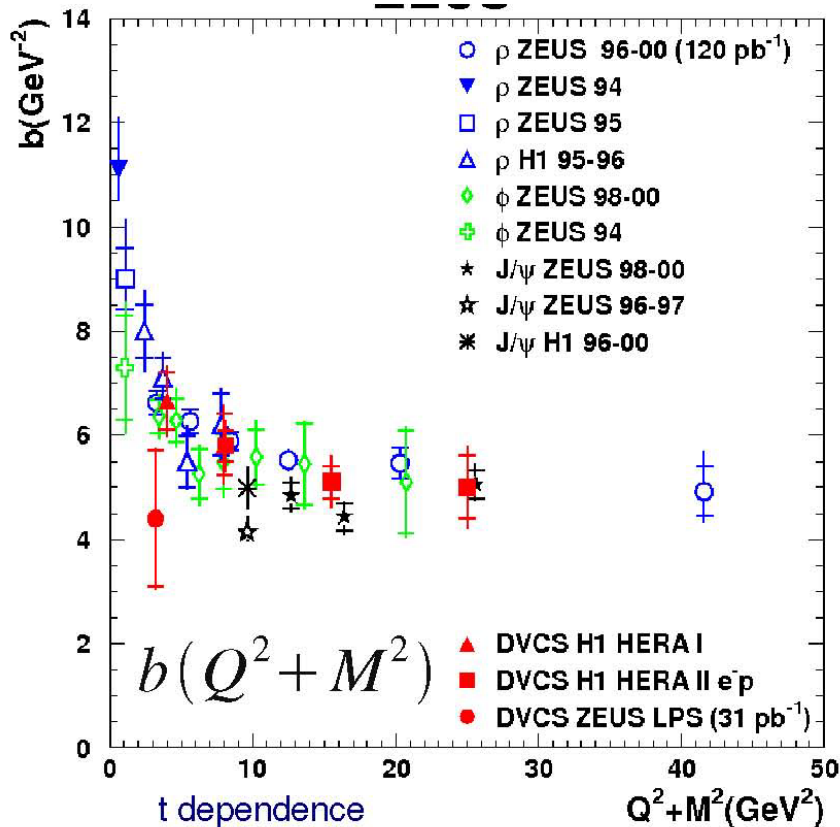
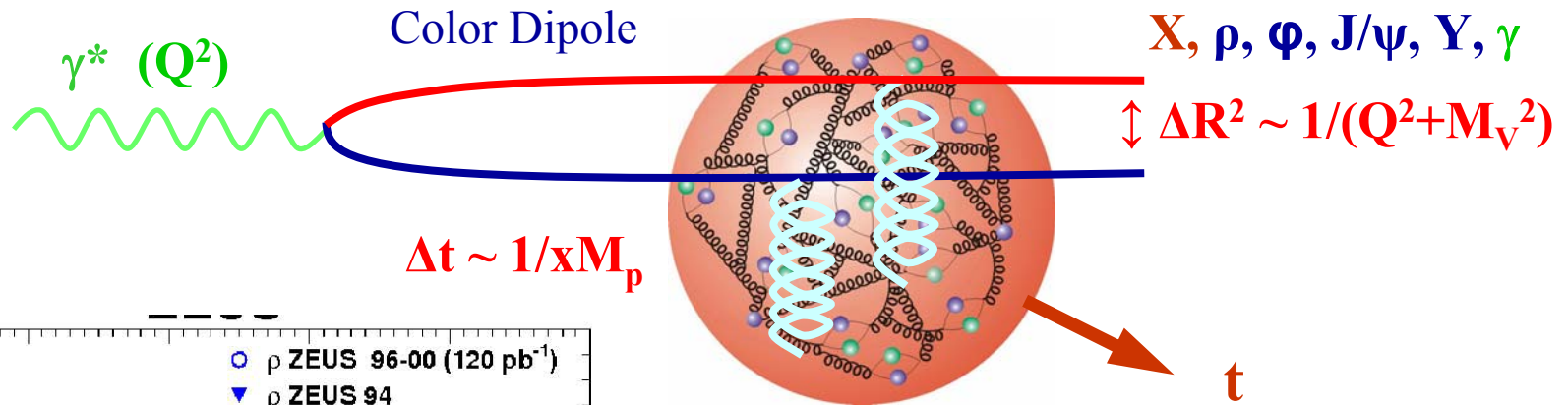
Charged Current e^+p Scattering



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

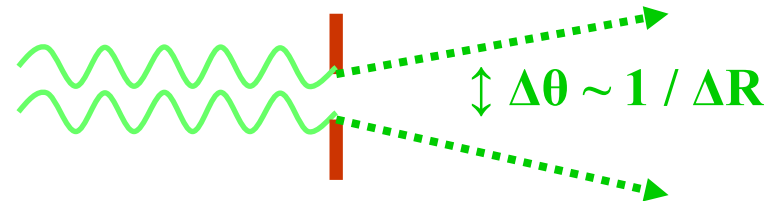


Diffraction processes: impact parameter



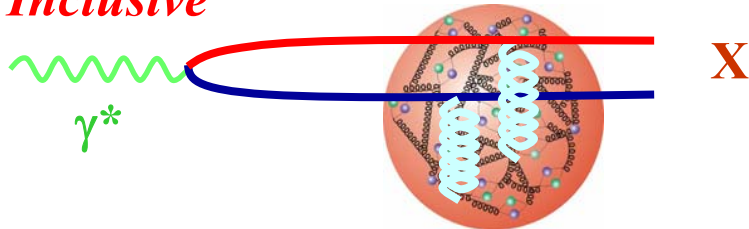
$$d\sigma/dt \sim e^{bt}$$

In the hard regime interaction size saturates down to the proton size



Perturbative QCD description of hard diffraction

Inclusive



DVCS

