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Elementarteilchenphysik
Großgeräte der physikalischen Grundlagenforschung

F_2 combination and HERAPDF1.0

(JHEP01 (2010) 109)

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on behalf of

H1 and ZEUS

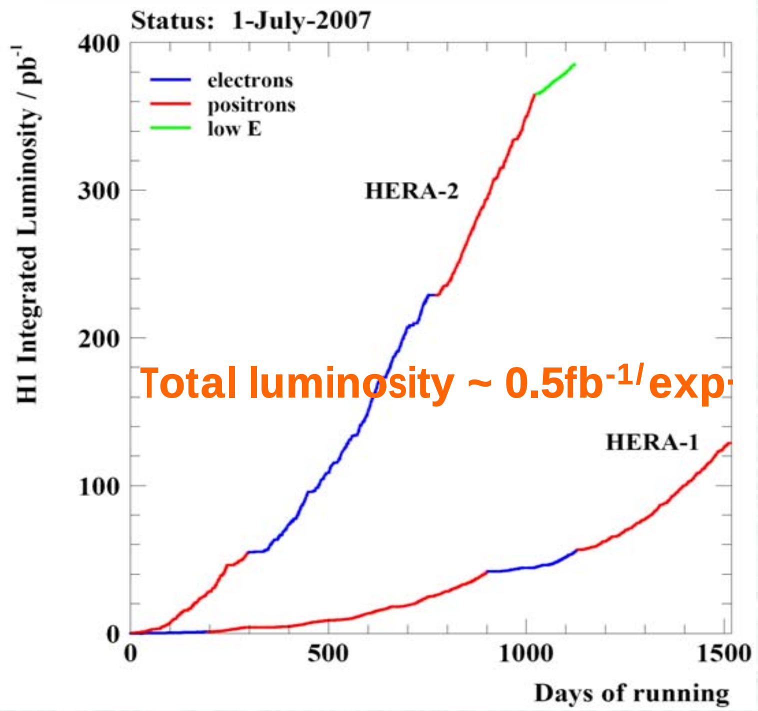
Outline:

- H1 and ZEUS at HERA
- Deep Inelastic ep Scattering
- Data combinations
- QCD fits and HERAPDF1.0
- HERAPDF1.0 for LHC & TeVatron

Low x meeting, Kavala, June 23, 2010

HERA: World's Only ep Collider

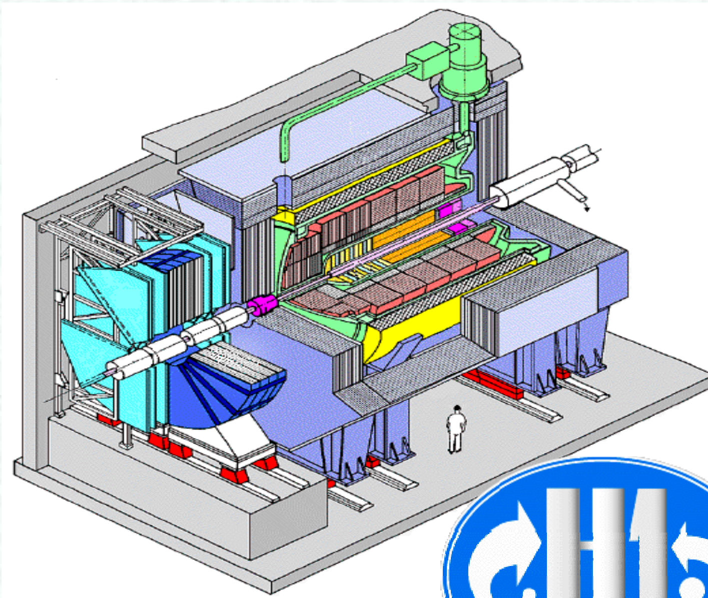
HERA: world's largest "electron-microscope"!
(with "resolving power": $Q^2 \sim 1/\lambda^2$ (10^{-18}m))

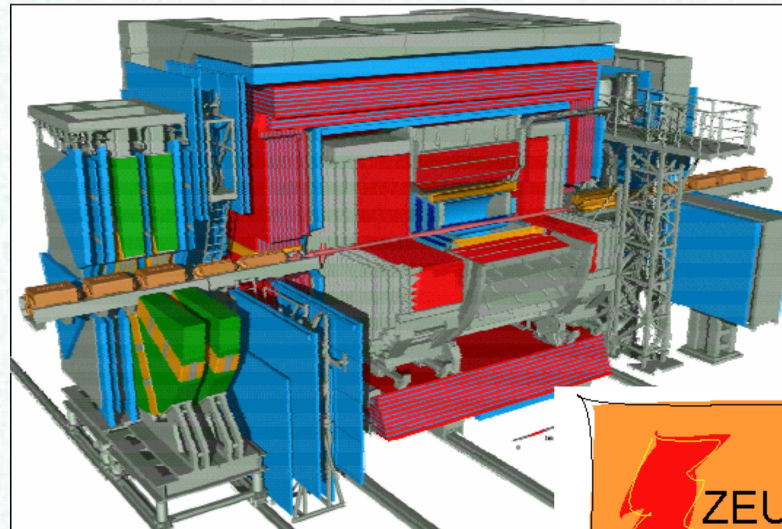


Presented results:

- ➢HERA-I: 1992-2000 L~120 pb^{-1}/exp.
- \- precision measurements at low/medium-Q^2
- ...and a glimpse of high-Q^2 potential

H1 & ZEUS: Hermetic multi-purpose detectors





Liquid Argon Calorimeter

optimized for precision measurement of the scattered lepton

$\sigma_E / E = 11\% / \sqrt{E}$ **(ele)**

$\sigma_E / E = 50\% / \sqrt{E}$ **(had)**

Uranium-scintillator Calorimeter

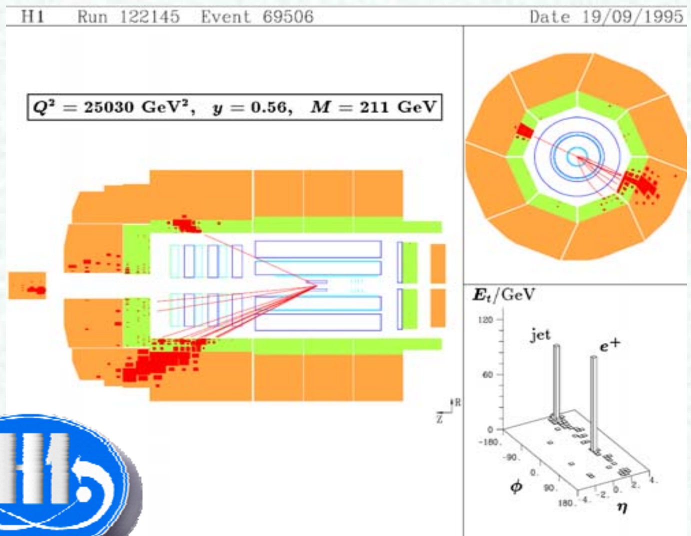
optimized for precision measurement of the hadronic final state

$\sigma_E / E = 18\% / \sqrt{E}$ **(ele)**

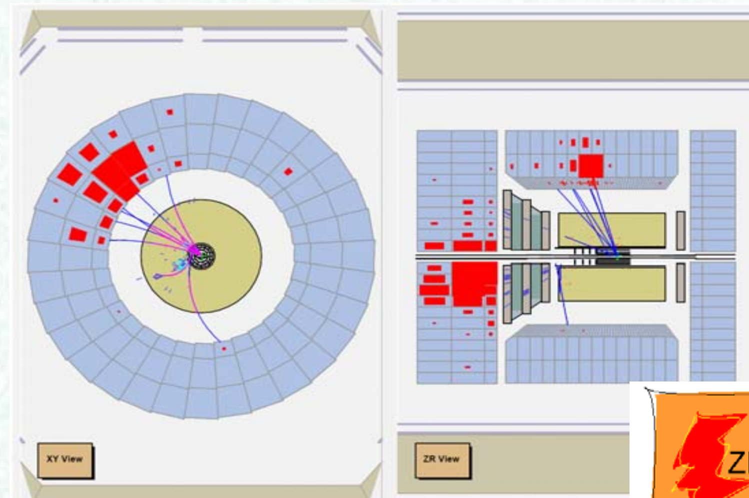
$\sigma_E / E = 35\% / \sqrt{E}$ **(had)**

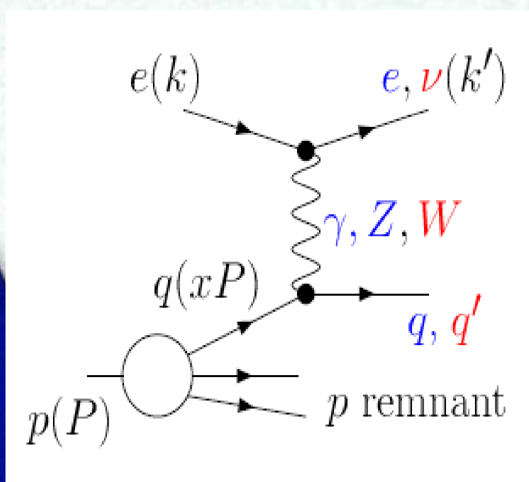
Deep Inelastic ep Scattering

Neutral Current



Charged Current





$$Q^2 = -(k - k')^2$$

$$x = \frac{Q^2}{2P \cdot (k - k')}$$

$$y = \frac{P \cdot (k - k')}{P \cdot k}$$

Q^2 = -(4-momentum of propagator)^2 – the virtuality of the exchanged boson.

x – fractional momentum of proton carried by struck quark q

y – fractional energy of the incoming lepton transferred to the proton in the proton's rest frame (inelasticity)

Deep Inelastic ep Scattering

NC: Sensitive to gluons, valence quarks and see quarks

$$\frac{d^2\sigma^{\pm}_{NC}}{dx\,dQ^2} \approx \frac{2\alpha\pi^2}{xQ^4}\left[Y_+ F_2 \mp Y_- xF_3 - y^2 F_L\right] \qquad Y_{\pm} = \tfrac{1}{2}\left(1 \pm (1-y^2)\right)$$

$$F_2 \propto \sum_i e_i^2 (xq_i + x\bar{q}_i)$$

All quarks at LO.
Gluon from scaling violations.

$$xF_3 \propto \sum_i xq_i - x\bar{q}_i$$

Valence quarks

$$F_L \propto \alpha_s xg$$

Gluon at NLO

Use 'reduced cross section' to remove kinematic dependence:

$$\sigma_r = \frac{xQ^2}{2\alpha\pi^2 Y_+}\frac{d^2\sigma^{\pm}_{NC}}{dx\,dQ^2} \approx F_2$$

CC: Flavour decomposition

e-p:

$$\frac{d^2\sigma^{-}_{CC}}{dx\,dQ^2} = \frac{G_F^2}{2\pi}\left(\frac{M_W^2}{M_W^2+Q^2}\right)\left[u + c + (1-y)^2(\bar{d}+\bar{s})\right]$$

e+p:

$$\frac{d^2\sigma^{+}_{CC}}{dx\,dQ^2} = \frac{G_F^2}{2\pi}\left(\frac{M_W^2}{M_W^2+Q^2}\right)\left[\bar{u} + \bar{c} + (1-y)^2(d+s)\right]$$

Inclusive cross section combination

- H1 & ZEUS have combined inclusive DIS cross sections from HERA I data => New average with L=240 pb^{-1}

- **<u>Combination procedure:</u>**

1) Swim all point to a common Q^2-x grid
2) Move 820 GeV data to 920 GeV p-beam energy (not for NC at y>0.35)
3) Calculate average values and uncertainties
4) Evaluate "procedural uncertainties"

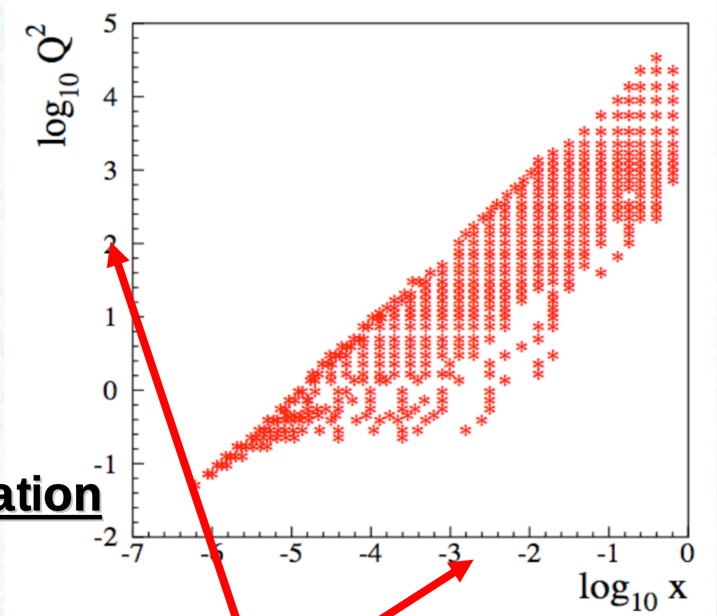
- **<u>$\chi 2$ minimalisation method for data combination</u>**

1402 data points combined to 741 cross section measurements:

- 110 correlated syst. error sources (H1 & ZEUS)

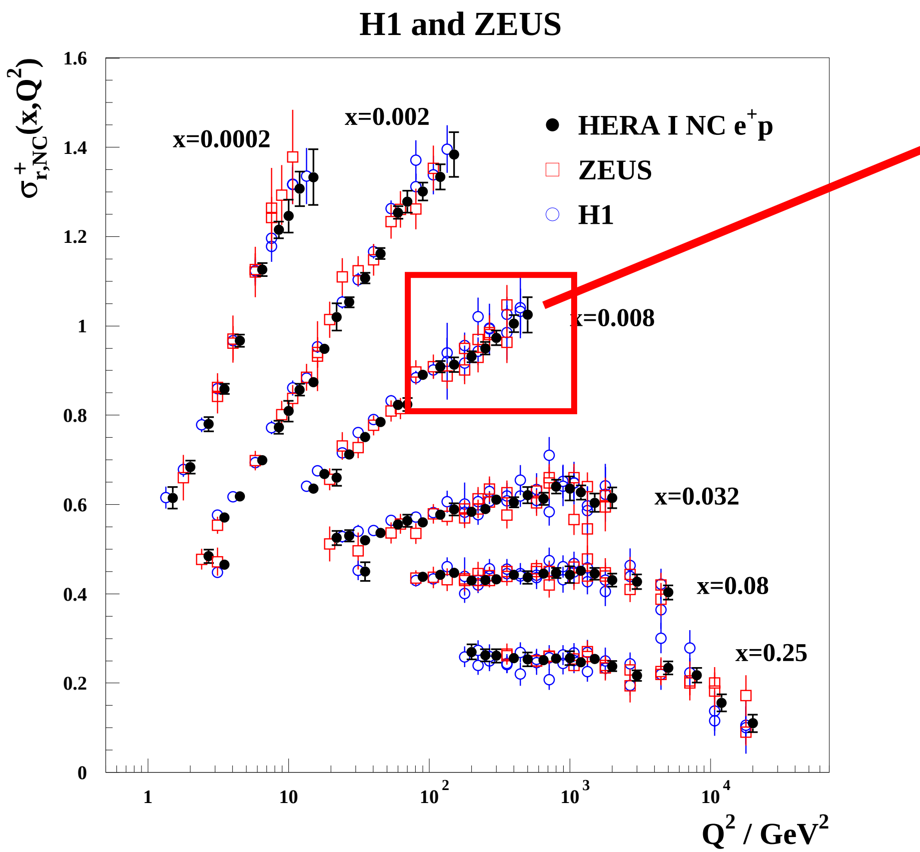
- 3 procedural uncertainties

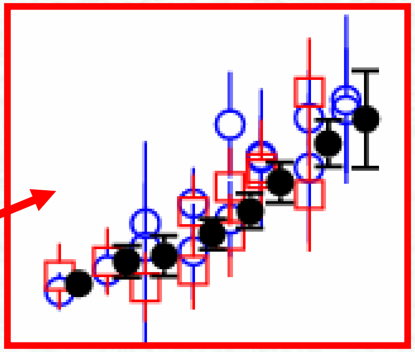
-H1 & ZEUS syst. assumed independent (except 0.5% lumi normalisation)



Span 6 orders of magnitude in x and Q^2

Combined H1 & ZEUS data





- Unprecedented precision due to cross calibration of detectors

- Data show good consistency

$\chi 2/n_{dof}$ = 637/656

- Precision:

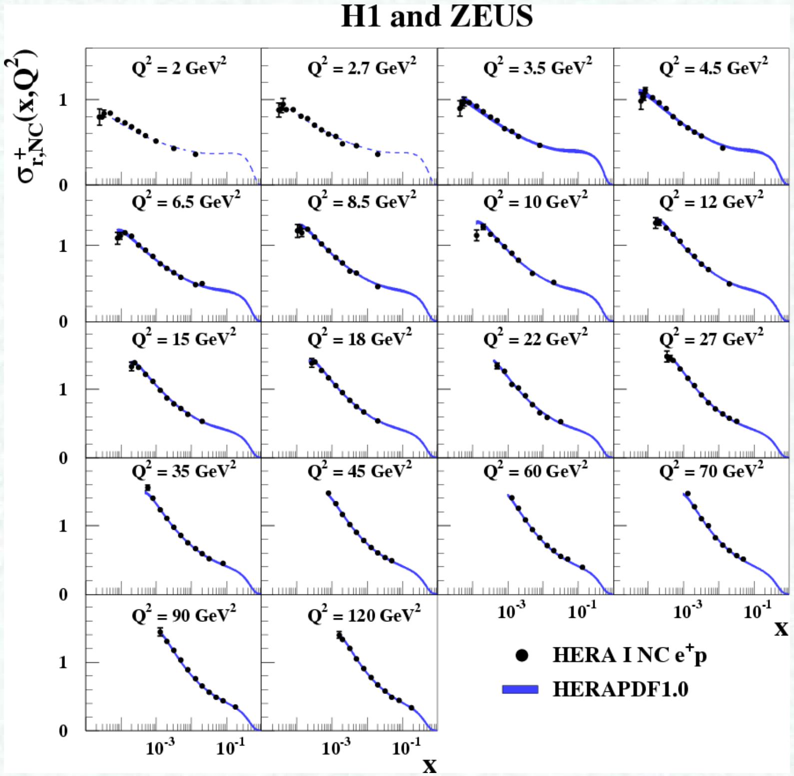
2% for $3<Q^2<500$ GeV^2

1% for $20< Q^2<100$ GeV^2

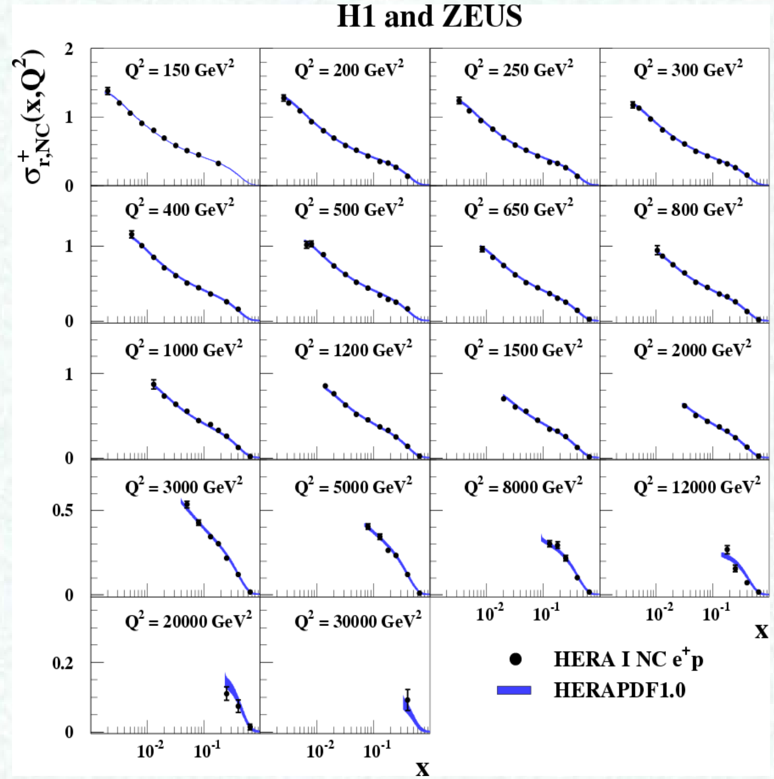
Combination of H1 & ZEUS HERA I data provides a model independent tool to study consistency of the data and to reduce systematic error!

F_2 with combined e+p NC

Low/medium Q^2 bins (2-150 GeV^2)



High Q^2 bins(150-30000 GeV^2)

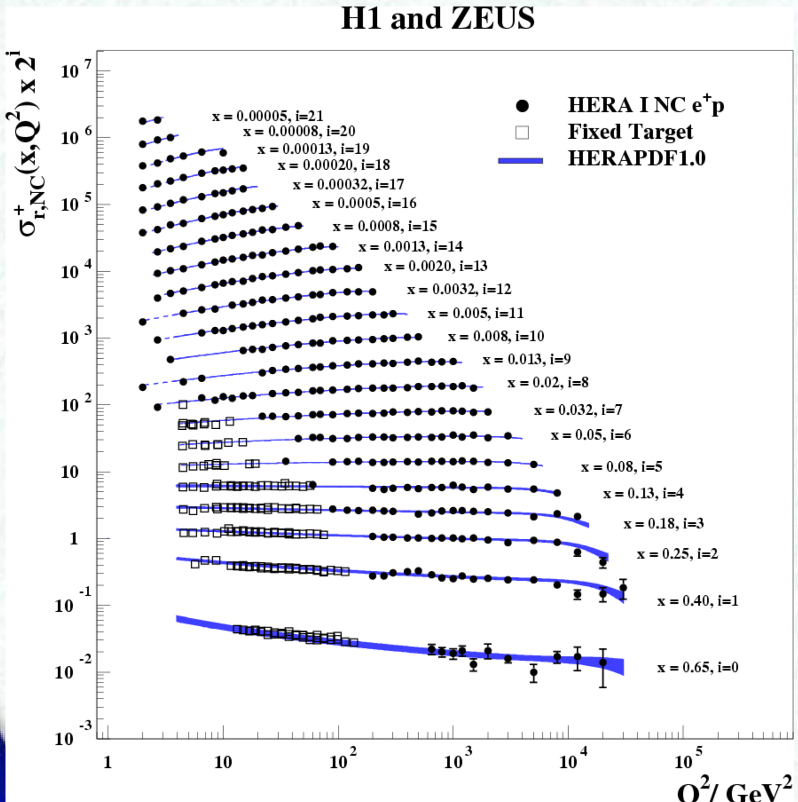


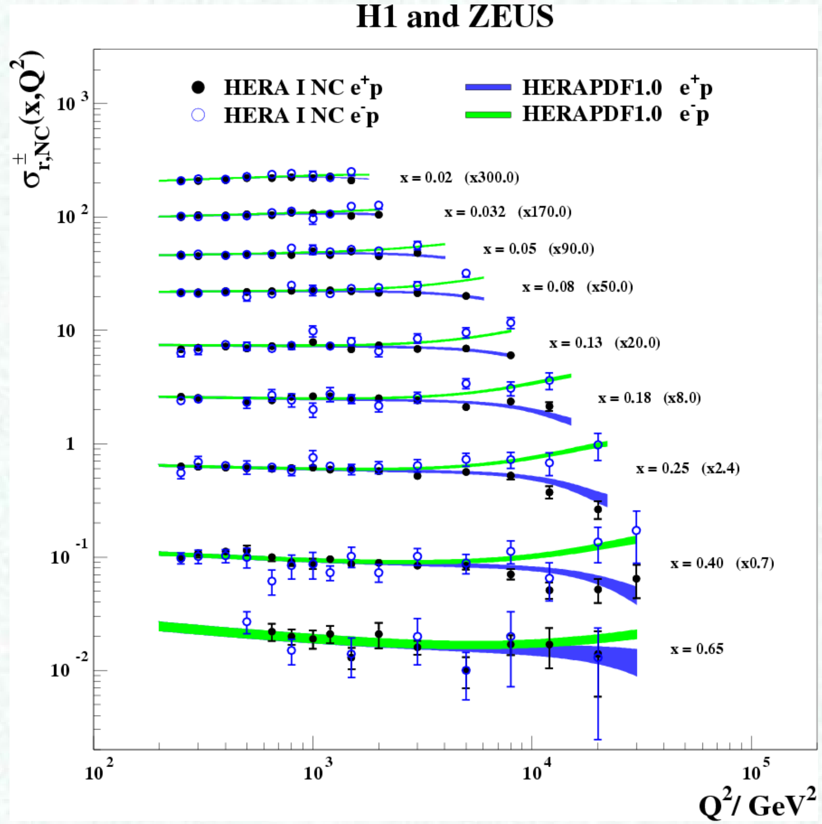
- **F_2 (x,Q^2) shows strong rise as $x \to 0$, the rise increases with increasing Q^2**
- **Data well described by QCD fit from Q^2=2 to 30000 GeV^2**

HERA combined NC data

➢Data show strong **scaling violations at low x** → large gluon density

➢NC data at high-Q2:
Zγ interference **destructive (e+p)** and **constructive (e-p)**





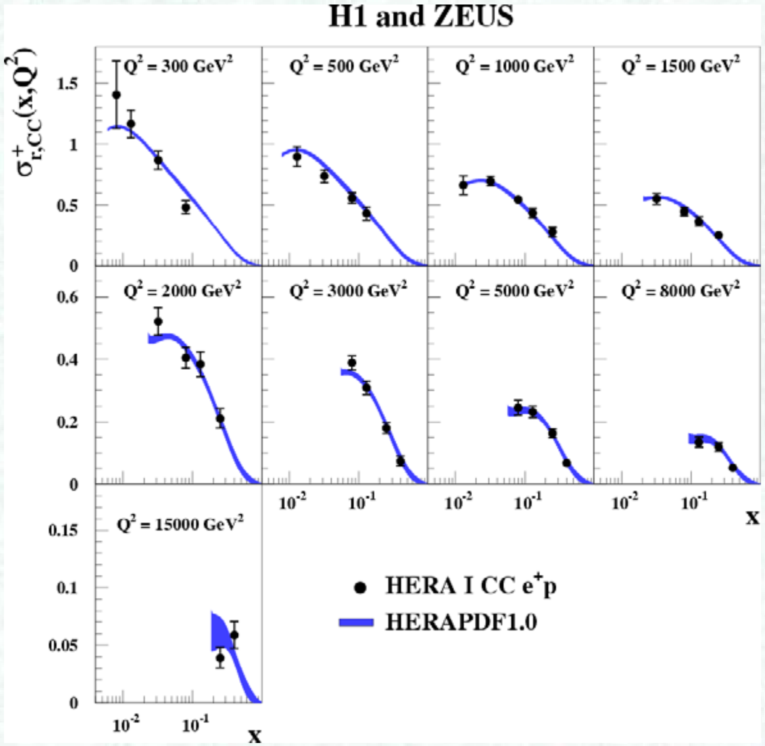
Good agreement between data and NLO QCD fit!

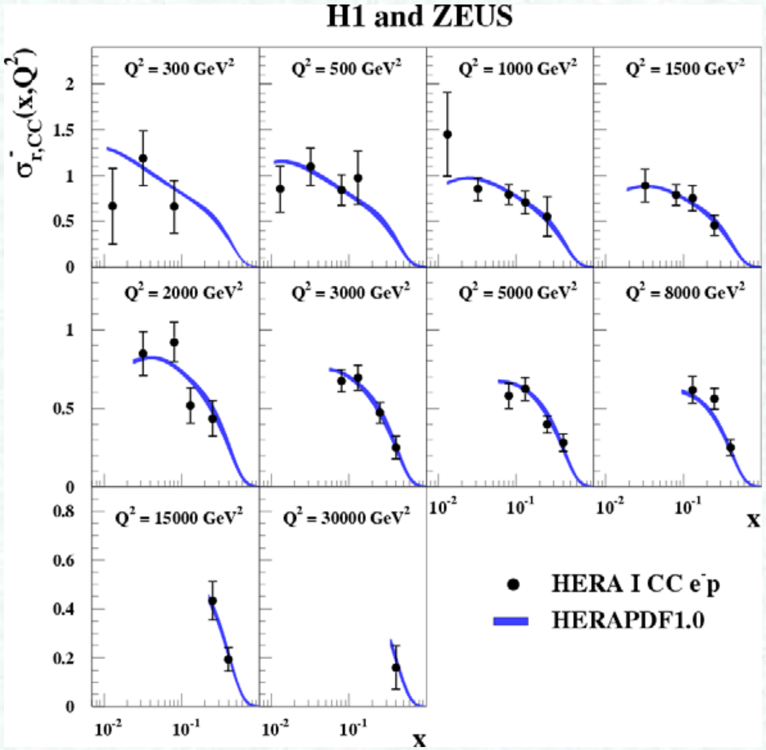
HERA combined CC data

- CC e^+p / e^-p allows to disentangle contributions of d and u quarks
- Probes flavor structure of the proton

$$\tilde{\sigma}_{cc}^{e+p} \sim \bar{u} + \bar{c} + (1-y)^2 (d+s)$$

$$\tilde{\sigma}_{cc}^{e-p} \sim u + c + (1-y)^2 (\bar{d}+\bar{s})$$





- e^+p most sensitive to $d(x,Q^2)$
- e+p valence quarks suppressed by factor $(1-y)^2$

- e^-p most sensitive to $u(x,Q^2)$

HERA-I QCD fit - HERAPDF1.0

- Fit uses **combined H1&ZEUS NC, CC data only**
- DGLAP equations at **NLO in MSbar scheme**
- Parameterize parton distribution functions at starting scale and evolve with Q^2.
- **Thorne-Roberts Variable Flavour Number Scheme** (as for MSTW08):
  →takes the quark masses into account

Scheme	TRVFNS
Evolution	QCDNUM17.02
Order	NLO
Q_0^2	1.9 GeV^2
$f_s = s/D$	0.31
Renorm. scale	Q^2
Factor. scale	Q^2
Q^2_{min}	3.5 GeV^2
$\alpha_S(M_Z)$	0.1176
M_c	1.4 GeV
M_b	4.75 GeV

PDFs at the starting scale parameterised as:

$$xf(x,Q_0^2) = Ax^B(1-x)^C(1+Dx+Ex^2)$$

where xf = xu_{val}, xd_{val}, xg, xUbar, xDbar

PDF	A	B	C	D	E
xg	sum rule	FIT	FIT	-	-
xu_{val}	sum rule	FIT	FIT	-	FIT
xd_{val}	sum rule	$=B_{u_{val}}$	FIT	-	-
$x\overline{U}$	$\lim_{x\to 0}\bar{u}/\bar{d} \to 1$	FIT	FIT	-	-
$x\overline{D}$	FIT	$=B_{\overline{U}}$	FIT	-	-

Results:
10 parameters for central fit
$\chi 2/n_{dof}$ = 574/582

HERA-I QCD fit - uncertainties

- **Experimental uncertainty:**
  Take into account experimental errors including, correlations bin to bin and between experiments/datasets => $\Delta\chi^2=1$

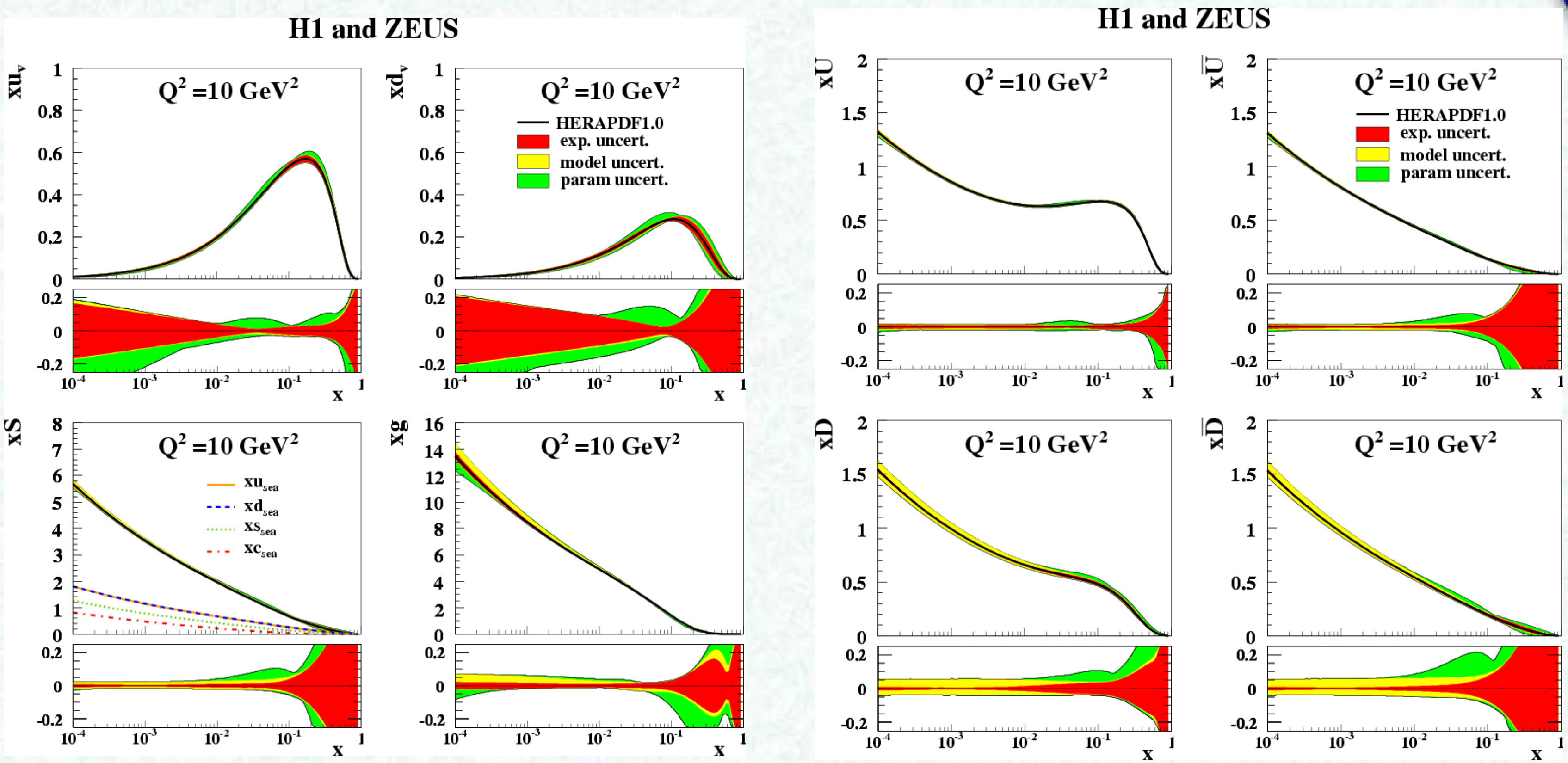
- **Model uncertainty includes theoretical errors:**

Variation	Standard Value	Lower Limit	Upper Limit
f_s	0.31	0.23	0.38
m_c [GeV]	1.4	$1.35^{(a)}$	1.65
m_b [GeV]	4.75	4.3	5.0
Q^2_{min} [GeV^2]	3.5	2.5	5.0
Q^2_0 [GeV^2]	1.9	$1.5^{(b)}$	$2.5^{(c,d)}$

$^{(a)}Q^2_0 = 1.8$ $^{(c)}m_c = 1.6$
$^{(b)}f_s = 0.29$ $^{(d)}f_s = 0.34$

- **Parameterisation uncertainty:**
  Vary parameterisation of PDFs at starting scale by adding in extra parameters in the fit

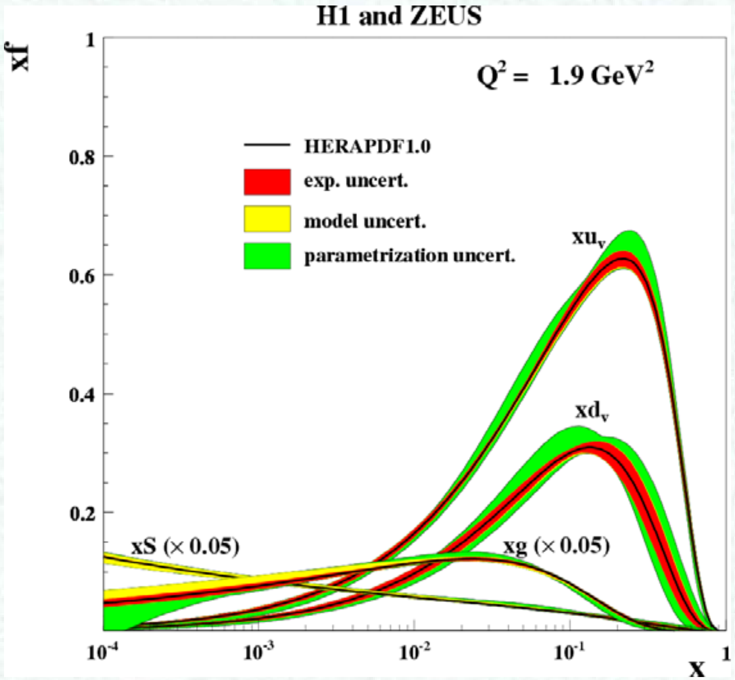
HERAPDF1.0 at Q^2=10GeV^2

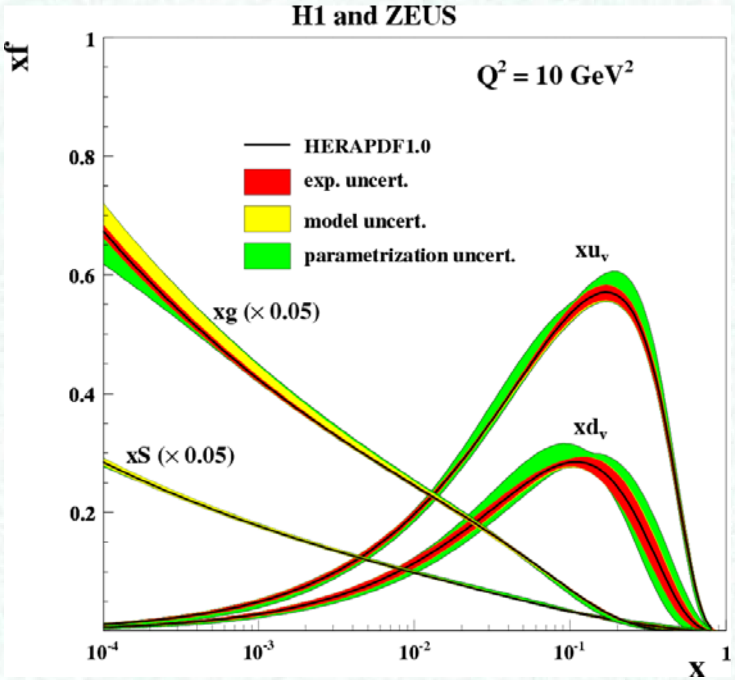


- **High precision** for sea and gluon at **low x**
- **Reasonable precision for valence at high x**
- **Gluon error relatively large at high x**

HERAPDF1.0

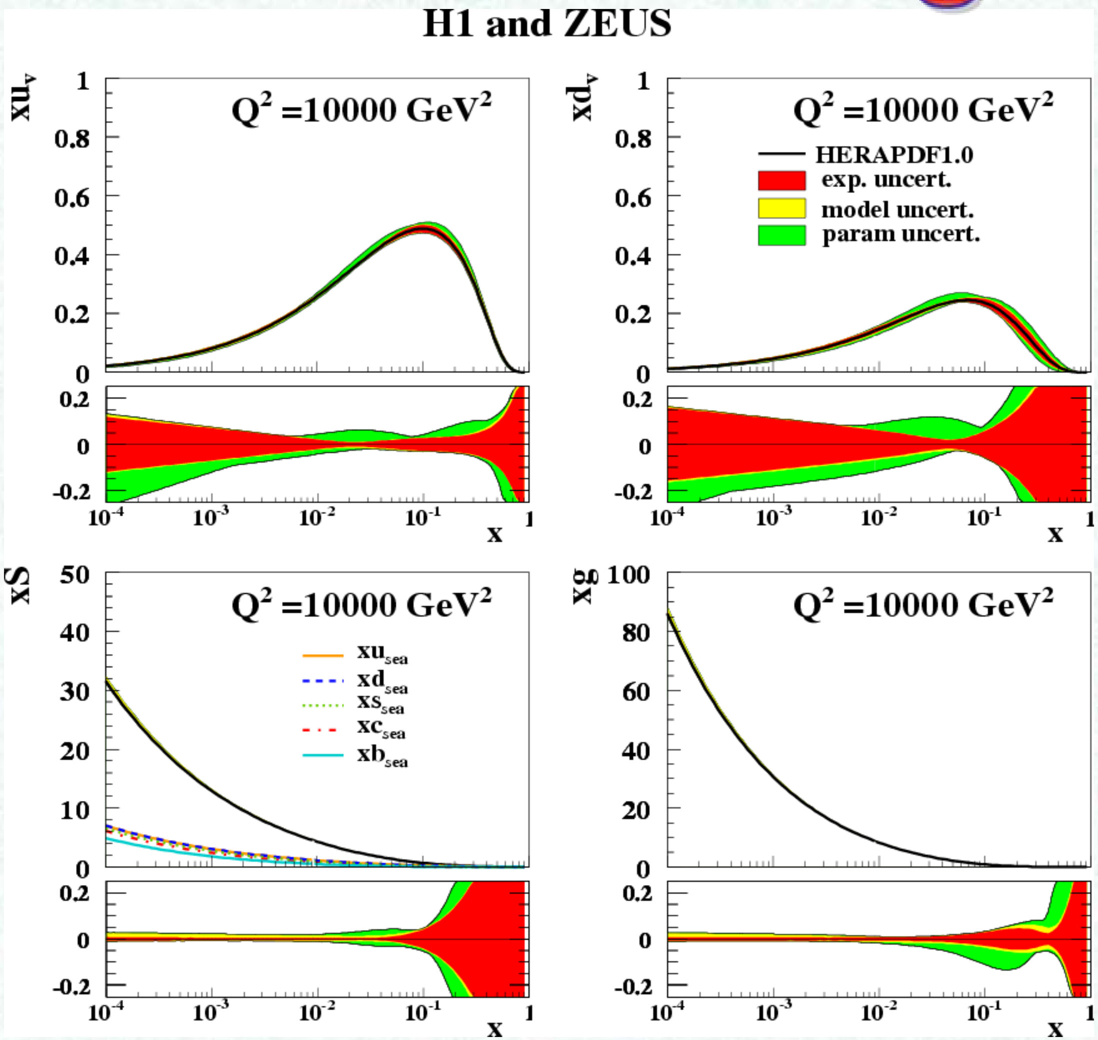
Distributions for valence quarks, see and gluons





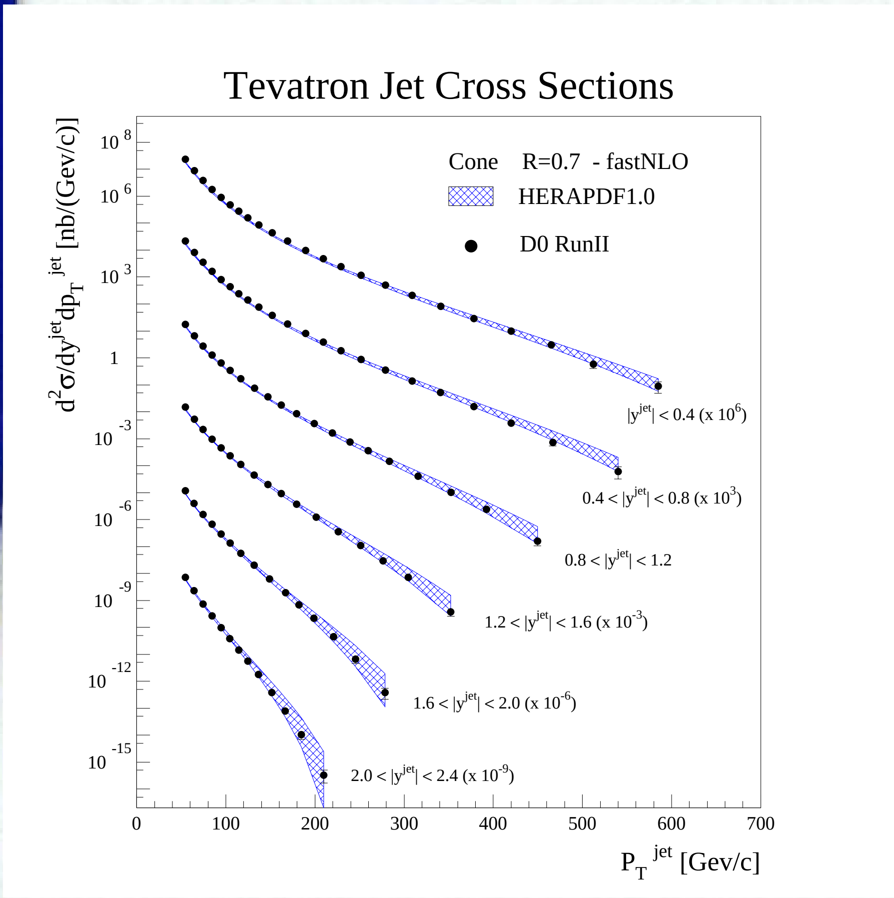
Gluon and see distributions are scaled by factor 20

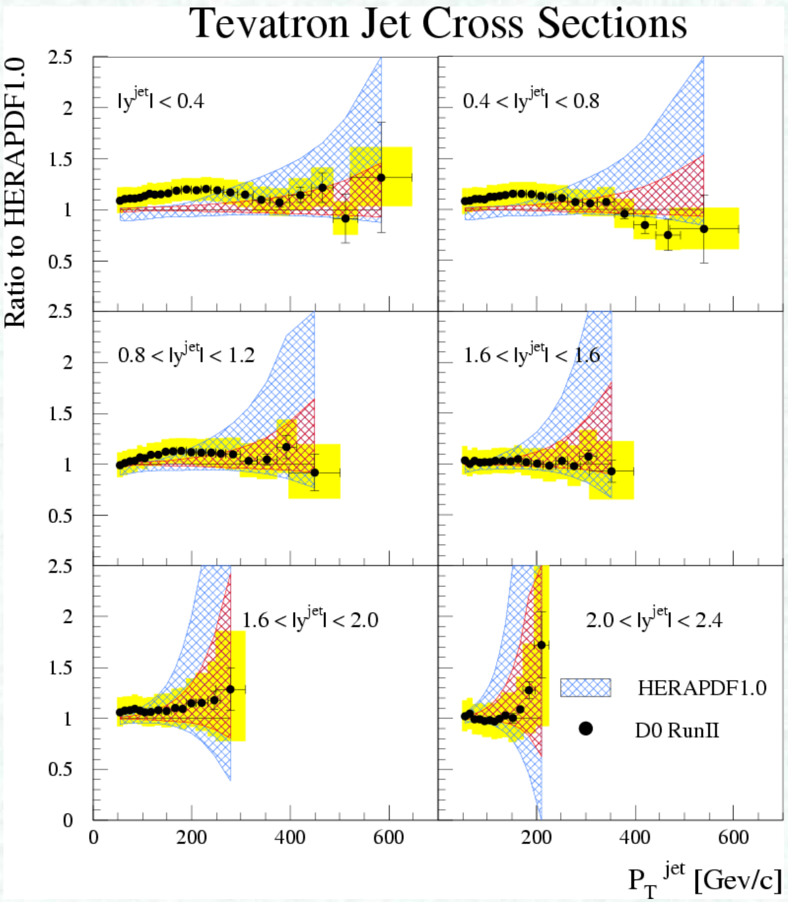
HERAPDF1.0 at high Q^2



Small errors on gluon & see distributions at LHC energies
→ enables precise predictions for LHC cross sections

HERAPDF1.0: Crosscheck with TeVatron data





HERAPDF1.0 describes TeVatron data up to the high-Et jet production!

Ratio of D0 high Et jet cross-section to HERAPDF1.0 prediction:

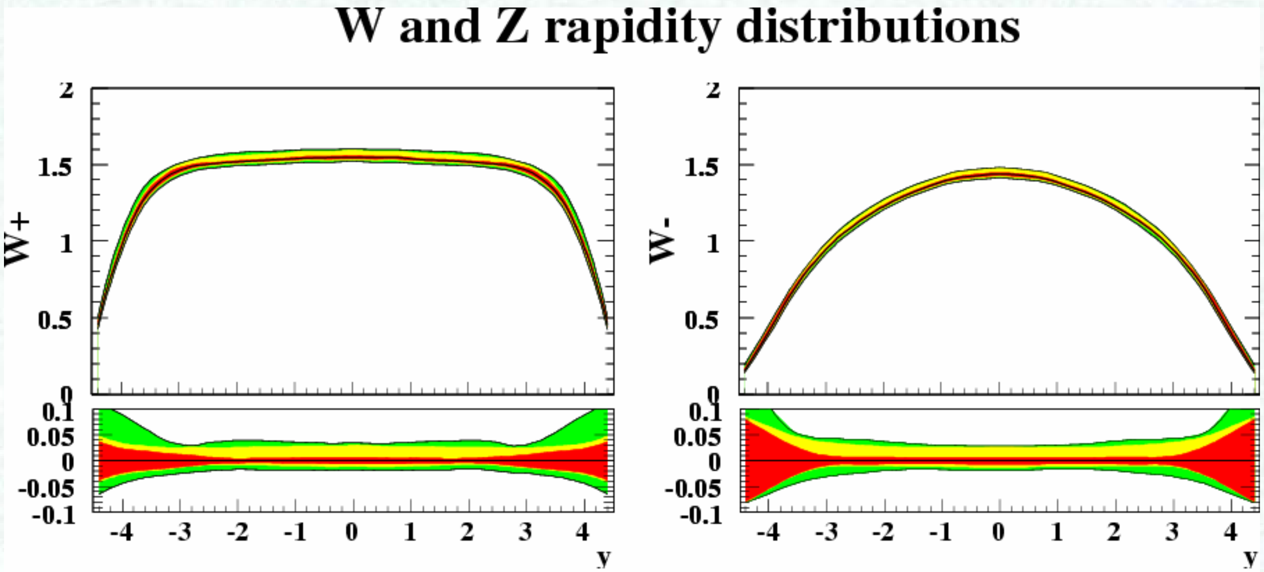
- Total PDF uncertainty blue

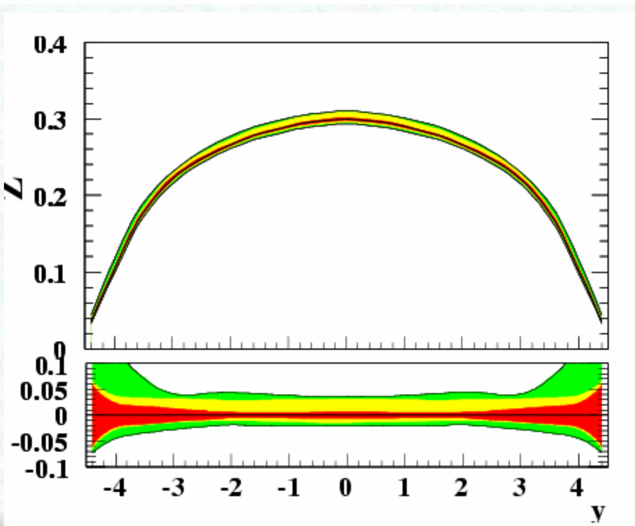
- PDF experimental red

- Systematic experimental error yellow

HERAPDF1.0: Impact on LHC

Predictions for the W/Z production cross sections using HERAPDF1.0 (including experimental, model and parameterisation uncertainties)





- **Precision:**
  4% uncertainties in the central rapidity range
- **Improvement is expected with HERAII data at large y (high-x)**

Summary

- The H1 and ZEUS HERA-I cross sections have been combined using a model-independent approach that leads to a cross-calibration of the H1 and ZEUS measurments:
  - Combined data span six orders of magnitude in x and Q2
  - Large reduction of the systematic uncertainties
  - 1%-level precision for $20 < Q^2 < 100$ GeV^2

- Combined cross-sections used as sole input in a new QCD analysis resulting in a new set of PDFs (HERAPDF1.0):
  - Detailed study of the uncertainties of the PDFs (exp, model, parametrisation)
  - %-level accuracy at low x, at medium-x and high-Q2 ➔ expected improvement with HERAII data

- **HERAPDF1.0 has been published & it can be used:**

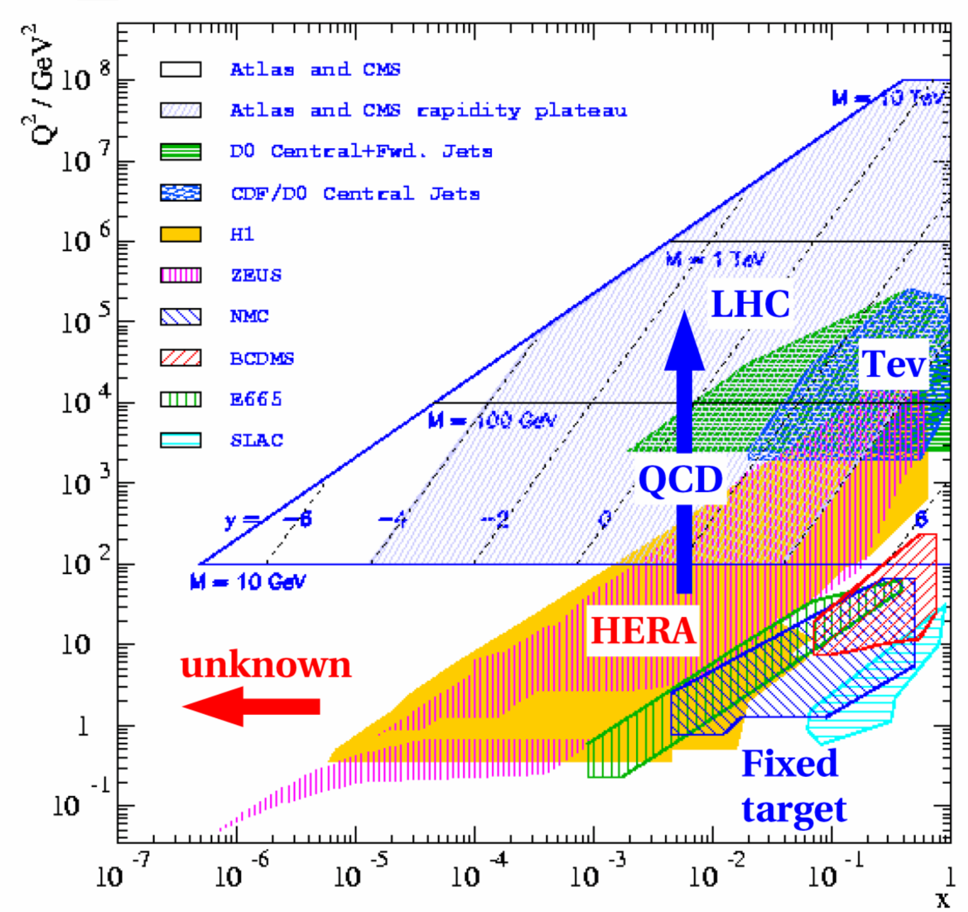
https://www.desy.de/h1zeus/combined_results/benchmark/herapdf1.0.html

- **LHC:** HERAPDF1.0 is good for the central rapidity region at the scale of W/Z
- **TeVatron:** HERAPDF1.0 describes the data- up to the high-Et jet production

Latest results in fitting combined F_L data and F_2 charm (talks by: H. Kowalski, V. Radescu)

Extra-slides

Kinematic plane

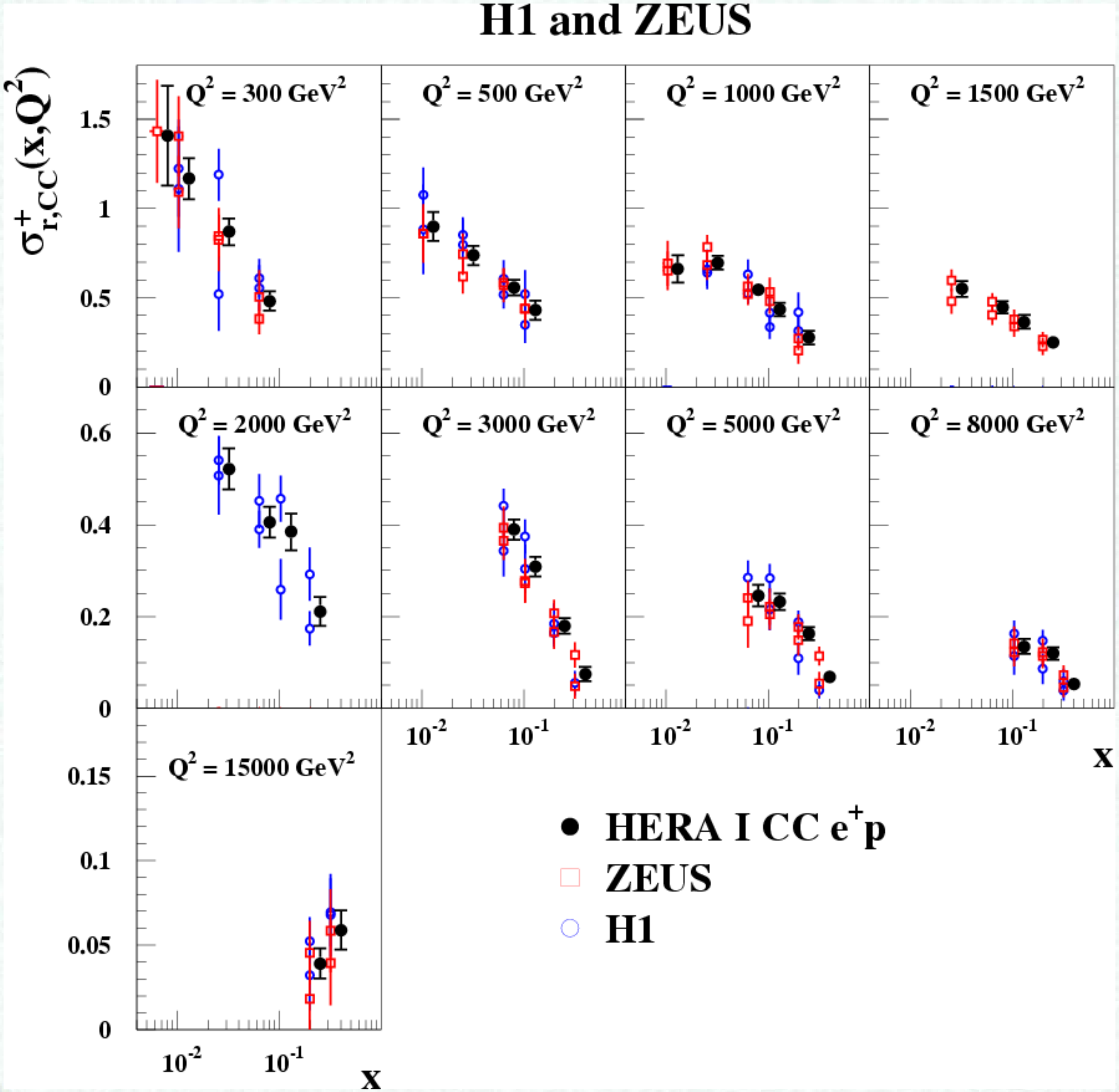


QCD evolution extrapolates HERA measured PDFs to LHC

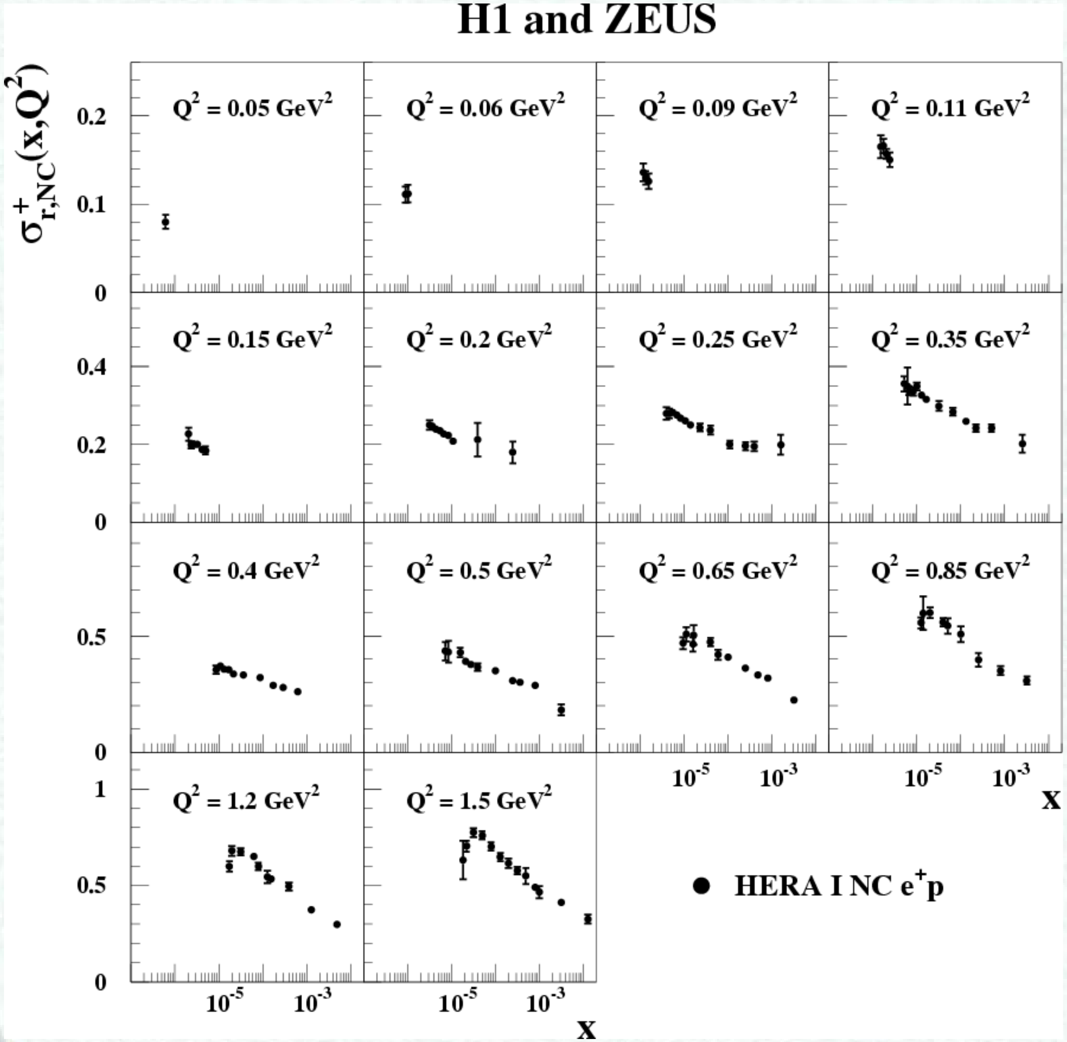
PDF's obtained in low x regime at HERA are applicable to LHC

HERA data cover LHC central rapidity range for M > 100 GeV

HERA combined CC e+p

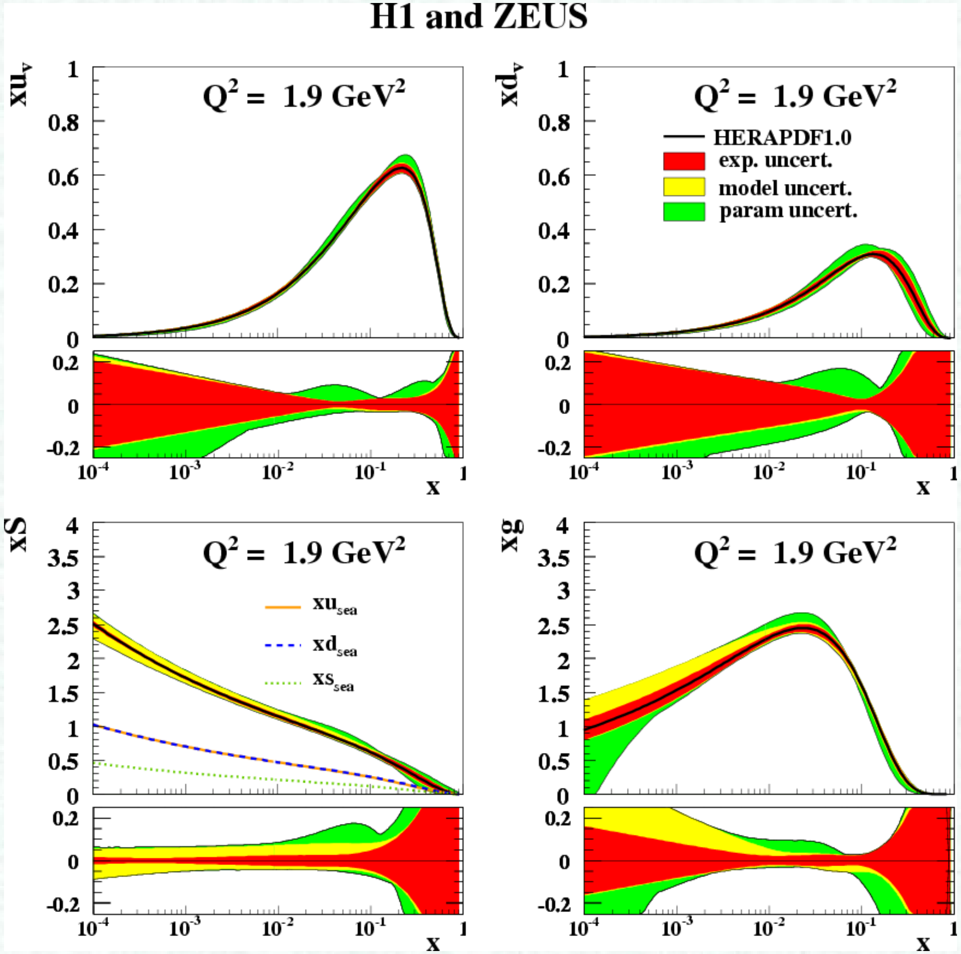


HERA combined NC e+p at very low Q2

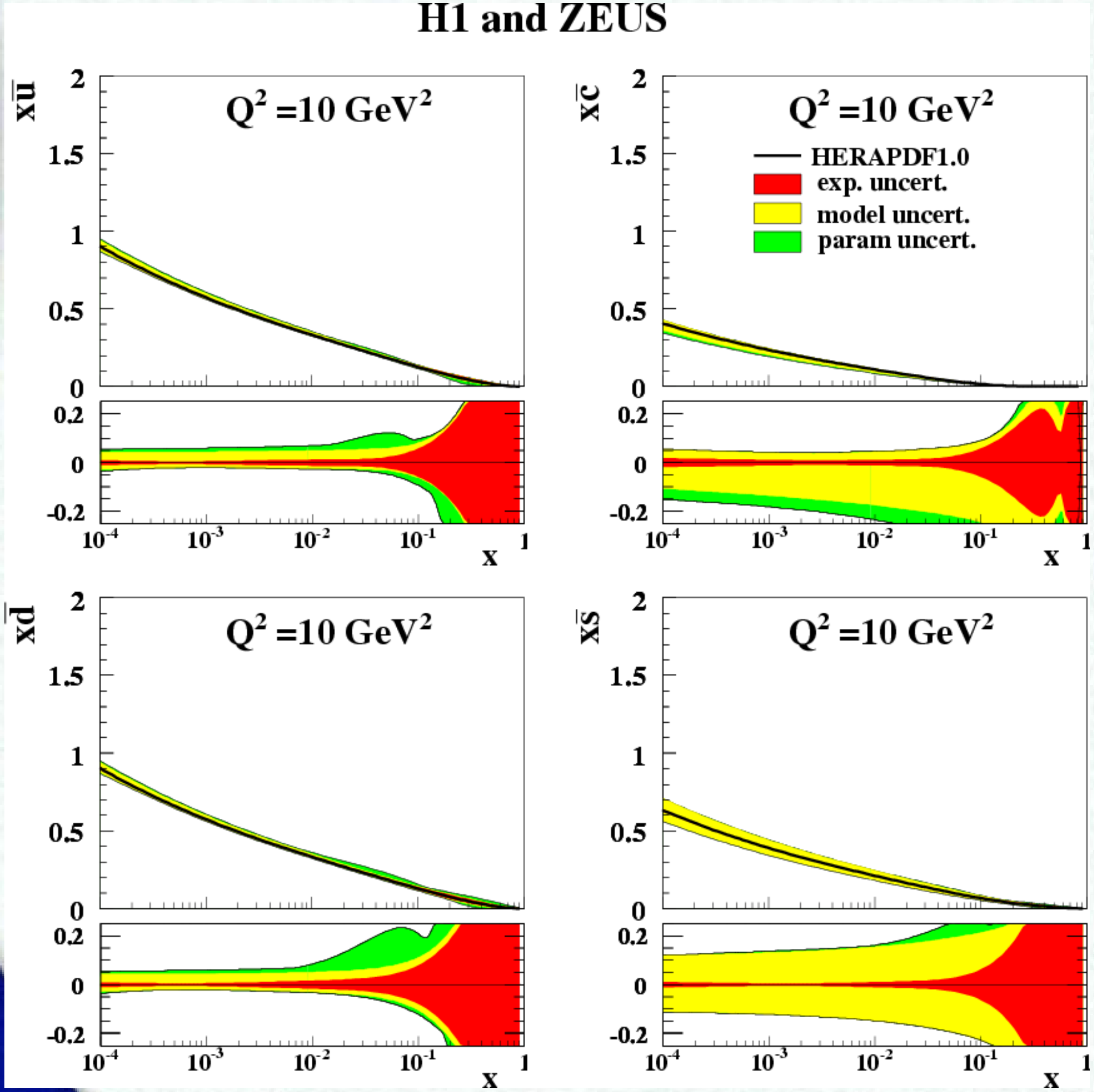


- Data shown in very low Q^2 region (0.05-1.5 GeV2)
- pQCD not expected to work in the very low Q^2 region.

PDF from HERAPDF1.0 at low Q2

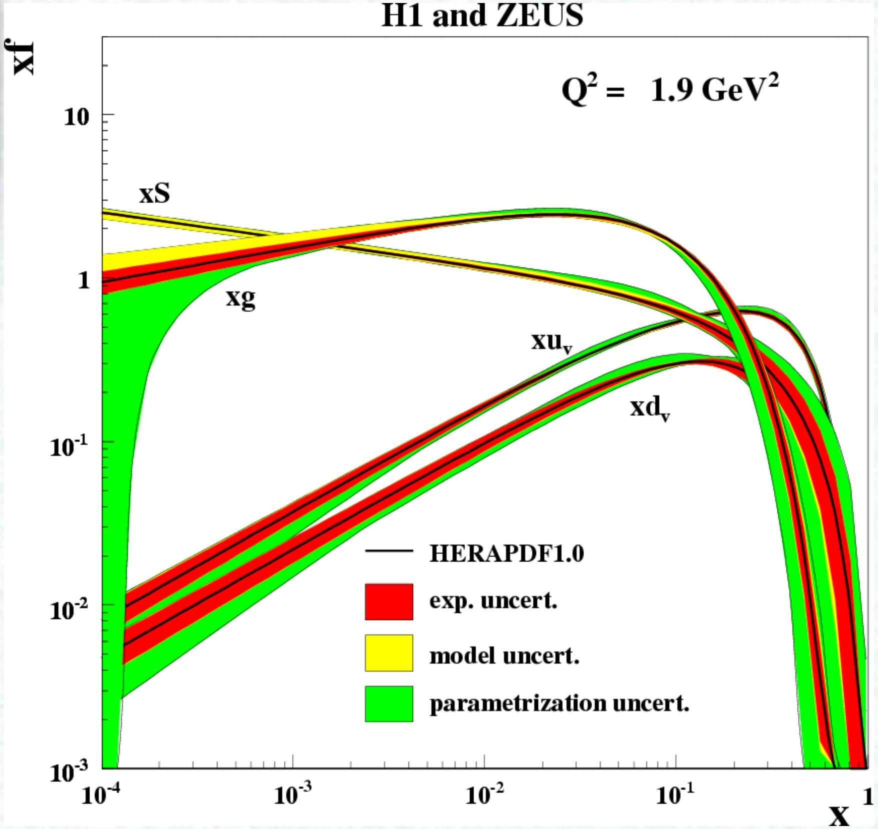


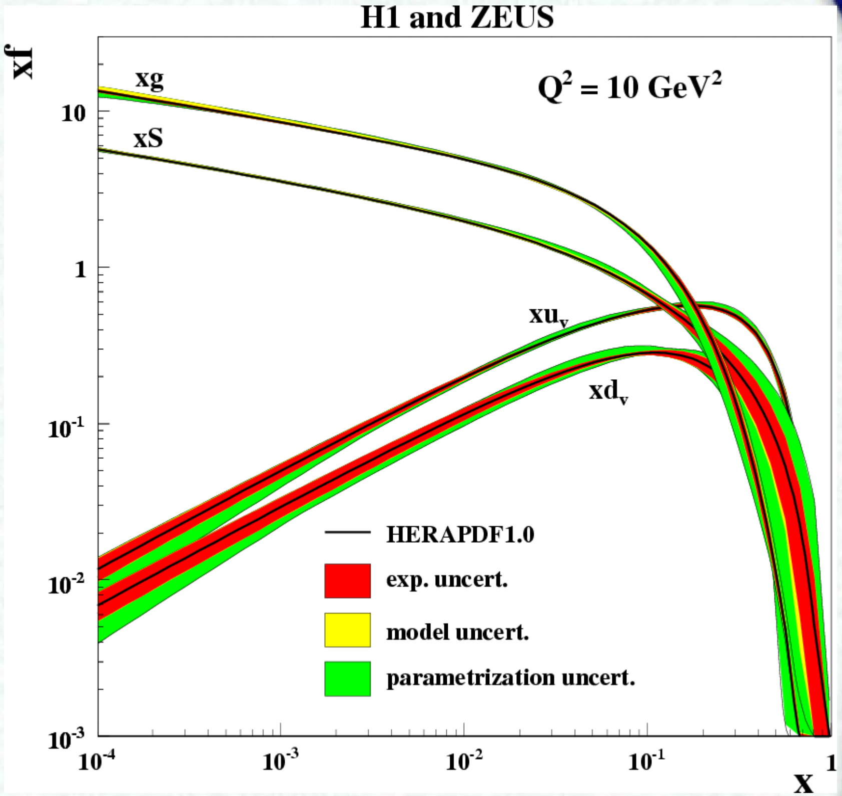
HERAPDF1.0



Parton Distribution Function xu, xd, xs and xc at Q^2 = 10 GeV^2

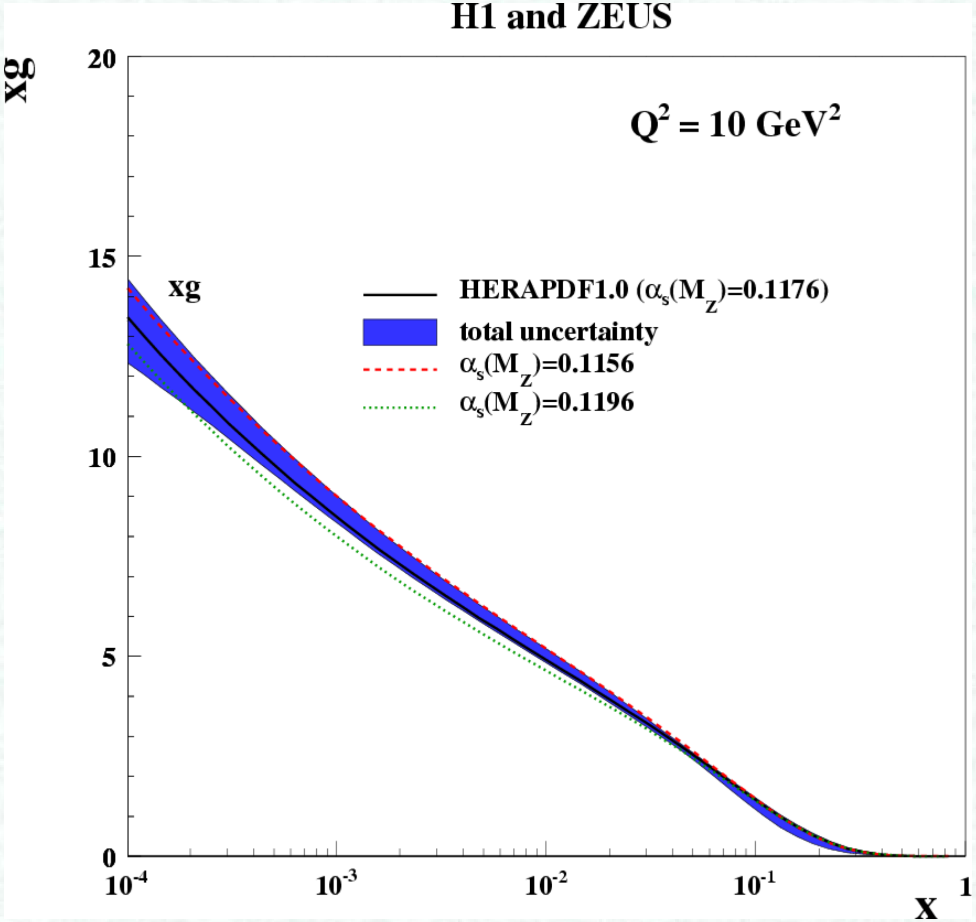
PDF from HERAPDF1.0



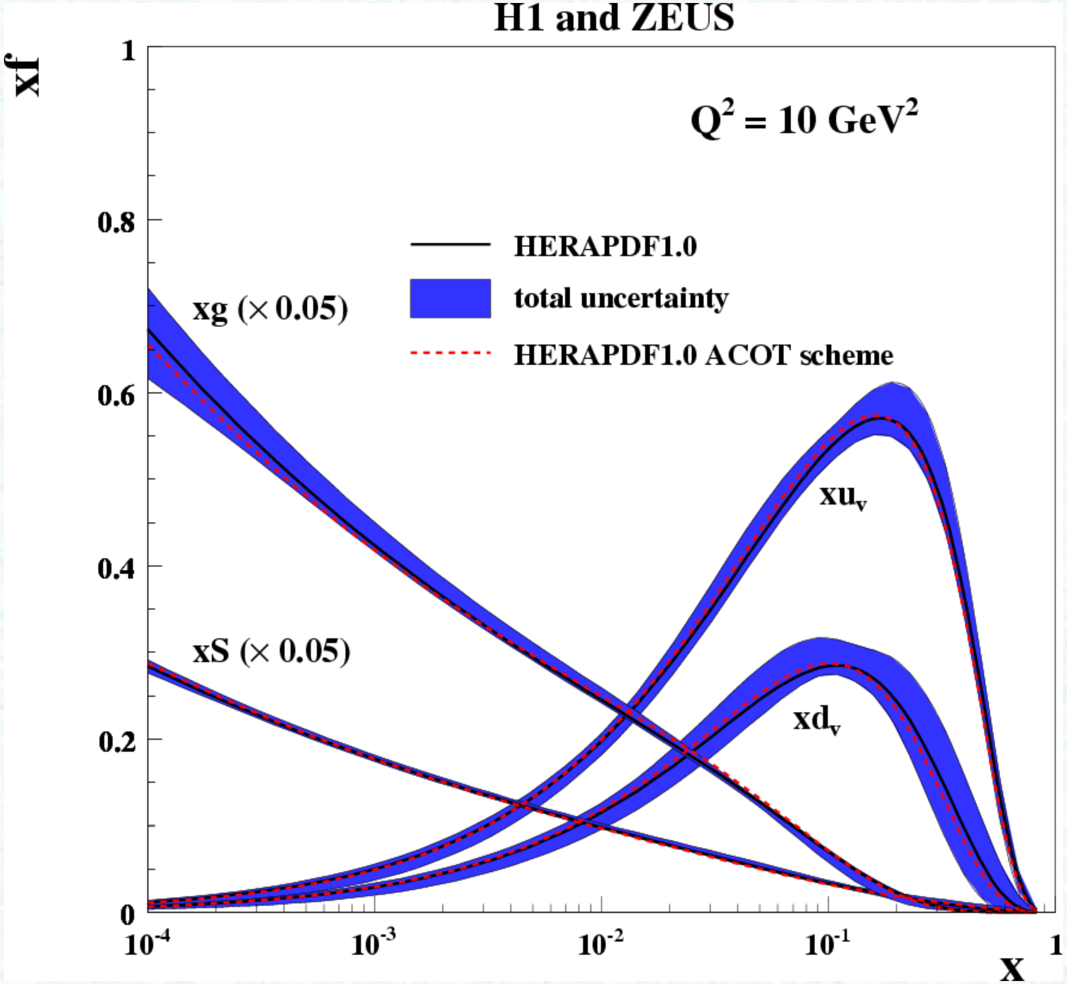


Distributions for valence quarks, see and gluons (logarithmic scale)

Gluon density vs different α_s values

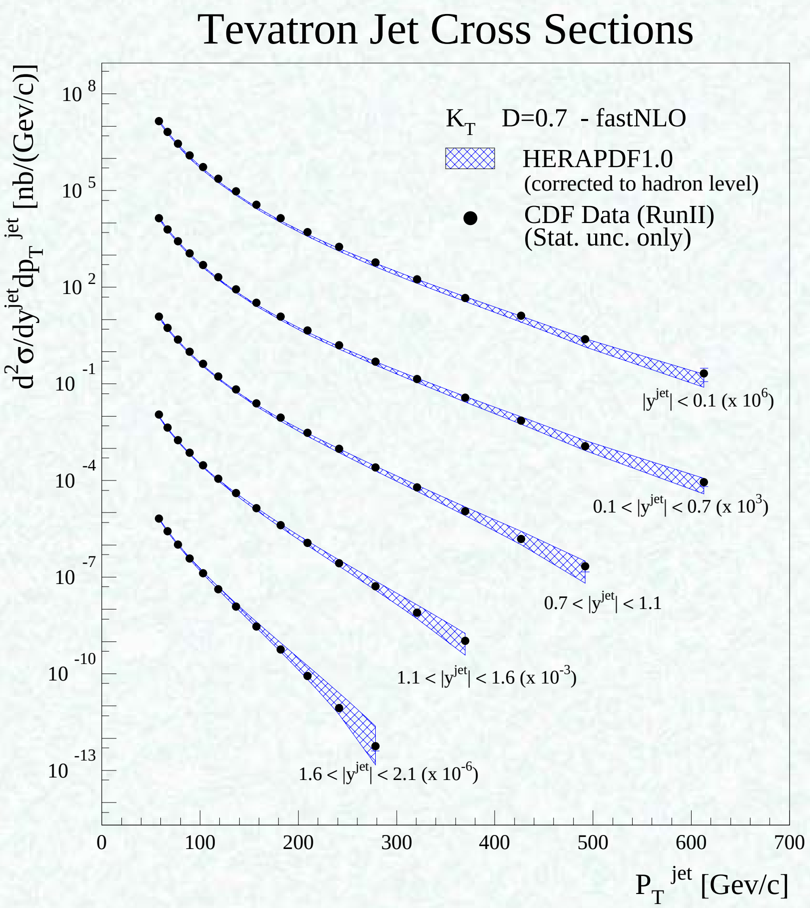


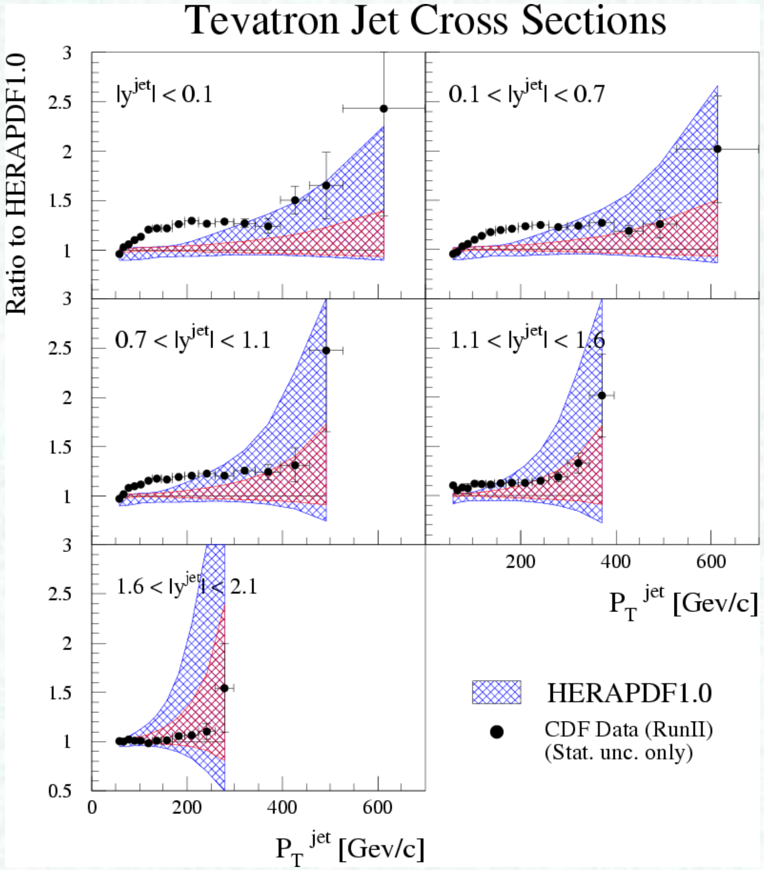
HERAPDF1.0 vs. HERAPDF1.0 ACOT scheme

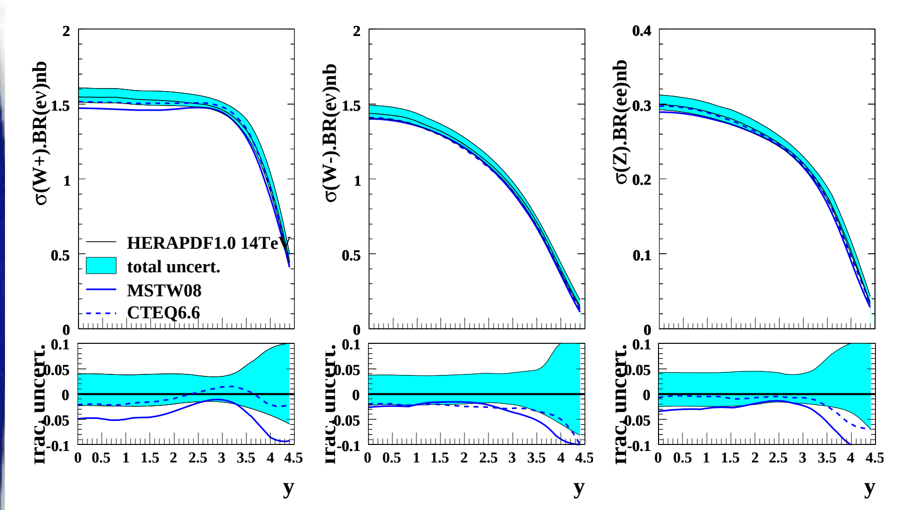


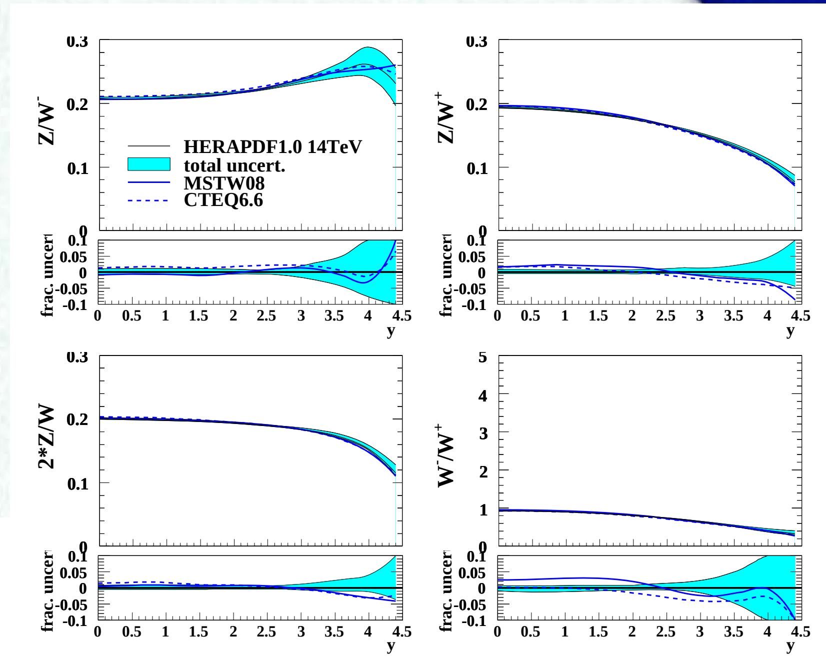
Distributions for valence quarks, see and gluons

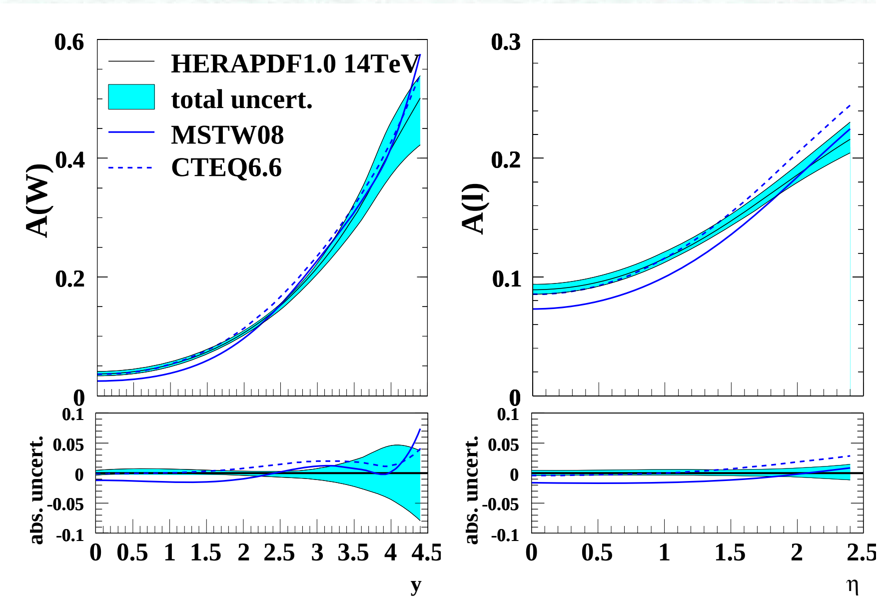
CDF jet data with HERAPDF1.0











HERAPDF1.0 predictions for W/Z production at LHC

These are at 14TeV but 10TeV and 7TeV exist

These show the full uncertainty bands of HERAPDf1.0 and compare to CTEQ66 and MSTW08 central values

Procedural Uncertainties

1. **Additive vs Multiplicative nature of the error sources**

Only normalizations uncertainties are taken as multiplicative
(=> Typically below 0.5%, a few % at high-Q2)
A general study of the possible correlated systematic uncertainties between H1 and ZEUS has been performed:
- Identified 12 possible uncertainties of common origin
- compared 212 averages taking all pairs as corr/uncor in turn

Mostly negligible except for:

2. **Correlated syst. uncert. for the photoproduction background**

(Typically below 0.5%, but larger at high-y)

3. **Correlated syst. uncert. for the hadronic energy scale**

(Typically below 0.5%, significant only at low-y)