HERAFitter a tool for PDFs and more

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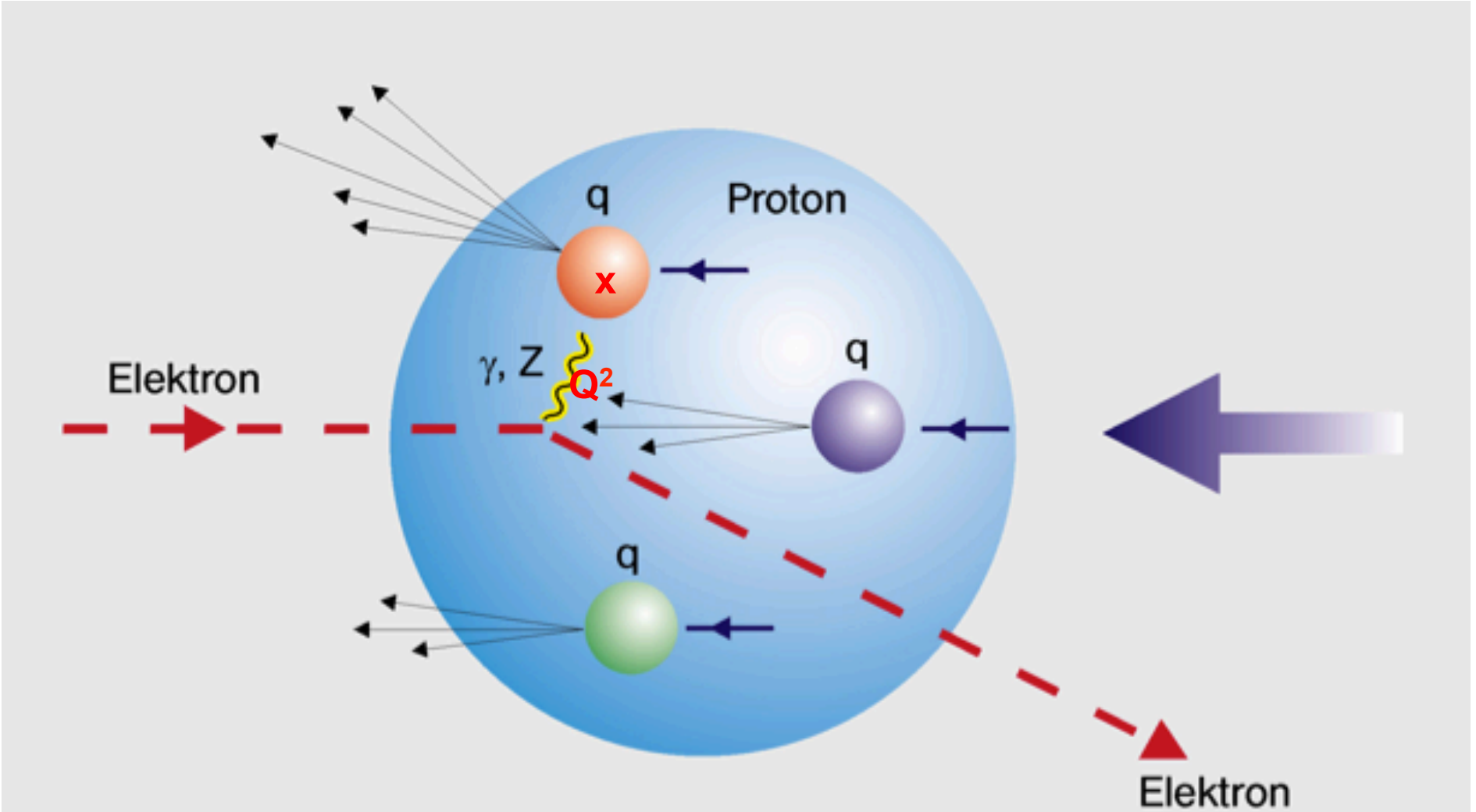
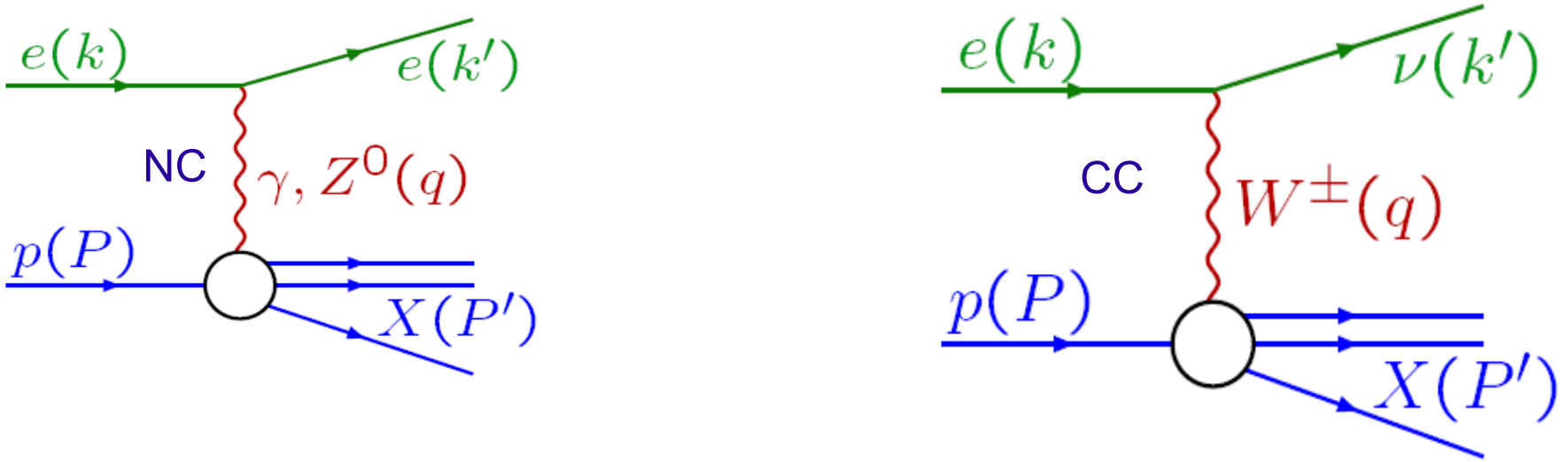
Deep-Inelastic Scattering



Kinematics x, Q2 can be measured from the detected particles

Charged current interactions also accessible (neutrino in the final state)

Deep-Inelastic Scattering



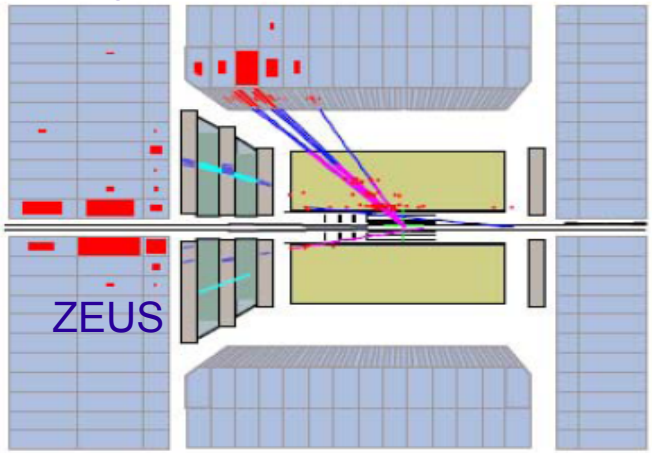
- $Q^2 = -q^2 = -(k - k')^2$ virtuality/resolving power
- $x = \frac{Q^2}{2P \cdot q}$ Bjorken scaling variable, momentum fraction of the scattered parton
- $y = \frac{q \cdot P}{k \cdot P}$ inelasticity

Related by $Q^2 = xys$

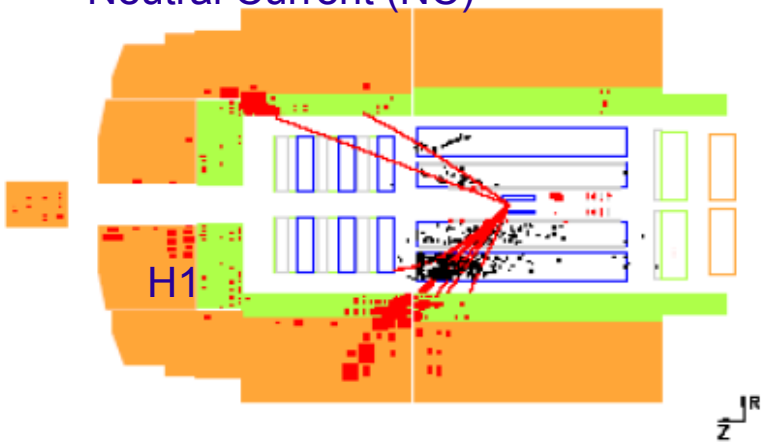
Partons = Quarks + Gluons (QCD improved quark parton model)

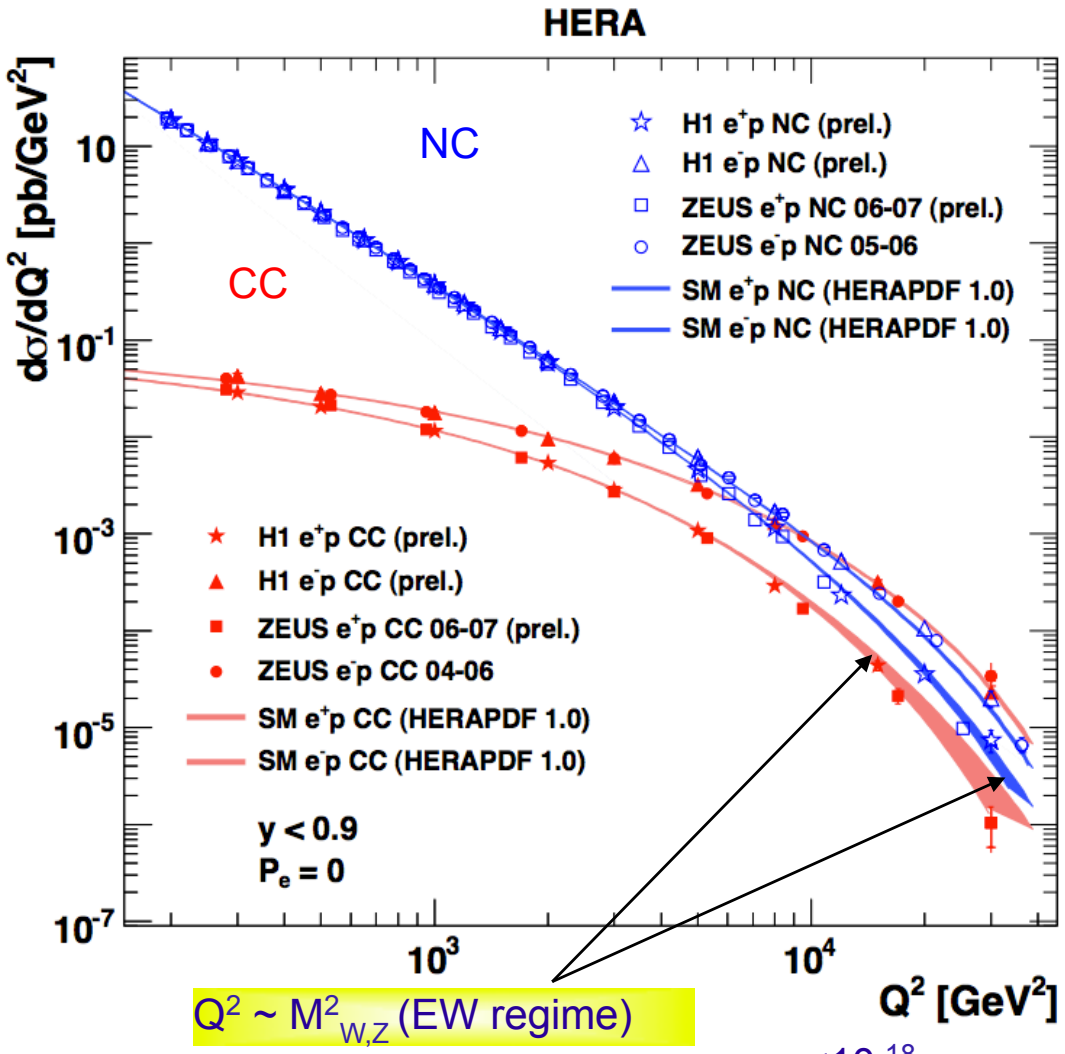
DIS at HERA

Charged Current (CC)



Neutral Current (NC)



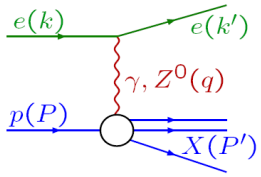


$Q^2 \sim M^2_{W,Z}$ (EW regime)

$r_{quark} < 10^{-18}$m

"p"/1000

DIS: Cross sections, structure functions, partons



$$\tilde{\sigma}^{\pm}_{NC} = \frac{\mathrm{d}^2\sigma^{e^{\pm}p}_{NC}}{\mathrm{d}x\mathrm{d}Q^2}\frac{xQ^4}{2\pi\alpha^2 Y_+} = \tilde{F}_2 - \frac{y^2}{Y_+}\tilde{F}_L \mp \frac{Y_-}{Y_+}x\tilde{F}_3, \quad Y_\pm = 1 \pm (1-y)^2$$

Leading Order picture of the proton

Parton Distribution Functions

→ F_2 $\left[F_2, F_2^{\gamma Z}, F_2^Z\right] = x\sum_q \left[e_q^2, 2e_q v_q, v_q^2 + a_q^2\right](q + \bar{q})$ quarks

gluons from scaling violations

F_3 $\left[xF_3^{\gamma Z}, xF_3^Z\right] = 2x\sum_q \left[e_q a_q, v_q a_q\right](q - \bar{q})$ (valence) quarks

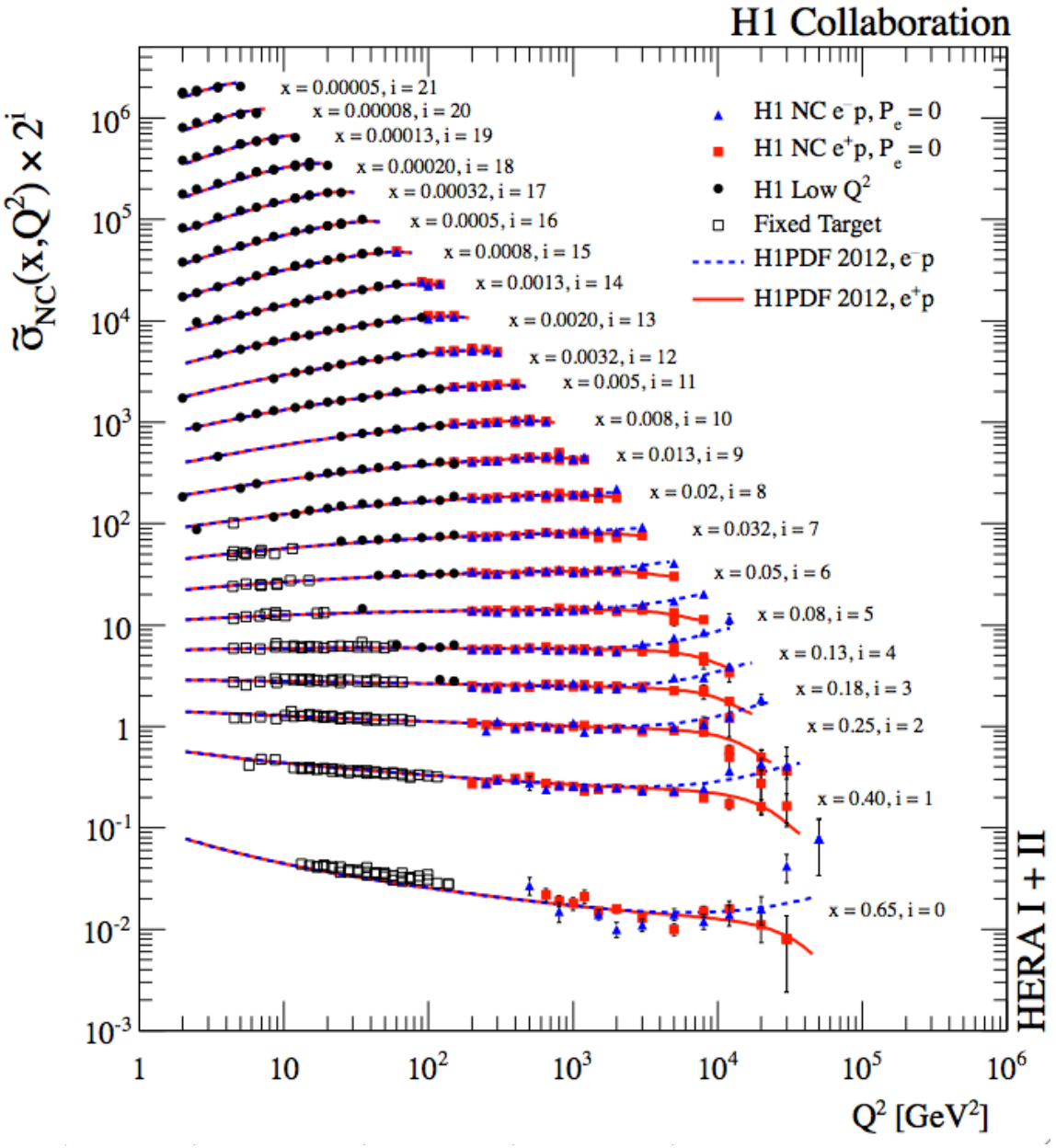
F_L $F_L \sim x\alpha_s g$ gluons

NC: weak flavor sensitivity $F_2 \sim 0.44x(u + \bar{u} + c + \bar{c}) + 0.11x(d + \bar{d} + s + \bar{s} + b + \bar{b})$

CC: similar decomposition, but different quarks combinations accessed

flavour sensitive (separate in e+p/e-p)

Measurements of the proton structure



$$\tilde{\sigma}^{\pm}_{NC} = \frac{\mathrm{d}^2\sigma^{e^{\pm}p}_{NC}}{\mathrm{d}x\mathrm{d}Q^2}\frac{xQ^4}{2\pi\alpha^2 Y_+}$$

Coherent data sets combined:

vast coverage of the proton “map”

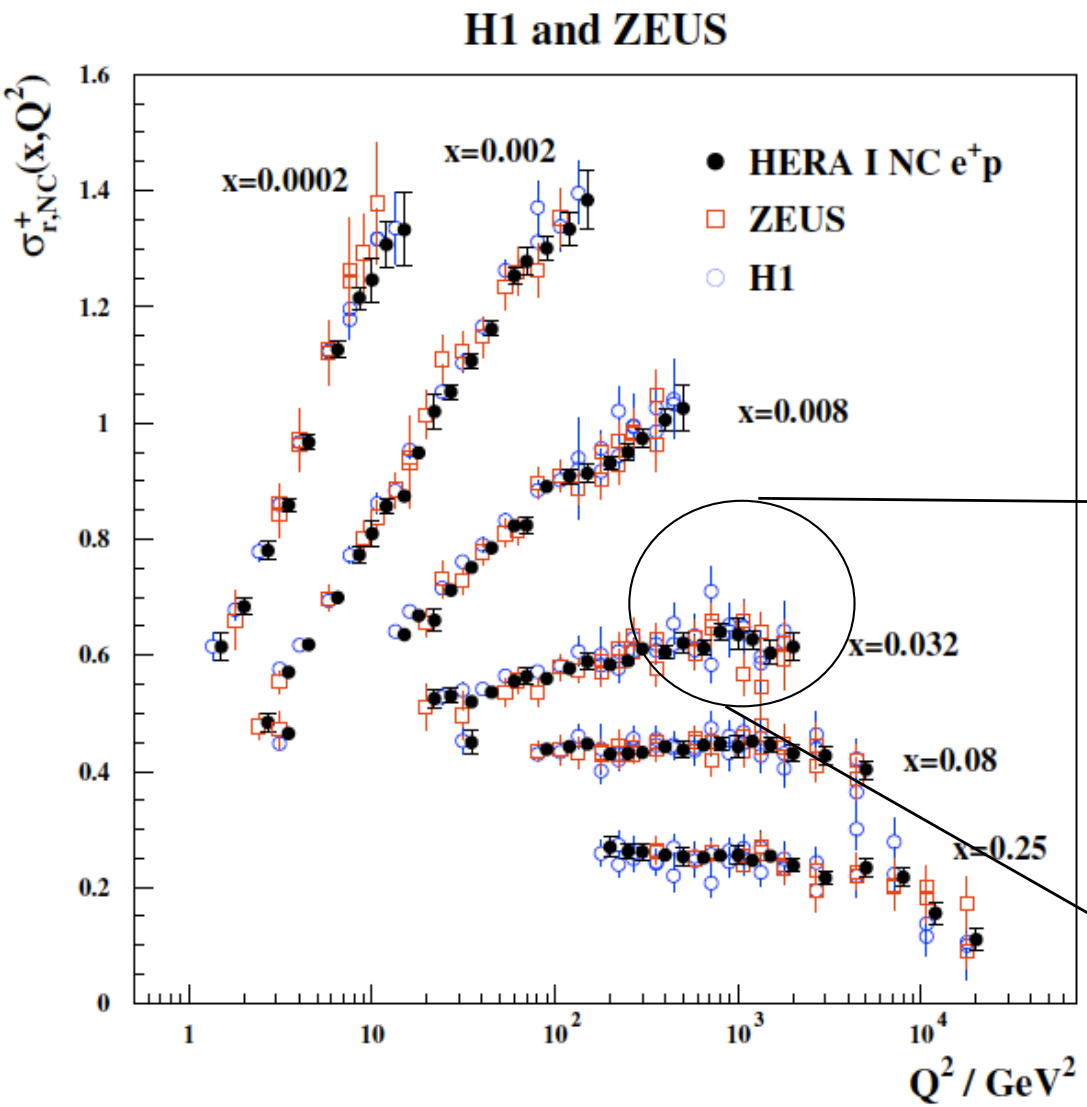
Scaling violations regions low x (gluon)

Constrain the

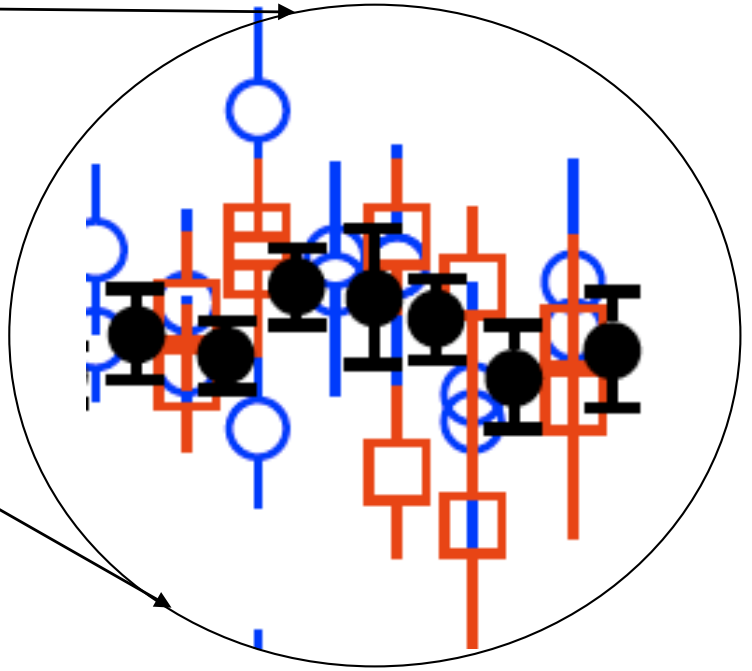
Parton Distribution Functions

PDFs

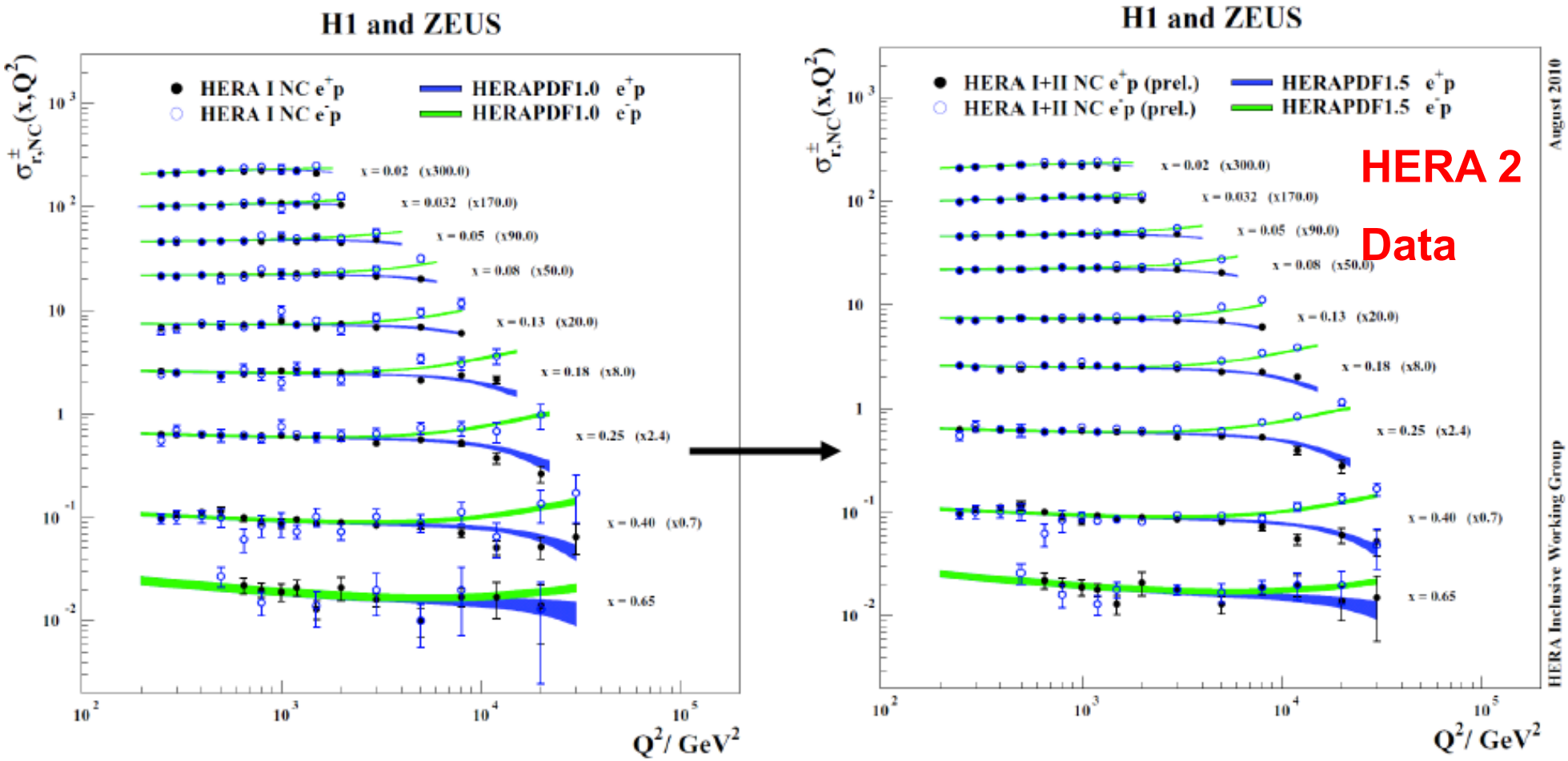
H1 and ZEUS DIS cross sections



Ultimate precision from combination

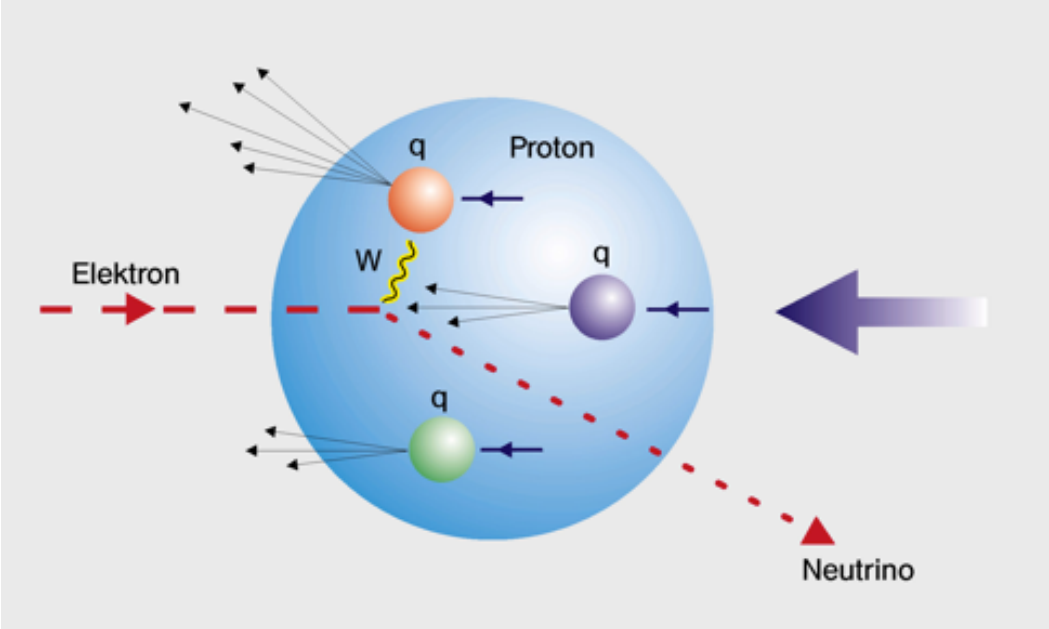


The electroweak regime



$$\tilde{F}_2 - \frac{y^2}{Y_+}\tilde{F}_L \mp \frac{Y_-}{Y_+}x\tilde{F}_3 \rightarrow 2x\sum_q \left[e_q a_q, v_q a_q\right](q-\bar{q})$$

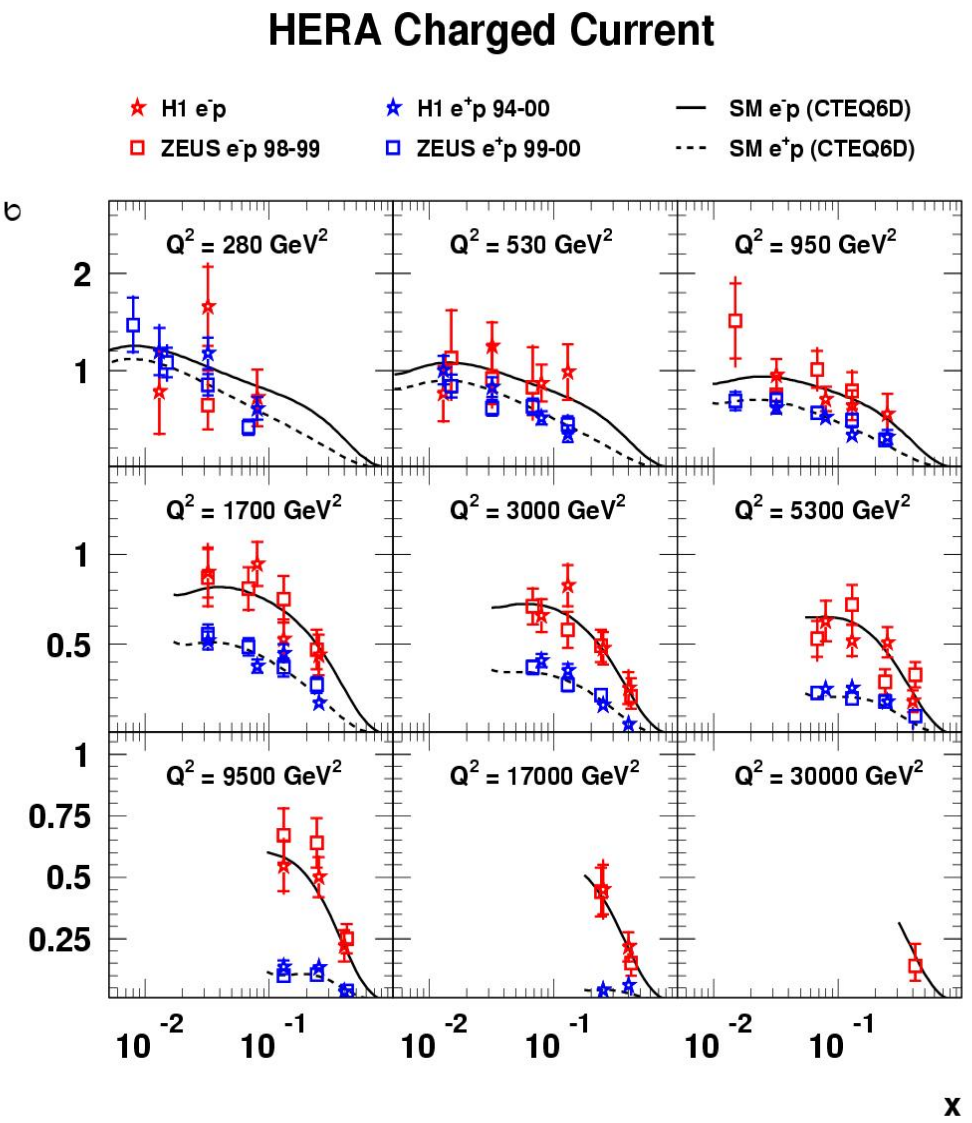
Charged Currents



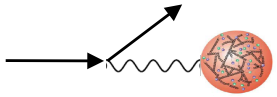
$$\tilde{\sigma}^{+}_{CC} \sim \overline{u} + \overline{c} + (1-y)^2 (d+s)$$

$$\tilde{\sigma}^{-}_{CC} \sim u + c + (1-y)^2 (\overline{d} + \overline{s})$$

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



The PDF determination: factorisation and evolution



Calculate — PDF:Extract from data

$$\sigma_{DIS} \equiv C_{\text{lepton}-\text{parton}} \otimes f(x, Q^2)$$

perturbative QCD — non-perturbative

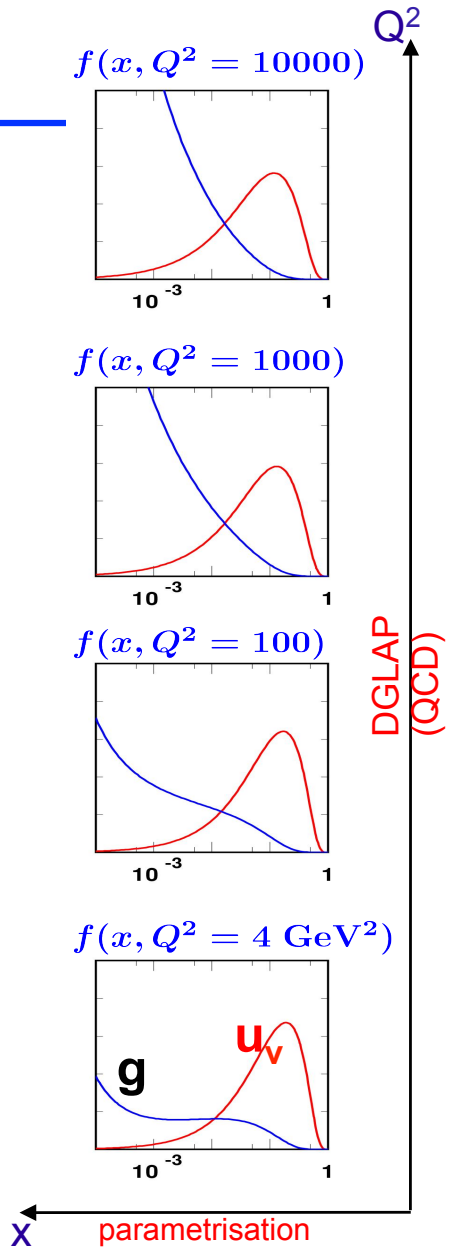
Process-dependent — Universal

factorisation

PDFs:

parametrisation as a function of x at a given scale Q^2_0

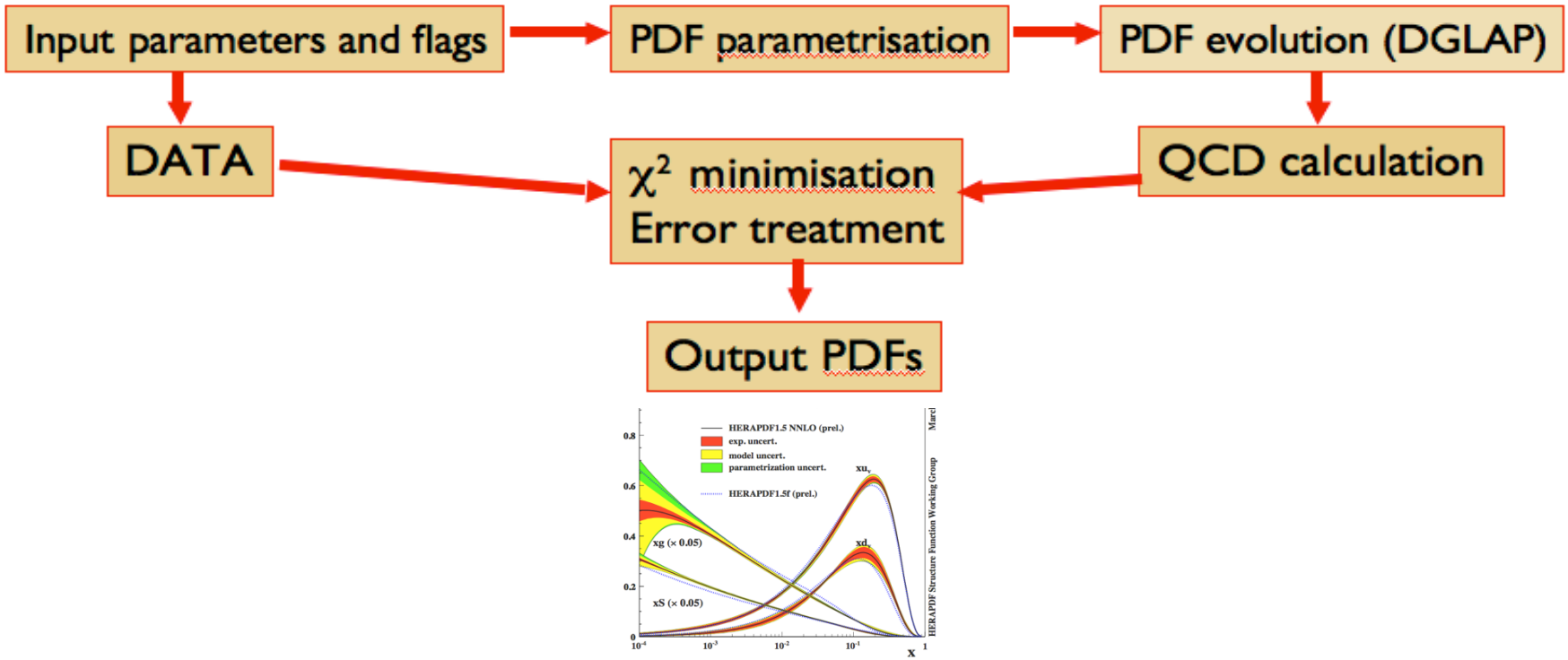
evolution in Q^2 **calculable** in QCD (DGLAP):



The PDF's play two key roles:

- nucleon chemistry: understand how the baryonic matter is made
- predictions for other processes (LHC)

Schematics of PDF extractions



PDFs are extracted from QCD fits to cross section data:

Parametrise PDFs at a starting scale by smooth functions with sufficient parameters;

Evolve PDFs to other scales by the evolution equations (DGLAP);

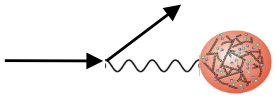
Compute cross sections for DIS/DY (or other processes) at NLO (NNLO);

Calculate χ^2 measure of agreement between data and theory model;

Obtain the best estimate of the PDFs by varying the free parameters to minimize χ^2

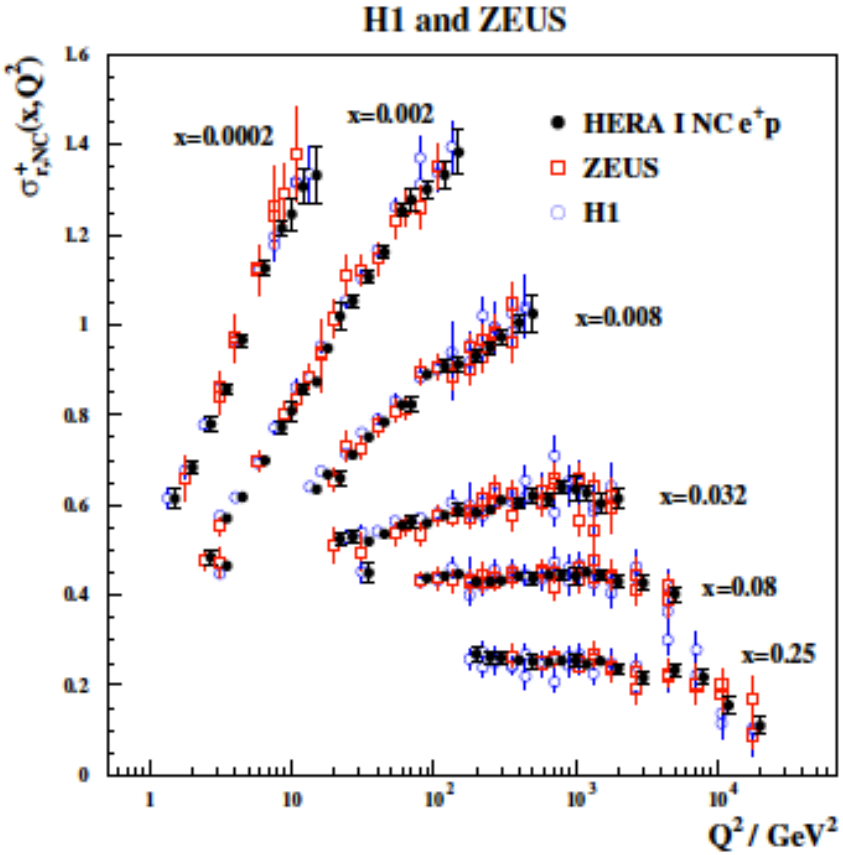
Proton structure from HERA data

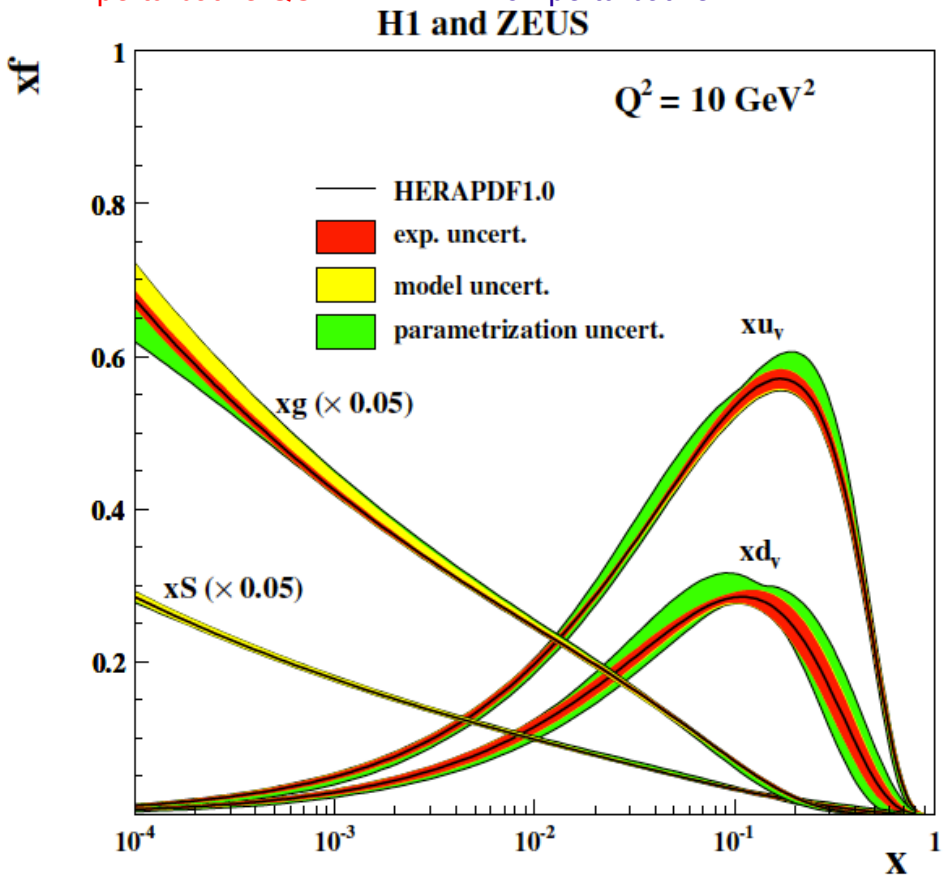
- **Combination of data with consistent treatment of systematics**
- **Extraction of parton distribution functions (PDFs) using HERA data only**
  - **A milestone of HERA physics program: HERAPDF 1.0 (2009)**



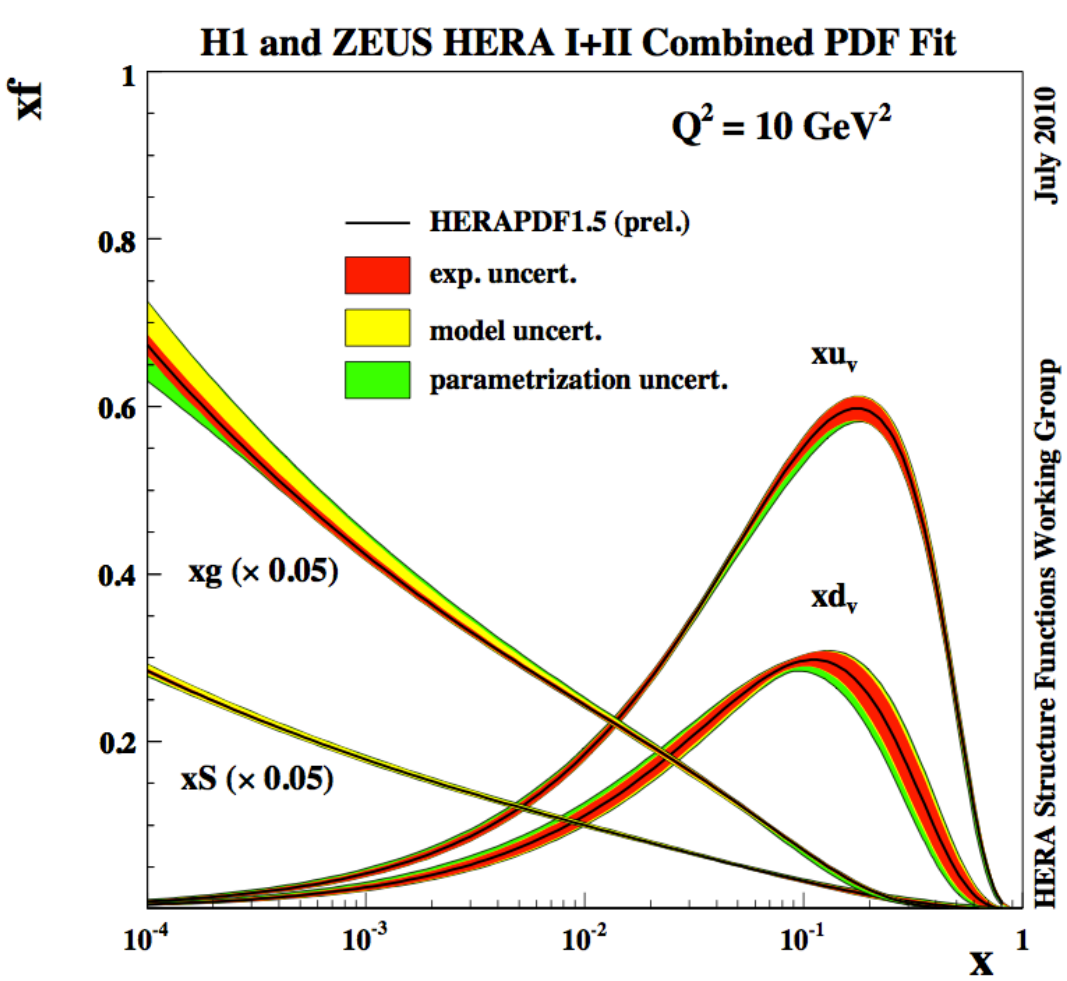
$$\sigma_{DIS} \equiv \mathcal{C}_{\text{lepton-parton}} \otimes f(x, Q^2)$$

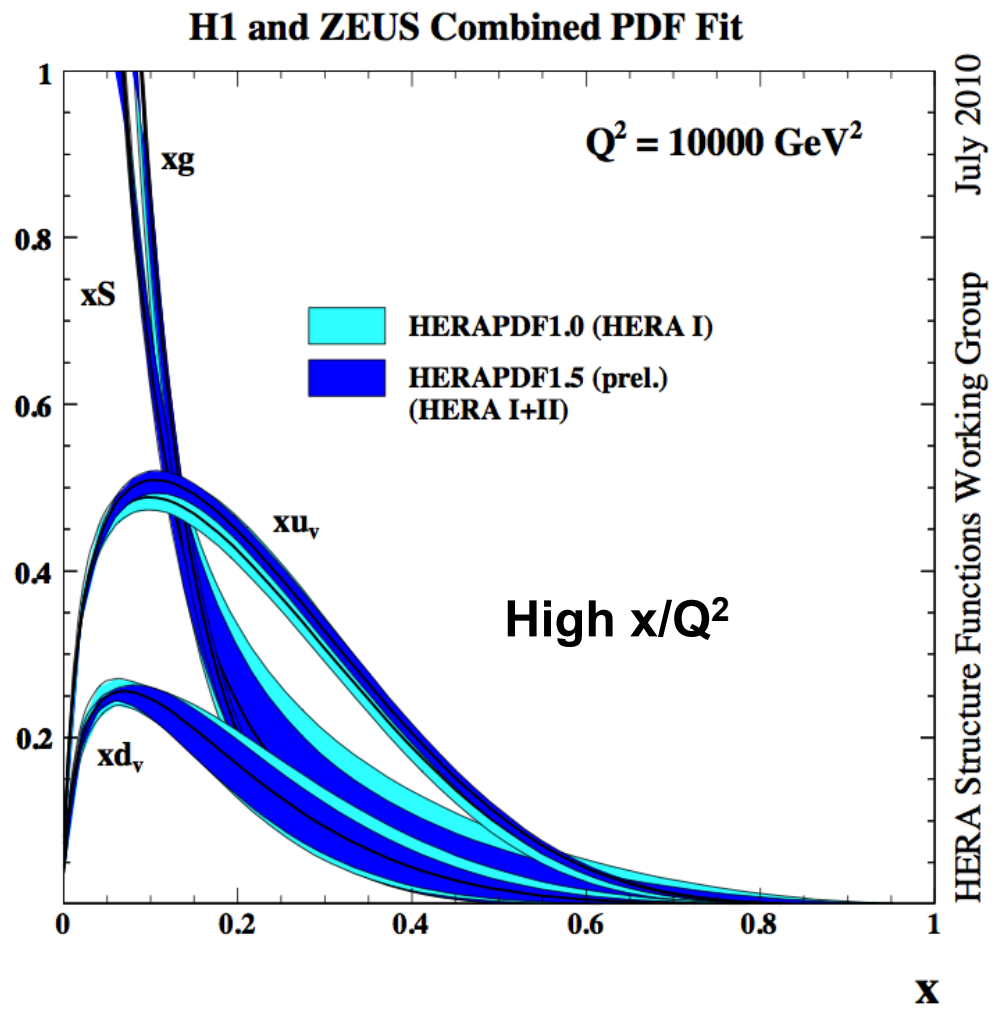
perturbative QCD — non-perturbative





HERAPDF 1.5

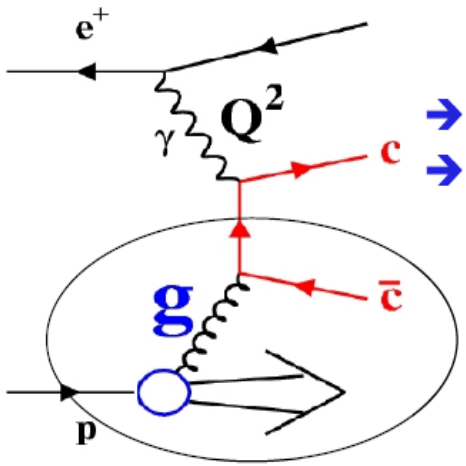




High Q2 data improve the precision at high x

Proton's charm

The proton (1 GeV) "contains" charm (1.6 GeV) and beauty (4.4 GeV) quarks



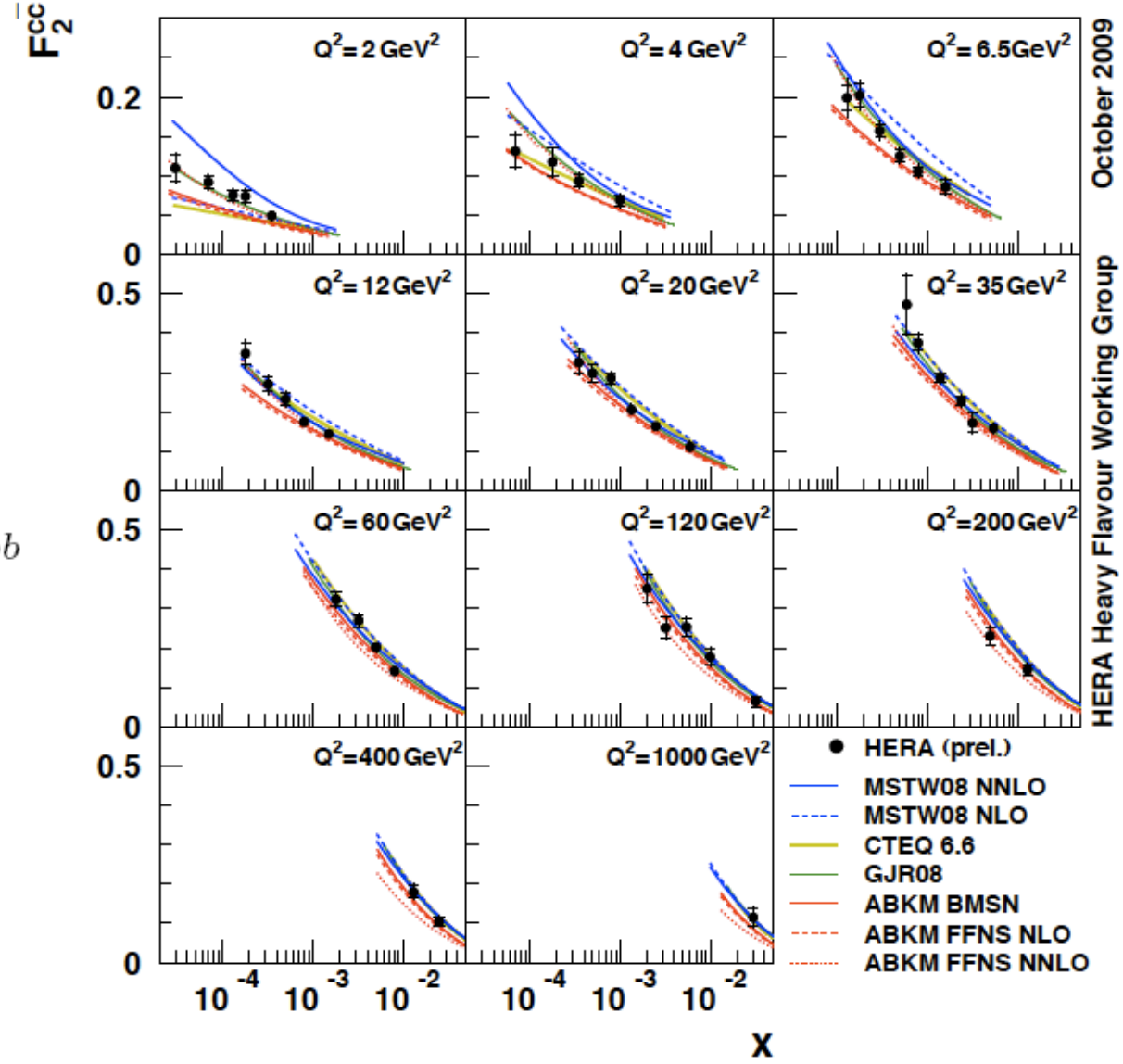
➔ D*, D+, etc.

➔ Displaced tracks

$$\sigma_r^{cc/bb} = F_2^{cc/bb} - y^2/Y_+ F_L^{cc/bb}$$

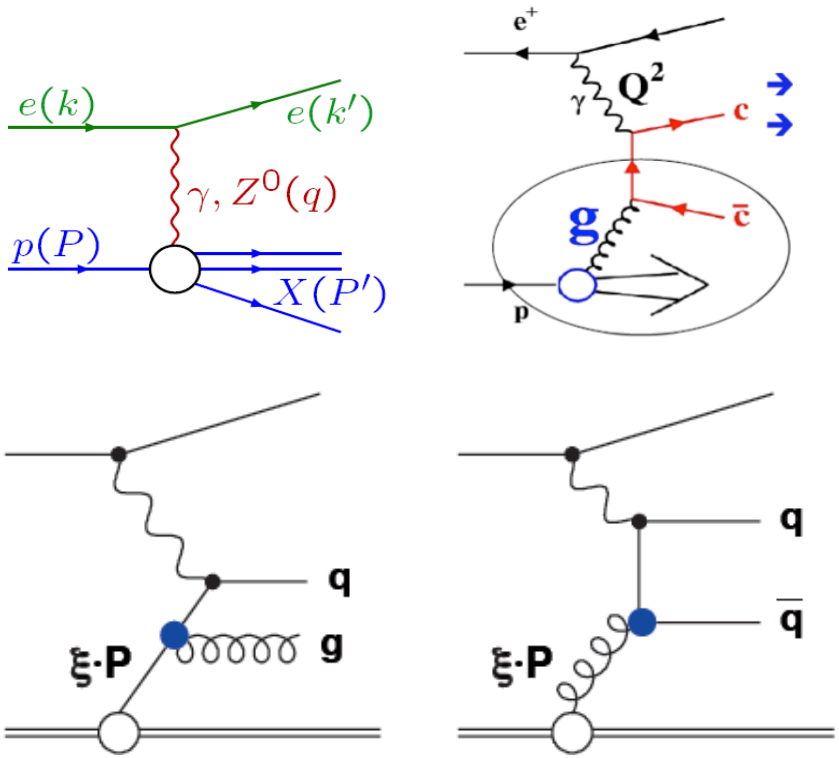
About 20% of the proton "is" charm (at high Q2)!

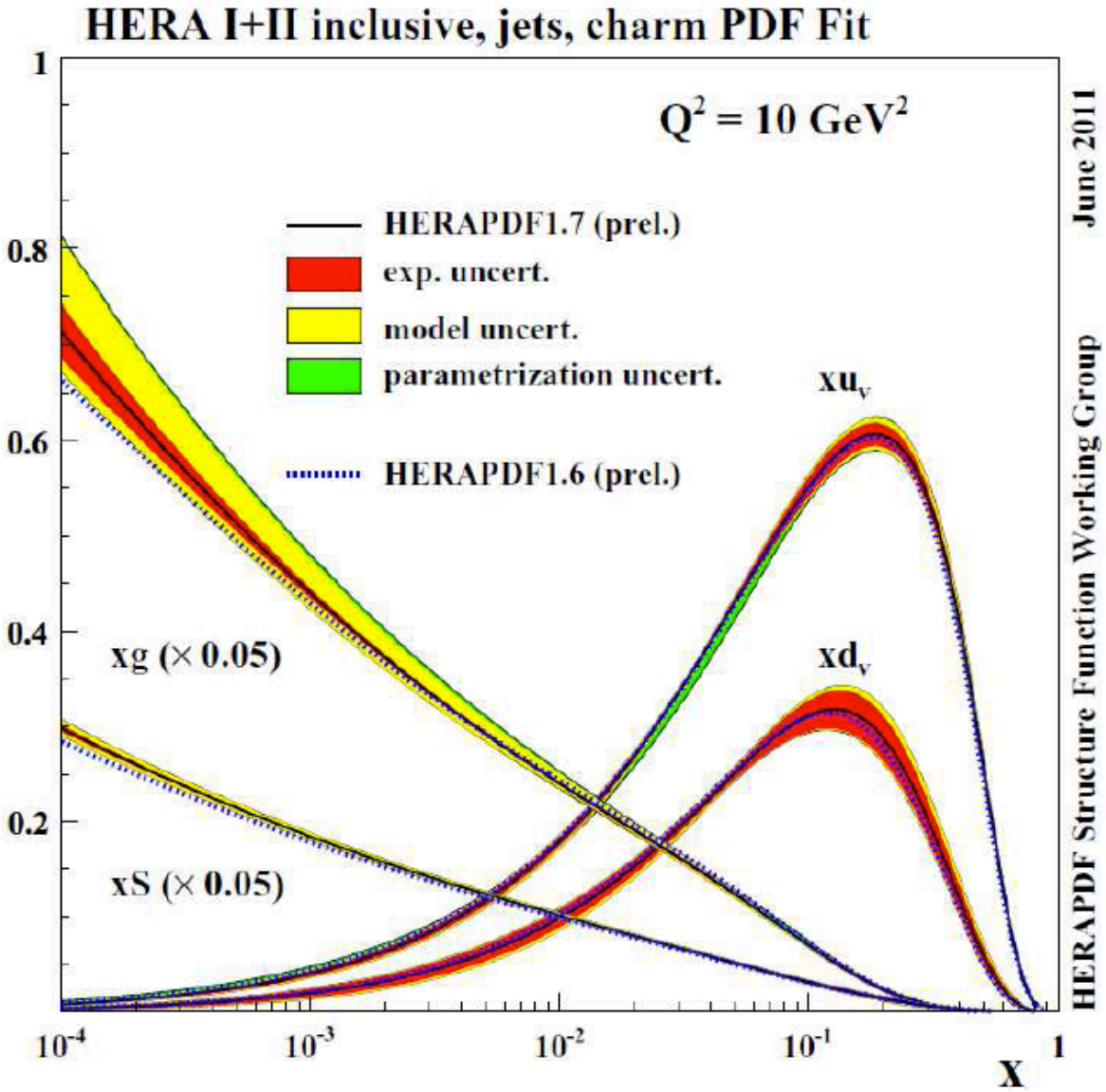
Important constraints for LHC



HERAPDF 1.7

- **HERA « global » fit**
  - **Inclusive data**
  - **Charm data**
  - **Jets in DIS data**

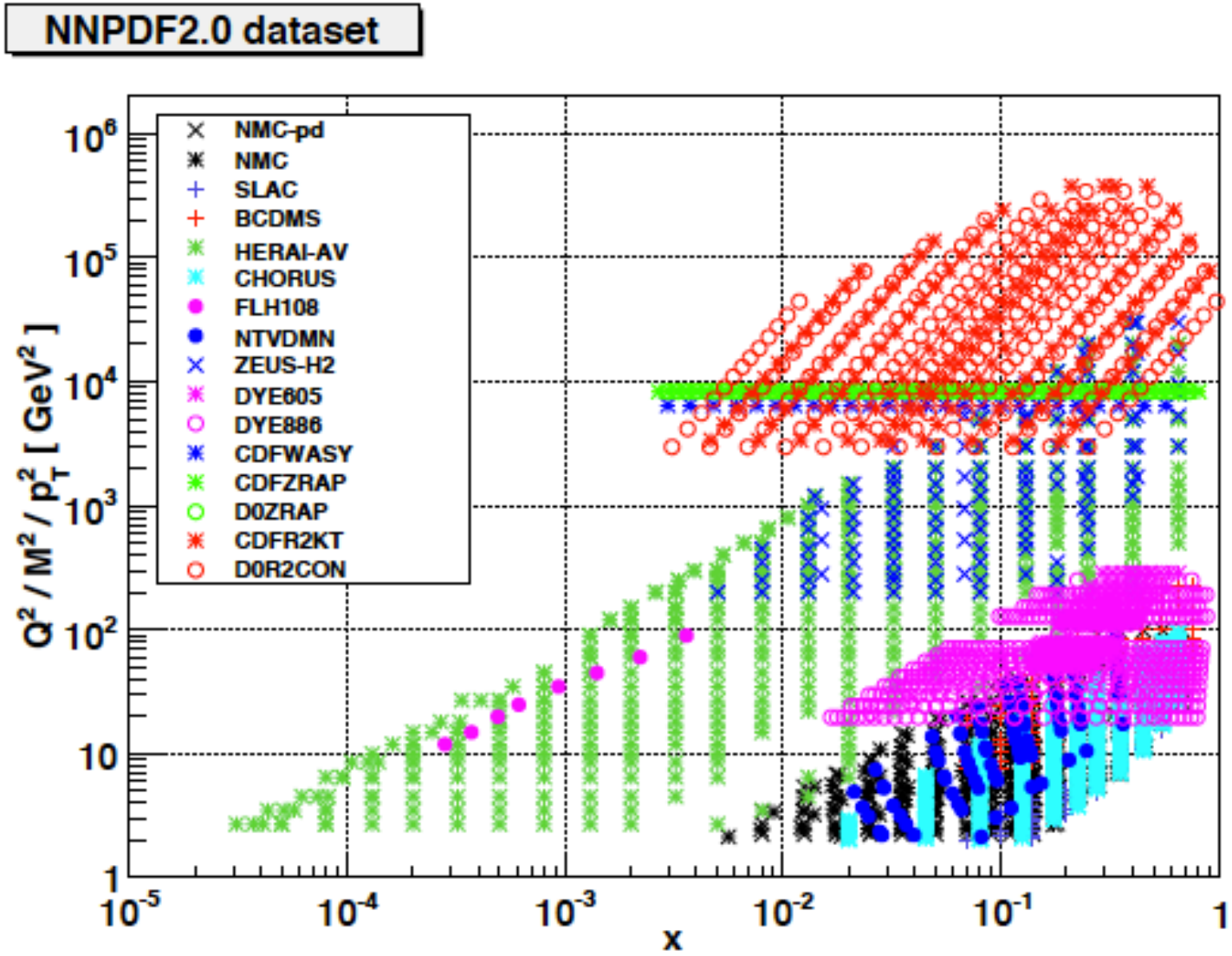




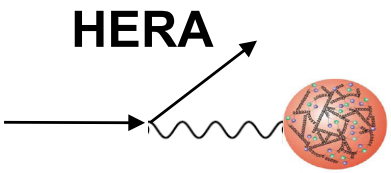
The data for PDF's(before LHC)

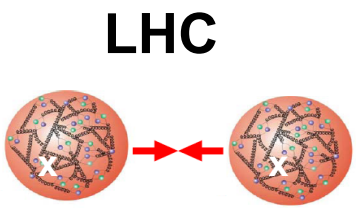
	Process	Subprocess	Partons	x range
Fixed Target	$\ell^{\pm}\{p,n\} \to \ell^{\pm} X$	$\gamma^* q \to q$	$q, \bar{q}, g$	$x \gtrsim 0.01$
	$\ell^{\pm} n/p \to \ell^{\pm} X$	$\gamma^* d/u \to d/u$	d/u	$x \gtrsim 0.01$
	$pp \to \mu^+\mu^- X$	$u\bar{u}, d\bar{d} \to \gamma^*$	$\bar{q}$	$0.015 \lesssim x \lesssim 0.35$
	$pn/pp \to \mu^+\mu^- X$	$(u\bar{d})/(u\bar{u}) \to \gamma^*$	$\bar{d}/\bar{u}$	$0.015 \lesssim x \lesssim 0.35$
	$\nu(\bar{\nu})\, N \to \mu^-(\mu^+)\, X$	$W^* q \to q'$	$q, \bar{q}$	$0.01 \lesssim x \lesssim 0.5$
	$\nu\, N \to \mu^-\mu^+ X$	$W^* s \to c$	s	$0.01 \lesssim x \lesssim 0.2$
	$\bar{\nu}\, N \to \mu^+\mu^- X$	$W^* \bar{s} \to \bar{c}$	$\bar{s}$	$0.01 \lesssim x \lesssim 0.2$
HERA	$e^{\pm} p \to e^{\pm} X$	$\gamma^* q \to q$	$g, q, \bar{q}$	$0.0001 \lesssim x \lesssim 0.1$
	$e^+ p \to \bar{\nu}\, X$	$W^+\{d,s\} \to \{u,c\}$	d, s	$x \gtrsim 0.01$
	$e^{\pm} p \to e^{\pm} c\bar{c}\, X$	$\gamma^* c \to c, \gamma^* g \to c\bar{c}$	c, g	$0.0001 \lesssim x \lesssim 0.01$
	$e^{\pm} p \to \text{jet} + X$	$\gamma^* g \to q\bar{q}$	g	$0.01 \lesssim x \lesssim 0.1$
Tevatron	$p\bar{p} \to \text{jet} + X$	$gg, qg, qq \to 2j$	g, q	$0.01 \lesssim x \lesssim 0.5$
	$p\bar{p} \to (W^{\pm} \to \ell^{\pm}\nu)\, X$	$ud \to W, \bar{u}\bar{d} \to W$	$u, d, \bar{u}, \bar{d}$	$x \gtrsim 0.05$
	$p\bar{p} \to (Z \to \ell^+\ell^-)\, X$	$uu, dd \to Z$	d	$x \gtrsim 0.05$

PDF constrains



From HERA to LHC



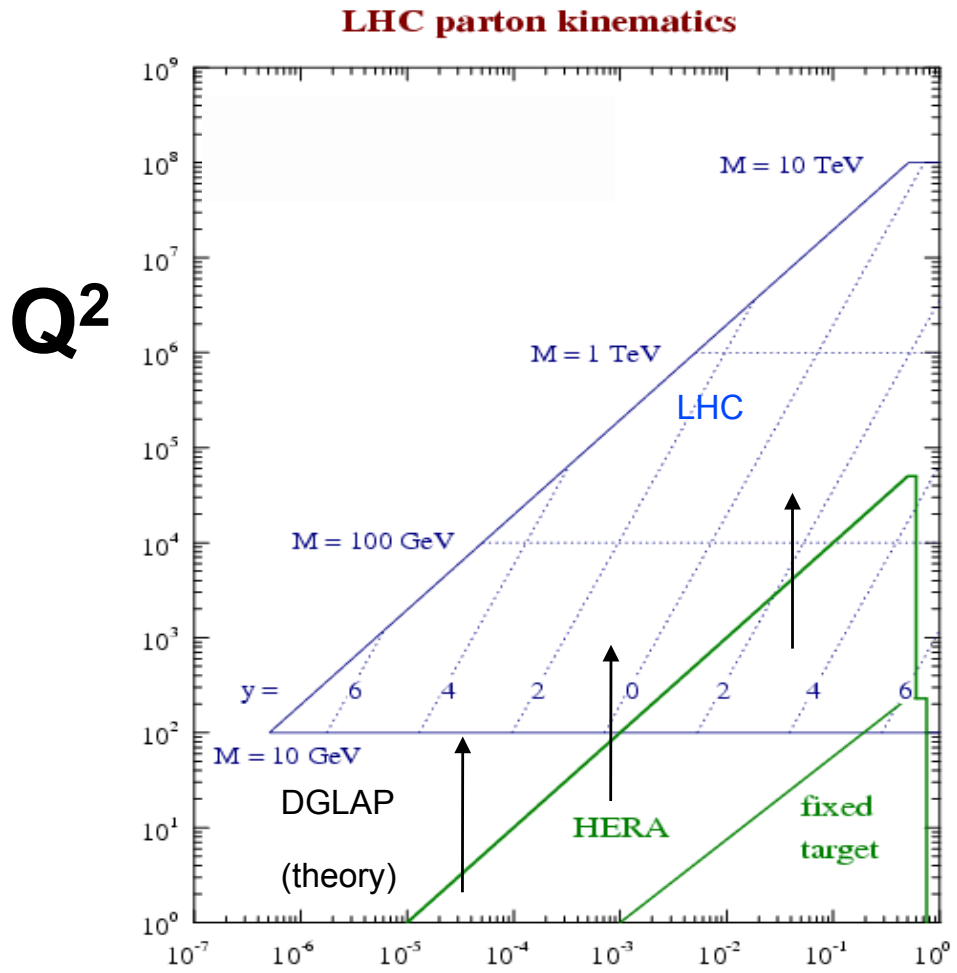


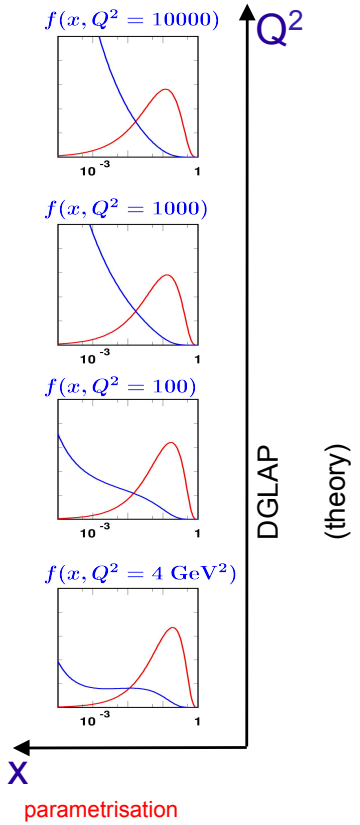
Example

W (at rest) corresponds to

$Q^2=M_W^2 = 6400\ GeV^2$

x=0.005 for LHC (14 TeV)





HERA data is a support for predictions at LHC

LHC data constrain PDFs

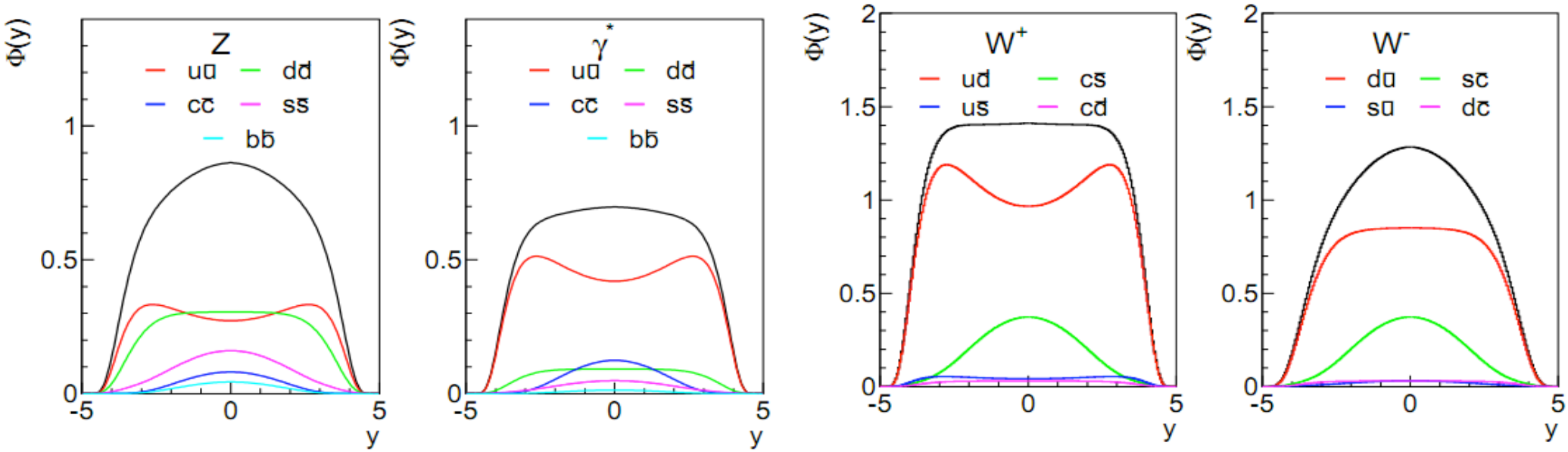
- **Many processes measured with high precision using first data at LHC are sensitive to PDFs:**
  - **W and Z production**
  - **W+heavy flavor**
  - **Drell-Yan production**
  - **Inclusive jet production**
  - **Dijet production**
  - **Photon inclusive production**
- **More measurements may fall into this category at high luminosity:**
  - **Higgs cross sections and couplings**
  - **Top production**
  - **Electroweak precision measurements: M_W, $\sin^2\theta_{eff}$**

PDF constraints from W/Z bosons production at LHC

- **DIS data at HERA (ep): probes linear combination of quarks:**
  - **CC: provides constraints on valence quarks**
  - **NC: No flavour decomposition of the sea distribution [S=2(ubar+dbar+sbar)]**
- **DY and jet data at the LHC: probe a bi-linear combination of quarks**

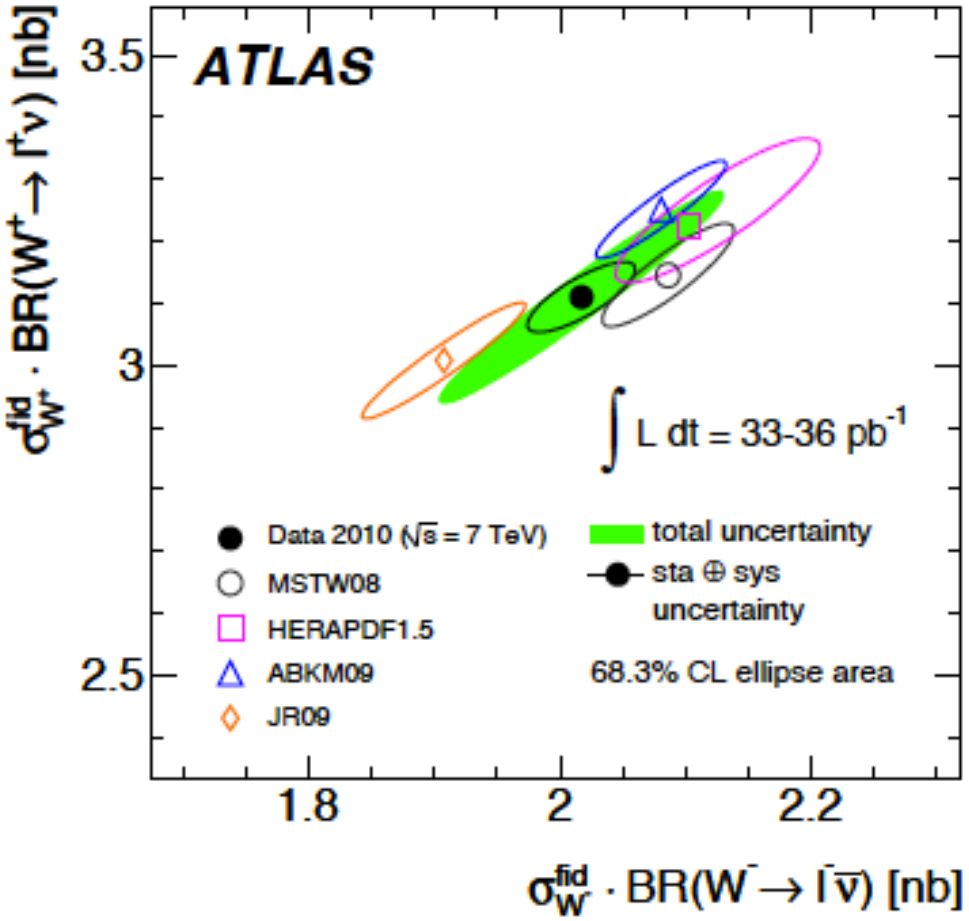
$$Z \sim 0.29(u\bar{u} + c\bar{c}) + 0.37(d\bar{d} + s\bar{s} + b\bar{b}) \qquad W^+ \sim 0.95(u\bar{d} + c\bar{s}) + 0.05(u\bar{s} + c\bar{d})$$

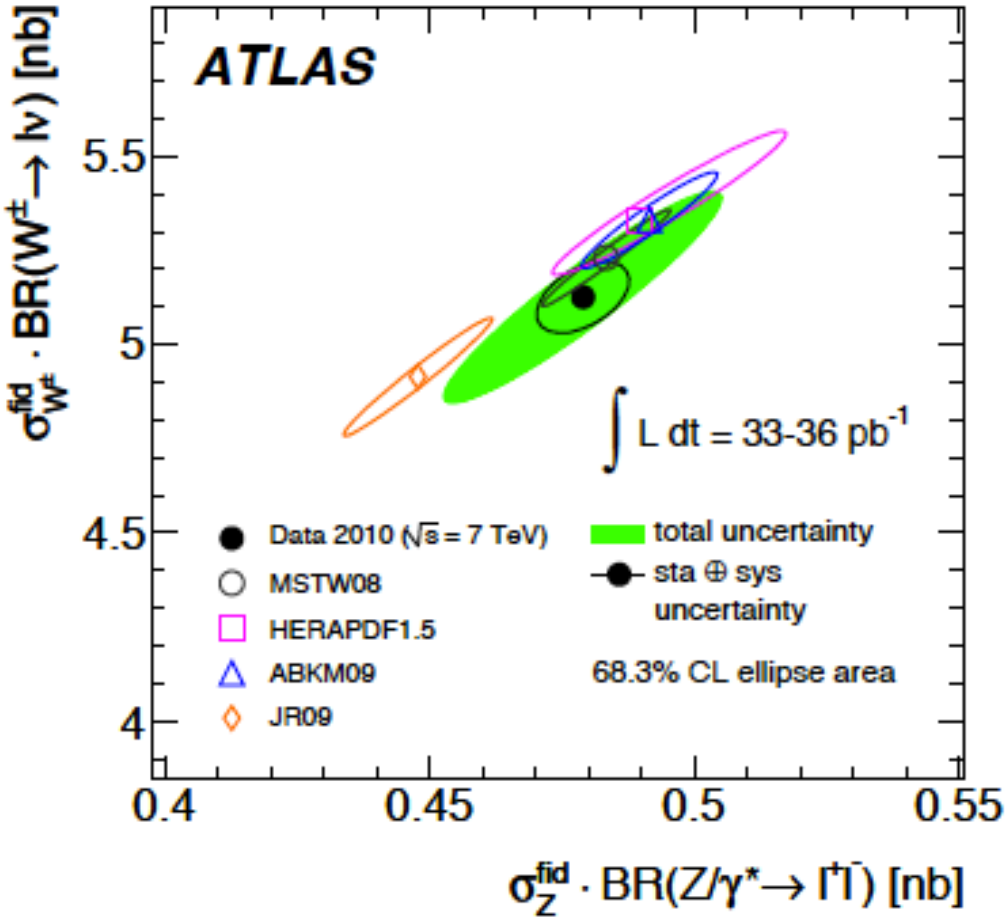
$$\gamma^* \sim 0.44(u\bar{u} + c\bar{c}) + 0.11(d\bar{d} + s\bar{s} + b\bar{b}) \qquad W^- \sim 0.95(d\bar{u} + s\bar{c}) + 0.05(d\bar{c} + s\bar{u})$$



LHC data can provide complementary information, for instance flavour decomposition of the quark sea at low x

W/Z production





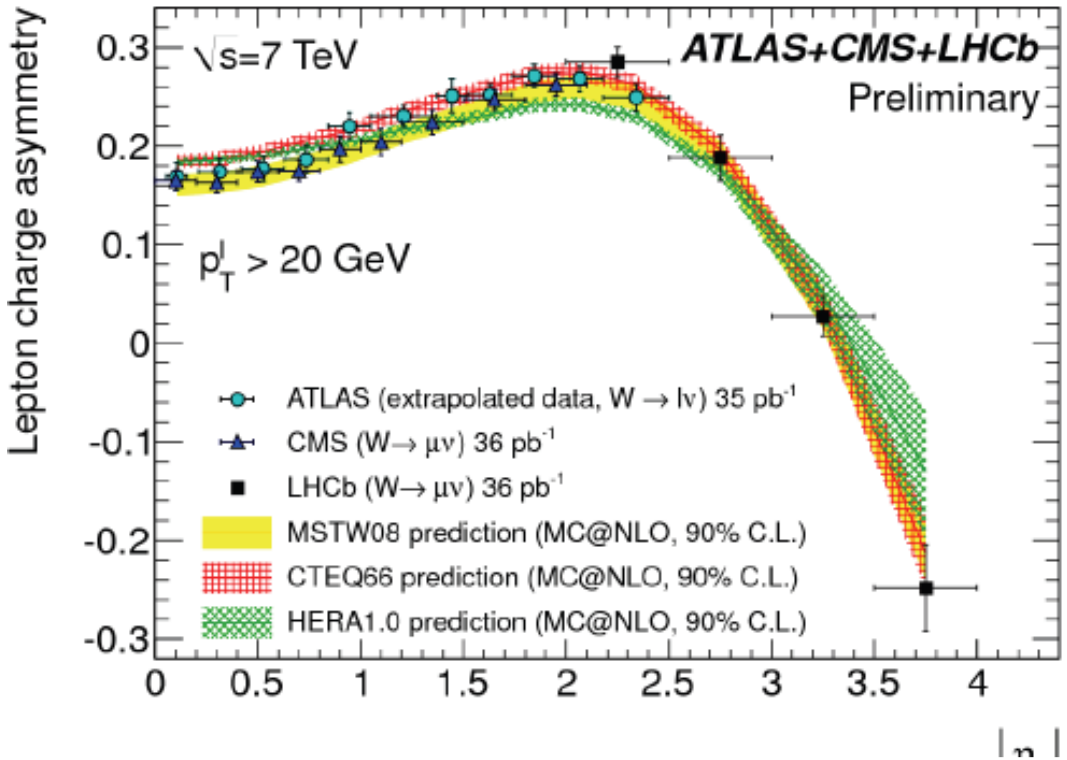
W/lepton charge asymetry

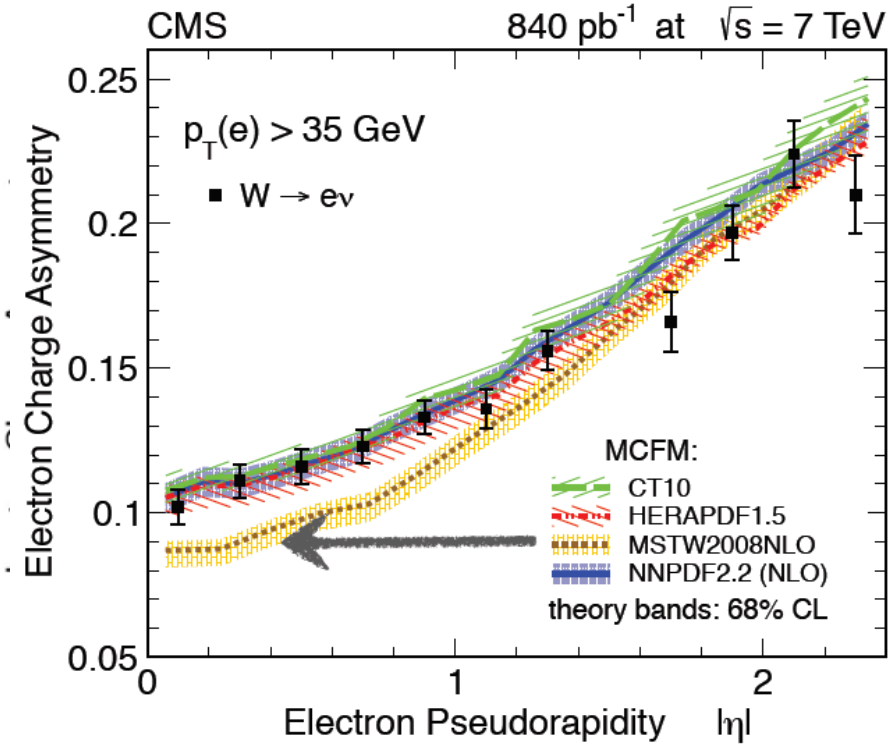
W lepton asymmetry is sensitive to differences between u and d:

$$A_W = \frac{W^+ - W^-}{W^+ + W^-}$$

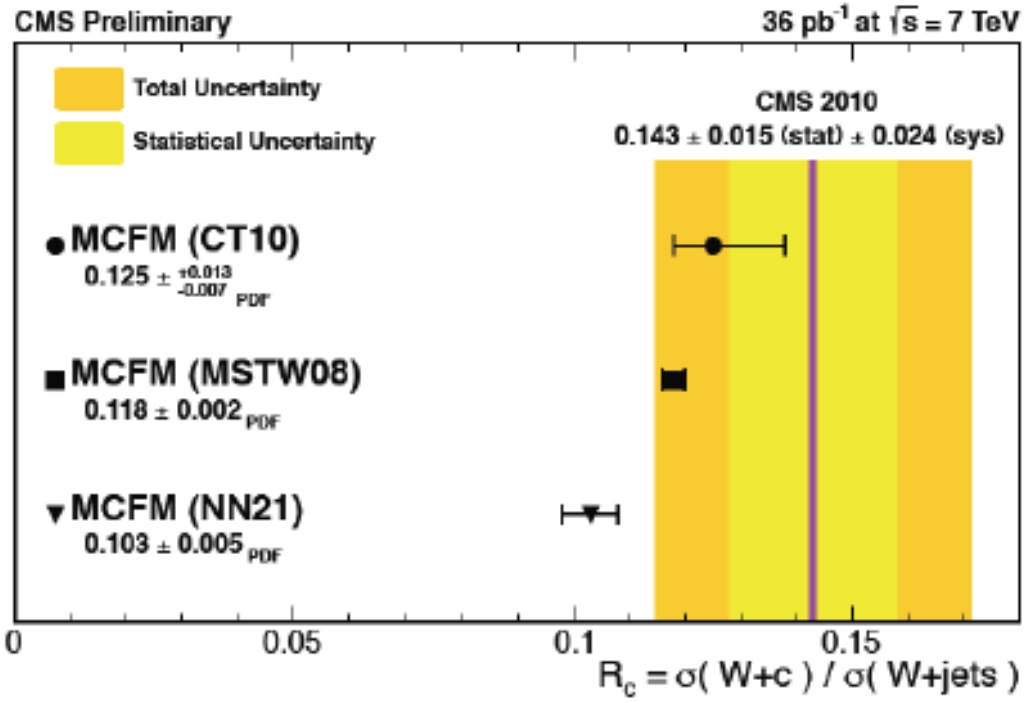
in terms of valence quarks:

$$A_W \sim \frac{u_v - d_v}{u_v + d_v + 2u_{sea}}$$

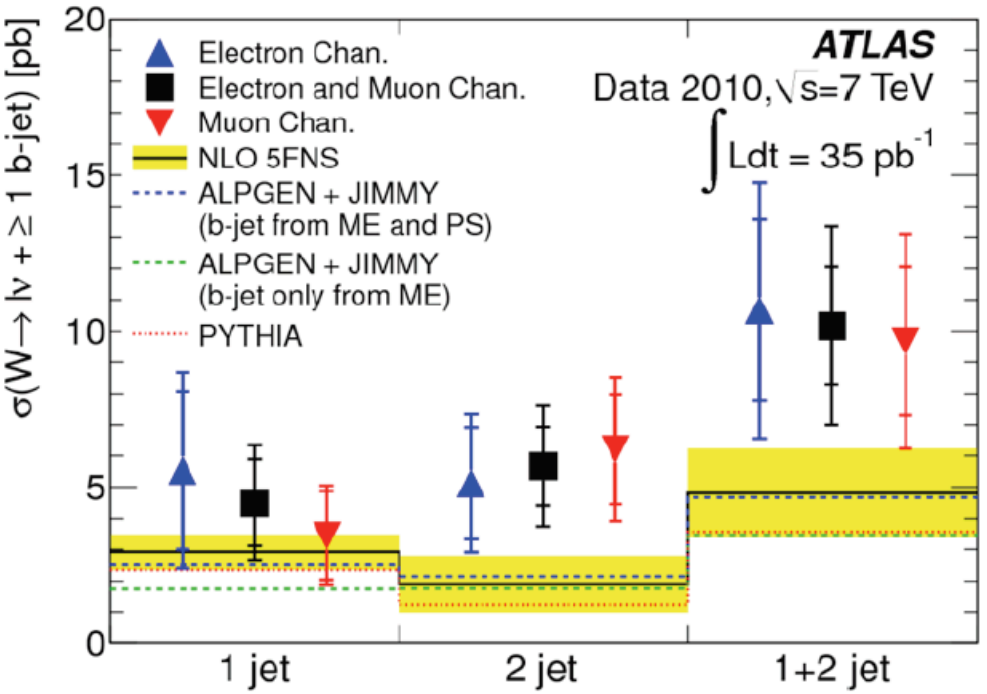




W+c/b

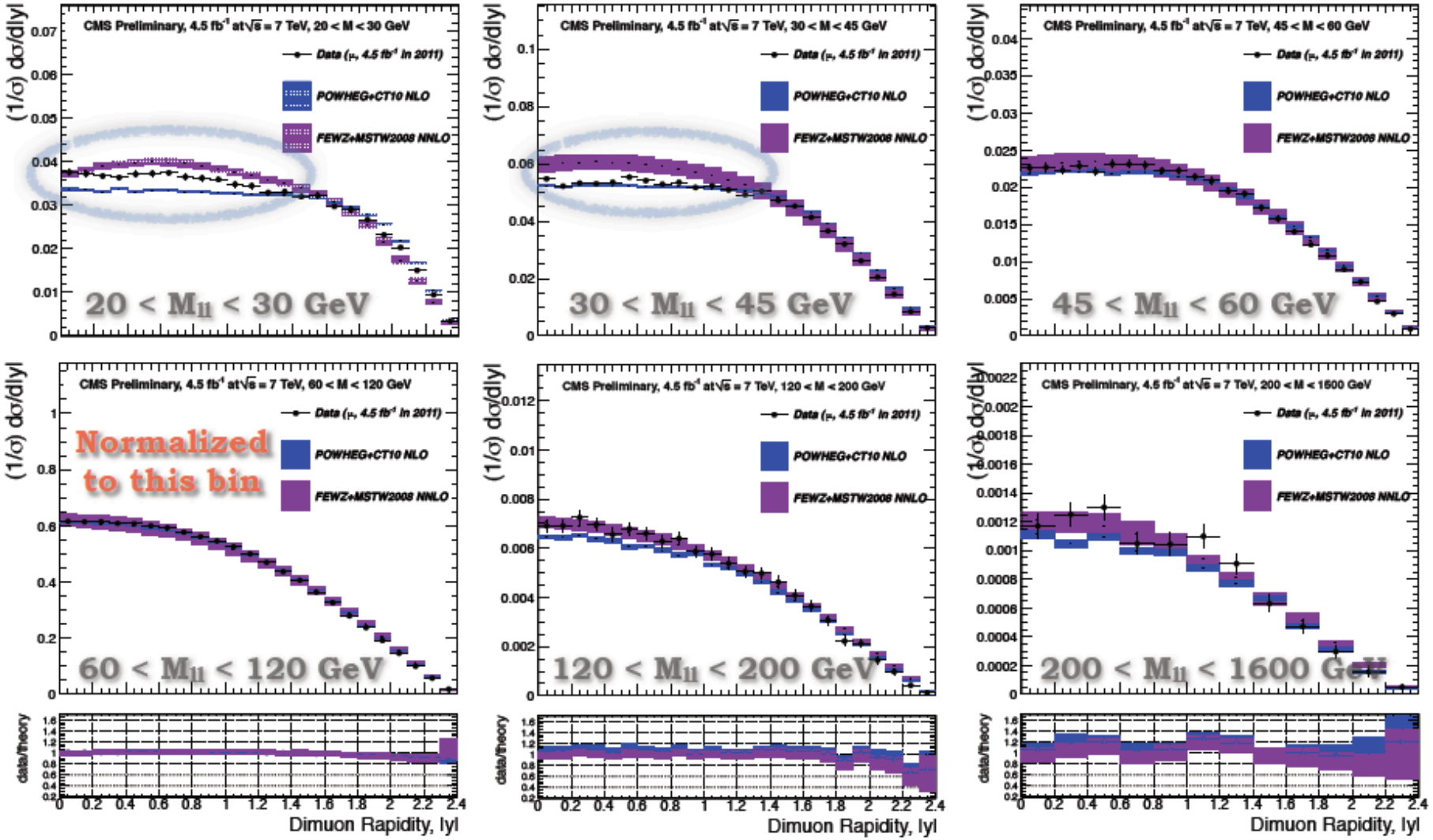


Probe strangeness

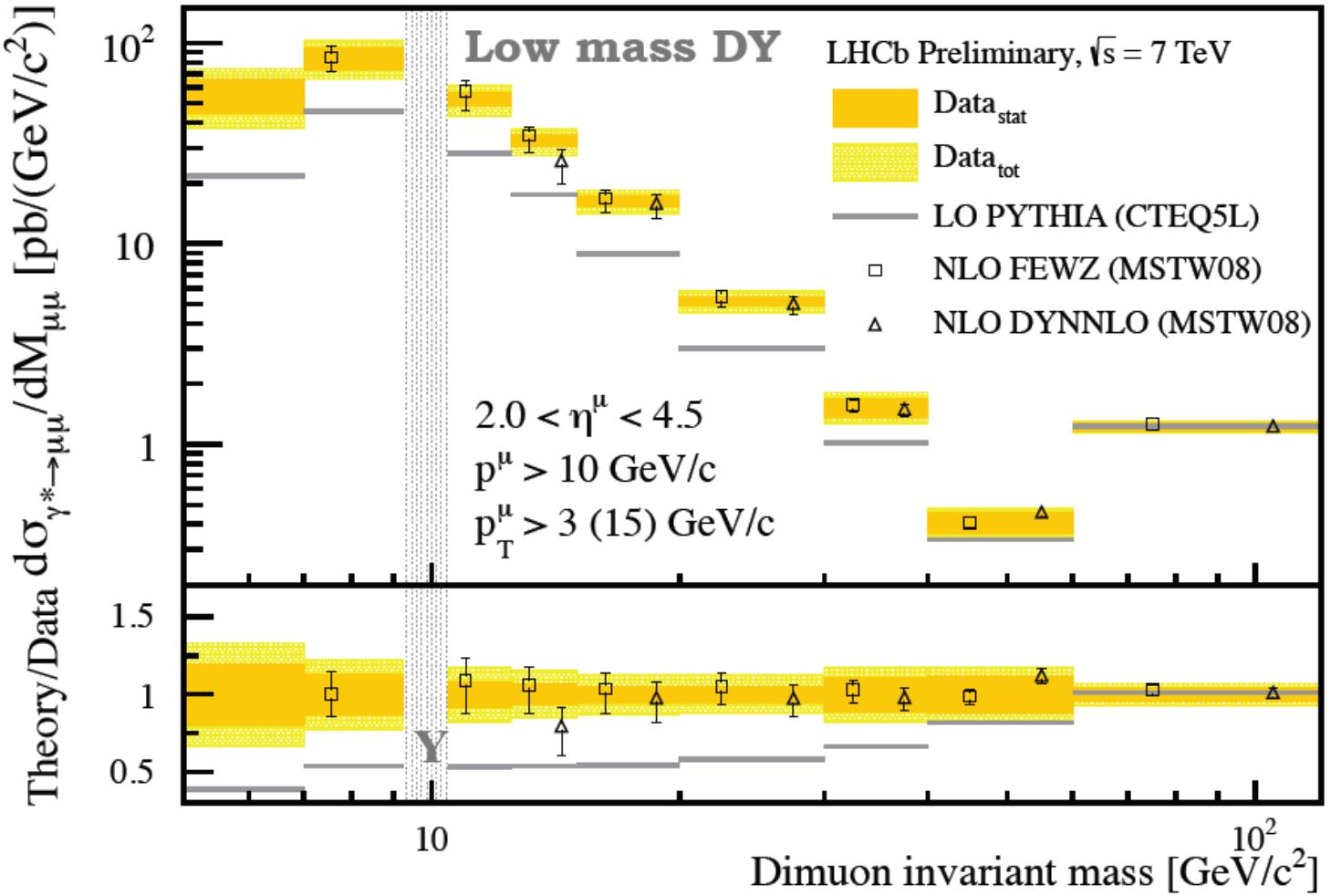


Important background for Higgs /top

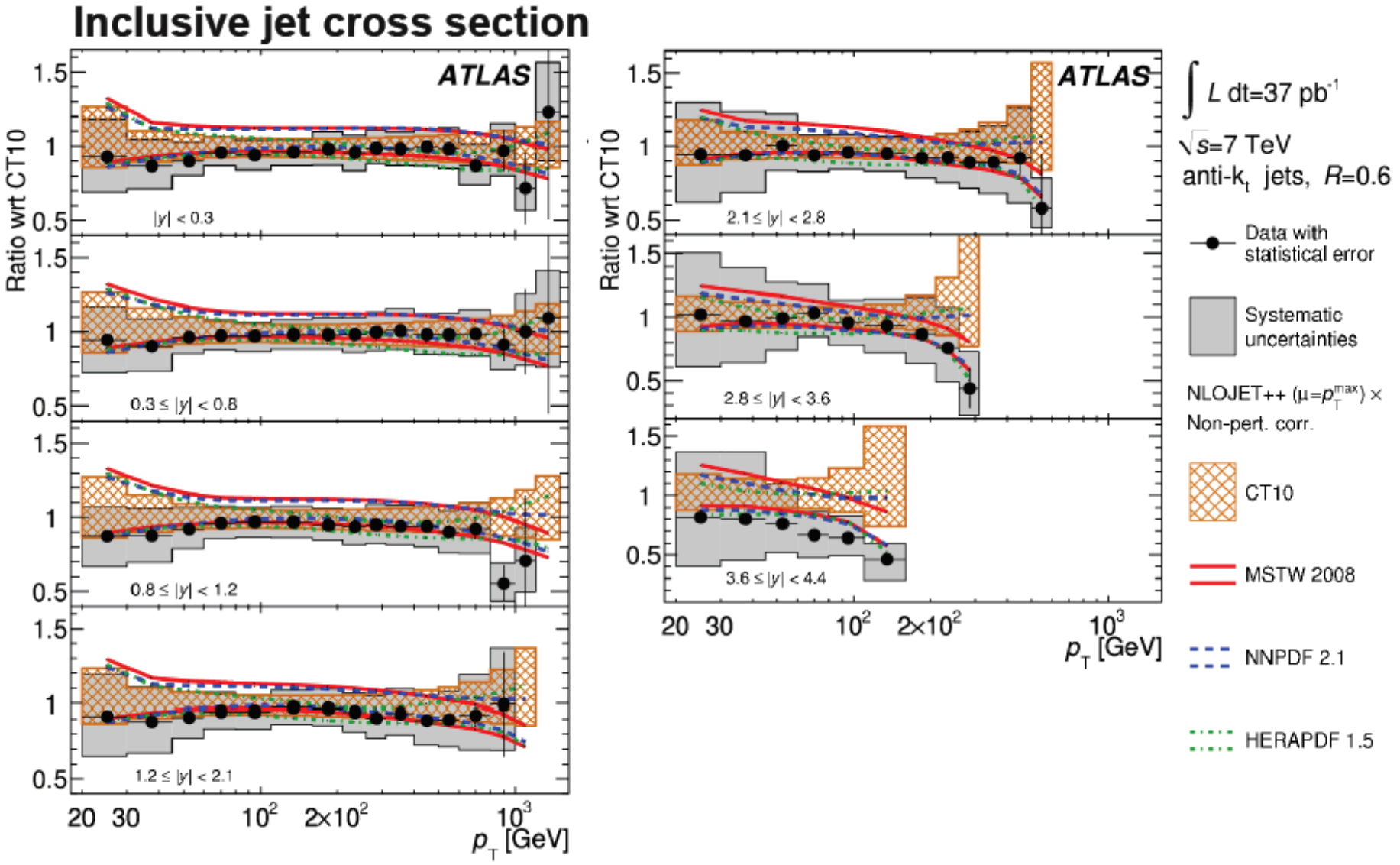
Drell Yan at low mass



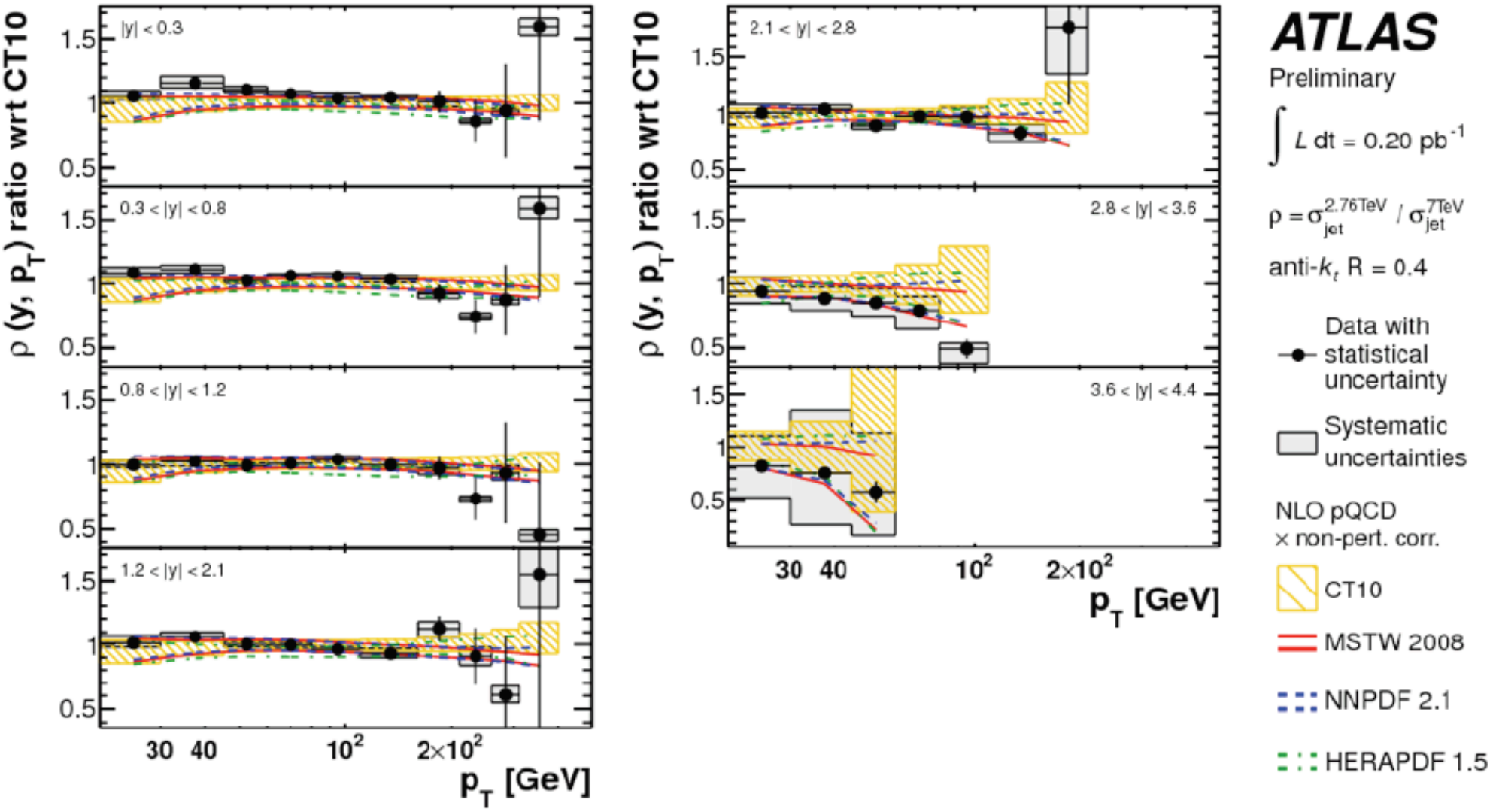
DY measurement at LHCb



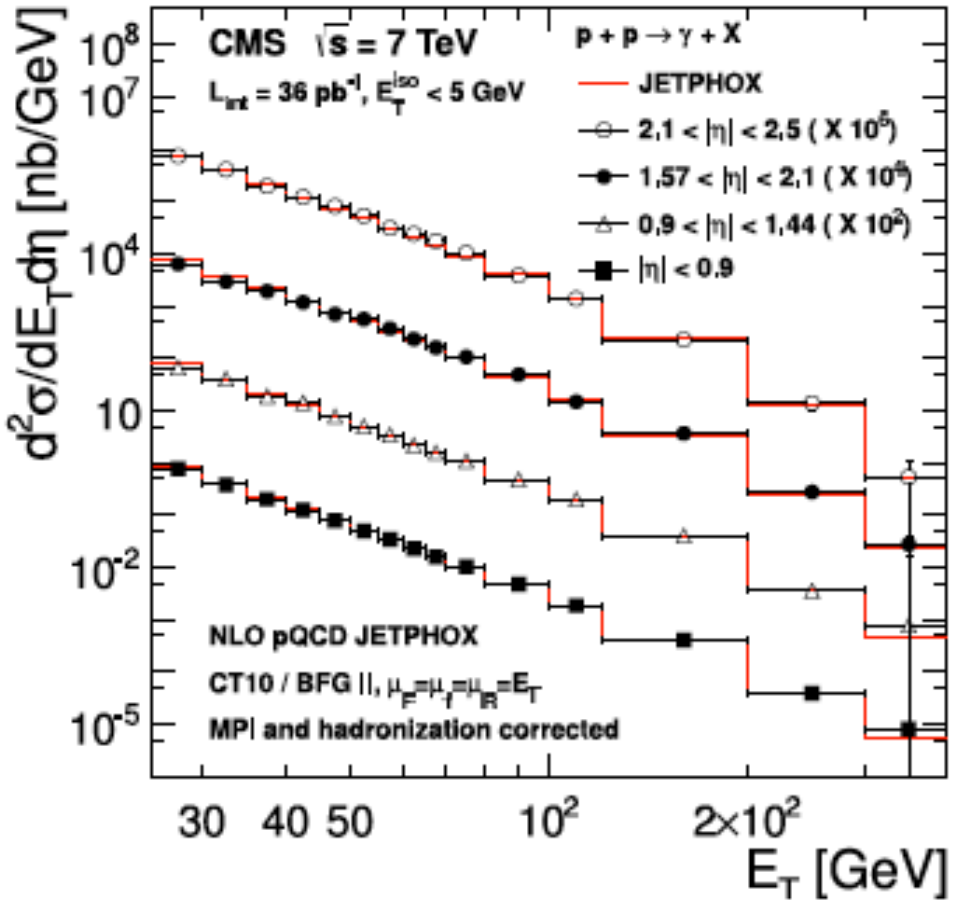
Jets at LHC

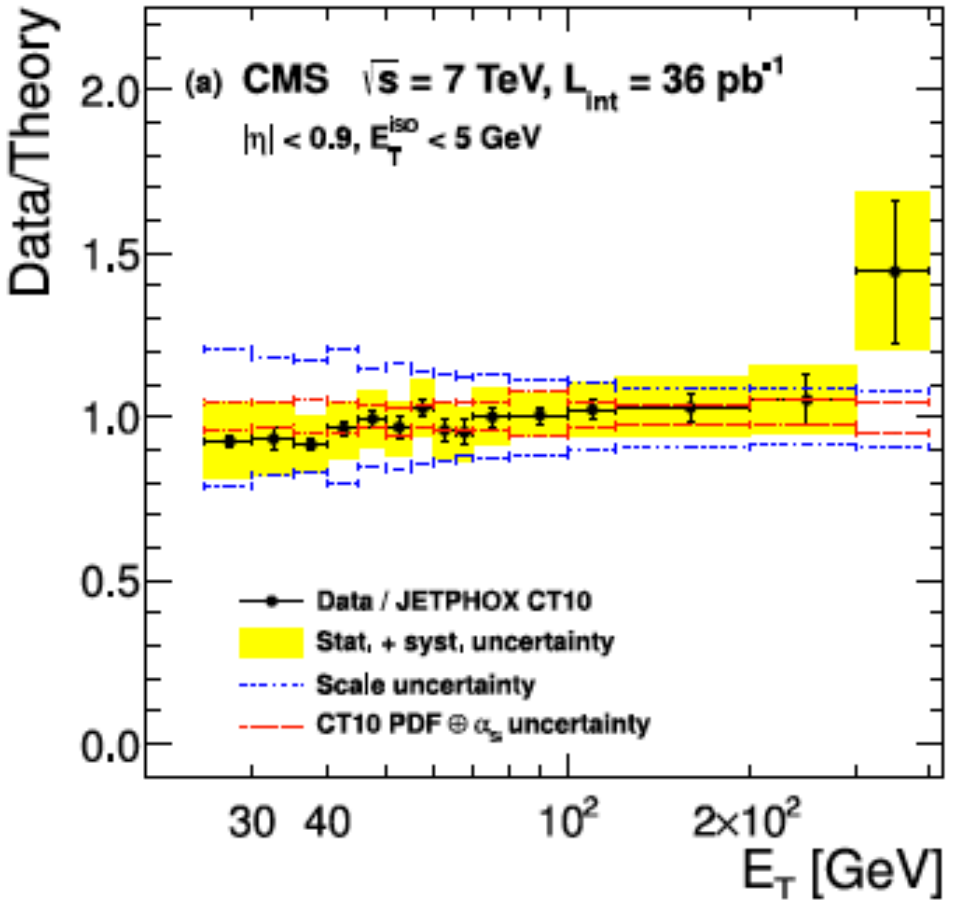

Inclusive jet cross section
ATLAS
Ratio wrt CT10
|y| < 0.3
0.3 ≤ |y| < 0.8
0.8 ≤ |y| < 1.2
1.2 ≤ |y| < 2.1
2.1 ≤ |y| < 2.8
2.8 ≤ |y| < 3.6
3.6 ≤ |y| < 4.4
p_T [GeV]
∫ L dt=37 pb^-1
√s=7 TeV
anti-k_t jets, R=0.6
Data with statistical error
Systematic uncertainties
NLOJET++ (μ=p_T^max) × Non-pert. corr.
CT10
MSTW 2008
NNPDF 2.1
HERAPDF 1.5

Jets cross section ratios 2.76/7 TeV



Prompt photon production

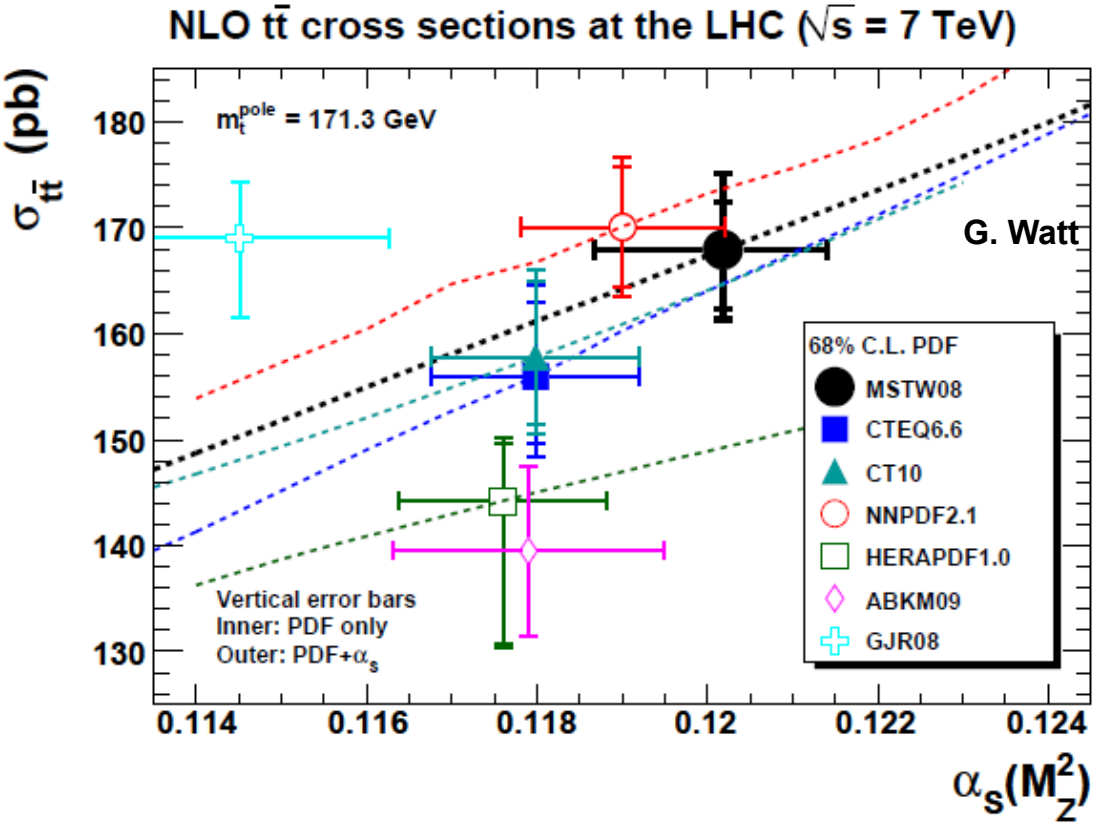




PDFs: Differences and benchmarking

Main sources of difference between different PDFs:

- inclusion of different data
- methods of determining 'best fit'
- uncertainty treatment/sources
- assumptions in procedure (parametrisation)
- heavy flavour treatment
- PDF and α_s correlation



Benchmarking is addressing the differences – but difficult to see the pattern

A generic framework for PDF studies: HERAFitter

PDF Fit Analysis Group

- **Following Fit groups are active:**

S. Glazov, ICHEP2012

	MSTW08	CTEQ6.6/CT10	NNPDF2.1/2.3	HERAPDF1.0/1.5	ABKM09/ABM11	GJR08/JR09
Evolution	LO	LO	LO	—	—	—
Order	NLO	NLO	NLO	NLO	NLO	NLO
	NNLO	NNLO	NNLO	NNLO	NNLO	NNLO
HF Scheme	RT-GMVF	ACOT-GMVF	FONLL-GMVF	RT-GMVF (*)	BMSN-FFNS	FFNS
α_S NLO	0.120	0.118(f)	0.1191(b)	0.1176(f)	0.118	0.1135
α_S NNLO	0.1171	0.118(f)	0.1174(b)	0.1176(f)	0.1135	0.1124
HERA DIS	not up-to-date	+	+	+/prelim.	partial	+
Fixed target DIS	+	+	+	-	+	+
DY	+	+	+	-	+	+
Tevatron W,Z	some	some	some	-	some	some
Tevatron jets	some	+	+	-	some	some
LHC	-	-	W, Z+jets (NNPDF2.3)	-	-	-

- **Different data sets**
- **Different parametrisations**
- **Different arrangements of the perturbative series**
- **Different input values for alphas, charm masses**
- **Different treatment for heavy quark**

– **Plenty of opportunities to differ…fully used!**

Motivation for a QCD Fit Platform

- **Ultimate precision is obtained by combining measurements**
  - **Improvement on Statistical precision**
  - **Improvement of Systematic precision**

  → QCD Fits within experiments proved to be a very useful tool to interpret data!
- **Data from HERA and LHC reach ~1% accuracy. The data are correlated point-to-point and across different processes due to common detector effects.**

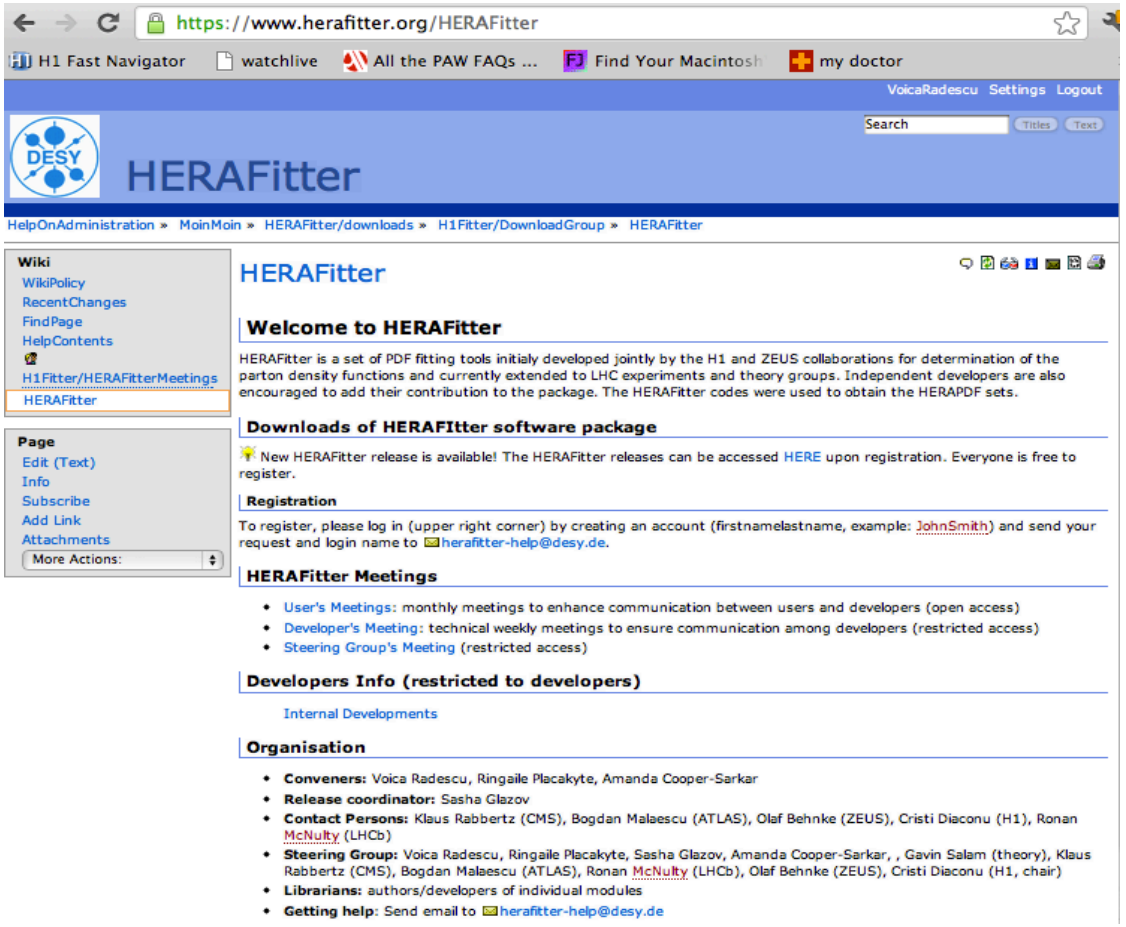
  → Treatment of the correlations very important
- **Theoretical calculations for DIS and DY processes are available to NNLO accuracy in QCD (and NLO in EW). However, calculations, e.g. FEWZ programs for W,Z production are not fast, taking days to reach percent accuracy:**
  - **effect of PDFs in these calculations can be factorised, leading to fast computation tools: FastNLO, APPLGRID**
  - **→ Need a tool which combines the data and theory together.**

HERAFitter Package

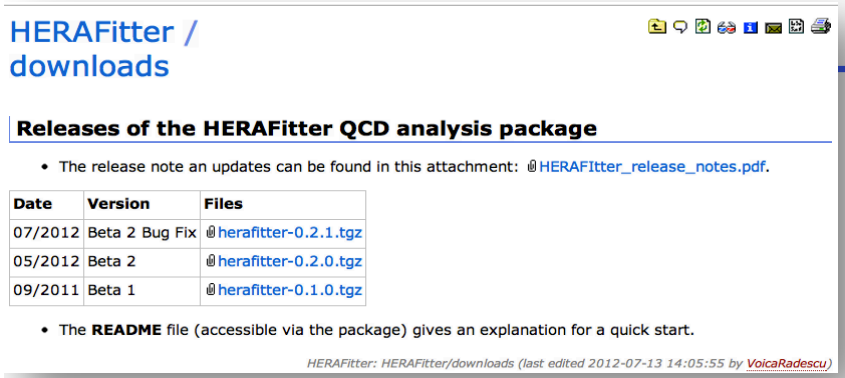
- A ready platform to analyse new data and their impact.
- The beta releases can be accessed through the HEPFORGE site http://projects.hepforge.org/herafitter

  [it requires the QCDNUM package [M. Botje] for evolution]

  - Accessible to anyone for download via registration to feedback users



HERAFitter Package Installation



HERAFitter / downloads

Releases of the HERAFitter QCD analysis package

- The release note an updates can be found in this attachment: HERAFItter_release_notes.pdf.

Date	Version	Files
07/2012	Beta 2 Bug Fix	herafitter-0.2.1.tgz
05/2012	Beta 2	herafitter-0.2.0.tgz
09/2011	Beta 1	herafitter-0.1.0.tgz

- The **README** file (accessible via the package) gives an explanation for a quick start.

HERAFitter: HERAFitter/downloads (last edited 2012-07-13 14:05:55 by VoicaRadescu)

- **The HERAFitter code uses automake tools to configure and build the package:**

```
./configure
make
make install
```

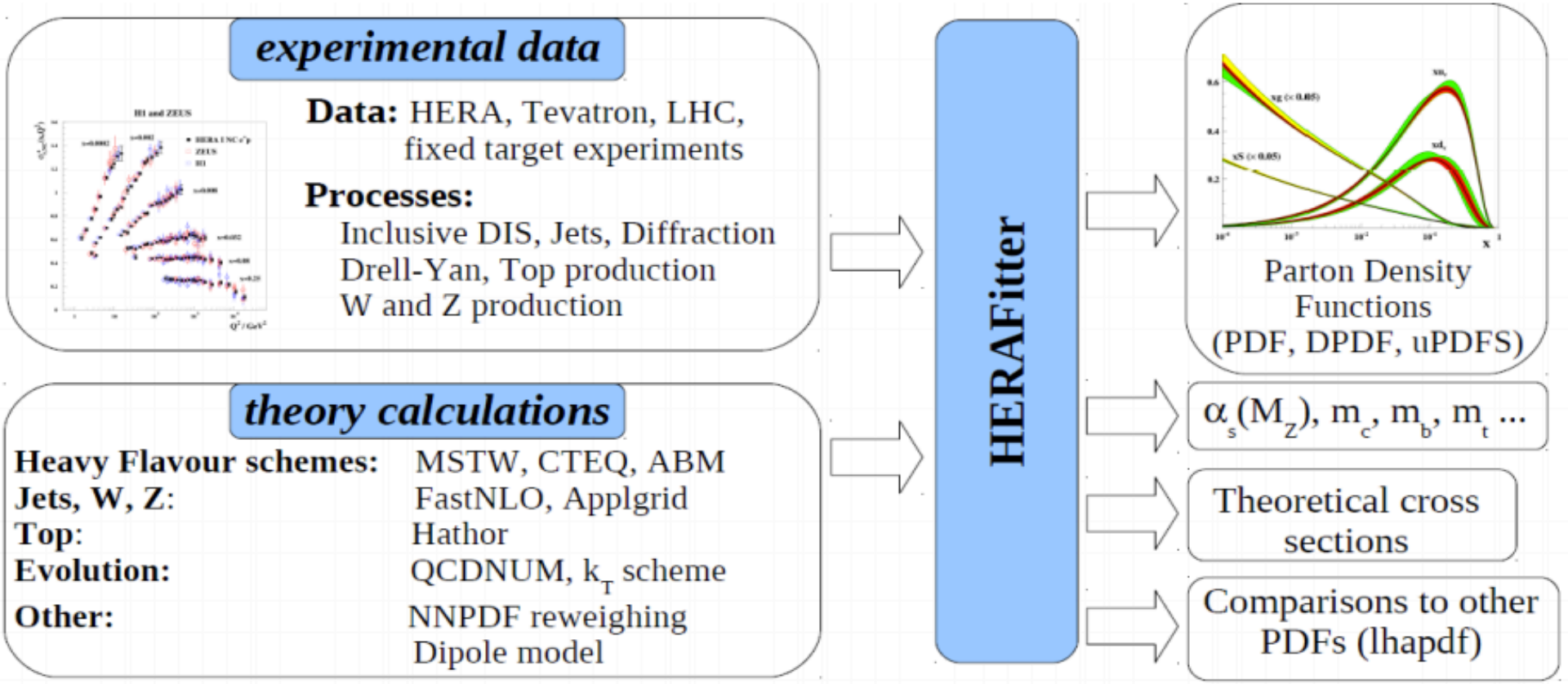
  - **Configure options: (./configure –help)**

```
--enable-trapFPE        Stop of floating point errors (default=no)
--enable-checkBounds    add -fbounds-check flag for compilation (default=no)
--enable-nnpdfWeight    use NNPDF weighting (default=no)
--enable-lhapdf         use lhapdf (default=no)
--enable-applgrid       use applgrid for fast pdf convolutions (default=no)
--enable-hathor         use hathor for ttbar cross section predictions
                        (default=no)
```

  - **Currently the pre-requested packages are high energy physics specific CERNLIB, QCDNUM**

- **Tested on the virtual machine (UBUNTU) ☺.**

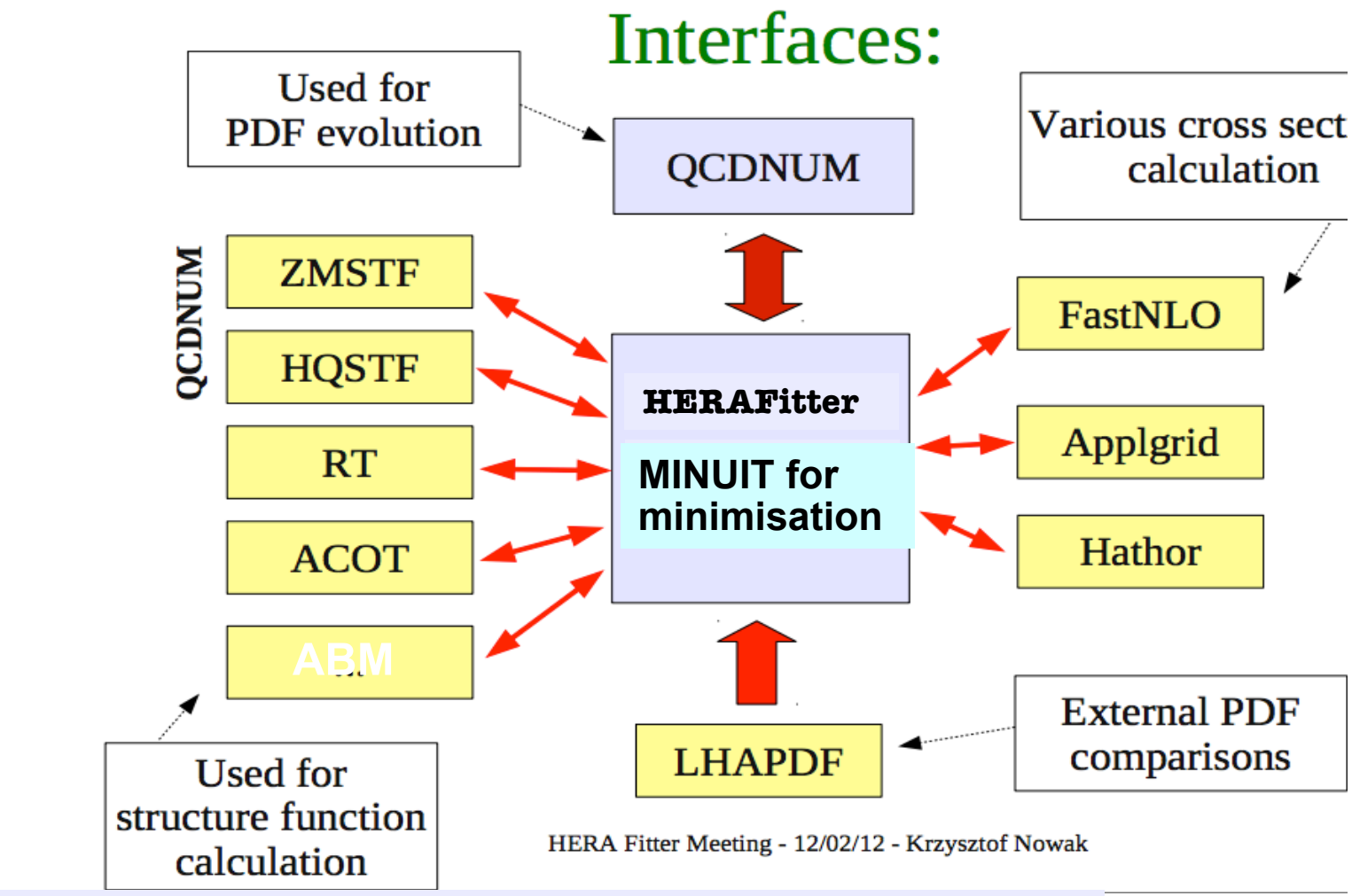
HERAFitter Functionality



Includes various methods for:

- **Error propagation: Hessian vs Monte Carlo: benchmark with NNPDF [PDF4LHC Report arXiv: 1101:0536]**
- **Experimental Error treatment: Correlated, Uncorrelated, Offset**
- **Parametrisation:**
  - **Standard Functional form (a la MSTW, CTEQ, ABM)**
  - **Chebyshev polynomials [PLB27193]**
- **Chisquare definitions**

HERAFitter Structure



- ABM/
- ACOT/
- DIPOLE/
- DY/
- DiffDIS/
- FastNLO/
- HS/
- Hathor/
- NNPDF/
- RT/
- bin/
- datafiles/
- include/
- input_steering/
- interfaces/
- minuit/
- output/
- src/
- theoryfiles/
- tools/
- LICENCE
- Makefile.am
- README
- REFERENCES

- **Beta releases contain a set of tools for its use at the LHC experiments**
  - **It can produce out of the box HERAPDF1.0, (ATLAS strange determination)**
  - **It contains additional data from HERA, Fixed target, Tevatron, LHC**

HERAFitter Physics Cases

- **Determination of proton PDFs from HERA data**
  - Inclusive NC and CC processes
    - involving low Q2 phenomenology (DIPOLE vs DGLAP models)
    - Mixed DGLAP-Dipole fits
  - DIS charm data (submitted to journal)
  - Inclusive DIS jets * (PDF + alphas)
  - Diffractive PDF fits

- **Production of W, Z at LHC: additional lever arm to constrain PDFs**
  - Inclusive Differential W, Z cross sections
  - Drell Yan at low and higher masses
  - Jet production * (PDF + alphas)
  - W+charm

- **Studies concerning different treatment of correlations (Hessian vs MC vs Offset):**
- **Top production at LHC:**
  - ttbar cross sections
  - Ratio of top/antitop cross sections
- **Further developments:**
  - QED evolution, photon PDFs
  - Benchmarking of theories
  - Fits using kt evolution
  - Nuclear PDFs

HERAFitter Package Specifics

- The software code is a mixture of C++ and Fortran codes. The core interfaces are provided in the Fortran part of the code.

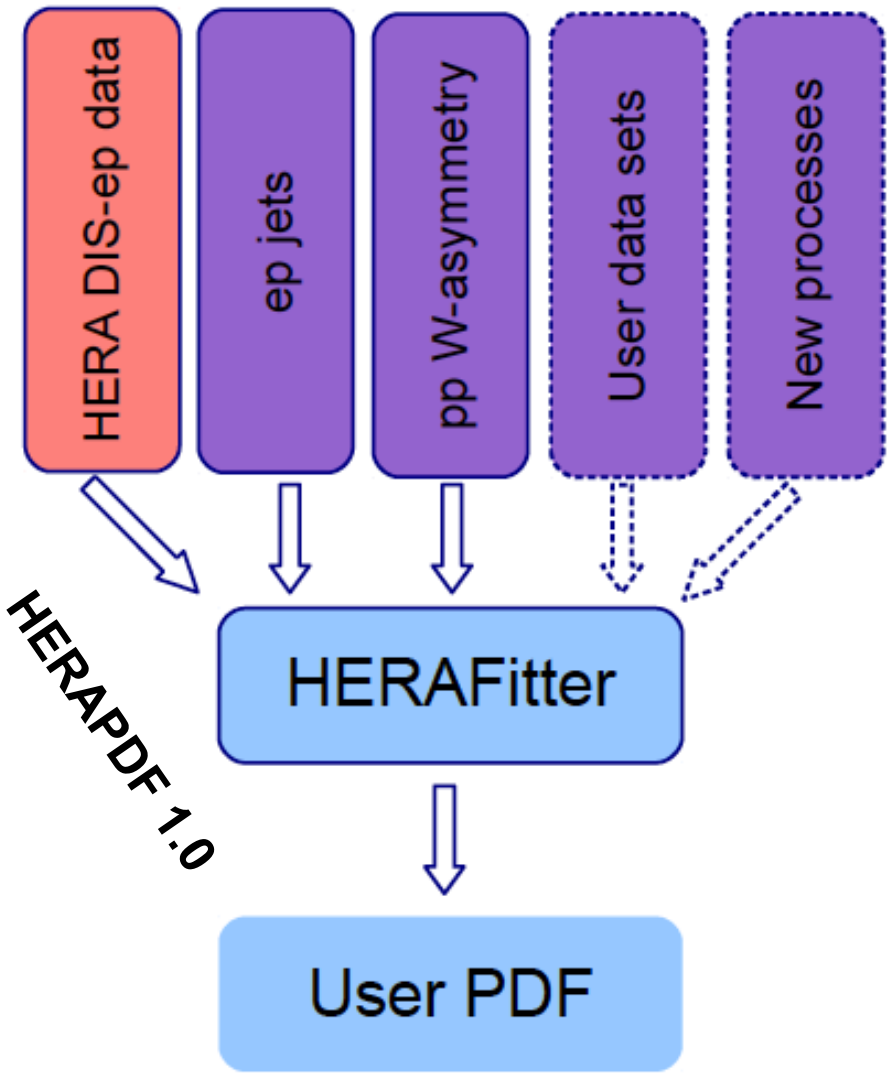
- Central steering file to define input data, fitting parameters steering.txt
- Central steering file to define input PDF parameters minuit.in.txt
- Central steering file to define input ew constants ewparam.txt

- Package includes a ready to use data sets from various experiments:

bcdms hera lhc tevatron

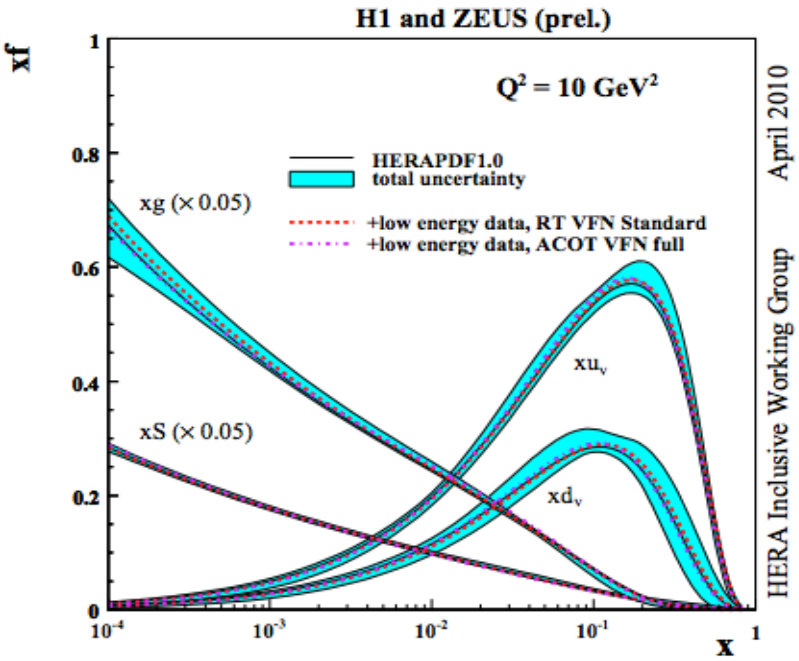
- Inclusion of new data tables for existing processes should be possible without code recompilation. Data are provided as text files with a specified header and the main body, as a table.

HERAFitter usage



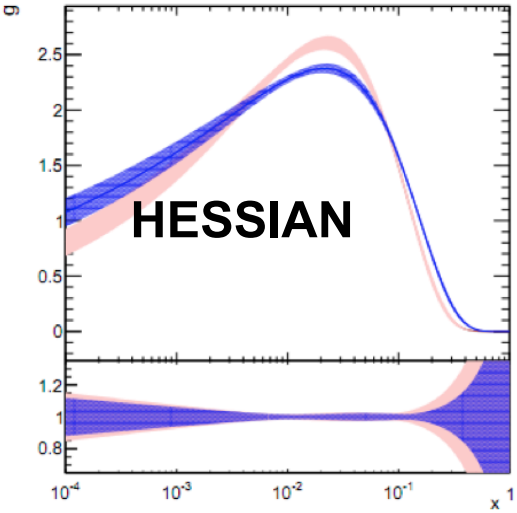
- **The framework is extendable:**
  - **New data:**
    - **User level**
  - **New processes, new theories, schemes etc.:**
    - **Expert work**
  - **Fit Methods:**
    - **Expert work**
  - **More modules**
    - **Average code**
    - **Plotting methods**
    - **…**

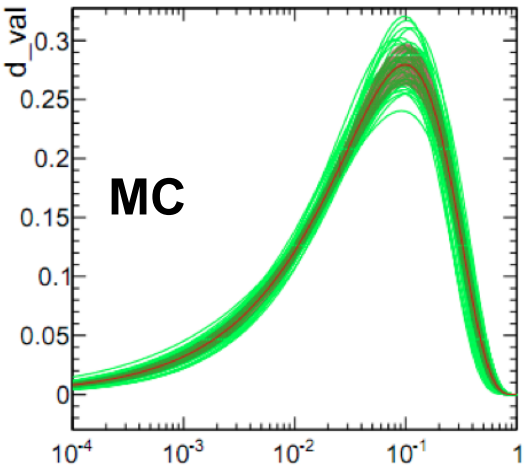
HERAFitter Outputs

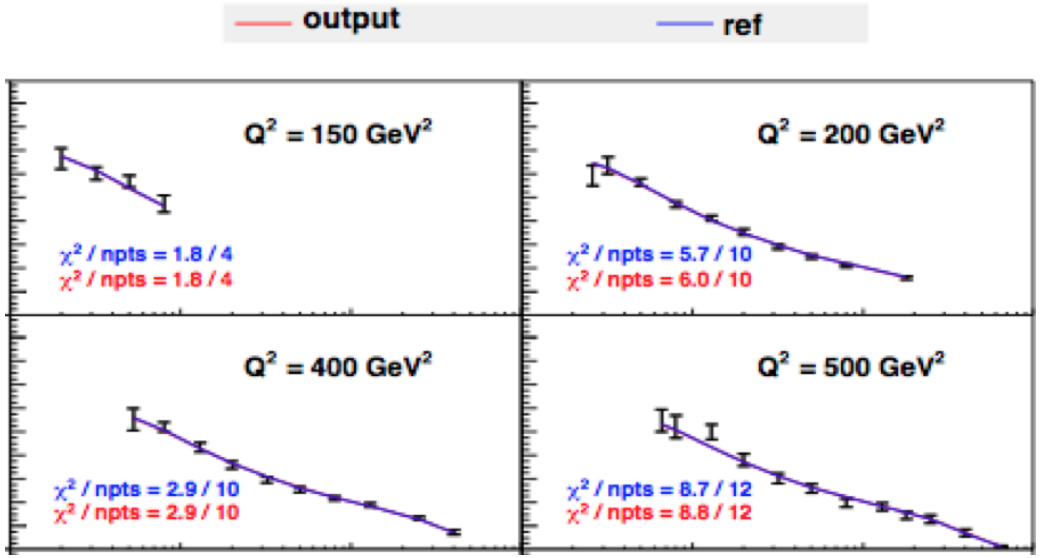


Output contains basic text (and graphic) information stored in output directory:

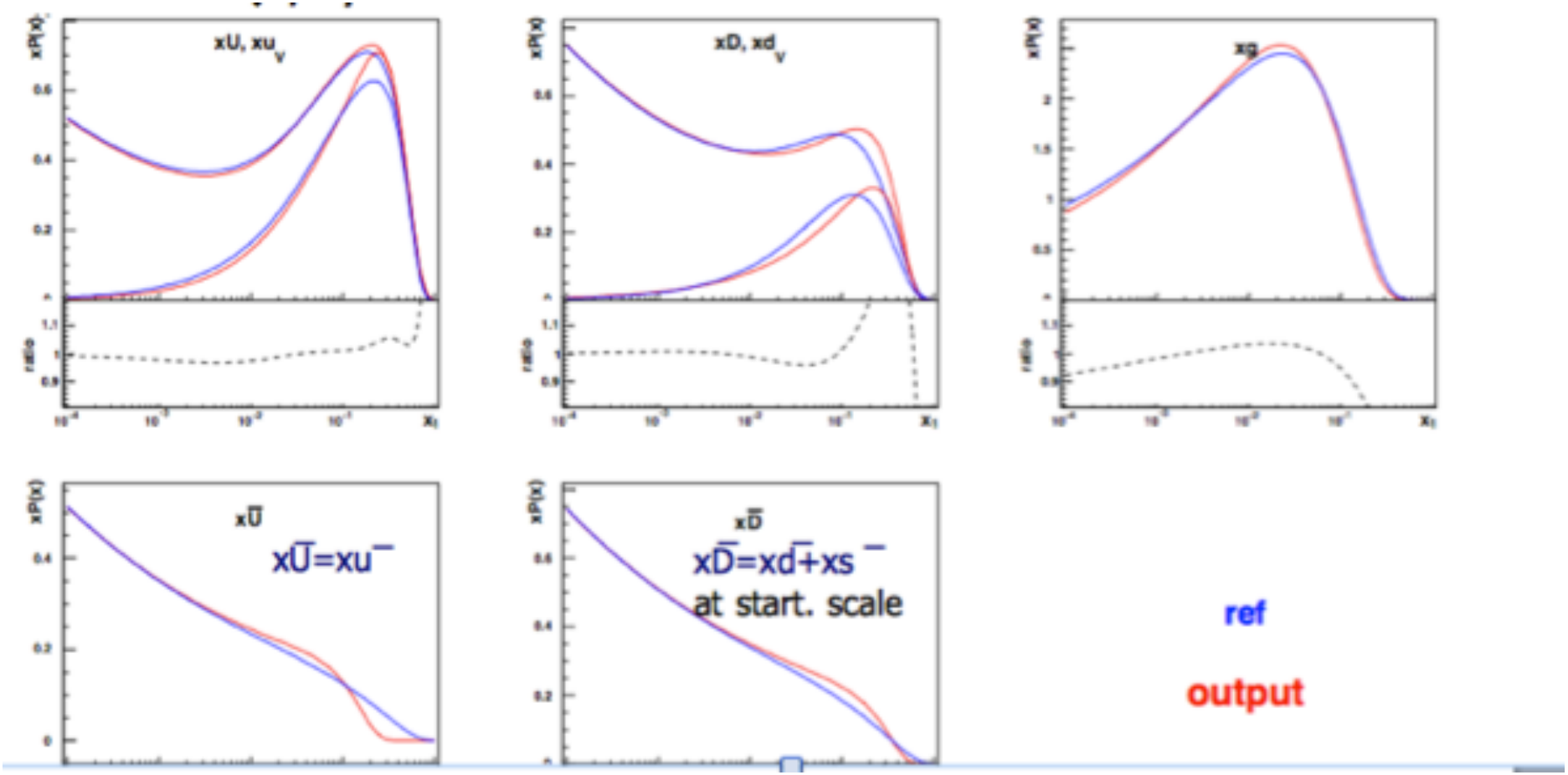
- **Quality of the fit (chisquares, pulls)**
- **Resulting PDFs:**
  - **text and HERALHGRID LHAPDF format grids ready to plug into the MC generators**
- **Hessian vs MC replicas error estimation**



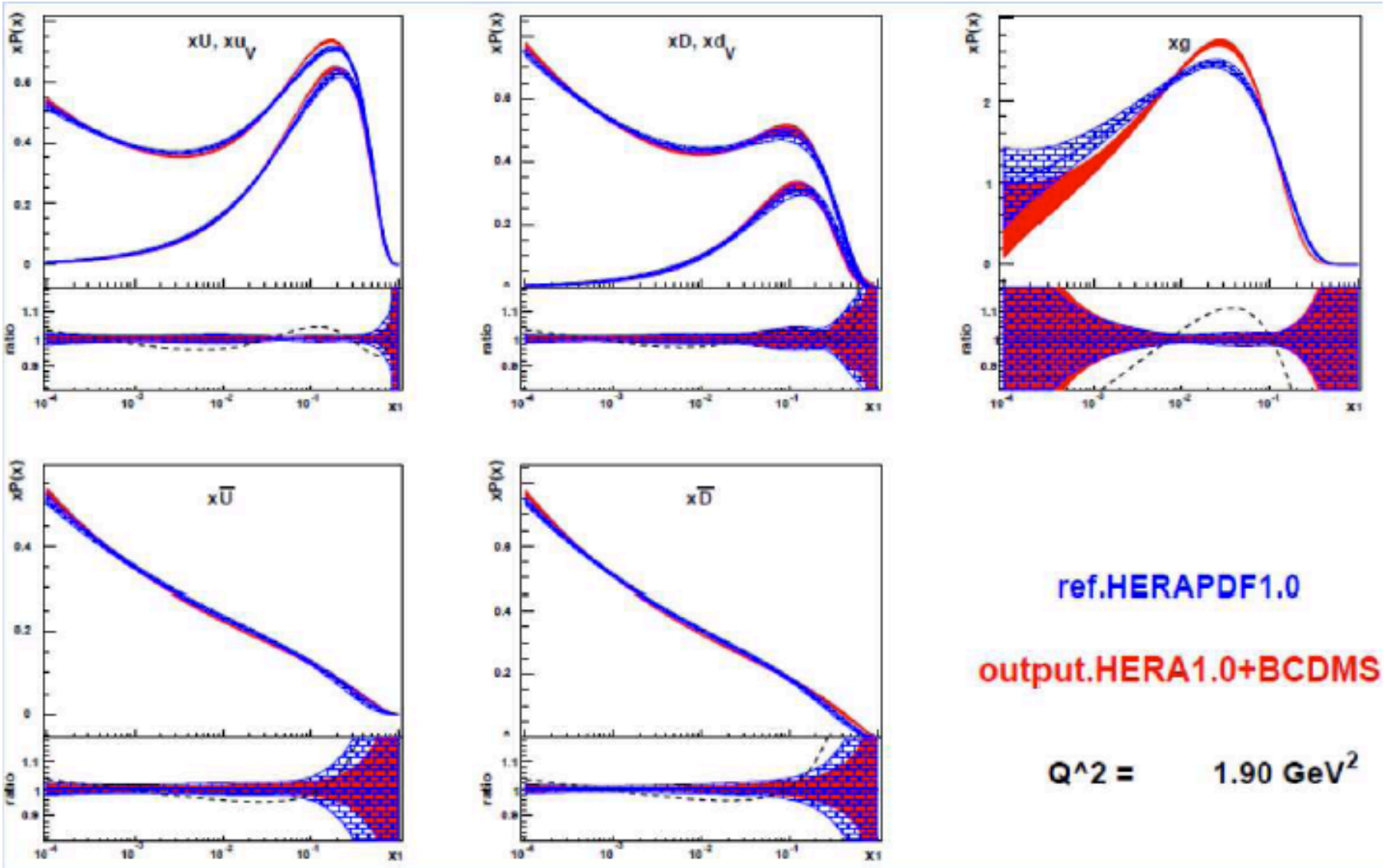




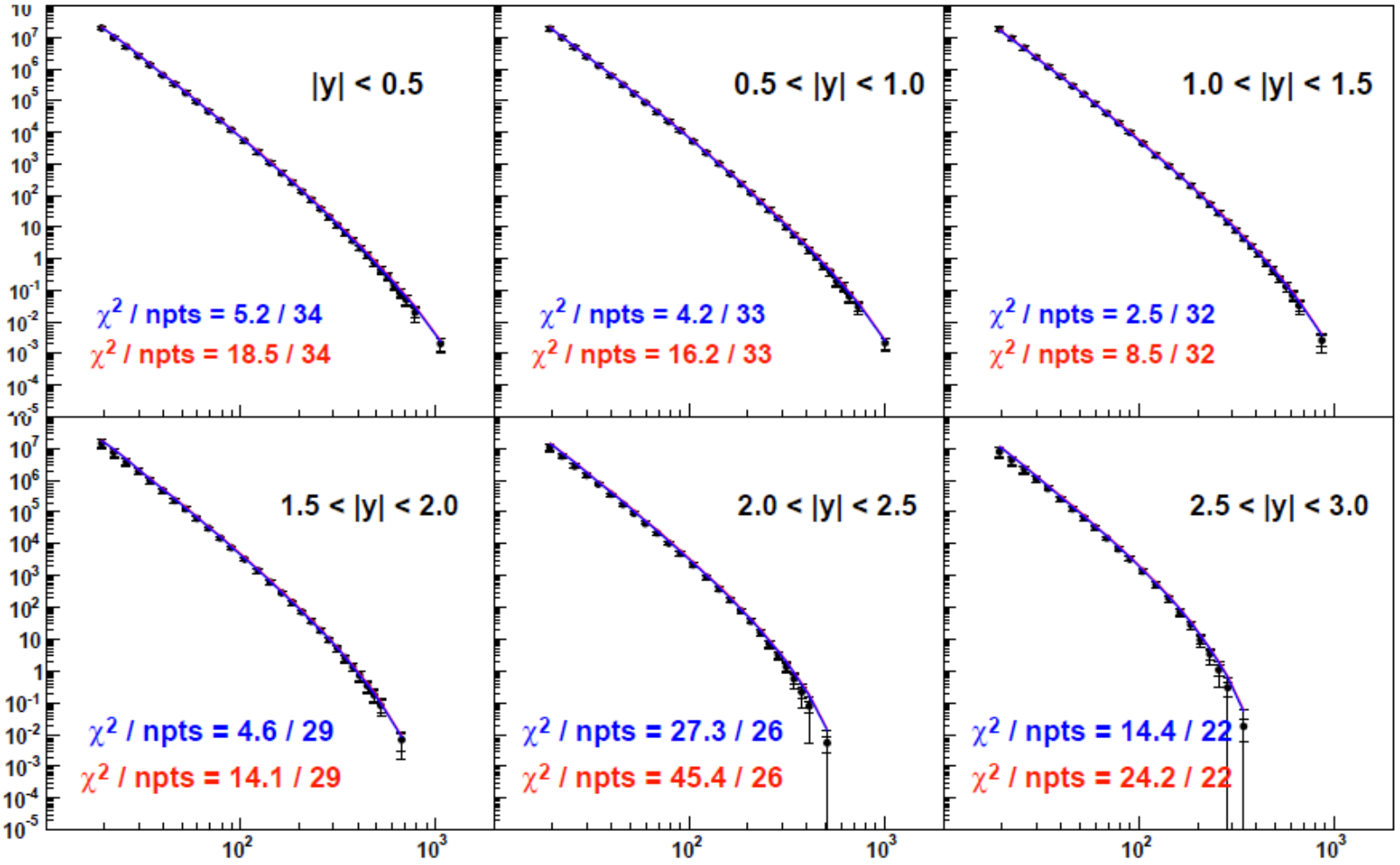
HERAFitter output



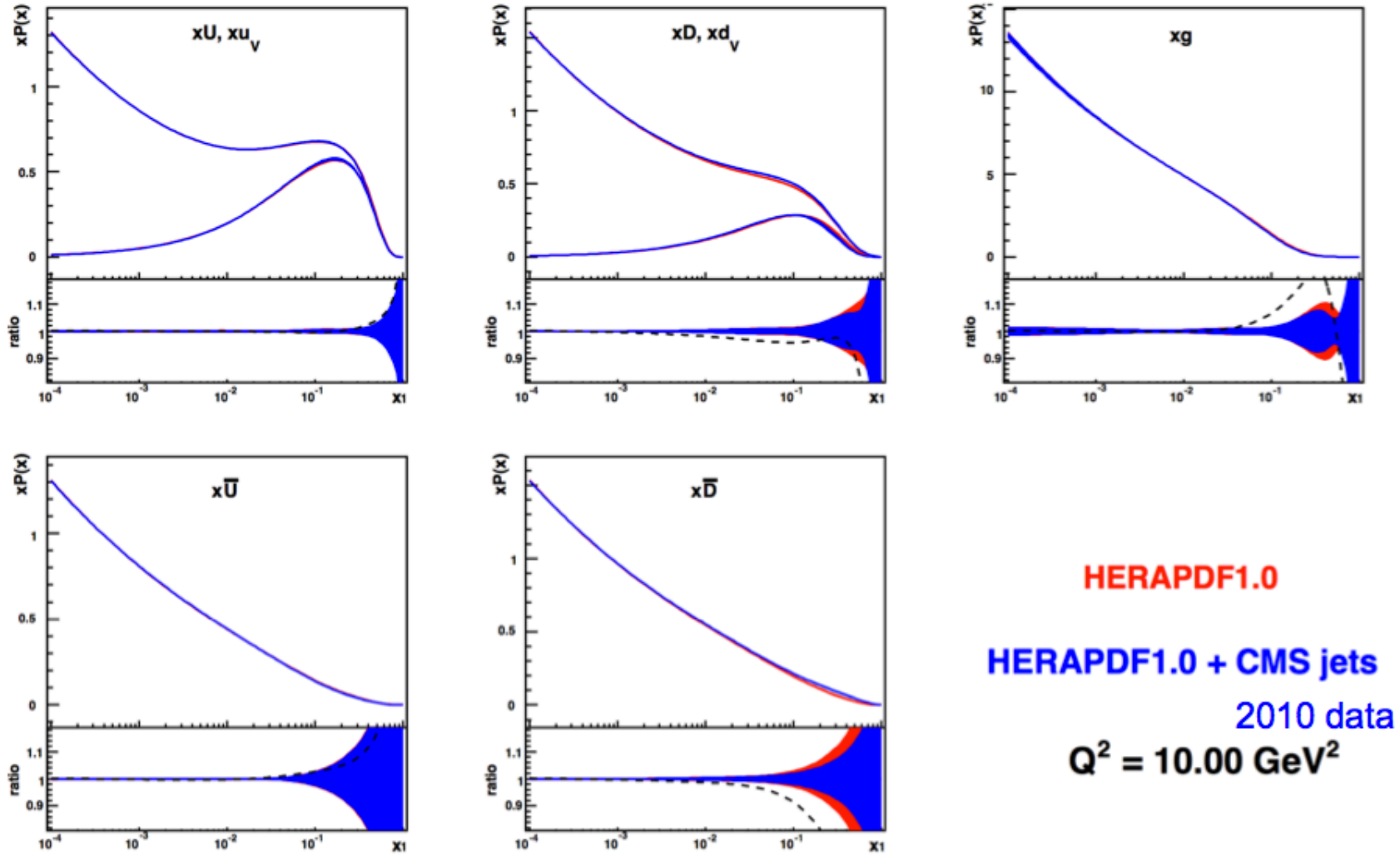
HERA and BCDMS



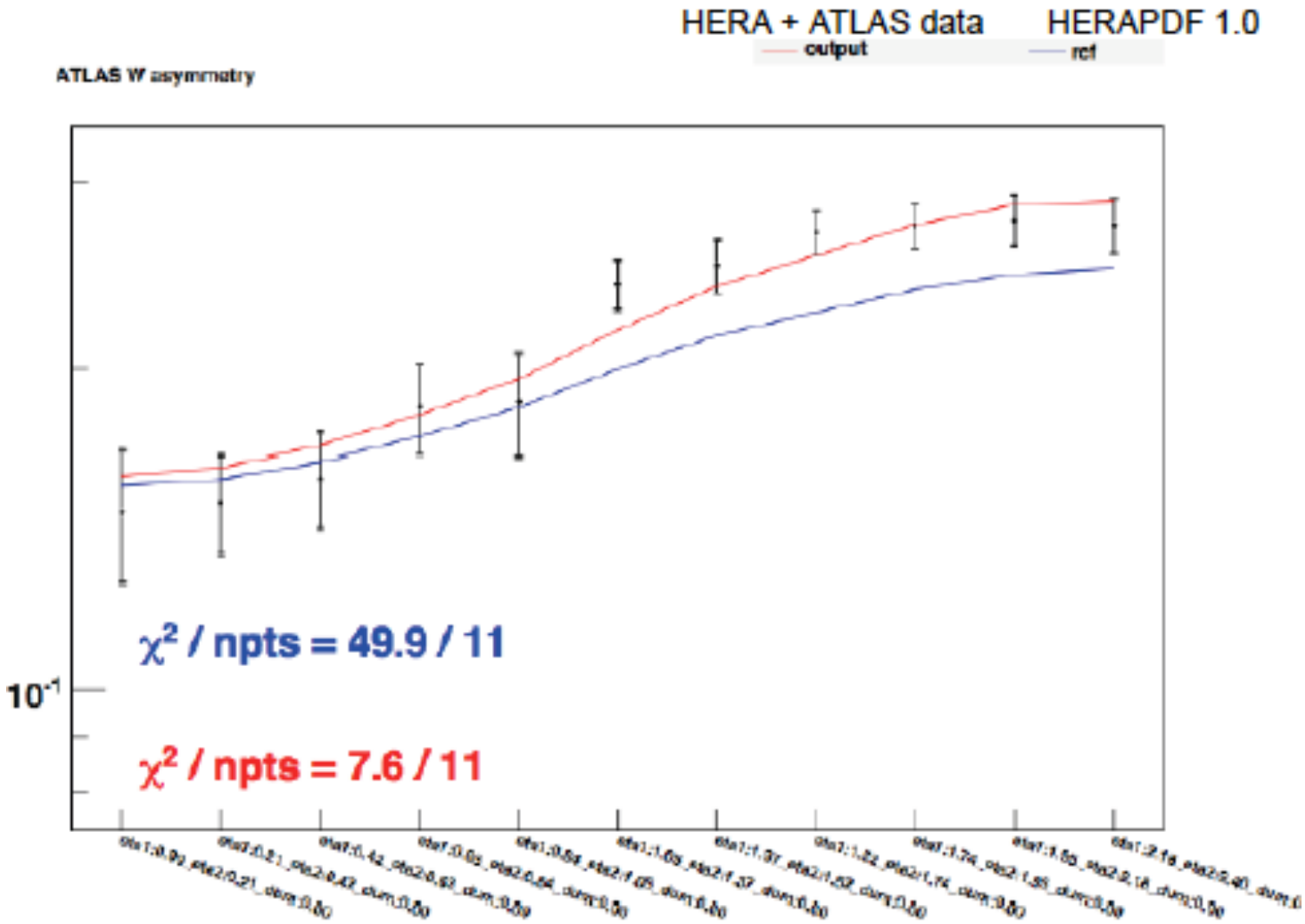
Jet production at LHC (CMS)



Influence of CMS jets

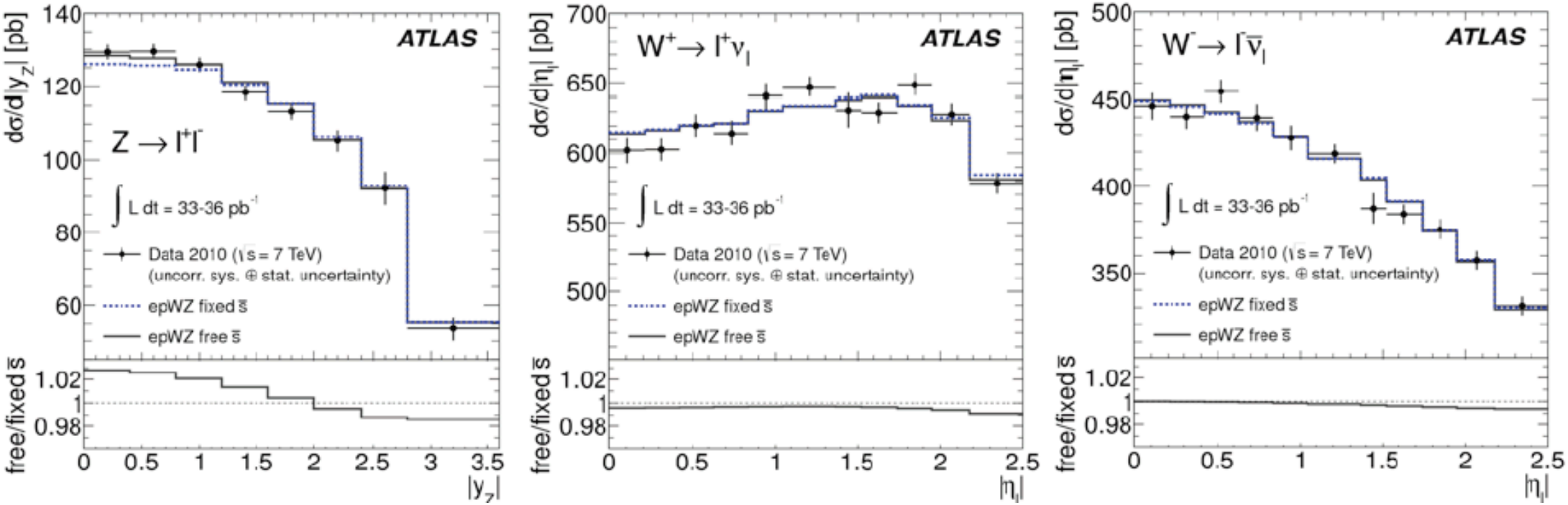


W asymmetry

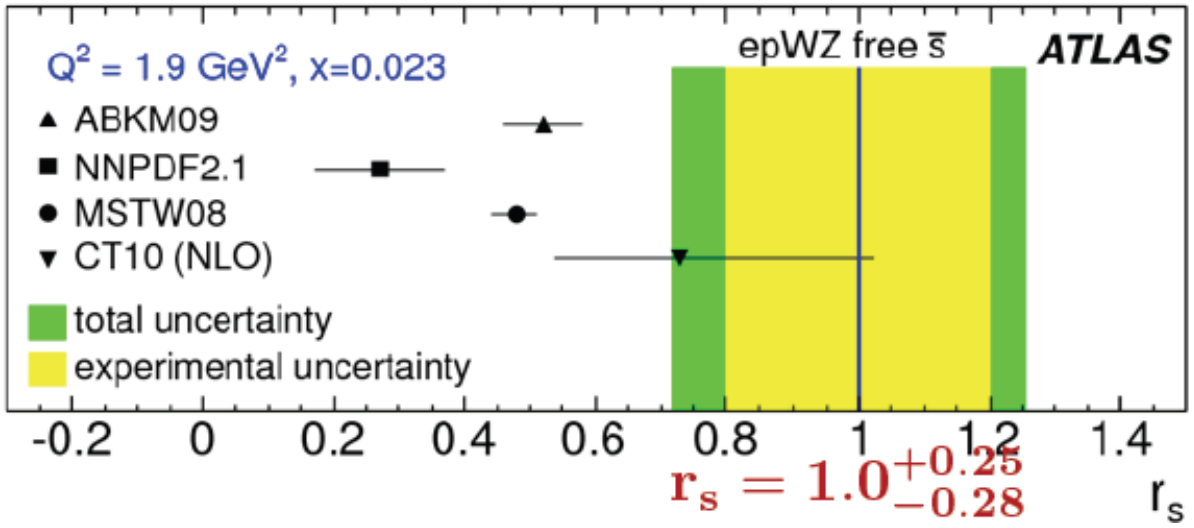

HERA + ATLAS data
HERAPDF 1.0
output
ref
ATLAS W asymmetry
χ^2 / npts = 49.9 / 11
χ^2 / npts = 7.6 / 11
10^{-1}

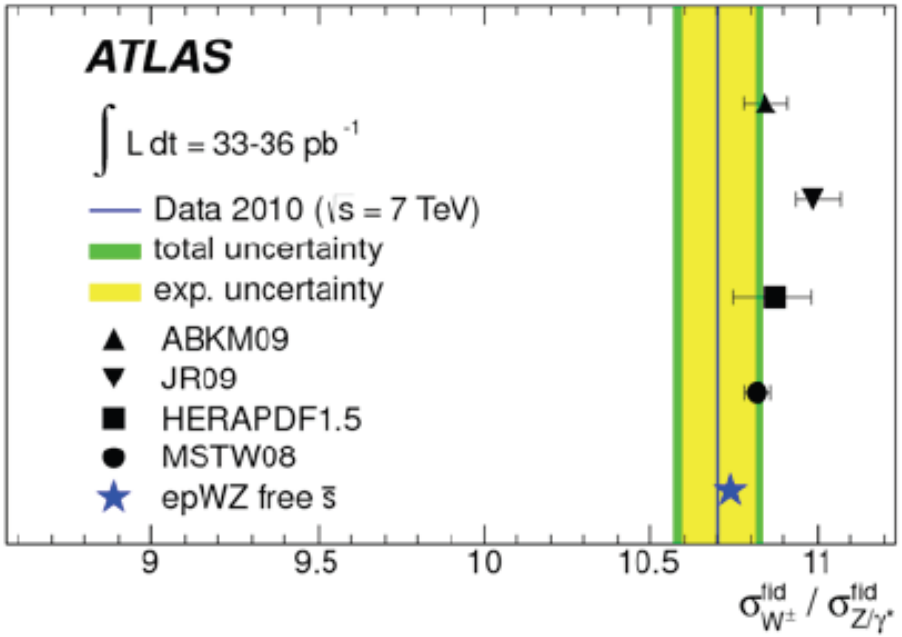
Usage of HERAFiter at LHC

- **QCD fit of ATLAS differential distributions for W+, W and Z with HERA e±p DIS data**
- **NNLO pQCD analysis**
  - **HERAFitter framework with MCFM+APPLGRID NLO QCD**
- **Corrected to NNLO QCD using k factors**
  - $r_s = 0.5(s + \bar{s})/\bar{d}$



Strangeness determination at low x





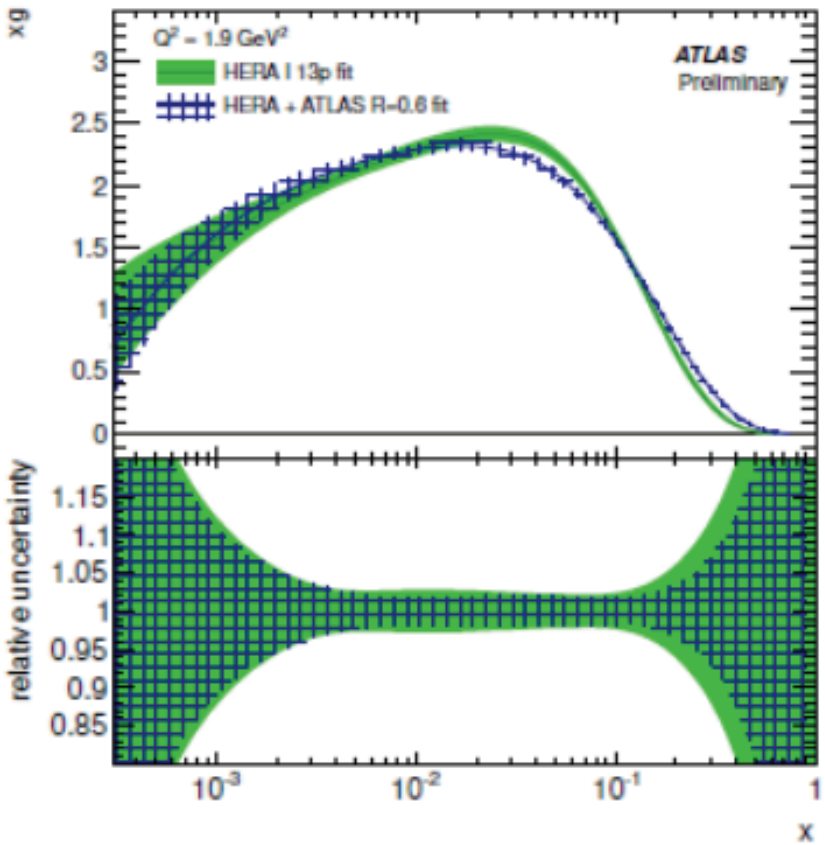
Light quark sea

is flavour symmetric

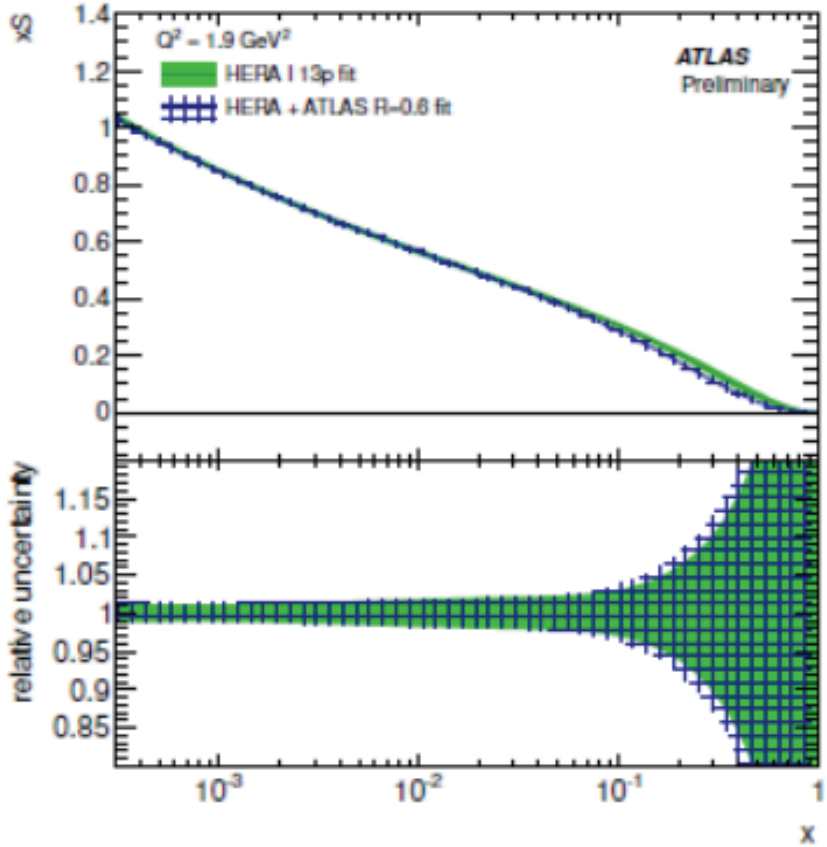
at low x

Phys.Rev.Lett. 109 (2012) 012001

Using HERA and ATLAS data in the fit



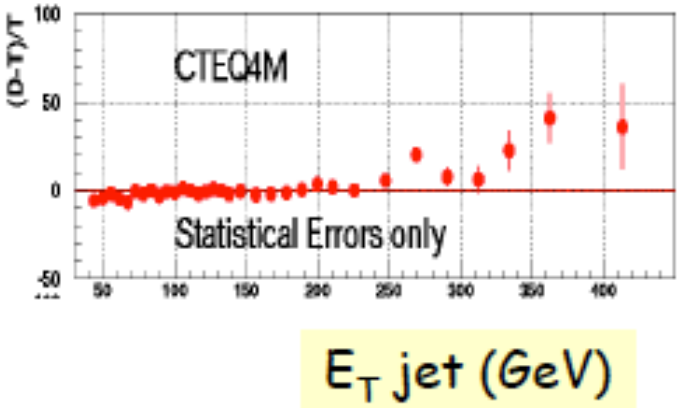
(a) xg

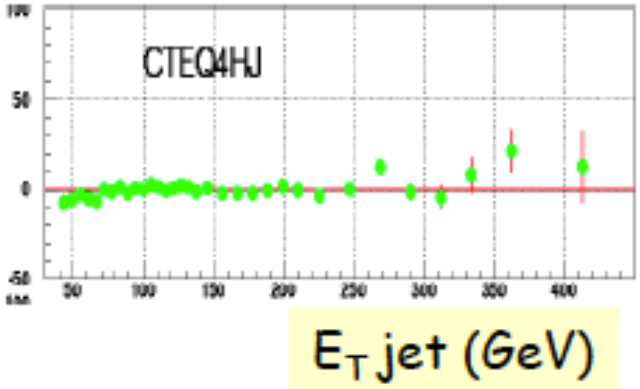


(b) xS

Further physics case: new physics searches

- **Uncertainties dominated by PDF**
  - **Parton distributions and new phenomena strongly connected**
  - **Common analysis desirable: rigorous statistical approach**
- **Example from the history:**
  - **Jets at Tevatron**



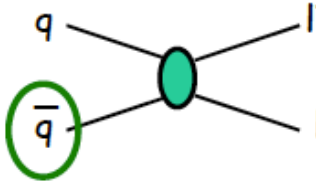


CDF, 1995

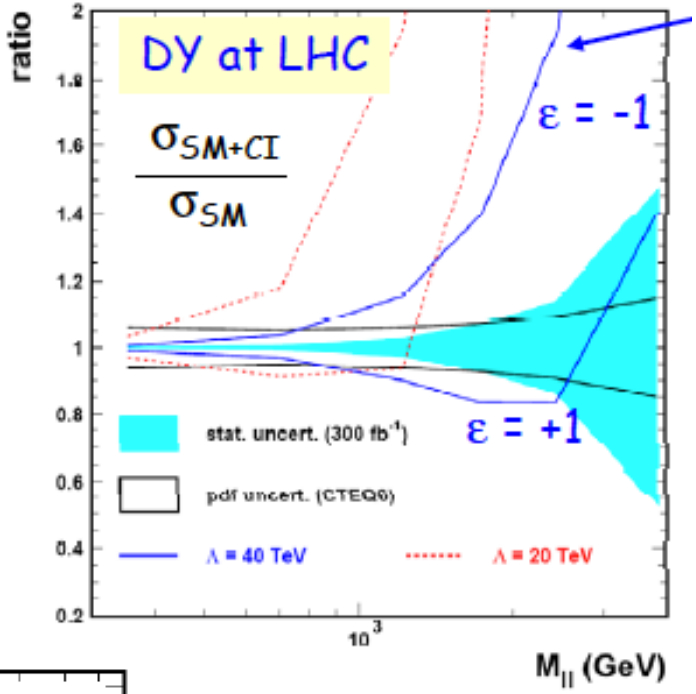
New physics at high x: a toy example

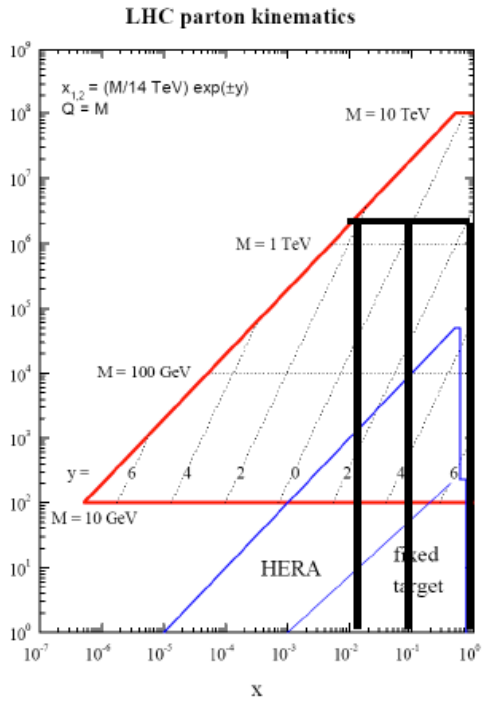
High Mass Drell-Yan at the LHC

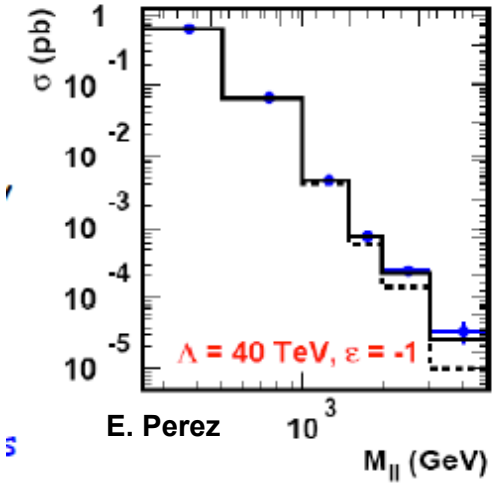
Drell-Yan with M_{ll} ~ TeV involves quarks and antiquarks with x_{Bj} ~ 0.1

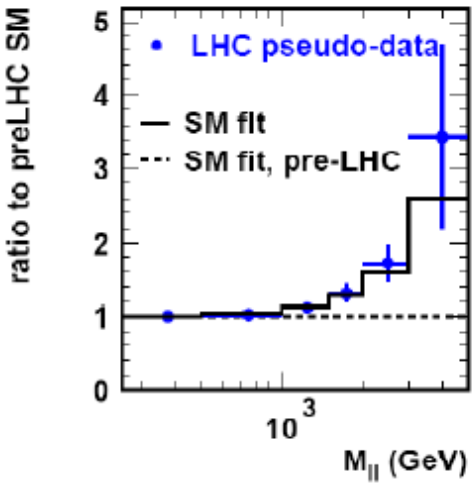


$$\mathcal{L}_{CI} = \sum_{i,j=L,R} \varepsilon_{ij}^{eq} \frac{4\pi}{\Lambda^2} (\bar{e}_i \gamma^\mu e_i)(\bar{q}_j \gamma_\mu q_j)$$







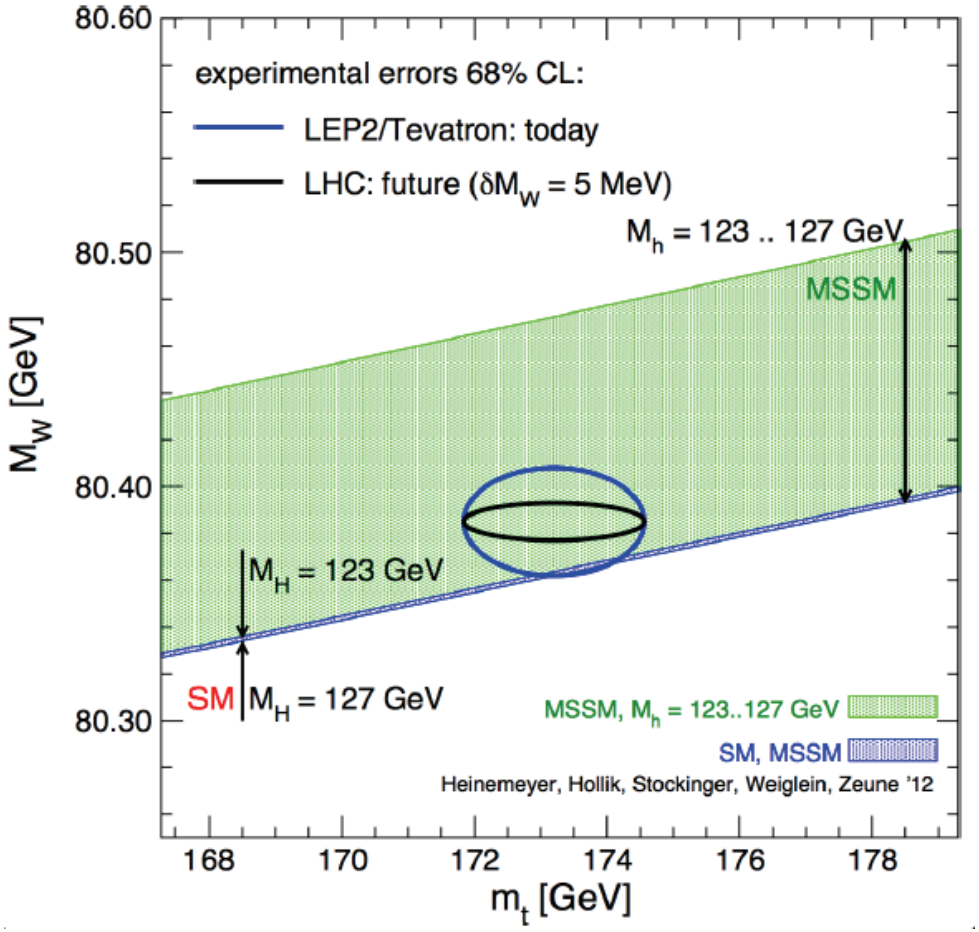


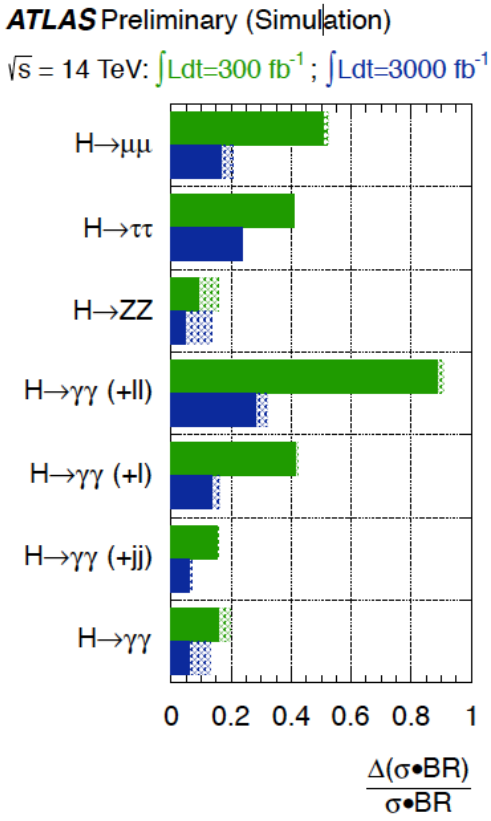
A "pdf" fit using only HERA+BCDMS+LHC would accommodate new physics into PDFs

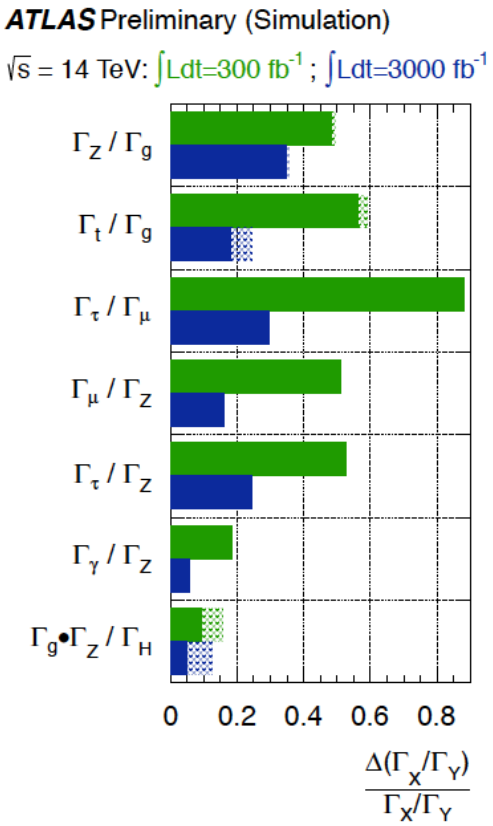
(nb: this is only a toy example, using Tevatron data would here remove the ambiguity)

Far future issues?

- **QCD/PDF uncertainties may be the last to fight: get prepared**

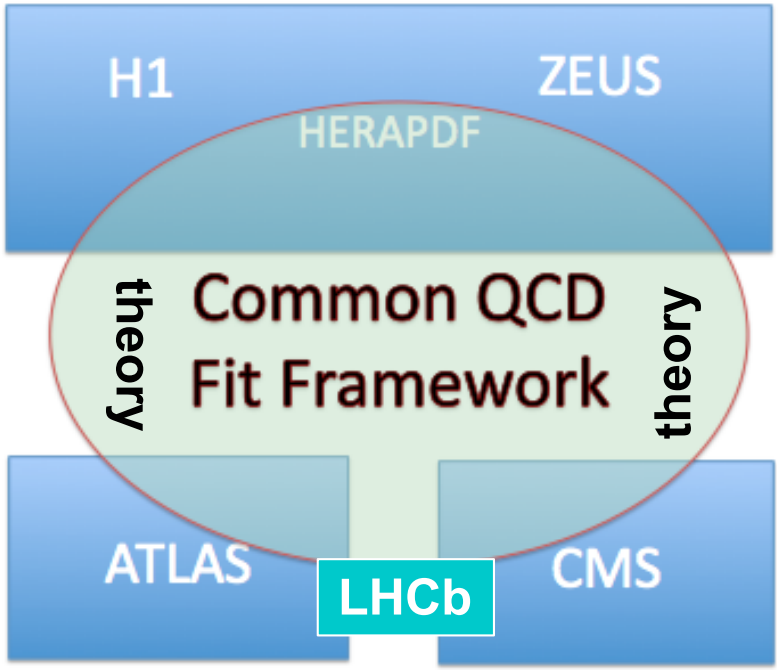






HERAFitter Project

- **Timescale:**
  - September 2011 First Beta Releas, package presented to the LHC community (ATLAS and CMS)
  - October 2011 First HERAFitter User's Meeting
  - February 2012 HERAFitter Workshop in Marseille
  - May 2012 Second Beta Release
  - Winter 2012 Next release
- **Package is supported by**
  - a group of developers originally from H1 and ZEUS collaborations and extended to LHC experiments and theory
  - a steering group committee with contact persons to HERA, LHC and theory
    - C. Diaconu (H1), O. Behnke (ZEUS), B. Malaescu (ATLAS), K. Rabbertz (CMS), R. McNaulty (LHCb), G. Salam (theory), V. Radescu, R. Placakyte, A.Cooper-Sarkar, A. Glazov

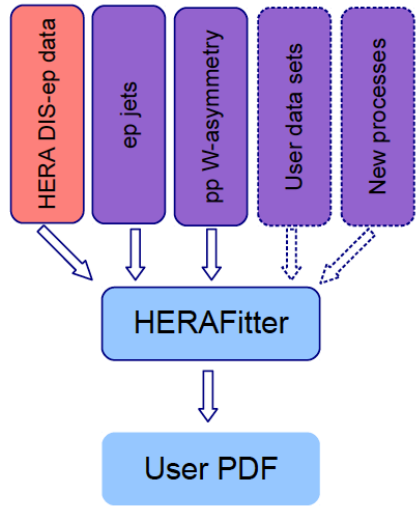


Weekly developer's meeting https://herafitter.org/HERAFitter/HERAFitter/HERAFitterInternal/FitForumMeetings

Monthly users's meeting (https://herafitter.org/HERAFitter/HERAFitter/HERAFitterMeetings)

Conclusions

- **LHC data starts to be sensitive to PDFs**
  - **there is a short and long term physics case for PDF determinations beyond HERA**
- **HERAFitter is a fitting tool based on HERAPDF available for a fast feedback on analyses sensitive to PDF's**
  - **Versatile: extensible to many theories and experimental data sets**
  - **Open access and community driven utility**
- **Users and contributors are welcome:**

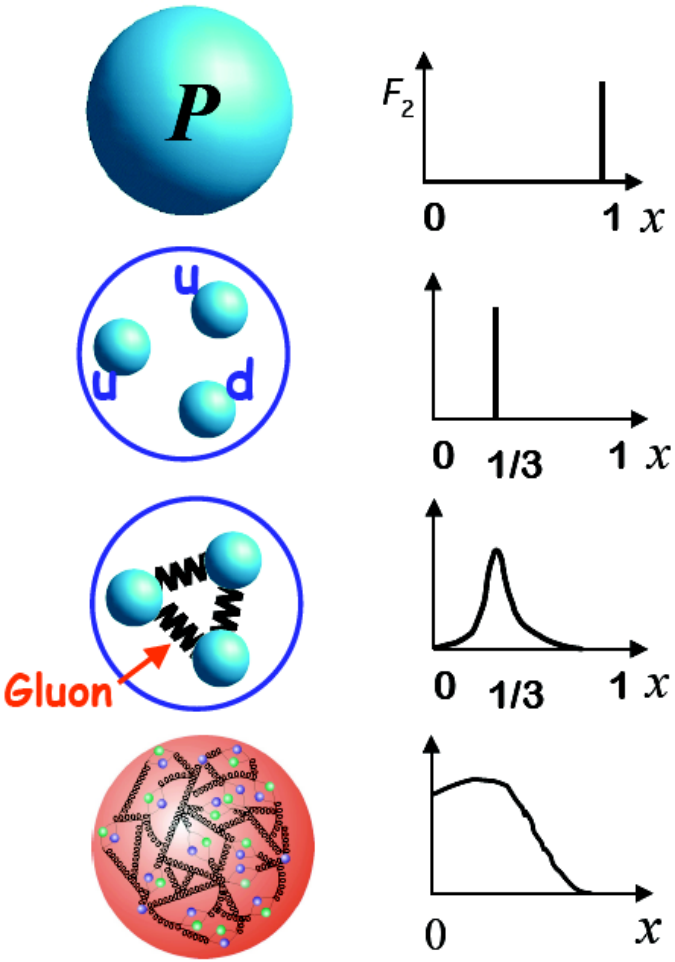


http://www.herafitter.org

Thanks: V.Radescu, S.Glazov, R.Placakyte, P.Below, K.Nowak

Backup slides

Proton make-up



no substructure

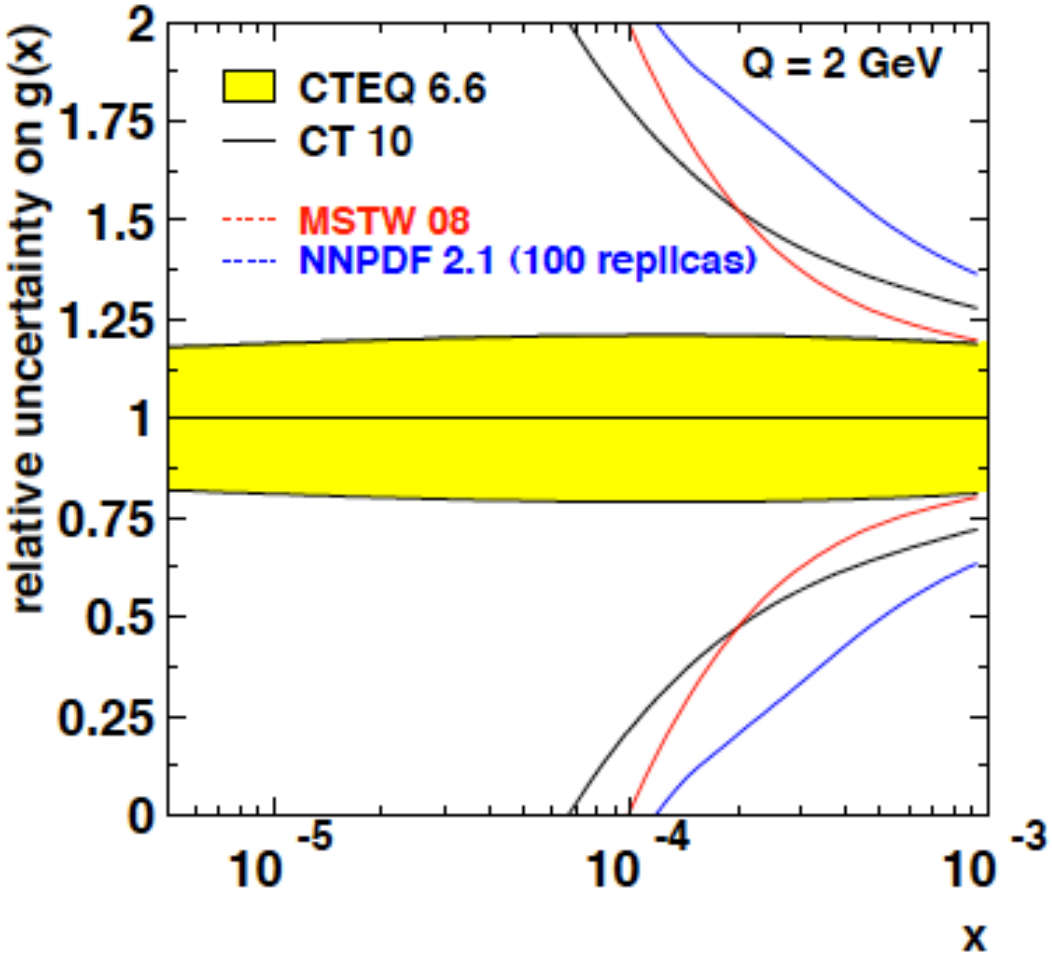
3 free valence quarks

3 bound quarks

Valence quarks
Sea quarks
gluons

Strong force at work!

PDF parameterisation: an issue



HERAFitter Functionality

- Can perform fits to DIS, DIS diffractive, jets, DY data:
  - FastNLO and APPLGRID interfaces implemented
- QCD evolution based on QCDNUM package:
  - NLO, NNLO DGLAP equations
- Access to various heavy flavour schemes:
  - RT standard and optimal as in MSTW (NLO, NNLO)
  - ACOT as in CTEQ (LO, NLO)
  - FFNS and BMSN as in ABM (NLO, NNLO)
  - Developments in the top area: ttbar cross section using HATHOR package
- Includes various methods for:
  - Error propagation:
    - Hessian vs Monte Carlo: benchmark with NNPDF [PDF4LHC Report arXiv:1101:0536
  - Experimental Error treatment: Correlated, Uncorrelated, Offset
  - Parametrisation:
    - Standard Functional form (a la MSTW, CTEQ, ABM)
    - Chebyshev polynomials [PLB27193]
  - Chisquare definitions
- Possibility to link to LHAPDF and draw/compare various predictions
- Access to the NNPDF reweighting tool
- kt-evolution for the unintegrated PDFs
- Various DIPOLE Models

Common fits of HERA and Tevatron

Fit results with CDF data: **Fit**: 13 parameters, RT FAST scheme is used

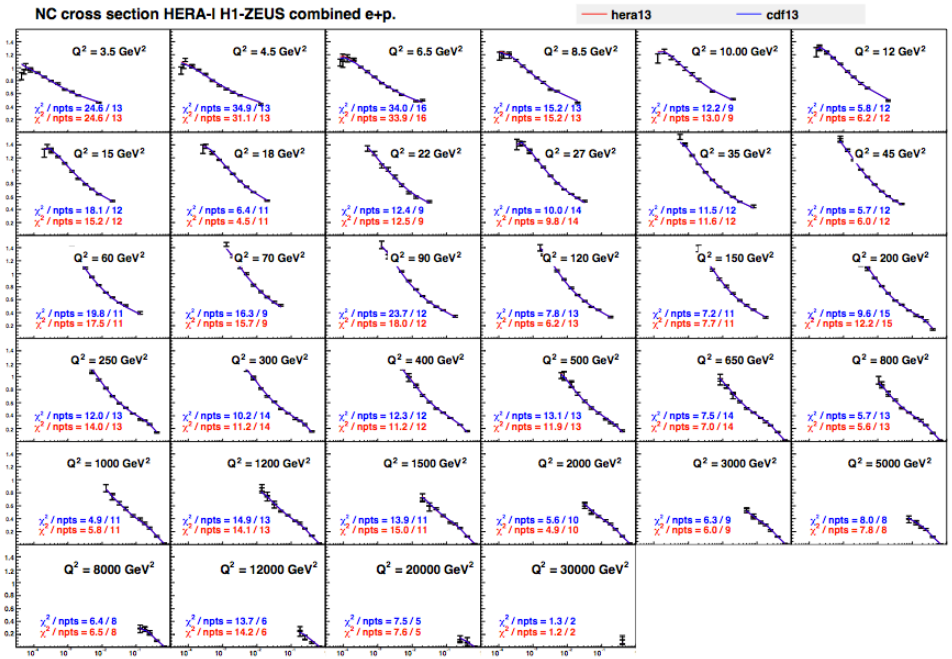
HERA 1.0 data

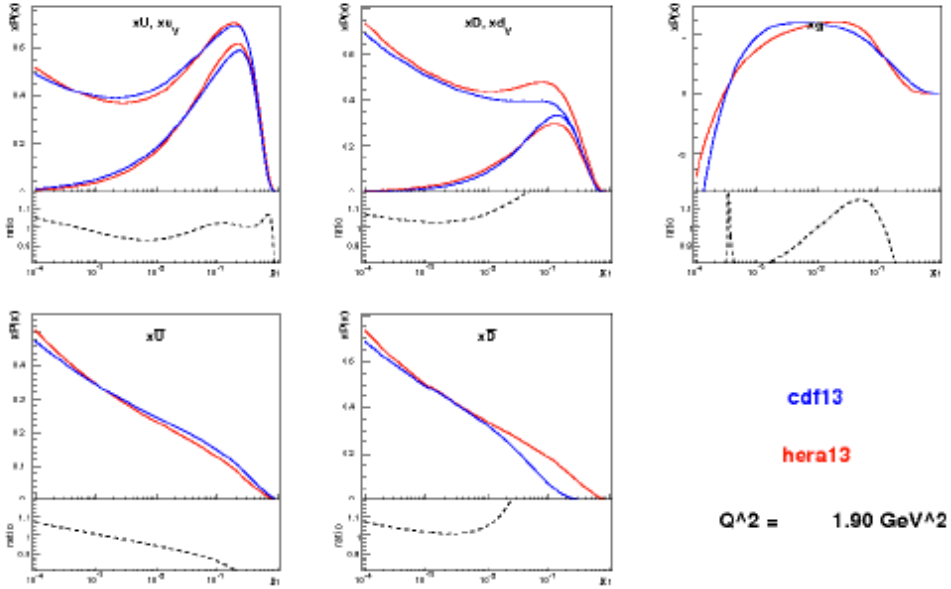
- $\chi^2 = 0.973$
- NC $e^- p$ 107.74 / 145
- NC $e^+ p$ 404.96 / 379
- CC $e^- p$ 20.20 / 34
- CC $e^+ p$ 30.27 / 34

HERA 1.0 data + CDF data

- $\chi^2 = 1.093$
- NC $e^- p$ 109.48 / 145
- NC $e^+ p$ 418.57 / 379
- CC $e^- p$ 26.26 / 34
- CC $e^+ p$ 37.26 / 34
- **CDF 103.21 / 72**

arXiv:0807.2204





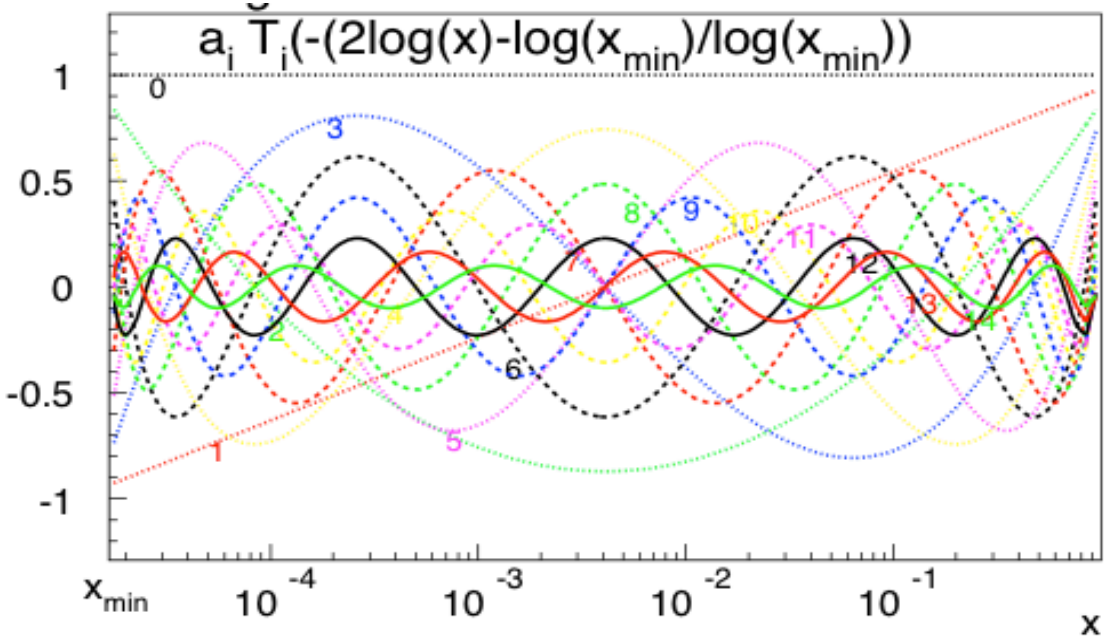
The comparison of the parton distributions for $Q^2 = 1.9 GeV^2$: red line is HERA1 data, blue line is HERA1+CDF data

HERAFitter Functionality

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

$$xf(x) = \sum_{i=0}^{N-1} a_i T_i\left(\frac{-(2\log x - \log x_{min})}{\log x_{min}}\right)$$

$$T_0(x) = 1$$
$$T_1(x) = x$$
$$T_2(x) = 2x^2 - 1$$
$$T_3(x) = 4x^3 - 3x$$
$$T_4(x) = 8x^4 - 8x^2 + 1$$
$$T_5(x) = 16x^5 - 20x^3 + 5x$$
$$T_6(x) = 32x^6 - 48x^4 + 18x^2 - 1$$
$$T_7(x) = 64x^7 - 112x^5 + 56x^3 - 7x$$
$$T_8(x) = 128x^8 - 256x^6 + 160x^4 - 32x^2 + 1$$
$$T_9(x) = 256x^9 - 576x^7 + 432x^5 - 120x^3 + 9x.$$



- **Includes various methods for:**
  - **Error propagation: Hessian vs Monte Carlo: benchmark with NNPDF [PDF4LHC Report arXiv:1101:0536**
  - **Experimental Error treatment: Correlated, Uncorrelated, Offset [see Mandy's, Sasha's slides]**
  - **Parametrisation:**
    - **Standard Functional form (a la MSTW, CTEQ, ABM)**
    - **Chebyshev polynomials [PLB27193]**
  - **Chisquare definitions**

HERAFitter Functionality

Various Chisquares options:

- This definition corrects for possible biases introduced by the low statistics samples:
  - Uncertainties are scaled with expected number of events rather than observed
  - Logarithm term arises from the transition of likelihood to chisquare
- Correlated sources are taken into account (and a penalty term arises in the chisquare)

$$\chi^2 = \sum_i \frac{\left[\mu_i - m_i\left(1 - \sum_j \gamma_j^i b_j\right)\right]^2}{\delta_{i,\mathrm{unc}}^2 m_i^2 + \delta_{i,\mathrm{stat}}^2 \mu_i m_i \left(1 - \sum_j \gamma_j^i b_j\right)} + \sum_j b_j^2 + \sum_i \ln \frac{\delta_{i,\mathrm{unc}}^2 m_i^2 + \delta_{i,\mathrm{stat}}^2 \mu_i m_i}{\delta_{i,\mathrm{unc}}^2 \mu_i^2 + \delta_{i,\mathrm{stat}}^2 \mu_i^2}$$

Measured | Theoretical | Correl. sources | Correl. shifts | Log likelihood transition

- **Simplified options:**
  - **No scaling of the errors**
  - **Including scaling of the errors but no log term**

(NOT IN BETA RELEASE: covariance matrix)

Proton structure is essential for LHC physics

Examples: