

# WG1 Highlights: Structure Functions and Parton Densities

WG1 conveners: Richard Ball, Vladimir Chekelian and Karol Kovarik

## ***Experimental part:***

- 1. Completion of the HERA inclusive DIS cross section measurements :**
  - NC  $E_p=460, 575$  GeV and model independent  $F_L$  measurements
  - NC measurements at highest  $x \rightarrow 1$
  - beauty and charm production in DIS
- 2. Combination of all inclusive HERA measurements and HERAPDF2.0**
- 3. LHC data and an impact of the data on pdfs**
  - gluon density (jets, isolated photons,  $t\bar{t} \rightarrow$  WG3/WG5 )
  - u, d and valence quarks densities (W&Z, DY, W charge asymmetry)
  - strange quark density (W&Z, W+c)

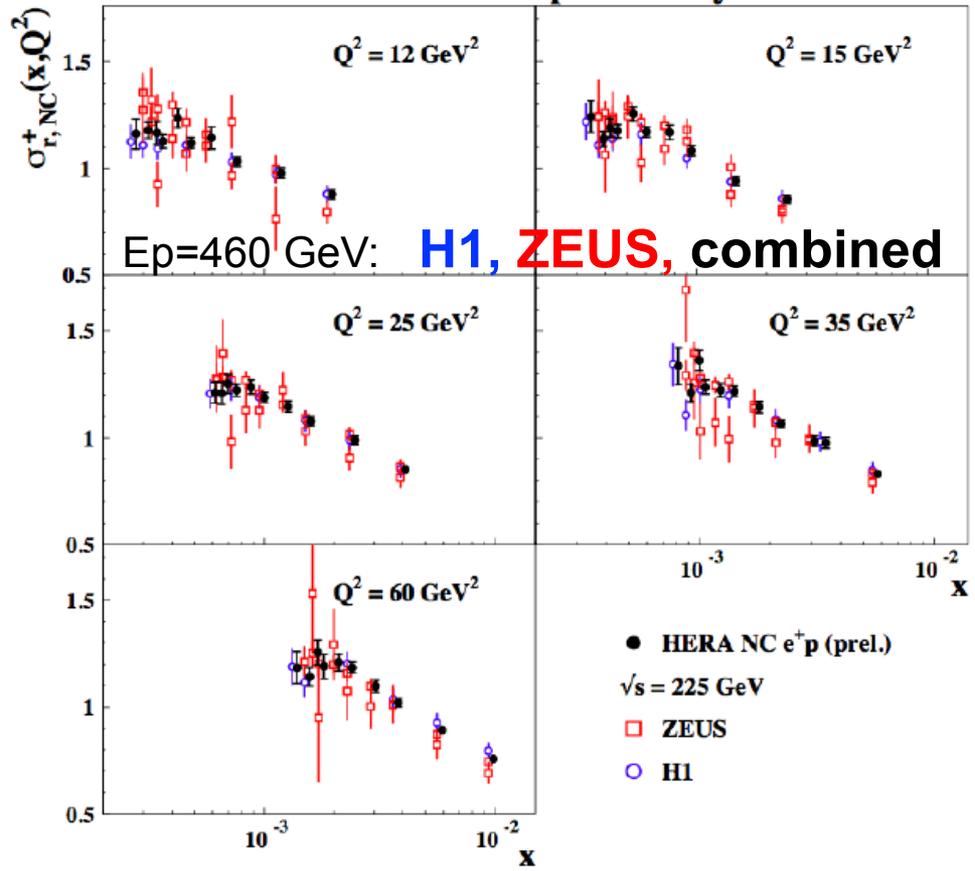
# Completion of inclusive NC,CC meas. at HERA

J.Grebenyuk, S.Shushkevich

A. Levy

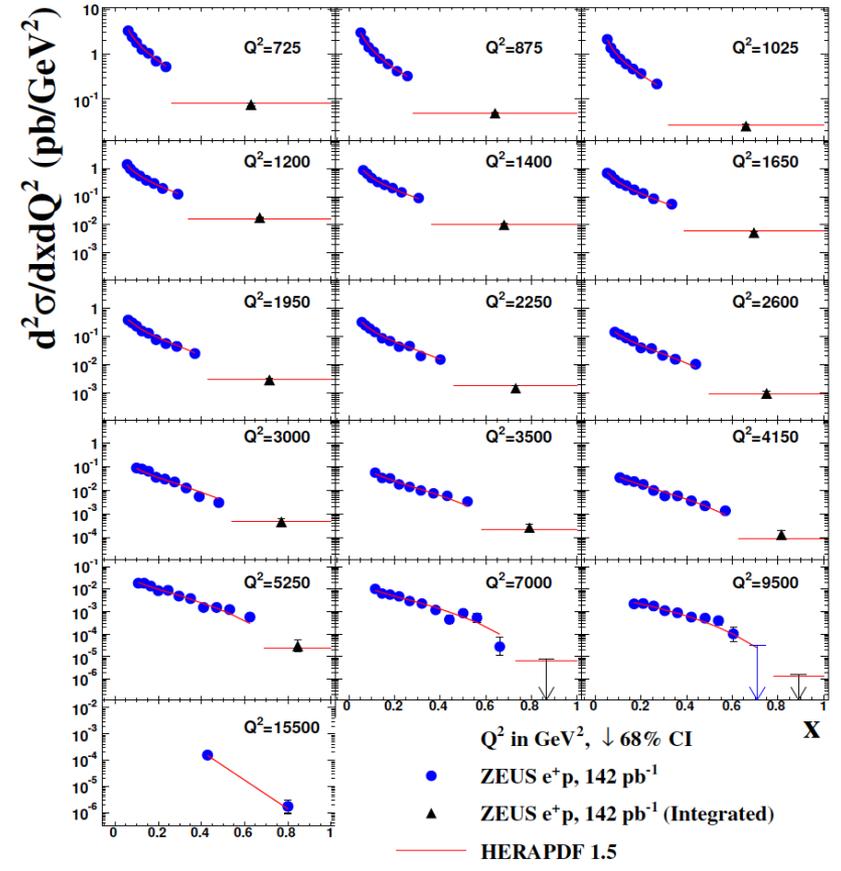
## NC at $E_p=460$ and $575$ GeV

H1 and ZEUS preliminary



## $e^\pm p$ NC at highest $x \rightarrow 1$

ZEUS

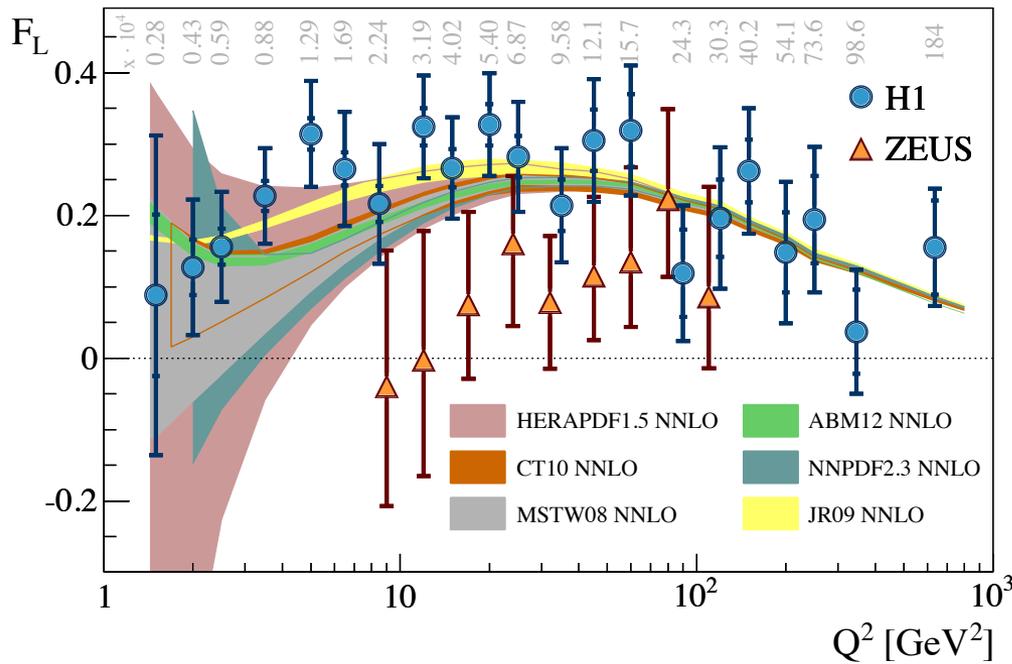


**Beauty and charm production in DIS using secondary vtx (ZEUS) (V. Libov)**  
 $\rightarrow F_2^{cc}, F_2^{bb}$  and determination of beauty mass,  $m_b(m_b) = 4.07^{+0.17}_{-0.16} \text{ GeV}$

# Longitudinal structure function $F_L$

Longitudinal structure function  $F_L$  is determined in a model independent way using cross section measurements at the same  $x$  and  $Q^2$  and  $E_p = 460, 575$  and  $920$  GeV

H1 and ZEUS



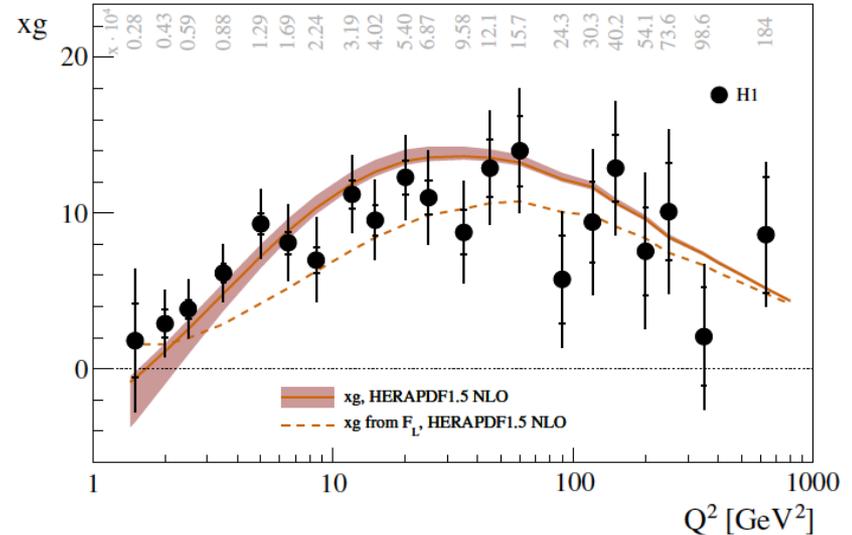
$$R = \sigma_L / \sigma_T = F_L / (F_2 - F_L) = 0.23 \pm 0.04 \text{ (H1)}$$

$$R = 0.105 + 0.055 - 0.037 \text{ (ZEUS)}$$

approximate relation between  $F_L$  and gluon (order of  $\alpha_s$ , with  $a=1$ )

$$xg(x, Q^2) \approx 1.77 \frac{3\pi}{2\alpha_s(Q^2)} F_L(ax, Q^2)$$

H1 Collaboration



# Combination of all NC and CC inclusive data from H1 and ZEUS

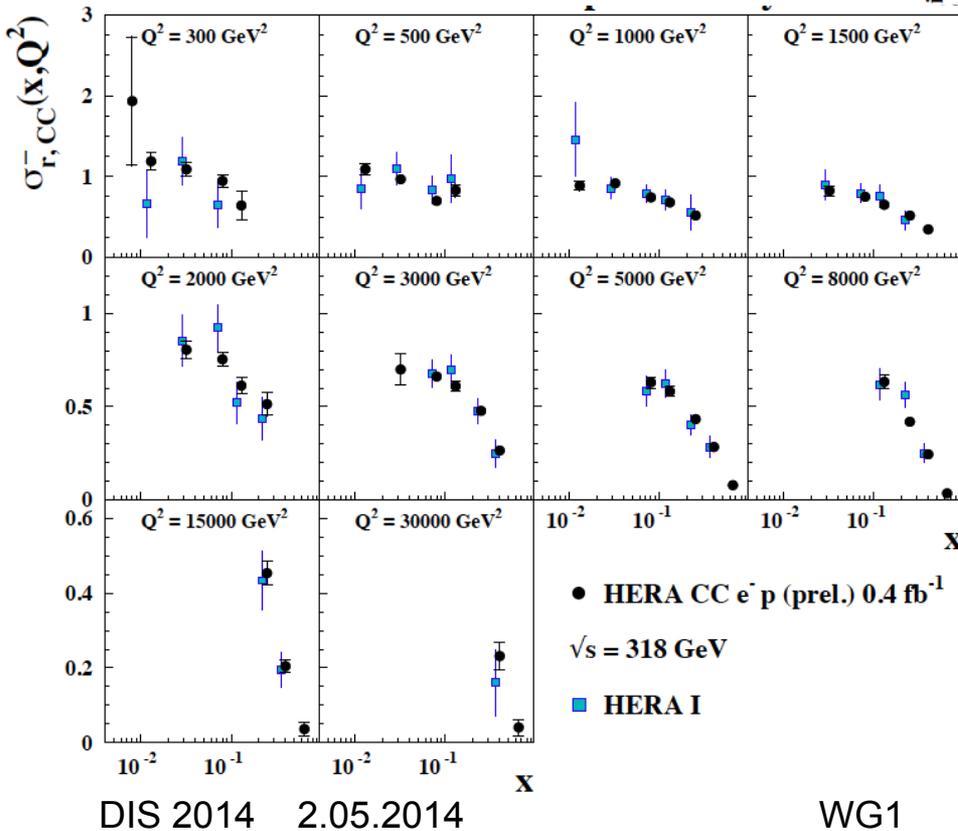
O.Turkot

Input: 41 data sets from H1 and ZEUS at  $E_p = 920, 820, 575$  and  $460$  GeV,  $1 \text{ fb}^{-1}$

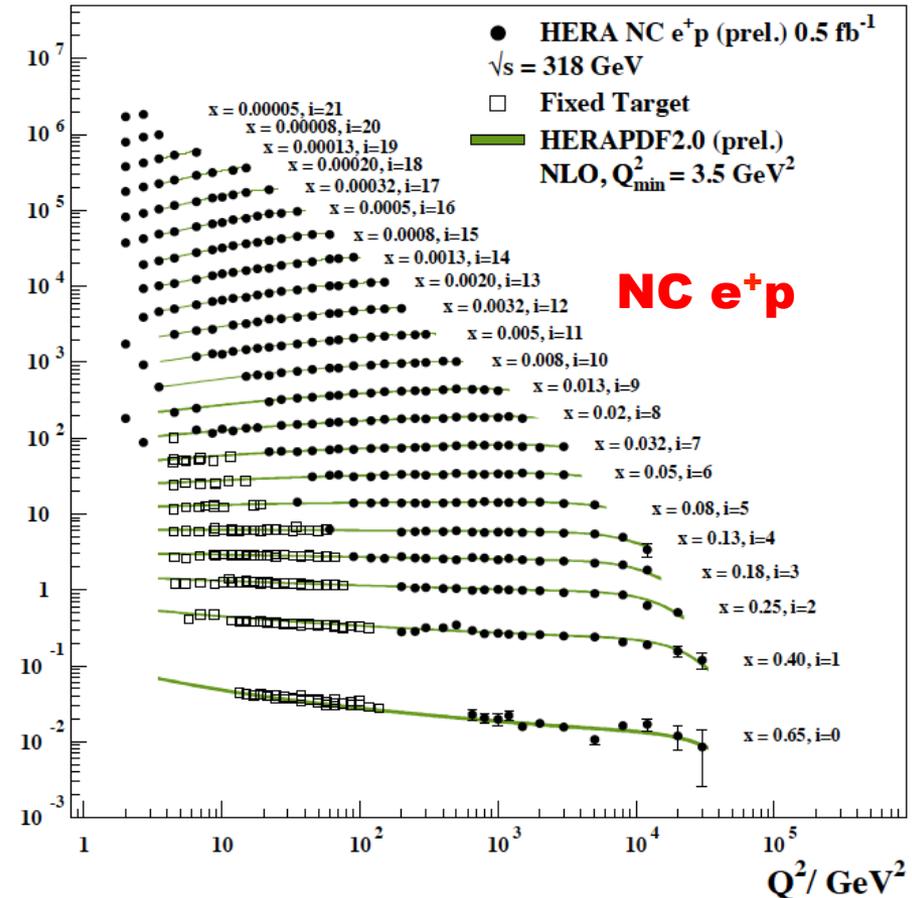
NC:  $0.045 \leq Q^2 \leq 50000 \text{ GeV}^2$ ,  $6 \cdot 10^{-7} \leq x \leq 0.65$

→ Combination done using the same method as for input to HERAPDF1.0 and HERAPDF1.5  
 2927 data points combined to 1307 points,  $\chi^2/\text{ndf} = 1685/1620$  (165 corr. sys. errors)

## CC $e^+p$ HERA I+II vs HERA I



## H1 and ZEUS preliminary



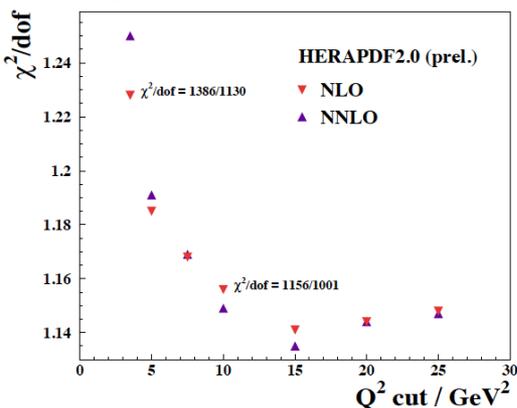
# HERAPDF2.0 (prel.)

**input:** new combined inclusive NC and CC data from HERA I+II

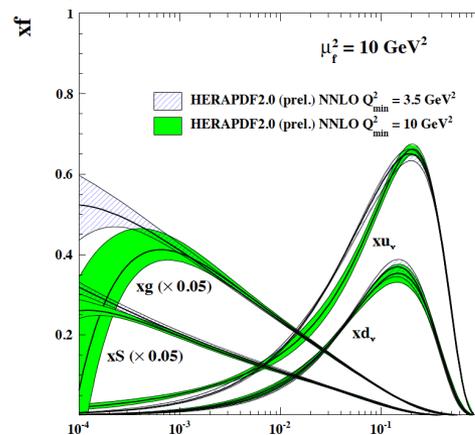
**PDF fit settings** are similar to previous HERAPDF1.0, HERAPDF1.5 (15 free par.)

**NLO and NNLO PDF sets** are obtained using data at  $Q^2 > 3.5$  and  $>10 \text{ GeV}^2$

$\chi^2/\text{ndf}$  vs.  $Q^2_{\text{min}}$

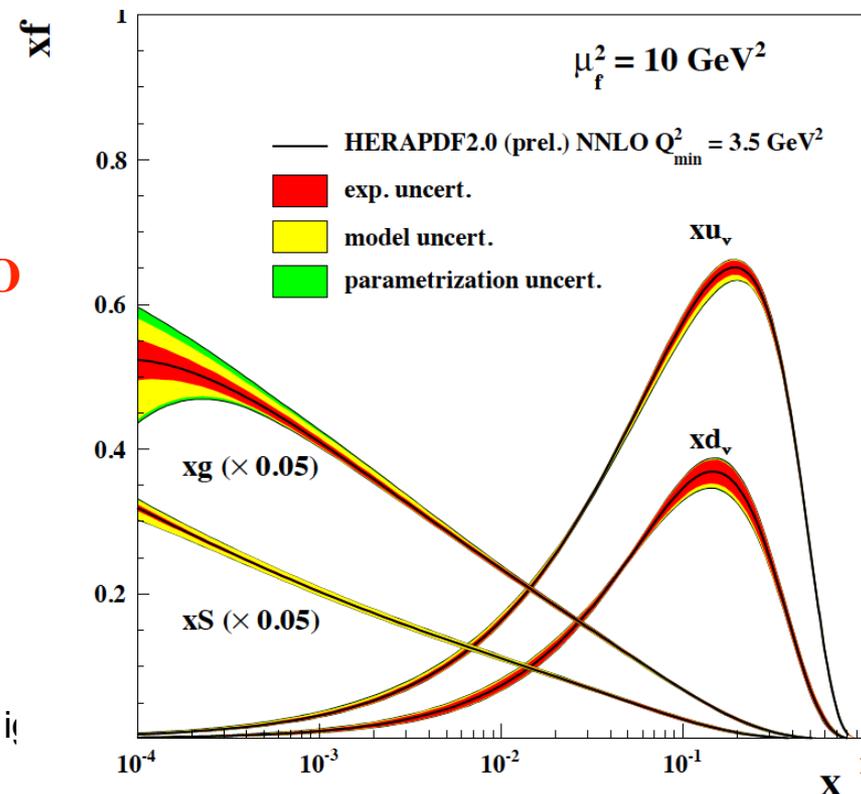


$Q^2 > 3.5$  vs.  $>10 \text{ GeV}^2$

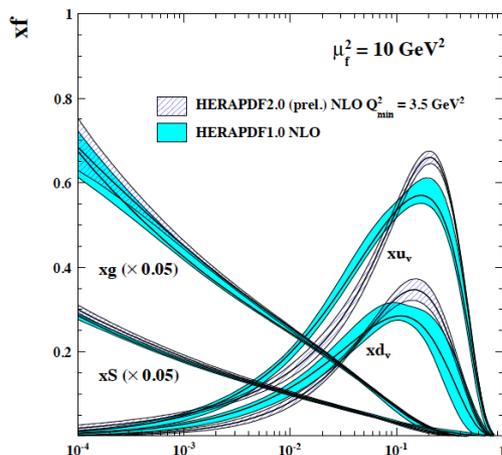


$\rightarrow \chi^2/\text{ndf}$  flattens at  $Q^2_{\text{min}}=10 \text{ GeV}^2$   
 $\rightarrow$  HERAPDF2.0 set is close to HERAPDF1.5 with better precision

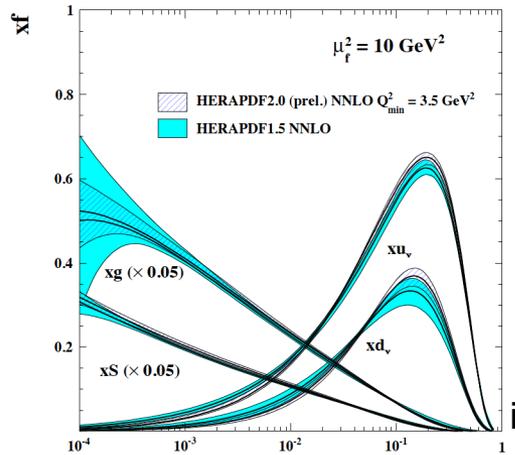
**HERAPDF2.0NNLO (prel.)**



**vs. HERAPDF1.0NLO**



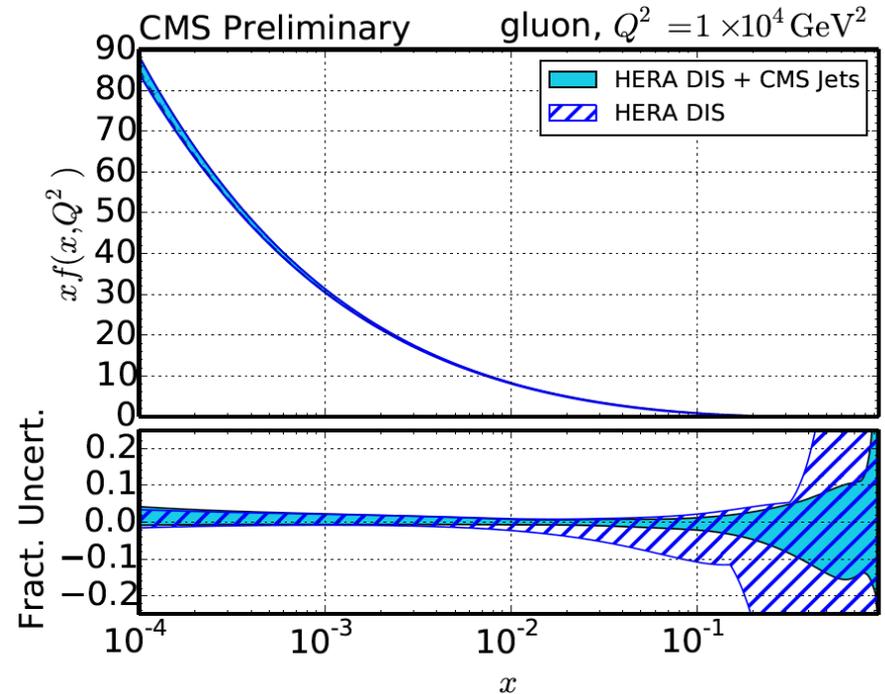
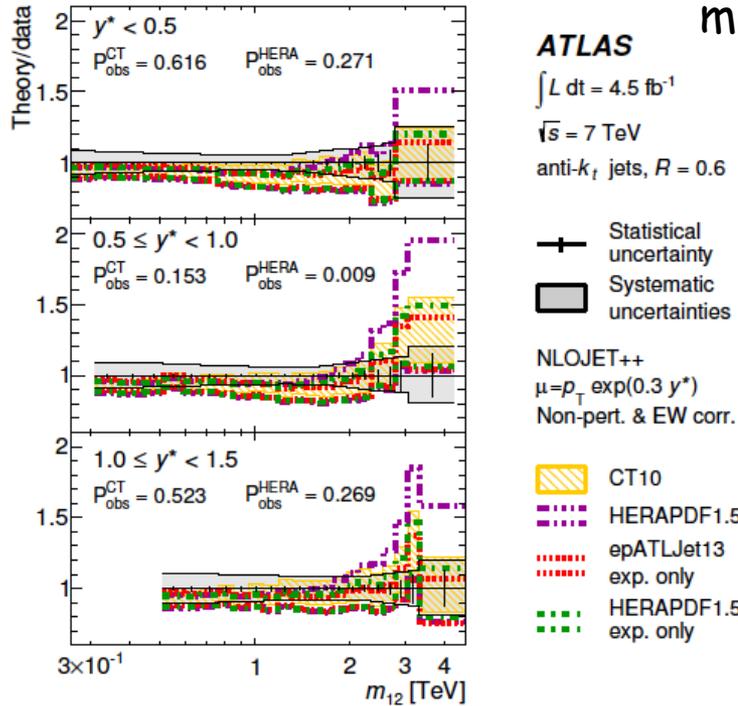
**vs. HERAPDF1.5NNLO**



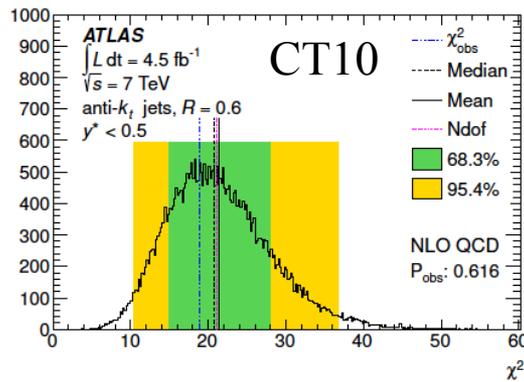
# Impact of the LHC jet measurements on gluon

→ quantitative comparisons of the ATLAS dijet data with various PDF sets using frequentist method.

impact of inclusive CMS jet cross section data on pdfs



Comparisons with  
 CT10  
 HERAPDF1.5  
 MSTW2008  
 NNPDF2.1  
 ABM11

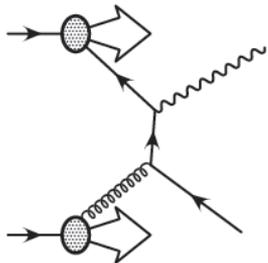


→ jet data constrain PDFs, notably for gluon at high x  
 → strong coupling from CMS jets

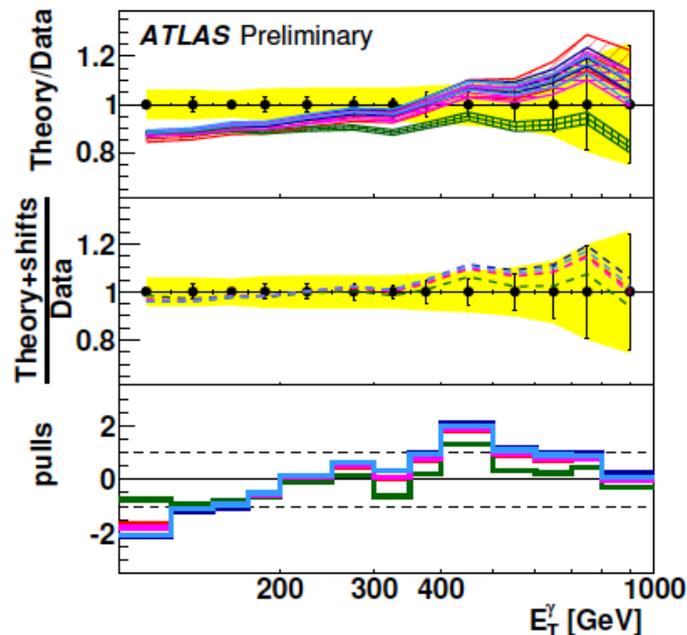
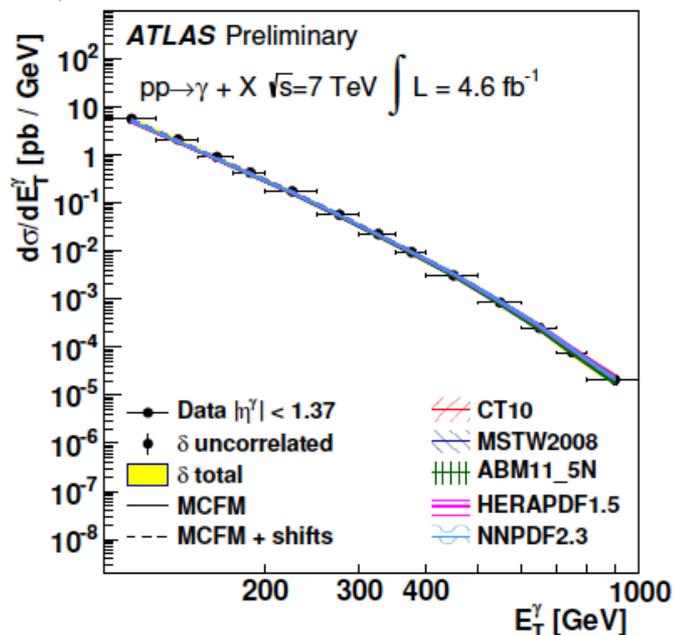
$$\alpha_S(M_Z) = 0.1185^{+0.0065}_{-0.0041}$$

Highlights

# Inclusive isolated prompt photons in ATLAS

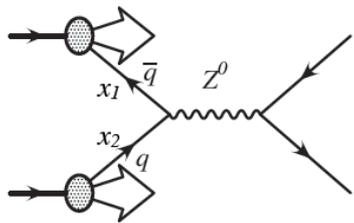


- the  $ug$  contribution dominates due to large  $u$ -quark content in the proton and large charge of the  $u$ -quark
- gluon density is probed in the range  $0.03 < x < 0.3$



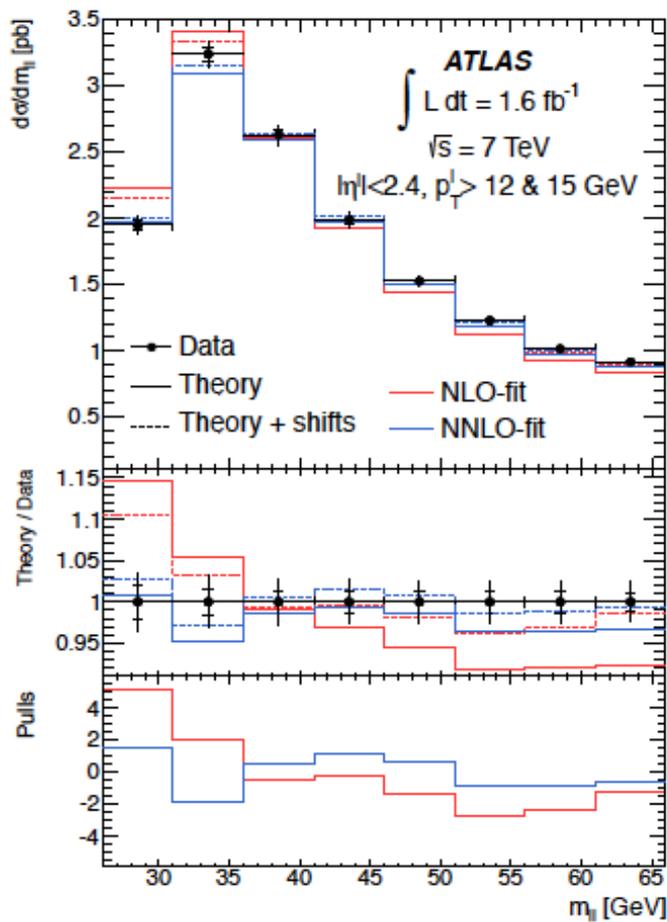
- The data have potential to constrain the shape and to reduce uncertainty of the gluon distribution
- Large scale uncertainty: NNLO QCD predictions are necessary to fully exploit the precision of the measurements

# Drell-Yan

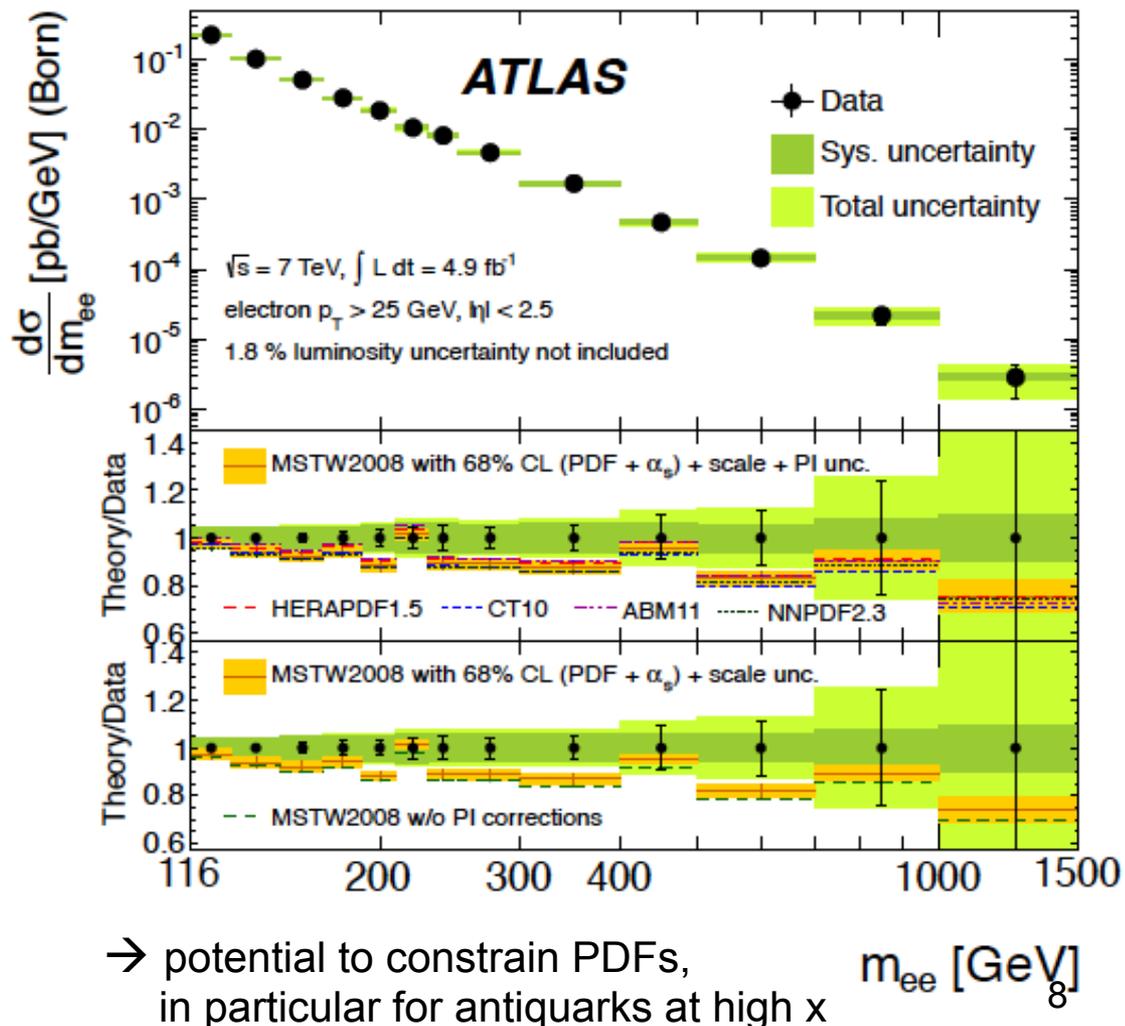


sensitive to quark and antiquark content of the proton

ATLAS: low mass  $12 < m_{ll} < 66$  GeV; high mass  $116 < m_{ee} < 1500$  GeV



HERA+DY fit: NNLO is significantly better than NLO



→ potential to constrain PDFs, in particular for antiquarks at high x

$m_{ee}$  [GeV]

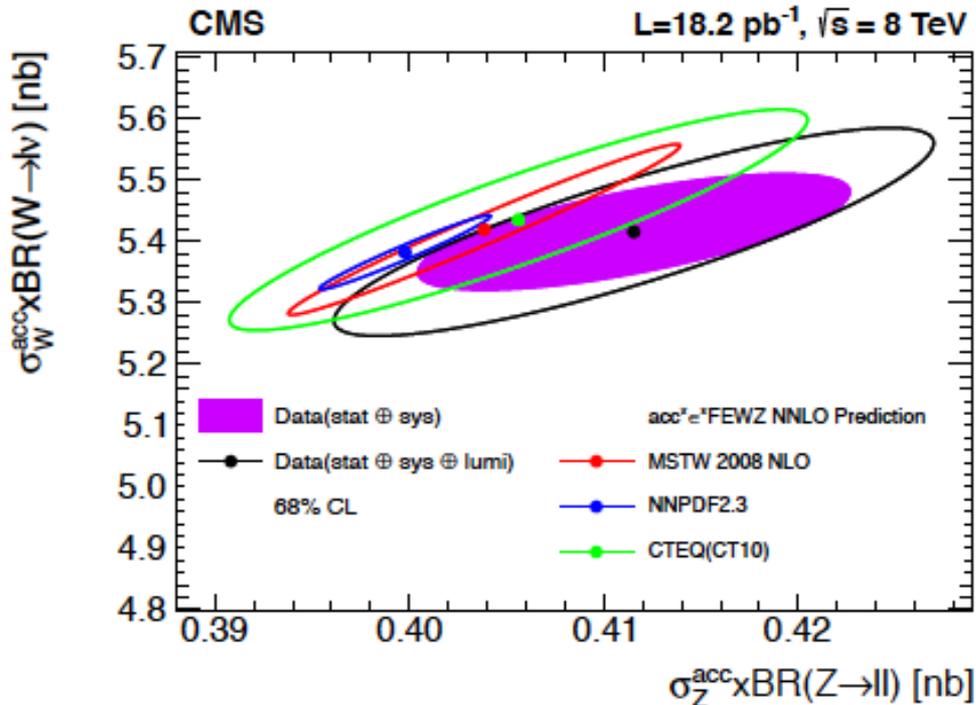
# W&Z vector boson production

**CMS: W and Z at  $\sqrt{s}=8$  TeV (18.2 pb<sup>-1</sup>)**

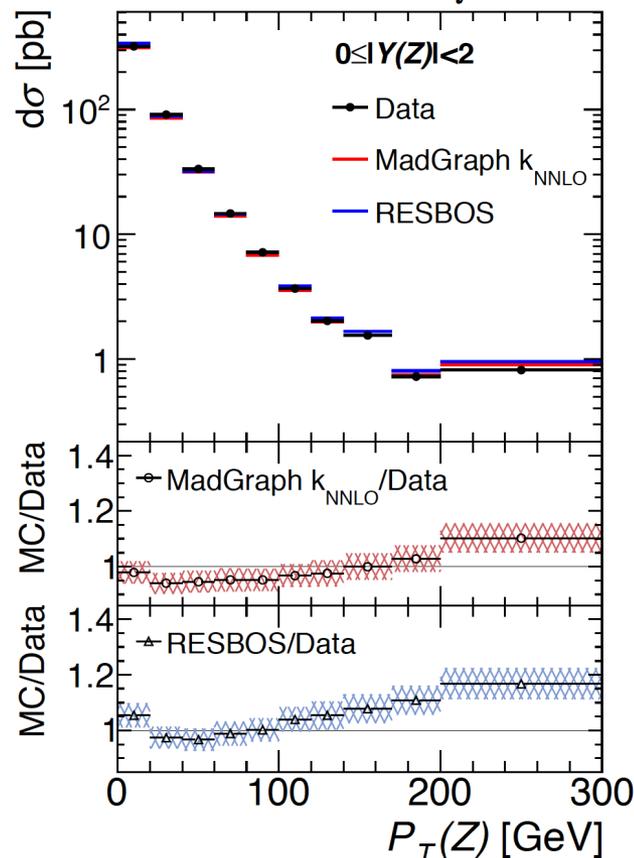
inclusive: total and visible

... and for Z differentially

$$\frac{d^2\sigma}{dP_T dY}$$

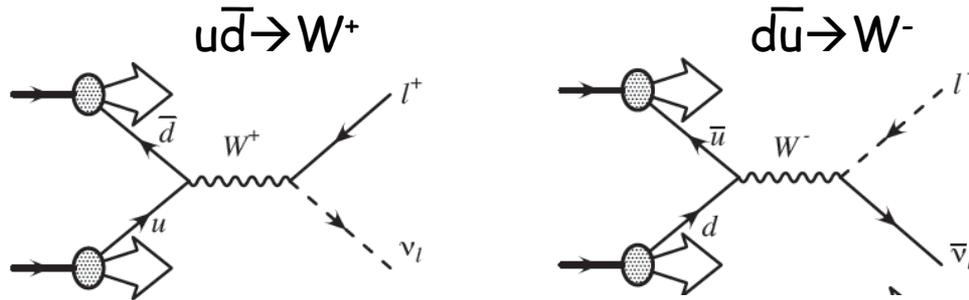


→ test of QCD at NNLO and constraint on PDFs



→ at large  $P_T$ : potential to constrain gluon, the shape is not reproduced yet by theory (similar observation in ATLAS: H. Martinez, WG3)

# The W charge asymmetry



The W charge asymmetry in pp/ppbar (FNAL, LHC) is sensitive to valence quark distributions :

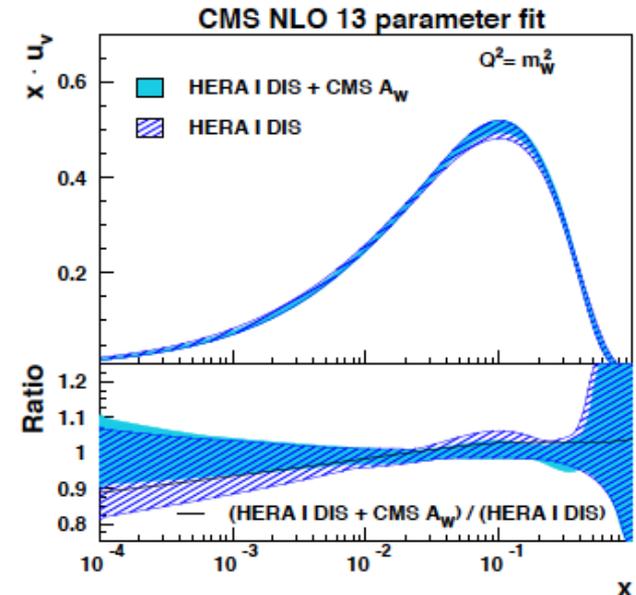
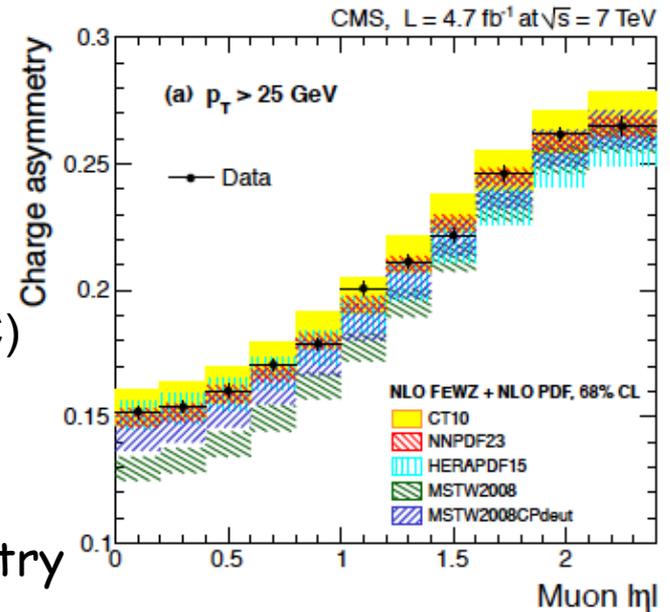
$$A_W \approx (u_v - d_v)/(u + d)$$

CMS reported about the W muon charge asymmetry

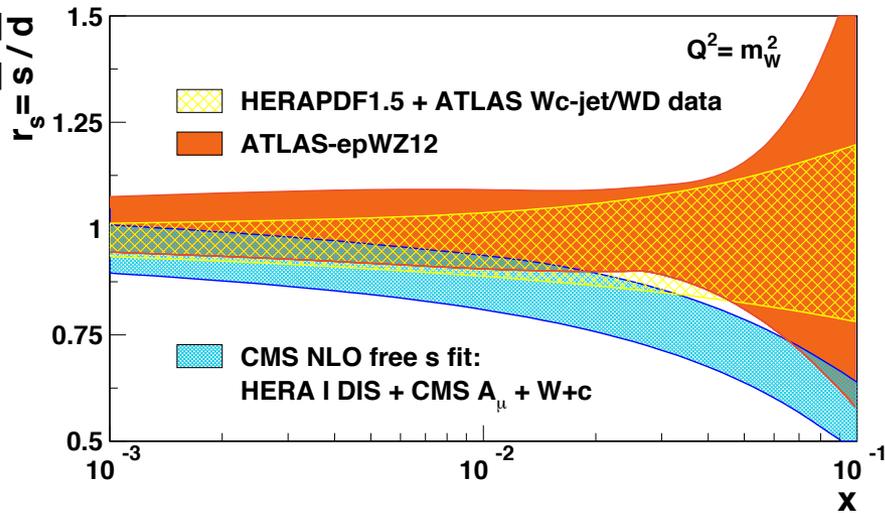
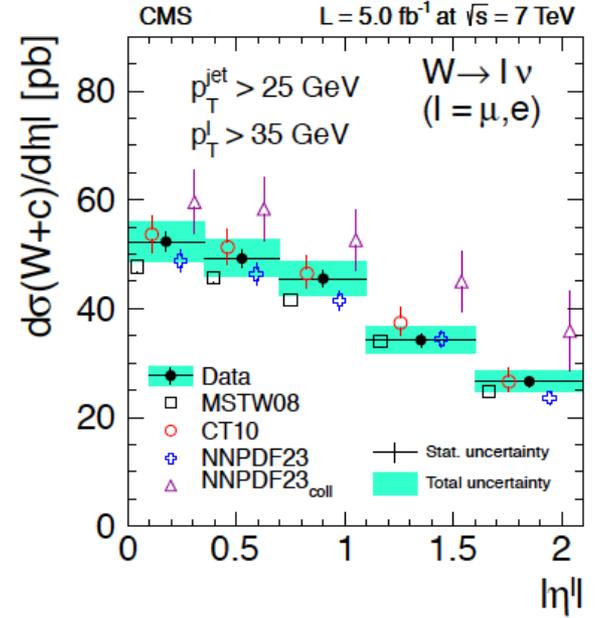
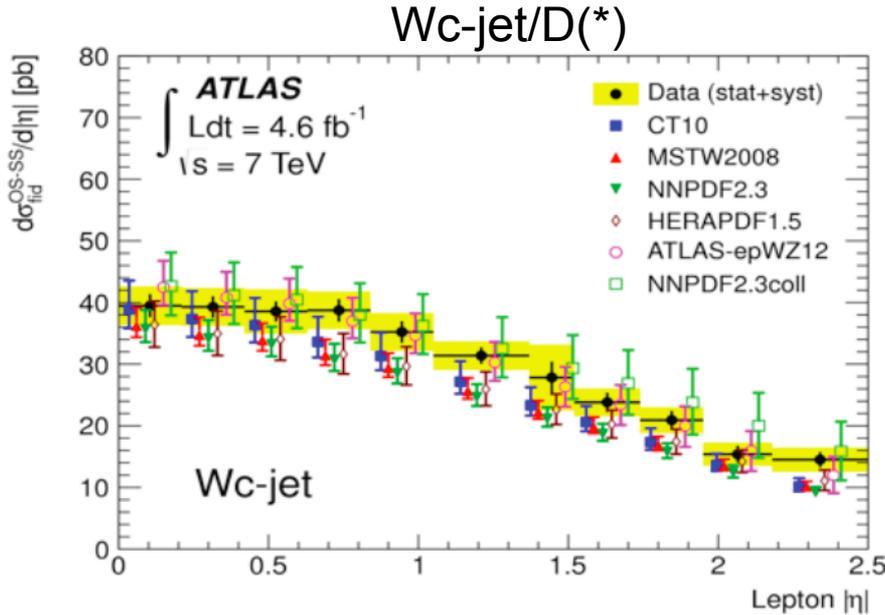
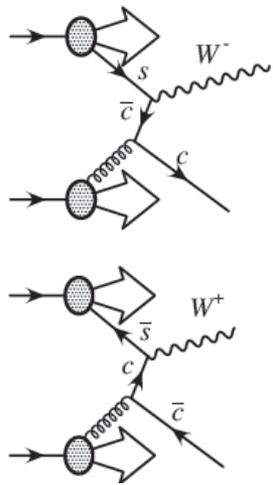
$$A(\eta) = \frac{\frac{d\sigma}{d\eta}(W^+ \rightarrow \ell^+ \nu) - \frac{d\sigma}{d\eta}(W^- \rightarrow \ell^- \bar{\nu})}{\frac{d\sigma}{d\eta}(W^+ \rightarrow \ell^+ \nu) + \frac{d\sigma}{d\eta}(W^- \rightarrow \ell^- \bar{\nu})}$$

- W production uncertainty is dominated by QCD background which cancels out in asymmetry, as many other systematic uncertainties.

→ impact on the precision of  $u_v$ ,  $d_v$  pdfs :



# W+charm and strange quark density



ATLAS  $r_s = \bar{s} / \bar{d}$  at  $Q^2 = 1.9 \text{ GeV}^2$

HERA + W,Z:  $r_s = 1.00 + 0.25 - 0.28$  at  $x = 0.023$

HERA + Wc-jet/D(\*) :  $r_s = 0.96 + 0.26 - 0.30$

$$\kappa_s(Q^2) = \frac{\int_0^1 x [\bar{s}(x, Q^2) + s(x, Q^2)] dx}{\int_0^1 x [\bar{u}(x, Q^2) + \bar{d}(x, Q^2)] dx}$$

CMS

HERA +  $A_W$  + Wc :  $k_s(20 \text{ GeV}^2) = 0.52 + 0.18 - 0.15$

(NOMAD  $k_s(20 \text{ GeV}^2) = 0.591 \pm 0.019$ )

→ ATLAS/CMS are in broad agreement, although in favor of non- / suppressed strange quark

→ ratio  $(W^+c\text{bar})/(W^-c)$  can distinguish s and sbar

# Structure Functions and Parton Densities: Theory

- Global Fits
  - data
  - theory
  - methodology
- Miscellany
- Future perspectives

Richard Ball, Vladimir Chekelian, Karol Kovarik

Warsaw Apr 2014

# Global PDFs: updates

Current Public sets: <http://projects.hepforge.org/lhapdf>

At DIS14 all the main groups presented work in progress, mainly to include LHC data.

- MSTW08 (2008): becomes HMMT14? Thorne
- CT10 (2010-12): becomes CT1X Schmidt
- NNPDF2.3 (2012): becomes NNPDF3.0 Ubiali
- HERAPDF1.5 (2010): becomes HERAPDF2.0 Radescu
- ABM11/12 (2011-13): becomes ABM14? Alekhin
- CJ12 (2012): becomes CJ14 Accardi

PDF4LHC prescription (2010): combine MSTW,CT10,NNPDF

Stated at NLO: but now also works at NNLO

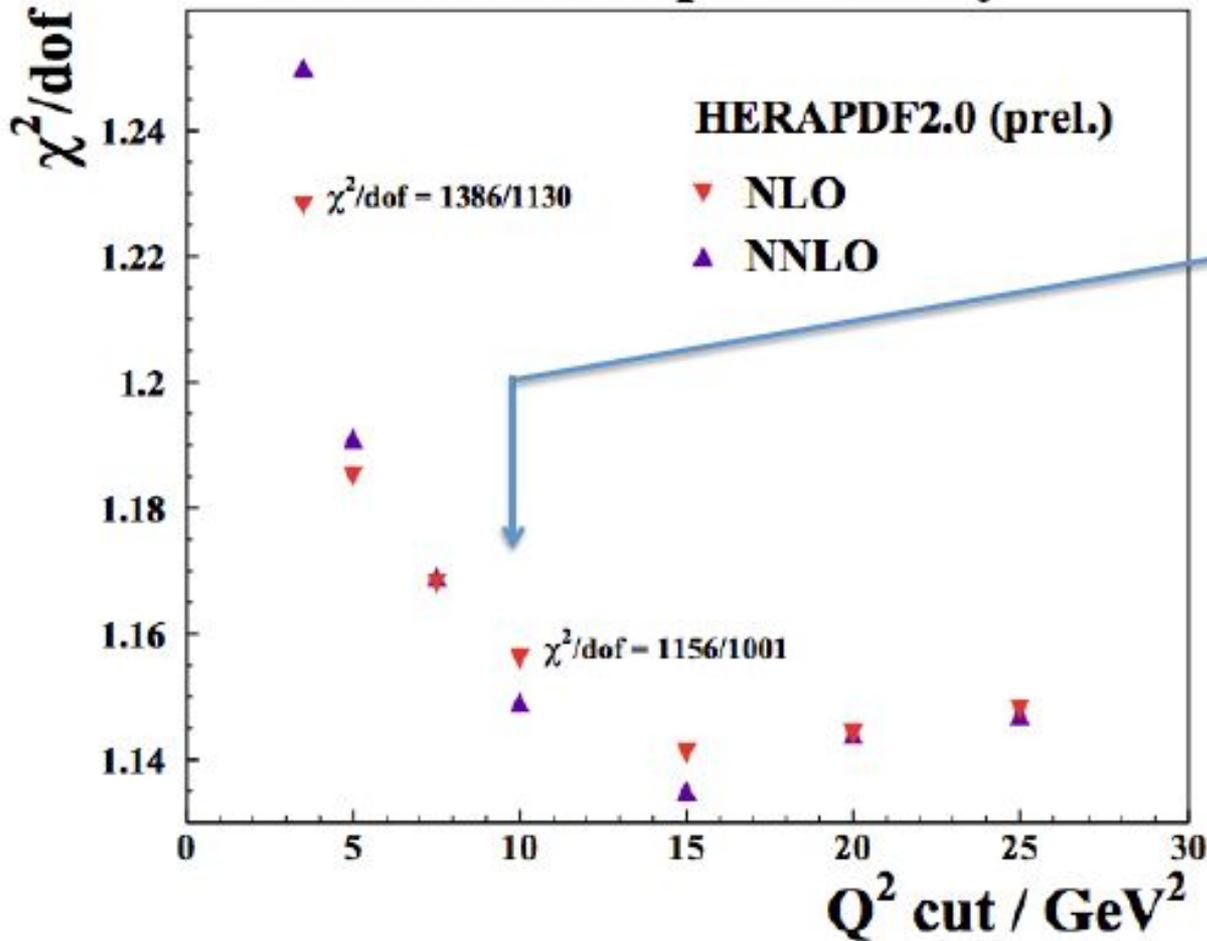
# Data

	MSTW08	CT10	NNPDF2.3	HERAPDF1.5	ABM11	CJ12
HERA DIS	✓	✓	✓	✓	✓	✓
Fixed-target DIS	✓	✓	✓	✗	✓	✓
Fixed-target DY	✓	✓	✓	✗	✓	✓
Tevatron $W+Z$ +jets	✓	✓	✓	✗	✗	✓
LHC $W+Z$ +jets	✗	✗	✓	✗	✗/✓	✗

- HERA2 data: wait for combination Turkot
- LHC  $W/Z$  data: impact on  $u/d$  Newman
- LHC incl jet data: mild impact on  $g$  Sieber
- LHC  $W+c$  data: mild impact on strangeness Aad, Placakyte

PDF fitters need data with fully correlated systematics  
 and need to know if systematics additive or multiplicative  
 (to avoid d' Agostini bias)

# H1 and ZEUS preliminary



At  $Q^2_{\text{min}} = 10$  is when the fit stabilises with respect of  $\chi^2/\text{dof}$  vs  $Q^2\text{cut}$

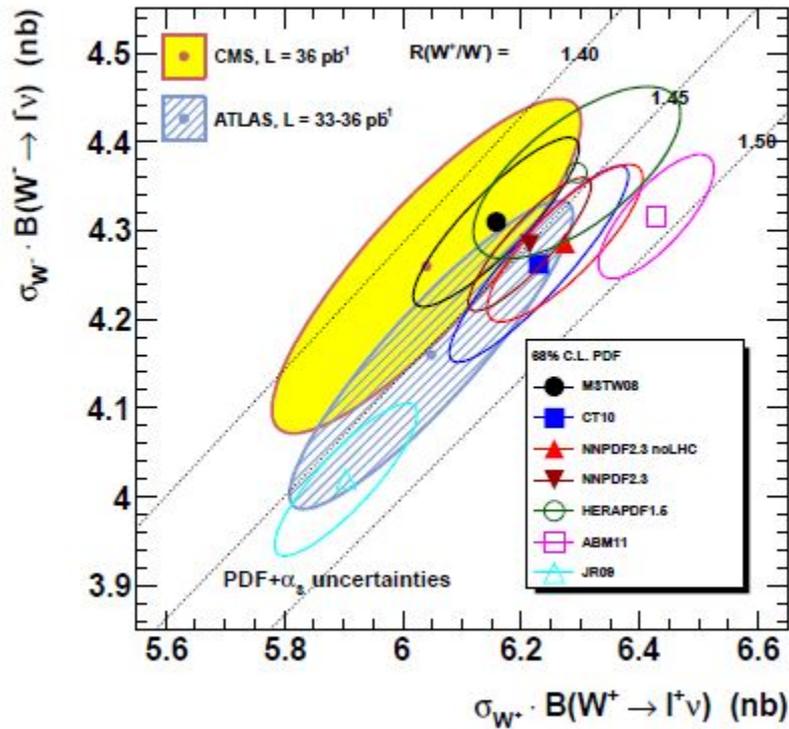
For  $Q^2_{\text{min}} = 3.5 \text{ GeV}^2$   
Chi2/dof (NLO) = 1386/1130  
Chi2/dof(NNLO)= 1414/1130

For  $Q^2_{\text{min}} = 10 \text{ GeV}^2$   
Chi2/dof (NLO) = 1156/1001  
Chi2/dof(NNLO)= 1150/1001

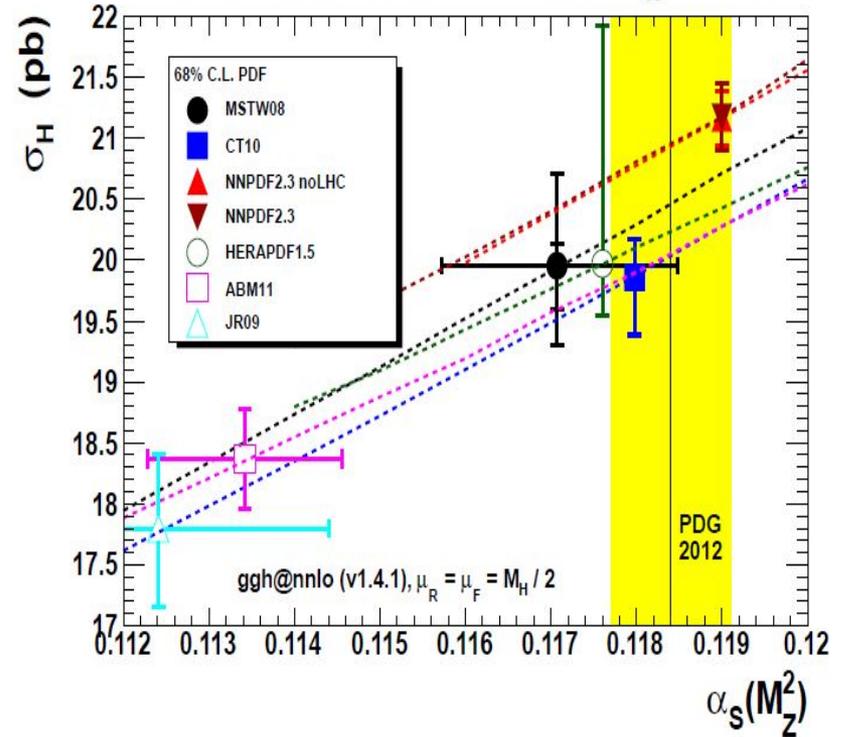
Limitations of NNLO pt at small x?

Radescu

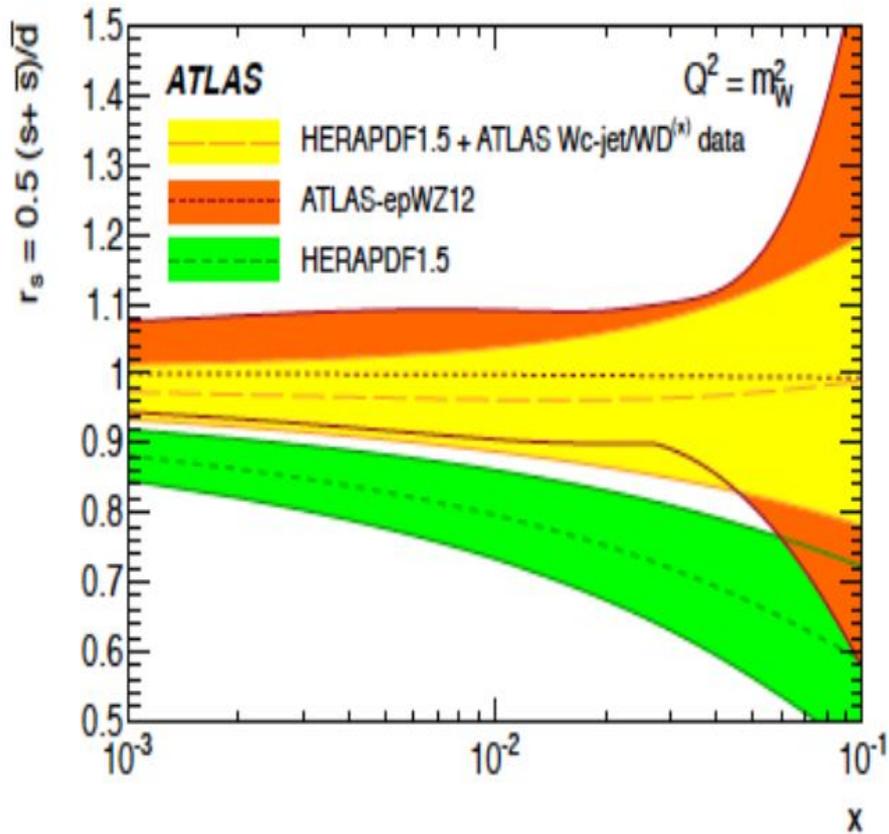
NNLO  $W^+$  and  $W^-$  cross sections at the LHC ( $\sqrt{s} = 7$  TeV)



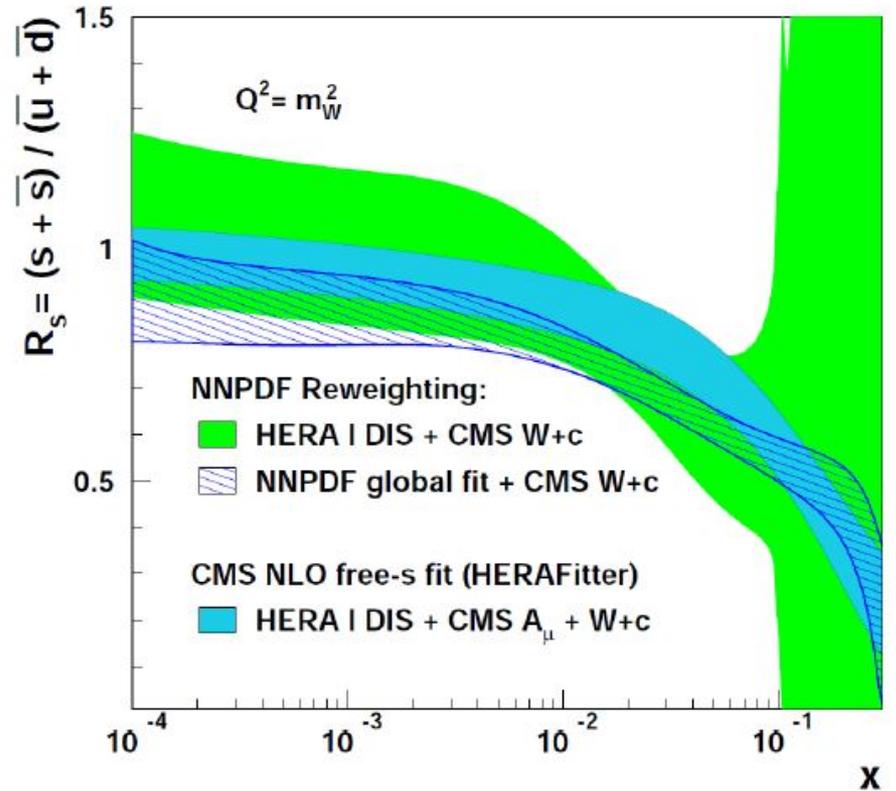
NNLO  $gg \rightarrow H$  at the LHC ( $\sqrt{s} = 8$  TeV) for  $M_H = 126$  GeV



# Strangeness



Aad



Placakyte

More compatible with usual expectations,  
eg dimuon data, NOMAD

Alekhin

# Data

	MSTW08	CT10	NNPDF2.3	HERAPDF1.5	ABM11	CJ12
HERA DIS	✓	✓	✓	✓	✓	✓
Fixed-target DIS	✓	✓	✓	✗	✓	✓
Fixed-target DY	✓	✓	✓	✗	✓	✓
Tevatron $W+Z$ +jets	✓	✓	✓	✗	✗	✓
LHC $W+Z$ +jets	✗	✗	✓	✗	✗/✓	✗

- HERA2 data: wait for combination Turkot
- LHC  $W/Z$  data: impact on  $u/d$  Newman
- LHC incl jet data: mild impact on  $g$  Sieber
- LHC  $W+c$  data: mild impact on strangeness Aad, Placakyte

PDF fitters need data with fully correlated systematics  
 and need to know if systematics additive or multiplicative  
 (to avoid d' Agostini bias)

# Theory

	MSTW08	CT10	NNPDF2.3	HERAPDF1.5	ABM11/12	CJ12
NNLO	✓	✓	✓	✓	✓	✗
varying $\alpha_s$	✓	✓	✓	✓/✗	✓	✗
PDF + $\alpha_s$ unc?	✓	✓	✓	✓	✗	✗
Heavy quarks	VFN TR	VFN ACOT	VFN FONLL	VFN TR	FFN	VFN ZM
$s + \bar{s}$ fitted	✓	✓	✓	✗	✓	✗
$s - \bar{s}$ fitted	✓	✗	✓	✗	✗	✗
$c \pm \bar{c}$ fitted	✗	✗	✗	✗	✗	✗

- c,b,t: VFN vs FFN: fragmentation fns

Libov, Ubiali, Pietrulewicz

- NNLO ttbar (Top++, HATHOR, DiffTop)

Guzzi

- NNLO inclusive jets (gg channel only, rest soon)

Thorne

- New fitting tool, HERAFitter

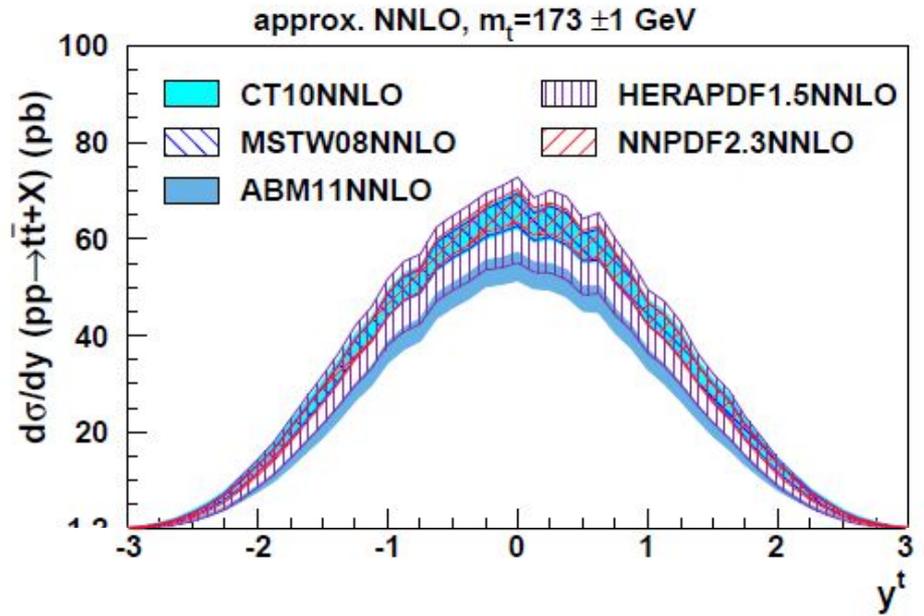
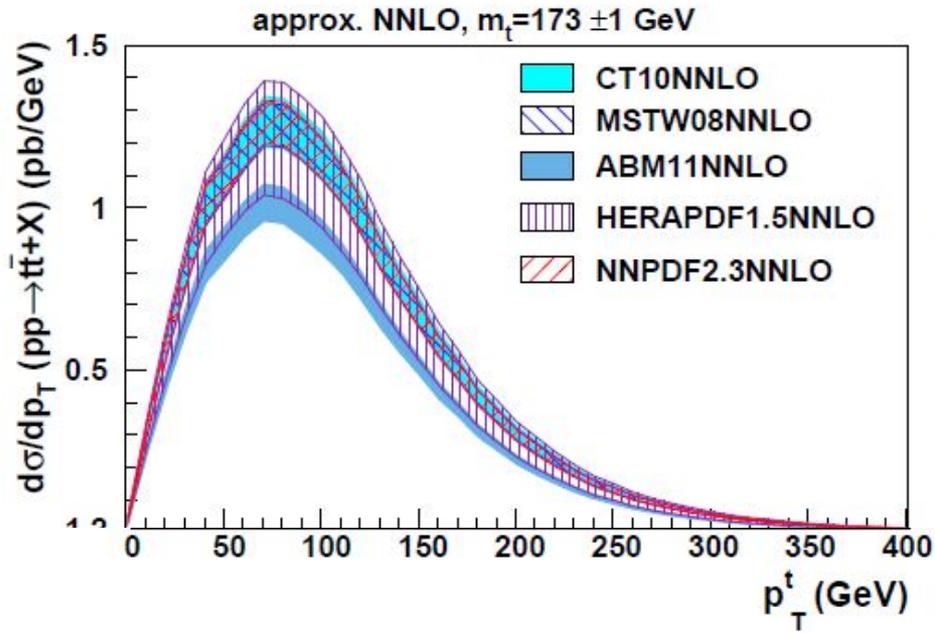
Pirumov, Lisovyi

- to include hadronic data in fits, need tools like

fastNLO (+toolkit), FastKernel, Applgrid,...

Britzger

# DiffTop



Guzzi

# Theory

	MSTW08	CT10	NNPDF2.3	HERAPDF1.5	ABM11/12	CJ12
NNLO	✓	✓	✓	✓	✓	✗
varying $\alpha_s$	✓	✓	✓	✓/✗	✓	✗
PDF + $\alpha_s$ unc?	✓	✓	✓	✓	✗	✗
Heavy quarks	VFN TR	VFN ACOT	VFN FONLL	VFN TR	FFN	VFN ZM
$s + \bar{s}$ fitted	✓	✓	✓	✗	✓	✗
$s - \bar{s}$ fitted	✓	✗	✓	✗	✗	✗
$c \pm \bar{c}$ fitted	✗	✗	✗	✗	✗	✗

- c,b,t: VFN vs FFN: fragmentation fns

Libov, Ubiali, Pietrulewicz

- NNLO ttbar (Top++, HATHOR, Diftop)

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- NNLO inclusive jets (gg channel only, rest soon)

Thorne

- New fitting tool, HERAfitter

Pirumov, Lisovyi

- to include hadronic data in fits, need tools like

fastNLO (+toolkit), FastKernel, Applgrid, ... Britzger

# Methodology

	MSTW08	CT10	NNPDF2.3	HERAPDF1.5	ABM11/12	CJ12
No. of PDFs	7	6	7	5	6	5
Statistics	Hess.+DT	Hess.+DT	MC	Hess.+Par.	Hess.	Hess.+T
NLO par.	20+8	26	259	10	24	25
NNLO par.	20+8	25	259	14	24	no fit
Closure test	(✓)	(✓)	✓	✗	✗	✗
Reweighting	(✓)	(✗)	✓	(✓)	✗	✗

- Tolerance, and Dynamical Tolerance
- Closure tests: if statistical methodology perfect

Perfect data + Perfect theory = Perfect fit

Ubiali

- 1) Take a set of data, an assumed theory (eg NLO QCD), and some prior pdf,  $f_0$
- 2) Generate a set of perfect pseudodata from  $f_0$ , by MC, using data errors
- 3) Fit the pseudodata using you statistical methodology, giving fitted pdf,  $f$
- 4) If the methodology is perfect, should find  $\text{chisq}=1$ ,  $f = f_0$

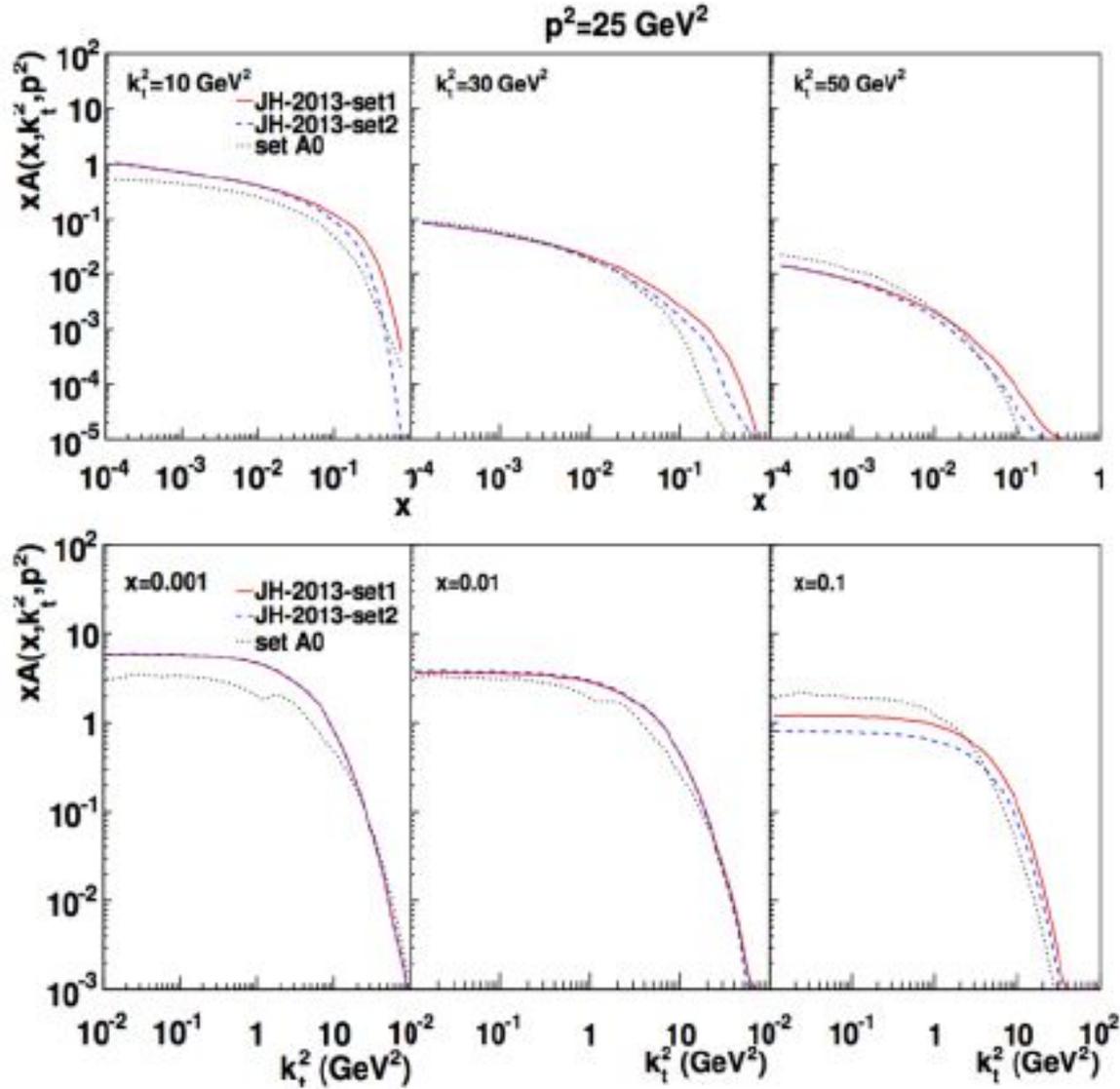
- Reweighting and Monte Carlo

Lisovyi, Paukkunen

# Miscellany

- Collider only fits (eg HERAPDF) – need better data
- LO fits: MSTW, CTEQ, NNPDF, HERAPDF, for MC  
Sarkar
- PDFs with QED corrections: new set from NNPDF  
Schmidt
- Polarized PDFs (see WG6) Accardi, Nocera
- Nuclear PDFs (nCTEQ soon) Paukkunen, Kusina
- Unintegrated (TMD) PDFs (getting there...)  
Jung, Vladimirov

# CCFM gluon



## Summary & Outlook

### Better data:

Now: FT + HERA + Tev + LHC

Future: HERA + Tev + LHC

Far future: LHeC + LHC

Theorists need to keep up:

Better theory: NNLO, tools, resummation

Better methodology: closure tests

Thanks to all the speakers!