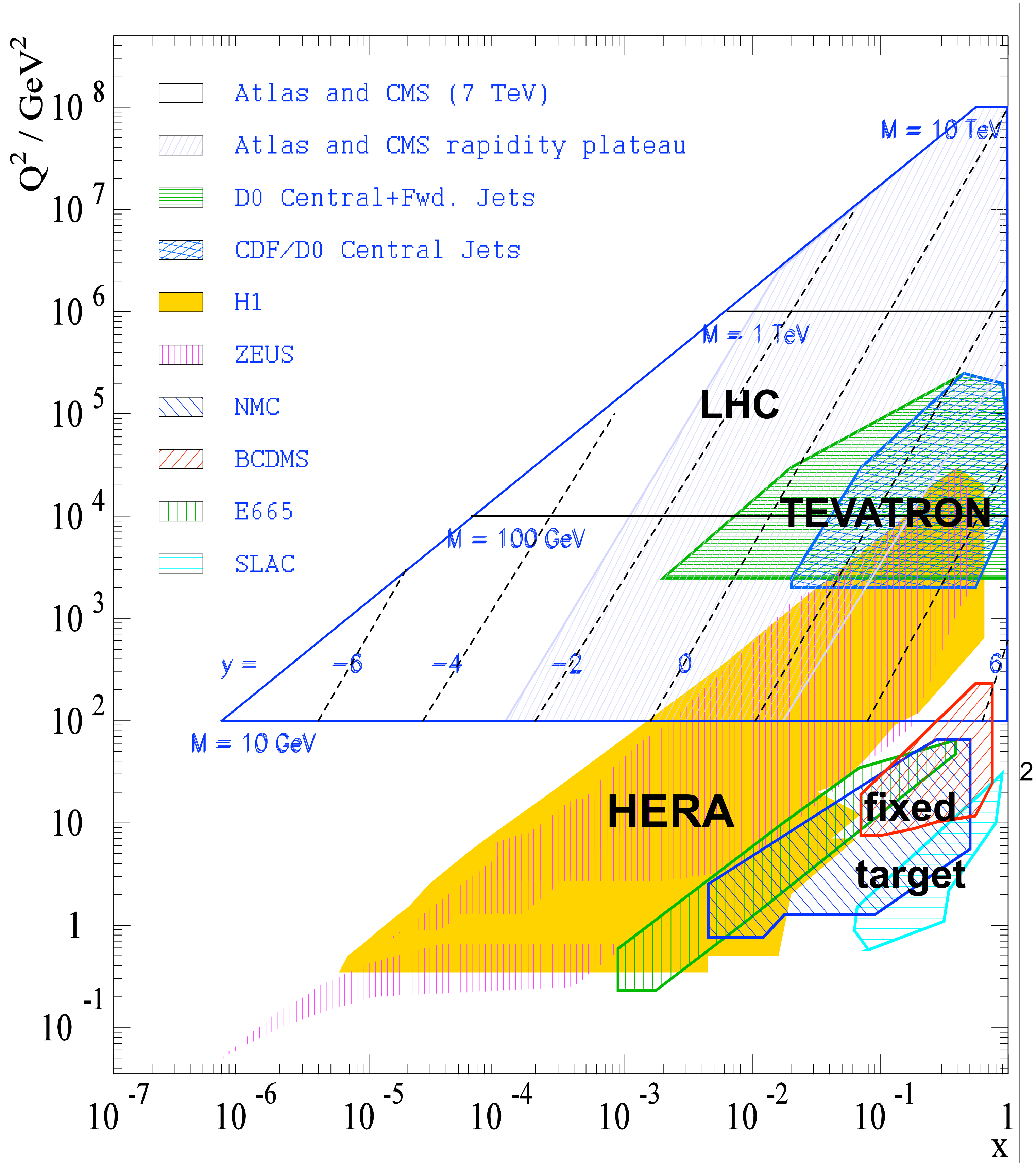
Summary Structure Functions

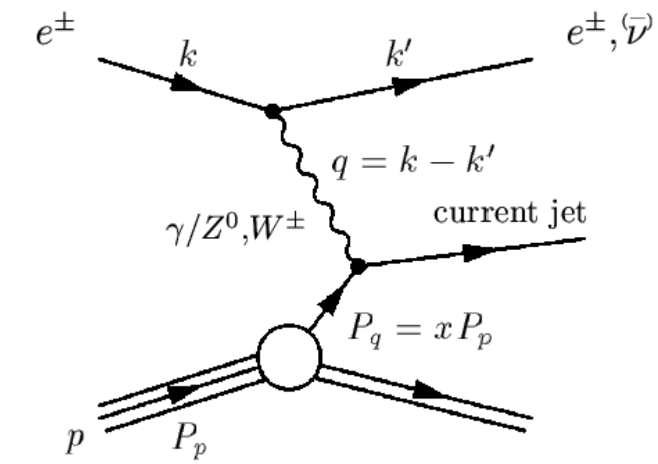
K. Lipka, P. Nadolsky, C. Keppel

Experimental Highlights

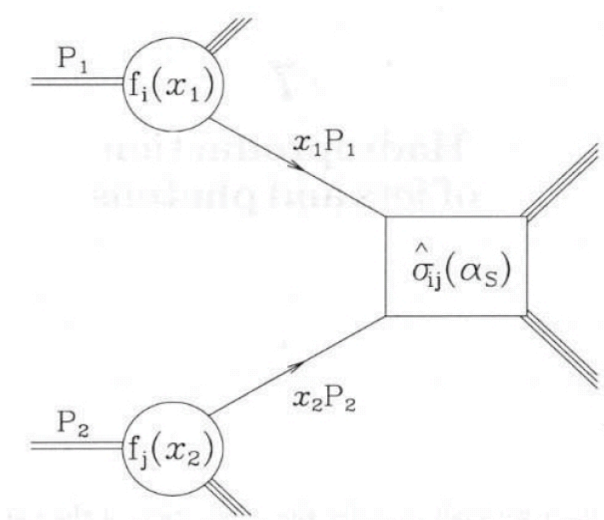
Experimental access to the proton structure



HERA: low and medium x



LHC: important constraints on g(x), flavour separation

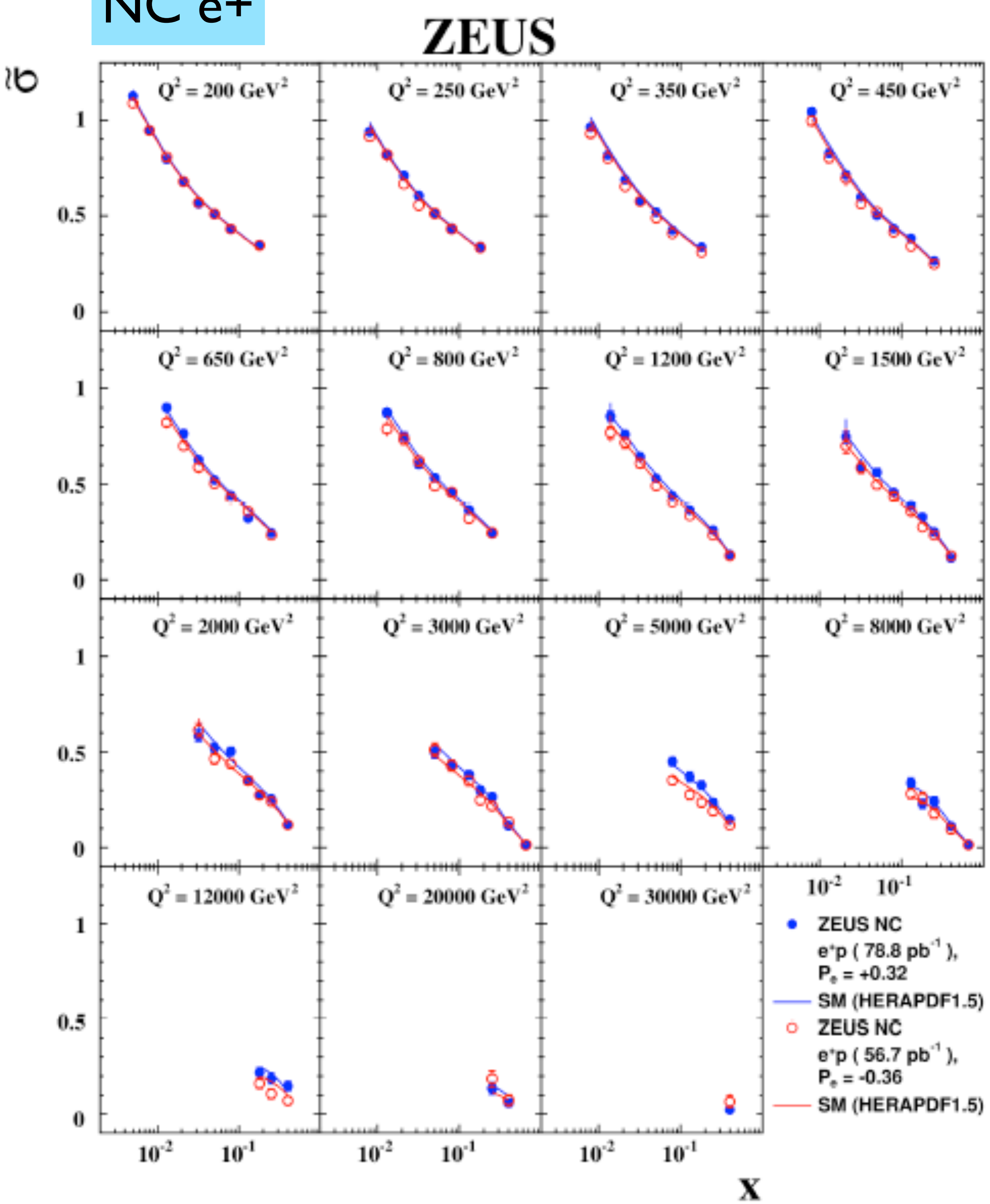


Fixed Target: high x, nuclear PDFs

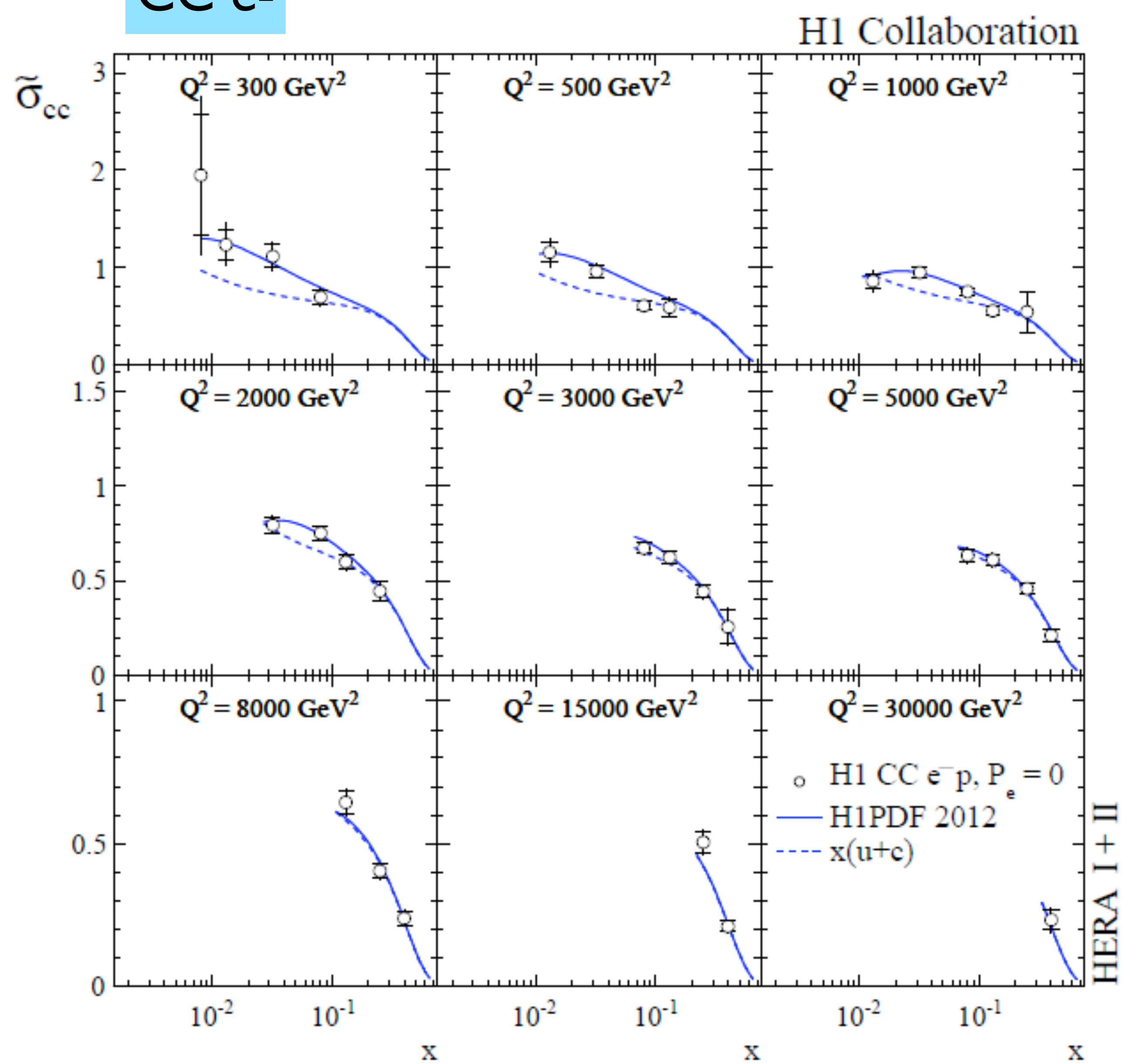
Recent HERA inclusive DIS data: almost at final precision

ultimate precision from H1/ZEUS final HERAII data out *(S. Shushkevich, I. Brock)*

NC e+



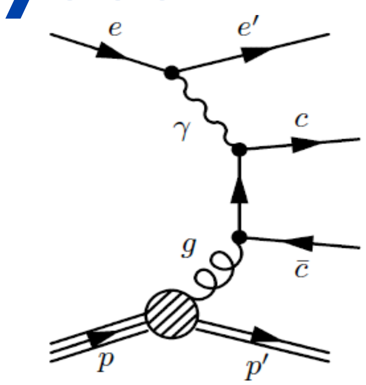
CC e-



HERA data is reaching ultimate precision,
final combination on the way
backbone for PDFs @ lox, medium x

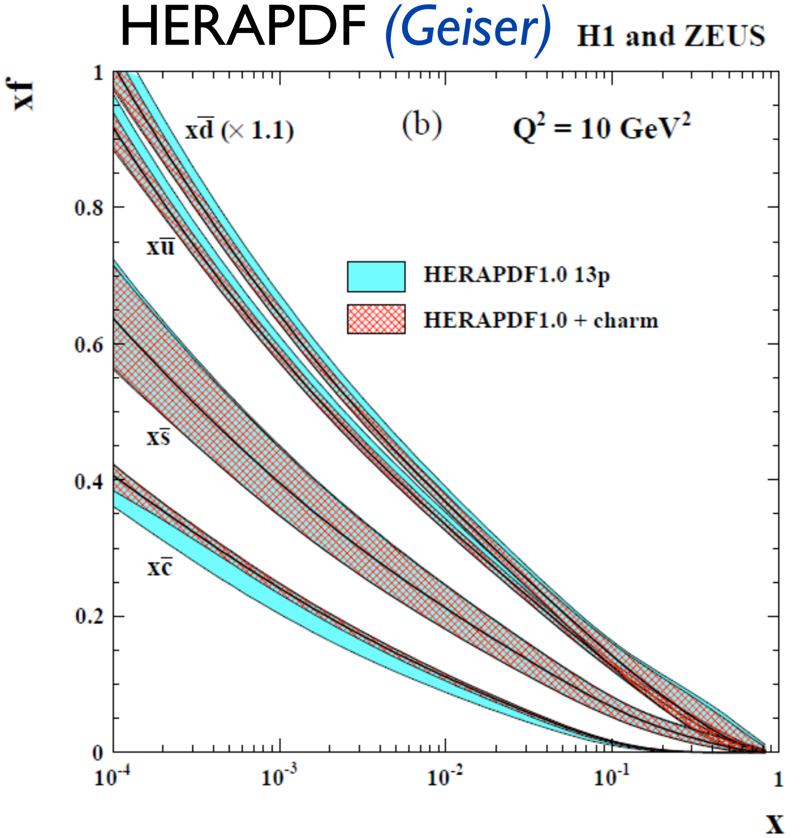
Recent HERA CHARM data in QCD analyses

Heavy flavor treatment of particular importance in the QCD analyses
HERA Charm cross sections used in PDF fits,
more data to go into final combination (Zeniaev, Bachynska)



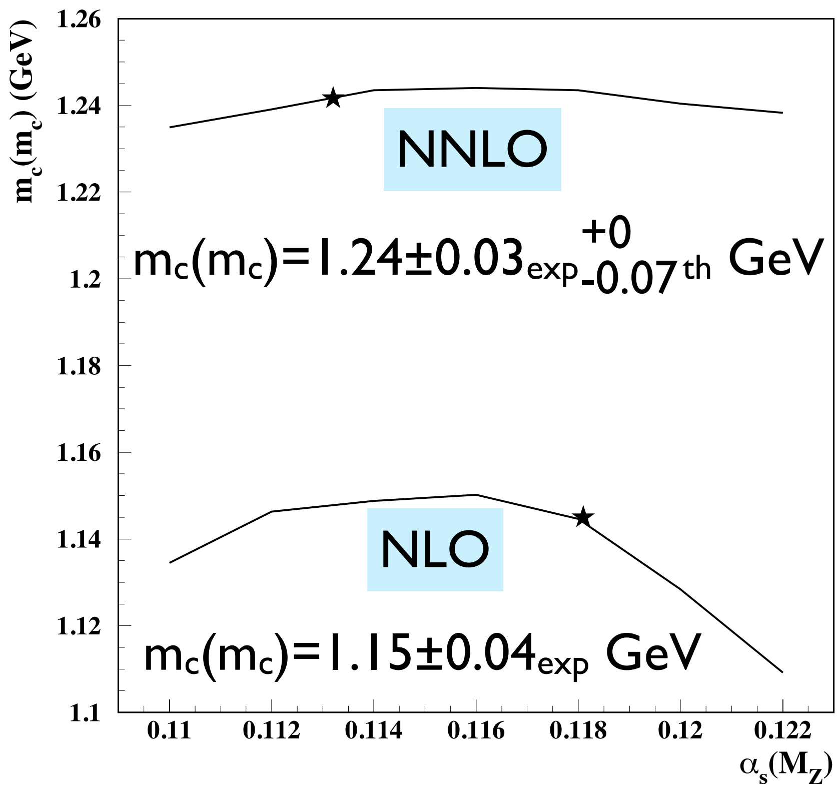
reduced errors on $g(x)$, $\bar{c}(x)$

HERAPDF *(Geiser)*

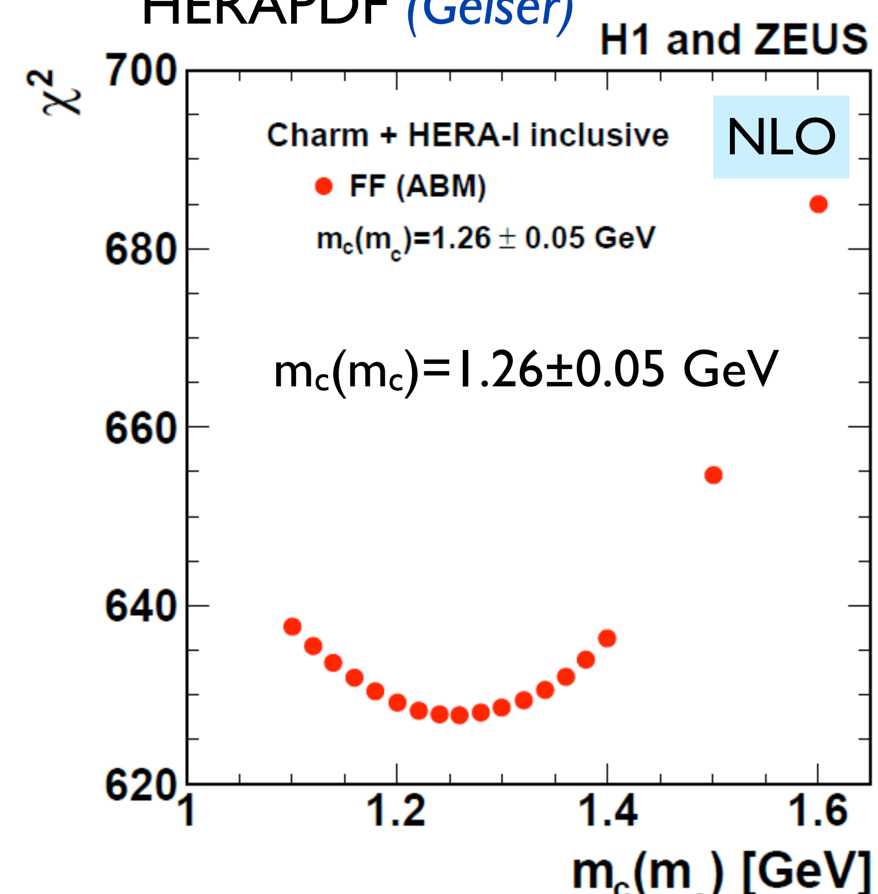


handle on determination of m_c (m_c)

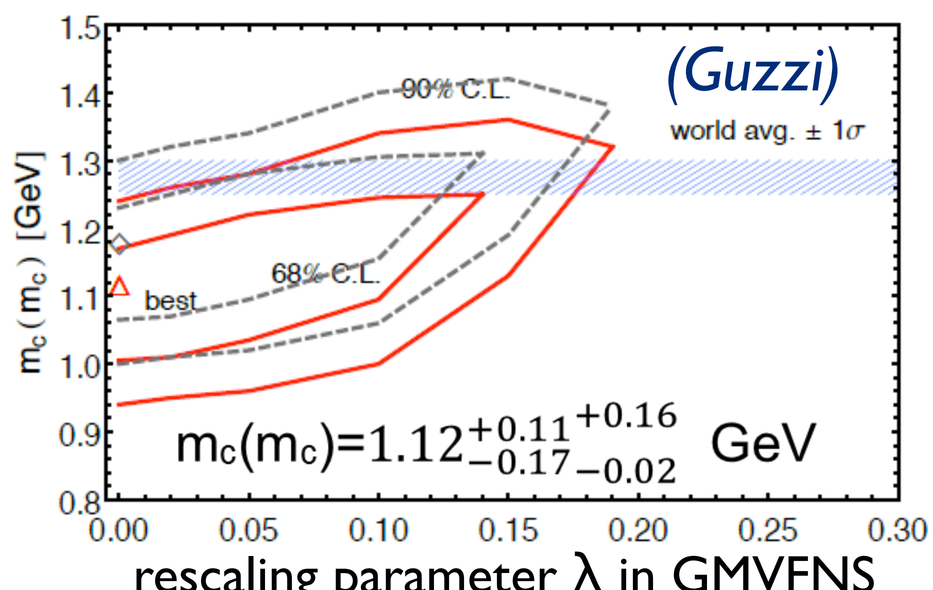
ABM *(Alekhin)*,



HERAPDF *(Geiser)*

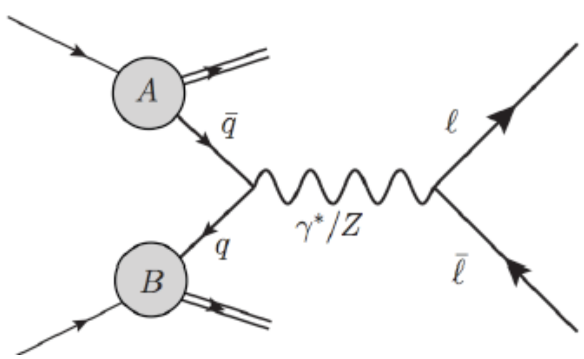


Scans in m_c(m_c) also performed by CTEQ *(Nadolsky)* and m_c(pole) by MSTW *(Thorne)*



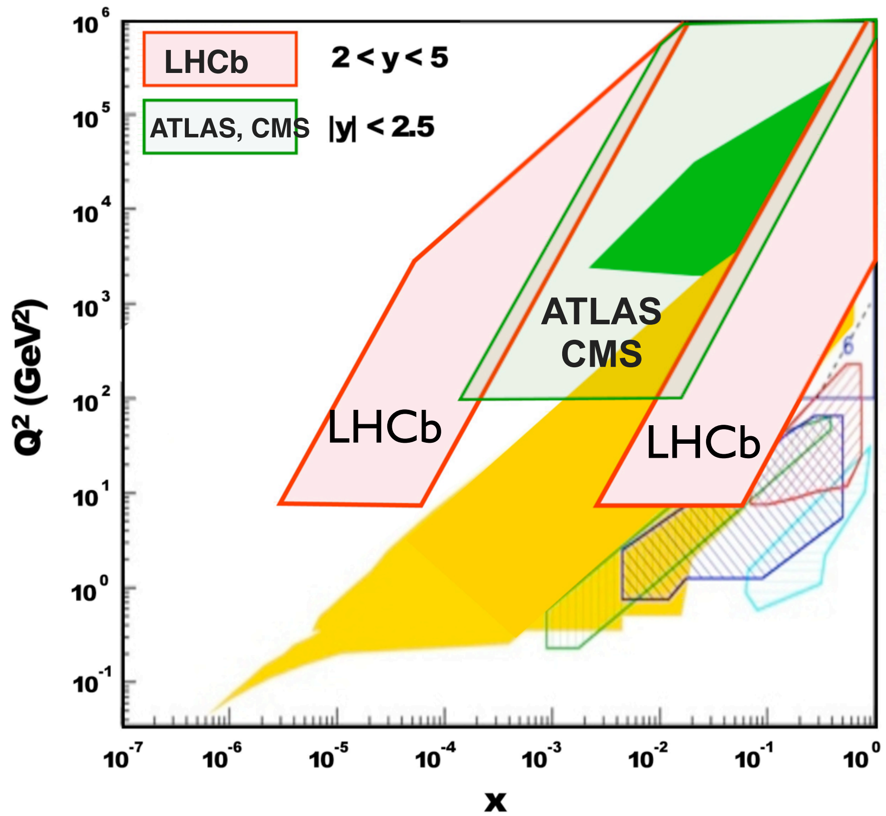
HERA data allow for determination of m_c(m_c) from DIS data consistent with world average (enters world average in 2013)

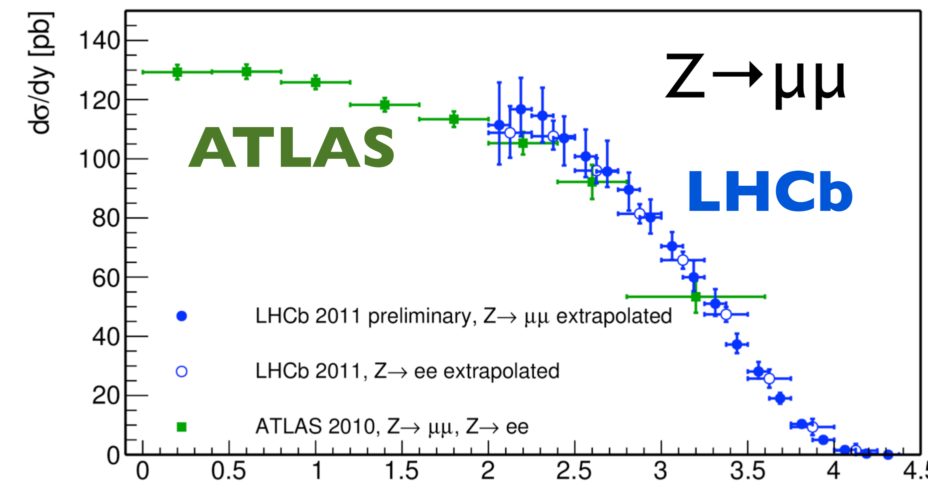
Constraints from the LHC: Electroweak Boson Production

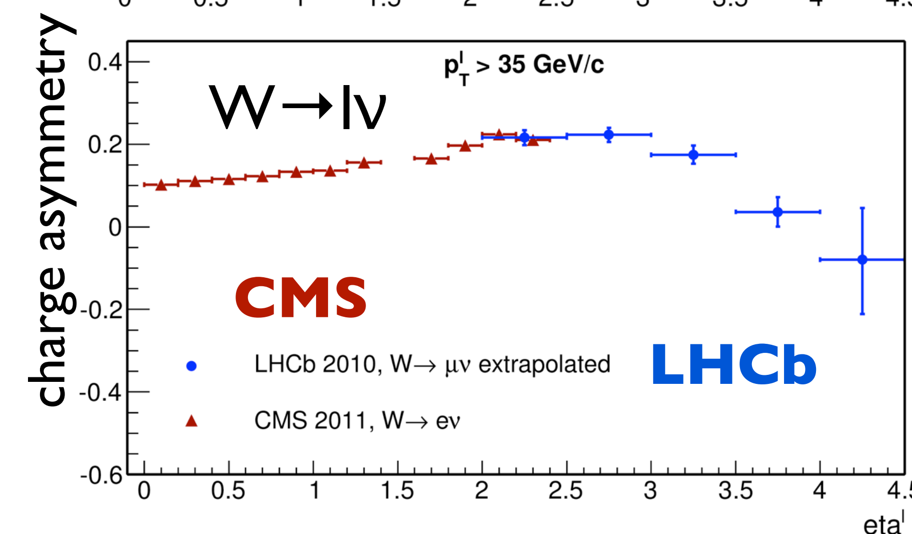


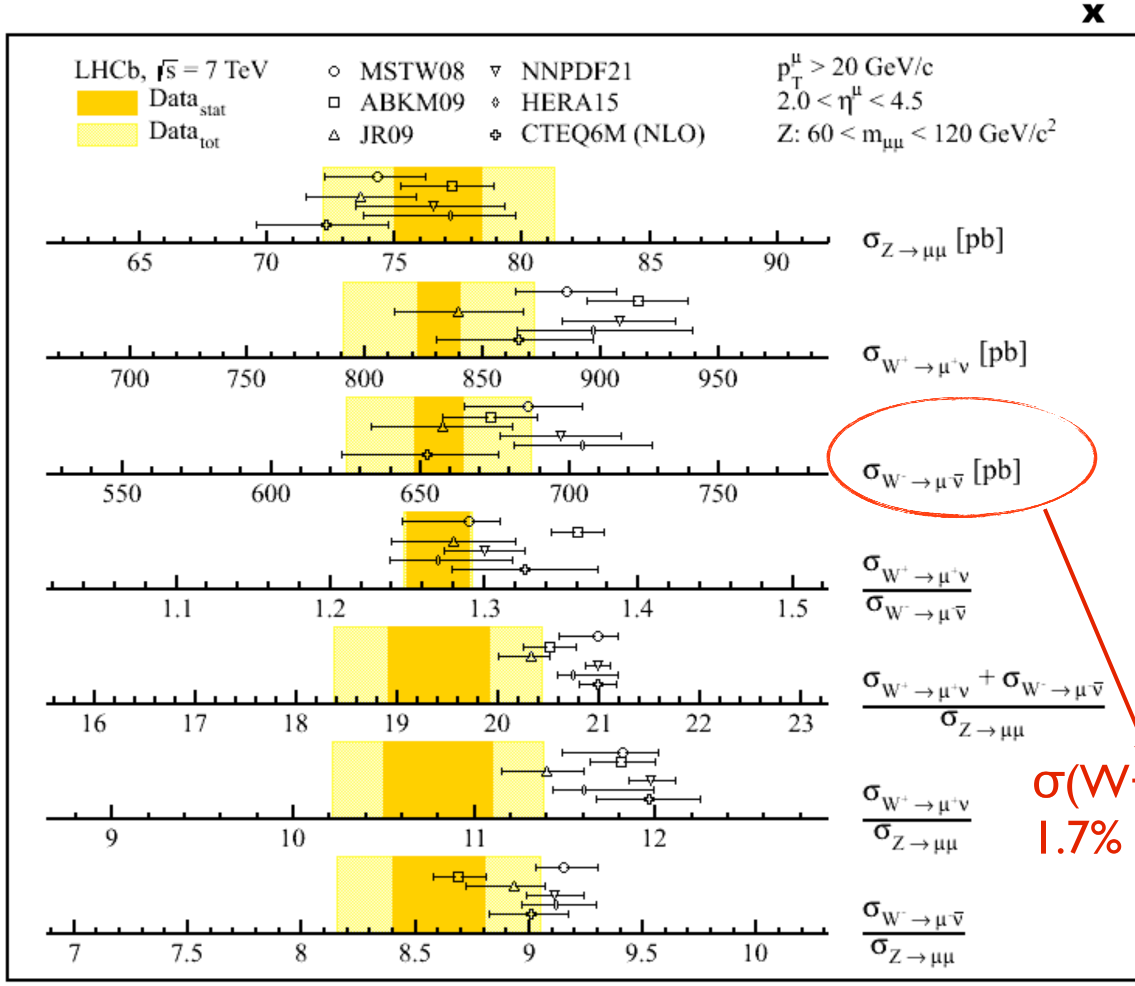
probe light quarks at low and high x

LHCb (S.Tourneur)

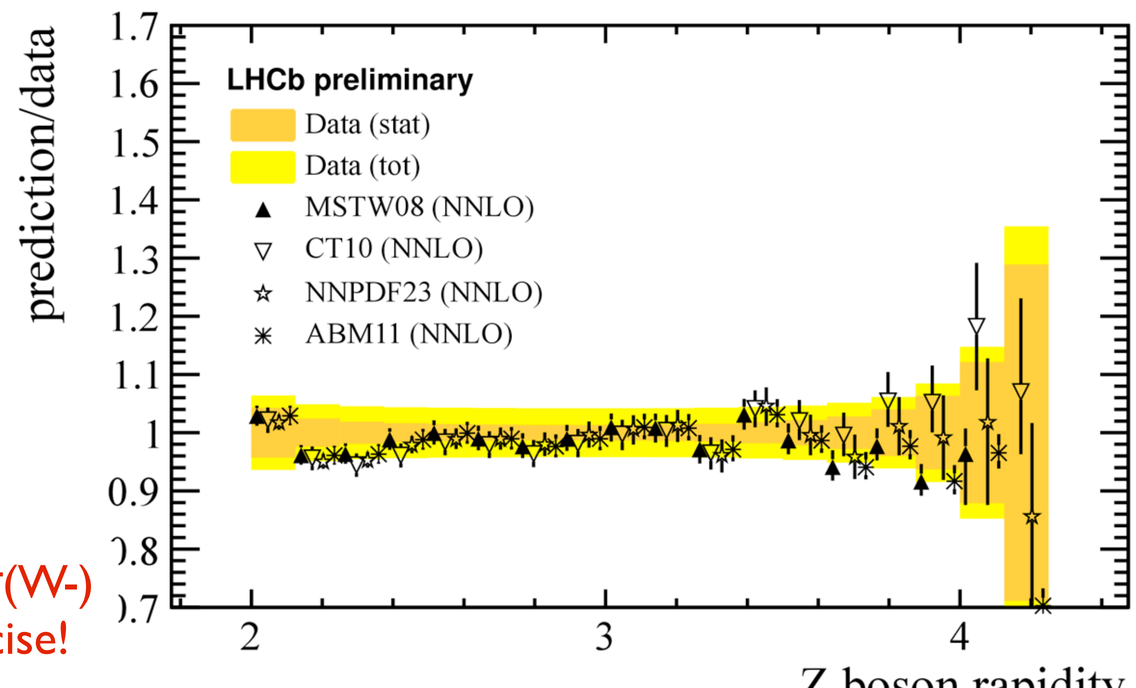








σ(W+)/σ(W-)
1.7% precise!



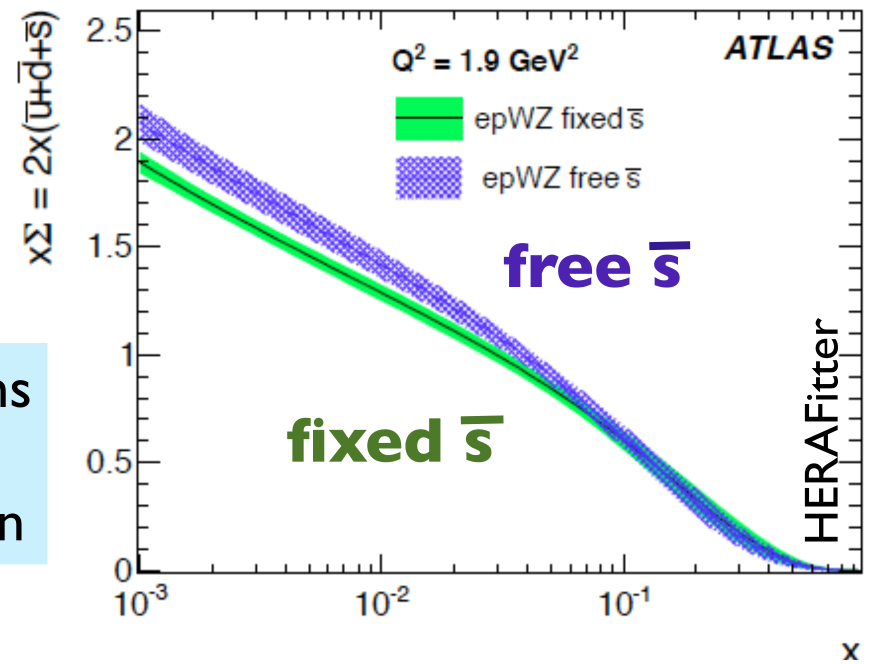
Systematic error comparable with PDF error
Benchmarking different PDF sets

Constraints from the LHC: Electroweak Boson Production

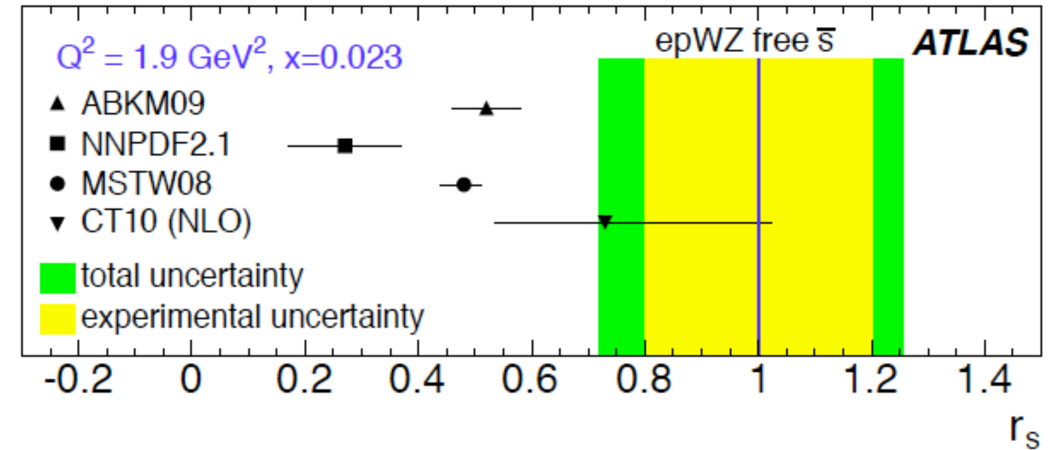
ATLAS *(K. Nikolics)*

$\sqrt{s}$=7 TeV, L=35 pb^{-1}

Z,W rapidity distributions sensitive to strangeness in the proton



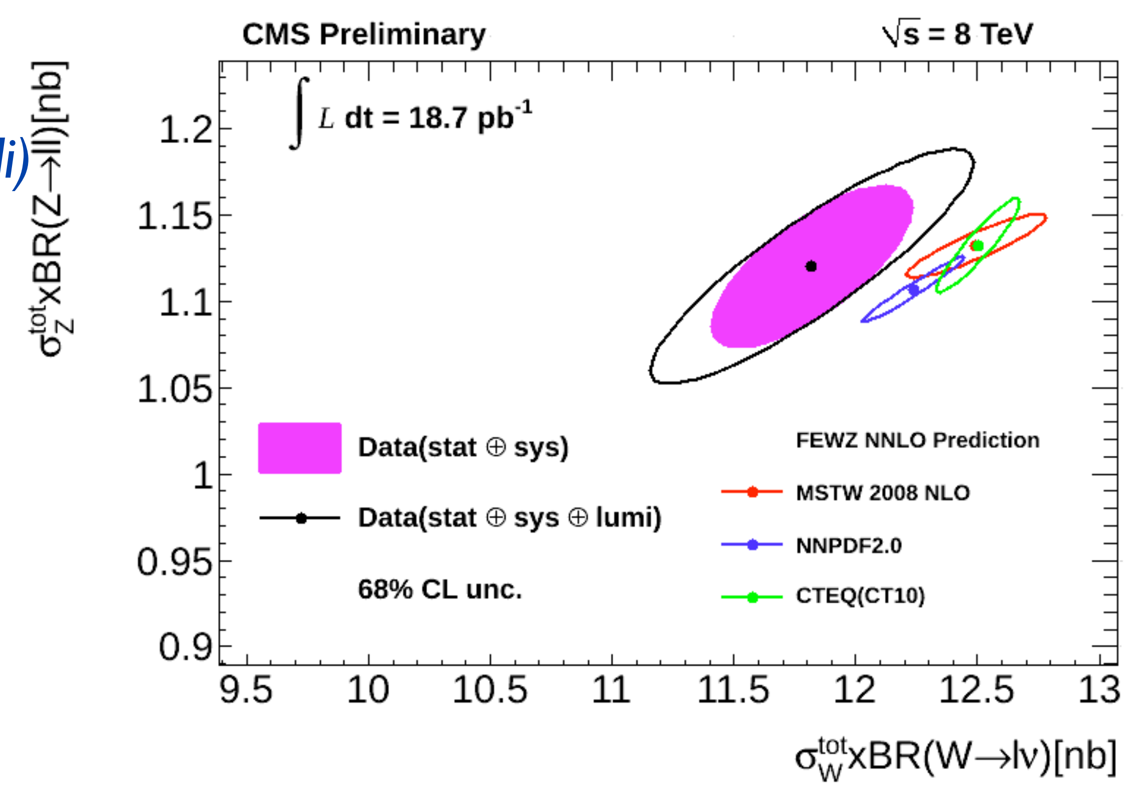
$r_s = 0.5(s+\bar{s})/\bar{d} = 1.00^{+0.25}_{-0.28}$

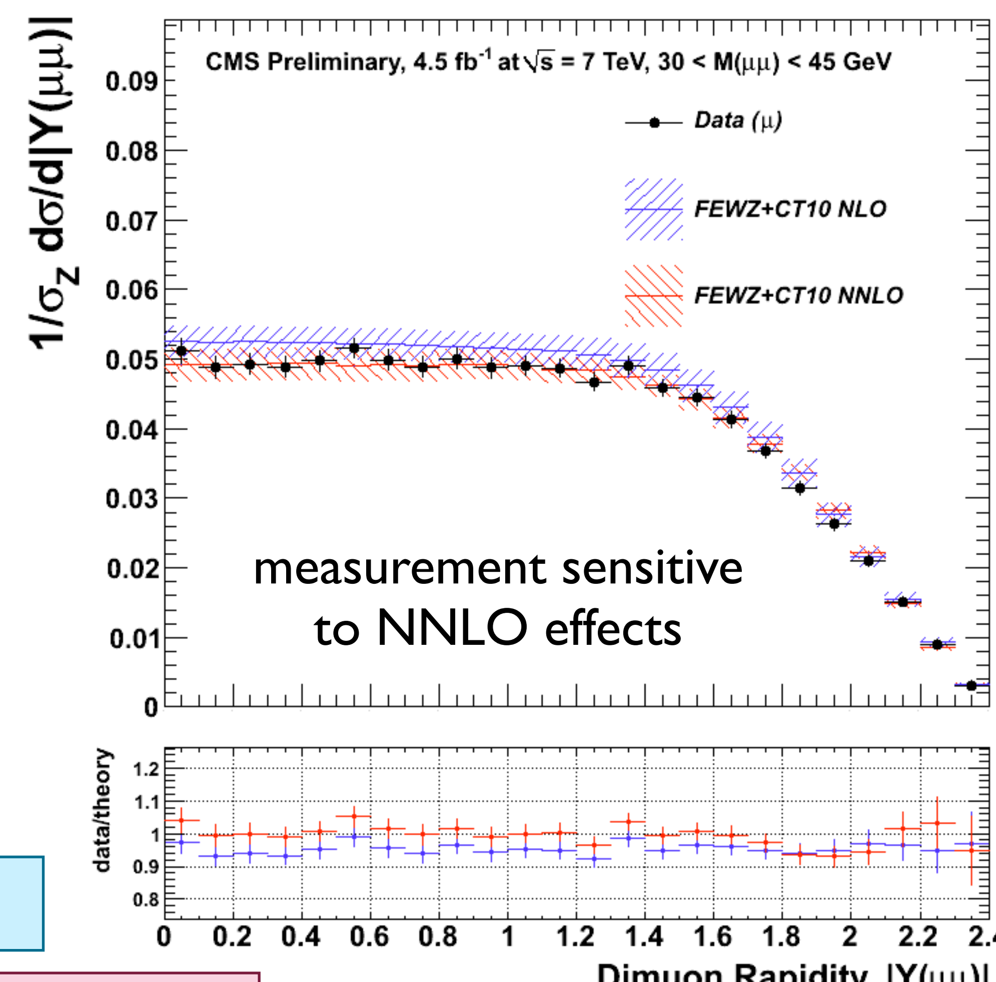


data disfavors strangeness suppression

CMS
(A. Khukhunaishvili)

$\sqrt{s}$= 8 TeV



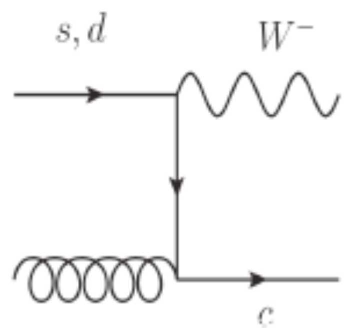


Very precise data available, high potential to constrain PDFs

Important information is lost in the normalized measurements
Instead, non-normalized distribution with error correlation is preferable

Constraints from the LHC: Electroweak Boson+Heavy Quark

W+c probe strangeness



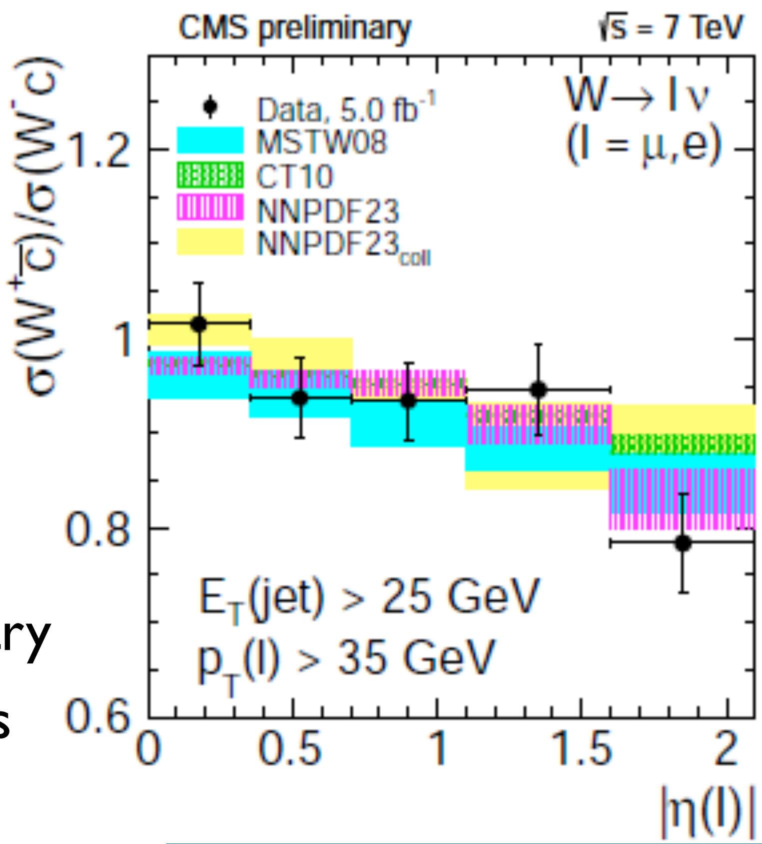
+ c.c.

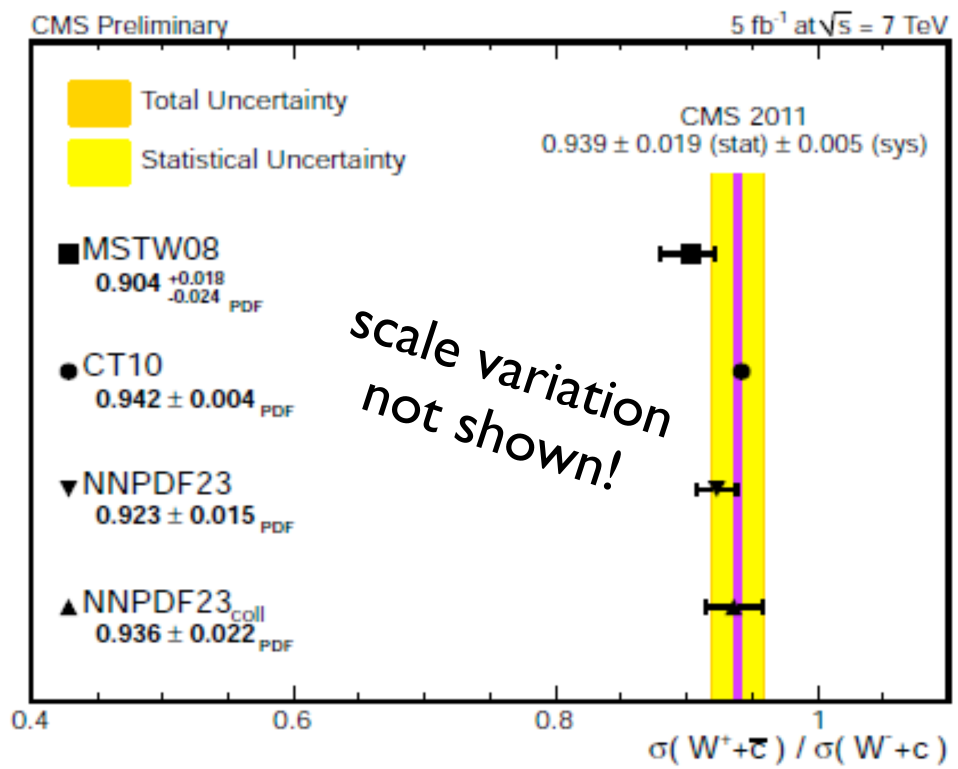
(E.Vryonidou)

Ratios: $\frac{W^+ + \bar{c}}{W^- + c}, \frac{W + c}{W + jets}$

Strangeness and strange asymmetry

Precise data could constrain PDFs





W+b: probe b pdf

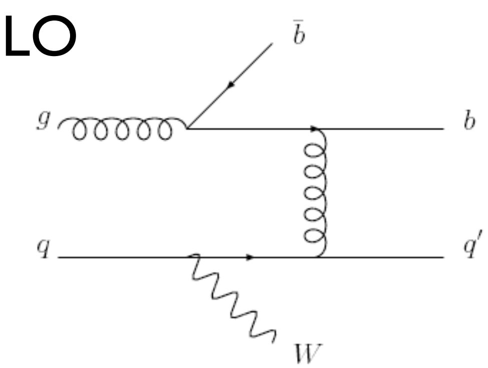
(C.Lange)

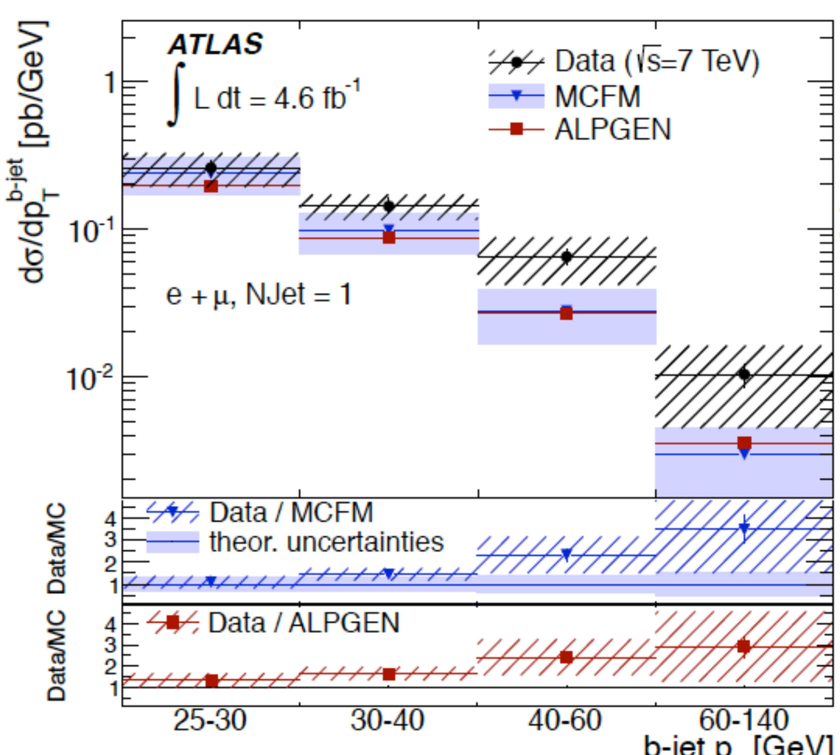
- test different flavour schemes
-analog to Higgsbbar production
- contributions from double-parton interactions

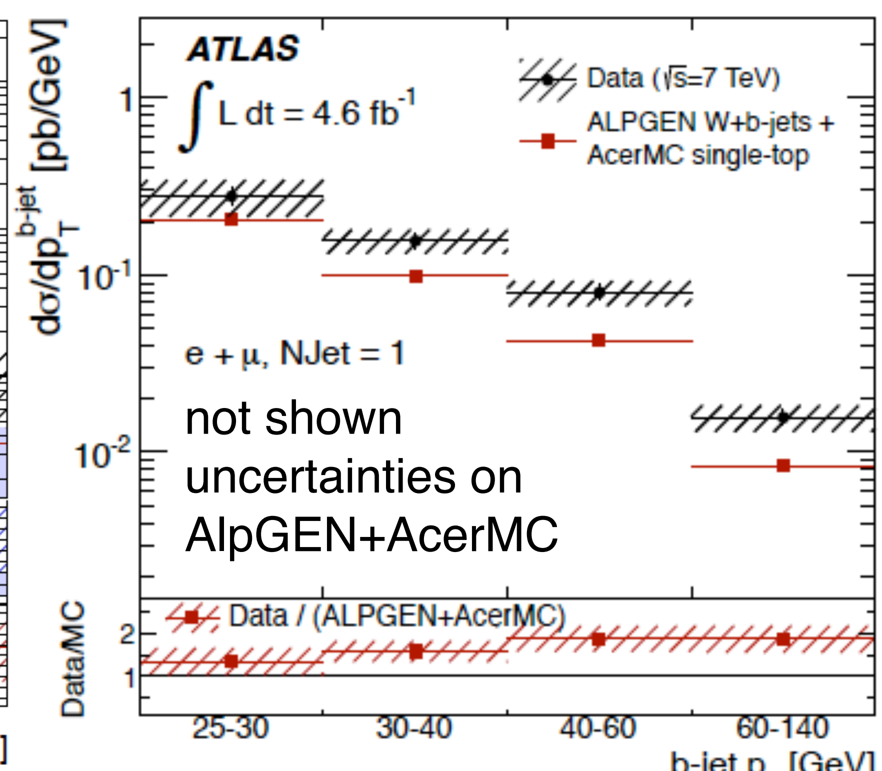
first measurement of W+b jet

+ single top

NLO



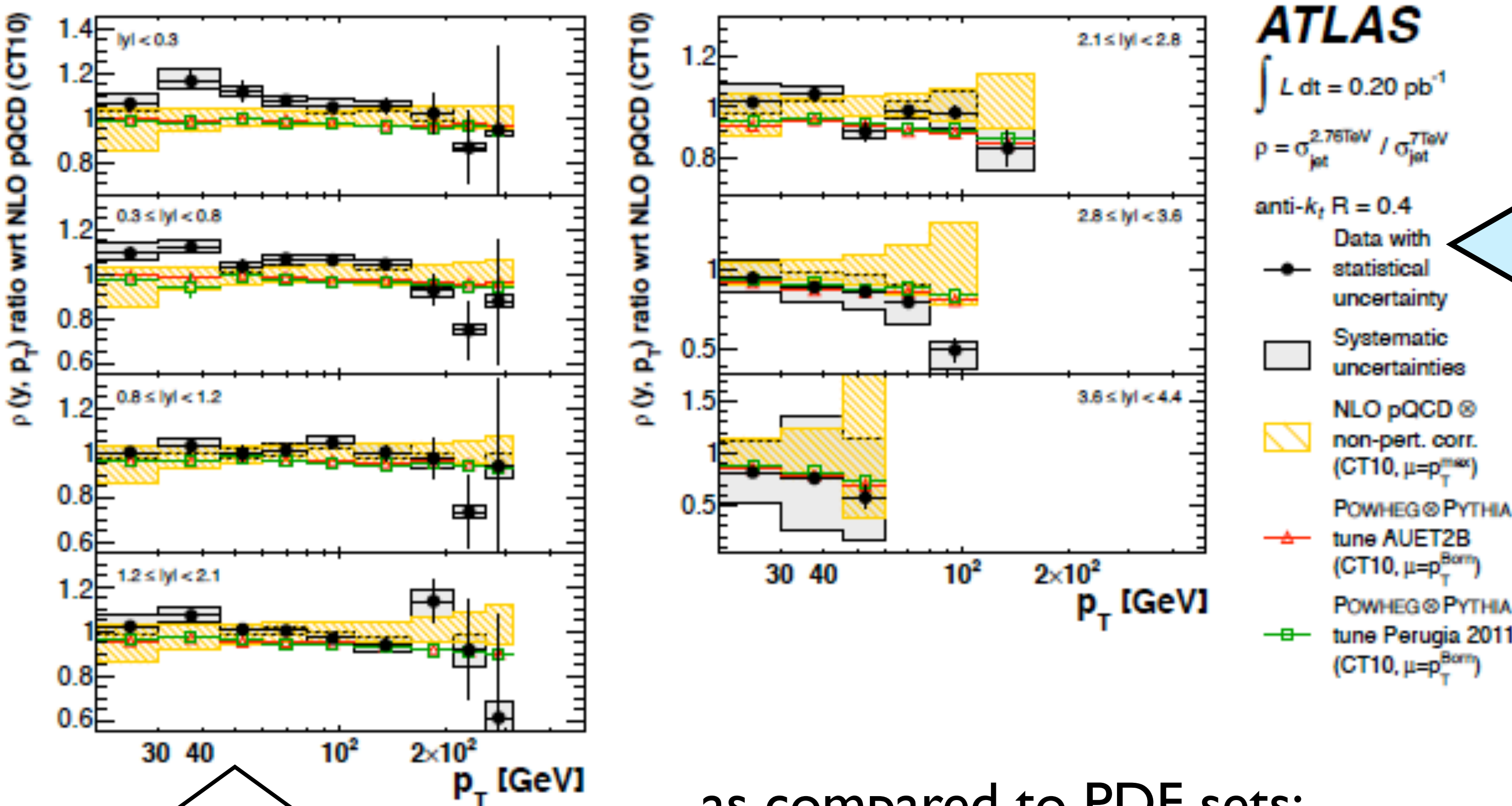




W+b and single top reduces experimental uncertainties, needs more input from theory

Constraints from the LHC: Jets

ATLAS Jet data included into QCD analysis@NLO *(P. Starovoitov)*



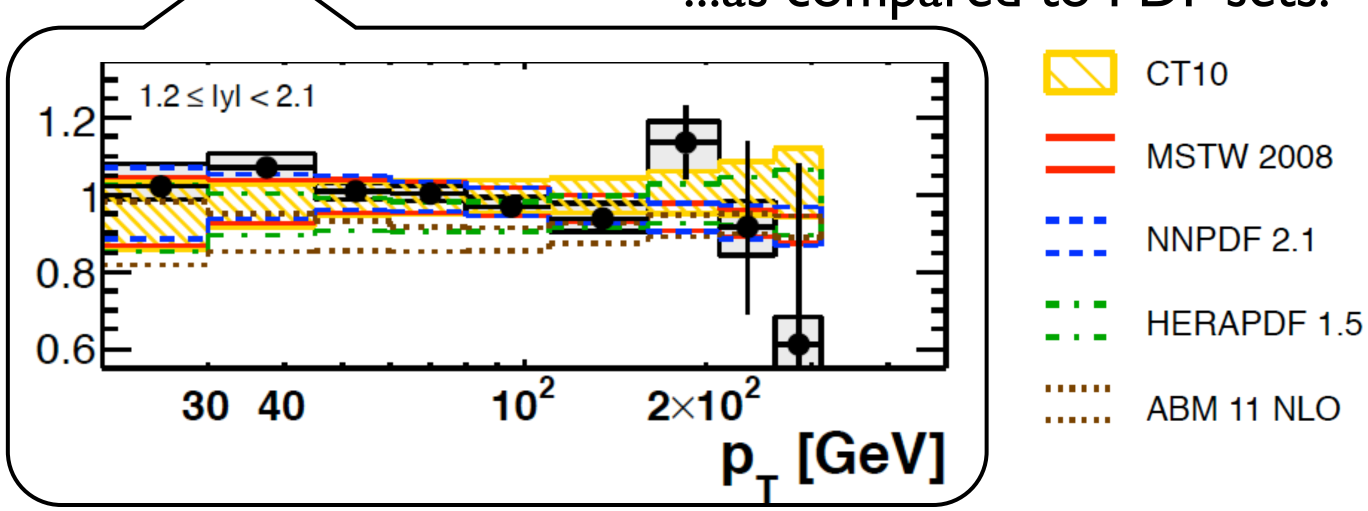
Data: $\sqrt{s}$=2.76 TeV, 7 TeV, L=0.2 pb^{-1}

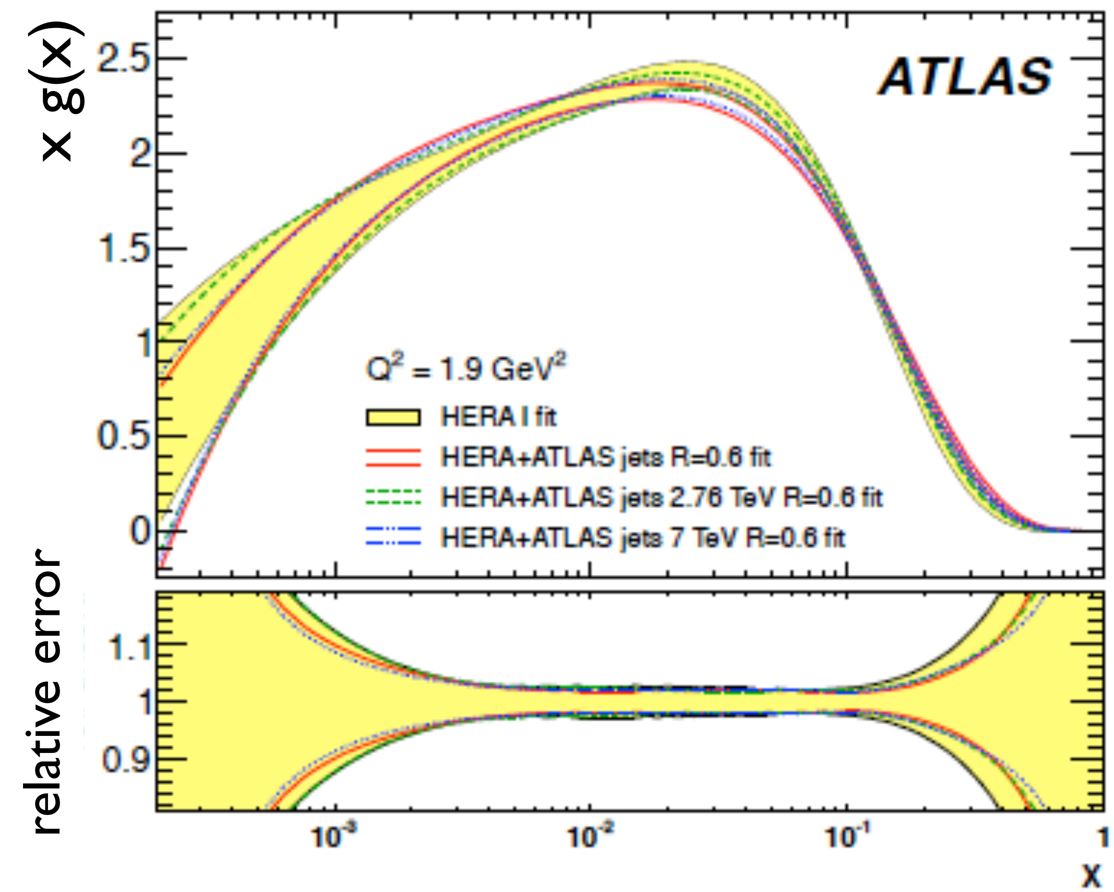
anti-$k_{t,}$ R=0.4, 0.6

Ratio 2.76/7 TeV to pQCD@NLO (CT10)

correlations taken into account

...as compared to PDF sets:

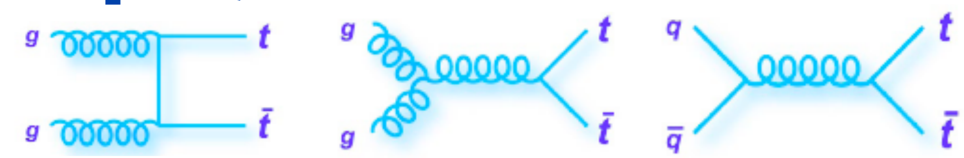




Measurement in good agreement with MC and pQCD@NLO
Agreement with QCD x different PDF sets
Used together with HERA DIS data to determine PDFs

Moderate error reduction
Harder gluon distribution

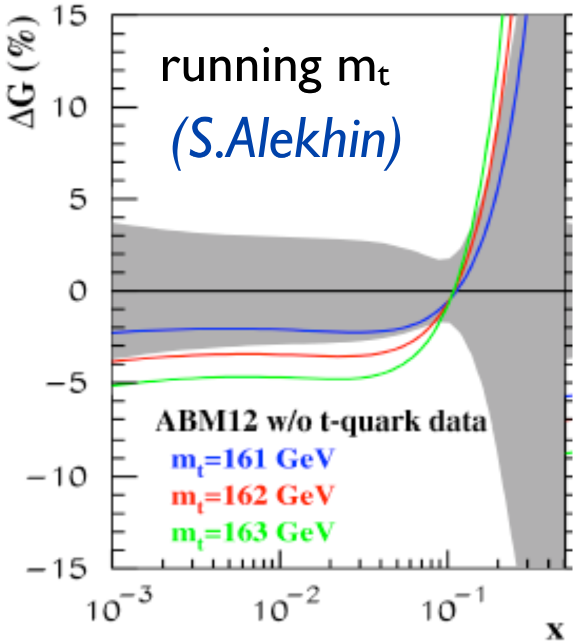
Constraints from the LHC: Top Quarks

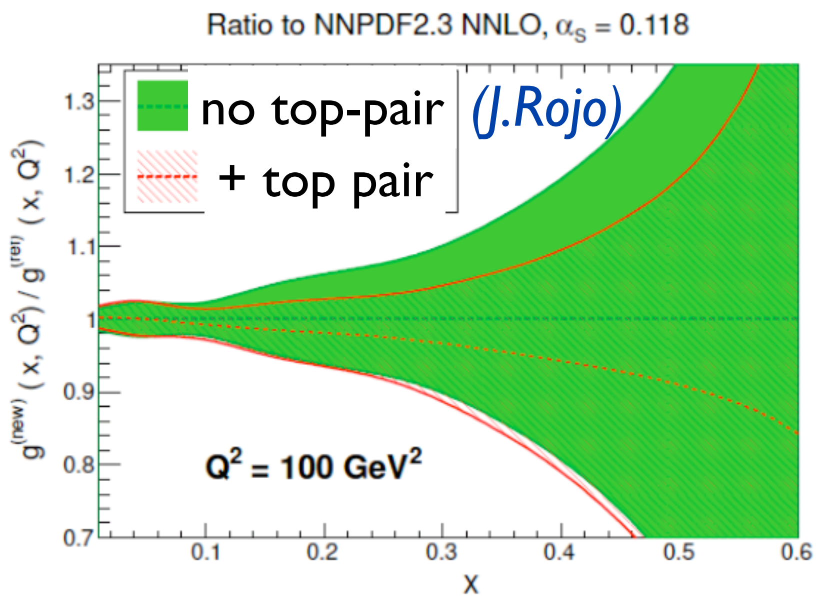


Top-Pair production @ LHC: Strong correlation PDF, m_t, α_S

Inclusive cross sections: precision up to 4% in 2l channel at CMS to 10% in ATLAS
used to extract top mass in pole and $\overline{\text{MS}}$ definition, and strong coupling α_S *(J.Kieseler)*

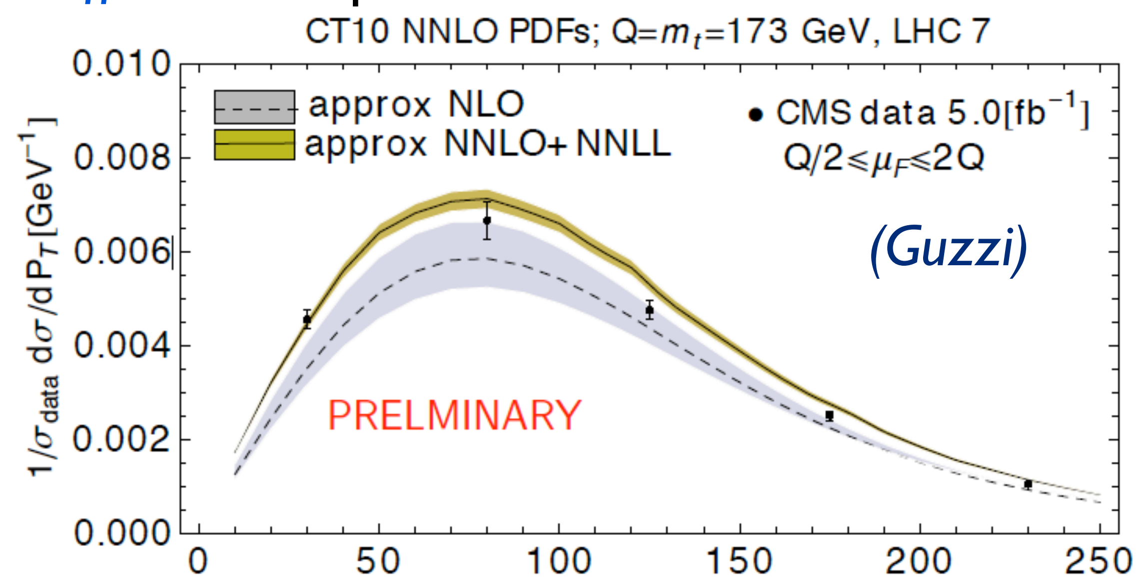
Inclusive $t\bar{t}$: Included into PDF fits *(ABM, NNPDF):*





additional constraints on g(x), large correlations with m_t, α_S

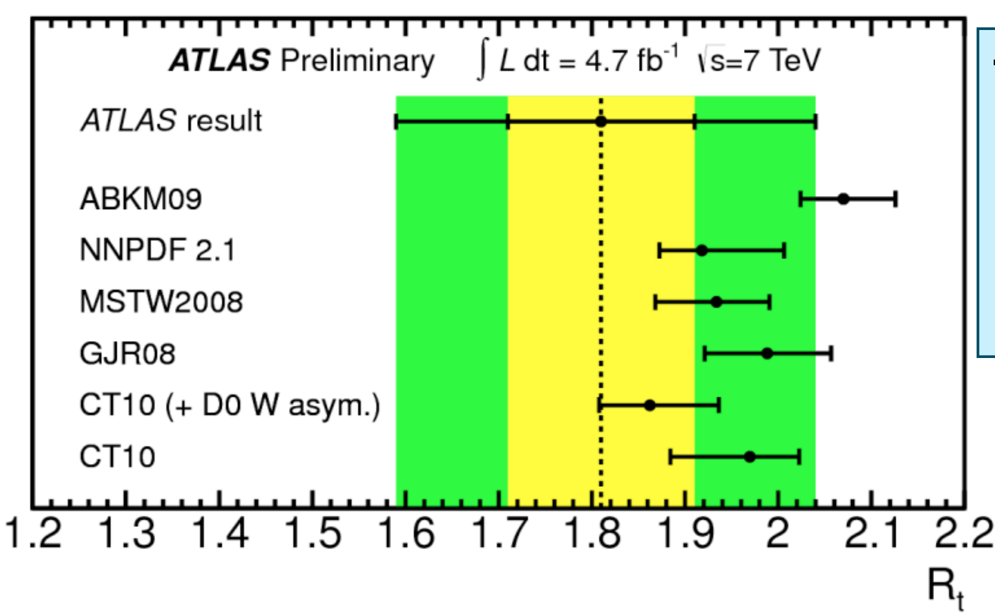
Differential $t\bar{t}$: precision ~ 8%, 7 and 8 TeV.



large K-factors P^t_T[GeV]

significant dependence on PDFs, α_S, m_t

Single top at the LHC: sensitive to u/d *(Bertella)*



Top production@LHC sensitive to g(x), α_S, m_t, flavor separation
Data available with essential precision
Recent NNLO calculation for inclusive x-section completed
Open source at NLO+NNLL in development

Experimental precision matched by theory developments

Theoretical Highlights

Nucleon PDFs
Nuclear PDFs
Photon PDFs
TMD PDFs

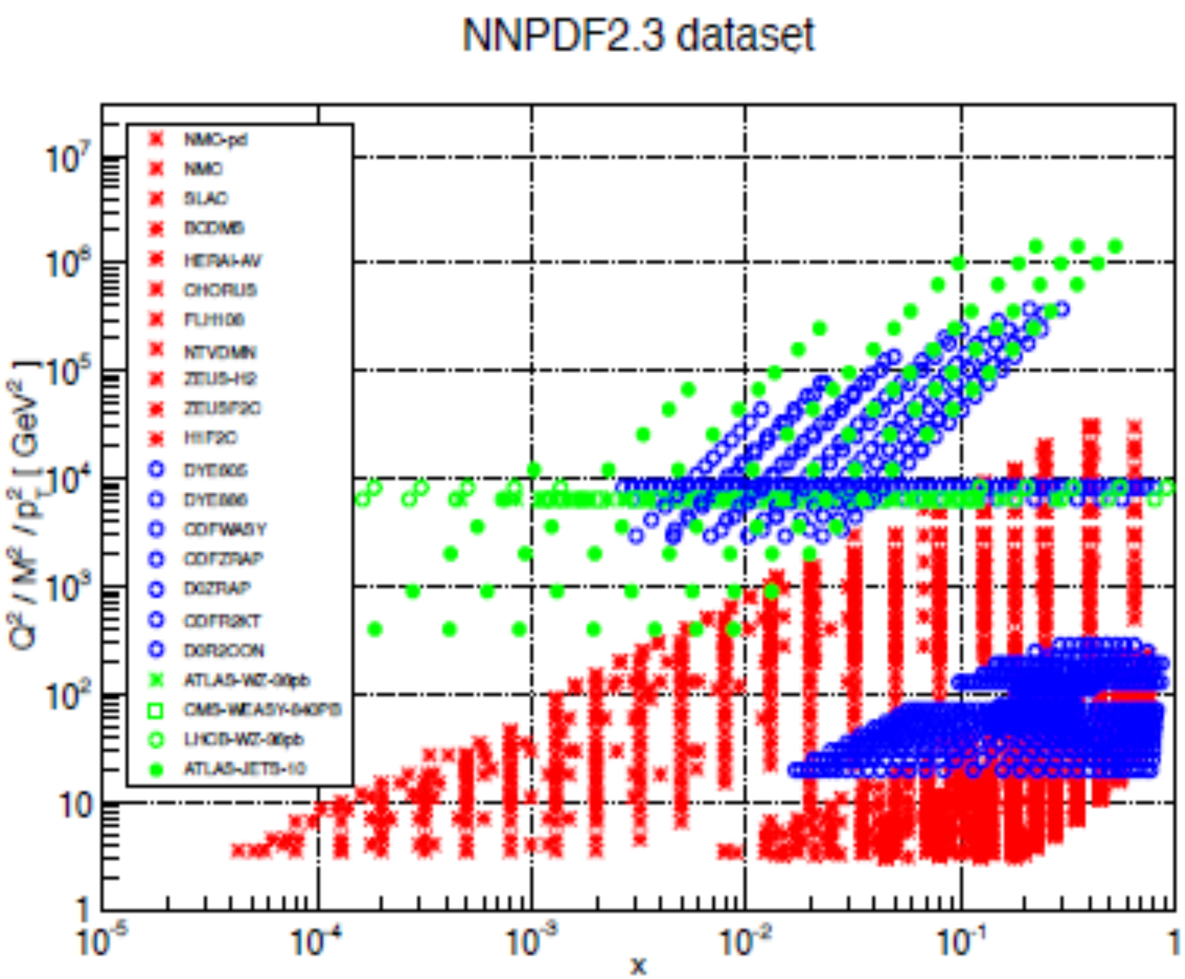
Experiments at
- LHC, Tevatron, RHIC
- Fixed-target facilities

on nucleon and nuclear targets

Theory
NNLO DGLAP
TMD factorization
NLO parton showers
BFKL/CCFM

Progress occurs when experiment, theory, and PDF analysis talk to each other

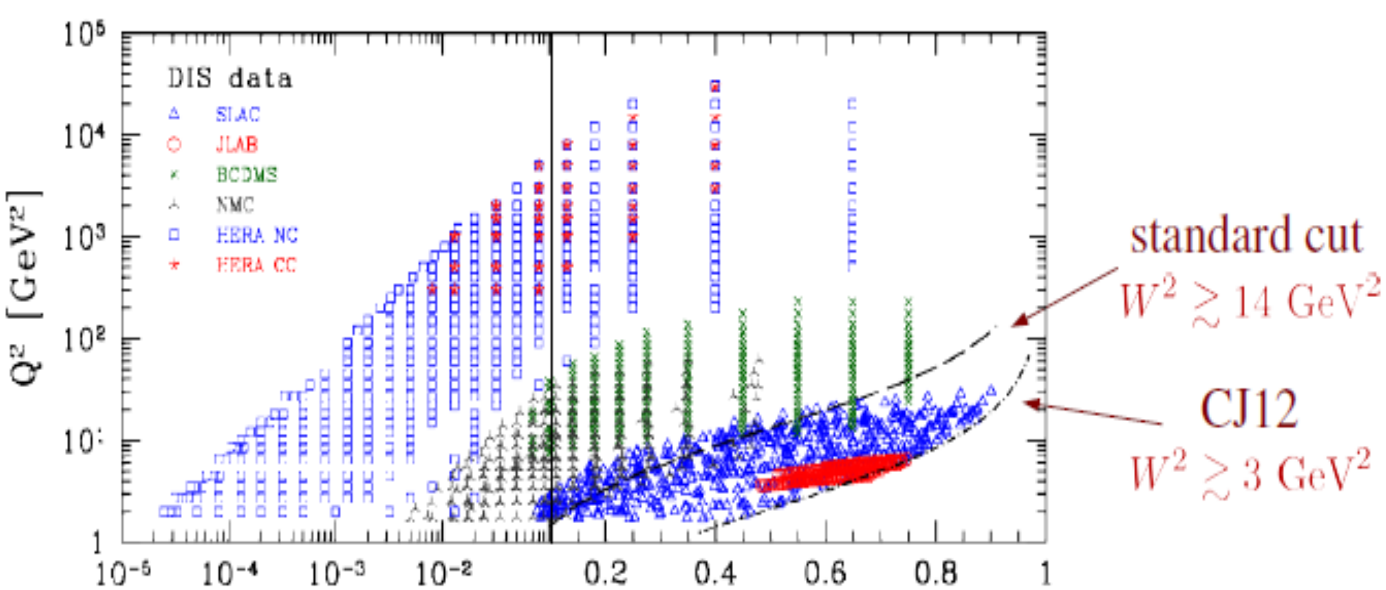
Experiments ⇒ nucleon PDFs



Updates on NNLO PDF analyses by ABM, CT, MSTW, NNPDF groups *(Alekhin, Hartland, P.N., Thorne)*

Precise PDF parametrizations for a variety of QCD applications

ABM: arXiv:1302.1516
CT10 NNLO: arXiv:1302.6246
NNPDF2.3: arXiv:1207.1303
MSTW'12: arXiv:1211.1215



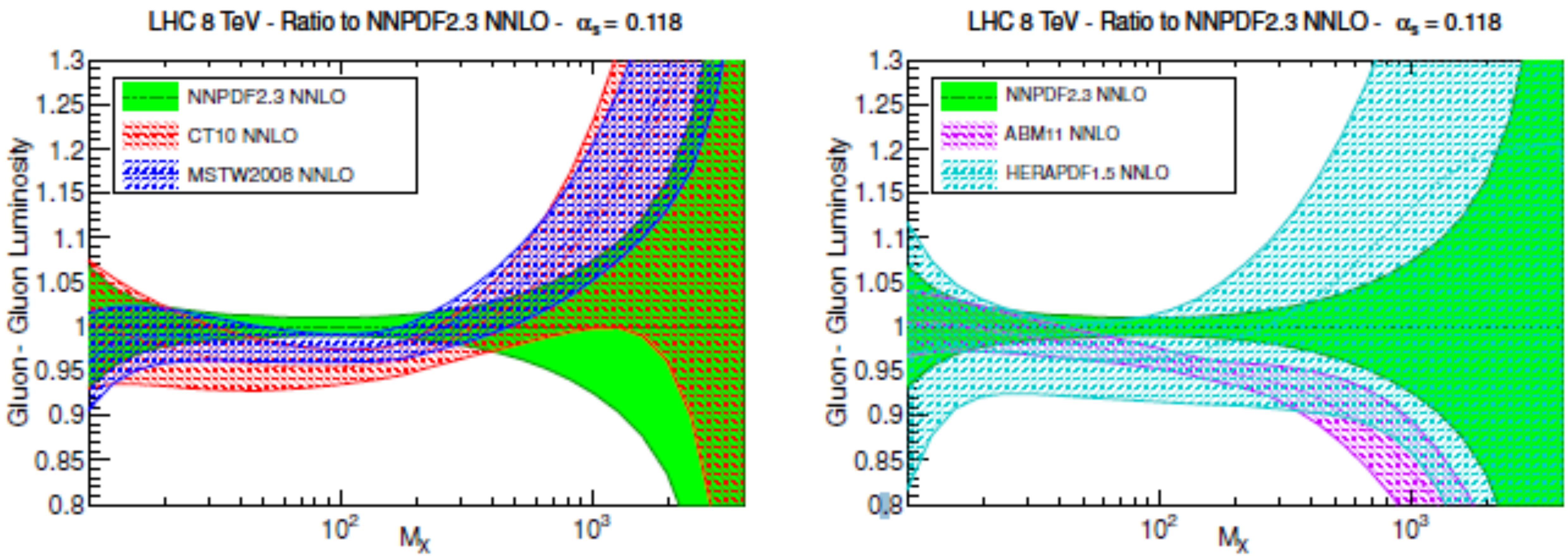
CTEQ-Jlab (CJ) (Accardi):
NLO global QCD analysis of large-x, small-Q DIS region

important for fixed-target experiments, collider searches for TeV

Comparison of unpolarized PDFs

N. Hartland

[arXiv:1211.5142] - Benchmark study of different PDF determinations.
Detailed comparison at common α_S of the most up to date NNLO fits from the ABM, CT, HERAPDF, MSTW and NNPDF collaborations.



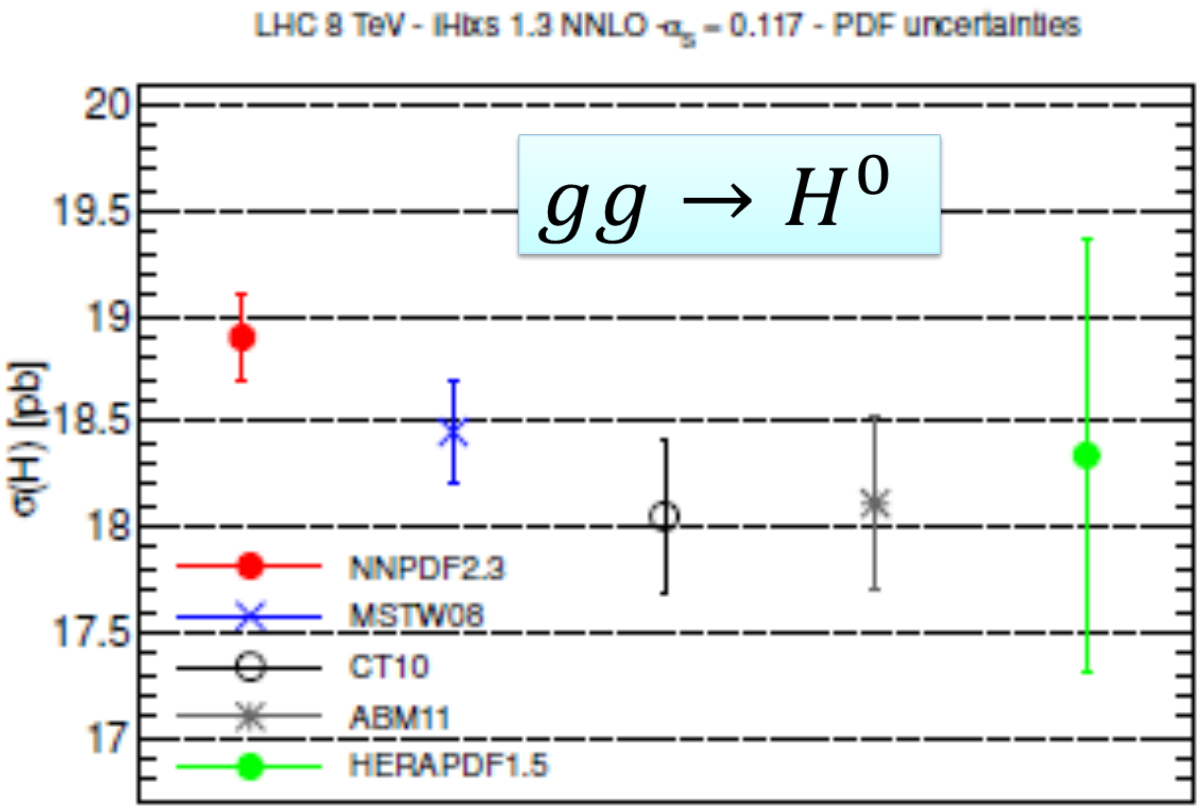
Reasonable agreement was found between CT, MSTW, NNPDF.

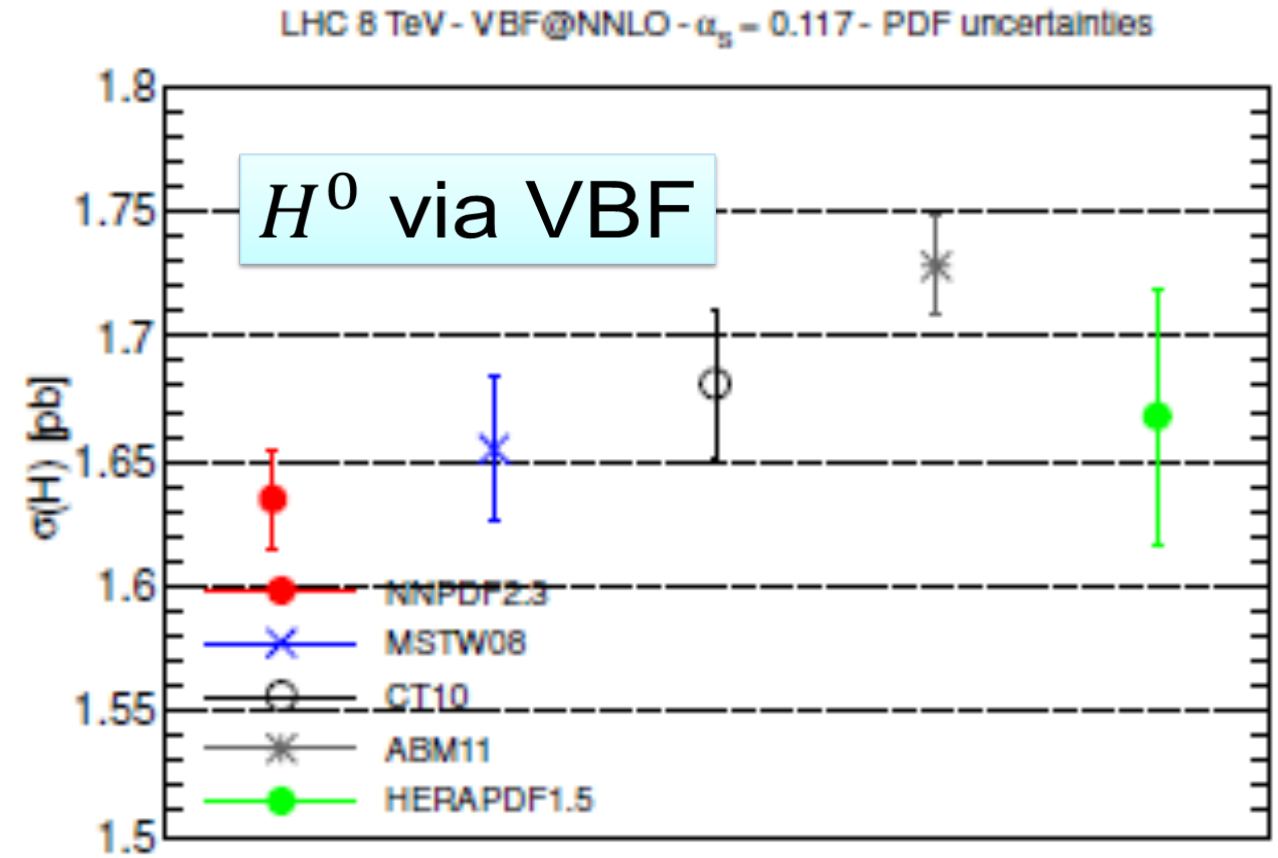
ABM softer large-x gluon and harder quarks.

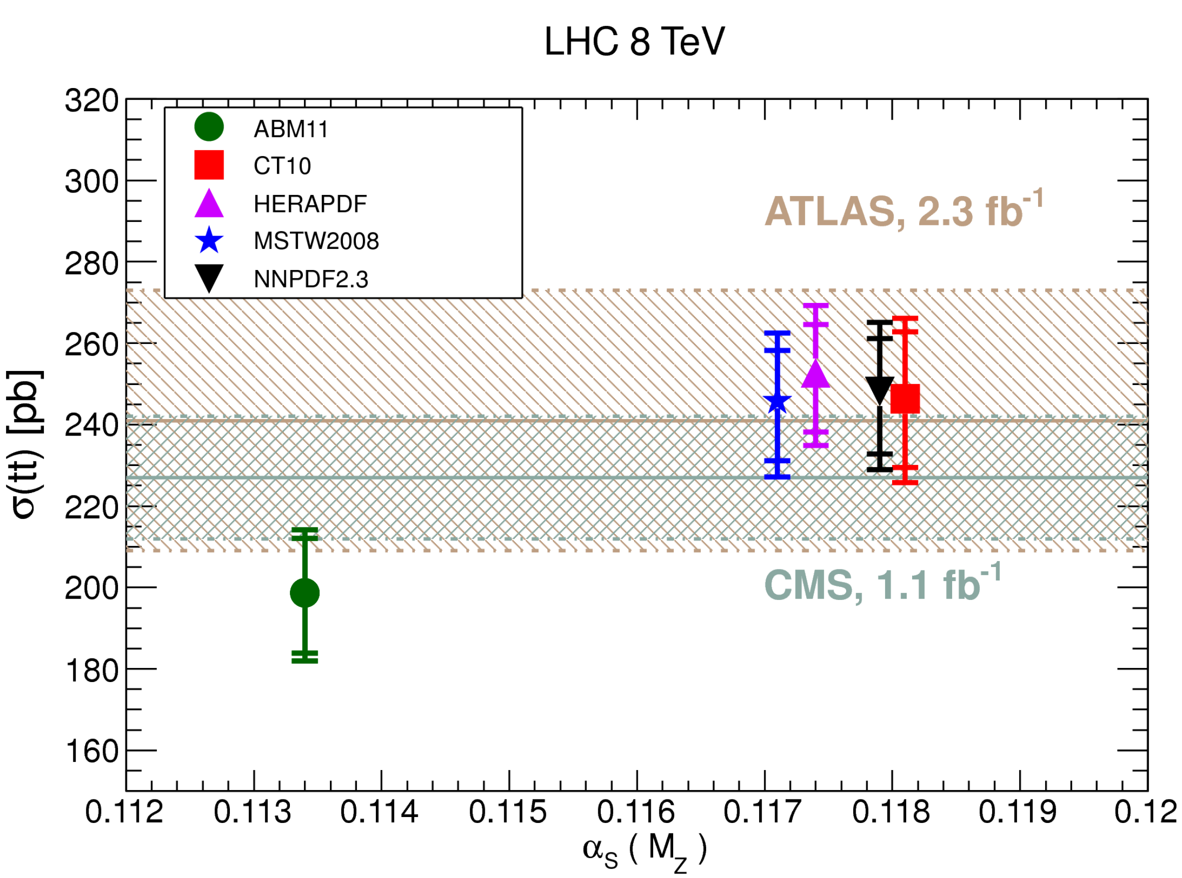
Central values of HERAPDF1.5 NNLO agree with global fits, larger uncertainties due to reduced dataset.

PDFs ⇒ LHC Experiments:

Predictions to benchmark LHC cross sections







The ABM set is different from other sets, requires to reduce $\alpha_s\,(M_Z)$ and m_t^{pole} by ~3"σ" below the PDG values to describe the LHC data **(Alekhin)**

Differences are likely due to the ABM heavy-quark scheme, not higher twists or nuclear corrections **(Hartland, Thorne)**

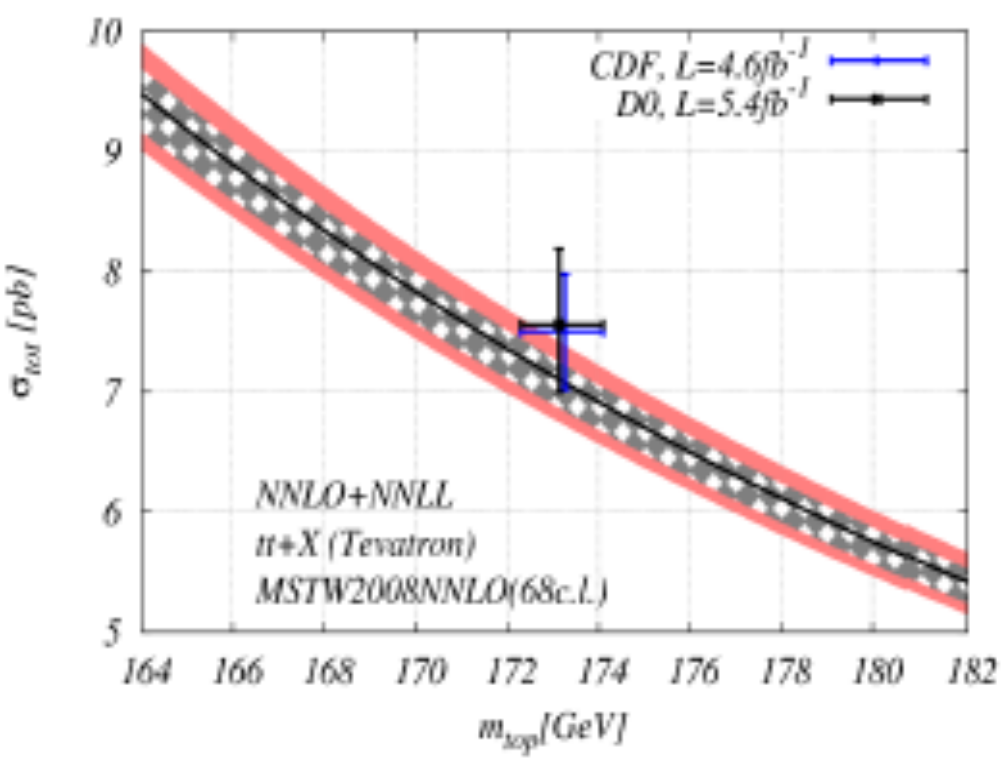
R. Ball et al., **arXiv:1211.5142**

t-quark mass

S. Alekhin

- m_t(MC)=173.3±1 GeV (Tevatron/LHC)
- m_t(pole)≈ m_t(MC) - 1 GeV
- $m_t(m_t)$≈ m_t(pole) - 9 GeV

Using $\overline{MS}$ top mass is more perturbatively stable in the ABM fit than the pole mass, better describes the data, and produces $m_t(m_t) \approx 163$ GeV compatible with PDG $\overline{MS}$ value of 160^{+5}_{-4} GeV from cross section measurements



CDF&D0	ABM11	JR09	MSTW08	NN21
$m_t^{\overline{MS}}(m_t)$	$162.0^{+2.3}_{-2.3}{}^{+0.7}_{-0.6}$	$163.5^{+2.2}_{-2.2}{}^{+0.6}_{-0.2}$	$163.2^{+2.2}_{-2.2}{}^{+0.7}_{-0.8}$	$164.4^{+2.2}_{-2.2}{}^{+0.8}_{-0.2}$
m_t^{pole}	$171.7^{+2.4}_{-2.4}{}^{+0.7}_{-0.6}$	$173.3^{+2.3}_{-2.3}{}^{+0.7}_{-0.2}$	$173.4^{+2.3}_{-2.3}{}^{+0.8}_{-0.8}$	$174.9^{+2.3}_{-2.3}{}^{+0.8}_{-0.3}$
(m_t^{pole})	$(169.9^{+2.4}_{-2.4}{}^{+1.2}_{-1.6})$	$(171.4^{+2.3}_{-2.3}{}^{+1.2}_{-1.1})$	$(171.3^{+2.3}_{-2.3}{}^{+1.4}_{-1.8})$	$(172.7^{+2.3}_{-2.3}{}^{+1.4}_{-1.2})$

ABM11 χ^2/Npt with account of the PDF uncertainties (Npt=5)

mt(pole)=172 / 171 GeV : 17.4 / 12.5

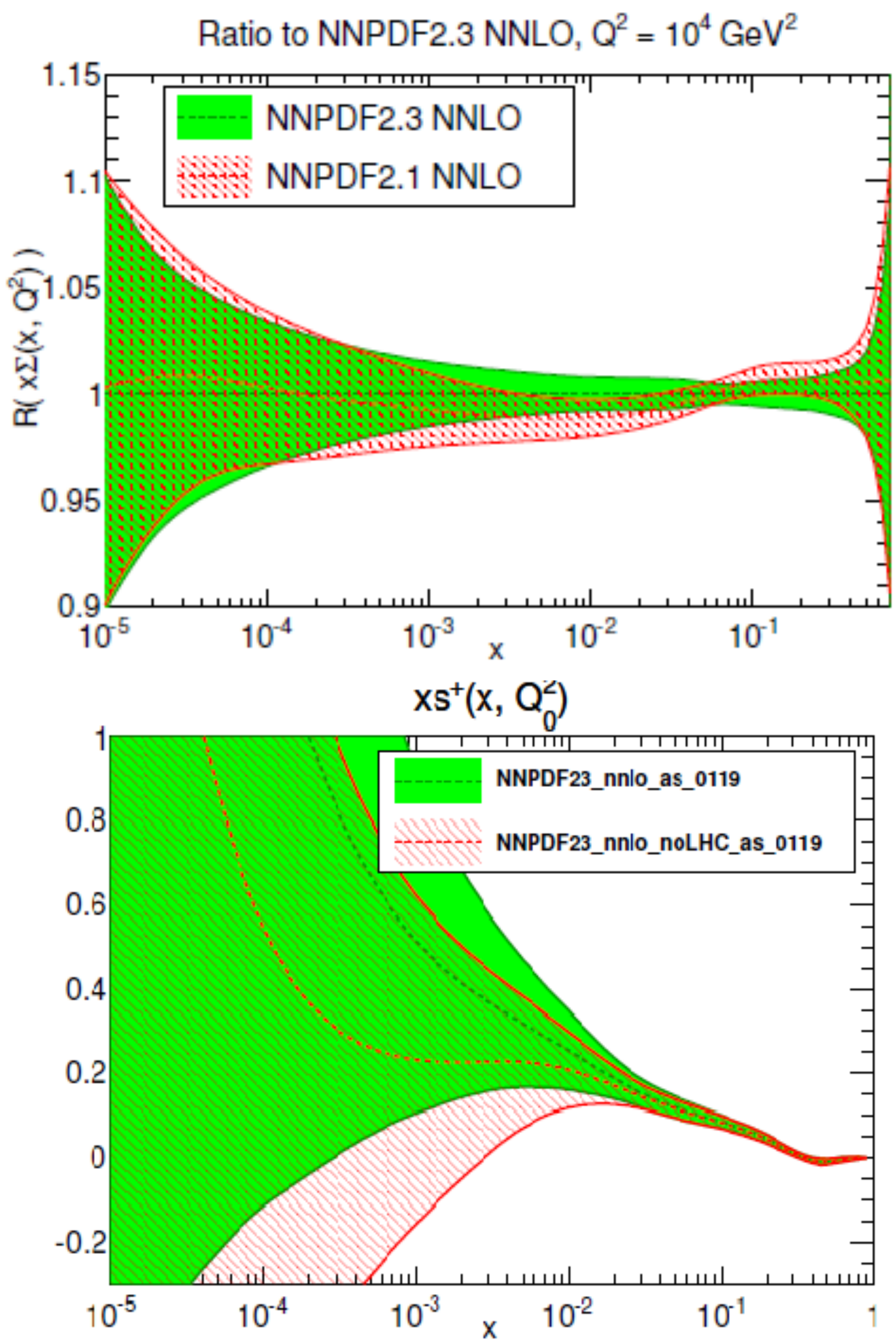
or m**t**(mt)=163 / 162 GeV: 10.6 / 7.0

ATLAS&CMS	ABM11	JR09	MSTW08	NN21
$m_t^{\overline{MS}}(m_t)$	$159.0^{+2.1}_{-2.0}{}^{+0.7}_{-1.4}$	$165.3^{+2.3}_{-2.2}{}^{+0.6}_{-1.2}$	$166.0^{+2.3}_{-2.2}{}^{+0.7}_{-1.5}$	$166.7^{+2.3}_{-2.2}{}^{+0.8}_{-1.3}$
m_t^{pole}	$168.6^{+2.3}_{-2.2}{}^{+0.7}_{-1.5}$	$175.1^{+2.4}_{-2.3}{}^{+0.6}_{-1.3}$	$176.4^{+2.4}_{-2.3}{}^{+0.8}_{-1.6}$	$177.4^{+2.4}_{-2.3}{}^{+0.8}_{-1.4}$
(m_t^{pole})	$(166.1^{+2.2}_{-2.1}{}^{+1.7}_{-2.3})$	$(172.6^{+2.4}_{-2.3}{}^{+1.6}_{-2.1})$	$(173.5^{+2.4}_{-2.3}{}^{+1.8}_{-2.5})$	$(174.5^{+2.4}_{-2.3}{}^{+2.0}_{-2.3})$

Stronger correlation between m_t, PDFs and α_s at LHC

9

LHC data ⇒ new PDFs



NNPDF2.3: the first published PDF set that includes LHC 7 TeV data sets:

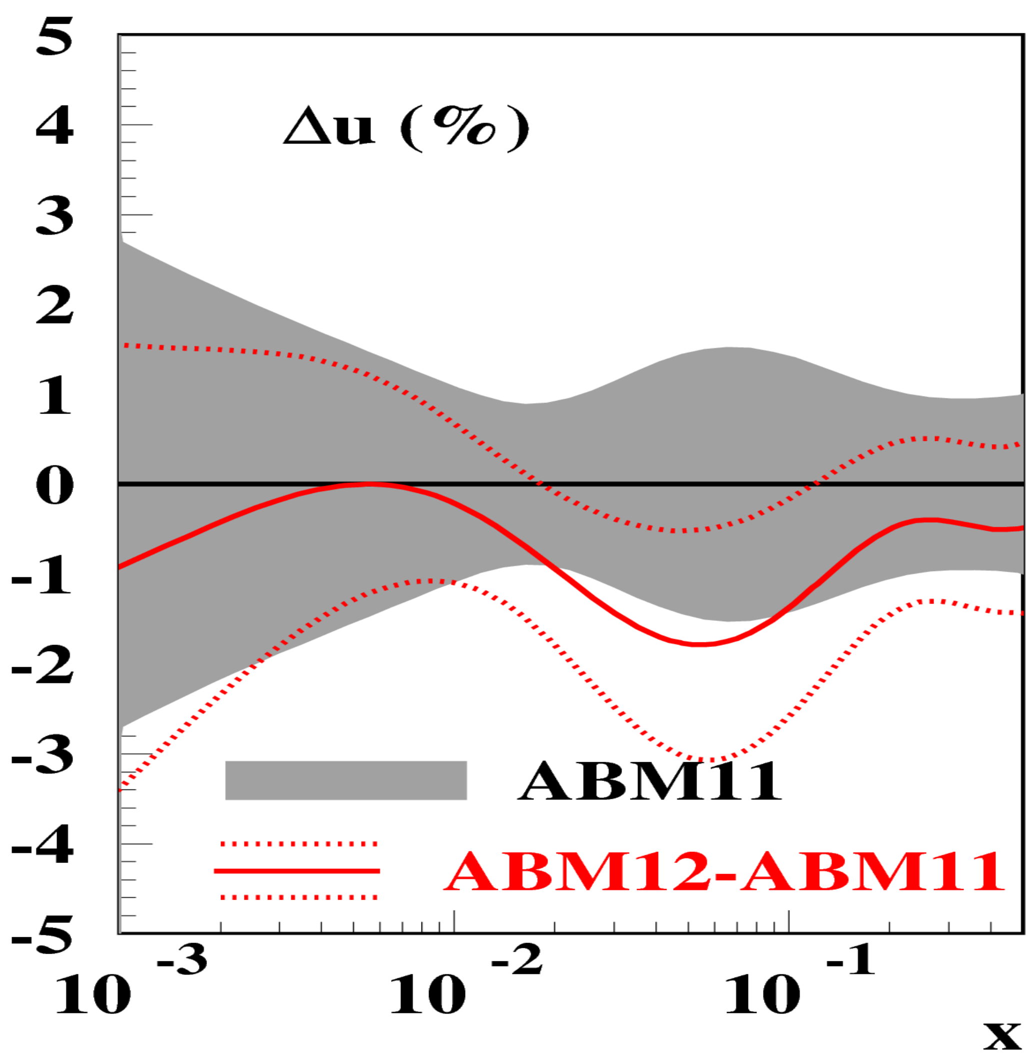
ATLAS inc. jets and $W^{\pm}/Z$ rapidity distributions,
LHCb $W^{\pm}$ rapidity distributions,
CMS W asymmetry

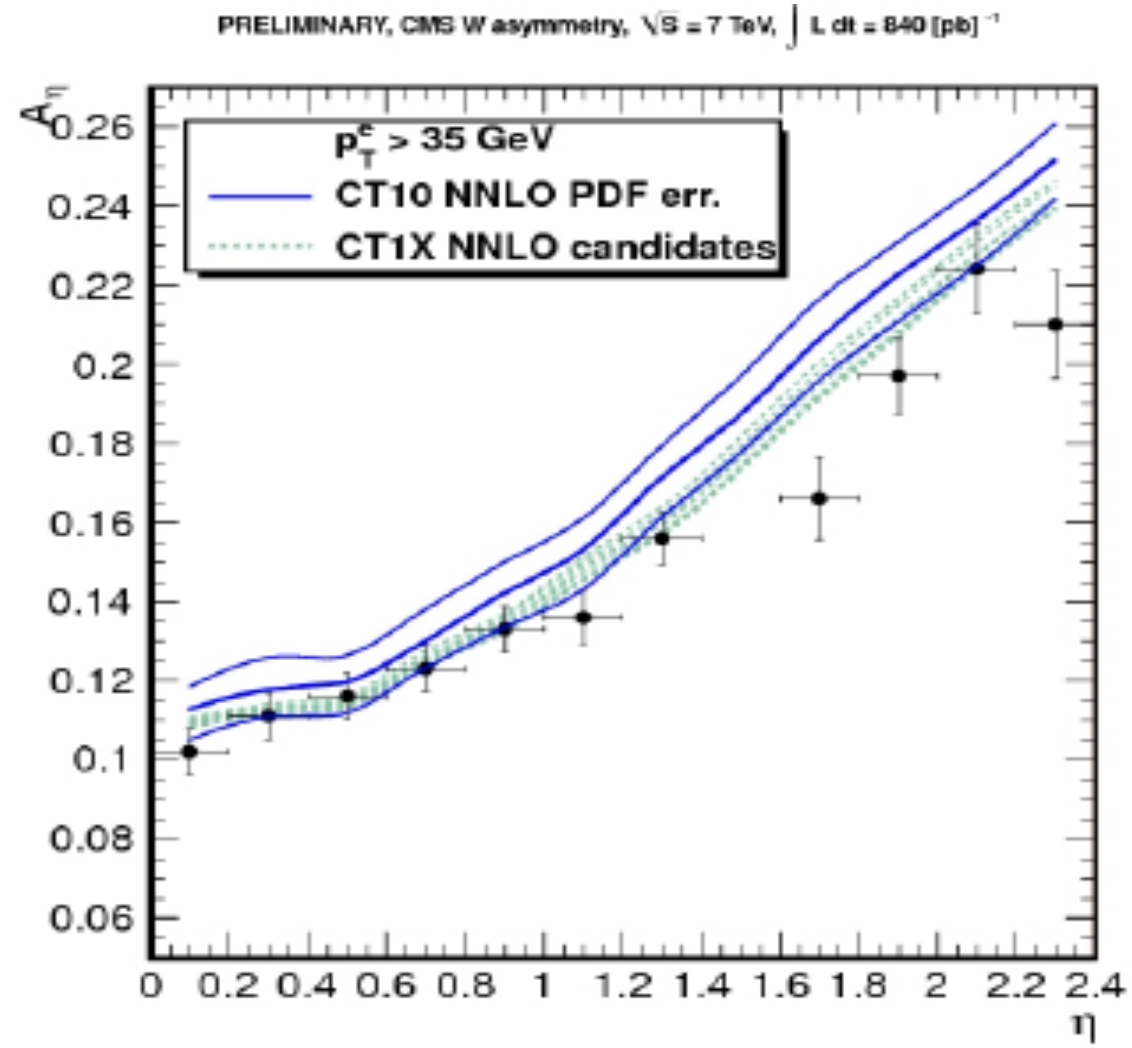
Some reduction in the PDF uncertainty compared to pre-LHC PDFs

Reduced error on strangeness PDFs

Large constraint for "collider only PDFs"

LHC data ⇒ new PDFs





ABM:
inclusion of ATLAS W/Z data modifies u and d PDFs

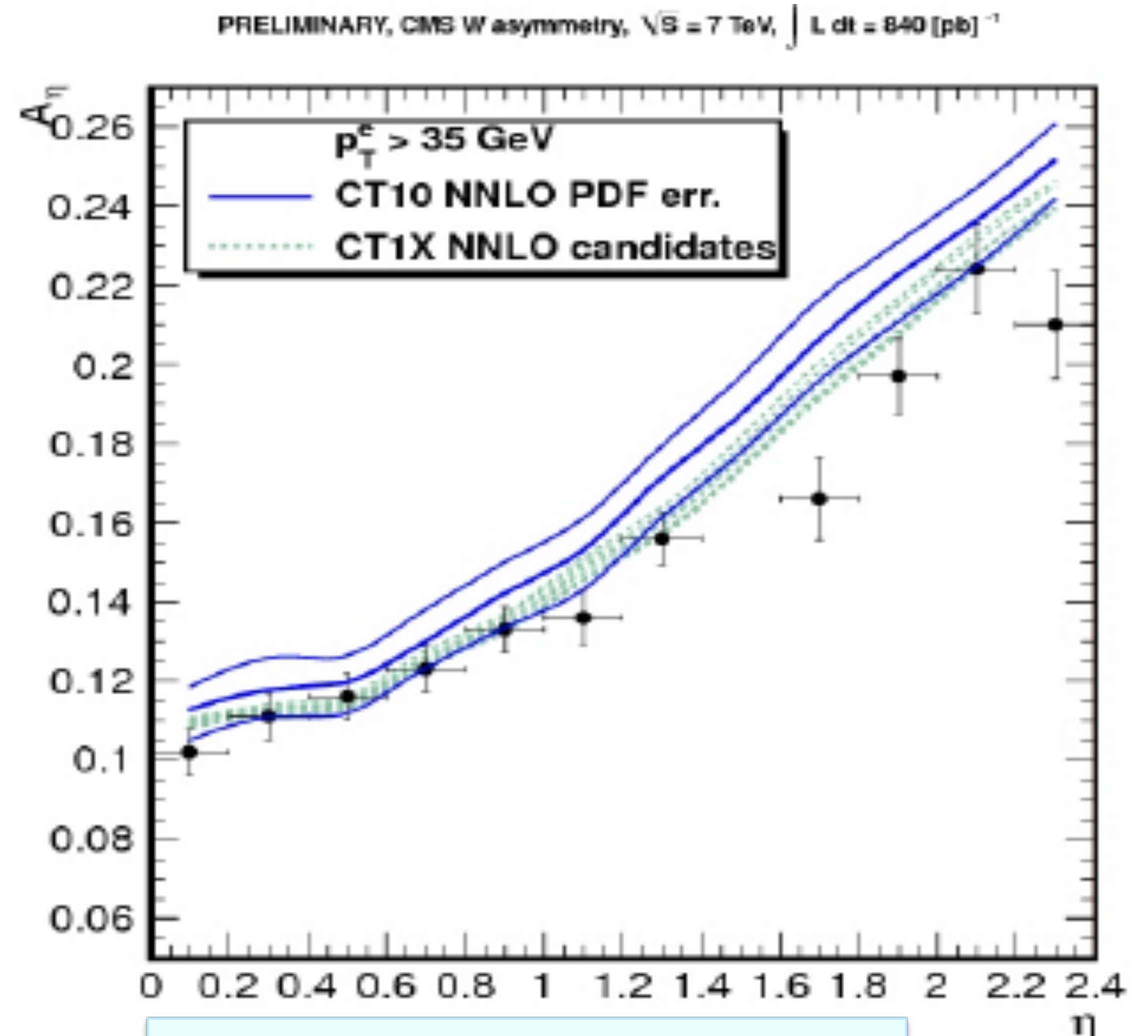
Preliminary fits CT1X and MMSTWW with LHC data

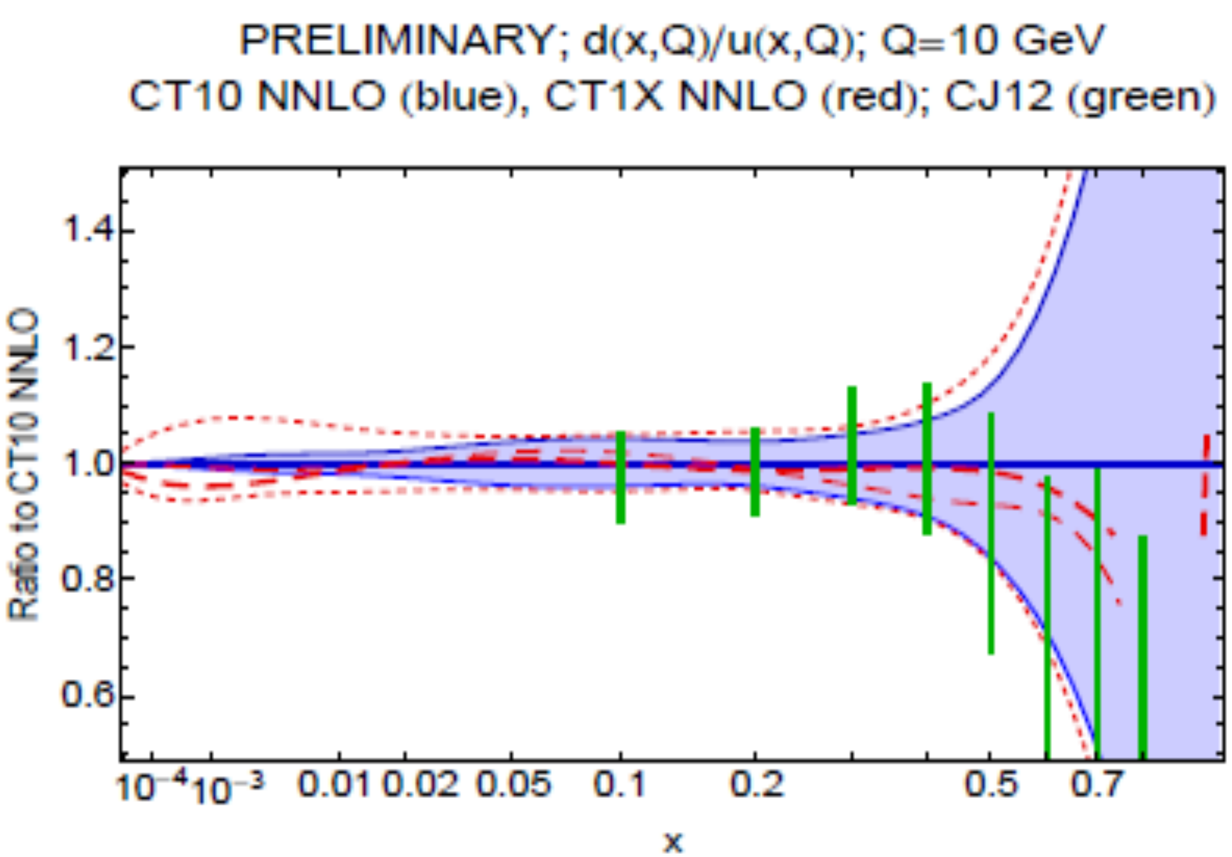
The CMS W asymmetry modifies separation between $u, \bar{u}, d, \bar{d}$ PDFs at $x \sim 0.01$ and d/u at $x > 0.1$

LHC data ⇒ new PDFs

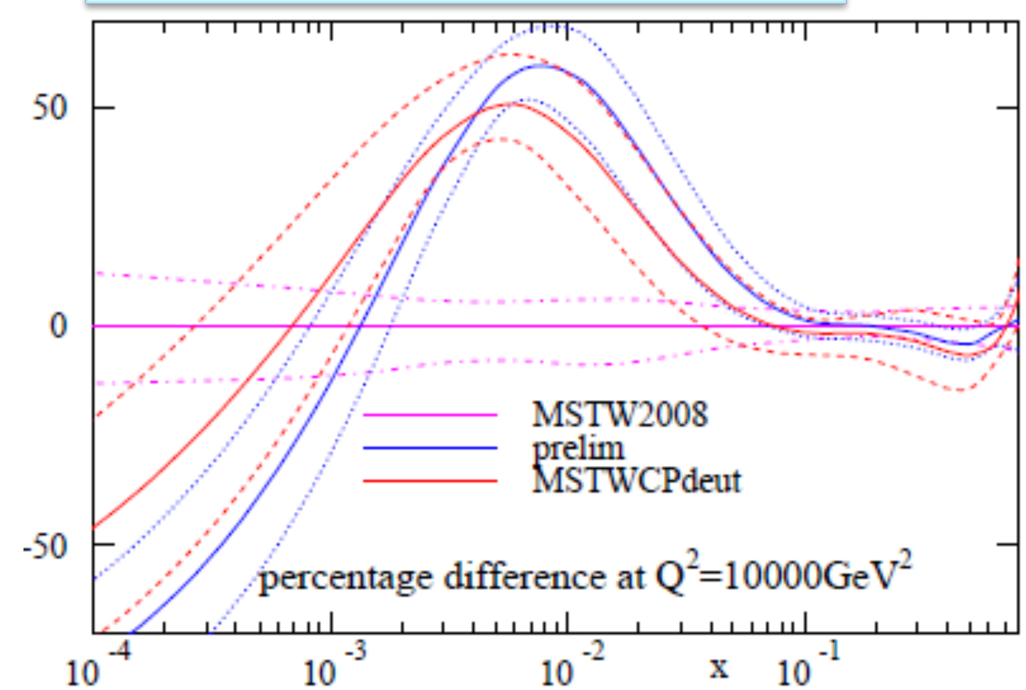
CT1X: modified d/u at x>0.1, increased uncertainties on d/u and $\bar{d}/\bar{u}$ at $x \to 0$

MSTW'2012: $d(x,Q)$ is modified across all x, now in agreement with CMS W asy data



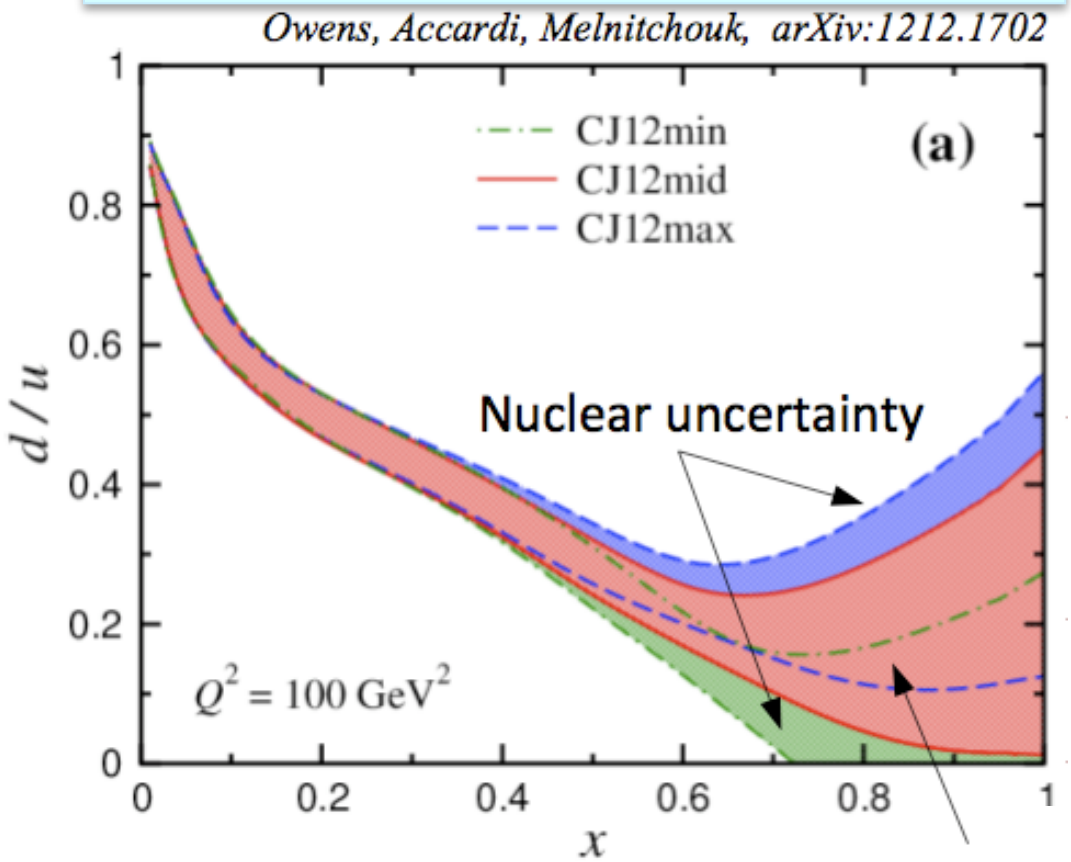


$x(u_V - d_V), Q = 100\ GeV$



Nuclear PDFs

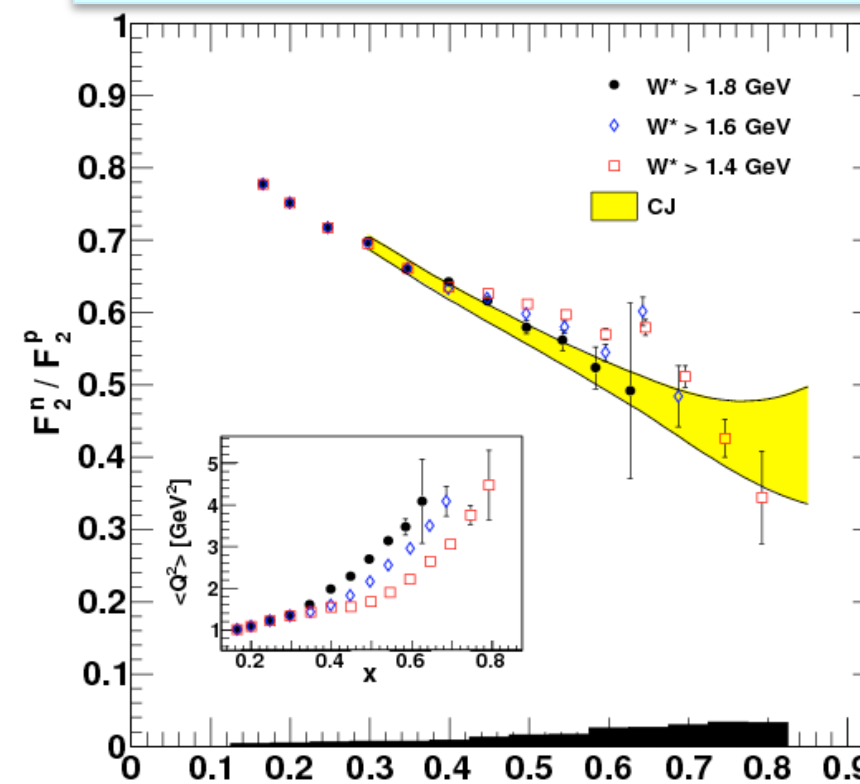
CJ 12 *(Accardi)*, d(x)/u(x) at large x



• Systematic evaluation of deuteron/neutron corrections improves large x pdf precision

• Leverages extended data (JLab) data set

BONUS Experiment at Jlab



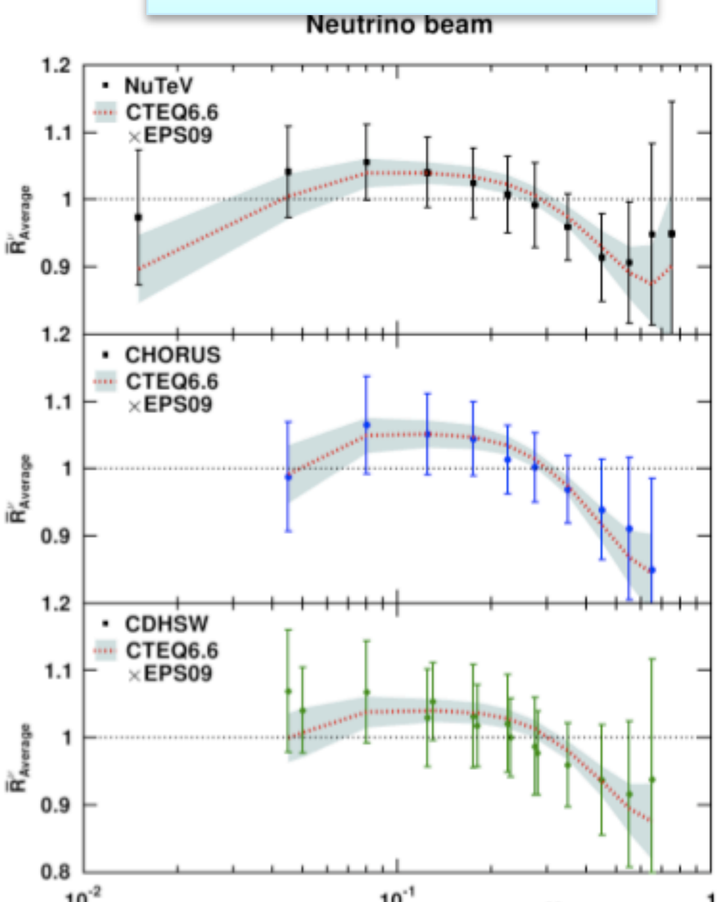
NUCLEAR pdfs

• Needed for ATLAS, RHIC, neutrino oscillations,…..

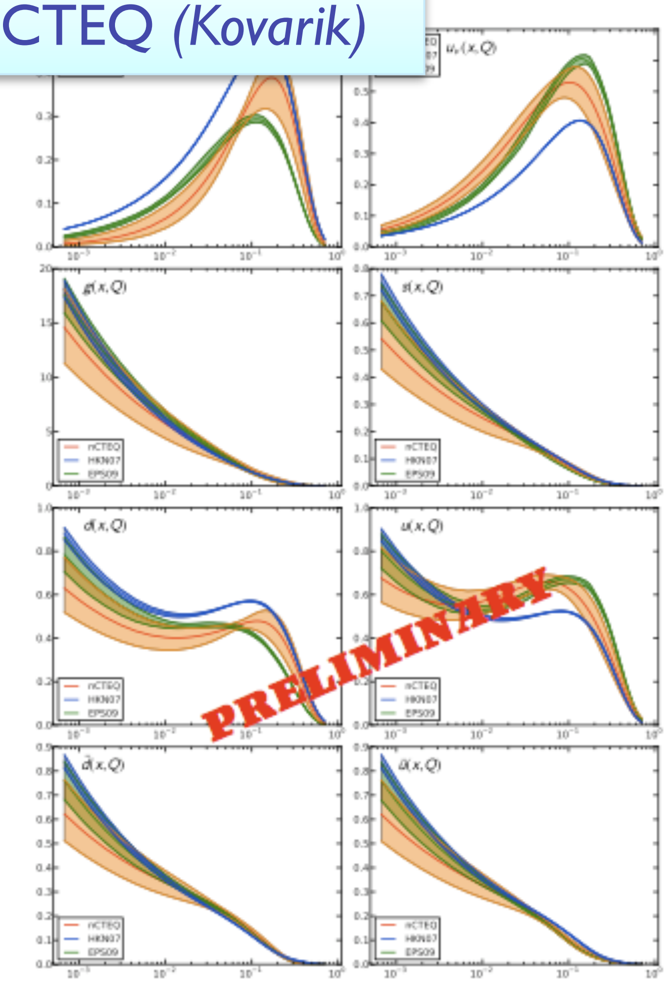
• Some controversy over including (or not!) neutrino data

• EIC, LHeC,… will help A LOT

EPS *(Paukkunen)*



nCTEQ *(Kovarik)*

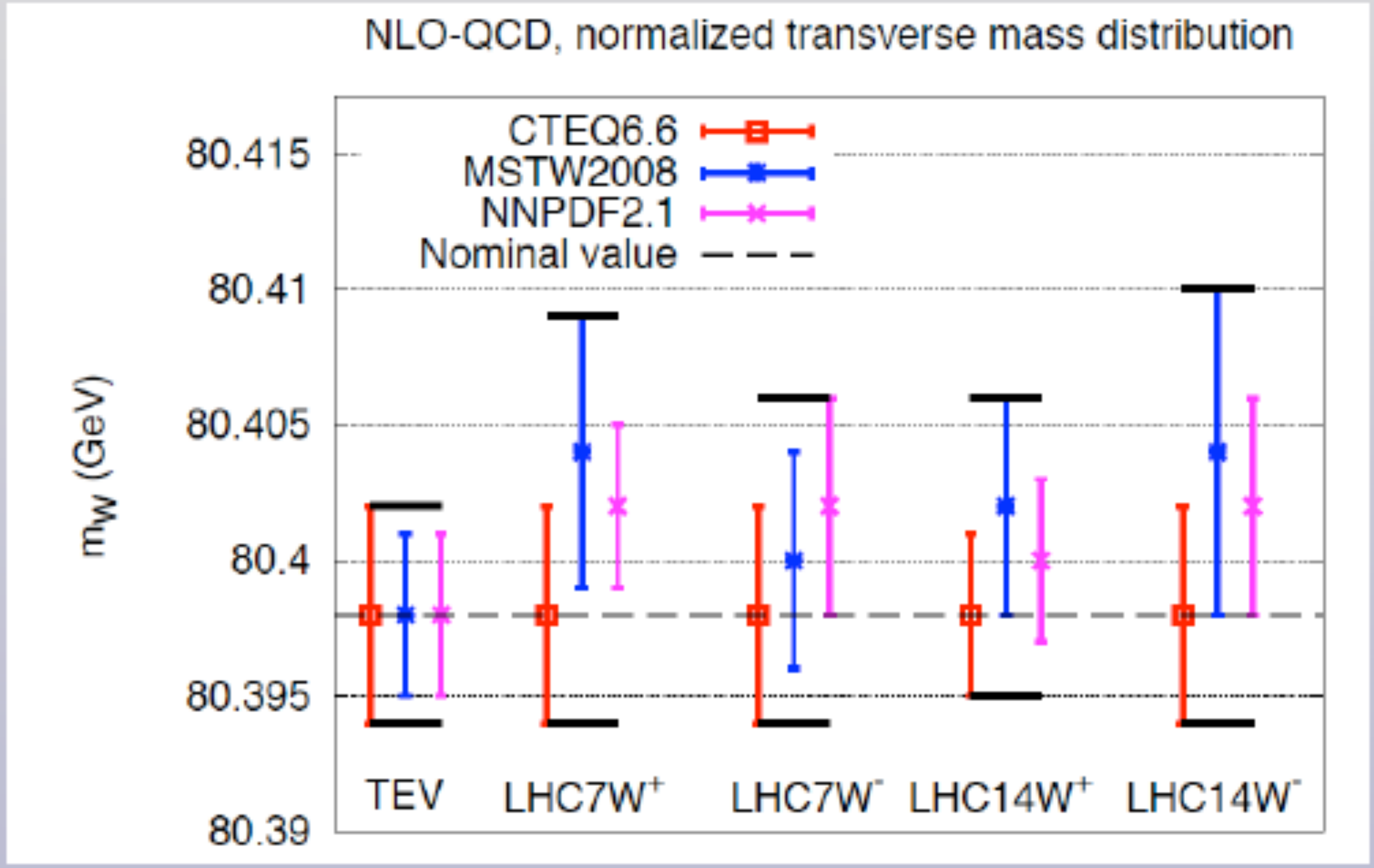


PDFs⇒Error on W mass measurements

J. Rojo

Bozzi, Rojo, Vicini, ***1104.7215****;* Bozzi, Ferrera, Vicini, in preparation

NB: only PDFs pre-LHC considered in this study



- To provide a conservative estimate of PDF errors, we use the **PDF4LHC prescription**: combine in envelope NNPDF, CT and MSTW
- We found that a **20 MeV** uncertainty at the LHC was a reasonable estimate. No huge increase of PDF errors from Tevatron to LHC as claimed in the literature
- Our study based on **parton level templates**, but checked that simple detector-like smearing did not modify our results qualitatively.
- Variations in α_S and in the **heavy quark masses** explicitly shown to be negligible

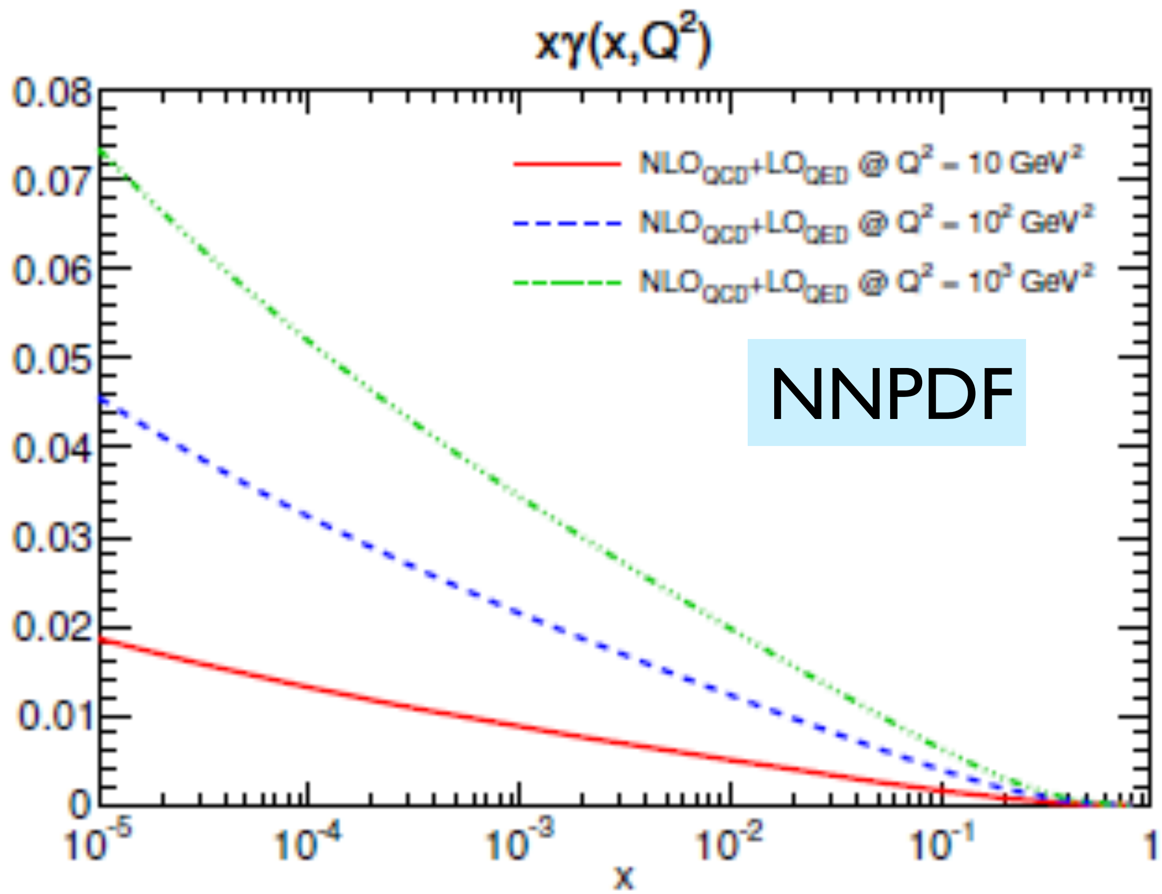
Photon PDFs ⇒ include γ as a new parton

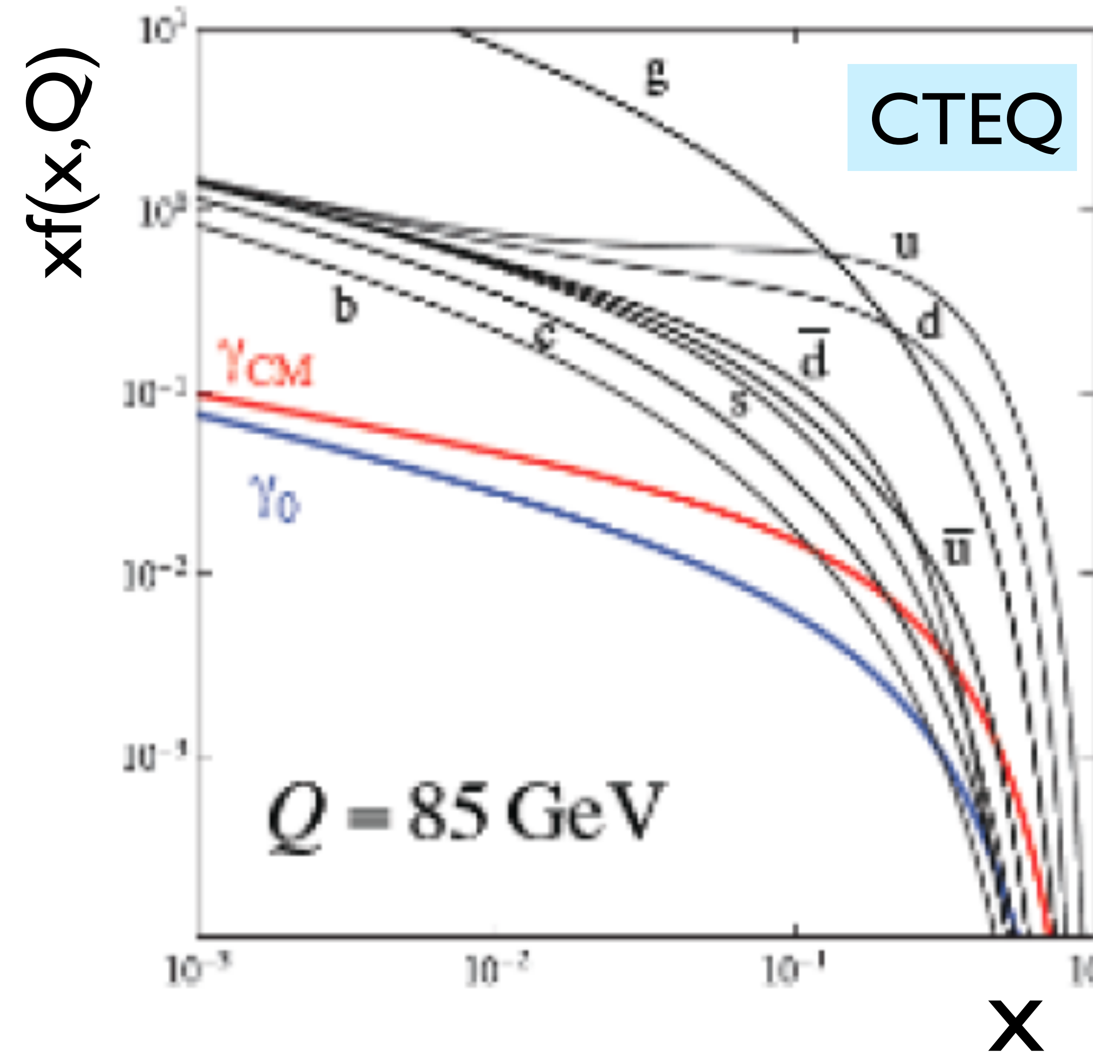
S. Carrazza

Important for EW precision physics (W mass measurements), require deep revisions in the PDF analysis

The only existing QCD+QED PDF set is MRST'2004 QED, not updated for detailed studies

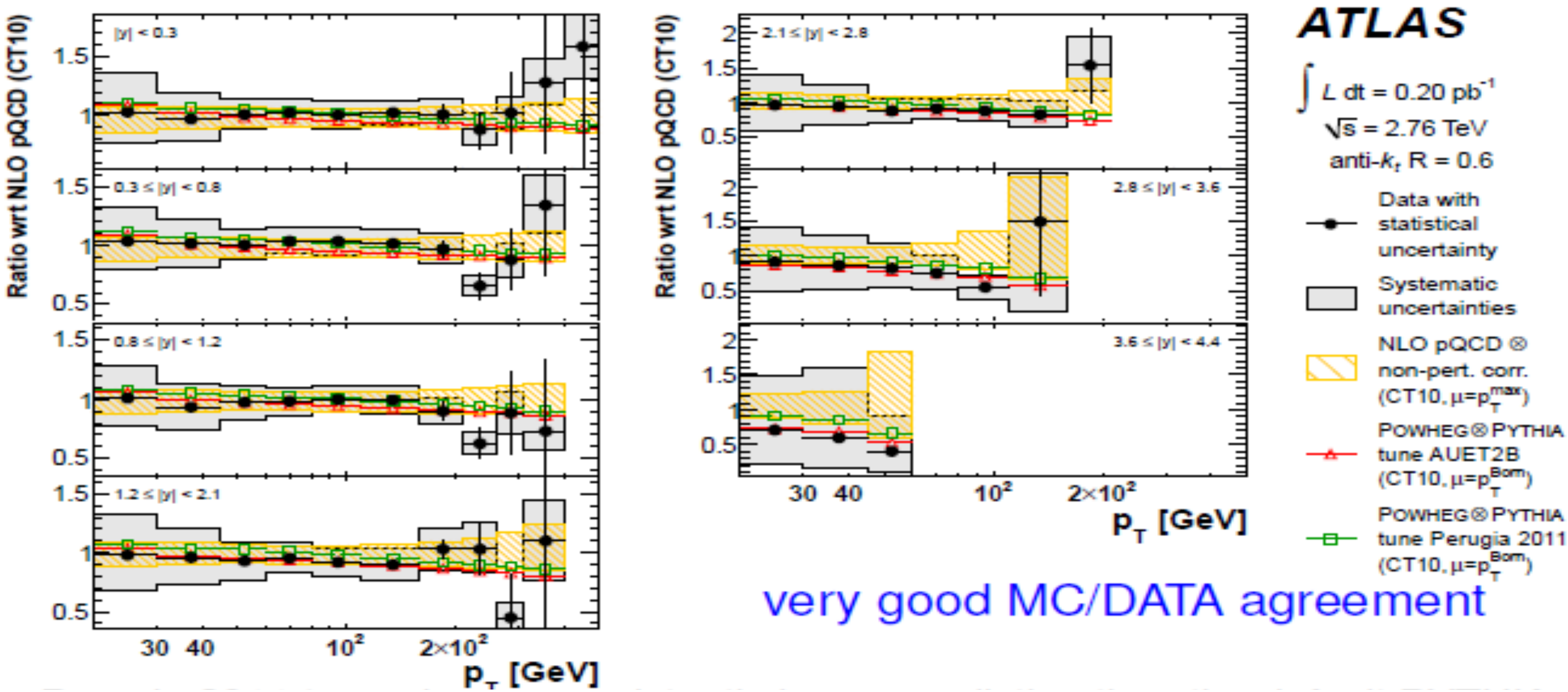
Preliminary NNLO QCD+LO QED PDFs presented by CTEQ and NNPDF groups, undergo validation





PDF analysis ⇒ experiment+theory:
NLO predictions for jet production

P. Starovoitov



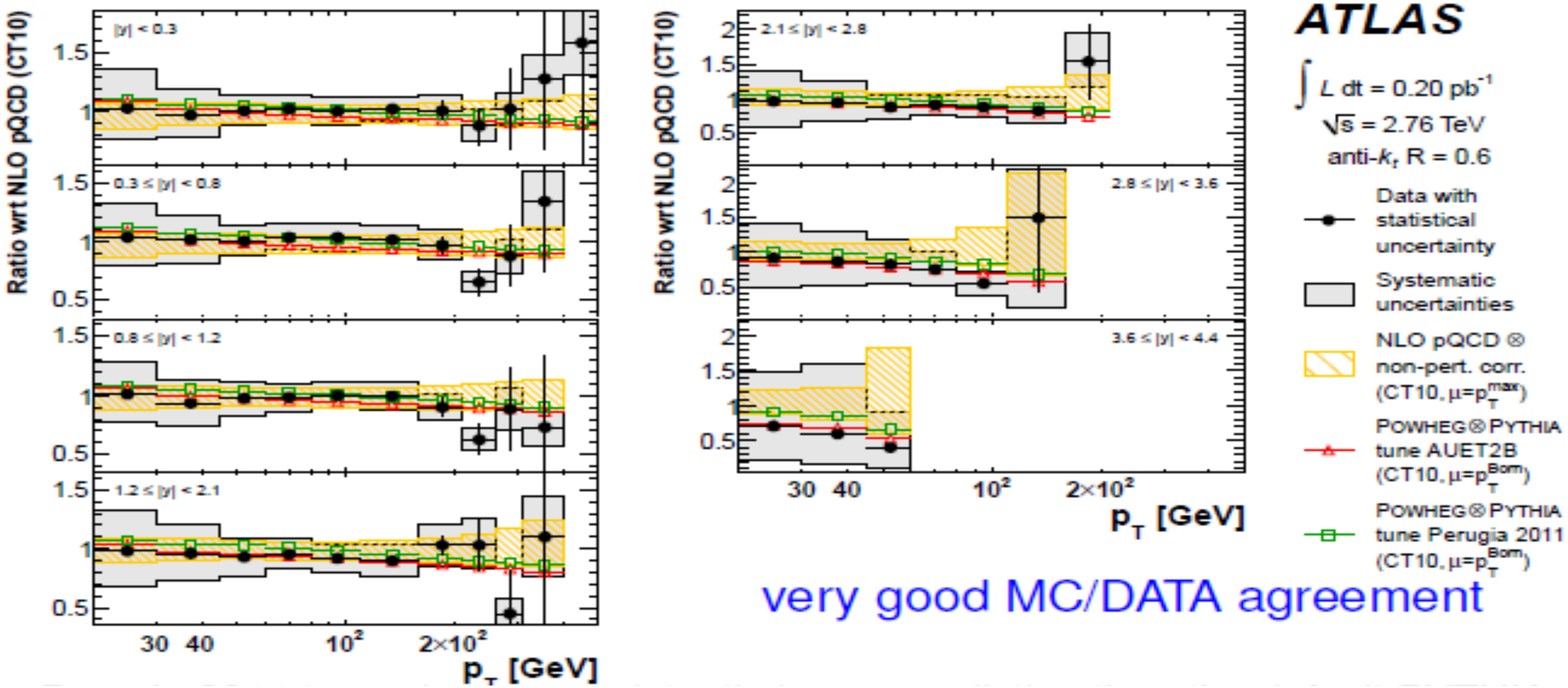
very good MC/DATA agreement

The need to have reliable predictions for LHC (di)jet production for PDF analysis inspired revisions/tuning of NLO theory calculations.

PDF analysis ⇒ experiment+theory:

NLO predictions for jet production

P. Starovoitov



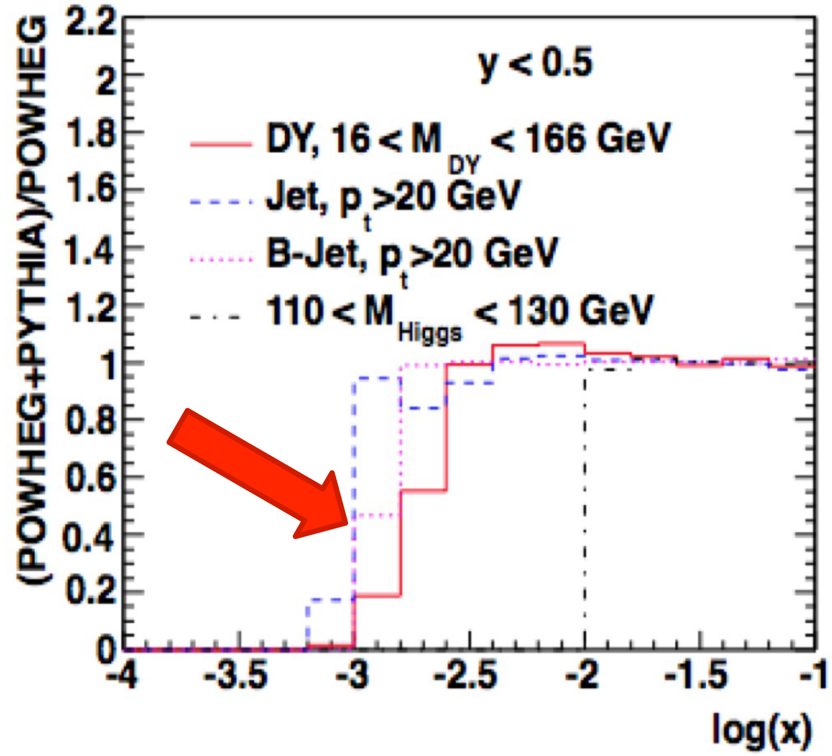
very good MC/DATA agreement

Through various tests, two available families of NLO codes (**NLOJet++/ApplGrid/FastNLO** and **MEKS**) **AND** NLO event generators (**MC@NLO** and **Powheg**) were brought into excellent agreement (non-trivial!)

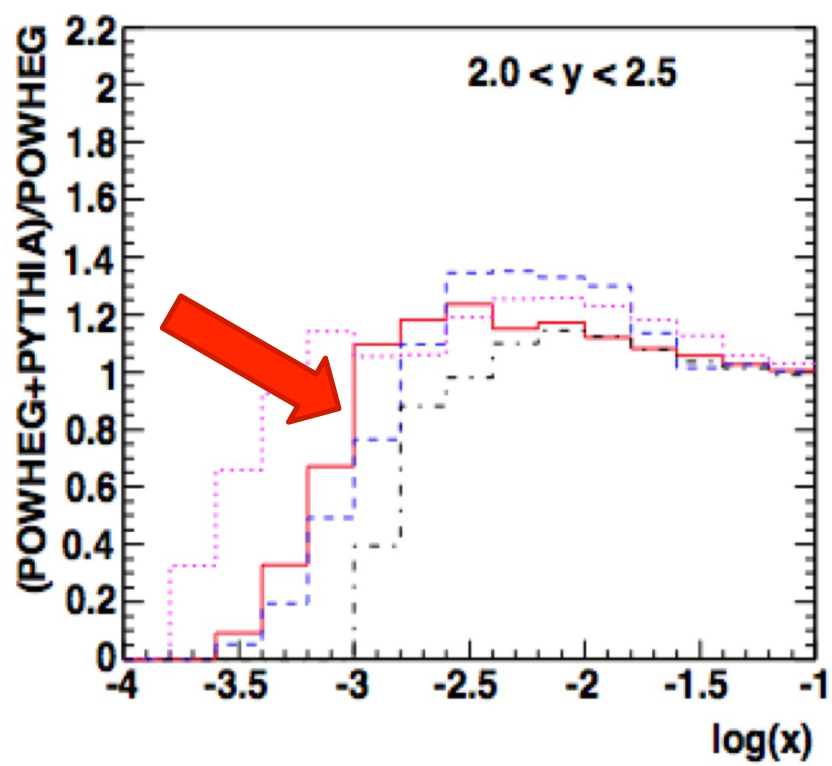
TMD Effects in pp

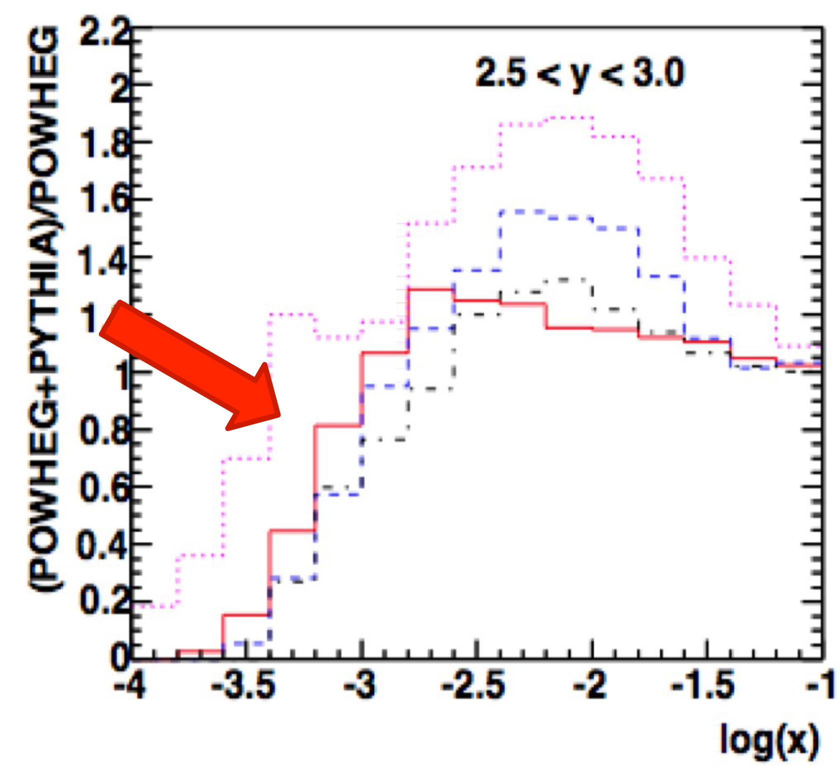
H. Jung
M. Hentschinski

- TMDs are relevant for many processes at LHC
- parton shower matched with NLO (POWHEG) generates additional k_t, leading to energy-momentum mismatch
- detailed discussion by S.Dooling: *Non-perturbative and Parton Shower corrections in matched NLO-shower event generators* n WG4 QCD and HFS

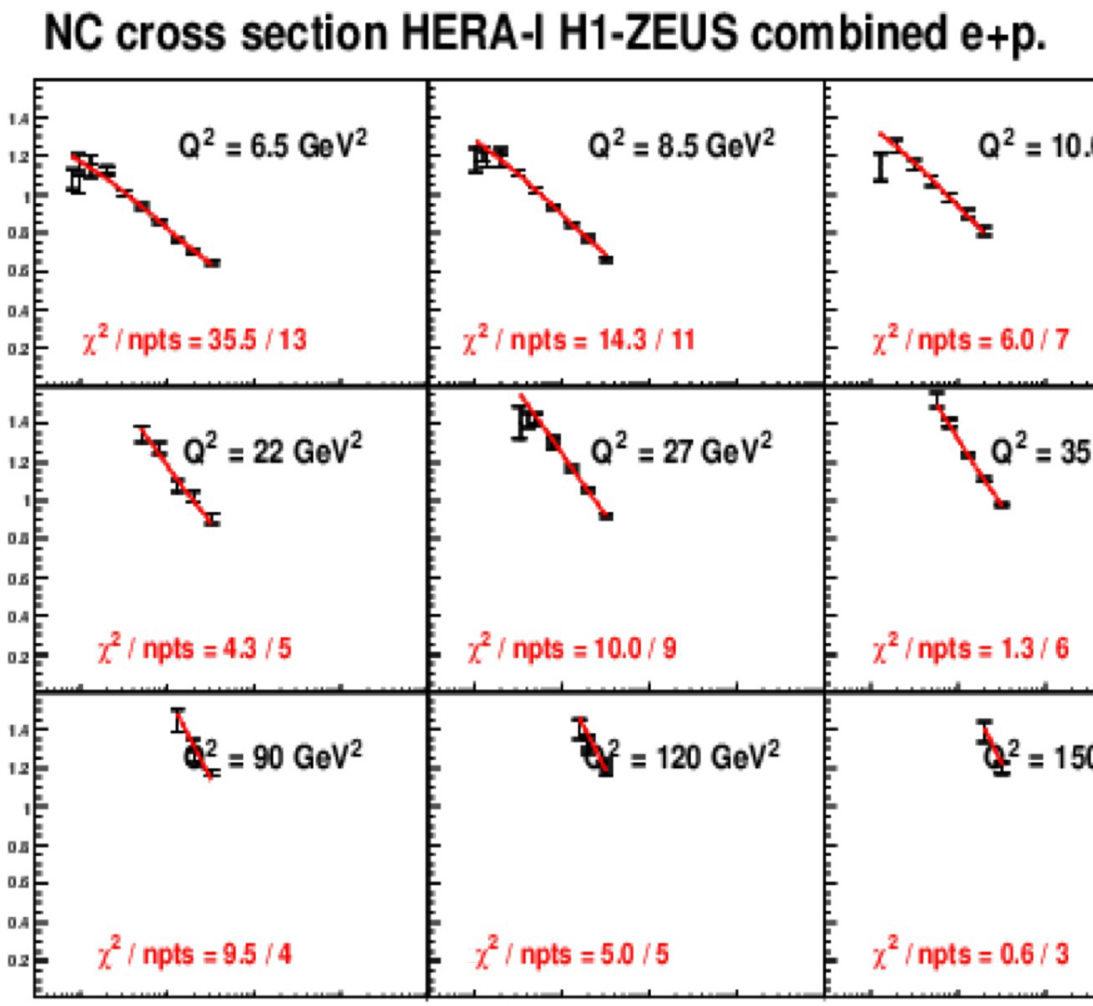


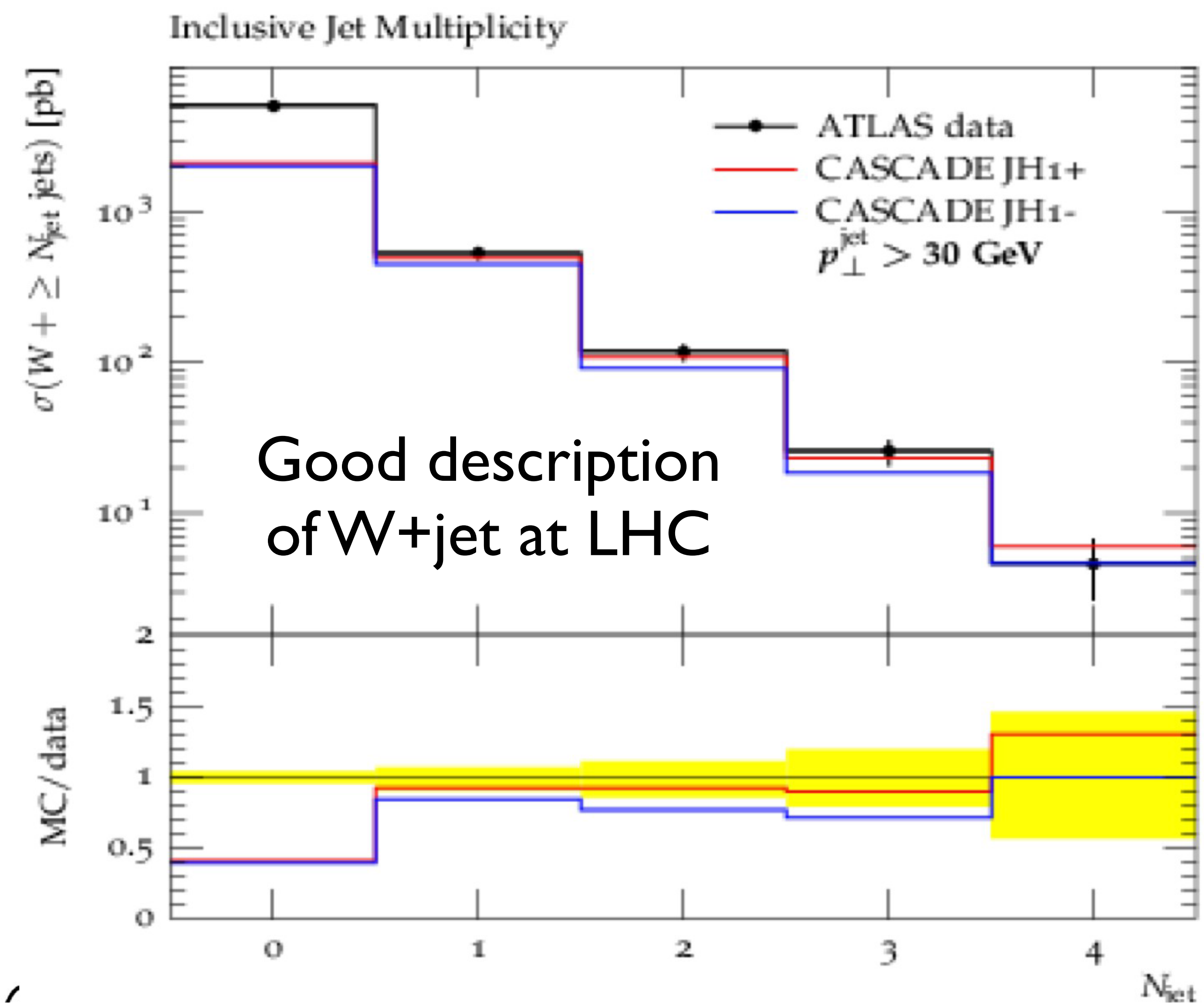
Parton showering generates particularly large k_t smearing at small x, which may be better handled by programs based small-x TMD PDFs





σ_r from HERA and small x improved gluon TMD





Good description of W+jet at LHC

- fit performed with `herafitter` p

$Q^2 > 5$ GeV, $x < 0.005$

➔ $\chi^2/ndf \sim 1.2$

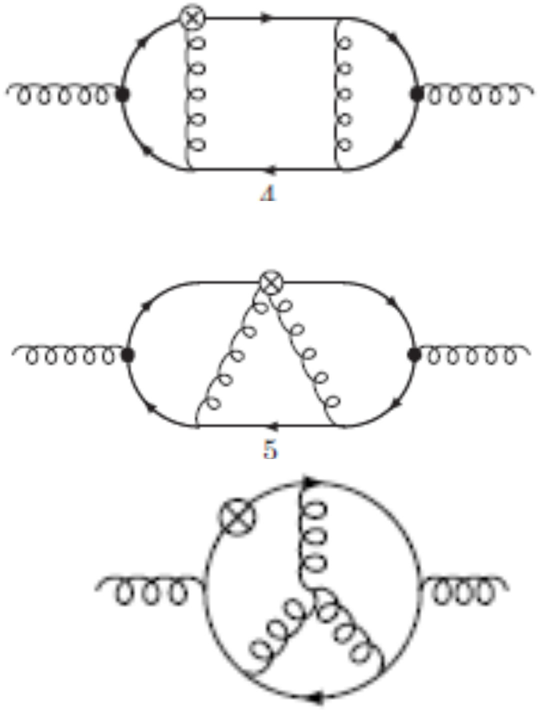
PDFs ⇒ theory: inspiration for new calculations

Since the CTEQ6.6 paper in 2008, several "nearly impossible" calculations were inspired to satisfy the needs of the PDF analysis:

- **NNLO $t\bar{t}$ total cross sections** (Baernreuther, Czakon, Mitov, 1204.5201; Czakon, Fiedler, Mitov, 1303.6254) -- completed, used in the PDF analysis!

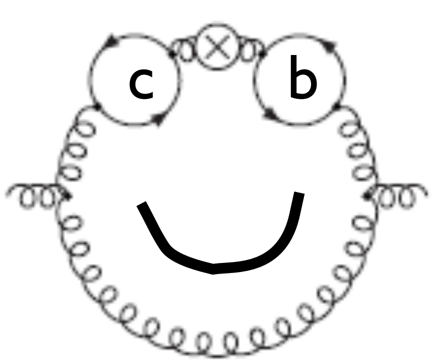
At full steam:

- **NNLO inclusive jet cross sections** (Gehrmann-De Ridder, Gehrmann, Glover, Pires, 1301.7310)
- **Three-loop heavy flavor Wilson coefficients in DIS** (**Bluemlein**, Ablinger, De Freitas, Hasselhuhn, von Manteuffel, Raab, Schneider, Round, Wissbrock)



A tour-de-force calculation; diagrams with two different masses (c, b); rich mathematical structure (hyperlogarithms, harmonic sums, Dodgson polynomials)

Both calculations are essential for improving accuracy of PDFs



PDF whishlist at the LHC

Traditional

- Inclusive jets and dijets, central and forward: large-x quarks and gluons
- Inclusive W and Z production and asymmetries: quark flavor separation, strangeness

Relevant for M_W

New @ LHC

- Isolated photons, photons+jets: medium-x gluons
- W production with charm quarks: direct handle on strangeness
- W and Z production at high p_T: medium and small-x gluon
- Off resonance Drell-Yan and W production at high mass: quarks at large-x
- Low mass Drell-Yan production: small-x gluon
- Top quark cross-sections and differential distributions: large-x gluon

Relevant for M_W

Relevant for M_W

Relevant for M_W

Speculative

- Z+charm: intrinsic charm PDF
- Single top production: gluon and bottom PDFs
- Charmonium production: small-x gluon
- Open heavy quark production: gluon and intrinsic heavy flavor

Relevant for M_W

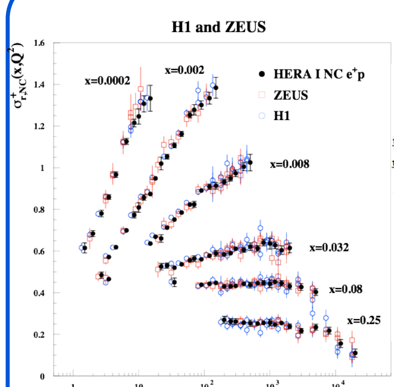
J. Rojo

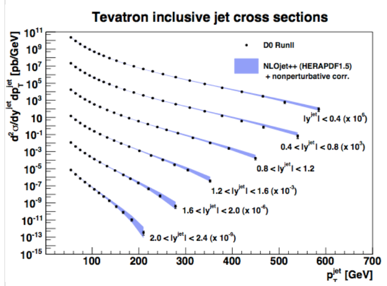
Benchmarking tools: HERAFitter

Developed at HERA, extended to LHC and theory groups

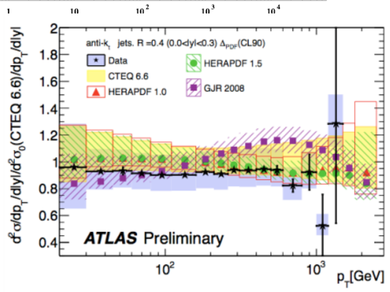
Study the impact of different data on PDFs and test different theory approaches

experimental input





experiments:
HERA, Tevatron, LHC, fixed target



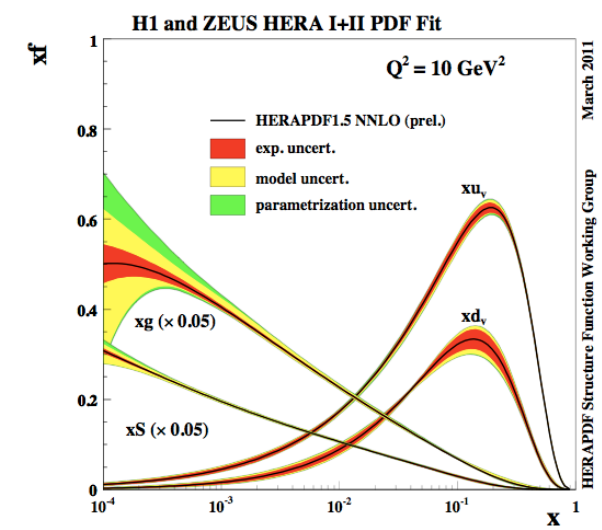
processes:
NC, CC DIS, jets, diffraction, heavy quarks (c,b,t)
Drell-Yan, W production

theoretical calculations/tools

Heavy quark schemes:	MSTW, CTEQ, ABM
Jets, W, Z production:	fastNLO, Applgrid
Top production	NNLO (Hathor)
QCD Evolution	DGLAP (QCDNUM)
	k_T factorisation
Alternative tools	NNPDF reweighting
Other models	Dipole model

+ Different error treatment models
+ Tools for data combination (HERAaverager)

HERAFitter



PDF or DPDF,...

$\alpha_S(M_Z), m_c, m_b, m_t, f_s, ..$

Theory predictions

Benchmarking

Comparison of schemes

Open source code, available at https://www.herafitter.org/HERAFitter

Version 0.3.0 released in March 2013.

R. Placakyte

We thank all the speakers! Merci!

Stanislav SHUSHKEVICH
Inclusive Deep Inelastic Scattering at High Q2 with Longitudinally Polarised Lepton Beams at HERA and Determination of the Integrated Luminosity at HERA using Elastic QED Compton Events
Ian BROCK
Measurement of high-Q2 neutral current deep inelastic e+p scattering cross sections with a longitudinally polarised positron beam at HERA
Sergey ALEKHIN
ABM PDFs updated
Alberto ACCARDI
The CJ12 parton distributions
Pavel NADOLSKY
Developments in CTEQ-TEA analysis
Robert THORNE
Developments Related to MSTW PDFs
Nathan HARTLAND
Parton Distributions with LHC data
Ringaile PLACAKYTE
HERAFitter - an open source QCD fit framework
Pavel STAROVOITOV
Inclusive jet production measured with ATLAS, and constraints on PDFs
Benjamin WATT
The Effect of Recent Jet Results on MSTW PDFs
Ms. Claudia BERTELLA
Top quark production cross section in ATLAS
Jan KIESELER
Top Quark Pair Cross Section Measurements at CMS
Marco GUZZI
Top quark production at the LHC: differential cross section and phenomenological perspectives
Juan ROJO CHACON
Constraints on the gluon PDF from top quark pair production at hadron colliders
Jacques SOFFER
Theoretical foundations of the quantum statistical approach to parton distributions and recent results

Dr. Hannu PAUKKUNEN
- Neutrino-nucleus DIS data and their consistency with nuclear PDFs
- Nuclear PDFs from the LHeC perspective
Karol KOVARIK
The nCTEQ PDFs
Barbara BADELEK
Investigating the Nucleon Structure at COMPASS
Aleko KHUKHUNAISHVILI
W and Z boson production at CMS
Katalin NIKOLICS
Measurement of the Neutral Current DY process with the ATLAS detector
Stefano CARRAZZA
Electroweak corrections to Parton distributions
Juan ROJO CHACON
The Impact of PDF uncertainties on the measurement of the W boson mass at the Tevatron and the LHC
Stephane TOURNEUR
Electroweak boson production at LHCb
Martin HENTSCHINSKI
- TMD quark distributions at small x
- Proton structure functions and physical evolution kernels
Hannes JUNG
Determination of TMDs with HERA data
Henri Paul KOWALSKI
BFKL Evolution as a Communicator Between Small and Large Energy Scales
Cynthia KEPPEL
Neutron Structure at Large x
Harold E JACKSON JR
Re-evaluation of the Parton Distributions of Strangeness in the nucleon
Eric VOUTIER
Helium Compton Form Factor Measurements at CLAS

Eliezer PIASETZKY/Rolf ENT
The EMC Effect and Short-Range Correlations
Eleni VRYONIDOU
Charm production in association with an electroweak gauge boson at the LHC
Alexander HUSS
Weak radiative corrections to dijet production at hadron colliders
Clemens LANGE
Measurement of V+heavy flavour production at ATLAS
Bernd SURROW
Recent STAR results on the W boson program at RHIC at BNL
Achim GEISER
Combination and QCD Analysis of Charm Production Cross Section Measurements in Deep-Inelastic ep Scattering at HERA *Sergey ALEKHIN*
Heavy-quark production in deep-inelastic scattering
*Aleksander KUSINA***Impact of scheme dependence in PDFs on measurable quantities**
Oleksandr ZENAIEV
Measurement of D+ production in Deep Inelastic ep Scattering with the ZEUS detector at
*Olena BACHYNSKA et al.***Measurement of charm production in DIS with D* mesons and extraction of F2cc**
Johannes BLUEMLEIN
3-Loop Heavy Flavor Corrections to Deep-Inelastic Scattering
Marco GUZZI
Charm quark mass dependence in CTEQ NNLO global analysis
Tzvetalina STAVREVA
Probing the intrinsic heavy quark content of the nucleon through direct photon plus heavy quark production