PDF Measurement at LHC

Chiara La Licata
on behalf of the ATLAS, CMS and LHCb Collaboration

Università degli Studi e Sezione INFN di Trieste

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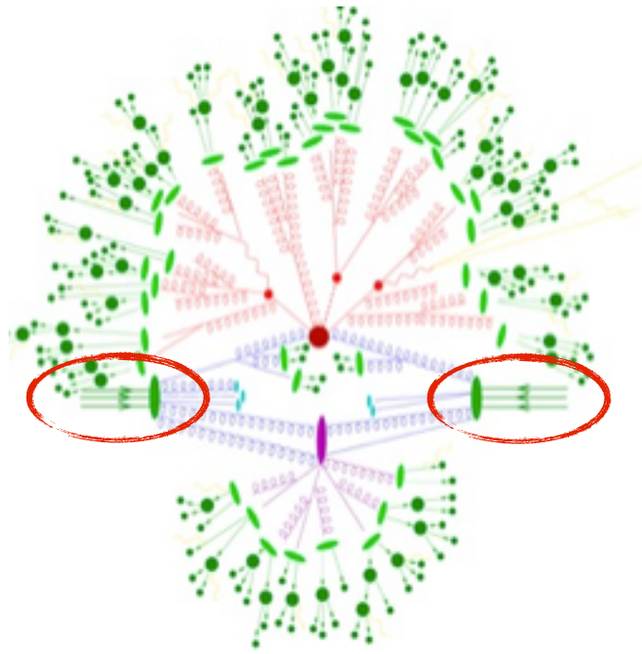
Introduction

• key ingredient to make theoretical predictions at hadron colliders is the parton distribution functions (PDF) of the proton



• for each process under study in a hadron collider the initial state, and so the PDFs, have to be known

• knowledge of the PDFs can be improved using results from LHC measurements

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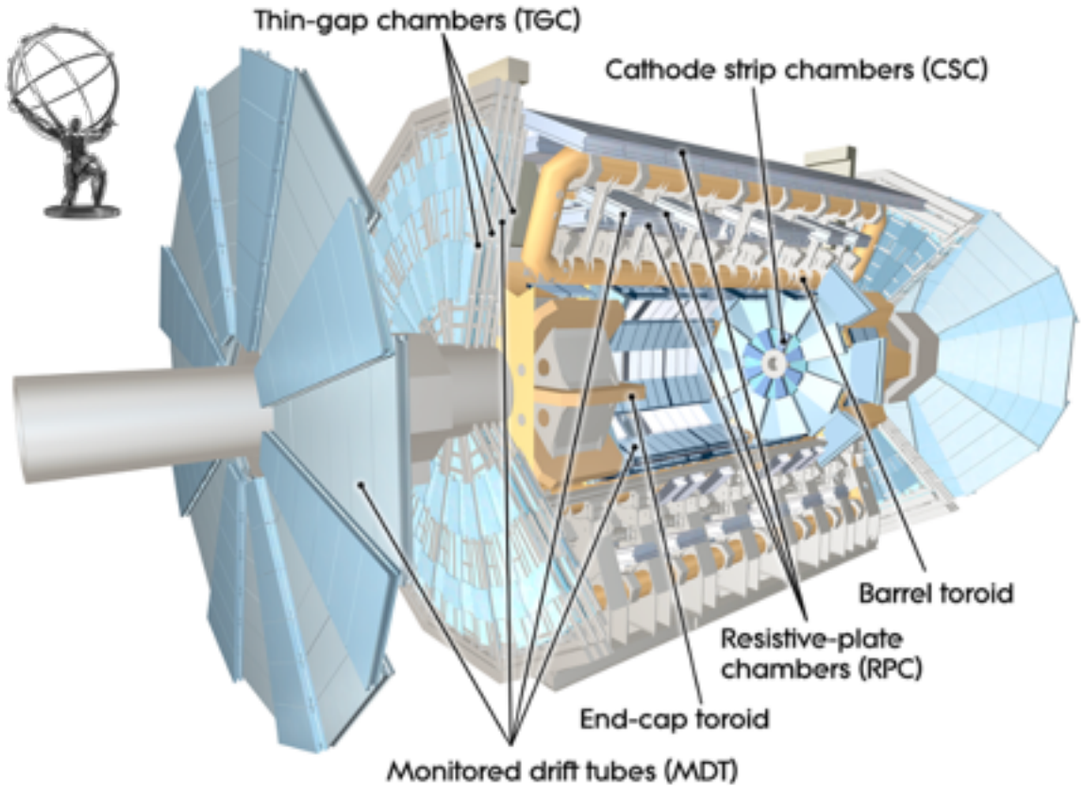
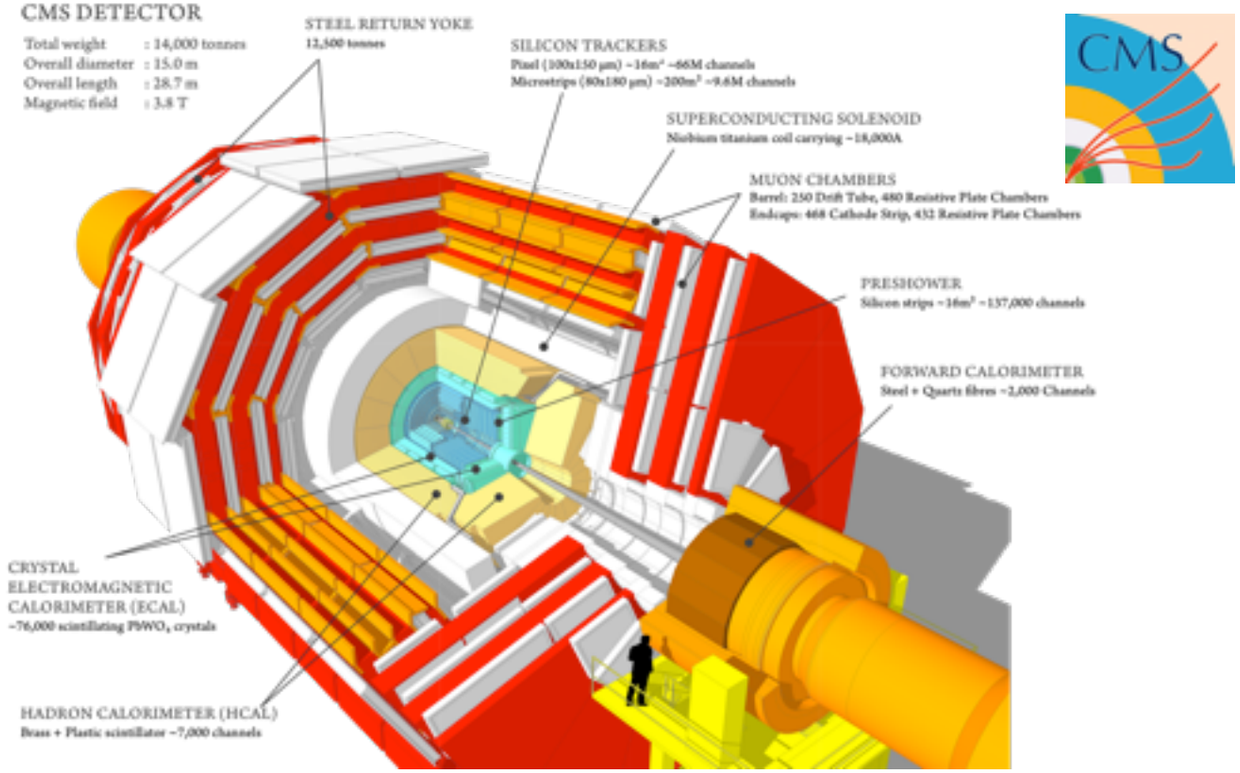
In this talk different results from ATLAS, CMS and LHCb are presented. They allow us to constrain the proton PDFs

- jet production (ATLAS, CMS)
- lepton charge asymmetry in W deacy (ATLAS, CMS)
- associated production of W boson and c-quark (ATLAS, CMS)
- isolated photon production (ATLAS)
- Z+jet production (LHCb)

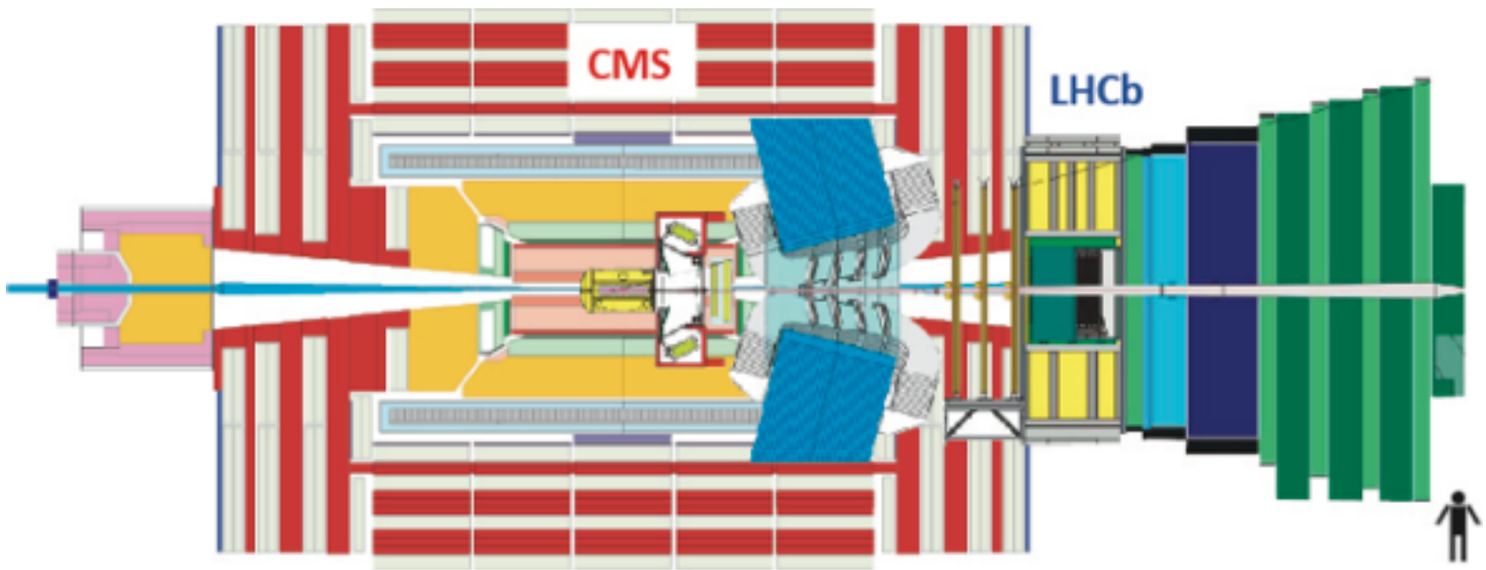
Detectors



ATLAS



CMS

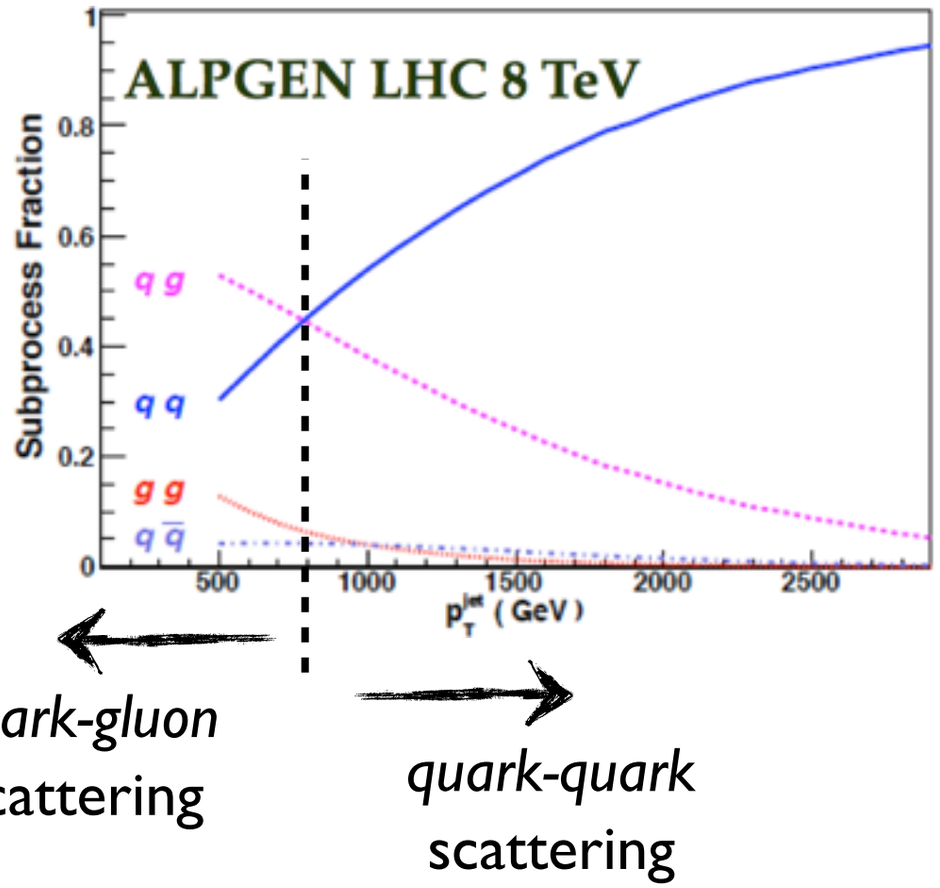


LHCb

Jet Production

Jet cross section provides precise information about the structure of the proton

• at LHC multijet production is the dominant high transverse momentum process



quark-gluon scattering

quark-quark scattering

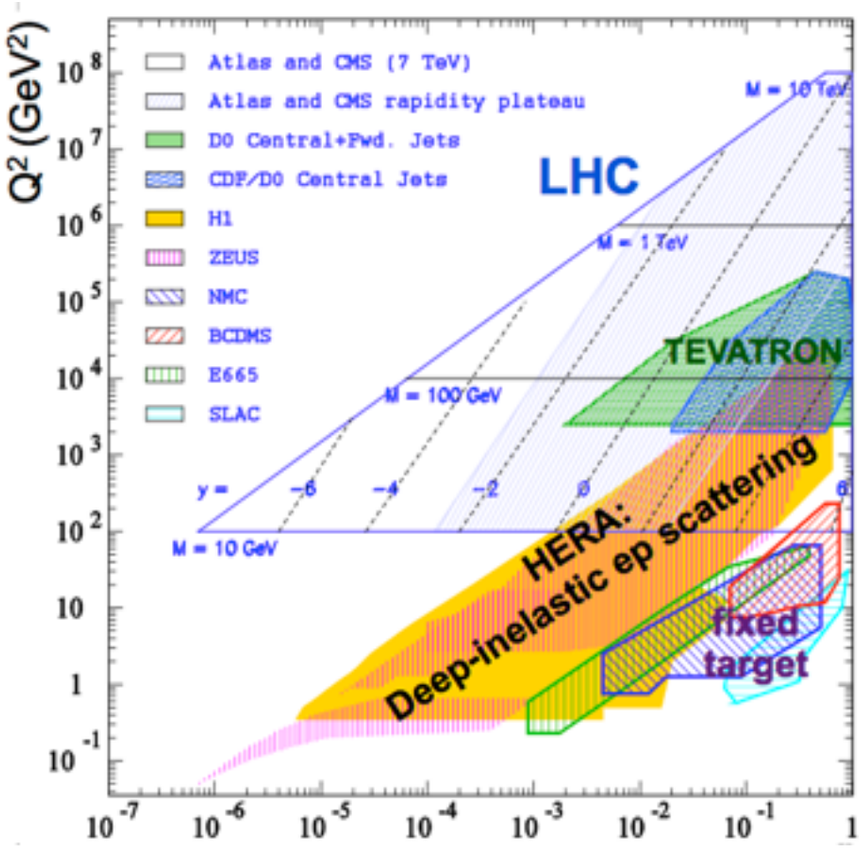
• for pT < 800 GeV, quark-gluon scattering is the dominant

→ jet production sensitive to the gluon

• for pT > 800 GeV, quark-quark scattering is the dominant

→ jet production sensitive to the quark

• LHC jet data provide constraints in high-x region and probe QCD at high scales



ATLAS analysis

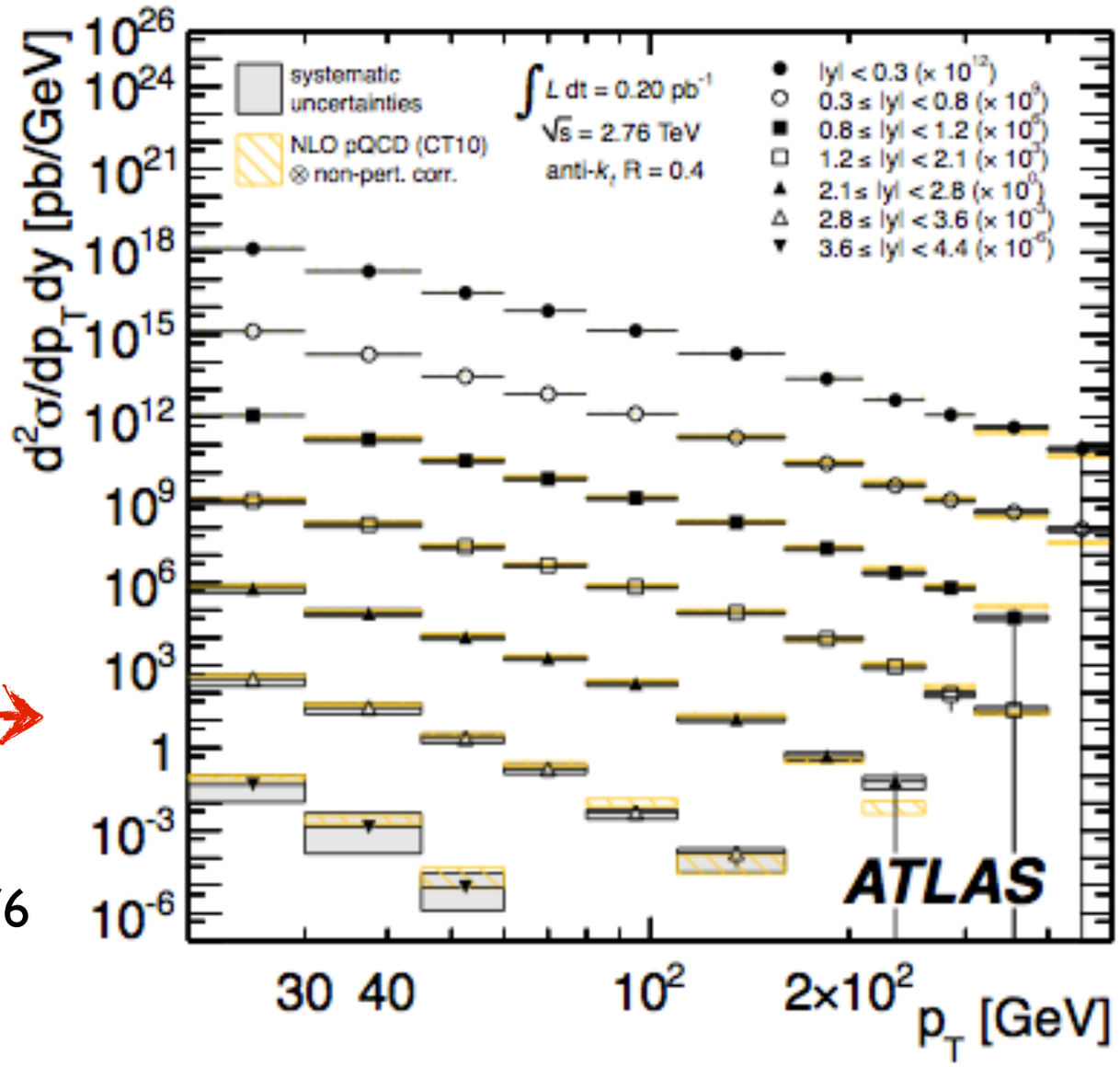
➤ EPJC ***(2013) 73 2509***

measurement of the inclusive jet double-differential cross section as function of transverse momentum pT in bins of jet rapidity at $\sqrt{s}$ =2.76 TeV (0.20 pb^{-1})

- jet clustering → anti-k_T with R = 0.4 R=0.6

kinematic range of the measurement

- 20 GeV < p_T < 430 GeV
- |y| < 4.4



Data are found to be generally well described by NLO pQCD calculations, corrected for non-perturbative effects from hadronisation and the underlying event

- Ratio of the inclusive jet cross-section at $\sqrt{s}$ =2.76 TeV and $\sqrt{s}$ =7 TeV performed

Taking into account the correlation of the sources of common uncertainties a reduction of the systematic uncertainties in the ratio measurement is obtained

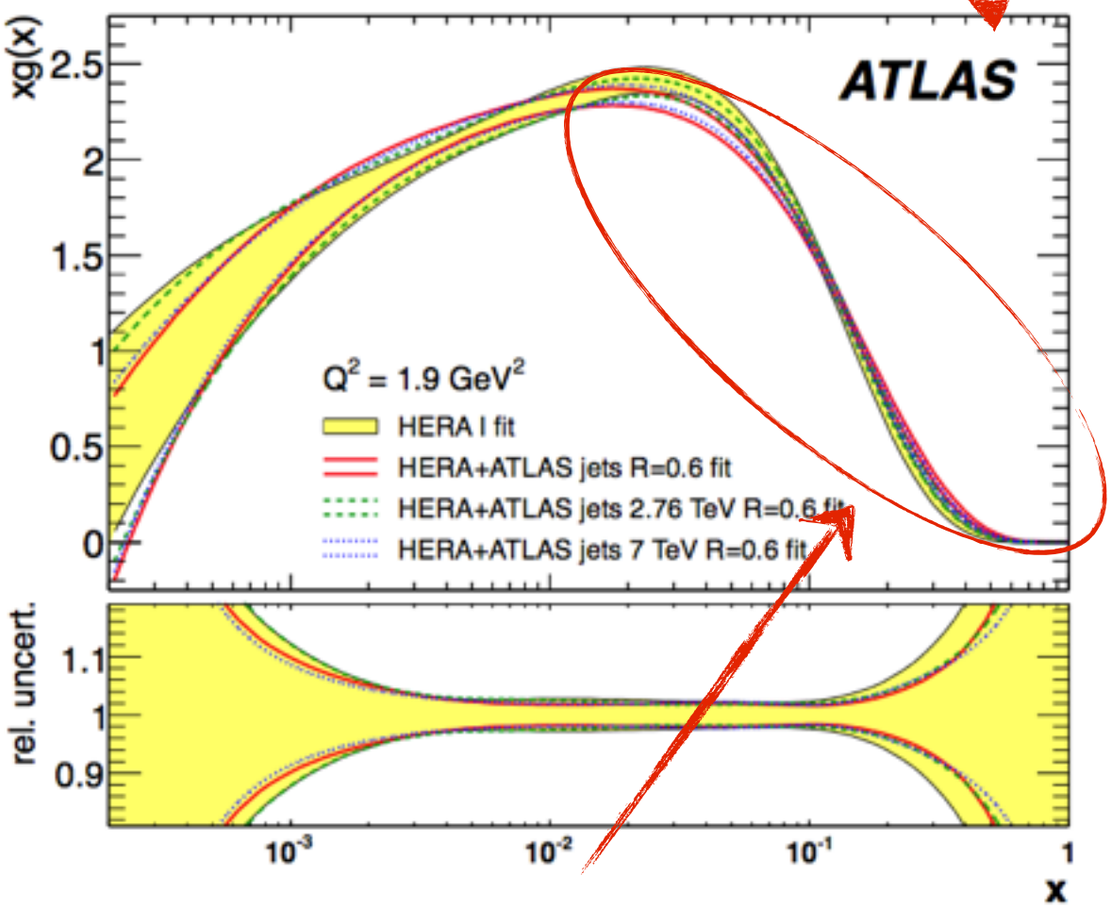
Taking into account the correlations of the systematic uncertainties jet cross section at $\sqrt{s}$ =2.76 TeV may contribute to constraint the PDF uncertainties in a global PDF fit

PDF constraints

A combined NLO pQCD analysis of the inclusive jet cross-section at $\sqrt{s}$ = 2.76 TeV together with the inclusive cross-section at $\sqrt{s}$ = 7 TeV and HERA I data has been performed

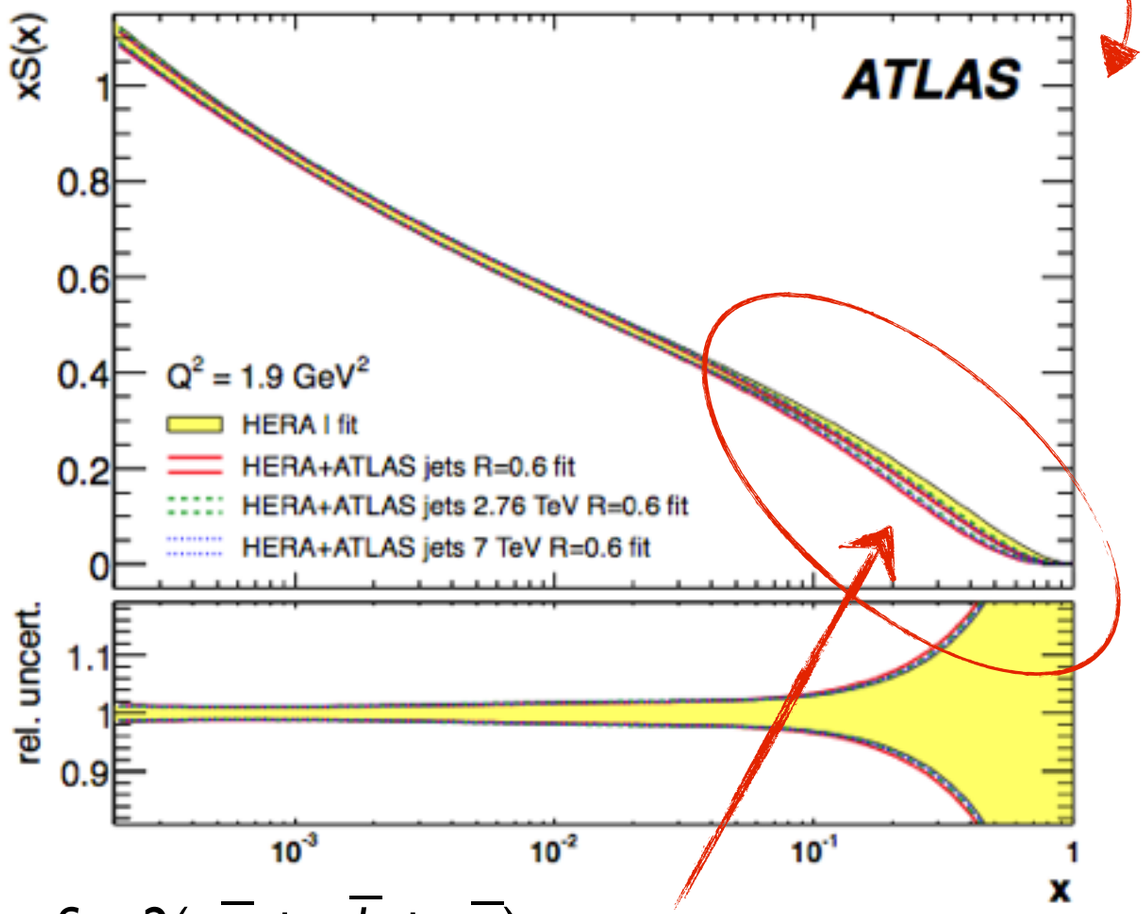
- analysis performed using the HERAFitter package

momentum distribution of the gluon *xg* at the scale Q^2 = 1.9 GeV^2



the uncertainty in *xg* is reduced including the ATLAS jet data in the fit

momentum distribution of the sea quarks at the scale Q^2 = 1.9 GeV^2



$xS = 2(x\bar{u} + x\bar{d} + x\bar{s})$

softer sea-quark distribution in the high Bjorken-*x* region are obtained with respect to the fit of HERA data only

CMS analysis

- Event selection

  - at least one reconstructed vertex

  - at least two particles (one charge hadron) in the jet

- Jet reconstruction

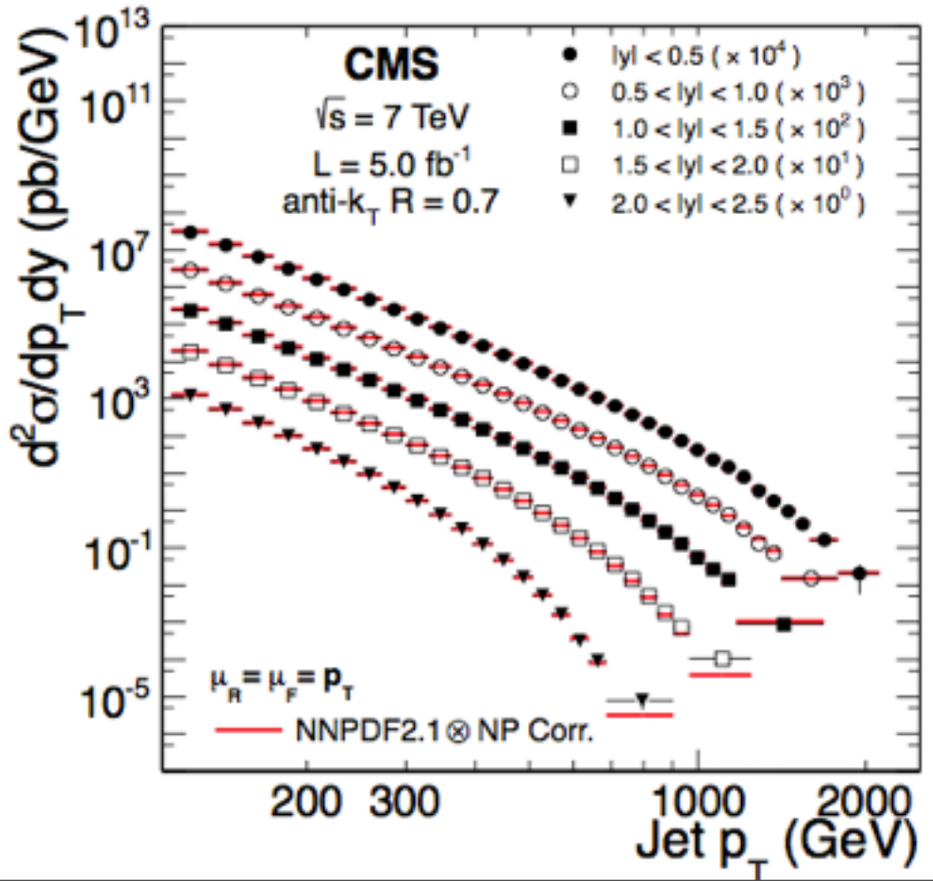
  - clustering ➜ anti-k_T with R = 0.7

  - corrected for pile-up, not uniformity of the response of the detector in η and p_T

- data unfolded for theoretical comparison

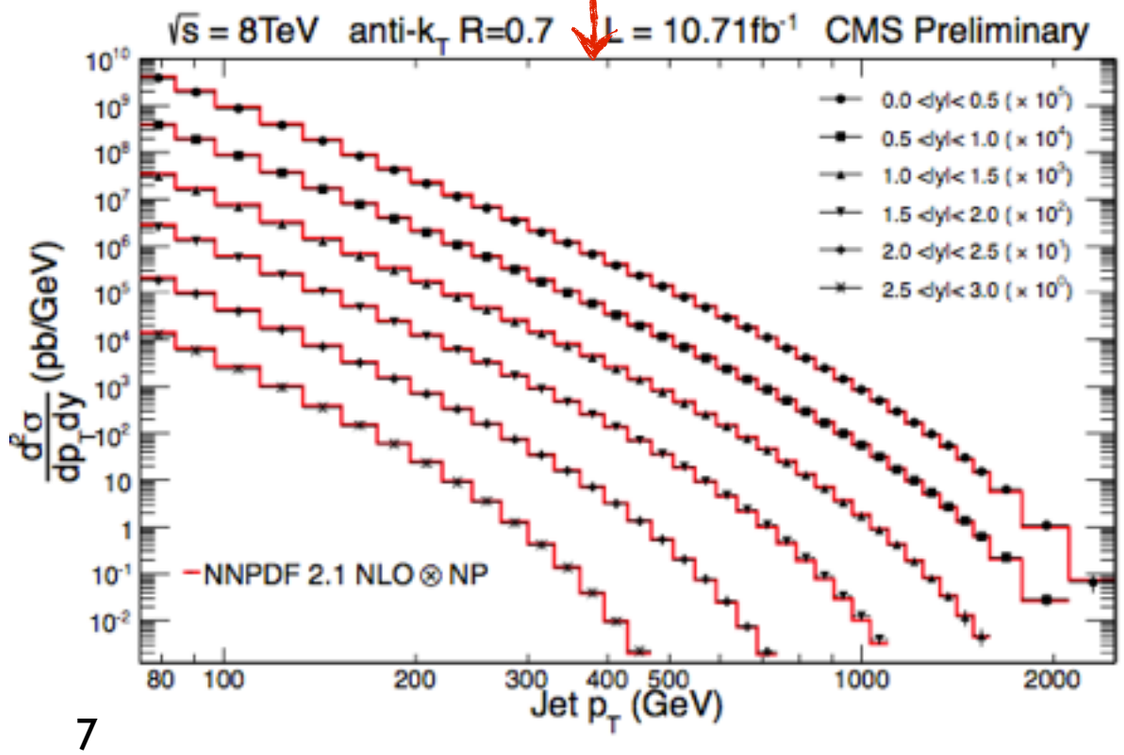
7 TeV (5.0 fb^{-1}) ➤ ***Phys. Lett. B 718 (2013) 752***

comparison with theoretical prediction corrected for NP effects performed using NNPDF2.1 PDF



➤ SMP-12-012 8 TeV (10.71 fb^{-1})

theoretical prediction performed using 5 sets of PDF:
CT10, MSTW2008, NNPDF2.1, HERAPDF1.5, ABM11

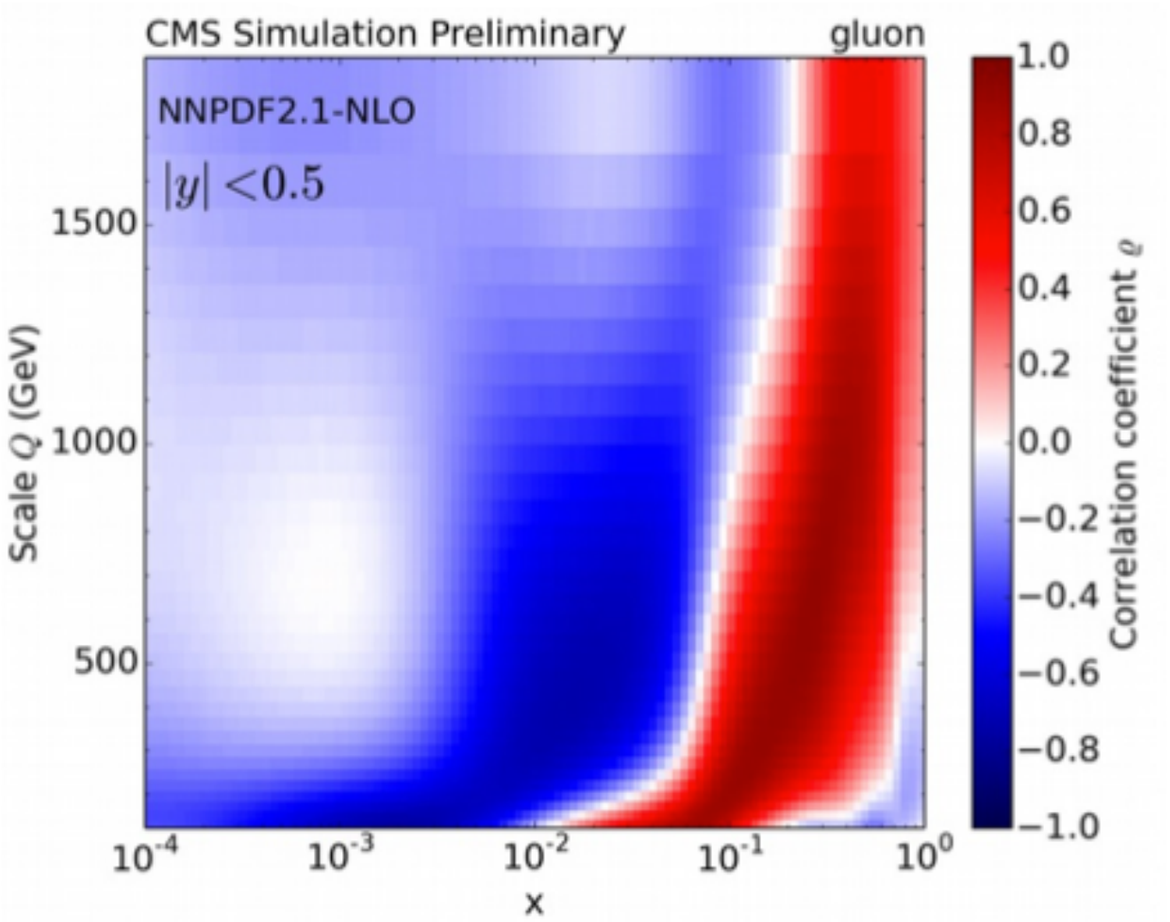


PDF constraints

➤ ***CMS-PAS-SMP-12-028***

the impact of the measurement of the double differential inclusive jet cross section on PDFs constraints is studied using results based on data collected at 7 TeV in CMS experiment

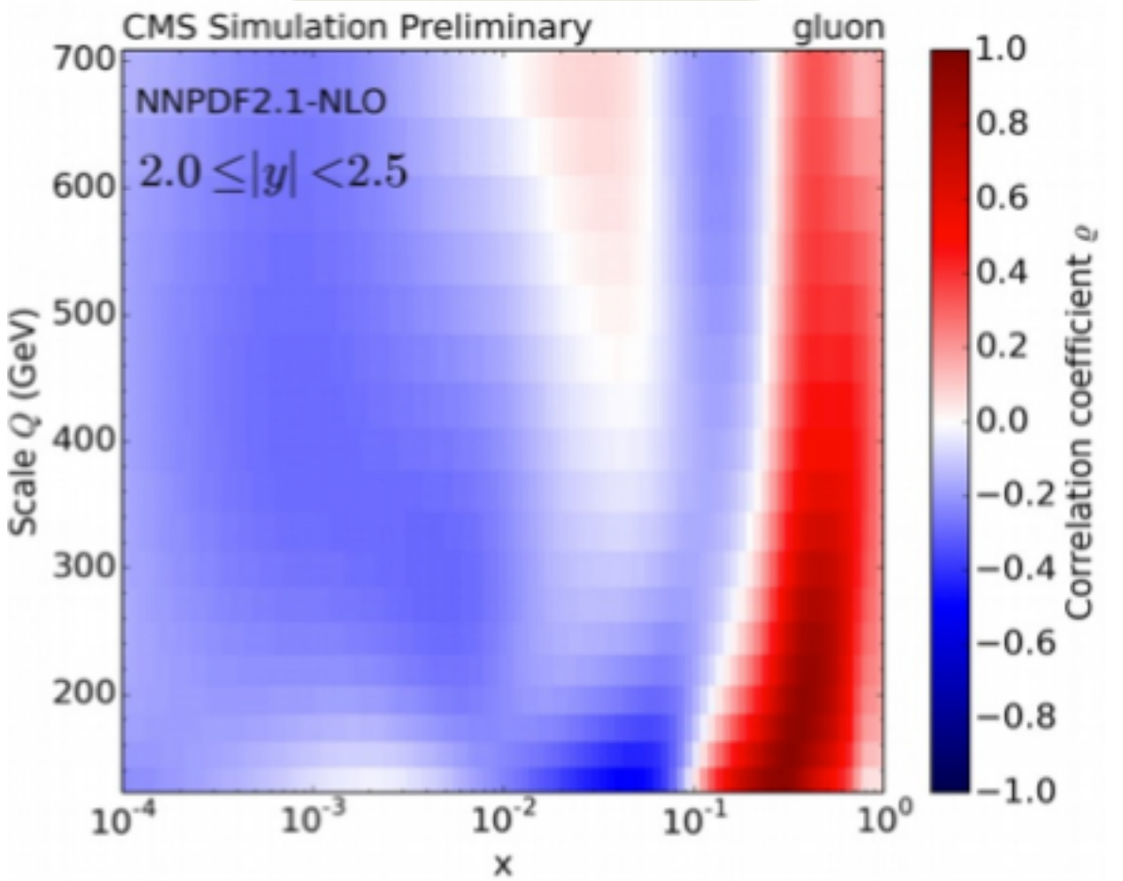
- inclusive jet cross section contains additional information respect to DIP data from HERA
- constraint for the gluon PDF in the region of high fractions x



central region ➜ high correlation for all jet transverse momenta

forward region ➜ high correlation for Q < 300GeV

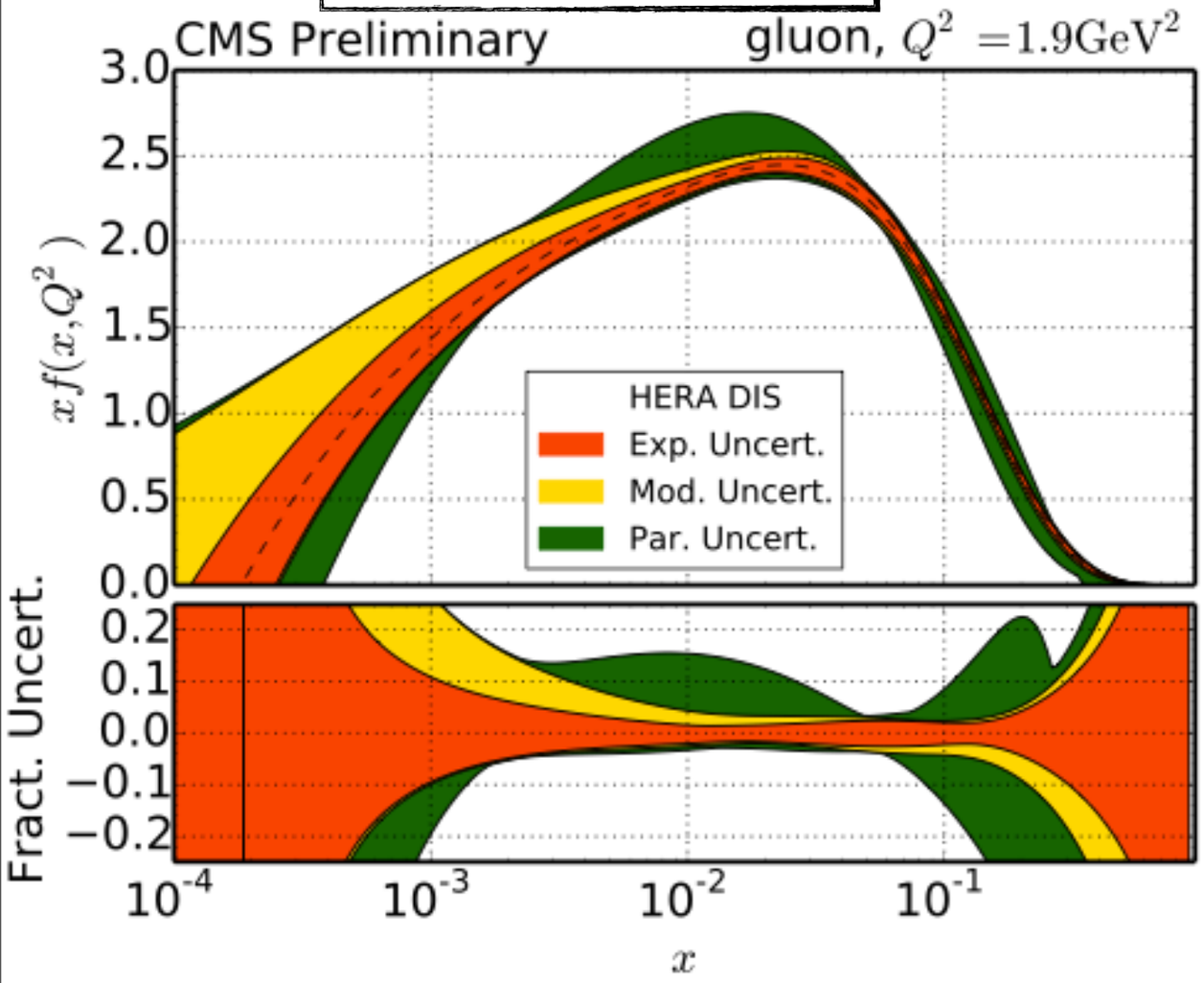
correlation between inclusive jet cross section and gluon PDF



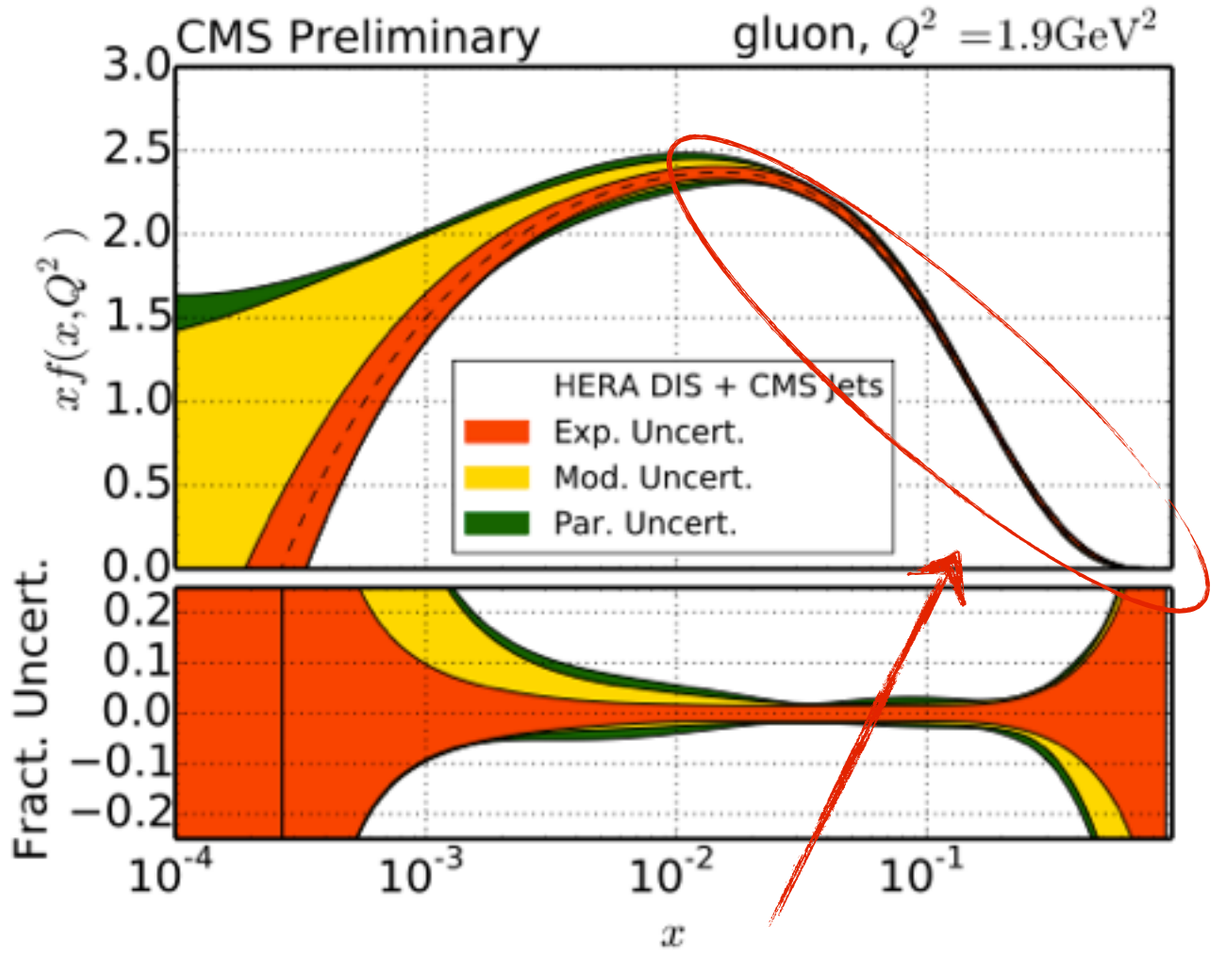
PDF constraints

• fitting framework used to derive PDFs from data ➜ HERAFitter
here employed to estimate the impact of the CMS inclusive jet data on PDFs

HERA inclusive DIS



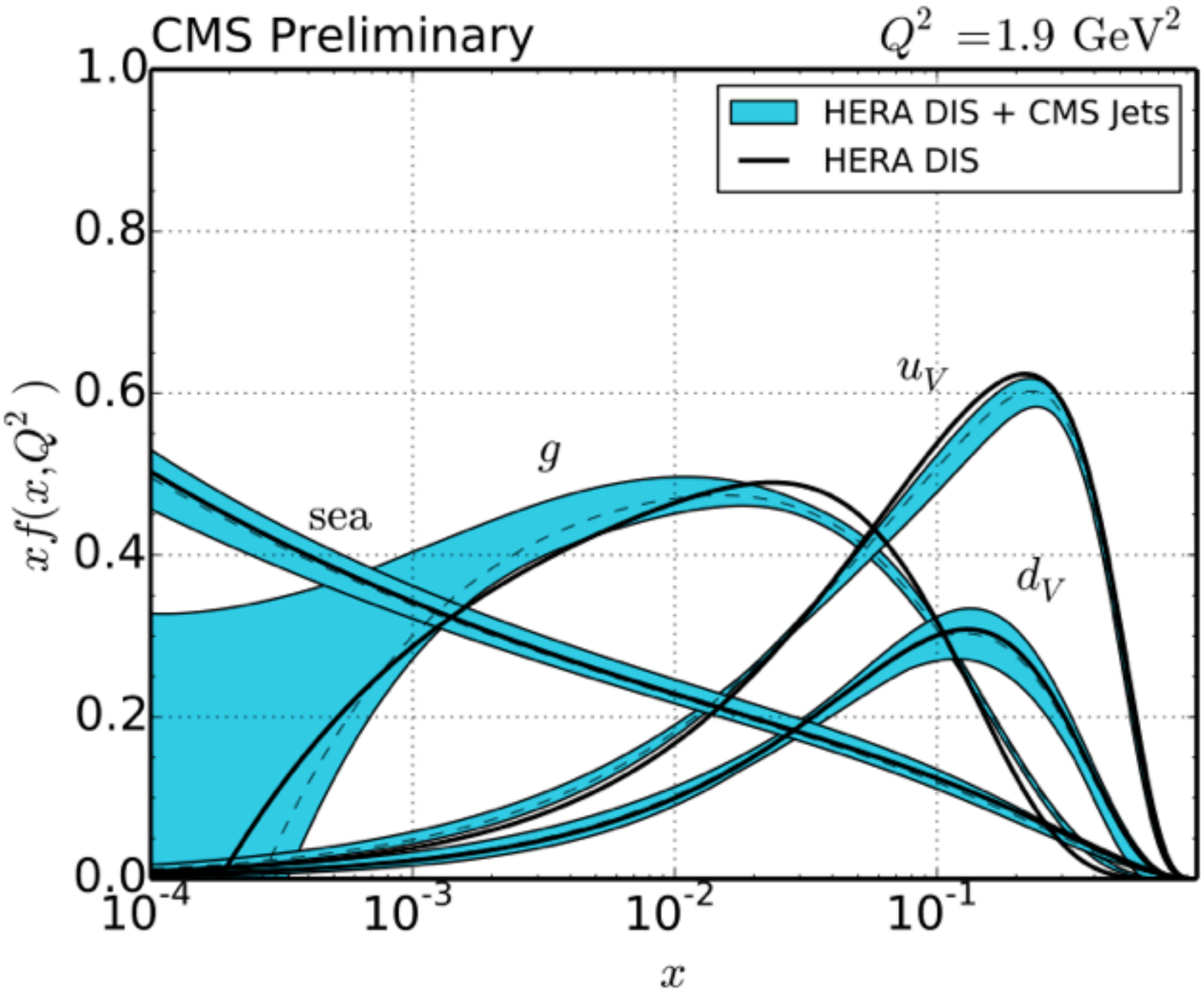
HERA inclusive DIS + CMS data



significant improvement of precision in the high-x region (x>0.01)

PDF constraints

- fitting framework used to derive PDFs from data ➜ HERAFitter
  here employed to estimate the impact of the CMS inclusive jet data on PDFs



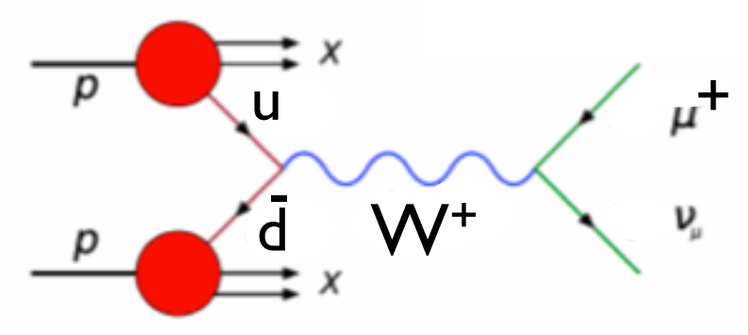
overview of the gluon , sea, u valence and d valence distributions at Q^2 = 1.9 GeV^2

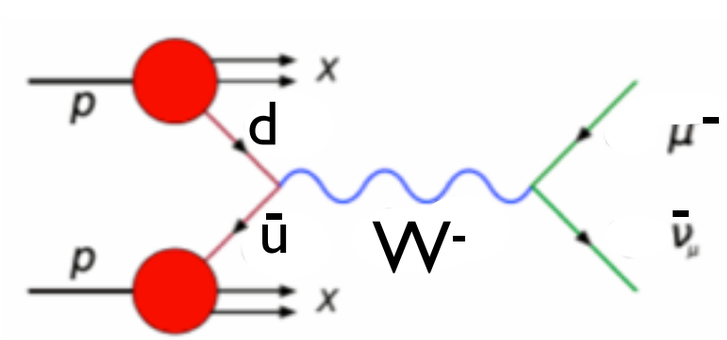
- full line ➜ only DIS data from HERA (central fit)
- dashed line ➜ after inclusion of CMS jet data
- blue band ➜ HERA DIS + CMS central fit + uncertainties

Lepton Charge Asymmetry in W decay

$pp \rightarrow W+X$

$$A(\eta) = \frac{d\sigma/d\eta(W^+) - d\sigma/d\eta(W^-)}{d\sigma/d\eta(W^+) + d\sigma/d\eta(W^-)}$$





- in pp collision an excess in production for W^+ respect to W^-
- important information on parton distribution function
- mainly sensitive to valence quark distribution via the production:

$$u\bar{d}(\bar{u}d) \rightarrow W^{+(-)}$$

- this measurement at LHC can contribute to the understanding of PDF in $10^{-3} \leq x \leq 10^{-1}$

Analysis performed by ATLAS and CMS

ATLAS analysis

7 TeV (35 pb^{-1})

➤ Phys. Rev. D85, 072004 (2012)

• combination of the electron and muon data for the W charge asymmetry measurement

Event selection:

• high transverse momentum lepton with stringent requirements:

- high quality tracks -> minimum number of hits

- p_T > 20 GeV & $|\eta|$ < 2.4 (muons)

- E_T > 20 GeV & $|\eta|$ < 2.47 excluding 1.37< $|\eta|$ < 2.47 (electrons)

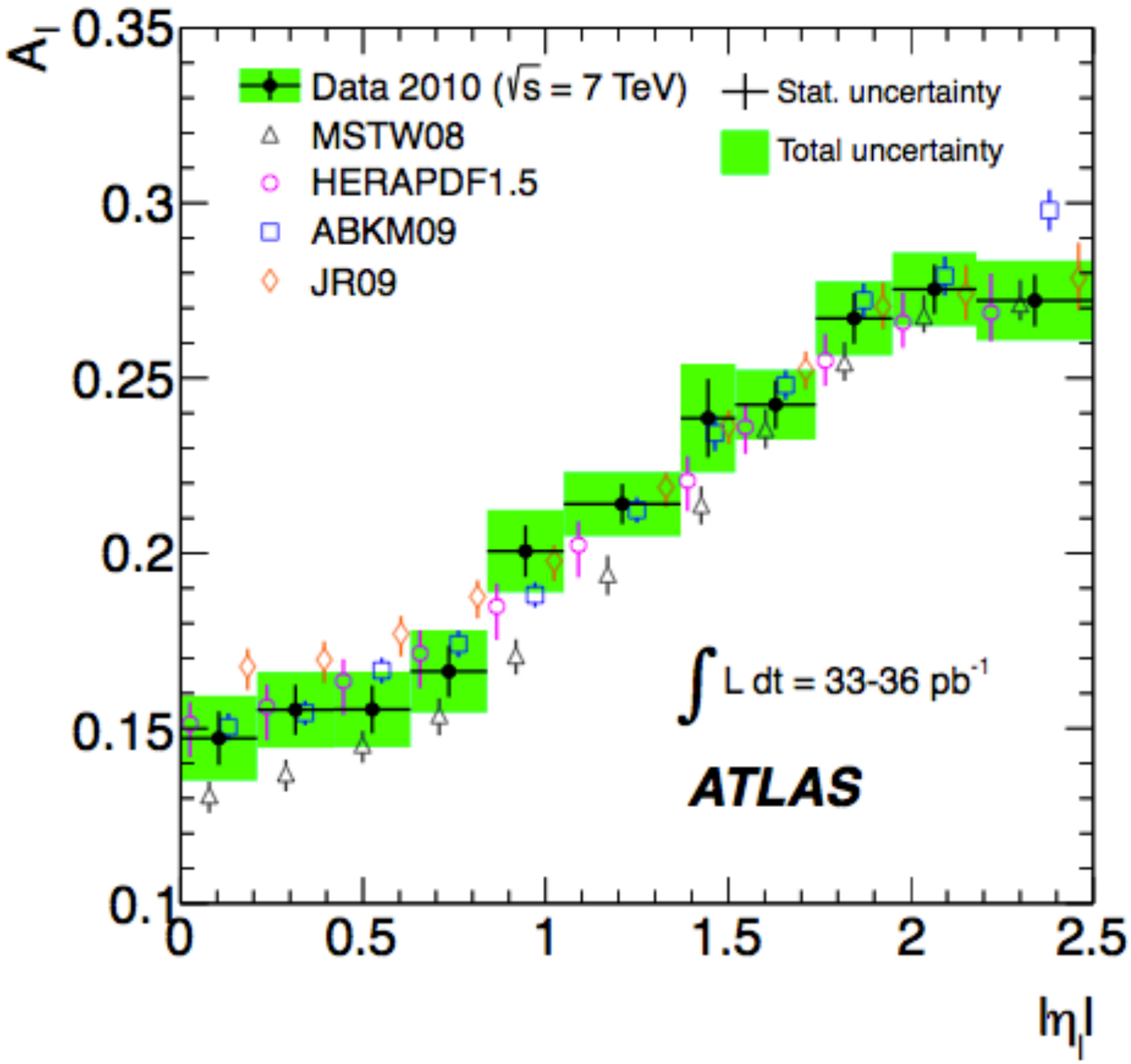
- track-based isolation requirements

• $W \rightarrow l\,\nu$ selected requiring:

- MET > 25 GeV

- m_T > 40 GeV

$$m_{\mathrm{T}} = \sqrt{2p_{\mathrm{T}}^{\mu}p_{\mathrm{T}}^{\nu}(1-\cos(\phi^{\mu}-\phi^{\nu}))}$$



comparison of the measured asymmetry with the NNLO predictions using different PDF sets

CMS Analysis

➤ SMP-12-021

Signature: $W \rightarrow \mu\, \nu$

• high p_T muon

+

• missing transverse momentum

7 TeV (4.7 fb^{-1})

Muon selection:

• isolated muon trigger requirement

• high p_T muons matching the trigger object:

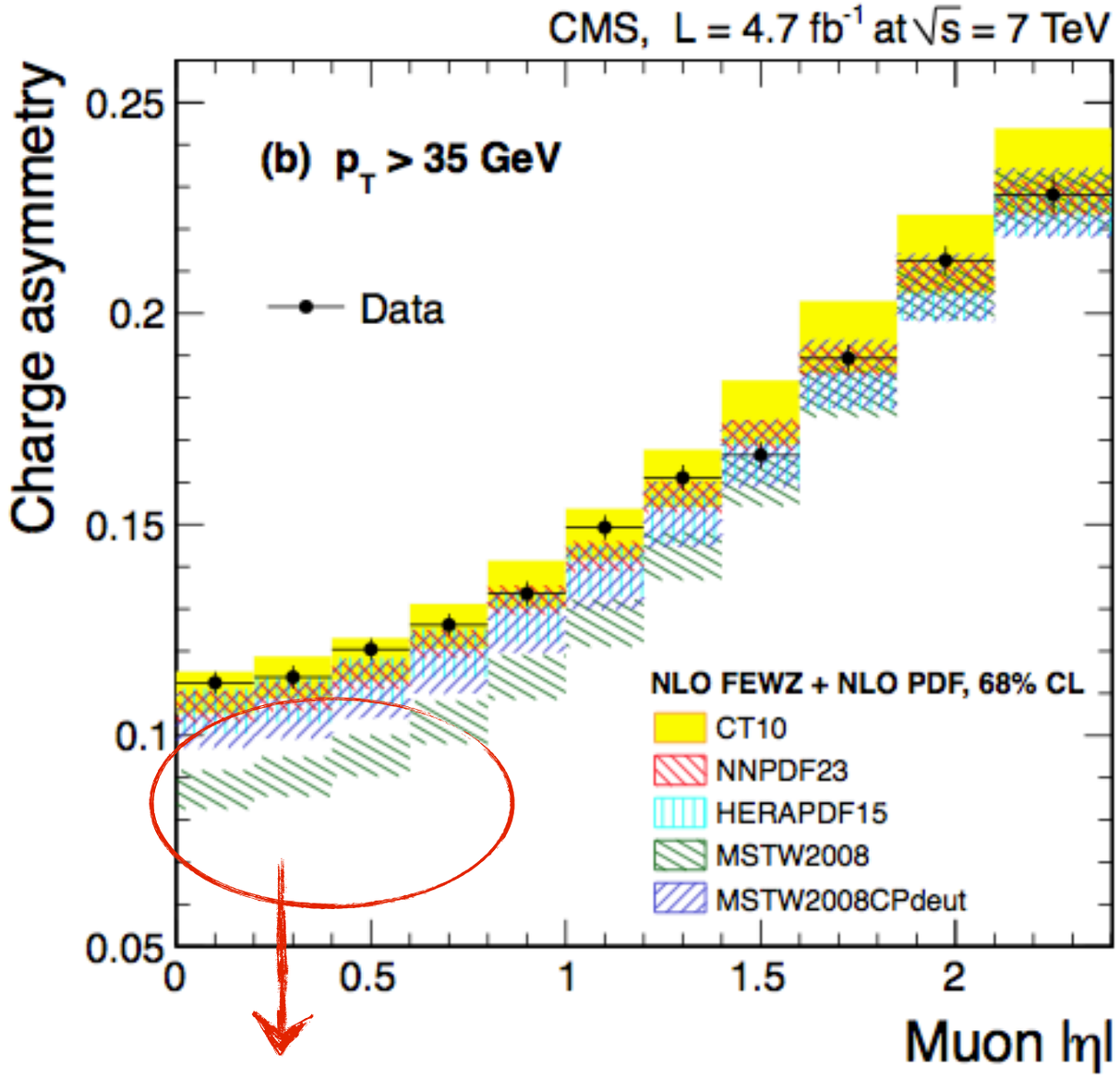
$p_T > 25$ GeV & $|\eta| < 2.4$

• rejected events with a second muon with $p_T > 15$ GeV

• trigger, reconstruction and identification efficiencies extracted with tag&Probe method

• The signal is extracted from fits to the MET distribution in different pseudorapidity regions

comparison with NLO prediction using FEWZ 3.1 with PDF sets

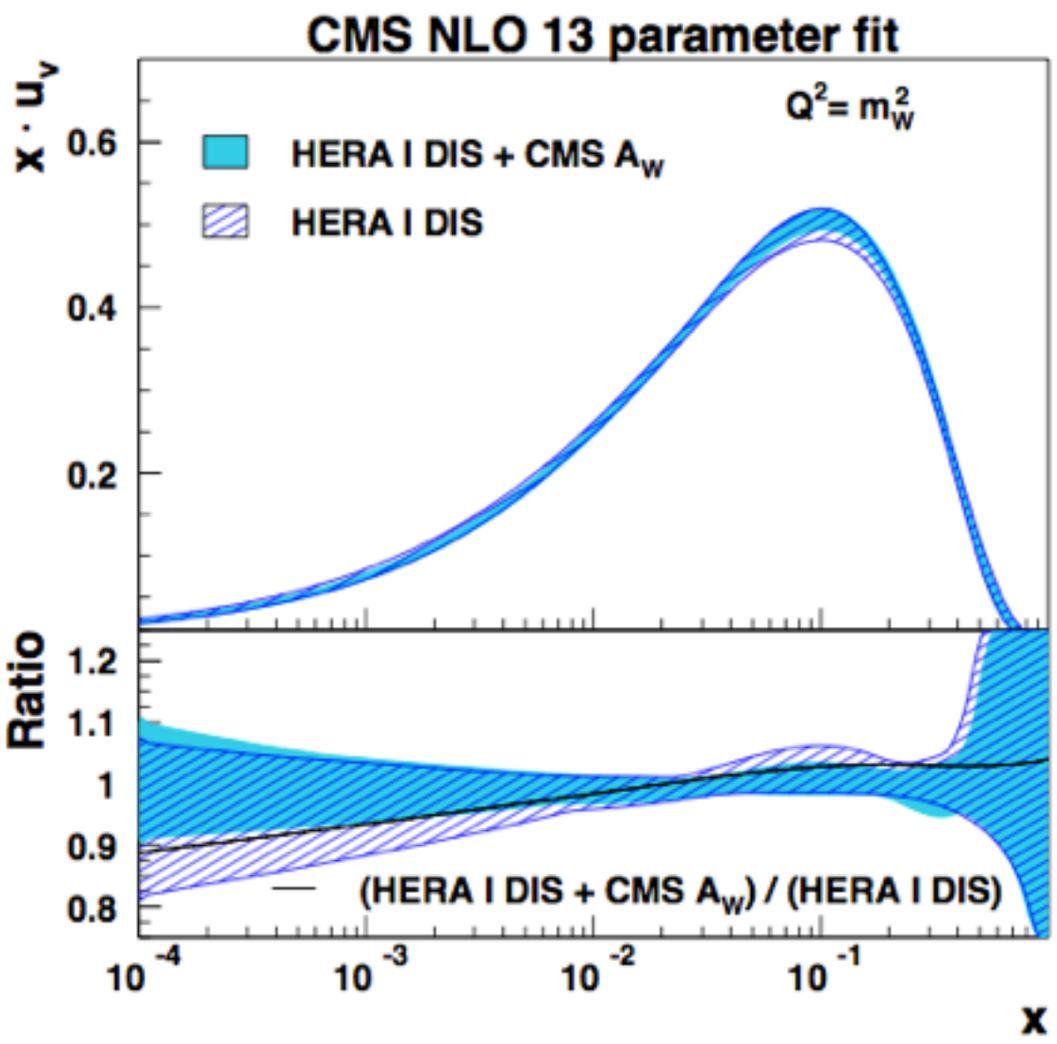


disagreement between prediction with MSTW2008 and data

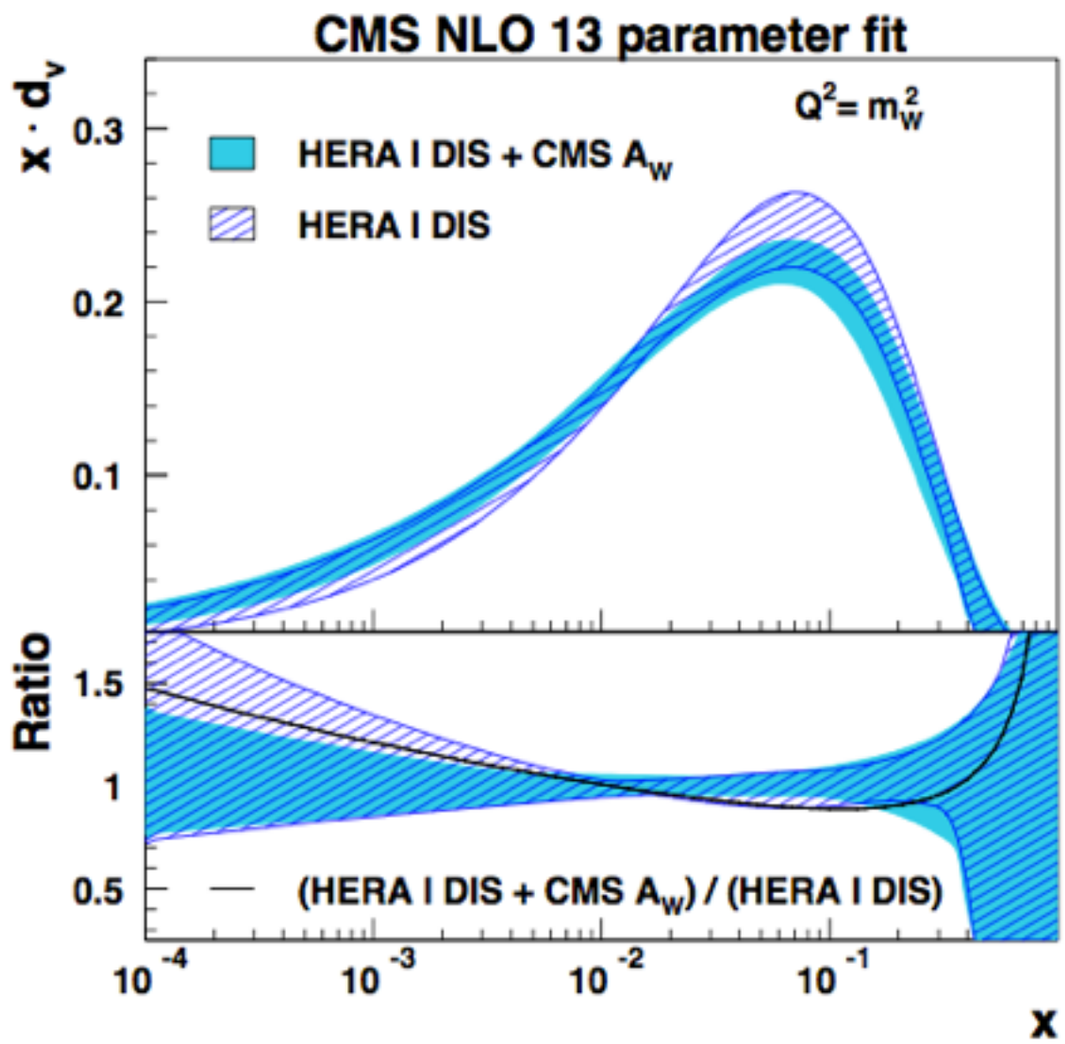
PDF constraints

measurement of the muon charge asymmetry in W production used in conjunction with DIS data from HERA for PDF constraints

u-valence quark

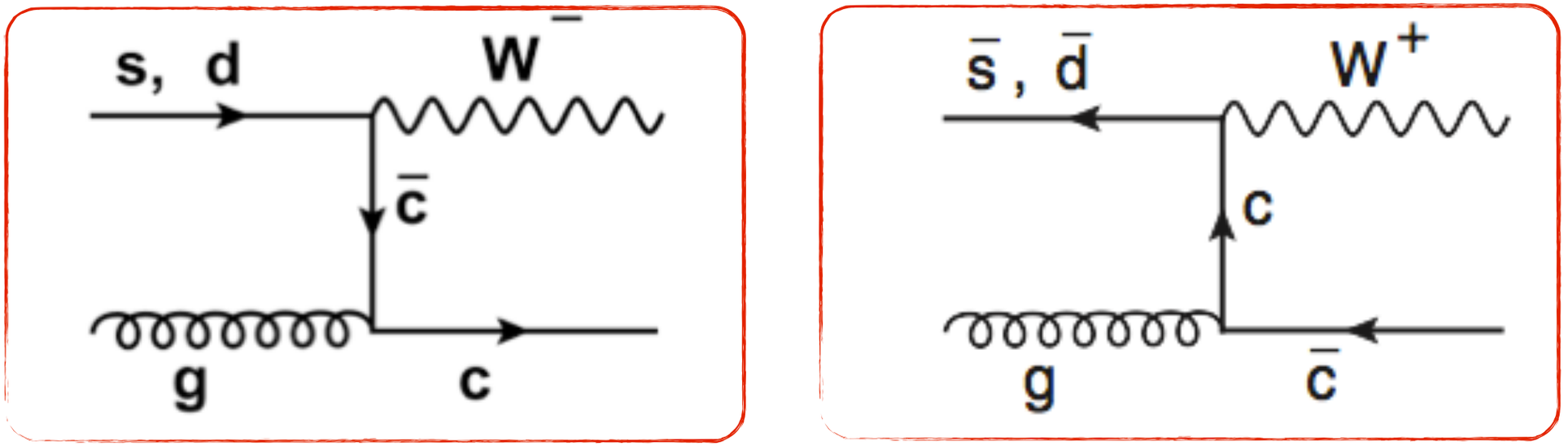


d-valence quark



improvement precision of the valence quark and change of PDF shape

W + charm



- dominance of $sg \rightarrow W^- + c$ and $\bar{s}g \rightarrow W^+ + \bar{c}$ contribution at hard-scattering level while the $dg \rightarrow W$ process is Cabibbo suppressed

- σ(W + c-jet) sensitive to strange-quark content of the proton at an energy scale of $Q^2 \sim (100\text{GeV})^2$

- precise measurement of this process at LHC probes strange quark directly to LO and may reduce the uncertainties in the s and $\bar{s}$ PDF

CMS Analysis

7 TeV (5 fb^{-1})

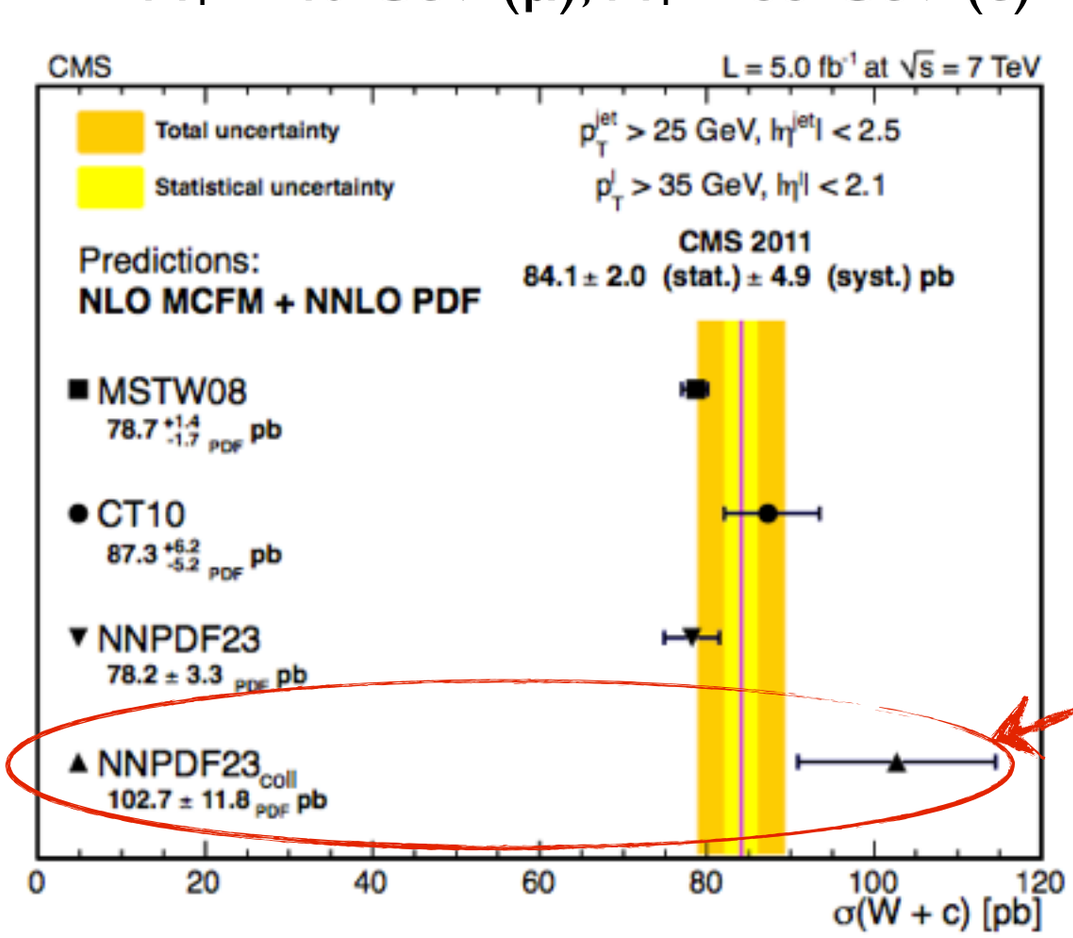
➤ JHEP 02 (2014) 013

total cross section measurement and differential cross section as a function of lepton pesudorapidity for the process:

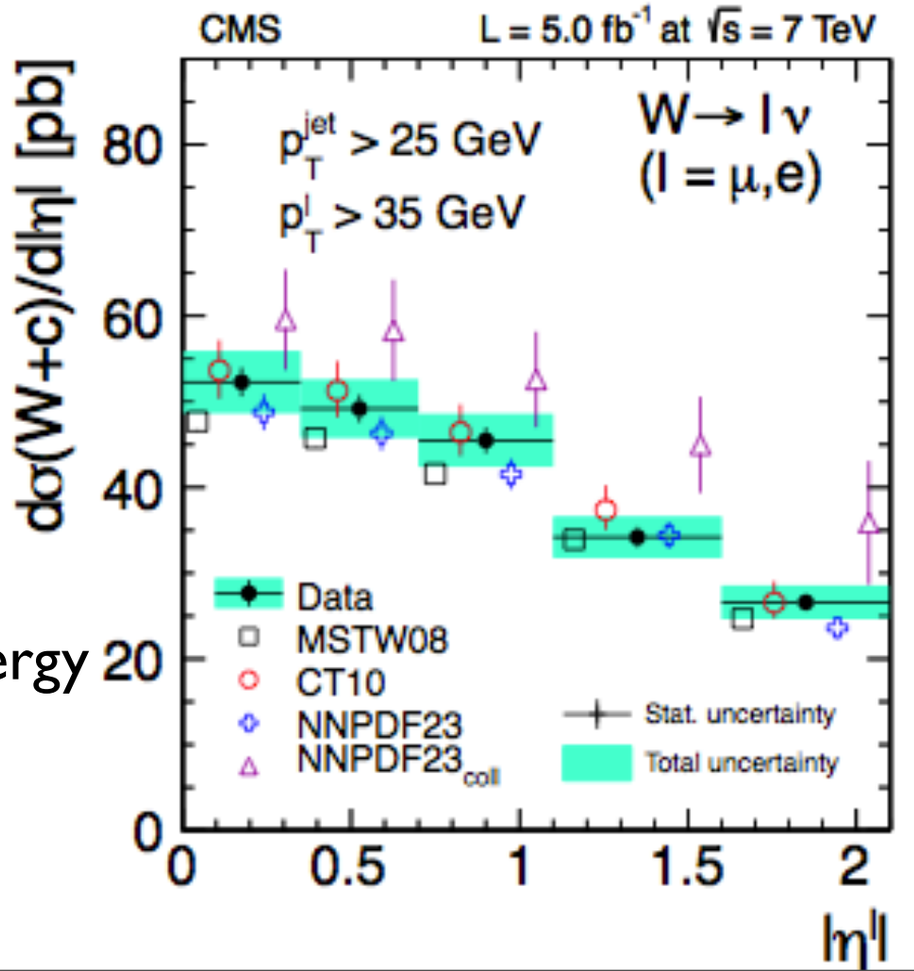
$$pp \rightarrow W + c + X$$

- Final state: $W \rightarrow l\,\nu$ + leading c-jet
- muon and electron decay channel
- c-jets with pT > 25 GeV and $|\eta| < 2.5$
- $M_T > 40$ GeV (μ), $M_T > 55$ GeV (e)

- c-jet identified using 3 different signatures:
  - $D^+ \rightarrow K^- \pi^+\pi^+$ ($D^- \rightarrow K^+ \pi^- \pi^-$)
  - $D^0 \rightarrow K^- \pi^+$ ($\bar{D}^0 \rightarrow K^+ \pi^-$)
  - semileptonic decay



based on high energy collider data only



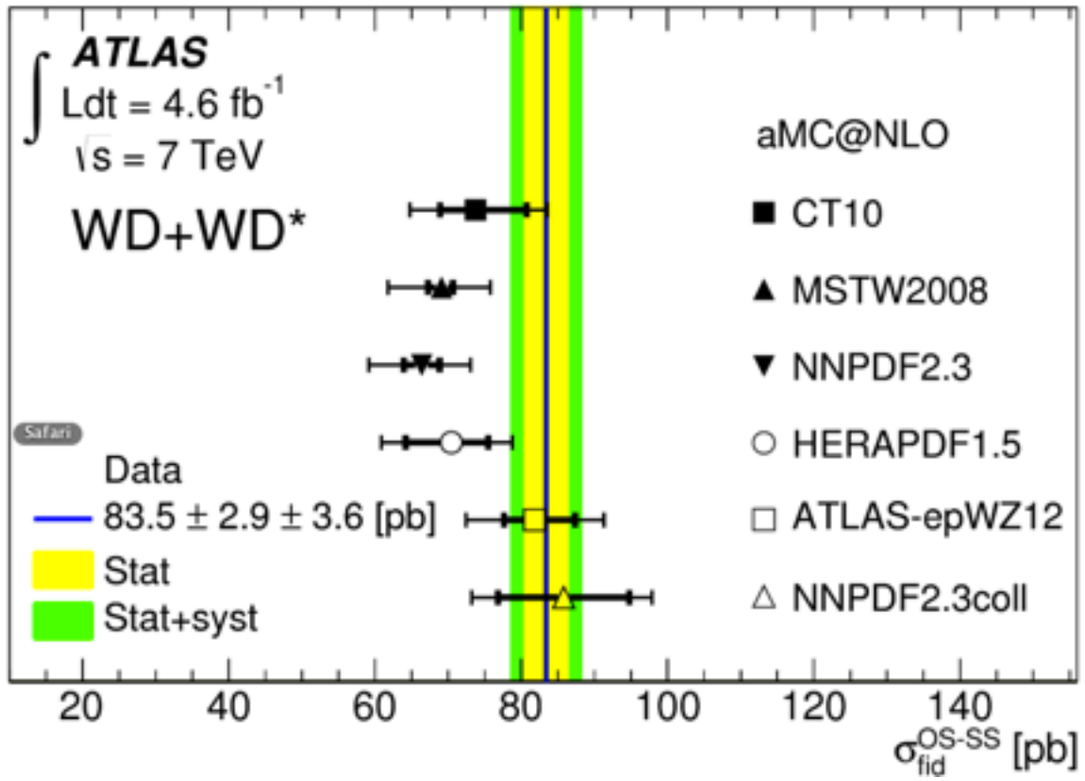
ATLAS analysis

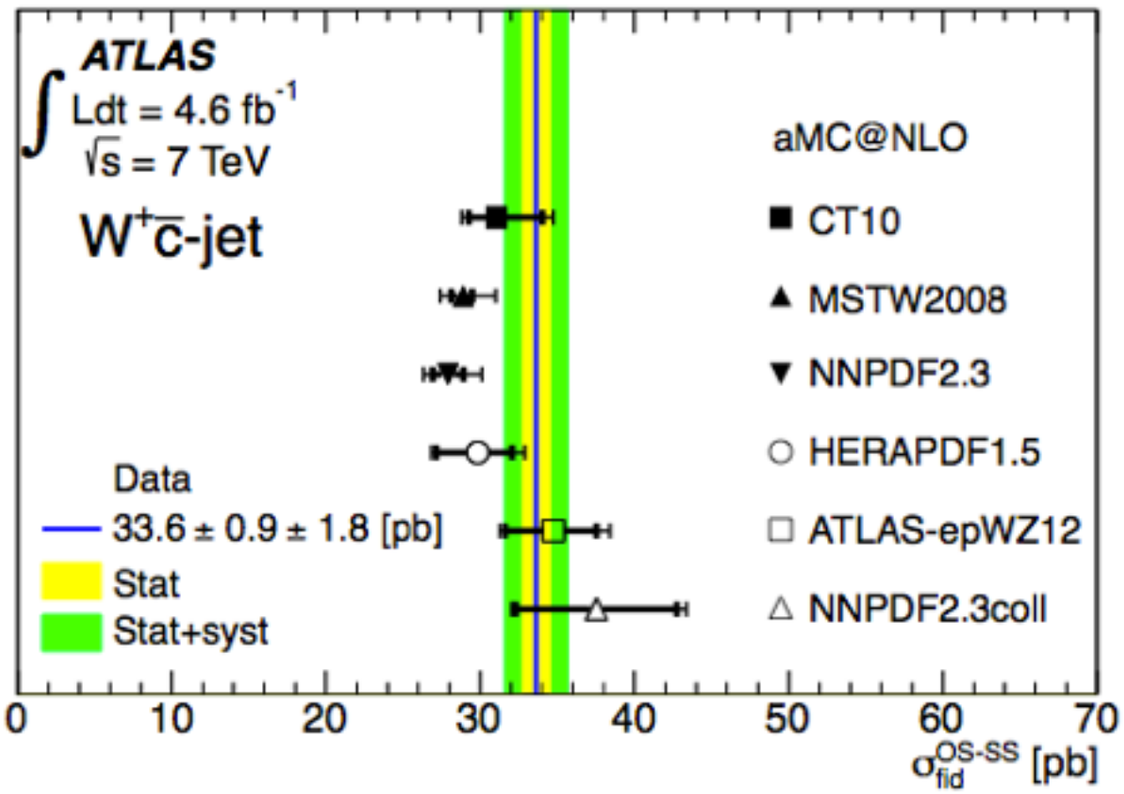
measurement of the integrated and differential cross section as a function of the pseudorapidity of the lepton from the W decay

- W reconstruction from leptonic decay:
  - $W \rightarrow \mu \nu$ - $W \rightarrow e \nu$
- c-jet tagged by:
  - semileptonic decay to a muon
  - charge D (D*) meson

Results are compared to the predictions of NLO QCD calculations with various PDF parametrizations

- ATLAS-epWZ12, NNPDF2.3coll
  - best agreement with data
- NNPDF2.3
  - less favoured





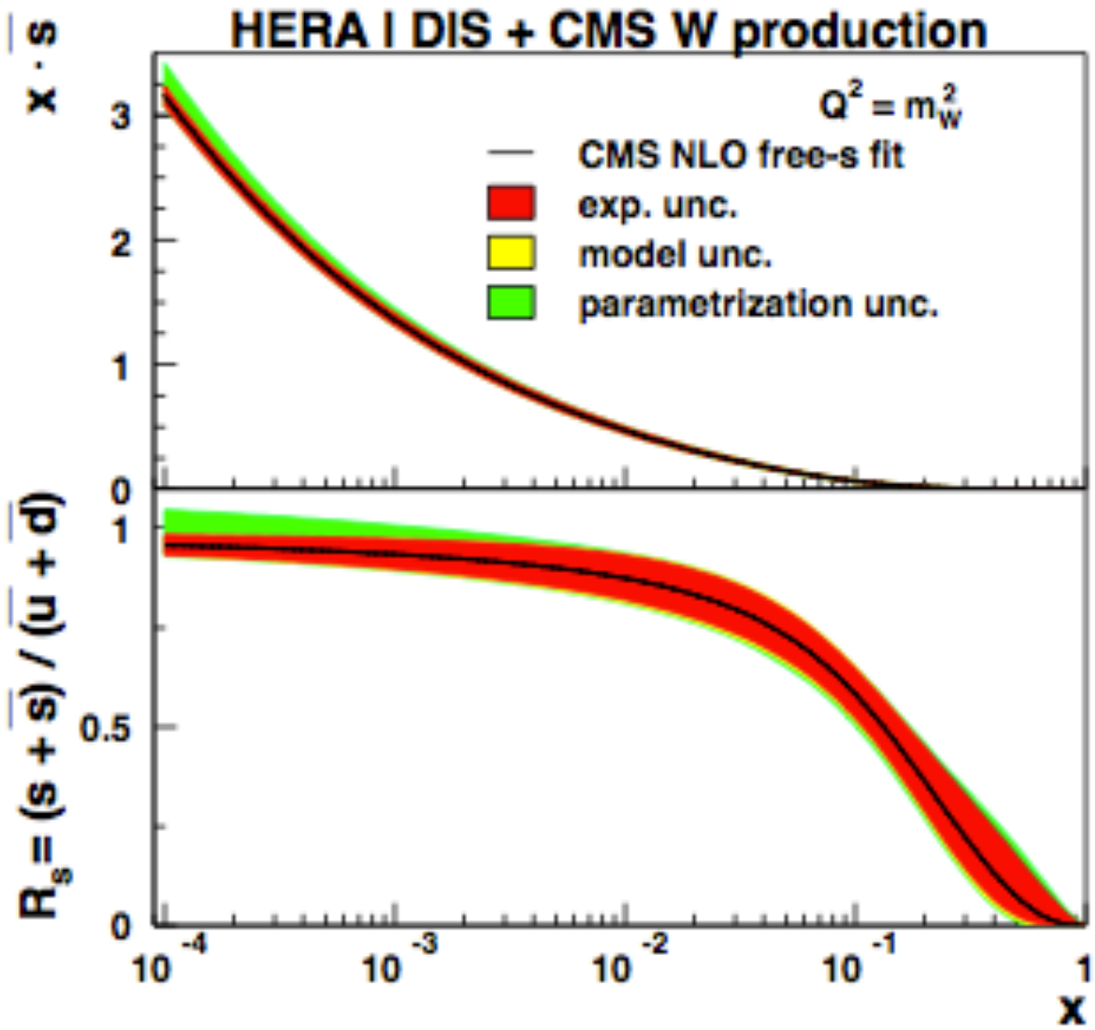
PDF constraints

W+ charm measurement used together the HERA DIS data and CMS muon charge asymmetry used to constraint the PDFs

constraints on s-quark minimizing χ^2 in comparing measurement with NLO ⊗ HERAPDF1.5

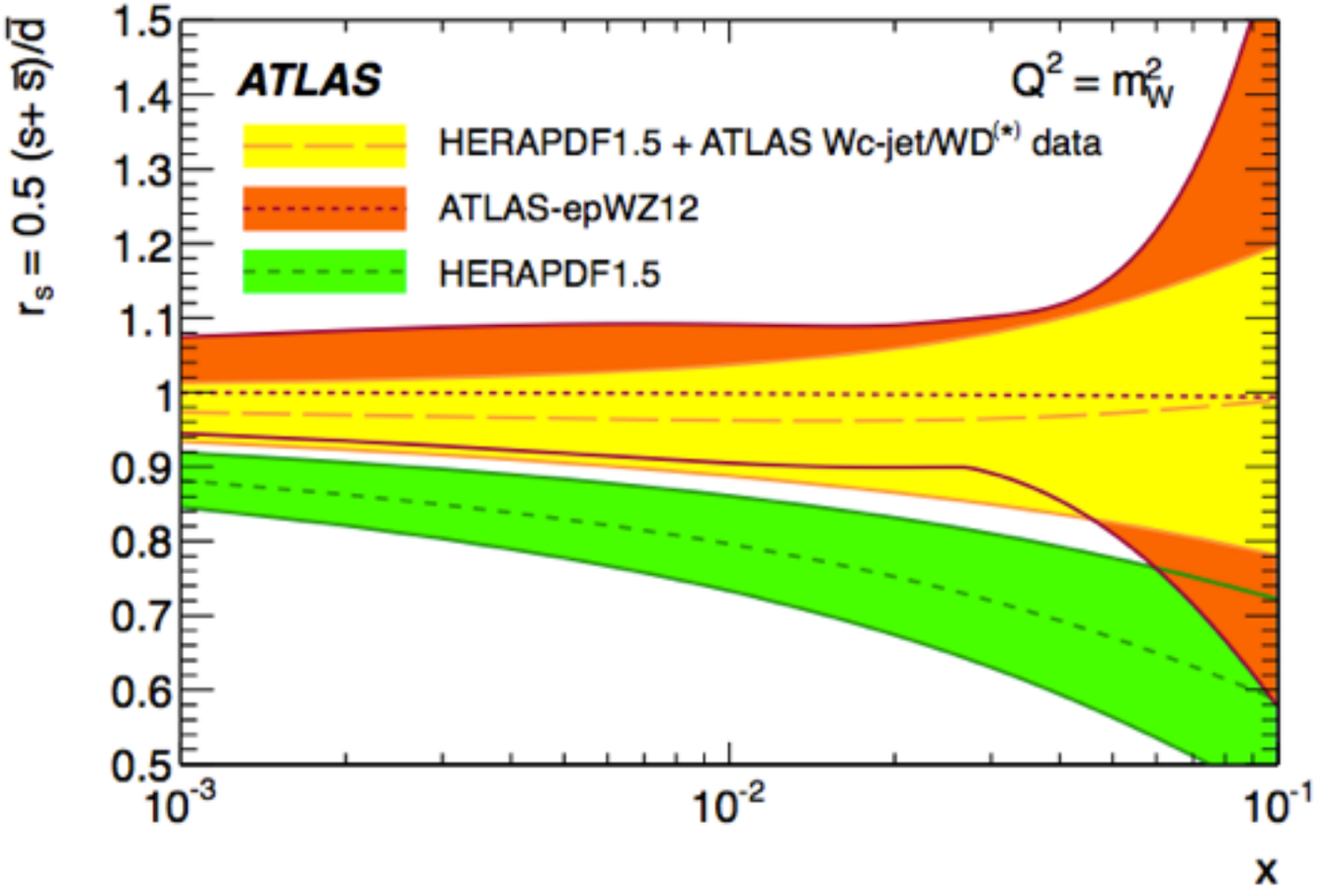
• the strange-quark distribution and the fraction Rs are determined

$$R_s(x,Q^2) = (s+\bar{s})/(\bar{u}+\bar{d})$$



• for the HERAPDF1.5 PDF the s-quark sea density is lower than the d-quark sea density at low values of x and it is further suppressed at higher values of x

• including the ATLAS Wc-jet/WD(*) the s-quark sea density seems symmetric over the whole x range relevant



7 TeV (4.6 fb^{-1})

Isolated prompt Photons

➤ *Phys. Rev. D 89, 052004 (2014)*

measurement of the cross section for the production of isolated prompt photons as a function of photons pseudorapidity and transverse energy

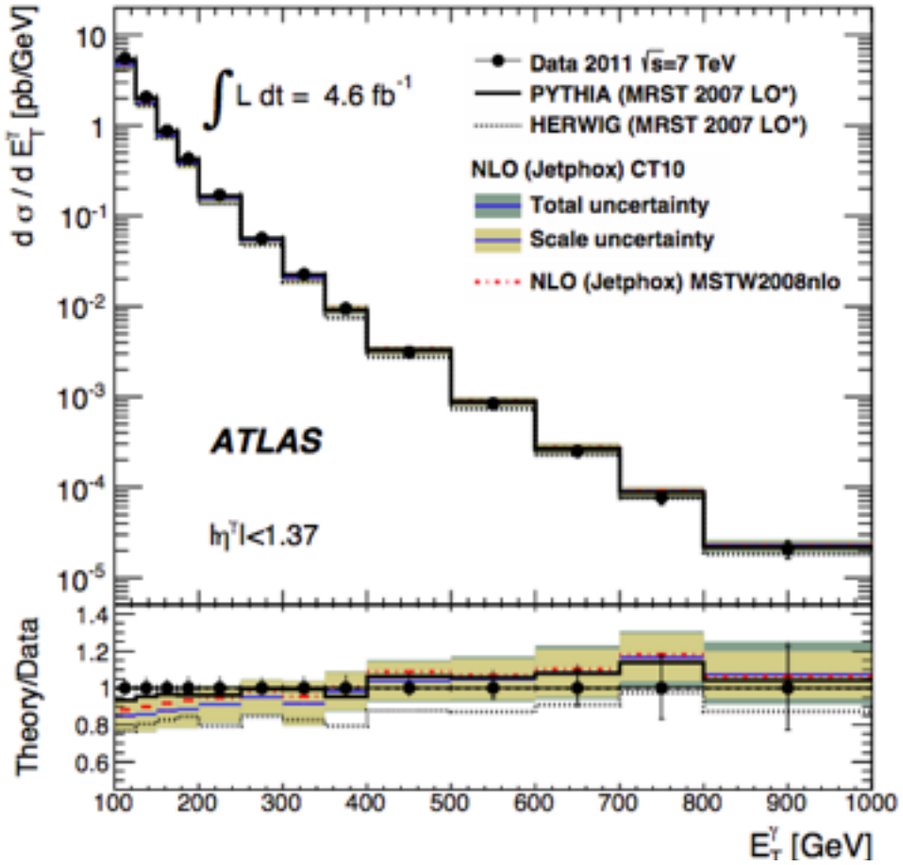
- sensitive to the gluon content of the proton through:

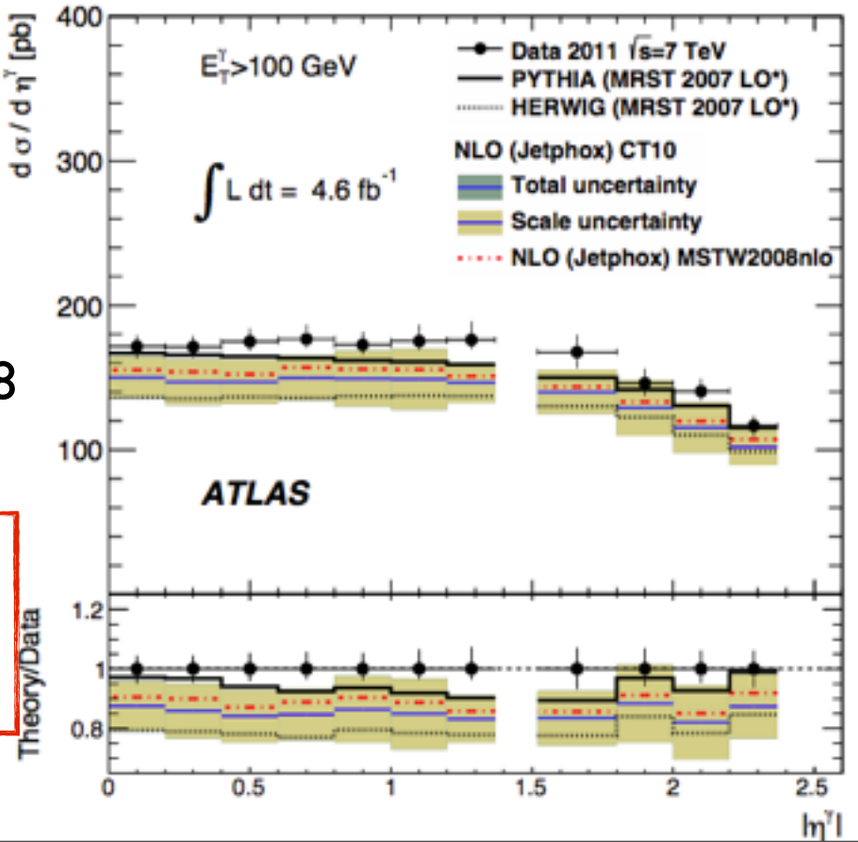
dominant prompt photons production at LHC

$q\,g \rightarrow q\,\gamma$

prompt photon:

- "direct" photon from hard process
- "fragmentation" photon produced by high p_T parton





- preselection: 80 GeV trigger with calibrated transverse energy > 100 GeV
- isolation criteria applied

  $E_T^{ISO} < 7$ GeV in isolation with $R = \sqrt{(\Delta\eta^2 + \Delta\varphi^2)} = 0.4$

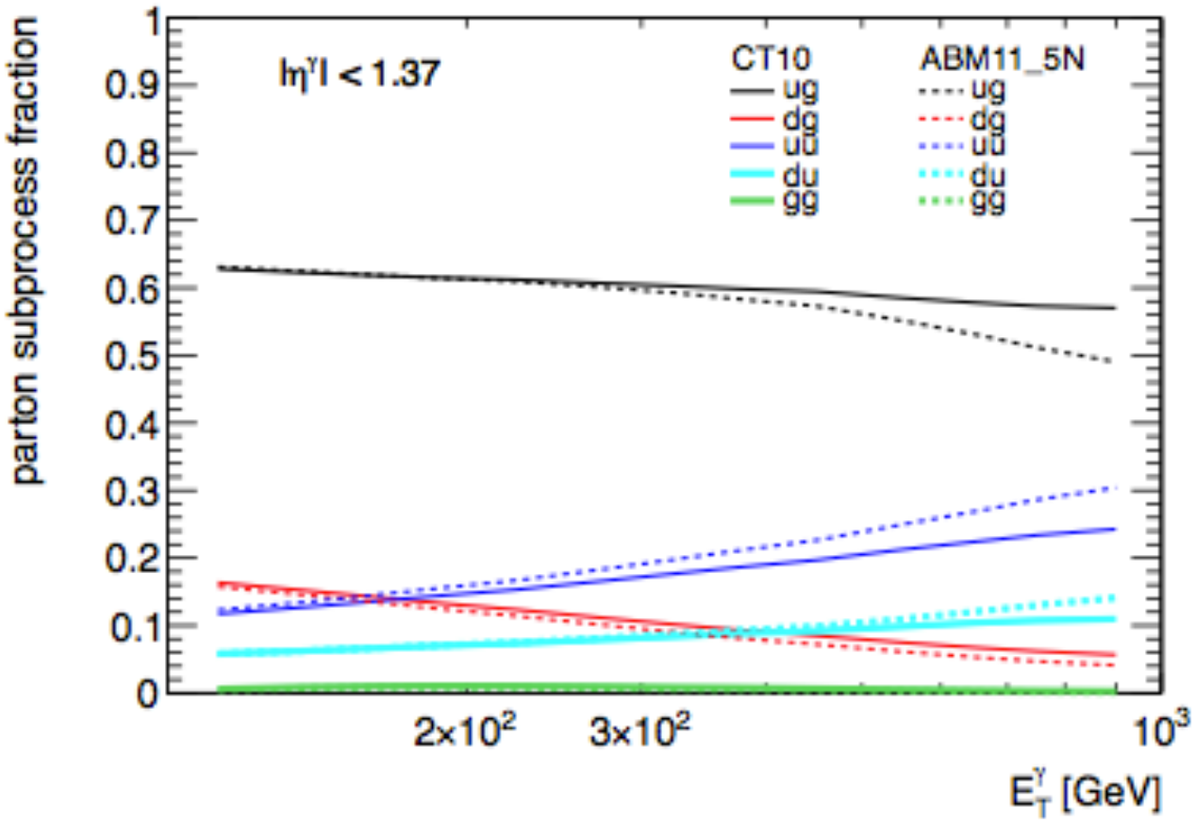
- shape variables studied to discriminate signal from background
- $100 \leq E_T^{\gamma} \leq 1000$ GeV
- $|\eta^{\gamma}| < 1.37$ or $1.52 \leq |\eta^{\gamma}| < 2.37$

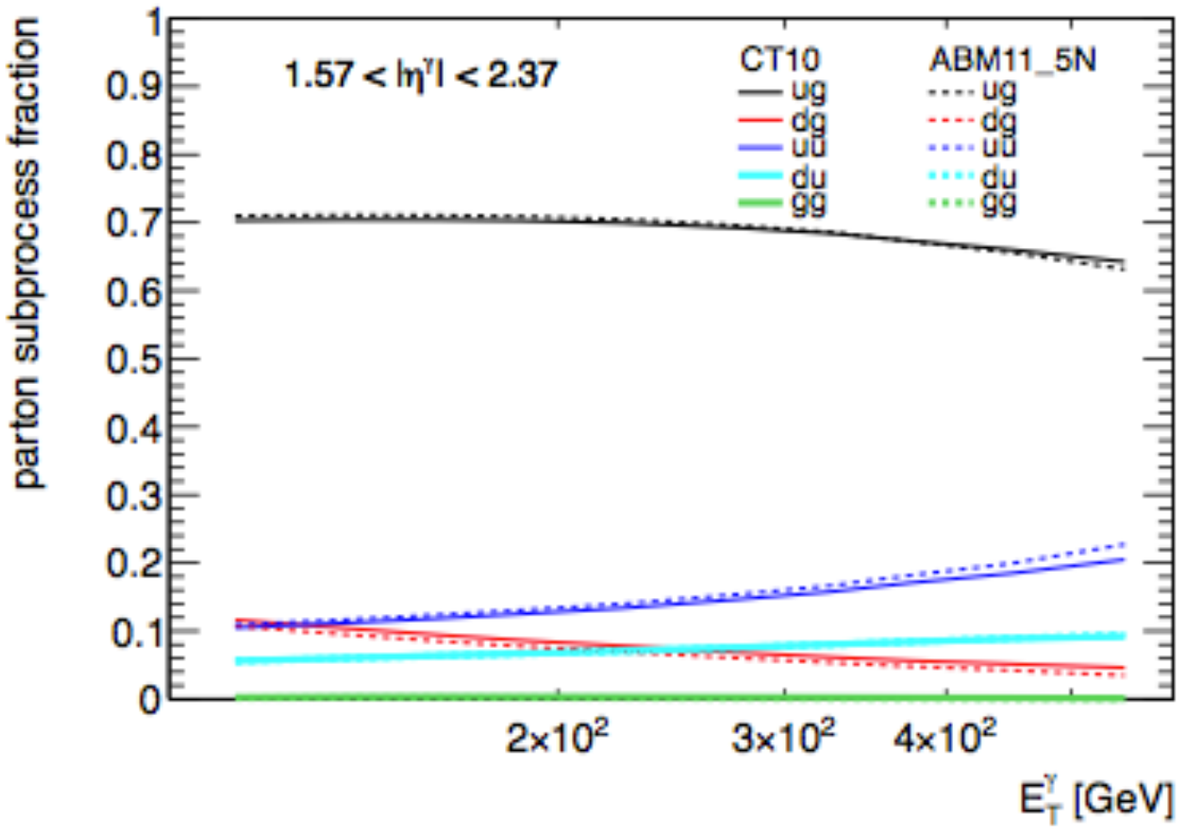
data agree with NLO prediction based on CT10 and MSTW2008

it provides additional constraint on the proton PDF

Sensitivity to PDF

→ *Investigated the sensitivity of the inclusive photon production cross section to the PDFs*





dominant process → u-g →

the inclusive photon production cross section can provide significant constraints on the gluon distribution

Z+jet Production

➤ arXiv:1310.8197

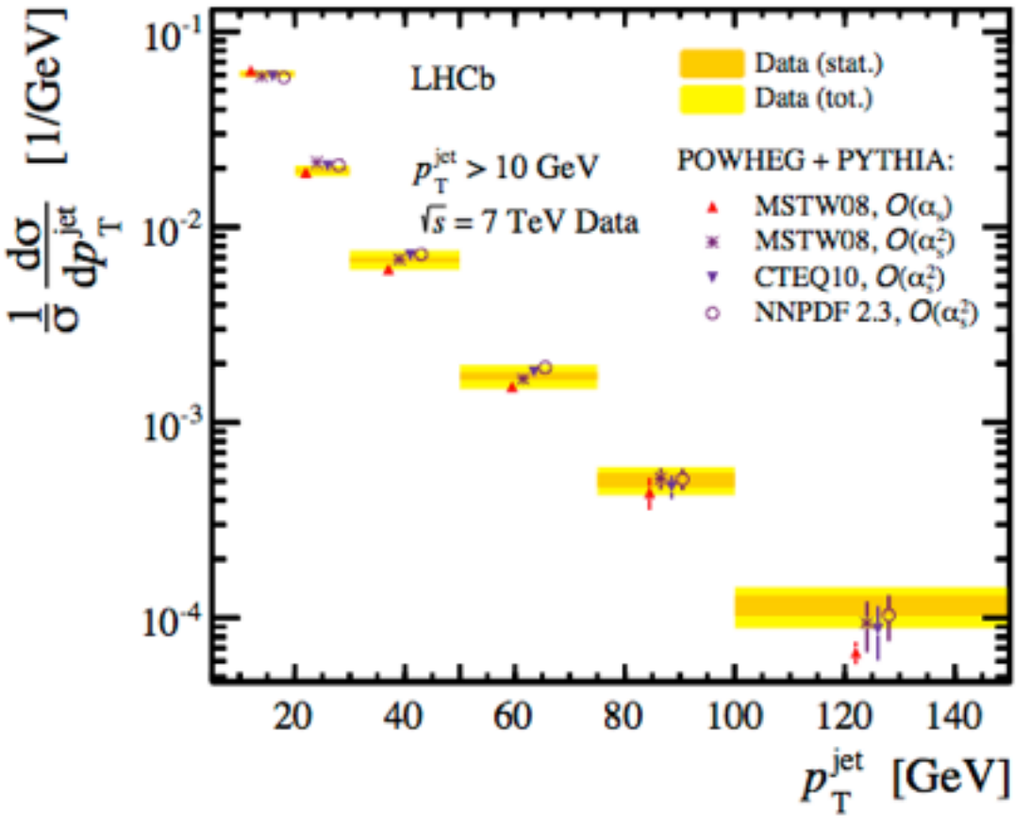
7 TeV (1.0 fb^{-1})

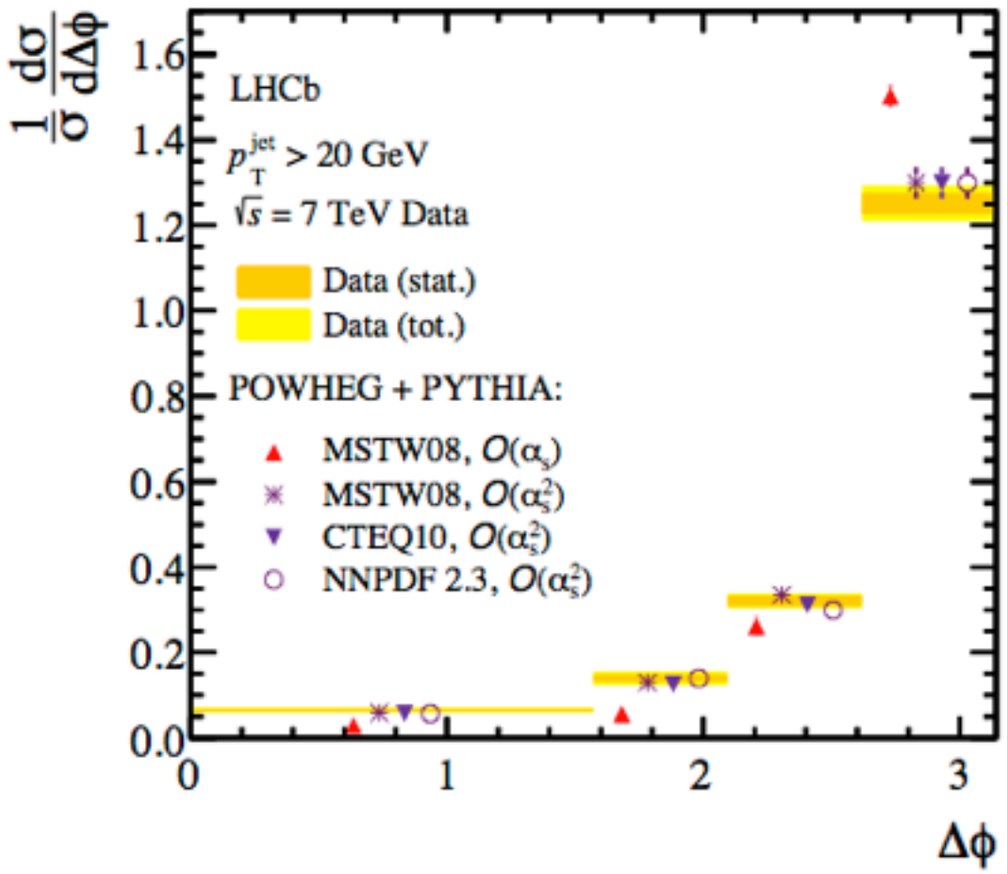
measurement of the inclusive Z+jet production cross section

• Z boson production in association with jets is sensitive to gluon content

• LHCb is sensitive to a region of phase space in which both the Z boson and jets are produced in the forward region

• comparison of different PDF prediction in unprobed region of space space at low Bjorken-x





- 2 reconstructed muons with
  - $p_T^{\mu} > 1$GeV & $2.0 \leq \eta^{\mu} < 4.5$
- $60 \leq M_{\mu\mu} < 120$ GeV
- jet reconstructed using anti-kt with R=0.5
  - $p_T^{\mu} > 7.5$ GeV & $2.0 \leq \eta^{jet} < 4.5$

measured cross section compared to theoretical prediction at NLO calculated with POWHEG + PYTHIA with different NLO and NNLO PDF:

MSTW08, CTEQ10, NNPDF 2.3

The measured cross sections show agreement with expectations from NNLO calculations for all the PDFs

Conclusions

- The knowledge of the initial state is crucial for precision measurement at hadron colliders
- These measurements provide constraints to precisely determine the proton PDFs giving more information about the initial state of the event at LHC
- An overview of the ATLAS, CMS and LHCb results has been presented

BACKUP

QCD analysis

➤ ***CMS-PAS-SMP-12-028***

- Starting scale $Q_0^2 = 1.9\ \text{GeV}^2$
- Strong coupling: $\alpha_s(m_Z)=0.1176$
- $m_c = 1.4$ GeV, $m_b = 4.75$ GeV
- the fit has 13 free parameters to describe the PDFs

fixed strange distribution

$$xu_v(x) = A_{u_v} x^{B_{u_v}} (1-x)^{C_{u_v}} (1 + E_{u_v} x^2),$$
$$xd_v(x) = A_{d_v} x^{B_{d_v}} (1-x)^{C_{d_v}},$$
$$xU(x) = A_U x^{B_U} (1-x)^{C_U},$$
$$xD(x) = A_D x^{B_D} (1-x)^{C_D},$$
$$xg(x) = A_g x^{B_g} (1-x)^{C_g} - A'_g x^{B'_g} (1-x)^{C'_g}$$

PDFs assumed to be indipendent in the fit procedure: xuv(x), xdv(x), xg(x), xU(x), xD(x)

$x\bar{U} = x\bar{u}$ $\quad x\bar{D} = x\bar{d} + x\bar{s}$

$B_{\bar{U}} = B_{\bar{D}}$ $\quad A_{\bar{U}} = A_{\bar{D}}(1-f_s)$

$f_s = x\bar{s}/(x\bar{d}+x\bar{s}) = 0.31$

normalization parameters A_g, A_{uv} and A_{dv} are constrained by QCD sum rules

correlation cross section and PDF

•The NNPDF Collaboration provides PDF sets in the form of an ensemble of PDFs called replicas, which sample variations in the PDF parameter space allowed within uncertainties

•For an NNPDF ensemble with Nrep replicas, the correlation coefficient between a cross section and the PDF for flavour i is then defined as:

$$\varrho_i\left[\sigma_{\rm jet}(x,Q^2), xf_i(x,Q^2)\right] = \frac{N_{\rm rep}}{(N_{\rm rep}-1)} \frac{\langle \sigma_{\rm jet}(x,Q^2) xf_i(x,Q^2)\rangle - \langle\sigma_{\rm jet}\rangle\langle xf_i(x,Q^2)\rangle}{\Delta_{\sigma_{\rm jet}(x,Q^2)}\Delta_{xf_i(x,Q^2)}}$$

$\Delta\sigma_{jet}$ -> jet cross section uncerainties

Δ_{xf} (x,Q^2) -> jet cross section uncerainties

xf_i -> PDF for flavour i