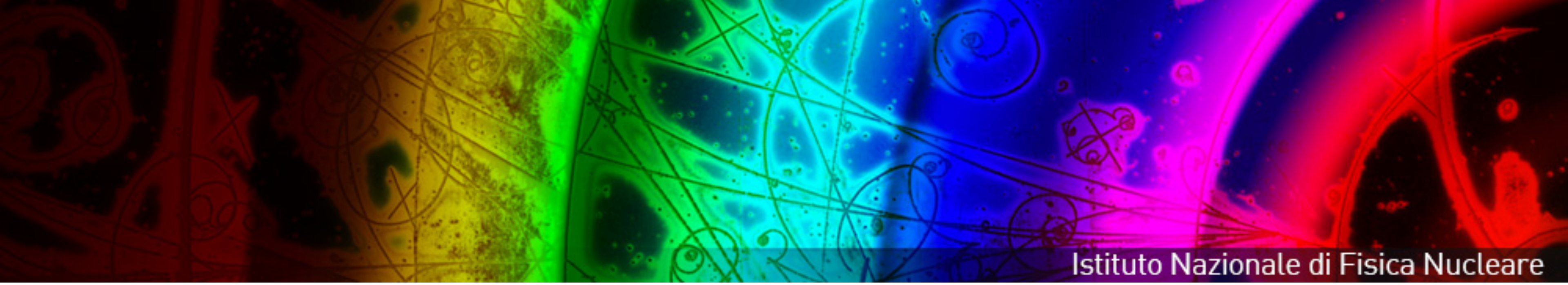

W and Z production at the LHC

Pasquale Di Nezza
INFN LNF Istituto Nazionale di Fisica Nucleare

on behalf of

ATLAS EXPERIMENT CMS LHCb

TRANSVERSITY 2017

Frascati, 14/12/17

In the LHC physics, the precise understanding of Parton Distribution Functions plays a major role (e.i. Higgs boson discovery, searches for new physics, …).
In recent years a new generation of PDF sets have been developed for the LHC Run II and this has a fall-out also on other research fields.

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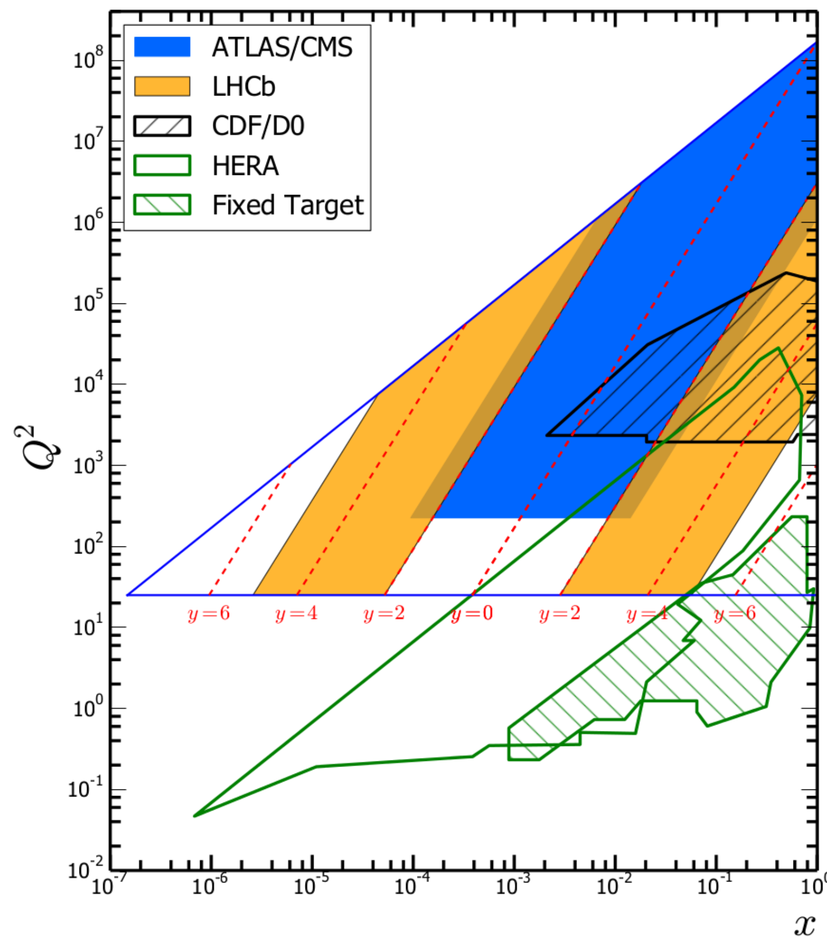
W, Z production (sensitive to the underlying dynamics of strongly interacting particles):

- constitutes important tests for the SM (e.w. mixing angle, W mass, etc…)

-provides access to PDFs in different regions on the phase-space. In particular:
    -at high-x
    -at low-x ~10^{-6} (unexplored by other experiments)

LHC 13 TeV Kinematics

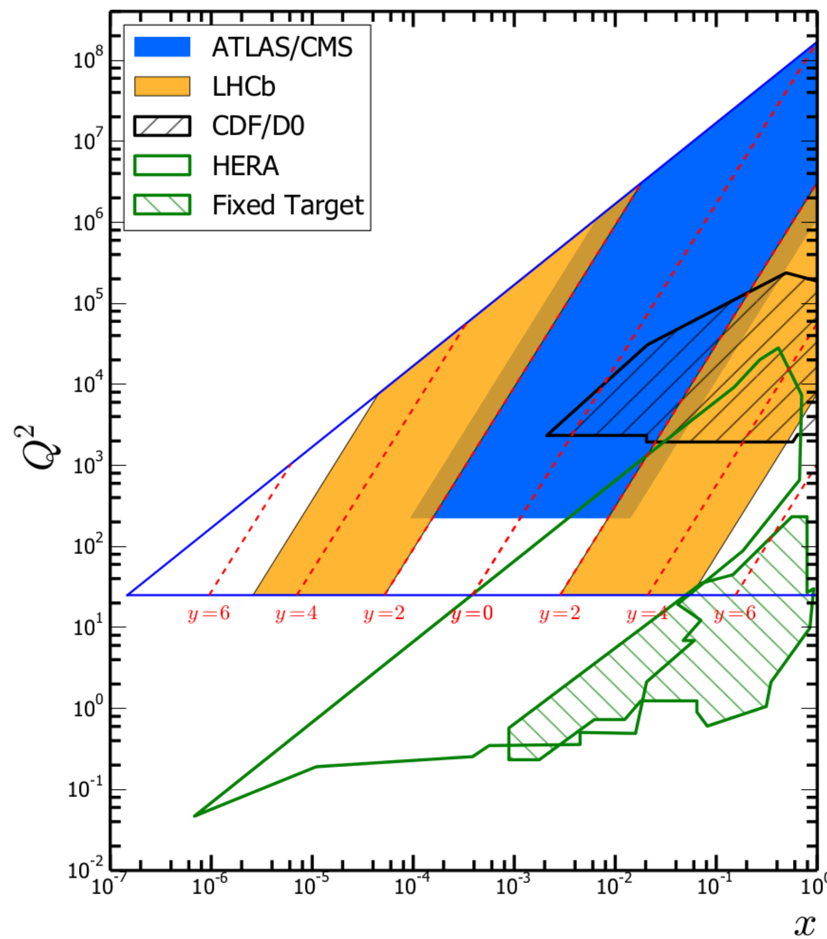


In the LHC physics, the precise understanding of Parton Distribution Functions plays a major role (e.i. Higgs boson discovery, searches for new physics, …).
In recent years a new generation of PDF sets have been developed for the LHC Run II and this has a fall-out also on other research fields.

-**ATLAS** and **CMS** have precision tracking in central region and can reconstruct electrons and jets in the forward calorimeter for the Vector Boson associate production

-**LHCb** provides precision measurements with a coverage for 2<η<5, performing complementary measurements

LHC 13 TeV Kinematics

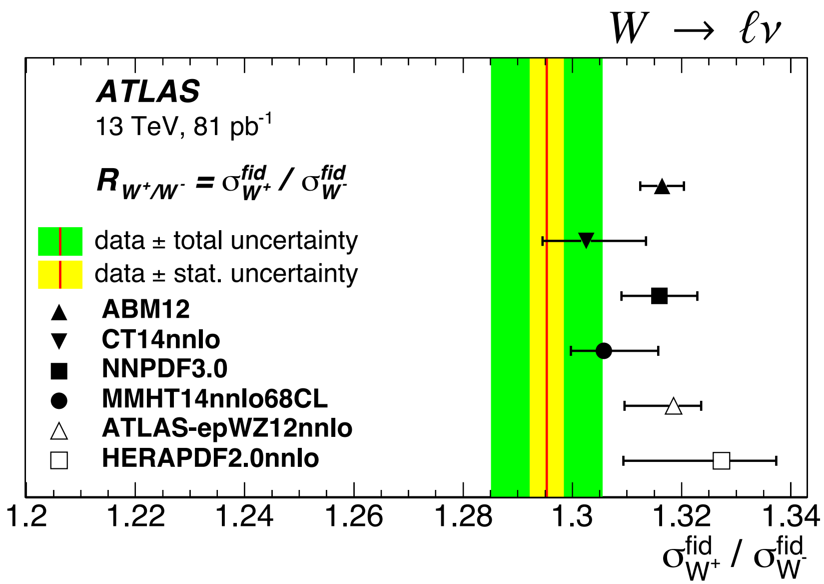


Measurements

- Inclusive
- Vector Boson + Jet
- Vector Boson + Heavy Flavour Jet

13 TeV production cross section -

PLB 759 (2016) 601

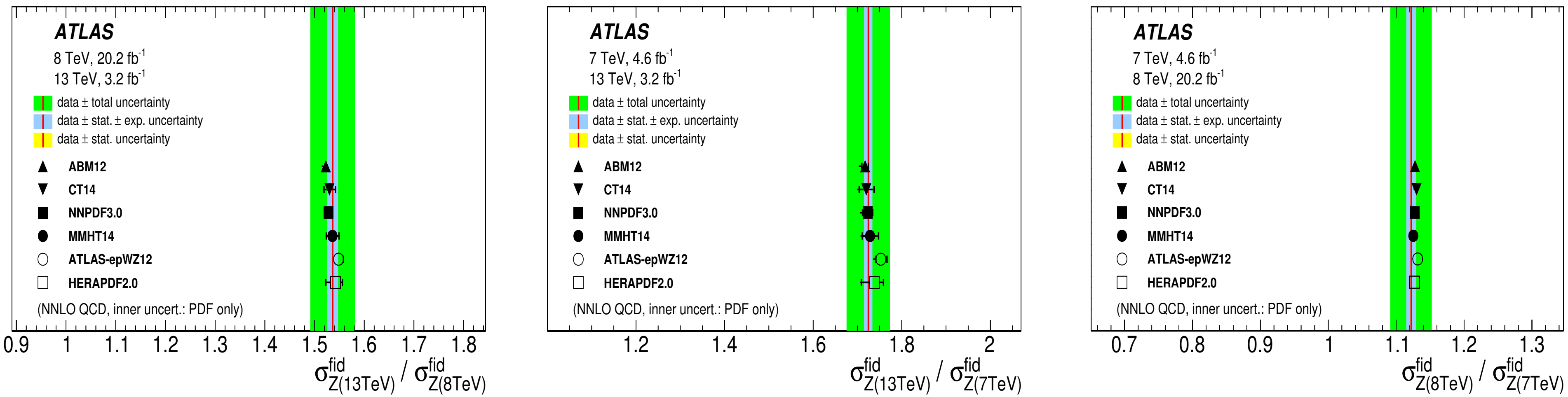


Cross section ratios performed in the fiducial region of the detector

Results compared to NNLO pQCD prediction for different PDF sets, variation shows the sensitivity to PDFs

Z cross section ratios at different center-of-mass energies

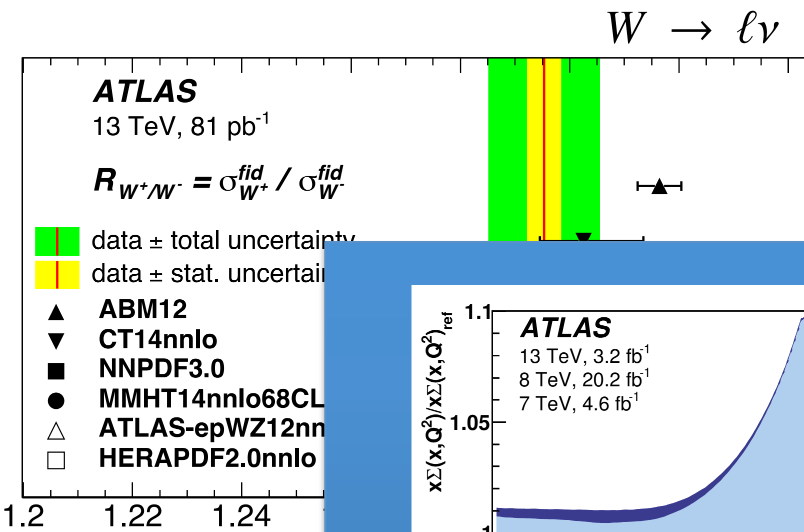
JHEP 02 (2017) 117



PDF uncertainty small → a precision test for understanding the energy evolution

13 TeV production cross section - ATLAS EXPERIMENT

PLB 759 (2016) 601



Cross section ratios performed in the fiducial region of the detector

CD

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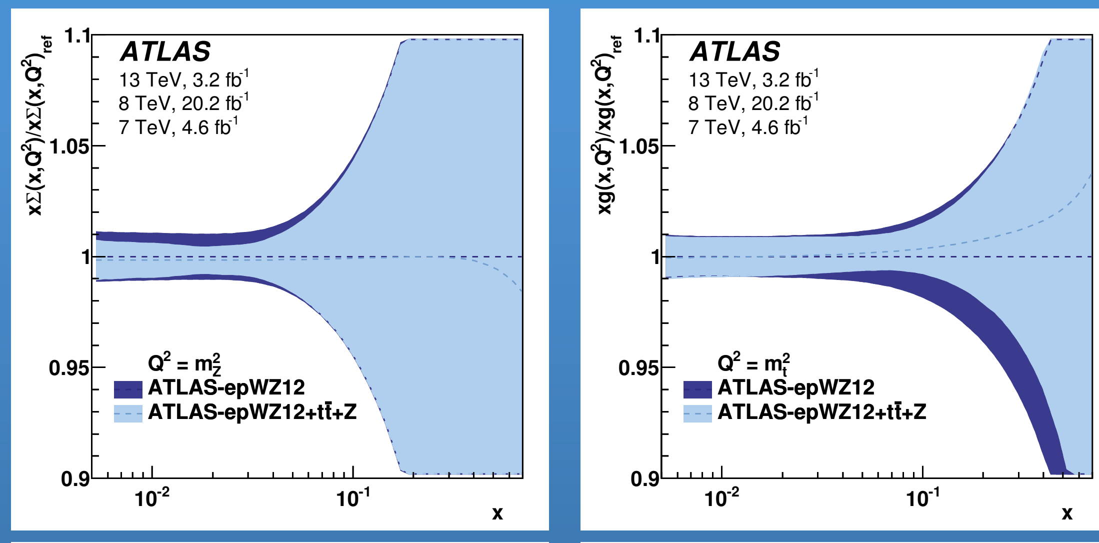
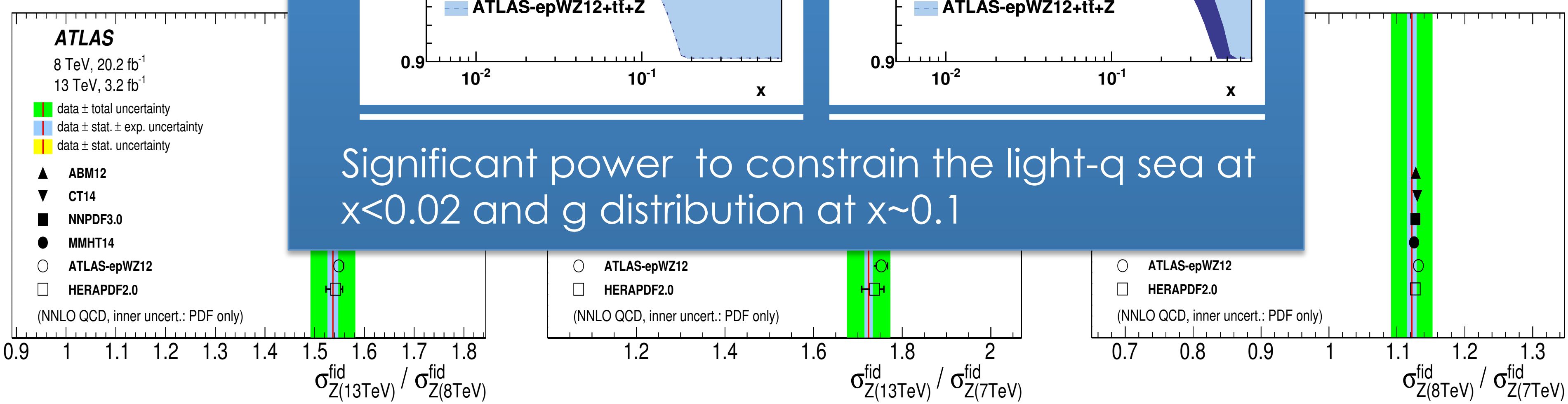
Z cross sectio

JHEP 02 (2017) 117



Significant power to constrain the light-q sea at x<0.02 and g distribution at x~0.1

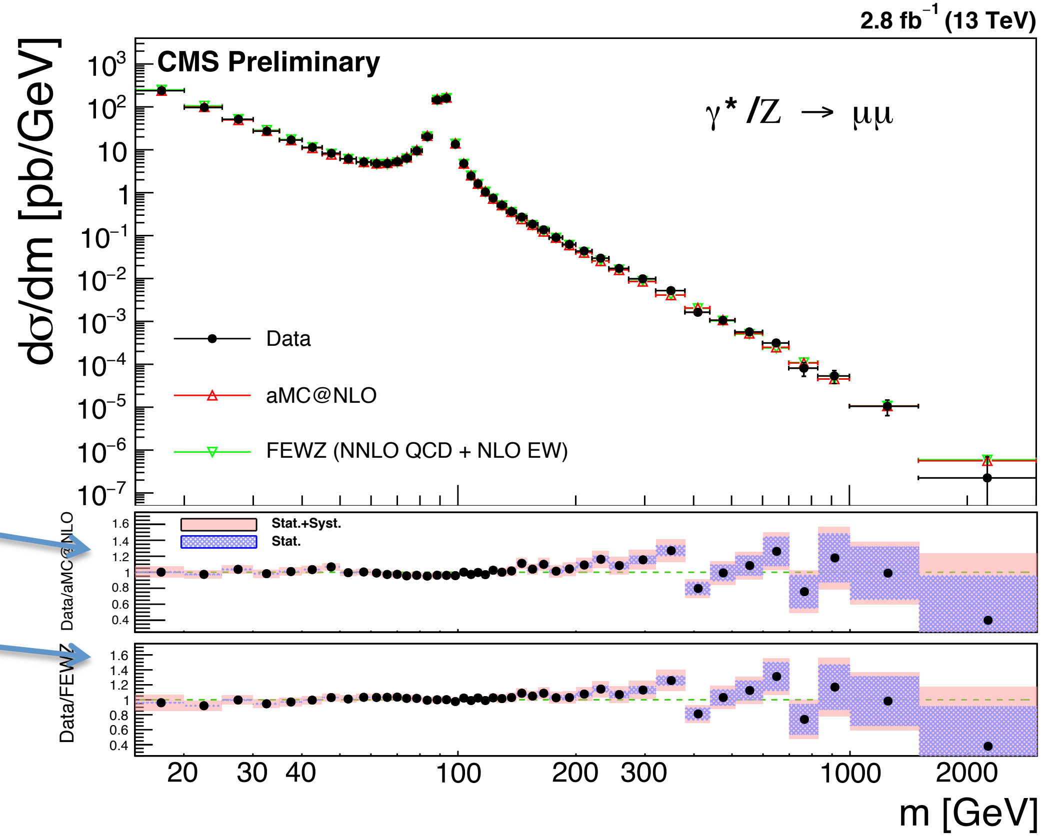


PDF uncertainty small → a precision test for understanding the energy evolution

13 TeV production cross section -

CMS-PAS-SMP-16-009

Drell-Yan cross section ($15<m_{ll}<3000$ GeV) via s-channel exchange of γ^*/Z bosons



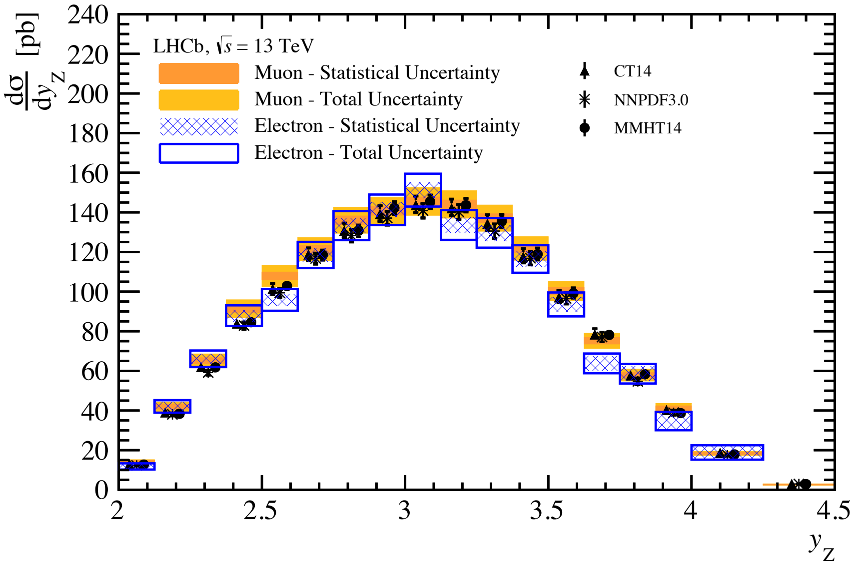
Good agreement with the SM theoretical predictions NLO predictions calculated with aMC@NLO and NNLO predictions calculated with FEWZ

x region probed $10^{-4}<x<1$

Z production -

JHEP 09 (2016) 136

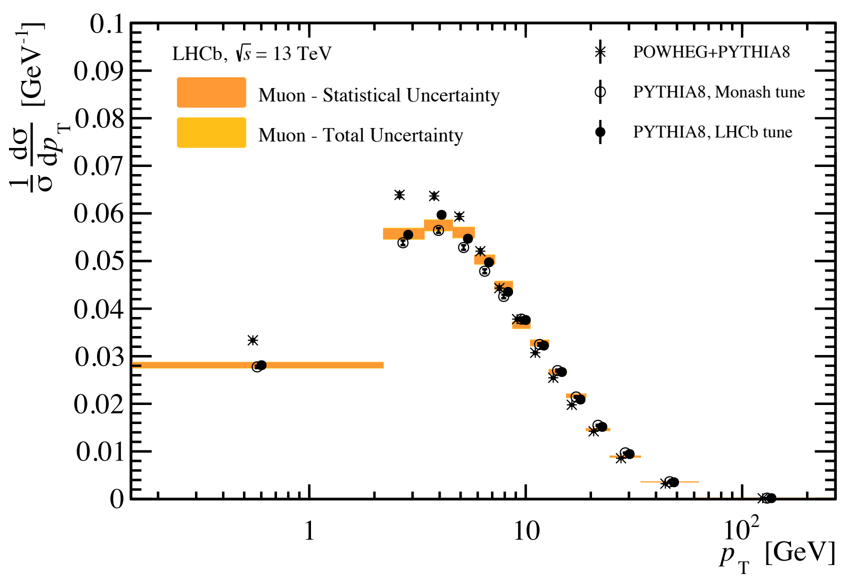
leptonic final states: Z→ μμ and Z→ ee

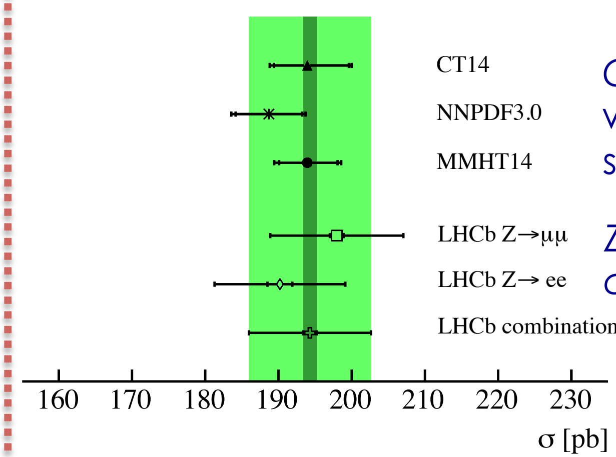


Data points

$O(\alpha_s^2)$ predictions with different PDF sets, generators or tune

Differential cross section combined with predictions





$O(\alpha_s^2)$ predictions with different PDF sets

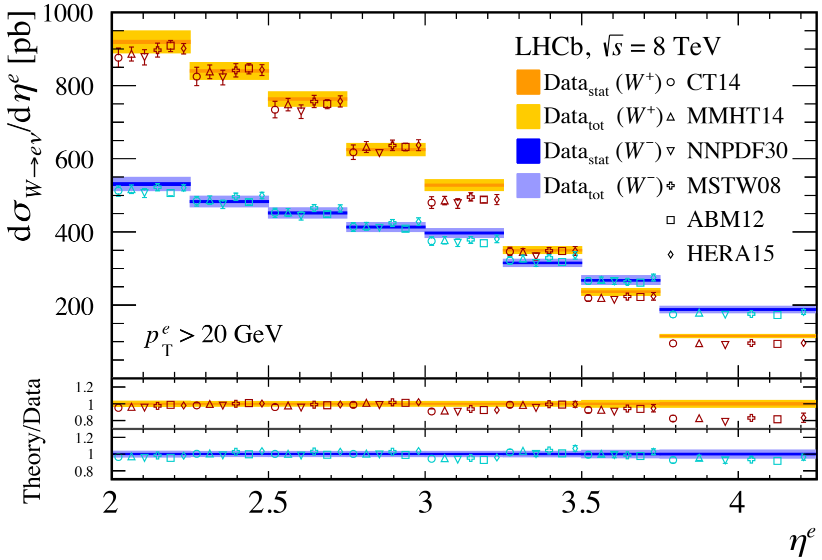
Z→ μμ and ee compatible

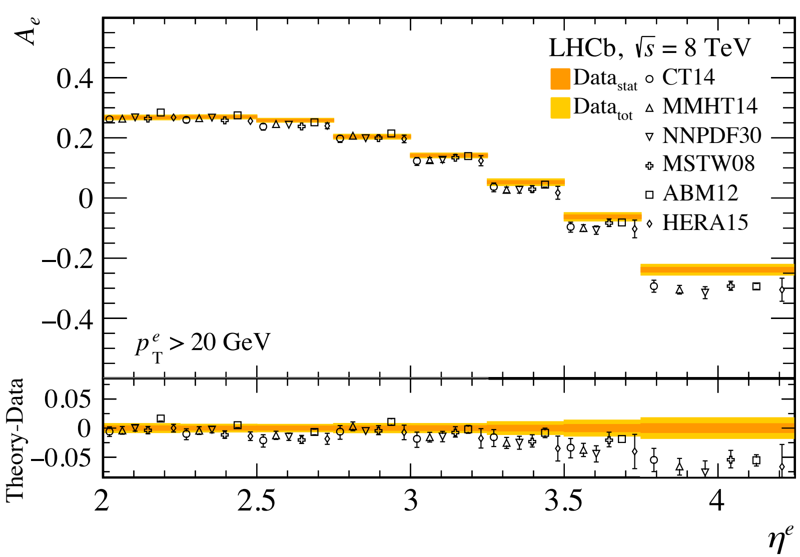
Integrated xsection

W production - LHCb

JHEP 10 (2016) 030

W→ eν





NNLO predictions with different parameterizations of the PDFs

Overall the measurements are compatible with the theory predictions.
Discrepancy (3σ) seen for W^+ cross section in the very forward region

$$A_e \equiv \frac{\sigma_{W^+\to e^+\nu_e} - \sigma_{W^-\to e^-\bar{\nu}_e}}{\sigma_{W^+\to e^+\nu_e} + \sigma_{W^-\to e^-\bar{\nu}_e}}$$

Change in sign of asymmetry due to V – A structure of weak force

It extends ATLAS and CMS measurements into the forward region

Lepton (e–μ) universality in the weak vector-boson decays

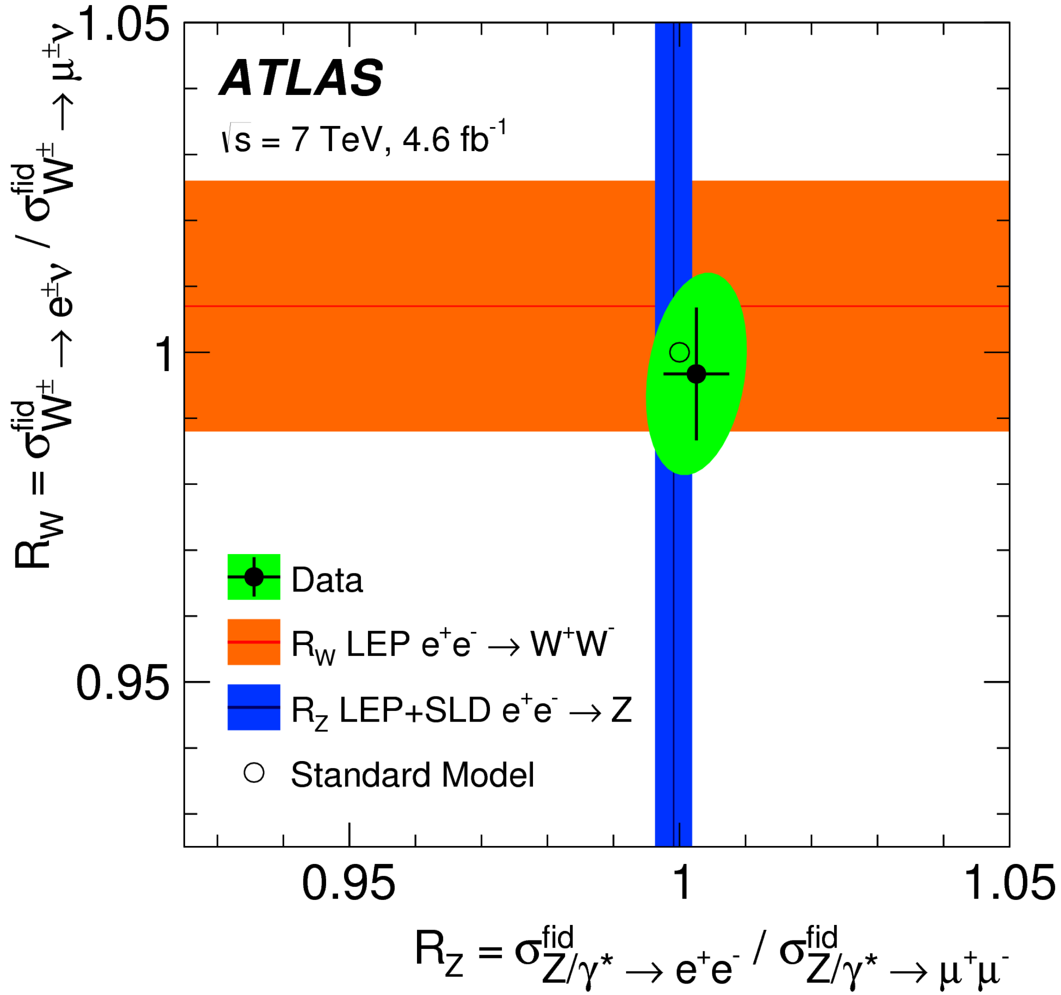
EPJ C 77 (2017) 367

Measurement of the electron-to-muon cross-section ratios for the W and Z production

SM expectation of $R_W=R_Z=1$

The ellipse represents the 68% CL for the correlated measurement of R_W and R_Z

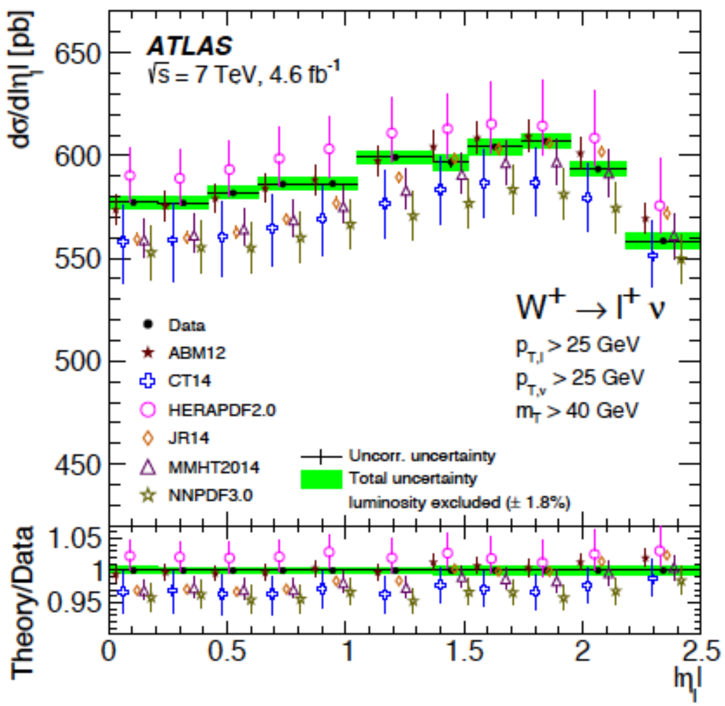
Well confirmed!



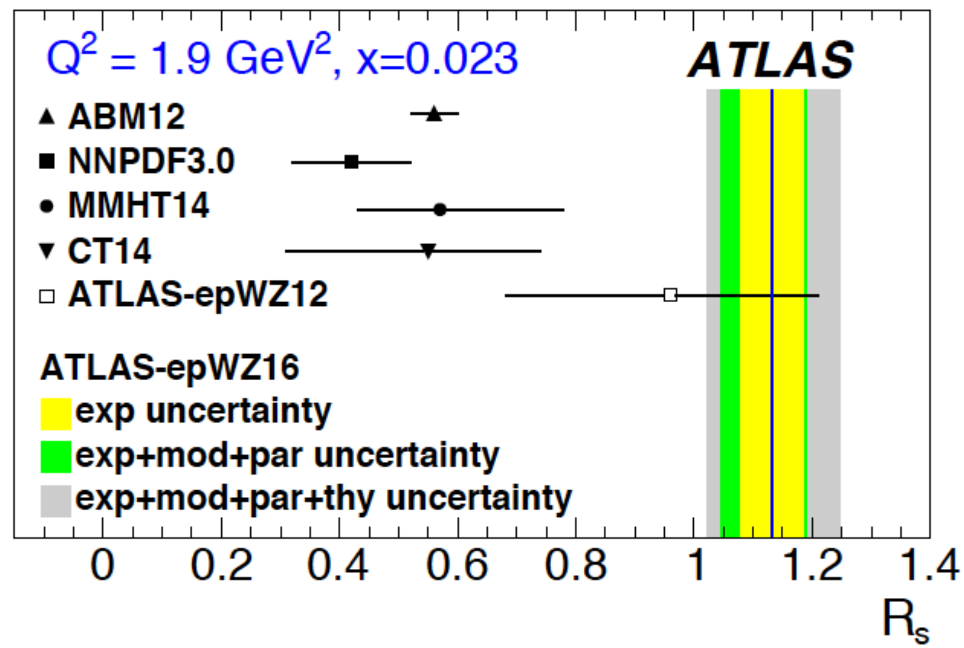
The strangeness content of the proton by ATLAS EXPERIMENT

EPJ C 77 (2017) 367

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



Deviations of the predictions obtained with many PDF sets, hint to a special impact of the data on the determination of the quark distributions, in particular on the strange

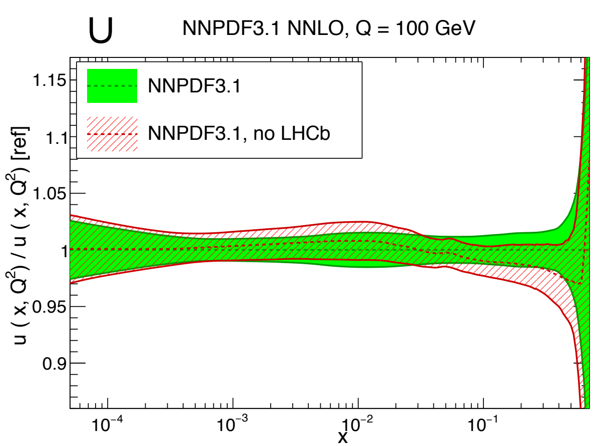


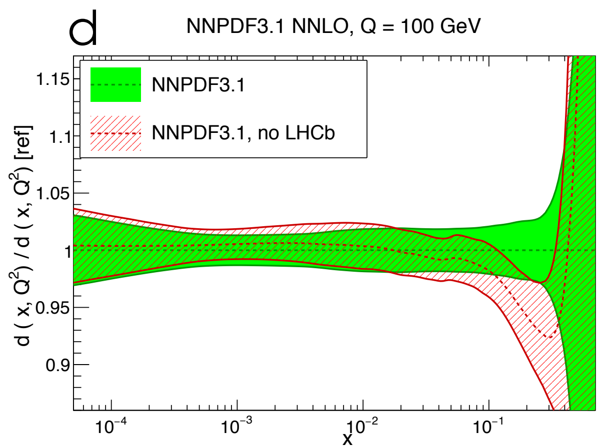
- Global fit results favour suppression of strangeness
- Data suggest more strange than up and down sea quarks in the proton
  → Difficult to explain by non-perturbative QCD arguments

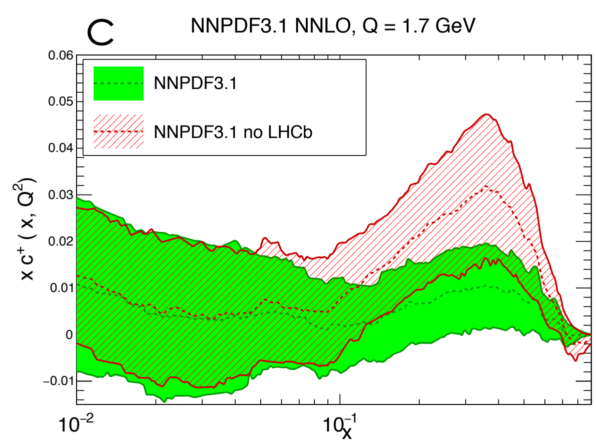
PDF constraints by LHCb data

arXiv: 1705.04468

Because of the longitudinal boost required for a W,Z boson to be produced in the forward region, LHCb results are particularly sensitive to effects at low and high values of x







-shift of the central values
-uncertainties are reduced up to a factor 2, more marked at large x

Models where non-perturbative charm can carry much more than 1% of the total proton's momentum are strongly disfavoured

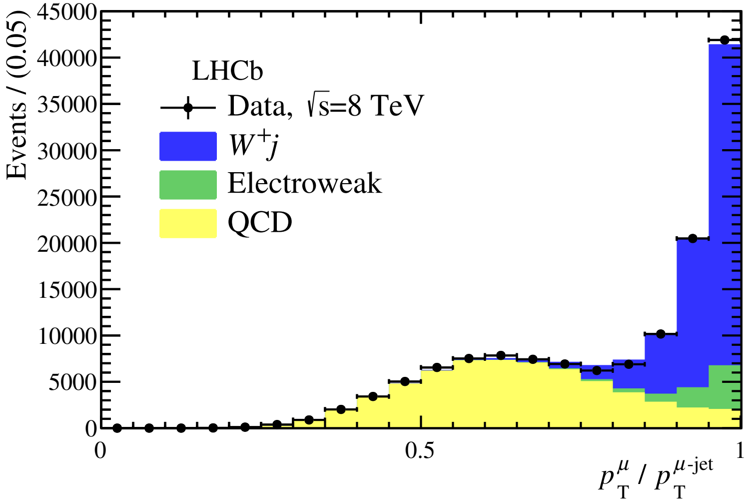
Measurements

- Inclusive
- Vector Boson + Jet
- Vector Boson + Heavy Flavour Jet

W and Z + jet production at LHCb

W→ $\mu\nu$, Z→ $\mu\mu$, jet → anti-k_T with R=0.5

JHEP 05 (2016) 131



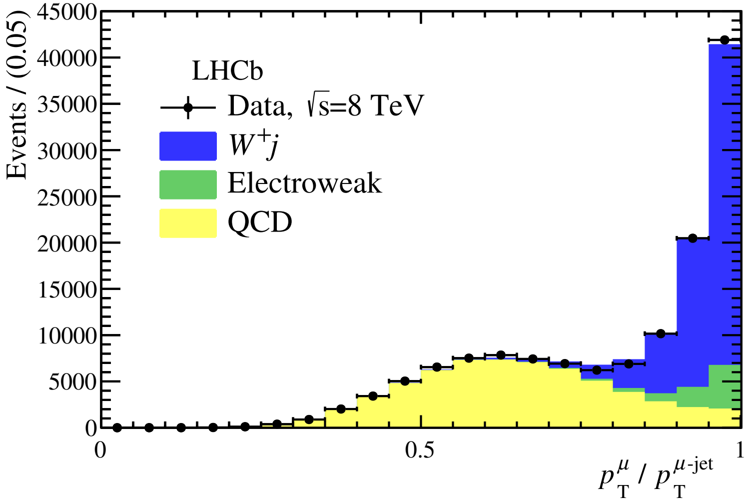
Benchmark for the jet reconstruction at LHCb

Different contributions by NLO predictions (MCFM)

W and Z + jet production at LHCb

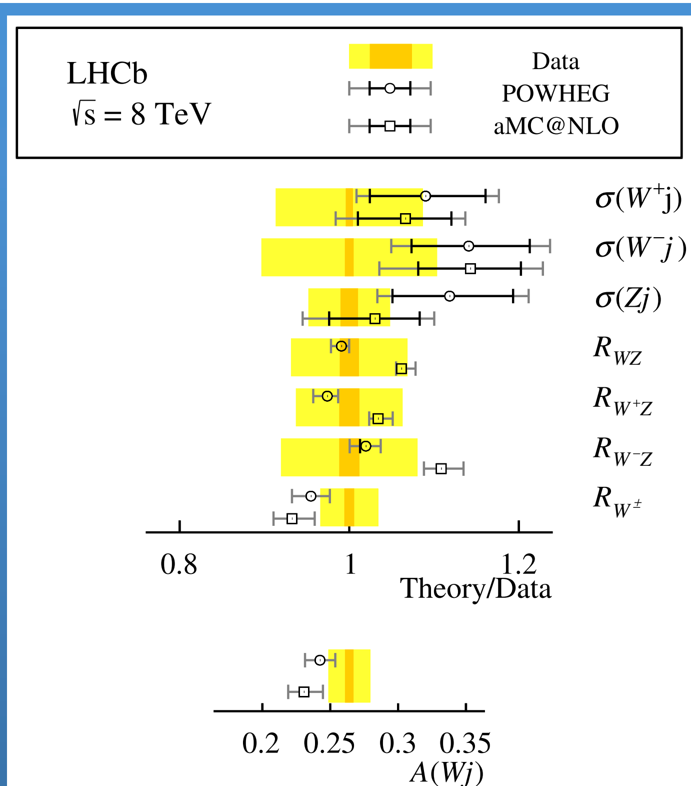
W→ $\mu\nu$, Z→ $\mu\mu$, jet → anti-k_T with R=0.5

JHEP 05 (2016) 131



Benchmark for the jet reconstruction at LHCb

Different contributions by NLO predictions (MCFM)

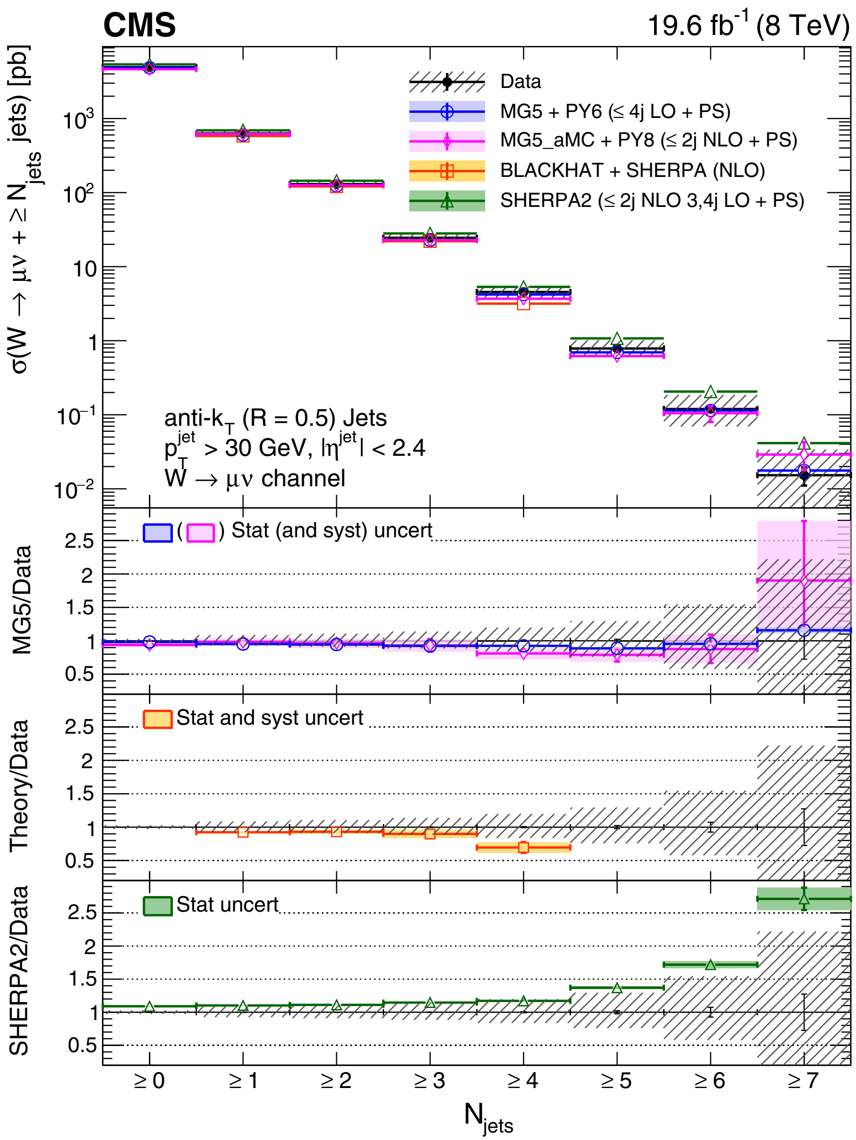


Measurements are in good agreement with POWHEG and aMC@NLO predictions

W + jet at CMS

W→ μν + jet (anti-k_T with R=0.5)

PRD 95 (2017) 052002



- Comparison over 30 different differential distributions
- Comparison to different MC varying the factorization and renormalization scales by a factor of 0.5 or 2

The predictions generally describe the jet multiplicity within the uncertainties

QCD splitting at ATLAS EXPERIMENT

JHEP 08 (2017) 026

Jet k_T algorithm (R=0.4, R=1.0) combines particles using:

$$d_{ij} = \min\left(p_{\mathrm{T},i}^2, p_{\mathrm{T},j}^2\right) \times \frac{\Delta R_{ij}^2}{R^2}$$

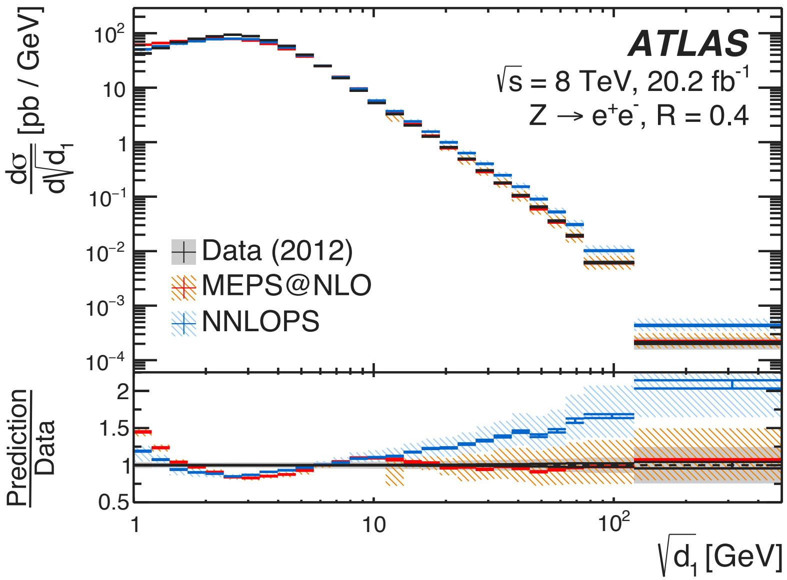
Splitting scale d_k with k the order of the scale

$$d_k = \min_{i,j}(d_{ij}, d_{ib}).$$

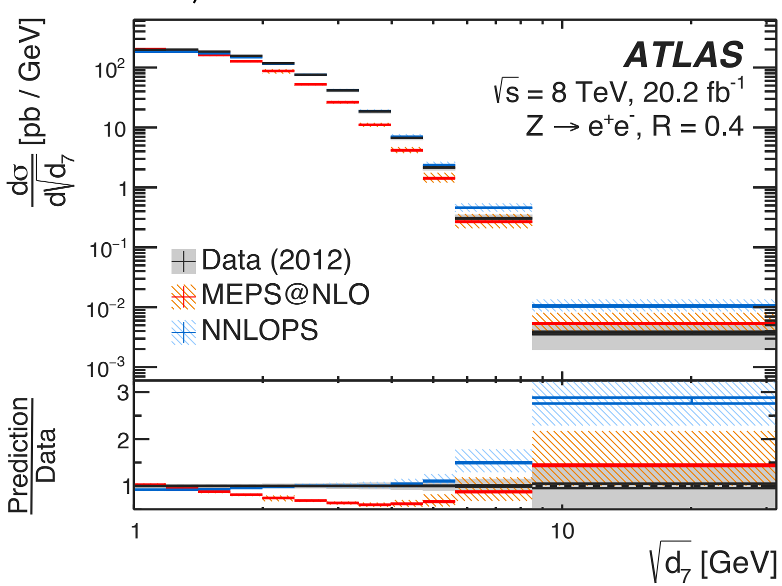
- Distributions sensitive to both hard and soft non-perturbative QCD

Clear discrepancy between data and theory at low scales

d_1



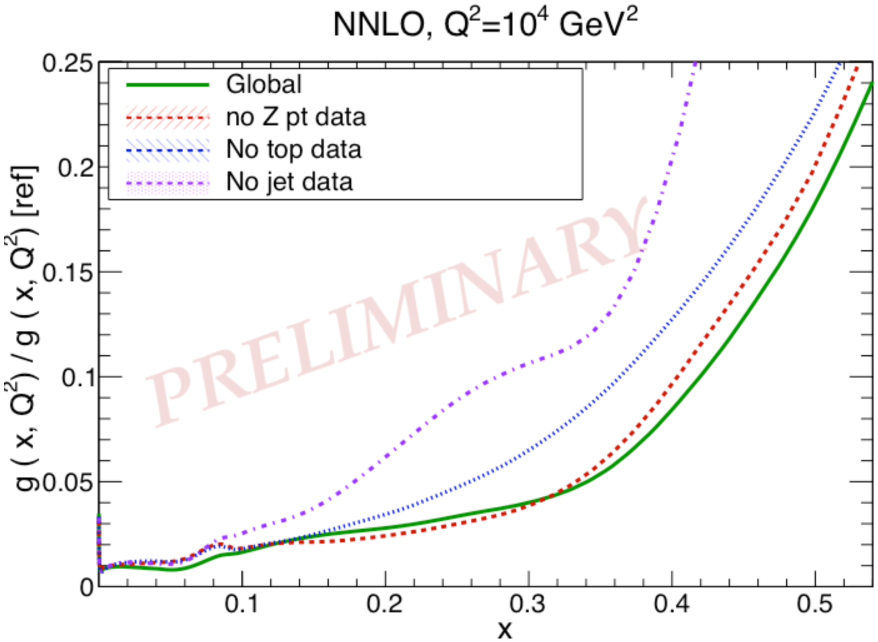
d_7

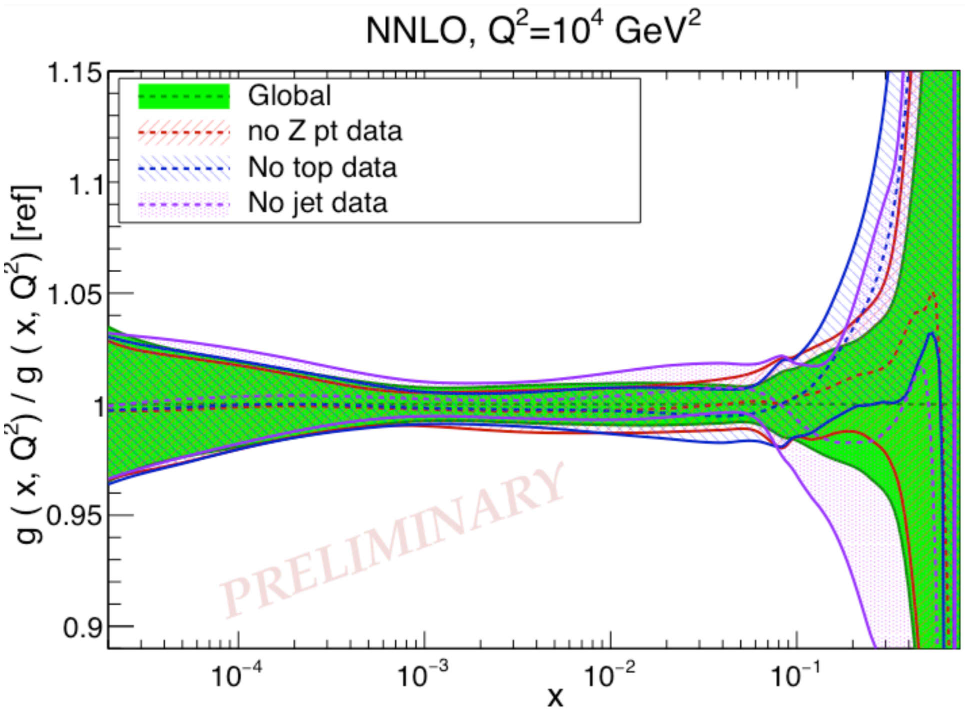


Impact on the gluon distribution for NNPDF3.1

arXiv 1706.00428

The best precision in the large-x gluon description is achieved by combining jets, top-pair and Z pt data





Measurements

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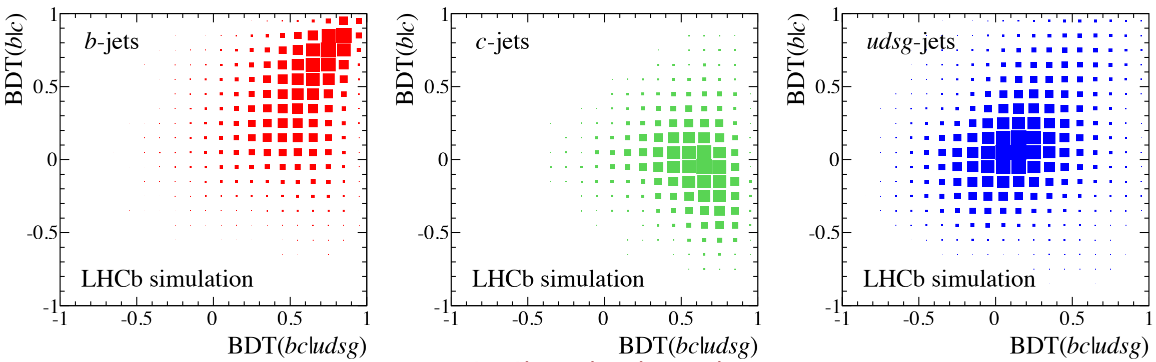
- Vector Boson + Jet
- Vector Boson + Heavy Flavour Jet

Jets heavy flavour identification at LHCb

JINST 10 (2015) P06013

Jets reconstructed if secondary Vx compatible with c or b-hadron decay and within the jet radius 0.5

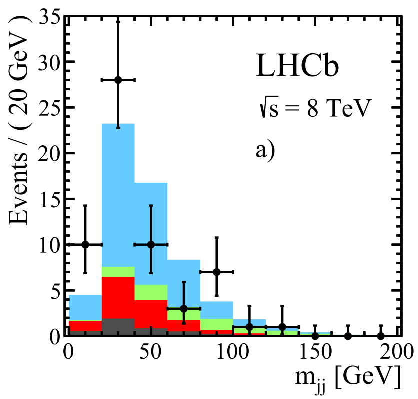


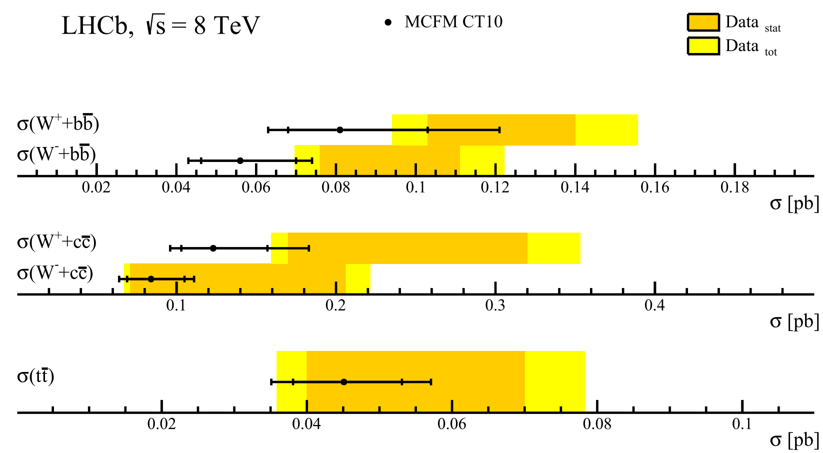
Boosted Decision Tree:
-BDT(bc | udsg) separates HF from L-jets
-BDT(b | c) separates b from c-jets

Very good discriminating power

W→ e/μ ν + 2 HF jet (anti-k_T with R=0.5)

PLB 767 (2017) 110





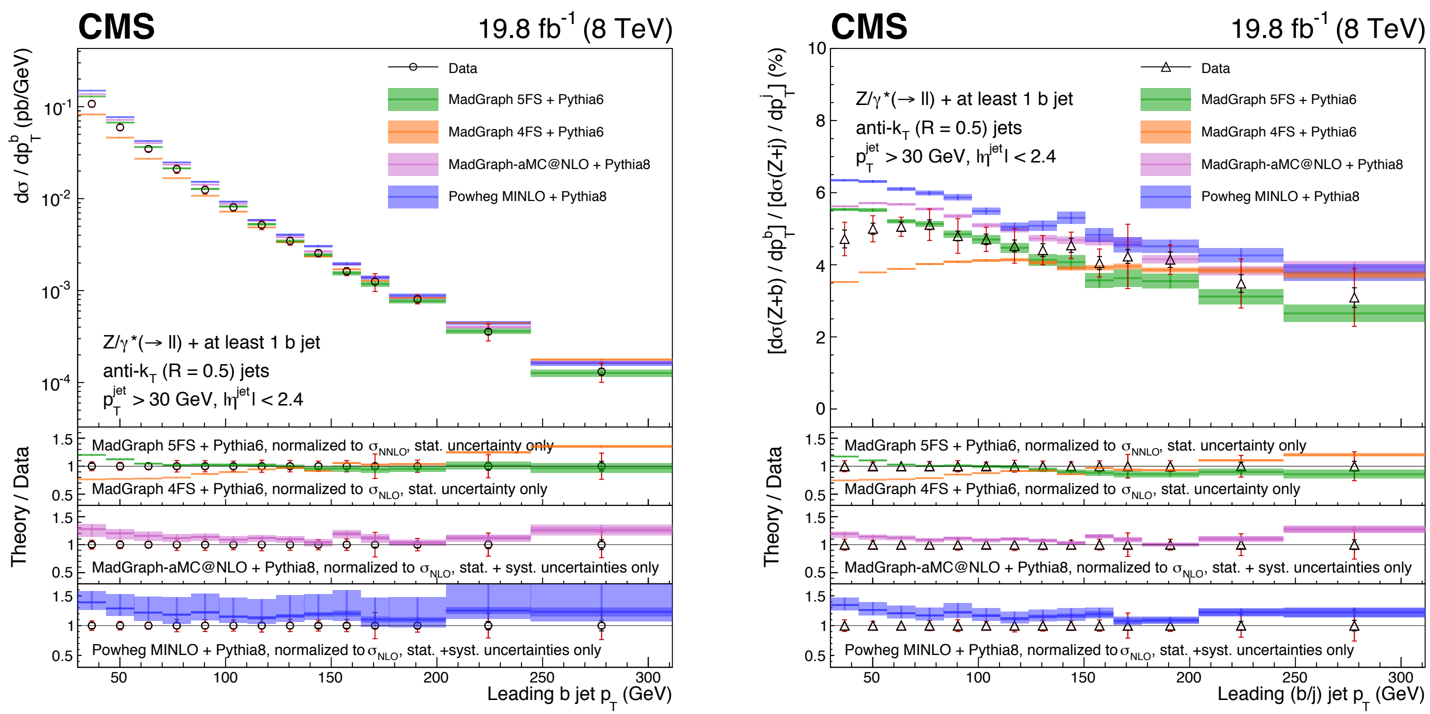
-W+cc̄ is the first of its kind
-top production in W+b final state, very sensitive at high-x for gluon PDF

cross-sections in agreement with the SM predictions calculated at NLO using MCFM and CT10 PDF set.

Z+b-jet production at CMS

EPC J 77 (2017) 751

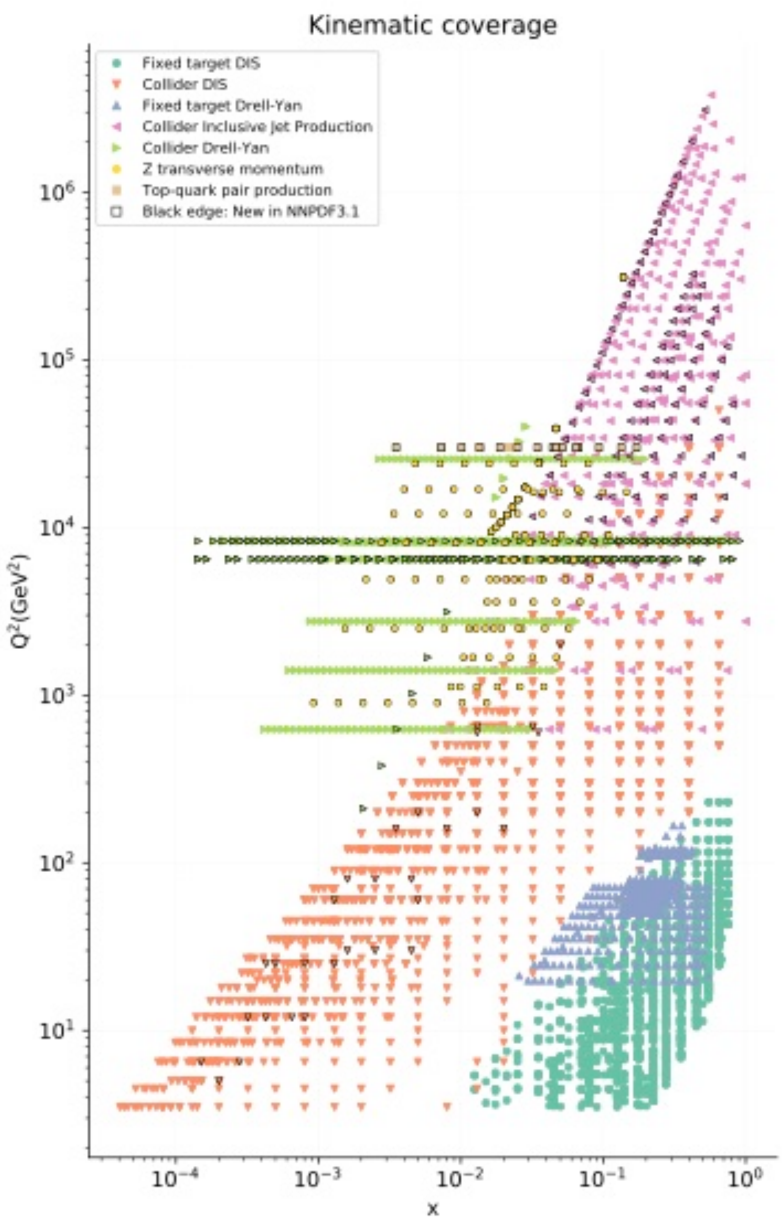
b-jets discriminated from lighter-jets using fit to mass of secondary vertex within jet

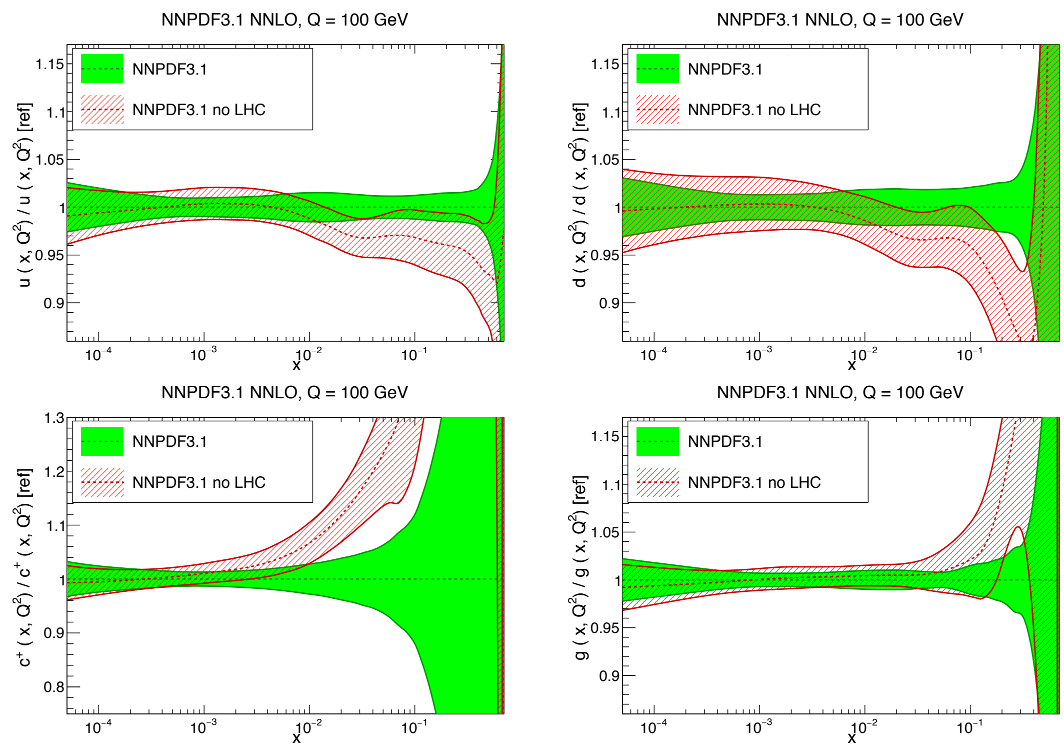


theoretical predictions agree with the data, although MADGRAPH event generator fails to describe simultaneously both the low- and high-p_T b-jet regions

The ratios of differential cross sections for the production of a Z boson in association with at least one b-jet and the inclusive Z+jets production shows clear discrepancies between theory and data in softer regime

Impact of the LHC data on NNPDF (an example)





Most PDFs are affected at the one-sigma level and in some cases (such as the down and charm quarks) at up to the two-sigma level

PDFs remain considerably more accurate after LHC and should be used for precision phenomenology

Conclusions

ATLAS, CMS and LHCb access the electroweak sector in a very precise and complementary way

-Inclusive measurements put important constraints on the PDFs providing precision information on the inner structure of the proton. Some intriguing discrepancies?

-Jets coupled to the Vector Boson production are able to create the interplay between pQCD in parton showers and hard matrix elements

-Heavy Flavour tagging adds more information on PDFs and reduces the background processes

Conclusions

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-Jets coupled to the Vector Boson production are able to create the interplay between pQCD in parton showers and hard matrix elements

-Heavy Flavour tagging adds more information on PDFs and reduces the background processes

These measurements provide a unique handle on the SM and on the structure of the proton, from the quark flavour separation at large-x, to the gluon distribution at small-x or to the constraint of the non-perturbative charm