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Physics Prospects for SM(QCD), PDFs and α_s

Workshop ATLAS Italia

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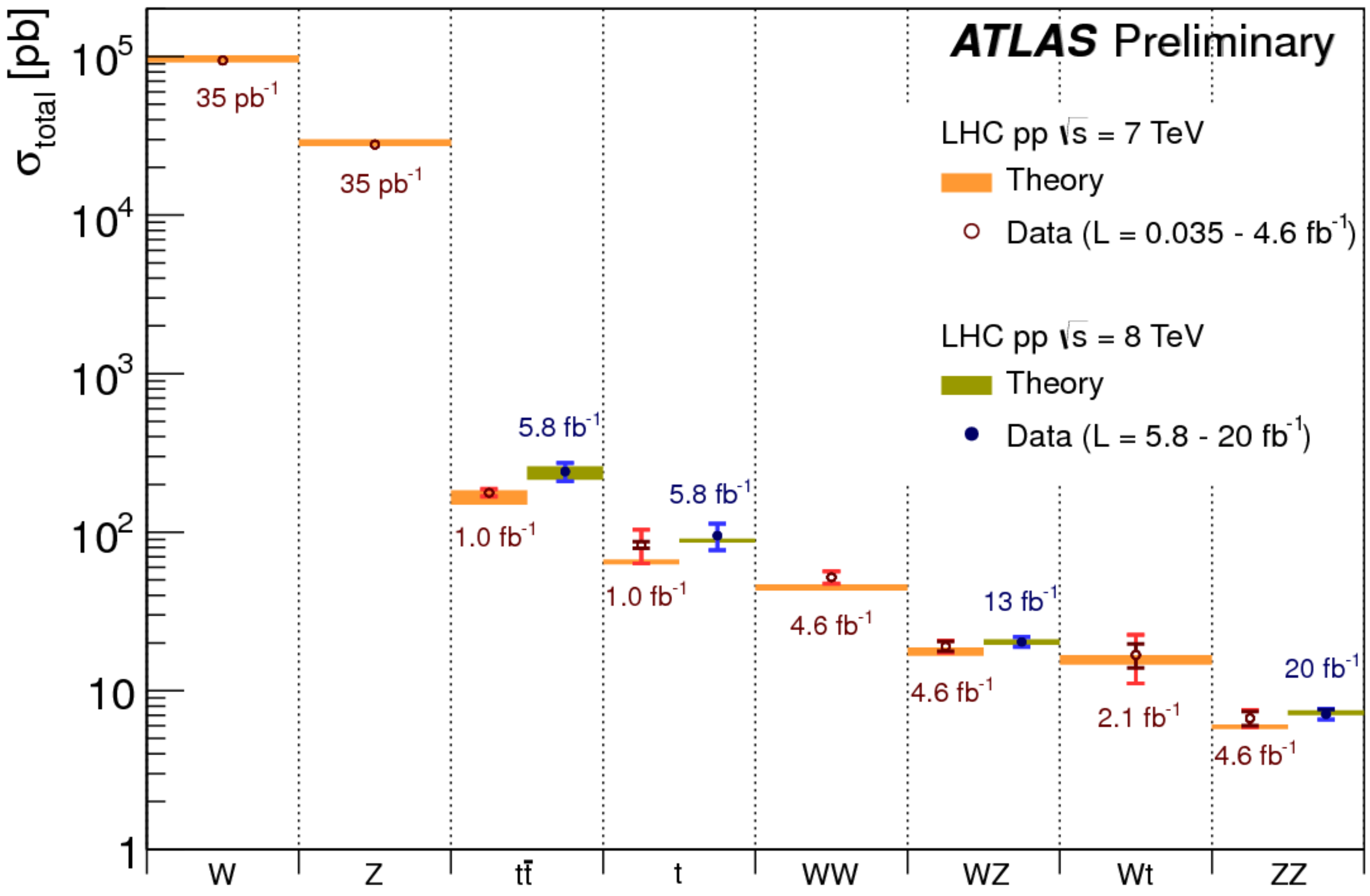
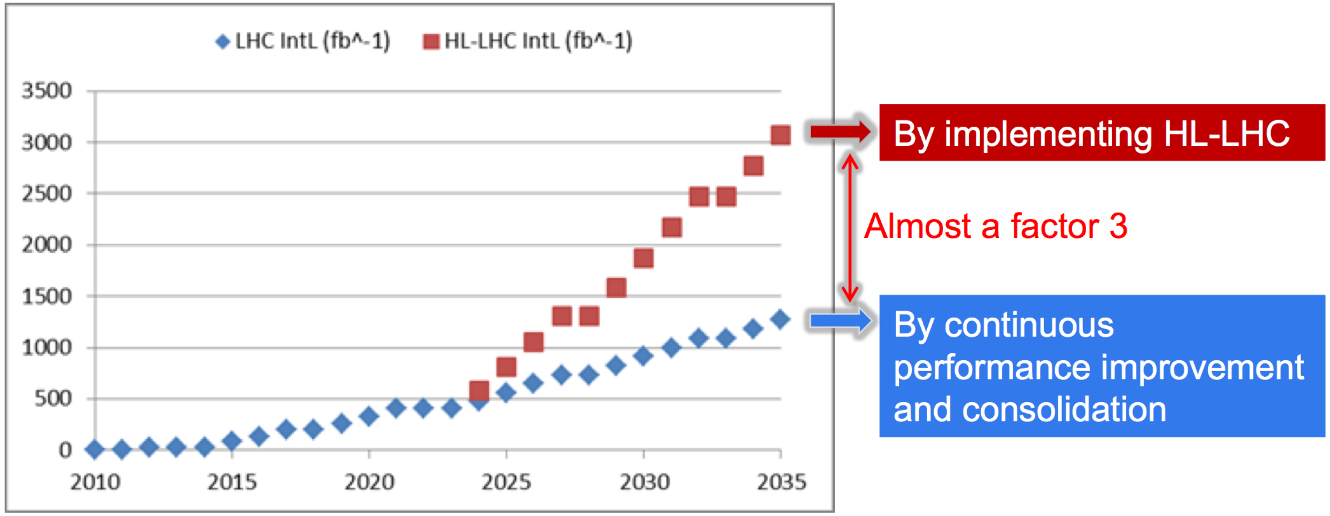
Introduction



Summary of SM total cross sections measurements compared to theory

Introduction



Run2 (and Run3) will focus on precision Higgs physics and BSM searches

However the huge data samples that will be collected by the LHC experiments will provide a unique opportunity to test the SM (QCD in particular) with an unprecedented precision

Will focus in the following on QCD (PDFs, Hadronic Jets and α_s)

Theoretical Framework

Collinear Factorization in Hadroproduction:

$$\sigma_X(s, M_X^2) = \sum_{a,b} \int_{x_{\min}}^1 \mathrm{d}x_1\, \mathrm{d}x_2\, f_{a/h_1}(x_1, M_X^2)\, f_{b/h_2}(x_2, M_X^2)\, \hat{\sigma}_{ab\to X}\left(x_1 x_2 s, M_X^2\right)$$

$$= \sum_{a,b} \sigma_{ab}^0 \int_\tau^1 \frac{\mathrm{d}x_1}{x_1} \int_{\tau/x_1}^1 \frac{\mathrm{d}x_2}{x_2}\, f_{a/h_1}(x_1, M_X^2)\, f_{b/h_2}(x_2, M_X^2)\, C_{ab}\left(\frac{\tau}{x_1 x_2}, \alpha_S(M_X^2)\right)$$

$$= \sum_{a,b} \sigma_{ab}^0 \int_\tau^1 \frac{\mathrm{d}x}{x}\, \mathcal{L}_{ab}\left(x, M_X^2\right)\, C_{ab}\left(\frac{\tau}{x}, \alpha_S(M_X^2)\right),$$

DGLAP Equations:

$$\frac{\partial}{\partial \ln Q^2} \begin{pmatrix} \Sigma(x, Q^2) \\ g(x, Q^2) \end{pmatrix} = \int_x^1 \frac{\mathrm{d}y}{y} \begin{pmatrix} P_{qq}^S\left(\frac{x}{y}, \alpha_S(Q^2)\right) & 2n_f P_{qg}^S\left(\frac{x}{y}, \alpha_S(Q^2)\right) \\ P_{gq}^S\left(\frac{x}{y}, \alpha_S(Q^2)\right) & P_{gg}^S\left(\frac{x}{y}, \alpha_S(Q^2)\right) \end{pmatrix} \begin{pmatrix} \Sigma(y, Q^2) \\ g(y, Q^2) \end{pmatrix},$$

$$\frac{\partial}{\partial \ln Q^2}\, q_{ij}^{\mathrm{NS}}\left(x, Q^2\right) = \int_x^1 \frac{\mathrm{d}y}{y} P_{ij}^{\mathrm{NS}}\left(\frac{x}{y}, \alpha_S(Q^2)\right) q_{ij}^{\mathrm{NS}}(y, Q^2),$$

Need precise predictions for hard scattering processes and PDFs

Sources of theoretical Uncertainty

Sources of uncertainty?

- **Missing higher orders** ("scale") in QCD and EW. **~ 10%**

  [Need higher-order inclusive X-sections]

- Extra QCD uncertainties in the presence of **cuts** (e.g. jet vetoes). **~ 10%**

  [Need higher-order differential X-sections, fixed-order, resummed & MC]

- **PDF uncertainties** (within/between groups), **~ 7%**

  [Need better data & better theory to interpret it]

- **Fundamental constants** (α_s, m_b, etc.) ~ few %

m_H (GeV)	Cross Section (pb)	+error %	- error %	+scale %	-scale %	+(PDF+α_s) %	-(PDF+α_s) %
125	49.85	19.6	-14.6	12.2	-8.4	7.4	-6.2

HXSWG gg→ H

LHC and proton's PDFs

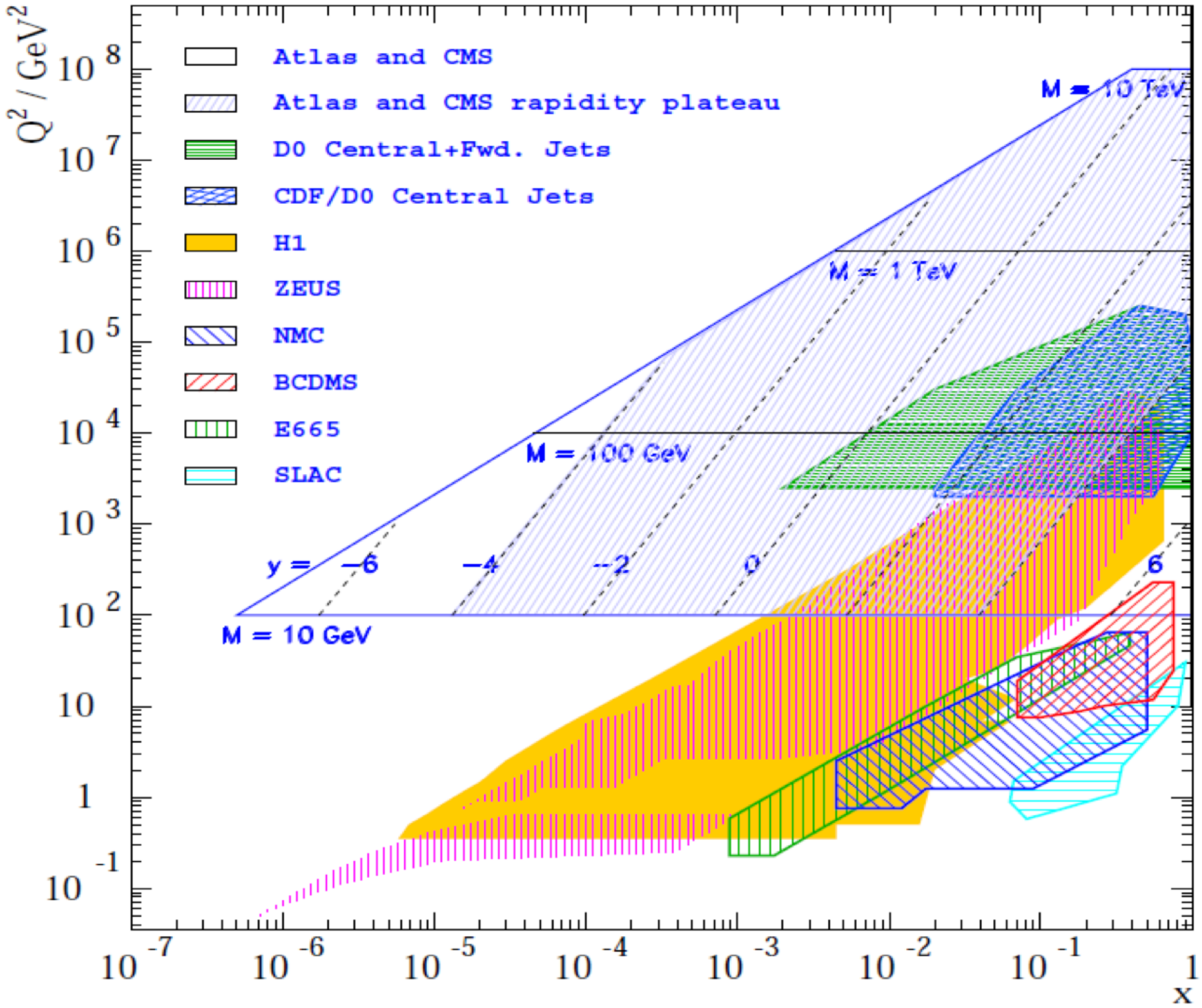
The LHC data have already started to provide new information on PDFs and this is going to be even more the case in the coming years.

It is Likely that in the next couple of decades most of the new constrains on PDF will come from the LHC (the only possible exception being the LHeC in case this machine is built).

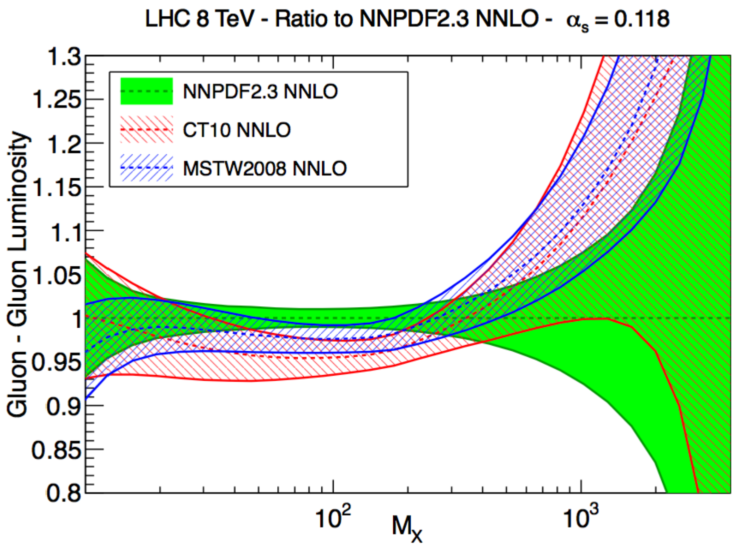
The accuracy required by the present and future global DGLAP fits demand the inclusion, in the future LHC measurements, of the full information on the correlation among systematic uncertainties.

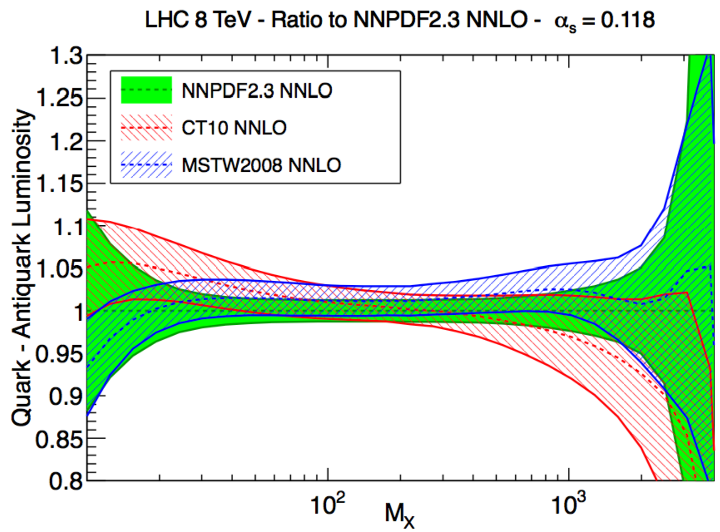
For Run 2 and 3 the LHC experiments should in addition converge on an agreed way to present the uncertainties and correlation of their measurements. This in order to ease combination (to avoid a proliferation of data sets to be included in DGLAP Fits).

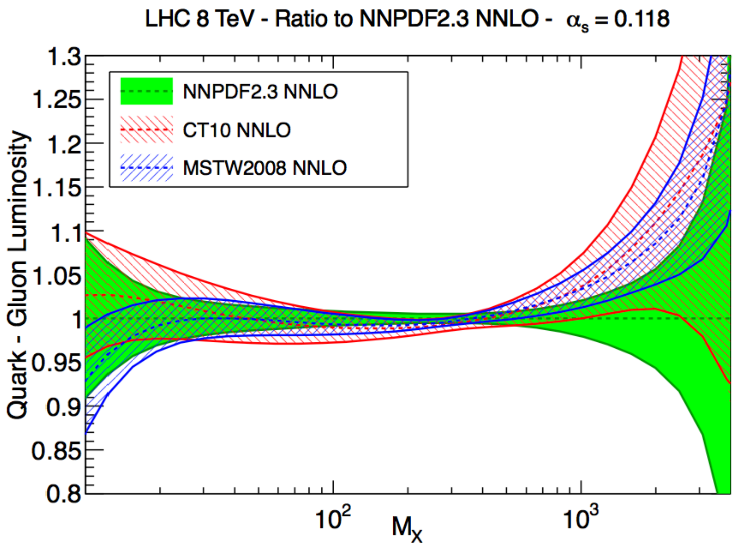
Q^2-x kinematic plane

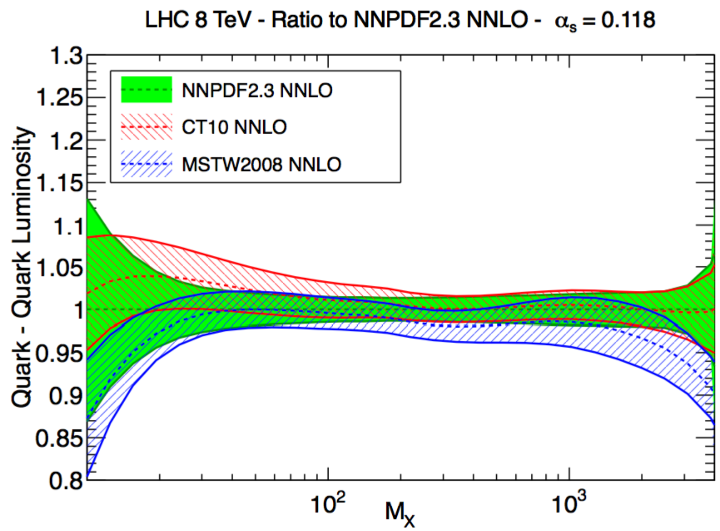


Parton Luminosities









LHC and proton's PDFs

In the following will try to high-light those observables that have the highest potential to improve our knowledge of the PDFs

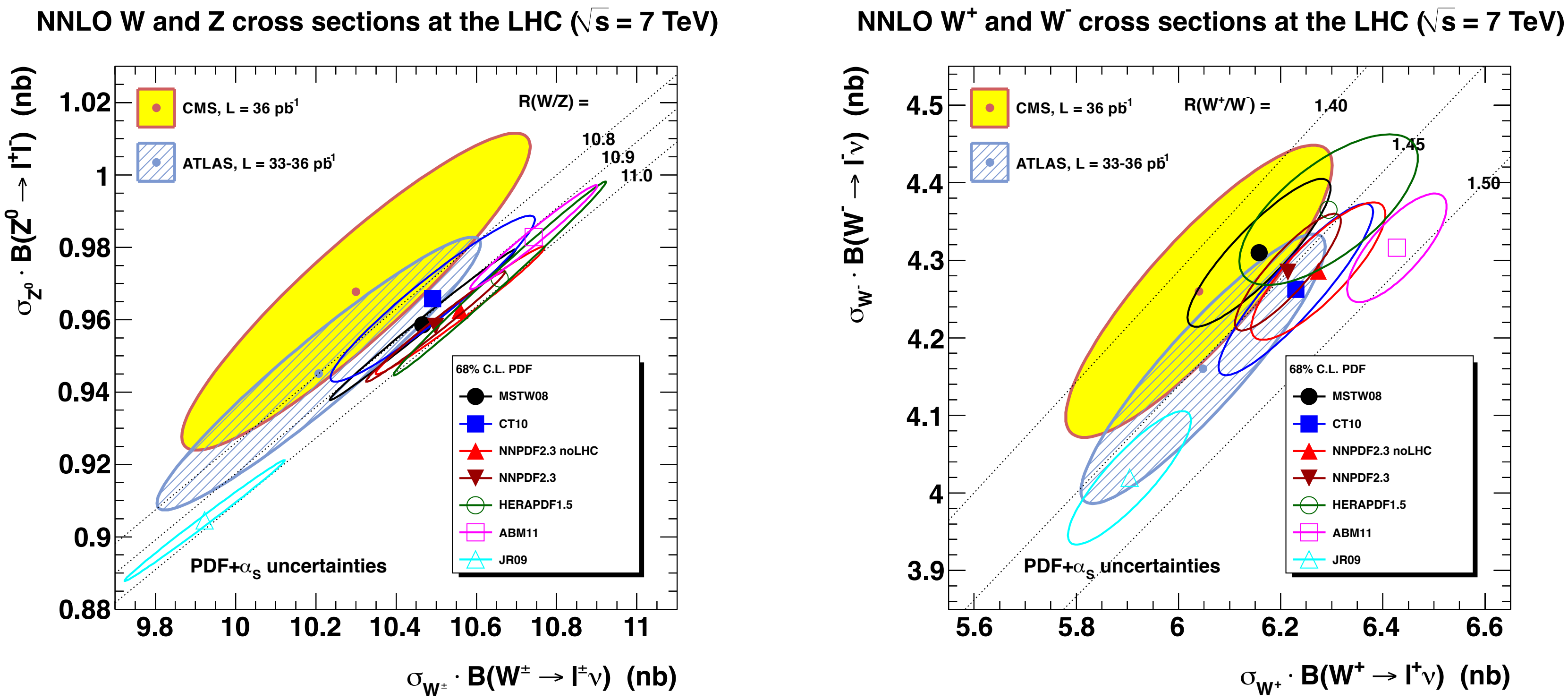
Will present, somewhat artificially, the various observable according to the 'most affected parton densities':

- Light quarks (valence, sea and strange)
- Gluon
- Heavy flavours

Caveat: only in a global fit one can fully quantify the correlations among PDFs and the full impact of the measured observables

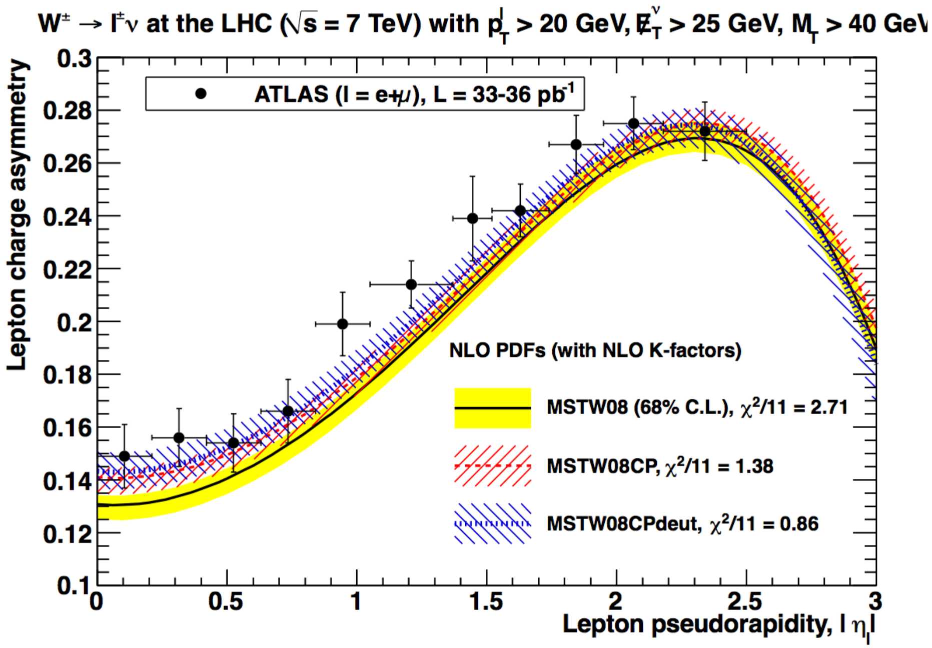
W and Z production

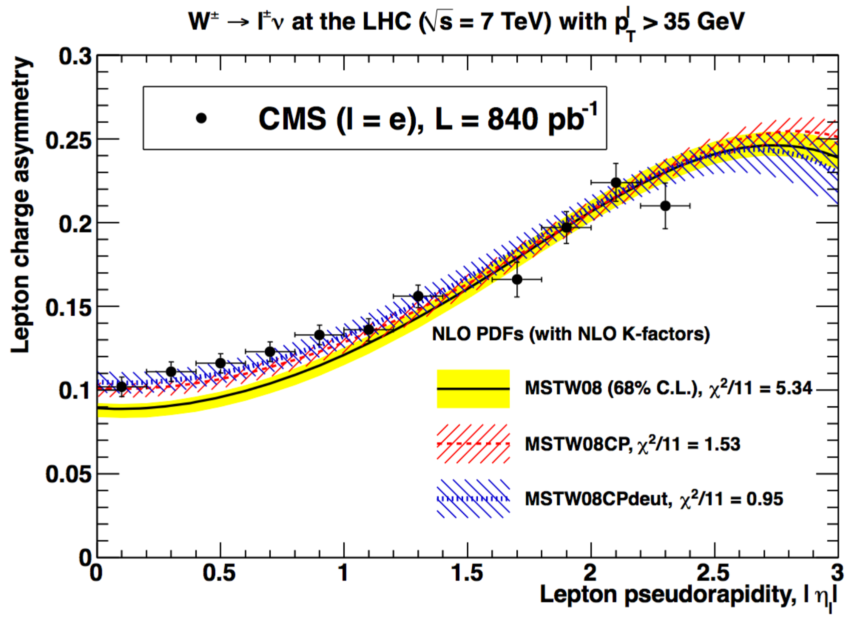
W and Z production: mostly diff (pT, η) distributions + asymmetries
Theory: NNLO(QCD) and EW contribution (NLO)



Charge Asymmetry

Sensitive to valence quarks (u_v, d_v): $$A_W \sim \frac{u_v - d_v}{u_v + d_v + 2\bar{q}}$$

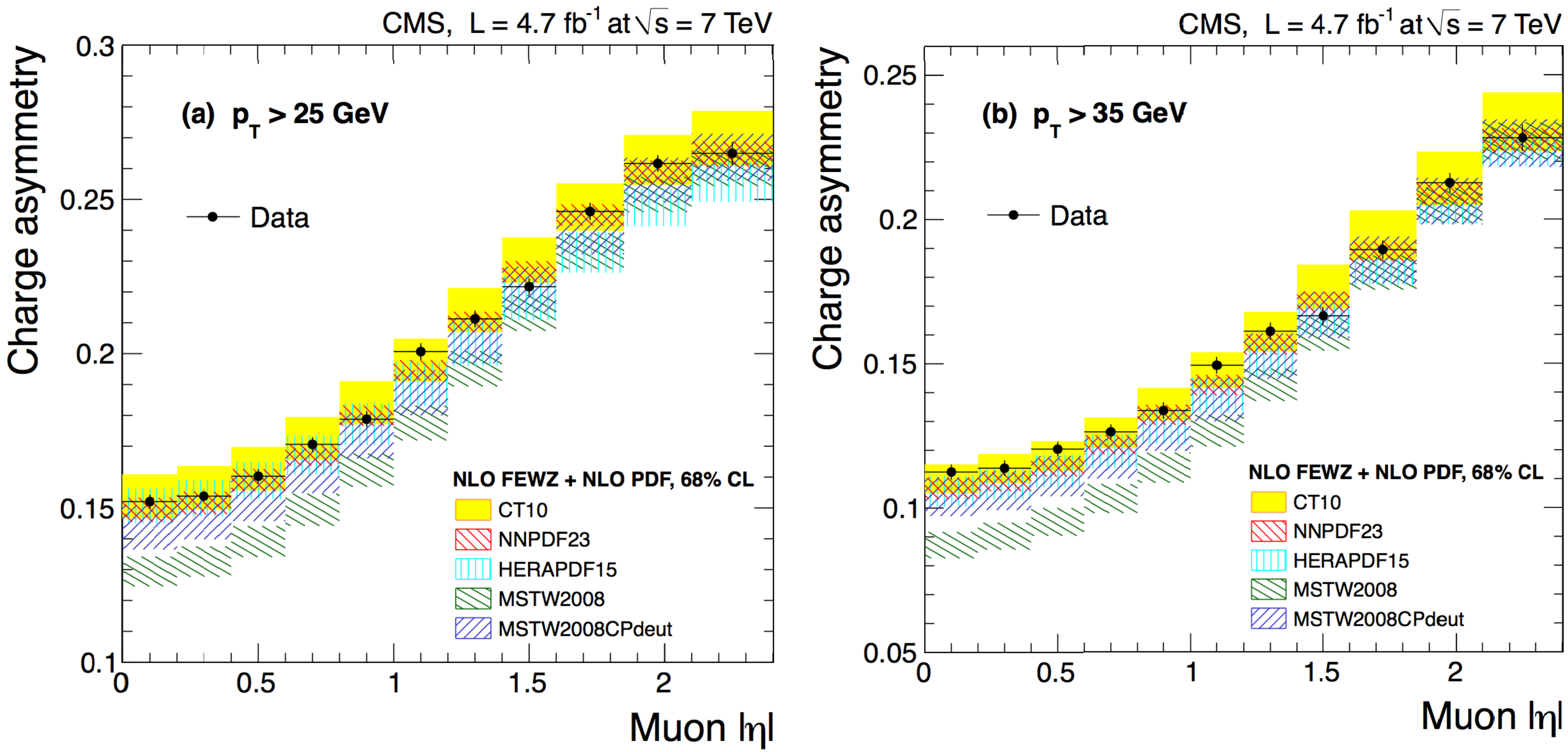




Early measurements prompted MSTW08 “fix” (MSTW08CPdeut)

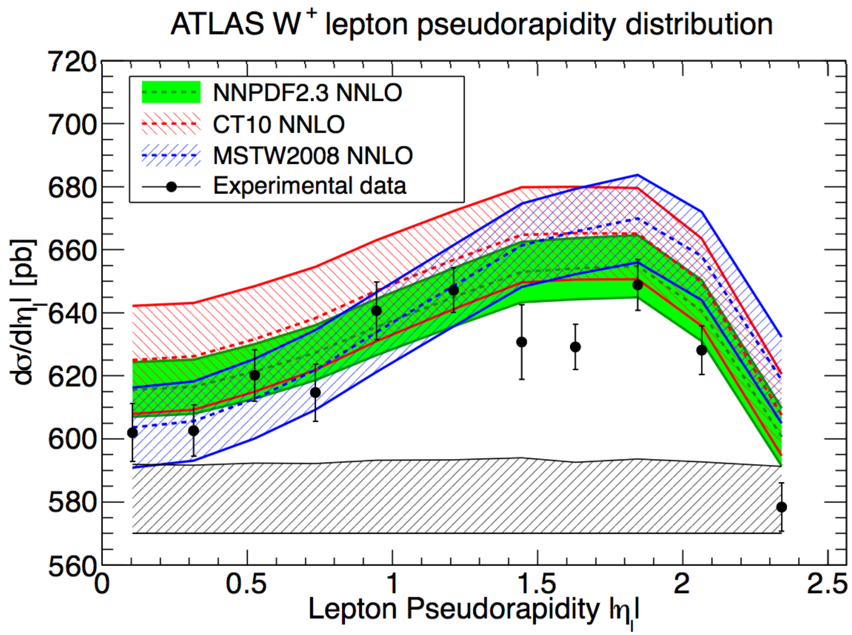
Charge Asymmetry

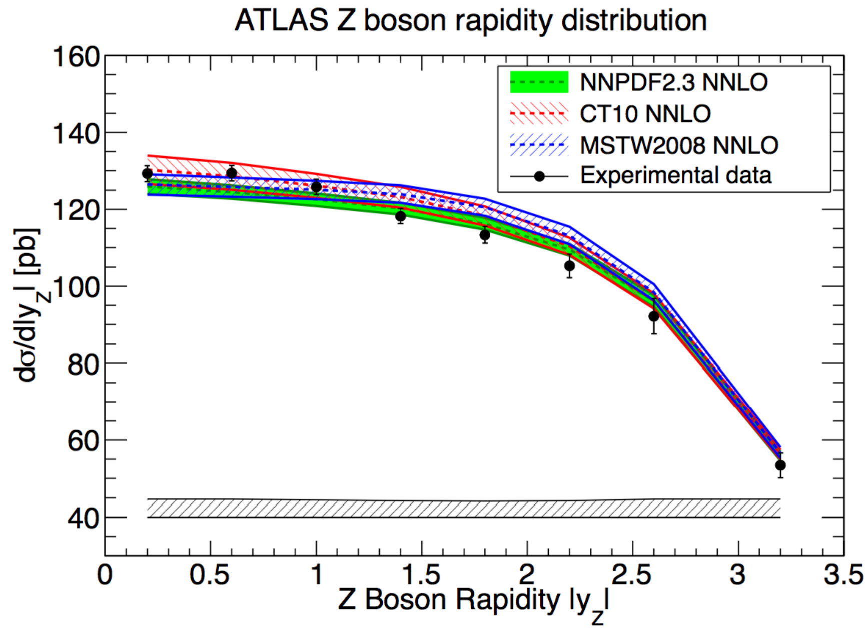
Latest CMS result (7 TeV - 4.7fb^{-1})

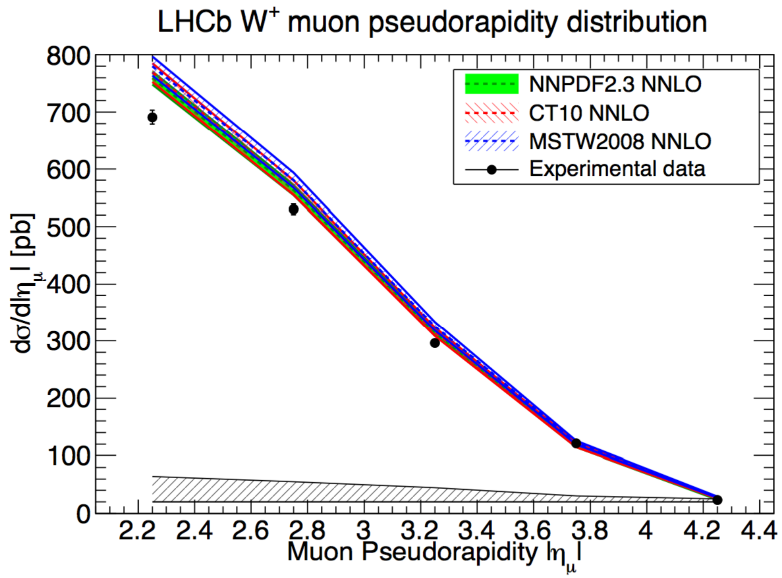


Precise enough to discriminate already among different PDFs sets

Drell-Yan Differential Cross sections

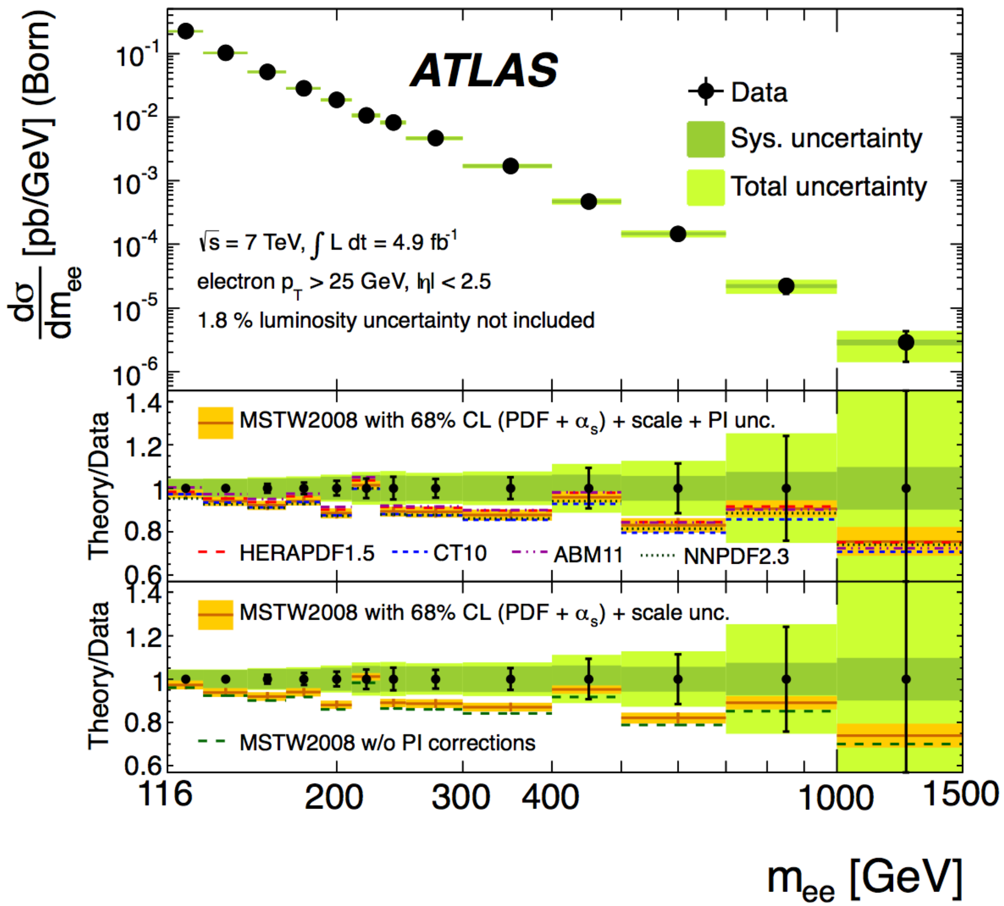






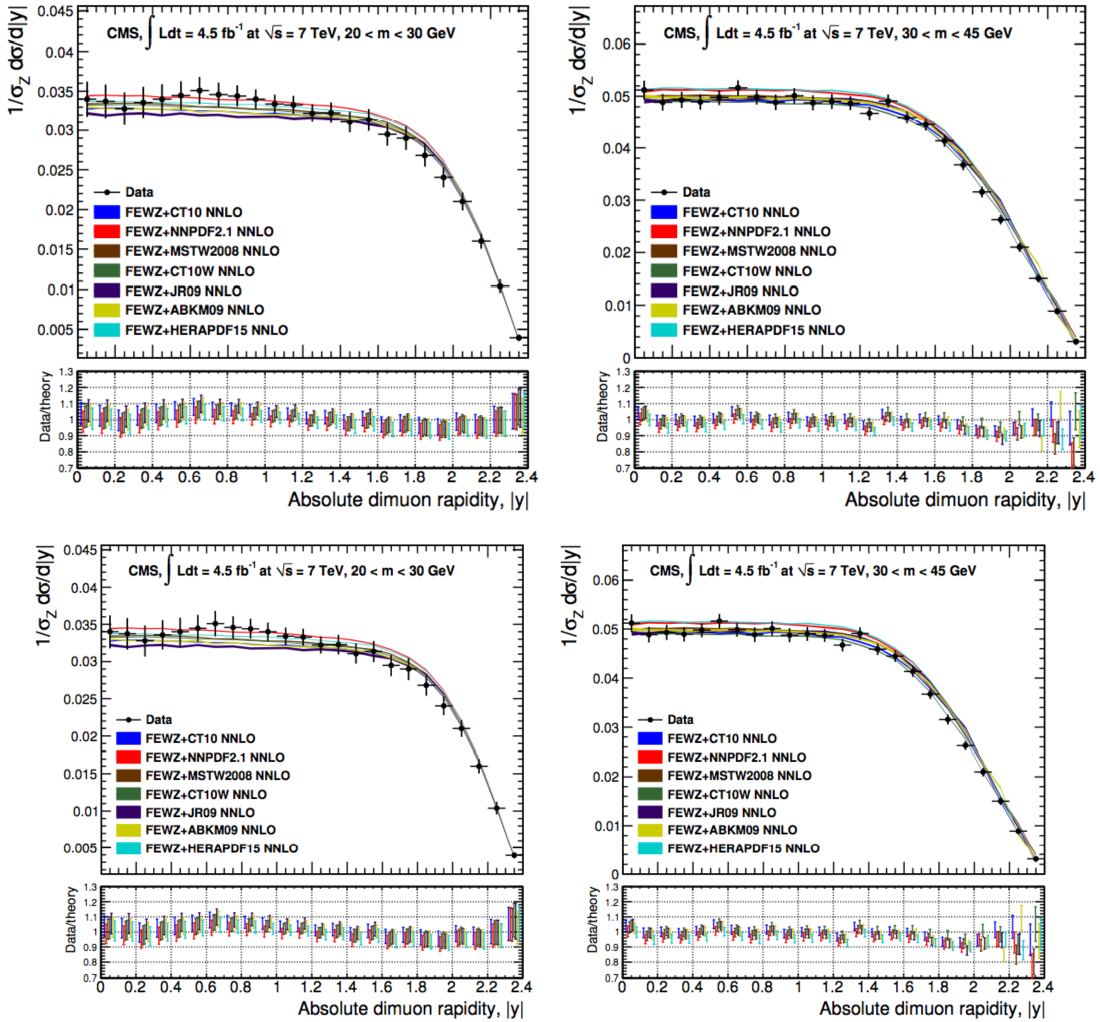
LHCb data probe complementary
Phase-space wrt ATLAS and CMS

High Mass Drell-Yan Cross sections



Data systematically above theory (NNLO(QCD)+EW(NLO)+PI)
Measurement have the potential to constrain PDFs (antiquarks at large x)

Low Mass DY Cross sections



Agreement in shape. Full correlations provided

Should we start considering to replace fixed target DY data with LHC ones?

Strange

W production provide handle on strangeness (Tevatron: s - sbar)

Do we confirm 'Strange suppression'? -> (CCFR/NuTeV dimuon cross sections)

ATLAS tried to address this issue by a DGLAP fit using W, Z diff cross sections combined with inclusive HERA Data:

$$\sigma(W) \sim c\bar{s} + \bar{c}s + \dots \quad , \quad \sigma(Z) \sim s\bar{s} + \dots$$

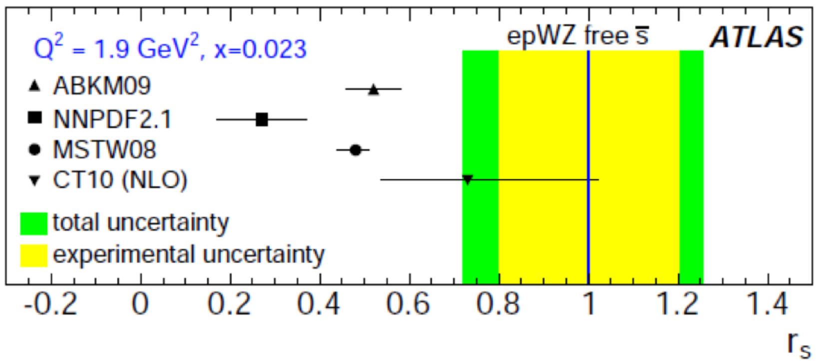
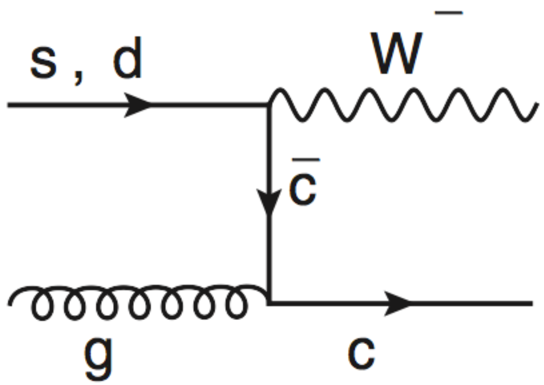
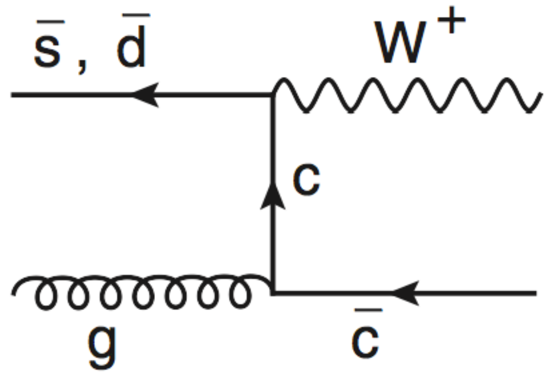


FIG. 2. Predictions for the ratio $r_s = 0.5(s+\bar{s})/\bar{d}$, at $Q^2 = 1.9\,\mathrm{GeV}^2$, $x = 0.023$. Points: global fit results using the PDF uncertainties as quoted; bands: this analysis; inner band, experimental uncertainty; outer band, total uncertainty.

Strange: From W+c production

A direct handle on strangeness come s from W production with an associated charmed-tagged jet or c-meson





ATLAS and CMS have presented recently interesting results

Strange: W+c production

Signature:

$W+c$

$l\nu$

where $l=\mu, e$

Requires the reconstruction of $D^{\pm}$ D^{*} in the inner detectors

$$D^{-}\rightarrow K^{+}\pi^{-}\pi^{-} \quad D^{*+}\rightarrow D^{0}\pi^{+}$$

with $D^{0}\rightarrow K^{-}\pi^{+}$ $D^{0}\rightarrow K^{-}\pi^{+}\pi^{0}$ $D^{0}\rightarrow K^{-}\pi^{+}\pi^{-}\pi^{+}$

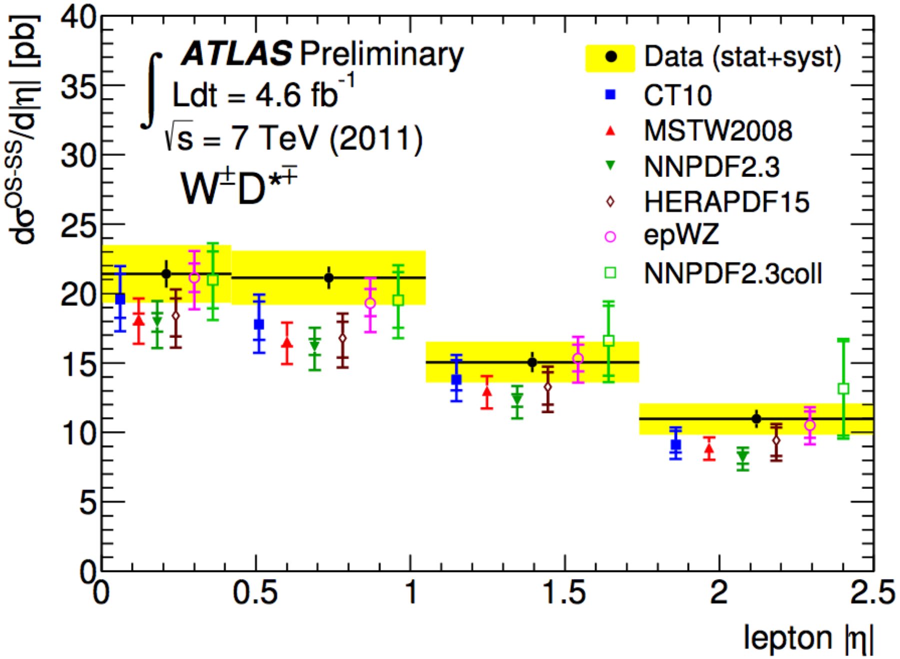
- ATLAS --> reconstructed tracks
- CMS --> Secondary vertices & jets
  the channel $c\rightarrow\mu+X$ is also considered

Background events like $W+c\bar{c}, W+b\bar{b}$ contribute to opposite charge sign (OS) and same sign (SS) distributions in the same amount. The W+c signal is enhanced by considering:

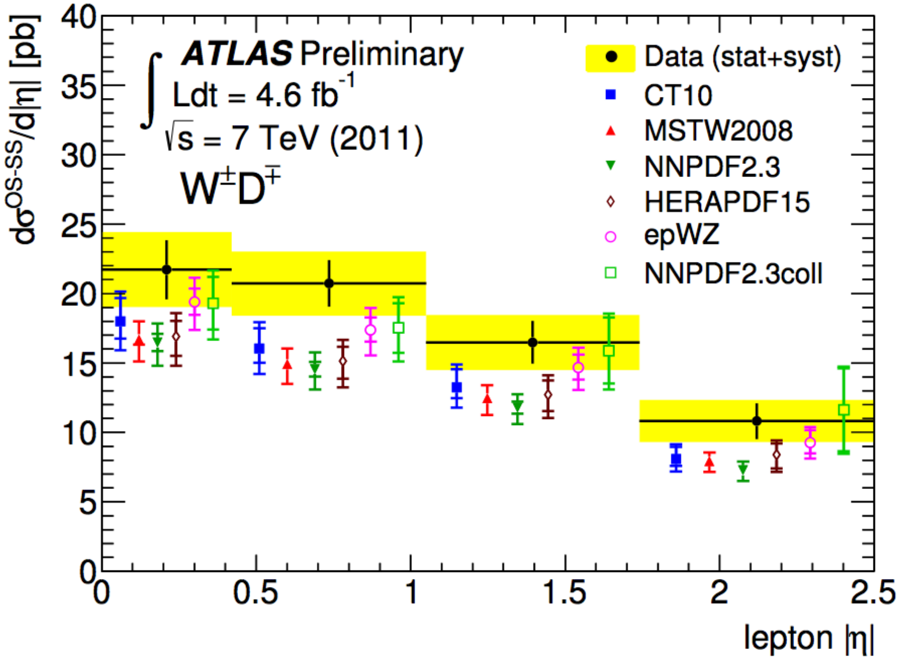
Opposite Sign - Same Sign (OS-SS)

Differential Cross sections

WD*



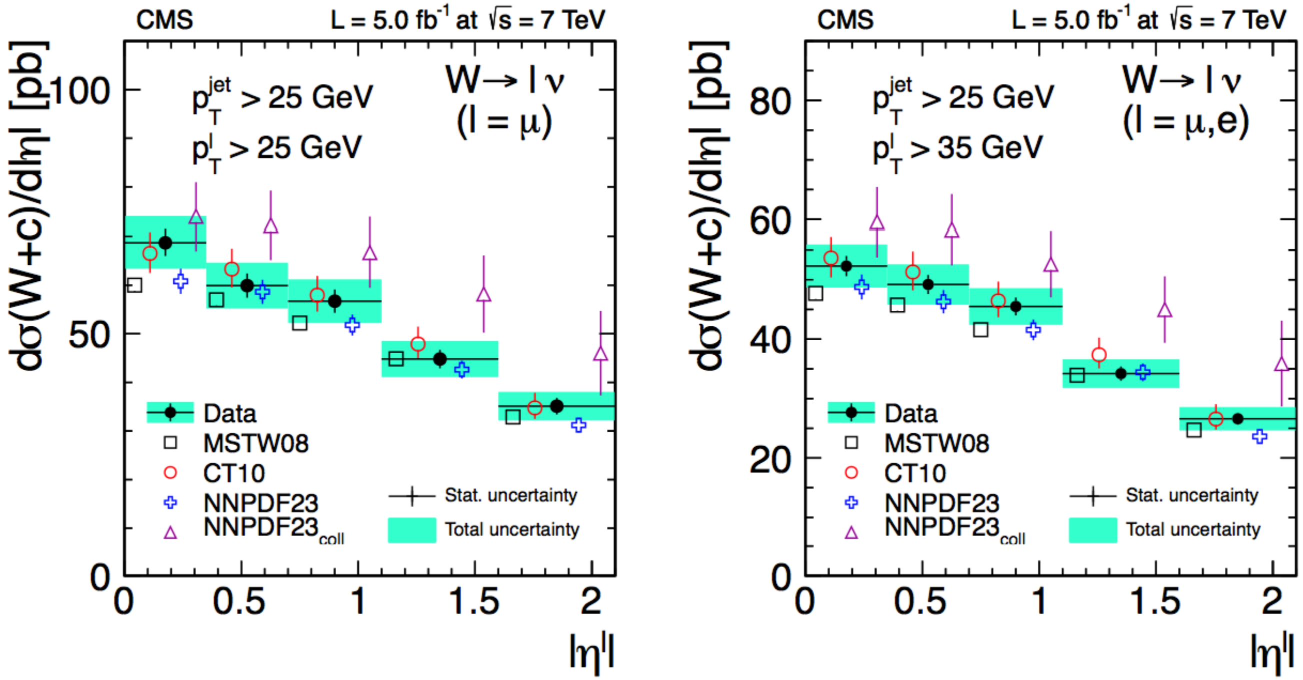
WD



ATLAS data favour PDFs where s-quark and d-quark contribution are comparable

Reminder: MSTW08, NNPDF2.3 and HERAPDF1.5 have strange suppressed by 0~.5 vs d
CT10 by ~0.75 vs d

Differential cross sections

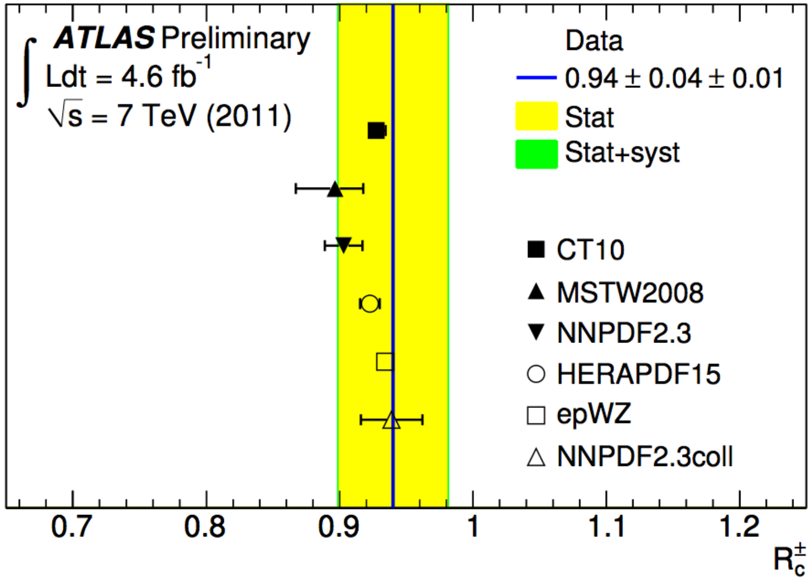


Somewhat different picture emerge:
Cross sections are well described by theoretical predictions (using PDFs sets with suppressed s-quark).
Note: Measurements refer to different phase space regions

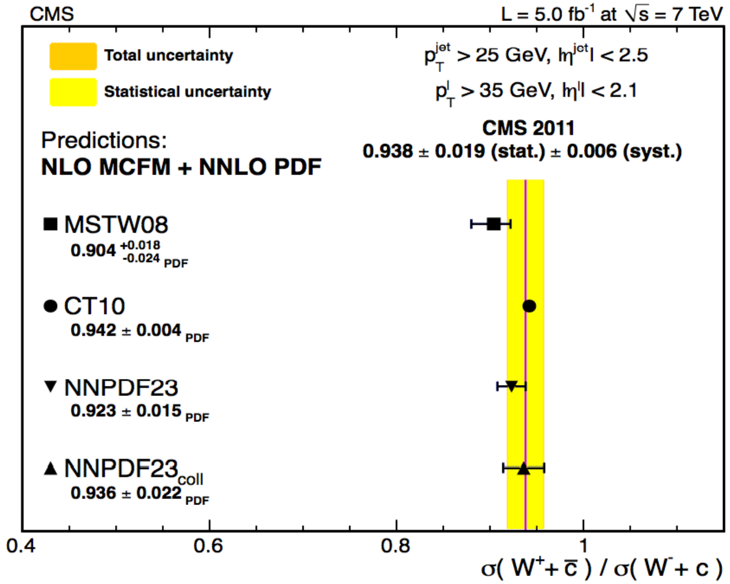
Charged cross section ratio

$$R_c^{\pm} = \frac{\sigma(W^+ D^{(*)-})}{\sigma(W^- D^{(*)+})}$$

$$R_c^{\pm} = \frac{\sigma(W^+ + \bar{c})}{\sigma(W^- + c)} = \frac{N_{OS}^+ - N_{SS}^+}{N_{OS}^- - N_{SS}^-}$$



aMC@NLO

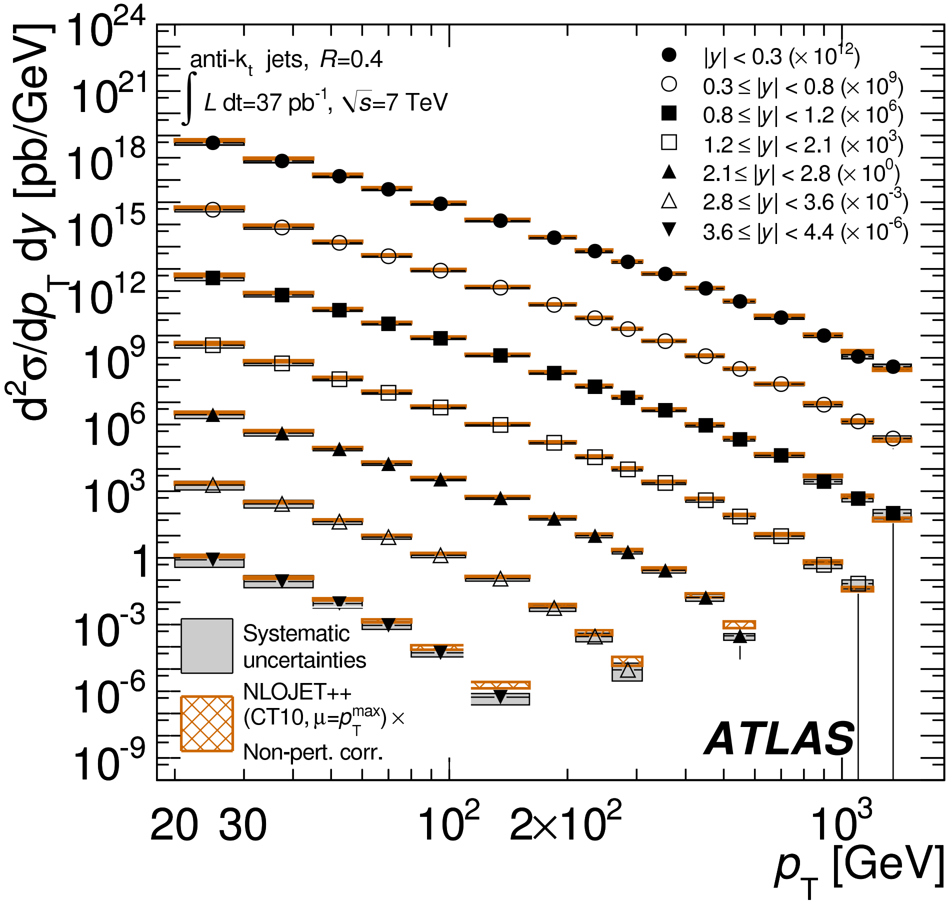


MCFM (NLO)

For Rc: measurements are in agreement with theoretical predictions

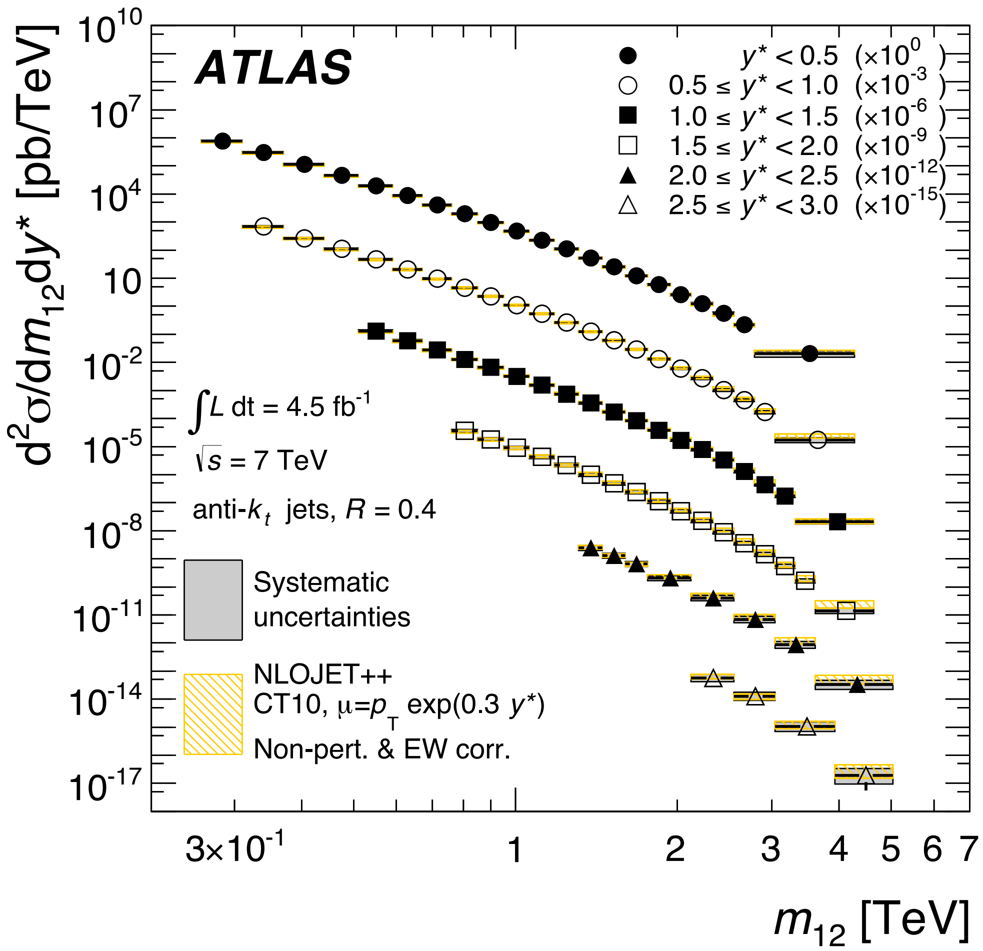
Jet Production and high-x gluon

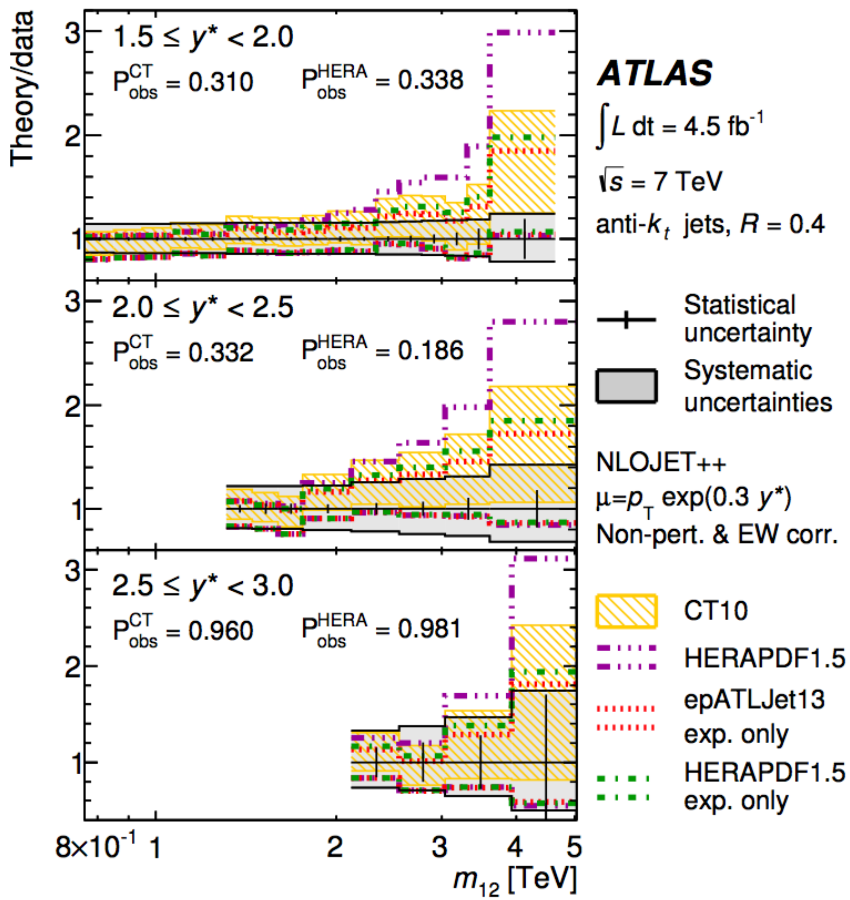
Test (NLO) pQCD, probes (mostly) the high-x gluon



Already included in NNPDF2.3

Dijet Cross Sections

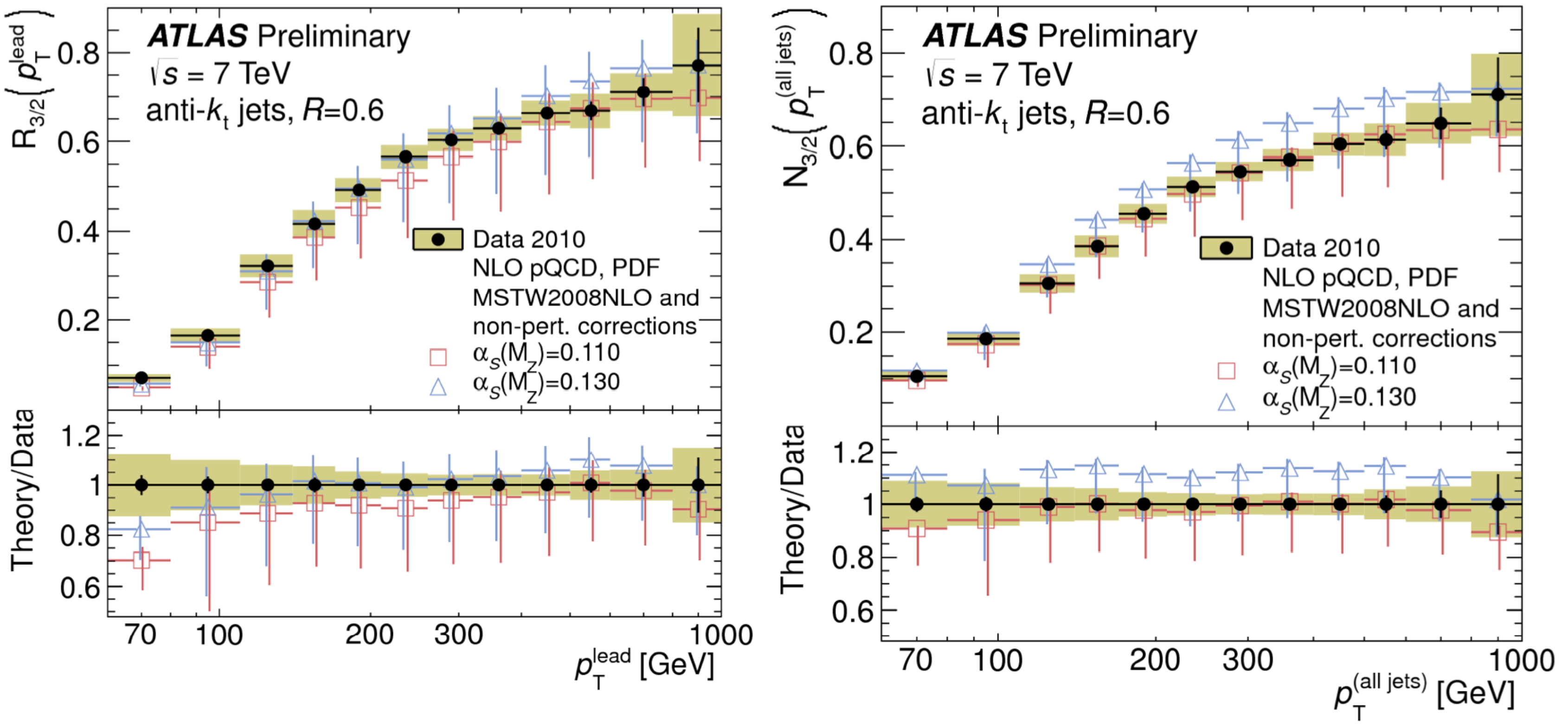




Should be included in forthcoming DGLAP fits. Impact on high-x gluon

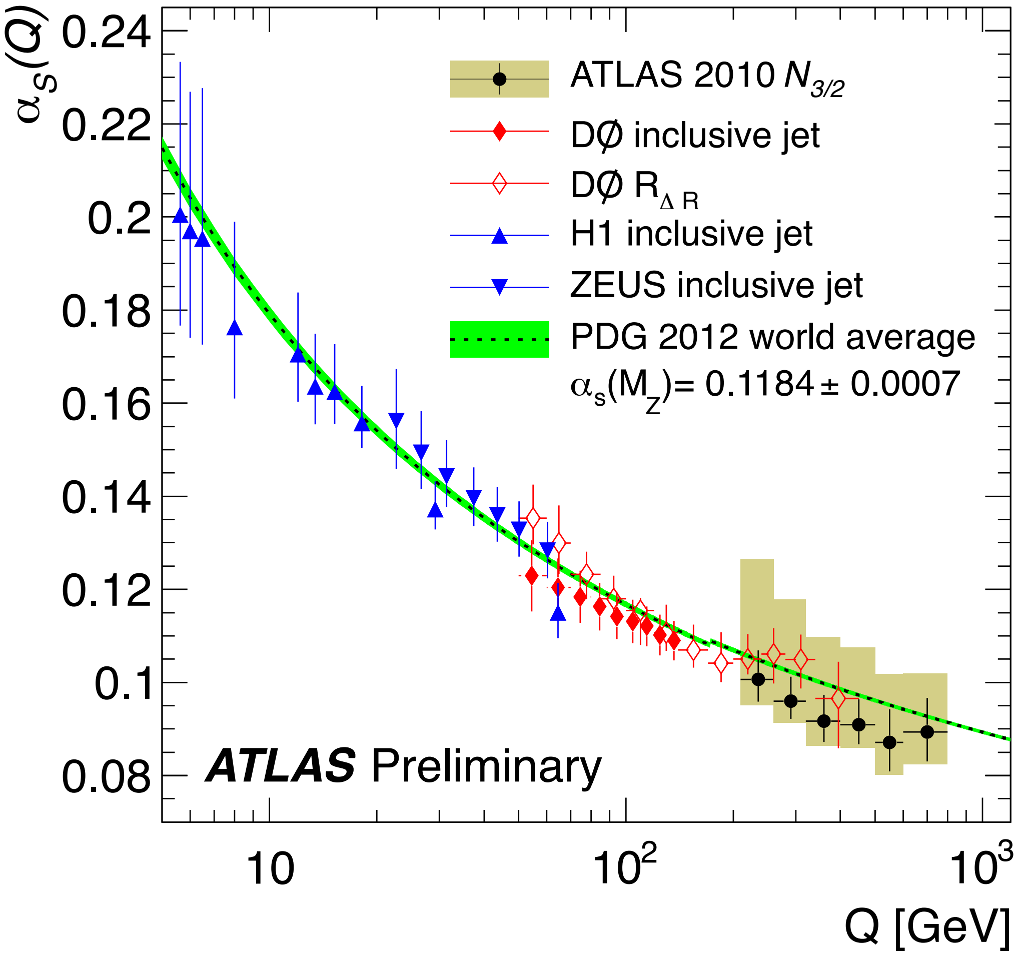
α_s from 3 to 2 jet ratio ($N_{3/2}$)

$$N_{3/2}(p_T^{(\text{all jets})}) = \sum_i^{N_{\text{jet}}} \frac{d\sigma_{N_{\text{jet}}\geq 3}}{dp_{T,i}} \Bigg/ \sum_i^{N_{\text{jet}}} \frac{d\sigma_{N_{\text{jet}}\geq 2}}{dp_{T,i}} \sim f(\alpha_s)$$



Comparable sensitivity to α_s ; N3/2 smaller dependence on scale choice

α_s from $N_{3/2}$

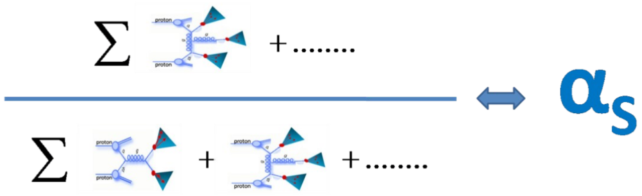


Test RGE at the TeV energy range.

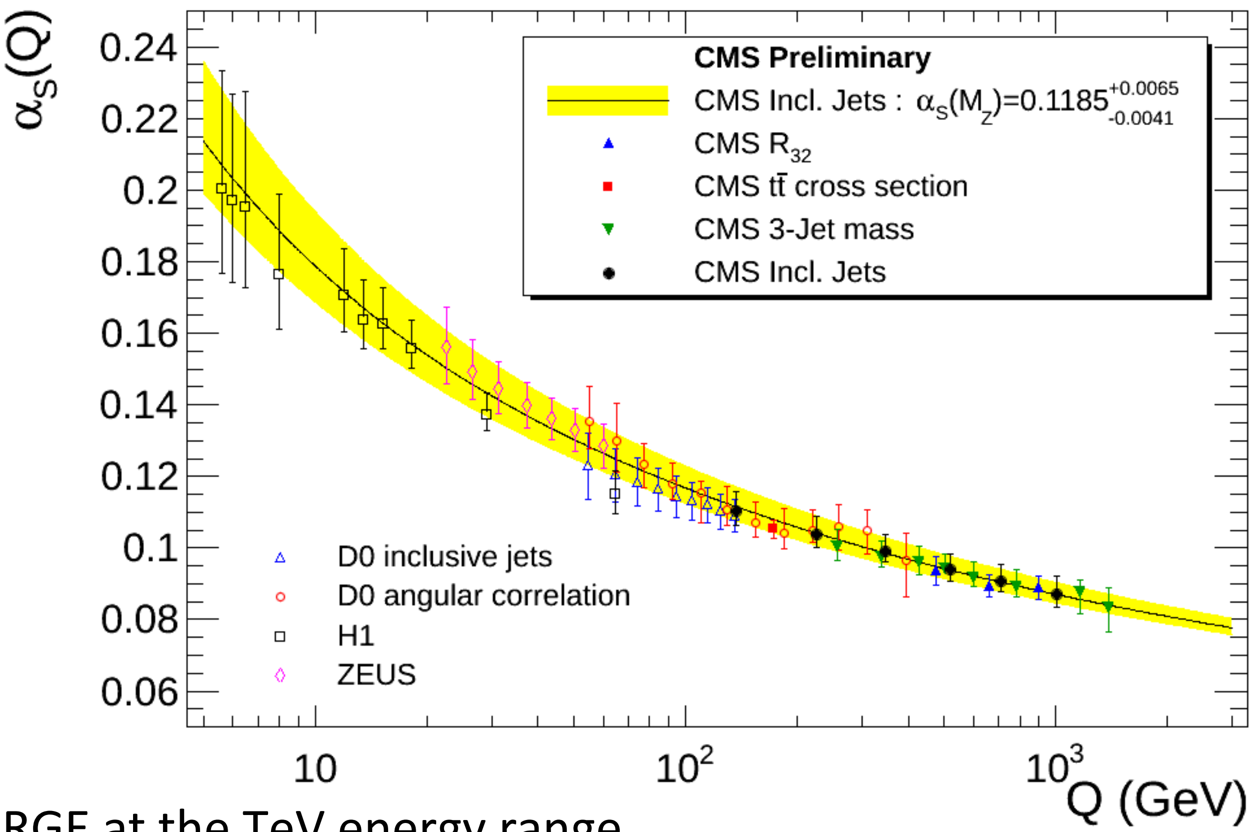
$N_{3/2}$, very effective observable for α_s determination

α_s from R_{32},3-jet mass and tt

$$R_{32} = \frac{\sigma_3}{\sigma_2} = \frac{\sigma(pp \rightarrow n \text{ jets } + X;\ n \geq 3)}{\sigma(pp \rightarrow n \text{ jets } + X;\ n \geq 2)} =$$



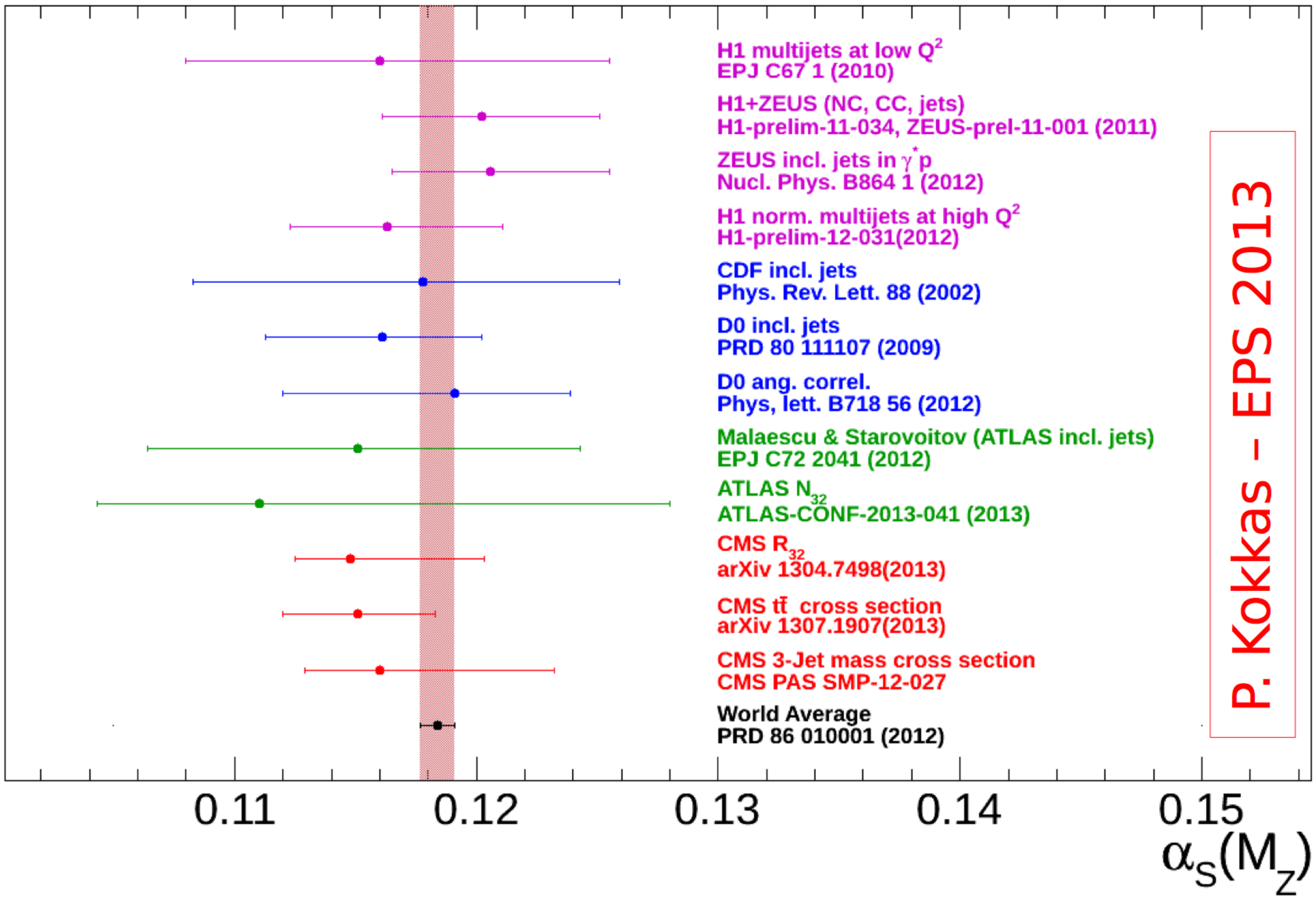
$$\text{vs} \quad \langle p_{T1,2} \rangle = \frac{p_{T1} + p_{T2}}{2}$$



Test RGE at the TeV energy range.

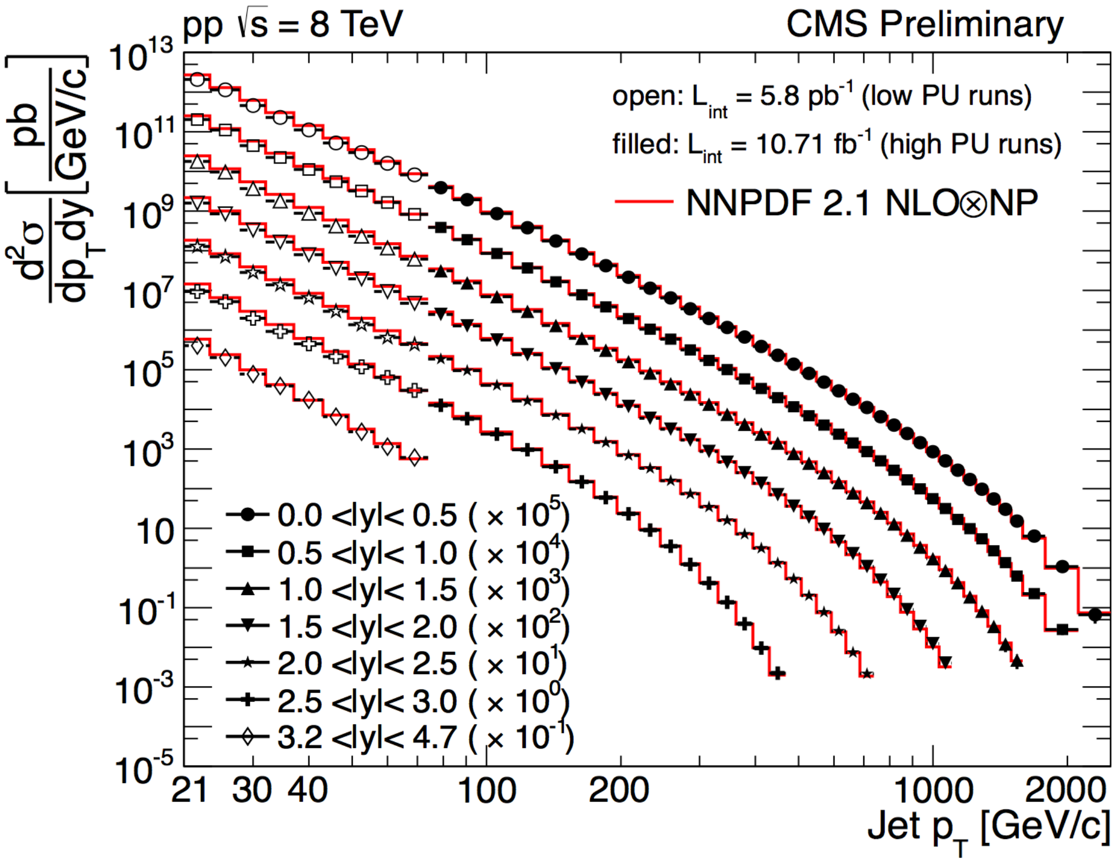
Various processes exploited. Should try to expand the energy range

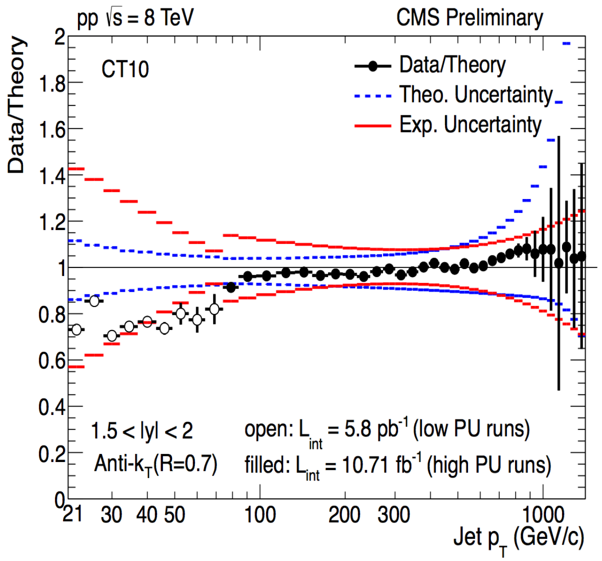
$\alpha_s(M_Z)$

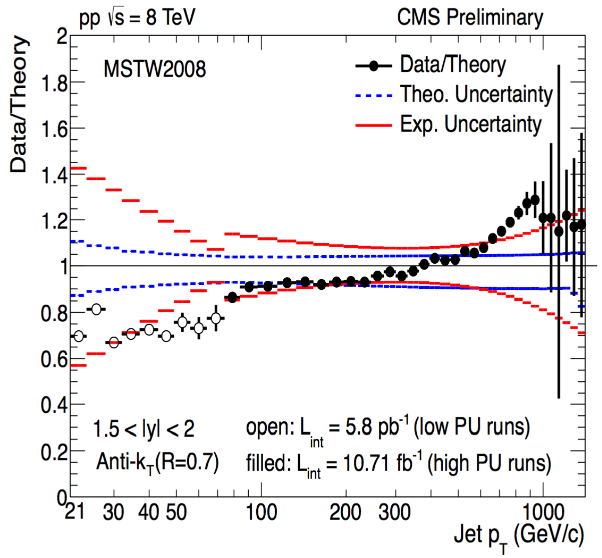


H1 multijets at low Q^2
EPJ C67 1 (2010)
H1+ZEUS (NC, CC, jets)
H1-prelim-11-034, ZEUS-prel-11-001 (2011)
ZEUS incl. jets in γ^*p
Nucl. Phys. B864 1 (2012)
H1 norm. multijets at high Q^2
H1-prelim-12-031(2012)
CDF incl. jets
Phys. Rev. Lett. 88 (2002)
D0 incl. jets
PRD 80 111107 (2009)
D0 ang. correl.
Phys, lett. B718 56 (2012)
Malaescu & Starovoitov (ATLAS incl. jets)
EPJ C72 2041 (2012)
ATLAS N_{32}
ATLAS-CONF-2013-041 (2013)
CMS R_{32}
arXiv 1304.7498(2013)
CMS $t\bar{t}$ cross section
arXiv 1307.1907(2013)
CMS 3-Jet mass cross section
CMS PAS SMP-12-027
World Average
PRD 86 010001 (2012)
P. Kokkas – EPS 2013
0.11
0.12
0.13
0.14
0.15
$\alpha_S(M_Z)$

Jets and α_s







Span 15 orders of magnitude, 20 GeV < pT(jet) < 2TeV
Need NNLO theory and dedicated low PU runs. Impact on high-x gluon.

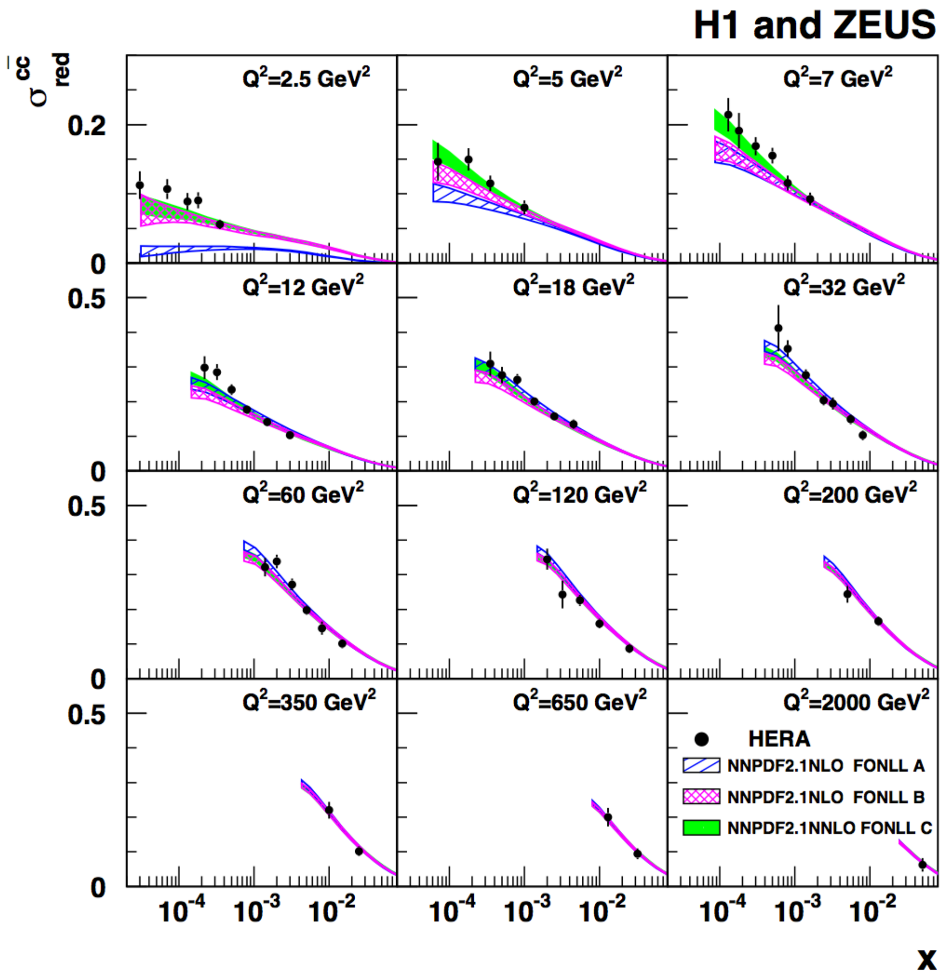
Heavy Flavours

Important contribution to SM predictions

Different HF treatment schemes (VFNS, FFS)

Present and forthcoming HERA data (c,b)
still important in the middle term

At the LHC, Z production in association to tagged c- and b-jets should provide significant constraints.



Instead of Conclusion

Uncertainties on PDFs limit our knowledge of cross sections whether SM or BSM

Any claim for New Physics at the highest masses depend on the PDFs determined from SM processes

SM LHC measurements are in a unique position to greatly improve our knowledge of the proton's structure