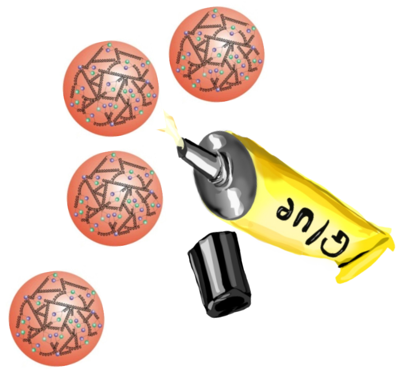
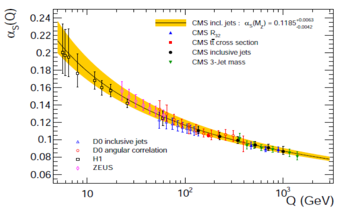
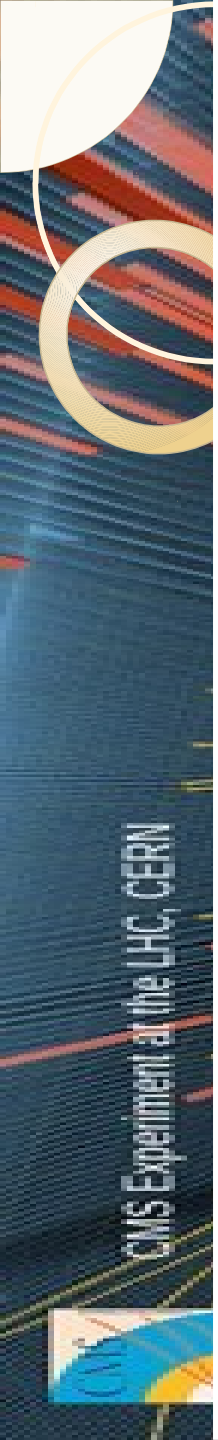
Maxime Gouzevitch

Constraints on PDF and α_s from CMS

on behalf of the CMS collaboration







0) Scope document: Run I legacy from LHC

arXiv:507.00556

4.2. Constraints from CMS

CMS				
Measurement	$\sqrt{s}$, $\mathcal{L}_{\rm int}$	Motivation	Reference	Used in PDF or α_S fits
High and low mass Drell-Yan	7 TeV, 5 fb^{-1}	Sect. 3.4.	[36]	[21, 118]
High and low mass Drell-Yan	8 TeV, 20 fb^{-1}	Sect. 3.4.	[45]	–
Drell-Yan AFB	7 TeV, 5 fb^{-1}	Sect. 3.4.	[176]	–
W asymmetry	7 TeV, 36 pb^{-1}	Sect. 3.3.	[177]	–
W e asymmetry	7 TeV, 880 pb^{-1}	Sect. 3.3.	[178]	–
W μ asymmetry	7 TeV, 4.7 fb^{-1}	Sect. 3.3.	[26]	[26, 118]
W, Z production and rapidity	7 TeV, 3 pb^{-1}	Sect. 3.3.	[179]	–
W, Z inclusive production	7 TeV, 36 pb^{-1}	Sect. 3.3.	[180]	–
W, Z inclusive production	8 TeV, 19 pb^{-1}	Sect. 3.3.	[181]	–
Z p_T and rapidity	7 TeV, 36 pb^{-1}	Sect. 3.5.,3.3.	[182]	–
Z p_T and rapidity	8 TeV, 19.7 fb^{-1}	Sect. 3.5.,3.3.	[132]	–
Inclusive jets	7 TeV, 5 fb^{-1}	Sect. 3.1.	[25, 183]	[21, 48, 91]
Dijets	7 TeV, 5 fb^{-1}	Sect. 3.1.	[25]	–
Three-jets	7 TeV, 5 fb^{-1}	Sect. 3.1.	[184]	[184]
Three-jets/Di-jets ratio	7 TeV, 5 fb^{-1}	Sect. 3.1.	[49]	[49]
W+charm	7 TeV, 5 fb^{-1}	Sect. 3.6.	[29]	[26, 31, 91]
Z+beauty	7 TeV, 5 fb^{-1}	Sect. 3.6.	[185]	–
γ inclusive production	7 TeV, 36 pb^{-1}	Sect. 3.2.	[186]	[28]
γ+jets	7 TeV, 2.1 fb^{-1}	Sect. 3.2.	[187]	–
$t\bar{t}$ inclusive	7 TeV, 2.3 fb^{-1}	Sect. 3.7.	[188]	[32, 33, 139]
$t\bar{t}$ differential	7 TeV, 5.0 fb^{-1}	Sect. 3.7.	[189]	[33]
$t\bar{t}$ inclusive	8 TeV, 1.14 fb^{-1}	Sect. 3.7.	[190]	[32]
$t\bar{t}$ inclusive	8 TeV, 2.8 fb^{-1}	Sect. 3.7.	[191]	[32]
$t\bar{t}$ inclusive	8 TeV, 2.4 fb^{-1}	Sect. 3.7.	[192]	[33]
$t\bar{t}$ differential	8 TeV, 19.7 fb^{-1}	Sect. 3.7.	[193]	–

0) Scope document: Run I legacy from LHC

arXiv:507.00556

The PDF4LHC report on PDFs and LHC data: Results from Run I and preparation for Run II

Juan Rojo[1], Alberto Accardi[2,3], Richard D. Ball[4,5], Amanda Cooper-Sarkar[6], Albert de Roeck[5,7], Stephen Farry[8], James Ferrando[9], Stefano Forte[10], Jun Gao[11], Lucian Harland-Lang[12], Joey Huston[13], Alexander Glazov[14], Maxime Gouzevitch[15], Claire Gwenlan[6], Katerina Lipka[14], Mykhailo Lisovyi[16], Michelangelo Mangano [5], Pavel Nadolsky[17], Luca Perrozzi[18], Ringaile Plačakytė[14], Voica Radescu[16], Gavin P. Salam[5] and Robert Thorne[12]*

Based on a workshop in the Center Perdo Pasqual in Benasque, Spain :

http://benasque.org/2015lhc/

0) Scope document: Run I legacy from LHC

arXiv:507.00556

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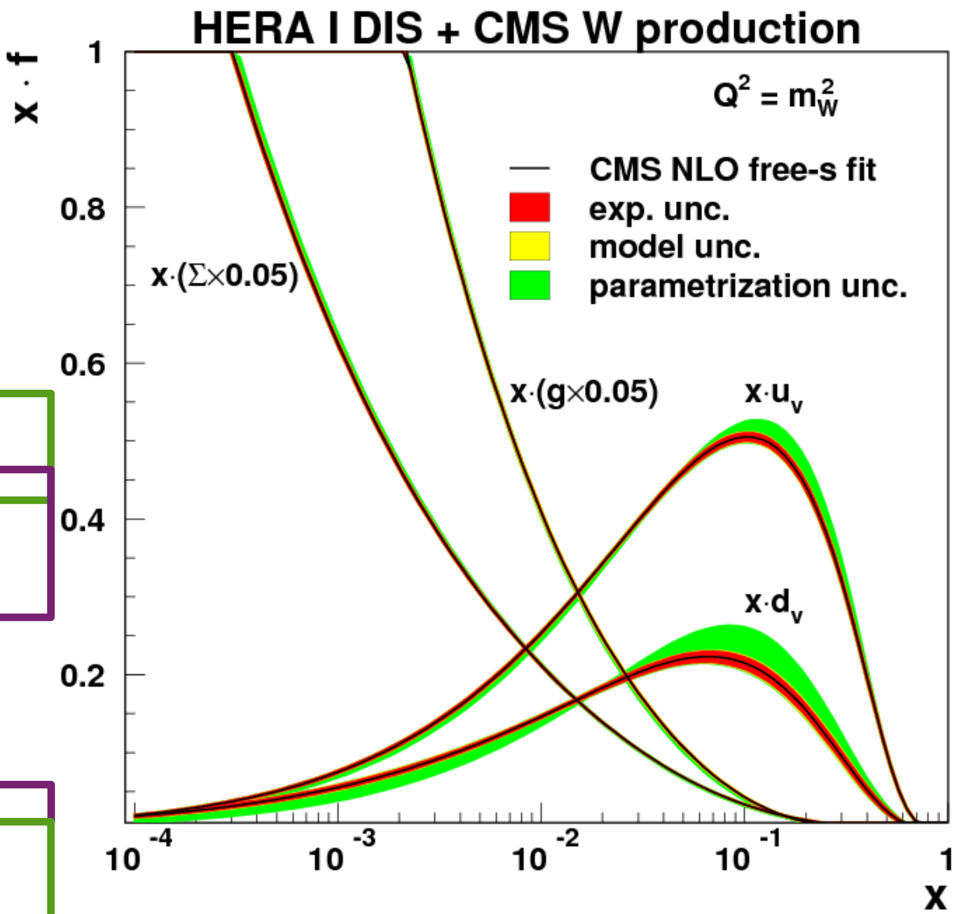
0) Scope document: Run I legacy from LHC

Measurement	
High and low mass Drell-Yan	1) Quarks
High and low mass Drell-Yan	
Drell-Yan AFB	
W asymmetry	
W e asymmetry	
W μ asymmetry	
W, Z production and rapidity	
W, Z inclusive production	
W, Z inclusive production	
Z p_T and rapidity	2) Gluons
Z p_T and rapidity	
Inclusive jets	
Dijets	3) α_s
Three-jets	
Three-jets/Di-jets ratio	
W+charm	
Z+beauty	
γ inclusive production	
γ+jets	
$t\bar{t}$ inclusive	
$t\bar{t}$ differential	
$t\bar{t}$ inclusive	
$t\bar{t}$ inclusive	
$t\bar{t}$ inclusive	
$t\bar{t}$ differential	



Quarks

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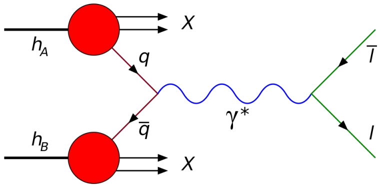
γ+jets	7 TeV, 2.1 fb^{-1}	Sect. 3.2.	[187]	–

All quarks together

u_v, d_v mainly

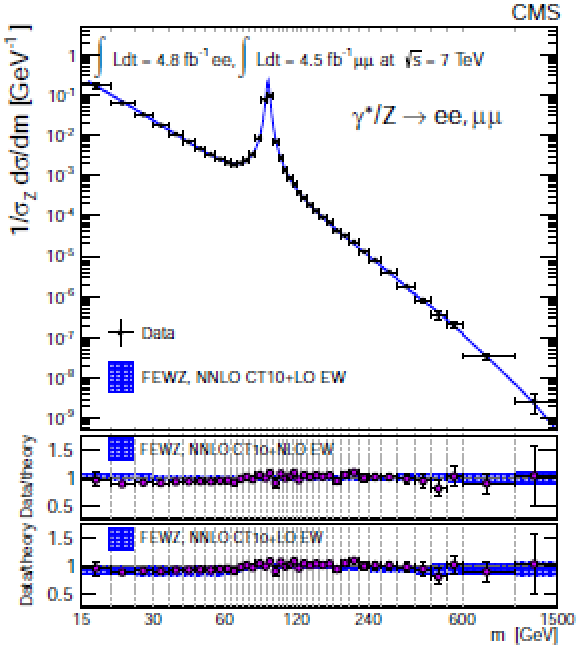
Strangeness

1.1) DY production



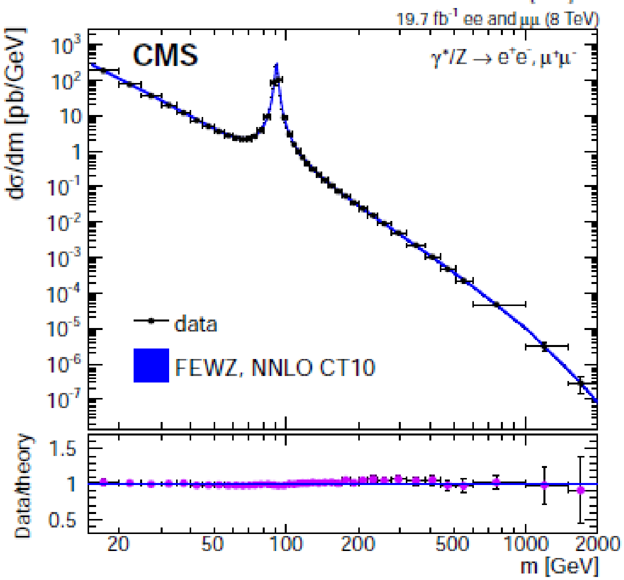
- Muons/electrons : **7 TeV, 5 fb^{-1}**

SMP-13-003 – HEPDATA
arXiv:1310.7291



- Muons/electrons : **8 TeV, 20 fb^{-1}**

SMP-14-003 – no yet HEPDATA
arXiv:1412.1115

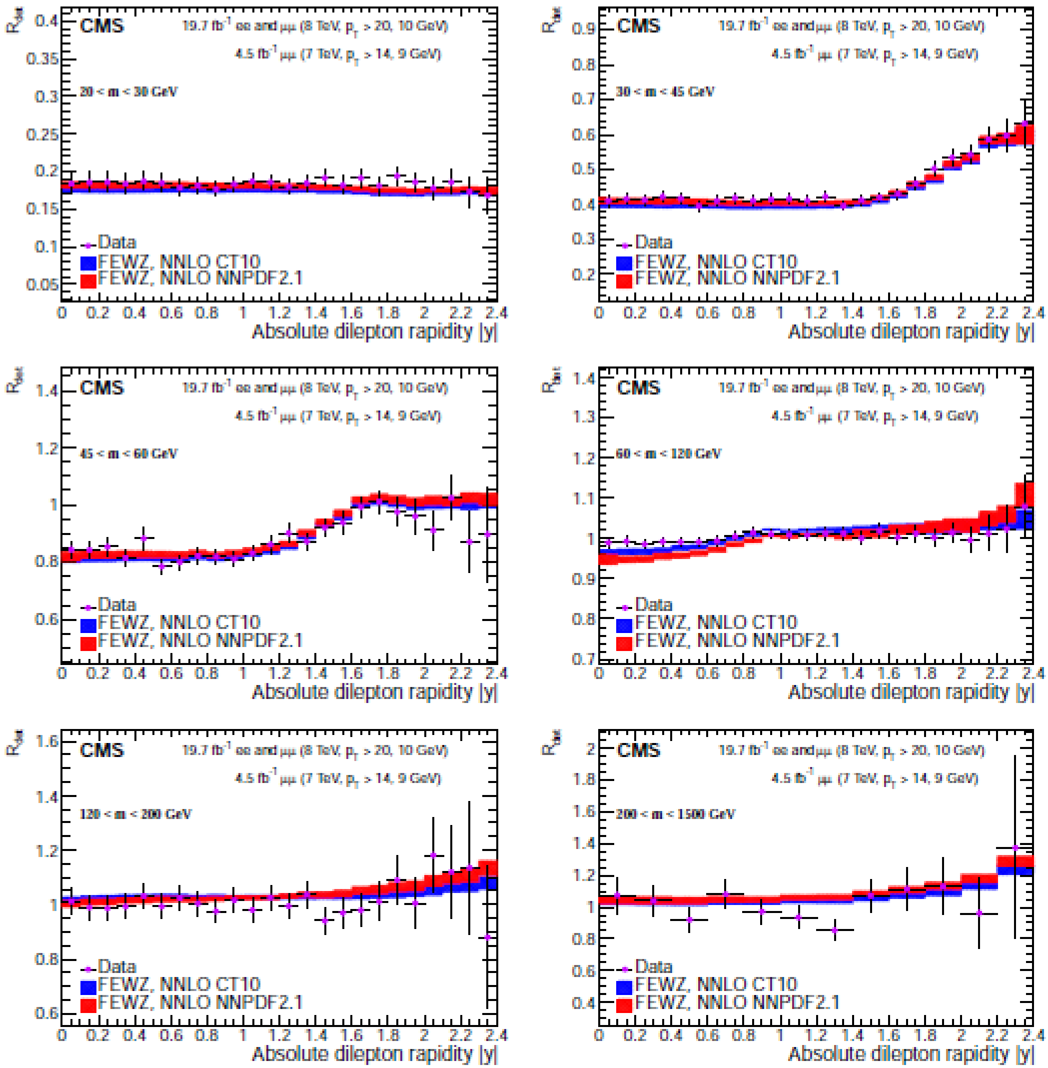


- Single and double differential measurements.
At 7 TeV normalized cross section is measured and the total cross section, while at 8 TeV un-normalized one.

- For fun : third most accessed CMS measurement at HEPDATA 1415 times (Oct. 2015 courtesy of G. Watt and M. Whalley)

1.1) DY production

$$R_{\mathrm{det}}(\mathrm{pp} \to \gamma^*/\mathrm{Z} \to \ell^+\ell^-) = \frac{\left(\frac{1}{\sigma_Z}\frac{d^2\sigma}{dm\,d|y|}\right)(8\,\mathrm{TeV}, p_T > 10, 20\,\mathrm{GeV})}{\left(\frac{1}{\sigma_Z}\frac{d^2\sigma}{dm\,d|y|}\right)(7\,\mathrm{TeV}, p_T > 9, 14\,\mathrm{GeV})}$$



- First 8/7 TeV ratio published by CMS.

- Combined muons/electrons used at 8 TeV and muons at 7 TeV.

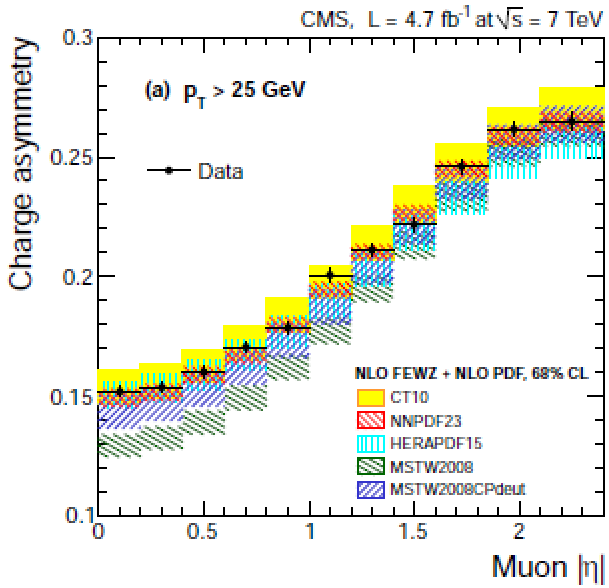
- Well described by theory predictions and known at percent level.

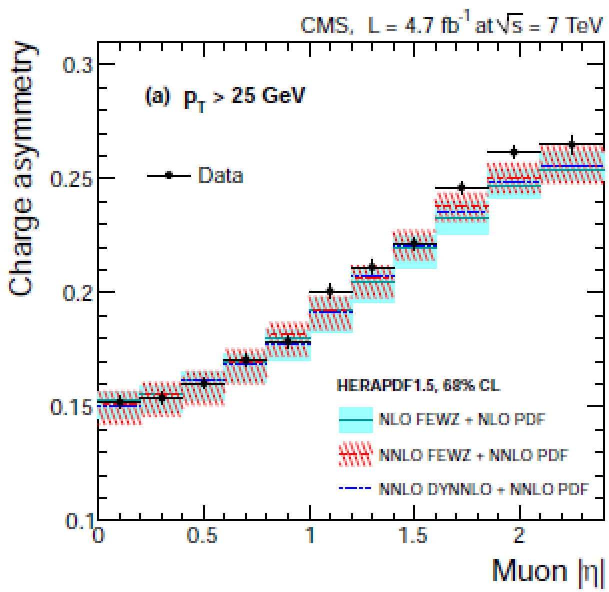
- The interplay between different rapidity regions for a given mass give a handle to x at different scales.

- High mass statistically dominated by 7 TeV.

1.2) W charge asymmetry

Phys. Rev. Lett. 109 (2012) 111806





$$\mathcal{A}(\eta) = \frac{\frac{d\sigma}{d\eta}(W^+ \to \ell^+\nu) - \frac{d\sigma}{d\eta}(W^- \to \ell^-\overline{\nu})}{\frac{d\sigma}{d\eta}(W^+ \to \ell^+\nu) + \frac{d\sigma}{d\eta}(W^- \to \ell^-\overline{\nu})}$$

1) Electron 7 TeV, 1 fb^{-1}

SMP-12-001 – HEPDATA
arXiv:1206.2598

2) Muon 7 TeV, 5 fb^{-1}

SMP-12-021 – HEPDATA
arXiv :1312.6283

Included in PDF fits
by CMS, ABM, NNPDF
at NLO and NNLO

1.2) W charge asymmetry

Phys. Rev. Lett. 109 (2012) 111806

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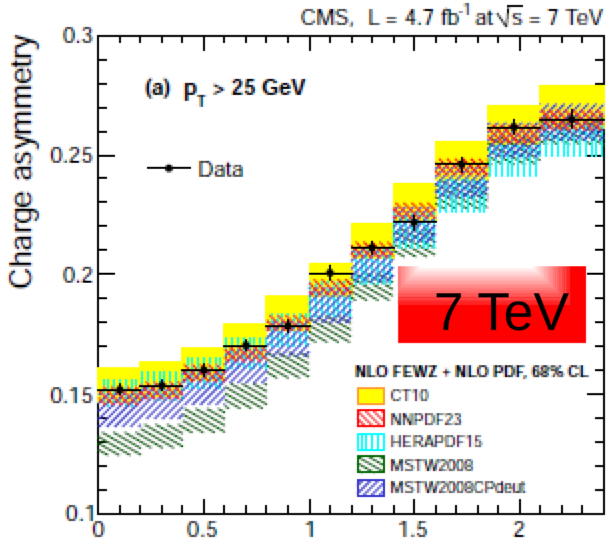
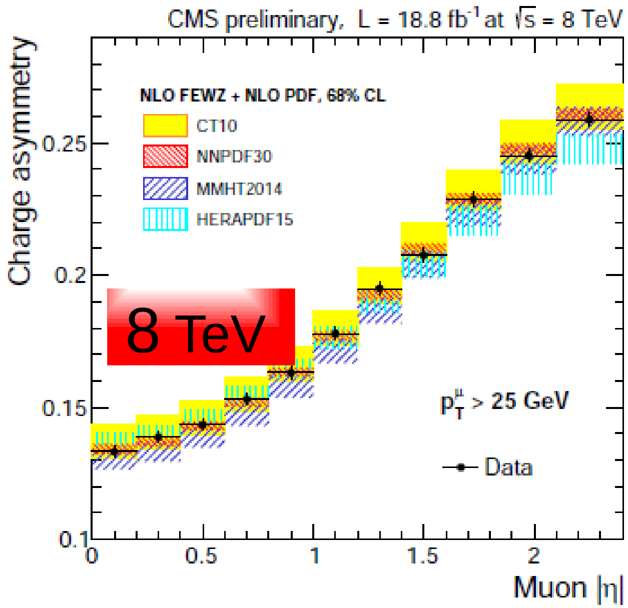


3)Muons

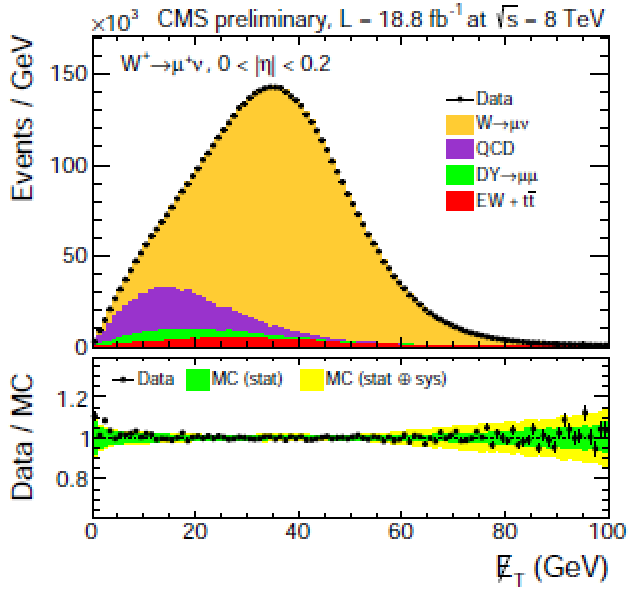
8 TeV, 20 fb-1

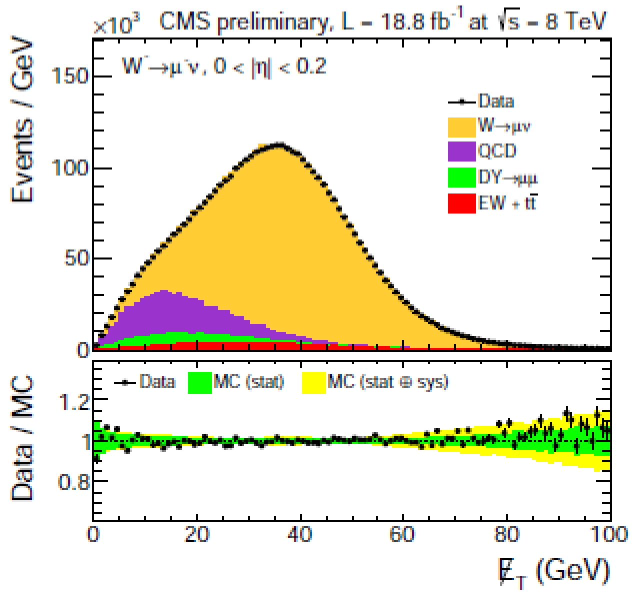
SMP-14-022 – Prelim.



1.2) W charge asymmetry

Phys. Rev. Lett. 109 (2012) 111806





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3)Muons **8 TeV, 20 fb^{-1}**

SMP-14-022 – Prelim.

- 8 and 7 TeV compatibles.
- Stat. Unc. and experimental syst. Reduced especially for high eta bins : Better tag/probe and side band stats.

7 TeV

$\lvert\eta\rvert$ bin	0.0–0.2	2.1–2.4
Stat. unc.	0.096	0.106
Efficiency	0.111	0.268
QCD +/−	0.120	0.183
QCD shape	0.070	0.087
Total syst. unc.	0.203	0.364
Total unc.	0.225	0.379

8 TeV

$\lvert\eta\rvert$ bin	0.0–0.2	2.1–2.4
Stat. Unc.	0.062	0.072
Efficiency	0.058	0.134
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Total Sys. Unc.	0.191	0.221
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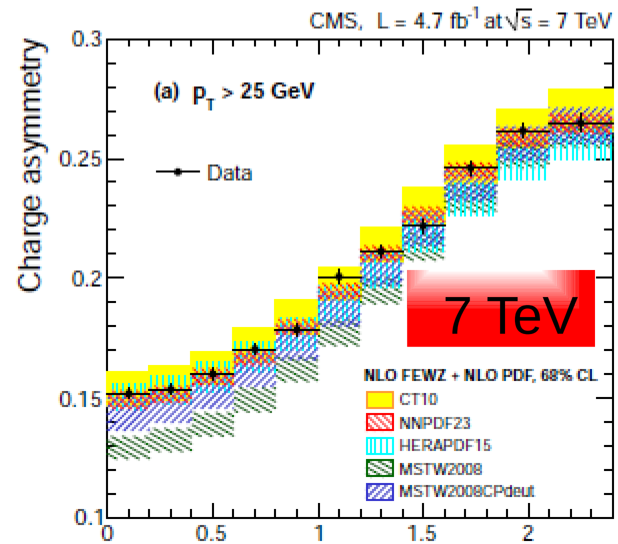
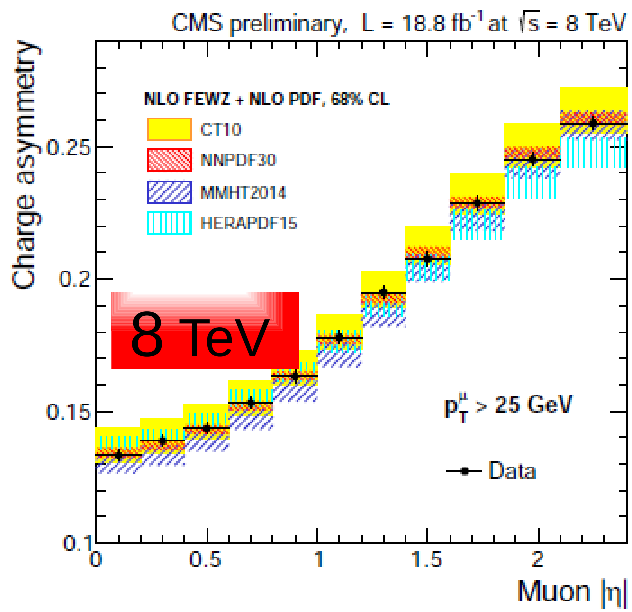
1.2) W charge asymmetry

Phys. Rev. Lett. 109 (2012) 111806





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3)Muons

8 TeV, 20 fb^{-1}

SMP-14-022 – Prelim.

- 8 and 7 TeV compatibles.
- Stat. Unc. and experimental syst. Reduced especially for high eta bins : Better tag/probe and side band stats.
- Impact for high x valence.

7 TeV

$\|\eta\|$ bin	0.0–0.2	2.1–2.4
Stat. unc.	0.096	0.106
Efficiency	0.111	0.268
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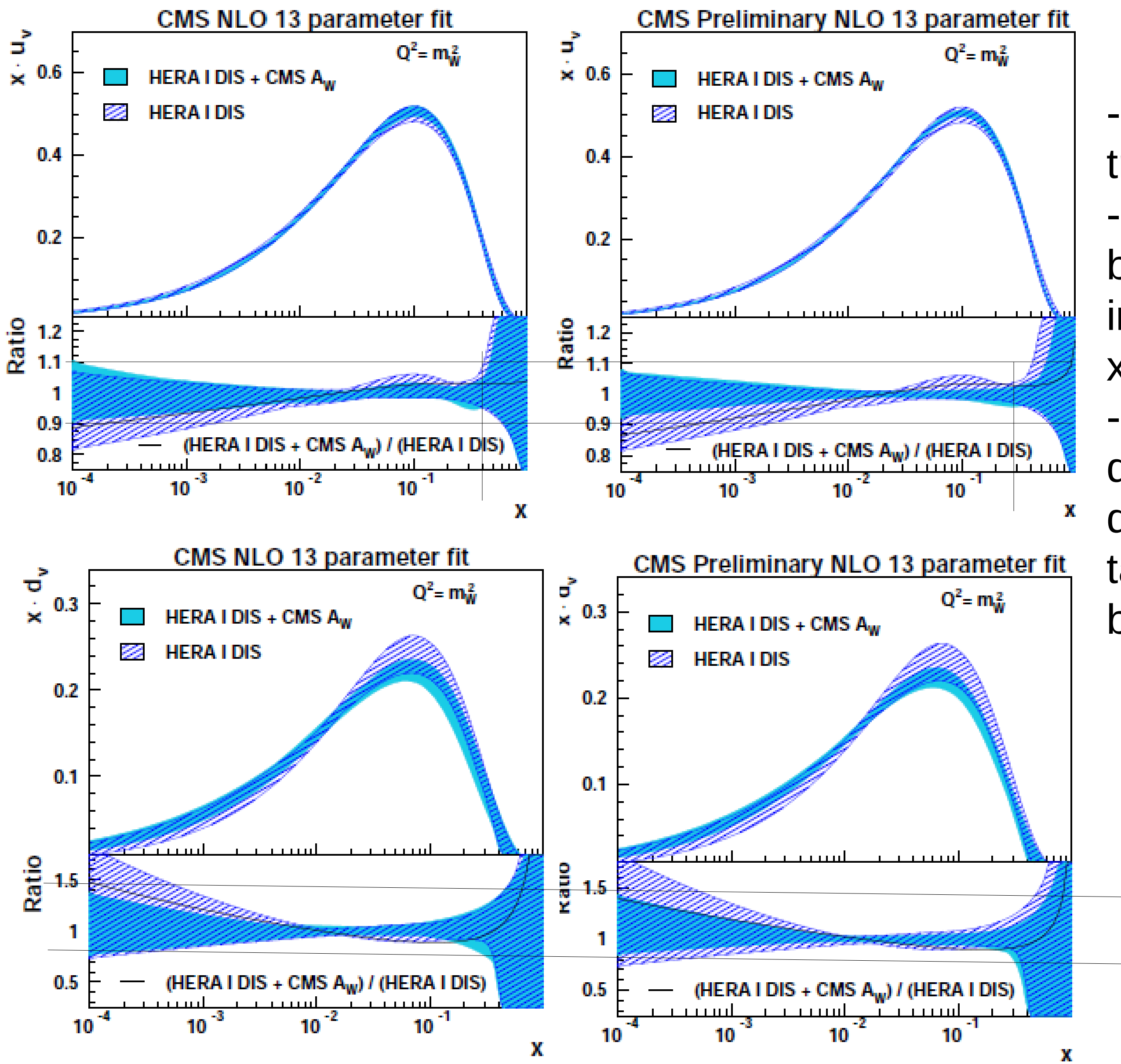
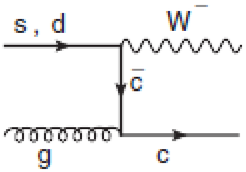
- NNPDF includes 7 TeV μ/e asymmetry and MMHT2014 e asymmetry

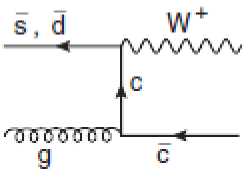
1.2) W charge asymmetry



- 7 and 8 TeV trends are similar.
- 8 TeV provides a bit more stringent impact for high/low x valence.
- Systematics are quite uncorrelated : dominated by tag/probe and side band statistics.

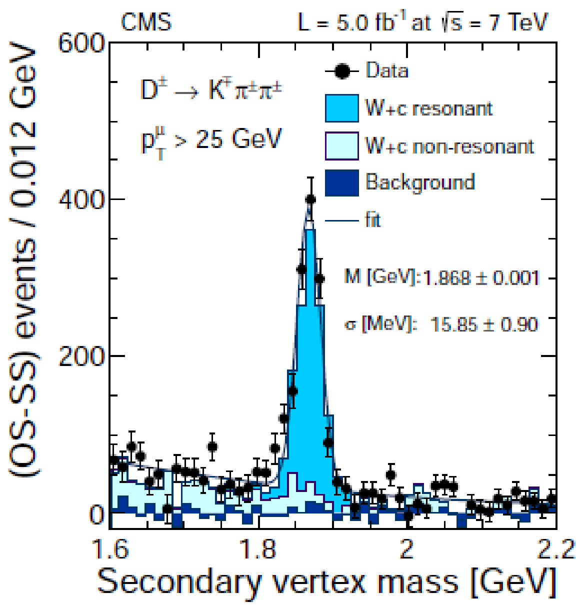
1.3) W+c and strangeness

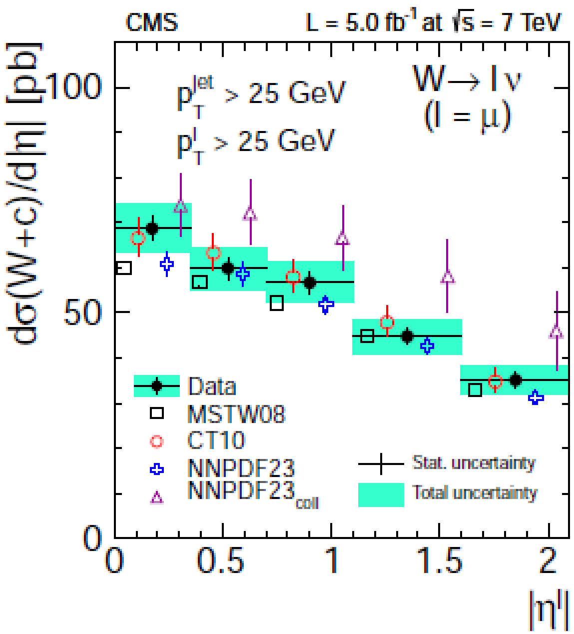




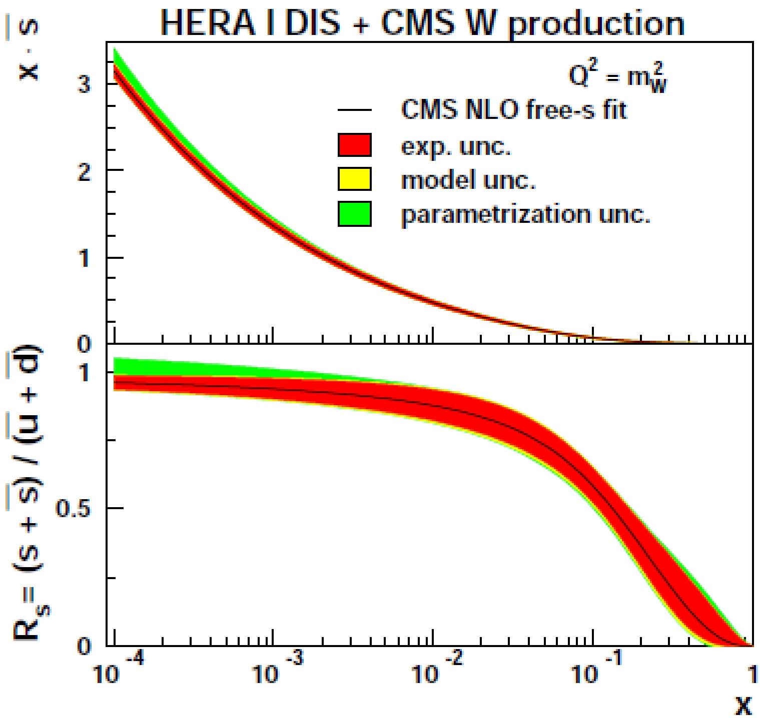
SMP-12-002 HEPDATA
arXiv:1310.1138

1) A very nice peace of art to tag the charm production.
2) Use exclusive decays where the charge can be measured. Take opposite charge between W and c to remove QCD background.
3) Very low efficiency : O(1 %), but good purity after QCD substraction
4) Complex discussions between ATLAS and CMS on how to account for fragmentation and PS.



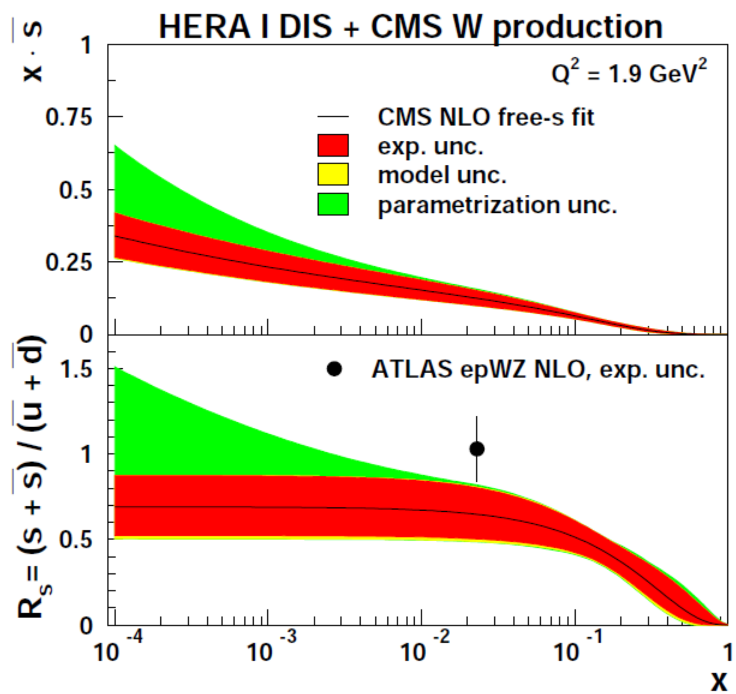


1.3) W+c and strangeness



1) QCD analysis done combining with 7 TeV W charge asymmetry :

$$\mathcal{A}(\eta) = \frac{\frac{d\sigma}{d\eta}(W^+ \to \ell^+\nu) - \frac{d\sigma}{d\eta}(W^- \to \ell^-\overline{\nu})}{\frac{d\sigma}{d\eta}(W^+ \to \ell^+\nu) + \frac{d\sigma}{d\eta}(W^- \to \ell^-\overline{\nu})}$$



Gluons

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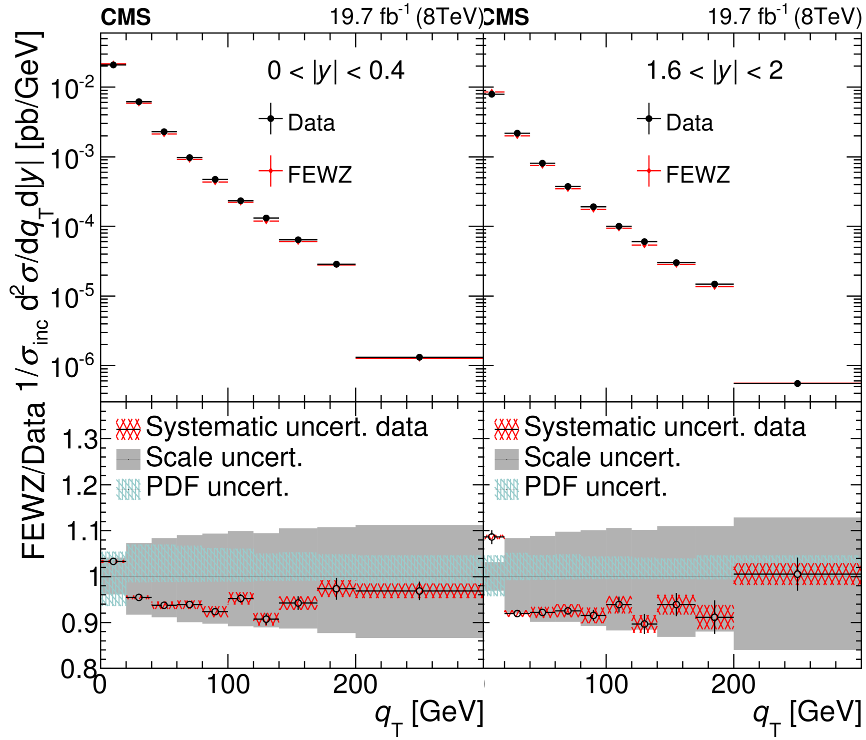
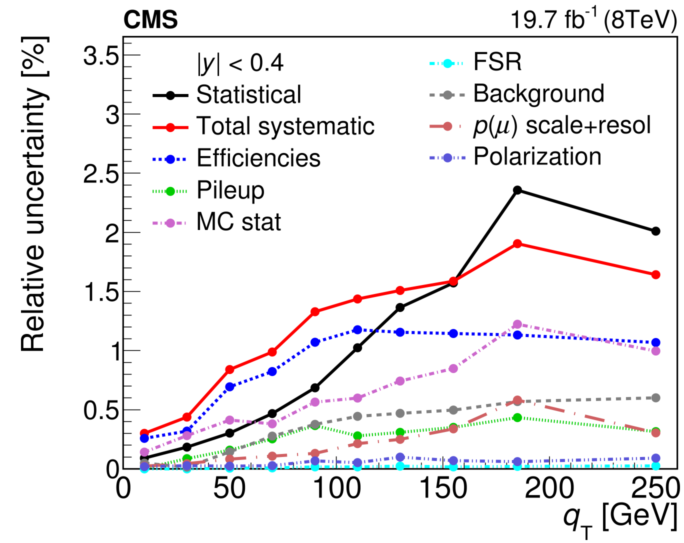
2.1) DY neutral production at high p_T





SMP-13-13 – HEPD.
arXiv :1504.03511

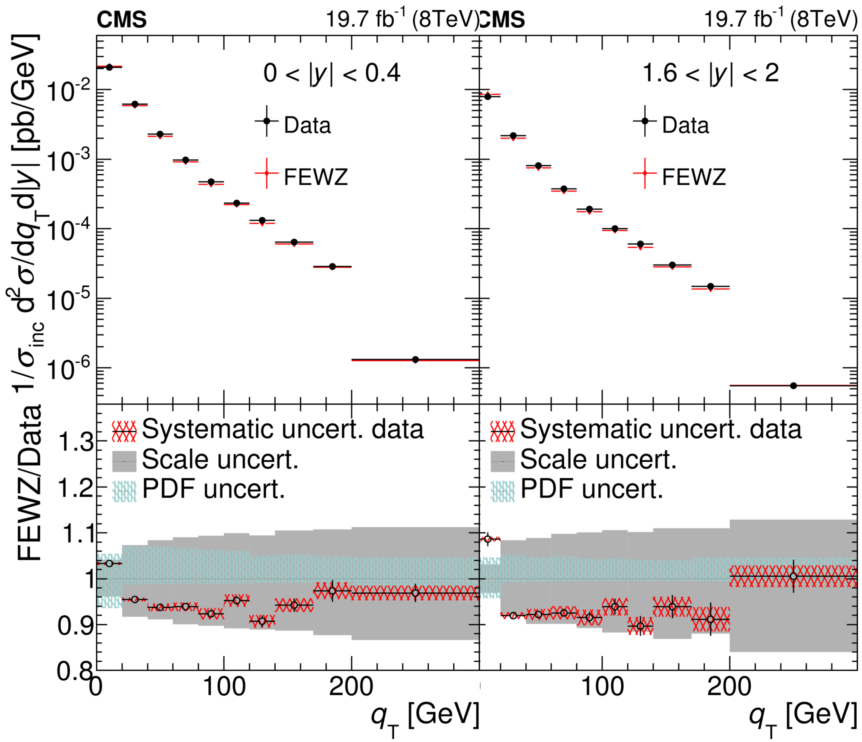
1) Measured double differentially to provide better constraint on PDFs (Scan of x values for different Q scale values).

2) A very promising variable :

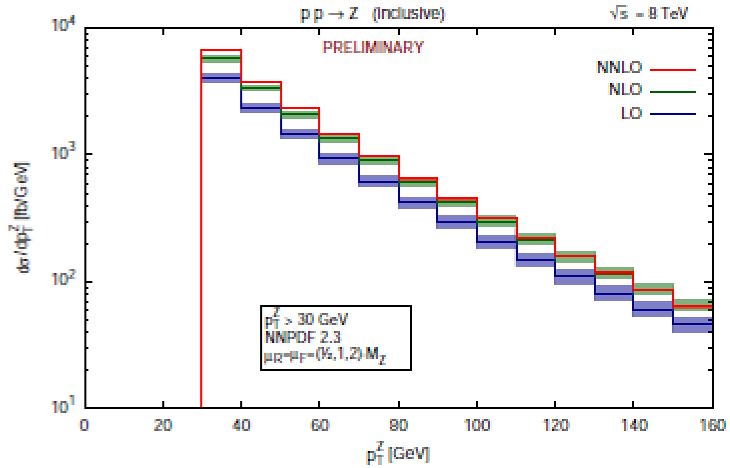
- Precision of 1.5 – 2 % on the normalized cross section based on muon scale (precision in jets final states ~ 10 %).
- Sensitive to gluon density

2.1) DY neutral production at high p_T

arXiv :1507.02850



Preliminary results!

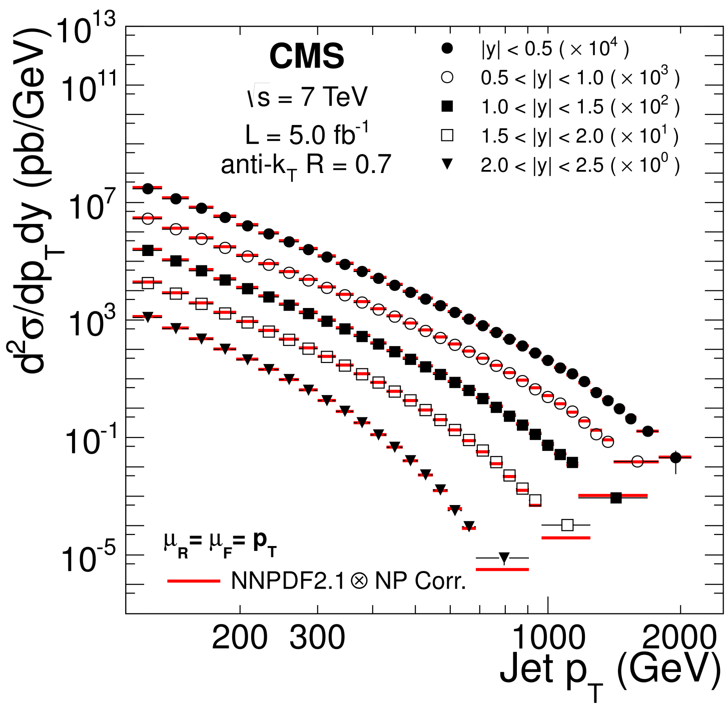


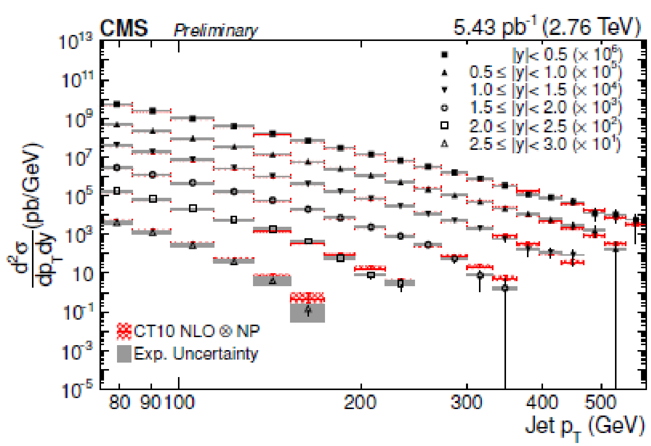
3) NLO prediction for p_T of Z is NNLO for Z inclusive !

Scale effects are rather large compared to data precision and tension observed.

4) NNLO for p_T of Z just made public

2.2) Inclusive jets cross section





1)Published : **7 TeV, 5 fb^{-1}**

QCD-11-004 - HEPDATA
arXiv:1212.6660

2) Preliminary : **8 TeV, 10 fb^{-1}**

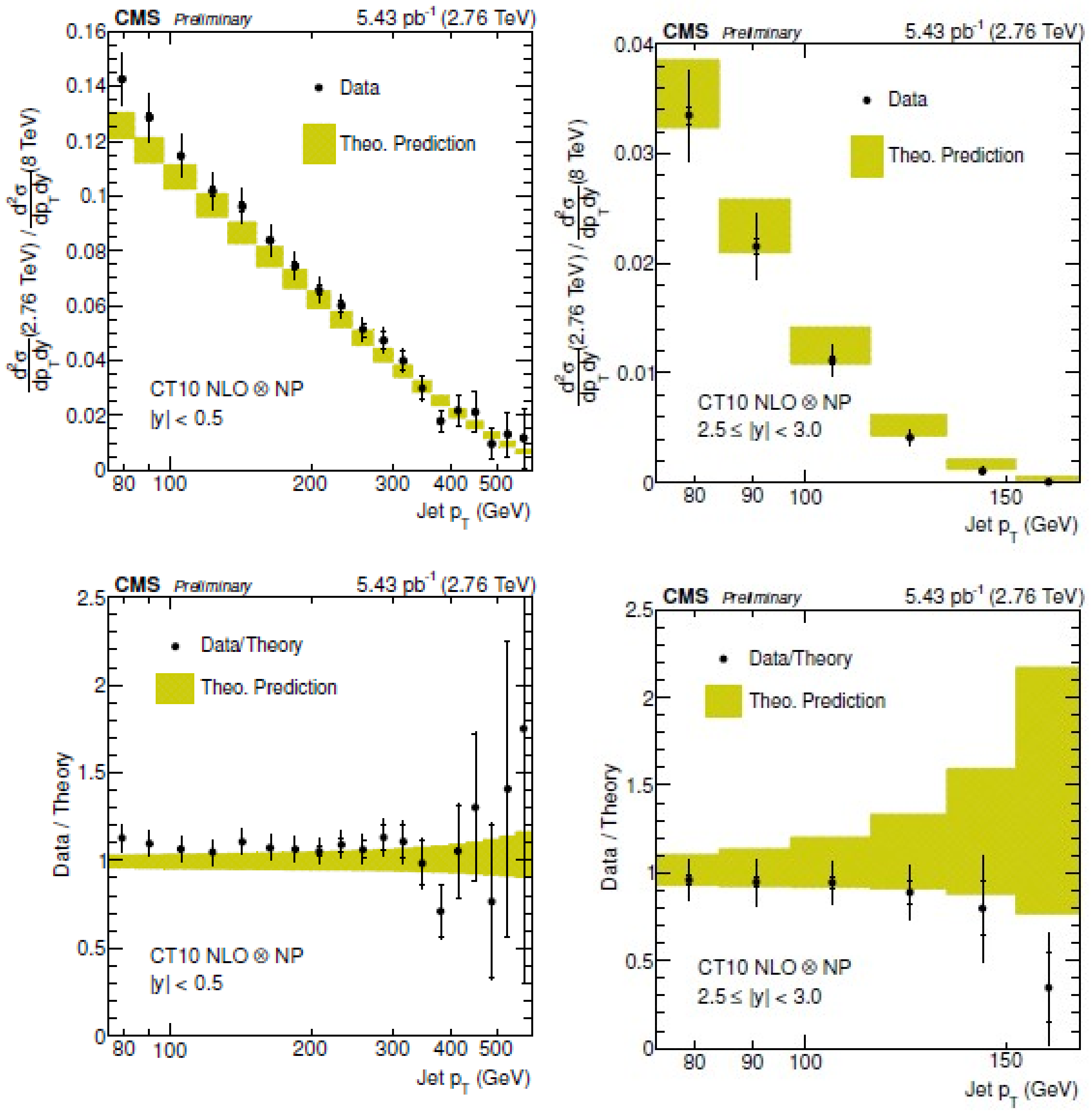
Preliminary SMP-12-012

2bis) Full data set preliminary with α_S fit and PDF extraction would be public In 2 weeks. Also ratio to 7 TeV included.

3) 2.76 TeV : **2.76 TeV, 5 pb^{-1}**

Preliminary SMP-14-017

2.2) Inclusive jets cross section

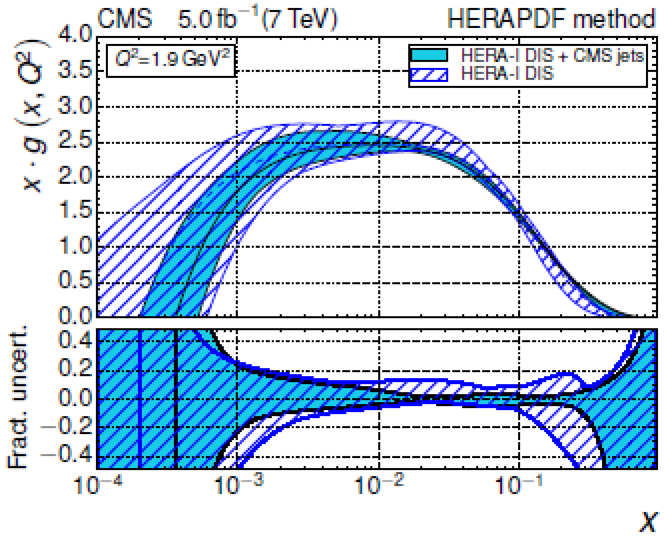


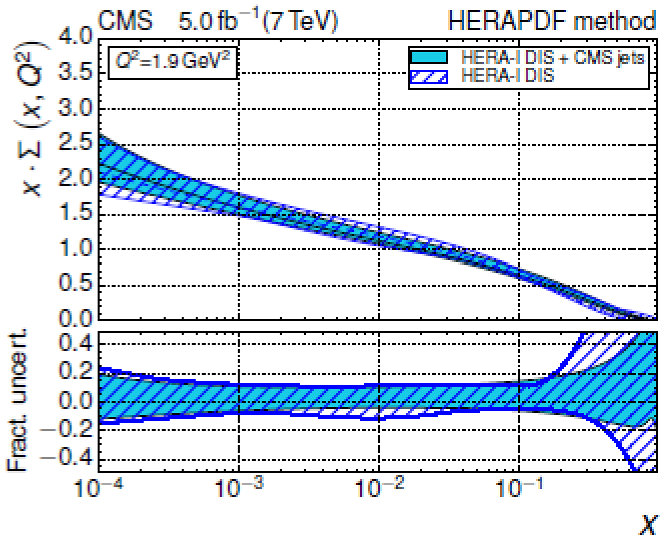
1) Ratio 2.76/8 TeV calculated
with high experimental precision
below 200 GeV :
2.76 and 8 TeV measurements was synchronized

2) Small theory uncertainties :
direct look on DGLAP evolution.

2.2) Inclusive jets cross section

arXiv:1410.6765





1) Impact of jet data for PDF fits demonstrated by a dedicated CMS paper :
- Jets data provides constraints wrt to DIS data (HERA I)
- Of course the real constraint in full PDF fits is lower since other jet data are used.

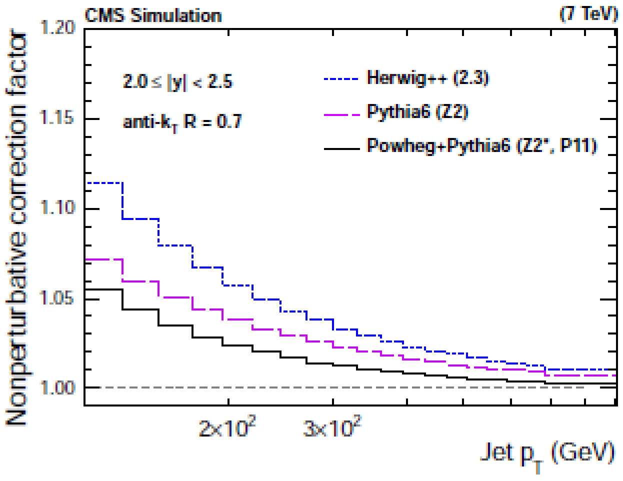
2) Full NNLO calculated do not exist. But gg → gg already available
PDF fits (like NNPDF) use the inclusive jets points that have a small k factor for gg → gg

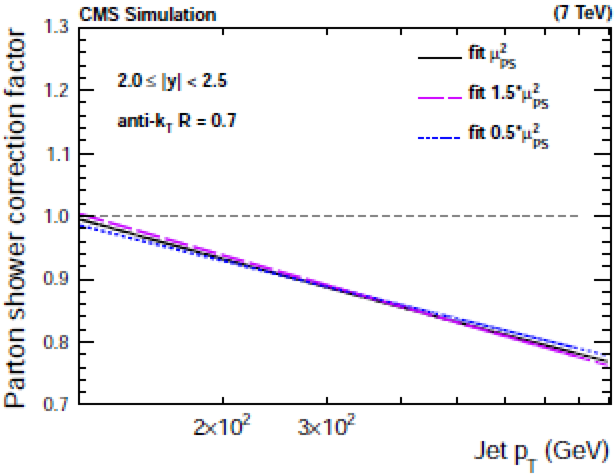
2.2) Inclusive jets cross section

arXiv:1410.6765

The PDF fits within CMS are used to :

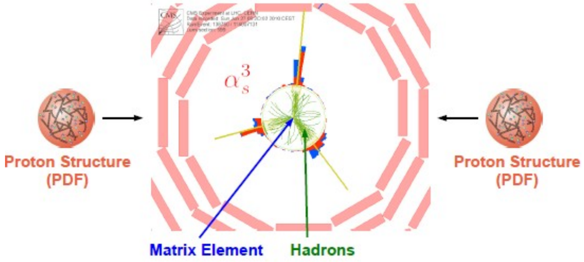
1) test data impact on PDFs
2) put data in a format easy to use for PDF fitting groups
3) spot potential features in data prior to a publication :
   - Correlations between different region of the detector was overestimated and revised.
   - NP corrections was revised to include POWHEG (NLO+PS) in addition to PYTHIA / HERWIG (LO+PS)
   - PS corrections from POWHEG was also studied but not suggested for PDF fits since uncertainties and tunes are not yet mature.



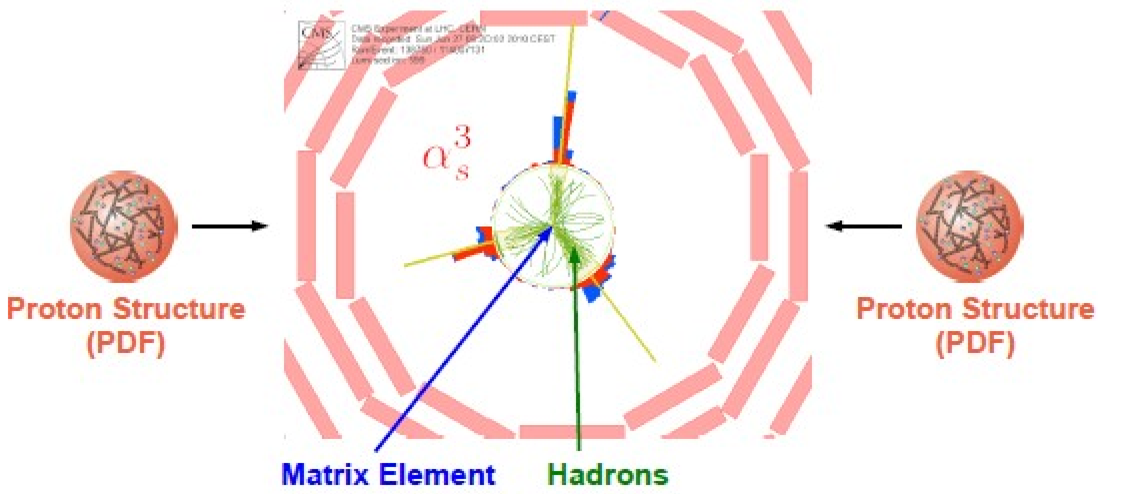


Strong coupling extraction

Inclusive jets	7 TeV, 5 fb^{-1}	Sect. 3.1.	[25, 183]	[21, 48, 91]
Dijets	7 TeV, 5 fb^{-1}	Sect. 3.1.	[25]	–
Three-jets	7 TeV, 5 fb^{-1}	Sect. 3.1.	[184]	[184]
Three-jets/Di-jets ratio	7 TeV, 5 fb^{-1}	Sect. 3.1.	[49]	[49]

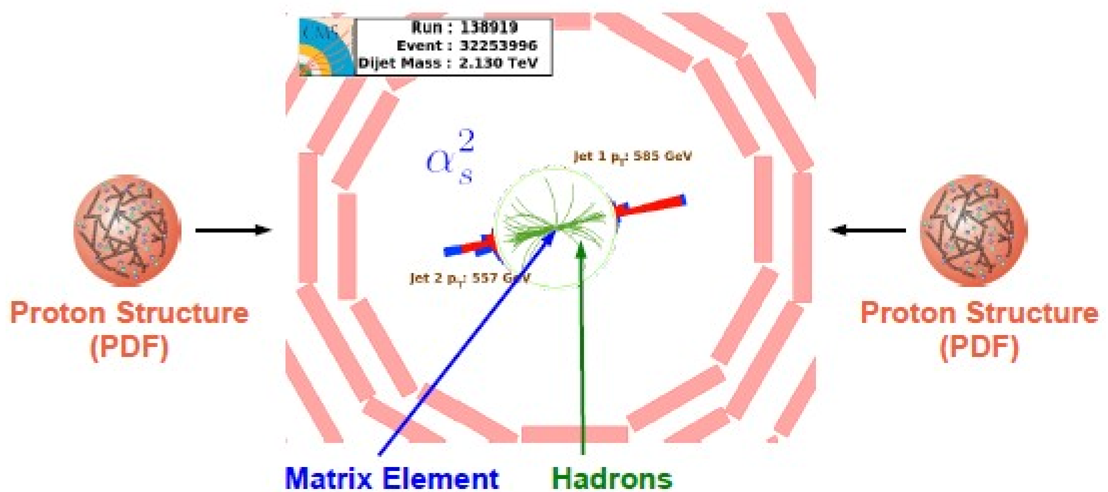


3.1) General concept for α_s from jet rates



3 jets production sensitive to α_s^2

Ratio 3/2 jets sensitive to α_s

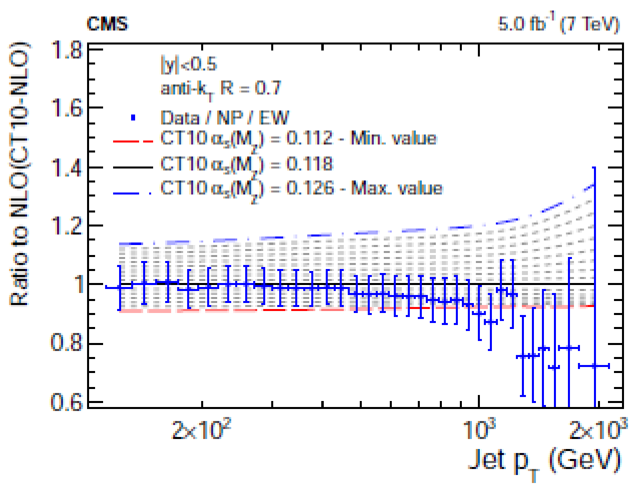


2 jets production (or inclusive jets) sensitive to α_s

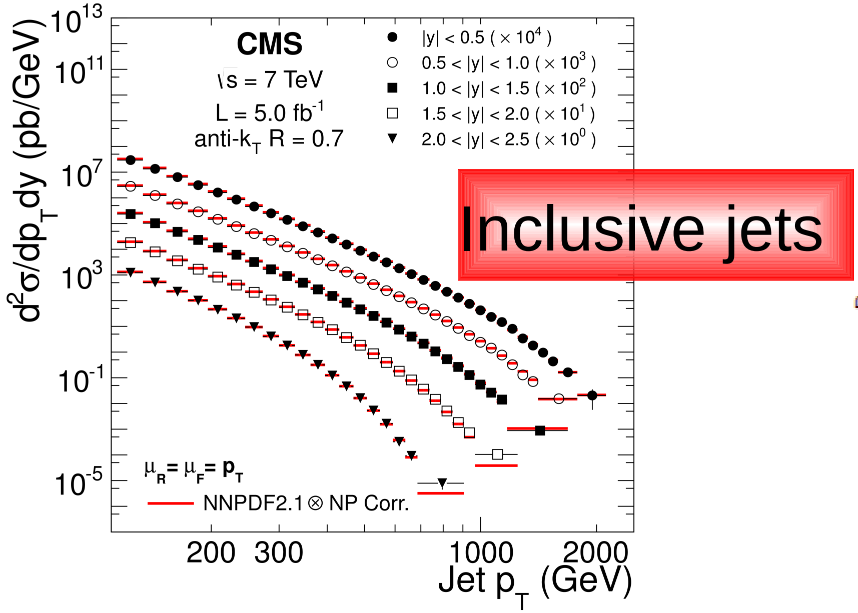
3.1) General concept for α_s from jet rates

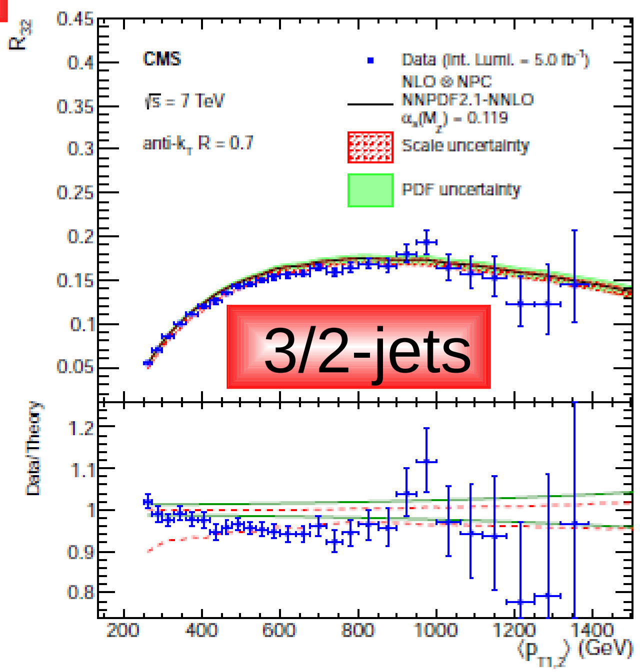
1) CMS specializes on strong coupling extraction from jet rates :
- Extract absolute strength
- Extract running from ~200 GeV up to 2 TeV.

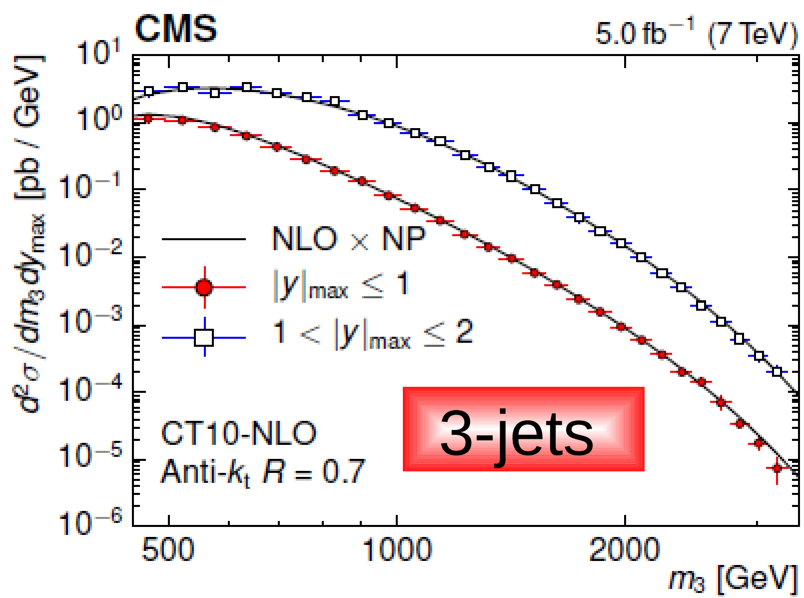
2) Well established approach :
- Compare data to FastNLO / NLOJET++ (theory at NLO) predictions corrected for NP.
- Vary strong coupling strength and marginalize over theory and experimental uncertainties.



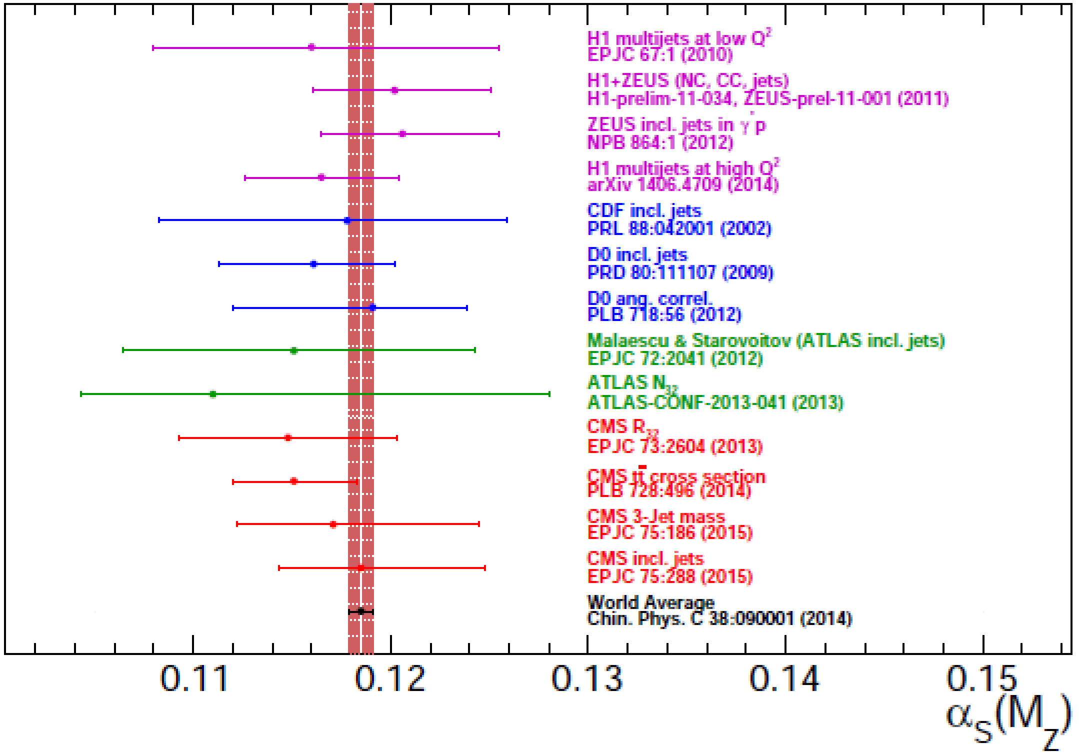
3.2) Data used for extraction at 7 TeV







3.3) Strong coupling results



1) All 3 measurements provide a coherent result with same sensitivity :

2) The most precise result from ttbar production cross section at NNLO.

3.3) Strong coupling results : rule of thumb

3/2-jets ~ α_S

$$\alpha_S(M_Z) = 0.1148 \pm 0.0014\,(\text{exp.}) \pm 0.0018\,(\text{PDF}) \pm 0.0050\,(\text{theory})$$

Incl.-jets ~ α_S

$$\alpha_S(M_Z) = 0.1185 \pm 0.0019\,(\text{exp}) \pm 0.0028\,(\text{PDF}) \pm 0.0004\,(\text{NP})\,^{+0.0053}_{-0.0024}\,(\text{scale})$$

3-jets ~ α_S^2

$$\alpha_S(M_Z) = 0.1171 \underset{(\text{exp.})}{\pm 0.0013} \underset{(\text{PDF})}{\pm 0.0024} \boxed{\underset{(\text{theory})}{\pm 0.0008} \,^{+0.0069}_{-0.0040}}$$

Whatever observable you choose in hadronic final state the uncertainty would be the same provided you stay at NL

- Larger is α_s « order » you are sensitive to
- Larger are the scale uncertainties on the observable
- Larger are experimental uncertainties on the observable related to Jet Energy scale

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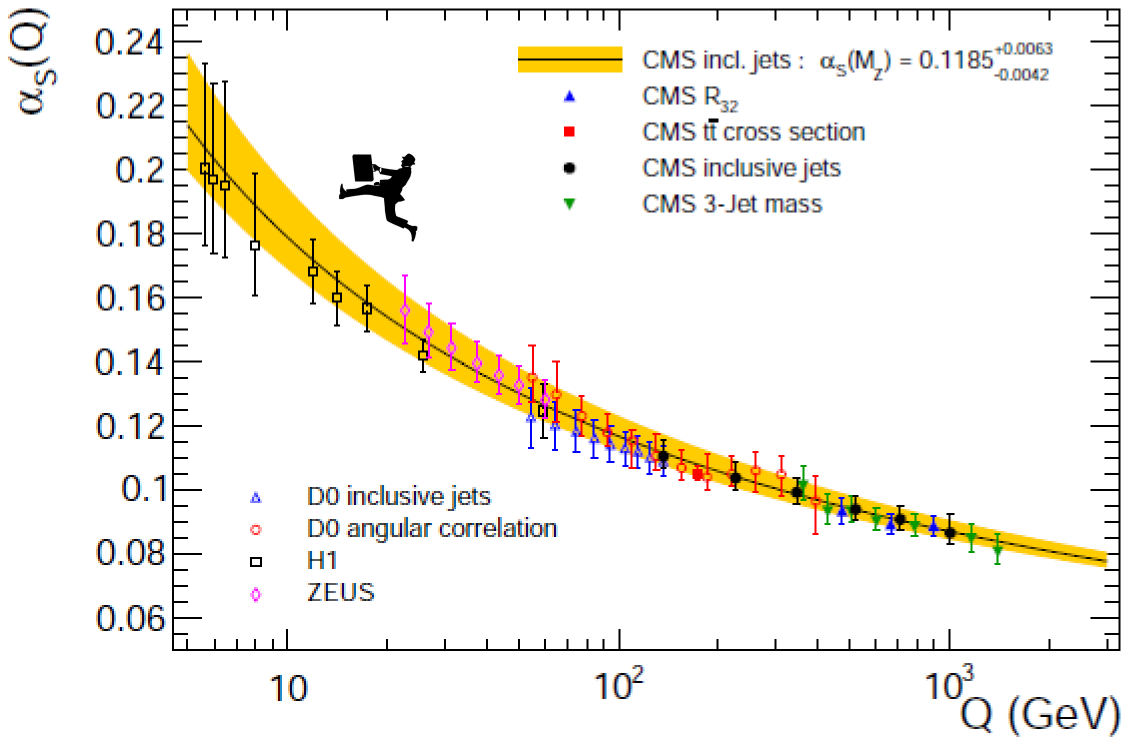
At the end things compensates more or less and you end up with 5 % precise result if you do your job well.

3.4) Strong coupling running



1) Fully coherent picture of strong coupling running between ep and pp collisions up to 1.5 TeV.

2) New theory uncertainties (1 %) considered due to new region reached :
- presence of top quark in running.
- EWK effects uncertainties.
- ttbar « contamination » of multijet results

SUMMARY

1) The most detailed summary is in arXiv:507.00556

2) Run I 7 TeV results are all public and used in new generation of PDFs.

3) Run I 8 TeV results are about to arrive : precise measurements Requires time.

4) In general LHC demonstrated the ability to provide O(%) level precise results and accepted by PDF community as major actor in the field:

> « LHC is its own best friend to constraint PDFs in is own energy regime »

BACKUP

1.3) Inclusive W/Z production

7 TeV, 36 pb^{-1}

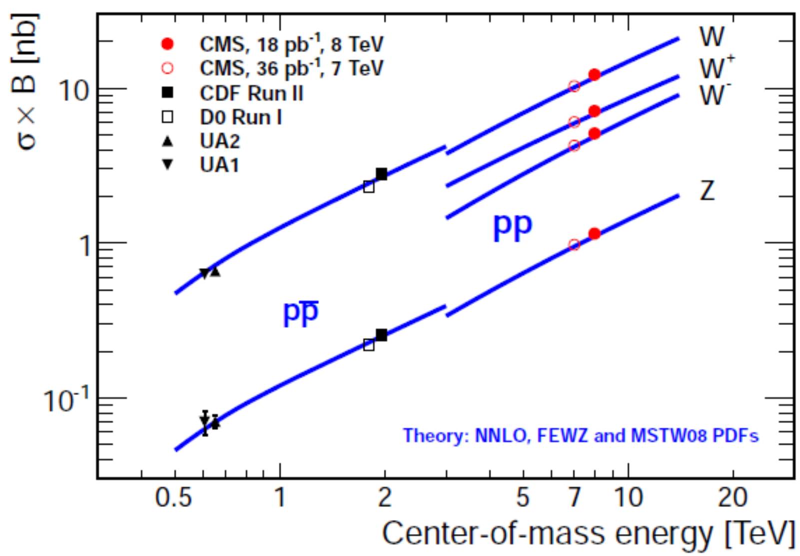
EWK-10-005 – HEPD.

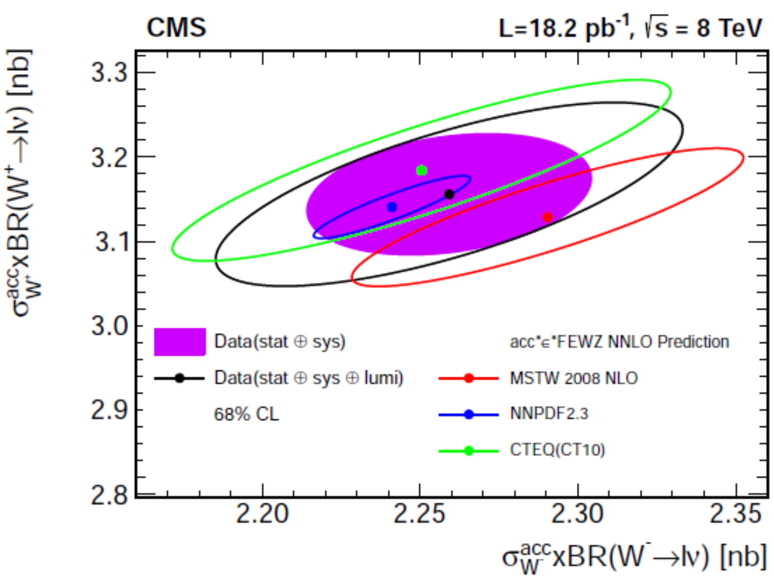
8 TeV, 18 pb^{-1}

SMP-12-011 – HEPD.

1) Precise results are public
based on low PU data.
Expected to be the
First result at 13 TeV using 50 ns data.

2) Clearly sensitive to the previous
generation of PDFs from
« PDF4LHC »-recommendation era.
Not differential like ATLAS ones.





1.6) Z+b and flavous scheme

7 TeV, 5 fb^{-1}

SMP-13-004 – HEPD.

JHEP 1406 (2014) 120, arXiv:1402.1521

Cross section	Measured	MADGRAPH (5F)	aMC@NLO (5F)	MCFM (parton level)	MADGRAPH (4F)	aMC@NLO (4F)
σ_{Z+1b} (pb)	$3.52 \pm 0.02 \pm 0.20$	3.66 ± 0.22	$3.70^{+0.23}_{-0.26}$	$3.03^{+0.30}_{-0.36}$	$3.11^{+0.47}_{-0.81}$	$2.36^{+0.47}_{-0.37}$
σ_{Z+2b} (pb)	$0.36 \pm 0.01 \pm 0.07$	0.37 ± 0.07	$0.29^{+0.04}_{-0.04}$	$0.29^{+0.04}_{-0.04}$	$0.38^{+0.06}_{-0.10}$	$0.35^{+0.08}_{-0.06}$
σ_{Z+b} (pb)	$3.88 \pm 0.02 \pm 0.22$	4.03 ± 0.24	$3.99^{+0.25}_{-0.29}$	$3.23^{+0.34}_{-0.40}$	$3.49^{+0.52}_{-0.91}$	$2.71^{+0.52}_{-0.41}$
$\sigma_{Z+b/Z+j}$ (%)	$5.15 \pm 0.03 \pm 0.25$	5.35 ± 0.11	$5.38^{+0.34}_{-0.39}$	$4.75^{+0.24}_{-0.27}$	$4.63^{+0.69}_{-1.21}$	$3.65^{+0.70}_{-0.55}$