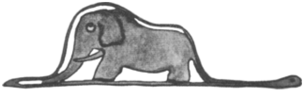
QCD Parameter Extraction:

α_s and PDFs from Top

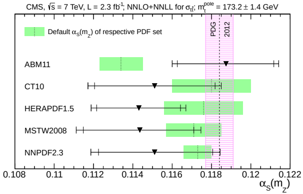
Sebastian Naumann-Emme (DESY)

on behalf of the ATLAS and CMS Collaborations

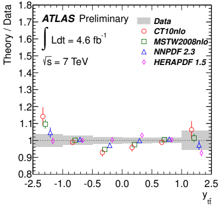
TOP2013, September 16th, Durbach



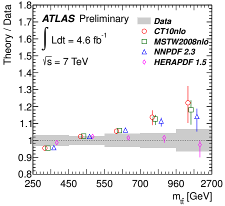
Outline



CMS, √s = 7 TeV, L = 2.3 fb⁻¹; NNLO+NNLL for σtt̄; m_t^pole = 173.2 ± 1.4 GeV
Default αS(mZ) of respective PDF set
PDG 2012
ABM11
CT10
HERAPDF1.5
MSTW2008
NNPDF2.3
0.108
0.11
0.112
0.114
0.116
0.118
0.12
0.122
αS(mZ)



ATLAS Preliminary
∫ Ldt = 4.6 fb⁻¹
√s = 7 TeV
Data
CT10nlo
MSTW2008nlo
NNPDF 2.3
HERAPDF 1.5
Theory / Data
y_tt̄



ATLAS Preliminary
∫ Ldt = 4.6 fb⁻¹
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Data
CT10nlo
MSTW2008nlo
NNPDF 2.3
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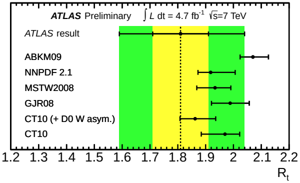
Theory / Data
m_tt̄ [GeV]

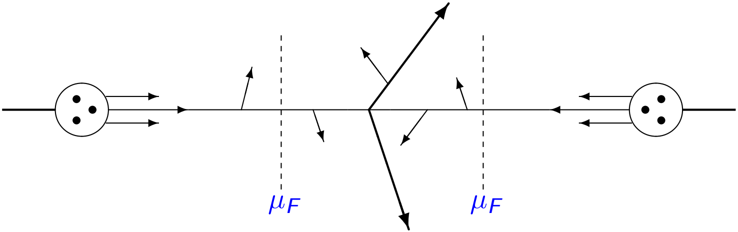


ATLAS Preliminary ∫ L dt = 4.7 fb⁻¹ √s=7 TeV
ATLAS result
ABKM09
NNPDF 2.1
MSTW2008
GJR08
CT10 (+ D0 W asym.)
CT10
R_t

Factorization theorem: $\sigma \propto \mathrm{PDFs}(x, \mu_F) \otimes \hat{\sigma}(x, \mu_F, \mu_R, \alpha_S(\mu_R))$

PDFs: parton distribution functions, determined from experimental data
$\rightarrow$ non-perturbative long-distance structure

$\hat{\sigma}$: hard scattering matrix element, perturbatively calculable
$\rightarrow$ short-distance structure



Strong Coupling

Renormalization group equation predicts the energy dependence of the strong coupling

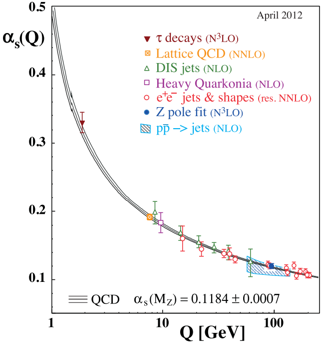
But: the absolute strength α_S is a free parameter of the theory

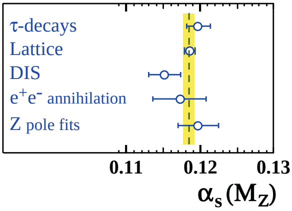
Measured in a variety of processes and at different energies

Precision of $\alpha_S(m_Z)$ world average: 0.6%

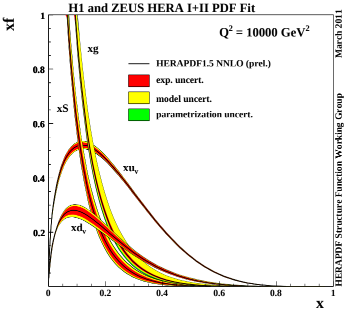
Precision driven by low-Q data

Jet data can probe α_S even up to the TeV scale already but only to NLO (or approx. NNLO) with sizable scale uncertainties and non-pert. corrections





Parton Distribution Functions



$f_i(x, Q^2)$: probability for parton i (valence quark, sea quark, gluon) to carry fraction x of the longitudinal hadron momentum at the energy scale Q^2

ABM CTEQ GJR HERAPDF MSTW NNPDF ...

Main differences between PDF sets:

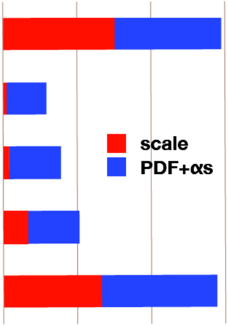
- Order of perturbation theory (LO, NLO, NNLO)
- Choice of data sets (fixed target, HERA, Tevatron, LHC)
- Treatment of systematic uncertainties in the data and correlations
- Parametrization at starting scale (Q_0)
- Choice of heavy-flavor scheme
- Values of $\alpha_S(m_Z)$ and quark masses

Gluon PDF

Significant uncertainty on the gluon PDF at medium–high x, affecting predictions for Higgs, $t\bar{t}$, jet production and BSM scenarios

For example:

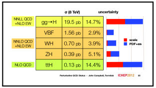
		σ (8 TeV)	uncertainty
NNLL QCD +NLO EW	gg→H	19.5 pb	14.7%
NNLO QCD +NLO EW	VBF	1.56 pb	2.9%
	WH	0.70 pb	3.9%
	ZH	0.39 pb	5.1%
NLO QCD	ttH	0.13 pb	14.4%



Perturbative QCD: Status - John Campbell, Fermilab ICHEP2012 30

Gluon PDF (cont.)

Significant uncertainty on the gluon PDF at medium–high x, affecting predictions for Higgs, $t\bar{t}$, jet production and BSM scenarios

For example: 

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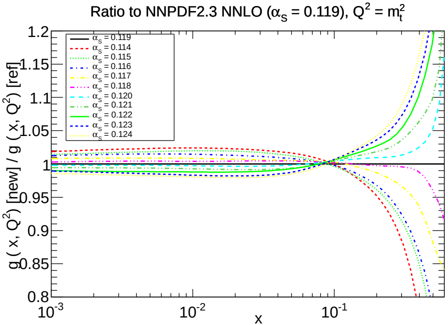
But also: Production of gluino pairs, Kaluza-Klein gravitons, ...

Jet and $t\bar{t}$ data can be used to further constrain the gluon PDF

α_S and gluon PDF are strongly correlated at large x



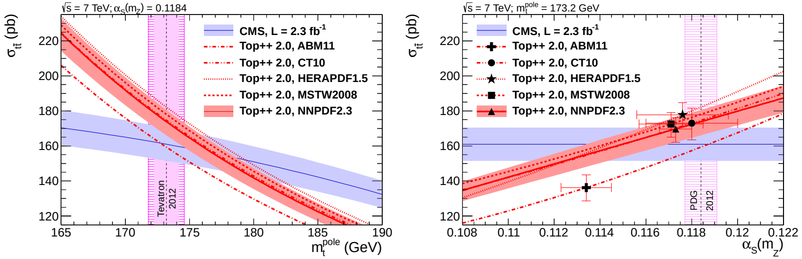
arXiv:1303.7215 (Czakon, Mangano, Mitov, Rojo)

The cross section for $pp \to t\bar{t} + X$ has been...

- ...calculated to NNLO+NNLL QCD → M. Czakon's talk yesterday
  - Uncertainties related to higher orders (μ_R, μ_F), PDF, α_S and m_t now roughly 3% each
- ...measured by ATLAS and CMS at $\sqrt{s} = 7$ and 8 TeV, using the various decay channels

→ Talks by A. Jung, M. Gallinaro and S. Protopopescu yesterday

Predicted $\sigma_{t\bar{t}}$ strongly depends on m_t and α_S, but also the measured $\sigma_{t\bar{t}}$ can depend on them (via the acceptance corrections):



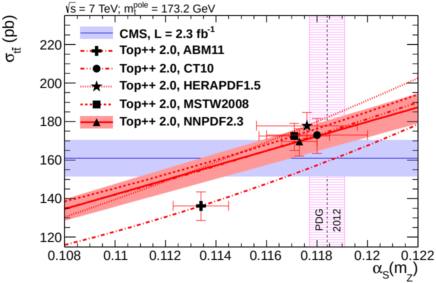
arXiv:1307.1907 (CMS-TOP-12-022)

α_s Extraction

arXiv:1307.1907 (CMS-TOP-12-022)

[→ Extractions of m_t to be discussed tomorrow]

- Take CMS' most-precise single measurement of $\sigma_{t\bar{t}}$ to date: result at 7 TeV in the dilepton channel JHEP 11 (2012) 067 (CMS-TOP-11-005)
  - Only minimal dependence on α_S found
- And the NNLO+NNLL prediction (via program Top++ 2.0)
- With five different NNLO PDF sets, each providing an $\alpha_S(m_Z)$ scan
  - α_S dependence of predicted $\sigma_{t\bar{t}}$ almost linear
  - Full α_S-PDF correlations taken into account
  - Relatively small differences between four of the five PDF sets
  - Default $\alpha_S(m_Z)$ of ABM significantly lower
  - Smaller gluon density of ABM



α_s Extraction: Technique

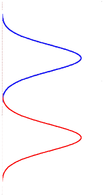
NNLO

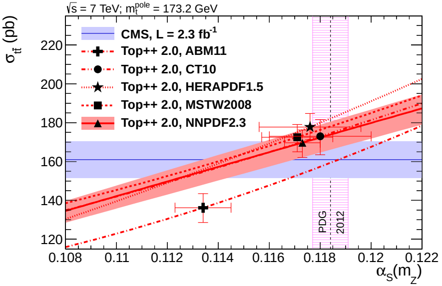
arXiv:1307.1907 (CMS-TOP-12-022)

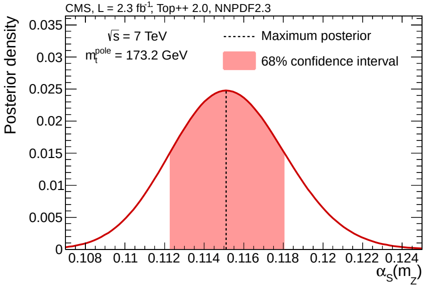
Two probability functions with α_S dependencies and uncertainties of measured and predicted $\sigma_{t\bar{t}}$:

$$f_{\mathrm{exp}}(\sigma_{t\bar{t}}|\alpha_S) \Rightarrow$$

$$f_{\mathrm{th}}(\sigma_{t\bar{t}}|\alpha_S) \Rightarrow$$







Obtain most probable α_S value from maximum of marginalized joint posterior:

$$\int f_{\mathrm{exp}}(\sigma_{t\bar{t}}|\alpha_S)\; f_{\mathrm{th}}(\sigma_{t\bar{t}}|\alpha_S)\, \mathrm{d}\sigma_{t\bar{t}}$$

α_s Extraction: Uncertainties

NNLO

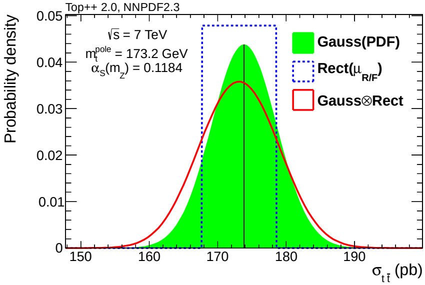
arXiv:1307.1907 (CMS-TOP-12-022)

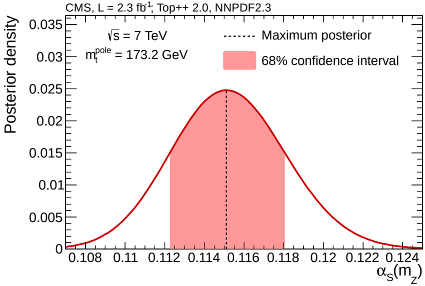
Uncertainty on measured $\sigma_{t\bar{t}}$ parametrized with Gaussian

For $f_{\rm th}$: Gaussian for PDF uncertainty, step function covering scale variations

No big changes when trying different parametrizations for scale uncertainty

Marginalized posterior yields Bayesian confidence interval: 2.5% uncertainty on α_S (with roughly 1% being due to the scale uncertainty)



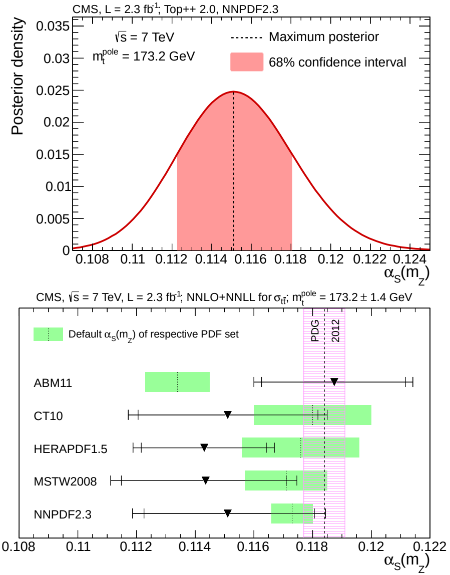


α_s Extraction: Uncertainties (cont.) NNLO

Additional uncertainties:

- Constrained m_t to Tevatron average of direct measurements, assigning additional 1 GeV uncertainty to $m_t^{MC} \stackrel{?}{=} m_t^{pole}$ ambiguity: 173.2 $\pm$1.4 GeV $\rightarrow$ 1.1% on α_S
- LHC beam energy: $\sqrt{s} = 7,000 \pm 46$ GeV $\rightarrow$ 0.7% on α_S

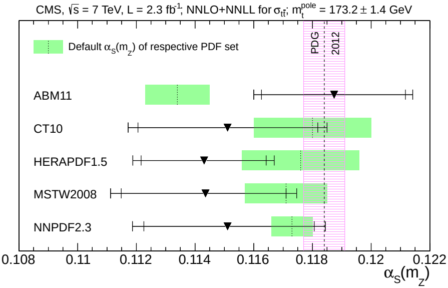
Final α_S uncertainty: 2.9%

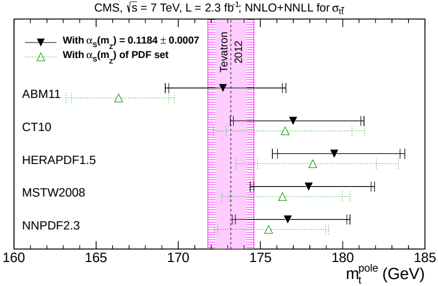


α_s Extraction: Results

NNLO

arXiv:1307.1907 (CMS-TOP-12-022)





First α_S from top

First α_S at NNLO from a hadron collider

Rather competitive precision

With NNPDF: $\alpha_S(m_Z) = 0.1151^{+0.0033}_{-0.0032}$

Same approach for m_t extraction

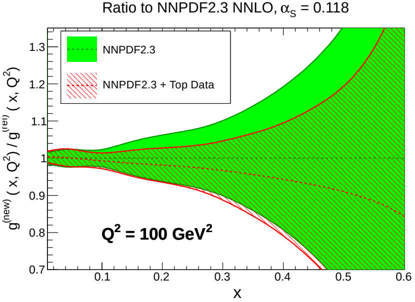
→ See tomorrow's top-mass session

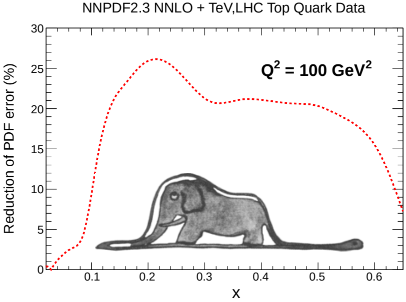
Smaller gluon density of ABM requires either higher α_S or lower m_t to reproduce the $\sigma_{t\bar{t}}$ measured by CMS arXiv:1303.7215 (Czakon, Mangano, Mitov, Rojo)

Take five data points for the total $\sigma_{t\bar{t}}$, neglecting correlations:

1. Latest CDF-D0 combination at 1.96 TeV (8.8/fb)
2. ATLAS combination at 7 TeV (up to 1/fb)
3. CMS dileptons at 7 TeV (2.3/fb)
4. ATLAS l+jets at 8 TeV (5.8/fb)
5. CMS dileptons at 8 TeV (2.4/fb)

And compare to NNLO+NNLL (Top++ 2.0) in an NNPDF2.3 fit:





Similar study was performed at approx. NNLO with NNPDF2.1

→ JHEP 1207 (2012) 194 (Beneke, Falgari, Klein, Piclum, Schwinn, Ubiali, Yan)

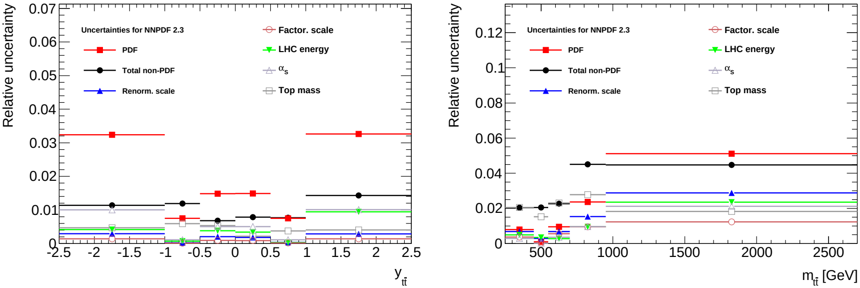
Differential Cross Sections

Variety of (normalized) differential $t\bar{t}$ cross sections measured by ATLAS and CMS at $\sqrt{s} = 7$ and 8 TeV, in l+jets and dileptons

→ See M. Aldaya's talk later today for more details

Predictions for some variables available at approx. NNLO; more being provided `arXiv:1308.1635 (Guzzi, Lipka, Moch)`, soon also with FastNLO interface

`ATL-PHYS-PUB-2013-008` Uncertainty of NLO prediction from MCFM, $\sqrt{s} = 7.00 \pm 0.07$ TeV, $m_t = 172.5 \pm 1$ GeV ⊗Applgrid



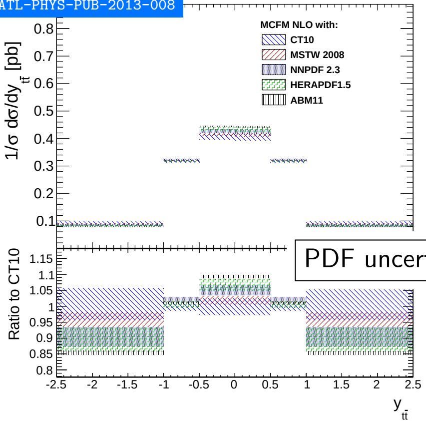
→ Where PDF uncertainty is larger than other modeling uncertainties, largest potential to improve the accuracy of future PDF fits

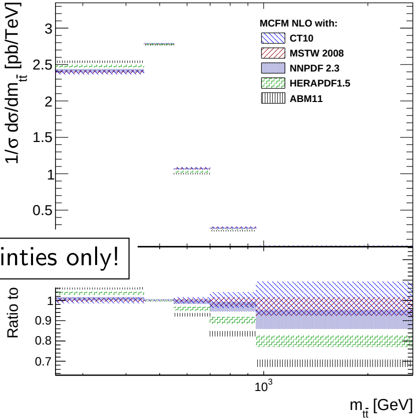
Differential Cross Sections

NLO

Largest PDF sensitivity found in rapidity and invariant mass of $t\bar{t}$ system:

ATL-PHYS-PUB-2013-008





PDF uncertainties only!

Large rapidity requires one incoming parton with high x, the other with small x

Electroweak corrections known to be non-negligible but typically not yet included

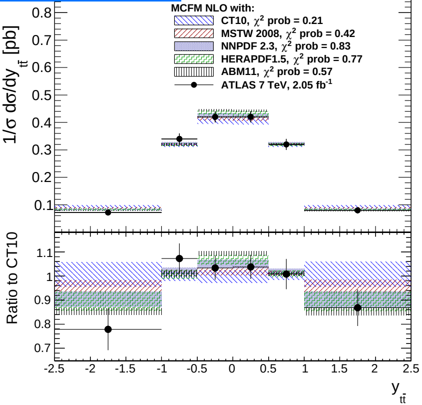
$\rightarrow$ Significant tension in shape between predictions with various PDF sets

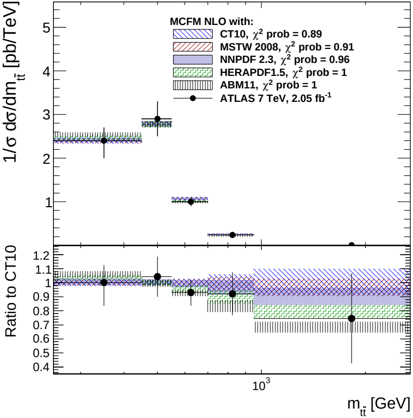
Differential Cross Sections

NLO

. . . adding in all uncertainties and data ($\sqrt{s} = 7$ TeV, 2.1 fb^{-1}, l+jets):

ATL-PHYS-PUB-2013-008





χ^2 probabilities calculated, including bin-to-bin correlation for the data

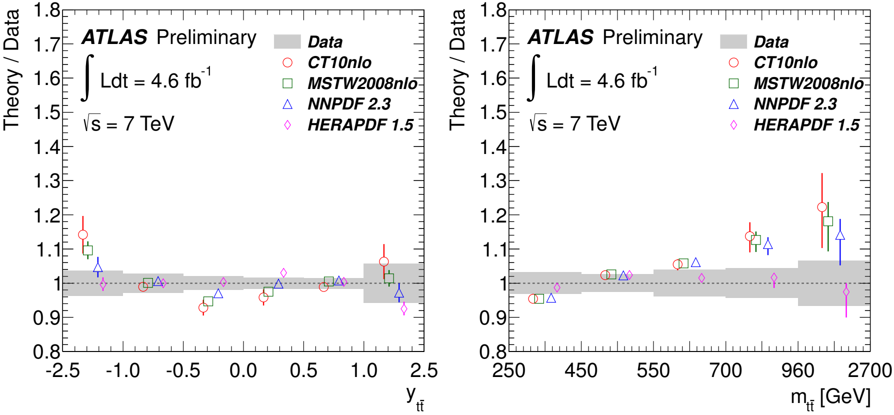
→ Best separation strength for $y_{t\bar{t}}$: from probability of 21% for CT10 to 83% for NNPDF

Differential Cross Sections

NLO

ATLAS-CONF-2013-099 NEW! Updated results from 2.1 fb^{-1} to 4.6 fb^{-1} ...

→ See M. Aldaya's talk later today for more details



Again, level of agreement CT10 < MSTW < NNPDF

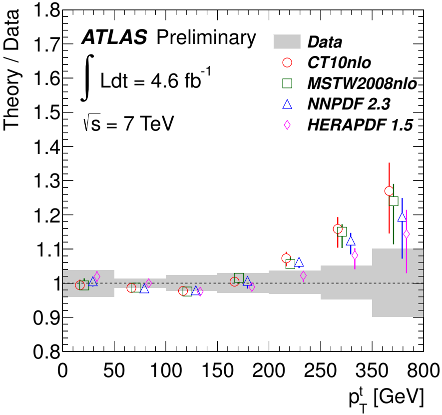
New: data seems to prefer HERAPDF1.5

Differential Cross Sections

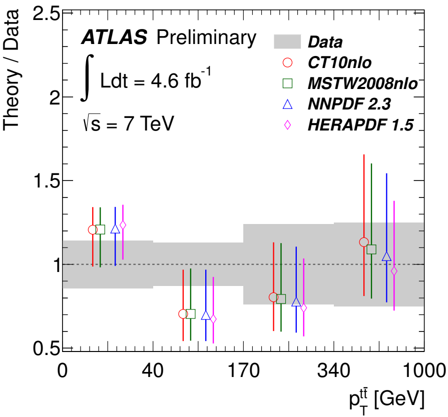
NLO

ATLAS-CONF-2013-099 **NEW!** . . . and added PDF sensitivity of top and top-pair p_T

→ See M. Aldaya's talk later today for more details

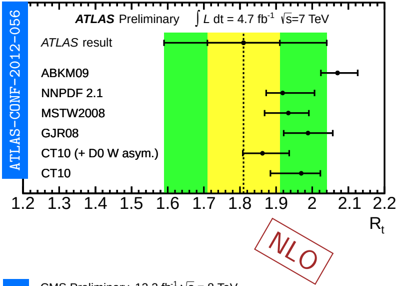


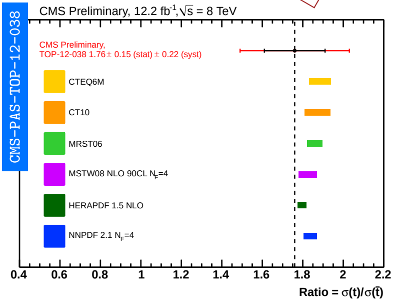
PDF dependence of p_T(top) slope above 200 GeV



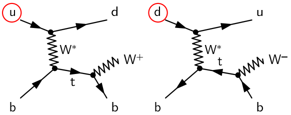
No significant PDF sensitivity in $p_T(t\bar{t})$ yet

Single Top





t-channel production:



↷ top/anti-top cross-section ratio sensitive to u/d ratio in the proton ($u/d \sim 2$)

Kinematic regime: $0.02 \lesssim x \lesssim 0.5$

Complementary to measurements via the W charge asymmetry, which probe $0.001 \lesssim x \lesssim 0.1$ at the LHC and $0.005 \lesssim x \lesssim 0.3$ at the Tevatron

Conclusions

- First determination of α_S from top production: first α_S from a hadron collider at NNLO, precision competitive with other processes
- Inclusive $t\bar{t}$ cross section currently the only process that directly allows us to probe the high-x gluon PDF at full NNLO
- Improved precision on gluon PDF crucial also for Higgs and BSM
- Differential cross sections (in particular large-$y_{t\bar{t}}$ region) starting to allow for even more explicit PDF discrimination
- First: Identify (and maximize) PDF sensitivity Then: Understand correlations (both between theory parameters and within the data) Eventually: Improve PDFs by including data in the fit
- Not yet incorporated: effects of electroweak corrections
- Cross-section ratios 8/7 TeV (and 14/8 TeV) still to be exploited: PDF uncert. 4 times larger than combined scale, α_S and m_t uncert.
- Single top (t-channel): $\frac{\sigma_t}{\sigma_{\bar{t}}}$ sensitive to u/d PDF ratio

BACKUP

Differences between PDF Groups

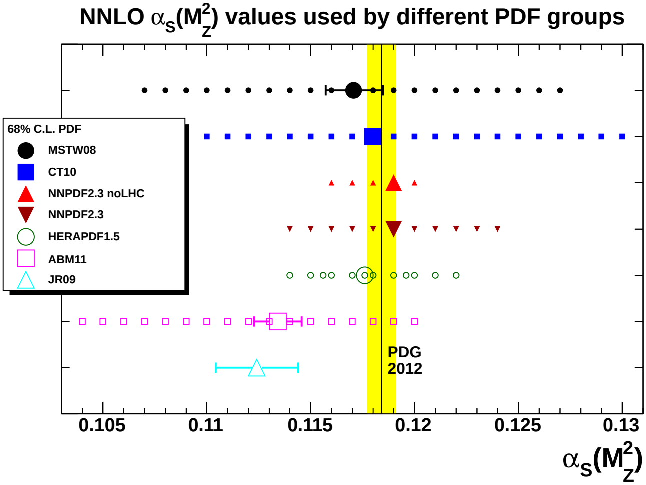
arXiv:1301.6754 (Forte, Watt)

	MSTW08	CT10	NNPDF2.3	HERAPDF1.5	ABM11	JR09
HERA DIS	✓	✓	✓	✓	✓	✓
Fixed-target DIS	✓	✓	✓	×	✓	✓
Fixed-target DY	✓	✓	✓	×	✓	✓
Tevatron $W+Z+$jets	✓	✓	✓	×	×	×
LHC $W+Z+$jets	×	×	✓	×	×	×

	MSTW08	CT10	NNPDF2.3	HERAPDF1.5	ABM11	JR09
No. of PDFs	7	6	7	5	6	5
Statistics	Hess.+DT	Hess.+DT	MC	Hess.+Model+Parm.	Hess.	Hess.+T
PDF parms.	20+8	25	259	14	24	12
Heavy quarks	VFN TR	VFN ACOT	VFN FONLL	VFN TR	FFN	FFN

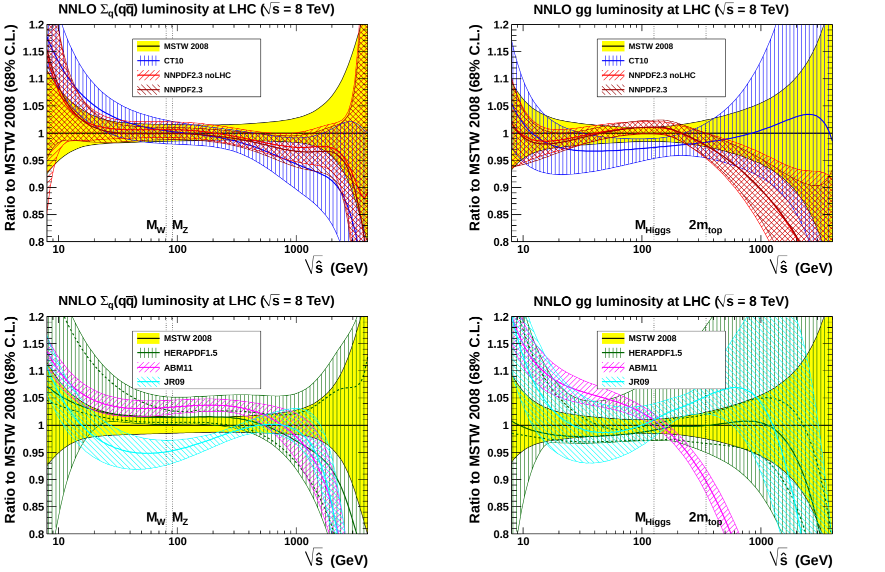
Different α_S

arXiv:1301.6754 (Forte, Watt)



Different Quark and Gluon Luminosities

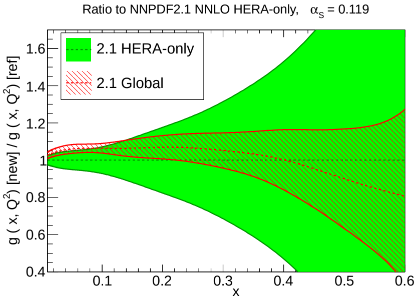
arXiv:1301.6754 (Forte, Watt)

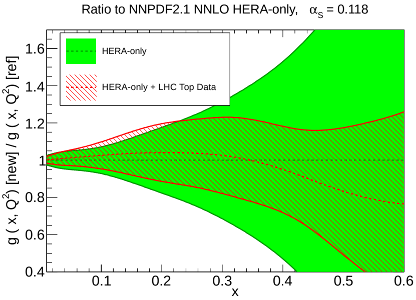


NNPDF Fits with $t\bar{t}$ Data

arXiv:1303.7215 (Czakon, Mangano, Mitov, Rojo)

Collider	NNPDF2.3	NNPDF2.3 + TeV, LHC data	NNPDF2.3 + TeV, LHC 7 TeV data
χ^2 (Total, $N_{\rm dat} = 5$)	6.28	4.88	4.87
χ^2 (LHC 8 TeV, $N_{\rm dat} = 2$)	1.64	1.24	1.24





Cross-Section Ratios

arXiv:1303.7215 (Czakon, Mangano, Mitov, Rojo)