First Determination of α_S from the $t\bar{t}$ Cross Section

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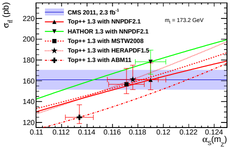
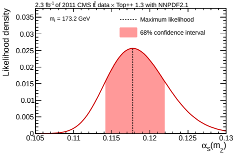
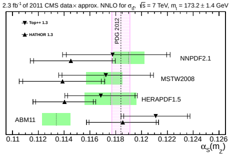
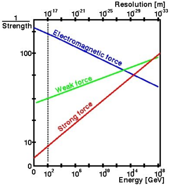






Beside the quark masses, there is only one free parameter in the QCD Lagrangian: the strong coupling constant α_S

QCD predicts a functional form for the energy dependence, $\alpha_S(Q)$, but actual values have to be obtained from experiments



Determinations of α_S at different Q are fundamental measurements

Tests of the coupling at high Q are of particular interest for the validity of the Standard Model

α_S does not only have an impact on the calculations on matrix-element level, it is an important parameter also for non-perturbative computations: parton distribution functions (PDFs), parton showers

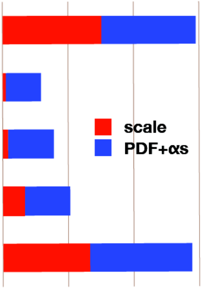
Motivation: Higgs

Higgs production at 125 GeV

https://twiki.cern.ch/twiki/bin/view/LHCPhysics/CrossSections

- Model testing requires assessment of theoretical uncertainties
  - uncertainties from scale variation and PDF+strong coupling

		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%

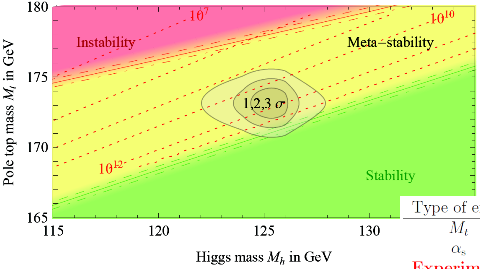


Perturbative QCD: Status - John Campbell, Fermilab ICHEP2012 30

And α_S contributes significant uncertainties also to other QCD predictions, e.g. for $t\bar{t}$

Motivation: Fate of the Universe

α_S and its uncertainty also crucial for the stability of the EW vacuum:

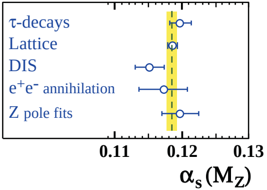


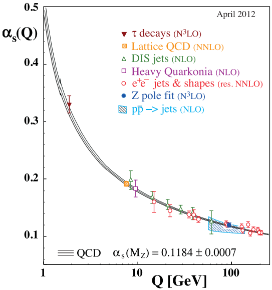
arXiv:1205.6497
arXiv:1207.0980
and others

Type of error	Estimate of the error	Impact on M_h
M_t	experimental uncertainty in M_t	±1.4 GeV
α_s	experimental uncertainty in α_s	±0.5 GeV
Experiment	**Total combined in quadrature**	±1.5 GeV
λ	scale variation in λ	±0.7 GeV
y_t	$\mathcal{O}(\Lambda_{\rm QCD})$ correction to M_t	±0.6 GeV
y_t	QCD threshold at 4 loops	±0.3 GeV
RGE	EW at 3 loops + QCD at 4 loops	±0.2 GeV
Theory	**Total combined in quadrature**	±1.0 GeV

$$M_h\ [\text{GeV}] > 129.4 + 1.4\left(\frac{M_t\ [\text{GeV}] - 173.1}{0.7}\right) - 0.5\left(\frac{\alpha_s(M_Z) - 0.1184}{0.0007}\right) \pm 1.0_{\rm th}$$

2012 world average: 0.1184 ± 0.0007





α_S has been measured in a variety of processes

Results are typically translated assuming the validity of the $\alpha_S(Q)$ evolution and compared at $Q = m_Z$

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

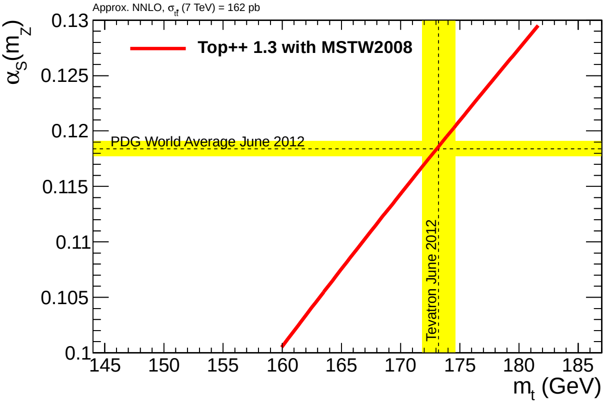
Average dominated by low-Q data

Still only few points above 209 GeV (LEP limit): jet data up to the TeV scale but suffering from large theory uncertainties and only NLO available

$t\bar{t}$ production occurs at $(2m_t + \text{boost}) \approx 360$ GeV

Full NNLO for $\sigma_{t\bar{t}}$ available "soon"?!?

Beside $\sqrt{s}$, two main parameters that determine the predicted $\sigma_{t\bar{t}}$:
α_S and m_t, both currently known with $\approx$ the same precision



Scale and PDF uncertainties on predicted $\sigma_{t\bar{t}}$ not shown here!

Beside $\sqrt{s}$, two main parameters that determine the predicted $\sigma_{t\bar{t}}$:
α_S and m_t, both currently known with $\approx$ the same precision

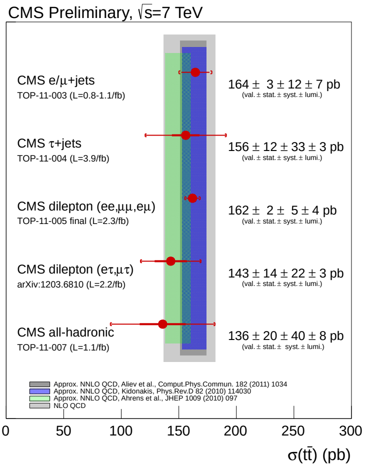
We can take the measured $\sigma_{t\bar{t}}$ and either ...

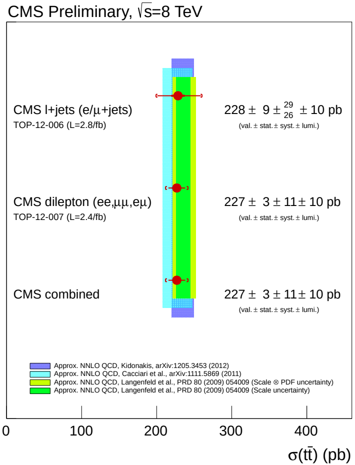
- fix α_S to extract m_t (this is what we have done last year and others had done before) or ...
- fix m_t to extract α_S (this is what we have done now for the very first time in CMS-PAS-TOP-12-022)

A simultaneous determination of m_t and α_S from the inclusive $\sigma_{t\bar{t}}$ fails because any variation of one of the two parameters in the predicted $\sigma_{t\bar{t}}$ can be compensated by a variation of the other

$\rightarrow$ At some point in time, differential cross sections should do the trick!

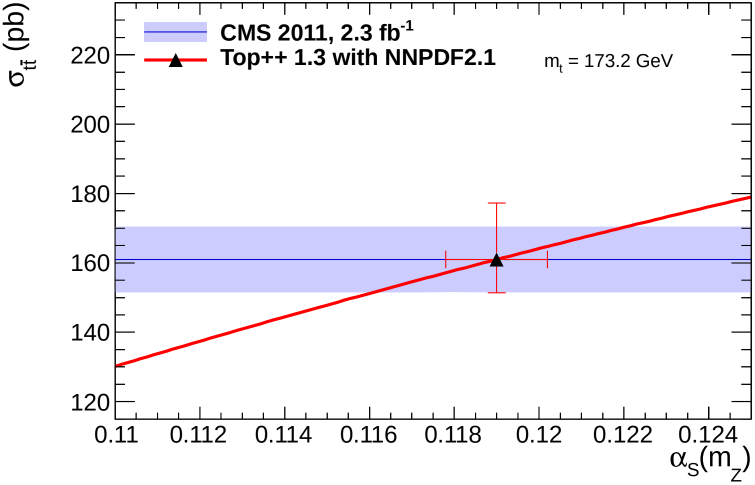
Measured $\sigma_{t\bar{t}}$



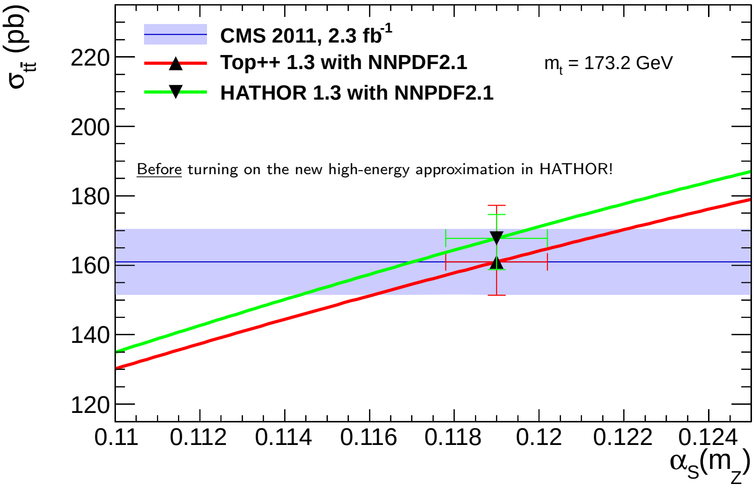


For the α_S extraction, we use the result of `CMS-TOP-11-005`: dileptonic channel, 2.3 fb^{-1} at $\sqrt{s} = 7$ TeV, accuracy of 4%, most precise $\sigma_{t\bar{t}}$ from the LHC so far

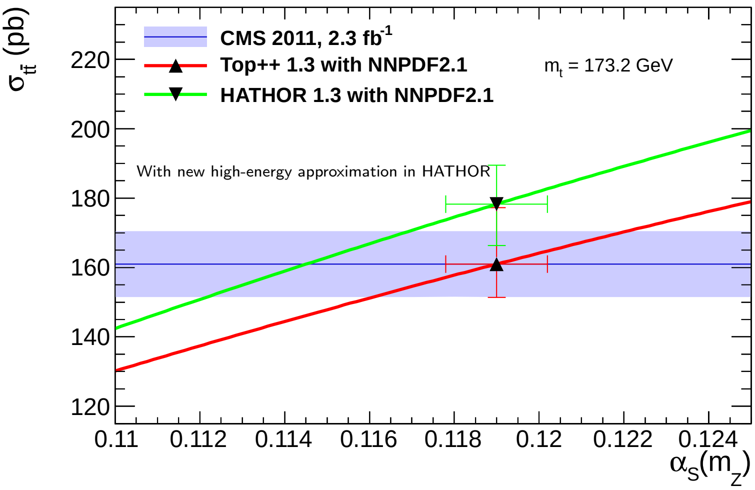
Predicted vs. Measured $\sigma_{t\bar{t}}$

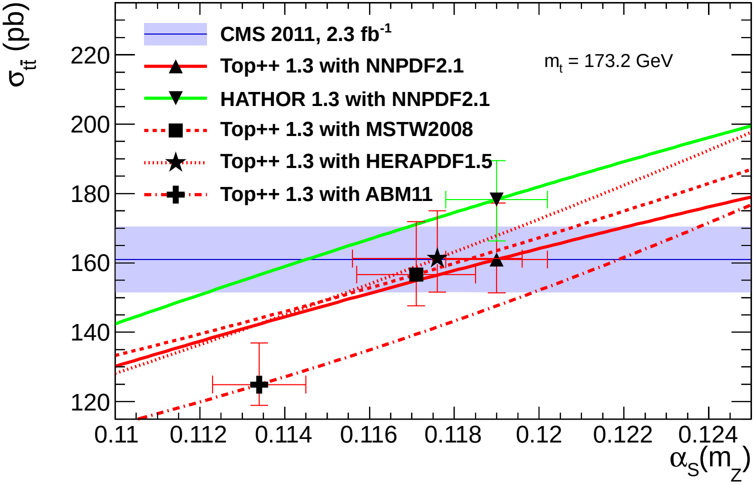


Predicted vs. Measured $\sigma_{t\bar{t}}$



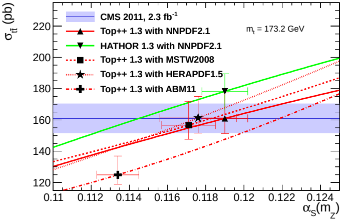
Predicted vs. Measured $\sigma_{t\bar{t}}$



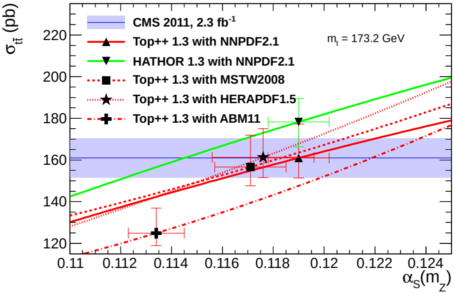


CMS 2011, 2.3 fb-1
Top++ 1.3 with NNPDF2.1
HATHOR 1.3 with NNPDF2.1
Top++ 1.3 with MSTW2008
Top++ 1.3 with HERAPDF1.5
Top++ 1.3 with ABM11
mt = 173.2 GeV
σtt̄ (pb)
220
200
180
160
140
120
0.11
0.112
0.114
0.116
0.118
0.12
0.122
0.124
αS(mZ)

Predicted vs. Measured $\sigma_{t\bar{t}}$



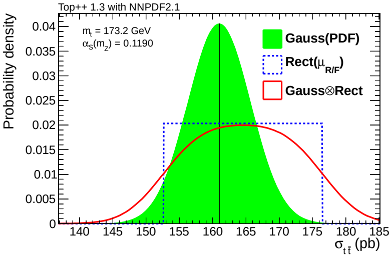
- Slope of predicted $\sigma_{t\bar{t}}$ determined by α_S evolution in the PDF set
- New high-energy approx. in HATHOR 1.3 increased prediction by $\approx$ 6% (without this Top++ and HATHOR were much closer)
- For a given $\alpha_S(m_Z)$, only small differences seen between NNPDF, MSTW and HERAPDF while ABM yields lower $\sigma_{t\bar{t}}$ prediction
  $\rightarrow$ reason: smaller gluon PDF in ABM
- Default ABM α_S rather small
  $\rightarrow$ explanation: higher-twist corrections (for low-Q data) in ABM α_S fit



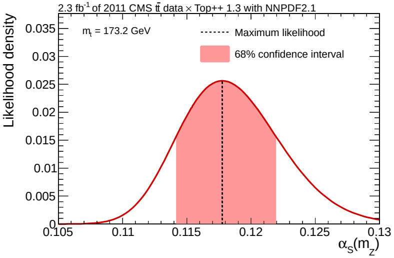
What about the α_S dependence of the measured $\sigma_{t\bar{t}}$?

- Studied α_S dependence of the MC-based acceptance corrections
- Found measured $\sigma_{t\bar{t}}$ to change by less than 1% when increasing/decreasing assumed $\alpha_S(m_Z)$ by 0.0100 from central value of 0.1180

$\rightarrow$ Increase uncertainty (blue bland) on measured $\sigma_{t\bar{t}}$ accordingly



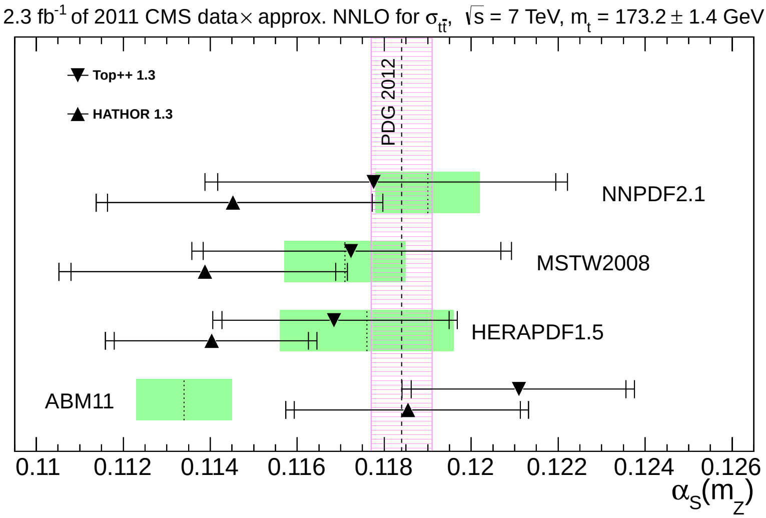
1.) Theory uncertainties (pred. $\sigma_{t\bar{t}}$): Convolve a Gaussian for the PDF uncertainty with a rectangular covering the whole range given by the variation of renormalization and factorization scale



2.) Theory × measurement: Obtain a likelihood by folding the probability function for the predicted $\sigma_{t\bar{t}}$ with a Gaussian probability function for the measured $\sigma_{t\bar{t}}$

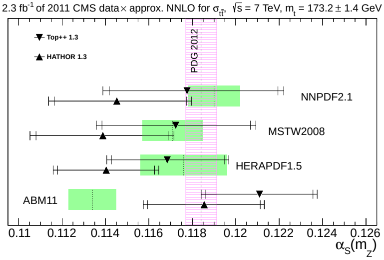
$$L(\alpha_S) = \int f_{\rm exp}(\sigma|\alpha_S)\ f_{\rm th}(\sigma|\alpha_S)\ d\sigma$$

Results



2.3 fb-1 of 2011 CMS data× approx. NNLO for σtt̄, √s = 7 TeV, mt = 173.2 ± 1.4 GeV
Top++ 1.3
HATHOR 1.3
PDG 2012
NNPDF2.1
MSTW2008
HERAPDF1.5
ABM11
0.11
0.112
0.114
0.116
0.118
0.12
0.122
0.124
0.126
αS(mZ)

Results



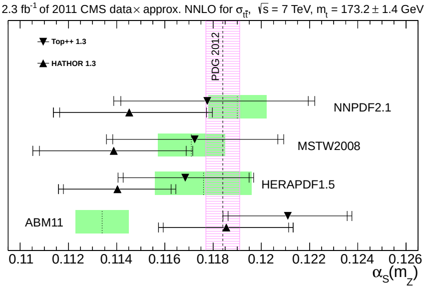
		Most likely value	Uncertainty Total	From δm_t
Top++ 1.3	with NNPDF2.1	0.1178	$^{+0.0045}_{-0.0039}$	$^{+0.0015}_{-0.0015}$
HATHOR 1.3		0.1145	$^{+0.0034}_{-0.0031}$	$^{+0.0013}_{-0.0013}$
Top++ 1.3	with MSTW2008	0.1172	$^{+0.0037}_{-0.0037}$	$^{+0.0013}_{-0.0014}$
HATHOR 1.3		0.1139	$^{+0.0033}_{-0.0034}$	$^{+0.0013}_{-0.0013}$
Top++ 1.3	with HERAPDF1.5	0.1168	$^{+0.0028}_{-0.0028}$	$^{+0.0010}_{-0.0011}$
HATHOR 1.3		0.1140	$^{+0.0024}_{-0.0024}$	$^{+0.0010}_{-0.0010}$
Top++ 1.3	with ABM11	0.1211	$^{+0.0027}_{-0.0027}$	$^{+0.0010}_{-0.0010}$
HATHOR 1.3		0.1185	$^{+0.0028}_{-0.0028}$	$^{+0.0010}_{-0.0010}$

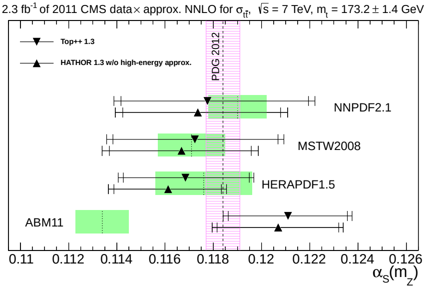
Which m_t do we use as constraint?

- No significant differences between results from Tevatron, ATLAS and CMS and between the size of their uncertainties

  $\curvearrowright$ Chose latest Tevatron average: 173.18 ± 0.94 GeV

- Studies suggest that these MC-based massed deviate by $\mathcal{O}$ (1 GeV) from the pole mass $\curvearrowright$ Increased uncertainty accordingly, i.e. use total δm_t of 1.4 GeV





- Results obtained with NNPDF, MSTW, HERAPDF very similar to each other
- ABM yields larger α_S due to smaller gluon PDF
- Can't find back the small ABM α_S (interesting because $t\bar{t}$ production should not be affected by their higher-twist corrections)
- The new high-energy approx. of HATHOR 1.3 results in 3% lower extracted $\alpha_S(m_Z)$ - without this, Top++ and HATHOR almost identical

Summary and Outlook

CMS-PAS-TOP-12-022

First determination of α_S from $t\bar{t}$ production:

- Interesting energy regime for α_S measurements
- Rather competitive precision (equal or superior to results from jets)
- Another example for the stringent tests of QCD possible with $t\bar{t}$ data
- Most complete study of α_S and PDF dependence of measured vs. predicted $t\bar{t}$ cross section so far
- Waiting for the full NNLO to resolve the current tension between different approximations

Outlook:

- Aiming at a simultaneous determination of α_S, m_t and gluon PDF from (differential) $t\bar{t}$ cross sections in addition to other data
- That would not only yield consistent results for these parameters but, at a later stage, also allow to test their running