Status of PDF Studies at CMS

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PDF4LHC Meeting, 2012-09-26

PDF-related studies are being performed in several of the physics analysis groups at CMS: QCD, electroweak, top, forward

Will give examples from . . .

Jets

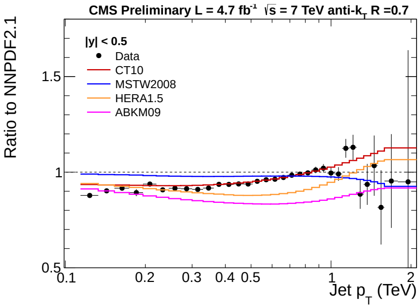
W and Z

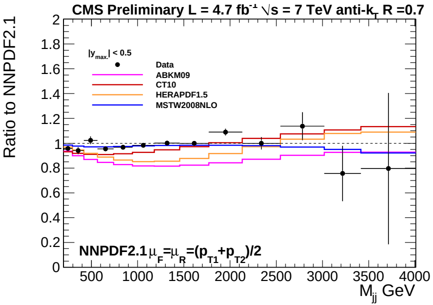
Top

Jets

QCD-11-004 Double-differential cross sections, up to $|y| = 2.5$

$\rightarrow$ PDF variation gives up to 30% uncertainty on prediction





Currently in progress: Integration of inclusive jet data into combined PDF and α_S fit, using the HERAFitter

Furthermore: Extraction of α_S from 3-jet/2-jet ratio

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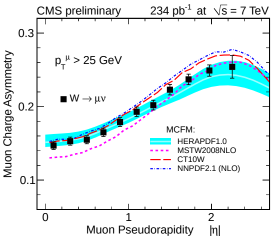
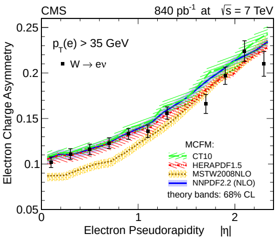
W charge asymmetry

EWK-11-005

SMP-12-001

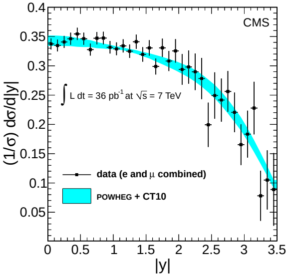
$$\mathcal{A}(\eta_\ell) = \frac{d\sigma/d\eta_\ell(W^+\to\ell^+\nu) - d\sigma/d\eta_\ell(W^-\to\ell^-\bar{\nu})}{d\sigma/d\eta_\ell(W^+\to\ell^+\nu) + d\sigma/d\eta_\ell(W^-\to\ell^-\bar{\nu})}$$





Z rapidity

EWK-10-010



Mostly affected by the up and down content of the PDF sets but also sensitive to the strange component

Standard HERAPDF parametrization

HERA data alone not sufficient to constrain the strange component
$\curvearrowright$ couple it to the down content:

$$x\bar{s} = f_s \cdot x\overline{D} \qquad \text{with} \qquad x\overline{D} = x\bar{d} + x\bar{s}$$
$$\text{and} \qquad x\overline{D} = A_{\overline{D}} \cdot x^{B_{\overline{D}}} \cdot (1-x)^{C_{\overline{D}}}$$

Free-s parametrization

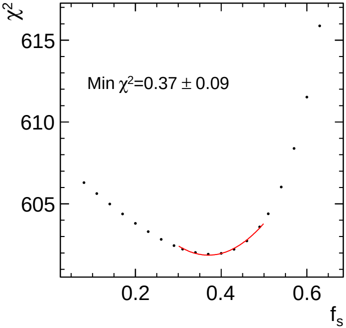
Decouple down and strange component (obtaining two additional free parameters):

$$x\overline{D} = A_{\bar{d}} \cdot x^{B_{\bar{d}}} \cdot (1-x)^{C_{\bar{d}}} + A_{\bar{s}} \cdot x^{B_{\bar{s}}} \cdot (1-x)^{C_{\bar{s}}}$$

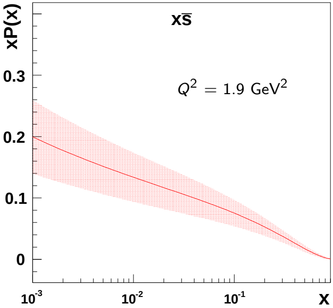
W and Z: Fits

QCD NLO analysis using the HERAFitter with free-s parametrization and HERA-I plus CMS W-asymmetry and Z-rapidity data

Experimental errors only (model and param. uncertainties to be added)!



K. Lipka,
R. Plačakytė,
A. Vargas



$f_s = 0.37$ corresponds to $r_s = \frac{x\bar{s}}{x\bar{d}} = 0.66$

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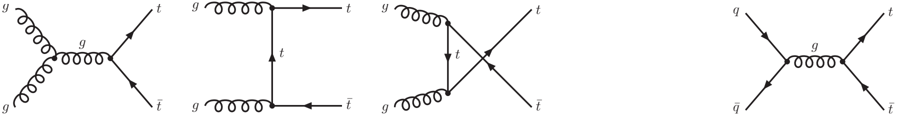
$t\bar{t}$ pairs produced via gg fusion (dominant at the LHC)

and $q\bar{q}$ annihilation



$Q^2 = (2m_t + \beta)^2$, where β is the boost of the $t\bar{t}$ system and on average 10-20 GeV at $\sqrt{s} = 7$ TeV $\curvearrowright$ $Q^2 \approx (360 \text{ GeV})^2$

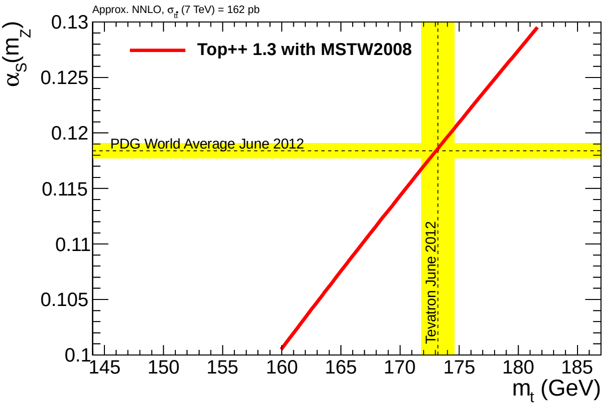
Inclusive $t\bar{t}$ cross section measured to 4% precision

CMS in the dileptonic decay channel: $\sigma_{t\bar{t}}$ (7 TeV) $= 161.9 \pm 6.7$ pb

Calculations available up to approx. NNLO for $gg \rightarrow t\bar{t}$ and full NNLO for $q\bar{q} \rightarrow t\bar{t}$, scales and experimental PDF error give 7-8% uncertainty on predicted $\sigma_{t\bar{t}}$, in addition: strong dependence on m_t and α_S

Top: α_S vs. m_t

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!

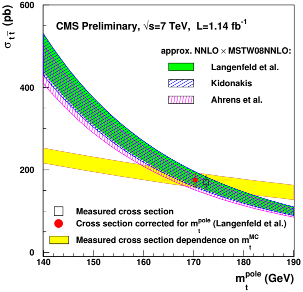
Beside $\sqrt{s}$, two main parameters that determine the predicted $\sigma_{t\bar{t}}$: α_S and m_t, both currently known with $\approx$ the same precision

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

- fix α_S to extract m_t (this is what has been done by D0, ATLAS and CMS in the last years) or ...
- fix m_t to extract α_S (this is new but based on the very same technique)

A simultaneous determination of m_t and α_S 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

$\rightarrow$ In the near future, differential cross sections should do the trick



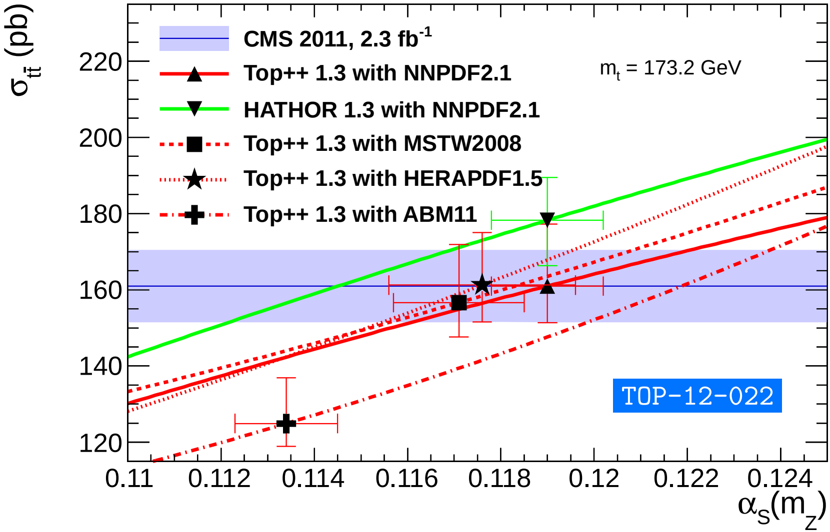
TOP-11-008 Extracted most-probable m_t values in pole and $\overline{\text{MS}}$ scheme

Significant uncertainty due to α_S error, even more important with decreased error on measured $\sigma_{t\bar{t}}$ (was still 11% for m_t results given here)

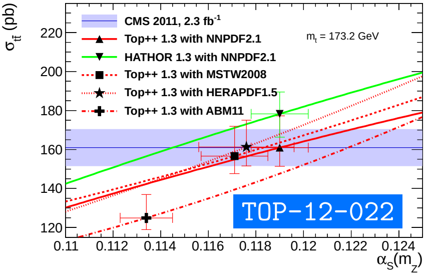
Approx. NNLO × MSTW08NNLO	m_t^{pole} / GeV	$m_t^{\overline{\text{MS}}}$ / GeV
Langenfeld et al. [7]	$170.3^{+7.3}_{-6.7}$	$163.1^{+6.8}_{-6.1}$
Kidonakis [8]	$170.0^{+7.6}_{-7.1}$	–
Ahrens et al. [9]	$167.6^{+7.6}_{-7.1}$	$159.8^{+7.3}_{-6.8}$

Approx. NNLO × HERAPDF15NNLO	m_t^{pole} / GeV	$m_t^{\overline{\text{MS}}}$ / GeV
Langenfeld et al. [7]	$171.7^{+6.8}_{-6.0}$	$164.3^{+6.5}_{-5.7}$
Ahrens et al. [9]	$169.1^{+6.7}_{-5.9}$	$161.0^{+6.8}_{-6.1}$

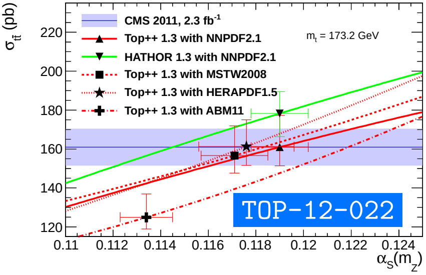
Top: α_S Dependence



Top: α_S Dependence

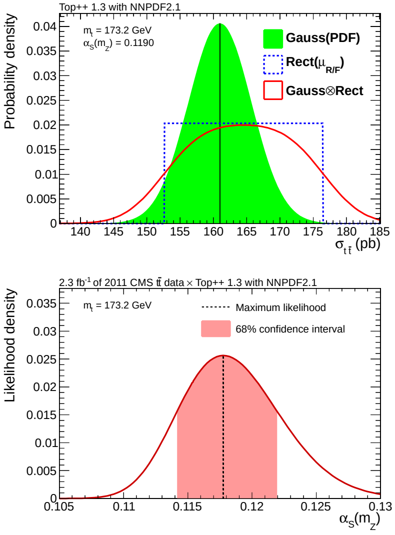


- Slope of predicted $\sigma_{t\bar{t}}$ determined by α_S evolution in the PDF set
- New high-energy approx. in HATHOR 1.3 increases prediction by $\approx$ 6% (without this Top++ and HATHOR much closer)
- For a given $\alpha_S(m_Z)$, only small differences seen between NNPDF, MSTW and HERAPDF while 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^2 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
- Increase uncertainty on measured $\sigma_{t\bar{t}}$ accordingly

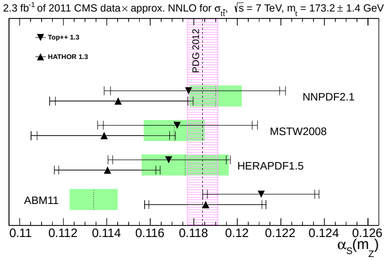


TOP-12-022

1. For the predicted $\sigma_{t\bar{t}}$, convolve a Gaussian for the PDF uncertainty with a rectangular covering the whole range given by the variation of renormalization and factorization scale

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

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

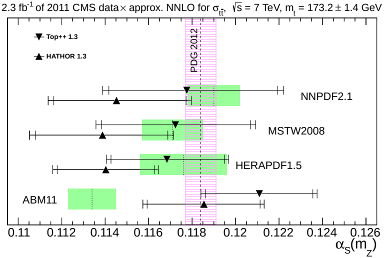


TOP-12-022		Most likely value	Uncertainty Total	Uncertainty From δm_t
Top++ 1.3	with NNPDF2.1	0.1178	$^{+0.0045}_{-0.0039}$	$^{+0.0015}_{-0.0015}$
HATHOR 1.3	with NNPDF2.1	0.1145	$^{+0.0034}_{-0.0031}$	$^{+0.0013}_{-0.0013}$
Top++ 1.3	with MSTW2008	0.1172	$^{+0.0037}_{-0.0037}$	$^{+0.0013}_{-0.0014}$
HATHOR 1.3	with MSTW2008	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	with HERAPDF1.5	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	with ABM11	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



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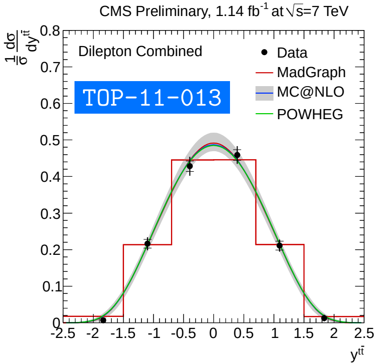
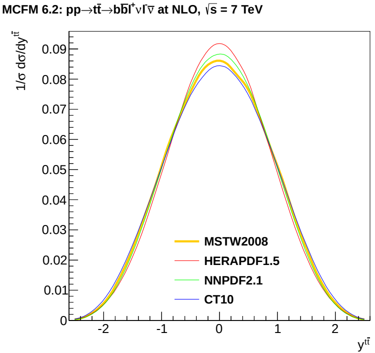
- Results obtained with NNPDF, MSTW, HERAPDF very similar to each other
- ABM yields larger α_S due to smaller gluon PDF
- Can't find back the small ABM α_S (interesting because $t\bar{t}$ production should not be affected by their higher-twist corrections)
- The new high-energy approx. of HATHOR 1.3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

The goal is to include $t\bar{t}$ cross sections in a PDF fit, ideally using differential cross sections to simultaneously constrain gluon PDF, m_t and α_S





Apart from the current precision of measured differential cross sections, the availability of suited predictions is an issue

Summary

Variety of PDF-related studies being performed within CMS

Ongoing analysis of strange PDF based on W asymmetry and Z rapidity to be compared to ATLAS' findings

$t\bar{t}$ data allows for stringent test of QCD

- New α_S extraction at high Q^2, with rather competitive precision
- Waiting for full NNLO predictions
- Goal: Simultaneously fit gluon PDF, α_S and m_t using differential cross sections

Bibliography

QCD-11-004 *Measurement of Differential Jet Cross Sections at* $\sqrt{s} = 7$ *TeV with the CMS Detector* (preliminary)

EWK-11-005 *Measurement of the Muon Charge Asymmetry in Inclusive W Production in pp Collisions at* $\sqrt{s} = 7$ *TeV* (preliminary)

SMP-12-001 *Measurement of the Electron Charge Asymmetry in Inclusive W Production in pp Collisions at* $\sqrt{s} = 7$ *TeV* (arXiv:1206.2598, accepted by Phys. Rev. Lett.)

EWK-10-010 *Measurement of the Rapidity and Transverse Momentum Distributions of Z Bosons in pp Collisions at* $\sqrt{s} = 7$ *TeV* (arXiv:1110.4973, Phys. Rev. D 85 (2012))

TOP-11-008 *Determination of the Top Quark Mass from the* $t\bar{t}$ *Cross Section at* $\sqrt{s} = 7$ *TeV* (preliminary)

TOP-12-022 *First Determination of the Strong Coupling Constant from the* $t\bar{t}$ *Cross Section* (preliminary)

TOP-11-013 *Measurement of Top Quark Pair Differential Cross Sections at* $\sqrt{s} = 7$ *TeV* (preliminary)

BACKUP

High-Energy Approximation in HATHOR