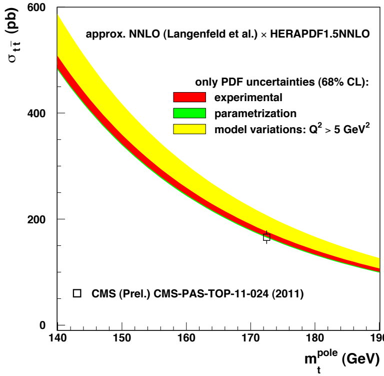
Integration of $t\bar{t}$ Cross Sections into the H1Fitter

Katerina Lipka, Sebastian Naumann-Emme

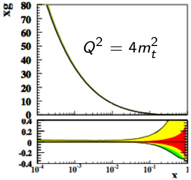
DESY

HERAFitter Meeting, 2012-02-13

Big impact of model variations ($Q^2 > 5.0$ instead of 3.5 GeV^2) in the PDF fit on the predicted $t\bar{t}$ cross section



Gluon PDF at high x is very sensitive to this:



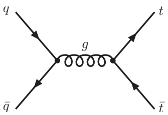
Side note: Electroweak production of single-top quarks should provide a handle on the b-quark PDF, but that's not what we (currently) look at!

Reminder: Top Quark Production and Decay

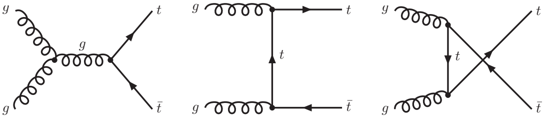
Main production mechanisms: $t\bar{t}$ pairs from ...

... $q\bar{q}$ annihilation (dominant in $p\bar{p}$ collisions at $\sqrt{s} = 2$ TeV, i.e. Tevatron)

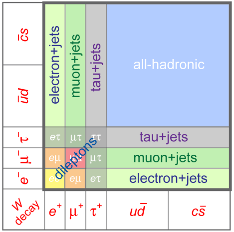
... from gg fusion (dominant in pp collisions at $\sqrt{s} = 7$ TeV, i.e. LHC)

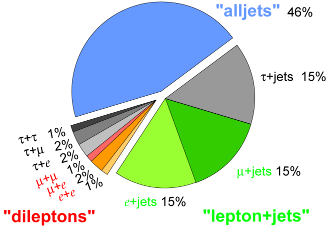


and



Decay almost 100% via $t \to Wb$, therefore $t\bar{t}$ events classified according to W decays:



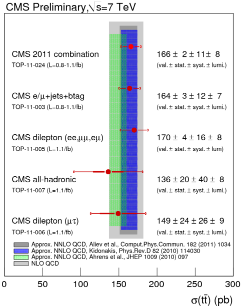


Most precise ATLAS result (lepton+jets channel):

$\sigma_{t\bar{t}} = 179 \pm 10$ (stat+syst) $\pm$ 7 (lumi) pb — ATLAS-CONF-2011-121

Latest combination of measurements by CMS in all $t\bar{t}$ decay channels:

$\sigma_{t\bar{t}} = 166 \pm 2$ (stat) $\pm$ 11 (syst) $\pm$ 8 (lumi) pb — CMS-PAS-TOP-11-024



Results consistent between ATLAS and CMS

Measurements consistent with predictions

Current precision: $\frac{\delta\sigma_{t\bar{t}}}{\sigma_{t\bar{t}}} \sim 6 - 8\%$

Updated results to be released soon but no *major* changes/improvements to be expected

Predicted Cross Section

Three different NLO calculations for $\sigma_{t\bar{t}}$ with higher-order corrections (approximate NNLO) available:

- Langenfeld, Moch, Uwer:
$$\sigma_{t\bar{t}} = 165.8^{+4.4}_{-7.0}\ (\text{scale}) \pm 9.1\ (\text{PDF}) \pm 11.6\ (\alpha_S)\ \text{pb}$$
- Kidonakis:
$$\sigma_{t\bar{t}} = 165.6^{+7.3}_{-5.1}\ (\text{scale}) \pm 9.1\ (\text{PDF}) \pm 12.9\ (\alpha_S)\ \text{pb}$$
- Ahrens et al.:
$$\sigma_{t\bar{t}} = 157.9^{+7.8}_{-8.9}\ (\text{scale}) \pm 8.7\ (\text{PDF}) \pm 11.9\ (\alpha_S)\ \text{pb}$$

These numbers (for $m_t^{\text{pole}} = 172.5$ GeV and MSTW2008NNLO PDF) are in good agreement with each other

No major differences when using HERAPDF15 (slightly better uncertainties due to smaller exp. errors in HERAPDF, see backup)

Uncertainties on measured and predicted $\sigma_{t\bar{t}}$ roughly of same size

"HAdronic Top and Heavy quarks crOss section calculatoR"

Developed by M. Aliev, H. Lacker, U. Langenfeld, S. Moch, P. Uwer and M. Wiedermann

Calculates the total $t\bar{t}$ cross section in $p\bar{p}$ and pp collisions, for a given center-of-mass engergy and top-quark mass (pole or $\overline{\mathrm{MS}}$ scheme)

Available from `http://www-zeuthen.desy.de/~moch/hathor/`

Documented in Comput.Phys.Commun.182:1034-1046,2011 (arXiv:1007.1327)

The default is to use PDF sets in LHAPDF format

But: using any PDF is possible when implementing a new PDF class that inherits from the PDF base class defined in Hathor

Installing H1Fitter+Hathor

1. Download Hathor from
   `http://www-zeuthen.desy.de/~moch/hathor/`
2. Install it according to instructions given there (requires LHAPDF)
3. Define a variable `HATHOR_ROOT` that points to your Hathor installation
4. Configure the H1Fitter with the new option "`--enable-hathor`" before building it (the trunk, not the beta release!)

Introduced a new reaction type into the H1Fitter: "ttbar"

Added a new sub-directory that hosts the necessary files for interfacing Hathor (C++) with the H1Fitter:

`h1fitter/trunk/Hathor/interface/`:
`H1FitterPdf.h`

`h1fitter/trunk/Hathor/src/`:
`H1FitterPdf.cc` `HathorInterface.cc` `Makefile.am`

For each fit iteration, the current PDFs and α_S are read via the corresponding QCDNUM routines and fed into Hathor for calculating a new $\sigma_{t\bar{t}}$ prediction

The assumed value of the top-quark mass is read from `ewparam.txt`

By the way: Is there a reason for keeping it at 174.0 GeV?
(latest Tevatron average: 173.2 ± 0.9 GeV)

The desired order (LO, NLO, NNLO) is read from `steering.txt`, but only NNLO is of real interest here

Center-of-mass energy and collider type are two parameters that are specified in the datafiles:

```
CInfo = 'sqrt(S)','ppbar'
DataInfo = 1960,1
```

Tevatron

```
CInfo = 'sqrt(S)','ppbar'
DataInfo = 7000,0
```

LHC

Testing H1Fitter+Hathor

First milestone: cross sections from stand-alone Hathor reproduced

Very helpful here: LHAPDF interface of the H1Fitter allowed using HERAPDF15NNLO in both cases

Then, MINUIT was complaining because the cross section from Hathor was not reproduced exactly when calling it twice with identical input

Reason: Finite precision of numerical integration in Hathor

Workaround: Cut off some decimal digits in predicted cross section

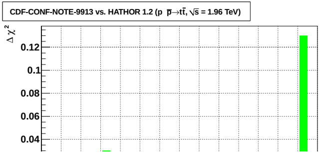
(Still to do: Implement a more flexible rounding that makes use of the statistical precision estimated by Hathor)

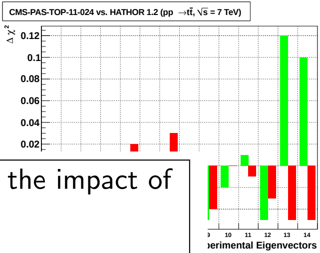
Now, fits with HERAPDF 1.0 data + CMS-TOP-11-024 seem to run fine but MINUIT quits after a couple of hours, claiming that no convergence could be reached $\rightarrow$ currently looking closer at evolution of the χ^2 and the obtained PDFs

CDF:

CMS:

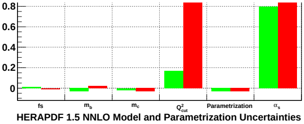
Exp. uncert.:

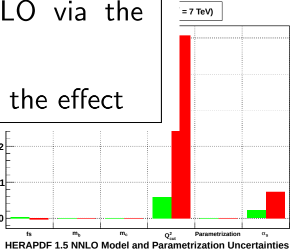




- Use H1Fitter to quickly study the impact of variations in the PDFs on $\sigma_{t\bar{t}}$
- Again, taking HERAPDF15NNLO via the LHAPDF interface
- Calculating the $\Delta\chi^2$ to quantify the effect

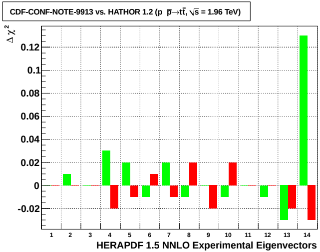
Model uncer

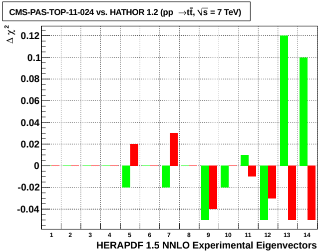




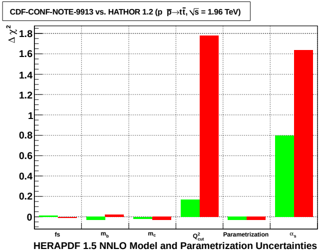
CDF: | CMS:

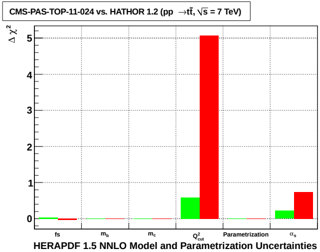
Exp. uncert.:





Model uncert.:



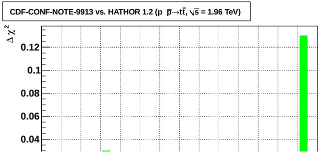


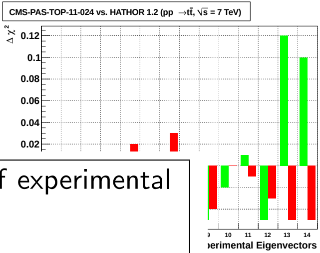
First Use Case for H1Fitter+Hathor

CDF:

CMS:

Exp. uncert.:



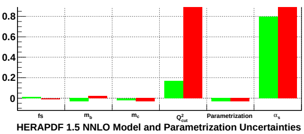


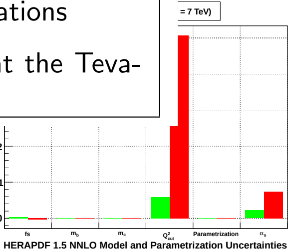
As expected: Small impact of experimental uncertainties

Large impact of α_S and Q^2 variations

Larger effect at the LHC than at the Tevatron

Model uncer



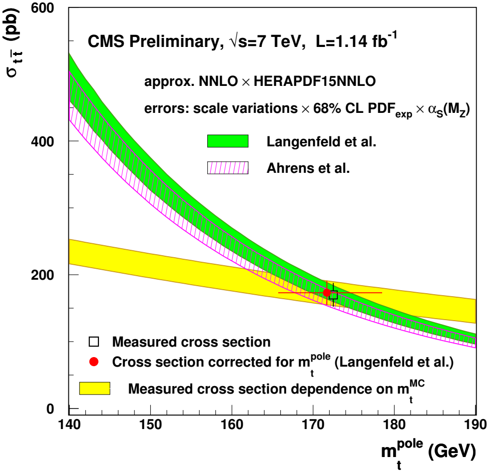


Predicted $t\bar{t}$ cross section is mass dependent

Measured cross section is mass dependent (due to acceptance correction)

This allows extracting of most-probable mass value - either in pole or $\overline{\text{MS}}$ scheme

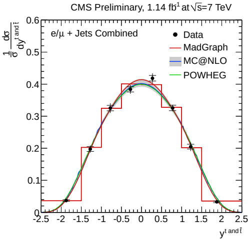
See, e.g., CMS-PAS-TOP-11-008

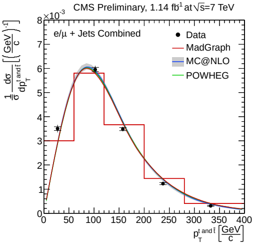


$\longrightarrow$ Goal: Include $\sigma_{t\bar{t}}$ in a PDF fit performing an m_t scan

Outlook: Differential Cross Sections

Last week, CMS released a first large set of differential cross sections





CMS-PAS-TOP-11-013:

$\frac{1}{\sigma}\frac{d\sigma}{dX}$ in lepton+jets and dileptonic channel with $X = p_T^{\ell}, \eta^{\ell}, p_T^{\ell\ell}, m^{\ell\ell}, p_T^{t/\bar{t}}, y^{t/\bar{t}}, p_T^{t\bar{t}}, y^{t\bar{t}}, m^{t\bar{t}}$

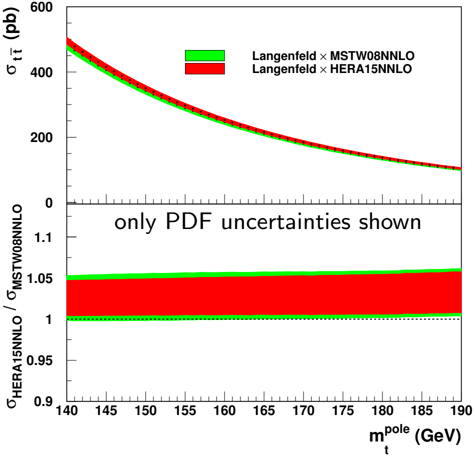
Such distributions should be of special worth also for PDF fits

But: Predictions beyond NLO only available for some of them and not from a program like Hathor, so far

BACKUP

Difference of 3% in $\sigma_{t\bar{t}}$ mostly due to different $\alpha_S(M_Z)$

MSTW: 0.1171; HERAPDF: 0.1176



To allow comparison:
only experimental errors
on HERAPDF used here!
(similar as in MSTW08)

$\curvearrowright$ Smaller uncertainty
from HERAPDF
($\approx$ 2% vs. 4%)