Measurement of Top Quark Pair Differential Cross-Sections.

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Motivation

First measurement

The presented results are the first measurements of **normalised differential cross sections** in top-quark pairs at 7 TeV:

$$\frac{1}{\sigma}\frac{\partial\sigma}{\partial X} \text{ for } X = \begin{cases} p_T(l),\ \eta(l),\ pT(ll),\ m(ll) \\ p_T(t/tbar), y(t/tbar) \\ pT(ttbar), y(ttbar) \\ m(ttbar) \end{cases}$$

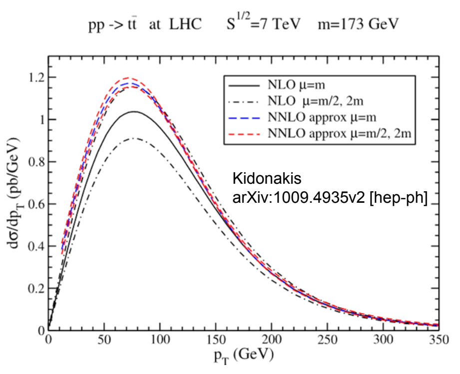
- ✓ Allows testing of pQCD for heavy-quark production at LHC energy scale
- ✓ Can constrain potential physics beyond the SM
- ✓ Sensitive to PDF

Analysis overview

- ✓ Use **lepton+jets and dilepton** channels
- ✓ measure **shapes** by normalising to inclusive cross section
- ✓ Restrict measurement to **visible phase space**
- ✓ Correct for detector and hadronisation effects → **parton level**

Compare to theory

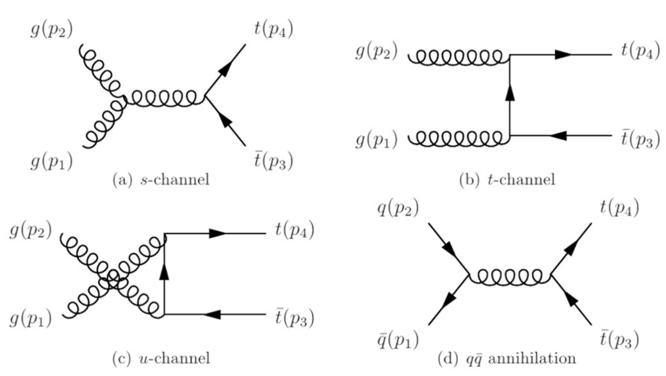
- ✓ MC Generators: compare to **MadGraph, MC@NLO, POWHEG**
- ✓ Theory predictions:



Top quarks at the LHC

Production

At a production cross section of 165 pb ($NNLO_{approx}$) about 190 thousand top quark pairs have been produced in the analysed dataset of 1.14/fb, mainly by gluon-gluon fusion. The LO diagrams are shown here:



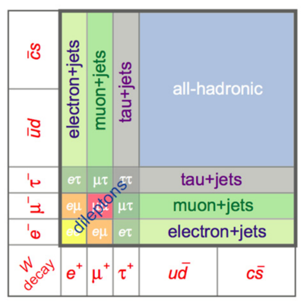
Decay

Top quarks decay into a *b* quark and a W boson. The Ws decay further into quarks (jets) or leptons.

The analysis considers only events with at least one lepton in the final state.

W → τ → e/μ decays considered as

- background in lepton + jets and
- signal in the dilepton case.



Event selection

To eliminate the large backgounds from non-top standard model processes, at least one top quark is required to decay leptonically. In addition the selection makes use of the jets from the *b* quarks and the missing transverse energy from the neutrino.

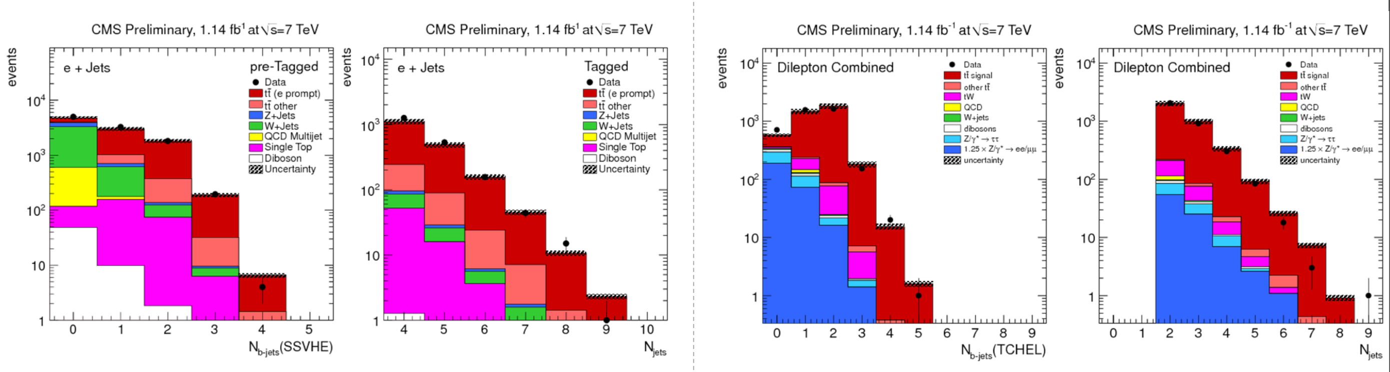
Main non-top backgrounds are W+jets (l+jets) and Drell-Yan (dileptons) events.

Lepton + jets selection

- Exacctly **1 isolated lepton**
  either electron: $p_T > 30$ GeV, $|\eta| < 2.5$; or muon: $p_T > 20$ GeV, $|\eta| < 2.1$
- veto events with other (loosely isolated) leptons
- At least **4 jets**
  - $p_T > 30$ GeV $|\eta| < 2.4$
- At lease **2 b tags**
  - simple secondary vertex algorithm
- **Kinematic fit**
  - Fixed W mass to 80.4 GeV
  - $m_t = m_{tbar}$
  - Identify neutrino with E_T^{miss}, set z component to 0 initially
  - Vary all 4-momenta within their resolution and take best fit based on a minimum χ^2

Dilepton selection

- At least **2 isolated leptons** with opposite sign
  - $p_T > 20$ GeV $|\eta| < 2.4$
  - Invariant mass $m_{ll} > 12$ GeV (QCD veto)
- At least **2 jets**
  - $p_T > 30$ GeV $|\eta| < 2.4$
- In **e+e- / μ+ μ-** channels
  - Veto the Z peak: $|m_Z - m_{ll}| > 15$ GeV
  - $E_T^{miss} > 30$ GeV
- At least **1 b tag** (Track counting algorithm)
- **Kinematic reconstruction** of an underconstrained system
  - fully reconstruct the event
    - $m_W = 80.4$ GeV
    - $E_T^{miss} = p_T^{\nu 1} + p_T^{\nu 2}$
    - fix $m_t = m_{tbar}$ and vary in 1GeV steps from 100 to 300 GeV
    - take solution with most b tags, then with most probable E(ν)
  - For **dσ/dm$_{tt}$**
    - set $p_z(n) = 0$
    - $m^2_{ttbar} = |\Sigma_i p_i|^2$
    - no reconstruction of other top quantities needed



Background determination

The main background in the dilepton ee and μμ channels is from Drell-Yan events. It is determined in a data-driven way from the events in the Z mass peak (76 GeV to 106 GeV):

$$N^{ll}_{out} = R^{ll}_{out/in}\left(N^{ll}_{in} - 0.5\, N^{e\mu}_{in}\, k_{ll}\right) \qquad k_{\mu\mu} = \sqrt{\frac{N^{\mu\mu,loose}}{N^{ee,loose}}}$$

- N^{ll}_{out}: Number of expected background events
- $R^{ll}_{out/in}$: Ratio from MC: Events outside Z peak over events inside the peak region
- N^{ll}_{in}: Number of events inside Z peak region
- $N^{e\mu}_{in}$: Number of events in the eμ channel – inside the Z mass peak
- k_{ll}: Lepton reconstruction efficiency correction factor to take the difference between muons and electrons into account

In the dilepton dσ/dm$_{tt}$ measurement also the QCD background is estimated from data using loosely isolated leptons.
In lepton+jets, all background contributions are taken from simulation.

Cross section calculation

In each bin of the measurement, the finite experimental resolution can cause migrations across bin boundaries from the bin in which an event was generated to the bin in which it was reconstructed. The binning is chosen such that the purity (migration into a bin) and stability (migration out of a bin) are above 50%. To correct for the migration, a bin-by-bin efficiency is calculated using MadGraph taking into account the signal efficiency and the unfolding corrections. The cross section is then calculated as:

$$\frac{1}{\sigma}\frac{d\sigma^i}{dX} = \frac{1}{\sigma}\frac{N^i_{\text{Data}} - N^i_{\text{BG}}}{\Delta^i_X\, \epsilon^i\, L}$$

- σ^i cross section in bin i
- Δ^i width of bin i
- ϵ^i efficiency in bin i
- L luminosity
- σ integrated cross section
- N^i_{Data} data events in bin i
- N^i_{BG} background events in bin i
- X observable

For the top quark system invariant mass measurement in the dilepton channels the unfolding is done using Singular Value Decomposition (also based on MadGraph). In SVD, a full covariance matrix is used to account for all correlations between bins. Regularisation is used to suppress non-significant components. Comparisons between bin-by-bin and SVD unfolding have produced similar results.

Systematic uncertainties

Systematic uncertainties of the measurement arise from detector effects as well as theoretical uncertainties. Each systematic is investigated separately and determined individually in each bin of each measurement by varying the corresponding input source within its uncertainty. The cross section result is then recalculated and the differences to the nominal result are added in quadrature.

By normalising the differential cross section to the integrated cross section, all flat systematics such as the luminosity cancel out. Other uncertainties are reduced in magnitude as only their shapes contribute.

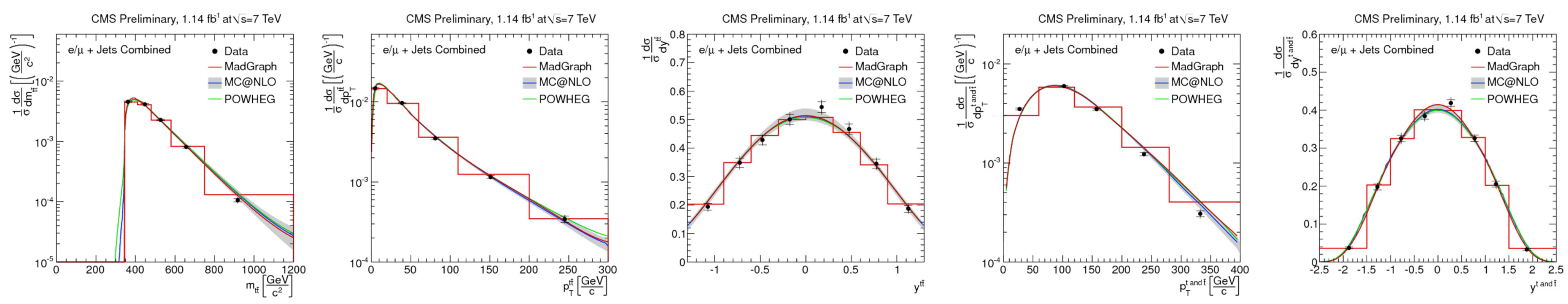
Dominant uncertainties

- ✓ Jet energy scale
- ✓ Lepton selection
- ✓ b tagging
- ✓ model uncertainties

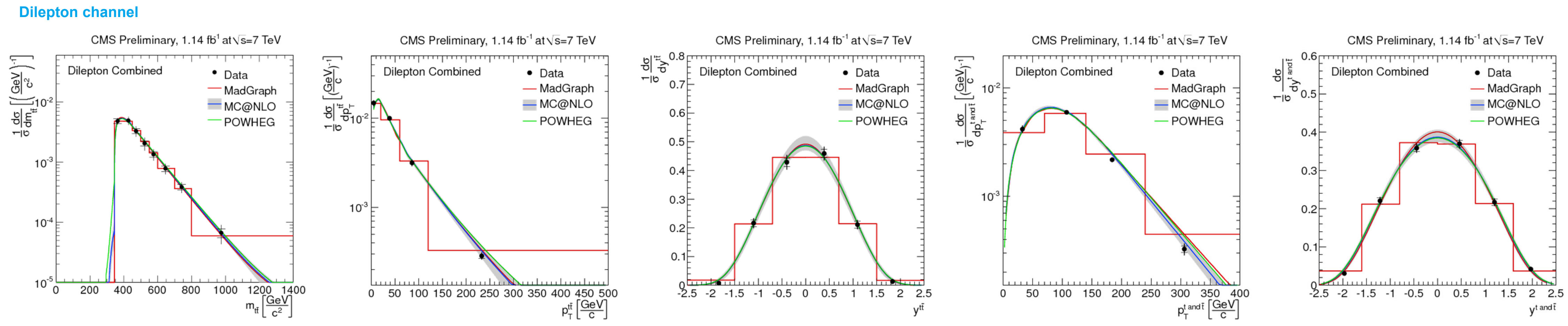
Results

Results from CMS-PAS-TOP-11-013

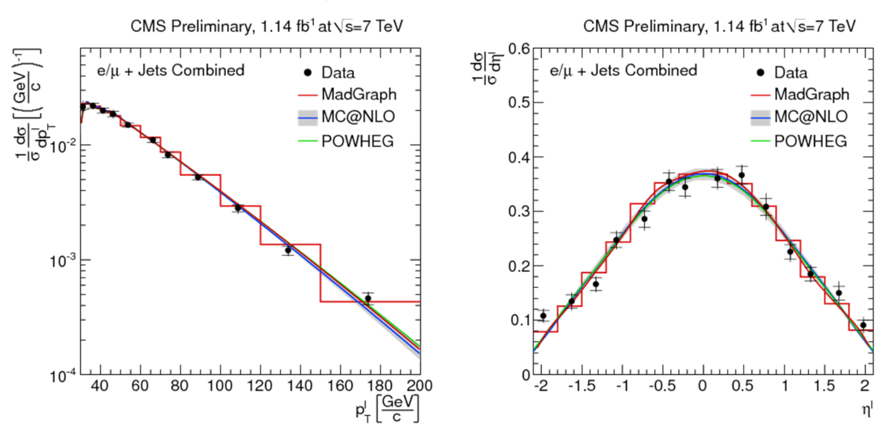
Lepton + jets channel



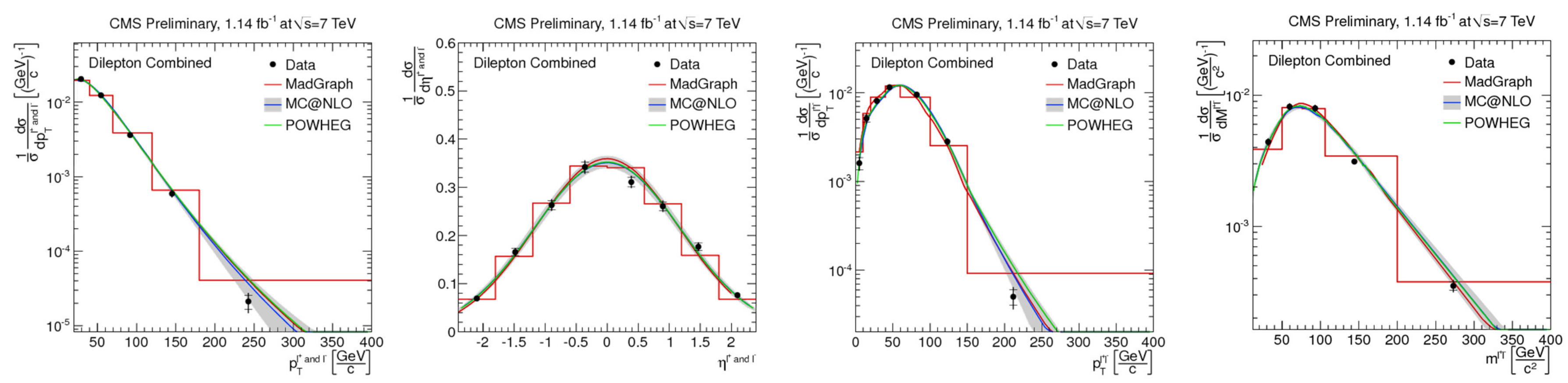
Dilepton channel



Lepton quantities - lepton + jets channel



Lepton quantities - dilepton channel



Why measure many observables?

- ✓ check description of data by QCD predictions
- ✓ radiation and higher order corrections (tt p_T)
- ✓ new physics (e.g. in tt mass spectrum)
- ✓ PDF constraints, high-x gluon (e.g. tt rapidity distribution)
- ✓ top quark production is background to BSM searches

Visible phase space

The detector acceptance restricts the measurement to a certain "visible" phase space:

	Lepton + jets	Dileptons
Leptons:	$p_T > 30$ GeV, $|\eta| < 2.1$	$p_T > 20$ GeV, $|\eta| < 2.4$
Partons:	$p_T > 30$ GeV, $|\eta| < 2.4$	$p_T > 30$ GeV, $|\eta| < 2.4$

Bin-centre corrections

The data points have been placed according to the **MadGraph** simulation at the intersection of the fit to the simulation and the binned simulated red curve.

Other predictions

Also shown are results of the **POWHEG** and **MC@NLO** simulation. The grey error band indicates the uncertainties MC@NLO on PDF, mass of the top quark, and Q^2 scale variation.

Good agreement is found between:

- ✓ data and simulations
- ✓ different channels
- ✓ different standard model predictions