Measurements of the Differential Top-Quark Pair Production Cross Sections in pp Collisions at 7 TeV with CMS

CMS TOP-11-013, arXiv:1211.2220 [hep-ex]

Jörn Lange
Universität Hamburg

For the CMS Collaboration

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GEFÖRDERT VOM
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PHYSICS AT THE TERA SCALE
Helmholtz Alliance

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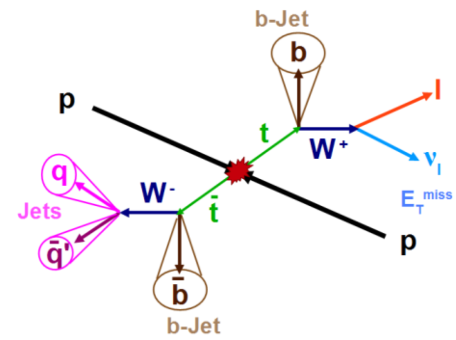
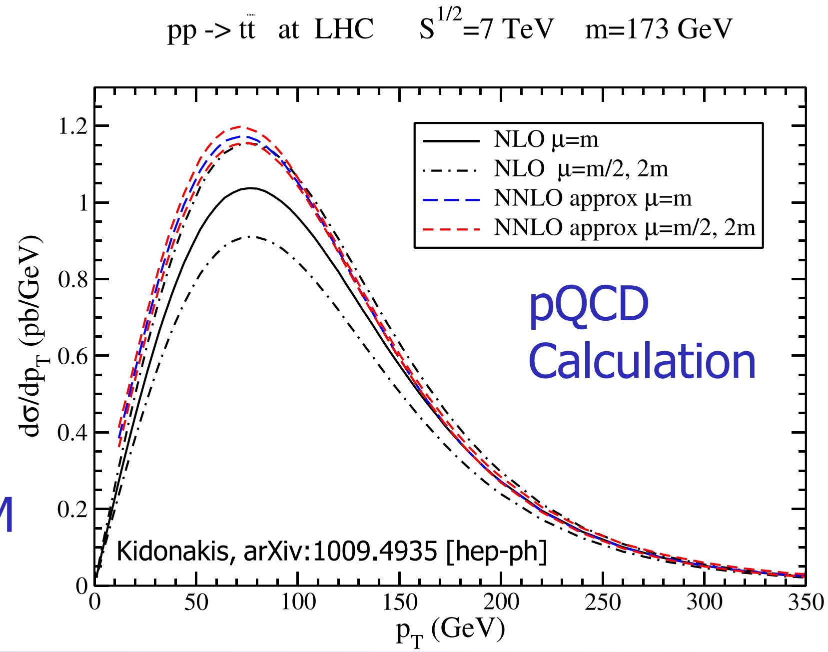
Introduction and Motivation

- First comprehensive measurement of differential $t\bar{t}$ cross sections
  Previously only limited set of variables: $p_T(t)$ (D0, arXiv:1001.1900); $m(t\bar{t})$ (CDF, 0903.2850); $p_T(t\bar{t})$, $y(t\bar{t})$, $m(t\bar{t})$ (ATLAS, 1207.5644)
- 11 differential variables of different objects:
  - Lepton: $p_T(\ell)$, $\eta(\ell)$
  - Lepton pair: $p_T(\ell\ell)$, $m(\ell\ell)$
  - b-jet: $p_T(b)$, $\eta(b)$ (only dilepton)
  - Top quark: $p_T(t)$, $y(t)$
  - Top quark pair: $p_T(t\bar{t})$, $y(t\bar{t})$, $m(t\bar{t})$
- ℓ+jets and dilepton (ℓ = e, μ) decay channels
- Motivation:
  - Test of pQCD at LHC energy scale
  - Sensitive to QCD parameters (PDFs, α_S)

  } SM
  - Better understanding of top background distributions for BSM searches
  - Sensitive to new physics in top final states

  } BSM





Dataset and Simulation

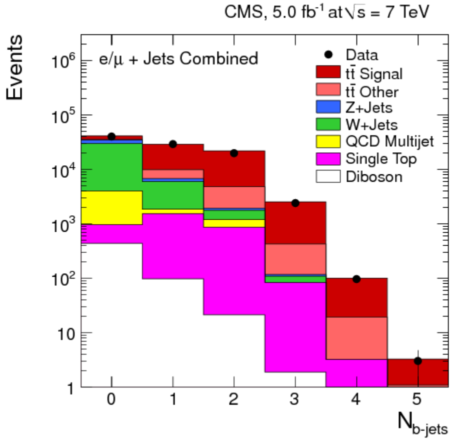
- 2011 CMS data: 5 fb^{-1} of 7 TeV pp collisions
- Simulation
    - MADGRAPH ($t\bar{t}$, V+Jets)
    - POWHEG (single top)
    - PYTHIA (QCD, VV)
- About 9 additional interactions / bunch crossing
    - Corrections for pile-up interactions applied
    - Simulation reweighted to match pile-up distribution in data
- Channel-optimised triggers
    - μ+jets: Single iso. muon
    - e+jets: Single iso. electron + TriJet
    - Dilepton: Dilepton according to channel (μμ, ee, μe)

Event Selection

ℓ+Jets

- Exactly 1 iso. lepton
  - p_T > 30 GeV, |η| < 2.1
  - Veto leptons with looser criteria
- ≥ 4 jets (PF, Anti-k_T algorithm, R=0.5)
  - p_T > 30 GeV, |η| < 2.4
- ≥ 2 b-tagged jets (CSVM)

- 9076/10766 events in e/μ+jets
- 93% $t\bar{t}$, 4% single top, 3% other
- Background from simulation



Dilepton

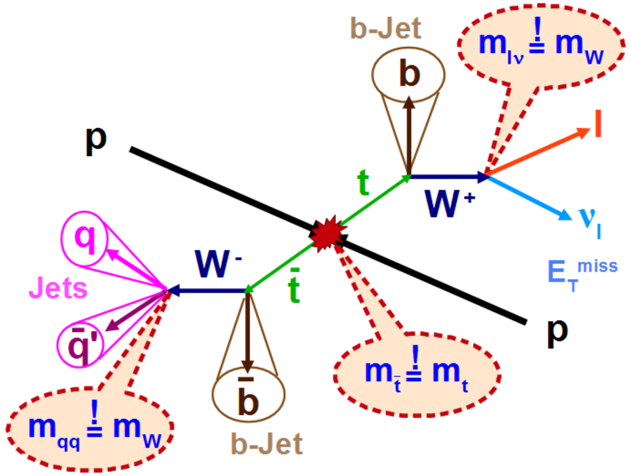
- 2 oppositely charged leptons
  - p_T > 20 GeV, |η| < 2.4
  - QCD veto: m(ll) > 12 GeV
- ≥ 2 jets (PF, Anti-k_T algorithm, R=0.5)
  - p_T > 30 GeV, |η| < 2.4
- ≥ 1 b-tagged jet (CSVL)
- In ee/μμ
  - Z veto: not 76 < m_{ll} < 106 GeV
  - $E_{T,miss}$ > 30 GeV

- 2632/3014 events in ee/μμ
- 82% $t\bar{t}$, 15% Z/γ+jets, 3% other
- 7408 events in eμ
- 94% $t\bar{t}$, 4% single top, 2% other
- Z/γ+jets background from Z mass control region, other from simulation

Kinematic Event Reconstruction

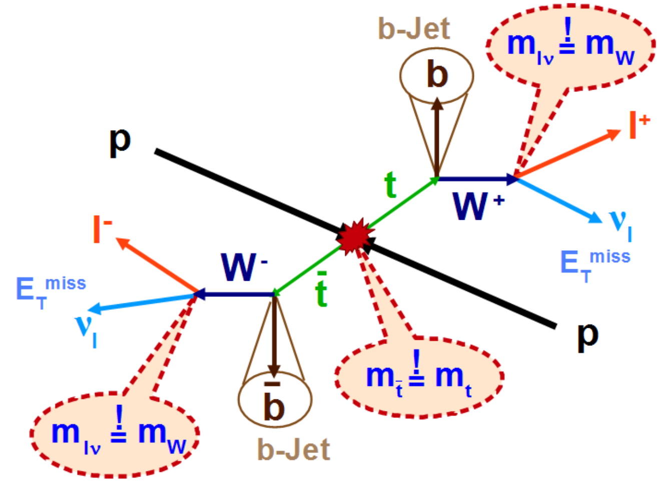
ℓ+Jets

- Kinematic fit
- Vary 4-momenta of ℓ, jets, ν
- Constraints
  - m_W = 80.4 GeV
  - $m_t = m_{\bar{t}}$
- Neutrino: $E_{T,miss}$ (initially p_Z=0)
- Jets: 5 leading jets considered, use b-tag information for b-jet association
- Permutation with minimum χ^2 taken

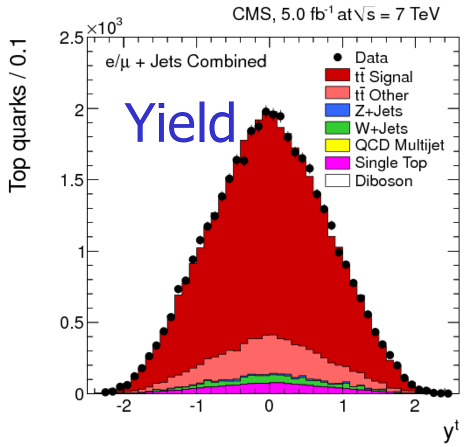


Dilepton

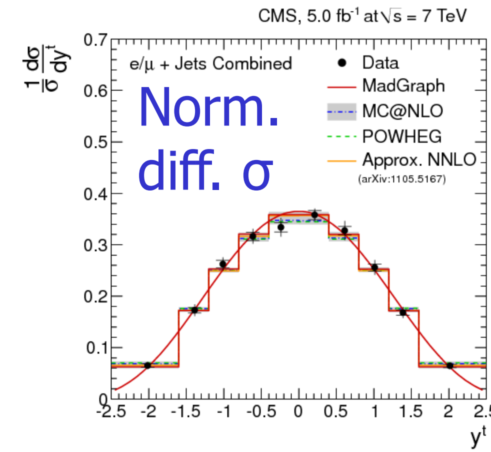
- Kinematic reconstr. similar to MWT
- Underconstrained system due to 2 ν
- Constraints
  - m_W = 80.4 GeV
  - $p_{x,y}(\nu_1) + p_{x,y}(\nu_2) = E_{T,miss\ x,y}$
  - $m_t = m_{\bar{t}}$ = fixed (vary m_t in 1 GeV steps betw. 100-300 GeV)
- Solution with b-tagged jets and best E_ν wrt. to simulated spectrum preferred



Normalised Differential Cross Section



$$\frac{1}{\sigma}\frac{d\sigma^i}{dX} = \frac{1}{\sigma}\frac{x^i}{\Delta_X^i\ \mathcal{L}}$$



- x^i: Event yield corrected for background, efficiency, acceptance and migration
  - Migration limited by choosing purity p^i, stability $s^i \gtrsim$ 0.4-0.5
  - Regularised unfolding method
  - Minimum-global-correlation criterion to determine regularisation level

$$p^i = \frac{N^i_{rec\&gen}}{N^i_{rec}}$$

$$s^i = \frac{N^i_{rec\&gen}}{N^i_{gen}}$$

- Δ^i_X: Bin width of bin i; L: integrated luminosity
- Normalised to unity using inclusive cross section σ

Phase Space and Correction Level

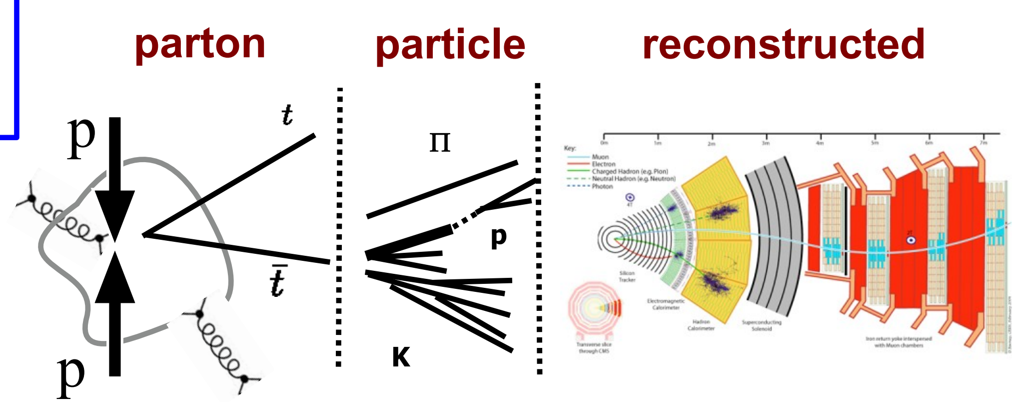
- **Decay products (lepton, b-jet)**
  - Directly accessible
  - Corrected only for detector effects

    → particle level
  - Restricted to visible phase space:
    - $p_T^{jets} > 30$ GeV, $\eta^{jets} < 2.4$
    - $p_T^{lep} > 20\ (30)$ GeV, $\eta^{lep} < 2.4\ (2.1)$ for dilepton (ℓ+Jets)

→ as model independent as possible

- **Top quark, $t\bar{t}$ system**
  - Reconstructed quantities
  - Corrected for detector AND hadronisation effects
    → parton level
  - Extrapolated to full phase space

→ as close to theory as possible

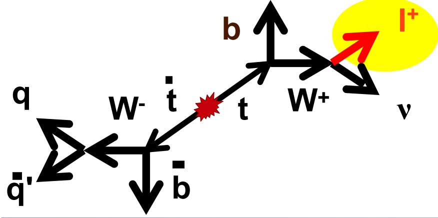


Systematic Uncertainties

- Normalised cross sections
  ⇒ Correlated normalisation uncertainties cancel
  (e.g. luminosity, flat SF, etc.)
  ⇒ Only shape uncertainties contribute

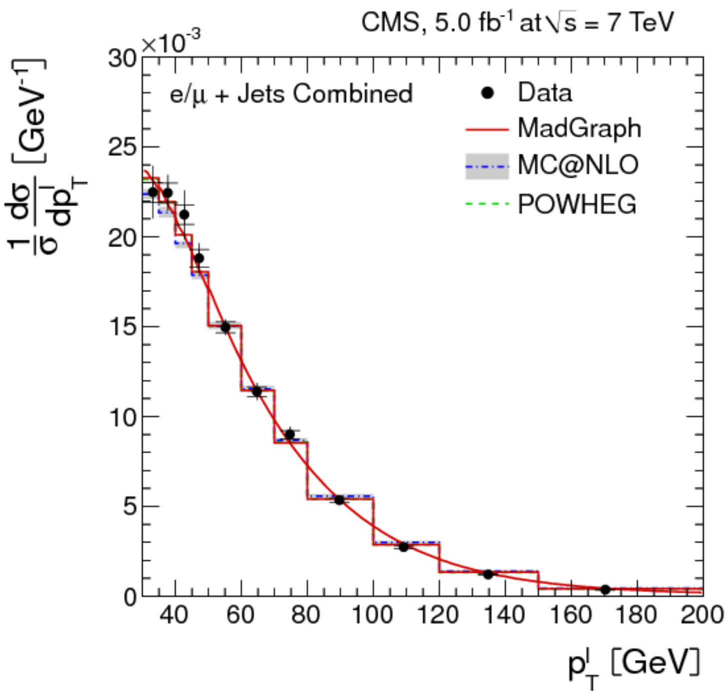
	Source	Systematic uncertainty (%)	
		ℓ+jets	dileptons
Experimental	Trigger efficiency	0.5	1.5
	Lepton selection	0.5	2.0
	Jet energy scale	1.0	0.5
	Jet energy resolution	0.5	0.5
	Background	3.5	0.5
	b tagging	1.0	0.5
	Kin. reconstruction	–	0.5
	Pileup	0.5	0.5
Model	Fact./renorm. scale	2.0	1.0
	ME/PS threshold	2.0	1.0
	Hadronisation	2.0	2.0
	Top-quark mass	0.5	0.5
	PDF choice	1.5	1.0

Typical values (varies from bin to bin)

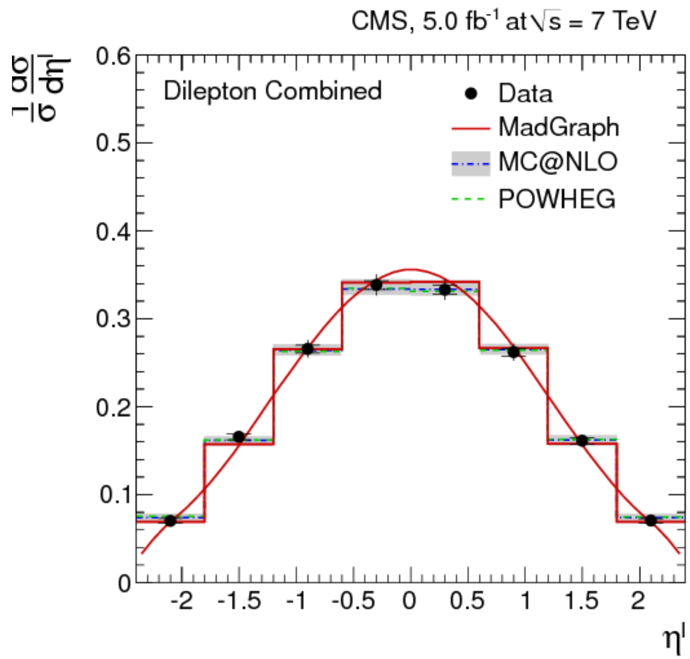


Results – Lepton p_T and η

Lepton p_T

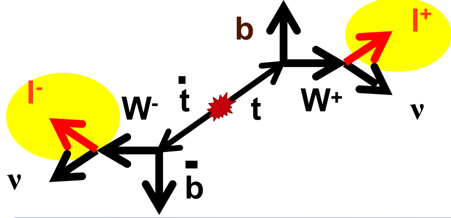


Lepton η



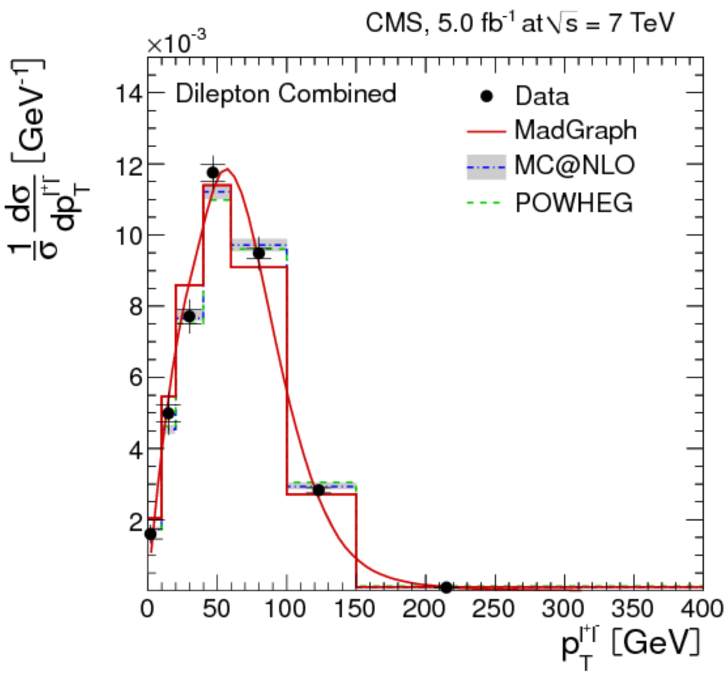
- Compared to different model predictions:
  - MadGraph
  - MC@NLO
  - POWHEG
- Horizontal bin-centre-corrections wrt. MadGraph

- For all lepton variables: bin widths statistically limited (good resolution)
- Good agreement between data and predictions
- For all distributions: all channels very consistent
- For almost all distributions: different model predictions very similar

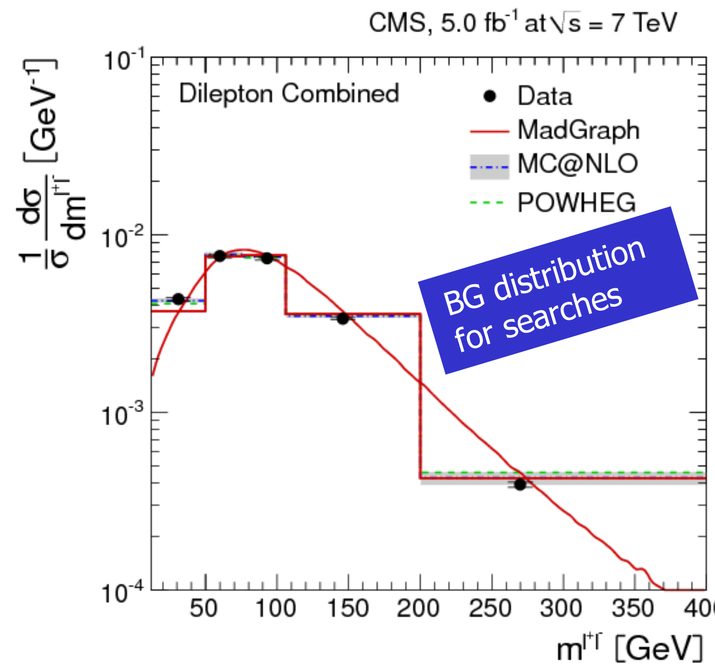


Results – Lepton Pair p_T, $m^{\ell\ell}$

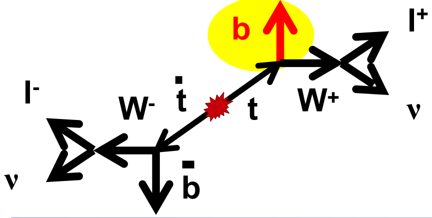
Lepton Pair p_T



Lepton Pair $m^{\ell\ell}$

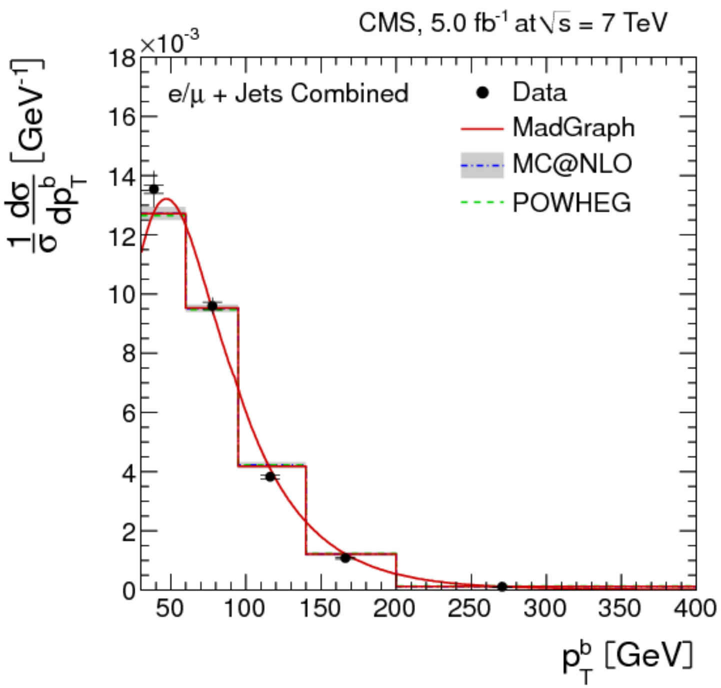


- Data agrees better with MC@NLO/POWHEG (spin correlations considered) than with MadGraph (not considered)

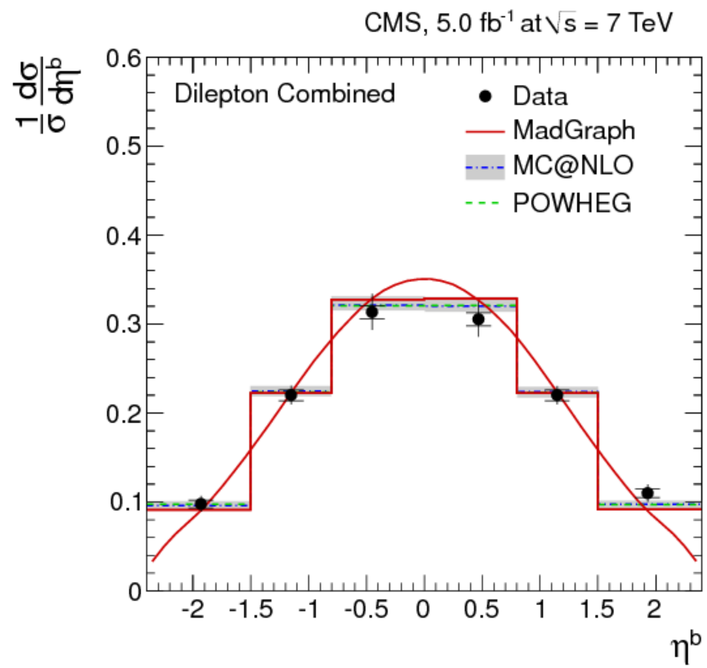


Results – b-Jet p_T and η

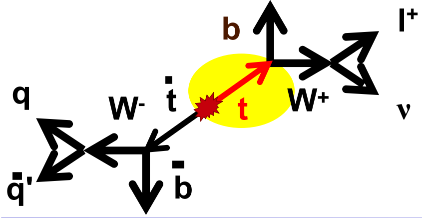
b-Jet p_T



b-Jet η

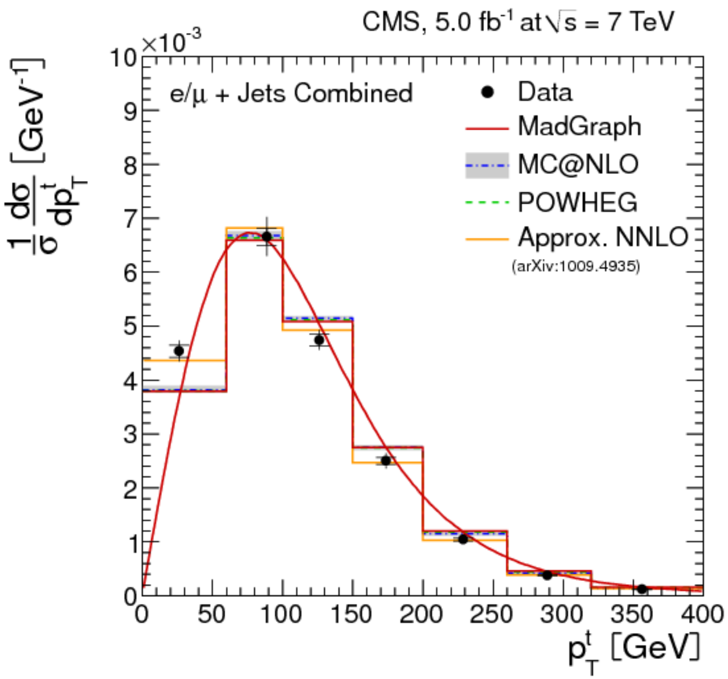


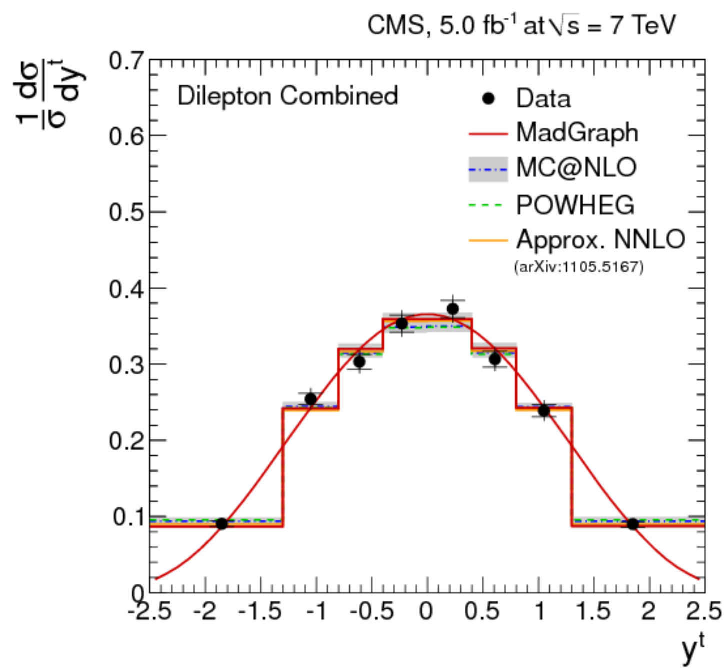
- Good agreement between data and predictions
  (slightly softer p_T spectrum in data than predicted)



Results – Top p_T and Rapidity

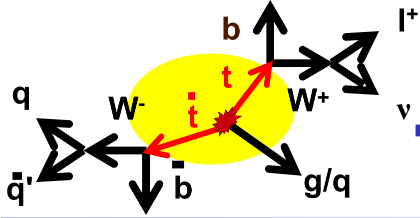
Top p_T	Top y





In addition to MC model predictions:
- approximate NNLO calculation

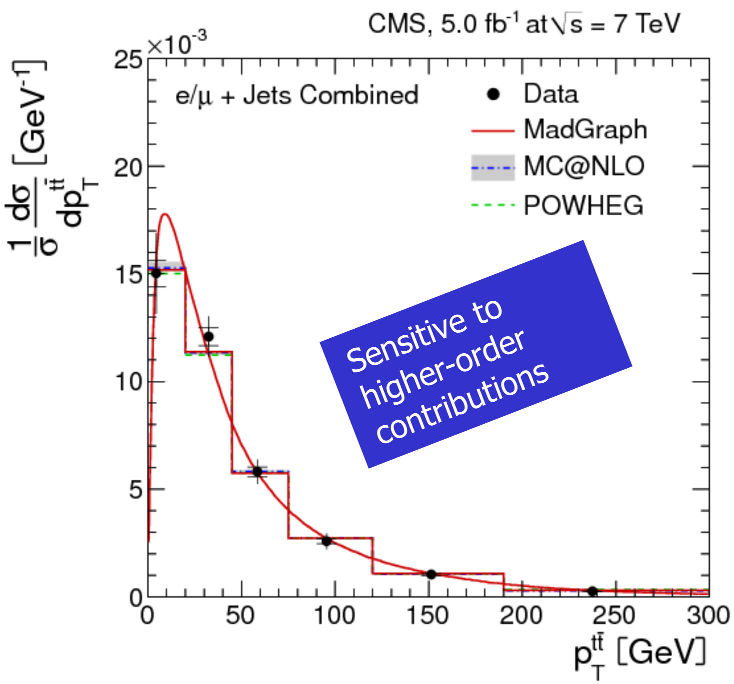
- All top and $t\bar{t}$ variables: obtained by kinematic reconstruction algorithms
  $\Rightarrow$ bin widths limited by migration effects due to lower resolution
- Measured p_T spectrum slightly softer than predicted by MC models
- In good agreement with approx. NNLO calculation

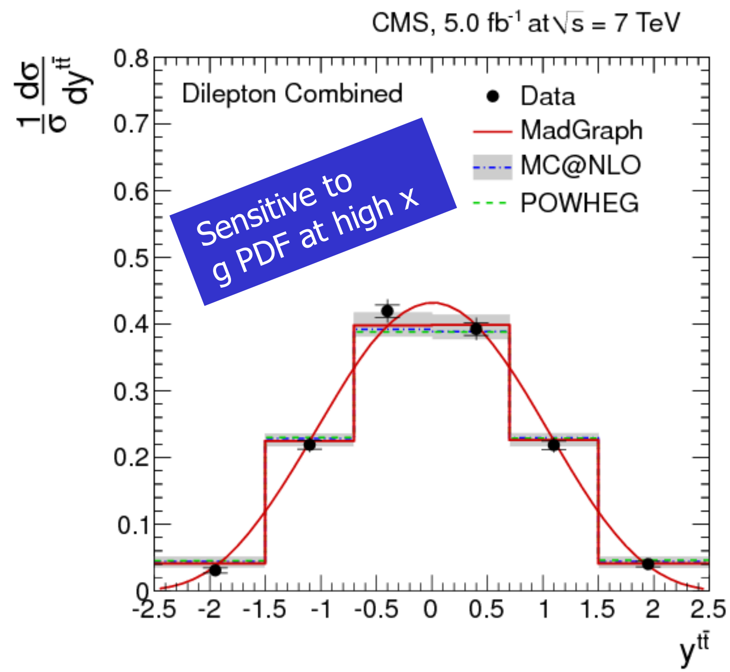


Results – Top Quark Pair p_T and Rapidity

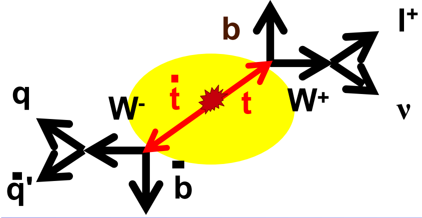
$t\bar{t}$ p_T

$t\bar{t}$ y



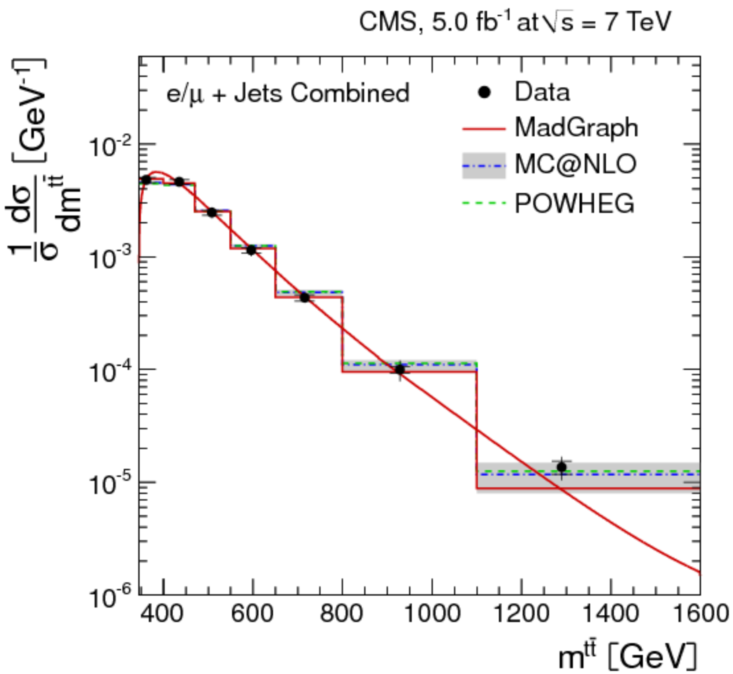


- Good agreement between data and predictions

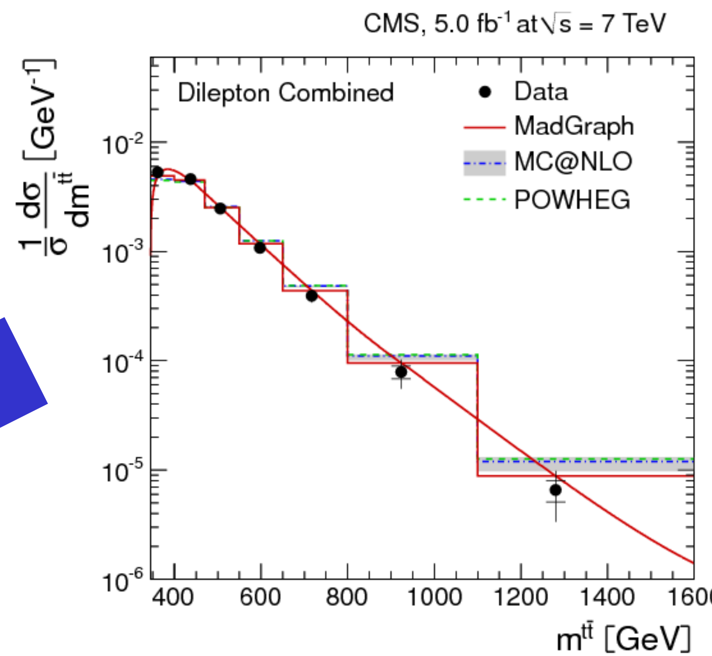


Results – Top Quark Pair $m^{t\bar{t}}$

[ℓ+jets](#)



[Dilepton](#)



Sensitive to resonances

- Sensitive to high-mass resonances
  - Narrow → bump
  - Wide → distortion of shape in wider range
- Good agreement between data and predictions

Conclusions

- First comprehensive measurement of differential $t\bar{t}$ cross sections at 7 TeV with 5 fb^{-1} in 5 different ℓ+jets and dileptonic channels
- Variety of 11 kinematic variables of different objects (lepton, lepton pair, b-jet, top, top pair)
- Normalised using incl. cross section
  ⇒ precise measurement (5-10% uncertainty)
- Good agreement between data and various predictions
  ⇒ Top kinematics well described by standard model
  ⇒ No indications of new physics
- Outlook
  - Measure at 8 TeV (see talk by Ivan Asin Cruz)
  - Study the use for PDF fits
  - Interested in more variables…?
    ⇒ Contact us ☺

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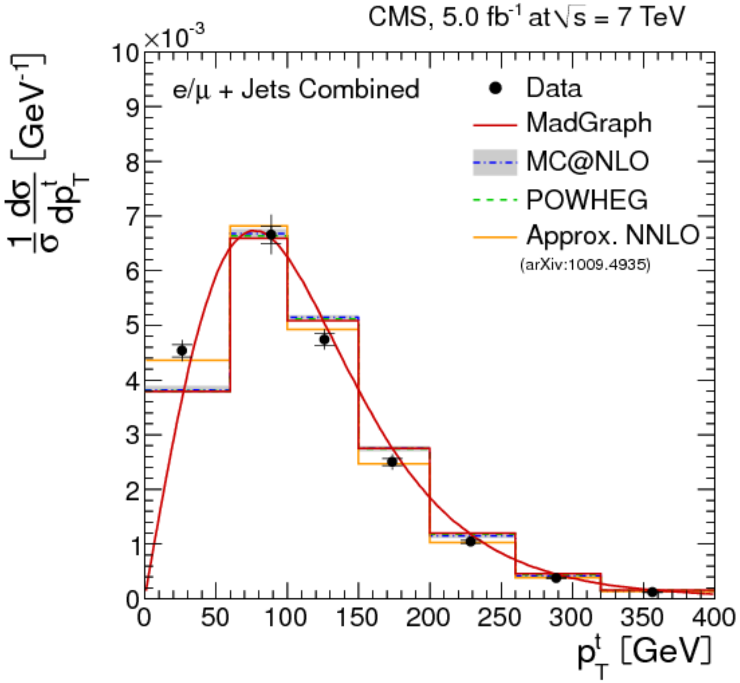
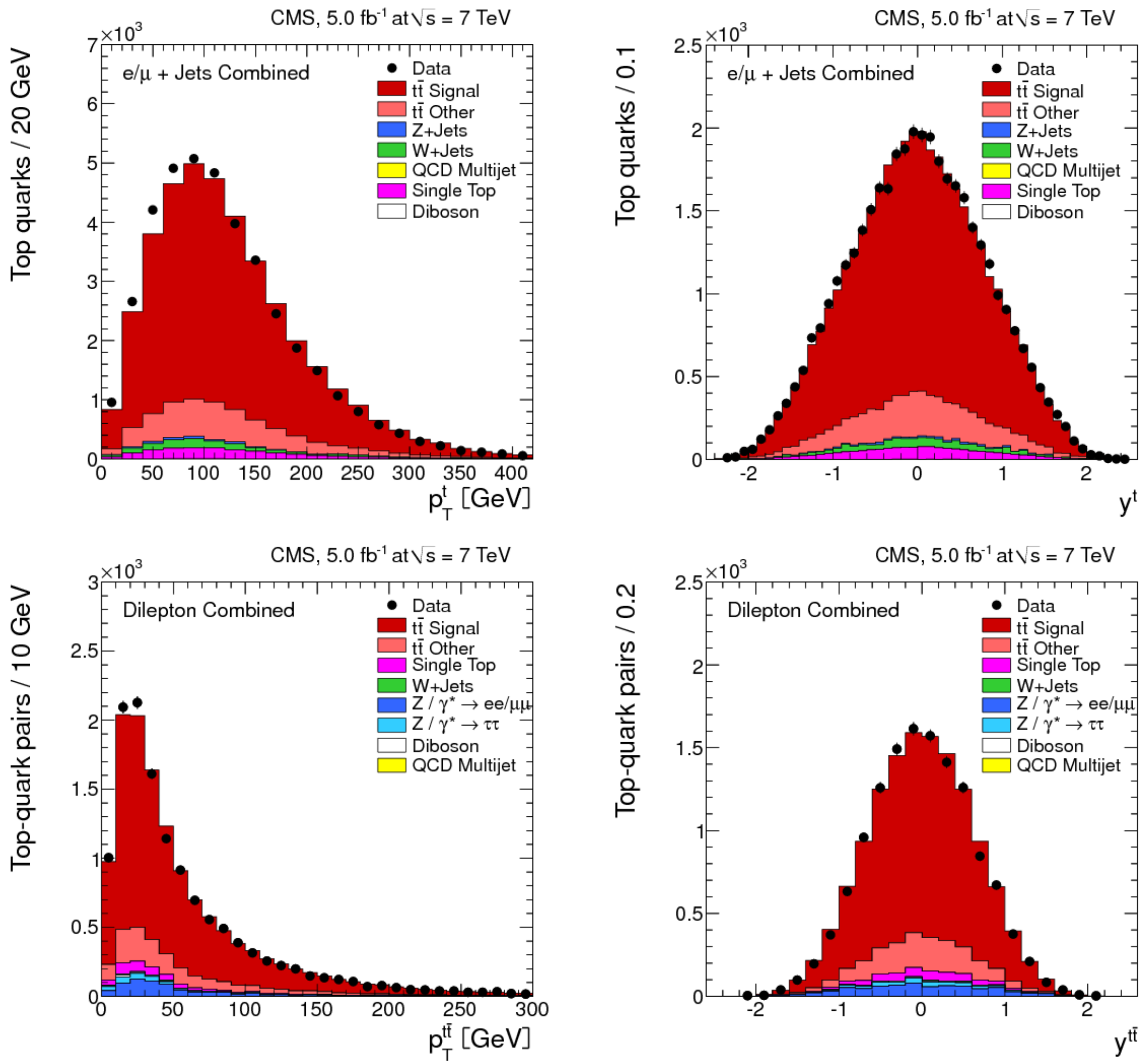


Reconstructed top and $t\bar{t}$ distributions



- Good agreement between data and simulation
- Slightly softer p_T(top) spectrum in data compared to simulation (see final results)