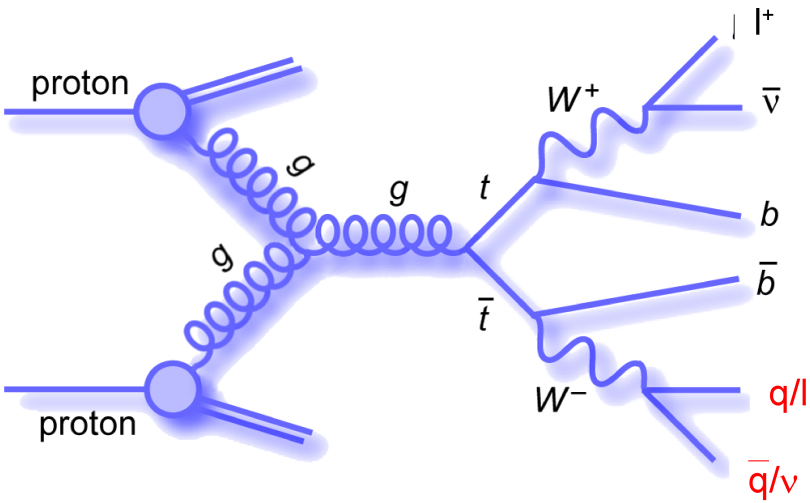
Normalised differential cross section measurements in the dilepton and l+jets channels with CMS

DESY and UHH CMS Top Groups



Wolf Behrenhoff (DESY), Martin Görner (University of Hamburg) for the DESY/UHH top groups

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„Physics at the Terascale“ – 5th Annual Workshop
Bonn, 2011-12-08

HELMHOLTZ ASSOCIATION

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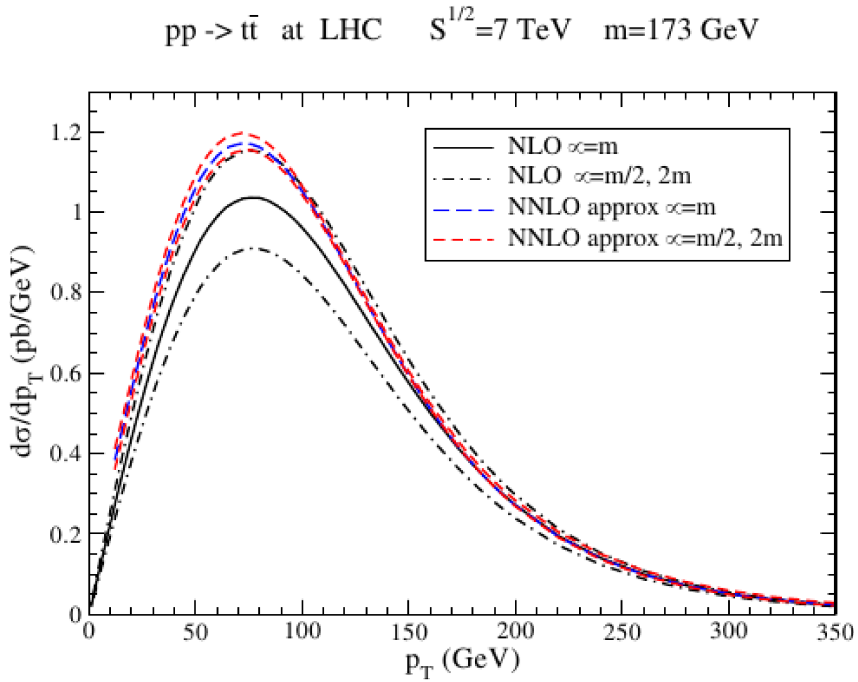
DESY

Contents

- Motivation
- Event selection and control plots
  - l + jets
  - dileptons
- Differential cross sections for lepton quantities
- Top reconstruction
- Differential cross sections for top quark quantities
- Summary

Motivation of the measurement

- First measurement of differential cross sections $1/\sigma\ d\sigma/dX$ at 7 TeV
- Allows for testing perturbative QCD for heavy quark production at LHC energy scale
- Could give hints for physics beyond the Standard Model
- Different predictions exist

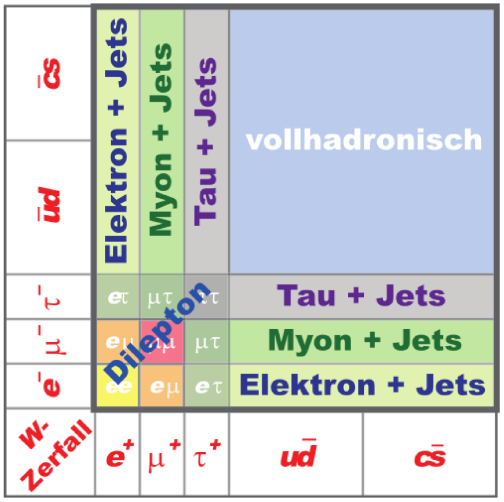


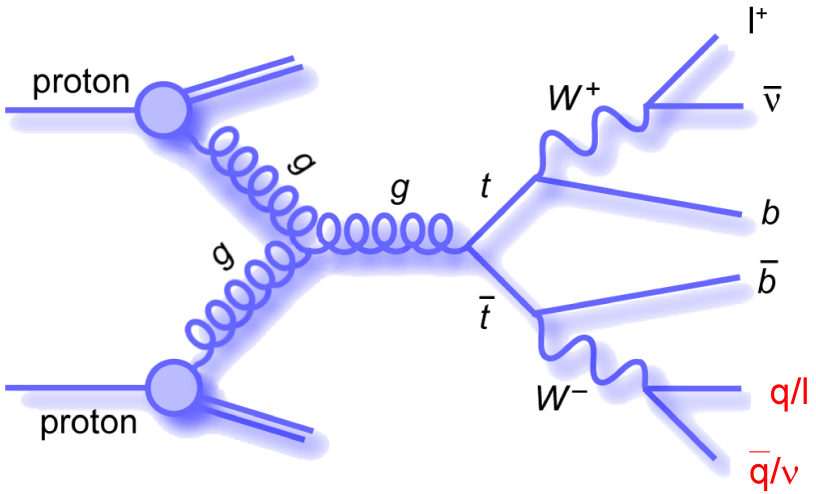
Kidonakis arXiv:1009.4935v2

- MC Generators
  - MADGRAPH
  - MC@NLO
  - POWHEG

Analysis overview

- Dileptonic and lepton + jets decay channels
- Measure shapes and compare with predictions
  - normalisation to inclusive cross section
  - many systematic uncertainties are reduced or cancel completely
- Restricted to visible phase space
  → no extrapolation to full phase space
- Corrected for detector and hadronisation effects
  → parton level
- Differential variables dX
  - $p_T(l)$, $\eta(l)$, $p_T(ll)$, $M(ll)$
  - $p_T(t / \bar{t})$, $y(t / \bar{t})$
  - $p_T(t\bar{t})$, $y(t\bar{t})$, $M(t\bar{t})$





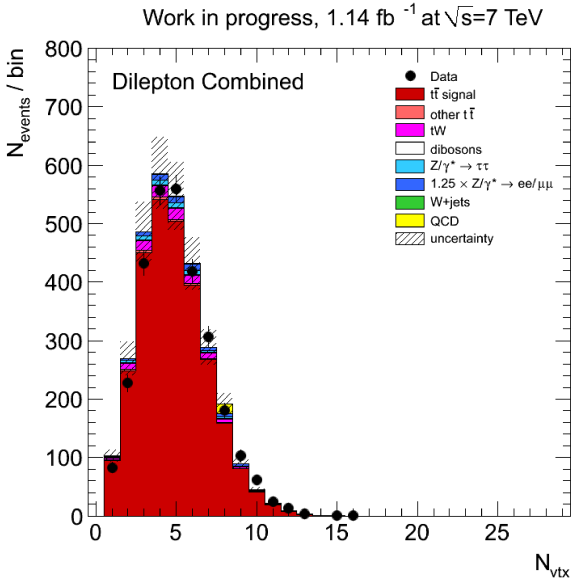
Data and Simulation

- Data
  - 1.14 fb^{-1}, recorded in 2011
- Simulation, Signal
  - $t\bar{t}$: MADGRAPH,
    in addition MC@NLO and POWHEG
- Simulation, Backgrounds
  - $t\bar{t}$: MadGraph — normalised to measured cross sections
  - Drell-Yan+Jets: Pythia, MadGraph — normalised to DY peak in dileptons
  - Single top: Powheg
  - W+Jets: MadGraph
  - QCD: Pythia (several samples)
  - Diboson (WW, WZ, ZZ): Pythia

  — normalised to (N)NLO cross section

- Pile-Up

reweight to get N_{Vertex} agreement



Event selection (lepton + jets channel)

1. trigger
- μ: p_T > 17 GeV/c, isolated
- e: p_T > 25 GeV/c, (isolated),
  ≥ 3 jets (p_T > 30 GeV/c, |η| < 2.6)

2. primary vertex (with quality criteria)

3. exactly 1 lepton
- from primary vertex
- μ: p_T > 20 GeV/c, |η| < 2.1
- e: E_T > 30 GeV, |η| < 2.5
- isolated (tracker & calorimeter)
- μ: quality requirements for track
- e: photon conversion veto

4. veto against additional leptons

5. ≥ 4 jets
- Anti-kT algorithm (cone 0.5)
- p_T > 30 GeV/c, |η| < 2.4
- Jet identification criteria

6. ≥ 2 b-tags

7. event interpretation (kinematic fit)

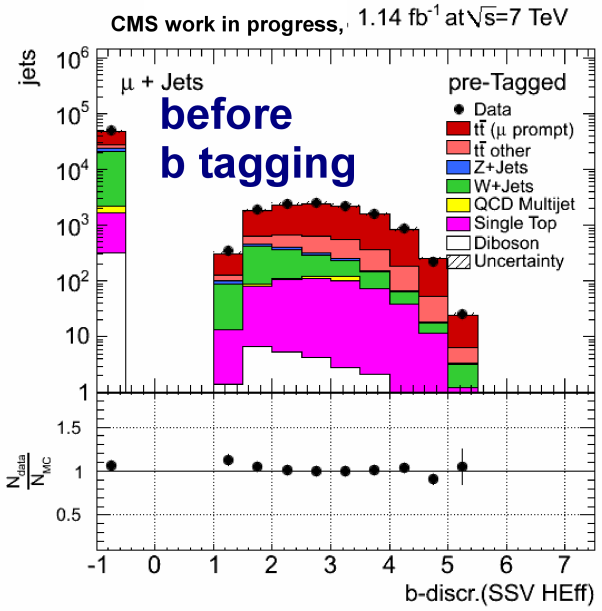
"golden channel"

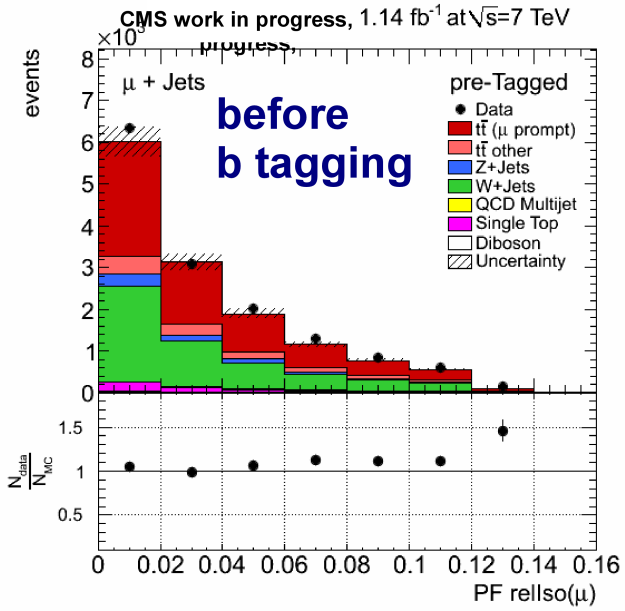
event composition (simulation, after step 7)

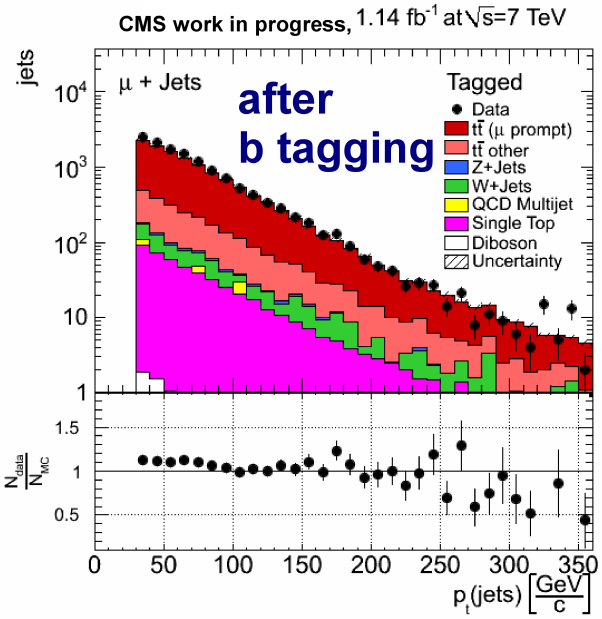
1.14 fb^{-1}	e + jets	μ + jets
events	**1595**	**2453**
$t\bar{t}$ signal	80 %	80 %
$t\bar{t}$ other	13 %	13 %
single top	4 %	4 %
W + jets	3 %	3 %
Z + jets	1 %	< 1 %
QCD	< 1 %	< 1 %
Di-Boson (WW,WZ,ZZ)	< 1 %	< 1 %

Control Distributions I (lepton + jets)

muon + jets:



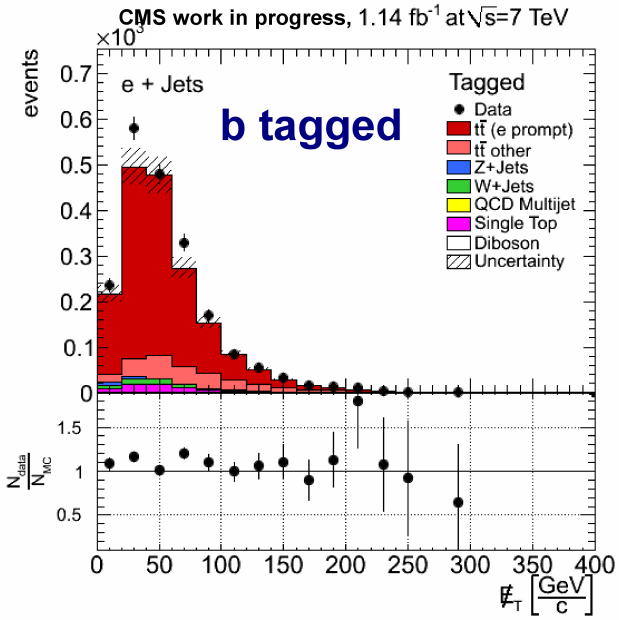


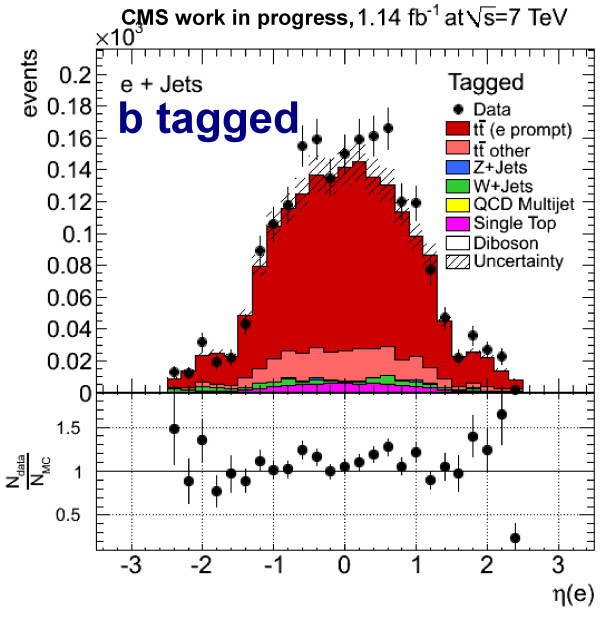


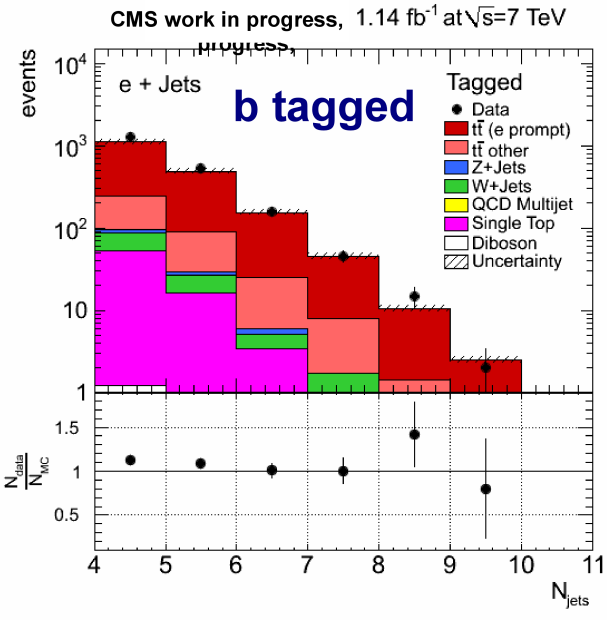
- simulation scaled to (N)NLO cross sections for BG
- $t\bar{t}$ scaled to measured cross section of 164.4 pb (CMS PAS-TOP-11-003, l+jets channel)
- good description of data by simulation

Control Distributions II (lepton + jets)

electron + jets:







- simulation scaled to (N)NLO cross sections for BG
- $t\bar{t}$ scaled to measured cross section of 164.4 pb (CMS PAS-TOP-11-003, l+jets channel)
- good description of data by simulation

Event selection (dilepton channel)

1. trigger
- μμ: p_T > 13 / 8 GeV/c
- eμ: p_T > 17 / 8 GeV/c
- ee: p_T > 17 / 8 GeV/c

e: isolation

2. primary vertex (with quality criteria)

3. at least 2 lepton
- quality criteria
- p_T > 20 GeV/c, |η| < 2.4
- isolated
- invariant mass M_{ll} > 12 GeV/c^2

4. Veto Z mass (ee and μμ only)
- M_{ll} < 76 GeV/c^2 or M_{ll} > 106 GeV/c^2

5. ≥ 2 jets
- Anti-kT algorithm (cone 0.5)
- p_T > 30 GeV/c, |η| < 2.4

6. ≥ Missing energy (ee and μμ only)
- MET > 30 GeV/c^2

7. ≥ 1 b-tag

8. event interpretation (kinematic reco)

dilepton triggers
allow low p_T thresholds
compare e + 3 jets trigger

don't veto additional leptons

threshold 20 GeV/c also for e

different cuts
due to different topology

different
kinematic reconstruction

Event selection (dilepton channel)

1. trigger
- μμ: p_T > 13 / 8 GeV/c
- eμ: p_T > 17 / 8 GeV/c
- ee: p_T > 17 / 8 GeV/c

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- p_T > 30 GeV/c, |η| < 2.4

6. ≥ Missing energy (ee and μμ only)
- MET > 30 GeV/c^2

7. ≥ 1 b-tag

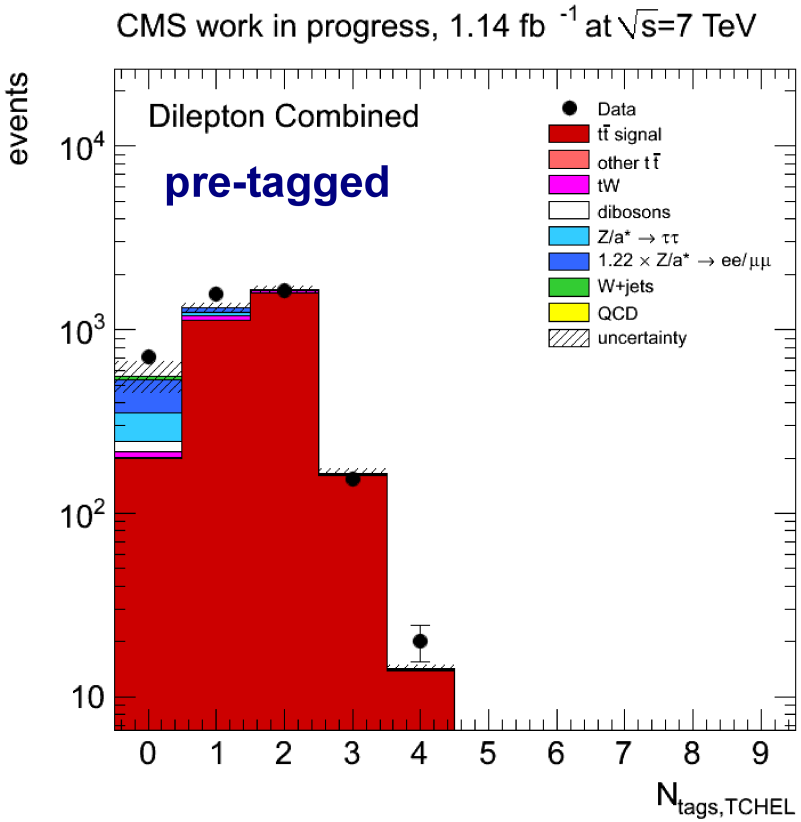
8. event interpretation (kinematic reco)

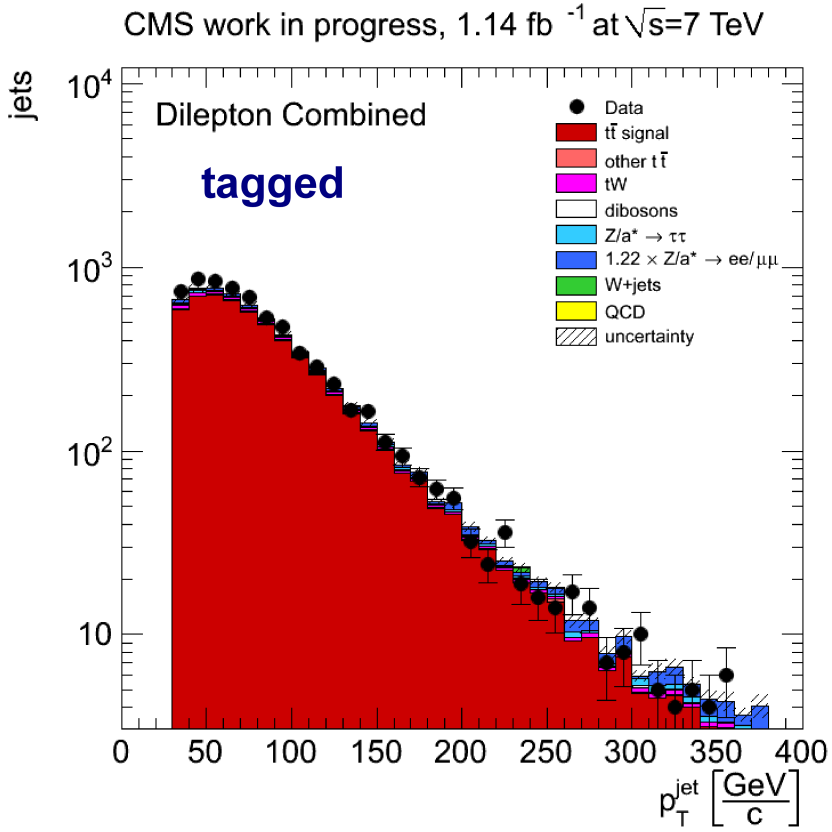
event composition (simulation, after step 8)

1.14 fb^{-1}	eμ	μμ + ee
events	**1112**	**708**
$t\bar{t}$ signal	95 %	93 %
$t\bar{t}$ other	0.7 %	0.8 %
single top	2 %	2 %
diboson	0.3 %	0.3 %
$Z \rightarrow \tau\tau$	1.6 %	1.2 %
$Z \rightarrow ee / \mu\mu$	0.1 %	3.2 %

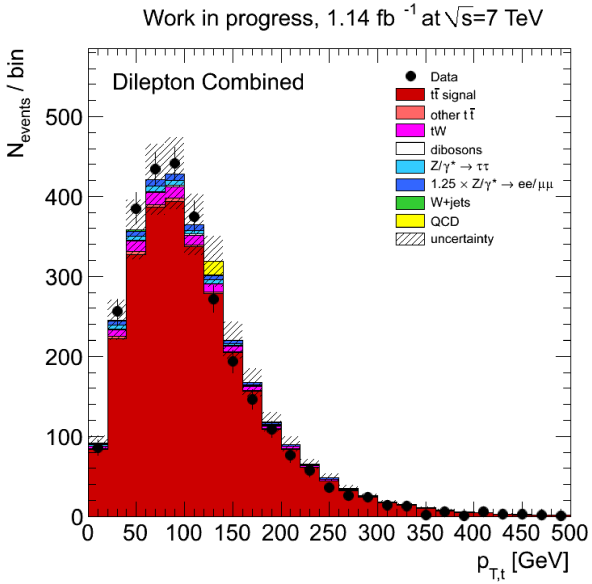
Control plots I (dileptons)

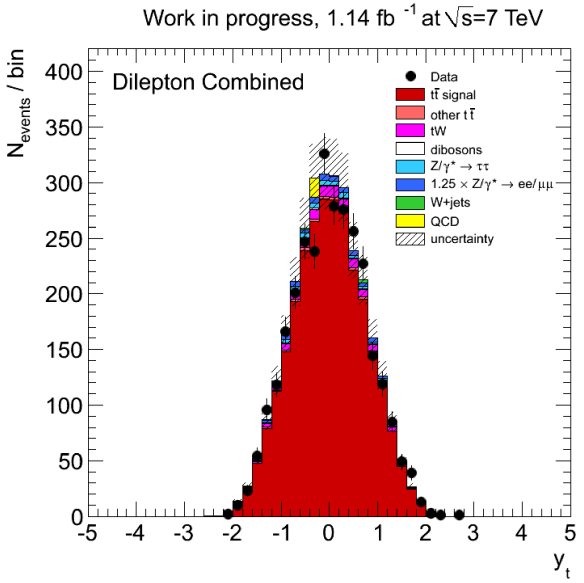
- All three dilepton channels combined



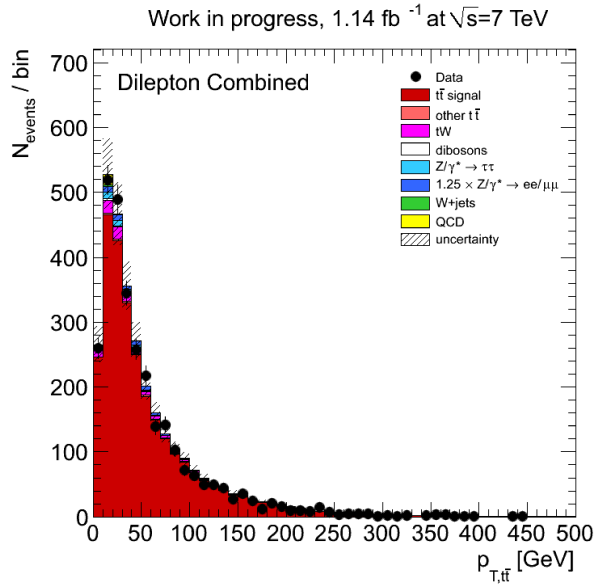


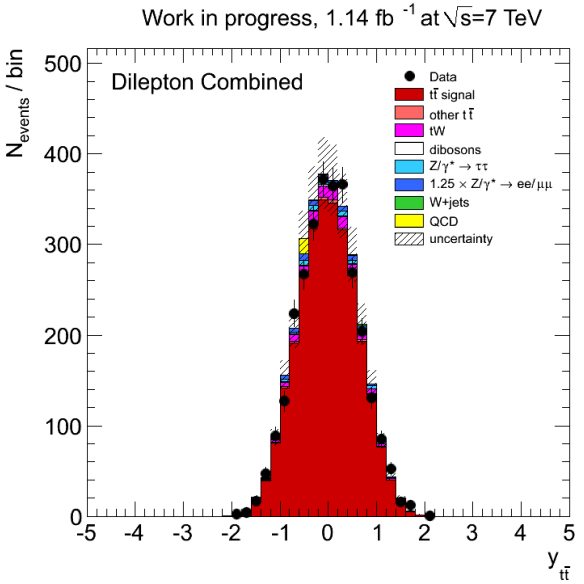
Control plots II (dileptons)





top quarks

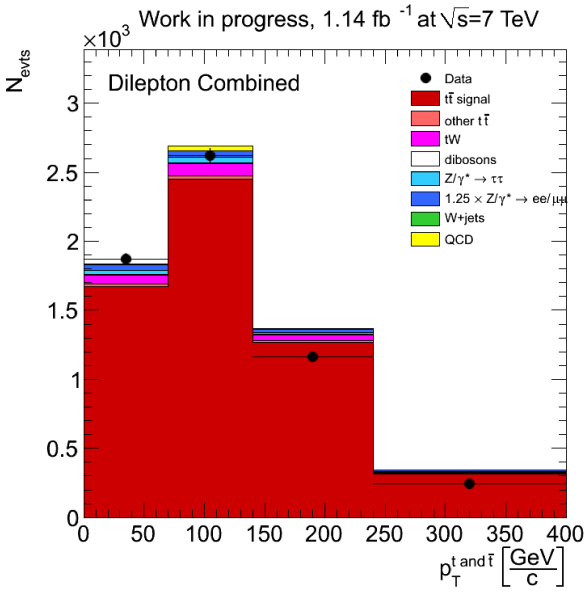




In all selection steps: good agreement Data/MC

tt̄ system

Getting to normalised differential cross sections



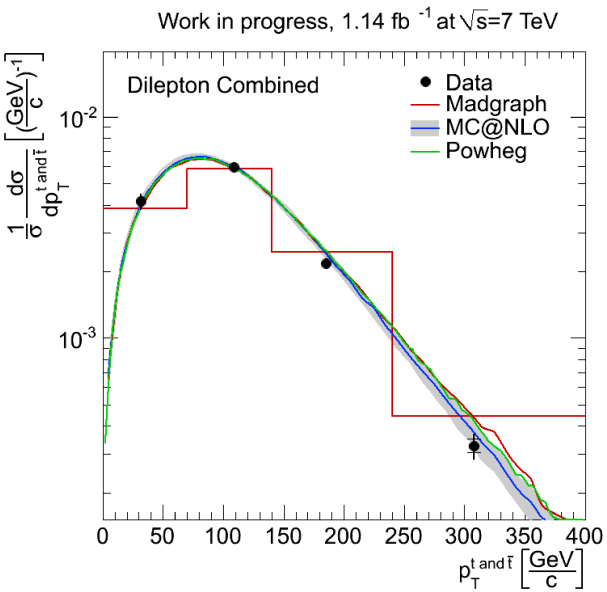
counting exp.

BG substr. (simulation)

$$\frac{1}{\sigma}\frac{d\sigma}{dX} = \frac{1}{\sigma}\frac{N_{\text{data}} - N_{\text{BG}}}{\Delta_{\text{Bin}} \cdot \epsilon' \cdot A \cdot L}$$

$$\epsilon'_i = \frac{N_{rec,i}}{N_{genIni,i}}$$

ε' contains migration

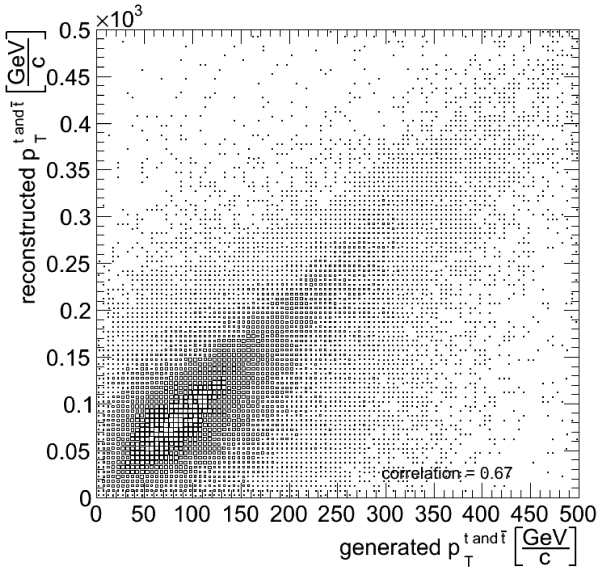


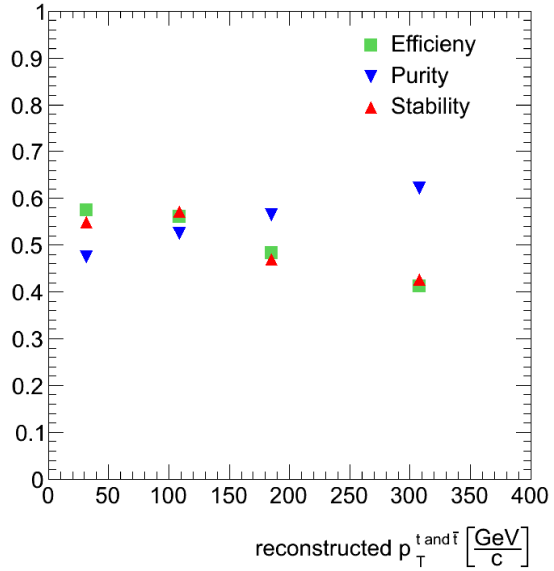
- Corrected back to parton level
- Measured in visible phase space:

Dileptons	L + Jets
Leptons: $p_T(l) > 20$ GeV/c, $\lvert\eta(l)\rvert < 2.4$	$p_T(l) > 30$ GeV/c, $\lvert\eta(l)\rvert < 2.1$
Partons: $p_T(q) > 30$ GeV/c, $\lvert\eta(q)\rvert < 2.4$	$p_T(q) > 30$ GeV/c, $\lvert\eta(q)\rvert < 2.4$

- Normalise to inclusive cross section in visible phase space
  - cancellation of many systematic uncertainties

Bin-by-bin unfolding





- Efficiency includes bin migration:

$$\epsilon_i' = \frac{N_{rec,i}}{N_{genIni,i}}$$

- Optimise bin size so that purity p and stability s ≈ 0.5

$$p_i = \frac{N_{rec\&gen,i}}{N_{rec,i}} \qquad s_i = \frac{N_{rec\&gen,i}}{N_{gen,i}}$$

  - p: migration **in** bin, s: **out of** bin
  - Limit bin migration
  - Limits the number of bins

- Take into account potential biases from model assumptions by using different generators (MADGRAPH, POWHEG, MC@NLO)

Simple, transparent and robust method

Systematic uncertainties

- Uncertainties determined individually for each bin
- only shape uncertainties contribute, no uncertainties due to normalisation, e.g. luminosity

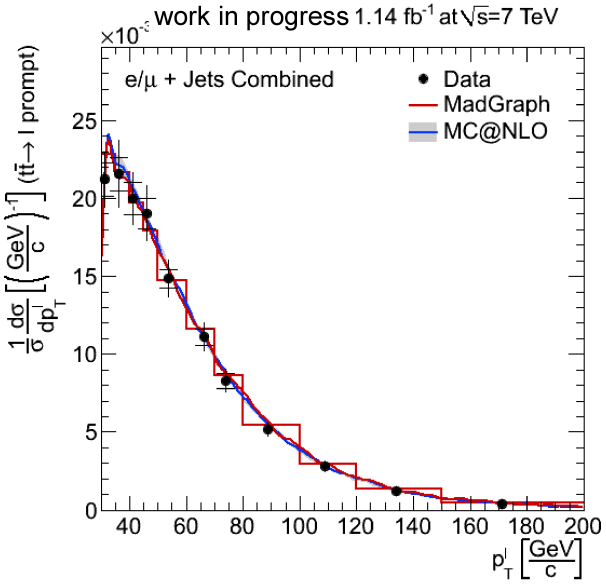
Semilepton channel (typical values)

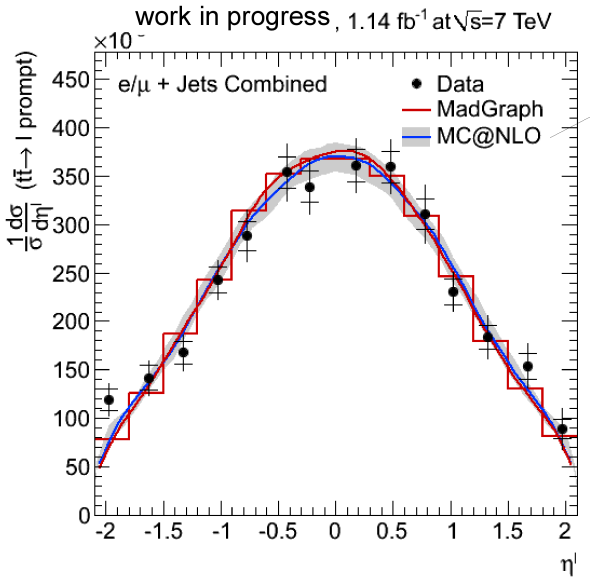
- **Background (± 2 %):**
  - QCD, diboson, single top (0.5 %)
  - W/Z+jets (2 %)
- **Efficiencies (± 1 %):**
  - trigger and lepton identification
  - b-tag efficiency
- **Experimental uncertainties (± 2 %):**
  - JES, JER, Pile-Up
- **Theory (± 6 %):**
  - Q2 and matching scale
  - pdf
  - top mass
  - hadronisation (5 %)

Dilepton channel (typical values)

- **Background**
  - DY: vary ± 50% → 1.5% for ee/μμ only
  - others: ± 30% → 0.3 %
- **Efficiencies (± 4 %):**
  - Trigger 2 %, Lepton 2 %
  - b tagging, conservative estimate: 3 %
- **Experimental uncertainties (± 1 %):**
  - JES, JER, Pile-Up
- **Theory (± 2 %)**
  - Q2 and matching scale
  - pdf
  - top mass
  - hadronisation

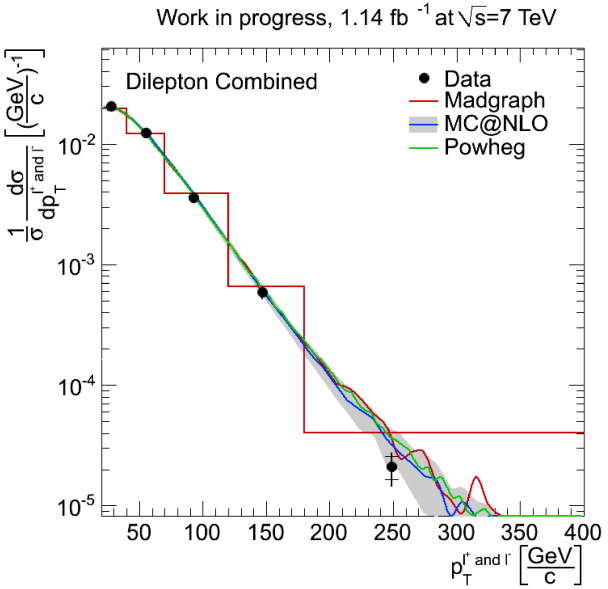
Results – single lepton quantities

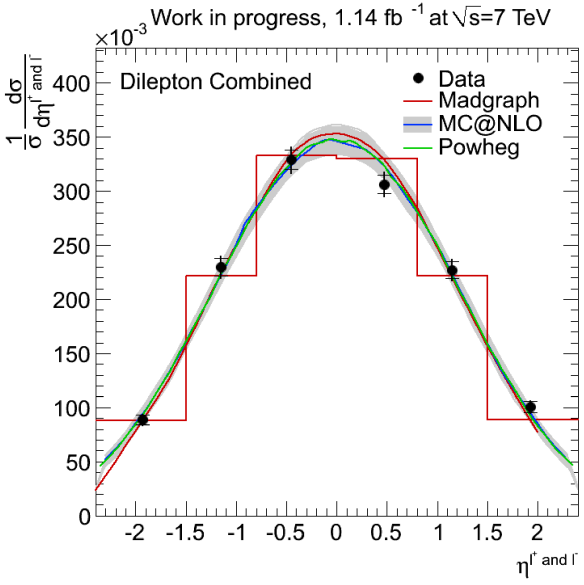




error band includes Q^2, m_t, PDF

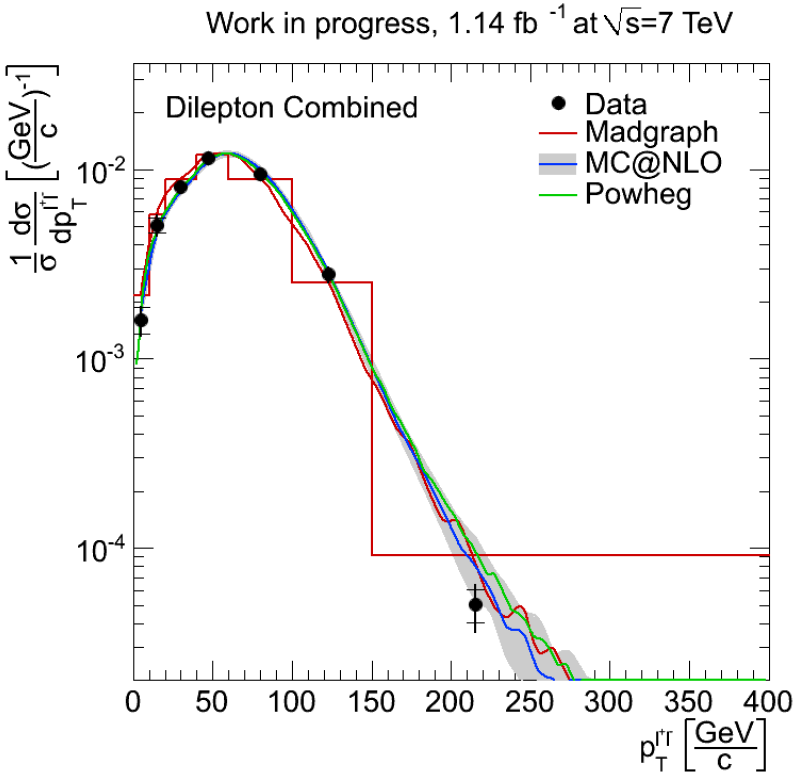
semilepton channel

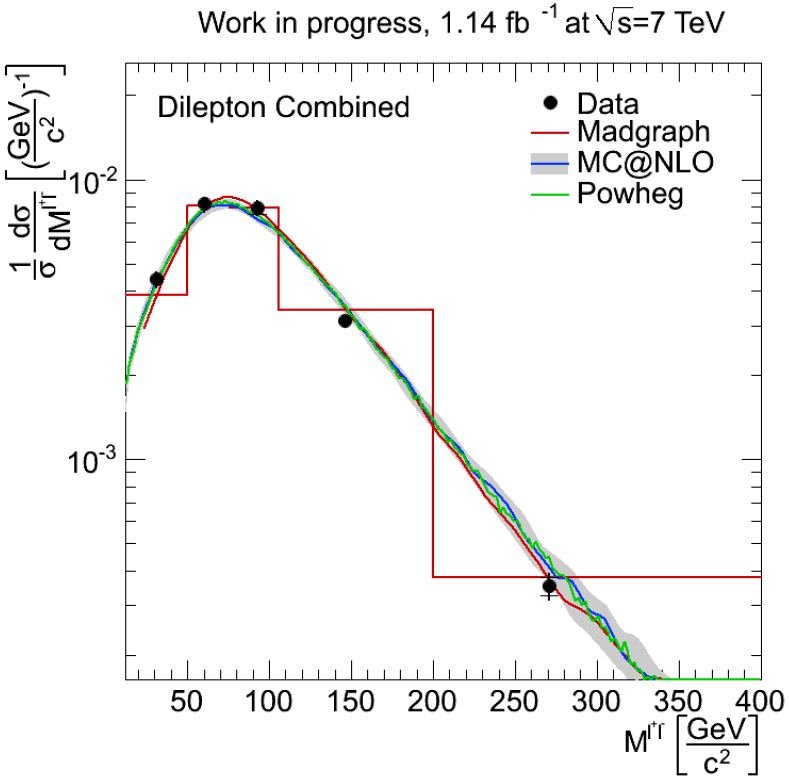




dilepton channel

Results – Lepton/antilepton system quantities





dilepton channel

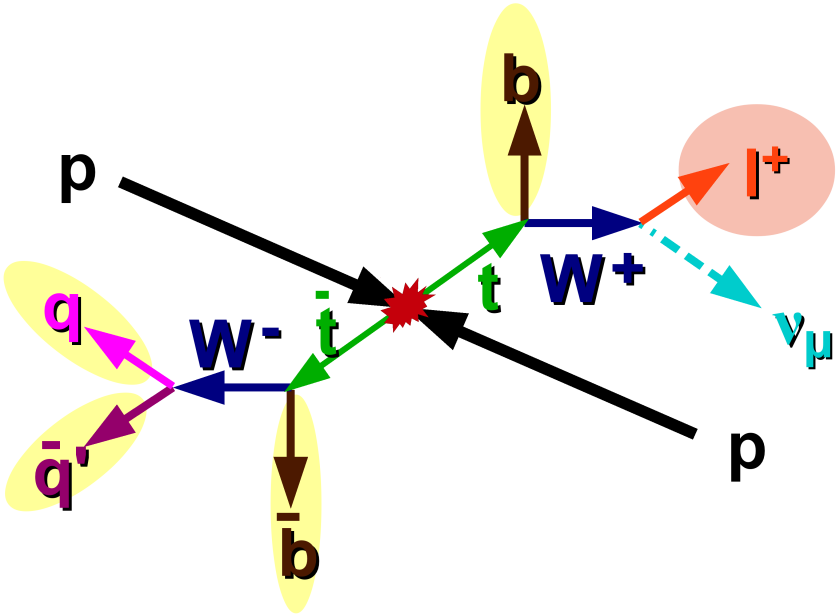
Top reconstruction (semiletonic channel)

goal: measurement as function of top quark variables

→ kinematic reconstruction of the top quarks necessary

challenge

- neutrino momentum not measured
- jet association → combinatorics



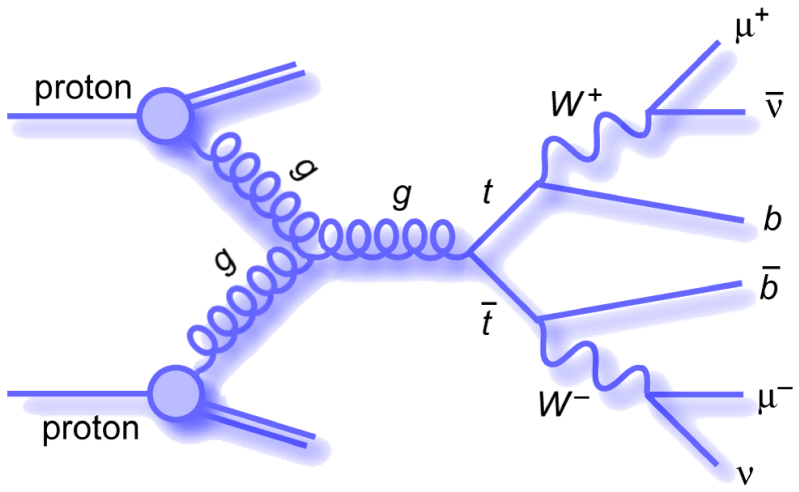
kinematic fit

- **constraints:**
  - m_W=80.4 GeV/c^2
  - $m_t = m_{\bar{t}}$
- the fit **varies** the measured **four momenta** for jets, lepton & neutrino within their resolutions
- neutrino vector from missing E_T, assume $p_z(\nu) = 0$ as initial value
- consider **5 leading jets**
- only **b-tagged jets** are considered as **b-quarks**
- choose solution with **lowest χ^2**

Top reconstruction (dileptons)

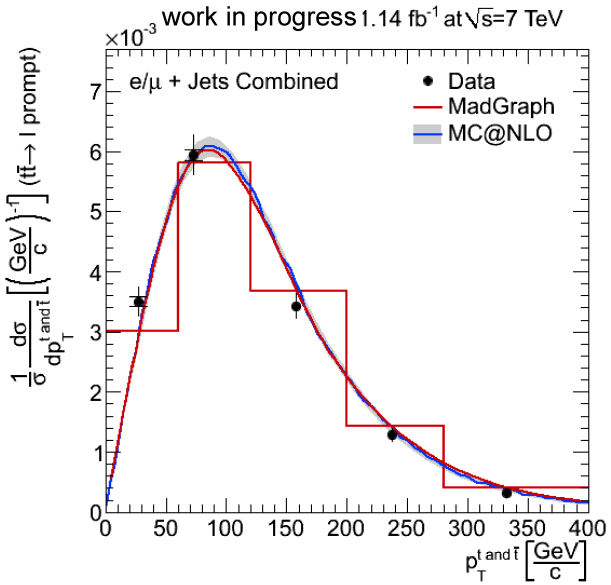
- Semileptonic events overconstrained
- Constrast: Dilepton events kinematically underconstrained
  - two neutrinos
- Measurements
  - both b jets (or leading jets)
  - both leptons
  - missing transverse energy
- Further assumptions
  - M_W = 80.4 GeV
  - $p_{x,y}(\nu 1) + p_{x,y}(\nu 2) = MET_{x,y}$
  - $m_t = m_{\bar{t}}$ = fixed

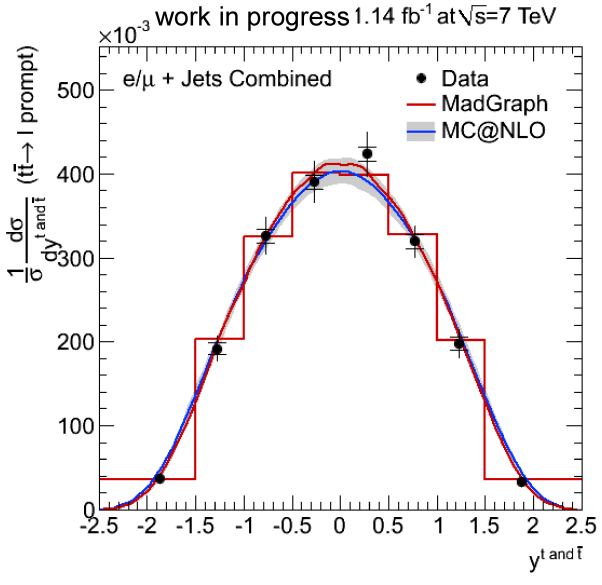
    vary m_t in 1 GeV steps from 100 to 300 GeV to account for mismeasurements



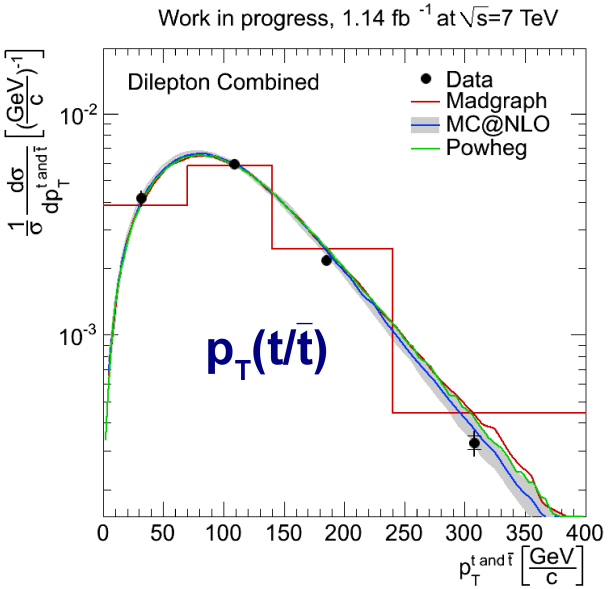
- Equation system still underconstrained
  - multiple solutions possible
- Compare to MC neutrino energy spectrum
  - choose solution with most probable neutrino energies

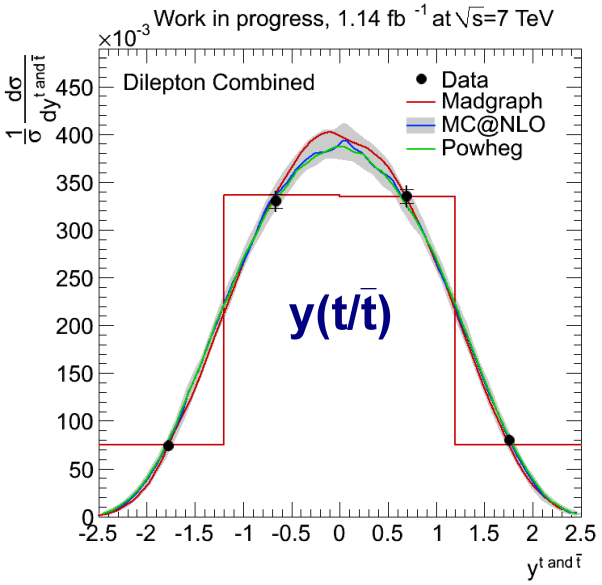
Results – Top Quantities 1/3 – tops / antitops





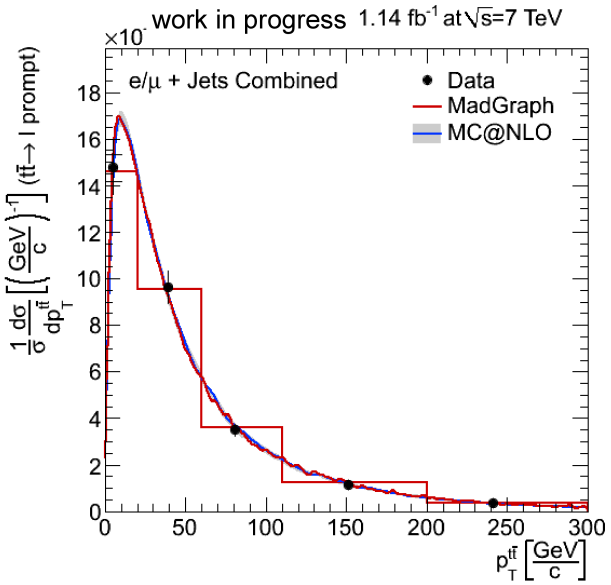
l + jets

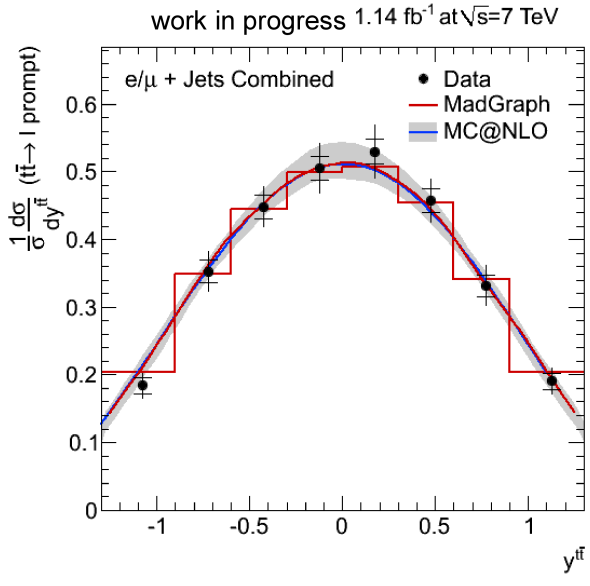




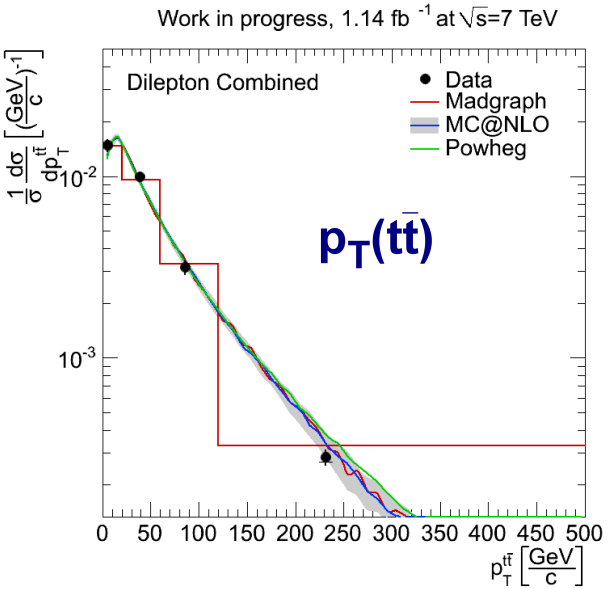
dileptons

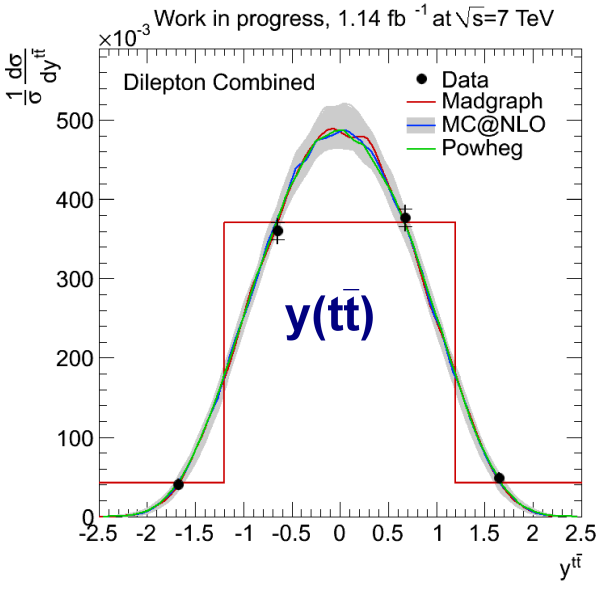
Results – Top Quantities 2/3 – $t\bar{t}$ system





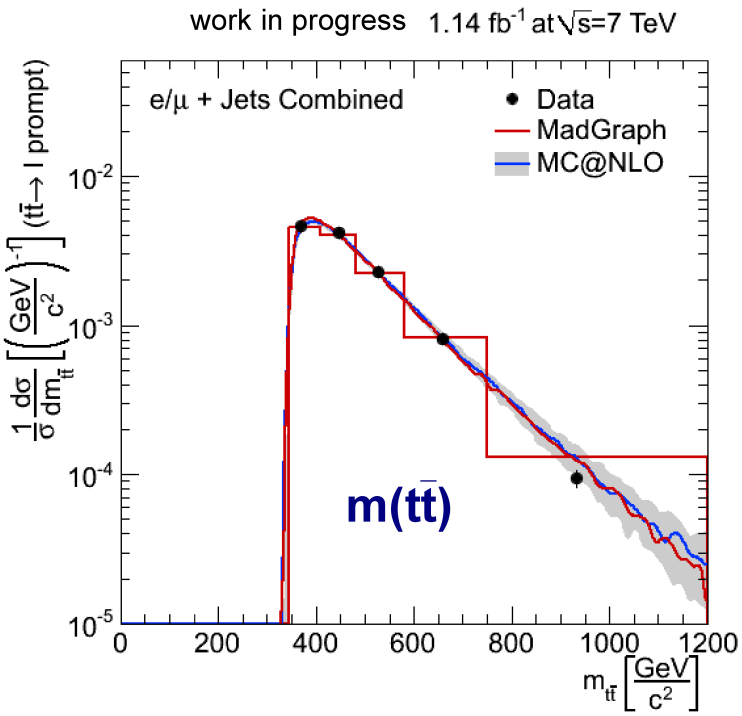
l + jets

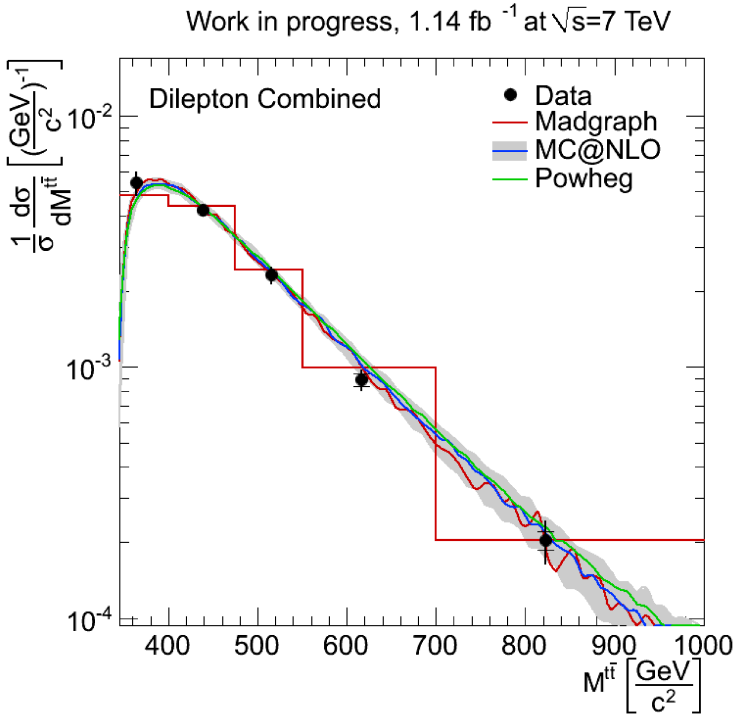




dileptons

Results – Top Quantities 3/3





Good agreement with SM theory,
no hints for new physics

Summary and Outlook

- **First Measurement** of normalised differential $t\bar{t}$ cross sections at 7 TeV centre of mass energy performed with 1.14 fb^{-1} of CMS data
  - used dilepton and lepton + jets channels
  - very pure sample after event selection
  - reconstructed top properties using a kinematic fit
- **Five different** channels for the measurement, nine quantities
- **Good agreement** between measurement and different predictions
  - Top kinematics are described by the standard model
  - No hints for new physics

End

- Thank you for your attention!