Karlsruhe Institute of Technology

Top Pair Production with N-jets at CMS

GK Workshop - Bad Liebenzell - Fall 2013

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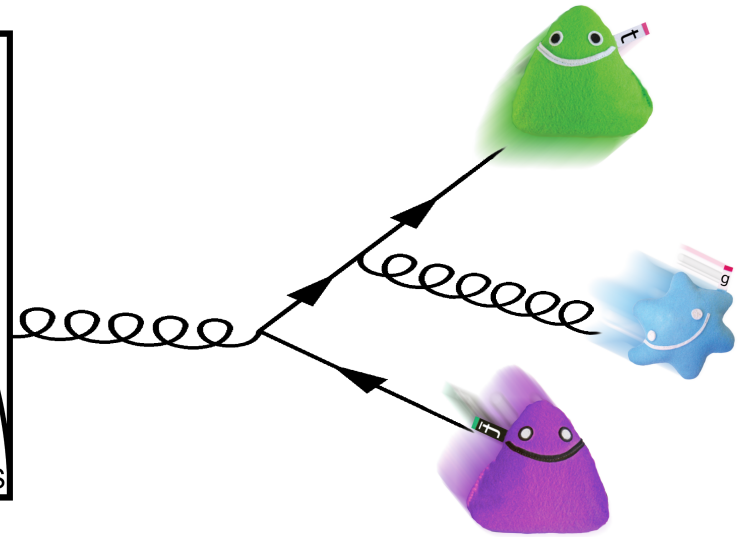
INSTITUT FÜR EXPERIMENTELLE KERNPHYSIK (IEKP)

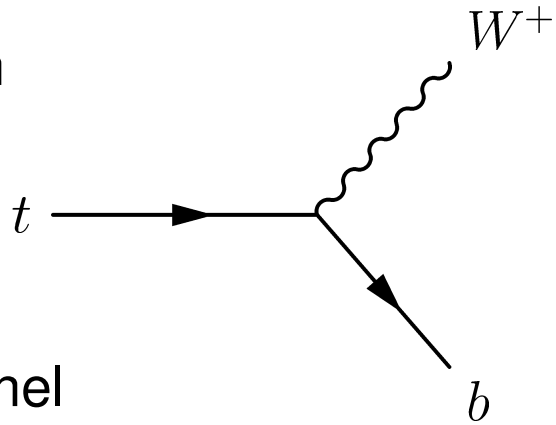


Introduction

- At the LHC a large fraction of top quark pair events ($t\bar{t}$) is produced with additional jets
- Investigating these processes is very interesting
  - Test perturbative QCD at top quark energy scale
  - Constrain modeling uncertainties in MC
  - Anomalous $t\bar{t}$ + jets production can be sign of new physics
  - Background to $t\bar{t}$ production with Higgs or with other bosons and BSM
- I am contributing to cross-section measurements of $t\bar{t}$ events as a function of jets at CMS

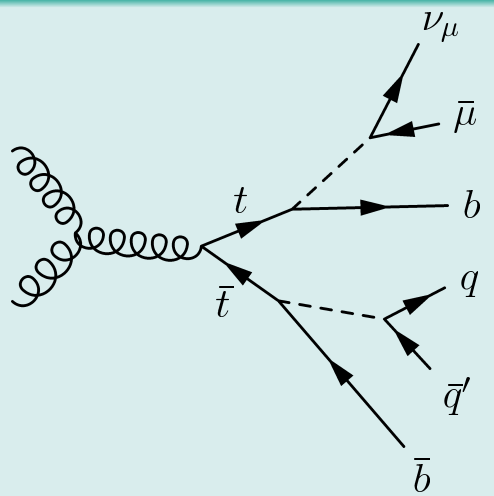
Investigated Processes: $t\bar{t}$ Events

- $t\bar{t}$ produced at LHC mostly with gluons in initial state
- Top quarks decay almost always into a W boson and a bottom quark



- Decay of a W boson into leptons and the other one in quarks $\rightarrow$ lepton+jets channel

Lepton+Jets Channel



Main Backgrounds

- W+jets and QCD multijet processes
  - Origin of leptons:
    - Lepton from W boson decay
    - Jets identified as leptons
    - $B/D \rightarrow \ell + X$ inside jets
  - Additional jets via QCD radiation
- Single top with additional jets

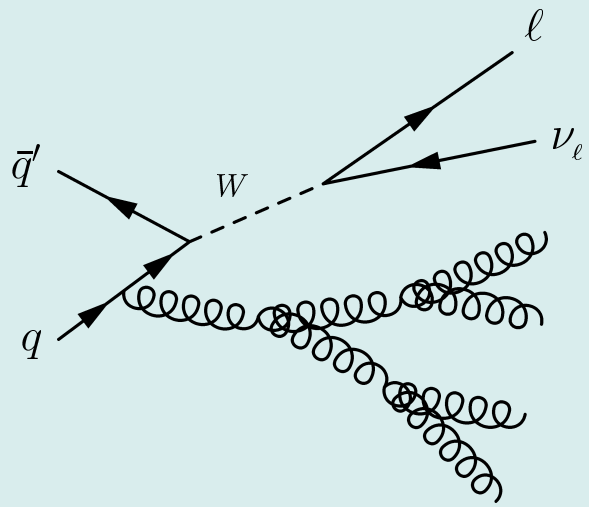
Analyzed Samples

- Datasets from 2011 LHC run: $\sqrt{s} = 7$ TeV, $\mathcal{L} = 5.0$ fb^{-1}
- Simulation of standard $t\bar{t}$ sample with LO generator:
  - Matrix element from MADGRAPH ($t\bar{t}$ + 0,1,2,3 jets)
  - Interfaced via MLM matching with PYTHIA for parton showering
  - Factorisation and renormalisation scale: $Q^2 = m_t^2 + \sum p_T^2$
- Comparison available with NLO $t\bar{t}$ generators:
  - POWHEG+PYTHIA
  - MC@NLO+HERWIG
- Background processes simulated with MC:
  - MADGRAPH+PYTHIA (W+jets and Drell-Yan)
  - POWHEG+PYTHIA (single top)
  - PYTHIA (boson pair: WW, WZ, ZZ)
- Modeling/correction of dominant backgrounds with data-driven methods: W+jets and QCD multijet

Data-Driven Background Estimation

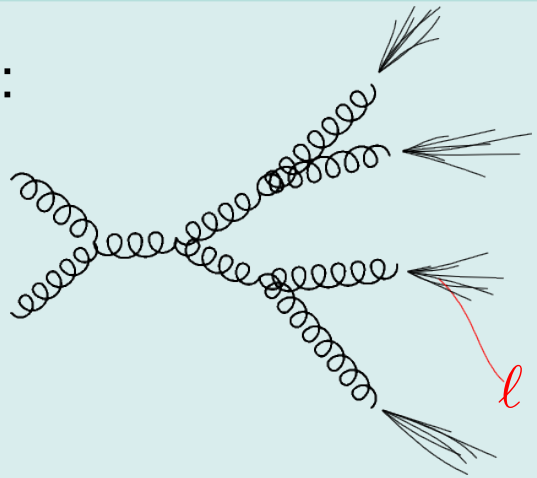
W+Jets

- Main lepton charge asymmetry at LHC via W boson production
  $\rightarrow A = W^+ - W^- = \ell^+ - \ell^-$
- Correction of MC with ratio: $A^{\text{data}} / A^{\text{MC}}_{W+\text{jets}}$
- Correction on $W + b(b)$ and $W + c(c)$ rates



QCD Multijet

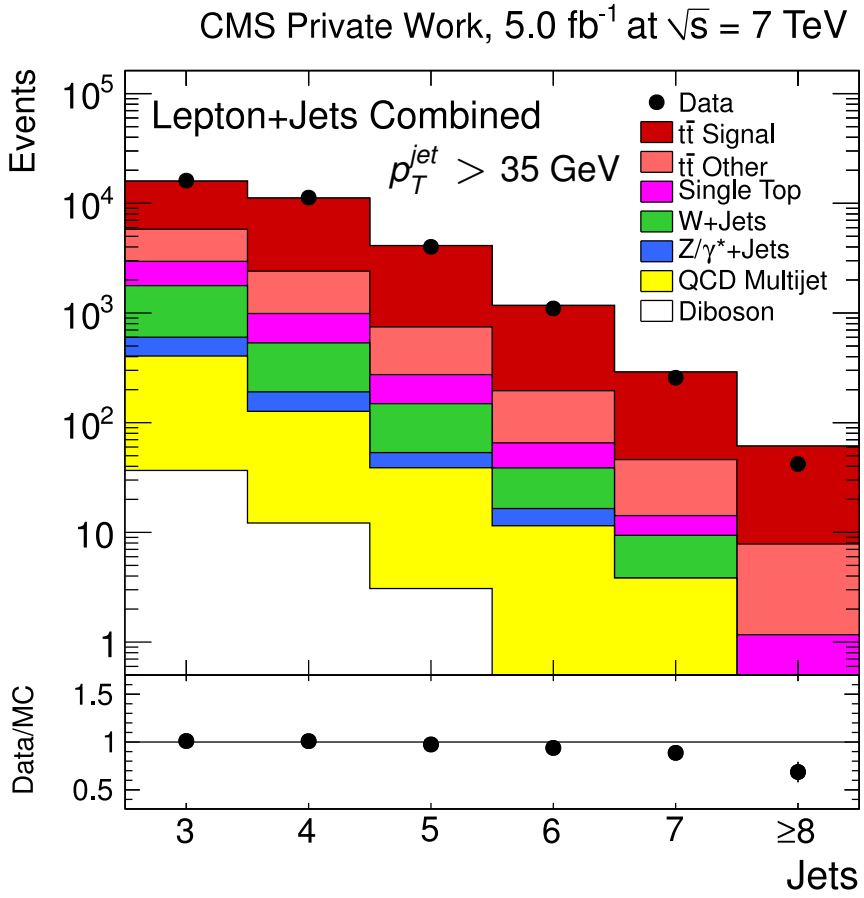
- QCD model from data using anti-isolated leptons:
  - Lepton in jet (decay of B or D hadron)
  - Jet identified as a lepton
- Scaling of the model through a fit to data outside of the measurement phase space



Events Selection

- One selected lepton (e or μ) with $p_T > 30$ GeV
- Veto against any additional leptons
- $\geq 3(4)$ selected jets with $p_T > 35(30)$ GeV
- ≥ 2 of these jets identified as b-jets

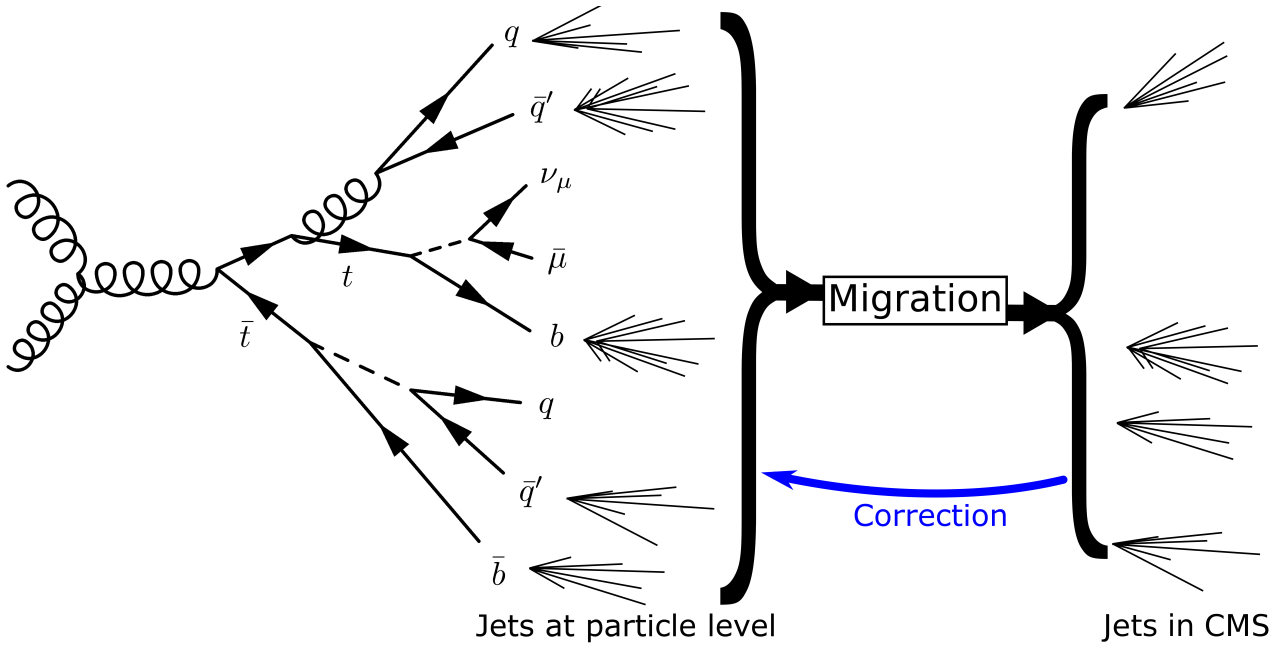
- Non-$t\bar{t}$ processes represent $\sim$15% of data after the selection
  - W+jets
  - Single top
  - QCD multijet
  - Z+jets



Measurement of the Differential Cross-Section as a Function of the number of Jets

Correction Back to Particle Level

- Subtract background from data $\rightarrow N^i_{data} - N^i_{bkg}$
- Correct migration from particle level to detector level:



- Invert migration effects back to particle level with MADGRAPH $\rightarrow N^i_{t\bar{t}}$
- Correction within the visible phase-space

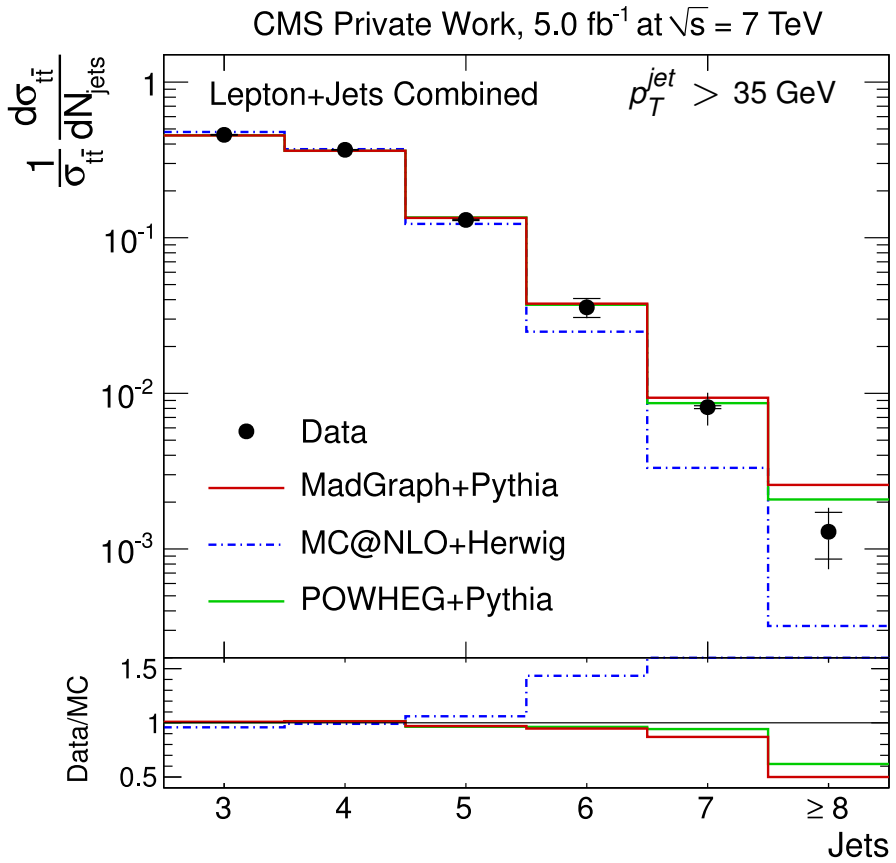
Differential Cross-Section and Theory Comparisons

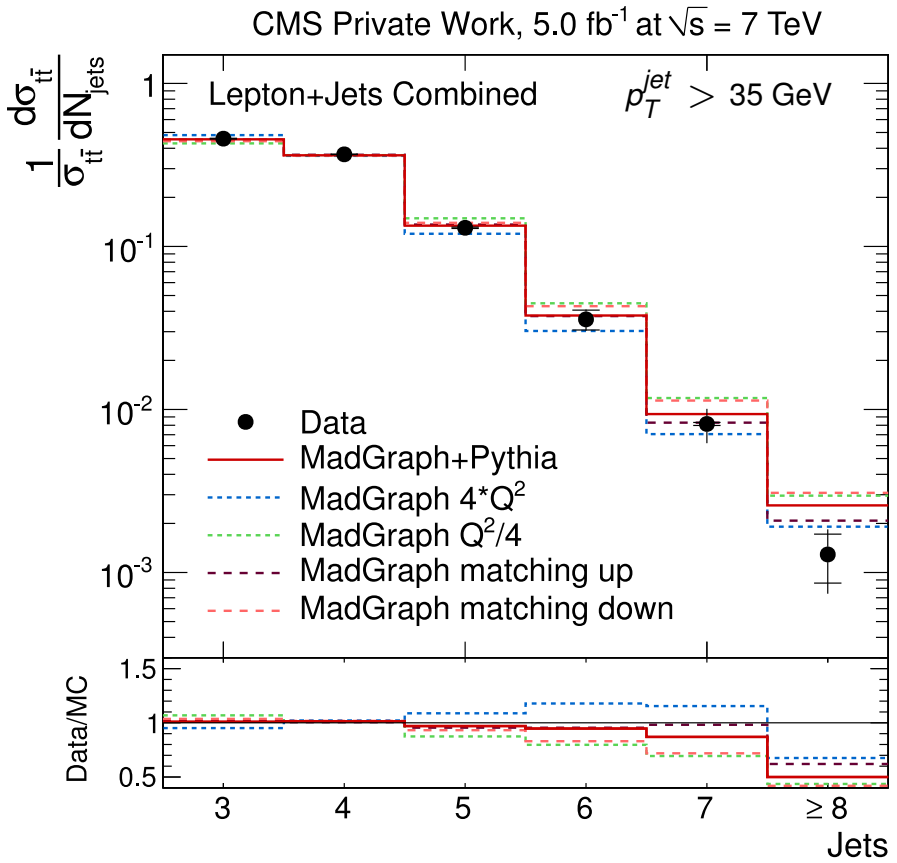
- Calculation of the differential cross-section for *i* jets:

$$\frac{1}{\sigma_{t\bar{t}}}\frac{d\sigma^{i}_{t\bar{t}}}{dN_{jets}} = \frac{1}{\sigma_{t\bar{t}}}\frac{N^{i}_{t\bar{t}}}{\mathcal{L}}, \text{ with measured cross-section: } \sigma_{t\bar{t}}$$

- Normalization to $\sigma_{t\bar{t}}$ reduces systematic uncertainty
- Combine results and compare to predictions from:
  - POWHEG+PYTHIA
  - MC@NLO+HERWIG
  - Variation up/down of Q^2 scale and of matrix-element/parton-showering matching threshold in MADGRAPH+PYTHIA
- Main systematic uncertainties:
  - Jet energy uncertainties (2-20%)
  - Modeling uncertainties (Q^2 scale and matching threshold uncertainty, 2-18%)

Differential Cross-Section in Lepton+Jets Channel





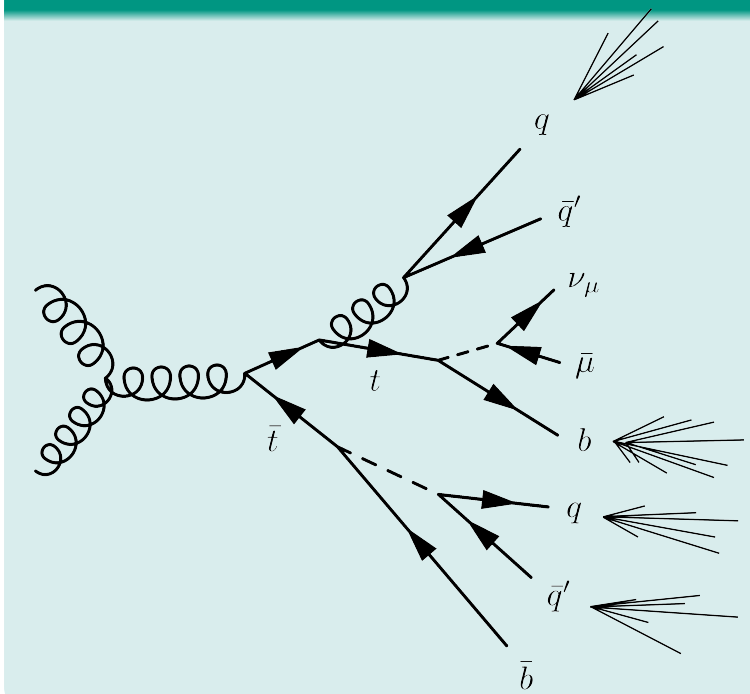
- Good agreement of data with predictions from MADGRAPH+PYTHIA and POWHEG+PYTHIA
- MC@NLO+HERWIG: jet multiplicity lower than data
- MADGRAPH+PYTHIA: best description for larger Q^2/match. threshold

Measurement of the Differential Cross-Section as a function of the number of Additional Jets

Definition of Additional Jets

- $t\bar{t}$ MC events are classified using MC information
  - particle level jets
  - $t\bar{t}$ decay products from matrix-element
- Use the angle ΔR between particle level jets and $t\bar{t}$ decay products:
  - two b quarks
  - two light quarks
  - prompt lepton
- Jets with $\Delta R > 0.5$ count as additional radiated partons
  $\Rightarrow$ classification of events in
  $t\bar{t}$ + 0, 1 and $\geq$ 2 additional jets
- Extracting rates of these $t\bar{t}$ classes from data via a template fit

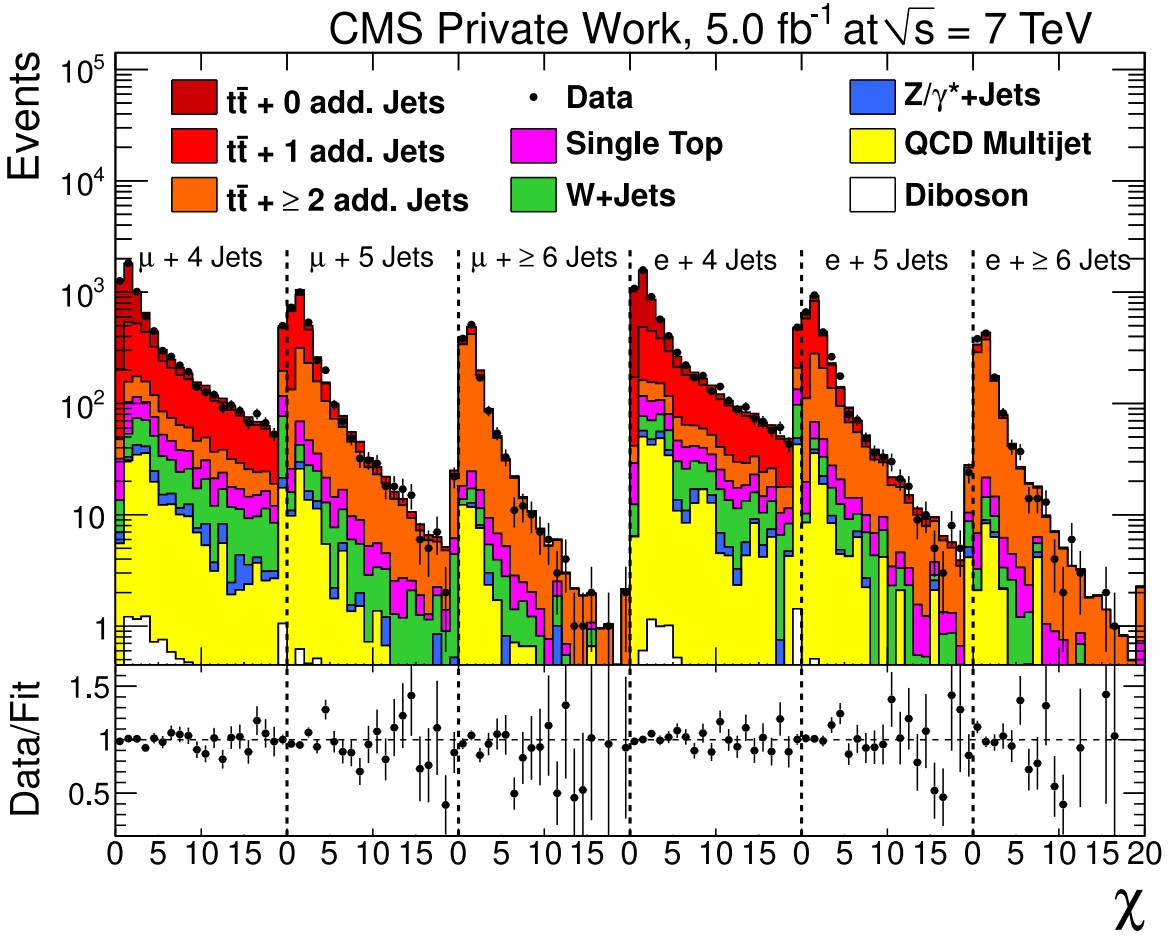
One Additional Jet



Template Fit Results

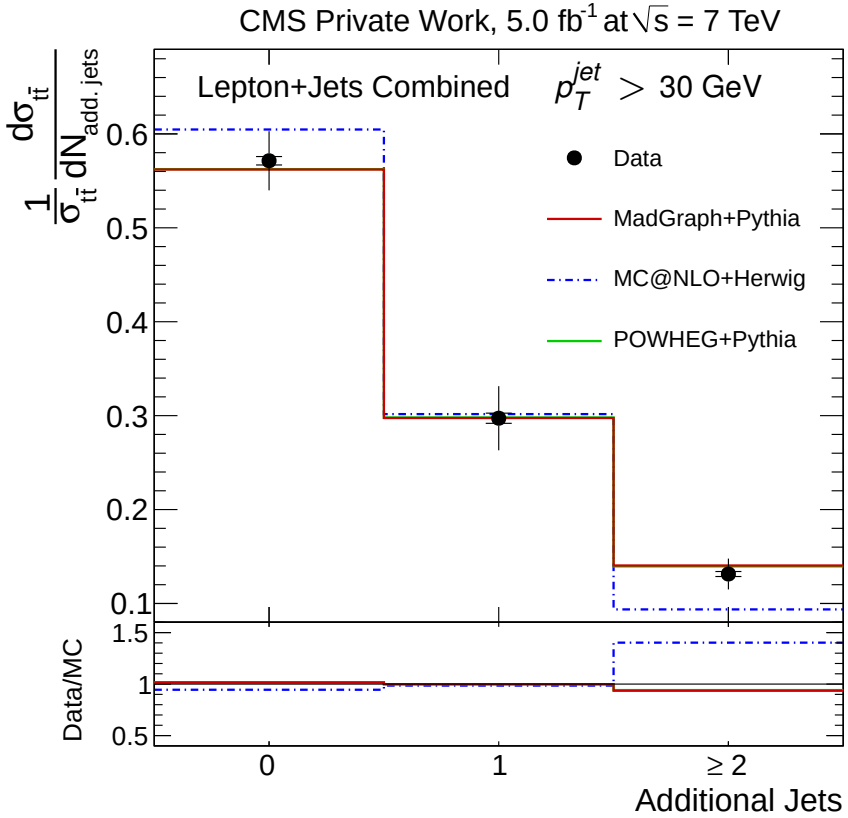
- Fit in χ: Quality of a $t\bar{t}$ full event reconstruction

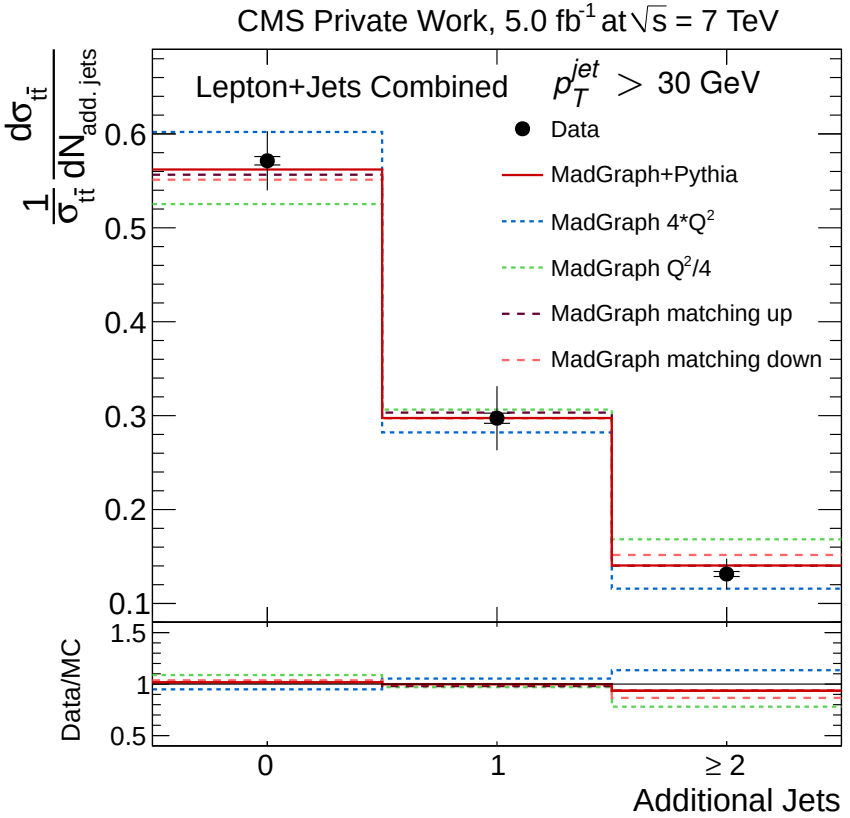
$$\chi = \sqrt{\left(\frac{m_{W^{had}}^{rec} - m_{W^{had}}^{true}}{\sigma_{W^{had}}}\right)^2 + \left(\frac{m_{t^{had}}^{rec} - m_{t^{had}}^{true}}{\sigma_{t^{had}}}\right)^2 + \left(\frac{m_{t^{lep}}^{rec} - m_{t^{lep}}^{true}}{\sigma_{t^{lep}}}\right)^2}$$



- Simultaneous fit in 6 regions:
  e/μ + 4, 5, and $\geq$ 6 jets
  $\rightarrow$ better discrimination between $t\bar{t}$ classes
- E.g. with 4 jets and 1 additional jet
  $\rightarrow$ a jet from $t\bar{t}$ lost
  $\rightarrow$ no proper reconstruction possible
  $\rightarrow$ larger χ

Cross-Section as a Function of Additional Jets





- Extract results with MADGRAPH prediction for the $t\bar{t}$ classes
- Like jet multiplicity measurement:
  - best agreement from MADGRAPH+PYTHIA and POWHEG+PYTHIA with data
  - MC@NLO shows discrepancies

Conclusion and Outlook

- Two measurements of jets in $t\bar{t}$ events: jet multiplicity and additional jet multiplicity $\rightarrow$ consistent results
- MADGRAPH+PYTHIA predictions agree mostly well with data
- Modelling uncertainties (Q^2 and matching) often larger than measurement precision $\rightarrow$ too conservative?
- MC@NLO+HERWIG produces fewer jets than observed. Comparison with POWHEG+HERWIG required (sample now available)
- Working towards comparisons with NLO+Parton Showering multileg generators like aMC@NLO and SHERPA
- Publication in collaboration review. Update to 8 TeV data will follow

Public results can be found here:

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsTOP $\rightarrow$ TOP-12-018

Thanks for your attention