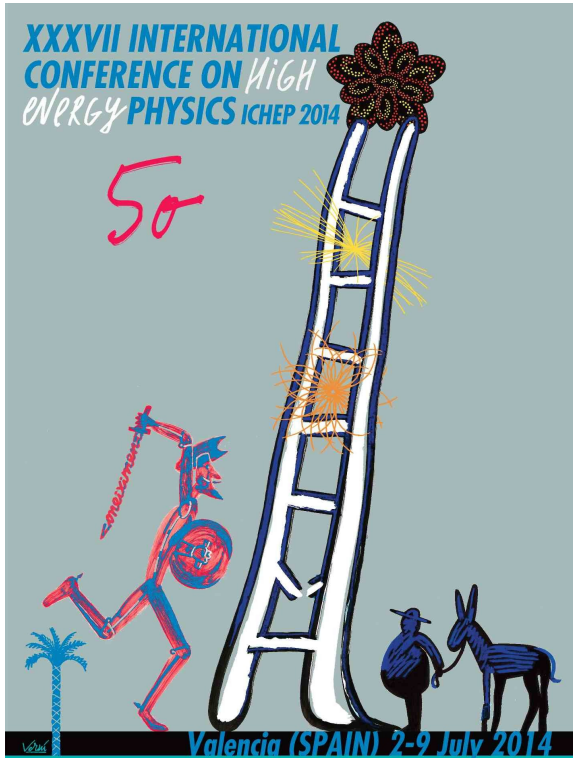
Top Quark Pair Differential Cross Section Measurements with the CMS Detector

- Motivation
- Event Selection
- $t\bar{t}$ Differential Cross Section
- Global Event Variables
- $t\bar{t}$+Jets
- $t\bar{t}+\gamma$, $t\bar{t}+W$ and $t\bar{t}+Z$ results
- Summary



Ivan Asin
on behalf of the CMS Collaboration
ICHEP 2014, Valencia 2014/July/03

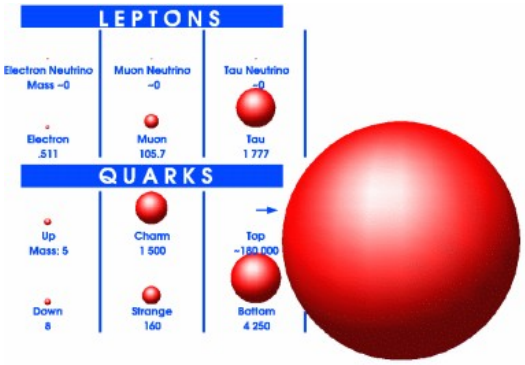
HELMHOLTZ ASSOCIATION

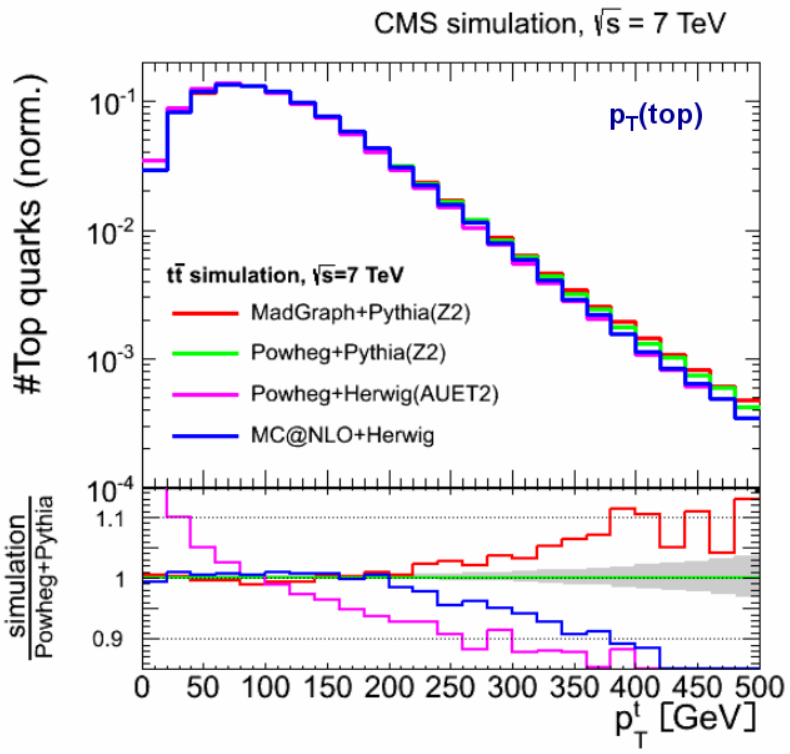
CMS Compact Muon Solenoid

DESY

Why $t\bar{t}$ Differential Cross Sections?

- Top quark properties plays an important role in the SM
- Large top mass: $m^t > m^H > m^Z$
  - Decays before hadronizing → no bound state
  - *Higgs* boson couples preferentially to *top*-quark
- **Precision test of $t\bar{t}$ modeling**
  - Perturbative QCD predictions
  - Theory tunes: scales, UE, …
- **$t\bar{t}$ process relevant background** for new physics searches





$t\bar{t}$ Standard Event Selection

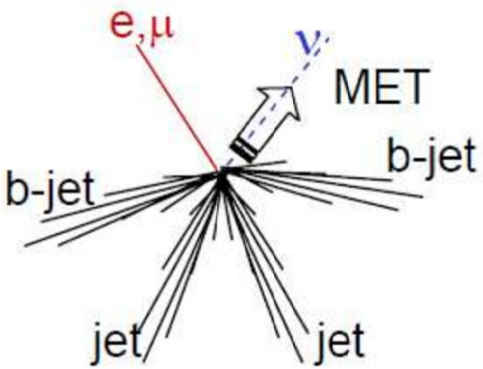
> Lepton

- From W-decays: Isolated, high-p_T
- Nr. leptons ≥ 1 or 2

> Can be used for trigger

> Additional lepton based cuts

- Veto add. leptons: *l*+jets channel
- QCD or Z-veto: dilepton channel



lepton + jets

> Jets

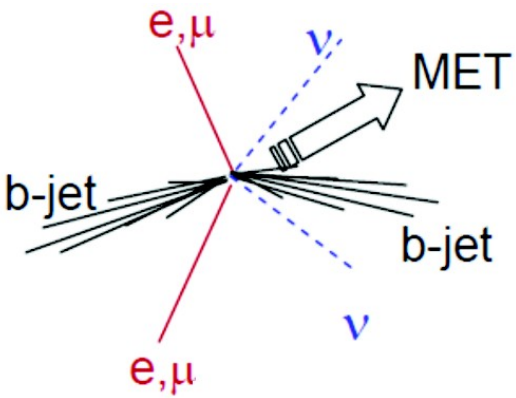
- Anti-k_T (R=0.5)
- Nr. jets ≥ 2-4

> Useful for triggering single lepton events

> Missing Transverse Energy

- Required more often in dilepton events

Dilepton



> b-Jets

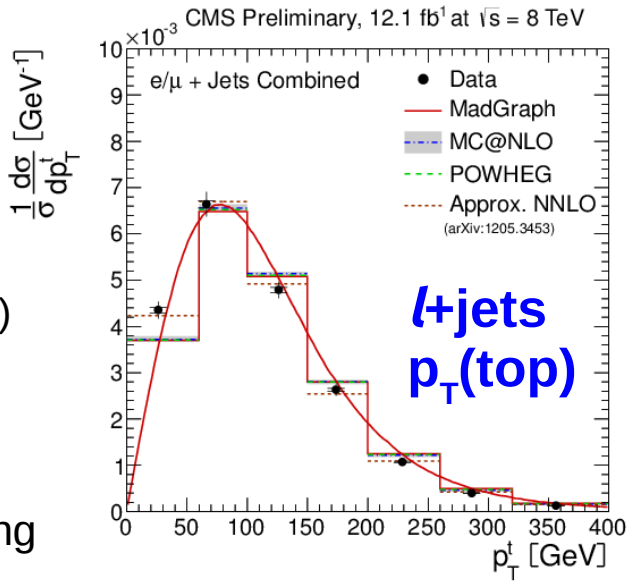
- Nr. jets ≥ 1-2

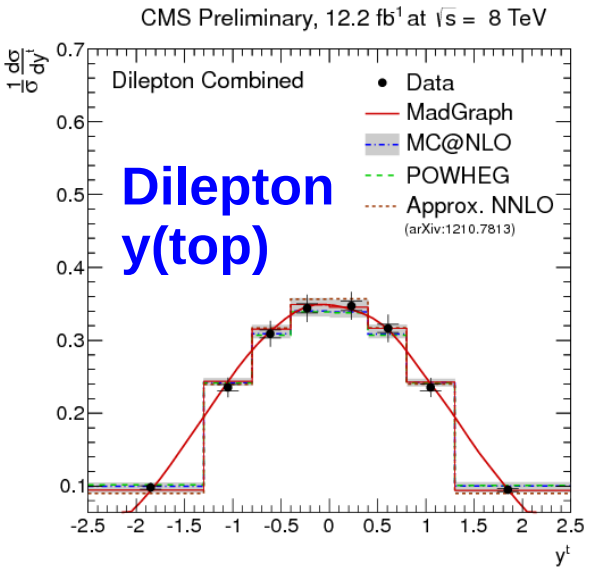
> Using secondary vertex and tracking information

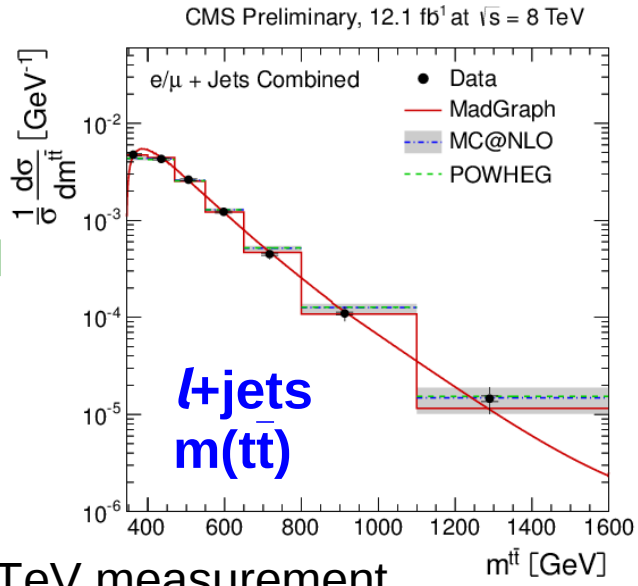
$t\bar{t}$ Differential Cross Section

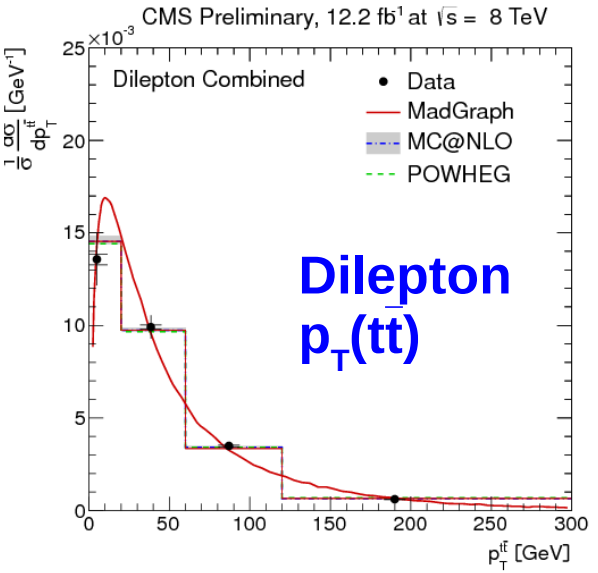
PAS-TOP-12-027 (link)
PAS-TOP-12-028 (link)

- Results compared to
  - MadGraph+Pythia
  - Powheg+Pythia
  - MC@NLO+Herwig
  - Approx. NNLO (arXiv:1210.7813)
- Typical syst. precision ~5-10%
  - Main uncertainty: signal modeling
- **Compatible results** in *l*+jets and dilepton channels
- **Good description by SM predictions**
  - p_T^t better described by Approx. NNLO prediction
- Results in agreement with 7 TeV measurement **EPJ C73 (2013) 2339**









Global Event Variables

PAS-TOP-12-042 (link)

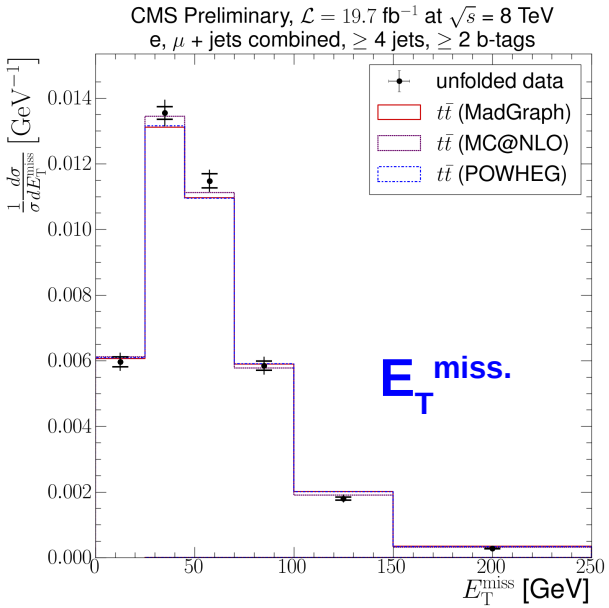
- Check simulation $t\bar{t}$ modeling
- Typical systematic precision: 2-15%
  - Main sources $t\bar{t}$ model and JES

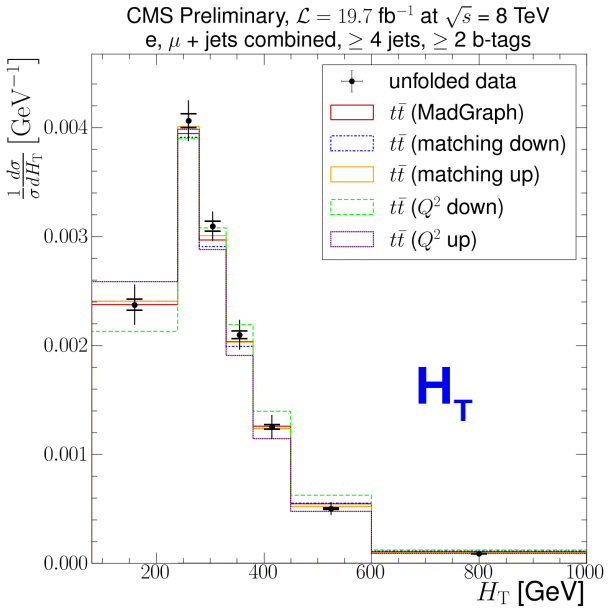
$$H_T = \sum_{all\ jets} p_T^{jet}$$

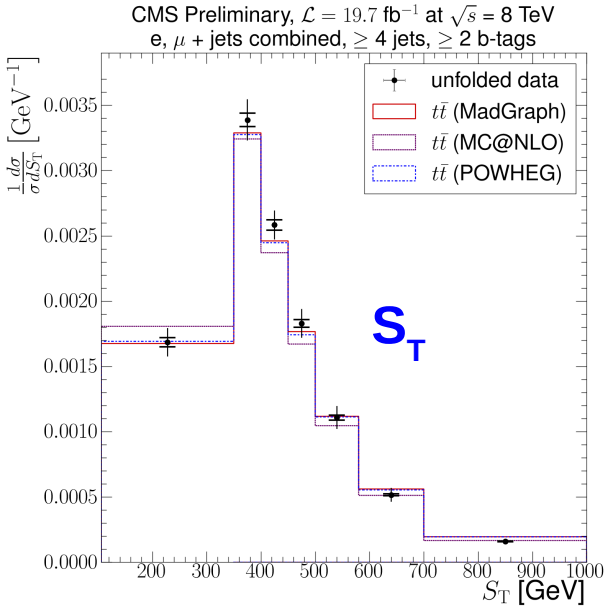
$$S_T = H_T + E_T^{miss.} + p_T^{lep}$$

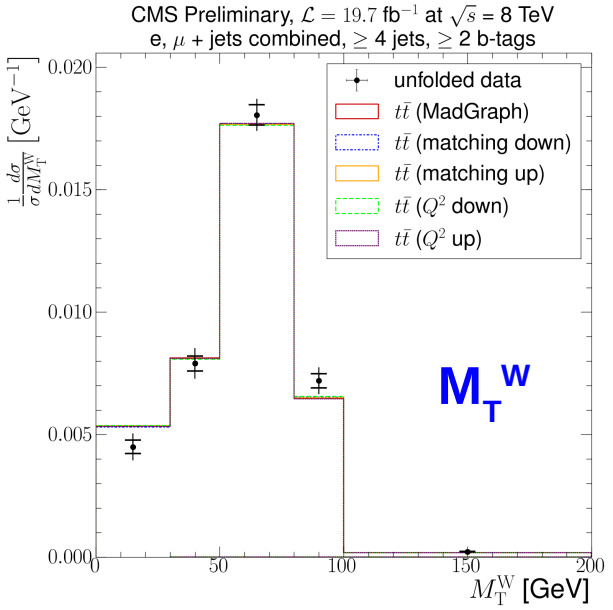
$$M_T^W = \sqrt{2 \cdot p_T^{lep} \cdot E_T^{miss.} \cdot (1 - \cos\Delta\phi^{l,\nu})}$$

- Results **well described by SM predictions**









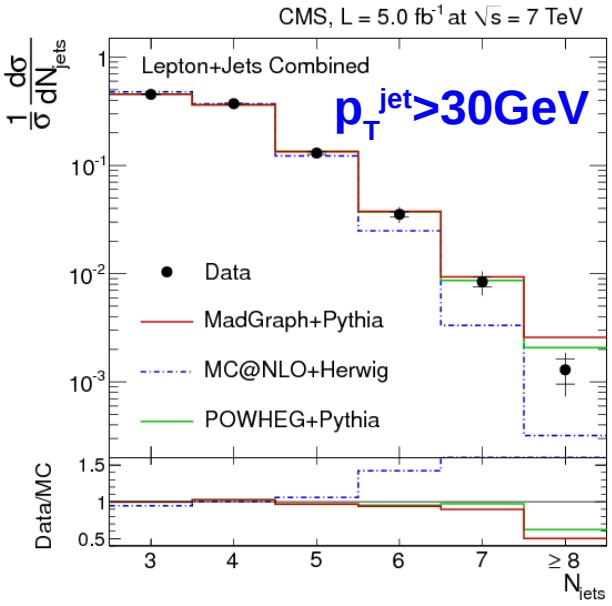
$t\bar{t}$+Jets (7 TeV)

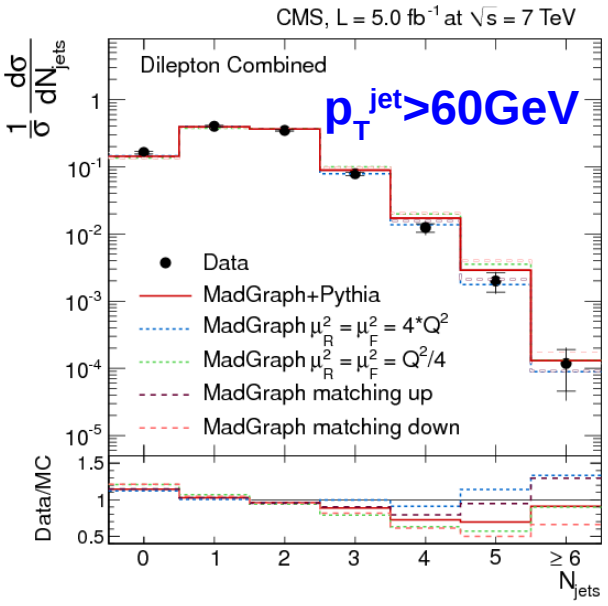
arXiv:1404.3171

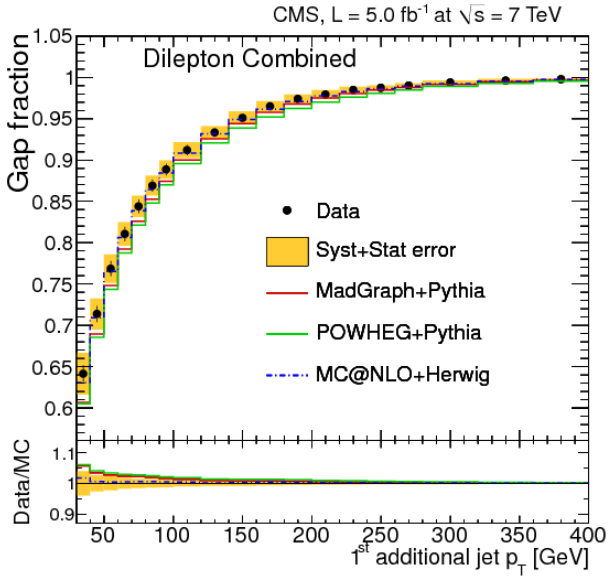
- Useful to understand radiation modeling of MC
- Results compared to
  - MadGraph+Pythia including Q^2 and ME-PS variations
  - Powheg+Pythia
  - MC@NLO+Herwig
- Main syst. uncertainty: JES and signal modeling
  - Jet Multiplicity: 3-30%
  - Gap Fraction: 0.2-3.5%

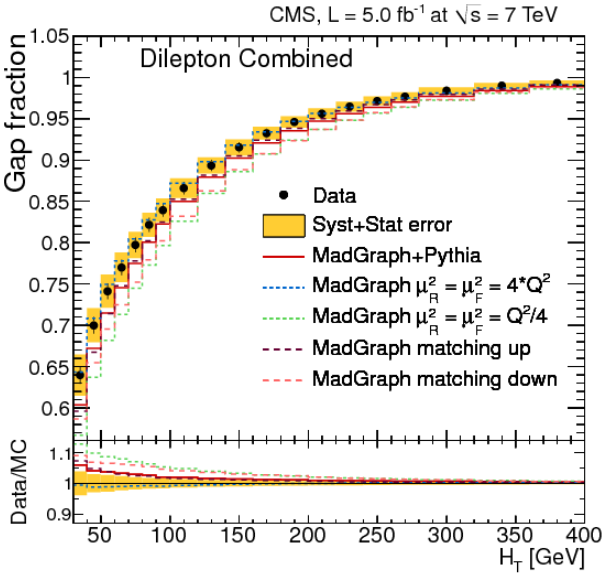
$$Gap\ Frac.(X) = \frac{N_{evts.}(X < X^{thres.})}{N_{all\ evts.}}$$

$$H_T = \sum_{add.\ jets} p_T^{jet}$$









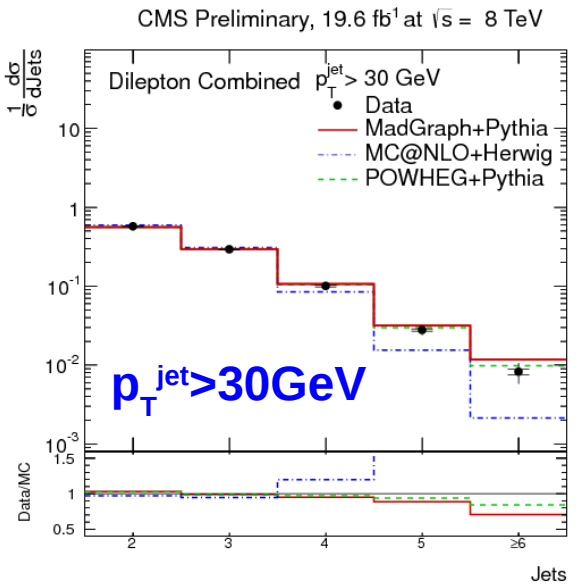
$t\bar{t}$+Jets (8 TeV)

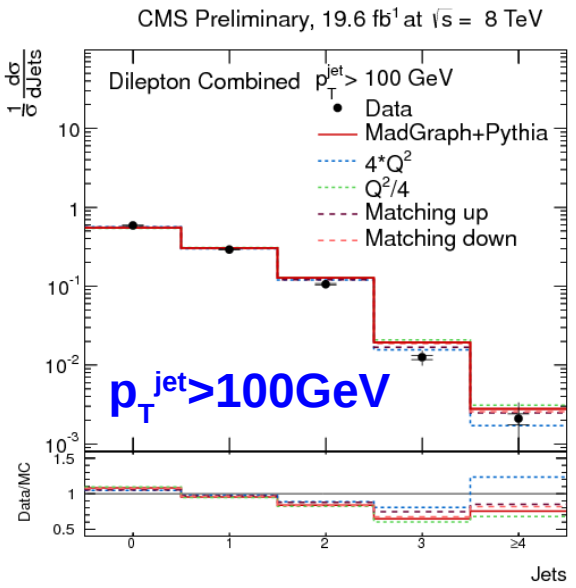
PAS-TOP-12-041 (link)

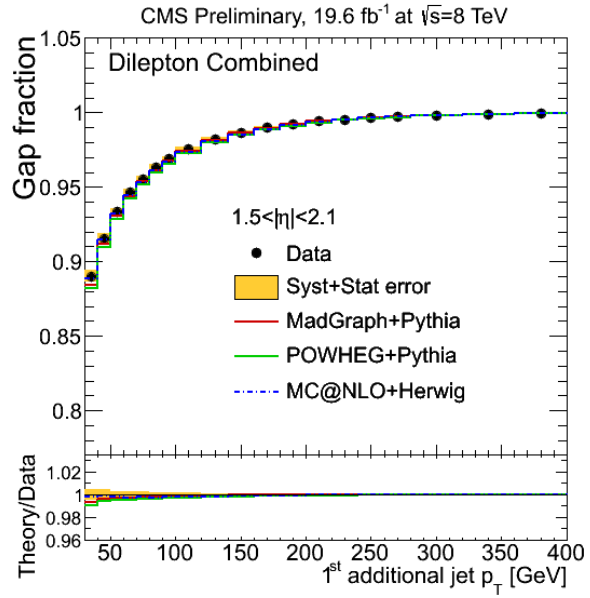
- Extend results...
  - … to higher p_T^{jet} thresholds
  - ... in $|\eta^{jet}|$ bins
- Dominant systematics: JES and signal modeling
- Total systematic precision
  - Diff. Cross Section: 3-20%
  - Gap Fraction: 0.2-3%

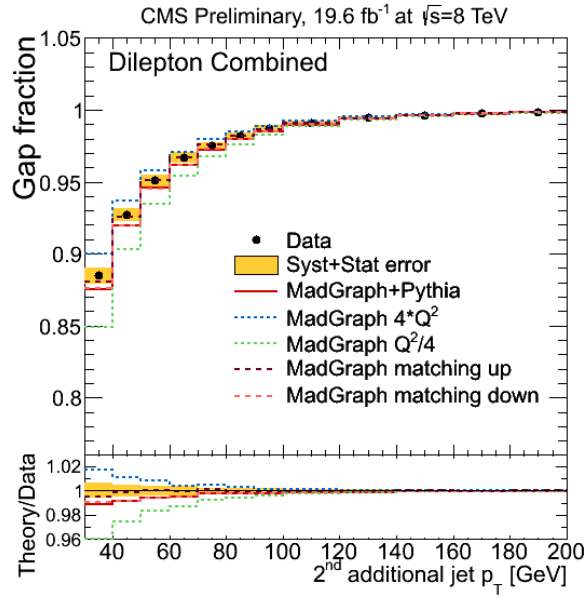
$$Gap\,Frac.(X) = \frac{N_{evts.}(X < X^{thres.})}{N_{all\,evts.}}$$

- **Consistent results with 7 TeV measurement**





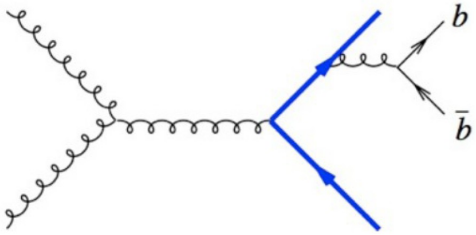


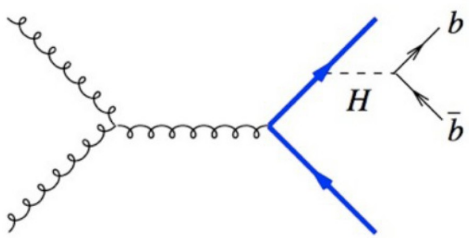


$t\bar{t}+b\bar{b}$ / $t\bar{t}+jj$ (8 TeV)

PAS-TOP-13-010 (link)

- Comparison with NLO QCD calculations
- $t\bar{t}+b\bar{b}$ irreducible background in $t\bar{t}H(b\bar{b})$ events



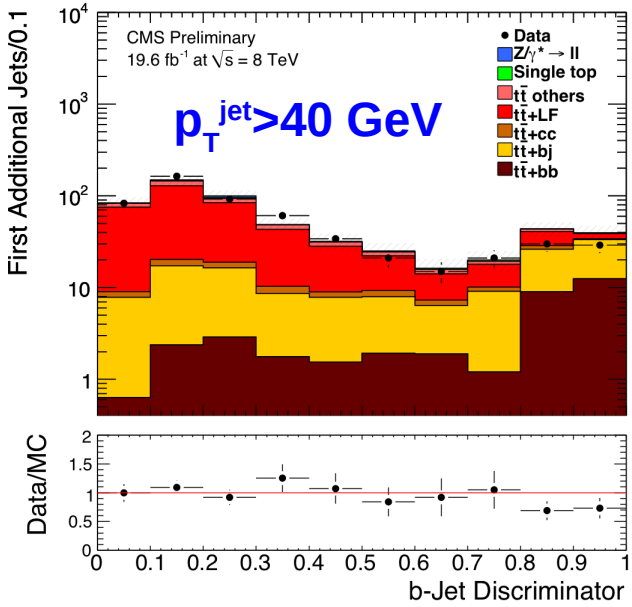


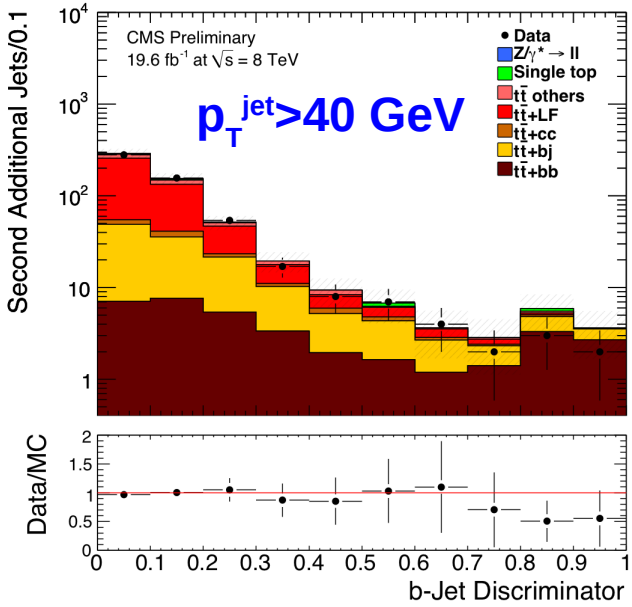
- $t\bar{t}$ dilepton events with at least 4 jets and 2 b-jets
- Total systematic uncertainty: ~23%
  - Main sources: b-tagging, Q^2-scale

$$R=\frac{\sigma\left(t\bar{t}+b\bar{b}\right)}{\sigma\left(t\bar{t}+jj\right)}$$

$$R\left(p_T^{jet}>40\text{GeV}\right)=0.022\pm0.004\left(stat\right)\pm0.005\left(syst.\right)$$

NLO prediction arXiv:1403.2046 $\longrightarrow$ $R=0.011\pm0.003$



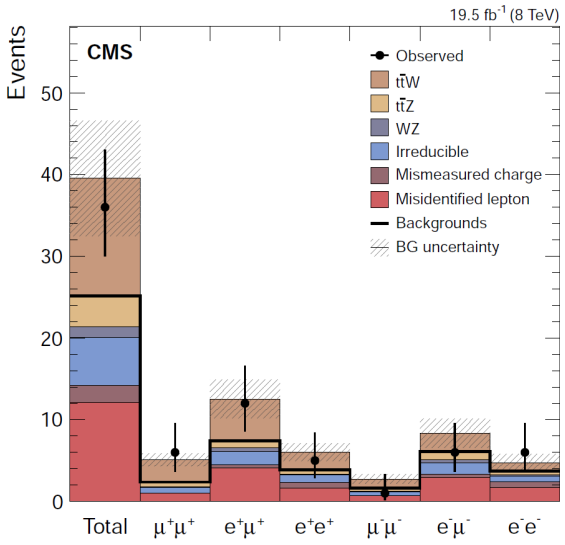


$t\bar{t}$+W/Z (8 TeV)

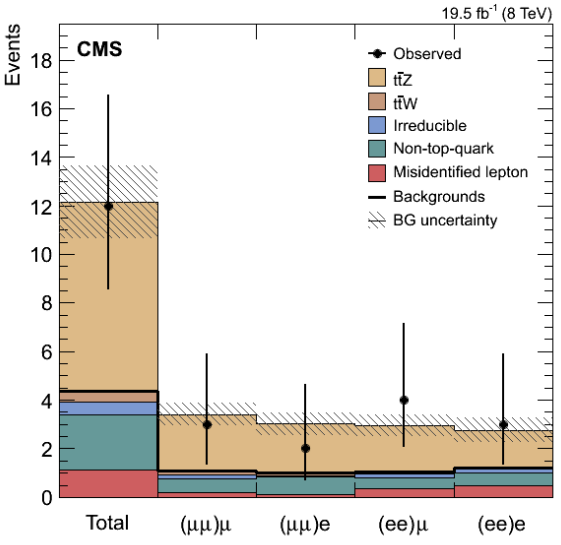
arXiv:1406.7830

- $t\bar{t}$+W/Z are rare SM processes
- Study $t\bar{t}$ in association with additional leptons
- **Same-sign dilepton** analysis $t\bar{t}$+W
- **Trilepton** and **Four-lepton** analysis for $t\bar{t}$+Z process

$t\bar{t}$+W Dilepton



$t\bar{t}$+Z Trilepton



- Dominant uncertainty lepton identification

- **Results in agreement with SM predictions**

Results

Channels used	Process	Cross section	Significance
2ℓ	$t\bar{t}W$	170^{+90}_{-80} (stat) $\pm$ 70 (syst) fb	1.6
3ℓ+4ℓ	$t\bar{t}Z$	200^{+80}_{-70} (stat)$^{+40}_{-30}$ (syst) fb	3.1
2ℓ+3ℓ+4ℓ	$t\bar{t}W + t\bar{t}Z$	380^{+100}_{-90} (stat)$^{+80}_{-70}$ (syst) fb	3.7

SM predictions

$\sigma(t\bar{t}W) = 206^{+21}_{-23}\,fb.$ arXiv:1204.5678

$\sigma(t\bar{t}Z) = 197^{+22}_{-25}\,fb.$ arXiv:1208.2665

$t\bar{t}+\gamma$ (8 TeV)

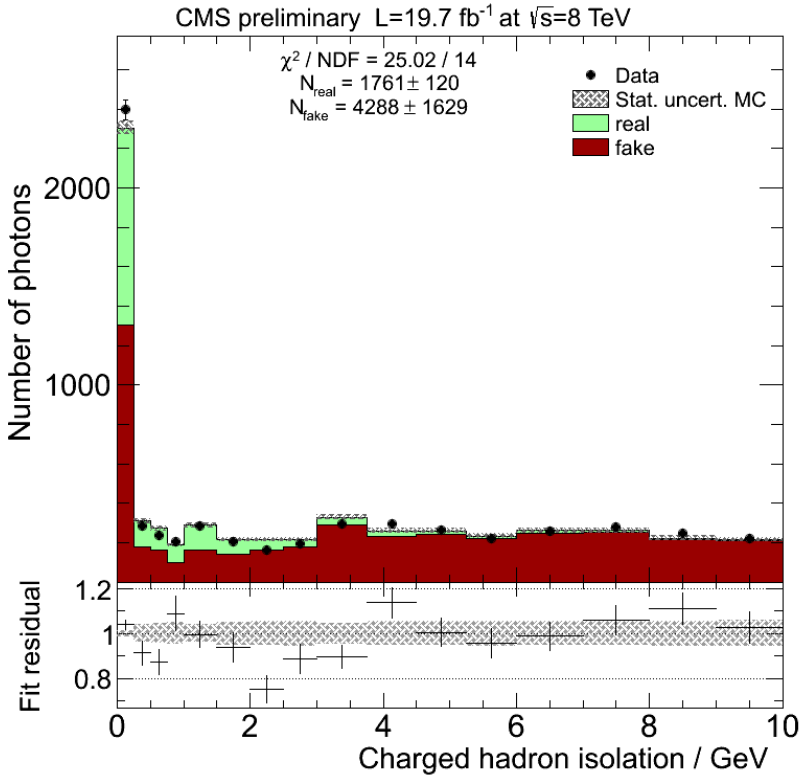
PAS-TOP-13-011 (link)

- $t\gamma$ -coupling can be studied via $\sigma(t\bar{t}+\gamma)$
- Template fit of charged hadron isolation variable in *μ+jets* events
  - Discriminate between real and misidentified photons
- Main uncertainty background modeling
- Results

$$\frac{\sigma(t\bar{t}+\gamma)}{\sigma(t\bar{t})}=(1.07\pm0.07(stat.)\pm0.27(syst.))\times10^{-2}$$

- Using $\sigma_{CMS}(t\bar{t})=227\pm15$ *pb.*
  (CMS-PAS-TOP-12-006)

$$\sigma(t\bar{t}+\gamma)=2.4\pm0.2(stat.)\pm0.6(syst.)\,pb.$$



- In **agreement with SM prediction** (arXiv:1102.1967)

$$\sigma(t\bar{t}+\gamma)=1.8\pm0.5\,pb.$$

Summary

- Top quark physics: key to QCD, EWK and new physics
- $t\bar{t}$ differential cross section measurements
  - Constrain SM
  - Ideal probe for looking for new physics
- First cross section measurements of $t\bar{t}$ accompanied by $b\bar{b}$, W, Z and γ production
- Current results systematically limited
- Gaining sensitivity to model differences

All results are in agreement with SM predictions

Most up-to-date CMS top-quark results can be found in
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsTOP