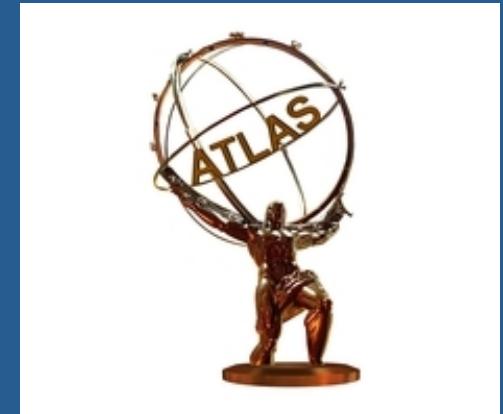
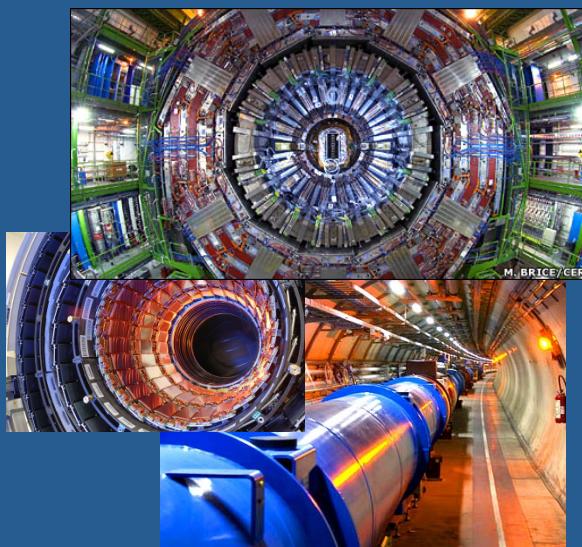
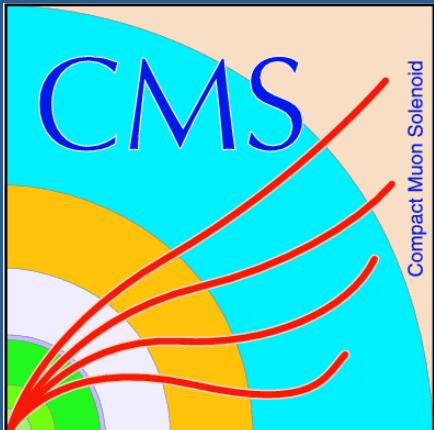


Studies of Top-Quark Production at the LHC

Chris Neu
University of Virginia

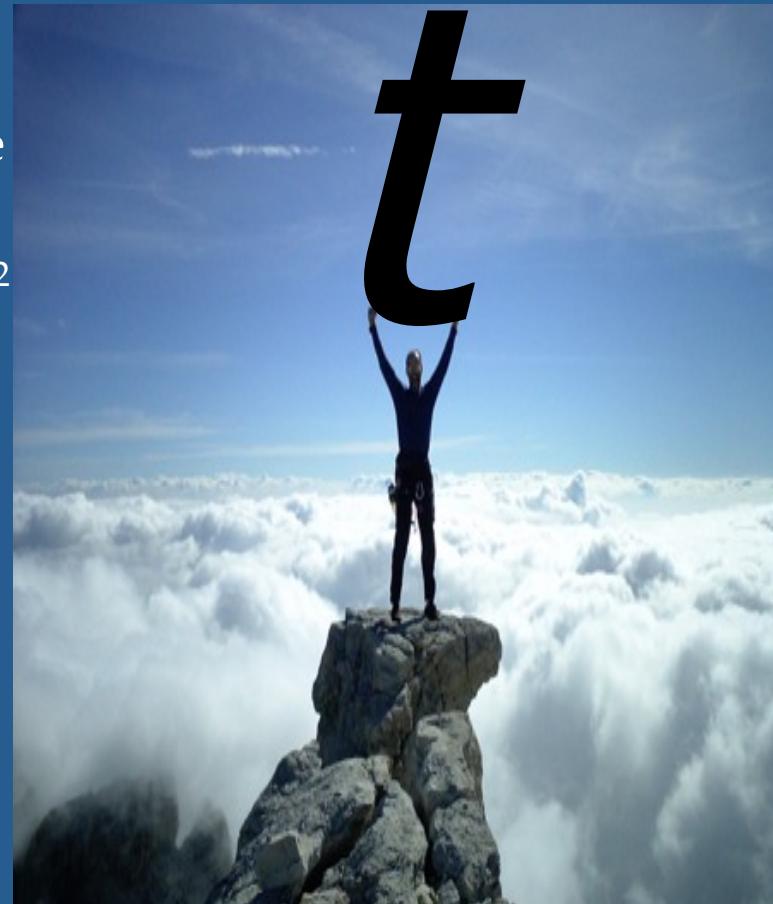


Chicago 2012 Workshop on LHC Physics
2 May 2012



Motivation

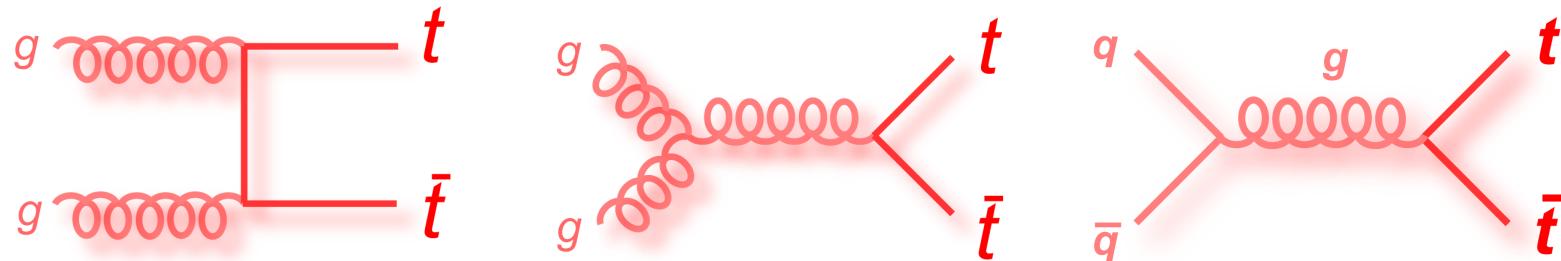
- Top-quark physics is a crucial component of the LHC program:
 - Access to fundamental parameters of the SM (m_t , V_{tb})
 - Exceptionally large mass: $m_t \sim 173 \text{ GeV}/c^2$ ($\sim 35^* m_b$, $\sim 2^* M_Z$)
 - Large mass \rightarrow large Higgs coupling
 - Large mass could indicate special role in EWSB in alternatives to Higgs Mechanism
 - Decays very rapidly – glimpse of free quark (studies of spin, charge, etc.)
 - Many signatures of NP share the same signature – or contain tops themselves
 - Hints from Tevatron of top-quark production as window to new physics



Opportunities!
Here mostly focus on 2012

Top-Quark Production

Top-quark pair production:

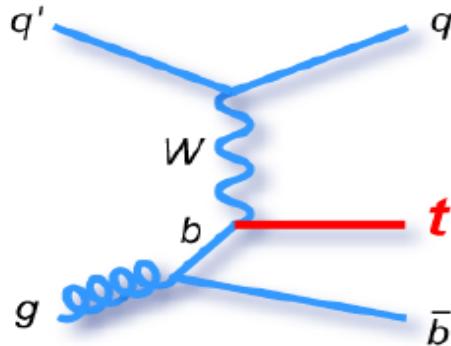


$$\sigma(7 \text{ TeV}) = 158 \pm 24 \text{ pb} @ \text{NLO (MCFM)}$$

- approximate NNLO calculations exist
- Expect $\sigma(8 \text{ TeV}) = \sim 1.5 * \sigma(7 \text{ TeV})$

Quigg: arXiv:1101.3201v2 [hep-ph]

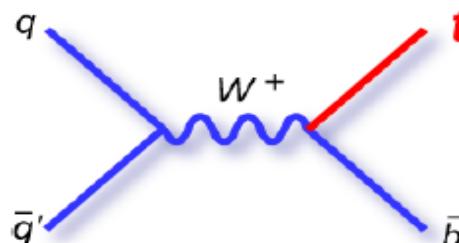
Single top production:



t-channel

$$\sigma(7 \text{ TeV}) = 64 \pm 2.9 \text{ pb}$$

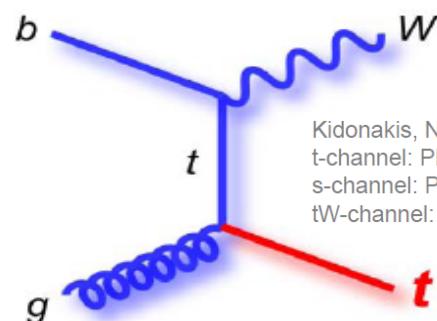
- Expect $\sigma(8) = \sim 1.3 * \sigma(7)$



s-channel

$$\sigma(7 \text{ TeV}) = 4.6 \pm 0.2 \text{ pb}$$

- Expect $\sigma(8) = \sim 1.15 * \sigma(7)$



tW-channel

$$\sigma(7 \text{ TeV}) = 15.6 \pm 0.9 \text{ pb}$$

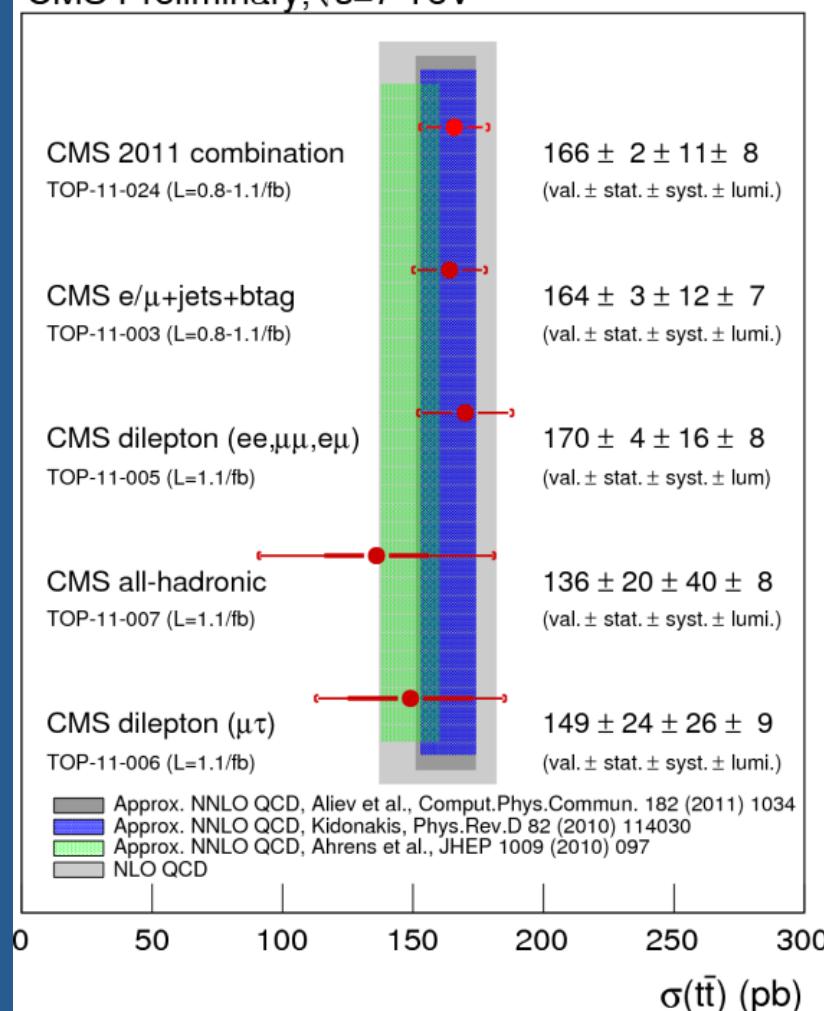
- Expect $\sigma(8) = \sim 1.3 * \sigma(7)$

Kidonakis, NLO+NNLL
t-channel: PRD 83 (2011) 091503
s-channel: PRD 81 (2010) 054028
tW-channel: PRD 82 (2010) 054018

Top-Quark Pair Production: Where Are We?

CMS Preliminary, $\sqrt{s}=7$ TeV

[CMS-TOP-11-024](#)



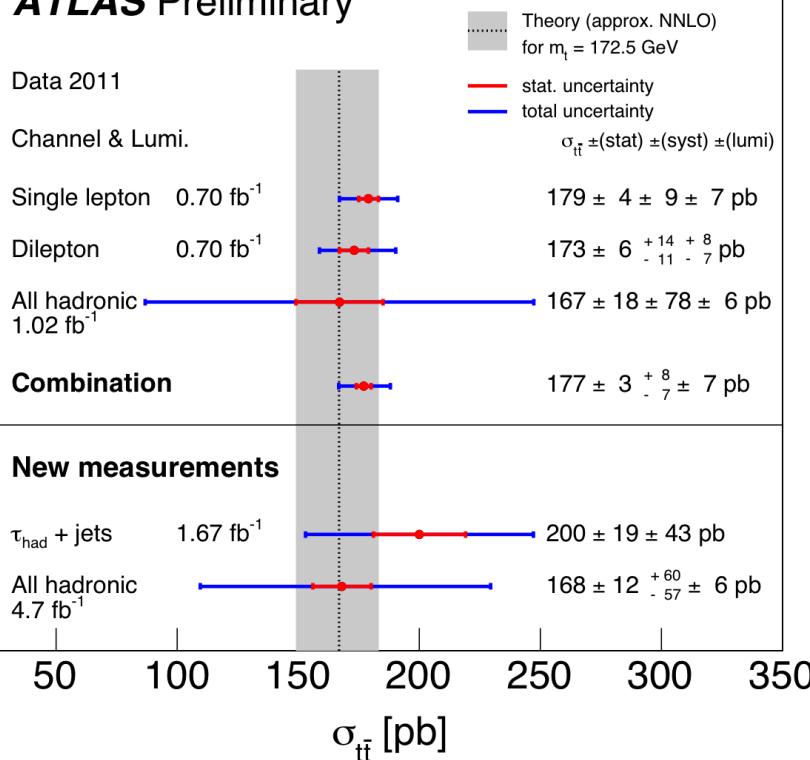
Updates:

- Recently updated tau-dilepton results
see [arXiv:1203.6810](https://arxiv.org/abs/1203.6810)
- New tau+jets result soon public

[Available here](#)

ATLAS Preliminary

19 March 2012

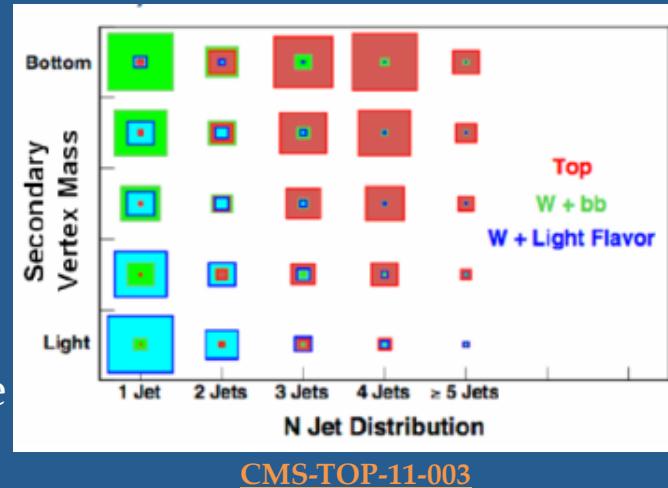


- **Channels:** categorized by W decays
 - e/μ/τ + jets (BR = ~44%)
 - e/μ/τ dilepton (10%, all covered except ττ)
 - all-hadronic (46%)
- **Precision:** 5-9% relative, systs dominated
 - **Best channel:** single lepton e/μ+jets

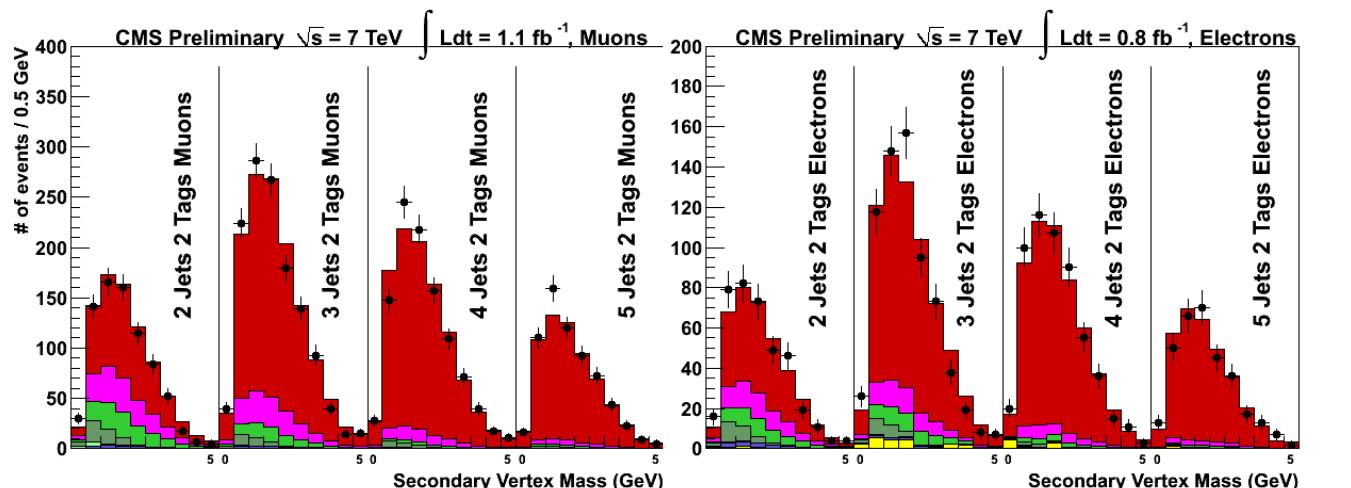


One Analysis: Result and Limitations

- CMS reference result in the $e/\mu+jets$ channel:
 - Profile likelihood fit in 3D: N_{jets} , N_{tags} , M_{vert}
 - Several systematic uncertainties treated as nuisance parameters in fit:
 - JES, b tag efficiency, LF tag efficiency, Q^2 scale in background modeling, etc.
 - Several syst uncertainties not profiled:
 - signal modeling (Q^2 , ME-to-PS matching, PDFs, PU reweighting)
 - these uncertainties dominate ultimate result



$$\sigma(t\bar{t}) = 164.4 \pm 2.8 \text{ (stat)} \\ \pm 11.9 \text{ (syst)} \\ \pm 7.4 \text{ (lum) pb}$$



How can we increase the precision of this and other results in 2012 and beyond?

Inclusive ttbar Cross Section in 2012

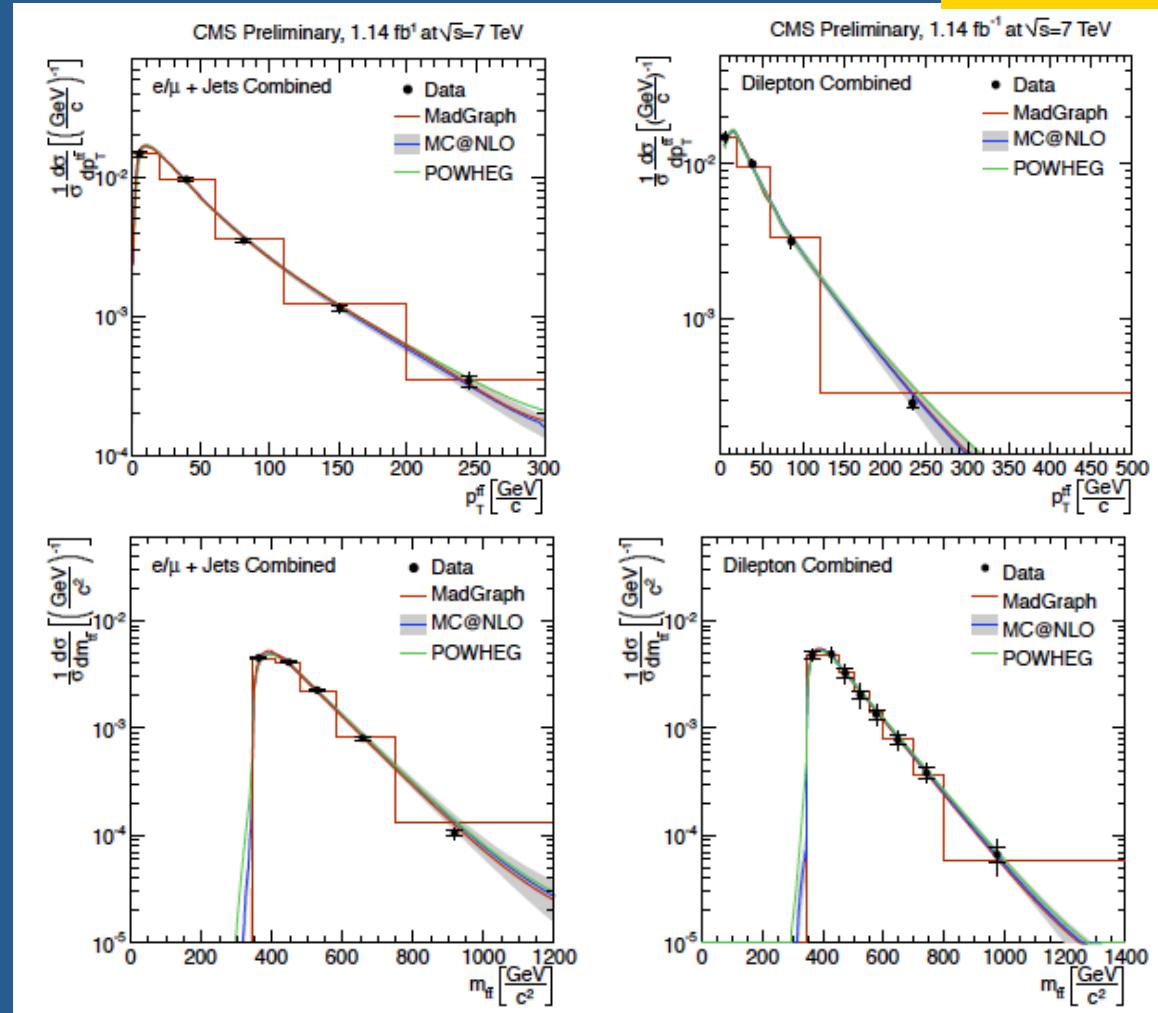
- Impact of 2012 run:
 - New measurements at 8 TeV: further tests of pQCD
 - 8 TeV running implies x1.5 increase in production cross section over 7 TeV
 - Potentially x3-4 increase in integrated luminosity
 - Statistics are not an issue however!
 - Higher instantaneous luminosity
 - Relatively insensitive to PU (< 1% relative effect) but we are entering uncharted territory
 - New deliverable: $R_{87} = \sigma(\text{tt}, 8 \text{ TeV}) / \sigma(\text{tt}, 7 \text{ TeV})$
 - Meaningful from a theoretical standpoint:
 - Do we understand pQCD as root(s) and root(s_hat) evolve?
 - Can benefit from cancellation of correlated uncertainties. Examples:
 - Same modeling of signal, hence effect of scale, matching, etc., are completely correlated in 8 and 7 TeV measurements
 - Luminosity measurement executed in the same manner, hence uncertainties are completely correlated



Differential ttbar Cross Section

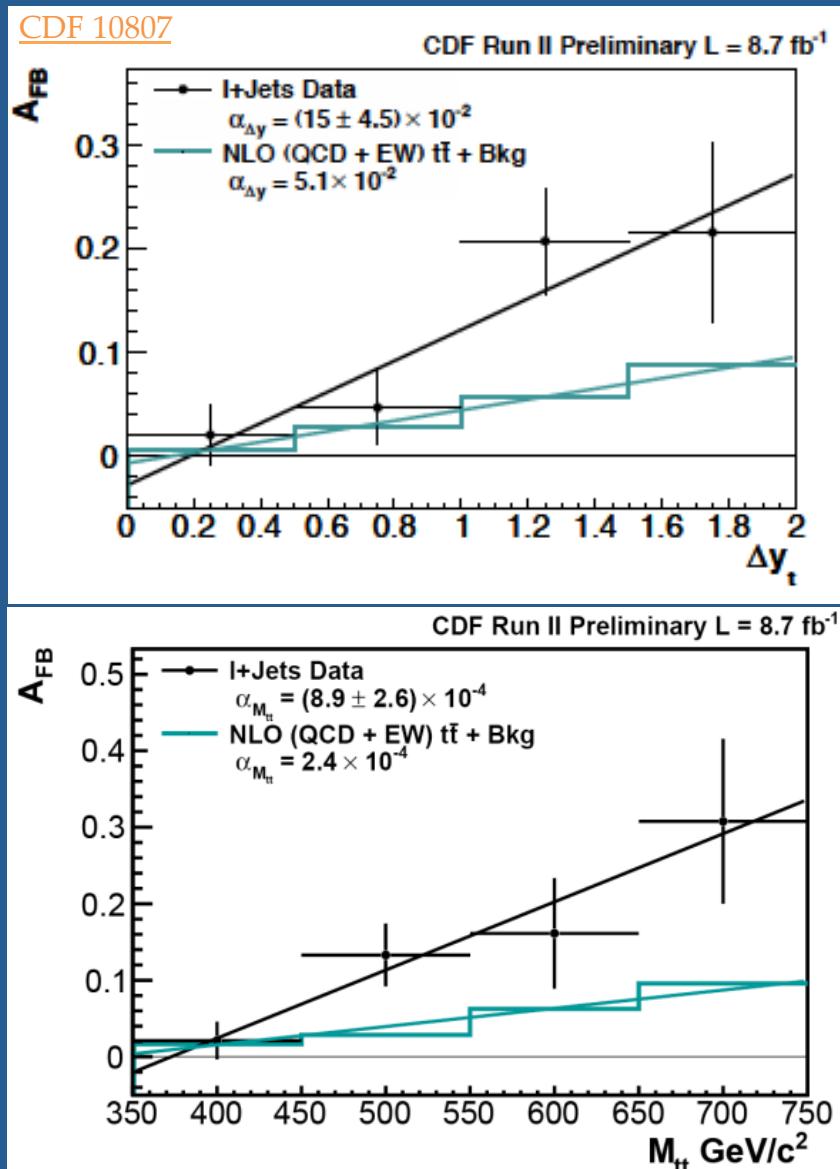
- High statistics relatively pure ttbar samples allow differential production cross section measurements – further tests of pQCD
[CMS-TOP-11-013](#)
- Probe of NP in top sector
 - NP could be “obvious” eg., M_{tt} resonance searches OR
 - NP could be subtle, affecting kinematics of ttbar production at higher order
- 2011: e/ μ +jets and dilepton channels:
 - Follow same selection as incl. analyses
 - Unfolded to parton level
 - Shape analyses
 - Main systs: btag, Q^2 , matching
- 2012 and beyond:
increased statistics help us

General good agreement



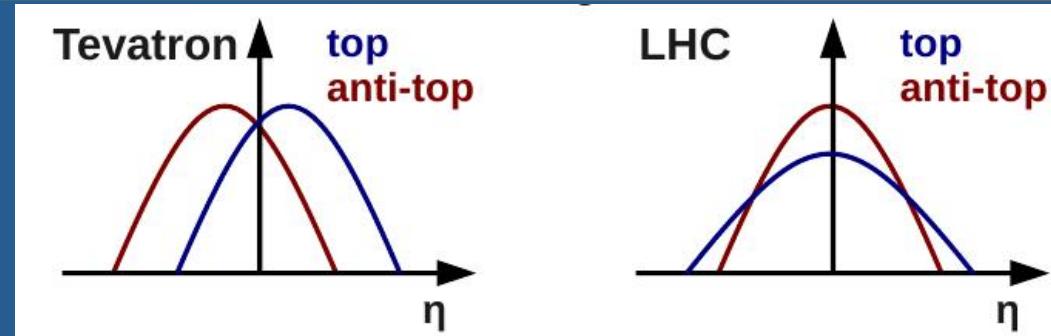
Charge Asymmetry in ttbar Production

- Many searches for NP conducted at CMS and ATLAS in 2010-11
 - Important exclusions, some hints, no discoveries (yet)
 - Not a disappointment: this is just the nature of our business
- However, indications from Tevatron of something interesting in top sector:
Forward-Backward Asymmetry
 - Enhancement at large M_{tt}
 - Could be a Z' , axigluon, others?
- Could such a hint of new dynamics come from similar studies at the LHC?
 - Promising – though less sexy – pursuit of NP through precision measurement



Charge Asymmetry in ttbar Production

- It's a challenging measurement at the Tevatron – moreso at the LHC
 - no preferred direction for t or tbar
 - effect is there but much more subtle



- Manifests as a diluted charge asymmetry:

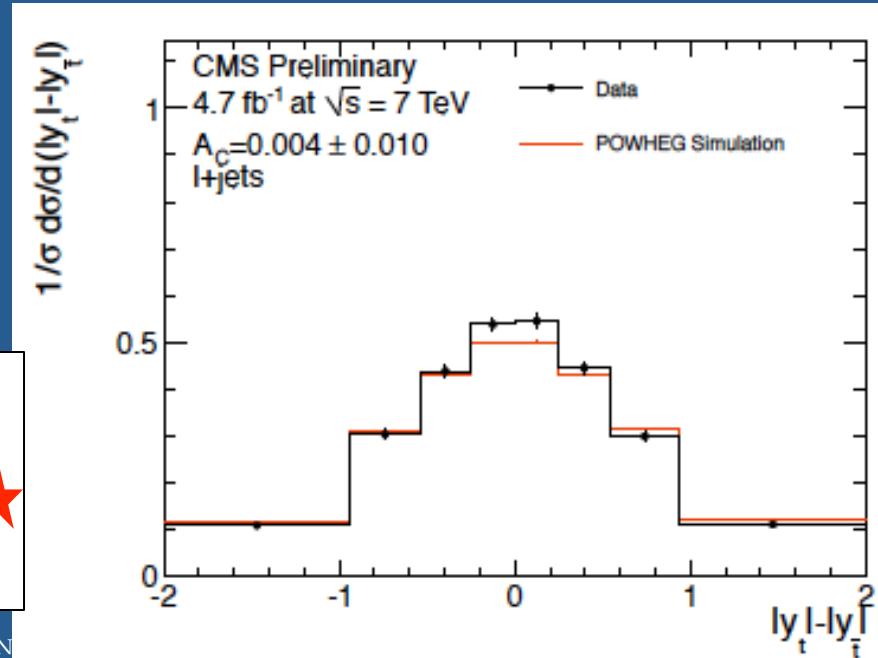
$$\Delta|y| = |y_t| - |y_{\bar{t}}| \rightarrow \begin{aligned} & -\Delta y > 0 \text{ implies } t\bar{t} \text{ more central than } t \\ & -\Delta y > 0 \text{ implies } t\bar{t} \text{ more forward than } t \end{aligned}$$

[CMS-TOP-11-030](#)

$$A_C = \frac{N(\Delta y > 0) - N(\Delta y < 0)}{N(\Delta y > 0) + N(\Delta y < 0)}$$

- Use l+jets events – t/tbar from l \pm charge
 - W mass constraint for p_z^W
 - Resolve ambiguities in combinatorics

Uncorrected	$0.003 \pm 0.004 \text{ (stat.)}$
BG-subtracted	$0.001 \pm 0.005 \text{ (stat.)}$
Final corrected	$0.004 \pm 0.010 \text{ (stat.)} \pm 0.012 \text{ (syst.)}$ ★
Theory prediction (SM)	0.0115 ± 0.0006



Main systs: unfolding, W+jets bkgd

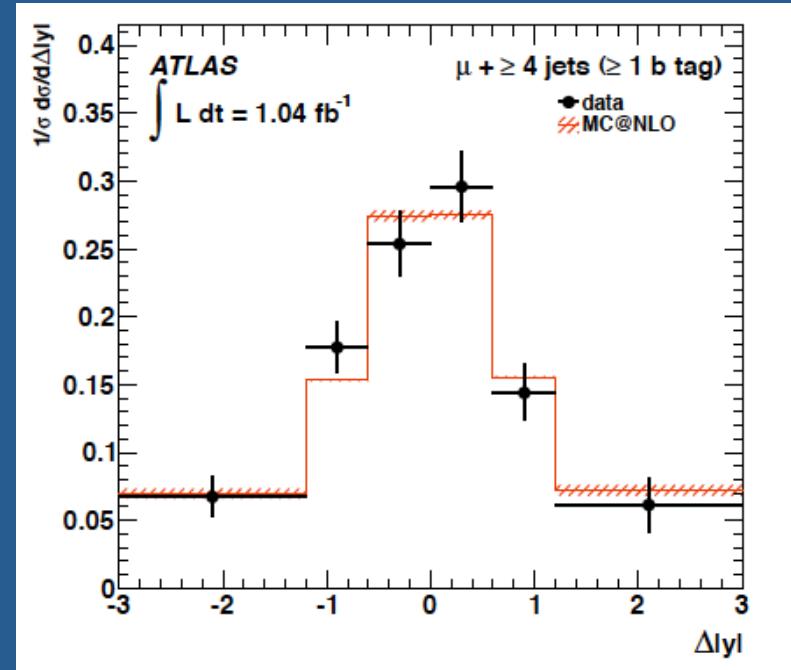
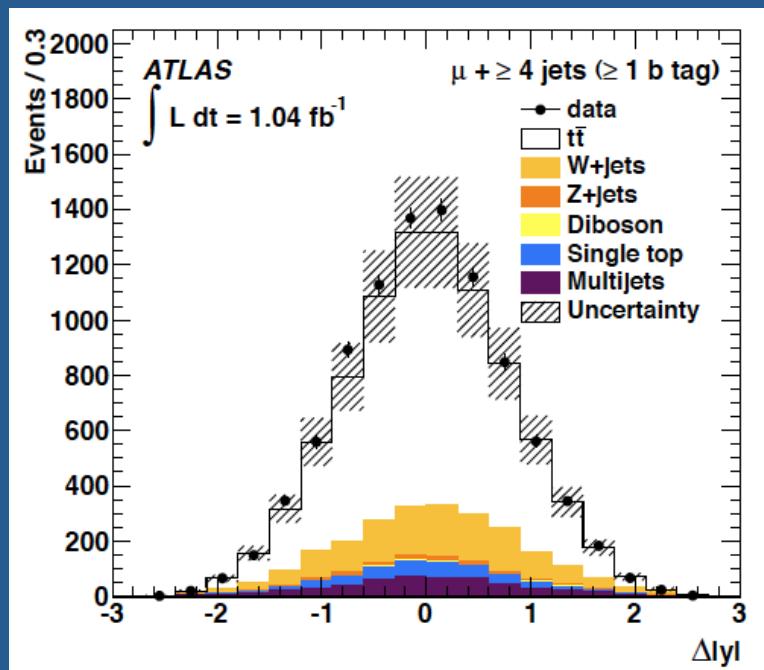


Christopher N

Charge Asymmetry in ttbar Production

ATLAS 1/fb results: see [arXiv:1203.4211v1](https://arxiv.org/abs/1203.4211v1)

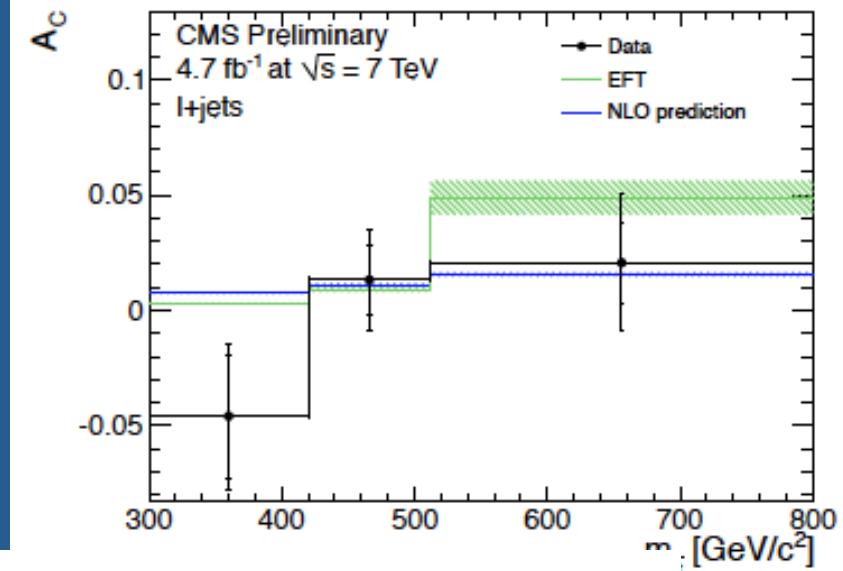
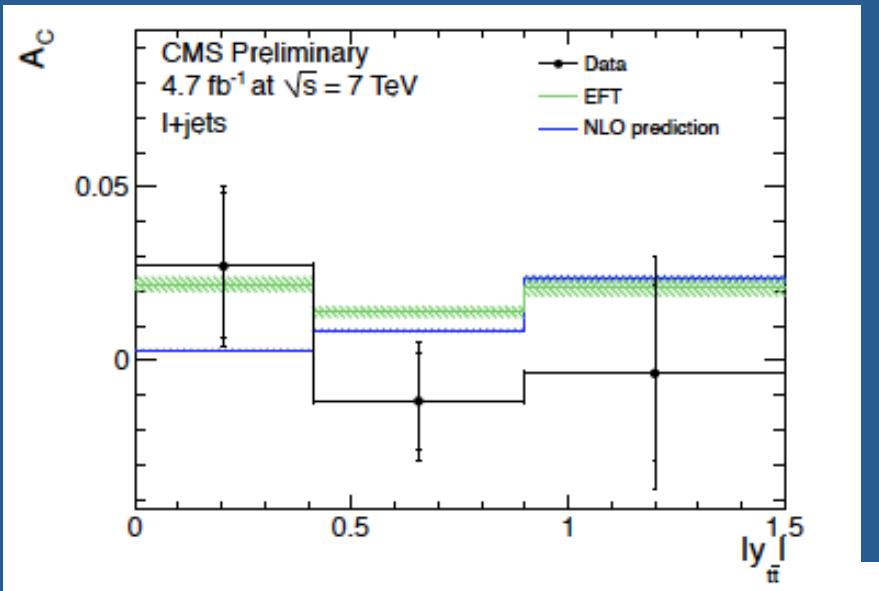
- e/mu+jets combined
- main systs: generator, fragmentation, ISR/FSR, JES



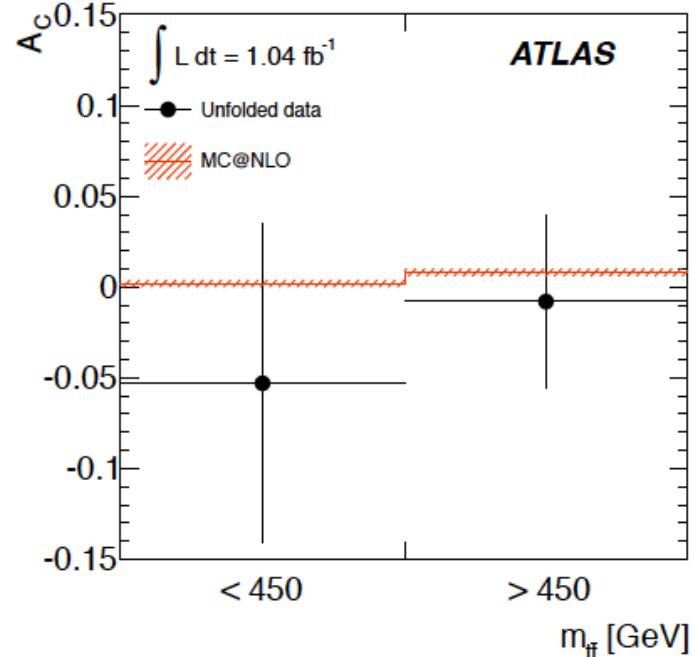
$$A_C = -0.018 \pm 0.028 \text{ (stat)} \pm 0.023 \text{ (syst)}$$

$$\text{MC@NLO prediction: } A_C = -0.006 \pm 0.002$$

Charge Asymmetry in ttbar Production

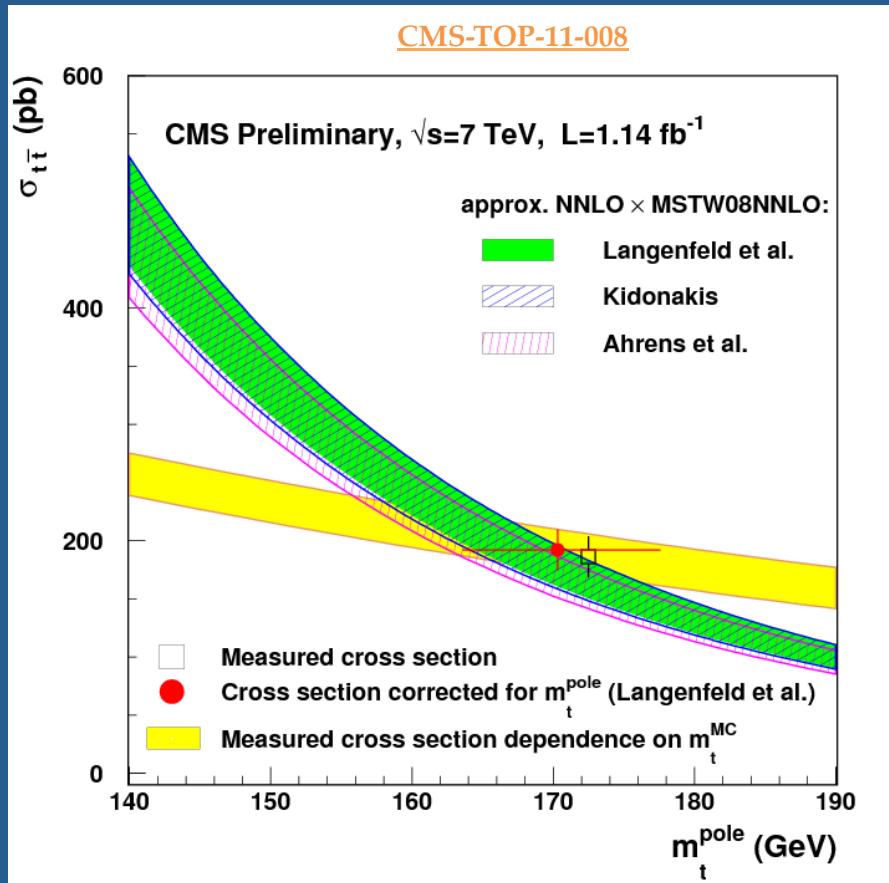


- In many new physics scenarios the asymmetry depends on phase space
 - High mass/p_T regimes enhance the quark annihilation part of the initial state
- 2012: higher statistics samples will help in terms of precision
- Difficult measurement but one we must push on



Top-Quark Pair Production: Other Measureables

- Top mass from cross section:
 - Use the dependence of $\sigma_{t\bar{t}}$ on m_t to infer the latter from the $\sigma_{t\bar{t}}$ measurement
 - Need full dependence of the acceptance of the analysis on m_t .
 - Theory uncertainties include scales, PDFs, $\alpha S(mZ)$
 - Extract both pole mass and MS mass
 - Extracted top mass not competitive with the direct determination



Approx. NNLO \times MSTW08NNLO	$m_t^{\text{pole}} / \text{GeV}$	$m_t^{\overline{\text{MS}}} / \text{GeV}$
Langenfeld et al. [7]	$170.3^{+7.3}_{-6.7}$	$163.1^{+6.8}_{-6.1}$
Kidonakis [8]	$170.0^{+7.6}_{-7.1}$	—
Ahrens et al. [9]	$167.6^{+7.6}_{-7.1}$	$159.8^{+7.3}_{-6.8}$

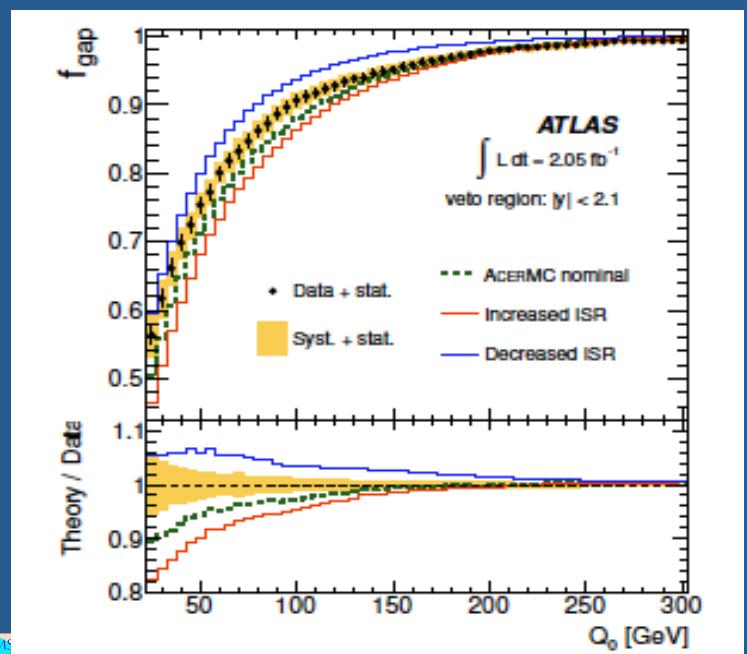
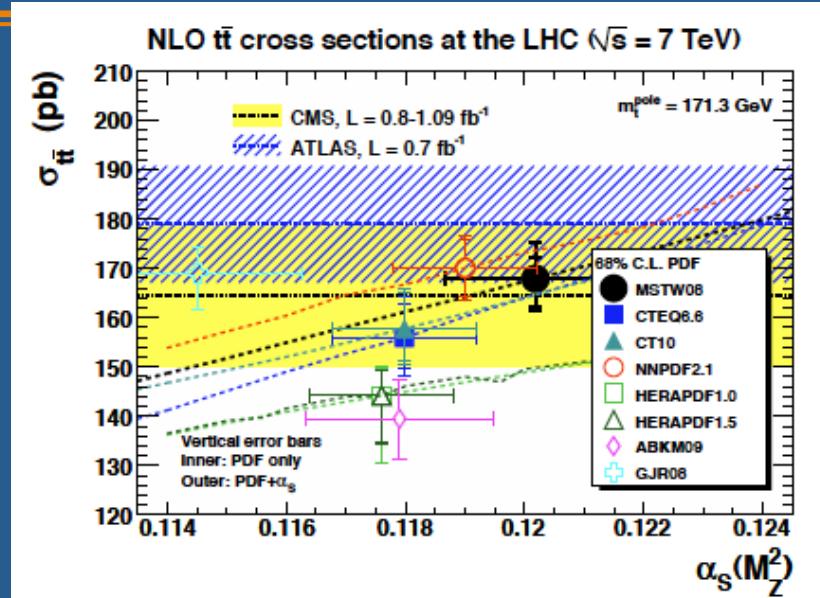
Top-Quark Pair Production: Other Measureables

- Use ttbar events for calibrating essential pieces:
 - Parton distribution functions:
 - ISR/FSR modeling:
 - ttbar+jets veto study

$$\text{Gap fraction: } f = \frac{n(Q_0)}{N}$$

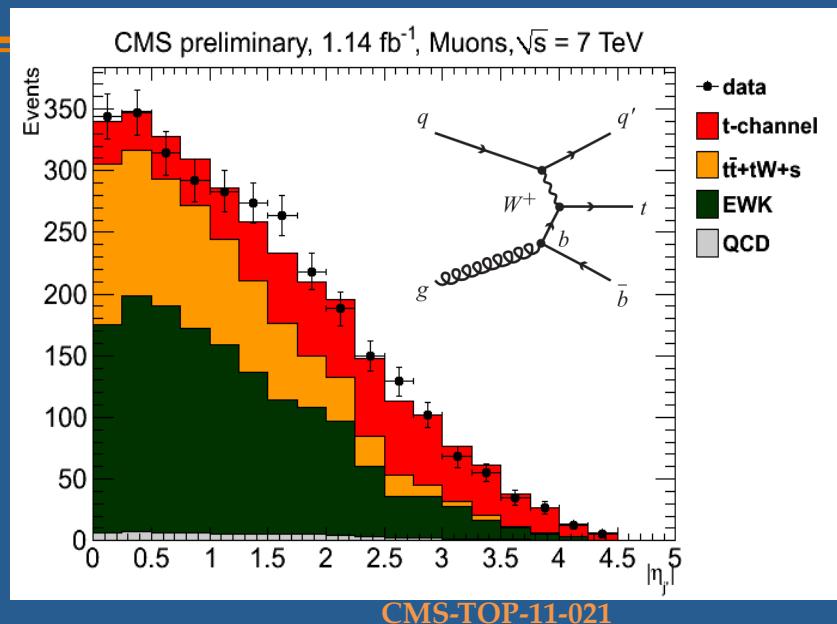
where $n(Q_0)$ is the number of events with no jet above threshold $p_t > Q_0$

Use such a study to constrain amount of radiation in the event!



Single Top Production: Where Are We?

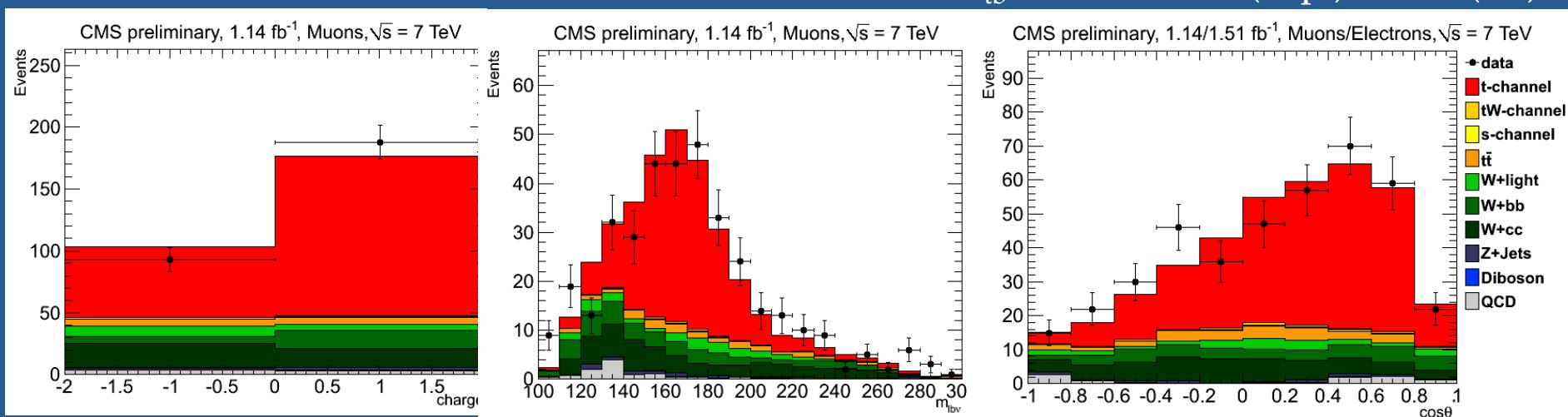
- CMS measurement of t-channel production:
 - Cross section extracted via fit in $|\eta_{\text{lep}}|$
 - All backgrounds taken from sideband data
 - Main systs: JES, bkgds from data-driven methods



[CMS-TOP-11-021](#)

$$\sigma_{t\text{-ch.}} = 70.2 \pm 5.2(\text{stat.}) \pm 10.4(\text{syst.}) \pm 3.4(\text{lumi.}) \text{ pb}$$

$$\rightarrow |V_{tb}| = 1.04 \pm 0.09(\text{exp.}) \pm 0.02 (\text{th.})$$

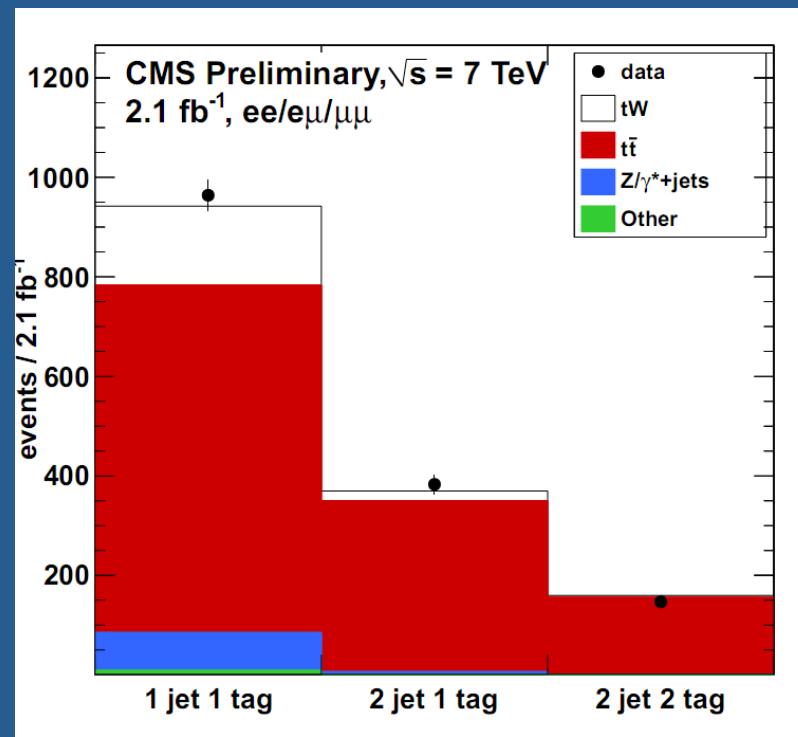
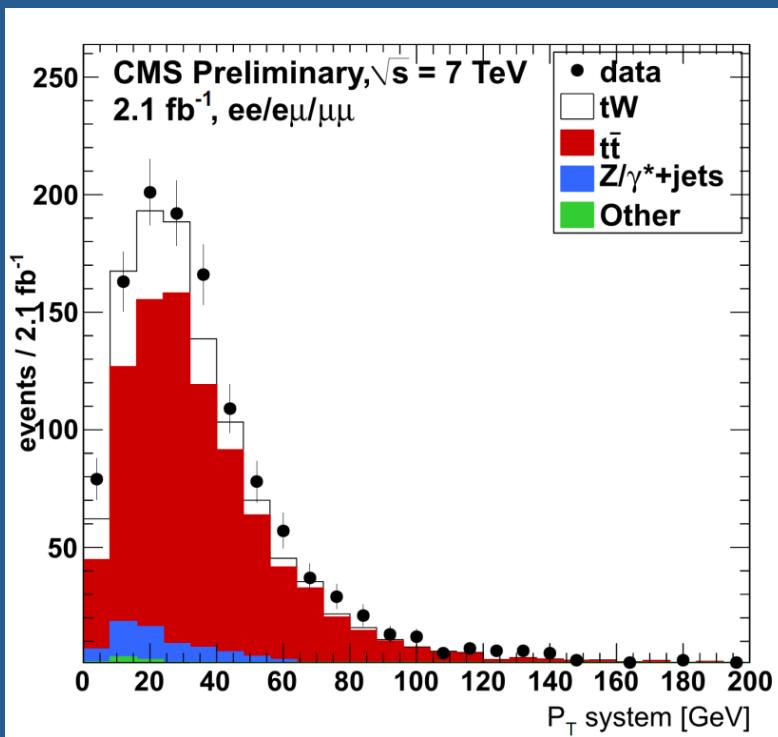
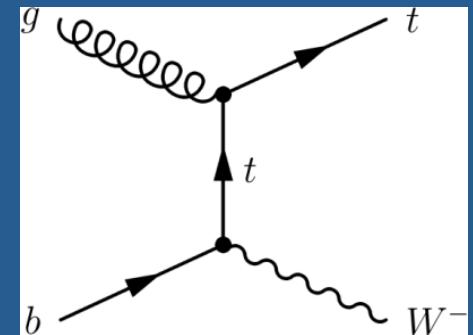


Single Top Production: Where Are We?

- tW channel: never before observed
 - Take care: at NLO interference from ttbar
 - Signature similar to dilepton ttbar channel
 - Just one b-jet

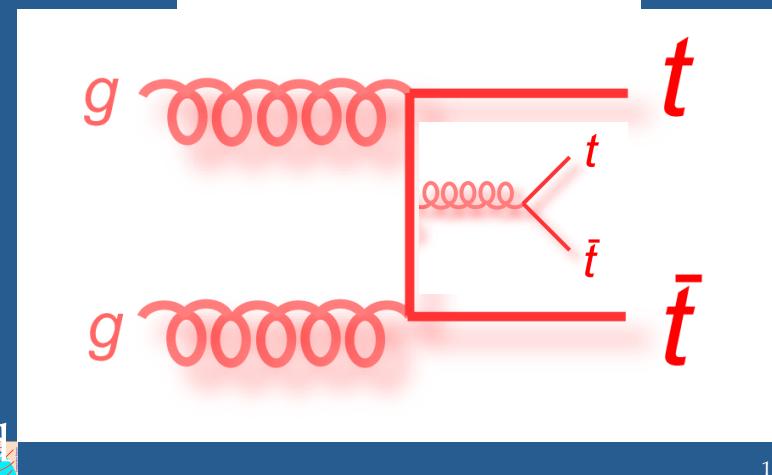
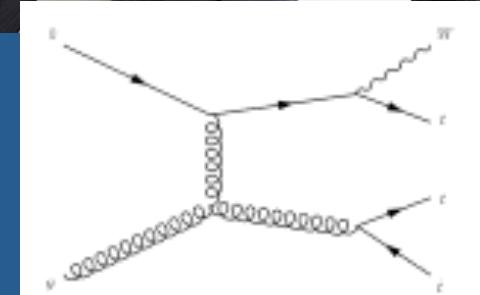
$$\sigma(tW) = 22^{+9}_{-7} \text{ (stat} \times \text{syst)}$$

[CMS-TOP-11-022](#)



Rare Processes

- High statistics samples in 2012 and beyond give us
 - Ability to perform precise measurements of rare-but-measured processes
 - s-channel single top (meas'd at CDF/D0)
 - ttbar+jets / ttbar + b-jets
 - ttbar + MET
 - ttbar + gamma
 - Access to yet-unmeasured processes:
 - ttbar+W/Z
 - SM three-top production (enhancements in MSSM) [arXiv:1001.0221](https://arxiv.org/abs/1001.0221)
 - SM four-top production (enhancements in several NP models) [arXiv:1101.1963](https://arxiv.org/abs/1101.1963), [arXiv:1112.3778](https://arxiv.org/abs/1112.3778), [arXiv:1107.4616](https://arxiv.org/abs/1107.4616), etc
- Ultimate testing grounds:
 - ttH will be crucial in the eventual understanding of a Higgs if one is found

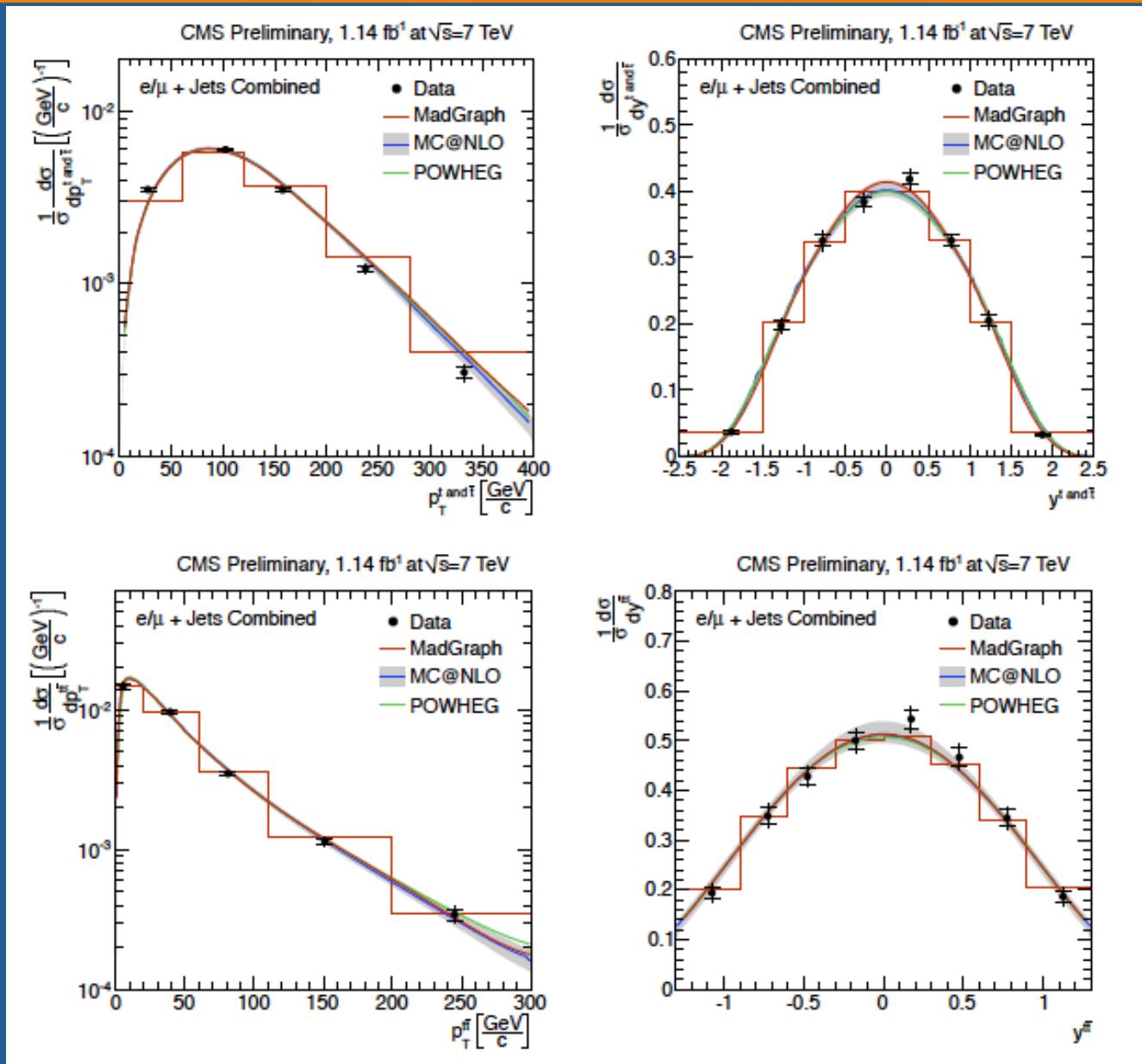


Summary and Outlook

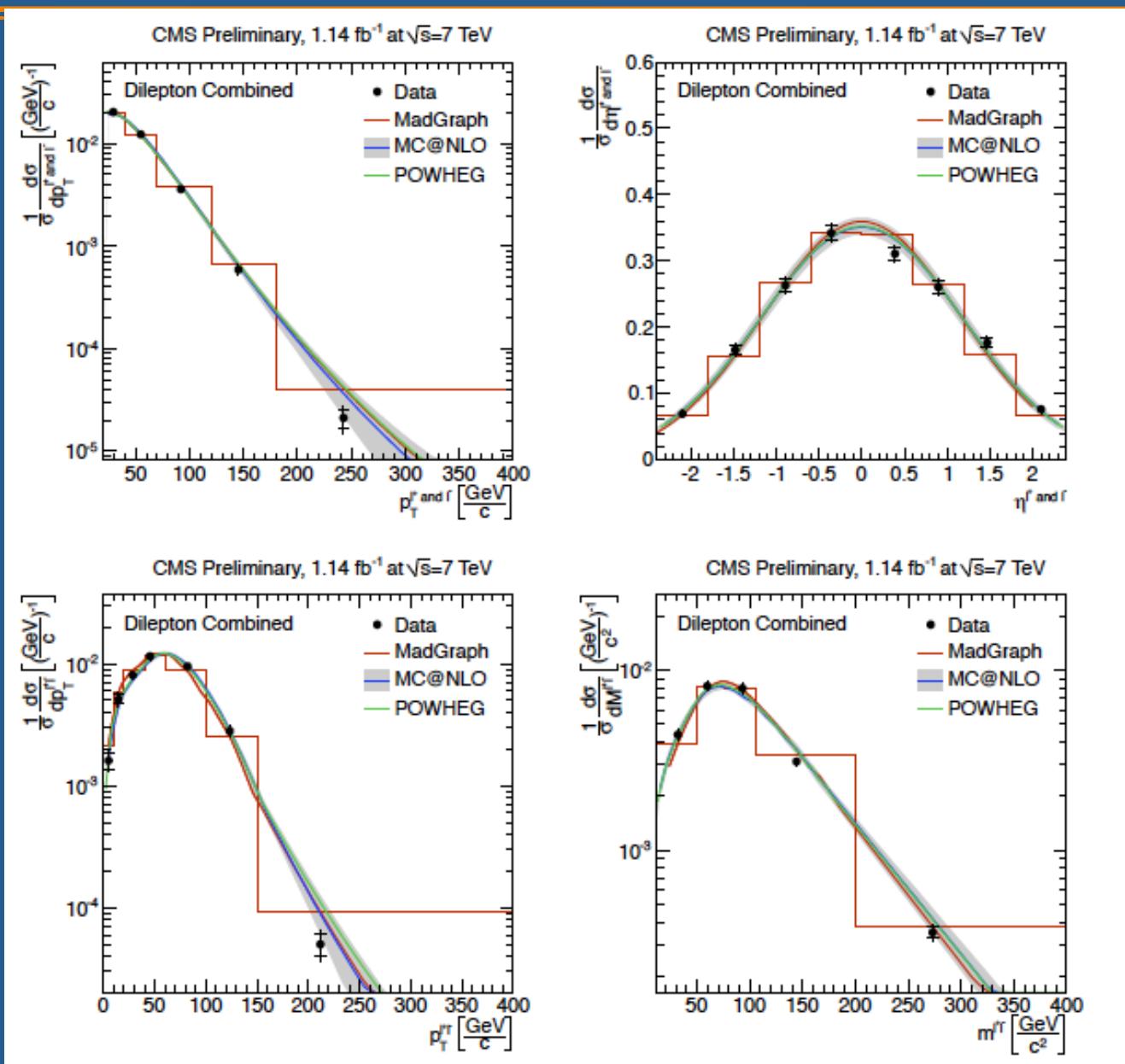
- Studies in the top-quark sector are a crucial component of the LHC physics program
- Near term future:
 - Precise, new measurements of the inclusive ttbar cross section
 - Differential cross sections of top-quark pairs
 - Exploration of the top-quark charge asymmetry – very important probe of possible new physics
- Many opportunities to contribute
 - Fundamental precision measurements
 - Exploration of uncharted territory
 - Unique measurements that further our SM and exotica programs
 - Important studies that could provide hints at new physics

Backup

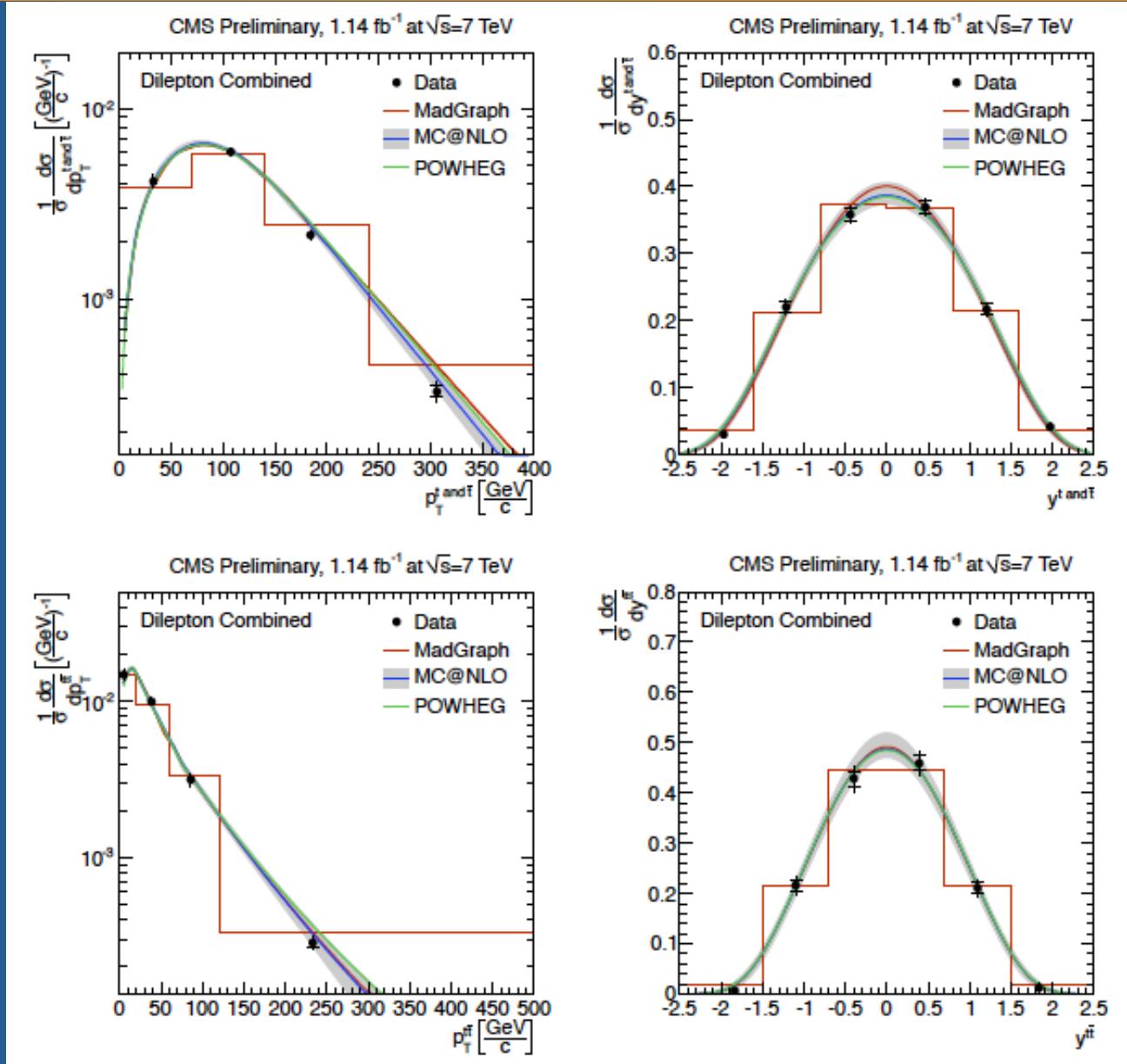
ttbar Differential Cross Section Results: l+jets



ttbar Differential Cross Section Results: dilepton



$t\bar{t}$ bar Differential Cross Section Results: dilepton



Charge Asymmetry: Tevatron Summary

