Top Physics

- a review of the results from the LHC and Tevatron experiments

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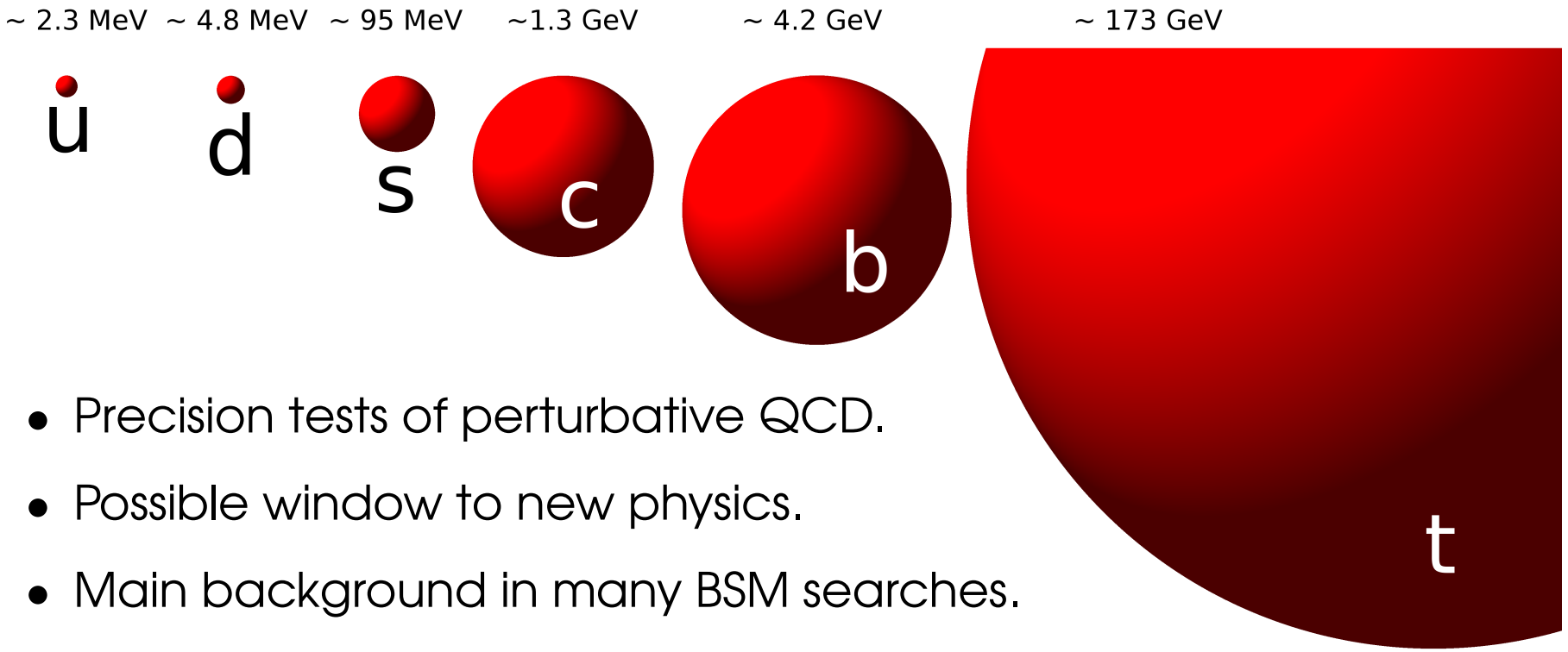
for the ATLAS, CDF, CMS and D0 collaborations

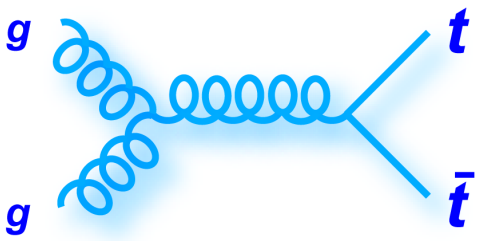
The top quark is special:

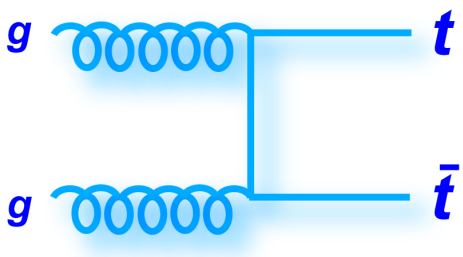
- Most massive elementary particle known to date. Special role in many theories beyond the Standard Model.
- Short-lived, so decays before hadronizing. Possible to study the properties of a bare quark.

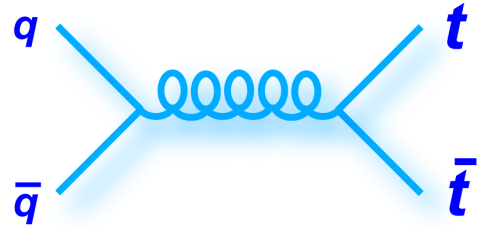


- Precision tests of perturbative QCD.
- Possible window to new physics.
- Main background in many BSM searches.

- Top pair production (through strong interaction):





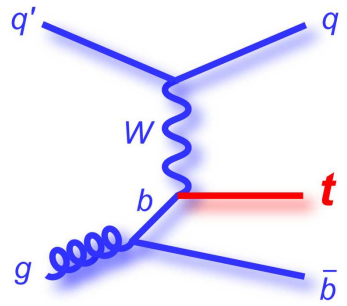


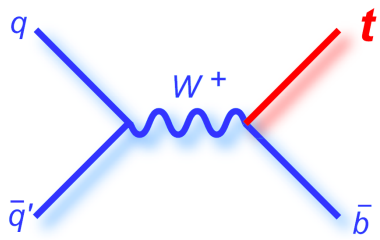
$\sim$ 85% at LHC

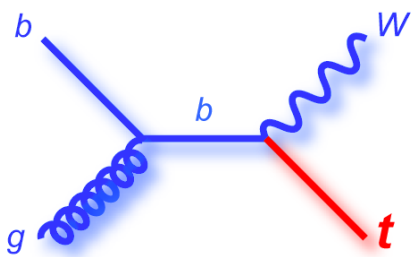
$\sim$ 85% at Tevatron

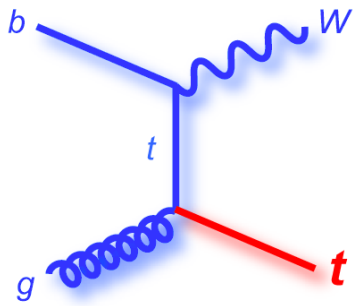
$\sim$ 7 pb @ Tevatron, $\sim$ 170 pb @ LHC 7TeV.

- Single top production (through electroweak interaction):









t-channel

2 pb @ Tevatron

65 pb @ LHC 7TeV

s-channel

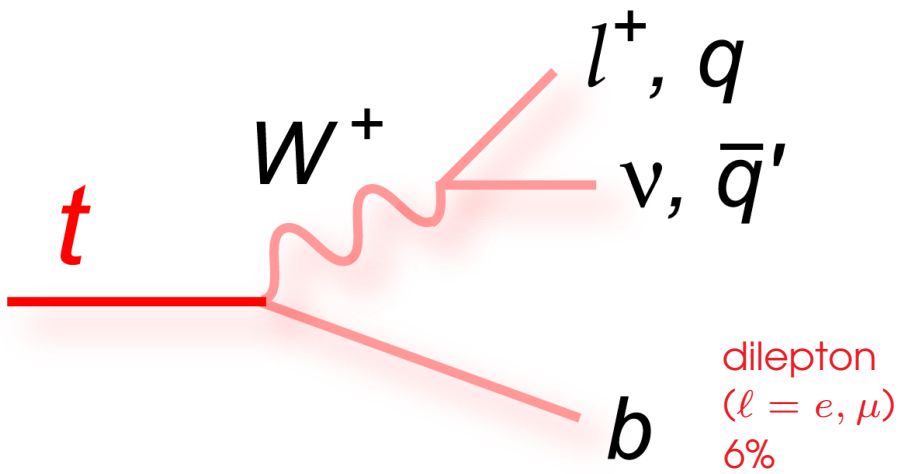
1 pb @ Tevatron

5 pb @ LHC 7TeV

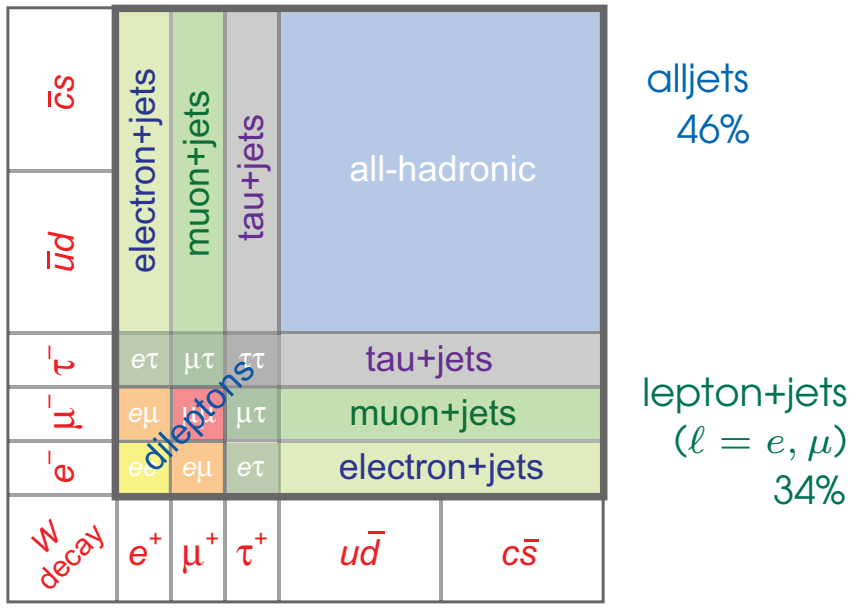
Wt-channel

0.3 pb @ Tevatron

16 pb @ LHC 7TeV



Top Pair Decay Channels

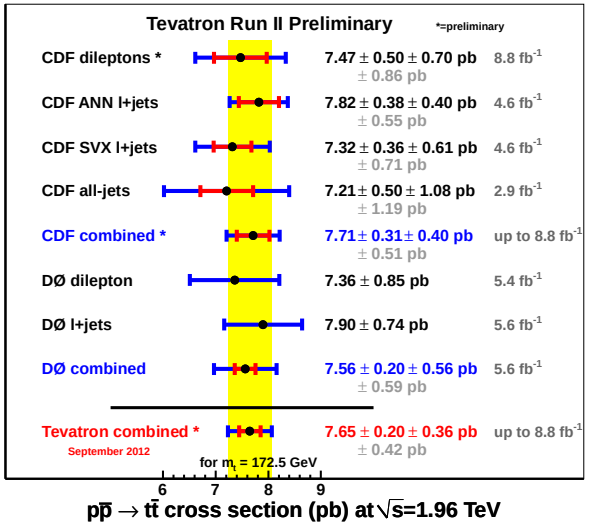


- The top quark decays almost exclusively to a W boson and a b quark.
- The W boson in turn decays hadronically (BR $\approx 70\%$) or leptonically (BR $\approx 30\%$).

- Alljets: Largest BR but also large backgrounds.
- Lepton+jets: Large BR and manageable backgrounds.
- Dilepton: Small BR and small backgrounds.

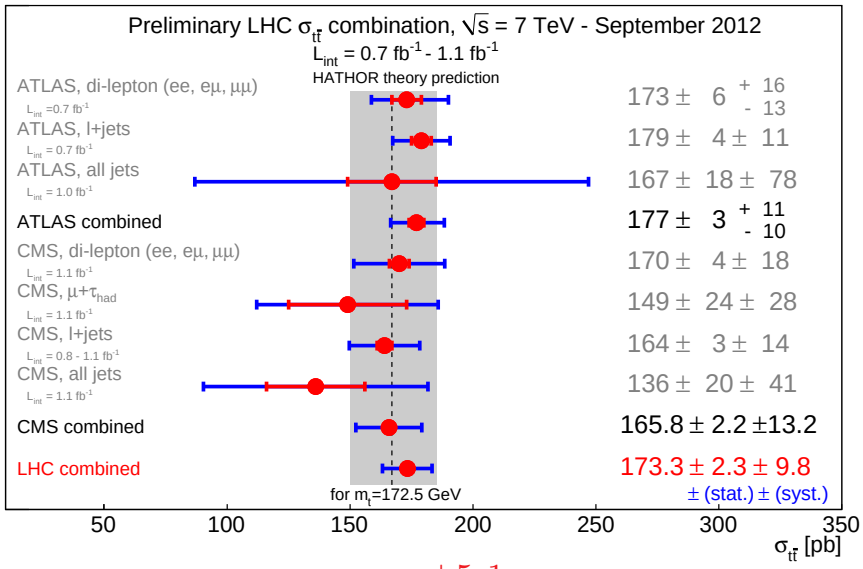
Top Pair Production Cross Section

1.96 TeV results:



Total uncertainty (Tevatron comb.): 5.4%

7 TeV results:



CMS $\ell\ell$: $161.9 \pm 2.5(\text{stat})^{+5.1}_{-5.0}(\text{syst}) \pm 3.6(\text{lumi})$ pb

Total uncertainty (CMS $\ell\ell$): 4.2%

- Cross sections consistent both with theory and across channels$^{(\star)}$.
- Systematics limited.
- Generator modeling uncertainties dominating.
- Power to constrain theory.

8 TeV results:

ATLAS ℓ+j: $232 \pm 2(\text{stat}) \pm 31(\text{syst}) \pm 9(\text{lumi})$ pb

CMS $\ell\ell$: $227 \pm 3(\text{stat}) \pm 10(\text{syst}) \pm 10(\text{lumi})$ pb

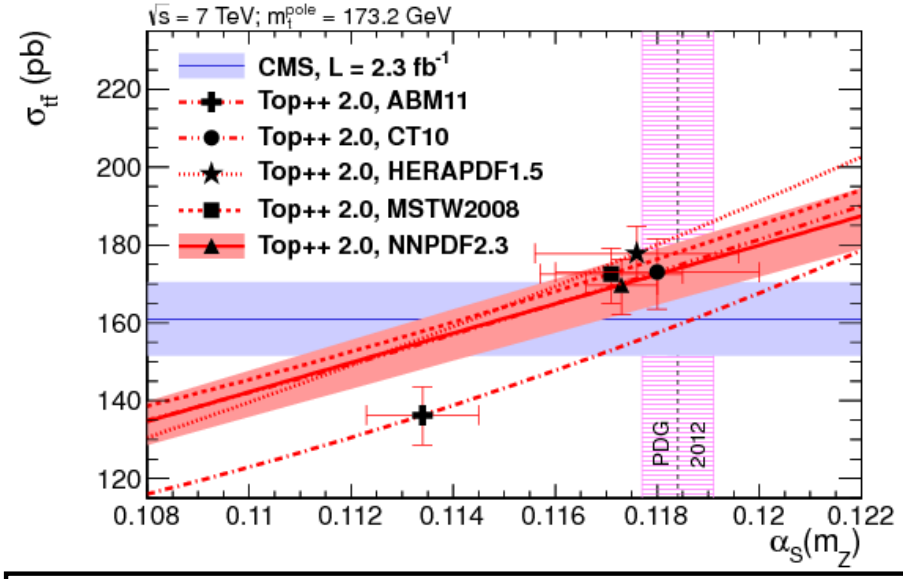
CMS ℓ+j: $228 \pm 9(\text{stat})^{+29}_{-26}(\text{syst}) \pm 10(\text{lumi})$ pb

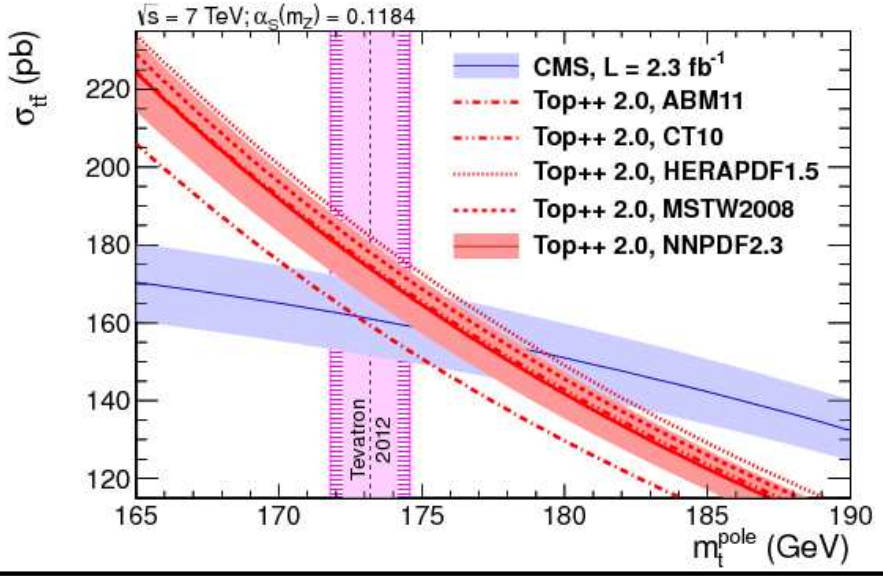
Total uncertainty (CMS $\ell\ell$): 6.3%

($\star$) $\sigma_{t\bar{t}}$ now available at full NNLO (Czakon, Fiedler, Mitov arXiv:1303.6254)

Strong Coupling Constant and Top Quark Pole Mass

- Cross section dependence on α_s and m_t^{pole} is used to constrain the strong coupling constant and/or the top quark pole mass.
- Pole mass determination complementary to direct top mass measurements (different systematics and theoretically well defined).





CMS: $m_t^{\text{pole}} = 176.7^{+3.8}_{-3.4}$ GeV (NNLO, arXiv:1303.6254)

NEW

CMS: $\alpha_s(m_Z) = 0.1151^{+0.0033}_{-0.0032}$ (if m_t^{pole} fixed to measured top quark mass)

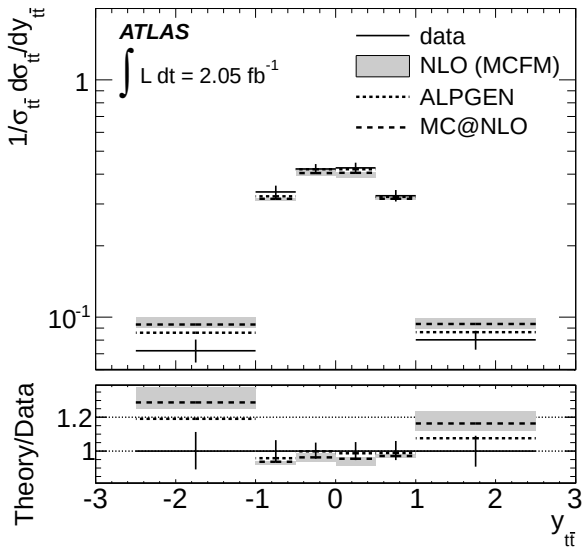
arXiv:1307.1907 (hep-ex)

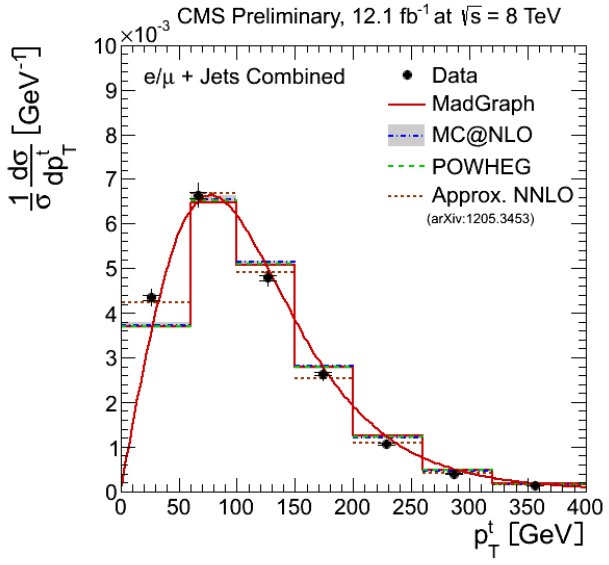
D0: $m_t^{\text{pole}} = 167.5^{+5.4}_{-4.9}$ GeV (approximate NNLO, Phys. Rev. D 80 (2009) 054009)

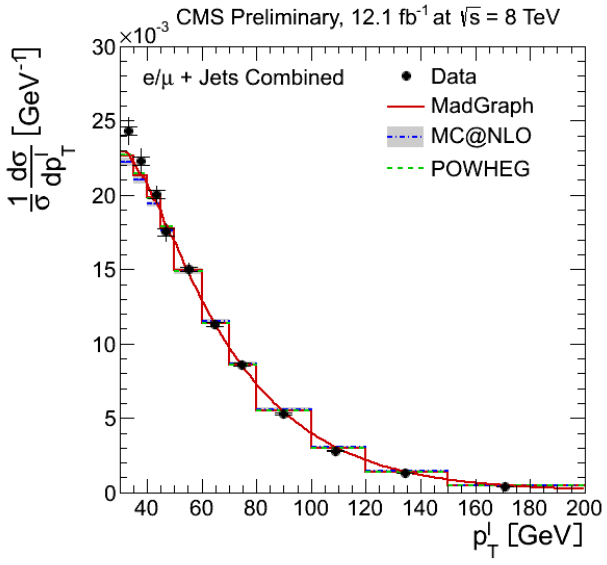
ATLAS: $m_t^{\text{pole}} = 166.4^{+7.8}_{-7.3}$ GeV (approximate NNLO, Phys. Rev. D 80 (2009) 054009)

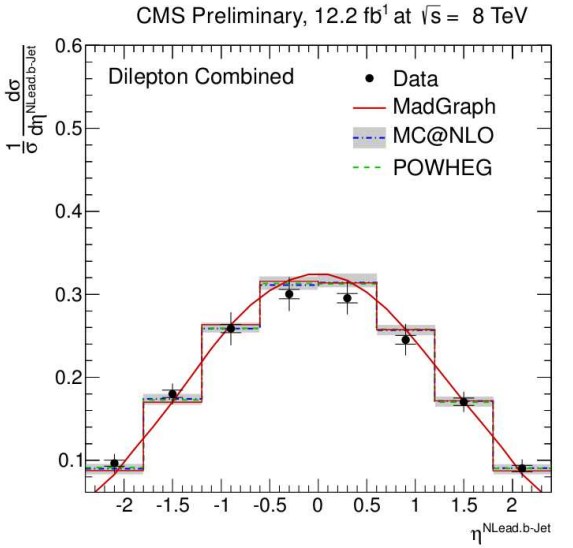
Phys. Lett. B 703, 422 (2011), ATLAS-CONF-2011-054

- Enough data to make a large set of differential cross-section measurements.
- Vs. kinematics of
  - $t\bar{t}$ system
  - top quark
  - decay products
- Good agreement with generators tested.
- Most bins are systematics limited.









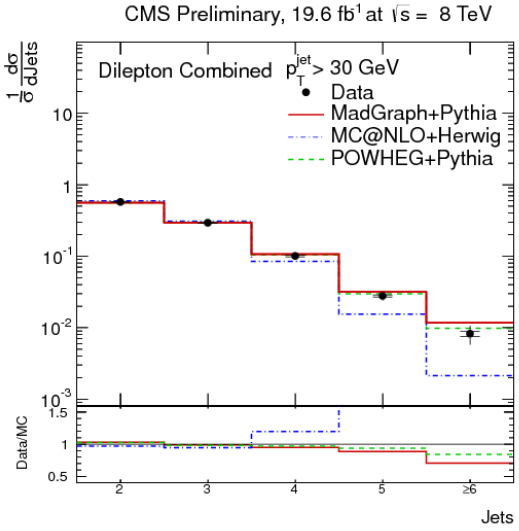
Eur. Phys. J. C (2013) 73:2261, CMS-PAS-TOP-12-027, CMS-PAS-TOP-12-028

Top Pair Production in Association with Jets

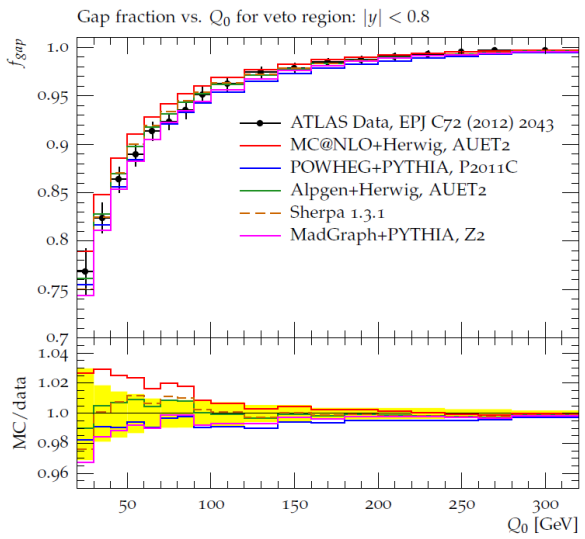
- Study additional jets to test QCD and MC generators.
- Extensive list of quantities probed.

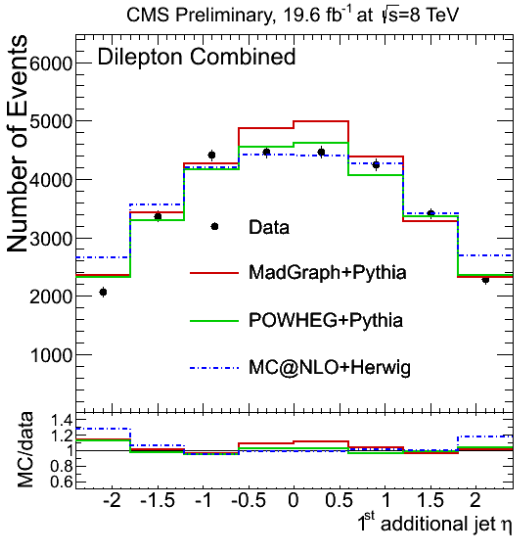
→ ISR/FSR variations reduced.

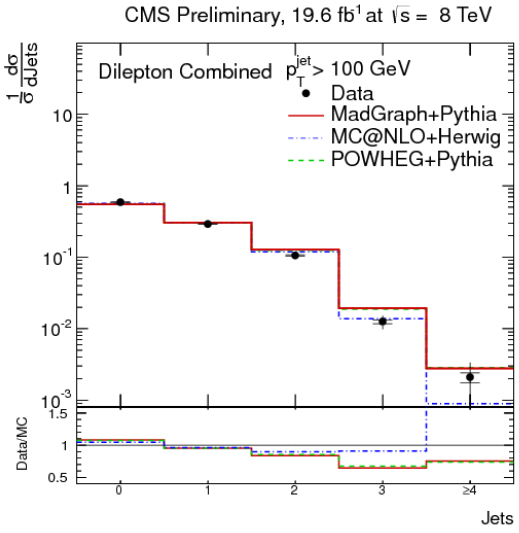
Eur.Phys.J. C (2013) 72:2043
CMS-PAS-TOP-12-041

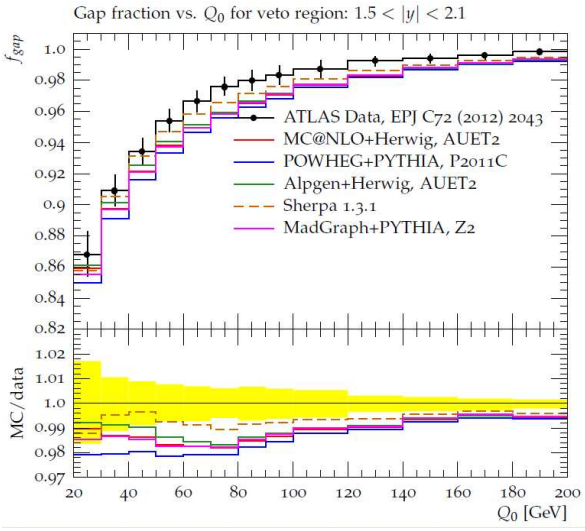


ATL-PHYS-PUB-2013-005
ATLAS-CONF-2012-155







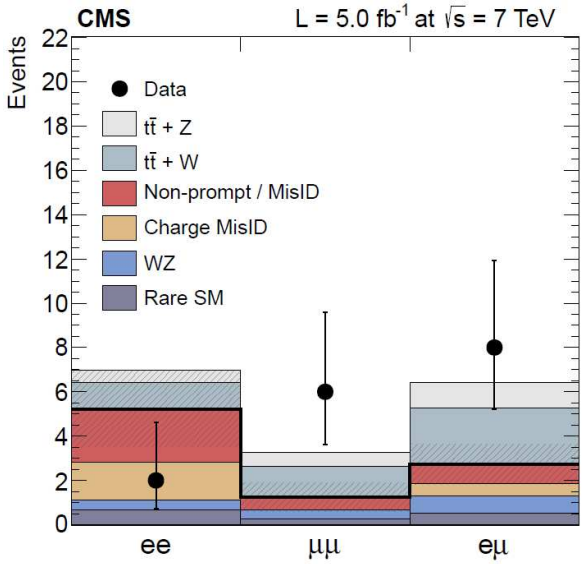


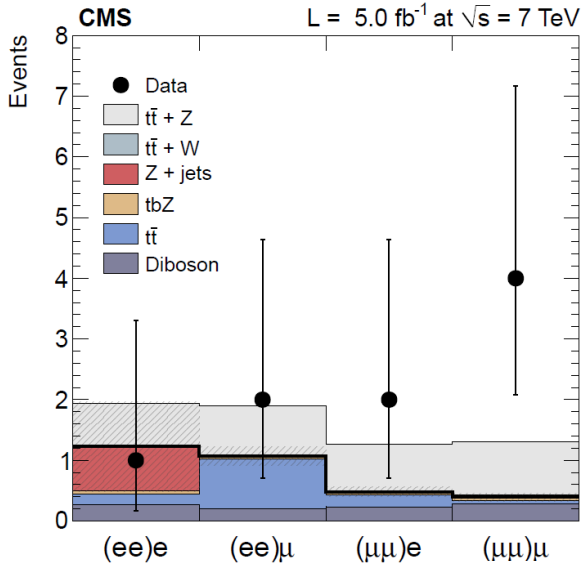
Dilepton analysis $t\bar{t}V$ $(V = W, Z)$

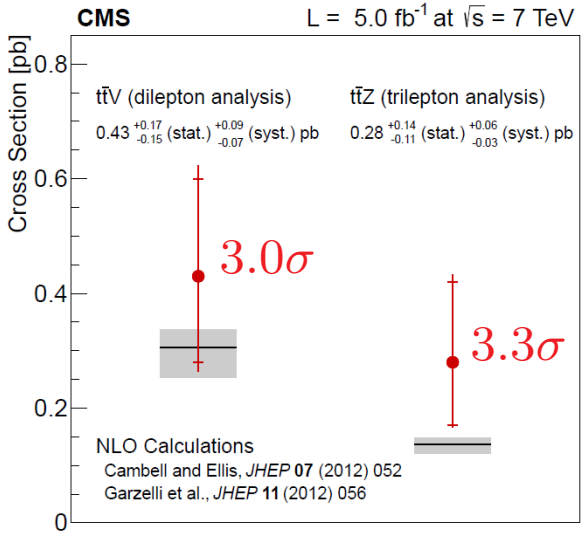
Trilepton analysis $t\bar{t}Z$

Phys. Rev. Lett. 110 (2013) 172002

ATLAS-CONF-2012-126

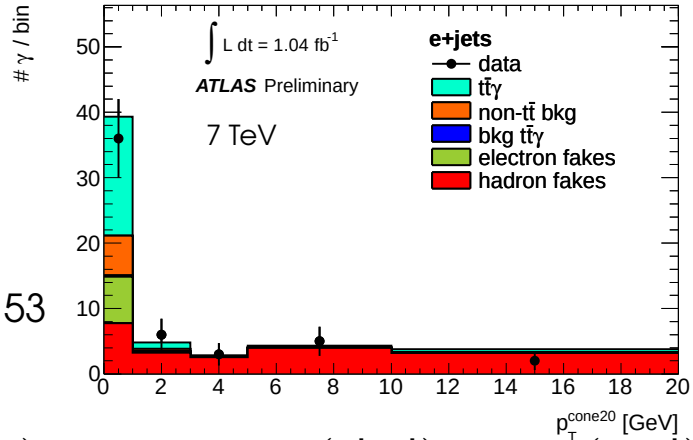


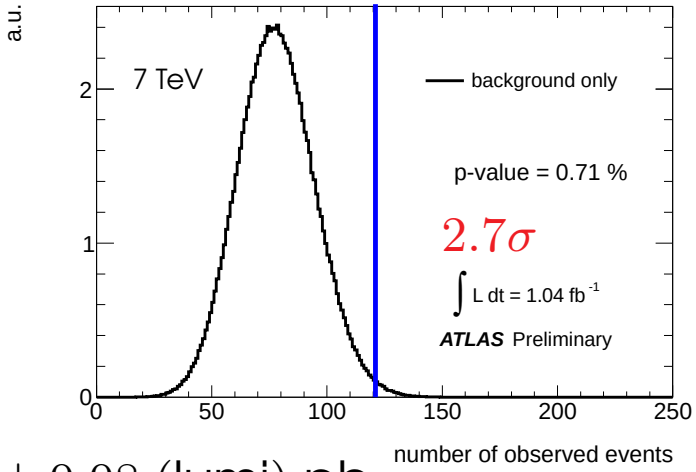




$t\bar{t}\gamma$

ATLAS-CONF-2011-153



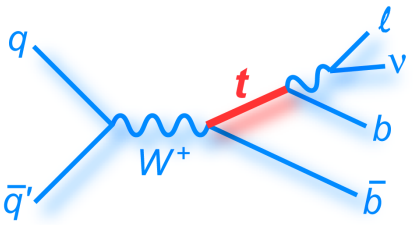


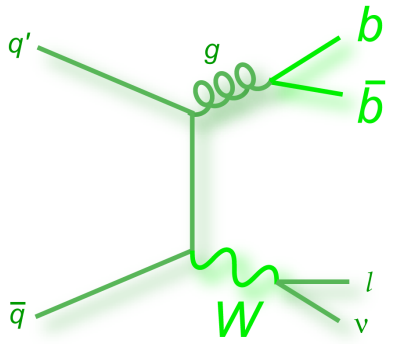
$$\sigma_{t\bar{t}\gamma}(p_{\mathrm{T}}^{\gamma} > 8\ \mathrm{GeV}) = 2.0 \pm 0.5\ (\mathrm{stat}) \pm 0.7\ (\mathrm{syst}) \pm 0.08\ (\mathrm{lumi})\ \mathrm{pb}$$

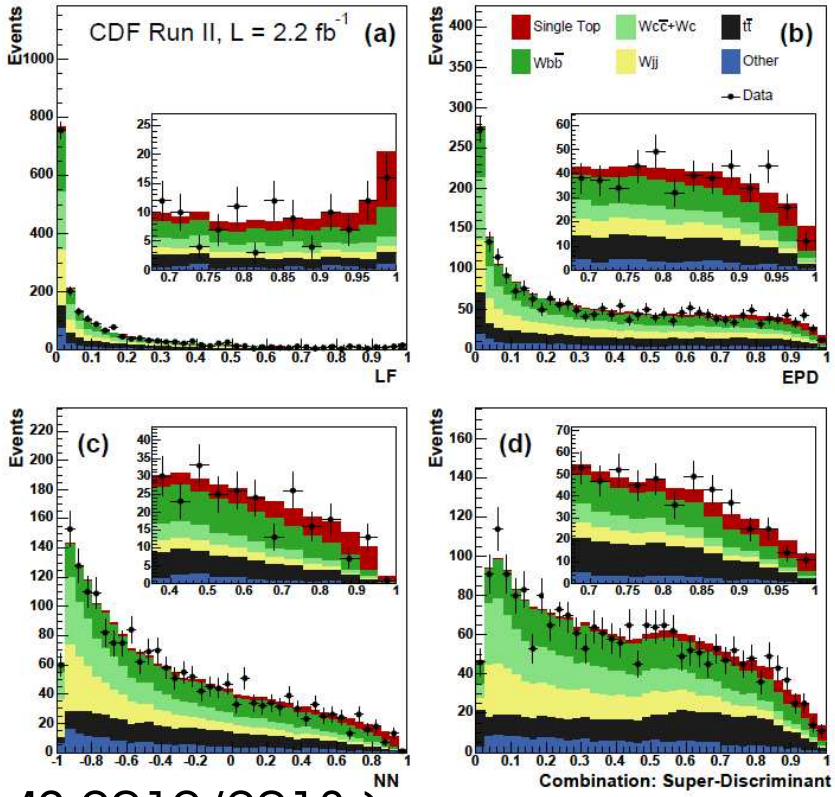
SM prediction $= 2.1 \pm 0.4$ pb (LO + LO→NLO k-factor)

- Direct probe of Wtb coupling and of V_{tb} in CKM matrix.
- Challenging, mainly due to the background from $W+$jets.
- Need MVA techniques.
- $s+t$-channel production observed at CDF and D0 in 2009.
- t-channel observed both at Tevatron and LHC.
- Evidence for s-channel production at D0. NEW
- Observation of Wt-channel production at CMS. NEW

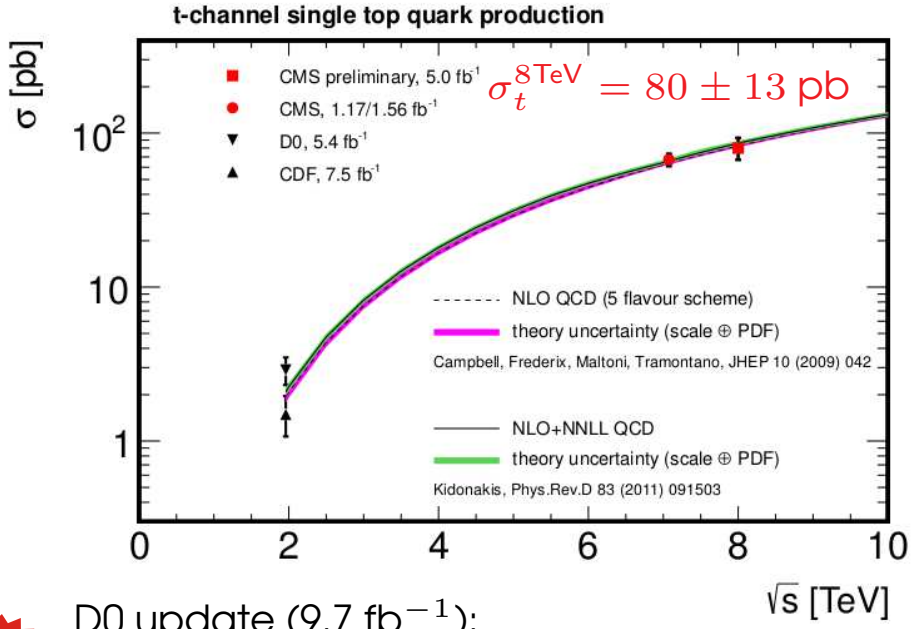
(Evidence by both ATLAS and CMS 2012/2013.)



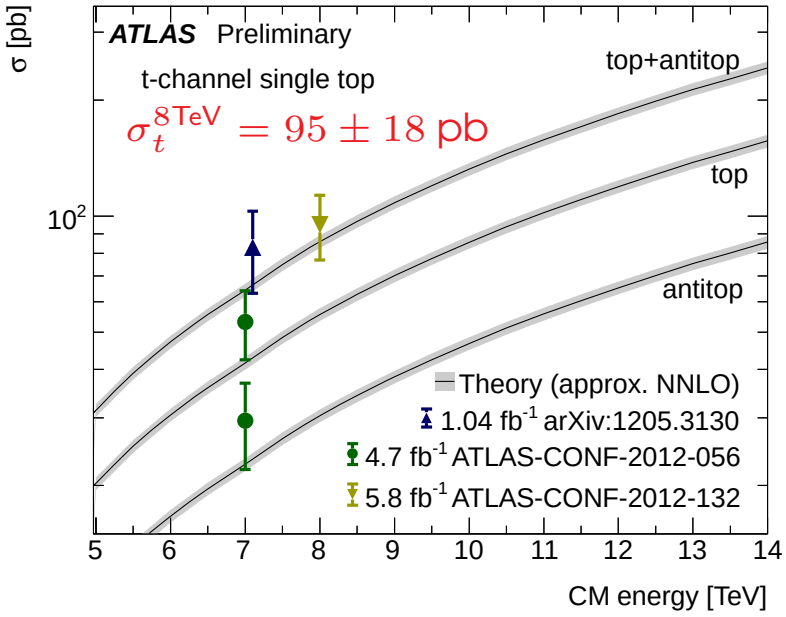




CMS-PAS-TOP-12-011



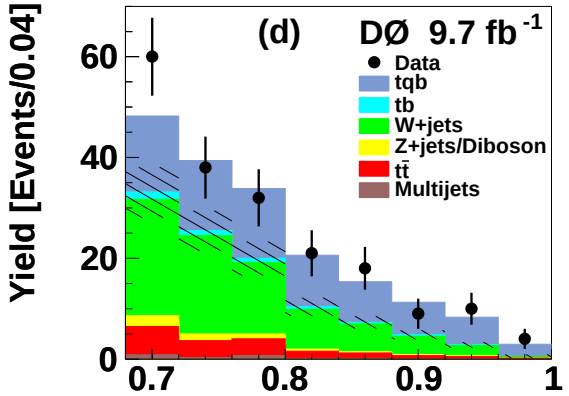
ATLAS-CONF-2012-056, ATLAS-CONF-2012-132

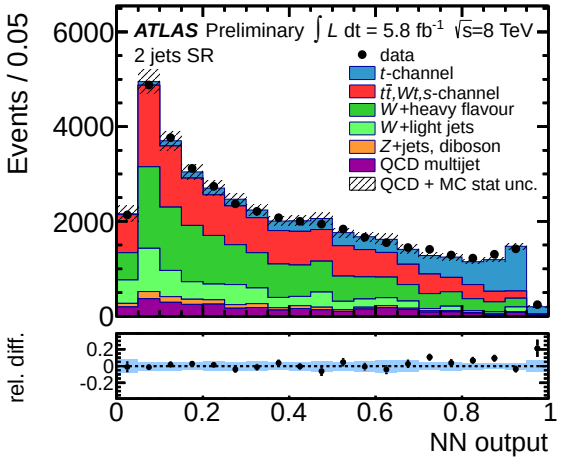


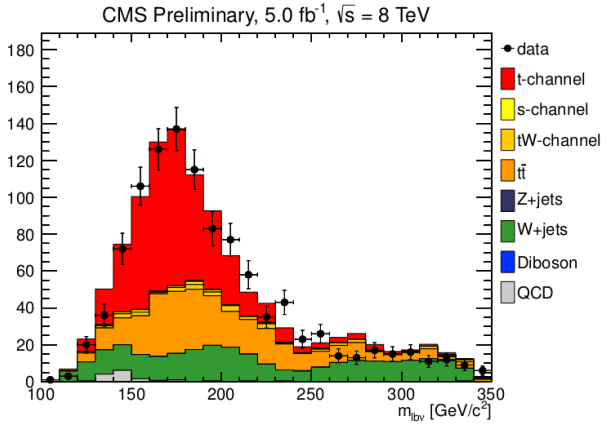
NEW

D0 update (9.7 fb^{-1}):

$\sigma_t = 3.07^{+0.54}_{-0.49}$ pb

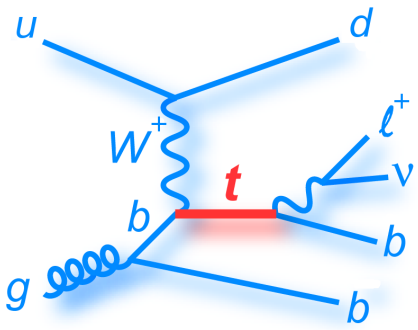


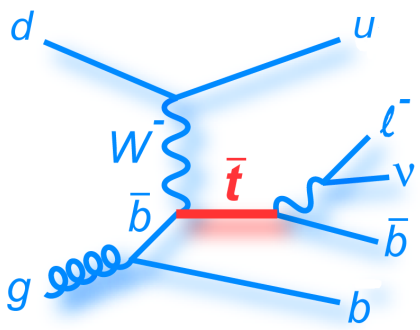




arXiv:1307.0731 (hep-ex)
submitted to Phys. Lett. B

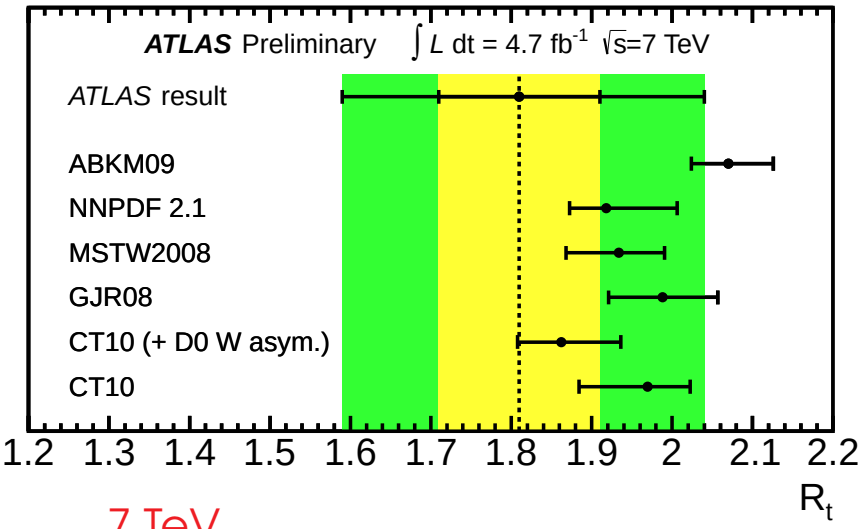
- Ratio $R_t = \sigma_t/\sigma_{\bar{t}}$ is sensitive to u/d content of proton.



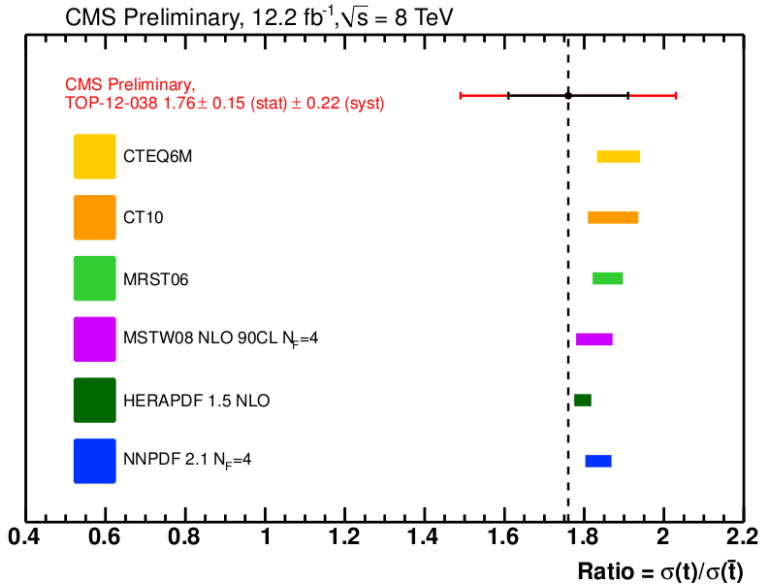


ATLAS-CONF-2012-056

CMS-PAS-TOP-12-038



7 TeV



8 TeV

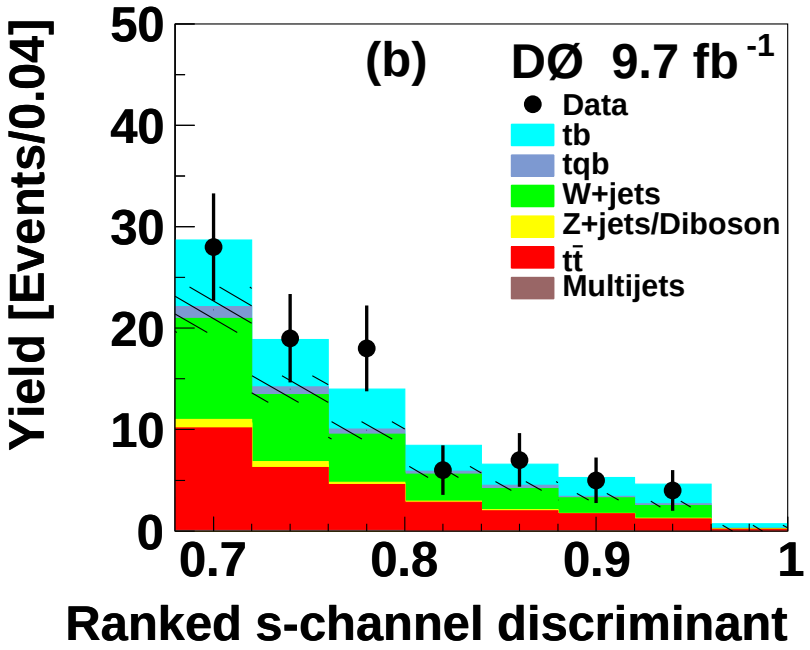
$R_t = 1.81 \pm 0.1(\text{stat}) \pm 0.21(\text{syst})$

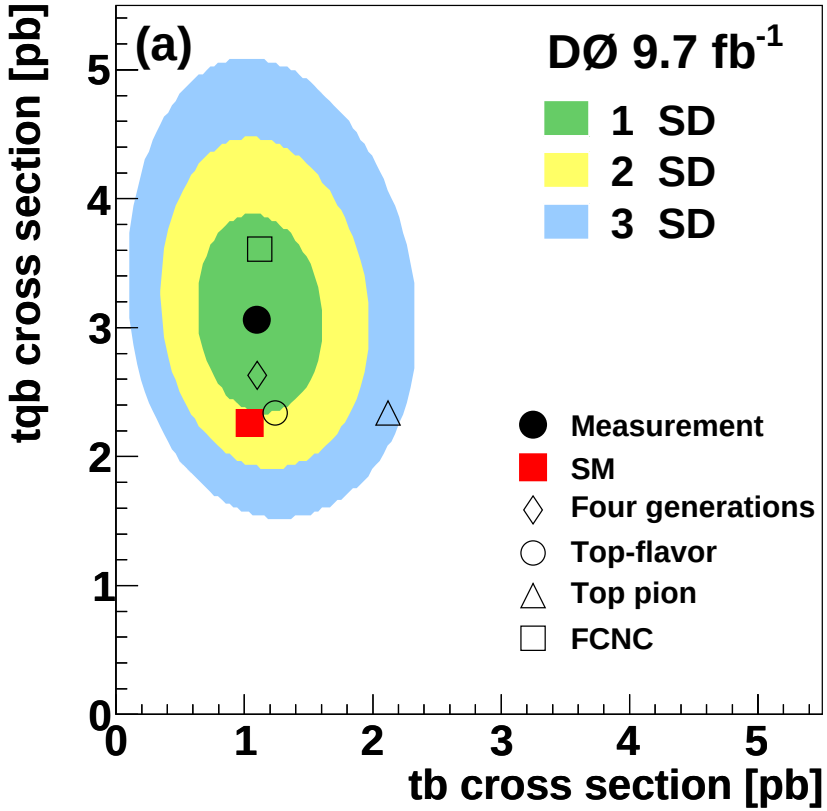
$R_t = 1.76 \pm 0.14(\text{stat}) \pm 0.21(\text{syst})$

- Both measurements agree with SM prediction.

- First evidence of s-channel production by D0.
- $\sigma(p\bar{p} \to tb + X) = 1.10^{+0.33}_{-0.31}$ pb

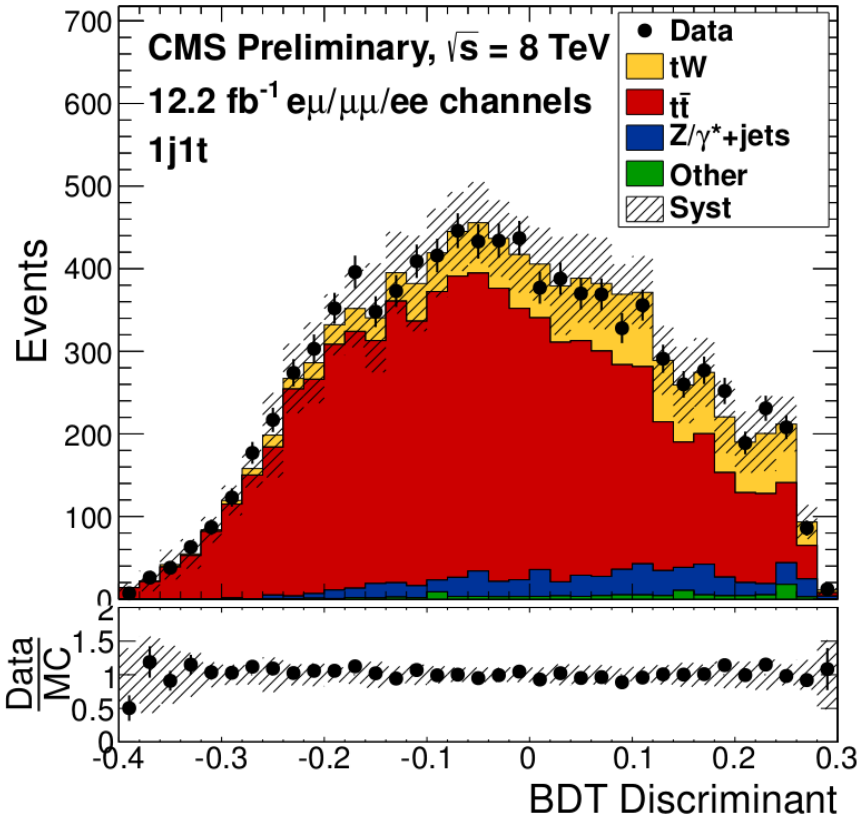
$\to$ 3.7σ significance.





arXiv:1307.0731 (hep-ex), submitted to Phys. Lett. B

- First observation of Wt production by CMS.



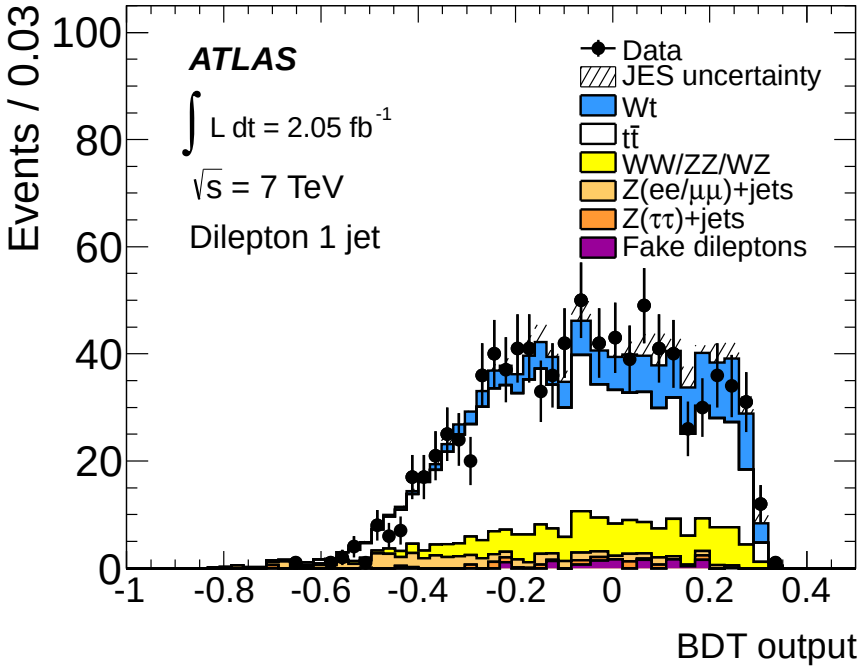
NEW

$\sigma = 23.4^{+5.5}_{-5.4}$ pb

6.0σ significance

CMS-PAS-TOP-12-040

- Evidence by ATLAS.



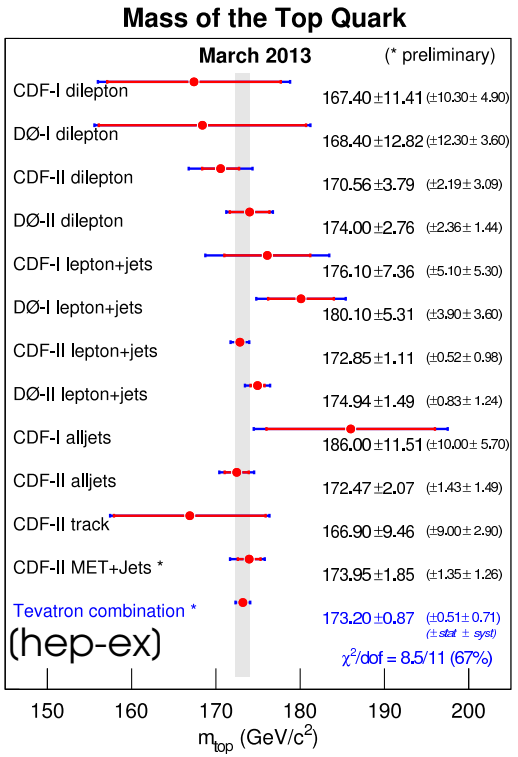
$\sigma = 16.8 \pm 2.9(\text{stat}) \pm 4.9(\text{syst})$ pb

3.3σ significance

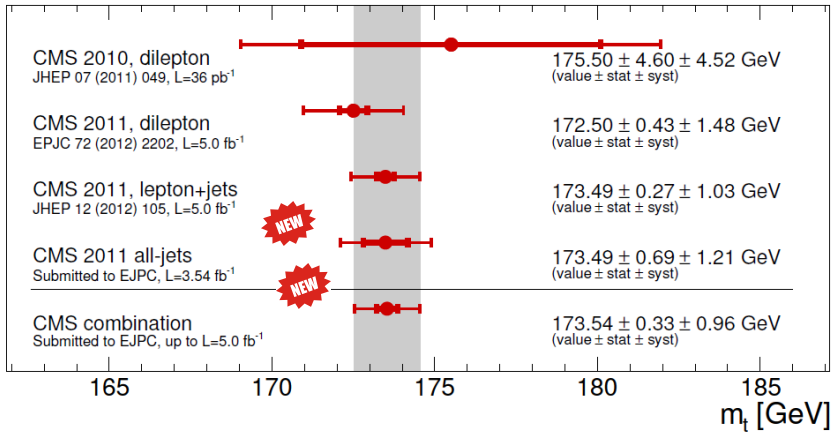
Phys. Lett. B 716, 142 (2012)

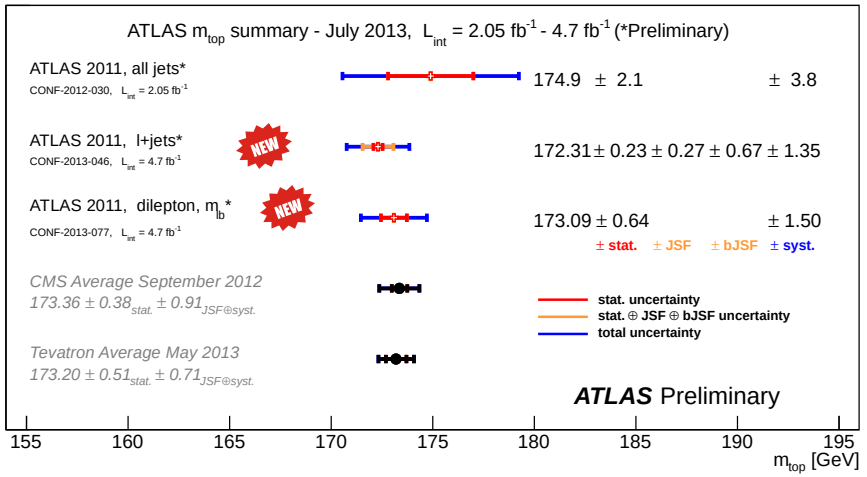
- Tevatron still provides the best mass measurement, with an uncertainty of 0.5%.
- Best single LHC measurement (from CMS) reaches 0.6%.
- Updated LHC mass combination in progress.

→ Harmonise systematic treatment e.g. generator modeling.

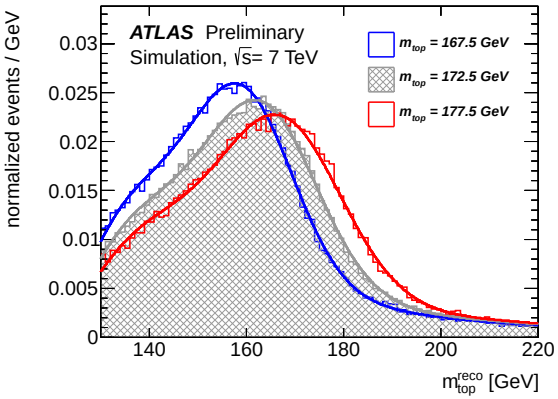


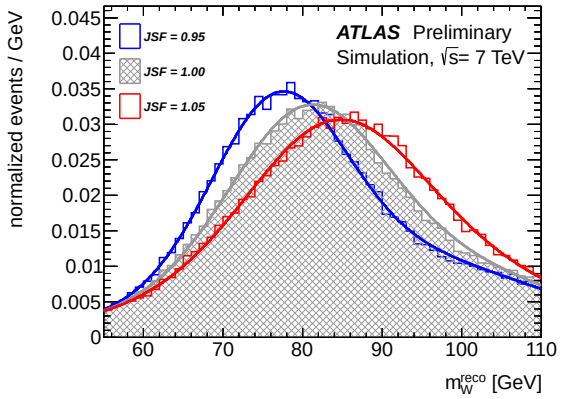
arXiv:1305.3929 (hep-ex)

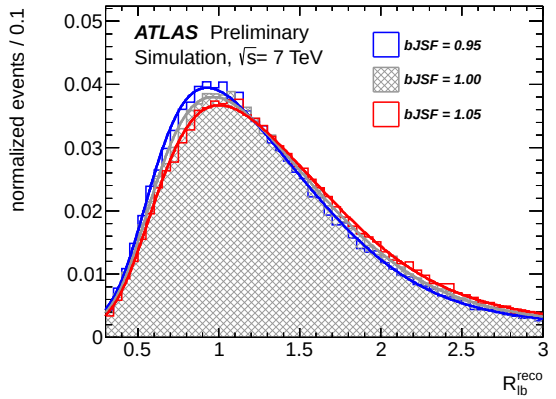




New 3D Fit by ATLAS





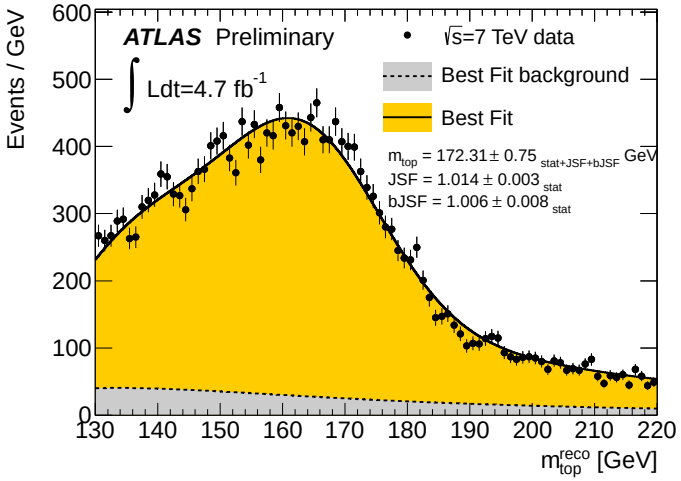


- 3D fit to $m_{\text{top}}^{\text{reco}}$, m_W^{reco} and $R_{\text{lb}}^{\text{reco}}$.

$$R_{\text{lb}}^{\text{reco},1b} = \frac{p_{\text{T}}^{b_{\text{tag}}}}{(p_{\text{T}}^{W_{\text{jet1}}} + p_{\text{T}}^{W_{\text{jet2}}})/2}$$

$$R_{\text{lb}}^{\text{reco},2b} = \frac{p_{\text{T}}^{b_{\text{had}}} + p_{\text{T}}^{b_{\text{lep}}}}{p_{\text{T}}^{W_{\text{jet1}}} + p_{\text{T}}^{W_{\text{jet2}}}}$$

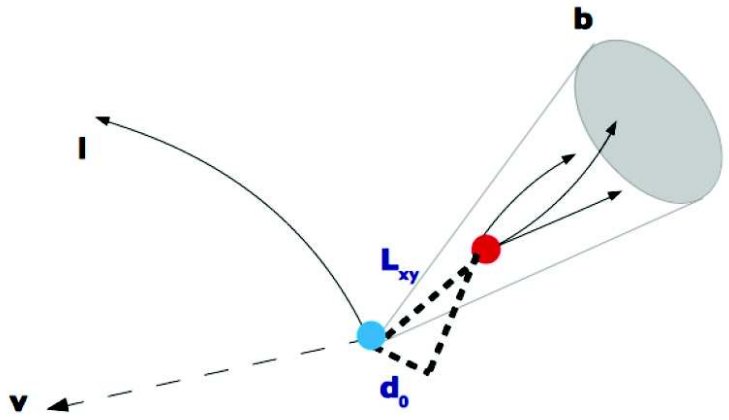
- In-situ calibration of JES and bJES.
- Systematic uncertainties reduced by 40% w.r.t. previous measurement.

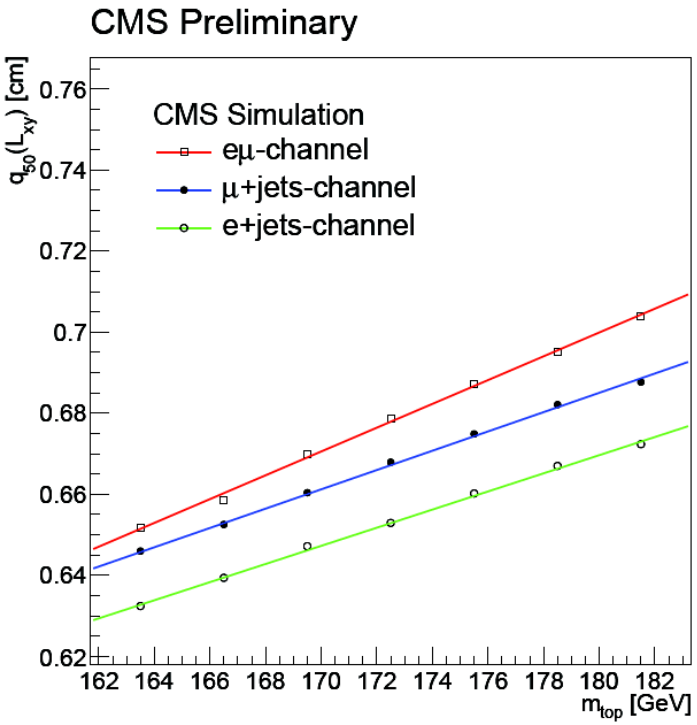


$$m_{\text{top}} = 172.31 \pm 0.23(\text{stat}) \pm 0.27(\text{JSF}) \pm 0.67(\text{bJSF}) \pm 1.35(\text{syst})\ \text{GeV}$$

NEW

New Lifetime-Based Measurement by CMS



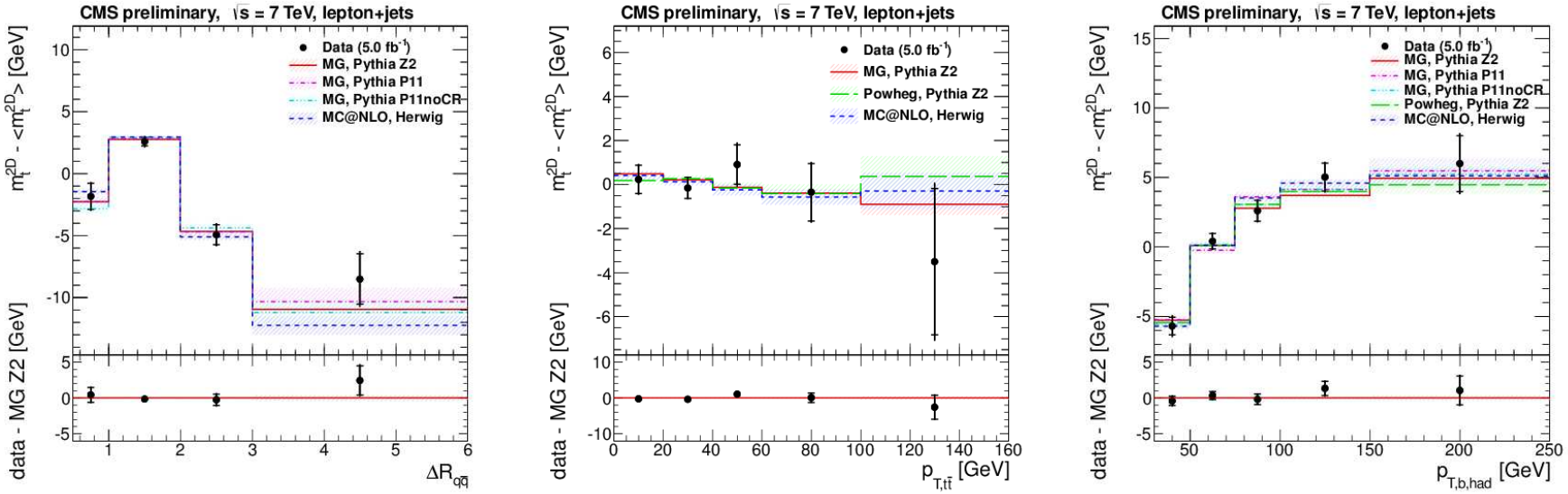


- Lifetime-based technique, using $L_{xy} = \gamma_b \beta_B \tau_B \approx 0.4 \cdot \frac{m_t}{m_B} \beta_B \tau_B$.
- First used at CDF.
  Phys. Rev. D75, 071102 (2007)
- Linear mass dependence, $\Delta L_{xy}/\text{GeV} = 25 - 30 \mu\text{m}$
- Complementary systematics to traditional measurements, e.g. minimal dependence on jet energy scale.
- In each event, select secondary vertex with largest L_{xy}.
- Median, $\widehat{L_{xy}}$, is used to extract m_{top}.

$$m_{\text{top}} = 173.5 \pm 1.5(\text{stat}) \pm 1.3(\text{syst}) \pm 2.6(p_T(t)) \text{ GeV}$$

NEW

- Differential mass measurements, to probe e.g. color reconnections and initial/final state radiation.



CMS-PAS-TOP-12-029

Top-antitop mass difference, to test CPT theorem:

$$\Delta m_t = -272 \ \pm 196(\text{stat}) \pm 122 \ (\text{syst}) \ \text{MeV}$$

CMS-PAS-TOP-12-031

Top Forward-Backward and Charge Asymmetries

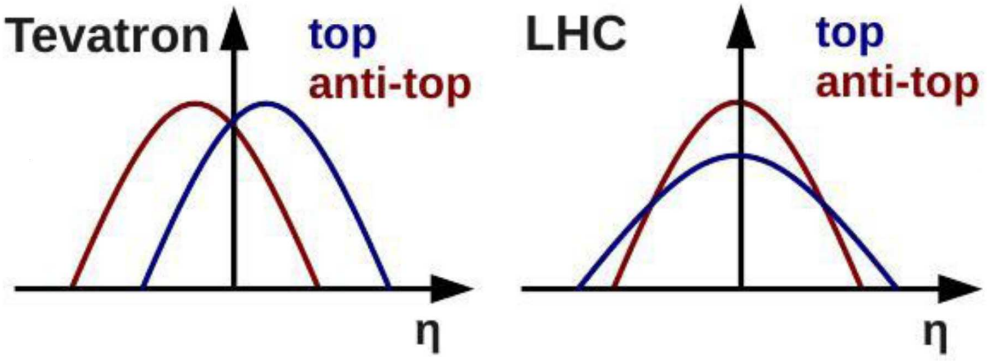
- New physics in top sector can alter angular distributions.
- Study forward-backward and charge asymmetries.

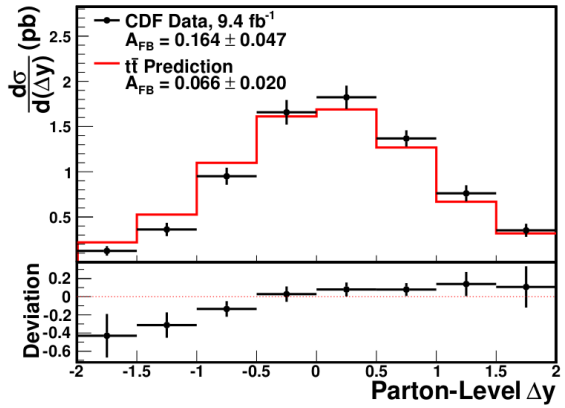
$$A_{FB}^{t\bar{t}} = \frac{N(\Delta y > 0) - N(\Delta y < 0)}{N(\Delta y > 0) + N(\Delta y < 0)}$$

with $\Delta y = y_t - y_{\bar{t}}$

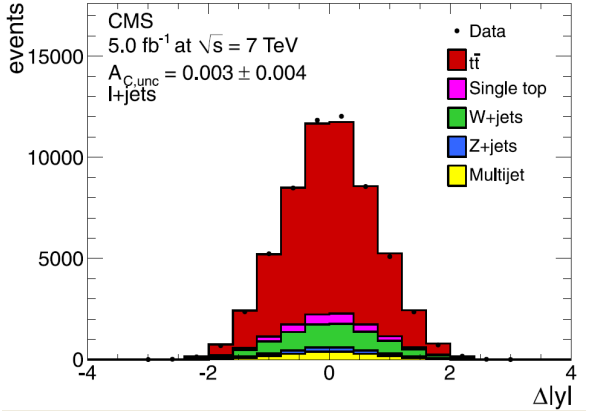
$$A_C^{t\bar{t}} = \frac{N(\Delta|y| > 0) - N(\Delta|y| < 0)}{N(\Delta|y| > 0) + N(\Delta|y| < 0)}$$

with $\Delta|y| = |y_t| - |y_{\bar{t}}|$

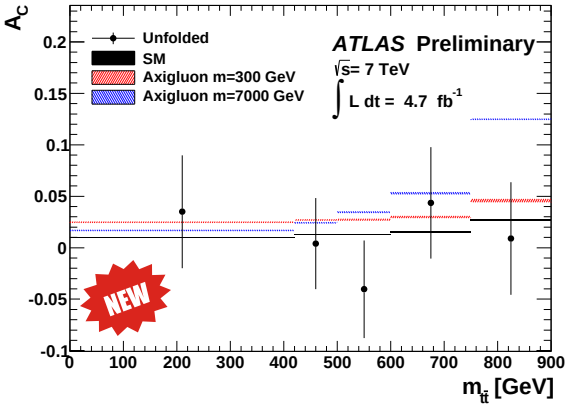




Phys. Rev. D 87 092002 (2013)



Phys. Lett. B 717, 129 (2012)



ATLAS-CONF-2013-078

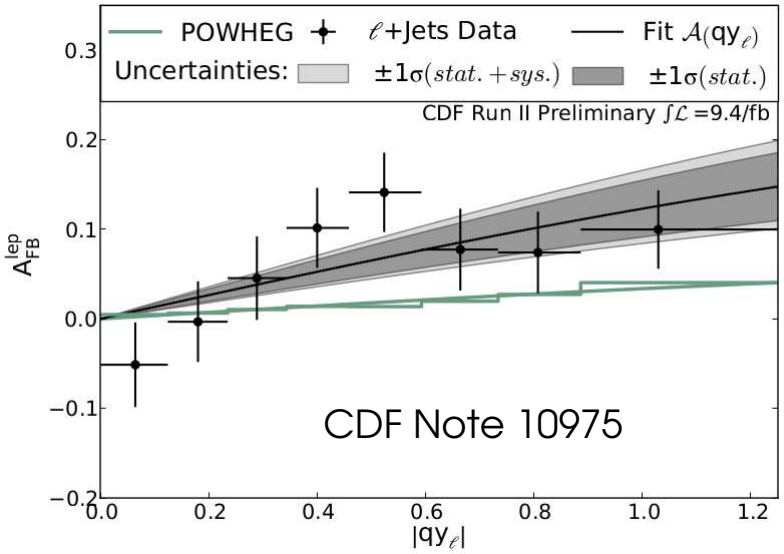
- Tevatron $A_{FB}^{t\bar{t}}$ measurements in tension with SM at $\sim 2.5\sigma$.
- LHC $A_C^{t\bar{t}}$ measurements consistent with SM.

Lepton Forward-Backward Asymmetry

- $A_{FB}^{t\bar{t}}$ measurement requires full reconstruction of $t\bar{t}$ system.
- Alternative method based on y of lepton from leptonic W decay.

$$A_{FB}^{\ell} = \frac{N(q_\ell y_\ell > 0) - N(q_\ell y_\ell < 0)}{N(q_\ell y_\ell > 0) + N(q_\ell y_\ell < 0)}$$

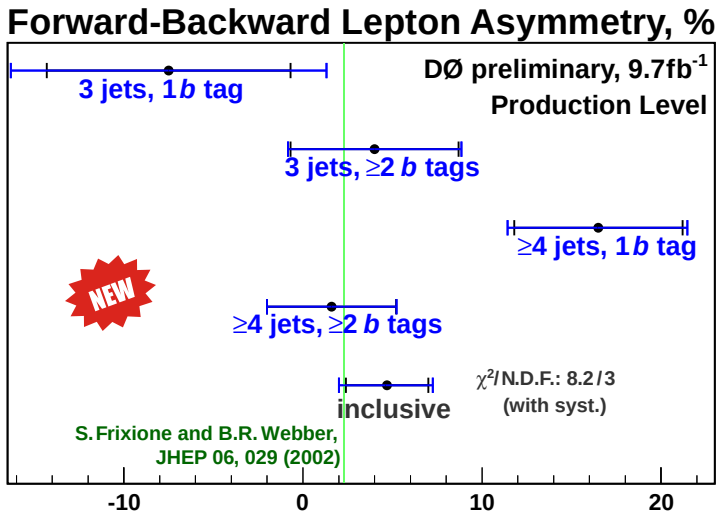
- $A_{FB}^{\ell} \approx 0.5 \cdot A_{FB}^{t\bar{t}}$ if no t polarization.
- Can also use events with jets out of acceptance (3-jet bin).



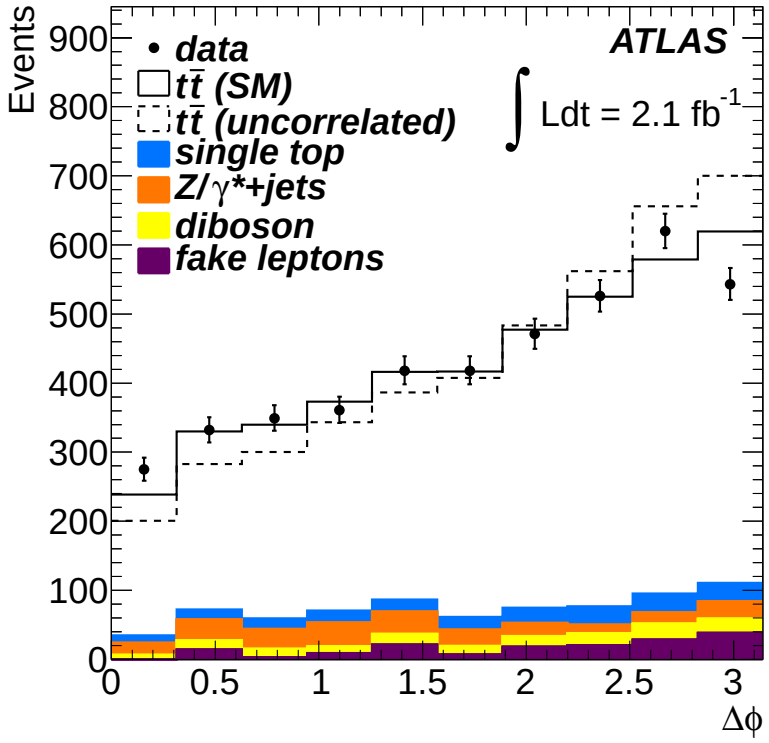
CDF: $A_{FB}^{\ell} = 0.094^{+0.032}_{-0.029}$

D0: $A_{FB}^{\ell} = 0.047 \pm 0.023(\text{stat})^{+0.011}_{-0.014}(\text{syst})$

- CDF result approximately 2σ above SM prediction.
- D0 measurement consistent with SM (and CDF) within errors.



- Spins of top and anti-top are correlated in SM.
- Short top quark lifetime ($\sim 5 \times 10^{-25}$ s) means spin information is carried on to decay products.



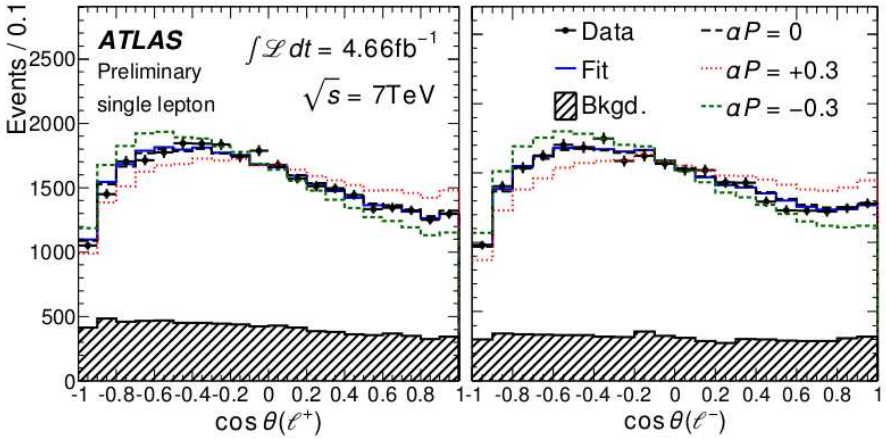
- Measure fraction of SM-like events, f^{SM}, using template fit to $\Delta\phi(\ell\ell)$ distribution.
  - $f^{SM} = 0 \rightarrow$ no correlations.
  - $f^{SM} = 1 \rightarrow$ correlations (SM).

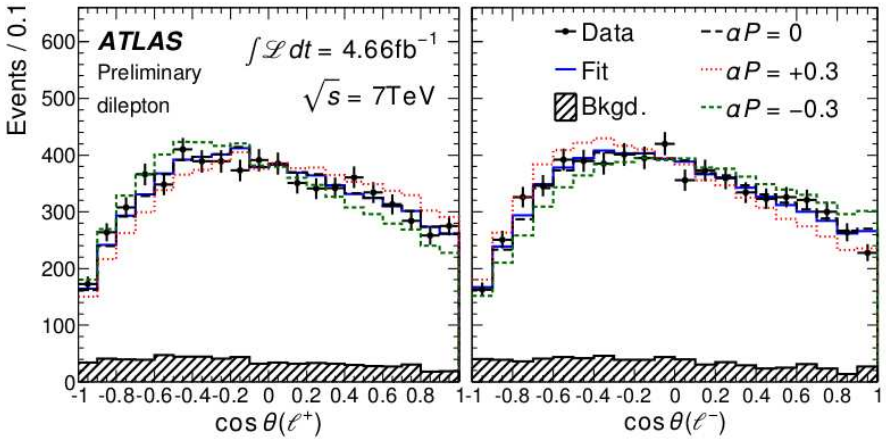
ATLAS: $f^{SM} = 1.30 \pm 0.14^{+0.27}_{-0.22} \rightarrow 5.1\sigma$
Phys. Rev. Lett. 108, 212001 (2012)

CMS: $f^{SM} = 0.74 \pm 0.08(\text{stat}) \pm 0.24(\text{syst})$
CMS-TOP-12-004

D0: $f^{SM} = 0.85 \pm 0.29 \rightarrow 3.1\sigma$
Phys. Rev. Lett. 108, 032004 (2012)

- Top quarks in $t\bar{t}$ events have negligible polarization in SM.
- Can occur in BSM scenarios (e.g. models with large FB asymmetry).
- Polar angle of decay product i distributed as:
  $W(\cos\theta_i) = \frac{1}{2}(1 + \alpha_i P \cos\theta_i)$
  P = degree of polarization,
  α_i = spin-analyzing power.
- At tree level, charged leptons and down-type quarks from W-boson decays have $\alpha_i = 1$.
- Fit $\cos\theta_\ell$ distributions for e and μ to extract $\alpha_\ell P$.





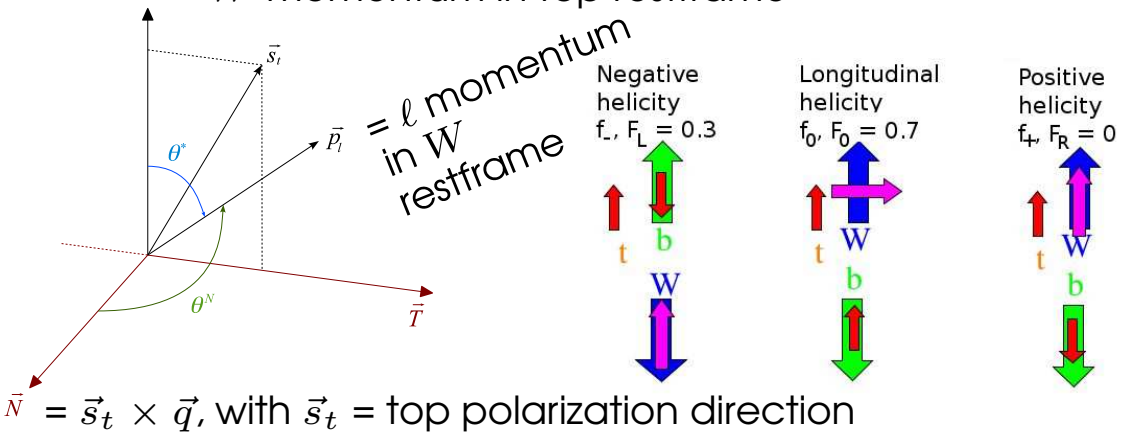
NEW

$$\alpha_l P_{\mathrm{CPC}} = -0.035 \pm 0.014 \pm 0.037$$
$$\alpha_l P_{\mathrm{CPV}} = 0.020 \pm 0.016^{+0.013}_{-0.017}$$

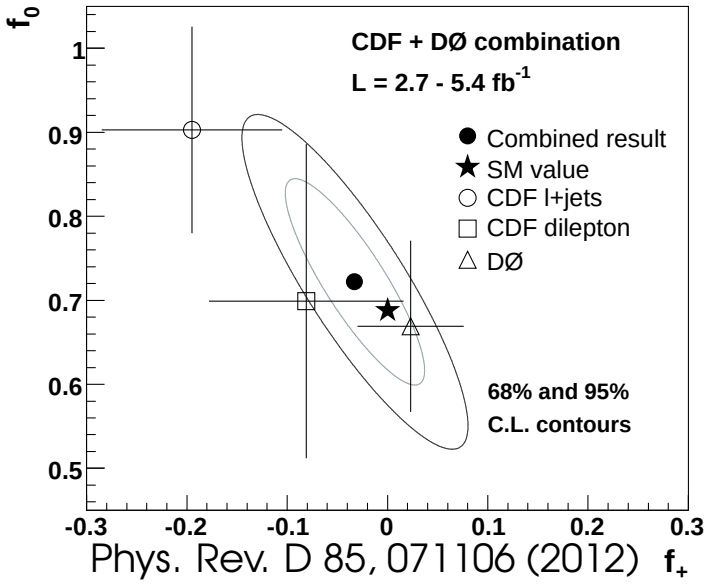
W Helicity Fractions in Top Quark Decays

- Probes (V-A) structure of Wtb vertex.

$\vec{q}$ = W momentum in top restframe



$\vec{N} = \vec{s}_t \times \vec{q}$, with $\vec{s}_t$ = top polarization direction

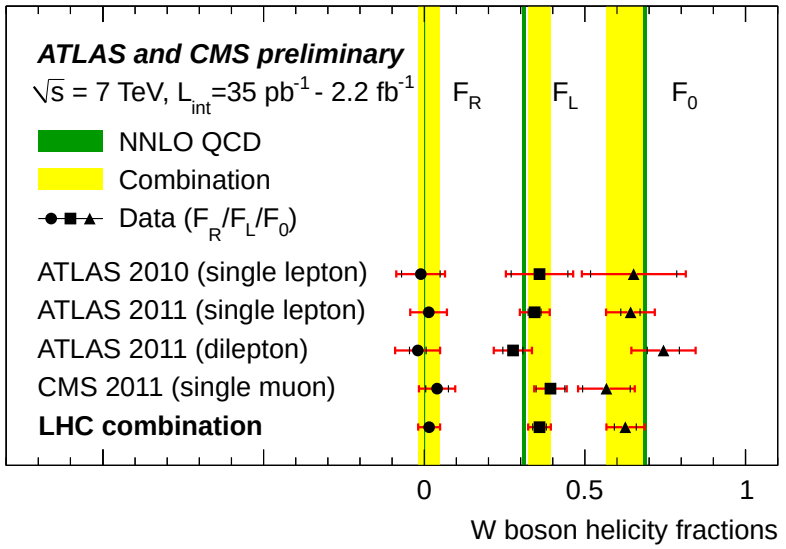


Phys. Rev. D 85, 071106 (2012)

- Extract helicity fractions from:
  - $\theta^\star$ in $t\bar{t}$ events (unpolarized).
  - e.g. θ^N in single top events (polarized).
- Not yet in LHC combination:
  - latest single lepton and dilepton measurements (CMS-TOP-11-020, CMS-PAS-TOP-12-015).
  - first measurement in single top t-channel (CMS-PAS-TOP-12-020).

NEW

ATLAS-CONF-2013-033, CMS-PAS-TOP-12-025



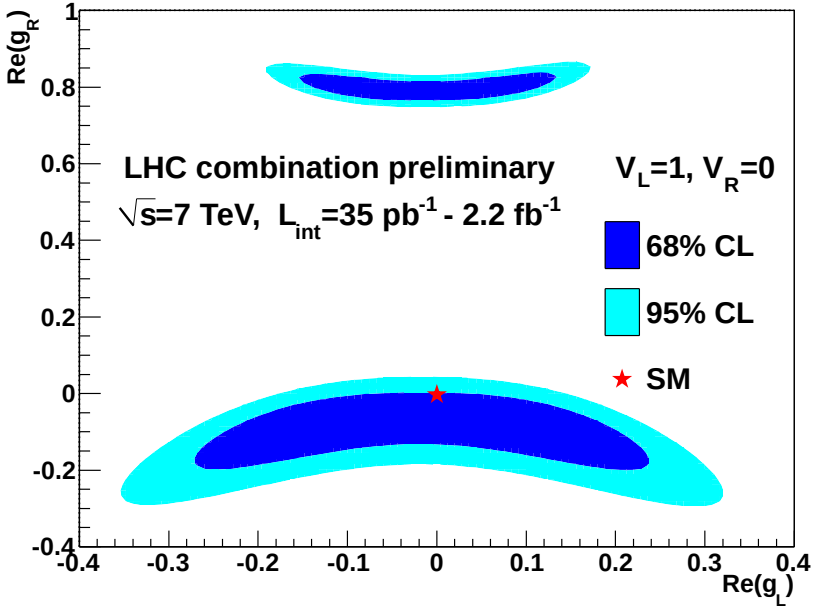
Effective lagrangian for Wtb vertex:

V_R, g_L, g_R anomalous couplings

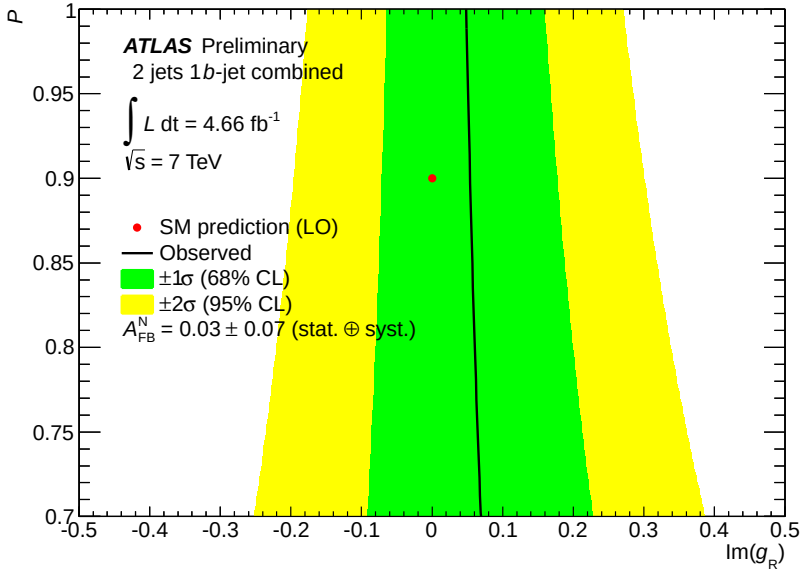
$$\mathcal{L}_{Wtb} = -\frac{g}{\sqrt{2}}\bar{b}\gamma^{\mu}(V_L P_L + V_R P_R)tW^-_{\mu} - \frac{g}{\sqrt{2}}\bar{b}\frac{i\sigma^{\mu\nu}q_{\nu}}{M_W}(g_L P_L + g_R P_R)tW^-_{\mu} + \text{h.c.}$$

- Interpret F_R, F_L, F_0 in terms of anomalous couplings.
- Assume $V_L = 1, V_R = 0$. Derive limits on g_L and g_R.
- CP violation if $Im(g_R) \neq 0$.
- A_{FB}^{N} in single top t-channel (top $\sim 90\%$ polarized).

$$A_{FB}^{N} = \frac{N(\cos\theta^N > 0) - N(\cos\theta^N < 0)}{N(\cos\theta^N > 0) + N(\cos\theta^N < 0)}$$



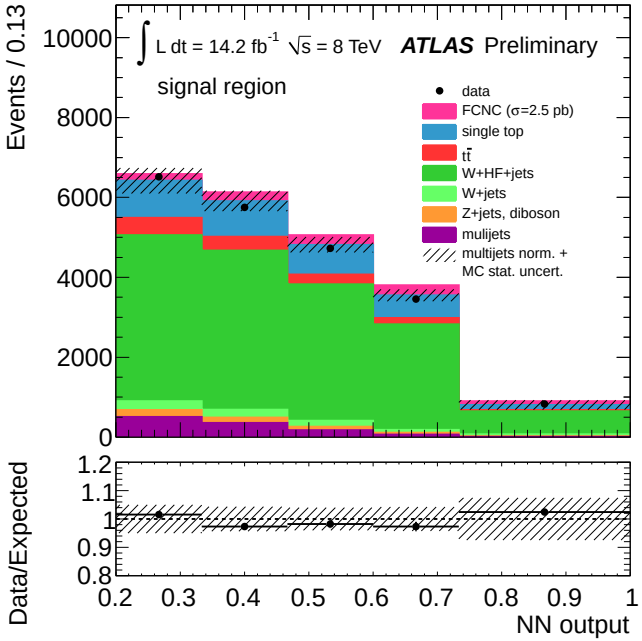
ATLAS-CONF-2013-033, CMS-PAS-TOP-12-025



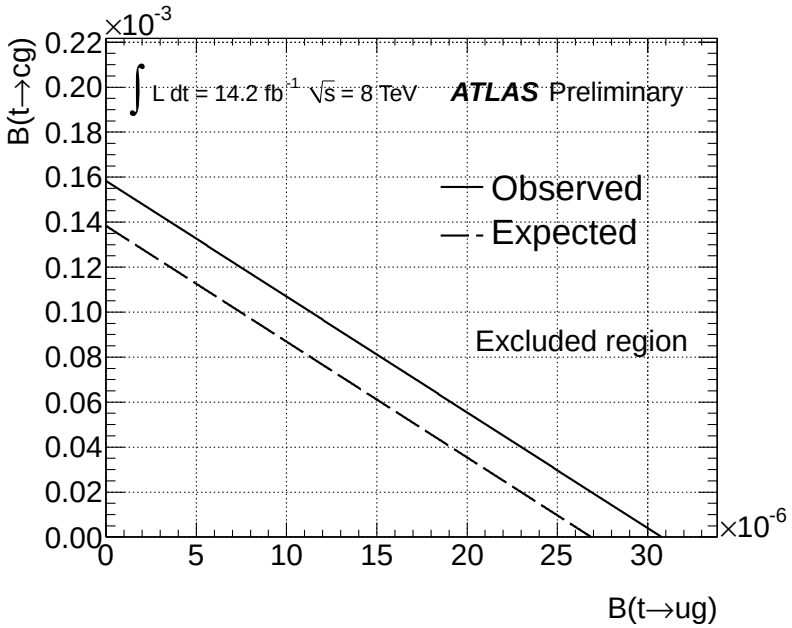
ATLAS-CONF-2013-032

Flavour Changing Neutral Currents

- $qg \to t \to Wb \to \ell\nu b \; (q = u, c)$



NEW

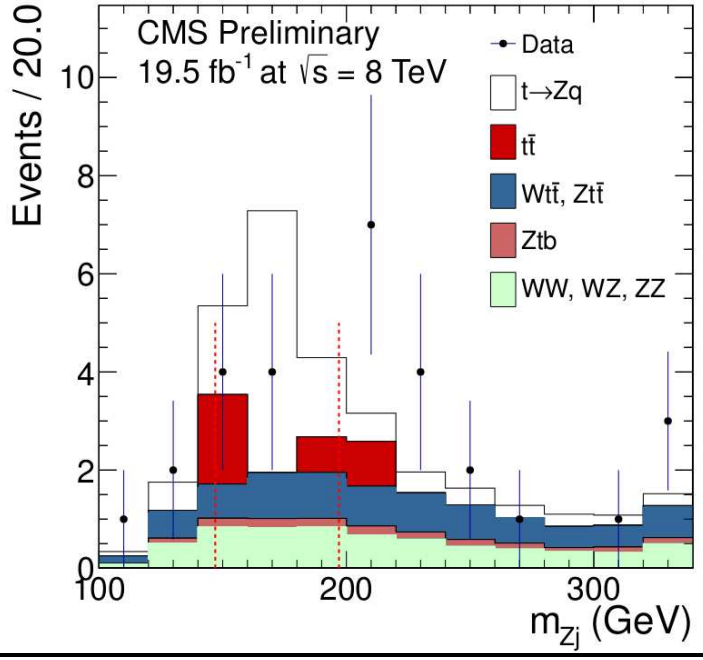


ATLAS-CONF-2013-063

- $t\bar{t} \to Wb + Zq \to \ell\nu b + \ell\ell q$

ATLAS: $BR(t \to Zq) < 0.73\%$ @ 95% C.L. (7 TeV)

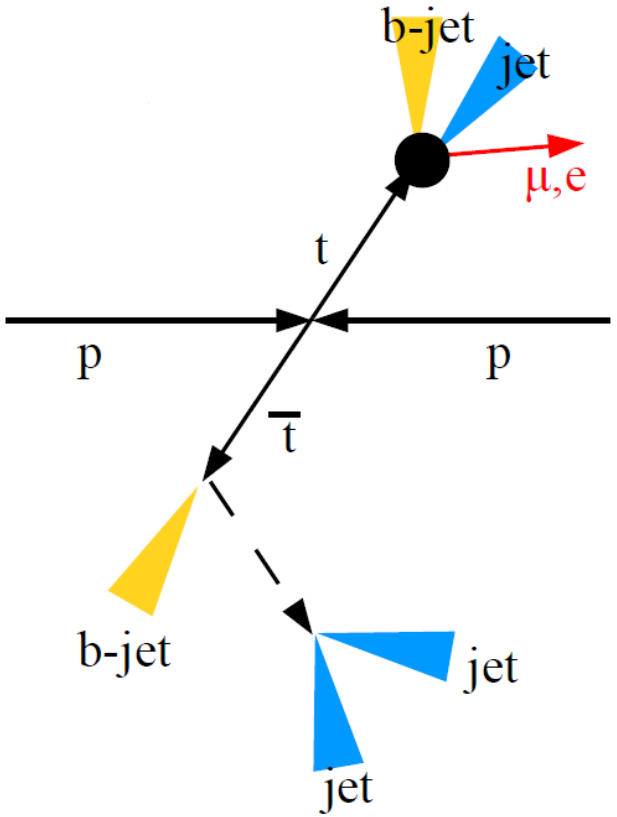
CMS: $BR(t \to Zq) < 0.07\%$ @ 95% C.L. (8 TeV)

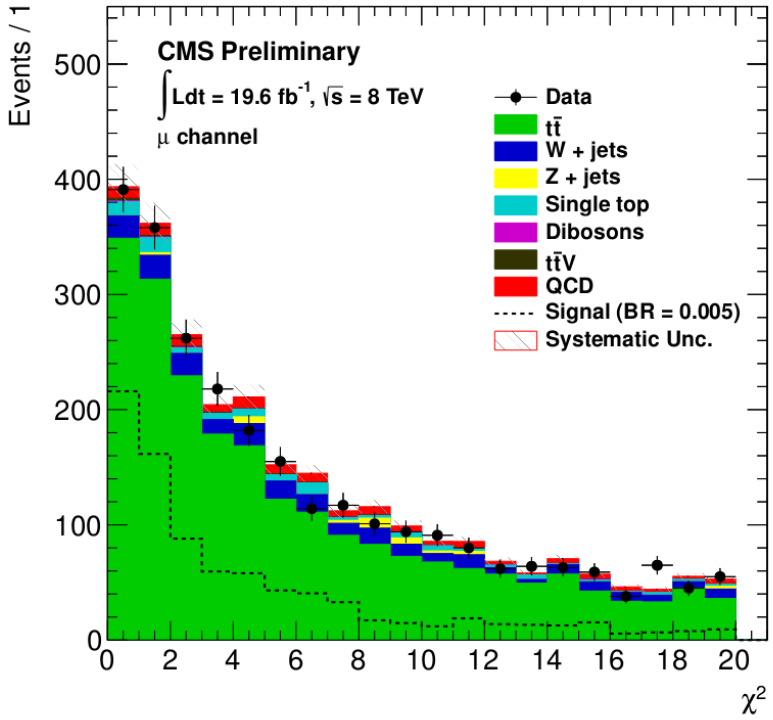


JHEP 1209 (2012) 139

CMS-PAS-TOP-12-037

- Baryon number violation possible in several BSM scenarios.
- Search for $t\bar{t}$ events in which one top decays through $t \to \bar{b}\bar{c}\mu^+$ or $t \to \bar{b}\bar{u}e^+$.





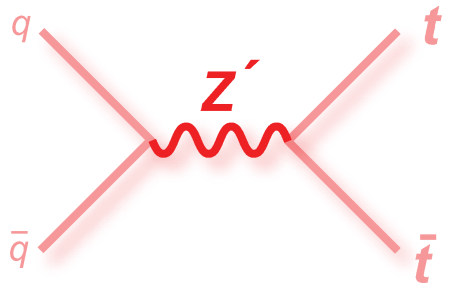
- No significant excess over expected background.

$$BR(t \to \bar{b}\bar{c}\mu^+) < 0.0016 \text{ @ 95\% C.L.}$$
$$BR(t \to \bar{b}\bar{u}e^+) < 0.0017 \text{ @ 95\% C.L.}$$

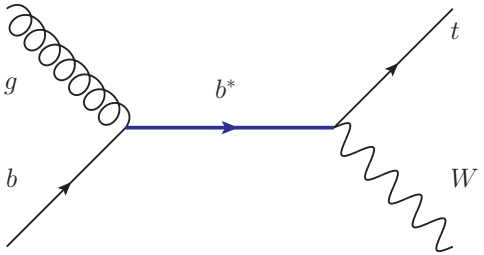
CMS-PAS-B2G-12-023

NEW

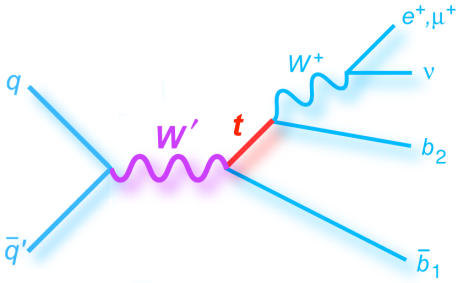
- Resonances in $m_{t\bar{t}}$ (e.g. Z' or KK gluon).
  Mass limits $\mathcal{O}$(2 TeV).
  More details in plenary talk by Fabienne Ledroit



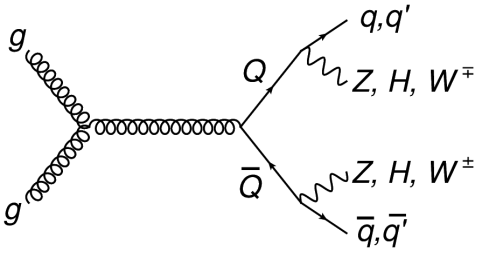
- Excited states ($t^\star, b^\star$).
  Mass limits $\mathcal{O}$(800 GeV).



- Heavy vector bosons (W').
  Mass limits $\mathcal{O}$(1-2 TeV).
  More details in plenary talk by Fabienne Ledroit



- Vector-like quarks ($T \to Zt, T \to Wb, T \to Ht, B \to Zb$).
  Mass limits $\mathcal{O}$(700 GeV).
  More details in plenary talk by Freya Blekman



- And many more...

- Very rich top physics program at LHC and Tevatron experiments.
- Most analyses are systematics limited.
- Top production
  - Pair production cross section with $\mathcal{O}$(4-6%) uncertainty.
  - Single top t-channel cross section with $\mathcal{O}$(20%) uncertainty.
  - s- and Wt-channel production observed at 3.7σ and 6σ level.
  - Associated production ($t\bar{t}V, t\bar{t}\gamma, t\bar{t}j$), differential cross section.
- Top properties
  - Top mass uncertainty is currently 0.5% (0.87 GeV).
  - Polarization, asymmetry and coupling measurements all consistent with SM (some tension in FB asymmetry).
  - Spin correlations observed.
  - Limits on FCNC and baryon number violation decays.
- Searches
  - Wide range of searches for new phenomena.

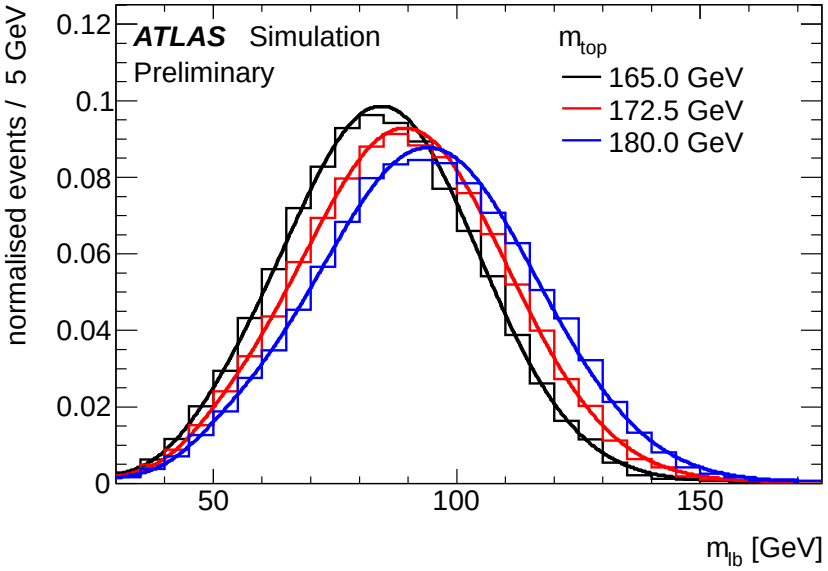
See Also - Parallel Session Talks

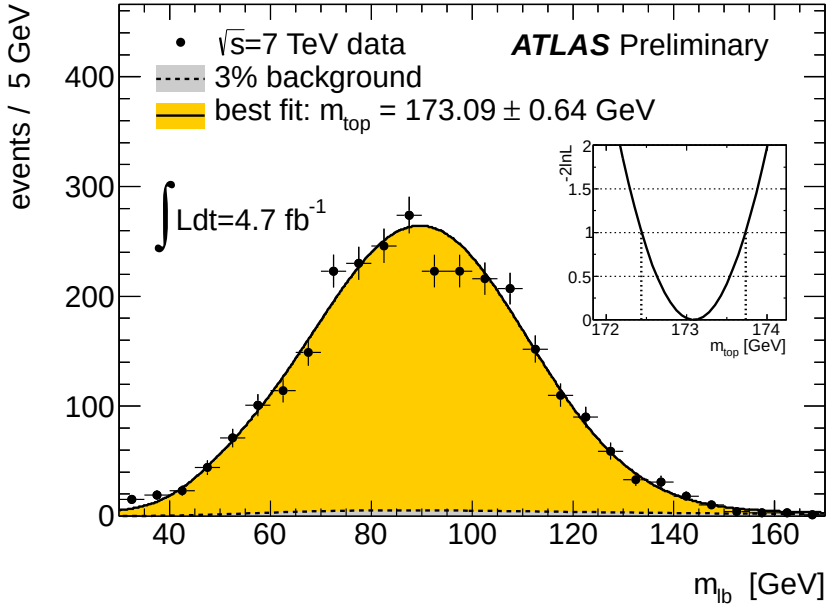
- *Differential cross sections for top-pair and single-top production*, KIDONAKIS, Nikolaos
- *Search for Single-Top Production in ep Collisions at HERA*, ANTONELLI, Stefano
- *Top quark mass measurements at and above threshold in e+e- collisions at Linear Colliders*, ROLOFF, Philipp
- *A precise determination of top quark electroweak couplings at the ILC operating at 500 GeV*, POESCHL, Roman
- *Measurement of the single top quark production cross section in pp collisions with the ATLAS detector*, KRASZNAHORKAY, Attila
- *Measurement of differential cross sections in top pair production in pp collisions with the ATLAS detector*, GARBERSON, Ford
- *Measurement of intrinsic top quark properties (top mass, charge, top and W polarisation, and search for FCNC in top decays) with the ATLAS detector*, MASETTI, Lucia
- *Top quark pair properties (spin correlations, charge asymmetry and complex final states) with the ATLAS detector*, MIJOVIC, Liza
- *t tbar b bbar production at NLO accuracy matched with parton shower*, TROCSANYI, Zoltan Laszlo
- *Measurement of the charge asymmetry in top quark pair production at the Tevatron*, DEMINA, Regina
- *Inclusive and differential top quark production at the Tevatron*, SORIN, Maria Veronica
- *Single top quark production cross section at the Tevatron*, GARCIA-BELLIDO ALVAREZ DE MIRANDA, Aran
- *Measurement of the top quark mass at the Tevatron*, PETERS, Reinhild
- *Top quark properties studies at the Tevatron*, LEONE, Sandra
- *Measurement of the inclusive top quark pair cross section in pp collisions at 7 and 8 TeV with the CMS detector*, MAES, Michael
- *Measurement of differential cross sections in top pair production in pp collisions with the CMS detector*, SYMONDS, Philip Hugh
- *Measurements of the production properties of top quark pairs in pp collisions (includes charge asymmetry and spin correlations) with the CMS detector*, DORLAND, Tyler Mc Millan
- *Measurement of the properties of top quarks in decays (top quark and W polarization, top quark charge and couplings) with the CMS detector*, SENGHI SOARES, Mara
- *CMS Measurements of the Top Quark Mass*, STADIE, Hartmut
- *New approaches in determining the mass of the top quark: alternative techniques and differential measurements*, BLYWEERT, Stijn
- *Measurement of t-channel single top quark production in pp collisions with the CMS detector*, IORIO, Alberto Orso Maria
- *Measurement of single top production in the tW-channel in pp collisions and search for FCNC with the CMS detector*, BENELLI, Gabriele
- *Top Decays with Flavor Changing Neutral Higgs Interactions at the LHC*, KAO, Chung
- *Probing for the t$\rightarrow$ch decay at the LHC*, HOU, George Wei-Shu
- *Four-loop on-shell integrals: MSbar – on-shell relation and g-2*, MARQUARD, Peter
- *NNLO top quark pair production*, FIEDLER, Paul
- *NLO merging in tt+jets*, SCHOENHERR, Marek
- *Top-quark Pair Production in a Running Mass Scheme*, DOWLING, Matthew
- *Measurement of the inclusive top quark pair cross section in pp collisions at 7 and 8 TeV with the ATLAS detector*, HENRICHS, Anna
- *Top quark mass measurements in ATLAS*, COMPOSTELLA, Gabriele
- *TOPLHCWG: combinations of top measurements at the LHC*, CRISTINZIANI, Markus

- *Search for ttbar resonances below 1 TeV in the semileptonic final state*, BROCHET, Sebastien
- *Search for Top Quark Flavour-changing Neutral-current Decays at 8 TeV*, CHAO, Yuan
- *Single top cross section measurements in the t-channel at CMS*, IORIO, Alberto
- *Measurement of differential top-quark-pair production cross sections in the lepton+jets channel with CMS*, LANGE, Joern
- *First measurement of single top production in the tW-channel in pp collisions*, BENELLI, Gabriele
- *Measurement of differential top-quark pair production cross sections in the dilepton final state at 8 TeV*, DORLAND, Tyler
- *A search of new charged heavy gauge W' bosons with the ATLAS detector at the LHC.*, GEOFFREY, Gilles
- *Measurement of jets in ttbar events with ATLAS.*, GRAHN, Karl-Johan
- *Probing QCD with top-quark pairs at CMS*, LIPKA, Katarina
- *Measurement of ttbar production with additional jet activity*, MARTIN, Maria

New Top Mass Measurement in Dilepton Channel by ATLAS

- Select events with exactly 2 charged leptons (e,μ), $E_{\mathrm{T}}^{\mathrm{miss}}$ and exactly 2 b-tagged jets.
- Background $<$ 3%.
- Template method with $m_{\ell b}$ as estimator for m_{top}.





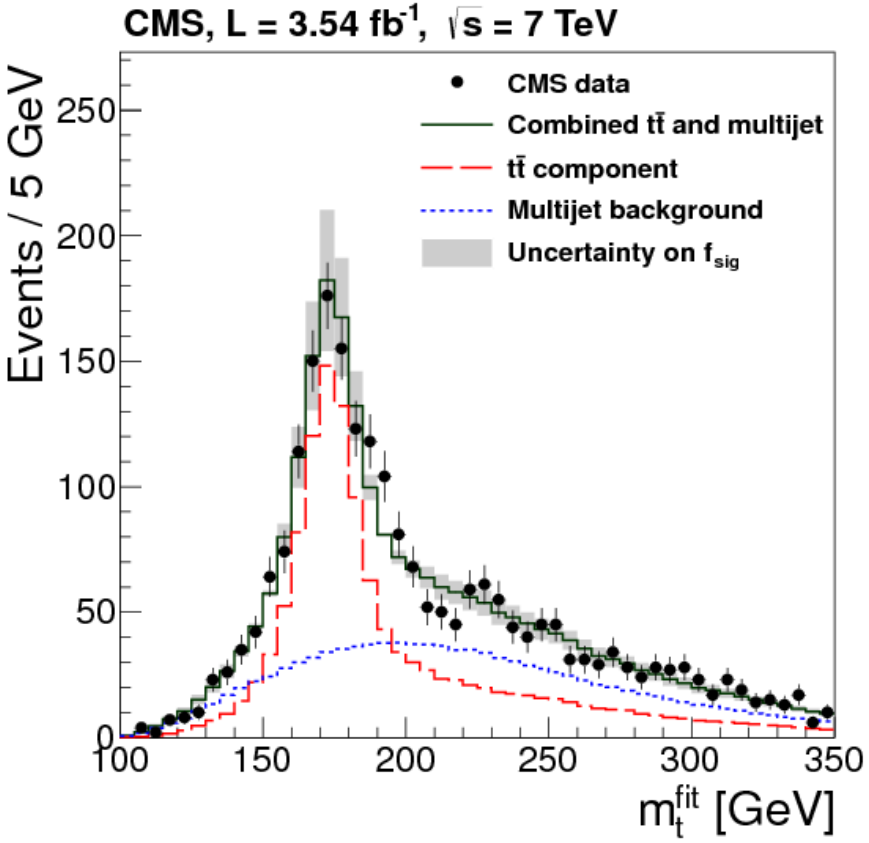
$$m_{\mathrm{top}} = 173.09 \pm 0.64(\mathrm{stat}) \pm 1.50(\mathrm{syst})\ \mathrm{GeV}$$

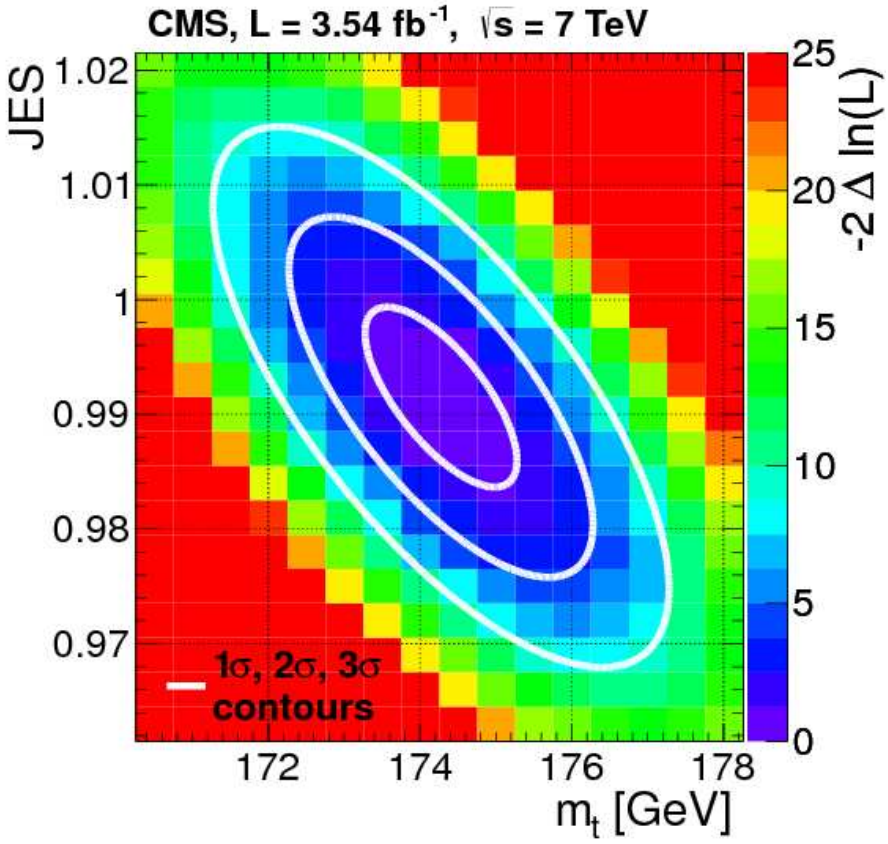
Dominant uncertainties: JES and bJES

NEW

New Top Mass Measurement in Alljets Channel by CMS

- Select events with exactly 6 jets (at least two b-tagged).
- Kinematic fit: 2×2 untagged jets ($m_{jj} = 80.4$ GeV). Combine with two b-jets ($m_{jjb} = m_{jj\bar{b}}$).





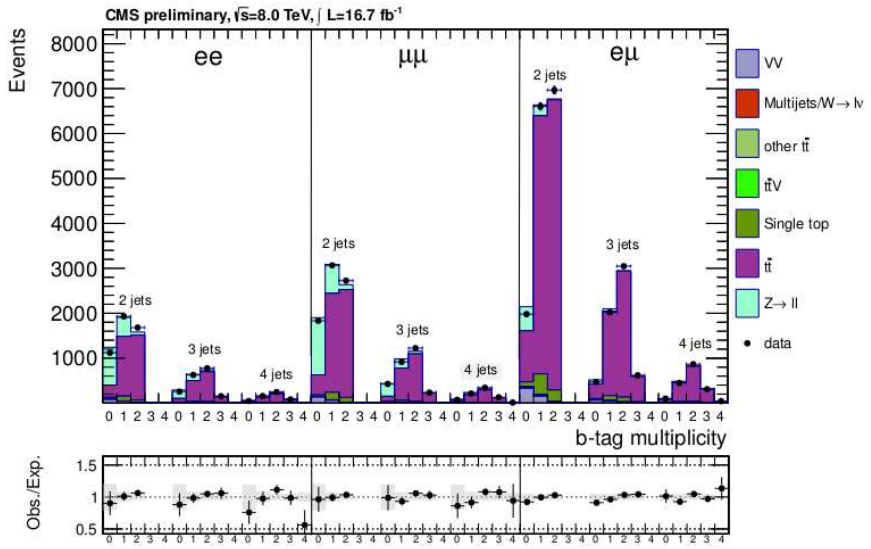
NEW

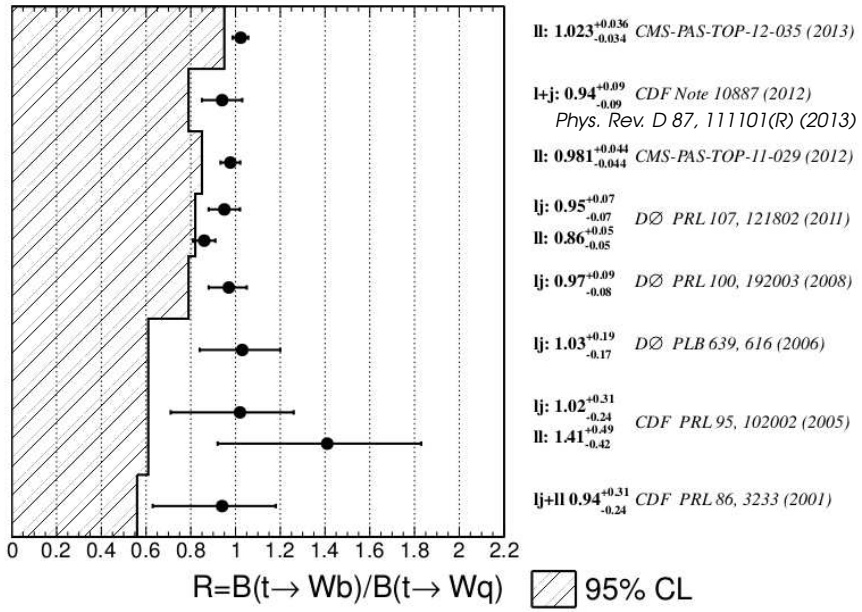
$$m_{\text{top}} = 173.54 \pm 0.33(\text{stat}) \pm 0.96(\text{syst}) \text{ GeV}$$

Dominant uncertainties: JES and bJES

Branching Ratio $BR(t \to Wb)/BR(t \to Wq)$

- Branching ratio $t \to Wb$ is ≈ 1 in SM.
- Measure $R = BR(t \to Wb)/BR(t \to Wq)$ by fitting number of b-jets in $t\bar{t}$ events.

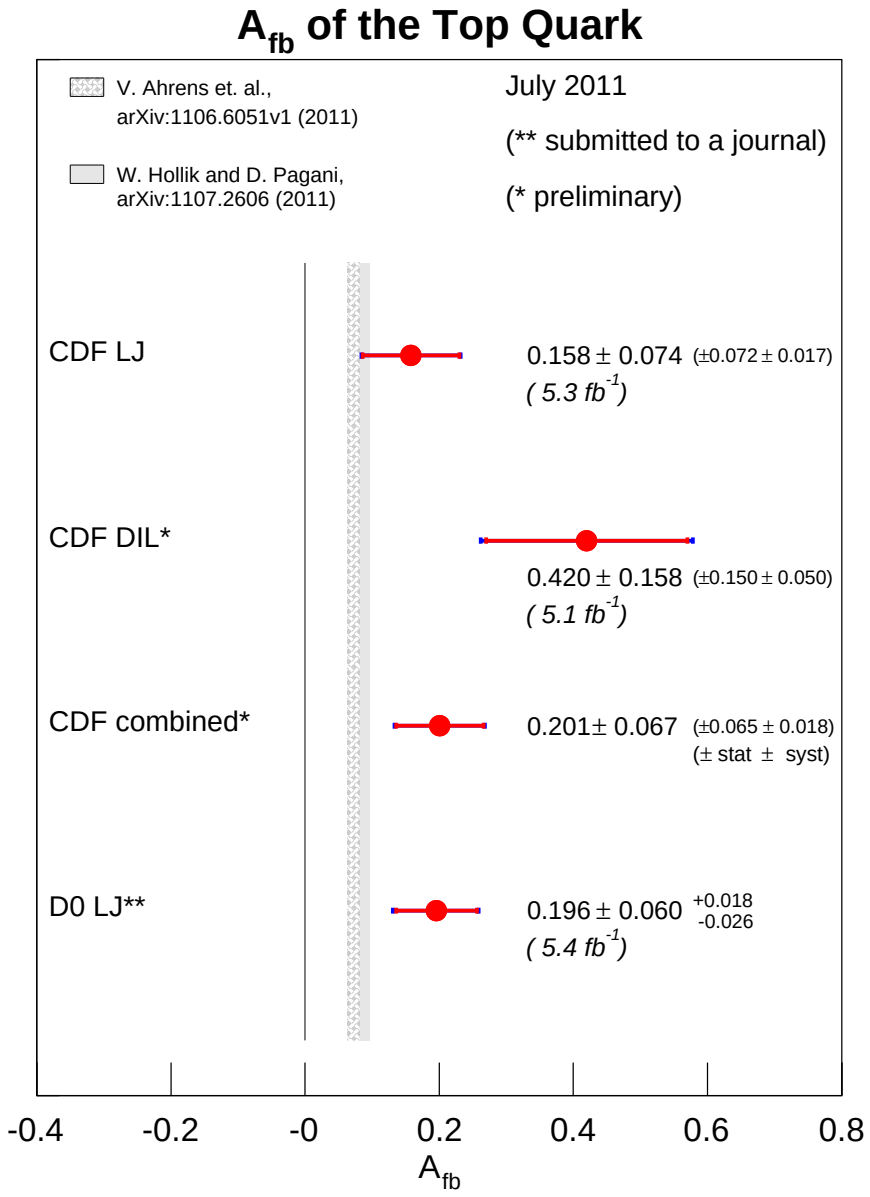


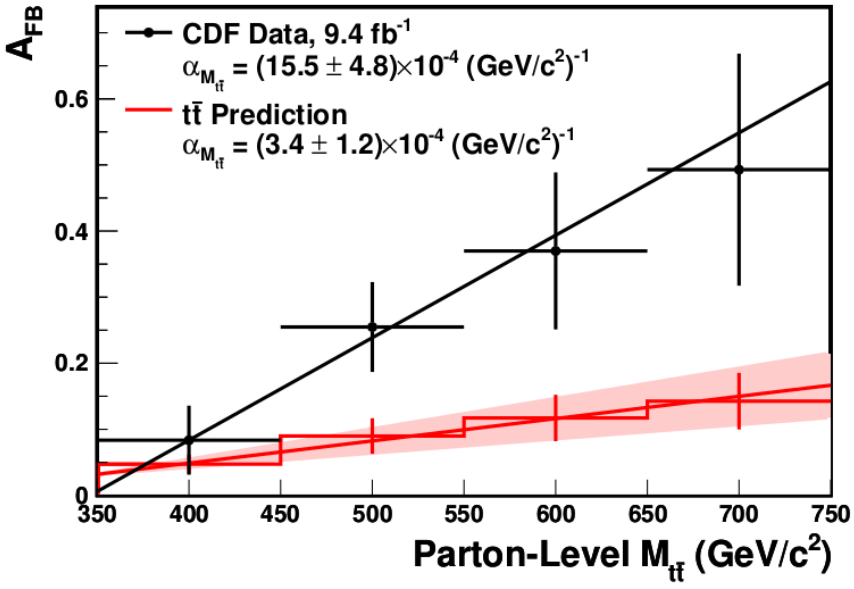


- Extract $|V_{tb}|$ by assuming a unitary, three-generation CKM matrix.
- Complementary to single top measurements.

CMS-PAS-TOP-12-035

Top Forward-Backward Asymmetry at the Tevatron

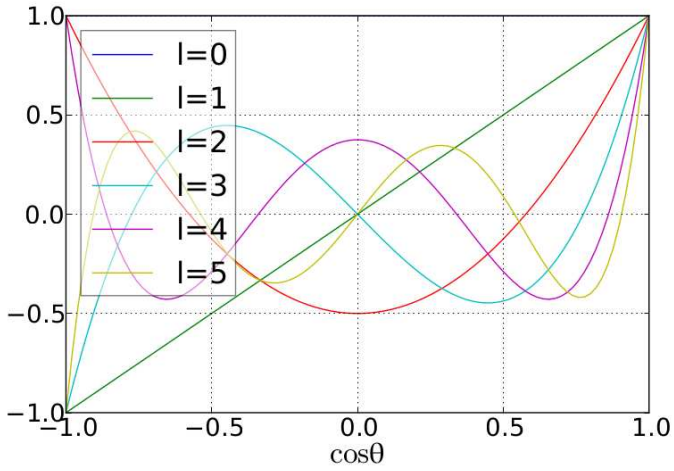


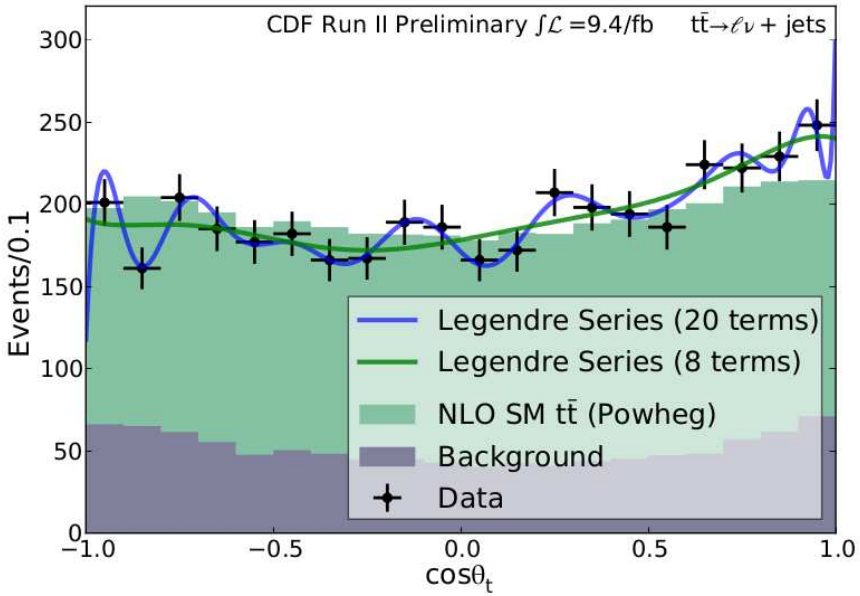


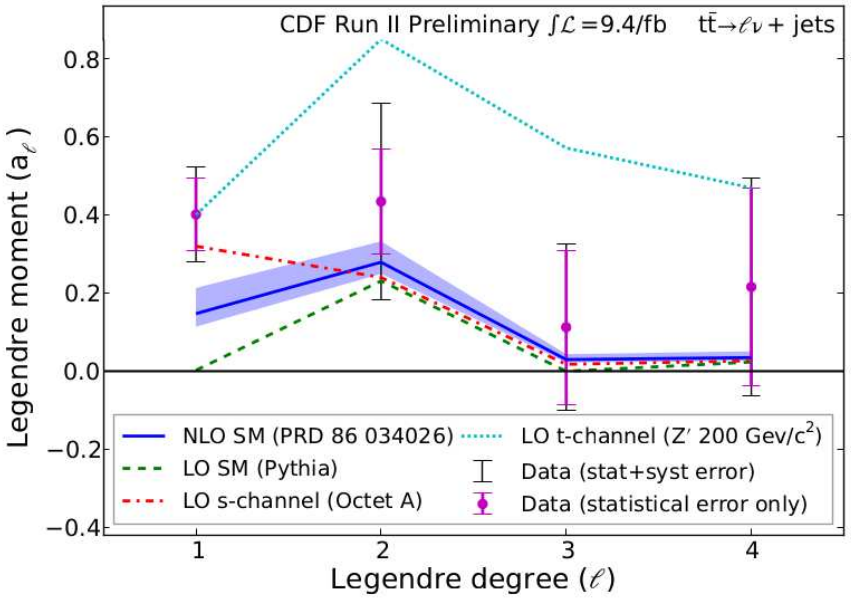
- Updated measurement from CDF in ℓ+jets.
- Measured A_{FB} deviate most from SM at large $M_{t\bar{t}}$.

CDF Note 10975

- Fit $\cos\theta_t$ distribution with Legendre polynomials.
- Discrepancy with SM prediction only for the linear term (consistent with s-channel new physics).

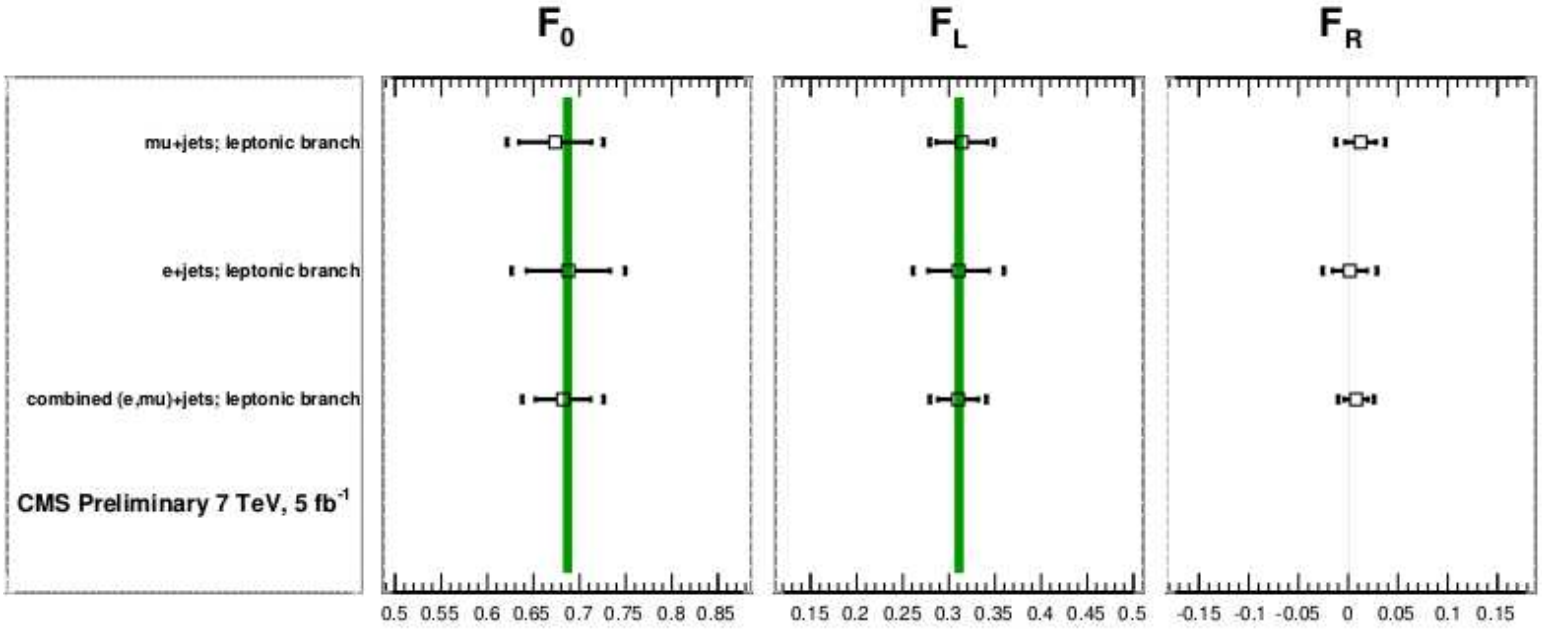


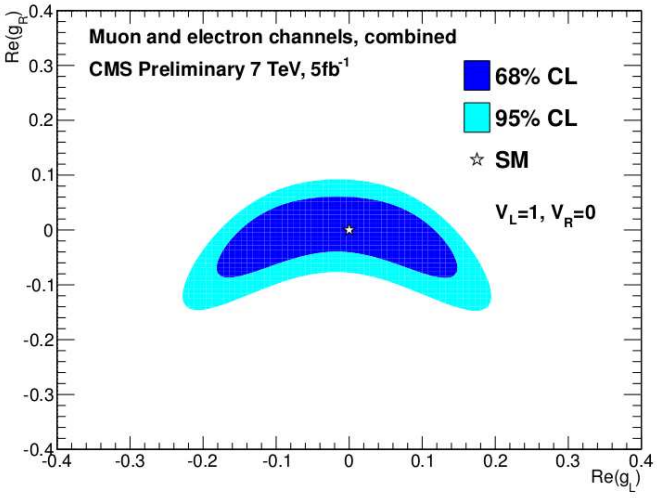




CDF Note 10974

W Helicity Fractions in Single Lepton Events from CMS





$$F_0 = 0.682 \pm 0.030(\text{stat}) \pm 0.033(\text{syst})$$

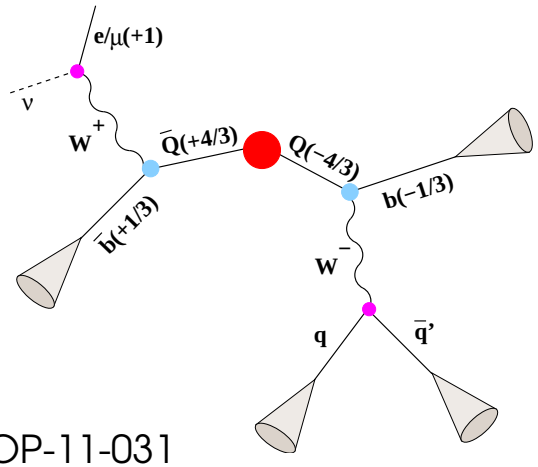
$$F_L = 0.310 \pm 0.022(\text{stat}) \pm 0.022(\text{syst})$$

$$F_R = 0.008 \pm 0.012(\text{stat}) \pm 0.014(\text{syst})$$

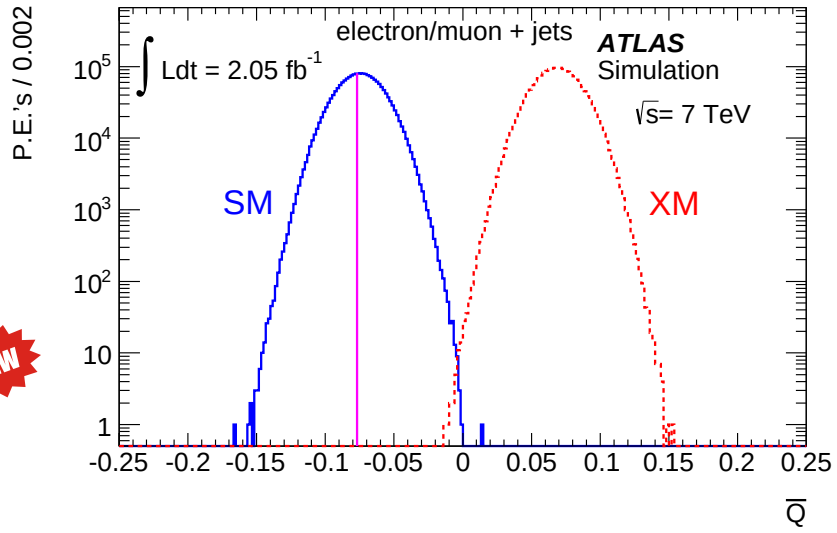
NEW

CMS-PAS-TOP-11-020

- Ambiguity when pairing W boson to b jet.
- Exotic models with $|q| = 4e/3$ instead of $|q| = 2e/3$ exist.



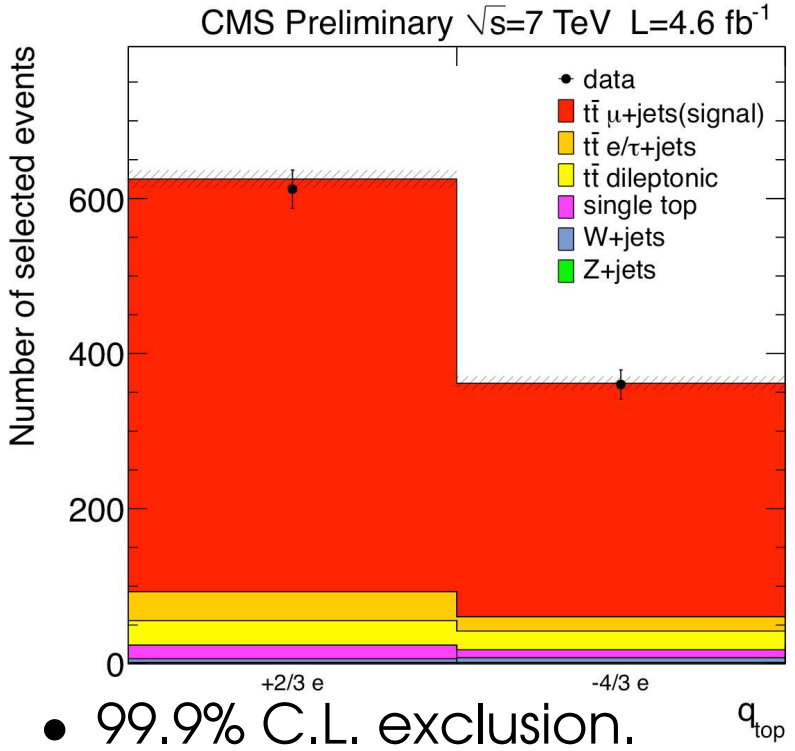
arXiv:1307.4568 (hep-ex)



NEW

- $q_{\text{top}} = 0.64 \pm 0.02(\text{stat}) \pm 0.08(\text{syst.})$
- Exotic model excluded at $> 8\sigma$.

CMS-PAS-TOP-11-031



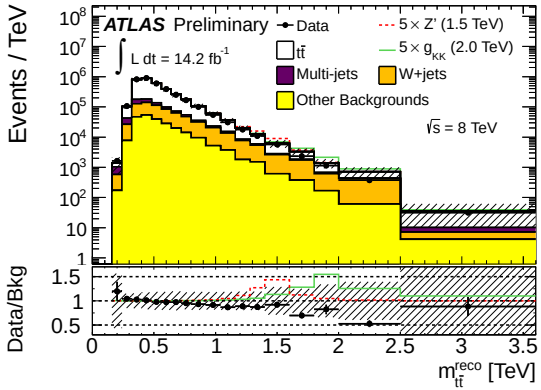
- 99.9% C.L. exclusion.

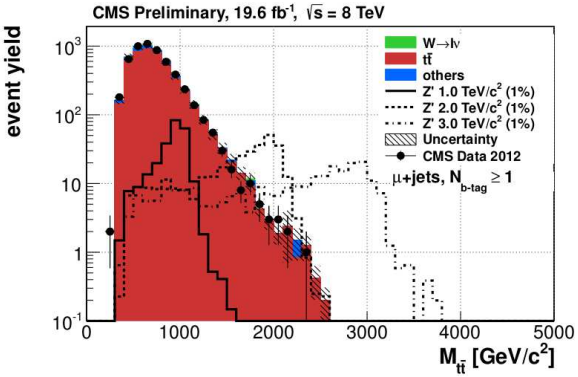
Resonances in $m_{t\bar{t}}$

- Top pair production can be enhanced by new particles decaying into $t\bar{t}$ pairs (e.g. Z' or KK gluon).
- Search for narrow and broad resonances in $t\bar{t}$ invariant mass.

l+jets

ATLAS-CONF-2013-052

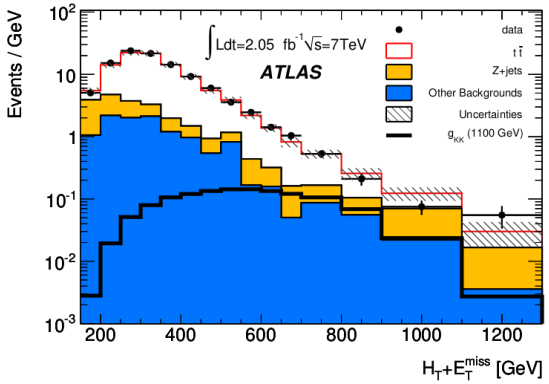


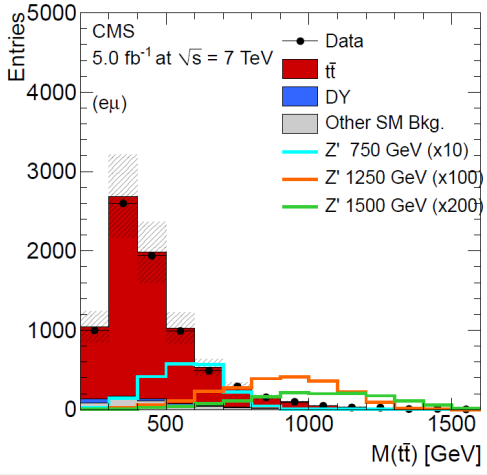


CMS-PAS-B2G-12-006

dilepton

ATLAS-CONF-2011-123

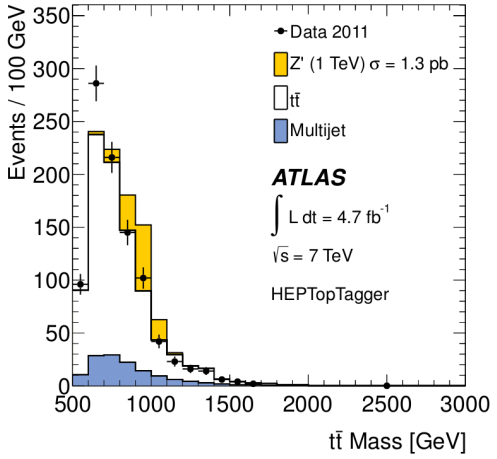


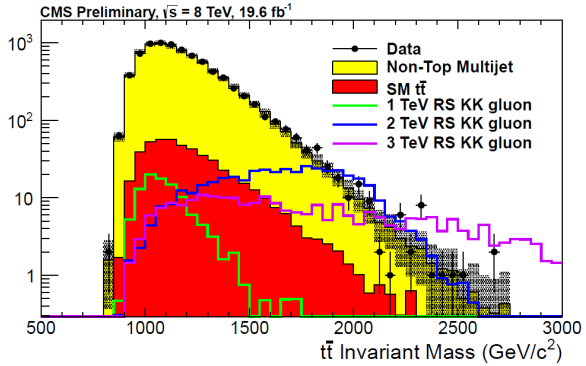


CERN-PH-EP-2012-324

alljets

JHEP01(2013)116

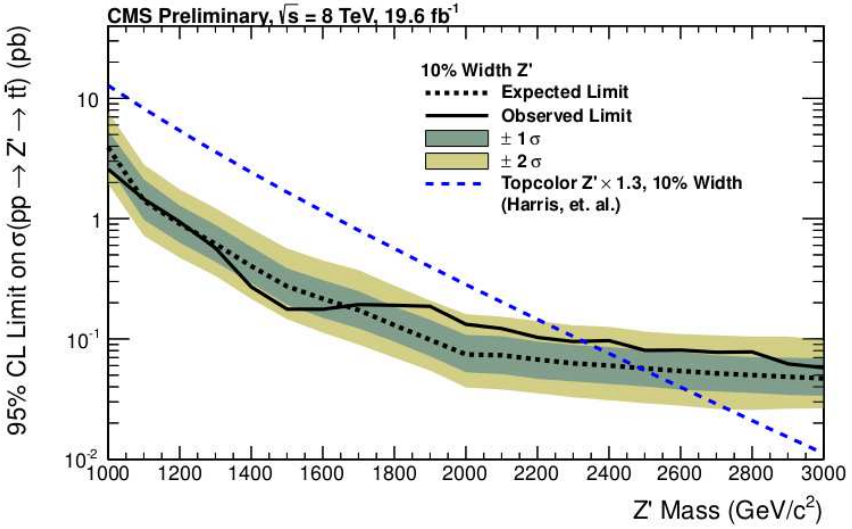




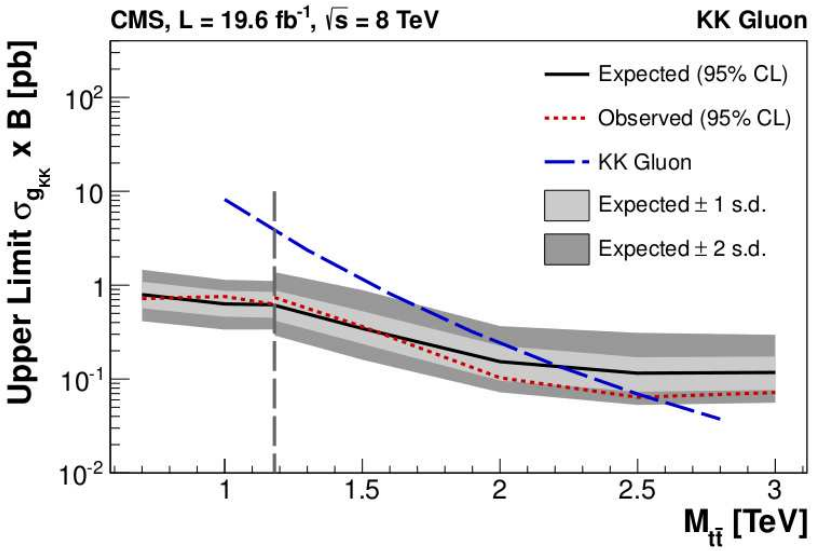
CMS-PAS-B2G-12-005

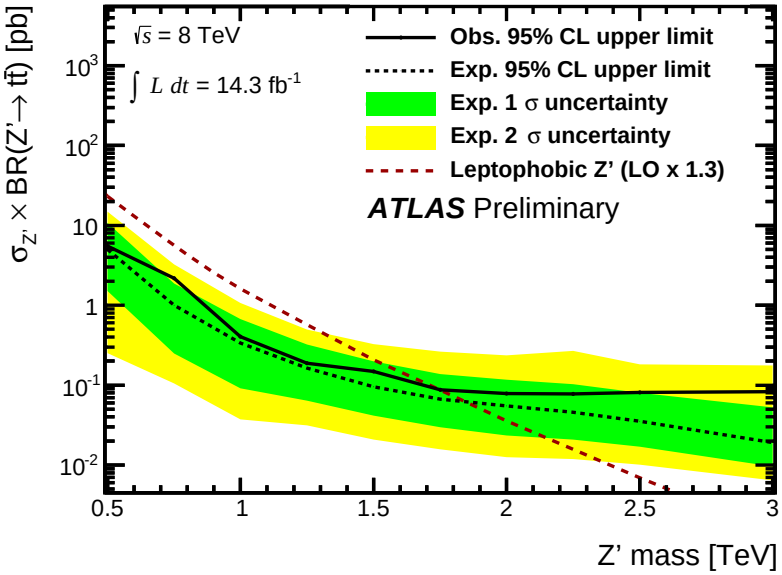
Resonances in $m_{t\bar{t}}$

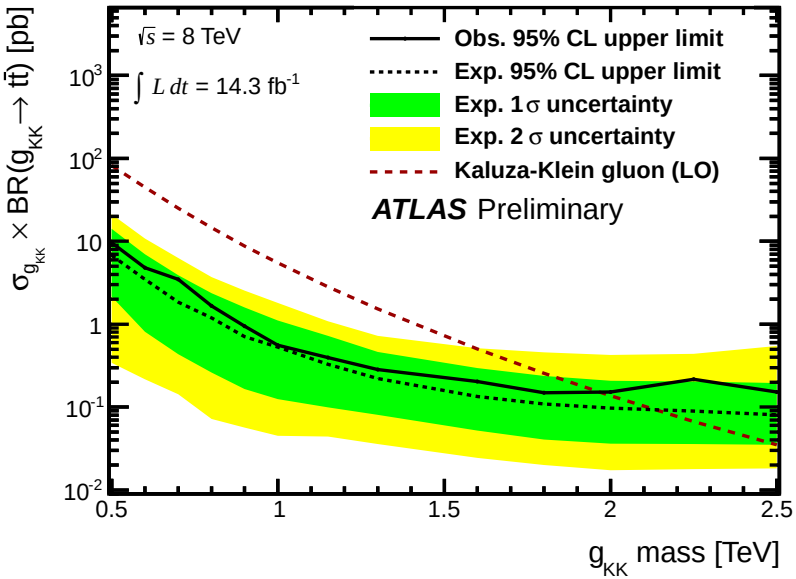
CMS-PAS-B2G-12-005



CMS-PAS-B2G-12-006

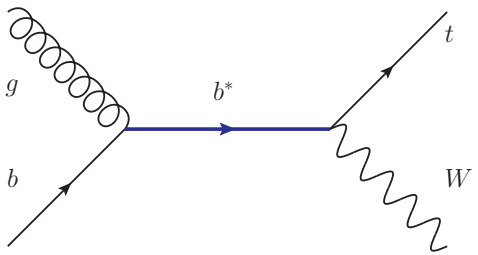






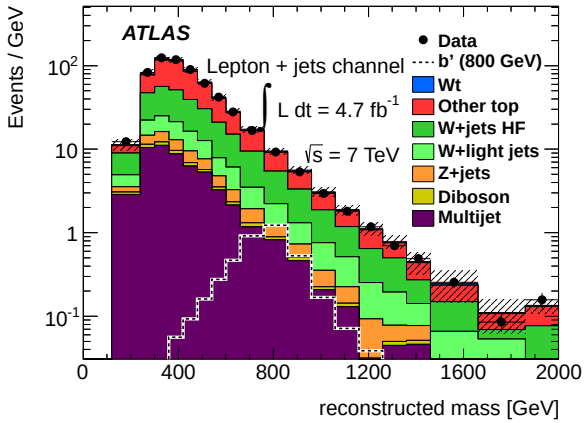
ATLAS-CONF-2013-052

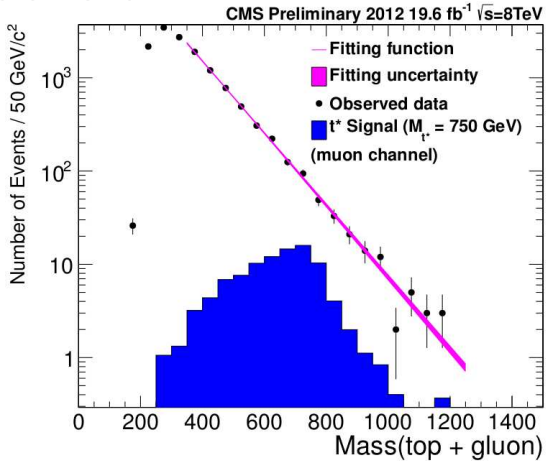
- Excited states ($t^\star, b^\star$). Mass limits around 800 GeV.



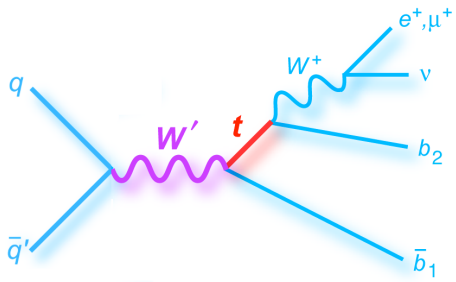
Phys. Lett. B 721 (2013) 171-189

CMS-PAS-B2G-12-014



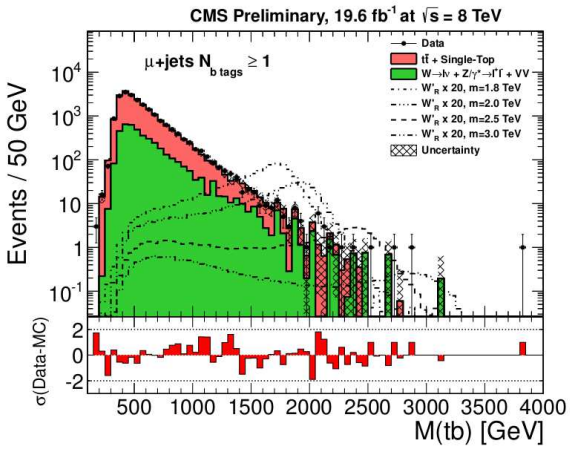


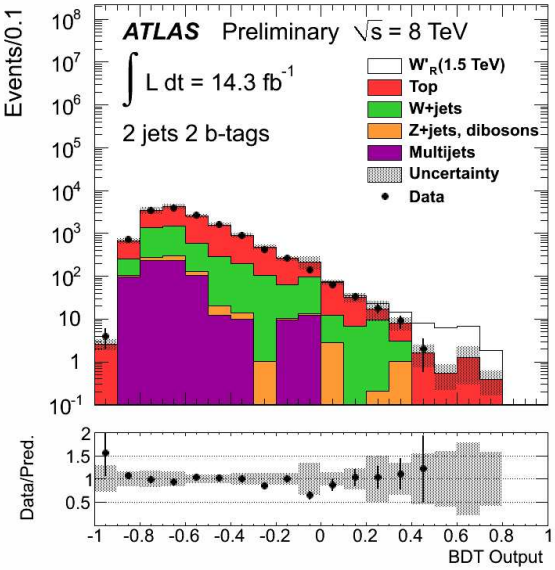
- Heavy vector bosons (W'). Mass limits $\mathcal{O}$(1-2 TeV).



ATLAS-CONF-2013-050

CMS-PAS-B2G-12-010

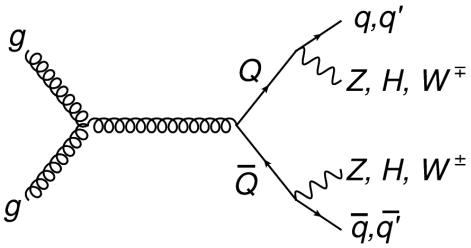


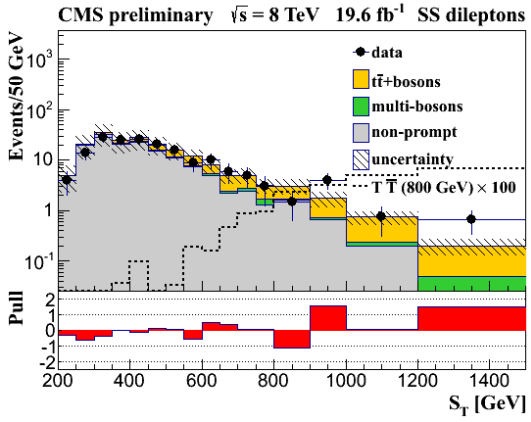


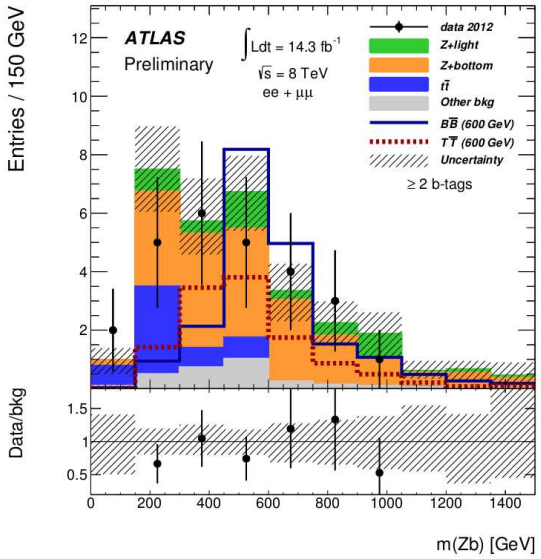
More details in plenary talk by Fabienne Ledroit

Other New Physics Searches

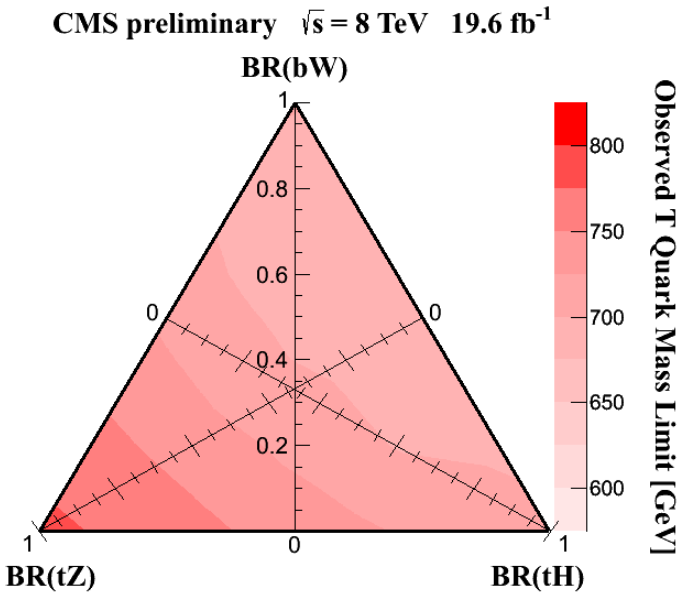
- Vector-like quarks. Mass limits $\mathcal{O}(700$ GeV).
  $(T \to Zt, T \to Wb, T \to Ht, B \to Zb)$

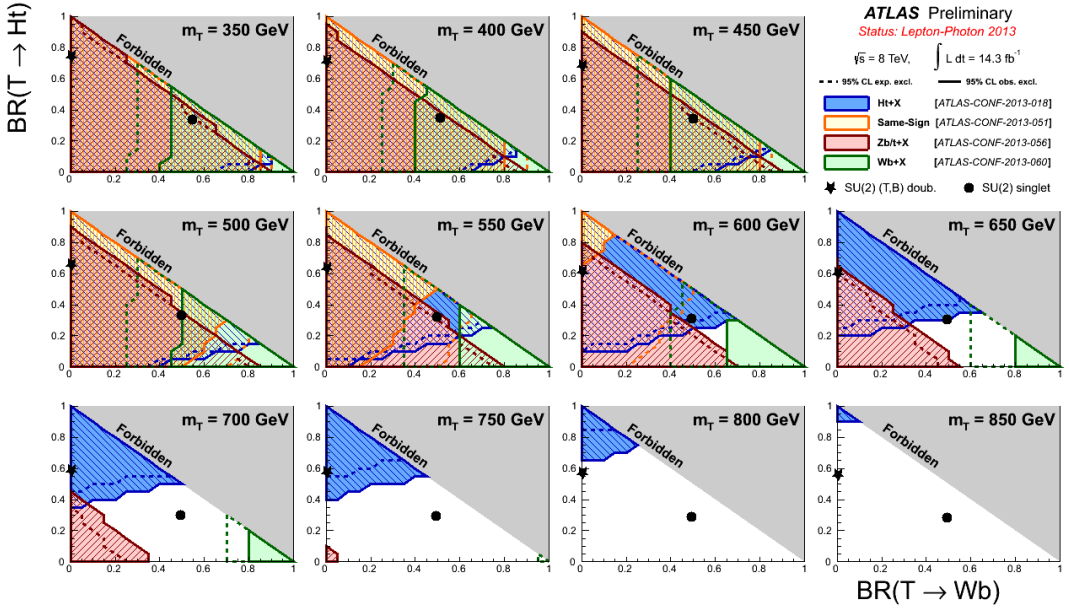






CMS-PAS-B2G-12-015





- And many more...

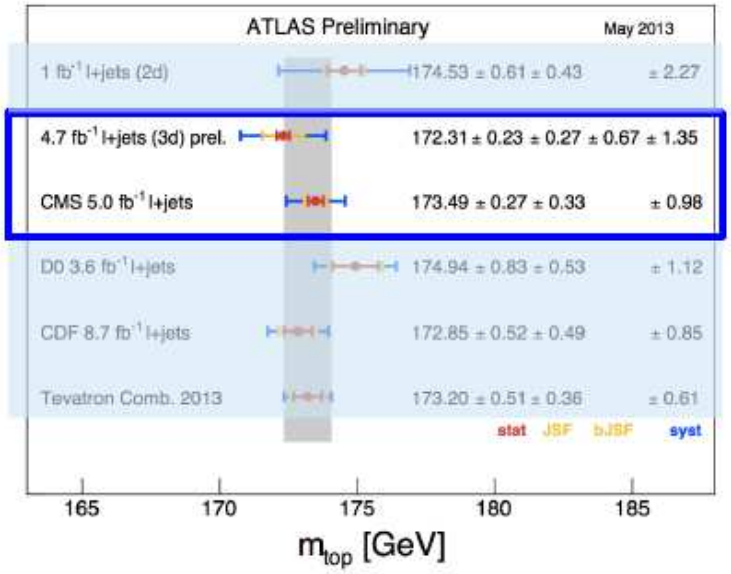
ATLAS-CONF-2013-018, ATLAS-CONF-2013-051
ATLAS-CONF-2013-056, ATLAS-CONF-2013-060

ATLAS-CMS Comparison of Top Mass Uncertainties

lepton+jets m_{top}: ATLAS vs CMS comparison

Uncertainty Categories			ATLAS / CMS	
Tevatron	ATLAS	CMS	2011 *l*+jets	2011 *l*+jets
	Measured m_{top}		172.31	173.49
	Jet Scale Factor	Jet Scale Factor	0.27	0.33
	bJet Scale Factor		0.67	
iJES	Sum	Sum	0.72	0.33
bJES	JES_{b-jet}	JES_{b-jet}	0.08	0.61
dJES	$JES_{light-jet}$	$JES_{light-jet}$	0.79	0.28
	Lepton p_T Scale		0.04	0.02
MC	MC Generator	MC Generator	0.19	
	Hadronisation		0.27	
	Sum	Sum	0.33	
Rad	ISR/FSR	ISR/FSR	0.45	
		Q-Scale		0.24
		Jet-Parton Scale		0.18
	Sum	Sum	0.45	0.30
CR	Colour Recon.		0.32	0.54
PDF	Proton PDF	Proton PDF	0.17	0.07
	Jet Energy Res.	Jet Energy Res.	0.22	0.23
	Jet Rec. Eff.		0.05	
	b-tagging	*b*-tagging	0.81	0.12
	E_T^{miss}	E_T^{miss}	0.03	0.06
DetMod	Sum	Sum	0.84	0.27
	Underlying Event		0.12	0.15
	BGMC			0.13
	BGData		0.10	
Method	Method Calib.	Method Calib.	0.13	0.06
MHI	Pile-up	Pile-up	0.03	0.07
		Statistics	0.23	0.27
		Rest	1.53	1.03
		Total Uncertainty	1.55	1.07

Summary table of public 2011 LHC m_{top} measurements in the lepton+jets channel, likely to drive the next LHC combination



Systematics categorized according to the first LHC combination CMS measurement from: JHEP (2012) 2012:105

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		Total Uncertainty	1.55	1.07

Statistical sensitivity

- extra statistical uncertainties on m_{top} introduced by the simultaneous JSF/bJSF fits
- Scale with luminosity, uncorrelated between experiments
- Similar sensitivity to JSF from the in-situ m_W fits (0.27 vs 0.33 GeV)
- ATLAS has larger JES stat component (iJES) due to the increased dimensionality of the fit (extra 0.67 GeV)

Similar statistical sensitivity to m_{top} (corresponds to a 1d fit)

top quark mass in ATLAS - EPS HEP 18-24 July 2013 26

ATLAS-CMS Comparison of Top Mass Uncertainties

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MHI	Pile-up	Pile-up	0.03	0.07
		Statistics	0.23	0.27
		Rest	1.53	1.03
		Total Uncertainty	1.55	1.07

Reduced bJES uncertainty thanks to 3rd dimension in the fit

top quark mass in ATLAS - EPS HEP 18-24 July 2013 27

ATLAS-CMS Comparison of Top Mass Uncertainties

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	Hadronisation		0.27	
	Sum	Sum	0.33	
Rad	ISR/FSR	ISR/FSR	0.45	
		Q-Scale		0.24
		Jet-Parton Scale		0.18
	Sum	Sum	0.45	0.30
CR	Colour Recon.		0.32	0.54
PDF	Proton PDF	Proton PDF	0.17	0.07
	Jet Energy Res.	Jet Energy Res.	0.22	0.23
	Jet Rec. Eff.		0.05	
	b-tagging	*b*-tagging	0.81	0.12
	E_T^{miss}	E_T^{miss}	0.03	0.06
DetMod	Sum	Sum	0.84	0.27
	Underlying Event		0.12	0.15
	BGMC			0.13
	BGData		0.10	
Method	Method Calib.	Method Calib.	0.13	0.06
MHI	Pile-up	Pile-up	0.03	0.07
		Statistics	0.23	0.27
		Rest	1.53	1.03
		Total Uncertainty	1.55	1.07

Different residual JES uncertainties, despite the in-situ m_W calibration

More pronounced p_T dependence of the JES uncertainty for ATLAS, softer jet p_T requirements

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ATLAS-CMS Comparison of Top Mass Uncertainties

lepton+jets m_{top}: ATLAS vs CMS comparison

Uncertainty Categories			ATLAS / CMS	
Tevatron	ATLAS	CMS	2011 l+jets	2011 l+jets
	Measured m_{top}		172.31	173.49
	Jet Scale Factor	Jet Scale Factor	0.27	0.33
	bJet Scale Factor		0.67	
iJES	Sum	Sum	0.72	0.33
bJES	JES_{b-jet}	JES_{b-jet}	0.08	0.61
dJES	$JES_{light-jet}$	$JES_{light-jet}$	0.79	0.28
	Lepton p_T Scale		0.04	0.02
MC	MC Generator	MC Generator	0.19	
	Hadronisation		0.27	
	Sum	Sum	0.33	
Rad	ISR/FSR	ISR/FSR	0.45	
		Q-Scale		0.24
		Jet-Parton Scale		0.18
	Sum	Sum	0.45	0.30
CR	Colour Recon.		0.32	0.54
PDF	Proton PDF	Proton PDF	0.17	0.07
	Jet Energy Res.	Jet Energy Res.	0.22	0.23
	Jet Rec. Eff.		0.05	
	b-tagging	b-tagging	0.81	0.12
	E_T^{miss}	E_T^{miss}	0.03	0.06
DetMod	Sum	Sum	0.84	0.27
	Underlying Event		0.12	0.15
	BGMC			0.13
	BGData		0.10	
Method	Method Calib.	Method Calib.	0.13	0.06
MHI	Pile-up	Pile-up	0.03	0.07
		Statistics	0.23	0.27
		Rest	1.53	1.03
		Total Uncertainty	1.55	1.07

MC generator and hadronization (Pythia/Herwig) uncertainties:

Not dominant uncertainties for ATLAS 3d analysis but could be large depending on the analysis

Within CMS:

- the MC generator systematics are found to be small (but are not documented for all the current public results)
- Hadronization systematics are meant to be covered by the JES uncertainty

Harmonized treatment is under discussion in the TOP-LHC-WG for the next LHC combination

Need to evaluate possible double counting effects between the hadronization and JES systematics

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ATLAS-CMS Comparison of Top Mass Uncertainties

lepton+jets m_{top}: ATLAS vs CMS comparison

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	Sum	Sum	0.45	0.30
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PDF	Proton PDF	Proton PDF	0.17	0.07
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	BGData		0.10	
Method	Method Calib.	Method Calib.	0.13	0.06
MHI	Pile-up	Pile-up	0.03	0.07
		Statistics	0.23	0.27
		Rest	1.53	1.03
		Total Uncertainty	1.55	1.07

ATLAS 3d analysis has a larger sensitivity to b-tag systematics, mainly due to p_T dependence of the b-tagging SF uncertainties, that affect the shape of R_{lb}^{reco}