Top quark properties (including mass) at CMS

Phenomenology 2014 Symposium

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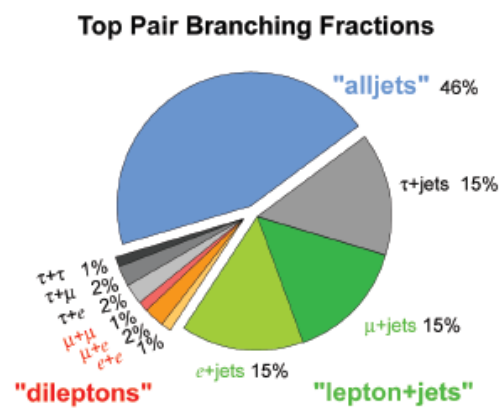
on behalf of the
CMS collaboration

Introduction

Heaviest elementary particle known

- Produced at the LHC predominantly through strong interactions - high production rate
- Decays predominantly through t→bW
- Decays before hadronization - access spin information via its decay products

x-sec (pb)	ttbar
Tevatron	7.08 (+0.00-0.24) (+0.36-0.27) approx. NNLO
LHC @ 7TeV	163 (+7-5)(±9) approx. NNLO
LHC @ 8TeV	234 (+10-7)(±12) approx. NNLO



Test Standard Model predictions

- Mass, couplings, and other properties have been measured precisely at the LHC

Probe to new physics

- Large couplings to the Higgs boston
- Special role in the EW symmetry breaking in many new physics scenarios

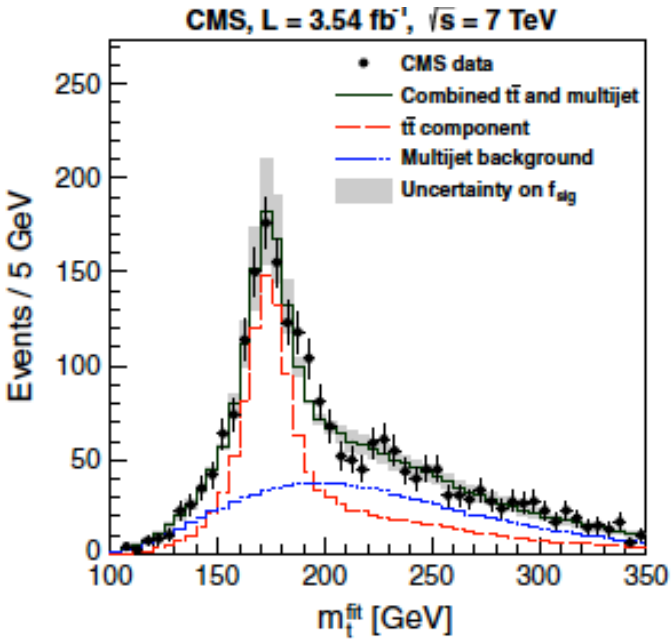
Outline:

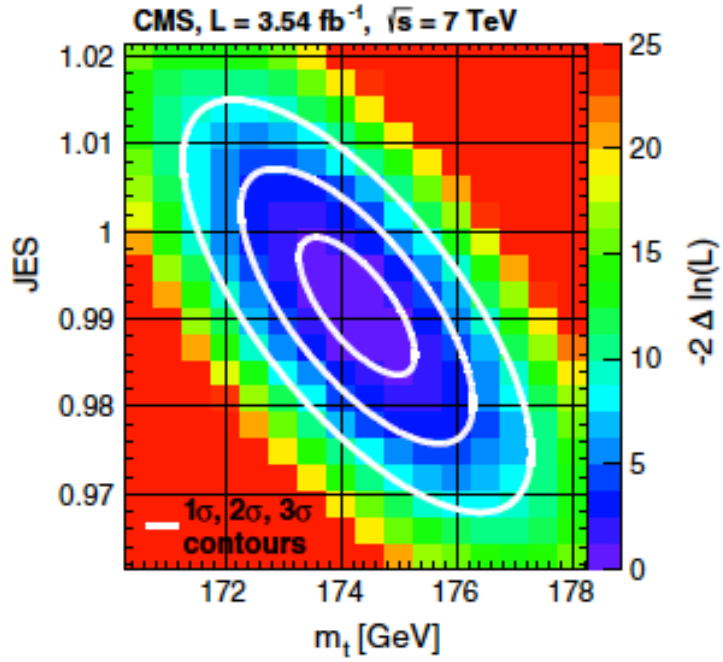
- Top mass
- TTbar spin correlation and top polarization
- Top pair charge asymmetry
- W helicity in top decays
- Search for anomalous couplings
- TTbar association production with photon

Top mass at 7 TeV - hadronic

- **2011 dataset at $\sqrt{s}$ = 7 TeV:3.54/fb**
- At least 6 jets, at least two of them are b-tagged
- Kinematic fit with the constraints that the reconstructed masses of two tops are equal and the mass of both W bosons is 80.4 GeV
- Cuts on the goodness of fit probability and separation of the two b jets are applied
- Ideogram method uses a likelihood function that allows the determination of the JES and the top quark mass simultaneously by a joint fit to all events in data

CMS-TOP-11-017
EPJC 74 (2014) 2758



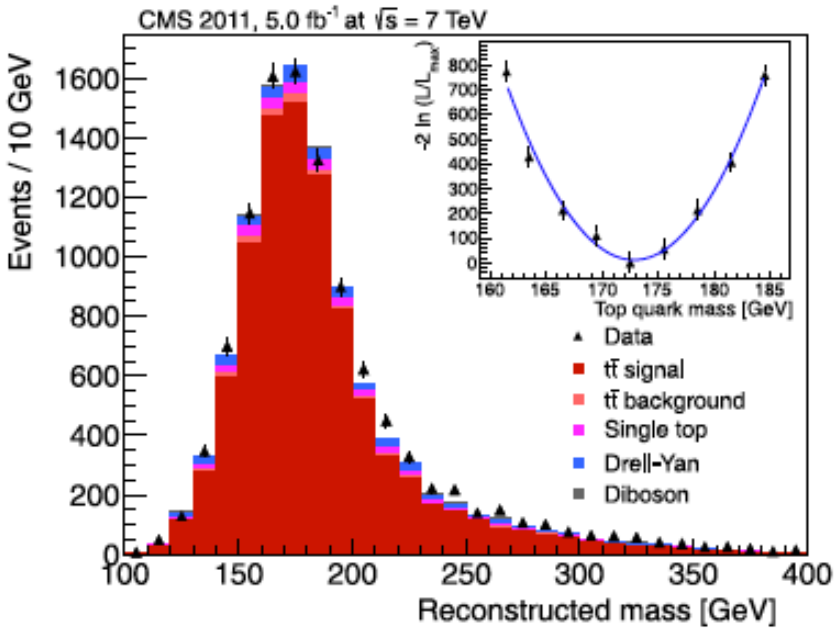


M_t = 173.49±0.69(stat)±1.21(syst) GeV (Fixed JES)
2D Fit Results: mt = 174.28±1.00(stat+JES)±1.23(syst) GeV and JES =0.991±0.008(stat)±0.013(syst)

Top mass at 7 TeV - dilepton

- **Full 2011 dataset at $\sqrt{s}$ = 7 TeV: 5.0/fb**
- Two isolated leptons, at least two jets (at least one b-tagged jet), MET
- Analytical Matrix Weighting Technique: the kinematic equations are solved many times per event using a series of top-quark mass hypotheses **between 100 and 400 GeV in 1 GeV steps.**
- Each solution is weighted according to top mass hypothesis and lepton momenta

CMS-TOP-11-016
EPJC 72 (2012) 2202



- For each event, the mass hypothesis with maximum weight is chosen
- For each value of M_t, a likelihood is computed by comparing the reconstructed mass distribution in data with the expectation in simulation

M_t = 172.5±0.4(stat)±1.5(syst) GeV

Top mass at 7 TeV - dilepton

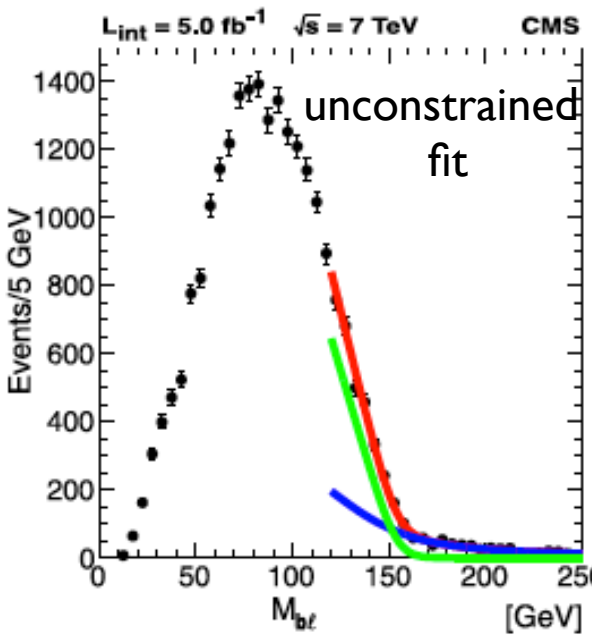
- **Full 2011 dataset at $\sqrt{s}$ = 7 TeV: 5.0/fb**
- Two isolated leptons, at least two b-tagged jets, MET
- Technique is based on edges of M_{T2} distributions
- M_ν^2, M_w and M_t are obtained in a simultaneous fit to three endpoints

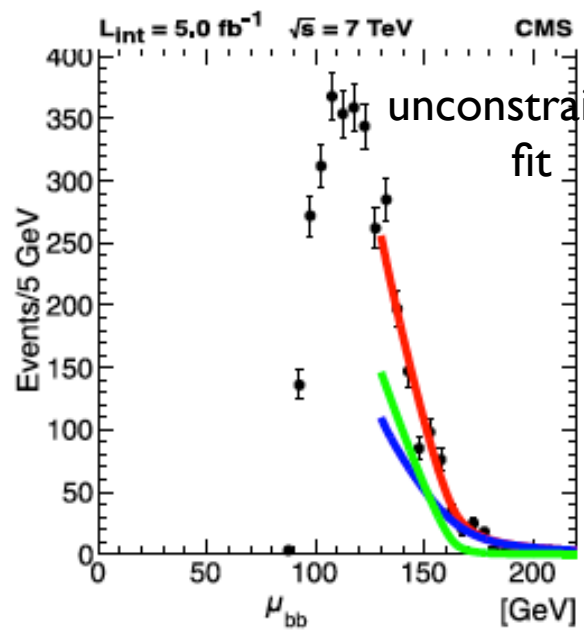
μ_{bb} : lower bound of m_t for known m_W

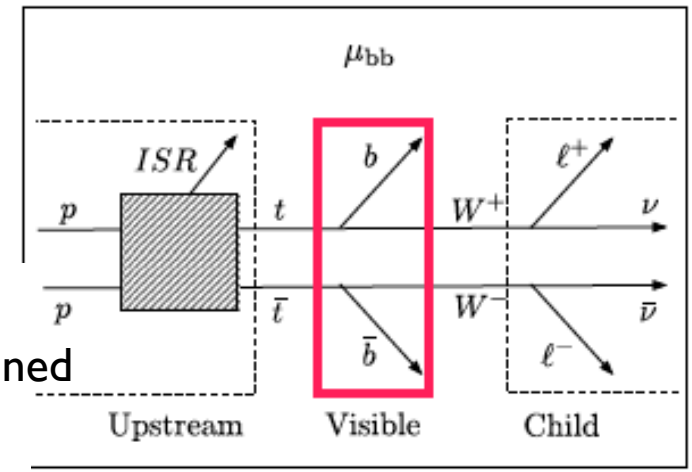
μ_{ll} : endpoint is the W boson mass at $m_\nu = 0$

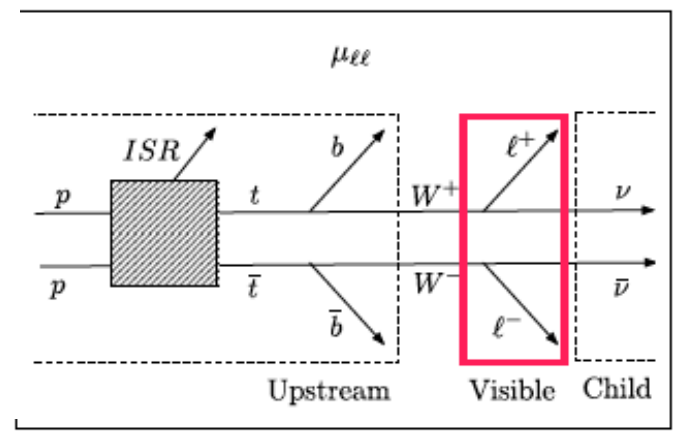
M_{bl} : endpoint is $\sqrt{(m_t^2 - m_W^2)(m_W^2 - m_\nu^2)/m_W^2}$

CMS-TOP-11-027
EPIC 73 (2013) 2494







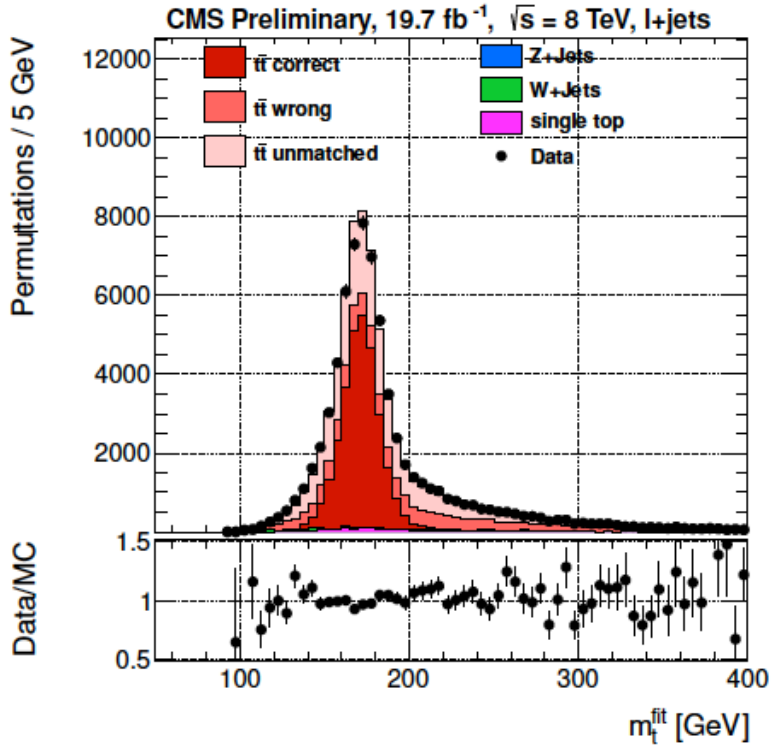


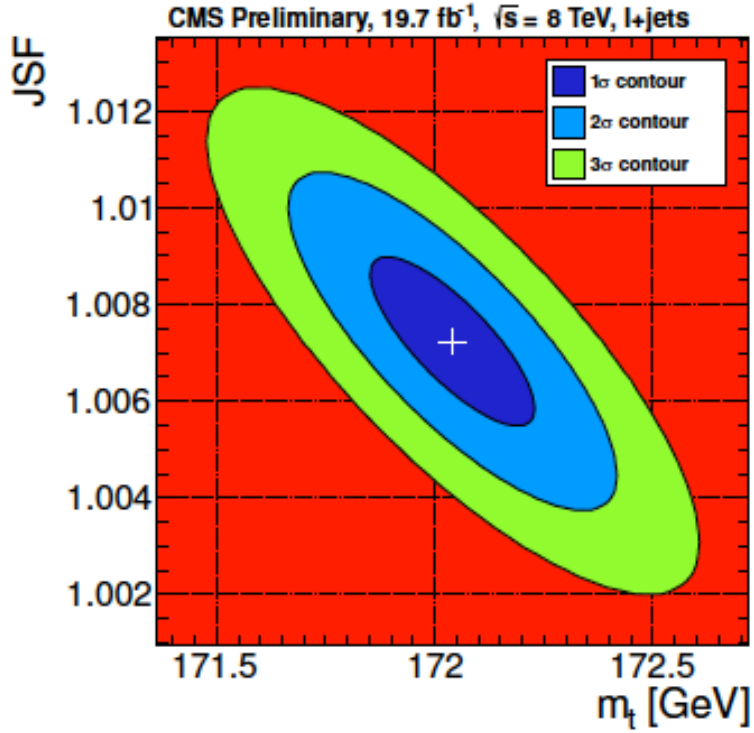
M_t = 173.9±0.9(stat)$^{+1.7}_{-2.1}$(syst) GeV - fixed M_w and M_ν^2

Top mass at 8 TeV - single lepton

- **Full 2012 dataset at √s = 8 TeV: 19.7/fb**
- One isolated lepton, at least 4 jets, two of them are b-tagged , MET
- A kinematic fit of the decay products to a ttbar hypothesis
- Ideogram method: 2D likelihood functions for each event to estimate simultaneously the top-quark mass and the jet energy scale factor(JSF)

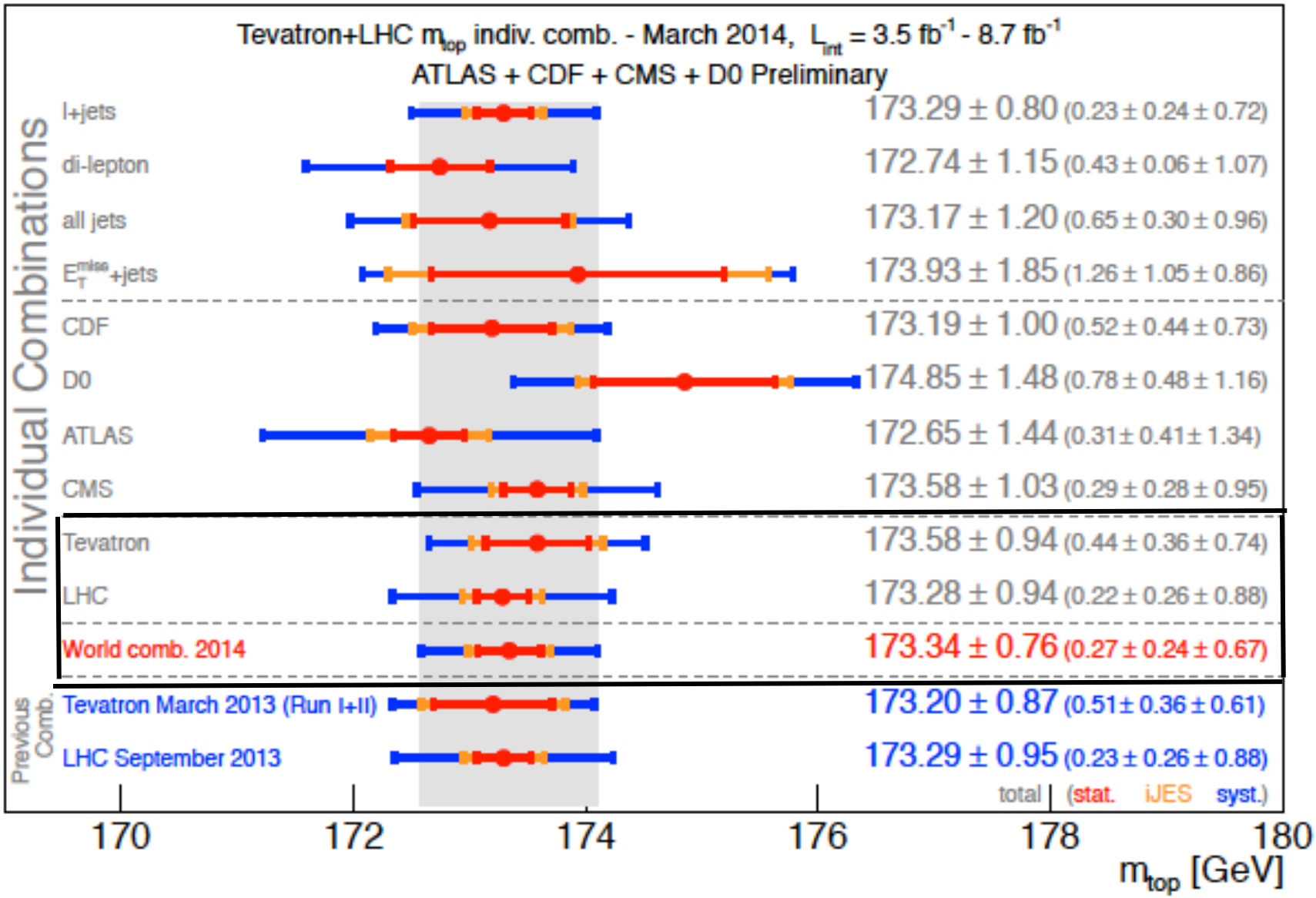
CMS-TOP-14-001





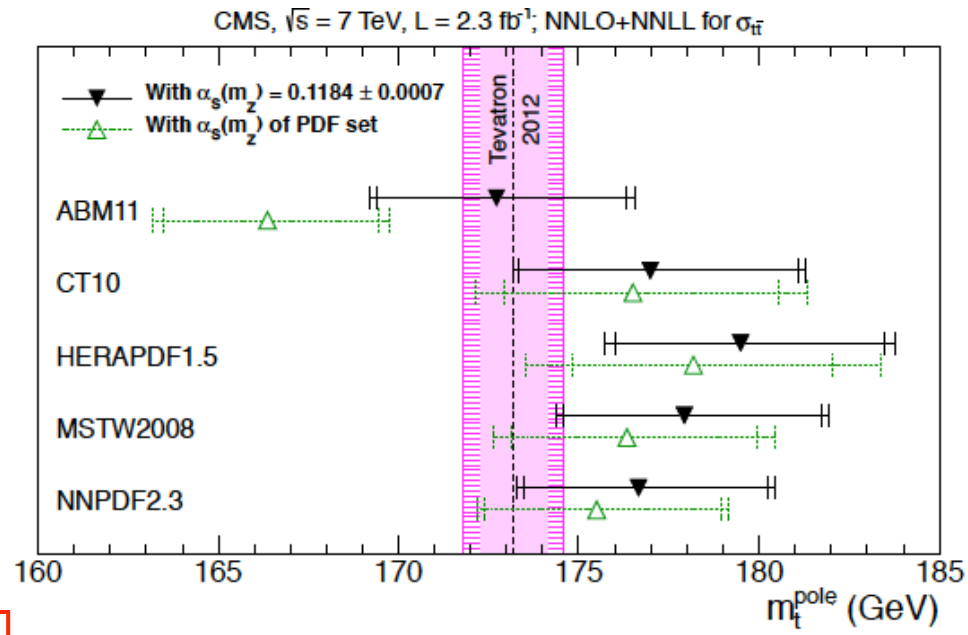
mt = 172.04±0.19(stat+JSF)±0.75(syst) GeV
JSF = 1.007±0.002(stat)±0.012(syst)

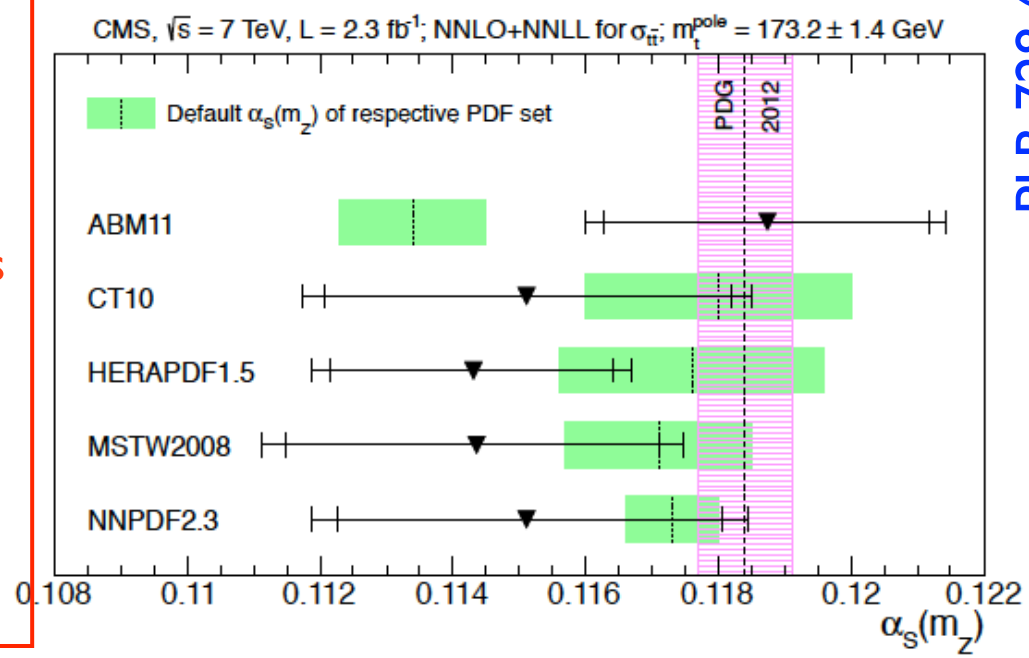
Top mass new combinations



Top mass and alpha_s extracted from ttbar cross section

- **2011 dataset at $\sqrt{s}$ = 7 TeV: 2.3/fb**
- The measured inclusive cross section for top-quark pair production is compared to the QCD prediction at NNLO to determine top pole mass or the strong coupling alpha_s





PLB 728 (2013) 496

Observed cross section in the dilepton channel with 2.3/fb: 161.9 ± 6.7 pb

With the PDF set NNPDF2.3, M_t = $176.7^{+3.8}_{-3.4}$ GeV when constraining alpha_s (M_z) = 0.1184

alpha_s (M_z) = $0.1151^{+0.0033}_{-0.0032}$ when constraining M_t = 173.2 GeV

Top spin correlation and polarization in ttbar

CMS-TOP-13-003 accepted by PRL

- **Full 2011 dataset at $\sqrt{s}$ = 7 TeV: 5/fb**
- Dilepton channel, **top kinematics reconstructed** using analytical matrix weighting technique (**AMWT**)
- An "**unfolding**" procedure is employed to correct acceptance and resolution effects
- In good agreement with the standard model predictions

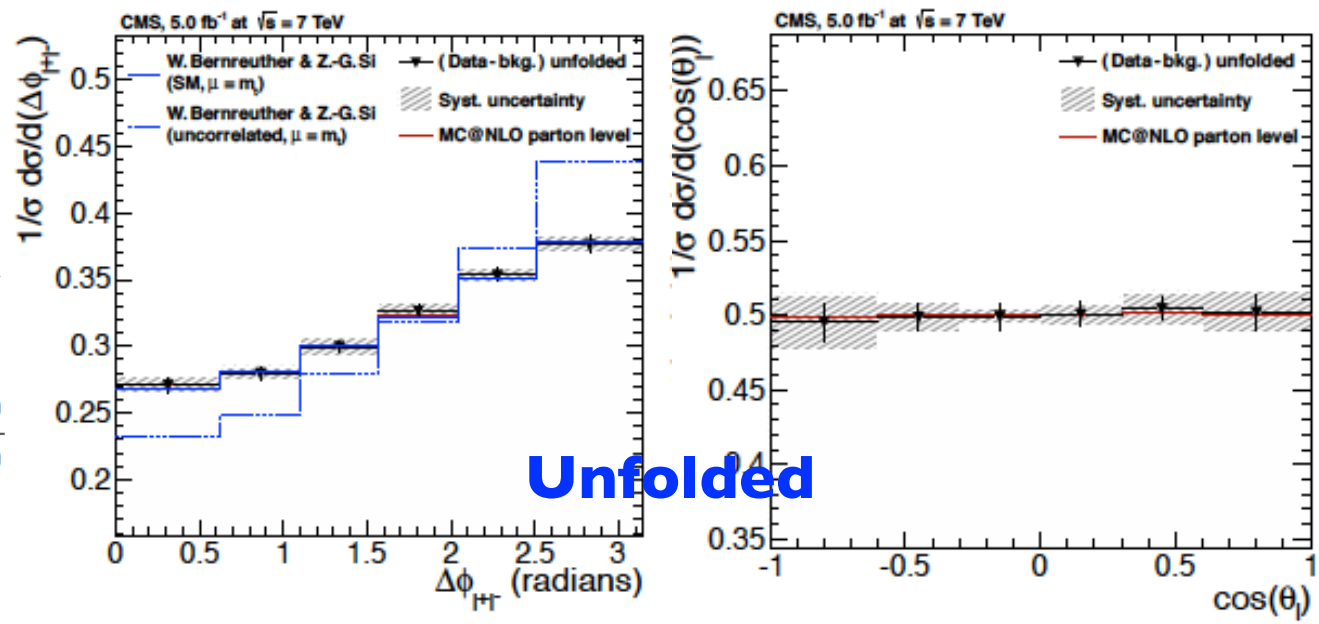
$$A_P = \frac{N(\cos(\theta_\ell) > 0) - N(\cos(\theta_\ell) < 0)}{N(\cos(\theta_\ell) > 0) + N(\cos(\theta_\ell) < 0)}$$

in the helicity basis

$$A_{\Delta\phi} = \frac{N(\Delta\phi_{\ell^+\ell^-} > \pi/2) - N(\Delta\phi_{\ell^+\ell^-} < \pi/2)}{N(\Delta\phi_{\ell^+\ell^-} > \pi/2) + N(\Delta\phi_{\ell^+\ell^-} < \pi/2)}$$

$$A_{c_1c_2} = \frac{N(c_1 \cdot c_2 > 0) - N(c_1 \cdot c_2 < 0)}{N(c_1 \cdot c_2 > 0) + N(c_1 \cdot c_2 < 0)}$$

where c1 = $\cos(\theta_{l+})$ and c2 = $\cos(\theta_{l-})$,



Asymmetry	Data (unfolded)	MC@NLO	NLO (SM, correlated)	NLO (uncorrelated)
$A_{\Delta\phi}$	$0.113 \pm 0.010 \pm 0.007 \pm 0.012$	0.110 ± 0.001	$0.115^{+0.014}_{-0.016}$	$0.210^{+0.013}_{-0.008}$
$A_{c_1c_2}$	$-0.021 \pm 0.023 \pm 0.027 \pm 0.010$	-0.078 ± 0.001	-0.078 ± 0.006	0
A_P	$0.005 \pm 0.013 \pm 0.020 \pm 0.008$	0.000 ± 0.001	N/A	N/A

Top polarization in t-channel single-top production

- **Full 2012 dataset at $\sqrt{s}$ = 8 TeV: 19.7/fb**
- One isolated lepton, two jets (one b-tagged), MET
- In t-channel single -top production, top quarks are almost 100% polarized through the V-A coupling structure
- New physics models may alter the coupling structure which affects the top quark polarization

CMS-TOP-13-001

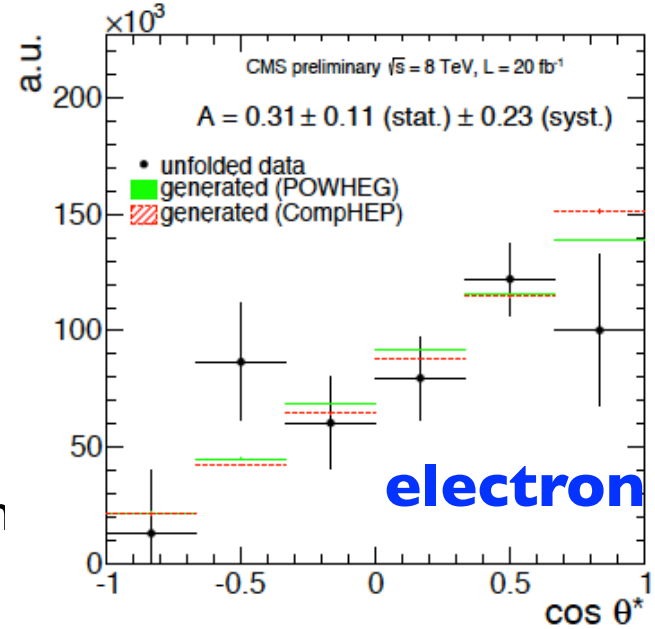
$$A_l = \frac{N(\cos\theta^*_{unfolded} > 0) - N(\cos\theta^*_{unfolded} < 0)}{N(\cos\theta^*_{unfolded} > 0) + N(\cos\theta^*_{unfolded} < 0)}.$$

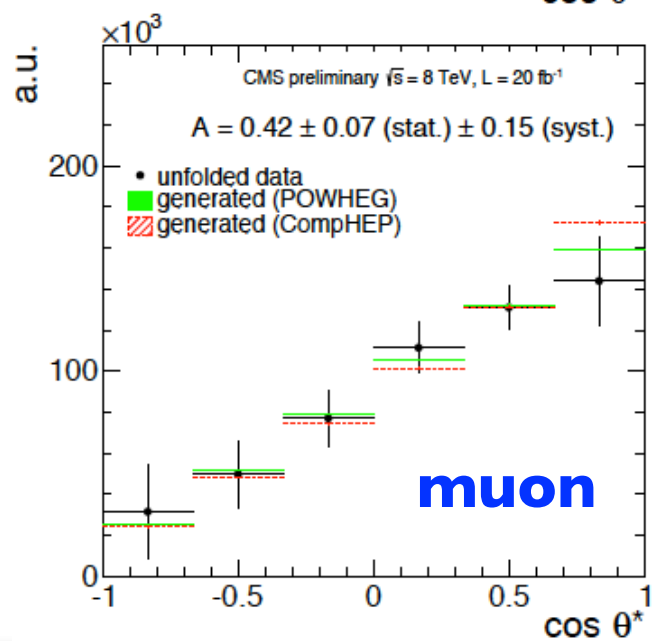
$$A_l \equiv \frac{1}{2} \cdot P_t \cdot \alpha_l$$

Polarization: 0.82±0.12(stat)±0.32(syst)
Asymmetry:

$$A_l^\mu = 0.42 \pm 0.07(stat.) \pm 0.15(syst.),$$
$$A_l^e = 0.31 \pm 0.11(stat.) \pm 0.23(syst.).$$

Unfolded



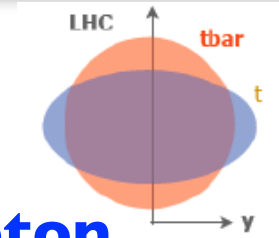


Top pair charge asymmetry at 7 TeV

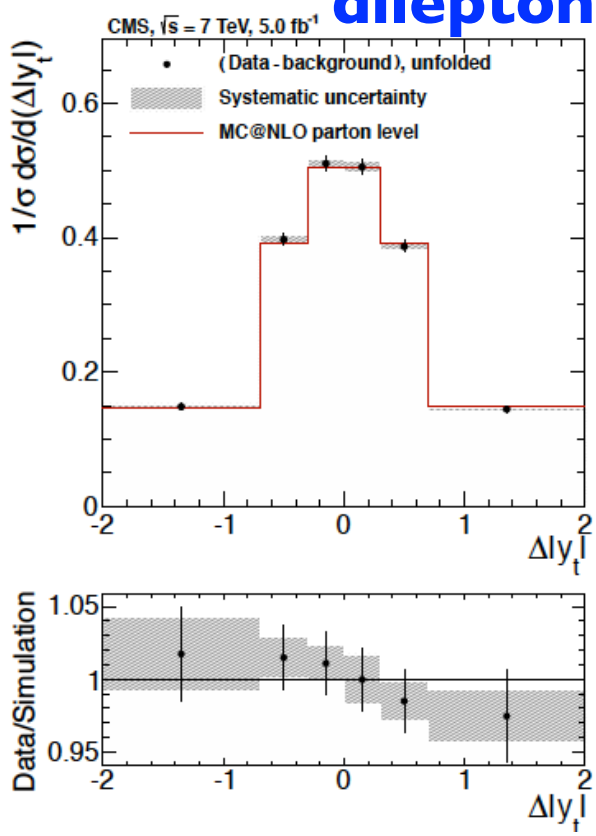
- **Full 2011 dataset at $\sqrt{s}$ = 7 TeV: 5.0/fb**

$$A_C^{lep} = \frac{N(\Delta|\eta_\ell| > 0) - N(\Delta|\eta_\ell| < 0)}{N(\Delta|\eta_\ell| > 0) + N(\Delta|\eta_\ell| < 0)}$$

$$A_C = \frac{N(|y_t| > |y_{\bar{t}}|) - N(|y_t| < |y_{\bar{t}}|)}{N(|y_t| > |y_{\bar{t}}|) + N(|y_t| < |y_{\bar{t}}|)}$$

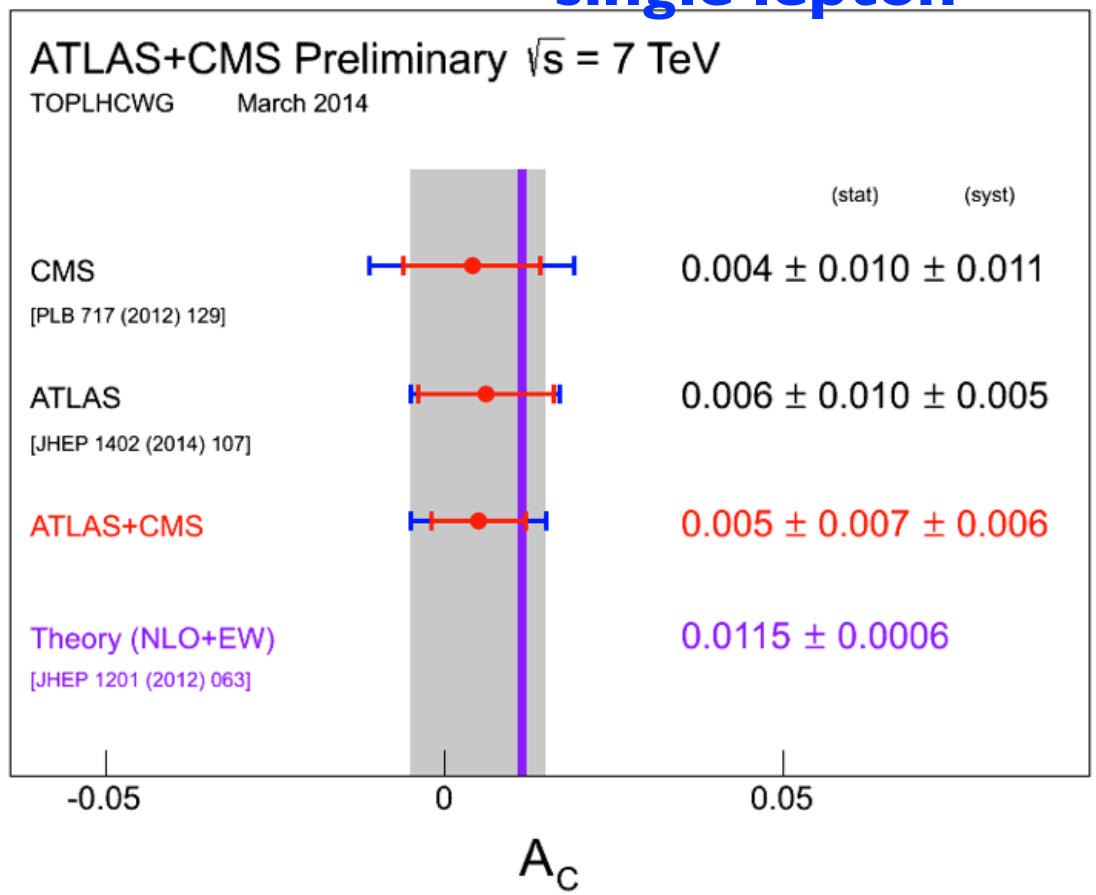


dilepton



CMS-TOP-12-010
accepted by JHEP

single lepton



CMS PAS TOP-14-006

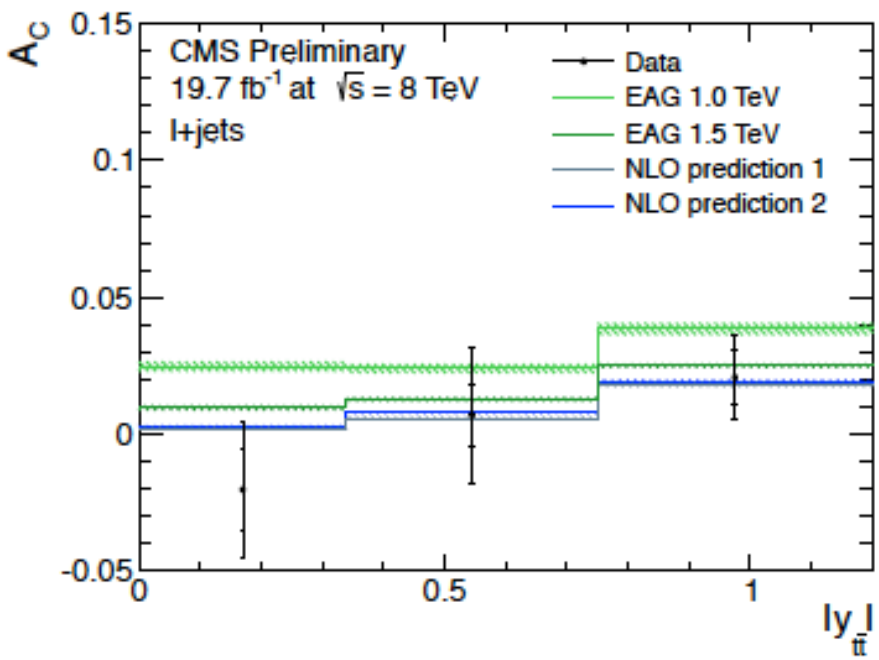
CMS dilepton channel
Ac = -0.010±0.017(stat) ±0.008(syst)
Ac^{lep} = 0.009±0.010(stat) ±0.006(syst)

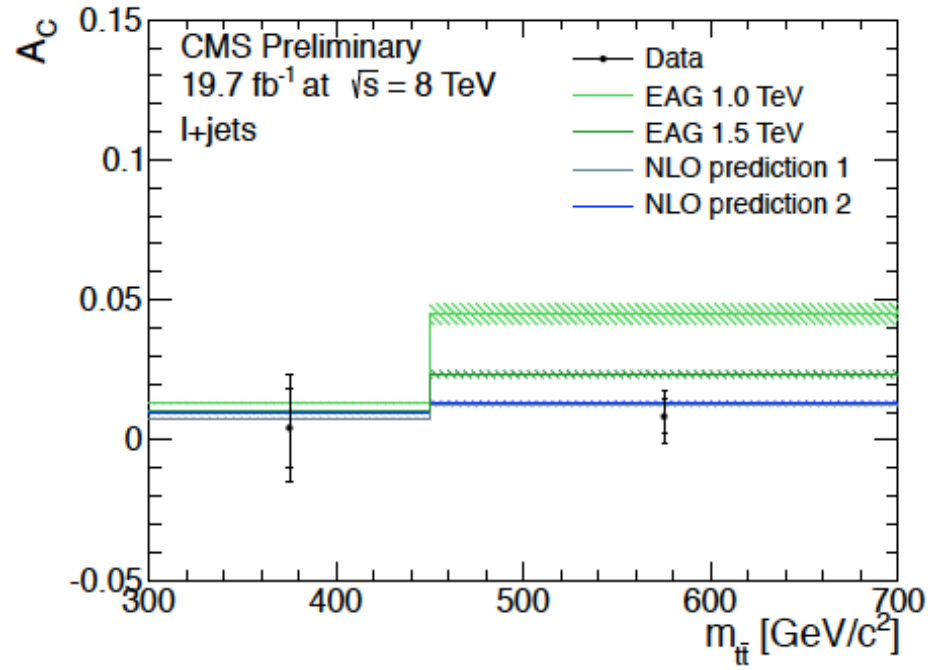
ATLAS+CMS: single lepton channel
Ac = 0.005±0.007(stat)±0.006(syst);
NLO: 0.0115 ± 0.0006 JHEP 1201 (2012) 063

Top pair charge asymmetry at 8 TeV

- **Full 2012 dataset at √s = 8 TeV: 19.7/fb**
- One isolated lepton, at least 4 jets, at least one jet tagged as b

$$A_C = \frac{N(|y_t| > |y_{\bar{t}}|) - N(|y_t| < |y_{\bar{t}}|)}{N(|y_t| > |y_{\bar{t}}|) + N(|y_t| < |y_{\bar{t}}|)}$$





CMS PAS TOP-12-033

Inclusive measurement: 0.005±0.007(stat)±0.006(syst)
NLO: 0.0111 ± 0.0004 Phys. Rev. D **86** (2012) 034026

EAG: Model featuring an effective axial-vector coupling of the gluon: Phys. Rev. D 85 (2012) 074021

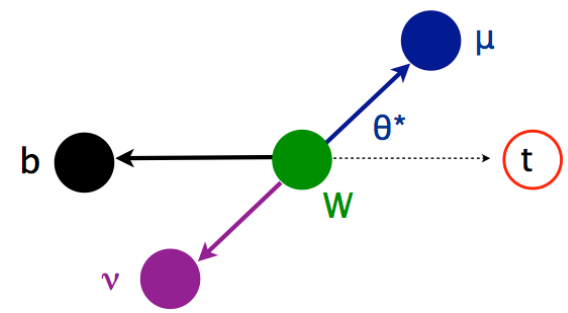
W helicity in top events

- W boson helicity fraction in top-quark decays are sensitive to the Wtb couplings
- Measure W helicity fractions (F_R, F_L, and F_0) using cos(θ*) distribution in ttbar events
- NNLO predictions in the SM: F_L=0.311±0.05, F_0=0.687±0.005, F_R =0.0017±0.0001
  Phys. Rev. D 81 (2010) 111503

$$\frac{1}{\Gamma}\frac{d\Gamma}{d\cos\theta^*} = \frac{3}{8}\left(1-\cos\theta^*\right)^2 F_L + \frac{3}{8}\left(1+\cos\theta^*\right)^2 F_R + \frac{3}{4}\left(\sin\theta^*\right)^2 F_0 \qquad F_L + F_R + F_0 = 1$$

7 TeV

Lepton+jets	FL = 0.310 ± 0.022 (stat.) ± 0.022 (syst.), FR = 0.008 ± 0.012 (stat.) ± 0.014 (syst.), F0 = 0.682 ± 0.030 (stat.) ± 0.033 (syst.) JHEP 10 (2013) 167
Dilepton	FL = 0.288 ± 0.035(stat) ± 0.040(sys), FR = 0.014 ± 0.027(stat) ± 0.042(sys), F0 = 0.698 ± 0.057(stat) ± 0.063(sys) CMS PAS TOP-12-015
Single top	FL = 0.293 ± 0.069(stat.) ± 0.030(syst.), FR = −0.006 ± 0.057(stat.) ± 0.027(syst.), F0 = 0.713 ± 0.114(stat.) ± 0.023(syst.) CMS PAS TOP-12-020
Atlas+CMS combination Lepton+jets and dilepton	FL = 0.359 ± 0.021 (stat.) ± 0.028 (syst.), FR = 0.015 ± 0.034, F0 = 0.626 ± 0.034 (stat.) ± 0.048 (syst.) CMS PAS TOP-12-025



8TeV

Lepton+jets	FL = 0.350 ± 0.010 (stat.) ± 0.024 (syst.), FR = −0.009 ± 0.006 (stat.) ± 0.020 (syst.), F0 = 0.659 ± 0.015 (stat.) ± 0.023 (syst.) CMS PAS TOP-13-008

Measurement of B(t to Wb)/B(t to Wq), q=d,s,b

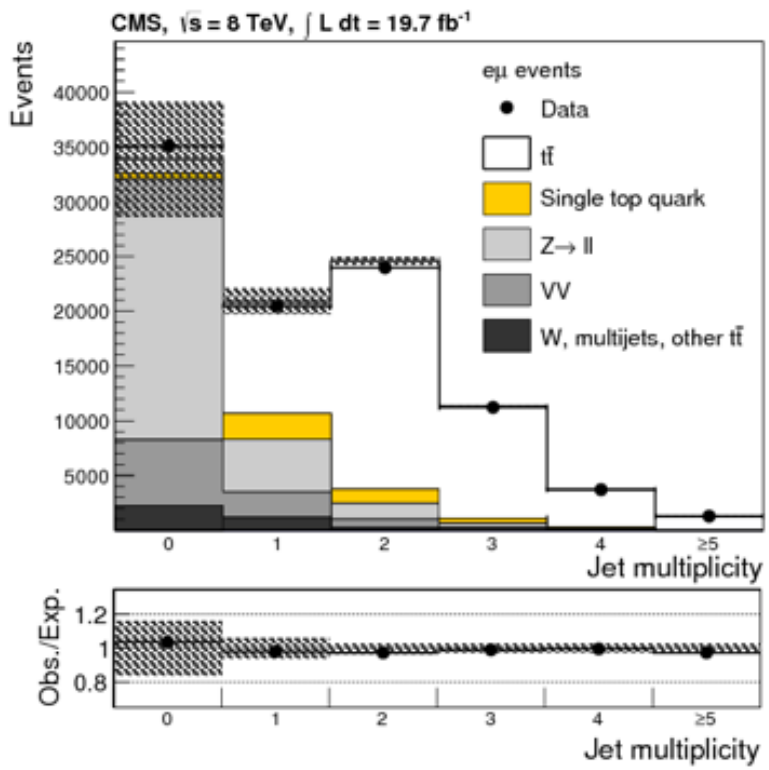
- **Full 2012 dataset at $\sqrt{s}$ = 8 TeV: 19.7/fb**
- Dilepton channel, purity of the signal sample is quantified by measuring the cross section
- In the SM, the top decays predominantly into Wb: R ~ 1
- R value is measured by fitting the observed b-tagged jet distribution with a parametric model

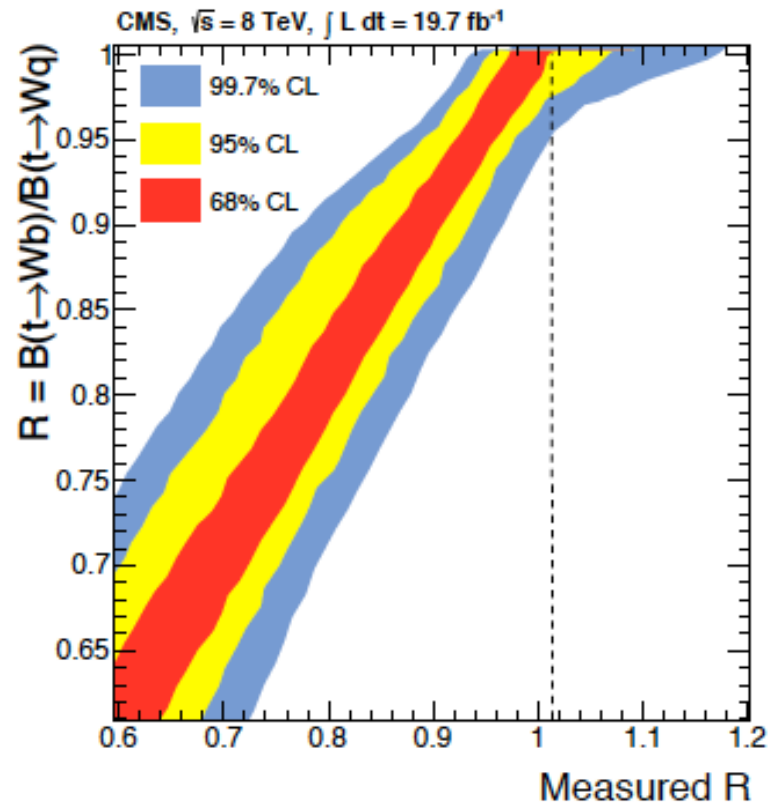
R = 1.014±0.003(stat)±0.032(syst)

At 95% C.L., R > 0.955, assuming R <=1. |Vtb| > 0.975, assuming the unitarity of CKM matrix

Indirect measurement on top total decay width 1.36±0.02(stat)$^{+0.14}_{-0.11}$ (syst) GeV

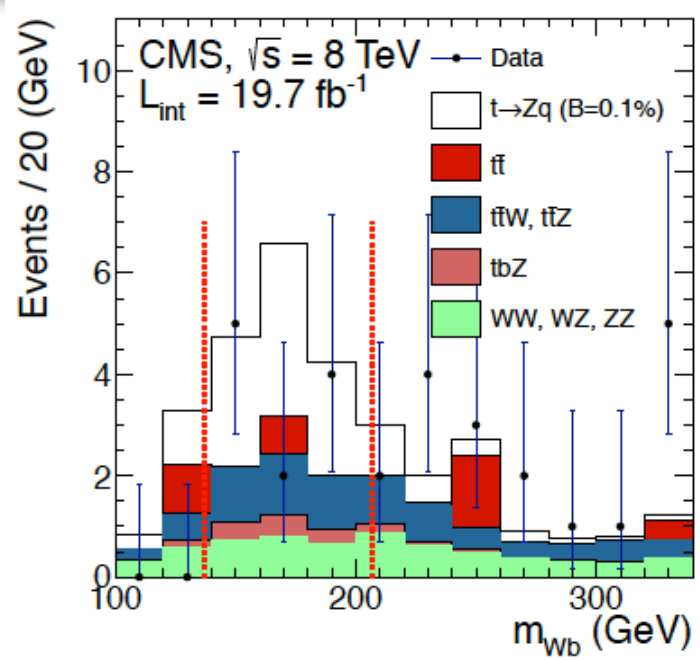
CMS-TOP-12-035
Submitted to PLB

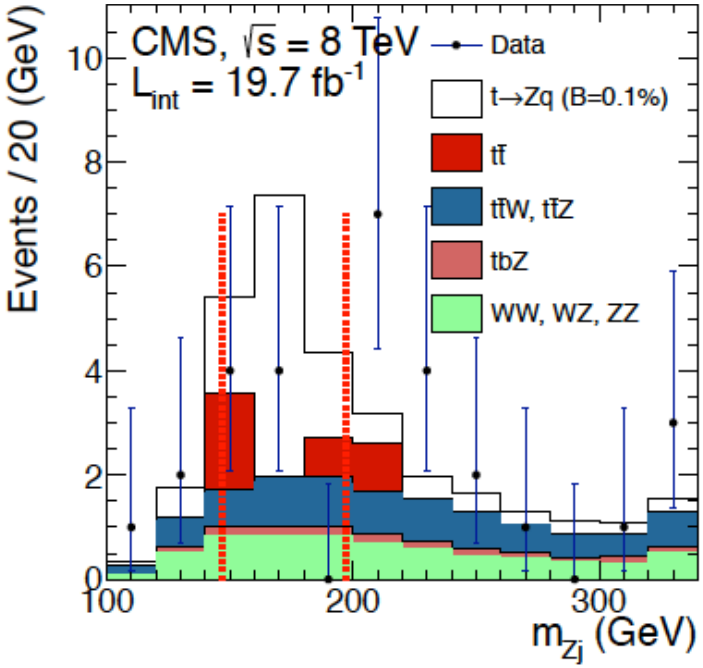




Search for FCNC in top decays

- **Full 2012 dataset at $\sqrt{s}$ = 8 TeV: 19.7/fb**
- t→Zq suppressed in SM but can be enhanced in new physics models
- 3 isolated leptons + at least two jets (exactly one is b-tagged)+missing transverse momentum





Process	Estimation from data	MC prediction
$t \to Zq$ ($\mathcal{B} = 0.1\%$)	—	$6.4 \pm 0.1 \pm 1.3$
Total background	$3.1 \pm 0.8 \pm 0.8$	$3.2 \pm 1.2 \pm 1.5$
Observed events	1	—

$\mathcal{B}(t \to Zq)$	8 TeV	7 TeV + 8 TeV
Expected upper limit	<0.10%	<0.09%
Observed upper limit	<0.06%	<0.05%
1 σ boundary	0.06–0.13%	0.06–0.13%
2 σ boundary	0.05–0.20%	0.05–0.18%

CERN-PH-EP-2013-208, accepted by PRL

TTbar + photon cross section

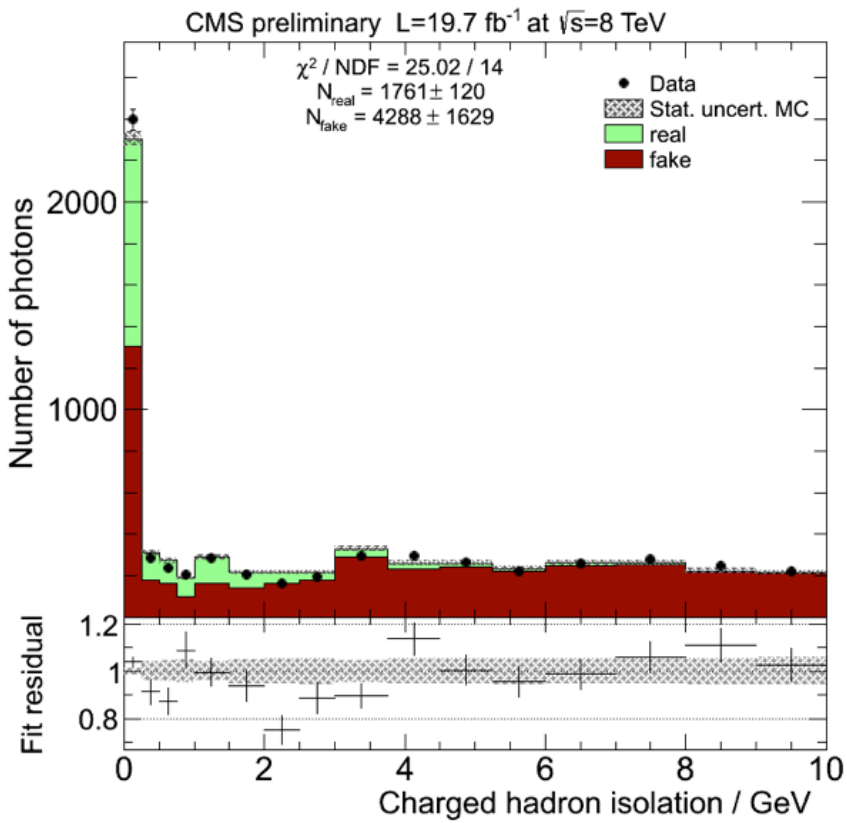
- **Full 2012 dataset at √s = 8 TeV: 19.7/fb**
- one muon, at least four jets (at least one b-tagged), one γ
- Delta R(b, γ) > 0.1
- quantity of correctly identified prompt photons is estimated using a binned maximum likelihood template fit

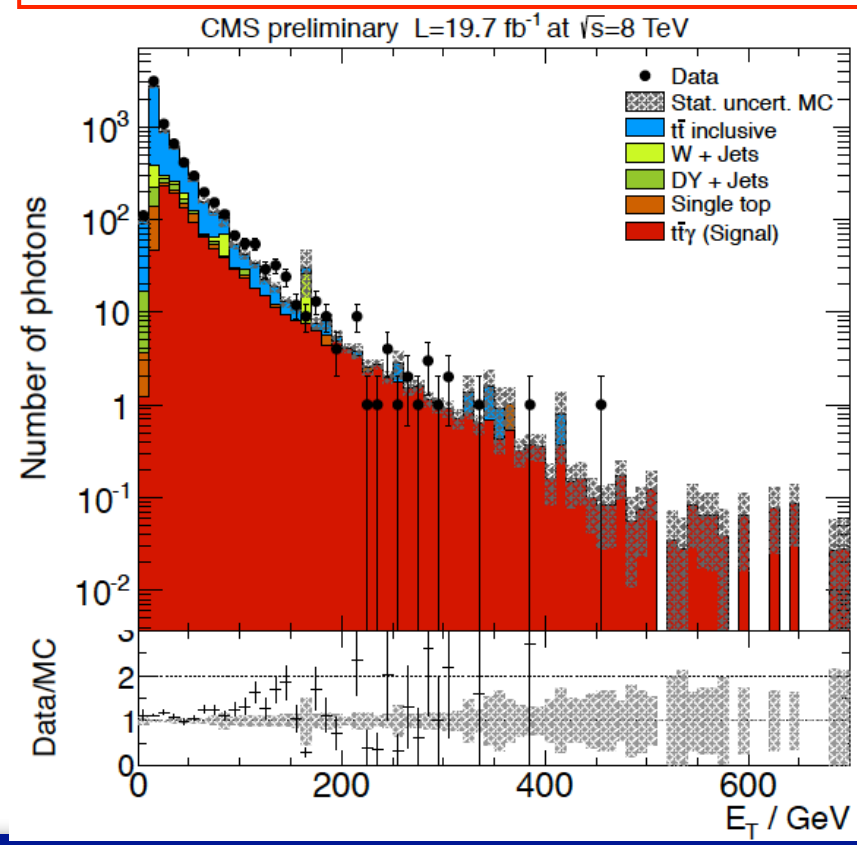
$$R = \sigma_{\bar{t}t+\gamma}/\sigma_{\bar{t}t} = (1.07 \pm 0.07(\text{stat.}) \pm 0.27(\text{syst.})) \cdot 10^{-2}$$

$$\sigma_{t\bar{t}+\gamma} = R \cdot \sigma_{\bar{t}t}^{\text{CMS}} = 2.4 \pm 0.2(\text{stat.}) \pm 0.6(\text{syst.})\,\text{pb}$$

$$\sigma_{\bar{t}t+\gamma}^{SM} = 1.8 \pm 0.5\,\text{pb}.$$

TOP-13-011





Conclusions

- As a top factory, LHC allows precision measurements of many top properties - they are not only the tests for the SM, but also good probes to new physics

- CMS latest results of top property measurements have been presented - all presented results are in good agreement with SM predictions