Top quark pair production and properties in CMS

Top Quark Physics Day

Thorsten Chwalek on behalf of the CMS collaboration

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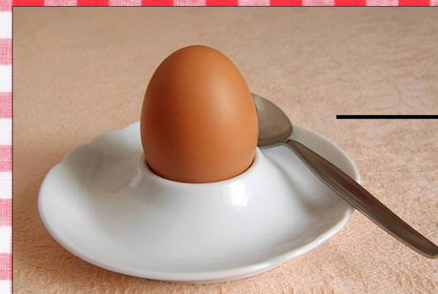
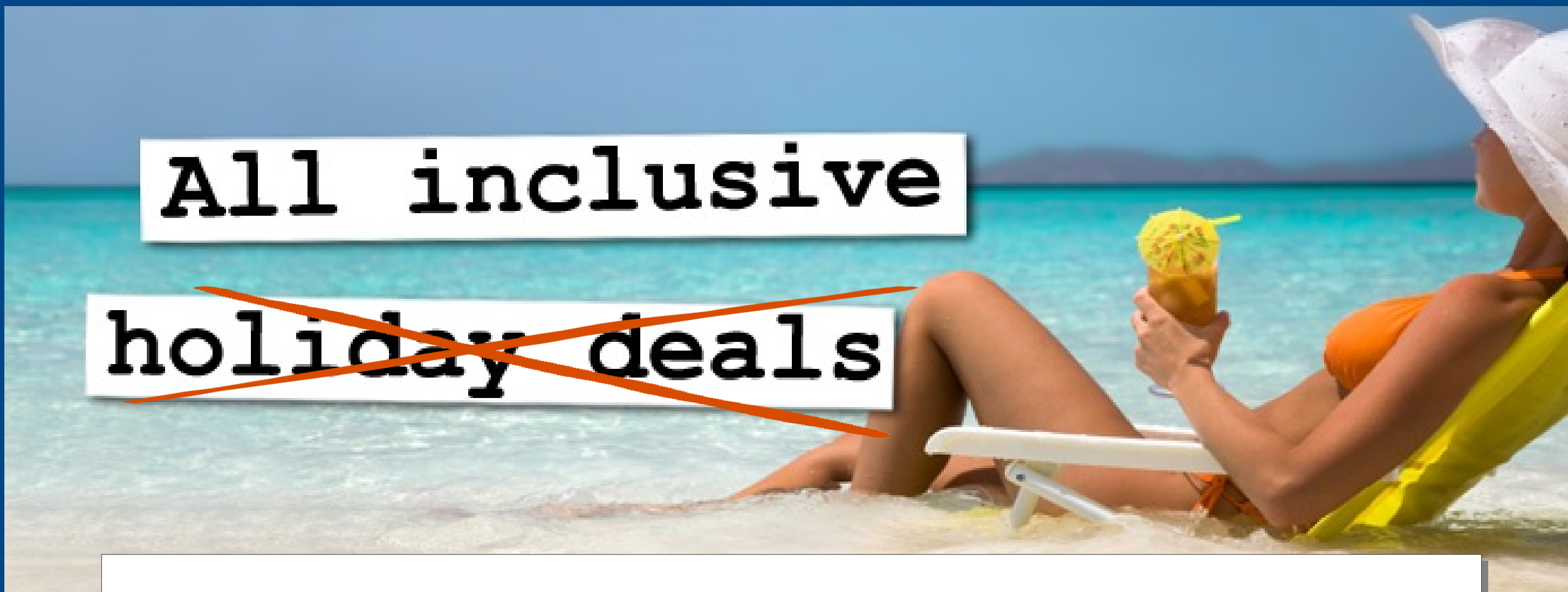
What's on the menu?



Inclusive top pair cross sections

Differential top pair cross sections

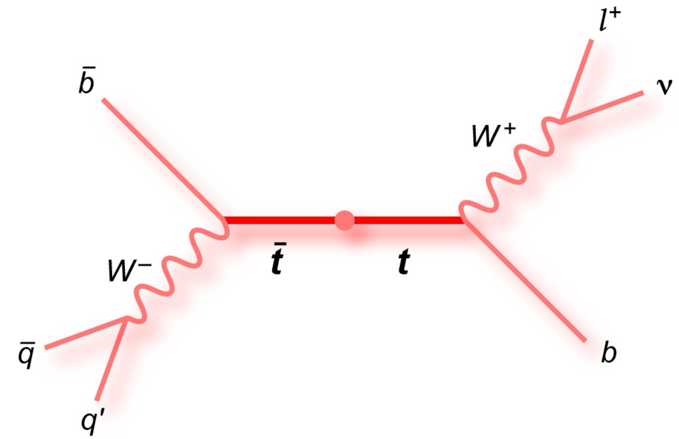
Properties of top quark production and decay



…top pair cross sections

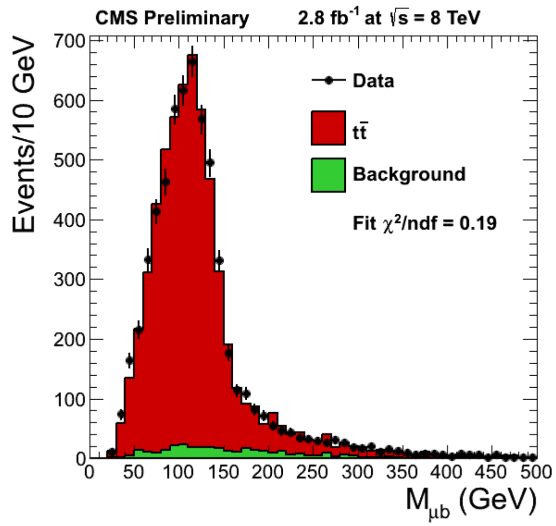
Lepton+Jets @ 8TeV PAS-TOP-12-006

- 2 channels: **e+jets** and **μ+jets**
  - 1 isolated e(μ) with p_T > 30(26)GeV
  - At least 4 jets with p_T > 45/45/35/35GeV
  - At least 1 of these jets b-tagged
- Binned **max. likelihood fit** to M_{lb}
  - Invariant mass of the l+b system
  - Jet-combination with lowest χ^2
  - Lept. b-candidate must be b-tagged
- Preliminary combined (e+μ) result based **on 2.8fb^{-1}**



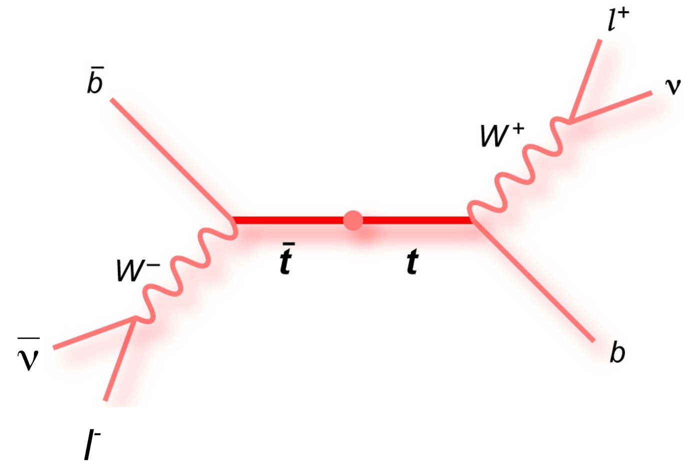
$$\sigma_{t\bar{t}} = 228.4 \pm 9.0\,(\text{stat.})^{+29.0}_{-26.0}\,(\text{syst.}) \pm 10.0\,(\text{lum.})\,\text{pb}$$

A paper with an **improved analysis** method and based on the **full 8 TeV dataset** is on the way...

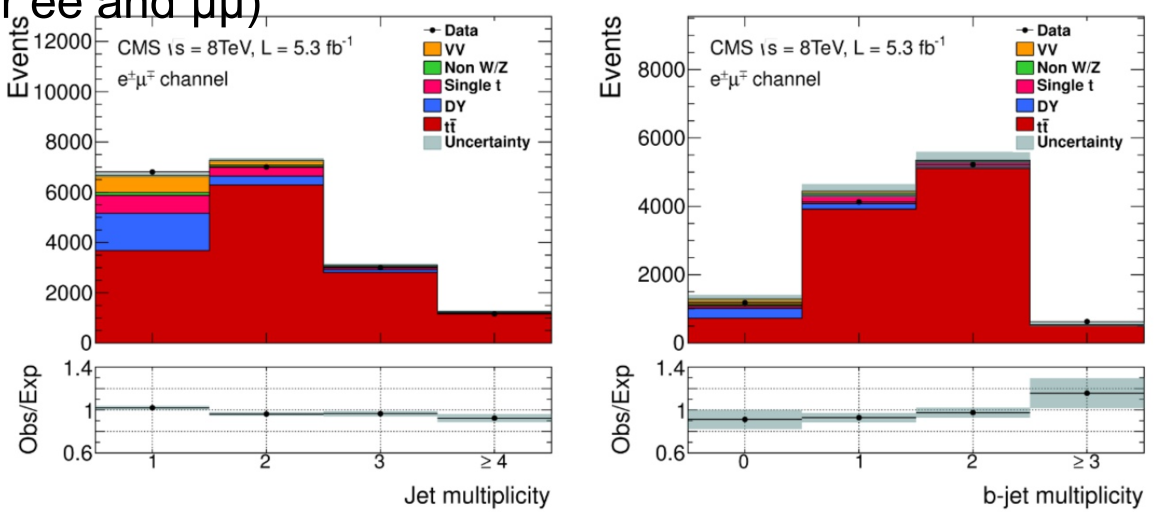


Dilepton @ 8 TeV JHEP 02(2014)024

- 3 channels: **e^+e^-, $\mu^+\mu^-$**, **$e^\pm\mu^\mp$**
  - 2 isolated oppositely charged leptons with p_T > 20 GeV
  - Inv. mass of the lepton pair m_{ll} > 20 GeV, Veto on Z mass window
  - 2 jets with p_T > 20 GeV
  - At least 1 of these jets b-tagged
  - MET > 40 GeV (only for ee and μμ)
- **Cut-and-count** analysis



High signal fraction in **eμ channel**
→ most precise channel



Dilepton @ 8 TeV JHEP 02(2014)024

- Results based **on 5.3fb^{-1}**, assuming a top mass of 172.5 GeV

	e^+e^-	$\mu^+\mu^-$	$e^\pm\mu^\mp$
ϵ_{total} (%)	0.203 ± 0.012	0.270 ± 0.017	0.717 ± 0.033
$\sigma_{t\bar{t}}$ (pb)	$244.3 \pm 5.2 \pm 18.6 \pm 6.4$	$235.3 \pm 4.5 \pm 18.6 \pm 6.1$	$239.0 \pm 2.6 \pm 11.4 \pm 6.2$
			Dominating channel

- Combined using BLUE

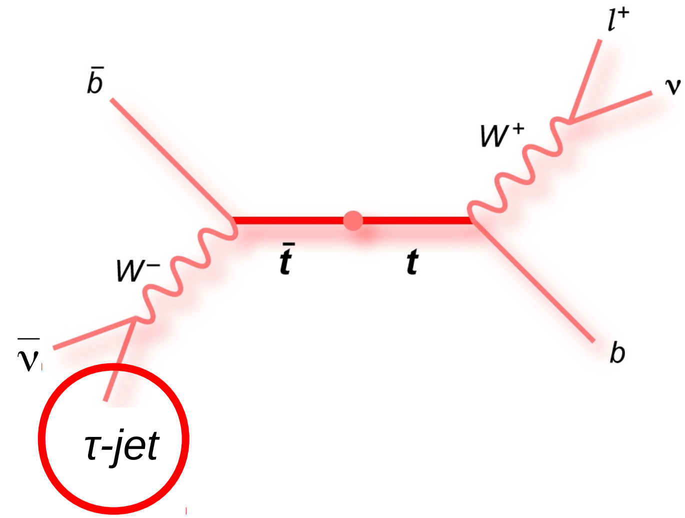
$$\sigma_{t\bar{t}} = 239.0 \pm 2.1\,(\text{stat.}) \pm 11.3\,(\text{syst.}) \pm 6.2\,(\text{lum.})\ \text{pb}$$

- The top mass dependence between 160 GeV and 185 GeV can be parameterized as

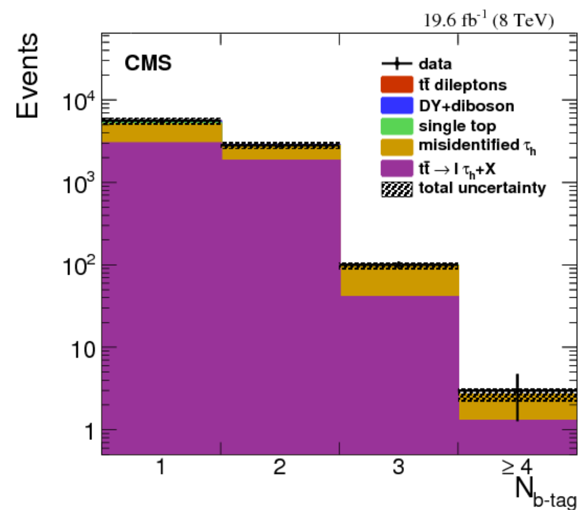
$$\sigma_{t\bar{t}}/\sigma_{t\bar{t}}\,(m_t = 172.5) = 1.00 - 0.009 \times (m_t - 172.5) - 0.000168 \times (m_t - 172.5)^2$$

Dilepton with a τ @ 8 TeV arXiv:1407.6643, sub. to PLB

- 2 channels: **eτ, μτ (hadronically dec. τ)**
  - 1 isolated e(μ) with p_T > 35(30)GeV
  - At least 3 jets with p_T > 30/30/20GeV
  - At least 1 of them b-tagged
  - 1 τ-jet with p_T > 20 GeV and opp. charge than e(μ)
  - MET > 40 GeV
- **Cut and count** analysis



- Background estimation:
  - Misidentified τ: mainly ttbar → e/μ +jets – misidentification probability is estimated in control samples (data)
  - All other BG normalizations are taken from MC simulation



Dilepton with a τ @ 8TeV arXiv:1407.6643, sub. to PLB

- Dominating systematic uncertainties τ_h jet identification, τ_h misidentification,
- Results based **on 19.7**$^{-1}$, assuming a top mass of 172.5 GeV

$$\sigma_{t\bar{t}}(e\tau_h) = 255 \pm 4\,(\text{stat}) \pm 24\,(\text{syst}) \pm 7\,(\text{lumi})\,\text{pb},$$
$$\sigma_{t\bar{t}}(\mu\tau_h) = 258 \pm 4\,(\text{stat}) \pm 24\,(\text{syst}) \pm 7\,(\text{lumi})\,\text{pb}$$

- Combined using BLUE

$$\boxed{\sigma_{t\bar{t}} = 257 \pm 3\,(\text{stat}) \pm 24\,(\text{syst}) \pm 7\,(\text{lumi})\,\text{pb}}$$

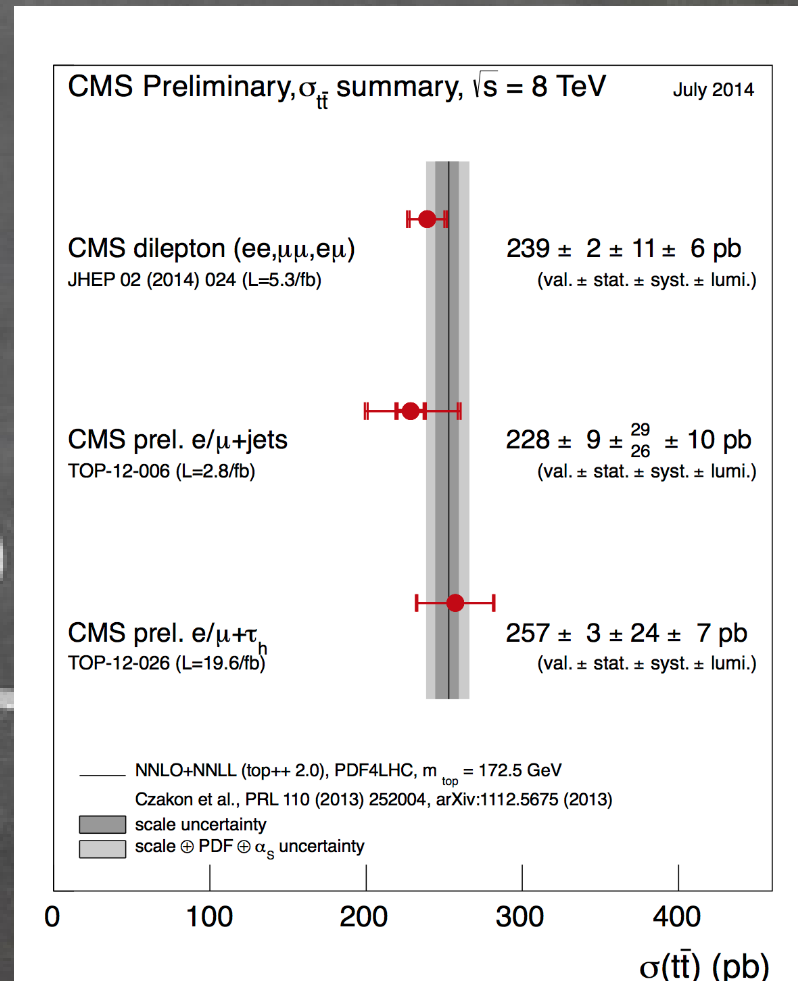
Linear dependence on the assumed top quark mass

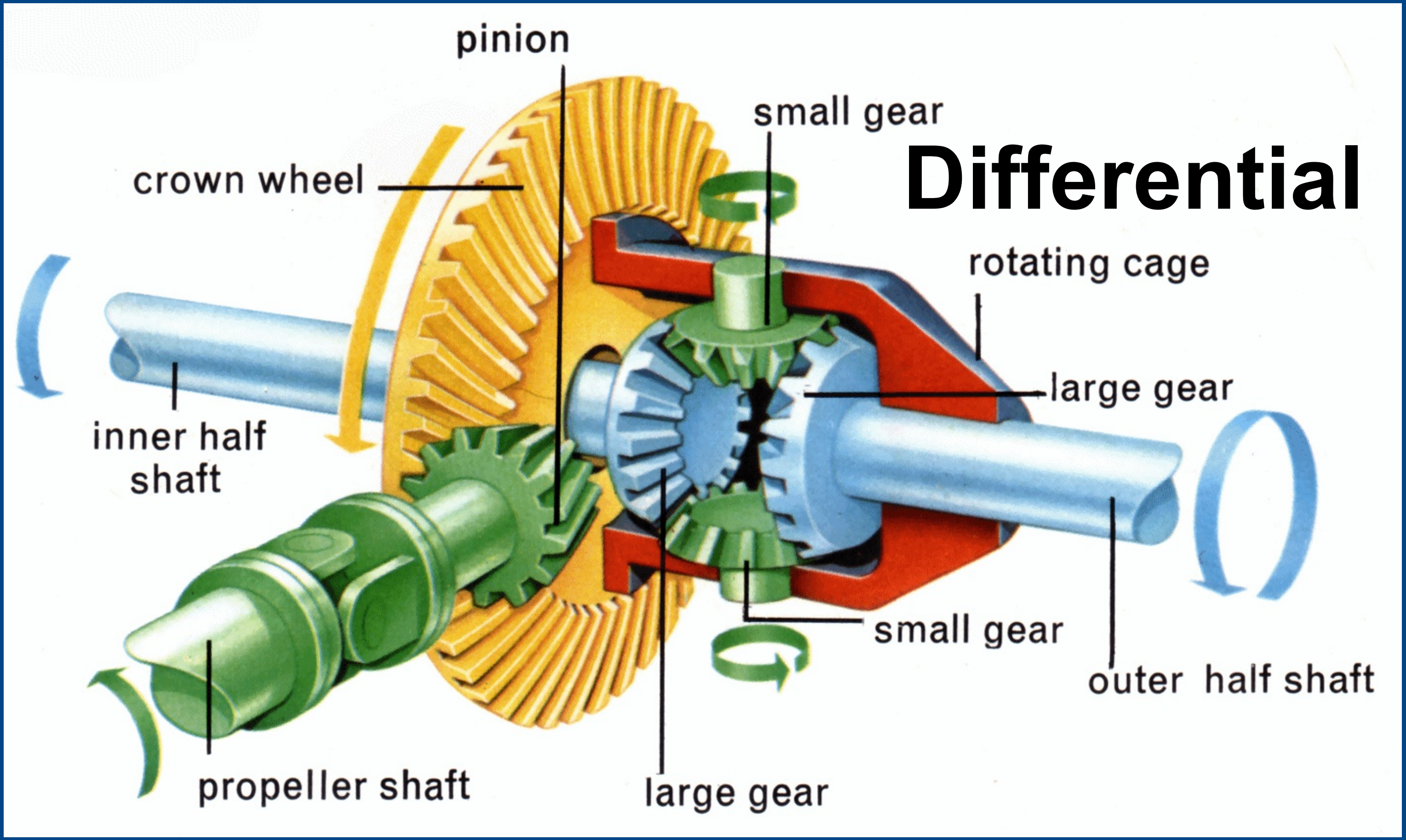
Summary of inclusive cross sections @ 8TeV

Summary of inclusive cross sections @ 8TeV

Will be updated with **full 8 TeV** dataset, paper on the way

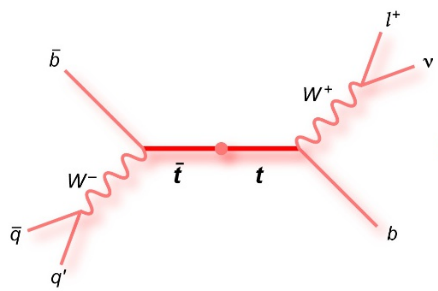
Paper submitted to PLB

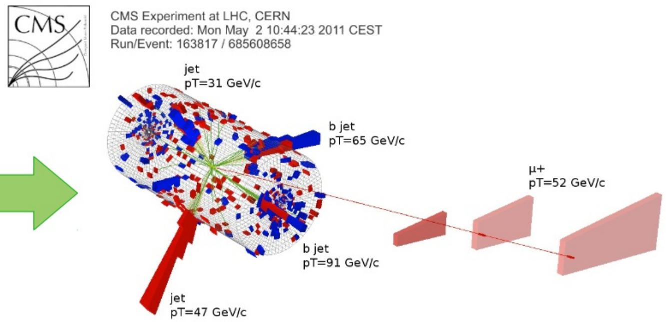




...top pair cross sections

Reconstruction and Unfolding

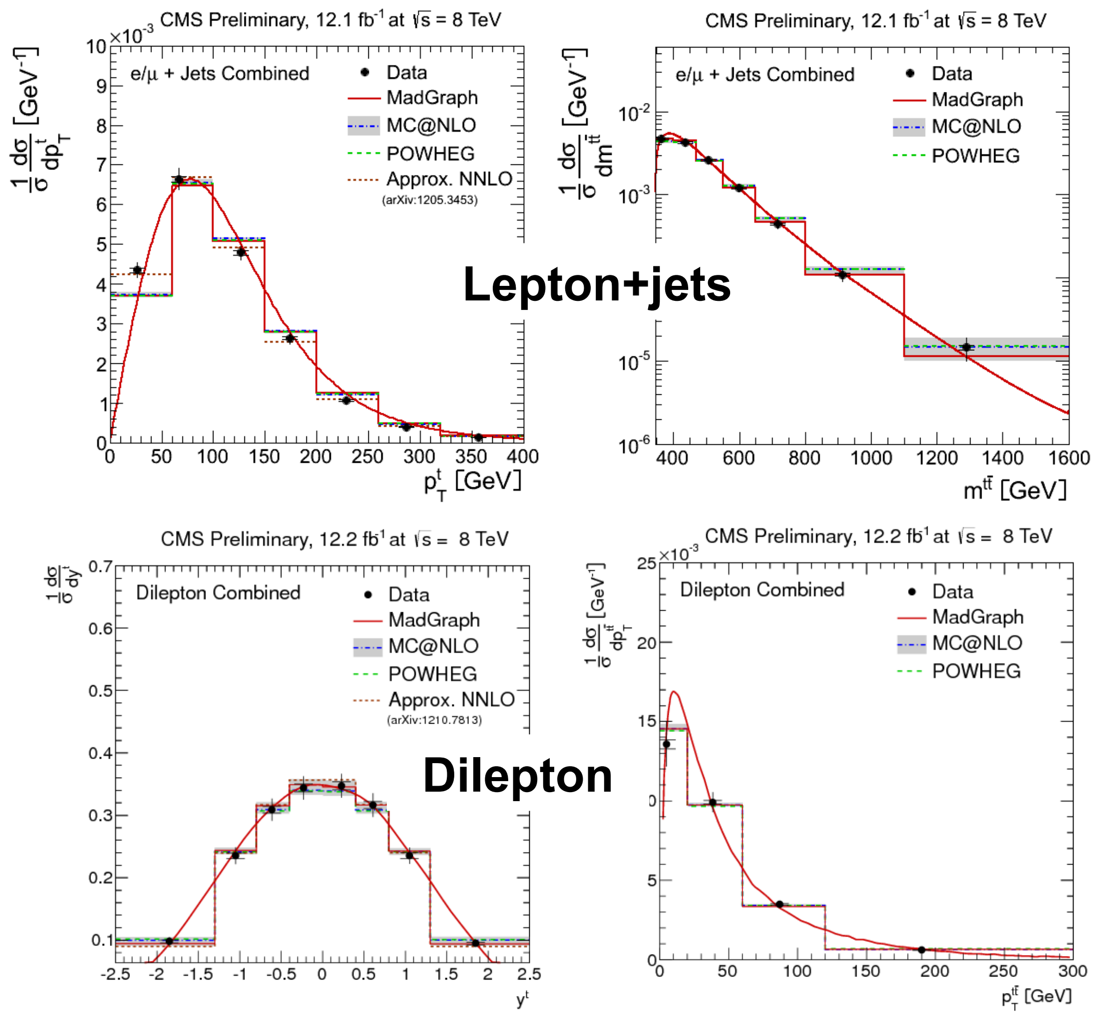




- Reconstruction of top pairs
  - Assignment of measured leptons and jets to the final state leptons and quarks
  - Ambiguities in the jet-quark assignment, missing jets due to acceptance
  - Ambiguities if more than one neutrino (dilepton)
- Unfolding to correct reconstructed top pairs to parton level
  - Event selection effects
  - Migration effects due to imperfect reconstruction
  - Describe these effects with a smearing matrix – unfolding done by matrix inversion
  - Regularization prevents stat. fluctuations getting bigger in unfolding
- **Normalized** cross sections: some of the syst. uncertainties cancel out

Lepton+jets and Dilepton @ 8 TeV PAS-TOP-12-027/028

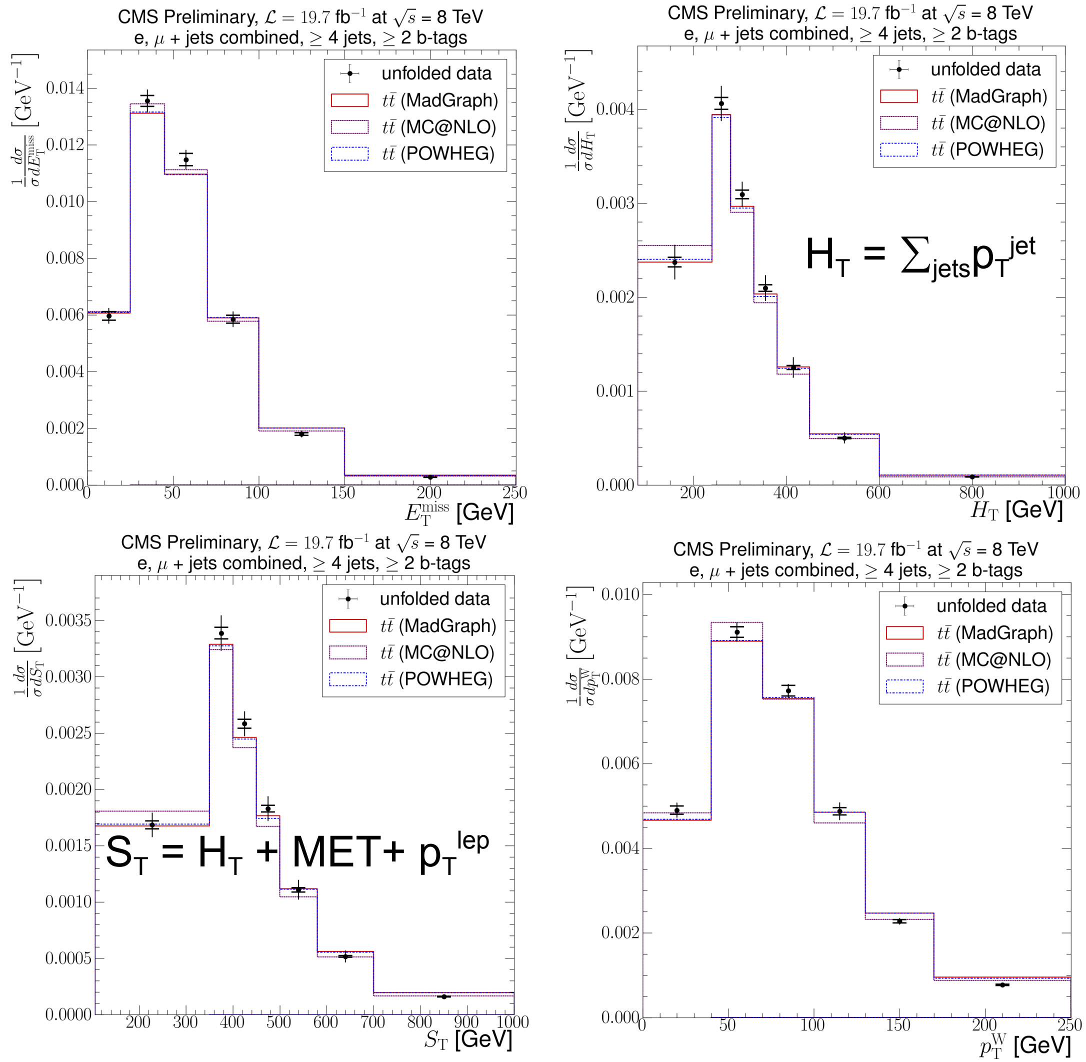
- **Normalized** diff. cross sections using **12.1(12.2)fb^{-1}**
- Compare **unfolded** distributions to predictions:
  - MadGraph+Pythia
  - PowHeg+Pythia
  - MC@NLO+Herwig
  - Approx. NNLO
- Main systematic uncertainty: Signal modeling (Q^2 scale,...)
- **Good description of data by SM predictions**
- Cross section also as a function of lepton- and jet-kinematics in visible phase space



A paper on lepton+jets and dilepton using the **full 8 TeV** dataset is on the way

Global event variables @ 8TeV PAS-TOP-012-042

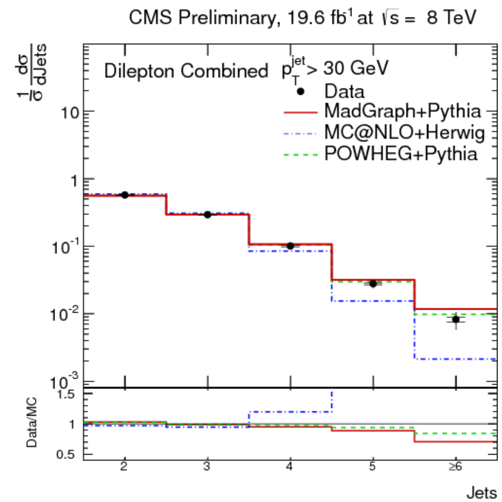
- **Normalized** diff. cross sections using **19.7fb^{-1}**
- **Lepton+Jets** (e/μ) channel
- Compare **unfolded** distributions to predictions:
  - MadGraph+Pythia
  - MC@NLO+Herwig
  - PowHeg+Pythia
- JES is largest systematic uncertainty
- **Unfolded data distributions are well described by predictions**

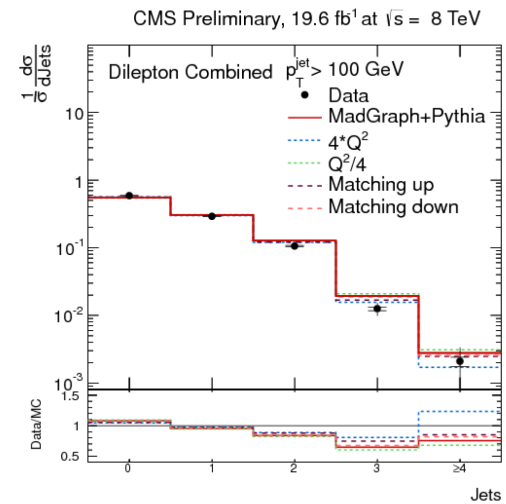


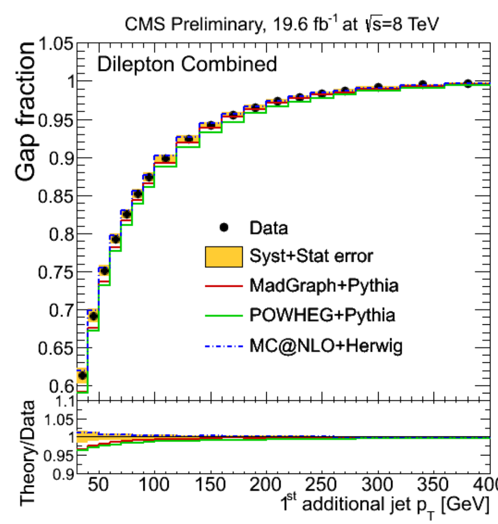
Jet-multiplicity in Dilepton @ 8TeV PAS-TOP-12-041

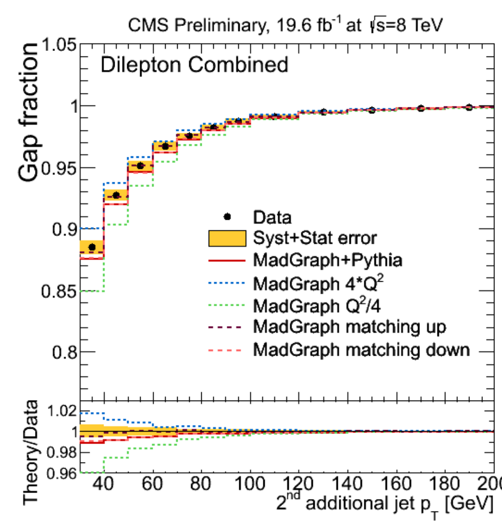
- **Normalized** diff. cross sections using **19.6fb^{-1}** as a function of the jet-multiplicity
- ...for 3 different jet-p_T thresholds
- Understand the **radiation modeling** in Monte Carlo
- Compare **unfolded** distributions to predictions:
  - MadGraph+Pythia
  - MC@NLO+Herwig
  - Powheg+Pythia
- Gap fraction:
  - fraction of events that do not contain additional jets above a given threshold

$$f(p_T) = \frac{N(p_T)}{N_{total}}$$









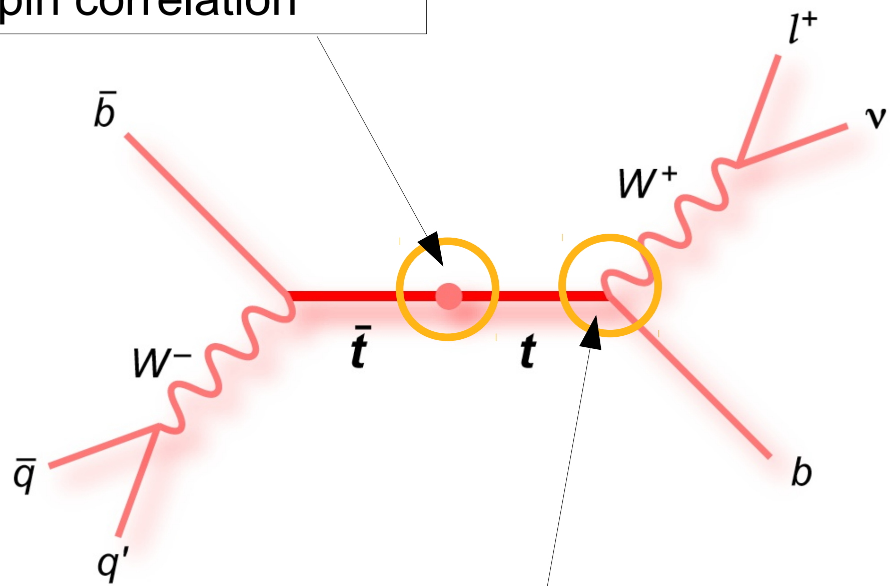
TOP PROPERTIES SA

your dream home is a call away

Overview about top properties

Covered in this talk:

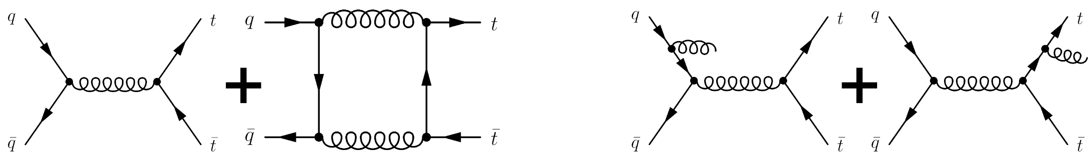
Production:
Charge asymmetry
Spin correlation

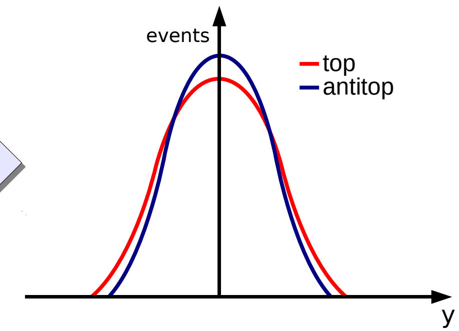


Decay:
Branching ratios
W helicity fractions

Charge asymmetry A_c

- Higher order effect: interference of diagrams





- Only in $q\bar{q}$-initial state, not for gg
  - Effect is smaller at LHC compared to Tevatron
- LHC: pp collisions → no FB-asymmetry

Sensitive variable:

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

Definition of charge asymmetry

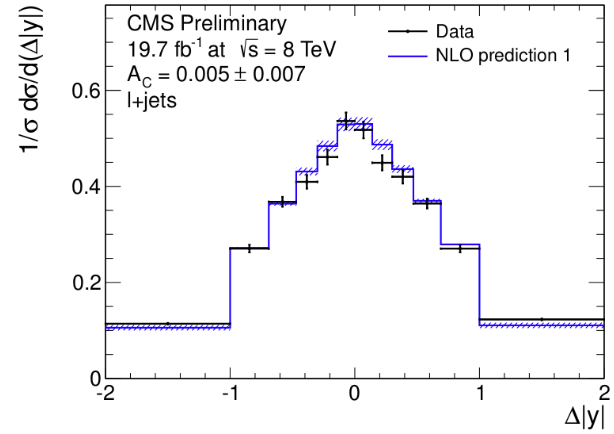
$$A_C = \frac{N_+ - N_-}{N_+ + N_-}$$

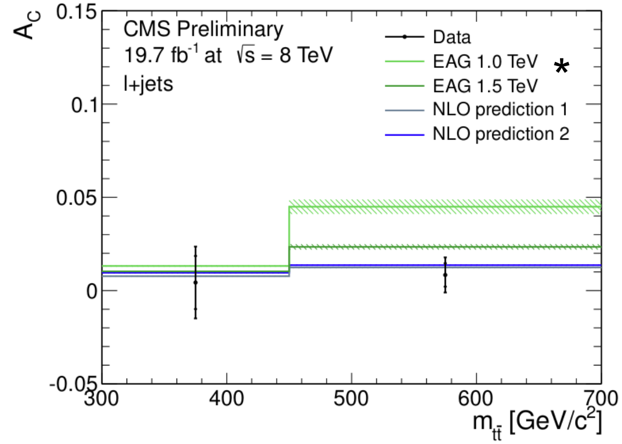
- Theory prediction
  - Kühn, Rodrigo: $A_c = 0.0102 \pm 0.0005$
  - Bernreuther, Si: $A_c = 0.0111 \pm 0.0004$

A_c in Lepton+jets @ 8TeV PAS-TOP-12-033

- **e+jets** and **μ+jets** combined
  - 1 isolated e(μ) with p_T > 30(26)GeV
  - At least 4 jets with p_T > 30 GeV
  - At least 1 of these jets b-tagged
- BG-contamination ~20%
- BG-subtraction and **regularized unfolding**
- **Inclusive** and **differential** ($m_{t\bar{t}}$, $p_{Tt\bar{t}}$, $y_{t\bar{t}}$) measurements using **19.7fb^{-1}**

Asymmetry	A_C
Reconstructed	0.003 ± 0.002 (stat.)
BG-subtracted	0.002 ± 0.002 (stat.)
Unfolded	0.005 ± 0.007 (stat.) ± 0.006 (syst.)
Theory prediction [Kühn, Rodrigo] [9, 33]	0.0102 ± 0.0005
Theory prediction [Bernreuther, Si] [34, 35]	0.0111 ± 0.0004

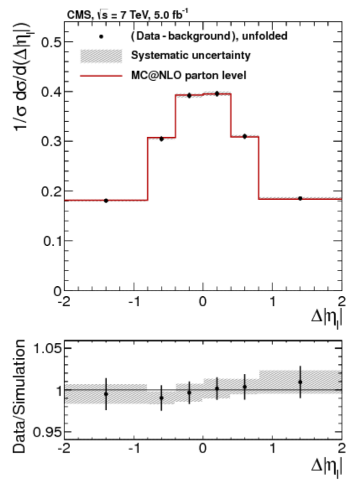


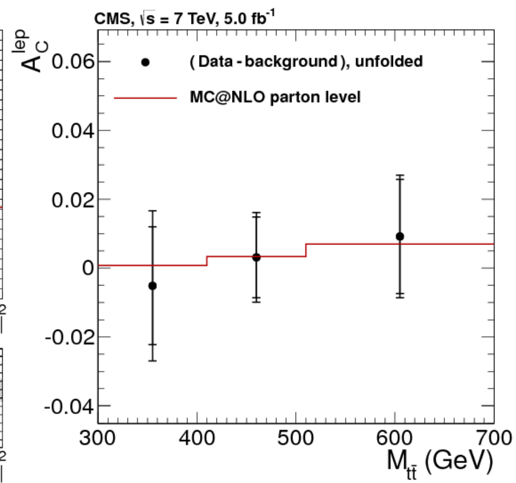


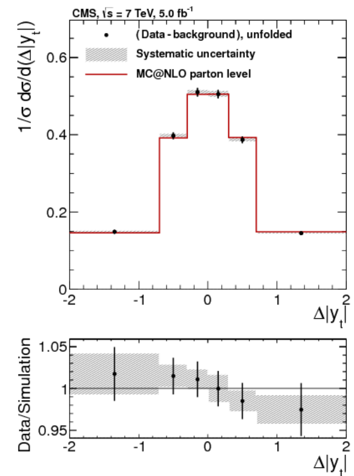
* **E**ffective **A**xialvector-coupling of the **G**luon

A_c in Dilepton @ 7TeV JHEP04(2014)191

- e^+e^-, $\mu^+\mu^-$, $e^\pm\mu^\mp$ combined
  - 2 isolated leptons with p_T > 20 GeV
  - At least 2 jets with p_T > 30GeV
  - At least on of them b-tagged
- Low BG-contamination ~8%
- BG-subtraction and regularized unfolding
- **Inclusive** and **differential** ($m_{t\bar{t}}$, $p_{Tt\bar{t}}$, $y_{t\bar{t}}$) measurements of $\mathbf{A_c^{lep}}$ using **5.0fb^{-1}**
- Inclusive measurement of $\mathbf{A_c}$



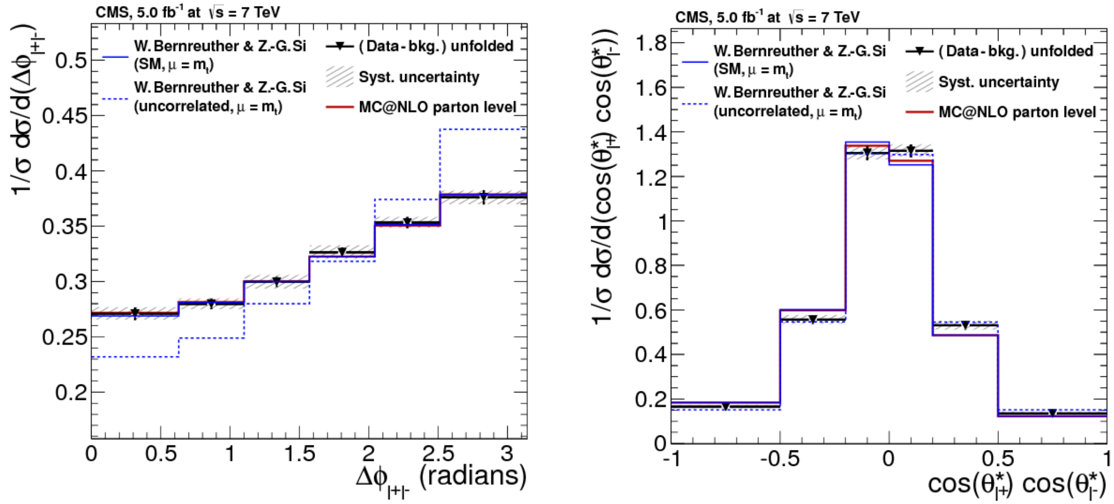




Variable	Data (unfolded)	MC@NLO prediction	NLO theory
A_C	$-0.010 \pm 0.017 \pm 0.008$	0.004 ± 0.001	0.0123 ± 0.0005
A_C^{lep}	$0.009 \pm 0.010 \pm 0.006$	0.004 ± 0.001	0.0070 ± 0.0003

Spin correlation @ 7TeV PRL112(2014)182001

The **difference in Φ** of the charged leptons is sensitive to $t\bar{t}$ spin correlations.
Can be measured precisely **without reconstructing** the full event kinematics



- **e^+e^-, $\mu^+\mu^-$, $e^\pm\mu^\mp$** combined
- BG-subtraction and **regularized unfolding**
- Results based on 5fb^{-1}
- The $A_{\Delta\Phi}$ result **strongly disfavors** the **uncorrelated** case

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

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

Asymmetry	Data (unfolded)	MC@TNLO	NLO (SM, correlated)	NLO (uncorrelated)
$A_{\Delta\phi}$	$0.113 \pm 0.010 \pm 0.006 \pm 0.012$	0.110 ± 0.001	$0.115^{+0.014}_{-0.016}$	$0.210^{+0.013}_{-0.008}$
$A_{c_1c_2}$	$-0.021 \pm 0.023 \pm 0.025 \pm 0.010$	-0.078 ± 0.001	-0.078 ± 0.006	0

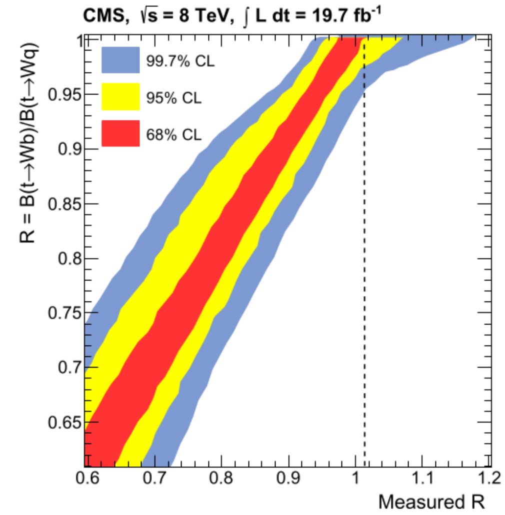
R = BR(t to bW) / BR(t to Wq) PLB 736(2014) 33

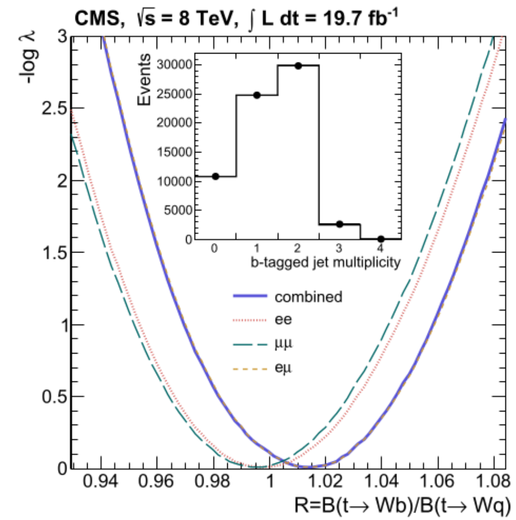
- Fraction of top decays into Wb
- SM predicts R ~1

- **e^+e^-, $\mu^+\mu^-$, $e^\pm\mu^\mp$** channels
- Use the b-jet multiplicity as sensitive variable
- Results are based on **19.7fb^{-1}**

Combined result:
R = 1.014 ±0.003 (stat.) ±0.032(syst.)
Interpret as limit on R:
R > 0.955 @95%C.L.

Assuming top decay into 3 generations and 3 generation CKM matrix being unitary → translates into limit on $|V_{tb}|$:
$|V_{tb}|$ > 0.975 @95%C.L.

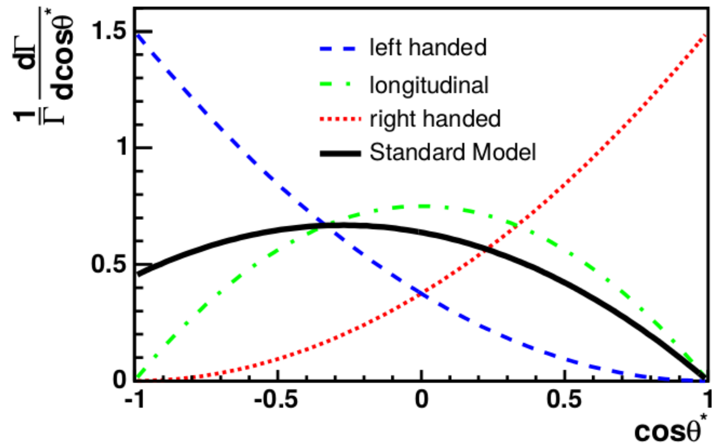




W helicity in top decays PAS-TOP-13-008

$$\frac{1}{\Gamma}\frac{d\Gamma}{d\cos\theta^*} = F_0 \cdot \frac{3}{4}(1-\cos^2\theta^*) + F_- \cdot \frac{3}{8}(1-\cos\theta^*)^2 + F_+ \cdot \frac{3}{8}(1+\cos\theta^*)^2$$

(SM: $F_0 = 0.69$ $F_- = 0.31$ $F_+ \sim 0$)

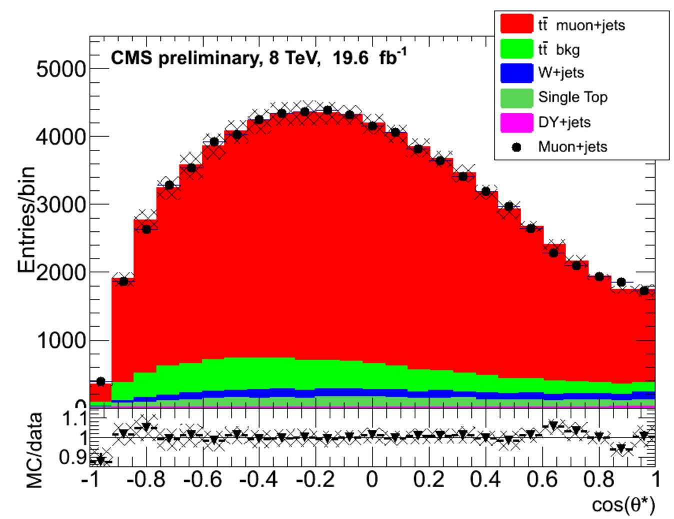


- **μ+jets** channel
- Reconstruct top quark kinematics
- Fit to the **cosθ* distribution**
- Results are based on **19.6fb⁻¹**

$$F_0 = 0.659 \pm 0.015(\text{stat.}) \pm 0.023(\text{syst.})$$
$$F_L = 0.350 \pm 0.010(\text{stat.}) \pm 0.024(\text{syst.})$$

From $F_0 + F_L + F_R = 1$:

$$F_R = -0.009 \pm 0.006(\text{stat.}) \pm 0.020(\text{syst.})$$



Good agreement with SM-predictions!

Summary

Summary

- Measurements of top pair **cross sections** and **properties** have been performed at 7 and 8 TeV
- Inclusive cross sections
  - Systematically limited
  - Good agreement with predicted cross sections
- Differential cross sections
  - Cross section measurements as function of the kinematics of top quarks, leptons, jets, and global event variables
  - Good description of the data by simulation
- Properties
  - No deviations from the SM predictions

Backup

Dilepton @ 8 TeV JHEP 02(2014)024

- Background estimation:
  - **Single top** and **diboson** from MC **simulation**
  - **Drell-Yan**: ratio of events outside/inside **Z mass window** from simulation is applied on data events in the Z mass window
  - **Non-prompt leptons** (jets misidentified as leptons): estimated in a **sideband region in data**
- Dominant systematic uncertainties:
  - Jet energy scale: 5 – 10%
  - Lepton efficiencies: 4 – 6%
  - Factorization and renormalization scales: 6%
  - Drell-Yan estimation (only ee and μμ): 10%

A_c in Lepton+Jets @ 7TeV PAS-TOP-14-006

CHARGE ASYMMETRY CMS ATLAS COMBINATION

Combination done within the TOPLHC working group

		ATLAS	CMS	Comb.	Corr.
	A_C	0.006	0.004	0.005	0.058
Uncertainties	Statistical	0.010	0.010	0.007	0
	Detector response model	0.004	0.007	0.004	0
	Signal model	< 0.001	0.002	0.001	1
	W+jets model	0.002	0.004	0.003	0.5
	QCD model	< 0.001	0.001	0.000	0
	Pileup+MET	0.002	< 0.001	0.001	0
	PDF	0.001	0.002	0.001	1
	MC statistics	0.002	0.002	0.001	0
	Model dependence				
	Specific physics models	< 0.001	*	0.000	0
	General simplified models	*	0.007	0.002	0
	Systematic uncertainty	0.005	0.011	0.006	
	Total uncertainty	0.011	0.015	0.009