Top-quark results from CMS and ATLAS

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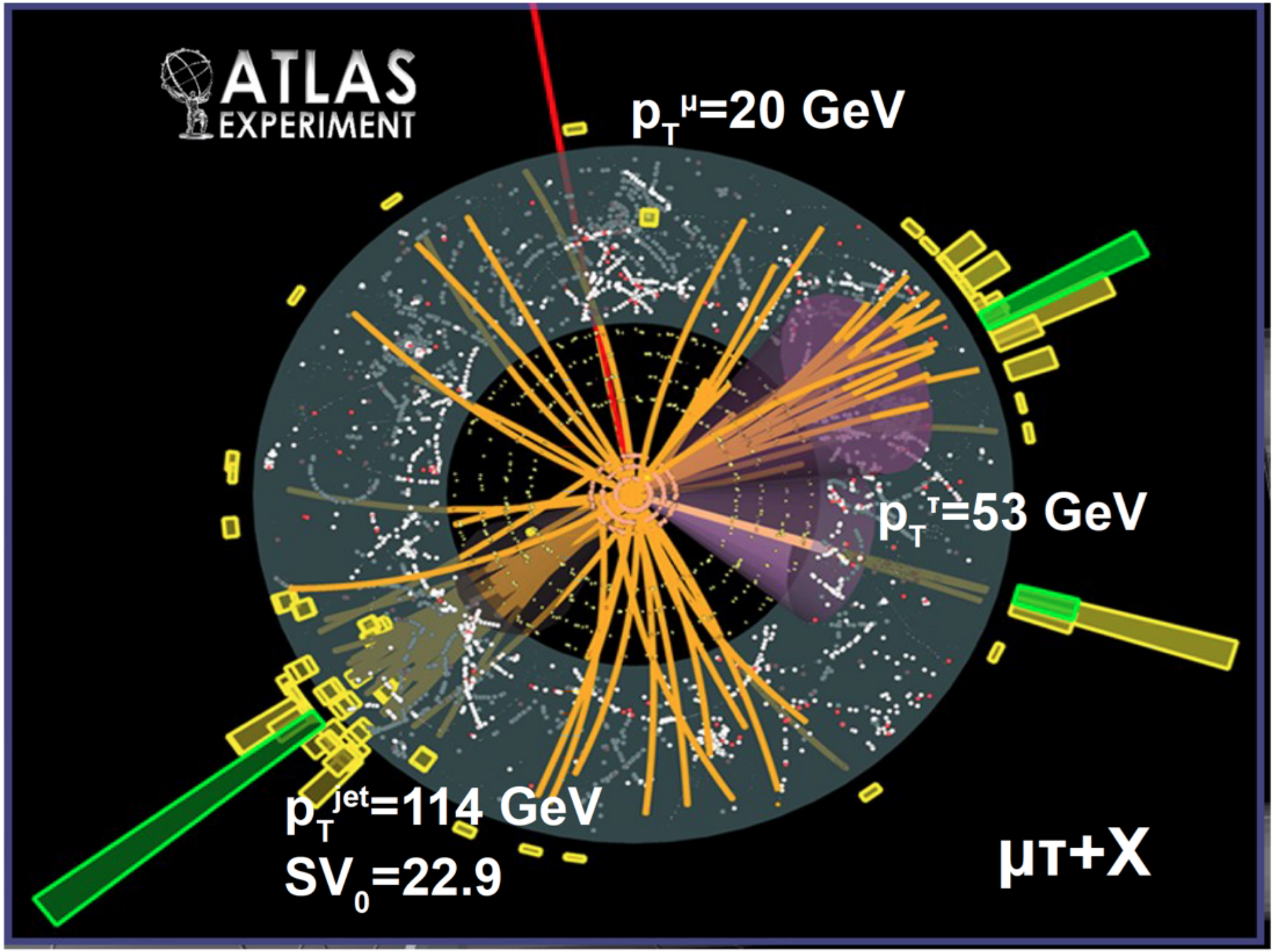
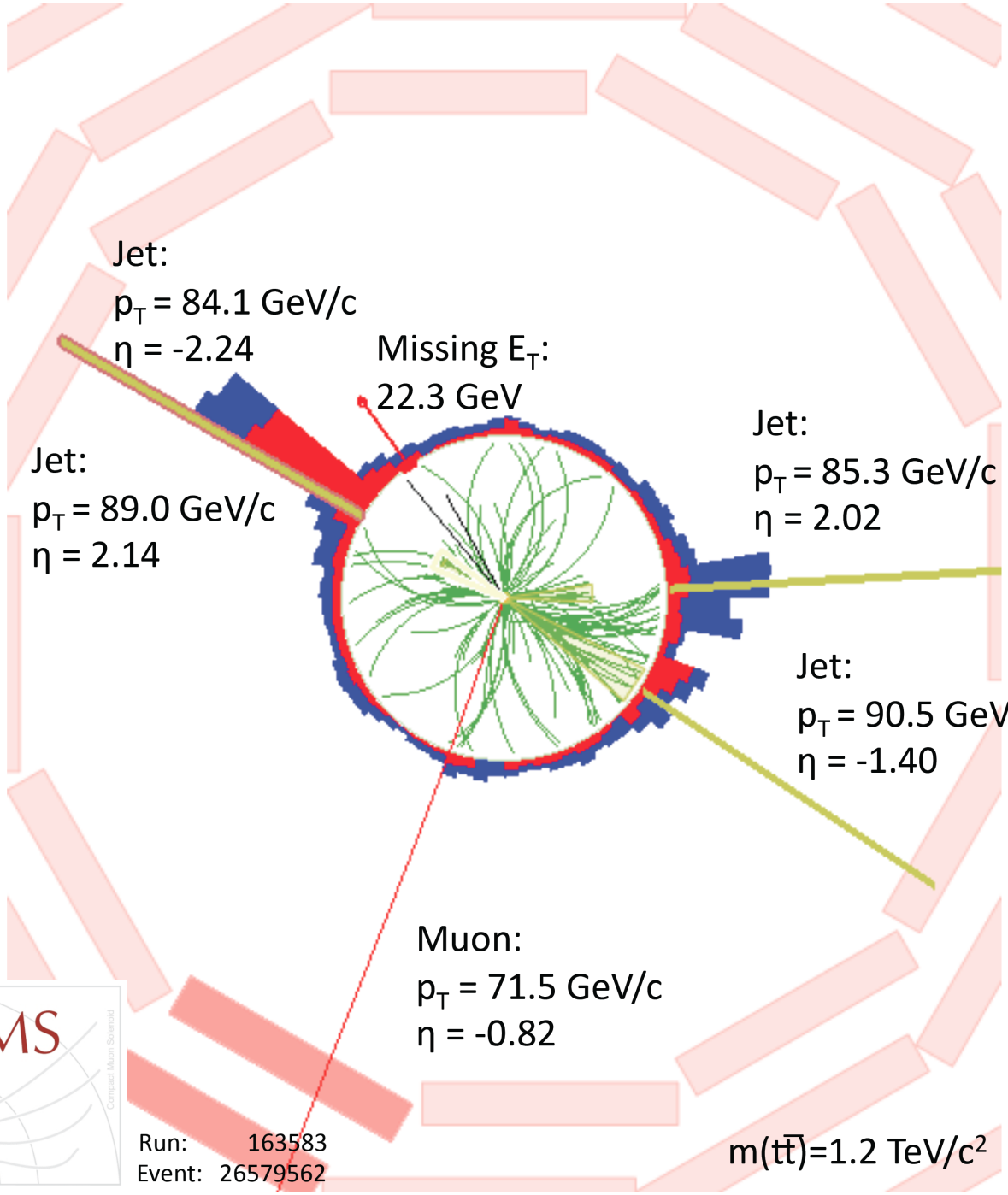
On behalf of CMS & ATLAS

LC13 Workshop, 16-20 Sep 2013, ECT* and INFN , Villazzano (Italy)

OVERVIEW

- Introduction
- Top Production
  - Pair Production via Strong Interaction
  - Single Top Production via Electroweak
  - Cross Section – Total & Differential
- Top Quark Properties
  - Mass
  - W helicity measurement
  - Spin Correlations
- Future Prospects and Conclusions


ATLAS
EXPERIMENT
p_T^{μ}=20 GeV
p_T^{τ}=53 GeV
p_T^{jet}=114 GeV
SV_0=22.9
μτ+X


Jet:
p_T = 84.1 GeV/c
η = -2.24
Missing E_T:
22.3 GeV
Jet:
p_T = 89.0 GeV/c
η = 2.14
Jet:
p_T = 85.3 GeV/c
η = 2.02
Jet:
p_T = 90.5 GeV/c
η = -1.40
Muon:
p_T = 71.5 GeV/c
η = -0.82
CMS
Run: 163583
Event: 26579562
$m(t\bar{t})$=1.2 TeV/c^2

INTRODUCTION

- Heaviest fundamental particle known (***40 times*** heavier than *b* quark, almost weigh equal to gold atom)
- Most precisely measured mass ***Δm/m ≈ 0.5%***
- Short lifetime ***4 x 10^{-25} s*** - hadronization scale ***2.8 x 10^{-24} s***.
- Top's Yukawa couplings to the Higgs Boson is 1.
- Weak isospin partner of *b* quark with spin ½ and charge ***+2/3 e***
- The most probable place for BSM physics to show up.

INTRODUCTION

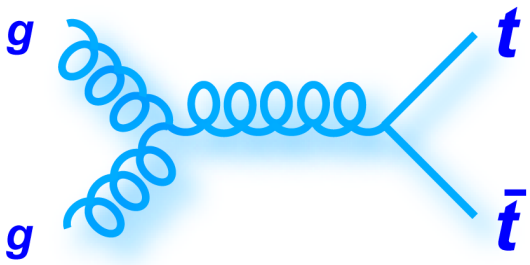
- tt pair is produced through strong interaction
  - ***E_{cm} = 7 TeV (80%)*** and @ ***14 TeV (90%)*** is due to gluon fusion - ***$x = 2m_t/E_{cm}$*** typical value
- Single top quarks produced through electroweak interaction and *Wtb* vertex.
  - t-channel mode
  - s-channel mode
  - associated production
- Decay width of top is ***1.33 GeV***

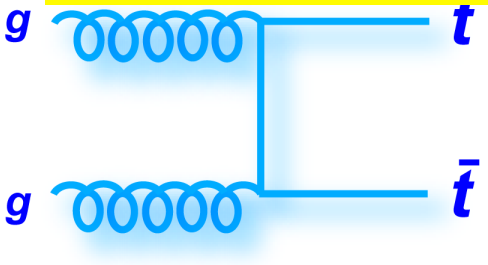
Top Measurement - Challenging

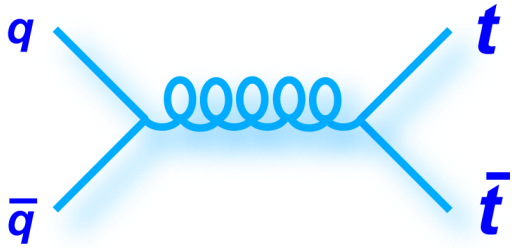
- **Top quark reconstruction**
  - reconstruction of all detector objects are needed: electron, muon, jets, missing energy, b-jets etc.
  - kinematical fit, under constrained kinematics in dilepton events
  - unfolding kinematical distributions
    - differential cross sections, polarizations, asymmetries
- **Background estimations from data**
  - multijets, W+jets, DY in corners of phase space
  - large data/MC scale factors
- **Control of the systematics**
  - accuracy of measurements is now limited by systematics

Top Quark Production

Pair Production





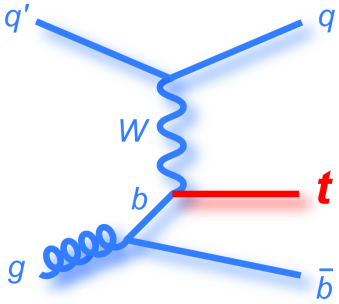


Ecm = 7 (14) TeV – contribution from gluon fusion 80% (90%)

σ ≈ 160 pb @ 7 TeV (NLO QCD)

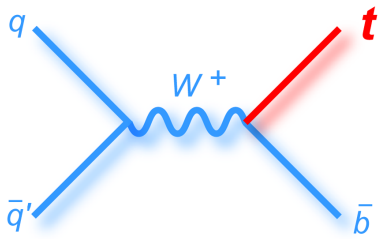
V. Ahrens et al
Phys. Lett. B703, 135 (2011)

Single top production



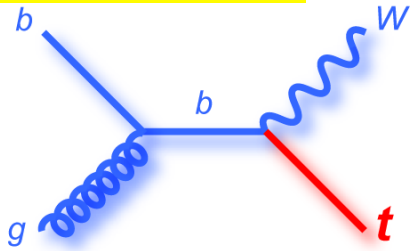
t-channel

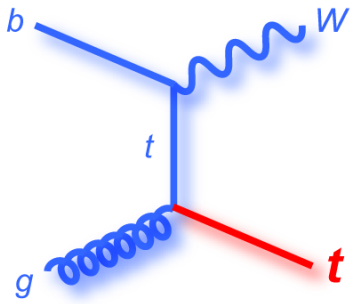
65 pb @ 7 TeV



s-channel

5 pb @ 7 TeV





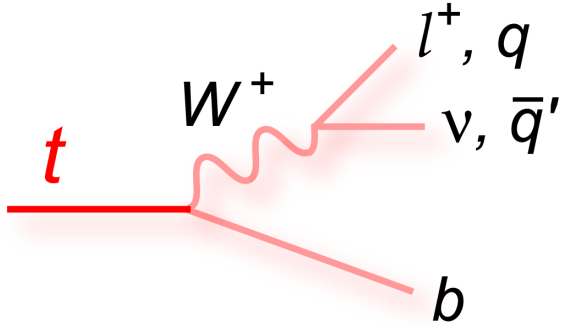
Wt-channel

16 pb @ 7 TeV

N. Kidonakis, Phys. Rev. D81, 054028 (2010), Phys. Rev. D82, 054018 (2010)
Phys. Rev. D83, 091503 (2011)

Top Quark Decay - *Pairs*

- Top decays 100% into W and b
- Decay products seen depends on the decay of W boson.
- ***W → lν*** or ***W → qq'***
  - ***tt → qq'bqq'b (46.2%)*** Alljets, largest BR but huge QCD background
  - ***tt → lνbqq'b (43.5%)*** Lepton plus jets with manageable background
  - ***tt → lνblνb (10.3%)*** Dilepton small BR with very little background
- Very interesting channel – almost all detector objects are there

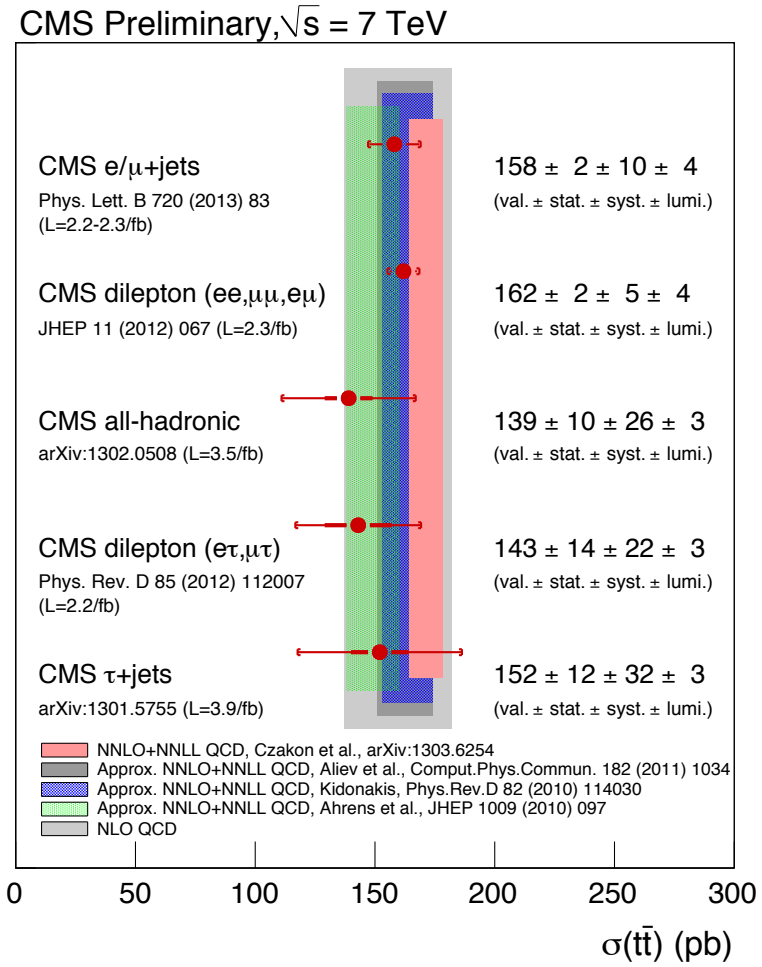


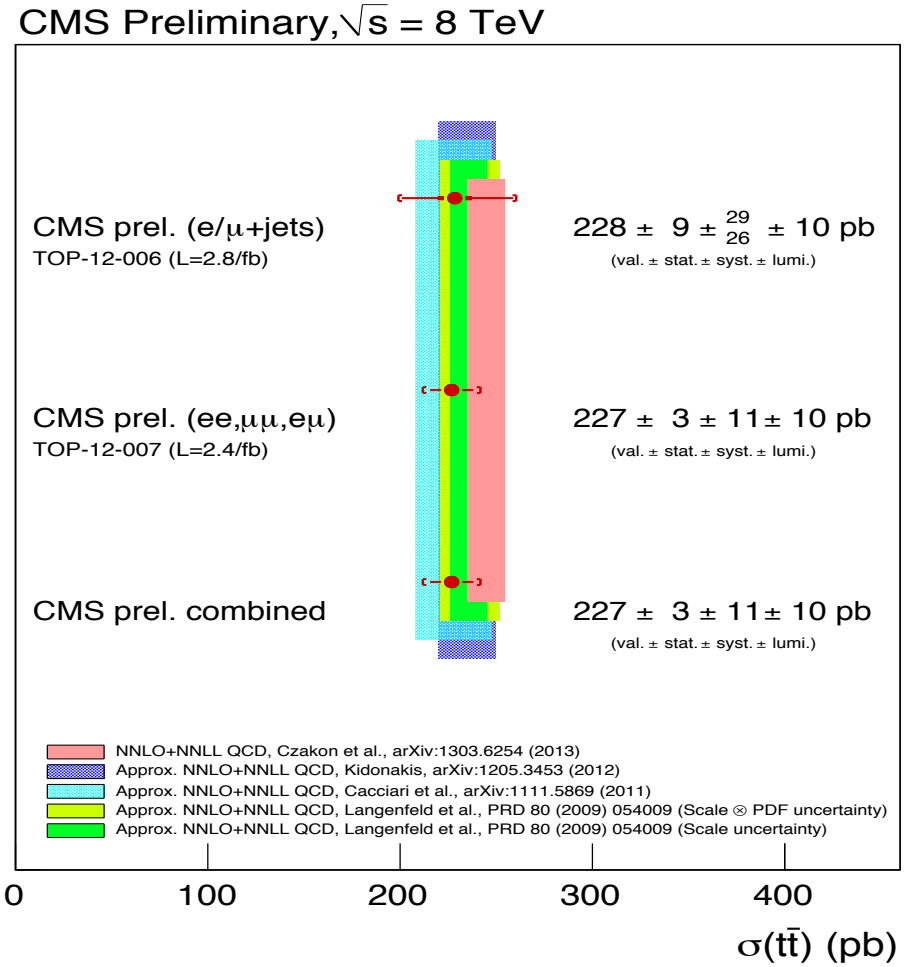
Top Pair Decay Channels

W decay	e^+	μ^+	τ^+	$u\bar{d}$	$c\bar{s}$
e^-	ee	$e\mu$	$e\tau$	electron+jets	
μ^-	$e\mu$	$\mu\mu$	$\mu\tau$	muon+jets	
τ^-	$e\tau$	$\mu\tau$	$\tau\tau$	tau+jets	
$\bar{u}d$	electron+jets	muon+jets	tau+jets	all-hadronic	
$\bar{c}s$					

dileptons

Top Cross Section - CMS

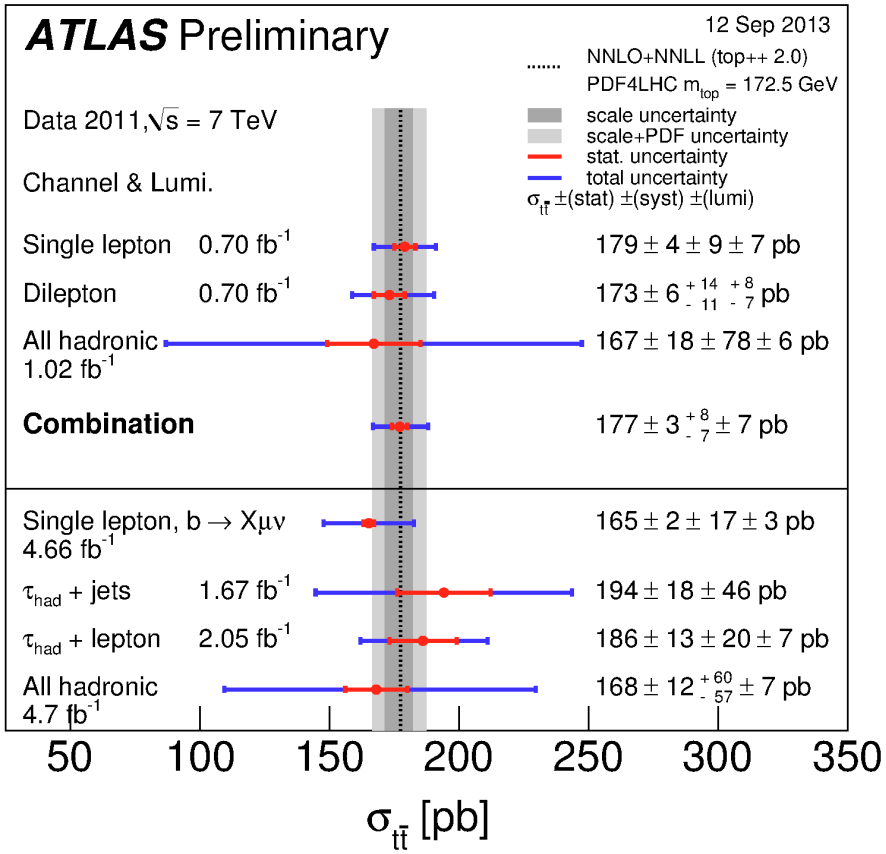


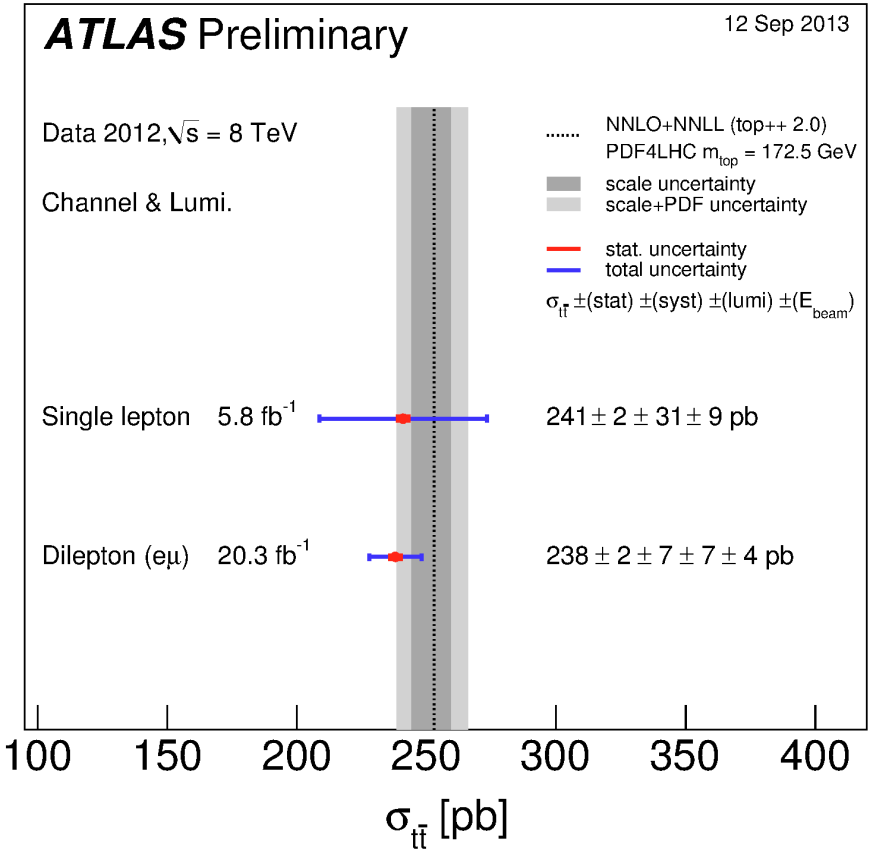


σ_{tt} = 162 ± 2(stat) ± 5(syst) ± 4(lumi) pb

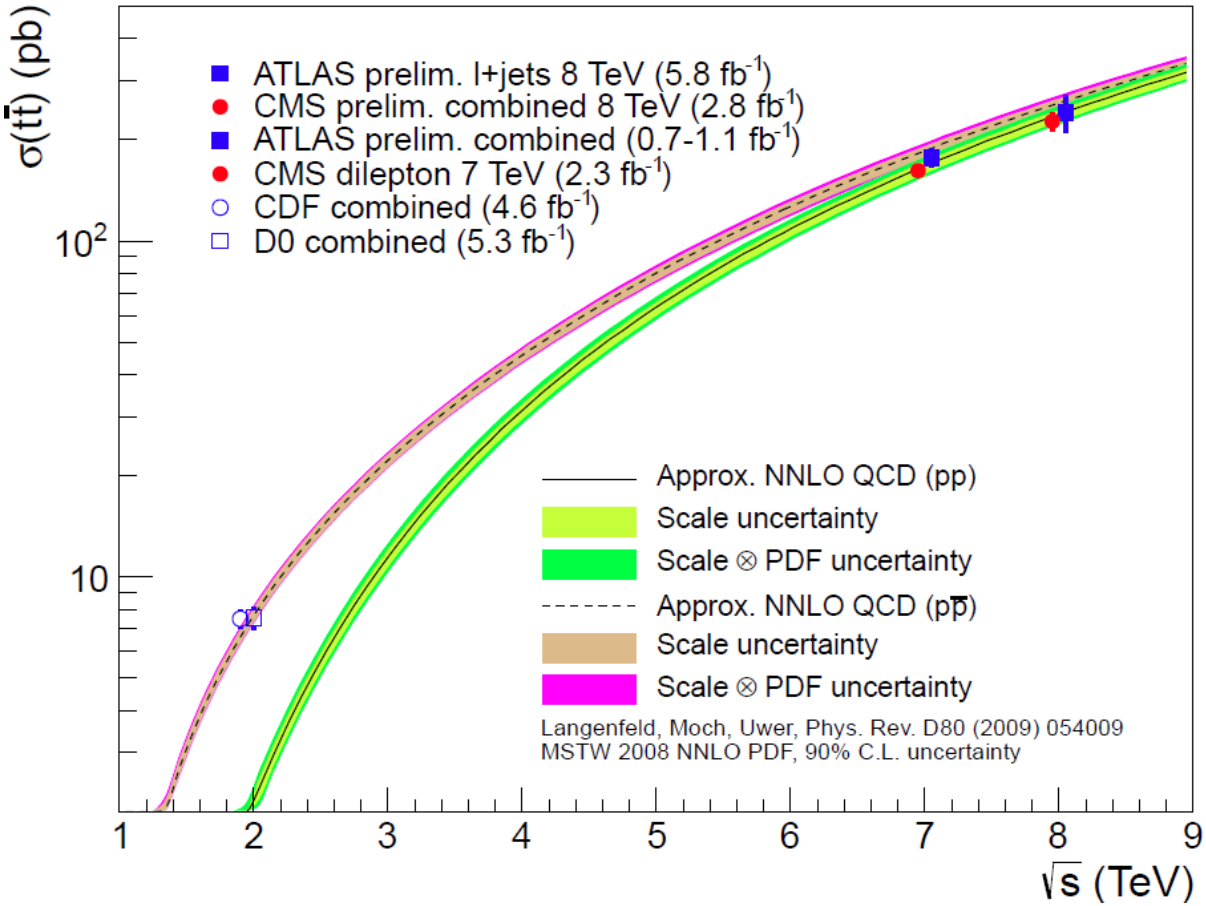
σ_{tt} = 227 ± 3(stat) ± 11(syst) ± 10(lumi) pb

Cross Section Summary - ATLAS





Total Xsec – Top pair



- First results from ATLAS and CMS at 8 TeV
- Excellent agreement between QCD prediction and measurement
- Theoretical and experimental uncertainties are comparable at 5% level.

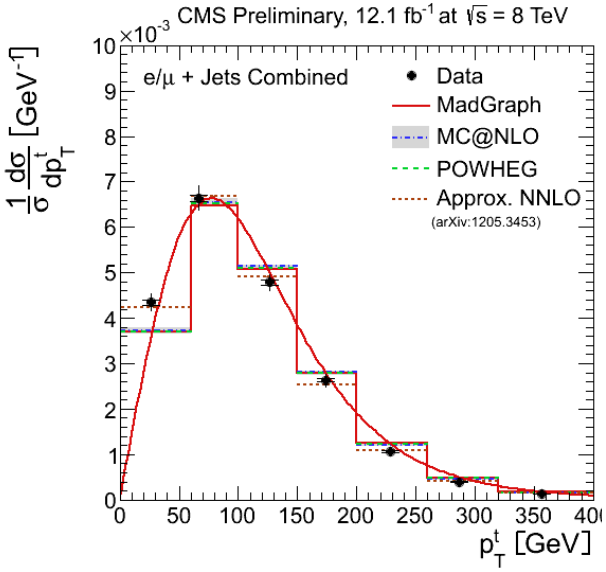
ATLAS-CONF-2012-149
CMS PAS TOP-12-007

Differential Cross Section

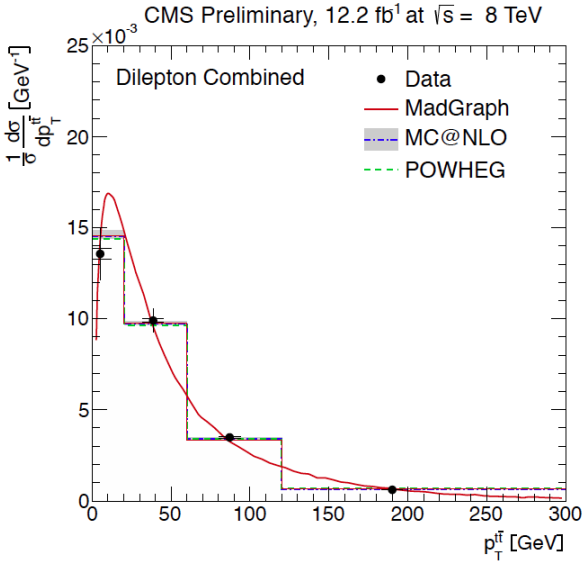
- With large top sample at LHC – it is possible to measure differential cross section
- Can be used to validate:
  - MC Models
  - Parton Distribution Function (PDF)
  - Higher order QCD calculations
- Deviations could signal contributions from new physics

ATLAS: Eur. Phys. J. C73 (2013):2261
CMS: Eur. Phys. J. C73 (2013):2339

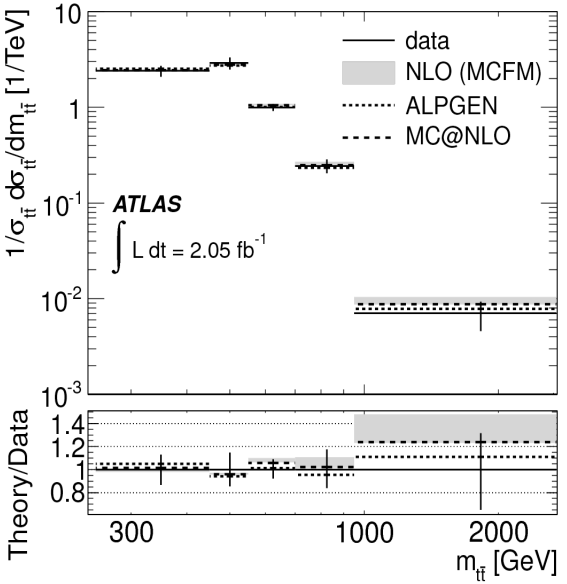
$p_T(t)$, l+jets



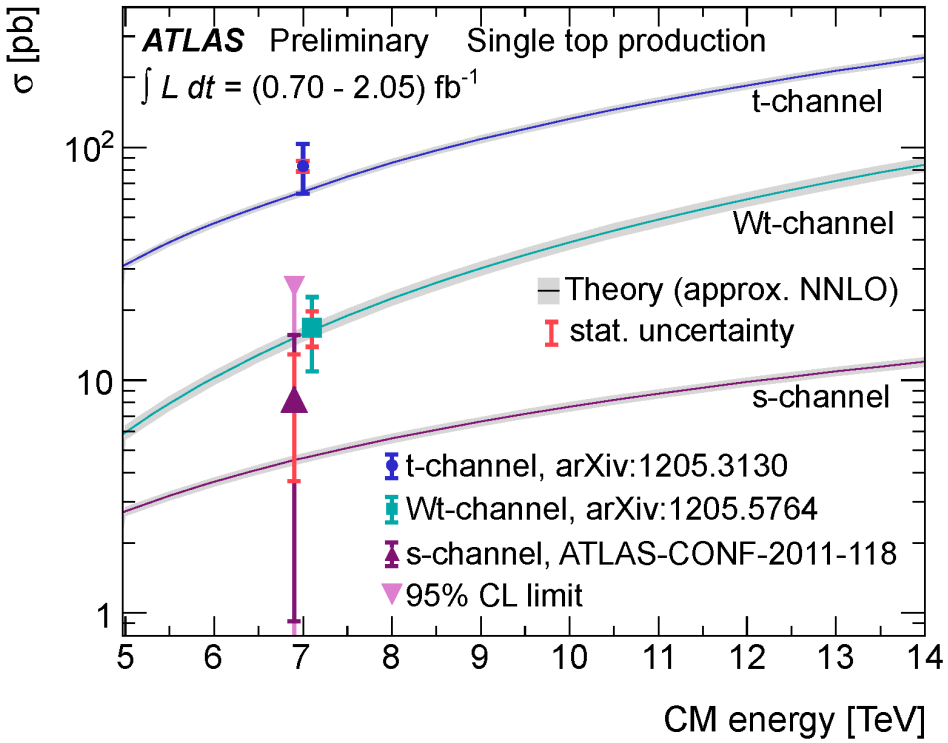
$p_T(t\bar{t})$, dilepton

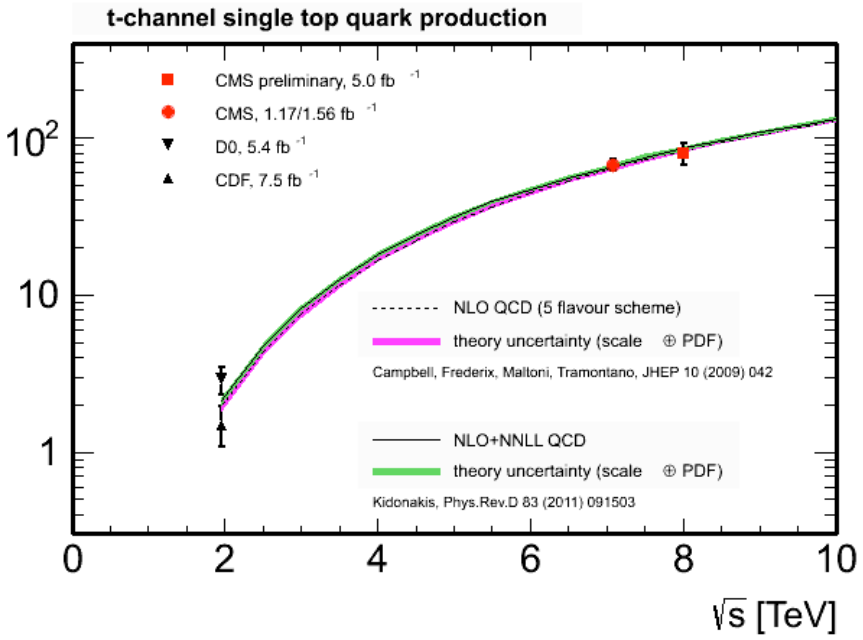


$m(t\bar{t})$, l+jets



Single Top Production





CMS-PAS-TOP-12-011

t-channel 8 TeV:

$\sigma_t = 80.1 \pm 13$ pb

$\sigma_t = 95 \pm 18$ pb

$\sigma^{th}_t = 87.2\ ^{+2.1}_{-0.7}$ (scale) $^{+1.5}_{-1.7}$(PDF) pb

CMS-PAS-TOP-12-011

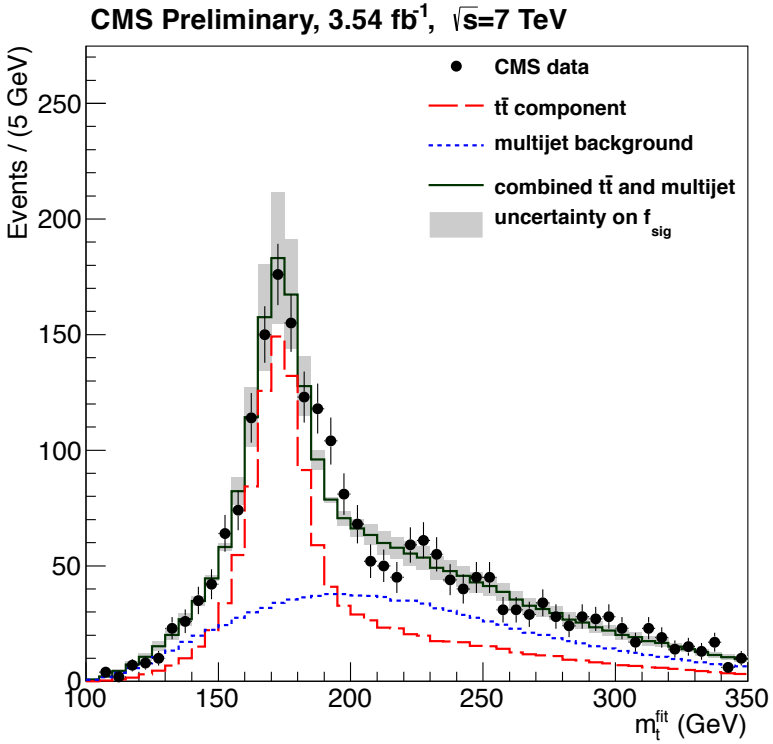
ATLAS-CONF-2012-132

N. Kidonakis, arXiv:1205.3453

Top Mass – fully hadronic

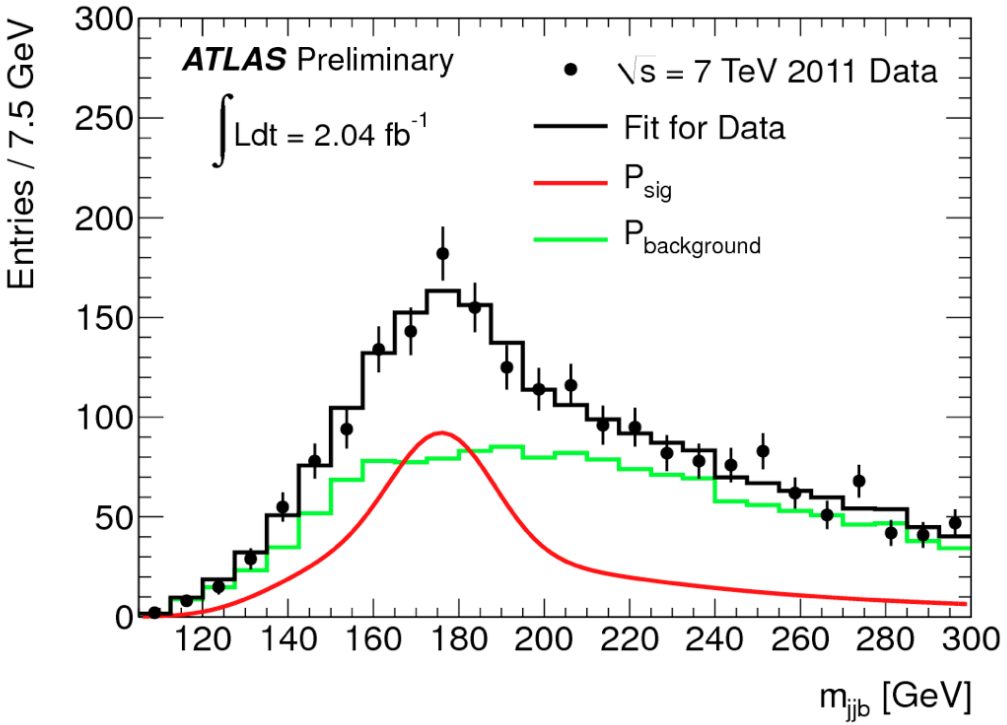
Ideogram method **3.5 fb−1**

CMS PAS-TOP-11-017 (2012)



Template method **2.0 fb−1**

ATLAS-CONF-2012-030 (2012)



M_t = 173.49±0.69(stat)±1.25(syst) GeV
δM_t = 1.5 GeV (0.85%)

M_t = 174.9±2.1(stat)±3.8 (syst) GeV
δM_t = 4.3 GeV (2.5%)

Top Mass – Lepton+Jets

- **CMS:** using Ideogram method – lepton+Jets at 7 TeV with 5 fb^{-1}: JHEP 12, 105 (2012)

  $M_t = 173.49 \pm 0.43(stat+JES) \pm 0.98(syst)$ GeV

  $\delta M_t = 1.1$ GeV (0.63%)

- **ATLAS:** using 3D Template method – lepton +Jets at 7 TeV with 4.7 fb^{-1} ATLAS-CONF-2013-046

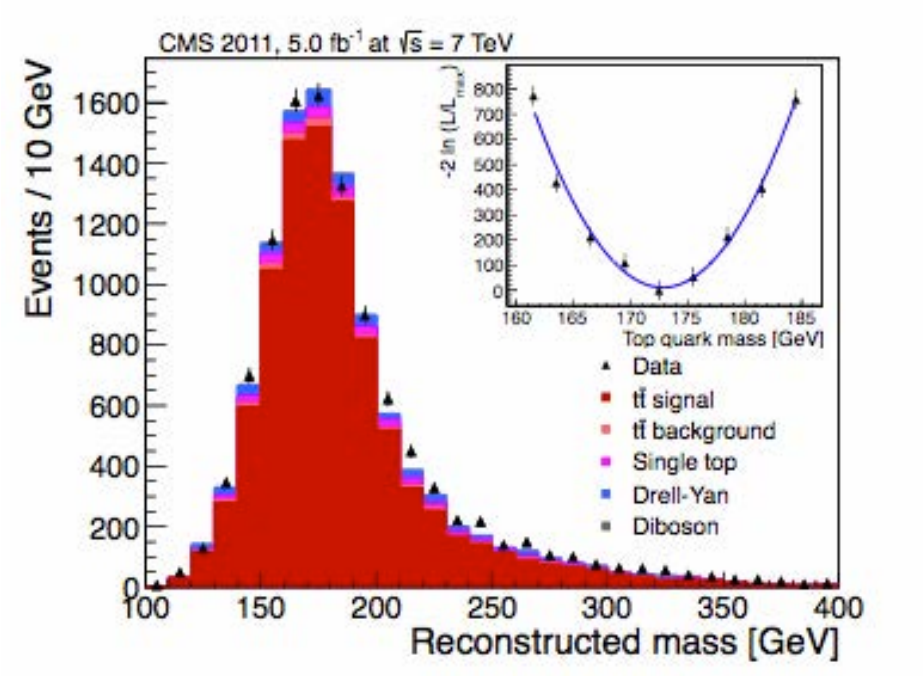
  $M_t = 172.31 \pm 0.75(stat+JSF) \pm 1.35(syst)$ GeV

  $\delta M_t = 1.5$ GeV (0.90%)

Top Mass - dilepton

CMS – 5 fb-1 @7 TeV

EPJC 72, 2202 (2012)

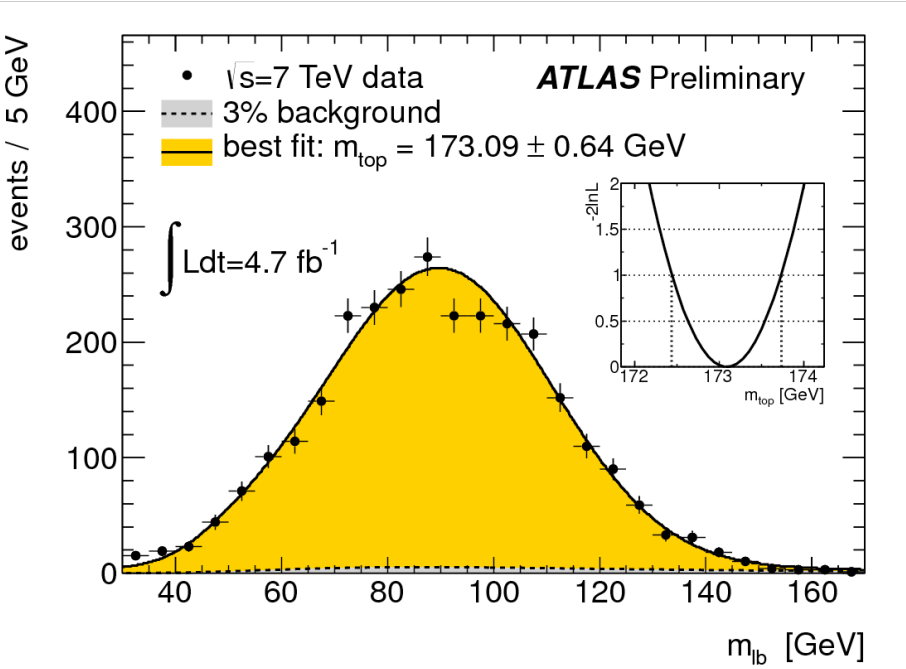


M_t = 172.5±0.4(stat)±1.5(syst) GeV

δM_t = 1.6 GeV (0.93%)

ATLAS – 4.7 fb-1 @7 TeV

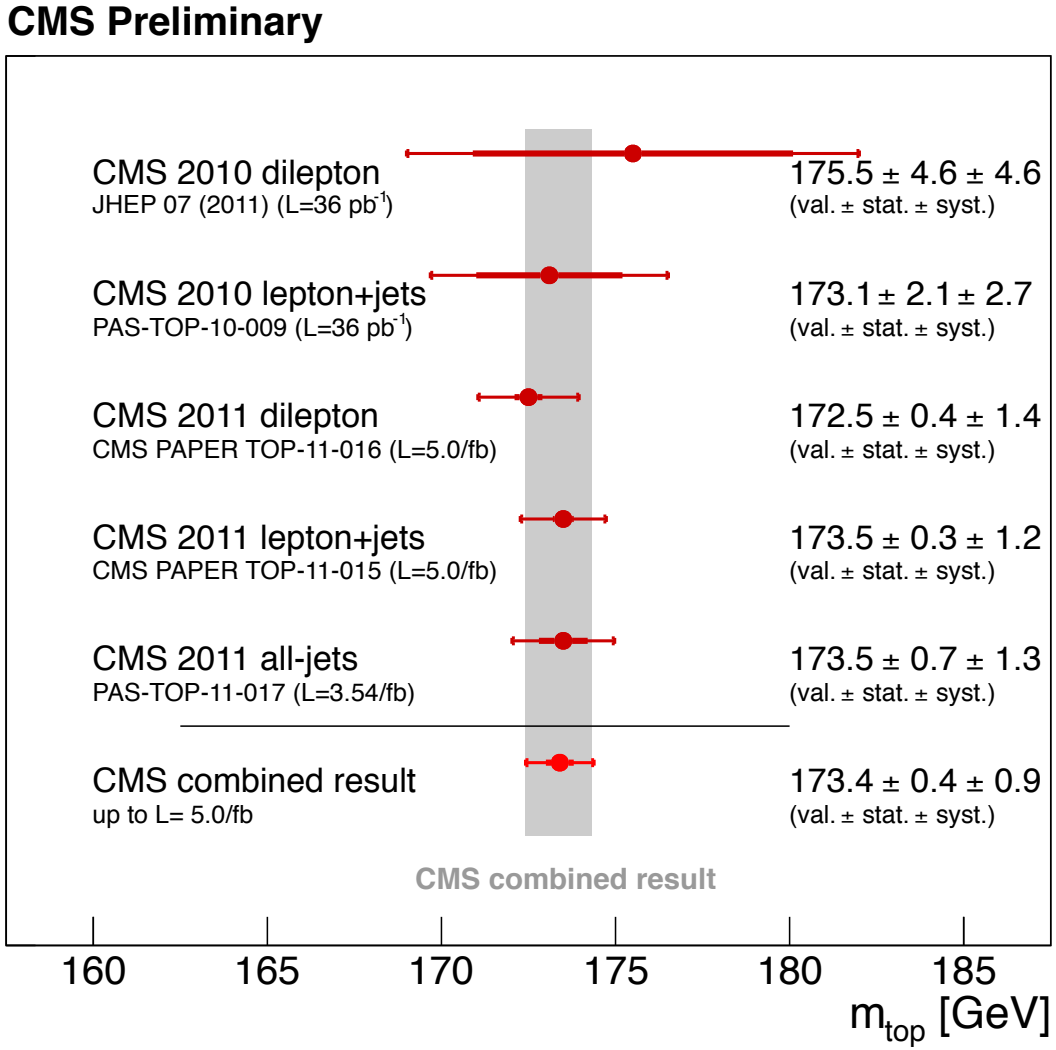
ATLAS-CONF-2013-077



M_t = 173.09±0.64(stat)±1.50(syst) GeV

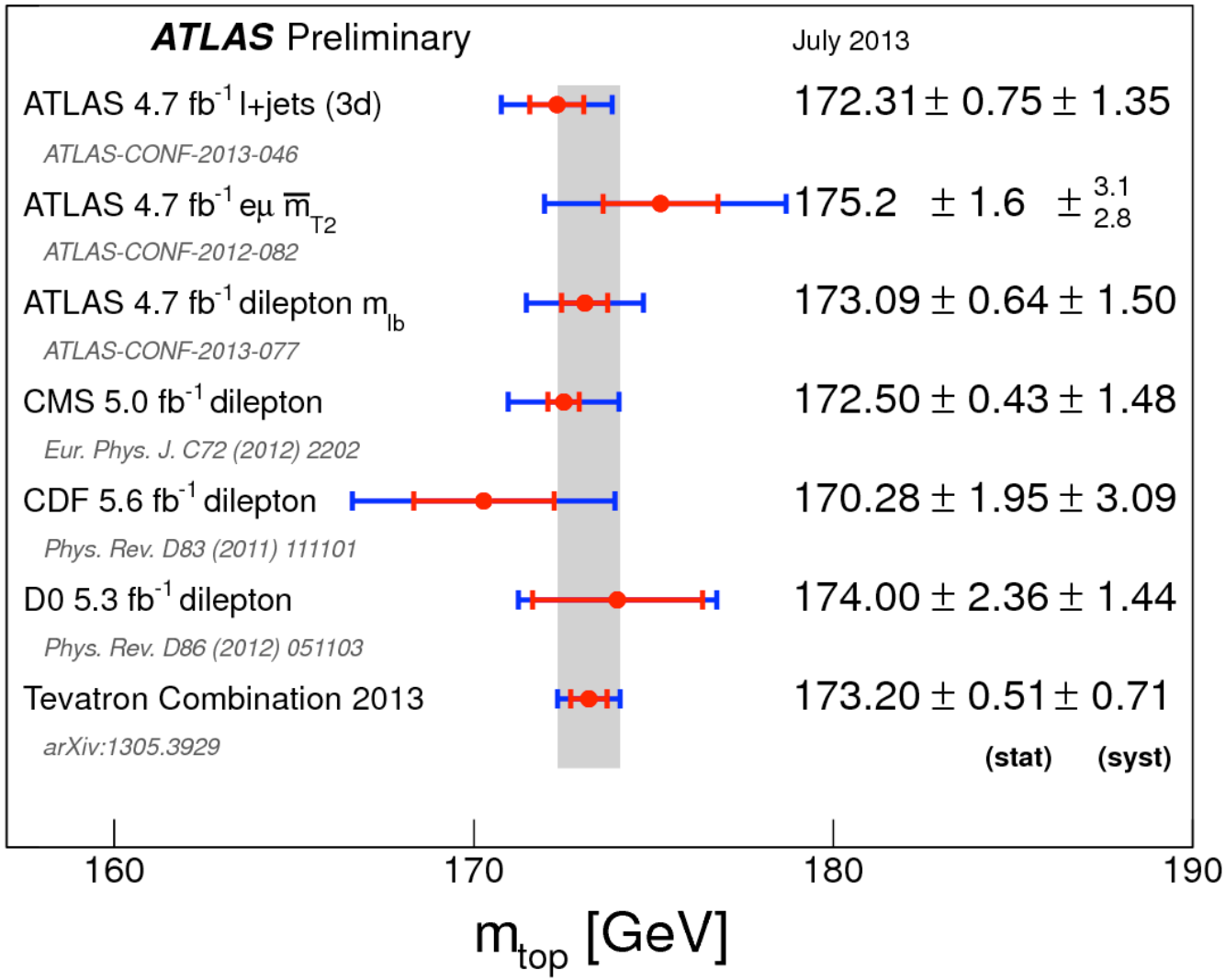
δM_t = 1.63 GeV (0.94%)

Top Mass – CMS Summary



- All channels considered including all jets
- 2011 data at 7 TeV
- Luminosity up to 5 fb-1
- Best single LHC measurement reaches a precision of 0.6%
- Tevatron still provides the best measurement with precision 0.5%

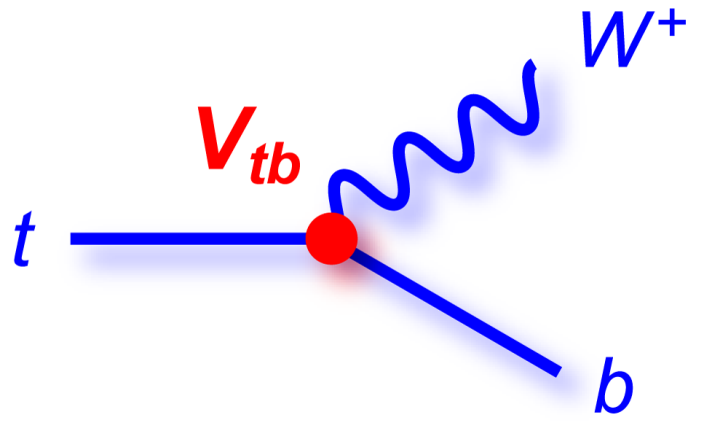
Top Mass – ATLAS Summary



W helicity in top decays

- Probe (V-A) structure of Wtb vertex
- Measure dσ/dcosθ*, the angle between the lepton and the b directions (in the W rest frame)

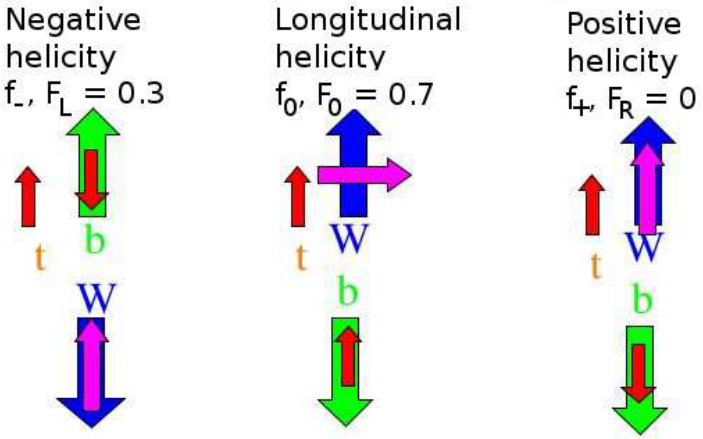
J. A. Aguilar-Saavedra et al, arXiv:1005.5382v2



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

- W polarization fractions calculated at NNLO:
  $F_0 = 0.687 \pm 0.005$
  $F_L = 0.311 \pm 0.005$
  $F_R = 0.0017 \pm 0.0001$

Czarnecki et al., PR D 81 (2010) 111503



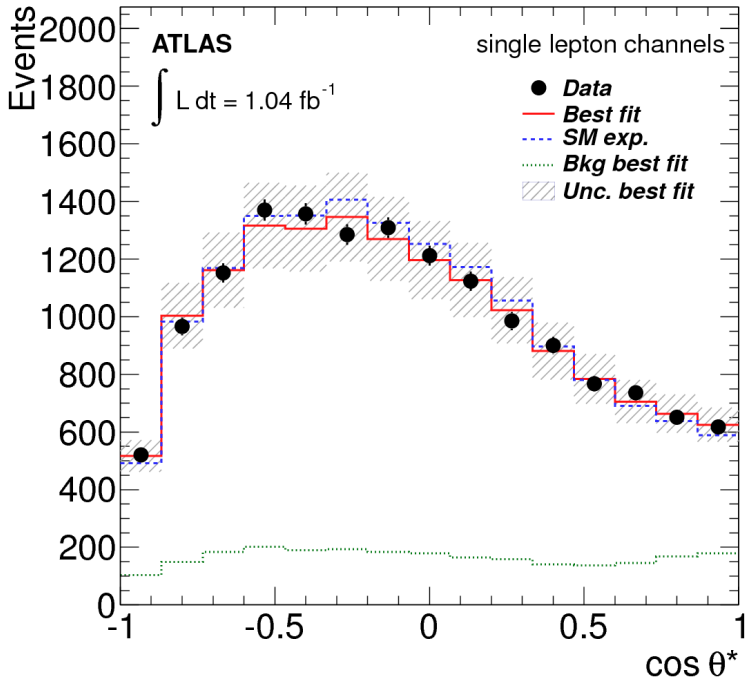
W helicity in top decays

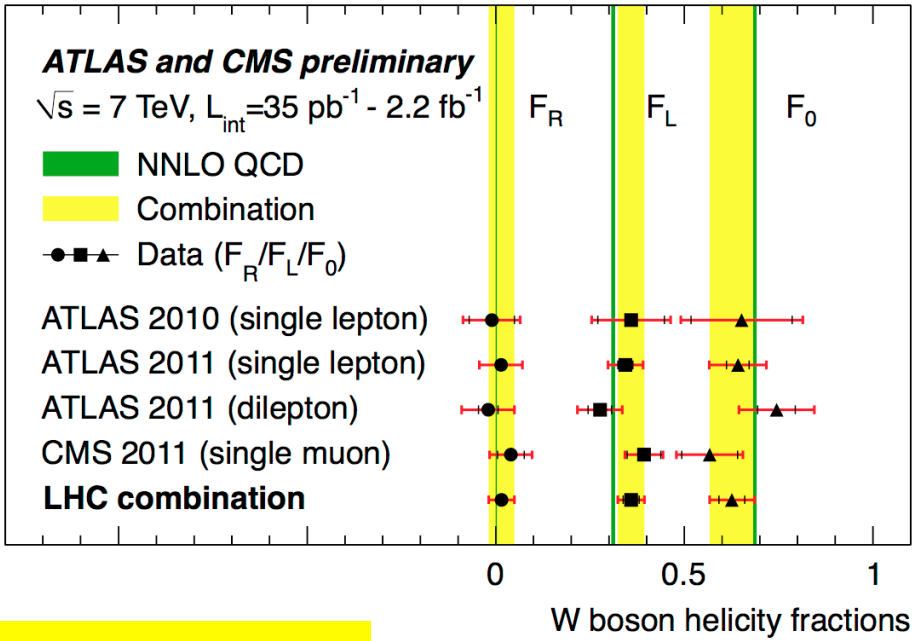
First LHC combination:

F0=0.626 ± 0.034 (stat.) ± 0.048 (syst.)

FL=0.359 ± 0.021 (stat.) ± 0.028 (syst.)

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





CMS PAS-TOP-12-015

CMS dilepton:

F_L = 0.288± 0.035(**stat.**)± 0.050(**syst.**)

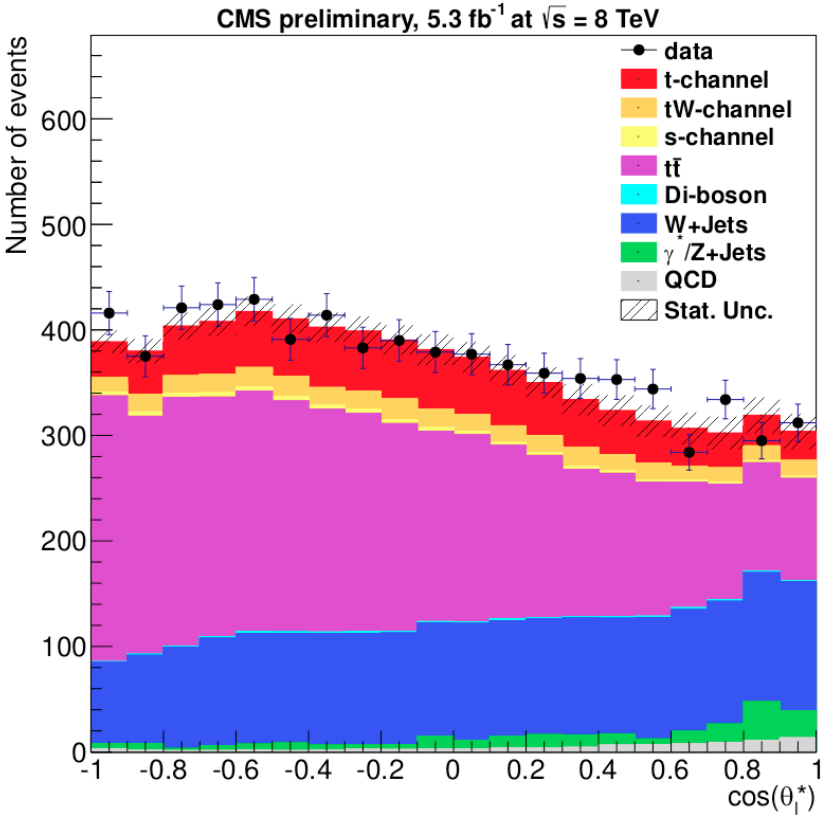
F_0 = 0.698± 0.057(**stat.**)± 0.063(**syst.**)

F_R = −0.014 ± 0.027(**stat.**)± 0.055(**syst.**)

JHEP 1206 (2012) 088

W helicity in single top

- **First measurement using single-top enriched sample**
- 7 and 8 TeV, **μ**+jets events
- Helicity fractions and W+jets contribution simultaneously extracted.
- Consistent with the SM and with the measurement in ttbar channels



F_L = 0.293± 0.069(**stat**.)± 0.030(**syst**.)
F_0 = 0.713± 0.114(**stat**.)± 0.023(**syst**.)
F_R = −0.006 ± 0.057(**stat**.)± 0.027(**syst**.)

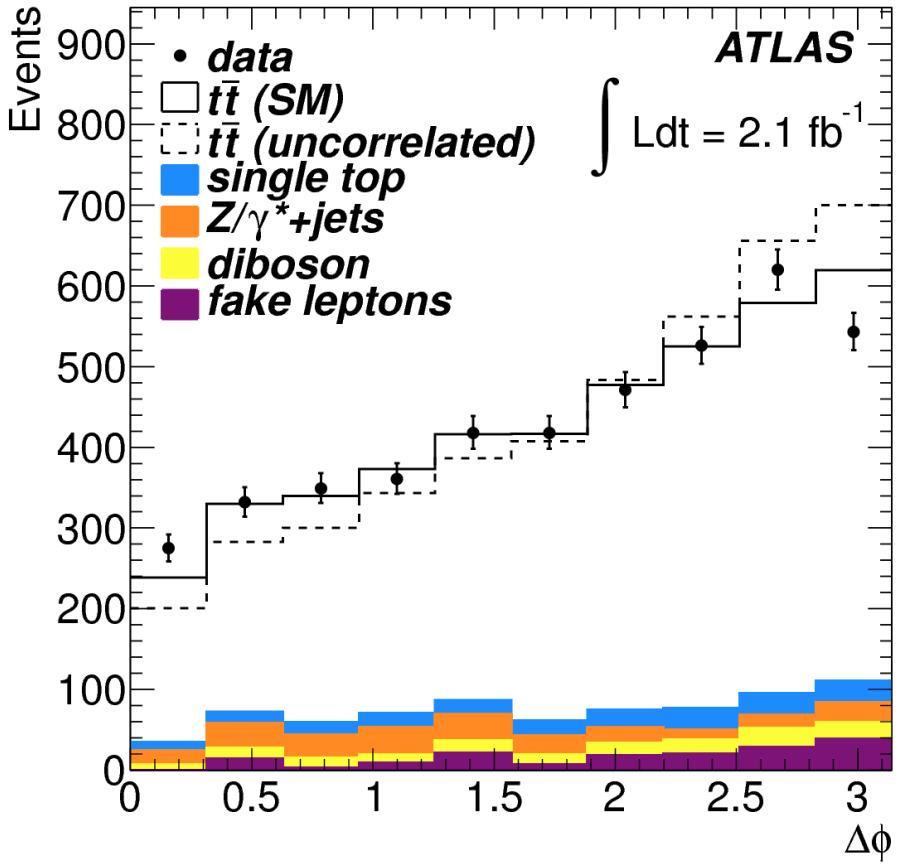
CMS PAS-TOP-12-020

Top spin correlations

- SM predicts correlation of spin of the top and antitop
- Measured from angular distributions of the top decay products
- Use **Δϕ** between leptons which don't require top reconstruction
- Sensitive to New Physics

Spin correlation coefficient:

$$A = \frac{N(\uparrow\uparrow) + N(\downarrow\downarrow) - N(\uparrow\downarrow) - N(\downarrow\uparrow)}{N(\uparrow\uparrow) + N(\downarrow\downarrow) + N(\uparrow\downarrow) + N(\downarrow\uparrow)}$$



ATLAS: 0.40 ± 0.08

CMS: 0.24 ± 0.08

PRL 108, 212001 (2012)
CMS PAS TOP-12-004

Future Prospects

- **LHC with high luminosity:**
  - Phase 1: 300 fb^{-1}
  - Phase 2 (HL-LHC): 3000 fb^{-1}
- **LHC - True top factory: E_{cm} = 13 TeV with 300 fb^{-1}, we expect per experiment:**
  - 50 M ttbar events in the lepton+jet channel
  - 10 M events in the dilepton channel
  - 15 M single top events
- **What can be studied?**
  - Top coupling to W and Z
  - Precise studies of the tWb vertex
  - FCNC decays of top t → Zq

Conclusions

- **Excellent measurements of top physics are now available:**
  - mass ~ 0.5%
  - cross sections: top pair ~ 5%, single top ~ 10%
  - Vtb ~ 2% (from R), 5% (from single top)
  - Charge asymmetry ~ 2%
  - W helicity fractions ~ 10%
  - differential cross sections challenging NLO QCD calculations
- **Most measurements are dominated by systematic uncertainties**
  - Jet energy scale, b-tagging, signal modeling
  - The road ahead will not be easy
- **The SM persists in describing the data remarkably well**
- **Bright prospects for top physics at LHC:**
  - Precise measurements
  - Searches involving top quarks in the final state