ATLAS results on top properties

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(on behalf of the ATLAS collaboration)

The 2nd annual conference on Large Hadron Collider Physics
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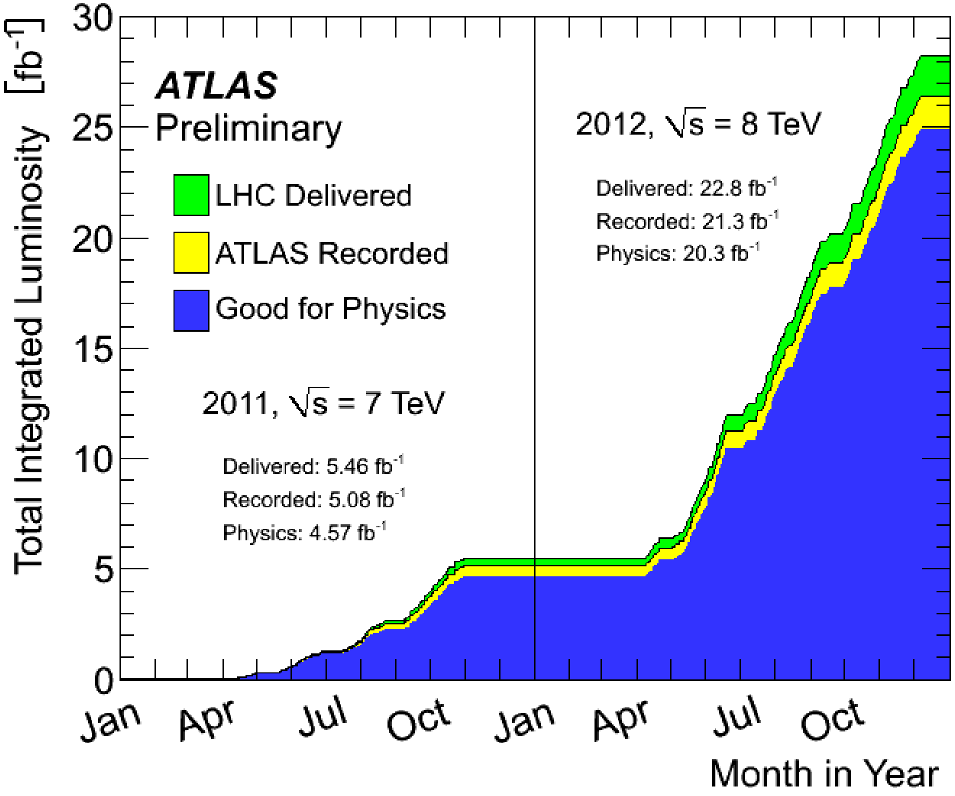
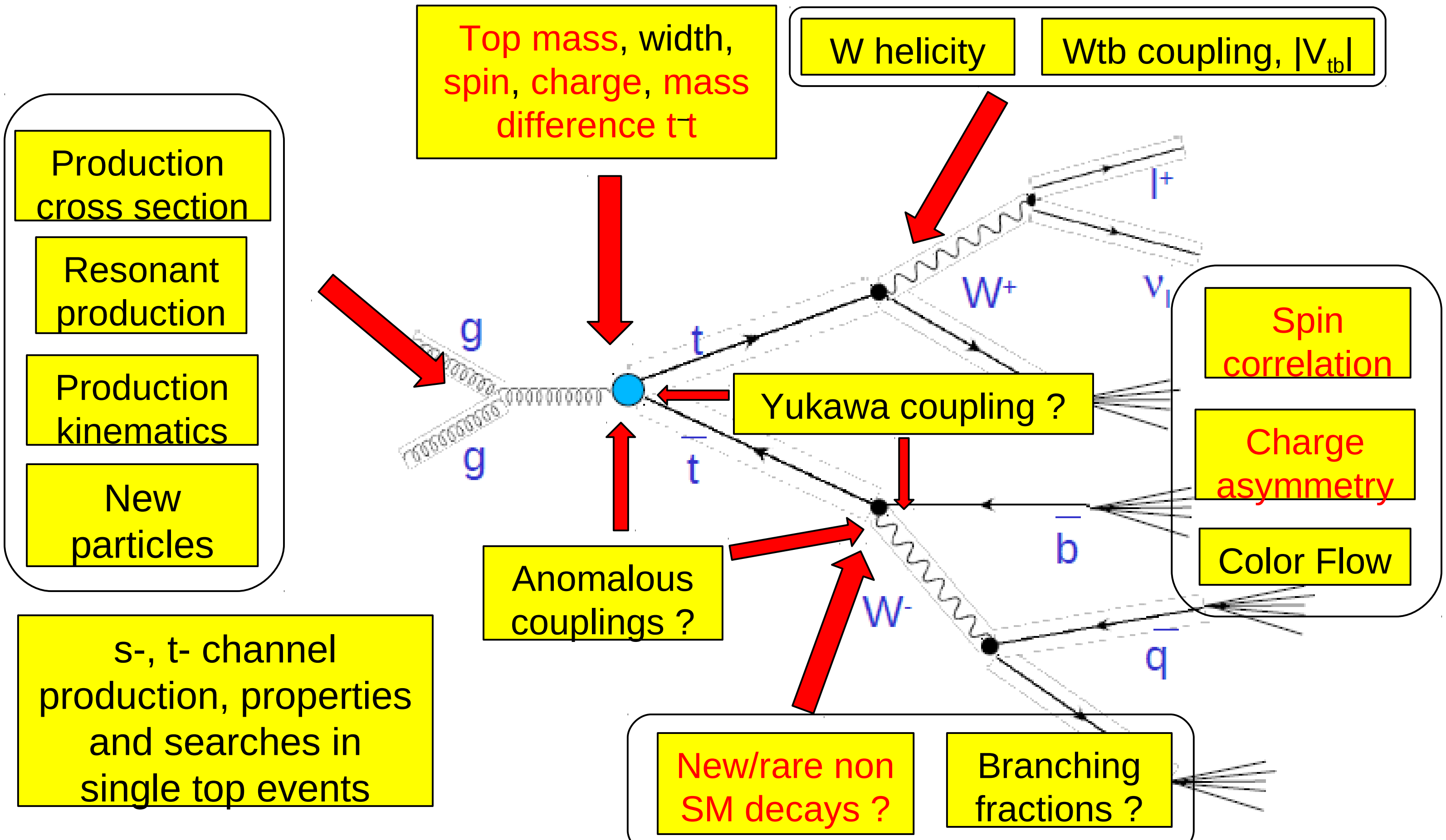


- Introduction
- mass
- charge
- polarization
- spin correlation
- charge asymmetry
- FCNC

7 TeV analyses ~1×10^6 pairs
8 TeV analyses ~5×10^6 pairs

What kind of physics with top quark ?

Heaviest fundamental particles → large Higgs coupling (special rôle in EWSB?)
Very short lifetime (~10^{-25}s) → decays before hadronization (10^{-23}s)
→ spin information carried to final state particles
Possibility to study bare quark
Great tool to study Standard Model – or search for New Physics



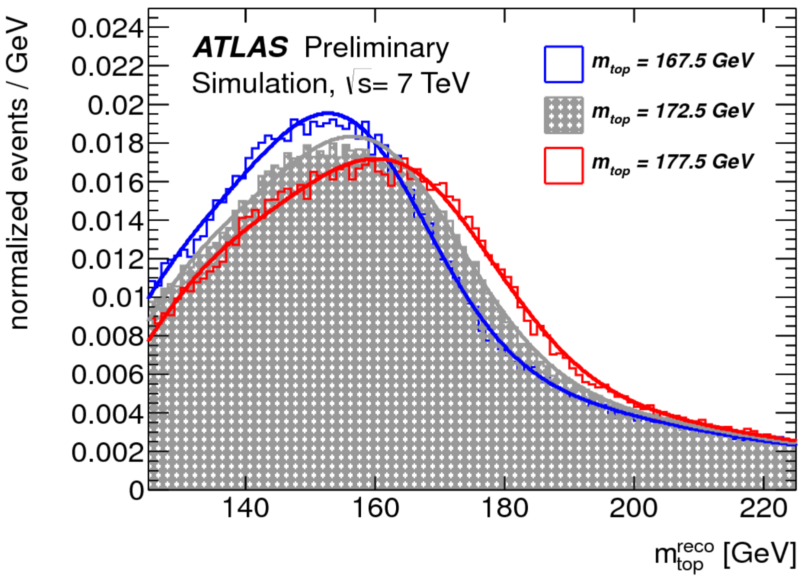
Top quark mass

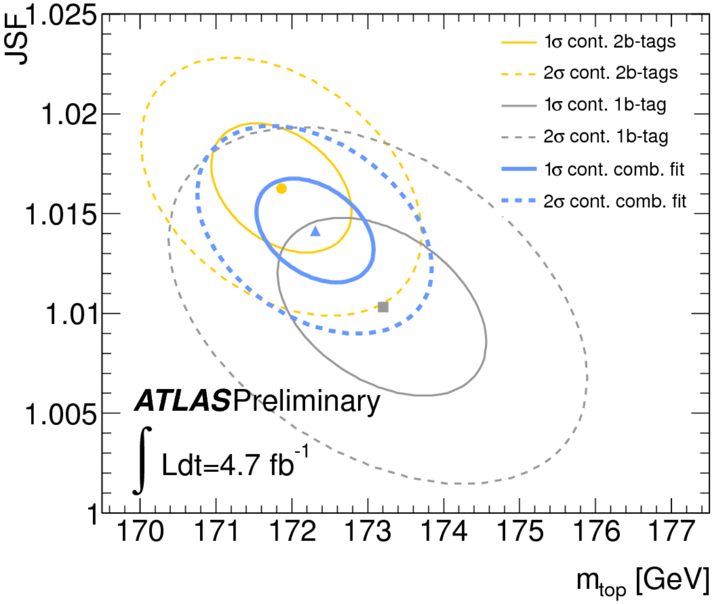
ATLAS-CONF-2013-046

- **Motivation**
  - test internal consistency and constrain of the SM and BSM theories
- **Strategy**
  - data : 4.7 fb^{-1} at 7 TeV, semileptonic
  - m_t from kinematic likelihood fit, reconstructed m_W, R_{lb}
  - templates for m_t [167.5,177.5] in 3D : mt ⊗ JSF ⊗ bJSF

$$R_{\rm lb}^{\rm reco,1b} = \frac{p_T^{b_{\rm tag}}}{(p_T^{W_{\rm jet_1}} + p_T^{W_{\rm jet_2}})/2}$$

$$R_{\rm lb}^{\rm reco,2b} = \frac{p_T^{b_{\rm had}} + p_T^{b_{\rm lep}}}{p_T^{W_{\rm jet_1}} + p_T^{W_{\rm jet_2}}},$$



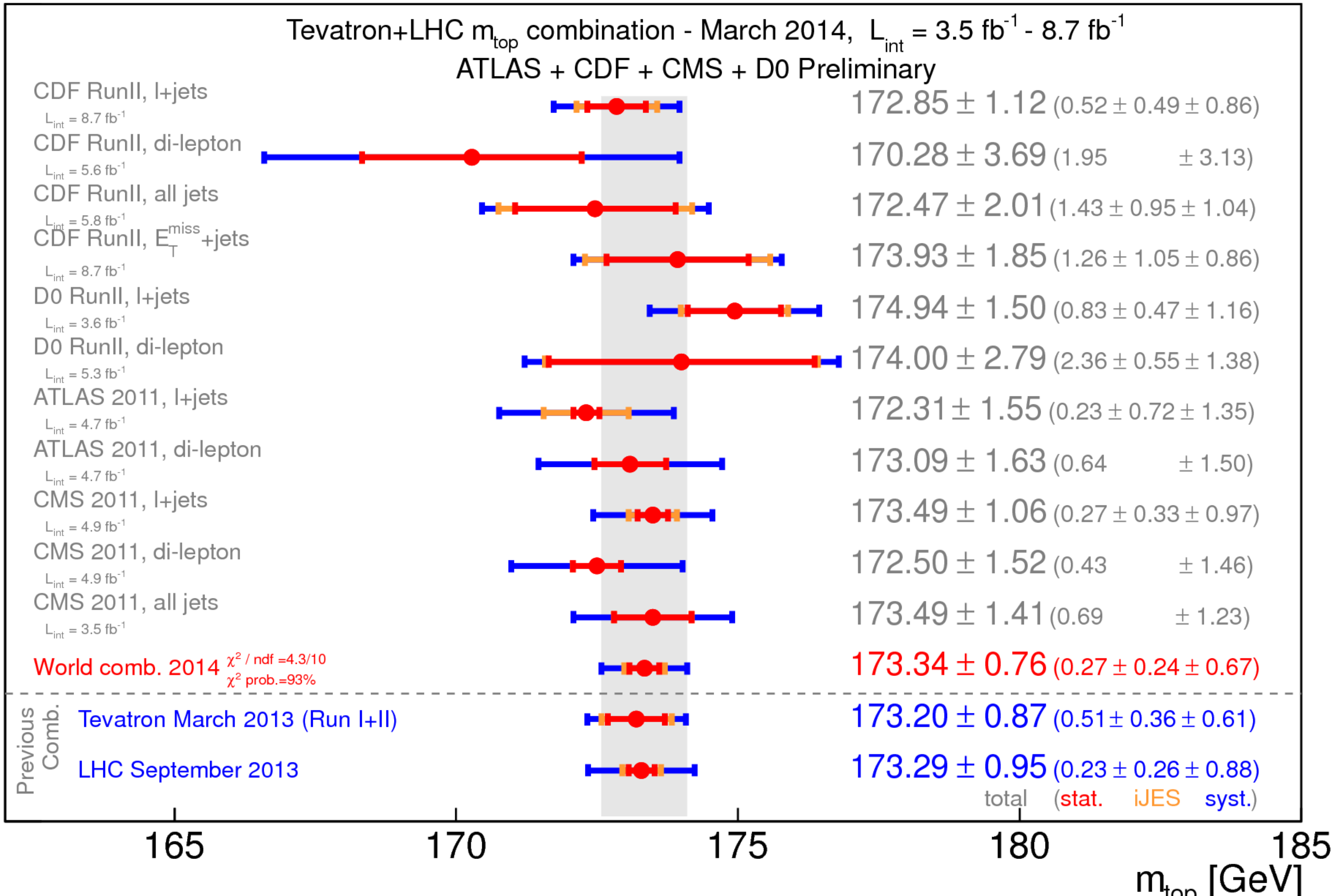


Main systematic uncertainties :
b-tagging eff, JSF, bJSF

m_{top} = 172.31 ± 0.75 (stat+JSF+bJSF) ± 1.35 (syst) GeV
JSF = 1.014 ± 0.003 (stat) ± 0.021 (syst)
bJSF = 1.006 ± 0.008 (stat) ± 0.020 (syst)

Top quark mass (combination)

First combination of LHC (ATLAS+CMS) and Tevatron (CDF+D0)

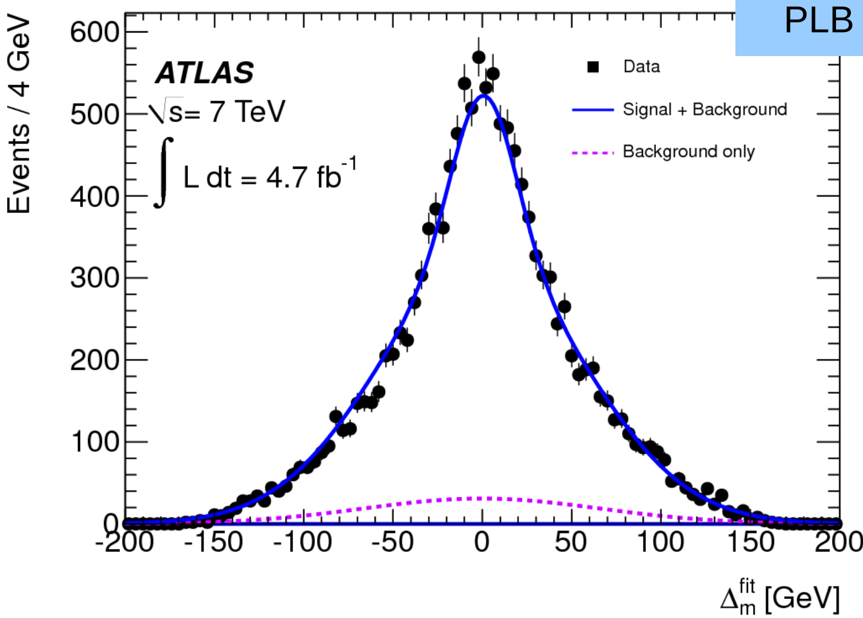


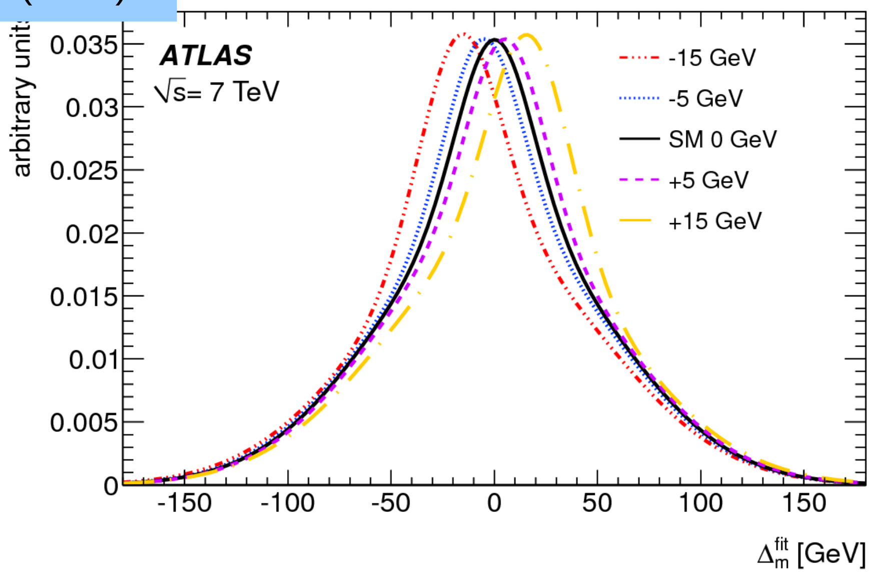
ATLAS-CONF-2014-008 ; CDF-NOTE-11071 ; CMS-PAS-TOP-13-014 ; D0-NOTE-6416; arXiv:1403.4427

Mass difference between t and $\bar{t}$

- **Motivation** — first ATLAS measurement of $\Delta m = m(t) - m(\bar{t})$
  - by CPT invariance $m(t)=m(\bar{t})$ is a condition for local field theory
- **Strategy**
  - data : 4.7 fb^{-1} at 7 TeV, semileptonic (2 btag)
  - kinematic fit allows to measure m(lvb)-m(jjb) for each events
  - 15 samples simulated with Δm=[-15,15] GeV, $(m_t+m_{\bar{t}})/2$=172.5 GeV
  - unbinned likelihood fit to extract Δm

PLB 728C (2014)





Main systematic uncertainties :
b/bbar decay uncertainties (0.34)

$\Delta m = 0.67 \pm 0.61$ (stat) ± 0.41 (syst) GeV
consistent with SM

- **Motivation**
  - test whether the charge Q is 2/3e (SM) or -4/3e
  - SM top can decay to l^+, $b^{-1/3}$, an exotic t_X to l^-, $b^{-1/3}$
- **Strategy**
  - data : 2.05 fb^{-1} at 7 TeV,
  - select semileptonic tt events
  - b jet charge Q(b) obtained from weighted sum of b tracks
  - pairing of lepton and b from m_{lb}
  - measure Q(comb) = Q(b)$\times$Q(l)

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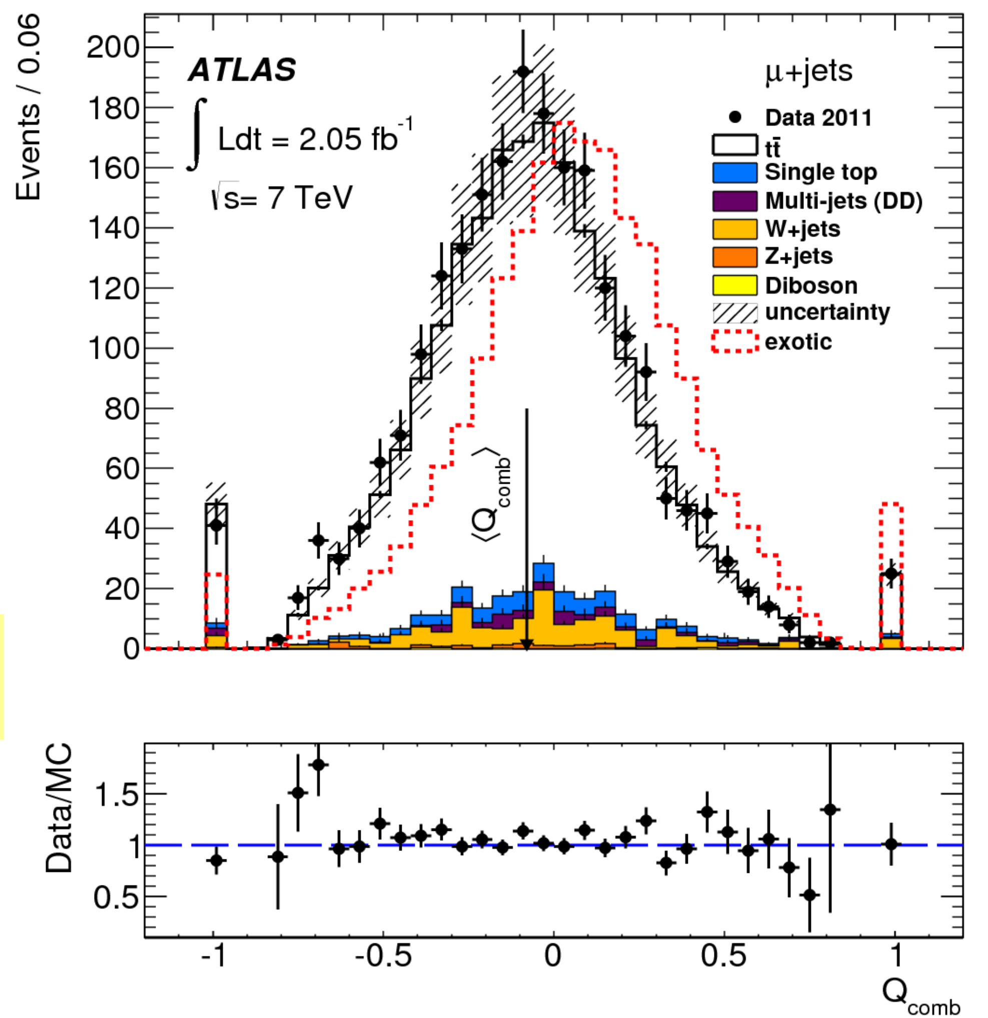
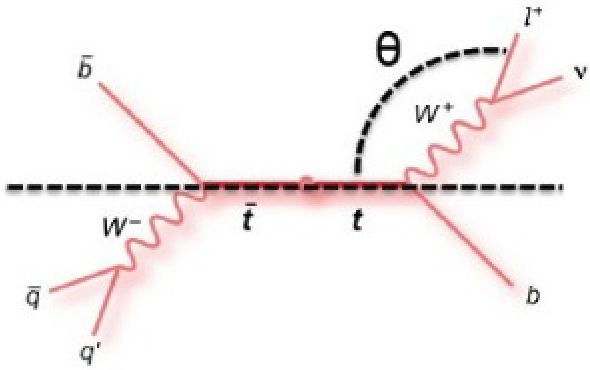


Q = 0.64 ± 0.02 (stat) ± 0.08 (syst) e
Q = -4/3 e excluded at 8σ

Main systematic uncertainties :
Jet energy scale (8.3%)
Parton shower (7.9%)

Polarization and spin correlation

- **Motivation**
  - top quarks produced in pairs are almost unpolarized in the SM, but the spins of the top and antitop are correlated
  - the study of these properties through the decay particles can be affected by BSM models either in top production or decay
  - study the angles of the top decay products



- **Strategy**
  - double differential cross section

$$\frac{1}{\sigma}\frac{\mathrm{d}\sigma}{\mathrm{d}\cos\theta_1\,\mathrm{d}\cos\theta_2} = \frac{1}{4}\left(1 + \alpha_1 P_1\cos\theta_1 + \alpha_2 P_2\cos\theta_2 - C\cos\theta_1\cos\theta_2\right)$$

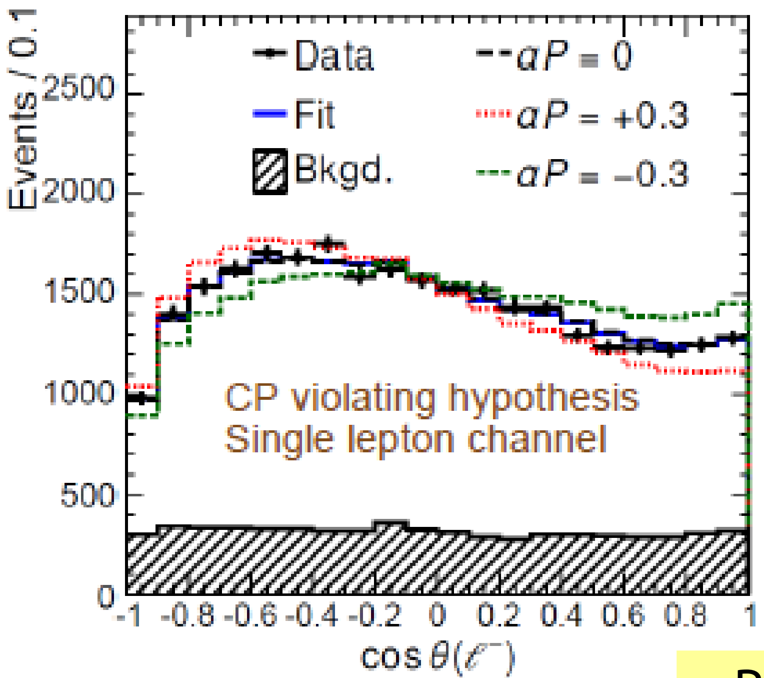
  - θ is the polar angle of the decay particles
  - α is the spin analyzing power (~1 for charged leptons)
  - C is the $t\bar{t}$ spin correlation : $C = -A\alpha_+\alpha_-$, with $A \equiv \frac{N(\uparrow\uparrow)+N(\downarrow\downarrow)-N(\uparrow\downarrow)-N(\downarrow\uparrow)}{N(\uparrow\uparrow)+N(\downarrow\downarrow)+N(\uparrow\downarrow)+N(\downarrow\uparrow)}$
  - P_1 (P_2) is the degree polarization of top (antitop)

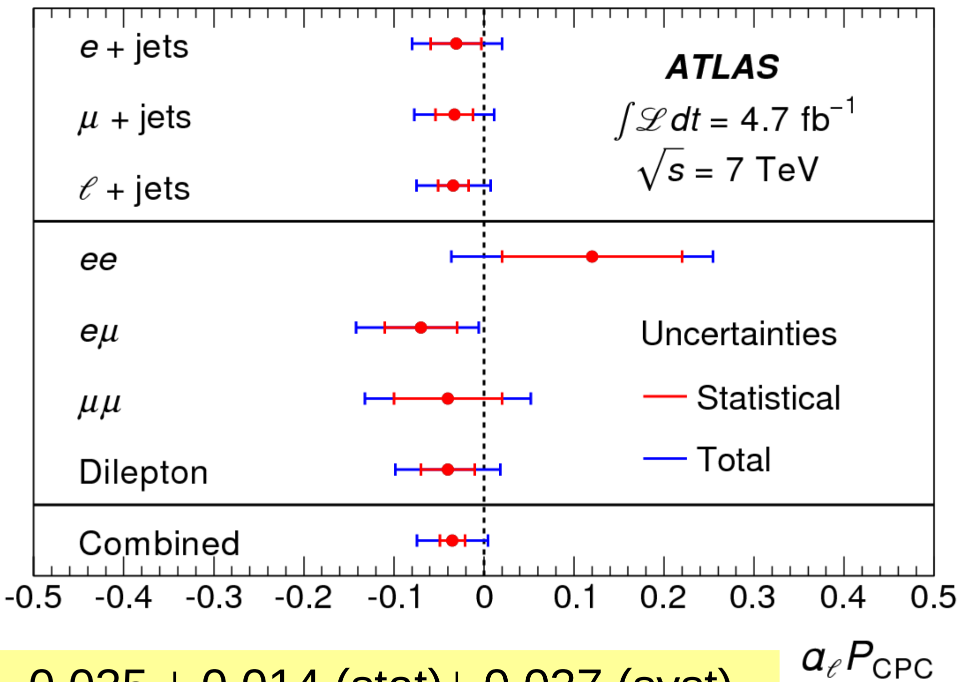
$$P = \frac{A_P}{2} = \frac{1}{2}\frac{N(\cos\theta_l > 0) - N(\cos\theta_l < 0)}{N(\cos\theta_l > 0) + N(\cos\theta_l < 0)}$$

Polarization

- **Strategy**
  - data : 4.66 fb^{-1} at 7 TeV, selection of semileptonic and dilepton events
  - produce templates with positive/negative polarization from MC $t\bar{t}$ sample
  - extract αP from fit $\cos(\theta_l)$ on data distributions to templates for two scenarii
    - CP conserving : same αP for top and antitop
    - CP violating : opposite αP for top and antiotop

Phys.Rev.Lett 111, 232002 (2013)





Main systematic uncertainties :
Jet reconstruction
(0.031 on $\alpha_l P_{CPC}$)

$\alpha_l P_{CPC} = -0.035 \pm 0.014\ (\text{stat}) \pm 0.037\ (\text{syst})$
$\alpha_l P_{CPV} = 0.020 \pm 0.016\ (\text{stat})\ ^{+0.013}_{-0.017}(\text{syst})$

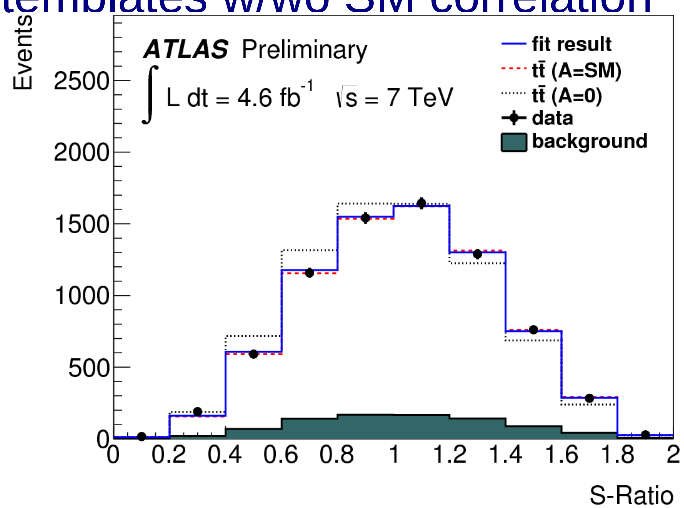
Results are in agreement with expectations from SM

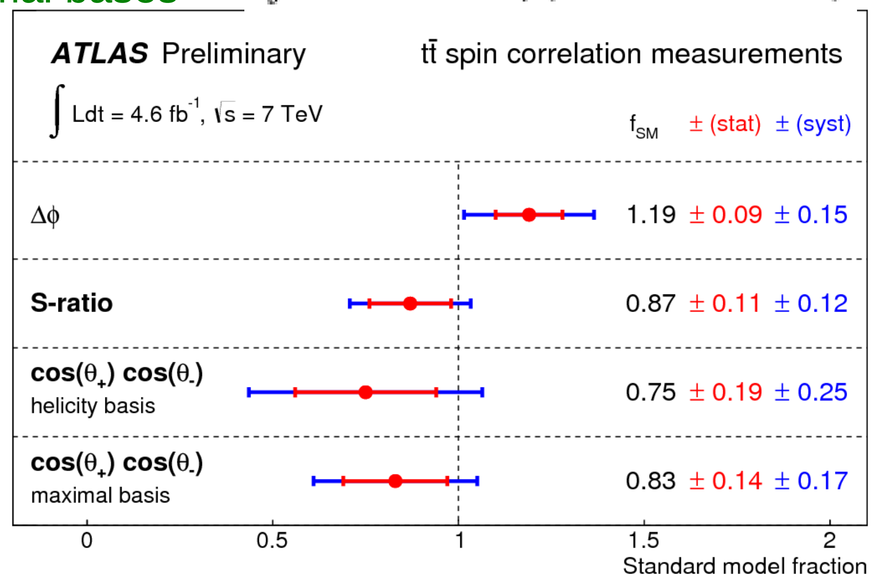
Spin correlation

- **Strategy**
  - data : 4.6 fb^{-1} at 7 TeV, dilepton
  - 4 observables sensitive to different sources of new physics in $t\bar{t}$ production
    - $\Delta\phi$ between the two leptons (lab frame)
    - cos(θ1)cos(θ2) in the helicity and maximal bases
    - S ratio $S = \frac{(|\mathcal{M}|^2_{RR} + |\mathcal{M}|^2_{LL})_{corr}}{(|\mathcal{M}|^2_{RR} + |\mathcal{M}|^2_{LL})_{uncorr}}$
  - templates w/wo SM correlation

ATLAS-CONF-2013-101

$$f_{SM} = N_{A=SM}/(N_{A=SM} + N_{A=0})$$





$$A^{measured}_{basis} = f_{SM} A^{SM}_{basis}$$

Main systematic uncertainties :
signal modeling and Jet energy scale

Basis	$\Delta\phi$	S-ratio	$\cos(\theta_+)\cos(\theta_-)_{helicity}$	$\cos(\theta_+)\cos(\theta_-)_{maximal}$
$A^{measured}_{helicity}$	$0.37 \pm 0.03 \pm 0.05$	$0.27 \pm 0.03 \pm 0.04$	$0.23 \pm 0.06 \pm 0.10$	—
$A^{measured}_{maximal}$	$0.52 \pm 0.04 \pm 0.07$	$0.38 \pm 0.05 \pm 0.06$	—	$0.36 \pm 0.06 \pm 0.09$

Results are in agreement with NLO predictions of SM

Charge asymmetry

- **Motivation**
  - $t\bar{t}$ pair production has a small asymmetry under charge conjugation in SM
  - BSM could lead to an enhancement in this effect
- **Strategy**
  - data : 4.7 fb^{-1} at 7 TeV, semileptonic $t\bar{t}$ events
  - differential measurements in p_T, mass and rapidity of $t\bar{t}$ pairs

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

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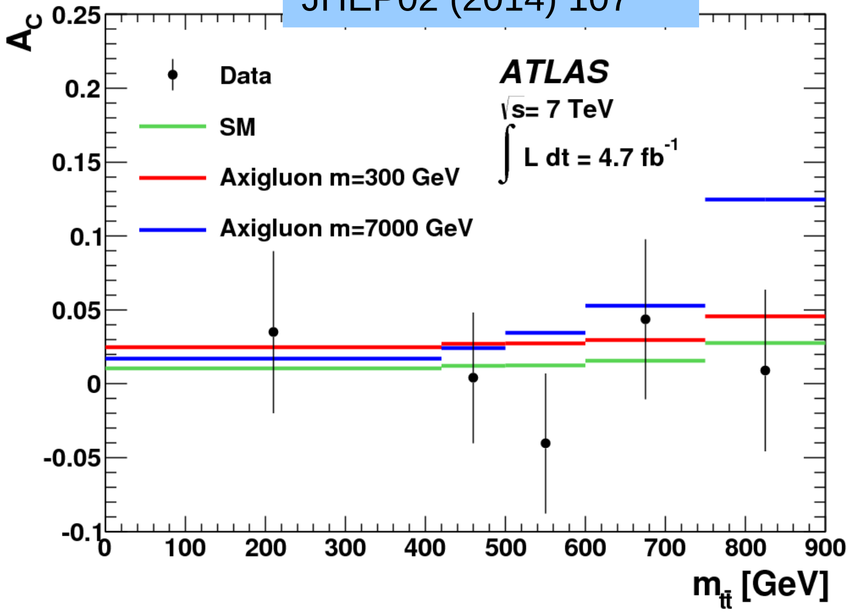
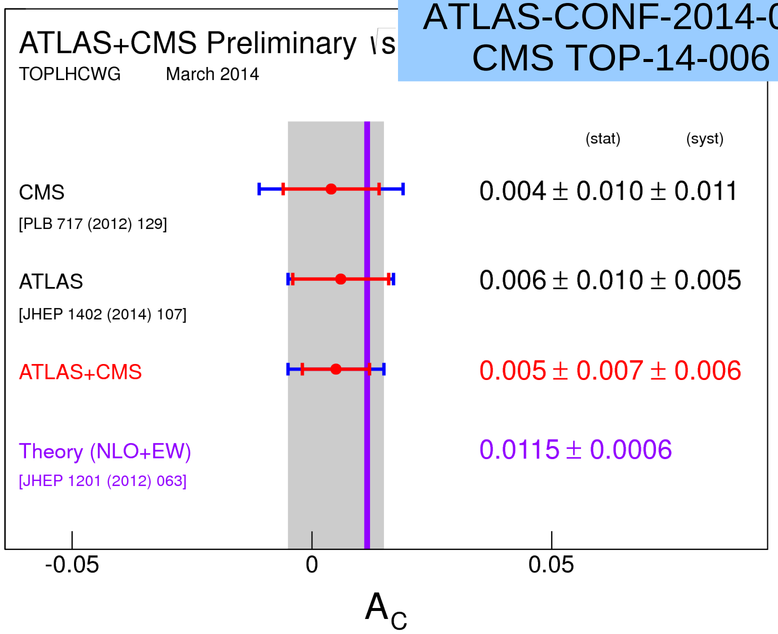


ATLAS-CONF-2014-012
CMS TOP-14-006



$A_C^{tt} = 0.006 \pm 0.010(\text{stat}) \pm 0.005$ (syst)
$A_C^{SM} = 0.0123 \pm 0.0005$

$A_C^{tt} = 0.005 \pm 0.007$ (stat) ± 0.006 (syst)

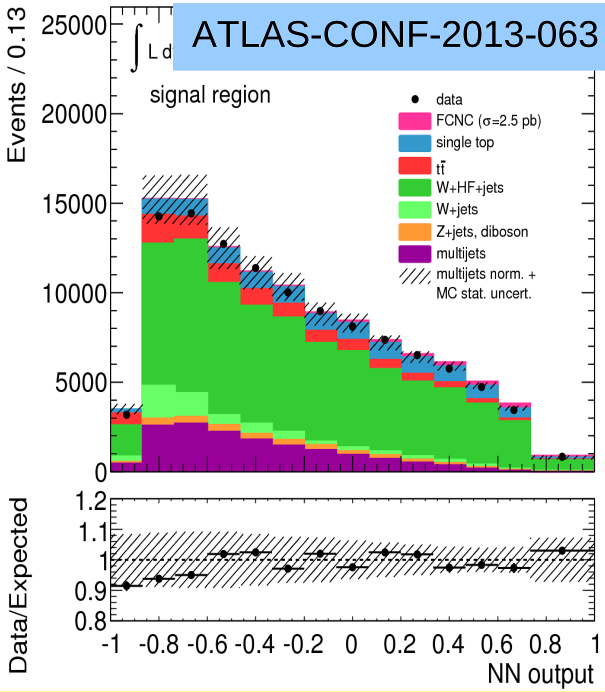
Results are in agreement with expectations from SM

Flavour Changing Neutral Current

- **Motivation**
  - in SM, FCNC processes forbidden at tree level and suppressed at higher orders
  - BSM with new sources of flavour predict order of magnitudes higher rates

- **Production**
  - data : 14.2 fb^{-1} at 8 TeV
  - single top (t-channel)

ATLAS-CONF-2013-063



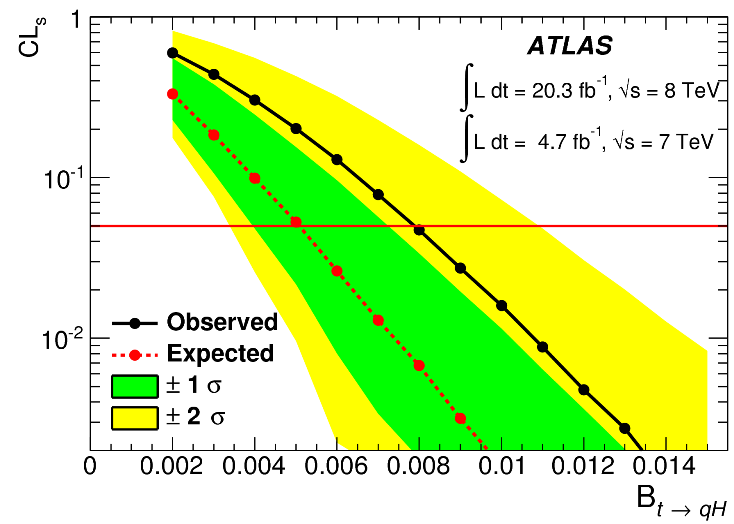
$\sigma_t(qg\rightarrow t)\times BR(t\rightarrow Wb) < 2.5$ pb @95% CL

$\kappa_{ugt}/\Lambda < 5.1\times10^{-3}\ TeV^{-1}$

$\kappa_{cgt}/\Lambda < 1.1\times10^{-2}\ TeV^{-1}$

- **Decay**
  - 4.7 fb^{-1} at 7 TeV / 20.3 fb^{-1} at 8 TeV
  - $t\rightarrow qH$ ($H\rightarrow\gamma\gamma$)
  - search in fully hadronic / semileptonic

JHEP acc. ArXiv 1403.6293



$BR(t\rightarrow qH) < 0.79\%$ @95% CL
(expected < 0.51%)

Summary

- **Precise measurements of top quark properties at LHC**
  - measurements of the top mass, mass difference between t and $\bar{t}$, charge, polarization as well as spin correlation, charge asymmetry and search for flavour changing neutrla current have been presented
  - most of the inclusive ones are systematically dominated
- **No hints of new physics in top quark properties measurements**
- **Lots of 8 TeV studies are still in progress**

Charge asymmetry
Look at poster of Daniel Marley !

Public results
https://twiki.cern.ch/twiki/bin/view/AtlasPublic/TopPublicResults

Backup slides

The ATLAS detector

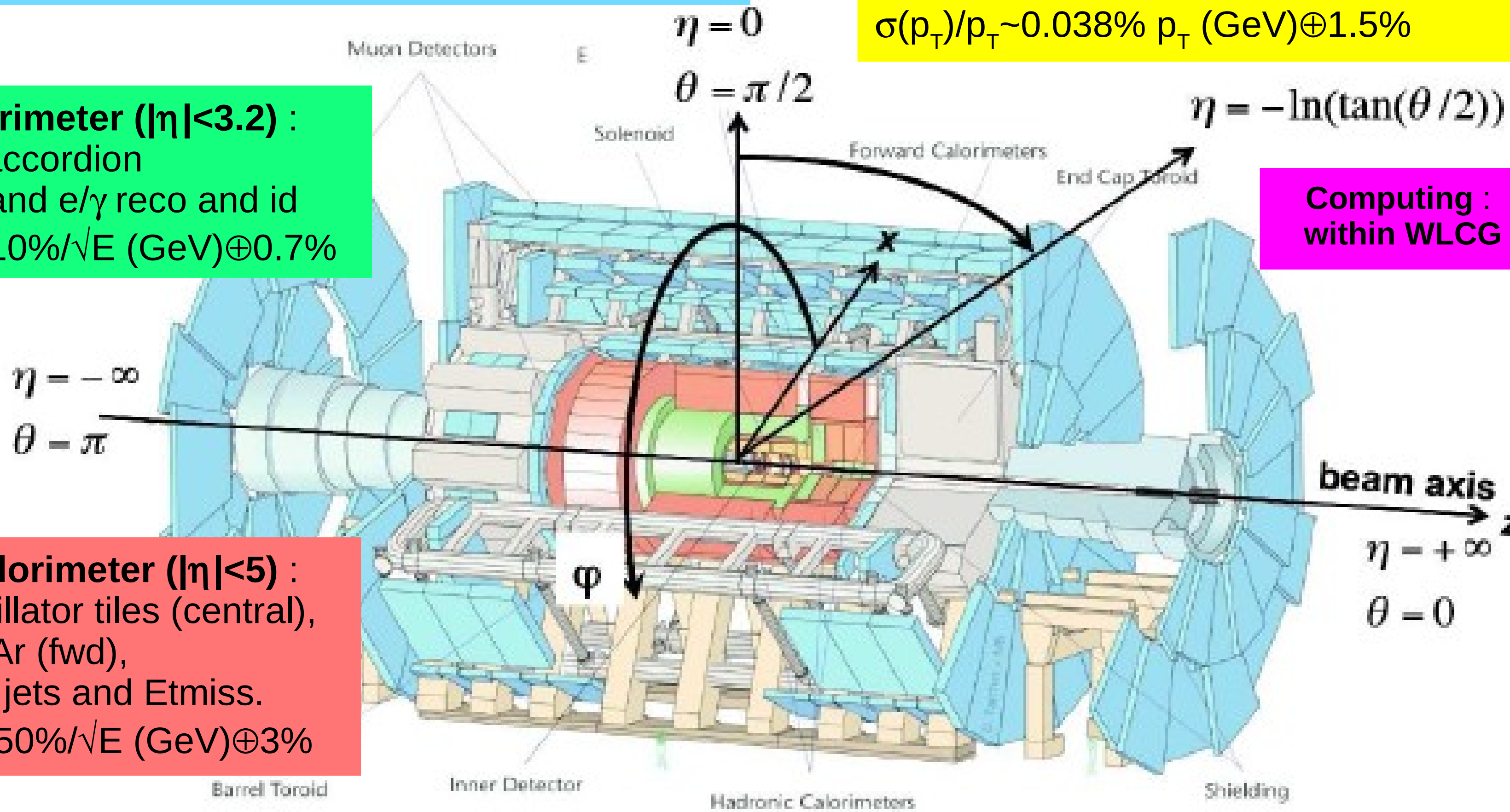
Muon spectrometer (|η|<2.7) : air-cores toroids with gas-based chambers. Trigger and measurement. Momentum resolution <10% up to Eμ~1 TeV

Inner Detector (|η|<2.5) :
Si pixel, SCT, TRT
Tracking and vertexing. e/π separation
$\sigma(p_T)/p_T \sim 0.038\%\ p_T\ (\mathrm{GeV}) \oplus 1.5\%$

EM calorimeter (|η|<3.2) :
Pb/LAr accordion
Trigger and e/γ reco and id
$\sigma(E)/E \sim 10\%/\sqrt{E}\ (\mathrm{GeV}) \oplus 0.7\%$

Computing : **within WLCG**

HAD calorimeter (|η|<5) :
Fe/scintillator tiles (central),
Cu/W LAr (fwd),
Trigger, jets and Etmiss.
$\sigma(E)/E \sim 50\%/\sqrt{E}\ (\mathrm{GeV}) \oplus 3\%$



$$\vec{p}_T = (p_x, p_y) \qquad p_T = p\sin\theta, \quad E_T = E\sin\theta \qquad \vec{E}_T^{miss} = -\sum_{\text{clusters}\,i} E_i \hat{n}_i$$

Trigger :
L1 : hardware, L2-EF, ~200 Hz in output

Object reconstruction

To study top quark it implies good understanding of many different objects reconstructed in all different ATLAS subdetectors

Muons

combined fitted tracks

tight identification

central : $|\eta|<2.5$, $p_T>25$ GeV

isolated

Tau (based on jets)

matched calo cluster + 1 or 3 tracks

identification using a BDT

$20<p_T<100$ GeV, $|\eta|<2.3$

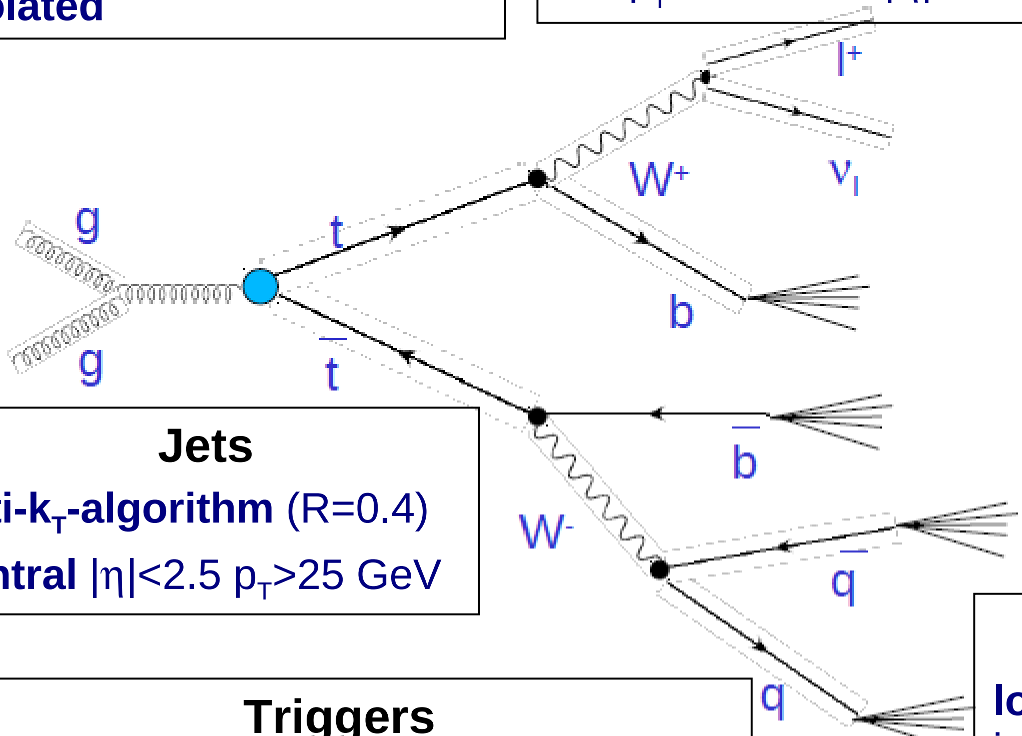
Electrons

matched track and EM cluster

tight identification using shower shape variables, ID

central : $|\eta|<2.5$, $p_T>25$ GeV

isolated



E_T^{miss}

vector sum of energy in calorimeter cells, ID, spectro projected in transverse plane, associated with high p_T object and dead material loss

$S_{ETmiss} = E_{Tmiss}/(0.5\times\sum E_T)$

Jets

anti-k_T-algorithm (R=0.4)

central $|\eta|<2.5$ $p_T>25$ GeV

Triggers

based on single lepton high p_T or N jets

b-tagging

long lifetime of B hadrons : NN based on impact parameter, secondary vertex, fragmentation properties, resonance mass

Top quark production and decays

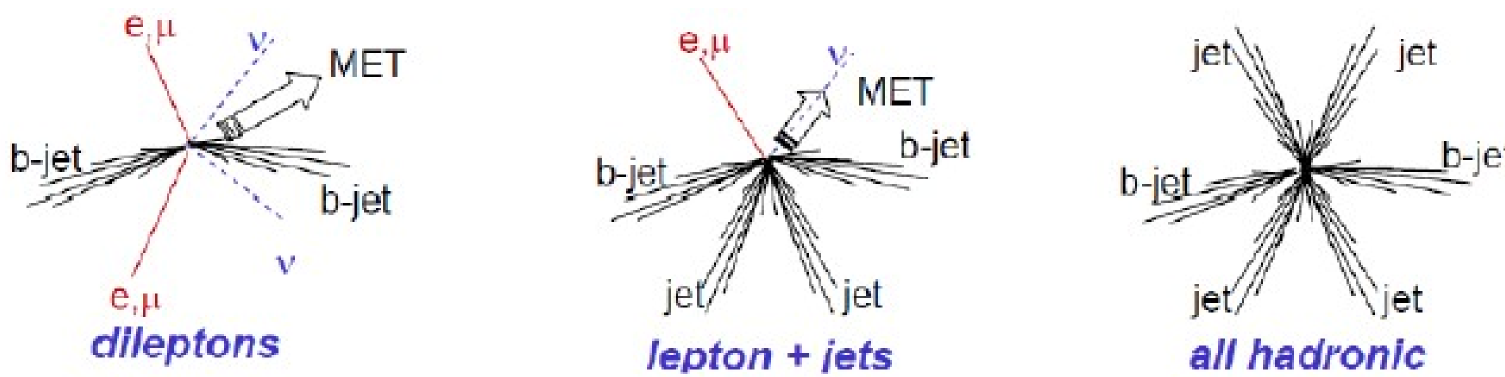
- **Production mechanism**
  - $t\bar{t}$ pair, 85% by gluon fusion, ~15% by $q\bar{q}$ production
  - single top (electroweak)

Predictions $\sqrt{s}$= 7 TeV

$\sigma(pp \rightarrow t\bar{t})_{NNLOapprox} = 167^{+17}_{-18}$ pb

Computed with: Aliev et. al., HATHOR, arXiv:1007:1327 (2011)

- **Top pair event classification according to W decays**



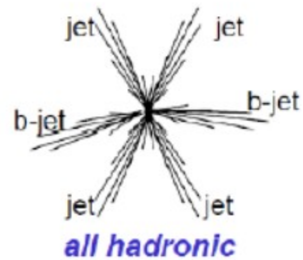
	dileptons	lepton + jets	all hadronic
Branching ratio	4.9%	29.6%	45.7%
Final state	2 isolated leptons large E_T^{miss} 2 b-jets	1 isolated lepton E_T^{miss} 2 b-, 2 light jets	no lepton no E_T^{miss} 2 b-, 4 light jets
Backgrounds	few (mainly Z+jets)	moderate (mainly W+jets)	huge (mainly QCD)

τ channels : 13.5% for τ+jets and 6.3% for τ+e/μ+jets

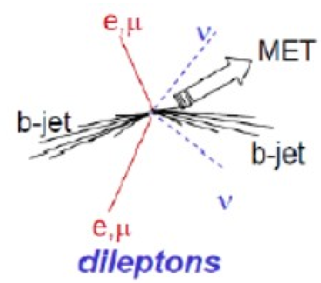
$t\bar{t}$ decay modes

General distinction according to the W± pairs decay modes

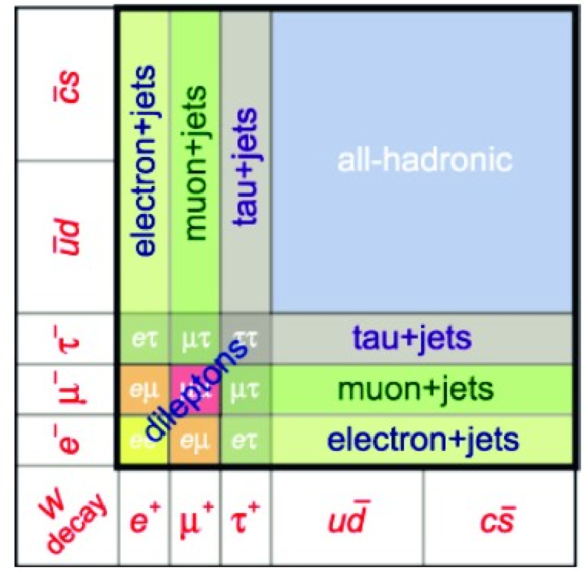
"All hadronic" 45.7% high background



$e^{\pm}\ \nu_e$ + jets 14.53 %
$\mu^{\pm}\ \nu_\mu$ + jets 14.29 %
} "lepton+jets"



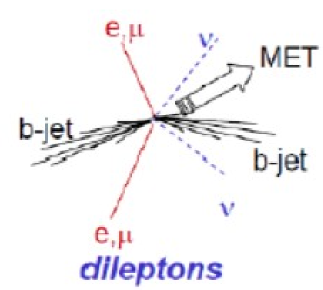
Top pair decay channels



Plot from Angela Barbaro Galtieri et al.
2012 Rep. Prog. Phys. 75 056201

$\tau^{\pm}\ \nu_\tau$ + jets 15.21 %
$e^{\pm}\ \tau^{\pm}\ \nu_\tau \nu_e$ 2.42 %
$\mu^{\pm}\ \tau^{\pm}\ \nu_\tau \nu_\mu$ 2.23 %
$\tau^{+}\ \tau^{-}\ \nu_\tau\ \nu_\tau$ 1.26 %
} leptonic or hadronic τ decay modes

$e^{+}\ e^{-}\ \nu_\tau \nu_\mu$ 1.15 %
$\mu^{+}\ \mu^{-}\ \nu_\tau \nu_\mu$ 1.12 %
$e^{\pm}\ \mu^{\pm}\ \nu_\tau \nu_\mu$ 2.27 %
} Clean in terms of trigger and selection
Presence of two ν's.
Transverse mass. "dilepton"



Top mass combination

On going effort to harmonize systematic uncertainties

	Input measurements and uncertainties in GeV											
	CDF				D0		ATLAS		CMS			World
Uncertainty	l+jets	di-l	all jets	E_T^{miss}	l+jets	di-l	l+jets	di-l	l+jets	di-l	all jets	Combination
m_{top}	172.85	170.28	172.47	173.93	174.94	174.00	172.31	173.09	173.49	172.50	173.49	173.34
Stat	0.52	1.95	1.43	1.26	0.83	2.36	0.23	0.64	0.27	0.43	0.69	0.27
iJES	0.49	n.a.	0.95	1.05	0.47	0.55	0.72	n.a.	0.33	n.a.	n.a.	0.24
stdJES	0.53	2.99	0.45	0.44	0.63	0.56	0.70	0.89	0.24	0.78	0.78	0.20
flavourJES	0.09	0.14	0.03	0.10	0.26	0.40	0.36	0.02	0.11	0.58	0.58	0.12
bJES	0.16	0.33	0.15	0.17	0.07	0.20	0.08	0.71	0.61	0.76	0.49	0.25
MC	0.56	0.36	0.49	0.48	0.63	0.50	0.35	0.64	0.15	0.06	0.28	0.38
Rad	0.06	0.22	0.10	0.28	0.26	0.30	0.45	0.37	0.30	0.58	0.33	0.21
CR	0.21	0.51	0.32	0.28	0.28	0.55	0.32	0.29	0.54	0.13	0.15	0.31
PDF	0.08	0.31	0.19	0.16	0.21	0.30	0.17	0.12	0.07	0.09	0.06	0.09
DetMod	<0.01	<0.01	<0.01	<0.01	0.36	0.50	0.23	0.22	0.24	0.18	0.28	0.10
b-tag	0.03	n.e.	0.10	n.e.	0.10	<0.01	0.81	0.46	0.12	0.09	0.06	0.11
LepPt	0.03	0.27	n.a.	n.a.	0.18	0.35	0.04	0.12	0.02	0.14	n.a.	0.02
BGMC	0.12	0.24	n.a.	n.a.	0.18	n.a.	n.a.	0.14	0.13	0.05	n.a.	0.10
BGData	0.16	0.14	0.56	0.15	0.21	0.20	0.10	n.a.	n.a.	n.a.	0.13	0.07
Meth	0.05	0.12	0.38	0.21	0.16	0.51	0.13	0.07	0.06	0.40	0.13	0.05
MHI	0.07	0.23	0.08	0.18	0.05	<0.01	0.03	0.01	0.07	0.11	0.06	0.04
Total Syst	0.99	3.13	1.41	1.36	1.25	1.49	1.53	1.50	1.03	1.46	1.23	0.71
Total	1.12	3.69	2.01	1.85	1.50	2.79	1.55	1.63	1.06	1.52	1.41	0.76

Table 3: Uncertainty categories assignment for the input measurements and the result of the world m_{top} combination. All values are in GeV. In the table, "n.a." stands for not applicable; "n.e." refers to uncertainties not evaluated (see text for details).

ATLAS-CONF-2014-008 ; CDF-NOTE-11071 ; CMS-PAS-TOP-13-014 ; D0-NOTE-6416; arXiv:1403.4427