Latest ATLAS results from the heavy flavour physics

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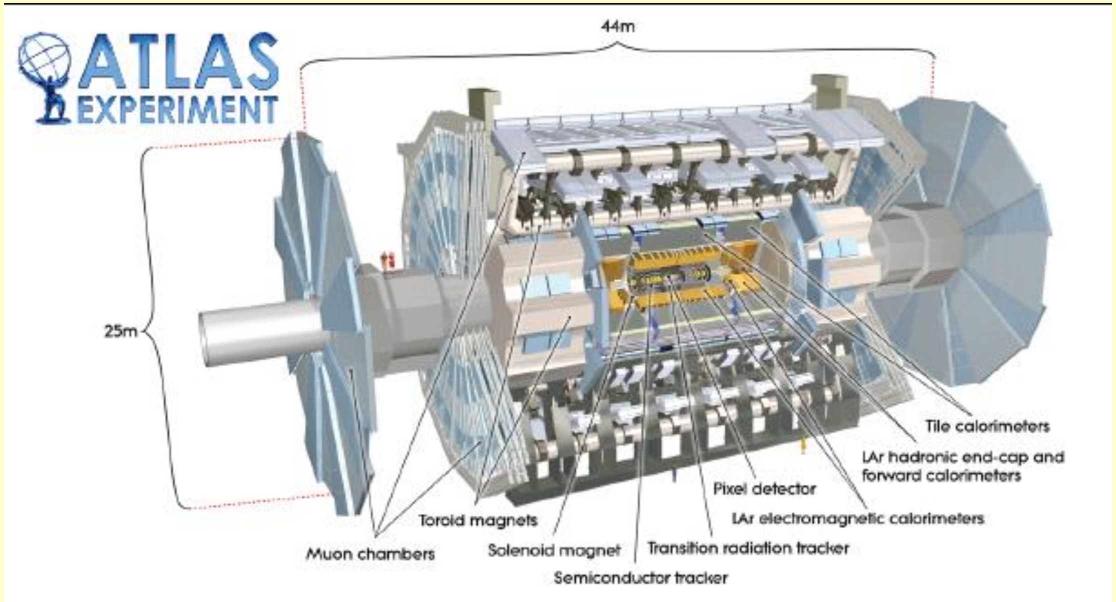
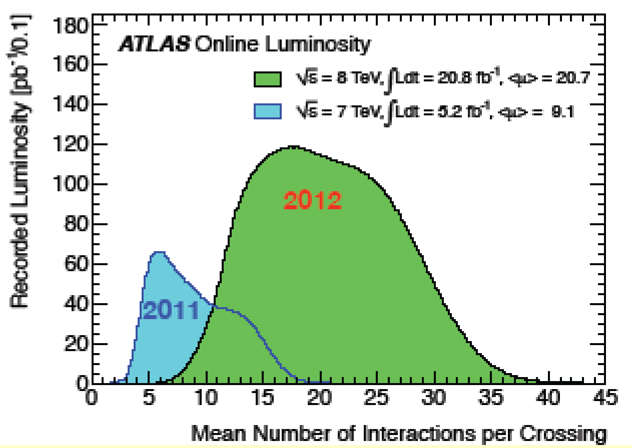
On behalf of the ATLAS collaboration

Topics in This Talk

- ATLAS basics
- Important moments of LHC 2011-13
- Motivation for top physics
- Top production cross section (7 TeV: diff. Xsec, 8 TeV total Xsec vs NNLO...)
- Top quark mass (3D template, ...)
- Single top production (t-channel, Wt-channel,...)
- B-quark processes ($B^0_s \to \mu^+\mu^-$, b-prod. X-section,)

Atlas experiment



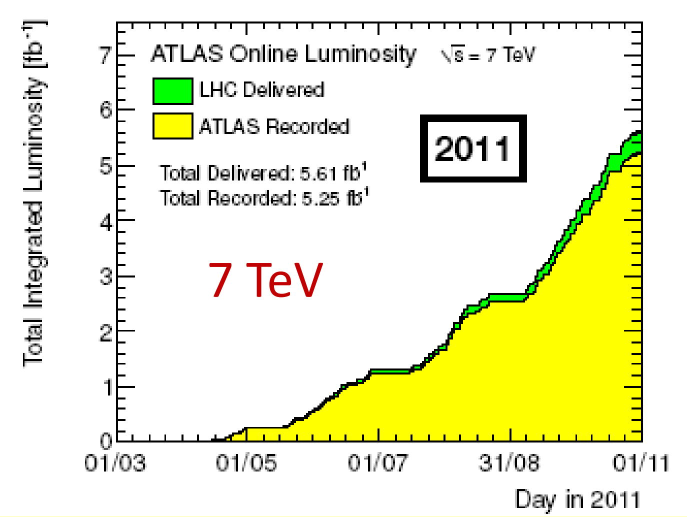


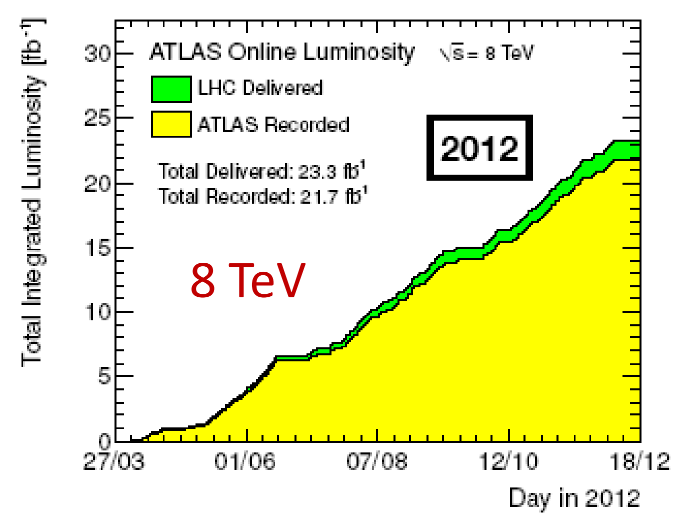
Level of pileup

Integrated luminosity:

- ✓ 2011: $5fb^{-1}$
- ✓ 2012: $22fb^{-1}$

Sample of $1fb^{-1}$ = 7×10^{13} inel.pp

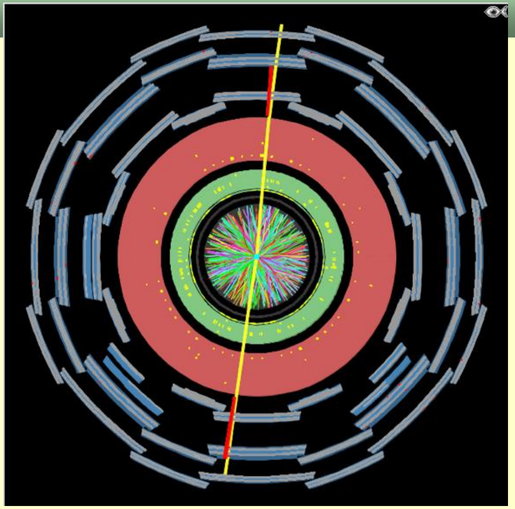


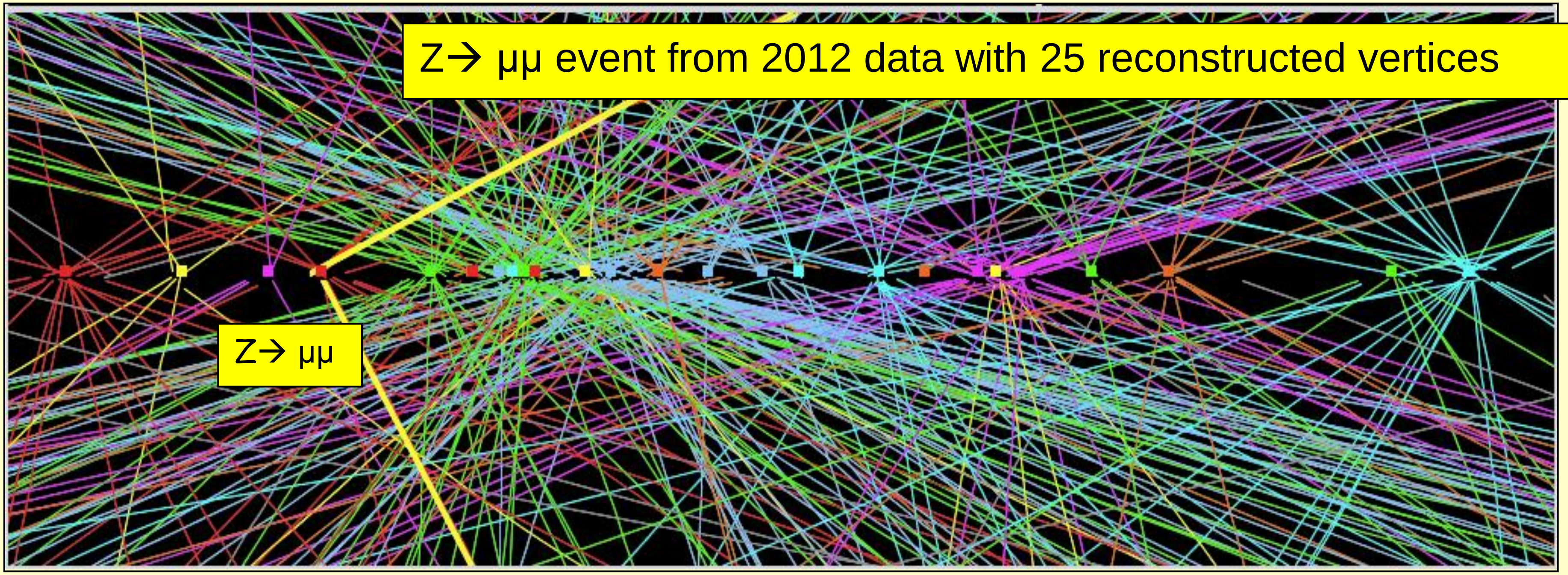


Pile-up example

At one bunch crossing:

- ✓ Triggered event contains $Z \to \mu^+\mu^-$
- ✓ In total 25 interactions



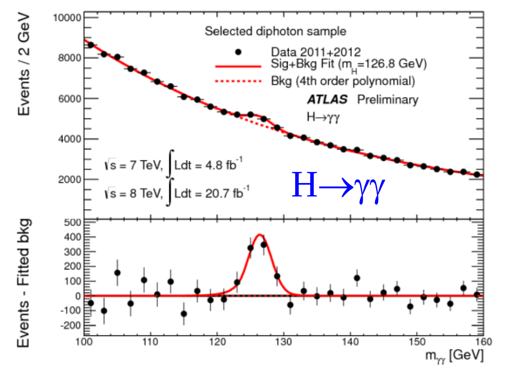


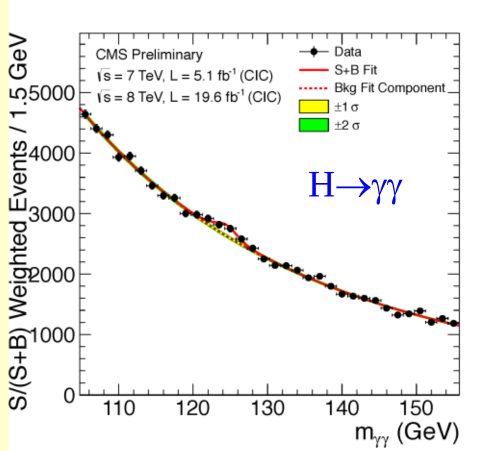
Important LHC-2012/3 moments

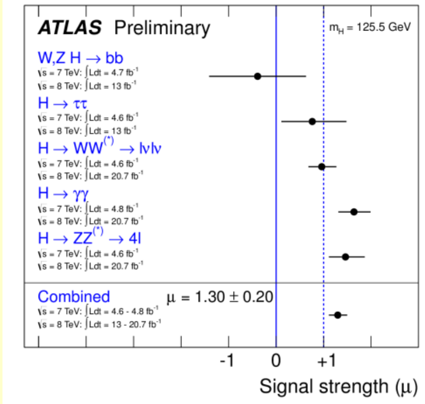
Higgs,

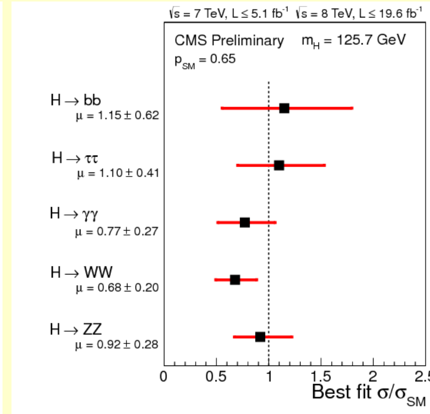
SuSy…

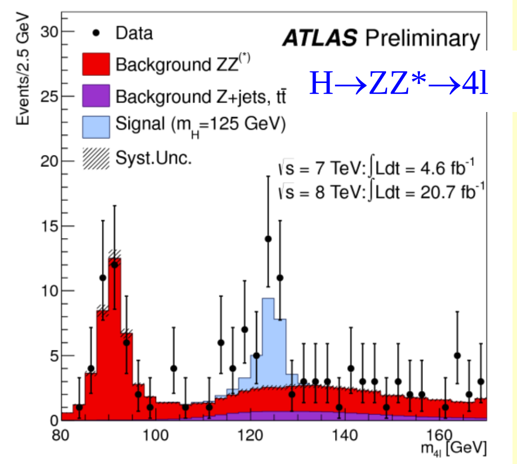
1st moment: Higgs boson

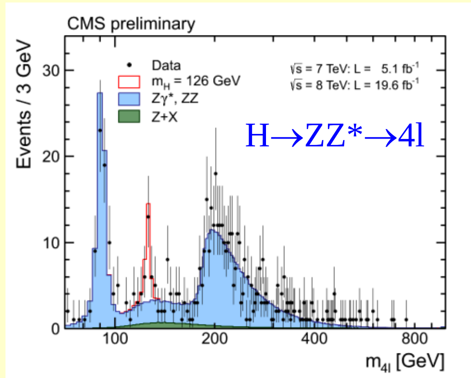












Signal strength

Decay Mode	ATLAS ($M_H = 125.5$ GeV)	CMS ($M_H = 125.7$ GeV)
$H \to bb$	-0.4 ± 1.0	1.15 ± 0.62
$H \to \tau\tau$	0.8 ± 0.7	1.10 ± 0.41
$H \to \gamma\gamma$	1.6 ± 0.3	0.77 ± 0.27
$H \to WW^*$	1.0 ± 0.3	0.68 ± 0.20
$H \to ZZ^*$	1.5 ± 0.4	0.92 ± 0.28
Combined	**1.30 ± 0.20**	**0.80 ± 0.14**

$$\langle \mu \rangle = 0.96 \pm 0.12\,, \quad \mu = \frac{\sigma \cdot Br}{\sigma_{SM} \cdot Br_{SM}}$$

$$M_H^{atlas} = (125.5 \pm 0.2 \pm 0.6)\ \text{GeV};$$

$$M_H^{cms} = (125.7 \pm 0.3 \pm 0.3)\ \text{GeV}$$

It looks we have SM Higgs, but …

1^{st} moment: Higgs- what is it?

What is Higgs boson?

- Fundamental Boson: New interaction which is not gauge
- Composite Boson: New underlying dynamics

If New Physics exist at Λ_{NP} radiative correction to M_H:

$$\delta M_H^2 = \frac{g^2}{(4\pi)^2} \Lambda_{NP}^2 \ln\left(\frac{\Lambda_{NP}^2}{M_H^2}\right)$$

Which symmetry keeps M_H away from Λ_{NP} ?

Fermions: Chiral symmetry, Gauge Bosons: Gauge symmetry

Scalar Bosons: Sypersymmetry, Scale/Conformal symmetry ...?

Hopes on SuSy: stop loops compensate the top loop contribution,

but no stop seen…

SM Higgs: Favoured by EW precision tests but…

a possible Scenarios of EWSB $\rightarrow$ Dynamical (non-perturbative) EWSB:

- ✓ Pseudo-Goldstone Higgs
- ✓ Scalar Resonance

New physics is in Higgs boson !!!

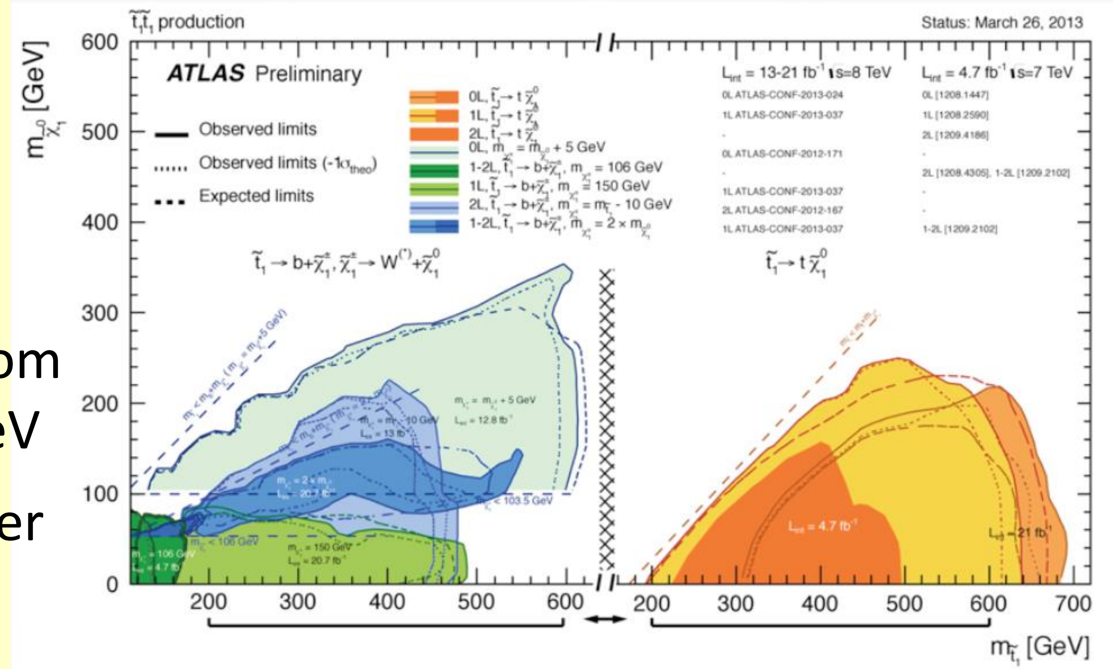
2nd moment: SuSy - no hints so far…

SuSy:

No hints of stop: m_{stop} > 600GeV
Problems with „naturalness“

Stop is scalar and can get also quadratic corrections - mainly from gluino – it should be light < 1.5 TeV

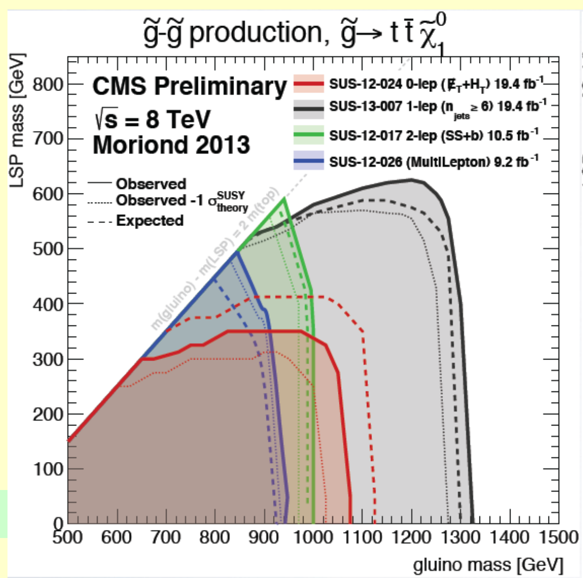
No hints of neutralino (dark matter candidate)

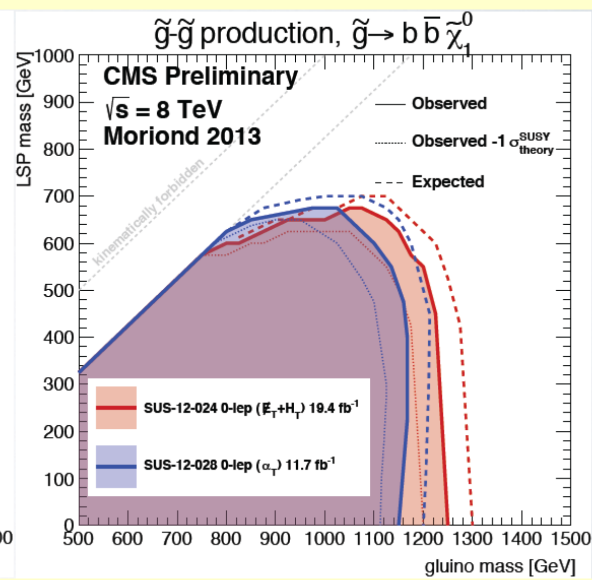


If SUSY is right, could well be **beyond the MSSM.**

If SUSY is **natural**, it *must* be beyond MSSM.

… but SuSy is still alive →
c.f. M.Reece/LHCP2013





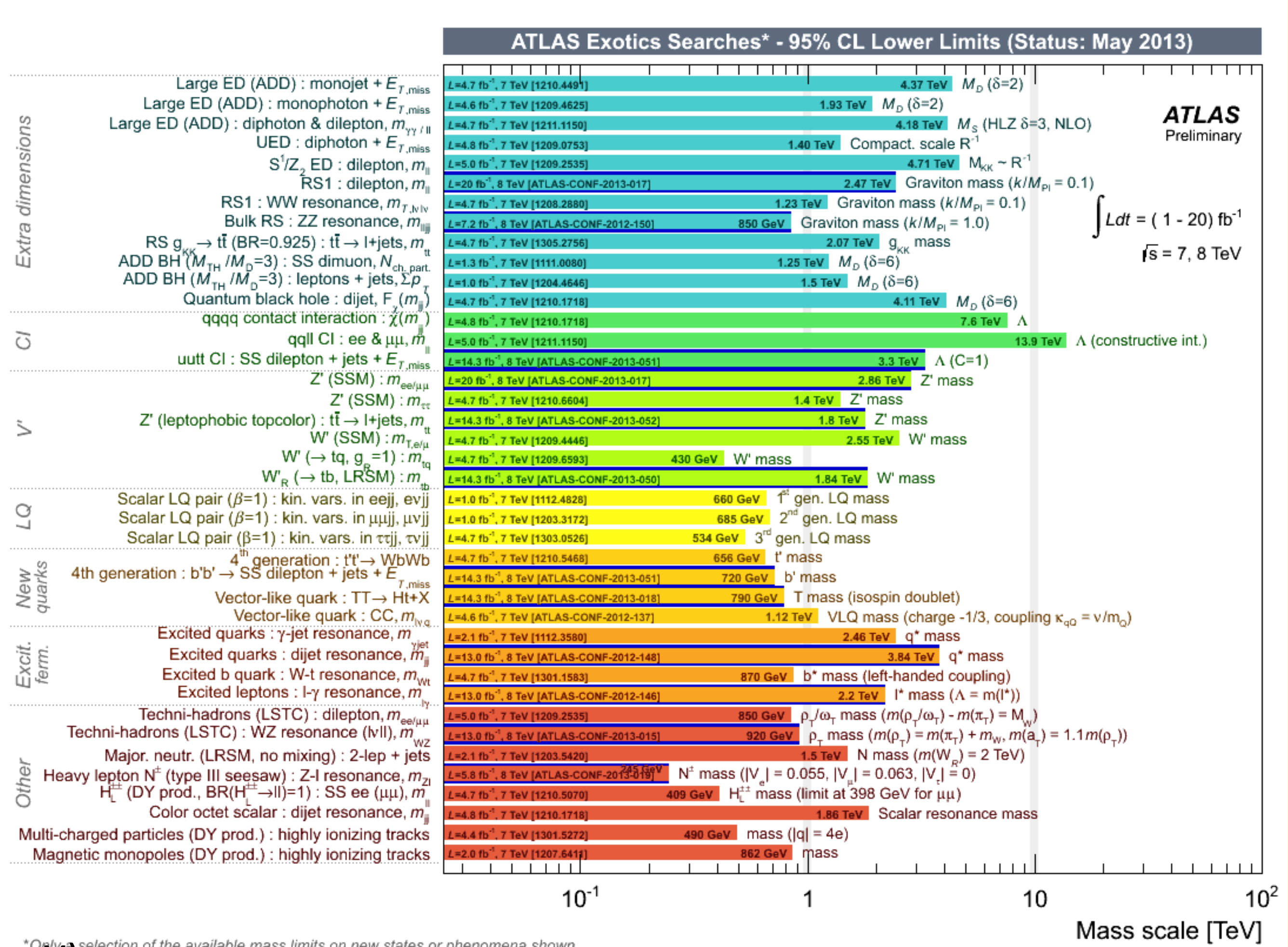
3rd moment: Exotics - no hints so far…

A lot of interesting searches, but no hints of:

- ✓ Extra dimensions (quantum BH, KK-gravitons)
- ✓ V' bosons
- ✓ New quarks
- ✓ Limits on Contact interaction set > 10 TeV

…

Compatibility with SM !



[1] ATLAS-CONF-2013-018 (Ht + X)

[2] ATLAS-CONF-2013-051 (Same-sign dilepton + b-tags)

[3] ATLAS-CONF-2013-056(Zb/t + X) [4] ATLAS-CONF-2013-060 (Wb + X)

Top quark physics on ATLAS

Motivation,

Cross section,

top quark mass

Single top quark

Top quark physics: Motivation

- Very high mass: near EWSB scale η

  Top quark Youkawa coupling $\lambda_t = \sqrt{2} m_{top}/\eta \approx 1$

- Top quark production X-sections: test of QCD

  → top is produced at very small distances $1/m_t$ ⇒

  $\alpha_s(m_{top}) \approx 0.1$: pert. expansion converges rapidly

- Top decays before hadronization

$1/m_t$	<	$1/\Gamma_t$	<	$1/\Lambda$	<	m_t/Λ^2
Production time	<	Lifetime	<	Hadronization time	<	Spin decorrelation time

  → study of spin characteristics (production mechanisms)

  → W helicity measurement (test of EW V-A structure)

- Cross sections sensitive to new physics

  → resonant production of $t\bar{t}$, decay: $t \to H^+ b$

Top is special!

Stringent tests of SM
+
Search for New physics

η = 246 GeV

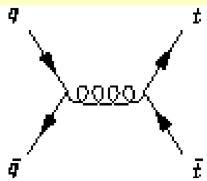
$\Lambda \approx$ 250 MeV

➢ Important background for Higgs studies

Top Quark Production

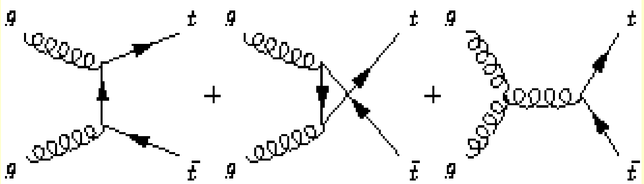
LHC √s = 7-14 TeV vs Tevatron √s = 1.96 TeV

Strong $t\bar{t}$ pair production | **EW single top quark production**



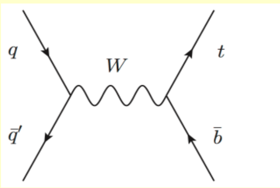
$q\bar{q} \to t\bar{t}$

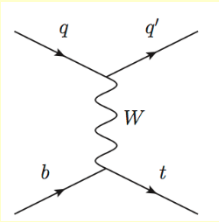
(13%, 85%)



$gg \to t\bar{t}$

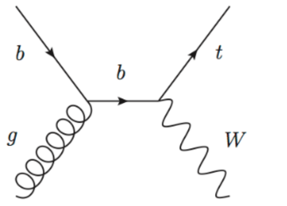
(87%,15%)

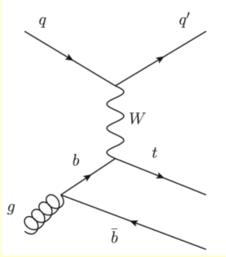




$q\bar{q} \to t\bar{b}$

(Drell-Yan)





$qg \to q' t\bar{b}$

(W-g fusion)

Tevatron: X-sec ≈ 7.2 pb (<5%) X-sec ≈ 3 pb ($t + \bar{t}$)

LHC /7TeV: 172 pb 85 pb

/8TeV: 246 pb ε<4% 116 pb ε<4%

/14TeV: 954 pb 320 pb

ε ≡ theoretical uncertainty

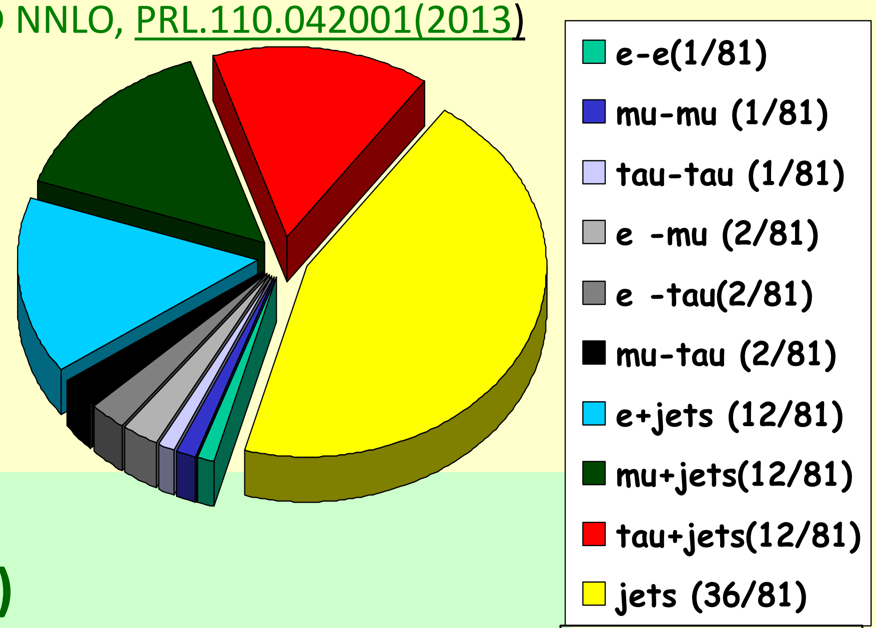
Top Quark Decay

SM: by far dominant *t→bW*

QCD NNLO, PRL.110.042001(2013)

$$\frac{\Gamma(t\to bW)}{|V_{tb}|^2} \approx f_{corr}\times\frac{G_F m_t^3}{8\pi\sqrt{2}} = 1.32\,GeV$$

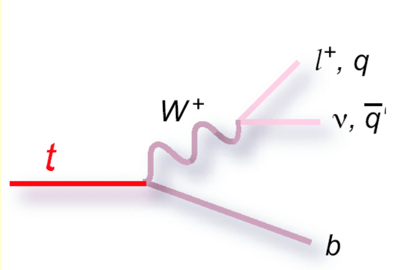
$\tau_{top} \approx 5\times10^{-25}$sec << τ_{hadr} (10^{-23}sec)



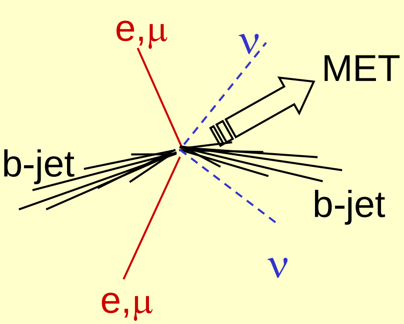
Born level

Top decays before hadronization !!!

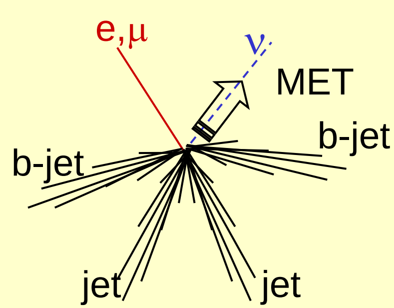
- **No tt-bar bound states (** gluon exchange **)**
- **t,W helicity from SM V-A** (no depolarization via hadronization)



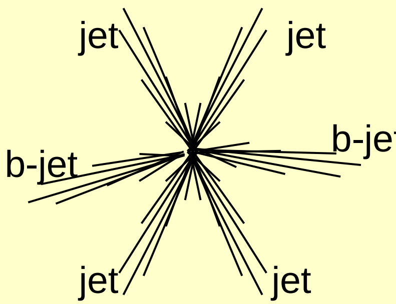
tt-bar samples via W decays



Dilepton (DiL)
(BR~5%, low bckg)



Lepton+jets (L+J)
(BR~30%, moderate bckg)



All-hadronic (A-H)
(BR~46%, huge bckg)

Cross Section of Top Quark production

Theory 2012-13 - big success:

Cross section of ttbar production known at NNLO + NNLL !!!

$t\,\bar{t}$ Production Cross Section

Top quark X-section: Experiment vs Theory

Factorization theorem:

theory

$$\sigma = \sum_{i,j} \int dx_1 dx_2\, F_i^{(1)}(x_1, \mu_F) F_j^{(2)}(x_2, \mu_F)\, \hat{\sigma}_{ij}(s; \mu_F, \mu_R)$$

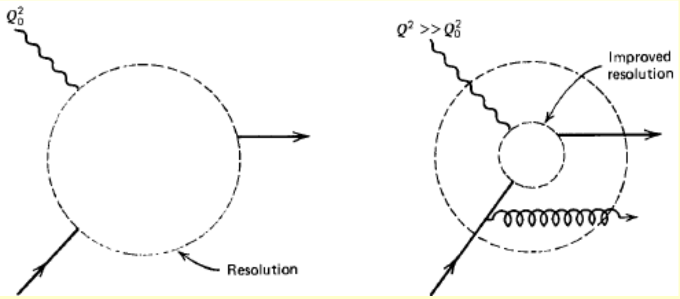
experiment

Parton Distribution Functions (PDFs)

$F_i^{(\lambda)}(x_\lambda, \mu_F)$ ≡ probability density to observe a parton ***i*** with longitudinal momentum fraction x_λ in incoming hadron λ, when probed at a scale μ_F

μ_F ≡ factorization scale (a free parameter) - it determines the proton structure if probed (by virtual photon or gluon) with $q^2 = -\mu_F^2$

μ_R ≡ renormalization scale – defines size of strong coupling constant



Usual choice: $\mu_F = \mu_R = \mu \in (m_t/2,\ 2m_t)$

$t\,\bar{t}$ Production Cross Section

Theory for top X-section is at NNLO:

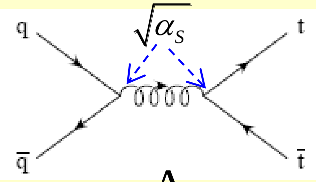
Xsec is expanded into series of strong coupling constant:

$$\sigma_{ij}\left(\beta,\frac{\mu^2}{m^2}\right)=\frac{\alpha_S^2}{m^2}\left\{\sigma_{ij}^{(0)}+\alpha_S\left[\sigma_{ij}^{(1)}+L\sigma_{ij}^{(1,1)}\right]+\alpha_S^2\left[\sigma_{ij}^{(2)}+L\sigma_{ij}^{(2,1)}+L^2\sigma_{ij}^{(2,2)}\right]+O\left(\alpha_S^3\right)\right\}$$

$LO\sim\alpha_S^2,\quad NLO\sim\alpha_S^3,\quad NNLO\sim\alpha_S^4\ \cdots\quad \beta=\sqrt{1-4m^2/s}\qquad L\equiv$ big log term

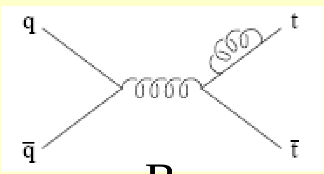
NLO: virtual and real corrections are added to LO

Virtual corrections:



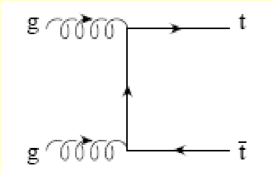
A

+



B

+ ...



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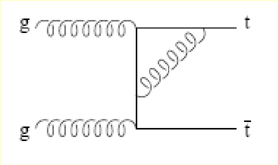
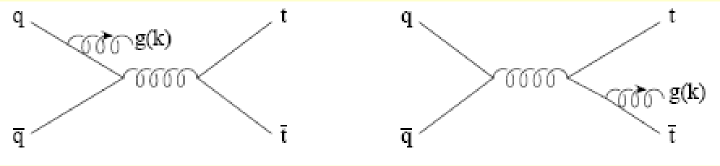
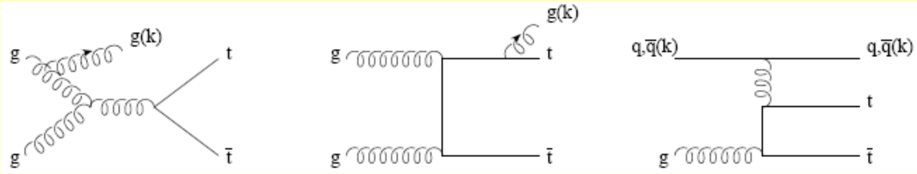


Taking $|A+B|^2= \ldots+AB^*+\ldots$, $AB^*\sim\alpha_S^3$

Real corrections – with real gluons ($\sim\alpha_S^3$):





Current status of top pair production

Before NNLO:

Beneke, Falgari, Klein, Schwinn `09-`11
Ahrens, Ferroglia, Neubert, Pecjak, Yang `10-`11
Kidonakis `04-`11
Aliev, Lacker, Langenfeld, Moch, Uwer, Wiedermann ’10
Cacciari, Czakon, Mangano, Mitov, Nason ‘11

NNLO:

qq: Bärnreuther, Czakon, Mitov, Phys. Rev. Lett., April ‘12
qq': Czakon, Mitov, JHEP, July ‘12
qg: Czakon, Mitov, JHEP, October ‘12
Gluon fusion: Czakon, Fiedler, Mitov, Phys. Rev. Lett., March'13

Publicly available software:

- **HATHOR:** Aliev, Lacker, Langenfeld, Moch, Uwer, Wiedemann `10
  NNLO
- **Top++,** Czakon, Mitov `11
  NNLO + NNLL soft gluon resummation in Mellin-space
- **TOPIXS,** Beneke, Falgari, Klein, Piclum, Schwinn, Ubiali, Yan `12
  NLO + approximations for NNLO + NNLL soft and Coulomb resummation in x-space

Theory (NNLO) vs Experiment

NNLO+NNLL

arXiv:1303.6254, PRL...

	σ_{tot} [pb]	scales [pb]	pdf [pb]
Tevatron	7.164	+0.110 (1.5%) -0.200 (2.8%)	+0.169 (2.4%) -0.122 (1.7%)
LHC 7 TeV	172.0	+4.4 (2.6%) -5.8 (3.4%)	+4.7 (2.7%) -4.8 (2.8%)
LHC 8 TeV	245.8	+6.2 (2.5%) -8.4 (3.4%)	+6.2 (2.5%) -6.4 (2.6%)
LHC 14 TeV	953.6	+22.7 (2.4%) -33.9 (3.6%)	+16.2 (1.7%) -18.8 (1.9%)

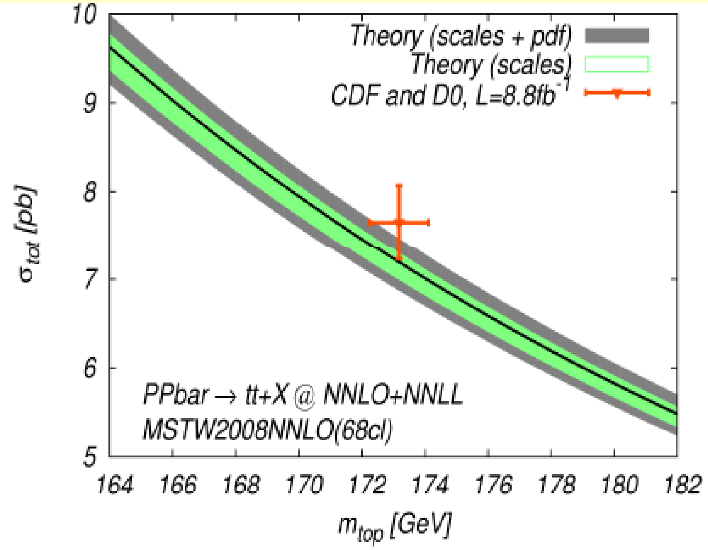
$NNLO_{approx} \xrightarrow{5\%} NNLO \xrightarrow{2.8\%} NNLO + NNLL$

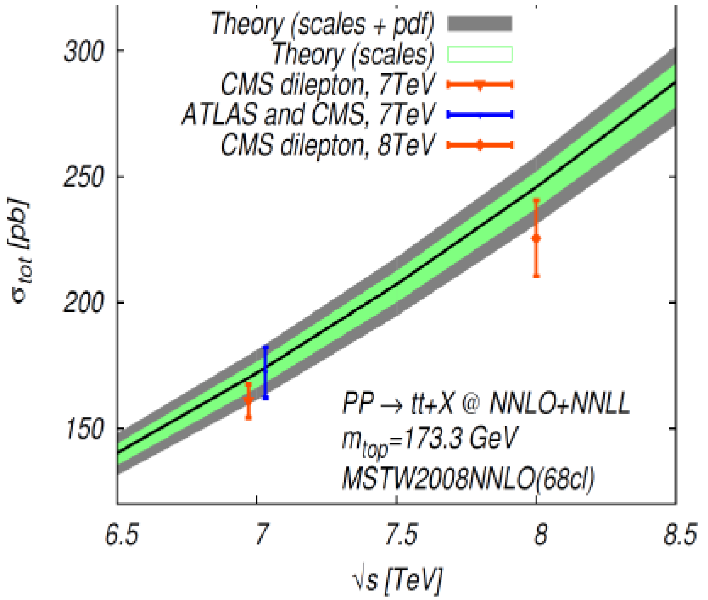
Experiment, LHC, $t\bar{t}$ cross section:

7 TeV: $161.9 \pm 2.5 \pm 5.0 \pm 3.6$ pb 5%, CMS DiL

$173.3 \pm 2.3 \pm 9.8$ pb 5.8% CMS+ATLAS

8 TeV: $227 \pm 3 \pm 9.8 \pm 10$ pb 6.7% CMS-comb.





$t\bar{t}$ cross section measurement

Selection criteria: trigger + offline selection $\Rightarrow$ candidate events

- Depends on the analysed channel of $t\bar{t}$ production
  - lepton+jets (L+J), dilepton (D-L) and all hadronic mode (A-H)
  - $l\nu 2b2j$ $2(l\nu)2b$ $2b4j$ all: $+1j, 2j...$
  - LJ: single lepton high-p_T (E_T) trigger applied + Reconstructed level:
    - ✓ 1 high-p_T lepton + ≥4high-p_T jets (1-2b-tagged) + high $\not{E}_T$
    - ✓ Restricted on pseudo-rapidity, p_T (E_T) > 20 GeV $\not{E}_T$ > 20 GeV
  - Selection criteria for DL and AH follow their topologies

- Background processes – non $t\bar{t}$ events also pass Selection criteria:
  - Basic bkgd processes for LJ channel:
    - ✓ W+jets, Z+jets, diboson, single top quark, multijets
  - Bkgd processes: studied using MC + data driven techniques

$$\sigma_{t\bar{t}} = \frac{N_{obs} - N_{bkg}}{A \cdot \varepsilon \int L dt}$$

$N_{obs}(N_{bkg}) \equiv$ observed (expected bkgd) events
$A \equiv$ acceptance, $\varepsilon \equiv$ trigger efficiency, $L \equiv$ luminosity

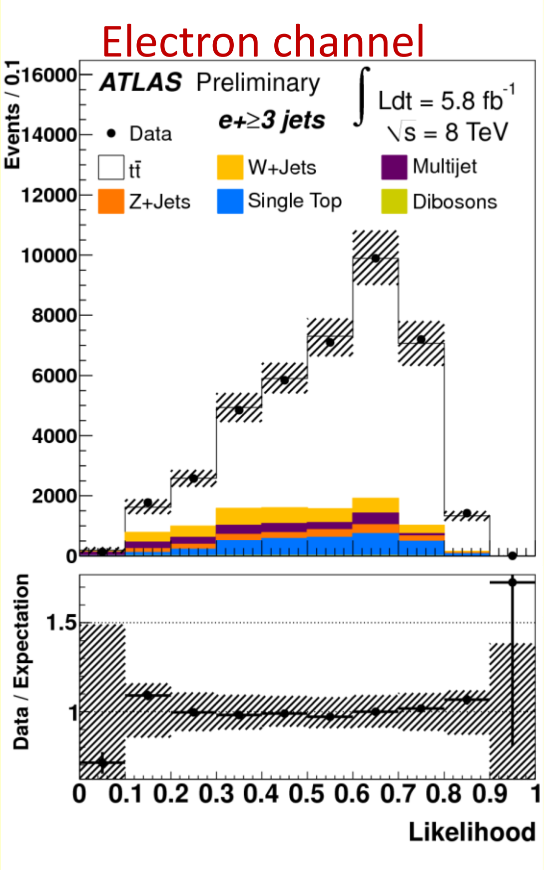
$t\bar{t}$ cross section: 8 TeV, lepton + jets

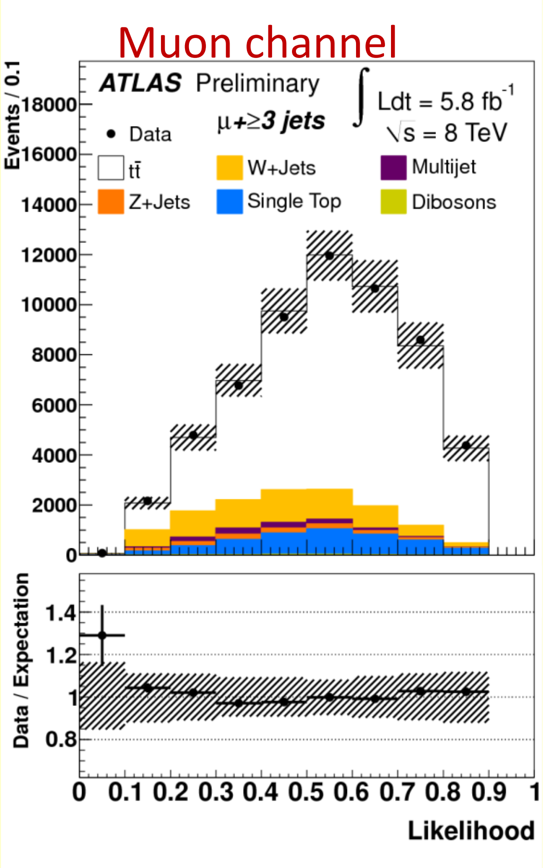
- Large E_T^{mis} and $m_T(W)$
  1 e/μ ($p_T(l) > 40$ GeV)
  ≥ 3 jets (p_T(jet) > 25 GeV)
  1 or more ***b***-tagged jet
- Employs likelihood discriminant for $t\bar{t}$ and W+Jets normalization
- Discriminant based on aplanarity and lepton pseudorapidity

$$D_i = \frac{L_i^s}{L_i^s + L_i^b}$$

- Dominant uncertainty (11%) is signal modeling

ATLAS-CONF-2012-149





From L.fit: $N(t\bar{t}) = 76000 \pm 500$

$$\sigma_{t\bar{t}} = 241 \pm 2(\text{stat.}) \pm 31(\text{syst.}) \pm 9(\text{lumi.})\ \text{pb}$$

$$\sigma_{t\bar{t}}^{theo} = 245.8\ ^{+6.2}_{-8.4}(\text{stat.})\ ^{+6.2}_{-6.4}(\text{pdf})\ \text{pb}$$

arXiv:1303.6254

$t\bar{t}$ cross section measurement at 8 TeV

Collision energy $\sqrt{s}$=8 TeV

ATLAS: ***l***+jets with 5.8 fb^{-1} : **241**±**2**(stat) ± **31**(syst) ± **9**(lumi) pb

ATLAS-CONF-2012-149

CMS – ***l***+jets with 2.8 fb^{-1} : 228 ± 9(stat) ± 29(syst(± 10(lumi) pb

CMS – dilepton with 2.4 fb^{-1}: 227 ± 3(stat) ± 11(syst) ± 10(lumi) pb

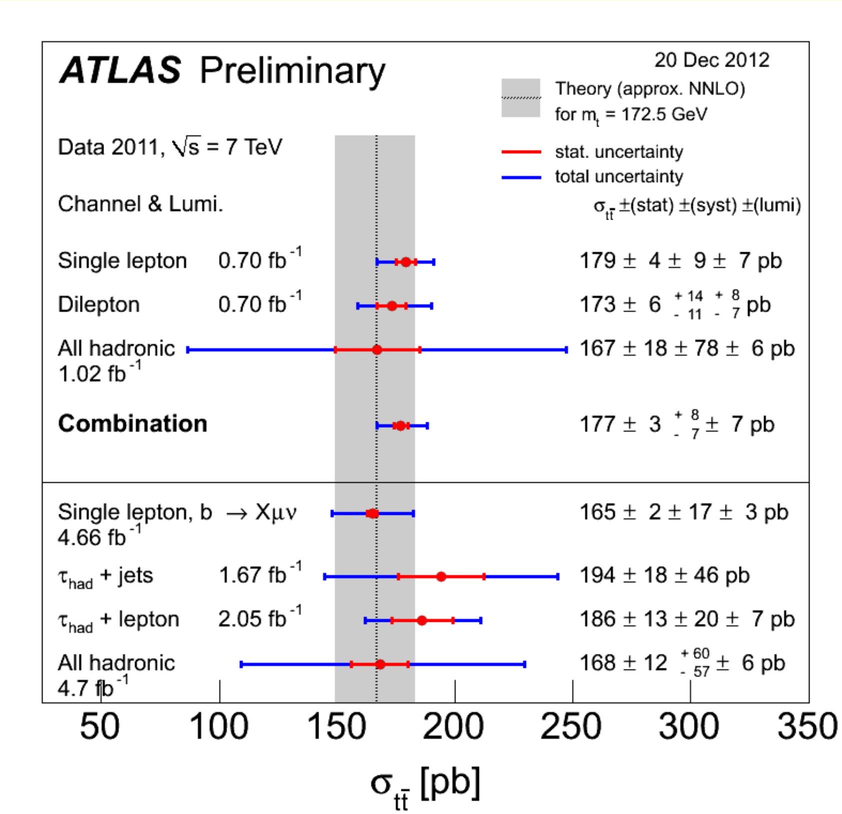
CMS PAS TOP-12-006, CMS PAS TOP-12-007

At $\sqrt{s}$=8 TeV not full sample taken – statistics plays no role at > 2fb^{-1}

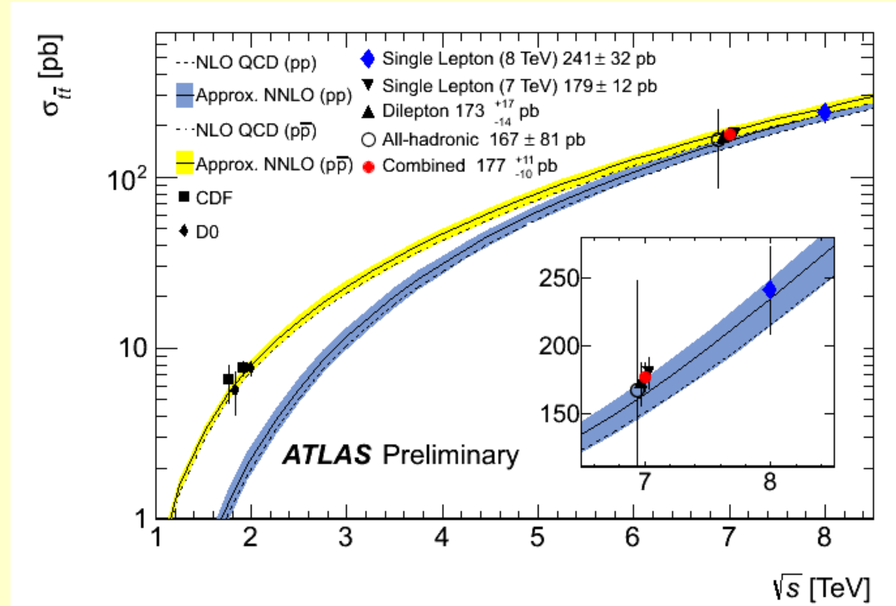
Main task: a correct treatment of systematics (hadronization, pileup...)

Progress in MC tools: a good perspective for going < 5% uncertainty

ATLAS $t\bar{t}$ cross section measurement



Collision energy √s=7 TeV



- ✓ A good agreement with theory
- ✓ Statistical error plays no role ...

CMS combined at 7 TeV: $165.8 \pm 2.2(\text{stat}) \pm 13.2(\text{syst})$

ATLAS + CMS combined at 7 TeV: $173.3 \pm 2.3(\text{stat}) \pm 9.8(\text{syst})$

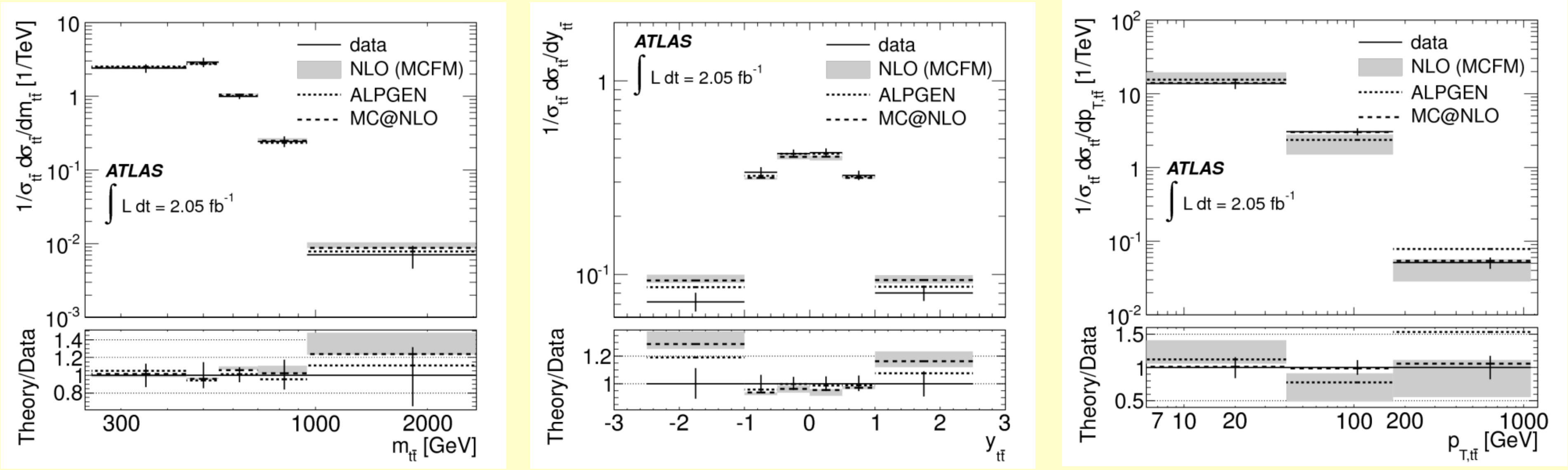
Total uncertainty : 5.8%

ATLAS-CONF-2012-134 / CMS PAS TOP-12-003

$t\bar{t}$ differential cross section @ATLAS

To be udated soon

- 7 TeV, 2.05 fb^{-1}, L+J, at least one b-tag
- $t\bar{t}$ reconstruction by likelihood-based kinematic fitter
- Robust unregularized unfolding of m_{tt} , y_{tt}, p_{Ttt} compared with MCFM, ALPGEN, MC@NLO (and approx. NNLO for m_{tt})
- Mostly systematics dominated (Jet/E_{Tmiss} reco.): 10~20% Full covariance matrix provided
- All the measurements are in agreement with SM!



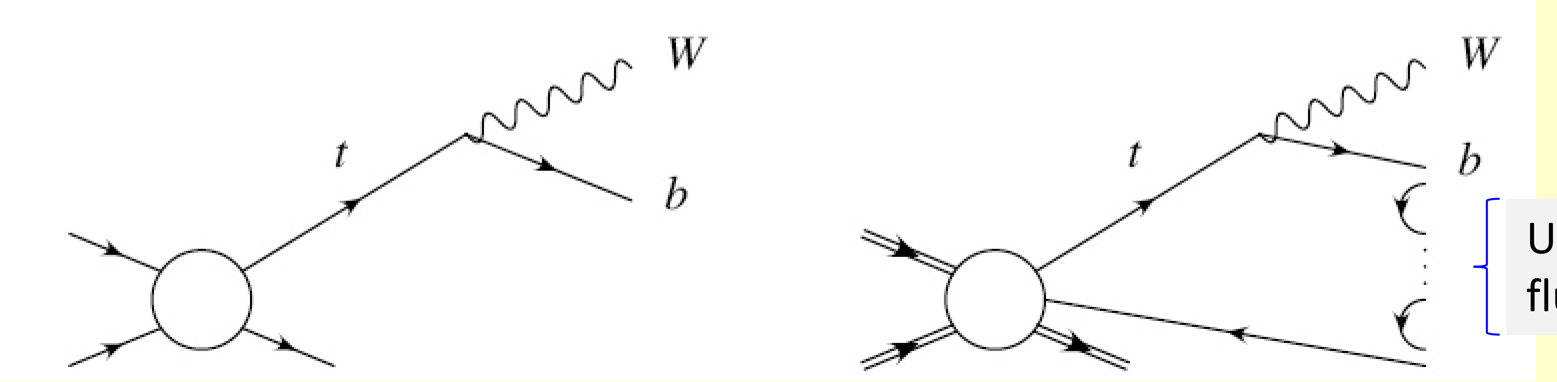
Top Quark Mass Measurement

Top quark mass is one of the SM 25 parameters...

Top Quark Mass

Pole mass: corresponds to pole in propagator of „free“ particle

it can never be determined with accuracy better than Λ_{QCD}.



Uncontrolled fluctuations

Pole mass is close to invariant mass of the top decay products.

Ambiguities: extra radiation, color reconnection and hadronization.

Pole mass vs short distance mass perturbatively (+ non-perturbative corrections):

Only short range (< $1/\overline{m}$) corrections to top propagator are taken into account

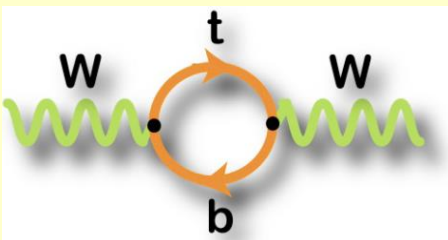
$$m_{pole} = \bar{m}(\bar{m})\left(1 + \frac{4}{3}\frac{\bar{\alpha}_s(\bar{m})}{\pi} + 8.28\left(\frac{\bar{\alpha}_s(\bar{m})}{\pi}\right)^2 + \cdots\right) + O(\Lambda_{QCD})$$

Top mass and EW precision physics

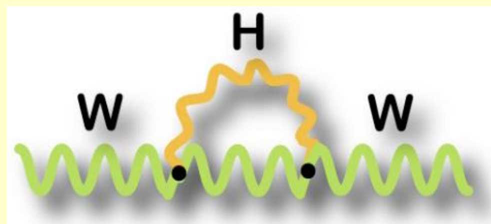
Masses of top, W and Higgs are bounded by

$$M_W^2\left(1-\frac{M_W^2}{M_Z^2}\right)=\frac{\pi\alpha}{\sqrt{2}G_F}(1+\Delta r)$$

From rad. corrections to W-boson propagator (any process, e.g. $\mu^- \to \nu_\mu W^- \to \nu_\mu e^- \bar{\nu}_e$) :



$$\Delta r_{top} \sim \frac{m_t^2}{M_W^2}$$

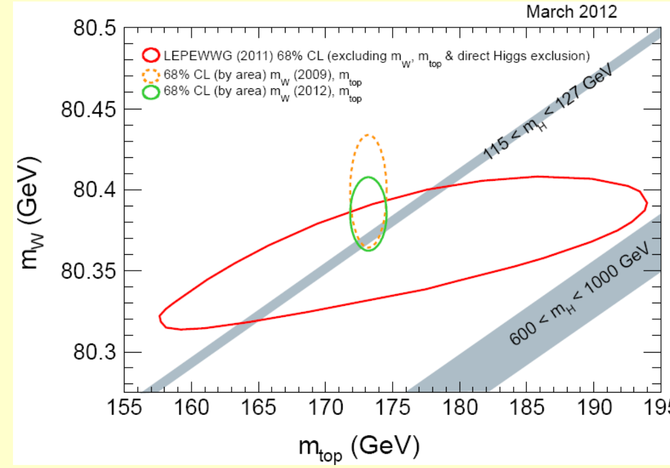


$$\Delta r_{higgs} \sim \ln\frac{M_H^2}{M_W^2}$$

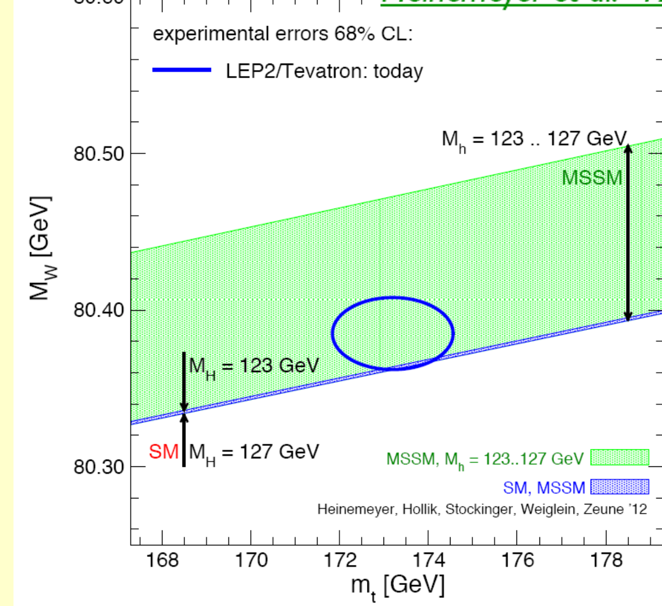
Precise M_W and m_t ⇒ constraint on M_H !

✓ LHC can improve: Δm_t and ΔM_W

✓ **Stringent consistency test of SM**



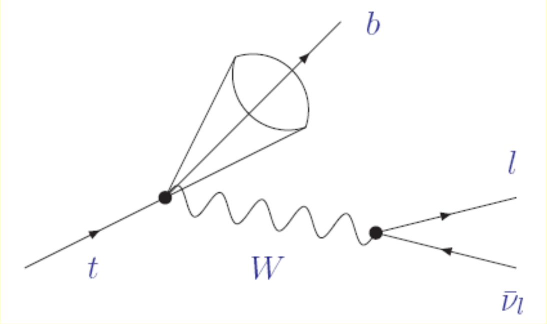
Heinemeyer et al. '12



How to measure top quark mass?

Top quark mass can be reconstructed in all $t\bar{t}$ topologies (L+J, DiL, A-H)

Best results usually in lepton + jets topology



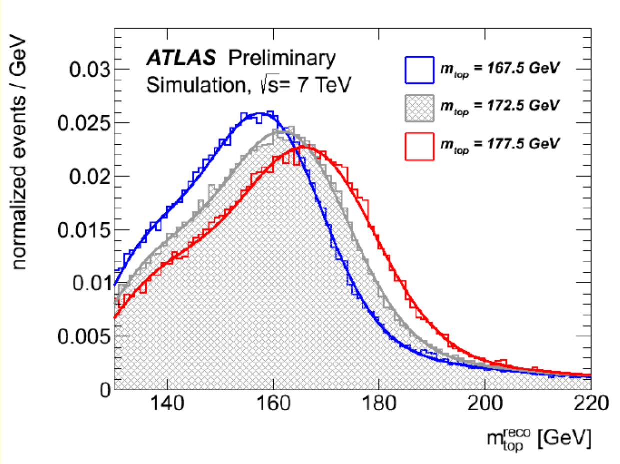
- Different approaches are used - usually:

✓ Template methods

- signal template: a distribution of an observable sensitive to m_{top} .
- Data distribution compared to combination of signal template (different m_{top}) + bkgd one

✓ Matrix element methods – use dependence of top pair production Xsec on top quark mass.

✓ Any variable correlated with top quark mass can be used for determination of top mass – e.g. mean lepton p_T (L+J, DiL)



$$m_{top}^{reco} = m(b, l, \nu_l)$$

m_{top}= 172.31 ± 0.75 (stat + JSF + bJSF) ± 1.35 (syst) GeV

ATLAS Top Mass: 3D Template

✓ Lepton+jets, 4.7fb^{-1}, 7TeV

✓ Event observables (recostr. by a kinematic likelihood fit):

m_{top}^{reco} , m_{W}^{reco} and R_{lb}^{reco}

$$R_{lb}^{reco} = \begin{cases} \dfrac{p_T^{b_{had}} + p_T^{b_{lep}}}{p_T^{W_{jet1}} + p_T^{W_{jet2}}} & \geq 2b\text{-tags} \\ \dfrac{p_T^{b_{tag}}}{0.5\left(p_T^{W_{jet1}} + p_T^{W_{jet2}}\right)} & 1b\text{-tag} \end{cases}$$

R_{lb}^{reco} is sensitive to bJSF ⇓

Signal and bkgd templates from MC:

Signal m_{top}^{reco} templates – as a function of

✓ m_{top} varied in (167.5 – 177.5 GeV),

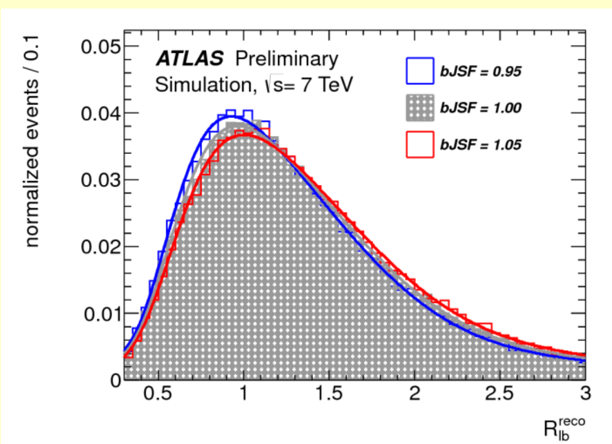
✓ JSF (Jet energy Scale Factor) - in (0.95,1.05)

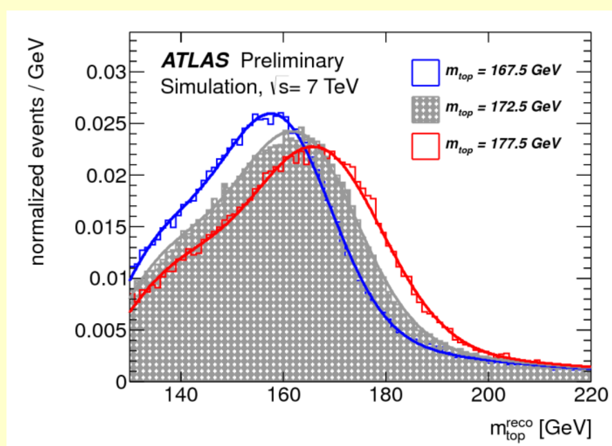
✓ bJSF (b-Jet energy Scale Factor) –in (0.95,1.05)

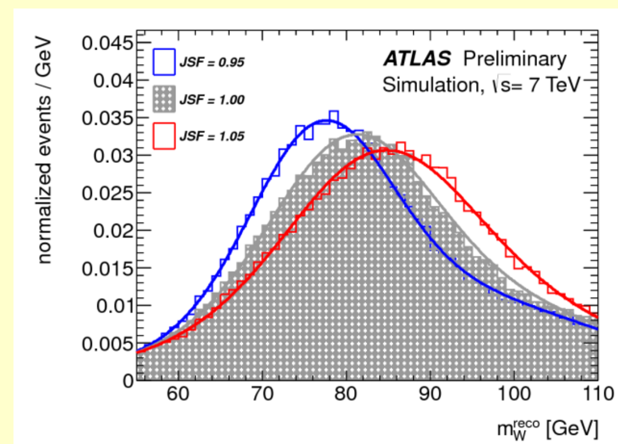
m_{W}^{reco} templates – functions of input *JSF*

R_{lb}^{reco} templates – functions of input (*bJSF, m_{top}*)

Fit m_{top}^{reco} , R_{lb}^{reco} - Landau+Gauss of input m_{W}^{reco} - 2×Gauss

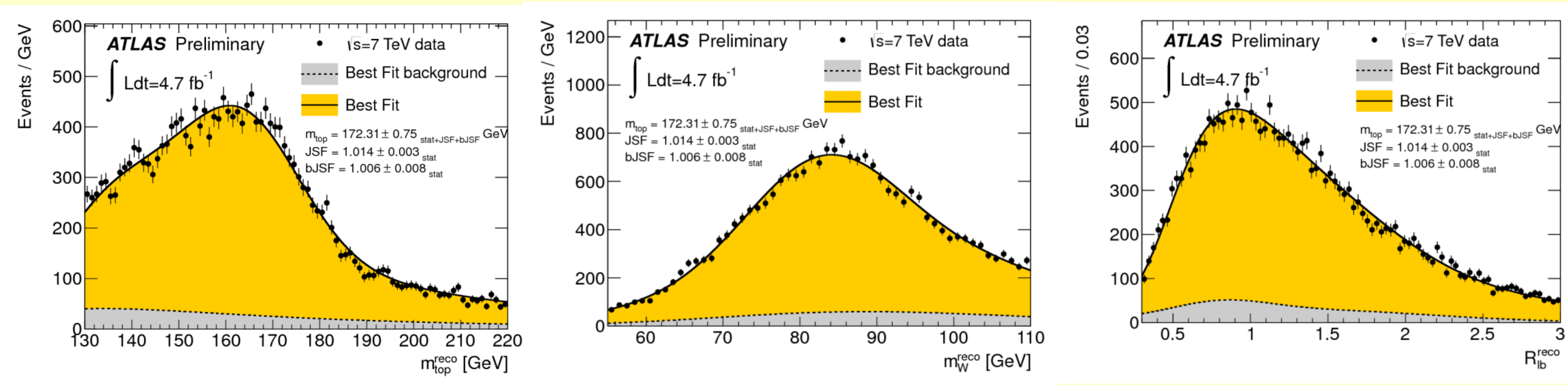






3D-template fit

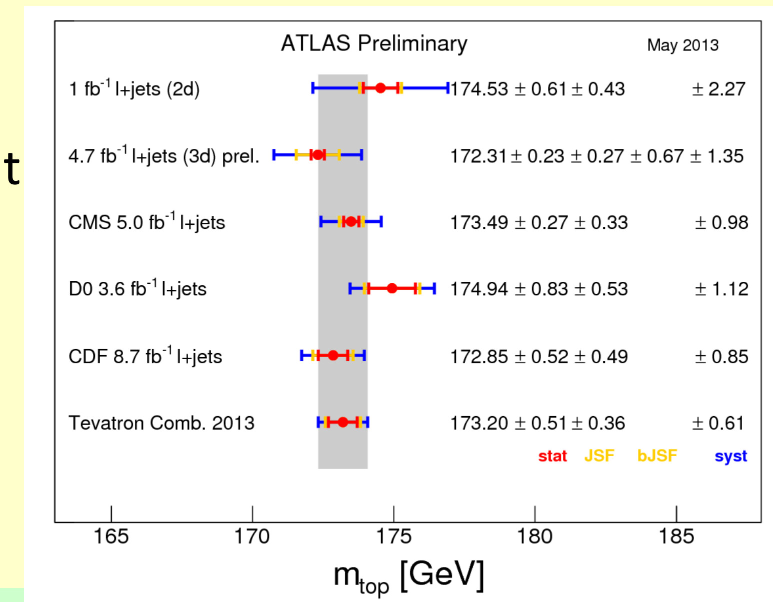
Unbinned likelihood fit to the data for all events - fit output: m_{top}, JSF, bJSF (and n_{bkg}):



m_{top} = 172.31 ± 0.75 (s+J+b) ± 1.35 (syst) GeV

New ATLAS measurement: significant improvement of systematic uncertainty 40%(b-tagging, ISR/FSR)

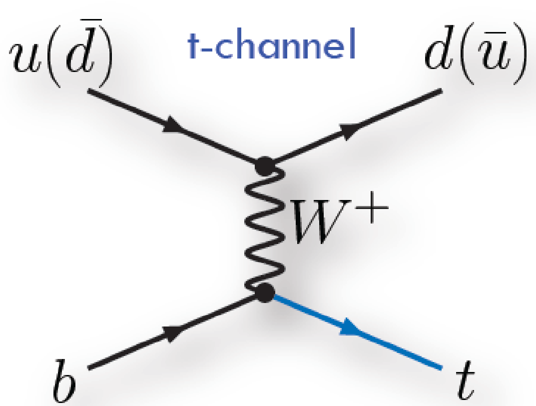
Work towards LHC combination ongoing: important to achieve a common treatment of modelling uncertainties (e.g. hadronisation)



Single Top Quark production

Single top quark production

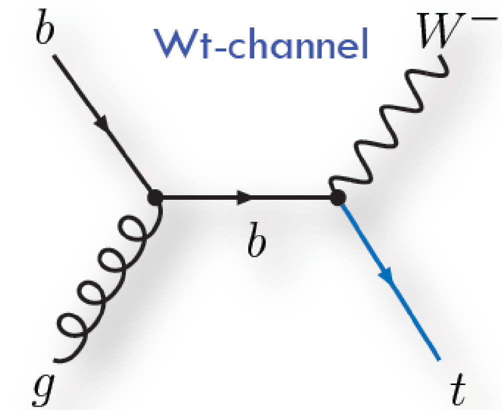
Production via EW forces (predicted by SM)



$\sigma = 64.57^{+2.63}_{-1.74}\,\mathrm{pb}$ @ 7 TeV

$\sigma = 87.76^{+3.44}_{-1.91}\,\mathrm{pb}$ @ 8 TeV

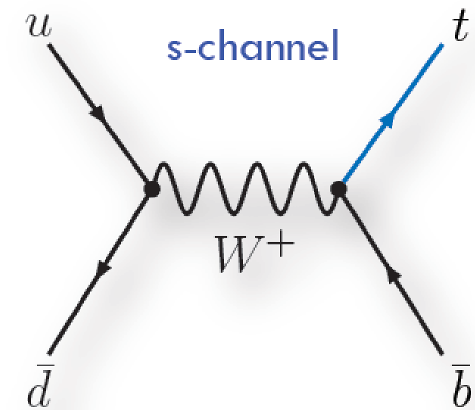
Phys. Rev. D 83, 091503(R) (2011)



$\sigma = 15.74^{+1.17}_{-1.21}\,\mathrm{pb}$ @ 7 TeV

$\sigma = 22.37 \pm 1.52\,\mathrm{pb}$ @ 8 TeV

Phys. Rev. D 82, 054018 (2010)



$\sigma = 4.63^{+0.20}_{-0.18}\,\mathrm{pb}$ @ 7 TeV

$\sigma = 5.61 \pm 0.22\,\mathrm{pb}$ @ 8 TeV

Phys. Rev. D 81, 054028 (2010)

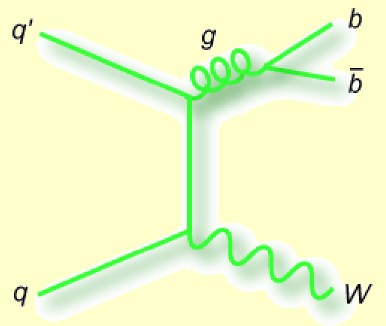
- ✓ Cross section measurement ($\sim|V_{tb}|^2$) to test SM predictions
- ✓ Direct measurement of CKM matrix element $|V_{tb}|$
- ✓ Charge asymmetry (t vs $\bar{t}$) is sensitive to proton PDF (u,d)
- ✓ Important for search of new physics
- ✓ Important background for Higgs studies

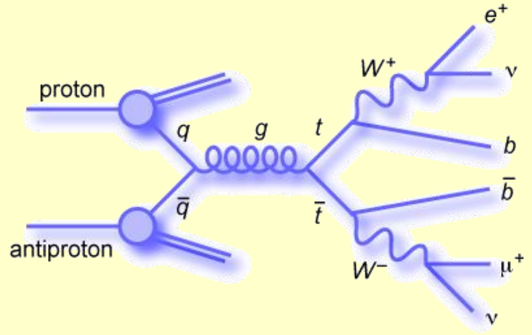
Single top: background for t-channel

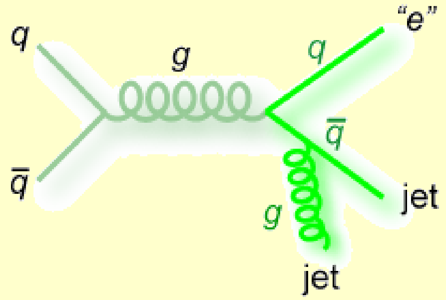
Single top quark production first observed by D0 and CDF in 2009

Main Backgrounds

W + jets   top-antitop pairs   QCD multijet production







Smaller backgrounds originate from *Z*+jets, *Wt*-channel and *s*-channel single top-quark production, and diboson production.

To cope with background Multivariate techniques (MVT) are used:
Neural Networks (NN), Boosted Decision Tree (BDT)...

Basic idea: a set of different kinematic variables ($M_{l\nu b}$, H_T, M_{jj}, M_T...) is used as input for MVT which employ them to optimize Signal vs Background.

Output of MVT: output discriminant – 1d representation of multidim. separation contour

Single top quark: *t*-channel cross section

L+jets, L=1.04 fb^{-1}, *pp* collision data at $\sqrt{s}$ = 7 TeV

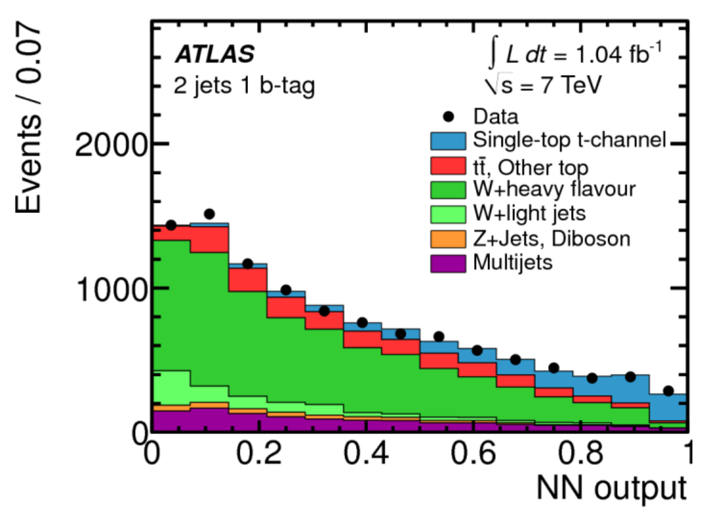
Event selection:

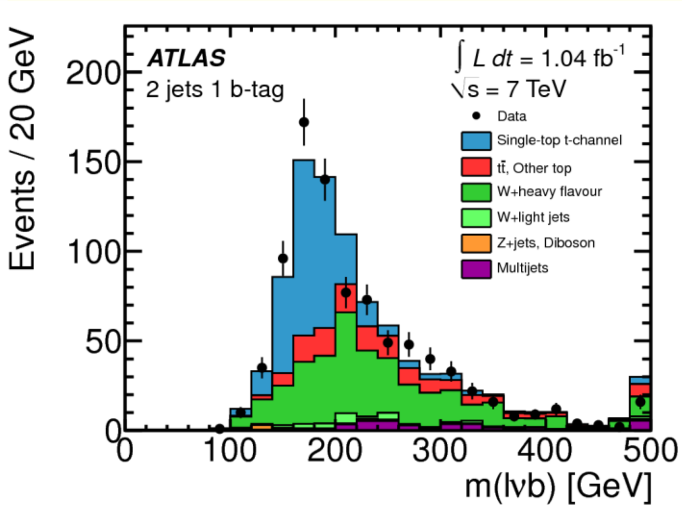
- ✓ exactly one charged lepton (e or μ), p_T>25 GeV
- ✓ 2 or 3 jets, |η|< 4.5, p_T> 25 GeV / *b*-tagged central jet
- ✓ and $\not{E}_T > 25\,\text{GeV}$, $m_T(W) > (60\,\text{GeV} - \not{E}_T)$

	Electron		Muon	
	2-jet	3-jet	2-jet	3-jet
single-top *t*-channel	447 ± 11	297 ± 7	492 ± 12	323 ± 8
$t\bar{t}$, other top	785 ± 52	1700 ± 120	801 ± 53	1740 ± 130
W+light jets	350 ± 100	128 ± 56	510 ± 150	209 ± 91
W+heavy flavour jets	2600 ± 740	1100 ± 400	3130 ± 880	1270 ± 480
Z+jets, diboson	158 ± 63	96 ± 44	166 ± 61	80 ± 31
Multijet	710 ± 350	580 ± 290	440 ± 220	270 ± 140
Total expected	5050 ± 830	3900 ± 520	5530 ± 930	3900 ± 520
Data	5021	3592	5592	3915

NN discriminant: 12 (18) input variables in *l*+2(3)-jets data set: $m(\ell\nu b)$, the highest p_T untagged jet $|\eta(j_u)|$, and $E_T(j_u)$ - most important

Single top quark: *t*-channel





Main uncertainties:

- ✓ ISR/FSR (14%)
- ✓ B-tag. eff. (13%)
- ✓ 24% total,5% stat.

Measured Xsec in the t-channel, simultaneously in 2-jet and 3-jet channels:

$$\sigma_t = 83 \pm 4(\text{stat})^{+20}_{-19}(\text{syst})\,\text{pb} = 83 \pm 20\,\text{pb}$$

Significance: ***7.2σ***

Phys. Lett.B717(2012)330

$|V_{tb}|^2$ extracted: ratio of the observed σ_t and SM expectation:

$|V_{tb}| = 1.13^{+0.14}_{-0.13}(\text{exp.}) \pm 0.02(\text{theo.})$ + 95% C.L. lower limit $|V_{tb}|$ is 0.75.

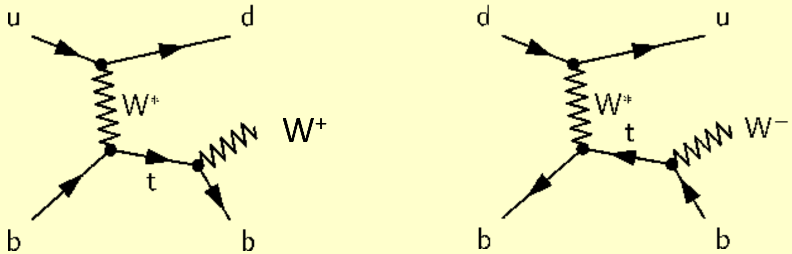
L = 5.8fb^{-1} @ 8 TeV, $\sigma_t = 95.1 \pm 2.4(\text{stat.}) \pm 18.0(\text{syst.})\,\text{pb}$

refined cuts (jets,miss-E_T) $|V_{tb}| = 1.04^{+0.10}_{-0.11}$ $|V_{tb}| > 0.80$ @ 95%CL

ATLAS-CONF-2012-132

t-channel – top/antitop cross-section

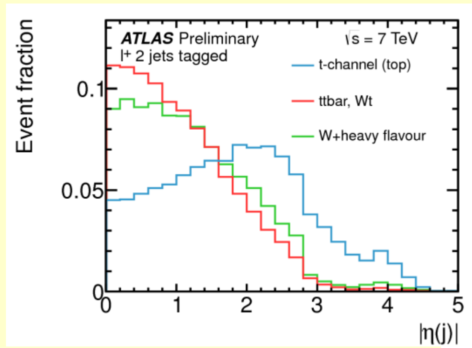
Measurement of separate t- and $\bar{t}$-quark cross-section, L=4.7fb^{-1} at 7TeV



$$\sigma_t(t) = 41.9^{+1.8}_{-0.8}\ \text{pb}$$
$$\sigma_t(\bar{t}) = 22.7^{+0.9}_{-1.0}\ \text{pb},$$

Lepton + jets (2 or3) used - lepton charge from W decay → charge of light quark

Several kinematic variables combined into one NN-discriminant
(l+2j: 15 var., l+3j: 19 var.)

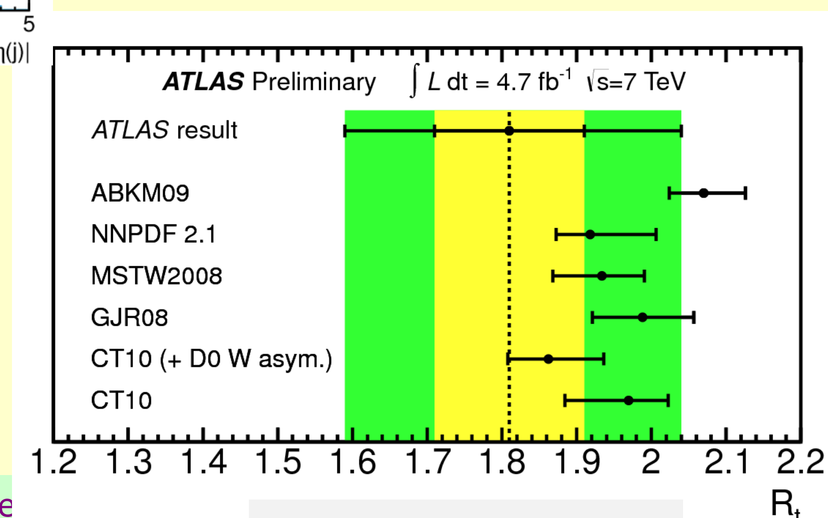


Main uncertainties:
Cross-section: JES (19.5 %)
R_t: stat. (5.5 %),
bkg. norm. (4.5 %), JES (4 %)

$$\sigma_t(t) = 53.2 \pm 1.7(\text{stat.}) \pm 10.7(\text{syst.})\ \text{pb}$$
$$\sigma_t(\bar{t}) = 29.5 \pm 1.5(\text{stat.}) \pm 7.3(\text{syst.})\ \text{pb}$$

$$R_t = 1.81 \pm 0.10(\text{stat.})\ ^{+0.21}_{-0.20}(\text{syst.})$$

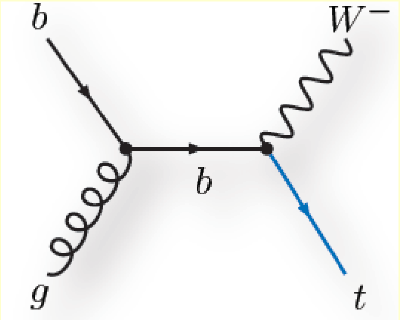
Sensitivity to u and d PDFs

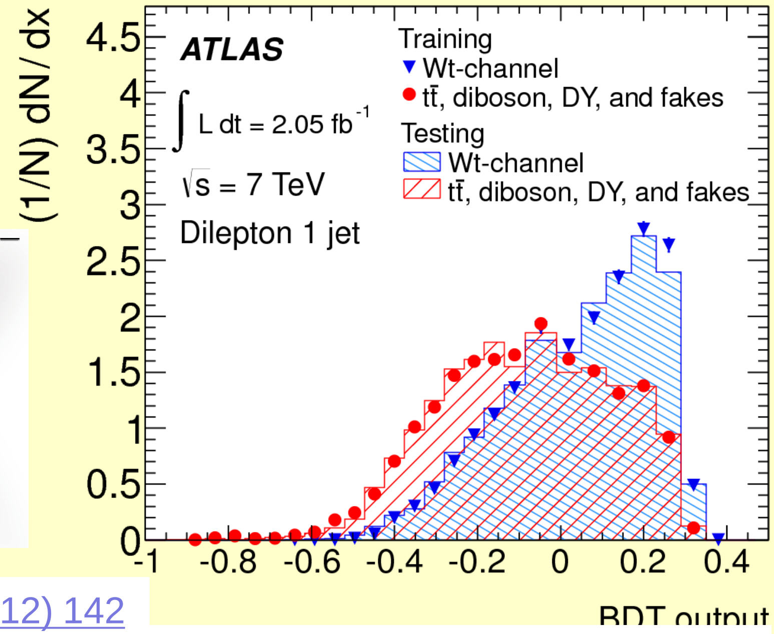


ATLAS-CONF-2012-056

Single top quark: Wt-channel

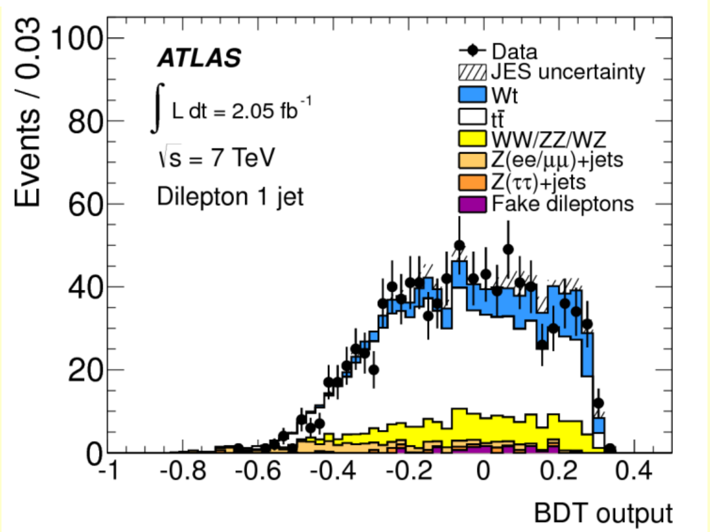
- Dilepton event selection 2.05fb^{-1} @7TeV
  - ✓ 2 central leptons, p_T > 25 GeV
  - ✓ E_T^{miss} > 50 GeV
  - ✓ 1 jet with p_T >30 GeV





Phys. Lett. B 716 (2012) 142

- Likelihood fit of BDT output for 1, 2 and 3+ jet bins
- Main uncertainties
  - ✓ Statistics (17 %)
  - ✓ JES (16 %), Parton shower model (15 %)



σ_t = 16.8 ± 2.9 (stat.) ± 4.9 (syst.) pb
Significance: 3.4σ exp., 3.3σ obs.

$$\sigma = 15.74^{+1.17}_{-1.21}\ \text{pb} \qquad |V_{tb}| = 1.03^{+0.16}_{-0.19}$$

Phys. Rev. D 82, 054018 (2010)

Single top quark summary

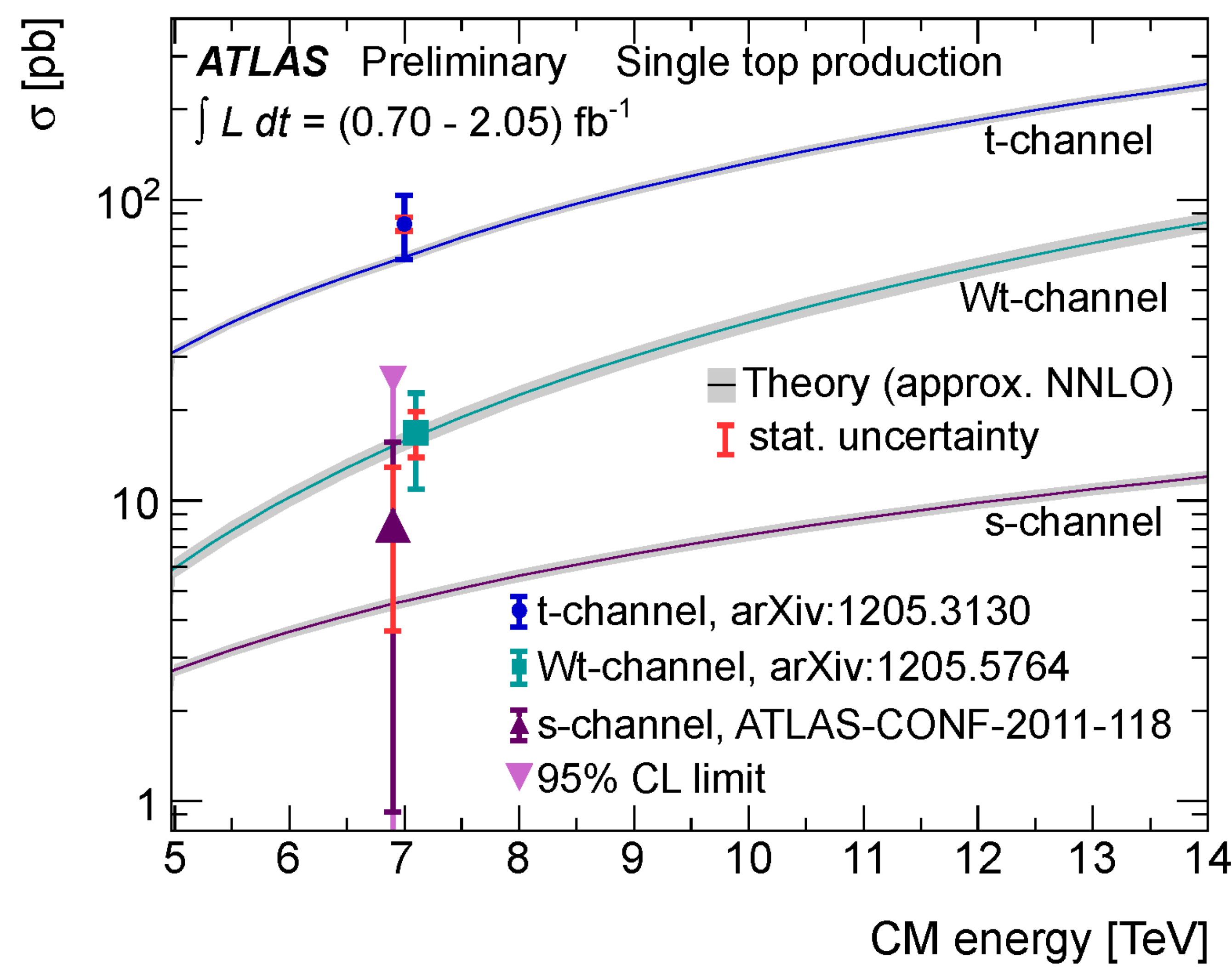
Single top s-channel:

at 7 TeV, L=0.7 fb^{-1}

The found limit:

$\sigma_{s\text{-}ch} < 26.5$ pb at 95% CL

Good agreement with SM



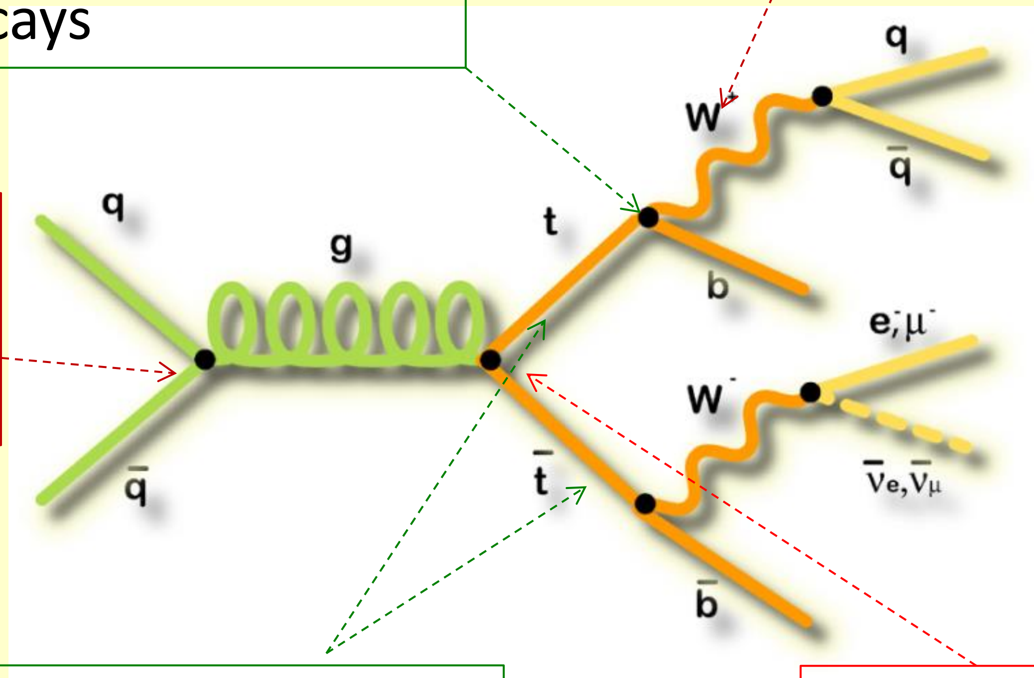
Top Quark properties

Top quark properties

Branching ratio
Anomalous couplings
rare decays

W polarisation

Production mechanisms ($q\bar{q}$ vs gg)



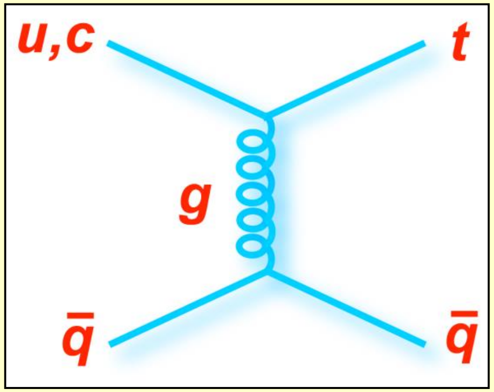
Test of SM
NP search

Top mass
Mass difference
Top charge
Width (Lifetime)

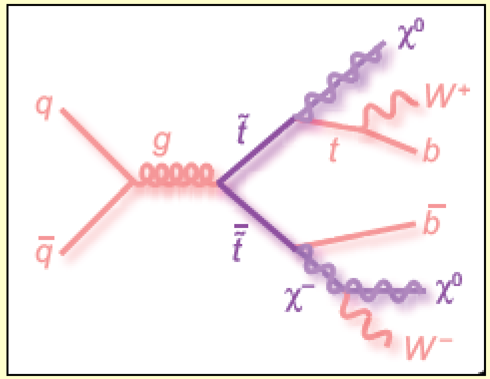
Spin correlations
Top polarisation
Charge asymmetry

Examples of new physics

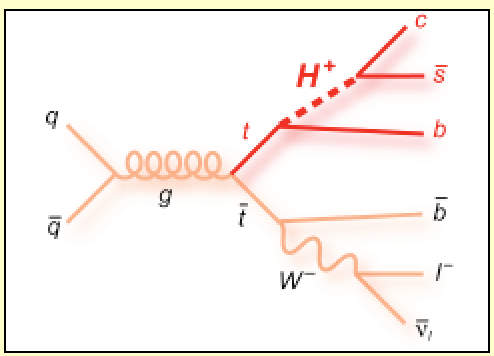
New physics contributions can change, w.r.t. the SM, properties of the Wtb vertex or modify the production mechanism of top quarks.



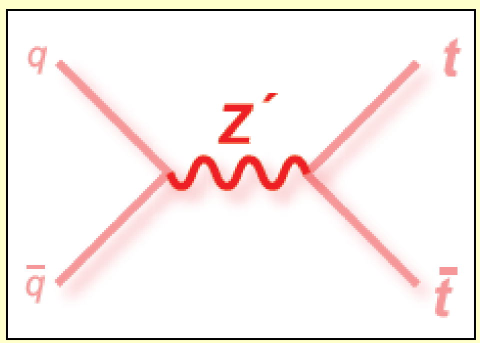
FCNC in top production



Single top *via* SuSy



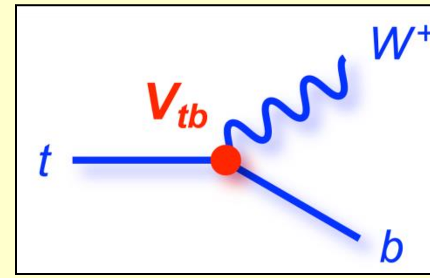
top decay *via* H^+

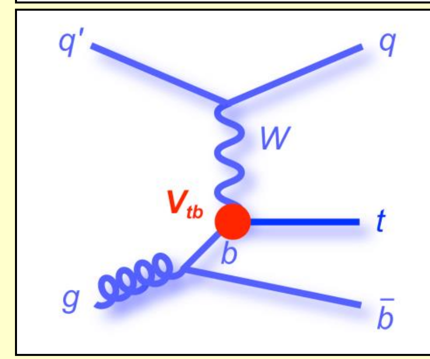


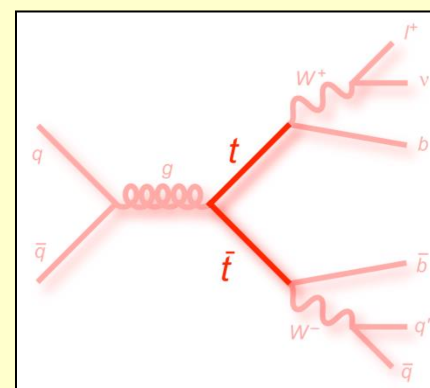
Top resonant production

New physics

Standard Model







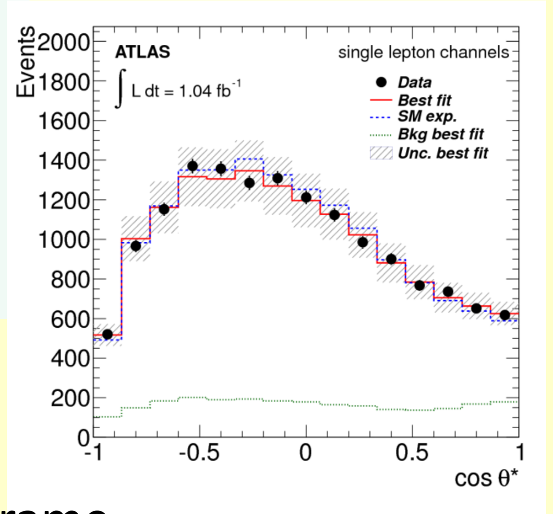
W helicity fractions in top decay

In SM *Wtb* vertex is given by EW V-A structure

SM expectation (NNLO) for *W* helicity fractions (PRD.81.111503):

$F_0 = 0.687 \pm 0.005$, $F_L = 0.311 \pm 0.005$ and $F_R = 0.0017 \pm 0.0001$

From angular distribution of top decay products (lepton):



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

$\theta^* \equiv$ angle (lepton, b-quark reversed mom.) in W boson rest frame

Combined (l+jets, dilepton) channel at 1.04 fb^{-1}:

$F_0 = 0.67 \pm 0.03$ (stat.) ± 0.06 (syst.)

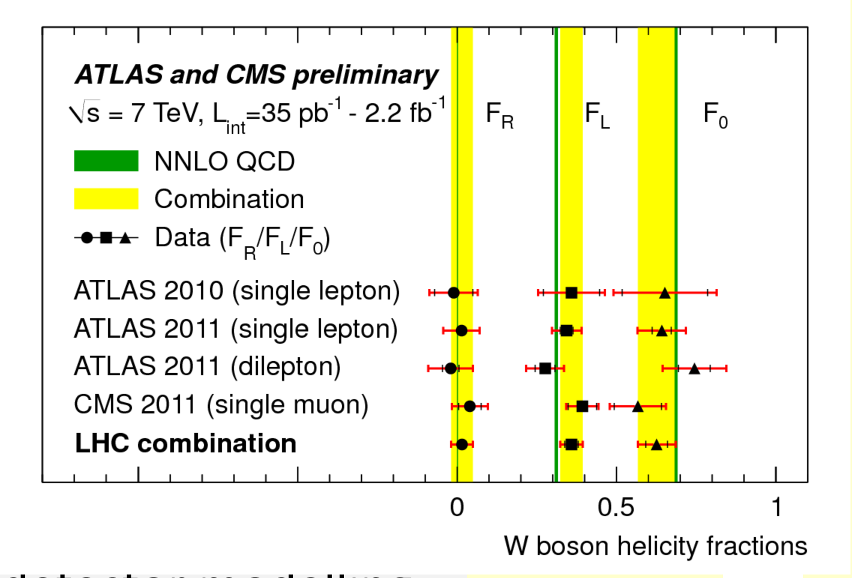
$F_L = 0.32 \pm 0.02$ (stat.) ± 0.06 (syst.)

$F_R = 0.01 \pm 0.01$ (stat.) ± 0.04 (syst.)

LHC combination

(ATLAS-CONF-2013-033, CMS_PAS_TOP-12-025)

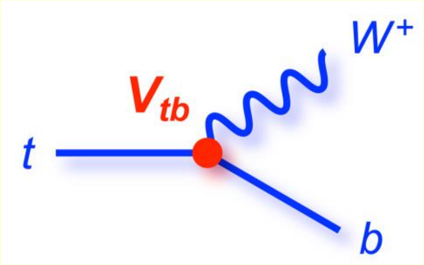
- $F_0 = 0.626 \pm 0.034$ (stat.) ± 0.048 (syst.)
- $F_L = 0.359 \pm 0.021$ (stat.) ± 0.028 (syst.)



Main syst: MC modelling, jet reconstruction, detector modelling

Anomalous Wtb couplings

Deviation of F_0, F_L, F_R from SM prediction $\Rightarrow$ New Physics contributing to Wtb:

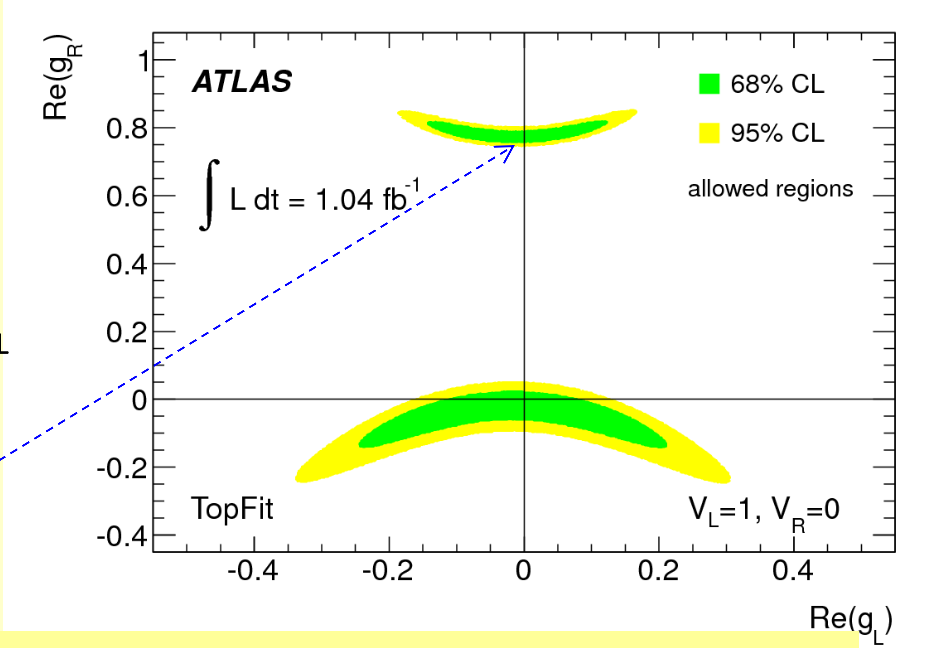


$$L_{Wtb} = -\frac{g}{\sqrt{2}}\bar{b}\gamma^{\mu}(V_L P_L + V_R P_R)W_{\mu}^{-} - \frac{g}{\sqrt{2}}\bar{b}\frac{i\sigma^{\mu\nu}q_{\nu}}{M_W}(g_L P_L + g_R P_R)W_{\mu}^{-} + h.c.$$

P_L (P_R) is the left (right)-handed chirality operator: $1 \mp \gamma_5$

In SM (tree level): $V_L = V_{tb} \approx 1$ and $V_R = g_L = g_R = 0$

- Couplings V_L, V_R, g_L and g_R can be expressed *via* new physics scale Λ
- Limits on anomalous couplings: from measurement of W hel. fractions using their dependence on the couplings
- The allowed regions of (g_L, g_R) obtained for V_L = 1 and V_R=0
- Large g_R region (2nd solution of quadratic eq.) - disfavoured by the single top production Xsection measurement
- Limits on $Im(g_R)$: $[-0.20, 0.30]$ at 95% CL



ATLAS-CONF-2013-032 (CP violation, single top)

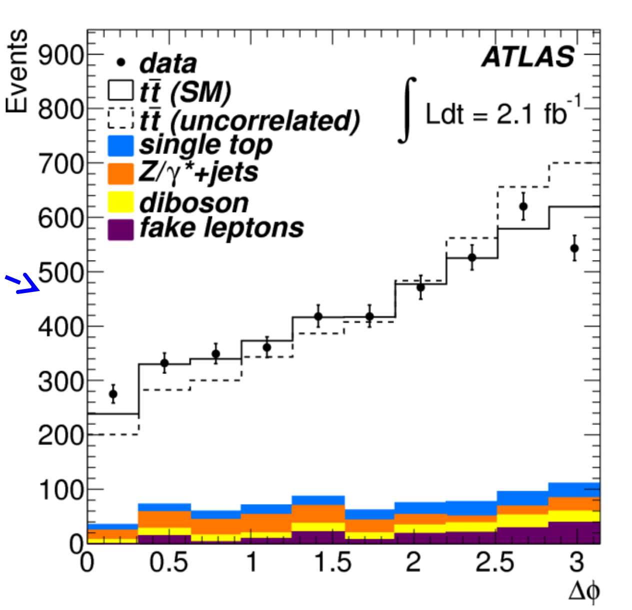
Spin correlation in $t\bar{t}$ events, at 7 TeV

Polarization of t and $\bar{t}$ quarks in $t\bar{t}$ sample is predicted to be very small but their spins should be correlated.

PRL.108,212001(2012)

- ✓ Dilepton topology with large missing E_T and ≥ 2jets: $t\bar{t} \to W^+W^-b\bar{b} \to l^+\nu l^-\bar{\nu}b\bar{b}$
- ✓ Reconstructed distribution of Δϕ (≡ azimuthal angle of two leptons) for $e^+e^-, \mu^+e^-, e^\pm\mu^\mp$ channels
- ✓ Degree of correlation:

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



Spin correlation: from Δϕ distribution → a binned likelihood fit for linear superposition

The combined fit: $f^{SM} \cdot N^{SM}_{t\bar{t}corr}(\Delta\phi) + (1 - f^{SM}) \cdot N^{MC}_{uncorr}(\Delta\phi)$

$$f^{SM} = 1.30 \pm 0.14(\text{stat.})^{+0.27}_{-0.22}$$

$$A^{meas}_{basis} = A^{SM}_{basis} \cdot f^{SM}$$

$$A_{helicity} = 0.40 \pm 0.04(\text{stat.})^{+0.08}_{-0.07} \quad \text{vs} \quad A^{SM}_{helicity} = 0.31$$

$$A_{max} = 0.57 \pm 0.06(\text{stat.})^{+0.12}_{-0.10} \quad \text{vs} \quad A^{SM}_{max} = 0.44$$

Main background:
- ✓ Z/γ* + jets
- ✓ Fake leptons
- ✓ single top
- ✓ dibosons

Top quark charge determination

SM ($t \to W^+ b$) vs eXotic Model ($t_X \to W^- b$)

Q(t) =+2/3 vs $Q(t_X)$ =-4/3

for top quark determination:

$W^\pm \to l^\pm \nu_l$

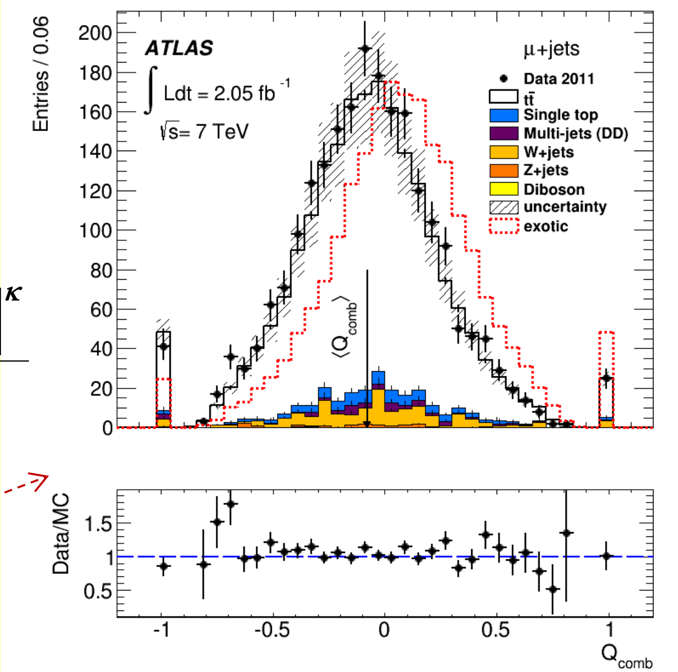
- Charge of W via its lept-decay
- Determination of b-jet charge ⟶ $Q_{b-jet} = \frac{\sum_i^N Q_i \left|\vec{j} \cdot \vec{p}_i\right|^\kappa}{\sum_i^N \left|\vec{j} \cdot \vec{p}_i\right|^\kappa}$
- Correct lepton – b-jet pairing

⬇

lepton+jets case (1 hi-p_T lep.)

$m(l, b_{jet}^{(1,2)}) < m_{cr}$ & $m(l, b_{jet}^{(2,1)}) > m_{cr}$

arXiv:1307.4568v1



Analysis: 7 TeV, $\int Ldt = 2.05 fb^{-1}$, L+J channel

Observable: $Q_{comb} = Q_l \times Q_{b-jet}$

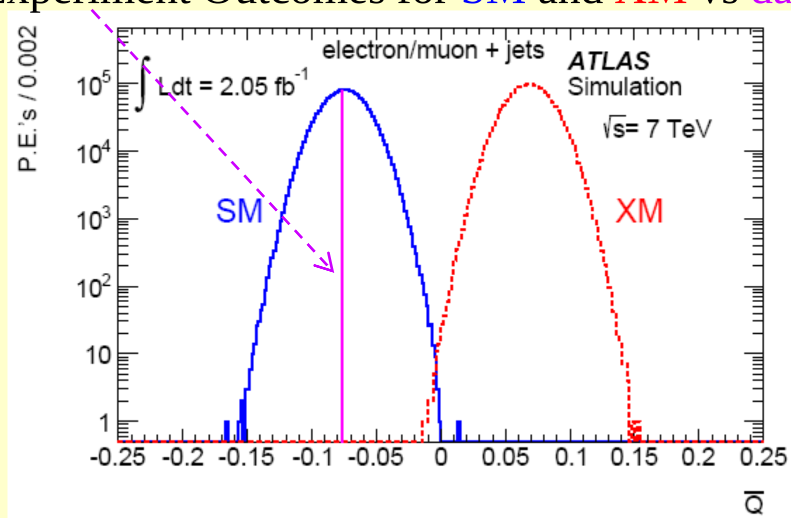
Idea: $\langle Q_{comb} \rangle \begin{cases} < 0: SM \\ > 0: XM \end{cases}$ arXiv:1307.4568v

XM exclusion: **> 8σ**

Inferred top charge [e]:

0.64 ±0.02 (stat.) ± 0.08 (syst.)

Experiment Outcomes for SM and XM vs data



B-physics results

Decay $B^0_s \to \mu^+\mu^-$,
b-hadron production cross section
Measurement of ϕ_s from B_s->$J/\psi\ \phi$
Angular Analysis of $B^0_d \to K^{*0}\ \mu^+\mu$
Υ(nS) production cross section

Search for the decay $B^0_s \to \mu^+\mu^-$

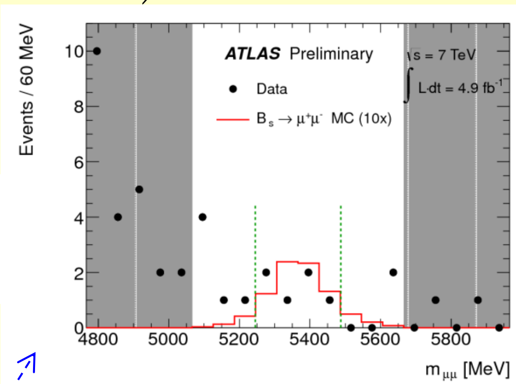
ATLAS-CONF-2013-076

- ✓ $B^0_s \to \mu^+\mu^-$ is highly suppressed in SM: BR=$(3.5\pm0.3)\times10^{-9}$
- ✓ Analysis is based on dimuon trigger, sample 4.9fb^{-1}at 7 TeV
- ✓ BR($B_s^0 \to \mu^+\mu^-$) is measured w.r.t. reference decay $(B^\pm \to J/\psi K^\pm)$

LHCb evidence
$BR = \left(3.2^{+1.5}_{-1.2}\right)\times10^{-9}$

$$BR\left(B_s^0 \to \mu^+\mu^-\right) = BR\left(B^\pm \to J/\psi K^\pm \to \mu^+\mu^- K^\pm\right) \times \frac{f_u}{f_s} \times \frac{N_{\mu^+\mu^-}}{N_{J/\psi K^\pm}} \times \frac{A_{J/\psi K^\pm}}{A_{\mu^+\mu^-}} \frac{\varepsilon_{J/\psi K^\pm}}{\varepsilon_{\mu^+\mu^-}}$$

relative production probability of $B^\pm$ and B^0_s (f_u/f_s) , event yields after bkgd subtraction and acceptance and efficiency ratios



Background:

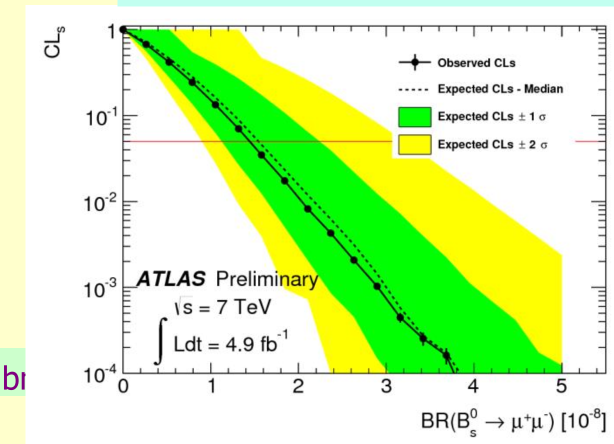
- continuous - smooth dependence on m(μμ), from $b\bar{b} \to \mu^+\mu^- X$
- Resonant one B decay with 1 or 2 hadrons identified as muons.

N_{obs}= 6 events
P-value(B) = 58%
P-value(S_{SM}+B) =24% !

Discriminating variables for BDT:

- takes into account - $B_s{}^0 \to \mu^+\mu^-$ separated from PVtx
- Two body topology

Multivariate technique BDT applied to select candidate events



Extracted limits: $BR\left(B_s^0 \to \mu^+\mu^-\right) < 1.5\times10^{-8}$ at 95% CL.

b-hadron production cross section

- Single muon trigger used with p_T > 6GeV
- Based on partial reconstruction of the b-hadron decay final state $D^{*+}\mu^- X$, with $D^{*+} \to \pi^+ D^0 (\to K^- \pi^+)$
- selection: $p_T(K^-\pi^+\pi^+)$>4.5 GeV and $|\eta(K^-\pi^+\pi^+)|$<2.5 inv. Mass 2.5 <$m(D^{*+}\pi^-)$<5.4 GeV

pp collisions at $\sqrt{s}$ = 7 TeV, $\int Ldt$= 3.3 pb^{-1}

Nucl.Phys.B864(2012)341

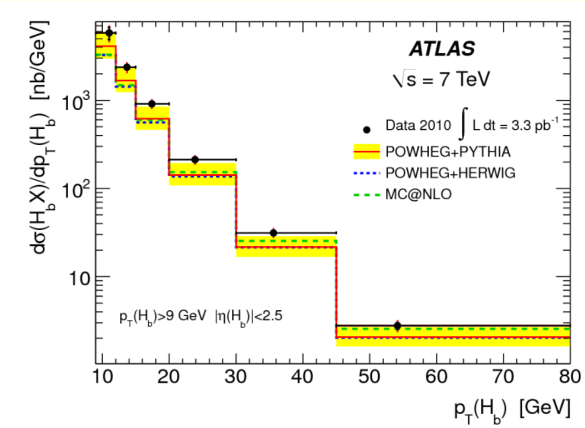
$H_b \to D^{*+}\mu^- X$ cross section:

Fraction of $H_b \to D^{*+}\mu^- X$

Candidate events

$$\sigma\left(pp \to H_b X' \to D^{*+}\mu^- X\right) = \frac{f_b \times N\left(D^{*+}\mu^- + D^{*-}\mu^+\right)}{2\varepsilon B L}$$

Efficiency, branching $D^{*+} \to \pi^+ D^0 (\to K^- \pi^+)$, integrated luminosity



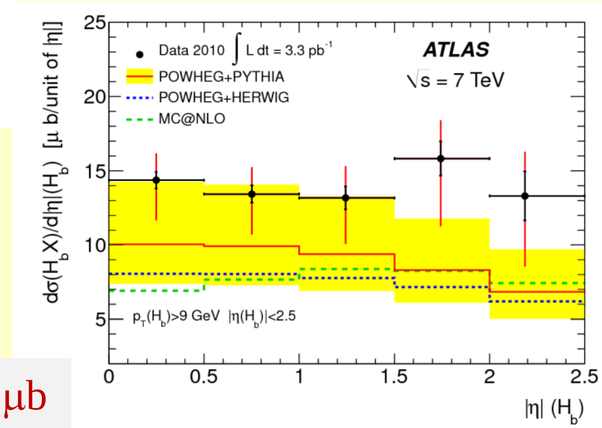
- ✓ For efficiency $b\bar{b}$ MC sample is used
- ✓ Unfolding is used to extract b-component
- ✓ Main systematics: tracking + μ-reconstruction

Integ. b-hadron X-sec. for $p_T(H_b)$> 9 GeV and $|\eta(H_b)|$< 2.5:

$$\sigma\left(pp \to H_b X\right) = 32.7 \pm 0.8(\text{stat.}) \pm 3.1\,(\text{syst.})\,{}^{+2.1}_{-5.6}(\alpha) \pm 1.1(L)\ \mu\text{b}$$

$$\sigma\left(pp \to b\bar{b}X\right) = 288 \pm 4(\text{stat.}) \pm 48(\text{syst.})\ \mu\text{b}$$

LHCb: 284±20±48 μb

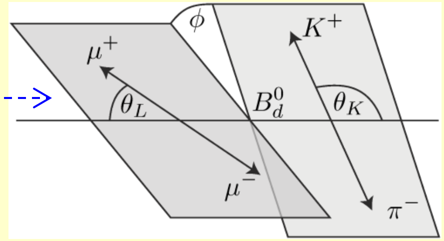


Comparison with theory: POWHEG+PYTHIA $\sigma = 22.2\,{}^{+8.9}_{-5.4}(\text{scale})\,{}^{+2.1}_{-1.9}(m_b)\,{}^{+2.2}_{-2.1}(\text{PDF})\,{}^{+1.6}_{-1.5}(\text{hadr})$

Angular Analysis of $B^0_d \rightarrow K^{*0} \mu^+\mu$

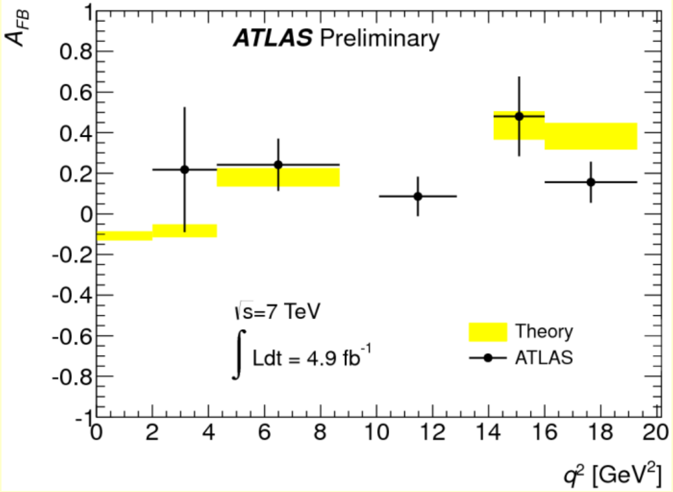
SM: $B^0 \rightarrow K^{*0}\mu^+\mu^-$ with $K^{*0}\rightarrow K^+\pi^-$ is a FCNC decay – via loops, BR=$(1.06\pm0.1)\times10^{-6}$

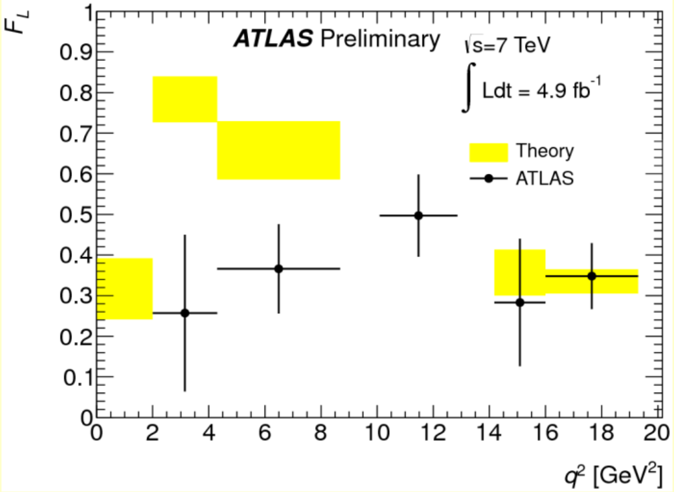
- ✓ Described by: μμ invariant mass (q^2) + 3 angles (θ_L, θ_K and ϕ)
- ✓ Usually $d^2\Gamma/dq^2 d\cos\theta_L$ and $d^2\Gamma/dq^2 d\cos\theta_K$
- ✓ extracted: K^{*0} longitudinal polarisation fraction F_L
  lepton forward/backward asymmetry A_{FB}



$$\frac{1}{\Gamma}\frac{d^2\Gamma}{dq^2 d\cos\theta_L} = \frac{3}{4}F_L(q^2)(1-\cos^2\theta_L) + \frac{3}{8}(1-F_L(q^2))(1+\cos^2\theta_L) + A_{FB}(q^2)\cos\theta_L, \quad \frac{1}{\Gamma}\frac{d^2\Gamma}{dq^2 d\cos\theta_K} = \cdots$$

Analysis: 7TeV, $\int Ldt = 4.9\ \text{fb}^{-1}$. Likelihood fit applied to the angular distributions





F_L and A_{FB} found for 6 q^2 (dimuon inv. mass squared) bins

ATLAS-CONF-2013-038

$B^0_d \to K^{*0} \mu^+\mu^-$: F_L and A_{FB} comparison

Summary results on

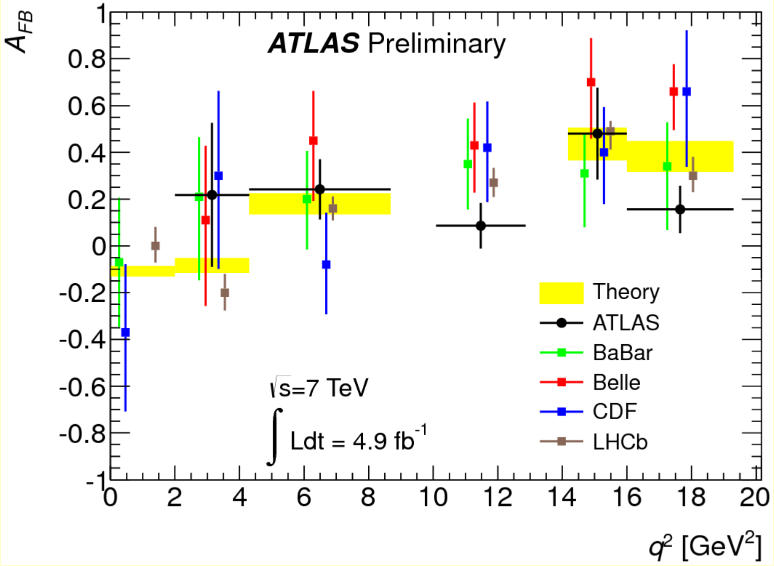
A_{FB} ≡ lepton FB asymmetry

F_L ≡ K^{*0} longit. polarisation

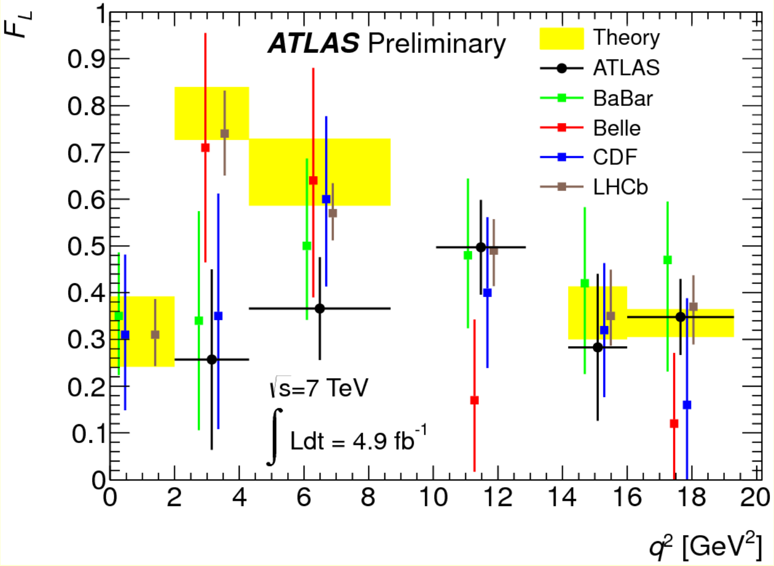
N_{sig} ≡ Nr. of signal events

q^2 range (GeV^2)	N_{sig}	A_{FB}	F_L
$2.00 < q^2 < 4.30$	19 ± 8	$0.22 \pm 0.28 \pm 0.14$	$0.26 \pm 0.18 \pm 0.06$
$4.30 < q^2 < 8.68$	88 ± 17	$0.24 \pm 0.13 \pm 0.01$	$0.37 \pm 0.11 \pm 0.02$
$10.09 < q^2 < 12.86$	138 ± 31	$0.09 \pm 0.09 \pm 0.03$	$0.50 \pm 0.09 \pm 0.04$
$14.18 < q^2 < 16.00$	32 ± 14	$0.48 \pm 0.19 \pm 0.05$	$0.28 \pm 0.16 \pm 0.03$
$16.00 < q^2 < 19.00$	149 ± 24	$0.16 \pm 0.10 \pm 0.03$	$0.35 \pm 0.08 \pm 0.02$
$1.00 < q^2 < 6.00$	42 ± 11	$0.07 \pm 0.20 \pm 0.07$	$0.18 \pm 0.15 \pm 0.03$

lepton forward-backward asymmetry A_{FB}

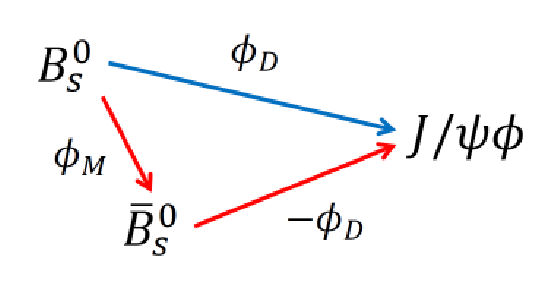


fraction of longitudinal polarised K^{*0} F_L



Comparison with others: ATLAS vs BaBar, Belle, CDF and LHCb

Measurement of ϕ_s from $B_s \to J/\psi\ \phi$



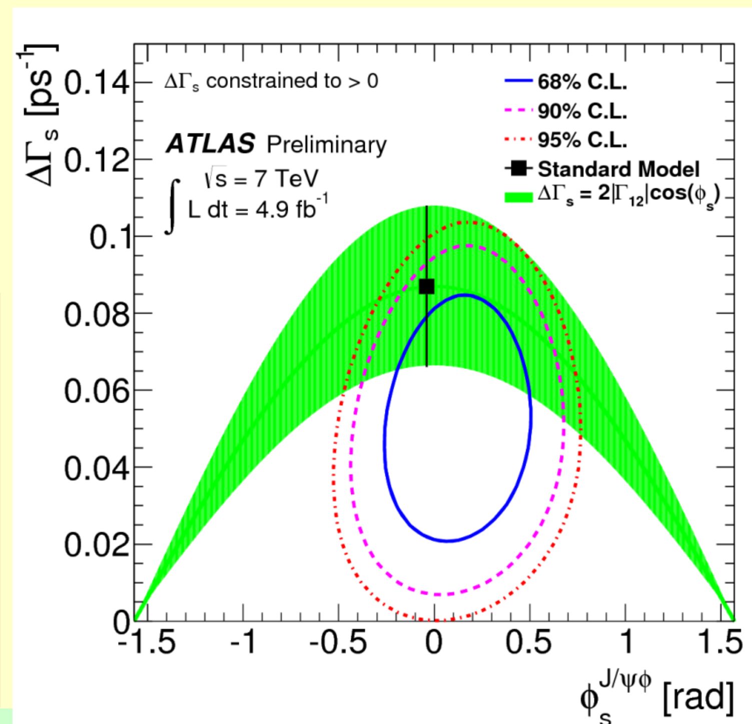
CPV phase ϕ_s : phase difference between $B_s - \bar{B}_s$ mixing followed by $\bar{B}_s$ decay and direct B_s ($\to J/\psi\ \phi$) decay

Analysis: 4.9fb^{-1}, at 7 TeV

SM prediction: $\phi_s^{SM} \approx -2\beta_s = -0.0363^{+0.0016}_{-0.0015} \approx 2°$

ATLAS-CONF-2013-039

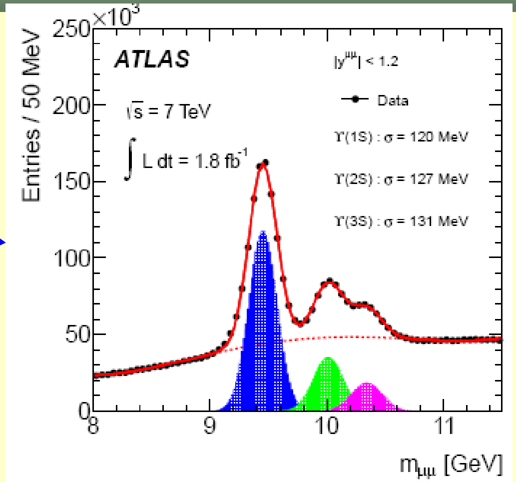
- ✓ Uses $B_s^0 \to J/\psi(\to \mu^+\mu^-)\phi(\to K^+K^-)$
- ✓ Disentangle (final state of B^0_s decay)
  - CP-even states: (CP= +1, /L=0, L=2)
  - and CP-odd states: (CP= -1, /L=1)
- ✓ Analyzed: angular distributions in transversity coordinate system



$$\phi_s = 0.12 \pm 0.25(stat.) \pm 0.11(syst.)\ \text{rad}$$
$$\Delta\Gamma = 0.053 \pm 0.021(stat.) \pm 0.009(syst.)\ ps^{-1}$$
$$\Gamma = 0.677 \pm 0.007(stat.) \pm 0.003(syst.)\ ps^{-1}$$
$$|A_0(0)|^2 = 0.529 \pm 0.006(stat.) \pm 0.011(syst.)$$
$$|A_\parallel(0)|^2 = 0.220 \pm 0.008(stat.) \pm 0.009(syst.)$$
$$\delta_\perp = 3.89 \pm 0.46(stat.) \pm 0.13(syst.)$$

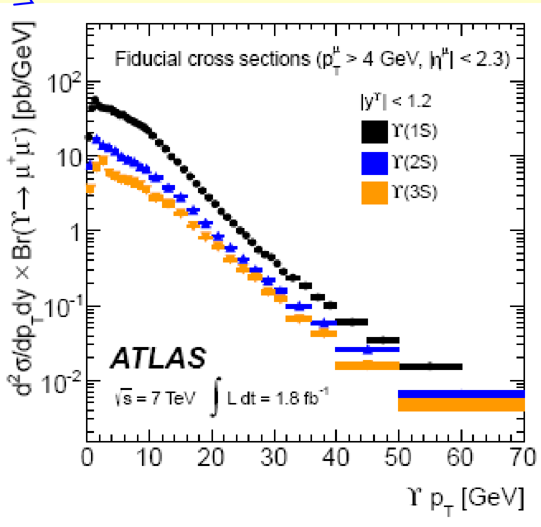
$\Upsilon(nS)$ production cross section

- ✓ Study of Υ(nS), $b\bar{b}$ systems - important test of QCD
- ✓ dominant production mechanism is gluon fragmentation
- ✓ Reconstructed: using the di-muon decay mode.
- ✓ Total production cross sections for Υ(1S), Υ(2S), Υ(3S) and differential Xsec vs upsilonium p_T and η measured



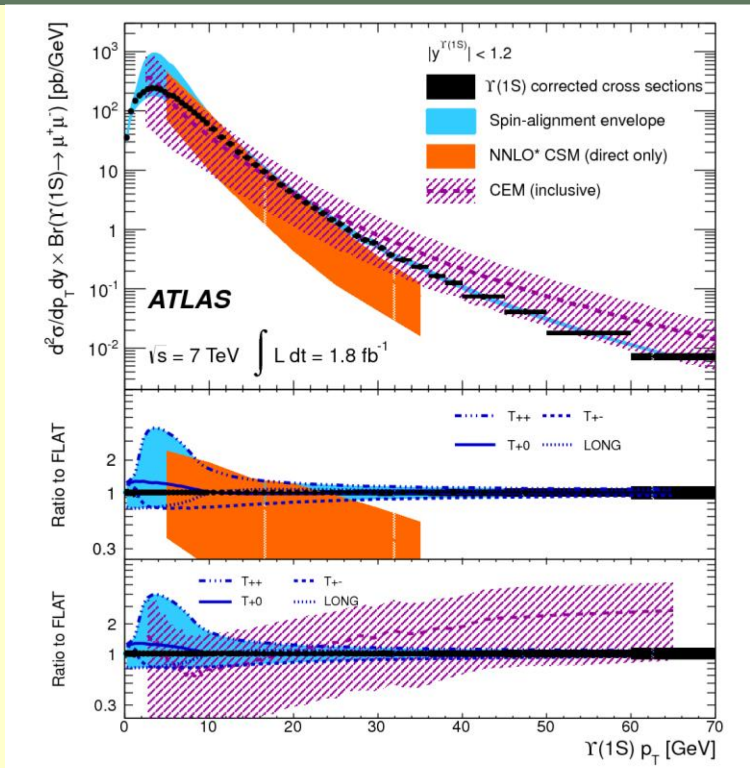
PRD 87, 052004(2013))

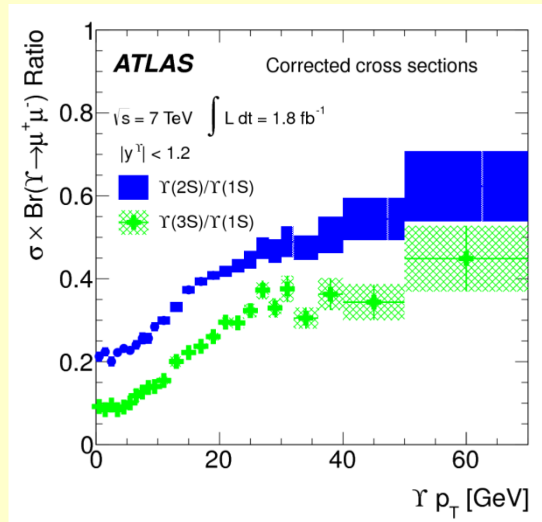
Integrated corrected cross sections	
State	$\sigma(pp \to \Upsilon) \times \mathrm{Br}(\Upsilon \to \mu^+\mu^-)$ Range: $p_T^{\Upsilon} < 70\,\mathrm{GeV}$, $\lvert y^{\Upsilon}\rvert < 2.25$
$\Upsilon(1S)$	$8.01 \pm 0.02 \pm 0.36 \pm 0.31$ nb
$\Upsilon(2S)$	$2.05 \pm 0.01 \pm 0.12 \pm 0.08$ nb
$\Upsilon(3S)$	$0.92 \pm 0.01 \pm 0.07 \pm 0.04$ nb

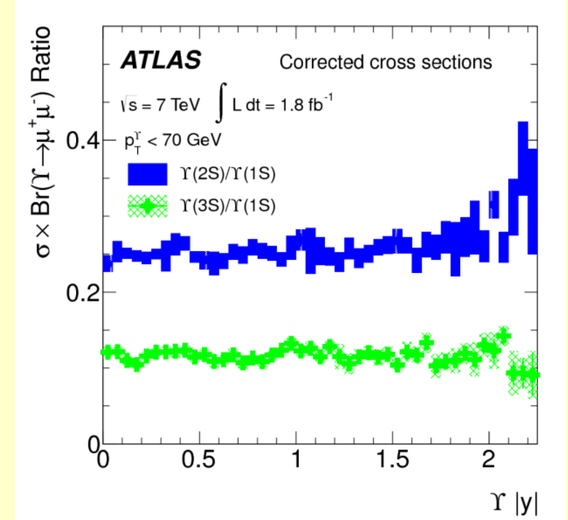


Uncertainties: statistical, systematic, and luminosity

ϒ(nS) production cross section







Ratios of differential ϒ(2S)/ ϒ(1S) and ϒ(3S)/ ϒ(1S) X-sec × Br($\Upsilon \to \mu^+\mu^-$) vs ϒ p_T and ϒ |y| (direct production vs prod. via excited states)

Dif. Xsec $d^2\sigma\ /dp_T dy \times Br(\Upsilon \to \mu^+\mu^-)$ for $\Upsilon(1S)$, full phase space, vs

- ✓ NNLO* Color Singlet Mechanism (CSM)
- ✓ Color Evaporation Model (CEM).

A tension between data and theoretical model seen!

Other b-physics results: https://twiki.cern.ch/twiki/bin/view/AtlasPublic/BPhysPublicResults

Summary

- LHC measurements at 7 and 8 TeV have a significant impact on theoretical conceptions.
- Top quark physics, with full NNLO from theory and new LHC measurements, enters into high precision era !
- Potential of heavy quark (top, b) physics:
  - ✓ Internal tests of SM (precise measurement of top mas, top Xsec, top spin correlations, b-quark Xsec…)
  - ✓ Window for a new physics (single top, anomalous coupling, ttbar resonances, …)
  - ✓ B-production cross section (QCD tests)
  - ✓ Study of B-decay ($B^0_s \to \mu\mu$, $B^0_d \to K^{*0} \mu^+\mu$ …)
  - ✓ Production of upsilonia
  - ✓ Measurement of CPV phase ϕ_s

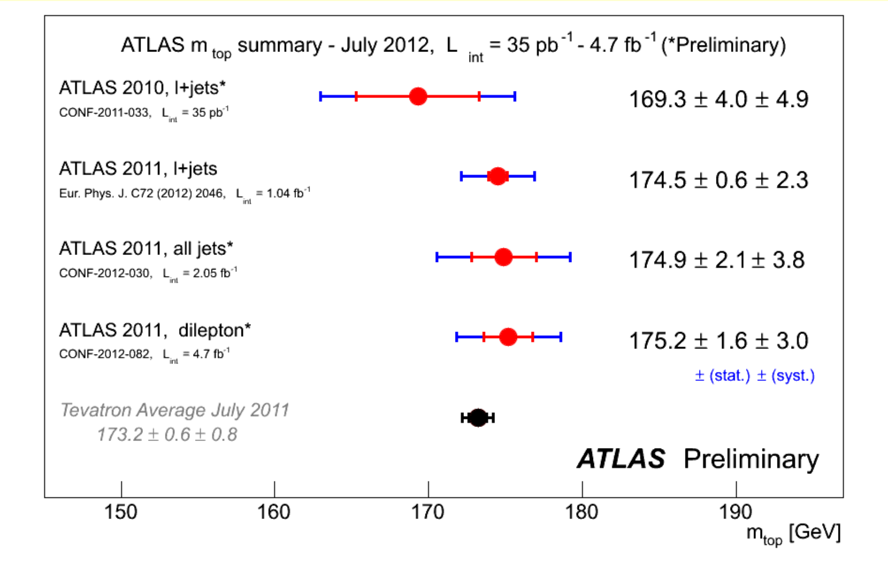
- Perspectives: to improve systematics (hadronisation, pileup,ISR/FSR,...)
  to process full statistics at 7 and 8 TeV

Thank you!

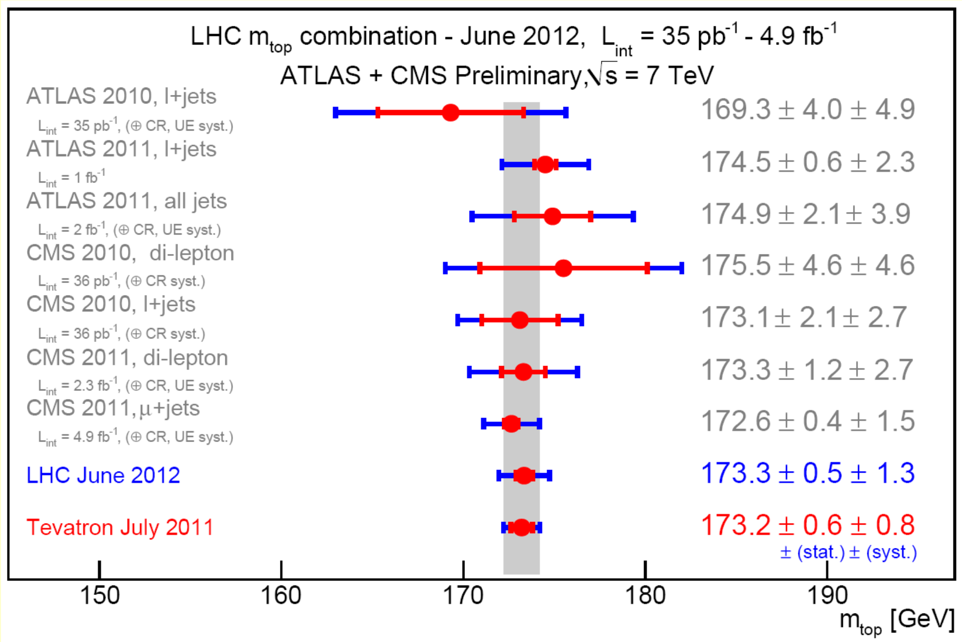
Top quark mass summary

2d-analysis: m_{top} + jet energy scale factor (JSF) are determined simultaneously using $m_{top}^{reco}, m_W^{reco}$ distributions → in-situ jet scaling.

ATLAS top mass results



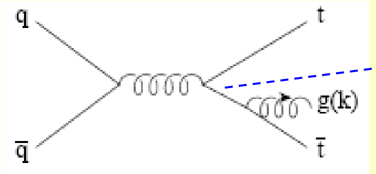
ATLAS and CMS top mass summary



A few top Cross Section issues

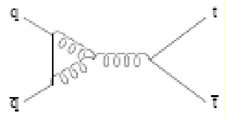
Higher order real and virtual corrections exhibit IR and UV divergences:

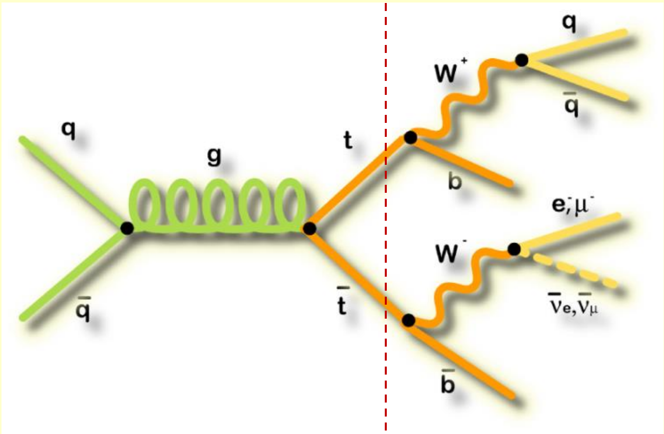
Example:



$$\text{propagator} = \frac{1}{(p+k)^2} = \frac{1}{2E_pE_k}\cdot\frac{1}{1-\beta_p\cos\theta}, \quad \beta_p = \sqrt{1-m^2/E_p^2}$$

✓ IR singularity: $E_k \to 0$ and $1-\beta_p\cos\theta \to 0$ ⇒ cancelled when Xsec of virtual and real emission are summed also mass singularities are cancelled ⇒ Cancelation is not full ⇒ presence of big logs (L) in Xsec terms !

✓ UV singularities in loops () are handled by renormalization.



In real we observe $t\bar{t}$ decay products not $t\bar{t}$

Factorization is used based on the narrow width approximation:

- ✓ polarized top quarks are produced on mass shell
- ✓ polarized on-shell top quarks decay

Narrow width app. vs direct pp→WWbb:

For LHC 7TeV/DIL: Xsec(fb) 837 vs 841 also done for 14 and 1.96TeV

3D-template fit

Unbinned likelihood fit to the data for all events - fit output: m_{top}, JSF, bJSF (and n_{bkg}):

$$L\left(m_{top}^{reco}, m_W^{reco}, R_{tlb}^{reco} \middle| m_{top}, JSF, bJSF, n_{bkg}\right) =$$

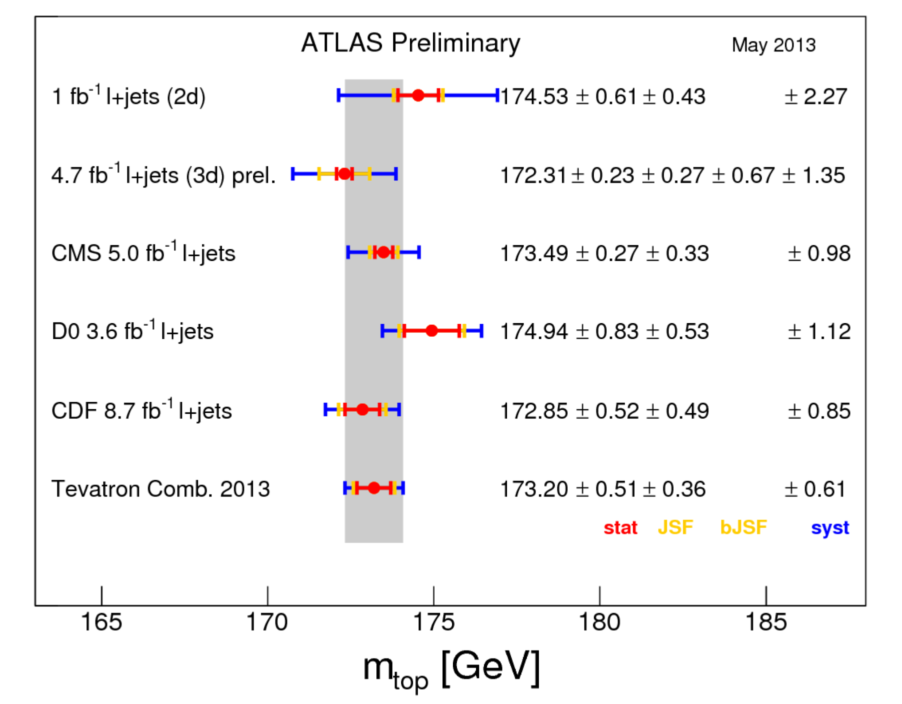
$$\prod_i^N P_{top}\left(m_{top}^{reco} \middle| m_{top}, JSF, bJSF, n_{bkg}\right)_i \times P_W\left(m_W^{reco} \middle| JSF, n_{bkg}\right)_i \times P_{R_{lb}}\left(R_{lb}^{reco} \middle| m_{top}, bJSF, n_{bkg}\right)_i$$

$$P_{top} = \left(N - n_{bkg}\right) P_{top}^{sig} + n_{bkg} P_{top}^{bkg} \cdots$$

m_{top} = 172.31 ± 0.75 (s+J+b) ± 1.35 (syst) GeV

JSF = 1.014 ± 0.003 (stat) ± 0.021 (syst)

bJSF = 1.014 ± 0.003 (stat) ± 0.021 (syst)



New ATLAS preliminary measurement: significant improvement of sytematic uncertainty (especially b-tagging)

Work towards LHC combination ongoing: important to achieve a common treatment of modelling uncertainties (e.g. hadronisation)

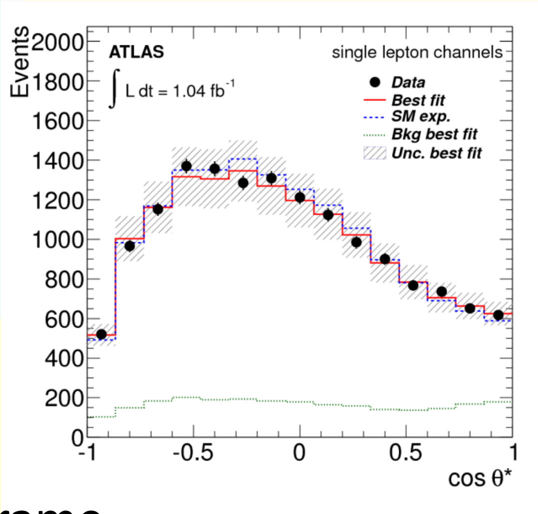
W helicity fractions in top decay

In SM *Wtb* vertex is given by EW V-A structure

SM expectation (NNLO) for *W* helicity fractions (PRD.81.111503):

$F_0 = 0.687\pm0.005$, $F_L = 0.311\pm0.005$ and $F_R = 0.0017\pm0.0001$

From angular distribution of top decay products (lepton):



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

$\theta^* \equiv$ angle (lepton, b-quark reversed mom.) in W boson rest frame

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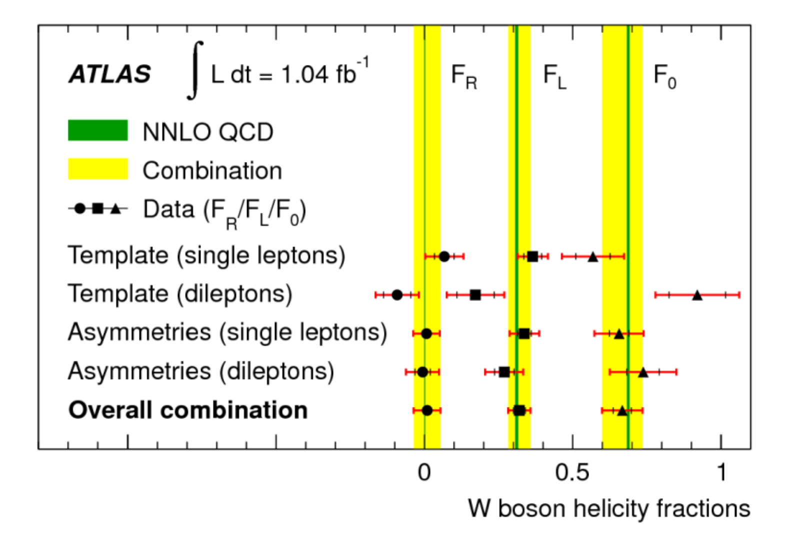
Combined (l+jets, dilepton) channel at 1.04 fb^{-1}:

$F_0 = 0.67 \pm 0.03$ (stat.) ± 0.06 (syst.)
$F_L = 0.32 \pm 0.02$ (stat.) ± 0.06 (syst.)
$F_R = 0.01 \pm 0.01$ (stat.) ± 0.04 (syst.)



LHC combination
(ATLAS-CONF-2013-033, CMS_PAS_TOP-12-025)

- $F_0 = 0.626 \pm 0.034$ (stat.) ± 0.048 (syst.)
- $F_L = 0.359 \pm 0.021$ (stat.) ± 0.028 (syst.)

Main syst: MC modelling, jet reconstruction, detector modelling

b-hadron production cross section

$p_T(D^{*+}\mu^-)$	$N(D^{*+}\mu^-)$
9–12 GeV	334 ± 33
12–15 GeV	1211 ± 56
15–20 GeV	1527 ± 55
20–30 GeV	1049 ± 42
30–45 GeV	310 ± 21
45–80 GeV	76 ± 10

$\|\eta(D^{*+}\mu^-)\|$	$N(D^{*+}\mu^-)$
0.0–0.5	1330 ± 47
0.5–1.0	1207 ± 47
1.0–1.5	919 ± 48
1.5–2.0	890 ± 60
2.0–2.5	317 ± 37

Table 1: Fitted number of opposite charge $D^*\mu$ pairs for different p_T and $|\eta|$ bins.

Various processes contribute to the $D^{*+}\mu^-$ data sample:

- ✓ Direct semileptonic decay: $b \to D^+\mu^-X$; ≡ the signal contribution used for this measurement.
- ✓ Decays of two c-hadrons, one of them decaying semileptonically: $c \to D^{*+}X$; $\underline{c} \to \mu^-X'$.
- ✓ Direct semileptonic τ decay: $b \to D^{*+}\tau^-X$; $\tau^- \to \to \mu^-\underline{\nu}_\mu\, \nu_\tau\, (\gamma)$.
- ✓ Decays of b-hadrons with two c-hadrons in the final state, one of them decaying semileptonically:
- ✓ $b \to D^{*+}\, \underline{D}\, X$; $\underline{D} \to \mu^-X'$.
- ✓ Decays of two b-hadrons, one of them decaying semileptonically: $b \to D^{*+}X$; $b \to \mu X'$.
- ✓ A D+ meson accompanied by a fake muon, contributing to both opposite-sign and same-sign charge combinations. The contribution from combinations with misidentied muon charge is negligible.