



TOP PHYSICS AT ATLAS

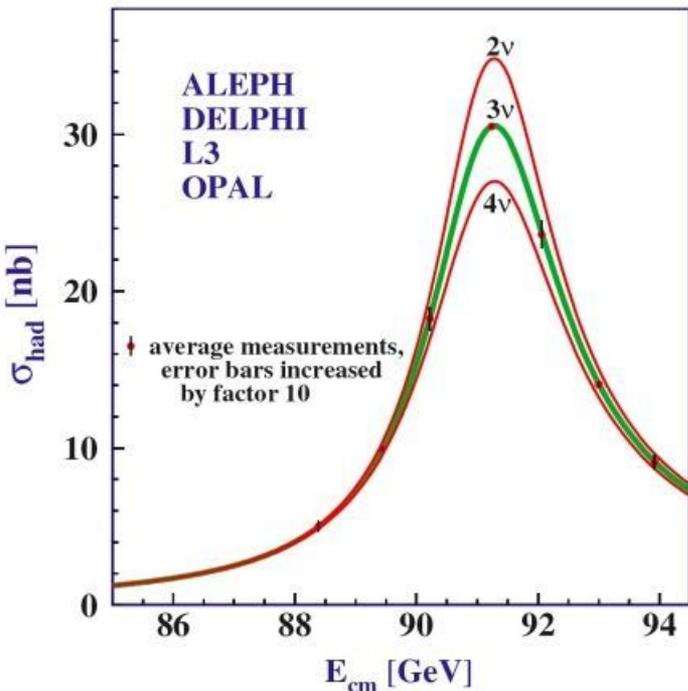
Review of recent results

Saverio D'Auria

University of Glasgow

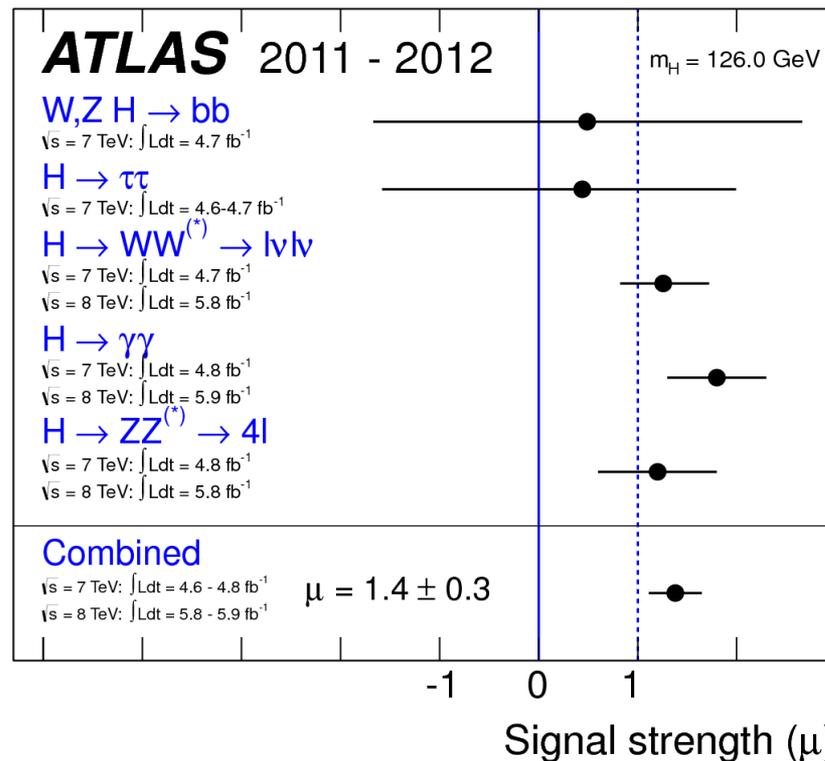
School of Physics and Astronomy

On behalf of the ATLAS collaboration



LEP: 3 generations of fermion families with light neutrinos

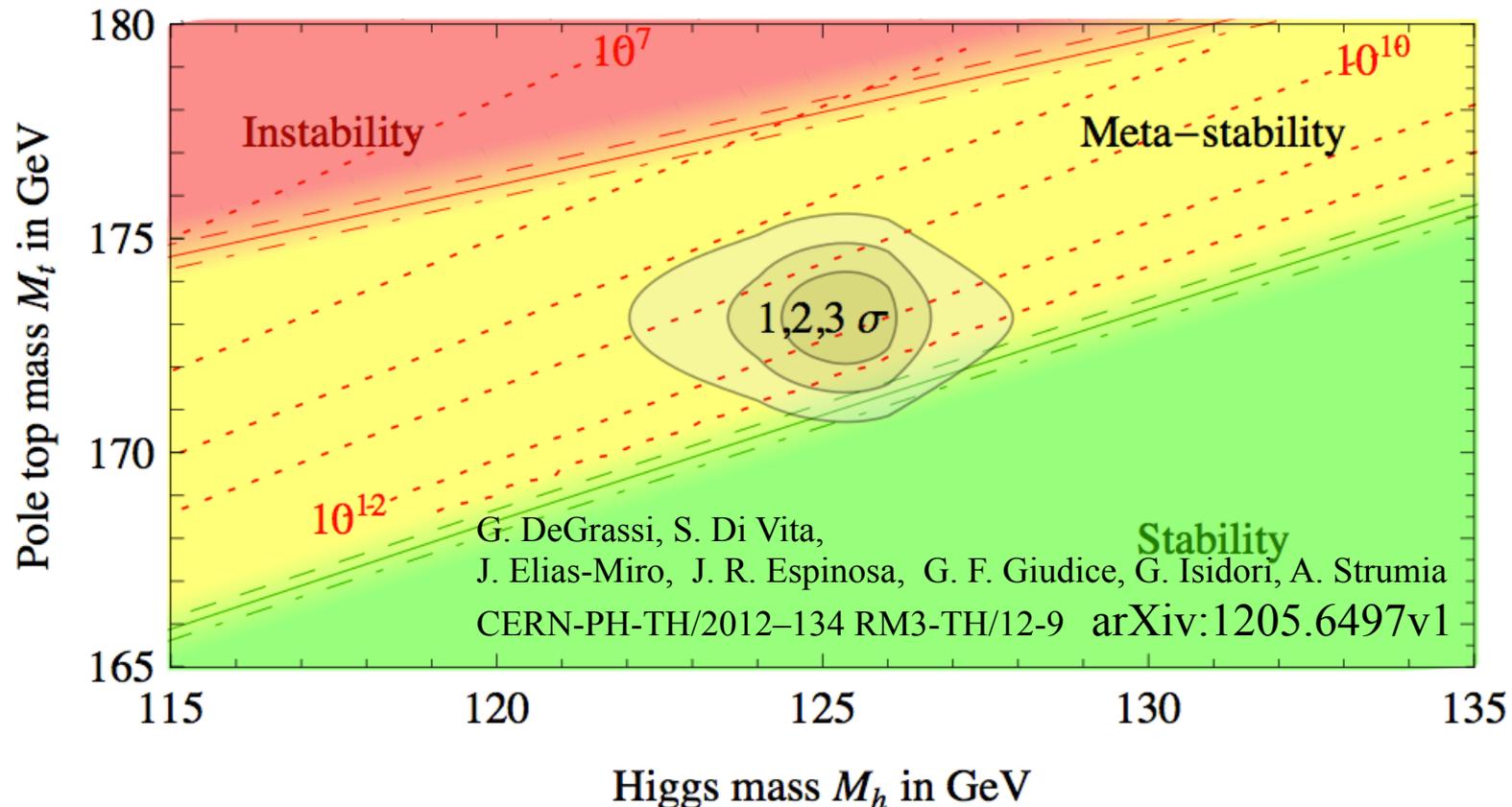
LHC Higgs-like signal strength ~ 1 (SM)
 No heavy particle in Higgs production loop
 (unless cancellations ??)



Extrapolating at high energy, Standard Model stability.

Meta-stable corner.

Top mass (Higgs Yukawa (running) coupling) a critical parameter for SM stability

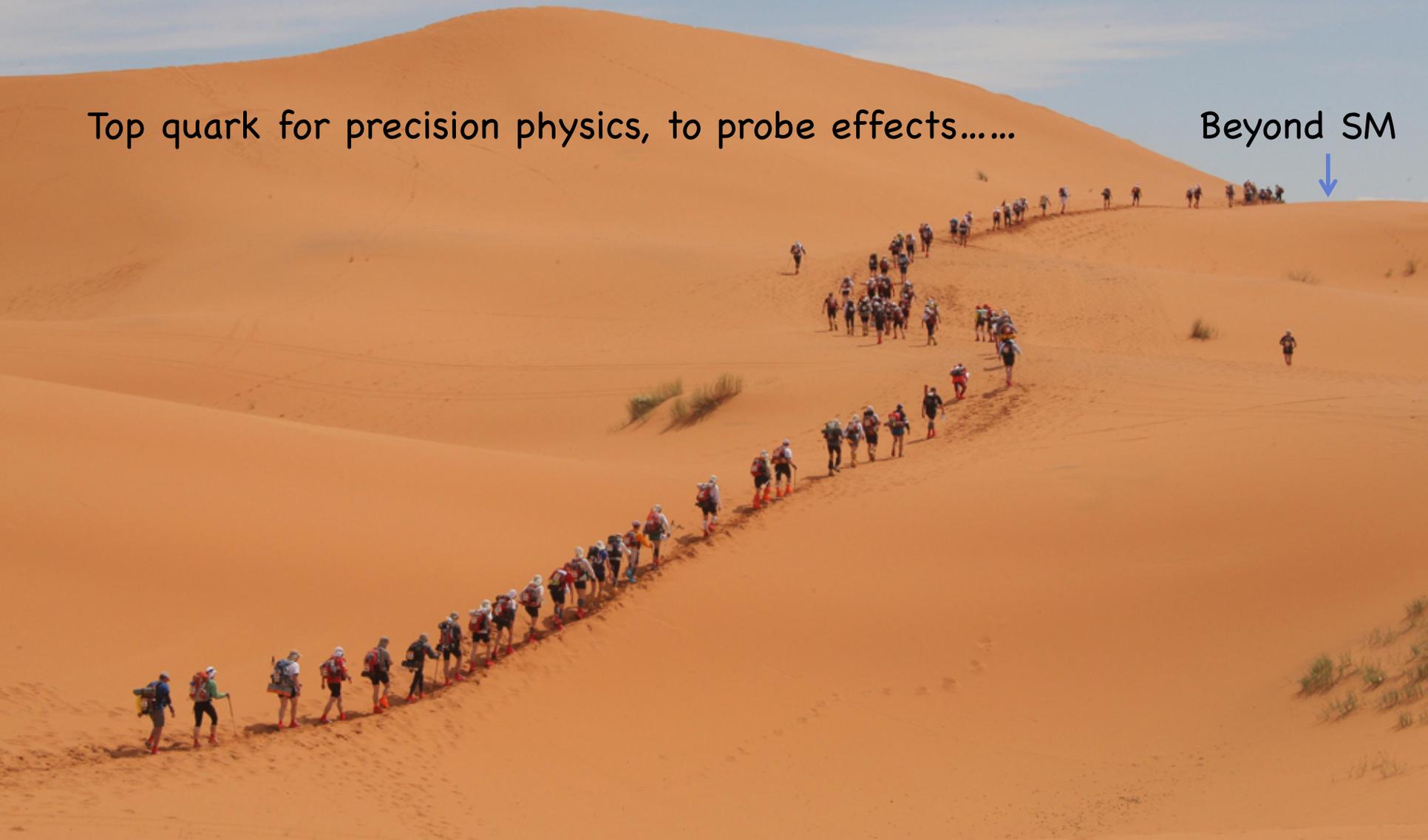


Standard Model stable to $10^{10} - 10^{12}$ GeV

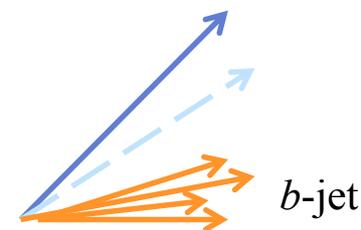
See also G. Isidori, V. S. Rychkov, A. Strumia,
and N. Tetradis, Phys. Rev. D77, 025034 (2008)

Top quark for precision physics, to probe effects.....

Beyond SM



- Introduction to ATLAS top measurements
- Top mass measurements ← Most important of many intrinsic properties
- Top Quark pair production:
 - Cross section
 - Polarization and Spin correlations
- Electroweak production
 - Single top cross section
- Searches for resonances with t
- $t\bar{t}$ + jets



← Investigating the production mechanisms

*This talk covers only **some** of the Top physics results achieved by the ATLAS Collaboration.*

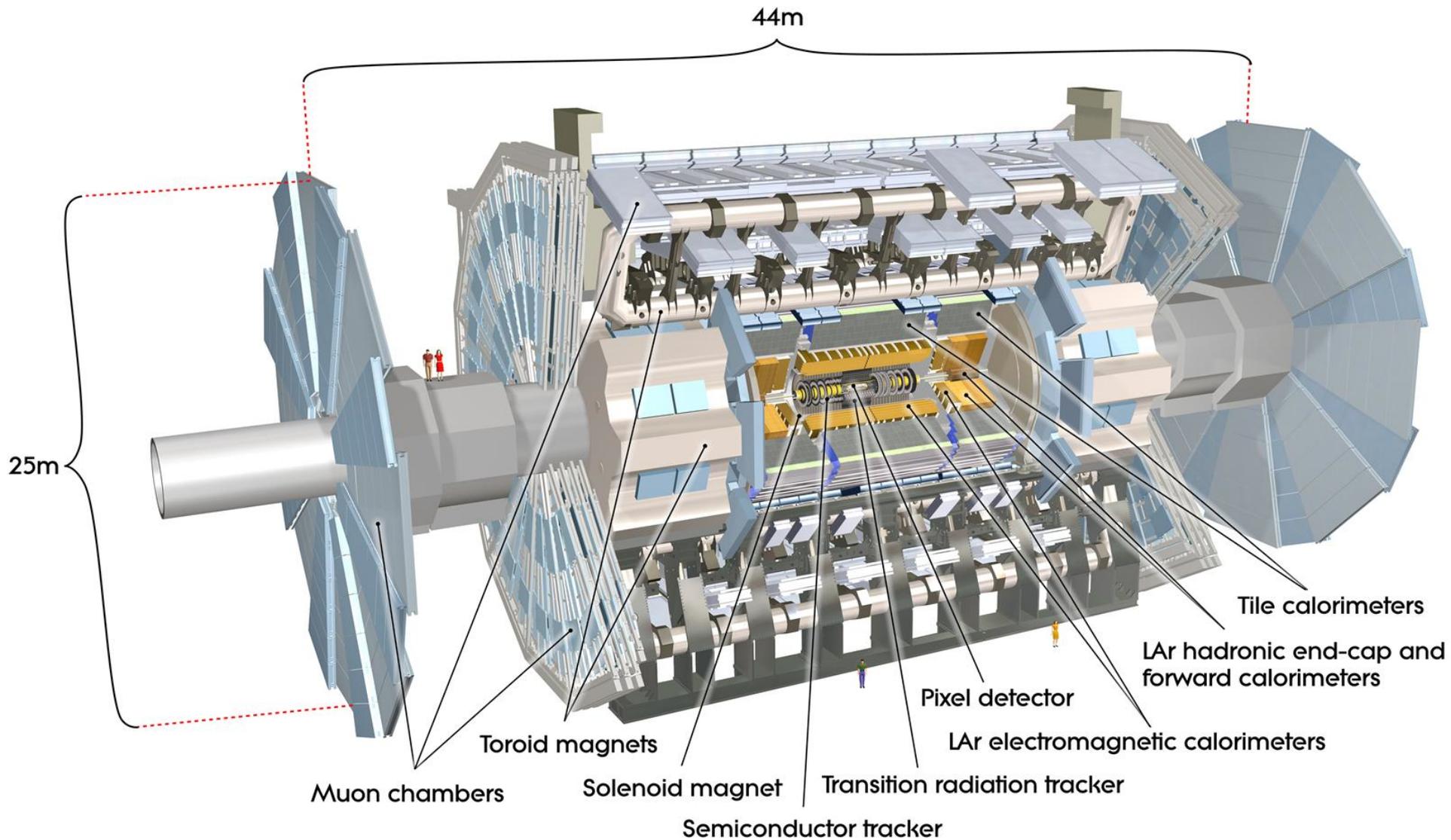
Please visit

<https://twiki.cern.ch/twiki/bin/view/AtlasPublic/TopPublicResults>

for the full list. In this talk most results are from 7 TeV data, with two 8 TeV results

Emphasis given to most recent results

The ATLAS detector



Top properties in pair production mode
 General distinction according to the W^\pm pairs decay modes (from P.D.G.)

All hadronic 45.7% ← high background
 $e^\pm \nu_e + \text{jets}$ 14.53 % }
 $\mu^\pm \nu_\mu + \text{jets}$ 14.29 % } Most results from these
“lepton+jets”

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

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

Top Pair Decay Channels

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

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

Dilepton channel

Latest ATLAS result from 7 TeV data in the $ee/\mu\mu/e\mu$ decay channel with full 7 TeV statistics

Use of transverse mass:

- 1) Pair lepton and b-jet
- 2) Calculate their “visible” invariant mass
- 3) Split the missing transverse momentum in two possible “neutrinos”
- 4) Calculate the transverse mass for each neutrino pt value
- 5) Take the minimum of the two
- 6) Take the minimum over the lepton and b-jet pairing. This is the transverse mass m_T in case of 2 neutrinos (m_{T2})

Most recent analysis

$$m_{top} = 175.2 \pm 1.6(stat.)^{+3.1}_{-2.8}(syst.) pb$$

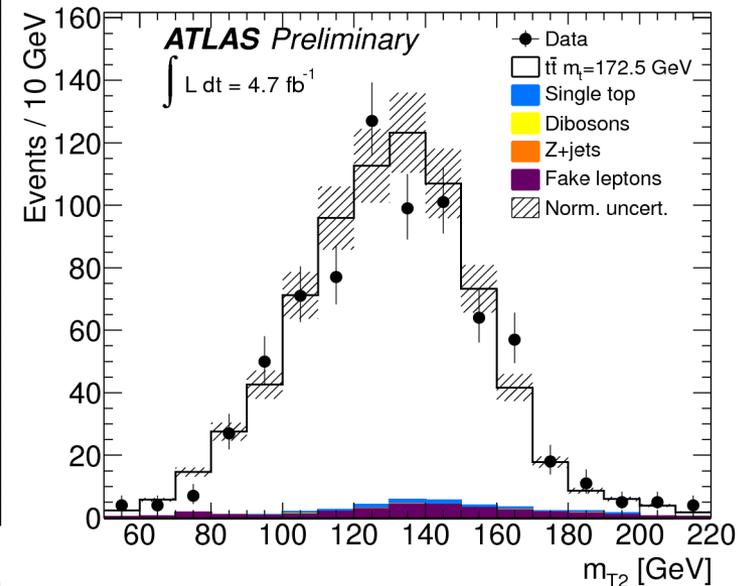
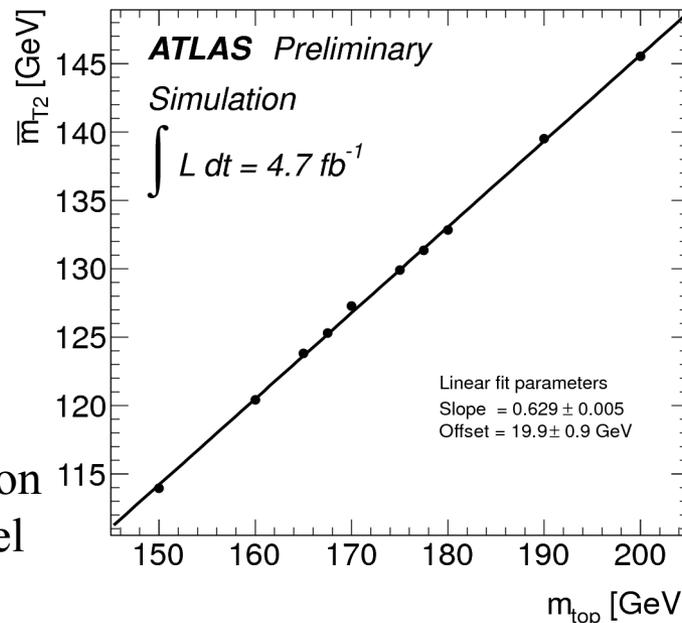
ATLAS-CONF-2012-082

Calibration
with MonteCarlo

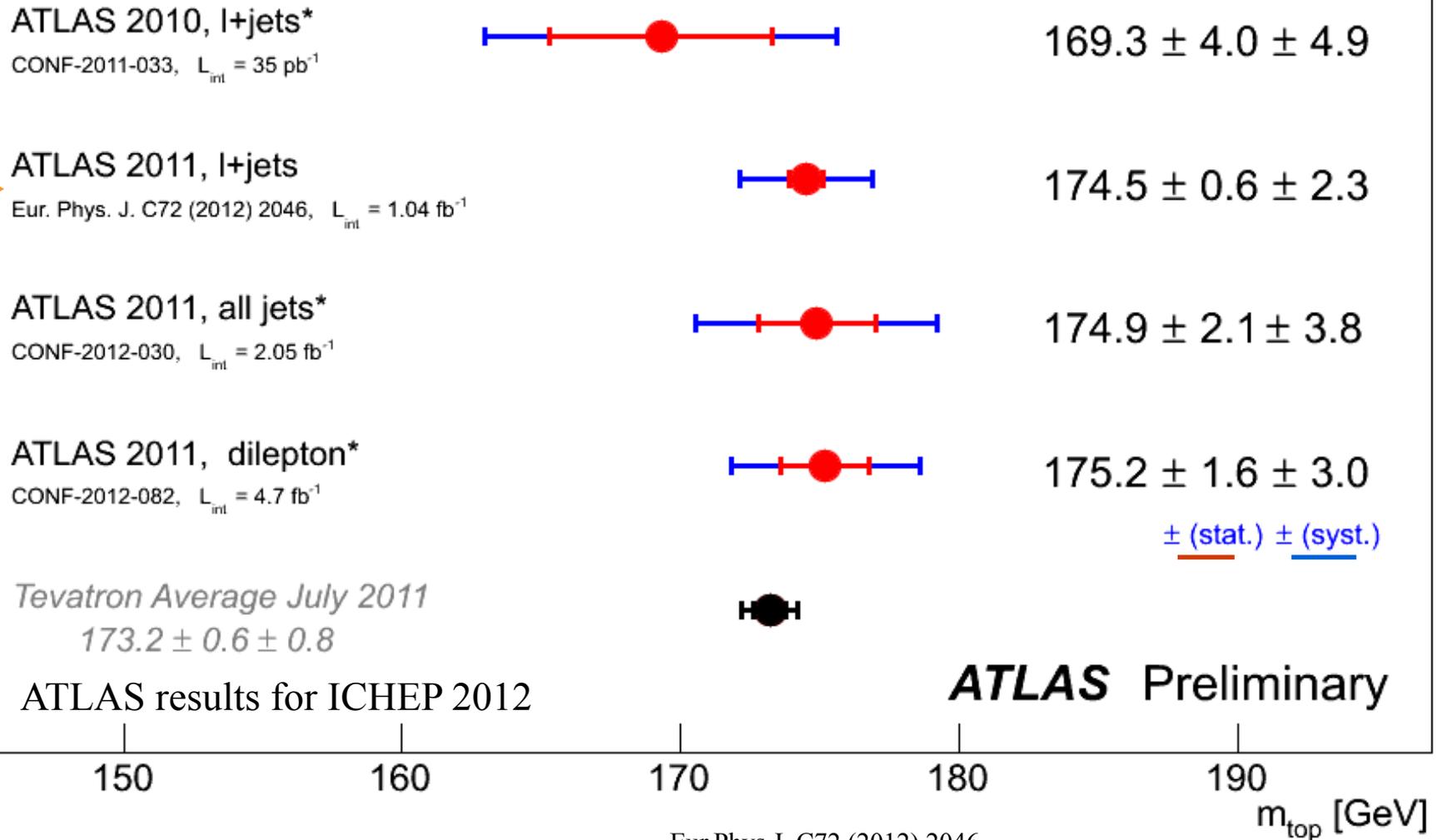
Require
2 b-tagged jets

Main Systematics

- Jet Energy Scale
- b-jet E.S.
- Colour reconnection
- Monte Carlo model



ATLAS m_{top} summary - July 2012, $L_{\text{int}} = 35 \text{ pb}^{-1} - 4.7 \text{ fb}^{-1}$ (*Preliminary)



Most precise analysis so far:

Eur.Phys.J. C72 (2012) 2046
 $m_{\text{top}} = 174.5 \pm 0.6 \text{ (stat.)} \pm 2.3 \text{ (syst.) GeV}$

Top pair cross section measurement in the lepton+jets channel at 8 TeV top quark decay

ATLAS-CONF-2012-149

Event Selection

Electron $E_T > 40$ GeV Muon $p_T > 40$ GeV, no second lepton in event ($p_T > 25$ GeV)

$E_T > 30$ GeV and $m_T(W) > 30$ GeV (for e+jets)

$E_T > 20$ GeV and $m_T(W) + E_T > 60$ GeV (for μ +jets)

Number of jets in event ≥ 3 , each with $p_T > 25$ GeV, at least one of them b -tagged

Data Analysis

Binned max likelihood fit to a d.f.

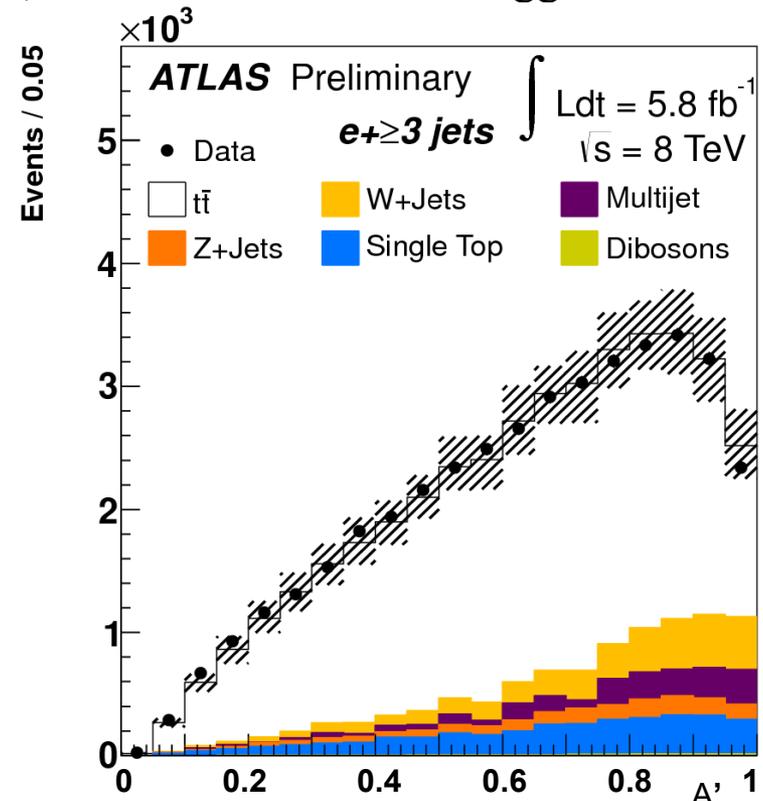
Discriminant function based on lepton η and transformed aplanarity $A' = \exp(-8A)$,

where $A = 3/2\lambda_3$,

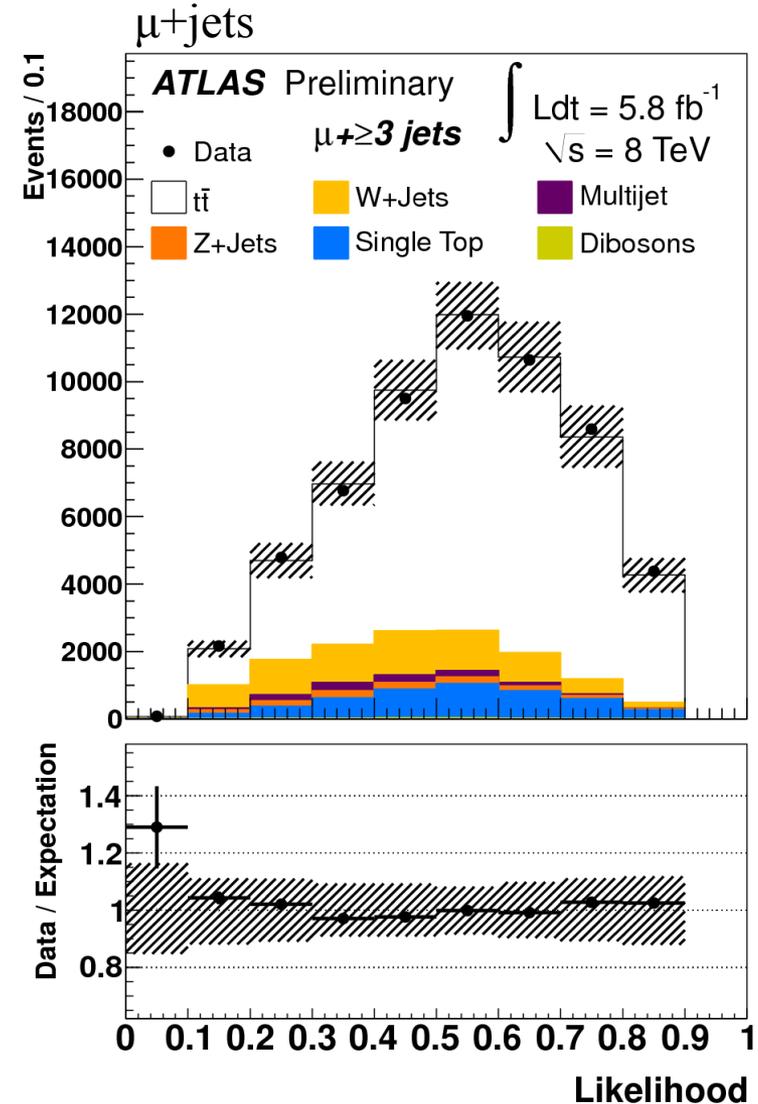
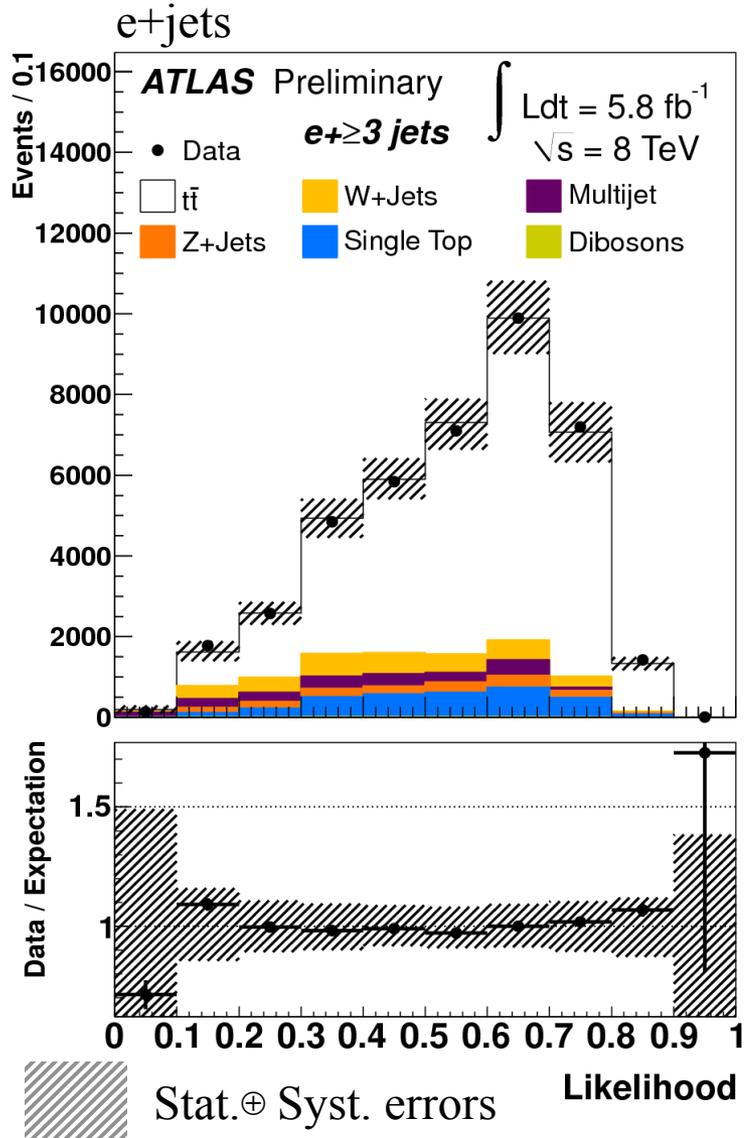
λ_3 smallest eigenvalue of the sphericity tensor.

| Channel | $N_{t\bar{t}}$ | $\sigma_{t\bar{t}}$ (pb) |
|-------------------|-----------------|--------------------------|
| $e+\geq 3$ jets | 31050 ± 350 | 239 ± 3 |
| $\mu+\geq 3$ jets | 45000 ± 400 | 242 ± 2 |
| $l+\geq 3$ jets | 76000 ± 500 | 241 ± 2 |

(Stat errors only)



Fit to the likelihood discriminant distribution $D(\eta_l, A')$ in data at 8 TeV



ATLAS-CONF-2012-149

Systematic errors

| Source | $e+ \geq 3 \text{ jets}$ | $\mu+ \geq 3 \text{ jets}$ | combined |
|---|--------------------------|----------------------------|-------------|
| Jet/MET reconstruction, calibration | 6.7, -6.3 | 5.4, -4.6 | 5.9, -5.2 |
| Lepton trigger, identification and reconstruction | 2.4, -2.7 | 4.7, -4.2 | 2.7, -2.8 |
| Background normalization and composition | 1.9, -2.2 | 1.6, -1.5 | 1.8, -1.9 |
| b-tagging efficiency | 1.7, -1.3 | 1.9, -1.1 | 1.8, -1.2 |
| MC modelling of the signal | ± 12 | ± 11 | $\pm 11 \%$ |
| Total | $\pm 14 \%$ | $\pm 13 \%$ | $\pm 13 \%$ |

Monte Carlo modeling:

| | |
|---|----|
| Production process: MC@NLO vs. POWHEG vs. ALPGEN: | 6% |
| Initial/Final state radiation ACERMC+PYTHIA parameters: | 4% |
| Parton Distribution Functions | 6% |
| Parton shower model: POWHEG+PYTHIA vs. POWHEG+HERWIG | 6% |

ATLAS-CONF-2012-149

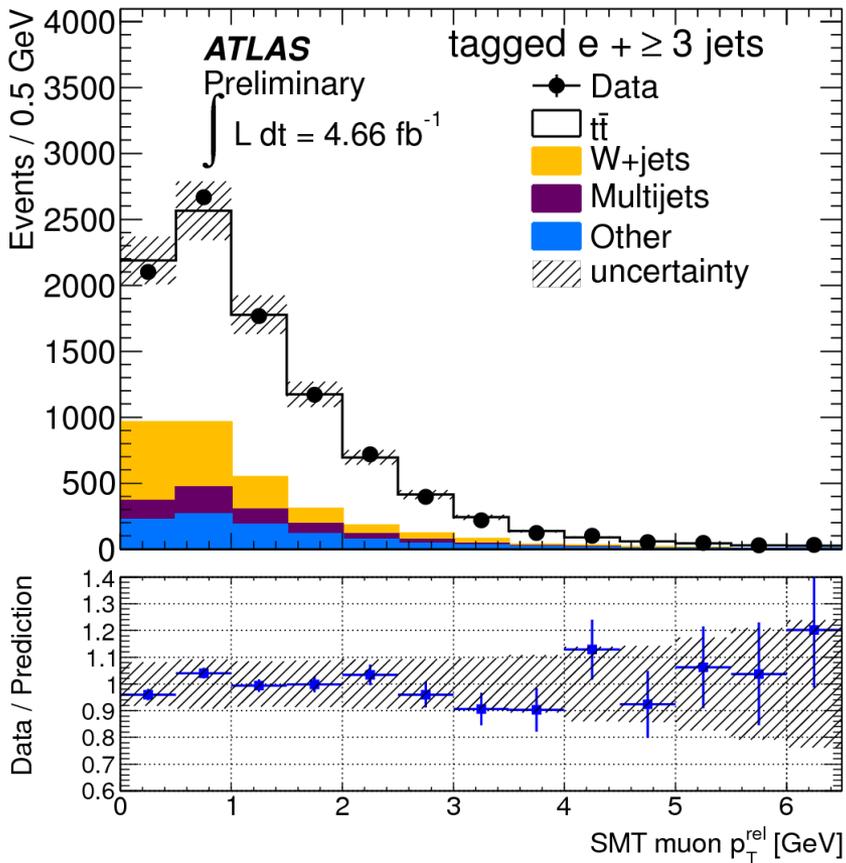
ATLAS cross section preliminary result at 8 TeV:

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

Theoretical prediction $\sigma_{th} = 238_{-24}^{+22} \text{ pb}$ M. Aliev et al., *HATHOR*

Top pair cross section at 7 TeV

ATLAS-CONF-2012-131



Recent analysis at 7 TeV

- Lepton+jets W's decay channel
- **Semi-leptonic B decays to identify b-jets.**
- Better luminosity determination
- b-tagging systematics non correlated with other cross section measurements (and smaller).

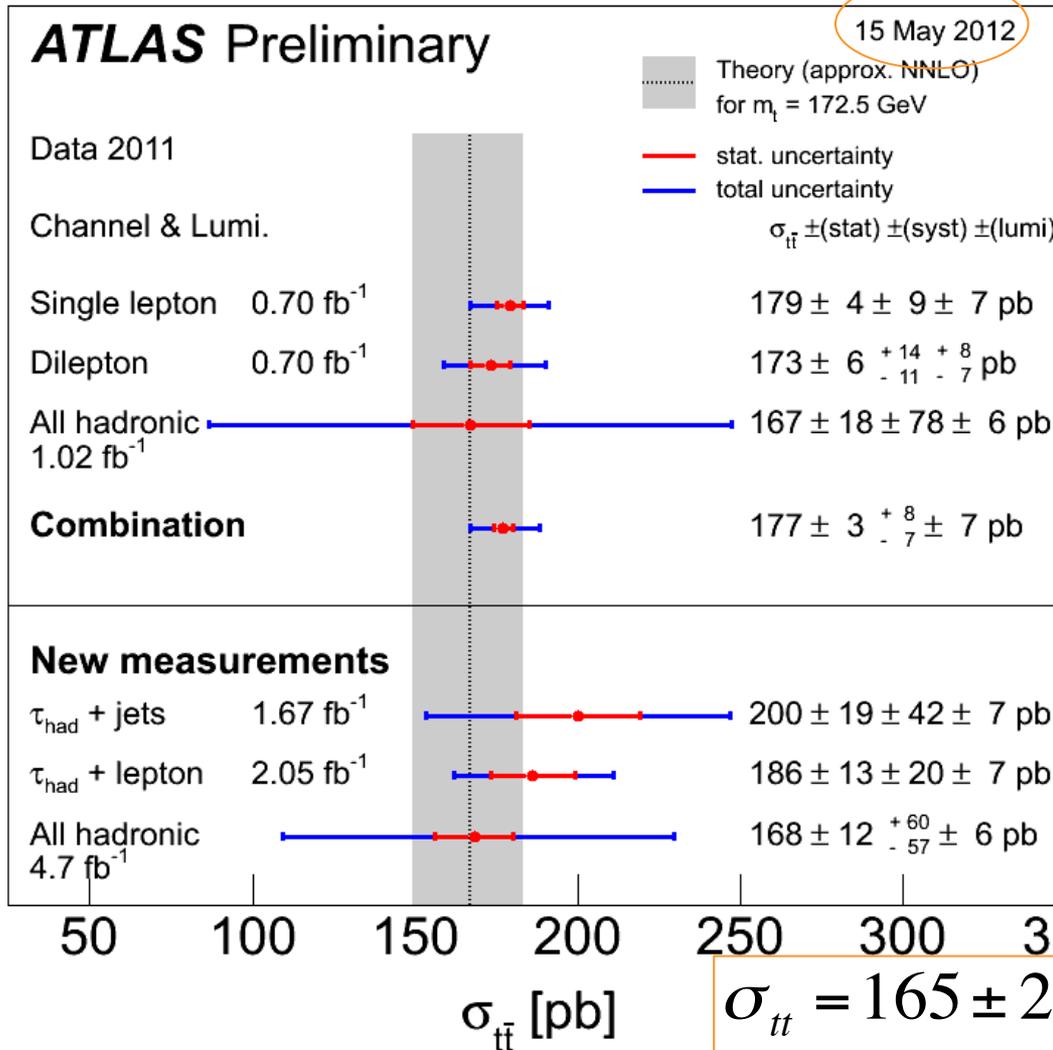
Recent ATLAS cross section result at 7 TeV:

$$\sigma_{t\bar{t}} = 165 \pm 2(\text{stat.}) \pm 17(\text{syst.}) \pm 3(\text{lumi.}) \text{ pb}$$

Cross section summary results at 7 TeV (.....where σ (pb) \approx m(GeV) !! ☺)

Top pair cross section at 7 TeV c.m.e.

ATLAS summary



M. Aliev, H. Lacker, U. Langefeld, S. Moch, and P. Uwer: HATHOR, Comput. Phys. Commun. 182 (2011) 10341046

Dilepton JHEP 1205 (2012) 059

Dilepton Phys.Lett. B707 (2012) 459-477

All hadronic 1.02 fb-1 ATLAS-CONF-2011-140

Combination ATLAS-CONF-2012-024

$\tau_{\text{had}} + \text{jets}$ ATLAS-CONF-2012-032

e/ μ + $\tau_{\text{had}} + \text{jets}$ Phys.Lett. B717 (2012) 89-108

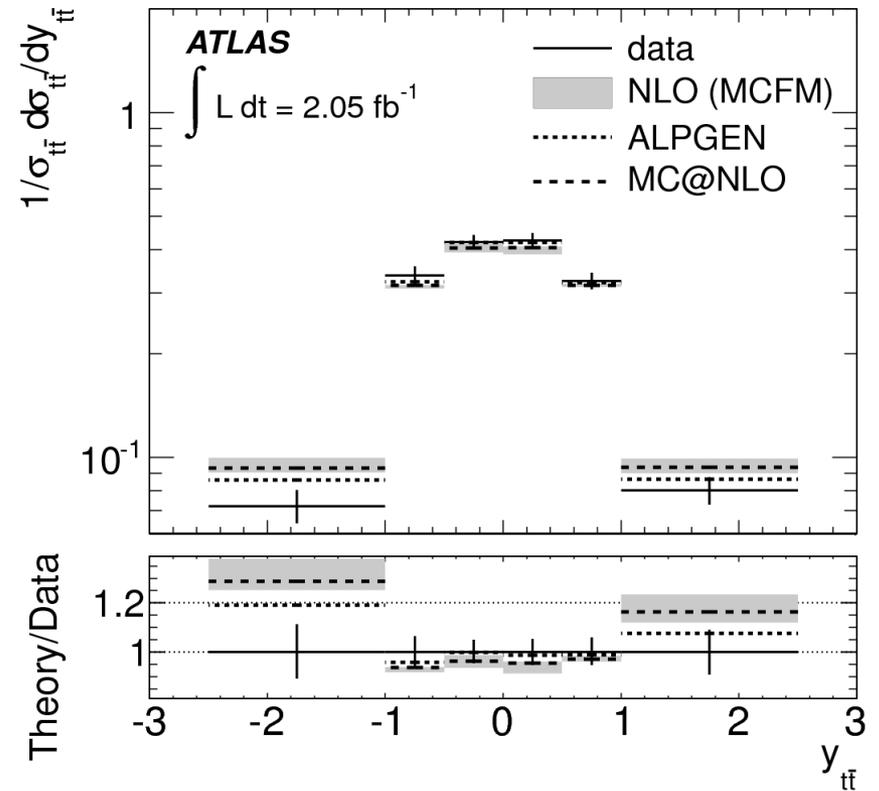
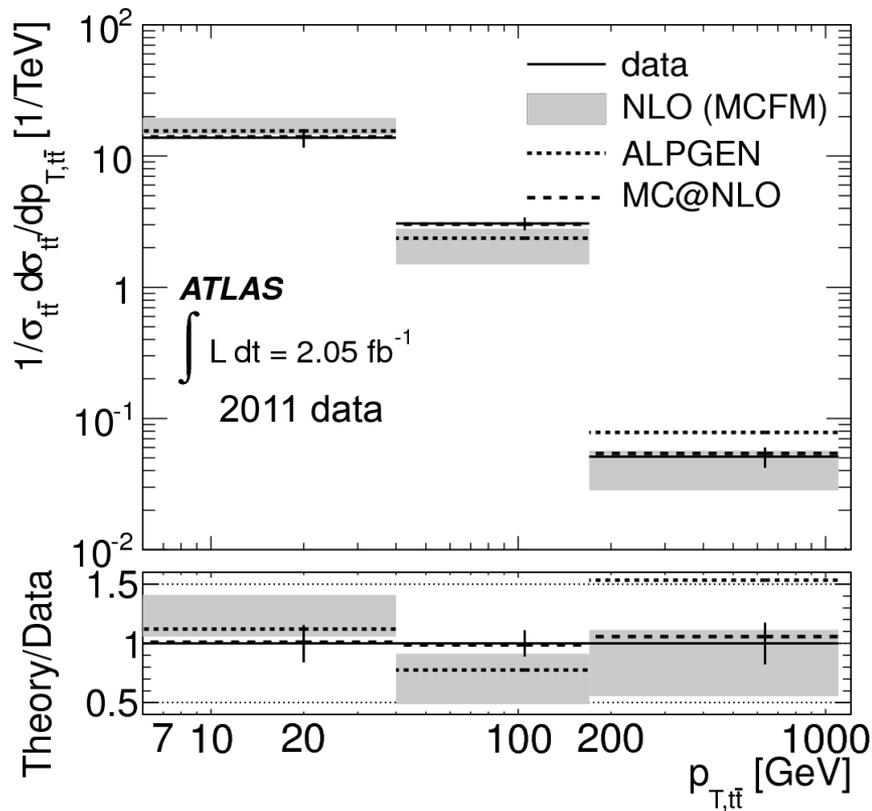
All hadronic ATLAS-CONF-2012-031

Not included in this plot:

$$\sigma_{t\bar{t}} = 165 \pm 2(\text{stat.}) \pm 17(\text{syst.}) \pm 3(\text{lumi.}) \text{ pb}$$

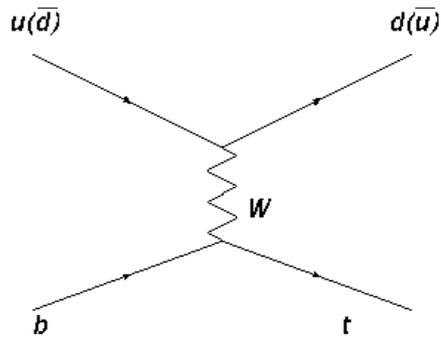
Differential top cross section

Lepton (e,μ) + jets @ 7 TeV



arXiv:1207.5644

Unfolded distributions, response matrix inversion (no need of regularization)
 No deviation from standard model expectations.

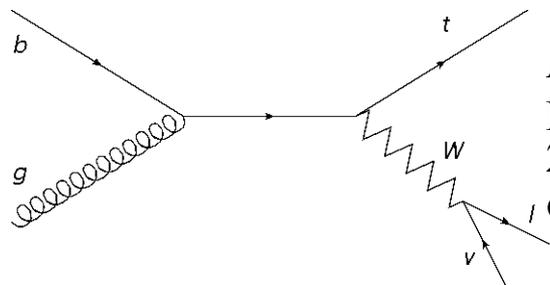


t-channel cross section:
 Physics Letters B 717 (2012) 330
 ATLAS-CONF-2012-132 (8TeV)

cross section in t-channel,
ratio top/antitop, 4.7 fb^{-1}
 ATLAS-CONF-2012-056

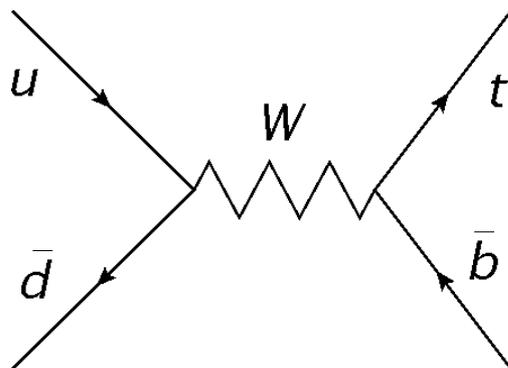
Only one *b*-jet (from top)

Using neural network
 Decay of *W* (from top) to *l v*



Associated *Wt* production
 Phys.Lett. B716 (2012) 142-159
 2.05 fb^{-1}
 $\sigma_{Wt} = 16.8 \pm 2.9(\text{stat}) \pm 4.9(\text{syst}) \text{ pb}$

Only one *b*-jet in event
 High p_T leptons from $W \rightarrow l\nu$
 $E_T > 50 \text{ GeV}$ (no *b*-tagging:
 Main background from *tt*)

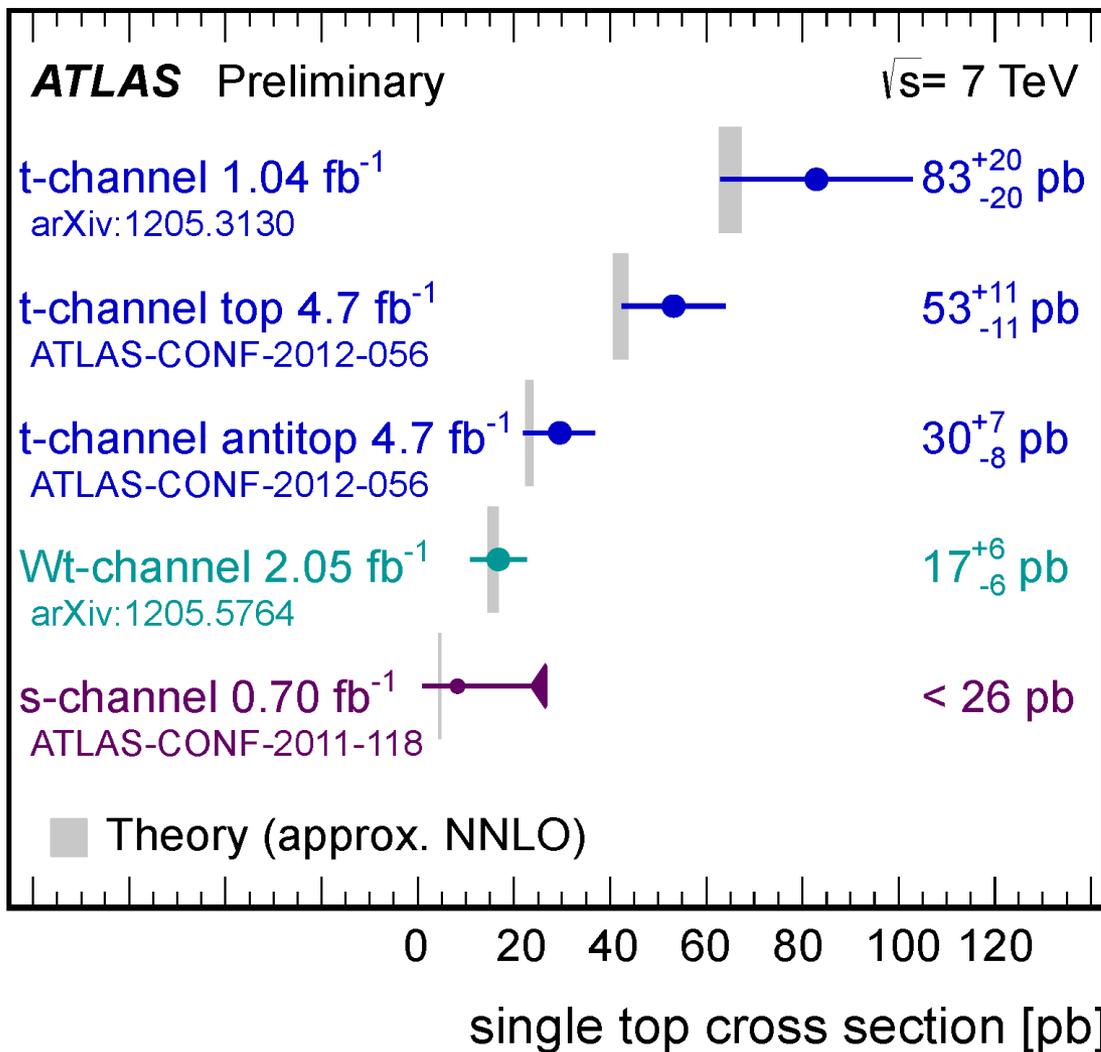


Search for s-channel
 ATLAS-CONF-2011-118
 0.7 fb^{-1}

Signature: two *b*-jets:
 One from *b*, other from top
 Just one high- p_T lepton from *W*
 Same structure as *WH*, $H \rightarrow bb$
Not observed so far.
W+jets & *tt* main background

Direct measurements of $|V_{tb}|$ CKM
 $|V_{tb}| > 0.80 @ 95 \% \text{ CL}$, $|V_{tb}| = 1.04^{+0.10}_{-0.11}$

from ATLAS-CONF-2012-132



t-channel cross section:
Physics Letters B 717 (2012) 330

σ in t-channel,
ratio top/antitop, with 4.7 fb⁻¹
ATLAS-CONF-2012-056

Associated Wt production
Phys.Lett. B716 (2012) 142-159

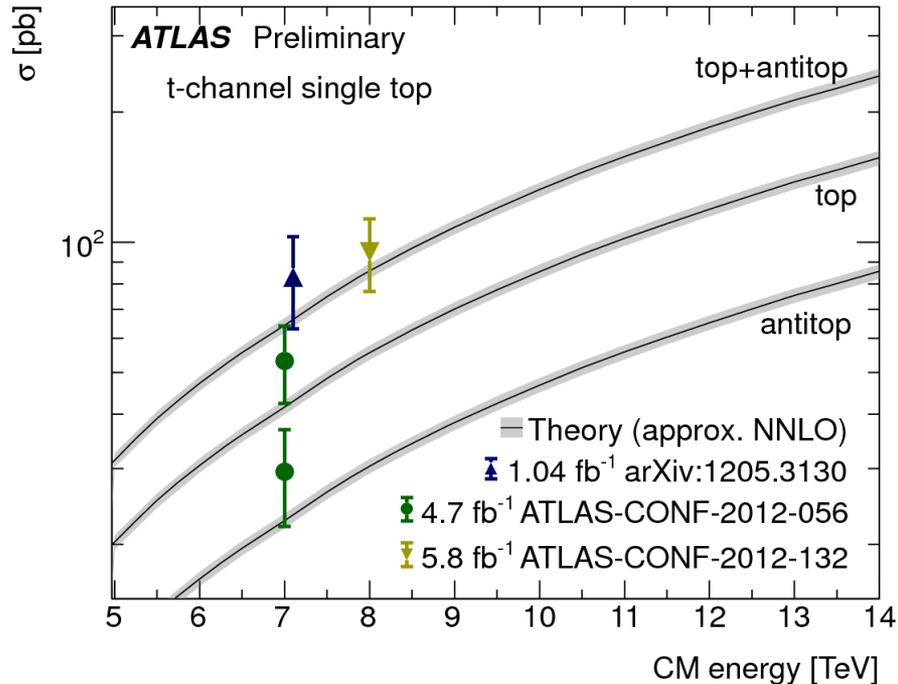
Search for s-channel
ATLAS-CONF-2011-118

NNLO theory: N. Kidonakis,
Phys. Rev. D 83 (2011) 091503

t-channel, 5.8 fb⁻¹ @ 8 TeV

ATLAS-CONF-2012-132

$\sigma_t = 95 \pm 2(\text{stat.}) \pm 18(\text{syst.}) \pm 3(\text{lumi.}) \text{ pb}$



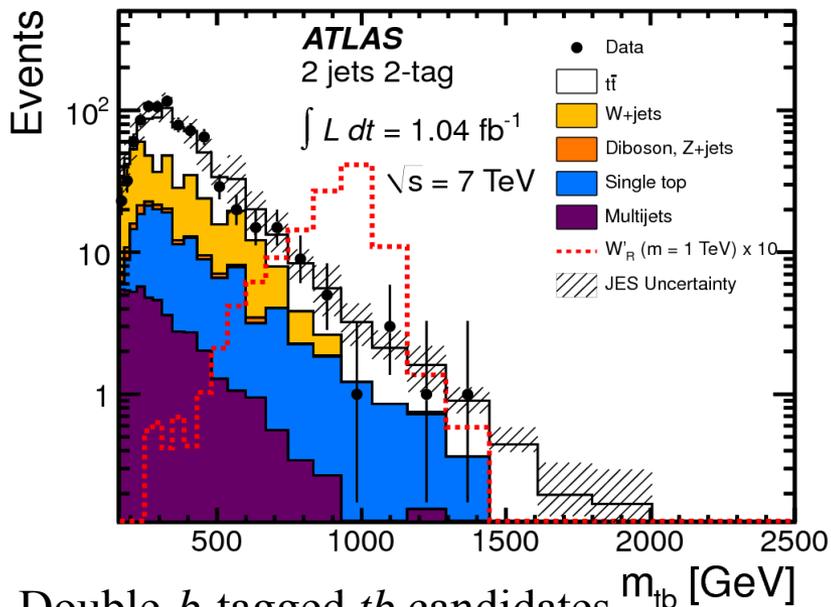
t-channel, 5.8 fb⁻¹ @8 TeV Theory value 87.8^{+3.4}_{-1.9} pb
 ATLAS-CONF-2012-132
 $\sigma_t = 95 \pm 2(\text{stat.}) \pm 18(\text{syst.}) \pm 3(\text{lumi.}) \text{ pb}$

Top decay to lepton+jets,
 includes leptonic decays of τ
 Require just one lepton in the event
 $E_T(e)$ or $p_T(\mu) > 25 \text{ GeV}$, $E_t^{\text{miss}} > 30 \text{ GeV}$
 Isolation on lepton tracks
 Jet vertex fraction $> 50\%$
 b -tagging required
 $M_T(W) > 50 \text{ GeV}$

Neural network used, dividing data (and MC) in 2-jet and 3-jet sub samples.
 Example variables:

- Invariant mass of b-tagged jet and untagged jet (2-jet sub sample)
- Invariant mass of two leading jets (3-jet sub sample)
- top mass from lepton, neutrino and E_T^{miss}

lepton + b-jet top channel, 7 TeV



Double-*b*-tagged *tb* candidates m_{tb} [GeV]

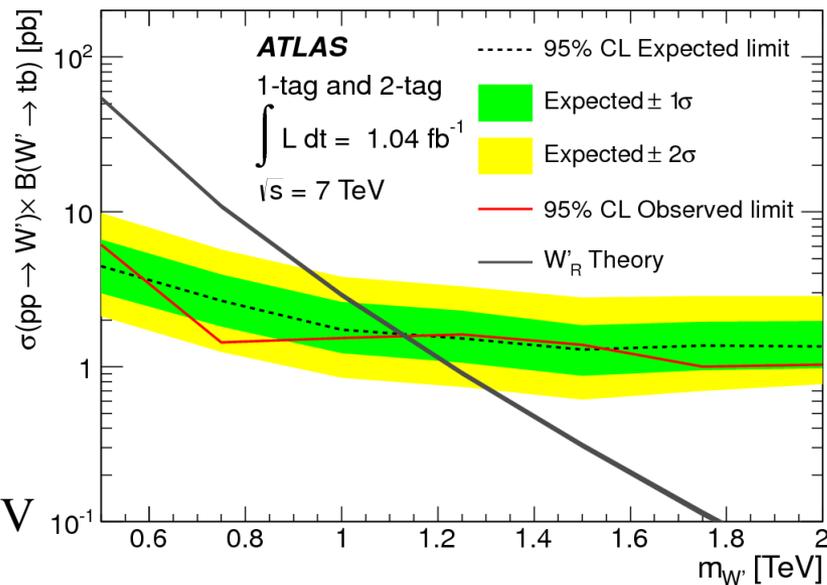
W' excluded with $\sigma \times \mathcal{BR} < 6.1-1.0$ pb for $0.5 < m(W'_R) < 2.0$ TeV
 $m(W'_R) > 1.13$ TeV at 95% CL.

Search for $W' \rightarrow tb$

Dominant backgrounds:

tt pair production and W +jets

[Phys.Rev.Lett. 109 \(2012\) 081801](https://arxiv.org/abs/1108.3591)



Fully hadronic decays, $\sqrt{s} = 7\text{TeV}$, 4.7 fb^{-1}

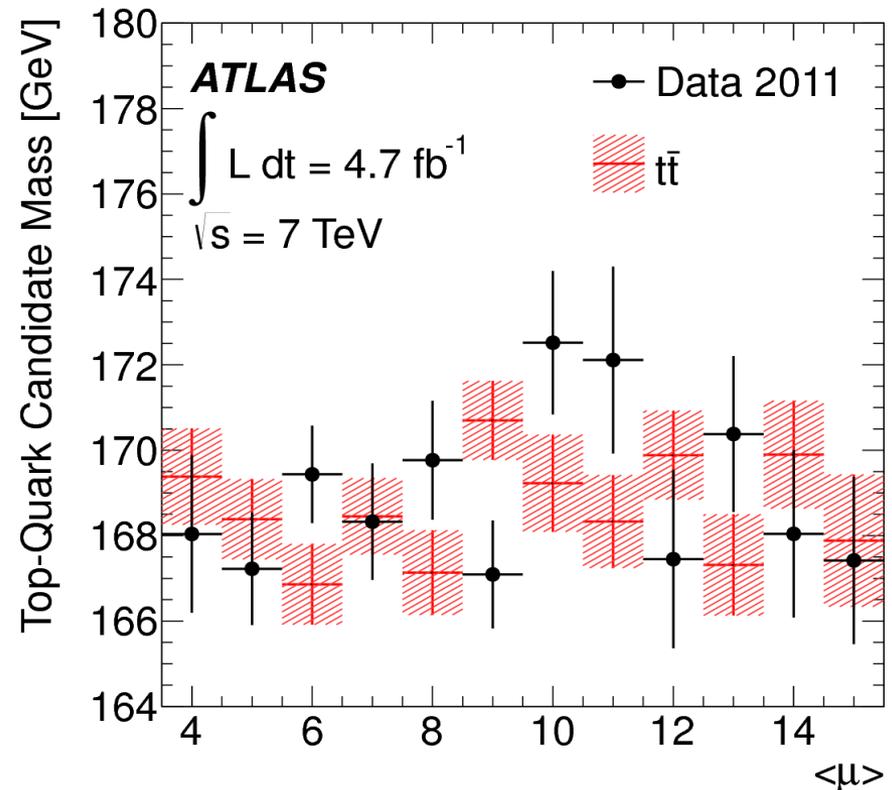
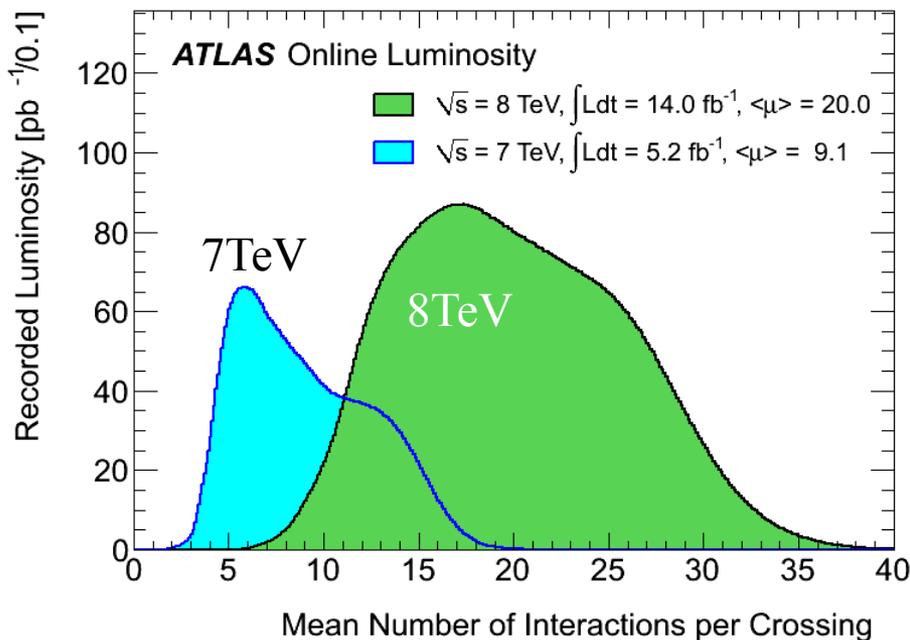
Effects of pile up events under control.

Hadronic top mass as a function of the pile-up (control plot)

2011 data $\langle\mu\rangle \leq 15$

“Jet vertex fraction” used to limit the effects: % of the total momentum which must come from tracks associated to the same event vtx

Use fat-jet definition (see later)



Fully hadronic decays, $\sqrt{s} = 7\text{TeV}$, 4.7 fb^{-1}

HEPTopTagger: Fat-jets: **Reconstructed with C/A algorithm, $R=1.5$**

TopTemplateTagger: anti- \vec{k}_T algorithm, $R=1.0$

comparison with patterns of energy deposition from MC decays.

Trigger for hadronic top: (all using anti- k_T)

HEPTopTagger

- $E_T(\text{jet}) > 100 \text{ GeV}$ && $\Sigma E_T > 350$ (later data: 400) GeV ||
- $N_{\text{jets}} \geq 5$, $E_T(\text{jet}) > 30 \text{ GeV}$

TopTemplateTagger:

- at least 1 jet with $E_T > 240 \text{ GeV}$, anti- k_T , $R = 1.0$

Event selection

b-jets have $R=0.4$

HEPTopTagger requires ≥ 2 jets $p_T > 200 \text{ GeV}$ in $|\eta| < 2.5$; top jet – b-jet $\Delta R < 1.4$

TopTemplateTagger ≥ 2 Jets $p_T > 500$ and $450 \text{ GeV GeV}/c$, $|\eta| < 2$; top jet – b-jet $\Delta R < 1.0$

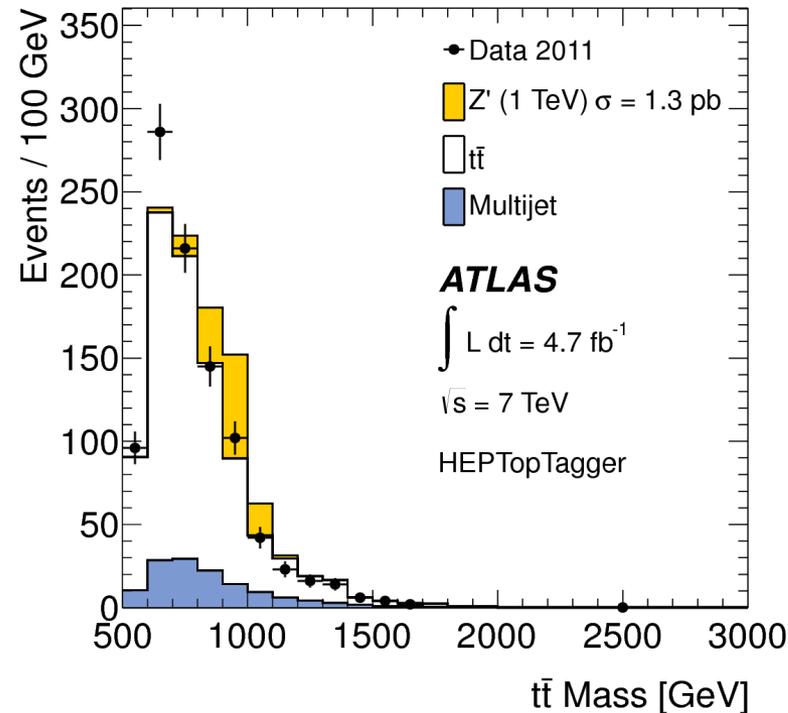
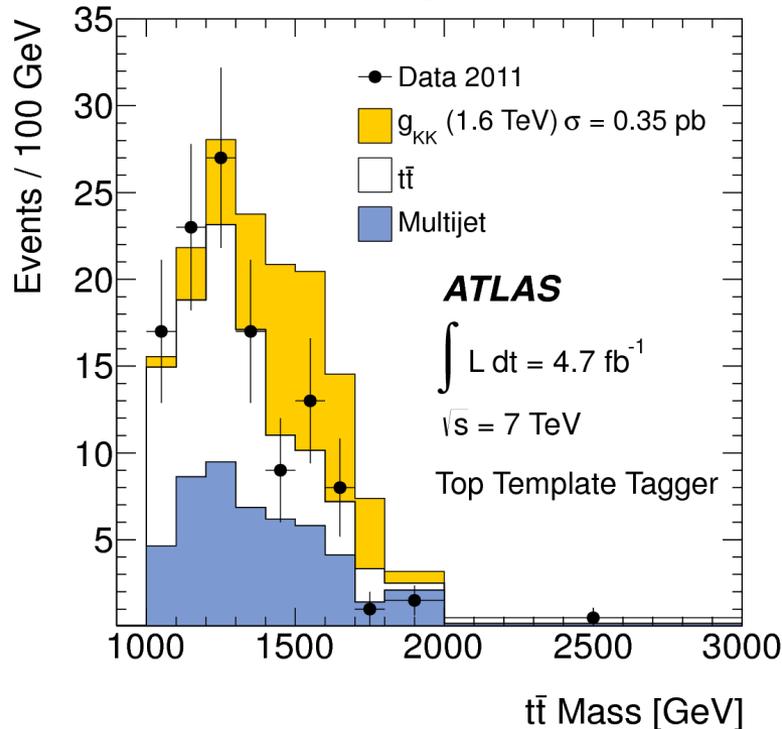
Jet Vertex fraction $> 75\%$

Lower cutoff on invariant mass.

Fully hadronic decays, $\sqrt{s} = 7\text{TeV}$, 4.7 fb^{-1}

No deviation from standard model.

Test against 2 hypothesis Kaluza-Klein gluon and leptophobic Z' , with narrow width.



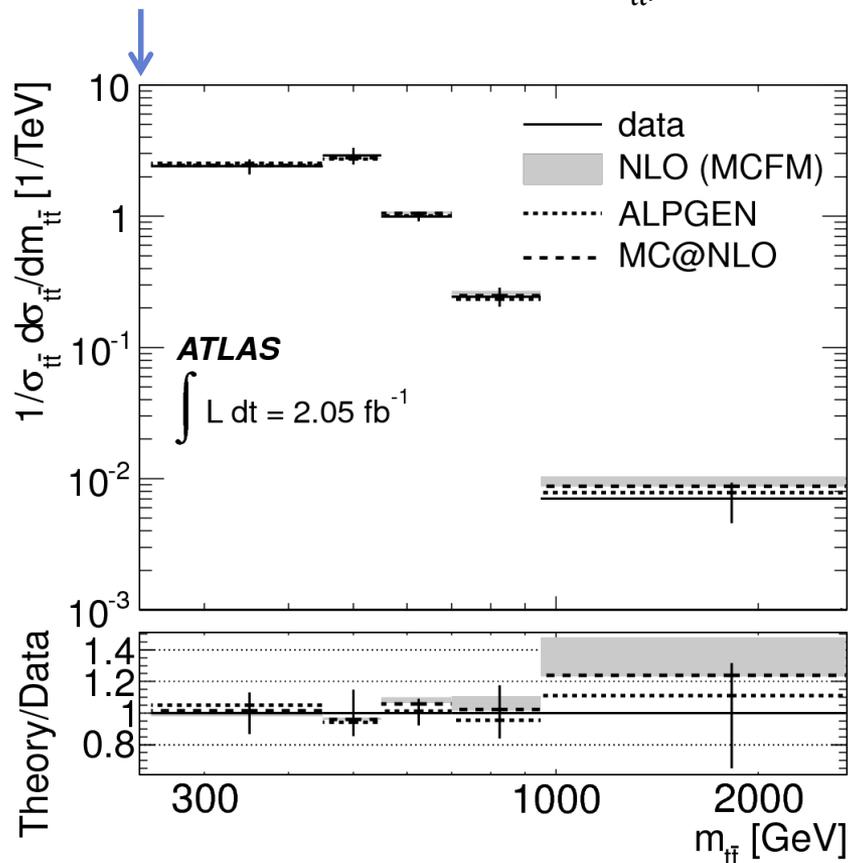
Excluded regions (95%CL):
 Z' 0.70– 1.00 TeV and 1.28–1.32 TeV
 KK gluons 0.70–1.62 TeV
 arXiv:1211.2202

Other ATLAS top analyses lepton+jets
 Eur. Phys. J. C 72 (2012) 2083 , JHEP 1209 (2012)
 Z' excluded 0.5–1.15 TeV
 KK gluons 0.5–1.5 TeV

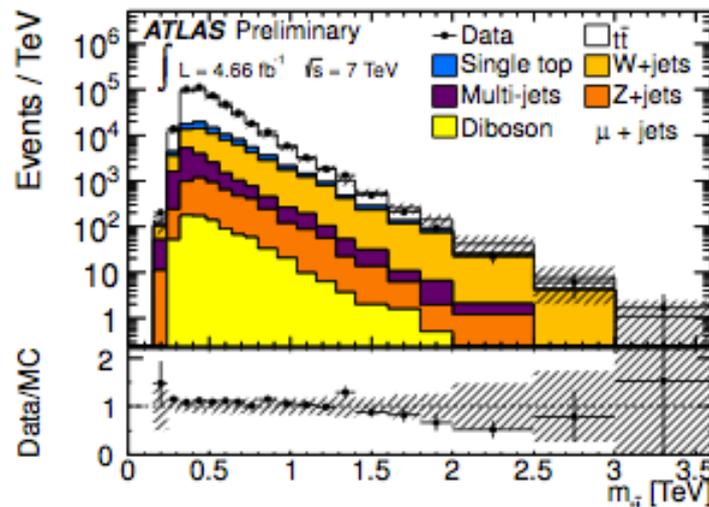
lepton+jets, $\sqrt{s} = 7\text{TeV}$

ATLAS-CONF-2012-136

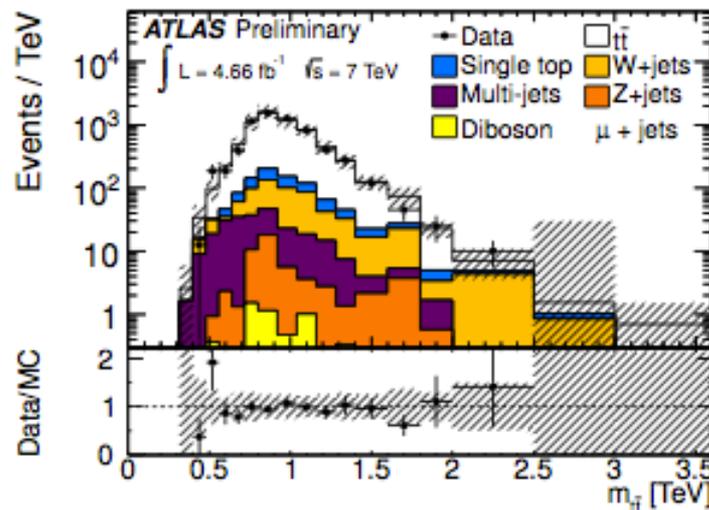
Differential cross section $d\sigma/dm_{t\bar{t}}$



No deviation from non-resonant production



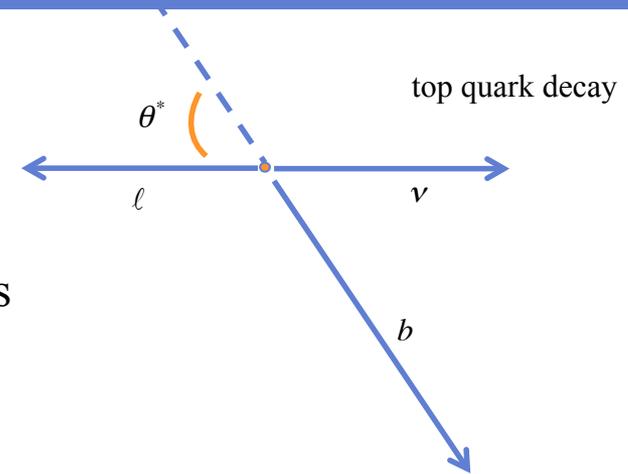
(b) μ +jets channel, resolved selection.



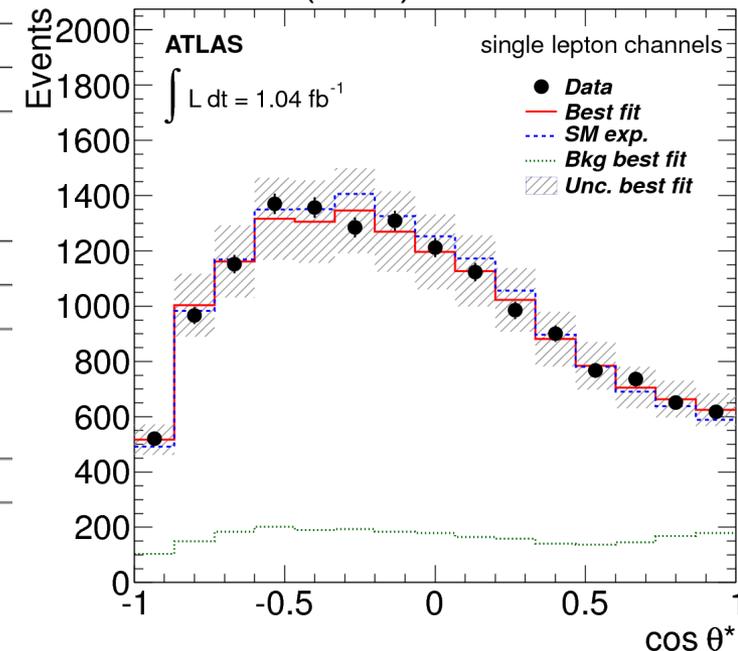
(d) μ +jets channel, boosted selection.

W decay helicity angle measured both in lepton+jets and two-leptons channels.
Two methods: template (fig.) and Angular asymmetries

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



JHEP 1206 (2012) 088

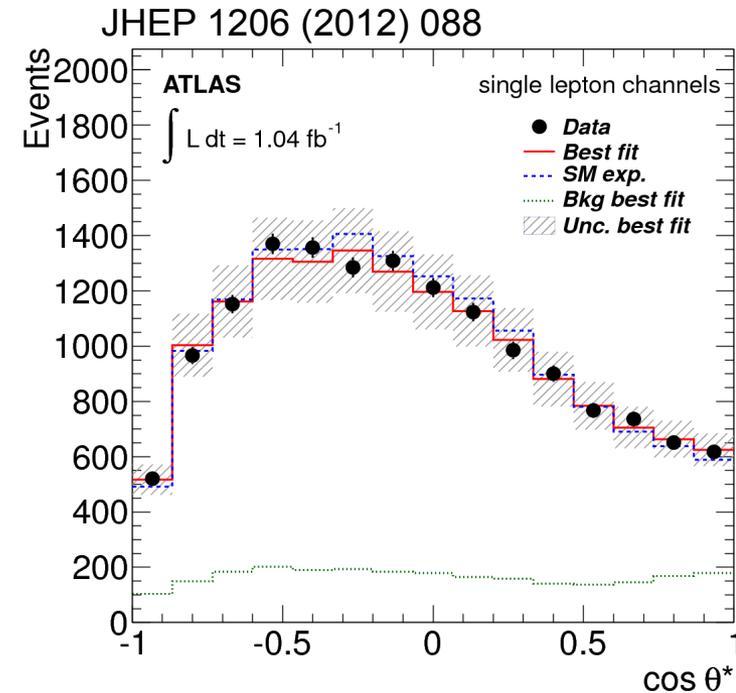
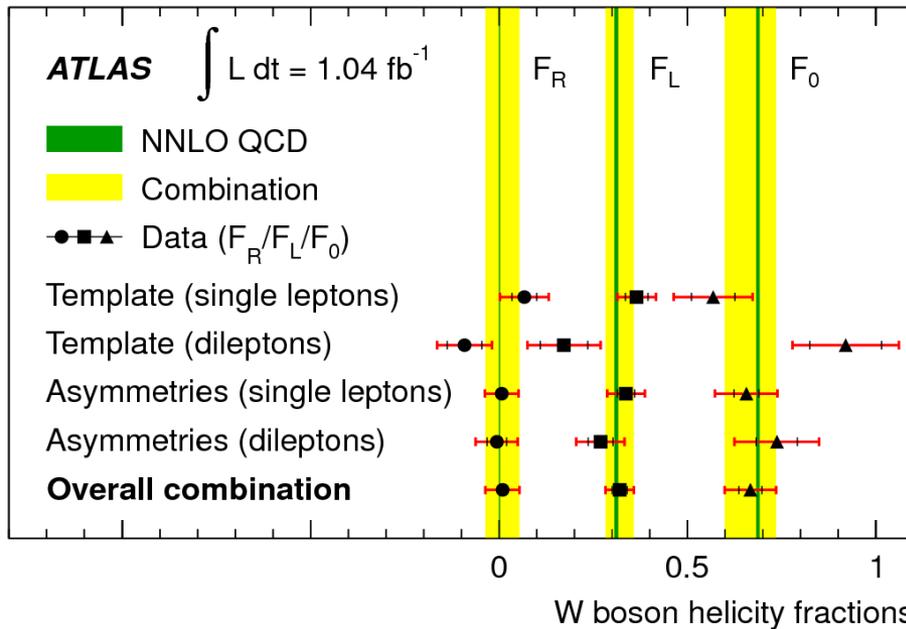
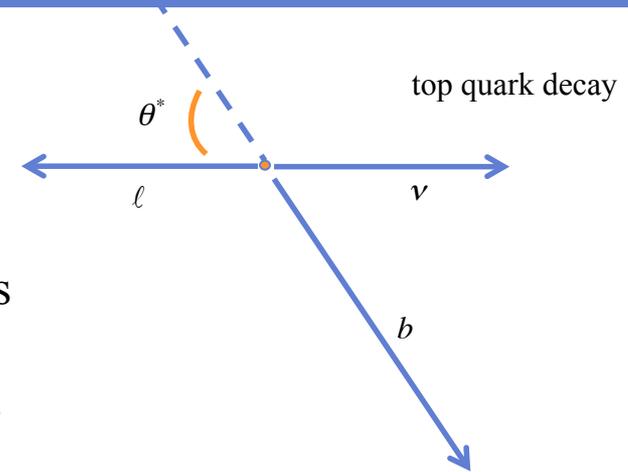


Best measurement so far,
no deviation from the standard model, agreement with
NLO QCD and with CMS, CDF and D0.

W decay helicity angle measured both in ℓ pton+jets and two-leptons channels.

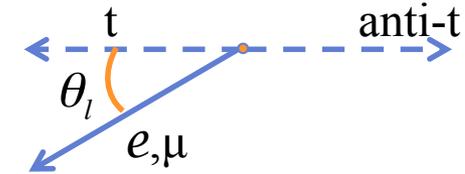
Two methods: template (fig.) and Angular asymmetries

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



Best measurement so far, no deviation from the standard model, agreement with NLO QCD and with CDF and D0.

top polarization measurement, 7 TeV, 4.66 fb⁻¹
lepton+jets sample, fully reconstructed decays to get
 axis: top direction in t-anti-t centre of mass frame
 Template method and asymmetry



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

$$\alpha_1 p = 2f - 1$$

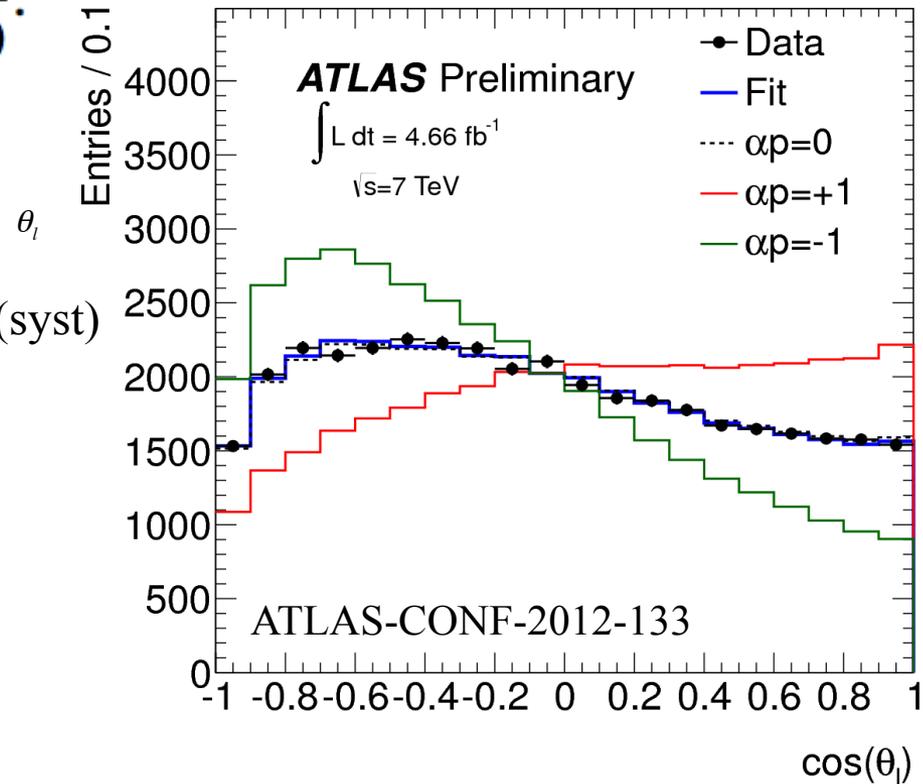
α_1 = spin analysing power = 1

p = degree of polarization

$$f (Fraction_+) = 0.470 \pm 0.009(\text{stat})^{+0.023}_{-0.032}(\text{syst})$$

Standard Model calculation 0.5

$$W(\cos \theta_i) \propto 1 + \alpha_i p \cos \theta_i,$$



Looking for correlations between top and anti-top in the dilepton top pairs.

g - g top pair production \rightarrow same helicity for t and \bar{t}
 $\Delta\phi$ angle between leptons (e/μ) in lab frame

Use helicity basis (top-pair rest frame) and “maximal basis”

Main systematics: fake leptons

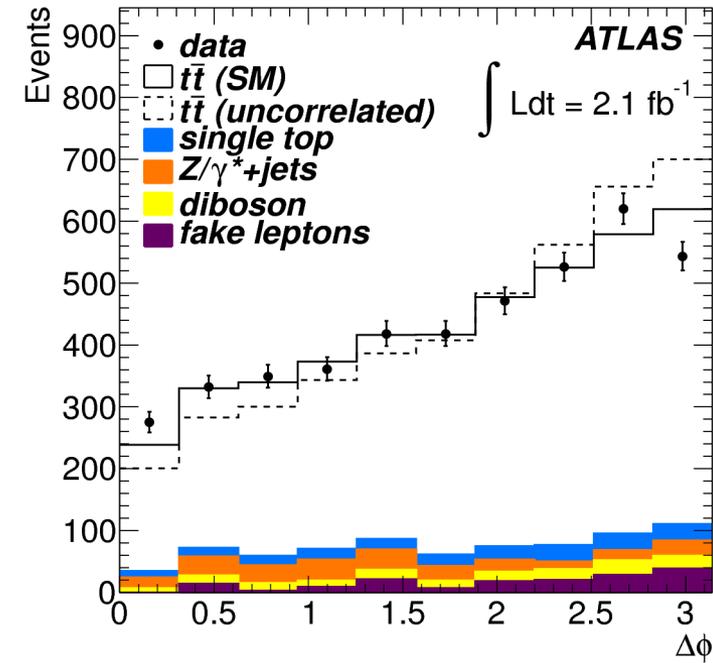
$$A_{\text{helicity}} = 0.40 \pm 0.04(\text{stat})^{+0.08}_{-0.07}(\text{syst})$$

$$A_{\text{maximal}} = 0.57 \pm 0.06(\text{stat})^{+0.12}_{-0.10}(\text{syst})$$

Standard model prediction

- $A_{\text{helicity}} = 0.31$
- $A_{\text{maximal}} = 0.44$

The hypothesis of uncorrelated production is excluded with a significance of 5.1 s.d.



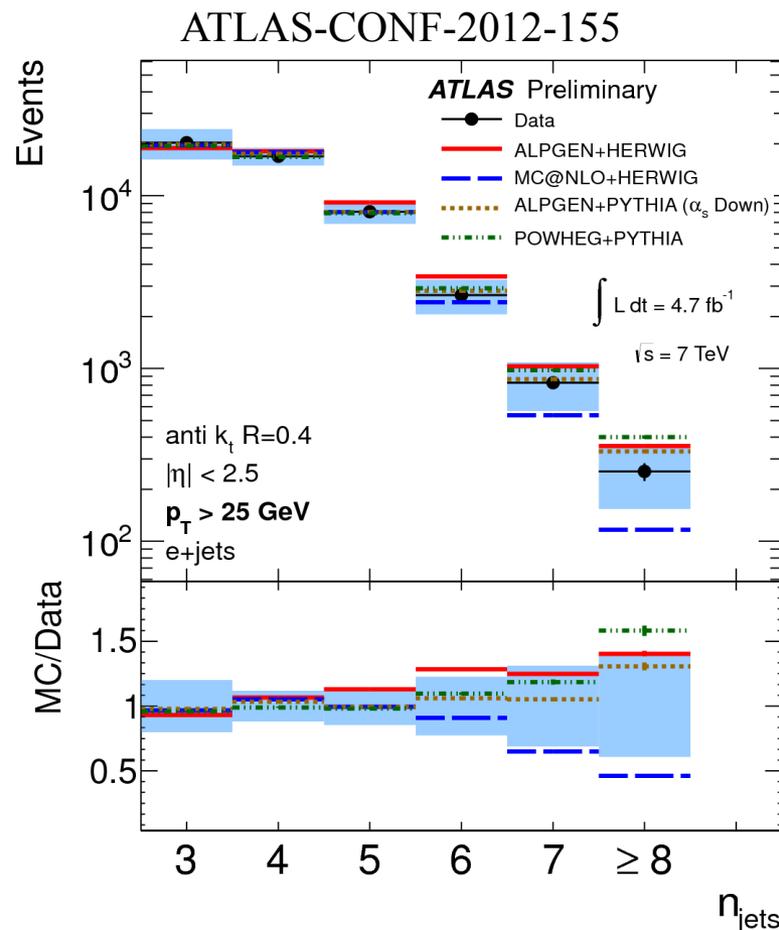
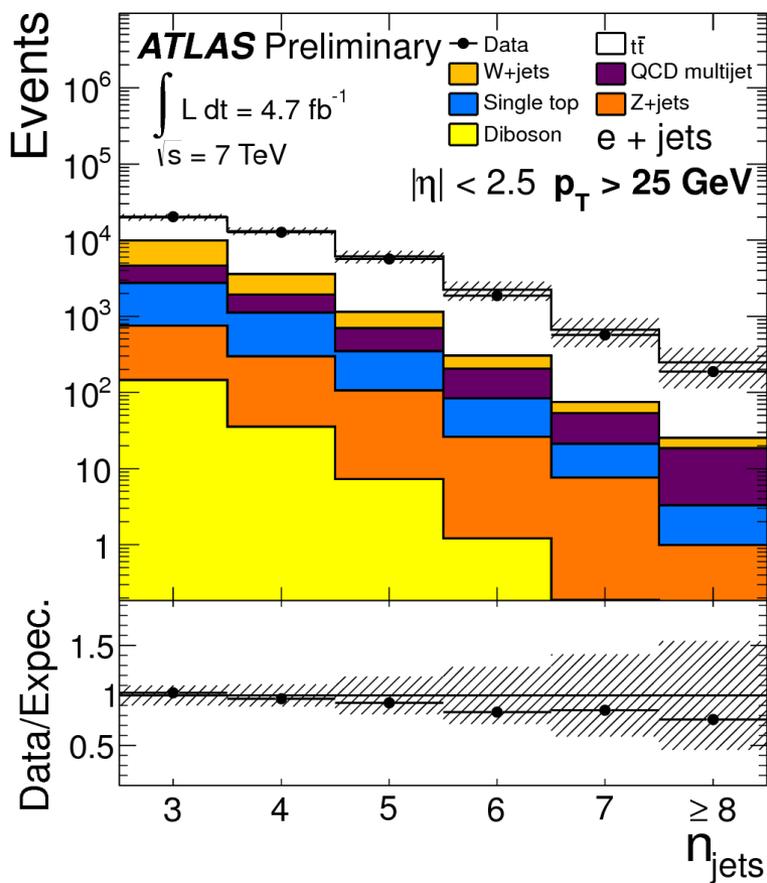
Phys. Rev. Lett. 108 (2012) 212001

Theoretical papers:

W. Bernreuther and Z. G. Si, Nucl. Phys. B 837, 90 (2010)

W. Bernreuther, A. Brandenburg, Z. G. Si, and P. Uwer, Nucl. Phys. B 690, 81 (2004).

- Additional jets in top production important for:
- QCD tests at NLO:
- Constraint on Monte Carlo generators (systematic effects in all top-related analyses)
- ISR/FSR assessment
- Background to other signals (e.g. top-Higgs associate production)



Physics of the top quark can answer fundamental questions.

Peculiar particle with Yukawa coupling $\sim 1 @ m_t$

Top as a powerful probe of physics beyond the standard model

- Production mechanism
- Decay ($|V_{tb}|$ and angular distributions)
- Direct search for resonances

So far no hint of new physics, or discrepancies from S.M.

Top is background for most of searches and Higgs production.

Associated production of top and Higgs: interesting with new statistics.

All measurements are limited by systematics.

New data being analysed, need to improve our understanding of detector (calibrations) and Monte-Carlo simulation of fundamental processes.

Additional difficulty with high pile-up, but not a show stopper.

Looking forward to calibrate and refine the analysis using full statistics at 8 TeV

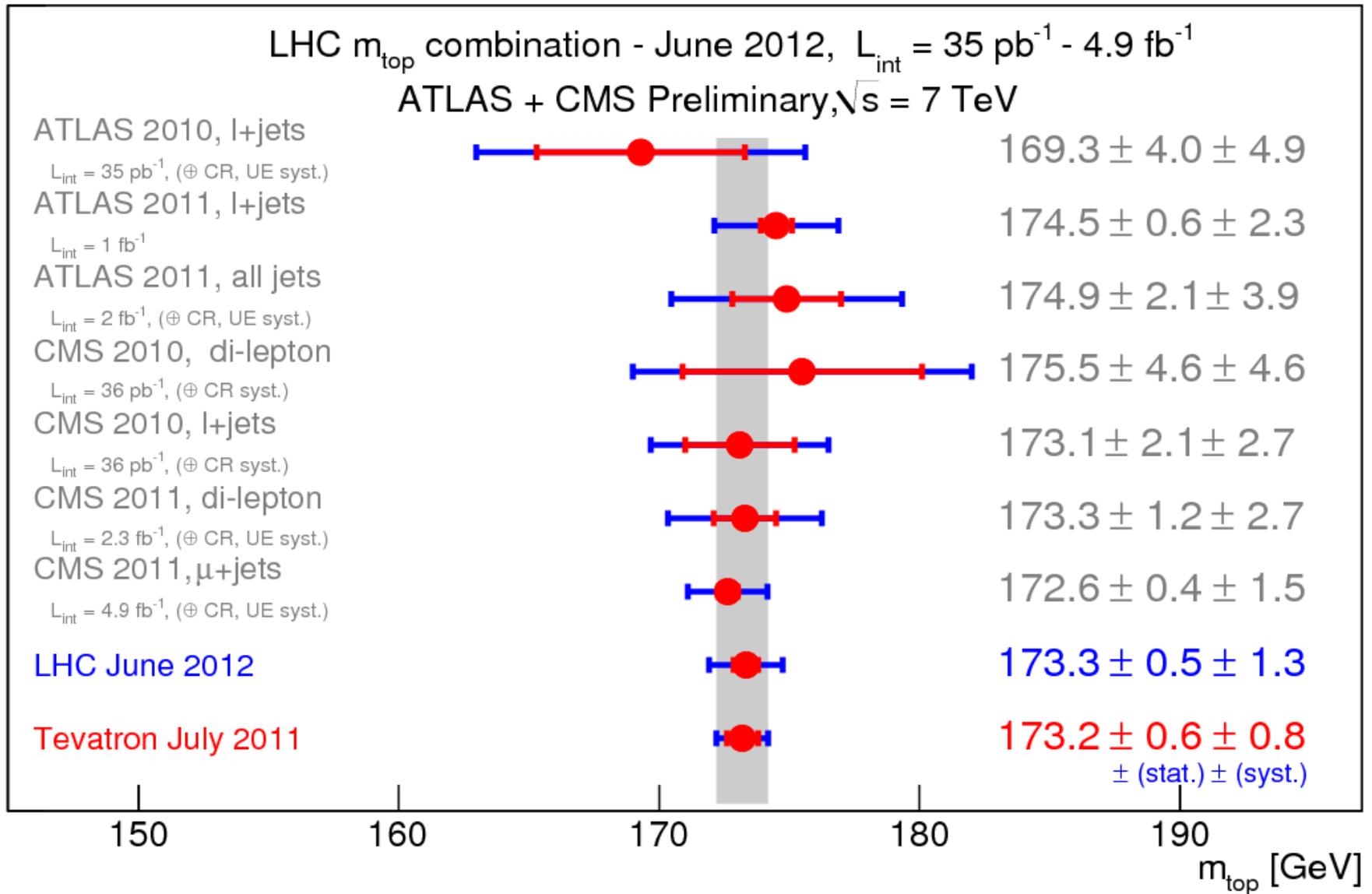
физики жаждут.....

(...без связи с последующими событиями сегодняшнего вечера)

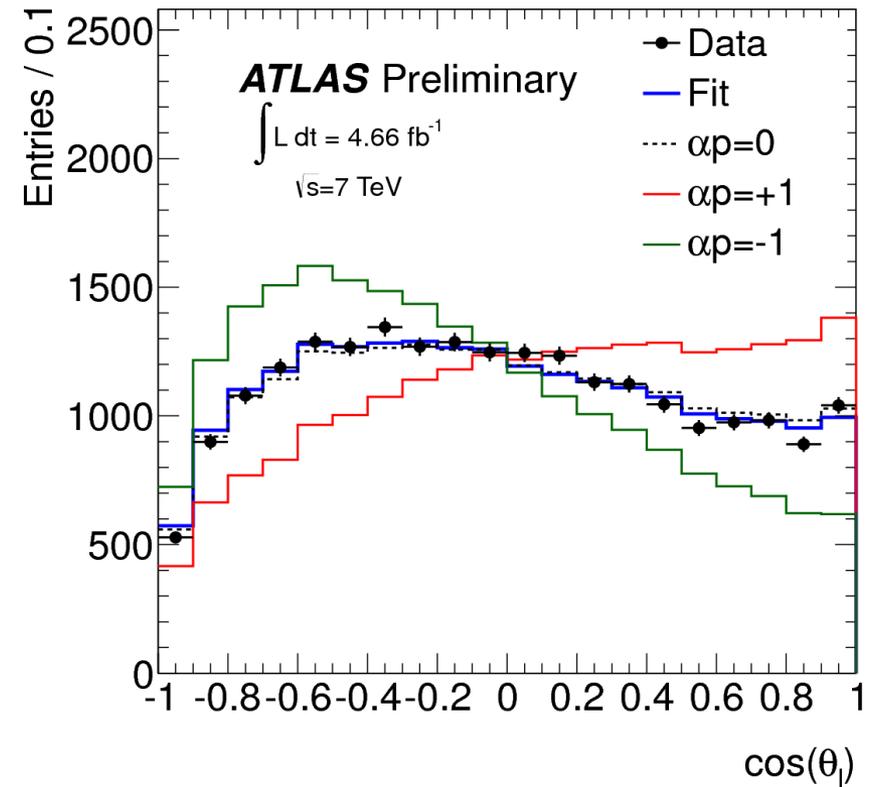
Благодарю вас за внимание

Благодарю Вас за организацию этой конференции

Backup slides

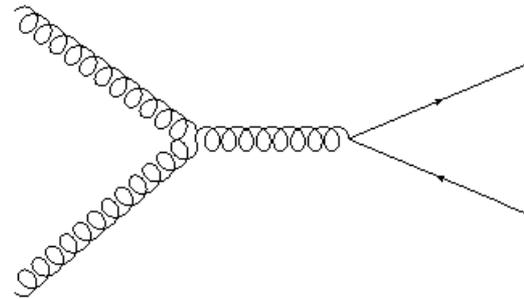
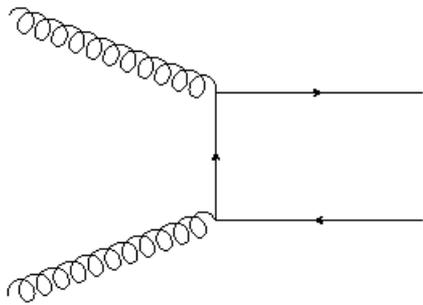


$$\frac{1}{2}f(1 + \cos \theta_\ell) + \frac{1}{2}(1 - f)(1 - \cos \theta_\ell) = \frac{1}{2}(1 + \alpha_{\ell p} \cos \theta)$$



Top quark pair cross section

At LHC gluon-gluon accounts for 85%



qq for ~15%

