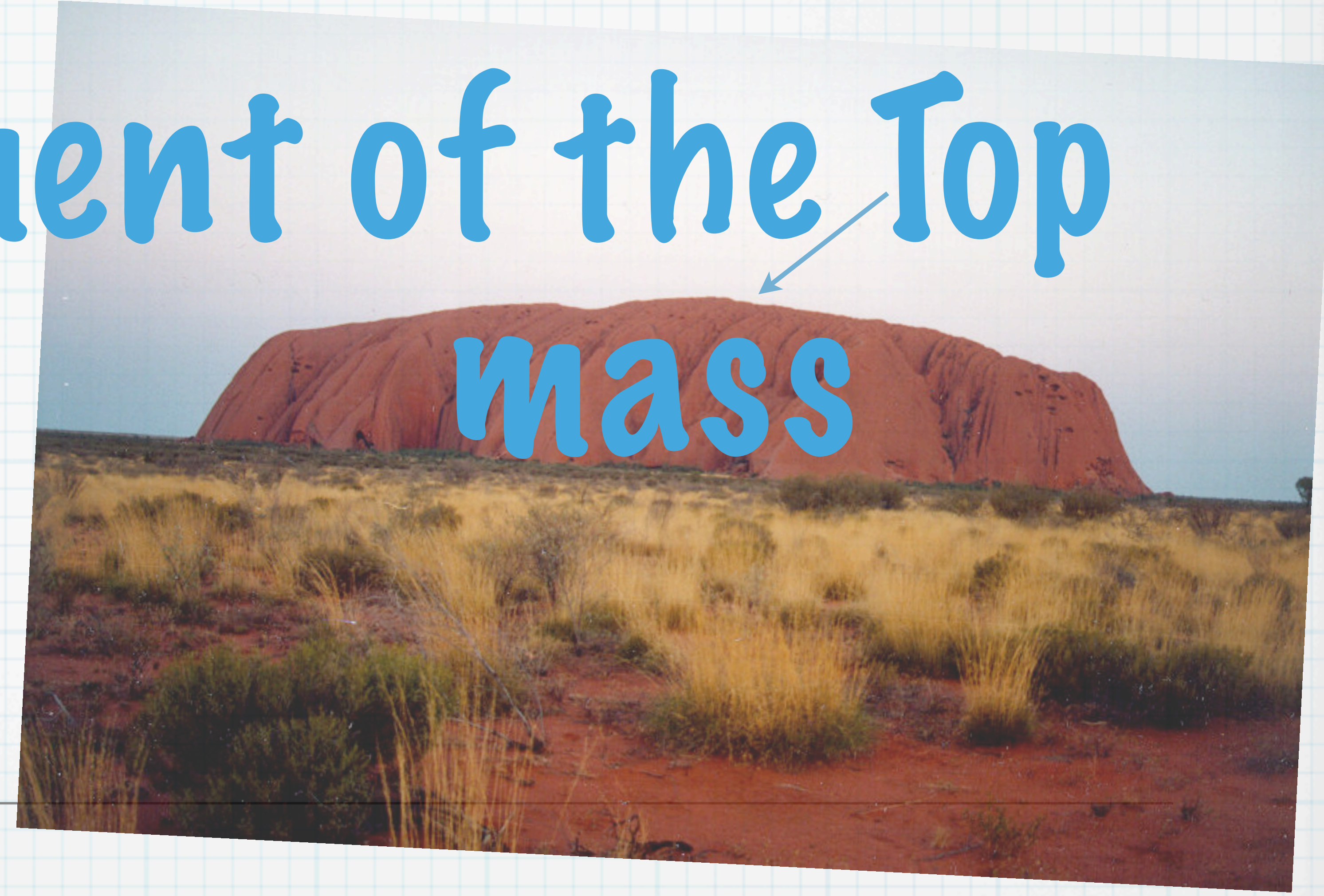
Measurement of the Top quark mass



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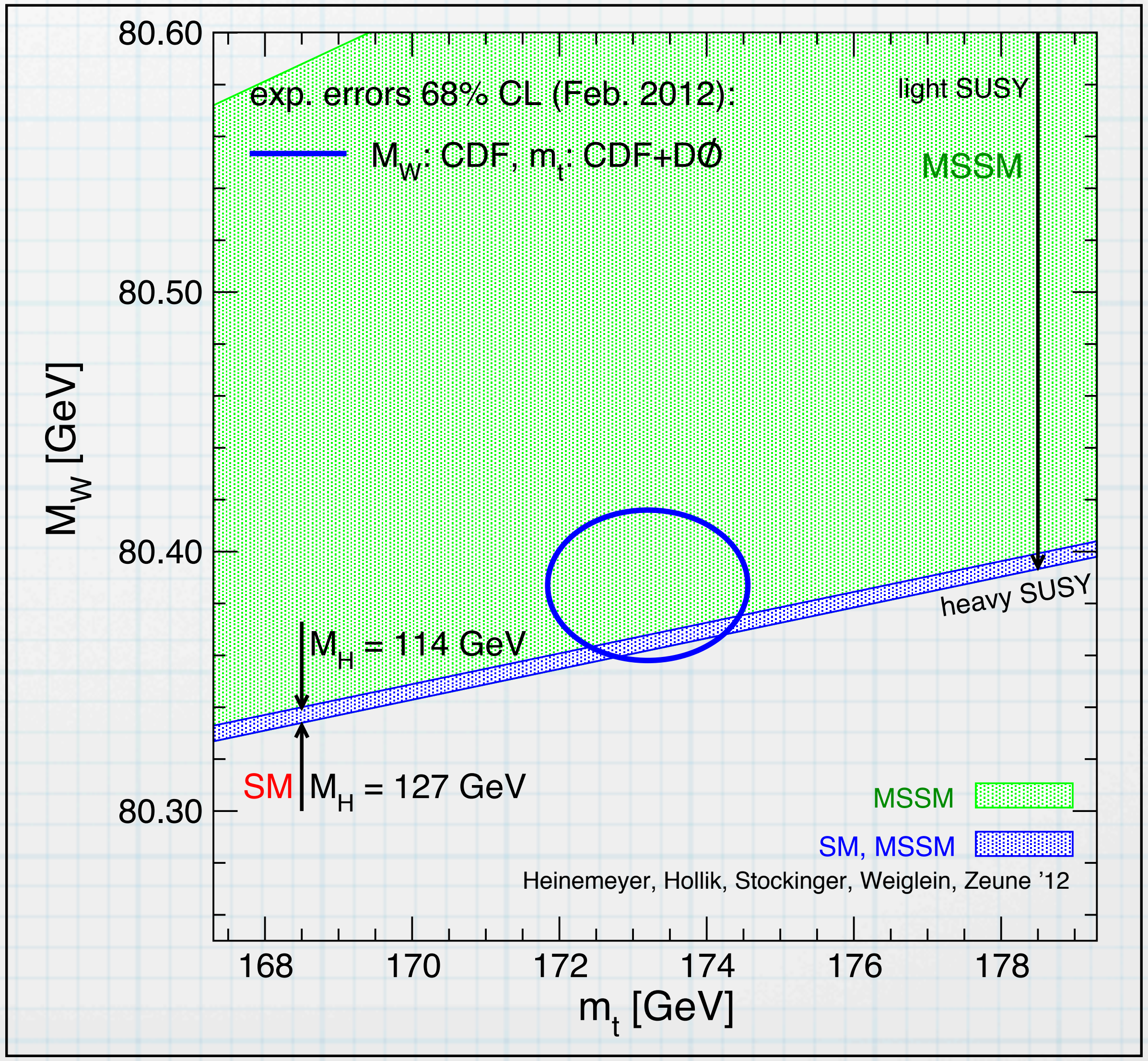
ICHEP 2012, Melbourne, Australia Jul 5th, 2012

Importance of m_t

* Top quark plays important role in EW sector
  * contribution to W mass
  * heaviest of quarks, only particle with Yukawa coupling O(1) → large radiative contribution to m_{Higgs}

⇨ Precise measurement of m_t vital to **check consistency of SM and complements direct H searches**



S. Heinemeyer, W. Hollik, D. Stockinger, G. Weiglein, L. Zeune '12

Experimental building blocks

for details see back-up

Leptons

p_T>20 (μ) or E_T>25 (e) GeV

|η| < 2.5

Isolated in tracker and calorimeter

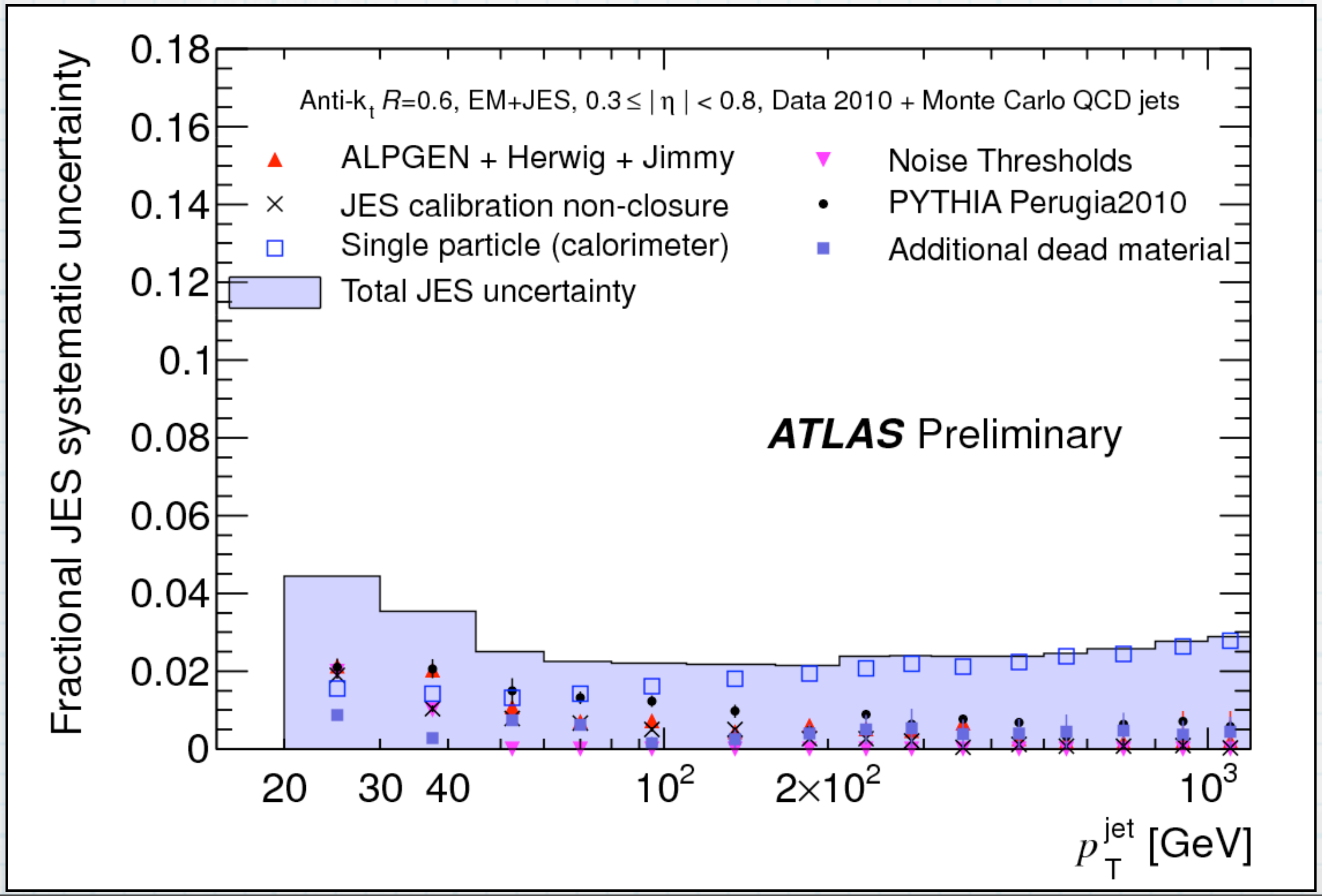
Jets: Anti-k_T, size 0.4

p_T > 25 GeV

|η| < 2.5

E_T^{miss} > 20-35 GeV (depends on channel)

1 or 2 b-tagged jet (depends on channel)



- uncertainty on JES: 2-3% in Top p_T^{jet} range
  - now improved to 1%
- additional JES uncertainty for b-jets: 1-2.5% depending on p_T^{jet}

2-D template (L=1.04 fb^{-1}, l+jets)

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⇨ Sensitivity of measured m_t to JES reduced by simultaneous fitting of global jet scaling factor (JSF)

- JSF sensitive to JES as well as MC modeling (fragmentation, radiation)
  - from optimum match of expected di-jet invariant mass in MC to data
- plus: before fitting, j-j-b mass (m_t^{reco}) calculated correcting jet energies back to parton level (α_i factors) to agree with m_W^{PDG}:

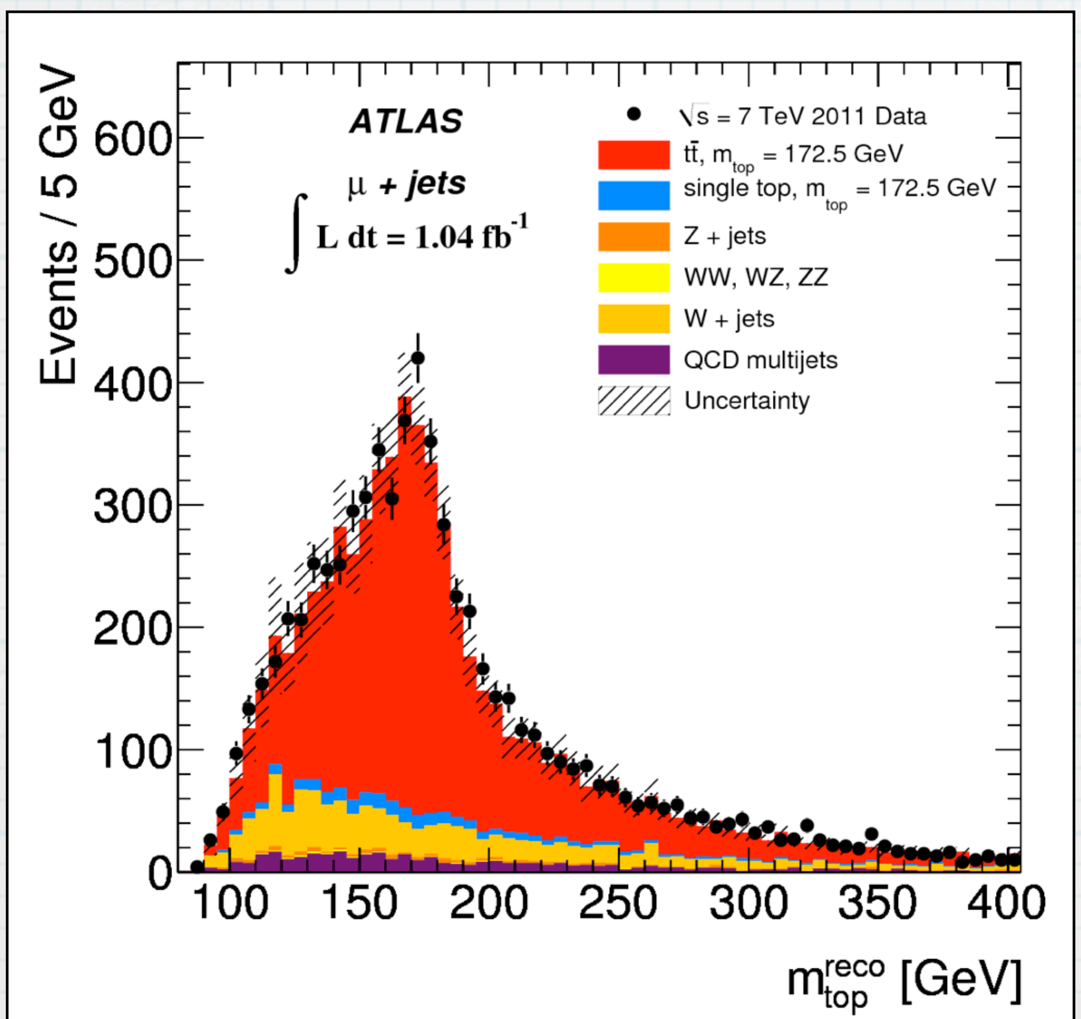
$$\chi^2 = \sum_{i=1}^{2} \left[\frac{E_{\mathrm{jet,i}}(1-\alpha_{\mathrm{i}})}{\sigma(E_{\mathrm{jet,i}})} \right]^2 + \left[\frac{M_{\mathrm{jet,jet}}(\alpha_1, \alpha_2) - m_W}{\Gamma_W} \right]^2$$

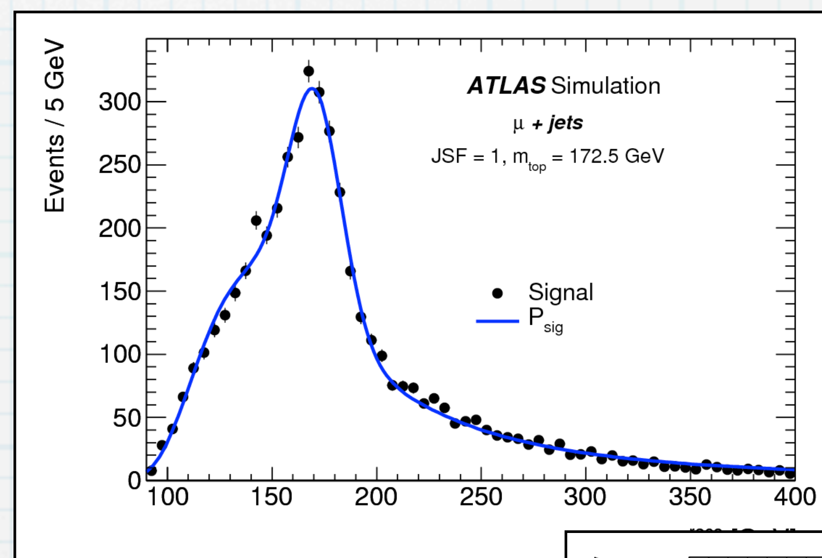
- bJES unconstrained by this method, most important syst (see later)

✓ Complementary 1-D template fit: approach of using observable with built-in small sensitivity to JES

2-D fit

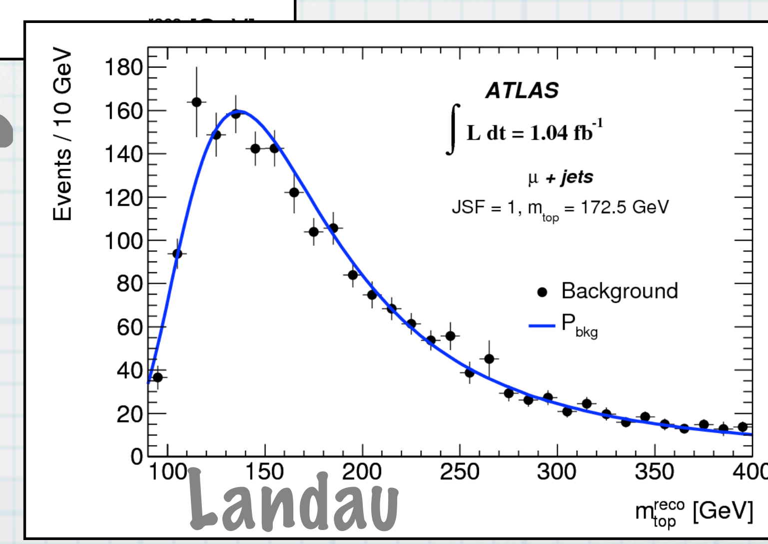
- use templates of reconstructed top mass from a grid of true top masses [160-190 GeV] and JSF [0.9-1.1]
- feed into unbinned likelihood fit
  - good linearity input m_t vs result of the fits checked with toy MC





Gauss+Landau

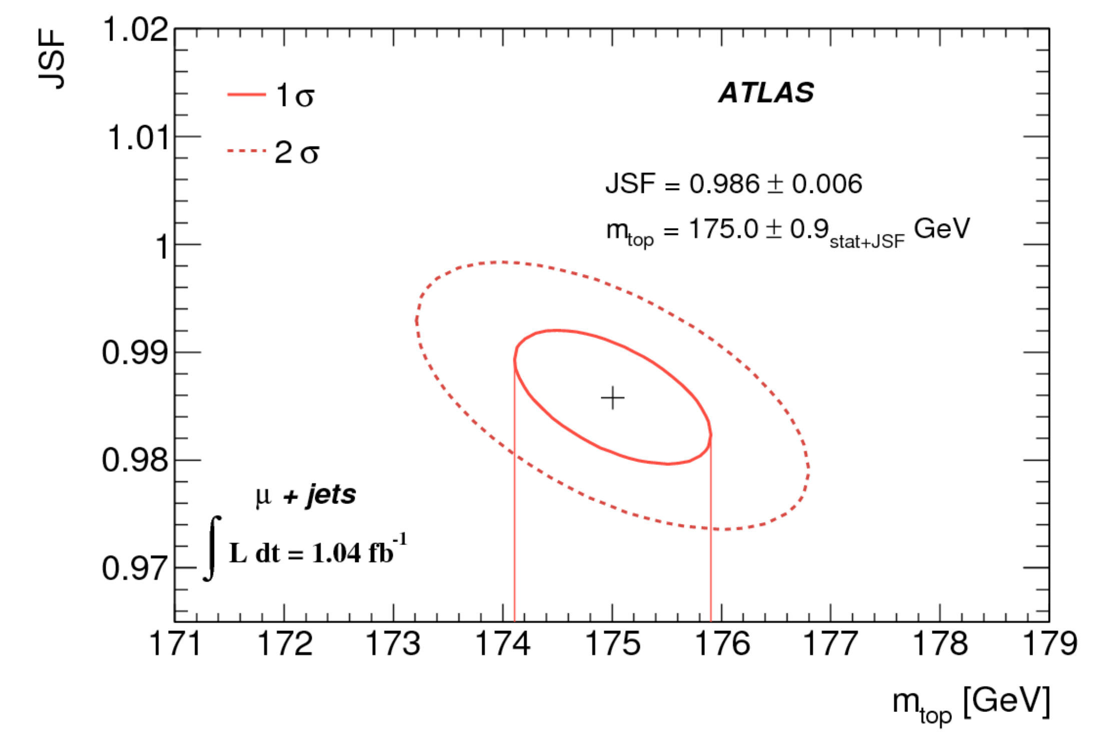
+



Landau

Results

	Combinations	
	1d	2d
Measured value of m_{top}	174.35	174.53
Data statistics	0.91	0.61
Jet energy scale factor	na	0.43
Method calibration	< 0.05	0.07
Signal MC generator	0.74	0.33
Hadronisation	0.43	0.15
Pileup	< 0.05	< 0.05
Underlying event	0.08	0.59
Colour reconnection	0.62	0.55
ISR and FSR (signal only)	1.42	1.01
Proton PDF	0.15	0.10
W+jets background normalisation	0.18	0.37
W+jets background shape	0.15	0.12
QCD multijet background normalisation	< 0.05	0.20
QCD multijet background shape	0.09	0.27
Jet energy scale	1.23	0.66
b-jet energy scale	1.16	1.58
b-tagging efficiency and mistag rate	0.17	0.29
Jet energy resolution	0.36	0.07
Jet reconstruction efficiency	0.10	< 0.05
Missing transverse momentum	< 0.05	0.13
Total systematic uncertainty	2.50	2.31
Total uncertainty	2.66	2.39



- low JES systematic uncertainty
- bJES dominant effect

- Ongoing effort to constrain MC modeling (radiation/PS/hadronization/colour reconnection) with ATLAS data
  - I/FSR variations in MC reduced by about 50% (arXiv:1203.5015), impact on m_t systematic uncertainty being studied

Calibration curve (L=4.7 fb^{-1}, e+μ)

ATLAS-CONF-2012-082

⇨ dilepton signature less JES-dependent, but challenging top candidate reconstruction due to neutrinos

* Use m_{T2} (conceived for final states with > 1 undetected particle)

$$m_{T2}(m_{invis}) = \min_{\vec{p}_T^{(1)},\, \vec{p}_T^{(2)}} \left[\max\left[m_T(m_{invis}, \vec{p}_T^{(1)}), m_T(m_{invis}, \vec{p}_T^{(2)}) \right] \right]$$

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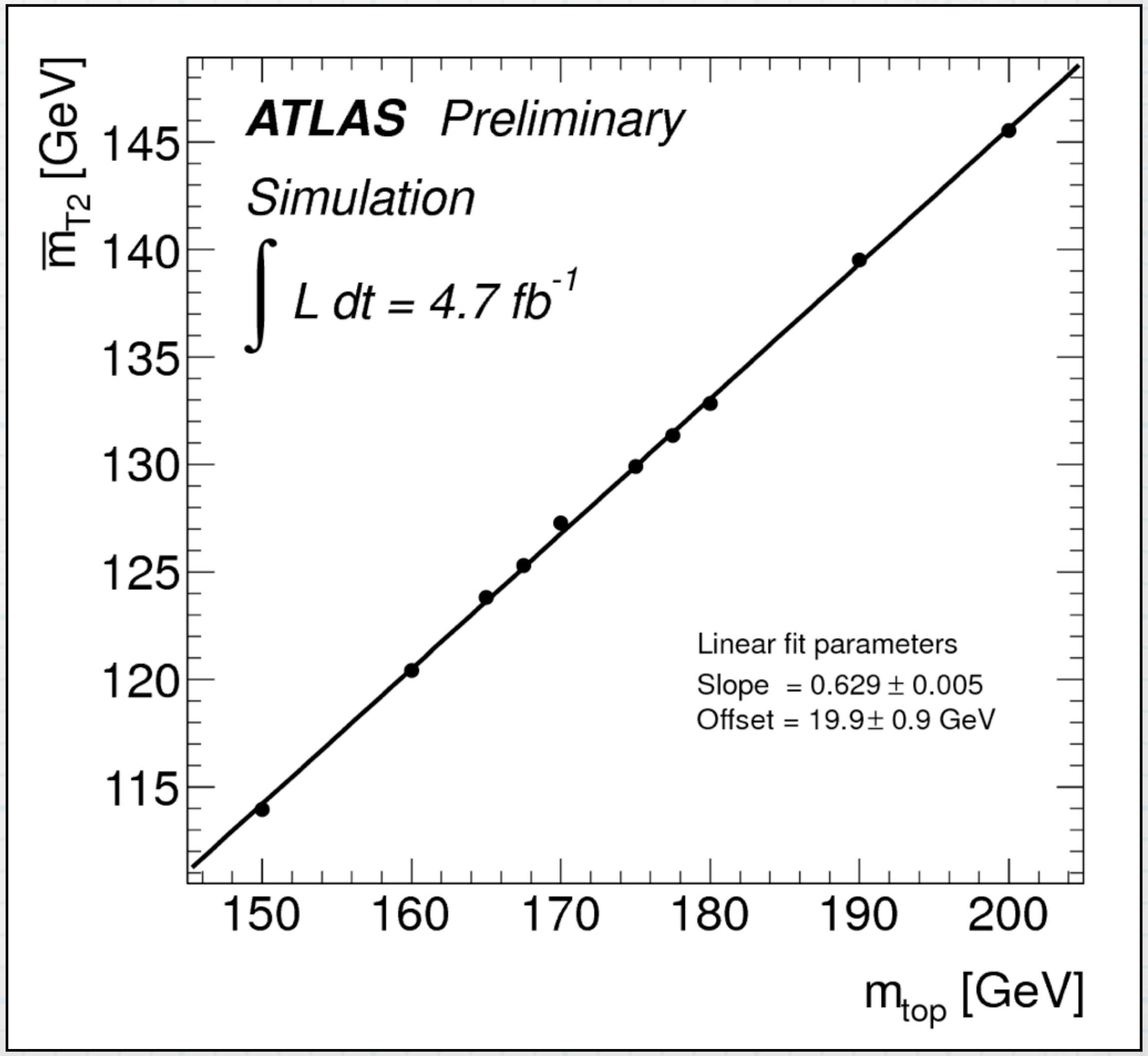
$$m_T(m_{invis}, \vec{p}_T^{(n)}) = \sqrt{m_{vis}^2 + m_{invis}^2 + 2(E_T^{vis} E_T^{invis} - \vec{p}_T^{vis} \cdot \vec{p}_T^{(n)})}$$

* use calibration curve of m_{T2} vs m_t from MC with different true m_t values to extract m_t from data

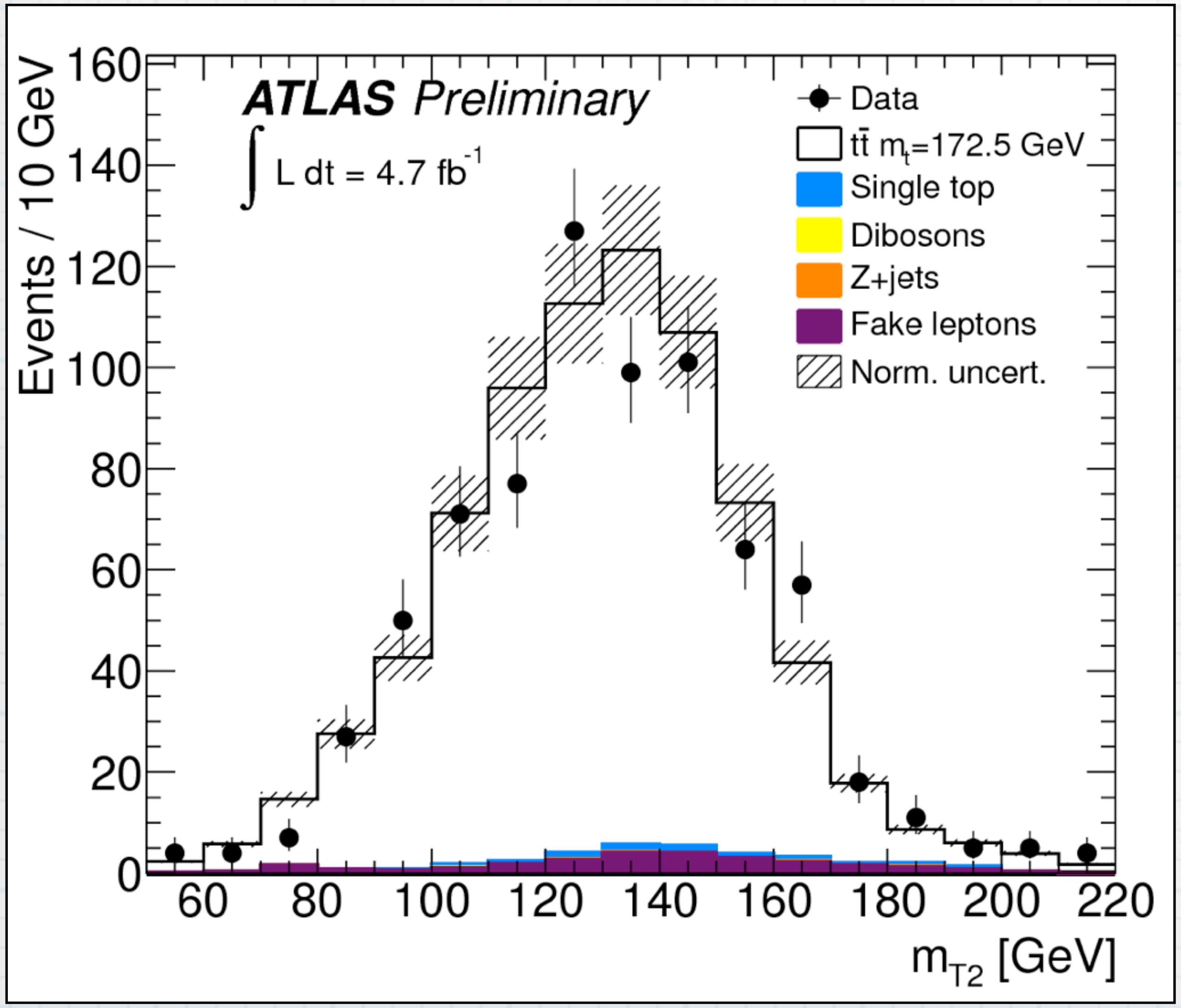
* estimator is mean of m_{T2} distribution

NEW for ICHEP



Results

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



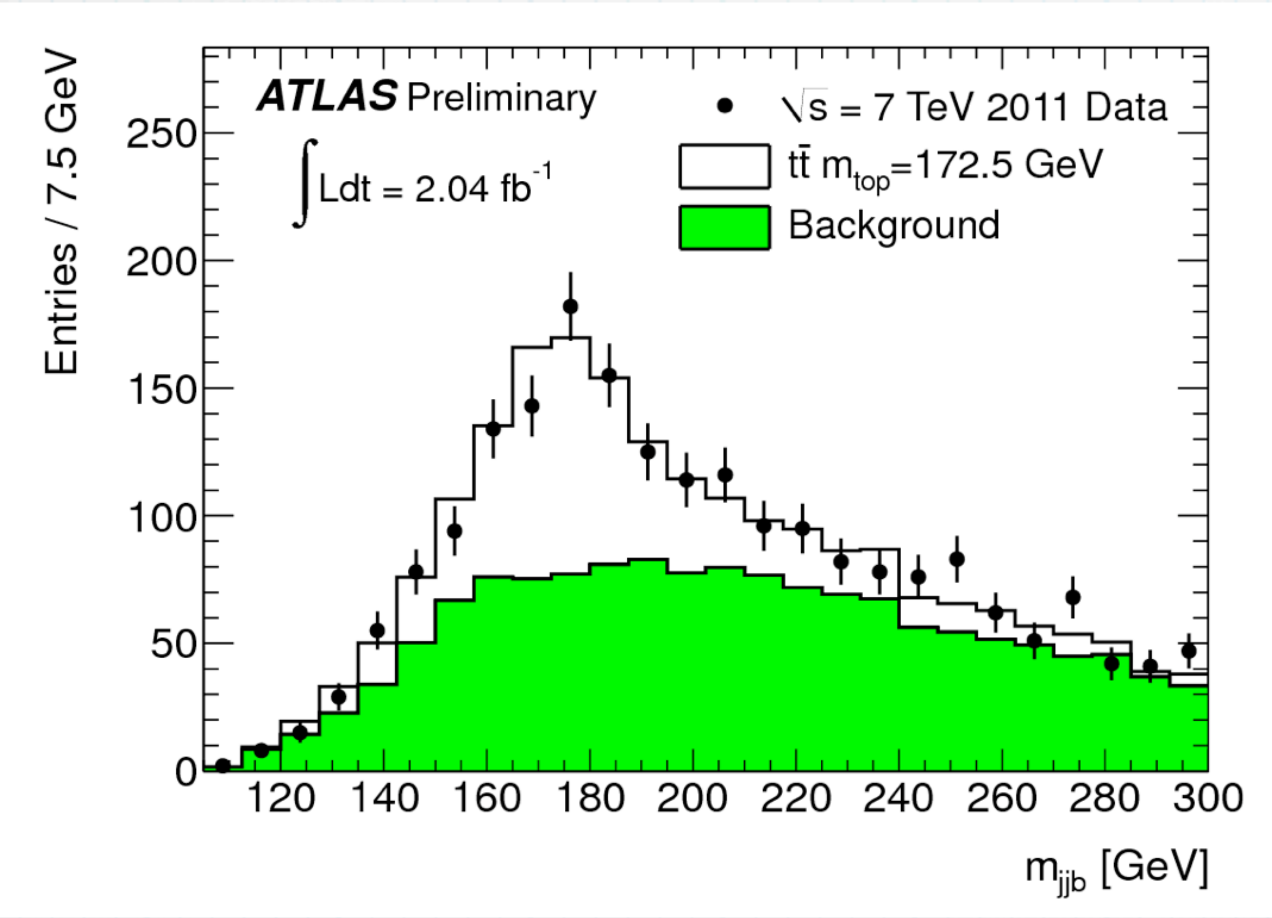
Source	Uncertainty [GeV]
$t\bar{t}$ generator model	−1.3 / +1.3
Parton shower	−0.9 / +0.9
Colour reconnection	−1.2 / +1.2
ISR/FSR	−0.5 / +0.5
PDF	−0.1 / +0.1
Fakes norm. and shape	−0.3 / +0.3
Calibration curve	−0.3 / +0.3
Underlying event	−0.2 / +0.2
Jet energy scale	−1.4 / +1.6
b-jet energy scale	−1.2 / +1.5
Jet energy resolution	−0.5 / +0.5
Leptons	−0.1 / +0.2
E_T^{miss} and jets	−0.1 / +0.1
b-tagging	−0.4 / +0.3
Syst. uncertainty	−2.8 / +3.1
Stat. uncertainty	−1.6 / +1.6
Total uncertainty	−3.3 / +3.5

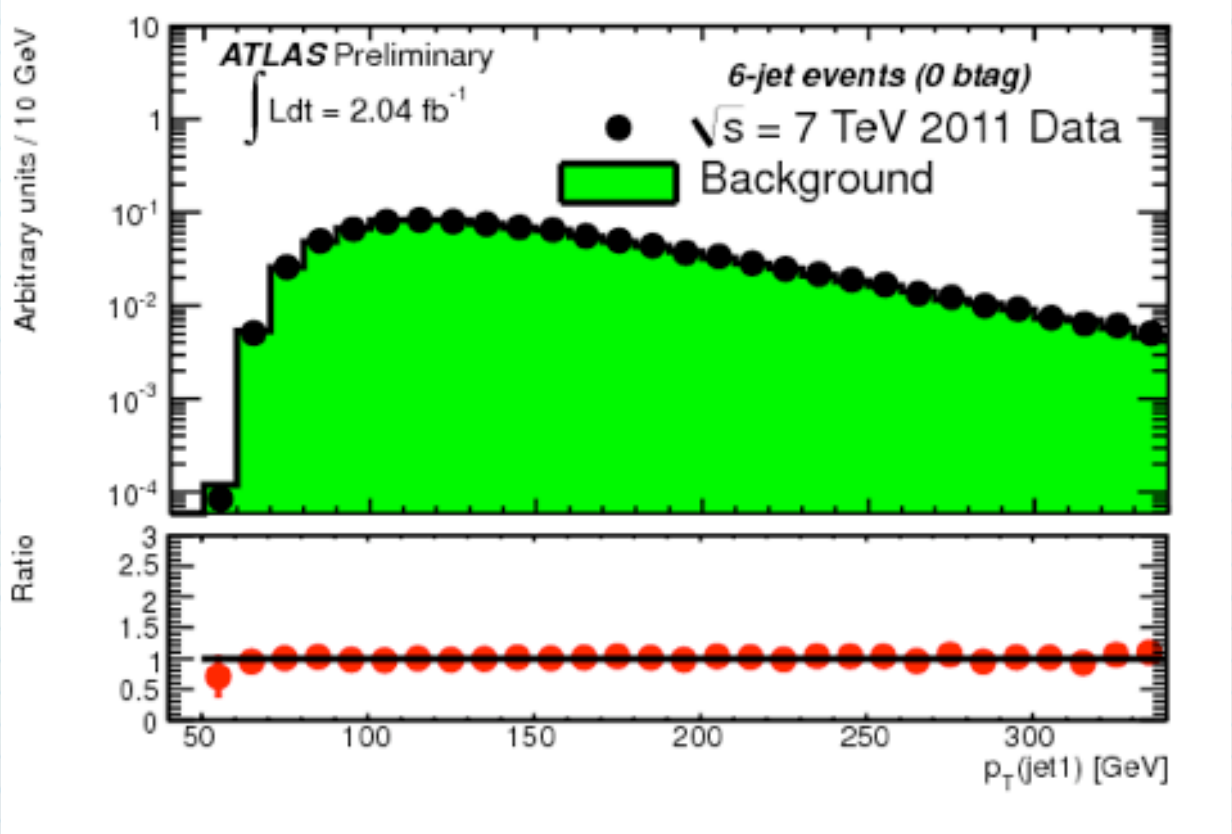
Good MC/data agreement all over m_{T2}

All-had template (L=2.04 fb^{-1}, all-hadronic)

ATLAS-CONF-2012-030

- Largest sample, but challenging large QCD bkg
    - Top candidates from minimization of χ^2
- bkg modeling from control regions obtained and validated from mixing different hard and soft jet multiplicities ("Evt mixing")





Event mixing models QCD correctly in Control region

All-had: results

$$m_t = 174.9 \pm 2.1 \text{ (stat.)} \pm 3.8 \text{ (syst.) GeV}$$

Source	Uncertainty [GeV]
Method	0.4
Template statistics	0.9
MC generator	0.5
ISR/FSR	1.7
PDF	0.6
Background modelling	1.9
Jet energy scale	2.1
b-jet energy scale	1.4
b-tag efficiency scale factors	0.3
Jet energy resolution	0.3
Jet reconstruction efficiency	0.2
Total systematic uncertainty	3.8

1.7x 2-D l+jets

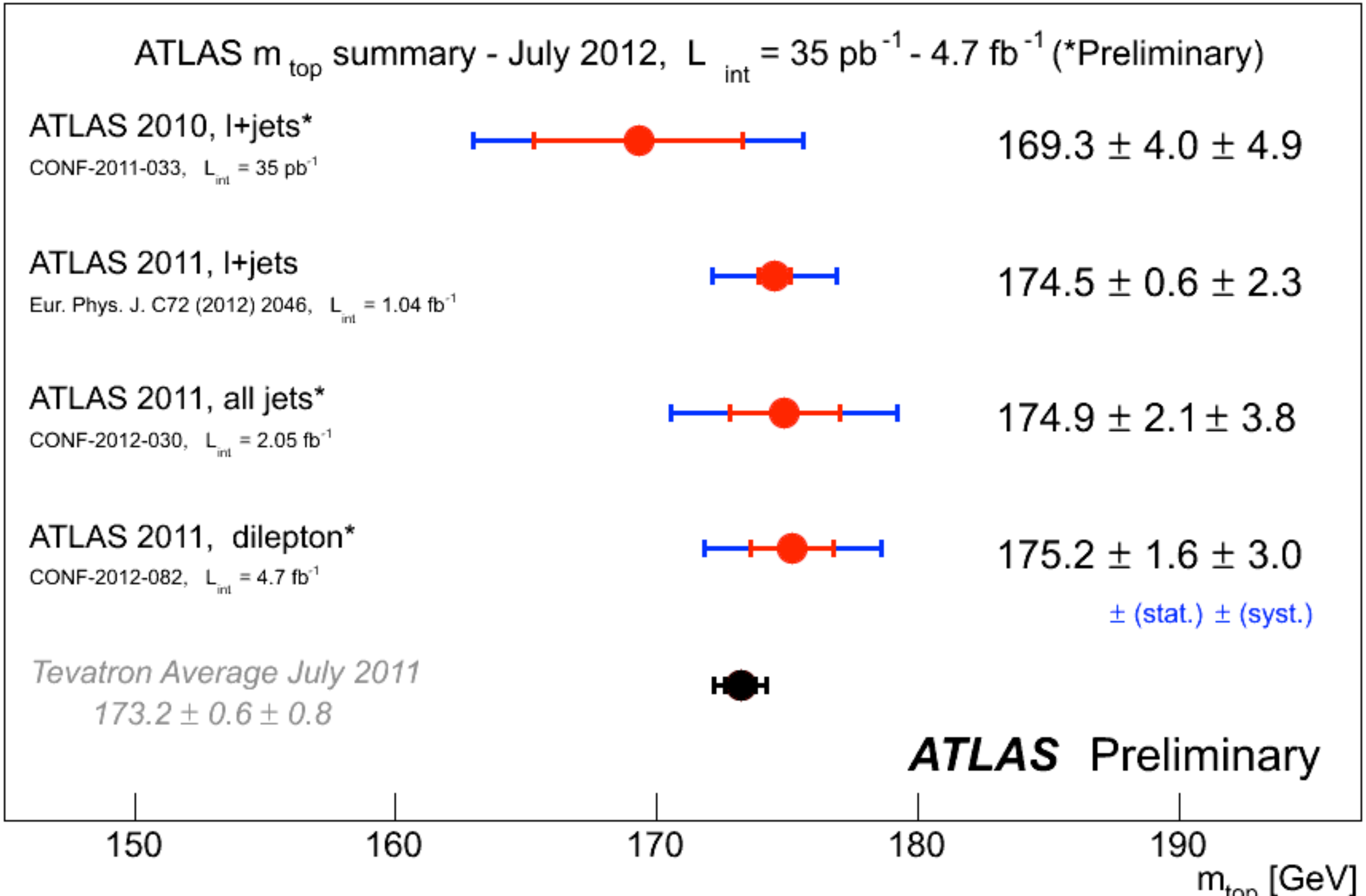
6x 2-D l+jets bkg shape

3x 2-D l+jets

Summary

* First direct m_t measurements at ATLAS obtained from all main channels
  * methods in place to reduce impact of JES
  * in progress: work to constrain MC modeling with data
* Combination with CMS measurements performed (see F.Deliot's talk)
* ☑ Also indirect measurement from $t\bar{t}$ cross-section (2010, 35 pb^{-1}): m_t = ($166.4^{+7.8}_{-7.3}$) GeV
  * interesting as gives access to $\overline{MS}$ mass

Summary



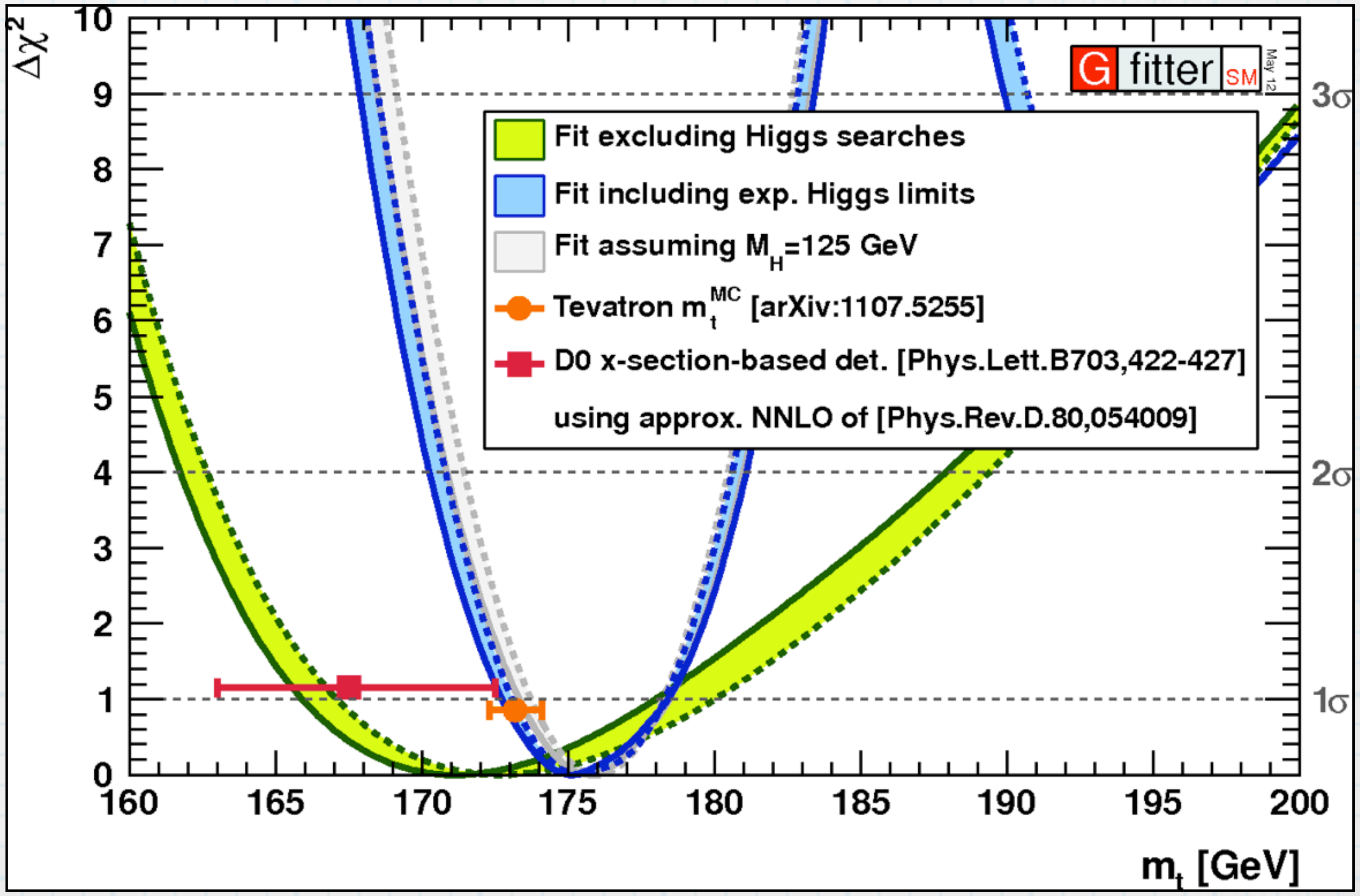
* Stay tuned for more from ATLAS on Top quark mass!

BACK-UP

What we measure

* ...but Top quark is a strong (coloured) object
  * what we measure is invariant mass of b-hadron + W system
  * basically the pole mass (divergent at high α_s orders) - or better: its proxy from MC simulations

* luckily can "navigate back" to renormalized mass used in EW fits



Selections l+jets

1 Lepton

p_T>20 (μ) or E_T>25 (e) GeV

|η| < 2.5

Low activity around track in tracker and calo

≥4 Jets: Anti-K_T, size 0.4

p_T > 25 GeV

|η| < 2.5

Triggers: 18 GeV single μ, 20 GeV single electron

Event-level selections:

μ+jets: E_T^{miss} > 20 GeV and E_T^{miss} + $M_T(W)$ > 60 GeV

e+jets: E_T^{miss} > 35 GeV and $M_T(W)$ > 25 GeV

1 b-tag with NN-based secondary vertex tagger

Basic selections e+μ

2 Leptons, opp. Q
p_T>20 (μ) or E_T>25 (e) GeV
|η| < 2.5
Low activity around track in tracker and calo

≥2 Jets: Anti-K_T, size 0.4
p_T > 25 GeV
|η| < 2.5

Triggers: 18 GeV single μ OR 20 GeV single electron

Event-level selections:
H_T > 130 GeV
2 b-tags with NN-based secondary vertex tagger, p_T > 45 GeV

Selections all-hadronic

$\geq$5 Jets: Anti-K_T, size 0.4

p_T>55 GeV

$|\eta| < 4.5$

An additional softer jet with $p_T >$ 30 GeV

Trigger: 5-jet with p_T>30 GeV

Event-level selections:

Good lepton veto

$E_T^{miss}/\sqrt{(H_T)} < 3\ GeV^{1/2}$

2 b-tags with NN-based secondary vertex tagger, ΔR>1.2

for more, see back-up

MC samples

- Nominal results:
  - signal (m_t = 172.5 GeV) +m_t scan: MC@NLO+Herwig/Jimmy, pdf: CT10
  - Z+jets: Alpgen, pdf: CTEQ6L1
  - single top: MC@NLO+Herwig/Jimmy for s- and Wt and AcerMC for t-
- Systematic uncertainties on MC modeling:
  - MC generator: Powheg
  - Parton shower/hadronization model: Pythia 6
  - I/FSR: AcerMC (tuned with data for 5 fb^{-1} analysis)
  - Colour reconnection/UE: AcerMC+Pythia with different tunes

- QCD multi-jet and W+jets estimated directly from data

MC parameters used/1

* Nominal results:
  * Herwig/Jimmy: AUET2-C10 tuned to ATLAS data, pdf: CT10
  * tt x-sec normalized to 166.8 pb using HATHOR
  * Z+jets: Alpgen, pdf: CTEQ6L1, k Factor = 1.25
  * single top: MC@NLO+Herwig/Jimmy for s- and Wt and AcerMC for t-

MC parameters used/2

* Systematic uncertainties on MC modeling:
  * MC generator: Powheg
  * Parton shower/hadronization model: Pythia 6
  * I/FSR: variations for MRSTMCal - MC (LO**) PDF [20651] (AUET2B(LO**) tune
    * ISR tuned with full 2011 data based on jet gap fraction in tt dileptonic events (arXiv:1203.5015)
    * FSR loosely tuned from inclusive jet shape measurements
  * Colour reconnection/UE: AcerMC+Pythia, CTEQ5L, Perugia2011 and A-Pro and ACR-Pro TeV tuneA+LEP