ATLAS EXPERIMENT

CERN Seminar, July 2nd 2013

Measurement of Top Mass and Properties with the ATLAS Detector:

experimental challenges for top-quark precision measurements

Giorgio Cortiana

Max-Planck-Institut für Physik München

on behalf of the ATLAS Collaboration

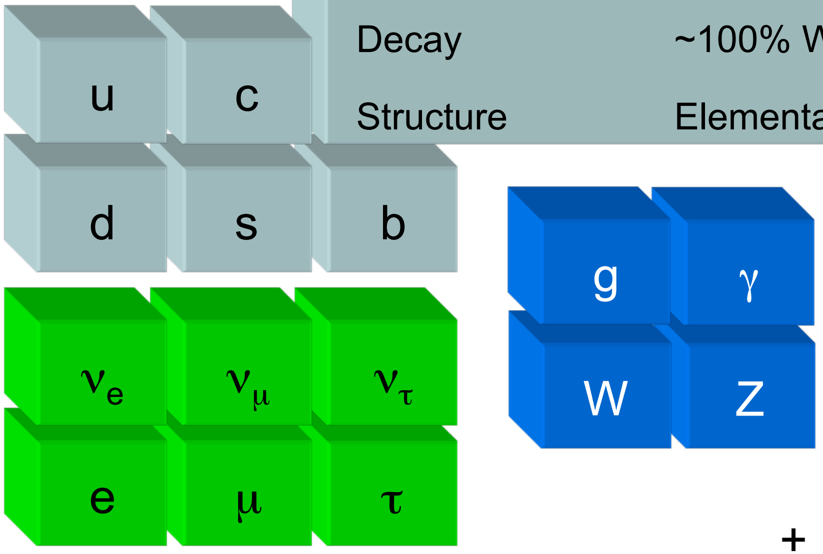
Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)

The top quark

- top-quark physics is one of the main pillars of the physics program at the LHC.
- The top-quark: a multipurpose physics candle at the LHC:
  - Precision measurements in the top-quark physics sector
    - drive improvements in the detector and physics tools understanding.
    - motivate refinements and tests of different physics aspects of top-quark modelling in the MC simulations;
    - boost the progress in physics analysis/searches where top-quark backgrounds are important;
    - allow for stringent tests of the SM and its extensions;
    - probe the EWSB mechanism (y_t~1);
    - enable searches for physics beyond the SM: production mechanism and the decays (Wtb coupling)

The top quark

up-type quark	3^{rd} generation
Symbol	***t***
Mass	$173.2 \pm 0.5 \pm 0.7$ GeV/c^2
	~186 u (*)
Charge	+2/3
Prod	proton-(anti)proton
Prod mechanism	gg,qq→tt; (qb →qt, qq →bt; bg →Wt)
Decay	~100% Wb
Structure	Elementary?

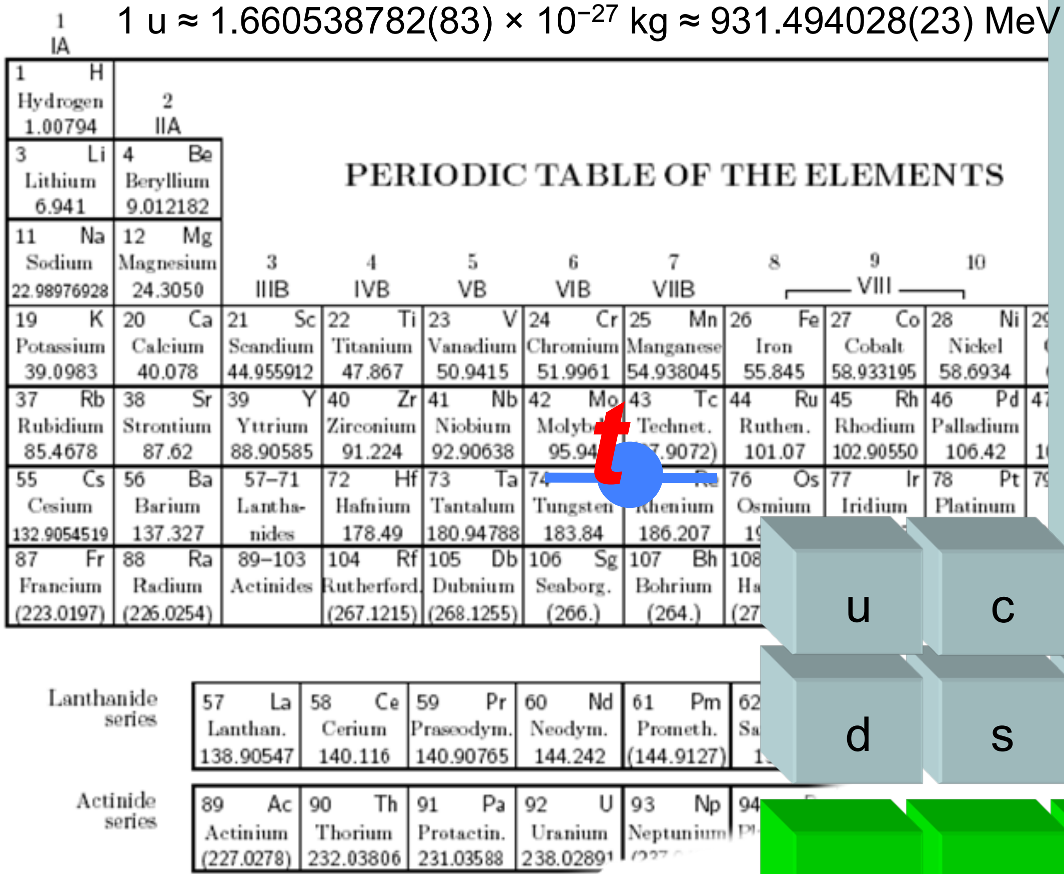


+ Higgs + …

(*) http://arxiv.org/abs/1305.3929

The top quark

1 u ≈ 1.660538782(83) × 10^{-27} kg ≈ 931.494028(23) MeV



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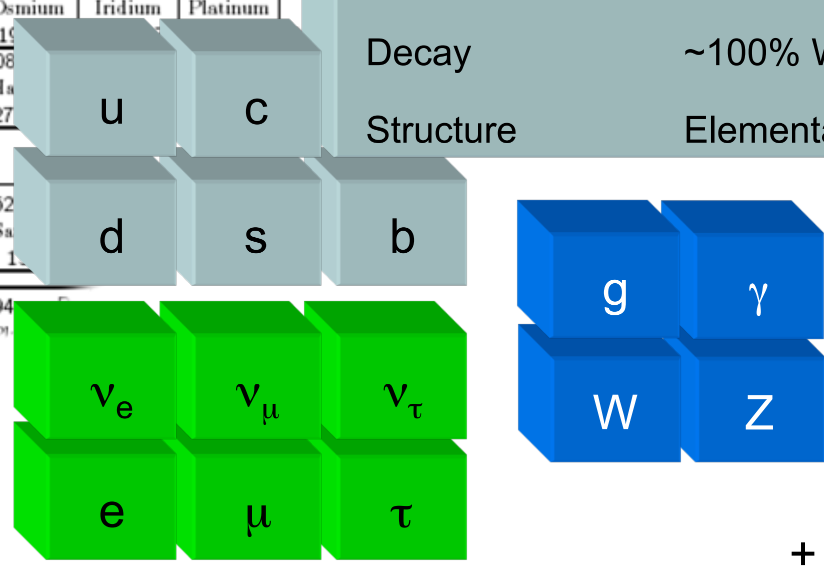

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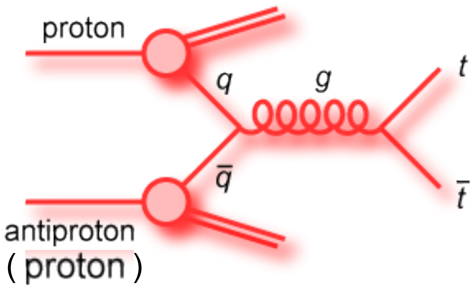
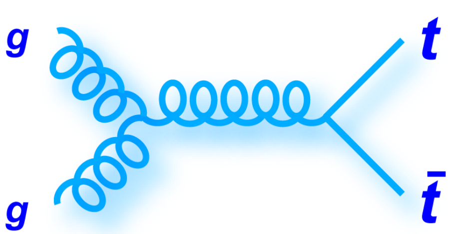
The top quark

Top-quark pair production



dominant at Tevatron
(proton-antiproton)
$\sqrt{s}$ = 1.96 TeV



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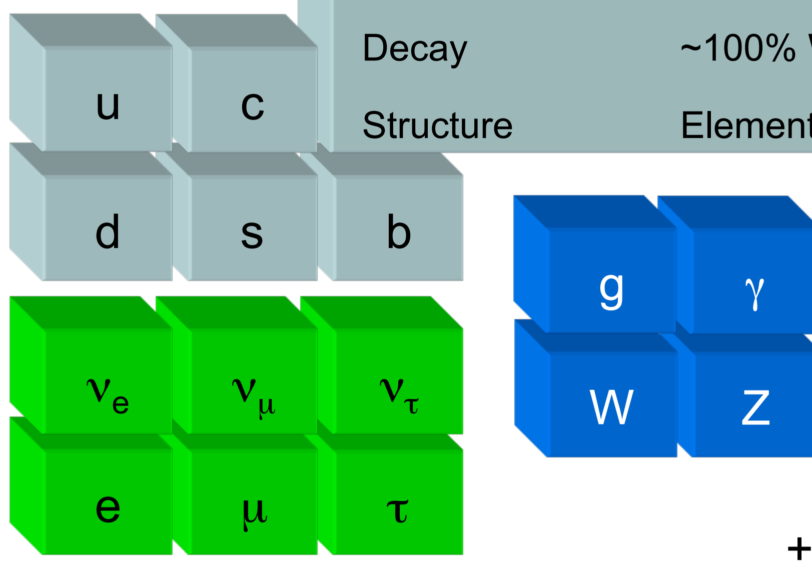

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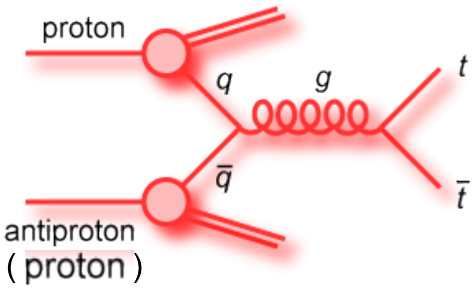

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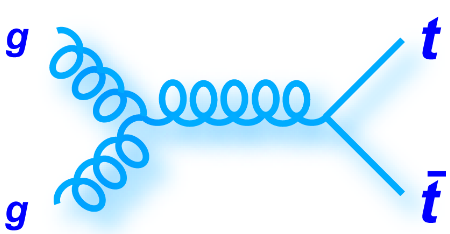

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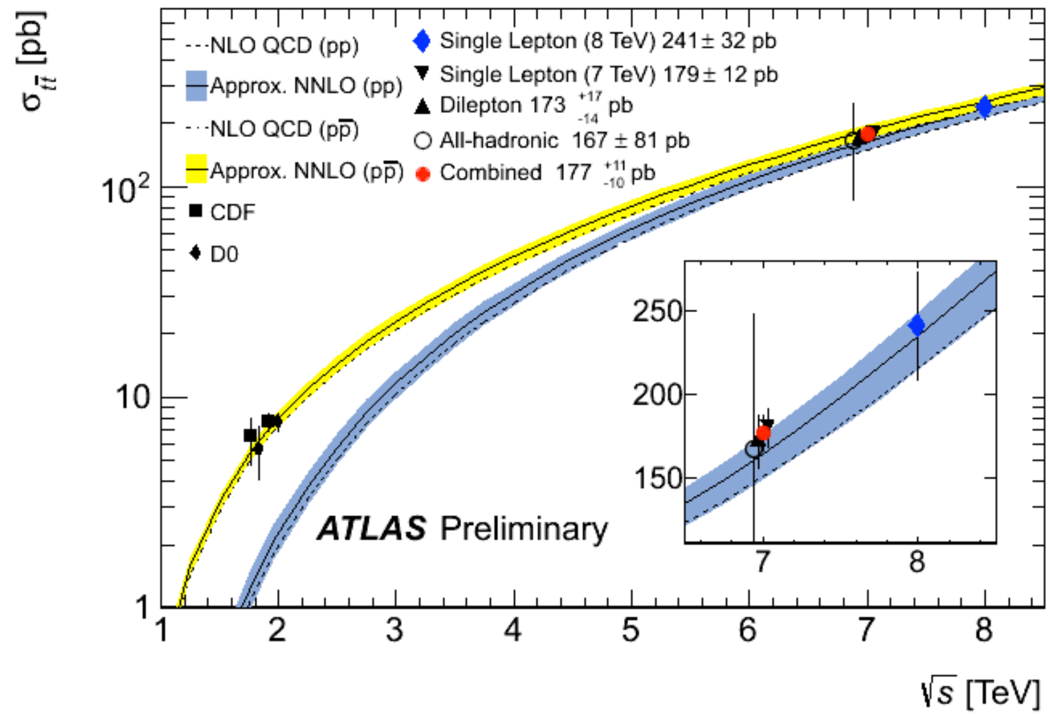


Agreement with the latest NNLO+NNLL calculations
(m_{top} = 173.3 GeV)

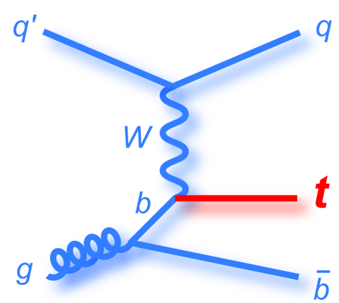
M. Czakon, P. Fiedler, A. Mitov arXiv:1303.6254

Collider	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%) −17.8(1.9%)

The top quark

Single top-quark production

t-chan.



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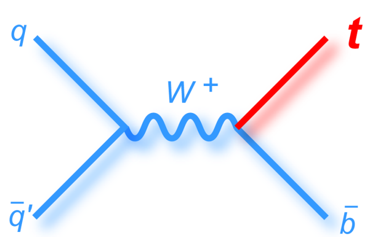
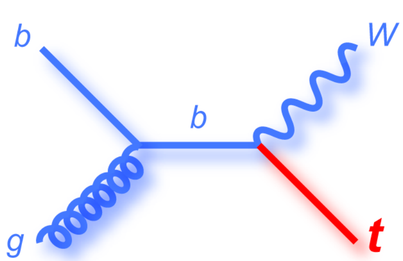


Wt-chan



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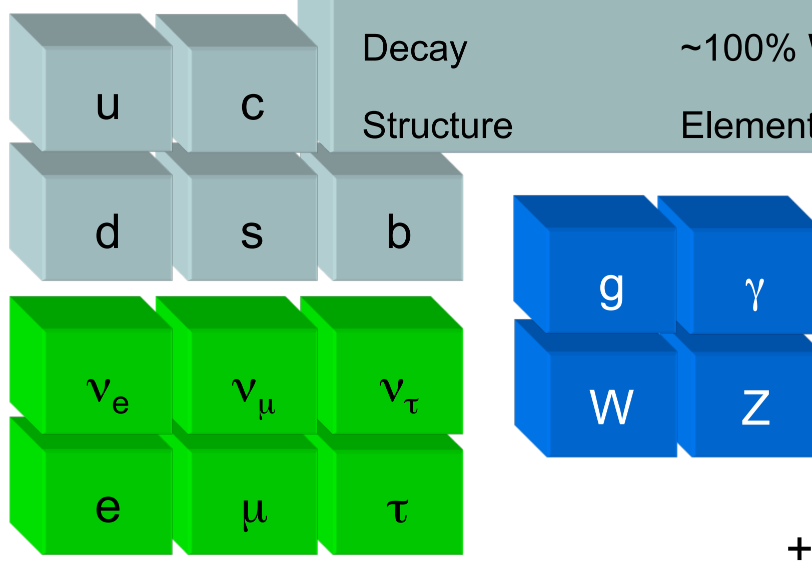

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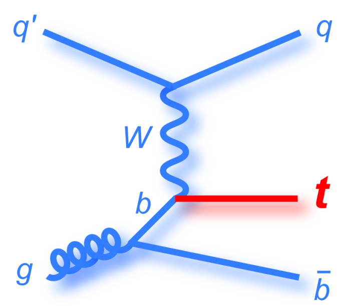

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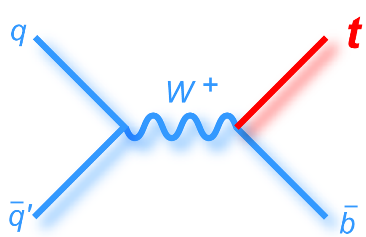

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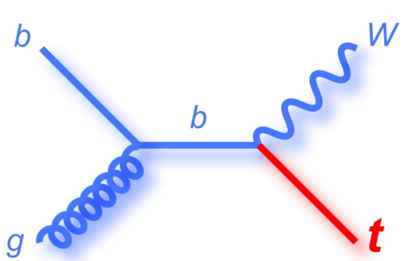

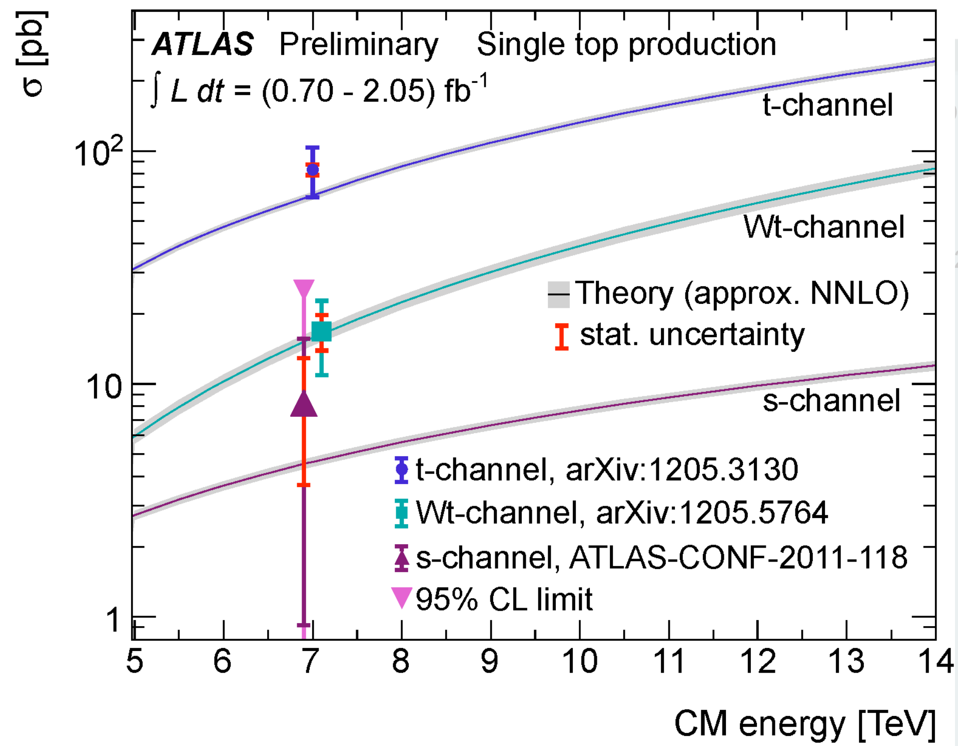

Agreement with approx. NNLO calculations

Approx. NNLO x-sec [pb]	√s=7TeV	√s=8TeV	references
t-channel	***$64.6^{+2.7}_{-2.0}$***	***$87.8^{+3.4}_{-1.9}$***	Phys. Rev. **D83** (2011) 091503 arxiv:1103.2792 N. Kidonakis
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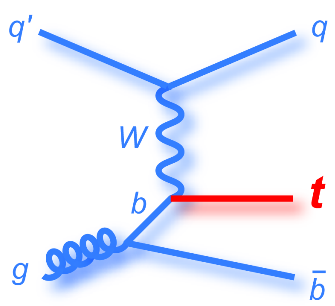

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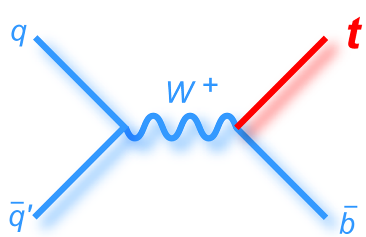

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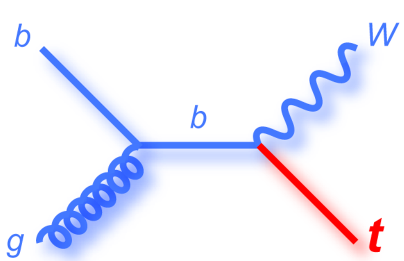

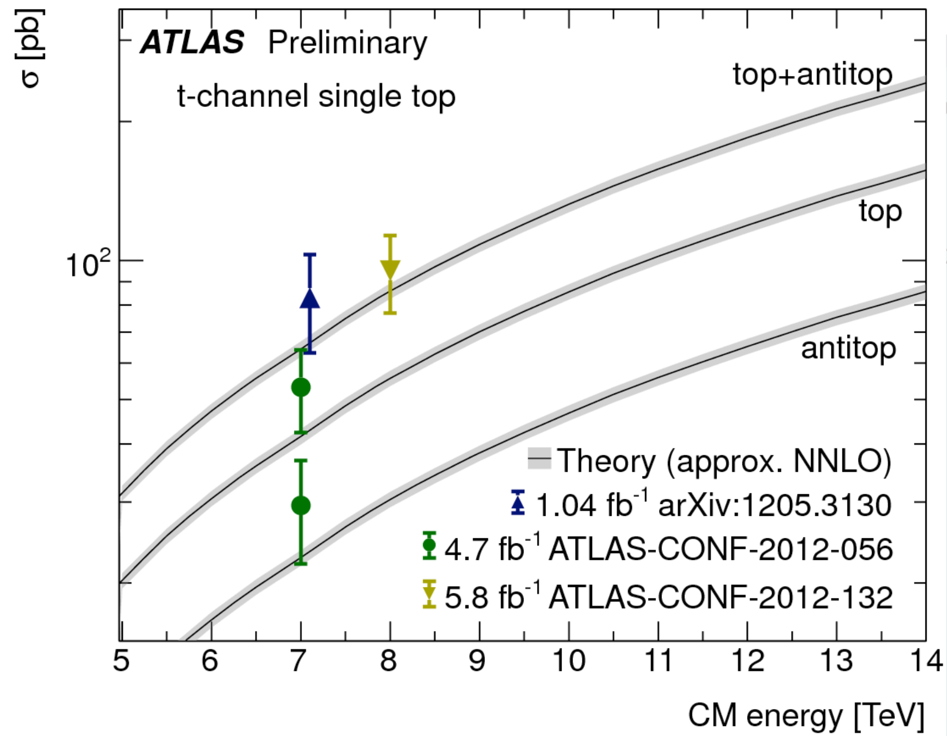

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The top quark

top-quark width @NLO:

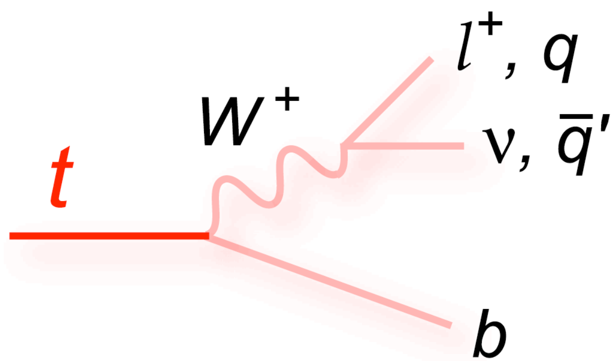
pdg2012

$$\Gamma_t = \frac{G_F m_t^3}{8\pi\sqrt{2}}\left(1-\frac{M_W^2}{m_t^2}\right)^2\left(1+2\frac{M_W^2}{m_t^2}\right)\left[1-\frac{2\alpha_s}{3\pi}\left(\frac{2\pi^2}{3}-\frac{5}{2}\right)\right]$$

$$\Gamma_t(m_t = 172.5\ \mathrm{GeV}) \approx 1.3\ \mathrm{GeV} \gg \Lambda_{\mathrm{QCD}}$$

the top lifetime is ~5x10^{-25}s.
The top quark decays before top flavored hadrons or top-quark bound states can form.
We have access to the “bare” quark properties

top-quark decays



Top decays into Ws or Wd are suppressed by the square of the corresponding CKM matrix elements $|V_{ts}|$ and $|V_{td}|$.

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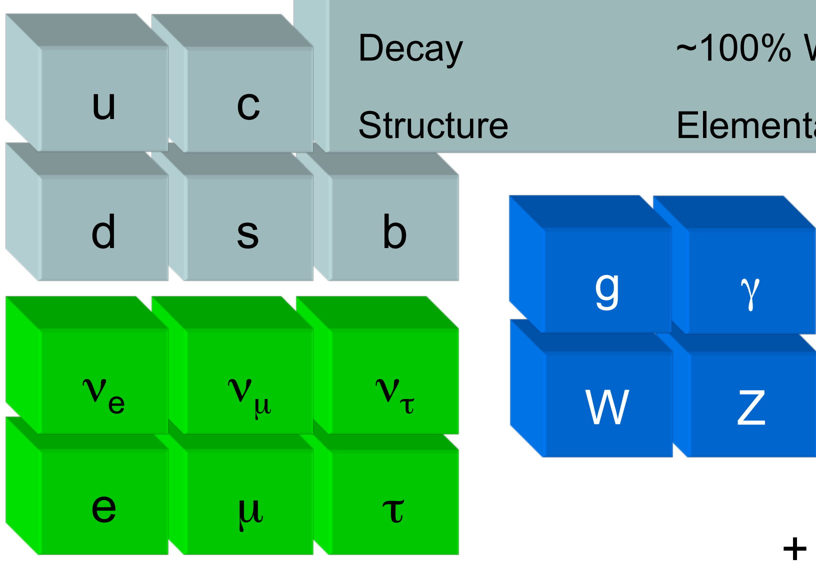
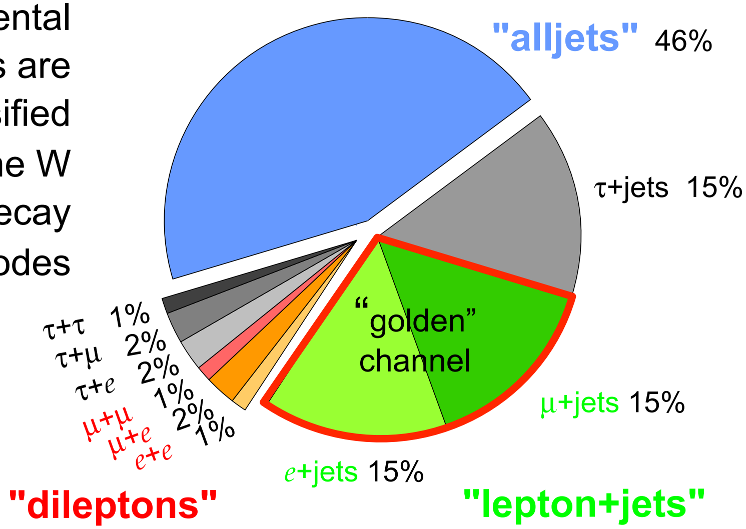


+ Higgs + …

Top Pair Branching Fractions

Experimental signatures are classified according to the W boson decay modes



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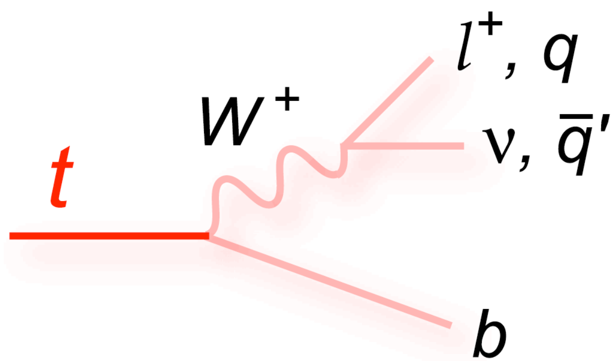

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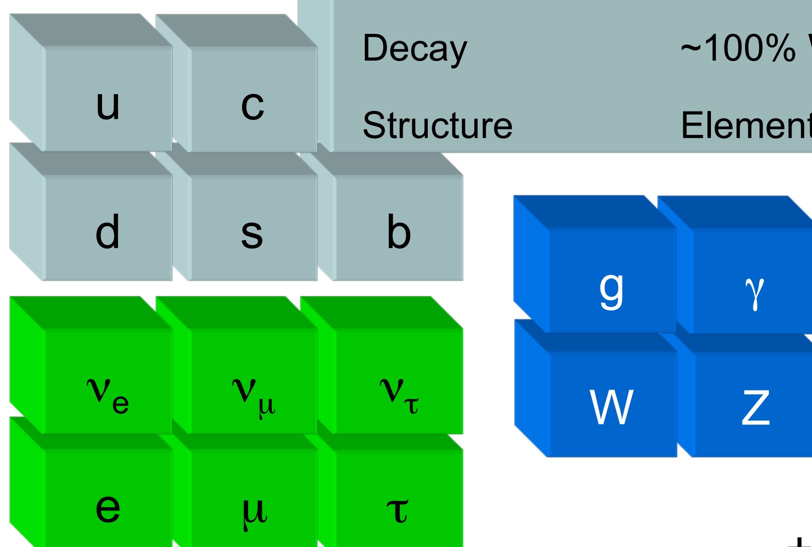

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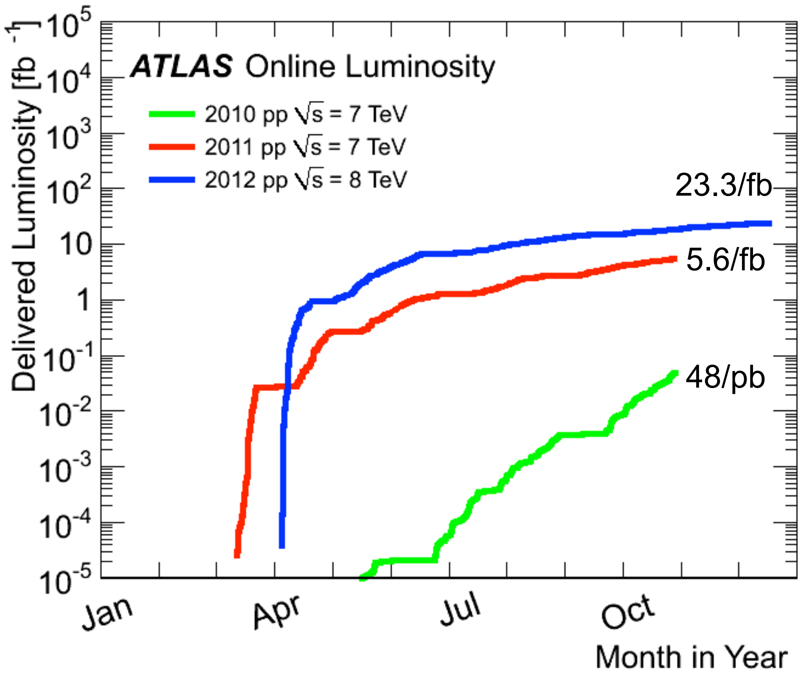
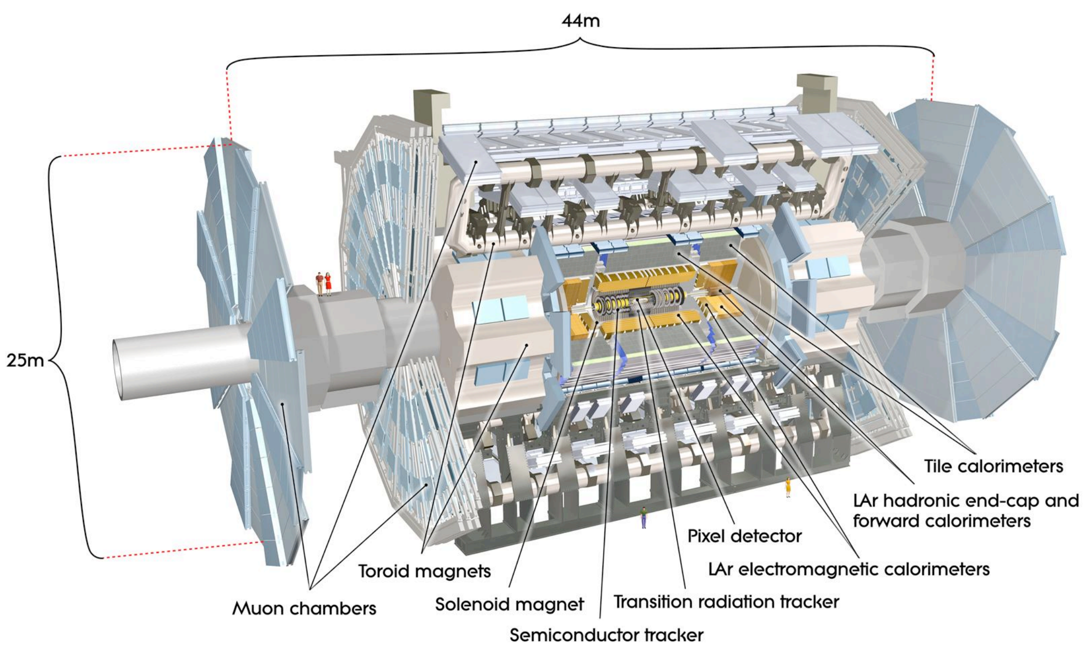
Top-quarks and ATLAS



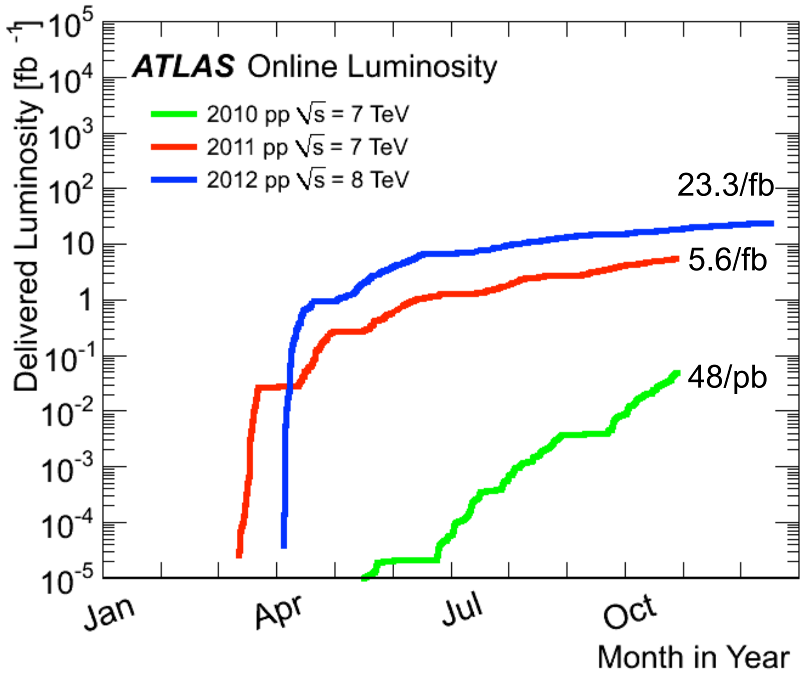
# of produced top-quark pairs (single top-quark) events:

- ~5.5 M (2.6 M) for 2012 data $\sqrt{s}$ = 8 TeV
- ~0.9 M (0.4 M) for 2011 data $\sqrt{s}$ = 7 TeV
- ~6 k (3 k) for 2010 data $\sqrt{s}$ = 7 TeV



- Thanks to the impressive performance of the LHC
- Unprecedented large top-quark enriched samples are now available.

Top-quarks and ATLAS



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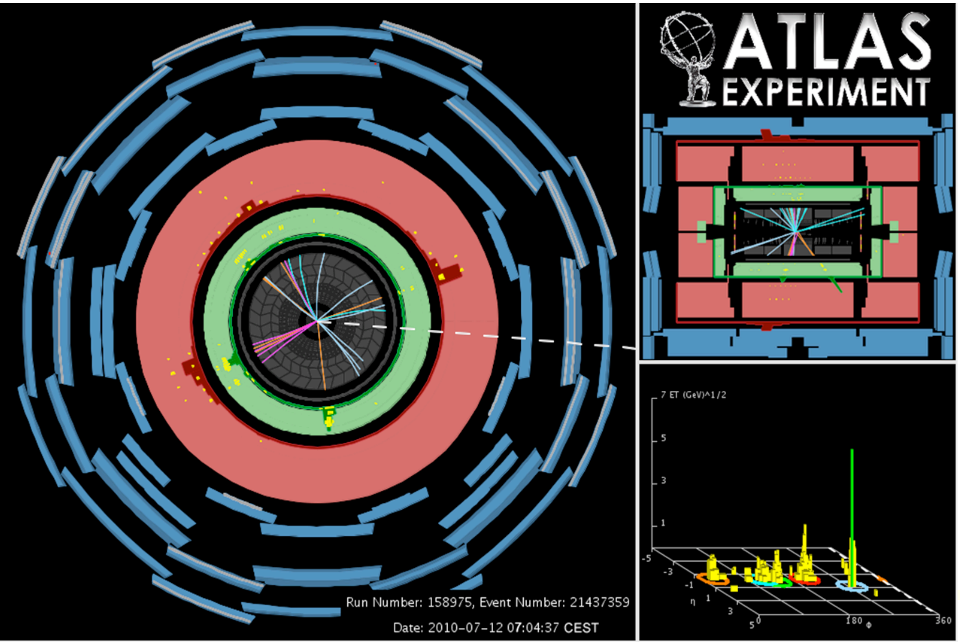
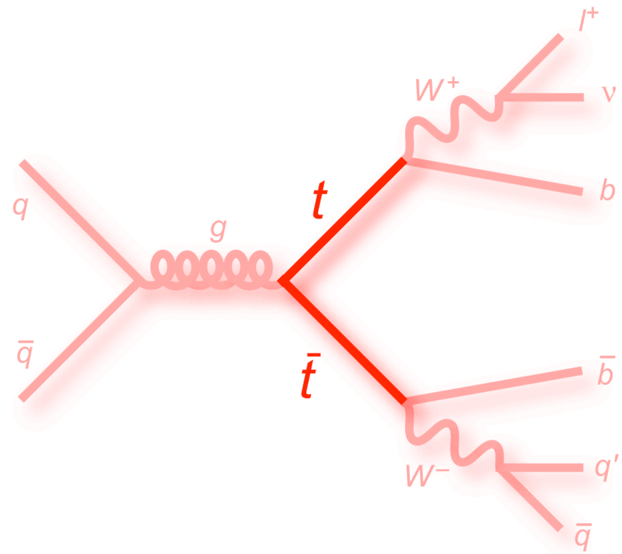


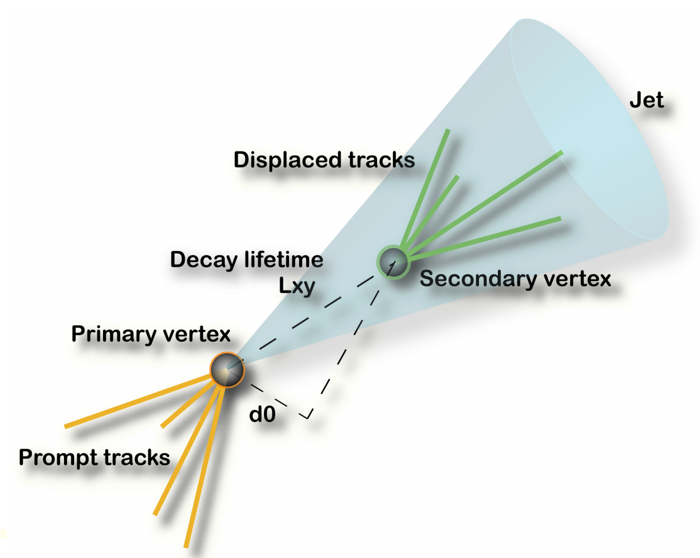
- Top-quarks decays involve charged leptons, jets and missing E_T (from ν)
- The full detector sub-systems are at play!
- Top quark enriched samples allow for the assessment and the refinement of the data analysis tools and of the detector performance
  - b-tagging calibration
  - jet energy scale cross checks

Top performance for top precision

- *b*-tagging:
  - it is an essential tool for physics processes including high-p_T *b*-quark jets in the final state
    - Top-quark physics, Higgs physics, new physics searches
  - a powerful tool in top-quark physics
    - to reduce background contamination
    - to limit the combinatorics in the kinematical reconstruction of the events.



- *b*-tagging algorithms exploit the b-hadron properties:
  - relative long life time: displaced tracks/decay vertices
  - relatively large B-hadron masses
  - semileptonic decays (~40% including b→c→lνX decay)
  - Advanced Neural net based algorithms (MV1), combine several information to improve the performance.



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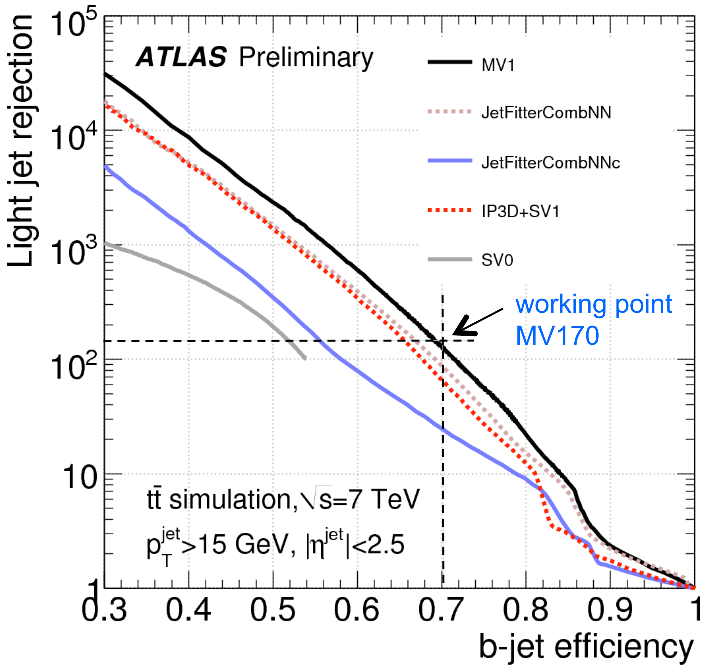

ATLAS-CONF-2012-043

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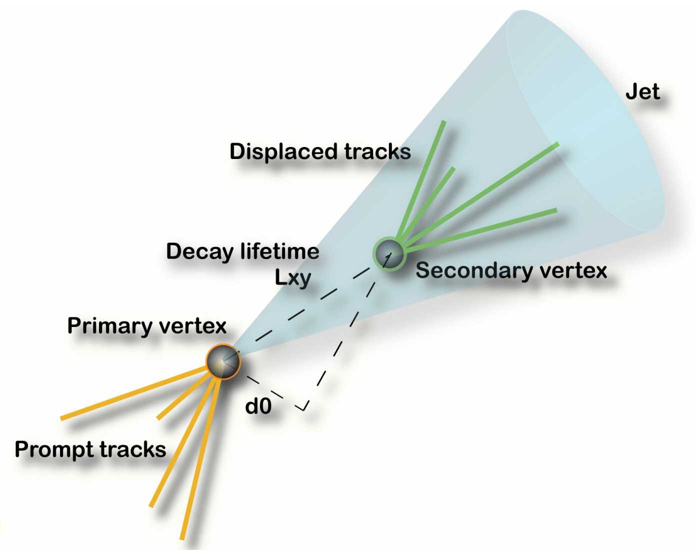
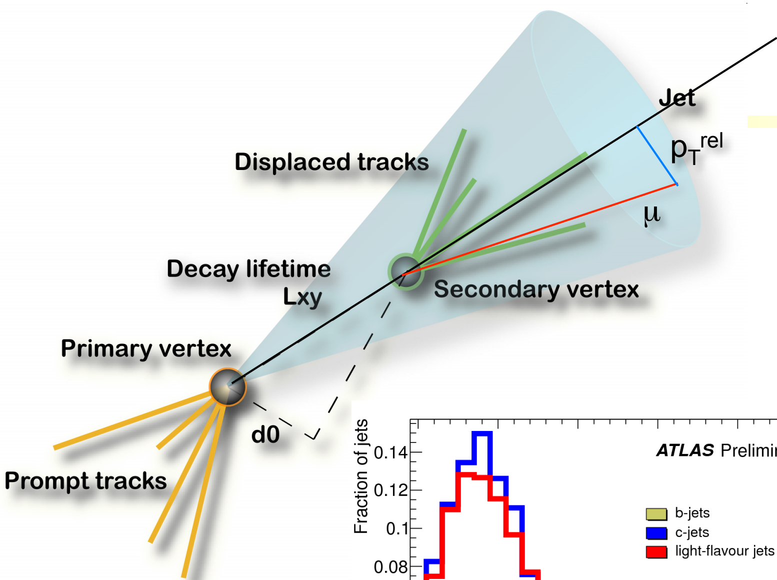
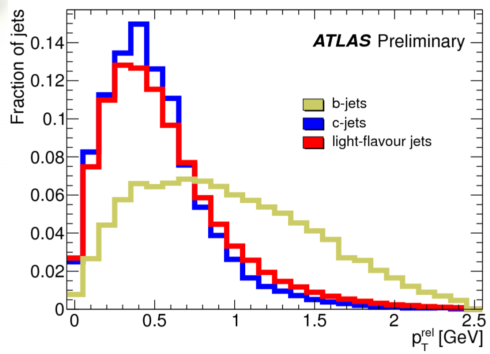
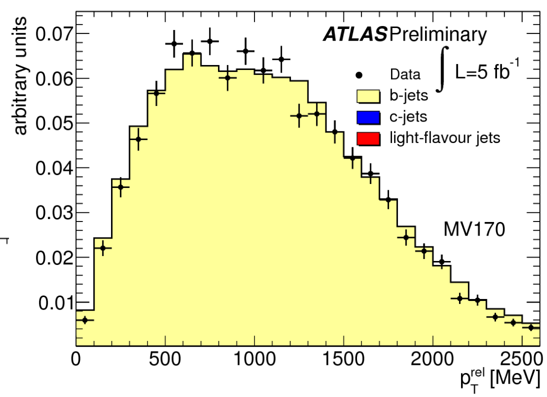


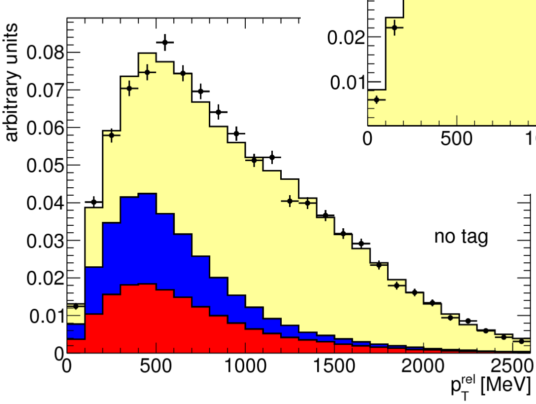
b-tag efficiency -1

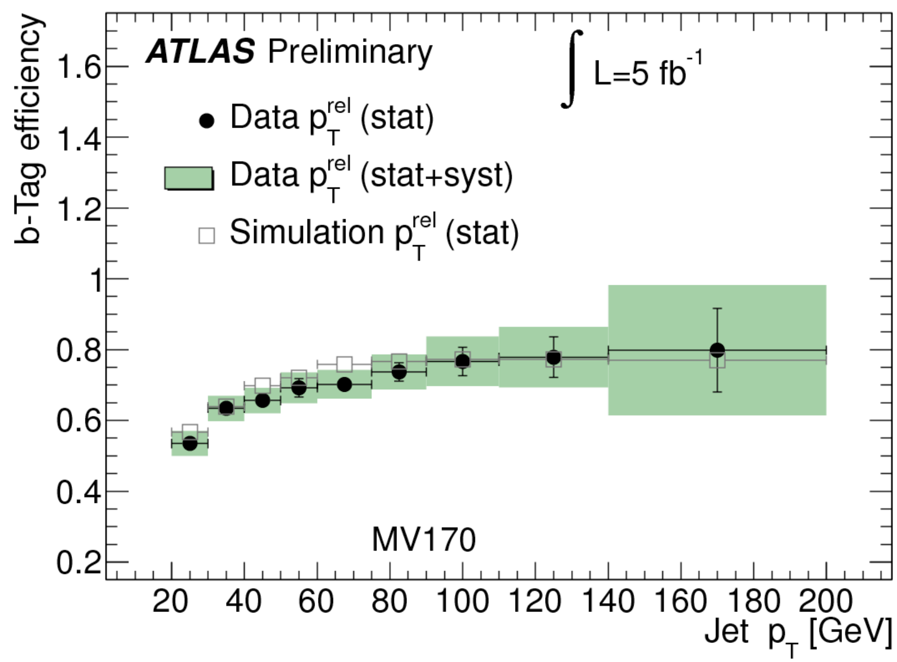
- Select a sample of events with jets containing muons
  - ***p_T^{rel}***: template fit of muon p_T with respect to the jet axis (p_T^{rel}) to get flavor fraction before and after b-tagging











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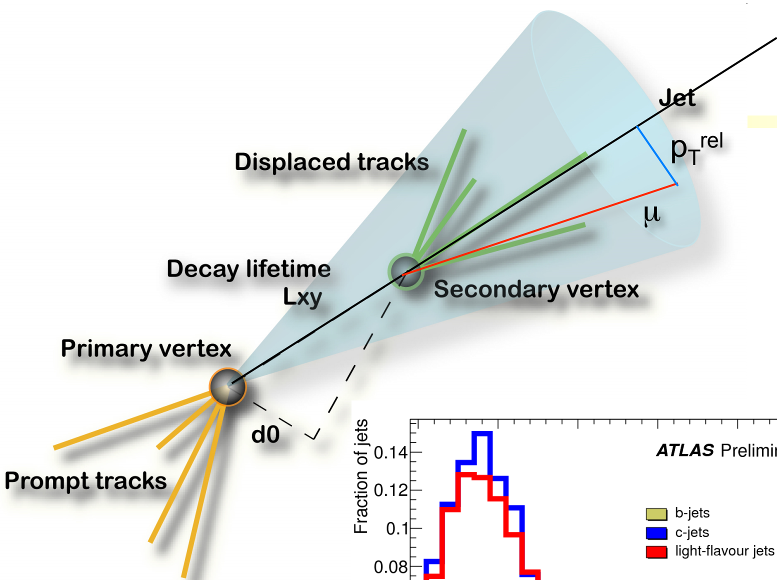

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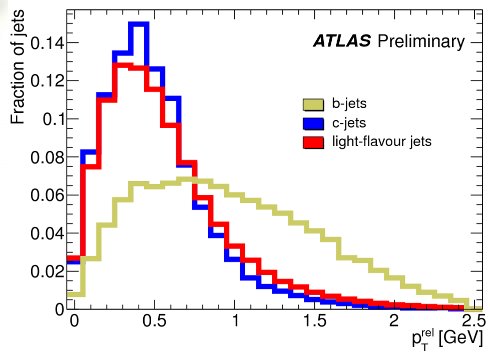
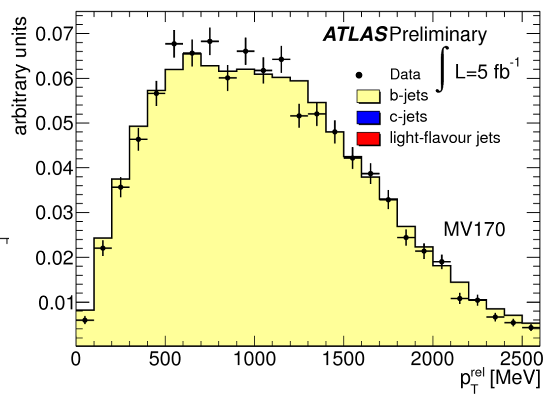
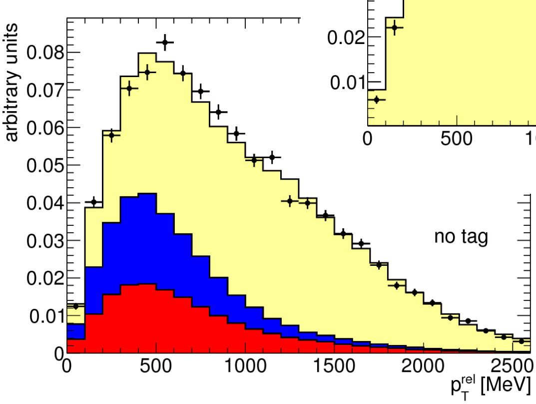
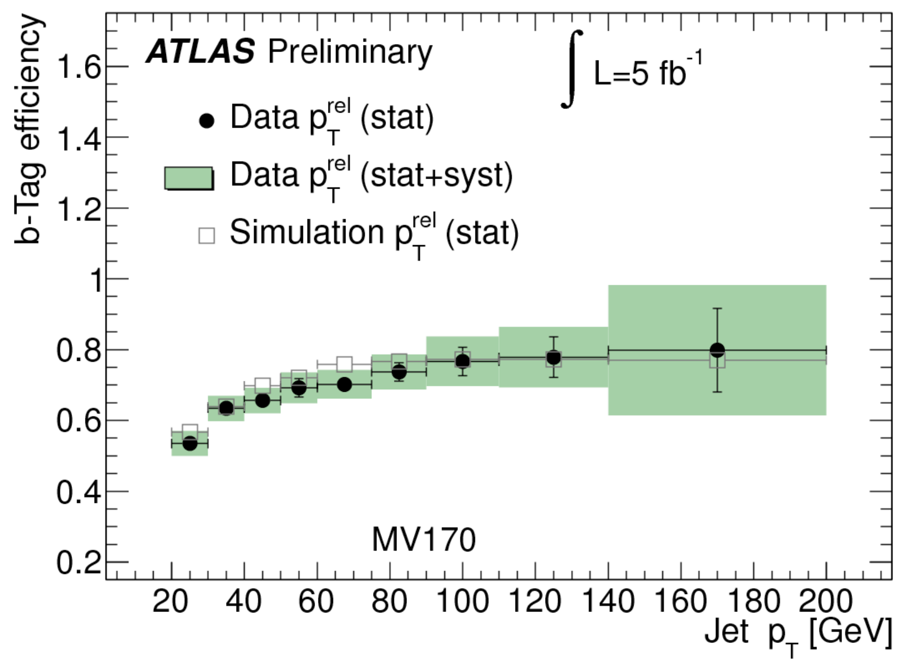
  - ***p_T^{rel}***: template fit of muon p_T with respect to the jet axis (p_T^{rel}) to get flavor fraction before and after b-tagging
  - ***System 8***: define independent jet selection criteria to construct 8 samples. Use event counts to solve for b-tagging efficiency.









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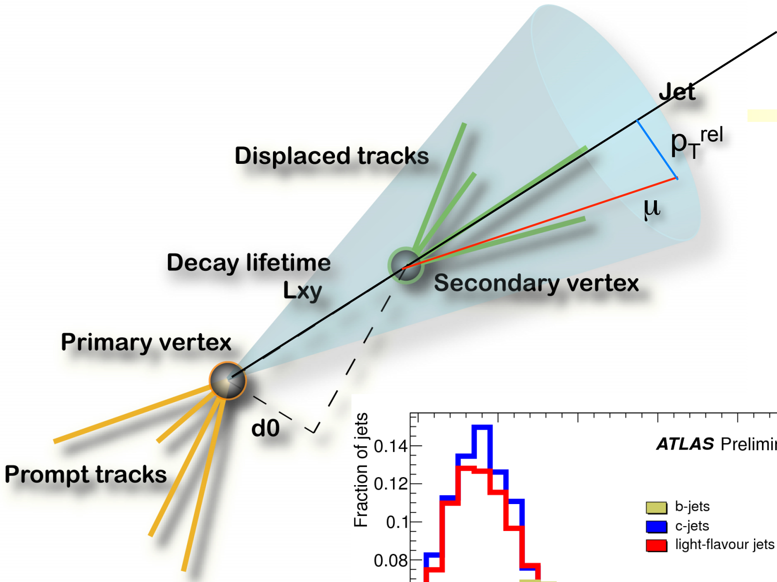
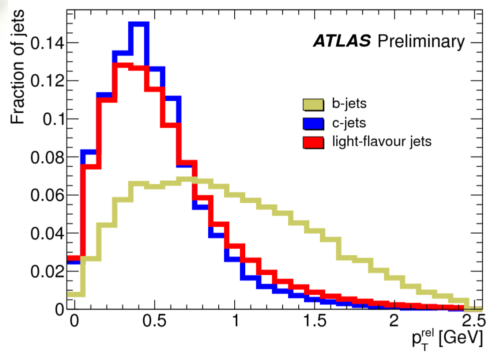
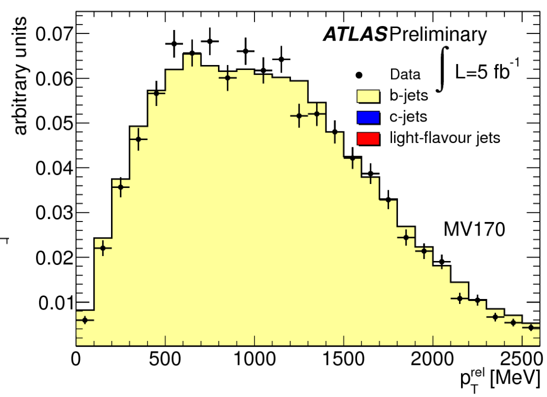
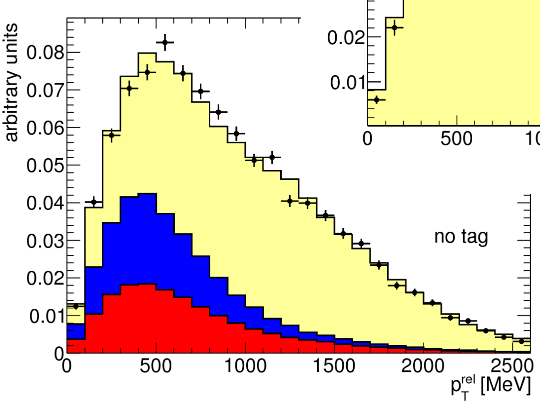
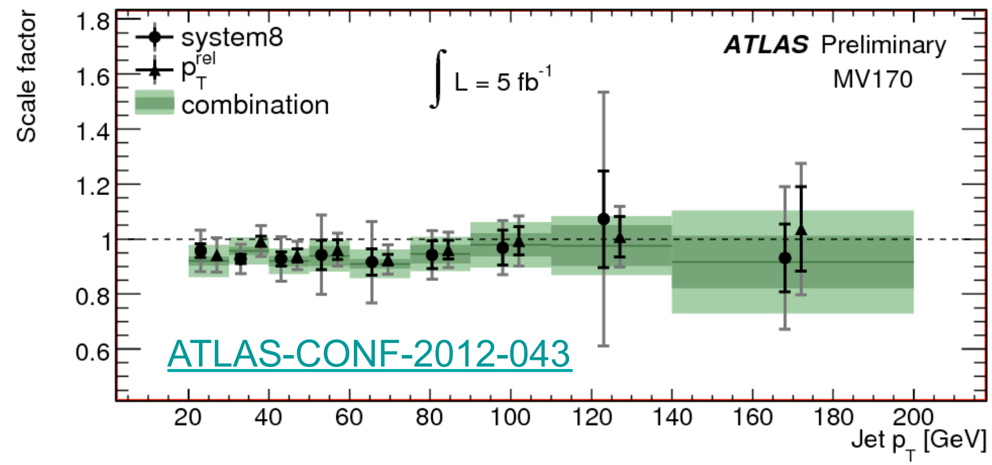








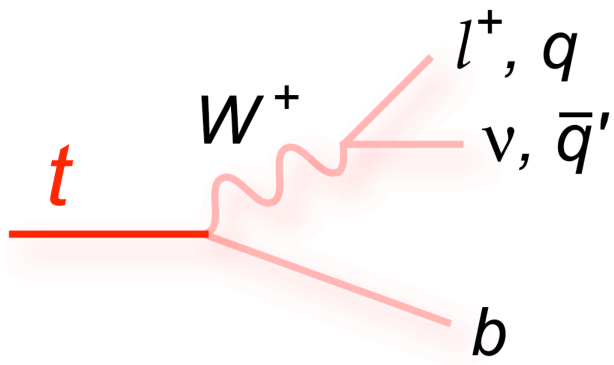
- Select a sample of events with jets containing muons
  - ***p_T^{rel}***: template fit of muon p_T with respect to the jet axis (p_T^{rel}) to get flavor fraction before and after b-tagging
  - ***System 8***: define independent jet selection criteria to construct 8 samples. Use event counts to solve for b-tagging efficiency.



- Uncertainties on the combined scale factors range from 5% to 19% at low and high jet p_T (reduced method sensitivities in the high p_T range)
- Significant systematics (4%) due to the extrapolation to inclusive b-jets from b-jets with semileptonic decays

b-tag efficiency -2

- The limitation of the di-jet based b-tagging calibrations can be mitigated using top-quark pair events.



- These constitute a powerful and complementary calibration source:
  - nominally each event contain 2 b-quark jets.
  - calibrations refer to inclusive b-jets (not limited to the semileptonic b's)

ATLAS-CONF-2012-097

b-tag efficiency -2

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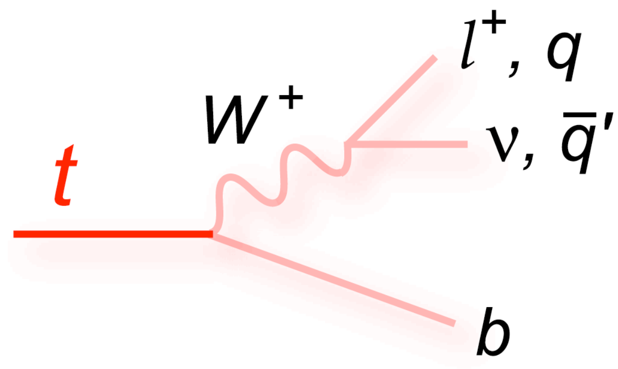
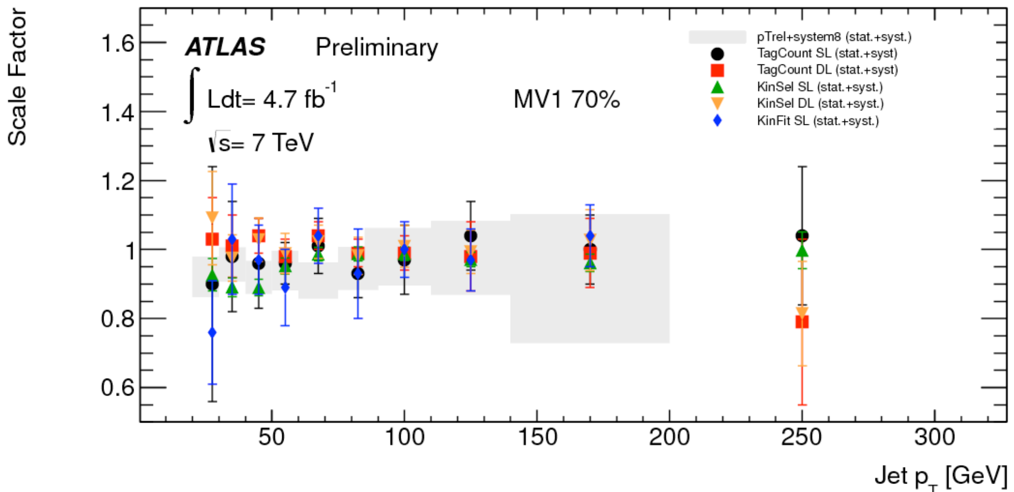


- These constitute a powerful and complementary calibration source:
  - nominally each event contain 2 b-quark jets.
  - calibrations refer to inclusive b-jets (not limited to the semileptonic b's)

ATLAS-CONF-2012-097

- Calibrations are derived from both dilepton / l+jets channels, with different methods
  - Tag counting
  - Kinematic selection (resting on the sample flavour comp.)
  - Kinematic fit (resting on the jet assignment from reconstruction algorithm)

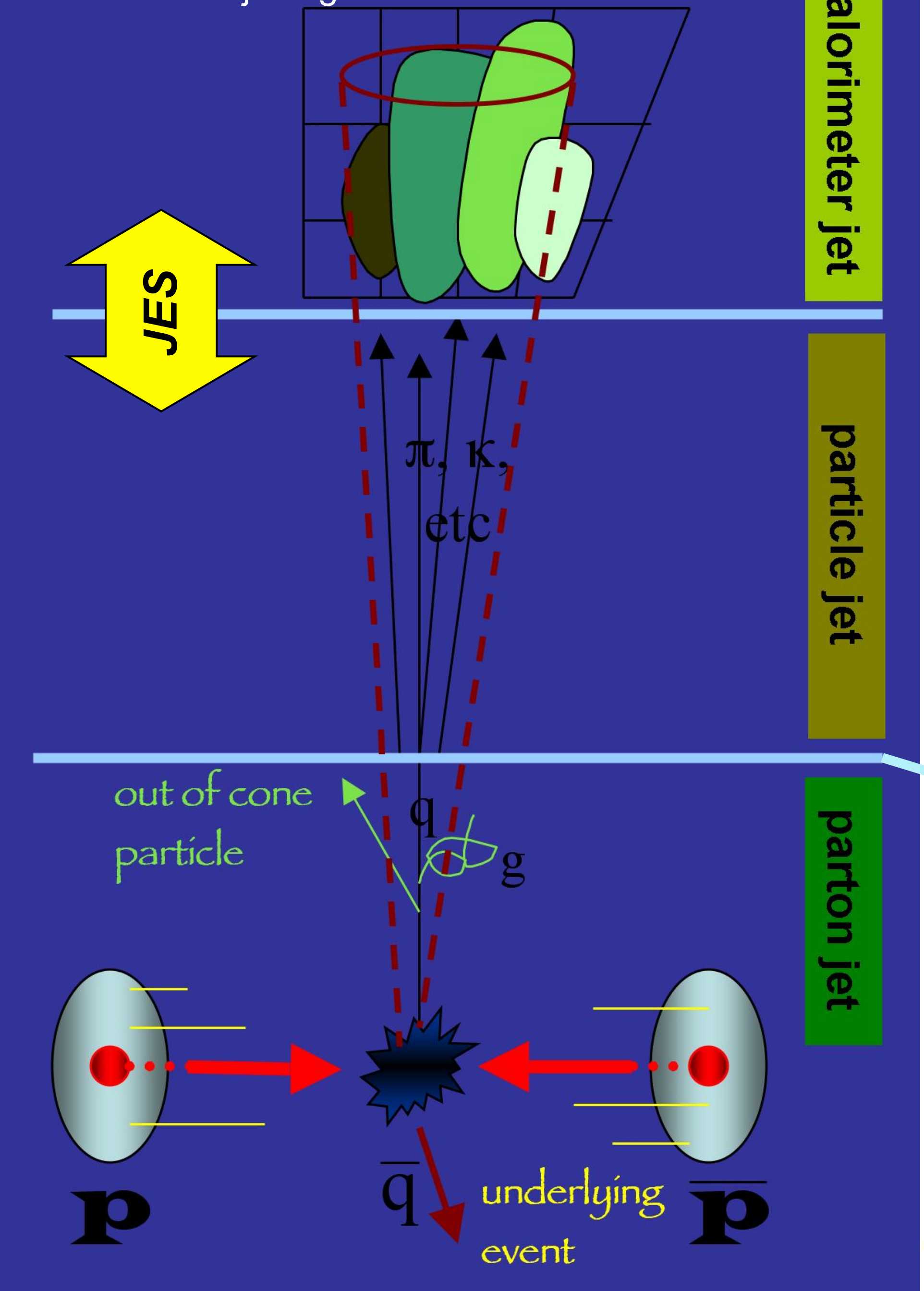


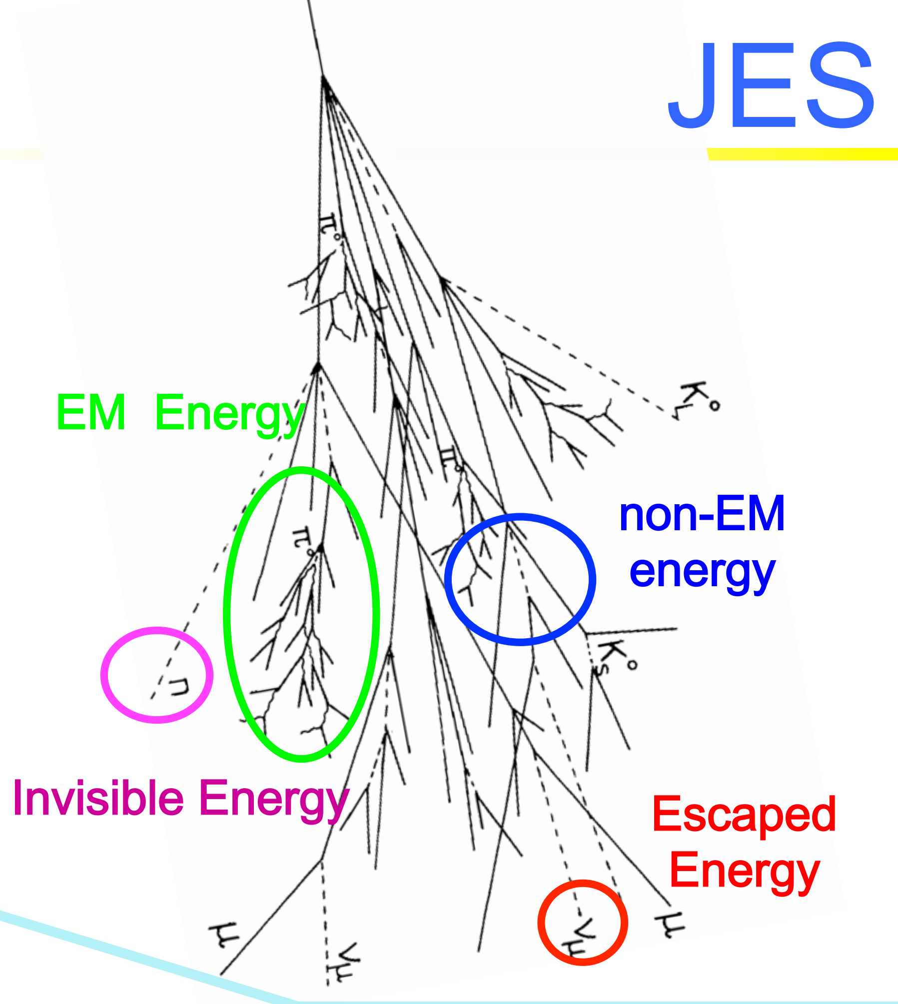
- Top-quark pair based calibrations allow:
  - a reduced p_T dependence of the SF uncertainties
  - to extend the SF p_T range
  - main/dominant systematics in common to top-quark physics analyses

- For analyses combined di-jets and top-pair (dilepton / l+jets) SF calibration are available

JES

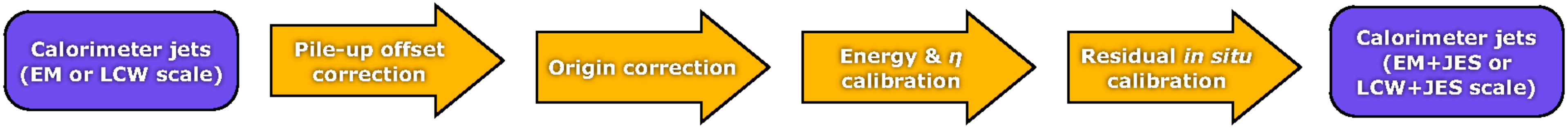
ATLAS top-quark analyses use anti-kt R=0.4 jet algorithm





- The energy determination of the impinging parton is complicated by
  - physics effects
  - not-instrumented regions of the detector
  - energy contribution from multiple interactions (pile-up)

ATLAS Jet energy calibration



Corrects for the energy offset introduced by pile-up. Depends on μ and N_{PV}. Derived from MC.

Changes the jet direction to point to the primary vertex. Does not affect the energy.

Calibrates the jet energy and pseudorapidity to the particle jet scale. Derived from MC.

Residual calibration derived using *in situ* measurements. Derived in data and MC. Applied only to data.

ATLAS-CONF-2013-004

Pile-up offset correction

Calorimeter jets (EM or LCW scale)

Corrects for the energy offset introduced by pile-up. Depends on μ and N_{PV}. Derived from MC.

Origin correction

Changes the jet direction to point to the primary vertex. Does not affect the energy.

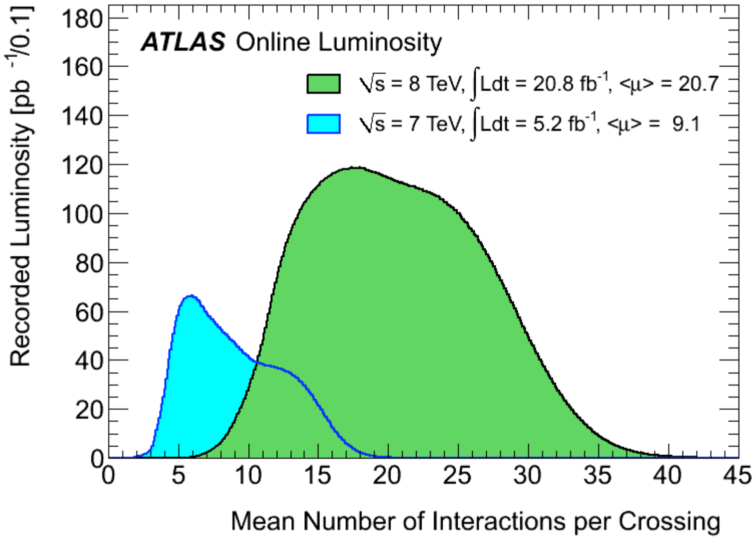
Energy & η calibration

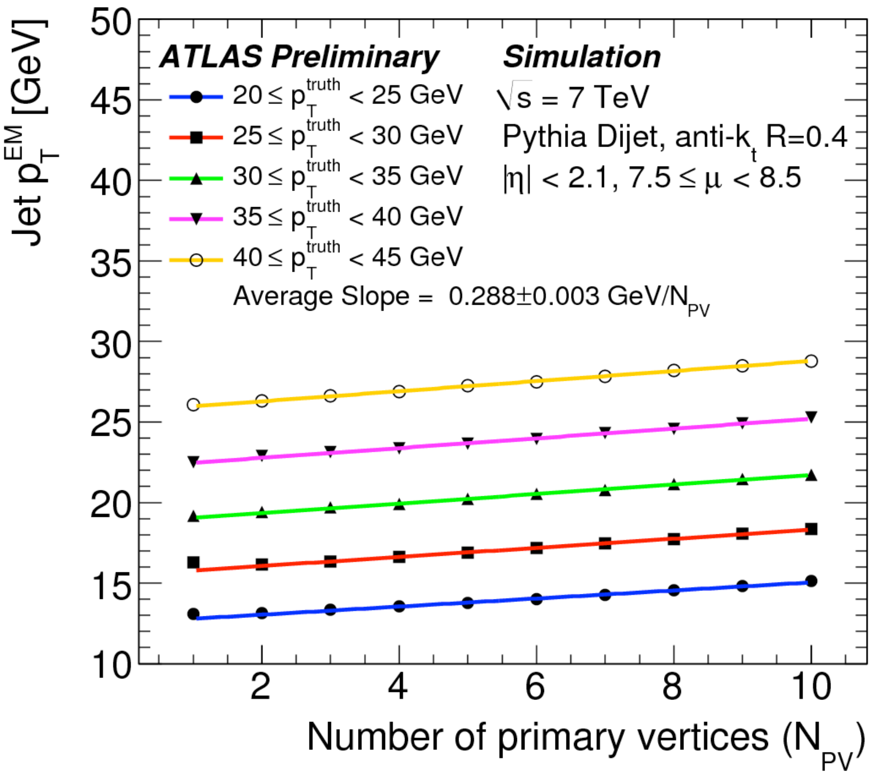
Calibrates the jet energy and pseudorapidity to the particle jet scale. Derived from MC.

Residual *in situ* calibration

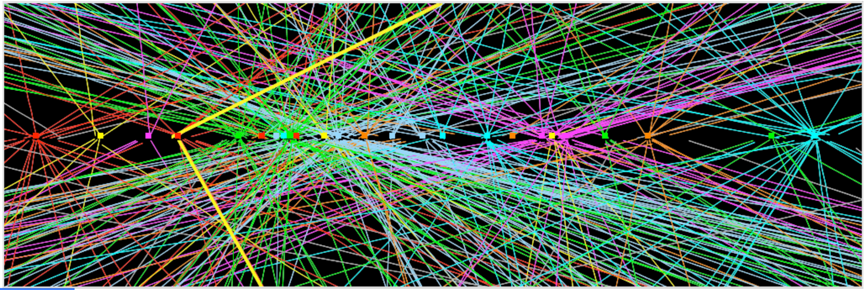
Residual calibration derived using *in situ* measurements. Derived in data and MC. Applied only to data.

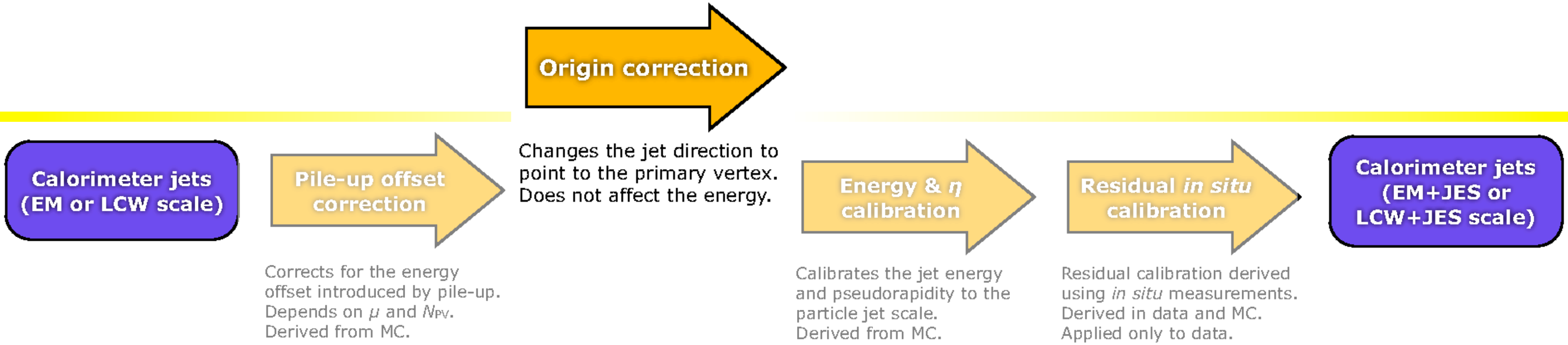
Calorimeter jets (EM+JES or LCW+JES scale)





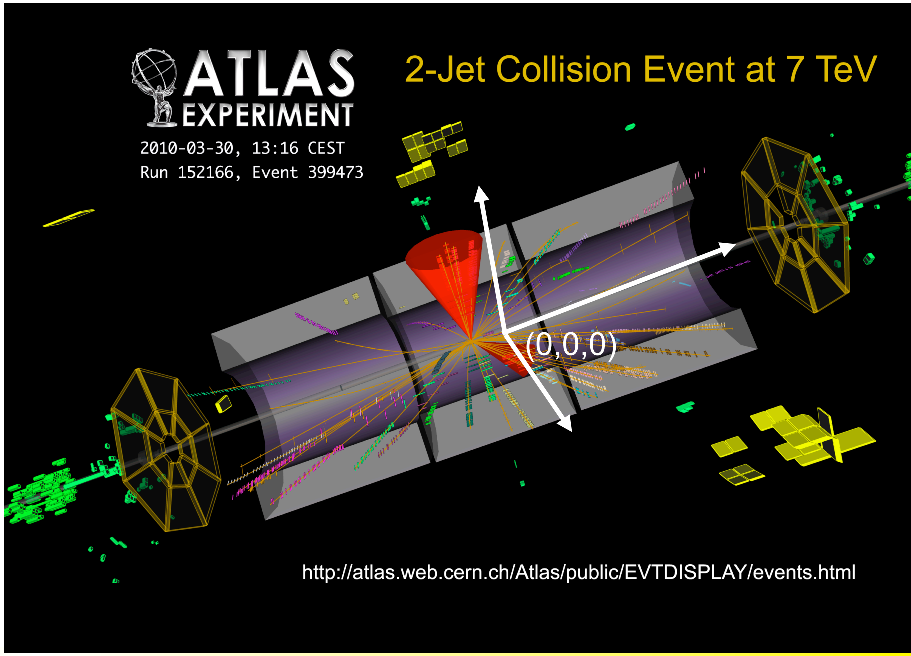
Z →μμ with 25 pileup events

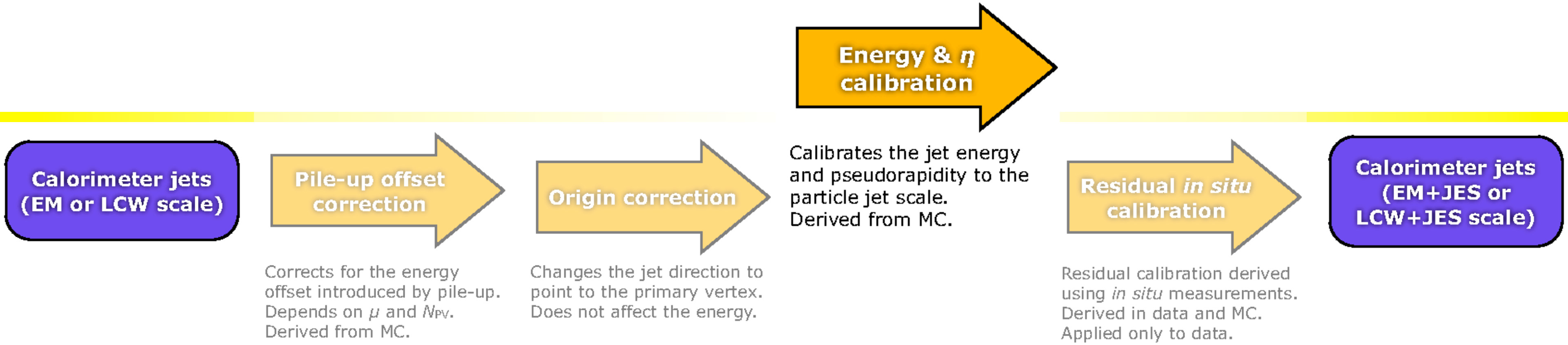




- The jet 4-momentum is corrected event-by-event by using the actual information of the primary vertex of the event (hard interaction)

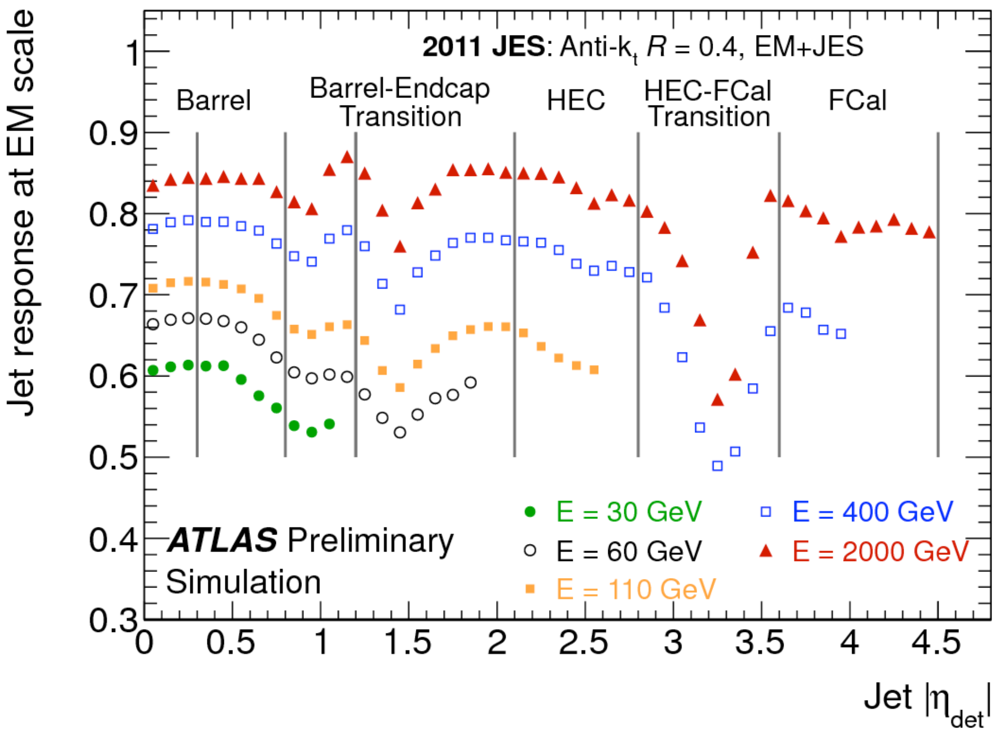
- Jets are initially reconstructed assuming the hard interaction to take place at the geometrical center of the detector.





- Restore the energy of the reconstructed jets at the EM scale to that of stable particle jets from MC.
  - The correction is parameterized as a function of the jet p_T and η and is defined as the inverse of (the response):

$$\mathcal{R}_{\mathrm{EM}}^{\mathrm{jet}} = E_{\mathrm{calo}}^{\mathrm{EM}} / E_{\mathrm{truth}}$$



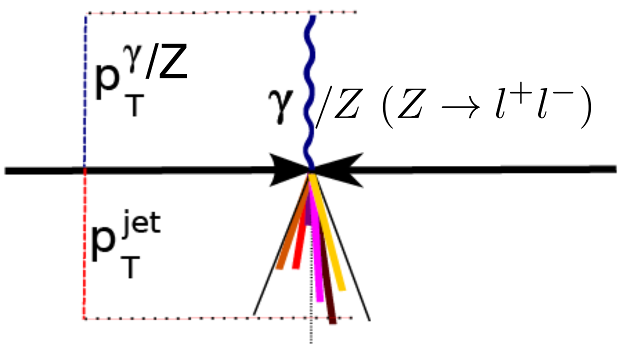
Residual *in situ* calibration

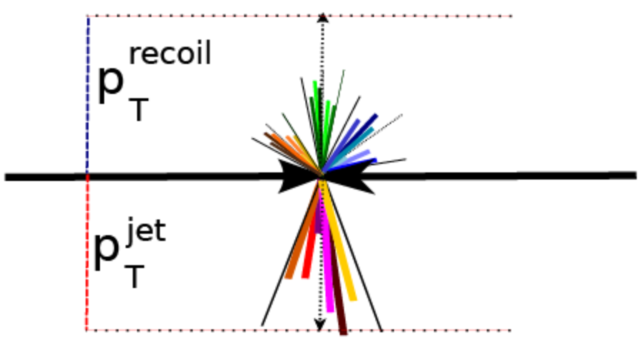
Residual calibration derived using *in situ* measurements. Derived in data and MC. Applied only to data.

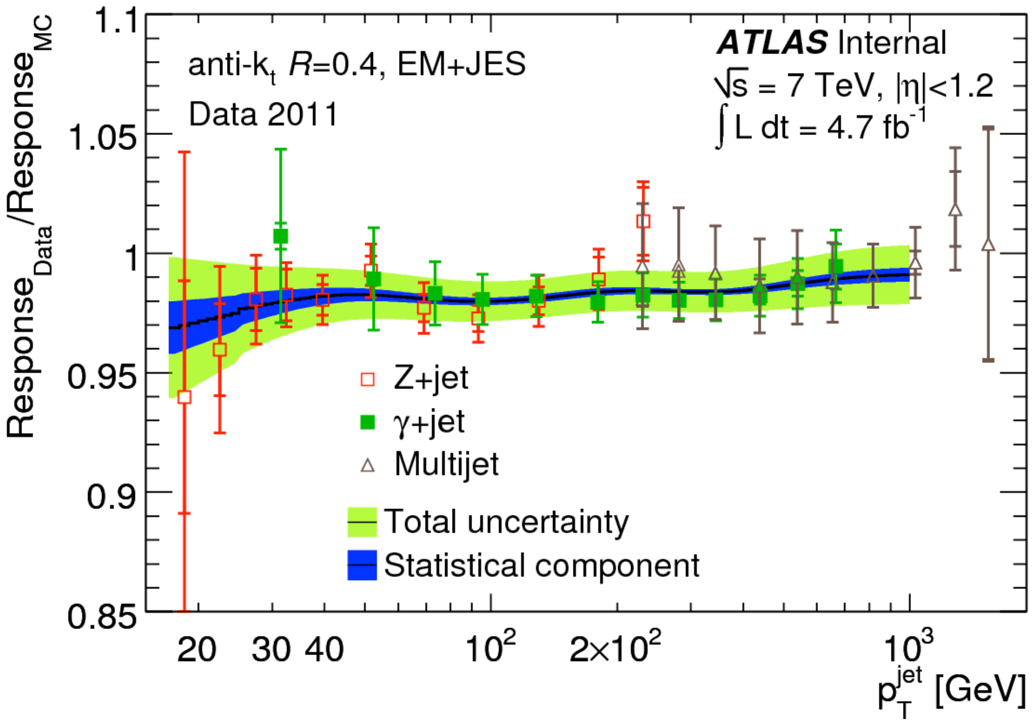
Calorimeter jets (EM or LCW scale) → **Pile-up offset correction** → **Origin correction** → **Energy & η calibration** → **Residual *in situ* calibration** → **Calorimeter jets (EM+JES or LCW+JES scale)**

- Pile-up offset correction: Corrects for the energy offset introduced by pile-up. Depends on μ and N_{PV}. Derived from MC.
- Origin correction: Changes the jet direction to point to the primary vertex. Does not affect the energy.
- Energy & η calibration: Calibrates the jet energy and pseudorapidity to the particle jet scale. Derived from MC.

- Exploit reference objects to refine the calibration:

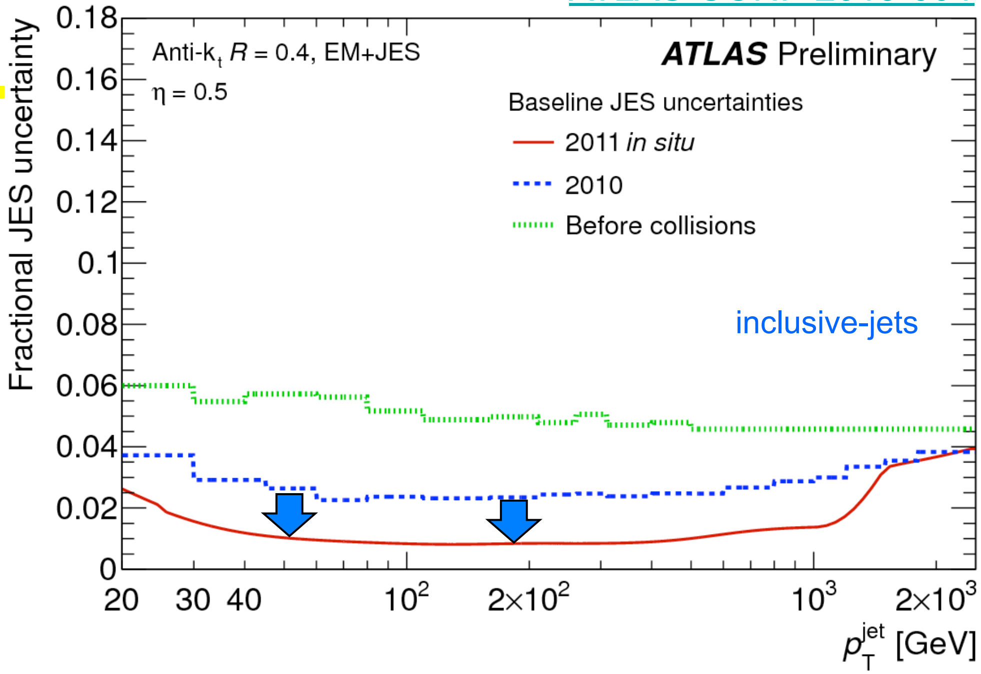






ATLAS-CONF-2013-004

JES uncertainty

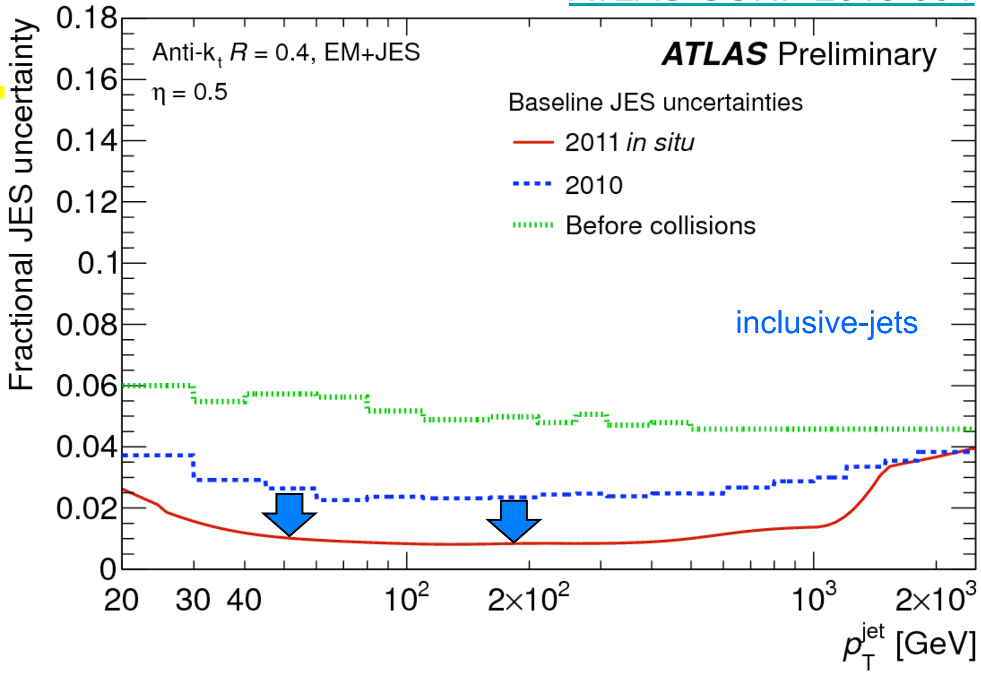


- Impressive improvements on the baseline JES determination using in-situ techniques.

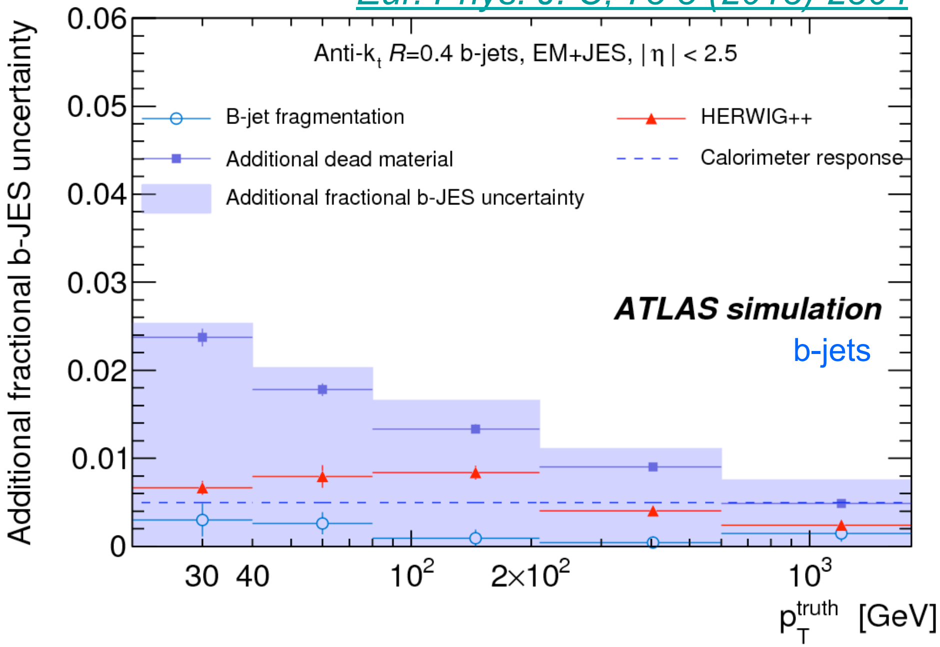
JES uncertainty

- Impressive improvements on the baseline JES/bJES determination using in-situ techniques.

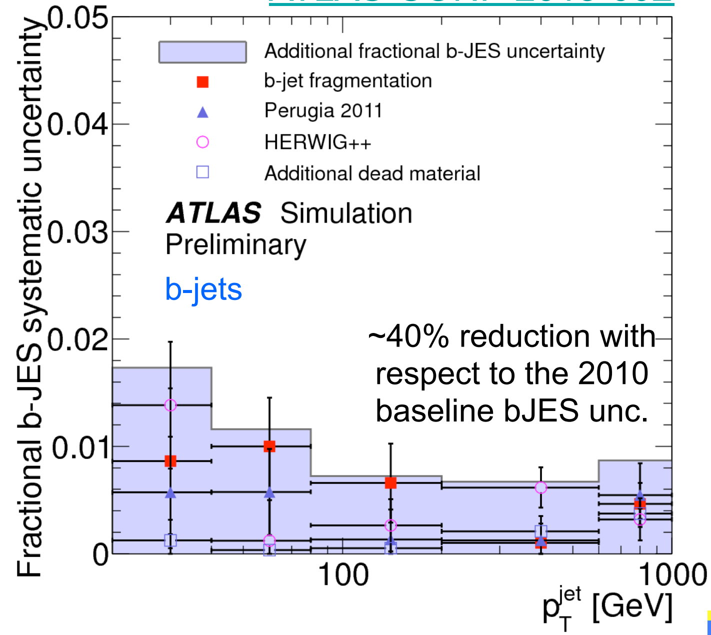
ATLAS-CONF-2013-004



Eur. Phys. J. C, 73 3 (2013) 2304

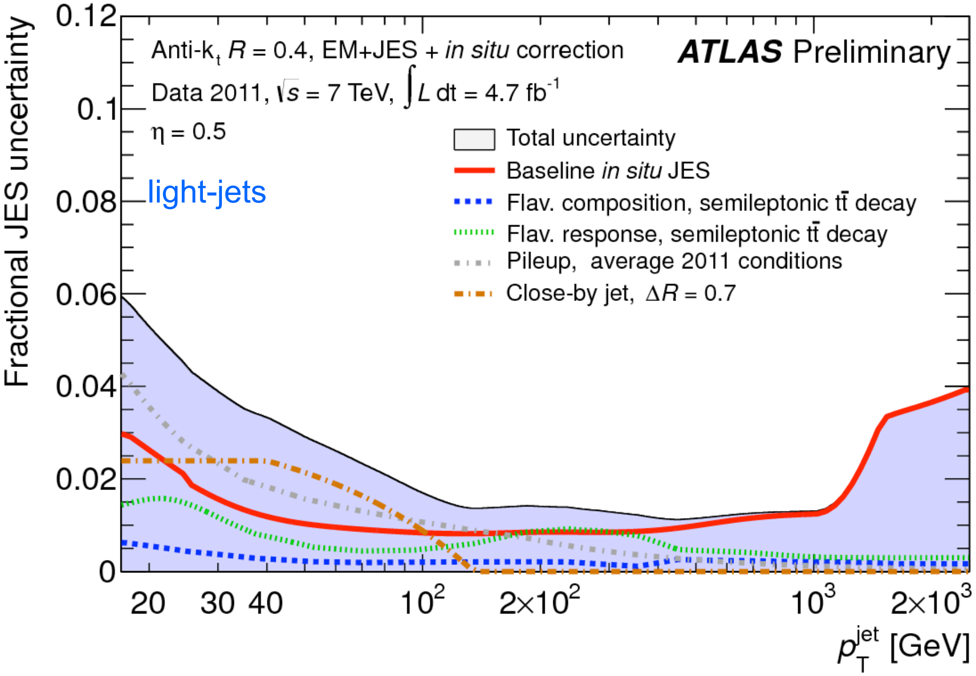


ATLAS-CONF-2013-002

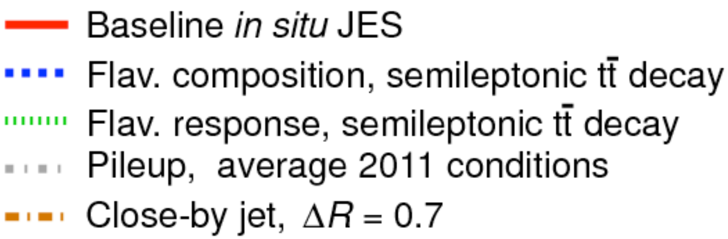


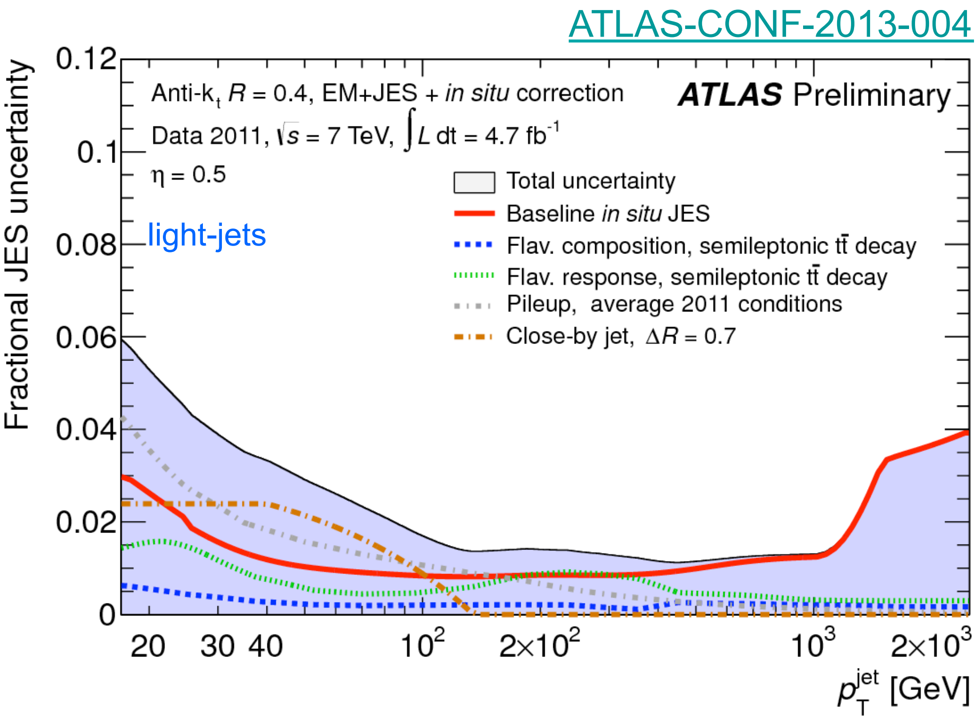
JES uncertainty

ATLAS-CONF-2013-004



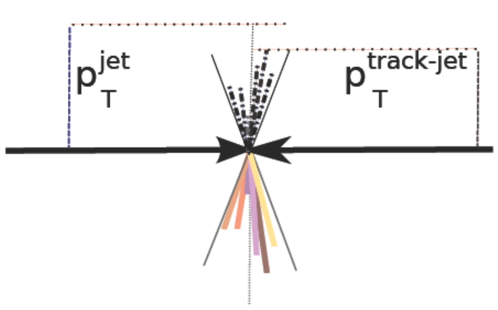
- Still the JES/bJES unc. are potential main sources of systematic uncertainty in top-quark analyses.
  - Additional topology/flavour dependent uncertainties affect the top-quark analyses.





JES uncertainty

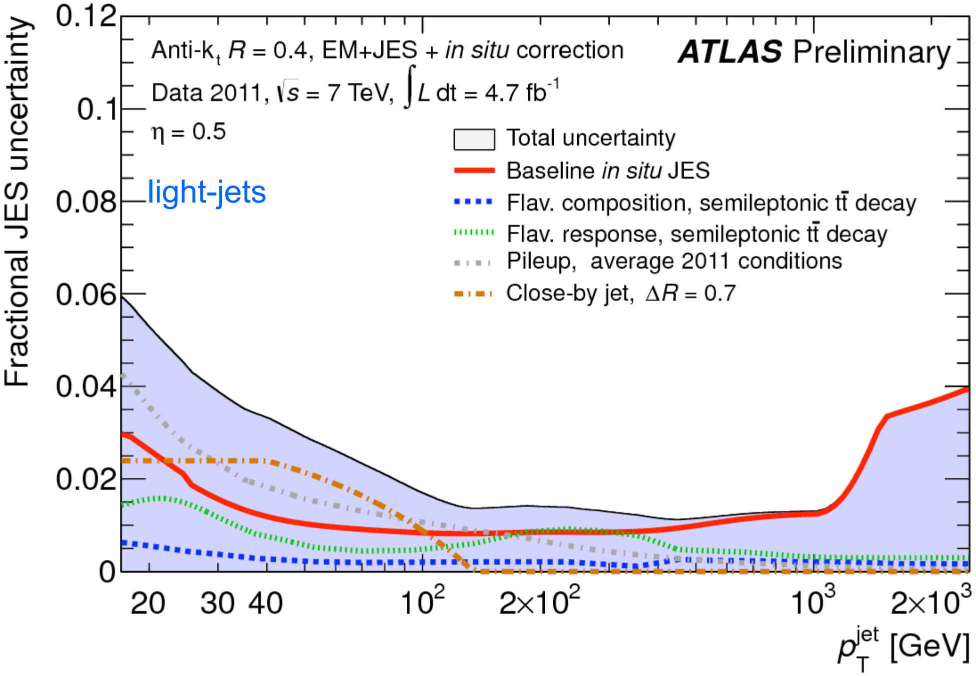
- Still the JES/bJES unc. are potential main sources of systematic uncertainty in top-quark analyses.
  - Additional topology/flavour dependent uncertainties affect the top-quark analyses.
- Important to have an independent validation of the JES uncertainty.
  - use tracks within jets in di-jets and top-pair events.

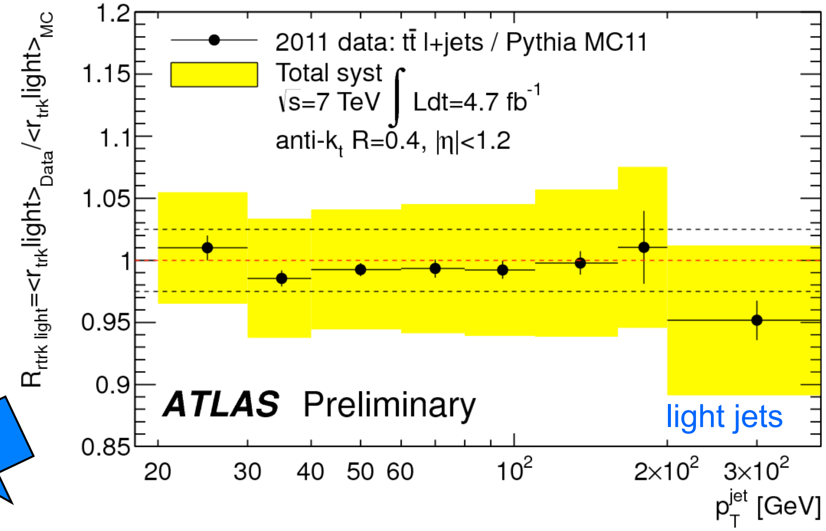


$$r_{\rm trk} = \frac{\sum \vec{p}_T^{\,\rm track}}{p_T^{\rm jet}}$$

$$R_{r_{\rm trk}} \equiv \frac{[< r_{\rm trk} >]_{\rm data}}{[< r_{\rm trk} >]_{\rm MC}}$$

ATLAS-CONF-2013-004





ATLAS-CONF-2013-002

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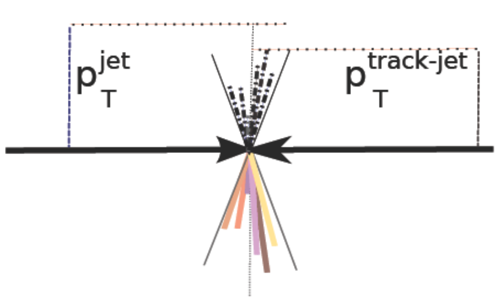

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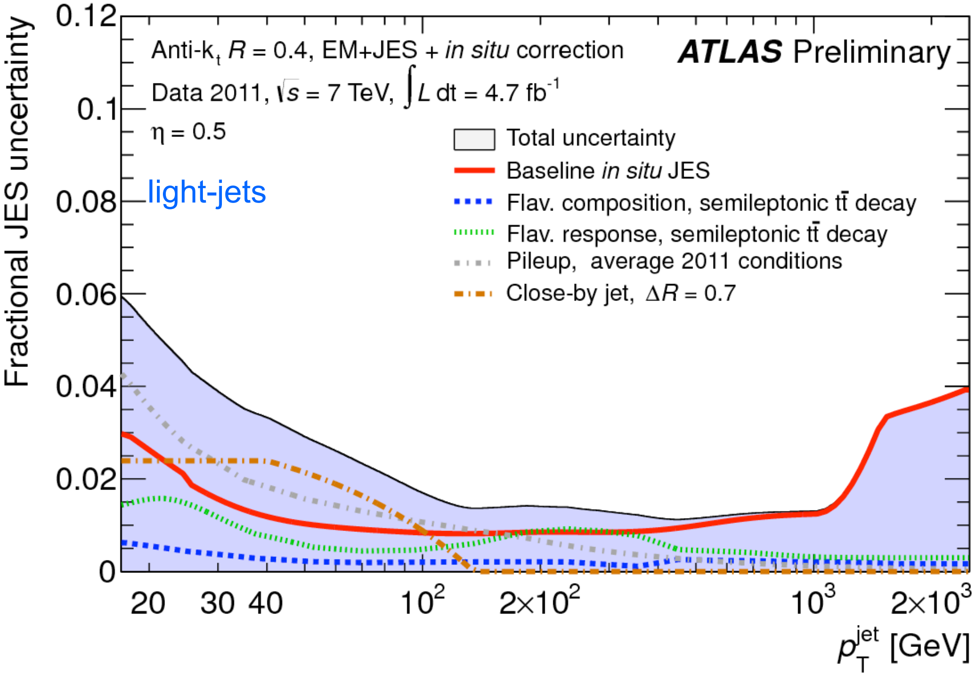
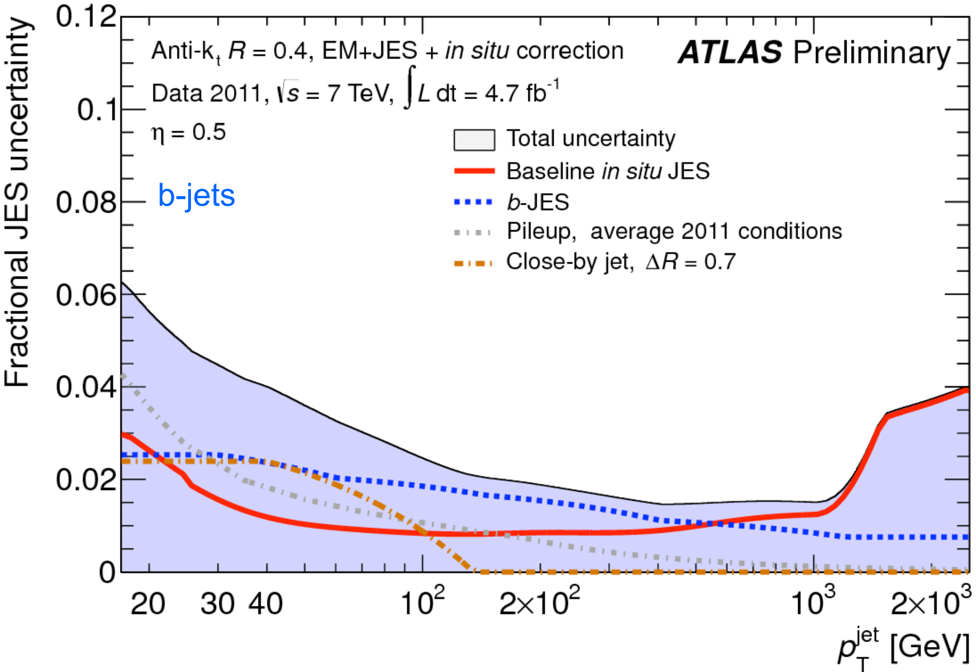
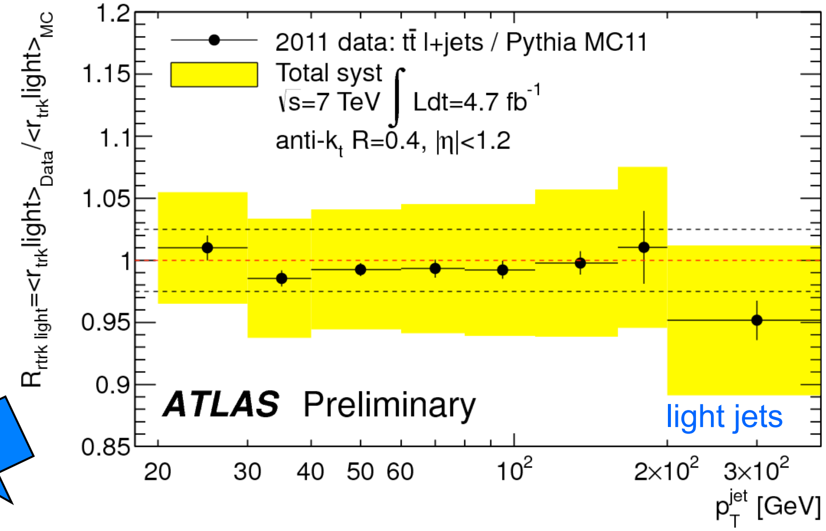
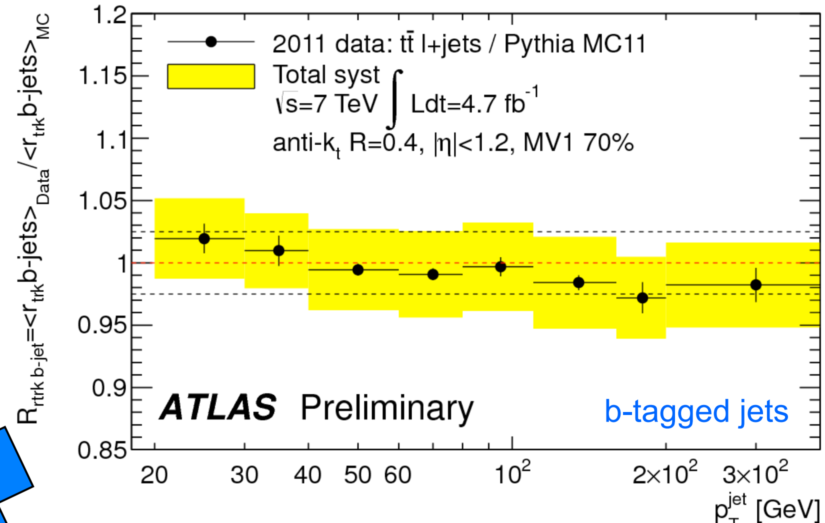
ATLAS-CONF-2013-004

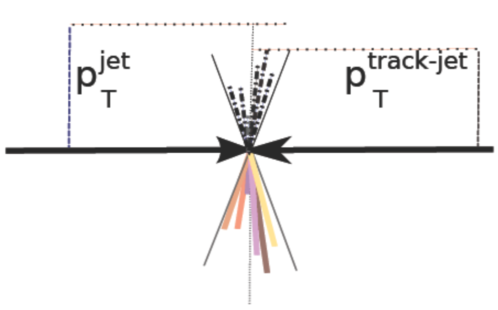








ATLAS-CONF-2013-002



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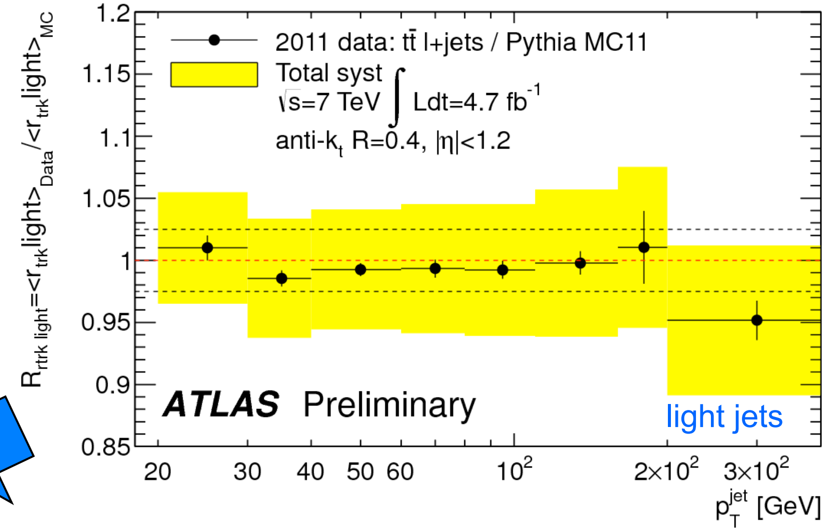
$$R_{r_{\mathrm{trk}}} \equiv \frac{[< r_{\mathrm{trk}} >]_{\mathrm{data}}}{[< r_{\mathrm{trk}} >]_{\mathrm{MC}}}$$

ATLAS-CONF-2013-004

$$R' \equiv \frac{R_{r_{\mathrm{trk,b-jets}}}}{R_{r_{\mathrm{trk,inclusive}}}}$$

Sensitive to the relative b-to-light jets energy scale



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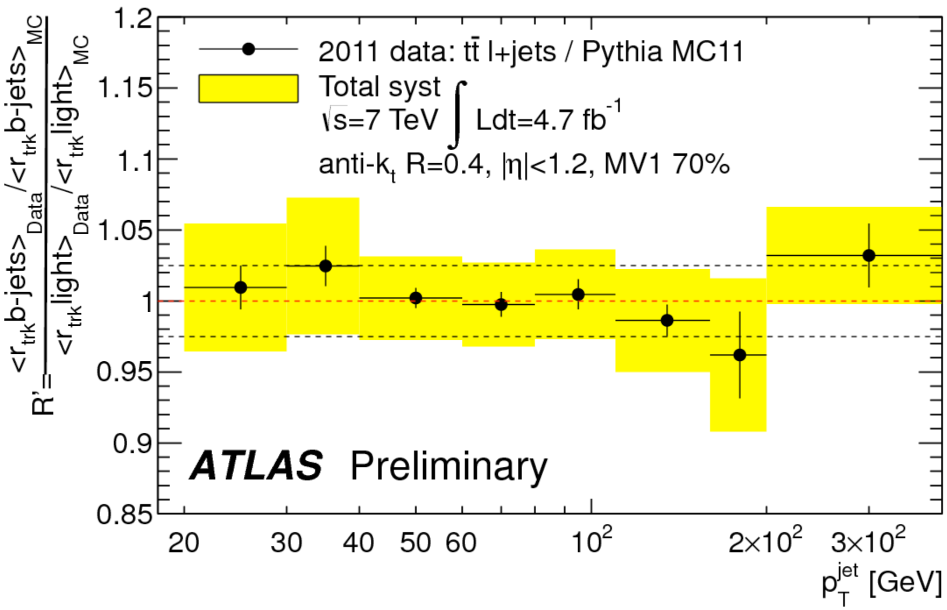
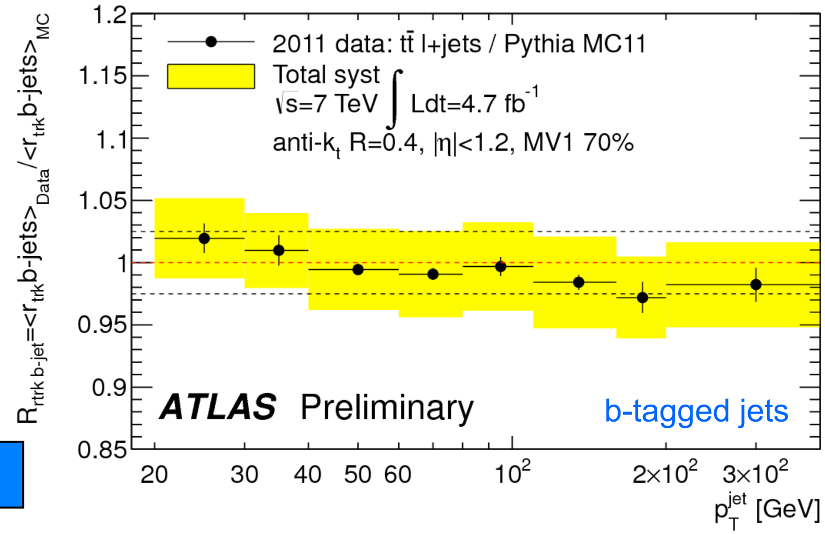
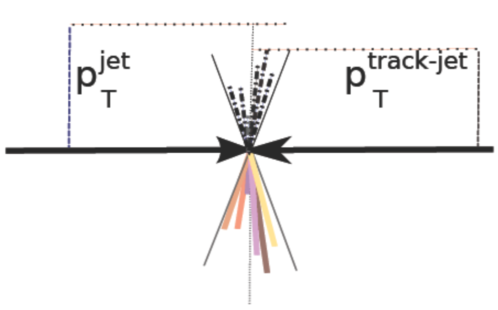




Top quark pair events complement the di-jet studies otherwise limited to intermediate to high p_T ranges due to jet trigger thresholds



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The top quark

- top-quark physics is one of the main pillars of the physics program at the LHC.
- The top-quark: a multipurpose physics candle at the LHC:
  - Precision measurements in the top-quark physics sector
    - drive improvements in the detector and physics tools understanding.
    - motivate refinements and tests of different physics aspects of top-quark modelling in the MC simulations;
    - boost the progress in physics analysis/searches where top-quark backgrounds are important;
    - allow for stringent tests of the SM and its extensions;
    - probe the EWSB mechanism (y_t~1);
    - enable searches for physics beyond the SM: production mechanism and the decays (Wtb coupling)

top-quark events: MC modelling

- Modelling of signal events is crucial for precision measurements
  - analysis calibration
  - event reconstruction
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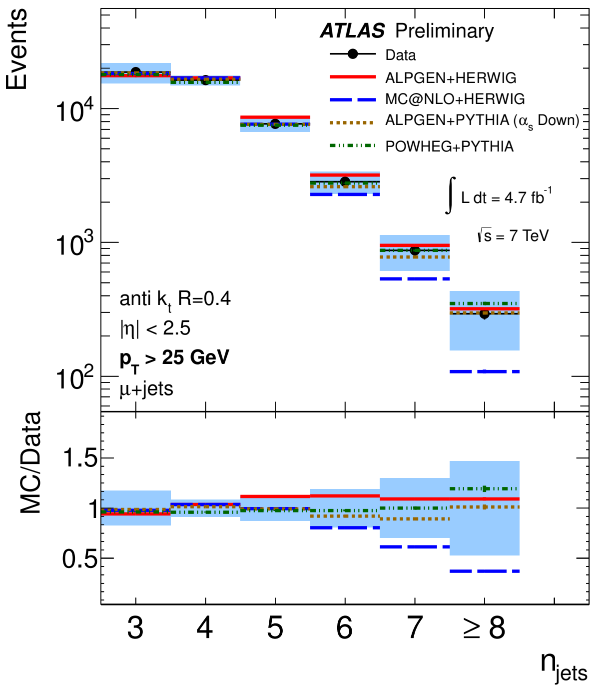
Observable/analysis	Modelling improvements
Jet multiplicity	MC@NLO+Herwig replaced by PowHeg+Pythia

ATL-PHYS-PUB-2013-005



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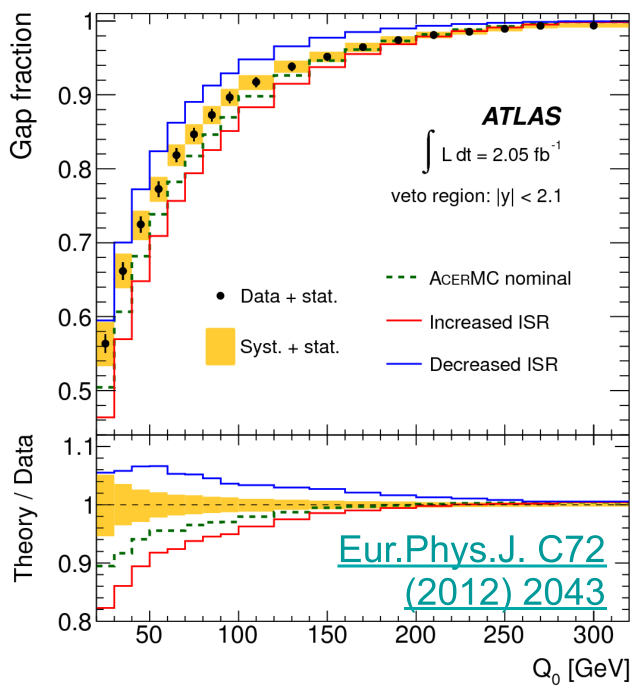
Observable/analysis	Modelling improvements
Jet multiplicity	MC@NLO+Herwig replaced by PowHeg+Pythia
Gap fraction	Reduced parameter range for ISR/FSR systematics

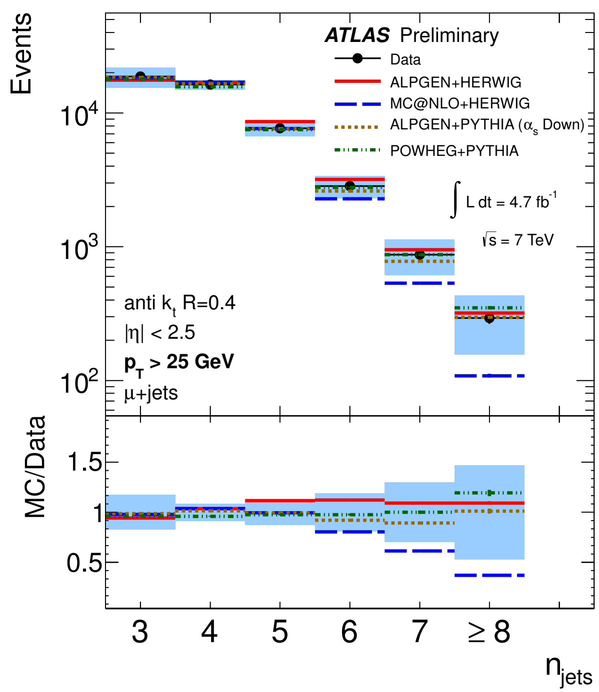
$$f(Q_0) \equiv \frac{n(Q_0)}{N}$$

measures the fraction of dileptonic top-pair events without an extra jet with $p_T > Q_0$



Eur.Phys.J. C72 (2012) 2043

ATL-PHYS-PUB-2013-005



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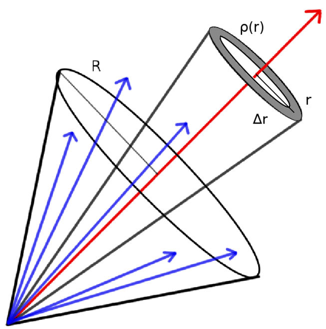


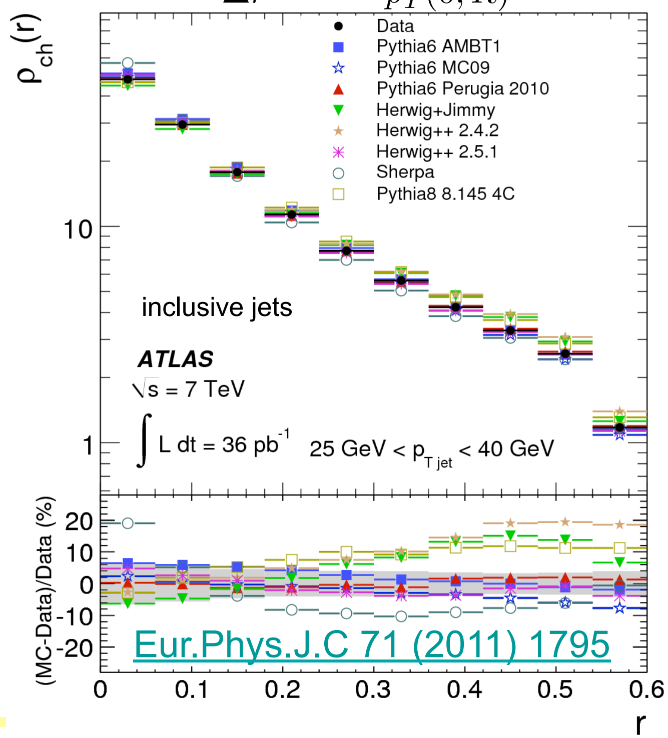
- Jet shapes are sensitive to the details of the parton shower models. (differential/integrated, using calorimeter clusters/tracks)

- Top pair events complement studies from the inclusive jet sample. Possibility to analyse separately b-quark and light-quark jets.

Observable/analysis	Modelling improvements
Jet multiplicity	MC@NLO+Herwig replaced by PowHeg+Pythia
Gap fraction	Reduced parameter range for ISR/FSR systematics
Jet shape	Hadronization: from Herwig to Pythia Perugia tunes

Differential jet shape

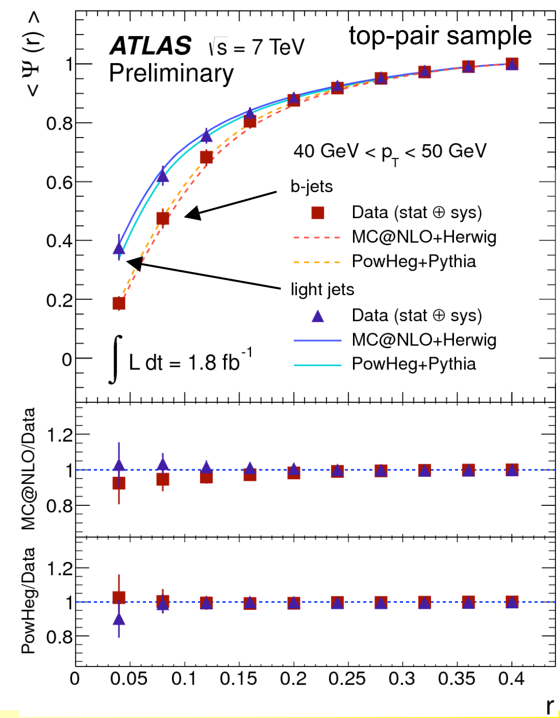
$$\rho(r) = \frac{1}{\Delta r}\frac{p_T(r-\Delta r/2, r+\Delta r/2}{p_T(0,R)}$$



Eur.Phys.J.C 71 (2011) 1795

Integrated jet shape:

$$\Psi(r) = \frac{p_T(0,r)}{p_T(0,R)}$$



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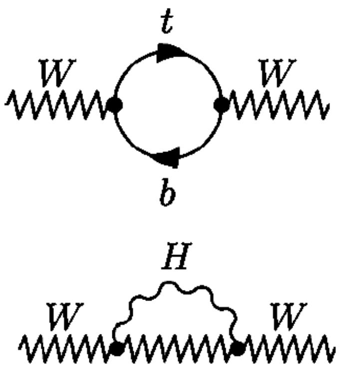
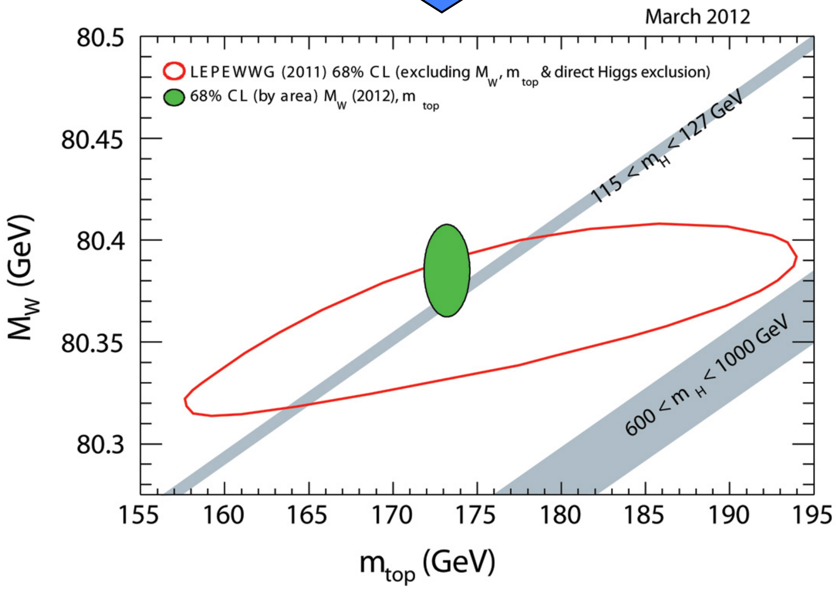
Top-quark relations with W and SM Higgs

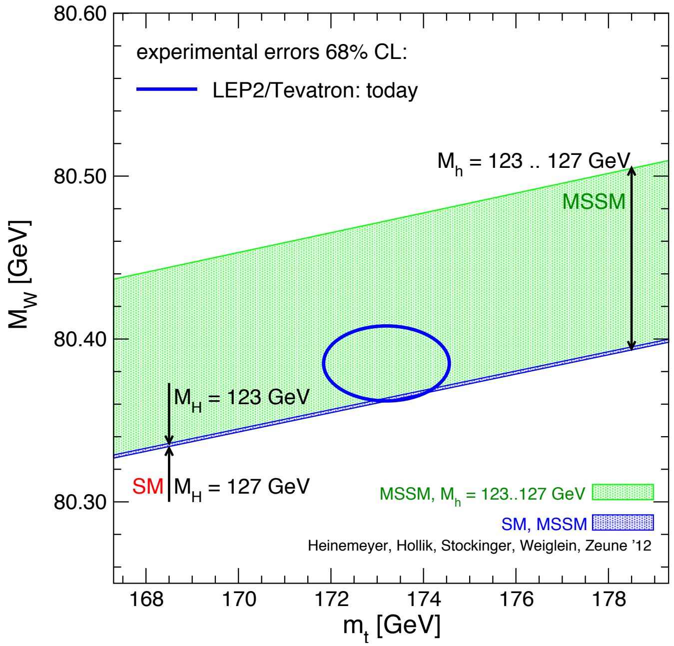
Higgs, top-quark, and W boson masses are related



- A precise determination of m_{top} constrains the Higgs boson mass when combined with EW precision measurements.
- Serves as a stringent test of SM and beyond SM models



July 2012: discovery of a Higgs-like boson. $m_{H?}$ ~ 125 GeV and particle's properties are so far consistent with the SM Higgs



precise experimental determination of m_{top} and m_W will help to disentangle different models

Higgs potential stability

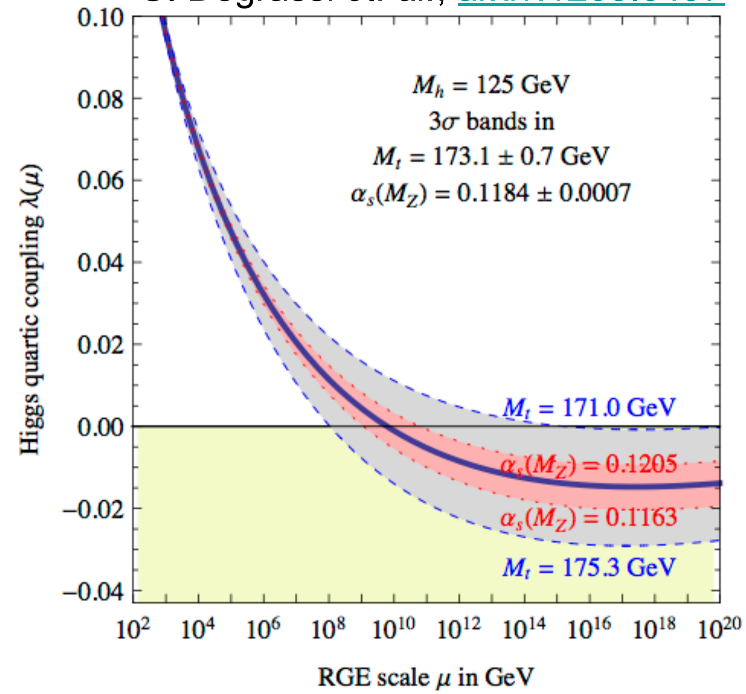
- The current experimental values of m_H and m_{top} are very intriguing from the theoretical point of view:
  - the Higgs quartic coupling could be rather small, vanish or even turn negative at a scale slightly smaller than the Planck scale.
  - if $\lambda(\mu)>0$

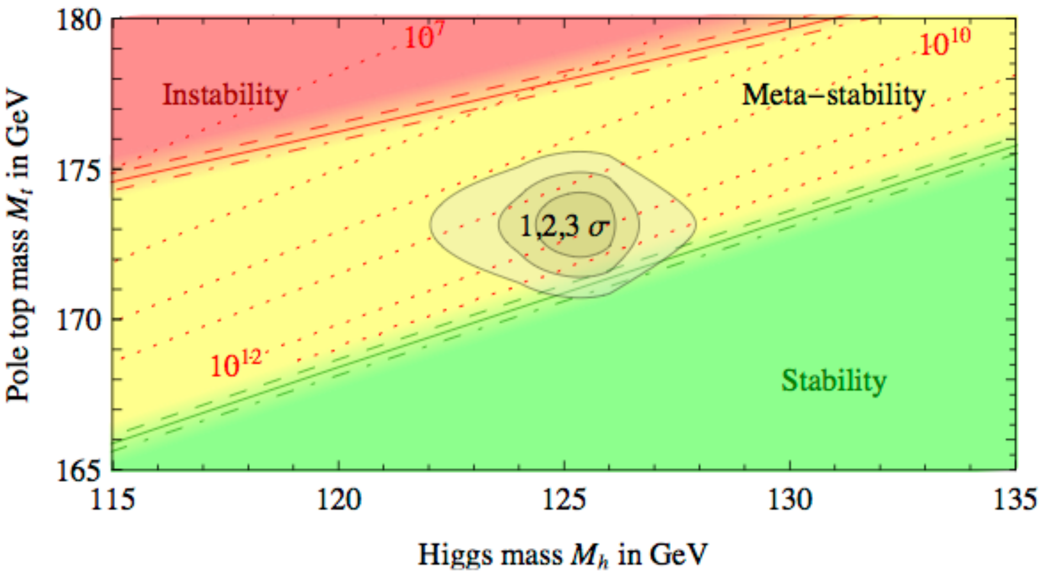
    the electroweak vacuum is a global minimum
  - if $\lambda(\mu) <0$

    the electroweak vacuum becomes metastable (does not become unstable over the age of the universe)

$$V = \frac{1}{2}\mu^2\Phi^2 + \frac{1}{4}\lambda\Phi^4$$

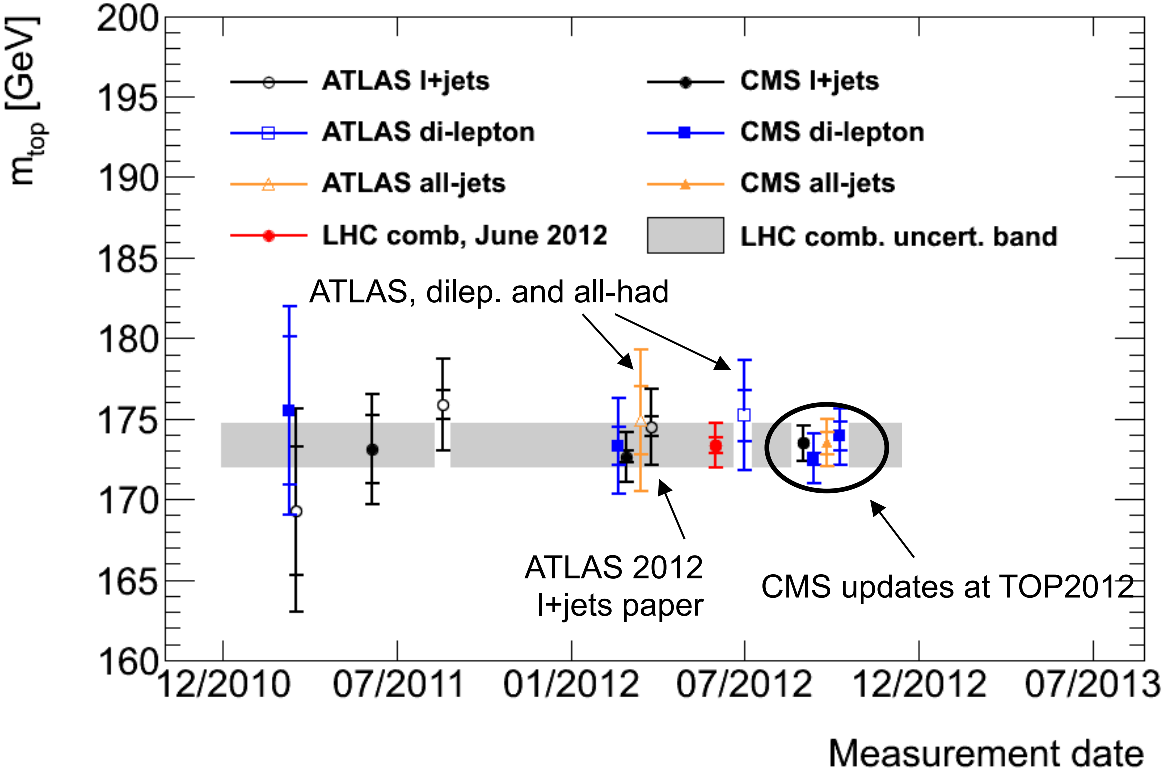
G. Degrassi *et. al.*, arxiv:1205.6497

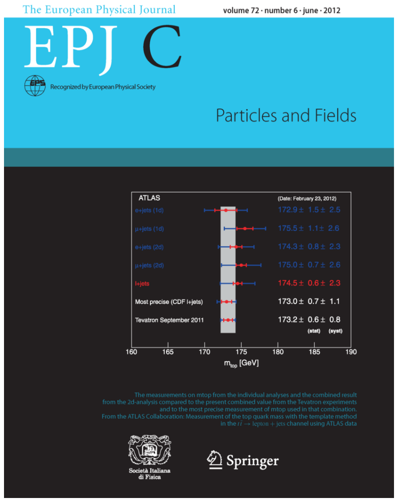




- Even in the absence of direct evidences for new physics at the LHC, the experimental information on m_H and m_{top} gives us useful hints on the structure of the theory at very short distances
- Renewed interest for precision m_{top} measurements

Were did we stand?





EPJC (2012) 72:2046

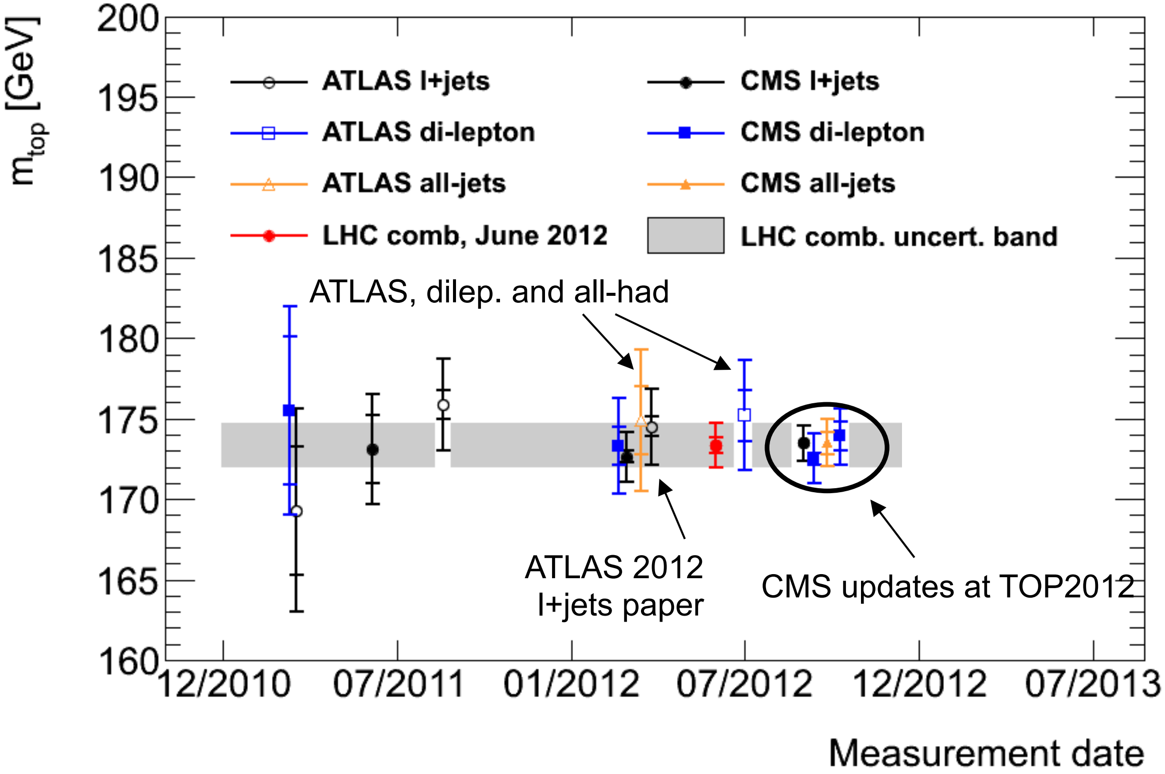
- The dominant uncertainties from the 2012 l+jets ATLAS paper using 1fb^{-1} of data are:
  - ISR/FSR
  - bJES/JES

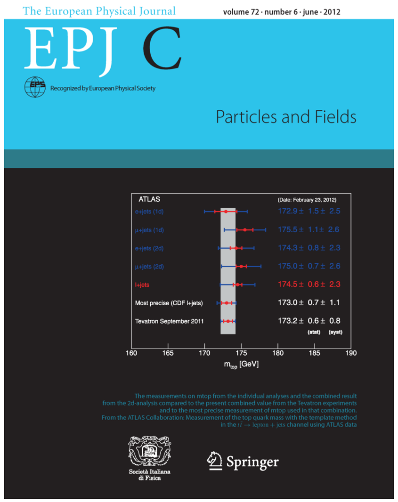
  (contribute to 86% of the total syst)

What did we do to improve?

- Reduced the parameter range used for estimating ISR/FSR systematics
  Eur.Phys.J. C72 (2012) 2043
- Reduced the base-line bJES uncertainty
  ATLAS-CONF-2013-002
- change default MC for top-quark physics:
  MC@NLO+Herwig ➔ PowHeg+Pythia ATL-PHYS-PUB-2013-005

Were did we stand?





EPJC (2012) 72:2046

- The dominant uncertainties from the 2012 l+jets ATLAS paper using 1fb^{-1} of data are:
  - ISR/FSR
  - bJES/JES

  (contribute to 86% of the total syst)

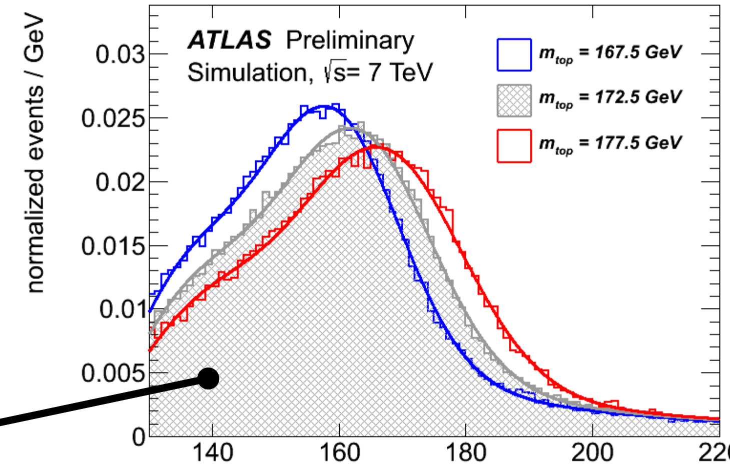
What did we do to improve?

...what about the analysis techniques?

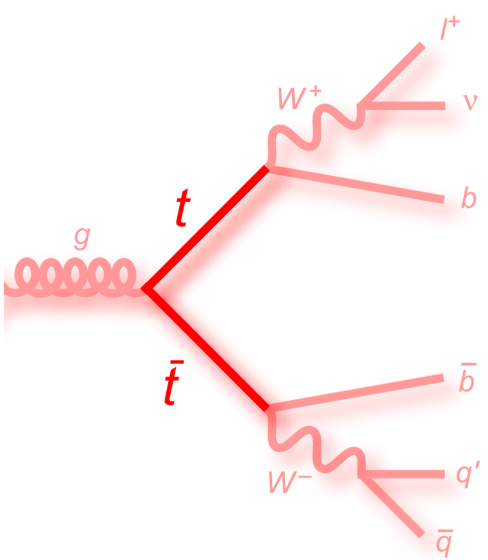
Template method / top reconstruction

- The idea is to fit the data distribution of a given m_{top} estimator (i.e. m_{top}^{rec}) to the sum of signal and background PDFs (probability distribution functions)

signal PDF from signal MC at different generated m_{top}



top mass estimator



Reconstruction

observed objects

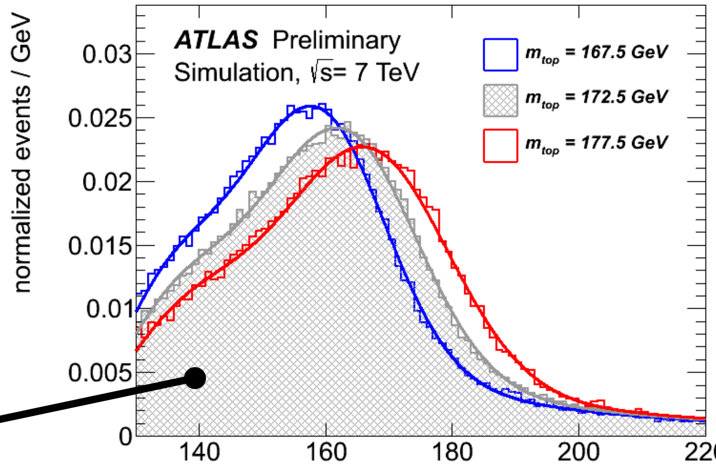
Lepton
E_T^{miss}
Jet1
Jet2
Jet3
Jet4

- The m_{top} estimator is obtained via reconstruction algorithms relating the reconstructed objects to the partons from the top-quark pair decay.

Template method / top reconstruction

- The idea is to fit the data distribution of a given m_{top} estimator (i.e. m_{top}^{rec}) to the sum of signal and background PDFs (probability distribution functions)

signal PDF from signal MC at different generated m_{top}



top mass estimator

Standard tool for top property measurements in the l+jets channel

- ***Kinematical Likelihood Fitter*** event reconstruction *(Choose the object topology that best fits the decay hypothesis).*

Template method / top reconstruction

- The idea is to fit the data distribution of a given m_{top} estimator (i.e. m_{top}^{rec}) to the sum of signal and background PDFs (probability distribution functions)

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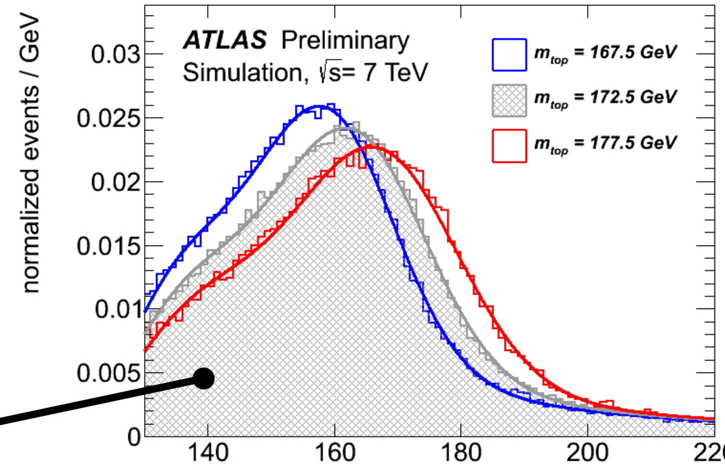

top mass estimator

Standard tool for top property measurements in the l+jets channel

$$
\begin{aligned}
L \;=\; & \mathcal{T}\left(E_{\text{jet}_1}|\hat{E}_{b_{\text{had}}}\right)\cdot\mathcal{T}\left(E_{\text{jet}_2}|\hat{E}_{b_\ell}\right)\cdot\mathcal{T}\left(E_{\text{jet}_3}|\hat{E}_{q_1}\right)\cdot \\
& \mathcal{T}\left(E_{\text{jet}_4}|\hat{E}_{q_2}\right)\cdot\mathcal{T}\left(E_x^{\text{miss}}|\hat{p}_{x,\nu}\right)\cdot\mathcal{T}\left(E_y^{\text{miss}}|\hat{p}_{y,\nu}\right)\cdot \\
& \left\{\begin{array}{cc} \mathcal{T}\left(E_e|\hat{E}_e\right) & \text{e+jets} \\ \mathcal{T}\left(p_{\text{T},\mu}|\hat{p}_{\text{T},\mu}\right) & \mu\text{+jets} \end{array}\right\}.
\end{aligned}
$$

- ***Kinematical Likelihood Fitter*** event reconstruction *(Choose the object topology that best fits the decay hypothesis).*
  - Reco. objects are mapped to the response of partons via transfer functions (*T*).

Template method / top reconstruction

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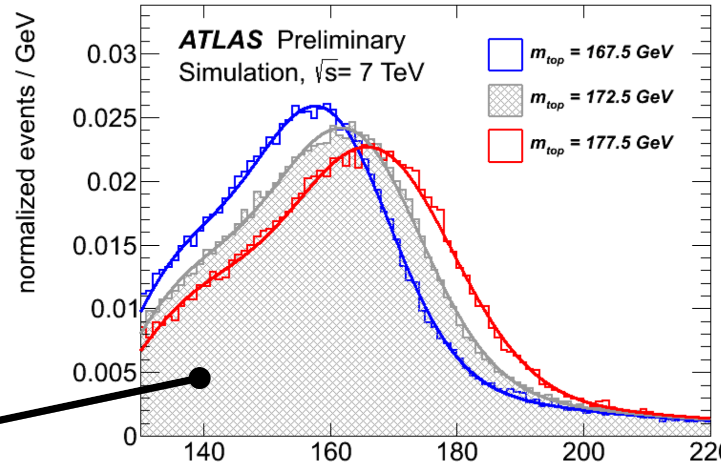


top mass estimator

$$
\begin{aligned}
L \;=\; & \mathcal{T}\left(E_{\mathrm{jet}_1}|\hat{E}_{b_{\mathrm{had}}}\right)\cdot\mathcal{T}\left(E_{\mathrm{jet}_2}|\hat{E}_{b_\ell}\right)\cdot\mathcal{T}\left(E_{\mathrm{jet}_3}|\hat{E}_{q_1}\right)\cdot\\
& \mathcal{T}\left(E_{\mathrm{jet}_4}|\hat{E}_{q_2}\right)\cdot\mathcal{T}\left(E_x^{\mathrm{miss}}|\hat{p}_{x,\nu}\right)\cdot\mathcal{T}\left(E_y^{\mathrm{miss}}|\hat{p}_{y,\nu}\right)\cdot\\
& \left\{\begin{array}{ll}\mathcal{T}\left(E_e|\hat{E}_e\right) & \mathrm{e{+}jets}\\ \mathcal{T}\left(p_{\mathrm{T},\mu}|\hat{p}_{\mathrm{T},\mu}\right) & \mu\mathrm{{+}jets}\end{array}\right\}\cdot\\
& \mathcal{B}\left[m(q_1\,q_2)|m_W,\Gamma_W\right]\cdot\mathcal{B}\left[m(\ell\,\nu)|m_W,\Gamma_W\right]\cdot\\
& \mathcal{B}\left[m(q_1\,q_2\,b_{\mathrm{had}})|m_{\mathrm{top}}^{\mathrm{reco}},\Gamma_{\mathrm{top}}\right]\cdot\\
& \mathcal{B}\left[m(\ell\,\nu\,b_\ell)|m_{\mathrm{top}}^{\mathrm{reco}},\Gamma_{\mathrm{top}}\right]\cdot W_{\mathrm{btag}}\,.
\end{aligned}
$$

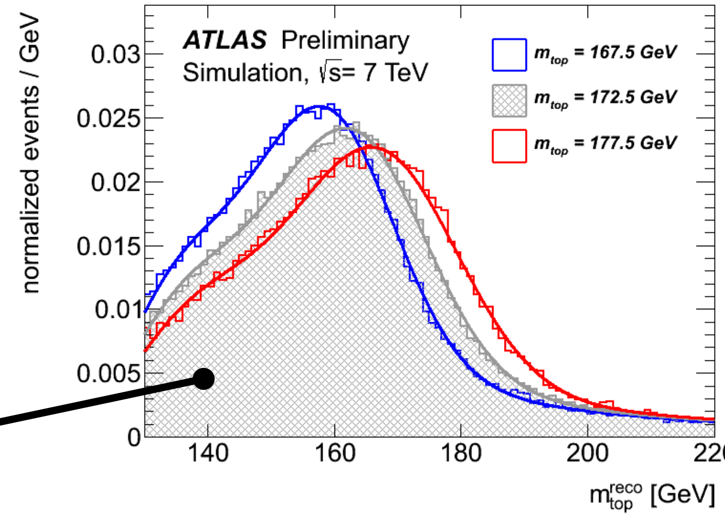
Standard tool for top property measurements in the l+jets channel

- ***Kinematical Likelihood Fitter*** event reconstruction *(Choose the object topology that best fits the decay hypothesis).*
  - Reco. objects are mapped to the response of partons via transfer functions (*T*).
  - Apply Breit-Wigner constraints, *B*, (Γ_{top} and Γ_W) for m_{top}^{reco} and m_W^{reco} (for both had/lep sides)
  - Reduce combinatorics by introducing b-tagging information in the likelihood

Template method / top reconstruction

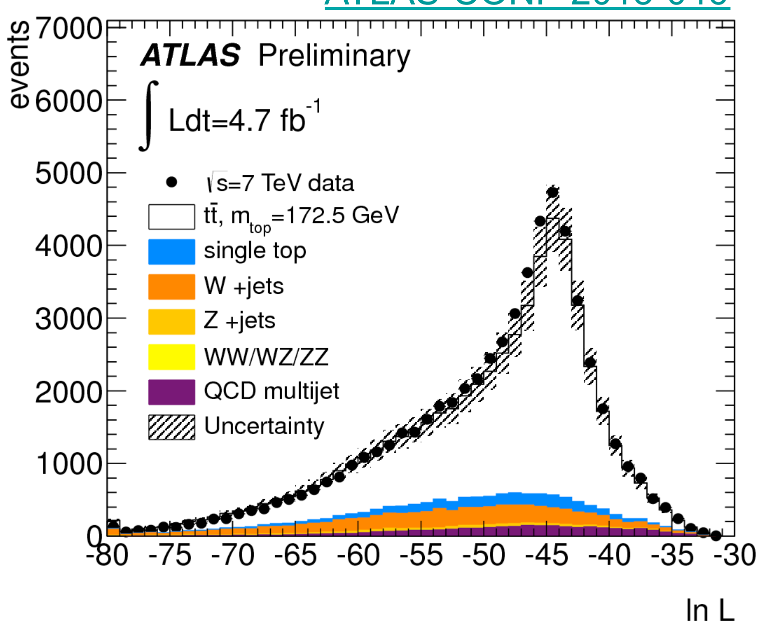
- The idea is to fit the data distribution of a given m_{top} estimator (i.e. m_{top}^{rec}) to the sum of signal and background PDFs (probability distribution functions)

signal PDF from signal MC at different generated m_{top}



ATLAS-CONF-2013-046

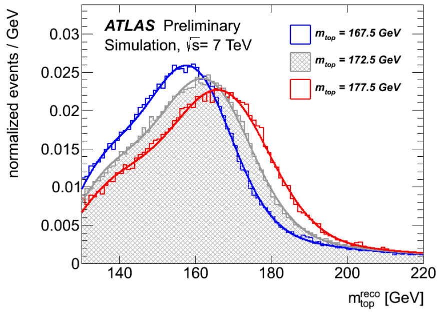
$$
\begin{aligned}
L = \; & \mathcal{T}\left(E_{\text{jet}_1}|\hat{E}_{b_{\text{had}}}\right)\cdot\mathcal{T}\left(E_{\text{jet}_2}|\hat{E}_{b_\ell}\right)\cdot\mathcal{T}\left(E_{\text{jet}_3}|\hat{E}_{q_1}\right)\cdot \\
& \mathcal{T}\left(E_{\text{jet}_4}|\hat{E}_{q_2}\right)\cdot\mathcal{T}\left(E_x^{\text{miss}}|\hat{p}_{x,\nu}\right)\cdot\mathcal{T}\left(E_y^{\text{miss}}|\hat{p}_{y,\nu}\right)\cdot \\
& \begin{Bmatrix} \mathcal{T}\left(E_e|\hat{E}_e\right) & \text{e+jets} \\ \mathcal{T}\left(p_{\text{T},\mu}|\hat{p}_{\text{T},\mu}\right) & \mu\text{+jets} \end{Bmatrix}\cdot \\
& \mathcal{B}\left[m(q_1\, q_2)|m_W,\Gamma_W\right]\cdot\mathcal{B}\left[m(\ell\,\nu)|m_W,\Gamma_W\right]\cdot \\
& \mathcal{B}\left[m(q_1\, q_2\, b_{\text{had}})|m_{\text{top}}^{\text{reco}},\Gamma_{\text{top}}\right]\cdot \\
& \mathcal{B}\left[m(\ell\,\nu\, b_\ell)|m_{\text{top}}^{\text{reco}},\Gamma_{\text{top}}\right]\cdot W_{\text{btag}}\,.
\end{aligned}
$$



Observables main dependences

m_{top}

Reco m_{top}

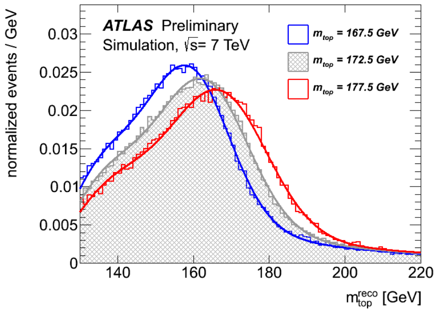


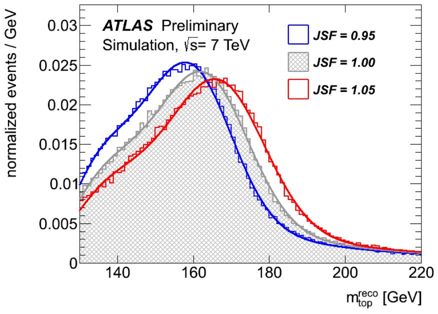
Good sensitivity to the underlying top quark mass. The quantity to be measured

The problem…

Observables main dependences m_{top} JES

Reco m_{top}





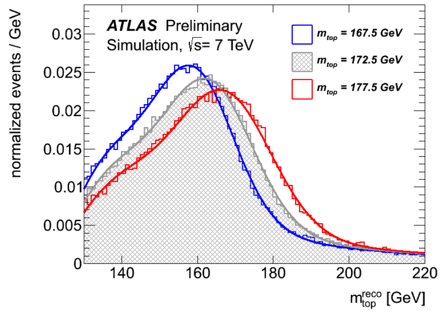
Good sensitivity to the underlying top quark mass. The quantity to be measured

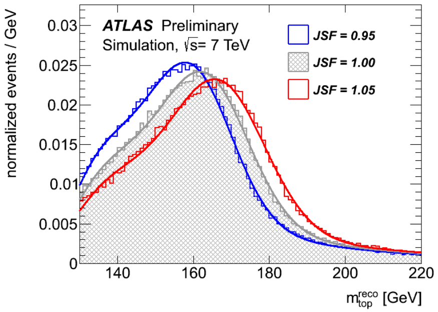
Large dependence on the jet energy scale.

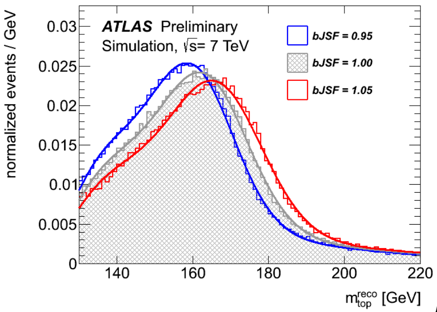
The problem…

Observables main dependences m_{top} JES bJES

Reco m_{top}







Good sensitivity to the underlying top quark mass. The quantity to be measured

Large dependence on the jet energy scale.

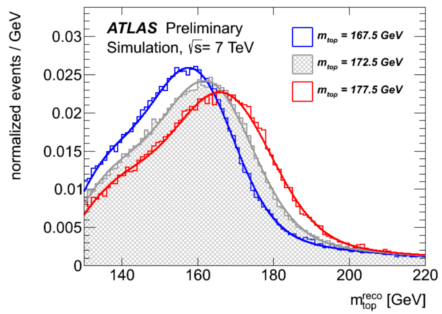
Large dependence on the b-jet energy scale.

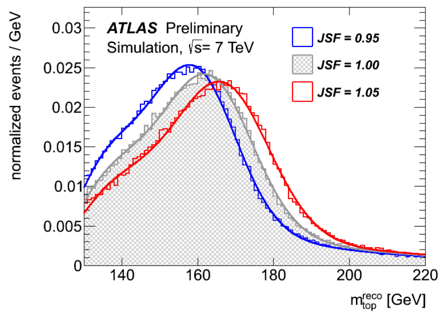
The problem…

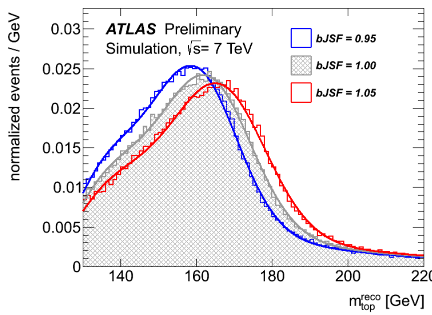
Observables main dependences

m_{top} JES bJES

Reco m_{top}







Good sensitivity to the underlying top quark mass. The quantity to be measured

Large dependence on the jet energy scale. Large systematics

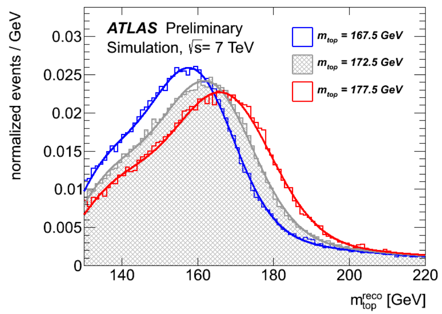
Large dependence on the b-jet energy scale. Large systematics

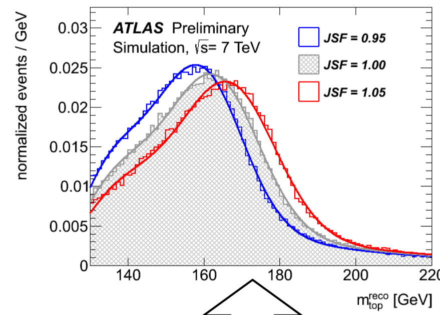
The problem… and its solution

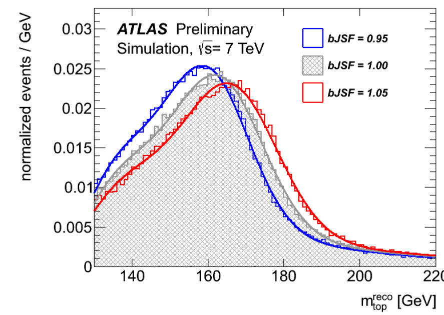
Observables main dependences m_{top} JES bJES

2dim fits for m_{top}, JSF

Reco m_{top}

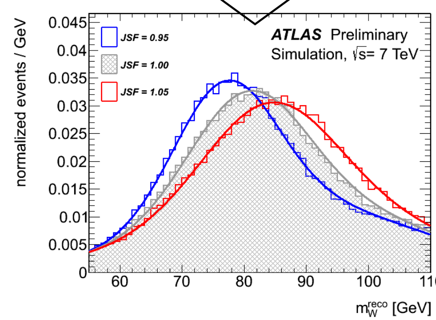






Reco m_W

in the l+jets channel, the light-quark jets from W can be used to determined a global jet energy scale factor (JSF) constraining the light jets JES variations



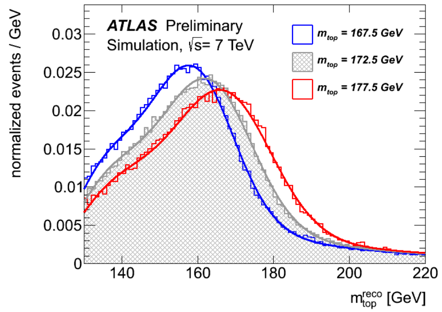
Pioneered by the CDF collaboration in [Phys.Rev.D73:032003,2006]

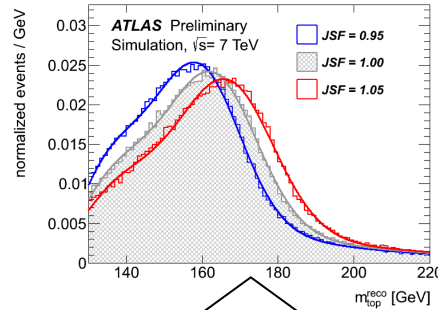
The problem… and its solution

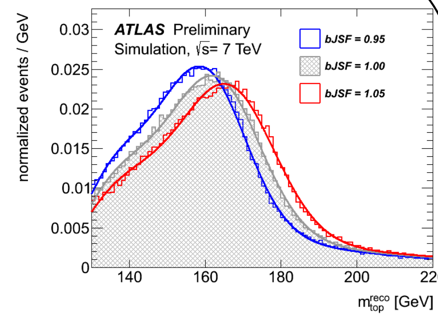
Observables main dependences m_{top} JES bJES

3dim fits for m_{top}, JSF, bJSF

Reco m_{top}







Reco m_W

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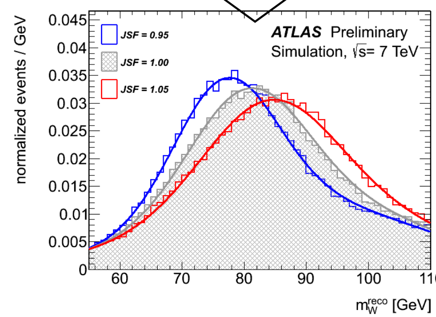
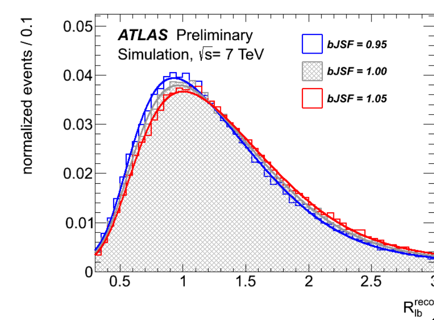


Reco R_{lb}

similarly a variable sensitive to the relative b-to-light jet energy scale (bJSF) can be used to constrain the b-jet JES variations (bJES)



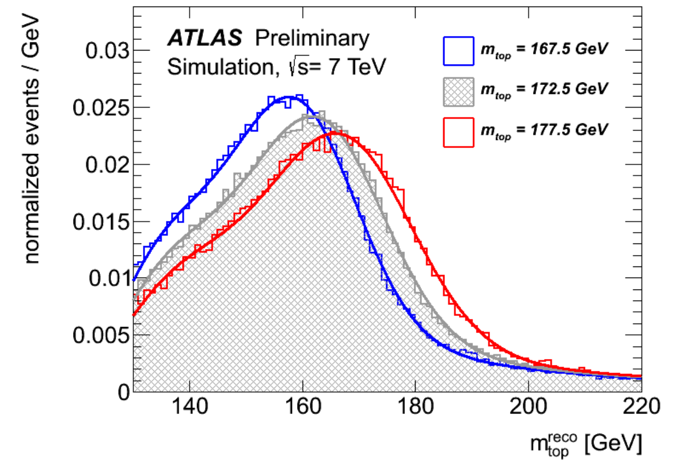
What did we do to improve?

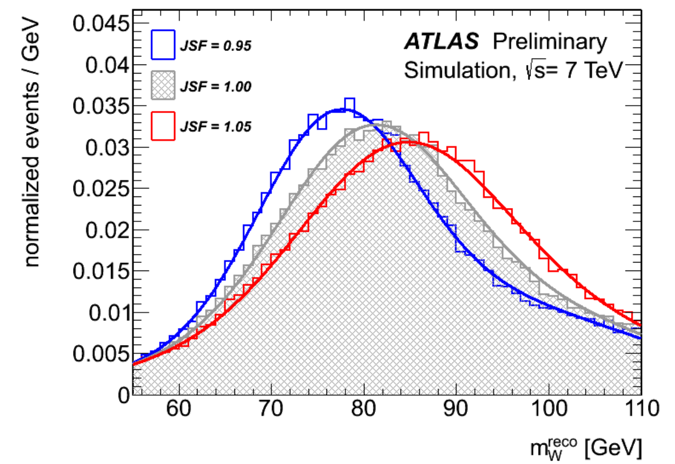
<u>3d template method (3dTMT)</u>

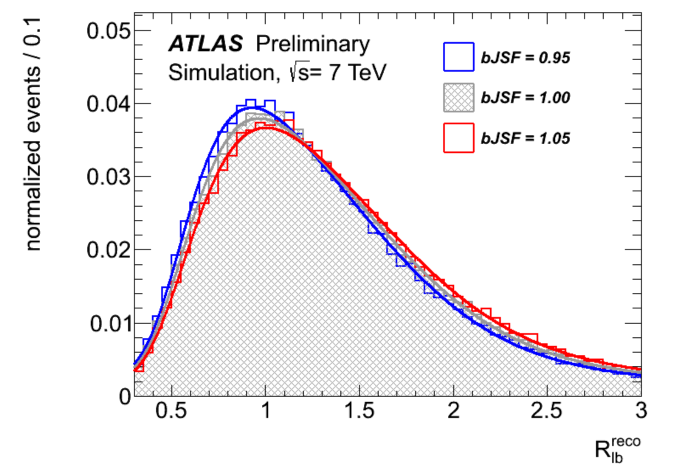
$$P_{m_{top}^{reco}}(m_{top}, JSF, bJSF)$$
$$P_{m_{W}^{reco}}(JSF)$$
$$P_{R_{lb}^{reco}}(m_{top}, bJSF)$$

- The 3rd variable in 3dTMT is defined to be sensitive to relative b-to-light jets energy changes (bJES), to constrain its uncertainty using data
  - 2b-tag events: $R_{lb}^{reco} = \frac{\sum p_T^{\mathrm{b-tag}}}{\sum p_T^{\mathrm{light\ jets}}}$
  - 1b-tag events: $R_{lb}^{reco} = \frac{p_T^{\mathrm{b-tag}}}{(\sum p_T^{\mathrm{light\ jets}})/2}$

light-jets = jets assigned to the W boson decay by the reconstruction algorithm

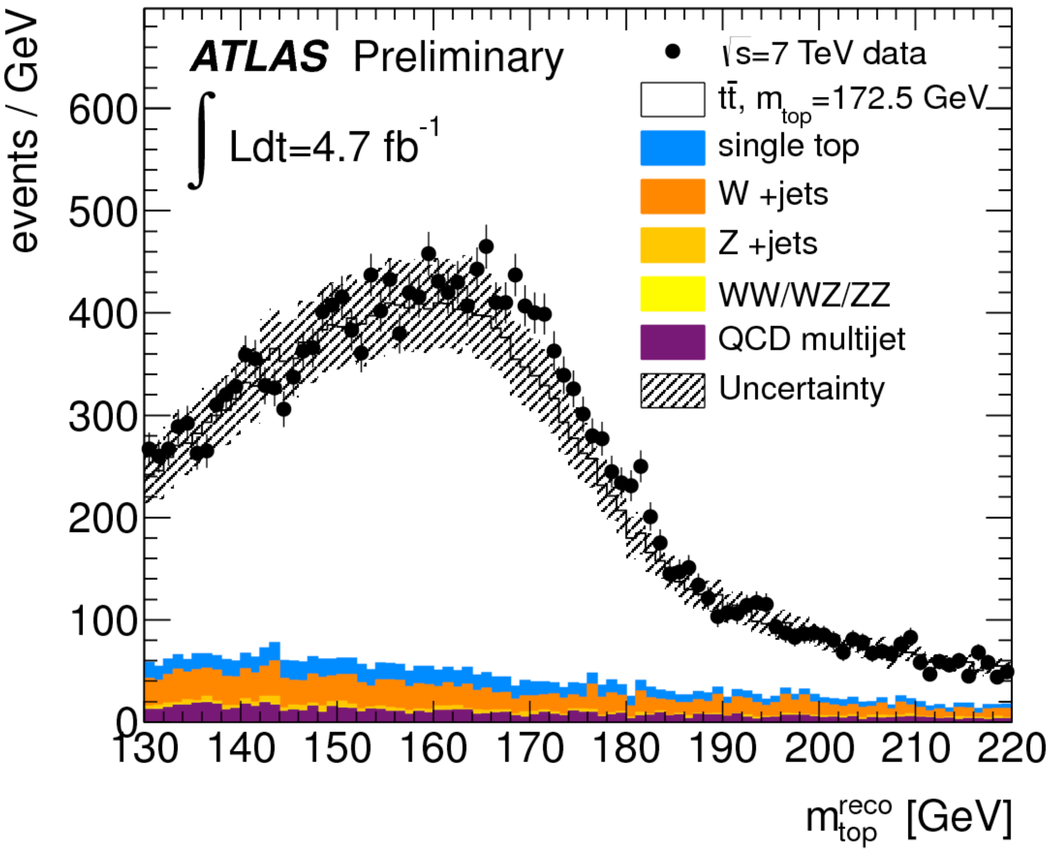


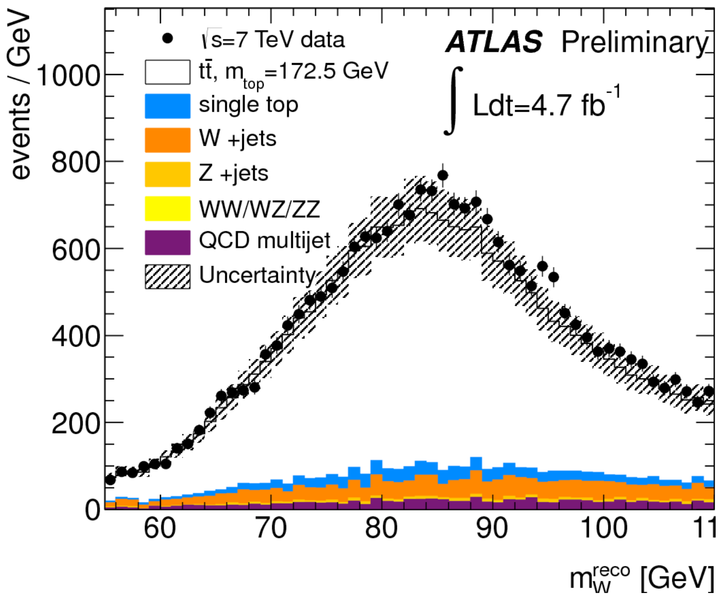


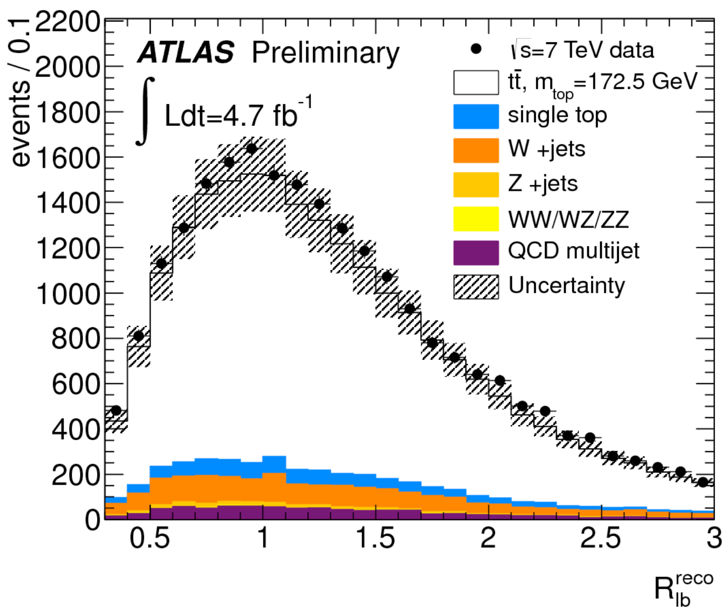


- Events with =1 or ≥2 b-tagged jets are treated separately: different sensitivities/resolution

3dTMT estimator distributions



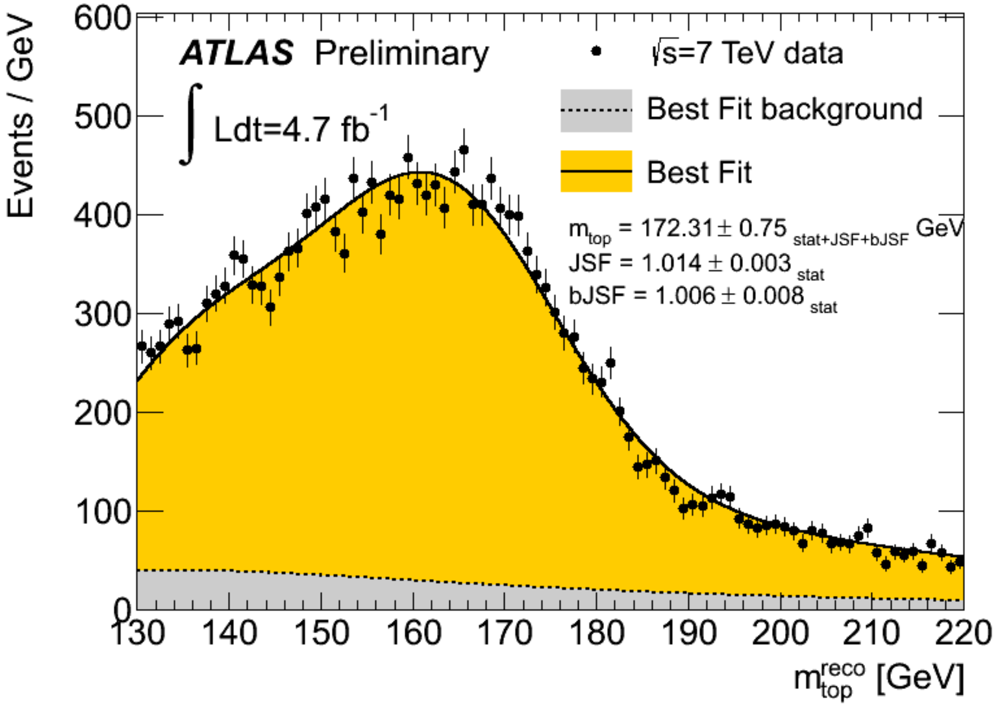


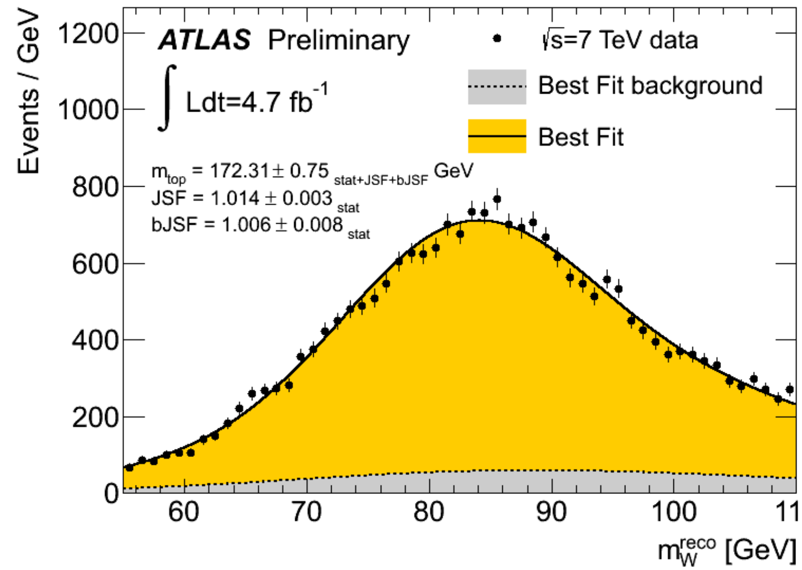


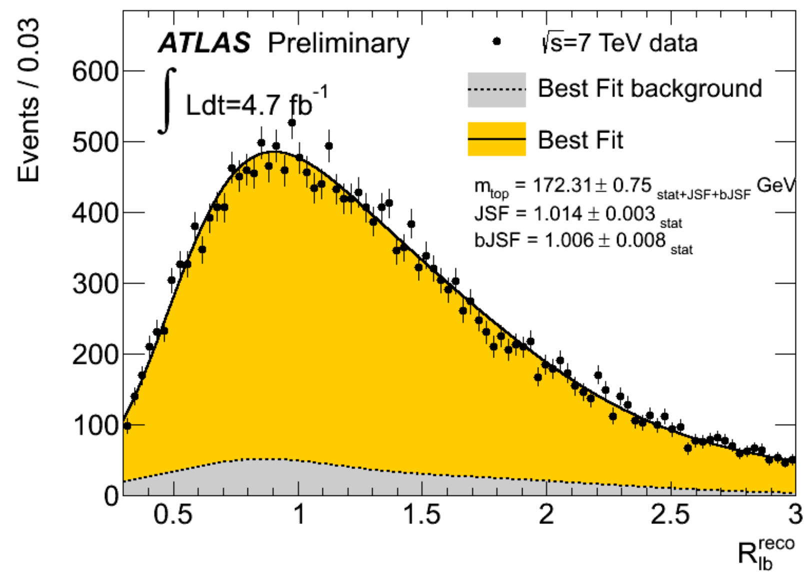
- Distributions for events with ≥1 b-tag.
- The shape changes between data and predictions are what we measure via an un-binned likelihood fit using the template parameterization as PDF.

Results on 2011 $\sqrt{s}$=7 TeV data

ATLAS-CONF-2013-046







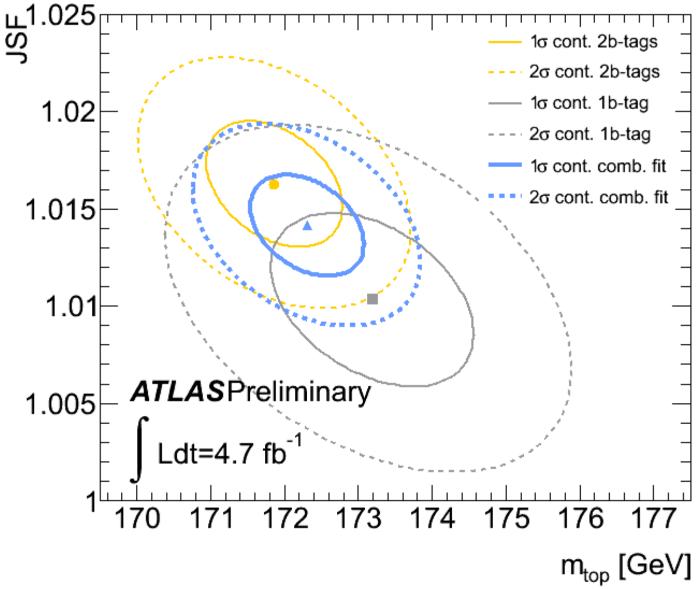
$$m_{top} = 172.31 \pm 0.75_{(\mathrm{stat}\oplus\mathrm{JSF}\oplus\mathrm{bJSF})}\mathrm{GeV}$$

$$\mathrm{JSF} = 1.014 \pm 0.003_{(\mathrm{stat})}$$

$$\mathrm{bJSF} = 1.006 \pm 0.008_{(\mathrm{stat})}$$

- stat. uncertainty only for the moment (syst. will be discussed in the next slides)

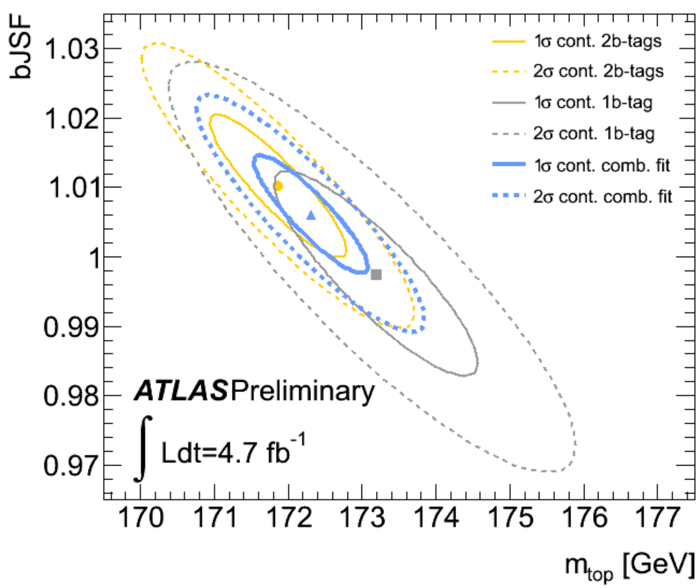
m_{top}, JSF, bJSF correlations

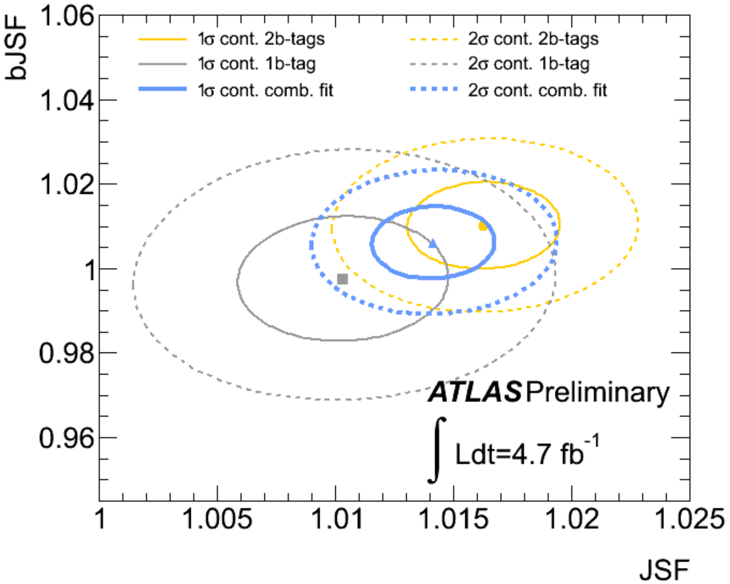


- Data results on:
  - ≥ 2 b-tags sample
  - 1 b-tag sample
  - combined sample

  show very good consistency

  (contours contain stat. only uncertainties)





Measurement uncertainties

	2d-analysis		3d-analysis		
	m_{top} [GeV]	JSF	m_{top} [GeV]	JSF	bJSF
Measured value	172.80	1.014	172.31	1.014	1.006
Data statistics	0.23	0.003	0.23	0.003	0.008
Jet energy scale factor (stat. comp.)	0.27	n/a	0.27	n/a	n/a
bJet energy scale factor (stat. comp.)	n/a	n/a	0.67	n/a	n/a
Method calibration	0.13	0.002	0.13	0.002	0.003
Signal MC generator	0.36	0.005	0.19	0.005	0.002
Hadronisation	1.30	0.008	0.27	0.008	0.013
Underlying event	0.02	0.001	0.12	0.001	0.002
Colour reconnection	0.03	0.001	0.32	0.001	0.004
ISR and FSR (signal only)	0.96	0.017	0.45	0.017	0.006
Proton PDF	0.09	0.000	0.17	0.000	0.001
single top normalisation	0.00	0.000	0.00	0.000	0.000
W+jets background	0.02	0.000	0.03	0.000	0.000
QCD multijet background	0.04	0.000	0.10	0.000	0.001
Jet energy scale	0.60	0.005	0.79	0.004	0.007
b-jet energy scale	0.92	0.000	0.08	0.000	0.002
Jet energy resolution	0.22	0.006	0.22	0.006	0.000
Jet reconstruction efficiency	0.03	0.000	0.05	0.000	0.000
b-tagging efficiency and mistag rate	0.17	0.001	0.81	0.001	0.011
Lepton energy scale	0.03	0.000	0.04	0.000	0.000
Missing transverse momentum	0.01	0.000	0.03	0.000	0.000
Pile-up	0.03	0.000	0.03	0.000	0.001
Total systematic uncertainty	2.02	0.021	1.35	0.021	0.020
Total uncertainty	2.05	0.021	1.55	0.021	0.022

- Table of uncertainties
  - The analysis is performed also switching off the 3rd dimension of the fit (bJSF fixed to unity), to highlight the improvements due to the developed technique

Measurement uncertainties

	2d-analysis		3d-analysis		
	m_{top} [GeV]	JSF	m_{top} [GeV]	JSF	bJSF
Measured value	172.80	1.014	172.31	1.014	1.006
Data statistics	0.23	0.003	0.23	0.003	0.008
Jet energy scale factor (stat. comp.)	0.27	n/a	0.27	n/a	n/a
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Method calibration	0.13	0.002	0.13	0.002	0.003
Signal MC generator	0.36	0.005	0.19	0.005	0.002
Hadronisation	1.30	0.008	0.27	0.008	0.013
Underlying event	0.02	0.001	0.12	0.001	0.002
Colour reconnection	0.03	0.001	0.32	0.001	0.004
ISR and FSR (signal only)	0.96	0.017	0.45	0.017	0.006
Proton PDF	0.09	0.000	0.17	0.000	0.001
single top normalisation	0.00	0.000	0.00	0.000	0.000
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QCD multijet background	0.04	0.000	0.10	0.000	0.001
Jet energy scale	0.60	0.005	0.79	0.004	0.007
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- Statistical components:
  - the extra statistical uncertainties on m_{top} introduced by the simultaneous JSF (bJSF) fits.
  - The 3dTMT has a larger stat component due to the increased dimensionality of the fit (extra 0.67 GeV).

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- reduced bJES uncertainty (3^{rd} dimension)

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  - The 3dTMT has a larger stat component due to the increased dimensionality of the fit (extra 0.67 GeV). This is more than compensated by…
- MC modelling
  - dominant uncertainties are reduced due to the simultaneous fit of the JSF/ bJSF
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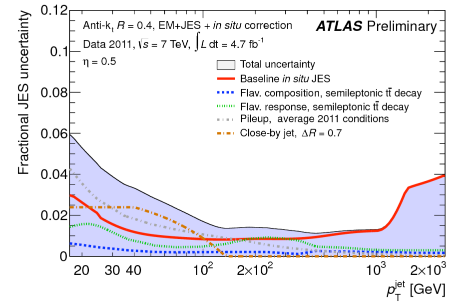
- Residual JES uncertainty.
  - despite the in-situ m_W calibration.
  - introduced by the p_T dependence of the JES uncertainty, not recoverable by a global JSF.



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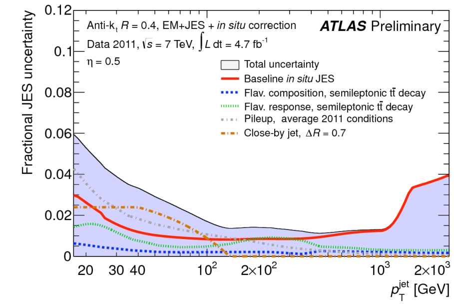
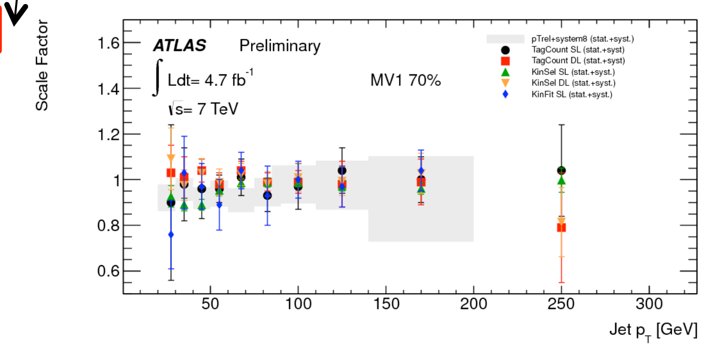


- b-tagging:
  - the 3dTMT has a large sensitivity to b-tag systematics (related to the p_T dependence of the SF uncertainties, affecting the shape of the R_{lb}^{reco}, the 3[rd] dimension).



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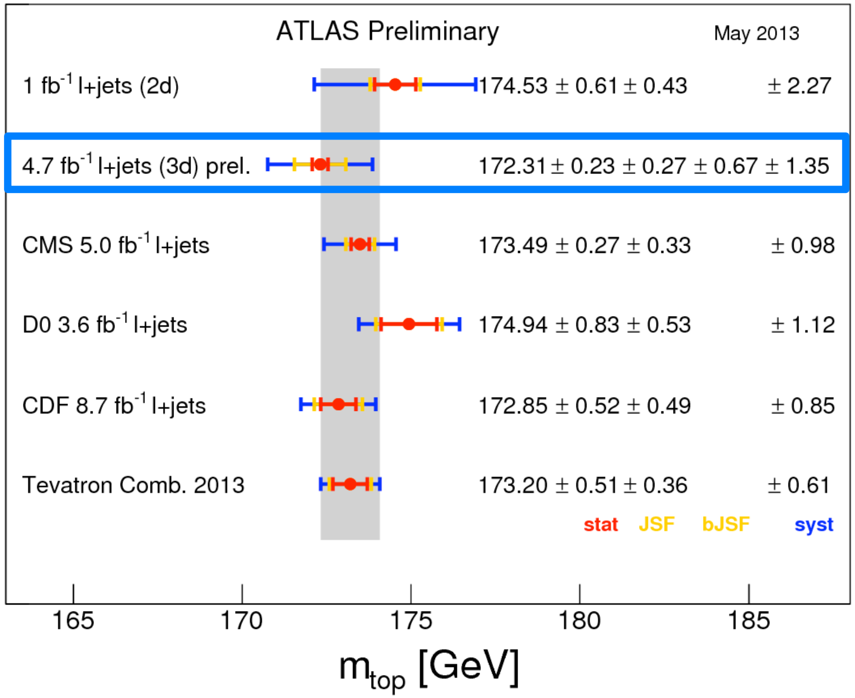
- Overall the 3dTMT analysis has a better total systematics, and reduced total uncertainty.
- The so far dominating bJES uncertainty has been absorbed by a the bJSF and its associated statistical uncertainty.
  - This will scale with luminosity, and be uncorrelated to other experiments in combinations.
  - An important step forward in view of 8 TeV analysis updates

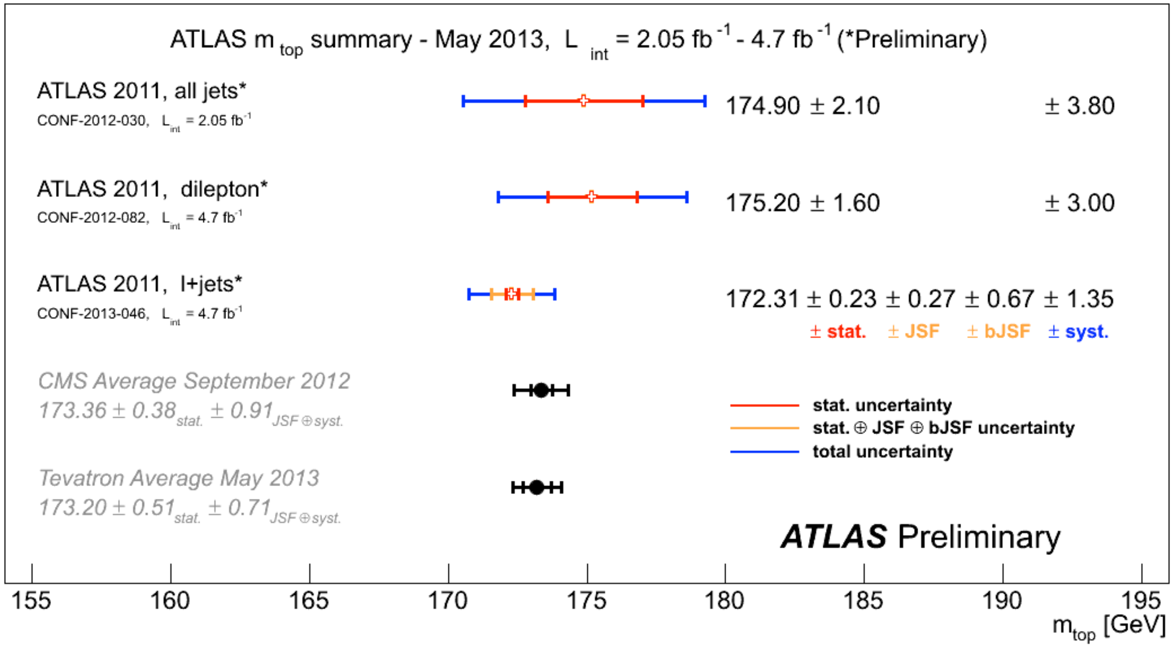
ATLAS m_{top} results

- 3d TMT results:

$$m_{top} = 172.31 \pm 0.75\,(\text{stat} + \text{JSF} + \text{bJSF}) \pm 1.35\,(\text{syst})\ \text{GeV},$$
$$\text{JSF} = 1.014 \pm 0.003\,(\text{stat}) \pm 0.021\,(\text{syst}),$$
$$\text{bJSF} = 1.006 \pm 0.008\,(\text{stat}) \pm 0.020\,(\text{syst}).$$

- With respect to the previous published results in the l+jets channel (1fb^{-1})
  - the total uncertainty has been reduced by ~ 40%

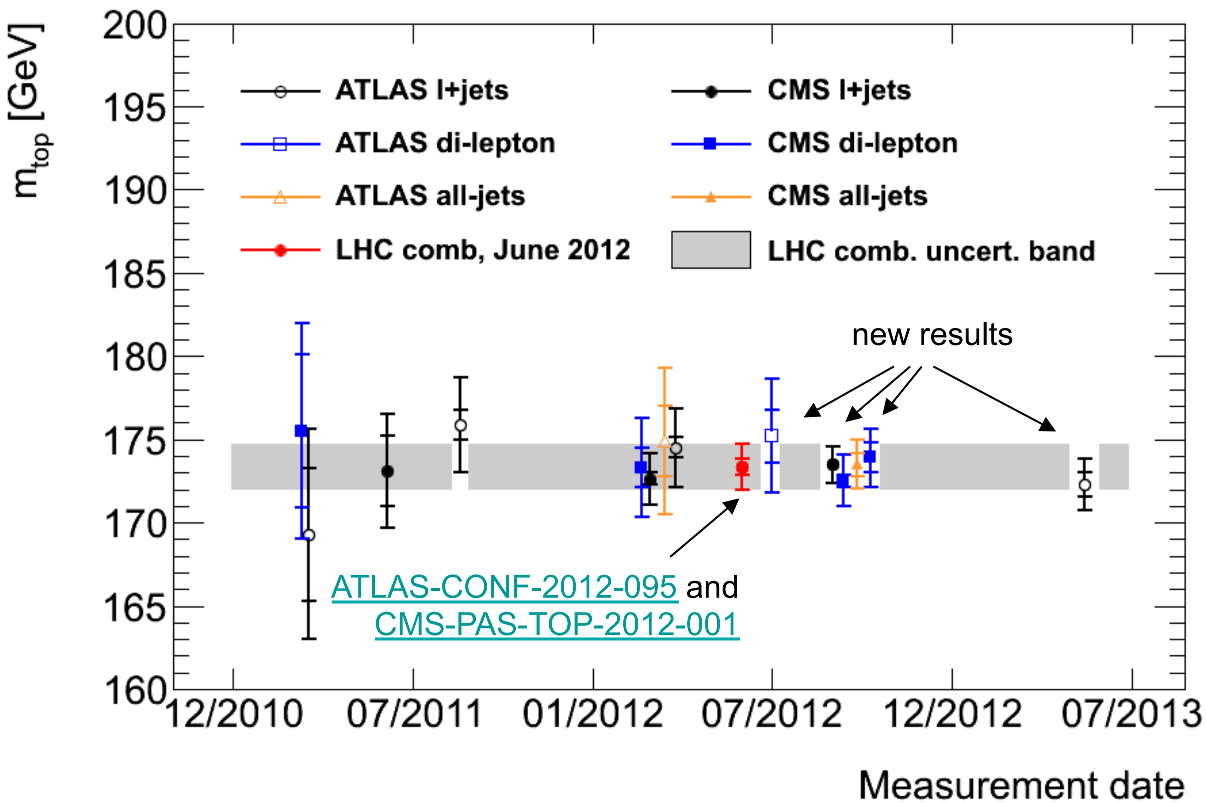




- In addition, ATLAS measures m_{top} in
  - the all-hadronic channel (1dim template method for m_{top}^{reco}) ATLAS-CONF-2012-030
  - The dilepton channel (calibration curve based on the <m_{T2}>) ATLAS-CONF-2012-082

- Analysis updates are in the pipeline and will profit from the improvements in the detector performances/MC/ systematics variations described before.

Outlook towards the next LHC comb



- Since the first LHC m_{top} combination (June 2012):
  - new LHC measurements of increased precision are available
  - individual m_{top} measurements have reached a precision better than 1%.

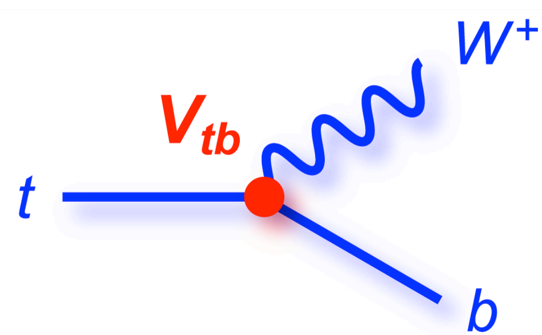
- Expected improved precision in the next LHC combination (competitive with Tevatron):
  - details about the best treatment of the systematics and their correlation are being sorted out and addressed within the TOP-LHC-WG.
    - MC modelling systematics (harmonization of the hadronization syst/MC generator treatments)
    - Finer splitting of the JES uncertainty contributions, agreed at the open TOP-LHC-WG meeting in April

The top quark

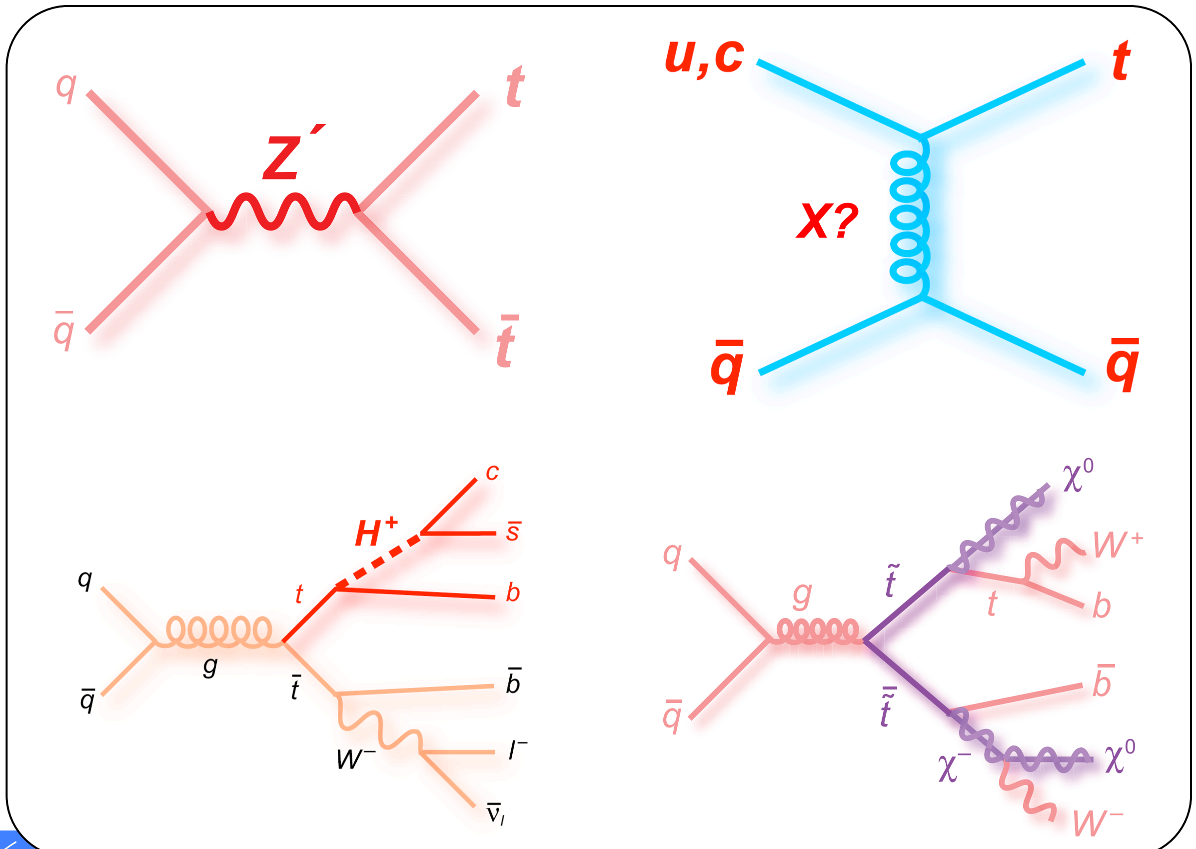
- top-quark physics is one of the main pillars of the physics program at the LHC.
- The top-quark: a multipurpose physics candle at the LHC:
  - Precision measurements in the top-quark physics sector
    - drive improvements in the detector and physics tools understanding.
    - motivate refinements and tests of different physics aspects of top-quark modelling in the MC simulations;
    - boost the progress in physics analysis/searches where top-quark backgrounds are important;
    - allow for stringent tests of the SM and its extensions;
    - probe the EWSB mechanism (y_t~1);
    - enable searches for physics beyond the SM: production mechanism and the decays (Wtb coupling)

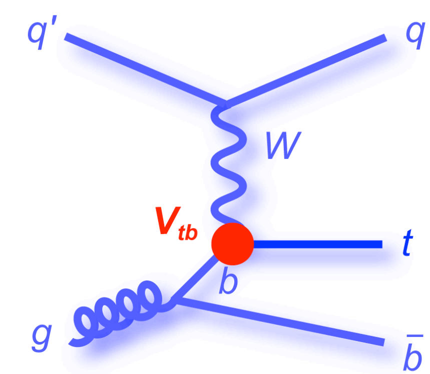
Top-quark properties / searches for new physics

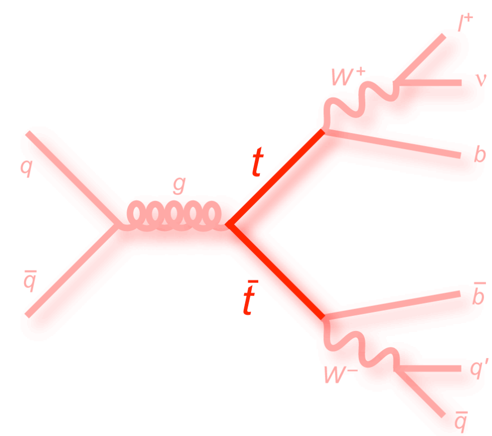
- New physics contributions can alter the properties of the Wtb vertex wrt the SM or modify the production mechanism of top-quarks.



examples of New Physics processes:



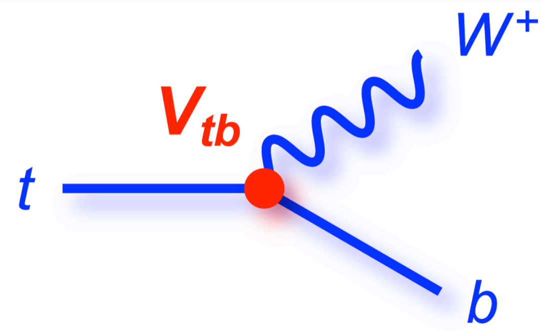


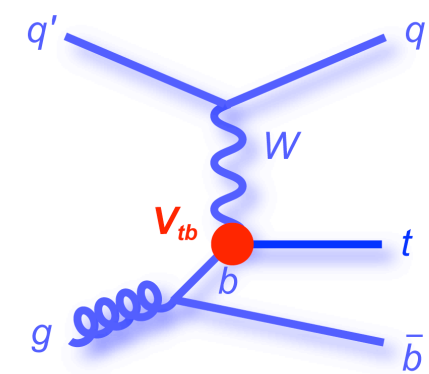


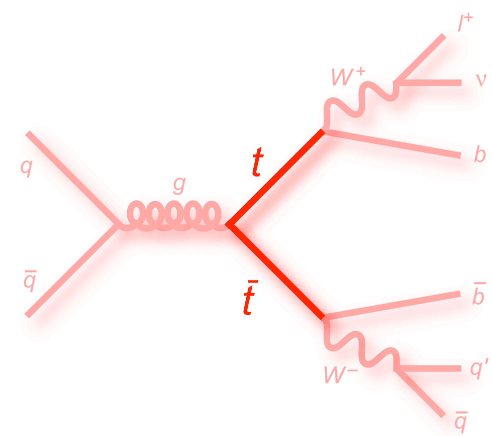
Top-quark properties / searches for new physics

- Precision measurements on the top-quark production mechanism and the top-quark decay properties can be use to constrain new physics models.

- Key measurements in this respects are:
  - Cross section measurements: total/differential
    - Single top ATLAS-CONF-2012-132, ATLAS-CONF-2012-056, ATLAS-CONF-2011-118, Phys. Lett. B 717 (2012) 330-350, Phys. Lett. B 716 (2012) 142-159
    - Top quark pair JHEP 1205 (2012) 059, Phys.Lett. B711 (2012) 244-263 Eur. Phys. J. C (2013) 73: 2261
  - Study of tt+Z/tt+γ, searches for FCNC in production or decay ATLAS-CONF-2012-126, ATLAS-CONF-2011-153, Physics Letters B 712 (2012) 351-369, JHEP 1209 (2012) 139
  - Top quark charge asymmetry Eur.Phys.J. C72 (2012) 2039
  - Spin correlation Phys. Rev. Lett. 108, 212001 (2012)
  - Top quark polarization
  - W polarization

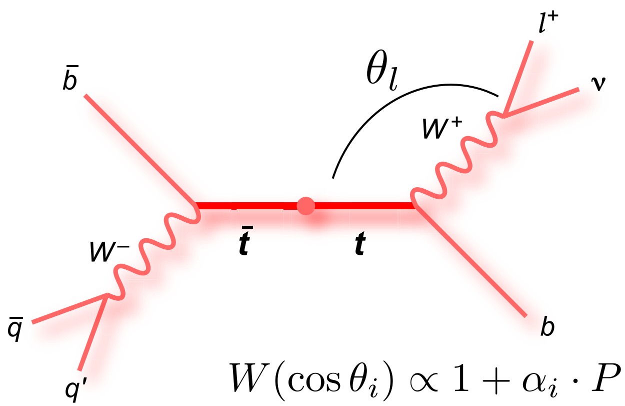






Probing the production mechanism

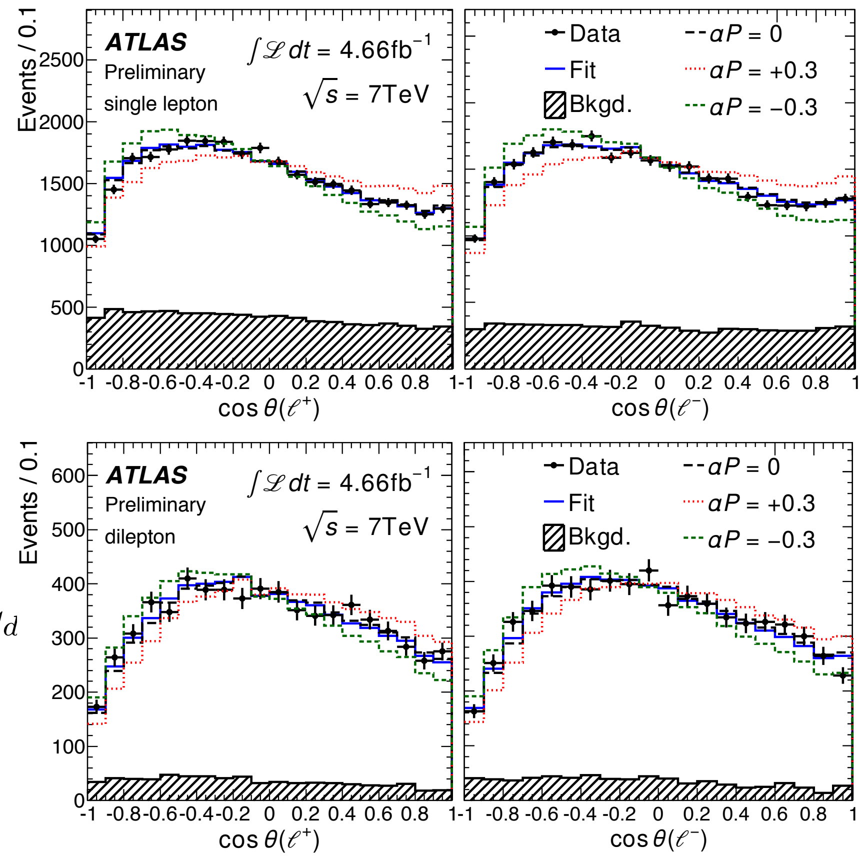
- Top-quark pair polarization
  - P conservation in QCD and unpolarised initial state at the LHC. Top quark pairs are produced unpolarised in SM



$$W(\cos\theta_i) \propto 1 + \alpha_i \cdot P \cdot \cos\theta_i$$

$$\text{where } P^{SM} \approx 0; \text{and } \alpha_i = 1 \text{ for } i = l, q_d$$

  - A net top polarisation would change the angular distributions of its decay products (i.e. for BSM models introducing large FB asymmetries as observed at Tevatron)



  - Full event reconstruction is needed to get the boost into the $t\bar{t}$ rest frame. Kinematical likelihood fit for the l+jets channel, ν-weighting method for the dilepton channel.

  - Template fit with different partial polarization assumptions to extract αP for charged leptons, together with the $\sigma(t\bar{t})$ to reduce normalization uncertainties.

CP conserving scenario ($P_{top}=P_{antitop}$):

$$\alpha_\ell P_{\text{CPC}} = -0.035 \pm 0.014(\text{stat}) \pm 0.037(\text{syst})$$

CP violating scenario (P_{top} = - $P_{antitop}$):

$$\alpha_\ell P_{\text{CPV}} = 0.020 \pm 0.016(\text{stat})^{+0.013}_{-0.017}(\text{syst})$$

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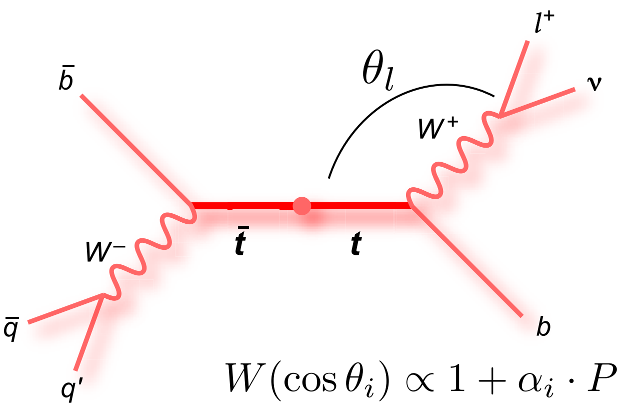

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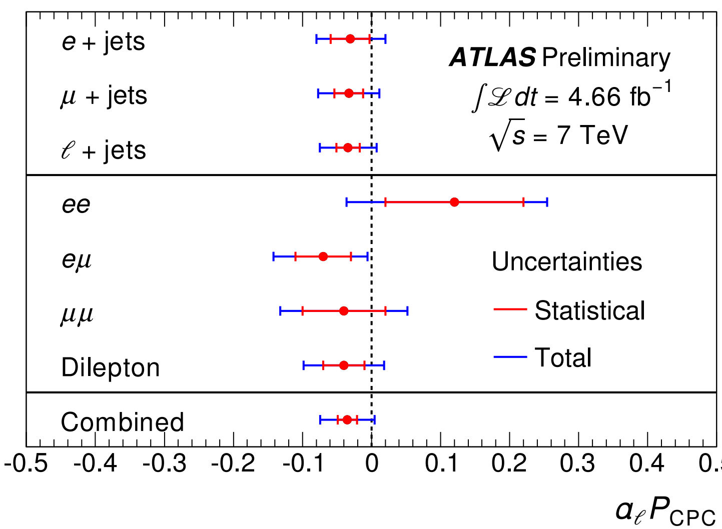

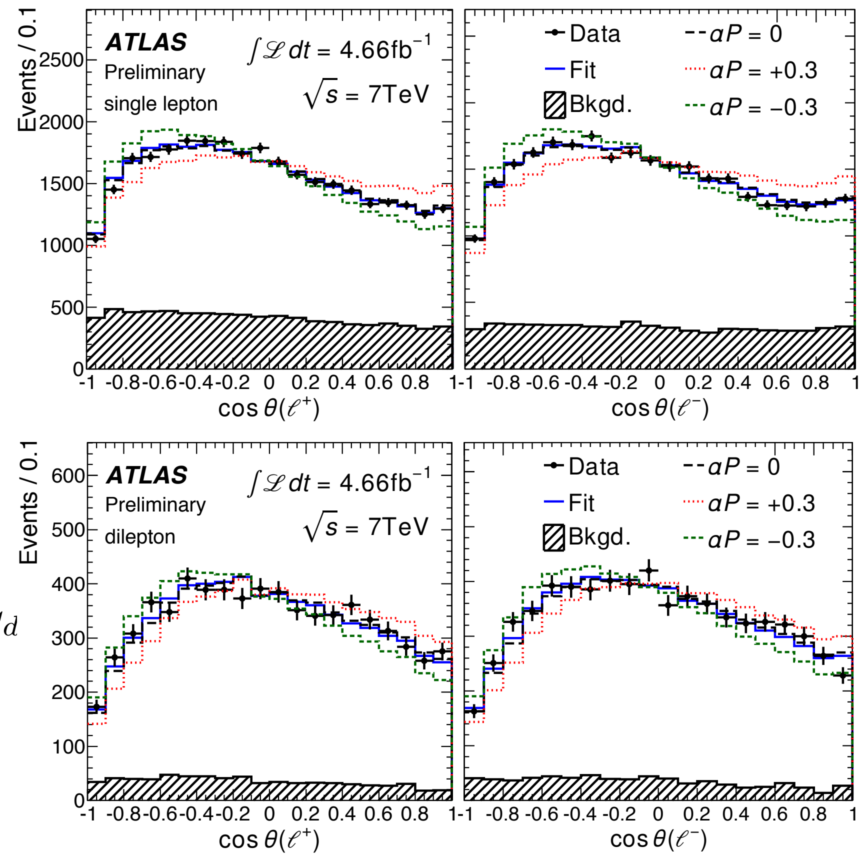

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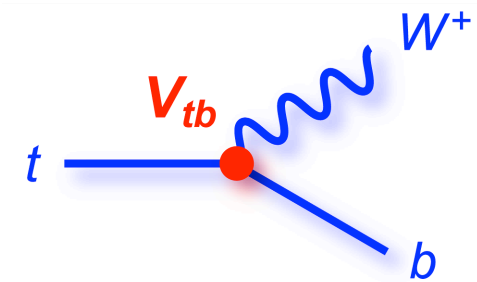
$$\alpha_\ell P_{\mathrm{CPC}} = -0.035 \pm 0.014(\mathrm{stat}) \pm 0.037(\mathrm{syst})$$

CP violating scenario (P_{top} = - $P_{antitop}$):

$$\alpha_\ell P_{\mathrm{CPV}} = 0.020 \pm 0.016(\mathrm{stat})^{+0.013}_{-0.017}(\mathrm{syst})$$

Main syst: MC modelling, jet reconstruction (resolution/scales)

Probing the Wtb vertex



Angular distribution of leptons from W in a given reference frame:

$$\frac{1}{\Gamma}\frac{d\Gamma}{d\cos\theta^X} = \frac{3}{8}(1+\cos\theta^X)^2 F_+^X + \frac{3}{8}(1-\cos\theta^X)^2 F_-^X + \frac{3}{4}\sin^2\theta^X)F_0^X$$

$$\text{where}: \ \mathrm{X} = *$$

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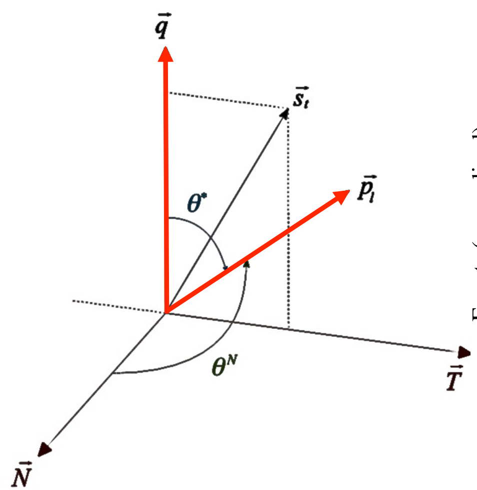
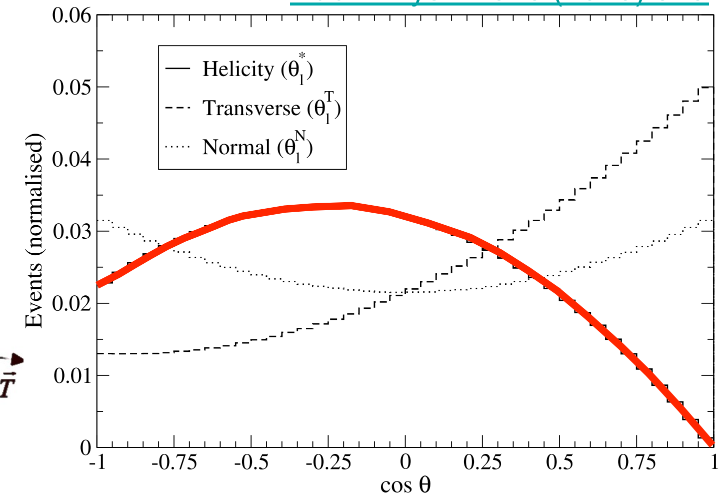
- For un-polarised top quark decays (e.g. top-quark pair production) use the helicity basis, exploit the W boson momentum direction (q) in the top quark rest frame





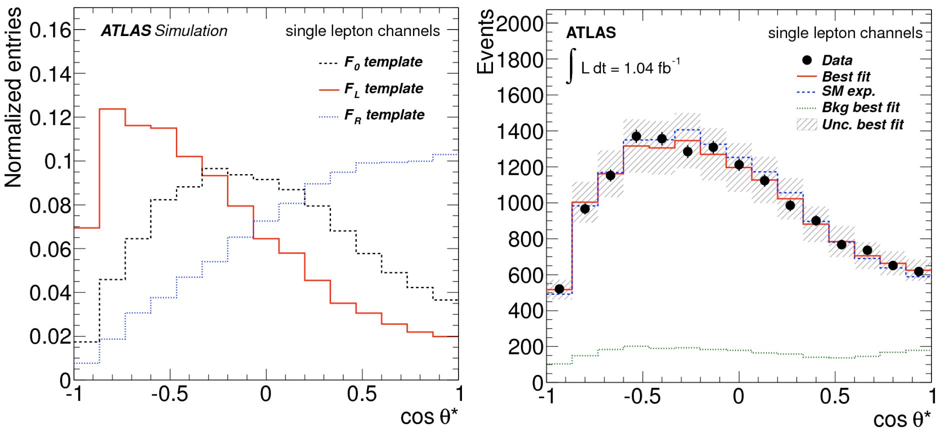
$$\mathcal{L}_{Wtb} = -\frac{g}{\sqrt{2}}\bar{b}\gamma^\mu(V_L P_L + V_R P_R)tW_\mu^- - \frac{g}{\sqrt{2}}\bar{b}\frac{i\sigma^{\mu\nu}q_\nu}{M_W}(g_L P_L + g_R P_R)tW_\mu^- + \mathrm{h.c.}$$

- In an effective operator framework: W helicity fractions (*) can probe the real part of the couplings

$$\mathrm{SM}^{\text{tree level}}: \mathrm{V_L} = \mathrm{V_{tb}} \approx 1 \text{ and } \mathrm{V_R} = \mathrm{g_L} = \mathrm{g_R} = 0$$

W helicity fractions

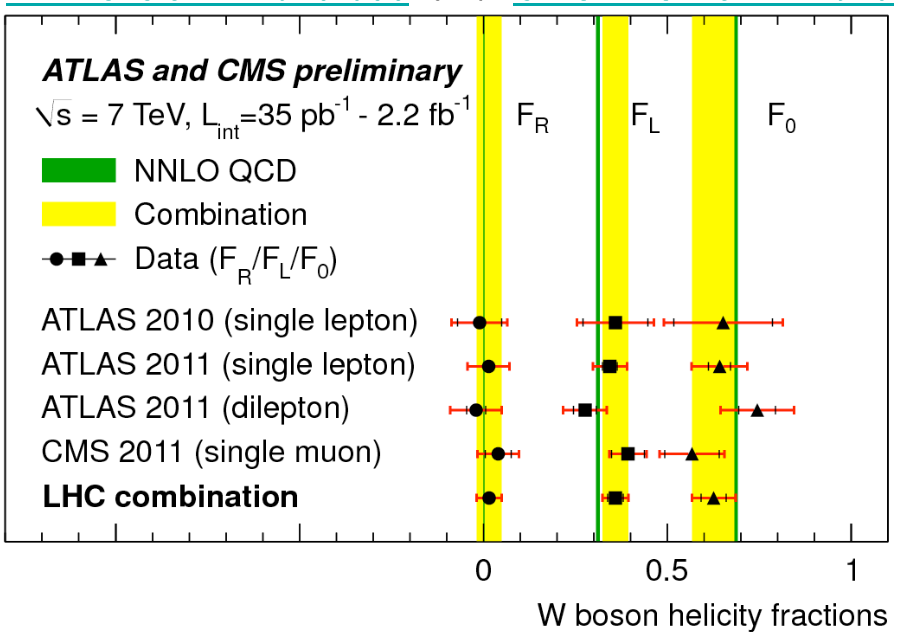
example measurement (ATLAS l+jets: templates)



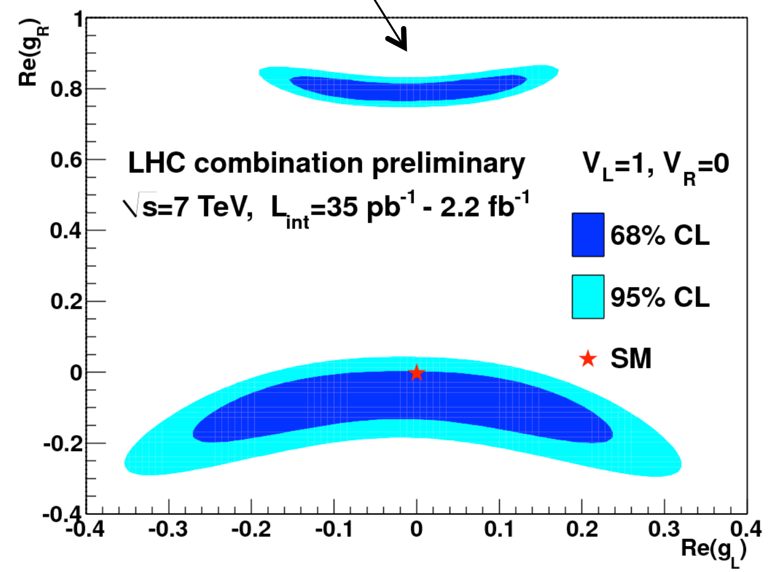
- World best determination via LHC combination*.
  - F_0 = 0.626 ± 0.034 (stat.) ± 0.048 (syst.)
  - F_L = 0.359 ± 0.021 (stat.) ± 0.028 (syst.)

Main syst: MC modelling, jet reconstruction, detector modelling

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

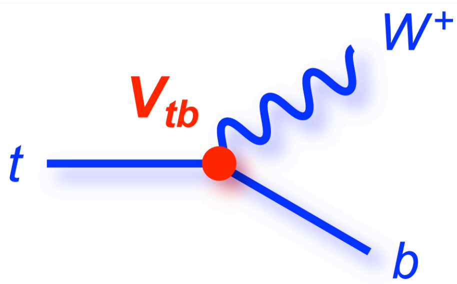


Region largely constrained by single top cross section measurements



*The combination does not include a new result from CMS in dilepton channel (CMS PAS TOP-12-015)

Probing the Wtb vertex



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$$\text{where}: \quad \mathrm{X} = *, \mathrm{T}, \mathrm{N}$$

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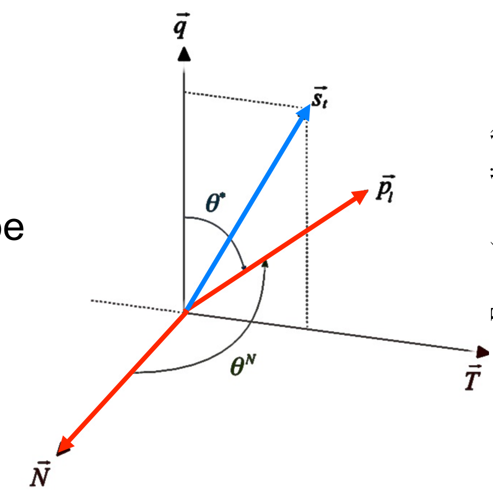
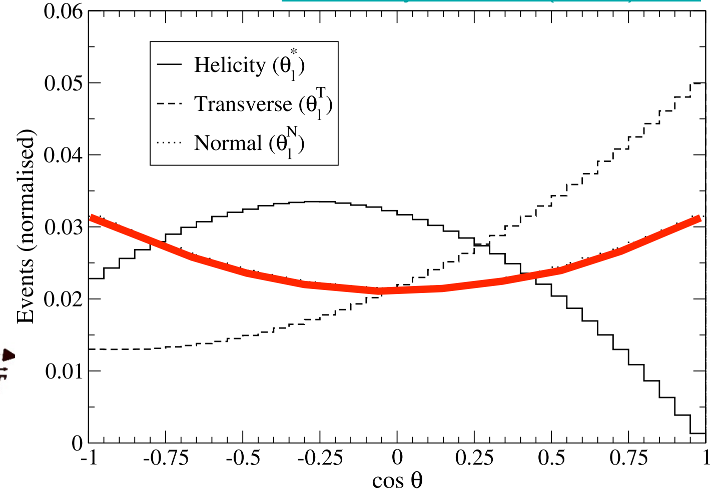
- For polarised top quark (s_t) decays further directions can be accessed N, T (e.g. t- channel top production)

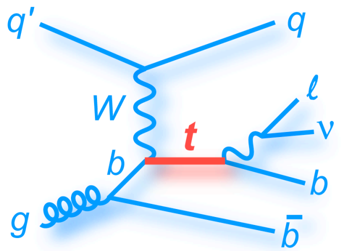




- In an effective operator framework: W helicity fractions (*) and T polarisations can probe the real part of the couplings while the N polarisations are sensitive to complex phases

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

$$\mathrm{SM}^{\text{tree level}}: \mathrm{V_L} = \mathrm{V_{tb}} \approx 1 \text{ and } \mathrm{V_R} = \mathrm{g_L} = \mathrm{g_R} = 0$$



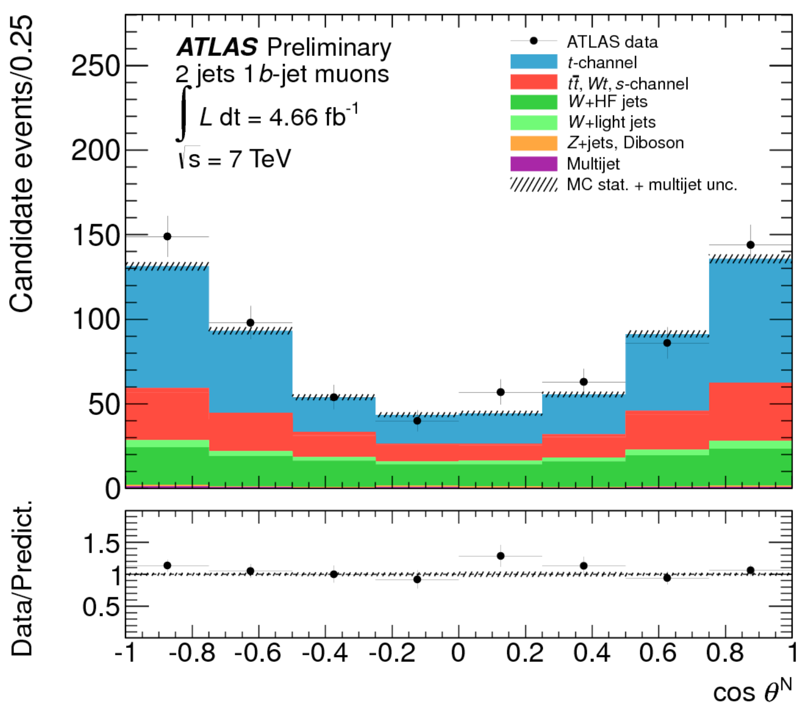
normal W polarization

ATLAS-CONF-2013-032

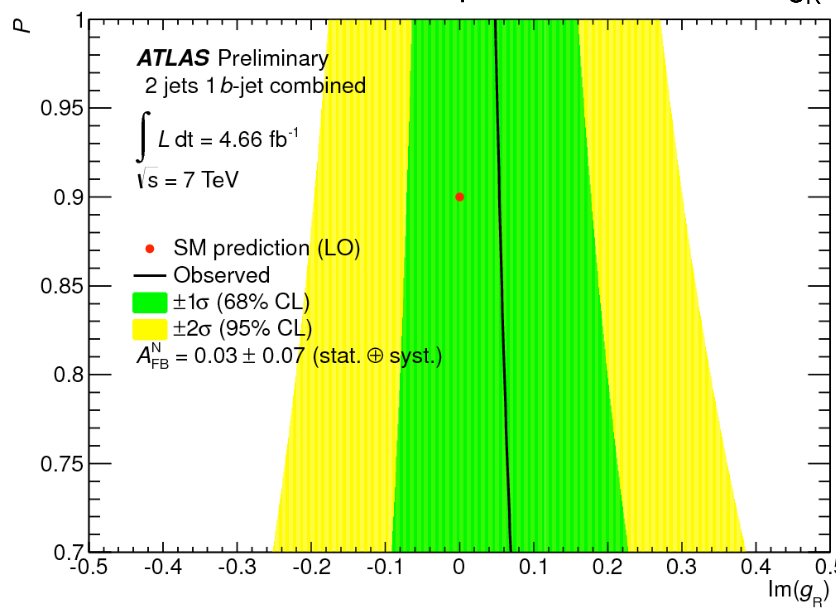
- t-channel single top production: a source of highly polarized tops (*P*~0.9).
- Search for CP violation in top decays.
  - $A_{FB}^{N} \neq 0$ implies CP violation

$$A^N_{FB} = \frac{N(\cos\theta_N > 0) - N(\cos\theta_N < 0)}{N(\cos\theta_N > 0) + N(\cos\theta_N < 0)}$$

$$A^N_{FB} \approx 0.64 \cdot P \cdot \mathrm{Im}(g_R)$$



First experimental limits on Im g_R



$$A^N_{FB} = 0.031 \pm 0.065(\mathrm{stat})^{+0.029}_{-0.031}(\mathrm{syst})$$

Main syst: MC modelling (single top & unfolding, top-quark pair), background normalization (ttbar/W+HF), jet reconstruction (resolution/scales)

Conclusions

- ATLAS is moving at full steam into the precision era of top-quark measurements.

  - Driven by the experimental challenges top-quark enriched data samples are used to complement, refine and improve the detector understanding and the performance of the analysis tools

  - Several top-quark event modeling aspects, as implemented in the Monte Carlo simulations, could be tested and refined with $\sqrt{s}$=7 TeV proton-proton data.

  - The recent m_{top} and top-quark properties measurements from ATLAS have been summarized, as key examples of a successful handshake between performance studies and precision physics results.

  - The 8 TeV dataset is awaiting us to deepen our understanding of top-quark physics
    - We will encounter new challenges to improve our precision…
    - … but challenges drive evolution, and keep pushing us developing new analysis techniques and tool to face them…

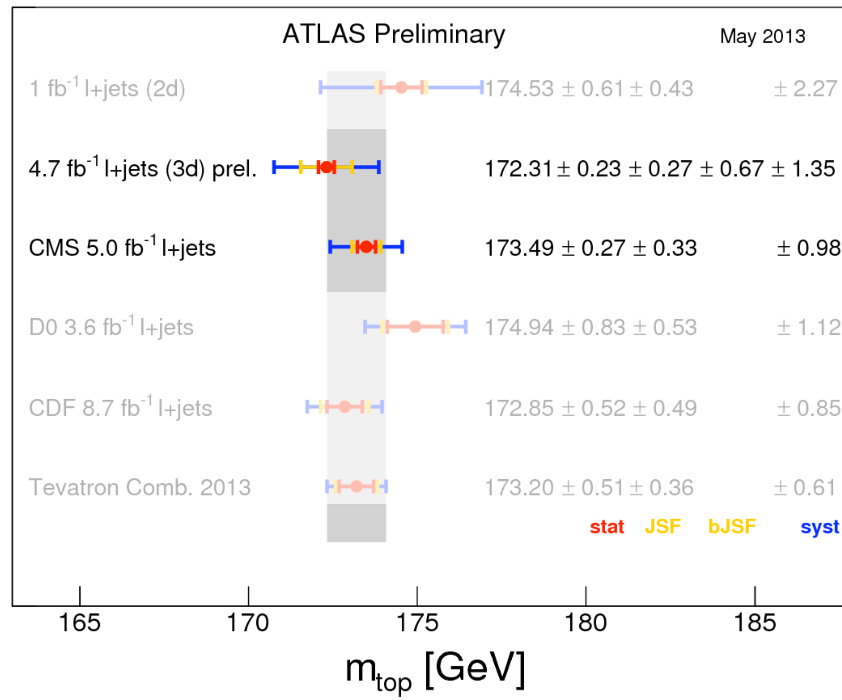
Stay tuned! (https://twiki.cern.ch/twiki/bin/view/AtlasPublic/TopPublicResults)

- Backup -

LHC: l+jets m_{top} measurements face-to-face

Uncertainty Categories			ATLAS / CMS	
Tevatron	ATLAS	CMS	2011 l+jets	2011 l+jets
Measured m_{top}			172.31	173.49
	Jet Scale Factor	Jet Scale Factor	0.27	0.33
	bJet Scale Factor		0.67	
iJES	Sum	Sum	0.72	0.33
bJES	JES_{b-jet}	JES_{b-jet}	0.08	0.61
dJES	$JES_{light-jet}$	$JES_{light-jet}$	0.79	0.28
Lepton p_{T} Scale			0.04	0.02
MC	MC Generator	MC Generator	0.19	
	Hadronisation		0.27	
	Sum	Sum	0.33	
Rad	ISR/FSR	ISR/FSR	0.45	
		Q-Scale		0.24
		Jet-Parton Scale		0.18
	Sum	Sum	0.45	0.30
CR	Colour Recon.		0.32	0.54
PDF	Proton PDF	Proton PDF	0.17	0.07
	Jet Energy Res.	Jet Energy Res.	0.22	0.23
	Jet Rec. Eff.		0.05	
	b-tagging	b-tagging	0.81	0.12
	$E_{\mathrm{T}}^{\mathrm{miss}}$	$E_{\mathrm{T}}^{\mathrm{miss}}$	0.03	0.06
DetMod	Sum	Sum	0.84	0.27
Underlying Event			0.12	0.15
BGMC				0.13
BGData			0.10	
Method	Method Calib.	Method Calib.	0.13	0.06
MHI	Pile-up	Pile-up	0.03	0.07
		Statistics	0.23	0.27
		Rest	1.53	1.03
		Total Uncertainty	1.55	1.07

- Summary table of public 2011 LHC m_{top} measurements in the lepton+jets channel, likely to drive the next LHC combination.



Systematics categorized according to the grouping used in the first LHC combination.
CMS measurement from [JHEP (2012) 2012:105]

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- Statistical sensitivities:
  - Similar m_{top} statistical sensitivity (corresponds to a 1dim fits)

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  - the extra statistical uncertainties on m_{top} introduced by the simultaneous JSF (bJSF) fits.
  - Similar sensitivity to JSF from the in-situ m_W fits (0.27 vs 0.33 GeV) .
  - ATLAS has a larger JES stat component (iJES) due to the increased dimensionality of the fit (extra 0.67 GeV).

scale with luminosity
uncorrelated between exp.

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  - ATLAS has a larger JES stat component (iJES) due to the increased dimensionality of the fit (extra 0.67 GeV). This is compensated by…
- reduced bJES uncertainty (3rd dimension)
  - Similar m_{top} statistical sensitivity (corresponds to a 1dim fits)

scale with luminosity
uncorrelated between exp.

LHC: l+jets m_{top} measurements face-to-face

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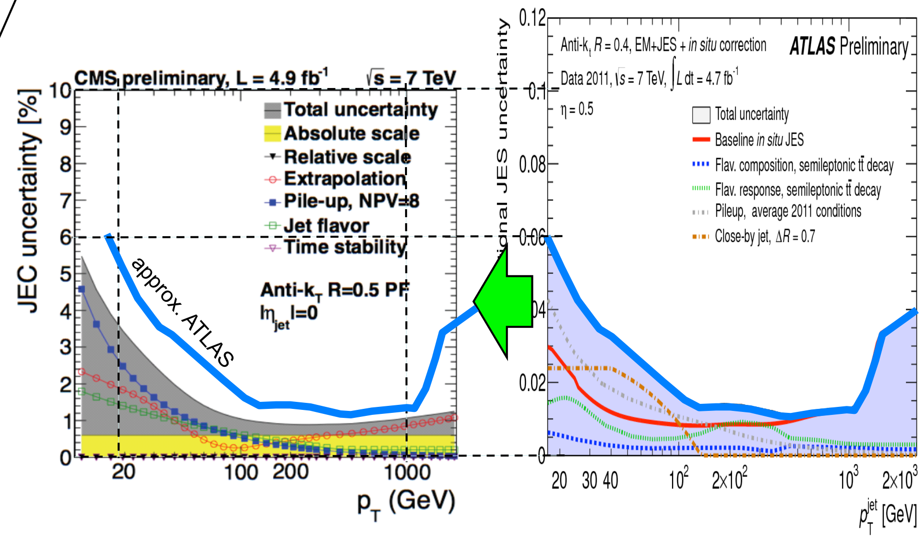
- Different residual JES uncertainties, despite the in-situ m_W calibration.



- The ATLAS JES uncertainty has a more pronounced p_T dependence at intermediate jet p_T
  - This is reflected in a larger residual JES uncertainty after in-situ calibration using m_W (only sensitive to the constant term).
  - Other effects may play here: small residual bJSF dependence on the JES, and JES component split…

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- MC generator and hadronization (Pythia/ Herwig) uncertainties:
  - Not dominant uncertainties for ATLAS 3dTMT, but each could be large depending on the analysis details
  - Within CMS:
    - the MC generator systematics are found to be small (but are not documented for all the current public results).
    - Hadronization systematics are meant to be covered by the JES uncertainty.
  - Harmonized treatment is being discussed within the TOP-LHC-WG for the next LHC combination.
  - In the long run need to evaluate possible double counting effects between the hadronization and JES syst. and improve our knowledge on these effects.

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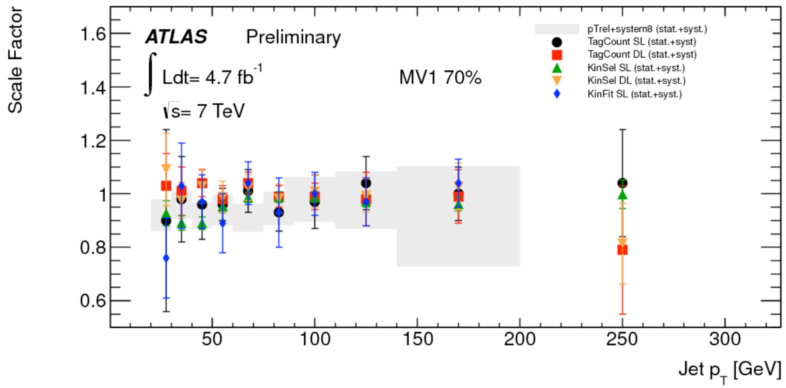
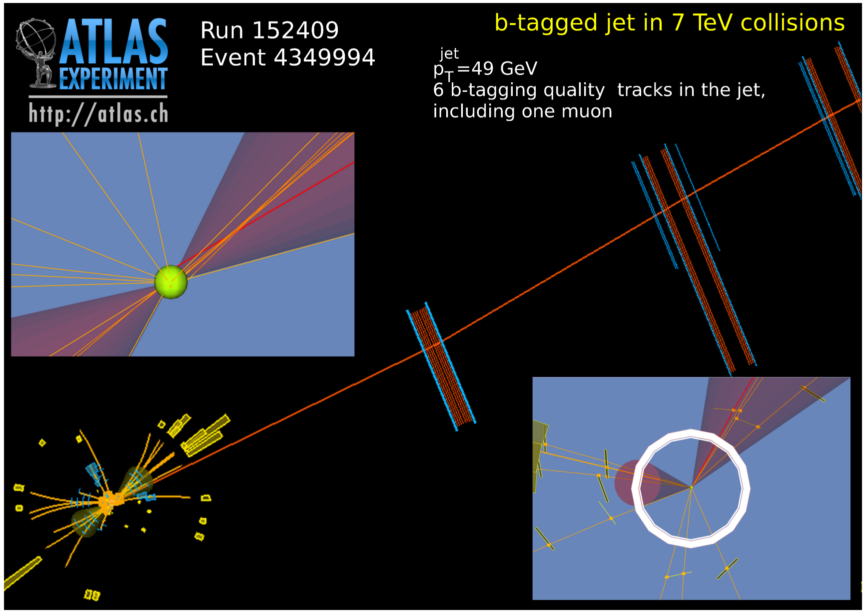
- ATLAS 3dTMT has a large sensitivity to b-tag systematics (related to the p_T dependence of the SF uncertainties, affecting the shape of the R_{lb}^{calo}, the 3[rd] dimension).



b-tagging

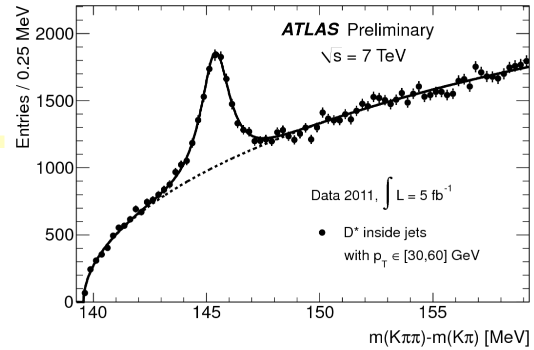
- Main algorithms within ATLAS
  - Impact parameter based:
    - IP3D: use impact parameter (d0) significance
  - Secondary vertex (SV) based
    - SV1: make use of the SV properties (mass, number of tracks ..)
    - JetFitter: exploit the topology of weak B/D-hadron decay chains ($b \rightarrow c \rightarrow X$) inside jets
  - Soft lepton based:
    - soft-μ tagger: exploit the properties of soft μ from b-quark semileptonic decays
  - Neural network based algorithms
    - MV1: based on multivariate technique using the IP3D/SV1/JetFitter output as input variables



b-tagging calibrations

- The performances of the b-taggers needs to be calibrated to account for detector effects and possible mis-modeling of the jet/event characteristics in the MC with respect to the data.

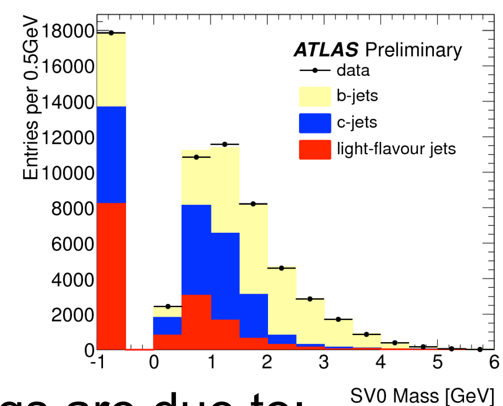
- Data samples are used to determined:
  - *b-tagging efficiency*: the fraction of b-quark originated jets which is correctly identified
  - *c-tagging efficiency*: the fraction of c-quark originated jets tagged by the algorithm.
  - *mis-tag rate*: the fraction of light-quark originated jets which are wrongly identified as b-jets.



ATLAS-CONF-2012-039

- Calibration by reconstructing exclusive D^{*+} decays within jets:

$$D^{*+} \rightarrow \pi^+ D^0 (\rightarrow K^- \pi^+)$$



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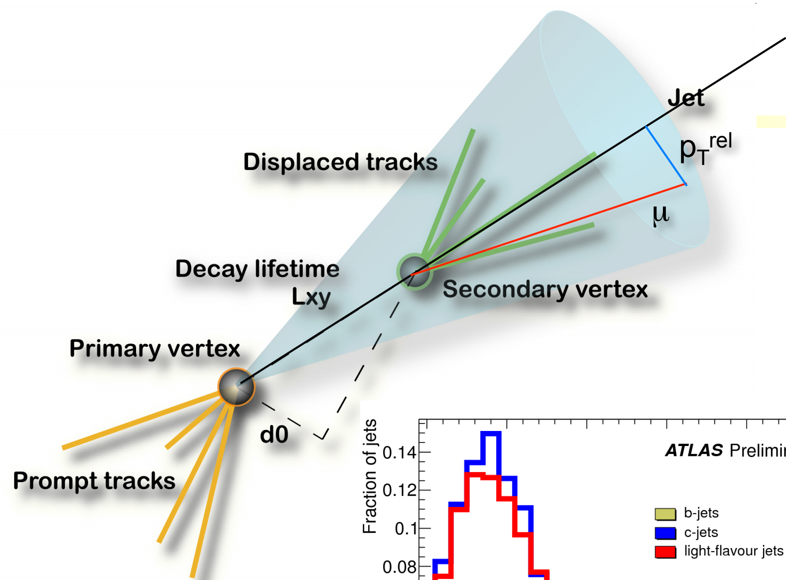
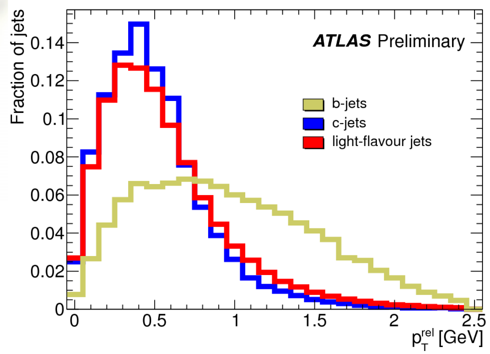
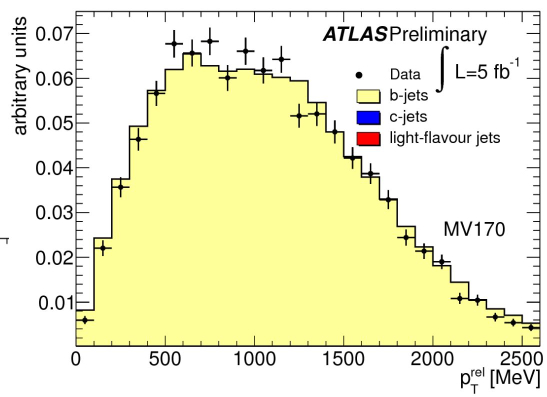
- Mis-tags are due to:
  - the detector resolution limitation, long-lived particles, and material interaction
  - Calibrated with di-jet data:
    - Secondary vertices with negative decays length
    - Fits to the invariant mass of the SV.

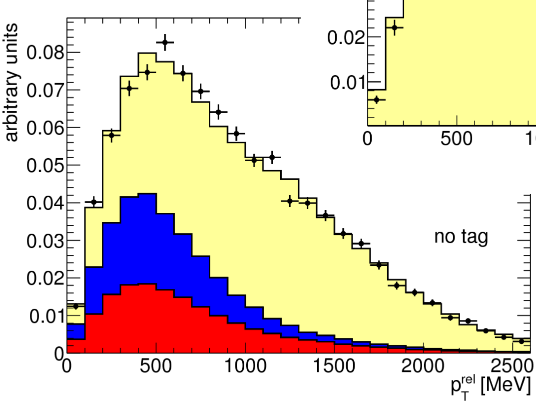
b-tag efficiency -1



- Select a sample of events with jets containing muons
  - ***p_T^{rel}***: Template fit of muon p_T respect to jet axis (p_T^{rel}) to get flavor fraction before and after b-tagging
  - ***System 8***: define independent jet selection criteria to construct 8 samples. Use event counts to solve for b-tagging efficiency.





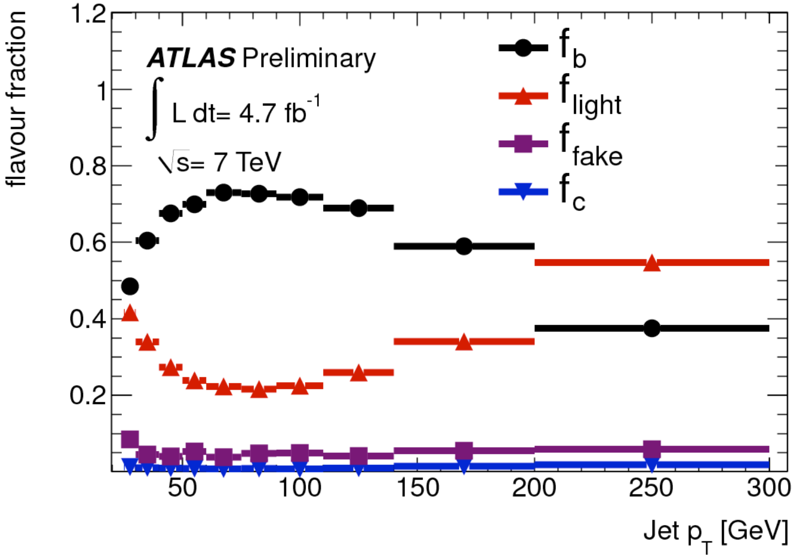


p_T^{rel}	Jet p_T [GeV]								
Source	20 to 30	30 to 40	40 to 50	50 to 60	60 to 75	75 to 90	90 to 110	110 to 140	140 to 200
simulation statistics	2.2	2.0	1.4	1.8	2.7	3.4	6.0	6.0	4.7
...									
charm-light ratio	3.0	2.4	2.1	2.0	1.2	0.4	0.9	1.5	16.0
...									
scale factor for inclusive *b*-jets	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
total systematic	6.4	5.3	4.9	5.1	5.4	5.7	7.5	8.1	17.7
statistical	1.8	1.9	2.5	3.7	2.1	3.5	5.2	7.4	14.8

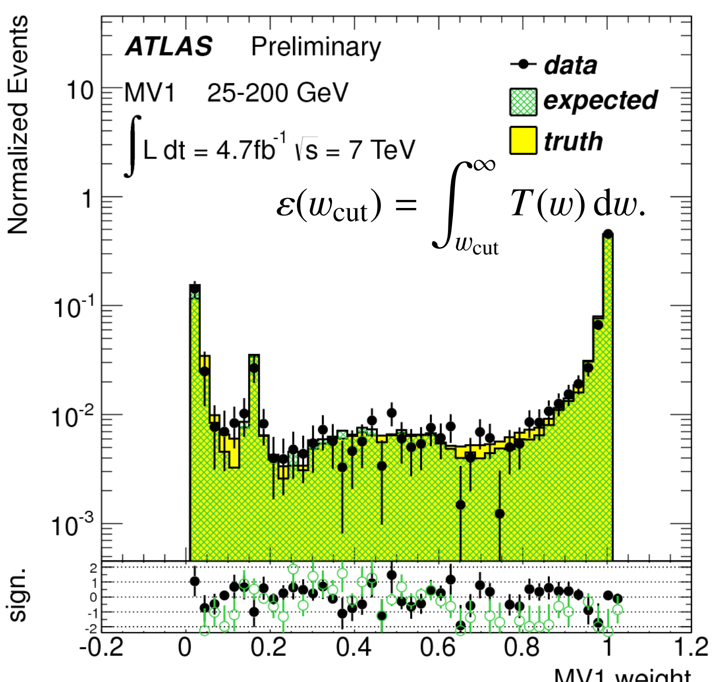
Uncertainties on the combined scale factors range from 5% to 19% at low and high jet p_T
(reduced method sensitivities in the high p_T range)
Significant systematics due to the extrapolation to inclusive b-jets from b-jets with semileptonic decays

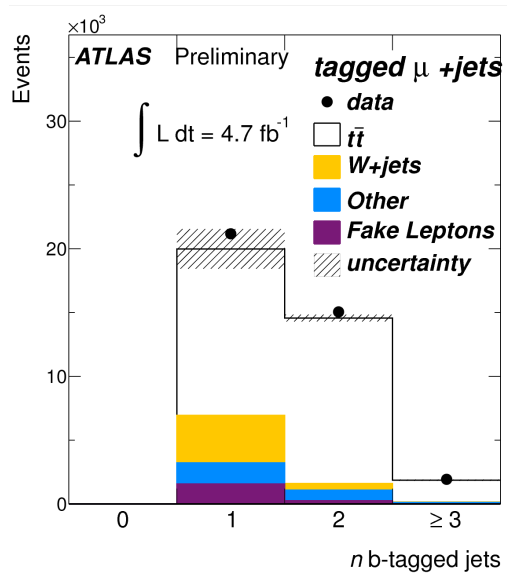
b-tag efficiency -2

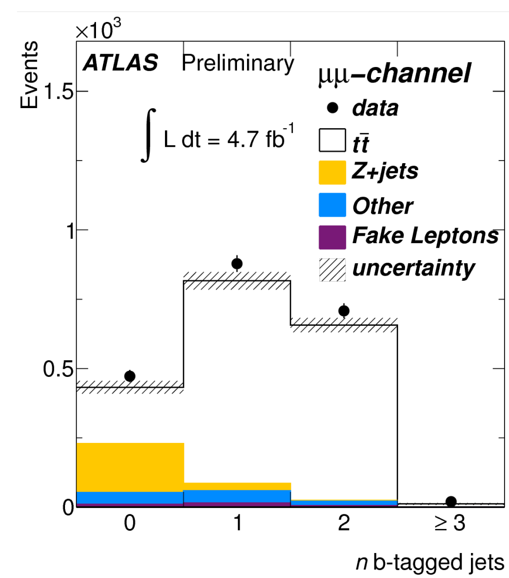
- Calibrations are derived from both diepton / l+jets channels
  - Tag counting: use multiplicity of b-tagged jets
  - Kinematic selection: measure tag rate for the jet, knowing the jet flavour composition as a function of the jet properties..
  - Kinematic fit: fit top-pair event topology to derive b-jet weight distribution (only l+jets) continuous calibration is possible!



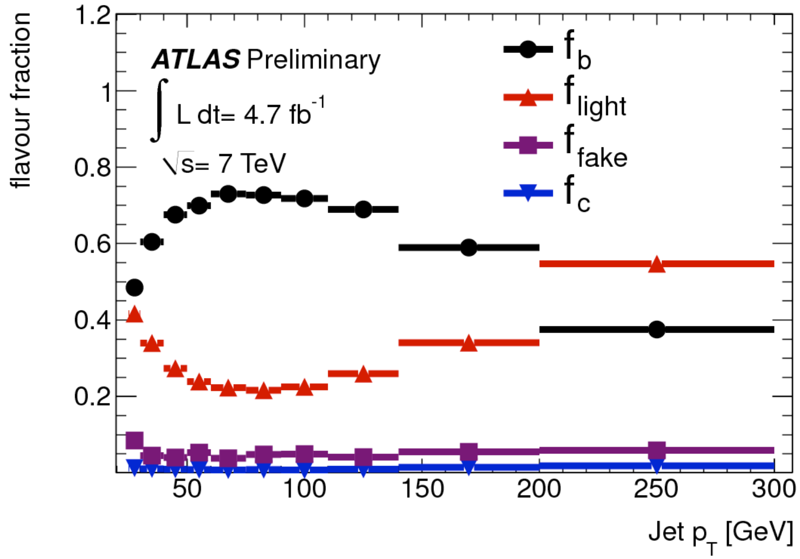
$$f_{b-\mathrm{tag}} = \varepsilon_b f_{b-\mathrm{jets}} + \varepsilon_c f_{c-\mathrm{jets}} + \varepsilon_l f_{l-\mathrm{jets}} + \varepsilon_{\mathrm{fake}} f_{\mathrm{fake}}$$





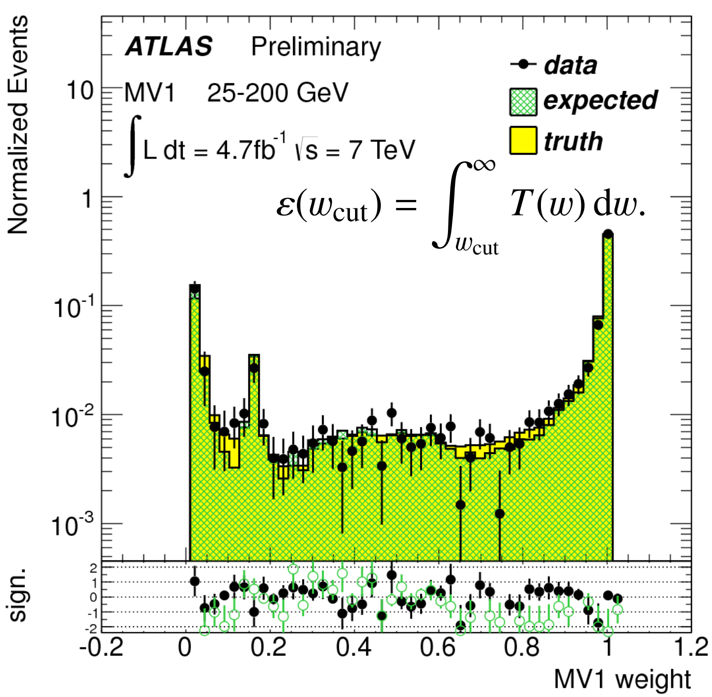


b-tag efficiency -2



$$f_{b-\text{tag}} = \varepsilon_b f_{b-\text{jets}} + \varepsilon_c f_{c-\text{jets}} + \varepsilon_l f_{l-\text{jets}} + \varepsilon_{\text{fake}} f_{\text{fake}}$$

- Calibrations are derived from both diepton / l+jets channels
  - Tag counting: use multiplicity of b-tagged jets
  - Kinematic selection: measure tag rate for the jet, knowing the jet flavour composition as a function of the jet properties..
  - Kinematic fit: fit top-pair event topology to derive b-jet weight distribution (only l+jets) continuous calibration is possible!

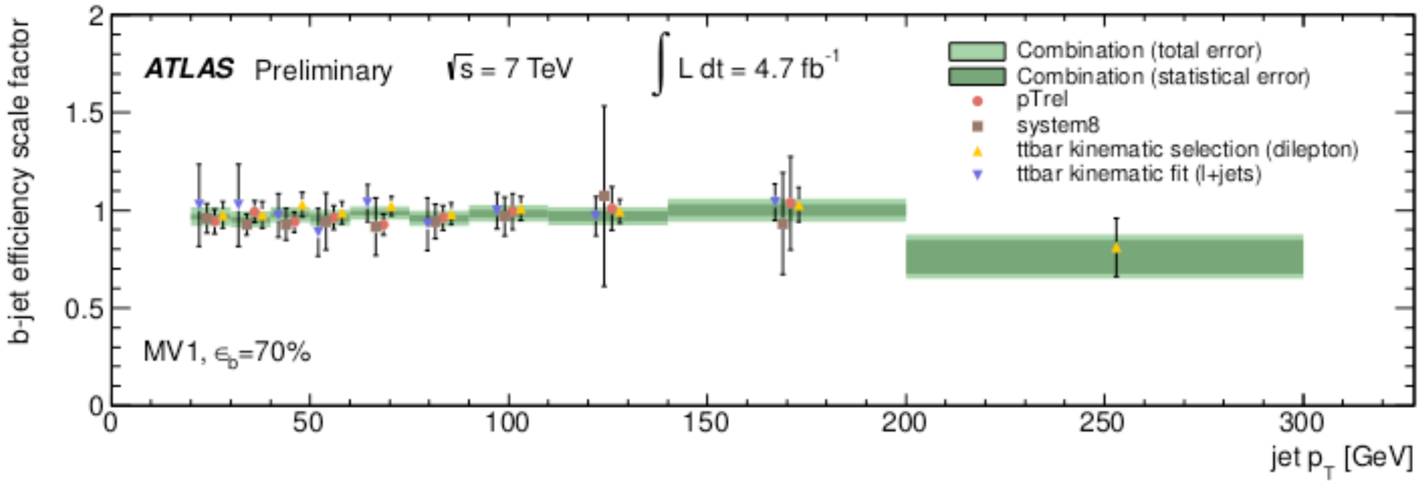


p_T[GeV]	25-30	30-40	40-50	50-60	60-75	75-90	90-110	110-140	140-200	200-300
IFSR	±5.0	±4.0	±4.0	±4.2	±3.5	±3.8	±4.7	±4.7	±6.0	±9.2
Generator	±1.1	±0.7	±1.3	±1.0	±0.6	±2.1	±1.2	±0.5	±2.9	±8.1
Fragmentation	±2.7	±1.4	±1.7	±0.9	±1.1	±0.9	±0.3	±1.2	±1.2	±3.9
...										
...										
Stat.	±5.5	±3.2	±2.6	±2.6	±2.1	±2.4	±2.5	±2.9	±3.7	±10.7
Total Syst	±11.1	±6.1	±5.6	±5.2	±4.2	±5.0	±5.4	±5.6	±7.8	±15.1
Total	±12.3	±6.8	±6.1	±5.8	±4.7	±5.5	±5.9	±6.2	±8.5	±18.3

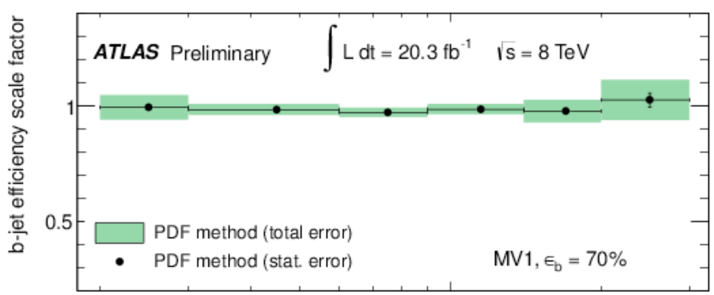
- Example: uncertainties on the dilepton kin sel SF:
  - Main/dominant systematics in common to top-quark physics analyses
- For analyses combined di-jet and top-pair SF calibration are available

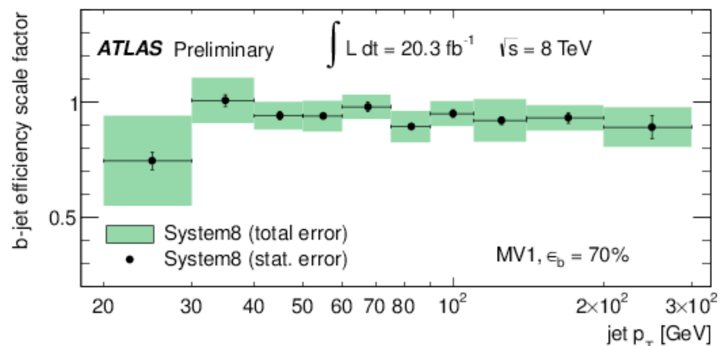
Combined di-jet / ttbar b-tag SF

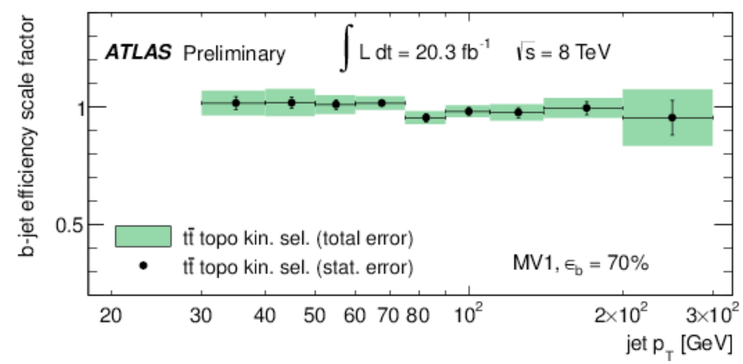
- 7 TeV



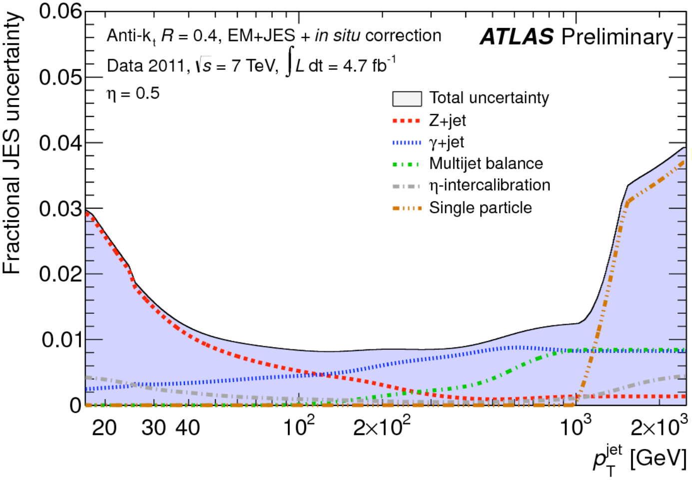
- 8 TeV







Baseline JES unc.



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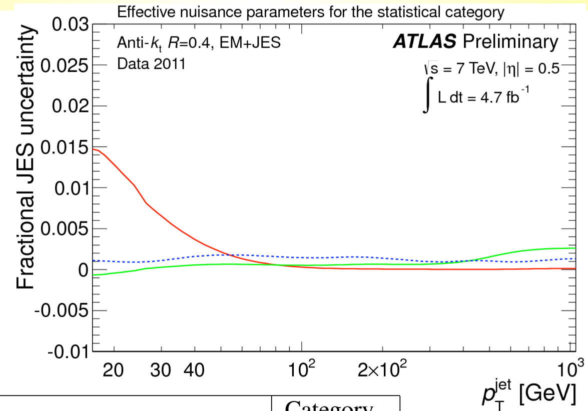
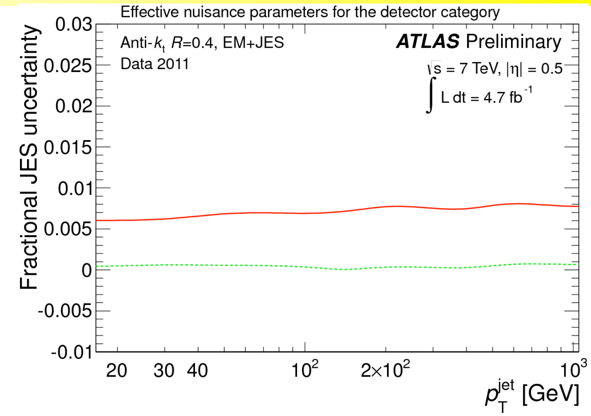
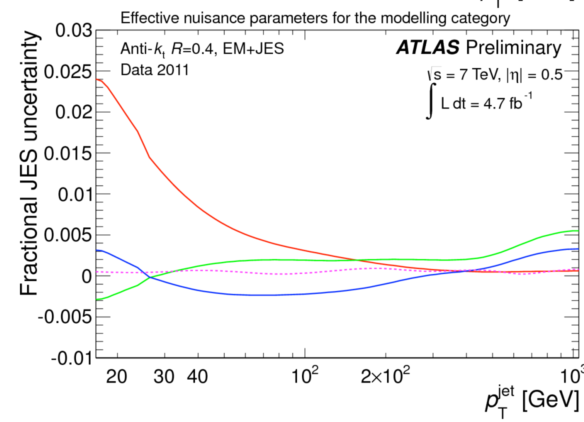
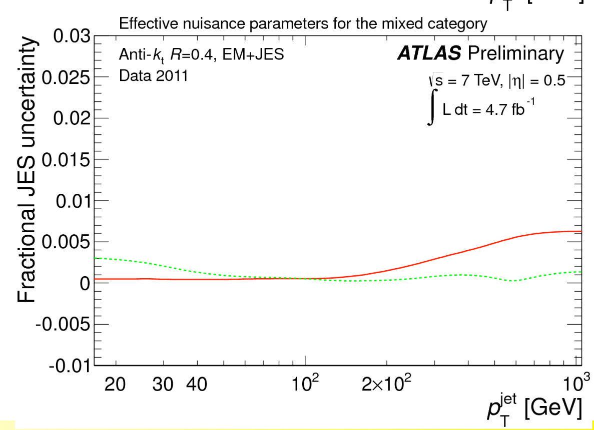




Name	Description	Category
Common sources		
Electron/photon E scale	electron or photon energy scale	det.
Z+jet p_T balance (DB)		
MC generator	MC generator difference between ALPGEN/HERWIG and PYTHIA	model
Radiation suppression	radiation suppression due to second jet cut	model
Extrapolation	extrapolation in $\Delta\phi_{\text{jet-}Z}$ between jet and Z boson	model
Pile-up jet rejection	jet selection using jet vertex fraction	mixed
Out-of-cone	contribution of particles outside the jet cone	model
Width	width variation in Poisson fits to determine jet response	stat./meth.
Statistical components	statistical uncertainty for each of the 11 bins	stat./meth.
γ+jet p_T balance (MPF)		
MC Generator	MC generator difference HERWIG and PYTHIA	model
Radiation suppression	sensitivity to radiation suppression due to second jet cut	model
Jet resolution	variation of jet resolution within uncertainty	det.
Photon Purity	background response uncertainty and photon purity estimation	det.
Pile-up	sensitivity to pile-up interactions	mixed
Out-of-cone	contribution of particles outside the jet cone	model
Statistical components	statistical uncertainty for each of the 12 bins	stat./meth.
Multijet p_T balance		
α selection	angle between leading jet and recoil system	model
β selection	angle between leading jet and closest sub-leading jet	model
Dijet balance	dijet balance correction applied for $|\eta| < 2.8$	mixed
Close-by, recoil	JES uncertainty due to close-by jets in the recoil system	mixed
Fragmentation	jet fragmentation modelling uncertainty	mixed
Jet p_T threshold	jet p_T threshold	mixed
p_T asymmetry selection	p_T asymmetry selection between leading jet and sub-leading jet	model
UE,ISR/FSR	soft physics effects modelling: underlying event and soft radiation	mixed
Statistical components	statistical uncertainty for each of the 10 bins	stat./meth.

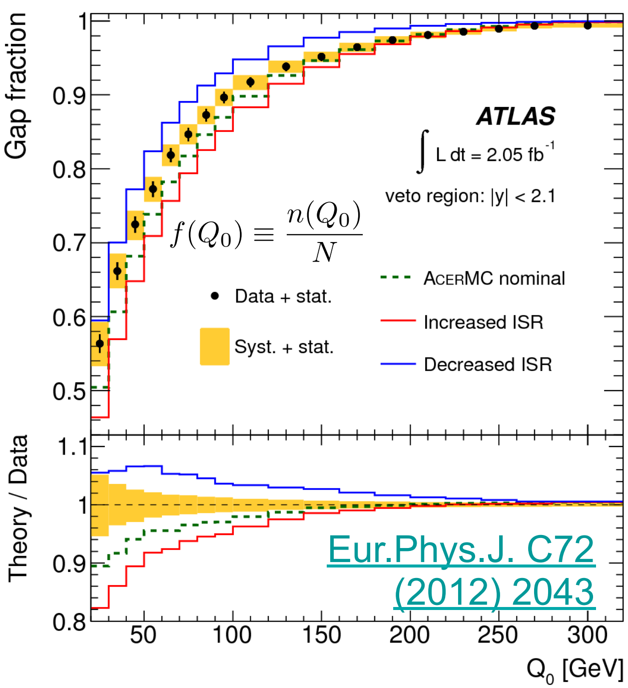


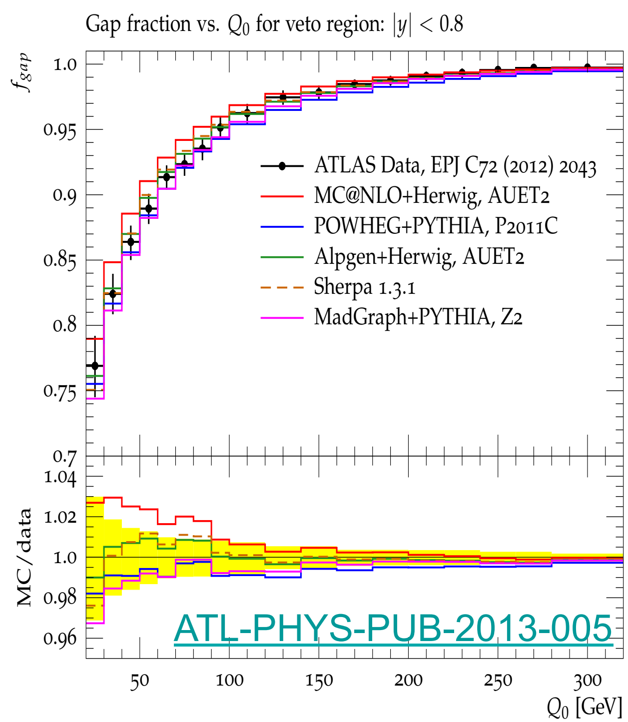


top-quark events: MC modelling

- Modelling of signal events is crucial for precision measurements
  - Analysis calibration
  - Event reconstruction
  - Definition of the parameter range used for systematic variations

Observable/analysis	Modelling improvements
Jet multiplicity	MC@NLO+Herwig replaced by PowHeg+Pythia
Jet veto	Reduced parameter range for ISR/FSR systematics





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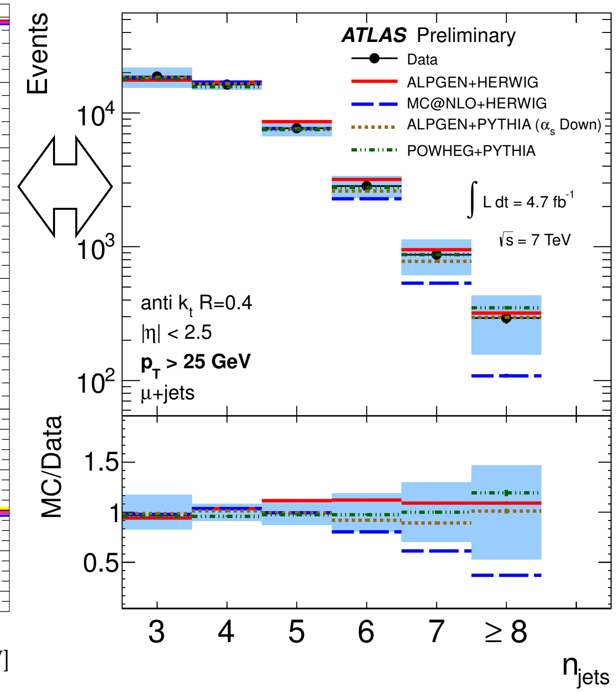
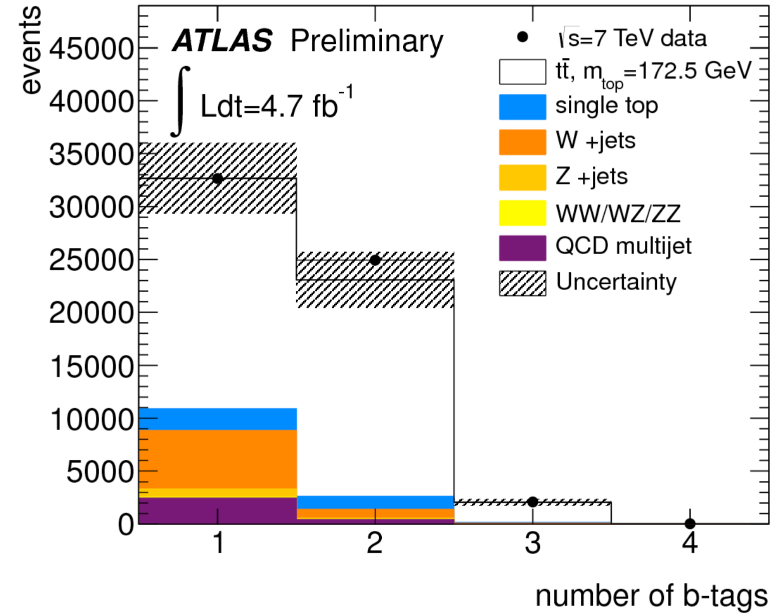


*measure the fraction of dileptonic top-pair events without an extra jet with $p_T > Q_0$

3dTMT m_{top}: event selection

- Event selection for the top-quark pair l+jets signature:
  - = 1 charged lepton, $E_T \geq 25$ / $p_T \geq 20$ GeV for e/μ
  - ≥ 4 jets with $p_T \geq$ 25 GeV, $|\eta|<2.5$, $|JVF| \geq 0.75$.
  - ≥ 1 b-tag jet (MV1 algorithm @ 70% efficiency)
    - Events with =1 or ≥2 b-tagged jets are treated separately: different sensitivities/resolution

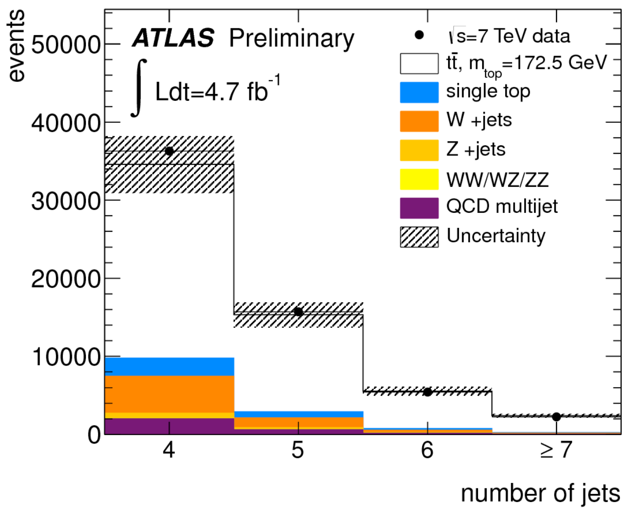
  To further suppress backgrounds:
  - e+jets: $E_T^{miss} \geq 30$ GeV, $m_W^T \geq 30$ GeV
  - μ+jets: $E_T^{miss} \geq 20$ GeV, $E_T^{miss} + m_W^T \geq 60$ GeV

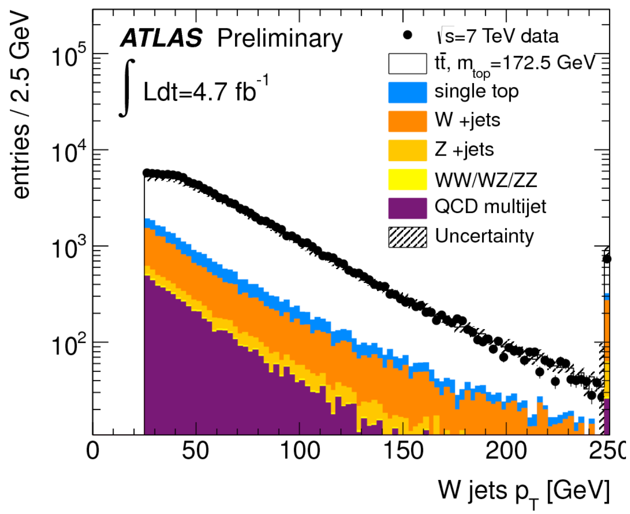


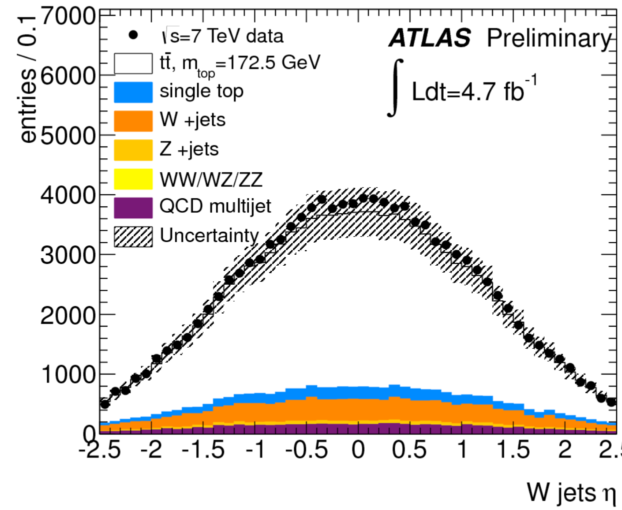
- Further selection after reconstruction:
  - Discard events with b-tagged W jets
  - =1 b-tag: 125 < m_{top}^{reco} < 225 GeV
  - ≥2 b-tags: 130 < m_{top}^{reco} < 220 GeV
  - 55 < m_W^{reco} < 110 GeV
  - 0.3 < R_{lb}^{reco} < 3.0

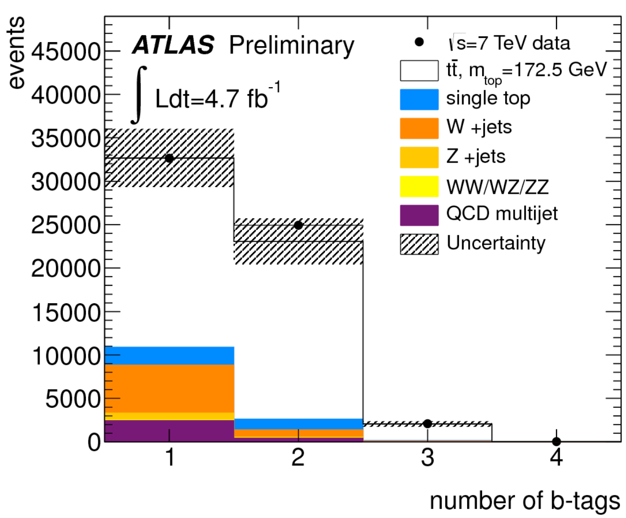
Process	Number of events after requiring = 1 *b*-tagged jet	≥ 2 *b*-tagged jets	≥ 1 *b*-tagged jet
$t\bar{t}$ signal	10700 ± 1100	6980 ± 780	17700 ± 1800
single top (signal)	816 ± 47	253 ± 48	1070 ± 84
W+jets (data)	1640 ± 500	124 ± 40	1770 ± 540
Z+jets	211 ± 65	17.5 ± 5.7	229 ± 70
ZZ/WZ/WW	34.6 ± 2.2	3.25 ± 0.38	37.9 ± 2.3
QCD multijet (data)	780 ± 390	71 ± 37	851 ± 430
Signal+background	14200 ± 1200	7450 ± 780	21600 ± 1900
Data	14358	8520	22878

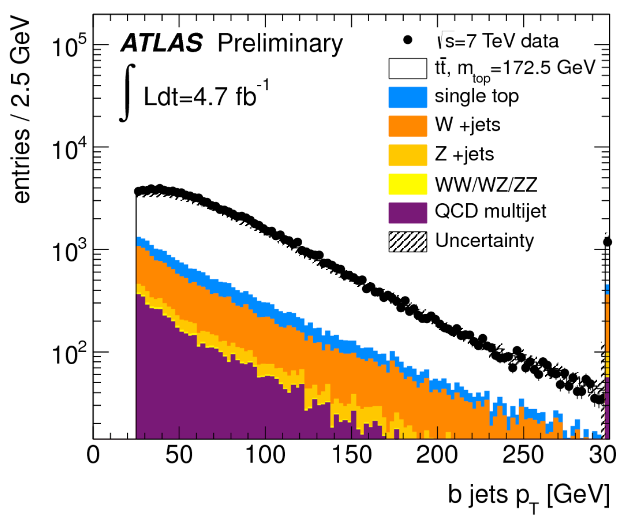
Control plots, after std. top-group selection

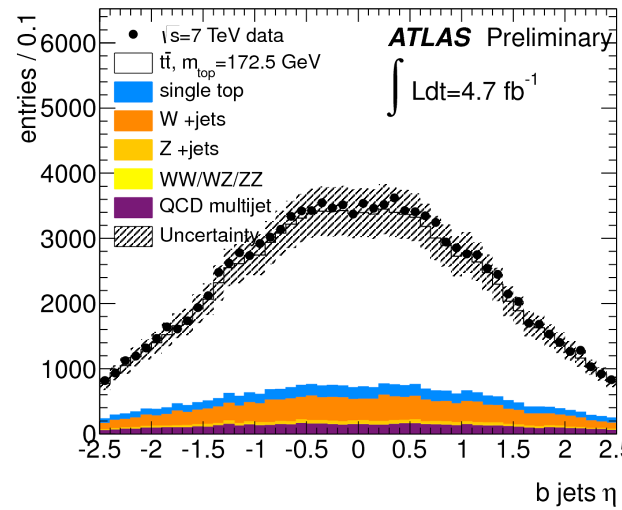






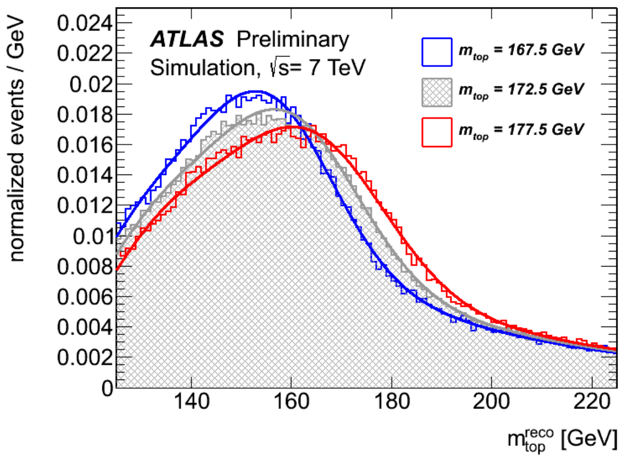


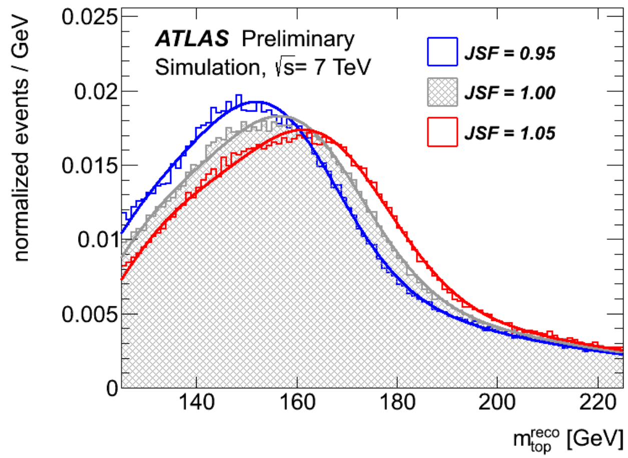


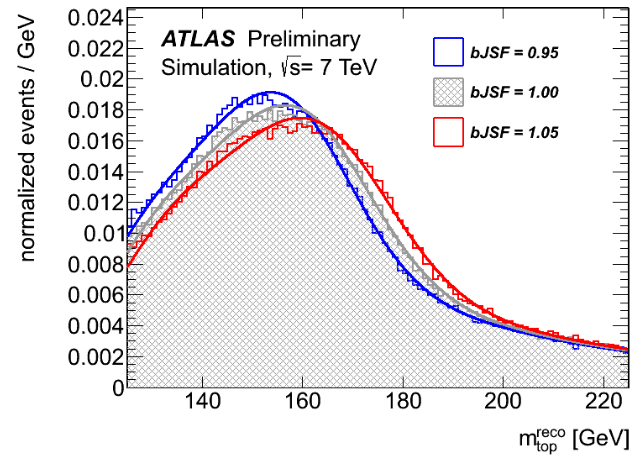


In all plots, the unc. band includes: stat, lumi, b-tag uncertainties. In addition: 10% on the ttbar x-sec, 30% on the W+jets norm, 50% on the QCD norm

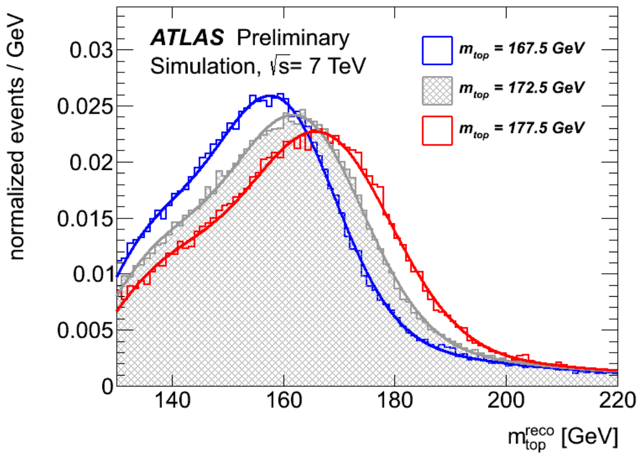
Templates fits and their sensitivity

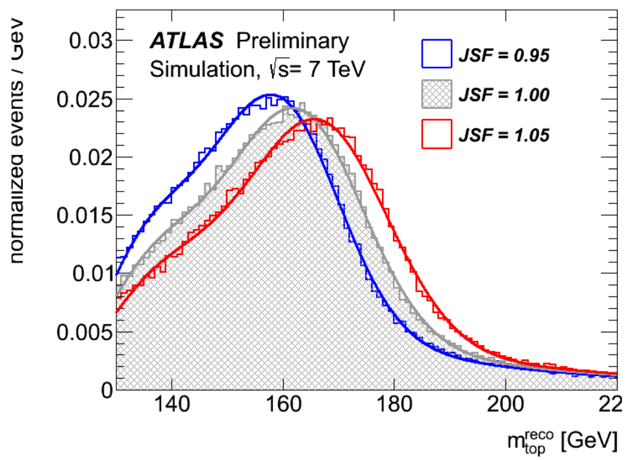


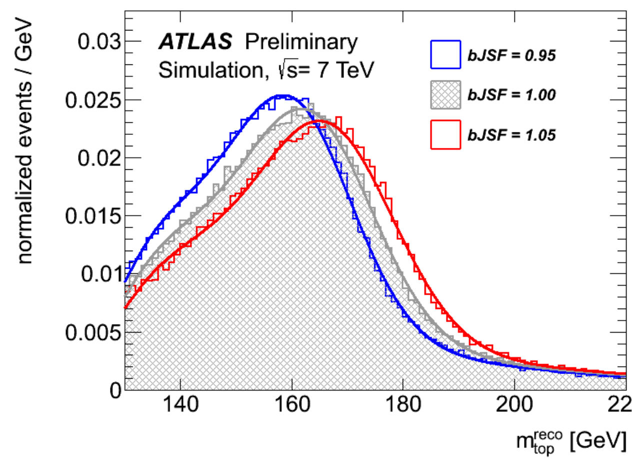




Distributions of m_{top}^{reco} for events with = 1 b-tag. Dependencies on m_{top}/JSF/bJSF are shown

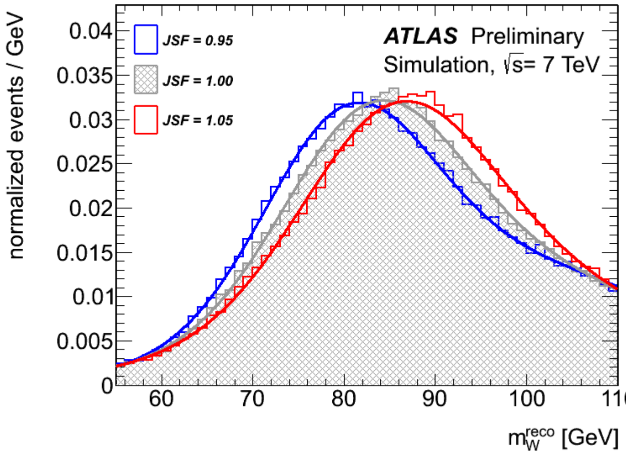


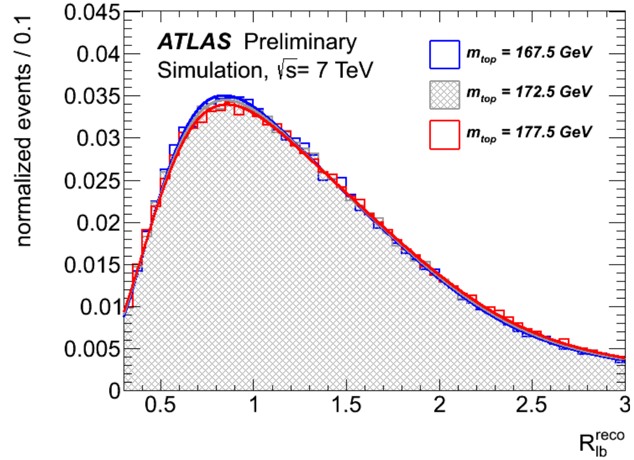


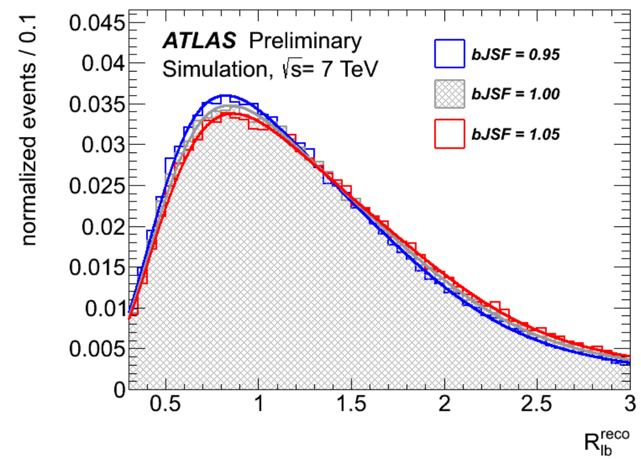


Distributions of m_{top}^{reco} for events with ≥2 b-tag. Dependencies on m_{top}/JSF/bJSF are shown

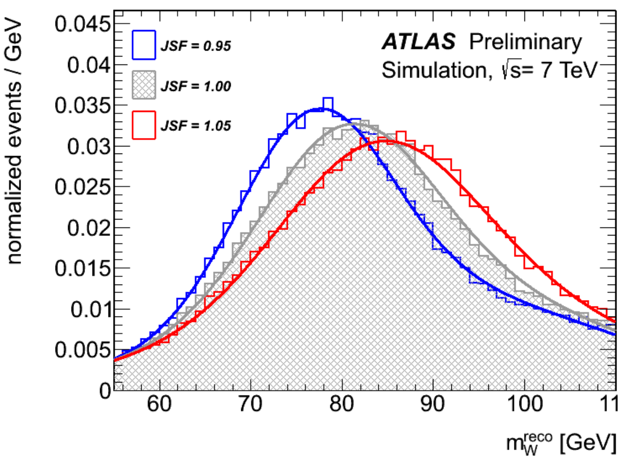
Templates fits and their sensitivity

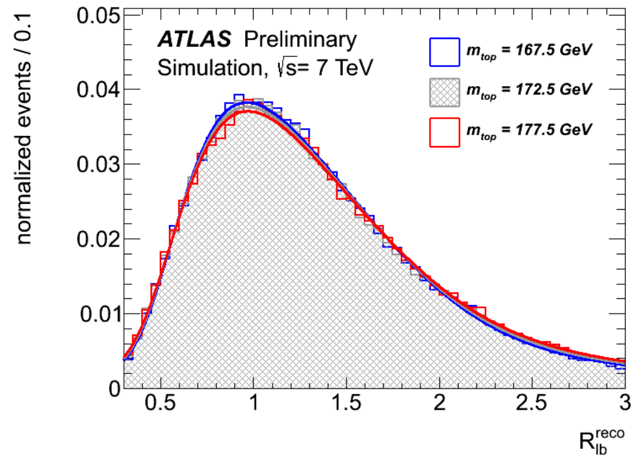


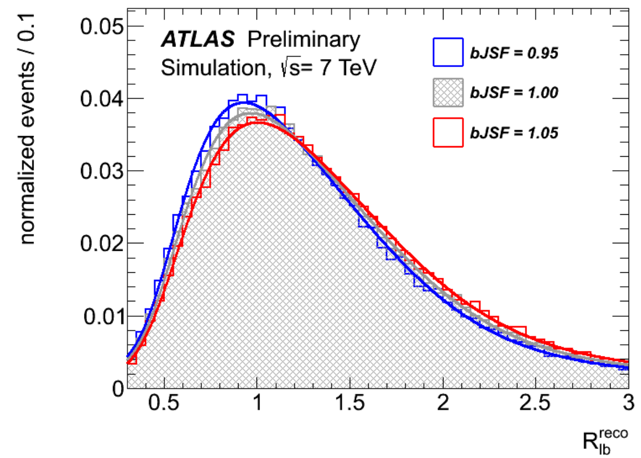




Distributions of m_W^{reco} / R_{lb}^{reco} for events with = 1 b-tag. Dep. on JSF and m_{top}/bJSF are shown







Distributions of m_W^{reco} / R_{lb}^{reco} for events with ≥ 2 b-tags. Dep. on JSF and m_{top}/bJSF are shown

Likelihood fit

- The (un-binned) likelihood function reads:

$$\begin{aligned}\mathcal{L}_{\text{shape}}(m_{\text{top}}^{\text{reco}}, m_{\text{W}}^{\text{reco}}, R_{\text{lb}}^{\text{reco}} | m_{\text{top}}, \text{JSF}, \text{bJSF}, n_{\text{bkg}}) &= \\ \prod_{i=1}^{N} P_{\text{top}}(m_{\text{top}}^{\text{reco}} | m_{\text{top}}, \text{JSF}, \text{bJSF}, n_{\text{bkg}})_i &\times \\ P_{\text{W}}(m_{\text{W}}^{\text{reco}} | \text{JSF}, n_{\text{bkg}})_i &\times \\ P_{\mathcal{R}_{\text{lb}}}(R_{\text{lb}}^{\text{reco}} | m_{\text{top}}, \text{bJSF}, n_{\text{bkg}})_i &\end{aligned}$$

- The performances of the fitting procedure have been checked using pseud-experiments.
  - Pull distributions are according to expectations (no bias / correct stat treatment).
  - The results of these tests are used to evaluated the method calibration syst.

Systematic uncertainties

	2d-analysis		3d-analysis		
	m_{top} [GeV]	JSF	m_{top} [GeV]	JSF	bJSF
Measured value	172.80	1.014	172.31	1.014	1.006
Data statistics	0.23	0.003	0.23	0.003	0.008
Jet energy scale factor (stat. comp.)	0.27	n/a	0.27	n/a	n/a
bJet energy scale factor (stat. comp.)	n/a	n/a	0.67	n/a	n/a
Method calibration	0.13	0.002	0.13	0.002	0.003
Signal MC generator	0.36	0.005	0.19	0.005	0.002
Hadronisation	1.30	0.008	0.27	0.008	0.013
Underlying event	0.02	0.001	0.12	0.001	0.002
Colour reconnection	0.03	0.001	0.32	0.001	0.004
ISR and FSR (signal only)	0.96	0.017	0.45	0.017	0.006
Proton PDF	0.09	0.000	0.17	0.000	0.001
single top normalisation	0.00	0.000	0.00	0.000	0.000
W+jets background	0.02	0.000	0.03	0.000	0.000
QCD multijet background	0.04	0.000	0.10	0.000	0.001
Jet energy scale	0.60	0.005	$\boxed{0.79}$	0.004	0.007
b-jet energy scale	0.92	0.000	0.08	0.000	0.002
Jet energy resolution	0.22	0.006	0.22	0.006	0.000
Jet reconstruction efficiency	0.03	0.000	0.05	0.000	0.000
b-tagging efficiency and mistag rate	0.17	0.001	0.81	0.001	0.011
Lepton energy scale	0.03	0.000	0.04	0.000	0.000
Missing transverse momentum	0.01	0.000	0.03	0.000	0.000
Pile-up	0.03	0.000	0.03	0.000	0.001
Total systematic uncertainty	2.02	0.021	1.35	0.021	0.020
Total uncertainty	2.05	0.021	1.55	0.021	0.022

- To enable a finer mapping of the JES uncertainty with CMS for future combinations. The following break down is given.

Component	Uncertainty [GeV]
Statistical	**0.22**
Statistical NP1	*0.13*
Statistical NP2	*0.06*
Statistical NP3	*0.12*
Eta intercalibration (statistical)	*0.12*
Modelling	**0.35**
Modelling NP1	*0.28*
Modelling NP2	*0.07*
Modelling NP3	*0.03*
Modelling NP4	*0.06*
Eta intercalibration (modelling)	*0.19*
Detector	**0.23**
Detector NP1	*0.22*
Detector NP2	*0.08*
Mixed	**0.11**
Mixed NP1	*0.09*
Mixed NP2	*0.07*
Single particle high p_T	**0.08**
Relative non-closure MC	**0.08**
Pile-up offset	**0.49**
Pile-up offset (NPV term)	*0.08*
Pile-up offset (μ term)	*0.48*
Close-by jets	**0.08**
Flavour	**0.36**
Flavour composition	*0.29*
Flavour response	*0.21*
bJES uncertainty	**0.08**
Total (without bJES uncertainty)	**0.79**

JES uncertainties ATLAS/CMS

- Split up ATLAS:

Component	Uncertainty [GeV]
Statistical	**0.22**
Statistical NP1	*0.13*
Statistical NP2	*0.06*
Statistical NP3	*0.12*
Eta intercalibration (statistical)	*0.12*
Modelling	**0.35**
Modelling NP1	*0.28*
Modelling NP2	*0.07*
Modelling NP3	*0.03*
Modelling NP4	*0.06*
Eta intercalibration (modelling)	*0.19*
Detector	**0.23**
Detector NP1	*0.22*
Detector NP2	*0.08*
Mixed	**0.11**
Mixed NP1	*0.09*
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Single particle high p_T	**0.08**
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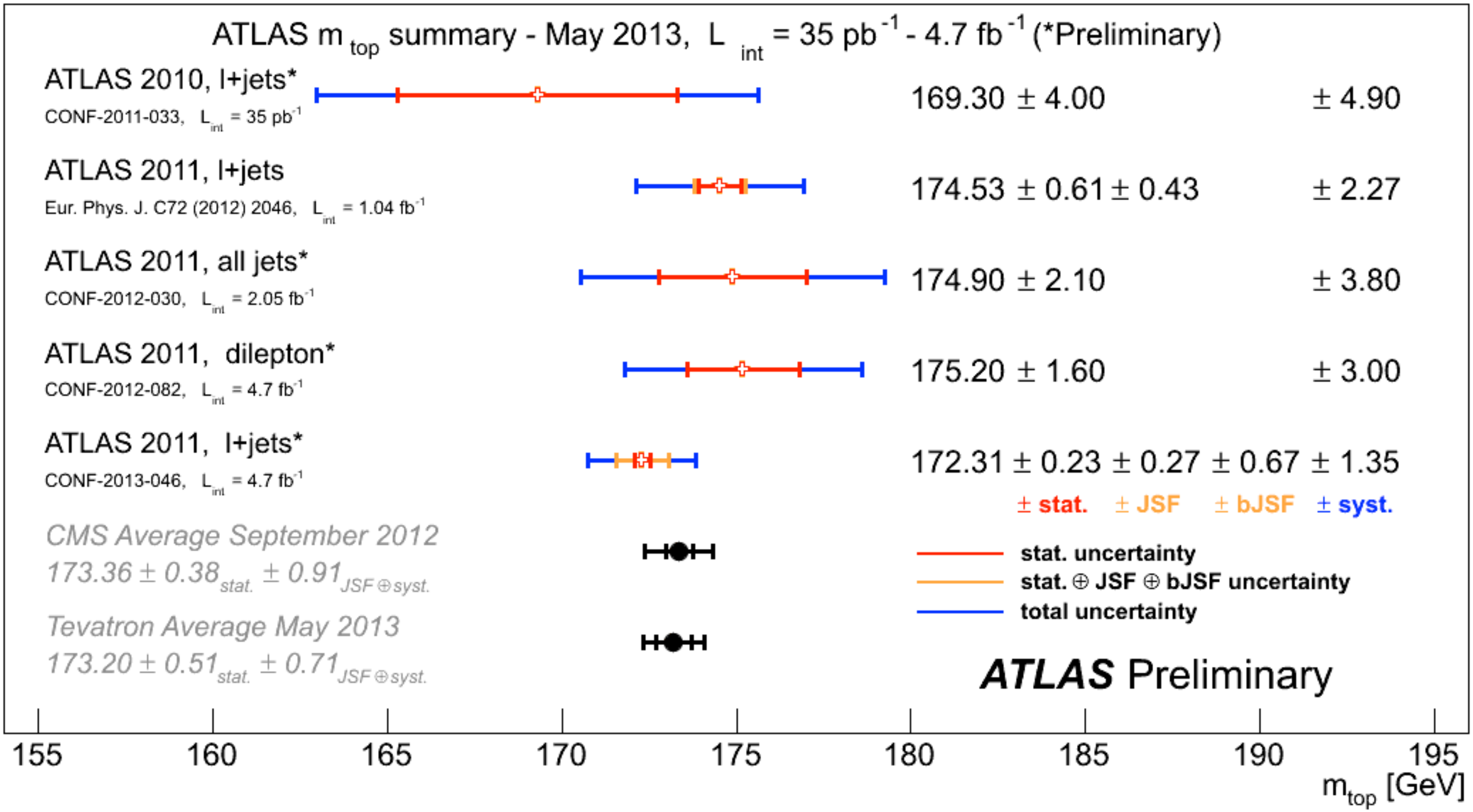
Pile-up offset (NPV term)	*0.08*
Pile-up offset (μ term)	*0.48*
Close-by jets	**0.08**
Flavour	**0.36**
Flavour composition	*0.29*
Flavour response	*0.21*
bJES uncertainty	**0.08**
Total (without bJES uncertainty)	**0.79**

- correlation categories
  - Uncorrelated
  - Correlated
  - Un-correlated
  - Partially correlated
  - Un-correlated
  - Un-correlated
  - Un-correlated (diff methods)
  - Un-correlated
  - Correlated
  - Correlated

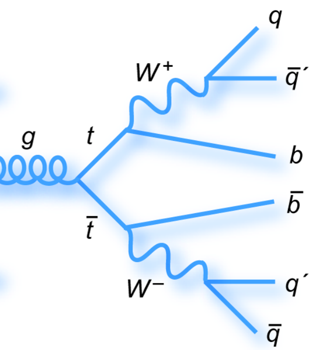
For more details see Caterina's, Bogdan's et al. talk at the last OPEN TOP-LHC-WG

ATLAS m_{top} history



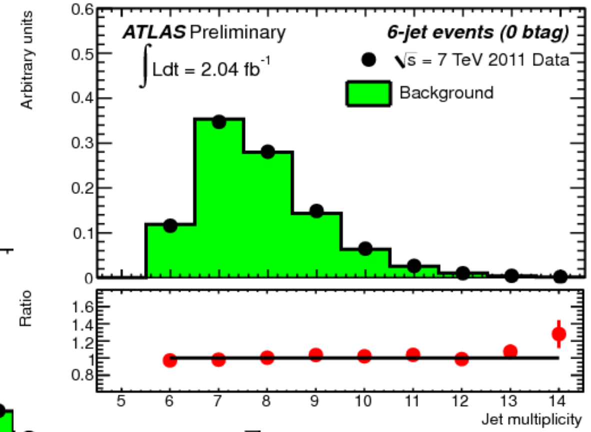
LHC 2011 m_{top} measurements

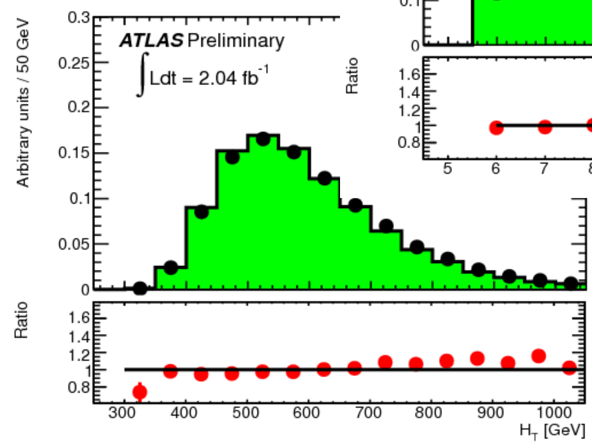
Uncertainty Categories			Size [GeV]					
			ATLAS			CMS		
Tevatron	ATLAS	CMS	2011 l+jets	2011 di-l	2011 all jets	2011 l+jets	2011 di-l	2011 all jets
Measured m_{top}			172.31	175.20	174.90	173.49	172.50	173.49
	Jet Scale Factor	Jet Scale Factor	0.27			0.33		
	bJet Scale Factor		0.67					
iJES	Sum	Sum	0.72			0.33		
bJES	JES_{b-jet}	JES_{b-jet}	0.08	1.35	1.40	0.61	0.71	0.49
dJES	$JES_{light-jet}$	$JES_{light-jet}$	0.79	1.50	2.10	0.28	0.94	0.97
Lepton p_{T} Scale			0.04	0.15		0.02	0.14	
MC	MC Generator	MC Generator	0.19	1.30	0.50		0.04	
	Hadronisation		0.27	0.90				
	Sum	Sum	0.33	1.58	0.50		0.04	
Rad	ISR/FSR	ISR/FSR	0.45	0.50	1.70			
		Q-Scale				0.24	0.55	0.22
		Jet-Parton Scale				0.18	0.19	0.24
	Sum	Sum	0.45	0.50	1.70	0.30	0.58	0.33
CR	Colour Recon.		0.32	1.20	0.55	0.54	0.13	0.15
PDF	Proton PDF	Proton PDF	0.17	0.10	0.60	0.07	0.09	0.06
	Jet Energy Res.	Jet Energy Res.	0.22	0.50	0.30	0.23	0.14	0.15
	Jet Rec. Eff.		0.05		0.20			
	b-tagging	b-tagging	0.81	0.35	0.30	0.12	0.09	0.06
	$E_{\text{T}}^{\text{miss}}$	$E_{\text{T}}^{\text{miss}}$	0.03	0.10		0.06	0.12	
DetMod	Sum	Sum	0.84	0.62	0.47	0.27	0.21	0.29
Underlying Event			0.12	0.20		0.15	0.05	0.32
BGMC						0.13	0.05	
BGData			0.10	0.30	1.90			0.20
Method	Method Calib.	Method Calib.	0.13	0.29	0.98	0.06	0.40	0.13
MHI	Pile-up	Pile-up	0.03			0.07	0.11	0.06
		Statistics	0.23	1.60	2.10	0.27	0.43	0.69
		Rest	1.53	2.98	3.87	1.03	1.41	1.25
		Total Uncertainty	1.55	3.38	4.40	1.07	1.47	1.43



ATLAS all-hadronic analysis

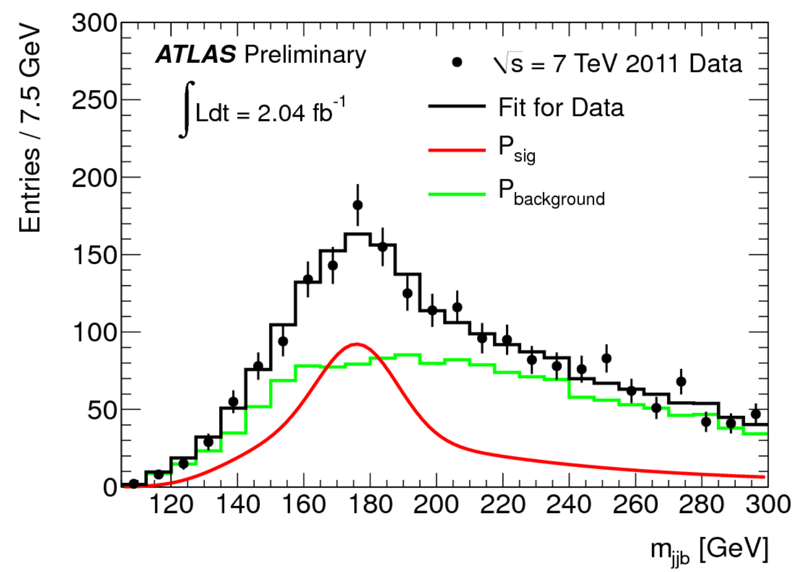
large BR (~46%),
large background:
▶ QCD multi-jet production





- Event selection:
  - ≥6 jets,
  - Exactly 2 b-tagged jets
  - Negligible E_T^{miss}:$E_T^{miss}/\sqrt{H_T} < 3$
- χ^2 based Kinematical reconstruction, template base method
- Fully data-driven background estimate. Event mixing 5jets+1 for shape

m_{top} = 174.9 ± 2.1 (stat) ± 3.8 (syst) GeV



ATLAS-CONF-2012-030

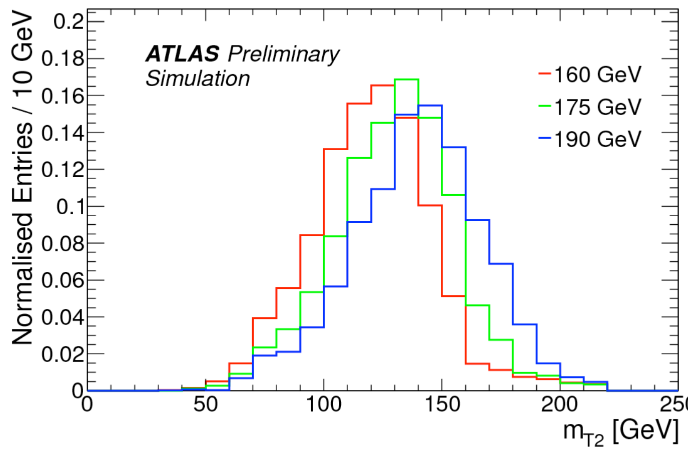
Main syst. (1.5-2 GeV each)

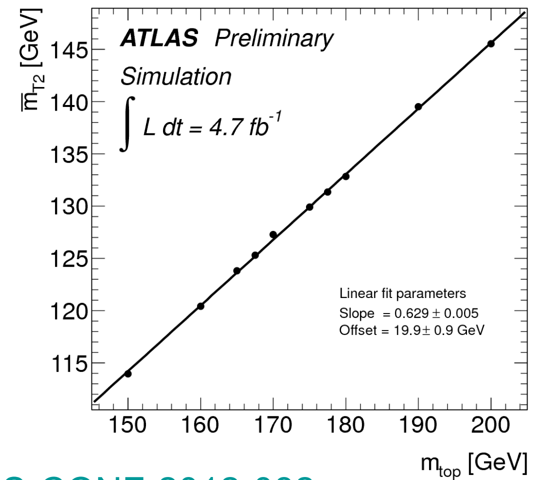
1) JES, bJES,
2) ISR/FSR
3) Background modeling

Max-Planck-Institut für Physik (Werner-Heisenberg-Institut)

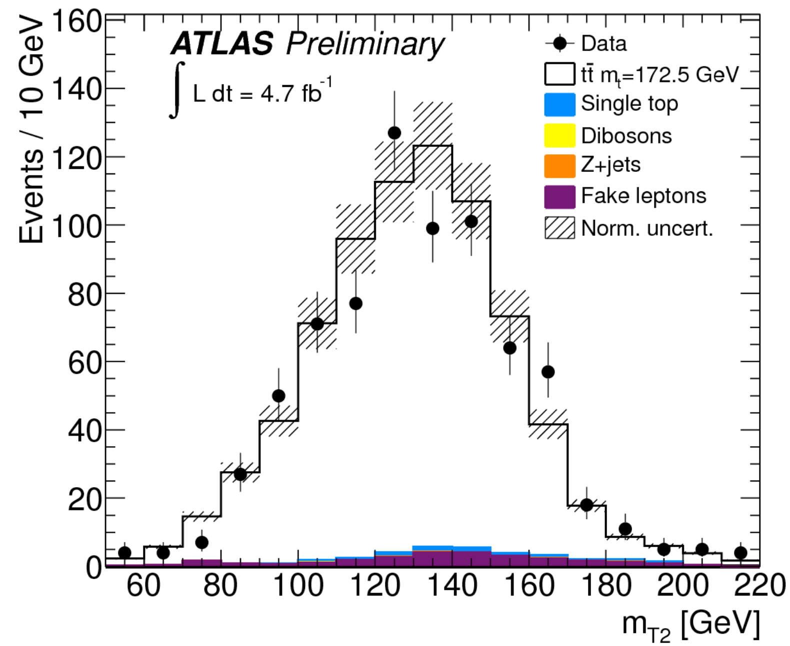
ATLAS: m_{T2} calibration curve method

- Dilepton e/μ channel.
  - Low background contamination
- Calibration curve method based on the $\langle m_{T2} \rangle$ stransverse mass. (represents a lower bound of the top quark mass)
- ≥2 b-tags event selection optimized to reduce the total m_{top} unc.
  - The impact of ISR/FSR variation is reduced by $\Delta\phi$(j,j) restrictions.





ATLAS-CONF-2012-082

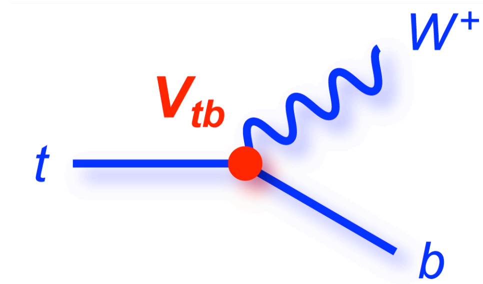


$$m_{top} = 175.2 \pm 1.6\ (\text{stat}) \pm 3.0\ (\text{syst})\ \text{GeV}$$

Main syst. (1.5 GeV each)

1) JES, bJES,
2) MC modeling

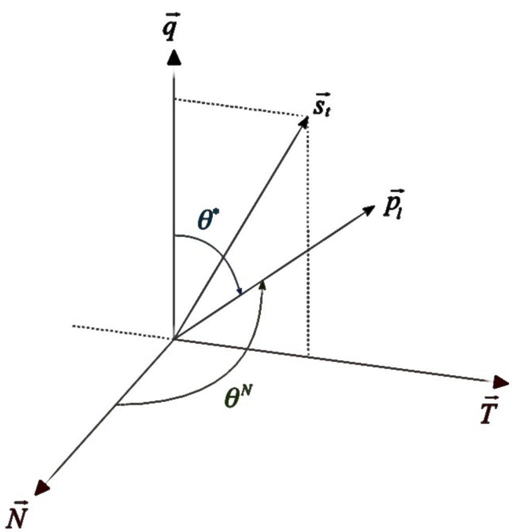
Probing the Wtb vertex

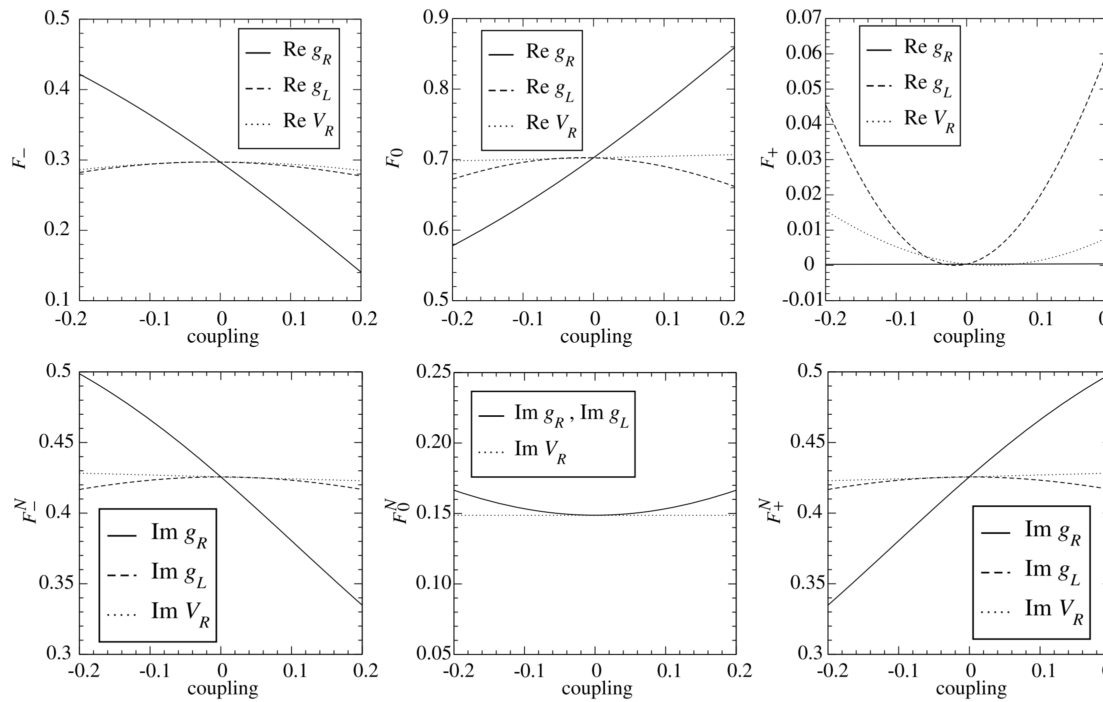


$$\mathcal{L}_{Wtb} = -\frac{g}{\sqrt{2}}\bar{b}\gamma^{\mu}(V_L P_L + V_R P_R)tW_{\mu}^{-}$$
$$-\frac{g}{\sqrt{2}}\bar{b}\frac{i\sigma^{\mu\nu}q_{\nu}}{M_W}(g_L P_L + g_R P_R)tW_{\mu}^{-} + \text{h.c.}$$

effective operator framework

$$\mathrm{SM}^{\text{tree level}}: \mathrm{V_L = V_{tb} \approx 1 \text{ and } V_R = g_L = g_R = 0}$$





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$$\frac{1}{\Gamma}\frac{d\Gamma}{d\cos\theta^X} = \frac{3}{8}(1+\cos\theta^X)^2 F_+^X + \frac{3}{8}(1-\cos\theta^X)^2 F_-^X + \frac{3}{4}\sin^2\theta^X) F_0^X$$

$$\text{where}: \ \mathrm{X} = *, \mathrm{T}, \mathrm{N}$$

W helicity LHC combination

- MC modelling (baseline MC + ISR/FSR) / bJES uncertainty updates were not included in the ATLAS inputs used in the LHC combination.
- Room for improvements!

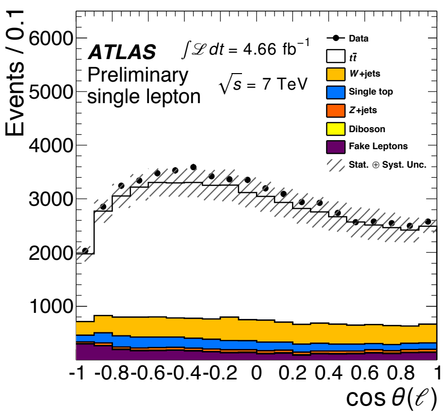
Uncertainties on F_0 and F_L for the ATLAS and CMS combination.

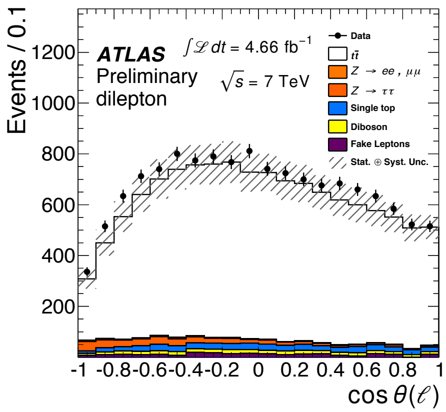
Category	LHC combination F_0	LHC combination F_L
Detector modeling		
Detector model	0.019	0.011
Jet energy scale	0.020	0.012
Luminosity and pile-up	0.006	0.003
Signal and background modeling		
Monte Carlo	0.012	0.008
Radiation	0.024	0.012
Top-quark mass	0.019	0.012
PDF	0.008	0.004
Background (MC QCD)	0.003	0.001
Background (MC W + jets)	0.007	0.002
Background (MC other)	0.011	0.006
Background (data-driven)	0.013	0.008
Method-specific uncertainties		
Method	0.008	0.005
Total uncertainties		
Total systematic uncertainty	0.048	0.028
Statistical uncertainty	0.034	0.021
Total uncertainty	0.059	0.035

m_{top} ± 1.4 GeV
(LHC comb 2012)

Top polarization

- baseline MC MC@NLO+Herwig





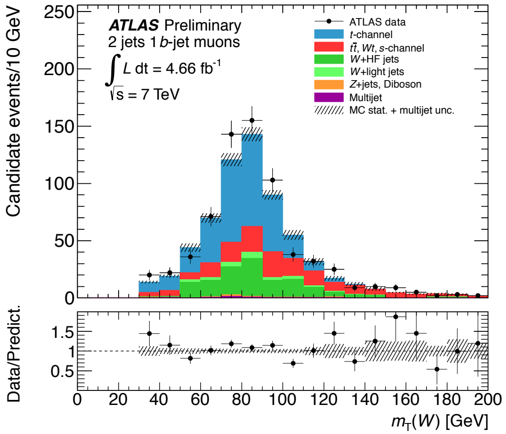
Source	e+jets	μ+jets	ee	$e\mu$	$\mu\mu$
$t\bar{t}$	16200	26500	570	4400	1660
Bkgd.	5100	9400	110	700	320
Total	21300	35900	690	5000	1980
Uncertainty	±1300	±1700	±80	±500	±180
Data	21956	37919	740	5328	2057

Source	$\Delta\alpha_\ell P_{\mathrm{CPC}}$		$\Delta\alpha_\ell P_{\mathrm{CPV}}$	
Jet reconstruction	+0.031	-0.031	+0.009	-0.005
Lepton reconstruction	+0.006	-0.007	+0.002	-0.001
$E_{\mathrm{T}}^{\mathrm{miss}}$ reconstruction	+0.008	-0.007	+0.004	-0.001
$t\bar{t}$ Modeling	+0.015	-0.016	+0.005	-0.013
Background Modeling	+0.011	-0.010	+0.005	-0.007
Template Statistical Uncertainty	+0.005	-0.005	+0.006	-0.006
Total Systematic Uncertainty	+0.037	-0.037	+0.013	-0.017

Jet Energy Scale Total	+0.029	-0.028	+0.009	-0.004
Modeling	+0.019	-0.019	+0.003	-0.001
Detector	+0.017	-0.015	+0.004	-0.002
Statistical	+0.005	-0.006	+0.004	-0.002
Mixed	+0.003	-0.000	+0.005	-0.000
Flavor uncertainty	+0.007	-0.006	+0.001	-0.003
Pile-up	+0.007	-0.007	+0.001	-0.001
b-JES	+0.007	-0.010	+0.004	-0.000
Close-by jets	+0.002	0.000	+0.002	-0.000

Top Mass	+0.012	-0.012	+0.000	-0.000
Signal MC Generator	+0.005	-0.008	+0.004	-0.013
ISR/FSR variation	+0.005	-0.004	+0.001	-0.002
Color reconnection	+0.001	-0.004	+0.002	-0.002
Fragmentation/Parton shower	+0.002	-0.002	+0.000	-0.001
Underlying event	+0.002	-0.004	+0.002	-0.002
PDF	+0.003	-0.003	+0.000	-0.000
Spin correlation	+0.003	-0.003	+0.000	-0.000

W normal polarization



	Electron		Muon	
	Preselection	Selection	Preselection	Selection
t-channel	1703 ± 9	262 ± 3	2053 ± 10	318 ± 4
s-channel	114 ± 2	3 ± 0	147 ± 2	5 ± 0
Wt-channel	574 ± 15	14 ± 3	700 ± 17	15 ± 2
Top quark pair	4065 ± 13	114 ± 2	4740 ± 15	140 ± 2
Diboson	121 ± 2	1 ± 0	142 ± 2	2 ± 0
Z+jets	196 ± 9	4 ± 1	190 ± 7	3 ± 1
W+HF jets	5226 ± 57	106 ± 8	7686 ± 65	137 ± 8
W+light jets	1339 ± 58	15 ± 8	1919 ± 70	23 ± 6
Multijet	1100 ± 500	20 ± 10	550 ± 280	6 ± 3
Total expected	14400 ± 600	539 ± 19	18130 ± 290	649 ± 12
S/B	0.13	0.95	0.13	0.96
ATLAS data	14738	576	17966	691

Source	ΔA_{FB}^{N}
t-channel generator	+0.024 / −0.024
$t\bar{t}$ generator and parton shower	+0.010 / −0.010
Background normalisation	+0.008 / −0.008
Jet energy resolution	+0.007 / −0.007
Jet energy scale	+0.005 / −0.009
Lepton id, reco., trigger and scale	+0.004 / −0.006
PDFs	+0.003 / −0.003
Unfolding	+0.003 / −0.003
E_{T}^{miss}	+0.002 / −0.004
b-tagging	+0.002 / −0.002
W+jets shape	+0.001 / −0.001
ISR/FSR	+0.001 / −0.001
Jet reconstruction efficiency	+0.001 / −0.001
Luminosity	+0.001 / −0.001
Jet vertex fraction	<0.001 / <0.001
Total systematic	+0.029 / −0.031