Review of top physics results from the ATLAS experiment

Oleg Brandt
(University of Heidelberg)
on behalf of the ATLAS Collaboration

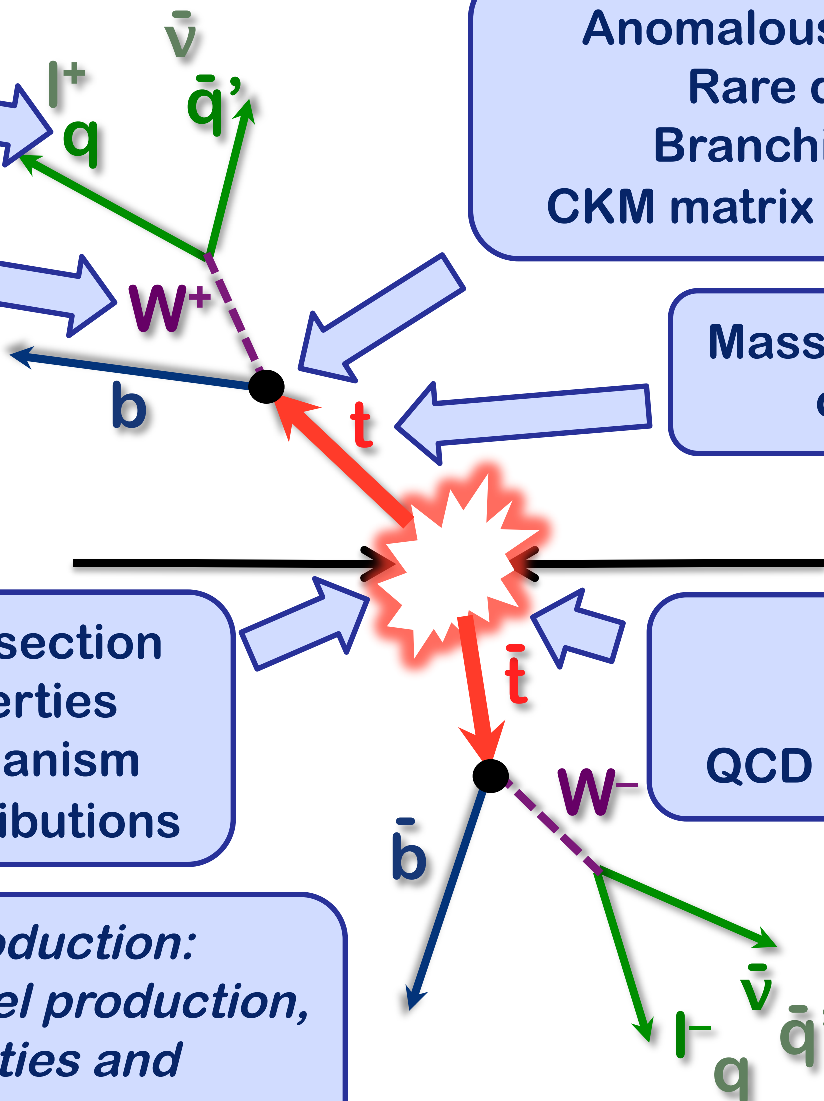
A wealth of top properties

Colour flow

W helicity

Anomalous couplings
Rare decays
Branching ratio
CKM matrix element $|V_{tb}|$

Mass, mass difference
charge, width



Production cross section
Kinematic properties
Production mechanism
New physics contributions

Spin correlation
Polarisation
QCD charge asymmetry A_{FB}

+ EW single top production:
- *t, Wt, s-channel production,*
- *kinem. properties and*
- *searches for new physics*

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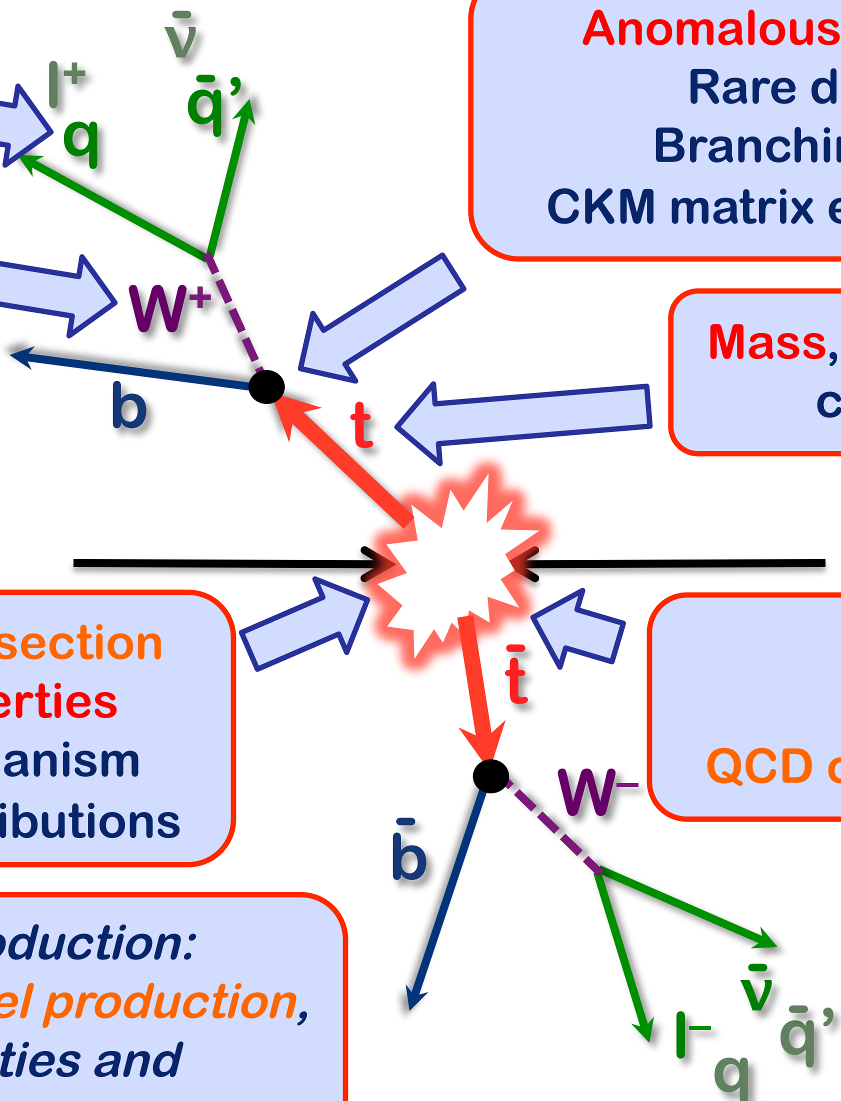

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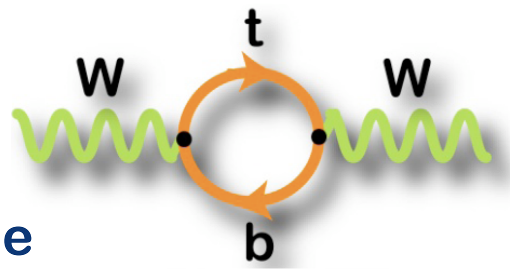
- *t, Wt, s-channel production,*
- *kinem. properties and*
- *searches for new physics*

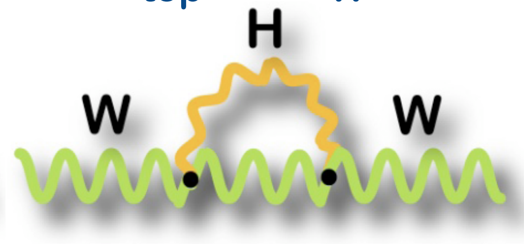
Why study m_{top} in the Higgs era?

- The **top quark is special:**
  - It is the heaviest quark of the SM!
    - Why is it so heavy?
    - Does it play a special role in EWSB?

- Infer m_{higgs} from m_{top} & m_W:



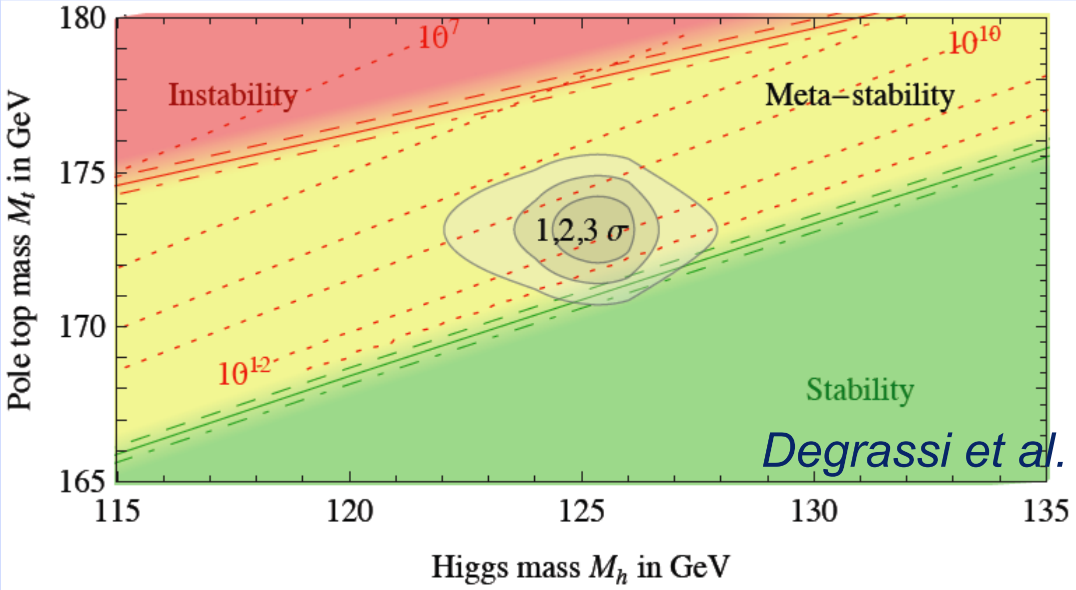
$\Delta M_W \propto M_{top}^2$



$\Delta M_W \propto \ln M_H$

Overconstrain m_{higgs}, m_{top}, and m_W → **Consistency check of the SM!**

The uncertainty on the **top quark mass** has **the biggest impact on the stability of the Universe** from the positiveness of the Higgs quartic self-coupling:



Top quark mass with 3D template method

- Measure m_{top} in l+jets using 4.7 fb^{-1} @ 7 TeV
- Event reconstruction with a kinematic likelihood fitter
  - Use transfer functions:
    - Better mapping of detector resolution tails
    - Better sensitivity than χ^2-based methods
- Large systematic uncertainty expected from the JES calibration for b-quark jets (bJSF)
  - Introduce R_{lb} variable to provide sensitivity to bJSF:

$$R_{\mathrm{lb}}^{\mathrm{reco,2b}} = \frac{p_{\mathrm{T}}^{b_{\mathrm{had}}} + p_{\mathrm{T}}^{b_{\mathrm{lep}}}}{p_{\mathrm{T}}^{W_{\mathrm{jet}_1}} + p_{\mathrm{T}}^{W_{\mathrm{jet}_2}}}$$

single b-tag

$$R_{\mathrm{lb}}^{\mathrm{reco,1b}} = \frac{p_{\mathrm{T}}^{b_{\mathrm{tag}}}}{(p_{\mathrm{T}}^{W_{\mathrm{jet}_1}} + p_{\mathrm{T}}^{W_{\mathrm{jet}_2}})/2}$$

two b-tags

World's first 3D fit analysis of m_{top}!

ATLAS-CONF-2013-046

Top quark mass with 3D template method

- **Final result:**

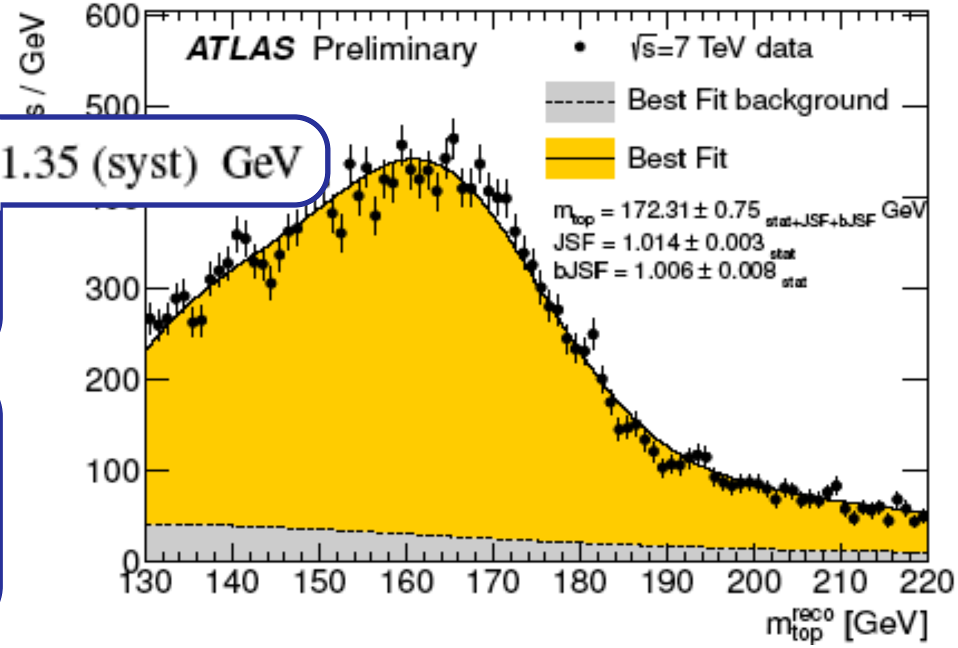
4.7 fb^{-1}

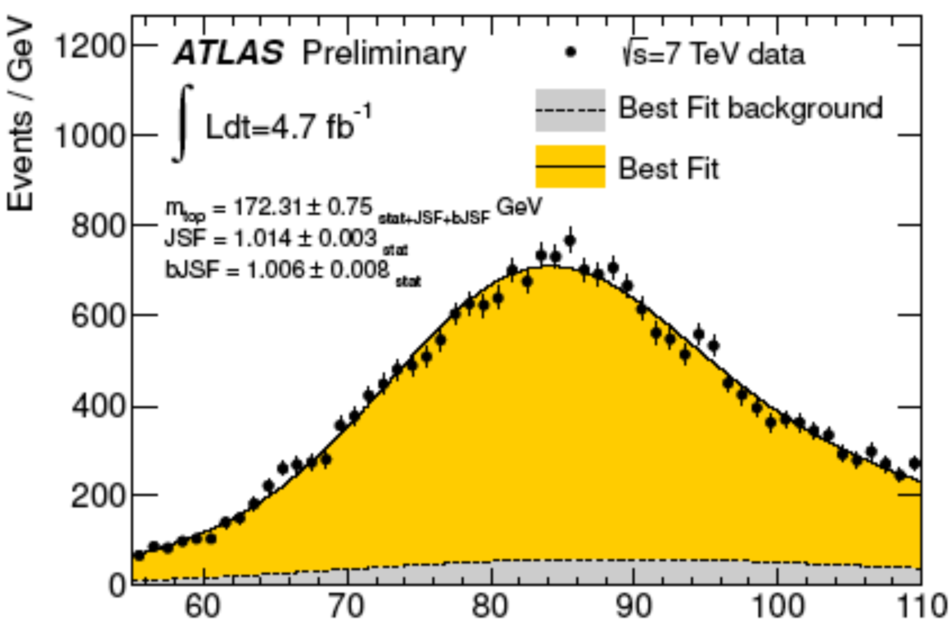
$$m_{top} = 172.31 \pm 0.75\,(\text{stat} + \text{JSF} + \text{bJSF}) \pm 1.35\,(\text{syst})\ \text{GeV}$$

$$\text{JSF} = 1.014 \pm 0.003\,(\text{stat}) \pm 0.021\,(\text{syst}),$$

$$\text{bJSF} = 1.006 \pm 0.008\,(\text{stat}) \pm 0.020\,(\text{syst}).$$

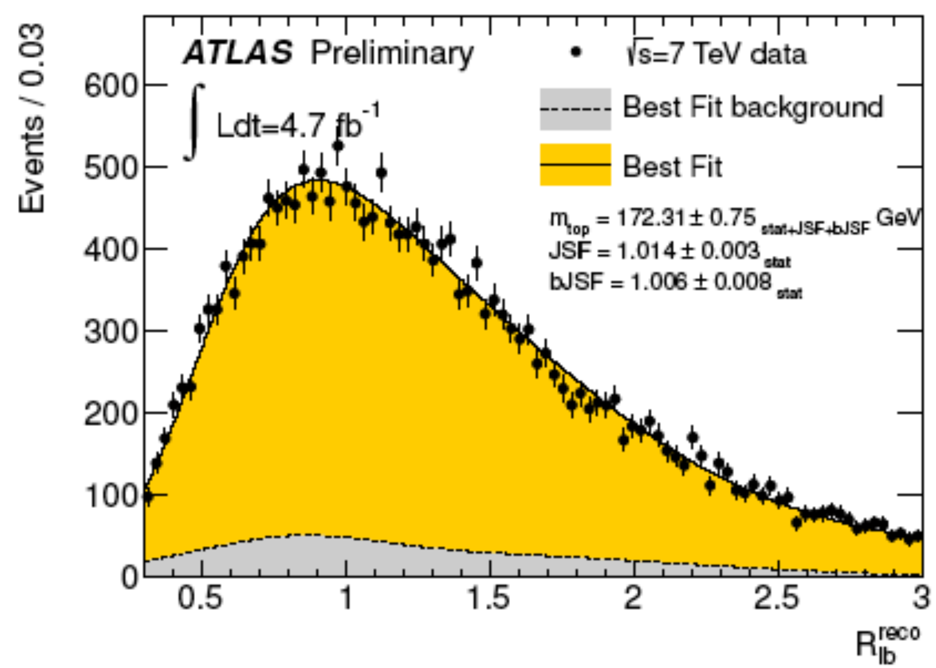
Note that the syst. uncertainty from bJES
is now much reduced,
as it is mostly absorbed in the bJSF!
→ at the cost of reduced stat. sensitivity





ATLAS-CONF-2013-046

m_W^{reco} [GeV]

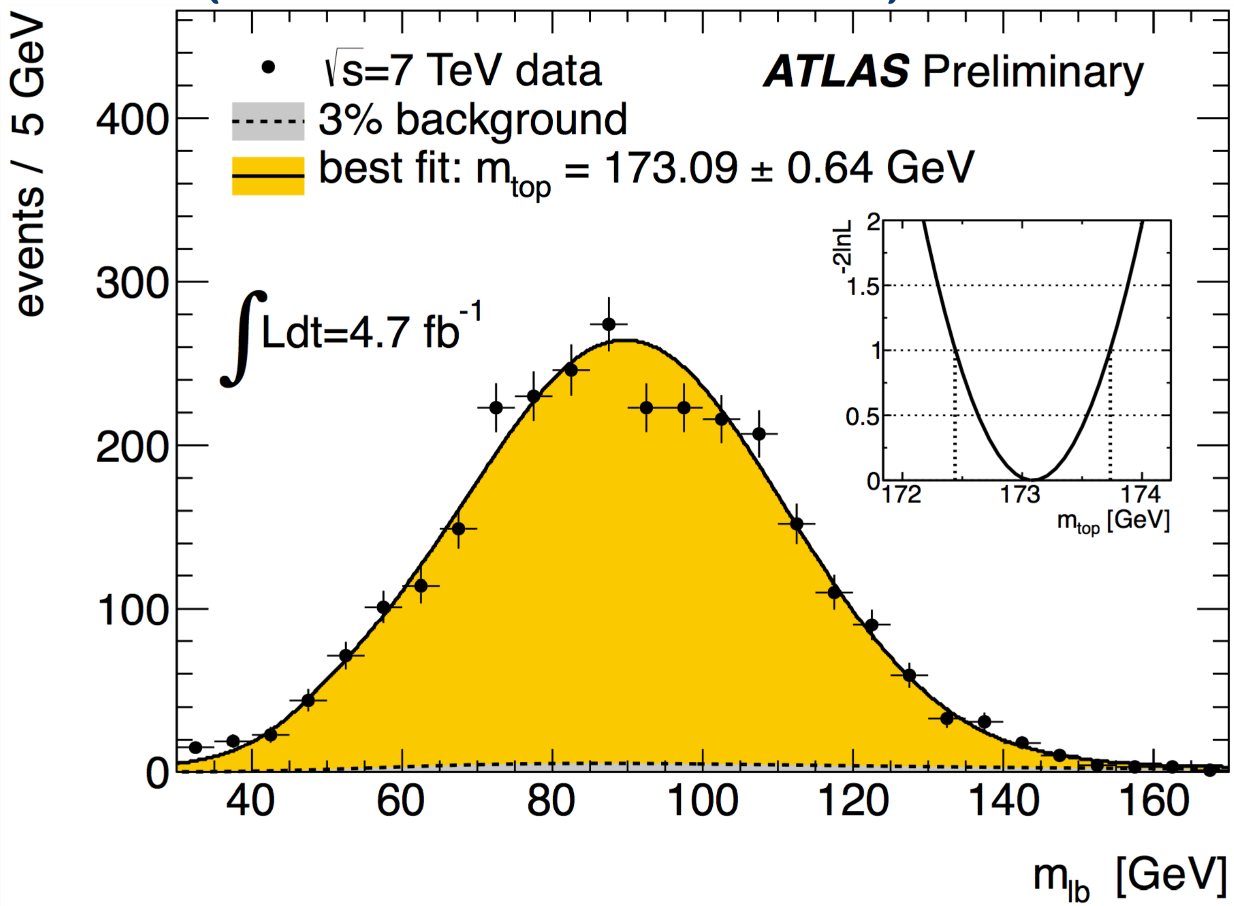


Top mass in the dilepton channel

- **Measure m_{top} in dilepton channel with 4.7 fb^{-1} @ 7 TeV**
  - Very low background contribution: ~3%
  - Use m_{lb}, the invariant mass of charged lepton and b-quark, as estimator
    - → reduced sensitivity to systematic uncertainties
  - Use the b-tagged jet-to-lepton assignment with minimum average m_{lb}
    - → 77% efficiency
  - No in-situ calibration of JES and bJES possible:
    - Dominant sources of systematic uncertainty (80%)

Top mass in the dilepton channel

- **Final result (best fit to data shown):**

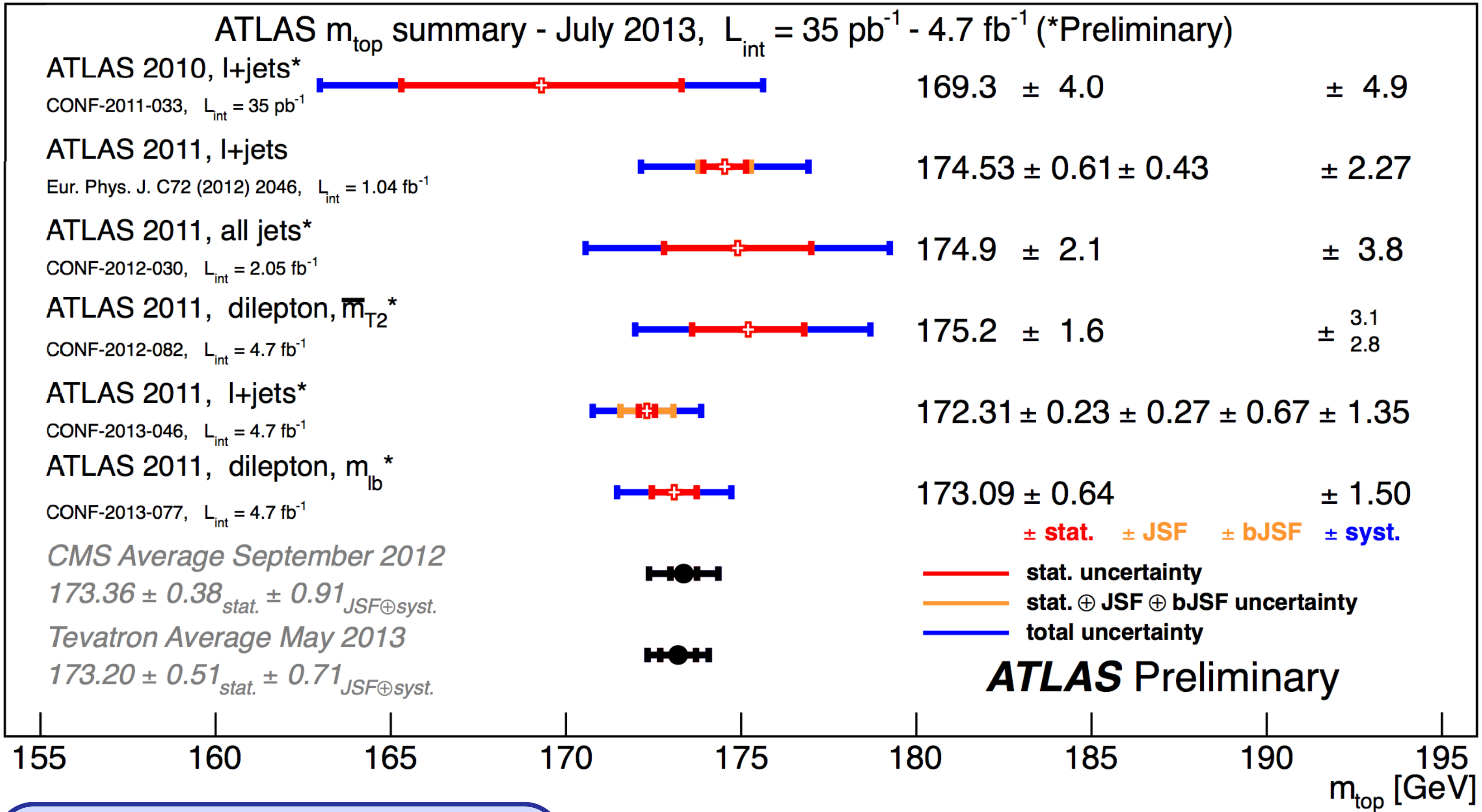


$$m_{\text{top}} = 173.09 \pm 0.64\ (\text{stat}) \pm 1.50\ (\text{syst})\ \text{GeV}$$

ATLAS-CONF-2013-077

4.7 fb^{-1}

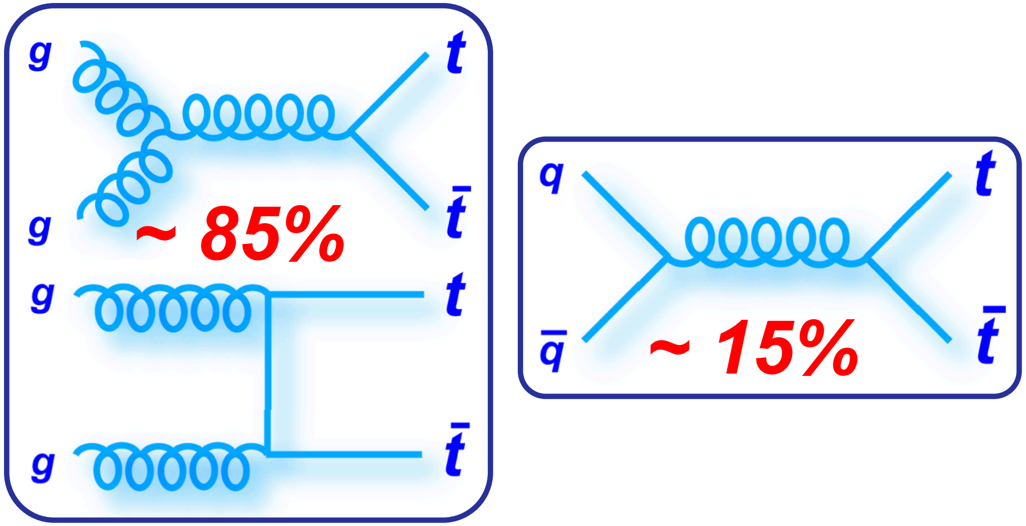
Top mass summary for ATLAS



Work ongoing within the Top LHC working group to harmonise the treatment of systematic uncertainties

Top pair production cross section

- The LHC is a top factory:
  - 5.7 M (0.9 M) $t\bar{t}$ pairs expected in 2012 (2011) data
  - Top pair production:



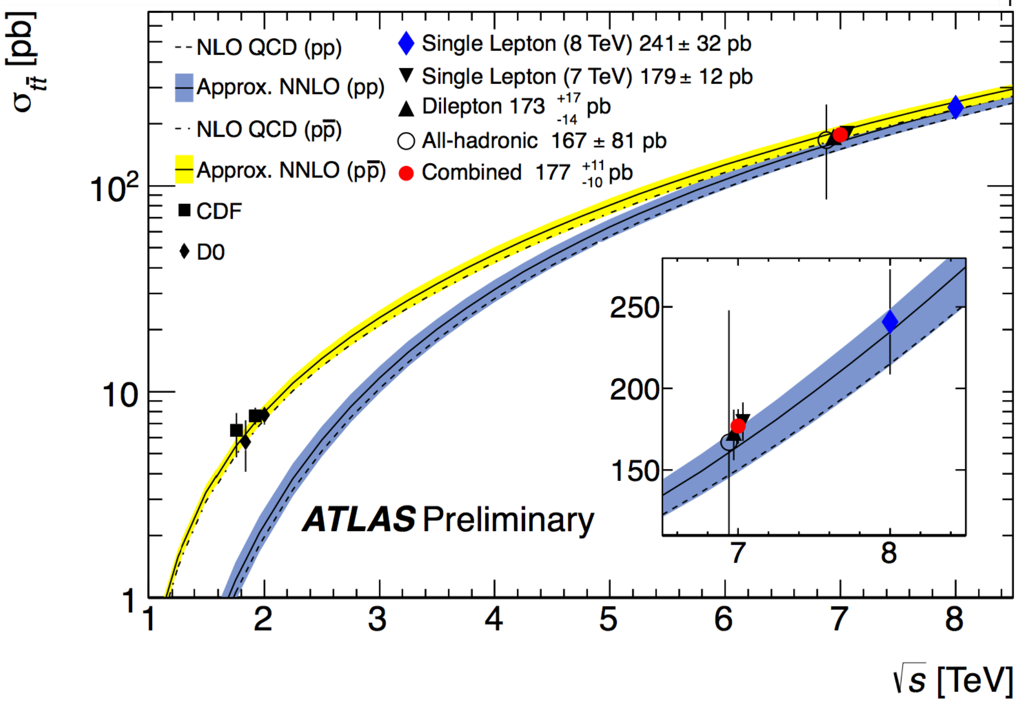
  - Theory predictions up to NNLO+NLL available:
    - $170.0^{+4.7}_{-7.5}$ pb @ 7 TeV and $245.8^{+8.8}_{-10.6}$ pb @ 8 TeV

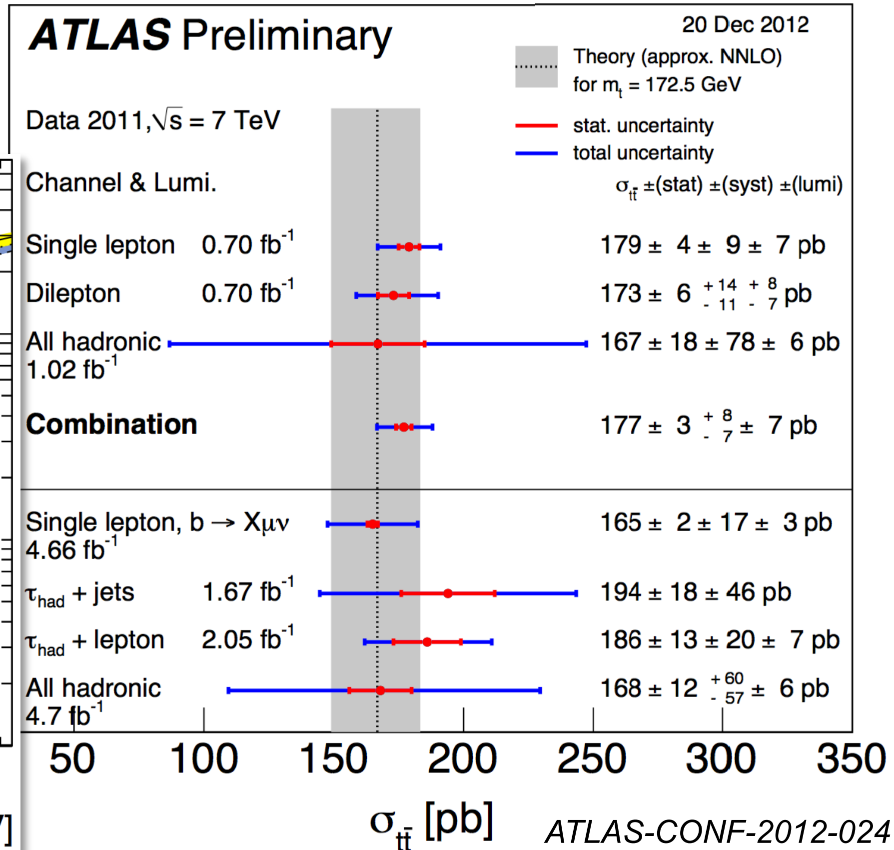
      ~4% precision! *Phys. Rev. Lett. 110 (2013) 252004*
  - Scrutinise our data to test the consistency with pQCD predictions and look for new physics contributions!

cf. talk by NN

Top pair production cross section

- **Wealth of measurements** of the $t\bar{t}$ cross section in various final states:





- All measurements so far consistent with pQCD predictions
  - Expect further, more precise measurements @ 8 TeV!

Top pair production cross section

- **Most precise measurement @ 7 TeV in l+jets channel:**

$$\sigma_{t\bar{t}} = 179.0 \pm 3.9\ (\text{stat.}) \pm 9.0\ (\text{syst.}) \pm 6.6(\text{lumi.})\text{pb}$$

~6.6% precision! ATLAS-CONF-2011-121 — **0.7 fb^{-1}**

  - Construct discriminant from η(l), pT(j$_1$), aplanarity, H$_{T,3}$
  - uses profile likelihood fit and utilises background-dominated regions to constrain background contributions
- **Complementary measurement @ 7 TeV in l+jets:**

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

~10.6% precision! ATLAS-CONF-2012-131 — **4.7 fb^{-1}**

  - using semileptonic B meson decays (~10% efficiency)
  - Fully consistent with above measurement!
- **Measurement @ 7 TeV in dilepton final states:**

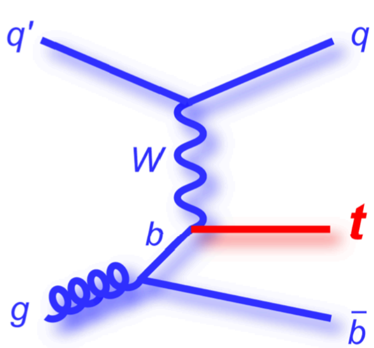
$$\sigma_{t\bar{t}} = 176 \pm 5\ (\text{stat.})^{+14}_{-11}\ (\text{syst.}) \pm 8(\text{lumi.})\text{pb}$$

~9.5% precision! JHEP 1205 (2012) 059 — **0.7 fb^{-1}**

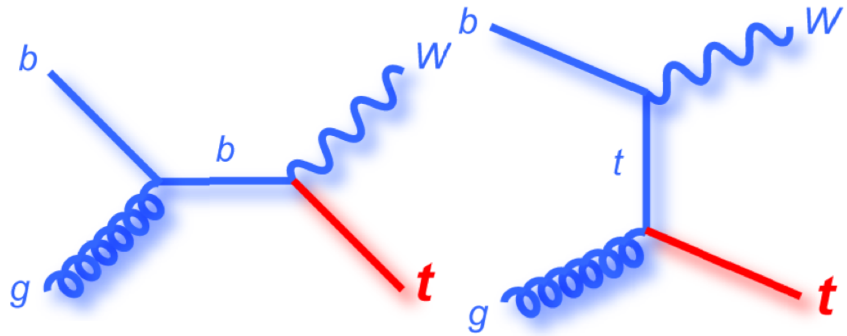
  - Counting experiment in various channels with profiling
  - Uses events with and without b-tag

Single top quark production cross section

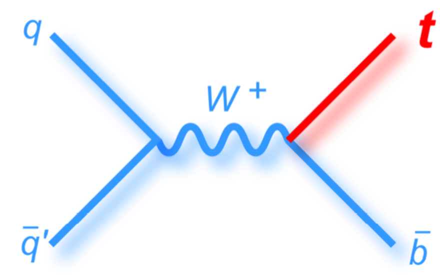
- The LHC is also a factory for single top quarks:
  - 2.6 M (0.4 M) single tops expected in 2012 (2011) data:



t-channel



Wt-channel



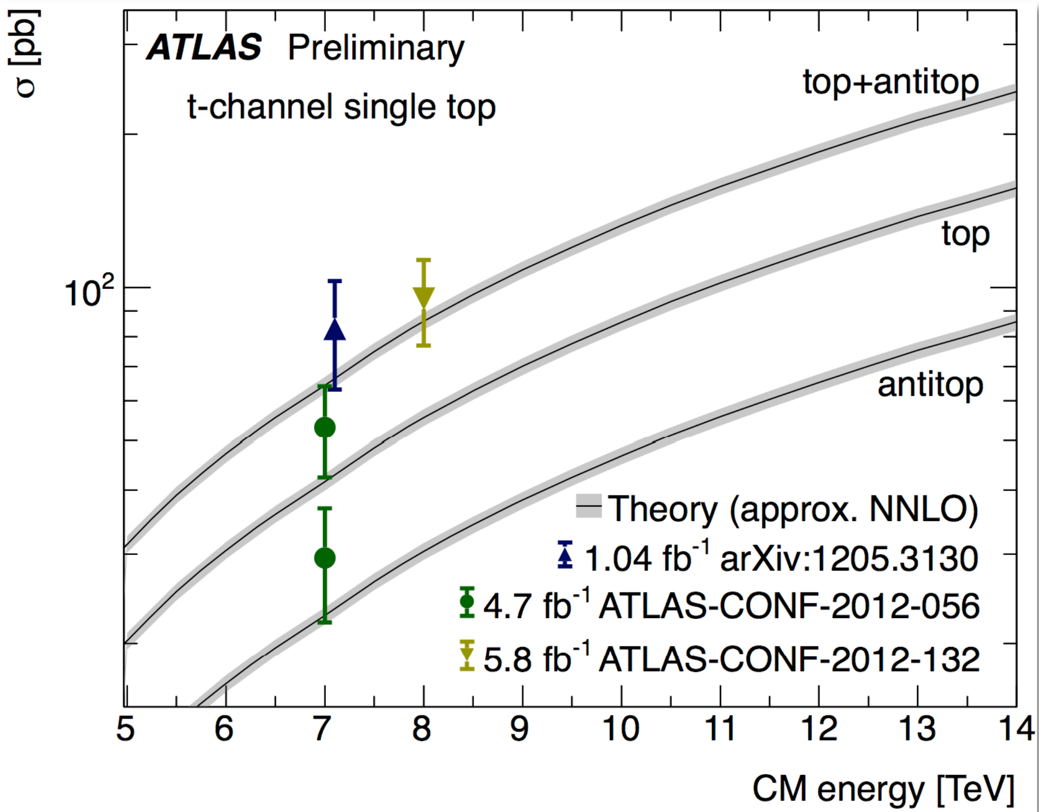
s-channel

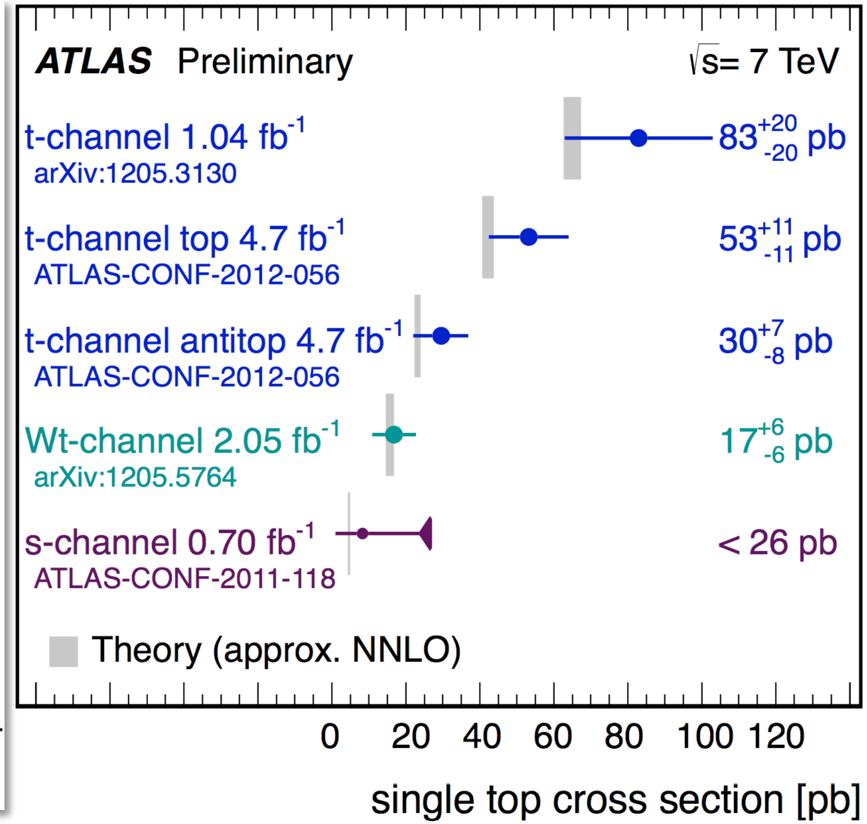
t-channel	Wt-channel	s-channel
$\sigma = 64.57^{+2.63}_{-1.74}$ pb @ 7 TeV	$\sigma = 15.74^{+1.17}_{-1.21}$ pb @ 7 TeV	$\sigma = 4.63^{+0.20}_{-0.18}$ pb @ 7 TeV
$\sigma = 87.76^{+3.44}_{-1.91}$ pb @ 8 TeV	$\sigma = 22.37 \pm 1.52$ pb @ 8 TeV	$\sigma = 5.61 \pm 0.22$ pb @ 8 TeV
Phys. Rev. D 83, 091503(R) (2011)	Phys. Rev. D 82, 054018 (2010)	Phys. Rev. D 81, 054028 (2010)

  - Stringent test of SM predictions, prime window for some new physics searches!
    - Charge asymmetry sensitive to u,d content of proton
    - Direct sensitivity to the $|V_{tb}|$ element of the CKM matrix

Single top quark production cross section

- **Plethora of measurements by ATLAS @ 7 & 8 TeV:**

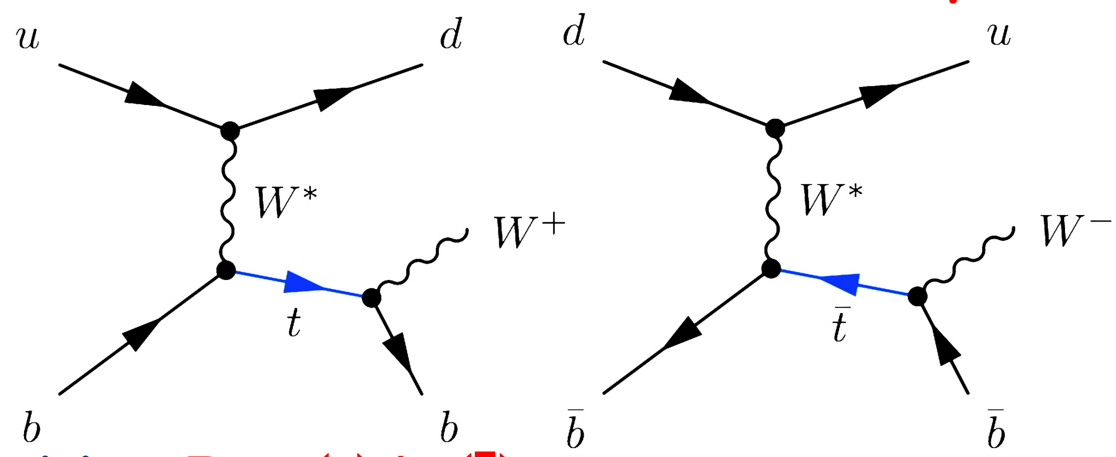




- **All of our measurements are in agreement with the SM**
  - **Further scrutinse data + improve detector understanding!**

Single top charge asymmetry

- The **charge asymmetry of single top quarks** is sensitive to the **u and d content of the proton:**

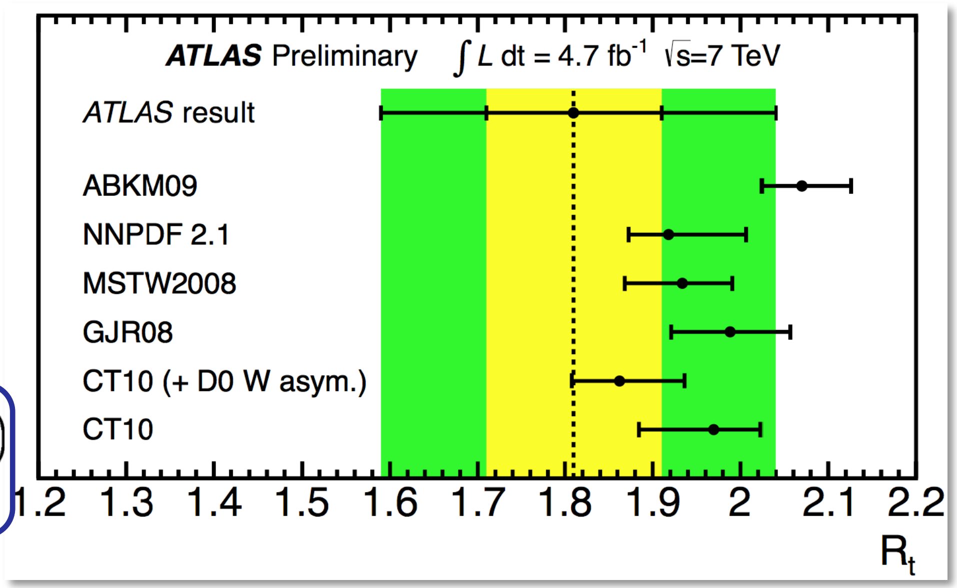


- Observable: $R_t = \sigma(t)/\sigma(\bar{t})$
- Similar analysis to the cross section analysis with 1 fb^{-1} @ 7 TeV

4.7 fb^{-1}

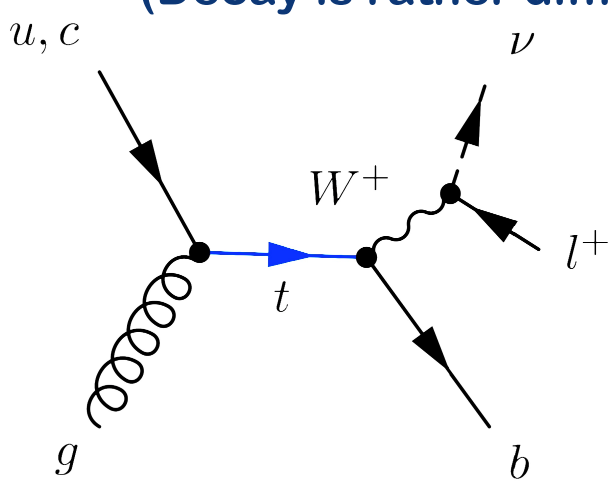
$$R_t = 1.81 \pm 0.10(\mathrm{stat.})^{+0.21}_{-0.20}(\mathrm{syst.})$$

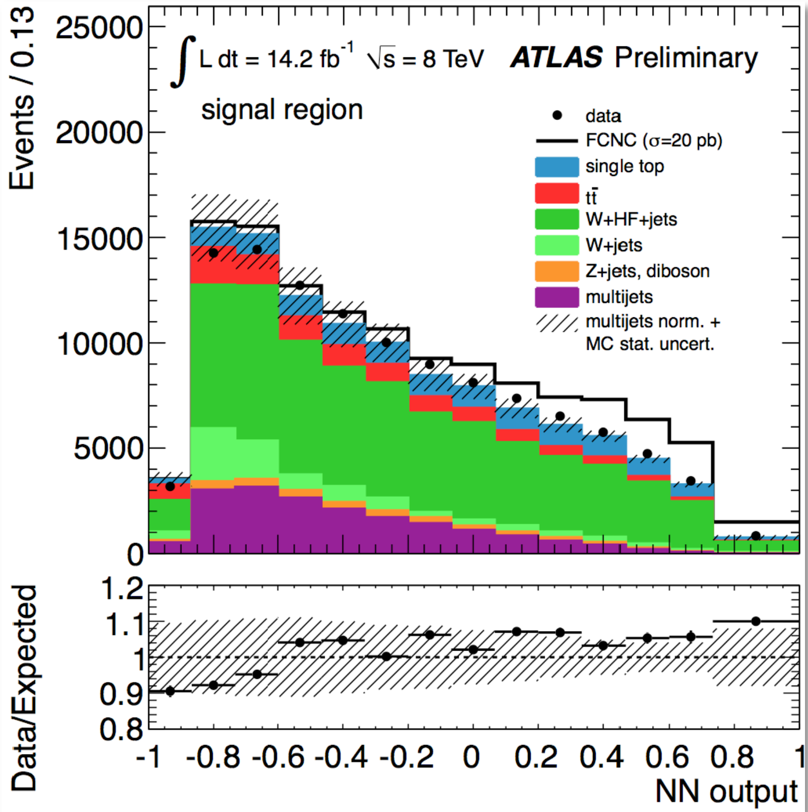
ATLAS-CONF-2012-056



Search for FCNC in single top production

- It is “easy” to look for FCNC of top quark in association with Z and γ
  - FCNC in the t→gq process has a challenging signature
    - → focus on gq→t process for single top production!
      - (Decay is rather difficult)





  - Require =1 b-tagged jet
  - Use NN of 11 variables

σ_{FCNC} < 2.5 pb @ 95% CL
ATLAS-CONF-2013-063

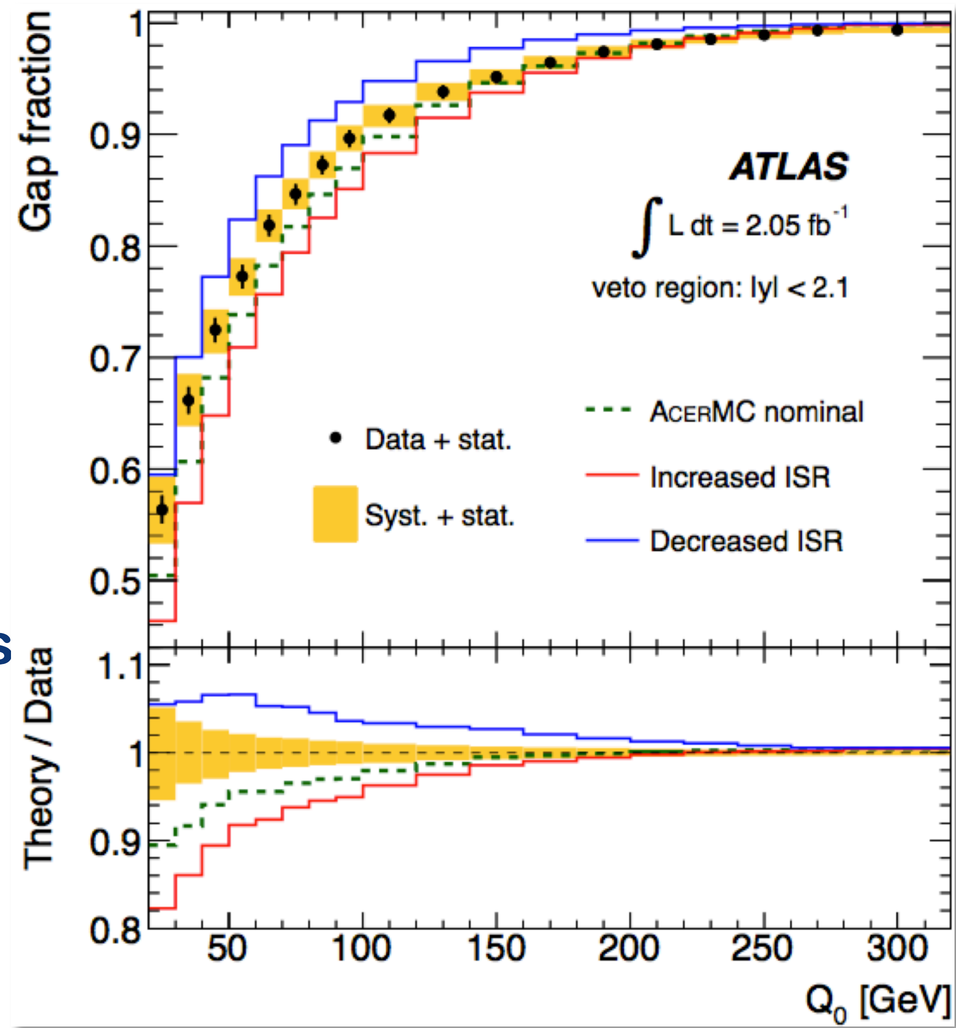
14.2 fb^{-1}

Differential cross section measurements

- Beyond the inclusive cross section measurements, we also perform them differentially
  - Help to constrain theory models:
    - Modelling of our signal (systematic uncertainties), e.g.
      - ISR/FSR
      - parton shower + hadronisation simulations
      - PDFs
      - ...
    - Easy to confront fixed-order theory predictions with our unfolded data
  - Dominant uncertainties are typically:
    - JES, JER, ISR/FSR, b-tagging (besides signal modelling!)

"Gap fraction" measurement

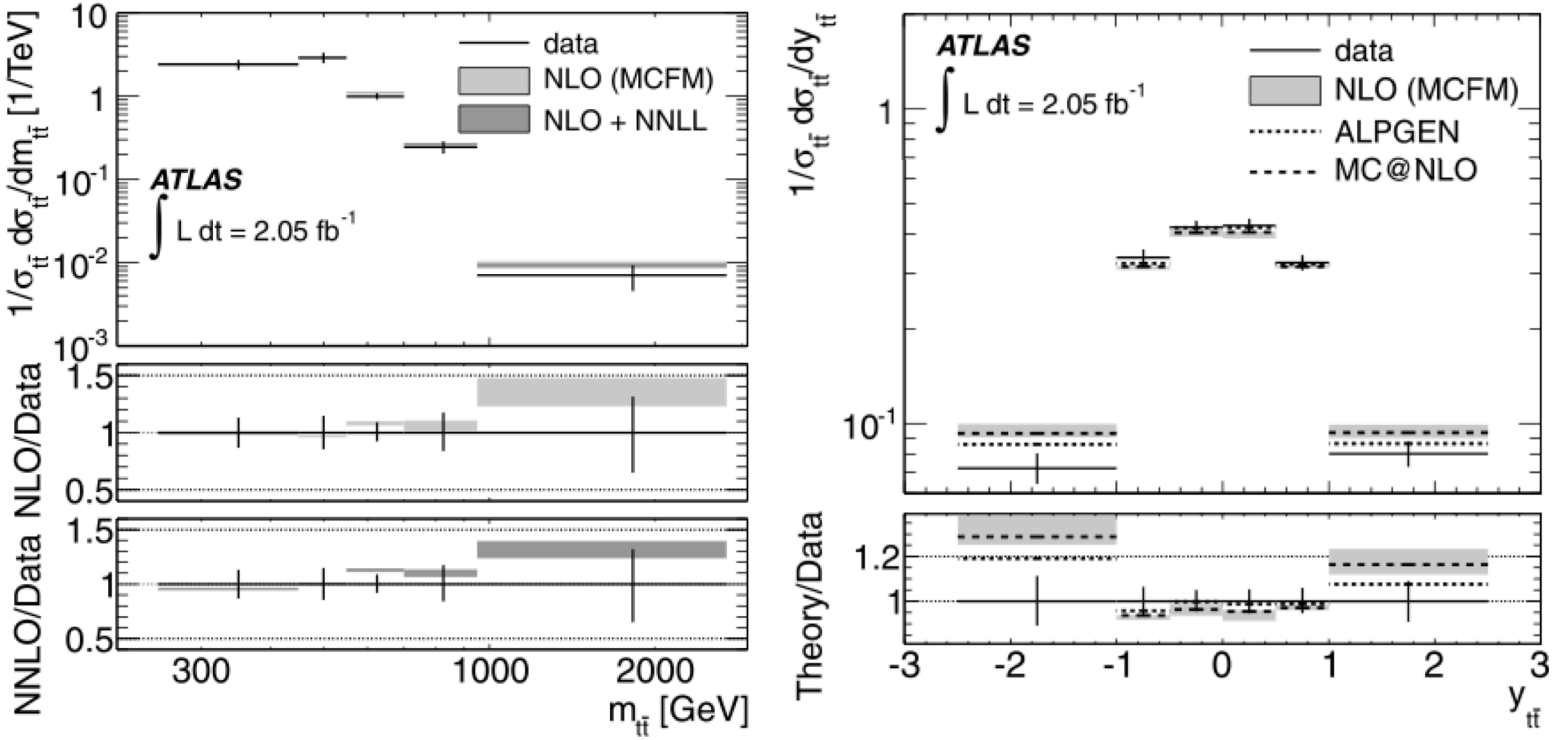
- **ISR/FSR** (AcerMC+pythia) **dominant uncertainty** for many measurements with early 2011 data
  - Measure the fraction of dilepton $t\bar{t}$ events w/o additional jets in |y|<2.1 and with $p_T > Q_0$
  - Direct constraint on the amount of ISR/FSR!
  - Reduce the variation of ISR/FSR uncertainties by about 50%!



Eur. Phys. J. C72 (2012) 2043

Differential $t\bar{t}$ cross section at 7 TeV

- **Differential $t\bar{t}$ cross section with 2.1 fb^{-1} @ 7 TeV:**
  - Use combined l+jets and ll channels
  - $\geq$ 4 jets, $\geq$ 1 b-tag
  - Event reconstruction with kinematic likelihood fitter
    - Uses m_W and m_{top} as constraints

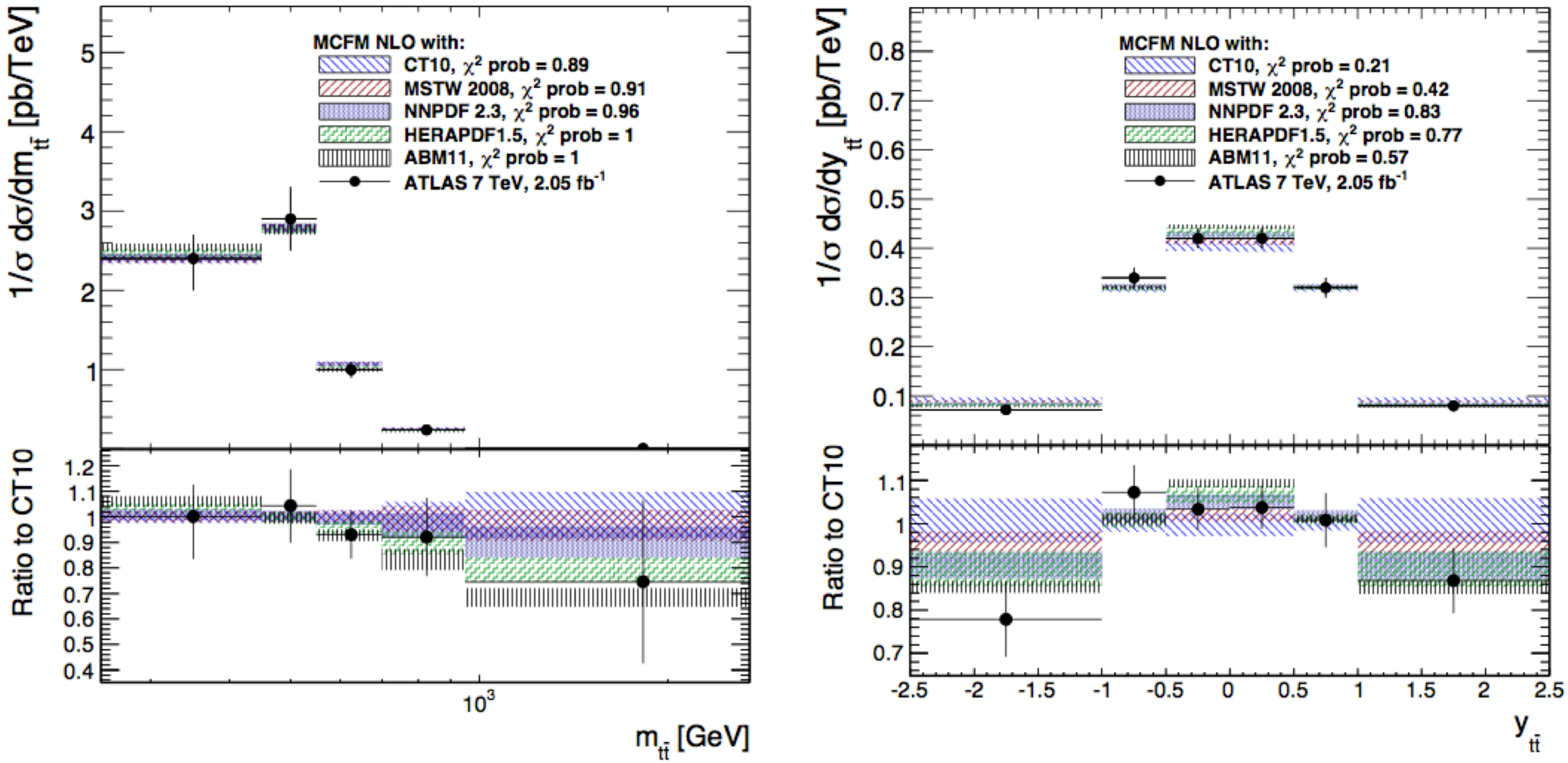


Selected results after unfolding

Eur. Phys. J. C (2013) 73: 2261

Differential $t\bar{t}$ cross section at 7 TeV

- **Investigate the disagreement for high $|y_{t\bar{t}}|$**
  - → **use this distribution to potentially constrain PDFs!**



  - **Need to further reduce experimental uncertainties to make conclusive statements**
    - **Already at present in conflict with CT10 at high $|y_{t\bar{t}}|$**

Eur. Phys. J. C (2013) 73: 2261

$t\bar{t}$ production in association with a b-quark

- The **production rate of b-quarks in association with $t\bar{t}$** is important for $t\bar{t}H$ and new physics searches
  - Extract it (for a given fiducial region) by measuring:

$$R_{\mathrm{HF}} = \frac{\sigma_{\mathrm{fid}}(tt+\mathrm{HF})}{\sigma_{\mathrm{fid}}(tt+j)}$$

  - To avoid ambiguities:
    - use **dilepton selection with ≥ 2 b-tagged jets**
  - Extract R_{HF} from the **mass of the secondary vertex**
    - The mass distribution of secondary vertex is similar for c- and b-quark jets, while acceptance is different
      - Use as **external input from simulations**:

$$F_{b/\mathrm{HF}} = (tt+b+X)/(tt+\mathrm{HF}+X)$$

  - **Final result:**

$$\boxed{R_{\mathrm{HF}} = [7.1 \pm 1.3\,(\mathrm{stat.})\,^{+5.3}_{-2.0}\,(\mathrm{syst.})]\%}$$

arXiv:1304.6386 [hep-ex]

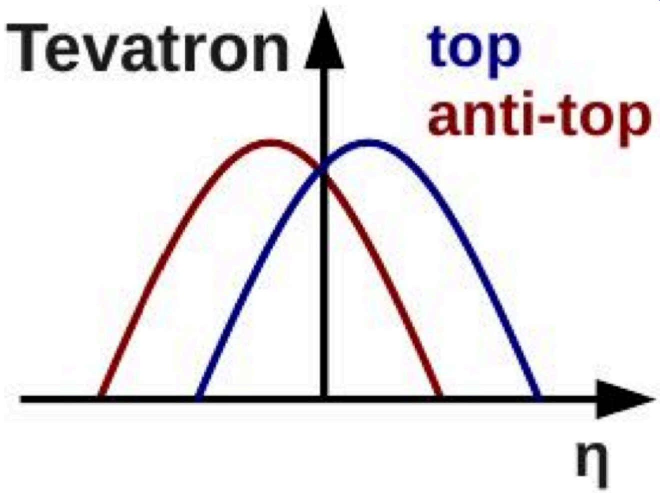
4.7 fb^{-1}

Powheg+herwig: $[5.2 \pm 1.7]\%$

arXiv:1304.6386 [hep-ex], submitted to PRD

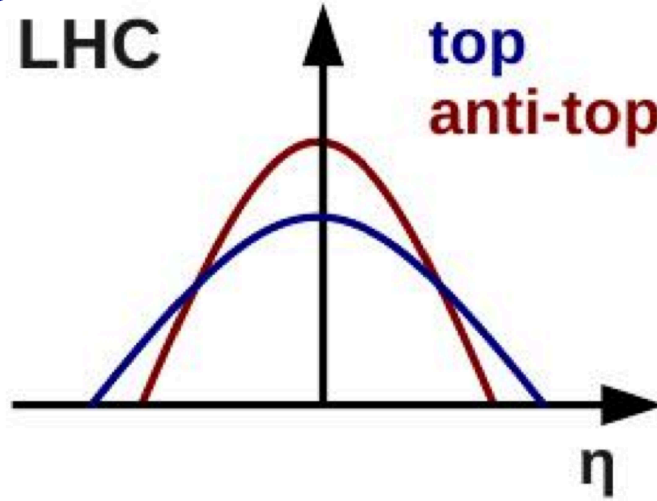
Strong charge asymmetry

- For the $q\bar{q}$ (and qg) production mode t is emitted preferentially in the direction of q at NLO
  - Caused by the interference of tree and box diagrams
  - Different observables due to the different initial state:



$p\bar{p}$ is a *CP* eigenstate
$q\bar{q}$ annihilation dominates

Deviation at the level of
~2 SD from SM for CDF and D0



pp is not a *CP* eigenstate
$q\bar{q}$ annihilation subdominant

Consistency with SM with 1 fb^{-1}
In Eur. Phys. J. C (2012) 2039

Strong charge asymmetry

- For LHC case, define observable:

$$A_C = \frac{N(\Delta|y| > 0) - N(\Delta|y| < 0)}{N(\Delta|y| > 0) + N(\Delta|y| < 0)} \qquad \Delta|y| \equiv |y_t| - |y_{\bar{t}}|$$

$$A_C^{SM} = 0.0123 \pm 0.0005$$ (NLO QCD + EW corrections)

- Requires **full event reconstruction** in order to determine y_t, $y_{\bar{t}}$
  - Kinematic likelihood filter
- **Bayesian unfolding to parton level**
- We obtain:

$$\boxed{A_C = 0.006 \pm 0.010 \text{ (stat. + syst.)}}$$

ATLAS-CONF-2013-078

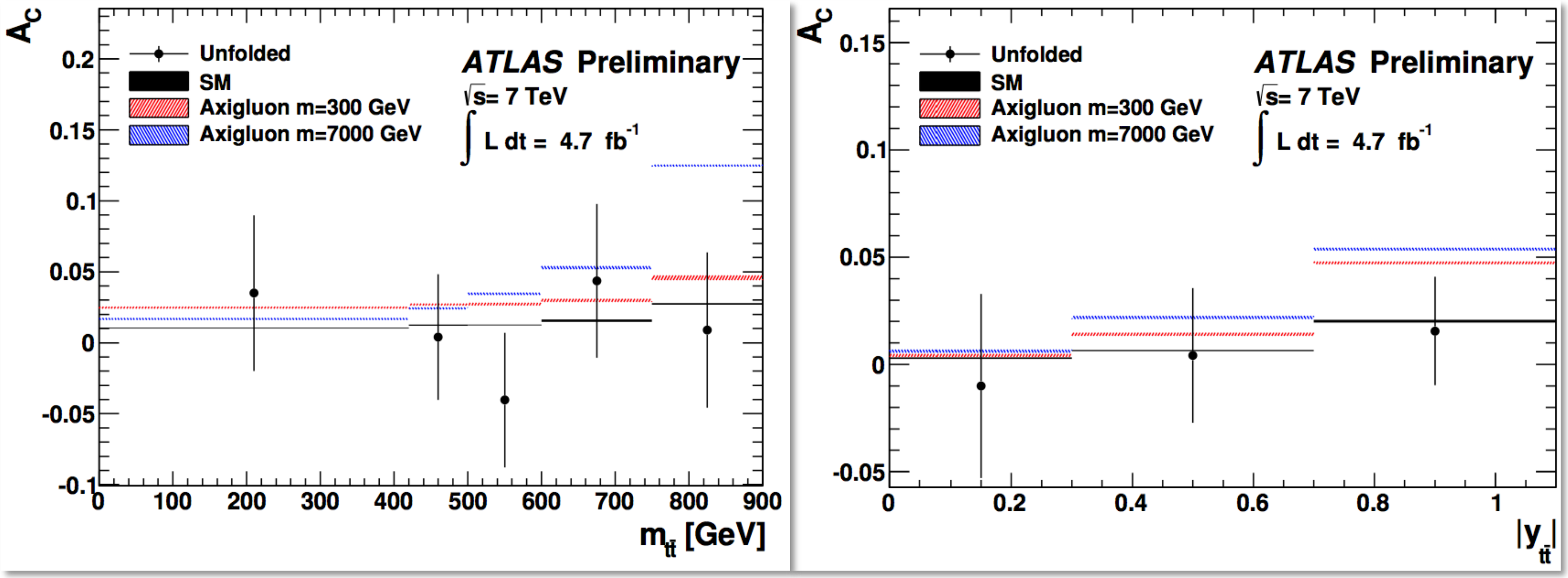
4.7 fb^{-1}

  - Consistent with SM predictions at NLO

ATLAS-CONF-2013-078

Colour charge asymmetry

- To gain additional sensitivity to some new physics models look in restricted regions of phase space:



  - $m_{t\bar{t}}$: invariant mass of $t\bar{t}$ system
  - $y_{t\bar{t}}$: rapidity of the $t\bar{t}$ system in lab frame
- No deviations from SM predictions found so far

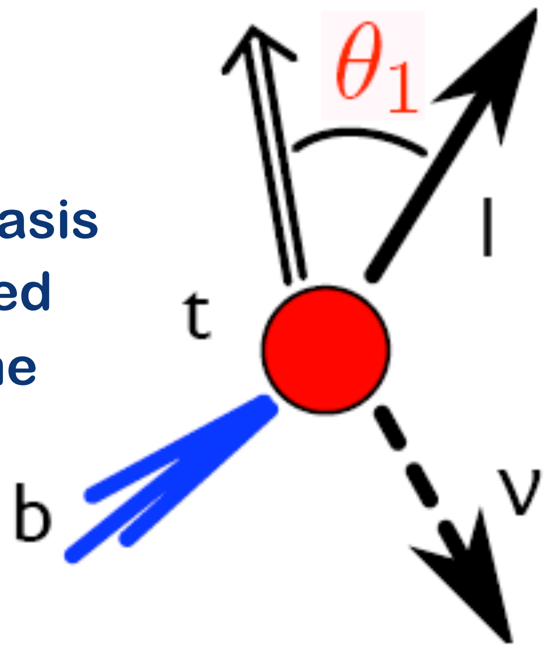
ATLAS-CONF-2013-078

Top quark polarisation

- The **top quark is produced mostly unpolarised** in the SM (small polarisation of 0.3% from EW corrections)
  - Some models for a **non-vanishing charge asymmetry** at the Tevatron **predict non-zero polarisation**
  - Use as an observable:

$$W\left(\cos\theta_i\right) = \frac{1}{2}\left(1 + \alpha_i P\ \cos\theta_i\right)$$

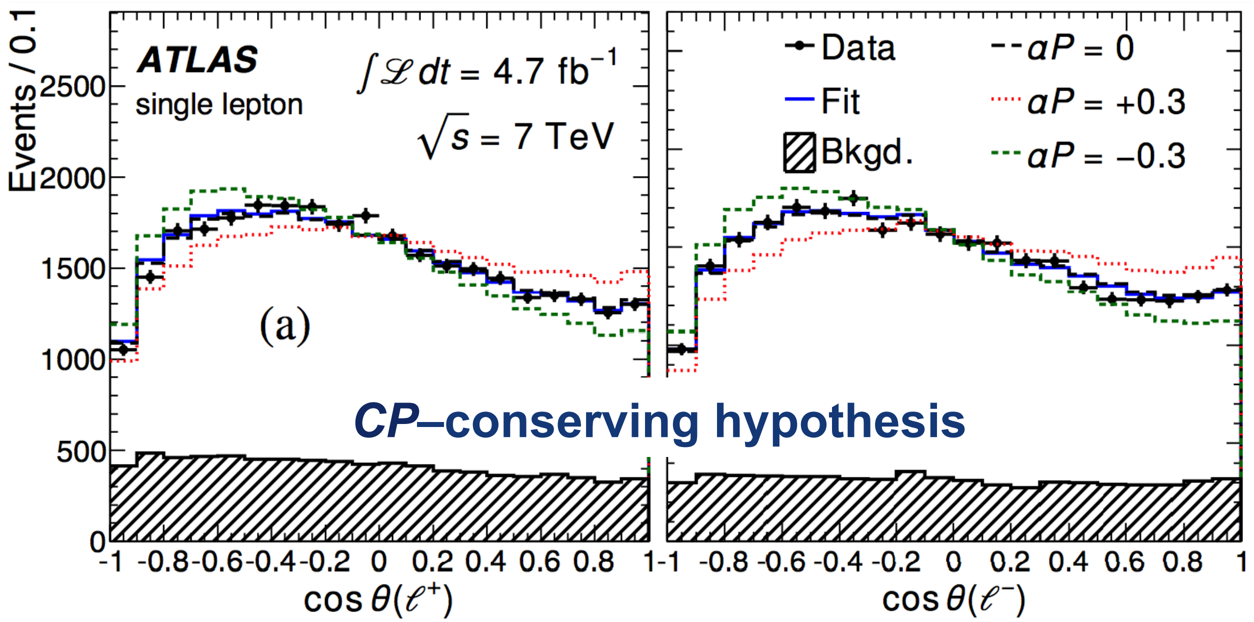
- θ_i is the angle between down-type fermion and the top quark in helicity basis (helicity basis: quantisation axis defined by momentum of t quark in tt rest frame
- P is the polarisation
- α_i is the spin analysing power (α_i = 1 for down-type fermions)



arXiv:1307.6511 [hep-ex], submitted to PRL

Top quark polarisation

- **Full event reconstruction**
  - **with neutrino-weighting method for dilepton final states**
  - **Kinematic likelihood fit in l+jets final states**



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

arXiv:1307.6511 [hep-ex]

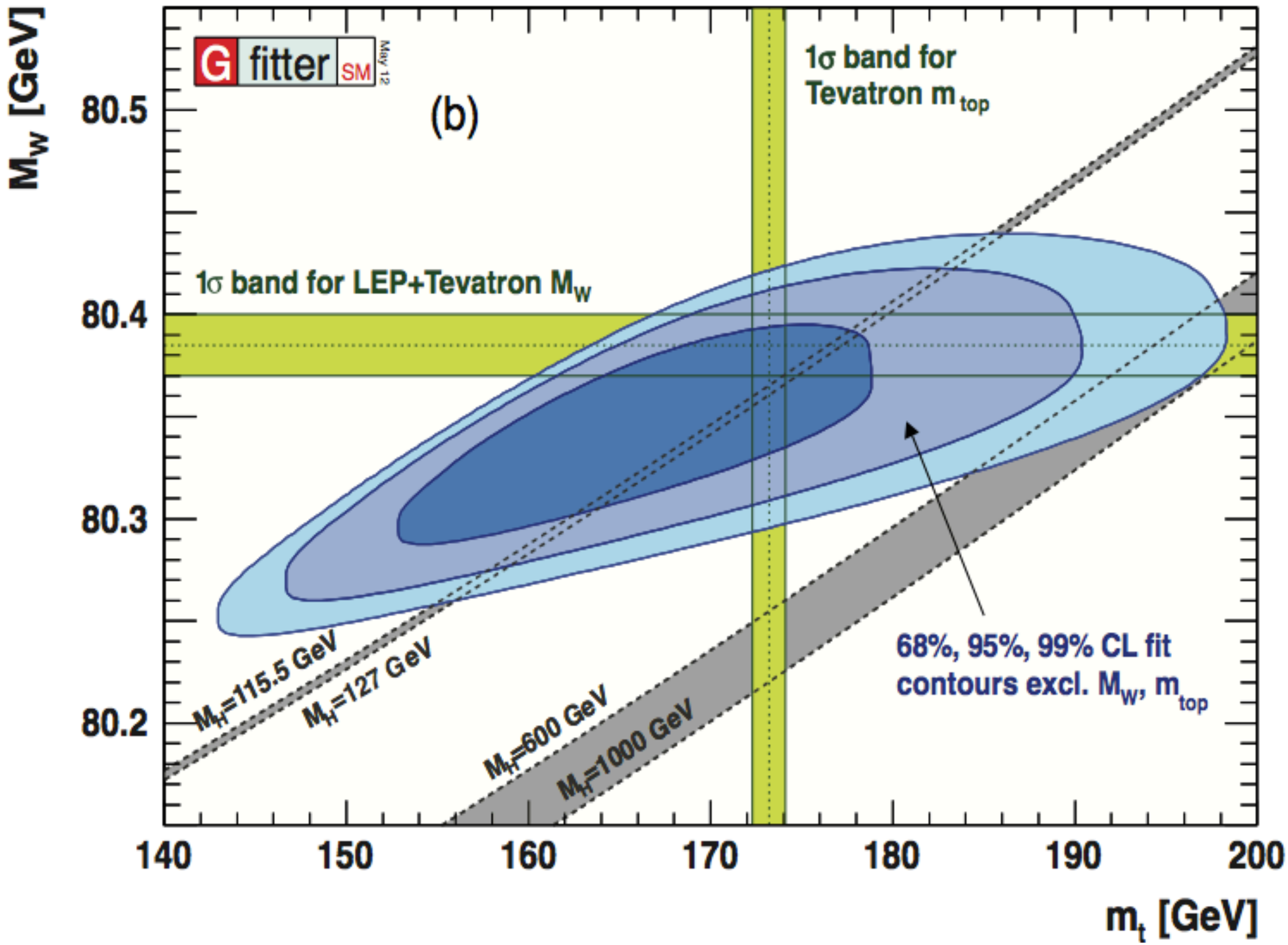
First measurement of top quark polarisation at the LHC!

4.7 fb^{-1}

Summary and Outlook

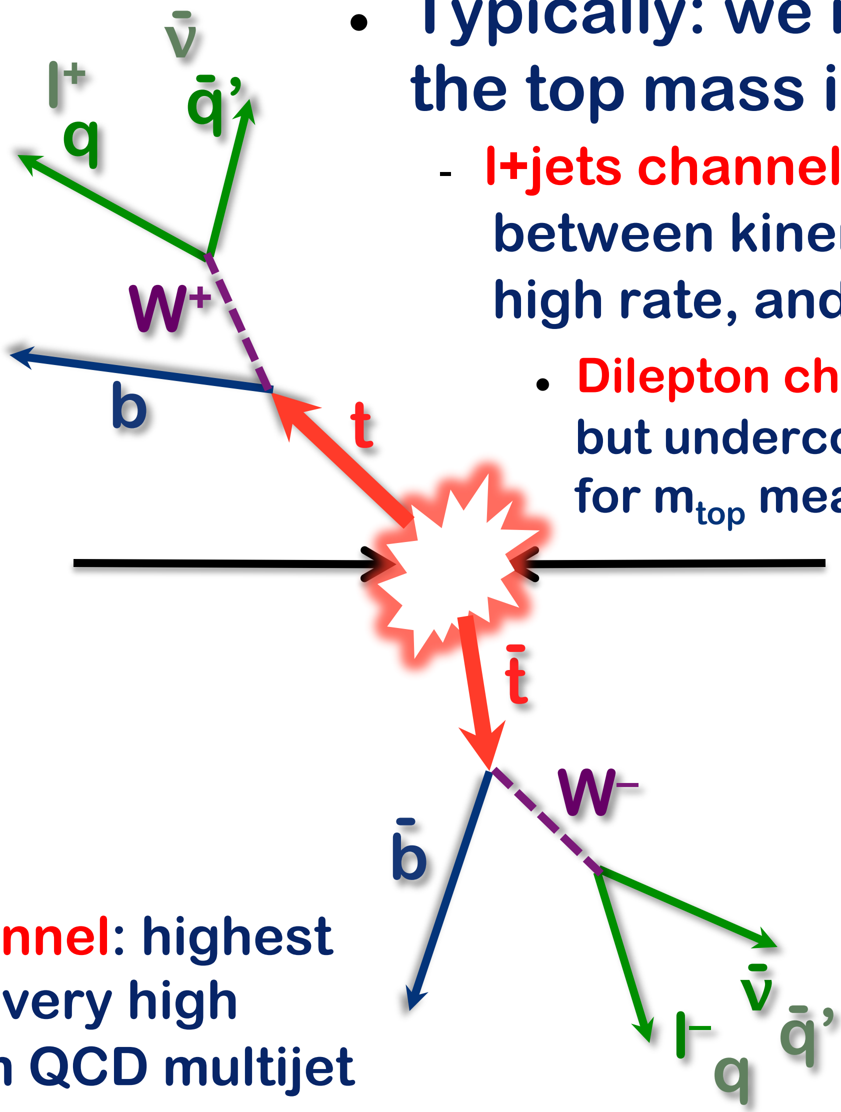
- Rich top quark physics programme at the ATLAS experiment!
  - Only a small fraction of results could be discussed in detail
  - For precision measurements like m_{top}, cross section,… the precision of the TeVatron is almost reached or surpassed
  - Already with 4.7 fb^{-1} @ 7 TeV many measurements are systematically limited
    - Our understanding of signal modelling has continually improved by confronting alternative models with data!
  - Expect many more results with 8 and 7 TeV datasets!
- Full list of public results:
  - https://twiki.cern.ch/twiki/bin/view/AtlasPublic/TopPublicResults


GAME OVER
BONUS MATERIAL


G fitter SM
May 12
(b)
1σ band for
Tevatron m top
1σ band for LEP+Tevatron M W
68%, 95%, 99% CL fit
contours excl. M W, m top
M H=115.5 GeV
M H=127 GeV
M H=600 GeV
M H=1000 GeV
M W [GeV]
80.5
80.4
80.3
80.2
140
150
160
170
180
190
200
m t [GeV]

A wealth of top properties

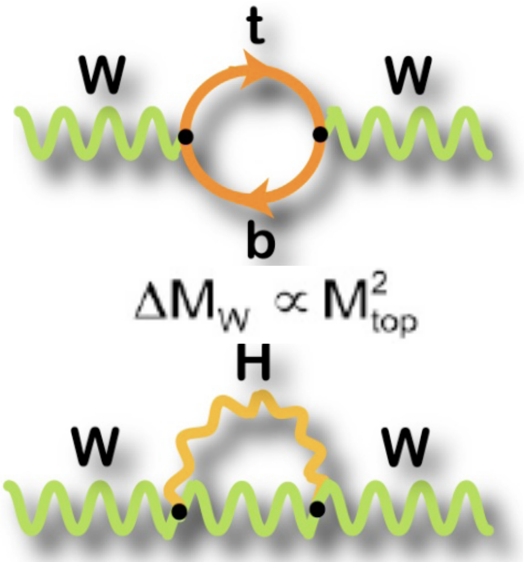
- Typically: we measure the top mass in tt events:
  - l+jets channel: good compromise between kinematic reconstruction, high rate, and backgrounds
    - Dilepton channel: low backgrounds, but underconstrained kinematics for m_{top} meas't and low rate



- All-hadronic channel: highest branching ratio, very high backgrouns from QCD multijet production

Why study m_{top} in the Higgs era?

- The top quark is special:
  - It is the heaviest quark of the SM!
    - Why is it so heavy?
    - Does it play a special role in EWSB?
  - Infer m_{higgs} from m_{top} & m_W:

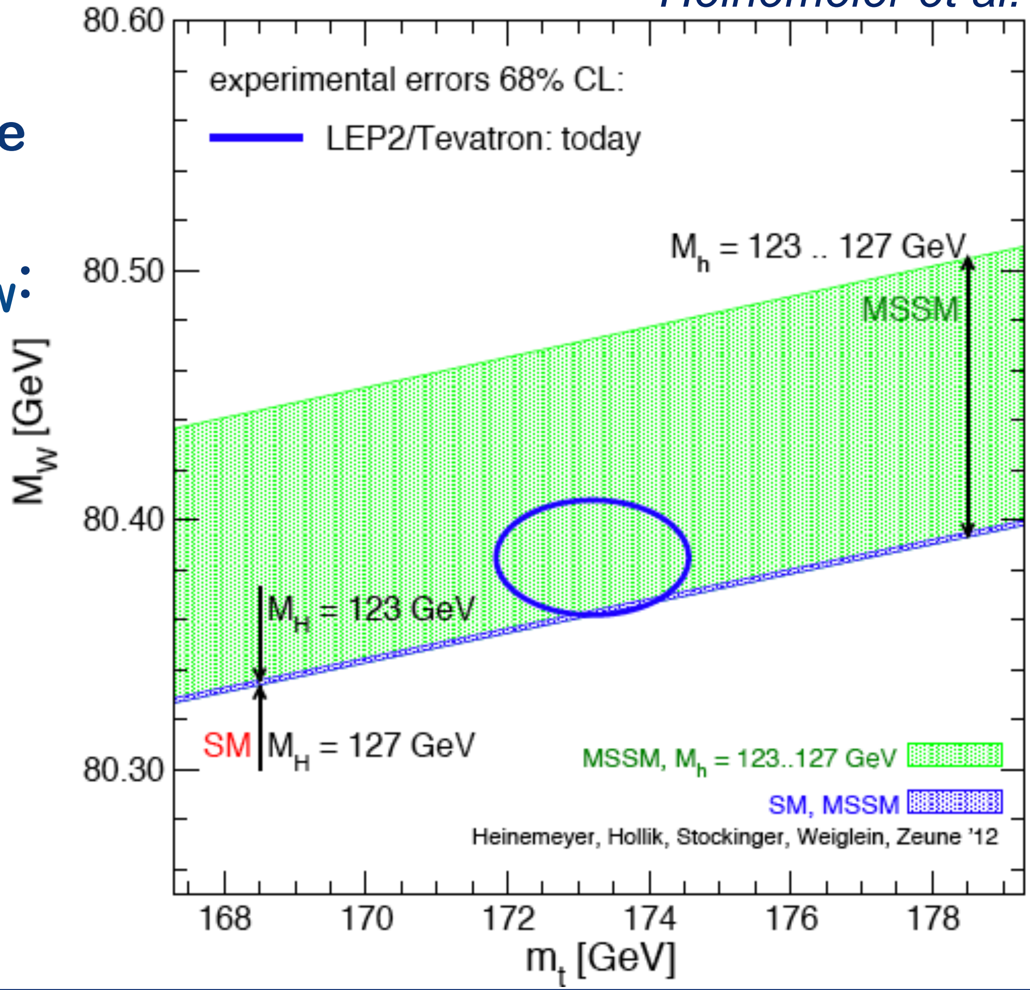


$\Delta M_W \propto M_{top}^2$

$\Delta M_W \propto \ln M_H$

Overconstrain m_{higgs}, m_{top}, and m_W
→ Consistency check of the SM!

Heinemeier et al.

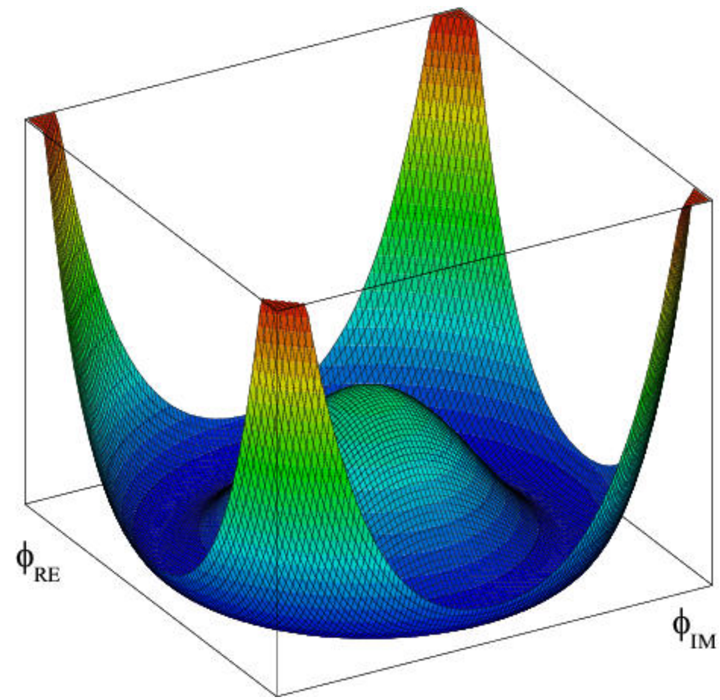


Why study m_{top} in the Higgs era?

- If this is not enough, the top quark mass is a fundamental parameter of the SM!
- The fate of our Universe depends on m_{top}!
  - Consider the Higgs Lagrangian:

$$\mathcal{L}_H = \left| \left(\partial_\mu - igW_\mu^a \tau^a - i\frac{g'}{2} B_\mu \right) \phi \right|^2 + \mu^2 \phi^\dagger \phi - \lambda (\phi^\dagger \phi)^2,$$

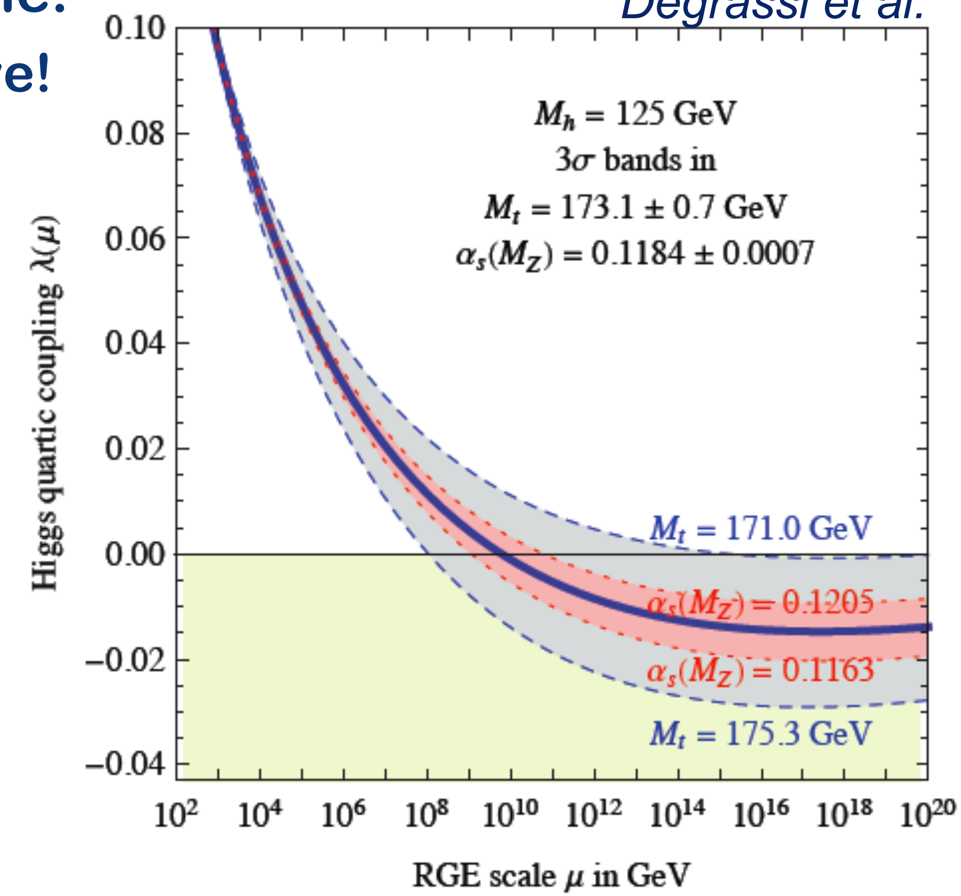
  - The quartic Higgs self-coupling term $\lambda(\phi^\dagger\phi)^2$ is responsible for the mexican-hat shape of the potential!
  - This works only if λ is positive!



Why study m_{top} in the Higgs era?

- λ receives radiative corrections from all particles of the SM, mostly from the top quark!
  - We can evolve these corrections using running group equations to Planck scale:
    - λ should remain positive!

Degrassi et al.



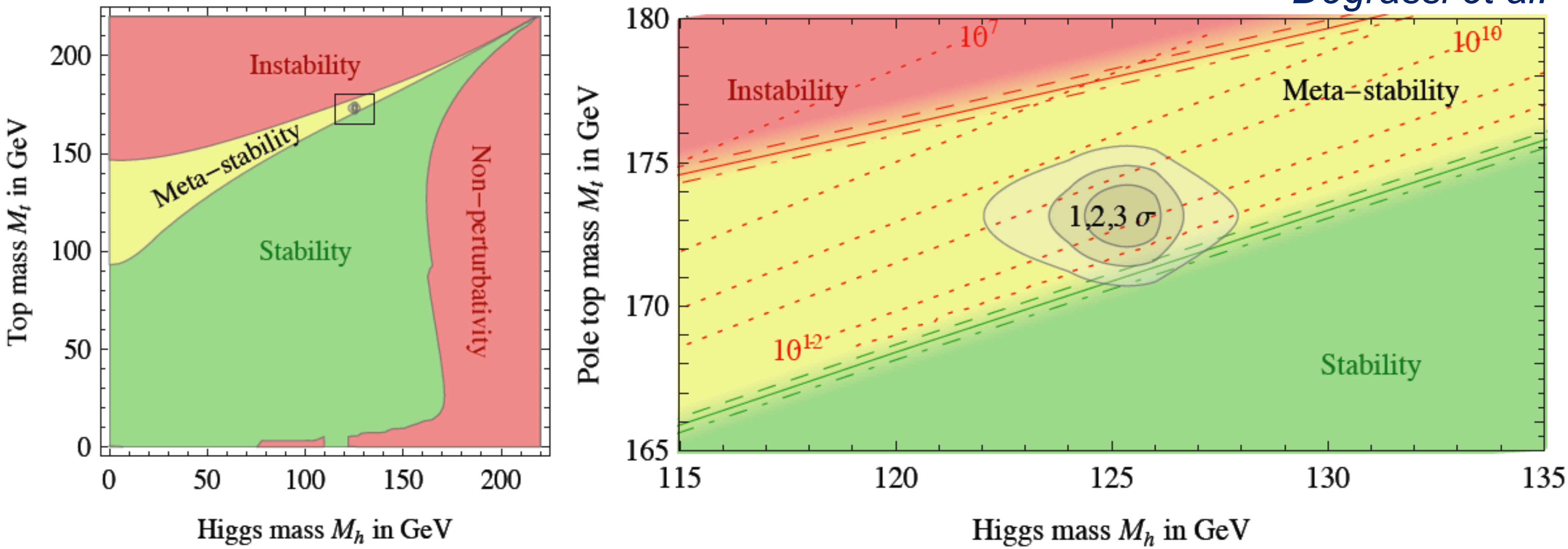
With the current world's best values for m_{top} and m_{higgs}:
→ Our Universe is only metastable!

The calculation includes NNLO effects, RG equation at NNNLO

Why study m_{top} in the Higgs era?

- **The phase diagram of the Universe:**

Degrassi et al.



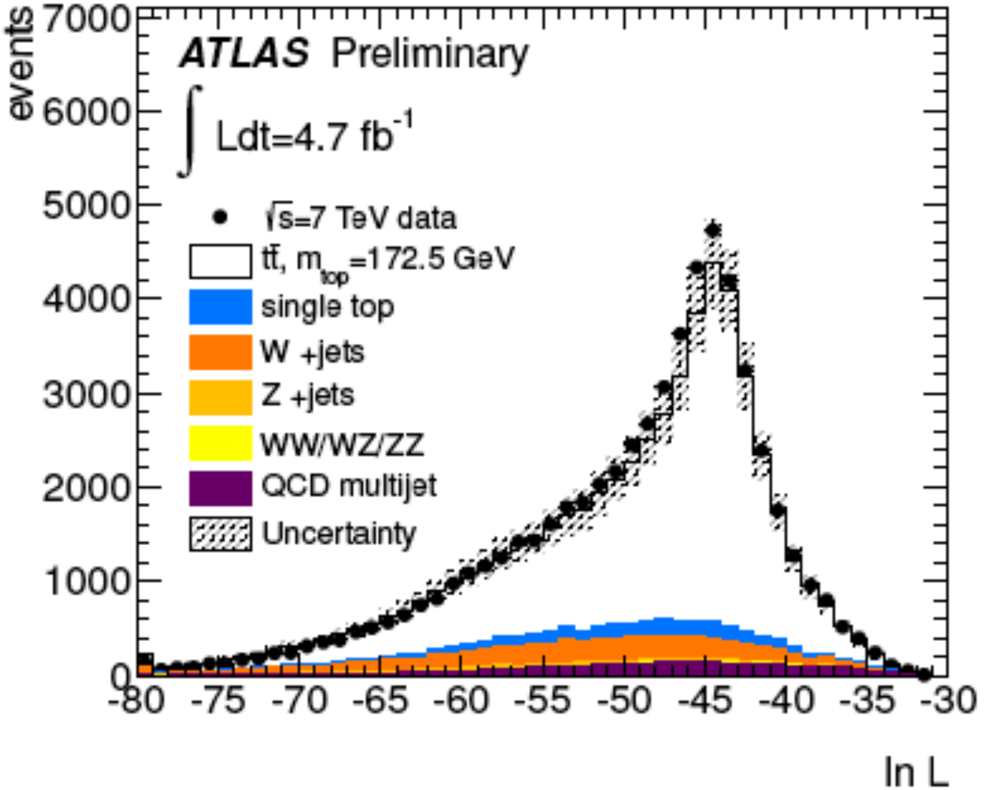
Type of error	Estimate of the error	Impact on M_h
M_t	experimental uncertainty in M_t	± 1.4 GeV
α_s	experimental uncertainty in α_s	± 0.5 GeV
Experiment	Total combined in quadrature	± 1.5 GeV
λ	scale variation in λ	± 0.7 GeV
y_t	$\mathcal{O}(\Lambda_{QCD})$ correction to M_t	± 0.6 GeV
y_t	QCD threshold at 4 loops	± 0.3 GeV
RGE	EW at 3 loops + QCD at 4 loops	± 0.2 GeV
Theory	Total combined in quadrature	± 1.0 GeV

Top quark mass with 3D template method

- Measure m_{top} in l+jets using 4.7 fb^{-1} @ 7 TeV
- Event reconstruction with a kinematic likelihood fitter
  - Use transfer functions:
    - Better mapping of detector resolution tails
    - Better sensitivity than χ^2-based methods

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

Correct jet-parton assignments:
70%: single b-tag
80%: two b-tags



ATLAS-CONF-2013-046

Top quark mass with 3D template method

ATLAS-CONF-2013-046

- **Large systematic uncertainty expected from the JES calibration for b-quark jets (bJSF)**
  - **Introduce R_{lb} variable to provide sensitivity to bJSF:**

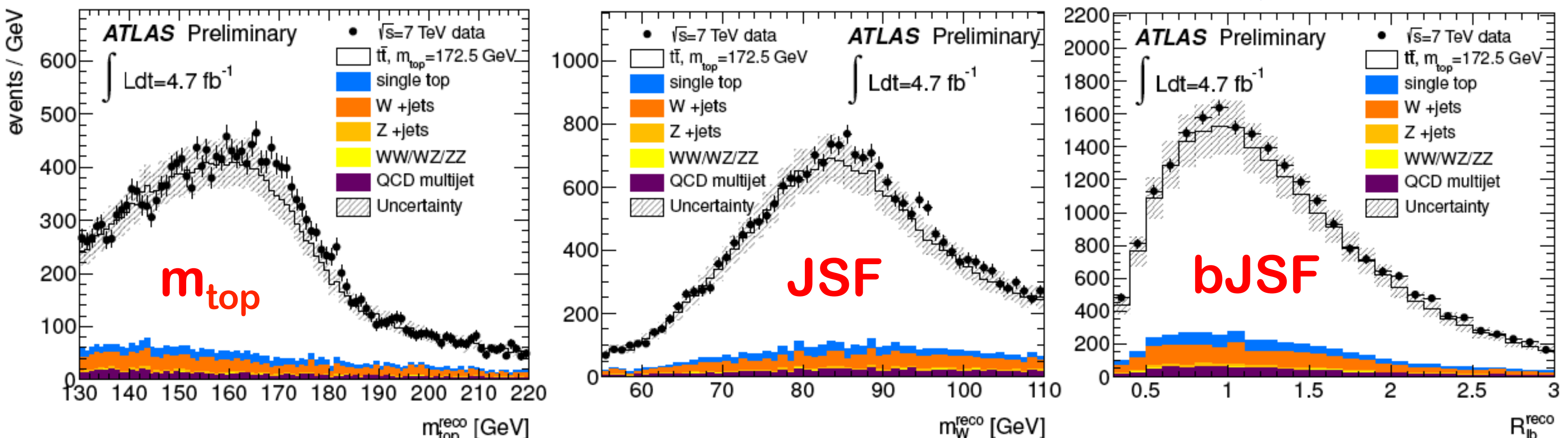
$$R_{\mathrm{lb}}^{\mathrm{reco,2b}} = \frac{p_{\mathrm{T}}^{b_{\mathrm{had}}} + p_{\mathrm{T}}^{b_{\mathrm{lep}}}}{p_{\mathrm{T}}^{W_{\mathrm{jet}_1}} + p_{\mathrm{T}}^{W_{\mathrm{jet}_2}}}$$

single b-tag

$$R_{\mathrm{lb}}^{\mathrm{reco,1b}} = \frac{p_{\mathrm{T}}^{b_{\mathrm{tag}}}}{(p_{\mathrm{T}}^{W_{\mathrm{jet}_1}} + p_{\mathrm{T}}^{W_{\mathrm{jet}_2}})/2}$$

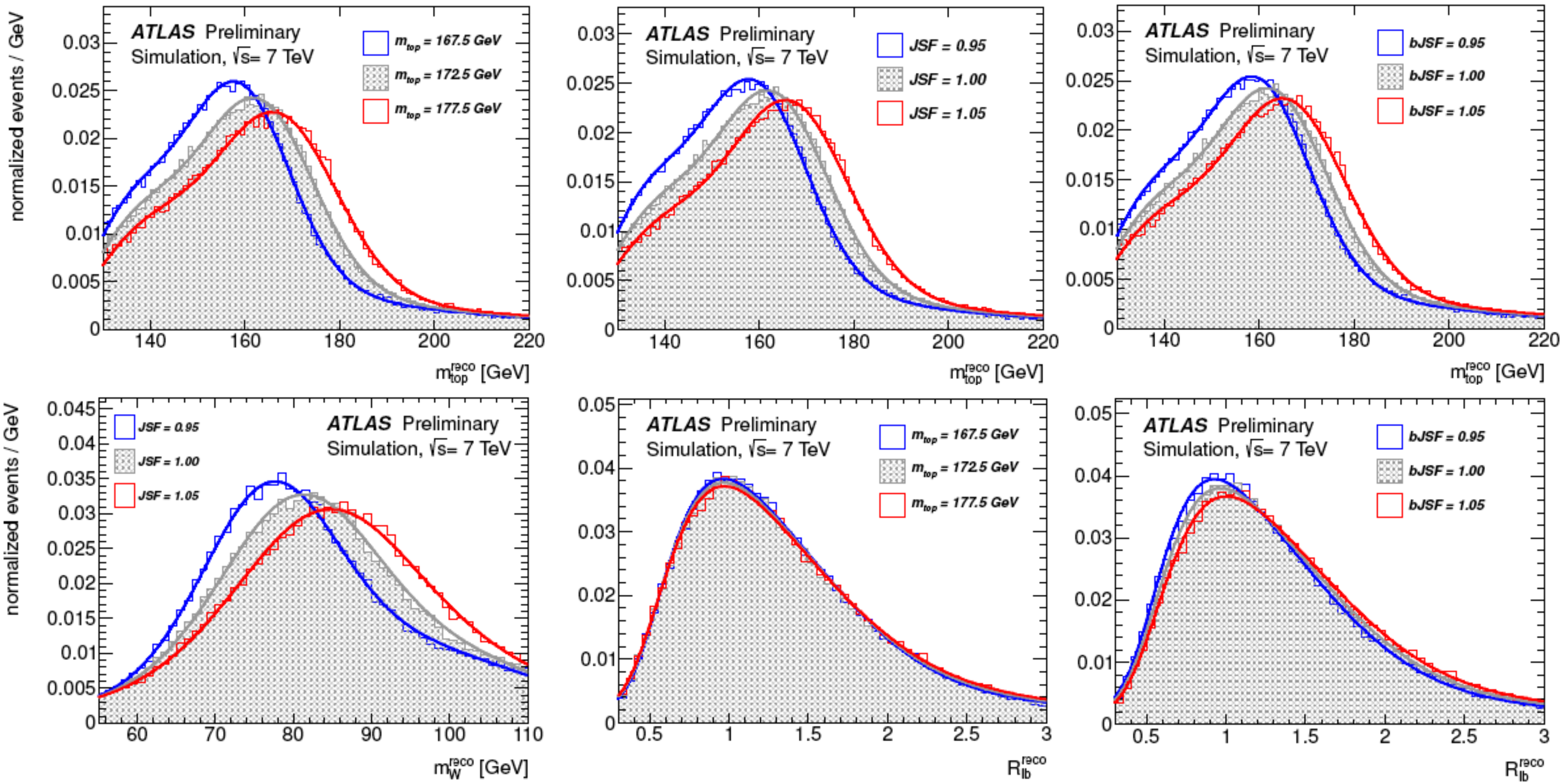
two b-tags

World's first 3D fit analysis of m_{top}!



Top quark mass with 3D template method

- Form templates on 5 x 5 x 5 grid in m_{top} x JSF x bJSF:



ATLAS-CONF-2013-046

Templates shown are for two b-tag events

3D Template method @ ATLAS

ATLAS-CONF-2013-046

	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	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Underlying event	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Colour reconnection	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
ISR and FSR (signal only)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Proton PDF	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
single top normalisation	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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

Note that the syst. uncertainty from bJES is now much reduced, as it is mostly absorbed in the bJSF!
→ at the cost of reduced stat. sensitivity

2D analysis is identical to 3D except for fixing Rlb to its default

KIRCHHOFF-INSTITUT FÜR PHYSIK

3D Template method @ ATLAS

ATLAS-CONF-2013-046

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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
W+jets background	0.02	0.000	0.03	0.000	0.000
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Jet reconstruction efficiency	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
b-tagging efficiency and mistag rate	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Lepton energy scale	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Missing transverse momentum	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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Also other effects which affect the modeling of jets like hadronisation (pythia vs herwig) and ISR/FSR are partially absorbed in bJSF through R_{lb} sensitivity!

2D analysis is identical to 3D except for fixing R_{lb} to its default

KIRCHHOFF-INSTITUT FÜR PHYSIK

3D Template method @ ATLAS

ATLAS-CONF-2013-046

	2D analysis m_{top} [GeV]	2D analysis JSF	3D analysis m_{top} [GeV]	3D analysis JSF	3D analysis bJSF
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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

No, there is no free lunch.

But at the bottom line we win!

2D analysis is identical to 3D except for fixing R_{lb} to its default

Top pair production cross section

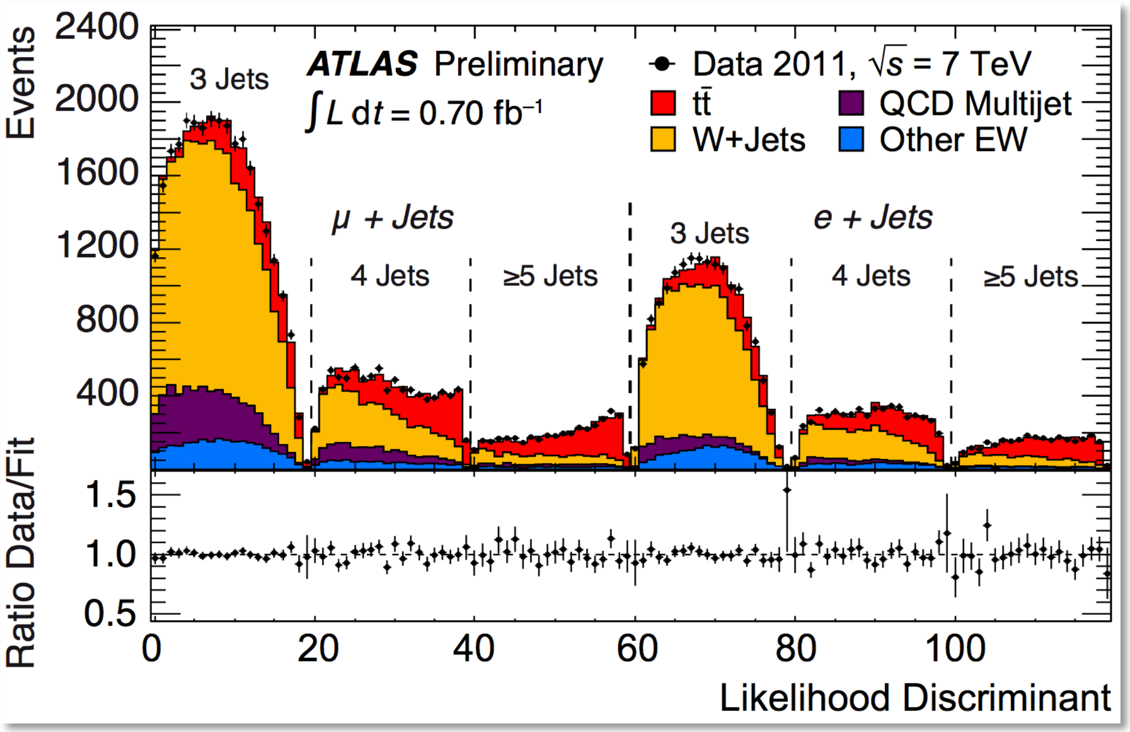
- **Most precise measurement @ 7 TeV in l+jets channel:**

$$\sigma_{t\bar{t}} = 179.0 \pm 3.9\ (\text{stat.}) \pm 9.0\ (\text{syst.}) \pm 6.6(\text{lumi.})\text{pb}$$

~6.6% precision! ATLAS-CONF-2011-121

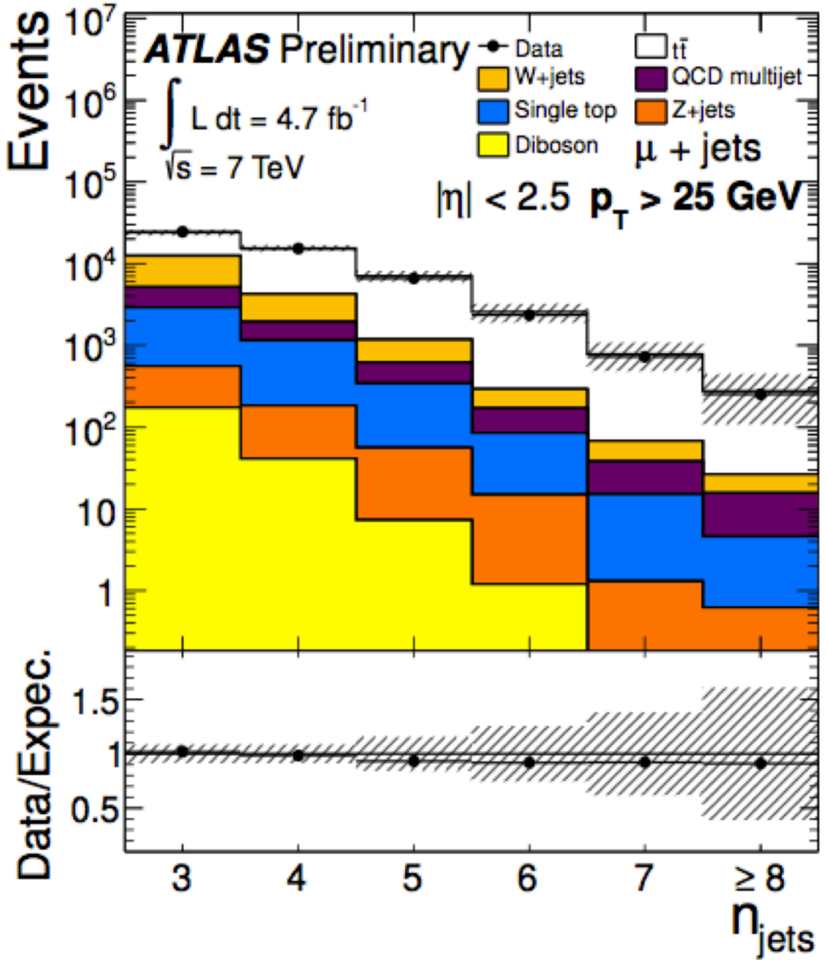
0.7 fb^{-1}

  - **Construct discriminant from η(l), pT(j$_1$), aplanarity, H$_{T,3}$**
  - **uses profile likelihood fit and utilises background-dominated regions to constrain background contributions**



Measurement of jet multiplicity in tT events

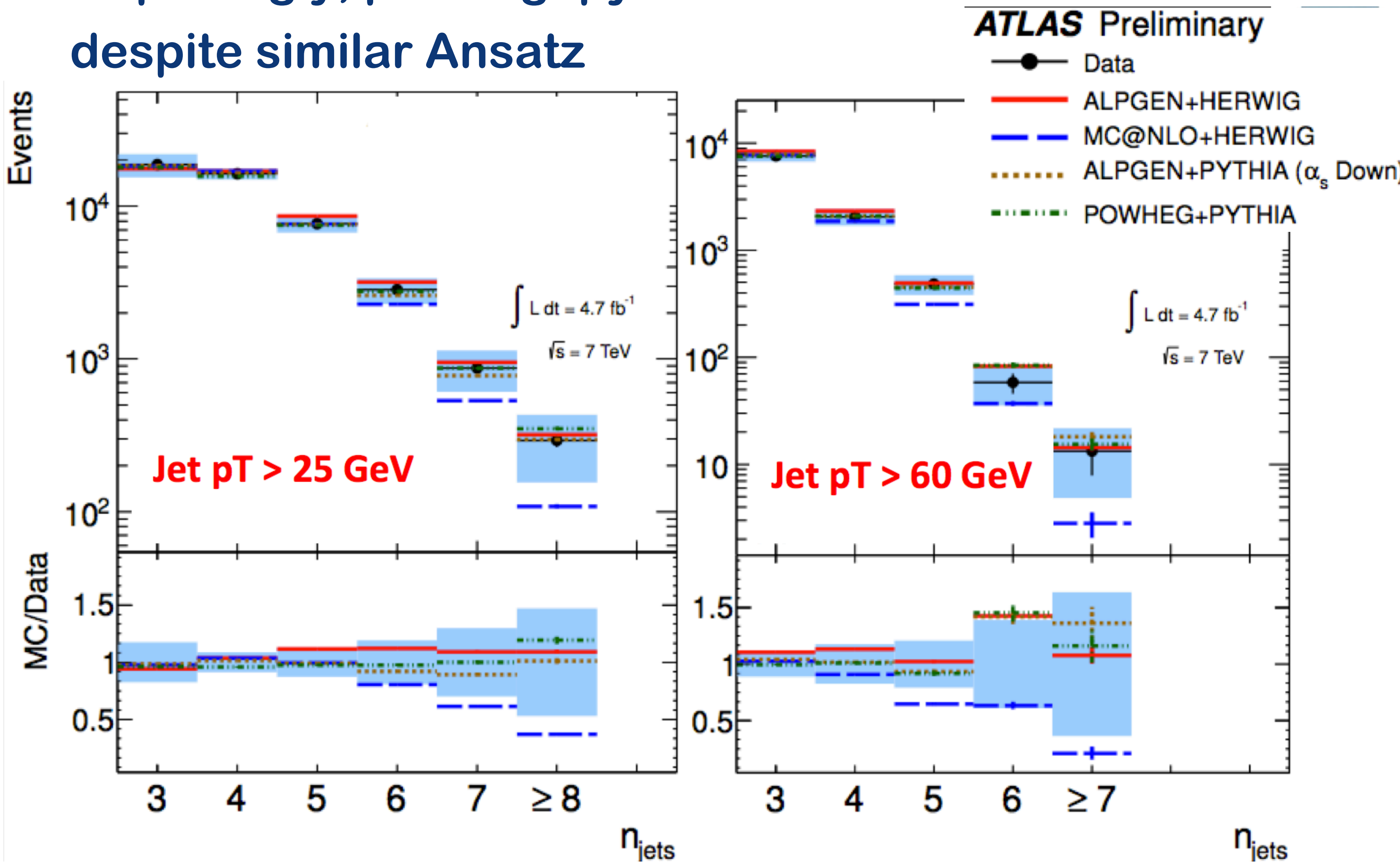
- Measurement of N_{jet} in tT events with 4.7 fb^{-1} @ 7 TeV
  - Important to understand tuning of simulation, backgrounds to new physics
- Selection:
  - l+jet channel
  - ≥3 jets, ≥1 b-tag
- Regularised unfolding to particle level



ATLAS-CONF-2012-155

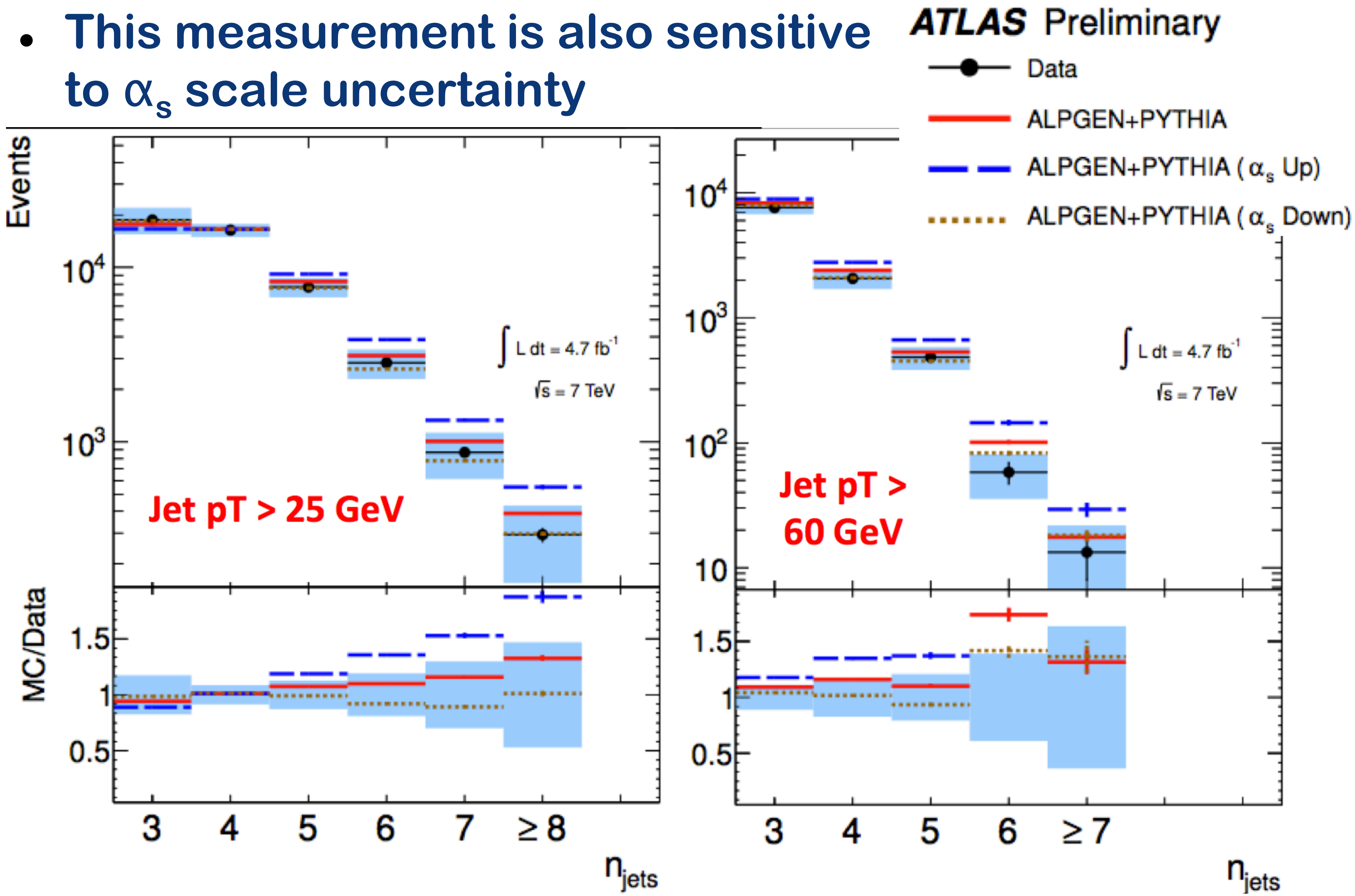
Measurement of jet multiplicity in tT events

- Clear mis-description of data by MC@NLO
  - Surprisingly, powheg+pythia does well despite similar Ansatz



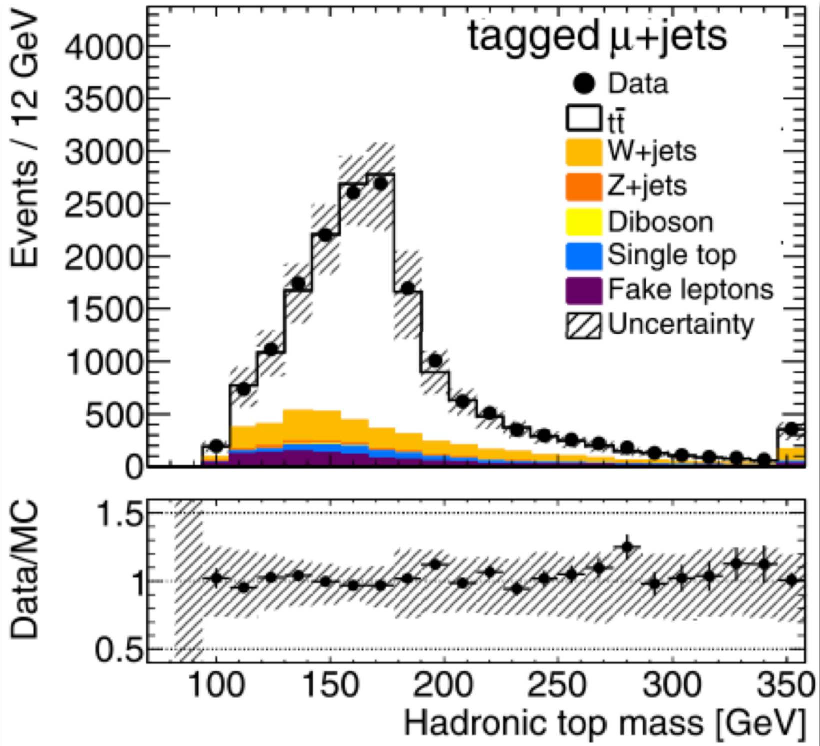
Measurement of jet multiplicity in tT events

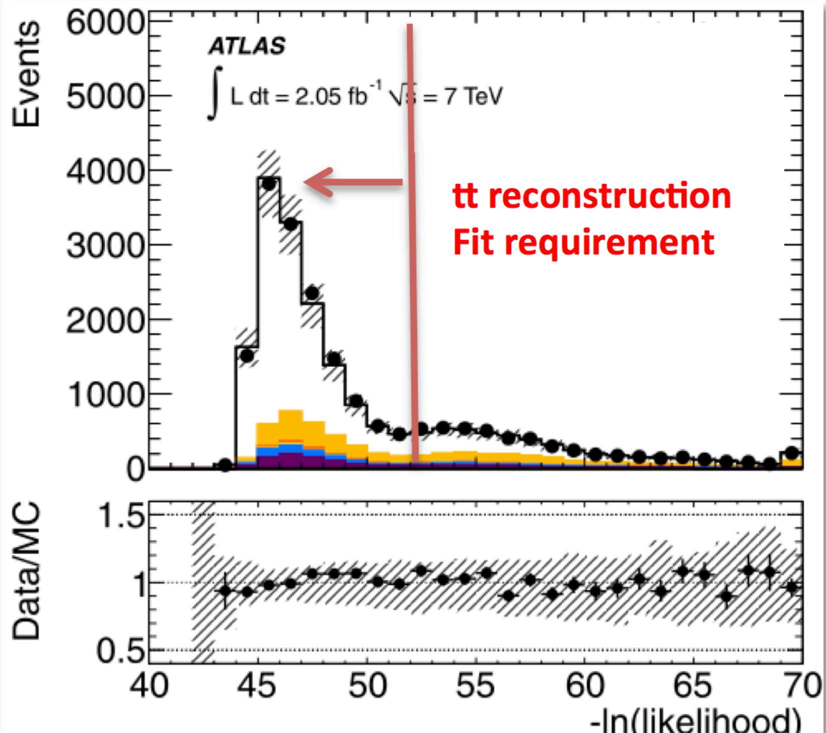
- This measurement is also sensitive to α_s scale uncertainty



Differential tT cross section at 7 TeV

- **Differential tT cross section with 2.1 fb^{-1} @ 7 TeV:**
  - **Use combined l+jets and ll channels**
  - **≥ 4 jets, ≥ 1 b-tag**
  - **Event reconstruction with kinematic likelihood fitter**
    - **Uses m_W and m_{top} as constraints**





Eur. Phys. J. C (2013) 73: 2261

Top quark charge

- The charge of the top quark in the SM is +2/3
  - In principle, can think of an exotic model with -4/3:

$$t_X^{(-4/3)} \rightarrow b^{(-1/3)} + W^{(-1)}$$

- Ansatz:
  - Determine Q_t from Q_b and Q_l of the associated lepton
  - Observable to infer Q_b: $Q_{b-\mathrm{jet}} = \frac{\sum_\mathrm{i} Q_\mathrm{i} |\vec{j} \cdot \vec{p}_i|^\kappa}{\sum_i |\vec{j} \cdot \vec{p}_\mathrm{i}|^\kappa}$
- We find:

$$\boxed{Q_\mathrm{top} = 0.64 \pm 0.02\ (\mathrm{stat.}) \pm 0.08\ (\mathrm{syst.})}$$

arXiv:1307.4568 [hep-ex], submitted to JHEP

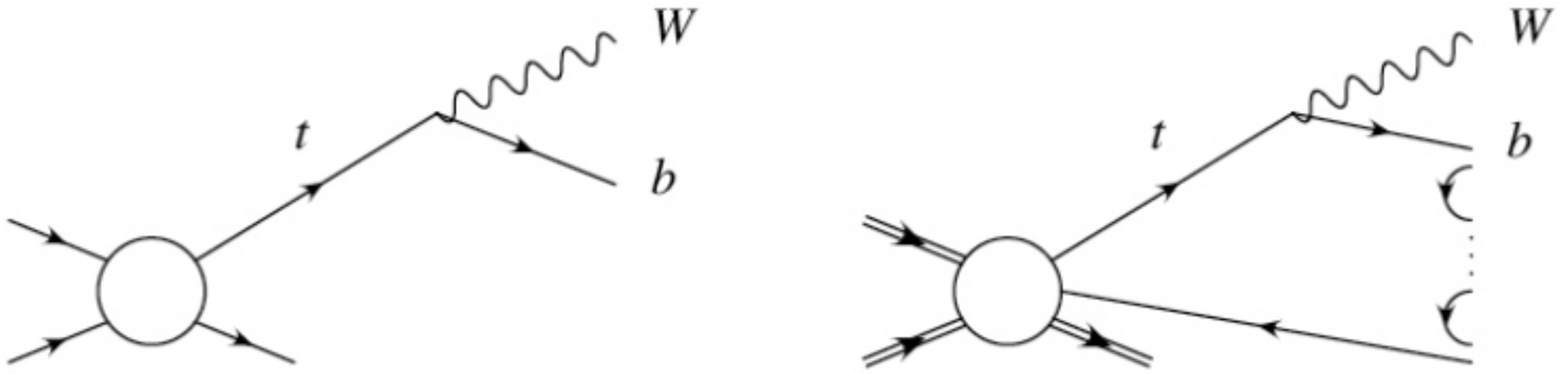
4.7 fb^{-1}

- Exclude exotic model @ 8.8 SD level!

Which m_{top} do we measure?

Which m_{top} do we measure?

- *(I only want to refresh our memory here)*
- The top **mass** is **not an observable** per se and has to be inferred from its effect on kinematic observables
- The mass **cannot be well-defined at LO**
- The **pole mass** corresponds to our physical intuition of a stable particle
  - m_{top} is the "pole" in the top quark propagator
    - Although this is not fully correct (hadronisation effects)
  - The pole mass can never be determined with **precision** better than Λ_{QCD}:



Which m_{top} do we measure?

- Other popular mass definition schemes:
  - e.g. modified minimal subtraction scheme ($\overline{MS}$), also referred to as running mass $m_{top}(\mu_r)$
    - The μ_r dependence can be used to absorb logarithmic corrections through resummation (in specific cases)
      - better behaviour of perturbative predictions
  - The $\overline{MS}$ mass can be translated into the pole mass at any fixed order of perturbation theory
- What we typically measure at hadron colliders, is:
  - Neither the $\overline{MS}$ mass, nor the pole mass → m^{MC}
  - "Close" to the pole mass
    - "Close" not quantified yet
- True also for NLO generators like e.g. powheg
  - finite width effects of top propagator are not simulated, but generated via reweighting

The birth size

- 24 Feb. 1995:
  - Simultaneous PRL submission by CDF and DØ

- CDF (67 pb^{-1}) :
  - $\sigma=6.8^{+3.6}_{-2.4}$ pb,
  - observed 19 events, expected 6.9 bkg
    - bkg-only hypothesis rejected at 4.8σ
  - m_{top}=176±13 GeV
- D0 (50 pb^{-1}):
  - σ=6.4±2.2 pb,
  - observed 17 events, expected 3.8 bkg
    - → bkg-only hypothesis rejected at 4.6σ
  - m_{top}=199±30 GeV

The birth weight

- **24 Feb. 1995:**
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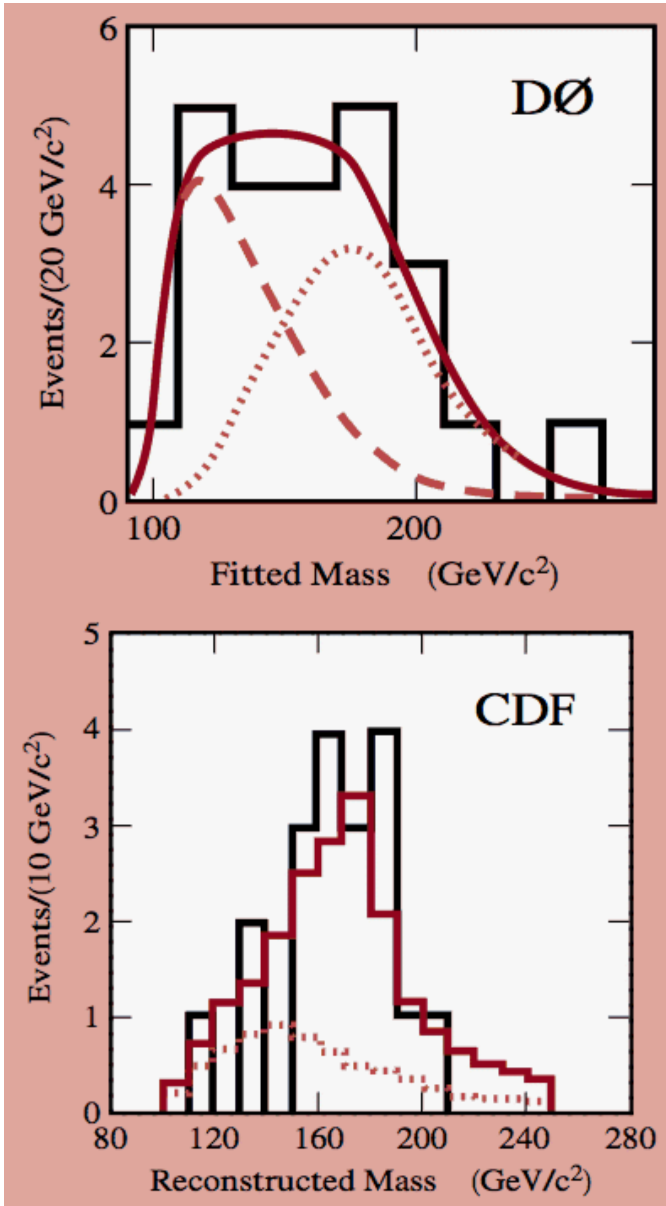
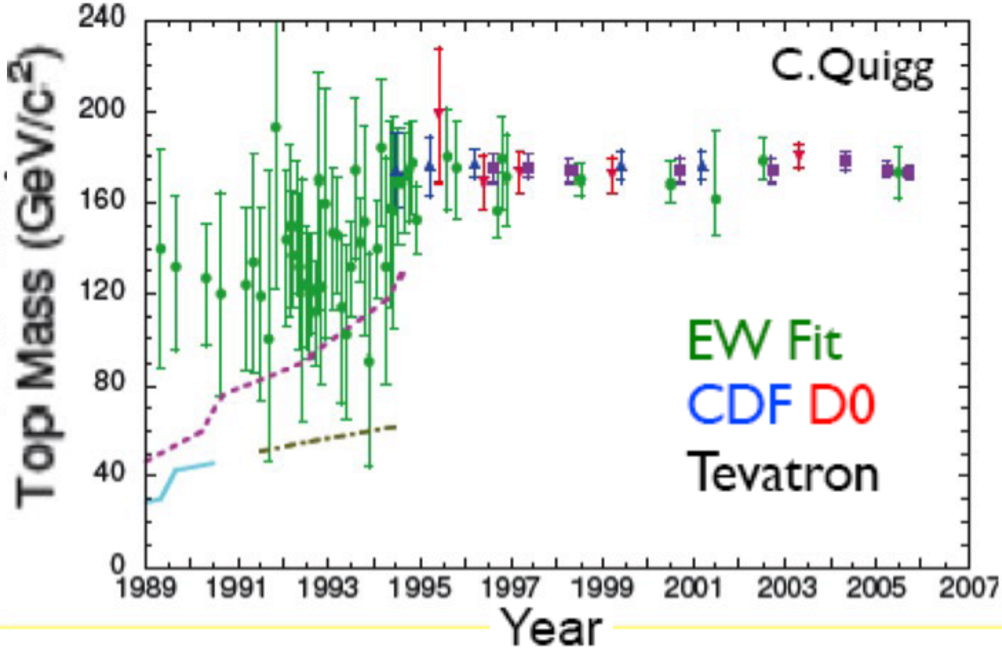


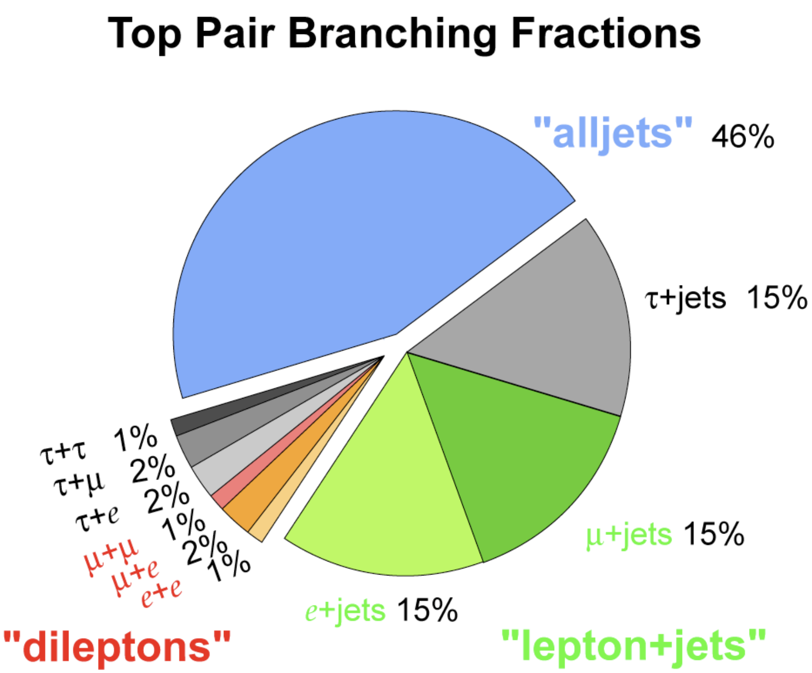
A bit of history

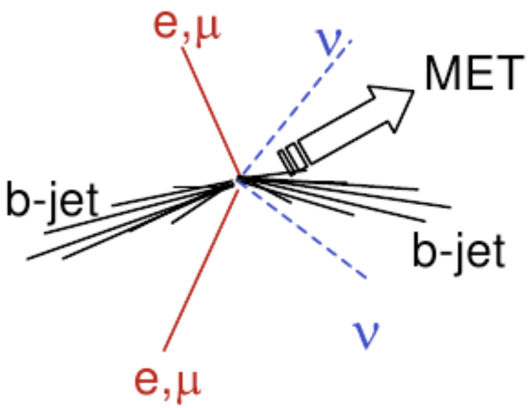
- 1976: discovery of the Ypsilon at Fermilab
  - indicates the existence of the top quark
  - from here on, the race for the top has begun!
- 1984: PETRA m_{top}>23.3 GeV
- 1988: UA1 m_{top}>44 GeV
- 1990:
  - TRISTAN m_{top}>30.2 GeV
  - SLC m_{top}>40.7 GeV
  - LEP m_{top}>45.8 GeV
  - UA1 m_{top}>60 GeV
  - UA2 m_{top}>69 GeV
- 1992: CDF m_{top}>91 GeV
- 1994: DØ m_{top}>128 GeV
- 1994: evidence of top quark from CDF



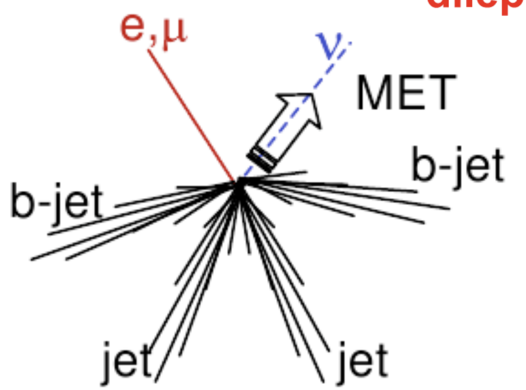
… and Decay

- **In the SM:**
  - $|V_{tb}|$ = 0.9990-0.9992 @ 95% C.L. assuming 3 CKM generations
- **Characterise tt final states by top decays!**

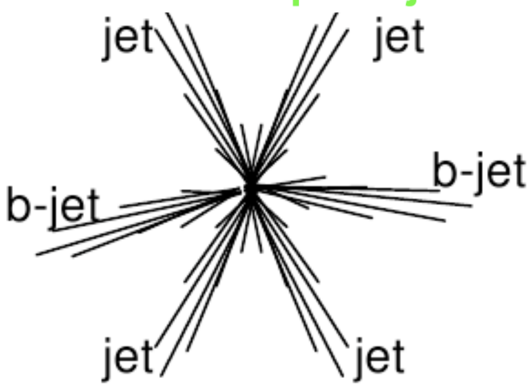




Dilepton
(BR~5%, low bckg)



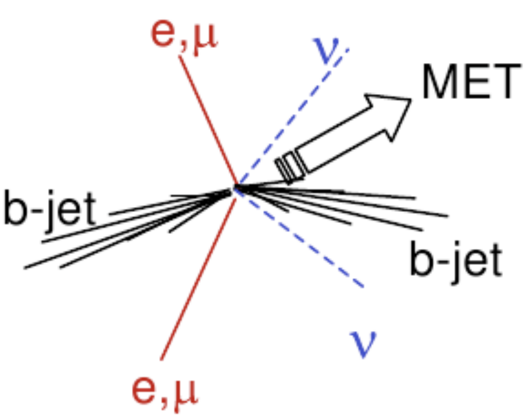
Lepton+jets
(BR~30%, moderate bckg)



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

Typical ttbar preselection

Dilepton	Lepton+jets	All-hadronic
2 high-p_T leptons	1 high-p_T lepton (>20 GeV)	No leptons
Missing E_T	Missing E_T (>40 GeV)	No missing E_T
2 jets	4 jets (> 20GeV)	6 jets
≥ 0 b-tags	≥ 1 b-tag	≥ 1 b-tag
S/B:		



Dilepton
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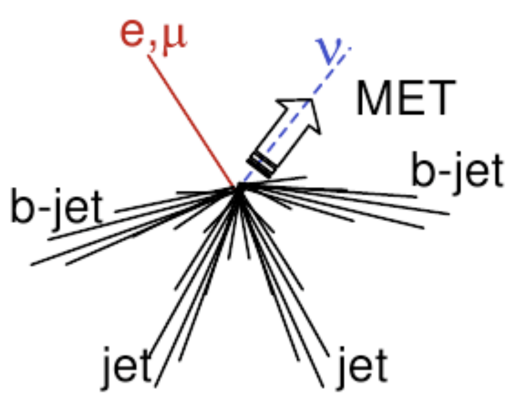

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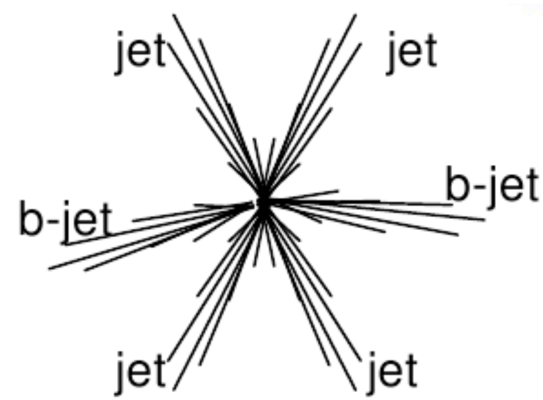

All-hadronic
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