ATLAS EXPERIMENT

IMPRS/GK YSW at Ringberg Castle
July 23rd 2012

The Top Quark Mass in the Dilepton Channel

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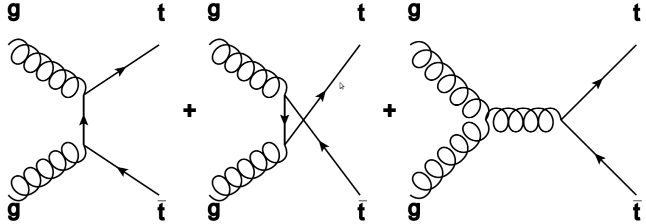
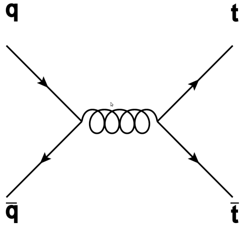
Top Quarks Pairs at LHC

- The LHC serves as a top quark factory
  - $\sigma_{t\bar{t}}(7TeV) = 164.6\ ^{+11.4}_{-15.7}\ pb$
  - 2011 dataset: ~800 000 top pair events (4.7 fb^{-1})
  - Production mechanism





- Decay channels for $t\bar{t} \rightarrow W^+ b W^- \bar{b}$:
  - "all jets" $WW \rightarrow qqqq$ 46 %
  - "lepton + jets" $WW \rightarrow l\nu qq$ 45 %
  - "dilepton" $WW \rightarrow l\nu l\nu$ 9 %

Top Quarks Pairs at LHC

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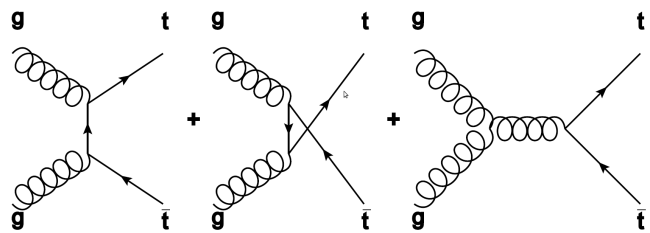
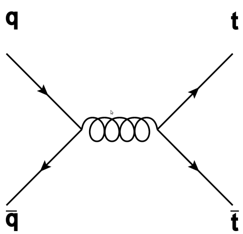


85%



15%

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  - "all jets" $WW \rightarrow qqqq$ 46 %
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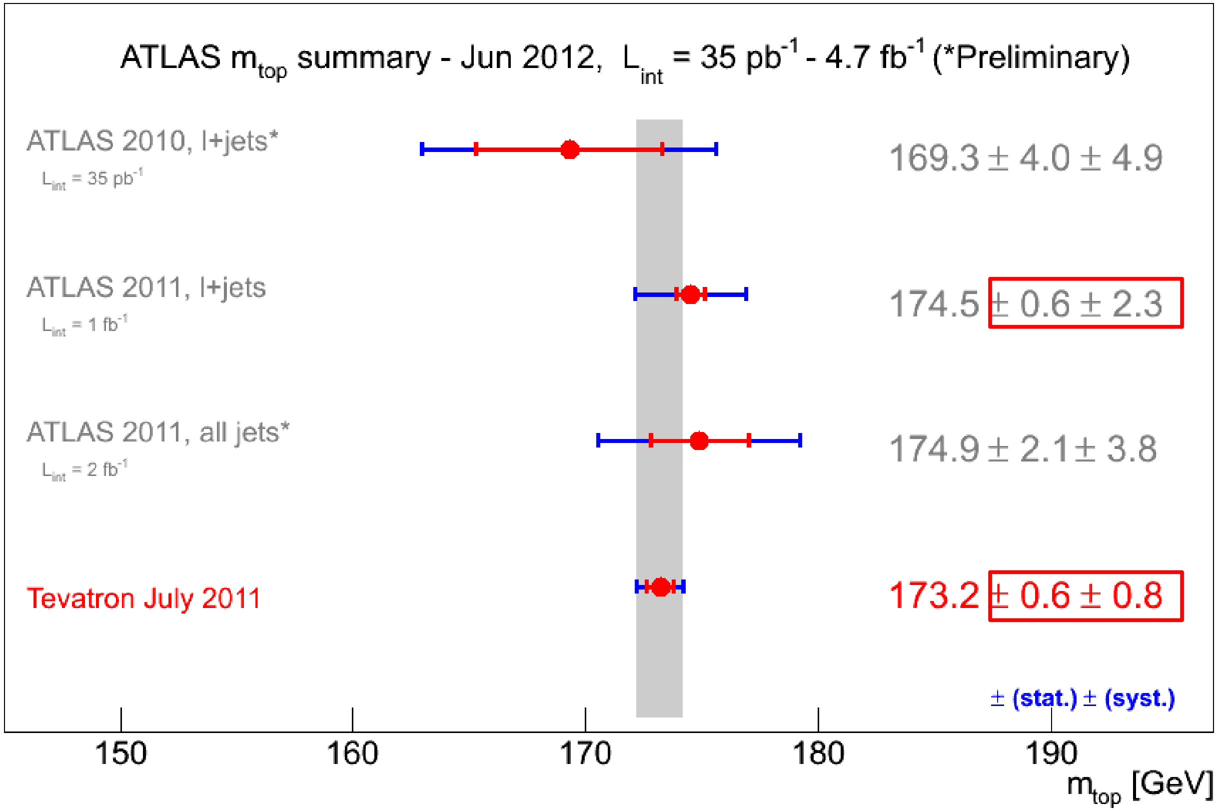
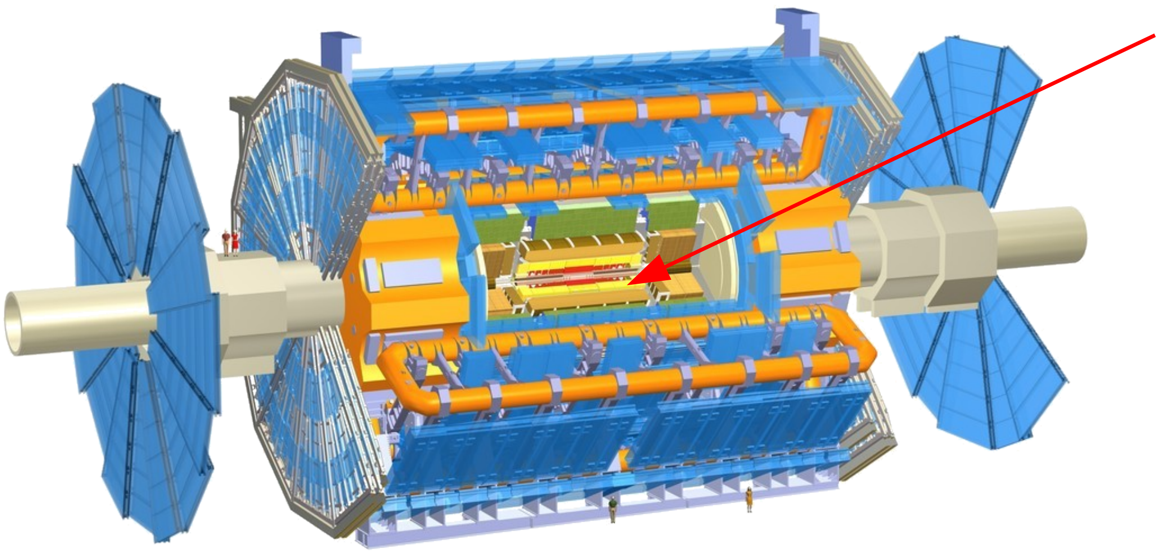
ATLAS Measurements

- ATLAS publications: up to now just lepton + jets, all jets
- Growing interest in the dilepton channel



The ATLAS Detector

- Multipurpose detector covering almost the full solid angle
- Analyzing pp collisions at LHC: 4.7 fb^{-1} in 2011



Inner detector

- b-quark identification
- Momenta of electrons and quarks

The ATLAS Detector

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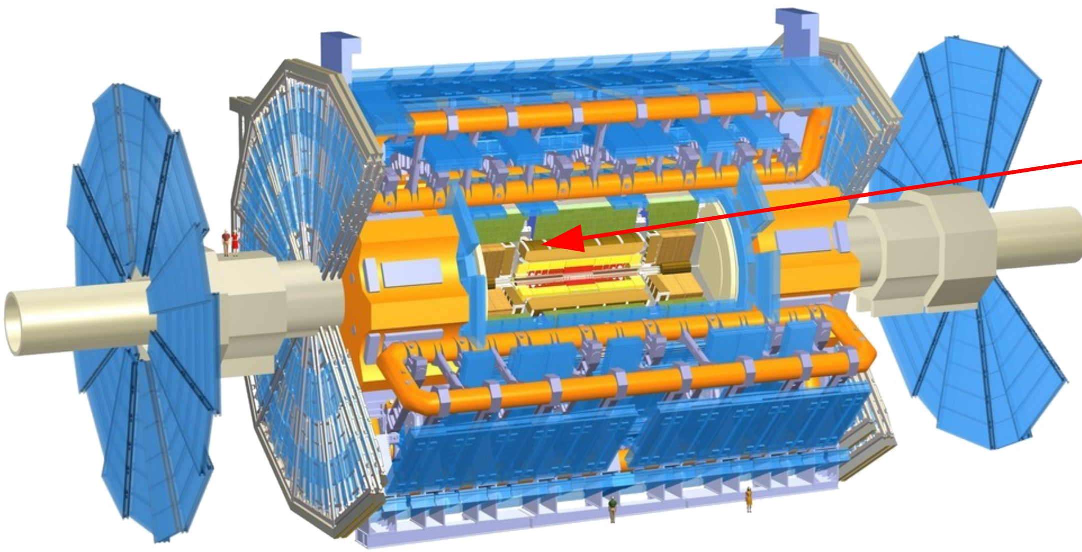

Inner detector

Calorimeters

- Electron energy
- Jet energy

The ATLAS Detector

- Multipurpose detector covering almost the full solid angle
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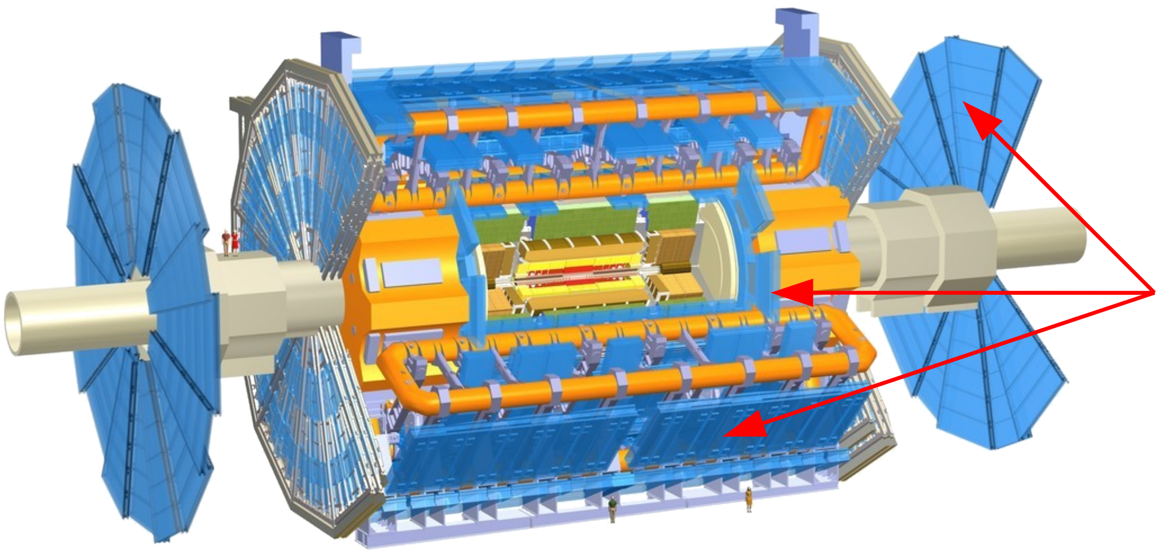


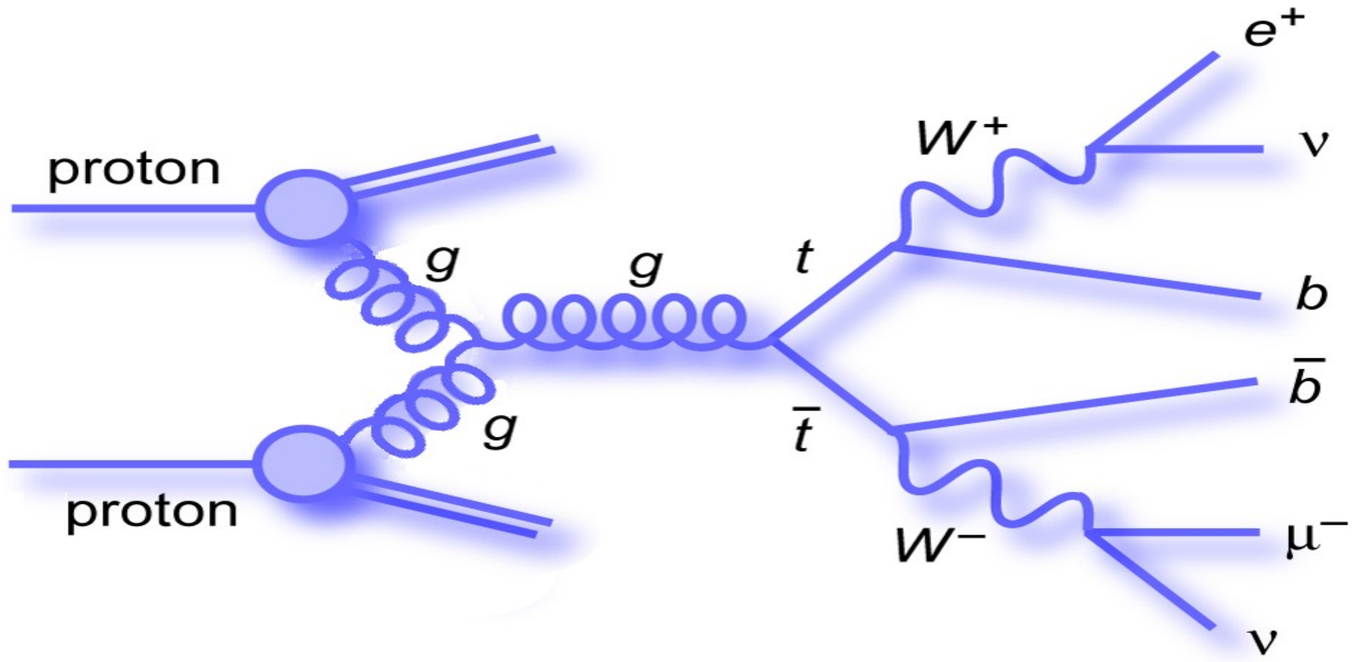
Inner detector

Calorimeters

Muon spectrometer

- Muon momenta
- Muon energy

Selection Cuts



- 2 oppositely charged isolated leptons with high p_T (no τ)
- High missing transverse energy E_T^{miss} caused by two neutrinos
- 2 jets identified as originating from a b quark
- Additional cuts to reduce background

→ Expected background O(5 %)[1] → up to now: signal only analysis

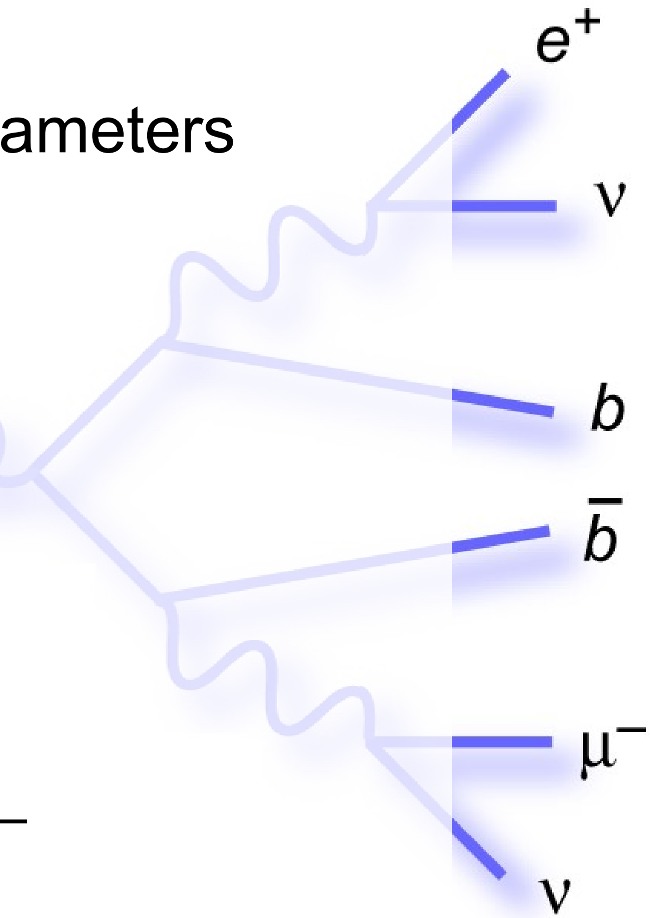
[1] ATLAS-CONF-2011-108

Event Reconstruction

- 6 final four-vectors $(E, \vec{p}) \rightarrow$ 24 parameters
- Available information:

	2 x 4	(charged leptons)
	2 x 4	(b-quarks from b-jets)
	2	(E_T^{miss})
+	2	(neutrino masses)
+	2	(W masses)
+	1	(equality of t-quark masses)
=	23	

- Problem: Underconstrained kinematics!



I Investigated the Following Solutions

- Scan all possible values for unknown variables:

Neutrino Weighting Method: event weight as estimator

- Scan over trial m_{top} and neutrino z-direction

- Do not fully reconstruct:

m_{lb} Method: invariant mass of lepton + b-jet system

- A new method: Use unfolded distributions (no detector effects)
- Compare with NLO calculations
- Cooperation with the Theory 2 group at MPP

m_{T2} Method: transverse mass of the t-quark

- Used for decays with 2 invisible products (e.g. SUSY searches[1])
- Scan transverse neutrino momenta $p_x^{\nu(1)}, p_y^{\nu(1)}$.
- This allows the calculation of m_{T2} observable for every assumption

[1] arXiv:1201.4659v1 [hep-ex] 23 Jan 2012

The m_{T2} Method

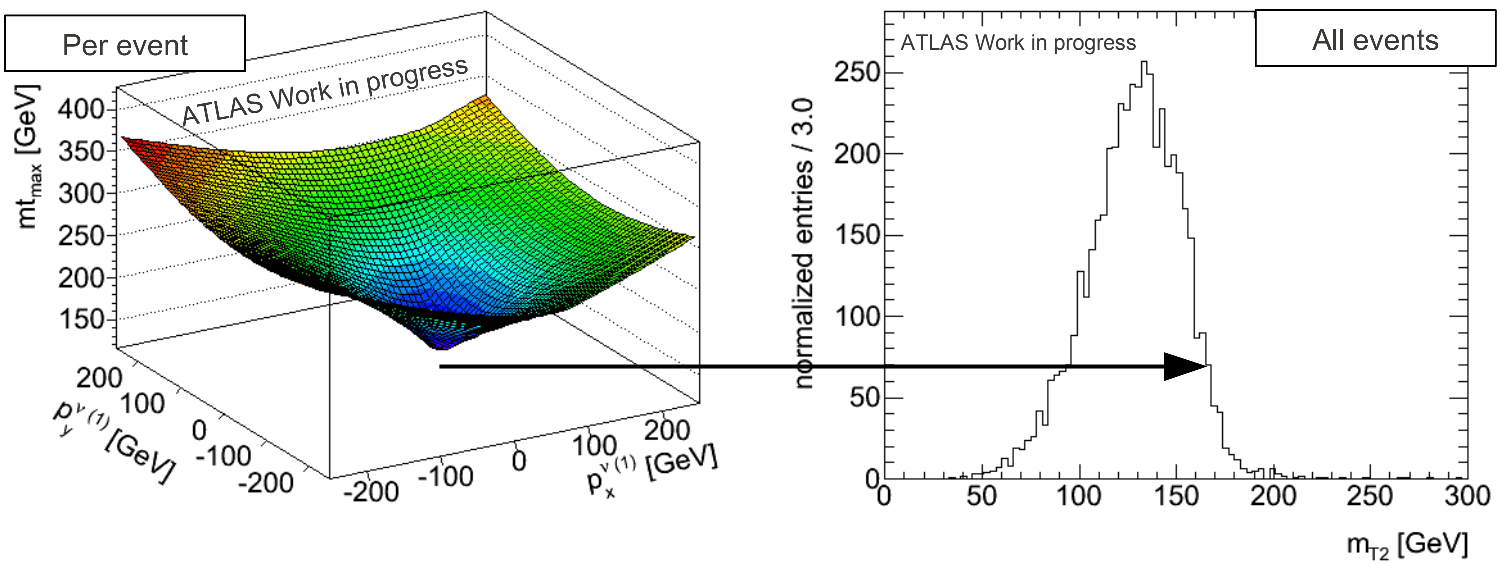
- Scan $p_x^{\nu(1)}, p_y^{\nu(1)}$. $\vec{p}_T^{\,\nu(2)}$ is then constrained by $\vec{p}_T^{\,\nu(1)} + \vec{p}_T^{\,\nu(2)} = E_T^{miss}$
- Definition[1]:

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

with:

$$m_T(m_\nu, \vec{p}_T^{\,\nu(i)}) = \sqrt{m_{lb}^2 + m_\nu^2 + 2(E_T^{lb} E_T^{\nu(i)} - \vec{p}_T^{\,lb} \cdot \vec{p}_T^{\,\nu(i)})}$$

- m_{T2} distribution has a cutoff at m_{top} (transverse mass)

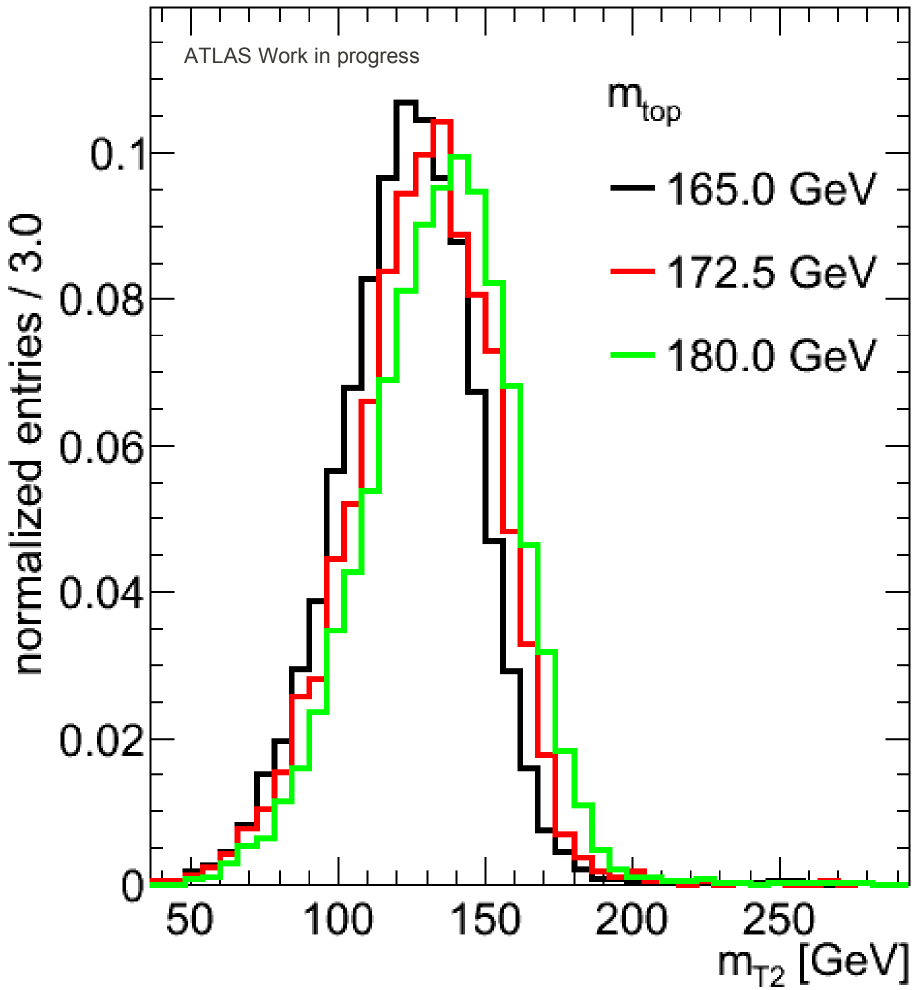


[1]Phys.Lett.B463:99-103,1999

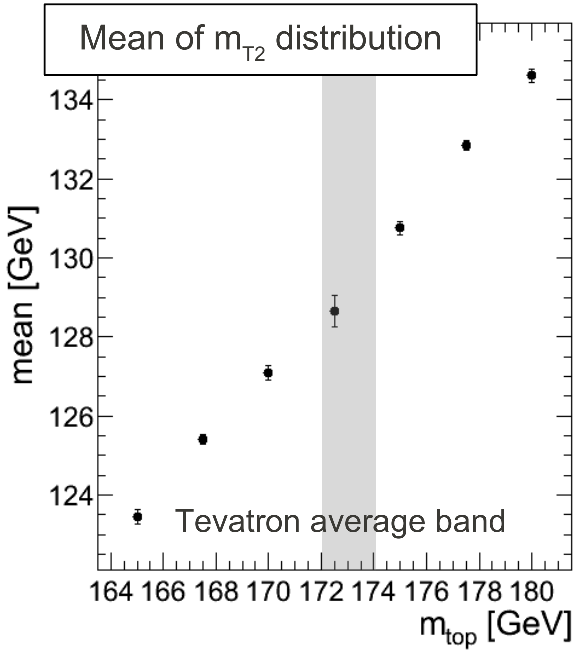
Change of Distributions with m_{top}

Using MC samples with different m_{top} as input

m_{T2} Method

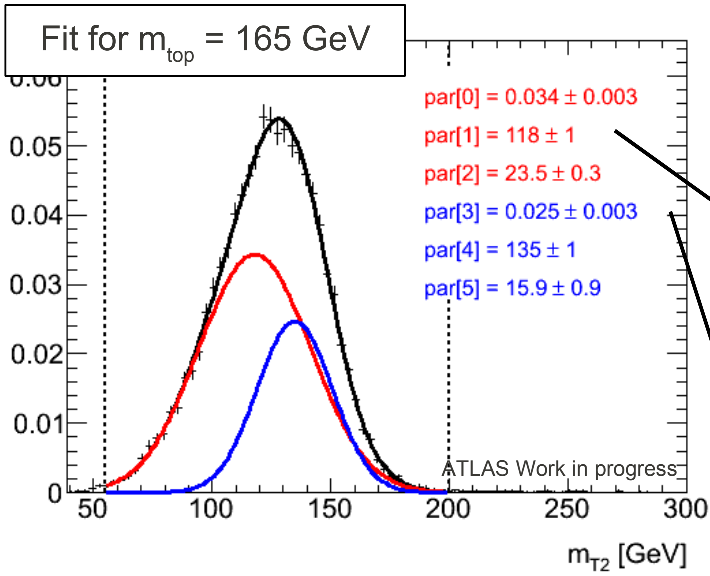


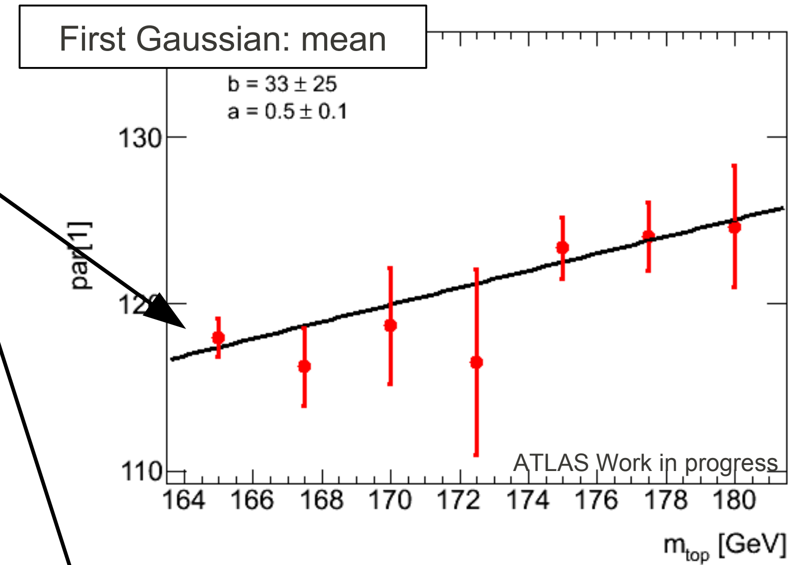
- Distributions change with m_{top}
- High sensitivity is illustrated by a simple estimator: the mean

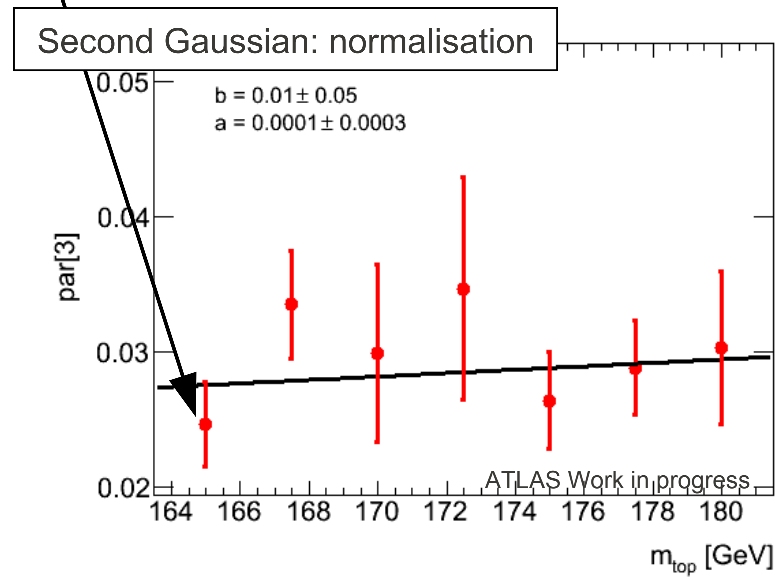


But we can do more ...

The Separate Fit



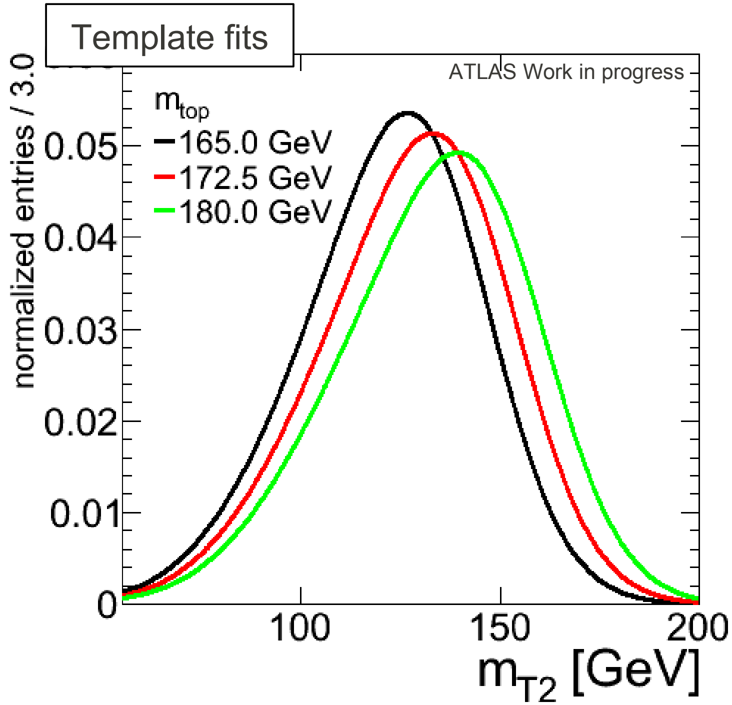




- Fit with sum of two Gaussian functions
- Shown here: 2 out of 6 parameters
- Linear dependence on m_{top}

$$p_i = a_i \cdot m_{top} + b_i \qquad i \in \{0, ..., 5\}$$

The Template Method



- Construct the template fit functions
  - Fit distributions separately for each m_{top}
  - Parameters approximately linear in m_{top}:

$$p_i(m_{top}) = a_i \cdot m_{top} + b_i \qquad i \in \{0, ..., 5\}$$

  - Get a_i and b_i from combined fit
  - Fit functions ready for use:

$$\boxed{f(p_i(m_{top}); m_{T2}) = f(m_{top}; m_{T2})}$$

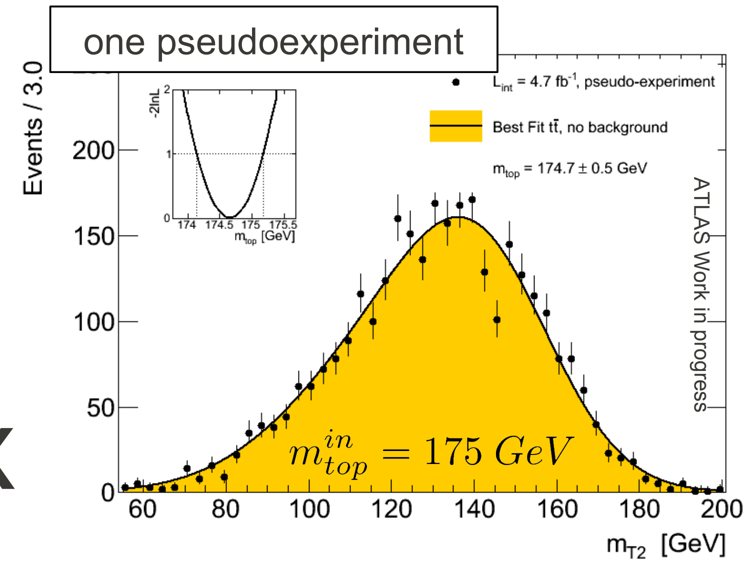
- Now we have a function with
  - m_{top} as the **only free** parameter
  - Strong **dependence** on m_{top} (position and shape)
- Fit to a distribution yields most probable value for m_{top}

Method Validation

- Perform pseudoexperiments: Analyze many times samples with known m_{top}^{in}
  - Draw random histograms from the same histograms used to create the template fit functions (pseudodata)
  - Determine m_{top}^{out} by applying the template method for each histogram
- Validate the method
  - Check agreement of m_{top}^{in} and m_{top}^{out}
  - Get statistical fluctuation from m_{top}^{out}
  - Check the pull distributions:

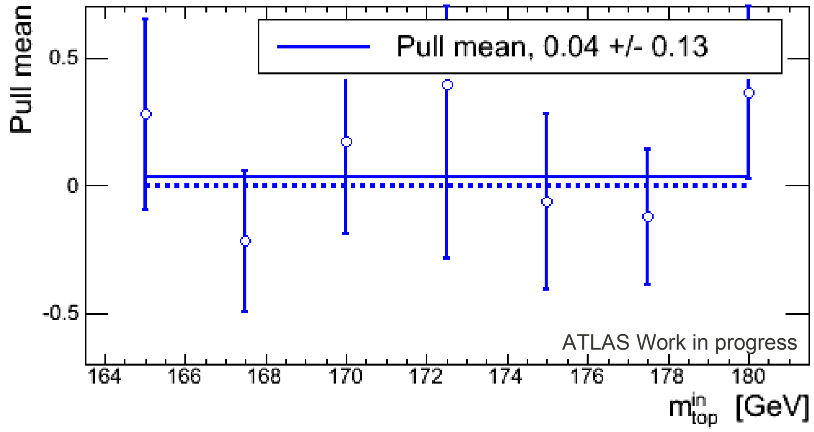
$$pull = \frac{m_{top}^{in} - m_{top}^{out}}{\sigma_{stat}}$$

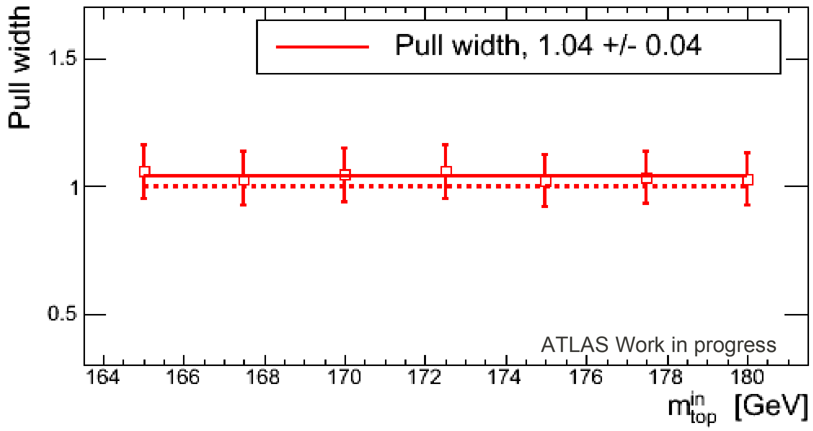
e.g. 50 x

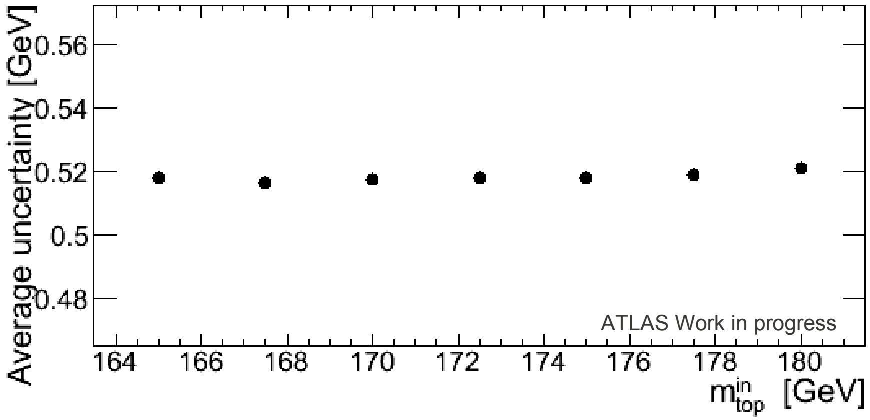


Pseudoexperiments for 4.7 fb^{-1}

Per definitionem: $$pull = \frac{m_{top}^{in} - m_{top}^{out}}{\sigma_{stat}}$$ ideally → $$mean = 0$$ $$width = 1$$



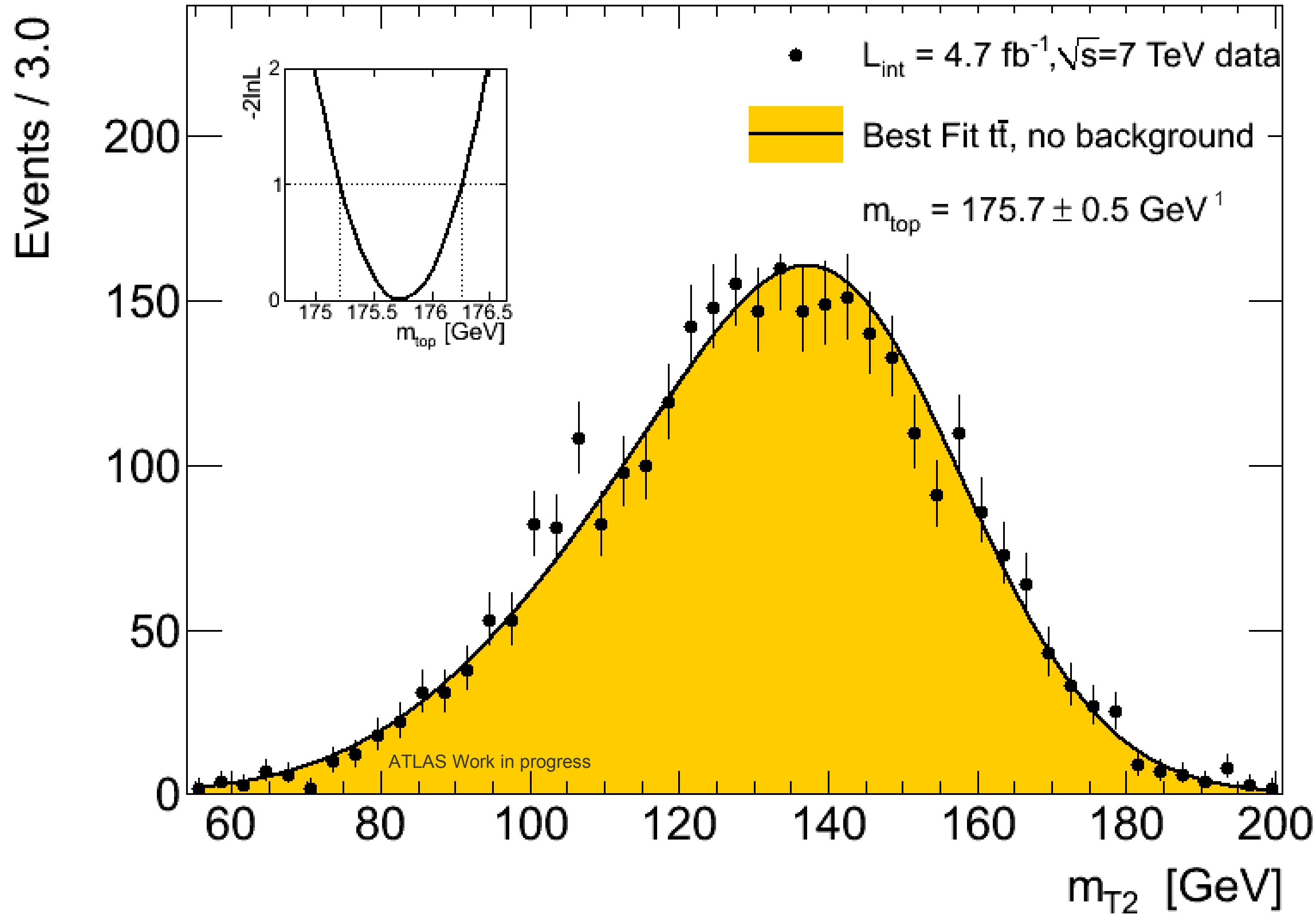




Expected statistical uncertainty:

- σ (172.5 GeV) = 0.52 GeV

Central value of m_{top} (2011 ATLAS data)



[1]no background

Systematic Uncertainties

Evaluate systematic uncertainties

- Analyse distributions varied by systematic effect
- Difference in m_{top}^{out} as estimate of the systematic effect

Systematic uncertainty[1] [GeV]	m_{T2}
Data Statistics	0.5
Signal MC generator	0.2
Hadronisation	0.9
ISR and FSR	0.8
Jet Energy Scale	1.8
b-Jet Energy Scale	1.8
Total Systematic Uncertainty	2.8
Total Uncertainty	2.8

[1]no background, just systematic effects shown here, ATLAS work in progress

Systematic Uncertainties

Difference in m_{top}^{out} using two different MC generators

- MC@NLO vs. POWHEG both using HERWIG

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Systematic Uncertainties

Difference in m_{top}^{out} using two different hadronisation programs

- Pythia vs. HERWIG both using POWHEG

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Systematic Uncertainties

Difference in m_{top}^{out} using different amount of QCD initial and final state radiation

- AcerMC using HERWIG

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Hadronisation	0.9
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Systematic Uncertainties

Difference in m_{top}^{out} using different jet energy scales

- Variation of the JES up and down by 1 σ

Systematic uncertainty[1] [GeV]	m_{T2}
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Hadronisation	0.9
ISR and FSR	0.8
Jet Energy Scale	1.8
b-Jet Energy Scale	1.8
Total Systematic Uncertainty	2.8
Total Uncertainty	2.8

[1]no background, just systematic effects shown here, ATLAS work in progress

Systematic Uncertainties

Difference in m_{top}^{out} using different b-jet energy scales

- Variation of the bJES up and down by 1 σ

Systematic uncertainty[1] [GeV]	m_{T2}
Data Statistics	0.5
Signal MC generator	0.2
Hadronisation	0.9
ISR and FSR	0.8
Jet Energy Scale	1.8
b-Jet Energy Scale	1.8
Total Systematic Uncertainty	2.8
Total Uncertainty	2.8

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Evaluate systematic uncertainties

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Preliminary result: $m_{top} = 175.7 \pm 0.5 \pm 2.8\ GeV^{1}$

[1]no background, just systematic effects shown here, ATLAS work in progress

Summary

- The Template Method for the m_{T2} Method was presented
  - Calculation of the observable
  - Construction of the templates
  - Method validation
  - Application on data
  - Evaluation of the most important systematics

Thank you for your attention!

Backup

Andreas Alexander Maier

Data and MC Samples

- Data sample
  - Corresponding to 4.7 fb^{-1}
  - Recorded by ATLAS in 2011
- MC samples for templates
  - Event generator: MC@NLO + HERWIG/Jimmy
  - Detector simulation: GEANT4
  - Jet reconstruction algorithm: AntiKt 0.4 TopoCluster jets
  - B-Jet identification:
    MV1 b-tag algorithm with 70 % efficiency, 1/134 mistag rate
  - Different m_{top} (160 GeV – 190 GeV)
  - Up to 20 times data statistics

Expected Background

Main background sources:

- Single top production
- Drell-Yan process
- Diboson production
- Fake leptons

Analysis taking the mean as estimator[1]

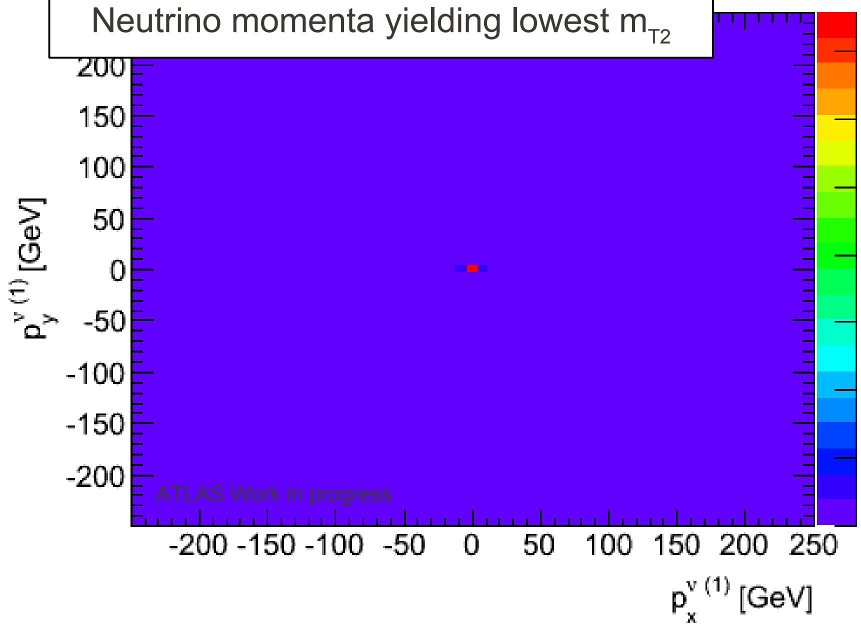
Total Signal	719
Total Background	38
Total Events	757
Background Fraction	5%

Expected background fraction: Same order of magnitude O(5%)

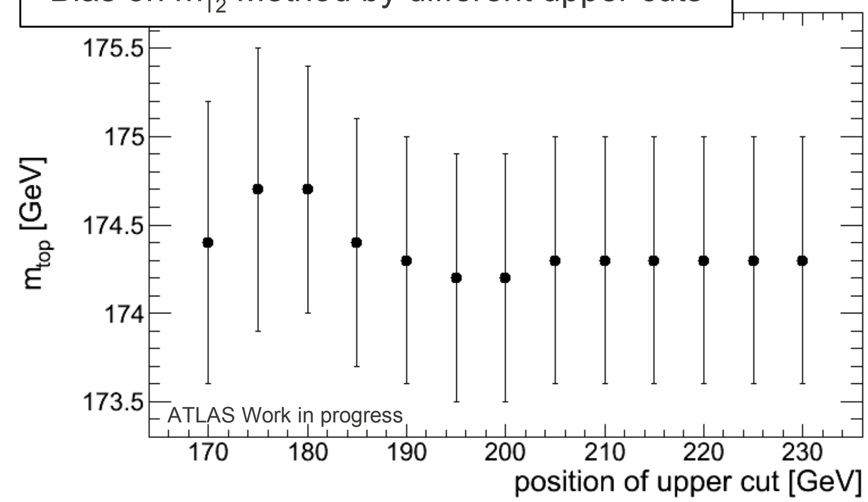
[1]ATLAS-COM-CONF-2012-096

Some Control Plots

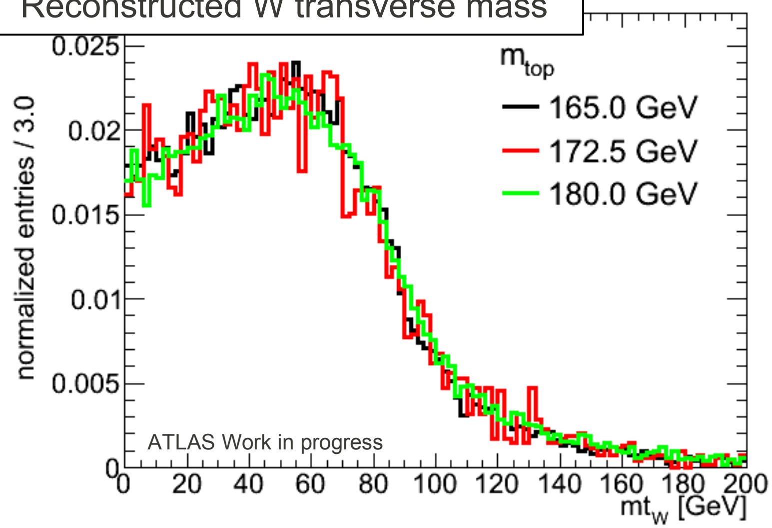
Neutrino momenta yielding lowest m_{T2}



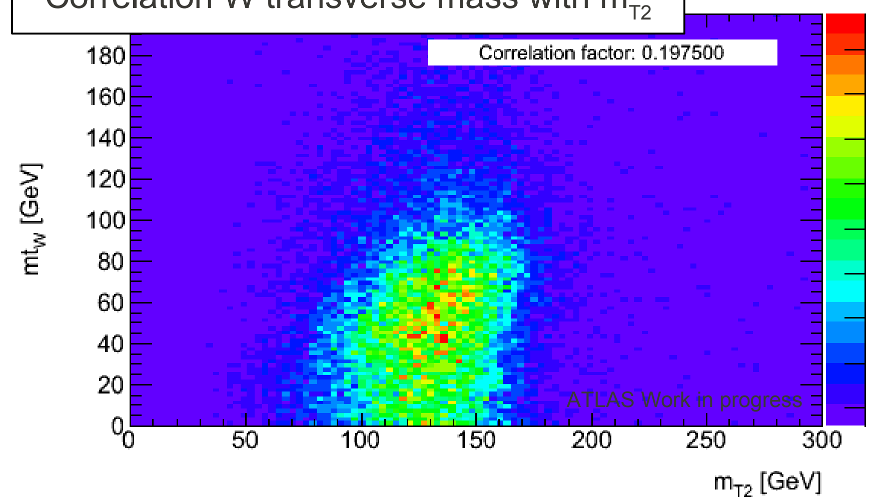
Bias on m_{T2} Method by different upper cuts



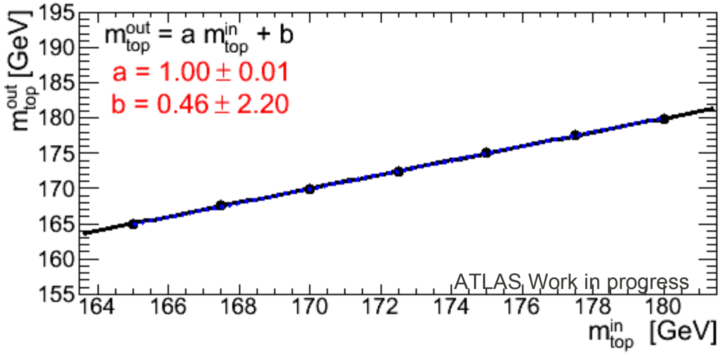
Reconstructed W transverse mass

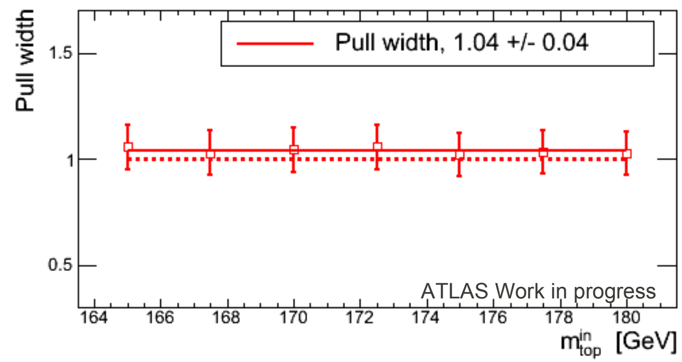


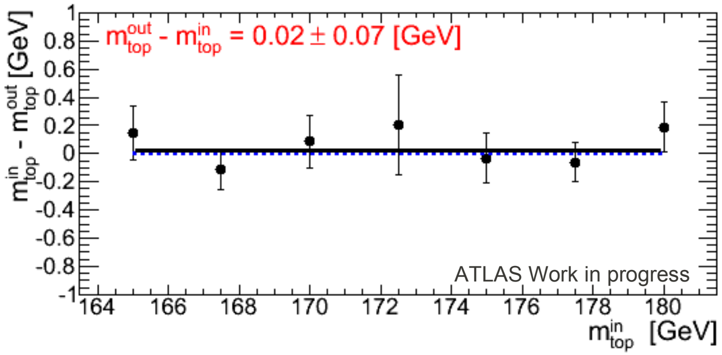
Correlation W transverse mass with m_{T2}

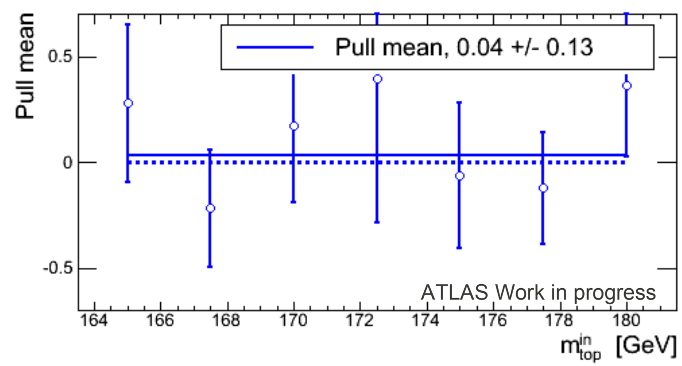


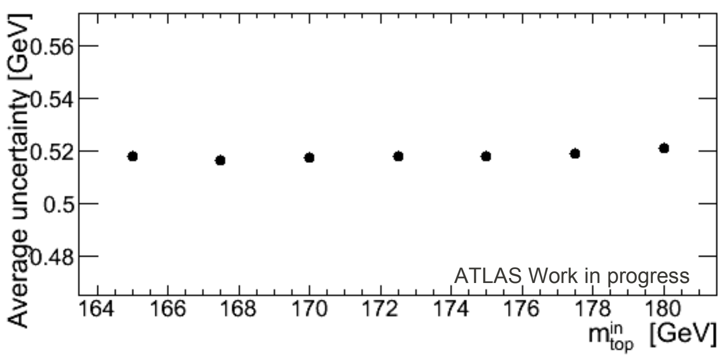
Pseudoexperiments for 4.7 fb^{-1}











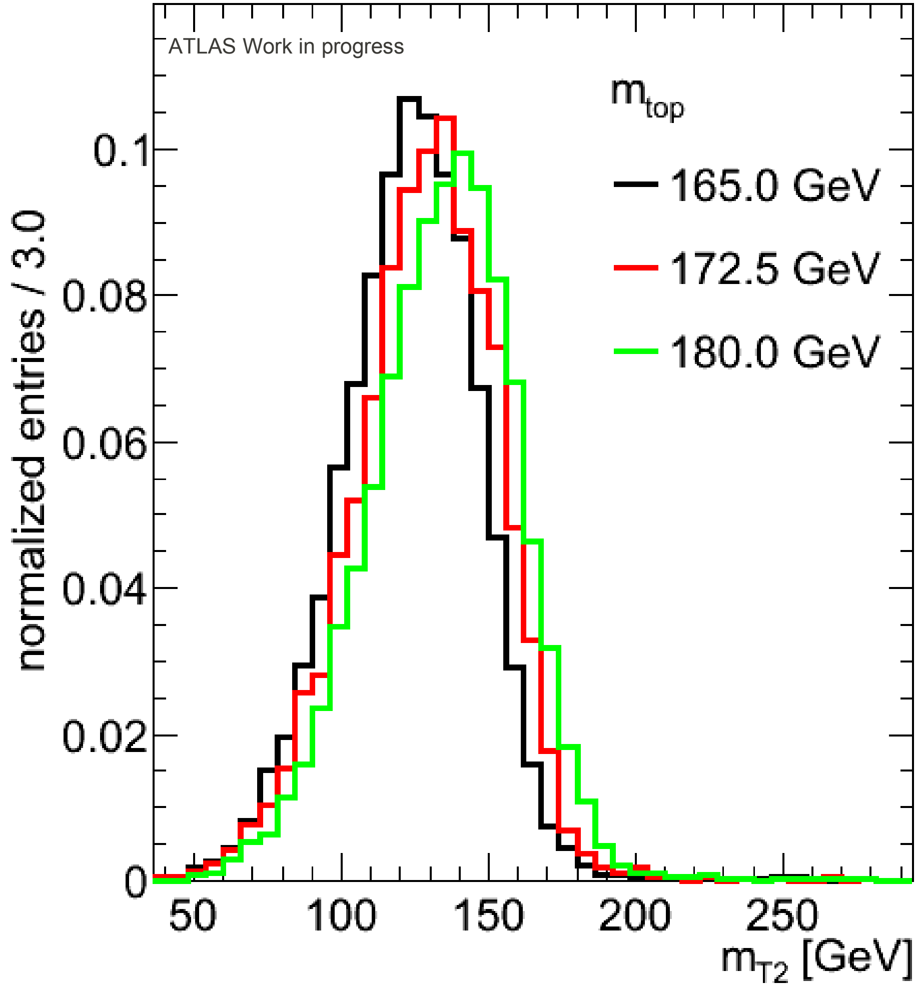
Expected statistical uncertainty:

- σ (172.5 GeV) = 0.52 GeV

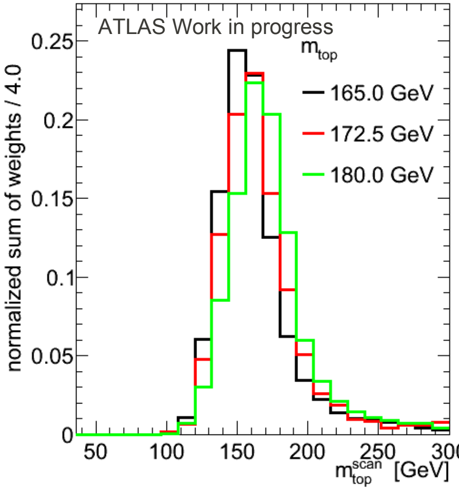
Change of Distributions with m_{top}

Using MC samples with different m_{top} as input

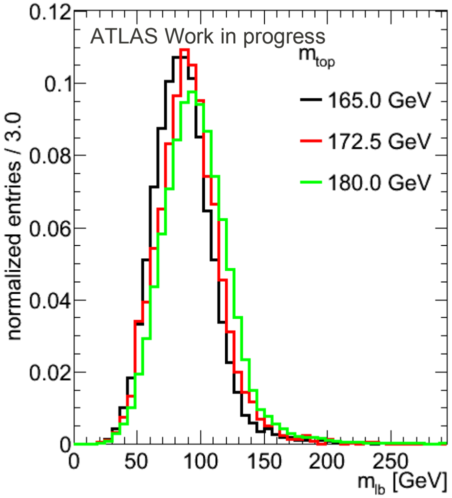
m_{T2} Method



Neutrino Weighting Method



m_{lb} Method:



Systematic Uncertainties

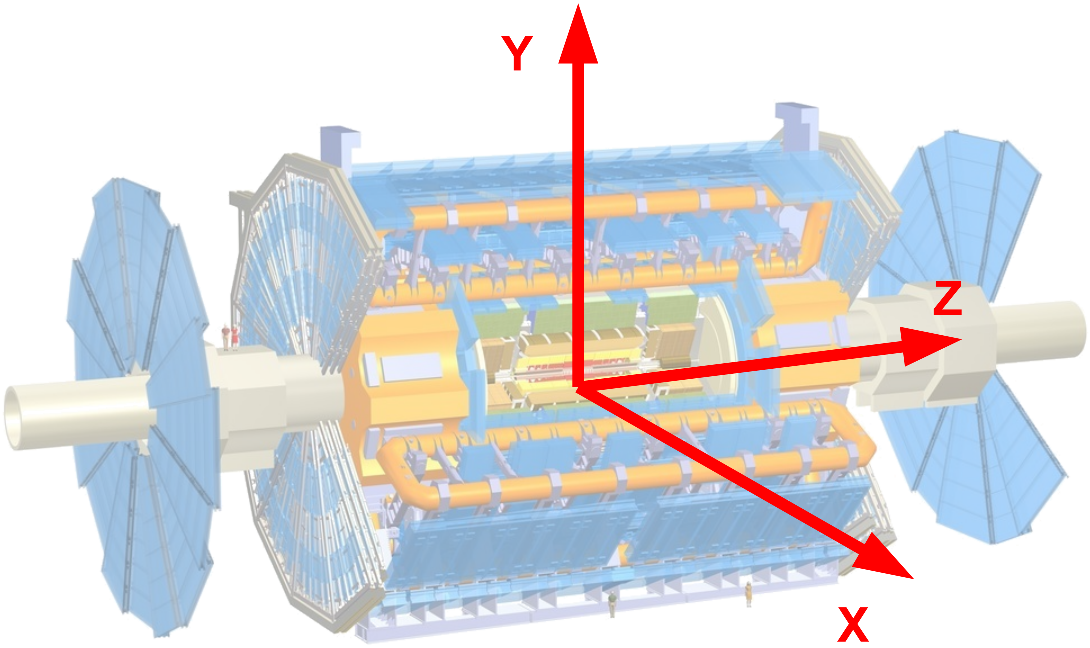
Systematic uncertainty	m_{T2}	Neutrino Weighting
Data Statistics	0.5	0.6
Signal MC generator	0.2	0.4
Hadronisation	0.9	0.6
ISR and FSR	0.8	1.0
Jet Energy Scale	1.8	1.5
b-Jet Energy Scale	1.8	1.6
Total Systematic Uncertainty	2.8	2.5
Total Uncertainty	2.8	2.6

Comparison m_{T2} and Neutrino Weighting Method

- Difference in uncertainty is not significant
- At the moment none of both is the better method

The ATLAS Detector

- Multipurpose detector covering almost the full solid angle
- Analyzing pp collisions at LHC: 4.7 fb^{-1} in 2011



Inner detector

Calorimeters

Muon spectrometer

Magnet system

Measure for forward direction: pseudorapidity $\eta = -\log \tan \Theta/2$

Neutrino Weighting Method[1]

- Scan neutrino etas $\eta_\nu, \eta_{\bar{\nu}}$ and m_{top}^{scan}
- Combinatorics: up to 4 solutions of kinematics
- Weight of solution $i, i \in \{1,2,3,4\}$

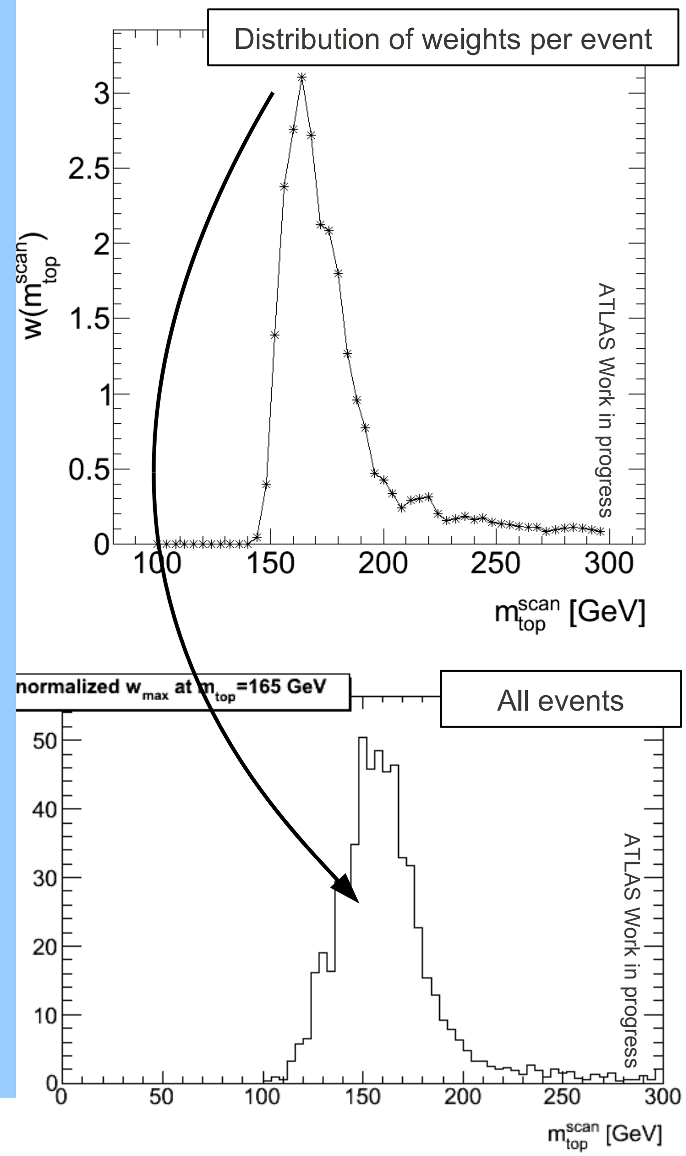
$$w_i = \exp\left(-\frac{(MET_x - p_{x,i}^{\nu} - p_{x,i}^{\bar{\nu}})^2}{2\sigma_x^2}\right) \cdot \exp\left(-\frac{(MET_y - p_{y,i}^{\nu} - p_{y,i}^{\bar{\nu}})^2}{2\sigma_y^2}\right)$$

- Sum it up for the event weight

$$w(m_{top}^{scan}, \eta_\nu, \eta_{\bar{\nu}}, b\,Paar) = \sum_{i=1}^{4} w_i$$

$$w(m_{top}^{scan}) = \sum_{bPaare} \int \mathrm{d}\eta_\nu \mathrm{d}\eta_{\bar{\nu}} P(\eta_\nu, \eta_{\bar{\nu}}) w(m_{top}^{scan}, \eta_\nu, \eta_{\bar{\nu}}, b\,Paar)$$

- For every event take the maximum w_{max}



[1]Phys. Rev. Lett. 80, 2063 (1998)

Cut Flow on MC samples

True dilepton events/after GRL for data	4%
trigger	82%
good vertex	100%
cosmic rejection	100%
>= 2 leptons	30%
one of the leptons matches the trigger	100%
remove events tagged as e-mu overlap	100%
Jet Cleaning	99%
MET & HT (MET(ee,mumu)>60 GeV, HT (emu)>130 GeV)	74%
At least 2 jets with pt > 25 GeV, |eta| < 2.5	80%
exactly 2 leptons	100%
Opposite-sign leptons	100%
M(ee, mumu)> 15 GeV	100%
|M(ee, mumu) - 91 GeV|> 10 GeV	94%
Both leptons match to truth leptons	100%
>=1 tagged jet with MV1 w> 0.601713	87%
>=2 tagged jet with MV1 w> 0.601713	51%