Top Mass Measurement in the Fully Hadronic $t\bar{t}$ Channel With The ATLAS Detector

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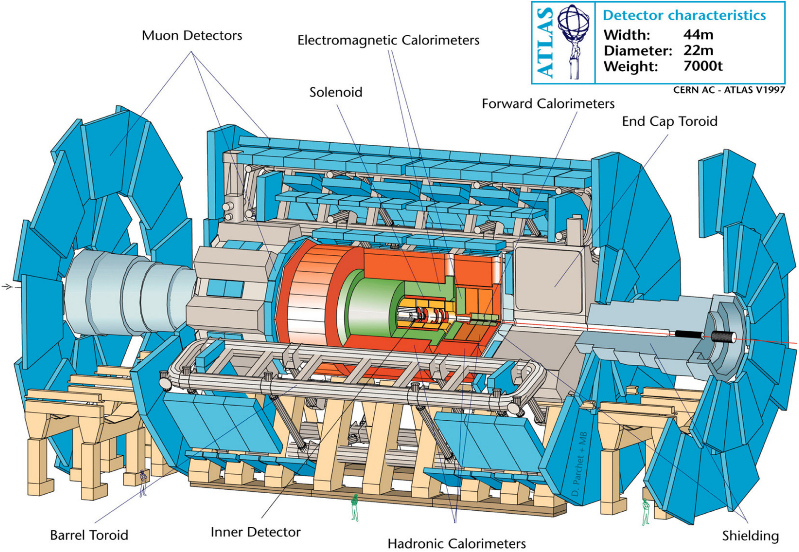
LMU Munich

Young Scientists Workshop
Ringberg Castle, July 2012

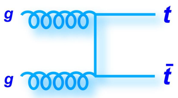
The ATLAS Detector

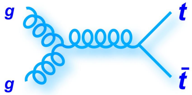


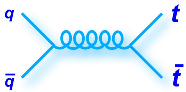
Introduction: The Fully Hadronic $t\bar{t}$ Decay Channel

Top Quark Production At The LHC

top anti-top production:

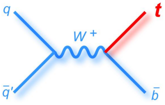


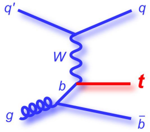


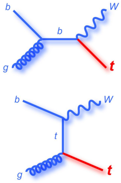


- $\sigma_{t\bar{t}} \approx$164 pb (@ 7TeV) $\Rightarrow$ good statistics
- gluon-gluon fusion dominant production process

single top production:



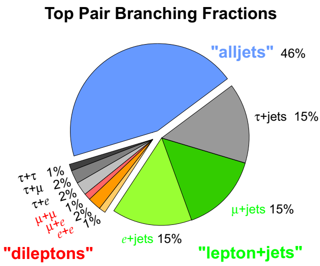


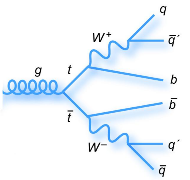


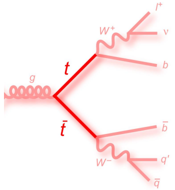
Top Anti-Top Decay Channels

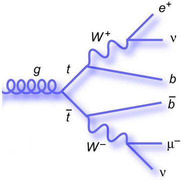
- short lifetime → no hadronization
- SM prediction: top exclusively decays into b-quark and W boson
- consecutive W-decay: leptonically (lepton + corresponding neutrino) or hadronically (quark anti-quark pair)

⇒ 3 decay channels: allssshadronic, single-lepton, dilepton



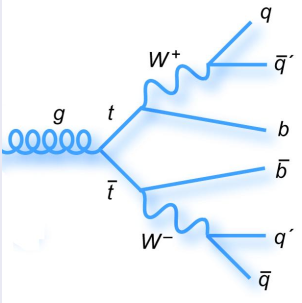




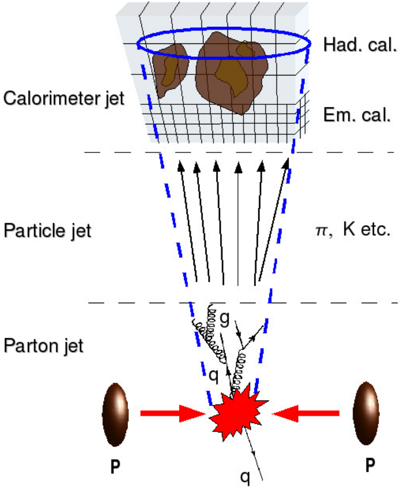


The Fully Hadronic $t\bar{t}$ Decay Channel

- 6 quarks from decaying $t\bar{t}$ pair
- ISR/FSR: additional partons



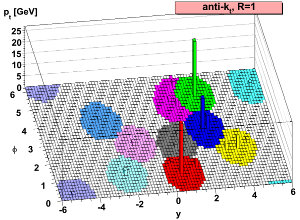
signature: $\geq$ 6 Jets



Jet Reconstruction

jets are reconstructed using the anti-k_t clustering algorithm:

- based on min(p_i^{-2},p_j^{-2}) scaled distance measurement $\Delta_{ij}^2 = (y_i - y_j)^2 + (\phi_i - \phi_j)^2$
- combine hardest objects first until all objects are separated by $\Delta R_{ij} > R$ (ATLAS standard: R=0.4/0.6)



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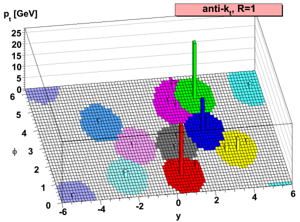

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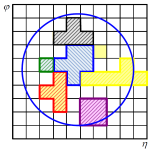
CALORIMETER JETS

starting from topological clusters:

- group of calorimeter cells with a signal-to-noise ratio above a certain threshold
- contain a variable number of cells, no fixed shape



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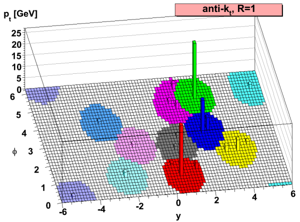

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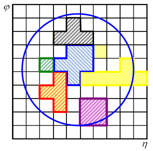

PARTICLE JETS

starting from stable particles

- particles with lifetime above 10 ps - excluding muons and neutrinos
- in Monte-Carlo samples

JES Calibration And JES Uncertainty

JES CALIBRATION:
correct kinematics of calorimeter jets to the values of the corresponding truth jet to compensate for

- non-compensating calorimeters
- inactive material
- out-of-cone effects

$\Rightarrow$ calibration constants (evaluated based on MC studies) to restore the JES

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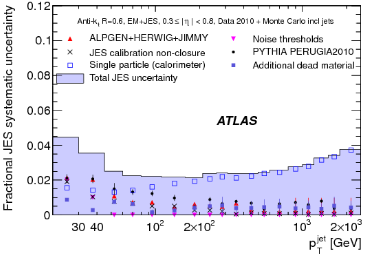
JES UNCERTAINTY = uncertainty on calibration constants:

- 2010 uncertainty: MC based studies (uncertainties on detector simulation, event modelling in Monte Carlo generators,...)
  <2.5% for central jets (pT =100 GeV),
  <9 (14)% in endcap (forward) region
- 2011 uncertainty: reduced uncertainty thanks to in-situ measurements



Measurement Of The Top Quark Mass In The Allhadronic $t\bar{t}$ Decay Channel

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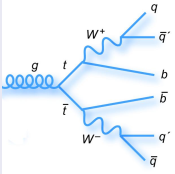

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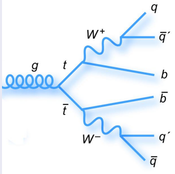

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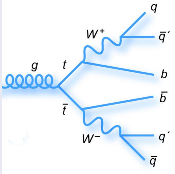

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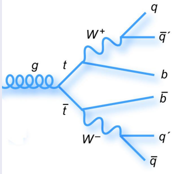

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1. large background due to QCD multijet production
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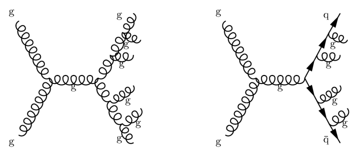
2. large combinatorial background: 6 jets result in 90 possible ways of assigning jets to partons
   $\rightarrow$ use kinematic likelihood fit to reconstruct allhadronic top quarks
3. sensitive to systematic uncertainties e.g. jet energy scale
   $\rightarrow$ evaluate the top quark mass via 2D template method

1. QCD Multijet Background

QCD-Multijet Background: Modelling

QCD Multijet Production:

- parton pair (except $t\bar{t}$) from hard scatter
- additional partons from gluon radiation, gluon splitting



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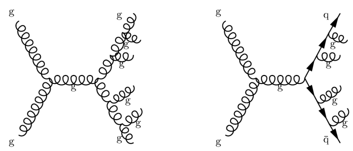

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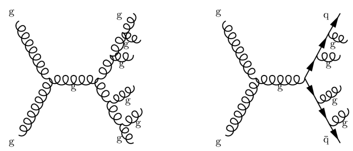

☹Monte-Carlo based modelling of QCD multijet production:
final states with seven or more partons cannot be simulated accurately (production matrix elements not available)

☺however, we have lots of data and the mulijet production cross section is rather large...
→ model background based on a selected data sample dominated by QCD multijet production

Data Driven QCD-Multijet Background Modelling...

...an example: EVENT MIXING

Donour Events
select events with n $\geq$ 6 jets and 0 leptons ($\rightarrow$ expect $t\bar{t}$ contamination)

select 5th-nth jet with lowest transverse momentum

$\Downarrow$

Acceptor events
events with n = 4 jets and 0 leptons
$\rightarrow$ no significant $t\bar{t}$ contribution

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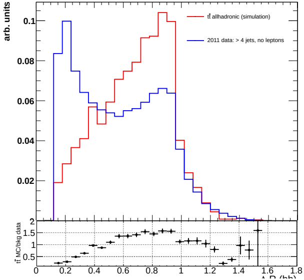
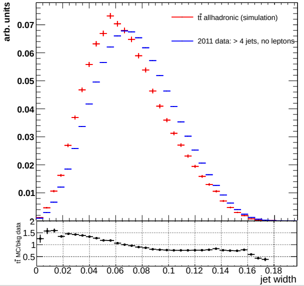
$\Rightarrow$ multijet events with n $\geq$ 6 jets ☺

Separating $t\bar{t}$ From QCD Multijet Events

- b-jet identification algorithms (see next slide): require exactly 2 b-tagged jets
- different b-production in signal and background: large fraction of b-jets in multijet events due to gluon splitting $\rightarrow$ collinear emission
- W-mass window: check dijet invariant mass of light jets from W-decay
- larger fraction of gluon jets in multijet events: exploit the different properties of light quark and gluon initiated jets (jet width, number of jet constituents)
- ...



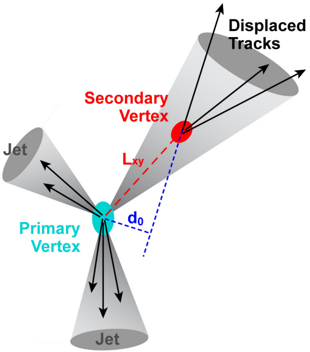


b-Jet Identification

long lifetime of b-flavoured hadrons

- significant flight path length L of b-hadrons
- measurable secondary vertex
- measurable impact parameters of tracks from b-hadron decay products

→ spatial taggers



semi-leptonic b-hadron decays

- tag soft leptons (from b-hadron decay) in the jets

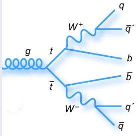
→ soft lepton taggers

2. Finding Jet Parton Pairs - Kinematic Likelihood Fit

Reconstructing The Allhadronic Event Topology: Kinematic Likelihood Fit

MODEL: allhadronic $t\bar{t}$ event topology

- 4 light quark jets from W-decay
- 2 b-jets from $t\bar{t}$ decay



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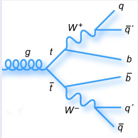

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ASSUMPTIONS:

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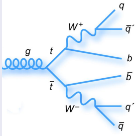

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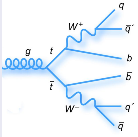

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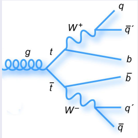

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$\Downarrow$ $\Downarrow$

$$L = BW\{m(q_1,q_2)|m_W,\Gamma_W\} \cdot BW\{m(q_4,q_5)|m_W,\Gamma_W\} \cdot$$
$$BW\{m(q_1,q_2,q_3)|m_{top},\Gamma_{top}\} \cdot BW\{m(q_4,q_5,q_6)|m_{top},\Gamma_{top}\} \cdot \prod_{i=1}^{6} W(\tilde{E}_i, E_i)$$

Reconstructing The Allhadronic Event Topology: Kinematic Likelihood Fit

⇒ include b-tagging information: veto permutations with b-jets on the position of light quarks from W decay

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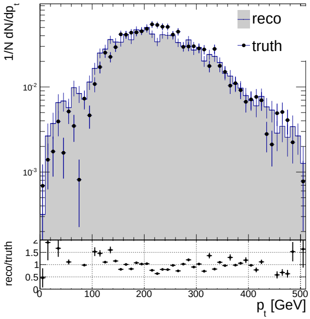
Monte-Carlo based performance studies:

- right jet to parton assignment in 80% of all events when including b-tagging veto
- good agreement between reconstructed and true kinematical variables of top quarks

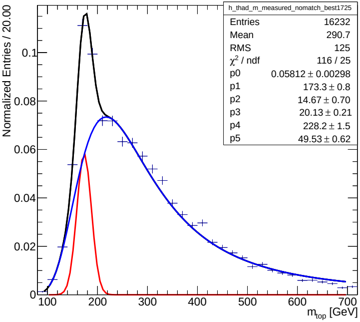


3. Measuring The Top Quark Mass - Building Templates




Measuring The Top Quark Mass: Building 1D Templates

⇒ parameterize m_{top}^{reco} as a function of m_{top}



Gaussian(p_0, p_1, p_2) +
Landau(p_3, p_4, p_5)

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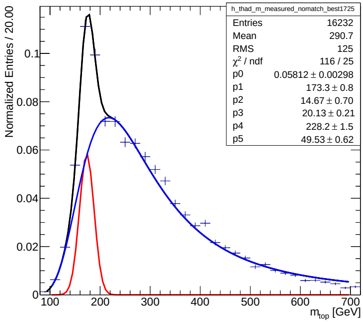
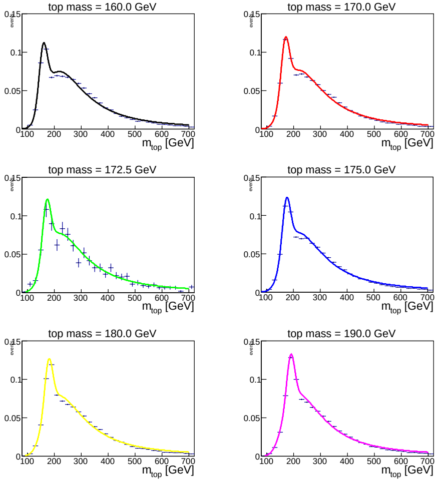


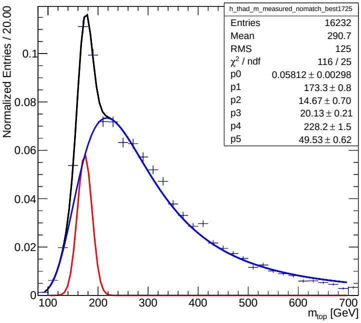


$\text{Gaussian}(p_0, p_1, p_2) +$
$\text{Landau}(p_3, p_4, p_5)$

$$p_i = p_i(m_{top})$$

Measuring The Top Quark Mass And The Jet Energy Scale: Building 2D Templates

⇒ parameterize m_{top}^{reco}
as a function of m_{top} and ΔJES

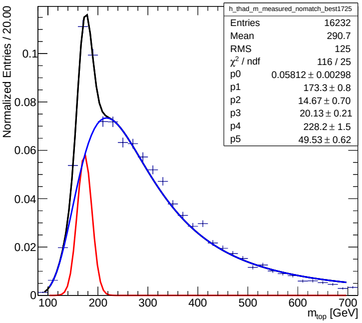


Gaussian(p_0, p_1, p_2) + Landau(p_3, p_4, p_5)

$$p_i = p_i(m_{top}, \Delta JES)$$

Measuring The Top Quark Mass And The Jet Energy Scale: Building 2D Templates

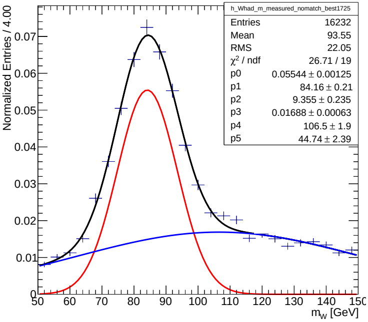
⇒ parameterize m_{top}^{reco} as a function of m_{top} and ΔJES



Gaussian(p_0, p_1, p_2) + Landau(p_3, p_4, p_5)

$$p_i = p_i(m_{top}, \Delta JES)$$

⇒ parameterize m_{W}^{reco} as a function of ΔJES

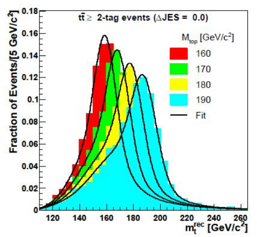


Gaussian(p_0, p_1, p_2) + Gaussian(p_3, p_4, p_5)

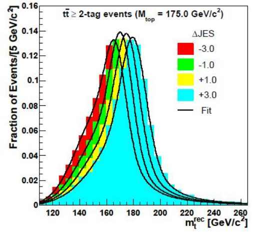
$$p_i = p_i(\Delta JES)$$

Building 2D Templates

Reconstructed Top Mass



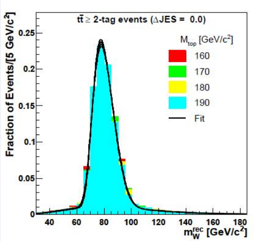
sensitive to top mass



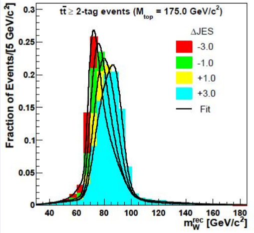
sensitive to JES

$\Rightarrow$ parameterize m_{top}^{reco} as a function of m_{top} and ΔJES

Reconstructed W Mass



insensitive to top mass



sensitive to JES

$\Rightarrow$ parameterize m_W^{reco} as a function of ΔJES

Measuring The Top Quark Mass Using Templates

- signal p.d.f.s: $P_s^{m_{top}^{reco}}(m_{top}^{reco}|m_{top}, \Delta JES)$, $P_s^{m_W^{reco}}(m_W^{reco}|\Delta JES)$ (previous slide)
- background p.d.f.s: $P_b^{m_{top}^{reco}}(m_{top}^{reco})$, $P_b^{m_W^{reco}}(m_W^{reco})$, independent of m_{top} and Δ JES (data driven estimate of QCD background)

$\Rightarrow$ find m_{top} and ΔJES which best reproduce the observed distribution of m_{top}^{reco} and m_W^{reco} in data

Measuring The Top Quark Mass Using Templates

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$\Rightarrow$ find m_{top} and ΔJES which best reproduce the observed distribution of m_{top}^{reco} and m_W^{reco} in data

recent results on the measurement of the top quark mass in the allhadronic channel:

- 2D: arXiv:1112.4891v2, submitted to Phys. Lett. B
  $\rightarrow m_{top} = 172.5 \pm 1.4$ (stat) $\pm$ 1.0(JES) $\pm$ 1.1(syst) GeV/c^2
- 1D: ATLAS-CONF-2012-030
  $\rightarrow m_{top} = 174.9 \pm 2.1$ (stat) $\pm$ 3.8 (syst) GeV/c^2

Summary

fully hadronic $t\bar{t}$ decay channel provides good statistics due to

1. relatively high $t\bar{t}$ production cross section
2. large allhadronic branching ratio

when measuring the allhadronic top mass one needs to get a handle on...

- the QCD background:
  $\rightarrow$ data driven modelling
  $\rightarrow$ finding efficient cuts in order to separate signal from background events
- the jet-to-parton assignment $\rightarrow$ kinematic likelihood fit
- the systematic uncertainties $\rightarrow$ in-situ measurement of light-JES via 2D template method