Top quark resonances in ATLAS simulation

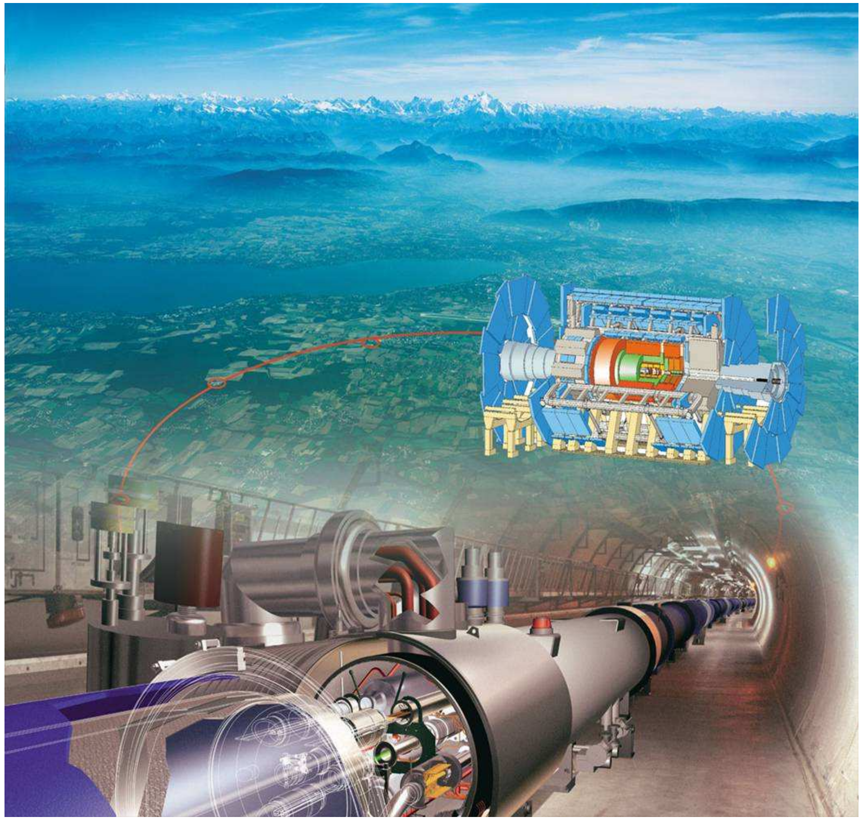

Image: CERN

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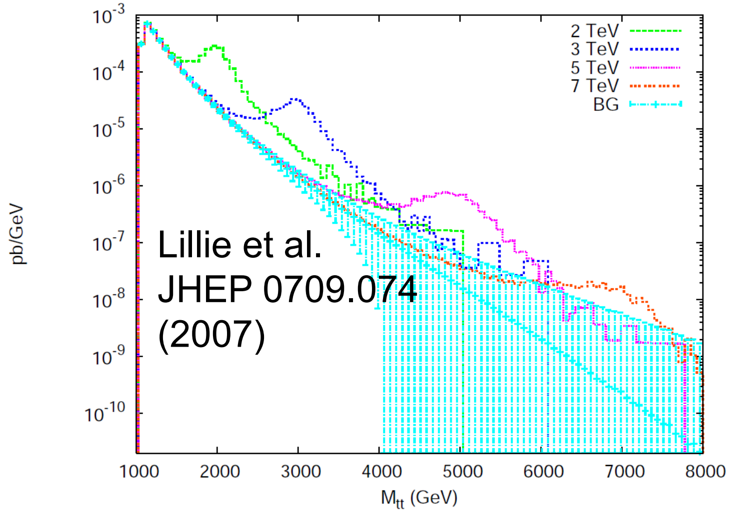
Motivation and goal



> Search for particles which decay into a top/anti top quark pair (m_t = 173 GeV/c^2):

Top Resonances

> Theoretic model predicts novel gauge boson

$$Z' \longrightarrow t\bar{t}$$

- hypothetical particle with the same properties as the Z-Boson but much larger mass
- Z' is so far unseen

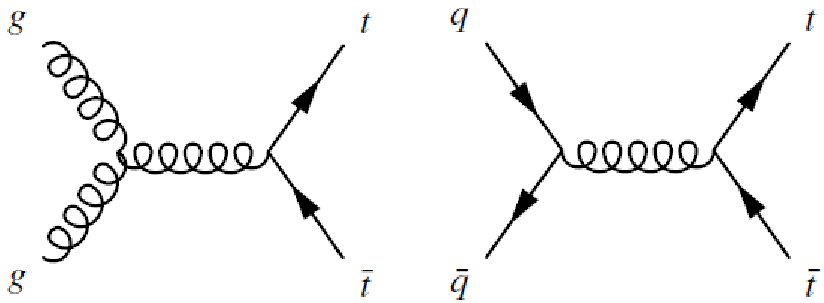
> **Aim:** Set upper limits on the Z' to $t\bar{t}$ cross section

> **Goal:** Study of different reconstruction methods of the $t\bar{t}$ system

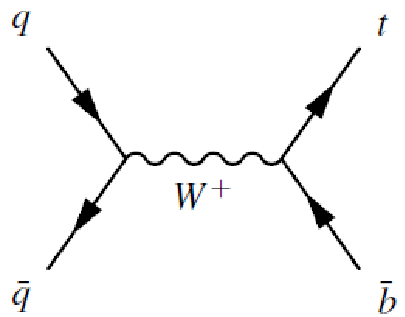
- invariant mass distributions
- Mini-isolation for leptons

Top quark physics at LHC

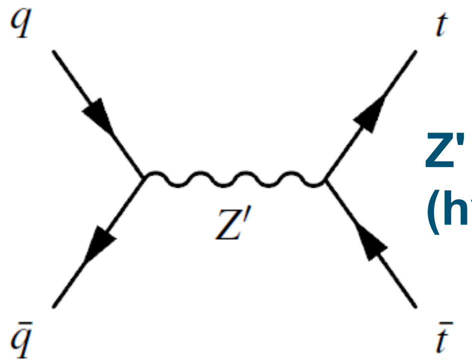
> Top quark production at LHC with proton-proton collisions at 8 TeV center-of-mass energy:



Top/anti top quark pair production
via the strong force



Single top quark production
via the weak force



Z' production (hypothetical)

Main background : Standard Model top/anti top production

Event selection

- Top quark decay (99,8%): t ⟶ Wb
  - W-Boson decay:

    W ⟶ pair of light quarks qq (67%)

    W ⟶ lepton l + neutrino v (33%)

- **Semileptonic** decay of top quark pair:

  $t\bar{t}$ ⟶ Wb + Wb ⟶ lvb + qqb

- **One charged lepton**: electron or muon

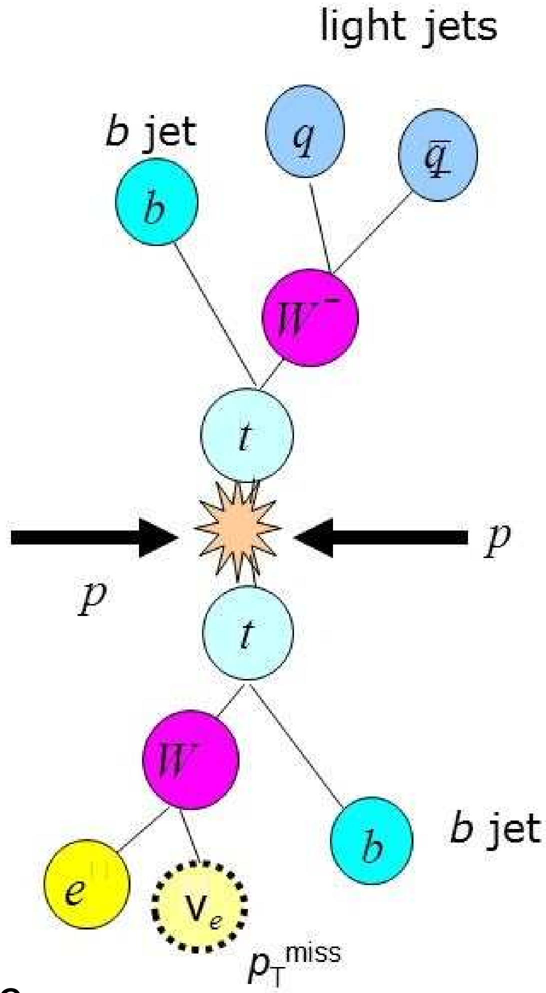
  → lepton isolation requirement!

- Missing transverse energy in event,

  E_T^{miss} ⟶ **neutrino**

- Quarks form **jets**

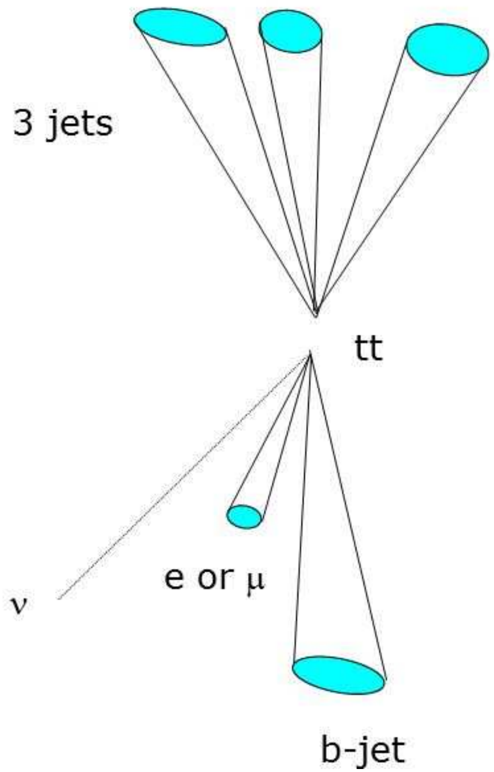
  → jet reconstruction from energy deposition in hadronic calorimeter with fixed radius parameter R



Reconstruction methods

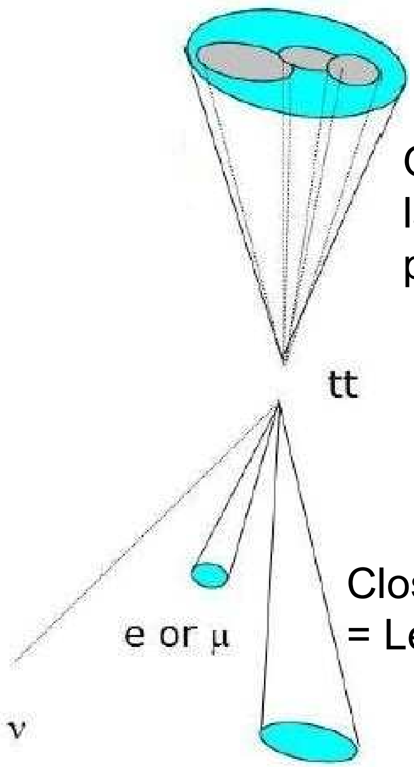
Low energy top pair decay:
Resolved reconstruction

High energy top pair decay:
Boosted reconstruction



Hadronic top decay

Leptonic top decay



One fat jet $j_{1.0}$ with large R = 1.0, high p_T, $m_{j1.0}$

Closest jet to lepton = Lepton jet

> Separate decay products can be detected
   - 4 small jets $j_{0.4}$ with R = 0.4

   OR 3 jets $j_{0.4}$, one with $m_{j0.4}$ > 60 GeV

> Highly boosted and collimated decay products

   → overlapping detection

Reconstruction of invariant mass of the $t\bar{t}$ system

- Add neutrino longitudinal momentum p_z to E_T^{miss}
- Add energy-momentum 4-vectors of all top decay products

- **Resolved** reconstruction:
  - Consideration of angular distribution of the jets

$t\bar{t}$ system = remaining 3/4 $j_{0.4}$ + e/μ + v

- **Boosted** reconstruction:

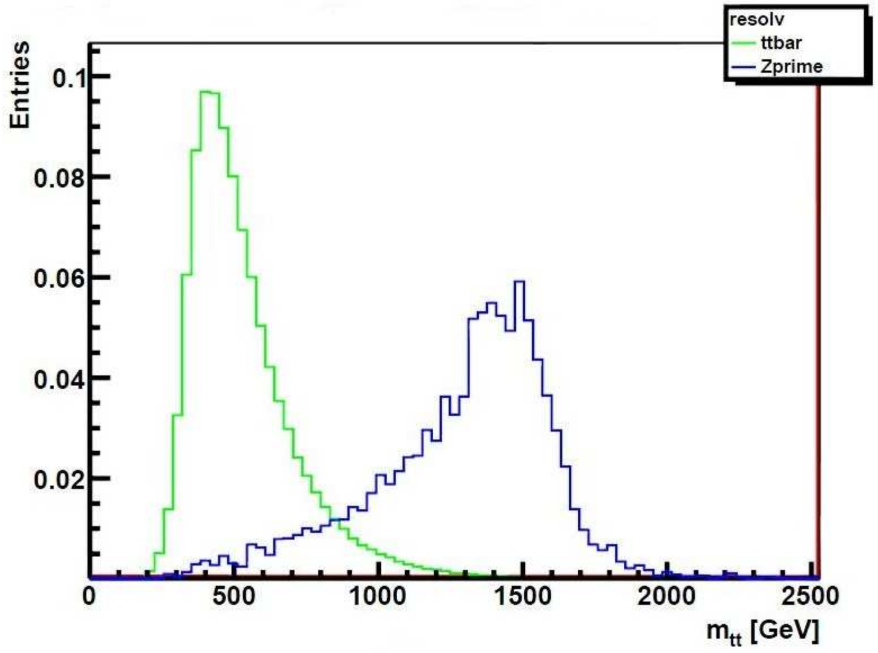
$t\bar{t}$ system = $j_{1.0}$ + Lepton jet $j_{0.4}$ + e/μ + v

- Invariant mass:

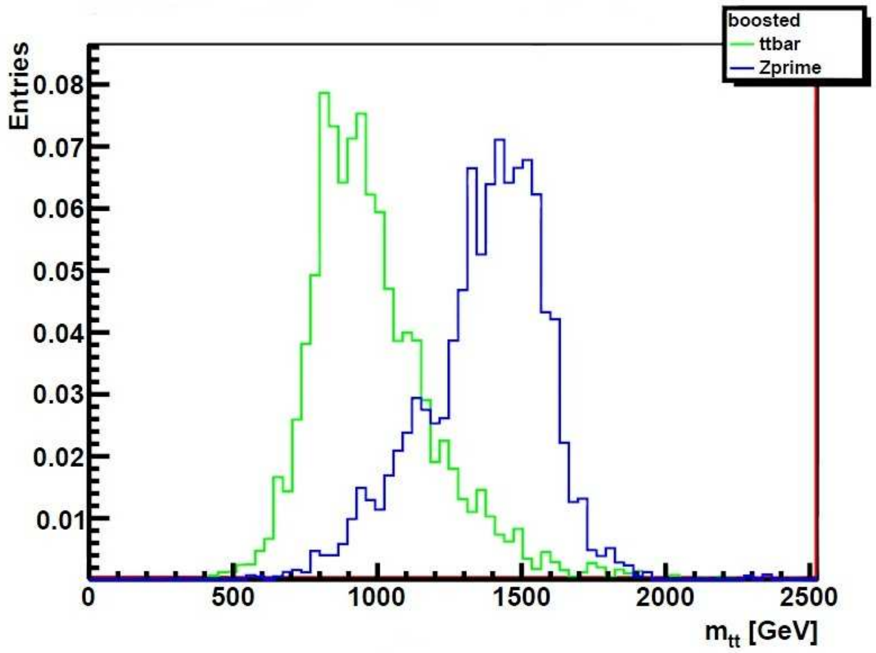
$$m = \sqrt{\left(\sum_i E_i\right)^2 - \left(\sum_i p_i\right)^2}$$

Comparison of $t\bar{t}$ and Z‘ simulated data

Resolved reconstruction



Boosted reconstruction



> Reconstructed invariant mass m_{tt} of the top/anti top decay for Standard Model $t\bar{t}$ and Z‘ ($m_{Z‘}$ = 1600 GeV) (electron channel)

→ Boosted event selection shifts to higher masses

Lepton isolation

- Selected event: isolated leptons required
- Standard isolation criterion: **fixed** cone isolation
  - Sum over all energy deposited in a fixed cone around the lepton

$$\mathrm{I}^{l}_{\text{fixed cone}} = \sum_{\text{cluster in cone}} E_T$$

$$\Delta R(\text{lepton,energy cluster}) < \text{const}$$

- Problem: boosted events

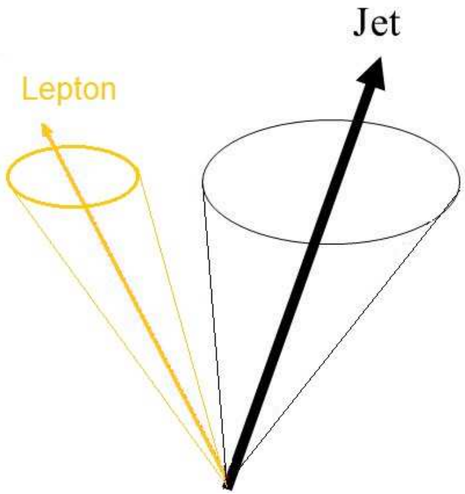
  → highly collimated decay products

  → loss of signal due to standard isolation criterion

- **Mini-isolation**: Cone radius is lepton p_T dependent

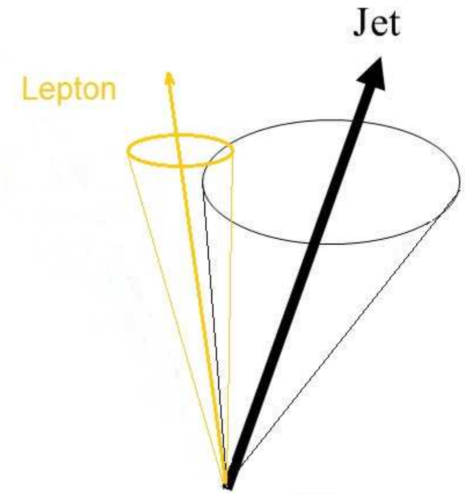
$$I^{\ell}_{\text{mini}} = \sum_{\text{tracks}} p_{\mathrm{T}}^{\text{track}} \qquad \Delta R(lepton, track) = \frac{10GeV}{p_T^l}$$

→ hard leptons can be less isolated!

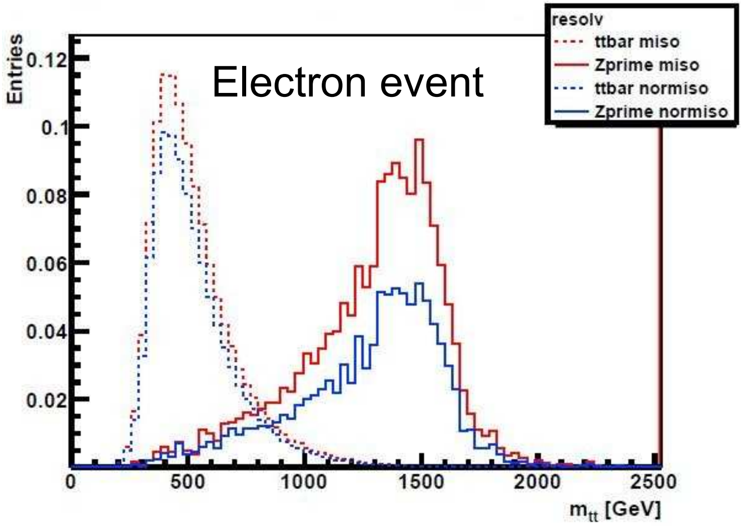


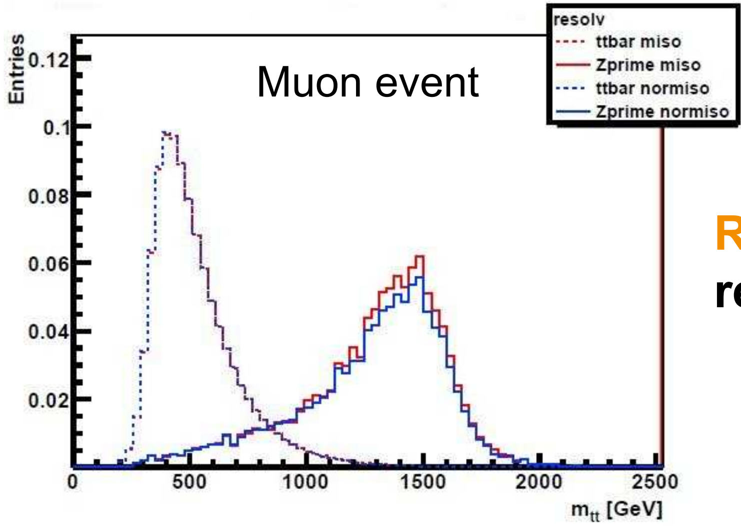
Low energy event

High energy event



Comparison of fixed cone isolation and mini-isolation

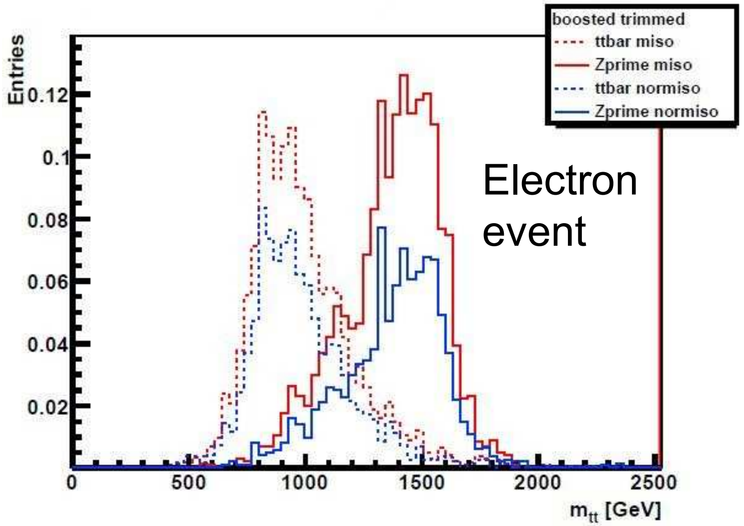


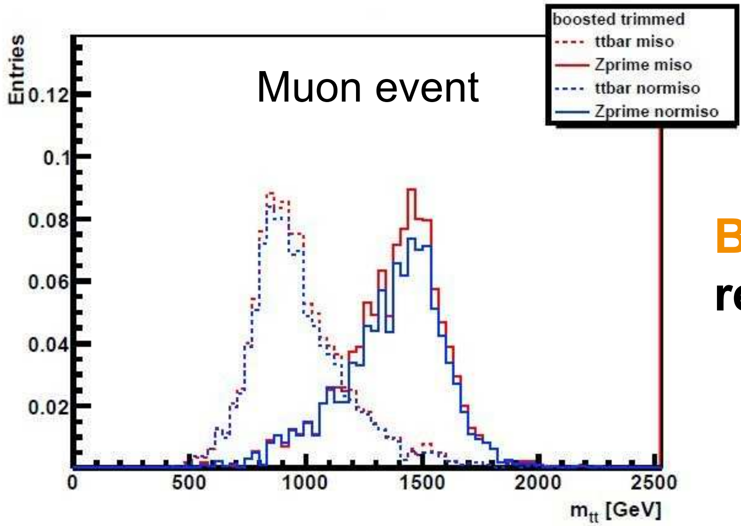


Resolved reconstruction

> Reconstructed invariant mass m_{tt} of the top/anti top decay for Standard Model $t\bar{t}$ and Z' ($m_{Z'}$ = 1600 GeV) with mini-isolation and fixed cone isolation

→ mini-isolation enhances number of selected electrons





Boosted reconstruction

Summary

- Boosted event selection increases the sensitivity to new physics processes with massive particles
- Mini-isolation: better performance for electrons in boosted topologies than fixed cone isolation

Summary

- Boosted event selection increases the sensitivity to new physics processes with massive particles
- Mini-isolation: better performance for electrons in boosted topologies than fixed cone isolation

Thanks for your attention!

Questions?

References

[1] Particle Data Group Collaboration, K.Nakamura et al., *Review of particle physics*, J.Phys. **G37** (2010) 075021.

[2] R. M. Harris, C. T. Hill, and S. J. Parke, *Cross section for topcolor Z'(t) decaying to t anti-t*, arXiv:hep-ph/9911288.

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[6] ATLAS Collaboration, *Performance of large-R jets and jet substructure reconstruction with the ATLAS detector*, ATLAS-CONF-2012-065, June 2012.

[7] ATLAS Collaboration, *A search for ttbar resonances in lepton+jets events with highly boosted top quarks collected in pp collisions at $\sqrt{s} = 7$ TeV with the ATLAS detector*, submitted to JHEP (2012), arXiv:1207.2409v1 [hep-ex].

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[9] ATLAS Collaboration, *Prospects for top anti-top resonance searches using early ATLAS data*, ATLAS public note, ATL-PHYS-PUB-2010-008, Jul, 2010.

[10] K. Rehermann and B. Tweedie, *Efficient Identification of Boosted Semileptonic Top Quarks at the LHC*, JHEP **1103** (2011) 059, arXiv:1007.2221 [hep-ph].

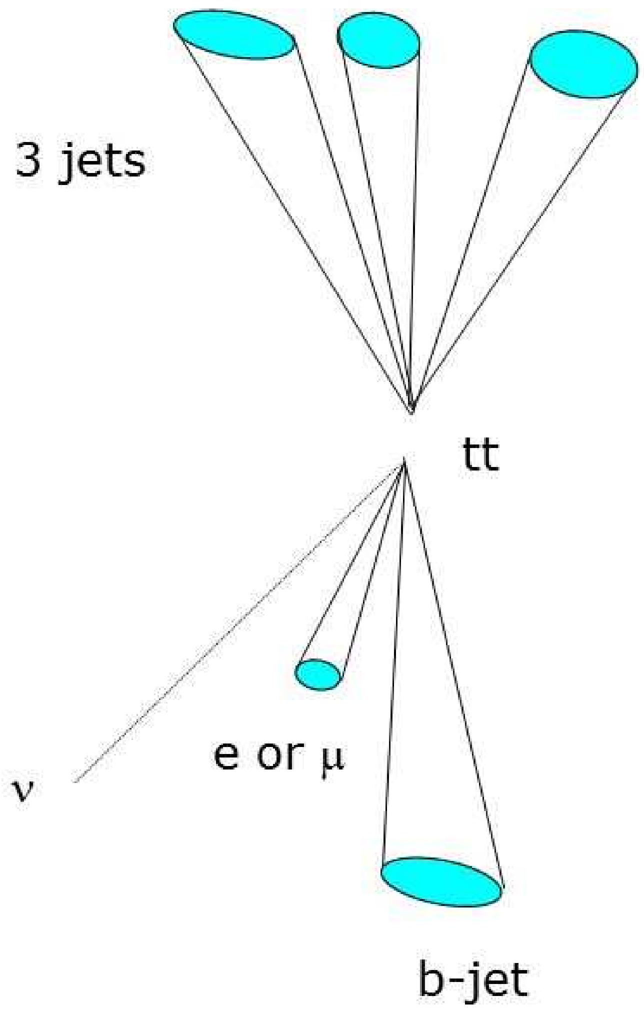
Resolved $t\bar{t}$ reconstruction

- Resolved events = low energy top quark pairs
  - 4 small jets $j_{0.4}$ with radius parameter R = 0.4

  OR 3 jets $j_{0.4}$ with $m_{j0.4}$ > 60 GeV for one of these
  - “b-tagging“ of any jet in the event

- Reconstruction of invariant mass of the $t\bar{t}$ system:
  - add neutrino transverse momentum p_z to E_T^{miss}
  - Consideration of angular distribution of the jets

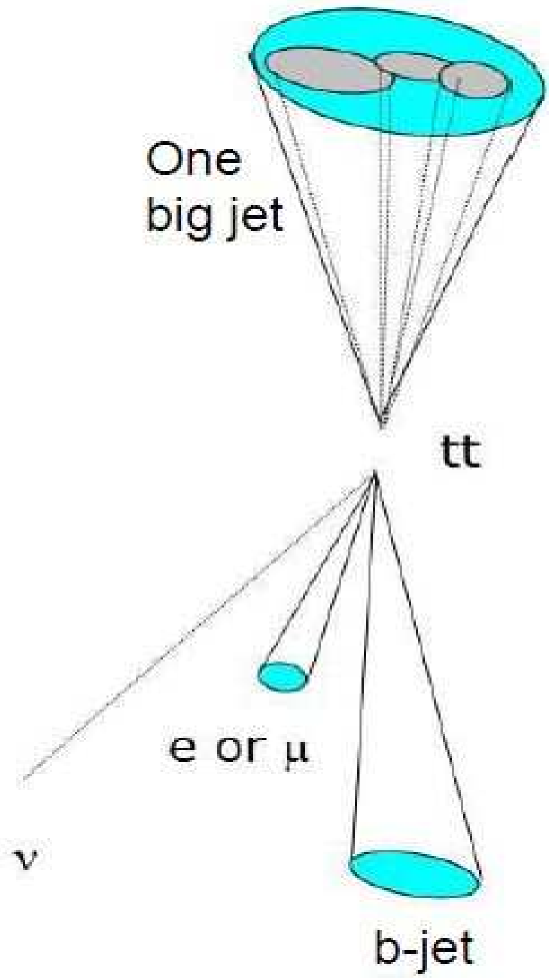
$t\bar{t}$ system = remaining 3/4 $j_{0.4}$ + e/μ + v



Boosted $t\bar{t}$ reconstruction

- Boosted events = high energy top quark pairs
  - Hadronic top decay = one fat jet $j_{1.0}$ with large R = 1.0 and high p_T, $m_{j1.0}$
  - Study of fat jet substructure
  - One small jet with R = 0.4 with “b-tagging“
  - Back-to-back creation of top and anti top quark
  - → Closest jet to lepton = Lepton jet
  - →Large angular separation between fat jet and Lepton jet/lepton
- Reconstruction of invariant mass of the $t\bar{t}$ system:

$t\bar{t}$ system = $j_{1.0}$ + Lepton jet + e/μ + ν



Jet trimming

> LHC at design luminosity:

- About 20 collisions per bunch crossing → “pile up“
- Every event is superposition of several interactions
- Interaction of interest (hard scattering) is always accompanied by soft interactions → Mass resolution of large jets diminishes

→ Jet trimming on large radius jets (R = 1.0)

- reduces influence of soft-scatter contributions
- Uses structural difference between jets from light quarks or gluons and large jets which contain hard-scatter quarks

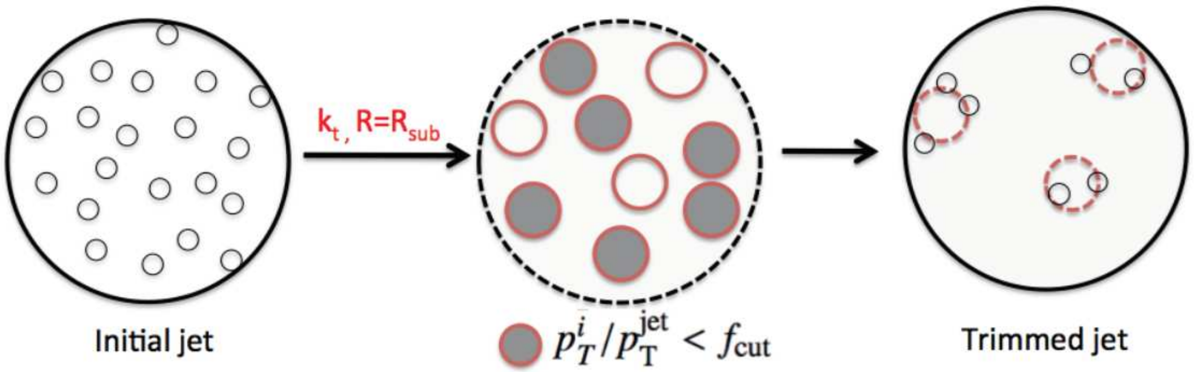


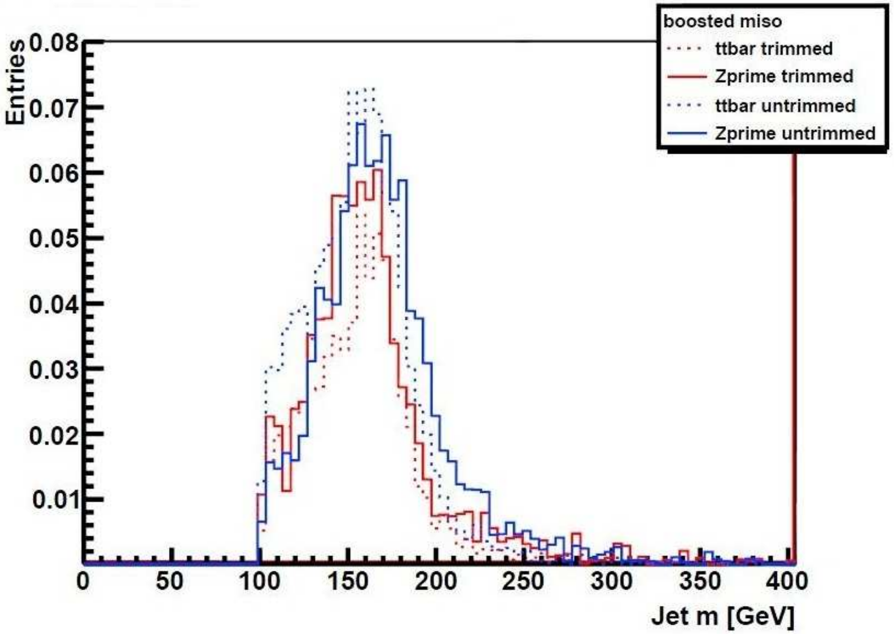
Figure from ATLAS-CONF-2012-065

Impact of jet trimming on the m_{tt} reconstruction

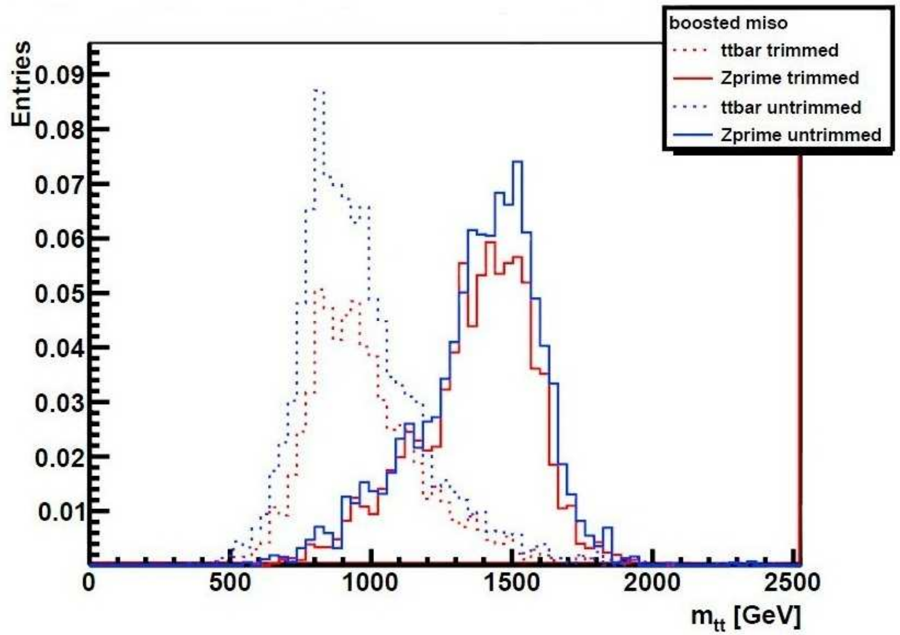
- Invariant mass reconstruction with trimmed and untrimmed large jets (only boosted selection)

→ Mass of large jet shifted to lower values due to subjet sorting

→ Less events for trimmed reconstruction due to mass drop



Jet mass $m_{j1.0}$ of the jet with R = 1.0



Boosted reconstruction: invariant mass of the $t\bar{t}$ system m_{tt}

Numbers of selected events

	$t\bar{t}$		Z'	
Channel	Electrons	Muons	Electrons	Muons
resolved (mini-isolation)	3,29 %	4,04 %	4,70 %	4,91 %
boosted (trimmed, mini-isolation)	0,02 %	0,02 %	1,4 %	1,8 %

Table 1: Number of selected events for the resolved and boosted event selection with respect to the total number of events before selection cuts were applied.

	$t\bar{t}$		Z'	
Channel	Electrons	Muons	Electrons	Muons
resolved (mini-isolation)	3,29 %	4,04 %	4,70 %	4,91 %
resolved (standard isolation)	2,77 %	4,05 %	2,89 %	4,91 %
boosted (trimmed, mini-isolation)	0,02 %	0,03 %	1,4 %	1,8 %
boosted (trimmed, standard isolation)	0,01 %	0,03 %	0,80 %	1,63 %

Table 2: Number of selected events for the resolved and boosted event selection for standard and mini-isolation with respect to the total number of events before selection cuts were applied.

	$t\bar{t}$		Z'	
Channel	Electrons	Muons	Electrons	Muons
boosted (untrimmed, mini-isolation)	0,03 %	0,04 %	1,70 %	2,19 %
boosted (trimmed, mini-isolation)	0,02 %	0,02 %	1,4 %	1,8 %

Table 3: Number of selected events for the resolved and boosted event selection for trimmed and untrimmed large-radius jets with respect to the total number of events before selection cuts were applied.

Summary

- Boosted event selection increases the sensitivity to new physics processes with massive particles
- Mini-isolation: better performance for electrons in boosted topologies than fixed cone isolation
- Jet trimming on large radius jets in boosted reconstruction
  - Reduction of sensitivity to pile-up on the invariant mass reconstruction
  - Improvement of the mass resolution
  - Consideration of further background studies needed