Search for top-antitop resonances in the lepton+jets channel with the ATLAS detector

Blockkurs Krippen 2013

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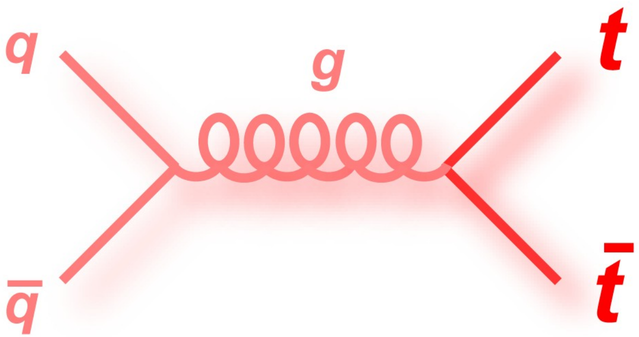
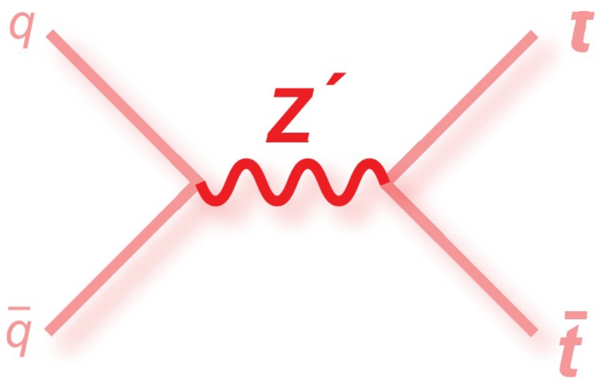
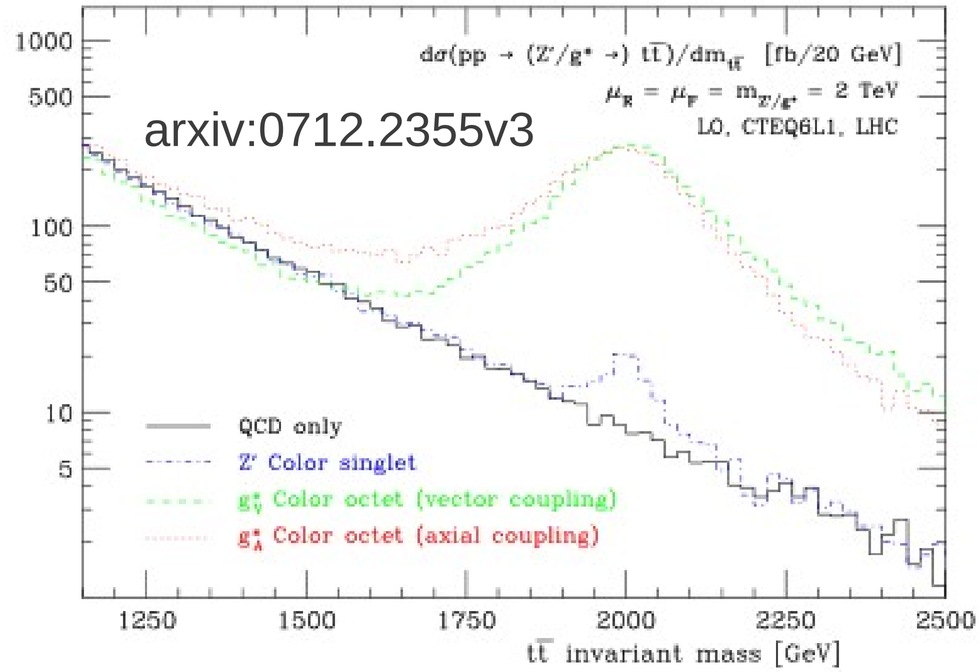
Motivation

Several models beyond the Standard Model postulate heavy particles decaying predominantly into top pairs (e.g. Kaluza-Klein gluons, Z')

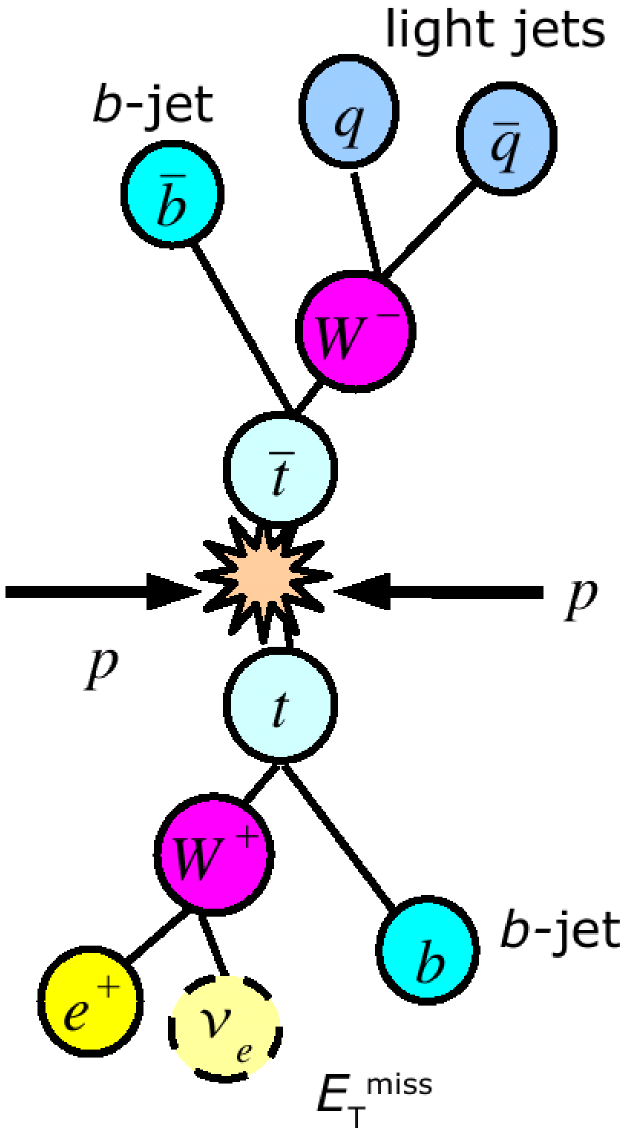






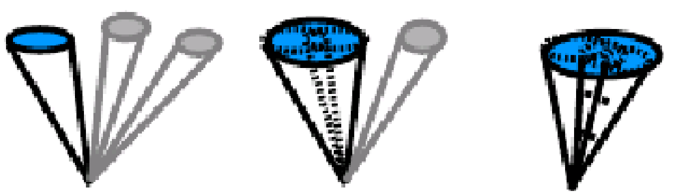
Top pairs at the LHC

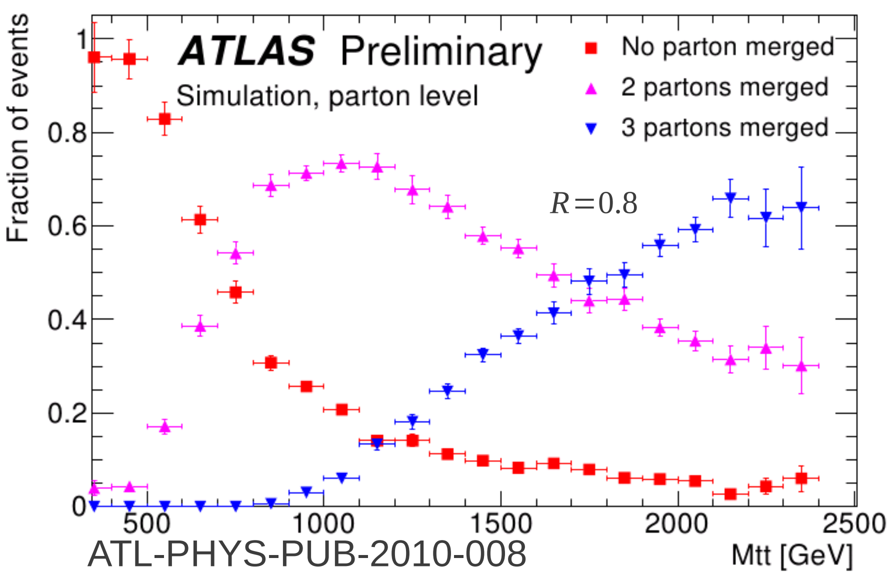
- Top quarks at LHC mainly produced in pairs via Standard Model
- Standard lepton+jets signature:
  - Missing transverse momentum
  - Exactly one isolated lepton
  - At least four jets, two of them b-tagged
- Other background processes: W/Z+jets, QCD multijets, single top, dibosons

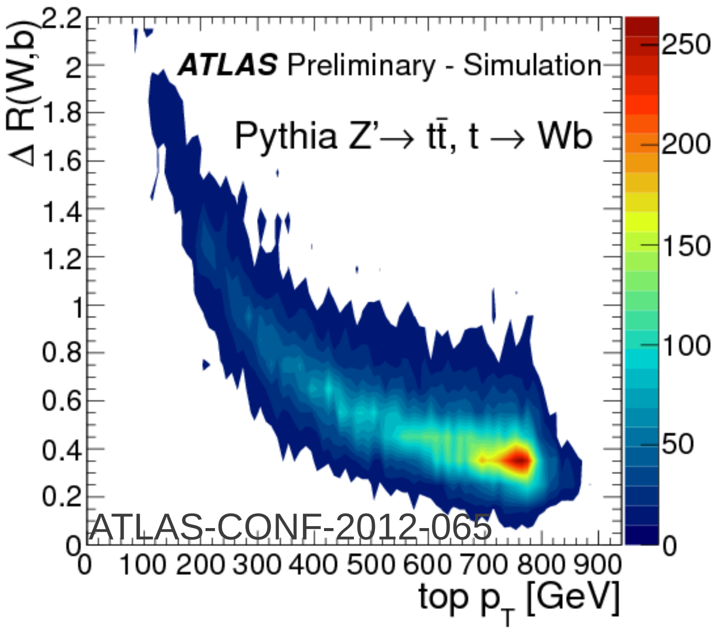


Boosted top quark decays

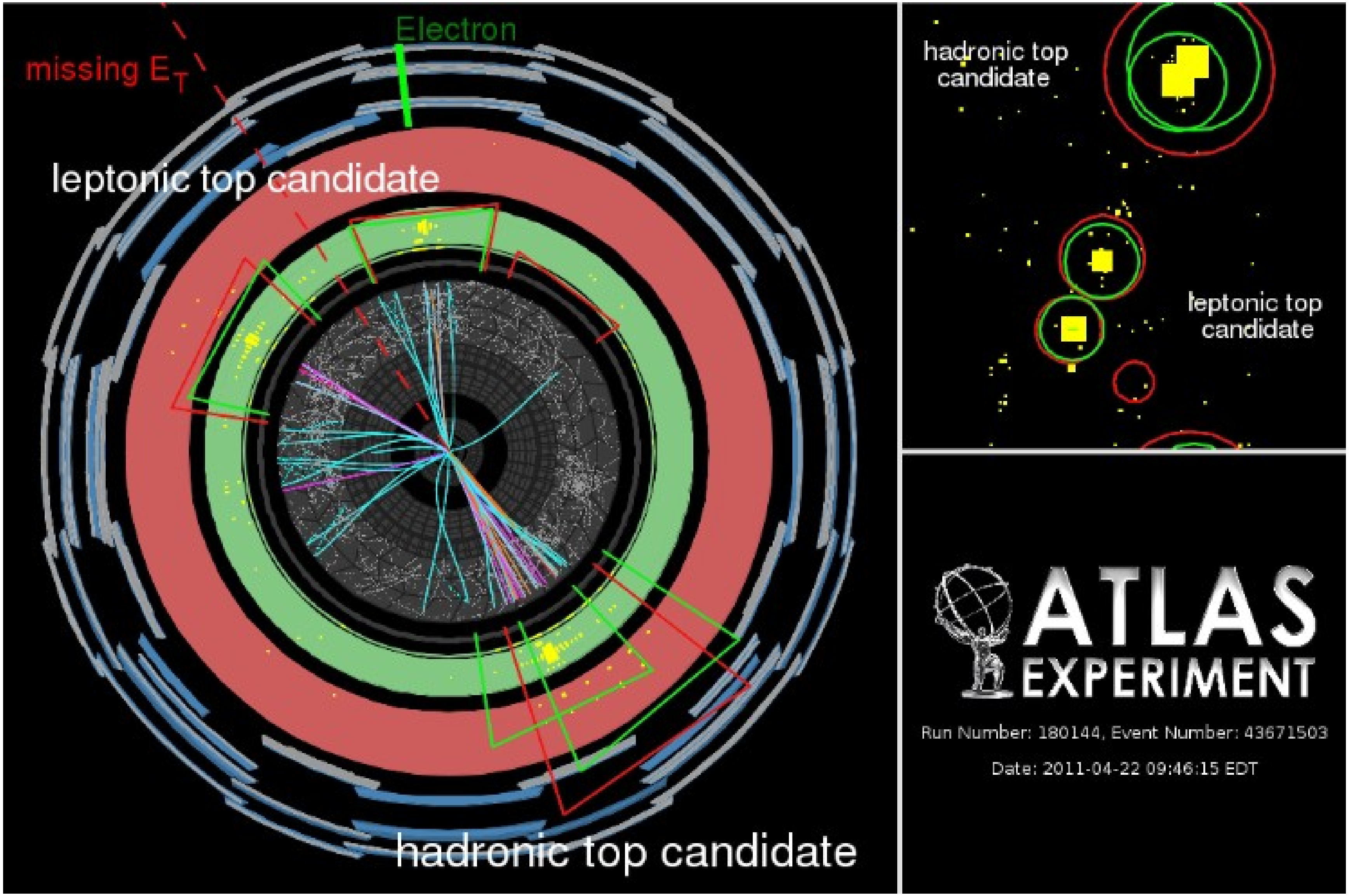
- Heavy particle decay into top pairs
  - top quarks have high momentum
  - reconstructed top decays products overlap
- Above p_T>350 GeV top decay products within $\Delta R < 1$ $(\Delta R \sim 2m/p_T)$
- Hadronic side: only one (fully merged) or two (partially merged) jets are reconstructed





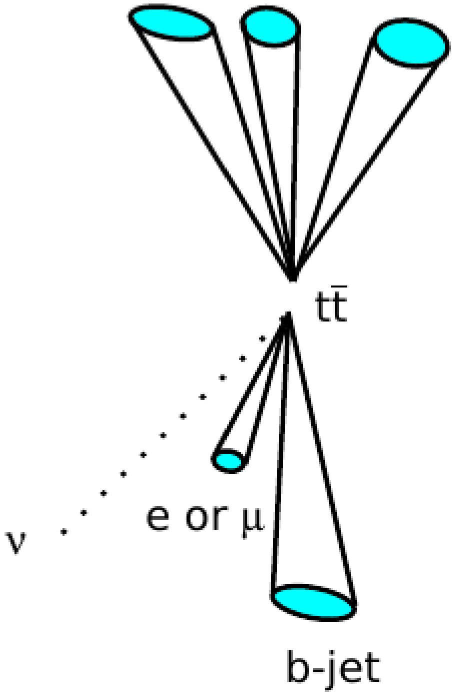


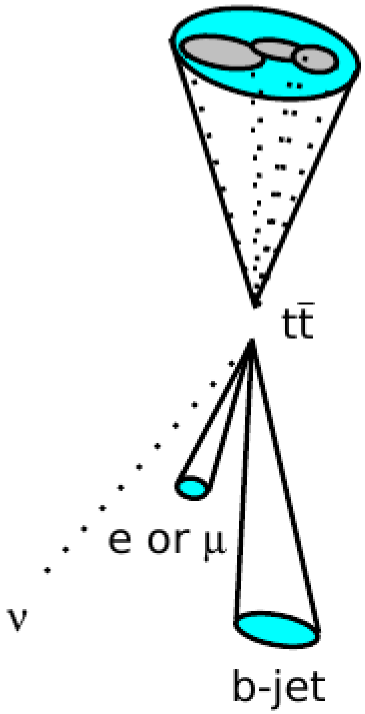
Event Display for m_{tt} = 2.5 TeV



Top pair lepton+jets event selection

- Resolved:
  - Four (three) anti-k_t R=0.4 jets (including one jet with jet mass > 60 GeV)
- Boosted: one fat jet (anti-k_t R=1.0) with
  - Transverse momentum > 300 GeV
  - Jet mass > 100 GeV
  - $\sqrt{d_{12}}$ > 40 GeV (see later in this talk)
  - Almost back to back to leptonic side
- One b-tagged jet (anti-kt 0.4)
- Missing transverse momentum
- Exactly one loosely isolated lepton



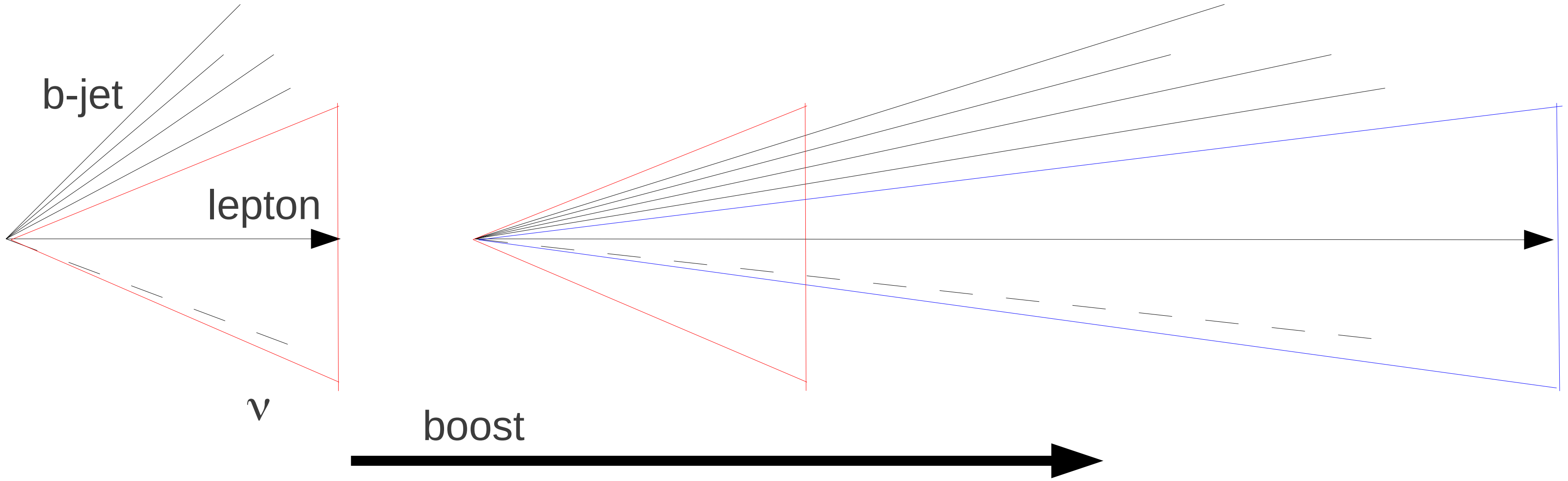


Lepton isolation

- In highly boosted scenarios fixed-cone isolation fails
- Mini-isolation:
  - Variable cone size:

$$MI = \sum_{tracks} p_{T,trk} < 0.05\, p_{T,lepton} \qquad \Delta R = \frac{k}{p_{T,lepton}} \qquad k = 10\,GeV$$

- Significant improvement of signal efficiency found for Z'->$t\bar{t}$



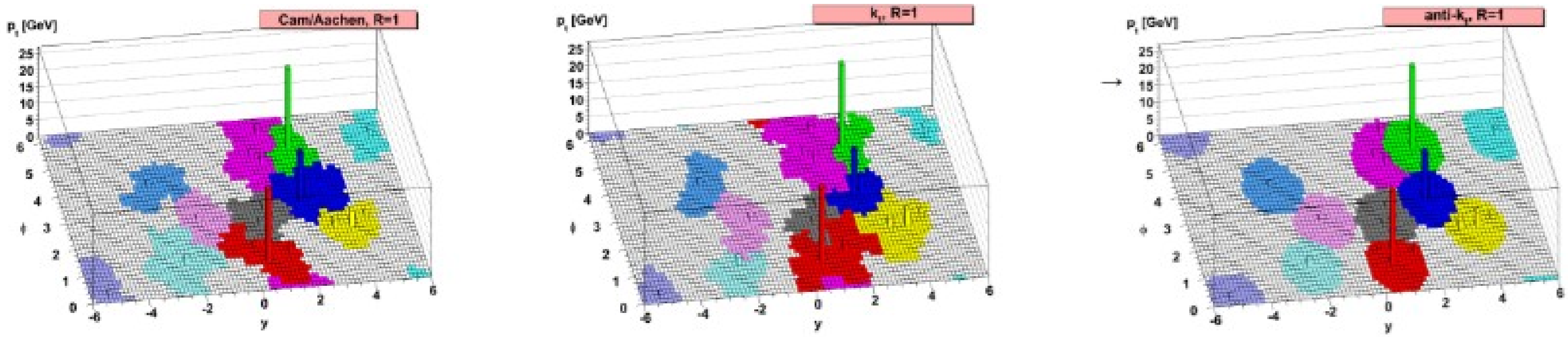
Jet substructure: recap jet algorithm

- Combine particles with smallest distances

$$d_{ij} = min(p_{Ti}^{2n}, p_{Tj}^{2n}) \frac{\Delta^2 R_{ij}}{R^2} \qquad d_{iB} = p_{Ti}^{2n}$$

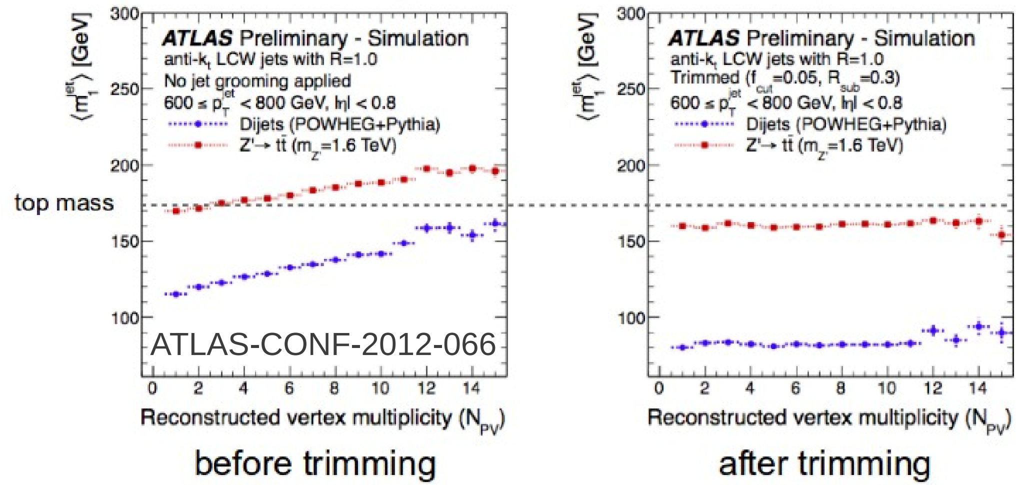
  - n=1: k_t, softer objects first
  - n=0: C/A, closer objects first
  - n=-1: anti-k_t, harder objects first

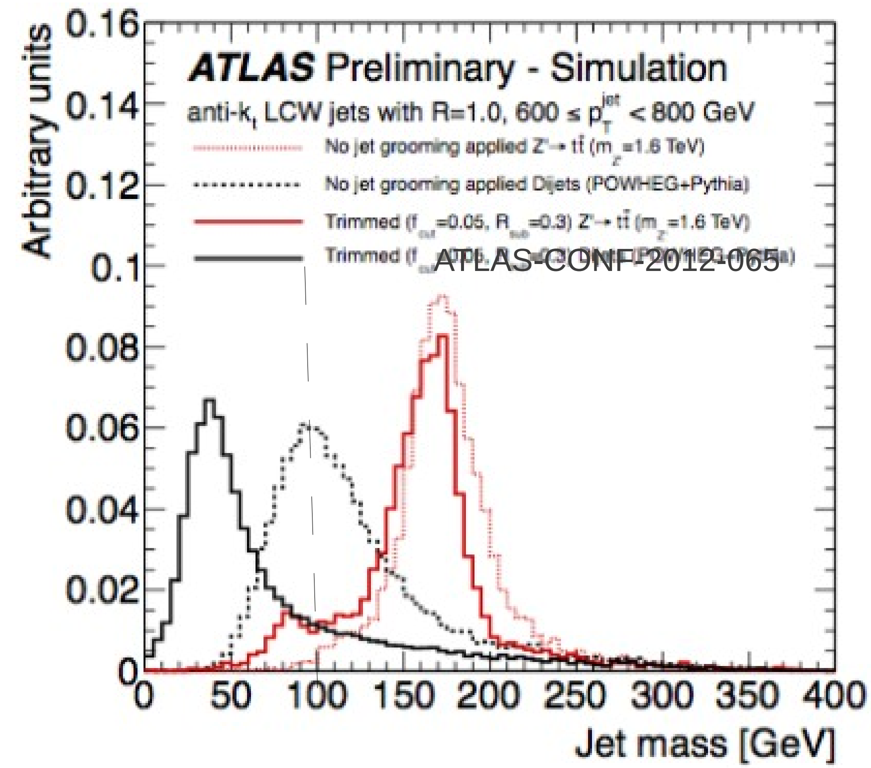
- Substructure information can be retained from cluster history of k_t and C/A algorithms

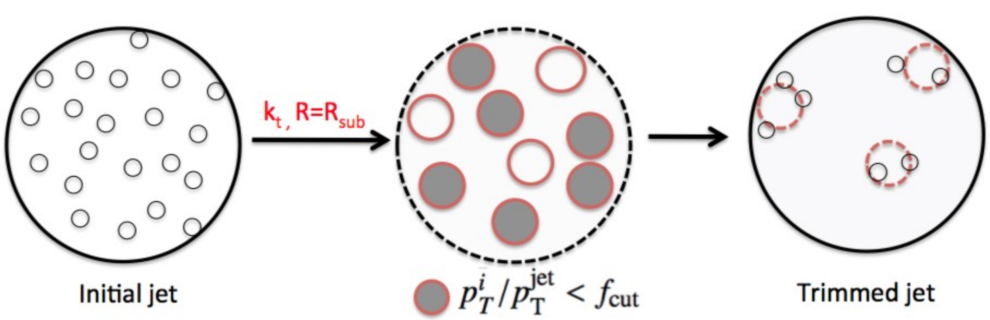


Pile-up correction: trimming

- Pile-up: multiple interactions per bunch crossing (up to 40 in 2012)
- Jet trimming, to get rid of contamination from pile-up:
  - re-cluster jet constituents with very small cone size and remove low-pt jets
  - better discrimination of signal from background
  - better mass resolution
  - mass is important discriminant





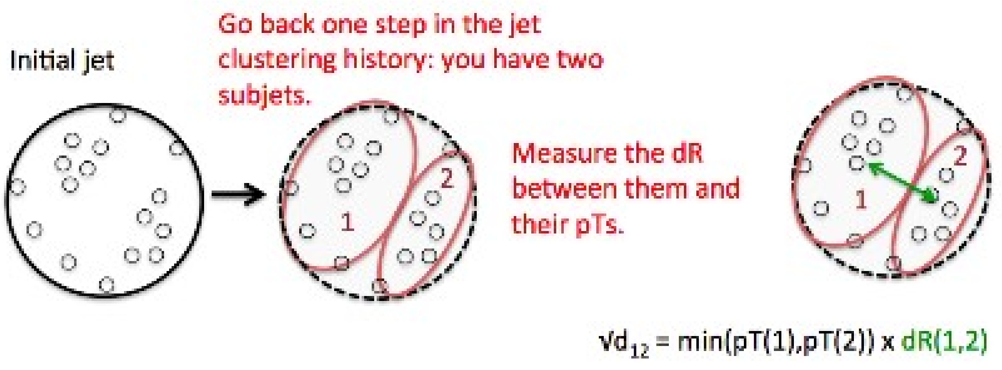


Jet substructure: Splitting scale

- Splitting scale: go back one step in jet clustering of kt-algorithm

$$\sqrt{d_{12}} = min(p_{T1}, p_{T2}) \times \Delta R_{12}$$

  - heavy particle: reasonably symmetric ~ m/2
  - QCD: asymmetric



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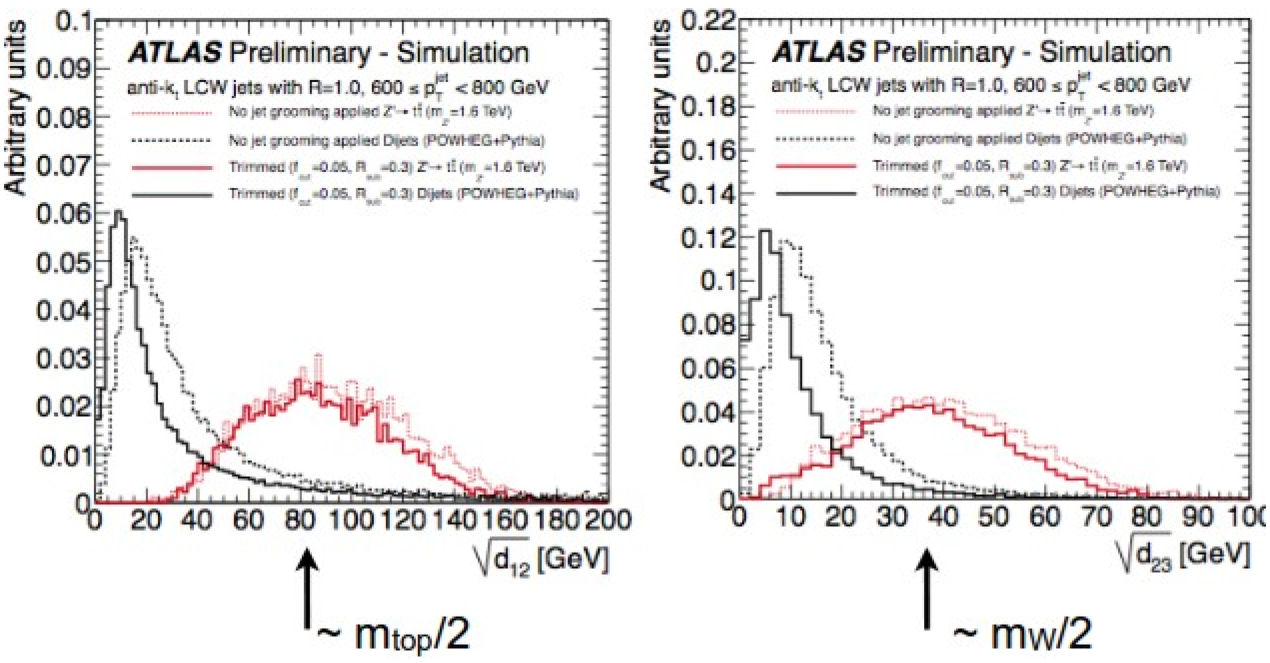
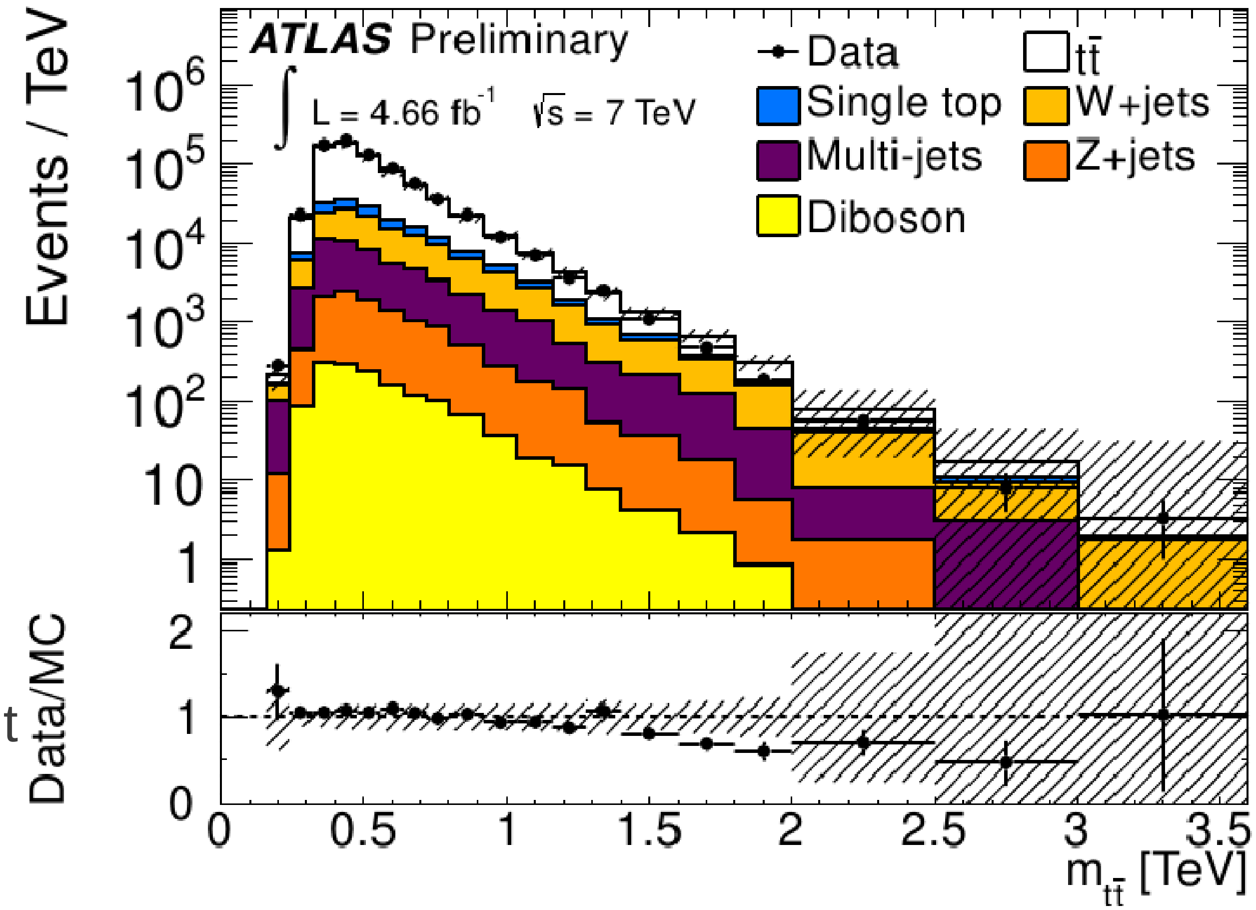


Top antitop mass reconstruction

- Reconstruction of top-antitop system with
  - Neutrino longitudinal momentum via W mass constraint
  - Two methods for resolved case:
    - Jets assigned via χ^2 minimisation with top and W mass constraint
    - Use hardest jets after rejecting far-away jets
  - Comparable performance for both methods
  - Fat jet for boosted case



combined invariant mass spectrum:
resolved and boosted
electron and muon channel
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Additional substructure observables

- Splitting scale highly correlated to mass
- Investigate additional jet shapes and their correlation (e.g. subjettiness, jet width, planar flow, and others)
- Additional variables come with new systematics

Subjettiness

- Recluster with k_t until exactly N subjets
- Sum over constituents:

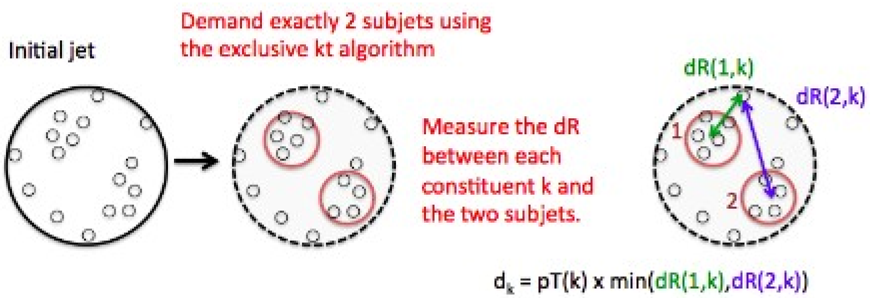
$$\tau_N = \frac{1}{d_0} \sum p_{Tk} \times min(\Delta R_{1k}, \Delta R_{2k}, \ldots \Delta R_{Nk})$$

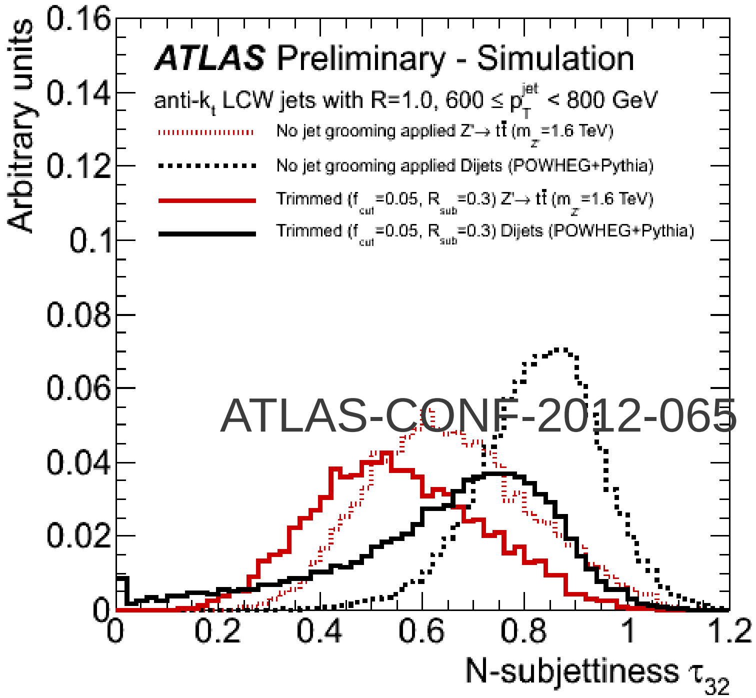
$$d_0 = \sum_k p_{Tk} \times R$$

  - τ_N~ 0: max. N subjets
  - τ_N >>0: at least N+1 subjets
  - e.g. $\tau_{32} = \tau_3 / \tau_2 \sim 0$

    jet better described by 3 subjets than 2

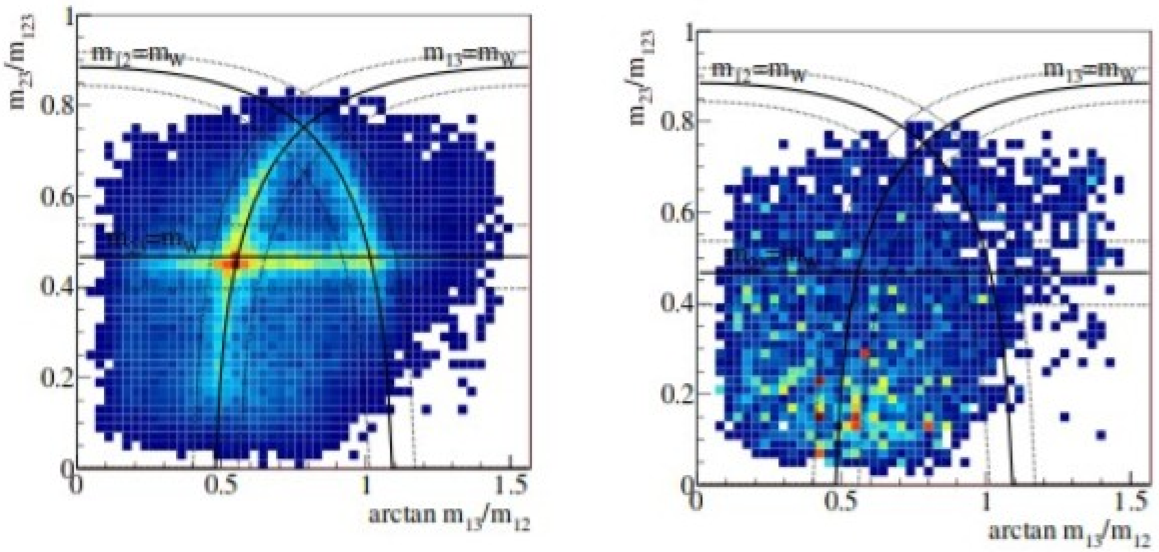
τ_N	top	QCD
3	~0	~0
2	>>0	~0
1	>>0	>>0





Outlook

- Top and W mass constraints in combinations of three hardest (sub)jets
  - already used in HepTopTagger algorithm



$$R_- < \frac{m_{23}}{m_{123}} < R_+$$

$$0.2 < \arctan \frac{m_{13}}{m_{12}} < 1.3$$

$$R_\pm = (1 \pm f_W)\frac{m_W}{m_{top}}$$

- Current limits on Z' ~ 2 TeV: smaller jet cones for high-p_T tops, e.g. tops with p_T > 860 GeV decay within R<0.4
- Build neural network

Summary

- Top-Antitop resonances search uses high energetic top quarks whose decay products can be merged
- Important to understand fat jets and their substructure to identify boosted top quarks
- Dedicated grooming algorithm cleans jets from pile-up contributions
- Investigate new substructure observables and their systematical uncertainties to distinguish boosted top pair events from their background processes