A new way to identify top quarks

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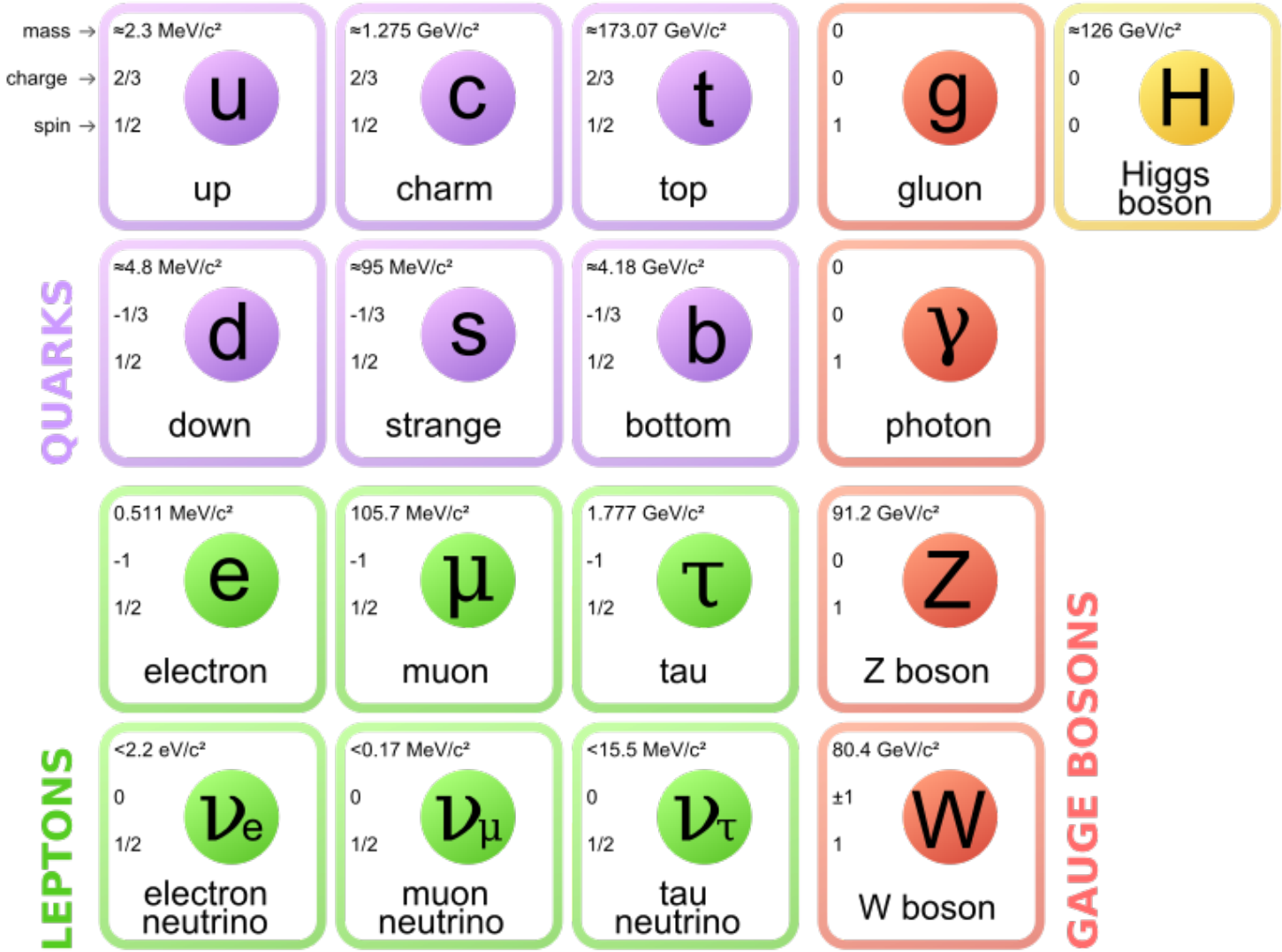
May 8, 2014

Outline

1. Top quarks?
2. From a hard process to a LHC event and back
3. HEPTopTagger

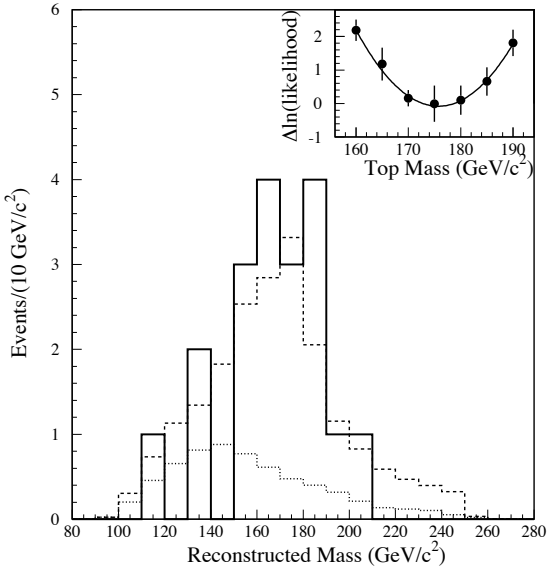
Standard Model of particle physics



[http://en.wikipedia.org/wiki/File:Standard_Model_of_Elementary_Particles.svg]

Top history and basics

- 1973 postulated by Kobayashi and Maskawa to allow for CP violation in the Standard Model
- 1995 discovery at the Tevatron
- mass $m_t \approx 173$ GeV



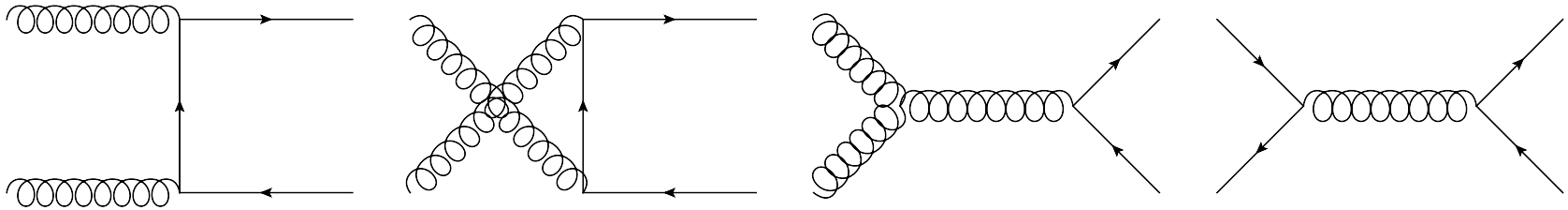
[CDF, Phys. Rev. Lett. **74**, 2626 (1995)]

Why are we interested in top quarks?

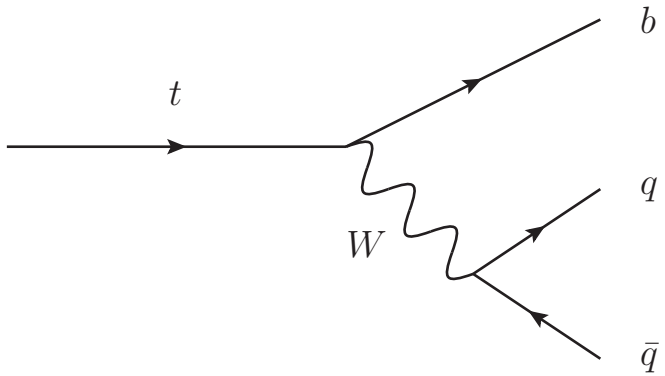
- decay before hadronization
- weak scale mass $\rightarrow$ largest coupling to the Higgs boson $\rightarrow$ perfect laboratory to study electroweak symmetry breaking
- mediate Higgs production and decay from/to massless particles
- physics beyond the Standard Model

Production and decay on parton level ...

- top quark pair production at leading order

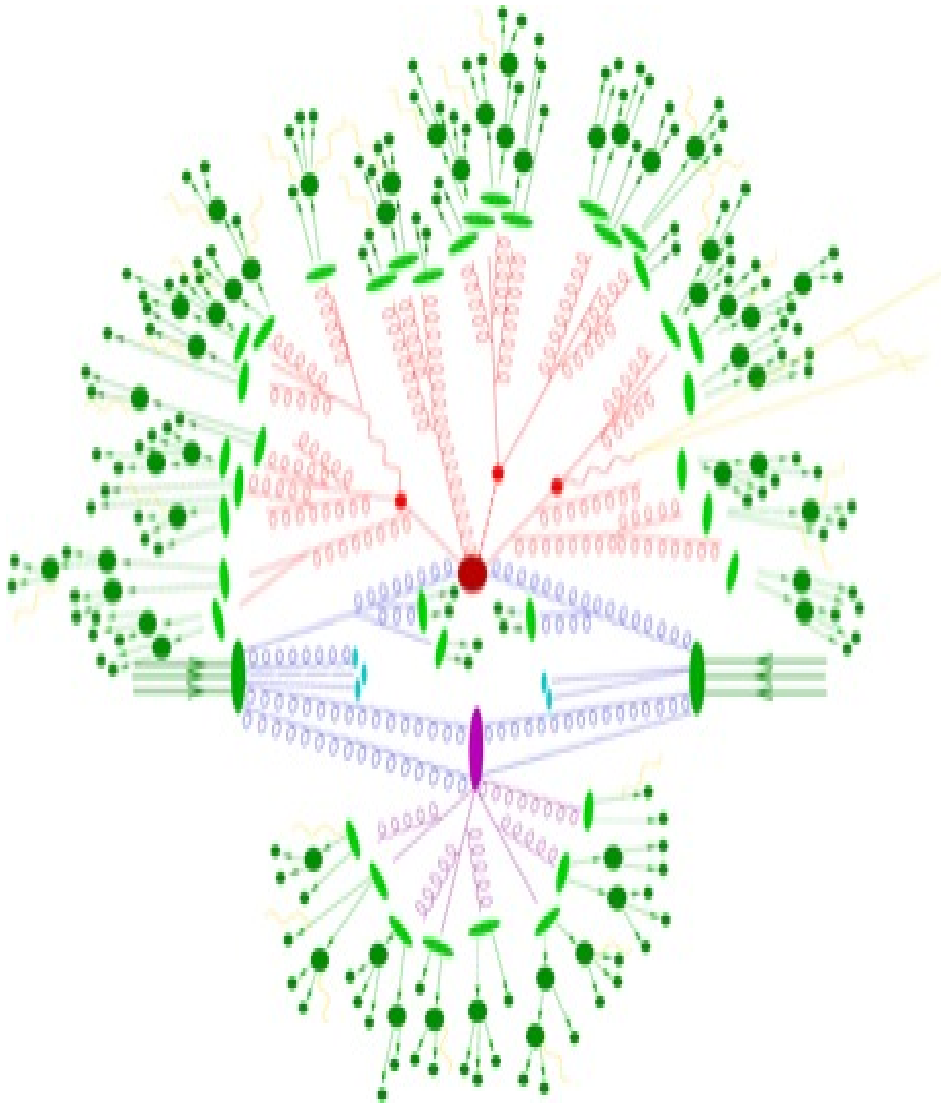


- top quark decay



... and an event simulation for the LHC

- parton density functions
- parton shower
- hard final and initial state radiation
- underlying event
- hadronization
- (pile–up)



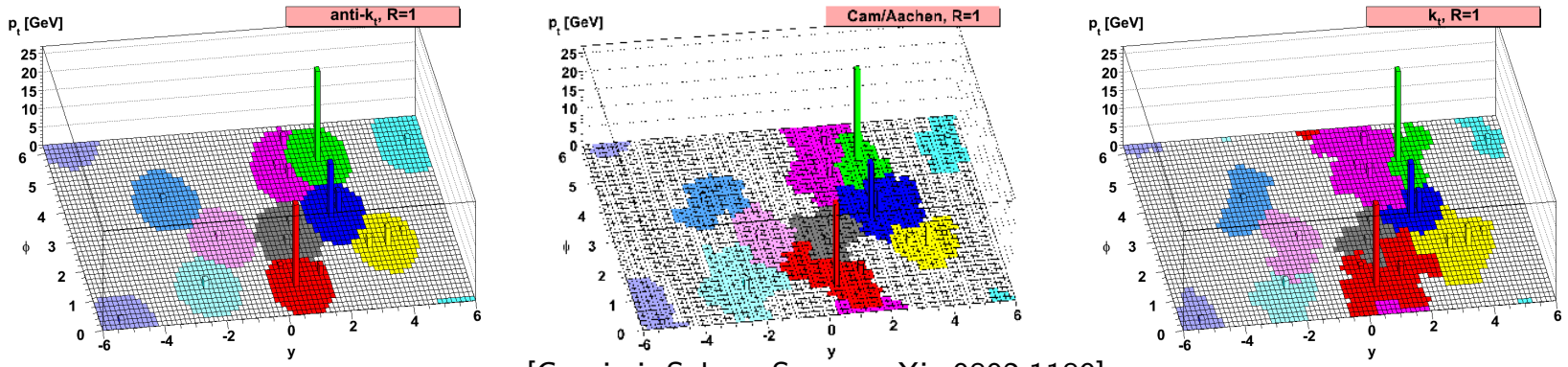
[SHERPA, arXiv:0811.4622]

Jet clustering

Reconstruction of parton level gluons and quarks from calorimeter data

1. Find the minimal distance of all objects $d_{\text{min}} = \min(d_{ij}, d_{iB})$.
2. If $d_{\text{min}} \in \{d_{ij}\}$, join the two corresponding objects.
   If $d_{\text{min}} \in \{d_{iB}\}$, remove object i $\rightarrow$ jet.
3. Iterate until no objects are left.

- k_T: $d_{ij} = \min(p_{T,i}, p_{T,j}) \frac{\Delta R_{ij}}{R}$
  $d_{iB} = p_{T,i}$
- C/A: $d_{ij} = \frac{\Delta R_{ij}}{R} \qquad d_{iB} = 1$
- anti-k_T:
  $d_{ij} = \min(\frac{1}{p_{T,i}}, \frac{1}{p_{T,j}}) \frac{\Delta R_{ij}}{R}$
  $d_{iB} = \frac{1}{p_{T,i}}$



[Cacciari, Salam, Soyez, arXiv:0802.1189]

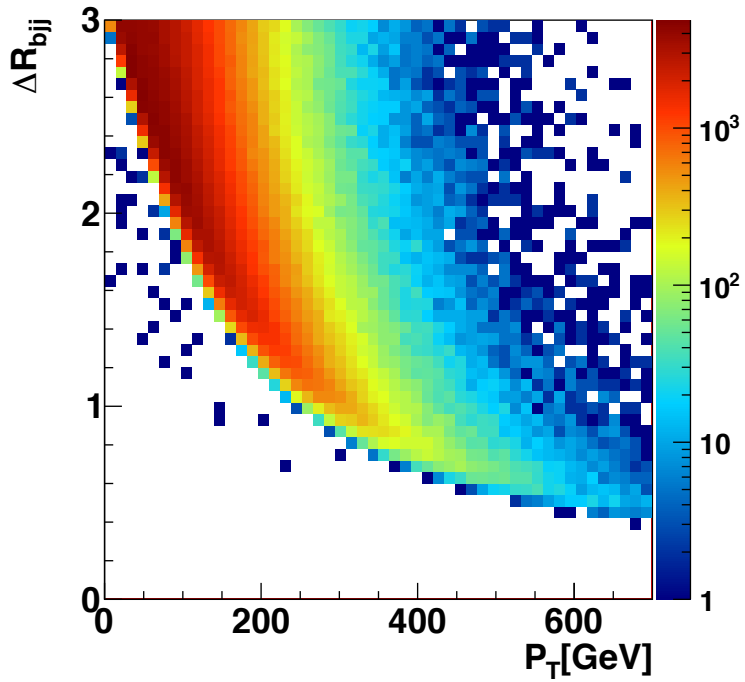
Jet filtering

Remove impurities from underlying event by reclustering the jet with an optimized cone size $\rightarrow$ reduced area.

- start from the calorimeter data that ended up in jet
- recluster with a reduced cone size R_{filt}
- keep only the N_{filt} hardest objects
- recluster to one object $\rightarrow$ filtered jet

How to detect top quarks?

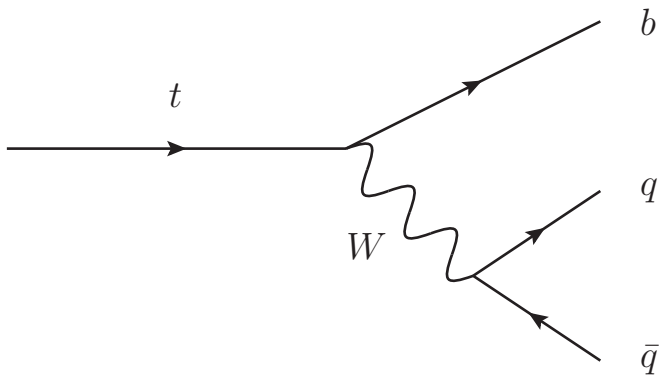
- problem: tops decay products will decay into all directions
  $\rightarrow$ can not be distinguished from background
- solution: boosted top quarks $\rightarrow$ fat jets
- use moderately boosted tops
- HEPTopTagger



[Plehn et al. arXiv:1006.2833]

HEPTopTagger – Steps I

[arXiv:1006.2833]



1. **construction of fat jets**:
   - C/A algorithm with $R = 1.5$
   - require $p_T > 200\ \mathrm{GeV}$
2. **search for hard substructures**:
   - undo last clustering step: $j \to j_1 j_2$
   - mass drop criterion: neglect j_2 if $m_{j_1} > 0.8 m_j$
   - iterate until $m_i < m_{sub} = 30\ \mathrm{GeV}$

$\to$ hard substructures

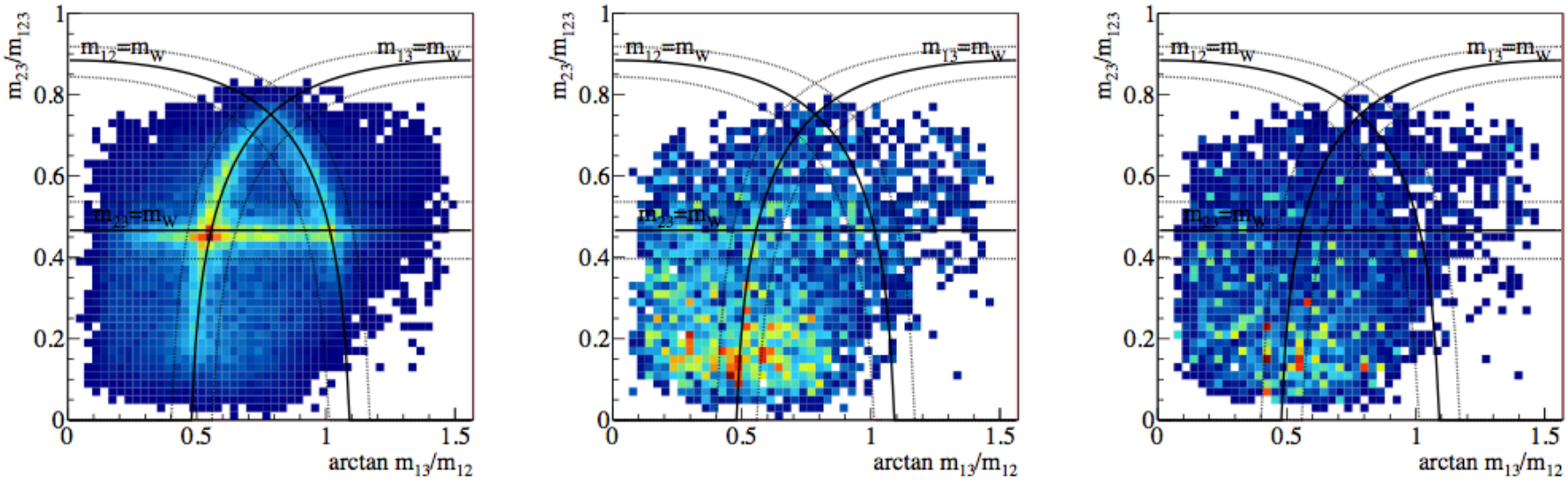
HEPTopTagger – Steps II

3. **filtering**:
   filter a triple of hard substructures to reduce contamination from underlying event $\rightarrow$ 3 jets (j_1, j_2, j_3).

4. **mass range cut**:
   reject the top candidate if its mass is not inside a mass window around m_t: 150 GeV $< m_{123} <$ 200 GeV

HEPTopTagger – Steps III

5. **mass plane cuts**: ask for $0.85\frac{m_W}{m_t} < \frac{m_{ij}}{m_{123}} < 1.15\frac{m_W}{m_t}$



[Plehn et al. arXiv:1006.2833]

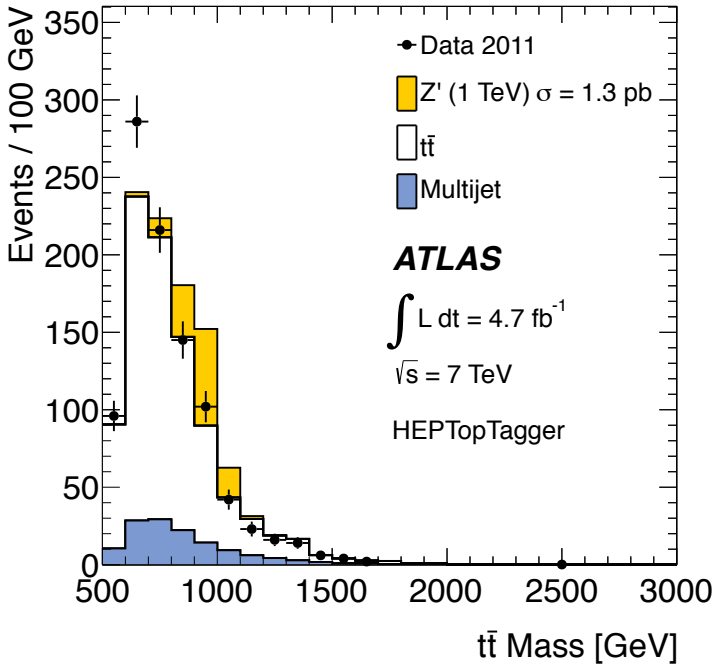
additional cuts to reduce background:

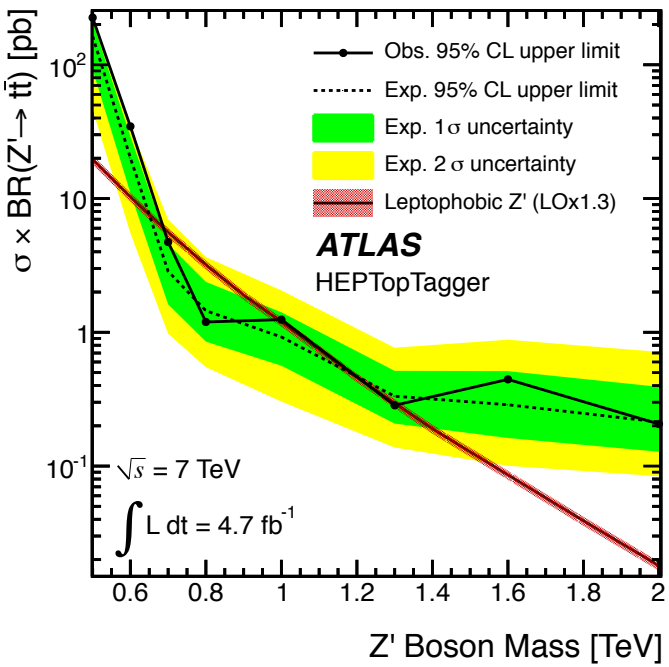
if $m_{23} \approx m_W$ $0.2 < \arctan\left(\frac{m_{13}}{m_{12}}\right) < 1.3$; else $\frac{m_{23}}{m_{123}} > 0.35$

6. **p_T-cut:** Finally, require $p_T^{(\text{tag})} > 200\ \text{GeV}$

It is actually used

- close collaboration with ATLAS group of Prof. Schöning
- used in ATLAS analyses [ATLAS, CERN-PH-EP-2012-291]





[ATLAS, CERN-PH-EP-2012-291]

- searches for flavor violation in the top-Higgs sector

[Greljo, Kamenik, Kopp, arXiv:1404.1278]

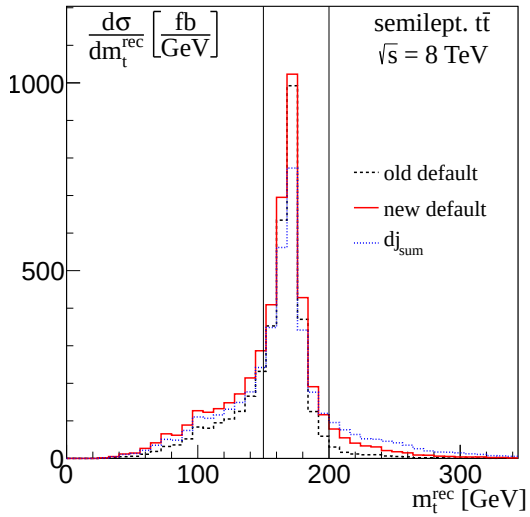
Recent developments

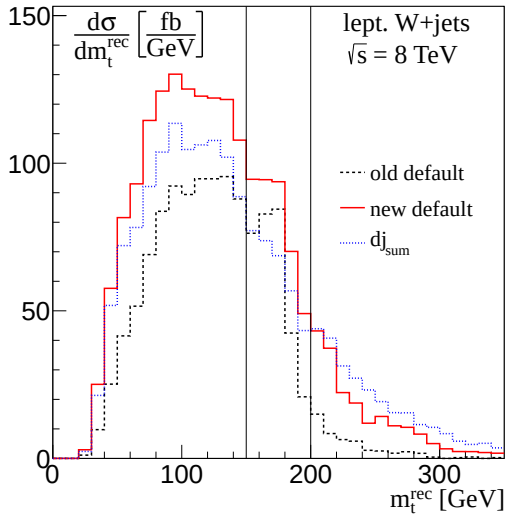
- extensions and improvements (cut order, distance measure, angular correlations, N–Subjettiness, low transverse momenta, . . .)

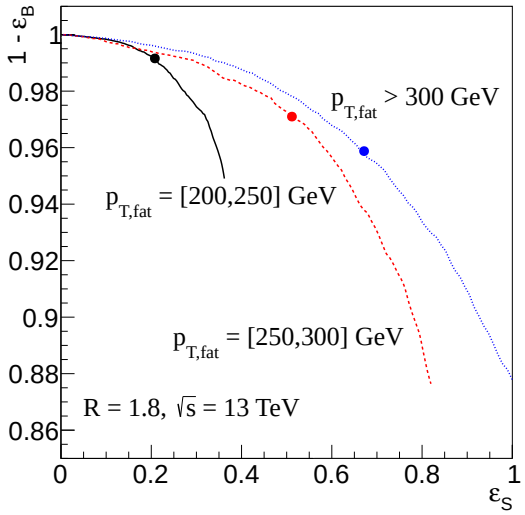
  [Plehn et al. arXiv:1111.5034 & arXiv:1312.1504]

- reconstruction of heavy resonances [in preparation]

- next step: full–hadronic decay of $t\bar{t}H$







Summary

- there are many reasons to study top quarks
- the HEPTopTagger allows to reconstruct hadronically decaying top quarks in a moderately boosted regime based on jet substructure
- close collaboration with experimentalists which use the HEPTopTagger in ATLAS analyses