Identifying and Using Boosted Top Quarks

Snowmass Energy Frontier
Top Group Meeting
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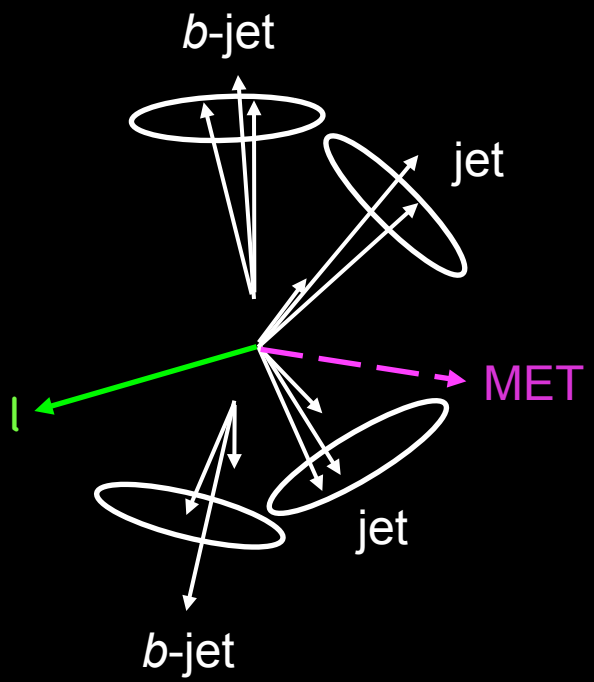
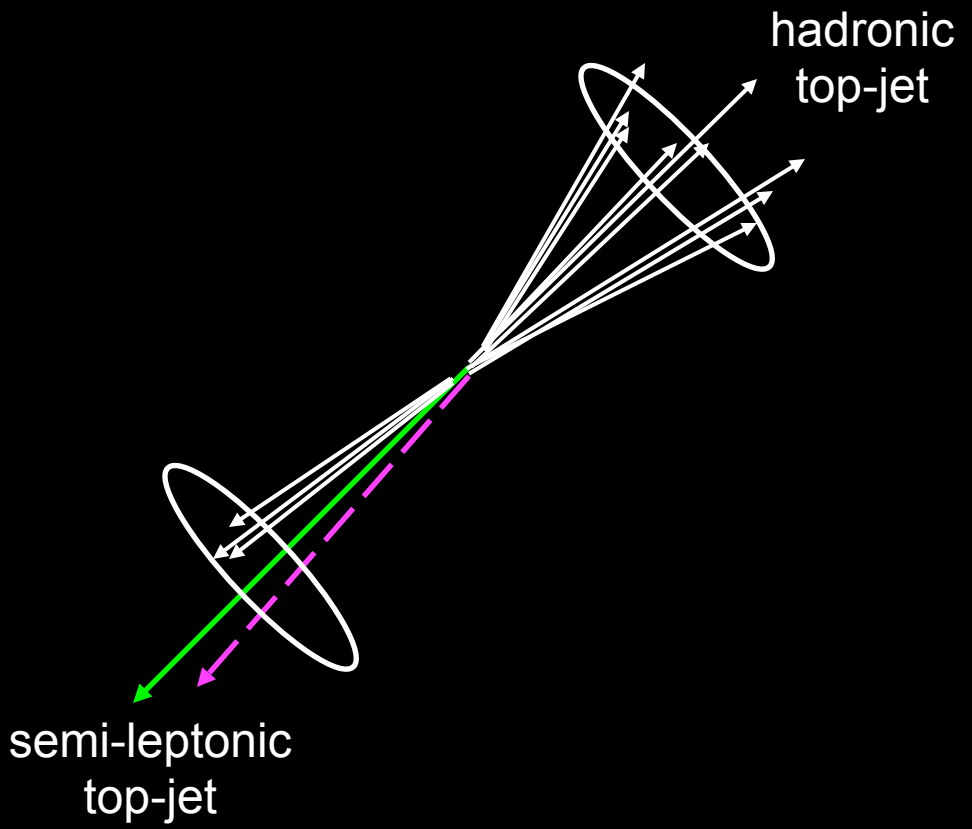
TeV >> m_t

$E_{CM} \sim 2m_t$



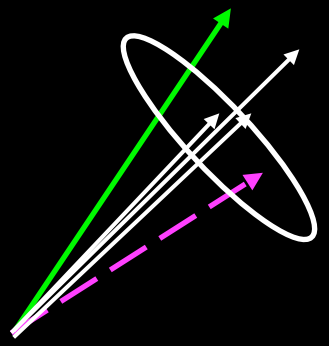
$E_{CM} >> 2m_t$



Goals

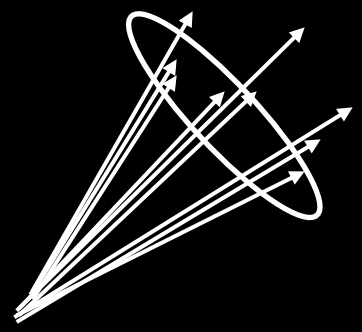
- Look for new physics with boosted tops ($p_T >> m_t$)
  - contact interactions affecting high m_{tt} tail
  - singly-produced resonances: Z', W', g', G', ...
  - heavy top partners: spin-0, spin-½
  - heavy gluinos
- Use boosted tops as a jet substructure laboratory
  - easy to get a pure top-pair sample in μ+jets
  - well-understood mass bumps
  - contains hadronic 2-body decay of a color-singlet boson (e.g., similar to h → bb)

Top-Tagging: Semileptonic



- ~22% of decays to e/μ
  - for top pairs, ~35% have at least one leptonic
- b-tag sometimes possible, not always (high-p_T)
- Capitalize on embedded lepton
  - can usually be ID'ed, but fails isolation
  - mimicked by bottom/charm (used in b/c-tagging)
  - dedicated strategies exploit ~100 GeV scale of top and W, versus <5 GeV scale of b/c

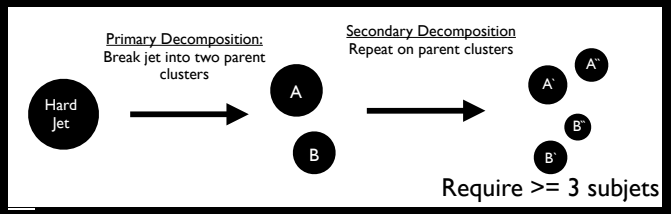
Top-Tagging: Hadronic



- ~66% of decays
  - for top pairs, ~75% have at least one hadronic, ~45% both are
- b-tagging even more difficult (crowded inner tracker)
- Jet with ~3 blobs of energy ("subjets") and mass ~ m_t
  - distinguish from QCD jets using jet substructure
- Still useful to think of "top-jets" even if not very boosted (e.g., $p_T \sim m_t$)
  - substructure reconstructions more optimized than "add up three jets"
  - simple way to deal with combinatorics

Top-Tag Tactics

Declustering



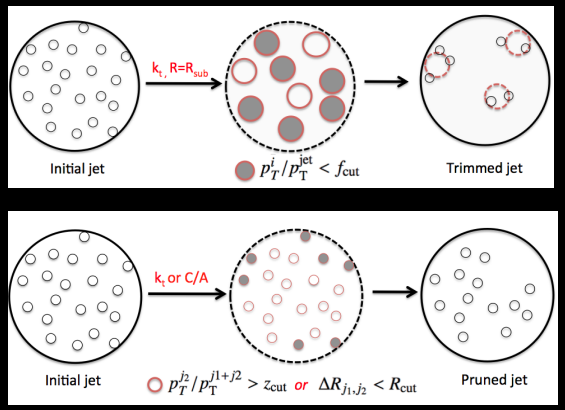
Jet Shapes

$$OV_3 = \max_{\{\tau_n\}} \exp\left[-\sum_{i=1}^{3} \frac{1}{2\sigma_i^2}\left(E_i - \sum_{\substack{\Delta R(\mathrm{topo},i) \\ <0.2}} E_{\mathrm{topo}}\right)^2\right]$$

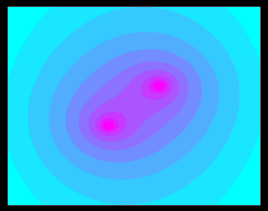
$$\tau_N = \frac{1}{d_0}\sum_k p_{T,k} \min\left\{\Delta R_{1,k}, R_{2,k}, \cdots, R_{N,k}\right\}$$

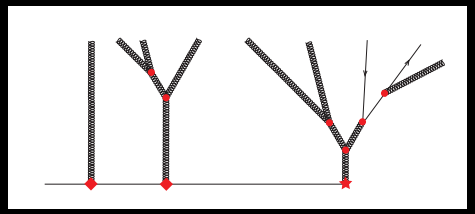
$$\Delta\mathcal{G}(R) \equiv R\,\frac{\sum_{i\neq j} p_{Ti}p_{Tj}\Delta R_{ij}^2 K(R-\Delta R_{ij})}{\sum_{i\neq j} p_{Ti}p_{Tj}\Delta R_{ij}^2 \Theta(R-\Delta R_{ij})}$$

Grooming

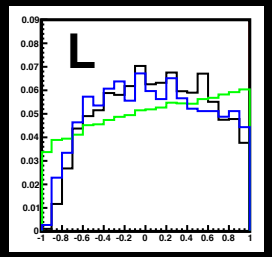


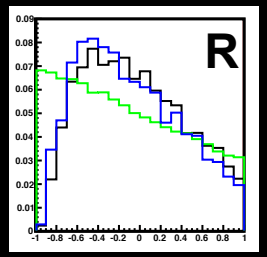
Color-flow / Radiation pattern





Polarization



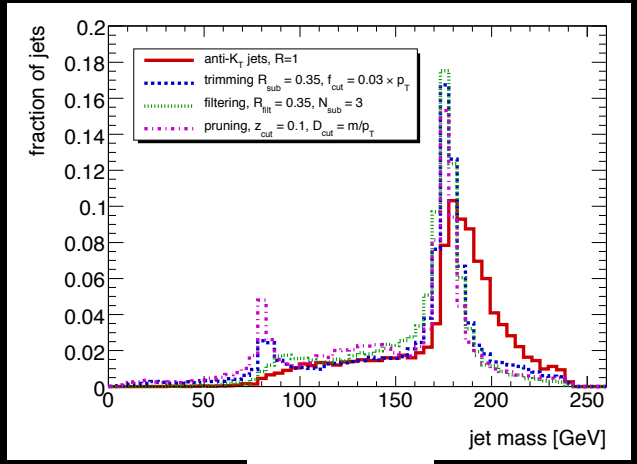


* Comparisons of taggers in BOOST2010/2011 proceedings, and in some individual papers

Boosted Tops as a Laboratory

- Behavior of groomers on boosted heavy particle decays
  - how do these affect our ability to see Higgs, RPV neutralino, etc?
- Color-sensitive variables, jet-charge variables
- Test new substructure techniques

BOOST2010 simulation of different groomers



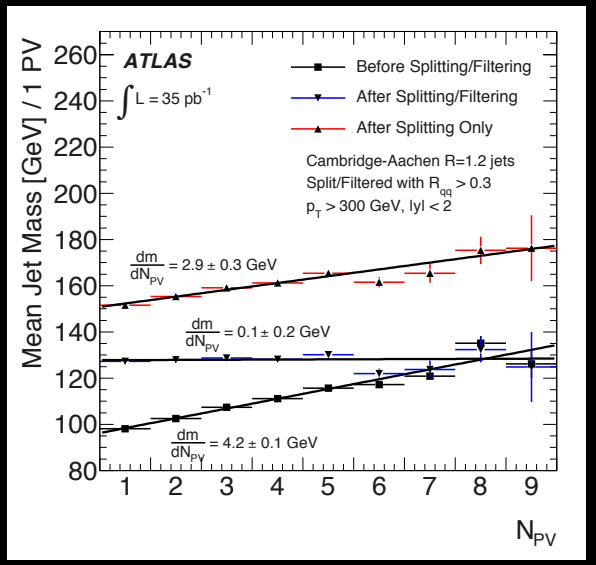
Experimental Issues

- Pileup
  - how effective are groomers? what settings?
- Calibration
  - unlike normal jet clustering, need accurate *local* calibrations
  - CMS: particle-flow, ATLAS: topo-clusters
- Finite detector resolution
  - HCAL cells ~0.1x0.1
  - is this the ultimate cutoff?

Much Has Now Been Measured

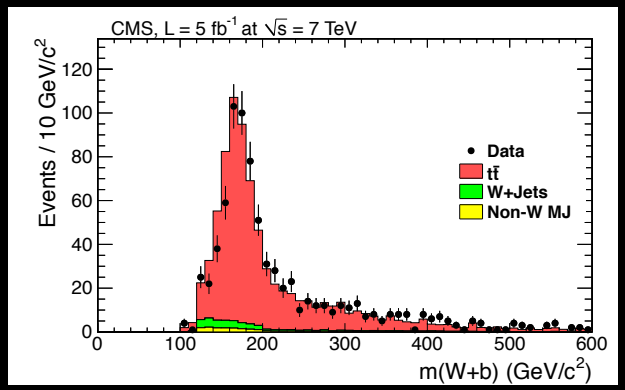
- Jet mass
- Subjet-pair masses
- Internal k_T scales
- N-subjettiness
- Subjet multiplicities
- Top-mistag rates in-situ (tag-and-probe)
- ....

ATLAS QCD jets declustered/filtered (1203.4606)

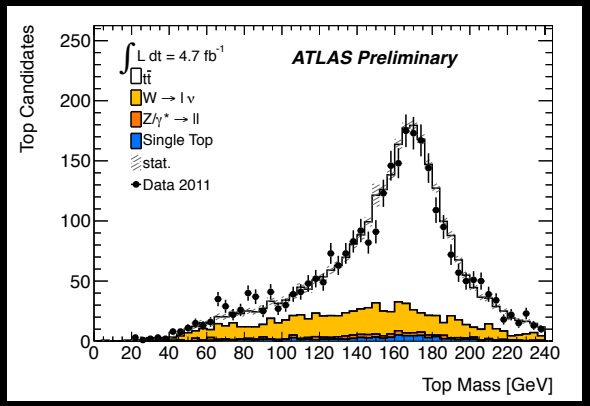


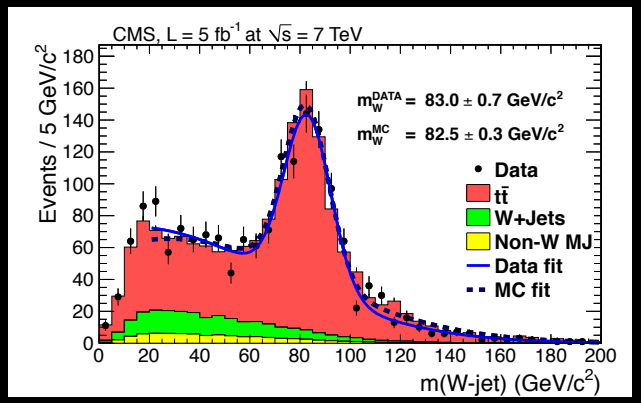
Rediscovering the Hadronic Top and Hadronic W

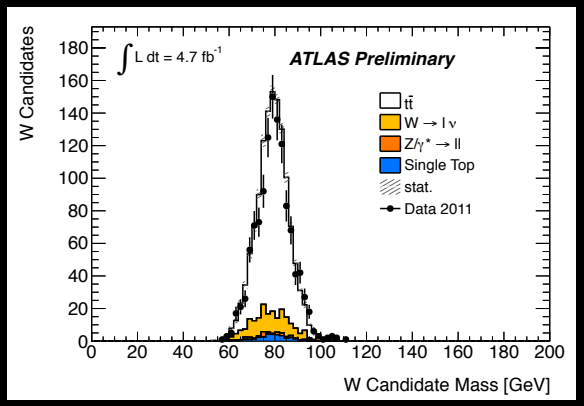
CMS: pruned W-jet plus nearby jet (1204.2488)



ATLAS: HEPTopTagger (1211.2202)



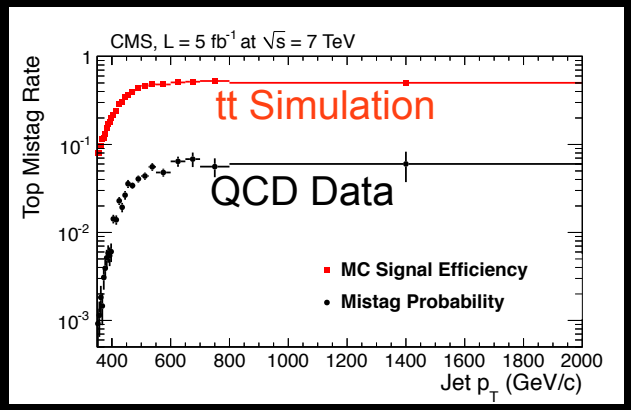




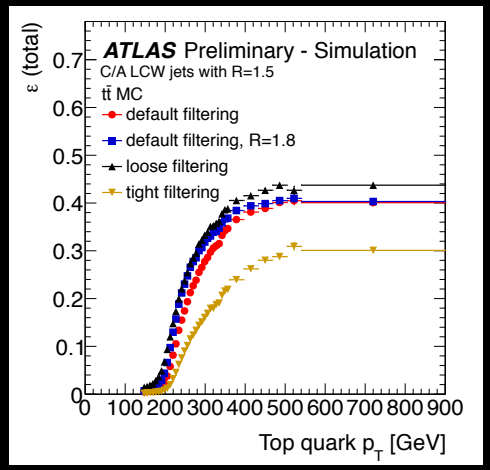
μ+jets control samples with b-tag

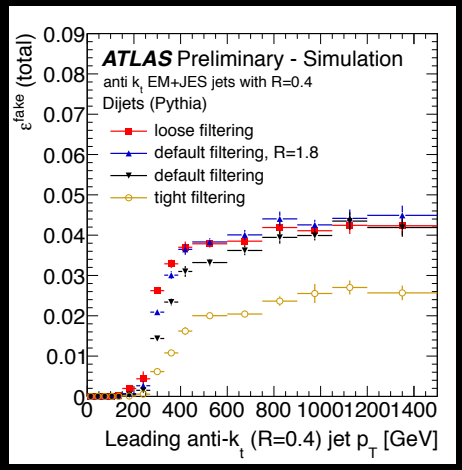
Top-Tagger Performance

CMS



ATLAS: HEPTopTagger simulation

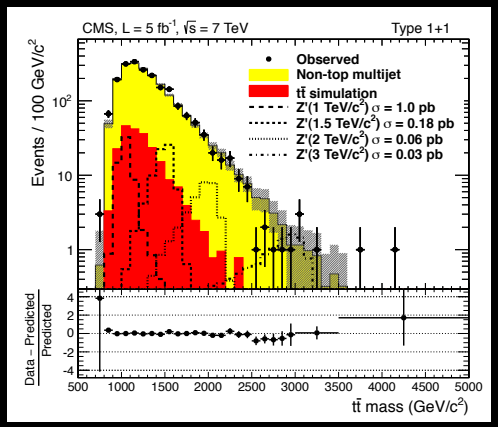


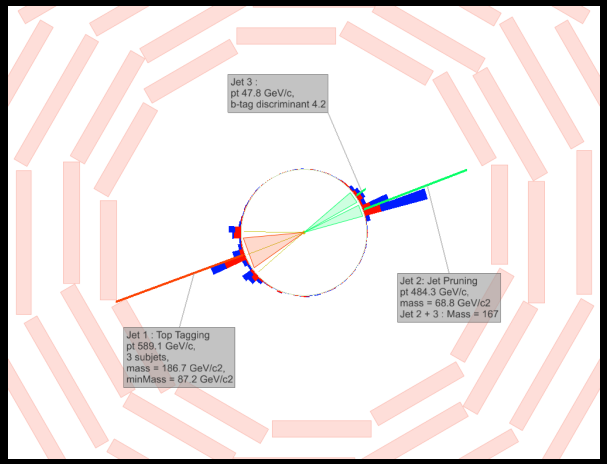


tag rate ~ 50%
mistag rate ~ 5%

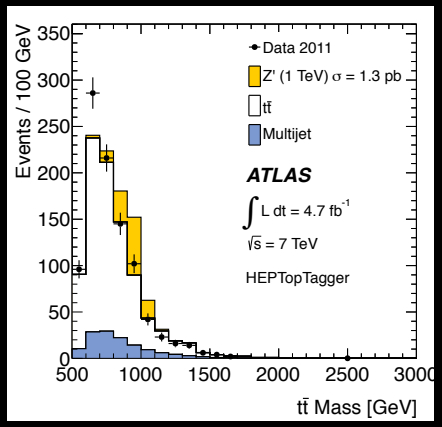
Application: tt Resonance Searches

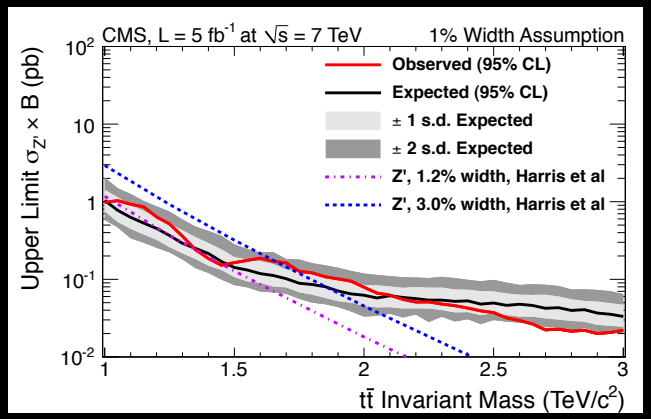
CMS (1204.2488)

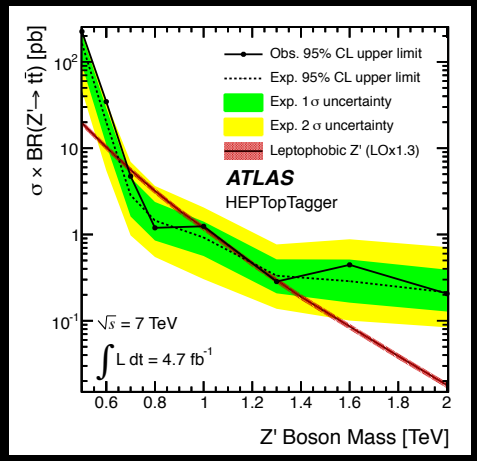


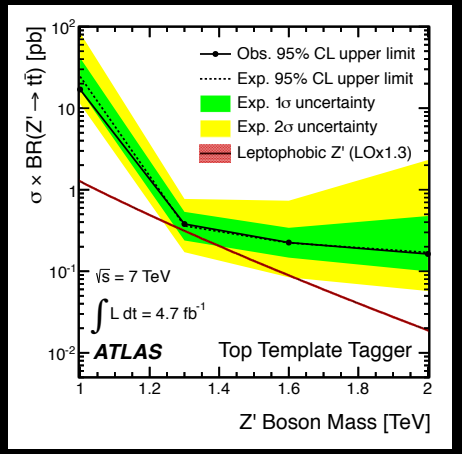


ATLAS (1211.2202)









All-hadronic searches are now possible!

Questions

- Future applications: What's being done? What's not being done that *should* be done?
  - contact interaction limits (centrality ratio?)
  - stops: helpful for highest masses at LHC8? seems inevitable for LHC14...
  - single top-partner (*I'm working on this)
- Future improvements possible?
  - can we still use b-tagging, even loose? (lepton seems robust)
  - more info from radiation pattern (or as testbed for h → bb variables)
  - overcoming detector granularity
- Longer-term: How hard must we work to top-tag at ILC/CLIC?
  - at high $\sqrt{s}$, N(tt)/N(qq) ~ 1/6
  - different detectors, different "pileup" conditions