Title: Boson Tagging with Wavelets

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Abstract: I'll present a proof-of-concept new technique for tagging boosted objects which decay into two colored particles based on the wavelet transform. It is able to moderately improve the sensitivity of searches for such particles by 6-7%. I will also discuss future directions of applicability.

Why Boosted Bosons?

- Cleaning out signal from background is very hard for hadronic final states
  - How can we tell a hadronic Higgs or W/Z apart from a quark or gluon? In the high-Pt regime we get one hard jet for each of these
  - Can require leptonic decays, but lose statistics
- Heavy particles decaying to electroweak bosons will always put us in this boosted situation

Why Boosted Bosons?

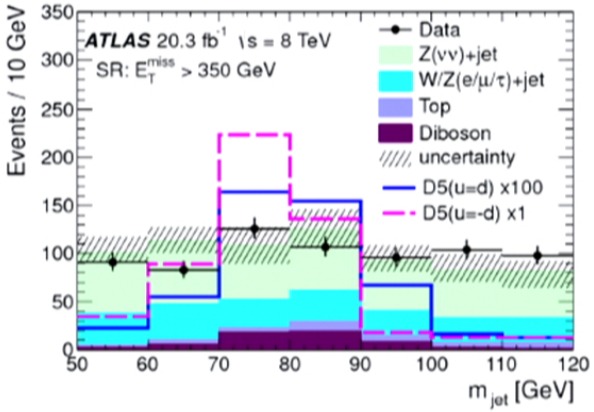
- Strong dynamics/Composite Higgs models
  - Generically have new weak boson resonances
- SUSY decays
  - Often have W/Z/H late in decay chain
- WW scattering probes
  - Verify unitarization
- ttbar resonances
  - FB Asymmetry, RS gluon, Topcolor, or…

Sampling of Applications

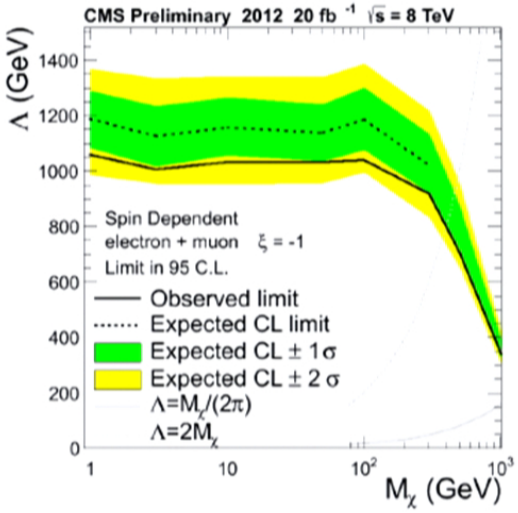
- A search for tt resonances in the lepton plus jets final state ATLAS-CONF-2013-052
- Search for pair production of heavy top-like quarks decaying to a high-pT W boson and a b quark in the lepton plus jets final state ATLAS-CONF-2013-060
- **Search for dark matter in events with a hadronically decaying W or Z boson and missing transverse momentum arXiv:1309.4017**

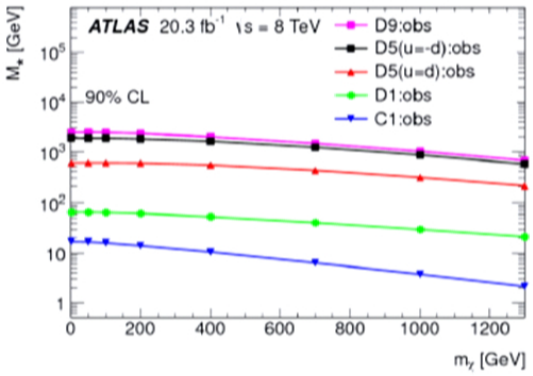
Boosted Boson DM Search

- Search for boosted hadronic bosons and missing energy
  - Two layers of boosted object tagging
    - Jet mass cut
    - Mass drop cut

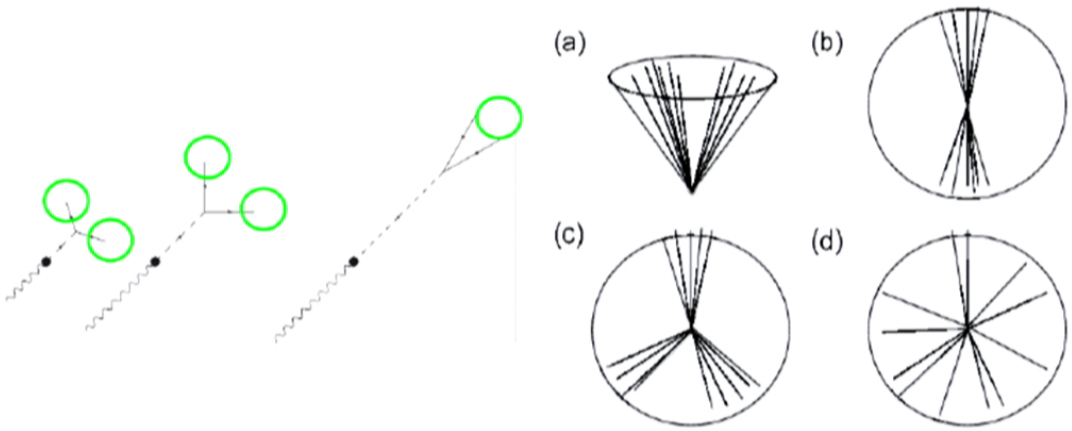


Boosted Boson DM Search





What are we Looking For?



Existing Techniques

Jet Mass Cut

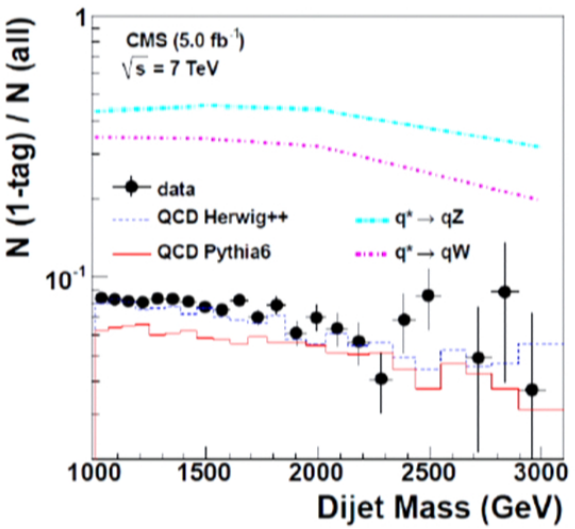
- Require jet mass to be close to the boson mass
  - On-shell boson sets jet mass
  - QCD jets have spread in mass
- Window generally of about 30 GeV width

Mass Drop Cut

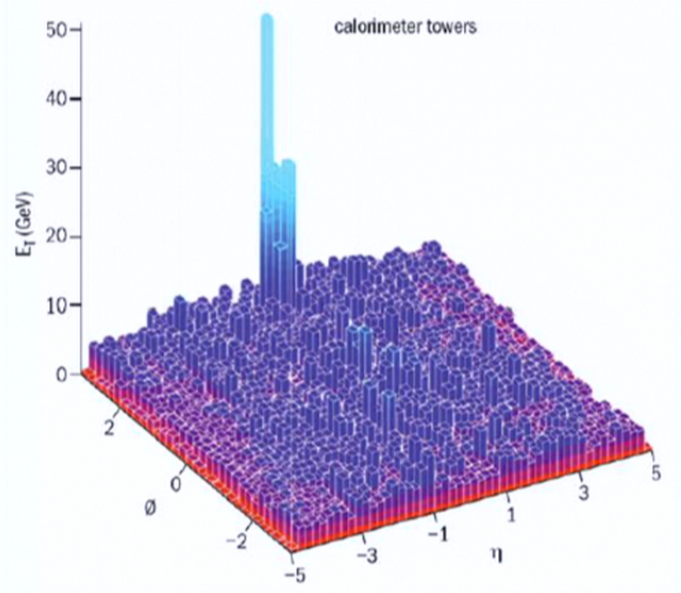
- Back up jet algorithm step by step
- Check mass before and after each step
- If mass drops significantly then tag jet as boson
- This finds jets that have well-separated subprongs

Current Tagging Performance

- Current study for Wj resonances in a highly boosted regime
- For a W acceptance of ~35% they have a jet mistag rate of ~8-10%
  - CMS arxiv/1212.1910



What do we see?

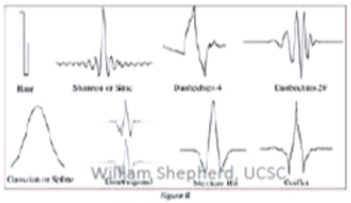


What do we see?

What do we see?

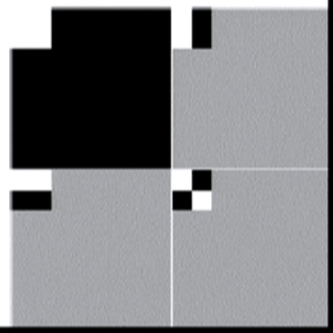
Wavelets

- Wavelets are a kind of localized Fourier transform
- They are particularly good at edge detection
  - Used e.g. in Fermi collaboration to measure bubbles and tag point sources
- Can be used for image compression, washing out features smaller than some scale
  - A part of the JPEG 2000 compression standard

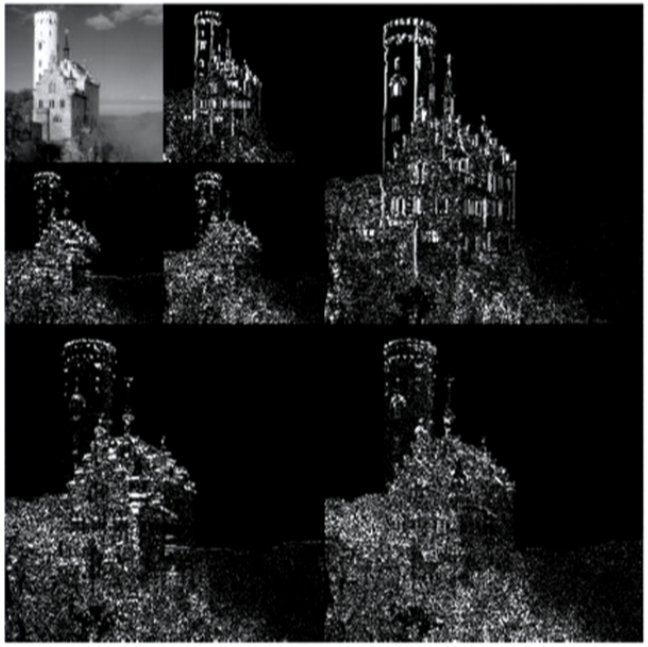


2D Wavelets

- Discrete images (like calorimeters with cells) lend themselves to the Haar wavelet basis
- In two dimensions there are four basis elements
  - Father Wavelet or scaling function
  - Horizontal, Vertical, and Diagonal



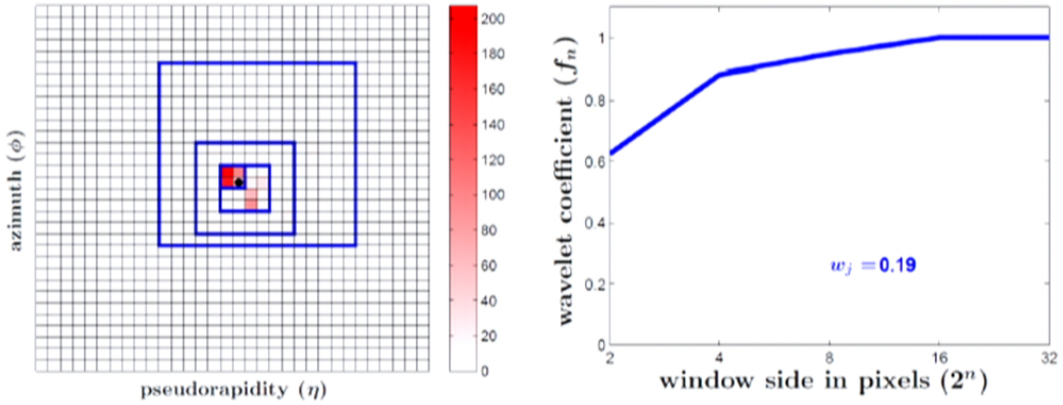
Wavelet Transform



Regions of Interest

- Averaging over an entire calorimeter loses the position-sensitivity of wavelets
- We use a standard jet algorithm (C-A jets) and use the jet's direction to choose a cell
- We look at the father wavelets that include the cell of interest, and keep the highest value at each size

Typical QCD Jet

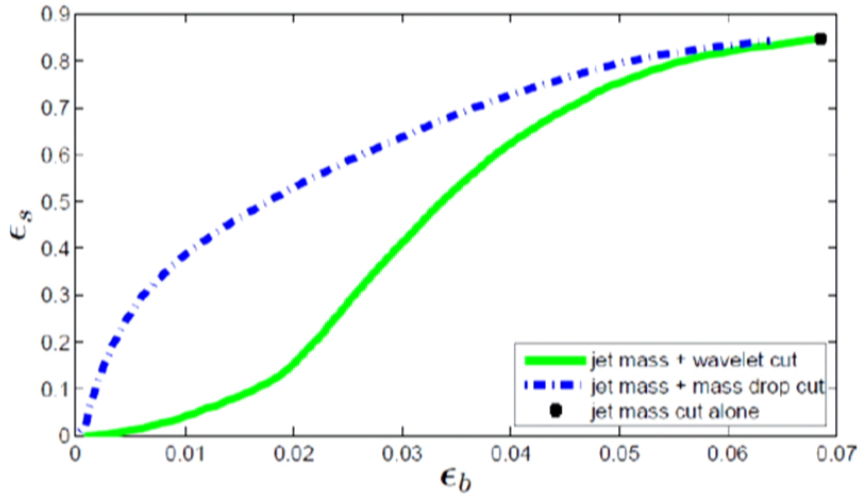


What's the Cut?

- While the two events are easy to tell apart by eye, the trick is to find something algorithmic
  - Experimental collaborations are big, but datasets are much bigger
- The 'power curves' are easier to analyze numerically
- We look at a discrete second derivative

$$w_j \equiv \mathrm{Max}\Big\{\, |f_3 - 2f_2 + f_1| \,,\;\; |f_4 - 2f_3 + f_2| \,\Big\}$$

Wavelet Tagging Results



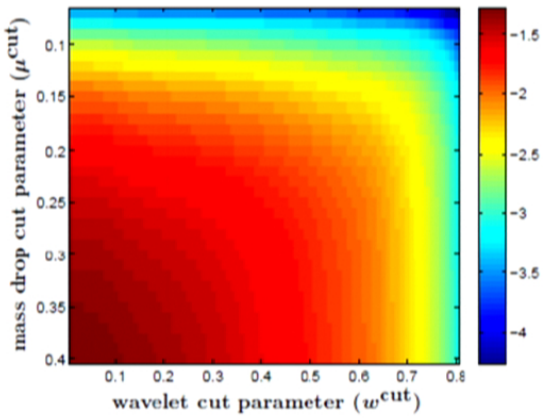
Why are we doing this?

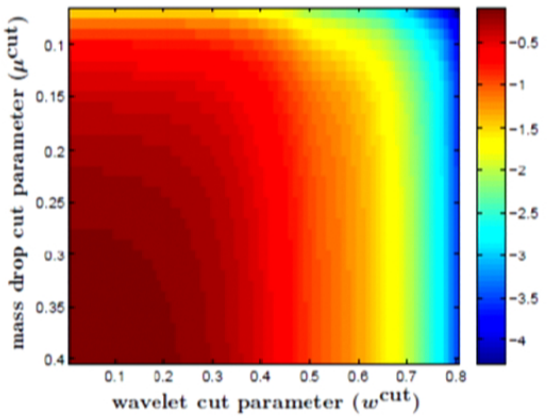
A Real Analysis

- In the real world, we can apply more than one cut at once, e.g. ATLAS's high jet multiplicity search (1308.1841)
  - Actually quite simple set of cuts

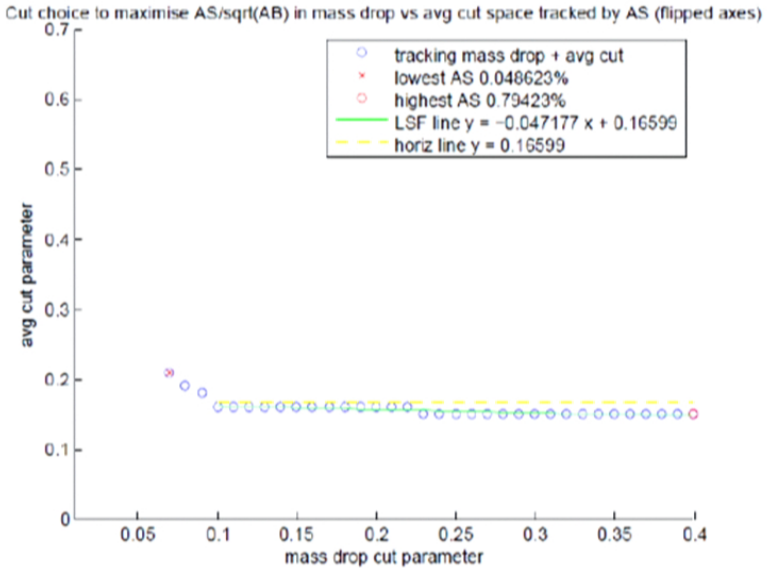
	Multi-jet + flavour stream									Multi-jet + M_J^Σ stream		
Identifier	8j50			9j50		≥ 10j50	7j80		≥ 8j80	≥ 8j50	≥ 9j50	≥ 10j50
Jet $\|\eta\|$	< 2.0						< 2.0			< 2.8		
Jet p_T	> 50 GeV						> 80 GeV			> 50 GeV		
Jet count	$= 8$			$= 9$		≥ 10	$= 7$		≥ 8	≥ 8	≥ 9	≥ 10
b-jets ($p_T > 40$ GeV, $\|\eta\| < 2.5$)	0	1	≥ 2	0	1	≥ 2	—	0	1	≥ 2	0	1	≥ 2	—		
M_J^Σ [GeV]	—						—			> 340 and > 420 for each case		
$E_T^{miss}/\sqrt{H_T}$	> 4 GeV$^{1/2}$						> 4 GeV$^{1/2}$			> 4 GeV$^{1/2}$		

Boosted Boson Cut Space

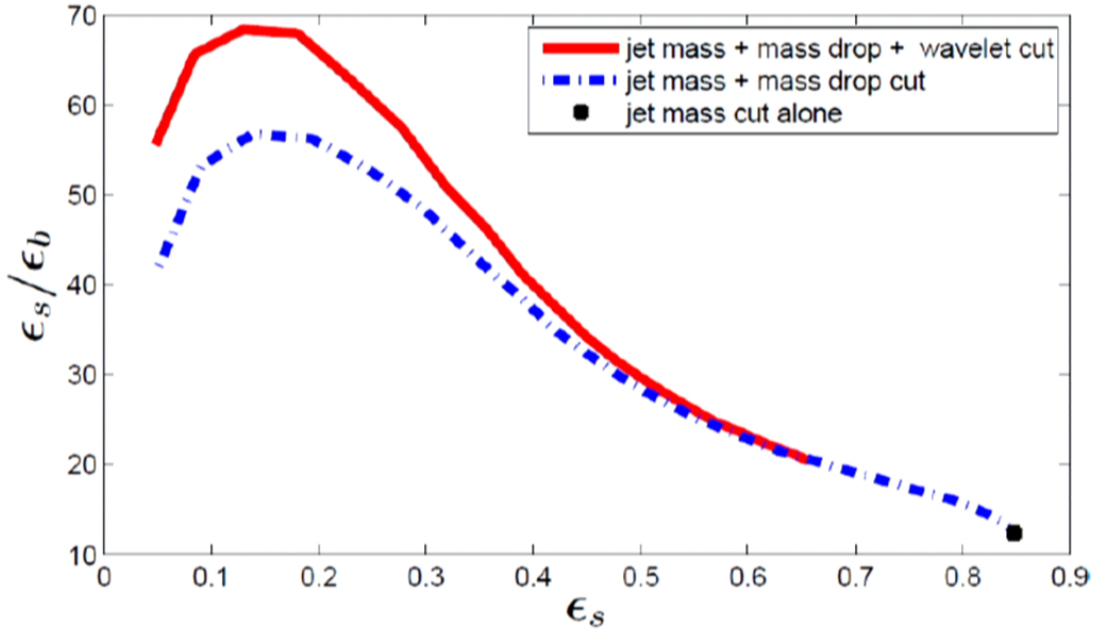




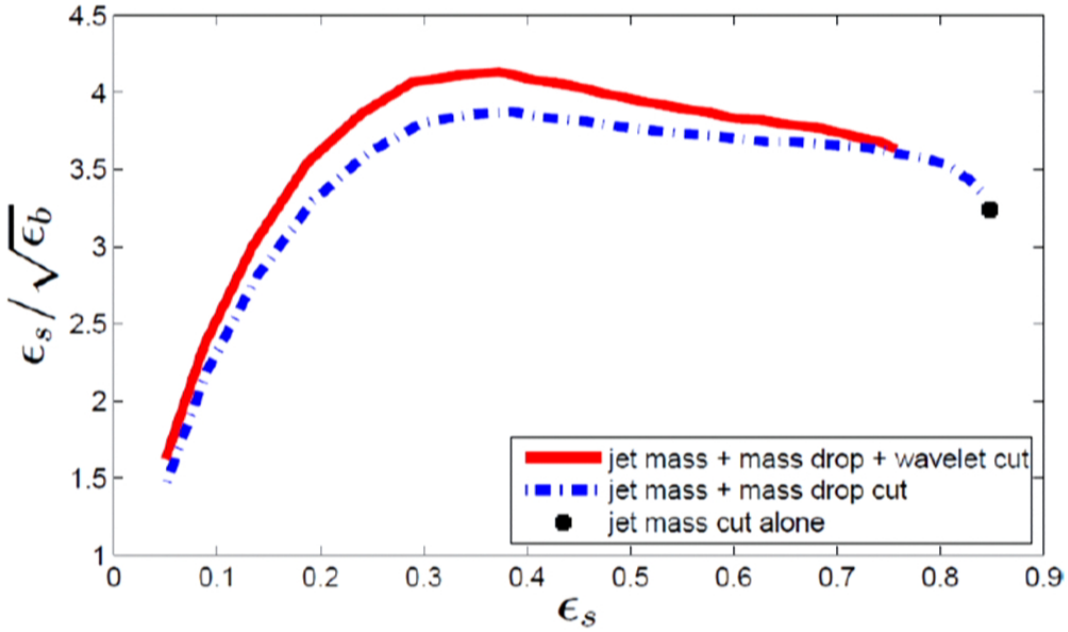
Optimized Cuts



Combined Results – Possible Purity



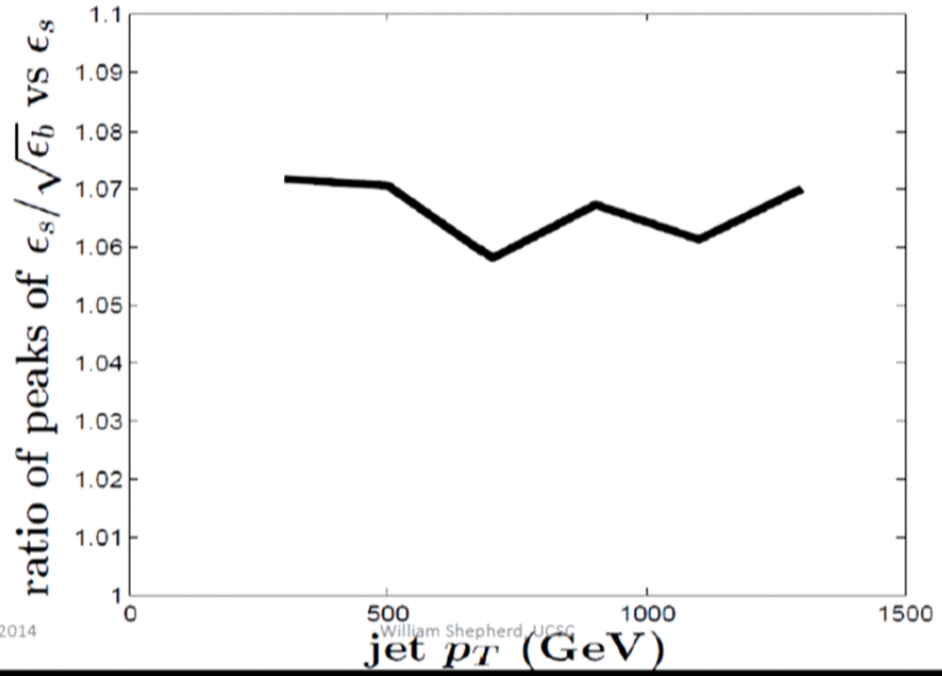
Combined Results – Discovery Reach



4/15/2014

William Shepherd, UCSC

Discovery Reach Gain



Future Directions

- This is a proof of concept, but other wavelet-based techniques may be even better taggers
- Opening angle can be an alternative measure of PT, can this be exploited?
- Asymmetry in prong energy is an indication of the polarization of the boson
- Generalization to include more complicated boosted objects

Conclusions

- Boosted bosons are a powerful probe of new physics, and wavelets can improve our tagging
  - Independent of jet algorithms, complementary to deconstructive techniques like the mass drop tag
- Watch for a Fastjet plugin to apply these techniques