Tracking the Identities of Boosted Objects

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W/ Matt Schwartz: arXiv:1111.xxxx
(also 1012.2077, w/ Y.Cui and M.Schwartz)

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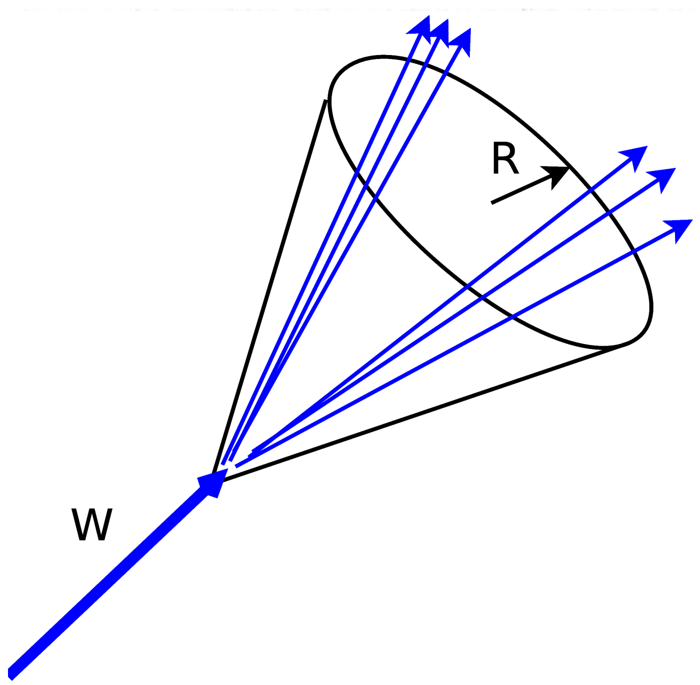
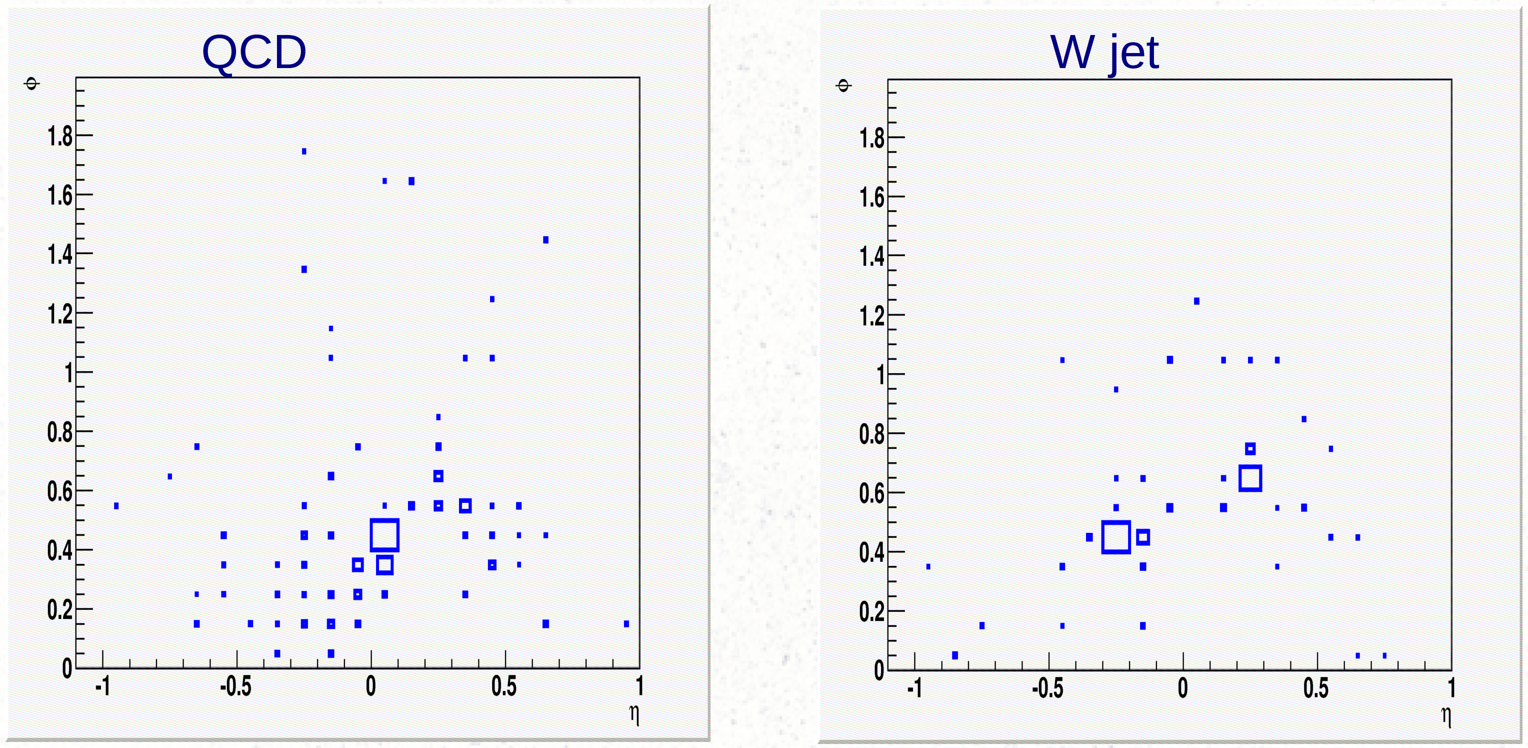
Motivation

- Boosted W's , Z's essential for studying TeV scale physics
  - WW scattering may become the most important measurement at the LHC
  - Boosted particles from heavy particle decay: Z' -> WW, t'->bW, etc.
- Hadronically decaying boosted W's, Z's, tops behave like a single jet at the LHC
  - Need to distinguish from QCD jets
  - Focus on W jets in this talk



Two differences between W jets and QCD jets

- Two hard subjets (filtering, trimming, pruning...)
- Color singlet (R-cores, *Y.Cui, ZH, M.Schwartz*)



Group the energy in 0.1x0.1 bins on (eta, phi) plane.
Jets found using R=1.2, C/A.
QCD jet from W+j->lvj, W-jet from WW->lvjj, Madgraph+Pythia 8

Using tracking information

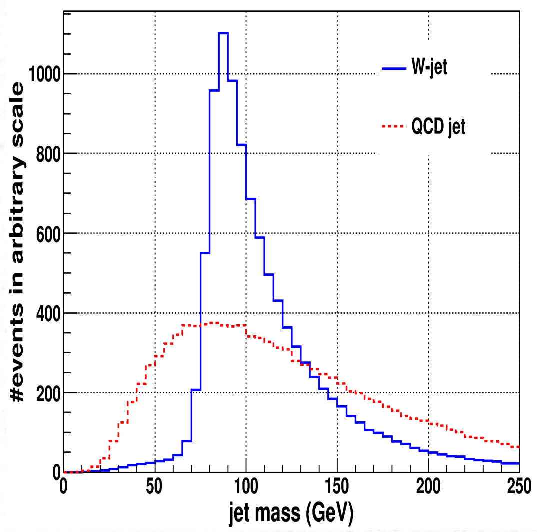
- HCAL assumed in most studies: 0.1x0.1 binning in (eta, phi)
- Tracking information very useful
  - Better resolution, finer granularity
  - Easier with pile-up: tracks from the primary vertex
  - Measures individual charged particles, manifests color connection

Outline

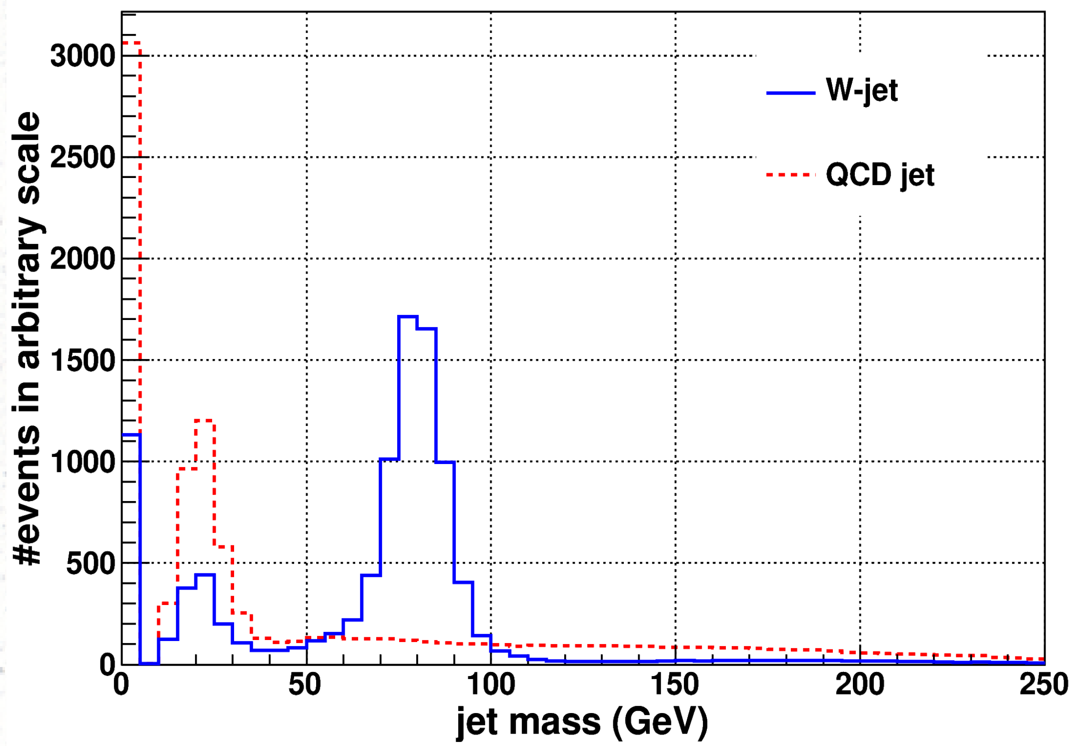
- Brief review of previous studies
- Identify W's using the tracking information
  - Lessons from LEP
  - LHC performance
- Conclusions

Identify subjets: jet grooming

- Filtering,trimming, pruning...
- Start from a fat jet with larger R, use smaller R to recluster, discard soft 'subjets' (Butterworth, Davison, Rubin &Salam)
- W: 2 hard subjets; QCD: 1 hard subjet



Jet mass (R=1.2),
pt~(500, 550)GeV

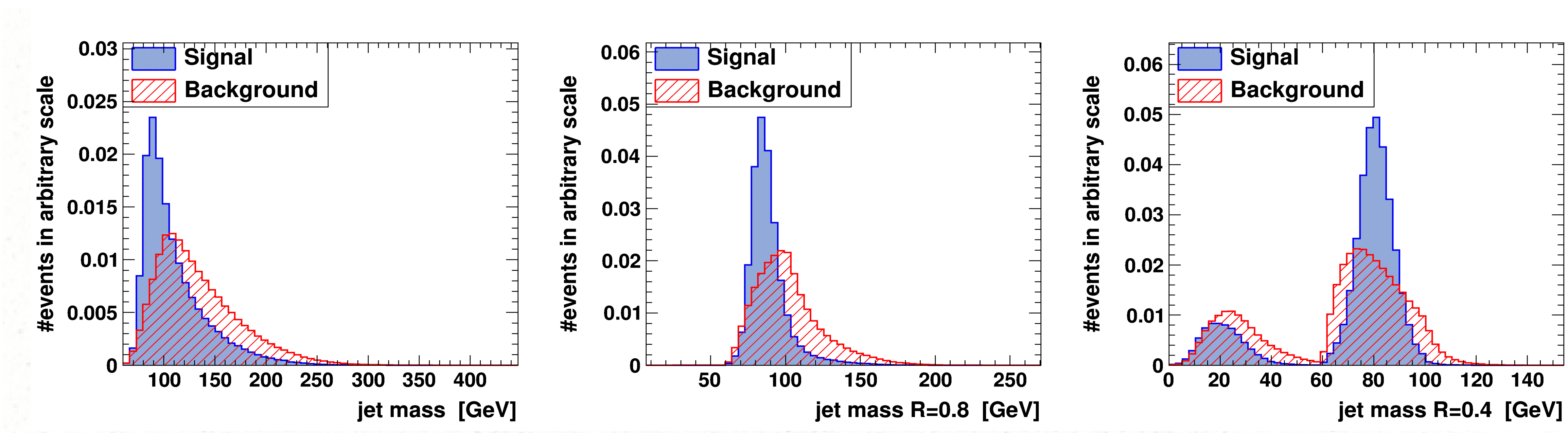


jet mass after filtering

Color connection

- W: color singlet, cleaner, radiation confined in a small cone; QCD: radiation more scattered

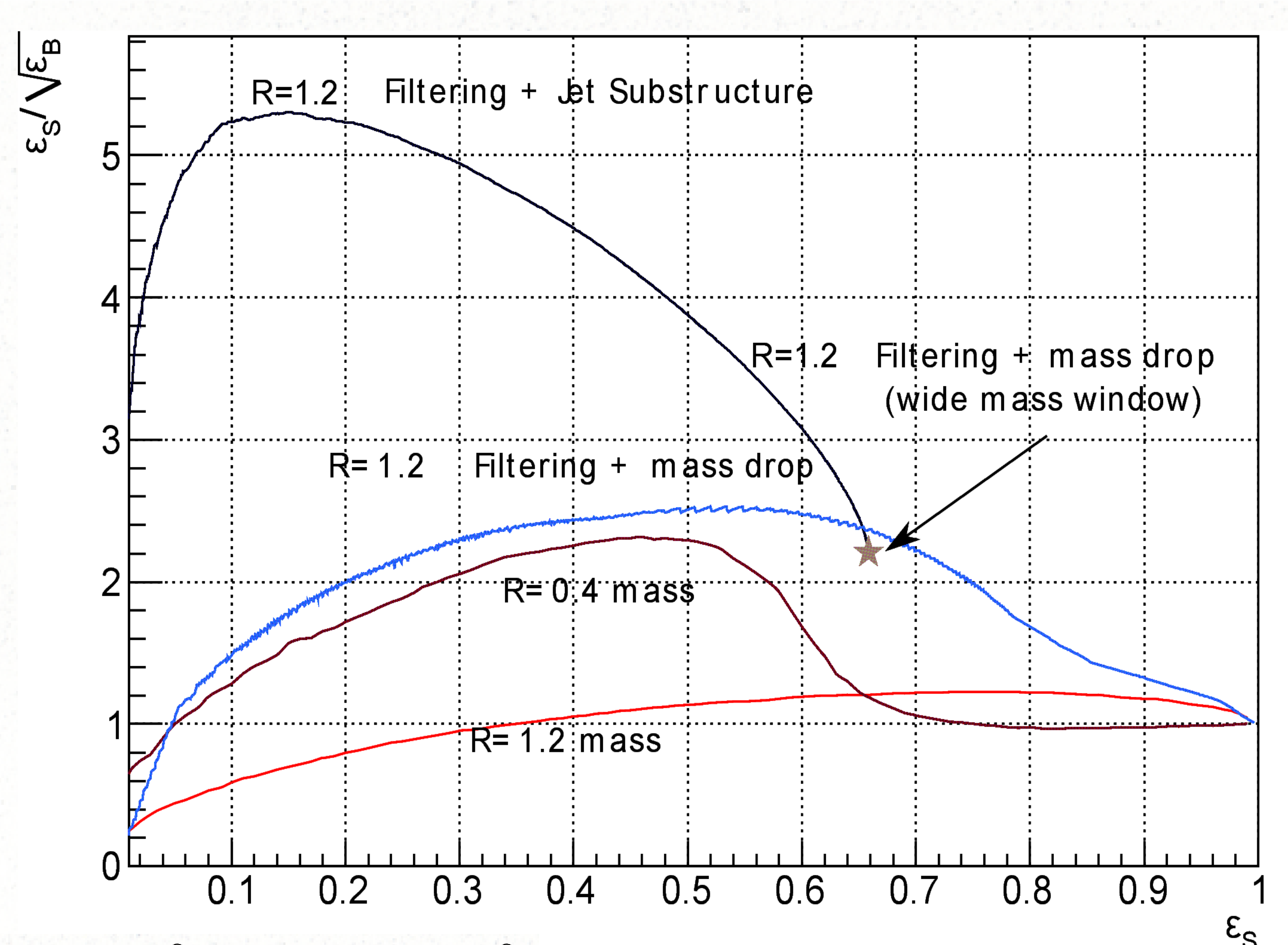
- R-cores: recluster the jet with a smaller R< Rfat, take $c_m(R) \equiv m(R)/m(R_{\text{fat}})$ (*Y.Cui, ZH, M.Schwartz, 2010*)



* For good W candidates: filtered mass (60, 100)GeV, PT=500GeV

Multivariate improvement

(*Y.Cui, ZH, M.Schwartz, 2010*)



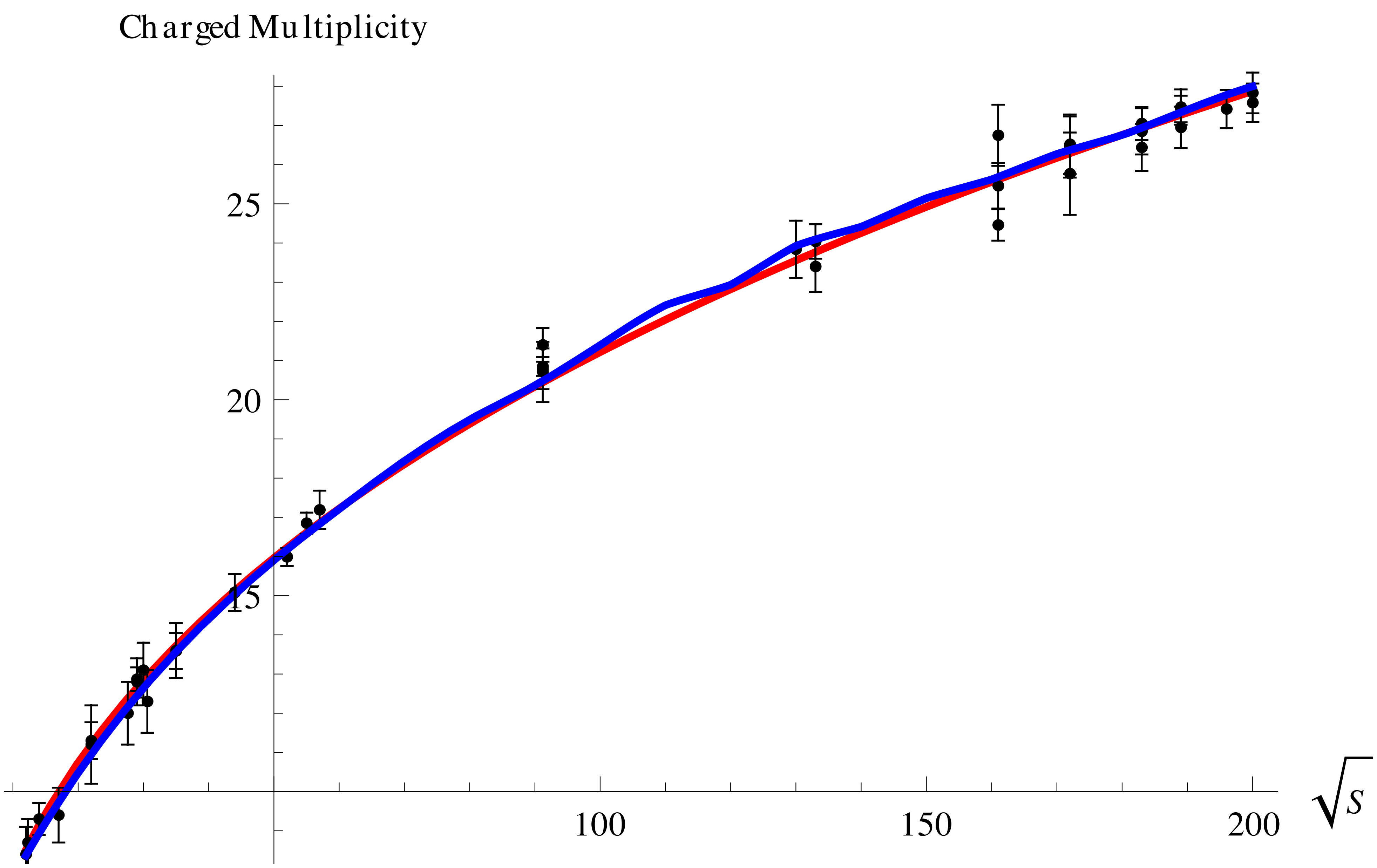
* $\varepsilon_S = n_S/n_S^0, \varepsilon_B = n_B/n_B^0$: signal and background efficiencies
* 25 variables used, jet pt (500, 550) GeV
* A smaller set of 7 variables give ~4.2

A factor of ~2 improvement over filtering for pt 200-1000 GeV

Variables using tracking

- Individual charged particles can be identified
  - Charged multiplicity
- All jet substructure variables can be defined for charged particles as well
  - Much better granularity than HCAL/ECAL. But cannot measure neutral particles--complementary information.
  - N-subjettiness as an example

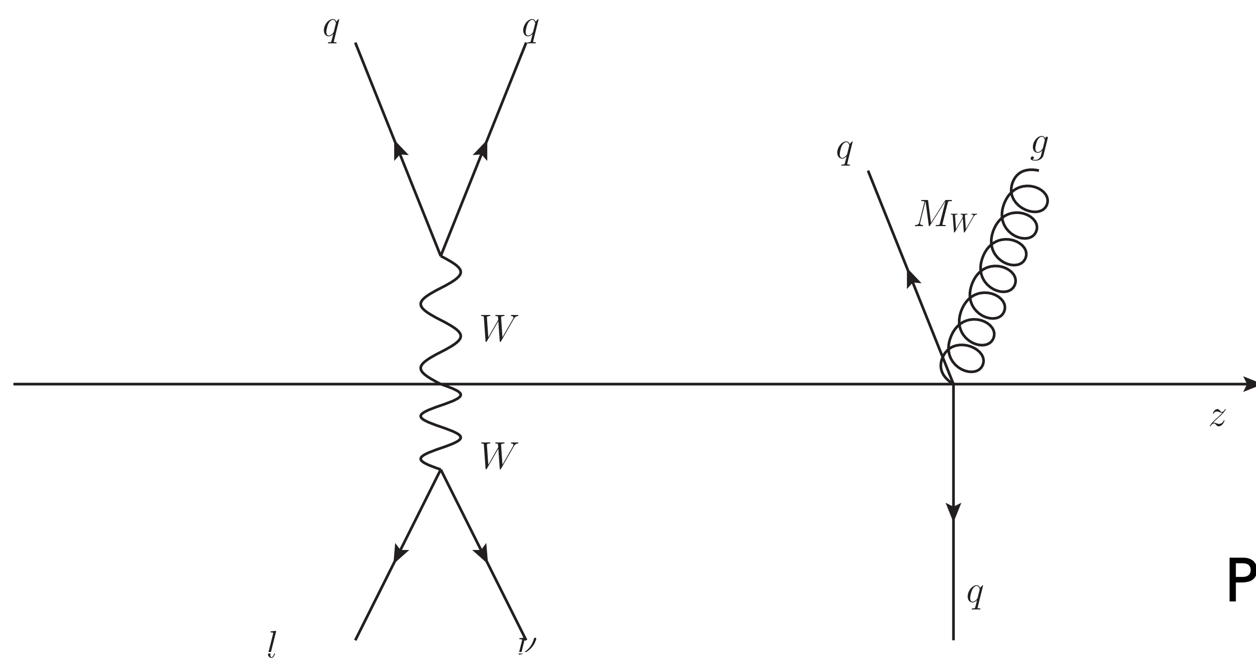
Charged multiplicity at e+e- machines



Points: experimental data, Red: MLLA+LPHD, Blue: Pythia 8

W jets *vs* QCD jets at high PT

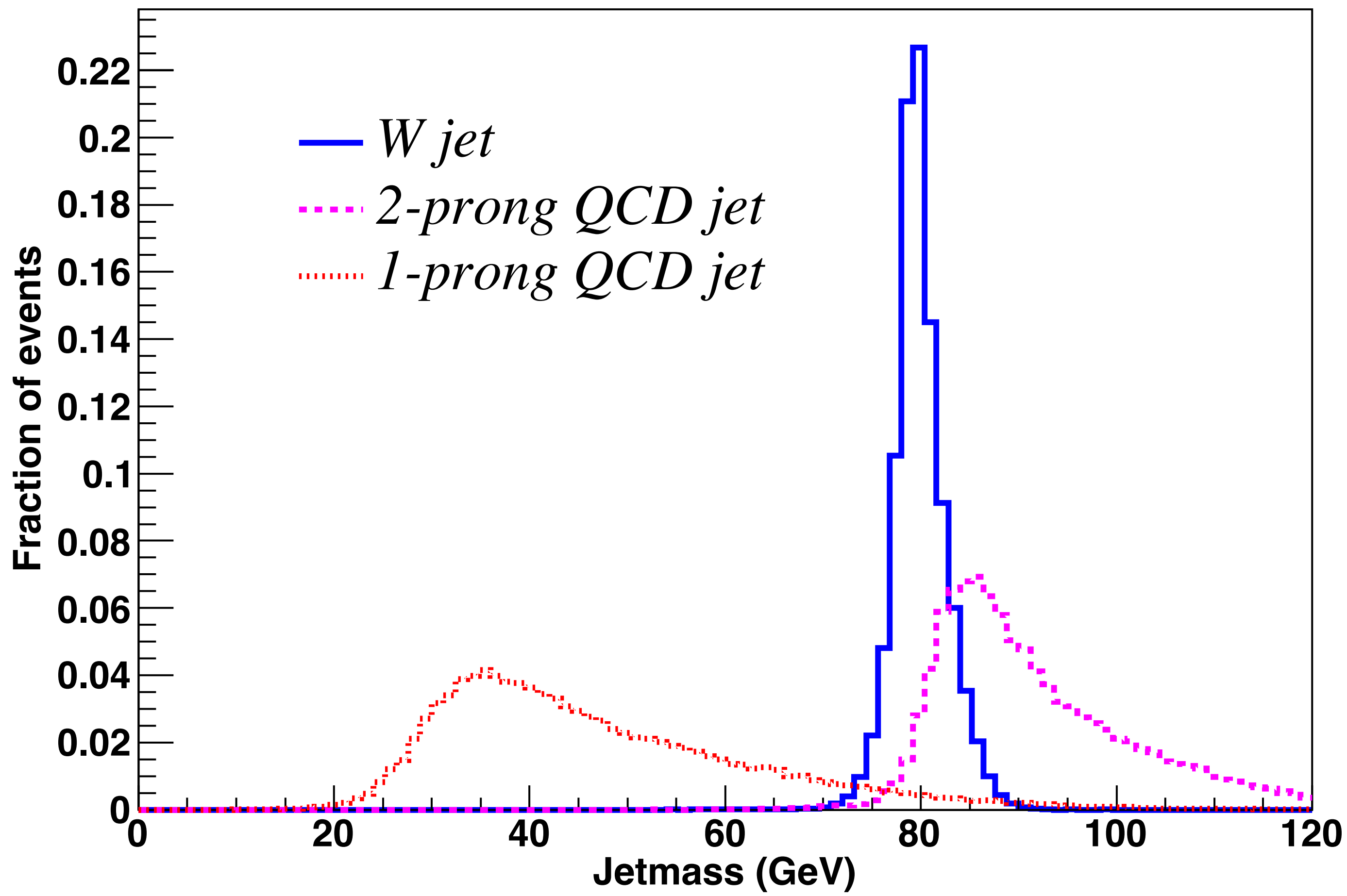
(e+e- machine)



PT=500GeV

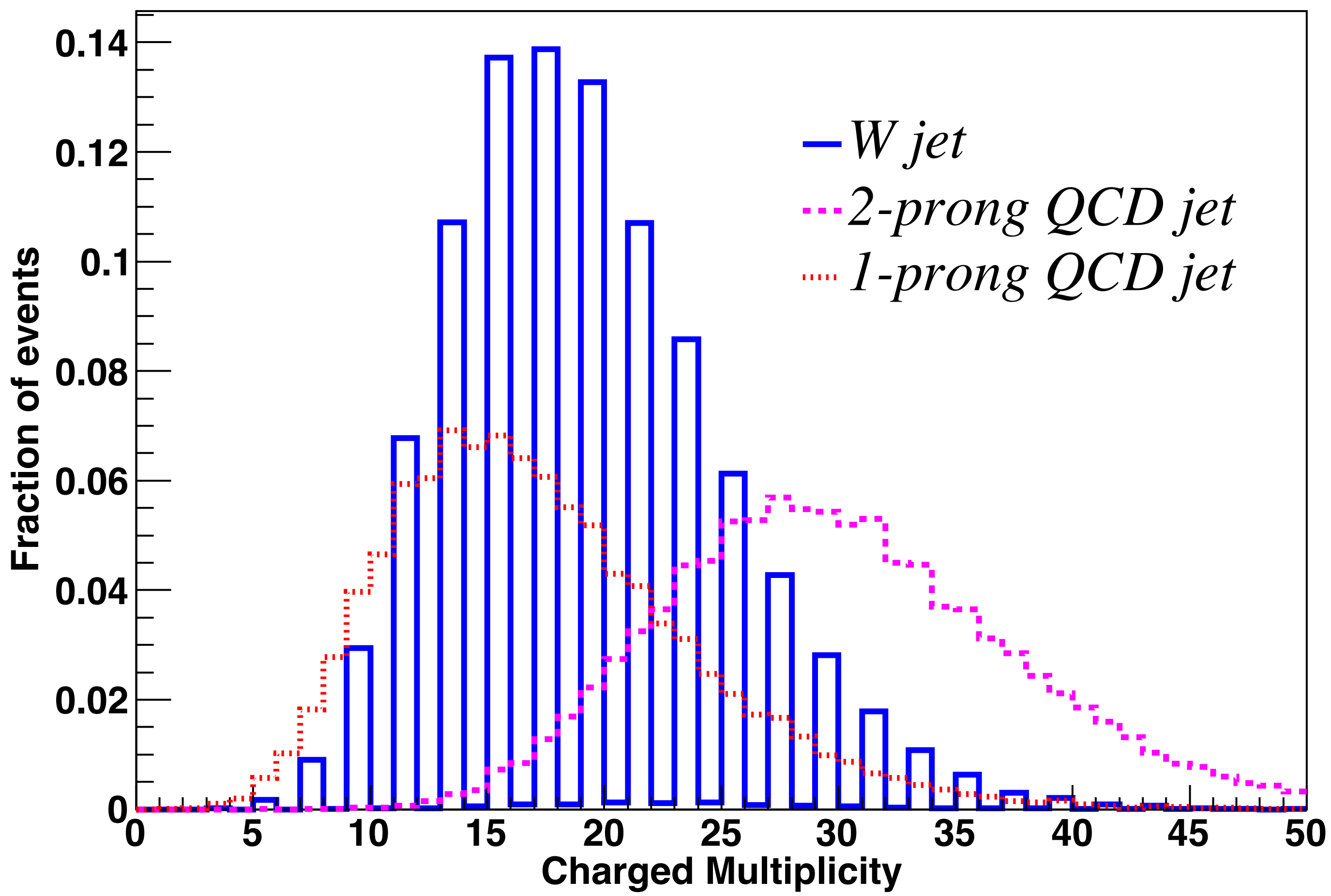
- Compare W-jets with QCD jet with (without) hard splitting, 2-prong (1-prong).
- Fix the momenta, simulate showering and hadronization over and over again with Pythia8

Jet mass



* Assumed 0.1x0.1 binning, R=1.2 jets

Charged Particle Multiplicity



N-subjettiness

(J. Thaler & K.V. Tilburg)

- Quantify how much a set of particles in a jet look like N subjets
  - For a set of particles and N axes, calculate the PT weighted sum of min distances (to some power beta)

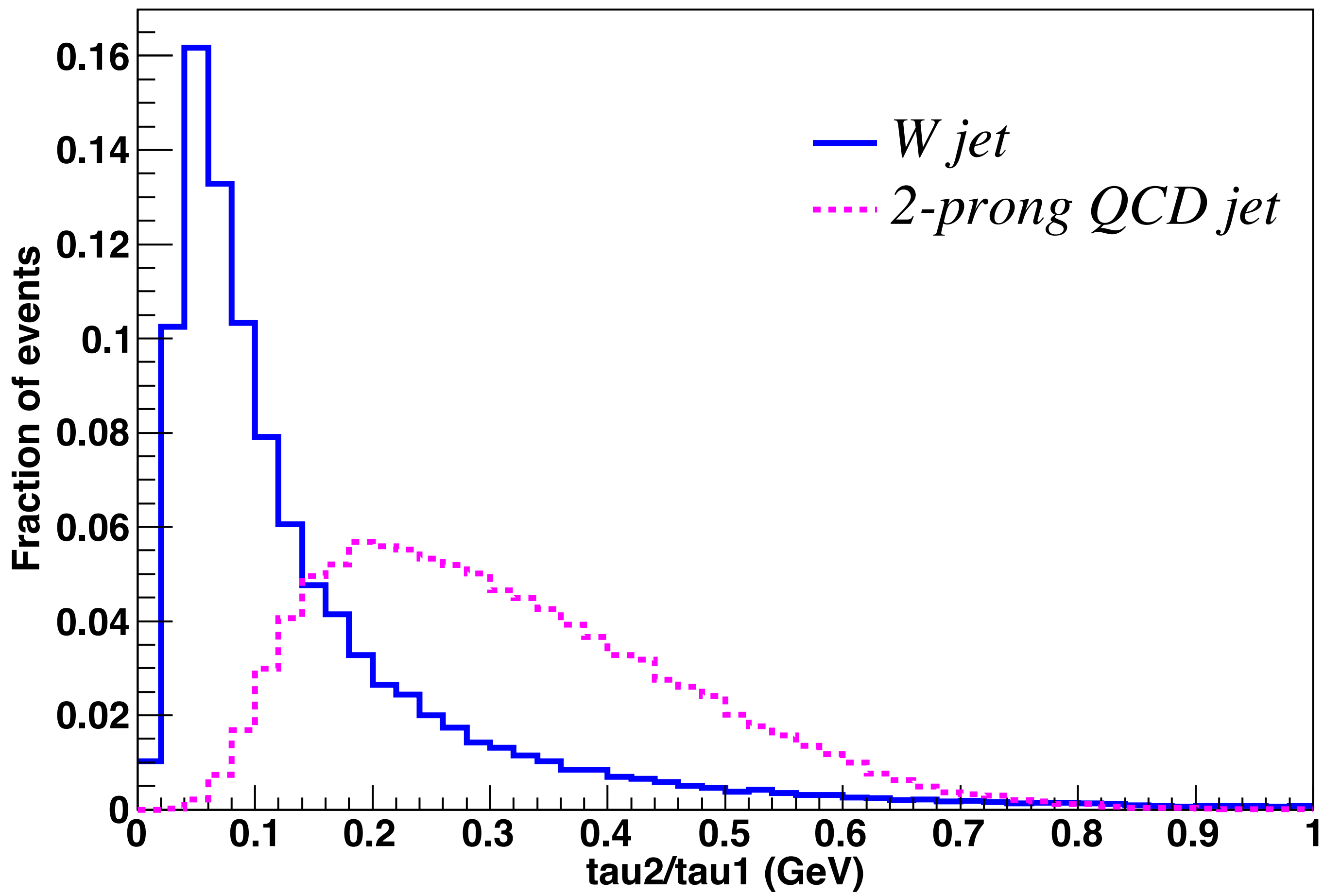
$$\tilde{\tau}_N^{(\beta)} = \frac{1}{d_0} \sum_i p_{T,i} \min \left\{ (\Delta R_{1,i})^\beta, (\Delta R_{2,i})^\beta, \ldots, (\Delta R_{N,i})^\beta \right\}$$

$$\Delta R_{J,i} = \sqrt{(\Delta y_{J,i})^2 + (\Delta \phi_{J,i})^2} \qquad d_0 = \sum_i p_{T,i} (R_0)^\beta \qquad R_0 \text{ Jet radius}$$

  - Vary the directions of the axes to find the minimum $\tilde{\tau}_N$

$$\tau_N^{(\beta)} = \min_{\hat{n}_1, \hat{n}_2, \ldots, \hat{n}_N} \tilde{\tau}_N^{(\beta)}$$

tau2/tau1

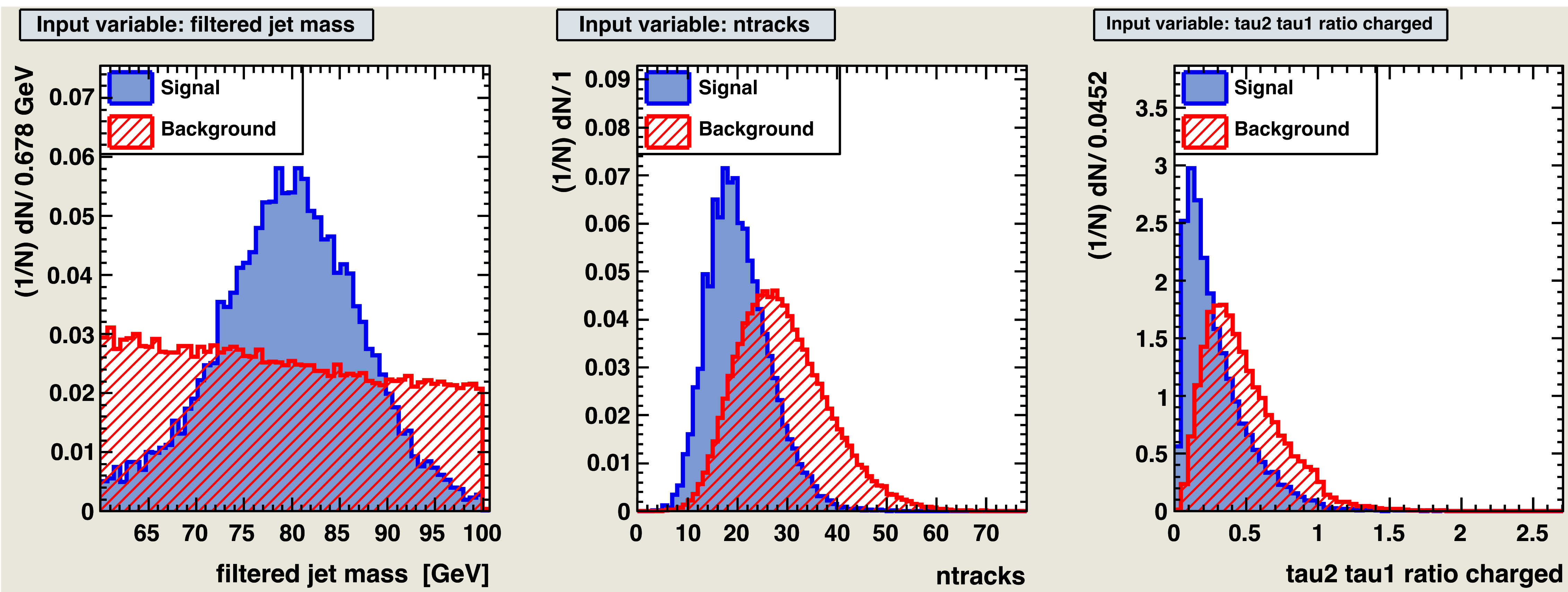


* Used charged particles only, no smearing.

Applications at the LHC

- More difficult: initial state radiation, underlying events
- Repeat the two-step procedure:
  - Events passed filtered mass cut (using HCAL info only): (60, 100) GeV
  - Use the variables to improve over the filtering result

Variables

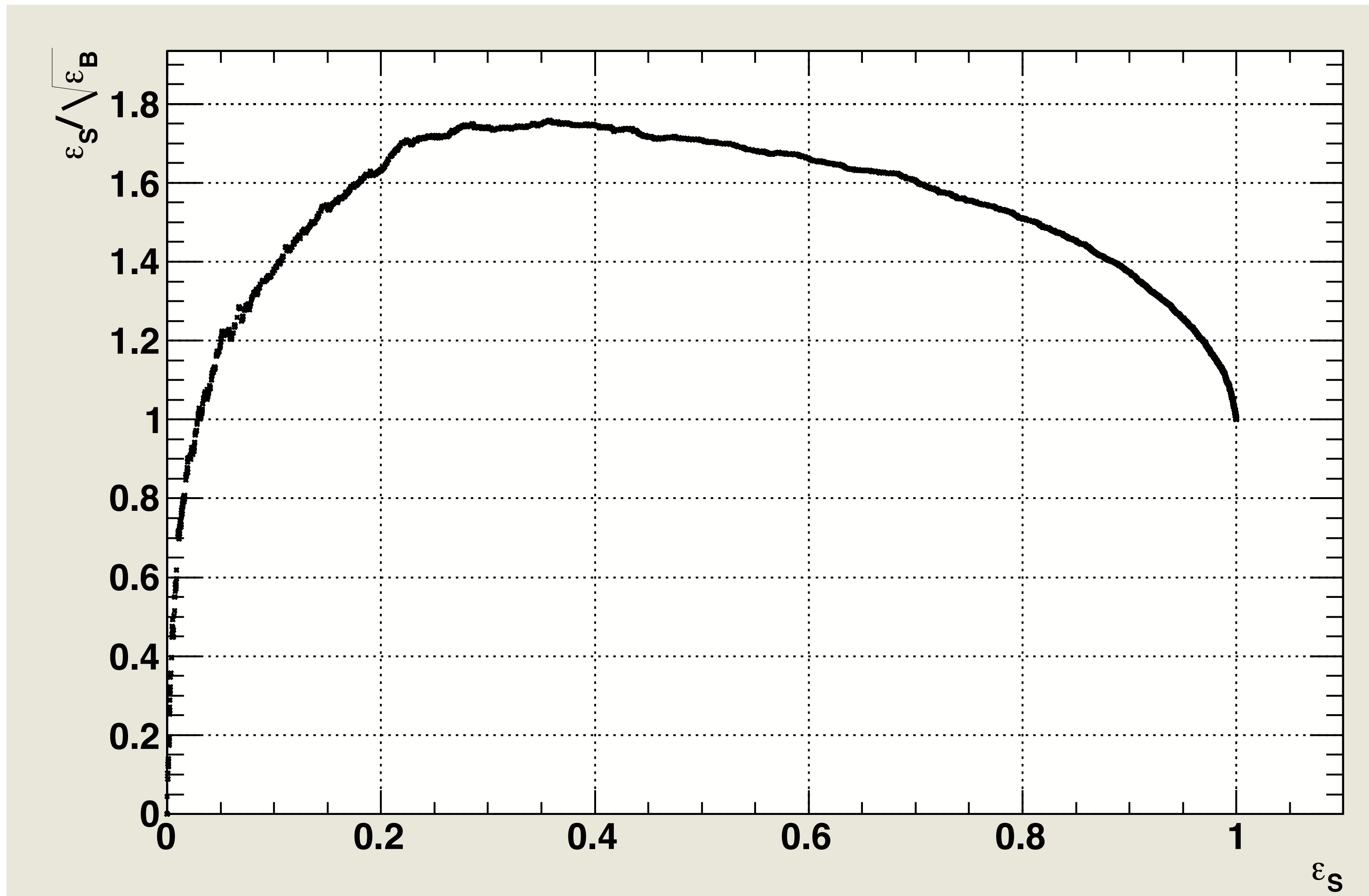


Input variable: filtered jet mass
(1/N) dN/ 0.678 GeV
Signal
Background
filtered jet mass [GeV]
Input variable: ntracks
(1/N) dN/ 1
Signal
Background
ntracks
Input variable: tau2 tau1 ratio charged
(1/N) dN/ 0.0452
Signal
Background
tau2 tau1 ratio charged

Performance

- Improvements over filtering for S/sqrt(B)
- Use single variables, rectangular cuts
  - filtered mass: 1.15, ntracks: 1.35, tau2/tau1: 1.35
- Combine two variables (Boosted Decision Tree)
  - filtered mass + ntracks: 1.63
  - filtered mass + tau2/tau1:1.59
  - tau2/tau1 + ntracks: 1.50

Combine all 3 variables



~1.75 improvement in significance at signal efficiency ~0.4, background efficiency ~0.05 (on top of filtering)

Discussions

- Did not include experimental resolution-- qualitatively insensitive
- Particle flow
- Z and Higgs the same
- Boosted top?
  - Not a color singlet, but contains a W --different from a 3 prong QCD jet

Conclusions

- Tracking information is very useful for measuring jet substructure and identifying boosted massive particles
- Variables defined with charged particles are simple and powerful
- Awaiting tests and applications at the LHC