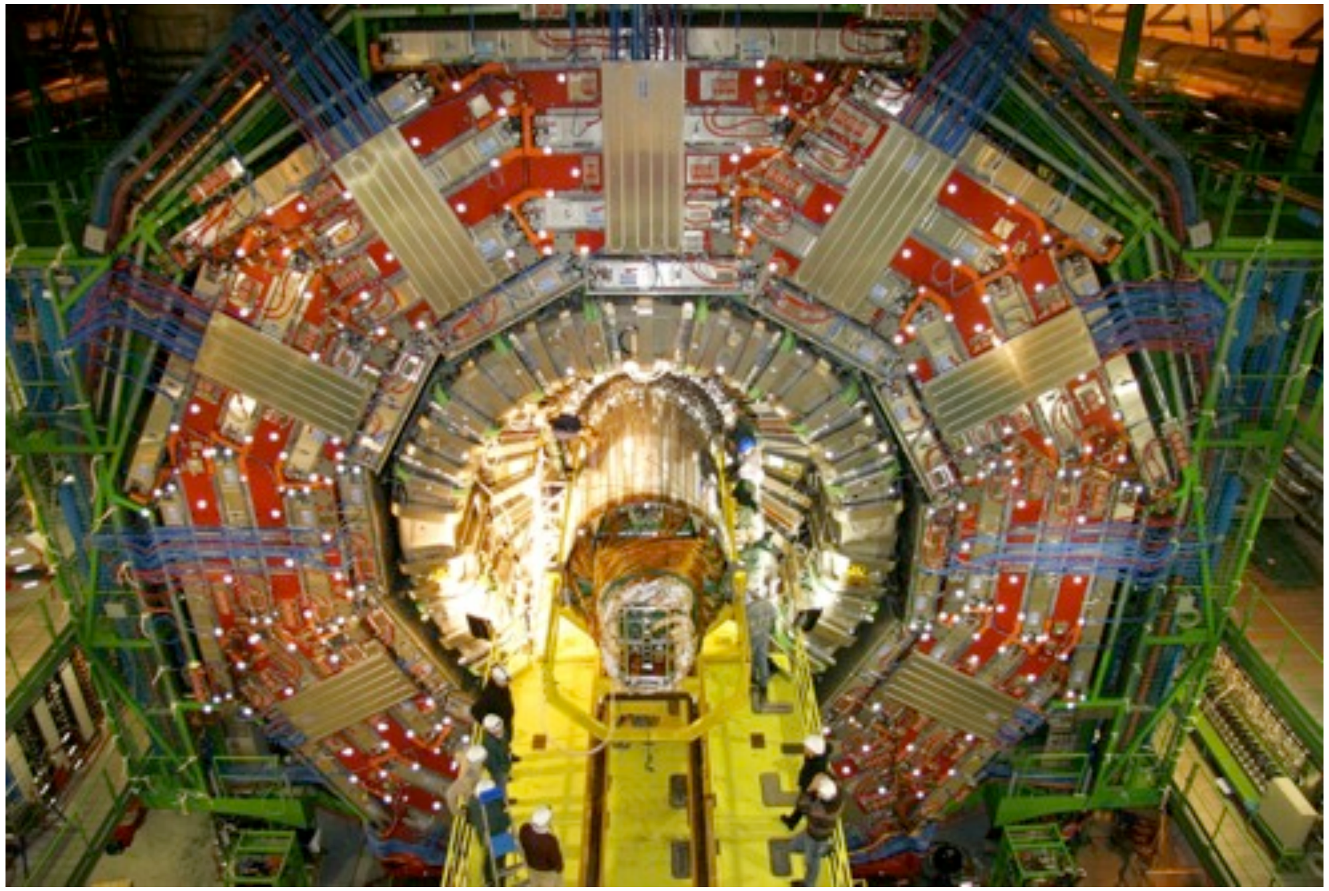
All-Hadronic Top Quark Resonances at CMS



James Dolen

UC Davis Physics Department

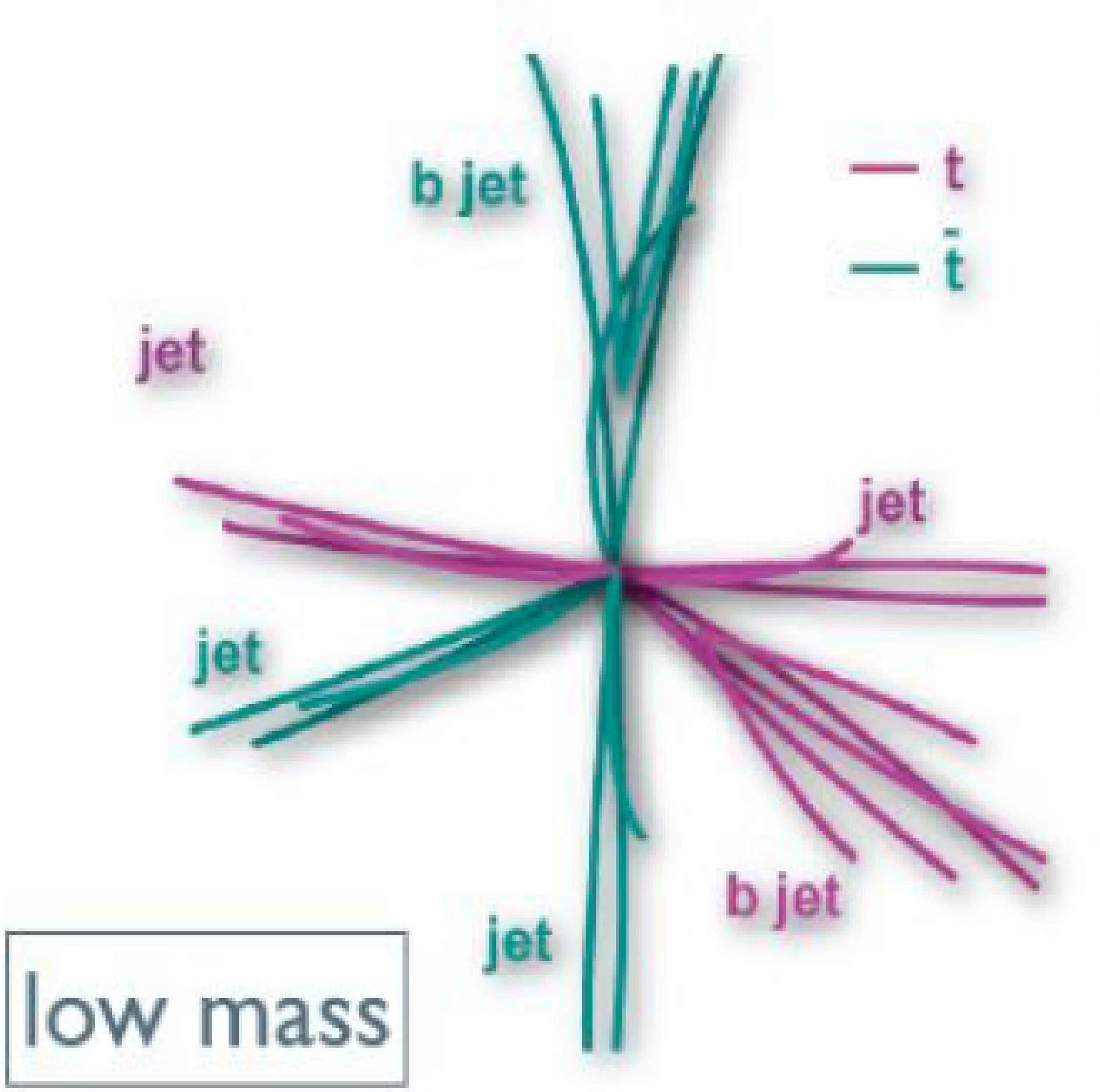
CMS Boosted Top Working Group

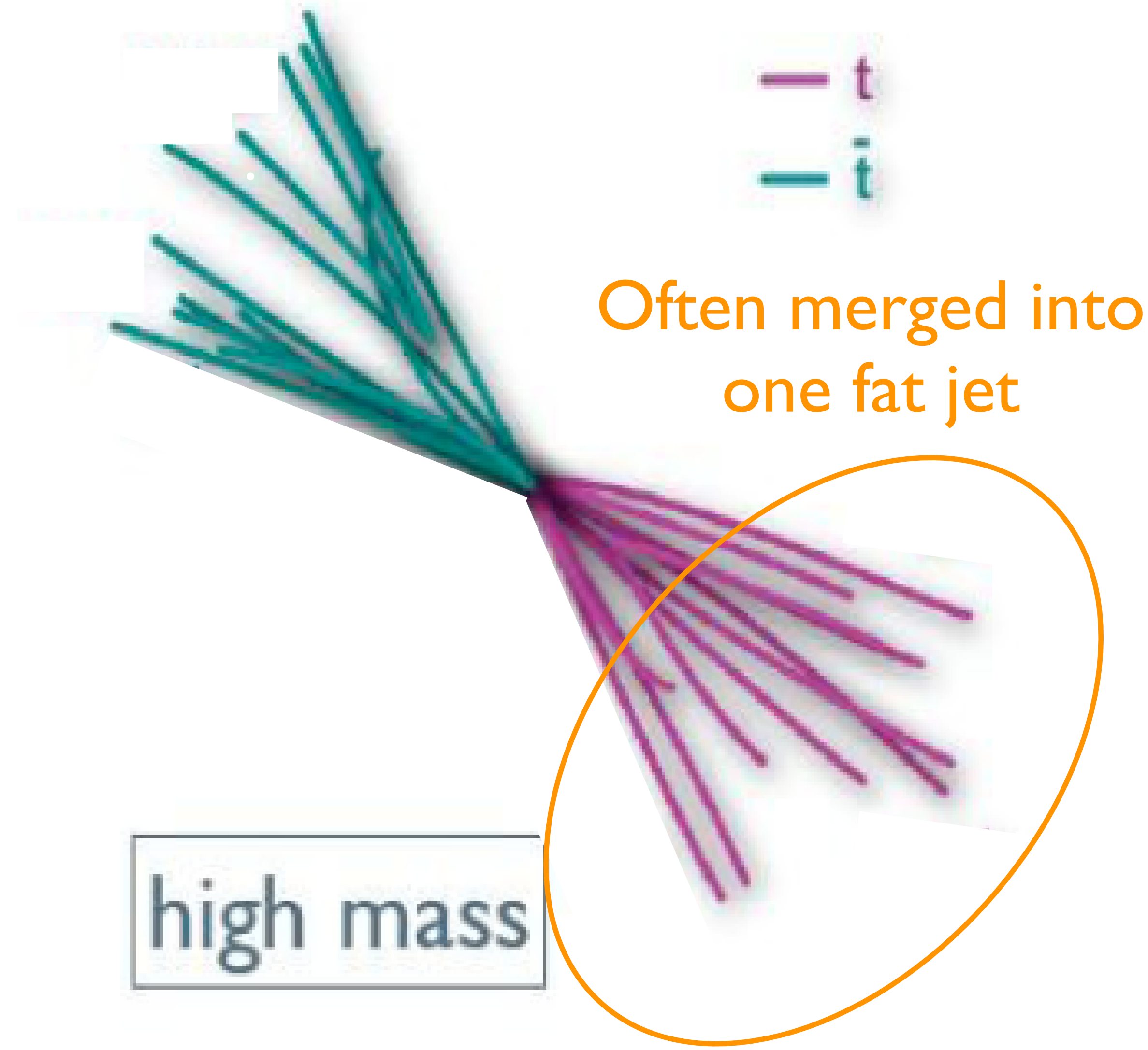
BOOST 2009

Introduction

- Top jets - When do they form?
- Top tagging
- Resonance search

Highly boosted tops ⇒ Easy to associate jets



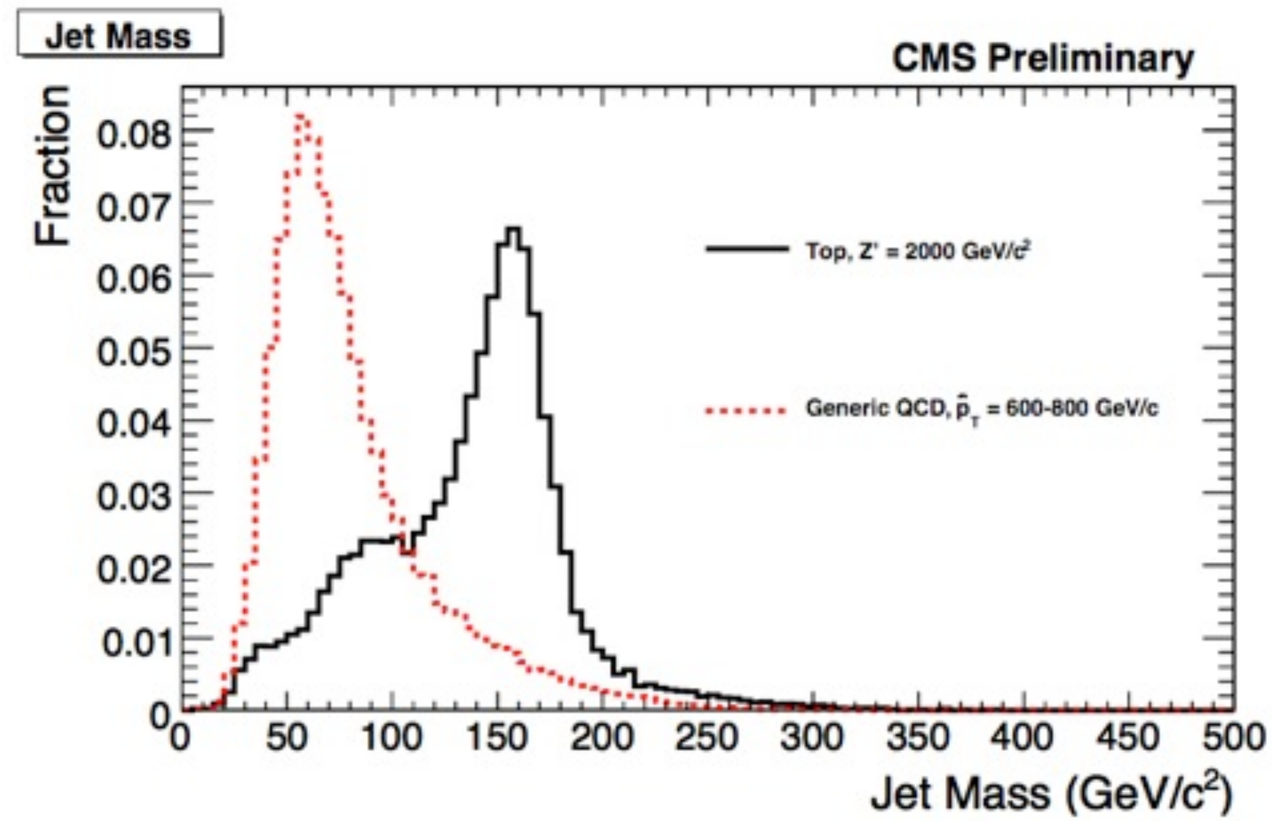


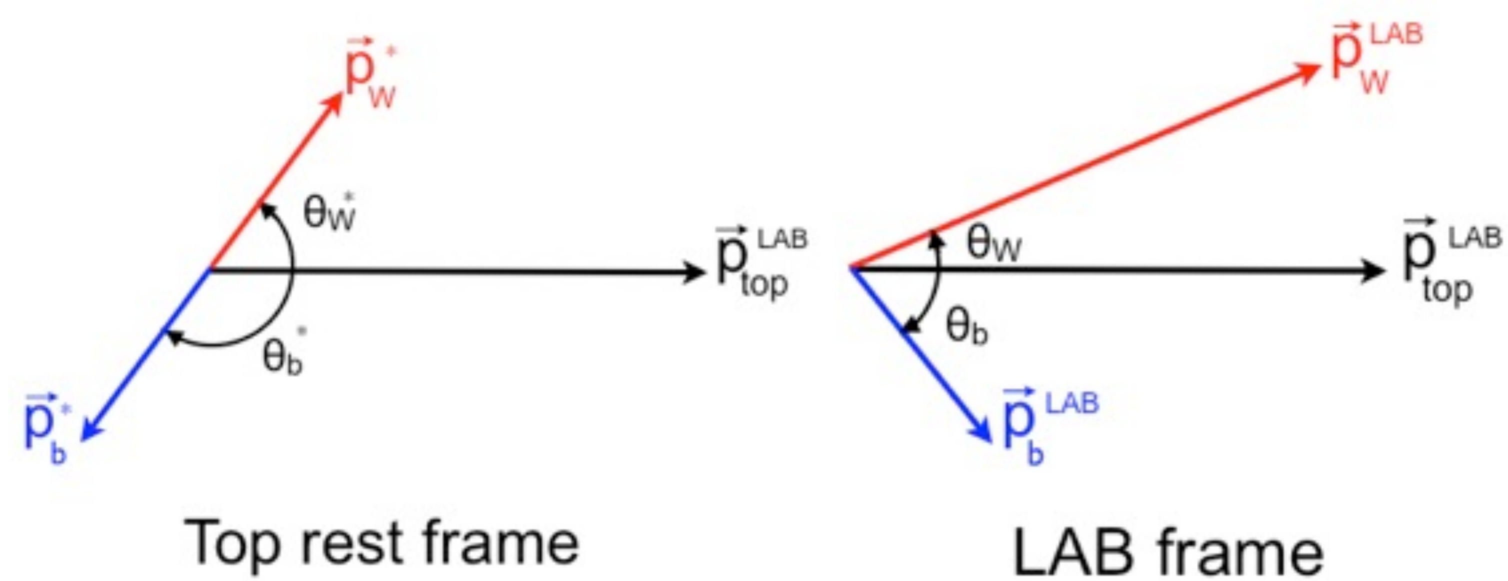
Top pair ~ at rest
~6 jets

Boosted top pairs
~2-3 jets

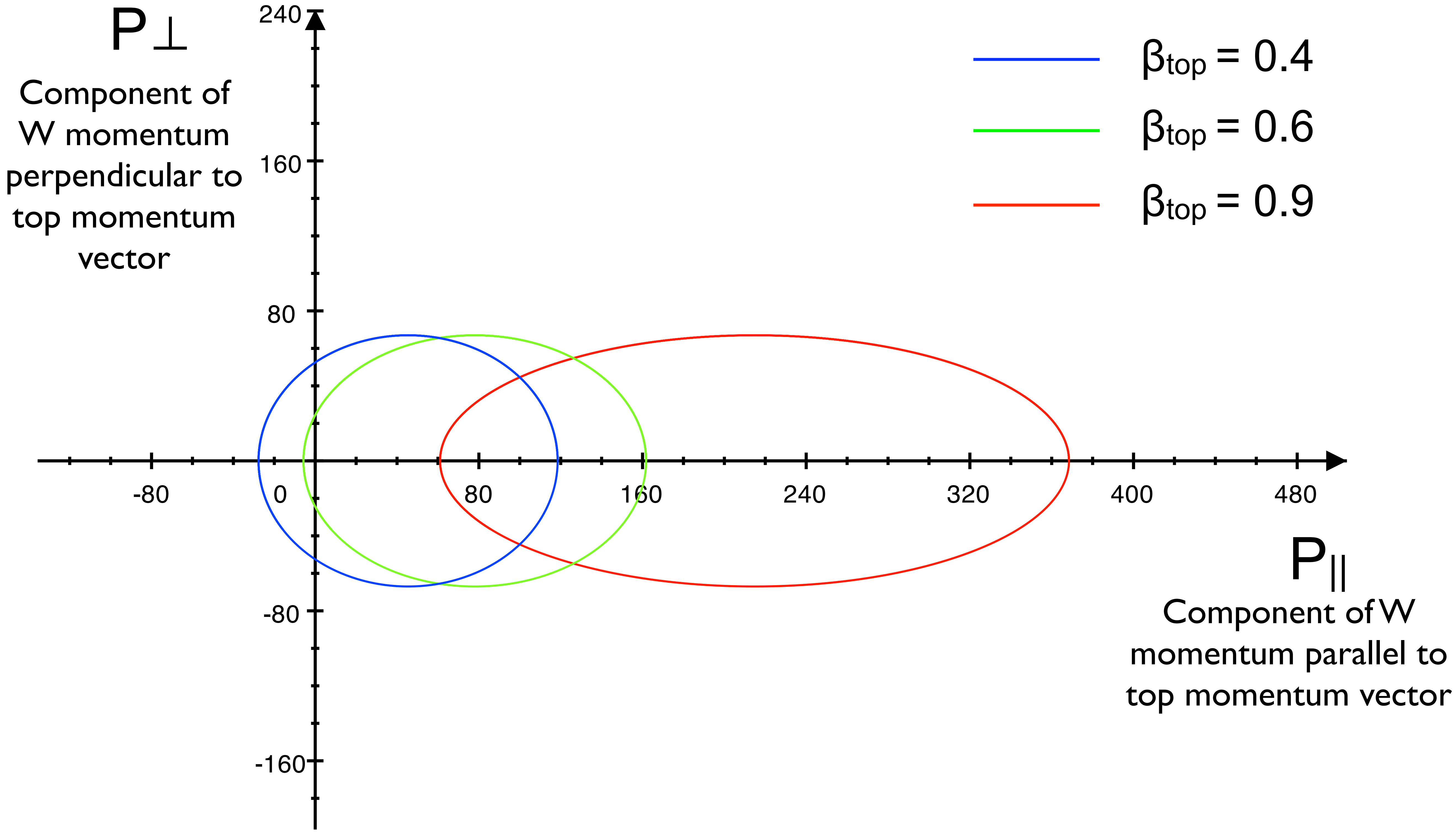
Top Jets

- All of the decay products of a hadronically decaying boosted top quark can be reconstructed within one jet
- Top jet formation depends on:
  - Top quark boost
  - Jet algorithm and jet size
  - Top daughter decay angle

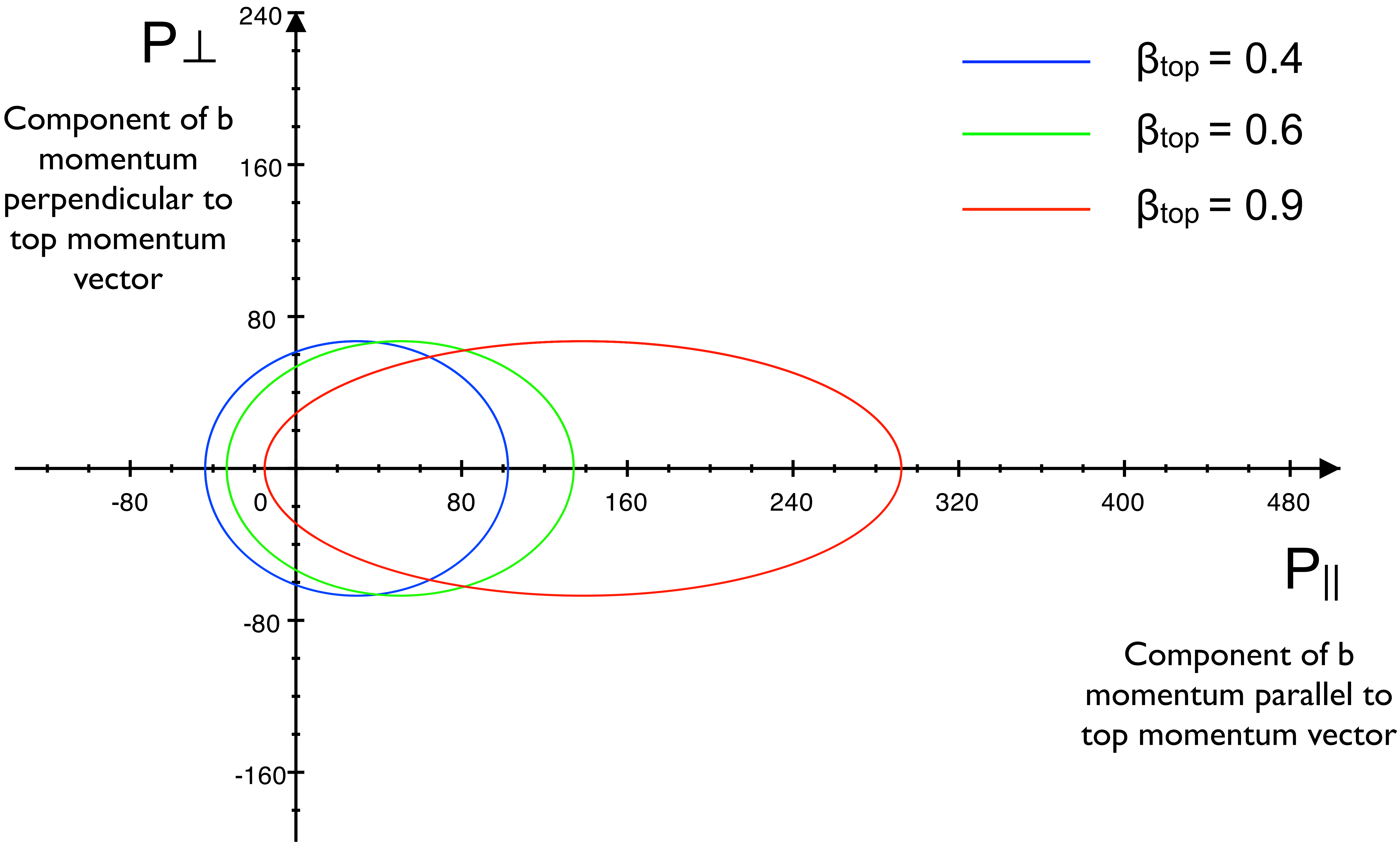




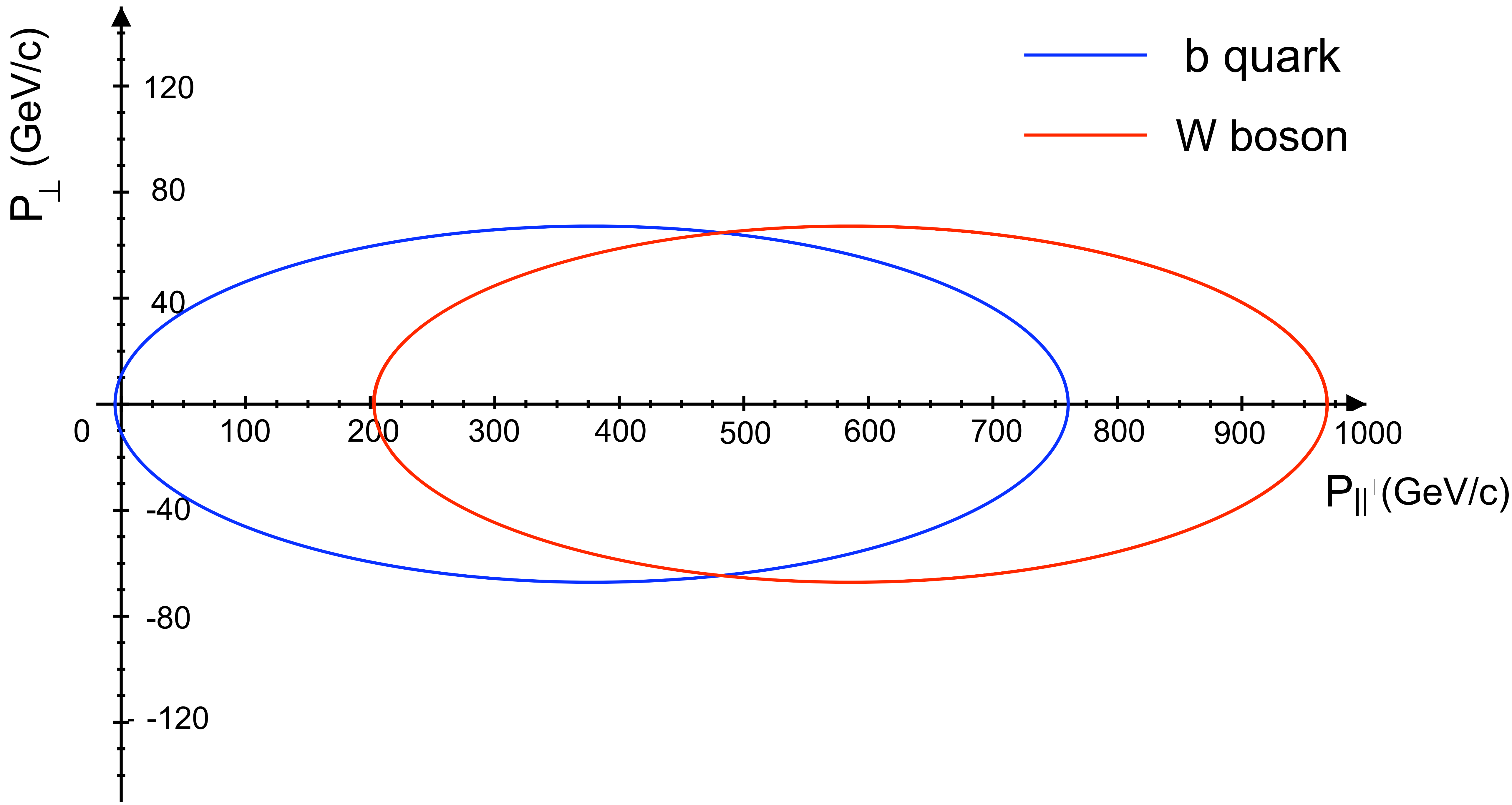
Top quark decay: W boson phase space



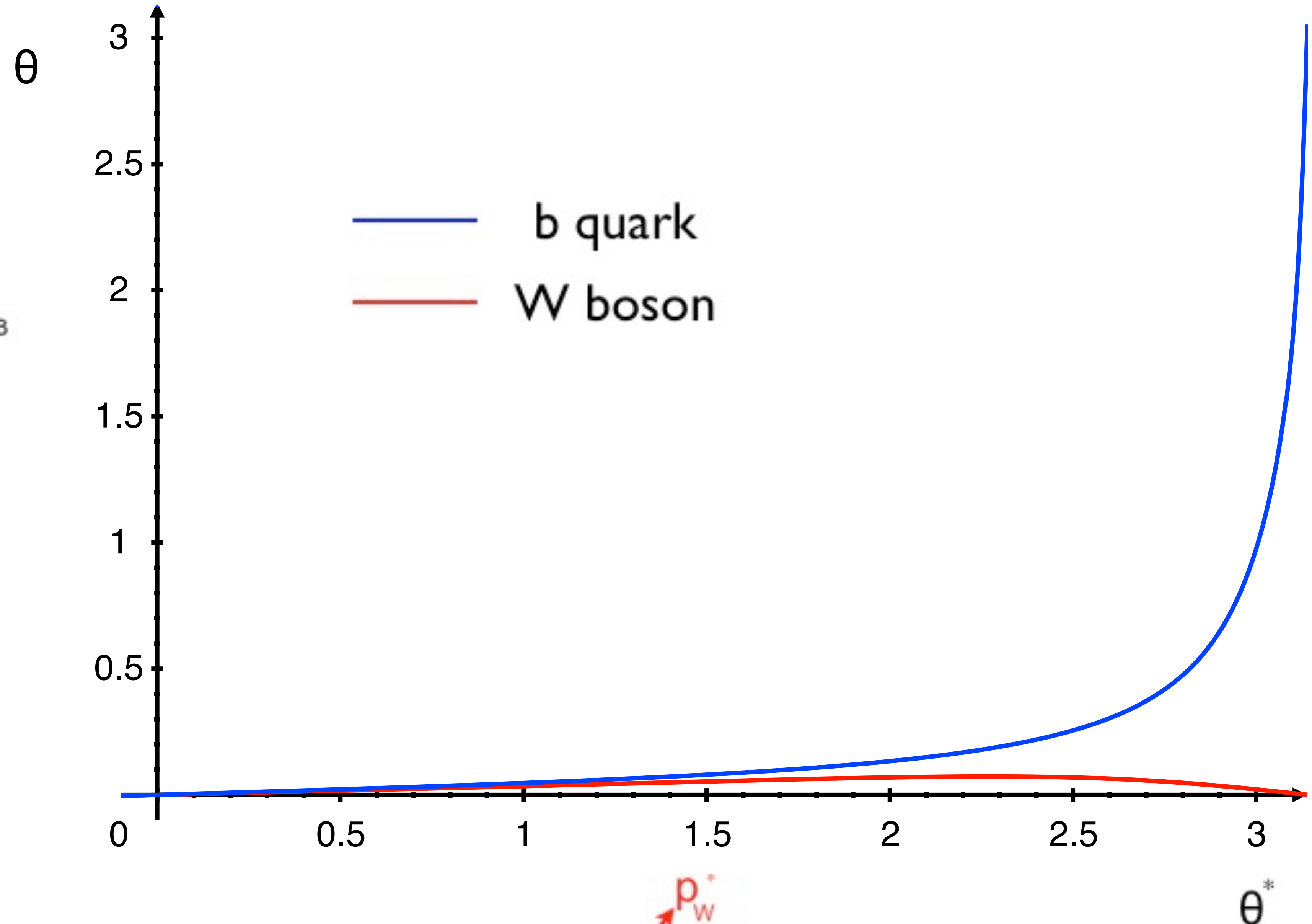
Top quark decay: b quark phase space

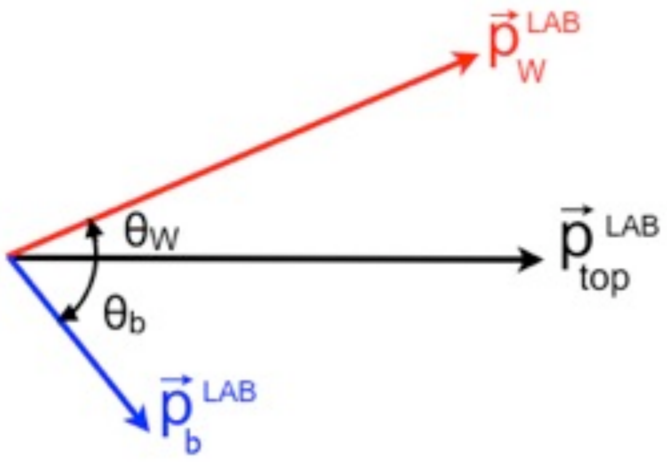


Top quark decay: top daughter phase space E_{top} = 1 TeV

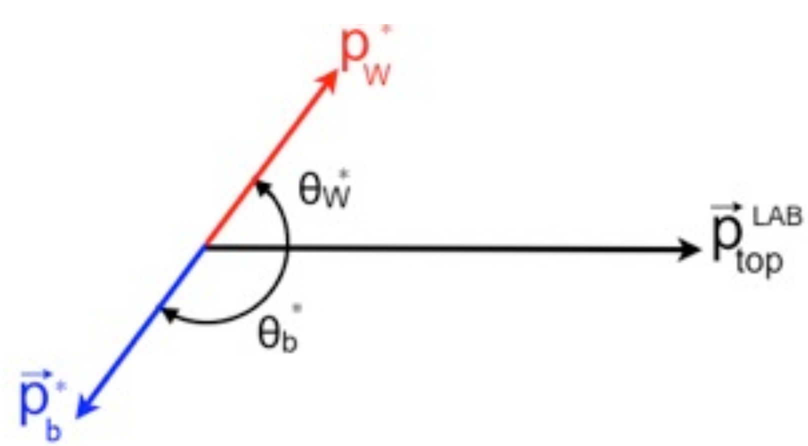


2 TeV Top Quark: Daughter Decay Angles





LAB frame

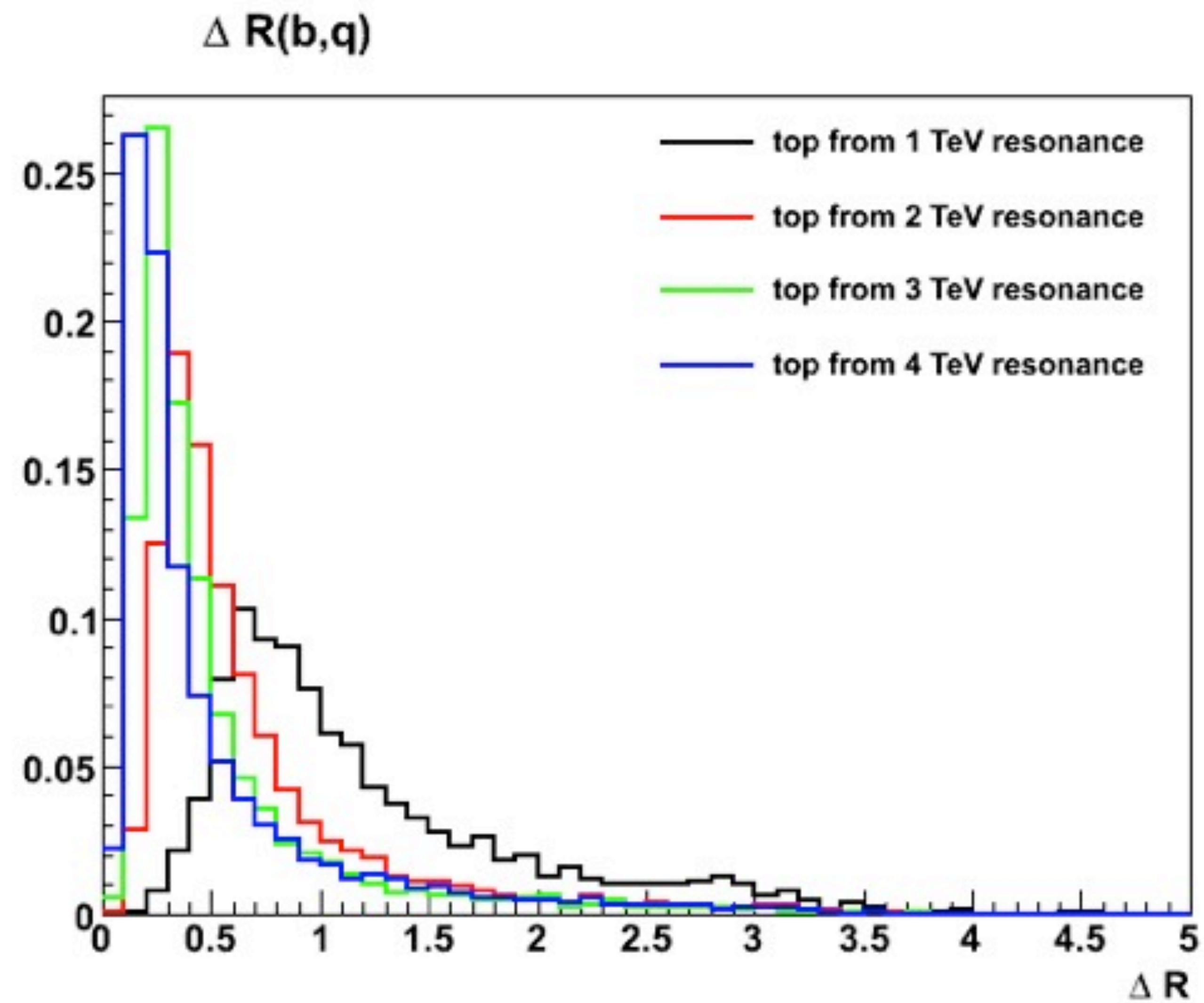


Top rest frame

When θ_b^* is large, the b quark can escape and a top jet will not be reconstructed.

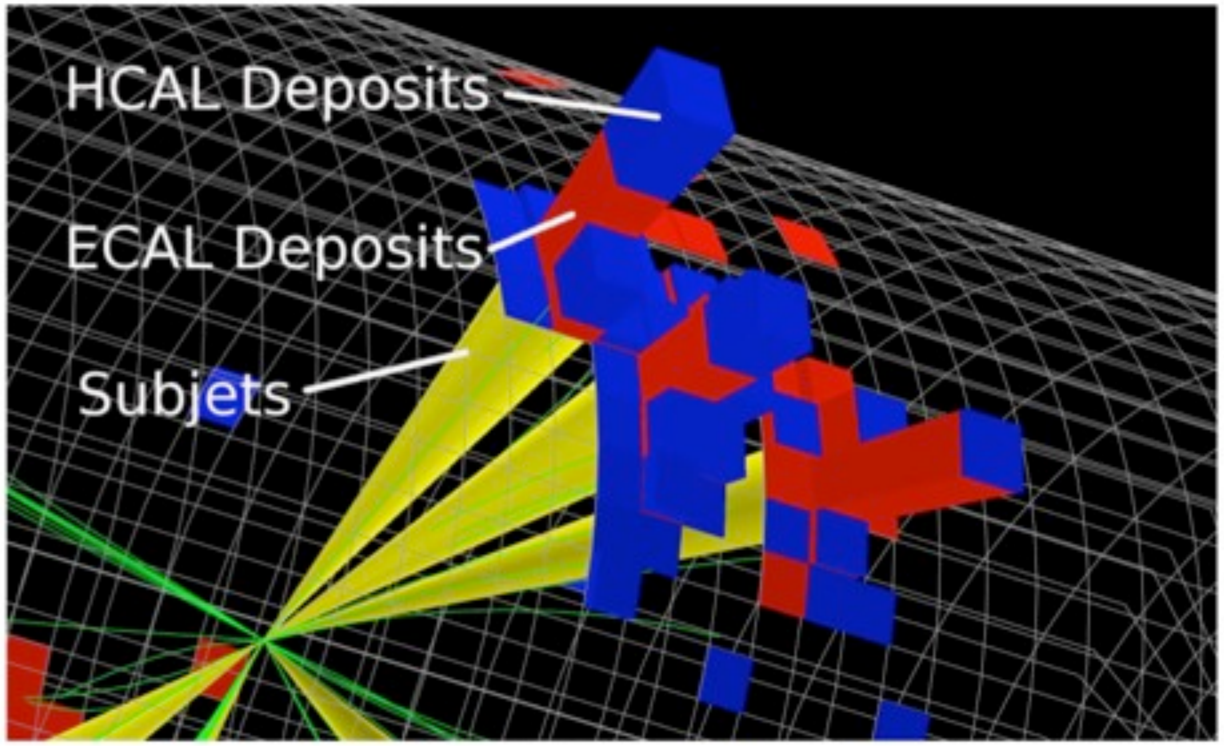
Top decay ΔR separation

- $t \rightarrow Wb \rightarrow q\bar{q}b$
- Generator level particle separation before hadronization
- Resonances larger than 2 TeV typically form top jets
- 1 TeV resonance requires different ideas
- Large tails

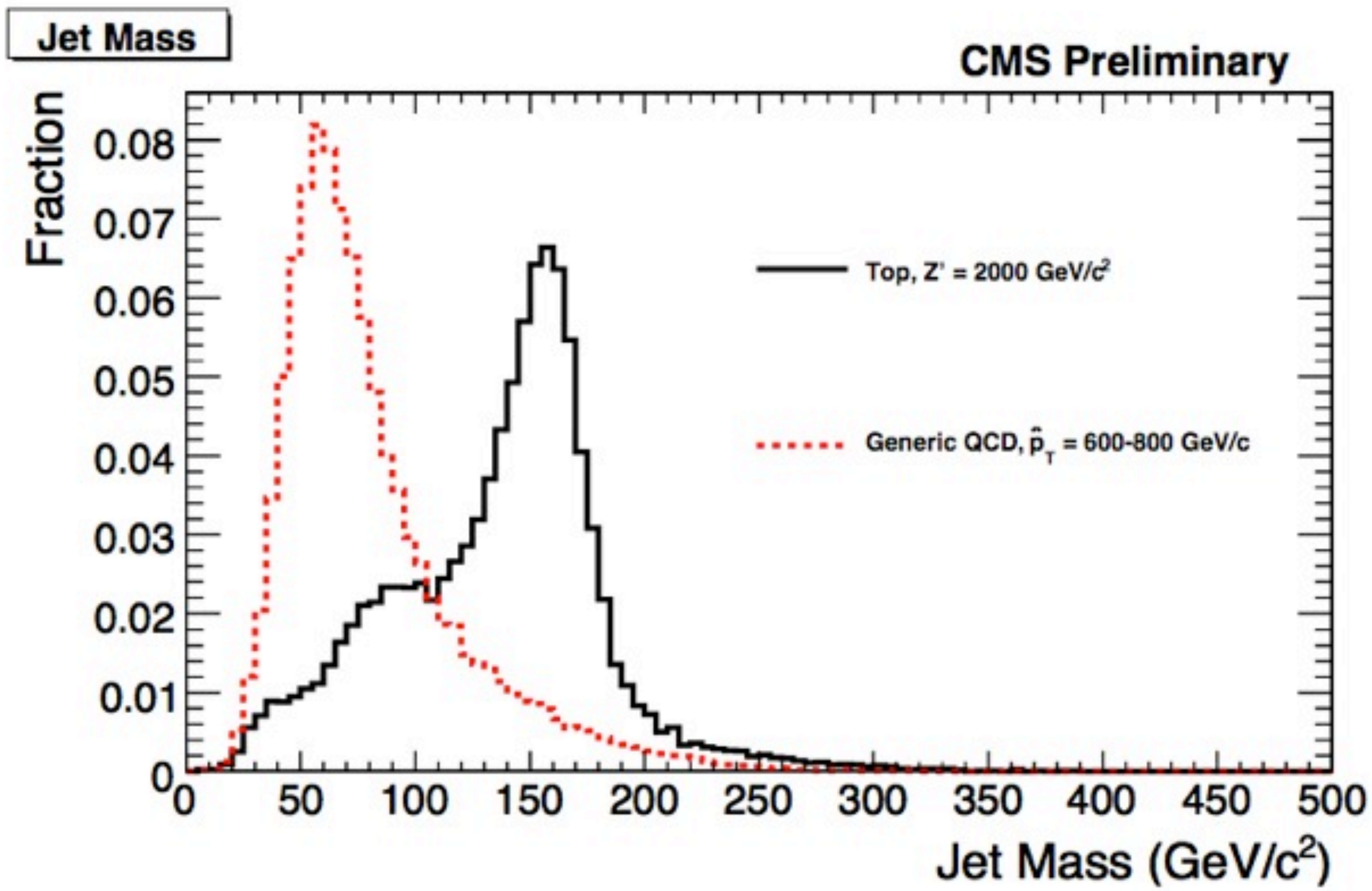


Top Jet Tagging

- CMS has implemented a top jet tagging algorithm based on Kaplan et al.
  - Theory: Phys.Rev.Lett 101:142001 (2008) arXiv:0806.0848v2
  - CMS Note: CMS PAS JME-09-001
- Cambridge-Aachen Jets with R=0.8
- Jet P_T > 250 GeV/c and $|y|<2.5$
- Use jet mass and subjets to identify top jets

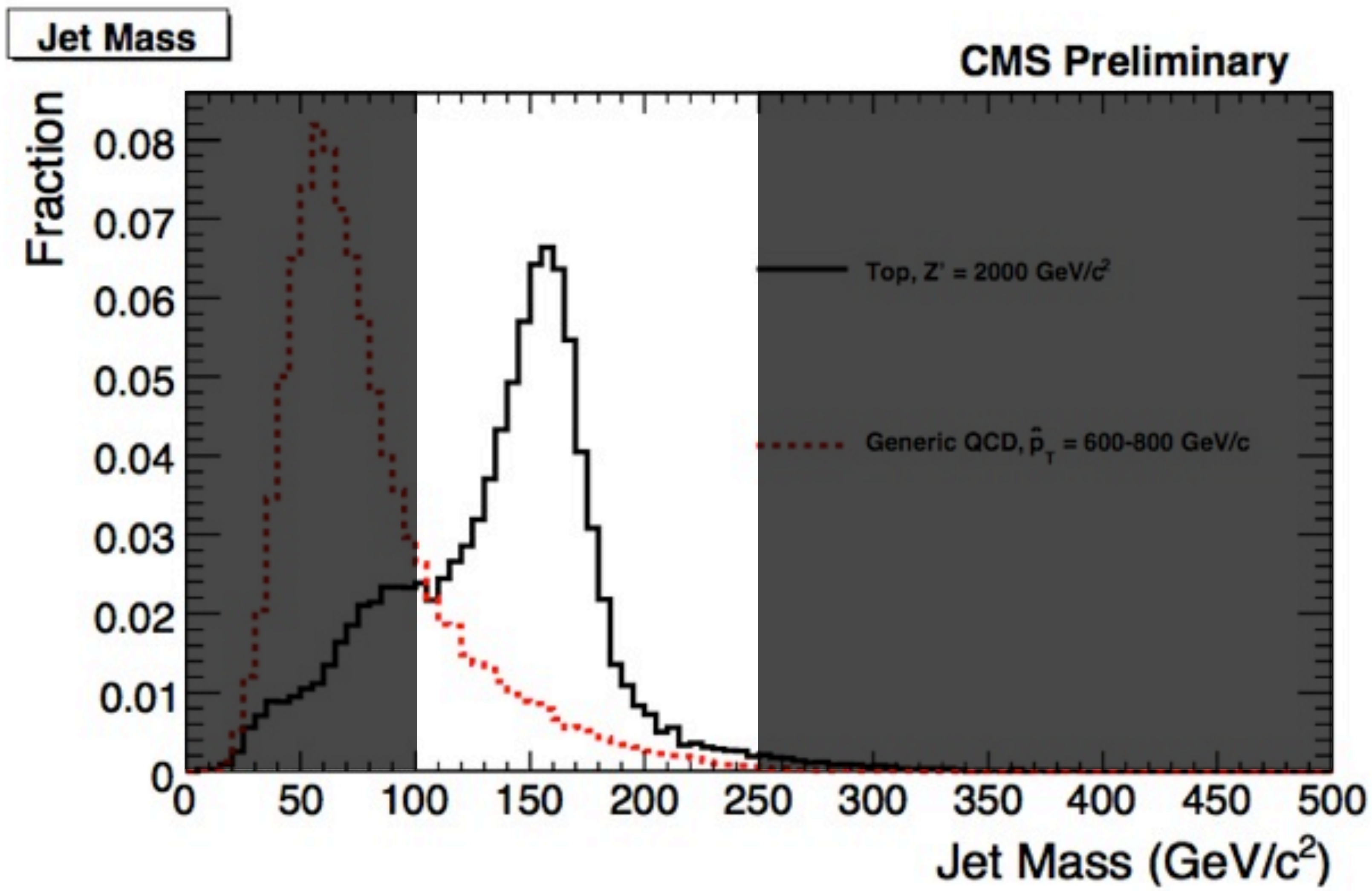


Jet Mass



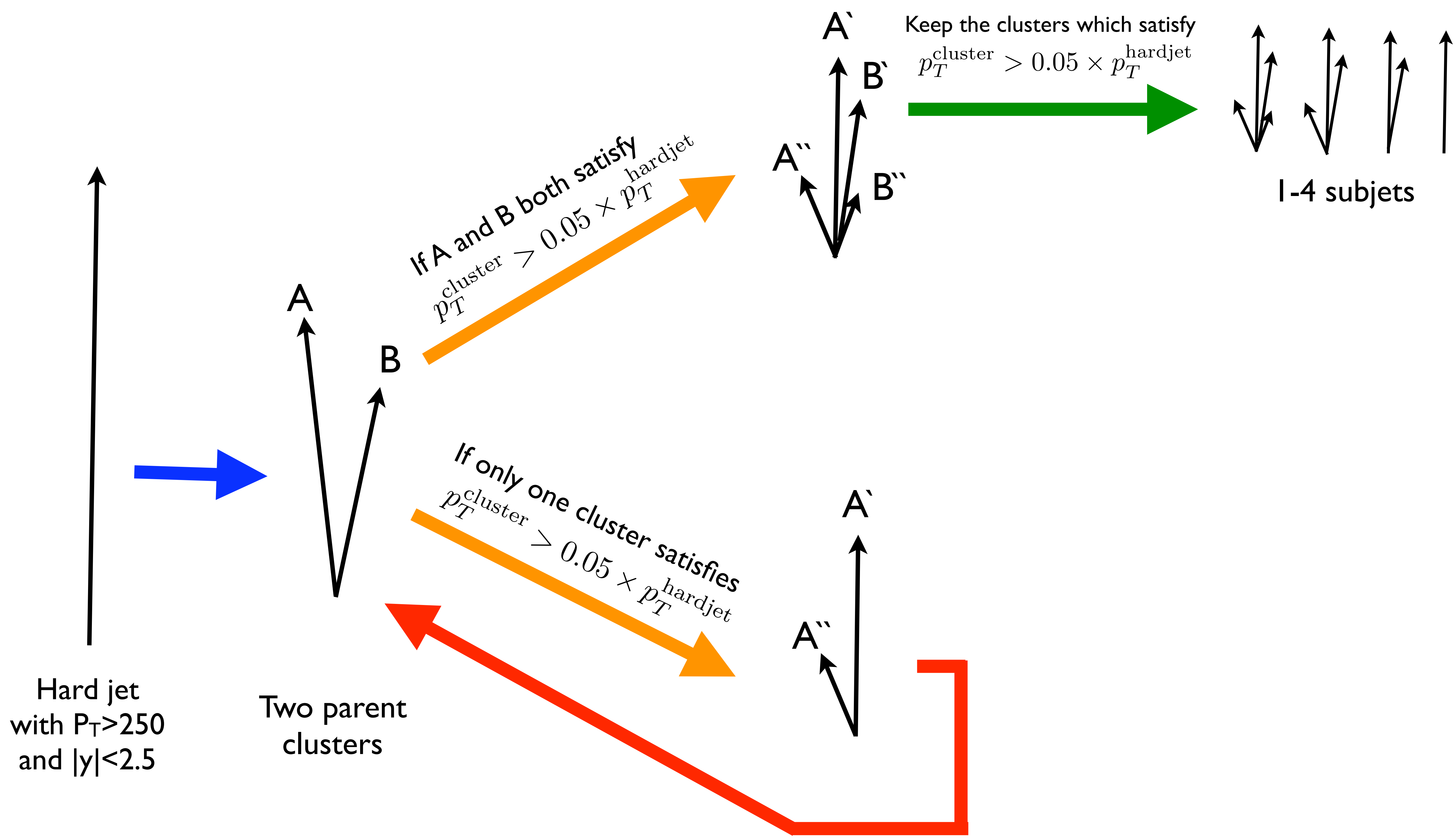
Jet Mass
CMS Preliminary
Fraction
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
0
50
100
150
200
250
300
350
400
450
500
Jet Mass (GeV/c²)
Top, Z' = 2000 GeV/c²
Generic QCD, $\hat{p}_T$ = 600-800 GeV/c

Jet Mass

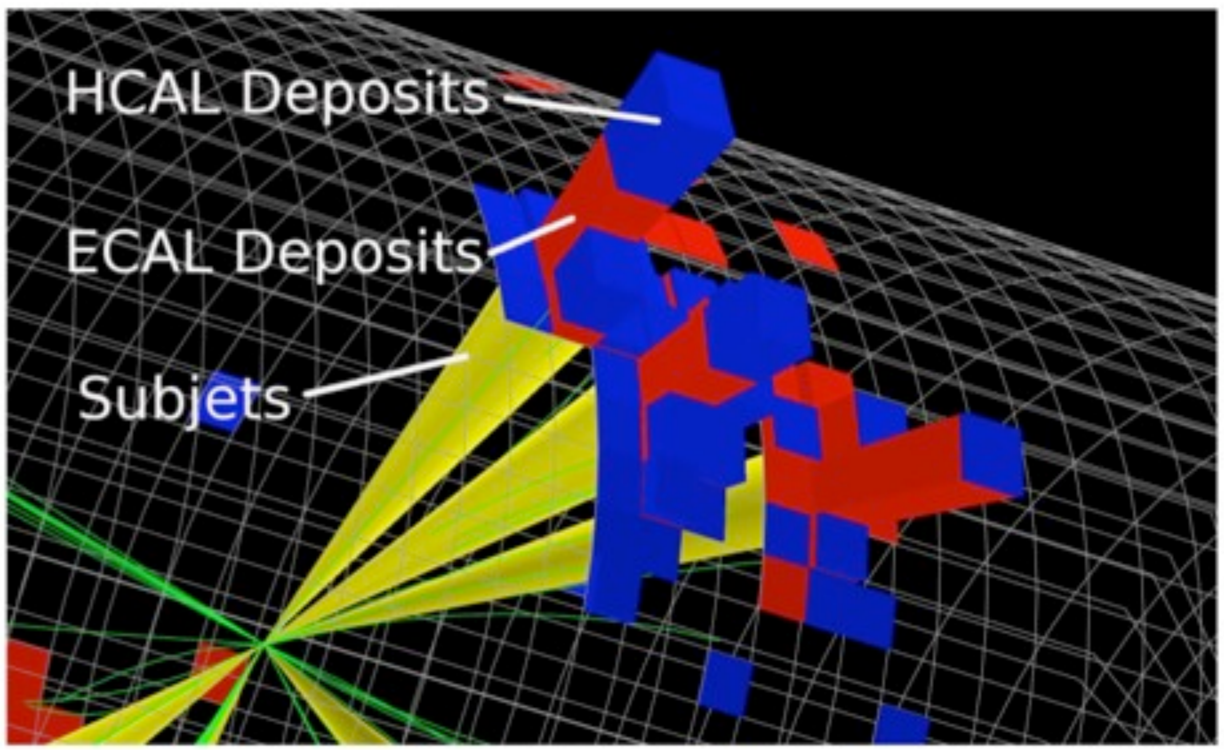


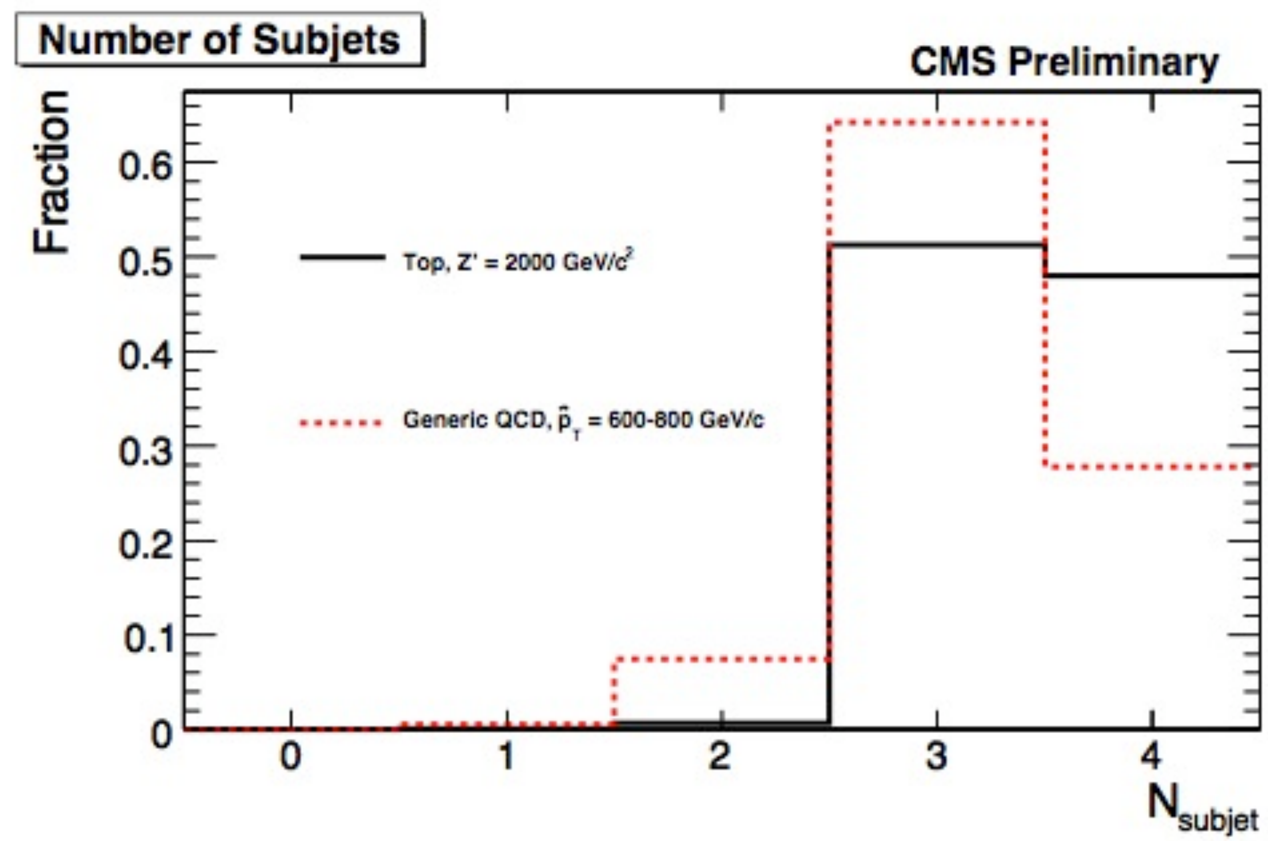
Top mass window

Top Tagging Algorithm: Finding Subjets

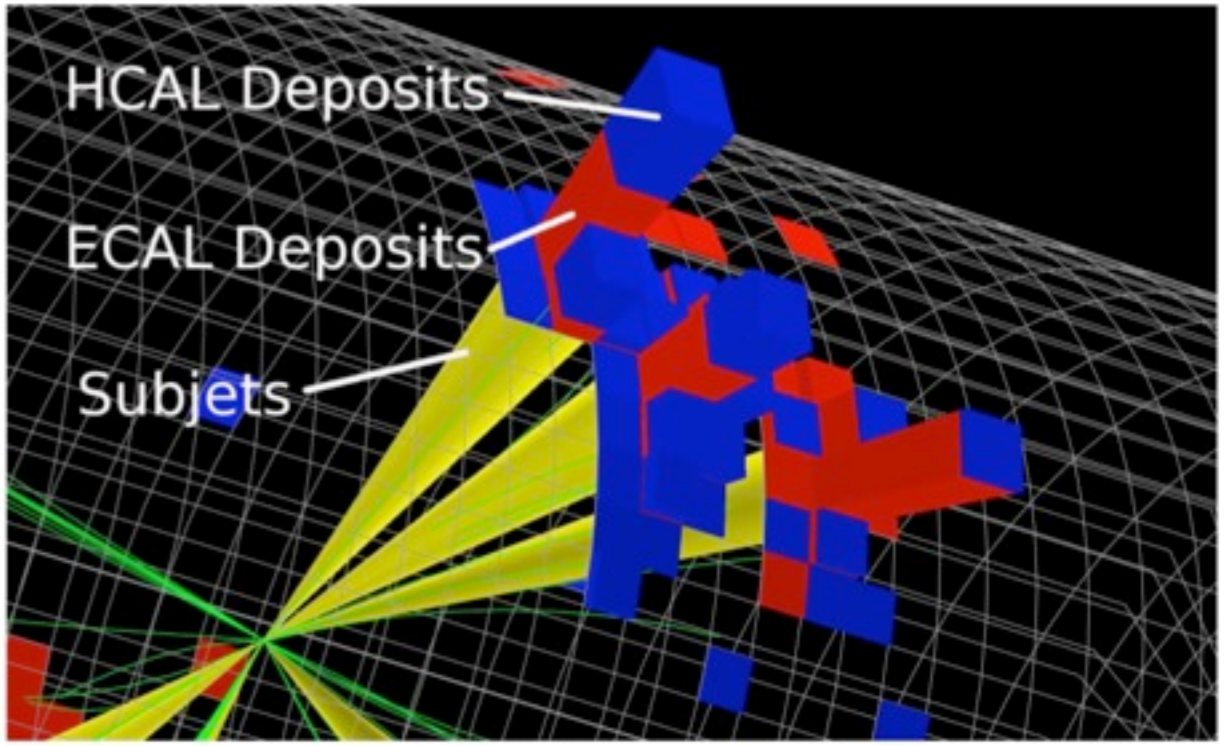


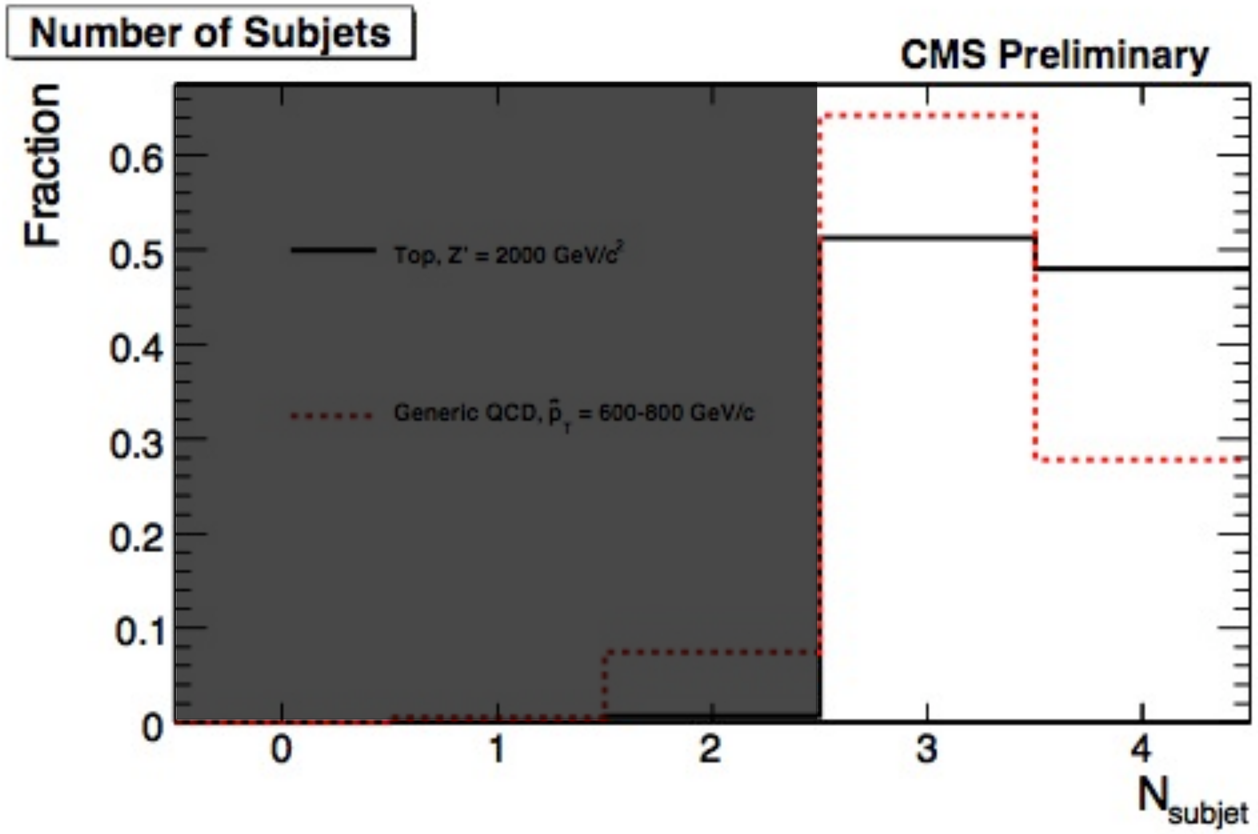
Subjets


HCAL Deposits
ECAL Deposits
Subjets


Number of Subjets
CMS Preliminary
Fraction
0
0.1
0.2
0.3
0.4
0.5
0.6
Top, Z' = 2000 GeV/c²
Generic QCD, p̂T = 600-800 GeV/c
0
1
2
3
4
N subjet

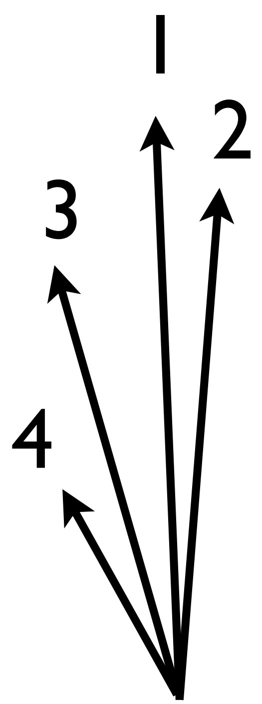
Subjets





Require at least 3 subjets

Minimum 2-Subjet Mass

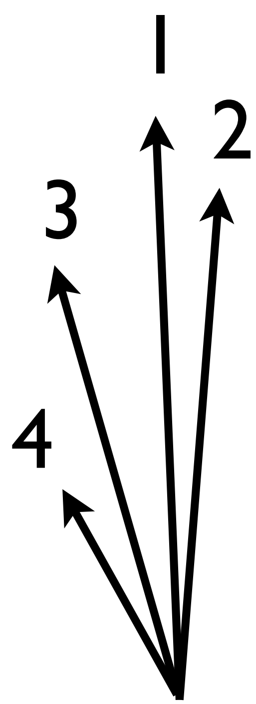


Jet with three or four subjets

$m_{ij}^2=(E_i+E_j)^2-(p_i+p_j)^2$

MinMass= $\min\{m_{12}, m_{13}, m_{23}\}$

Minimum 2-Subjet Mass

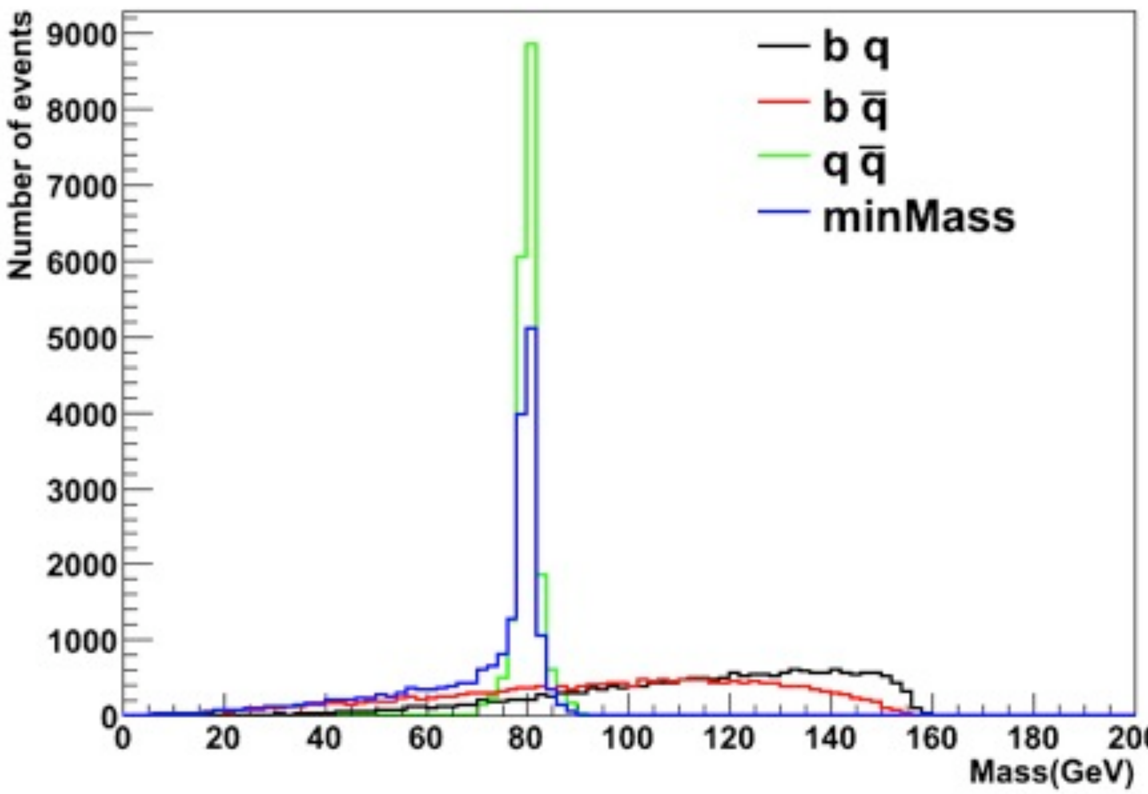


Jet with three or four subjets

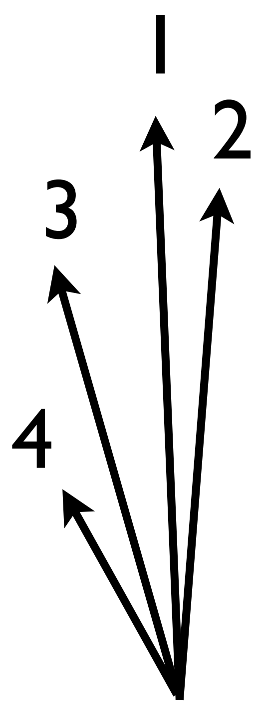
$$m_{ij}^2=(E_i+E_j)^2-(p_i+p_j)^2$$

$$\text{MinMass}= \min\{m_{12}, m_{13}, m_{23}\}$$

Generated top decay products: pairwise mass



Minimum 2-Subjet Mass

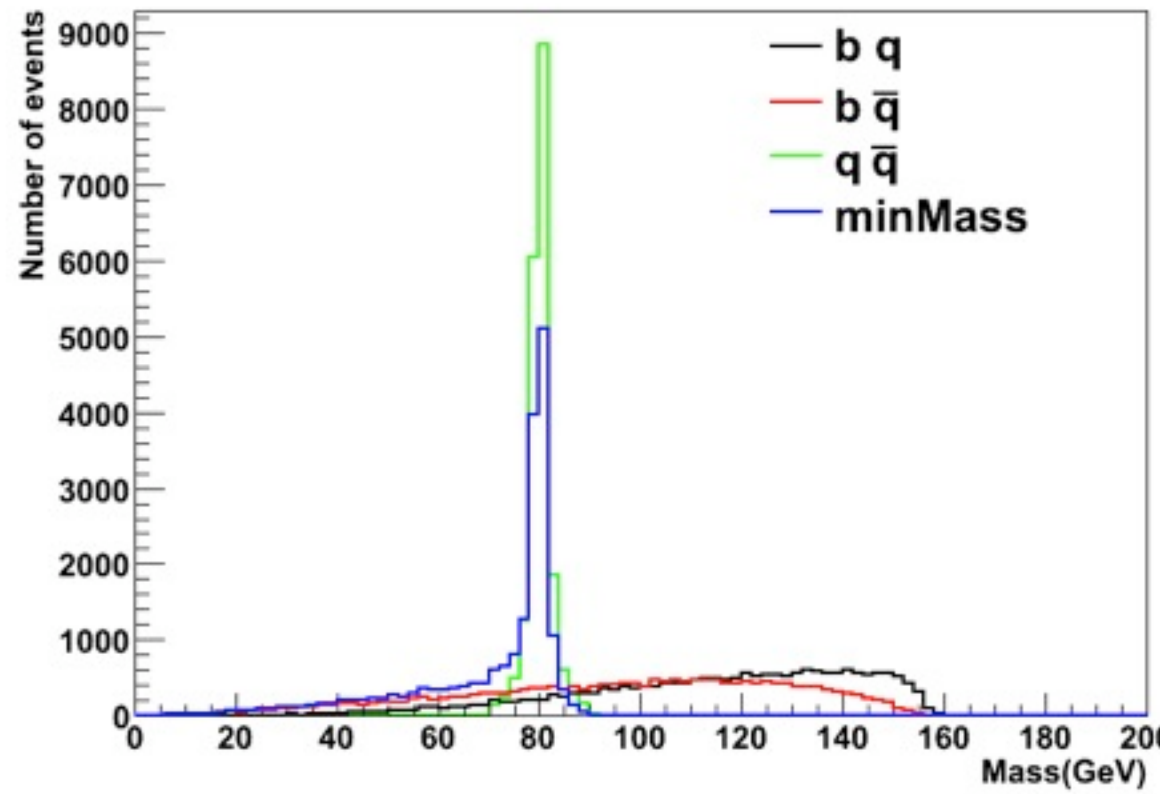


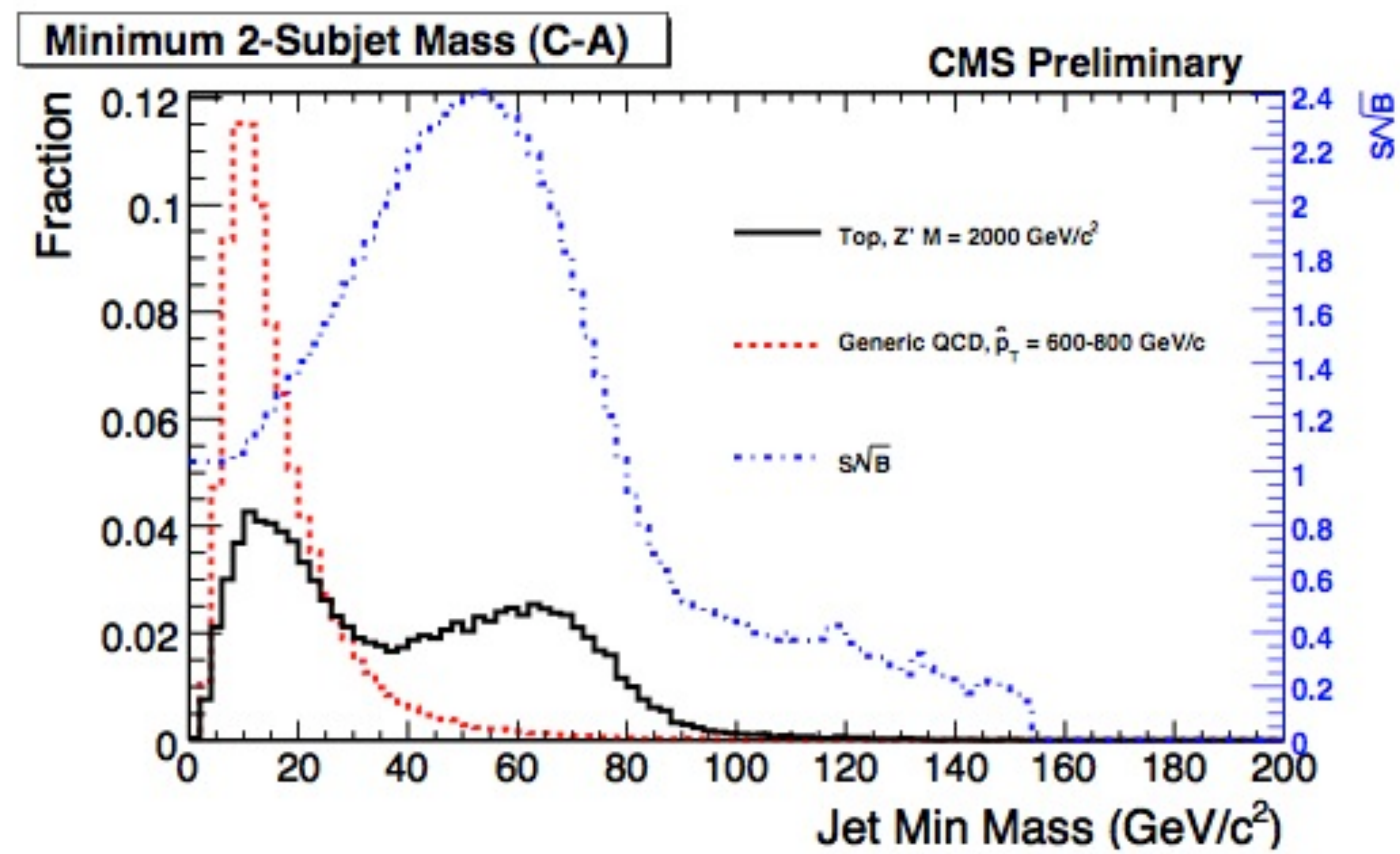
Jet with three or four subjets

$$m_{ij}^2=(E_i+E_j)^2-(p_i+p_j)^2$$

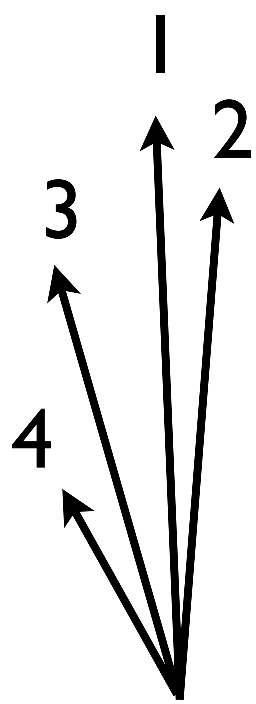
$$\text{MinMass}= \min\{m_{12}, m_{13}, m_{23}\}$$

Generated top decay products: pairwise mass





Minimum 2-Subjet Mass

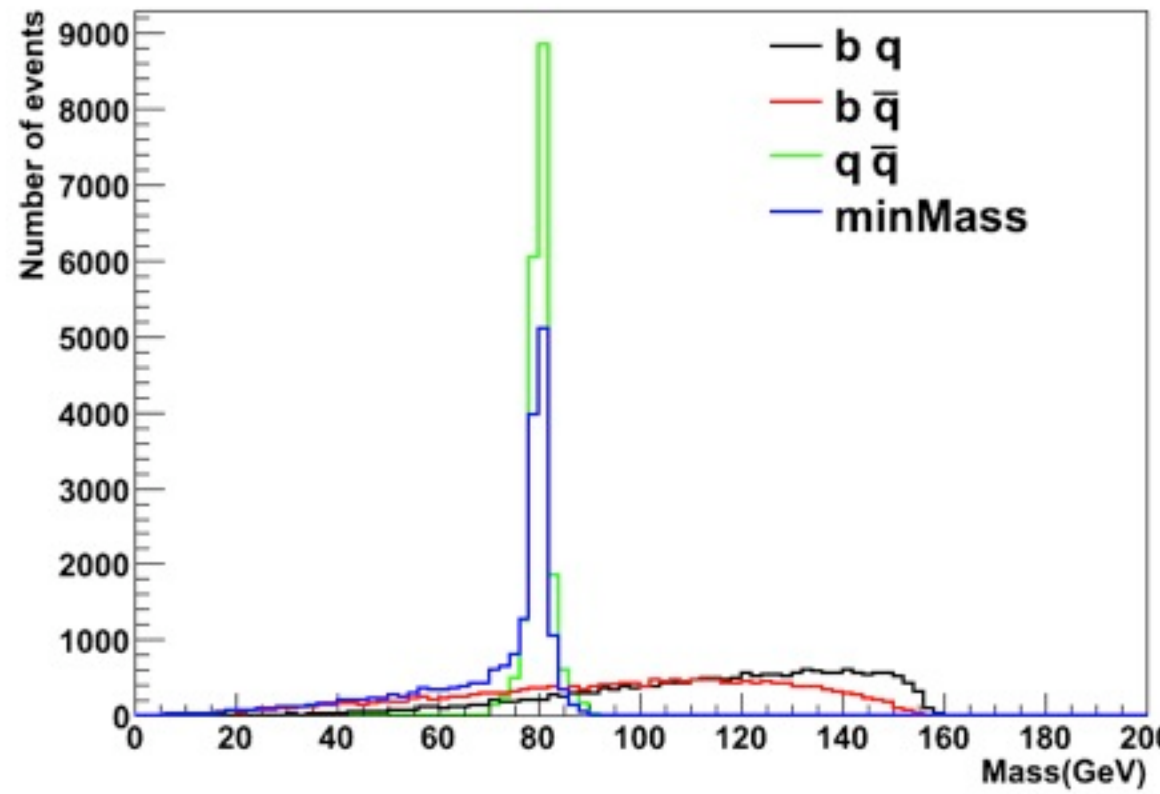


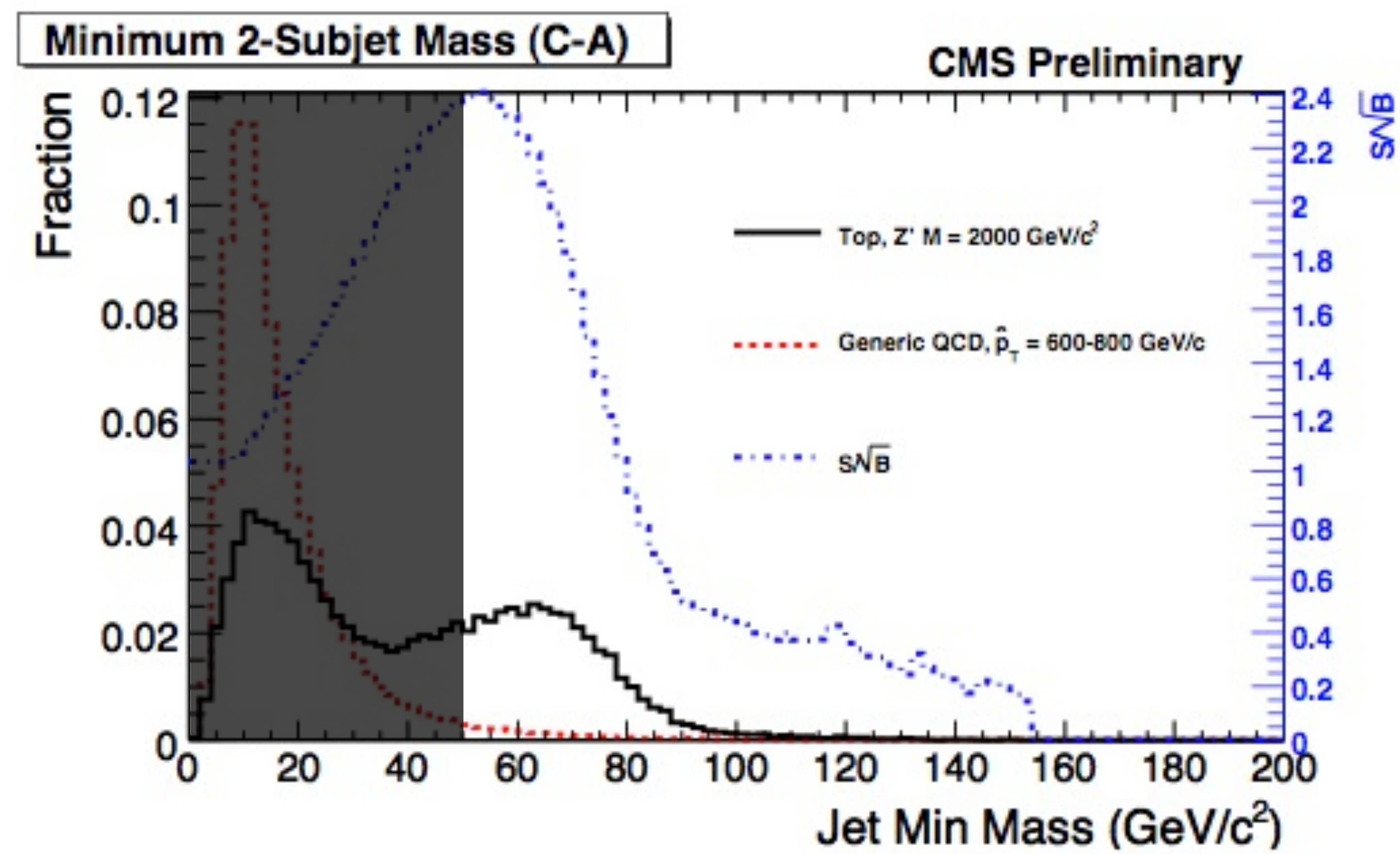
Jet with three or four subjets

$m_{ij}^2 = (E_i + E_j)^2 - (p_i + p_j)^2$

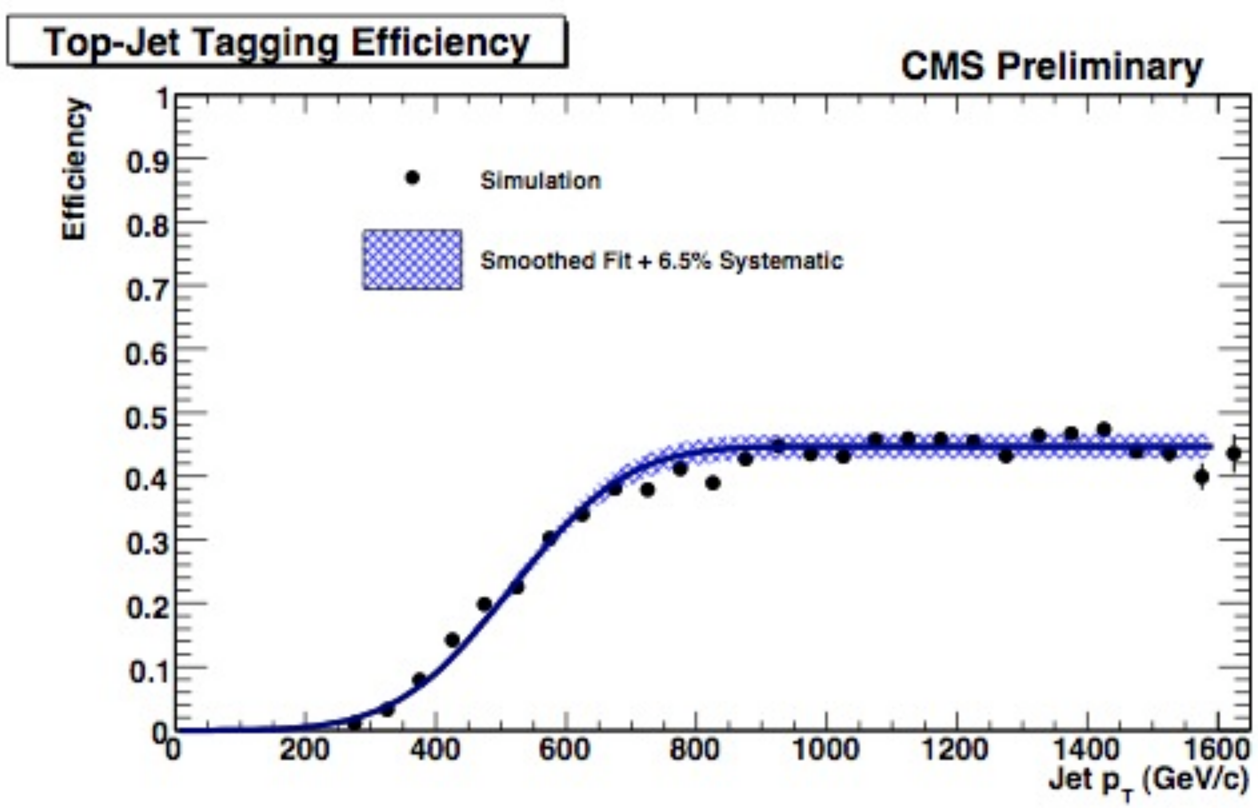
MinMass= $\min\{m_{12}, m_{13}, m_{23}\}$

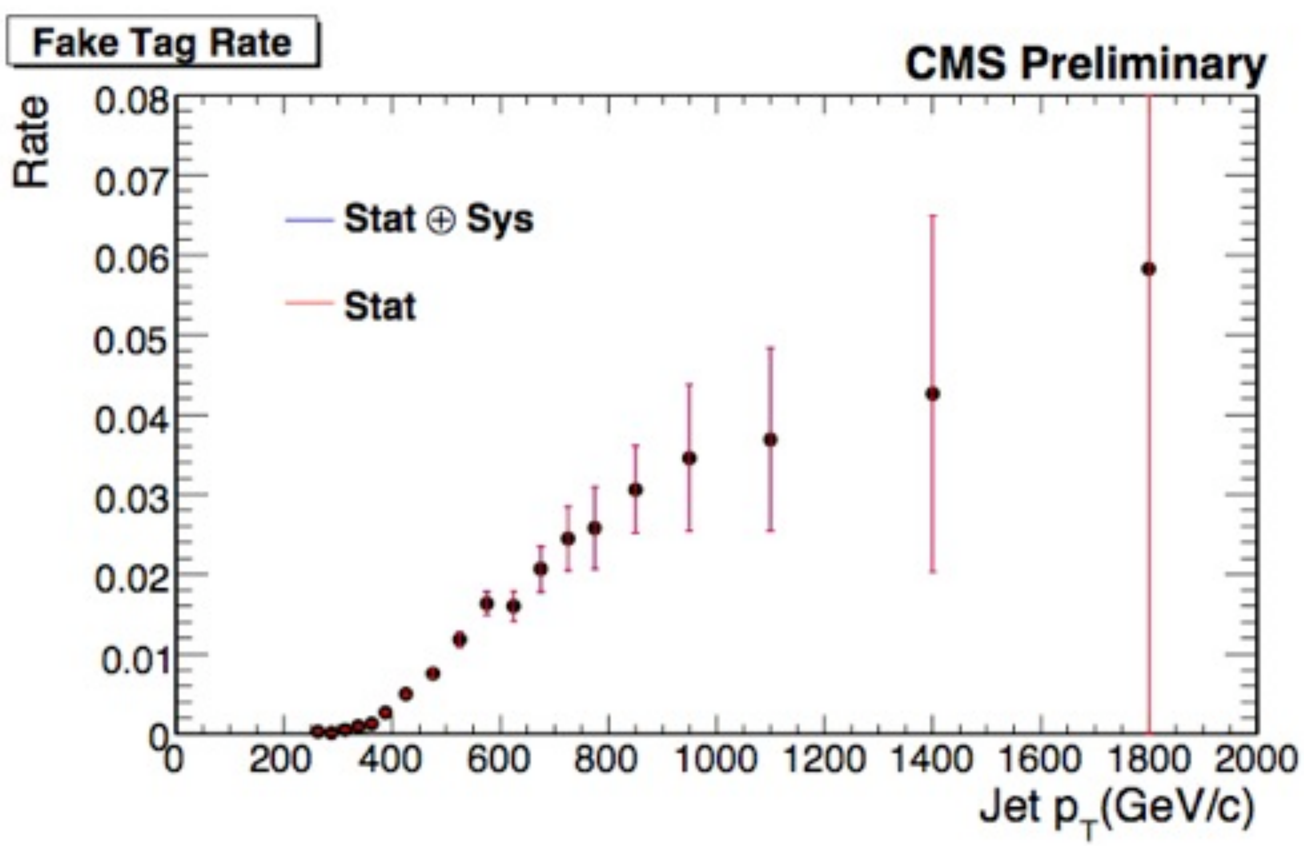
Generated top decay products: pairwise mass





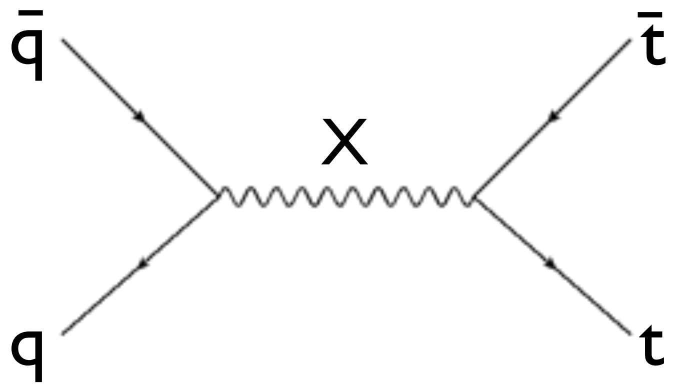
Top Tagging Efficiency and Fake Rate

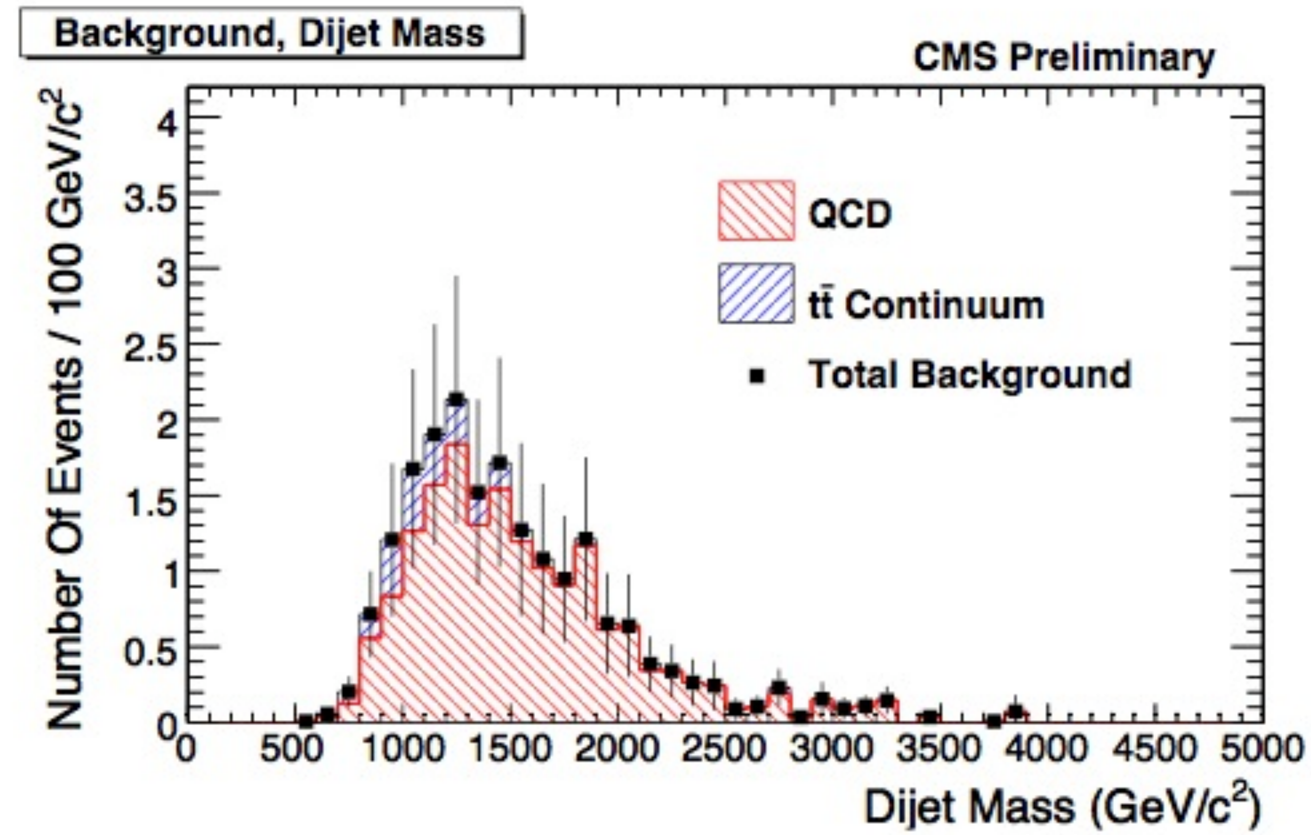




Data driven fake tag rate
Anti-tag and probe

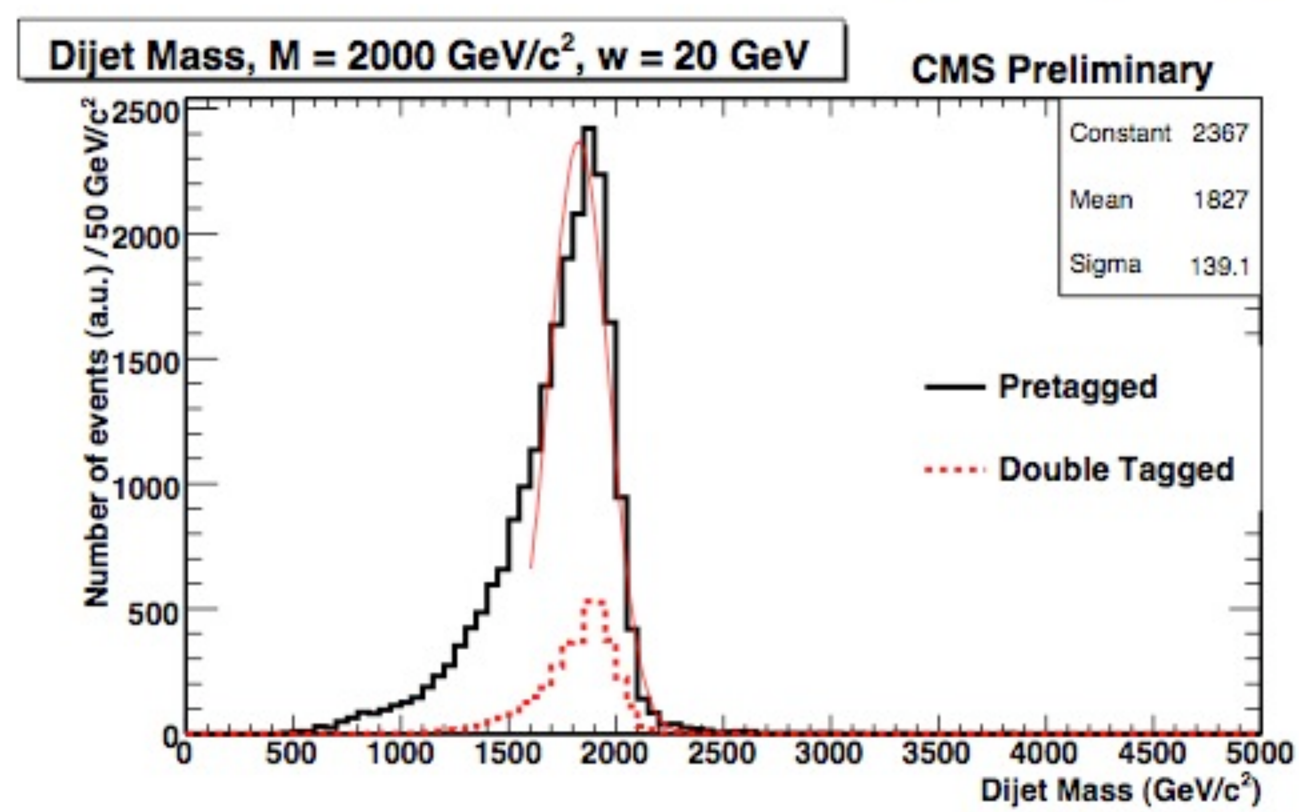
Top Resonance Search





Signal

- 1,2,3,4 TeV resonances
- Width 1%, 10% of mass

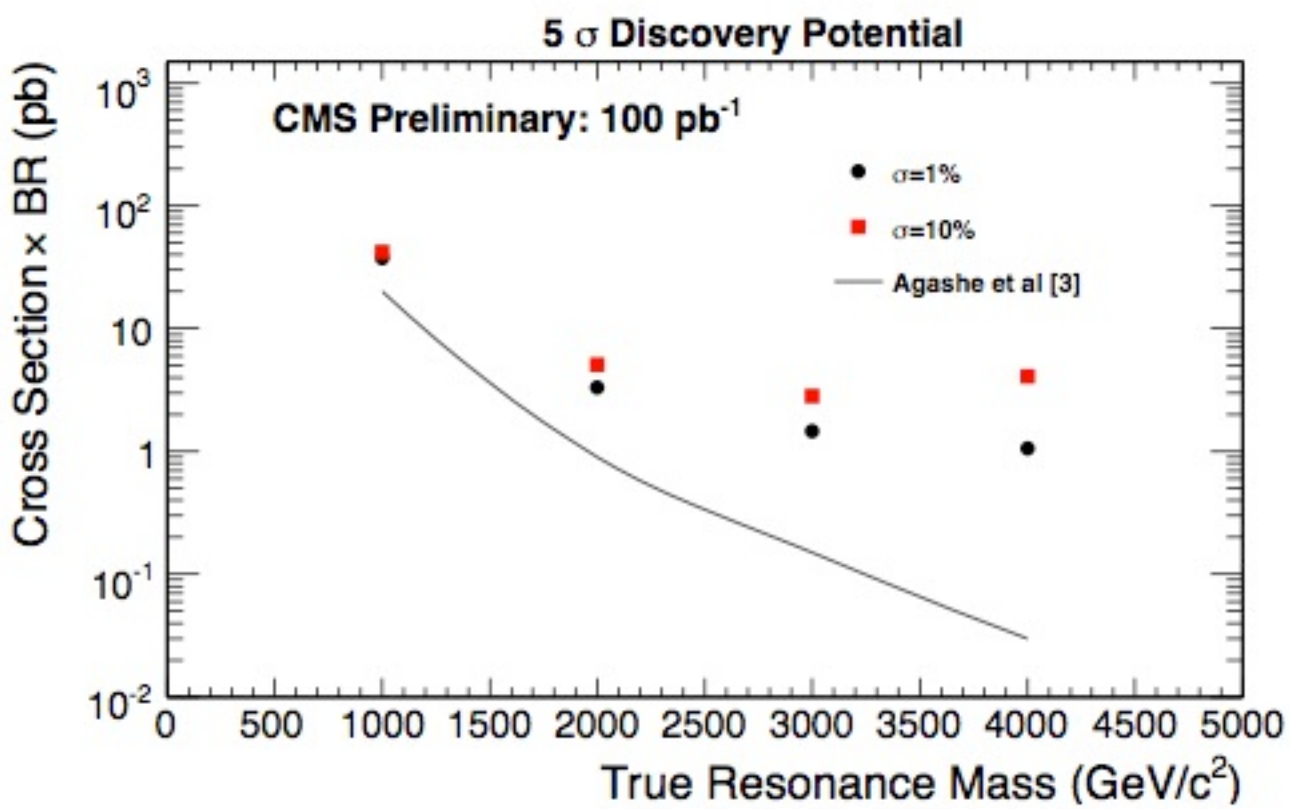


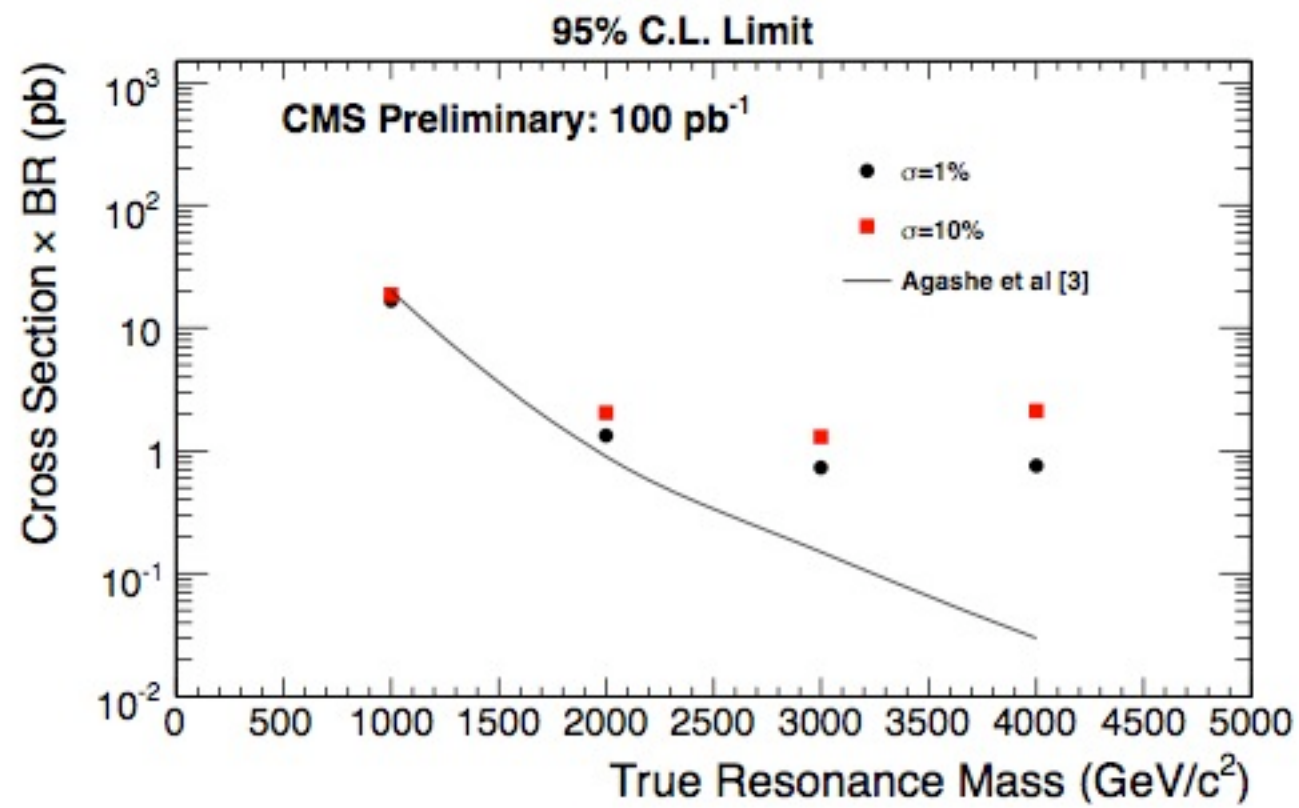
Backgrounds

- continuum $t\bar{t}$
- continuum W+jets and Z+jets
- single top
- QCD dijets

CMS Note: CMS PAS EXO-09-002

Discovery and Exclusion Potentials





Conclusions

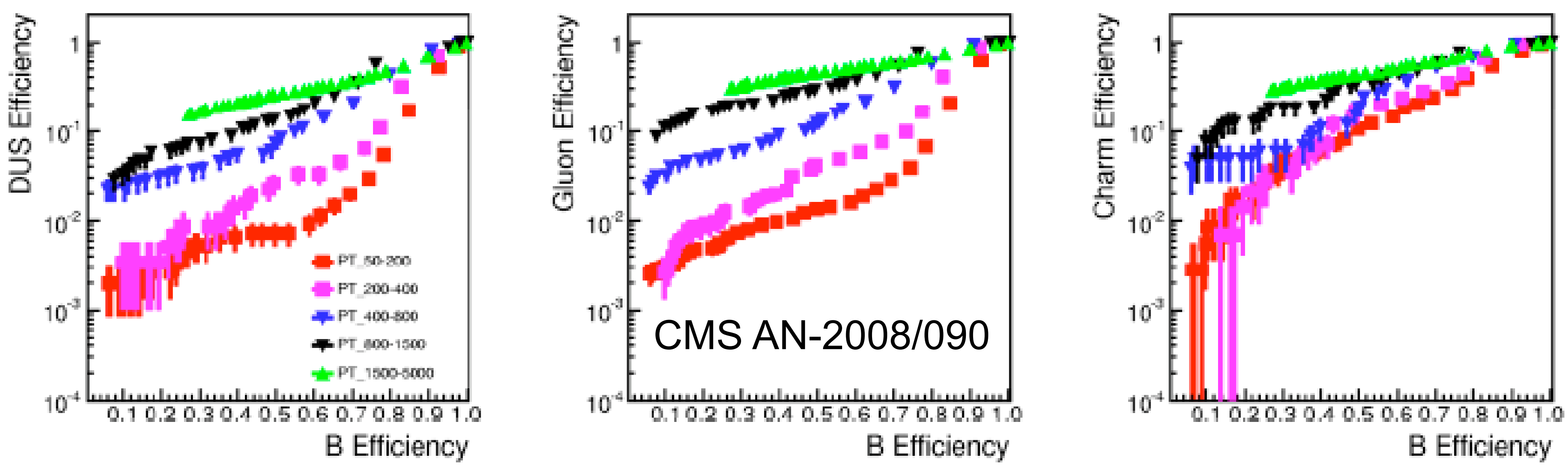
- Our early studies are very encouraging
  - Algorithm description: CMS PAS JME-09-001
  - Resonance search: CMS PAS EXO-09-002
- Room for improvements
  - Optimize cuts
  - Use ECAL or particle flow to improve resolution
  - Can we improve the minimum 2-subjet mass?

Backup

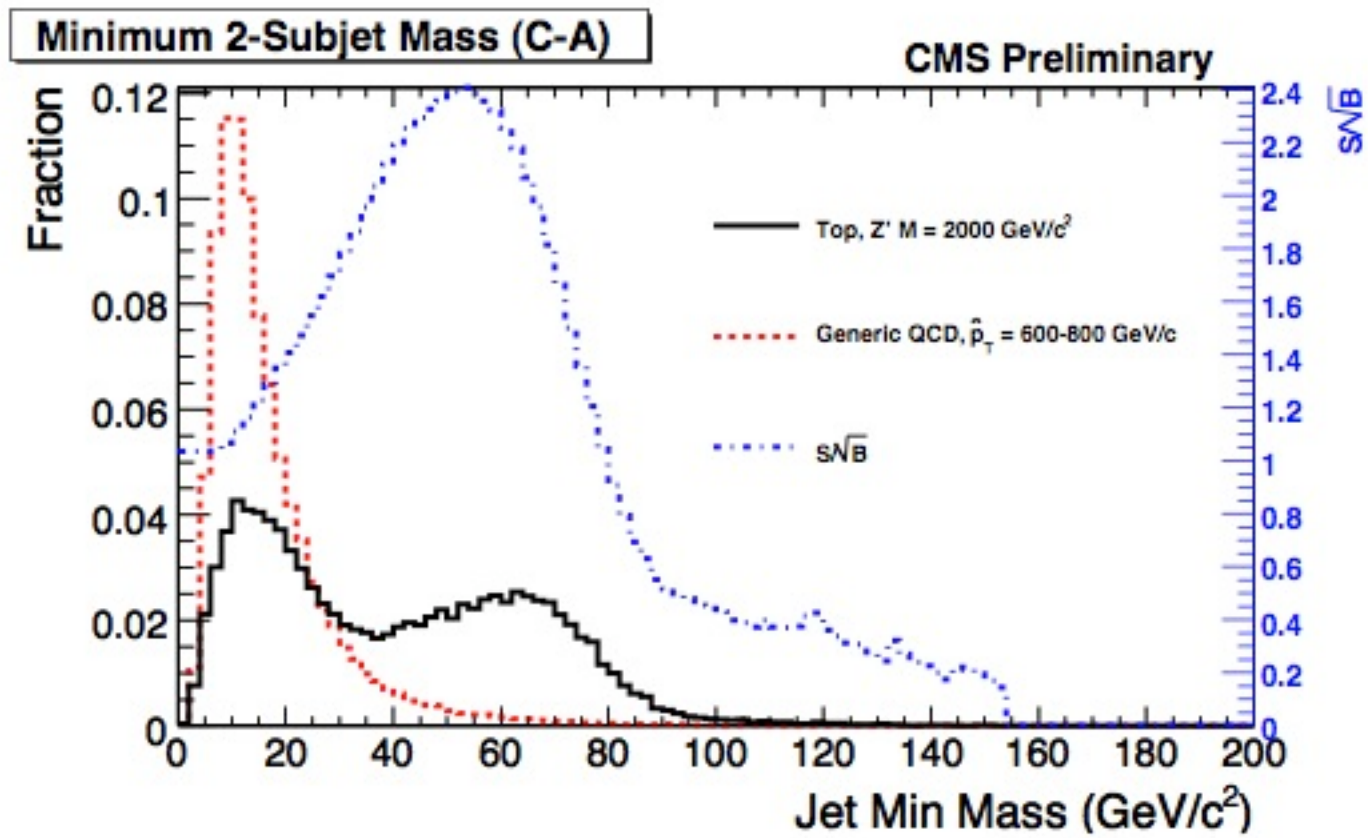
High P_T b-tagging

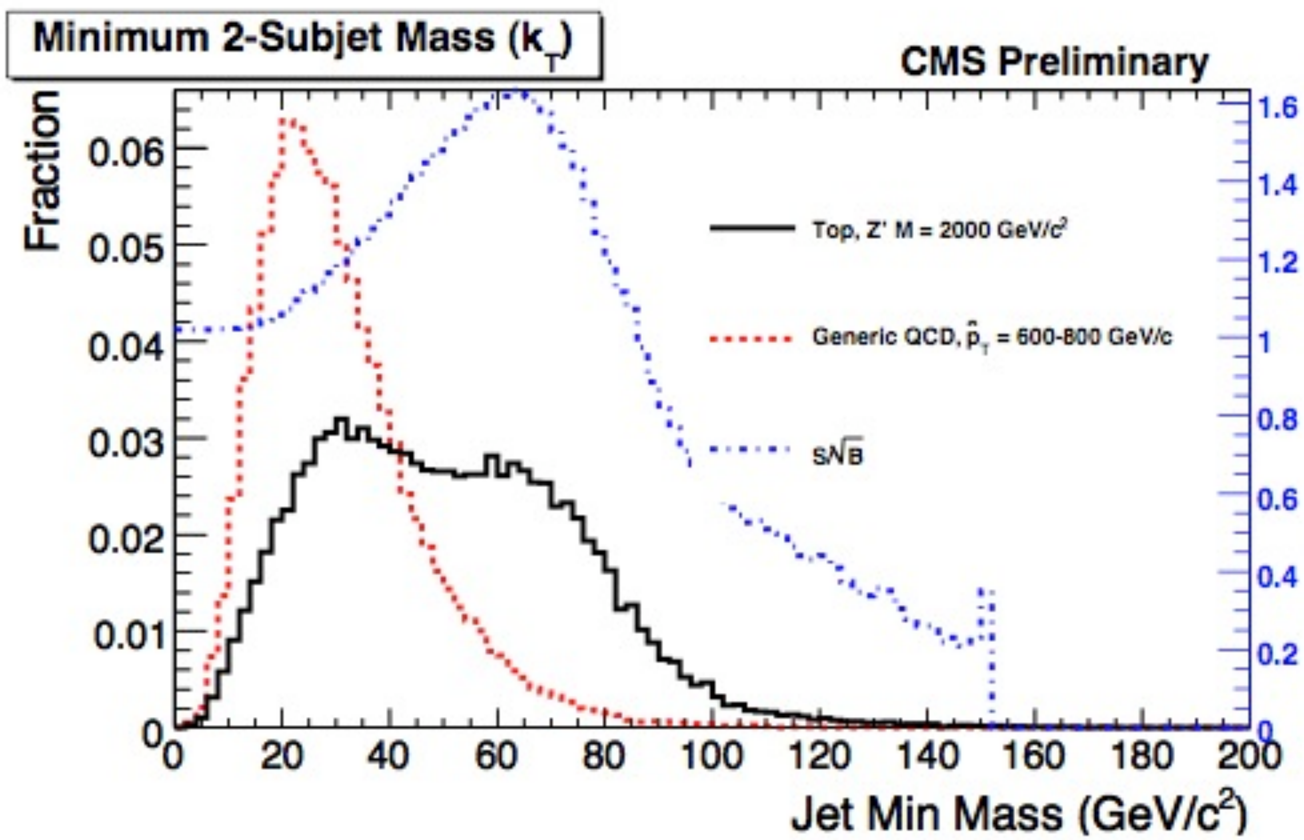
- Fake rate increases as jet P_T increases
- At high P_T, b-tag efficiency ≈ mistag rate
  - ➡ Currently, high P_T b-tagging is not an option!
- Probable cause: High hit density

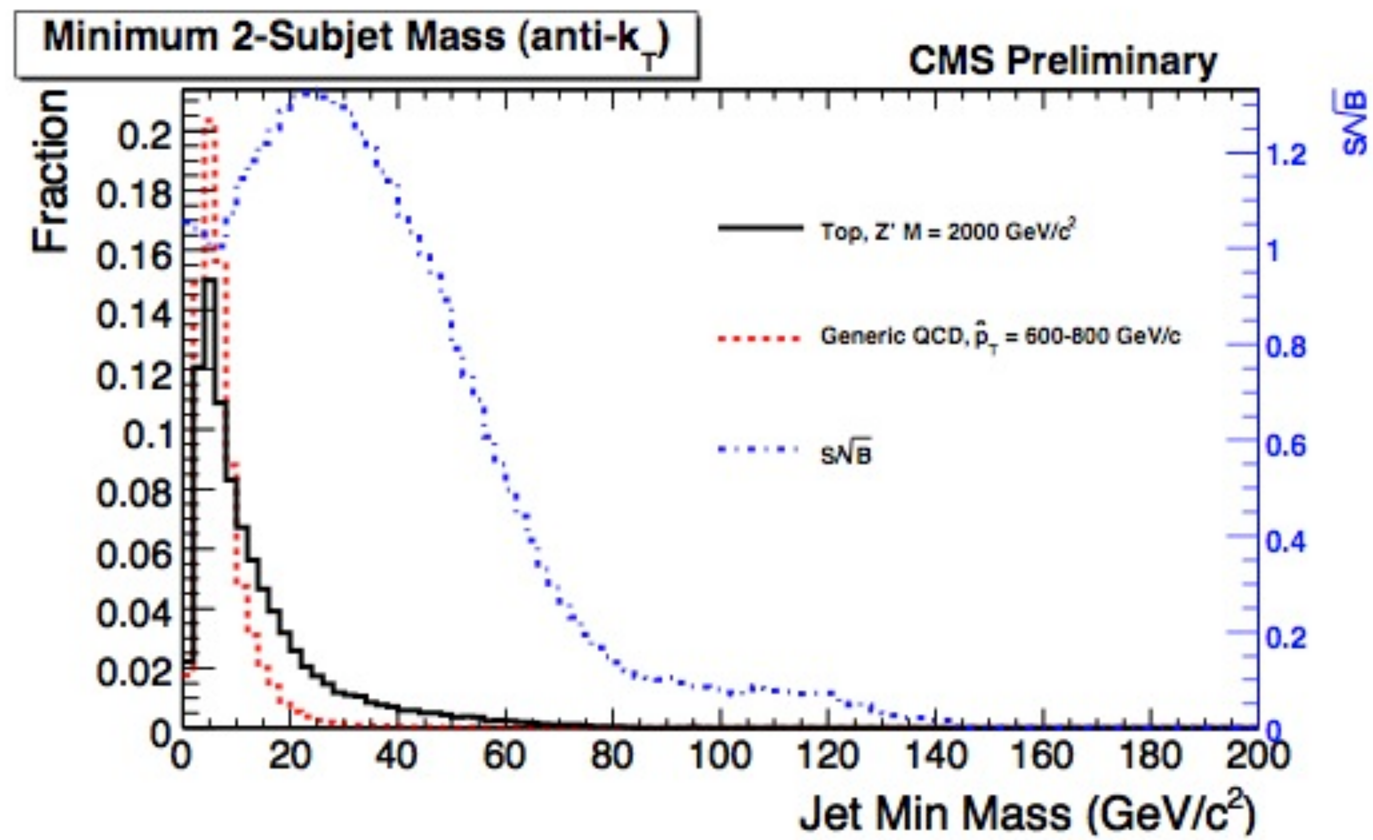
50- 200 GeV, 200- 400 GeV, 400- 800 GeV, 800-1500 GeV, 1500-5000 GeV



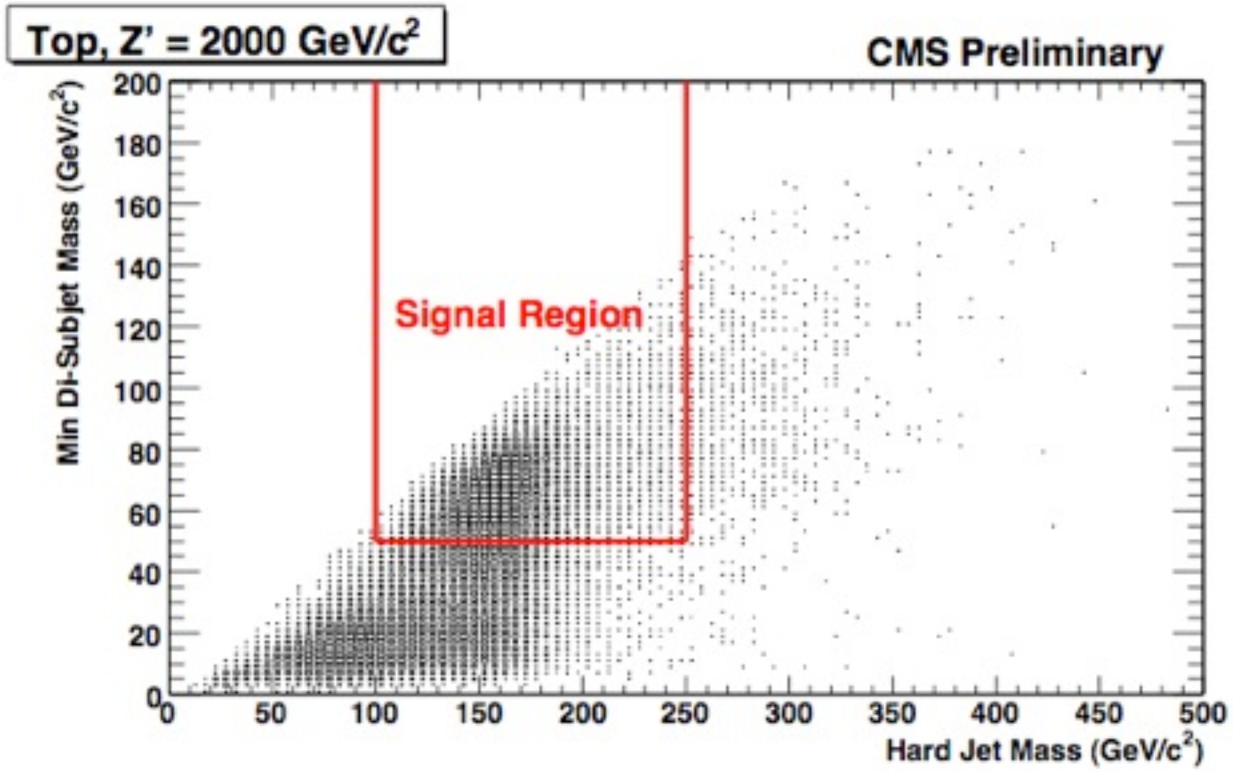
MinMass for different jet algorithms

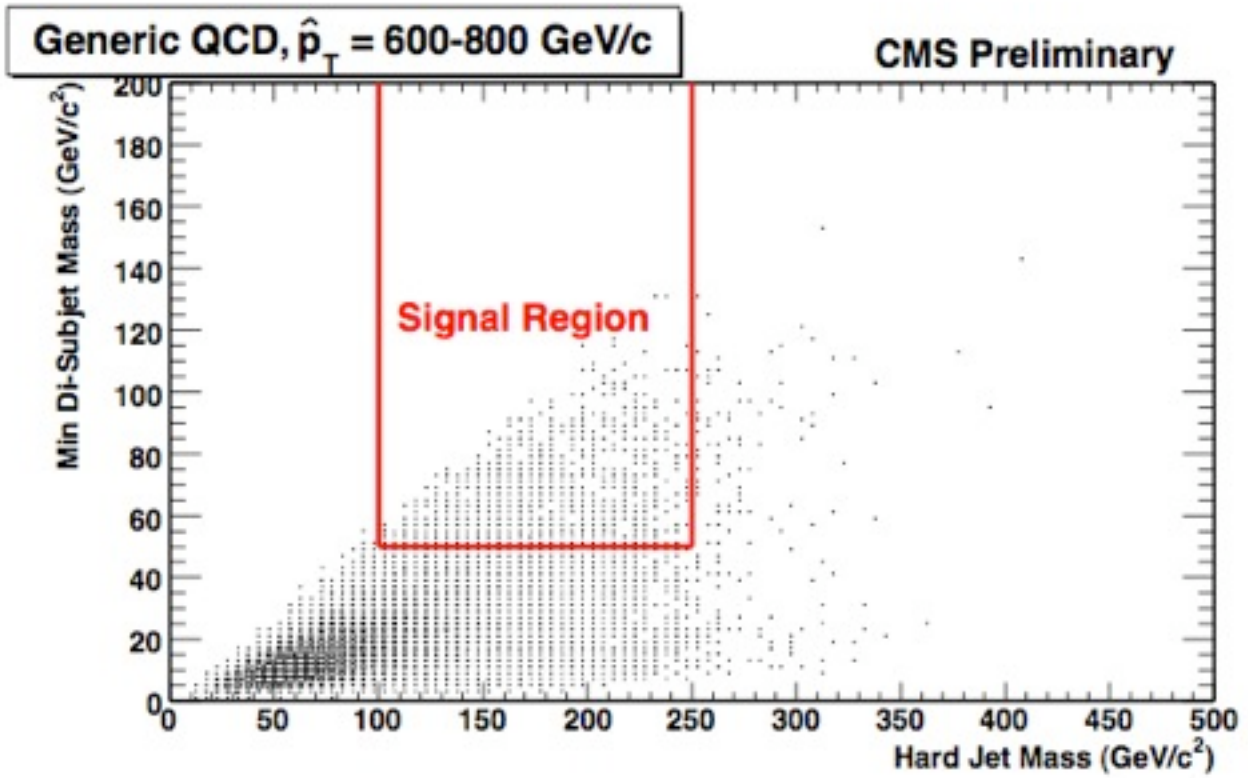




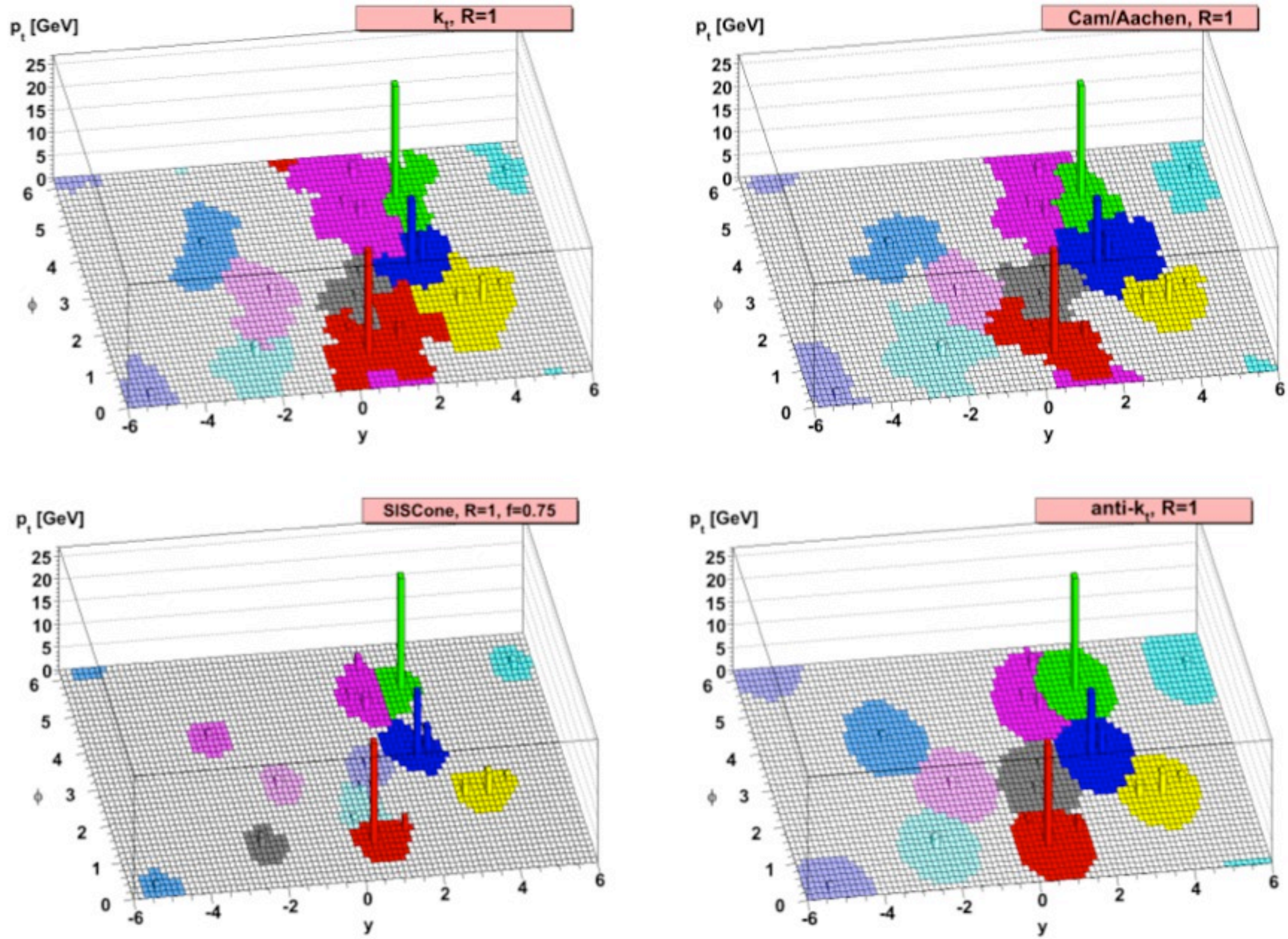


MinMass vs. Jet Mass

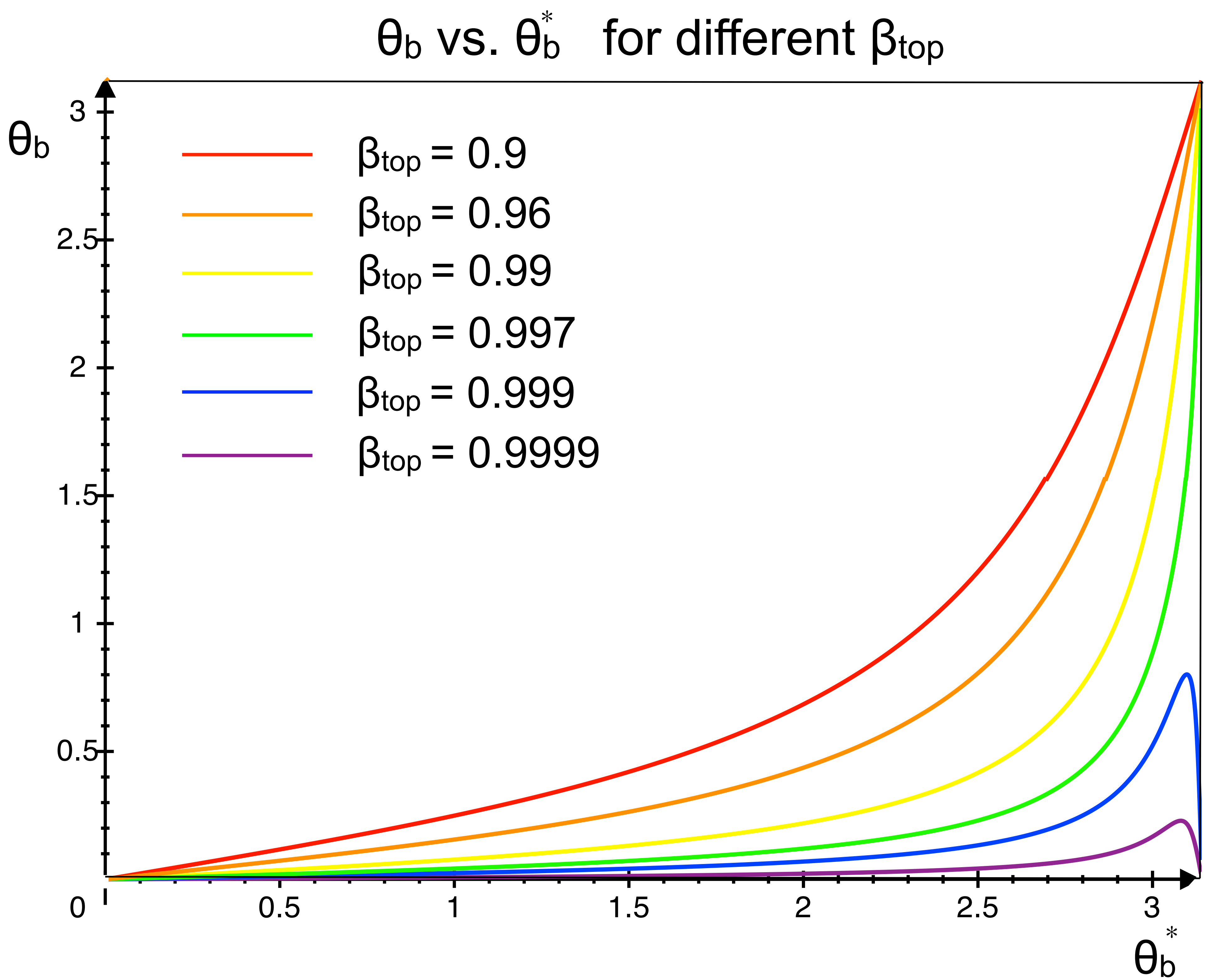




Jet Algorithms



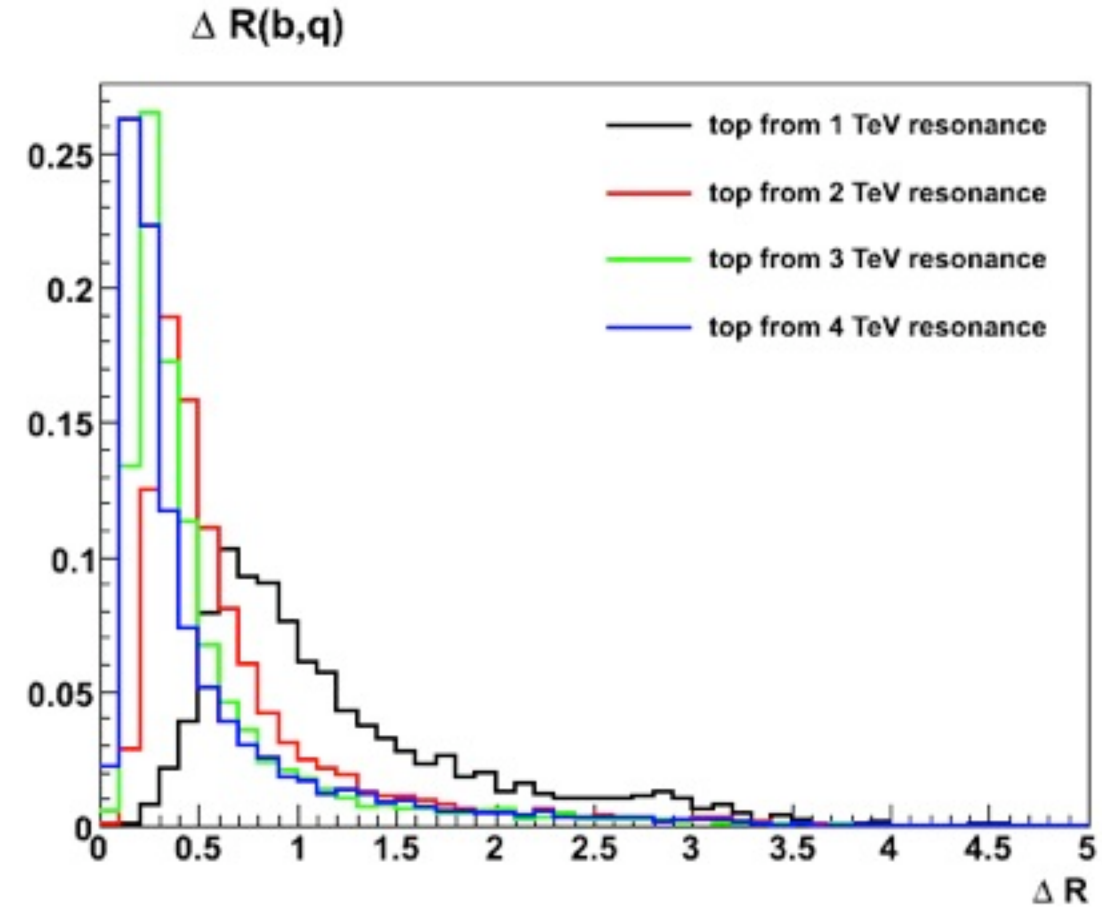
Cacciari, Salam, and Soyez

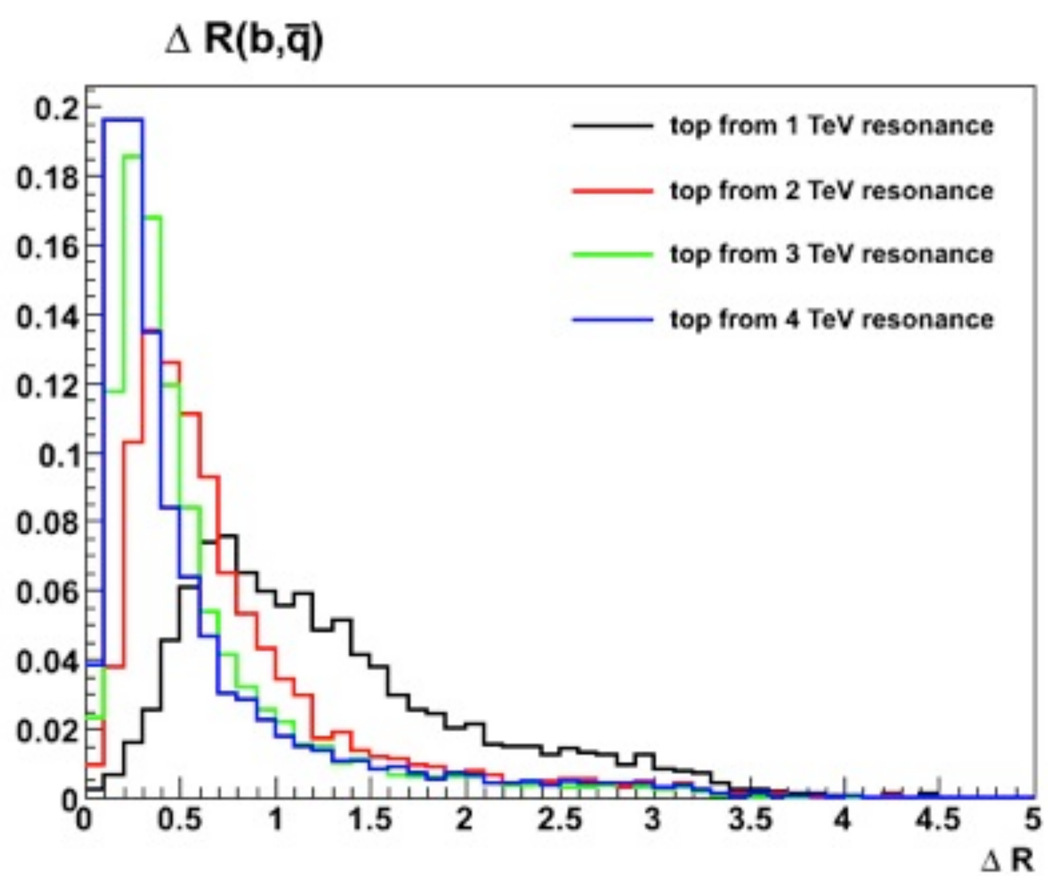


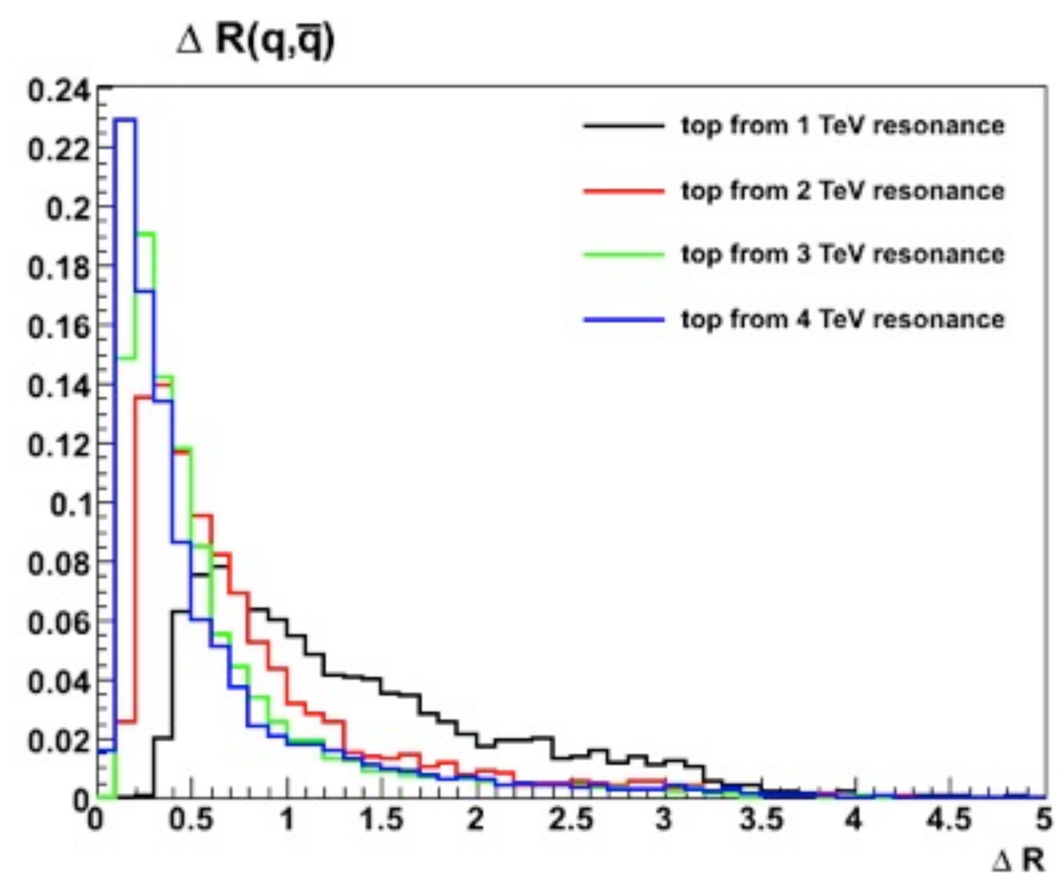
θ_b vs. θ_b^* for different β_{top}
θ_b
θ_b^*
β_{top} = 0.9
β_{top} = 0.96
β_{top} = 0.99
β_{top} = 0.997
β_{top} = 0.999
β_{top} = 0.9999
0
0.5
1
1.5
2
2.5
3

Top decay ΔR separation

$t \rightarrow Wb \rightarrow q\bar{q}b$

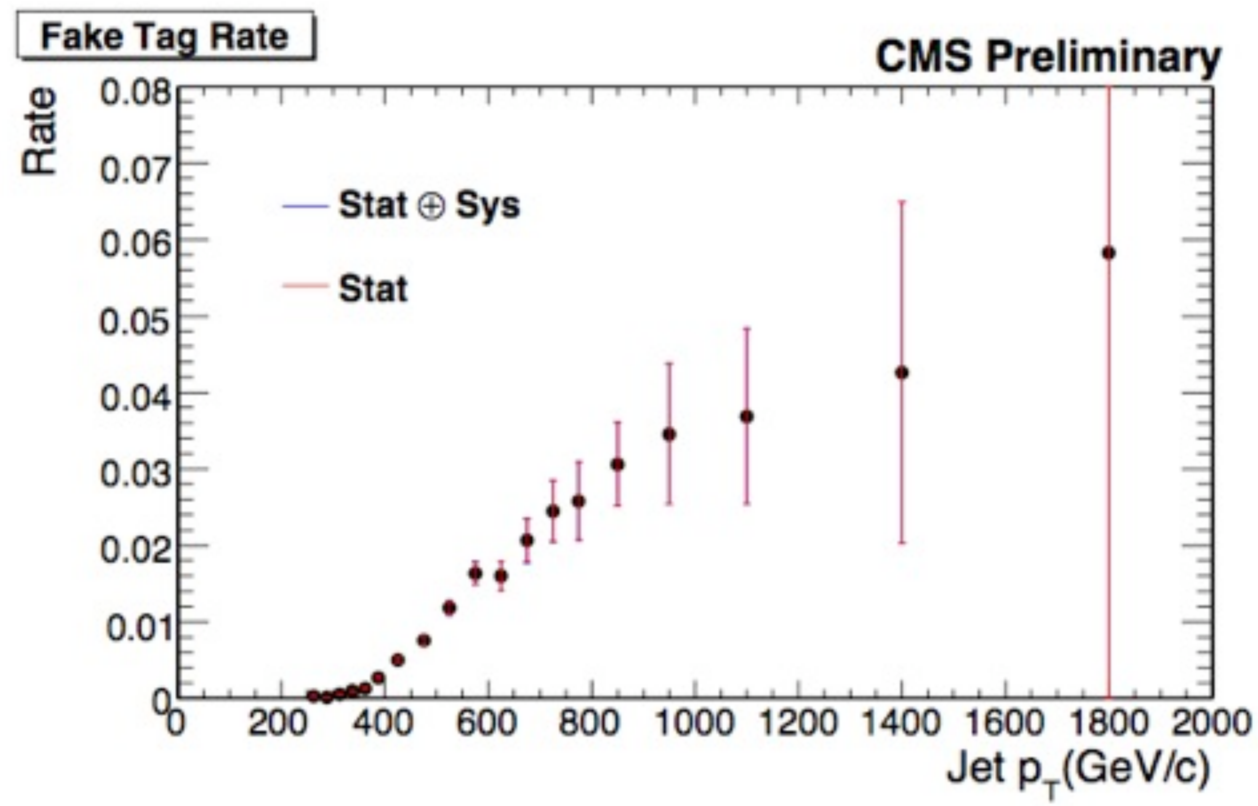






Fake Tag Rate

- QCD multijet background
- Data driven method
- Anti-tag one jet
  - Anti-tag ⇒ Jet fails at least one of these cuts:
    - Jet Mass
    - Number of subjets
    - Minimum 2-subjet mass
- Use the other jet in the event as a signal depleted sample
- Subtract continuum $t\bar{t}$ based on simulation
  - Systematic Uncertainty



Top Tagging Uncertainty

Effect	Systematic Uncertainty (%)
Initial State Radiation	1
Final State Radiation	2
Renormalization Scale	3
Light Quark Fragmentation	< 1
Heavy Quark Fragmentation	< 1
Theoretical Uncertainty	3.8
Momentum Smearing + 10%	3.3
Azimuthal Smearing + 50%	2.9
Rapidity Smearing + 50%	2.9
Detector-Based Uncertainty	5.3
Total Systematic Uncertainty	6.5

Signal and Background Systematic Uncertainty

Quantity	Relative Uncertainty	Uncertainty on S and B at $m_0 = 2$ TeV/c^2
Signal Uncertainties		
Top Tagging Efficiency	6.5%	13%
JES Uncertainty on Acceptance	5%	5%
	Total Signal Uncertainty	14%
Background Uncertainties		
Statistical uncertainty	10%	10%
JES Uncertainty on QCD Background	35%	33%
$t\bar{t}$ Continuum Contribution	100%	5%
Luminosity	10%	10%
	Total Background Uncertainty	36%