Top reconstruction for new physics search

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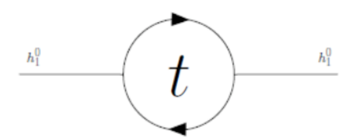
plan

- motivation: top, fat jet
- jet substructure
- HEPTopTagger
- application
- summary

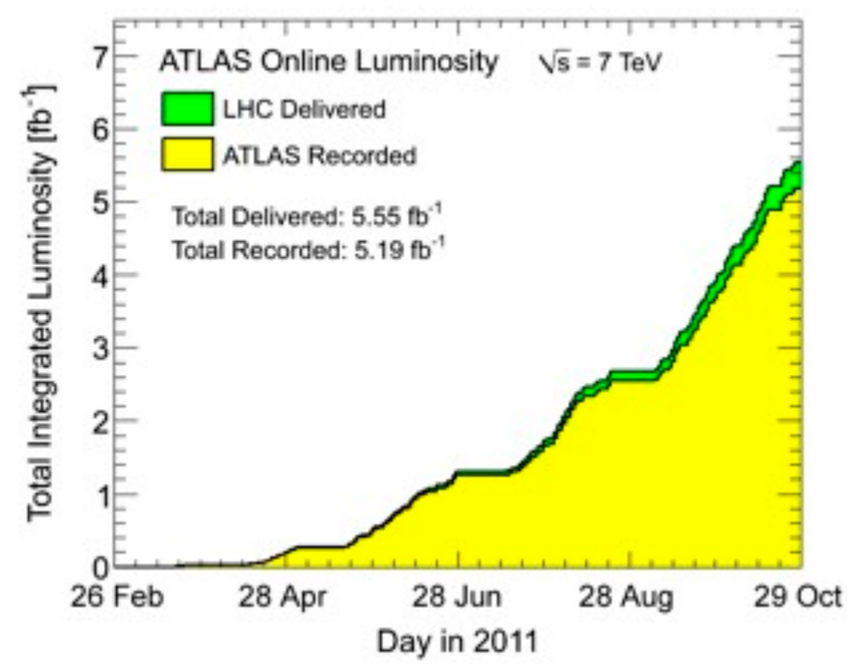
Top at LHC

- top: closest to new physics → probe for new physics
  - fine tuning problem: top partner $\delta m_h^2 \sim$  $-\frac{3}{4\pi} y_t^2 \Lambda_{\rm SM}^2$
  - Tevatron anomaly (A_{FB}^t , single top, W+jets, etc.)
- Main BG for new physics search
- LHC : precision physics by statistics

$$\sigma_{tt}^{14\rm TeV} = 918 \text{ pb},$$

$$\sigma_{tt}^{7\rm TeV} = 165 \text{ pb} \to 800,000\ t\bar{t} \text{ for } 5\text{fb}^{-1}.$$

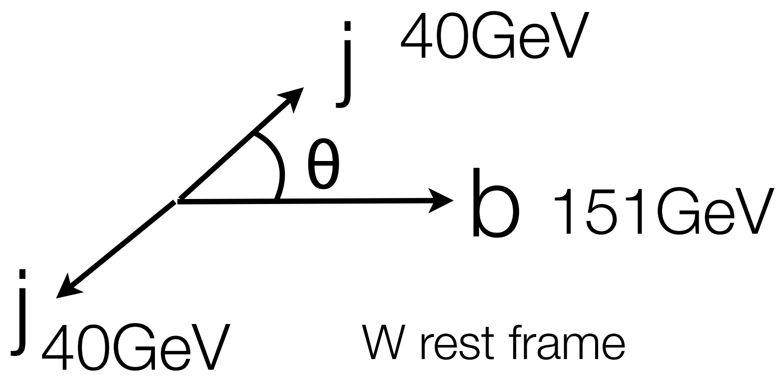
$$\text{Tevatron} \sim 40,000\ t\bar{t}\ (7.5\text{pb} \times 5.3\ \text{fb}^{-1})$$



- focus on hadronic top : 3 jets
  - advantage: full momentum reconstruction
  - disadvantage: combinatorics problem, how to reduce QCD

top BG, combinatorics BG

- W+jets CDF anomaly



top kinematics has several physical mass scales

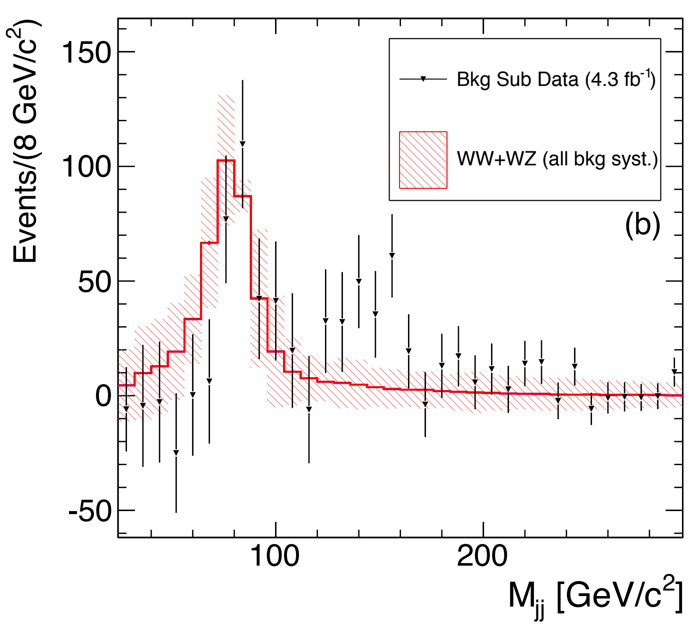
$$t \to bjj \ \text{(combinatorics)}$$
$$m_{bj} \text{ peak} \sim 140 \text{ GeV}$$

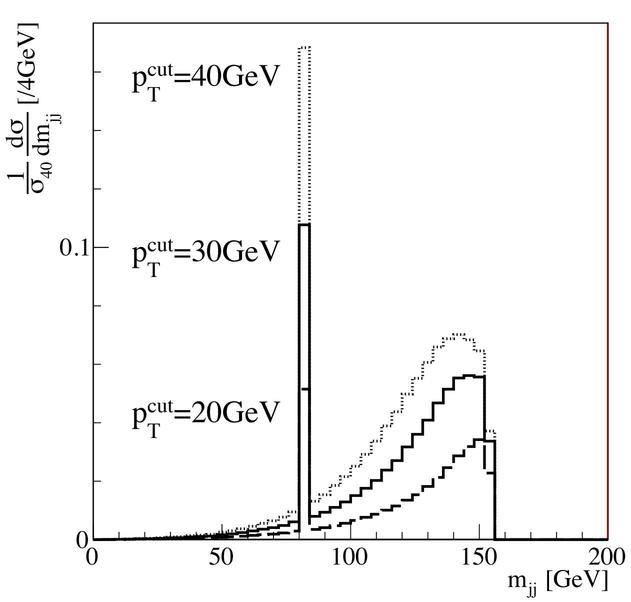
understanding top BG is crucial

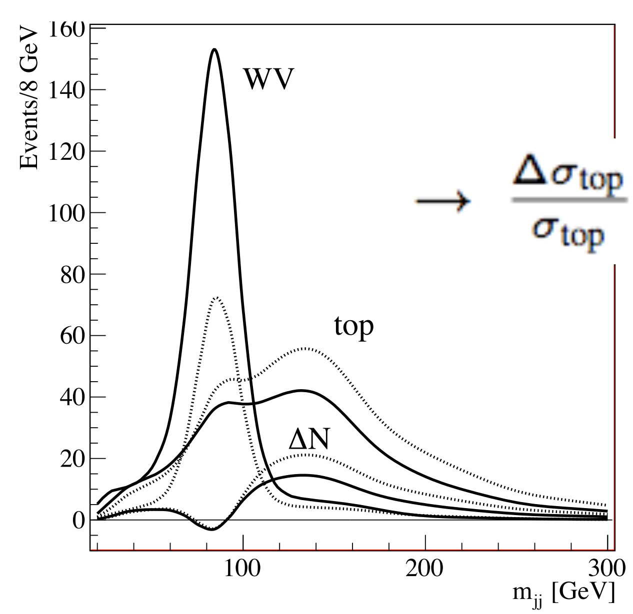
di-boson production cross section

- $\sigma(WW + WZ) = 18.1 \pm 3.3(\text{stat}) \pm 2.5(\text{syst})$ pb (combined channels)
  $\sigma(WW + WZ) = 23.5 \pm 4.9$pb (muon channel)
  $\sigma(WW + WZ) = 13.5 \pm 4.4$pb (electron channel)
- large systematic uncertainty?

[arXiv:1104.4087[hep-ph]T.Plehn,MT]





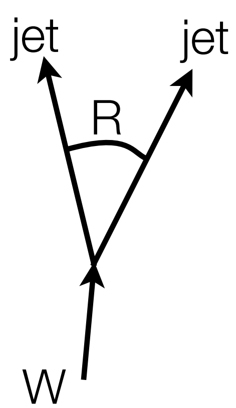


$$\rightarrow \frac{\Delta\sigma_{top}}{\sigma_{top}} \sim 40\% \text{ needed}$$

Boosted objects at the LHC

- new physics search with E_{Tmiss} : need recoiled SM particle as a probe
- low p_T tops: not useful as a probe
- high p_T tops: better S/B in boosted region (ex. MT2 endpoint)

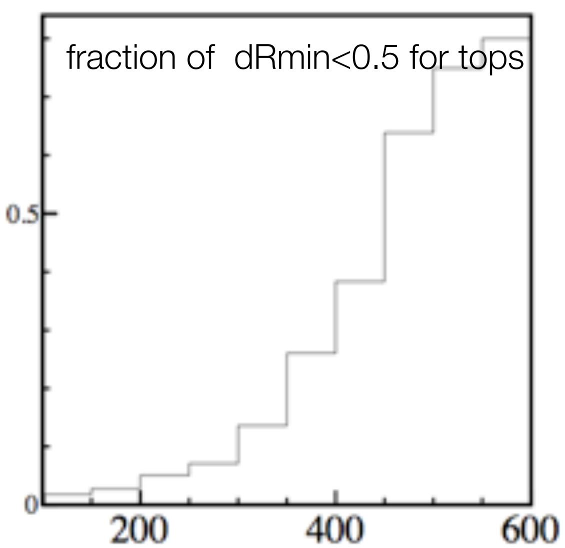
  overlapping decay jets → large jet (fat jet) & look substructure



$$R \sim \frac{2m}{p_T}$$

$$0.7 = 2 \times 175/500$$

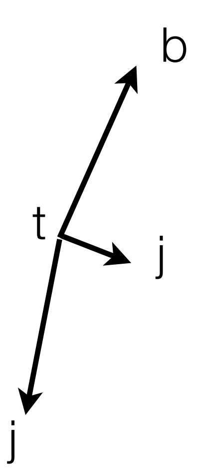
$$0.4 = 2 \times 80/400$$



- fat jet: reduce QCD combinatorics BG

$\sigma_{t\bar{t}}^{14TeV} = 918\text{pb}$ $\sigma_{QCD}^{14TeV} = 10^8\text{pb}$ ($\sigma_{3jets}^{14TeV} = 2 \times 10^6\text{pb}$)

low pT



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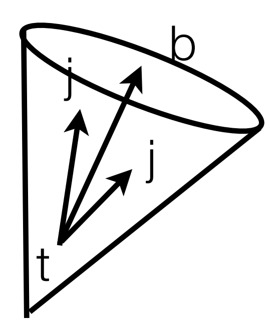
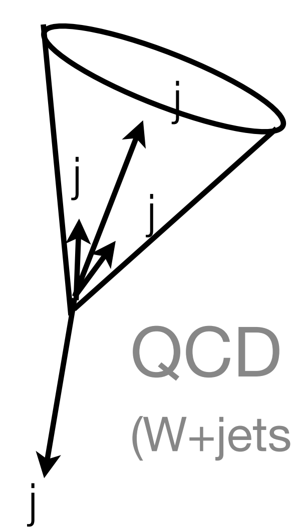


high pT

$m_{jjj} \sim m_t$ $m_{jj} \sim m_W$

$$m_J \sim m_t$$



QCD

(W+jets ⇔ jets + W)

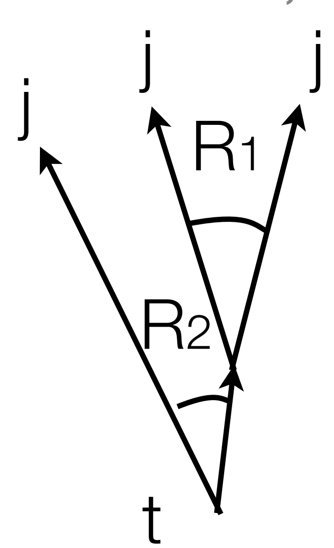
Moderately boosted tops

- fat jet & jet substructure
- highly boosted tops (pT>500GeV): low statistics

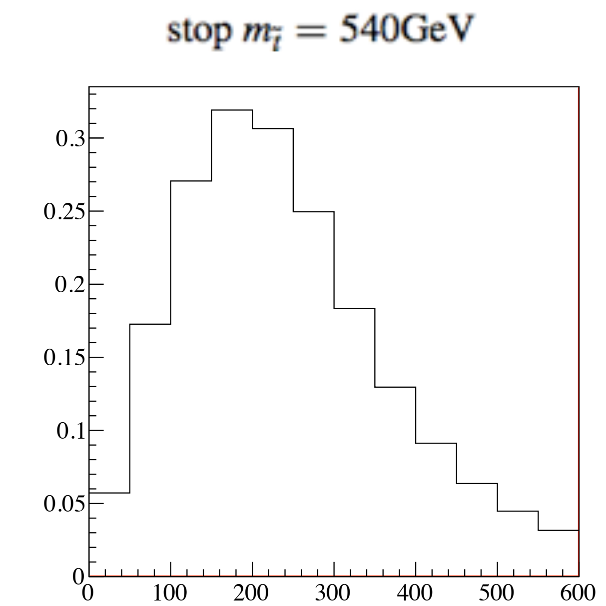
$p_{T,t}^{\rm min}$ [GeV]	0	100	150	200	250	300	400	500
fraction	100%	53%	28%	14%	6.8%	3.4%	0.96%	0.33%

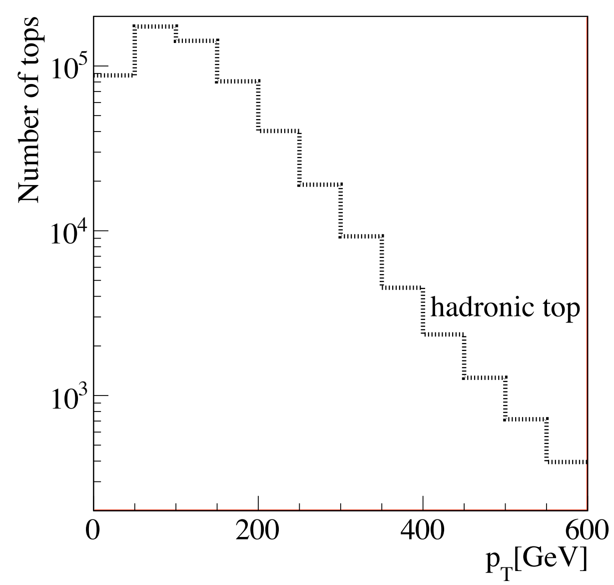
- target：moderately boosted tops (pT>200GeV)
  testable with SM tops

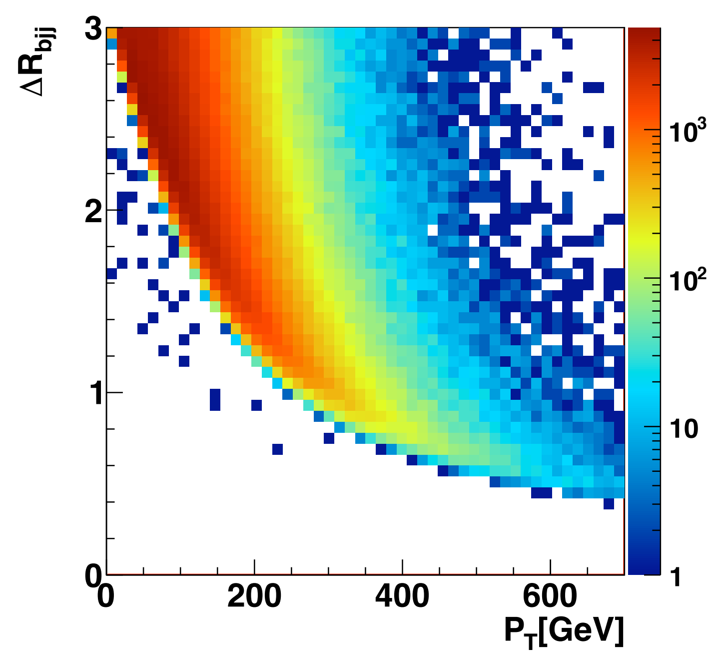
- starting with C/A, R=1.5 fat jet



$$\Delta R_{bjj} = \max\{R_1, R_2\}$$





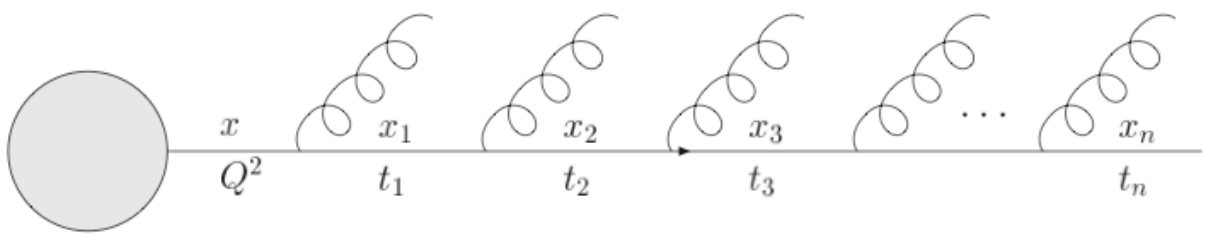


basic idea of jet substructure analysis

- mass drop criterion
- filtering

basic idea of jet substructure analysis

- QCD jets: well described by parton shower approx.

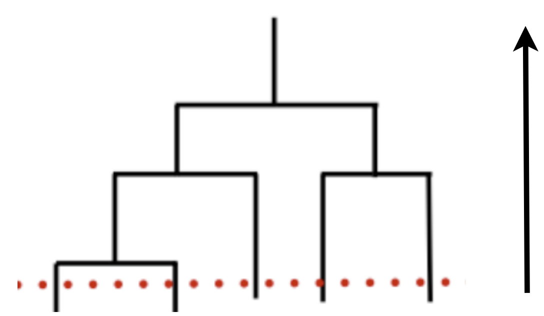


$$Q^2 > t_1 > t_2 > \dots$$
$$t = E_1 E_2 (1 - \cos\theta) \sim E^2\theta^2/2$$
$$\mathcal{M} \propto \frac{1}{t_1}\frac{1}{t_2}\cdots$$

soft-collinear property

- Clustering jet algorithm

1. find smallest d_{ij}, d_{iB}
2. if d_{ij}, recombine ij
   if d_{iB}, call i as a jet
3. repeat 1-2 until no particles left

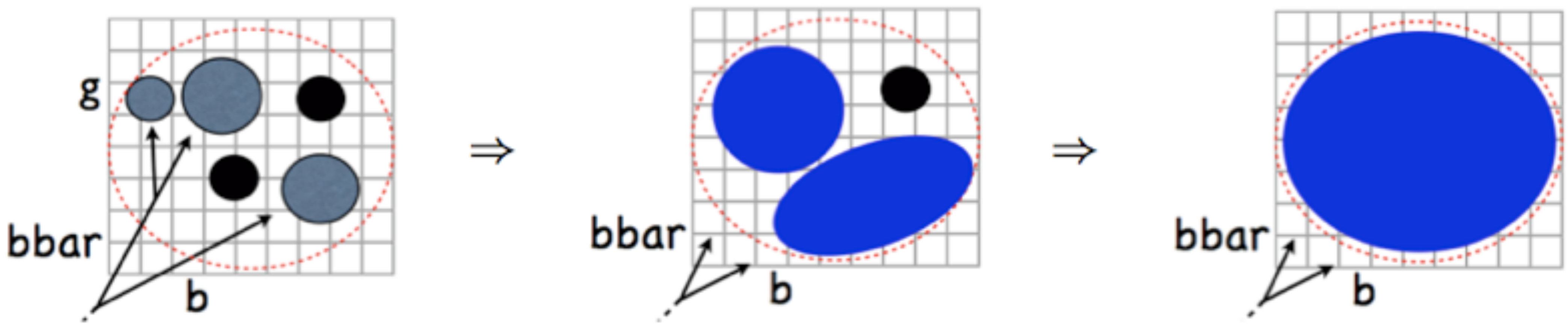


C/A $\qquad d_{ij} = \frac{\Delta R_{ij}^2}{R^2}, \quad d_{iB} = 1$

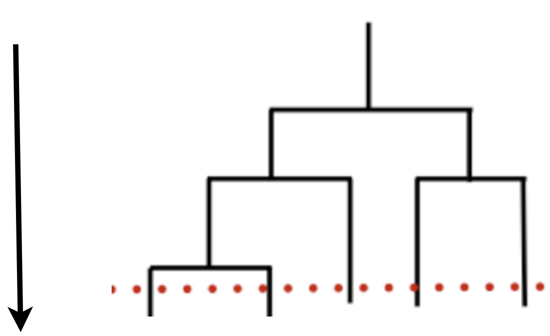
- expect: shower history = clustering history

Mass drop

- boosted decay products also clustered into fat jet.



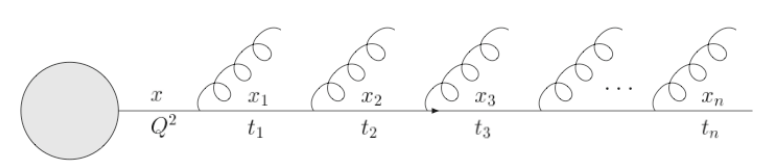
- de-clustering the jet (going backward the history) to find mass drops



$$j = j_1 + j_2$$

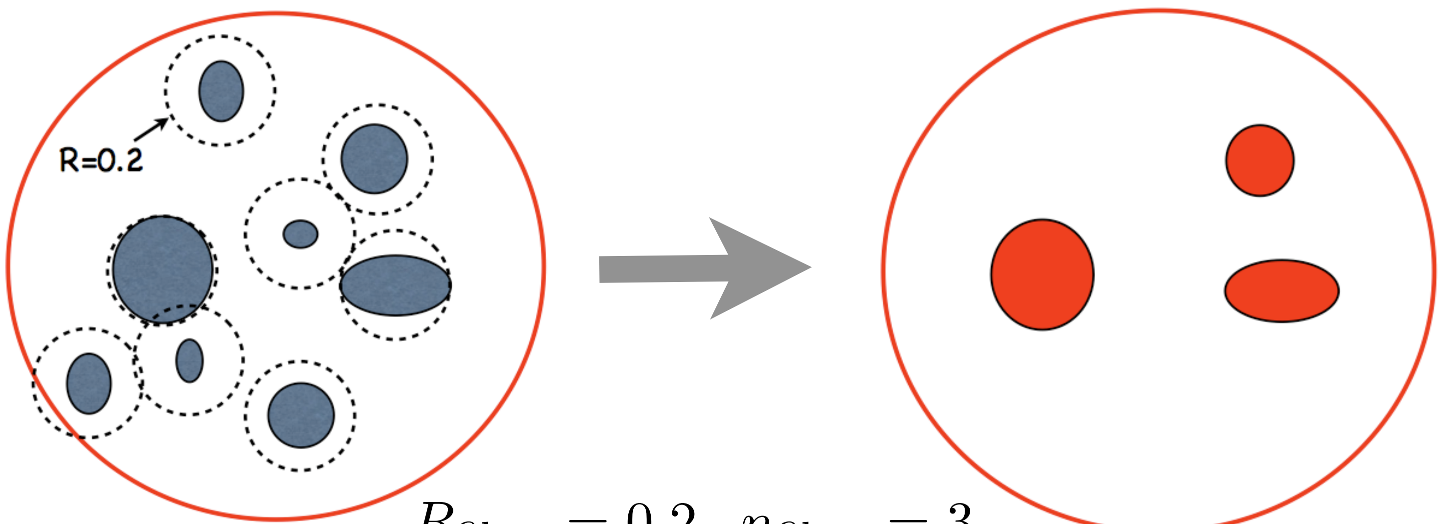
$$\boxed{m_j \gg m_{j1}, m_{j2} \text{ (decay)}} \leftrightarrow \boxed{m_j \sim m_{j1} \gg m_{j2} \text{ (QCD)}}$$

- For massive jet, no mass drop if QCD jet



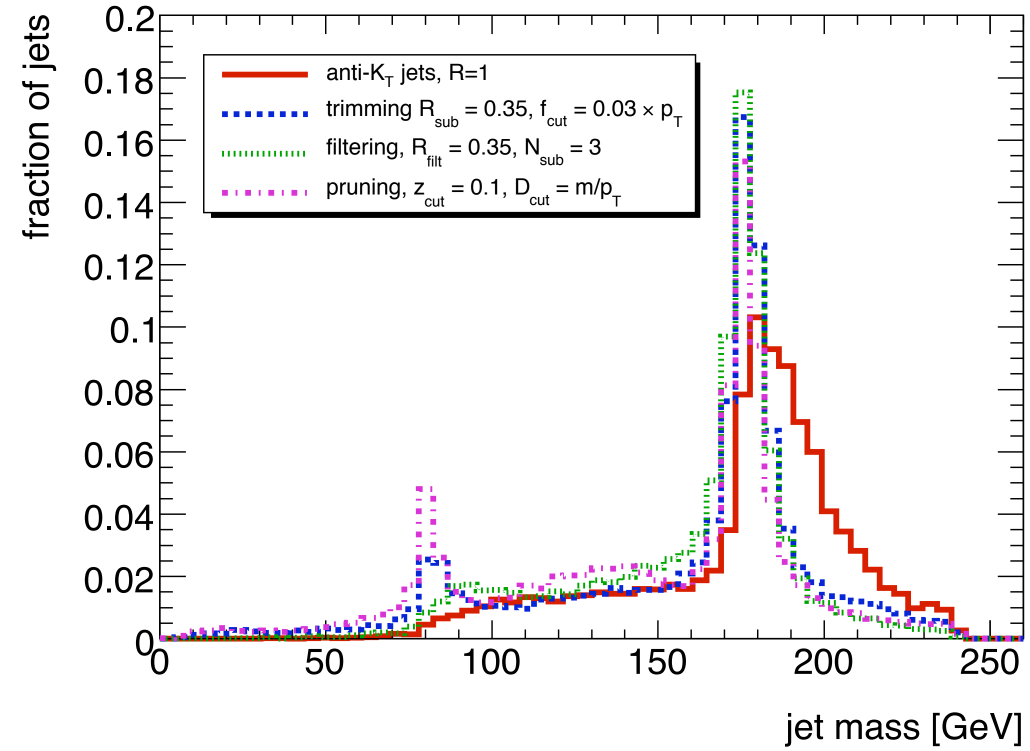
Filtering

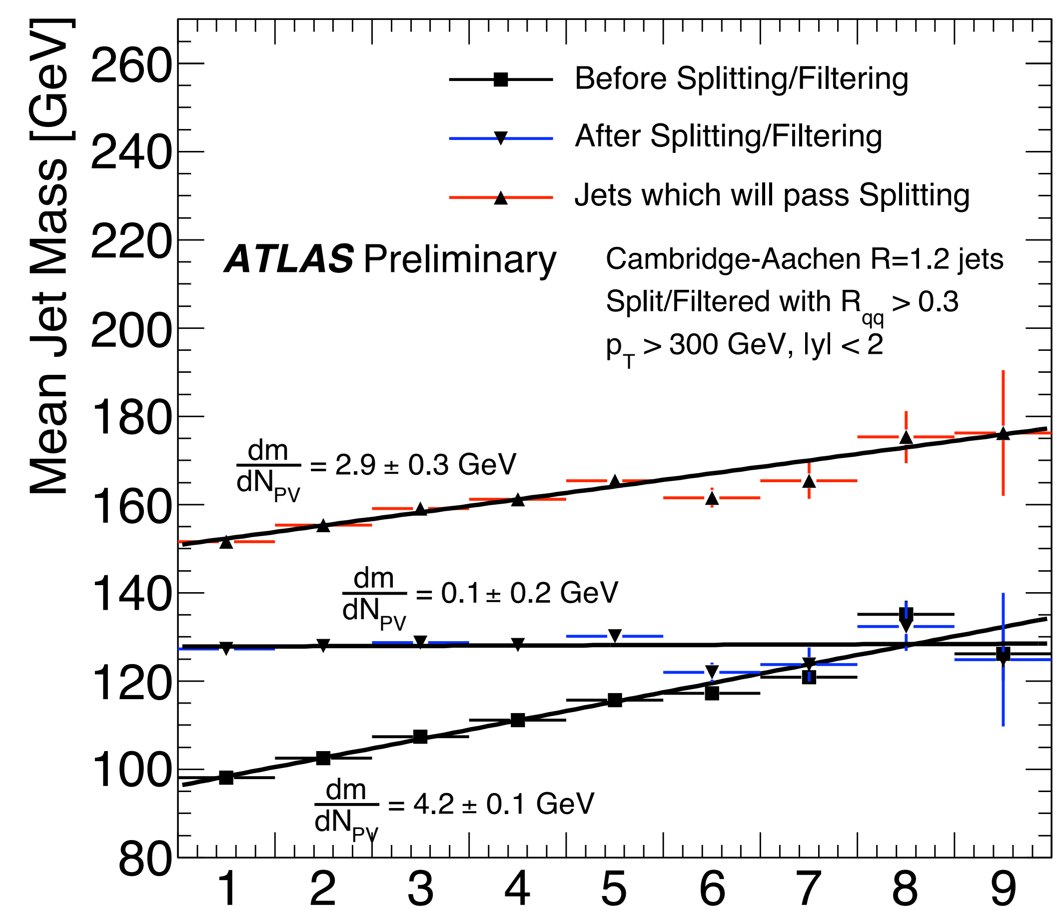
- large R
  - large pile-up, underlying events ~ R^2



$$R_{\text{filter}} = 0.2,\ n_{\text{filter}} = 3$$

- jet mass vs. number of primary vertices





HEPTopTagger

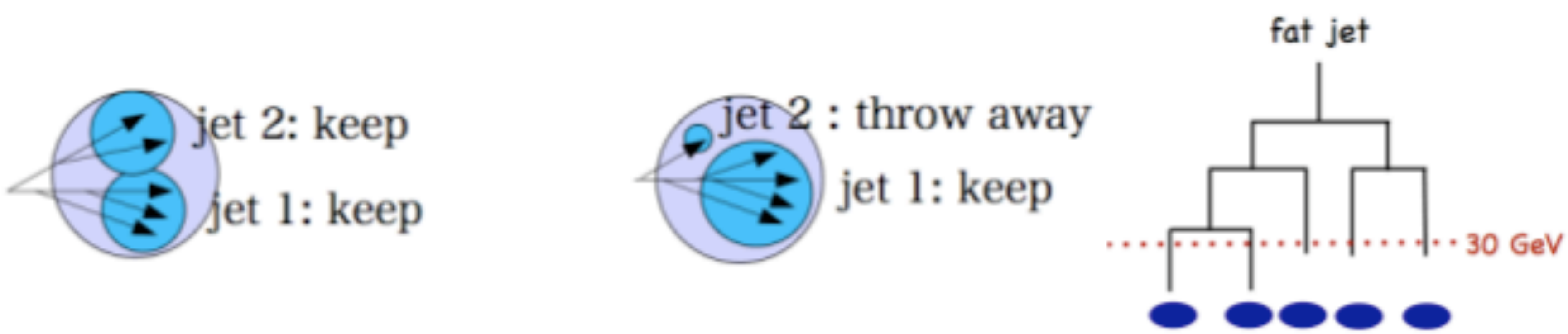
[JHEP1010:078,2010. arXiv:1006.2833[hep-ph] T.Plehn,M.Spannowsky,D.Zerwas,MT]

HEPTopTagger [JHEP1010:078,2010. arXiv:1006.2833[hep-ph] T.Plehn,M.Spannowsky,D.Zerwas,MT]

1. fat jets – C/A($R = 1.5$), $p_T^{\text{fatjet}} > 200$ GeV

2. mass drop criterion

– find hard proto-jets $m_j < 30$ GeV, $m_{j1} < 0.8 m_j$ to keep j_1 and j_2

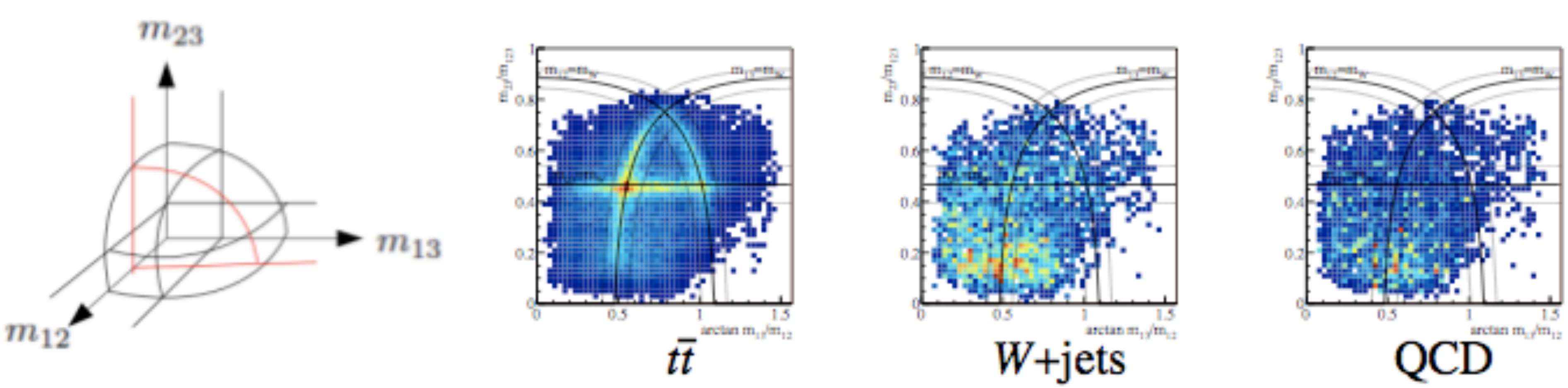


3. choose 3 hard proto-jets with best filtered mass

– $|m_{jjj}^{\text{filt}} - m_t| < 25$ GeV and $p_T^{\text{rec}} > 200$ GeV $\rightarrow$ top candidate

4. check mass ratios

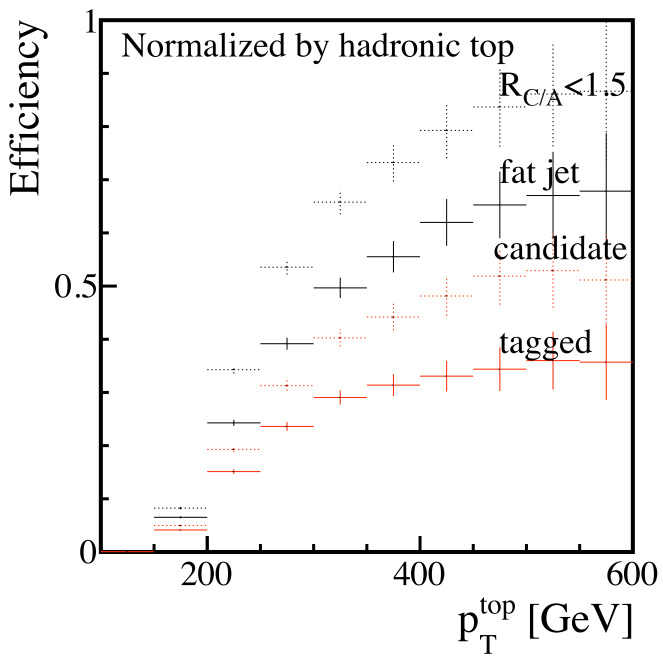
– m_t condition: $m_t^2 = m_{123}^2 = m_{12}^2 + m_{13}^2 + m_{23}^2$ $\rightarrow$ spherical surface: 2D mass ratios

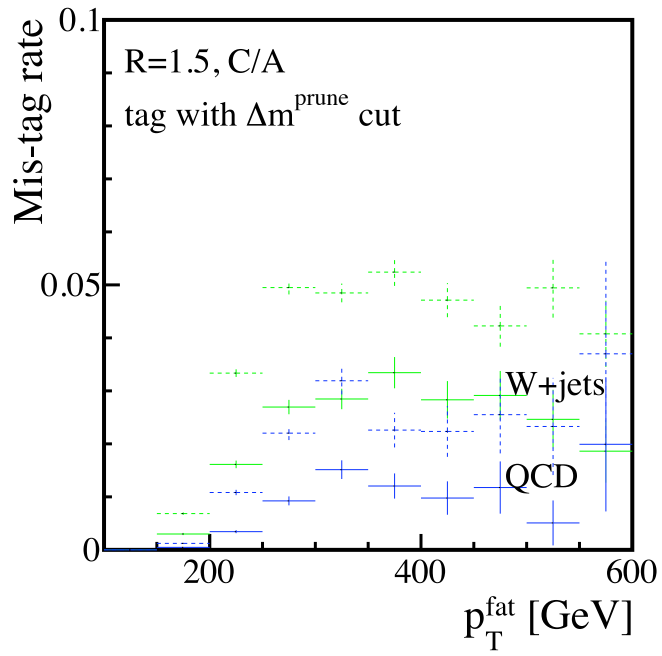


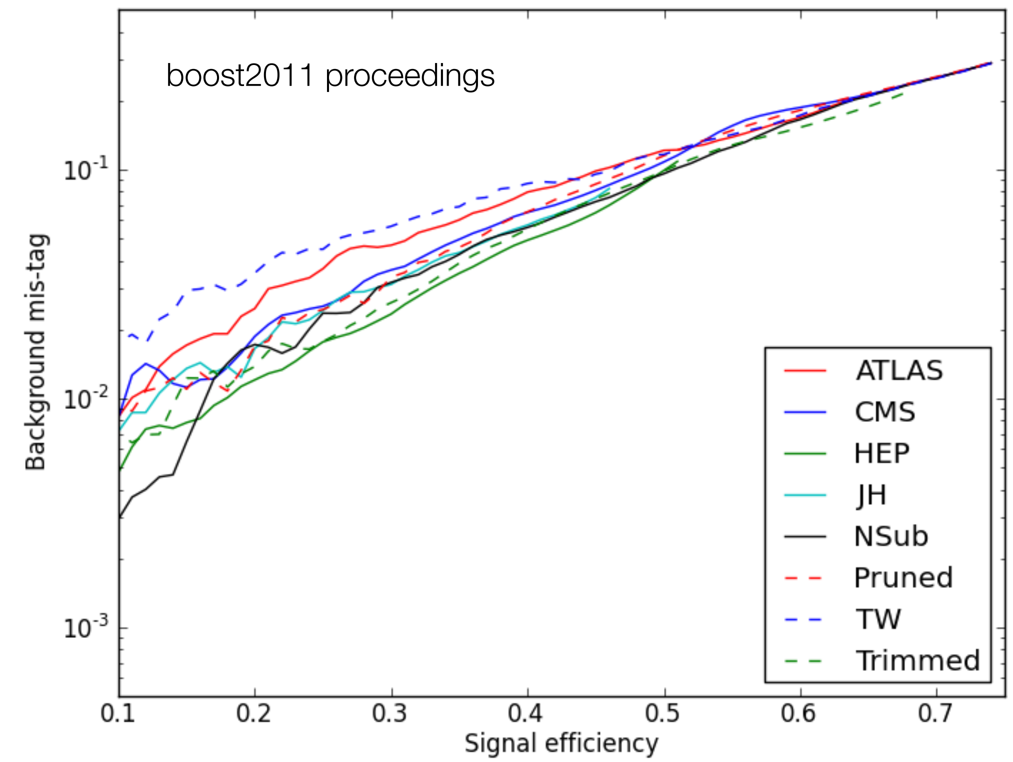
– W mass condition, soft-collinear cut $\rightarrow$ tagged top

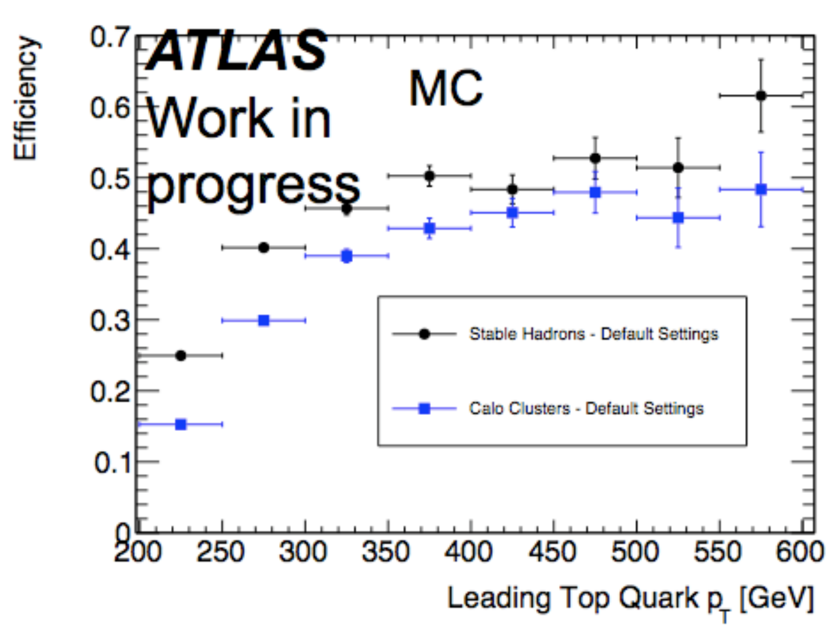
HEPTopTagger [JHEP1010:078,2010. arXiv:1006.2833[hep-ph] T.Plehn,M.Spannowsky,D.Zerwas,MT]

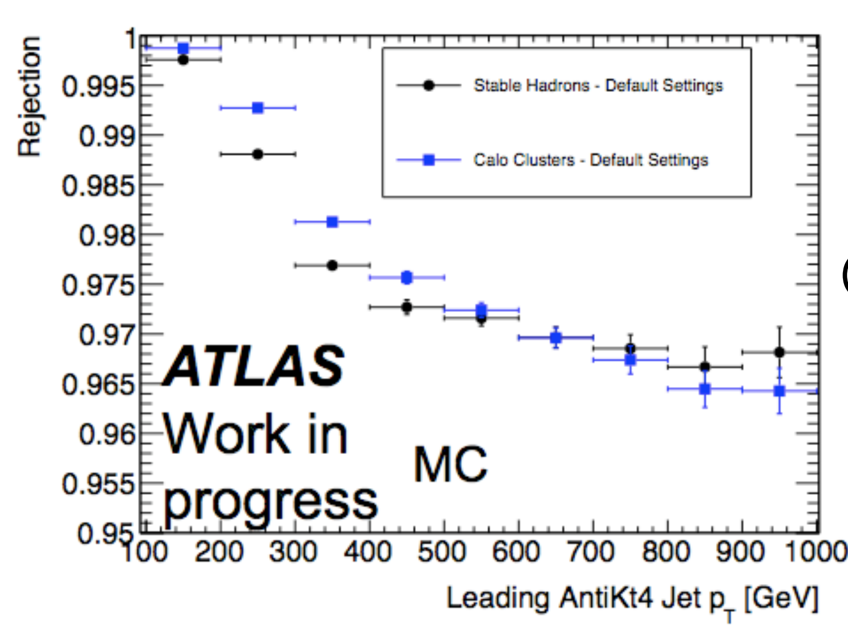
- efficiency: ~ 30%, mistag: 2~4% (1~2% with pruning)











G. Kasieczka, S. Schaetzel, A. Schoening (Heidelberg)

HEPTopTagger [JHEP1010:078,2010. arXiv:1006.2833[hep-ph] T.Plehn,M.Spannowsky,D.Zerwas,MT]

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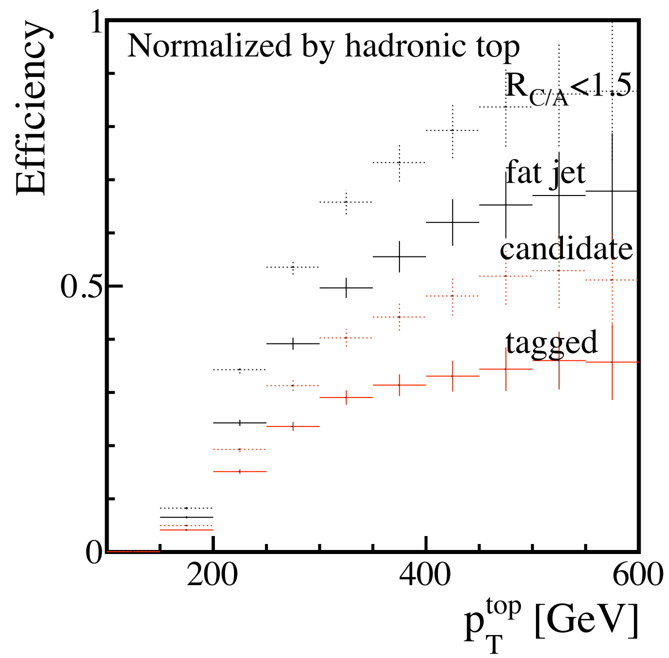
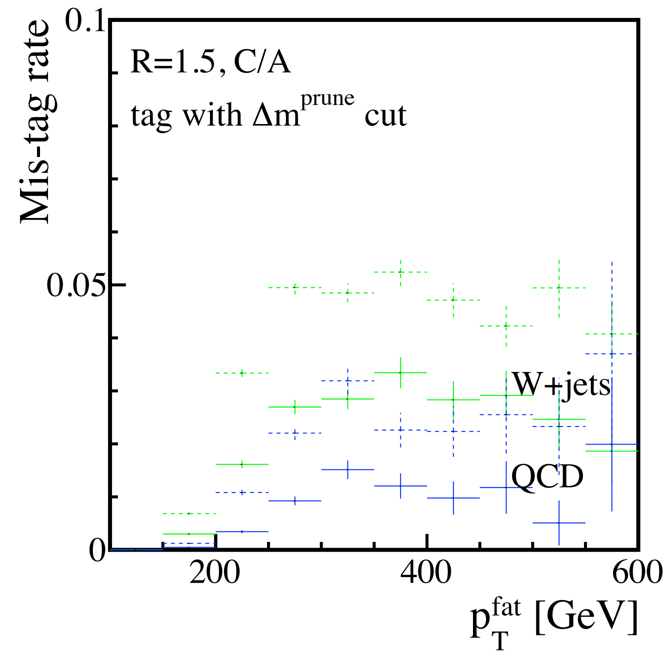
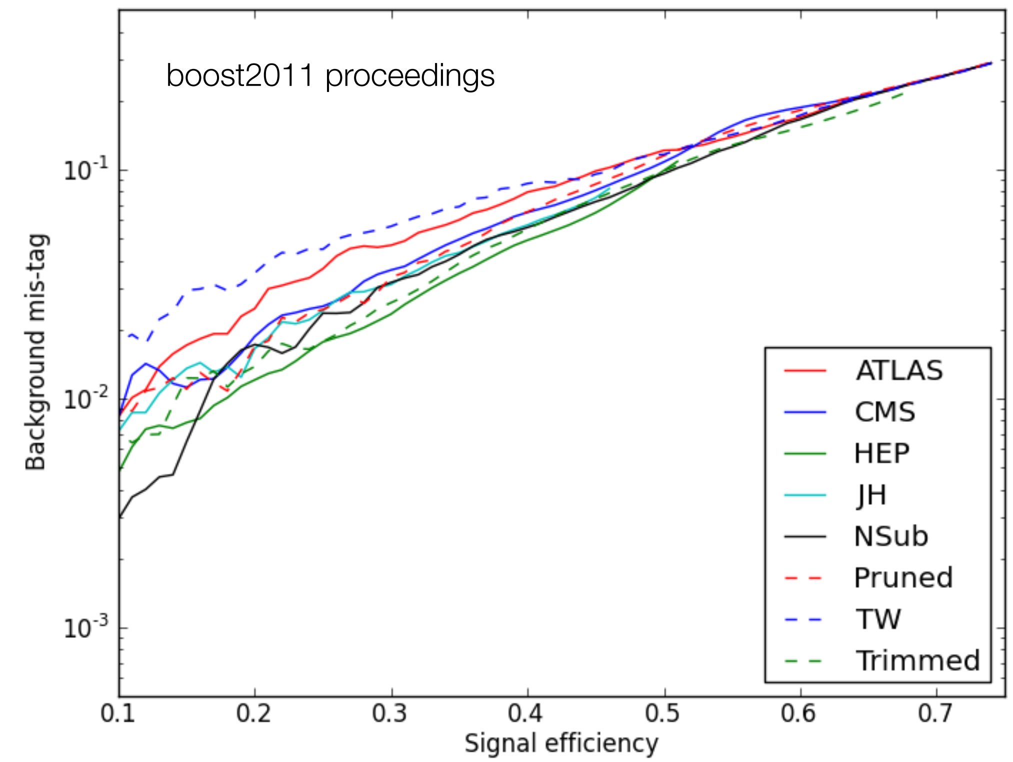
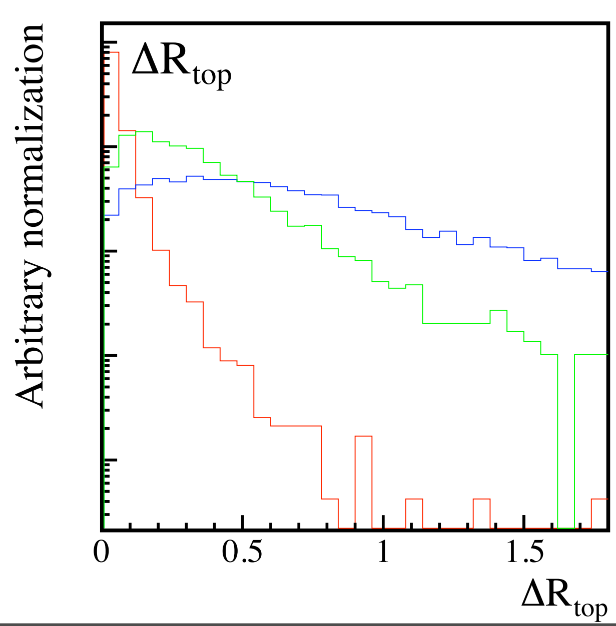
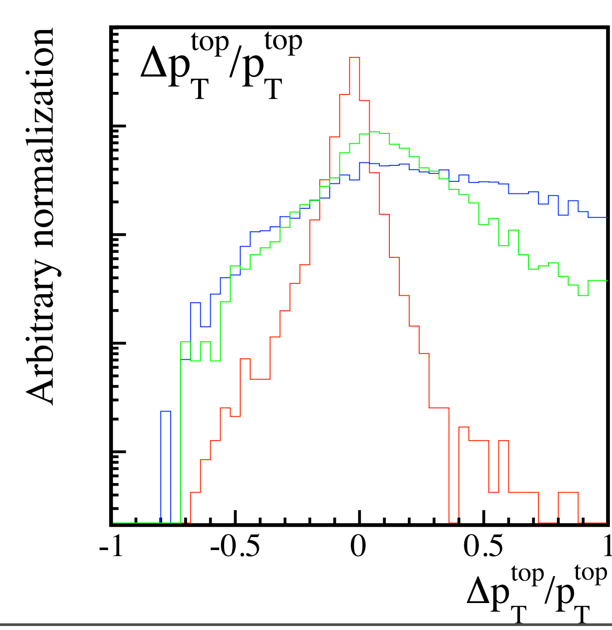






- momentum reconstruct well



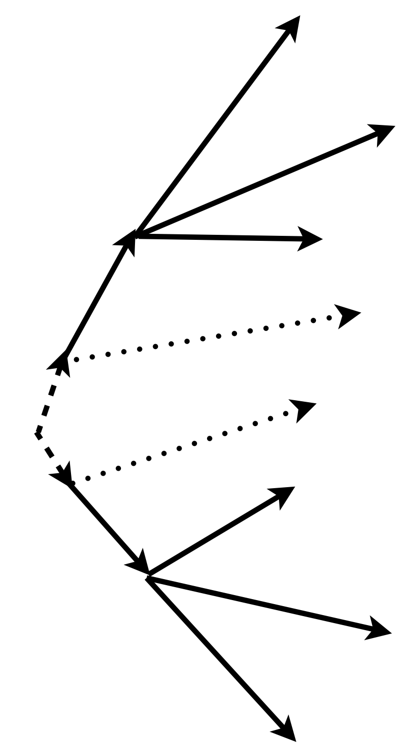


Application

Scalar top reconstruction

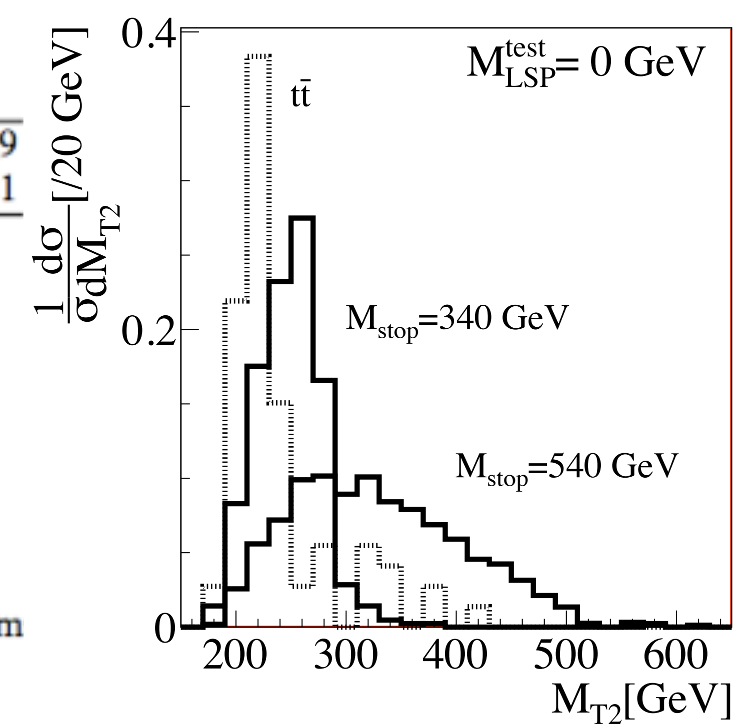
[JHEP1010:078,2010. arXiv:1006.2833[hep-ph] T.Plehn,M.Spannowsky,D.Zerwas,MT]

- $m_{\tilde{\chi}_1^0} = 98$ GeV, $\tilde{t}_1 \to t\tilde{\chi}_1^0$ (100%)
- main BG: $t\bar{t}$+jets, W+jets and QCD *(Alpgen-Pythia)*
- set of cuts
  - no lepton, $\not{E}_T > 150$ GeV
  - 2 tagged tops with $p_T^{\rm rec} > 200/200$GeV → W+jets, Z+jets negligible
  - b-tag for 1st tagged top → QCD negligible
  - $m_{T2} > 250$GeV → reduce $t\bar{t}$



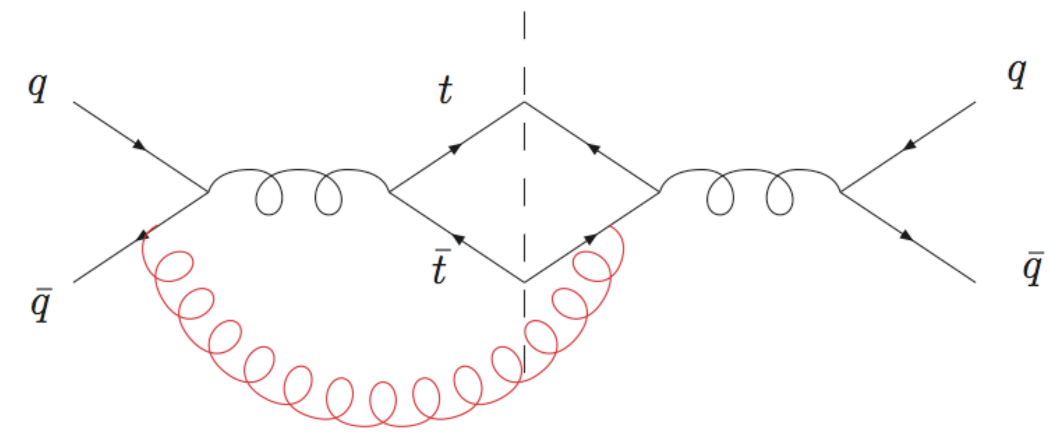
events in 1 fb^{-1}	$\tilde{t}_1\tilde{t}_1^*$						$t\bar{t}$	QCD	W+jets	Z+jets	S/B	$S/\sqrt{B}_{10\,\rm fb^{-1}}$
$m_{\tilde{t}}$[GeV]	340	390	440	490	540	640					340	
$p_{T,j} > 200$ GeV, ℓ veto	728	447	292	187	124	46	87850	$2.4 \cdot 10^7$	$1.6 \cdot 10^5$	n/a	$3.0 \cdot 10^{-5}$	
$\not{E}_T > 150$ GeV	283	234	184	133	93	35	2245	$2.4 \cdot 10^5$	1710	2240	$1.2 \cdot 10^{-3}$	
first top tag	100	91	75	57	42	15	743	7590	90	114	$1.2 \cdot 10^{-2}$	
second top tag	15	12.4	11	8.4	6.3	2.3	32	129	5.7	1.4	$8.3 \cdot 10^{-2}$	
b tag	8.7	7.4	6.3	5.0	3.8	1.4	19	2.6	$\lesssim 0.2$	$\lesssim 0.05$	0.40	5.9
$m_{T2} > 250$ GeV	4.3	5.0	4.9	4.2	3.2	1.2	4.2	$\lesssim 0.6$	$\lesssim 0.1$	$\lesssim 0.03$	0.88	6.1

- $S/B \sim 1, S/\sqrt{B} > 5$ for 10fb^{-1}
- stop mass from $m_{T2}(m_{\tilde{\chi}_1^0})$ endpoint [C. G. Lester, D. J. Summers] [like sleptons or sbottom



Top forward backward asymmetry A^t_{FB}

[arXiv:1103.4618 [hep-ph], J. L. Hewett, J. Shelton, M. Spannowsky, T.M.P. Tait, MT]



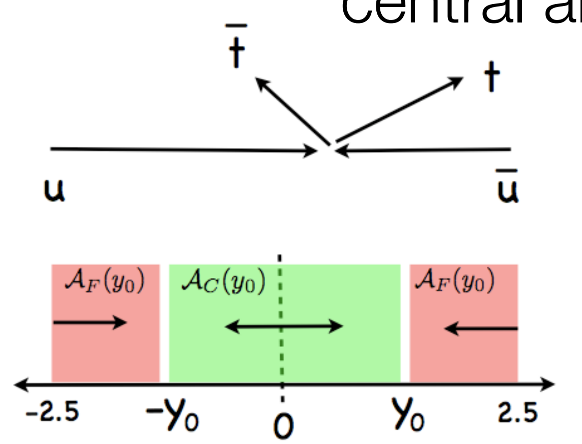
- QCD A^t_{FB} : small NLO effect ~ 6%
- Tevatron anomaly

  D0: $A^t_{FB} = 8 \pm 4 \pm 1\%$

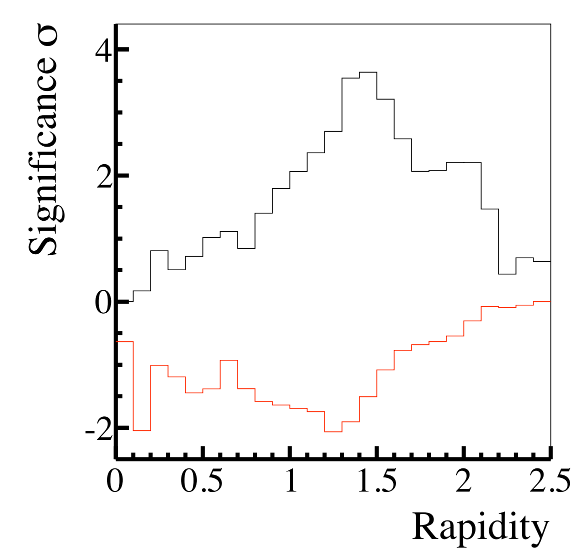
  CDF: $A^t_{FB} = 15 \pm 5 \pm 2.4\%$

- LHC : harder q PDF → charge asymmetry in η distributions

central anti-top



- semi-leptonic mode
  - 1 isolated lepton
  - 1 hadronic top tag with HEPTopTagger
  - b-tag in tagged top → W+jets neglegible



– SM: 5σ after 60 fb^{-1}(14TeV)

– BSM: 5σ after 2 fb^{-1}(14TeV)

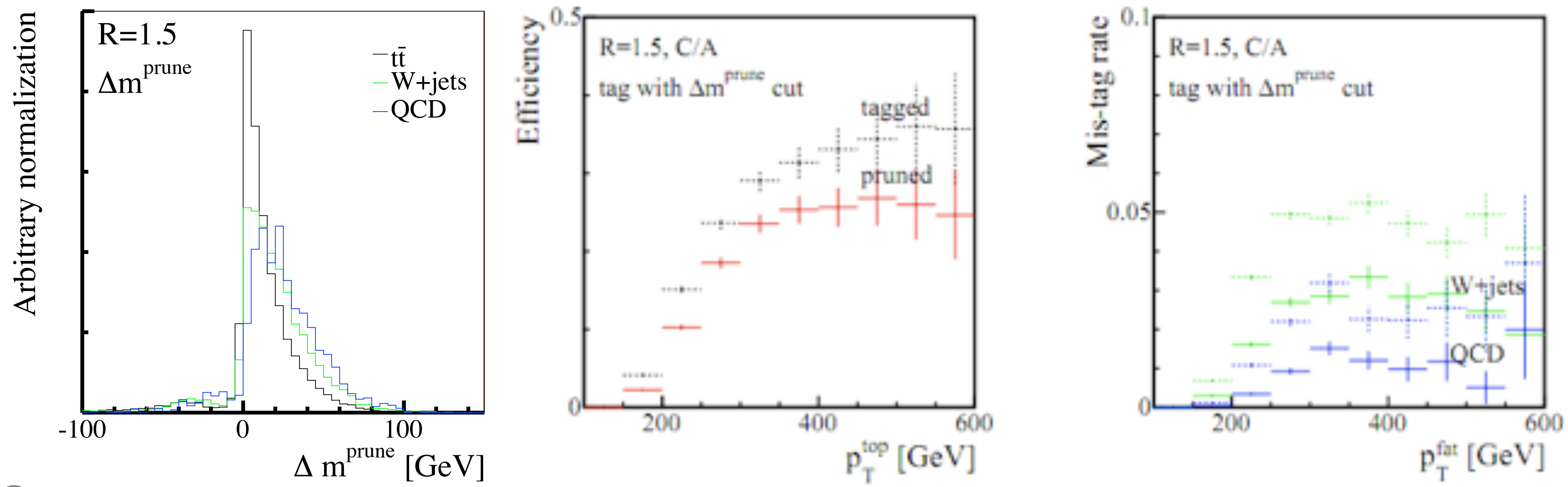
2.8σ after 10 fb^{-1} (7TeV)

Improving Top Tagging

[arXiv:1111.5034[hep-ph] T.Plehn,M.Spannowsky,MT]

- Pruning
  - cluster only when

$$z = \frac{\min(p_{T,i}, p_{T,j})}{|\vec{p}_{T,i} + \vec{p}_{T,j}|} > z_{\rm cut}$$



  - S/B: improved by factor 2
- b-tag
  - correct b-subjet identification without b-tag ~70%
  - b-tag for subjet selection → unnecessary factor 3 only for mis-tag rate
  - b-tag should be checked at the last step

- R=1.8 helps to tag low pT tops.

Summary

- top：as a tool for new physics search

- Jet substructure : information usually thrown away

- HEPTopTagger - target for tops with pT>200GeV (testable with SM tops)

- Efficiency: ~30%, mis-tag rate: 2~4% (1~2% with pruning)

– stop pairs
  – hadronic channel: $S/B \sim 1$, $S/\sqrt{B} > 5$ for 10fb^{-1}
  – semi-leptonic channel: $S/B \sim 2$, $S/\sqrt{B} > 5$ for 10fb^{-1}

– A^t_{FB}
  – SM: 5σ after 60fb^{-1}(14TeV)
  – BSM: 5σ after 2fb^{-1}(14TeV) 2.8σ after 10fb^{-1} (7TeV)

– HEPTopTagger: (Heidelberg-Eugine-Paris)

available on http://www.thphys.uni-heidelberg.de/~plehn/