Reconstructing (s)tops using fat jets

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→ HEPTopTagger

arxiv: 1006.2833[hep-ph]

Top tagger for low pT range

Top quark: strongly related to EWSB sector
top tagging at LHC: important for new physics search

Hadronic top : full momentum reconstruction possible

Inspired by very heavy X→tt, several top taggers available

[D.E.Kaplan, K.Rehermann, M.D.Schwartz and B.Tweedie]
[D. Krohn, J. Thaler, L.T. Wang]
[L.G. Almeida, S.J. Lee, G. Perez, G. Sterman, I. Sung]

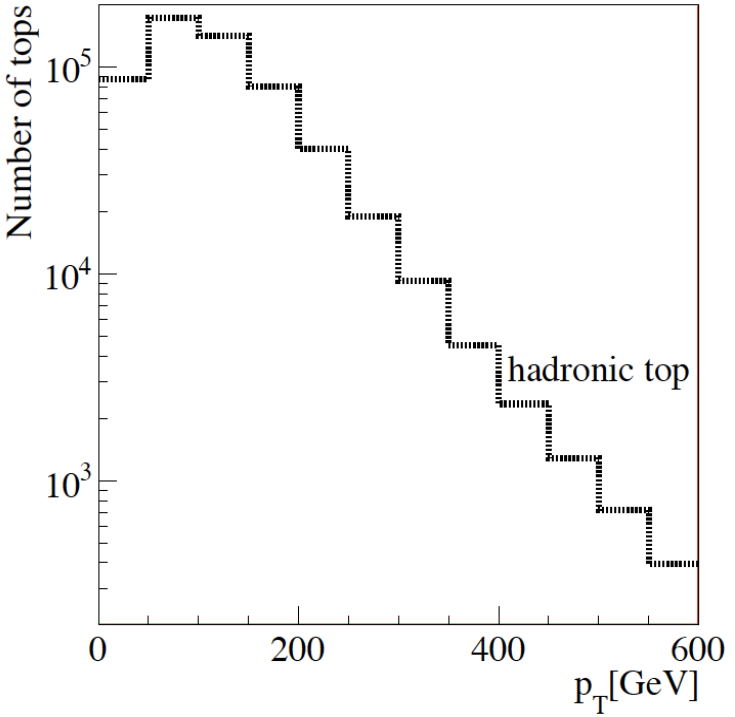
Look into jet substructure.

Designed for pT>500GeV,
not expected in the SM.

For example Standard Model

➡ Establish top tagger
in low pT range (200 ~ 500 GeV)

(Same for $pp \to \tilde{t}_1 \tilde{t}_1^* \to (t\tilde{\chi}_1^0)\,(\bar{t}\tilde{\chi}_1^0)$)

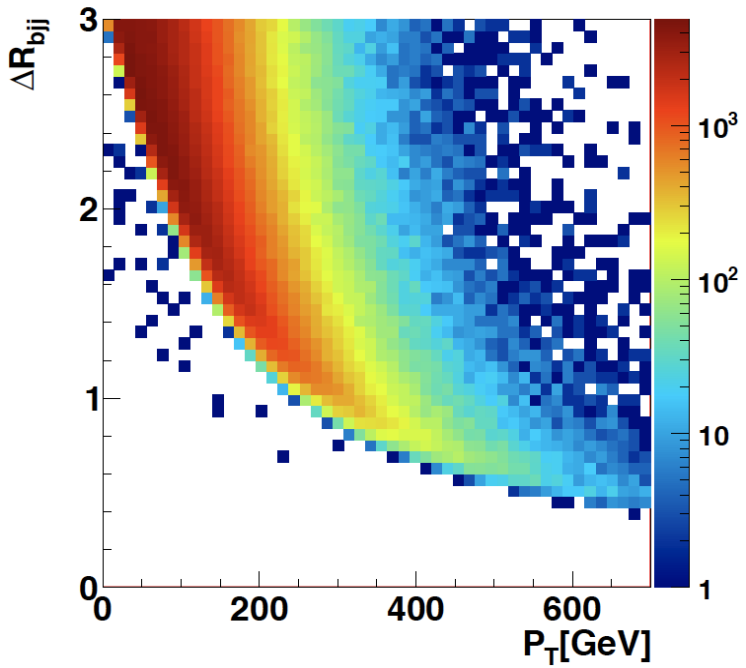


Fat jets

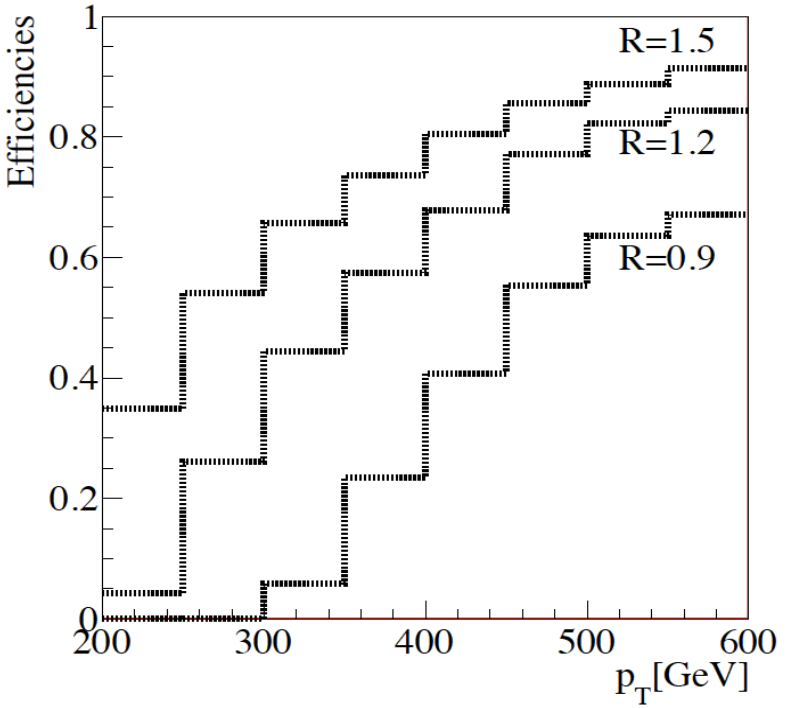
Top Tagger: C/A algorithm with large R

top: heavy mass → with modest pT, decay products well separated.

C/A distance at parton level



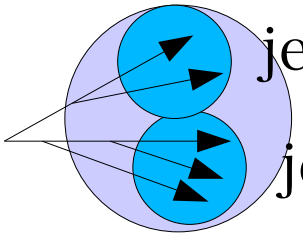
Fraction of tops within various R

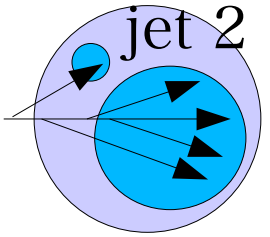


R=1.5 to have top ~ 200 GeV inside fat jet.

HEPTopTagger algorithm

1. **Find fat jets using C / A algorithm with R=1.5, p_T > 200 GeV**
   Large R collects QCD (ISR, FSR, UE and other jets).
2. **Find hard objects using mass drop criterion**
   hard objects inside fat jet by mass drop criterion:
   Undoing clustering, $m_{j_1} < 0.8\, m_j$ to keep j_1 and j_2. stop when $m_j < 30$ GeV





(mass drop in t→Wb and W→jj)

3. **Filter and choose pairing**
   Take 3 sub-jets, re-cluster with R_{filt} and compute mass of first 5
   keep pairing with best top mass.
   top candidate

$$|m_{jjj} - 172.3\ \text{GeV}| < 25\ \text{GeV} \qquad p_T^{\text{rec}} > 200\ \text{GeV}$$

No b-tag, no W-mass cut yet.

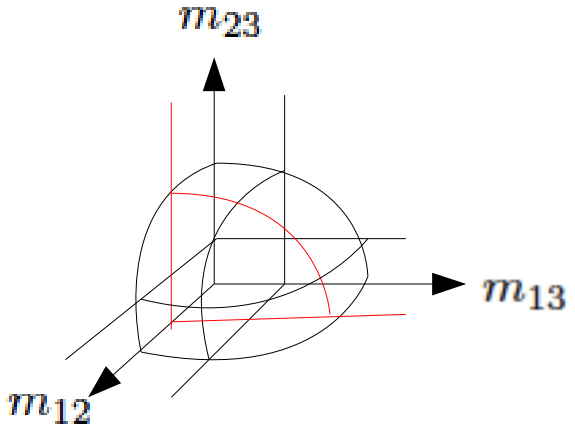
tt vs. QCD, W+jets

4. check mass ratios

Cluster top candidate constituents into 3 subjets p_1, p_2, p_3

m_{12}, m_{13}, m_{23} $\qquad m_t^2 = m_{123}^2 = m_{12}^2 + m_{13}^2 + m_{23}^2$

After imposing top mass cut, 2 independent mass ratios.



$$R_{\min} < \frac{m_{23}}{m_{123}} < R_{\max} \quad \text{and} \quad 0.2 < \arctan\frac{m_{13}}{m_{12}} < 1.3$$

$$R_{\min}^2\left(1+\left(\frac{m_{13}}{m_{12}}\right)^2\right) < 1-\left(\frac{m_{23}}{m_{123}}\right)^2 < R_{\max}^2\left(1+\left(\frac{m_{13}}{m_{12}}\right)^2\right) \quad \text{and} \quad \frac{m_{23}}{m_{123}} > 0.35$$

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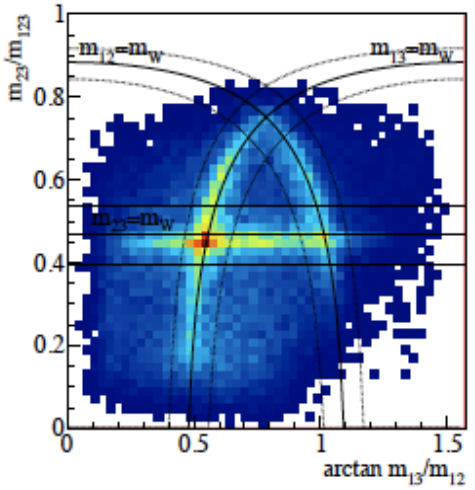
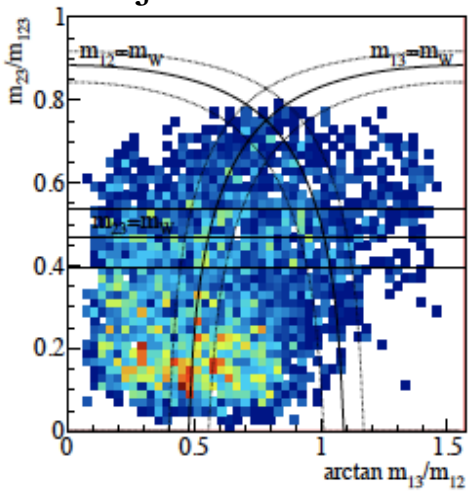
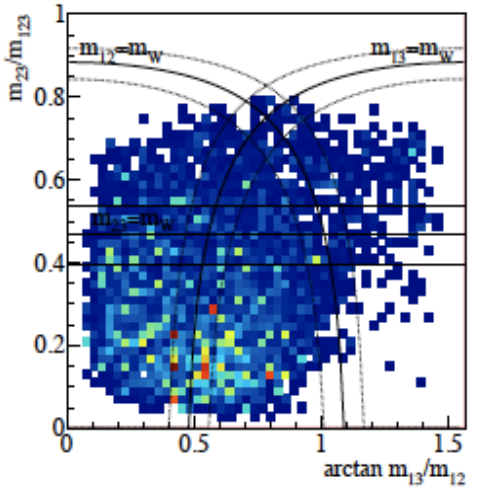
tt



W+jets



QCD



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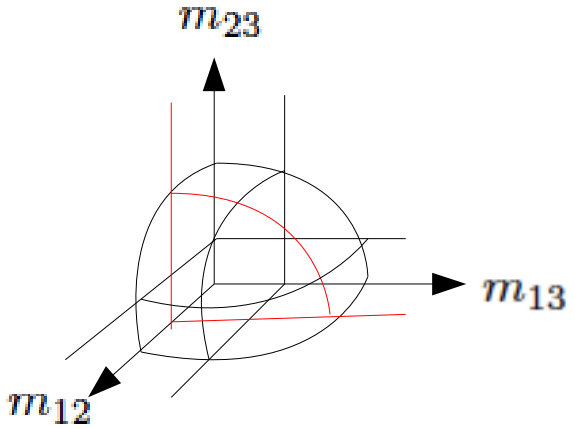

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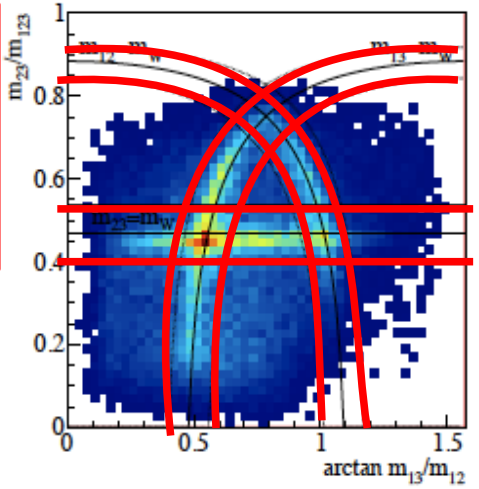
W mass

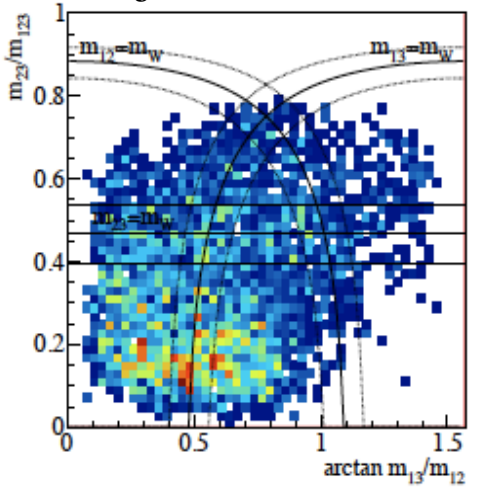
$$R_{\min} = 85\%\frac{m_W}{m_t}$$

$$R_{\max} = 115\%\frac{m_W}{m_t}$$

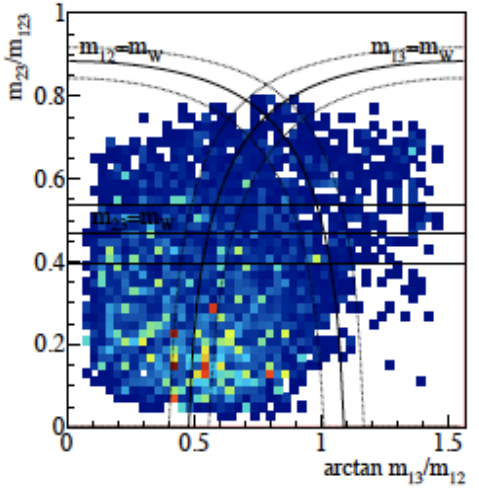
tt



W+jets



QCD



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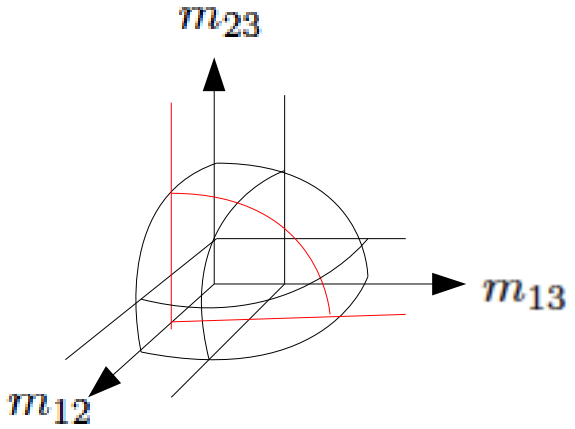

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$$R_{\min} = 85\%\frac{m_W}{m_t}$$

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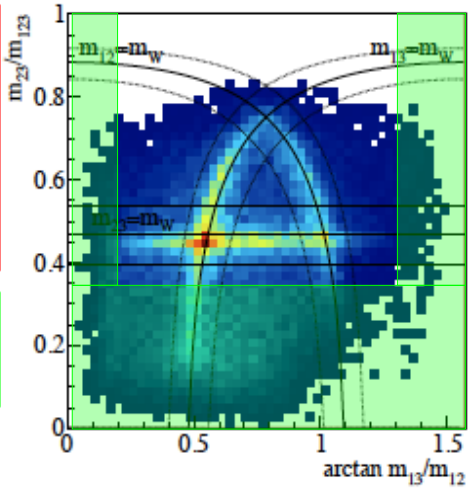
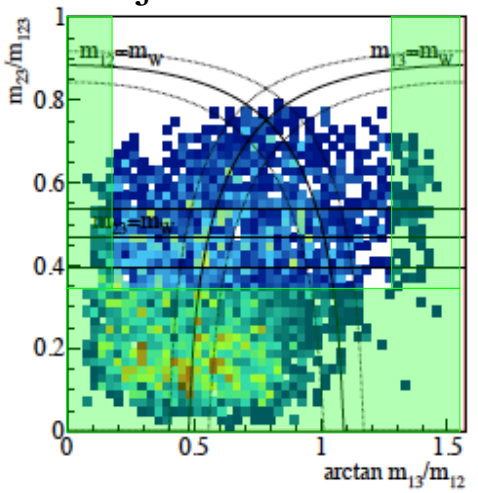
soft/collinear

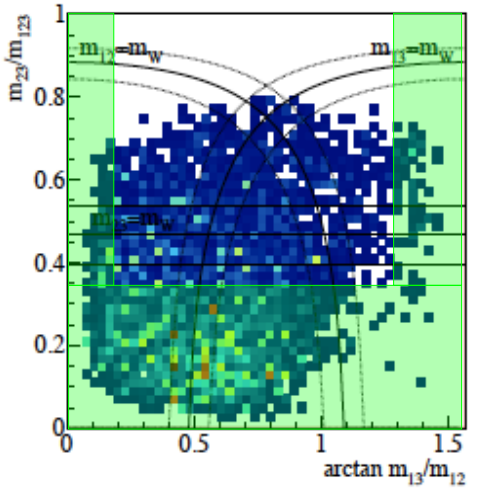
tt



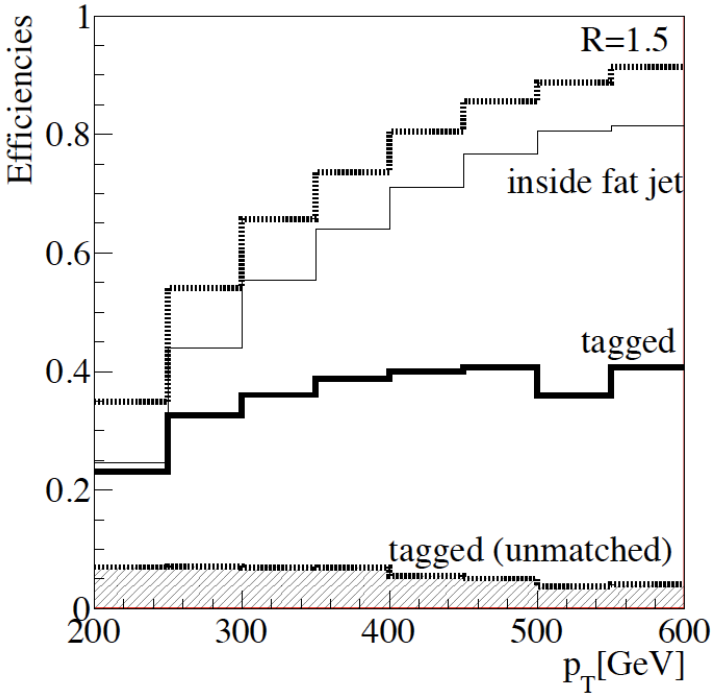
W+jets

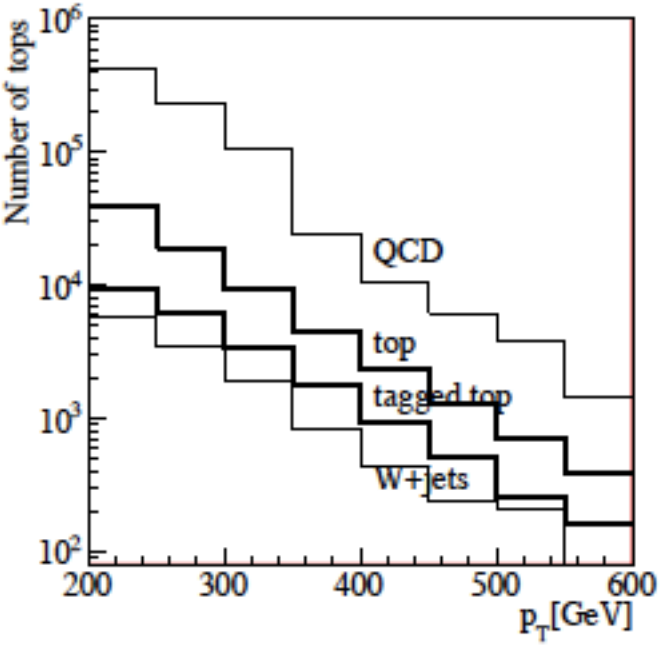


QCD



Efficiencies

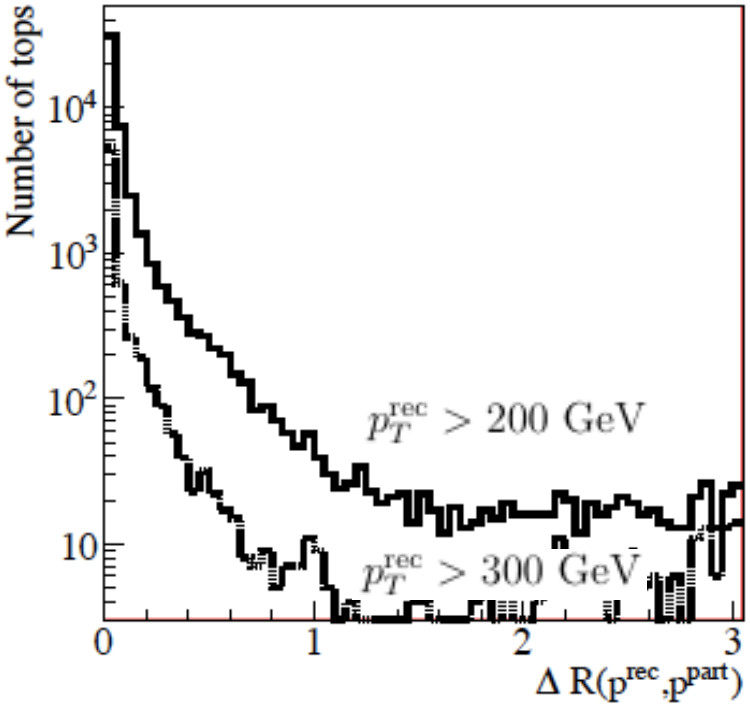




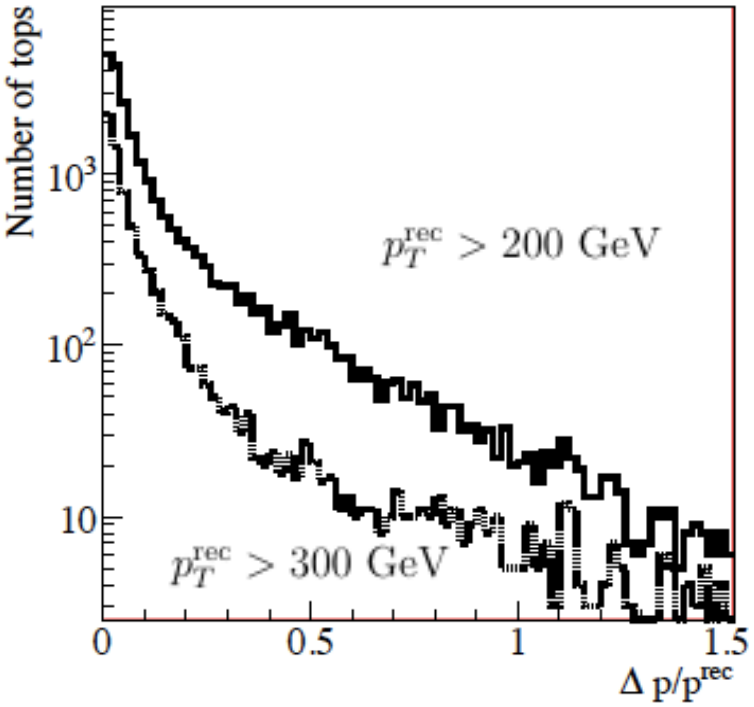
~40% hadronic tops tagged, 2~4% mis-tag.

	$t\bar{t}$			QCD	W+jets	$t\bar{t}$			QCD	W+jets	
$p_{T,t}^{\min}$[GeV]	0	200	300			0	200	300			
one fat jet	92200	36100	8250	$4.10 \cdot 10^7$	$3.19 \cdot 10^5$	100%	100%	100%	100%	100%	
two fat jets	40700	20300	5810	$2.16 \cdot 10^7$	$1.60 \cdot 10^5$	44%	57%	70%	53%	50%	relative to one fat jet
one top tag	20900	13400	4160	$8.18 \cdot 10^5$	$1.27 \cdot 10^4$	23%	37%	51%	2.0%	3.9%	relative to one fat jet
two top tags	1880	1630	700	11000	233	2.0%	4.5%	8.5%	0.027%	0.07%	relative to one fat jet
						4.5%	8.0%	12%	0.05%	0.15%	relative to two fat jets

Parton-jet matching



95% in $\Delta R < 0.5$



80% in $\Delta p/p^{\mathrm{rec}} < 20\%$

Momentum reconstructed well

stop pairs

$$pp \to \tilde{t}_1\tilde{t}_1^* \to (t\tilde{\chi}_1^0)(\bar{t}\tilde{\chi}_1^0) \to (bjj\tilde{\chi}_1^0)(\bar{b}jj\tilde{\chi}_1^0)$$

cuts:

- 2 fat jets: $p_{T,j} > 200/200$ GeV
- lepton veto
- $\not{p}_T > 150$ GeV
- 2 tagged tops: $p_T^{\rm rec} > 200/200$ GeV
- b tag for 1st tagged top
- $m_{T2} > 250$ GeV

	$\tilde{t}_1\tilde{t}_1^*$						$t\bar{t}$	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	$3.0 \cdot 10^{-5}$	
$\not{p}_T > 150$ 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

top tag : W + jets, Z + jets negligible

b tag : QCD negligible

m_{T2} : reduce $t\bar{t}$

Summary

Focus on low pt tops (200 to 500 GeV)

Fat jets killing combinatorics

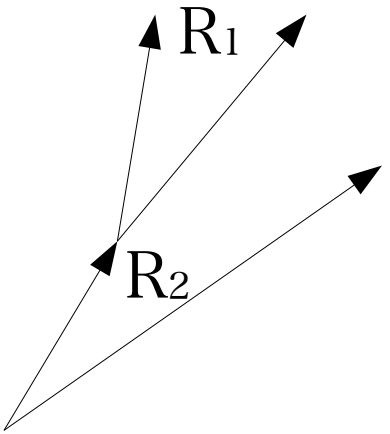
Efficiency: top: ~40%, W+jets: 4%, QCD: 2%

Top momentum reconstructed

Stop pairs: $S/B \sim 1$ and $S/\sqrt{B} \sim 5$ with 10 fb^{-1}.

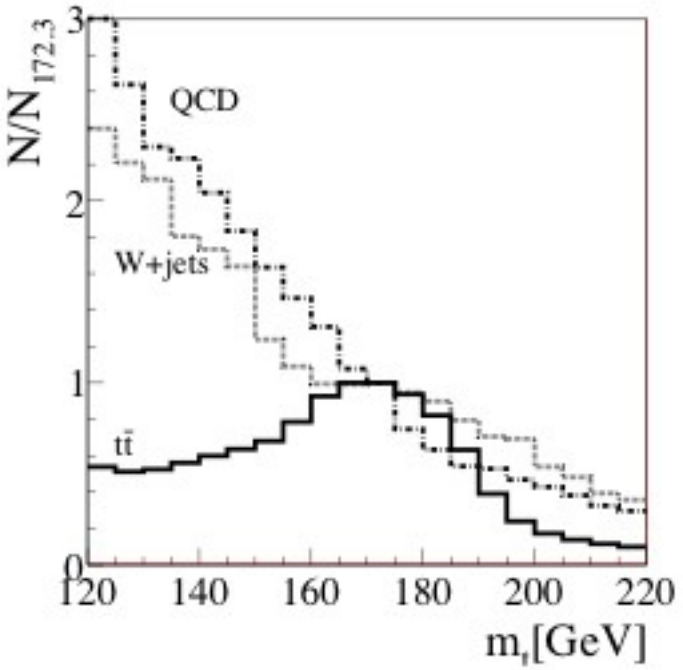
Heidelberg, **E**ugene(Oregon), **P**aris(Orsay) → HEPTopTagger

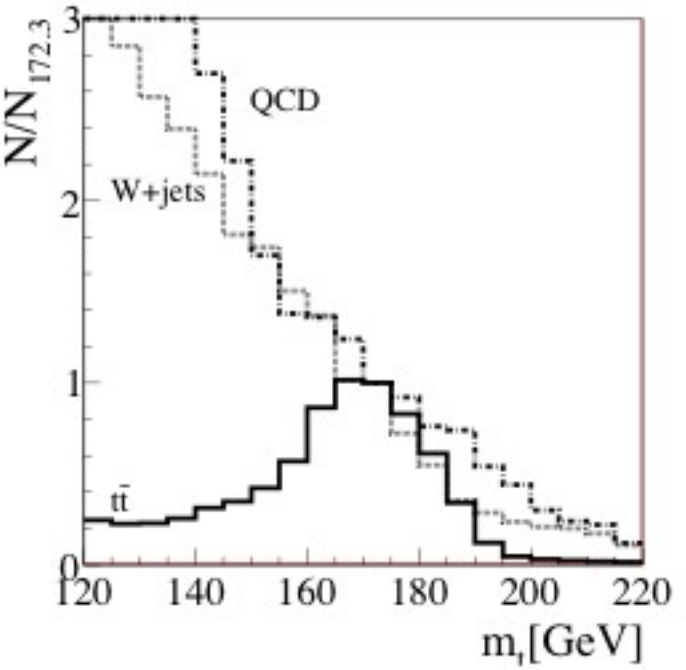
Back up (R_bjj)



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

Back up


N/N172.3
QCD
W+jets
tt̄
0
1
2
3
120
140
160
180
200
220
mt[GeV]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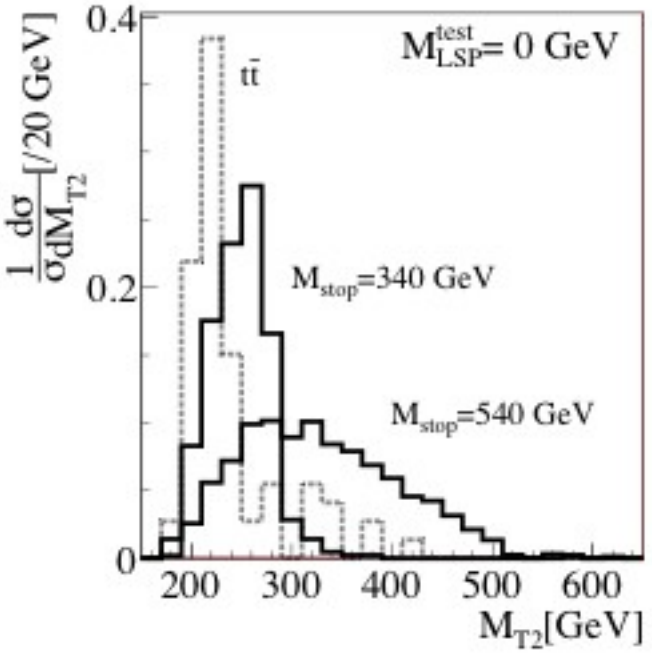
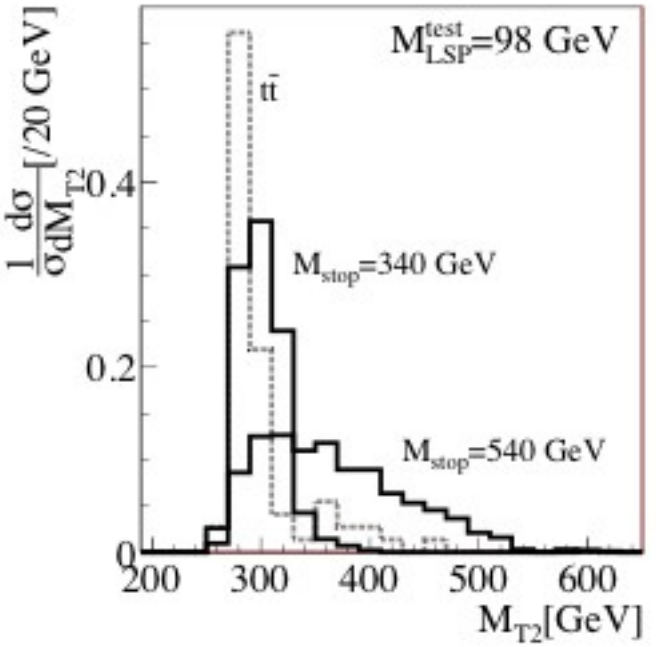

$\frac{1}{\sigma}\frac{d\sigma}{dM_{T2}}$[/20 GeV]
0.4
0.2
0
M_{LSP}^{test}= 0 GeV
$t\bar{t}$
M_{stop}=340 GeV
M_{stop}=540 GeV
200
300
400
500
600
M_{T2}[GeV]


$\frac{1}{\sigma}\frac{d\sigma}{dM_{T2}}$[/20 GeV]
0.4
0.2
0
M_{LSP}^{test}=98 GeV
$t\bar{t}$
M_{stop}=340 GeV
M_{stop}=540 GeV
200
300
400
500
600
M_{T2}[GeV]