Buckets of Tops

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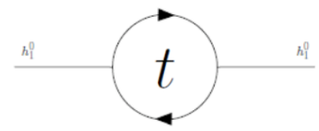
arxiv:1302.6238　　M. R. Buckley, T. Plehn, M. T.

Top at LHC

- top : closest to new physics

  fine tuning problem $\rightarrow$ top partner $\quad \delta m_h^2 \sim$  $-\frac{3}{4\pi} y_t^2 \Lambda_{\rm SM}^2$

  anomalies (A_{FB}^t, single tops, ...)

- $t\bar{t}H$: largest yukawa coupling to higgs to be measured

- $t\bar{t}$: main background for new physics search

- hadronic top: momentum reconstruction vs. combinatorics

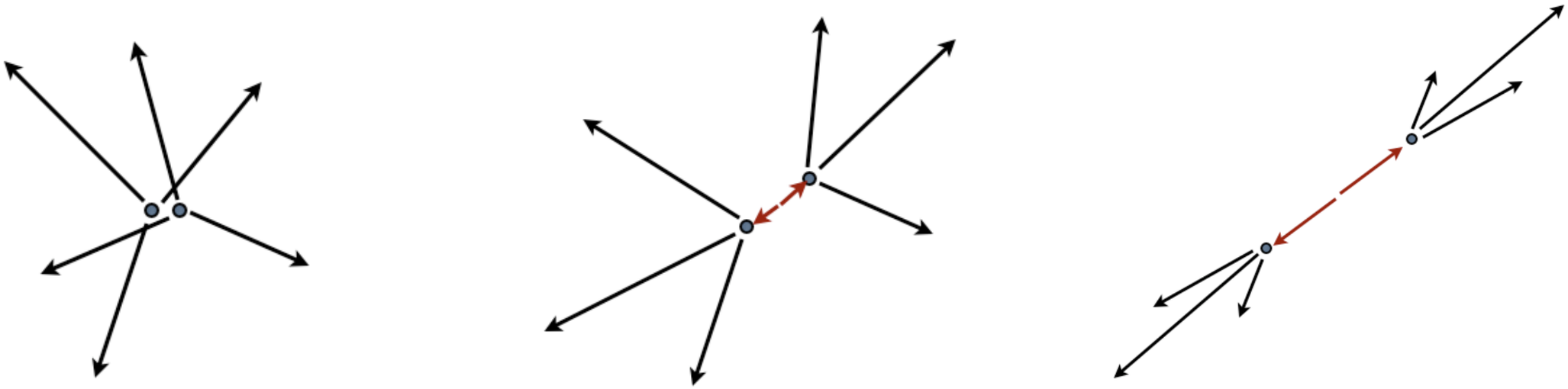
  need fight against QCD

  ISR makes the situation worse

  $\rightarrow$ boosted tops

Moderately boosted tops

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



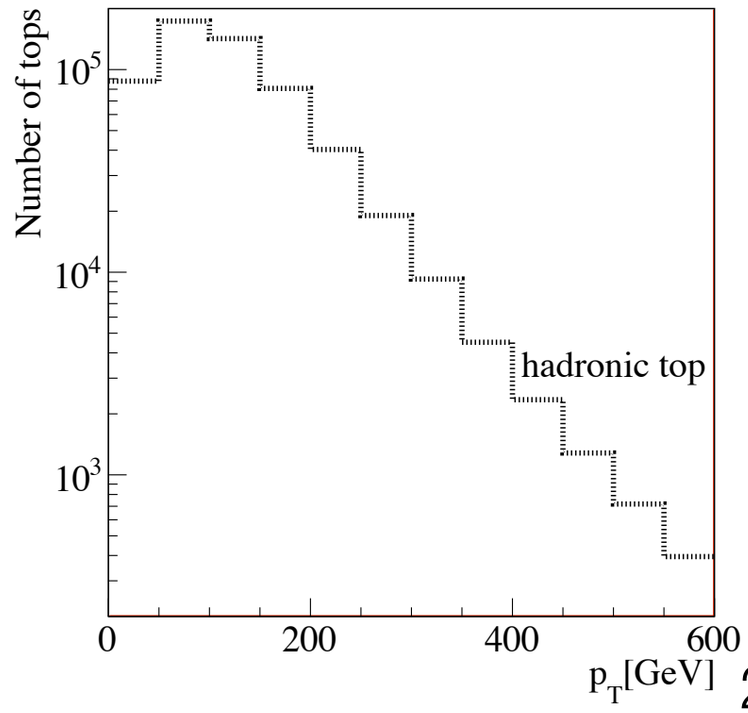
moderate boost help to solve combinatorics

stop search, $t\bar{t}H$ with 25fb^{-1}

keeping signal important

HEPTopTager: down to $p_T \sim 200$ GeV

How can we tag $p_T \sim 100$ GeV?



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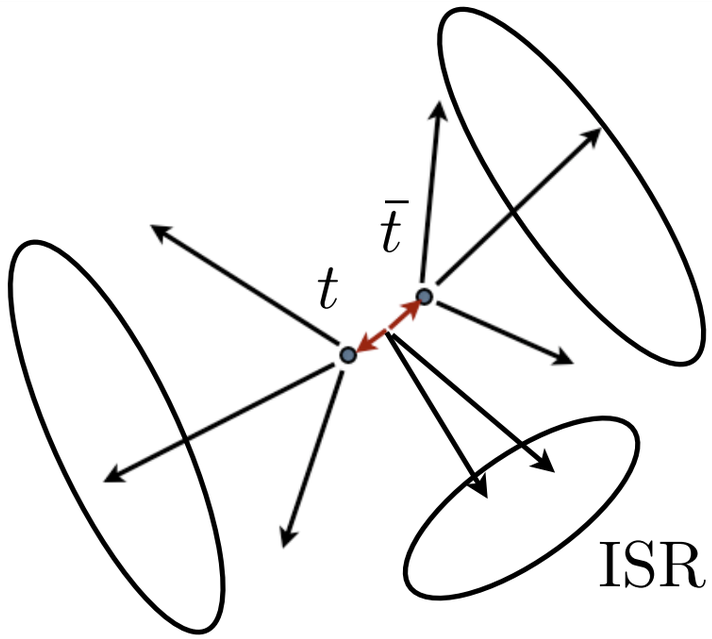
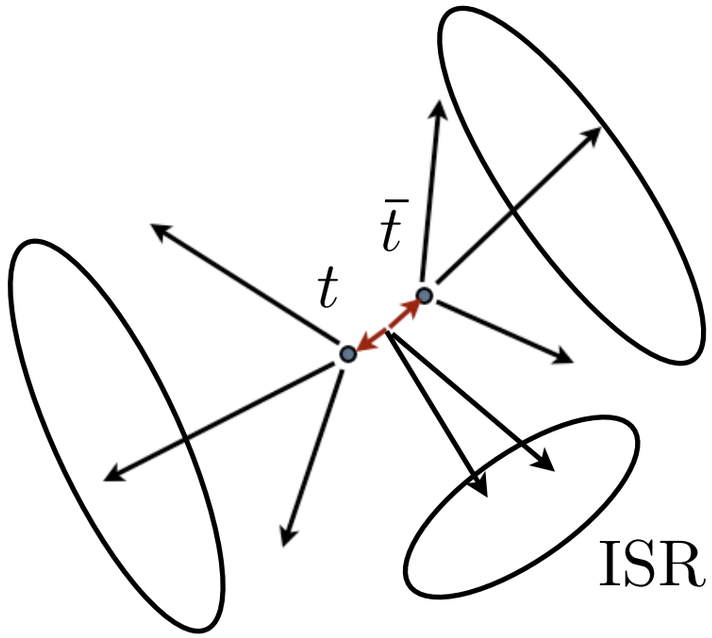


start with standard jets (C/A $R = 0.5$)

Aim: find jets corresponding to 2 tops

Buckets of tops



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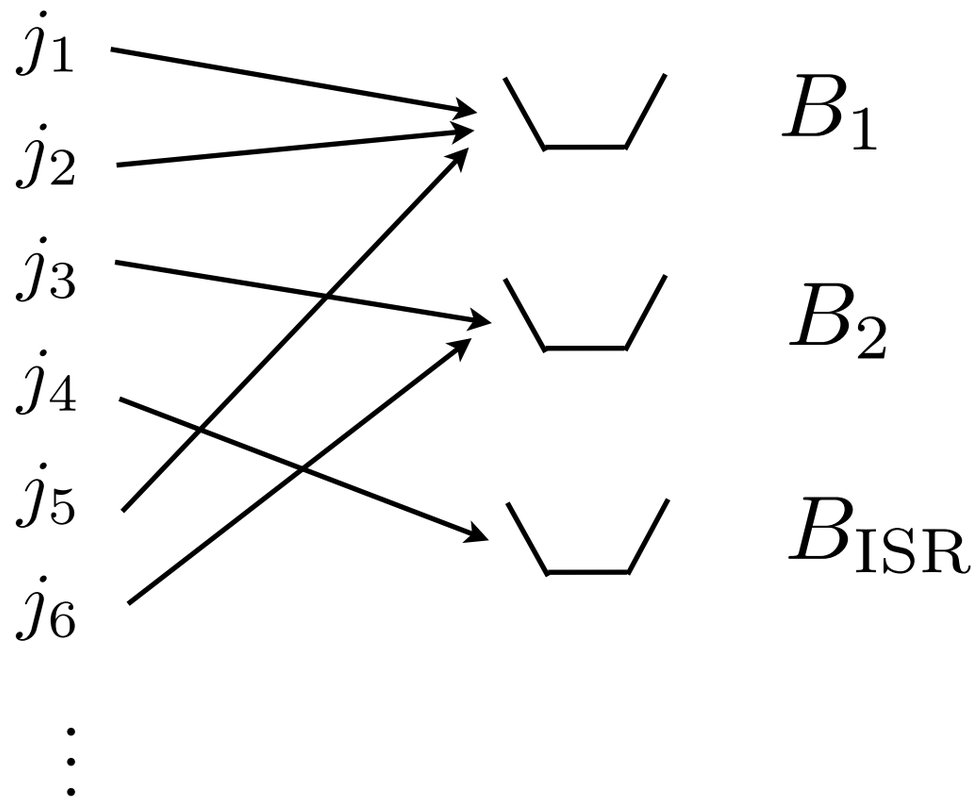


scan all permutation,

select the grouping minimizing

$$\Delta^2 = \omega \Delta_{B_1}^2 + \Delta_{B_2}^2$$

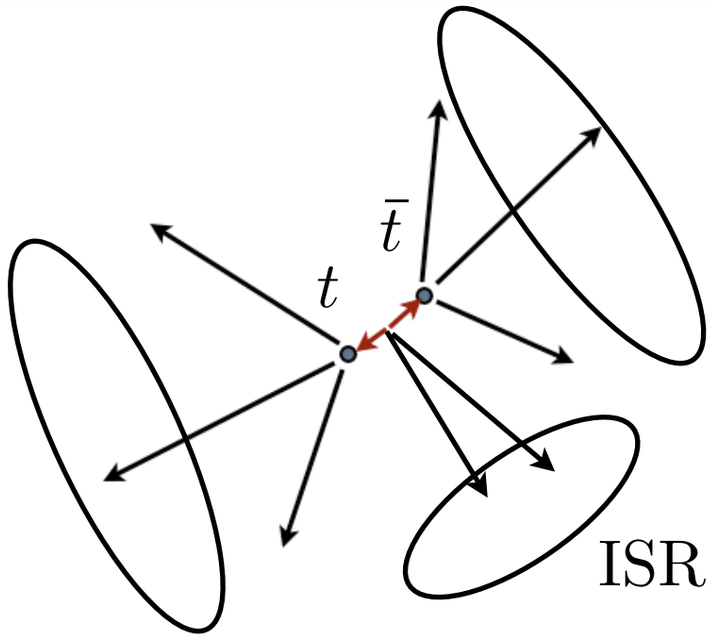
$$\Delta_{B_i} = |m_{B_i} - m_t|$$

$$m_{B_i}^2 = \left(\sum_{j \in B_i} p_j \right)^2$$

One event provides $\{B_1, B_2, B_{\mathrm{ISR}}\}$

always 2 top tags

Buckets of tops



start with standard jets (C/A $R = 0.5$)

with 2 b-jets

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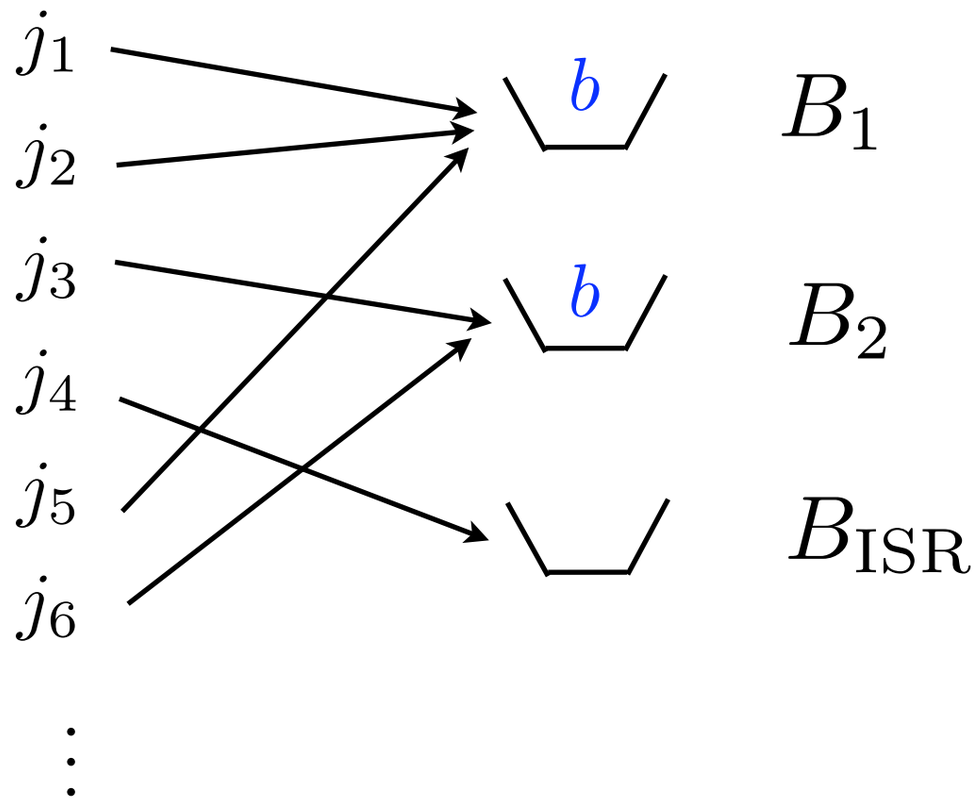

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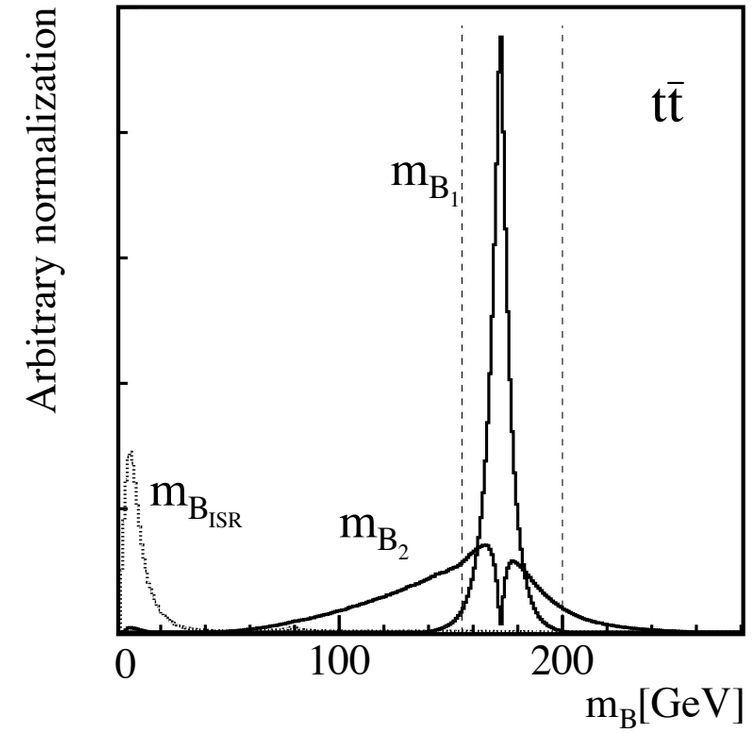
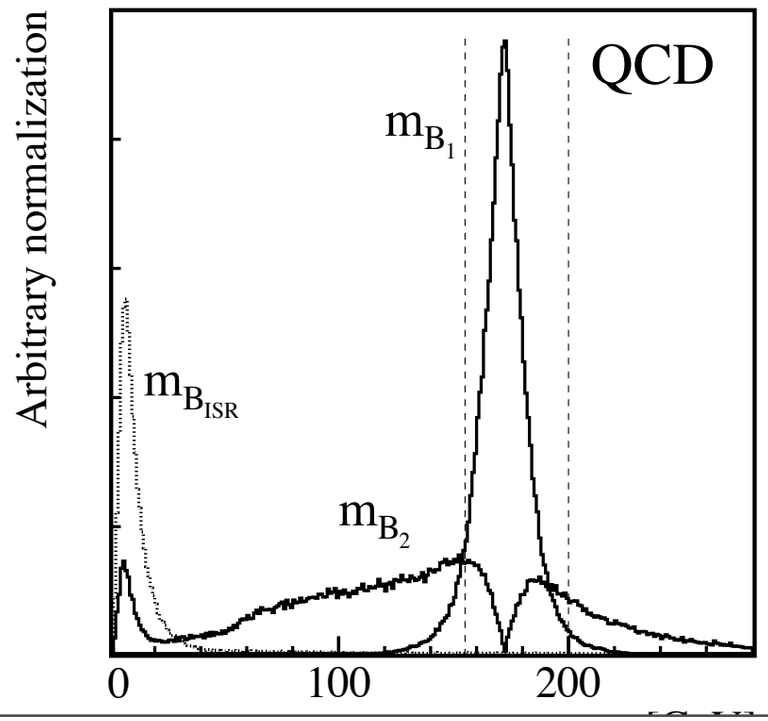
Bucket mass, W condition





- top mass window

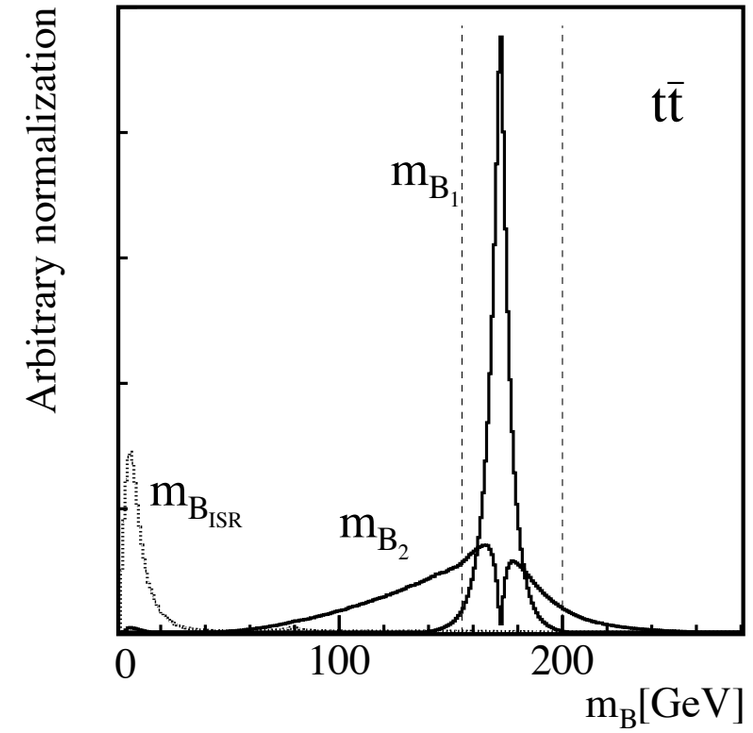
$$155\ \text{GeV} < m_{B_{1,2}} < 200\ \text{GeV}$$

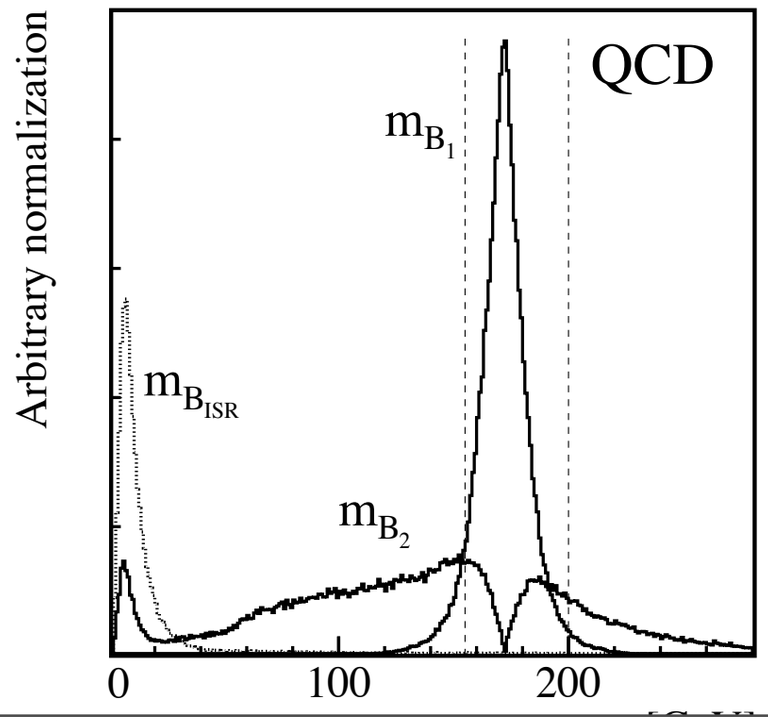
- W mass window

if in 2 jets in a bucket satisfy $\left|\frac{m_{k\ell}}{m_{B_i}} - \frac{m_W}{m_t}\right| < 0.15$

we regard B_i contains W

Bucket mass, W condition





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$\rightarrow$ 4 categories

$$(\mathrm{t}_w, \mathrm{t}_w) : B_1 \ni W, B_2 \ni W$$
$$(\mathrm{t}_w, \mathrm{t}_-) : B_1 \ni W, B_2 \not\ni W$$
$$(\mathrm{t}_-, \mathrm{t}_w) : B_1 \not\ni W, B_2 \ni W$$
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Efficiency & Momentum reconstruction

$R_i < 0.5$: good reconstruction $\qquad R_i = \Delta R(B_i, p_t^{\mathrm{MCtruth}})$

	$t_h\bar{t}_h$+jets [fb]	$R_1, R_2 < 0.5$	QCD [fb]	S/B_{QCD}
5 jets, 2b-tag	21590		16072	1.36
(t_w,t_w)	2750	68.9%	126.2	21.8
(t_w,t_-)	2517	23.4%	727.1	3.5
(t_-,t_w)	1782	21.8%	596.5	3.0
(t_-,t_-)	2767	9.0%	2002	1.4

$(\mathrm{t}_w, \mathrm{t}_w)$ provide reasonable momentum, $\epsilon_{(\mathrm{t}_w,\mathrm{t}_w)} \sim 13\%$

t_- not reconstruct correct momentum

only 45% double tagged in total

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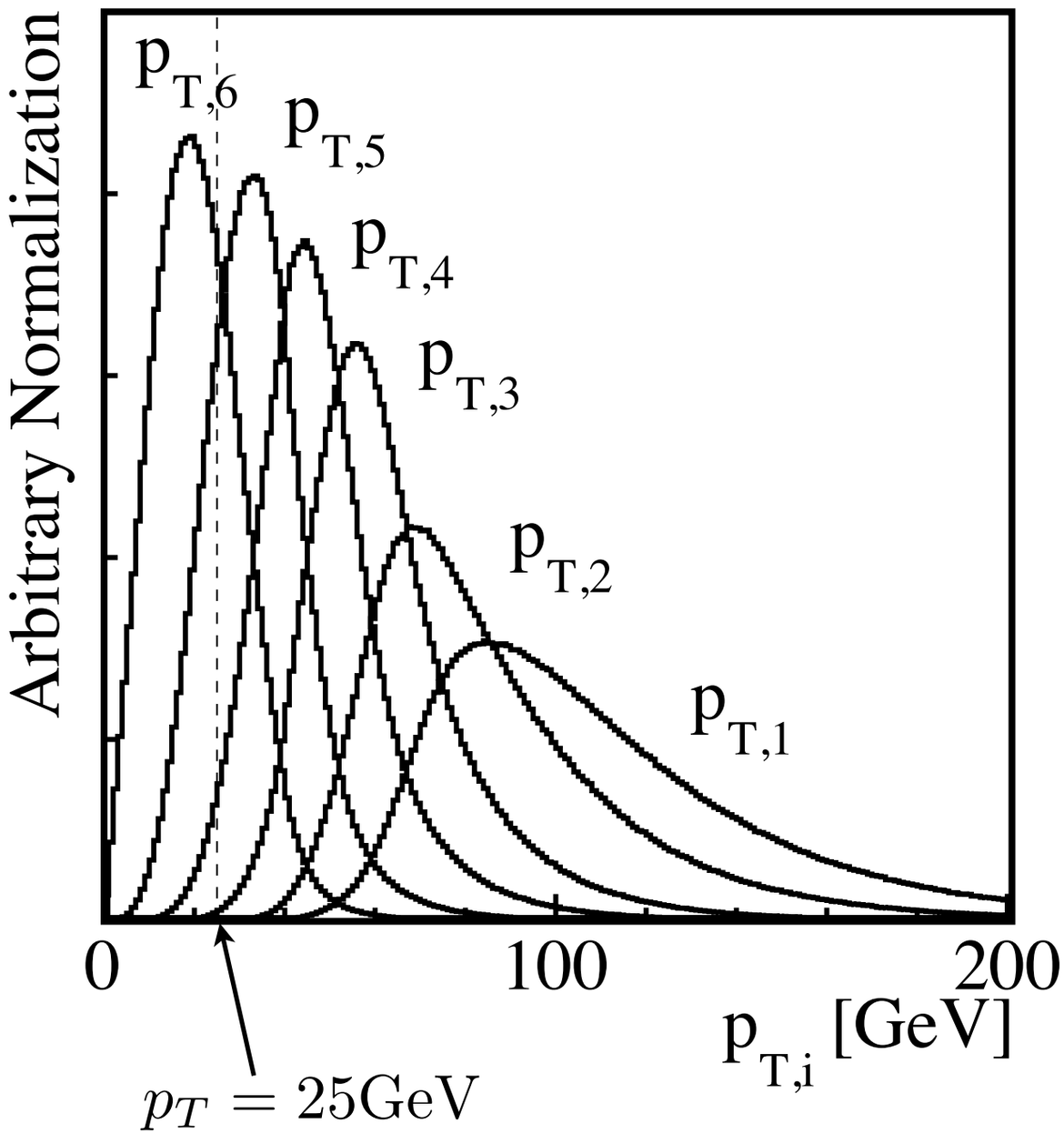
6 jets not often survive due to jet p_T threshold

Jet pT threshold

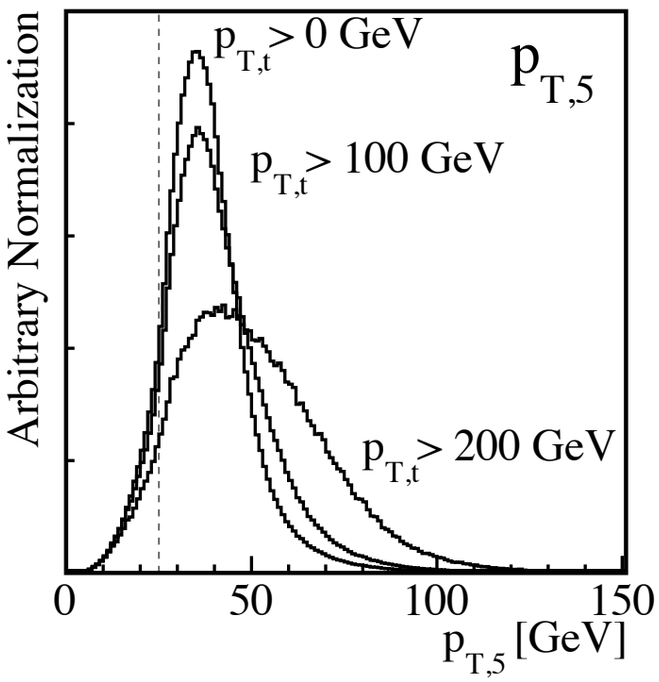
6 partons from top pair decays

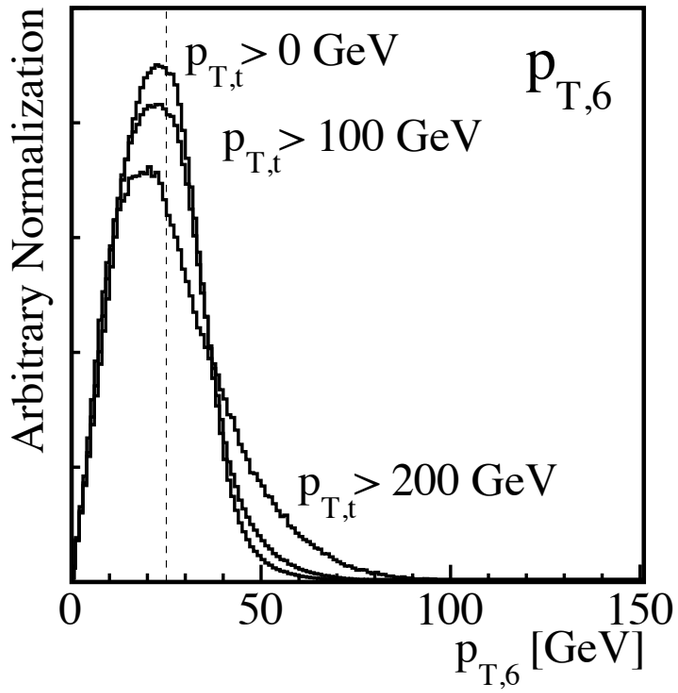


$p_{T,j} > 25$ GeV kills 6th jet

98% from W

Jet pT threshold





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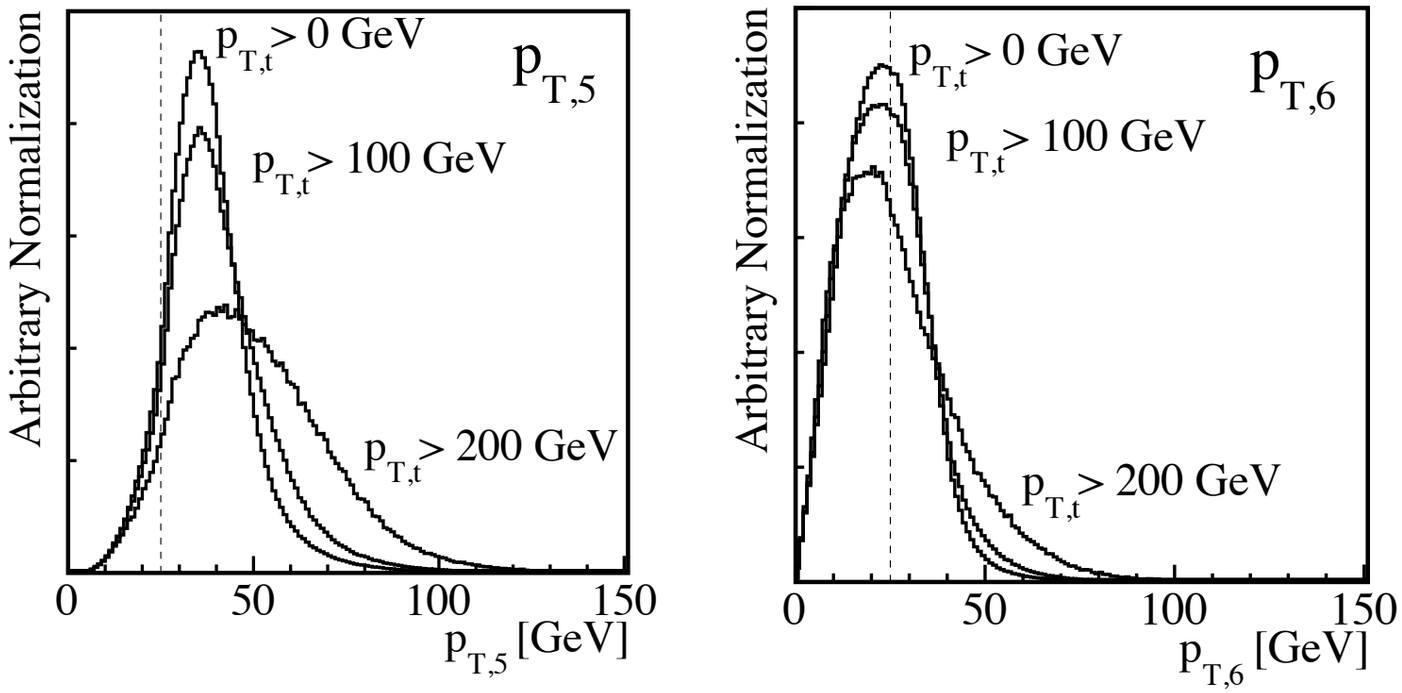
Weak top p_T dependence

		$t_h\bar{t}_h$+jets [pb]	$p_{T,6} > 25$ GeV	$p_{T,5} > 25$ GeV $> p_{T,6}$
lepton veto		104.1	33.4%	44.9%
$n_j \geq 5$		70.5	42.5%	46.4%
$n_j \geq 6$		36.7	54.7%	38.0%
$n_j \geq 5$	$p_{T,t_2} > 100$ GeV	32.7	43.6%	46.2%
	$p_{T,t_2} > 200$ GeV	6.7	47.4%	44.7%

Jet pT threshold



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Weak top p_T dependence

What can we do with 5 jets?

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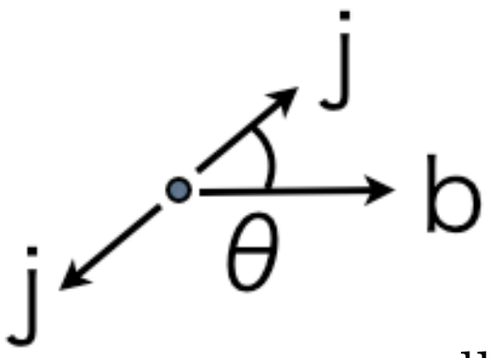
bj-buckets

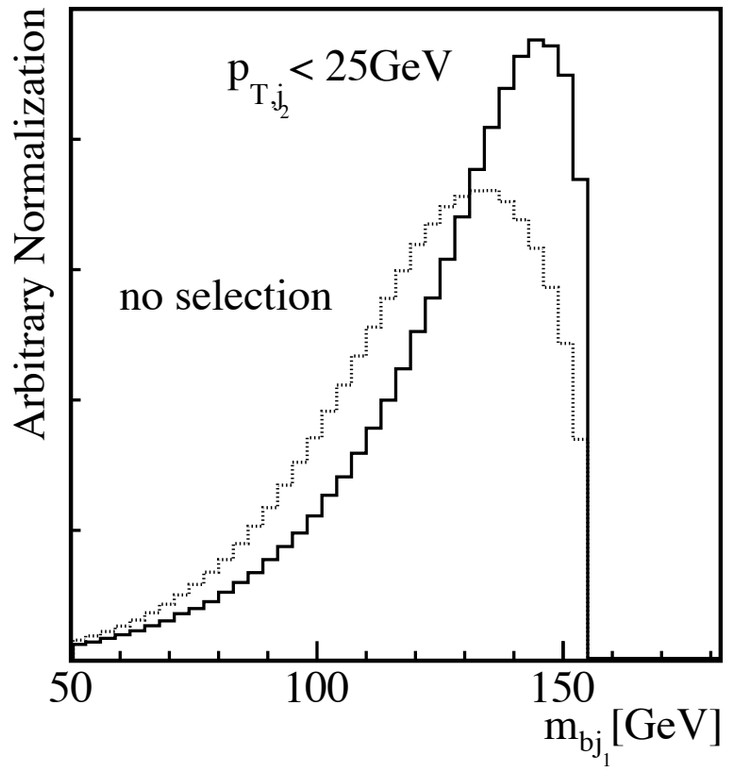
- m_{bj}-peak from top decay kinematics



$$m_{bj} < \sqrt{m_t^2 - m_W^2} \sim 155\text{GeV}$$

unique feature of 3 body decay

more pronounced peak with $p_{T,3} < 25\text{GeV}$



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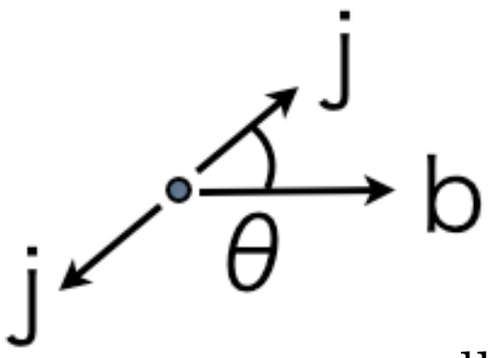

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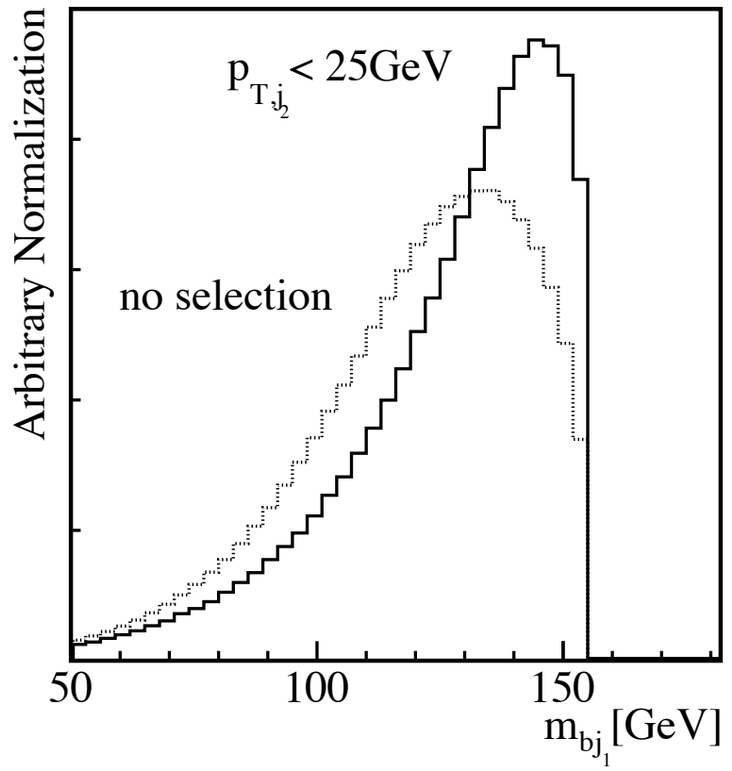
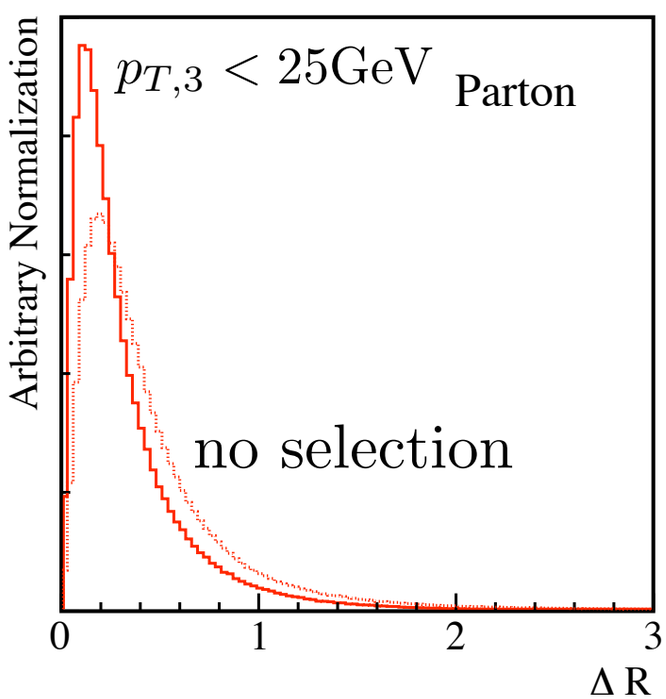
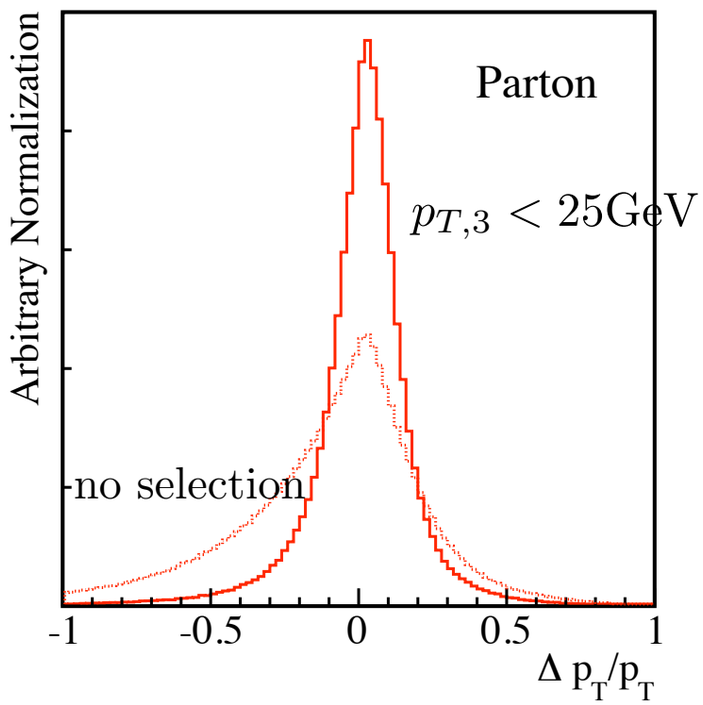


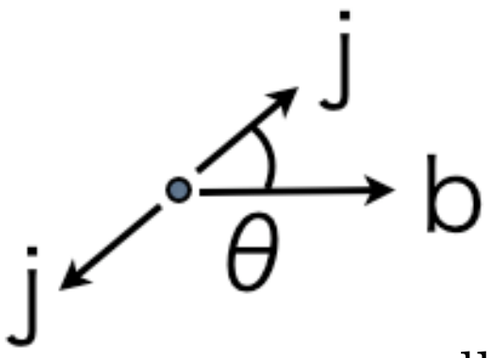
- acceptable momentum reconstruction





bj-buckets

- m_{bj}-peak from top decay kinematics



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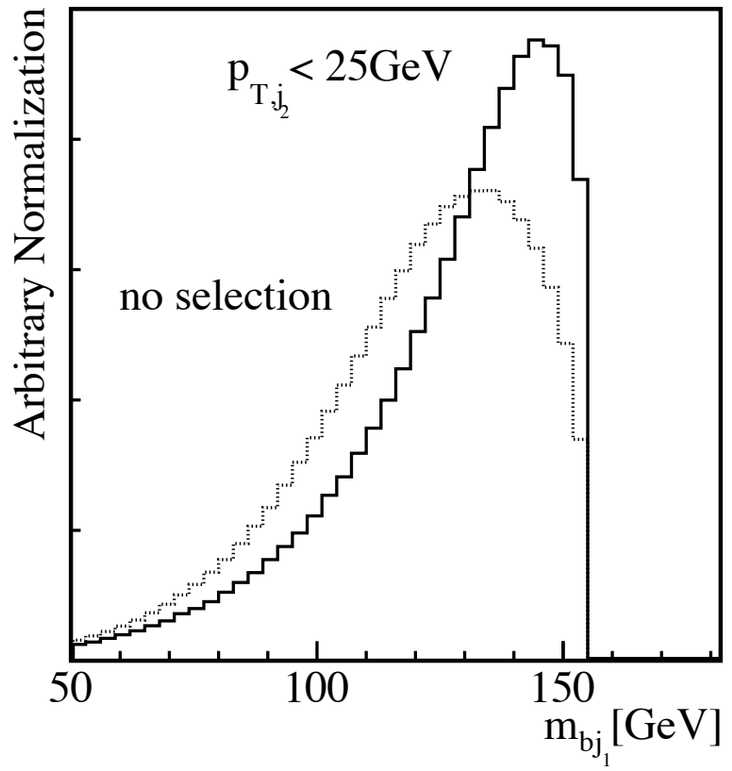

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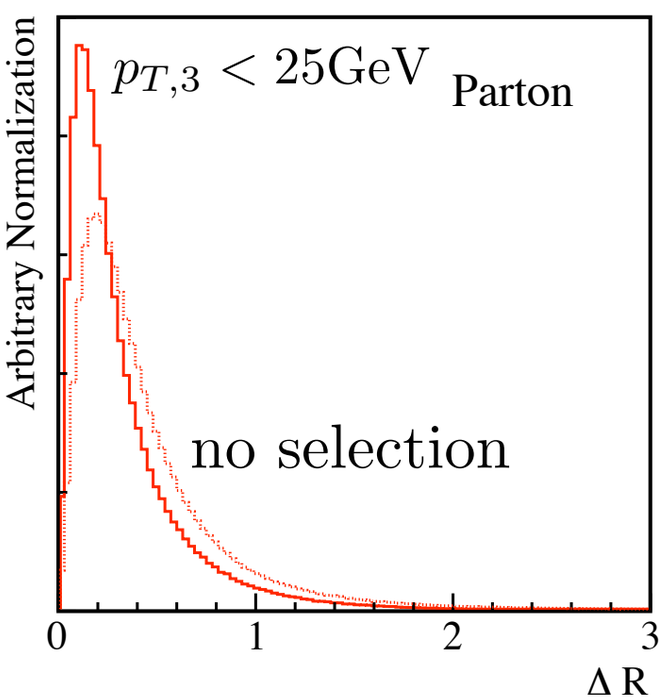

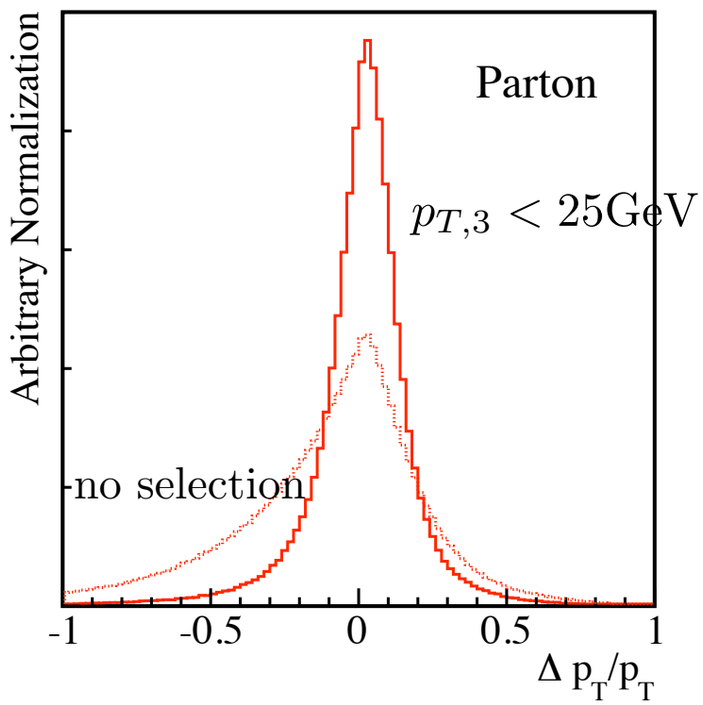

new metric:

$$\Delta_B^{bj} = |m_B - 145\text{GeV}|$$

if $m_B > 155\text{GeV}$, thrown away

Algorithm

$(\mathbf{t}_w, \mathbf{t}_w)$: keep them

$(\mathbf{t}_w, \mathbf{t}_-)$: reconstruct $\mathbf{t}_-$ with Δ_B^{bj}

$(\mathbf{t}_-, \mathbf{t}_-)$: reconstruct $\mathbf{t}_-$ to minimize $\Delta_{B_1}^{bj} + \Delta_{B_2}^{bj}$

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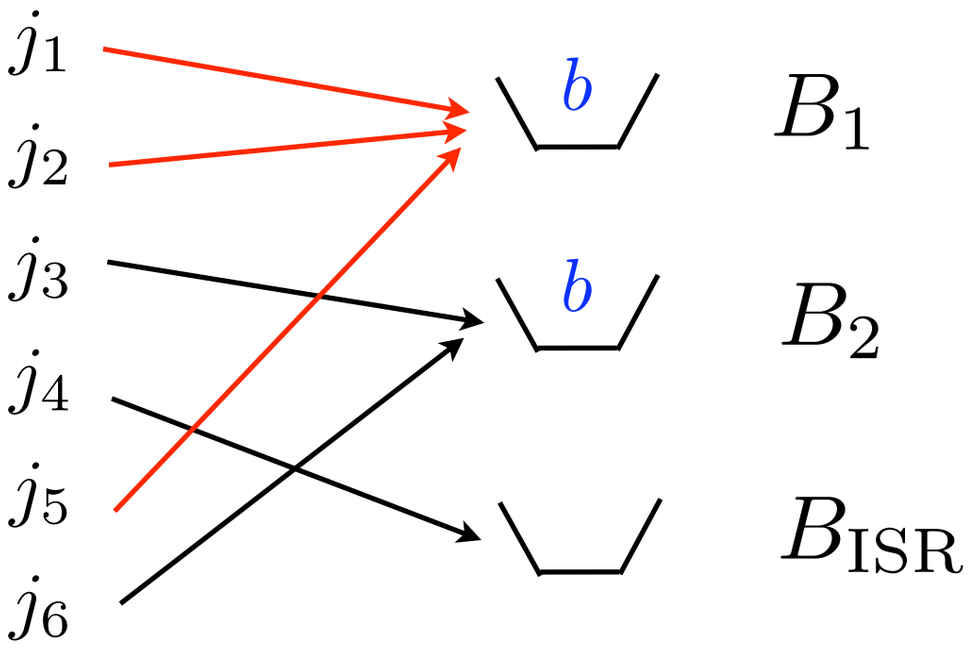

$\Delta_{B_i} = |m_{B_i} - m_t|$ $\quad\quad$ $\Delta_B^{bj} = |m_B - 145\mathrm{GeV}|$

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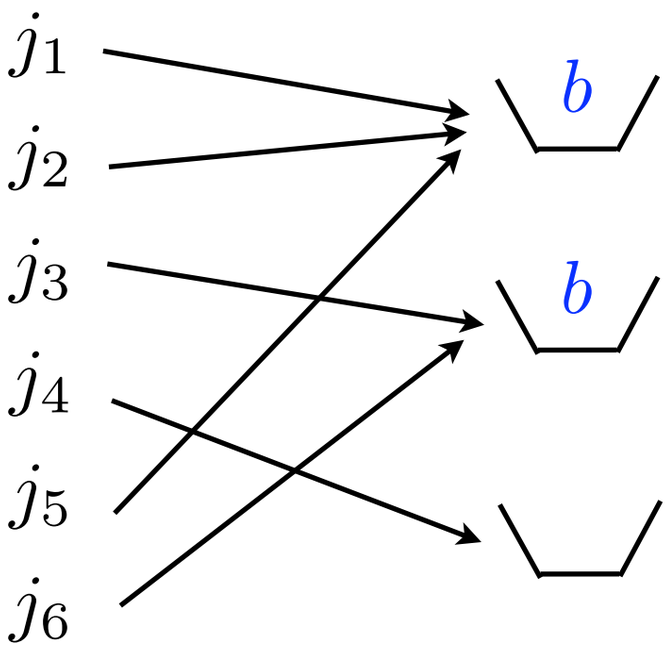

B_1 t_- recompute

B_2 t_- recompute

B_{ISR}

$\Delta_{B_i} = |m_{B_i} - m_t|$ $\Delta_B^{bj} = |m_B - 145\mathrm{GeV}|$

Algorithm

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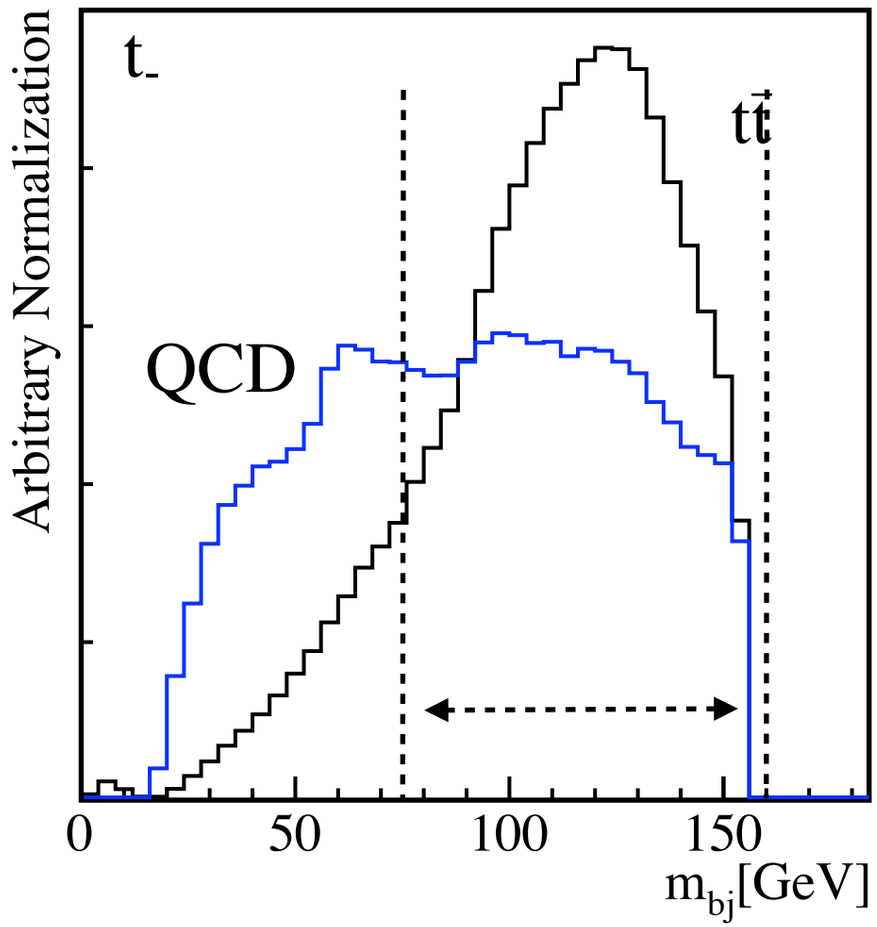


$m_{\mathrm{t}_-} (= m_{bj})$ distribution

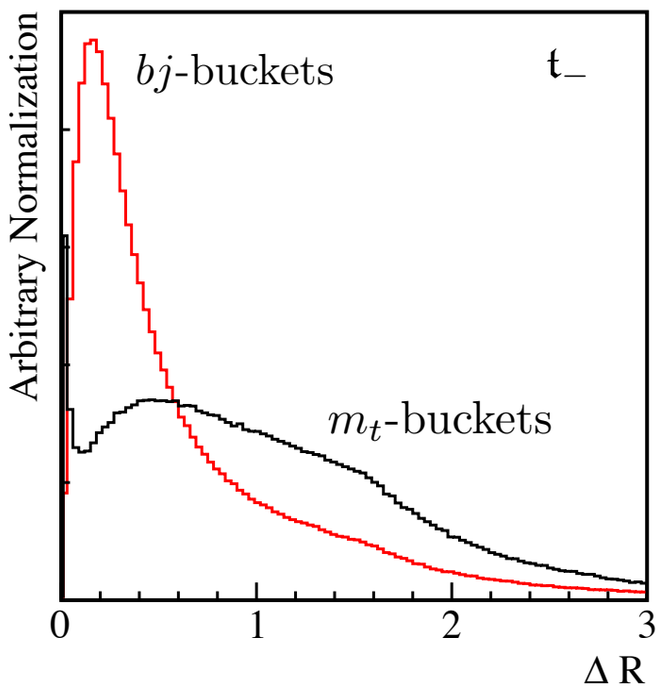
accept t_- as a top

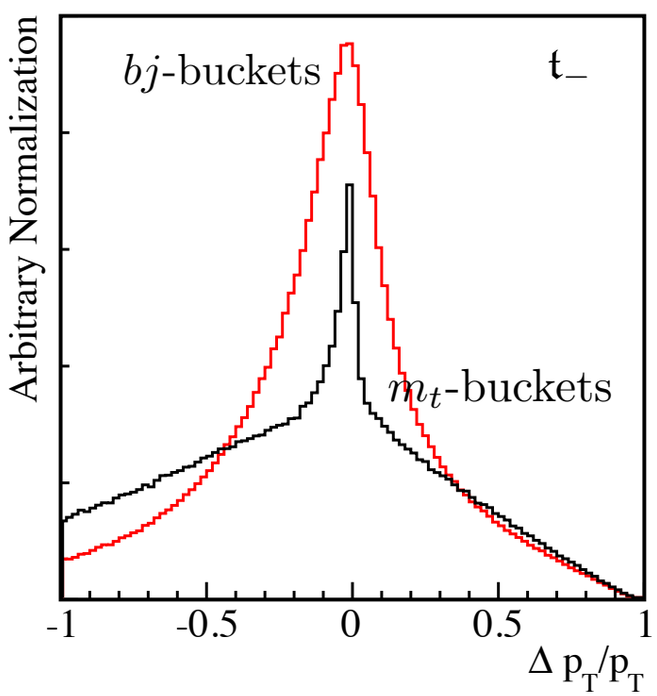
$$75 \text{ GeV} < m_{bj} < 155 \text{ GeV}$$

Efficiency and momentum reconstruction

		$t_h\bar{t}_h$+jets [fb]	$R_1, R_2 < 0.5$	QCD [fb]	$S/B_{\rm QCD}$
	5 jets, 2b-tag	21590		16072	1.4
unchanged →	(t_w,t_w)	2750	68.9%	126.2	21.8
increase →	(t_w,t_-)	7465	49.0%	2145	3.5
	(t_-,t_w)	997	29.5%	160.2	6.2
	(t_-,t_-)	3979	38.7%	2575	1.6

70% double tagged in total



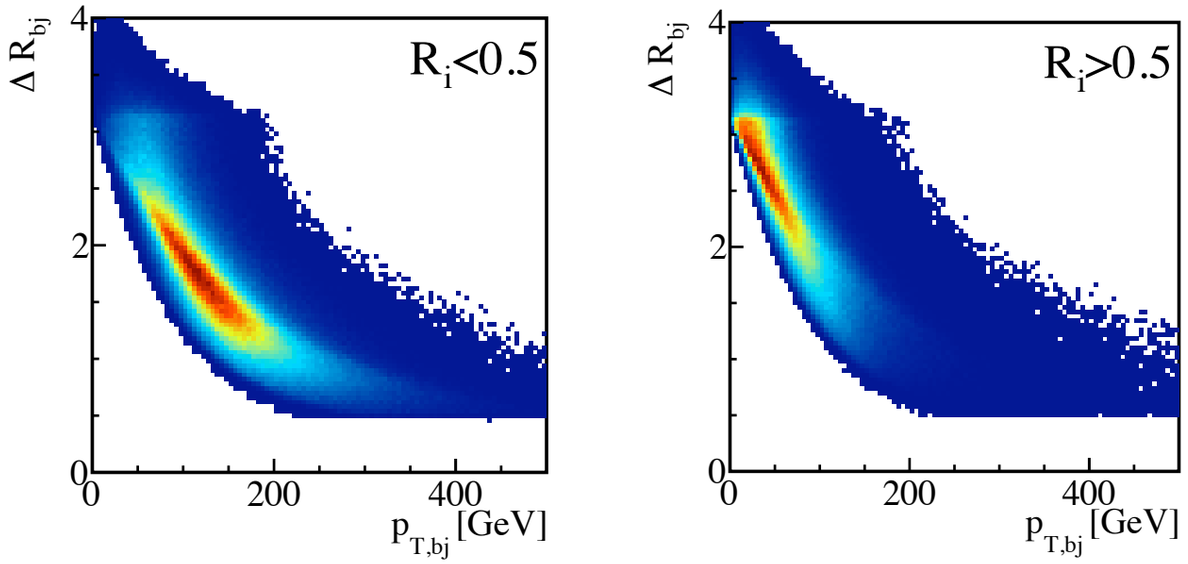


better reconstruction

Consistency check

$$p_T^{\rm rec} > 100{\rm GeV}$$

to get $R_i < 0.5$



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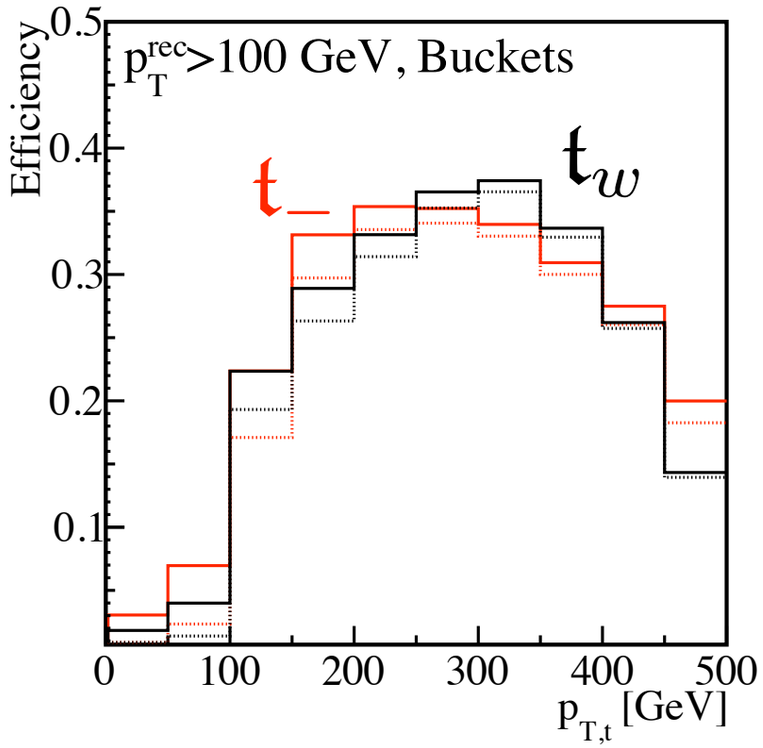
5 jets, 2b-tag	21590		16072	1.36
(t_w,t_w), $p_T^{\rm rec} > 100$ GeV	1417	86.4%	27.1	52.3
(t_w,t_-), $p_T^{\rm rec} > 100$ GeV	2875	80.1%	308.3	9.3
(t_-,t_w), $p_T^{\rm rec} > 100$ GeV	309.1	60.2%	26.6	11.6
(t_-,t_-), $p_T^{\rm rec} > 100$ GeV	1507	68.5%	417.2	3.6
total, $p_T^{\rm rec} > 100$ GeV	6109	77.7%	779.2	7.8

30% double tagged in total

$\sim$ 80% provide good momentum for both tops

Efficiency as functions of pT

base number: after $5j$ with $2b$-tag selection



$p_{T,t} = 100 - 150$ GeV: $\quad t_w + t_-$ 40%

$p_{T,t} = 150 - 350$ GeV: $\quad t_w + t_-$ 60-70%

Efficiency as functions of pT

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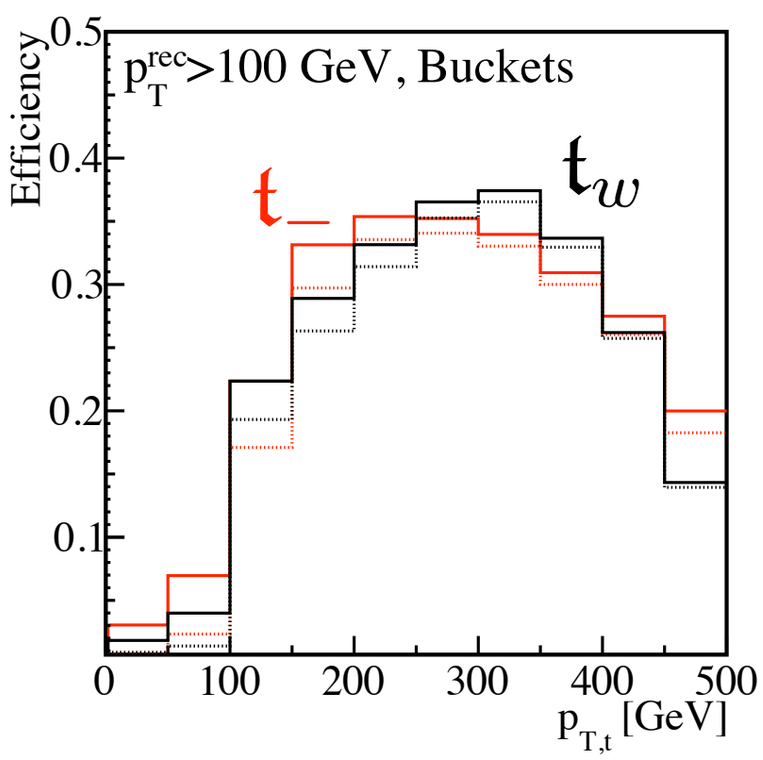
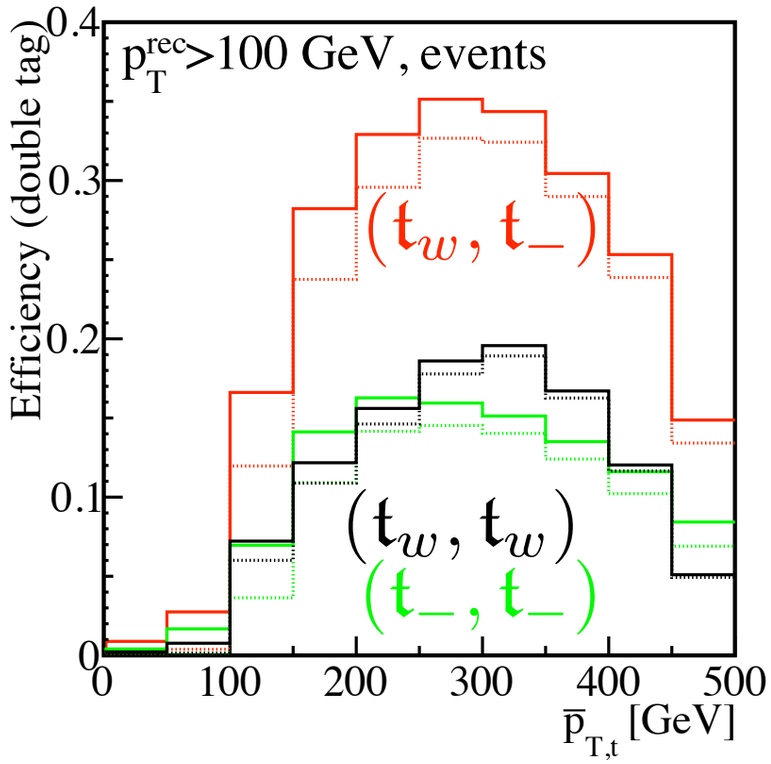




$p_{T,t} = 100 - 150$ GeV: $t_w + t_-$ 40%

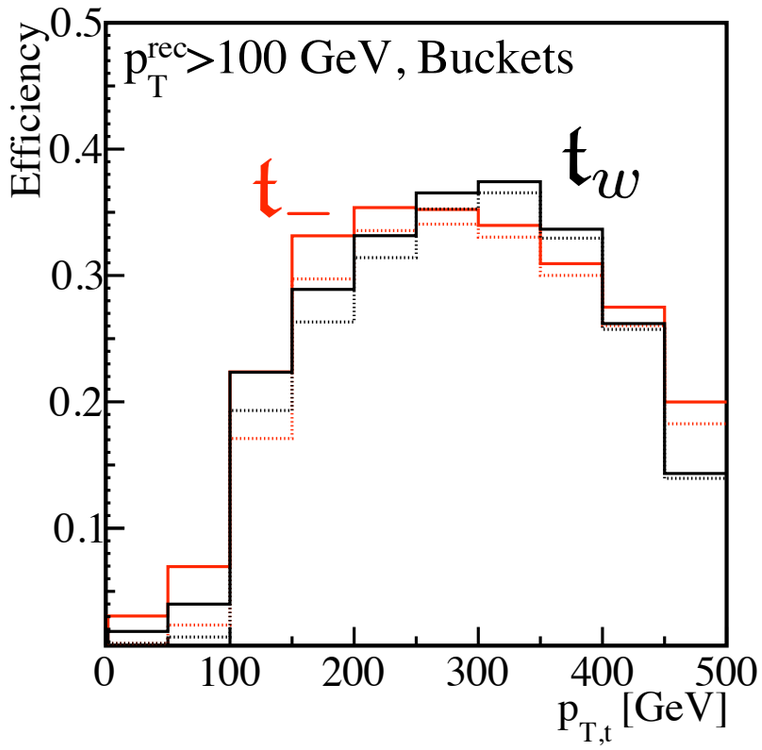
$p_{T,t} = 150 - 350$ GeV: $t_w + t_-$ 60-70%

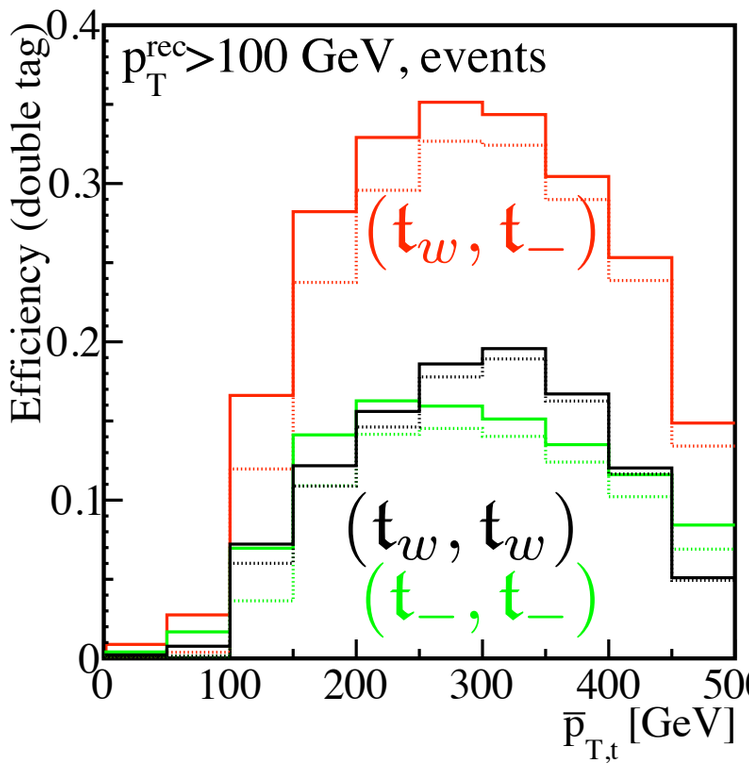
$\bar{p}_{T,t} = 100 - 150$ GeV: 30% (double top tags)

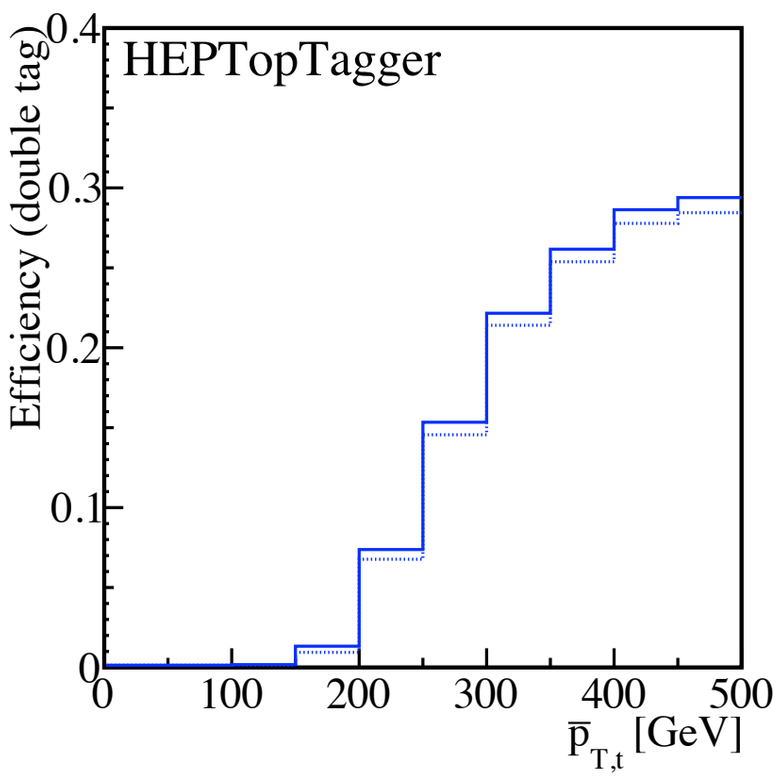
$\bar{p}_{T,t} = 150 - 300$ GeV: 50-70% (double top tags)

Efficiency as functions of pT

base number: after $5j$ with $2b$-tag selection







$p_{T,t} = 100 - 150$ GeV: $t_w + t_-$ 40%

$p_{T,t} = 150 - 350$ GeV: $t_w + t_-$ 60-70%

$\bar{p}_{T,t} = 100 - 150$ GeV: 30% (double top tags)

$\bar{p}_{T,t} = 150 - 300$ GeV: 50-70% (double top tags)

for $\bar{p}_{T,t} > 350$ GeV, jet substructure method start to be efficient

Stop pair search

[arXiv:1302.6238[hep-ph] M. Buckley, T. Plehn, MT]

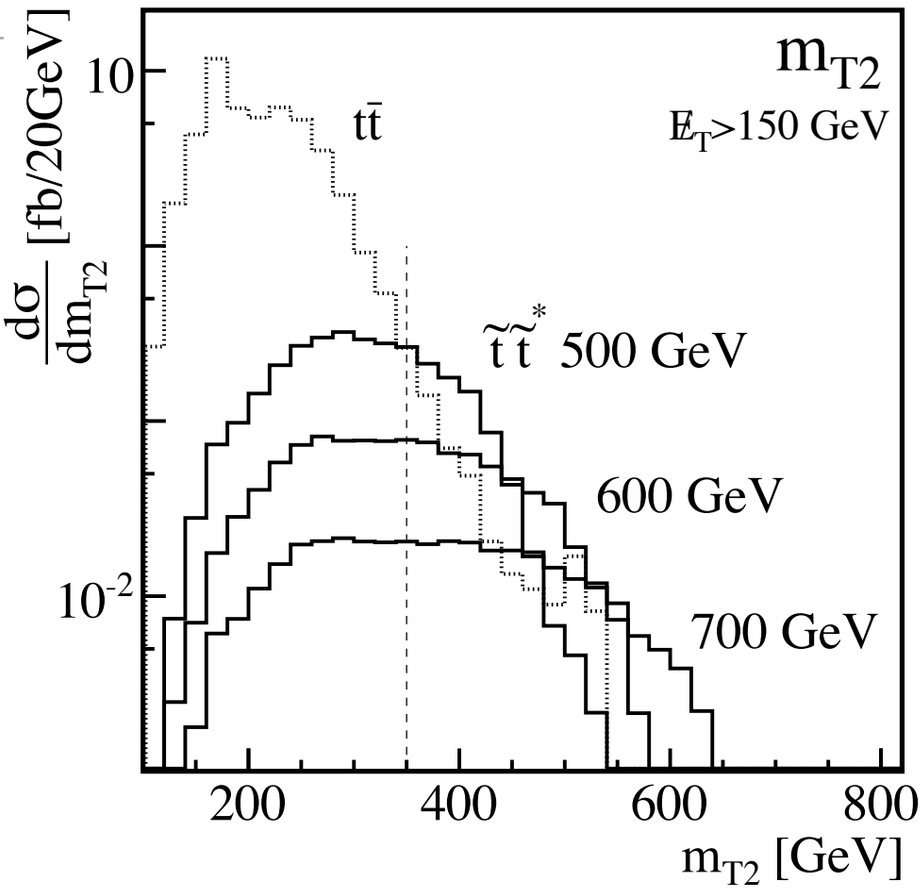
- $\tilde{t}\tilde{t}^* \to t\bar{t}\chi\chi$: $t\bar{t} + \not{E}_T$

  typically 10^4 difference in cross section

- include t_- increase both signal and BG

- LHC 8 TeV with 25 fb^{-1} :

$S/B \sim 1$ for $m_{\tilde{t}} = 600$ GeV



$m_{\tilde{t}}$ [GeV]	$t\bar{t}$+jets [fb]	$\tilde{t}\tilde{t}^*$ [fb] 500	600	700	S/B 600	$S/\sqrt{B}$ 600
before cuts	234×10^3	80.50	23.00	7.19		
veto lepton	157×10^3	50.45	14.38	4.46		
≥ 5 jets	85.9×10^3	37.87	10.90	3.37		
2 b-tags	28.0×10^3	11.41	3.30	1.02		
2 tops reconstructed, $p_{T,t}^{\mathrm{rec}} > 100$ GeV	6.90×10^3	4.19	1.30	0.40	0.0002	0.08
$\not{E}_T > 150$ GeV	48.53	2.98	1.04	0.35	0.02	0.8
$m_{T2} > 350$ GeV	0.45	0.84	0.46	0.19	1.0	3.5
100% τ rejection	0.12	0.77	0.42	0.17	3.6	6.1

Summary

- top : tool for new physics search
- keep low p_T tops to keep signal : $p_{T,t} = 100 - 350$ GeV
- buckets help study of tops
- bj-buckets provide ~ 4 times the signal