

Buckets of Tops

Michihisa Takeuchi (King's College London)

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

Top at LHC

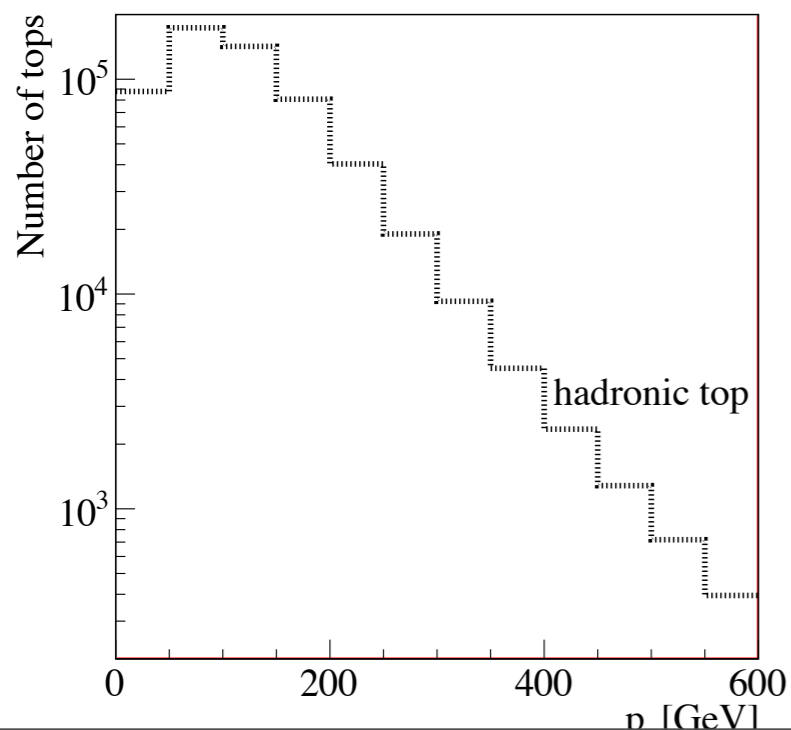
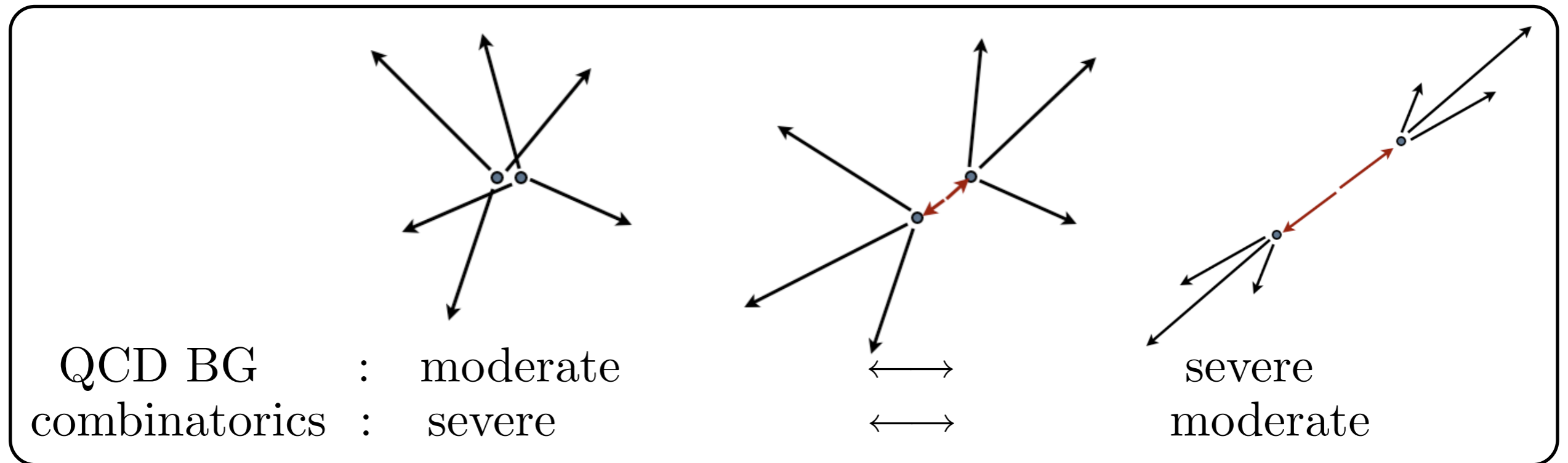
- top : closest to new physics

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

- $\tilde{t}\tilde{t} \rightarrow t\bar{t}\chi\chi$: stop search
- $t\bar{t}H$: largest yukawa coupling to higgs to be measured
- $t\bar{t}$: main background for new physics search
- hadronic top:
 - advantage : momentum reconstruction
 - disadvantage : QCD and combinatorics \rightarrow boosted tops
 - ISR makes the situation worse

Moderately boosted tops

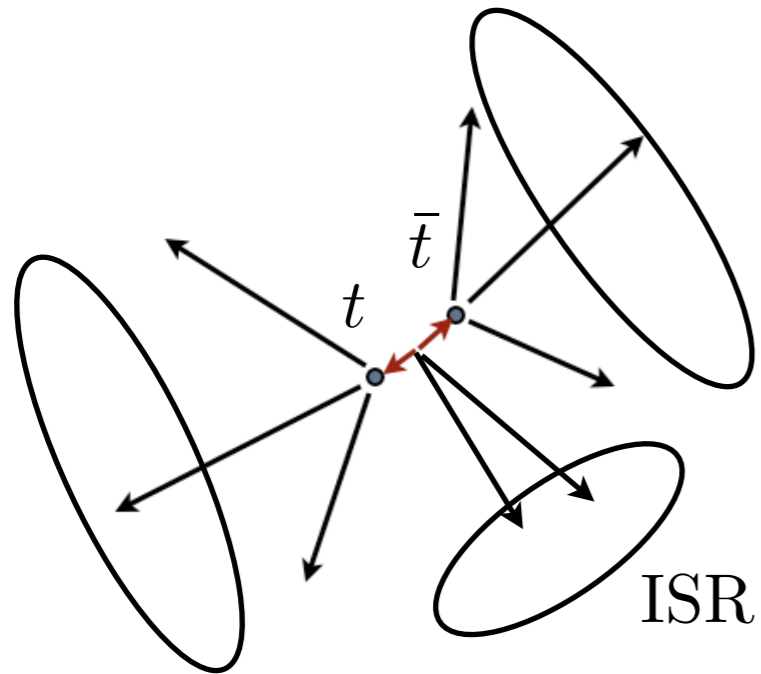
- events look different depending on $p_{T,t}$



moderate boost help to solve combinatorics
HEPTopTager: down to $p_T \sim 200$ GeV

How can we tag $p_T \sim 100$ GeV?
stop search, $t\bar{t}H$ with 25fb^{-1}
keeping signal important

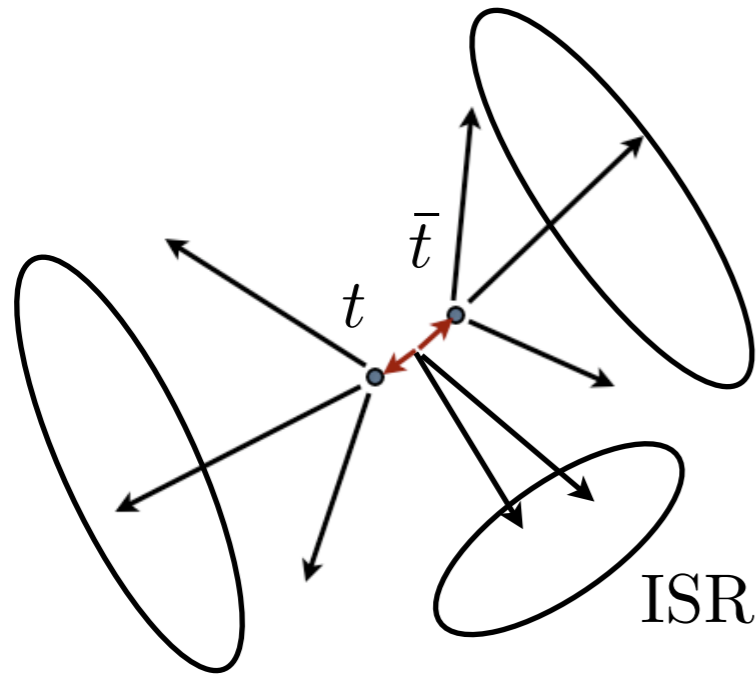
Buckets of tops



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

Aim: find jets corresponding to 2 tops

Buckets of tops



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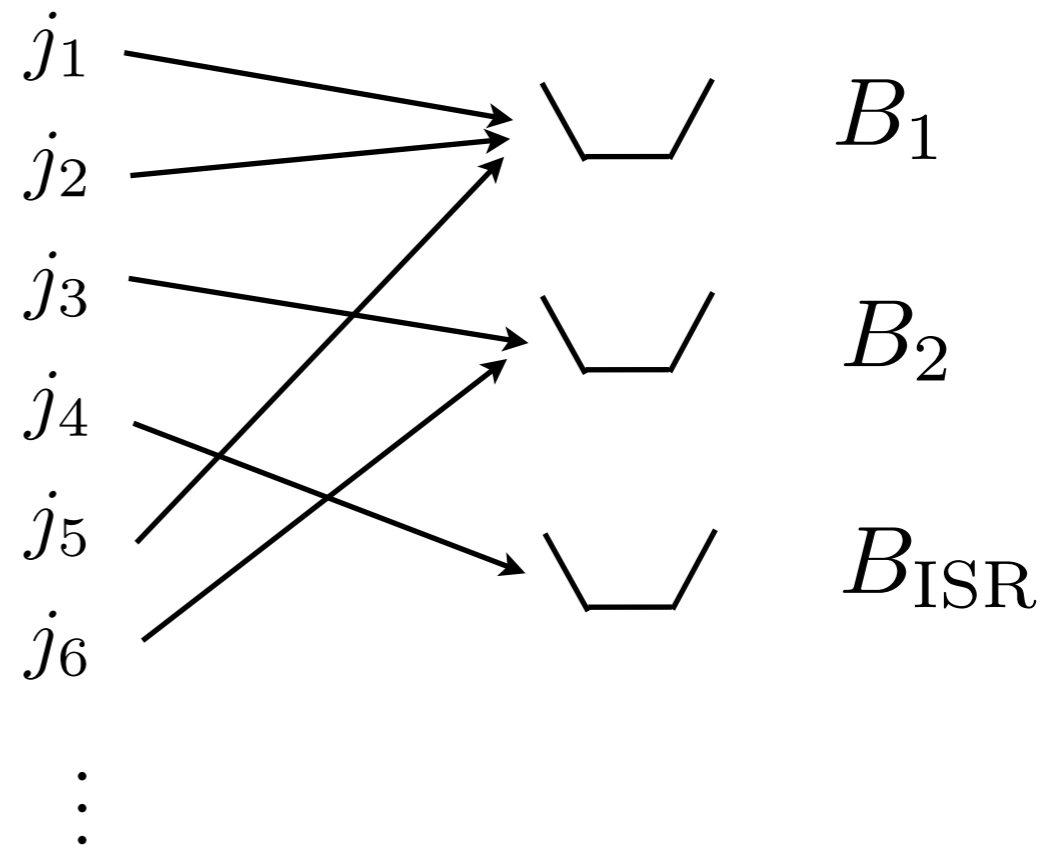
Aim: find jets corresponding to 2 tops

scan all permutation,
select the grouping minimizing

$$\Delta^2 = \omega \Delta_{B_1}^2 + \Delta_{B_2}^2 \quad (\omega = 100)$$

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

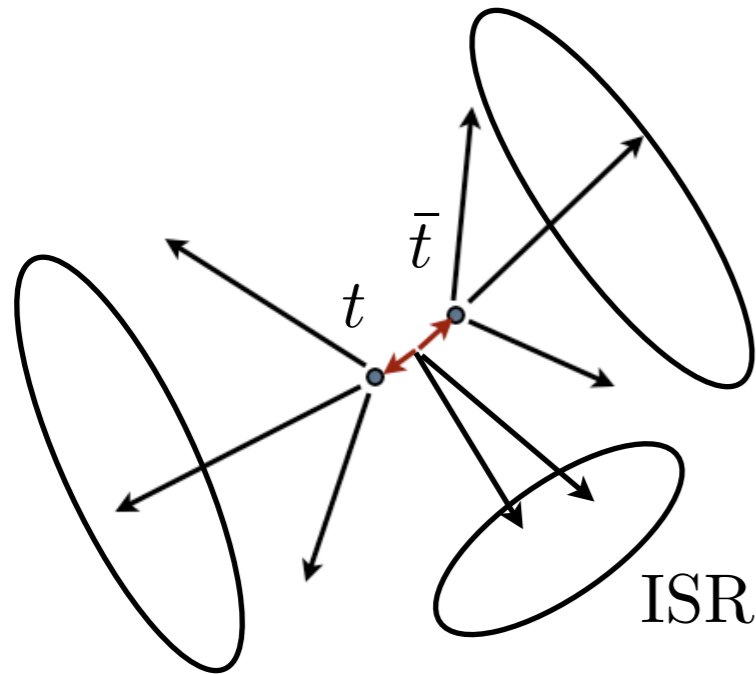
$$m_{B_i}^2 = \left(\sum_{j \in B_i} p_j \right)^2$$



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

always 2 top tags

Buckets of tops



start with standard jets (C/A $R = 0.5$)
with 2 b -jets

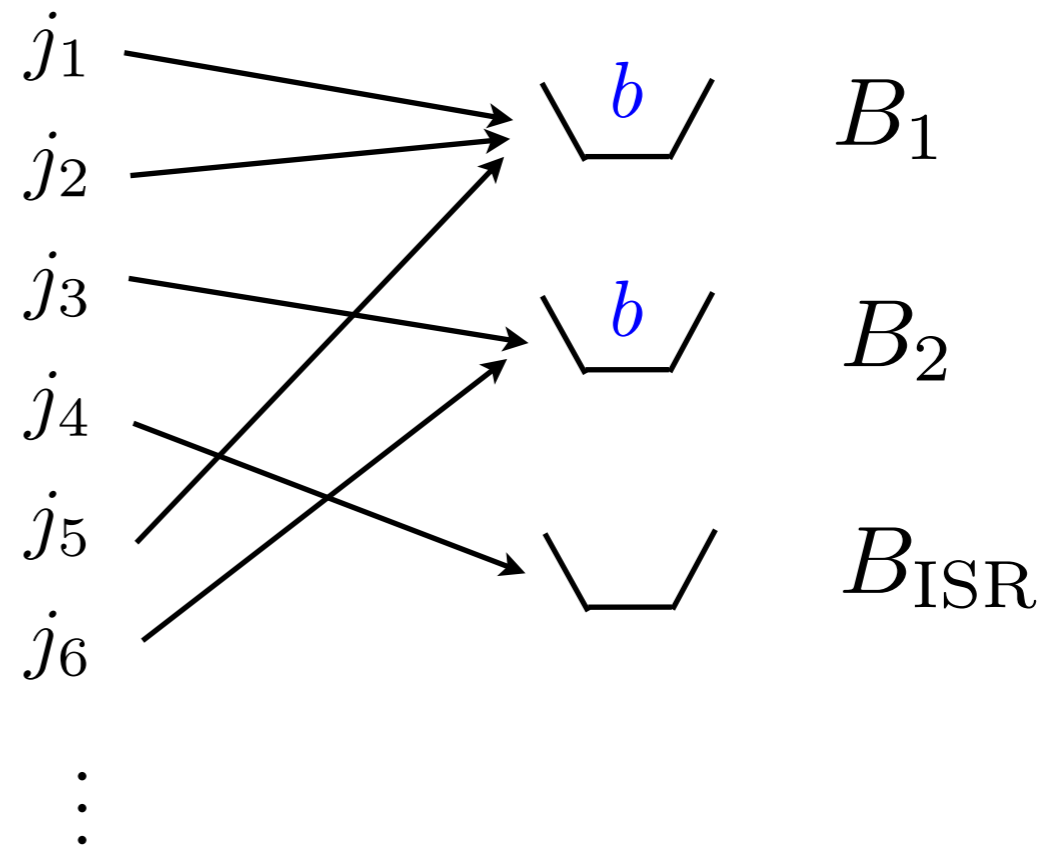
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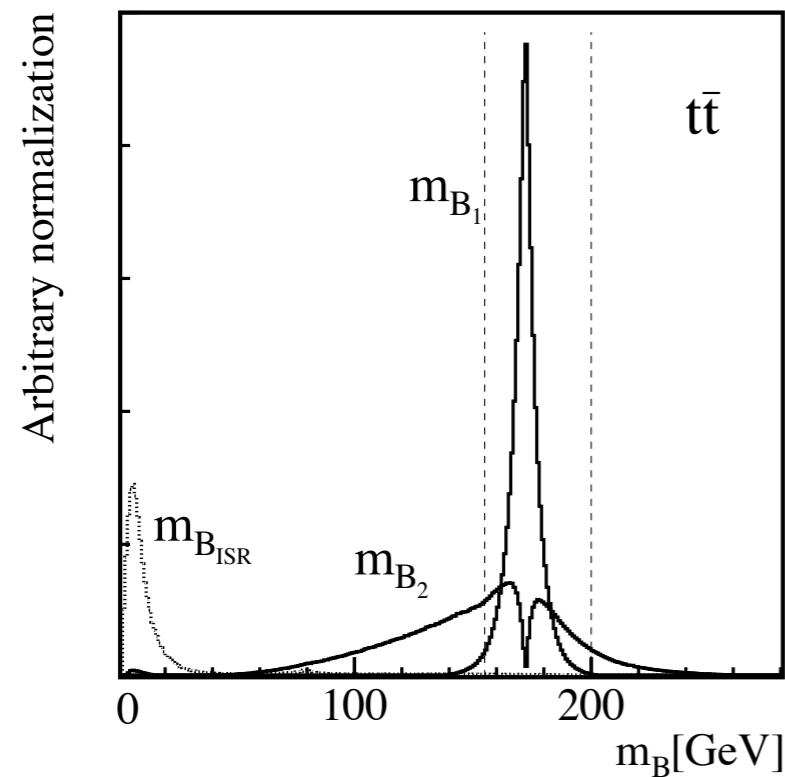
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Bucket mass, W condition



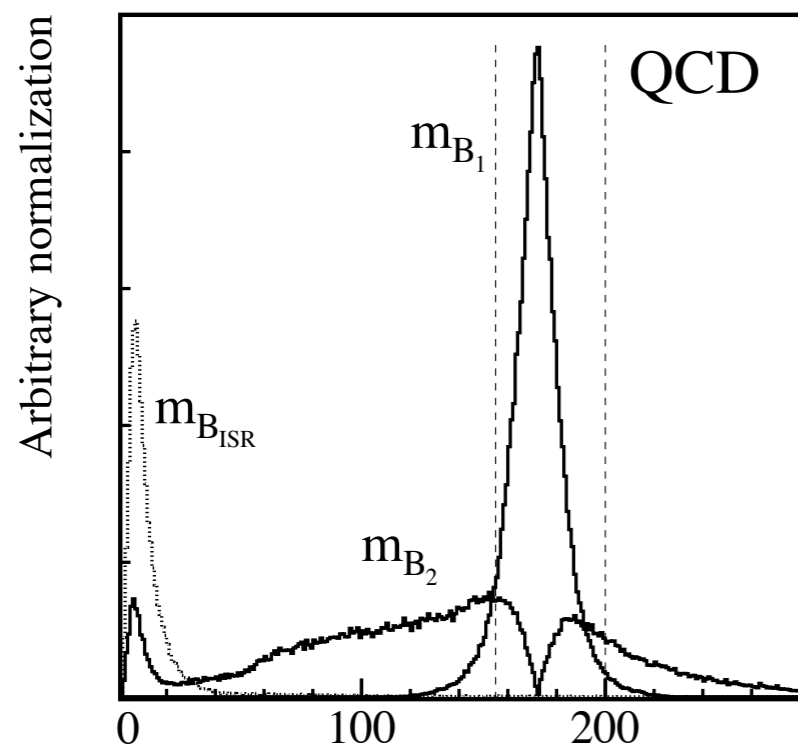
- top mass window

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

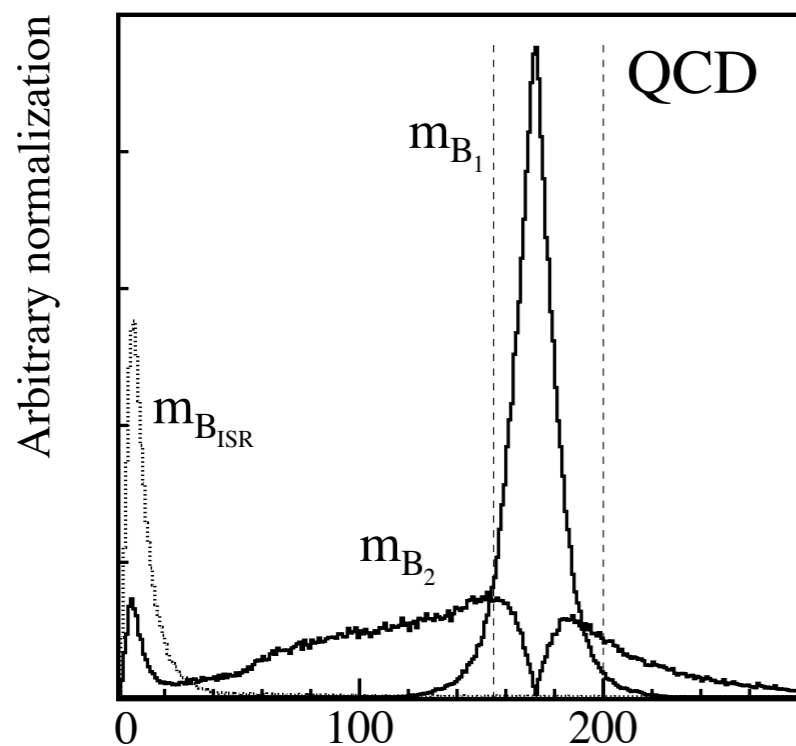
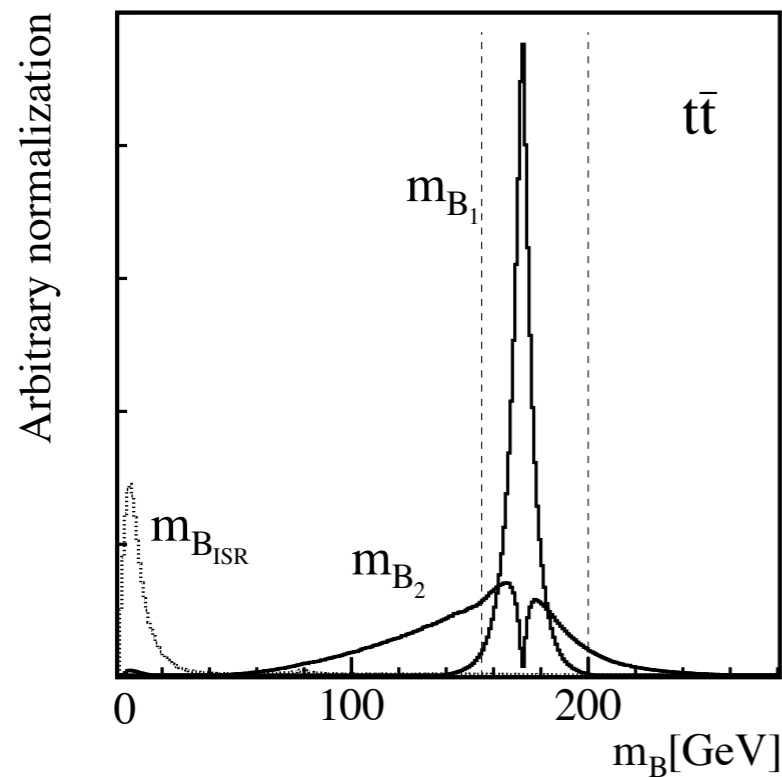
- W mass window

regard B_i contains W if 2 jets in a bucket satisfy

$$\left| \frac{m_{kl}}{m_{B_i}} - \frac{m_W}{m_t} \right| < 0.15$$



Bucket mass, W condition



- top mass window

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→ 4 categories

$$(t_w, t_w) : B_1 \ni W, B_2 \ni W$$

$$(t_w, t_-) : B_1 \ni W, B_2 \not\ni W$$

$$(t_-, t_w) : B_1 \not\ni W, B_2 \ni W$$

$$(t_-, t_-) : B_1 \not\ni W, B_2 \not\ni W$$

Efficiency & Momentum reconstruction

$R_i < 0.5$: good reconstruction

$$R_i = \Delta R(B_i, p_t^{\text{MCtruth}})$$

	$t_h \bar{t}_h + \text{jets}$ [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

(t_w, t_w) provide reasonable momentum, $\epsilon_{(t_w, t_w)} \sim 13\%$

t_- not reconstruct correct momentum

only 45% double tagged in total

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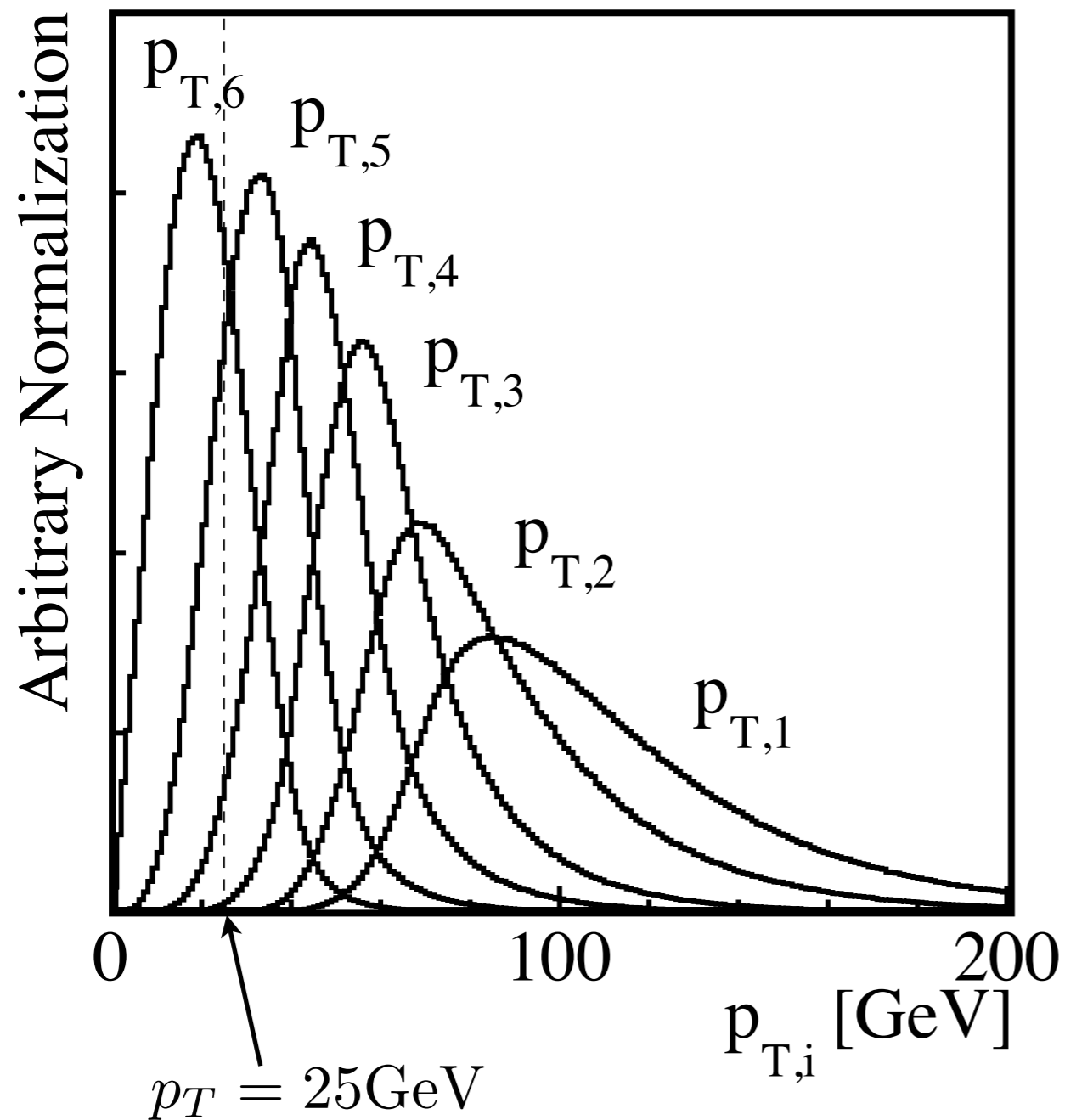
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6 jets not often survive due to jet p_T threshold

Jet p_T threshold

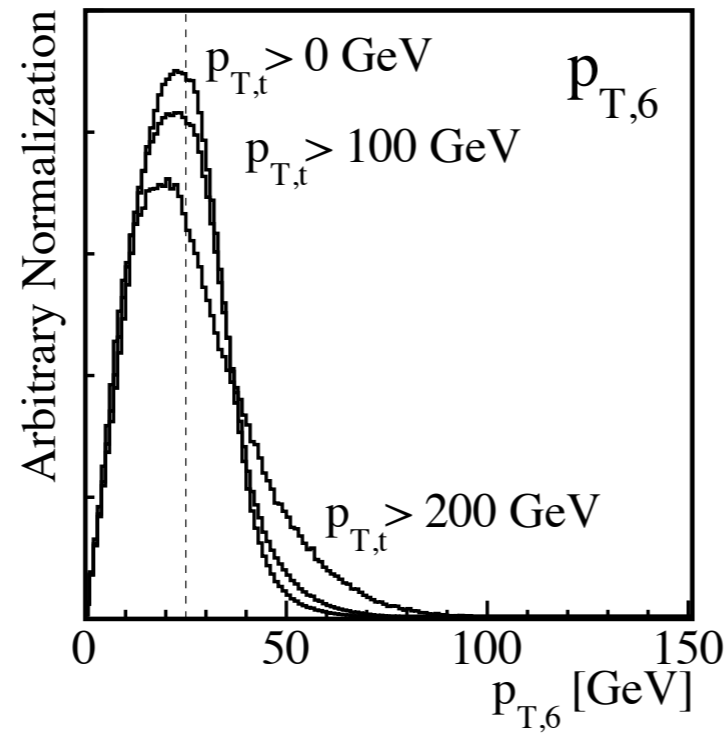
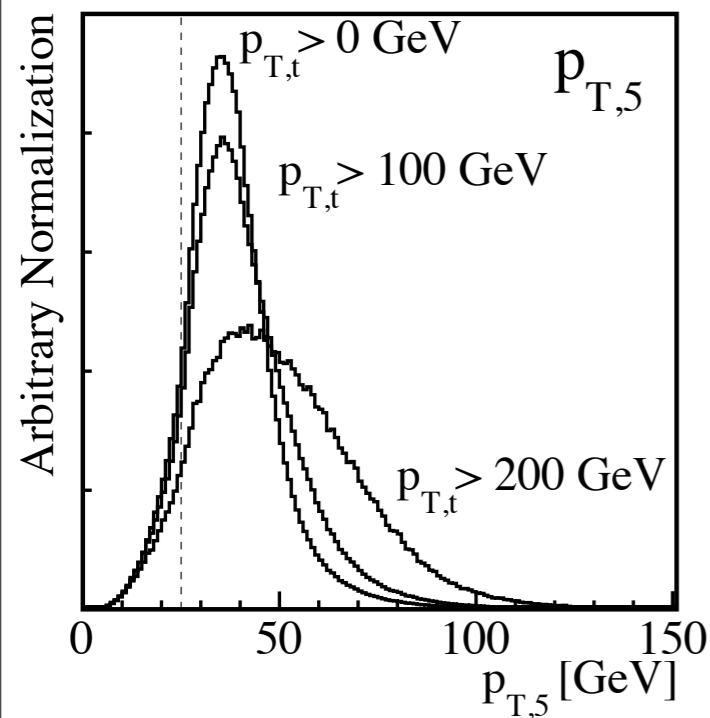
6 partons from top pair decays



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

98% of j_6 from W

Jet p_T threshold



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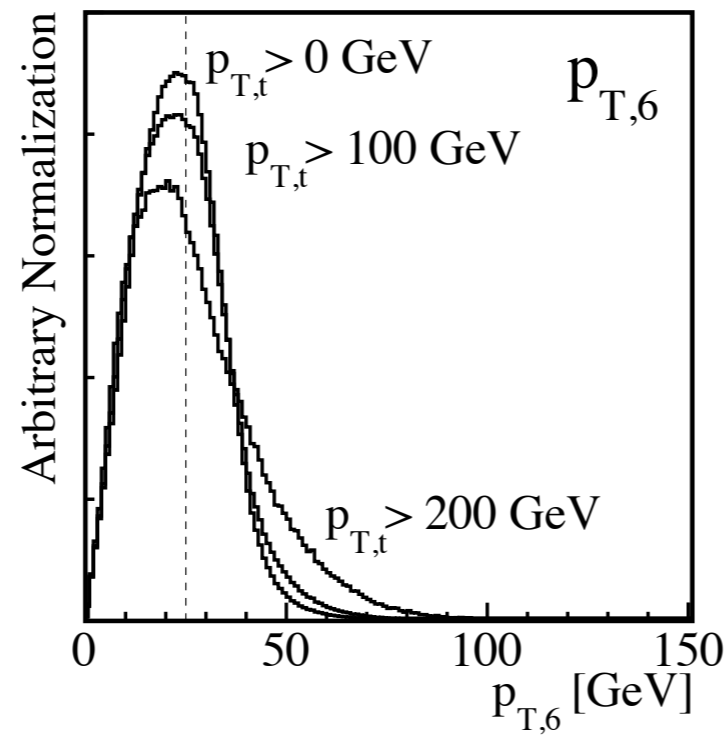
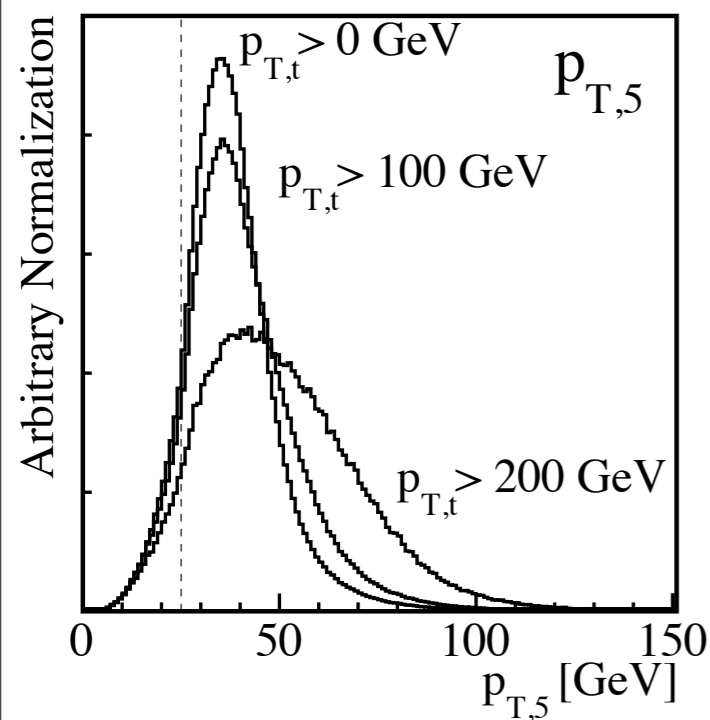
98% of j_6 from W

distributions:

weak top p_T dependence

	$t_h \bar{t}_h + \text{jets}$ [pb]	$p_{T,6} > 25 \text{ GeV}$	$p_{T,5} > 25 \text{ GeV} > p_{T,6}$
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%
$n_j \geq 5$ $p_{T,t_2} > 100 \text{ GeV}$	32.7	43.6%	46.2%
$n_j \geq 5$ $p_{T,t_2} > 200 \text{ GeV}$	6.7	47.4%	44.7%

Jet p_T threshold



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distributions:

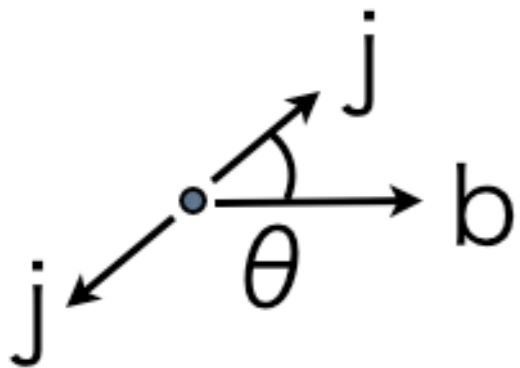
weak top p_T dependence

What can we do with 5 jets?

	$t_h \bar{t}_h + \text{jets}$ [pb]	$p_{T,6} > 25$ GeV	$p_{T,5} > 25$ GeV $>$ $p_{T,6}$
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bj -buckets

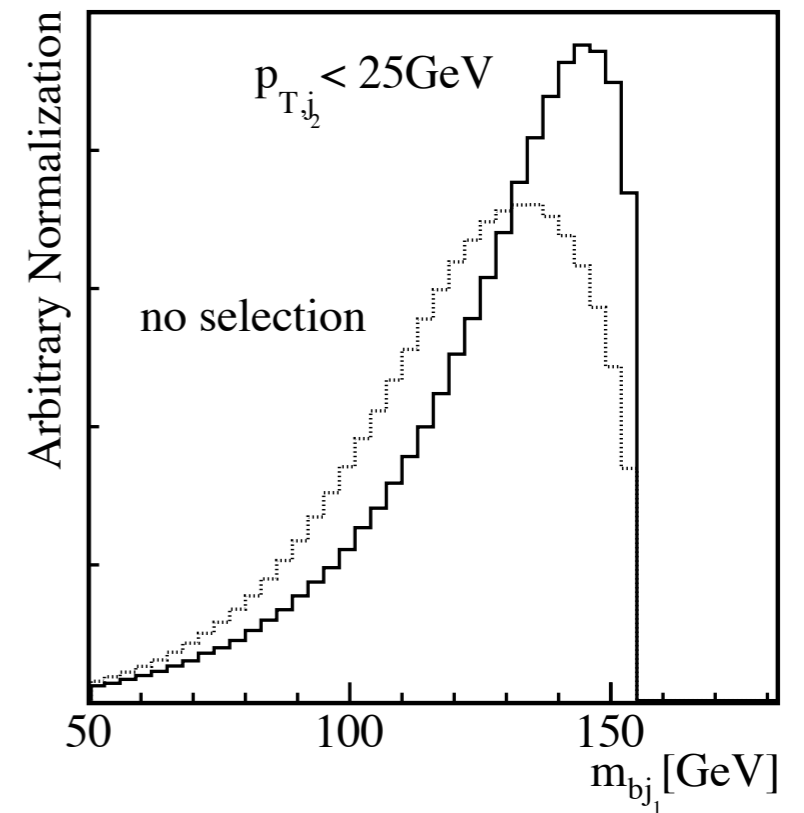
- m_{bj} -peak from top decay kinematics



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

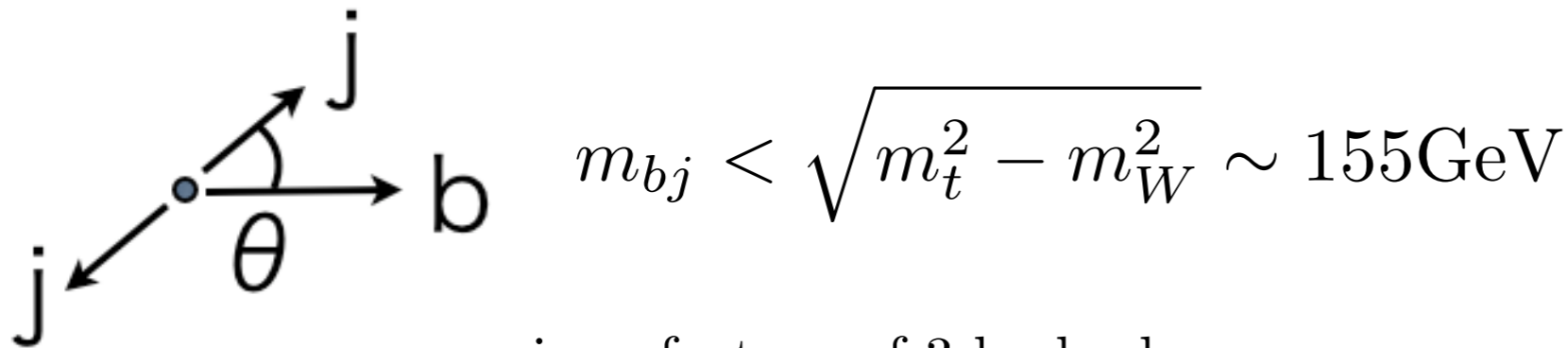
unique feature of 3 body decay

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



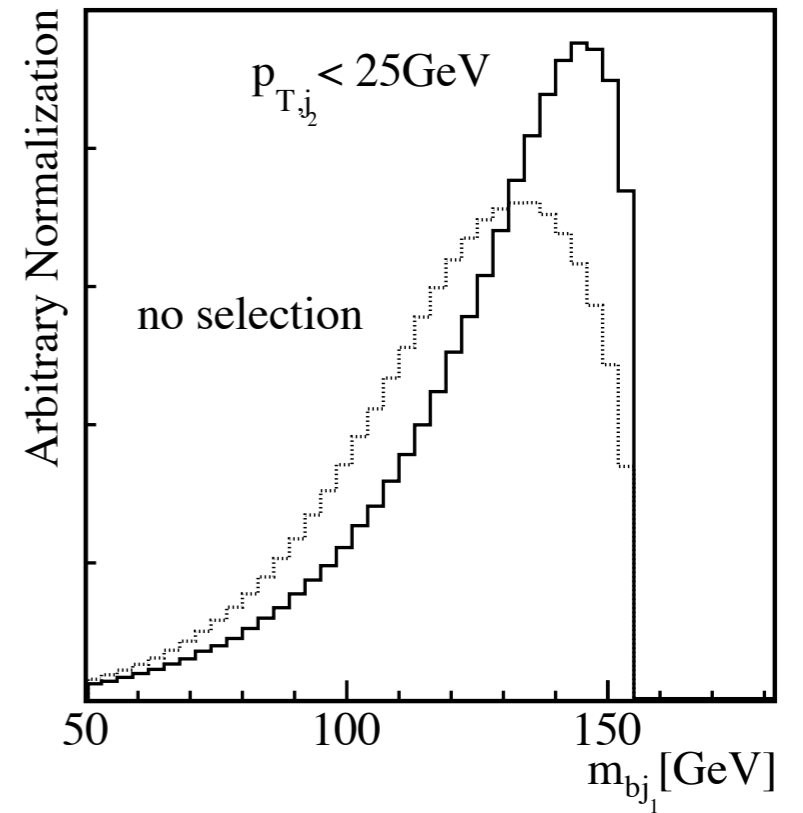
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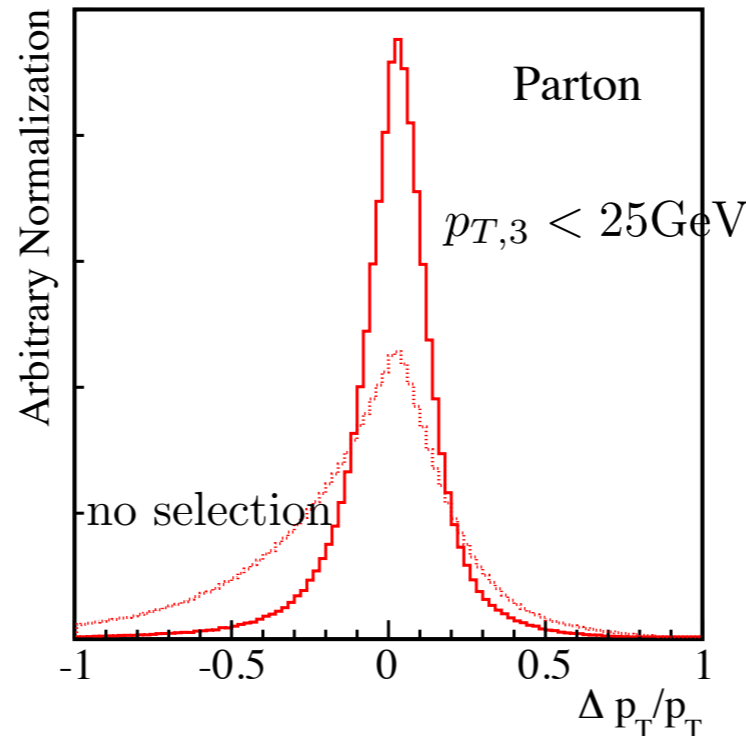
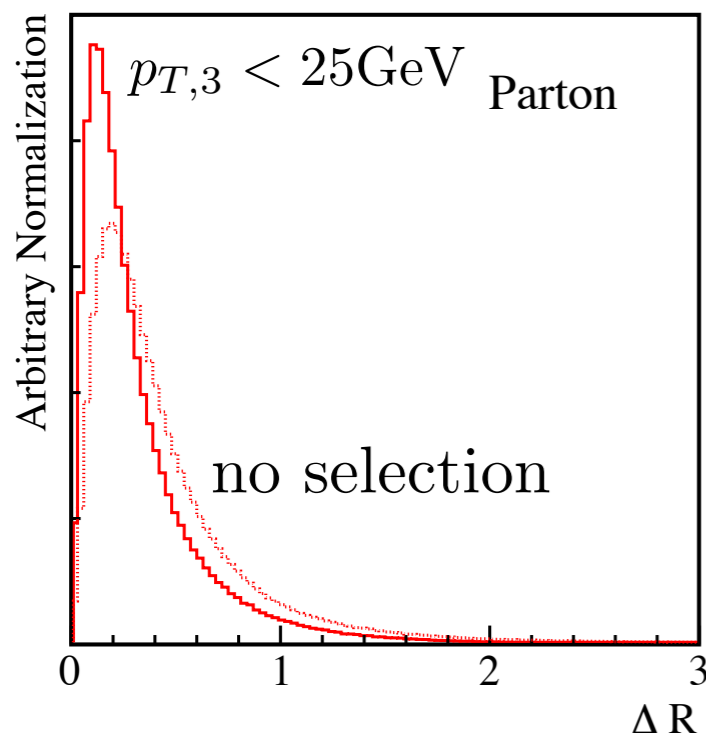


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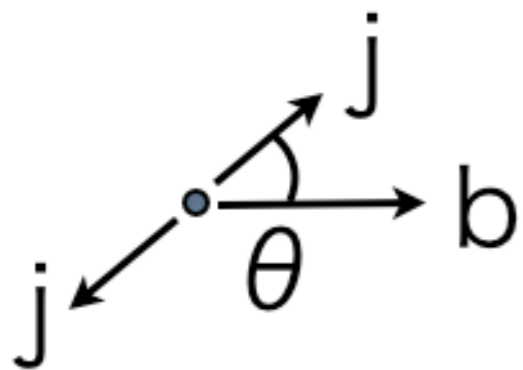


- acceptable momentum reconstruction



bj -buckets

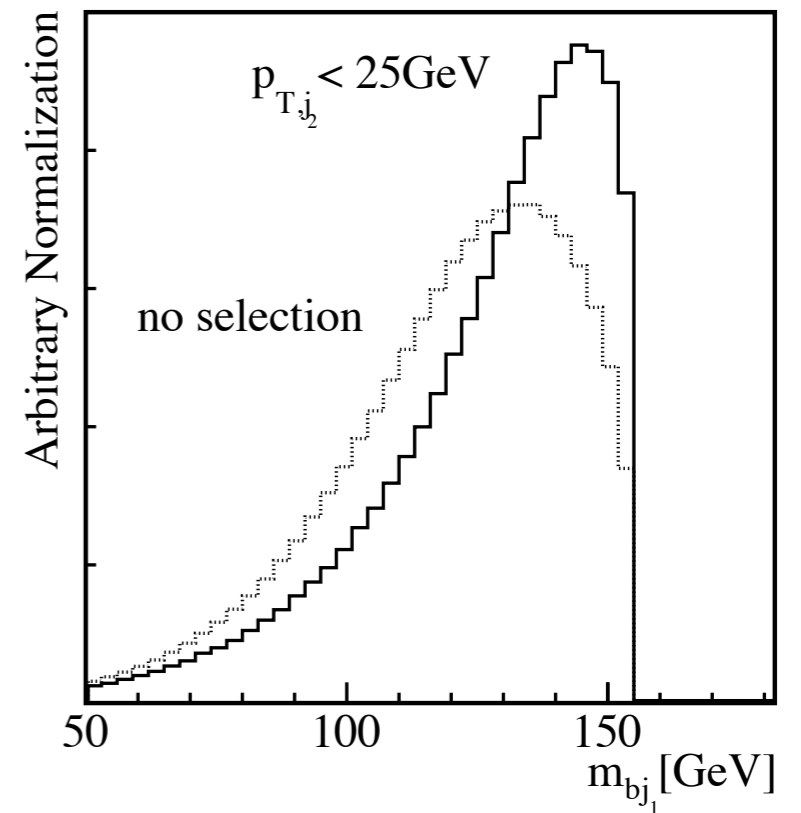
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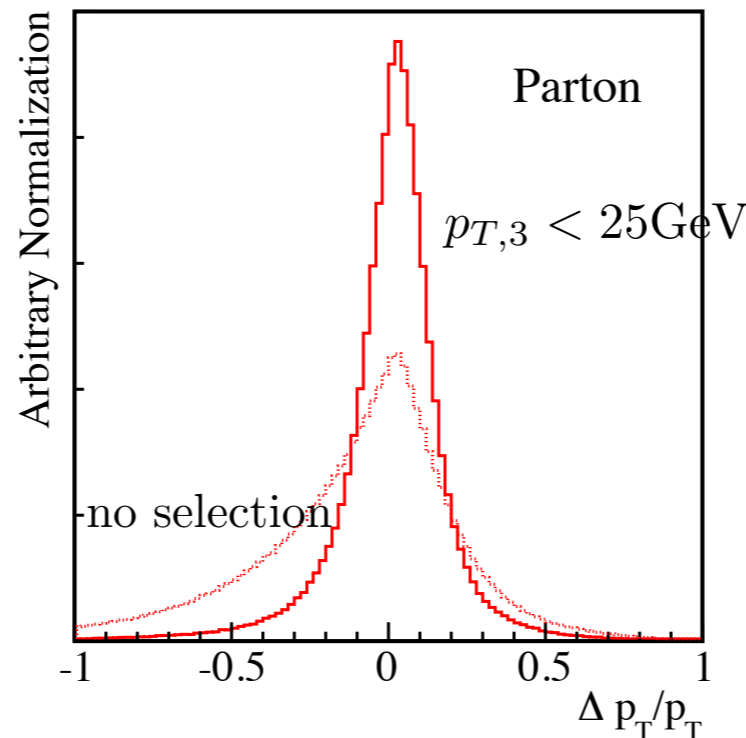
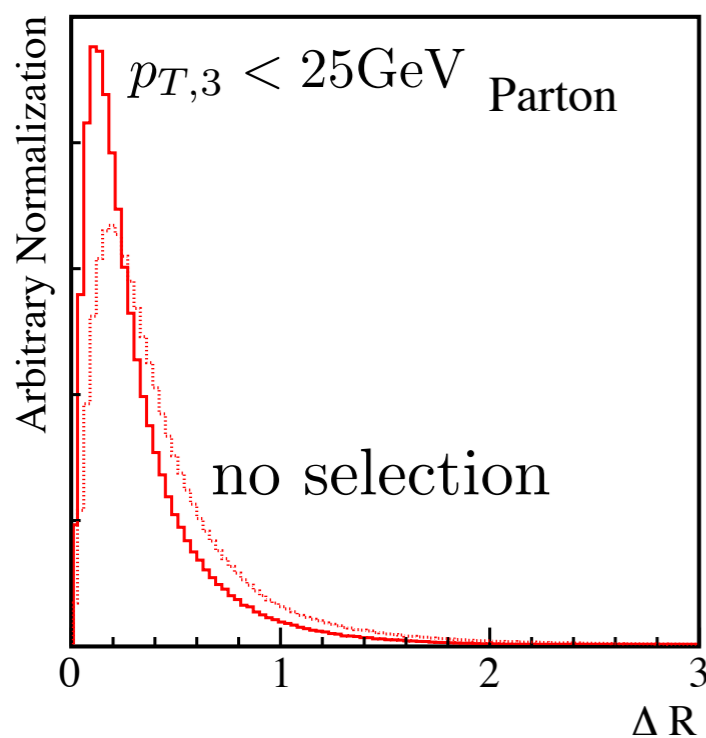
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- acceptable momentum reconstruction



new metric:

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

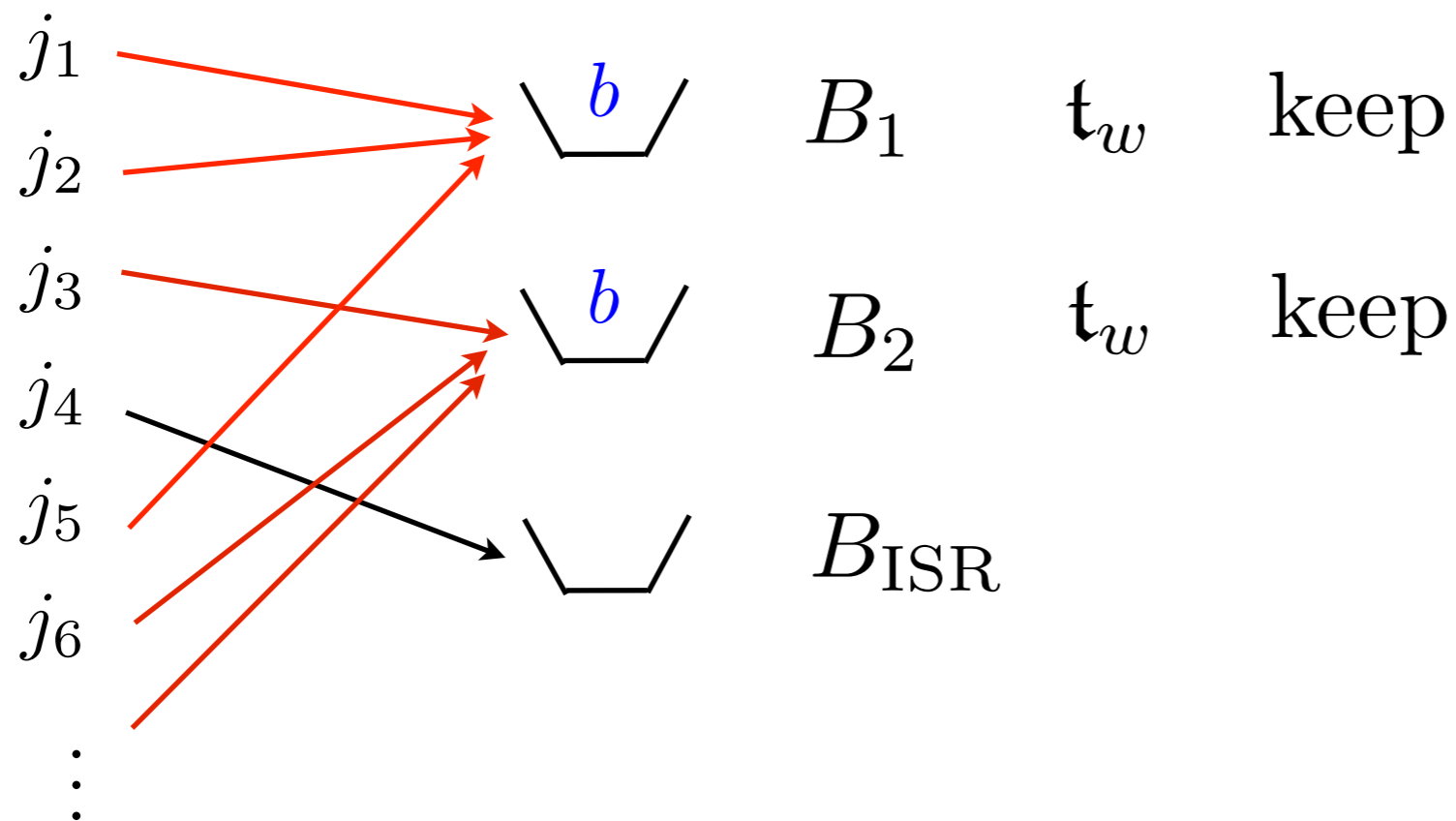
if $m_B > 155\text{GeV}$, thrown away

Modified 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 $\Delta_{B_1}^{bj} + \Delta_{B_2}^{bj}$

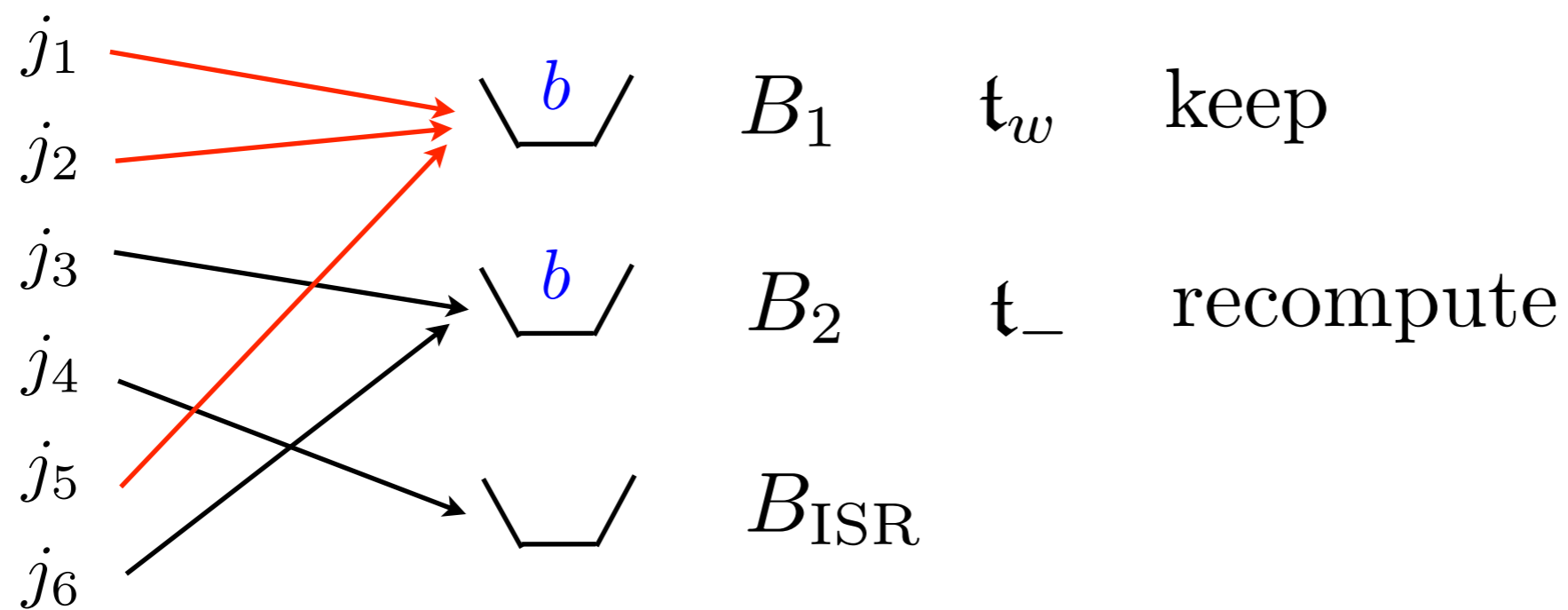


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$$\Delta_{B_i} = |m_{B_i} - m_t|$$

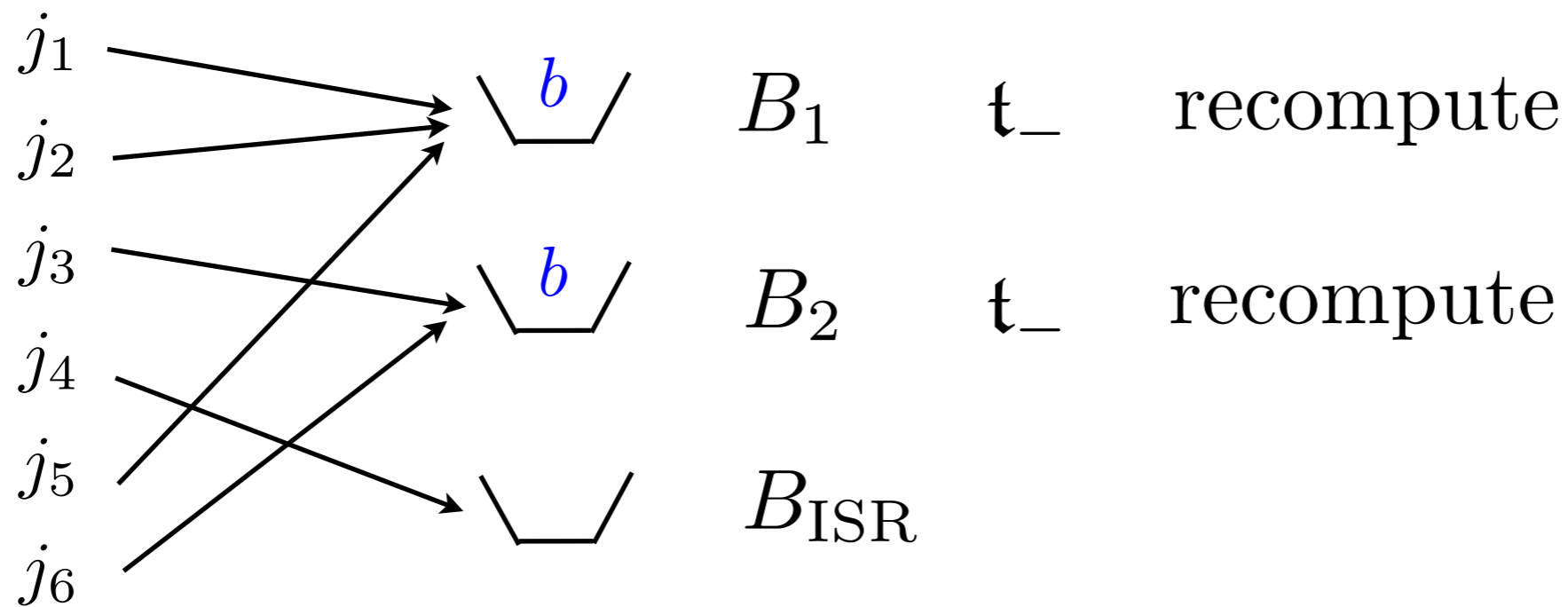
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\vdots

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

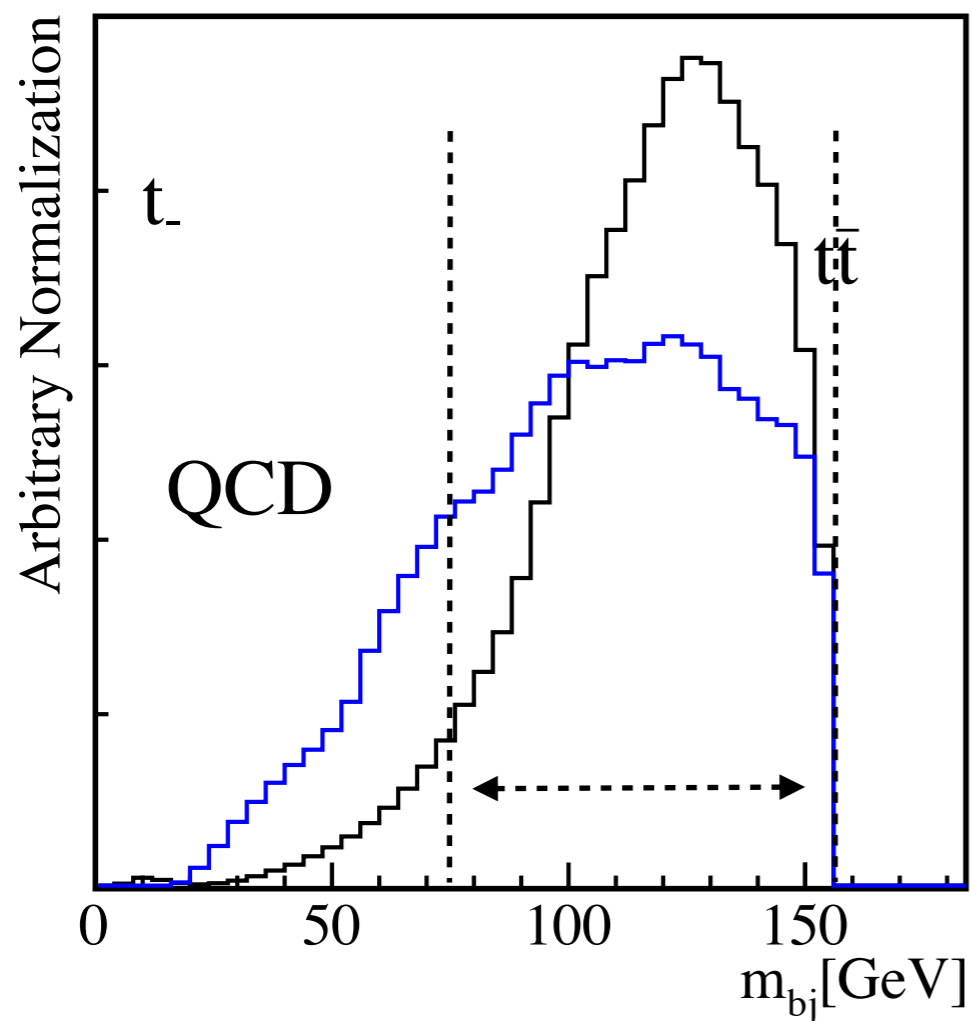
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$m_{\mathbf{t}_-} (= m_{bj})$ distribution

accept \mathbf{t}_- as a top

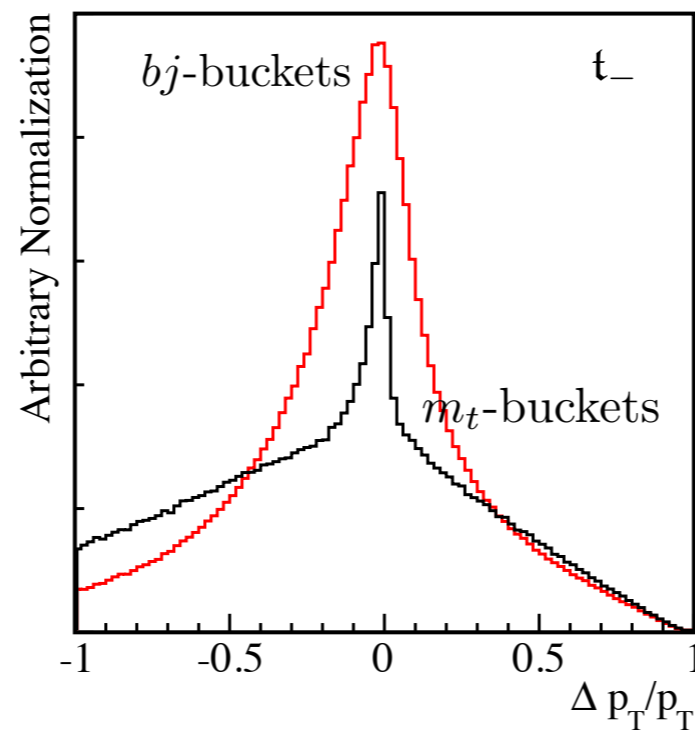
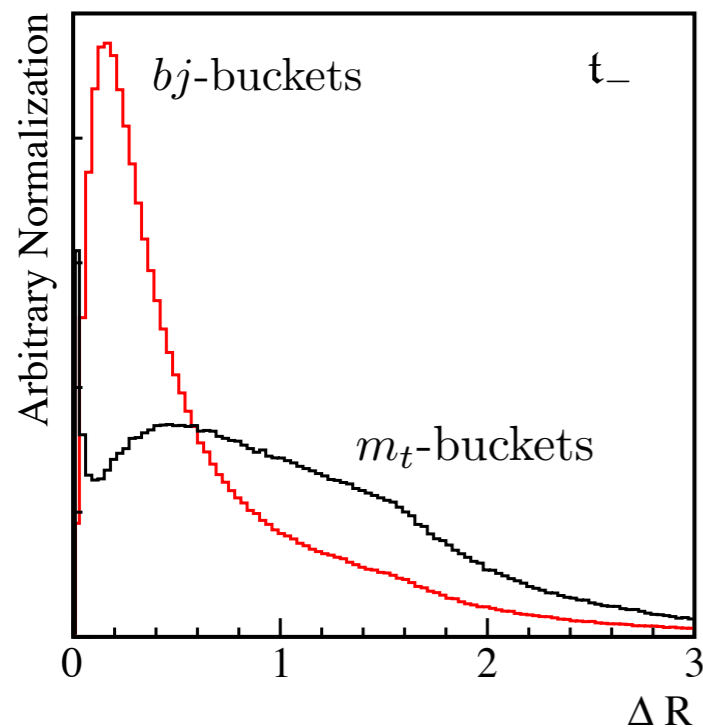
$$75 \text{ GeV} < m_{bj} < 155 \text{ GeV}$$

Efficiency and momentum reconstruction

unchanged \rightarrow

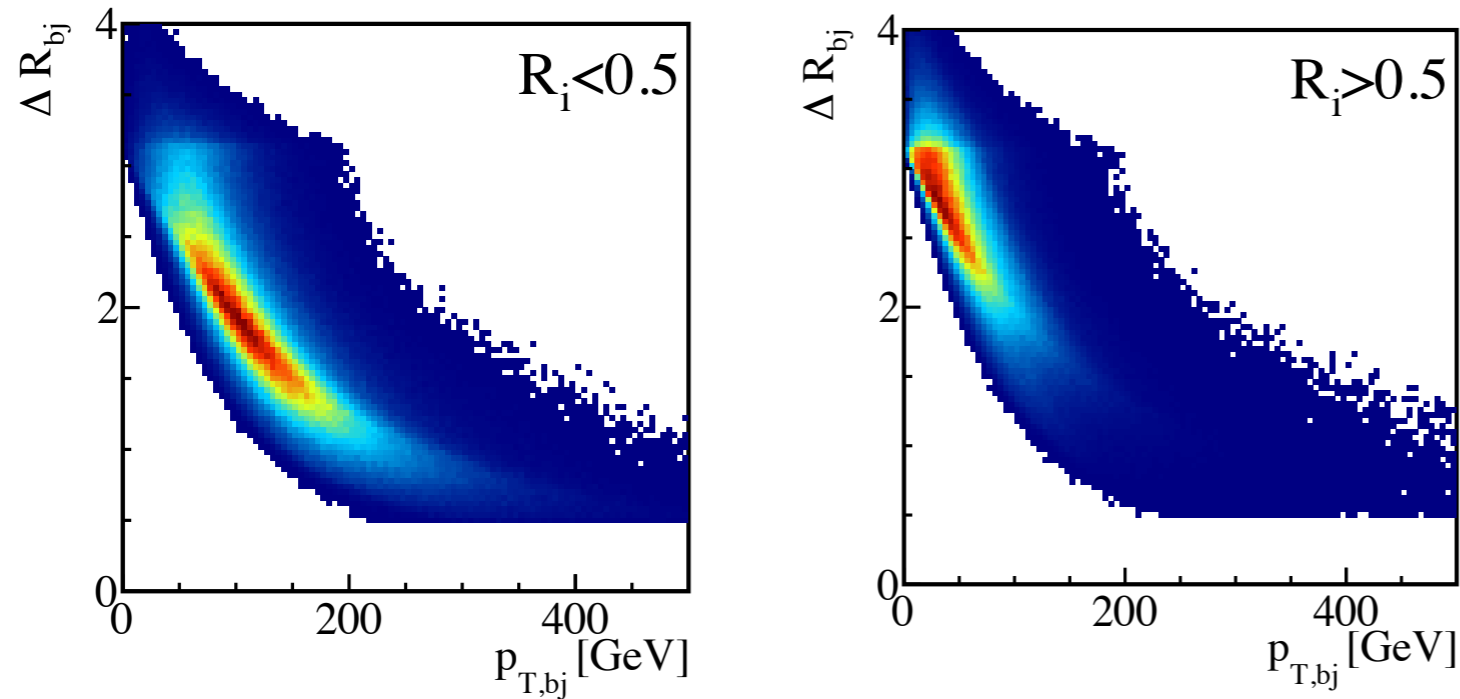
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5 jets, 2b-tag	21590		16072	1.4
(t_w, t_w)	2750	68.9%	126.2	21.8
(t_w, t_-)	7787	47.3%	2259	3.4
(t_-, t_w)	1093	27.3%	190.5	5.7
(t_-, t_-)	4887	28.5%	4077	1.2

increase in number and quality
70% double tagged in total



better reconstruction

Consistency check



to enhance $R_i < 0.5$

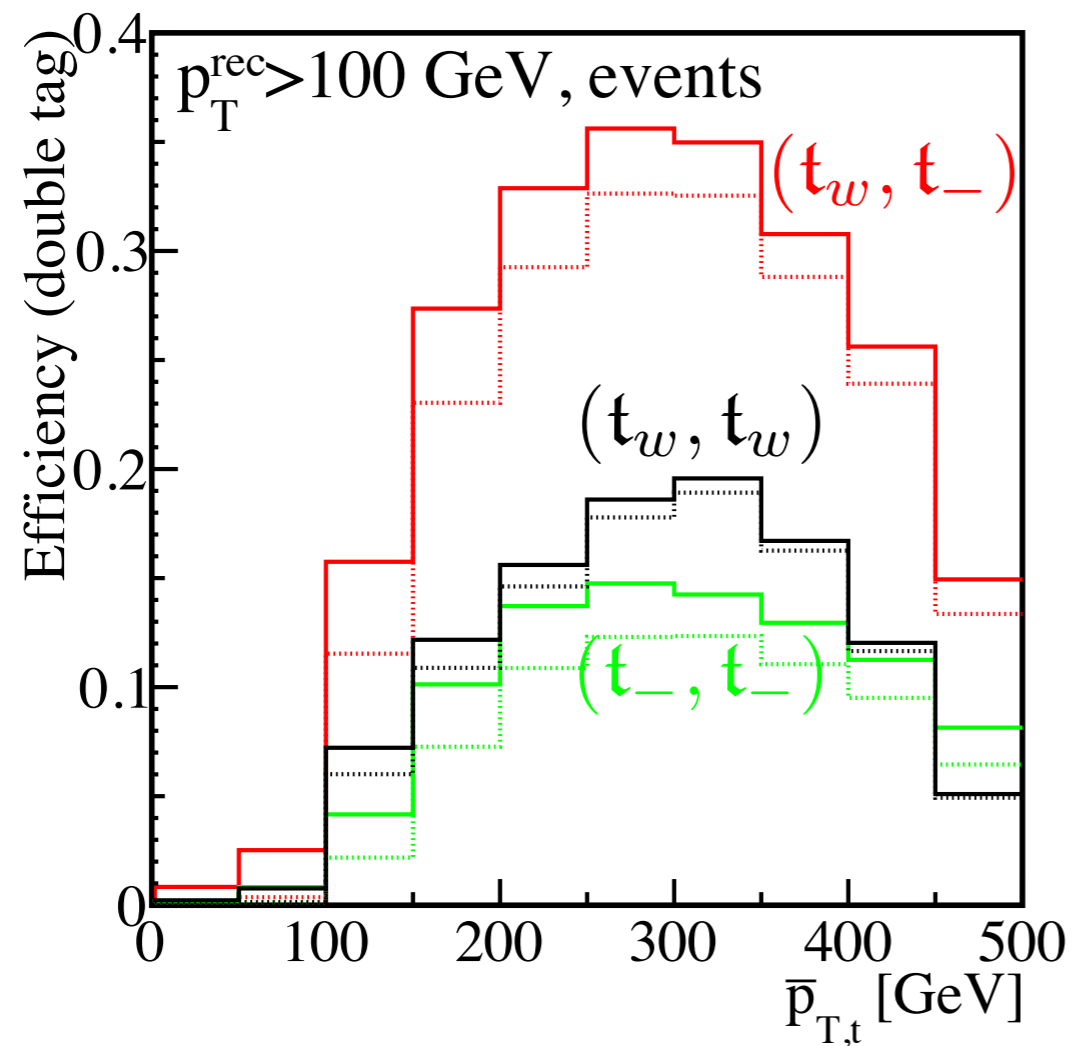
$$p_T^{\text{rec}} > 100 \text{ GeV}$$

	$t_h \bar{t}_h + \text{jets}$ [fb]	$R_1, R_2 < 0.5$	QCD [fb]	S/B_{QCD}
5 jets, 2b-tag	21590		16072	1.36
$(t_w, t_w), p_T^{\text{rec}} > 100 \text{ GeV}$	1417	86.4%	27.1	52.3
$(t_w, t_-), p_T^{\text{rec}} > 100 \text{ GeV}$	2805	80.5%	305.4	9.2
$(t_-, t_w), p_T^{\text{rec}} > 100 \text{ GeV}$	287.9	60.5%	26.4	10.9
$(t_-, t_-), p_T^{\text{rec}} > 100 \text{ GeV}$	1084	67.7%	339.3	3.2
total, $p_T^{\text{rec}} > 100 \text{ GeV}$	5593	78.5%	698.2	8.0

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

Efficiency as functions of p_T

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

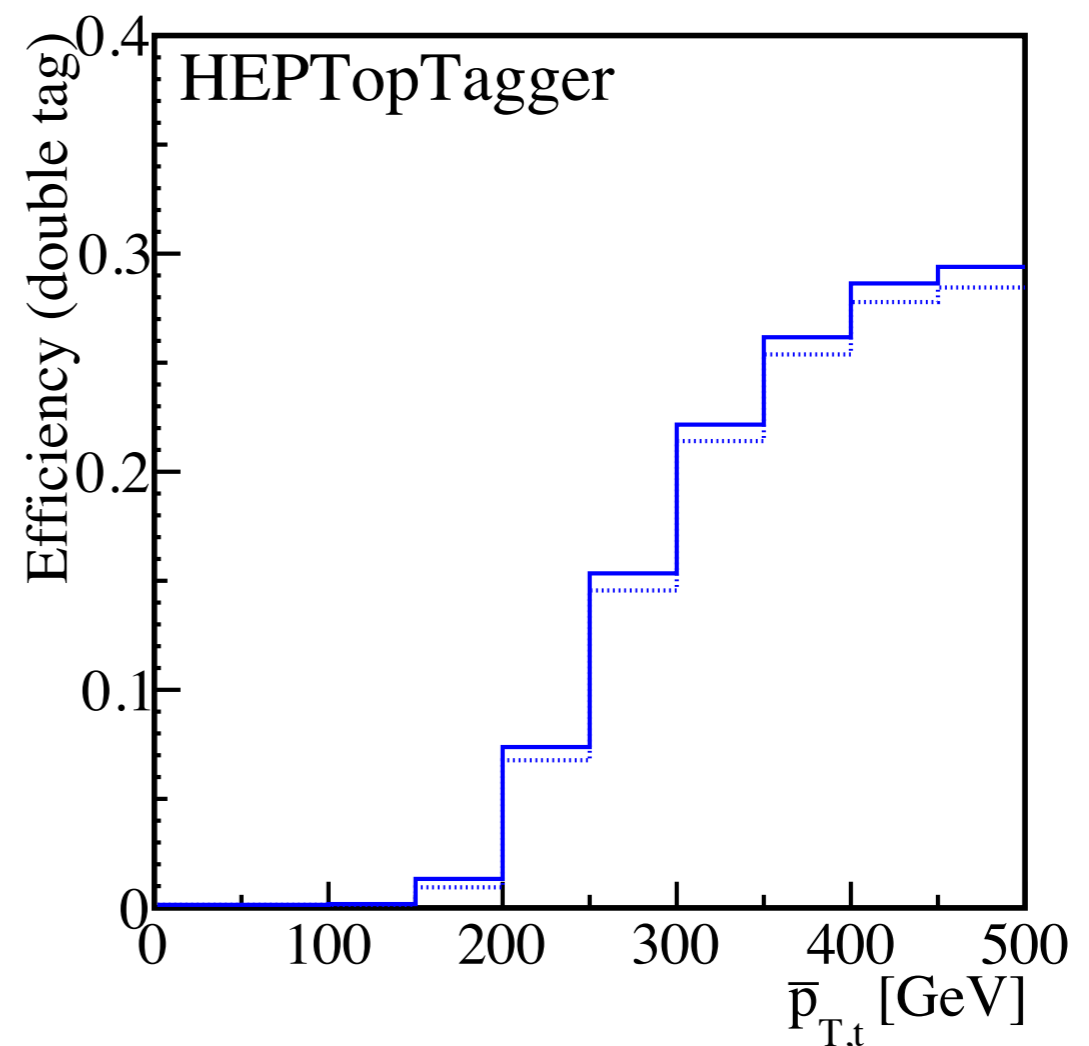
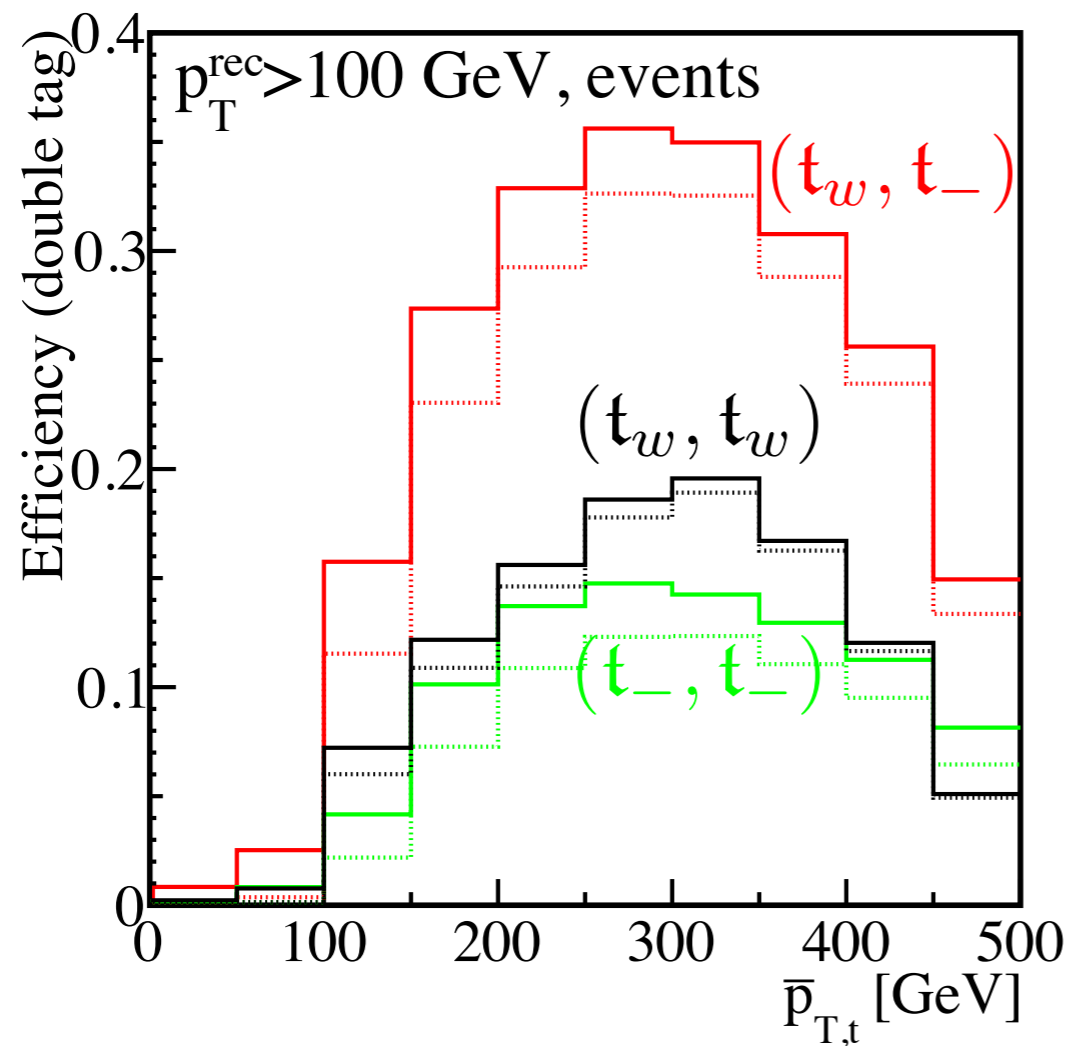


$\bar{p}_{T,t} = 100 - 150 \text{ GeV: } 30\% \text{ (double top tags)}$

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

Efficiency as functions of p_T

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



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

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

for $\bar{p}_{T,t} > 300 \text{ GeV}$, jet substructure method start to be efficient

Stop pair search

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

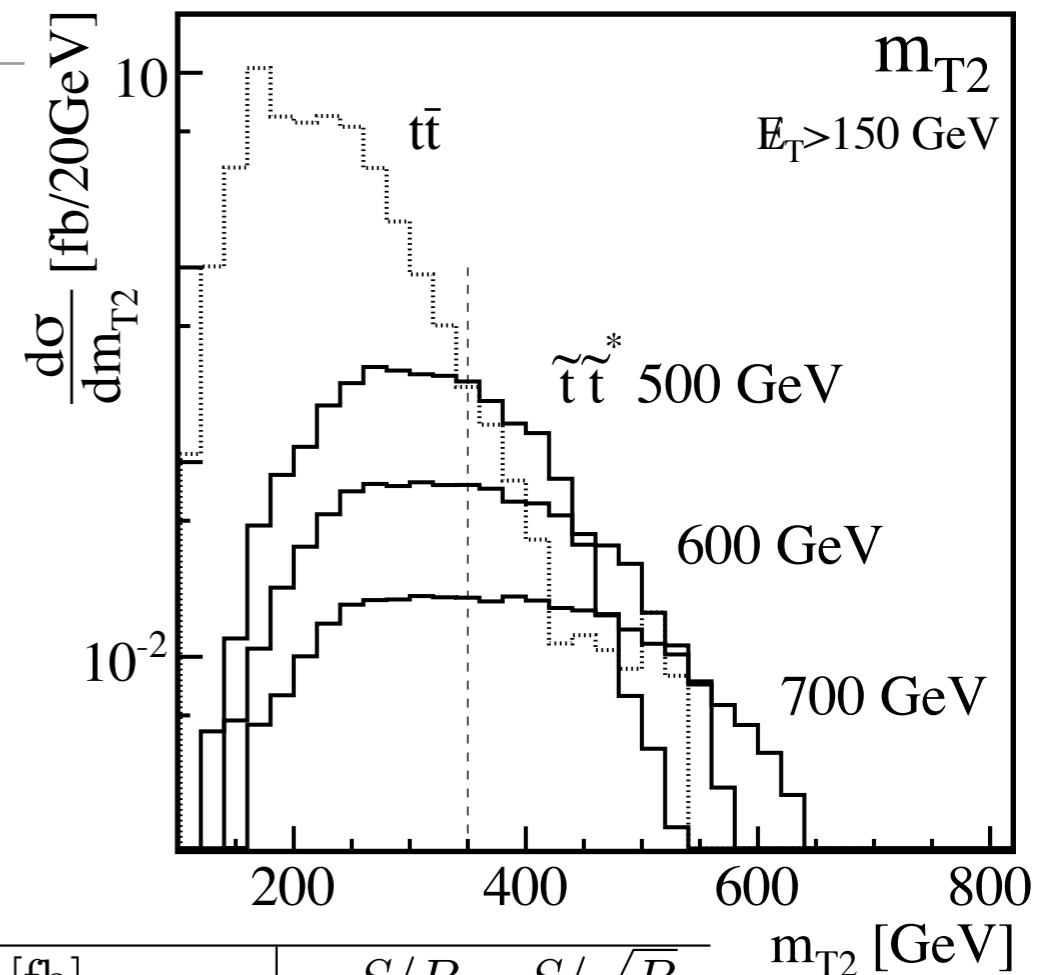
- $\tilde{t}\tilde{t}^* \rightarrow t\bar{t}\chi\chi: t\bar{t} + \cancel{E}_T$

typically 10^4 difference in cross section

- include t_{\perp} increase both signal and BG

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

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



$m_{\tilde{t}}$ [GeV]	$t\bar{t}+\text{jets}$ [fb]	$\tilde{t}\tilde{t}^*$ [fb]			S/B	S/\sqrt{B}
		500	600	700		
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, $p_{T,t}^{\text{rec}} > 100 \text{ GeV}$	6.32×10^3	3.90	1.23	0.38	0.0002	0.08
$\cancel{E}_T > 150 \text{ GeV}$	44.71	2.80	0.98	0.33	0.02	0.7
$m_{T2} > 350 \text{ GeV}$	0.45	0.79	0.44	0.18	1.0	3.3
100% τ rejection	0.14	0.73	0.40	0.16	2.8	5.3

Forward-Backward charge asym. at ILC

- semi-leptonic top pairs

LC-REP2012-003: I. Garcia, E.Ros, J.Trenado, M.Vos

ℓ, \not{p} , at least 4 jets

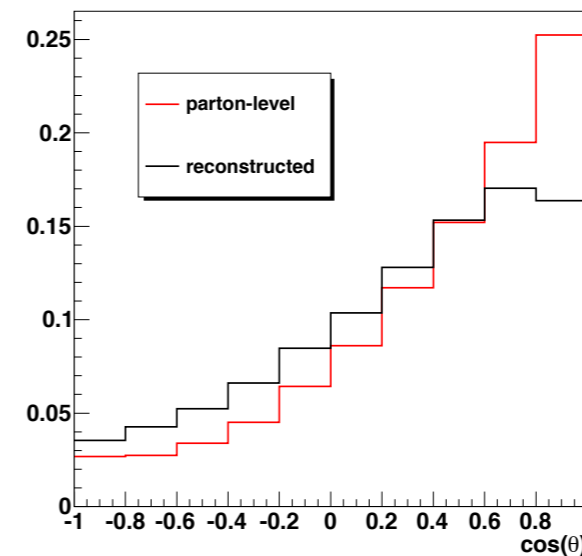
$$|m_{\ell\nu} - m_W| < 25 \text{ GeV}$$

$$|m_{\ell\nu j} - m_t| < 35 \text{ GeV}$$

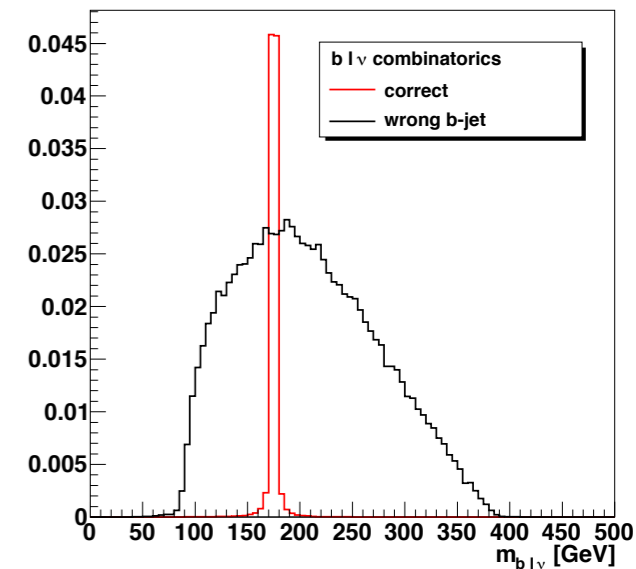
$$|E_{\ell\nu} + E_j - E_{\text{beam}}| < 75 \text{ GeV}$$

→ $\cos \theta_\ell$ reconstruction

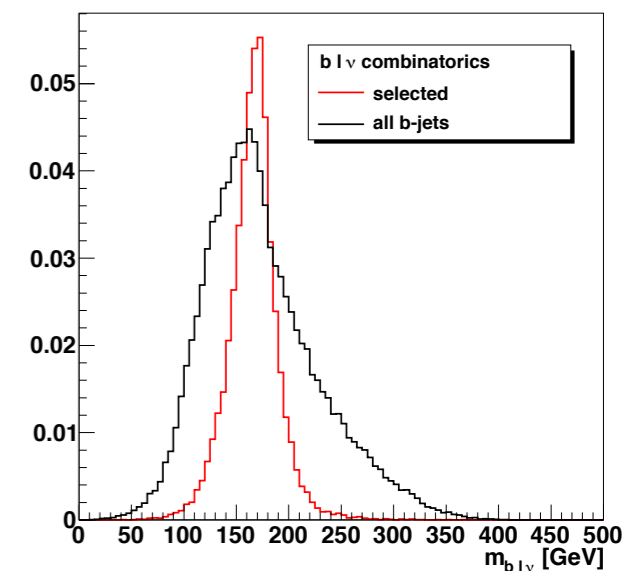
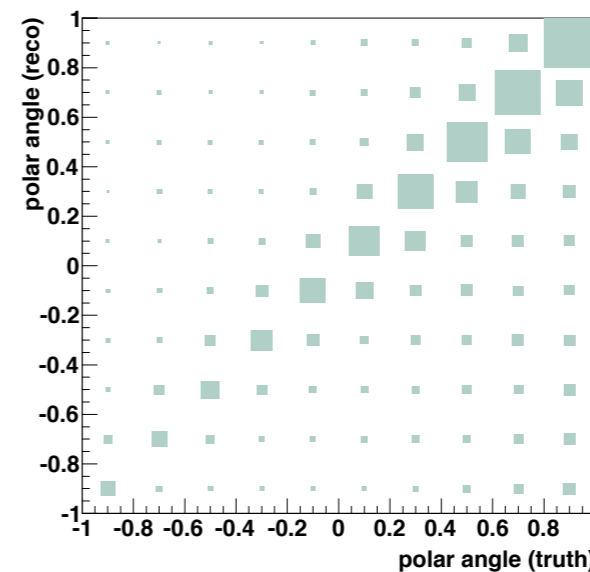
- migration effect due to wrong j
- consider a bucket for t_h ?



(a) 500 GeV



(a) 500 GeV



Summary

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