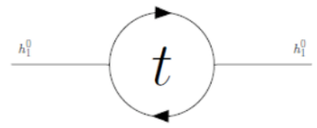
Buckets of Tops

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

- $\tilde{t}\tilde{t} \to t\bar{t}\chi\chi$: stop search
- ttH: largest yukawa coupling to higgs to be measured
- $t\bar{t}$: main background for new physics search

- hadronic top:

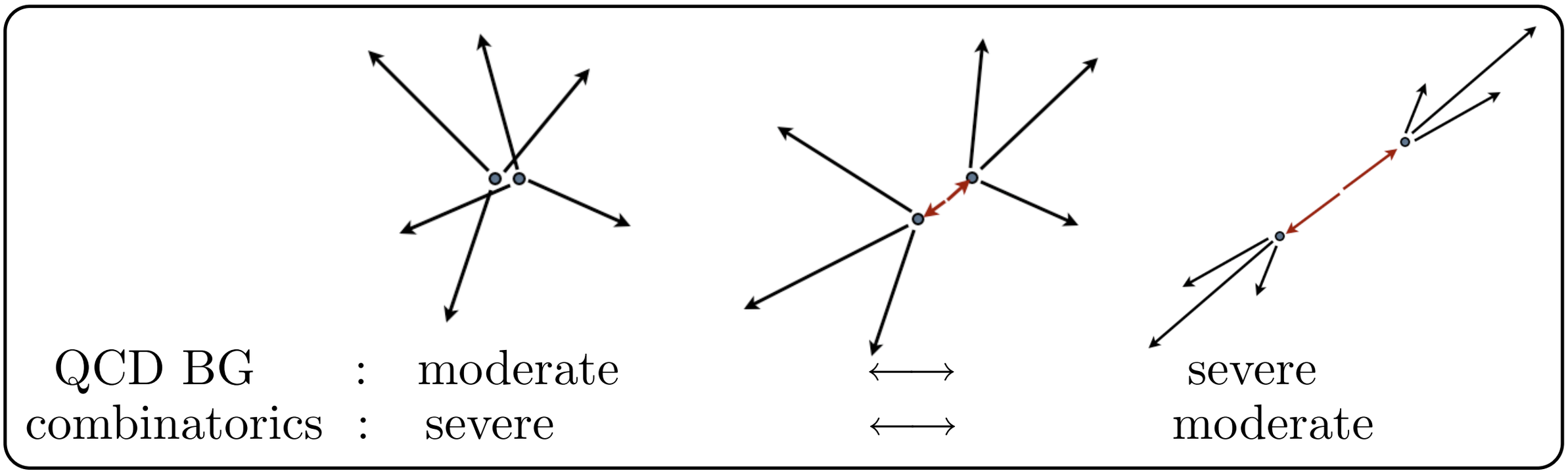
  advantage : momentum reconstruction

  disadvantage : QCD and combinatorics → boosted tops

  ISR makes the situation worse

Moderately boosted tops

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



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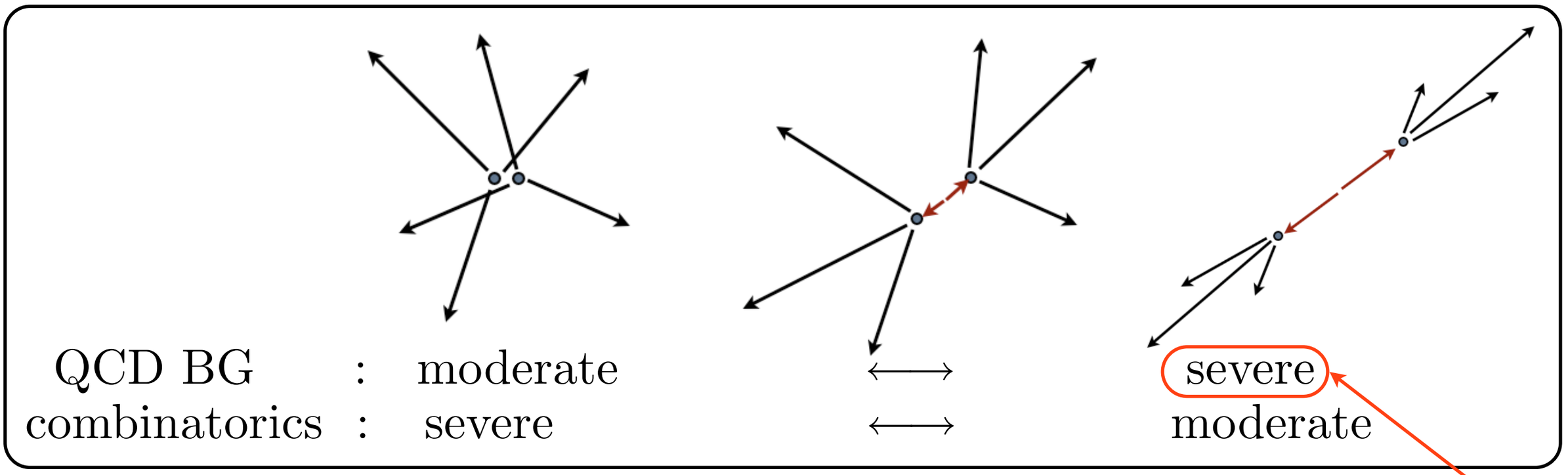

jet substructure method solve QCD problem

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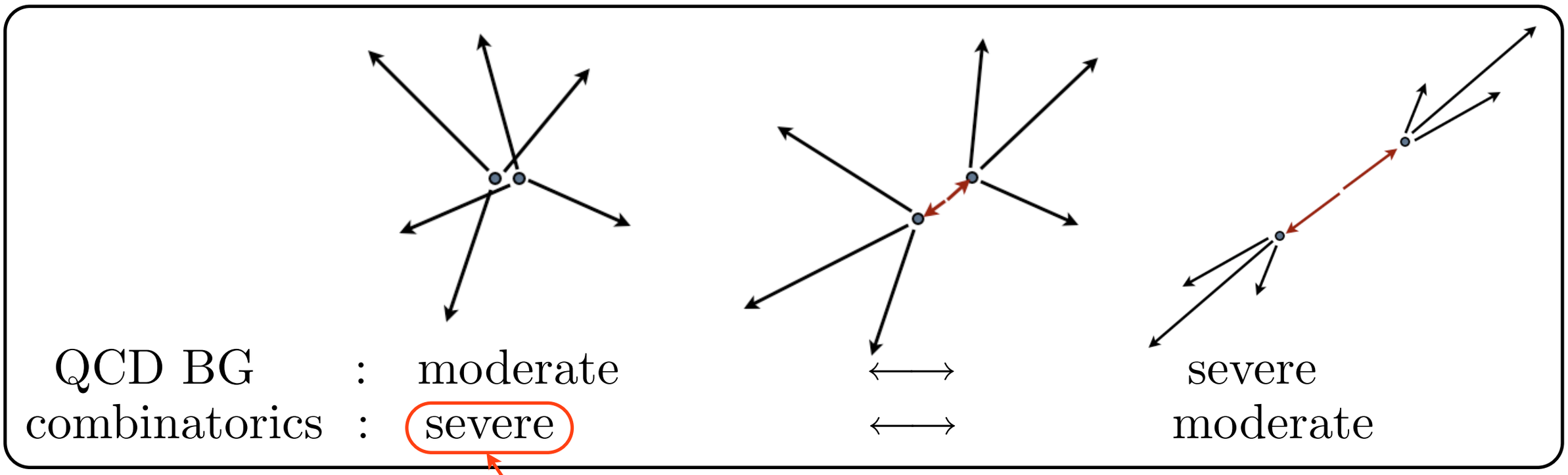

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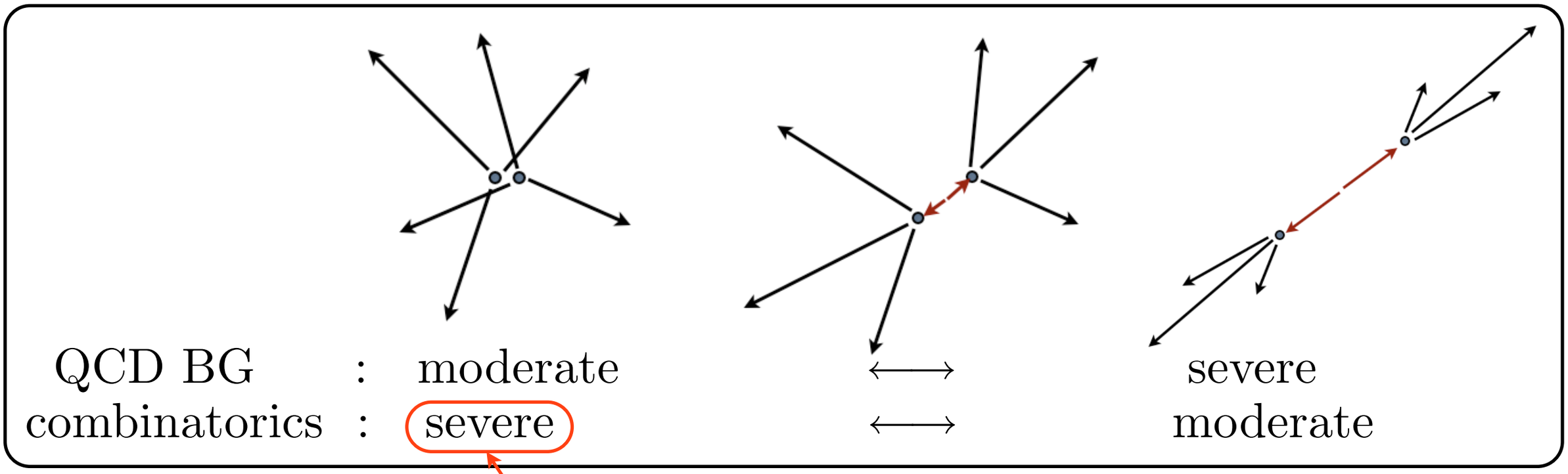

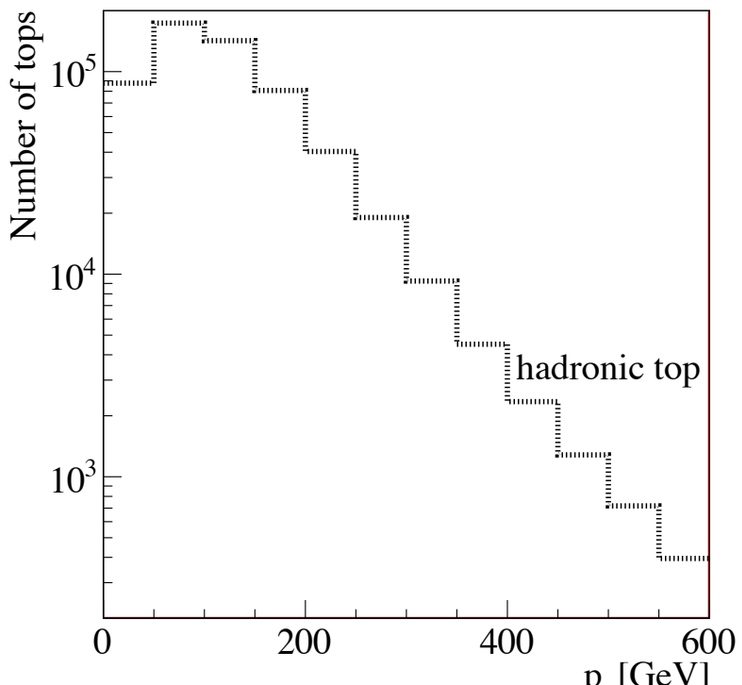

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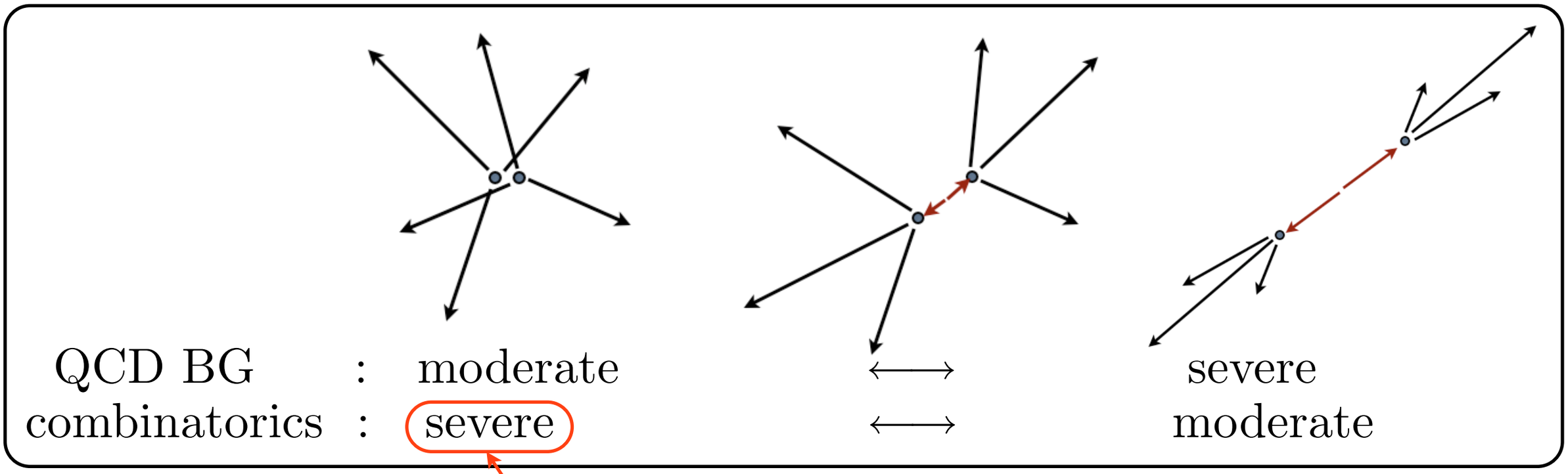

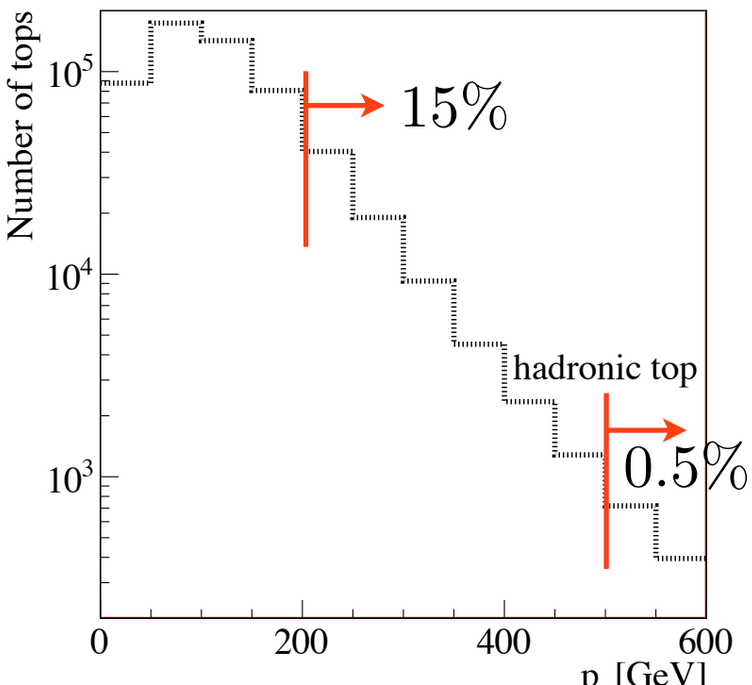

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HEPTopTager: down to $p_T \sim 200$ GeV

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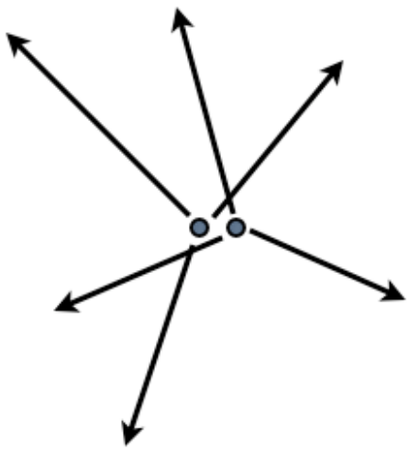
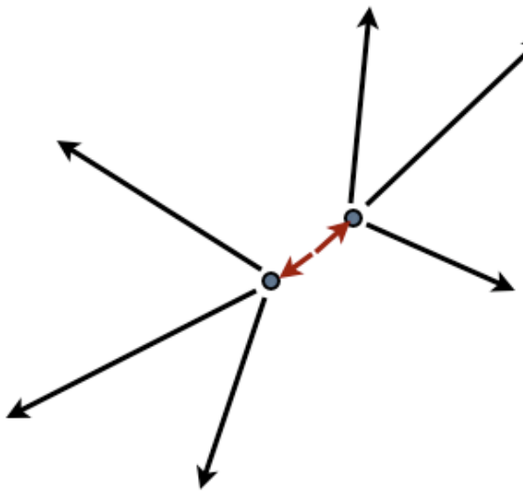
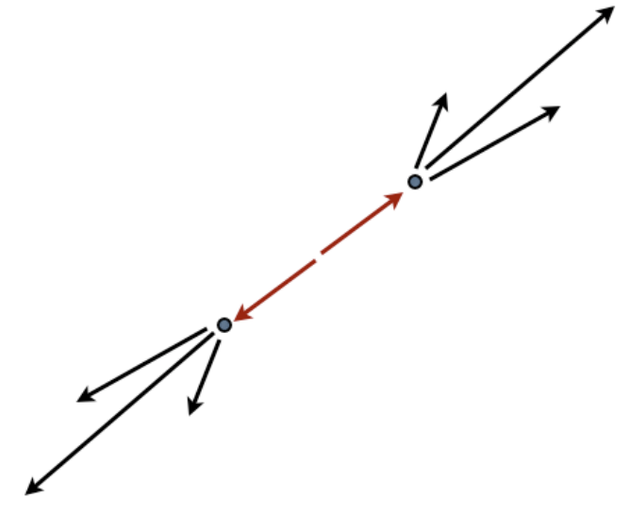
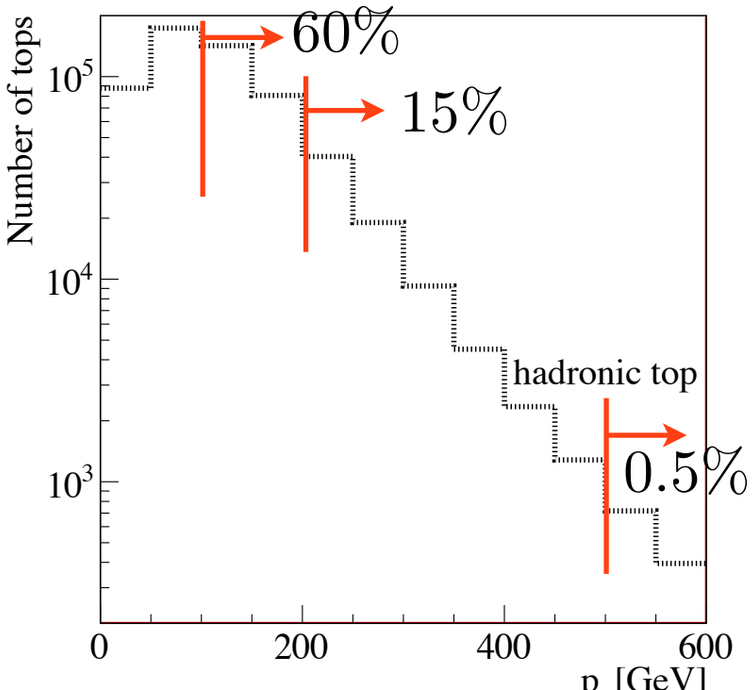






QCD BG	:	moderate	$\longleftrightarrow$	severe
combinatorics	:	severe	$\longleftrightarrow$	moderate



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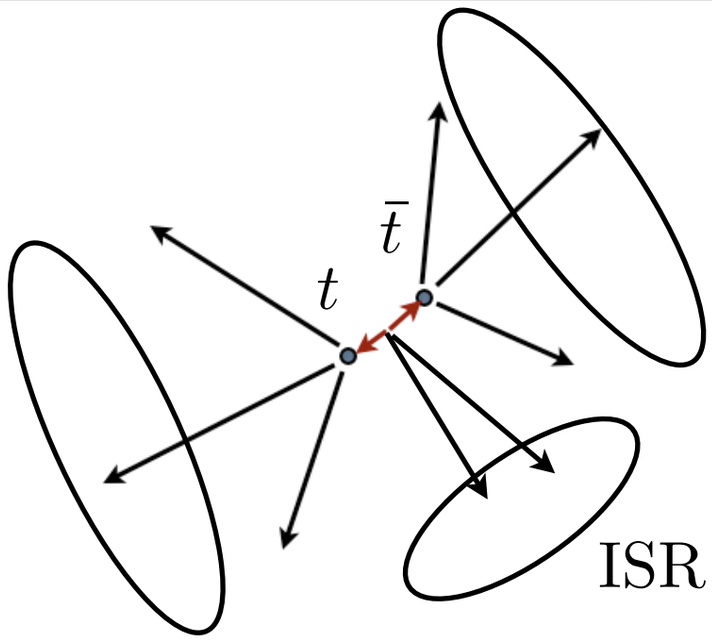
HEPTopTager: down to $p_T \sim 200$ GeV

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

keeping signal important

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

Buckets of tops



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Aim: find jets corresponding to 2 tops

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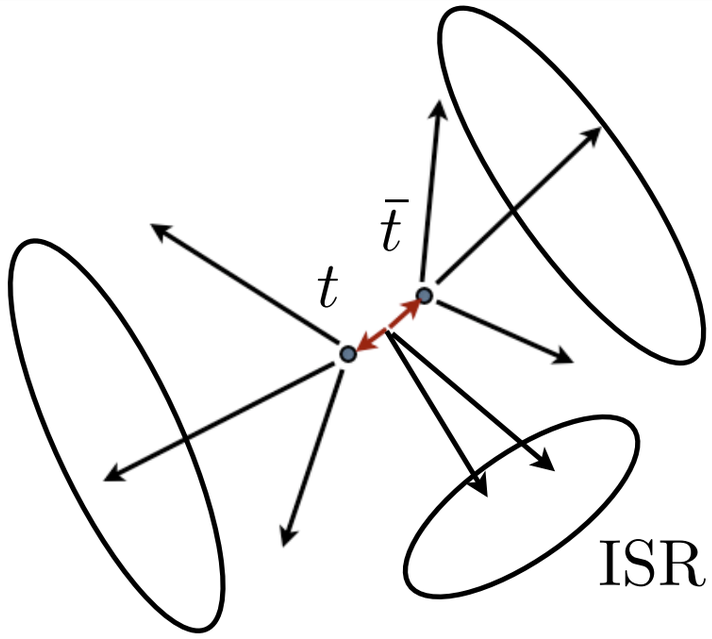

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Aim: find jets corresponding to 2 tops

scan all permutation,
select the grouping minimizing

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

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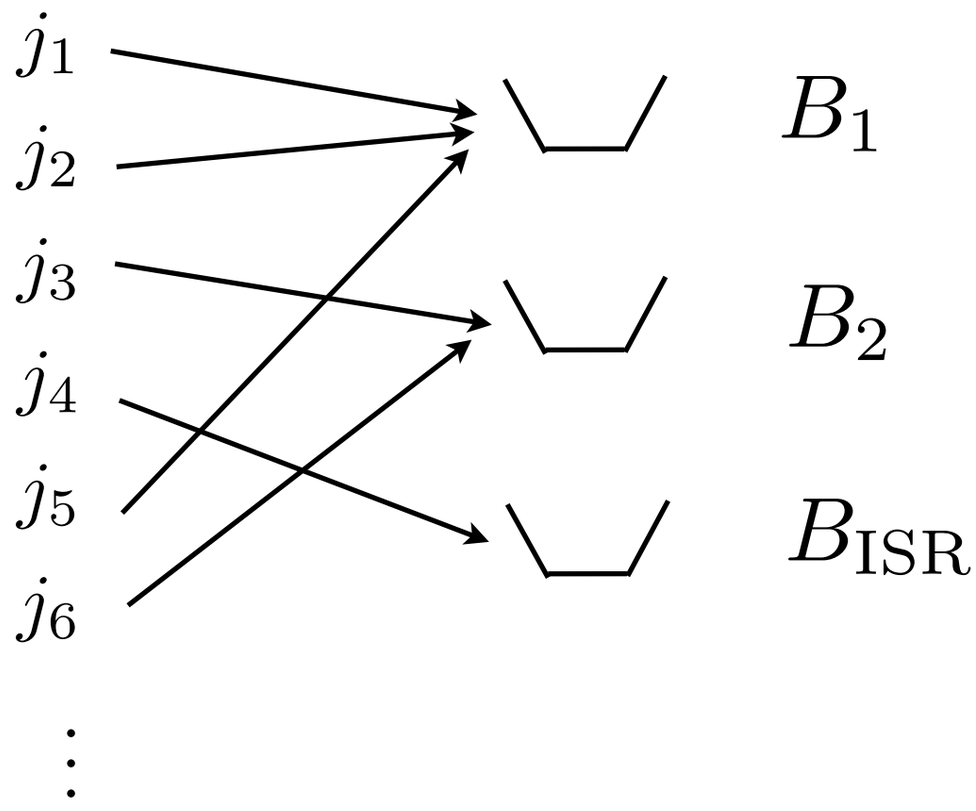
$$m_{B_i}^2 = \left(\sum_{j \in B_i} p_j \right)^2$$



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

always 2 top tags

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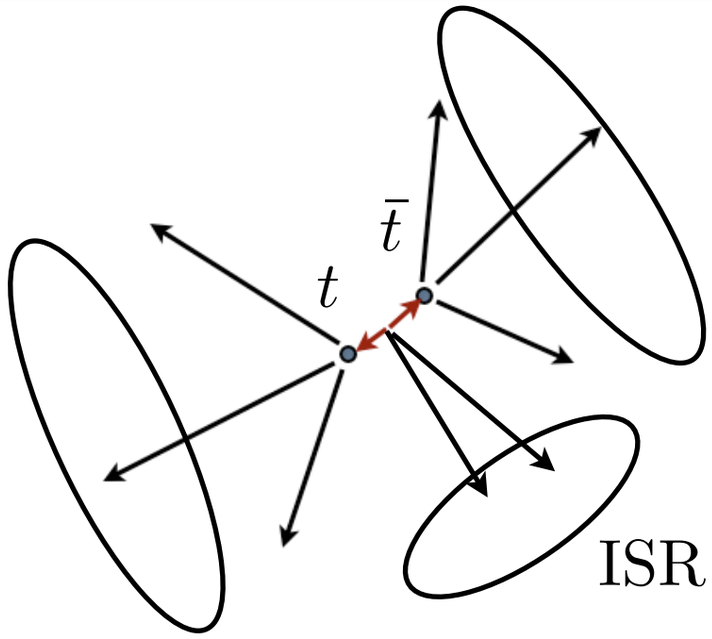

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with 2 b-jets

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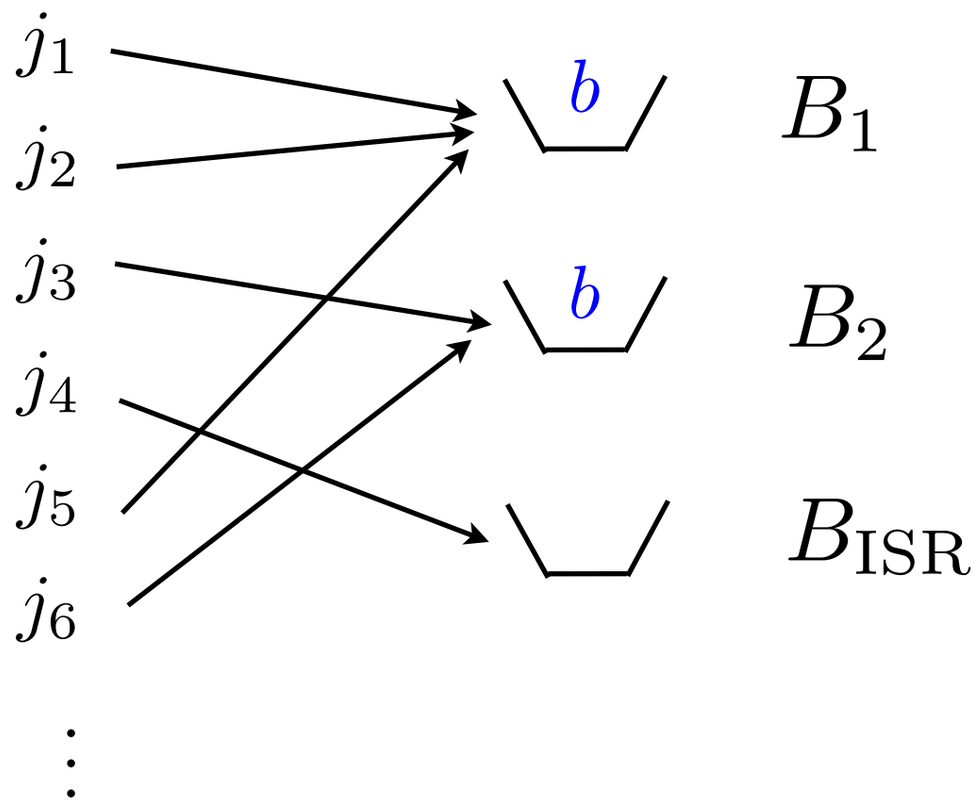

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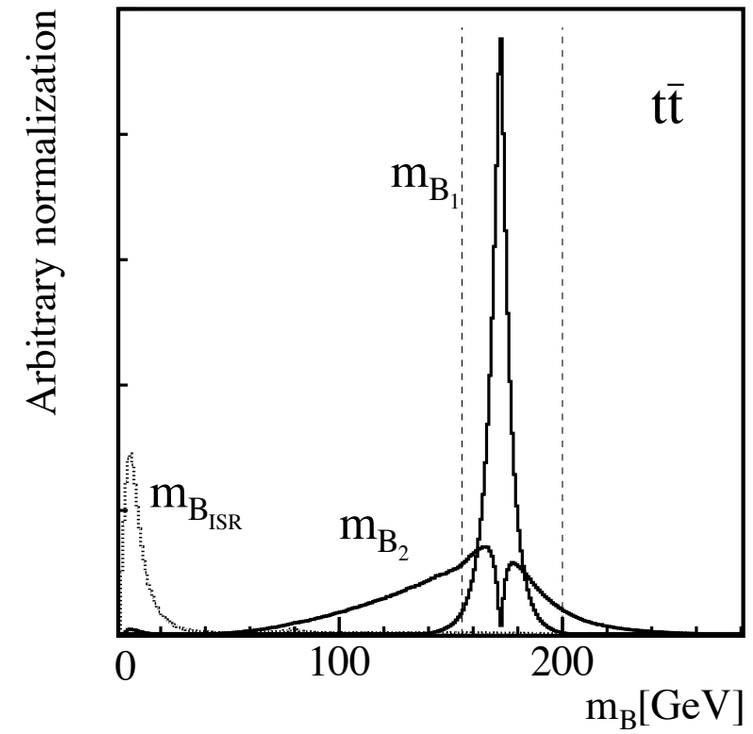
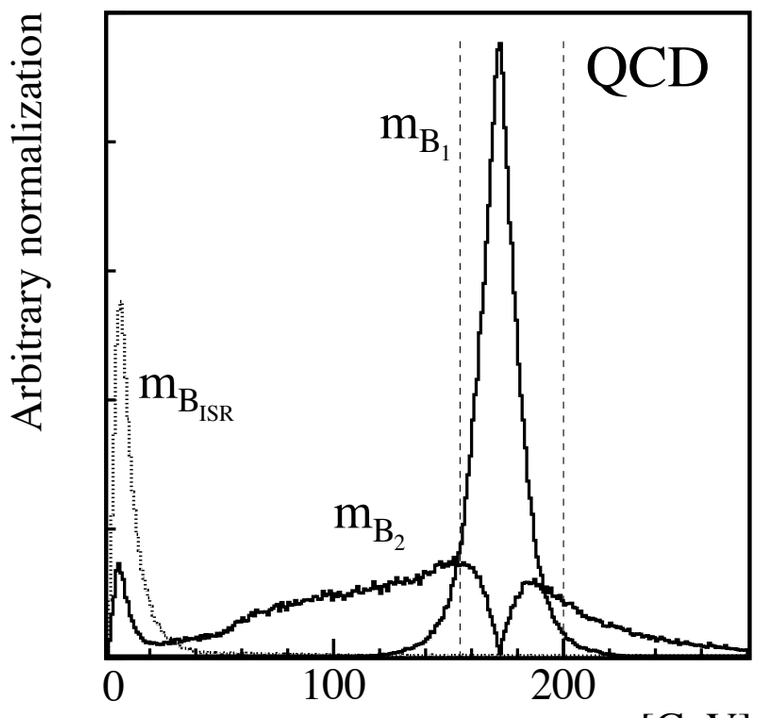
Bucket mass, W condition





- 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

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

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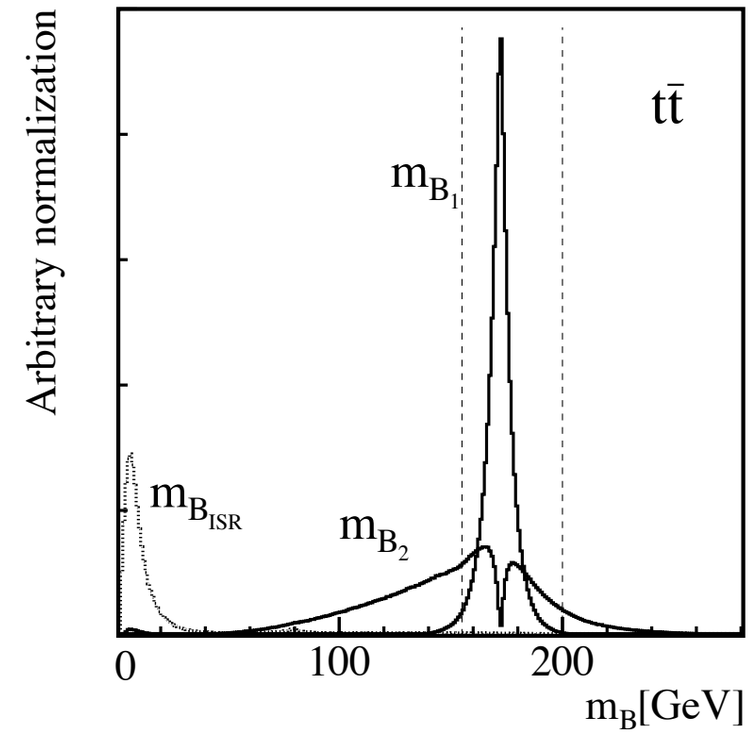

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$\rightarrow$ 4 categories

$$(\mathrm{t}_w, \mathrm{t}_w) : B_1 \ni W, B_2 \ni W$$
$$(\mathrm{t}_w, \mathrm{t}_-) : B_1 \ni W, B_2 \notni W$$
$$(\mathrm{t}_-, \mathrm{t}_w) : B_1 \notni W, B_2 \ni W$$
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Efficiency & Momentum reconstruction

	$t_h\bar{t}_h$+jets [fb]	$R_1, R_2 < 0.5$	QCD [fb]	S/B_{QCD}
5 jets, $2b$-tag	21590		16072	1.36
$(\mathrm{t}_w,\mathrm{t}_w)$	2750	68.9%	126.2	21.8
$(\mathrm{t}_w,\mathrm{t}_-)$	2517	23.4%	727.1	3.5
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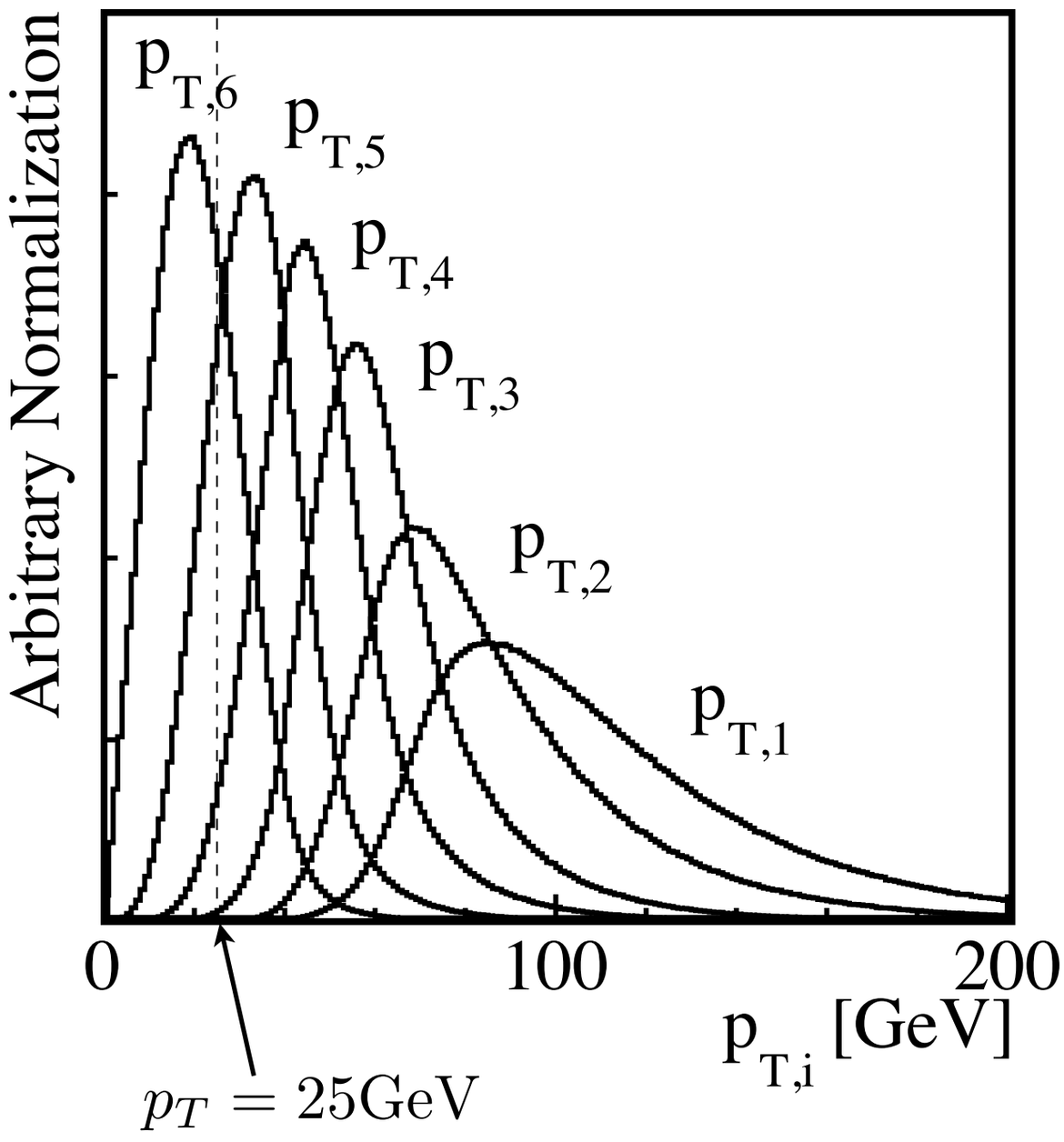
⇒ 6 jets not often survive due to jet p_T threshold

Jet pT threshold

6 partons from top pair decays



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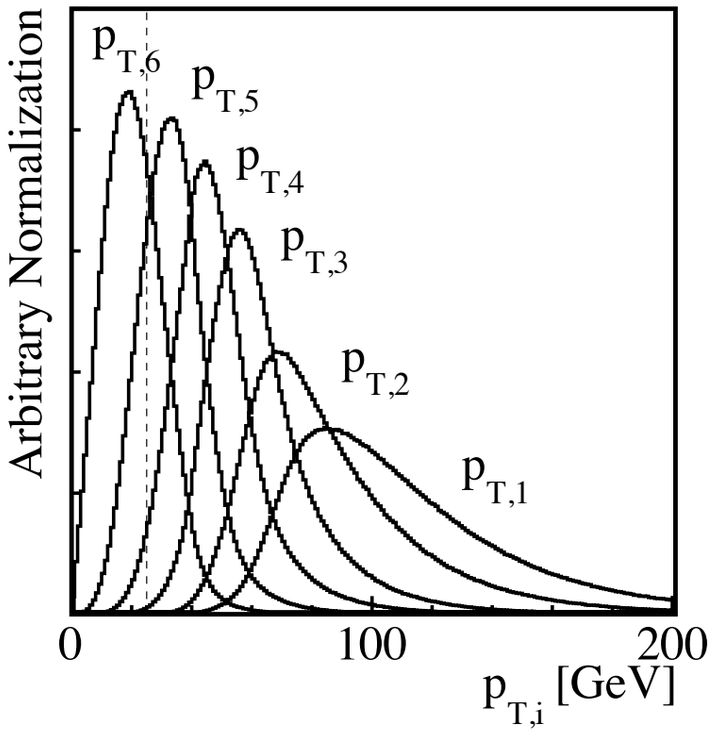

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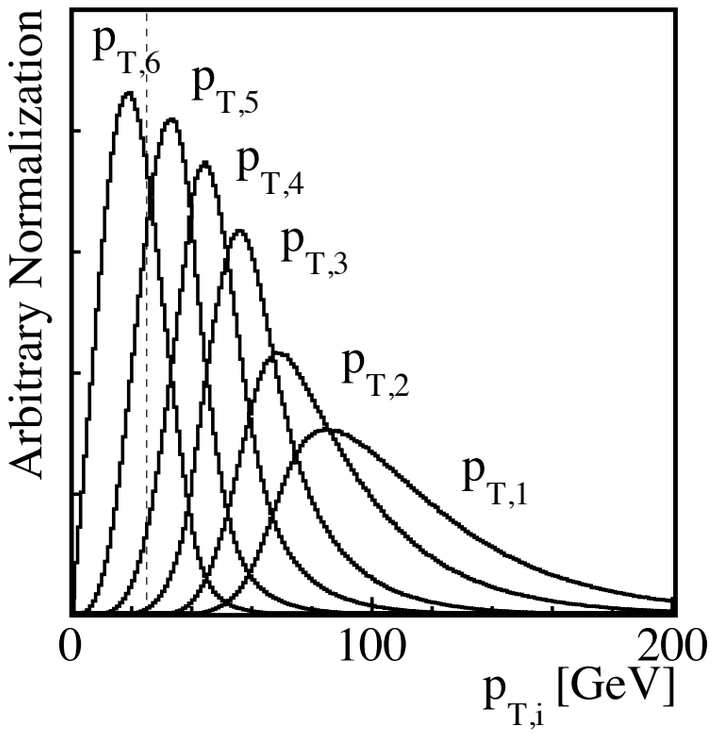

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Even 6 jets events, about 40% with only 5 partons.

(due to ISR)

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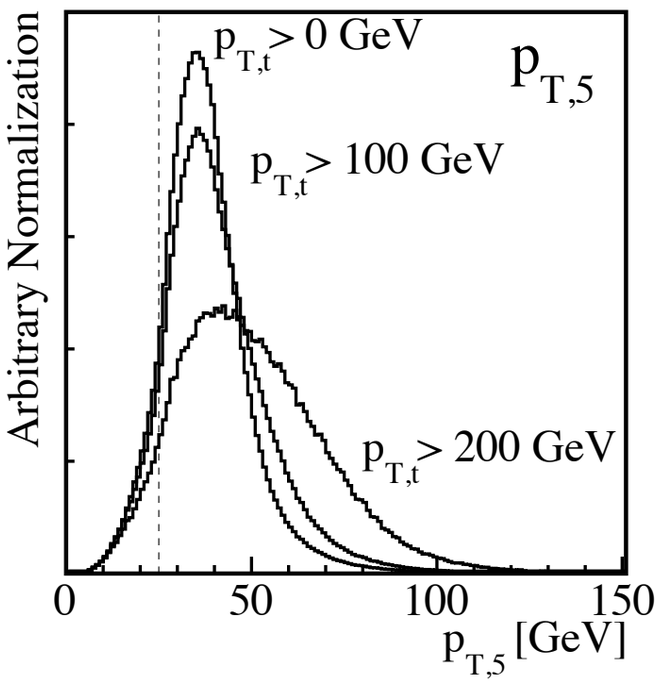

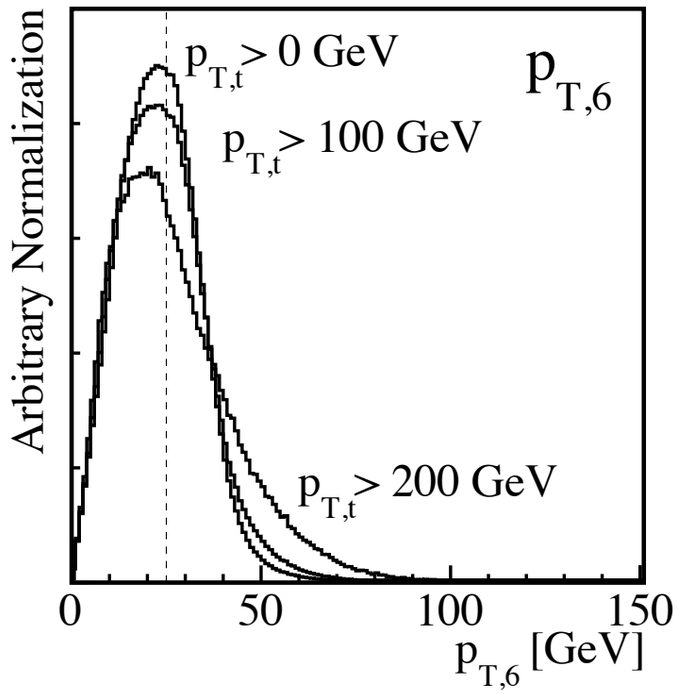

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weak top p_T dependence

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$n_j \geq 5$ $p_{T,t_2} > 200$ GeV	6.7	47.4%	44.7%

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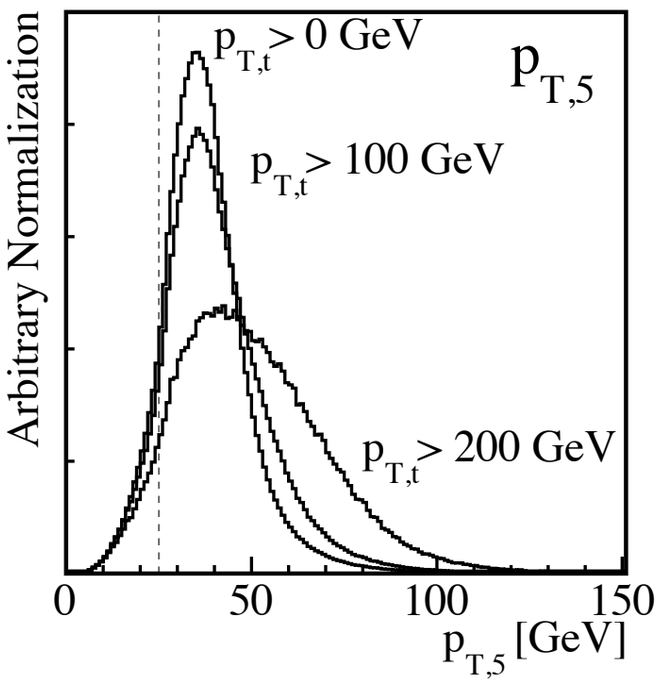

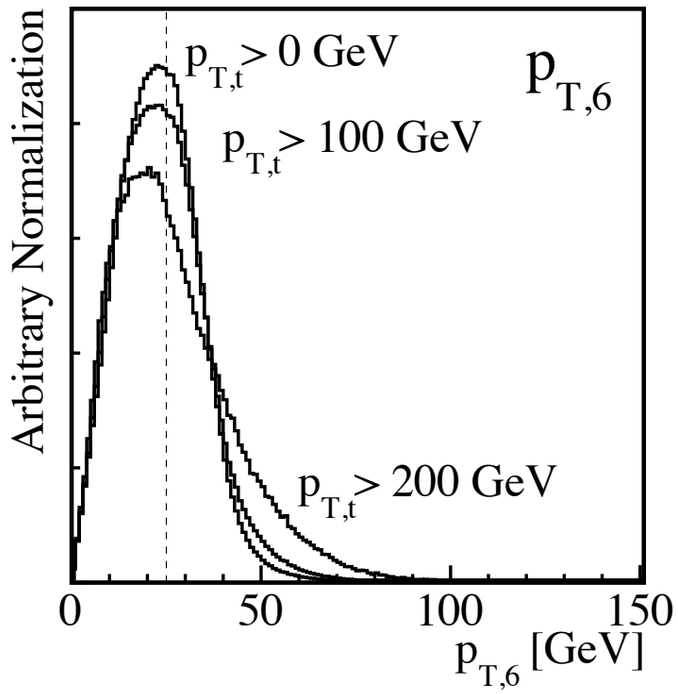

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What can we do with 5 jets?

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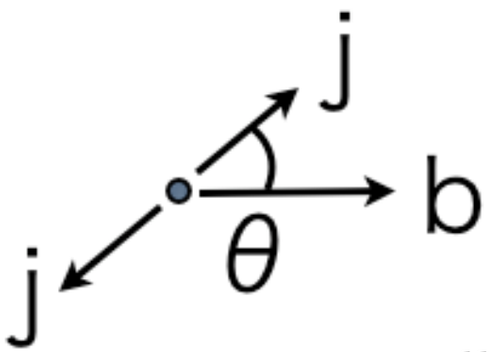
bj-buckets

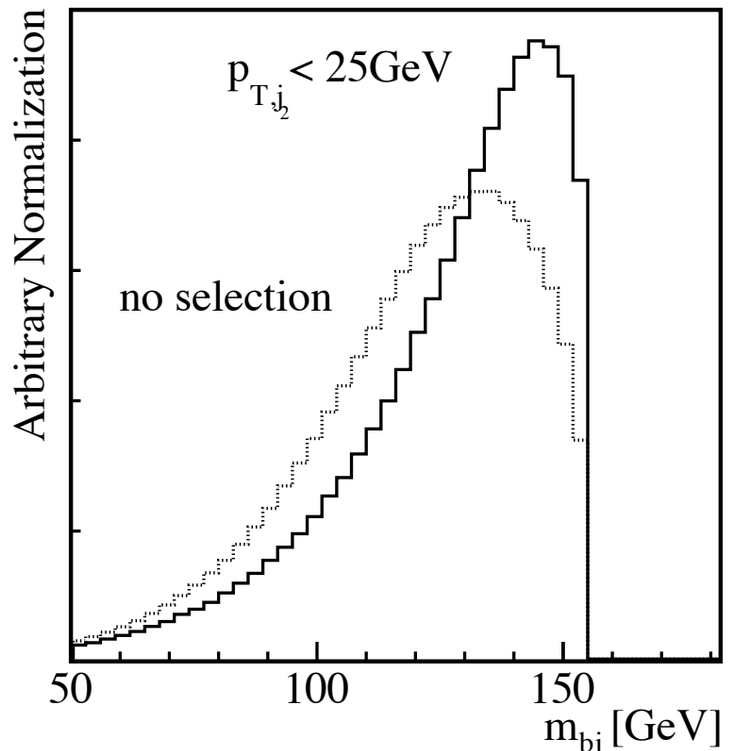
- m_{bj}-peak from top decay kinematics



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

unique feature of 3 body decay

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



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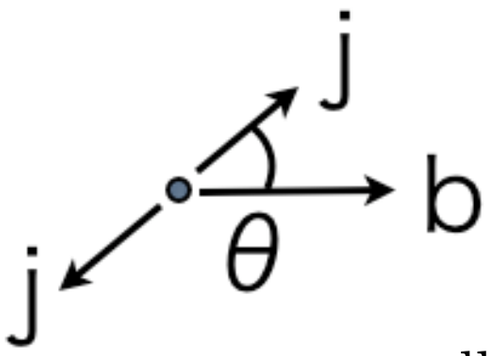

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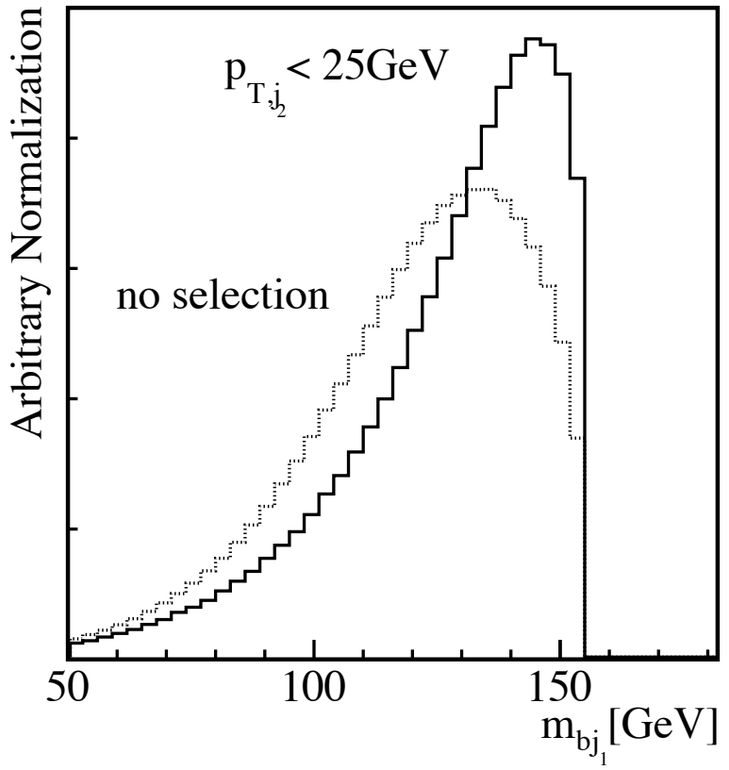
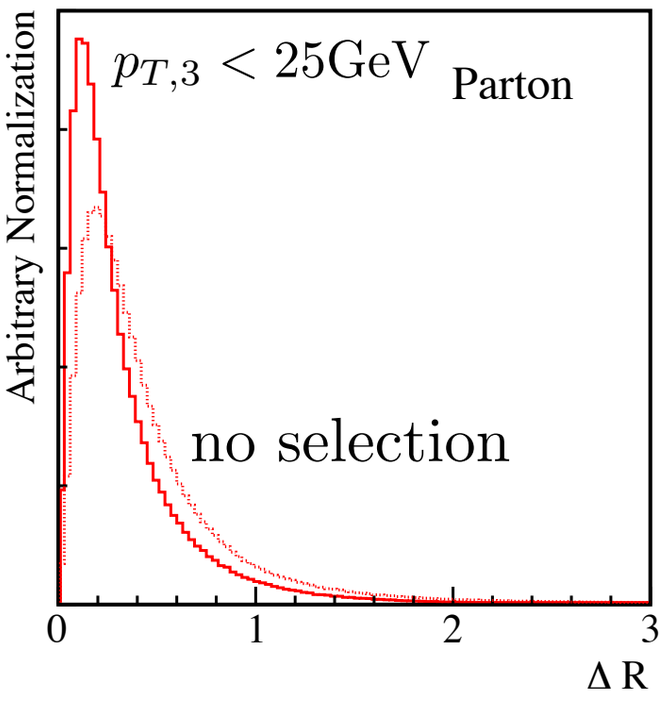
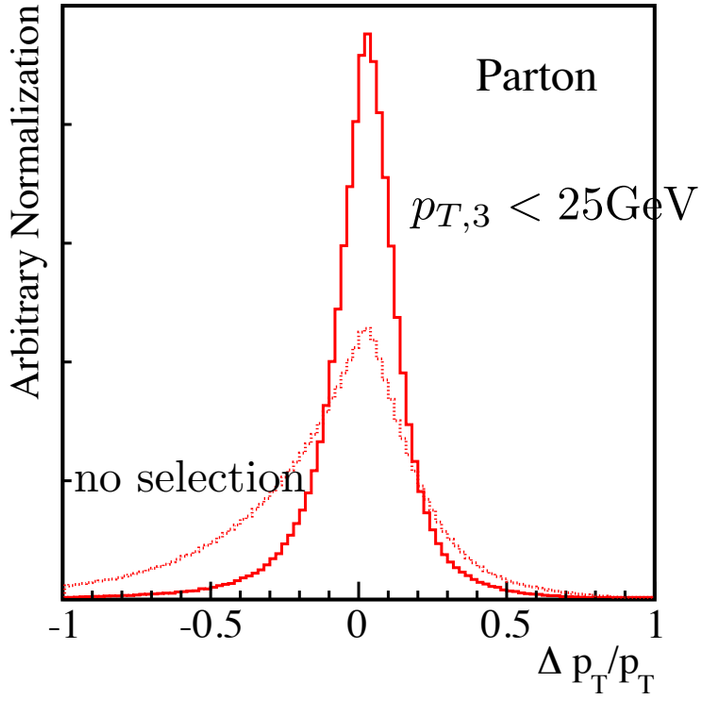


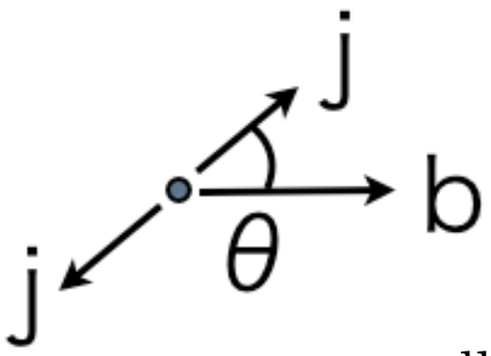
- acceptable momentum reconstruction





bj-buckets

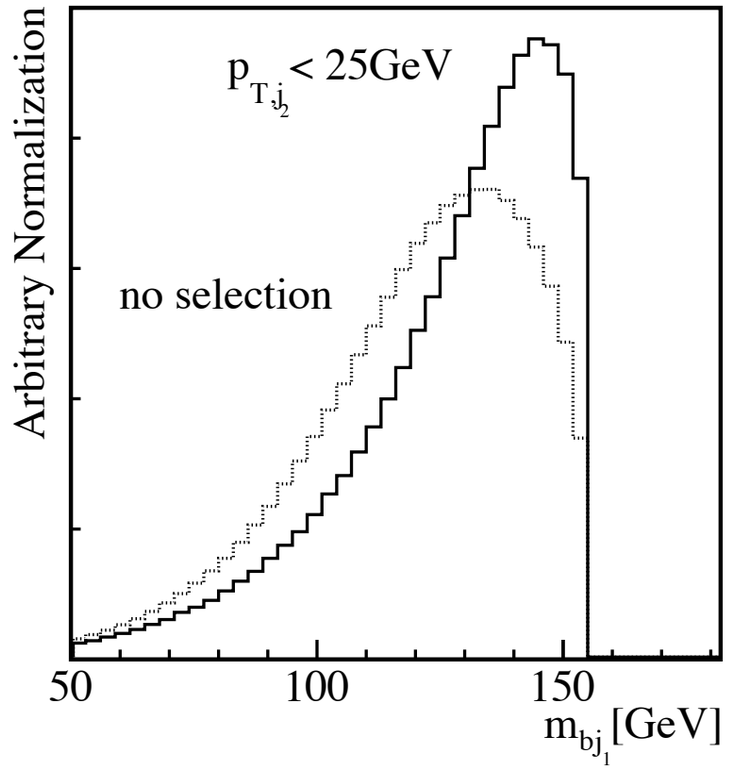
- m_{bj}-peak from top decay kinematics



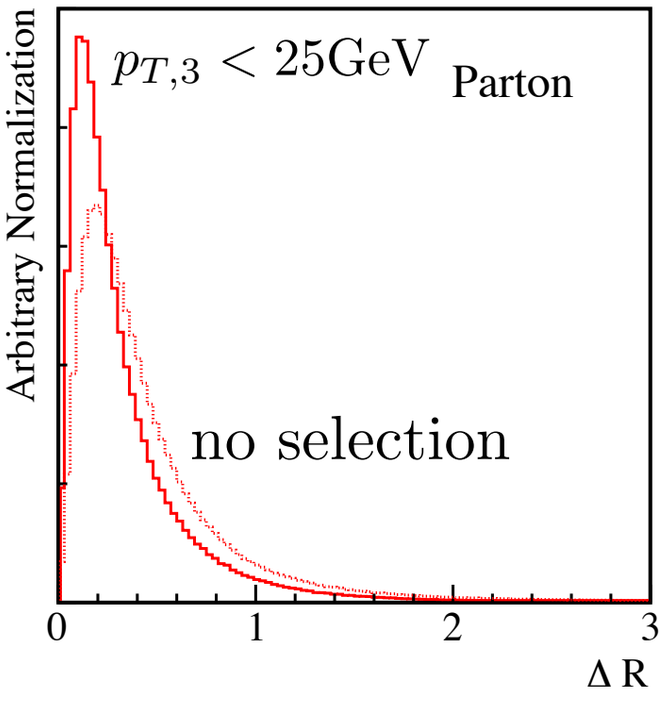
$$m_{bj} < \sqrt{m_t^2 - m_W^2} \sim 155\text{GeV}$$

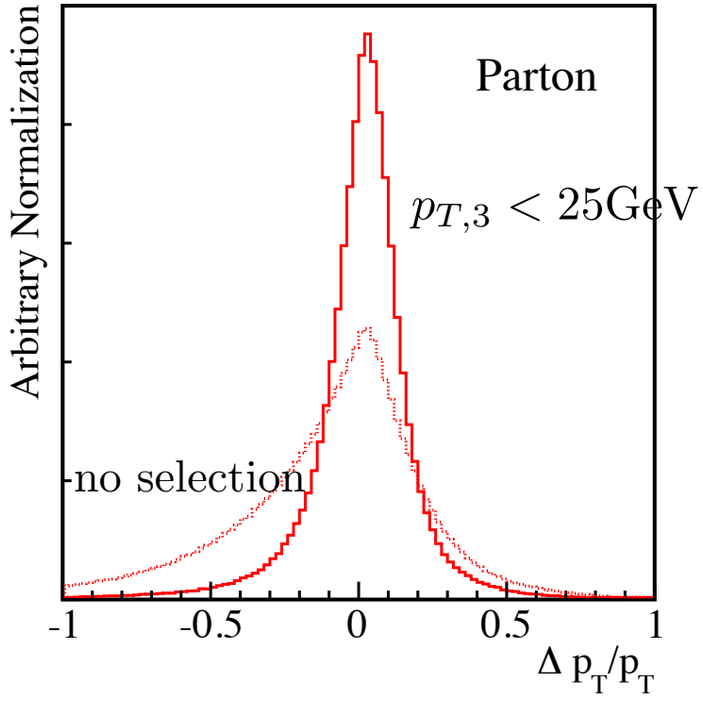
unique feature of 3 body decay

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



- acceptable momentum reconstruction





new metric:

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

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

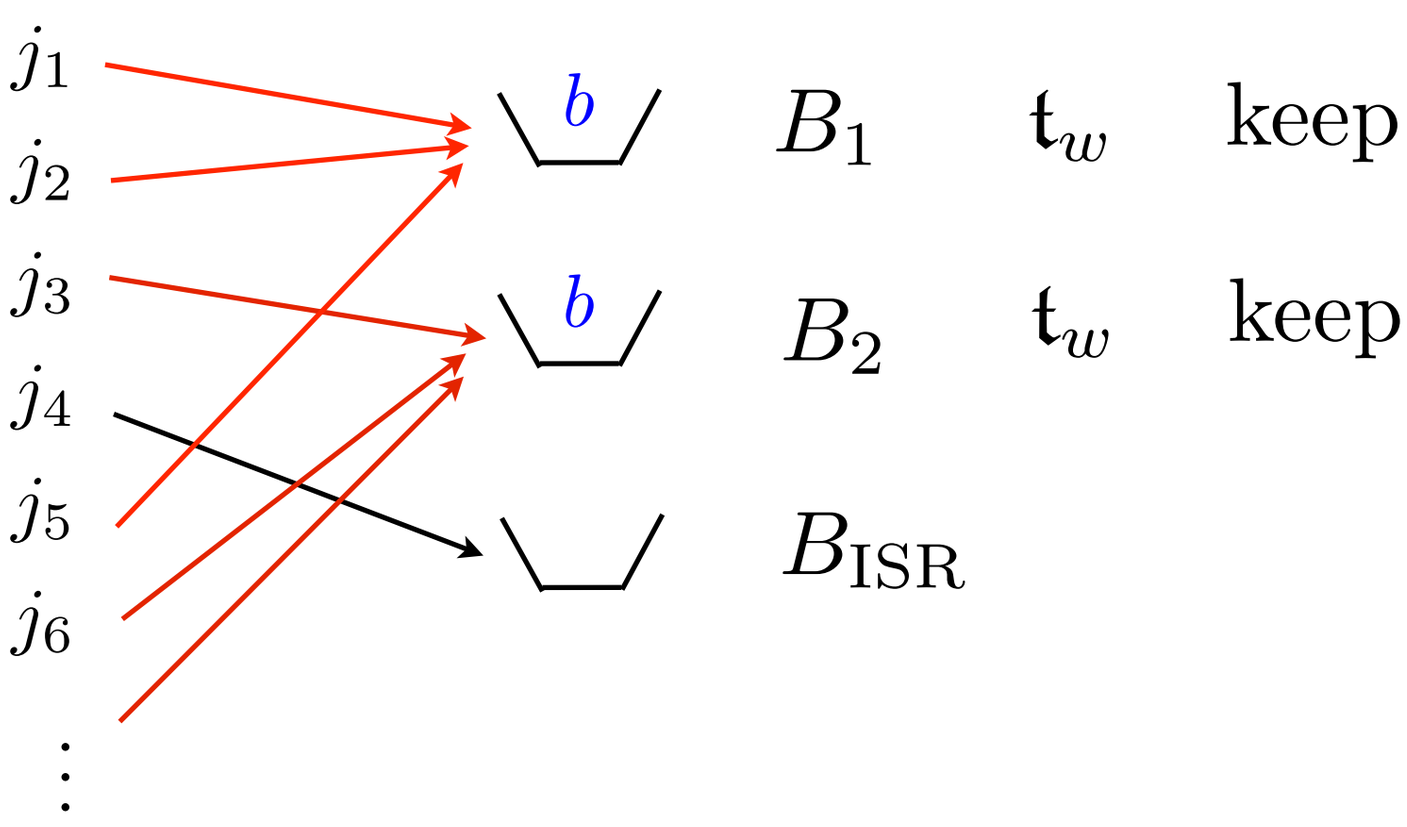
Modified algorithm

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

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

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

.



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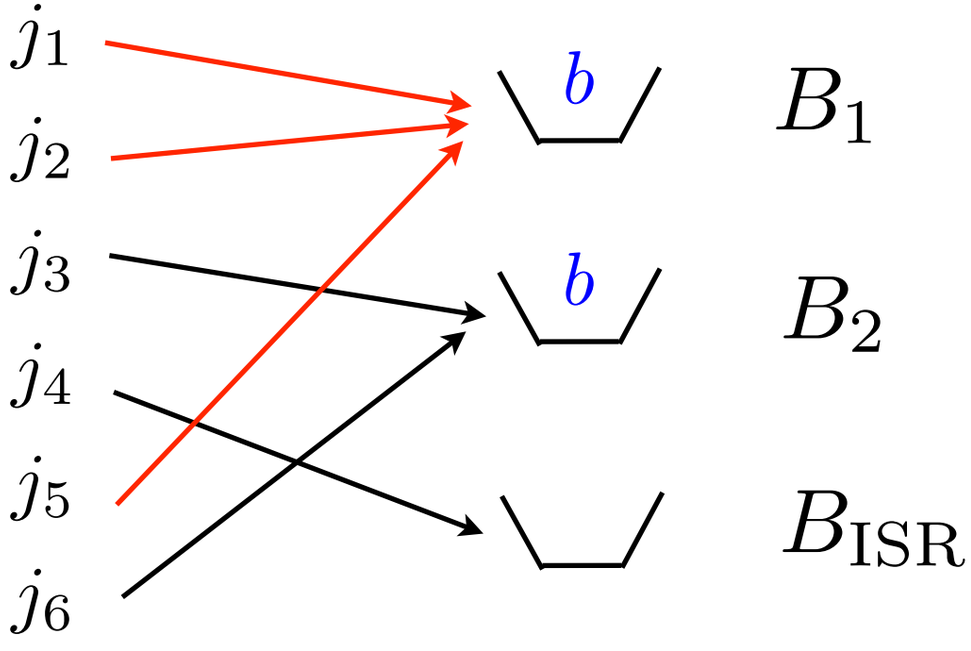

$\vdots$

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

Modified algorithm

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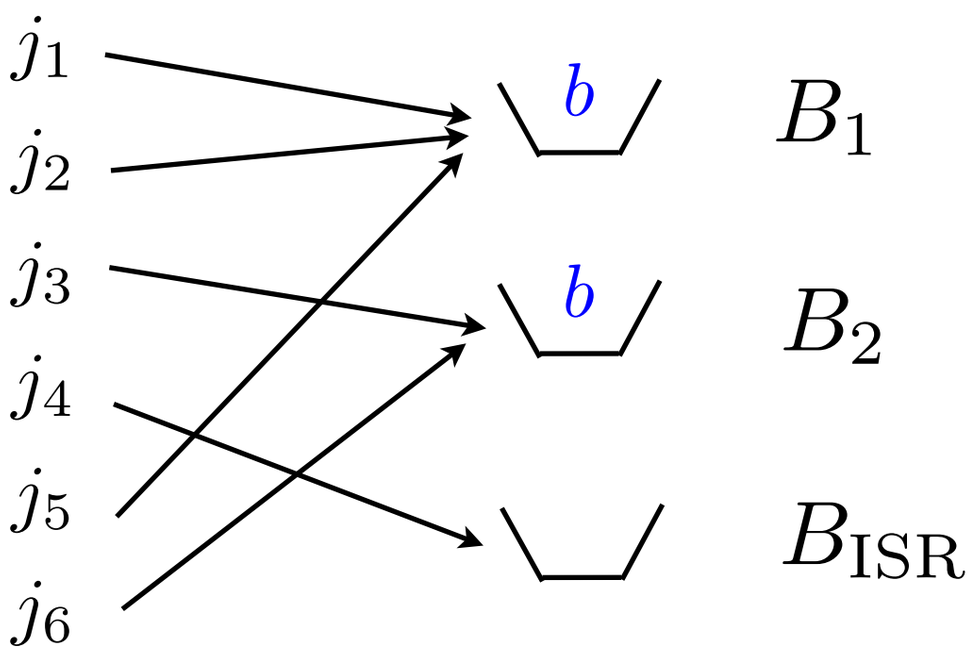

$\vdots$

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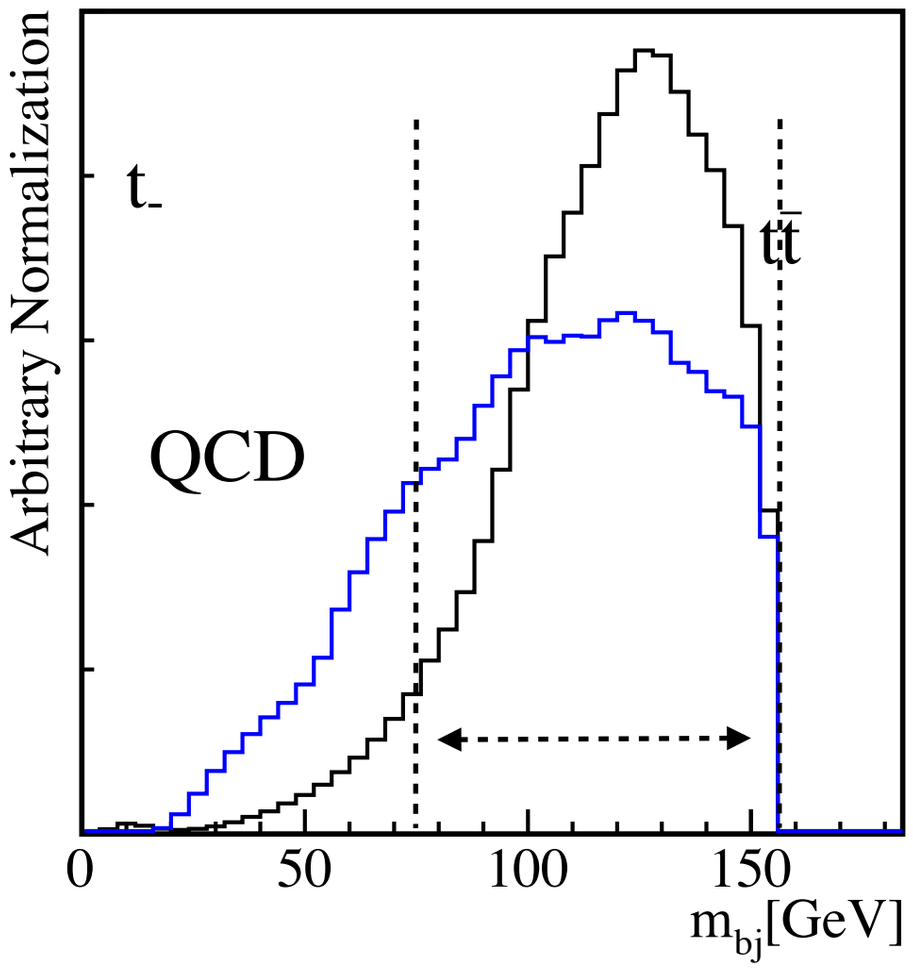
$(\mathrm{t}_-, \mathrm{t}_-)$: reconstruct t_- to minimize $\Delta_{B_1}^{bj} + \Delta_{B_2}^{bj}$



$m_{\mathrm{t}_-} (= m_{bj})$ 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_{QCD}
5 jets, $2b$-tag	21590		16072	1.4
unchanged $\rightarrow$ $(\mathrm{t}_w,\mathrm{t}_w)$	2750	68.9%	126.2	21.8
$(\mathrm{t}_w,\mathrm{t}_-)$	7787	47.3%	2259	3.4
$(\mathrm{t}_-,\mathrm{t}_w)$	1093	27.3%	190.5	5.7
$(\mathrm{t}_-,\mathrm{t}_-)$	4887	28.5%	4077	1.2

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increase in number and quality

70% double tagged in total (45% before)

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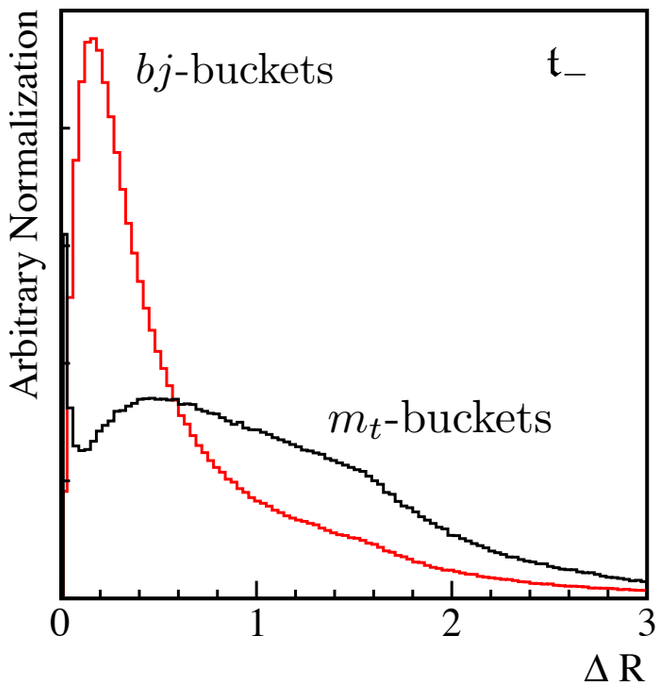
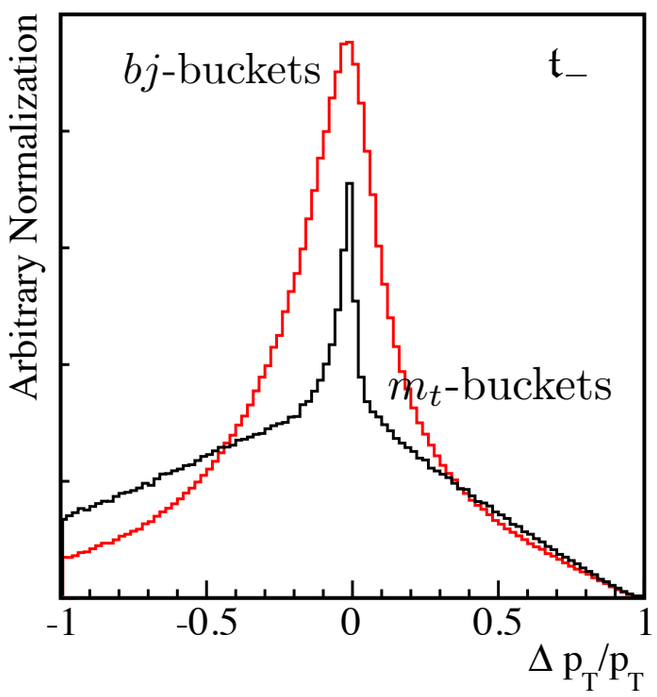
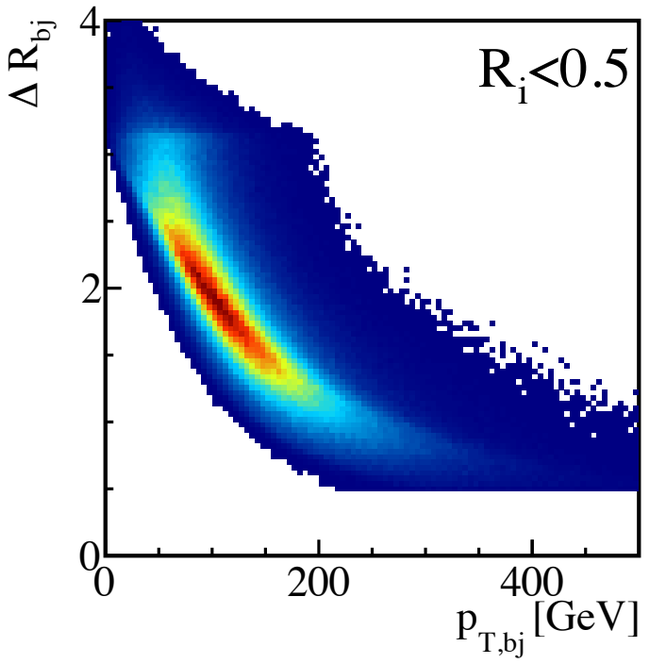




better momentum reconstruction

Slight boost improve quality

$R_i < 0.5$: good reconstruction



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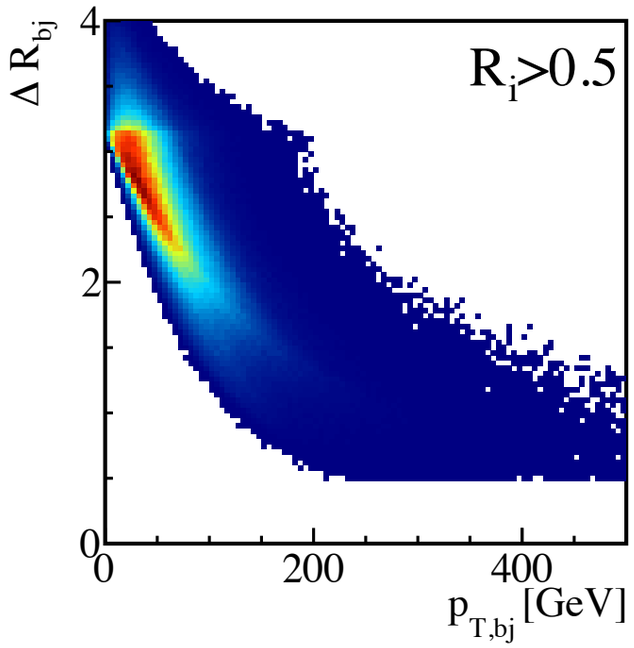

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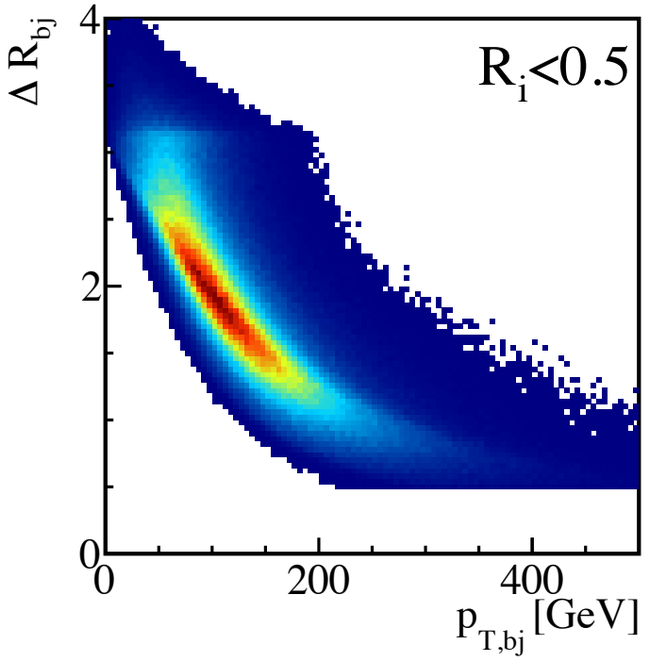
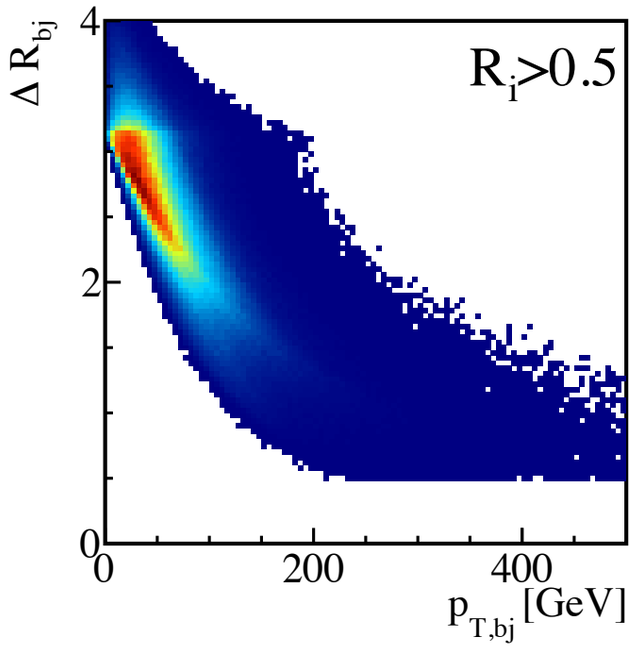


$R_i > 0.5$: bad reconstruction



to enhance $R_i < 0.5$

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

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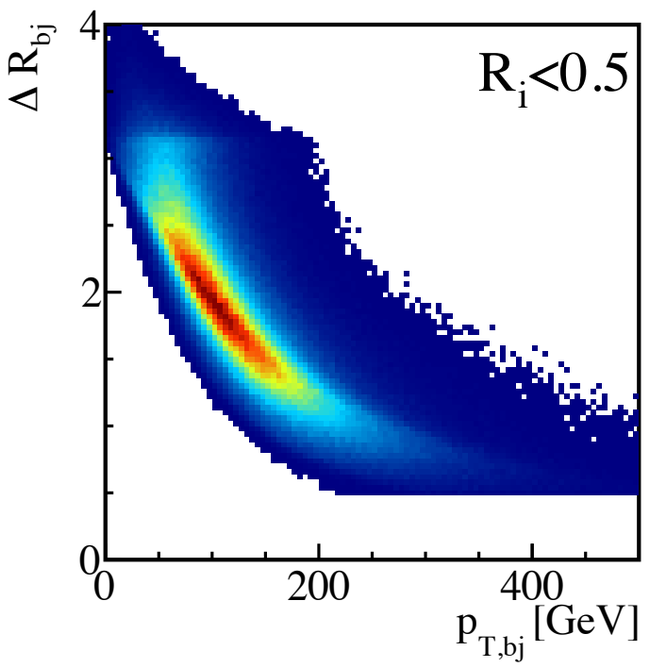

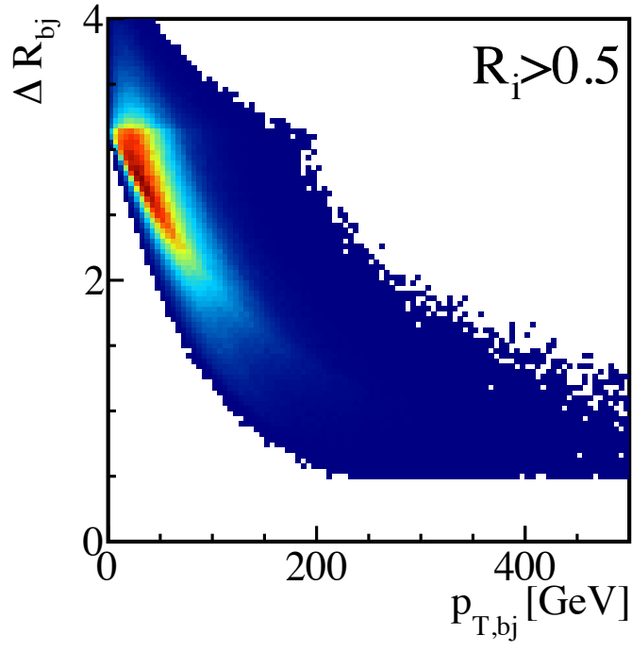

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$p_T^{\rm rec} > 100{\rm GeV}$

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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	2805	80.5%	305.4	9.2
(t_-,t_w), $p_T^{\rm rec} > 100$ GeV	287.9	60.5%	26.4	10.9
(t_-,t_-), $p_T^{\rm rec} > 100$ GeV	1084	67.7%	339.3	3.2
total, $p_T^{\rm rec} > 100$ GeV	5593	78.5%	698.2	8.0

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

Slight boost improve quality

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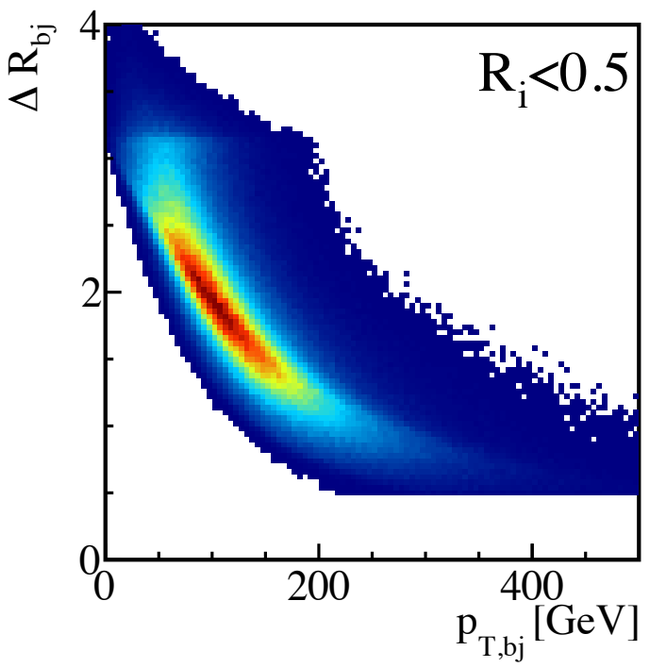

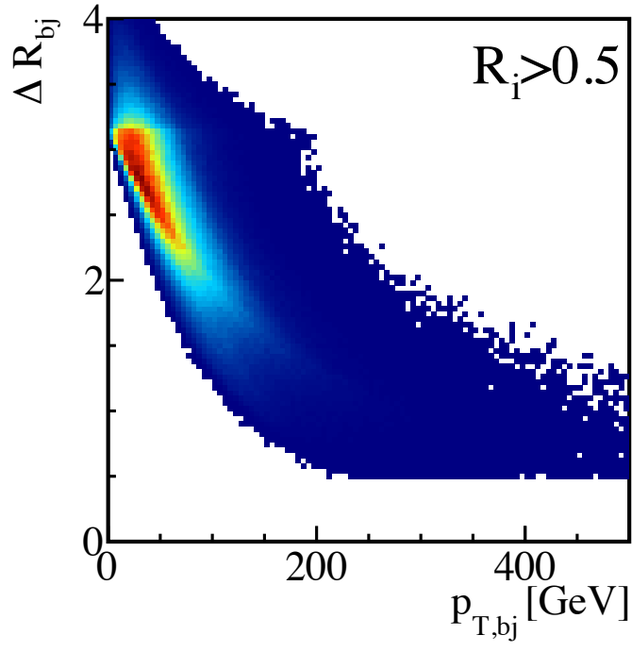

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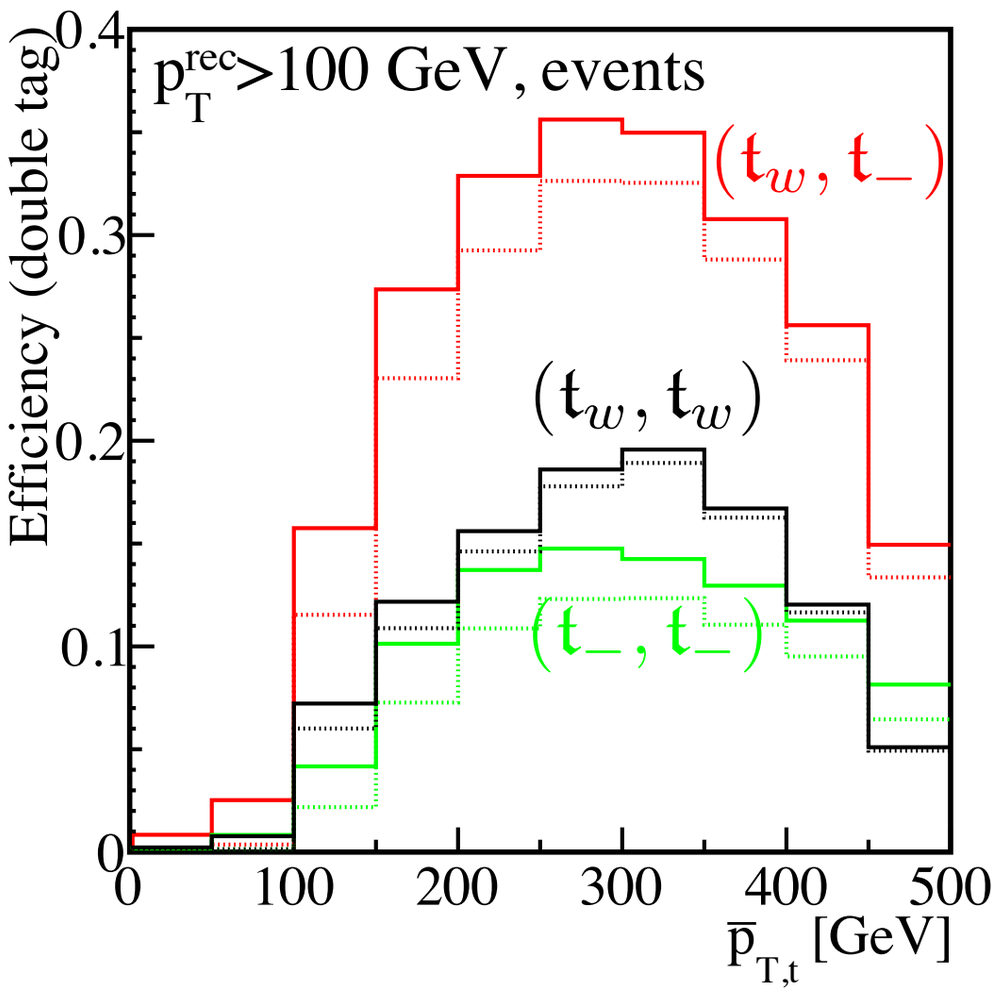
total, $p_T^{\rm rec} > 100$ GeV	5593	78.5%	698.2	8.0

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

25% double tagged in total

Efficiency as functions of pT

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



$\bar{p}_{T,t} = 100 - 150$ GeV: 30% (double top tags)
$\bar{p}_{T,t} = 150 - 300$ GeV: 50-70% (double top tags)

Efficiency as functions of pT

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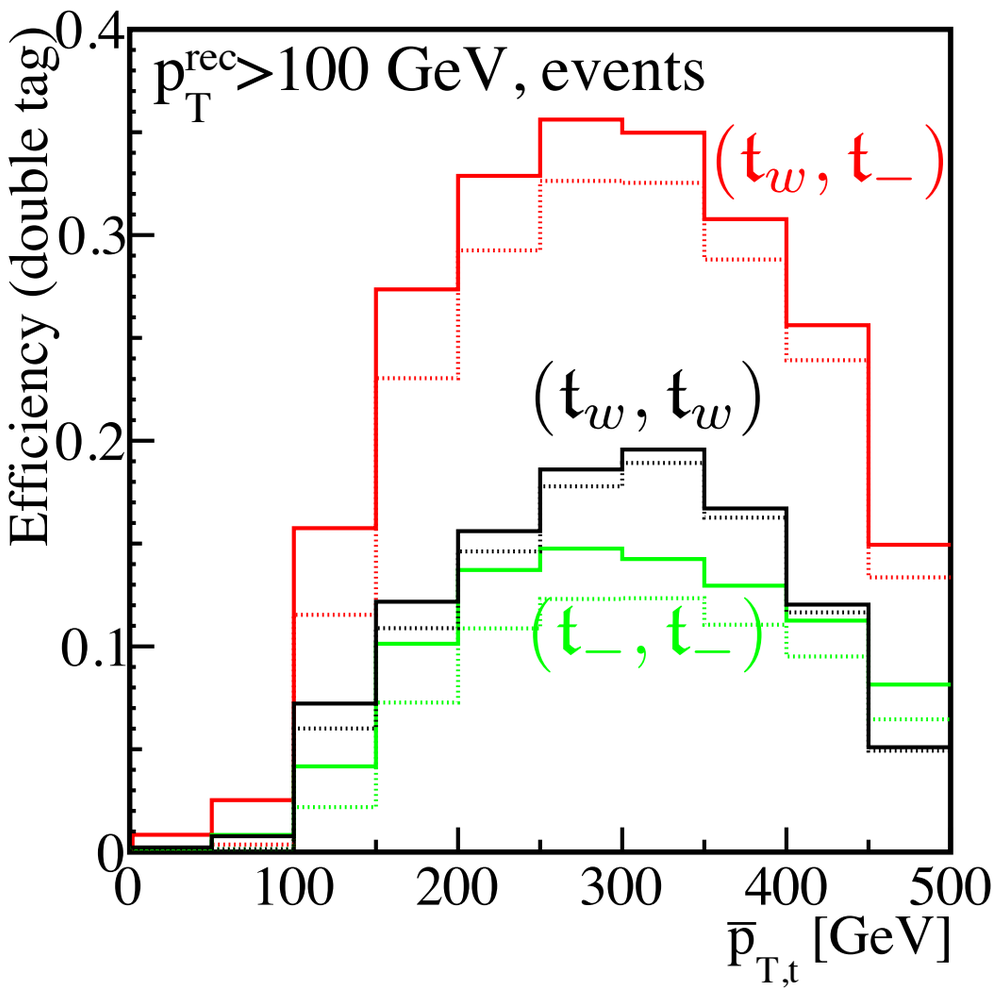
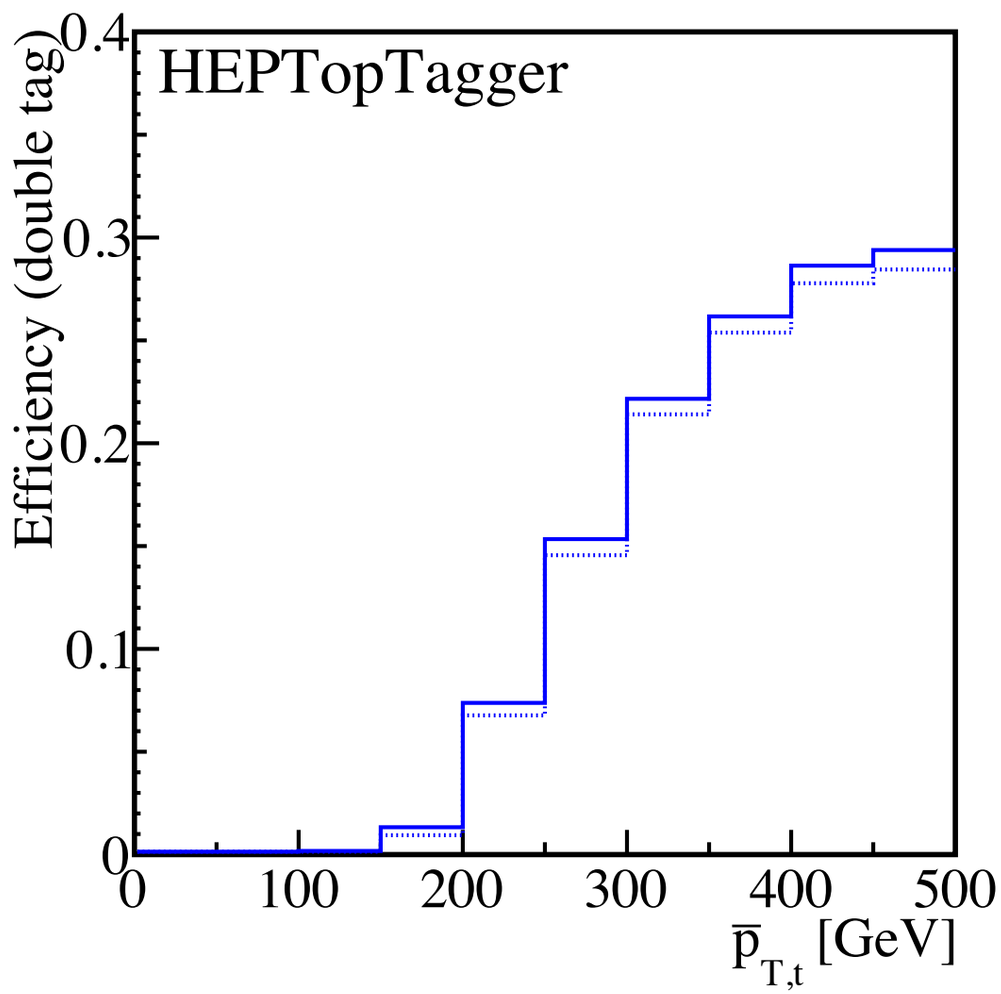




$\bar{p}_{T,t} = 100 - 150$ GeV: 30% (double top tags)
$\bar{p}_{T,t} = 150 - 300$ GeV: 50-70% (double top tags)

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

Stop pair search

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

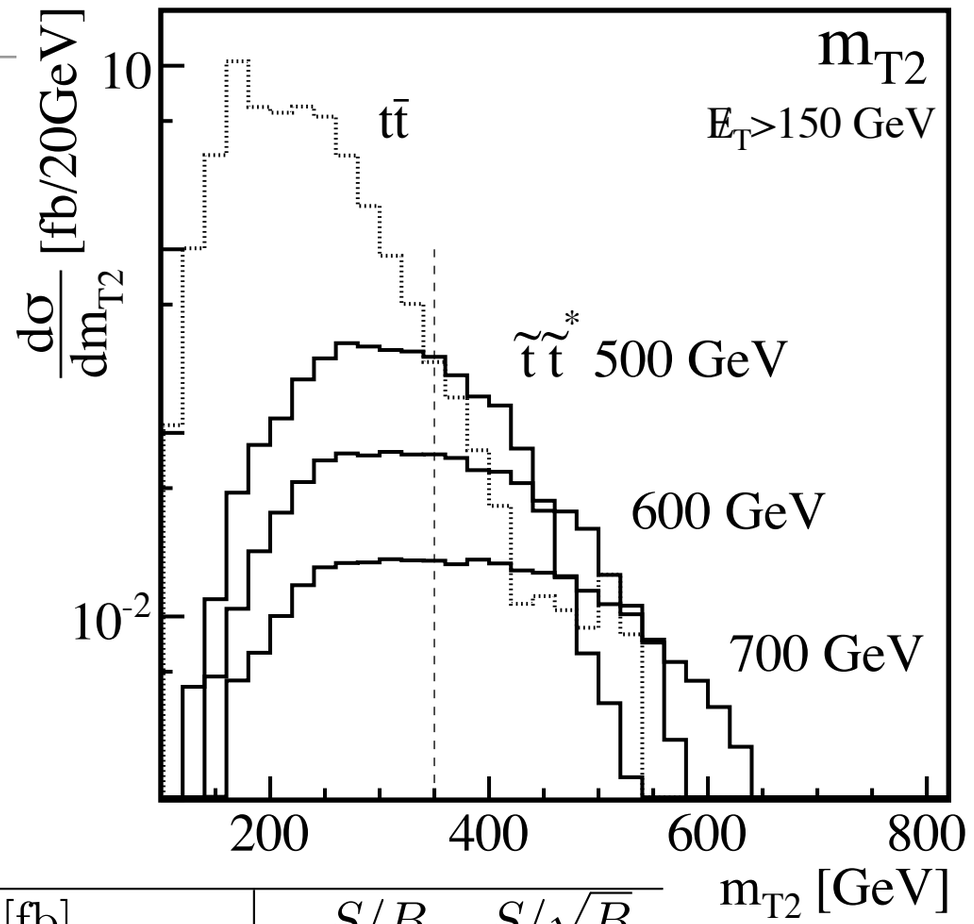
- $\tilde{t}\tilde{t}^* \to t\bar{t}\chi\chi$: $t\bar{t} + \not{E}_T$

  typically 10^4 difference in cross section

- include t_- increase both signal and BG

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

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



$m_{\tilde{t}}$ [GeV]	$t\bar{t}$+jets [fb]	$\tilde{t}\tilde{t}^*$ [fb] 500	600	700	S/B 600	$S/\sqrt{B}$
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	6.32×10^3	3.90	1.23	0.38	0.0002	0.08
$\not{E}_T > 150$ GeV	44.71	2.80	0.98	0.33	0.02	0.7
$m_{T2} > 350$ 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

Summary

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