Tagging Tops

Advertizing our HEPTopTagger

Tilman Plehn

Universität Heidelberg

Zürich 1/2011

Fat jets

Boosted particles at the LHC

1994 boosted $W \to 2$ jets from heavy Higgs [Seymour]

1994 boosted $t \to 3$ jets [Seymour]

2002 boosted $W \to 2$ jets from strongly interacting WW [Butterworth, Cox, Forshaw]

2006 boosted $t \to 3$ jets from heavy resonances [Agashe, Belyaev, Krupovnickas, Perez, Virzi]

2008 boosted $H \to b\bar{b}$ [Butterworth, Davison, Rubin, Salam]

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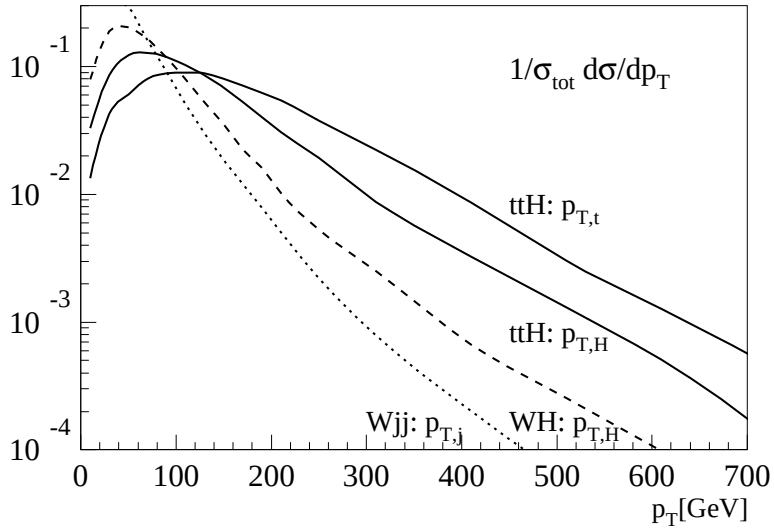
Since Gavin is not talking about it...

New strategy for $H \to bb$ [Butterworth, Davison, Rubin, Salam]

- desperately needed [2/3 of all light Higgses; impact Dührssen & SFitter]
- S: large m_{bb}, boost-dependent R_{bb}
  B: large m_{bb} only for large R_{bb}
  S/B: go for large m_{bb} and small R_{bb}, so boost Higgs
- fat Higgs jet $R_{bb} \sim 2m_H/p_T \sim 0.8$
- $q\bar{q} \to V_\ell H_b$ sizeable in boosted regime [$p_T \gtrsim$ 300 GeV, few % of total rate]



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$\Rightarrow$ non-trivial challenge to jet algorithms

jet definition	σ_S/fb	σ_B/fb	$S/\sqrt{B_{30}}$
C/A, $R = 1.2$, MD-F	0.57	0.51	4.4
$k_\perp$, $R = 1.0$, y_{cut}	0.19	0.74	1.2
SISCone, $R = 0.8$	0.49	1.33	2.3

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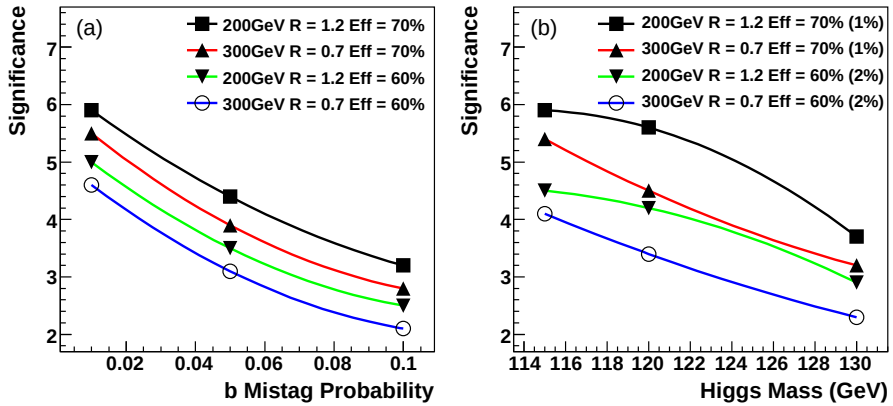
Results and checks

- combined channels $V \to \ell\ell, \nu\nu, \ell\nu$
- Z peak as sanity check
- confirmed by Freiburg [Piquadio]
  subjet b tag excellent [70%/1%]
  charm rejection challenging
  $m_H \pm 8$ GeV tough



Saving $t\bar{t}H$

Traditional $t\bar{t}H, H \to b\bar{b}$ [Atlas-Bonn study, CMS-TDR even worse]

- trigger: $t \to bW^+ \to b\ell^+\nu$
  reconstruction and rate: $\bar{t} \to \bar{b}W^- \to \bar{b}jj$
- continuum background $t\bar{t}b\bar{b}$, $t\bar{t}jj$ [weighted by b-tag]
- not a chance:
  1– combinatorics: m_H in $pp \to 4b_{tag}\ 2j\ \ell\nu$
  2– kinematics: peak-on-peak
  3– systematics: $S/B \sim 1/9$

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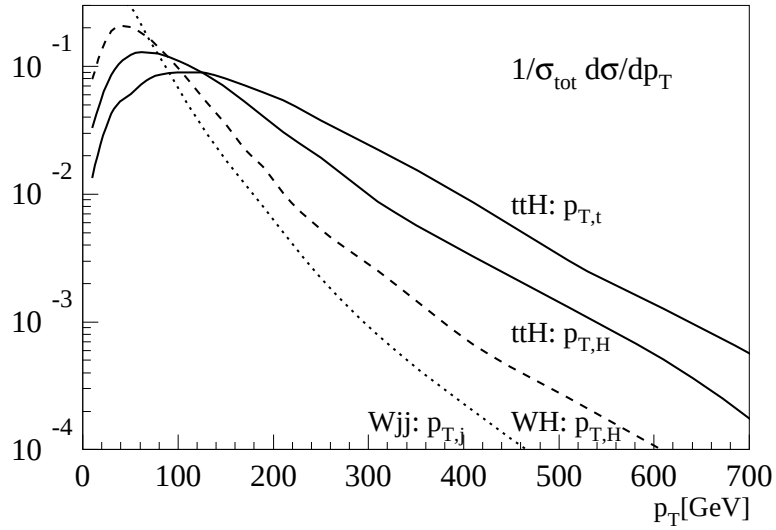
Two fat jets in $pp \to t_\ell t_h H_b$ [TP, Salam, Spannowsky]

- S/B: large m_{bb} and small R_{bb}; correct bottom pair boosted [solves 1]
- boost with different impact for S and B [solves 2]
- see how far we get... [watch S/B for 3]
- cool: fat Higgs jet + fat top jet
  German: including higher orders



Saving $t\bar{t}H$

Proof of promise

- require tagged top and Higgs
  trigger on lepton
- remove 'Higgs' as $t_\ell \to b$ plus QCD
  3rd b tag in continuum [costing $S/\sqrt{B}$]
  only continuum $t\bar{t}b\bar{b}$ left

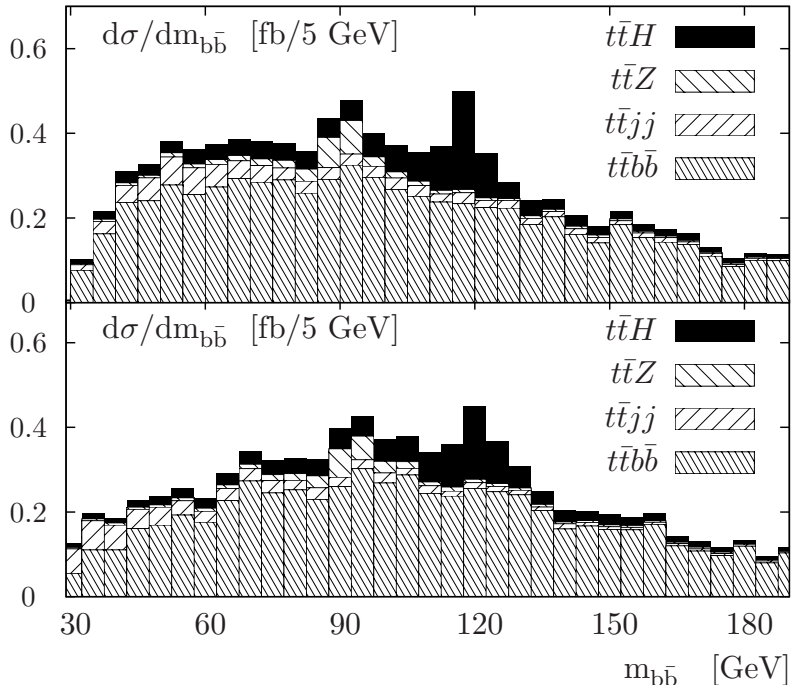
per 1 fb^{-1}	signal	$t\bar{t}Z$	$t\bar{t}b\bar{b}$	$t\bar{t}$+jets
events after acceptance	24.1	6.9	191	4160
events with one top tag	10.2	2.9	70.4	1457
events with $m_{bb} = 110 - 130$ GeV	2.9	0.44	12.6	116
corresponding to subjet pairings	3.2	0.47	13.8	121
subjet pairings two b tags	1.0	0.08	2.3	1.4
including a third b tag	0.48	0.03	1.09	0.06

Saving $t\bar{t}H$

Proof of promise

- require tagged top and Higgs trigger on lepton
- remove 'Higgs' as $t_\ell \to b$ plus QCD 3rd b tag in continuum [costing $S/\sqrt{B}$] only continuum $t\bar{t}b\bar{b}$ left

m_H	S	S/B	$S/\sqrt{B}$
115	57	1/2.1	5.2 (5.7)
120	48	1/2.4	4.5 (5.1)
130	29	1/3.6	2.9 (3.0)



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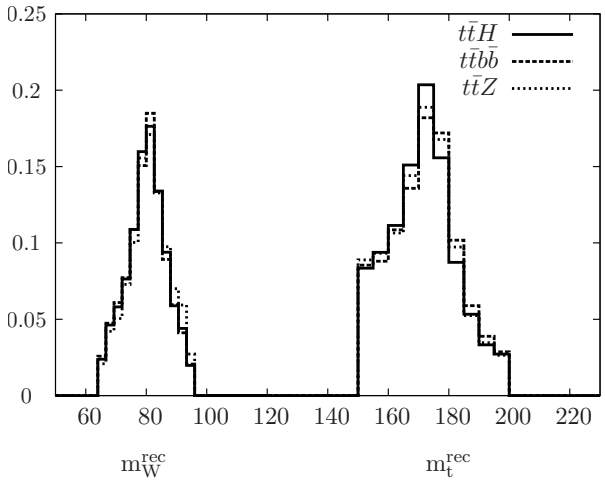
Pre-HEPTopTagger [cf Johns Hopkins, Princeton, Washington]

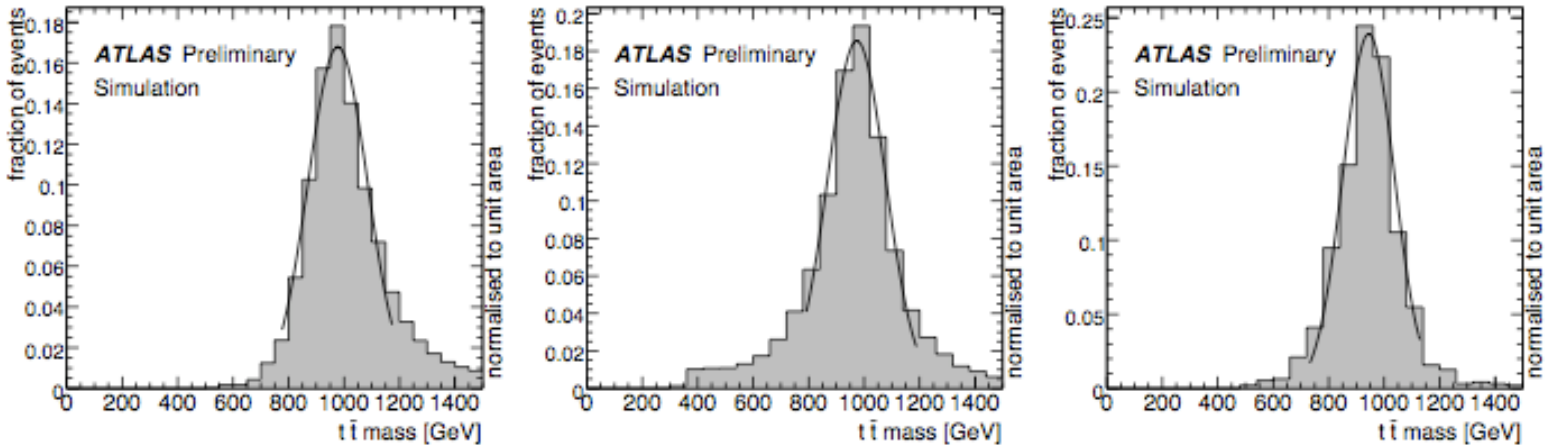
- start with C/A jet [$R = 1.5$] [Johns Hopkins]
- uncluster one-by-one: $j \to j_1 + j_2$
  1– unbalanced $m_{j_1} > 0.8 m_j$ means QCD; discard j_2
  2– soft $m_{j_1} < 30$ GeV means QCD; keep j_1
- top decay kinematics in relevant substructures
  reconstruct $m_W = 60...95$ GeV
  reconstruct $m_t = 150...200$ GeV
  helicity angle $\cos\theta_{t,j_1} > 0.7$ [changed later]
  no b tag
- underlying event rejection needed
  filter reconstruction jets [BDRS]
  decay plus one add'l jet at $R_{\text{filt}} \sim R_{jj}/2$
  reconstruct masses w/ QCD jet



HEPTopTagger

Highly boosted top quarks [Kaplan, Rehermann, Schwartz, Tweedie; Princeton, Seattle...]

- identify hadronic tops with $p_T \gtrsim 800$ GeV
  isolation and b tagging challenging
- C/A algorithm with p_T drop criterion
  all top decay jets identified
  3 kinematic constraints: $m_W, m_t, \cos\theta_{\text{hel}}$ [no b tag]
- top mass included, no sidebins
- ATLAS studies for semileptonic top pairs [adapted Y-splitter, full sim, ATLAS-2010-008]



(a) minimal (b) full reconstruction (c) mono-jet

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Standard Model: HEPTopTagger [TP, Salam, Spannowsky, Takeuchi]

- extend lower $p_T \gtrsim 250$ GeV
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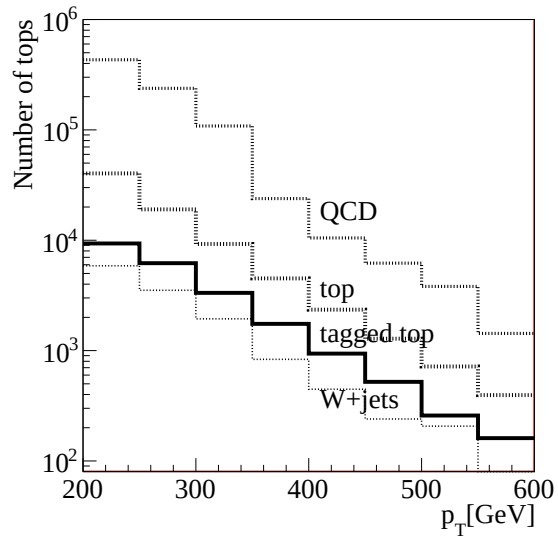

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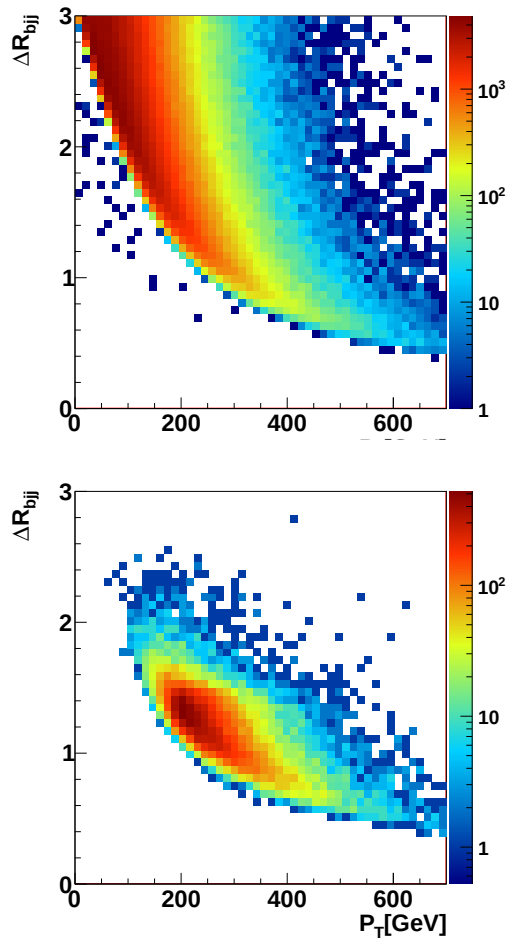

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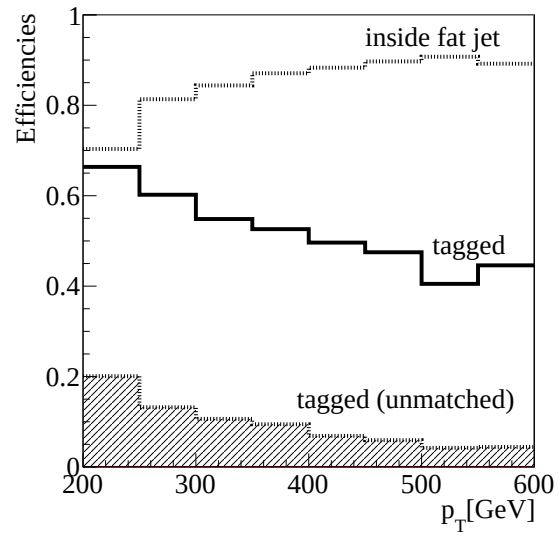

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	$t\bar{t}$			QCD	W+jets	
$p_{T,t}^{\text{min}}$[GeV]	0	200	300			
one fat jet	100%	100%	100%	100%	100%	
two fat jets	44%	57%	70%	53%	50%	rel to one fat jet
one top tag	23%	37%	51%	2.0%	3.9%	rel to one fat jet
two top tags	2.0%	4.5%	8.5%	0.027%	0.07%	rel to one fat jet
	4.5%	8.0%	12%	0.05%	0.15%	rel to two fat jets

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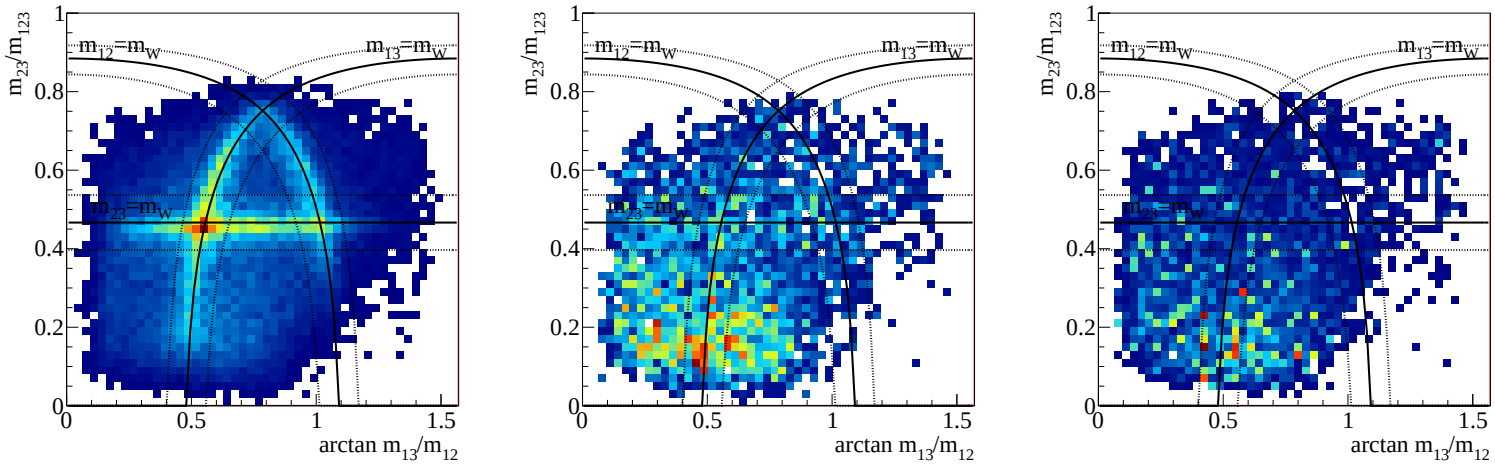
HEPTopTagger: kinematic selection

- kinematic criteria in terms of invariants [no boost]



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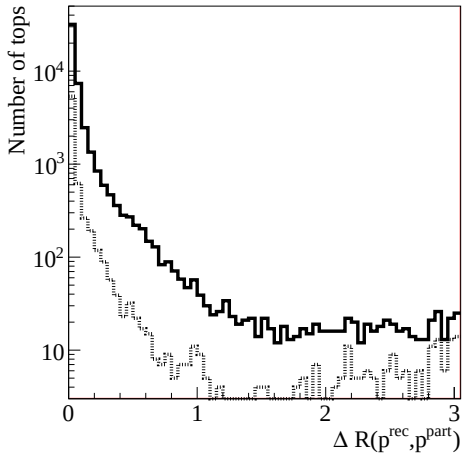
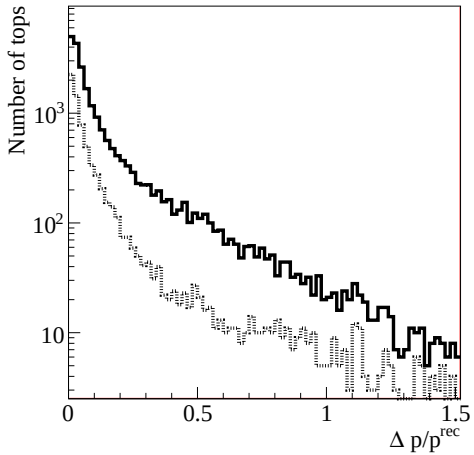
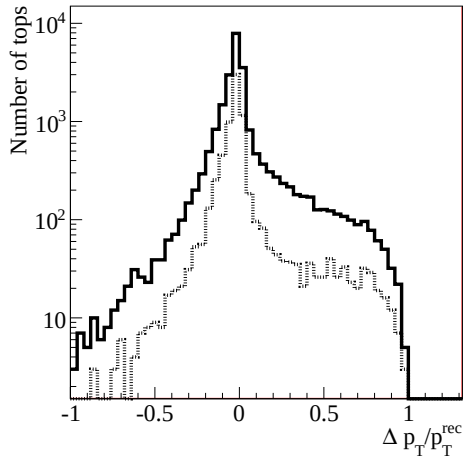
HEPTopTagger: momentum reconstruction

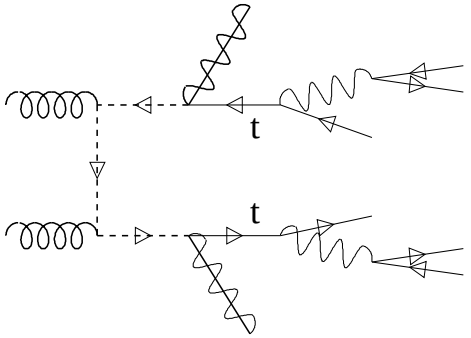
- top momentum reconstruction [$p_T > 200, 300$ GeV]







Stops pairs



Stop pairs as the first application [TP, Spannowsky, Takeuchi, Zerwas]

- stop most important particle for hierarchy problem
  comparison to other top partners [Meade & Reece]
- dark matter means difficult semi-leptonic channel [possibly impossible]
- hadronic: $\tilde{t}\tilde{t}^* \to t\tilde{\chi}_1^0\ \bar{t}\tilde{\chi}_1^0$ [CMS: leptons as spontaneous life guards; Meade & Reece overly optimistic]

events in 1 fb^{-1}	$\tilde{t}_1\tilde{t}_1^*$						$t\bar{t}$	QCD	W+jets	Z+jets	S/B	$S/\sqrt{B}_{10\text{ fb}^{-1}}$
$m_{\tilde{t}}$[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

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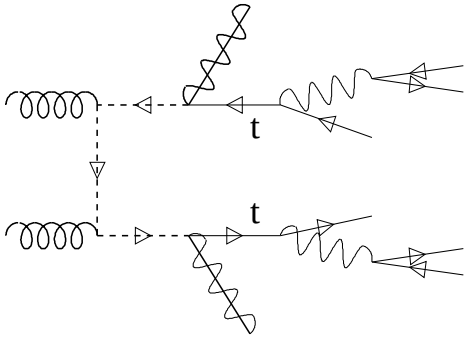

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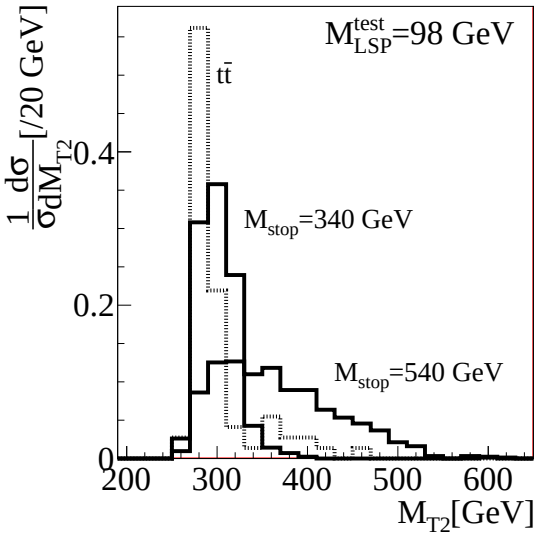
- stop mass from m_{T2} endpoint [like sleptons or sbottoms]
- as easy as $b\bar{b} + \not{E}_T$



Leptonic top tag

Leptonic tag [Thaler & Wang; Rehermann & Tweedie; TP, Spannowsky, Takeuchi]

- known: masses of top decay products
  measurable in rest frame: $E_b, E_\ell, m_{b\ell}$
  unknown: 3-momentum of neutrino
- use W and t mass constraints
  do not use measured $\not{p}_T$ vector
  find third parameter elsewhere

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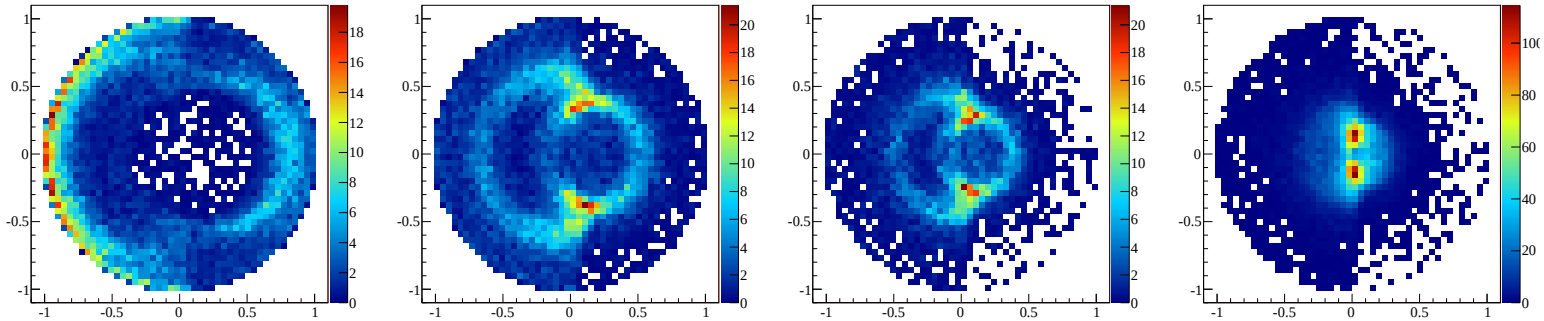
- coordinate system for neutrino
  leading component in $b - \ell$ direction
  sub-leading component in $b - \ell$ decay plane
  sub-leading component orthogonal to $b - \ell$ decay plane

  momentum components $(p_\nu^{\parallel}, p_\nu^{\perp})$



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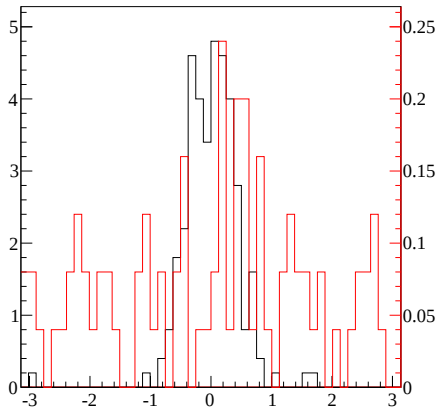
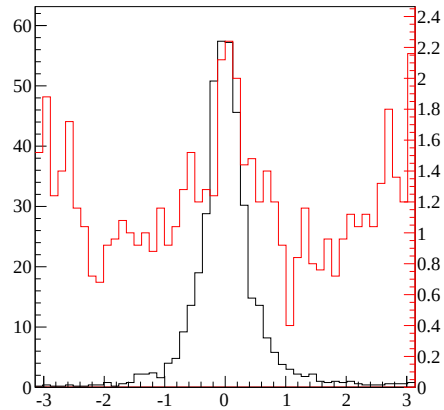
  sub-leading component orthogonal to $b - \ell$ decay plane
- two approximations for $\Delta\Phi(\not{p}_T, \hat{p}_t)$ and m_{T2}

  decay plane: $p_\nu^\perp = 0$

  orthogonal: $p_\nu^\parallel = 0$





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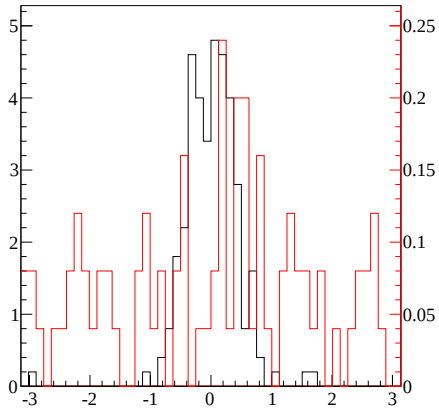
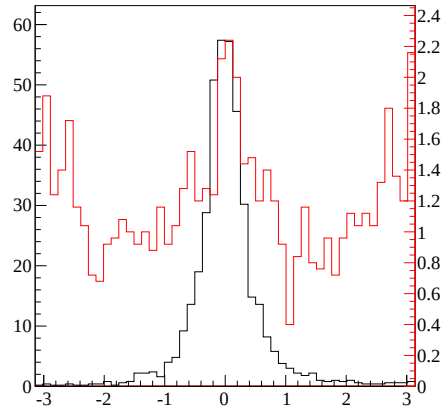
  decay plane: $p_\nu^\perp = 0$
  orthogonal: $p_\nu^\parallel = 0$





- scoop us and you will get killed in a really ugly manner...

Outlook

Fat jets — Aspirin of LHC phenomenology

- $t\bar{t}H$: curing combinatorics and backgrounds
- $\tilde{t}\tilde{t}^*$: curing backgrounds
- leptonic tagger on the way