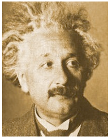
Fat jets

Tilman Plehn

Universität Heidelberg

Higgs Days, Santander 10/2010

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]

2009 boosted $\tilde{\chi}_1^0 \to 3$ jets in R parity violating SUSY [Butterworth, Ellis, Raklev, Salam]

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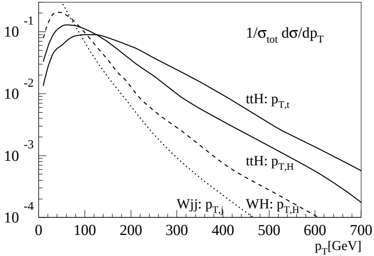
Higgs to bottoms

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 [details later]

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

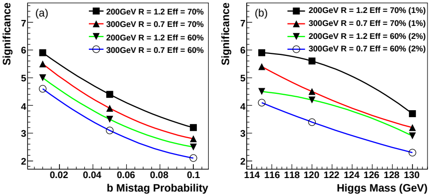
– combined channels $V \to \ell\ell, \nu\nu, \ell\nu$

– NLO rates [bbV notorious, not from data alone]

– Z peak as sanity check

– checked by Freiburg [Piquadio]
subjet b tag excellent [70%/1%]
charm rejection challenging
$m_H \pm 8$ GeV tough

$\Rightarrow$ confirmed at 20% level



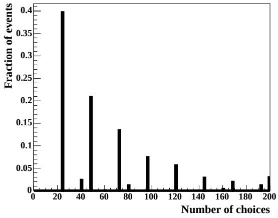
Rescuing $t\bar{t}H$

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]

– no chance:
1– combinatorics: m_{bb} from $pp \to 4b_{tag}\ 2j\ \ell\nu$



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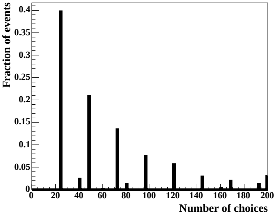

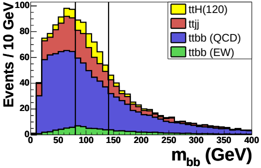

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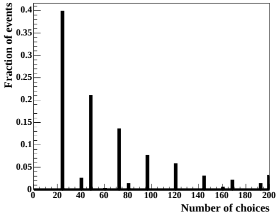

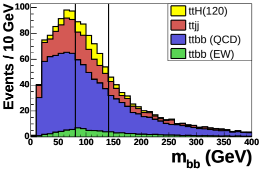

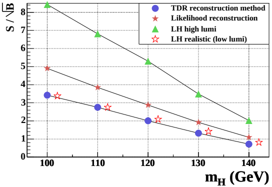

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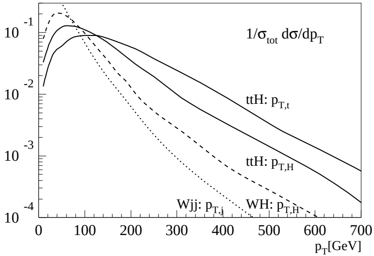
Fat jets analysis [TP, Salam, Spannowsky]

- S: large m_{bb}, boost-dependent R_{bb}
  B: large m_{bb} only for large R_{bb}
  S/B: large m_{bb} and small R_{bb}; correct bottom pair boosted [solves 1]
- $pp \to t_\ell t_h H_b$ even harder than VH
  also boost different for S and B [solves 2]
- cool: fat Higgs jet + fat top jet
  uncool: QCD [Dittmaier et al: $K = 2.3$ for $t\bar{t}b\bar{b}$]
- see how far we get... [watch S/B for 3]

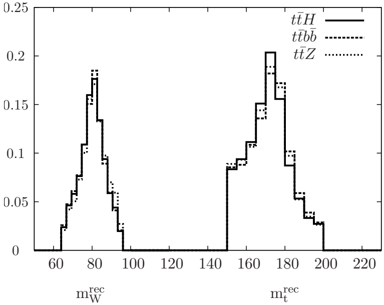


Rescuing $t\bar{t}H$

Top tag [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 needed
- underlying event scaling like R^4
  filter reconstruction jets [Butterworth–Salam]
  decay plus one add'l jet at $R_{\text{filt}} \sim R_{jj}/2$
  reconstruct masses w/ QCD jet

$\Rightarrow$ HEPTopTagger



Rescuing $t\bar{t}H$

Higgs tag

– same as top tag [stricter mass drop criterion, harder jets]
  but: Higgs mass unknown

– double b tag [$\mathcal{O}(10\%)$ from leptonic top]
  combinations ordered by $J = p_{T,1} p_{T,2} (\Delta R_{12})^4$
  three leading combinations vs m_{bb}^{filt}

$\Rightarrow$ like Butterworth-Salam for busy QCD

Analysis

– require tagged top and Higgs
  trigger on lepton

– remove 'Higgs' as $t_\ell \to b$ plus QCD
  3rd b tag in continuum
  $B = 3.8S \to 2.4S$ [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

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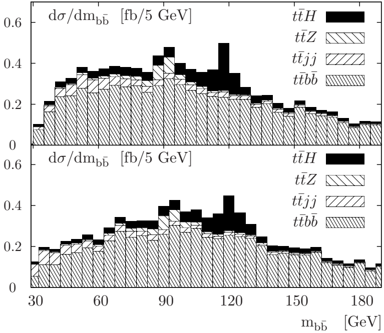
m_H	S	S/B	$S/\sqrt{B}$
115	57	1/2.1	5.2 (5.7)
120	48	1/2.4	4.5 (5.1)
130	29	1/3.6	2.9 (3.0)

$\Rightarrow$ under experimental scrutiny



Boosted top

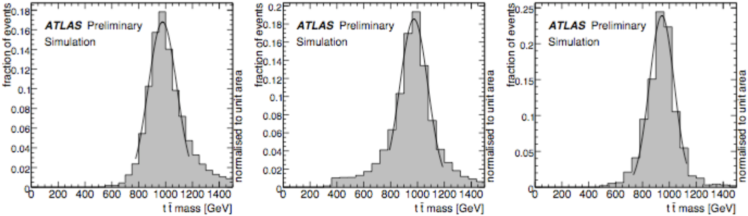
Highly boosted top quarks [Kaplan, Rehermann, Schwartz, Tweedie; Princeton, Seattle...]

– 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

– general ATLAS studies [ATLAS-2010-008]



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

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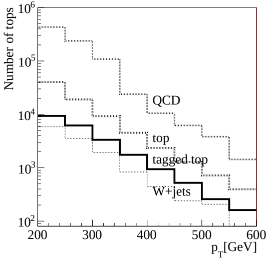
Standard Model: HEPTopTagger [TP, Salam, Spannowsky, Takeuchi]

– extend lower $p_T \gtrsim 250$ GeV
testable in Standard Model $t\bar{t}$

– start like Higgs tagger [mass drop, $R = 1.5$]
kinematic selection: $m_{jjj}, m_{jj}^{(1)}, m_{jj}^{(2)}$ [no b tag, filtered]



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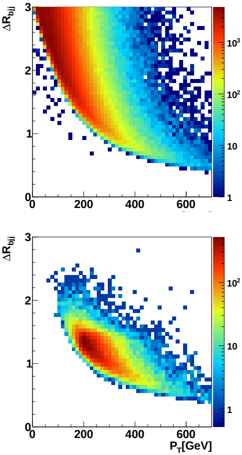

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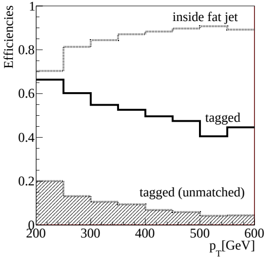
– promising tests by ATLAS [Kasieczka & Schätzel]

– hadronic top like tagged b



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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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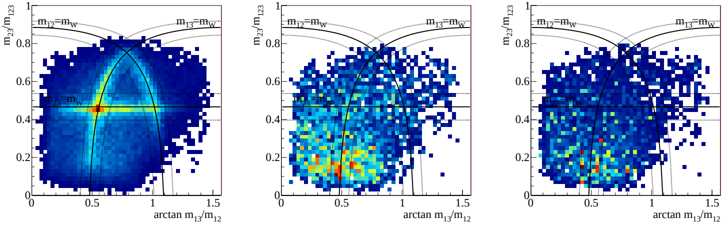
HEPTopTagger: kinematic selection

– kinematic criteria without boosts etc



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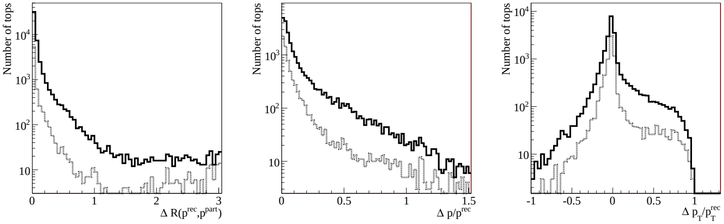
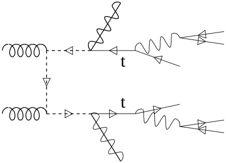
HEPTopTagger: momentum reconstruction

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



Stops



Stop pairs [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
- purely hadronic: $\tilde{t}\tilde{t}^* \to t\tilde{\chi}_1^0\ \bar{t}\tilde{\chi}_1^0$ [CMS TDR: leptons as spontaneous life guards]

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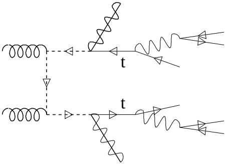

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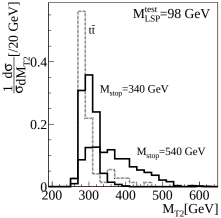
- stop mass from m_{T2} endpoint [like sleptons or sbottoms]
- not harder analysis than $b\bar{b} + \not{E}_T$

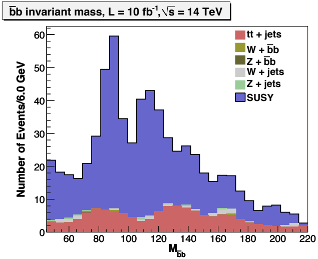


More Higgs

Higgs in cascade decays [Kribs, Martin, Roy, Spannowsky]

- idea: find Higgs in cascade decays [Cambridge]
- BSM sample after missing energy or hard γ cut
- Higgs tag over the remaining event
- side bin analysis in m_{bb}

...



Outlook

Fat jets — Aspirin of LHC phenomenology

- VH: curing QCD backgrounds
- $t\bar{t}H$: curing combinatorics and backgrounds
- $\tilde{t}\tilde{t}^*$: curing backgrounds
- cascade Higgs: curing lack of strategie
- heavy resonances: curing calorimeter resolution
- try using it against your headache...