Boosted hadronically decaying tops in new physics searches

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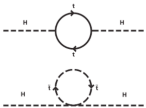
Universität Heidelberg

Bonn, 28th March 2012

Top at the LHC

closest to new physics → probe for new physics



- fine tuning problem: cancellation via top partner
- Tevatron anomalies (A^t_{FB}, single top etc.)
- copiously produced via strong interaction at LHC → precision physics

  7TeV LHC $\sim 800,000\ t\bar{t}$

  Tevatron $\sim 40,000\ t\bar{t}$

hadronic top $t \to 3j$

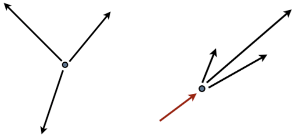
- full momentum reconstruction possible in principle
- large M_{eff}, combinatorics → main BG for new physics search
- how to identify hadronic top against 10^3 larger QCD?

  $\sigma^{14\text{TeV}}_{tt} = 918$ pb $\leftrightarrow \sigma^{14\text{TeV}}_{3j} \sim 2 \cdot 10^6$ pb

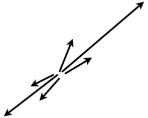
  3 jets with m_t, m_W condition → large QCD combinatorics BG

Boosted Tops at the LHC

massive jet



- top at rest $\longrightarrow$ separate 3 jets
- boosted top $\longrightarrow$ massive jet
  $R \sim 2m/p_T$



- take massive jet & look into jet substructure

  QCD combinatorics significantly reduced

  QCD massive jet: soft-collinear nature in its substructure

Boosted Tops at the LHC

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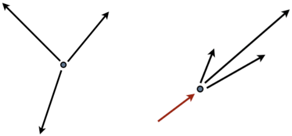

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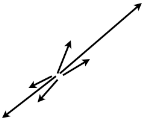

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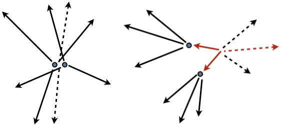
top as a probe



- new physics search with $\not{E}_T$ $\longrightarrow$ need recoil
  - · top at rest: not useful
  - · boosted tops: carry information on dark matter

    better S/B (cf. M_{T2} end point.)

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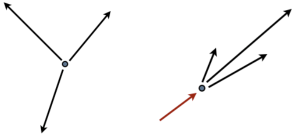

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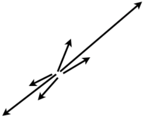

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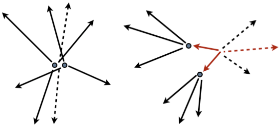


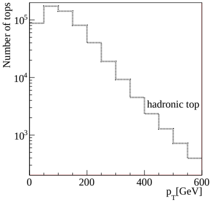
several top taggers available: focus on $p_T > 500$ GeV.

[Kaplan, Rehermann, Schwartz, Tweedie] [Thaler, Wang] [Almeida, Lee, Perez, Sterman, Sung]

Moderately Boosted Tops at the LHC

top p_T distribution

- not expected many in SM for $p_T > 500$ GeV
  - $\sigma(p_T > 200 \text{ GeV}) \sim 50\sigma(p_T > 500 \text{ GeV})$
- need top tagger valid down to low p_T range → testable



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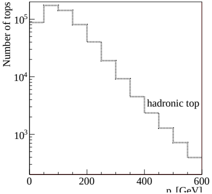
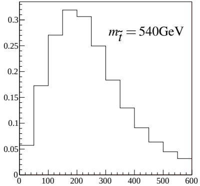


- light top partner also provide tops in the same range



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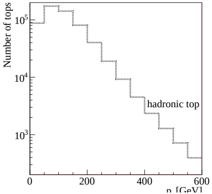

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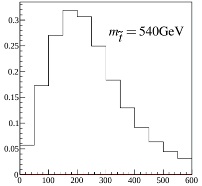
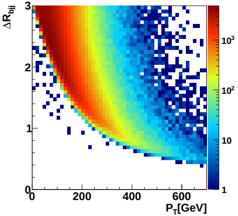


we focus on $p_T > 200$GeV

fat jet

- top p_T vs. R_{jjj} distribution
- to catch $t \longrightarrow jjj$: need $R = 1.5$ for $p_T > 200$ GeV



Top at the LHC
HEPTopTagger
Applications
Summary

HEPTopTagger

[JHEP 1010:078,2010. arXiv:1006.2833 [hep-ph] T. Plehn, M. Spannowsky, D. Zerwas, MT]

1. fat jets – C/A with $R = 1.5$, $p_T^{\text{fatjet}} > 200$ GeV

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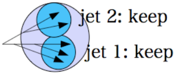

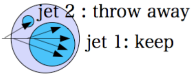

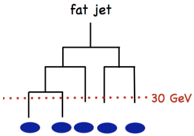

$j = j_1 + j_2$ $\quad$ $\boxed{m_j \gg m_{j1}, m_{j2} \text{ (decay)}} \leftrightarrow \boxed{m_j \sim m_{j1} \gg m_{j2} \text{ (QCD)}}$

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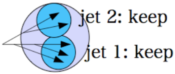

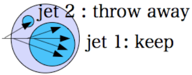

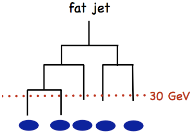

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3. **take 3 subjets with best filtered mass**

– $|m_{jjj}^{\text{filt}} - m_t| < 25$ GeV $\rightarrow$ top candidate

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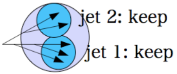

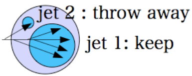

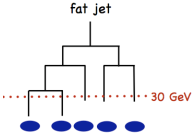

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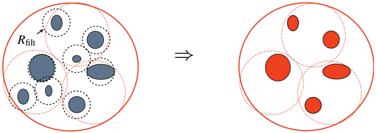
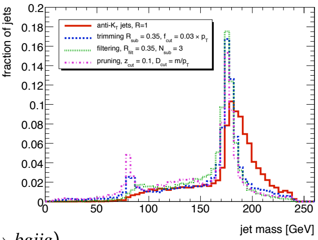
filtering

[Butterworth et al.]

– effect of pile-up, underlying events $\sim R^2$

– reduce effective area with smaller R_{filt} and n_{filt}





– $R_{\text{filt}} = \min\{0.3, R_{ij}/2\}$ and $n_{\text{filt}} = 5$ $(t \rightarrow bWg \rightarrow bgjjg)$

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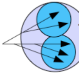

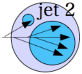

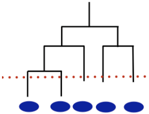

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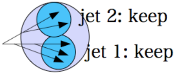

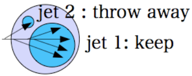

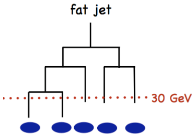

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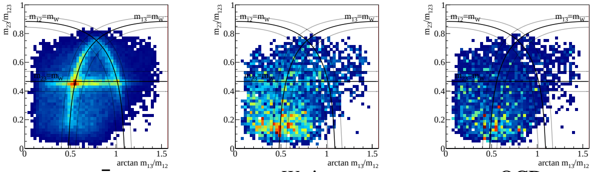
4. **check mass ratios**

– 3 subjets: $p_1, p_2, p_3 \rightarrow m_{12}, m_{13}, m_{23}$

– m_t condition: $m_t^2 = m_{123}^2 = m_{12}^2 + m_{13}^2 + m_{23}^2 \rightarrow$ spherical surface: 2D mass ratios

$m_{23} \downarrow 0$
$0 \leftarrow m_{13}$
$m_{12} \rightarrow 0$

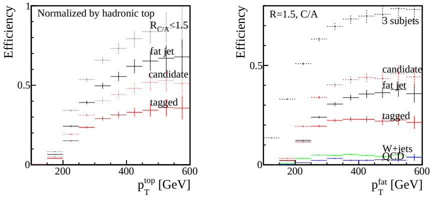


$t\bar{t}$ $\quad$ W+jets $\quad$ QCD

– W mass condition, soft-collinear cut $\rightarrow$ tagged top

HEPTopTagger [JHEP 1010:078,2010. arXiv:1006.2833 [hep-ph] T. Plehn, M. Spannowsky, D. Zerwas, MT]

efficiency



- efficiency $\sim$ 30% for hadronic tops, 2 $\sim$ 4% mis-tag rate
- validation with ATLAS experimentalists in Heidelberg [G. Kasieczka, S. Schätzel, A. Schöning]

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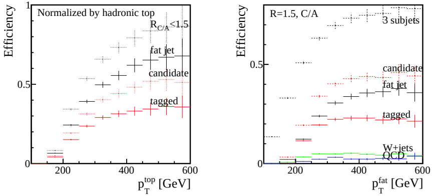

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additional pruning

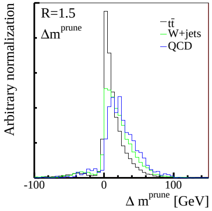
[Phys.Rev. D85 (2012) 034029 [arXiv:1111.5034[hep-ph]], T.Plehn,M.Spannowsky,MT]

– pruning [Ellis et al.]

veto recombination with $z = \frac{\min\{p_{Ti}, p_{Tj}\}}{|\vec{p}_{Ti} + \vec{p}_{Tj}|} < z_{\text{cut}}$

– pruned mass $\Delta m^{\text{pruned}} = m^{\text{pruned}} - m^{\text{filter}}$

– efficiency/mis-tag rate improves factor 2



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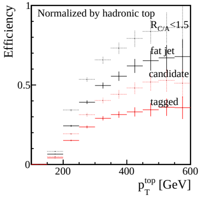

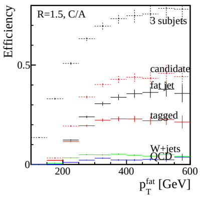

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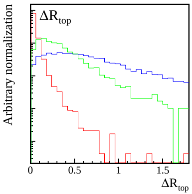
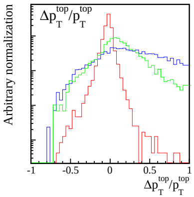
momentum reconstruction

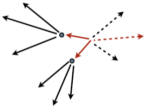
- well reconstructed
- better for larger p_T





Scalar Top Pairs at 14 TeV

hadronic mode [T. Plehn, M. Spannowsky, MT, D. Zerwas]



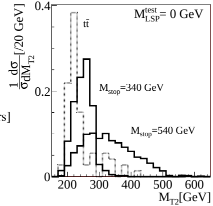
- $\tilde{t}_1\tilde{t}_1^* \to (t\tilde{\chi}_1^0)(\bar{t}\tilde{\chi}_1^0)$
- main BG: $t\bar{t}$+jets, W+jets and QCD

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 for 1st top 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

$$S/B \sim 1, S/\sqrt{B} > 5 \text{ at 14 TeV with } 10\text{fb}^{-1}$$

- stop mass from $m_{T2}(m_{\tilde{\chi}_1^0})$ endpoint [C. G. Lester, D. J. Summers]

  like sleptons or sbottoms



semi-leptonic mode [JHEP 1105 (2011) 135 [arXiv:1102.0557 [hep-ph]], T. Plehn, M. Spannowsky, MT]

$$S/B \sim 2, S/\sqrt{B} > 5 \text{ at 14 TeV with } 10\text{fb}^{-1}$$

Scalar Top Pairs at 8TeV [T. Plehn, M. Spannowsky, MT]

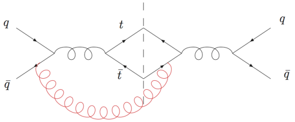
- $\sigma^{8\text{TeV}} \sim \frac{1}{10}\sigma^{14\text{TeV}}$: both for $t\bar{t}$ and $\tilde{t}_1\tilde{t}_1^*$
- 3 channels analyzed
  - no lepton, 2 top tags
  - no lepton, 1 top tag and 1 b-jet
  - 1 lepton, 1 top tag and 1 b-jet
- difficulty: $t\bar{t}$ BG $\rightarrow$ reduced by m_{T2} cut etc.

$\sqrt{s} = 8$ TeV, $R = 1.5$	$\tilde{t}1\tilde{t}1^*$						$t\bar{t}$	QCD$_{>3\text{jets}}$	W+jets	Z+jets	S/B	$S/\sqrt{B}_{10\text{fb}^{-1}}$
$m_{\tilde{t}}$[GeV]	350	400	450	500	600	700					400	
cross section [fb]	760	337	160	80.5	23.0	7.19	$1.63 \cdot 10^5$	$6.5 \cdot 10^8$	$1.6 \cdot 10^6$	12226	$\sim 10^{-7}$	0.04
ℓ veto, $\not{E}_T > 100$ GeV	103.87	65.04	38.48	22.45	7.76	2.74	1128	$2.0 \cdot 10^5$	1859	694		
$n_{\text{tag}} \geq 2$	2.34	1.65	1.12	0.76	0.34	0.14	4.69	18	0.5	0.00		
b-tag for 1st top tag	1.17	0.83	0.56	0.38	0.17	0.07	2.35	0.18	–	–		
$m_{T2} > 250$ GeV	0.42	0.45	0.37	0.27	0.13	0.06	0.40	0.03	–	–	1.05	2.2
$n_{\text{tag}} = 1$, additional b-jet	32.66	21.21	12.77	7.65	2.74	0.98	480.21	2637	81.68	42.38		
2 b-tag	8.17	5.30	3.19	1.91	0.69	0.25	120.05	0.26	0.01	–		
$m_{T2,b} > 250$ GeV	0.18	0.43	0.51	0.47	0.27	0.12	0.49	–	–	–	0.87	1.93
$n_\ell = 1$, $\not{E}_T > 100$ GeV	55.43	32.89	19.12	11.18	3.80	1.33	1548.15	–	2397.04	0.00		
$n_{\text{tag}} = 1$	6.94	4.62	3.13	2.04	0.79	0.31	238.99	–	25.32	0.00		
b-tag & $m_{lb} < 151$ GeV	1.35	0.91	0.62	0.41	0.17	0.07	53.67	–	0.10	0.00		
orthogonal approx.	0.68	0.42	0.29	0.20	0.08	0.03	29.59	–	0.07	0.00		
$\Delta\phi$ cut	0.12	0.13	0.12	0.09	0.05	0.02	0.05	–	–	–	2.6	1.86
total	0.72	1.01	1.00	0.83	0.45	0.20	0.94	0.03	–	–	1.0	3.2

- 3 channels combined: $S/B \sim 1, S/\sqrt{B} \sim 3.2$ with 10fb^{-1} at 8 TeV

Top forward backward asymmetry A^t_{FB}

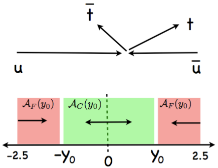
[Phys.Rev. D84 (2011) 054005 [arXiv:1103.4618 [hep-ph]], J. L. Hewett, J. Shelton, M. Spannowsky, T.M.P. Tait, MT]



- QCD A^t_{FB}: small NLO effect ($\sim 6\%$)
- D0 and CDF observed anomalously large A^t_{FB}

  D0: $A^t_{FB} = 8 \pm 4 \pm 1\%$

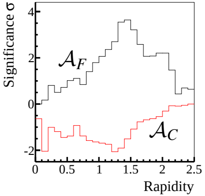
  CDF: $A^t_{FB} = 15 \pm 5 \pm 2.4\%$,
- LHC (pp collider): charge asymmetry in forward-central region



anti-tops are more central

- semi-leptonic mode: $t\bar{t} \to (bjj)(bl\nu)$
  - one isolated lepton
  - one hadronic top tagged with HEPTopTagger
  - b-tag in tagged top $\to$ W+jets negligible
  - top charge determined by lepton
- SM: 5σ after 60fb^{-1}(14TeV)
- BSM: 5σ after 2fb^{-1}(14TeV)

  2.8σ after 10fb^{-1} (7TeV)



Summary

HEPTopTagger

available on http://www.thphys.uni-heidelberg.de/∼plehn/

- focus on moderate p_T tops ($p_T > 200$GeV) → testable in SM
- fat jets kill combinatorics
- jet substructure: thrown information, use all available infomation
- momentum well reconstructed

general idea: tops at LHC identified just like bottoms

Applications

- stop pairs

  at 14 TeV with 10fb^{-1}
  - hadronic channel: $S/B \sim 1, S/\sqrt{B} > 5$
  - semi-leptonic channel: $S/B \sim 2, S/\sqrt{B} > 5$

  at 8 TeV with 10fb^{-1}
  - 3 channels combined: $S/B \sim 1, S/\sqrt{B} \sim 3$

- A^t_{FB} at 14 TeV
  - SM: 5σ with 60fb^{-1}
  - BSM: 5σ with 2fb^{-1} (2.8σ at 7TeV with 10fb^{-1})