Higgs

Hadronic tops

Leptonic tops

W/Z bosons

No trees

To do

Status of taggers

Tilman Plehn

Universität Heidelberg

BOOST 5/2011

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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2010 dedicated conference and meta-analysis [BOOST proceedings, Ed: Karagoz, Spannowsky, Vos]

Fat jets from boosted massive particles

1– collinear decay products

2– improved mass reconstruction

3– solution to signal combinatorics

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Standard Model Higgs

Starting frenzy: $VH, H \to b\bar{b}$ [Butterworth, Davison, Rubin, Salam]

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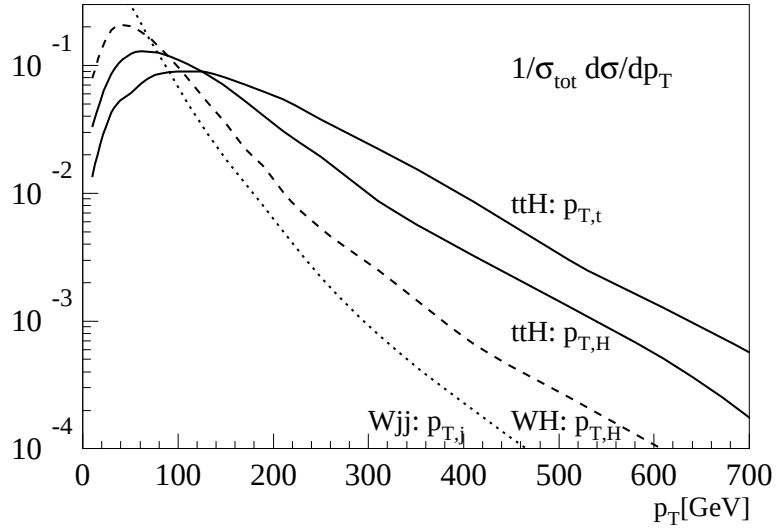
- S: large m_{bb}, boost-dependent R_{bb}
  B: large m_{bb} only for large R_{bb}
  S/B: go for large m_{bb} and small R_{bb}, so boost Higgs
- $q\bar{q} \to V_\ell H_b$ sizeable in boosted regime [$p_T \gtrsim$ 300 GeV, few % of total rate]
- Z peak as sanity check
  subjet b tag excellent [70%/1%]
- QCD rejection with two b tags $\sim 10^{-5}$ [used by Graham et al]



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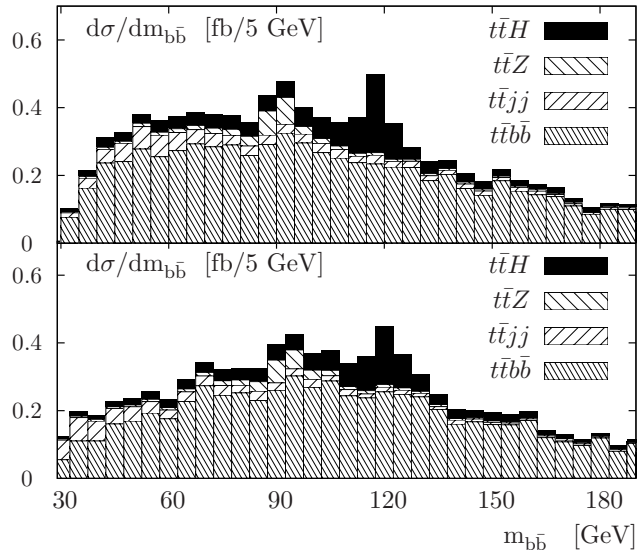
Hopeful: $t_h \bar{t}_\ell H$ [TP, Salam, Spannowsky]

- boost signal combinatorics
- 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
- BDRS adapted to high jet multiplicity:
  increased soft cutoff, increased mass drop
  three leading candidates in $p_{T,1}p_{T,2}(\Delta R)^4$
  but asymmetric tails



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Improving the Higgs tagger

- combine e.g. with QCD pre-jet observables, jet shapes
  multivariate analysis [Black, Gallicchio, Huth, Kagan, Schwartz, Tweedie]

  1– which new observables have power?
  2– do they survive detectors?
  3– do they survive pileup?
  4– then, combine them again
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- no changes in basic idea
- testable in $Z \to b\bar{b}$?

Non-standard Higgs

Hadronic 4-body decays [Falkowski, Krohn, Wang, Shelton, Thalapillil; Chen, Nojiri, Sreethawong]

- boost QCD background rejection
- search for $H \to 2a \to 4g$
- start with fat anti-k_T jet
  require mass balance $m_{J,1} \sim m_{j,2}$
  require $p_{T,3} < (p_{T,1} + p_{T,2})/200$
- applied to VH and $t\bar{t}H$ channels
  promising for $m_H = 100$ GeV and 100 fb^{-1}
- how do we test it?

Tops from heavy resonances

Different jet algorithms [Hopkins, Princeton, Seattle; jet shapes]

- boost top reconstruction with $p_T \gtrsim 500$ GeV [isolation and b tagging challenging]
- shown to work on MC [ATLAS, adapted Y-splitter, full sim, ATLAS-2010-008]
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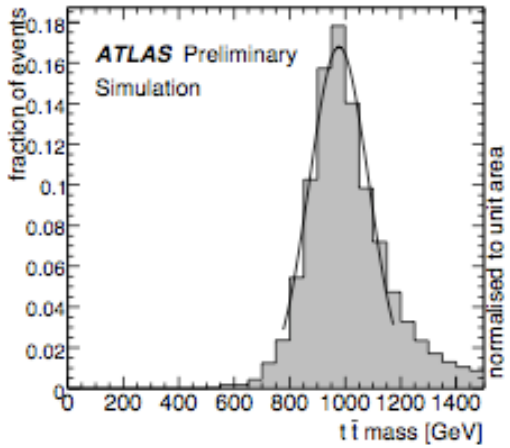
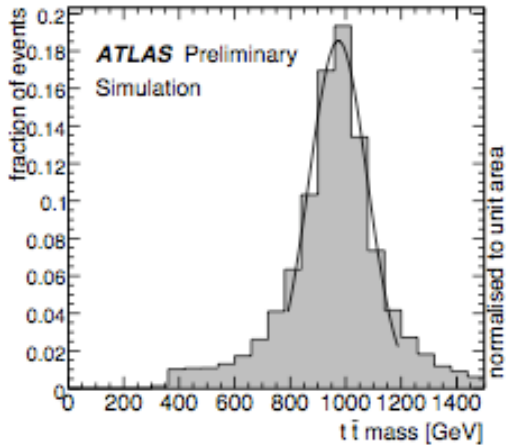
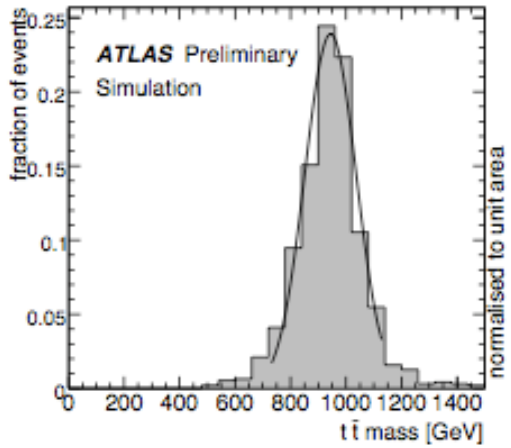
- open: do we need more than calo information?



(a) minimal



(b) full reconstruction



(c) mono-jet

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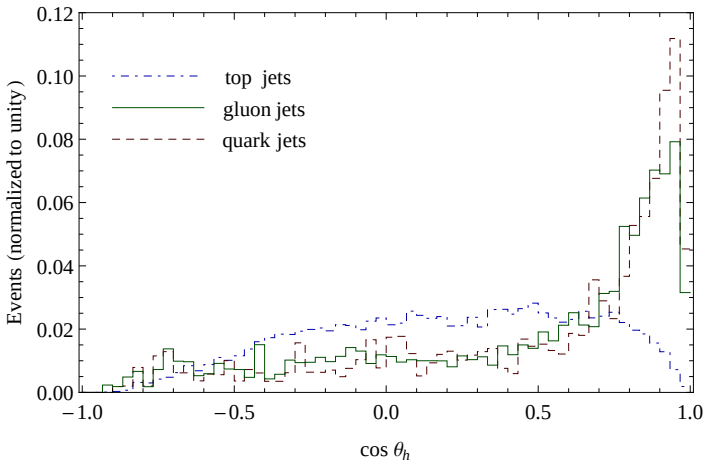

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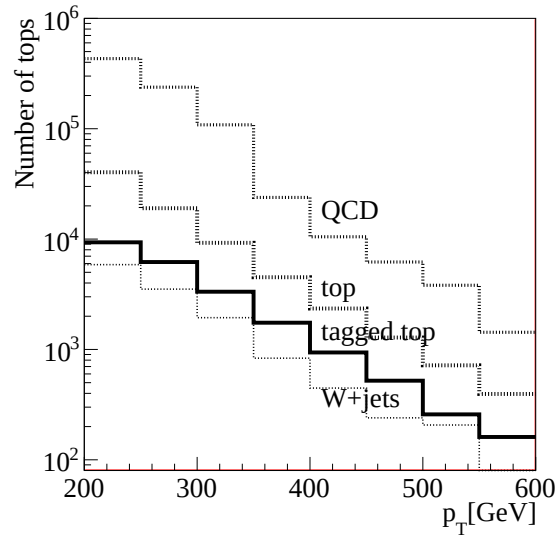
Reality

- many taggers similar at medium-high p_T
- but:
  there is no heavy Z'
  there is no RS graviton
  there are top pairs
- differences at low p_T
  $p_T \gtrsim 250$ GeV possible?
- how to extract 'poorly defined tops'?



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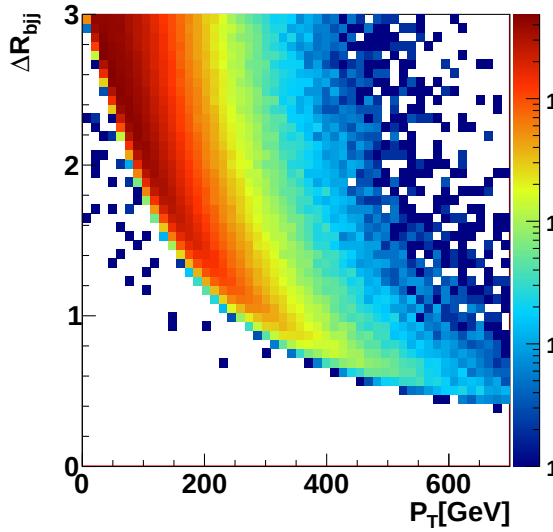

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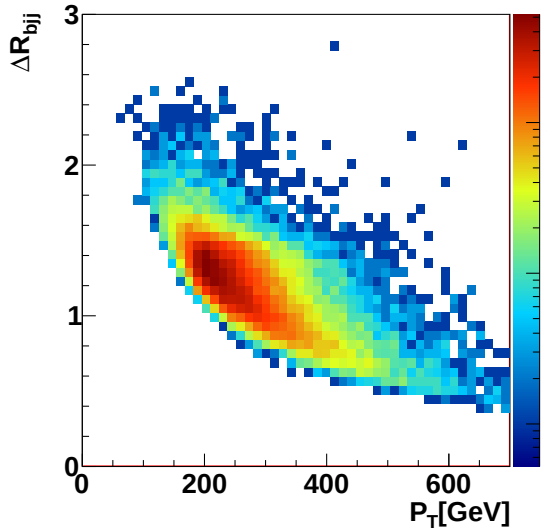

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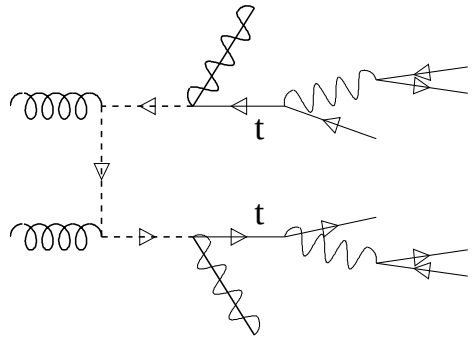

Stop pairs [TP, Spannowsky, Takeuchi, Zerwas; + Salam]

- boost QCD background rejection
- know there are top partners [Meade & Reece]
  know there is dark matter [and the WIMP miracle]
  know there are no FCNC
  search for $\tilde{t} \to t \not{p}_T$ [Graham et al use $\tilde{t} \to tH$]
- 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]
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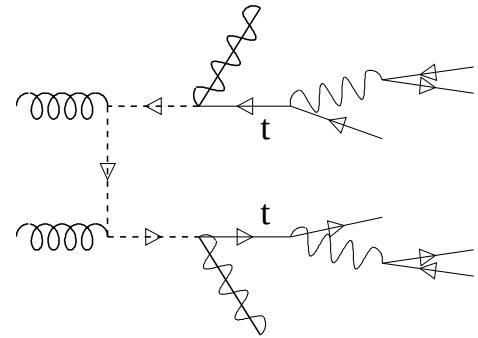

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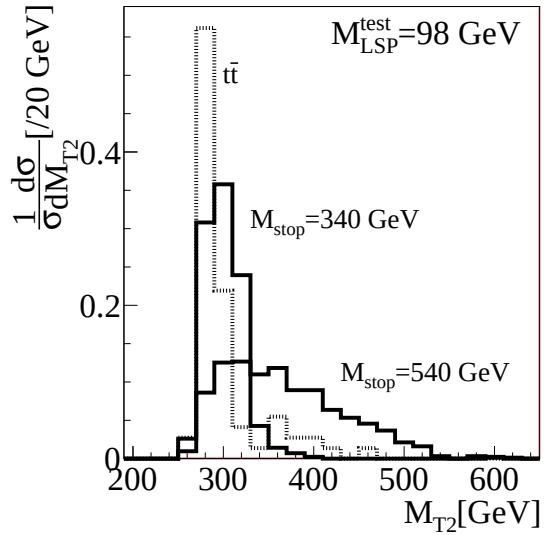

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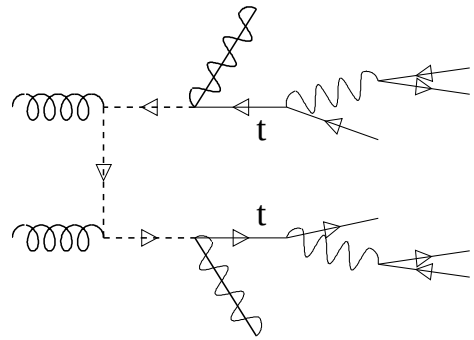

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  include QCD parameters
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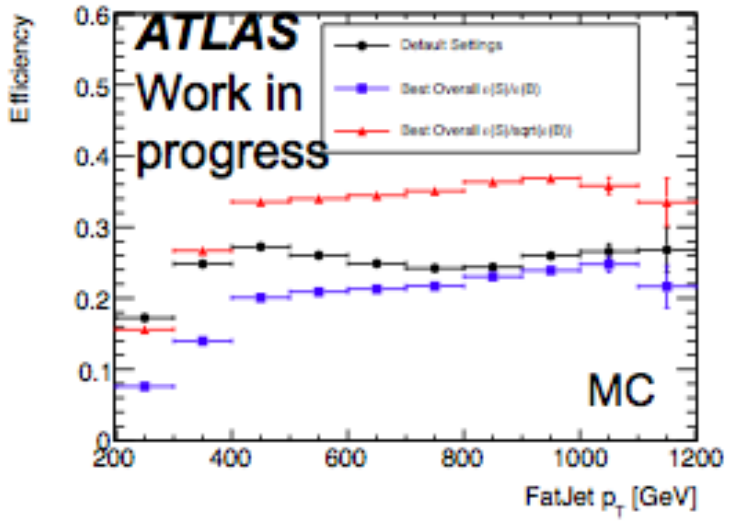
- different optimization for S/B or $S/\sqrt{B}$



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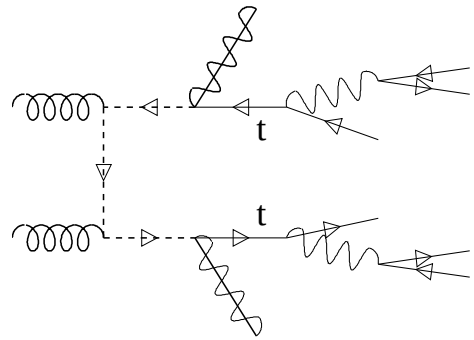

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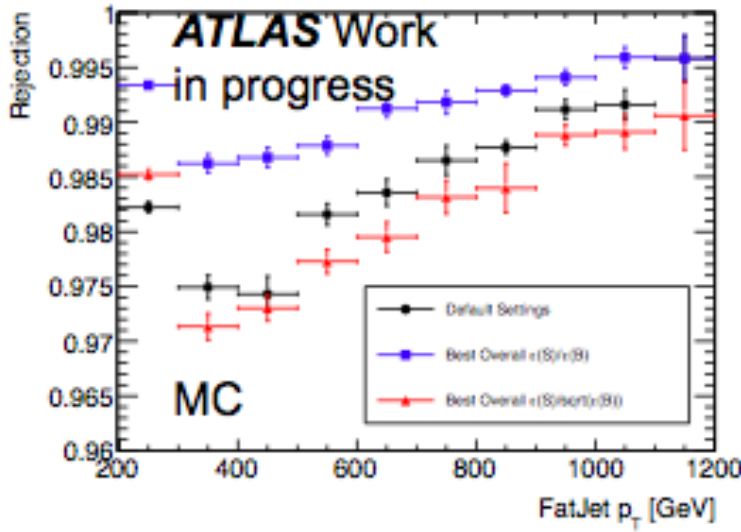

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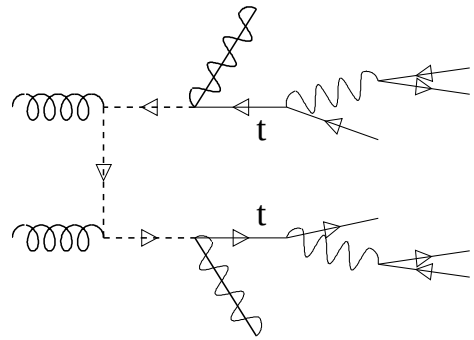

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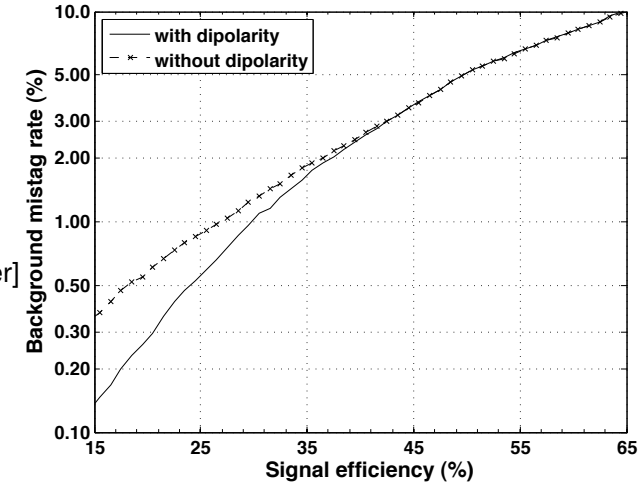
- small dipolarity from W [Baryakthar, Hook, Janowiak, Wacker]

$$\sum_{\text{cells}} p_{T,i} R_i^2$$



Semileptonic top partners

Leptonic (non-)tag [Thaler & Wang; Rehermann & Tweedie; TP, Spannowsky, Takeuchi]

- known: masses of top decay products
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- neutrino coordinates
  leading in $b - \ell$ direction
  sub-leading in $b - \ell$ decay plane
  sub-leading orthogonal to decay plane

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

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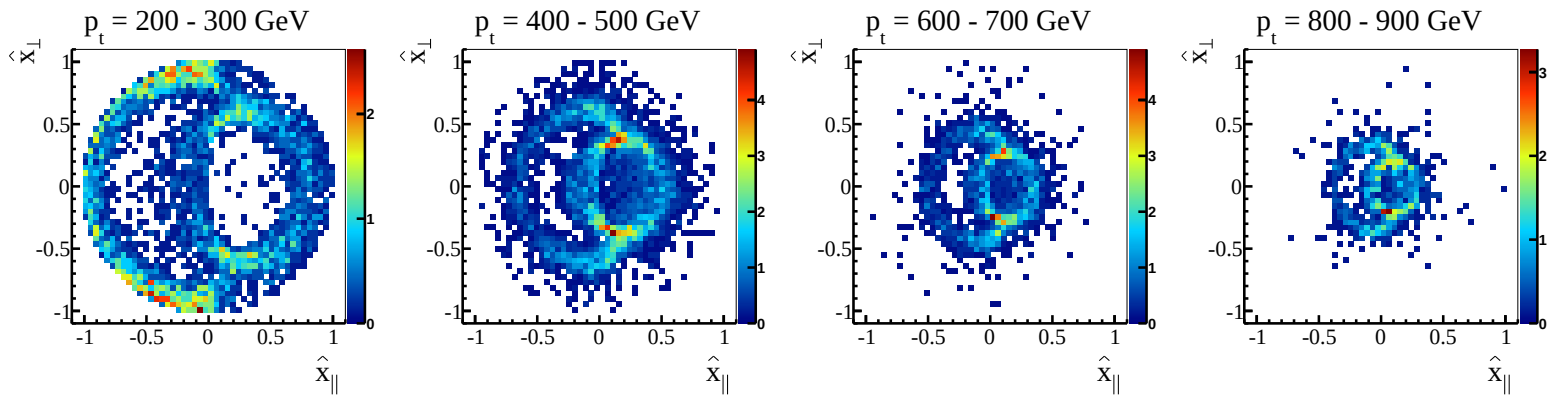

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  'At the LHC, combinatorics make it unlikely that we will be able to observe stop pair production with a decay to a semileptonic top pair and missing energy.' [TP, Spannowsky, Takeuchi, Zerwas]

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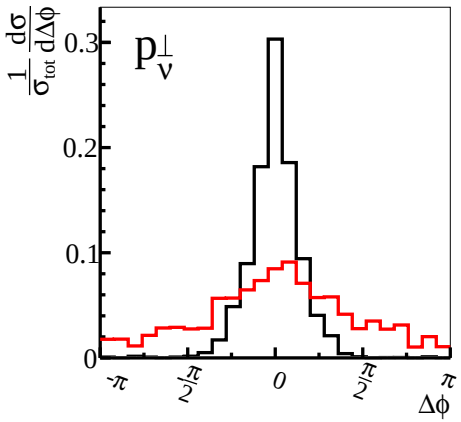

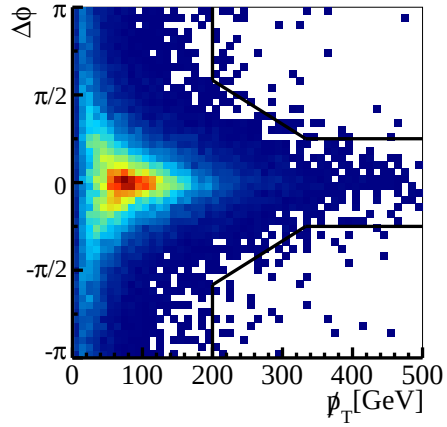

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  unknown: 3-momentum of neutrino
  measured: $E_b, E_\ell, m_{b\ell}$ [rest frame]
- W and t mass constraints
  third parameter elsewhere
  do not use measured $\not{p}_T$ vector
- neutrino coordinates
  leading in $b-\ell$ direction
  sub-leading in $b-\ell$ decay plane
  sub-leading orthogonal to decay plane

  [orthogonal approx $p_\nu^{\parallel}=0$]

  [decay plance approx $p_\nu^{\perp}=0$]
- semileptonic top partners at LHC:

  use approximate $\Delta\Phi(\not{p}_T, \hat{p}_t)$
- top partner decays observable

	orthogonal approximation						decay plane approximation					
	$\tilde{t}_1\tilde{t}_1^*$				$t\bar{t}$	W+jets	S/B	$\tilde{t}_1\tilde{t}_1^*$				$t\bar{t}$	W+jets	S/B
$m_{\tilde{t}}$[GeV]	340	440	540	640			440	340	440	540	640			440
1.-5. base cuts	27.38	13.71	6.33	2.89	642.72	2.63	0.021							
6. approximation	14.81	7.69	3.61	1.66	285.16	1.41	0.027	27.33	13.67	6.31	2.89	642.37	2.63	0.021
7. $p_T^{\text{est}} > 200$GeV	8.61	4.53	2.41	1.24	215.62	0.60	0.021	9.13	5.16	2.87	1.61	242.21	0.54	0.021
8. $\not{p}_T$ vs. $\Delta\phi$ cut	0.97	1.52	1.23	0.76	0.72	0.02	2.06	1.22	1.82	1.53	1.02	1.31	0.06	1.33

Back to the W and Z

Semileptonic $H \to ZZ$ [Englert, Hackstein, Spannowsky]

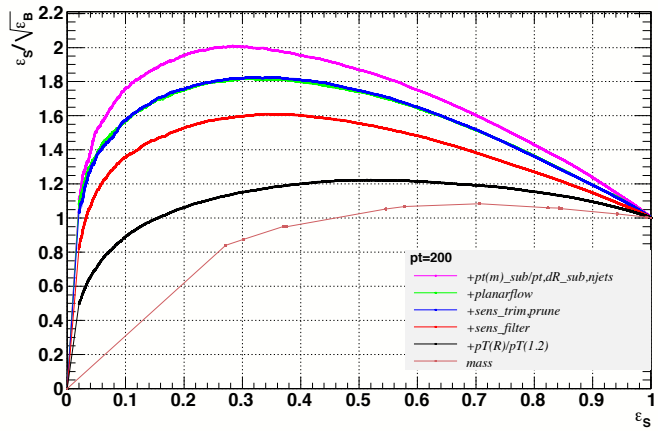
- boost Z+jets background rejection
- inclusive H with WBF contribution
- BDRS inspired, plus trimming+pruning
- promising for $m_H > 400$ GeV $[S/B \sim 1/2]$
- decay plane correlation usable

Again, use QCD structure [Cui, Han, Schwartz]

- boost QCD background rejection [SIC, aka significance improvement]
- mass and p_T in variable cone

$$c_p(R) = \frac{p_T(R)}{p_T(R_{\text{fat}})}$$

- combination in multivariate analysis
- possibility to extract W_L from W_T
- experimentalists, please check!



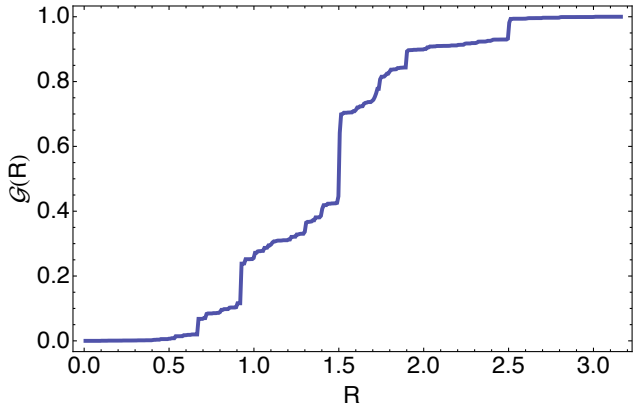
Make taggers less biased

Avoid unclustering [Jankowiak & Larkorski]

– angular correlation function

$$G(R) \sim \frac{\sum (p_{T,i} p_{T,j})\ \Theta(R - \Delta R_{ij})}{\sum (p_{T,i} p_{T,j})}$$

– featureless for QCD
ledge in R for massive particles



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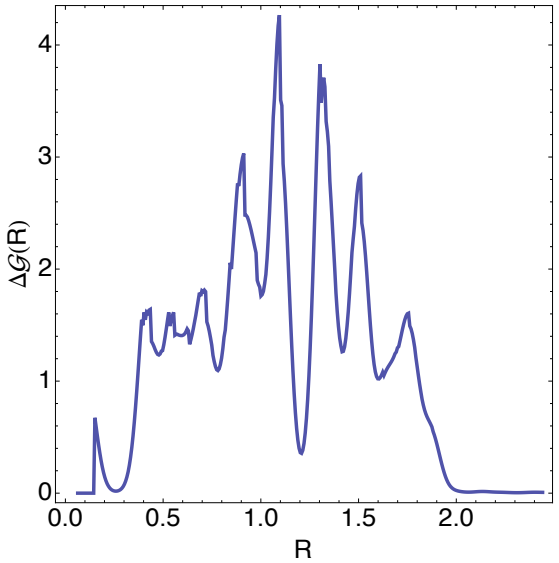
- interesting structure in derivative, $\Delta G(R)$
  look for peaks
  categorize by height ['topographic prominence']
  count number of peaks
- translate peak position into jet mass



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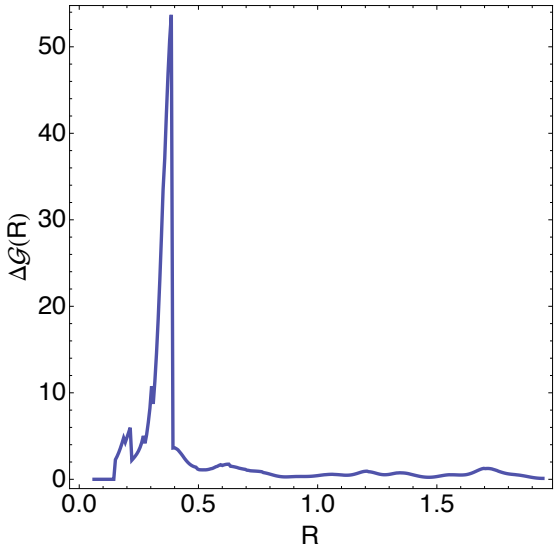

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- worth not using clustering history?

To do: jet algorithms and pileup

Filtering [BDRS, also used in HEPTopTagger]

- designed for C/A algorithm
- reduce effective fat-jet area
  zoom in on relevant final subjets
- number of jets and size negotiable

Pruning [Ellis, Vermillion, Walsh]

- designed for k_T algorithm
- extract relevant collinear splittings in splitting history
- soft/collinearity condition negotiable

Trimming [Krohn, Thaler, Wang]

- designed for anti-k_T algorithm
- remove soft fat jet regions [inverse to filtering]
  slightly different interpretation for k_T algo

- filtering + pruning useful [Spannowsky & Soper]
- should we use more/less of the clustering history?
- and can we do this with pileup?

Outlook

Bottom line from new physics guy turned German

- increase LHC luminosity
- increase LHC energy
- deal with underlying event/pileup
- test, test, test, and on data!

Communication issues solved here

- theorists write taggers
- experimentalists test taggers
- communication illegal [experiments prefers to blog Higgses and write CMSSM papers]
- we would be dead without Heidelberg-ATLAS and their coffee machine

Status of taggers

Tilman Plehn

Higgs

Hadronic tops

Leptonic tops

W/Z bosons

No trees

To do