introduction

HEPTopTagger

stop pairs

hadronic channel

semi-leptonic channel

Leptonic top tagger

Summary

Stop reconstruction with the HEPTopTagger

Michihisa Takeuchi (Uni Heidelberg)

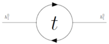
JHEP 1010:078,2010 (arXiv:1006.2833 [hep-ph])
arXiv:1102.0557 [hep-ph]

Princeton University, 24th May 2011

modestly boosted tops at LHC

top partner expected from naturalness

– cancellation expected via top partner in Higgs sector (ex. SUSY, Little Higgs)

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

– $m_{\tilde{t}} \sim 500$ GeV favored to avoid little hierarchy problem

top p_T distribution at the LHC

– boosted top can avoid combinatorics background

– several top taggers available, looking into substructure

[Kaplan, Rehermann, Schwartz, Tweedie] [Thaler, Wang]

[Almeida, Lee, Perez, Sterman, Sung]

designed for $p_T > 500$ GeV, not expected in SM

– $t\bar{t}$ at LHC 7 TeV

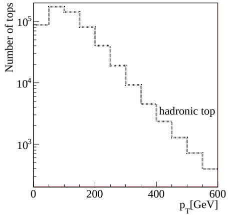
$p_T > 500$ GeV: 150 fb

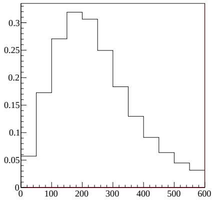
$200 < p_T < 500$ GeV: 8970 fb

– our target: modest p_T range ($200 < p_T < 500$ GeV),

· testable in SM

· expected in top-partner decay





stop $m_{\tilde{t}} = 540$GeV

Plan of talk

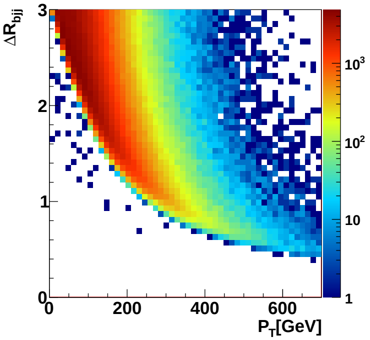
0. Introduction
1. HEPTopTagger (Heidelberg- Eugine-Paris)
2. Application for stop pairs
   2.1 hadronic mode
   2.2 semi-leptonic mode
3. Leptonic top tagger
4. Summary

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

fat jets

– focus on low p_T tops with heavy m_t
  $\longrightarrow$ decay products well separated, need large R

– $R = 1.5$ to have top with $p_T \sim 200$ GeV

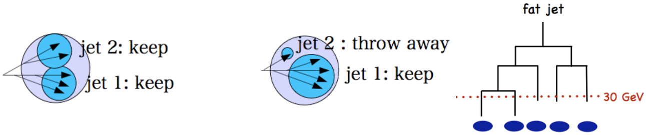


HEPTopTagger

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

1. **fat jets** – C/A($R = 1.5$), $p_T^{\rm fatjet} > 200$ GeV
2. **mass drop criterion**

– find hard proto-jets $m_j < 30$ GeV, $m_{j1} < 0.8 m_j$ to keep j_1 and j_2

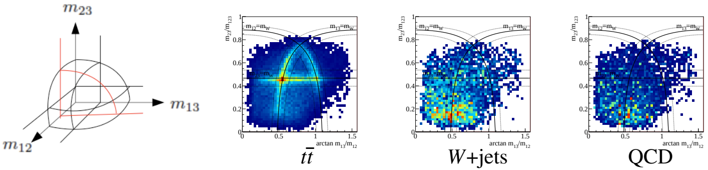


3. **choose 3 hard proto-jets with best filtered mass**

– $|m_{jjj}^{\rm filt} - m_t| < 25$ GeV and $p_T^{\rm rec} > 200$ GeV → top candidate

4. **check mass ratios**

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

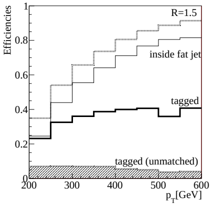


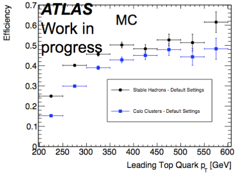
– W mass condition, soft-collinear cut → tagged top

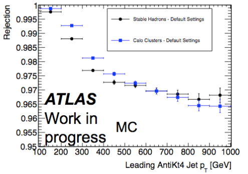
HEPTopTagger

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

efficiency







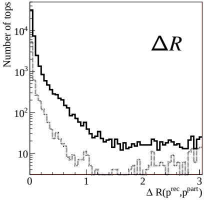
- efficiency $\sim$ 35% for hadronic tops, 2 $\sim$ 4% mis-tag rate
- validation with ATLAS experimentalists in Heidelberg

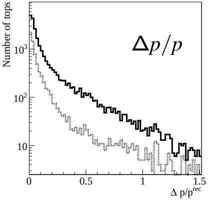
momentum reconstruction

- momentum well reconstructed
- better reconstruction for larger p_T

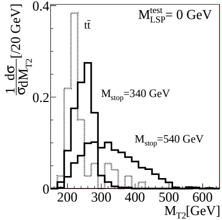
  solid: $p_T^{\rm rec} > 200$GeV

  dotted: $p_T^{\rm rec} > 300$GeV





stop pairs



hadronic $\tilde{t}\tilde{t}^*$ [T. Plehn, M. Spannowsky, MT, D. Zerwas]

- $m_{\tilde{\chi}_1^0} = 98$ GeV, $\tilde{t}_1 \to t\tilde{\chi}_1^0$ (100%)
- main BG: $t\bar{t}$+jets, W+jets and QCD *(Alpgen-Pythia)*
- set of cuts
  - no lepton, $\not{E}_T > 150$ GeV
  - 2 tagged tops with $p_T^{rec} > 200/200$GeV → W+jets, Z+jets negligible
  - b-tag for 1st tagged top → QCD negligible
  - $m_{T2} > 250$GeV → reduce $t\bar{t}$

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	$2.4\cdot10^7$	$1.6\cdot10^5$	n/a	$3.0\cdot10^{-5}$	
$\not{E}_T > 150$ GeV	283	234	184	133	93	35	2245	$2.4\cdot10^5$	1710	2240	$1.2\cdot10^{-3}$	
first top tag	100	91	75	57	42	15	743	7590	90	114	$1.2\cdot10^{-2}$	
second top tag	15	12.4	11	8.4	6.3	2.3	32	129	5.7	1.4	$8.3\cdot10^{-2}$	
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

- $S/B \sim 1, S/\sqrt{B} > 5$ for 10fb^{-1}
- stop mass from $m_{T2}(m_{\tilde{\chi}_1^0})$ endpoint [C. G. Lester, D. J. Summers] [like sleptons or sbottoms]

stop pairs

semileptonic $\tilde{t}_1 \tilde{t}_1^* \to (b \ell \nu \tilde{\chi}_1^0)\,(\bar{b} j j \tilde{\chi}_1^0)$ [arXiv:1102.0557 [hep-ph] T. Plehn, M. Spannowsky, MT]

1. exactly one lepton ($p_T > 20$ GeV, $|\eta| < 2.5$)
2. $\not{E}_T > 150$ GeV
3. one tagged hadronic top (HEPTOPTAGGER, $p_T > 200$ GeV)
4. one b tag among the leading 3 jets outside the tagged top ($p_T > 25$ GeV, $|\eta| < 2.5$)
5. $m_{b\ell} < \sqrt{m_t^2 - m_W^2} = 154.6$ GeV. [cf. CDF m_{jj} by tops (arXiv:1104.4087 T. Plehn, MT)]

	$\tilde{t}_1 \tilde{t}_1^*$				$t\bar{t}$	W+jets	S/B	$S/\sqrt{B}_{20\text{fb}^{-1}}$
$m_{\tilde{t}}$[GeV]	340	440	540	640			440	440
0. cross section	5090	1280	402	146	$9.2 \cdot 10^5$	$2.1 \cdot 10^5$	0.001	3.8
1. one lepton	1471	373	118	42.5	$2.6 \cdot 10^5$	$1.3 \cdot 10^5$	0.001	2.7
2. $\not{E}_T > 150$ GeV	569	239	90.2	35.5	9825	4512	0.017	8.9
3. hadronic top tag	74.5	38.0	16.8	7.72	1657	141	0.021	4.0
4. tagged b jet	31.2	15.9	7.33	3.38	668	4.35	0.024	2.7
5. $m_{b\ell} < m_{b\ell}^{\max}$	27.5	13.7	6.34	2.90	642	2.61	0.021	2.4

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– cut basis method:

· use $\not{E}_T = p_{\nu,T}$

· check solution for $p_{\nu,z}$

– not promising $S/B \sim 0.1$, $S/\sqrt{B}_{10\text{ fb}^{-1}} \sim 2.2$

– not reasonable with additional $\not{E}_T$ sources.

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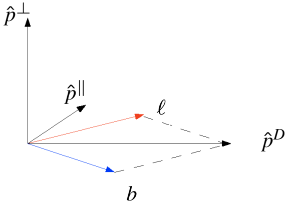
– not promising $S/B \sim 0.1$, $S/\sqrt{B}_{10\text{ fb}^{-1}} \sim 2.2$

– not reasonable with additional $\not{E}_T$ sources.

$\to$ our approach:
  · reconstruct top momentum
  · compare with $\not{E}_T$

Leptonic Top Tagger

[arXiv:1102.0557 [hep-ph] T. Plehn, M. Spannowsky, MT]



only 3 observable in lab. frame

$$E_\ell, \quad E_b, \quad m_{b\ell} \text{ (equivalent to } \theta_{bl})$$

ν momentum in lab. frame

$$\vec{p}_\nu = x_{\rm D}\hat{p}^{\rm D} + x_{||}\hat{p}^{||} + x_\perp \hat{p}^\perp .$$

$$\hat{p}^{\rm D} = \frac{\vec{p}_{b\ell}}{|\vec{p}_{b\ell}|}$$ leading $\vec{p}_{b\ell}$ direction in $b-\ell$ decay plane

$$\hat{p}^{||} = \frac{\vec{p}_\ell - (\vec{p}_\ell \cdot \hat{p}^{\rm D})\,\hat{p}^{\rm D}}{|\vec{p}_\ell - (\vec{p}_\ell \cdot \hat{p}^{\rm D})\,\hat{p}^{\rm D}|}$$ subleading direction in $b-\ell$ decay plane

$$\hat{p}^\perp = \hat{p}^{\rm D} \times \hat{p}^{||}$$ subleading direction to $b-\ell$ decay plane.

2 constraints

$$(p_\ell + p_b + p_\nu)^2 = m_t^2, \qquad (p_\ell + p_\nu)^2 = m_W^2 \ .$$

one additional assumption is needed to solve neutrino momentum.

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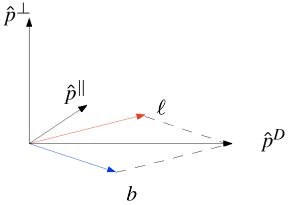

additional assumptions

$$\vec{p}_\nu = x_{\rm D}\hat{p}^{\rm D} + x_{\|}\hat{p}^{\|} + x_{\perp}\hat{p}^{\perp}.$$

decay plane approximation

- $x_{\perp} = 0$

orthogonal approximation

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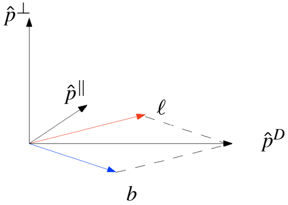

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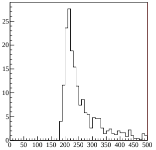
  - suggested by constrained probabilty distribution $P(p_{\rm top}, E_b, E_l, m_{bl})|_{E_b,E_l,m_{bl}}$



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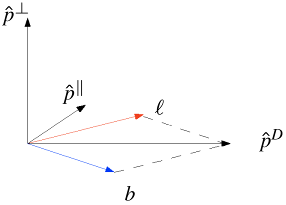

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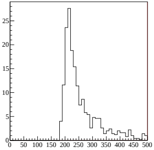

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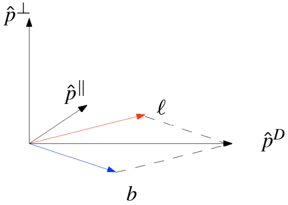

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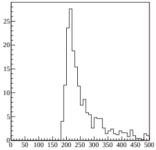

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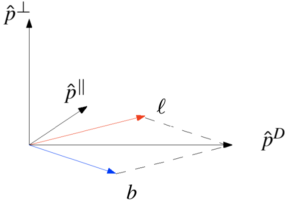

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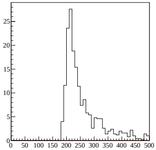

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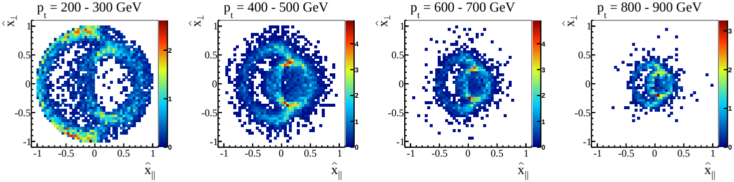
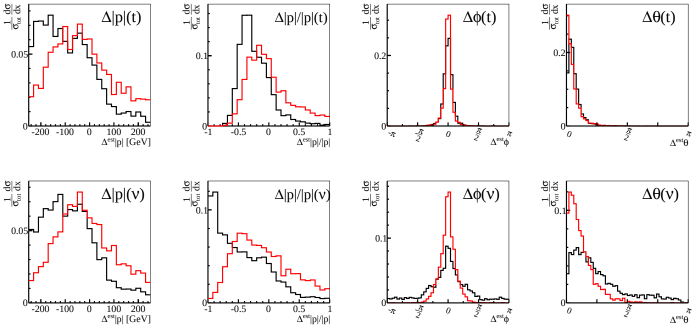


Leptonic Top Tagger

[arXiv:1102.0557 [hep-ph] T. Plehn, M. Spannowsky, MT]

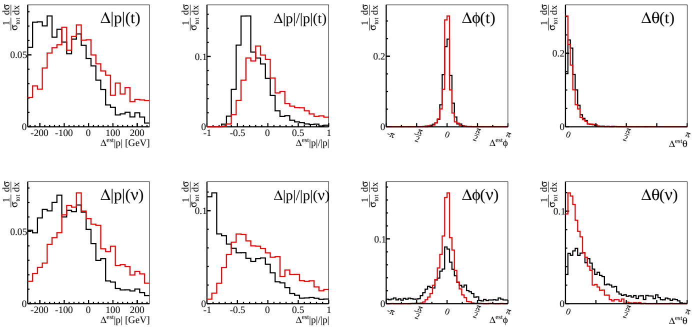
momentum reconstruction ($\not{E}_T > 200\text{GeV}$)



- red: orthogonal approx. black: decay plane approx.
- $\Delta|p|(t) = |p_{\text{top}}^{\text{rec}}| - |p_{\text{top}}^{\text{parton}}|, \quad \Delta|p|(\nu) = |p_{\nu}^{\text{rec}}| - |p_{\nu}^{\text{parton}}|$
- better top momentum reconstruction (compared with ν)
- in particular, good ϕ reconstruction.

Leptonic Top Tagger [arXiv:1102.0557 [hep-ph] T. Plehn, M. Spannowsky, MT]

momentum reconstruction ($\not{E}_T > 200\text{GeV}$)



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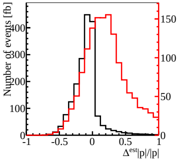
- better top momentum reconstruction (compared with ν)
- in particular, good ϕ reconstruction.
- without $\not{E}_T$ cut, better reconstruction for decay plane approx.

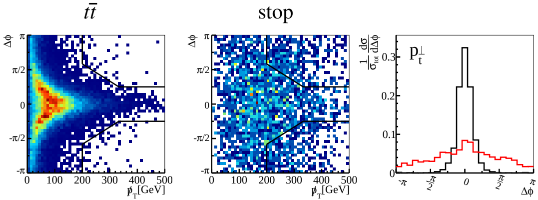


Leptonic Top Tagger

[arXiv:1102.0557 [hep-ph] T. Plehn, M. Spannowsky, MT]

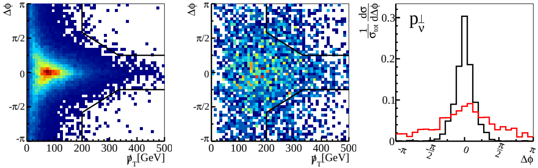
ϕ_{top} vs. $\not{E}_T$ correlation

$$\Delta\phi_{\text{top}} = \phi^{\text{rec}}_{\text{top}} - \phi(\not{E}_T)$$



for events with large $\not{E}_T$, top direction and neutrino direction is aligned.

$$\Delta\phi_{\nu} = \phi^{\text{rec}}_{\nu} - \phi(\not{E}_T)$$



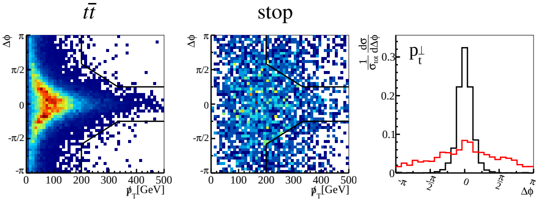
$\Delta\phi_{\text{top}}$ provides better separation

Leptonic Top Tagger

[arXiv:1102.0557 [hep-ph] T. Plehn, M. Spannowsky, MT]

ϕ_{top} vs. $\not{E}_T$ correlation

$$\Delta\phi_{\text{top}} = \phi^{\text{rec}}_{\text{top}} - \phi(\not{E}_T)$$



for events with large $\not{E}_T$, top direction and neutrino direction is aligned.

$$|\Delta\phi| > \frac{13}{12}\pi - \frac{\not{E}_T}{400\ \text{GeV}}\pi \qquad \not{E}_T > 200\ \ \text{GeV} \qquad |\Delta\phi| > \frac{\pi}{4}.$$

	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. $p_T^{\text{est}} >$ 200GeV	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. $\not{E}_T$ 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

– $S/B \sim 2, S/\sqrt{B}_{10\text{fb}^{-1}} \sim 5$ (cut basis: $S/B \sim 0.1, S/\sqrt{B}_{10\text{fb}^{-1}} \sim 2.2$)

Summary

- top: closest to new physics
- HEPTopTagger
  - focus on modest boosted p_T tops ($p_T > 200$GeV), testable in SM
  - fat jets kill combinatorics
  - efficiency: top $\sim 35\%$, mis-tag rate$W$+jets: 4%, QCD: 2%
  - hadronic top momentum well reconstructed
  - leptonic top: orthogonal approx. $\longrightarrow$ good direction reconstruction

- stop pairs
  - hadronic channel: $S/B \sim 1$, $S/\sqrt{B} > 5$ for 10fb^{-1}
  - semi-leptonic channel: $S/B \sim 2$, $S/\sqrt{B} > 5$ for 10fb^{-1}
- A^t_{FB} [$\longrightarrow$ Jessie's talk]

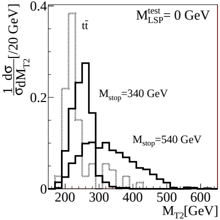
- HEPTopTagger: (Heidelberg-Eugine-Paris)

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

Back up

stop pairs

hadronic $\tilde{t}\tilde{t}^*$ [T. Plehn, M. Spannowsky, MT, D. Zerwas]



- main BG: $t\bar{t}$+jets, W+jets and QCD
- upto $t\bar{t}$+2jets, W+4jets and 5jets (QCD) by *Pythia-Alpgen*
- signal by *Herwig++*, $m_{\tilde{\chi}_1^0} = 98$ GeV, $\tilde{t}_1 \to t\tilde{\chi}_1^0$ (100%)
- set of cuts
  - 2 fat jets with $p_{T,j} > 200/200$GeV
  - veto isolated lepton
  - $\not{E}_T > 150$ GeV
  - 2 tagged tops with $p_T^{rec} > 200/200$GeV $\longrightarrow$ W+jets, Z+jets negligible
  - b-tag for 1st tagged top $\longrightarrow$ QCD negligible
  - $m_{T2} > 250$GeV $\longrightarrow$ reduce $t\bar{t}$

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

- $S/B \sim 1, S/\sqrt{B} > 5$ for 10fb^{-1}
- stop mass from $m_{T2}(m_{\tilde{\chi}_1^0})$ endpoint [C. G. Lester, D. J. Summers] [like sleptons or sbottoms]

introduction

HEPTopTagger

stop pairs

hadronic channel

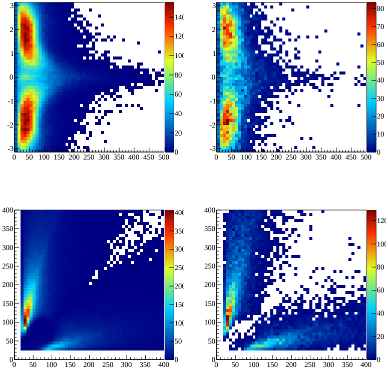
semi-leptonic channel

Leptonic top tagger

Summary

2d

	$t\bar{t}$	W+jets
CS	918000	211400
$n_\ell = 1$ (loose)	272608	140884
$n_\ell = 1$	192127	118570
l+jets	121835	58479
m_{bl}	120825	56930
LEPtagger	40665	17346
$\Delta\phi < \pi/4$	17131	6040
$\not{E}_T > 150$	1234	556
& $\Delta\phi < \pi/4$	1010	394



– $x : p_\ell, y : p_b$

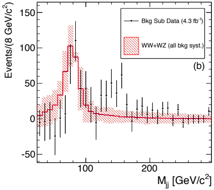
W+jets anomaly at CDF [arXiv:1104.4087 [hep-ph] T. Plehn, MT]

di-boson production cross section

- $\sigma(WW + WZ) = 18.1 \pm 3.3(\text{stat}) \pm 2.5(\text{syst})$ pb (combined channels)
  $\sigma(WW + WZ) = 23.5 \pm 4.9$pb (muon channel)
  $\sigma(WW + WZ) = 13.5 \pm 4.4$pb (electron channel)
- large systematic uncertainty?

hard cuts

- second peak at $\sim$ 150GeV
  - one isolated lepton
  - exactly 2 jets with $E_T > 30$GeV
  - second lepton veto
- $\Delta N_{[120,170]} > 100$ events including syst. uncertainty.



Intrinsic peak from hadronic top

- $t \to bjj$ (combinatorics)
- m_{bj} peak $\sim$ 140 GeV
- $\Delta N_{[120,170]} \sim 230 \dfrac{\Delta\sigma_{top}}{\sigma_{top}}$
  (including cut acceptance)

$\to \dfrac{\Delta\sigma_{top}}{\sigma_{top}} \sim 40\%$ needed