## Combination single top $+t\bar{t}$ $tZ \rightarrow 1b3\ell$

#### Lorenzo Basso

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#### Optimisation - almost matched Isis's

- LEPTONS:  $|\eta| < 2.5(2.4)$  for  $e/\mu$  $p_{\ell}^T > 20$  GeV, ISO: CONE04,  $I_{rel} < 0.20 \ e/\mu$
- JETS:  $p_i^T > 40 \text{ GeV}, |\eta| < 2.4, 1/\text{EEoverHE} > 0.15$ 
  - loose JETS  $30 < p_j^T < 40$  GeV,  $|\eta| < 2.4$ , 1/EeoverHE > 0.15
- Selections:
  - $N_J \ge 1$  (J =light and b jets); (if  $N_J \equiv 1$ , then also  $N_j^{loose} \equiv 0$ )
  - 2  $N_b \ge 1$  to reduce WZ,  $N_b \le 1$  once WZ is removed  $\Rightarrow N_b \equiv 1$
  - Solution 2 candidate as pair of  $e^+e^-(\mu^+\mu^-)$  closest to  $M_Z$ and  $|M_{\ell\ell} - M_Z| < 15$  GeV

Here, MVA or Cut&Count with

- loose W reco:  $10 < M^T(\nu \ell_W) / \text{GeV} < 150$
- loose top reco:  $M^T(\nu b \ell_W)/\text{GeV} < 215$
- top reco 2:  $M(b \ell_W)/\text{GeV} < 150$

## $N_j \ge 1$

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#### Backgrounds - cutflow



# MVA – BDT

- training on sum of signals (naive combination)
- one training each for κ<sub>zut</sub> and κ<sub>zct</sub>
- inclusive sample
- training on background without  $t\bar{t}$

#### Variables for $\kappa_{zut}$

Filled after the  $M(\ell^+\ell^-) - M_Z < 15$  GeV cut.

11 Variables with relative importance when trained considering all backgrounds without  $t\bar{t}$ :

Variable	Importance
$M(\ell b)$	$1.9910^{-1}$
M(jZ)	$1.4710^{-1}$
$p^T(Z)$	$1.1910^{-1}$
$\Delta R(b, \ell_W)$	$9.5810^{-2}$
M(tZ)	$8.3010^{-2}$
$p^T(j_1)$	$7.5010^{-2}$
$Q(\ell_W)$	$7.0910^{-2}$
$\Delta R(Z, \ell_W)$	$7.05  10^{-2}$
$\Delta R(t, Z)$	$5.1810^{-2}$
$\Delta R(Z, \text{MET})$	$4.2210^{-2}$
$\Delta \phi(t Z)$	$4.3910^{-2}$

where  $Q(\ell_W) \equiv Q(\ell_W) \times |eta(\ell_W)|$ . Low discriminating variables are kept because work well with  $t\bar{t}$ .

#### $\kappa_{zut}$ : overtraining



#### Variables for $\kappa_{zct}$

Filled after the  $M(\ell^+\ell^-) - M_Z < 15$  GeV cut.

10 Variables with relative importance when trained considering all backgrounds, including  $t\bar{t}$ :

Variable	Importance
$M(\ell b)$	$2.1110^{-1}$
M(jZ)	$1.6910^{-1}$
$p^T(j_1)$	$1.2010^{-1}$
$\Delta R(\ell_W, Z)$	$9.6410^{-2}$
MET	$9.2410^{-2}$
$p^T(Z)$	$8.7310^{-2}$
$\Delta R(b, W)$	$7.3610^{-2}$
$\Delta R(Z, \text{MET})$	$6.5410^{-2}$
$\Delta \phi(t, Z)$	$4.4510^{-2}$
$\Delta R(t, Z)$	$4.1110^{-2}$

#### $\kappa_{zct}$ : overtraining



#### **BDT** output



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#### Reading of sum of signals



#### Reading of sum vs single signals



Reading: Blue: zut, Red: zct

#### MVA: 2D limits



Present limit:  $BR(t \rightarrow Zq) < 0.05\%$ ,  $K_{Ztq} < 0.2 \text{ TeV}^{-1}$ 

#### Cut-and-count

Cut	Sum Bg	Signal K-zct	Signal K-zut	Signal ttbar Kc	Signal ttbar Ku
nocuts	$662298806 \pm 223501$	$267 \pm 0$	$2263 \pm 3$	$2133 \pm 1$	$2128 \pm 1$
$N_j >= 1$	$133102305 \pm 105036$	$218 \pm 0$	$1730 \pm 3$	$1988 \pm 1$	$1976 \pm 1$
lep = 3	$10901 \pm 385$	$27 \pm 0$	$176 \pm 1$	$217 \pm 0$	$215 \pm 0$
nOSSF > 0	$10610 \pm 384$	$27 \pm 0$	$176 \pm 1$	$216 \pm 0$	$214 \pm 0$
nbjets = 1	$973 \pm 16$	$17 \pm 0$	$103 \pm 1$	$108 \pm 0$	$104 \pm 0$
Mll - MZ  < 15	$618 \pm 9$	$16 \pm 0$	$93 \pm 1$	$103 \pm 0$	$99 \pm 0$
$M^T lnu < 120$	$535 \pm 8$	$15 \pm 0$	$85 \pm 1$	$97 \pm 0$	$94 \pm 0$
$M^T lbnu < 220$	$343 \pm 6$	$14 \pm 0$	$81 \pm 1$	$86 \pm 0$	$87 \pm 0$
M(lb) < 150	$308 \pm 6$	$14 \pm 0$	$79 \pm 1$	$82 \pm 0$	$84 \pm 0$
	$0 \pm 0$	$0 \pm 0$	$0 \pm 0$	$0 \pm 0$	$0 \pm 0$
	$0 \pm 0$	$0 \pm 0$	$0 \pm 0$	$0 \pm 0$	$0 \pm 0$
	$0 \pm 0$	$0 \pm 0$	$0 \pm 0$	$0 \pm 0$	$0 \pm 0$
	$0 \pm 0$	$0 \pm 0$	$0 \pm 0$	$0 \pm 0$	$0 \pm 0$
	$0 \pm 0$	$0 \pm 0$	$0 \pm 0$	$0 \pm 0$	$0 \pm 0$
	$0 \pm 0$	$0 \pm 0$	$0 \pm 0$	$0 \pm 0$	$0 \pm 0$
	$0 \pm 0$	$0 \pm 0$	$0 \pm 0$	$0 \pm 0$	$0 \pm 0$
	$0 \pm 0$	$0 \pm 0$	$0 \pm 0$	$0 \pm 0$	$0 \pm 0$

Cut	TT+V+jets	TT+jets	TZq	VV+jets	ZToLL
nocuts	$6087 \pm 11$	$7439298 \pm 2305$	$2097 \pm 1$	$286524 \pm 87$	$654564800 \pm 2234$
$Nj \ge 1$	$5842 \pm 11$	$6776868 \pm 2212$	$1747 \pm 1$	$101176 \pm 53$	$126216672 \pm 1050$
lep = 3	$504 \pm 3$	$794 \pm 24$	$181 \pm 0$	$7236 \pm 14$	$2186 \pm 384$
nOSSF > 0	$457 \pm 3$	$571 \pm 21$	$181 \pm 0$	$7215 \pm 14$	$2186 \pm 384$
nbjets = 1	$240 \pm 2$	$340 \pm 16$	$102 \pm 0$	$291 \pm 3$	$0 \pm 0$
Mll - MZ  < 15	$164 \pm 2$	$98 \pm 9$	$94 \pm 0$	$262 \pm 3$	$0 \pm 0$
$M^T lnu < 120$	$132 \pm 1$	$75 \pm 8$	$89 \pm 0$	$239 \pm 3$	$0 \pm 0$
$M^T lbnu < 220$	$84 \pm 1$	$44 \pm 6$	$84 \pm 0$	$131 \pm 2$	$0 \pm 0$
M(lb) < 150	$78 \pm 1$	$42 \pm 6$	$81 \pm 0$	$107 \pm 2$	$0 \pm 0$
	$0 \pm 0$	$0 \pm 0$	$0 \pm 0$	$0 \pm 0$	$0 \pm 0$
	$0 \pm 0$	$0 \pm 0$	$0 \pm 0$	$0 \pm 0$	$0 \pm 0$
	$0 \pm 0$	$0 \pm 0$	$0 \pm 0$	$0 \pm 0$	$0 \pm 0$
	$0 \pm 0$	$0 \pm 0$	$0 \pm 0$	$0 \pm 0$	$0 \pm 0$
	$0 \pm 0$	$0 \pm 0$	$0 \pm 0$	$0 \pm 0$	$0 \pm 0$
	$0 \pm 0$	$0 \pm 0$	$0 \pm 0$	$0 \pm 0$	$0 \pm 0$
	$0 \pm 0$	$0 \pm 0$	0 ± 0	$0 \pm 0$	$0 \pm 0$
	$0 \pm 0$	$0 \pm 0$	$0 \pm 0$	$0 \pm 0$	$0 \pm 0$

## Significance

Cut	Signal K-zct	Signal K-zut	Signal ttbar Kc	Signal ttbar Ku	comb (c)	comb (u)
nocuts	0.010	0.088	0.083	0.083	0.093	0.171
$Nj \ge 1$	0.019	0.150	0.172	0.171	0.191	0.321
lep = 3	0.260	1.677	2.054	2.035	2.309	3.680
nOSSF > 0	0.263	1.691	2.076	2.056	2.334	3.715
nbjets = 1	0.545	3.131	3.290	3.174	3.783	6.022
Mll - MZ  < 15	0.628	3.496	3.835	3.704	4.376	6.760
$M^T lnu < 120$	0.636	3.427	3.861	3.732	4.403	6.697
$M^T lbnu < 220$	0.756	3.947	4.156	4.218	4.767	7.462
M(lb) < 150	0.771	4.022	4.155	4.260	4.771	7.530
	-nan	-nan	-nan	-nan	-nan	-nan
	-nan	-nan	-nan	-nan	-nan	-nan
	-nan	-nan	-nan	-nan	-nan	-nan
	-nan	-nan	-nan	-nan	-nan	-nan
	-nan	-nan	-nan	-nan	-nan	-nan
	-nan	-nan	-nan	-nan	-nan	-nan
	-nan	-nan	-nan	-nan	-nan	-nan
	-nan	-nan	-nan	-nan	-nan	-nan

MVA highest significances when each signal is trained against itself:

$$\kappa_{zut} = 8.38\sigma, S = 139.727, B = 138.566,$$

$$\kappa_{zct} = 5.01\sigma, S = 72.925, B = 139.291$$

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# $N_j \equiv 1$

Need to drop M(jZ) as observable because there is no light jet For zct training, drop also MET

#### Backgrounds - cutflow



#### $\kappa_{zut}$ : overtraining

#### zut training

#### zct training



#### BDT output



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#### MVA: 2D limits



Present limit:  $BR(t \rightarrow Zq) < 0.05\%$ ,  $K_{Ztq} < 0.2 \text{ TeV}^{-1}$ 

#### Cut-and-count

0	C D	0: 1 IZ t	$0^{\circ} - 1 V - i$	0: 1.01 IZ	0	
Cut	Sum Bg	Signal K-zct	Signaí K-zut	Signal ttbar Ke	Signai übar Ku	
nocuts	$662298806 \pm 223$	501 $267 \pm 0$	$2263 \pm 3$	$2133 \pm 1$	$2128 \pm 1$	
Nj = 1	$94794063 \pm 8423$	$24  99 \pm 0$	$780 \pm 2$	$364 \pm 0$	$3/2 \pm 0$	
tep = 3	$6628 \pm 320$	$17 \pm 0$ $17 \pm 0$	$105 \pm 1$	$57 \pm 0$	$58 \pm 0$	
nOSSF > 0	$0507 \pm 320$	$17 \pm 0$	$105 \pm 1$	$57 \pm 0$	$58 \pm 0$	
nbjets = 1	$405 \pm 11$ $250 \pm 6$	$11 \pm 0$ 10 ± 0	$62 \pm 0$ 56 ± 0	$24 \pm 0$ $22 \pm 0$	$20 \pm 0$ 10 ± 0	
MU - MZ  < 15 MThm < 100	$239 \pm 6$ $320 \pm 6$	$10 \pm 0$ 0 ± 0	$50 \pm 0$ 52 ± 0	$23 \pm 0$ $21 \pm 0$	19 ± 0	
$M^* lnu < 120$ $M^T lhave < 0.00$	229 ± 0	$9 \pm 0$ 0 + 0	$52 \pm 0$ 50 ± 0	$21 \pm 0$ 18 ± 0	18 ± 0	
M(lb) < 150	$135 \pm 5$ $136 \pm 4$	$3 \pm 0$ $0 \pm 0$	$48 \pm 0$	$13 \pm 0$ $17 \pm 0$	16 ± 0	
m(m) < 100	$130 \pm 4$ 0 ± 0	$0 \pm 0$ 0 ± 0	40 ± 0	0 ± 0	0 ± 0	
	0 ± 0	$0 \pm 0$ 0 ± 0	0 ± 0	0 ± 0	0 ± 0	
	0 ± 0	$0 \pm 0$ 0 ± 0	0 ± 0	$0 \pm 0$ 0 ± 0	0 ± 0	
	$0 \pm 0$ 0 ± 0	$0 \pm 0$ 0 ± 0	0 ± 0	$0 \pm 0$ 0 ± 0	0 ± 0	
	$0 \pm 0$	$0 \pm 0$	$0 \pm 0$	$0 \pm 0$	$0 \pm 0$	
	$0 \pm 0$	$0 \pm 0$	$0 \pm 0$	$0 \pm 0$	$0 \pm 0$	
	$0 \pm 0$	$0 \pm 0$	$0 \pm 0$	$0 \pm 0$	$0 \pm 0$	
	$0 \pm 0$	$0 \pm 0$	$0 \pm 0$	$0 \pm 0$	$0 \pm 0$	
Cut	TT+V+jets	TT+jets	TZq	VV+jets	ZToLL	
nocuts	$6087 \pm 11$	$7439298 \pm 2305$	$2097 \pm 1$	$286524 \pm 87$	$654564800 \pm 2234$	
Nj = 1	$647 \pm 4$	$1320496 \pm 997$	$717 \pm 0$	$53818~\pm 39$	$93418384 \pm 8421$	
lep = 3	$99 \pm 1$	$342 \pm 16$	$94 \pm 0$	$4469 \pm 11$	$1624 \pm 319$	
nOSSF > 0	$87 \pm 1$	$245 \pm 14$	$93 \pm 0$	$4458 \pm 11$	$1624 \pm 319$	
nbjets = 1	$53 \pm 1$	$157 \pm 11$	$50 \pm 0$	$145 \pm 2$	$0 \pm 0$	
Mll - MZ  < 15	$32 \pm 1$	$50 \pm 6$	$46 \pm 0$	$130 \pm 2$	$0 \pm 0$	
$M^T lnu < 120$						
	$24 \pm 1$	$41 \pm 6$	$44 \pm 0$	$120 \pm 2$	$0 \pm 0$	
$M^T lbnu < 220$	$24 \pm 1$ $14 \pm 0$	$41 \pm 6$ $26 \pm 4$	$44 \pm 0$ $42 \pm 0$	$120 \pm 2$ $72 \pm 1$	$0 \pm 0 \\ 0 \pm 0$	
$M^T lbnu < 220$ M(lb) < 150	$24 \pm 1$ $14 \pm 0$ $13 \pm 0$	$41 \pm 6$ $26 \pm 4$ $23 \pm 4$	$44 \pm 0$ $42 \pm 0$ $40 \pm 0$	$120 \pm 2$ $72 \pm 1$ $59 \pm 1$	$0 \pm 0$ $0 \pm 0$ $0 \pm 0$	
$\begin{array}{l} M^T lbnu < 220 \\ M(lb) < 150 \end{array}$	$24 \pm 1$ $14 \pm 0$ $13 \pm 0$ $0 \pm 0$	$41 \pm 6$ $26 \pm 4$ $23 \pm 4$ $0 \pm 0$	$44 \pm 0$ $42 \pm 0$ $40 \pm 0$ $0 \pm 0$	$120 \pm 2$ $72 \pm 1$ $59 \pm 1$ $0 \pm 0$	$0 \pm 0$ $0 \pm 0$ $0 \pm 0$ $0 \pm 0$	
$\begin{array}{l} M^T lbnu < 220 \\ M(lb) < 150 \end{array}$	$24 \pm 1$ $14 \pm 0$ $13 \pm 0$ $0 \pm 0$ $0 \pm 0$	$41 \pm 6$ $26 \pm 4$ $23 \pm 4$ $0 \pm 0$ $0 \pm 0$	$44 \pm 0$ $42 \pm 0$ $40 \pm 0$ $0 \pm 0$ $0 \pm 0$	$120 \pm 2$ $72 \pm 1$ $59 \pm 1$ $0 \pm 0$ $0 \pm 0$	$0 \pm 0$ $0 \pm 0$ $0 \pm 0$ $0 \pm 0$ $0 \pm 0$ $0 \pm 0$	
$\begin{array}{l} M^T lbnu < 220 \\ M(lb) < 150 \end{array}$	$24 \pm 1$ $14 \pm 0$ $13 \pm 0$ $0 \pm 0$ $0 \pm 0$ $0 \pm 0$	$41 \pm 6$ $26 \pm 4$ $23 \pm 4$ $0 \pm 0$ $0 \pm 0$ $0 \pm 0$	$44 \pm 0$ $42 \pm 0$ $40 \pm 0$ $0 \pm 0$ $0 \pm 0$ $0 \pm 0$	$120 \pm 2$ $72 \pm 1$ $59 \pm 1$ $0 \pm 0$ $0 \pm 0$ $0 \pm 0$	$0 \pm 0$ $0 \pm 0$ $0 \pm 0$ $0 \pm 0$ $0 \pm 0$ $0 \pm 0$ $0 \pm 0$	
$M^T lbnu < 220$ M(lb) < 150	$24 \pm 1$ $14 \pm 0$ $13 \pm 0$ $0 \pm 0$ $0 \pm 0$ $0 \pm 0$ $0 \pm 0$	$41 \pm 6$ $26 \pm 4$ $23 \pm 4$ $0 \pm 0$ $0 \pm 0$ $0 \pm 0$ $0 \pm 0$	$\begin{array}{c} 44 \pm 0 \\ 42 \pm 0 \\ 40 \pm 0 \\ 0 \pm 0 \end{array}$	$120 \pm 2$ $72 \pm 1$ $59 \pm 1$ $0 \pm 0$ $0 \pm 0$ $0 \pm 0$ $0 \pm 0$	$0 \pm 0$ $0 \pm 0$ $0 \pm 0$ $0 \pm 0$ $0 \pm 0$ $0 \pm 0$ $0 \pm 0$	
$\begin{array}{l} M^T lbnu < 220 \\ M(lb) < 150 \end{array}$	$24 \pm 1$ $14 \pm 0$ $13 \pm 0$ $0 \pm 0$ $0 \pm 0$ $0 \pm 0$ $0 \pm 0$ $0 \pm 0$ $0 \pm 0$	$\begin{array}{c} 41 \pm 6 \\ 26 \pm 4 \\ 23 \pm 4 \\ 0 \pm 0 \end{array}$	$\begin{array}{c} 44 \pm 0 \\ 42 \pm 0 \\ 40 \pm 0 \\ 0 \pm 0 \end{array}$	$120 \pm 2$ $72 \pm 1$ $59 \pm 1$ $0 \pm 0$ $0 \pm 0$ $0 \pm 0$ $0 \pm 0$ $0 \pm 0$ $0 \pm 0$	$\begin{array}{c} 0 \ \pm \ 0 \\ 0 \ \pm \ 0 \end{array}$	
$\frac{M^T lbnu < 220}{M(lb) < 150}$	$24 \pm 1 \\ 14 \pm 0 \\ 13 \pm 0 \\ 0 \pm 0 \\ 0$	$\begin{array}{c} 41 \pm 6 \\ 26 \pm 4 \\ 23 \pm 4 \\ 0 \pm 0 \end{array}$	$\begin{array}{c} 44 \pm 0 \\ 42 \pm 0 \\ 40 \pm 0 \\ 0 \pm 0 \end{array}$	$\begin{array}{c} 120 \pm 2 \\ 72 \pm 1 \\ 59 \pm 1 \\ 0 \pm 0 \end{array}$	$\begin{array}{c} 0 \ \pm \ 0 \\ 0 \ \pm \ 0 \end{array}$	
$\frac{M^T lbnu < 220}{M(lb) < 150}$	$24 \pm 1  14 \pm 0  13 \pm 0  0 \pm 0 \\ 0$	$\begin{array}{c} 41 \pm 6 \\ 26 \pm 4 \\ 23 \pm 4 \\ 0 \pm 0 \end{array}$	$\begin{array}{c} 44 \pm 0 \\ 42 \pm 0 \\ 40 \pm 0 \\ 0 \pm 0 \end{array}$	$120 \pm 2 72 \pm 1 59 \pm 1 0 \pm 0 \\0 \pm$	$\begin{array}{c} 0 \ \pm \ 0 \\ 0 \ \pm \ 0 \end{array}$	

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## Significance

Cut	Signal K-zct	Signal K-zut	Signal ttbar Kc	Signal ttbar Ku	comb (c)	comb (u)
nocuts	0.010	0.088	0.083	0.083	0.093	0.171
Nj = 1	0.010	0.080	0.037	0.038	0.048	0.118
lep = 3	0.204	1.279	0.699	0.708	0.902	1.976
nOSSF > 0	0.205	1.286	0.704	0.712	0.907	1.986
nbjets = 1	0.521	2.868	1.147	0.964	1.639	3.710
Mll - MZ  < 15	0.598	3.177	1.342	1.129	1.894	4.116
$M^T lnu < 120$	0.604	3.098	1.351	1.138	1.904	4.038
$M^T lbnu < 220$	0.703	3.485	1.398	1.266	2.029	4.465
M(lb) < 150	0.722	3.564	1.398	1.288	2.042	4.542
27 28	-nan	-nan	-nan	-nan	-nan	-nan
	-nan	-nan	-nan	-nan	-11811	-nan
	-nan	-nan	-nan	-nan	-nan	-nan
	-nan	-nan	-nan	-nan	-nan	-nan
	-nan	-nan	-nan	-nan	-nan	-11211
	-nan	-nan	-nan	-nan	-nan	-nan
	-nan	-nan	-nan	-nan	-nan	-nan
	-nan	-nan	-nan	-nan	-nan	-nan

MVA highest significances when each signal is trained against itself:

$$\kappa_{zut} = 5.197\sigma, S = 46.678, B = 33.987$$

$$\kappa_{zct} = 2.058\sigma, S = 27.588, B = 152.086$$

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- separate training for different couplings
- possibility to isolate a pure single-top sample with MVA
- good improvement with BDT in inclusive sample