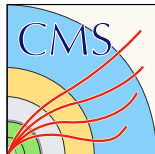


Assessment on the sensitivity of new potential observables for the $t\bar{t} + DM$ search

Exotics Weekly Meeting, 09.10.2020



HELMHOLTZ RESEARCH FOR
GRAND CHALLENGES



Current Input Variables in the NN

- MET
- $(M_{T2}^{ll})^2 = \min_{\not{p}_1 + \not{p}_2 = \not{p}_T} [\max\{m_T^2(p_{Tl_1}, \not{p}_1), m_T^2(p_{Tl_2}, \not{p}_1)\}]$
- $m_{bl}^t = \min_{j_a, j_b \in jets} [\max\{m_{l_1 j_a}, m_{l_2 j_b}\}]$
- nBJets
- $\Delta\phi(l\bar{l}, MET)$
- Reco-weight

⇒ still sufficient statistics in simulated samples to include more observables
⇒ some variables relatively correlated (eg: MET vs $(M_{T2}^{ll})^2$ and nBJets vs Reco-weight)

Generator-Level study on new observables

- ✓ Purpose:
 - ▷ assess the potential of adding new variables to the NN
 - discrimination power
 - correlation between pairs
- ✓ Purely based on parton-level observables:
 - ▷ no cuts applied on GEN-objects
 - ▷ reco-level distributions might differ slightly
- ✓ Targets only the $t\bar{t} + DM$ production:
 - ▷ categorization of $t\bar{t} + DM$ vs $t/\bar{t} + DM$?
 - ▷ further studies on single-top channel
- ✓ Signal and Background:
 - ▷ $\phi(a)t\bar{t}$ to dileptonic with randomized mass of mediator as signal process
 - ▷ $t\bar{t}$ to dileptonic as the only background considered (overwhelming contribution)

Observables Analyzed

Related to kinematics of $t\bar{t}$ system

- invariant mass of $t\bar{t}$ system: $M(t, \bar{t})$
- transverse momentum of $t\bar{t}$ system: $P_t(t, \bar{t})$
- difference in azimuthal angle of $t\bar{t}$ system: $\Delta\varphi(t, \bar{t})$
- rapidity of $t\bar{t}$ system: $y(t, \bar{t})$

Related to spin-correlation of $t\bar{t}$ system

- difference in azimuthal angle of leptons: $\Delta\varphi(l, \bar{l})$
- full angle between leptons in parents MF: c_{hel}
- 6 cross spin correlation coefficients for each pair of axes ($a, b : a \neq b$): $c_{ab} \pm c_{ba}$

Already considered for current NN (for correlation study)

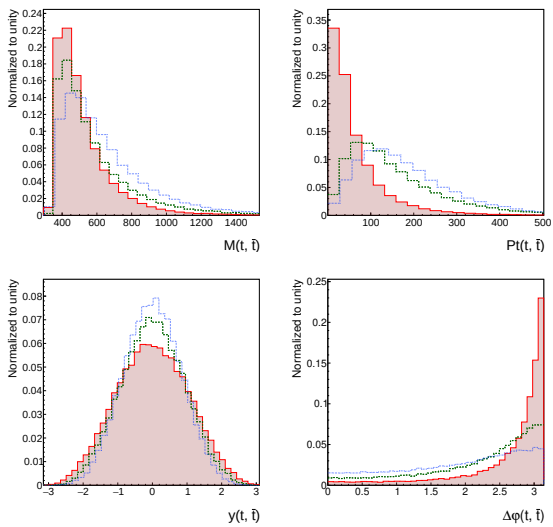
- MET
- $\Delta\phi(l\bar{l}, MET)$
- Dark-Pt

Signal vs Background Shape: $t\bar{t}$ kinematics

 $t\bar{t}\phi \rightarrow b\bar{b}l\bar{b}l\nu + \chi\bar{\chi}$ (BSM)

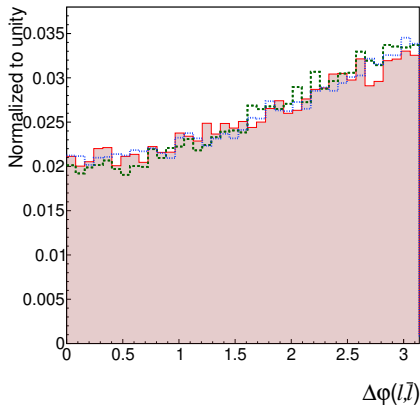
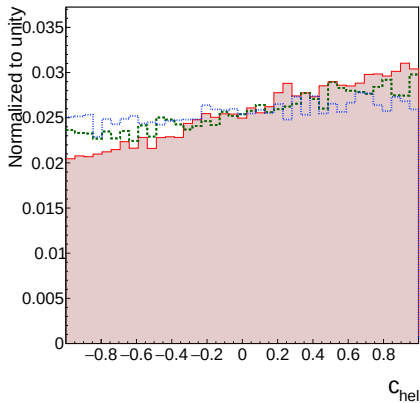
 $t\bar{t}a \rightarrow b\bar{b}l\bar{b}l\nu + \chi\bar{\chi}$ (BSM)

 $t\bar{t} \rightarrow b\bar{b}l\bar{b}l\nu$ (SM)

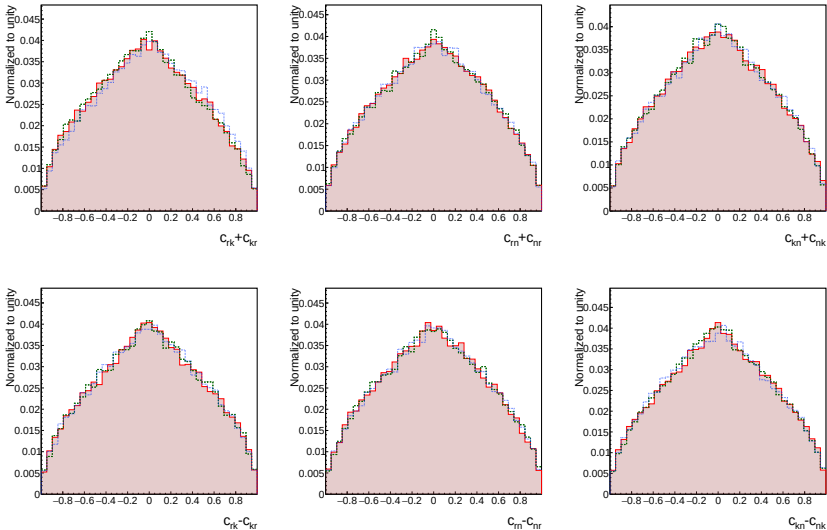
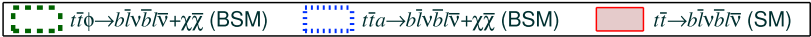


Signal vs Background Shape: $t\bar{t}$ spin correlation

$t\bar{t}\phi \rightarrow b\bar{l}v\bar{b}l\bar{v} + \chi\bar{\chi}$ (BSM) $t\bar{t}a \rightarrow b\bar{l}v\bar{b}l\bar{v} + \chi\bar{\chi}$ (BSM) $t\bar{t} \rightarrow b\bar{l}v\bar{b}l\bar{v}$ (SM)

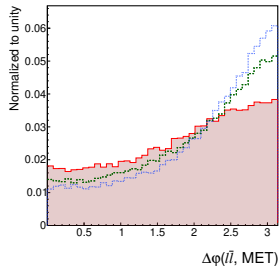
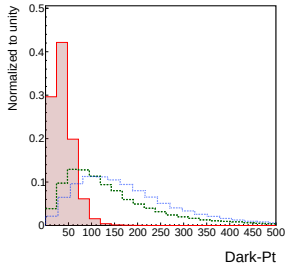
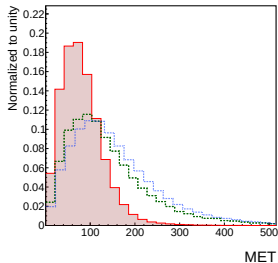


Signal vs Background Shape: $t\bar{t}$ spin correlation



Signal vs Background Shape: already implemented/studied before

$t\bar{t}\phi \rightarrow b\bar{l}v\bar{b}l\bar{v} + \chi\bar{\chi}$ (BSM) $t\bar{t}a \rightarrow b\bar{l}v\bar{b}l\bar{v} + \chi\bar{\chi}$ (BSM) $t\bar{t} \rightarrow b\bar{l}v\bar{b}l\bar{v}$ (SM)



Ranking of variables by separation power

TMVA definition for “separation power” (unspecific)

$$\langle \Delta^2 \rangle = \frac{1}{2} \int \frac{[f_S(x) - f_B(x)]^2}{f_S(x) + f_B(x)} dx$$

Ranking

$\phi t\bar{t}$ vs $t\bar{t}$

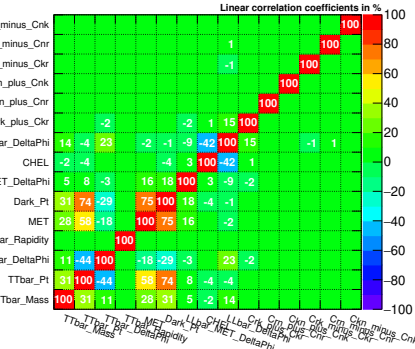
Rank	Var. Name	Separation (Δ^2)
1	Dark-Pt	4.934e-01
2	$Pt(t, \bar{t})$	2.764e-01
3	MET	1.509e-01
4	$\Delta\varphi(t, \bar{t})$	1.075e-01
5	$M(t, \bar{t})$	2.535e-02
6	$y(t, \bar{t})$	9.579e-03
7	$\Delta\phi(l\bar{l}, MET)$	8.922e-03
8	CHEL	1.006e-03
9	$\Delta\varphi(l, \bar{l})$	6.716e-04
10 – 15	$c_{ab} \pm c_{ba}$	$\sim 5\text{e-}04$

$at\bar{t}$ vs $t\bar{t}$

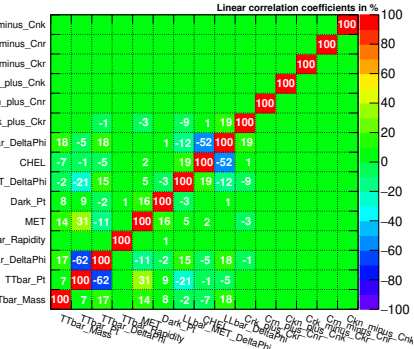
Rank	Var. Name	Separation (Δ^2)
1	Dark-Pt	6.487e-01
2	$Pt(t, \bar{t})$	3.830e-01
3	MET	2.166e-01
4	$\Delta\varphi(t, \bar{t})$	2.107e-01
5	$M(t, \bar{t})$	1.028e-01
6	$y(t, \bar{t})$	2.737e-02
7	$\Delta\phi(l\bar{l}, MET)$	2.371e-02
8	CHEL	2.941e-03
9 – 14	$c_{ab} \pm c_{ba}$	$\sim 5\text{e-}04$
15	$\Delta\varphi(l, \bar{l})$	4.607e-04

Linear correlation among variables

Correlation Matrix (signal)



Correlation Matrix (background)



Proposal

✓ Based on the Rank and the Correlation pattern, the following variables could be added:

$\Delta\varphi(t,\bar{t})$

$M(t,\bar{t})$

$y(t,\bar{t})$

CHEL

$c_{ab} \pm c_{ba}?$

Strategy for single-top channel?

- most of the new potential discriminating variables rely on the reconstruction of the $t\bar{t}$ system
 - for single-top production, the efficiency is pretty low and it brings meaningless information

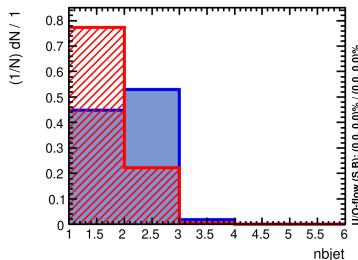


Figure: nBjets basically takes two values. DM-Single-Top(Red) vs DM-TTbar(Blue)

- **idea:** use this fact to create two categories, one DM-TTbar enriched and other DM-Single-Top enriched
 - efficiency of $t\bar{t}$ reconstruction in DM-TTbar category should be high $\rightarrow$ use new observables
 - perform Gen-Lev study to find new potential variables in single-Bjet category
 - train NN per-category with each set of variables and classify the events accordingly