Searching for Top Squarks at the LHC in Fully Hadronic Final State

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We pursue a scenario where the lighter top squark (stop) mass is accessible for the Large Hadron Collider (LHC) in the near future, while gluinos and first two generation squarks are too heavy. At $\sqrt{s} = 8$ TeV, we investigate the identification of stops which decay predominantly into a top quark and the stable lightest supersymmetric particle. We use a simple kinematical variable, $M3$, to reconstruct two top quarks which are pair-produced from the stops, in the fully hadronic channel. The dominant Standard Model (SM) background for this signal stems from $t\bar{t}$ plus jets, with one top quark decaying into $bl\nu$, where the lepton is undetected and the ν produces missing transverse momentum. The lepton identification efficiency is thus crucial in order to estimate the background correctly. We identify kinematical variables to reduce the SM background. We find that it is possible to achieve signal and background cross-section at similar levels for stop masses around $350 - 500$ GeV for a $\tilde{\chi}_1^0$ mass of 100 GeV.

I. INTRODUCTION

Experiments at the Large Hadron Collider (LHC) have recently reported preliminary evidence for a Higgs-like particle, with mass in the region of 125 GeV [1, 2].

In the Standard Model (SM), higher loop corrections to the Higgs mass are quadratically divergent; to avoid fine-tuning, new physics should appear around a scale of $\mathcal{O}(1)$ TeV and cut off the divergences. The problem is most severe in the case of the one-loop correction from the top sector, since other contributions to the Higgs mass are suppressed by gauge or smaller Yukawa couplings. Thus, reducing fine-tuning in the SM leads minimally to the conclusion that there should a partner for the top quark in the sub-TeV regime which is responsible for the cancellations.

The most widely studied mechanism for canceling the divergences is supersymmetry, and in particular the dangerous top quark loops are canceled by the scalar superpartner of the top quark, called a stop ($\tilde{t}$).While the LHC has already started to put constraints on the first two generation squarks-gluino plane, the paucity of strong constraints on stop masses is due to the small production cross-section of stop pairs and a huge background from top quark production. The current constraints are: (a) for a directly produced stop going to top quark plus next to lightest neutralino, with neutralino decaying to gravitino plus Z, ATLAS excludes stop masses upto $240-330$ GeV using 2.05 fb^{-1} [3] (b) at the Tevatron, the stop mass constraint is about $150-180$ GeV [4, 5].

In this paper, we will probe a technique for stop searches in the following decay mode

$$\tilde{t} \to t + \tilde{\chi}_1^0 \, , \qquad (1)$$

where the $\tilde{\chi}_1^0$ is the lightest neutralino, which we will take to be the lightest supersymmetric particle (LSP). In R-parity conserving models, the LSP is the main source of missing energy in the event. We will always be speaking about the lightest top quark superpartner $\tilde{t}_1$, which we will hereafter call $\tilde{t}$. We will not make any assumptions about the spectrum, except that the above decay mode is kinematically allowed and dominant.

The main challenge in such searches is the fact that the LHC is a top quark factory and distinguishing top quarks produced from stop decay, as opposed top quarks produced directly, can be very challenging. There are several established techniques of probing the $t\bar{t}$ system or identifying top quarks:

(i) α_T, the Razor, and M_{T2}: These techniques rely on the identification of two hemispheres to maximize sensitivity in searches for a pair of heavy colored objects and their cascade decays. These are inclusive searches that do not rely on the reconstruction of top quark(s); they have larger signal acceptance, but larger background [6–11].

(ii) Methods that reconstruct a top quark or two top quarks, followed by cuts on topology or kinematics to reduce the background. These methods have lower background, and lower acceptance of signal.

We choose to explicitly reconstruct the two-top quark system. Within this class of searches, several options are available:

(iia) $M3$: This is the invariant mass of trijet combinations with highest vectorially summed p_T. $M3$ has been used in top quark studies at CMS [12] and CDF [13];

(iib) Kinematic Fits: One minimizes χ^2 in dijet and trijet invariant masses, matching to W and top quark masses; for example [15];

(iic) Top Taggers: See [16] for a recent review;

(iid) Bi-Event Subtraction Technique (BEST): This method has been used to identify top quark system in [14]. Jet combinatorics is reduced by mixing events in hadronic decay chains.

For the two top quark system in Eq. 1, the highest p_T jets are most likely to be from the top quark, if it is signal. Intuitively, $M3$ should work well in such a system

(note that such an assumption is untrue in a SUSY environment with multiple superpartners undergoing decays, where the highest p_T jets are probably not from the top quark; BEST works better there).

In [17, 18], top taggers have been used to reconstruct top quarks coming from stop decay, while in [19], shape analyses of $\not{E}_T$-related distributions have been used to probe the stop system when the stop-LSP mass difference is degenerate with the top quark mass.

At the LHC, it is expected that the existence of stops will be indirectly established initially using inclusive jets + single lepton + $\not{E}_T$ analysis, however once any excess is observed the direct evidence of the stop can be established though the existence of top quarks in the signal. Our goal in the paper is to establish the existence of two top quarks in the final states along with the missing energy in all hadronic channel. In order to make our analysis realistic we use `PGS4` detector simulation [20] and consider $W + n$ jets, $Z + n$ jets and $t\bar{t} + n$ jets, with $n \leq 6$ as well as single top + jets backgrounds. Interestingly we noticed that $t\bar{t} + (3-6)$ jets contribution to the background is comparable to $t\bar{t} + (1-2)$ jets.

Our finding is that simple kinematical selections with the $M3$ variable is an effective tool for stop searches. At $\sqrt{s} = 8$ TeV, we achieve background and signal cross-sections at comparable levels for stop masses around $350 - 500$ GeV.

The outline of this paper is as follows. In Section II, we outline our search strategy. In Section III, we give our results in detail. The results are also summarized in Table V appearing at the end of the paper. We end with our conclusions.

II. SEARCH STRATEGY

We consider the fully hadronic mode

$$pp \rightarrow \tilde{t}\tilde{t}^* \rightarrow (t\tilde{\chi}_1^0)(\bar{t}\tilde{\chi}_1^0) \rightarrow (bjj\tilde{\chi}_1^0)(\bar{b}jj\tilde{\chi}_1^0) \qquad (2)$$

We investigate samples with at least four non b-tagged jets and at least two b-tagged jets, along with large missing energy. Signal events are generated with `ISAJET` [21] + `PYTHIA` [22], background events are generated with `ALPGEN` [23] + `PYTHIA`, followed by `PGS4` detector simulation.

The main source of missing energy for the $t\bar{t}$ background are neutrinos coming from the leptonic decay of a W, while for the signal the dominant source of missing energy is the neutralino. Clearly, after the missing energy cut, the most critical factor affecting the discrimination of signal over background in the fully hadronic mode is the lepton veto efficiency. Due to imperfections of the lepton veto, $t\bar{t}$ events with leptonic W decay could be a dominant source of background.

Our method is to (1) reconstruct a top quark using the trijet invariant mass $M3$, (2) use kinematic correlations between the constituents of the two (bjj) systems and $\not{E}_T$ to improve the reconstruction of the pair of top quarks
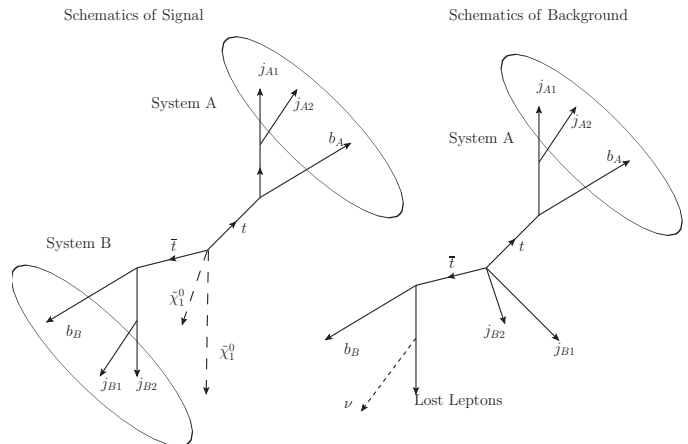

FIG. 1: [Left] schematic diagram of the signal. The stop pair gives rise to $t\bar{t}$ and neutralinos, which are the main source of $\not{E}_T$. In the fully hadronic mode, the top quarks decay into trijet systems. "System A" is the trijet system containing the leading p_T jet and reconstructed using $M3$, while the remaining jets are called "System B". [Right] $t\bar{t}$ background after lepton veto where the lepton is undetected. The main source of $\not{E}_T$ here is the neutrino from W decaying leptonically. The associated lepton passing the veto is termed a "lost lepton".

and (3) finally apply $M3$ again to identify the second top quark. We describe these steps below, before showing our results in the next section.

(1) We use $M3$ twice. First, combinations of three jets are made in the sample, keeping one b-tagged jet and two untagged jets in each trijet combination. Next, the trijet combination with the largest vectorially summed transverse momentum $p_{T,bjj}^{\text{leading}}$ is chosen. The invariant mass of this trijet combination is defined as $M3(p_{T,bjj}^{\text{leading}})$. It approximates the mass of the hadronically-decaying top quark. Similarly, we find a 2nd leading trijet combination $p_{T,bjj}^{2^{\text{nd}}}$ and invariant mass $M3(p_{T,bjj}^{2^{\text{nd}}})$. Associated with $M3$, we also define $M2$, which is the invariant mass of the two untagged jets in the trijet $M3$ combination.

Using $M3$, we identify a first top quark, which we call "System A". This is done by calculating χ^2 for the trijet and dijet combination corresponding to the leading p_T combination $M3(p_{T,bjj}^{\text{leading}})$ and also for the 2nd leading combination $M3(p_{T,bjj}^{2^{\text{nd}}})$, with a mean top quark mass of 170 GeV and width of 15 GeV, and a mean W mass of 80 GeV and a width of 10 GeV. The combination with the lowest χ^2 is then taken to represent System A. We call this combination $M3^{\text{min}}$.

We note that this χ^2 analysis allows for more signal events in the identification of System A. We show the results of this analysis in Section III C.

(2) After the identification of System A, we classify the remaining b-jet and non-tagged jets to be "System B"; thus, we would denote them as $(b_B j_B j_B)$. We employ various cuts on azimuthal angles between jets and $\not{E}_T$,

and M_T between b_B and $\not{E}_{\mathrm{T}}$. These are motivated by the fact that for signal, the main source of missing energy is the neutralino, while for the $t\bar{t}$ background, the main source of missing energy is the neutrino coming from the leptonic decay of the W, or from jet mismeasurement. Thus, for example, for the background, $\not{E}_{\mathrm{T}}$ is aligned along b_B, as is clear from the schematic diagram shown in Figure 1. For the stop decay, however, the correlation between the $\not{E}_{\mathrm{T}}$ in the form of neutralino and the b_B is far weaker. The results of this analysis are shown in Section III D.

(3) At the final stage, we employ $M3$ again to identify the second top quark, System B. The result of this analysis is shown in Section III E.

III. RESULTS

In this section, we describe our selection criteria and the cross sections after every stage of cuts (see Table V).

A. Background

We generate the following backgrounds with ALPGEN+ PYTHIA+ PGS4: $t\bar{t} + n$ jets with $n \leq 6$, single top + jets, $W(rightarrow\tau\nu) + n$ jets and $Z(\to \nu\nu, \tau\tau) + n$ jets with n upto 6. The background cross-sections are given in Table I. While Ref. [17] considers background with $t\bar{t} + (\leq)2$ jets in the stop analysis, we find that $t\bar{t} + (3-6)$ jets contribution is comparable to $t\bar{t} + (1-2)$ jets.

TABLE I: Main sources of background. "Others" includes single top + jets, $W + n$ jets and $Z + n$ jets with $1 \leq n \leq 6$. All cross-sections are in fb.

Background	$t\bar{t} + (\leq 2)j$	$t\bar{t} + (3-6)j$	Others
Cross-section	2.0×10^5	0.24×10^5	2.8×10^6

B. Baseline Cuts: 6 jets, Lepton veto, $\not{E}_{\mathrm{T}}$

Our baseline selection cuts are:
(i) $N_{\mathrm{non}\,b-\mathrm{jets}} \geq 4$, and at least two loosely tagged b-jets.
(ii) The leading jet has $p_T > 100$ GeV in $|\eta| \leq 2.5$, and all other jets have $p_T > 30$ GeV in $|\eta| \leq 2.5$.
(iii) Lepton veto: We reject isolated electrons and muons with $p_T > 10$ GeV in $|\eta| \leq 2.5$. The isolation criteria are $\sum p_{T\,\mathrm{iso}}^{\mathrm{track}} < 5$ GeV with $\Delta R = 0.4$.
(iv) τ veto: We also reject any hadronically decaying τ with $p_T > 20$ GeV in $|\eta| \leq 2.1$. We assume a τ identification efficiency of 60% and a fake rate of 2%.
(v) $\not{E}_{\mathrm{T}} > 100$ GeV.

C. $M3$: Tagging Top System A

In this section, we use $M3$ to tag the top quark in System A, after a $\not{E}_{\mathrm{T}}$ cut to further reduce SM background. The value of the $\not{E}_{\mathrm{T}}$ cut is determined by maximizing the significance for each choice of mass. This is shown in Table II.

TABLE II: $\not{E}_{\mathrm{T}}$ cut for various choices of masses. All masses are in GeV.

$\tilde{t}$	350	400	450	500	550	400	400
$\tilde{\chi}_1^0$	100	100	100	100	100	150	200
$\not{E}_{\mathrm{T}}$ cut	145	170	195	195	195	170	100

As described in Section II, we identify System A by using $M3$. Figure 2 shows the comparative distributions of $M3^{\mathrm{min}}$ and $M3(p_{T,bjj}^{\mathrm{leading}})$. We improve the top tagging by approximately 30% in signal events in the top quark mass region.
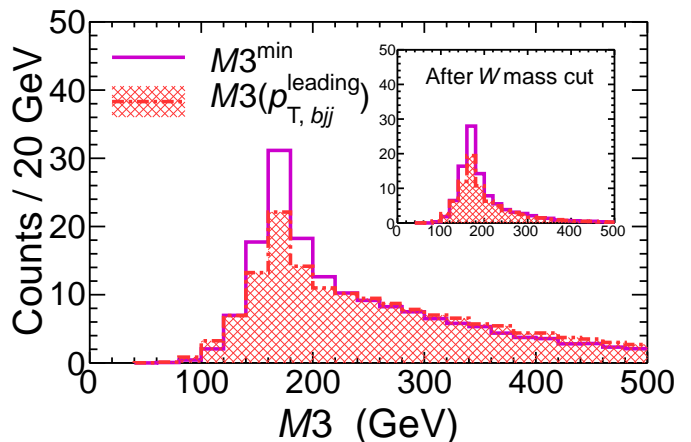

FIG. 2: Distributions of $M3^{\mathrm{min}}$ and $M3(p_{T,bjj}^{\mathrm{leading}})$. The inset shows the distribution after $M2$ mass window cut. A gain of $\sim 30\%$ in signal is obtained by using $M3^{\mathrm{min}}$. The luminosity is 50 fb^{-1}.

We next perform a W mass window cut on $M2^{\mathrm{min}}$, taking $40\,\mathrm{GeV} \leq M2^{\mathrm{min}} \leq 120\,\mathrm{GeV}$ and a top quark mass window cut on $M3^{\mathrm{min}}$, taking $120\,\mathrm{GeV} \leq M3^{\mathrm{min}} \leq 220\,\mathrm{GeV}$.

We show the $M3^{\mathrm{min}}$ distribution after $M2^{\mathrm{min}}$ mass cut in the inset of Figure 2.

We now proceed to probe the constituents of the "other top quark" in System B.

D. Angular and M_T Cuts: Kinematic Correlations between $\not{E}_{\mathrm{T}}$ and Jets

We denote the remaining b-jet and non-tagged jets as $(b_B j_B j_B)$. We clean up the system with various angular and M_T cuts, as mentioned in our search strategy in

Section II. The cuts values arechosen based on Figures 3 and 4:

(i) $\Delta\phi(b_B, \not{E}_T) > 1.2$ and $\Delta\phi(j_{B(1,2)}, \not{E}_T) > 0.7$, where $j_{B(1,2)}$ refer to the first and second leading jets in System B, respectively.

(ii) $M_T(b_B, \not{E}_T)$: We choose optimal cut values for different masses (see Table III).

TABLE III: $M_T(b_B, \not{E}_T)$ cuts for various choices of masses. All masses are in GeV.

$\tilde{t}$	350	400	450	500	550	400	400
$\tilde{\chi}_1^0$	100	100	100	100	100	150	200
$M_T(b_B, \not{E}_T)$	145	155	165	165	165	155	155

After the above cuts, we revert to the trijet $(b_A j_A j_A)$ in System A with similar angular cuts between missing energy and the b-tagged jet as well as non-tagged jets. These angular cuts are efficient in reducing events with "lost leptons". The cuts are chosen based on Figure 5:

(iii) $\Delta\phi(b_A, \not{E}_T) > 1.2$ and $\Delta\phi(j_{A(1,2)}, \not{E}_T) > 0.7$, where $j_{A(1,2)}$ refer to the first and second leading jets in System A, respectively.

E. $M3$: Tagging Top System B

As a last step, $M3$ is applied in System B, followed by a W mass window cut on $M2$ ($40\,\text{GeV} \leq M2 \leq 120\,\text{GeV}$). The $M3$ distribution is shown in Figure 6. Our final results with $110\,\text{GeV} \leq M3 \leq 230\,\text{GeV}$ are tabulated in Table V.

We note that for the point $(m_{\tilde{t}} = 350\,\text{GeV}, m_{\tilde{\chi}_1^0} = 100\,\text{GeV})$ we additionally impose $\Delta\phi(b_{A,B}, \not{E}_T) < 2.7$. Also, for the point $(m_{\tilde{t}} = 400\,\text{GeV}, m_{\tilde{\chi}_1^0} = 200\,\text{GeV})$, the W mass window cut on $M2$ of System B was taken as $60\,\text{GeV} \leq M2 \leq 100\,\text{GeV}$, while the top quark mass window was taken as $140\,\text{GeV} \leq M3 \leq 200\,\text{GeV}$.

IV. SUMMARY AND CONCLUSION

In this paper, we have explored a search strategy for a light stop at the LHC at 8 TeV, using $M3$ variable in the fully hadronic channel. The gluino and the first two generation squarks are assumed to be too heavy to be produced significantly at the LHC.

We first performed $M3^{\text{min}}$ to identify a top quark system (System A). Next, we performed $M3$ again to identify the second top quark (System B), along with a series of kinematical cuts to reduce the SM backgrounds. Throughout this study, we used PGS4 detector simulation and considered $W + n$ jets, $Z + n$ jets and $t\bar{t} + n$ jets, with $n \leq 6$ as well as single top + jets backgrounds. Interestingly we noticed that $t\bar{t} + (3-6)$ jets contribution to the background is comparable to $t\bar{t} + (1-2)$ jets.
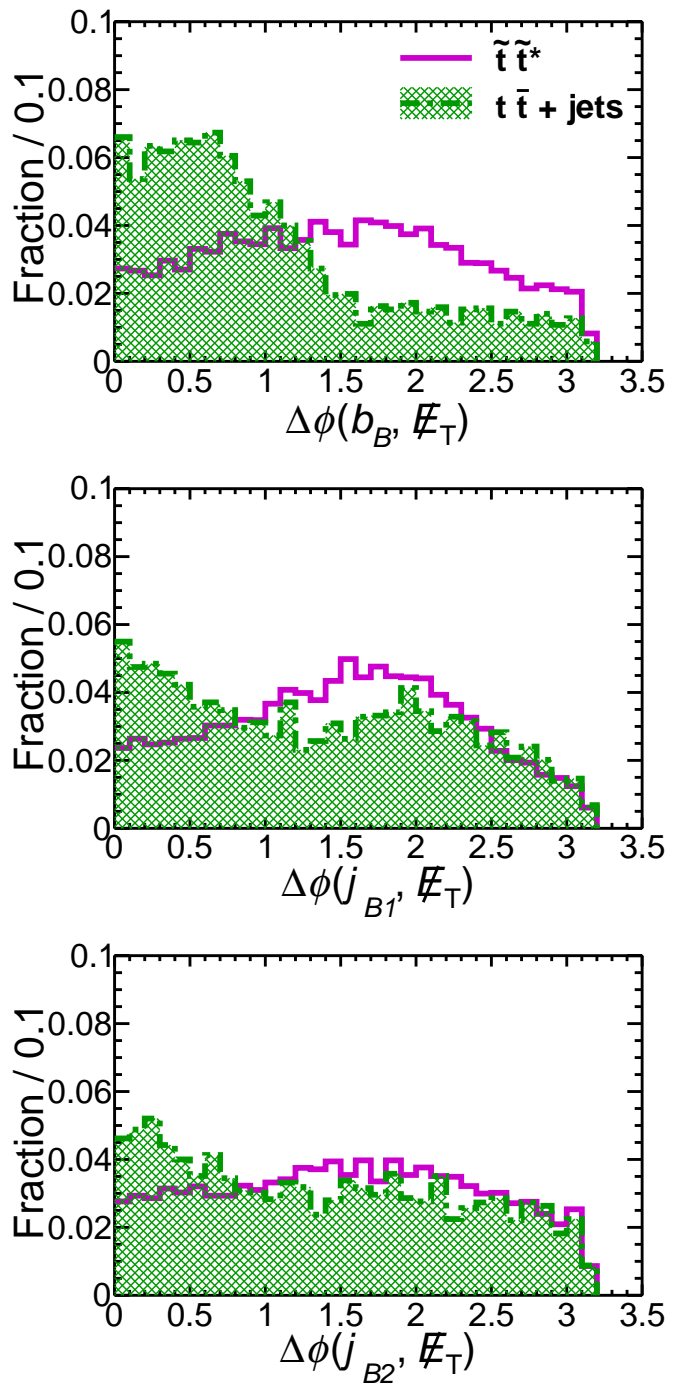

FIG. 3: Distributions of $\Delta\phi(b_B, \not{E}_T), \Delta\phi(j_{B1}, \not{E}_T), \Delta\phi(j_{B2}, \not{E}_T)$ for $t\bar{t}$ background and signal ($m_{\tilde{t}} = 400\,\text{GeV}, m_{\tilde{\chi}_1^0} = 100\,\text{GeV}$). We cut at $\Delta\phi(b_B, \not{E}_T) > 1.2, \Delta\phi(j_{B(1,2)}, \not{E}_T) > 0.7$. Here, b_B, j_{B1}, and j_{B2} denote the b, leading jet, and next leading jet of System B. The luminosity is 50 fb^{-1}.

Tables IV and V are a summary of the search performance for various choices of stop and neutralino masses.

In summary, a simple kinematical reconstruction technique using the $M3$ variable is an effective tool for stop
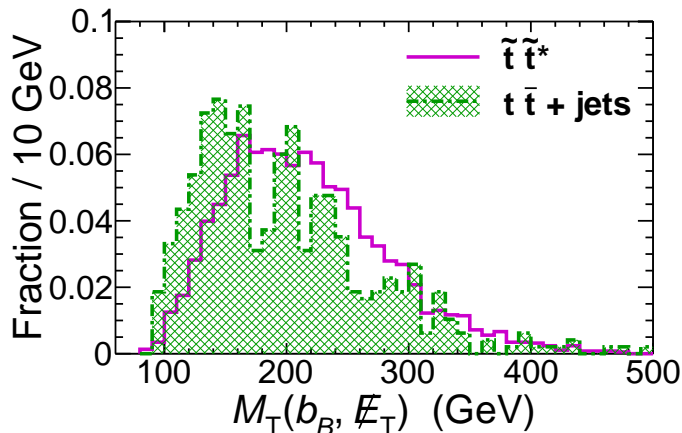
FIG. 4: Distribution of $M_T(b_B, \not{E}_T)$ for $t\bar{t}$ background and signal ($m_{\tilde{t}} = 400\,\text{GeV}, m_{\tilde{\chi}_1^0} = 100\,\text{GeV}$). We cut at $M_T(b_B, \not{E}_T) > 155$ GeV. The luminosity is 50 fb^{-1}.

TABLE IV: Final significances for various choices of masses. All masses are in GeV. The luminosity is 50 fb^{-1}.

$\tilde{t}$	350	400	450	500	550	400	400
$\tilde{\chi}_1^0$	100	100	100	100	100	150	200
$S/\sqrt{B}$	1.29	1.71	1.39	0.81	0.35	0.94	0.47

searches. We find that at $\sqrt{s} = 8$ TeV it is possible to reduce background down to a level of signal cross-section for stop masses around $350 - 500$ GeV for a $\tilde{\chi}_1^0$ mass of 100 GeV.

V. ACKNOWLEDGEMENTS

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TABLE V: Summary of effective cross sections (fb) for stop pair production and the SM background events in our stop search feasibility study. Masses and momenta are in GeV. "Other" sources of background include single top + jets, $W + n$ jets and $Z + n$ jets with $1 \leq n \leq 6$. The significance is given at 50 fb $^{-1}$.

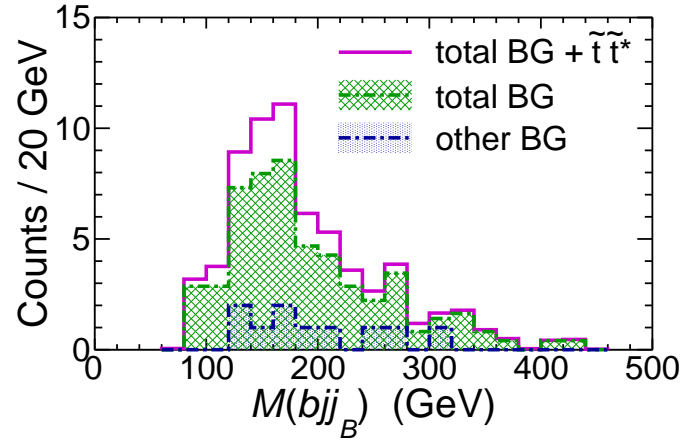|		Signal	$t\bar{t} + n(\leq 2)$jets	$t\bar{t} + n(\geq 3)$jets	Others
	Initial	760	2.0×10^5	0.24×10^5	2.8×10^6
	Baseline Cuts (Sec. III B)	9.96	192	147	31.7
$m_{\tilde{t}} = 350$	$\not{E}_{\mathrm{T}} > 145$ GeV	6.79	82.2	69.1	15.8
$m_{\tilde{\chi}_1^0} = 100$	System A: $M3$ (Sec. III C)	2.65	25.8	15.6	3.14
	Angular and M_T cuts (Sec. III D)	0.55	1.61	1.71	0.72
	System B: $M3$ (Sec. III E)	0.25	0.40	0.47	0.20
	$\Delta\phi(b_{A,B}, \not{E}_{\mathrm{T}}) < 2.7$	0.14	0.24	0.25	0.10
	Significance ($S/\sqrt{B}$)			1.29	
	Initial	337	2.0×10^5	0.24×10^5	2.8×10^6
	Baseline Cuts (Sec. III B)	5.55	192	147	31.7
$m_{\tilde{t}} = 400$	$\not{E}_{\mathrm{T}} > 170$ GeV	3.62	53, 4	47.0	11.1
$m_{\tilde{\chi}_1^0} = 100$	System A: $M3$ (Sec. III C)	1.46	15.4	9.73	1.82
	Angular and M_T cuts (Sec. III D)	0.44	0.96	1.06	0.54
	System B: $M3$ (Sec. III E)	0.20	0.26	0.28	0.14
	Significance ($S/\sqrt{B}$)			1.71	
	Initial	160	2.0×10^5	0.24×10^5	2.8×10^6
	Baseline Cuts (Sec. III B)	2.52	192	147	31.7
$m_{\tilde{t}} = 450$	$\not{E}_{\mathrm{T}} > 195$ GeV	1.61	34.5	31.9	8.08
$m_{\tilde{\chi}_1^0} = 100$	System A: $M3$ (Sec. III C)	0.62	9.17	6.32	1.30
	Angular and M_T cuts (Sec. III D)	0.25	0.55	0.69	0.40
	System B: $M3$ (Sec. III E)	0.12	0.17	0.14	0.06
	Significance ($S/\sqrt{B}$)			1.39	
	Initial	80.5	2.0×10^5	0.24×10^5	2.8×10^6
	Baseline Cuts (Sec. III B)	1.21	192	147	31.7
$m_{\tilde{t}} = 500$	$\not{E}_{\mathrm{T}} > 195$ GeV	0.86	34.5	31.9	8.08
$m_{\tilde{\chi}_1^0} = 100$	System A $M3$ (Sec. III C)	0.32	9.17	6.32	1.30
	Angular and M_T cuts (Sec. III D)	0.15	0.55	0.69	0.40
	System B: $M3$ (Sec. III E)	0.07	0.17	0.14	0.06
	Significance ($S/\sqrt{B}$)			0.81	
	Initial	43.0	2.0×10^5	0.24×10^5	2.8×10^6
	Baseline Cuts (Sec. III B)	0.57	192	147	31.7
$m_{\tilde{t}} = 550$	$\not{E}_{\mathrm{T}} > 195$ GeV	0.43	34.5	31.9	8.08
$m_{\tilde{\chi}_1^0} = 100$	System A: $M3$ (Sec. III C)	0.14	9.17	6.32	1.30
	Angular and M_T cuts (Sec. III D)	0.07	0.55	0.69	0.40
	System B: $M3$ (Sec. III E)	0.03	0.17	0.14	0.06
	Significance ($S/\sqrt{B}$)			0.35	
	Initial	337	2.0×10^5	0.24×10^5	2.8×10^6
	Baseline Cuts (Sec. III B)	4.78	192	147	31.7
$m_{\tilde{t}} = 400$	$\not{E}_{\mathrm{T}} > 170$ GeV	2.76	53.4	47.0	11.1
$m_{\tilde{\chi}_1^0} = 150$	System A: $M3$ (Sec. III C)	1.01	15.4	9.73	1.82
	Angular and M_T cuts (Sec. III D)	0.23	0.96	1.06	0.54
	System B: $M3$ (Sec. III E)	0.11	0.26	0.28	0.14
	Significance ($S/\sqrt{B}$)			0.94	
	Initial	337	2.0×10^5	0.24×10^5	2.8×10^6
$m_{\tilde{t}} = 400$	Baseline Cuts (Sec. III B)	3.34	192	147	31.7
$m_{\tilde{\chi}_1^0} = 200$	System A: $M3$ (Sec. III C)	1.13	67.2	38.8	7.40
	Angular and M_T cuts (Sec. III D)	0.87	45.8	28.3	6.04
	System B: $M3$ (Sec. III E)	0.18	4.12	2.59	0.54
	Significance ($S/\sqrt{B}$)			0.47	

FIG. 6: Distribution of $M3$ in System B, after requiring $40\,\text{GeV} \leq M2 \leq 120\,\text{GeV}$. Displayed are: "other" sources of background (single top + jets, $W + n$ jets and $Z + n$ jets with $n \leq 6$), total background including $t\bar{t} + n$ jets, and total background plus signal for our reference point ($m_{\tilde{t}} = 400\,\text{GeV}, m_{\tilde{\chi}_1^0} = 100\,\text{GeV}$). The luminosity is 50 fb^{-1}.

FIG. 5: Distributions of $\Delta\phi(b_A, \not{E}_\text{T})$, $\Delta\phi(j_{A1}, \not{E}_\text{T})$, and $\Delta\phi(j_{A2}, \not{E}_\text{T})$ for $t\bar{t}$ background and signal ($m_{\tilde{t}} = 400\,\text{GeV}, m_{\tilde{\chi}_1^0} = 100\,\text{GeV}$). We cut at $\Delta\phi(b_A, \not{E}_\text{T}) > 1.2$ and $\Delta\phi(j_{A(1,2)}, \not{E}_\text{T}) > 0.7$. Here, b_A, j_{A1}, and j_{A2} denote the b, leading jet, and next leading jet of System A. The luminosity is 50 fb^{-1}.

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