Jet substructure techniques for a supersymmetric scenario with gravitino LSP

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Outline

- Introduction : Compressed supersymmetry
- Collider analysis
  - New Channel (2 Fatjet + MET)
  - Jet-substructure variables and MVA
- Results and Discussion

Introduction & Motivation

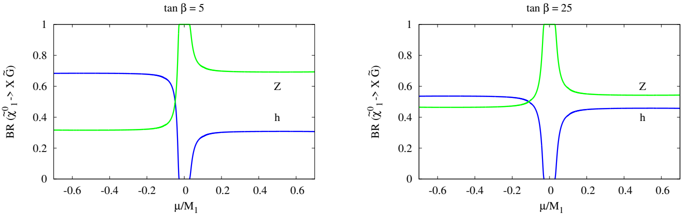
- In view of the null results at the Run 1 and Run 2 of LHC, compressed SUSY (cSUSY) has gained relevance in its ongoing pursuit.
- Compressed MSSM sector with the higgsino-like neutralino $\widetilde{\chi}_1^0$ as the NLSP along with a light Gravitino $\widetilde{G}$ LSP.
- Gravitino $\widetilde{G}$ LSP can the potential dark matter (DM) candidate.
- A dominantly higgsino-like $\widetilde{\chi}_1^0$ NLSP decays to a Higgs boson or a Z boson along with the $\widetilde{G}$.
- Improved analysis techniques, especially in the context of the high-luminosity Large Hadron Collider (LHC), are highly desirable in the pursuit of new fundamental physics.

Decay properties of a higgsino-like NLSP

The partial decay widths of the lightest neutralino in the decoupling limit ($\mu << M_1, M_2$) are

$$\Gamma(\tilde{\chi}_1^0 \to h\tilde{G}) \propto |N_{14}\cos\beta + N_{13}\sin\beta|^2\,(M_{Pl}m_{\tilde{G}})^{-2}$$

$$\Gamma(\tilde{\chi}_1^0 \to Z\tilde{G}) \propto (|N_{11}\sin\theta_W - N_{12}\cos\theta_W|^2 + \frac{1}{2}|N_{14}\cos\beta - N_{13}\sin\beta|^2)\,(M_{Pl}m_{\tilde{G}})^{-2}$$



Benchmarks

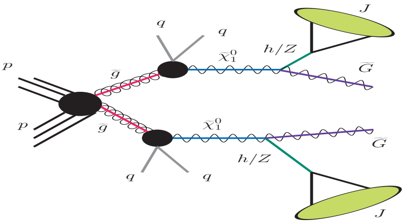
Parameters	**BP1**	**U2**
M_1	2900	2900
μ	2340	1000
$\tan\beta$	25	25
A_t	-3200	-3200
m_A	2500	2500
m_h	124.7	124.7
$m_{\widetilde{g}}$	2395.1	3031.7
$m_{\widetilde{q}_L}$	2399.1	2402.2
$m_{\widetilde{q}_R}$	2398.0	2395.7
$m_{\widetilde{\chi}_4^0}$	2899.0	2897.8
ΔM	59.6	644.4
$BR(\widetilde{\chi}_1^0 \to Z\widetilde{G})$	0.55	0.55
$BR(\widetilde{\chi}_1^0 \to h\widetilde{G})$	0.45	0.45

Table: List of benchmark points, corresponding parameters and NLSP branching ratios chosen for our study. The mass parameters are in GeV unless specified otherwise. For all benchmarks, gravitino mass is kept fixed at $m_{\widetilde{G}} = 1$ keV.

Signal topology

• The presence of the light gravitino as the LSP opens up new decay modes of the NLSP in the SM particles($h/Z/W^{\pm}$) and large large $\not{E}_T$.

$$pp \to 2\ \texttt{CA8}\ \text{Fat-jets}\ (J) + \text{large}\ \not{E}_T,$$



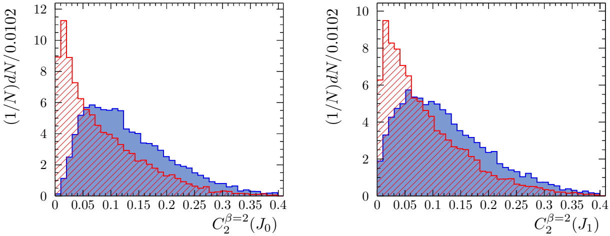
Backgrounds $Z \to \nu\bar{\nu}$ +jets, $W \to l\nu$ +jets , $VV + jets$, Single-top, $t\bar{t}$

Jet substructure variables to tag Higgs/Z like fatjet

- Energy Correlation Functions

$$C_2^{(\beta)} = \frac{e_3^{(\beta)}}{(e_2^{(\beta)})^2}$$

where, $e_2^{(\beta)} = \sum_{1\leq i<j\leq n_J} z_i z_j \theta_{ij}^{\beta}$ and $e_3^{(\beta)} = \sum_{1\leq i<j<k\leq n_J} z_i z_j z_k \theta_{ij}^{\beta}\theta_{ik}^{\beta}\theta_{jk}^{\beta}$ are 2-point and 3-point energy correlation functions respectively. The β represents the exponent.

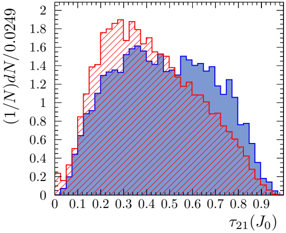


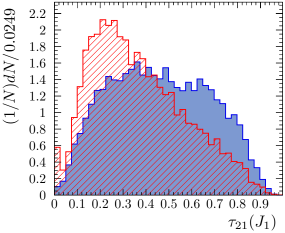
Jet substructure variables to tag Higgs/Z like fatjet

- The N-subjettiness ratio

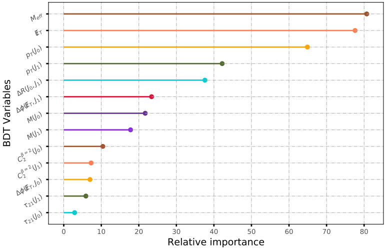
$$\tau_N^{(\beta)} = \frac{1}{\mathcal{N}_0} \sum_i p_{i,T} \ \text{min} \left\{ \Delta R_{i1}^{\beta}, \Delta R_{i2}^{\beta}, \cdots, \Delta R_{iN}^{\beta} \right\}$$

where, $\mathcal{N}_0 = \sum_i p_{i,T} R_0$ is the normalizing factor, R_0 is the radius parameter of the fat-jet.





Kinematic variables used for our MVA and their relative importance



The method unspecific ranking in terms of an observable λ is defined as

$$\Delta_{(\lambda)} = \int \frac{(\hat{y}_s(\lambda) - \hat{y}_b(\lambda))^2}{\hat{y}_s(\lambda) + \hat{y}_b(\lambda)} d\lambda$$

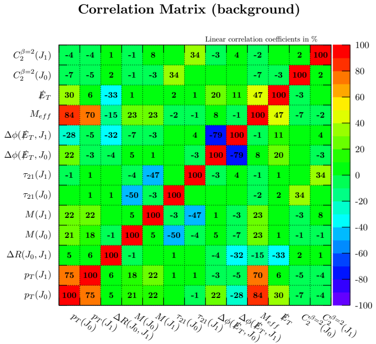
where $\hat{y}_s$ and $\hat{y}_b$ are the probability distribution functions for signal and background for a given observable λ respectively.

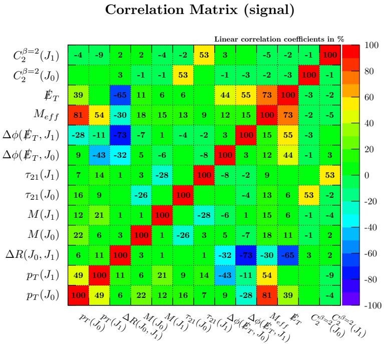
Correlation matrix for variables

The linear correlation ρ between two variable X and Y using the following equation

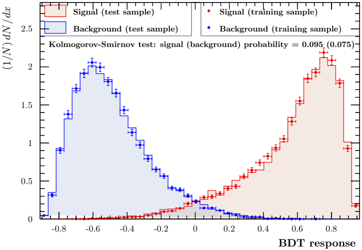
$$\rho(X, Y) = \frac{E(XY) - E(X)E(Y)}{\sigma(X)\sigma(Y)}$$

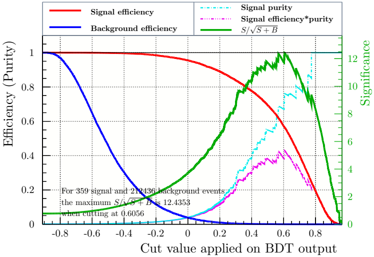
where $E(X), E(Y)$, and $E(XY)$ are the expectation value of the variable X, Y, and XY respectively.





Multivariate analysis





Cut efficiencies as functions of BDT cut values. All plots are evaluated for for benchmark point **BP1** using integrated luminosity of 200 fb^{-1} at the 14 TeV LHC.

Prospect of exclusion or discovery

BPs	$\mathcal{N}_S^{bc}$	BDT_{opt}	$\mathcal{N}_S(\epsilon_S)$	$\mathcal{N}_B(\epsilon_B \times 10^4)$	$\mathcal{N}_S/\sqrt{\mathcal{N}_S+\mathcal{N}_B}$	$\mathcal{L}_{(5\sigma)}^{req}\ fb^{-1}$
BP1	359	0.60	202 (0.56)	63 (2.9)	12.4	32.3
BP2	256	0.67	137 (0.56)	50 (2.3)	10.0	49.7
BP3	346	0.42	183 (0.52)	49 (2.3)	12.0	34.5
BP4	153	0.65	87 (0.56)	15 (0.7)	8.6	67.4
BP5	32	0.61	25 (0.78)	51 (2.4)	2.9	595.4
BP6	74	0.58	37 (0.50)	42 (1.9)	4.2	283.2
U1	266	0.57	149 (0.56)	49 (2.3)	10.6	44.4
U2	352	0.56	216 (0.61)	41 (1.9)	13.5	27.4
$\mathcal{N}_{\mathrm{SM}}$	212436	-	-	-	-	

Table: Total number of signal events and background events before and after utilising the optimum BDT criteria BDT_{opt} for an integrated luminosity of 200 fb^{-1} at the 14 TeV LHC.

Complementary signals at high energy and high luminosity upgrades of LHC

Channel	$\sqrt{s} = 14$ ($\mathcal{L} = 3ab^{-1}$) TeV	$\sqrt{s} = 27$ TeV ($\mathcal{L} = 15ab^{-1}$)
$(jj)(jj)$	4593	756177
$(jj)(ll)$	352	58011
$(ll)(ll)$	13	2126
$(jj)(jjl)$	4	664
$(ll)(jjl)$	1	157

Table: Number of events computed using $\sigma * BR$ for **BP1** at NLO for $\sqrt{s} = 14$ ($\mathcal{L} = 3\text{ab}^{-1}$) and 27 TeV ($\mathcal{L} = 15\text{ab}^{-1}$) at LHC before analysis cuts are applied.

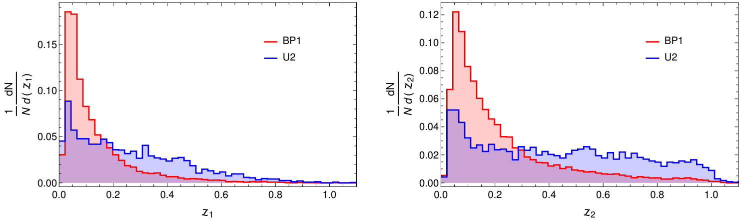
Distinction of Compressed and Uncompressed spectra

- The first observable is defined as the ratio of P_T of leading unique AK4 jet by the P_T of leading fat-jet, written as

$$\mathcal{Z}_1 = \frac{P_T(j_0)_{unique}}{P_T(J_0)}$$

- Similarly, we define another variable as the ratio of P_T of leading unique jet by the P_T of sub-leading fat-jet, written as

$$\mathcal{Z}_2 = \frac{P_T(j_0)_{unique}}{P_T(J_1)}$$



Conclusions

- With no clear indication of new physics yet at the LHC, compressed mass spectrum gained significant limelight as a possible explanation for the elusive nature in the realisation of new physics.
- We explore compressed SUSY scenario, where both coloured and electro-weak new physics sectors are sitting at multi-TeV scale in the presence of a light gravitino
- We exploit the characteristics of the jet substructure techniques which can lead to the discovery of the 2 fatjet + MET signal for the .
- One can exclude masses up to 3.2 TeV at $\mathcal{L} = 3000$ fb^{-1}, with a 3.2σ signal significance for $\Delta M \simeq 60$ GeV.

Thank you