Jet Substructure in SUSY

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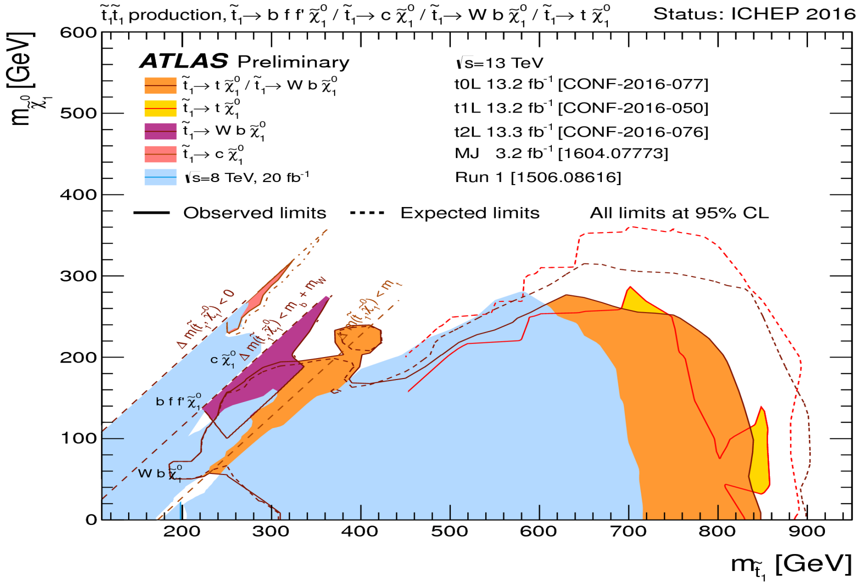
Stop searches

Stop exclusion



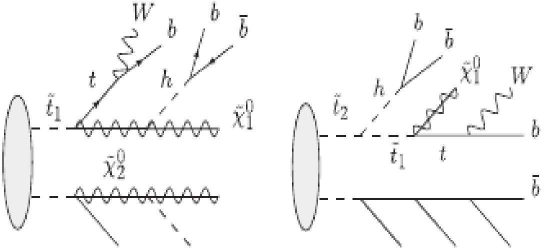
Top Tag in SUSY

Probable Decay modes of the top squark ($\tilde{t}$) in RPC MSSM:

a) $\tilde{t} \to t\tilde{\chi}_1^0$
b) $\tilde{t} \to b\tilde{\chi}_1^+$

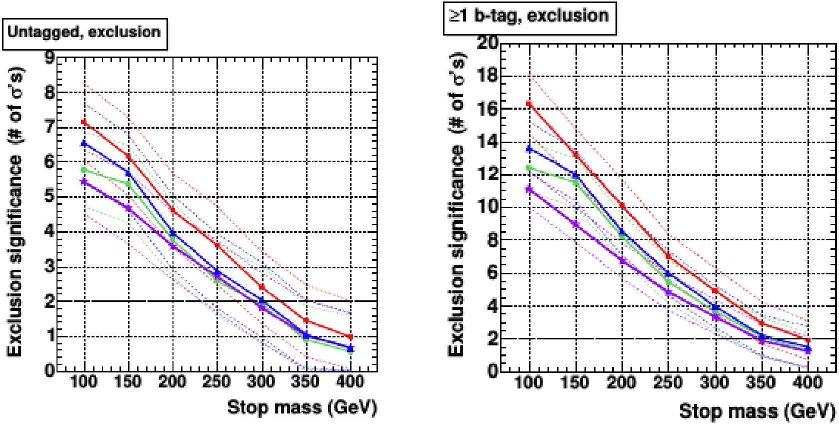
- $pp \to \tilde{t}\tilde{t};\ \tilde{t} \to t\tilde{\chi}_1^0$,
  Top decaying Hadronically
  David E Kaplan et. al., arXiv: 1205.5816
  Semi-leptonic Top Decays
  Tilman Plehn, Michael Spannowsky and Michihisa Takeuchi., arXiv:1102.0557
- $pp \to \tilde{g}\tilde{g};\ \tilde{g} \to t\tilde{t}$
  If $m_{\tilde{t}_2} \gg m_{\tilde{t}_1}$, then $\tilde{t}_2 \to \tilde{t}_1\ Z/H/A$
  Priyotosh Bandyopadhyay and Biplob Bhattacherjee, arXiv: 1012.5289

- Stop searches and light Higgsinos:



David Berenstein et. al., arXiv:1211.4288

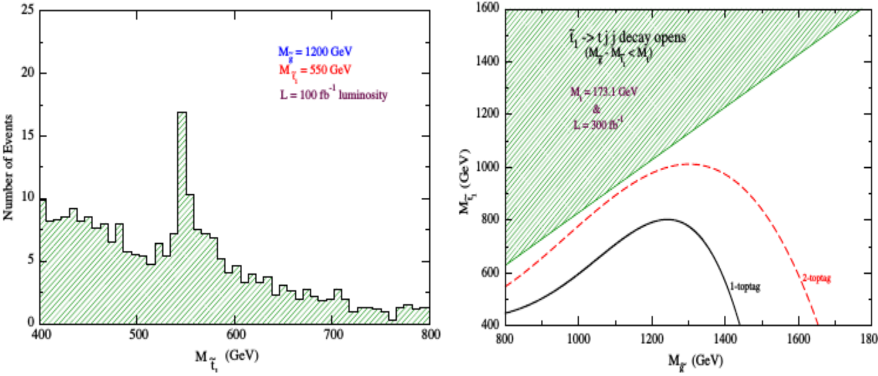
- Searching for RPV SUSY with all stop-jets
- $W = \lambda''_{ijk} \overline{U_i}\ \overline{D_j}\ \overline{D_k}$



- 20fb^{-1} at LHC8

  Yang Bai, Andrey Katz, Brock Tweedie, arXiv:1309.6631

- The same W, $\tilde{g} \to t\tilde{t}$, $\tilde{t} \to jj$

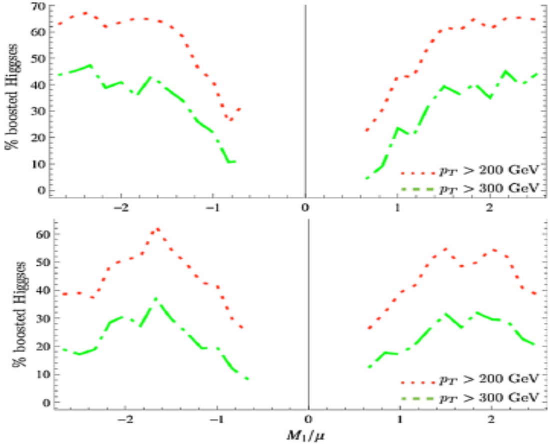


Biplob Bhattacherjee, Amit Chakraborty, arXiv: 1311.5785

Higgs Searches

Higgs Tagging

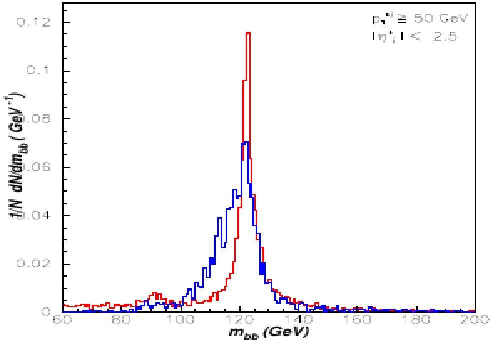
- $\widetilde{q}_L \to q + \widetilde{W}, \quad \widetilde{W} \to h/H/A + \widetilde{H}$
  $\widetilde{q}_R \to q + \widetilde{B}, \quad \widetilde{B} \to h/H/A + \widetilde{H}$



Kribs, Martin, Roy, Spannowsky, arXiv: 1006.1656

Higgs signal in chargino-neutralino production at the LHC

- Higgs boson may arise in $\widetilde{g}$ cascade ($m_{\widetilde{g}} = 1$ TeV)
- Probability of finding Higgs events via such cascades are 1-3%
- $m_{\widetilde{\chi}_2^0} \sim 300$ GeV and $m_{\widetilde{\chi}_1^0} \sim 100$ GeV



- Without Jet Substructure, With Jet Substructure

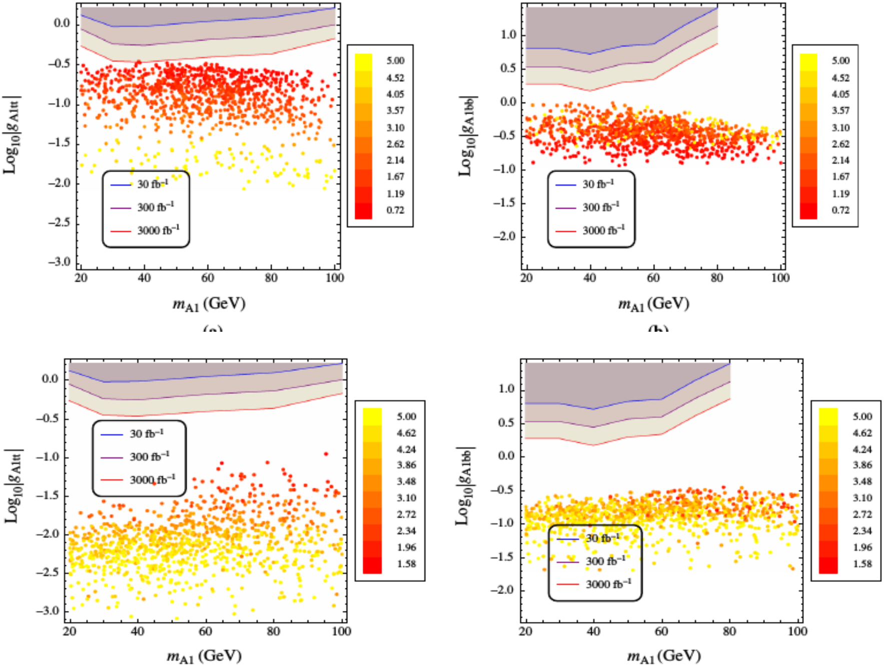
  Diptimoy Ghosh, Monoranjan Guchait, Dipan Sengupta, arXiv:1202.4937

Probing a light CP-odd scalar in di-top-associated production at the LHC

- Probing a CP-odd scalar in the mass range $20 < m_A < 100$ GeV
- Suitable choice of the parameter would yield a light CP-odd Higgs boson
- $y_{A_1 tt} = \frac{2\lambda v \cos^2\beta}{\mu}$, $y_{A_1 bb} = \frac{2\lambda v \sin^2\beta}{\mu}$

Mirkoantonio Casolino, Trisha Farooque, Aurelio Juste, Tao Liu, Michael Spannowsky, arXiv:1507.07004

David Curtin, Rouven Essig, Yi-Ming Zhong, arXiv:1412.4779



$\mathrm{Log}_{10}|g_{A1tt}|$
m_{A1} (GeV)
30 fb^{-1}
300 fb^{-1}
3000 fb^{-1}
5.00
4.52
4.05
3.57
3.10
2.62
2.14
1.67
1.19
0.72
$\mathrm{Log}_{10}|g_{A1bb}|$
m_{A1} (GeV)
30 fb^{-1}
300 fb^{-1}
3000 fb^{-1}
$\mathrm{Log}_{10}|g_{A1tt}|$
m_{A1} (GeV)
30 fb^{-1}
300 fb^{-1}
3000 fb^{-1}
5.00
4.62
4.24
3.86
3.48
3.10
2.72
2.34
1.96
1.58
$\mathrm{Log}_{10}|g_{A1bb}|$
m_{A1} (GeV)
30 fb^{-1}
300 fb^{-1}
3000 fb^{-1}

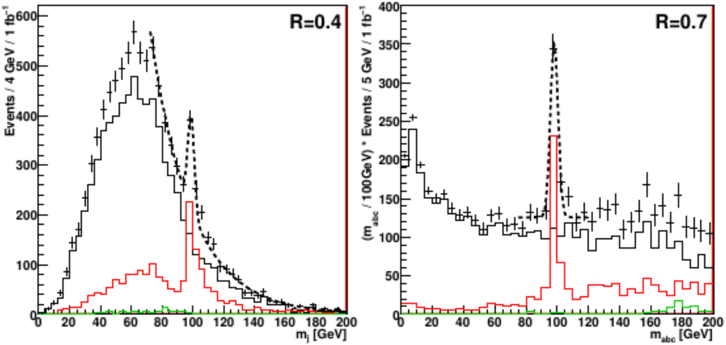
Neutralino decays

Baryon number violating neutralino decays at the LHC

- RPV decay: $\widetilde{\chi}_1^0 \to qqq$
- Swamped by QCD background
- $(m_{\widetilde{\chi}_1^0}, m_{\widetilde{q}}, m_{\widetilde{g}}) \simeq (96, 530, 600)$ GeV – $(161, 815, 915)$ GeV.
- $\lambda''_{112} = 0.001$

Butterworth, Ellis, Raklev, Salam: PRL 103, 241803

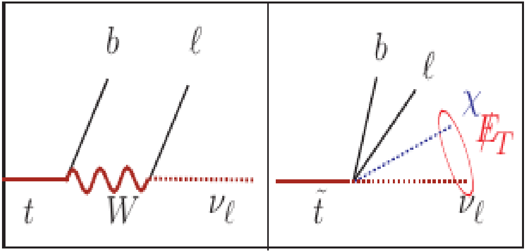
Baryon number violating neutralino decays at the LHC



- Jet mass distribution for the k_T algorithm (left) and C/A algorithm (right) after all the cuts. QCD (black) and signal (red).

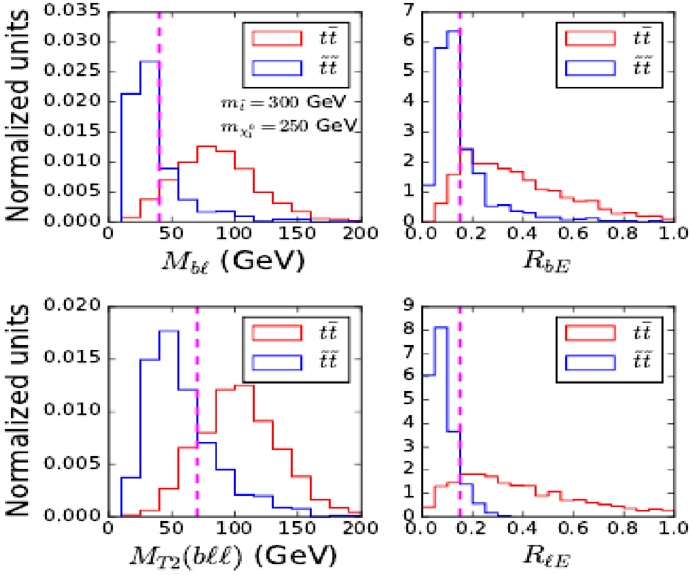
Compressed SUSY

- $\widetilde{t} \rightarrow b\ f\overline{f}'\widetilde{\chi}_1^0$

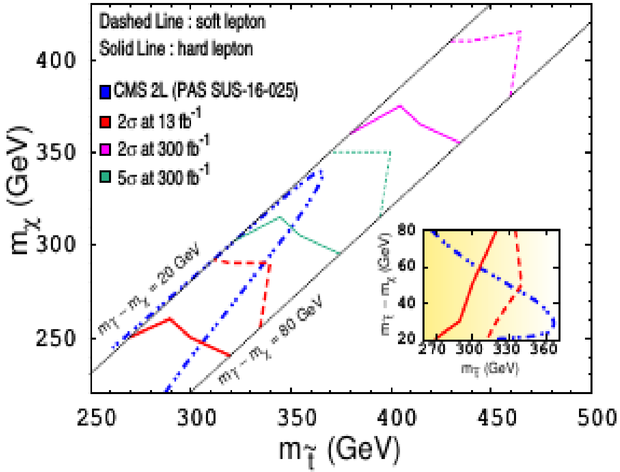


- $R_{bE} = \frac{\sum P_T^{b_i}}{\not{E}_T}$, $R_{\ell E} = \frac{\sum P_T^{\ell_i}}{\not{E}_T}$

Partha Konar, Tanmoy Mondal, Abhaya Kumar Swain, arXiv: 1612.03269



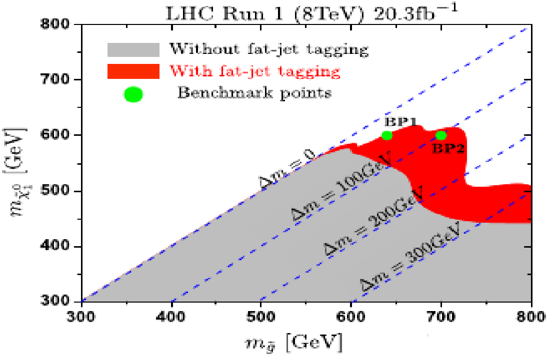
Normalized units
0.035
0.030
0.025
0.020
0.015
0.010
0.005
0.000
0
50
100
150
200
$M_{b\ell}$ (GeV)
$t\bar{t}$
$\tilde{t}\tilde{t}$
$m_{\tilde{t}} = 300$ GeV
$m_{\chi_1^0} = 250$ GeV
7
6
5
4
3
2
1
0
0.0
0.2
0.4
0.6
0.8
1.0
R_{bE}
Normalized units
0.020
0.015
0.010
0.005
0.000
$M_{T2}(b\ell\ell)$ (GeV)
9
8
$R_{\ell E}$



- Reach of $m_{\tilde{\chi}_1^0}$ can be enhanced from 270 GeV to 330 GeV

Revealing the jet substructure in a compressed spectrum of new physics

- $A \to q + q' + B$
- $\Delta m \equiv m_A - m_B$



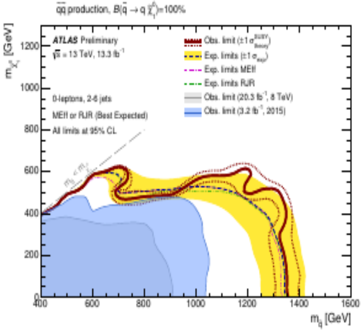
Chengcheng Han and Myeonghun Park, arXiv:1507.07729

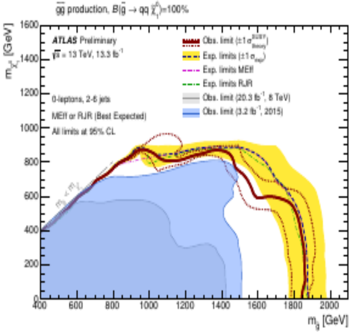
Chasing New Physics in Stacks of Soft Tracks

Work done in collaboration with Amit Chakraborty and Tuhin S. Roy, Phys.Rev. D94 (2016) no.11, 111703

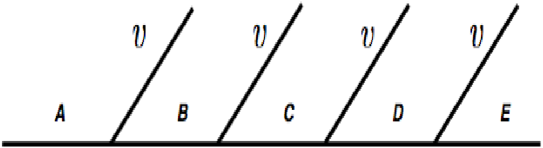
13 TeV results

- No sign of SUSY ATLAS-CONF 2016-078





Compressed region, the limit is roughly $m_{\tilde{g}} \sim m_{\tilde{q}} \sim 600$ GeV



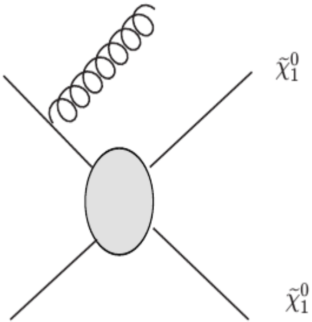
- $\Delta m = m_A - m_B = m_B - m_C = \ldots$

Two scenarios

Case 1	Case 2
Compressed	Supercompressed
$\Delta m = 25$ GeV	$\Delta m = 5$ GeV
$\mathcal{D} = \frac{\Delta m}{m_A} = 1/15$	$\mathcal{D} = \frac{\Delta m}{m_A} = 1/75$

Usual Search Strategy

- Visible energies are small and do not cross the threshold



- Topology: An energetic jet + $\not{E}_T$

Usual search strategy

Event Selection

I. Leading jet $p_T > 100$ GeV

II. $\not{E}_T > 200$ GeV

III. $M_{\text{EFF}} > 500$ GeV

IV. $\Delta\Phi(j, \not{E}_T) > 1.0$

V. SM backgrounds: $Z(\nu\nu)$+jets, $W(\ell\nu)$+jets, QCD

VI. The observables are highly correlated

Track Observables

Track Observables

I. Associated with the primary vertex

II. Not part of any other reconstructed objects

III. Ensured by using $\Delta R(\text{track}, j) > \text{jet radius} R$

IV. Number of tracks are binned in p_T

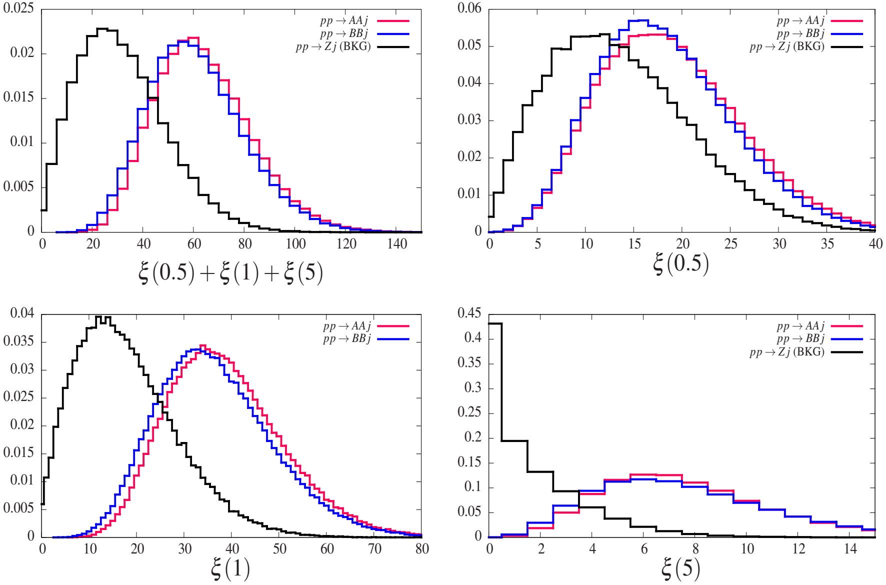
V. $\xi(5) \equiv p_T > 5$ GeV

VI. $\xi(1) \equiv 1$ GeV $< p_T < 5$ GeV

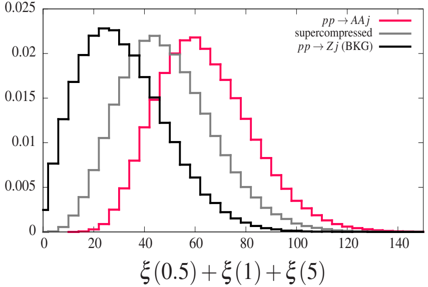
VII. $\xi(0.5) \equiv 0.5$ GeV $< p_T < 1$ GeV

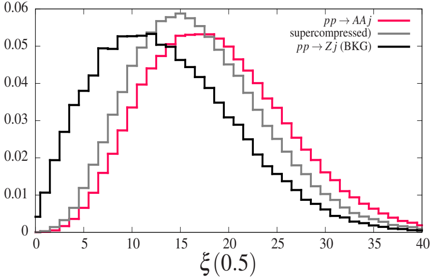
VIII. Conventional variables $V_C = p_T(j), \not{E}_T, H_T, M_{\text{EFF}}$

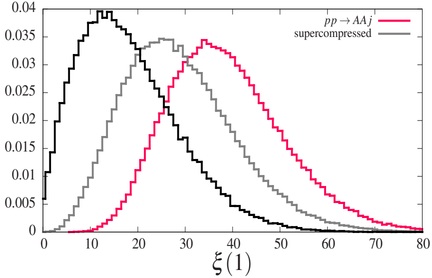
IX. Additional variables $V_A = \xi(5), \xi(1), \xi(0.5), p_T(j), \not{E}_T, H_T, M_{\text{EFF}}$

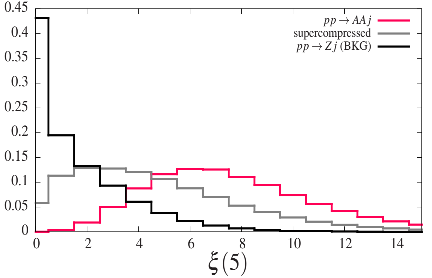


Amit Chakraborty, Sabyasachi Chakraborty, Tuhin S. Roy, arXiv: 1606.07826

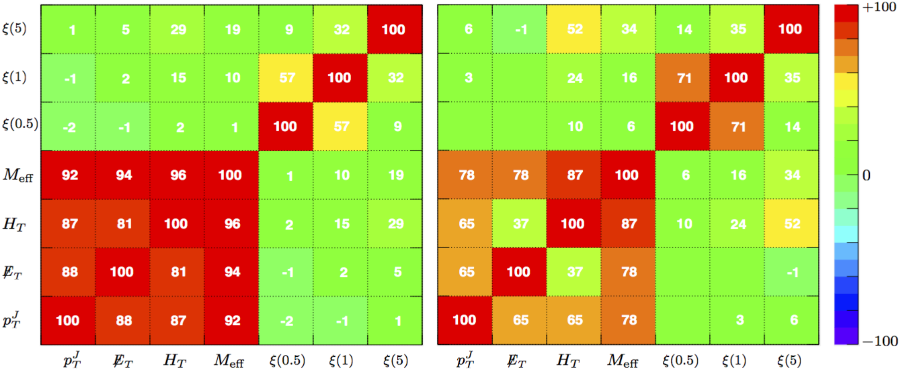

0.025
0.02
0.015
0.01
0.005
0
0
20
40
60
80
100
120
140
$pp \to AAj$
supercompressed
$pp \to Zj$ (BKG)
$\xi(0.5)+\xi(1)+\xi(5)$


0.06
0.05
0.04
0.03
0.02
0.01
0
0
5
10
15
20
25
30
35
40
$pp \to AAj$
supercompressed)
$pp \to Zj$ (BKG)
$\xi(0.5)$


0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
0
10
20
30
40
50
60
70
80
$pp \to AAj$
supercompressed
$\xi(1)$

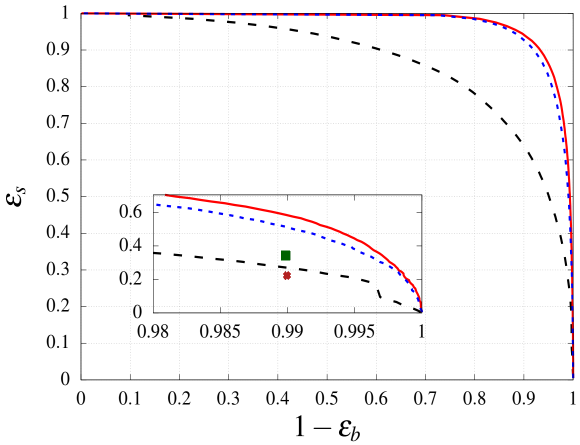

0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
2
4
6
8
10
12
14
$pp \to AAj$
supercompressed
$pp \to Zj$ (BKG)
$\xi(5)$

Correlations



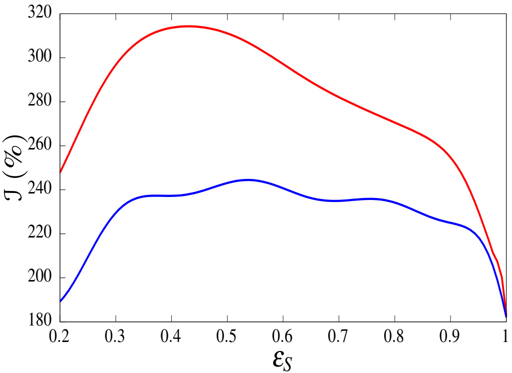
- Left Signal, right background
- Linear Correlation coeff. $= \text{Cov}(x, y)/\sigma_x\sigma_y$

Results for $\mathcal{D} = 1/15$



- **For a fixed bkg. efficiency around 50% or more improvement in signal effs. is observed in a simple minded cut based analysis**

Results

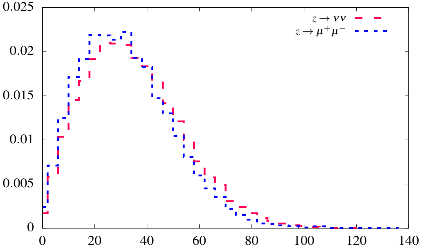


Improvement in $S/\sqrt{B}$:

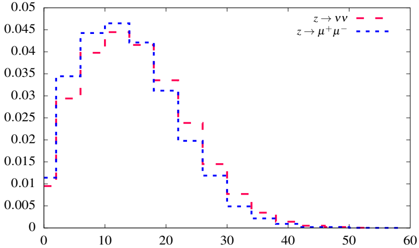
$$\mathcal{I}_a = \frac{(\epsilon_S/\sqrt{\epsilon_B})_a}{(\epsilon_S/\sqrt{\epsilon_B})_{V_C}}$$

- **Improvements:** $\mathcal{I}_{\mathcal{D}=1/15} \sim 200\%$, $\mathcal{I}_{\mathcal{D}=1/75} \sim 30\%$

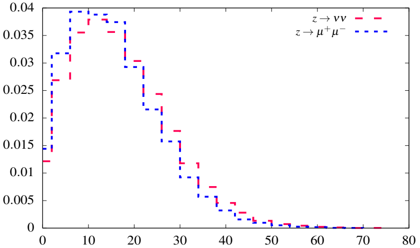
Data Driven way



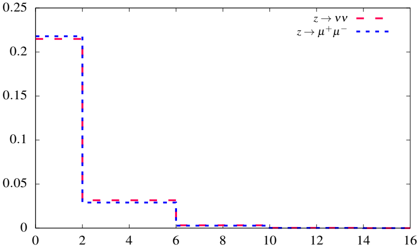
$\xi(0.5) + \xi(1) + \xi(5)$



$\xi(0.5)$



$\xi(1)$



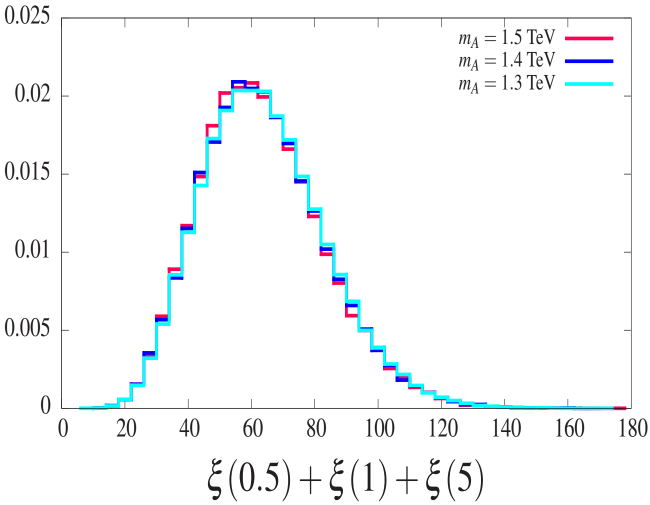
$\xi(5)$

Conclusion

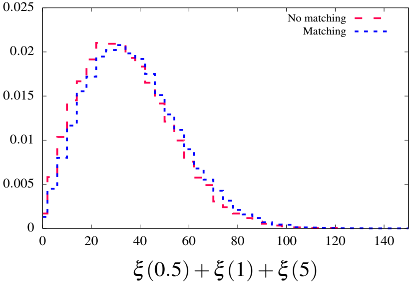
- Monojet + MET: challenging scenario at the LHC
- Conventional analysis fails to utilize the full event information
- We introduce ξ, a measure of soft tracks in an event not associated with reconstructed objects can play a big role.

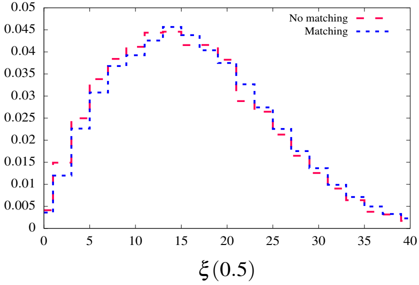
Thank You !

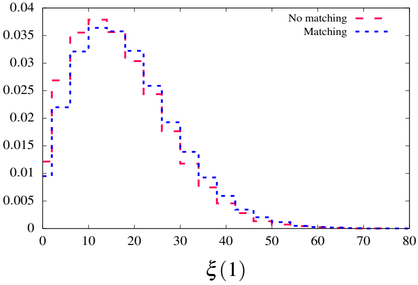
Different $\sqrt{s}$

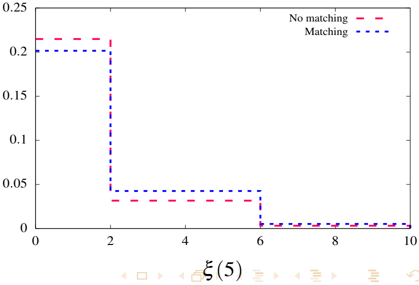


Matched Sample

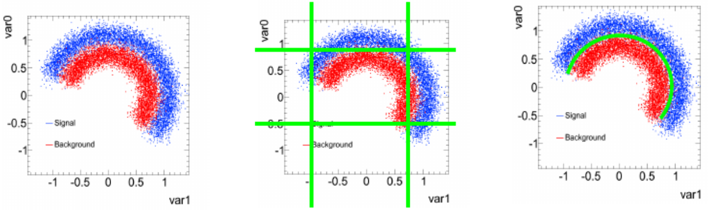


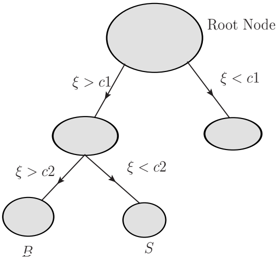




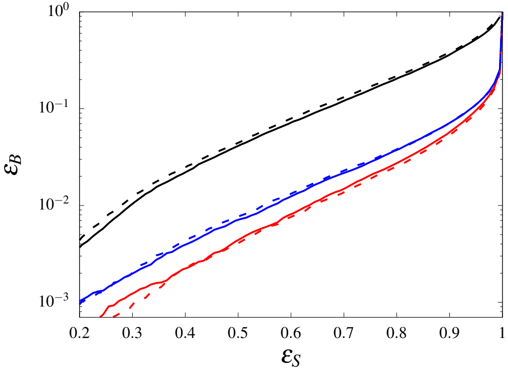


Multivariate Analysis





ROC for $\mathcal{D} = 1/15$



- Solid line with PU = 40. Dashed line PU = 20
- $V_{\text{sel}} = \{\xi(5), \xi(1), \xi(0.5), M_{\text{eff}}\}$ Red: V_{all}, Blue: V_{sel}, Black: V_C
- Analysis is pile-up robust and significant bkg reduction using tracks
- V_{sel} out-performs conventional set