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Probing new signature using Jet substructure at the LHC

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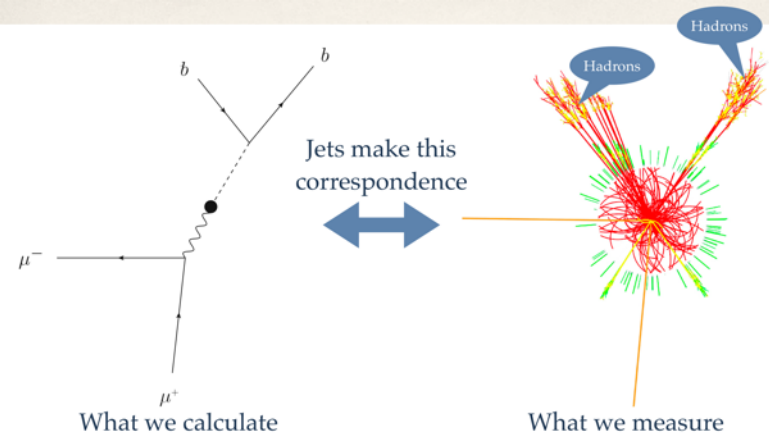
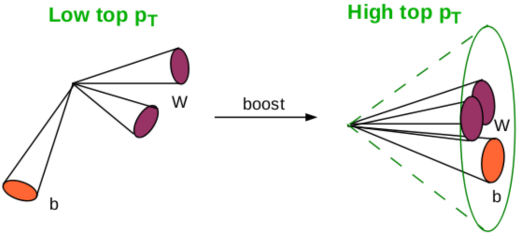
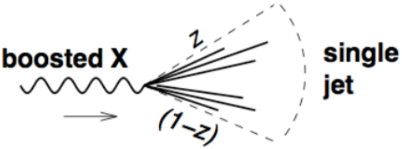
What we calculate and What we see at the LHC?



$h \to b\bar{b}$ 57% , Z and W boson decay almost 70% to hadronic channnel.

Boosted topology

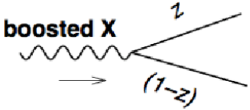




$$R \gtrsim \frac{m}{p_t} \frac{1}{\sqrt{z(1-z)}}$$

How to look for Jet Substructure ....

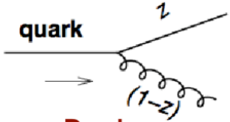
A possible approch for reducing the QCD background is to identify the two prongs of the heavy particle decay, and put a cut on thier momentum fraction.



Signal:

$$P(z) \sim 1$$

Will split mainly **symmetrically**



Background:

$$P(z) \sim \frac{1+z^2}{1-z} \qquad P(z) \sim \frac{1+(1-z)^2}{z}$$

Will split mainly **asymmetrically**

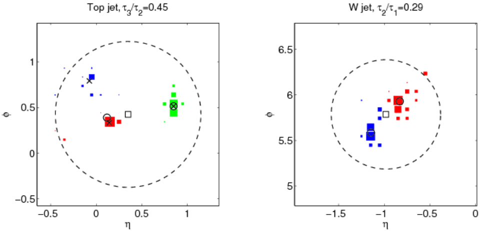
Selection of the symmetric splitting and identify two legs.

Identifying the 2 or 3 prong nature of the Fat-jet

N-subjettiness

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

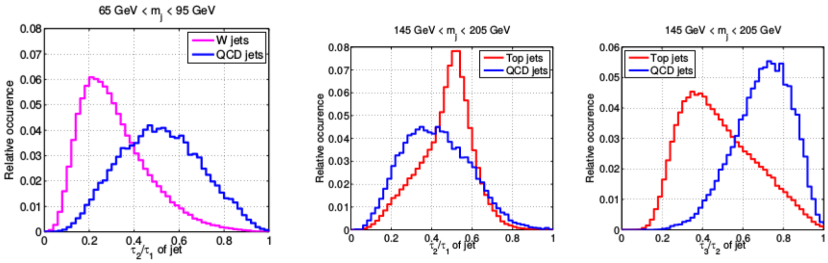
i runs over the constituent particles in a given jet.
Where, $\mathcal{N}_0 = \sum_i p_{i,T} R_0$ is the normalizing factor ,
R_0 is the jet radius parameter.



[0] J.Thaler and K. Van Tilburg [JHEP03(2011)015]

N-subjettiness Ratio

- Quantify how original jet seem to be composed of N daughter subjets
- $\tau_N \sim 0 \Rightarrow$Original jet consist of N or fewer sub-jets
- $\tau_N >> 0 \Rightarrow$ Large fraction of energy diluted from candidate N sub-jets
- A good discriminant the ratios of adjacent N-subjettiness values



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Inverse SeeSaw

The relevant part of the Lagrangian can be written as

$$\mathcal{L} \supset -Y_D^{\alpha\beta}\overline{\ell_L^\alpha} H N_R^\beta - M^{\alpha\beta}\overline{S_L^\alpha} N_R^\beta - \frac{1}{2}\mu_{\alpha\beta}\overline{S_L^\alpha} S_L^{\beta^C} + \mathrm{H.c.}$$

After the electroweak symmetry breaking we obtain the neutrino mass matrix as

$$M_\nu = \begin{pmatrix} 0 & M_D & 0 \\ M_D^T & 0 & M^T \\ 0 & M & \mu \end{pmatrix}.$$

we obtain the inverse seesaw formula for the light neutrinos as

$$M_\nu \simeq M_D M^{-1}\, \mu\, M^{-1^T} M_D^T.$$

Inverse SeeSaw : Two different cases

Single flavor (SF)

- One heavy Dirac pair is at the electroweak scale, while other heavy pairs are assumed to be beyond the kinematic reach of the LHC.
- The lightest heavy Dirac neutrino mass eigenstates dominantly couple to a single lepton flavor Assume μ

[0] Arindam Das, P. S. Bhupal Dev and Nobuchika Okada [Phys.Lett. B735 (2014)]

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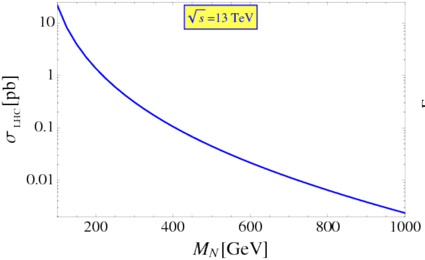
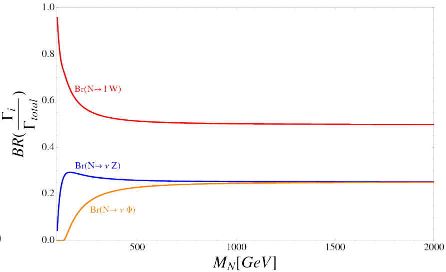
Flavor diagonal (FD)

- Two of the heavy Dirac neutrino pairs are degenerate with a equal mass m_N.
- Assuming that one pair dominantly couples to electrons, and the other one to muons with equal strength.

[0] Arindam Das, P. S. Bhupal Dev and Nobuchika Okada [Phys.Lett. B735 (2014)]

Heavy Neutrino at LHC

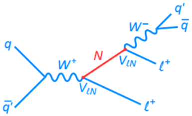


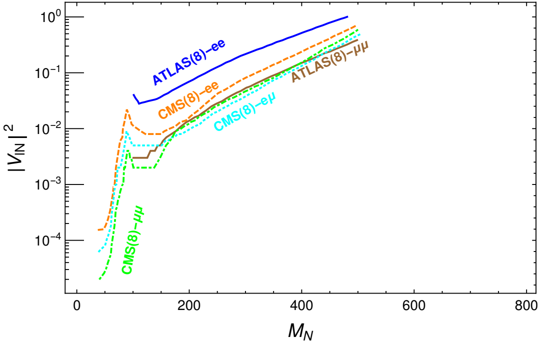


Total production cross-section and branching ratios of heavy Majorana neutrino as a function of its mass at the LHC with $\sqrt{s} =$ 13 TeV and normalised by the $|V_{\mu N}|^2$.

$$BR(N \to lW) : BR(N \to: \nu Z) : BR(N \to \nu h) \simeq 2 : 1 : 1$$

Conventional Experimental searches





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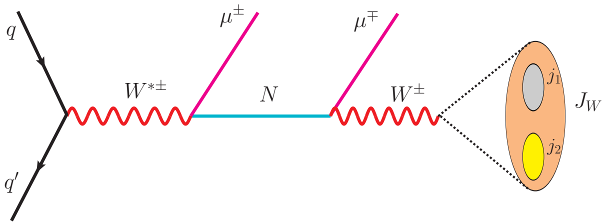
[0]CMS8: 1501.05566, 1603.02248 ATLAS8: 1506.06020

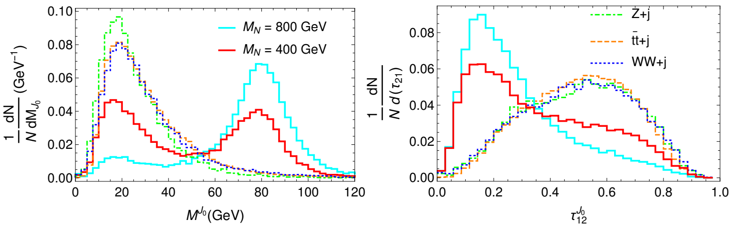
Fatjet from Heavy Neutrino (OSDL)

$$pp \to l_1^+ N, N \to l_2^- W^+, W^+ \to J_W$$
$$pp \to l_1^- \overline{N}, \overline{N} \to l_2^+ W^-, W^- \to J_W$$



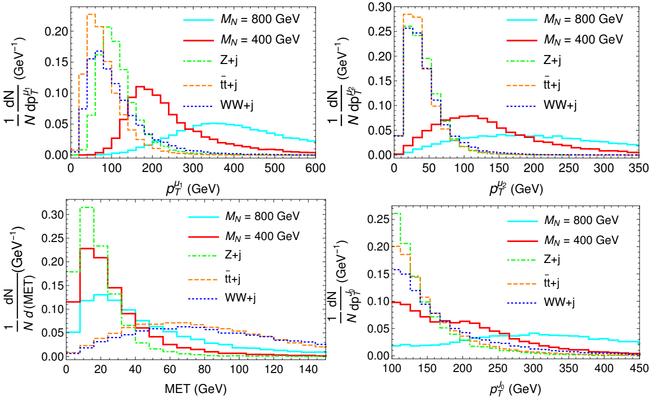
Fatjet signature will be seen if $W^{\pm}$ is sufficiently boosted.

Utilising Jetsubstructure for W-tagging



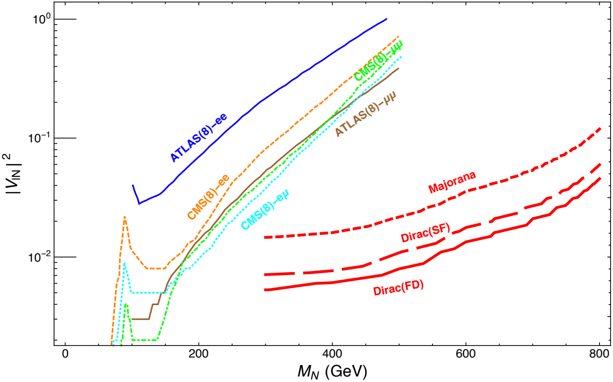
Normalised distribution invariant mass $M_{J_0}(left)$ and N-subjettiness ratio τ_{21} $(right)$ of the leading fat-jet after the application of the basic selection cuts; including $p_T^{J_0} > 100\,GeV$..

Utilising Jetsubstructure for W-tagging



Normalised distribution as a function of observables after the application of the basic selection cuts; including $p_T^{J_0} > 100\,GeV$.

Results and Discussion (OSDL)



Exclusion limit in terms of heavy neutrino mass M_N and $|V_{\mu N}|^2$ for an integrated luminosity of 3000 fb^{-1} at the 13 TeV LHC with other available limits.

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[0]AB, Arindam Das, Partha Konar and Arun Thalapillil, arXiv[1801.00797]

Conclusion

- Jet Substructure technique: one of the most efficient and popular discovery tool in the search of new physics signatures at the LHC.
- As the available center-of-mass energy at the LHC increases, more and more boosted particles, understanding of the physics in this boosted regime is extremely crucial.
- One of the most active field of research in particle physics phenomenology !

Conclusion

- Jet Substructure technique: one of the most efficient and popular discovery tool in the search of new physics signatures at the LHC.

- As the available center-of-mass energy at the LHC increases, more and more boosted particles, understanding of the physics in this boosted regime is extremely crucial.

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THANK YOU

Cut flow for OSDL + a fatjet

Cut	Signal	Background					
	$M_N = 400$(GeV)	$Z^l + j$	$t\bar{t} + j$	$W^l W^l + j$	$Z^l W^h + j$	$Z W^l + j$	$Z^l W^l W^h + j$
Pre-selection + $\mu^+\mu^- + 1J$	621.69 [100%]	5.1×10^7 [100%]	5.6×10^6 [100%]	2.2×10^5 [100%]	5.7×10^5 [100%]	2.9×10^4 [100%]	120.8 [100%]
$p_T(l_1) > 100$ GeV + $p_T(l_2) > 60$ GeV	532.1 [85.60%]	8.9×10^6 [16.88%]	6×10^5 [10.68%]	3.6×10^4 [16.86%]	10.2×10^4 [18.27%]	5556 [19.48%]	33.64 [27.85%]
$M_{\mu^+\mu^-} > 200$ GeV	446.4 [71.82%]	583.7 [0.0010%]	4.2×10^5 [7.37%]	2.2×10^4 [9.87%]	9.4 [0.0016%]	1471.2 [5.15%]	10.42 [8.62%]
b-veto	414.6 [66.71%]	530.6 [9.9×10^{-4}%]	14.8×10^4 [2.67%]	2.0×10^4 [9.52%]	8.54 [0.0014%]	1384.5 [4.85%]	9.15 [7.58%]
MET < 60	369.7 [59.49%]	371.4 [6.9×10^{-4}%]	5.4×10^4 [0.982%]	8104 [3.70%]	6.0 [10.3×10^{-4}%]	751.41 [2.63%]	4.04 [3.35%]
$p_T^{J_0} > 150$ GeV	240.3 [38.65%]	265.32 [4.9×10^{-4}%]	19606 [0.351%]	4032 [1.842%]	4.27 [7.3×10^{-4}%]	419.9 [1.47%]	2.75 [2.28%]
$M^{J_0} > 50$ GeV	171.2 [27.54%]	42.4 [7×10^{-5}%]	3560 [0.063%]	887.4 [0.40%]	0.68 [1.2×10^{-4}%]	105.7 [0.37%]	1.48 [1.233%]
$\tau_{21} < 0.4$	152.3 [24.50%]	21.18 [3.9×10^{-5}%]	2062 [0.036%]	433.8 [0.198%]	0.34 [5.8×10^{-5}%]	71.03 [0.24%]	1.13 [0.94%]