Mass Unspecific Supervised Tagging for Boosted Jets

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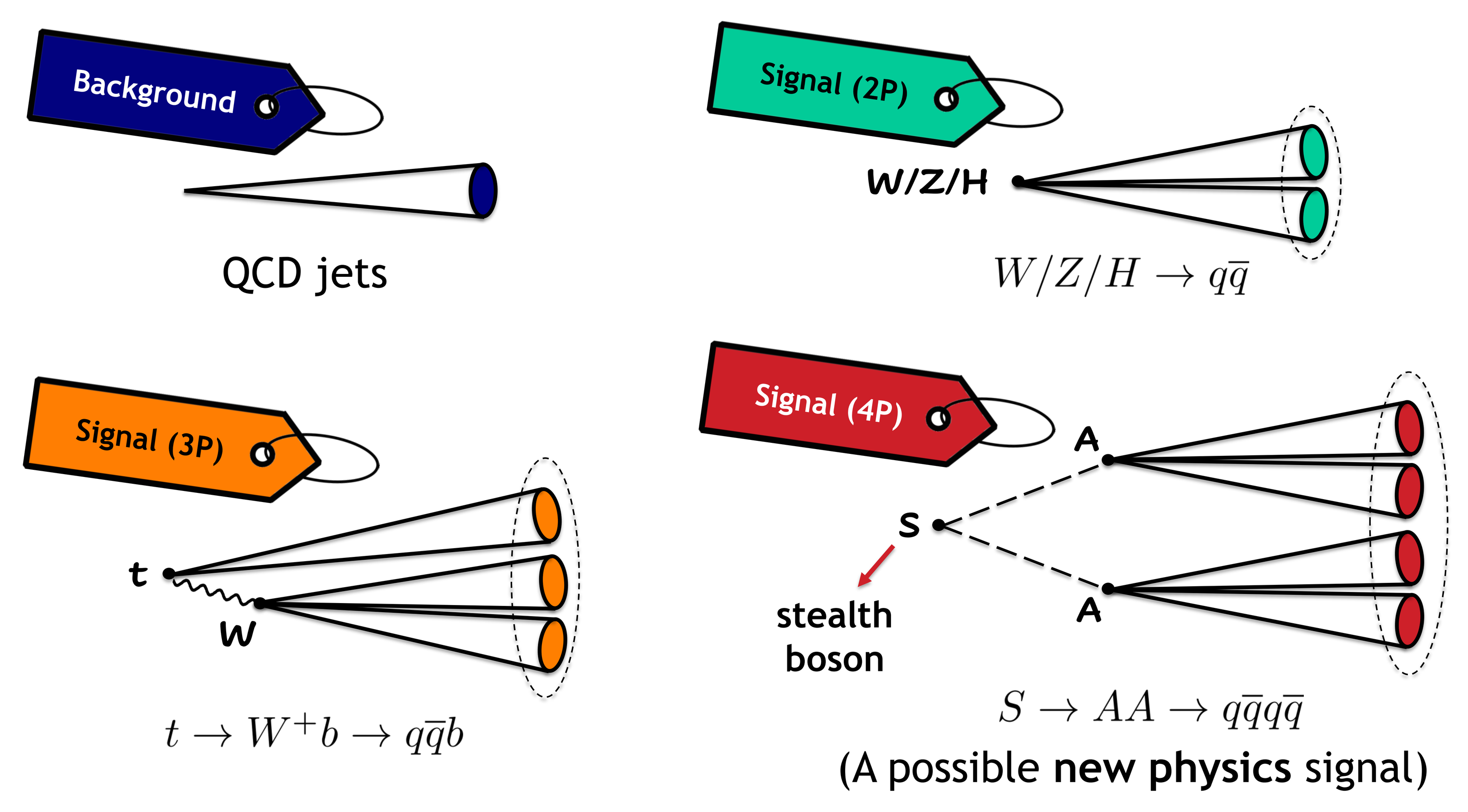
What is MUST?

J. A. Aguilar-Saavedra, F. R. Joaquim, J. F. Seabra, JHEP 03, (2021) 012

A new strategy for training jet taggers based on multivariate methods, where the mass and transverse momentum of jets are input variables, together with jet substructure observables, varying over wide ranges.

The importance of jet tagging

Hadronic jets are the most abundant collision products at the **LHC.** After quantifying their mass, one can get invaluable insights into collision events by inferring the number of quarks and gluons clustered inside them (**prongs**):

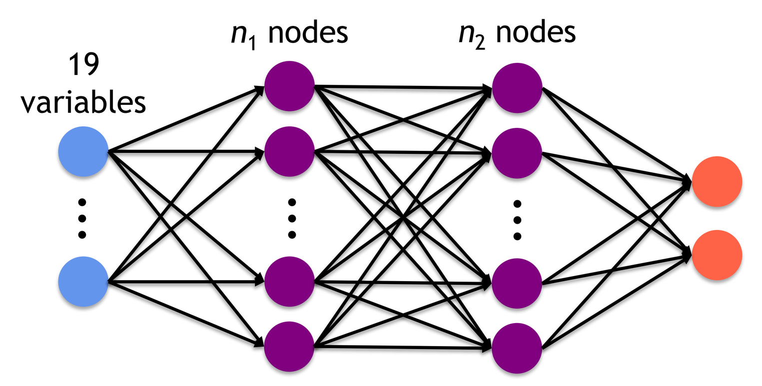


Jet tagging tools are crucial in new physics searches to distinguish QCD jets (Background) from those produced in collimated decays of heavy particles (Signal).

Building MUST-Taggers

Given training data with QCD jets and multi-pronged ones containing two or more quarks, we develop five taggers based on simple **neural networks** (NNs), with just two hidden layers.

The 19 input variables are m_J, p_T and **17 N-subjettiness observables**,



$$\left\{\tau_1^{(1/2)}, \tau_1^{(1)}, \tau_1^{(2)}, \cdots, \tau_5^{(1/2)}, \tau_5^{(1)}, \tau_5^{(2)}, \tau_6^{(1)}, \tau_6^{(2)}\right\},$$

which characterise **jet substructure**. The events used for training each tagger and further details about the architecture of the NNs are presented in the table below.

Tagger	Events used in training	n_1	n_2	Output layer
GenT	Background + 2P + 3P + 4P	2048	128	Sigmoid
GenT$_{2P}$	Background + 2P	1024	64	Sigmoid
GenT$_{3P}$	Background + 3P	1024	64	Sigmoid
GenT$_{4P}$	Background + 4P	1024	64	Sigmoid
Prongness selection tagger	2P + 3P + 4P	2048	128	Softmax

What can we achieve using the concept of MUST?

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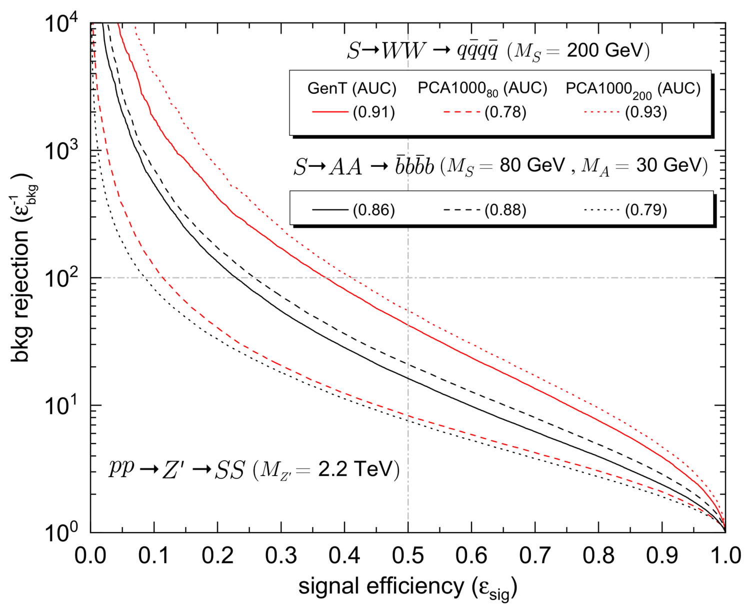
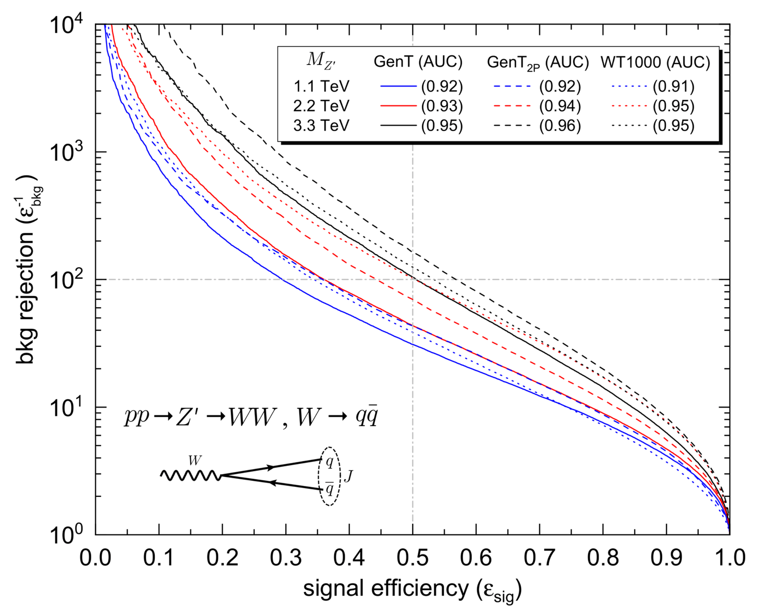
✓ Generic taggers with excellent performance over wide ranges of m_J and p_T

By comparing GenT with PCA1000$_{80}$ and PCA1000$_{200}$, two taggers trained in the narrow mass regions $m_J \in$ [60,100] GeV and $m_J \in$ [160,240] GeV respectively, we conclude that the latter perform slightly better than the former in the region they are trained, but much worse outside of it. A similar observation can be made when we compare GenT and GenT$_{2P}$ with WT1000, a tagger trained with W jets obtained from $Z' \to WW$ ($M_{Z'}$ = 2.2 TeV) and QCD jets with $p_T \geq$ 1 TeV and $m_J \in$ [60,100] GeV. Outside of that kinematical region, MUST-taggers can outperform WT1000, even though they are not trained specifically with W jets.

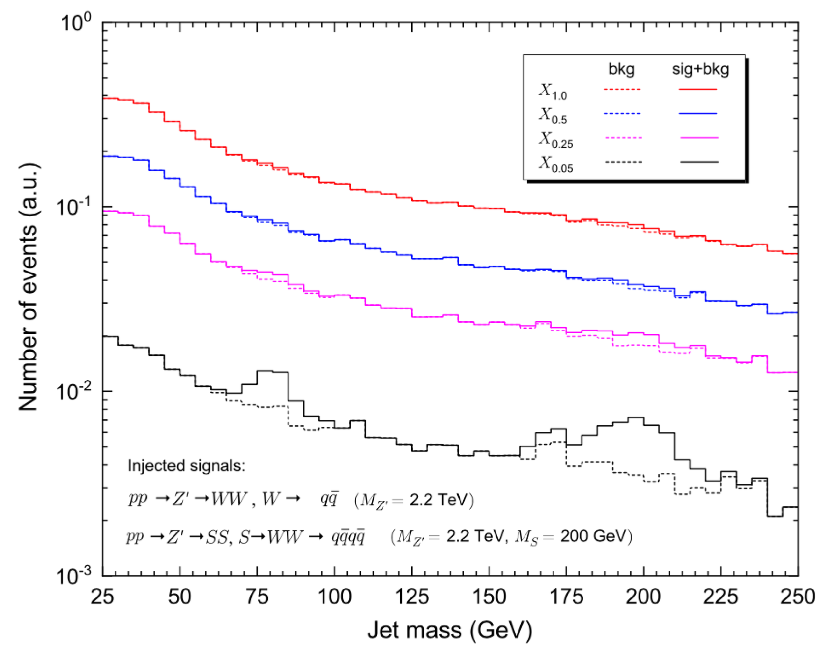




✓ Mass decorrelation

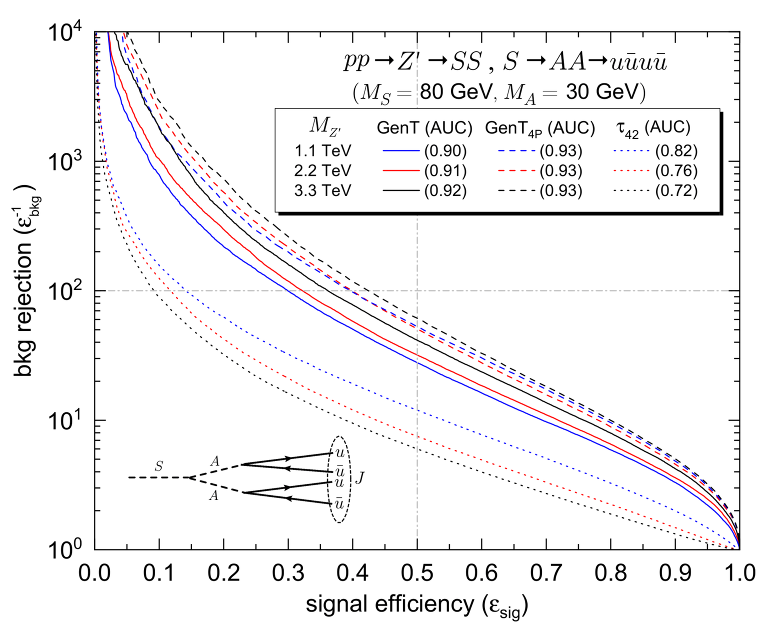
So far, the methods implemented in taggers to decorrelate m_J from jet substructure observables have been leaving a residual dependence on the training ranges of m_J and p_T. As a consequence, the performance of those taggers drops when applied to kinematical regions different from those used to train them. MUST removes the dependence of the taggers' efficiency on m_J and p_T, solving the mass correlation problem by preserving the shape of the jet mass distribution after applying the taggers.

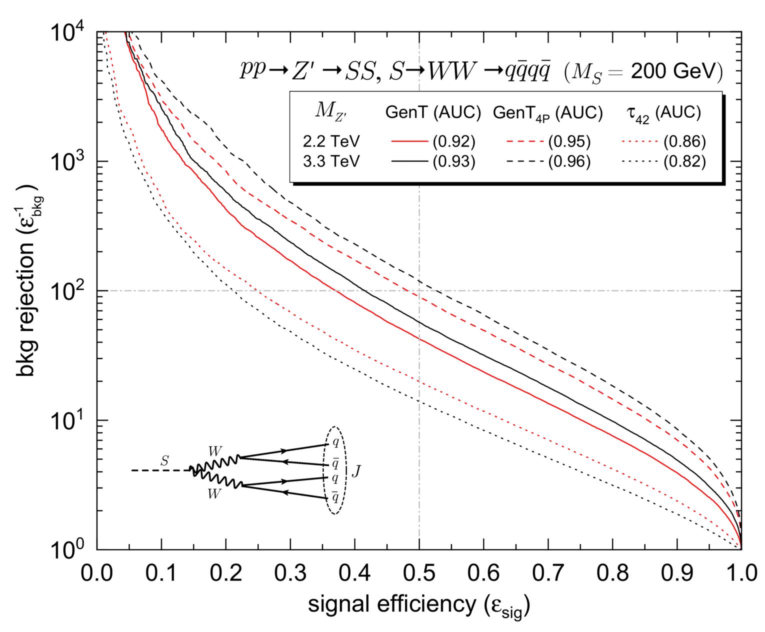
An example of that is illustrated by the plot on the right. There, it is drawn the jet mass distribution for Standard Model background plus two injected signals, after increasingly tighter cuts on GenT's NN score. This varying-threshold scheme keeps the shape of the background distribution and both injected signals show up when the cut becomes sufficiently tight.



✓ Better performance than variables commonly used in experiments

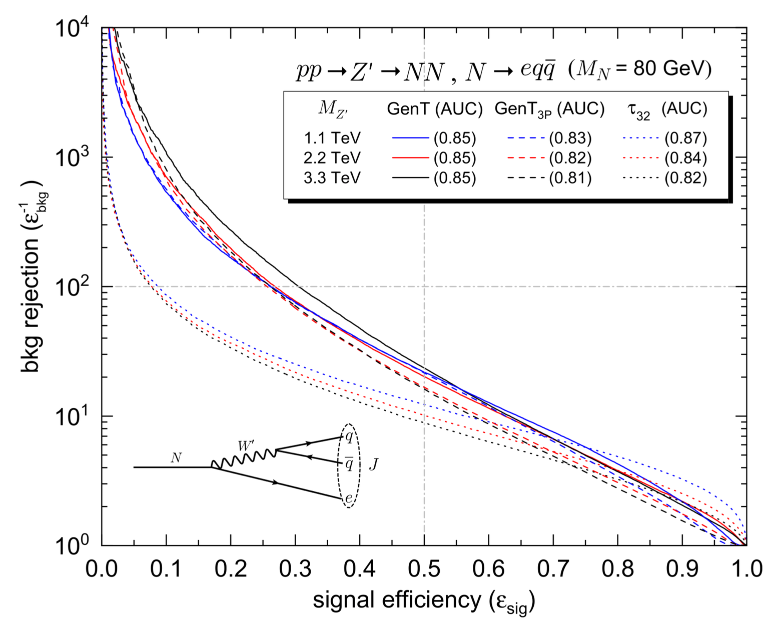
Represented by τ_{mn}, ratios of N-subjettiness observables τ_m/τ_n are commonly used by experiments to discriminate signal from background. The plots below provide examples of signals where MUST-taggers outperform those variables.

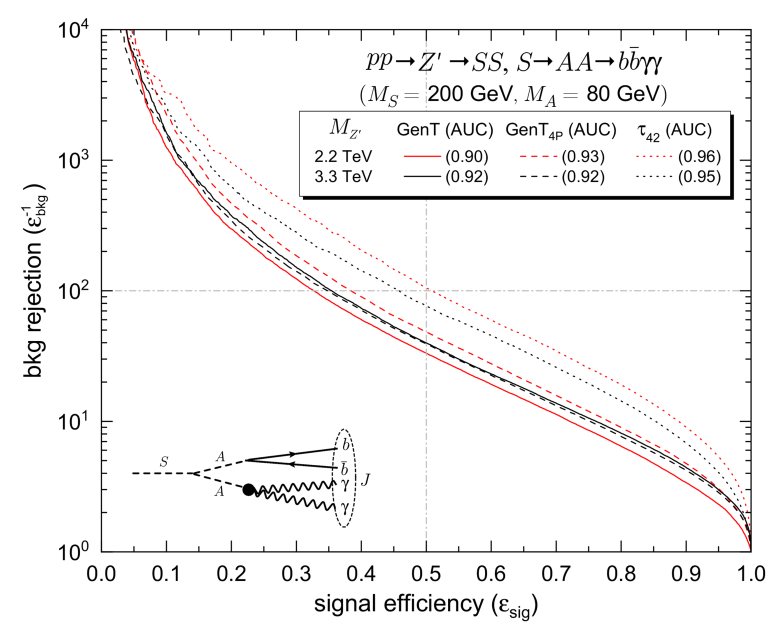




✓ Good efficiency on signals not used in training

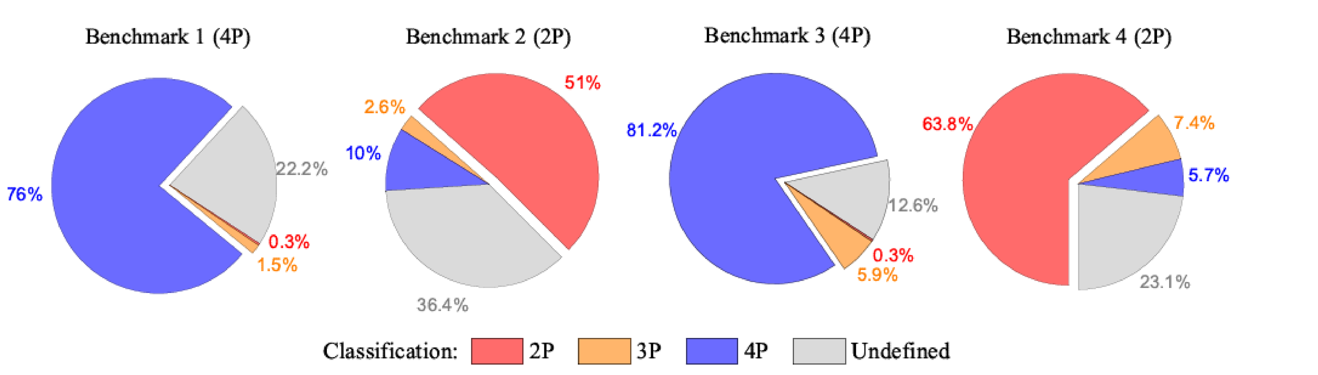
As the ROC curves below demonstrate, MUST-taggers efficiently spot signals not used to train them, namely neutrino jets with an electron in the final state and stealth boson decays into bottom quarks and photons.





✓ Discrimination of different kinds of signal events

The prongness selection tagger we have developed performs quite well in the four benchmarks we have built to test it. Considering a classification criteria where events are only classified as 2P, 3P or 4P if the probability of belonging to one of those classes is equal or bigger than 0.5 (otherwise the events are labelled as *Undefined*), the fraction of correctly identified jets is several times bigger than the fraction of misidentified ones.



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