ML-Assisted Reconstruction of Hadron-Collider Events with Mini-Jets

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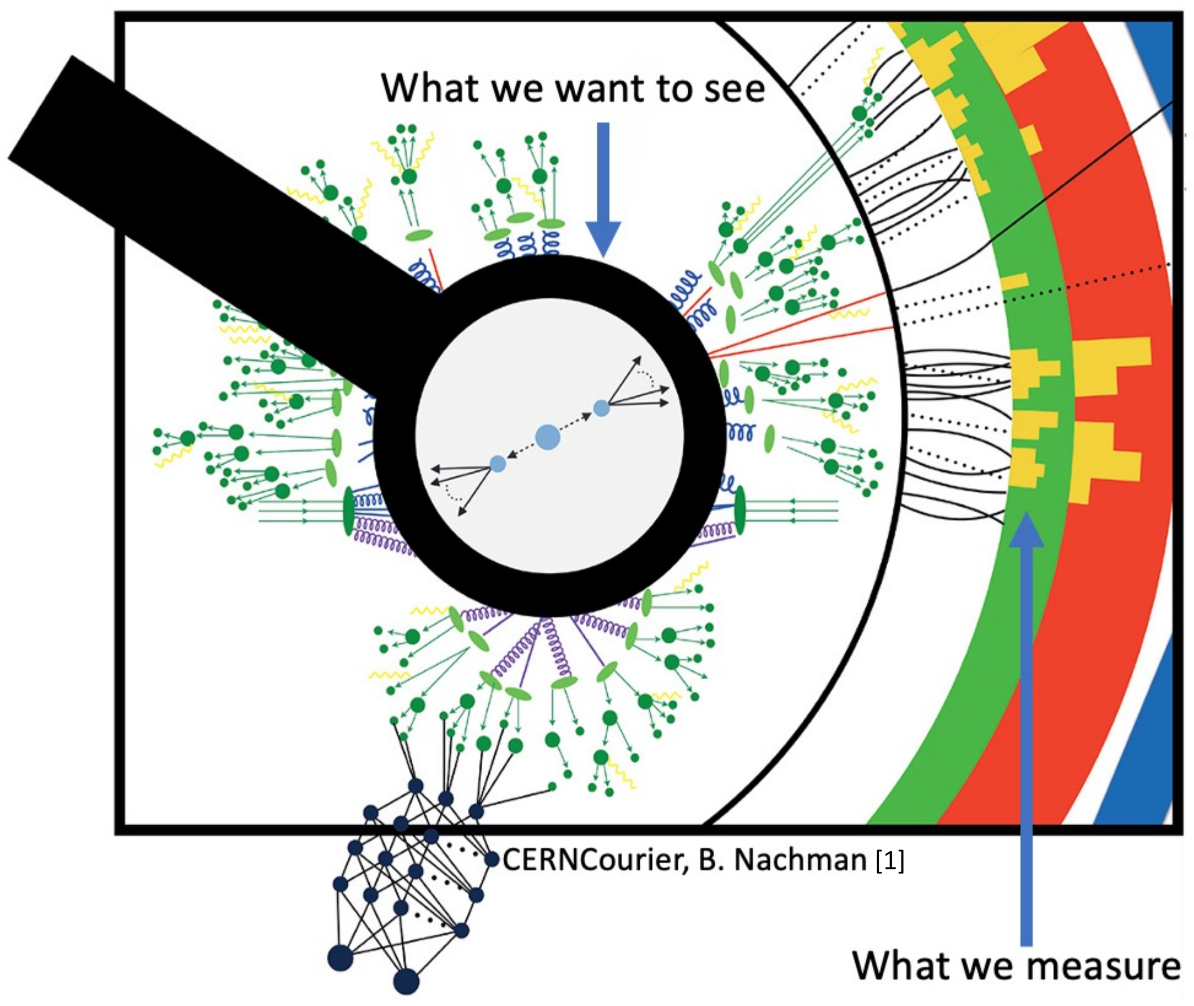
Abstract

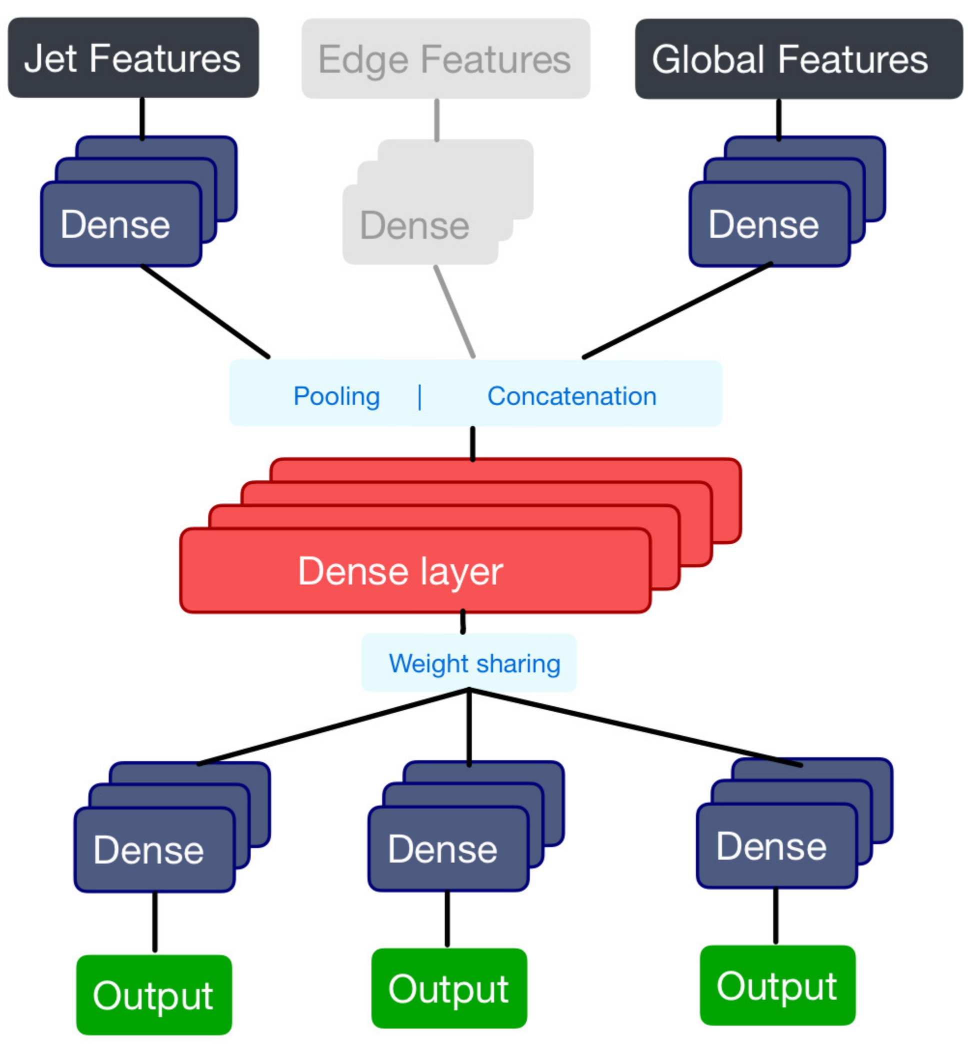
Reconstructing impactful physical observables from hadron collider data represents challenges due to combinatorial ambiguities and experimental effects. We propose a novel approach using mini-jets (R=0.1) as the sole reconstructed objects, employing a deep neural network for observable determination. This method condenses full event information into a manageable size, demonstrating superior efficiency and generality compared to classical algorithms for future LHC analyses.

Introduction



At hadron colliders, a critical task is the reconstruction of intermediate resonances from Higgs-, W- or Z-bosons or from a top-quark decay. Decays into quarks (hadronic decays) are particularly difficult, but also leptonic decays are challenging when neutrinos are involved. Due to colour confinement, quarks cannot be observed directly in experiment. Instead, they form jets of particles. Jet algorithms are commonly applied as a proxy for a single quark, or to reconstruct an intermediate resonance directly (H, W, Z, t).

Model Architecture

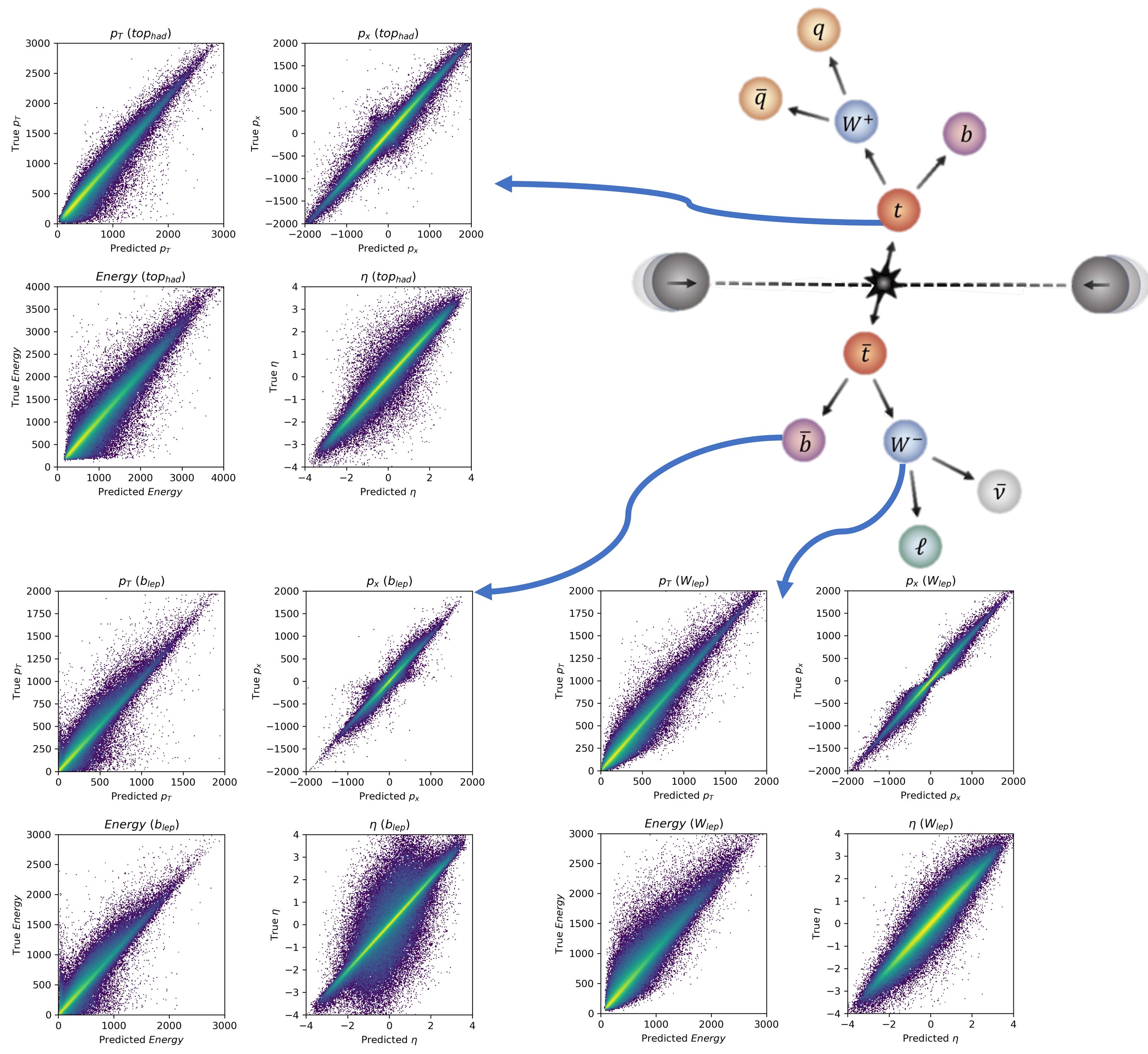


The input for our reconstruction model consists of a branch for the jet features and a branch for the global features (lepton & missing energy). With global pooling for jets and subsequent concatenation of jets and global features, the information is fed into the core layer (latent space). The core layer integrates multiple dense layers, capturing all relevant event information. In the output phase, specific resonance information is extracted through several dense layers, completing the analysis.

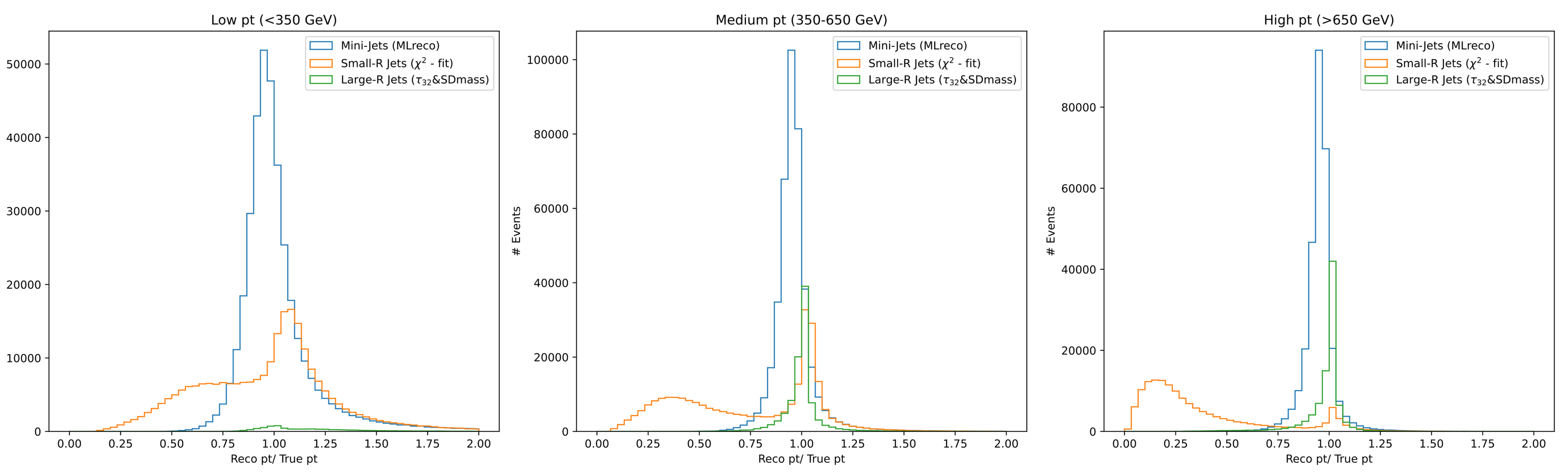
Results

All particles, excluding neutrinos, are input to the machine-learning algorithm. Mini-Jets uniquely represent the event, while missing energy and final-state leptons are considered separately. The details of the mini-jets are exploited by the DNN to regress the information on the intermediate resonances (H, W, Z, t).

One model can reconstruct selected features of all participating particles in a $t\bar{t}$-decay. Here are shown a few examples.



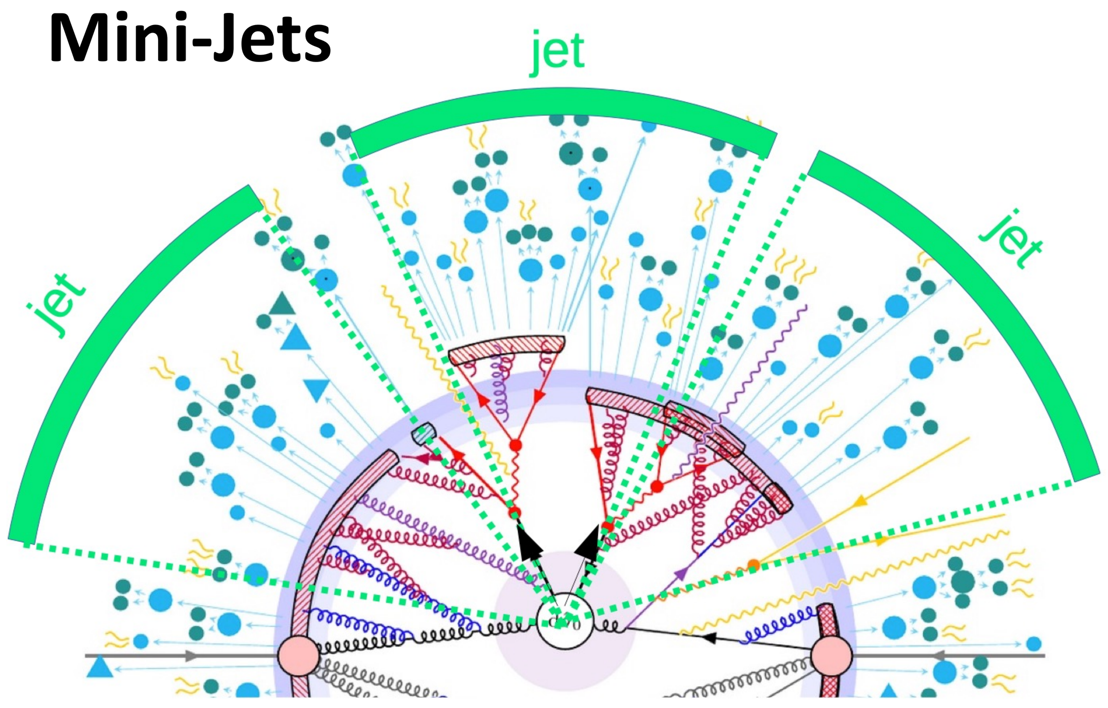
p_T-Reconstruction for different top quark kinematic regions

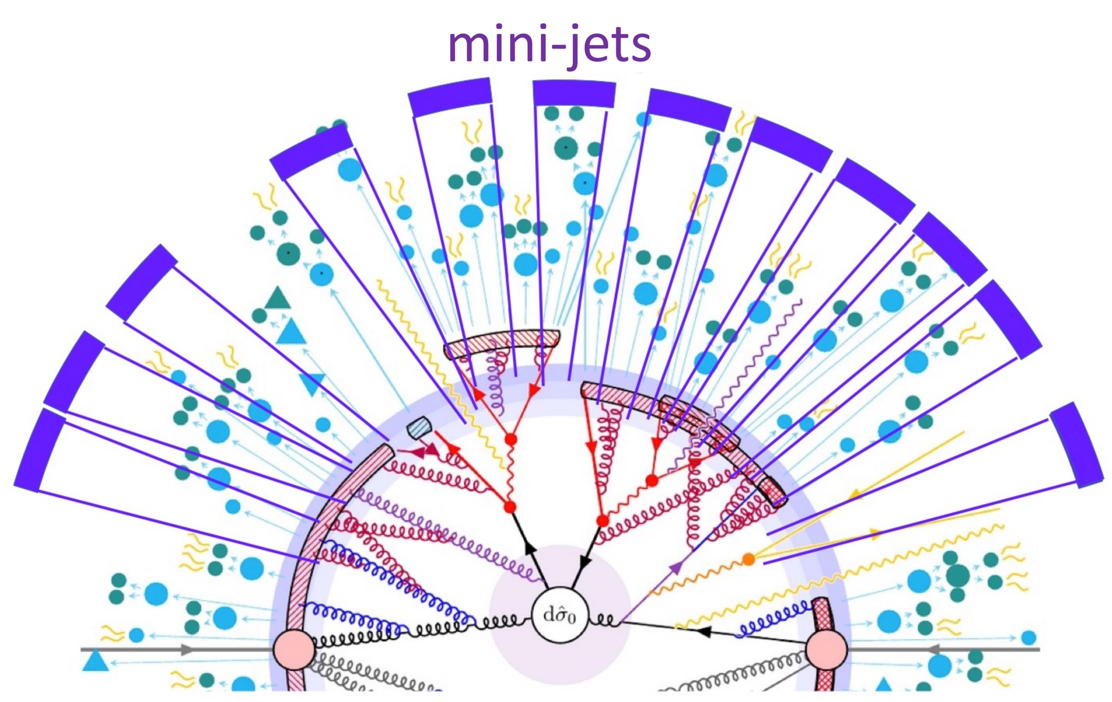


Here, a comparison of the machine-learning method with two classical approaches for small-R and large-R jets is shown for the p_T-Reconstruction of the hadronic decaying top quark.

The ML-assisted reconstruction with mini-jets results in significantly higher efficiency, and furthermore achieves higher resolution than small-R or large-R jets. The algorithm can handle different event topologies at different scales in a single algorithm: e.g. resolved and boosted top-quarks.

Mini-Jets





In standard LHC analyses, a suitable jet algorithm (e.g., R=0.4, 0.8) defines the selection of jets, assuming that all relevant hard process information is contained within them. Small-R or large-R jets, featuring substructure, act as proxies for the hard matrix element (ME), but inaccuracies may arise in matching jets with ME-partons due to sub-leading radiation as simulated with parton shower or higher order corrections.

Utilizing numerous mini-jets (jet-multiplicity <n> ≈ 15) enables comprehensive information collection. However, handling combinatorics for underlying hard physics reconstruction poses challenges, addressed by employing a neural network to manage abundant information [3].

For observable reconstruction, a Deep Neural Network (DNN) directly defines observables [2], overcoming inaccuracies associated with small-R or large-R jets' correspondence to ME-partons due to parton shower distortions.

References

[1] B. Nachman, CERN Courier 61 (2021) 5, 27
[2] M. Arratia, D. Britzger, O. Long and B. Nachman; arXiv:2110.05505
[3] J. Murnauer et al., publication in preparation.