Searching for Dark Matter at the LHC with GNN

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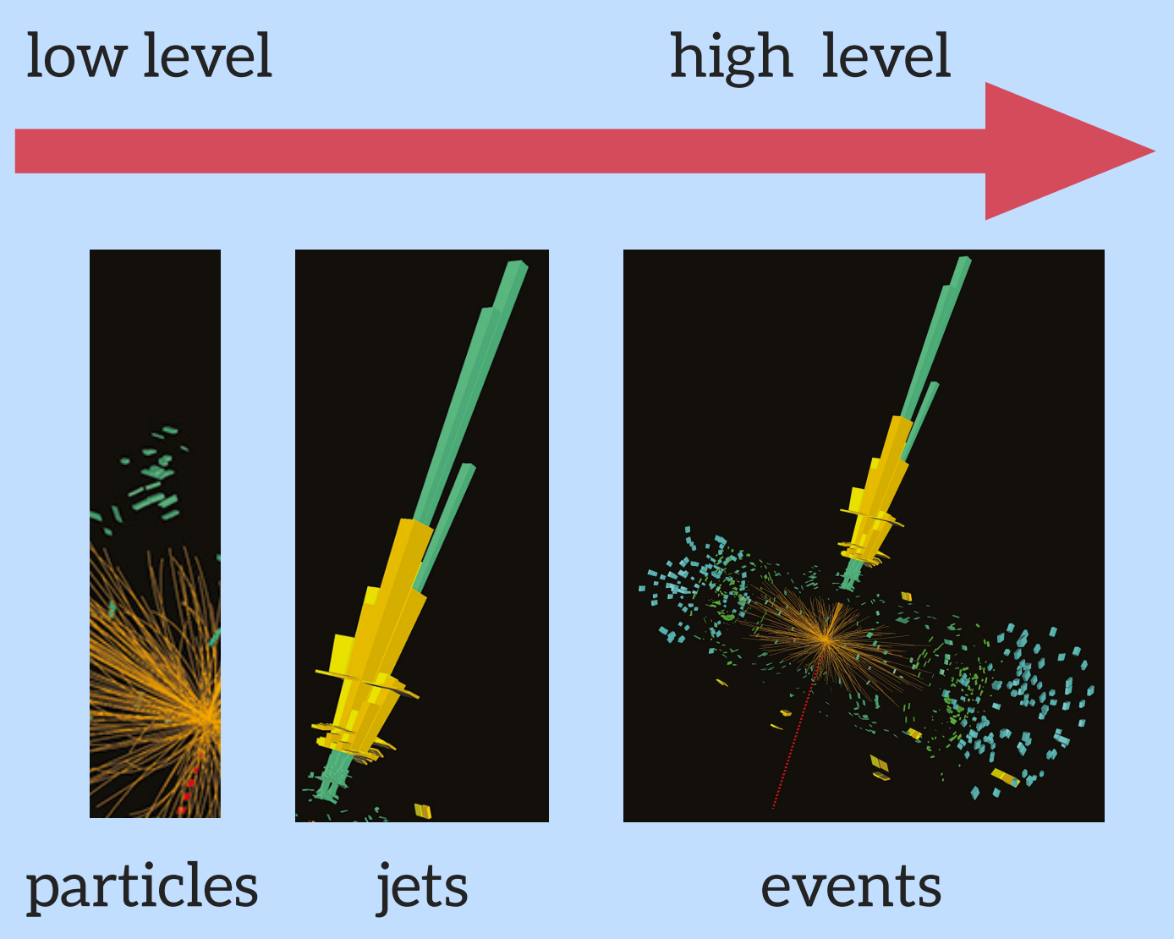
1 Introduction

Dark Matter particles can be discovered at the LHC using the monojet channel:

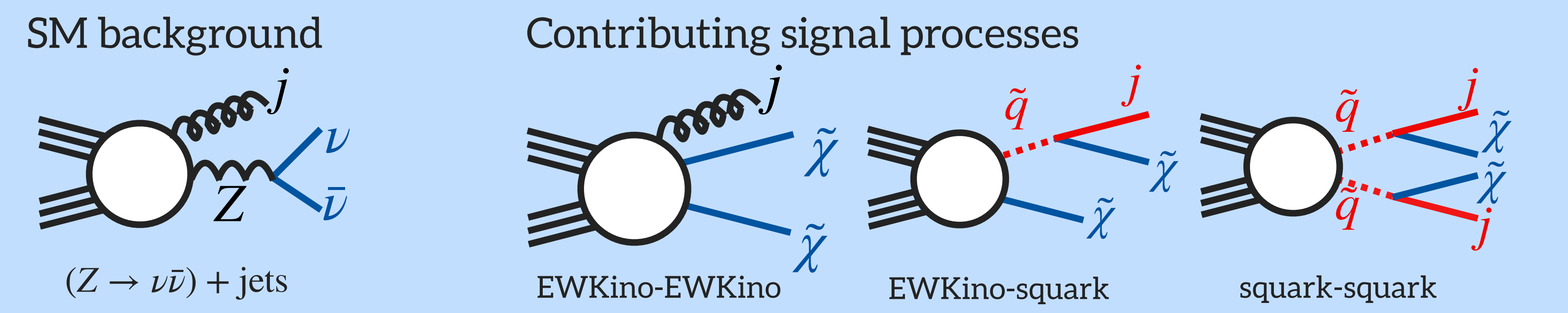
Monojet = at least 1 (but not more than a few) hard jet recoiling against $p_{\mathrm{T}}^{\mathrm{miss}}$ and no leptons.

Since DM is neutral, the detectors register only jets and $p_{\mathrm{T}}^{\mathrm{miss}}$, which makes the search challenging. We tackle the problem with a novel GNN-based analysis, using data at different levels: particles, jets and events. We consider the dominant SM background $(Z \to \nu\bar{\nu})$ + jets, and take SUSY simplified model as our benchmark DM scenario. DM candidate is wino- or higgsino-like neutralino that can be produced directly or via decaying squark. We assess the algorithm and derive the detection prospects for Run 3 and HL-LHC.

We use heterogenous data



We study MSSM with neutralino as DM benchmark.

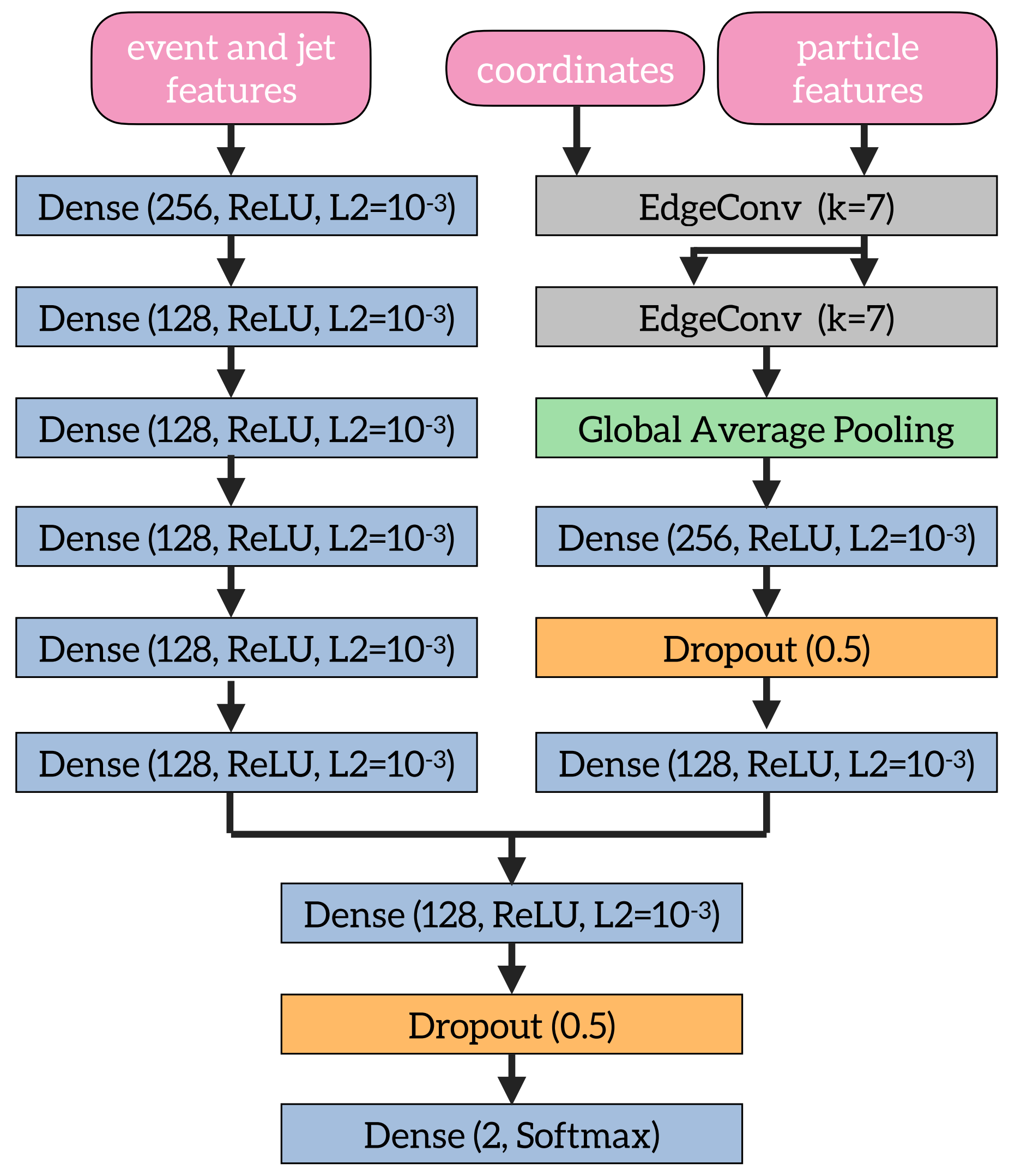


2 Analysis

Preselection

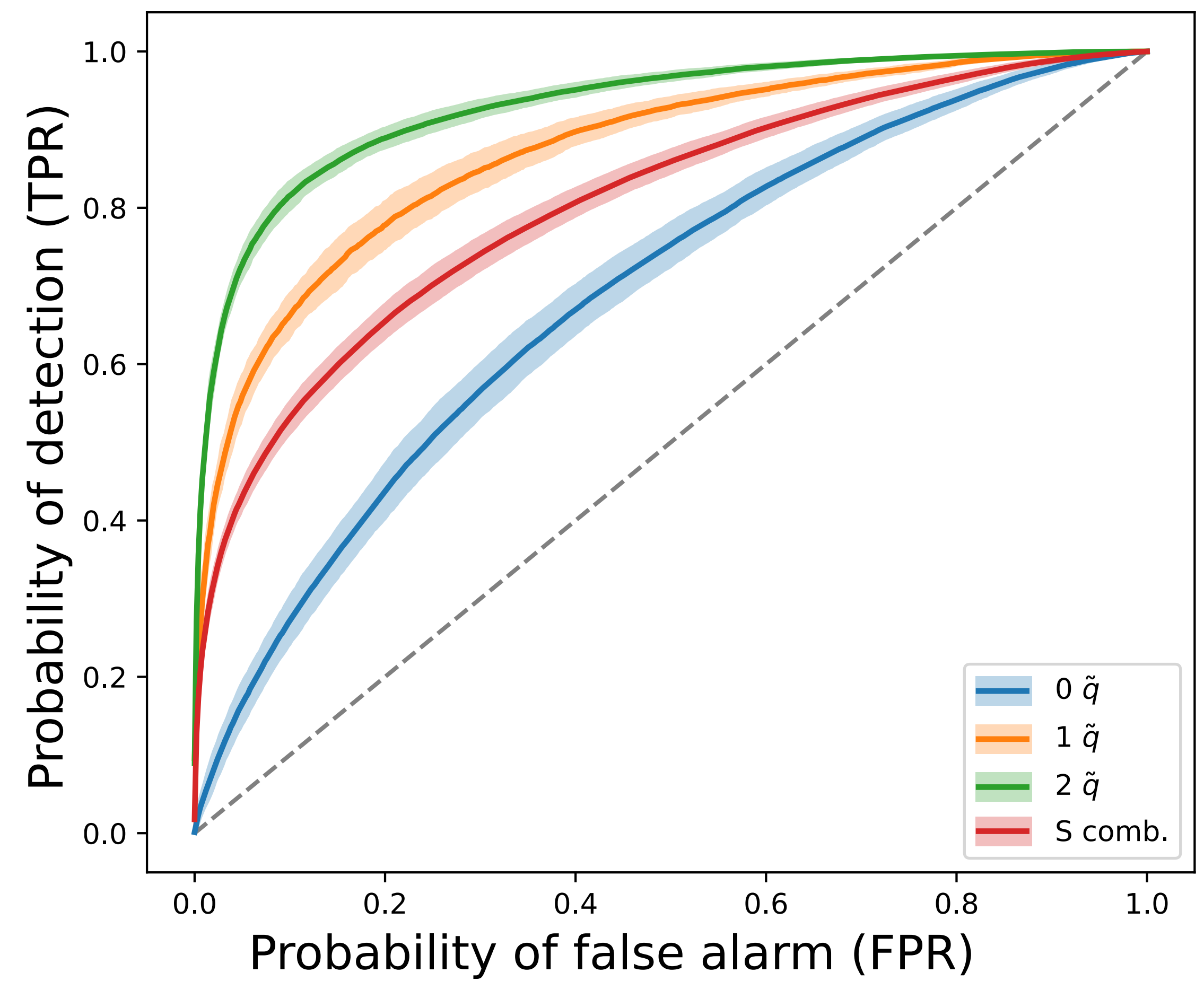
- $5 > \#\mathrm{jets} > 1$
- $p_T^{1\mathrm{j}} > 520$ GeV
- $\eta^{1\mathrm{j}} < 2.0$
- $p_T^{2\mathrm{j}} > 320$ GeV
- $\eta^{2\mathrm{j}} < 2.0$
- MET > 820 GeV
- lepton veto
- $\Delta\phi\left(\mathrm{j}^{1,2,3}, p_T^{\mathrm{miss}}\right) > 0.8$
- $\Delta\phi\left(\mathrm{j}^{4}, p_T^{\mathrm{miss}}\right) > 0.4$
- $\mathrm{MET}/\sqrt{\mathrm{H_T}} > 16\ \sqrt{\mathrm{GeV}}$
- $M_{\mathrm{eff}} > 1600$ GeV
- $p_{\mathrm{T}}^{\mathrm{particle}} > 1/5/10$ GeV

GNN architecture



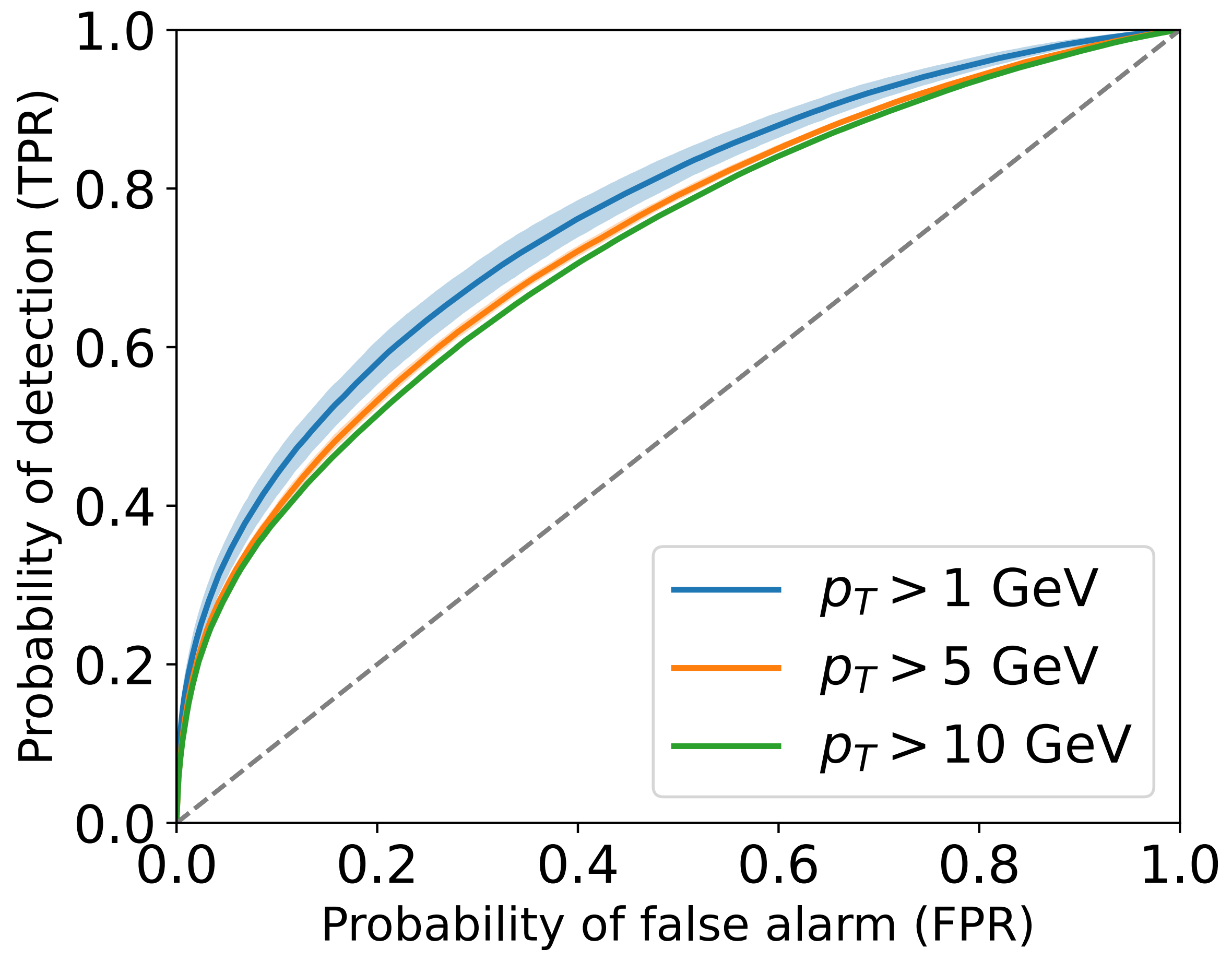
We propose analysis based on Convolutional Graph NN.

3 Evaluation



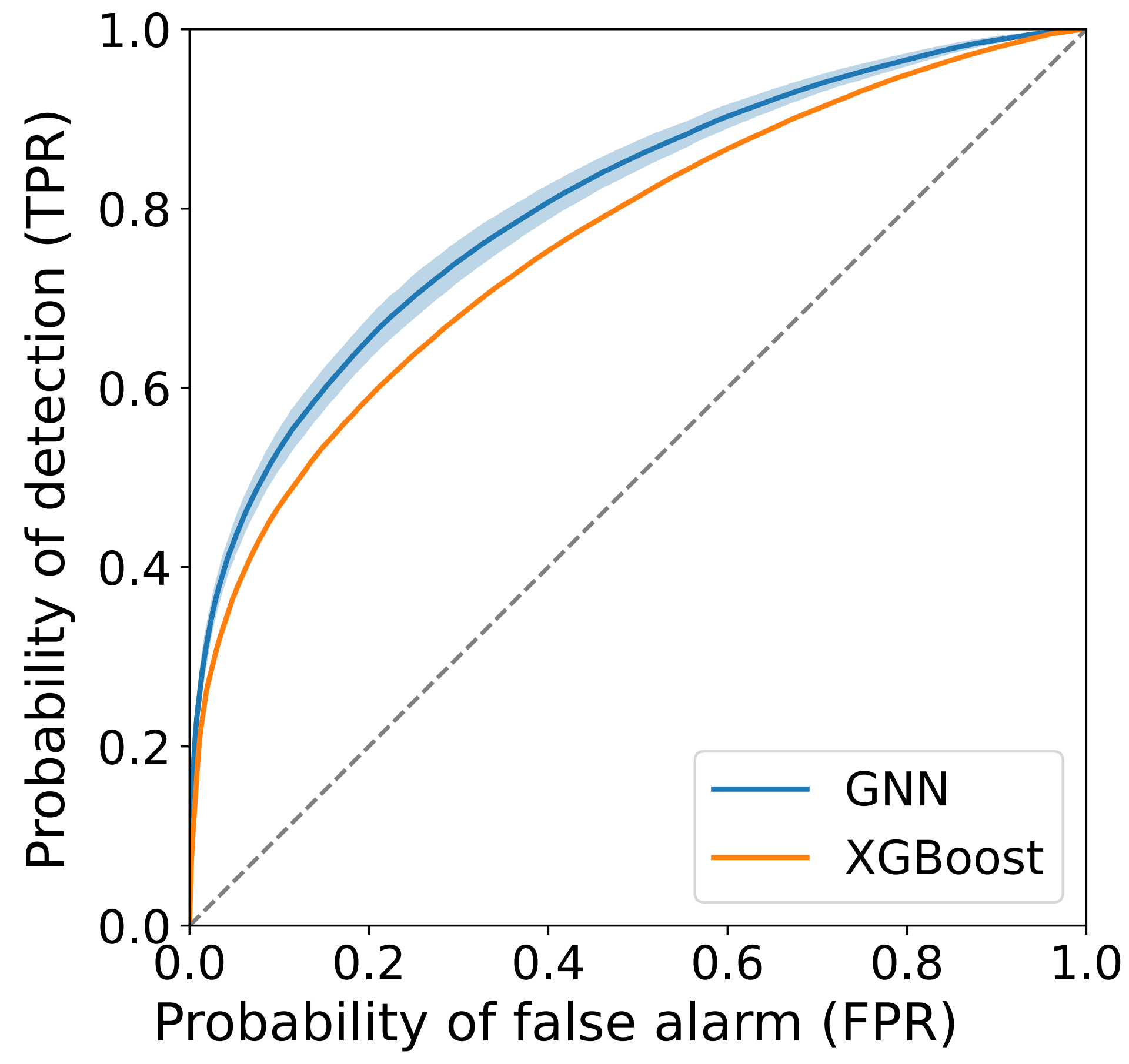
Events with decaying squarks (green and orange) are easier to classify because the resulting jets are boosted. Events without squarks (blue) closely resemble SM background, making them more challenging. **Total performance (red) highly depends on the composition of the considered sample.**

4 Impact of the $p_{\mathrm{T}}^{\mathrm{particle}}$ cut



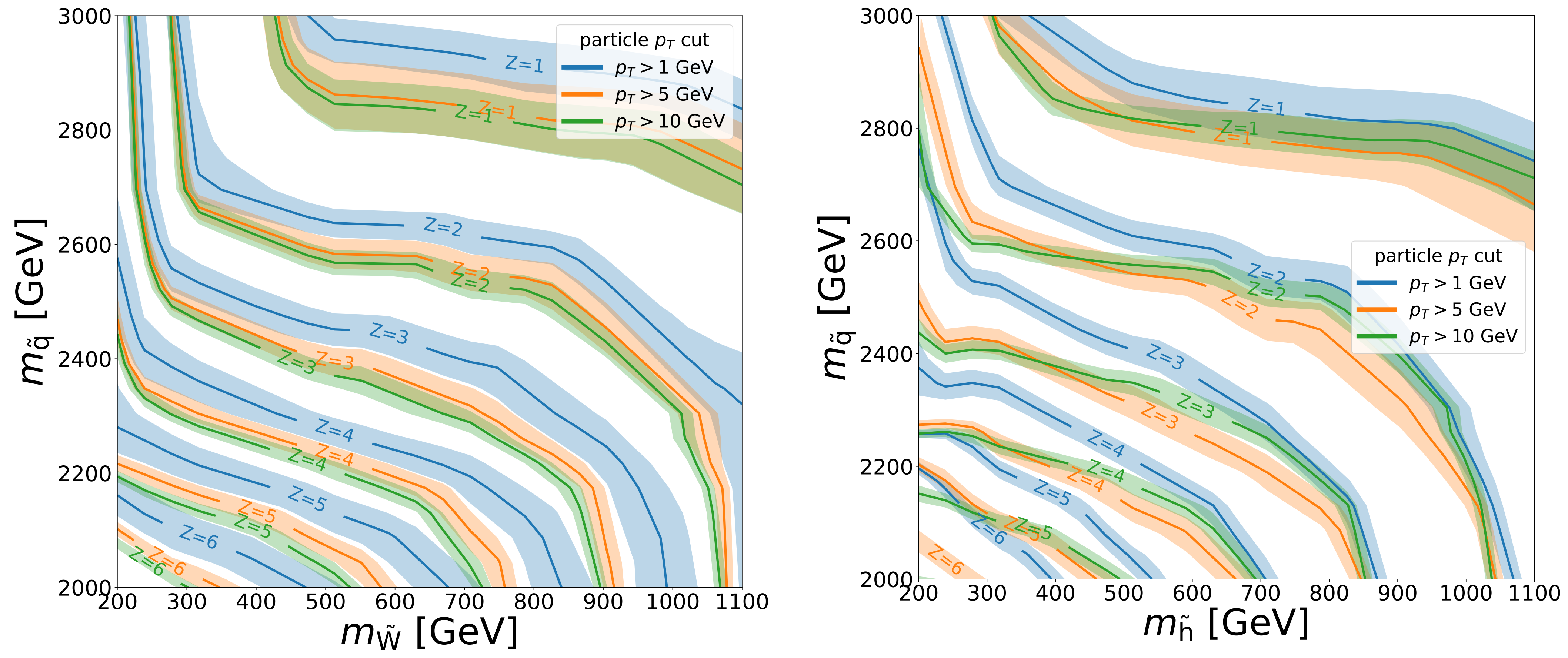
A higher cut on particles' p_{T} leads to more stable results and decreased classification performance. The effect is strongest for events without decaying squarks. **Information in soft particles is difficult to learn but helpful in discrimination, particularly for the most challenging signal events.**

5 GNN vs. BDT



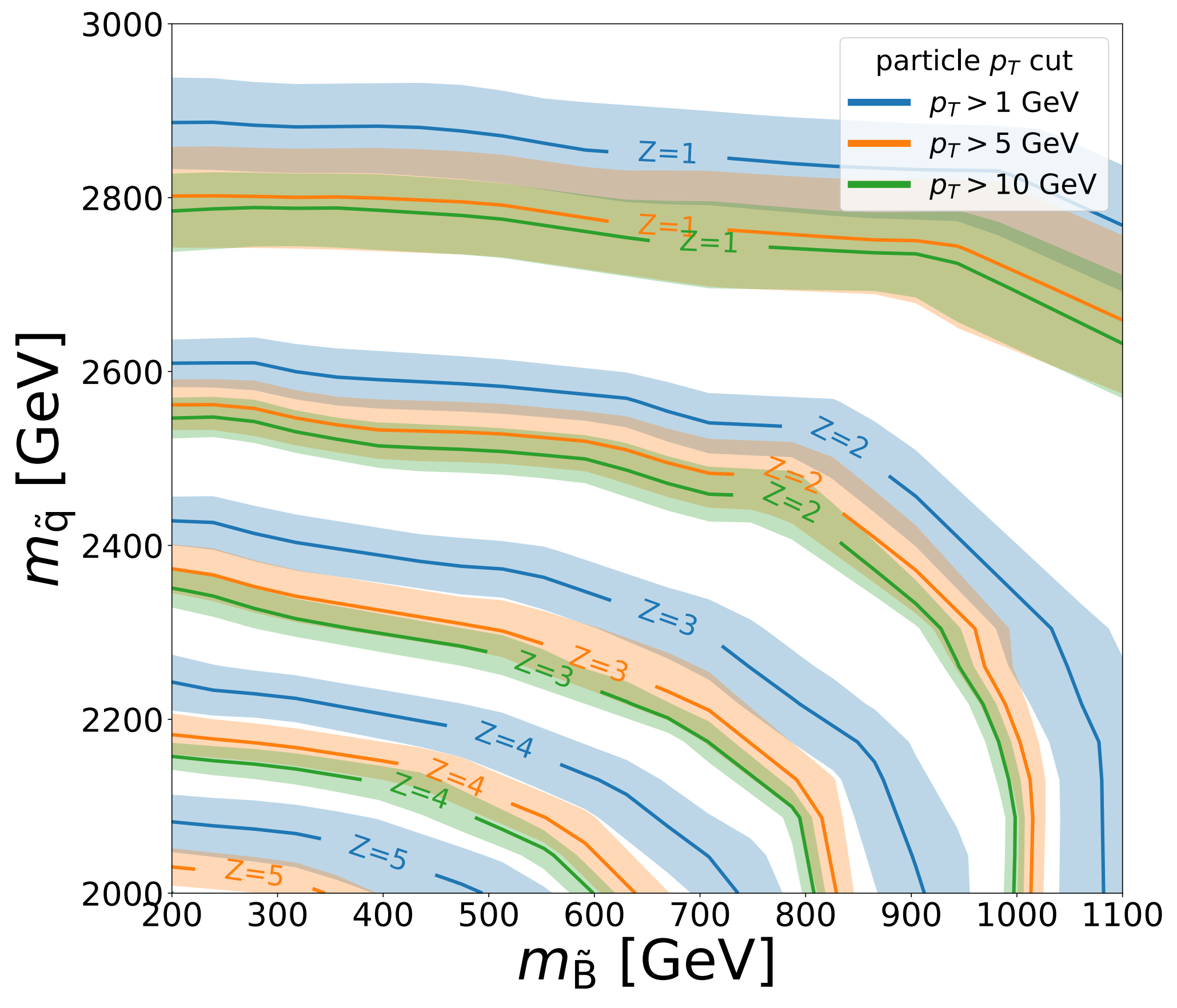
We compare our algorithm with Boosted Decision Trees and we find that **BDTs** are more stable but **offer worse classification performance for all classes of signal events.**

6 Limits on sparticle masses



We use our GNN algorithm trained on a single ($m_{\tilde{\chi}_1^0} = 300$ GeV, $m_{\tilde{q}} = 2{,}2$ TeV) mass point to calculate *naive* statistical significance, $Z = S/\sqrt{S+B}$, for a grid of mass points. Contours corresponding to different values of Z approximate exclusion/discovery limits with statistical significance $Z\sigma$. We present results for winos (left) and higgsinos (right), for HL-LHC with $L = 3\ \mathrm{ab}^{-1}$.

7 Application to Binos



We demonstrate the robustness of our approach by reusing a GNN model trained on a single mass point for wino-like neutralino to derive limits on bino-like neutralinos. This is possible because bino samples consist solely of events with decaying squarks, which are easy to discriminate from SM.

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