Identifying quenched jets with machine learning

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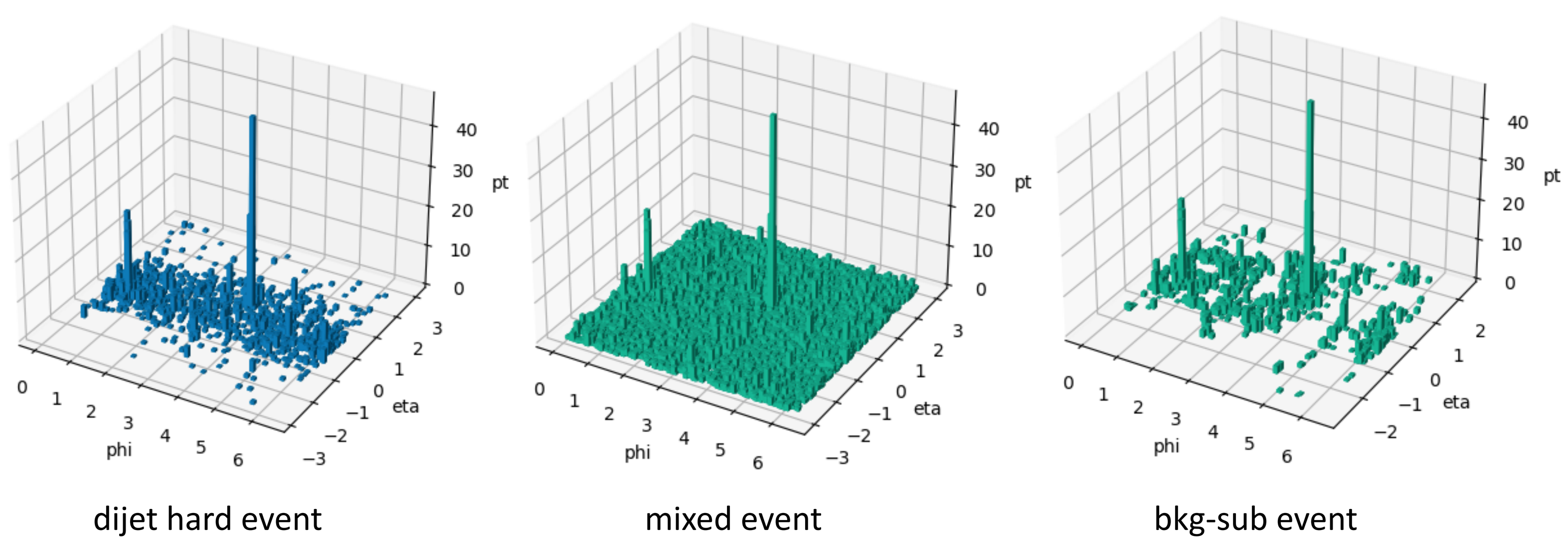
Motivation

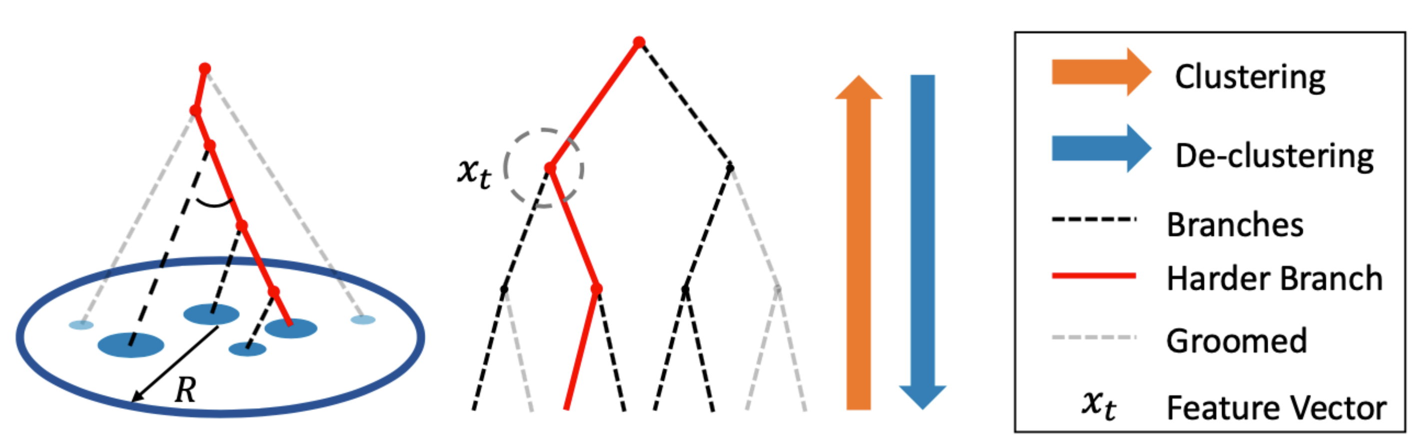
- In heavy-ion collisions, jets are quenched to different extents. **How can we know the energy lost by each jet?**
- **How to build a neural network that can learn from the jet substructure?**
- **How to build a neural network that is robust to realistic experimental conditions?**
  - Underlying event background
  - Detector effects

Methods

1. Thermal Background Embedding



2. Jet substructures and Feature Engineering

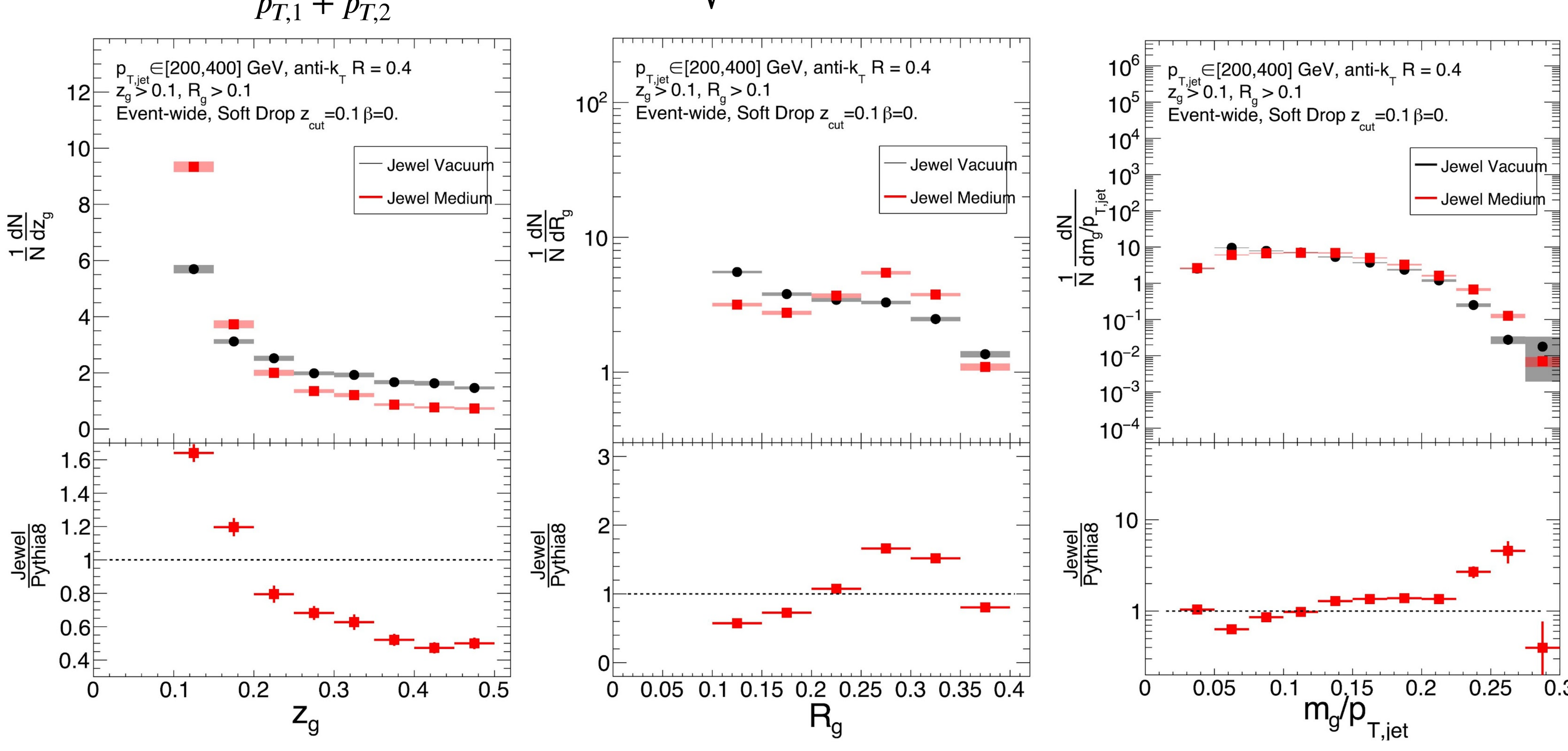


$x_t = [z,\ \Delta R,\ m, k_\perp,\ \dots]$ Binary tree structure exposed by Cambridge/Aachen algorithm.

Shared momentum ratio: $z = \frac{\min(p_{T,1},\ p_{T,2})}{p_{T,1} + p_{T,2}}$

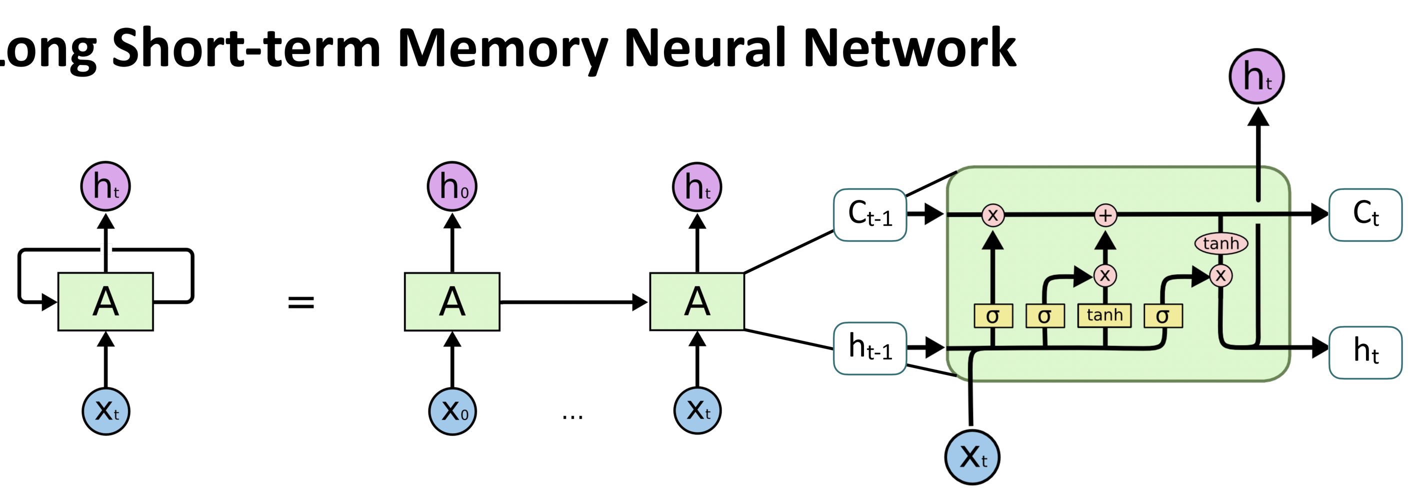
Angular separation: $\Delta R = \sqrt{(\varphi_1 - \varphi_2)^2 + (\eta_1 - \eta_2)^2}$

Invariant mass: $m = inv\_mass(j_1, j_2)$



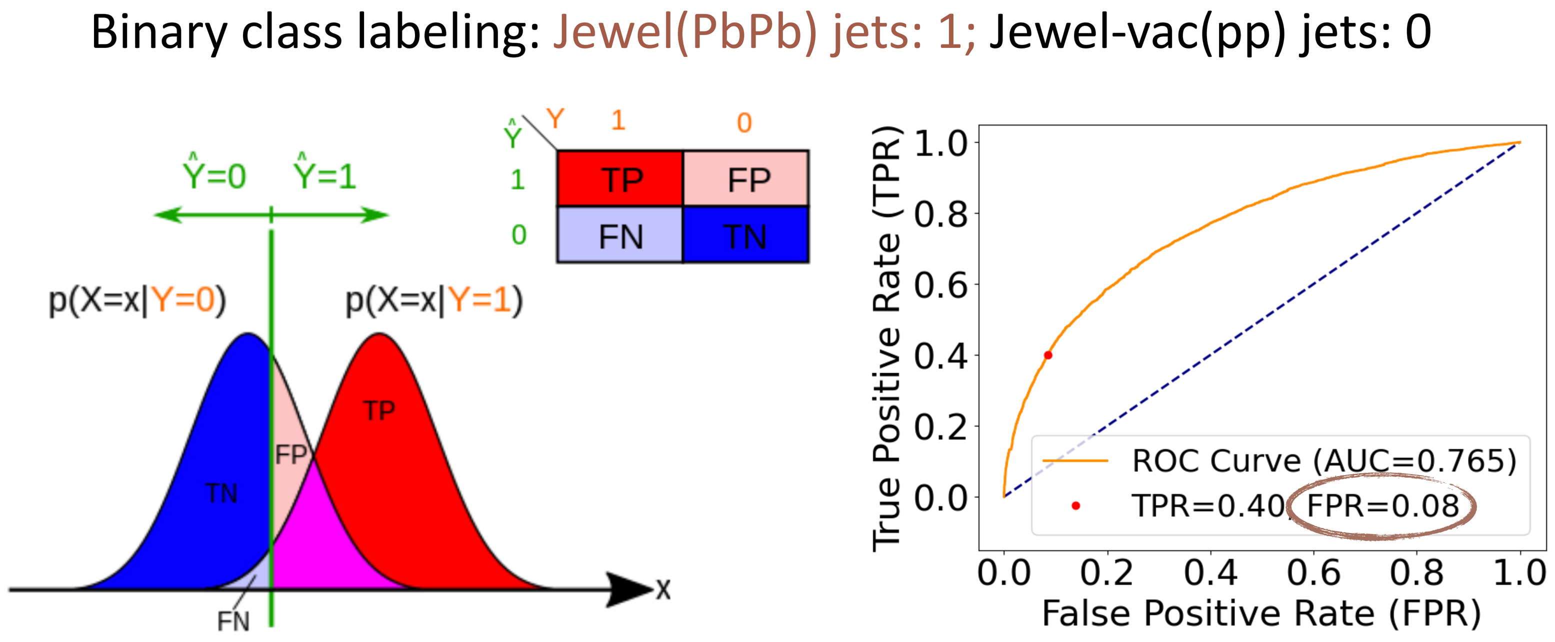
In heavy-ion collisions, jet substructures get modified compared to pp collisions.

3. Long Short-term Memory Neural Network



4. Supervised Learning—binary classification

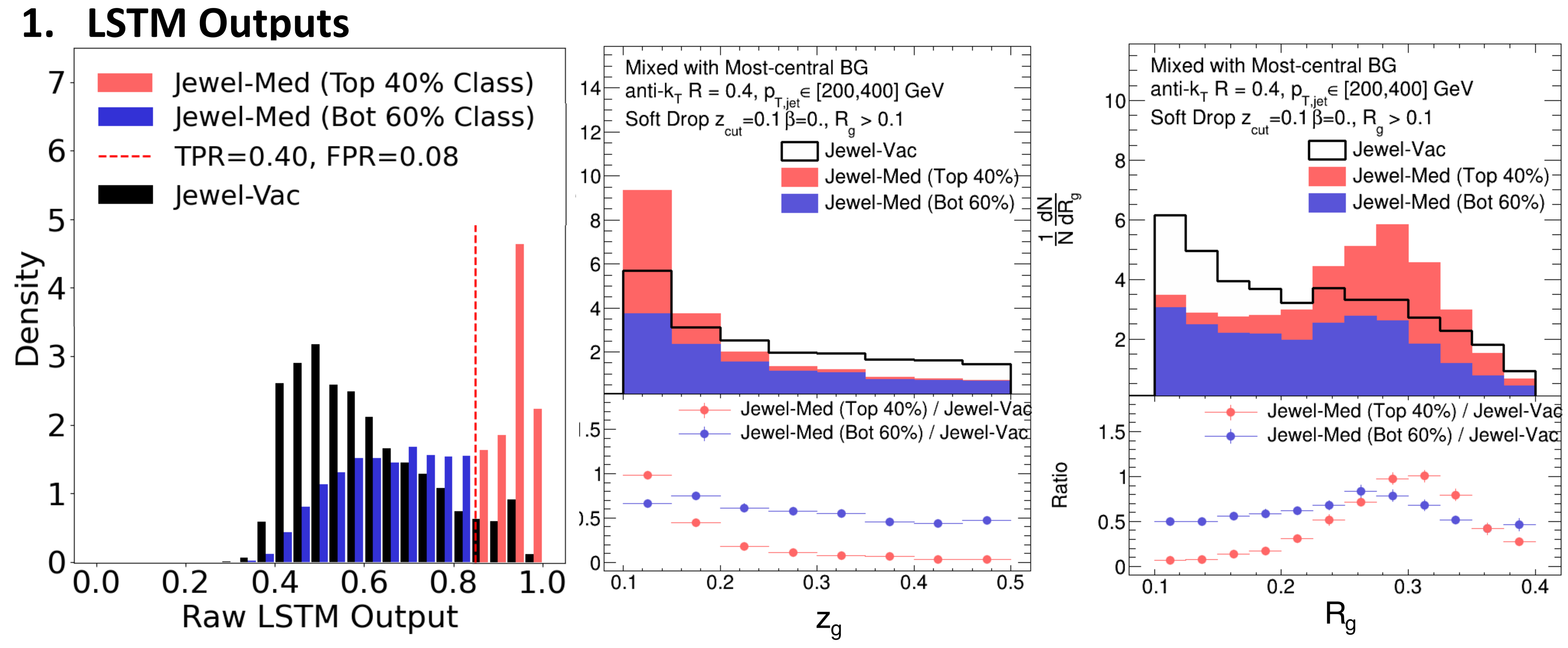
Binary class labeling: Jewel(PbPb) jets: 1; Jewel-vac(pp) jets: 0



How different are the two classes? Can we identify the quenched jets?

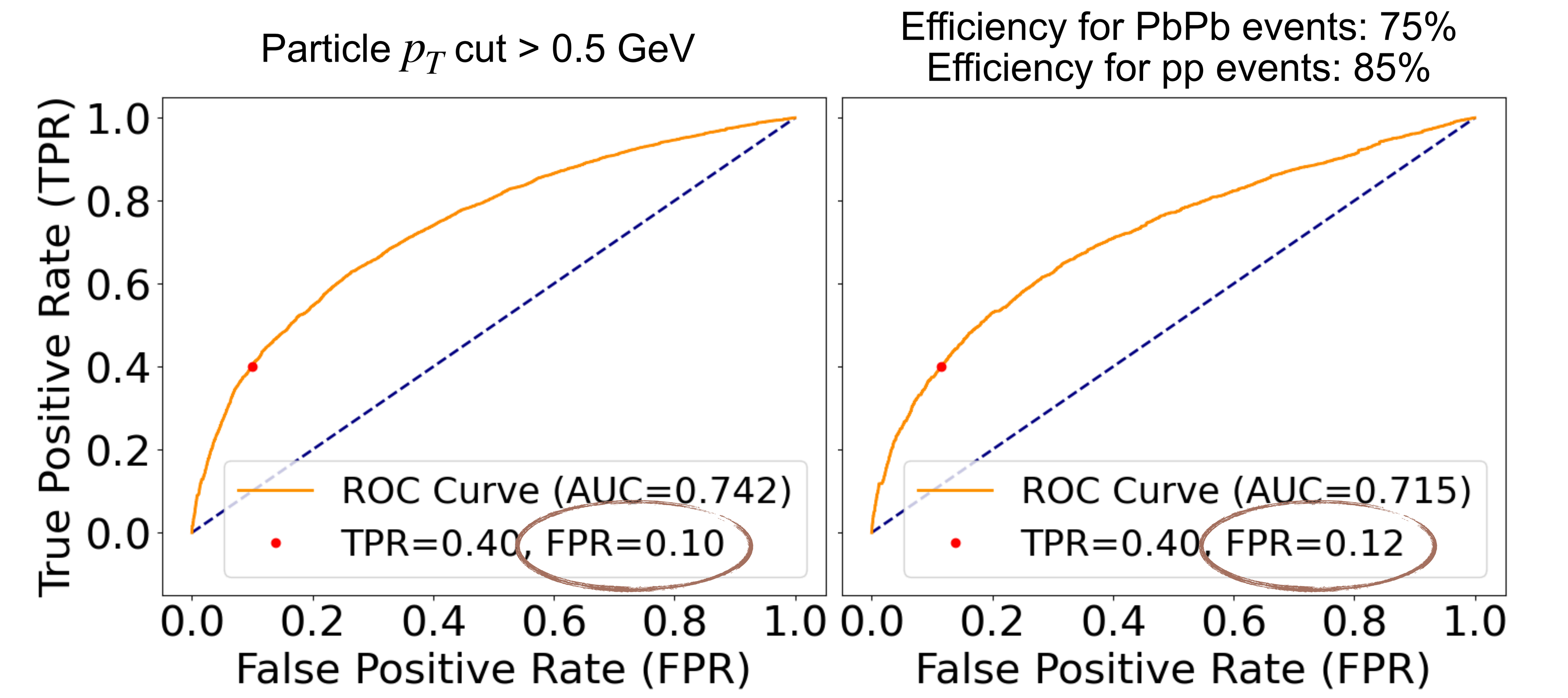
Results

1. LSTM Outputs



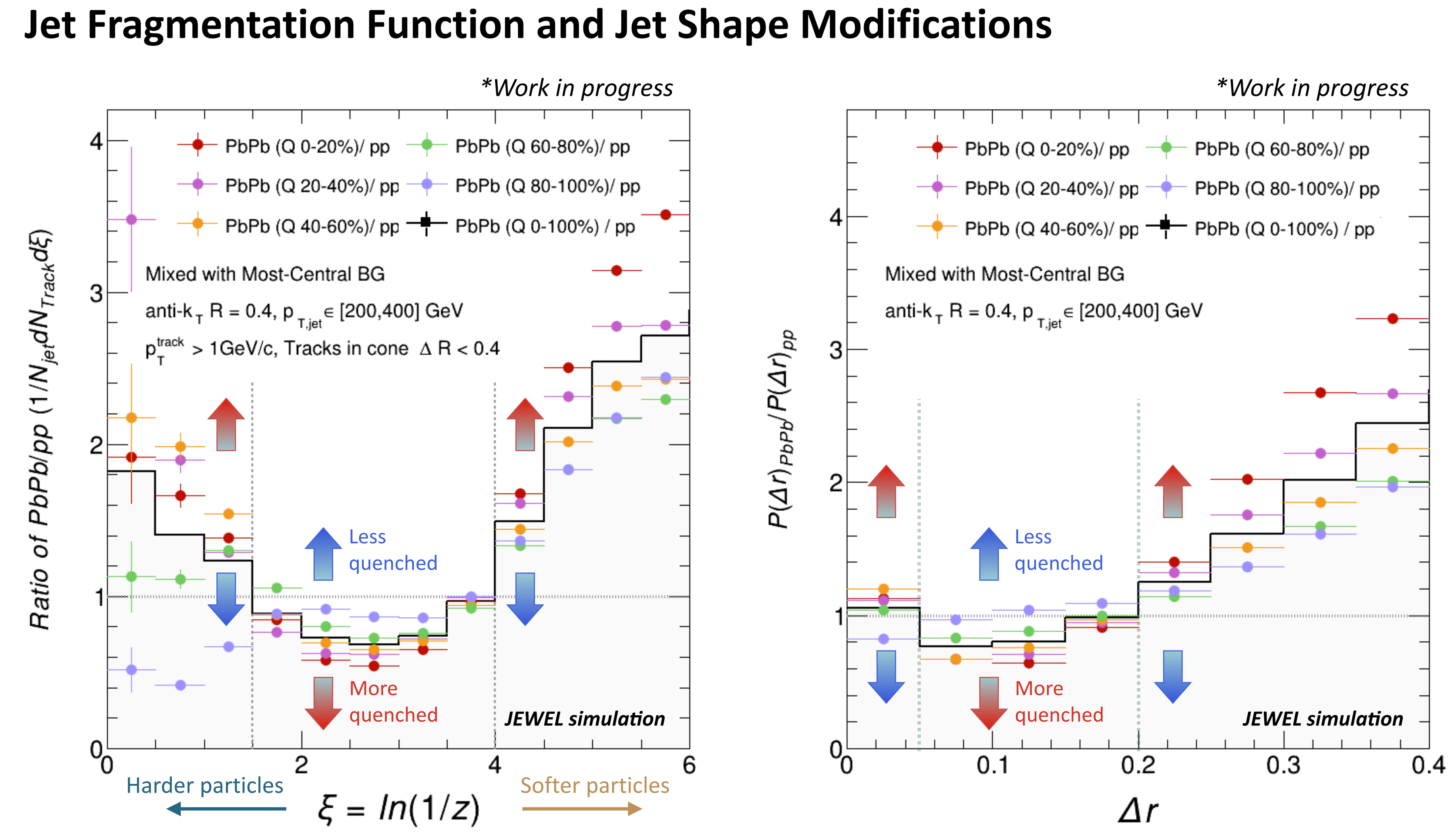
- Define two event classes based on quenching level using LSTM outputs
- Jet-substructure distributions for two quenching level classes

2. Toy models for detector effects



- The detector effects increase the FPR from 0.08
- More detector effects, like particle momentum/energy smearing, are being studied using the DELPHES fast simulation

3. Jet Fragmentation Function and Jet Shape Modifications



Left: The JFF ratios from five quenching classes of Jewel jets divided by the Jewel-vac jets.

- **0-20%** Jewel jets: large ξ is enhanced with a depletion of intermediate ξ
- **20-60%** Jewel jets: small ξ is enhanced (a bias towards jets that are less fragmented than the average quenched jets)
- **60-100%** Jewel jets: behave like biased pp jets (with small LSTM values) in the small ξ region

Right: The JS ratios from five quenching classes of Jewel jets divided by the Jewel-vac jets. They also show different jet quenching modes corresponding to the JFF ratio results.

Summary and Outlook

- The neural network is able to identify the quenching amount jet-by-jet in the presence of a large uncorrelated underlying event in heavy ion collisions.
- Simulations indicate that the method is still valid after including detector effects.

Reference: J. High Energ. Phys. 2023, 140 (2023)

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