Jet momentum reconstruction in the QGP background with machine learning

Based on arXiv:2412.06466

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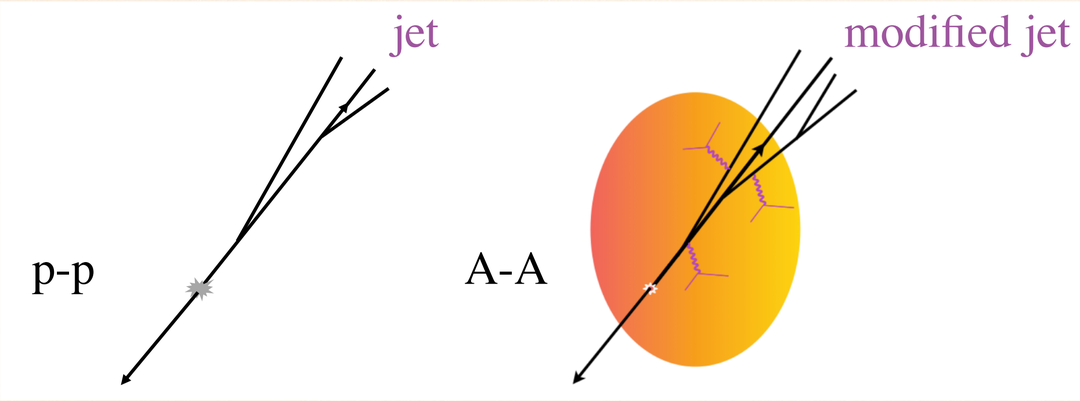
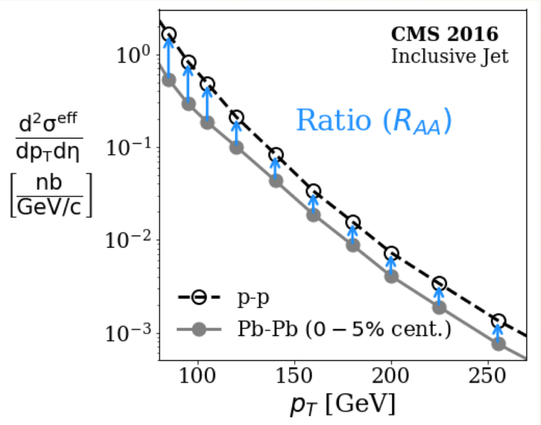
Outline

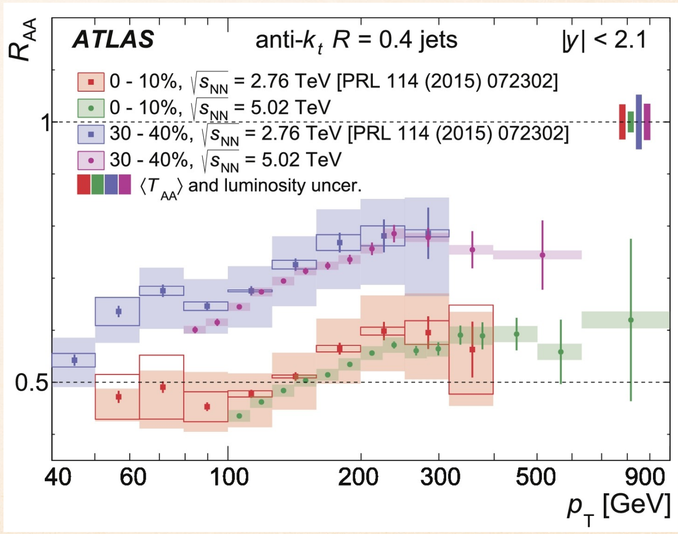
- Simulation Models: PYTHIA & LBT models
- Background Subtraction Methods
- Jet Momentum Reconstruction
- Jet Nuclear Modification Factor R_{AA}

QGP and Jet Modifications





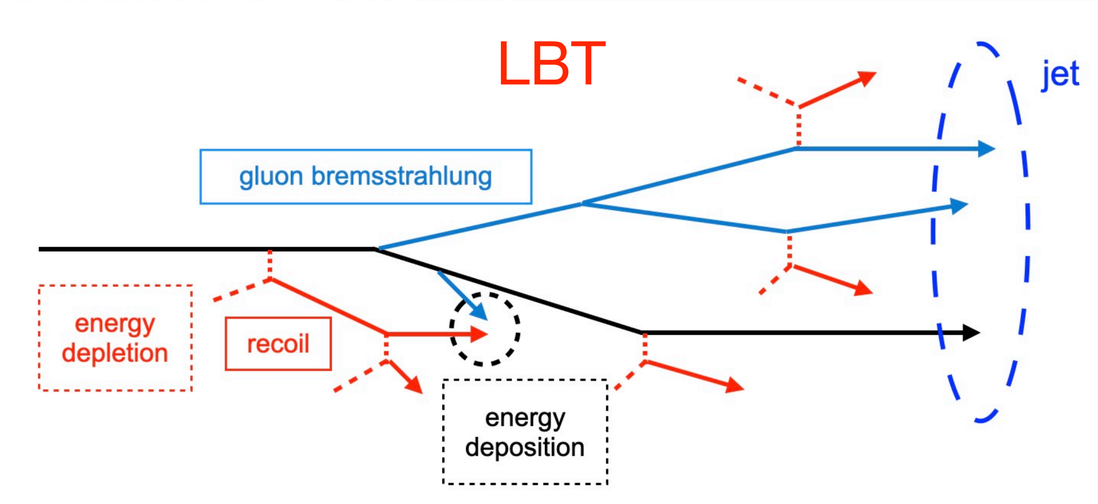
- Quark-gluon plasma (QGP) in heavy-ion collisions: deconfined phase, hot dense medium.
- Jets, collimated sprays of energetic particles, serving as hard probe to medium properties.
- Jets are quenched in the medium via parton energy loss.
- Jet transverse momentum p_T is the key quantity to measure the quenching effects.



PYTHIA & LBT Models

- Vacuum jets: PYTHIA8 model
- Jet interaction with QGP: Linear Boltzmann Transport (LBT) model
- Pb-Pb collisions in 0-10% centrality at √S=5.02TeV
- QGP background: a toy thermal model
- Reconstructed jets with anti-k_T, R=0.4

- Target p_T —sum of the (PYTHIA/LBT) jet particle p_T within jet cone, in the presence of background particles



Background

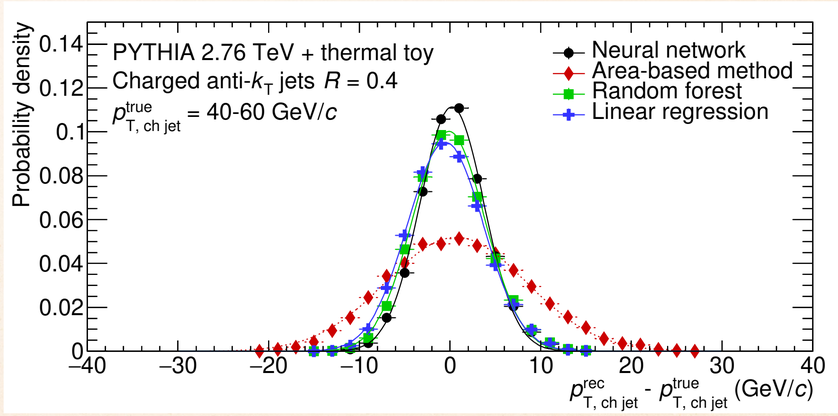
$\pi^+ + \pi^-$	
$\mathrm{d}N/\mathrm{d}y$	$< p_T >$
1699.80	0.5682 GeV

p_T follows a Boltzmann distribution

Background Subtraction Methods

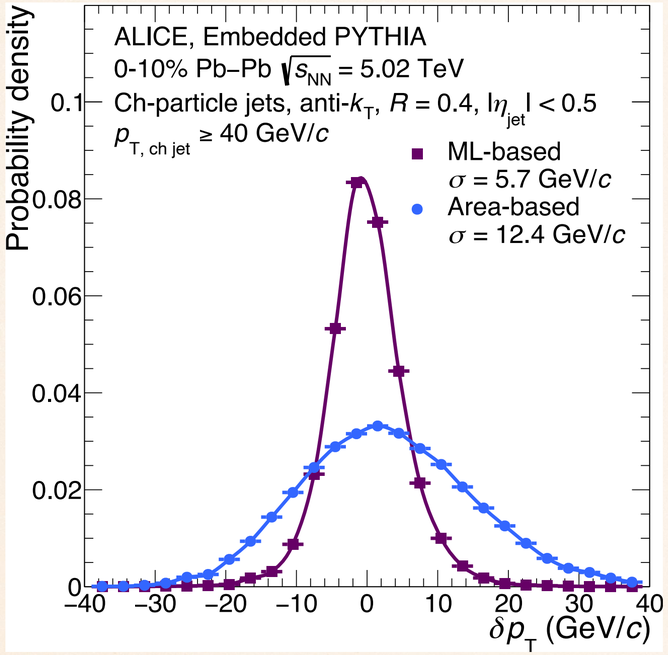
- Area-based method
  - Event-by-event basis: background momentum density ρ
  - For each jet: reconstructed jet momentum $p_T^{\mathrm{rec}} = p_T^{\mathrm{raw}} - \rho A$
  - Leading to large residual fluctuations
- Constituent Subtraction method
  - Local subtraction of soft background
  - Simultaneously correcting the 4-momentum of the jet and its substructures

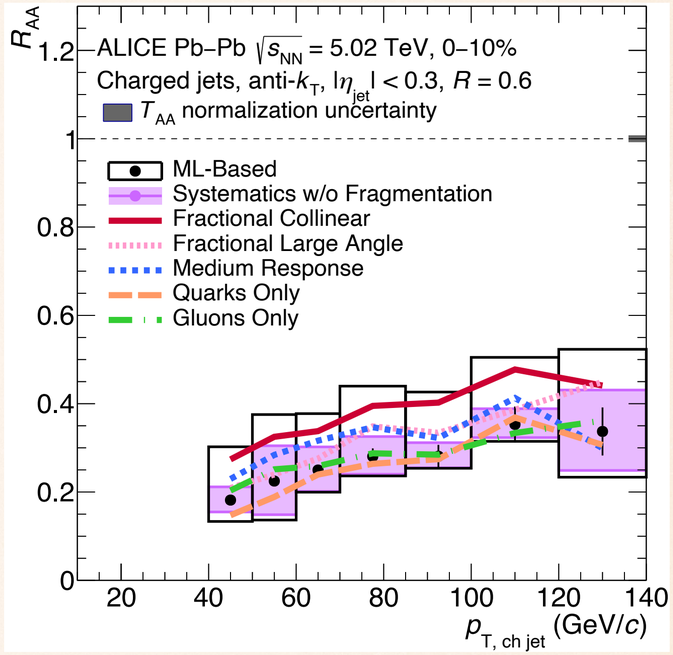
- ML techniques with following PYTHIA jet observables as inputs
  - The uncorrected jet momentum
  - The jet transverse momentum, corrected by the area-based method
  - Jet mass, radial moment, momentum dispersion, and LeSub
  - The number of constituents within the jet
  - Mean and median of all constituent transverse momenta
  - The transverse momenta of the first ten leading



R. Haake and C. Loizides, PHYS. REV. C 99, 064904 (2019)

Jet Momentum Reconstruction in ALICE





- More precise estimate for low p_T jet

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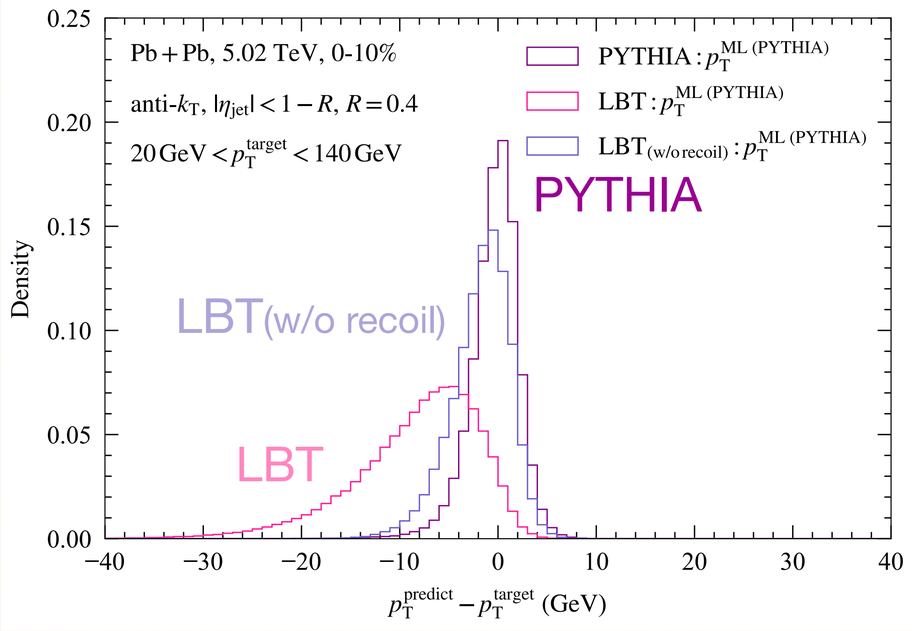
- PYTHIA & Quenching-aware Variants are employed to train DNNs separately to predict jet p_T and estimate R_{AA}
- How about training the datasets together?

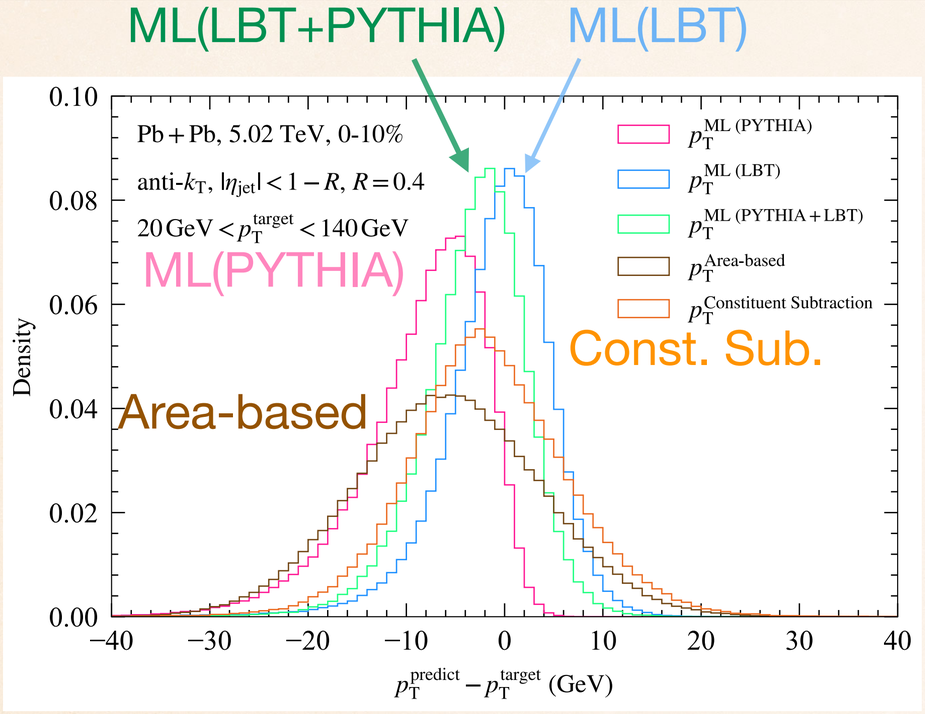
Jet Momentum Reconstruction



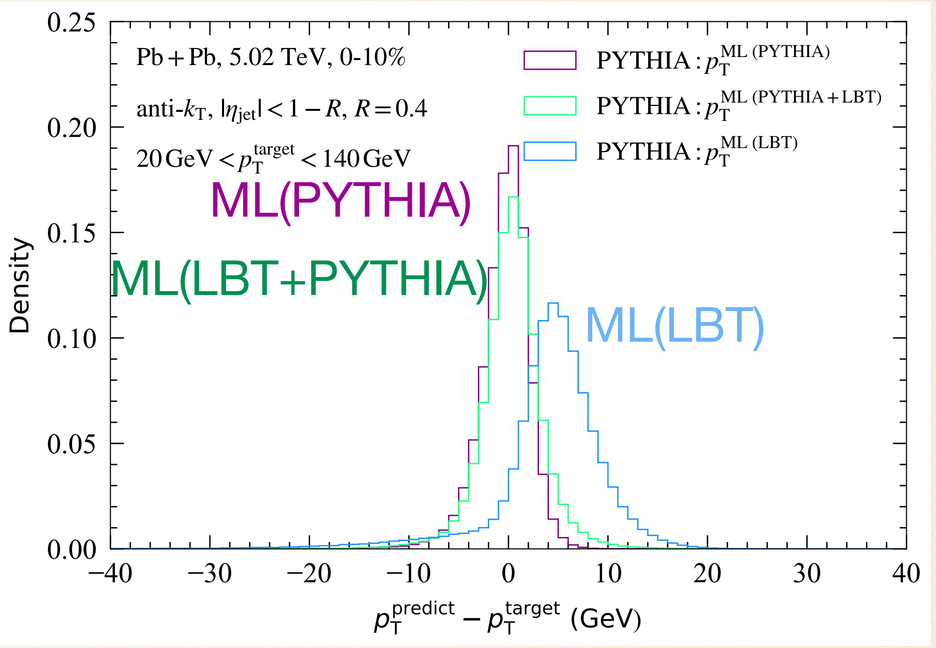
Test PYTHIA-trained ML on different datasets

- PYTHIA-trained ML has a prediction bias when applied on LBT jets.
- The bias is reduced when the ML model is applied on LBT jets without recoil particles: Recoil particles may be considered as the background.

Jet Momentum Reconstruction



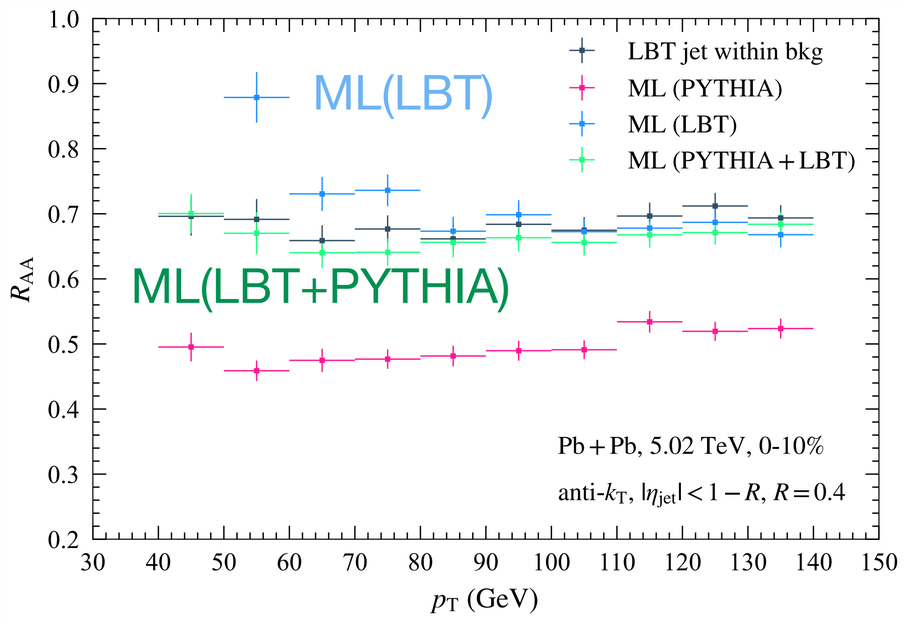
Testing on LBT data



Testing on PYTHIA data

- The bias is reduced when the ML model is trained by LBT jets directly or by LBT+PYTHIA jets.
- LBT+PYTHIA-trained ML can make accurate predictions on PYTHIA and LBT data simultaneously, demonstrating strong robustness.
- ML methods are more accurate than conventional methods (Area-based & Constituent Subtraction).

Jet Nuclear Modification Factor R_{AA}



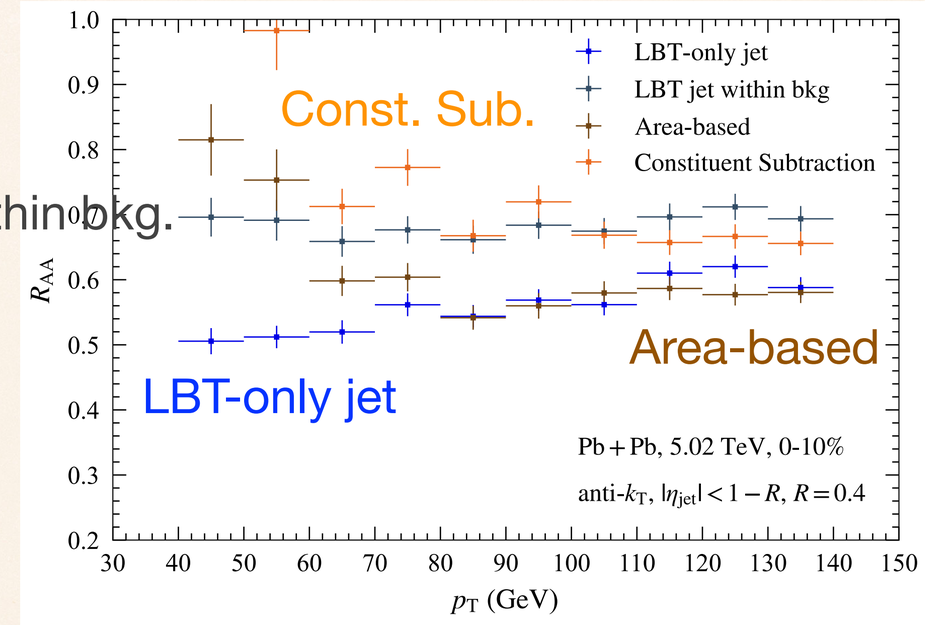
LBT jet within bkg.

ML(PYTHIA)

- R_{AA} from ML(LBT) & ML(LBT+PYTHIA) are closer to that of the current target baseline "LBT jet within bkg." than R_{AA} from ML(PYTHIA).

Jet Nuclear Modification Factor R_{AA}

LBT jet within bkg.

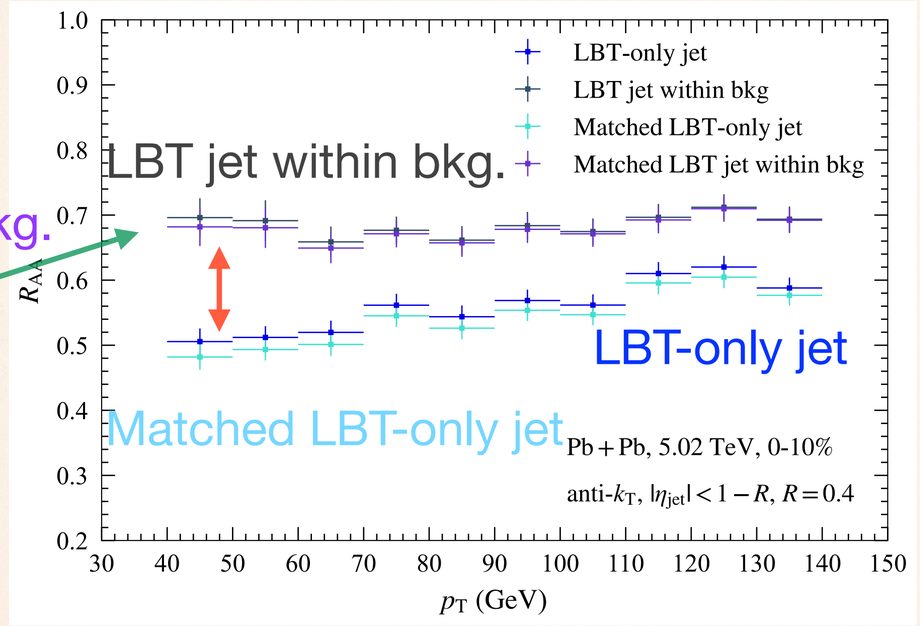


- Significant discrepancy between two baselines, i.e., Experiment vs Theory: jets reconstructed within background (LBT jet within bkg.) VS jets reconstructed without background (LBT-only jets).

Jet Nuclear Modification Factor R_{AA}

Matched LBT jet within bkg.

Small contribution from fake jets



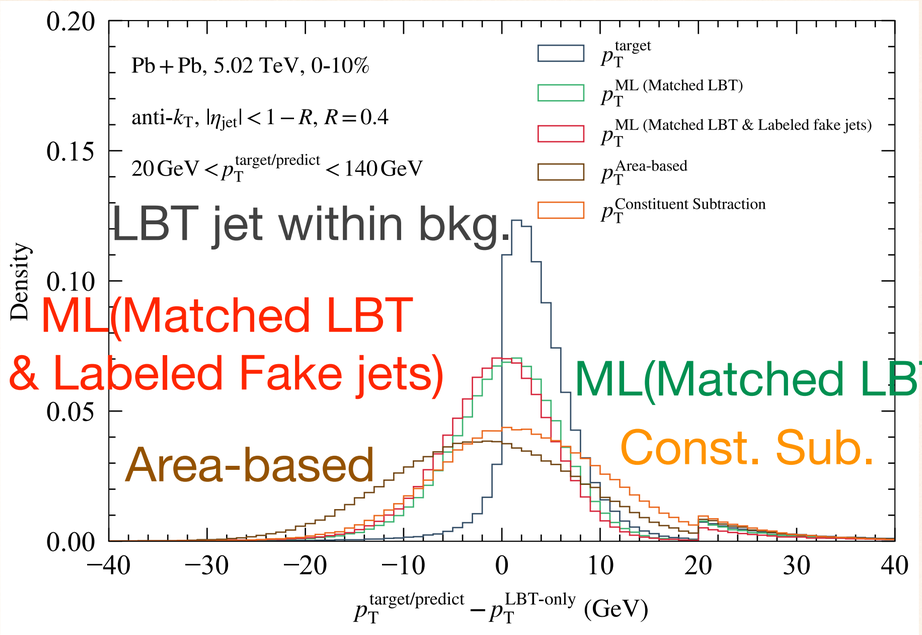
LBT jet within bkg.

Matching with $\Delta R = \sqrt{\Delta\eta^2 + \Delta\phi^2} < 0.4$

LBT-only jet

- We apply a matching procedure to reveal the contribution from fake jets and the p_T difference between matched jets.

Jet Momentum Reconstruction



LBT-trained ML with Matching Procedure

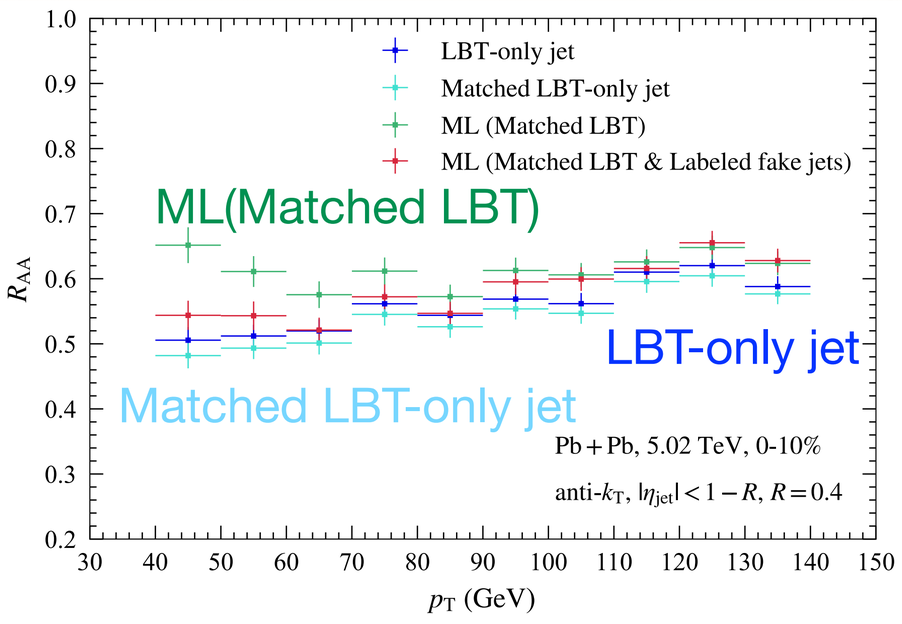
Matched LBT jet within bkg. → ML(Matched LBT) → Matched LBT-only jet p_T

LBT jet within bkg. → ML(Matched LBT & Labeled Fake jets) → Matched LBT-only jet p_T & Fake jets $p_T = 0$

- p_T of *LBT jets within bkg.* are generally larger than p_T of *LBT-only jets*, leading to an over-estimation of R_{AA}
- ML models are dedicated to predict *LBT-only jet* p_T from *LBT jet within bkg.*

Jet Nuclear Modification Factor R_{AA}

ML(Matched LBT & Labeled Fake jets)



- R_{AA} from LBT-only jet can be well reproduced with such ML setups
- By incorporating fake jets and labelling their $p_T = 0$ in the training, the performance will improve

Summary & Outlook

- To better reconstruct jet momentum with machine leaning, we suggest training the ML model with various quenched jets simultaneously to obtain strong robustness and generalizability.

- To more accurately obtain the jet nuclear modification factor R_{AA} in theory, we apply a matching procedure and reveal that the contribution from fake jets is relatively small though non-negligible. ML models are dedicated to predict the p_T of real target jets in theory from jets reconstructed in experiment.

- Develop novel ML models assisted with better jet representation to improve the prediction accuracy.

- Incorporate quenched jets from various MC models.

- Include the realistic anisotropic background and medium response.