Exploring Biases in Neural Network Jet Background Estimation in Heavy-Ion Collisions

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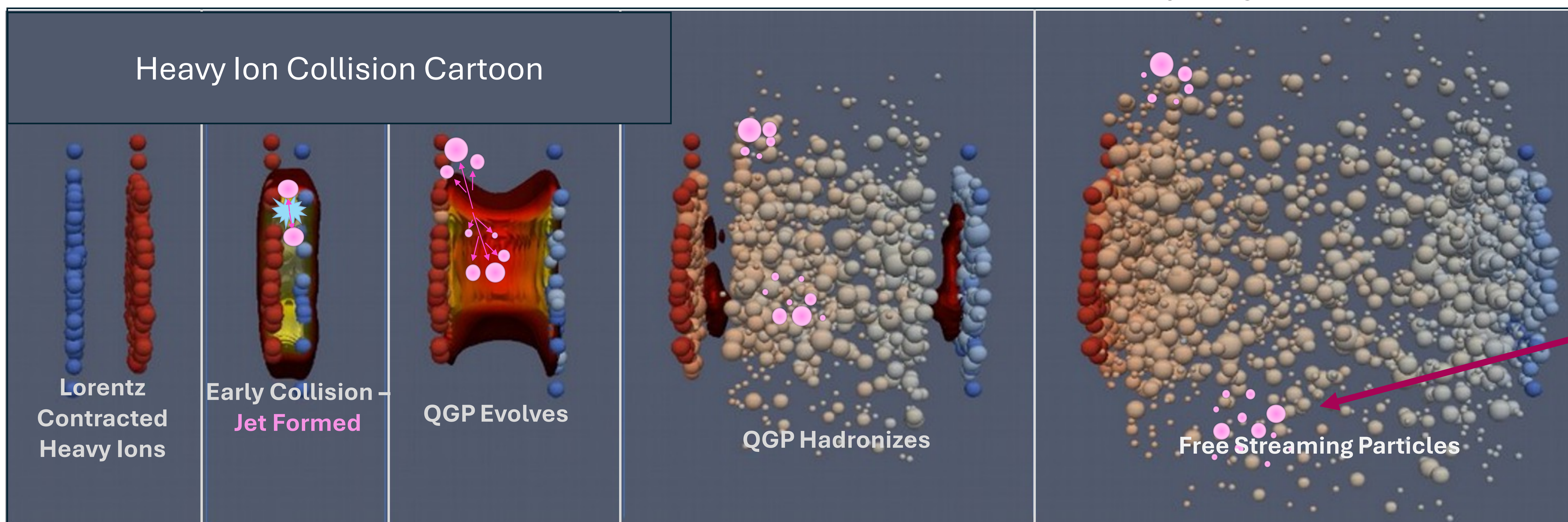
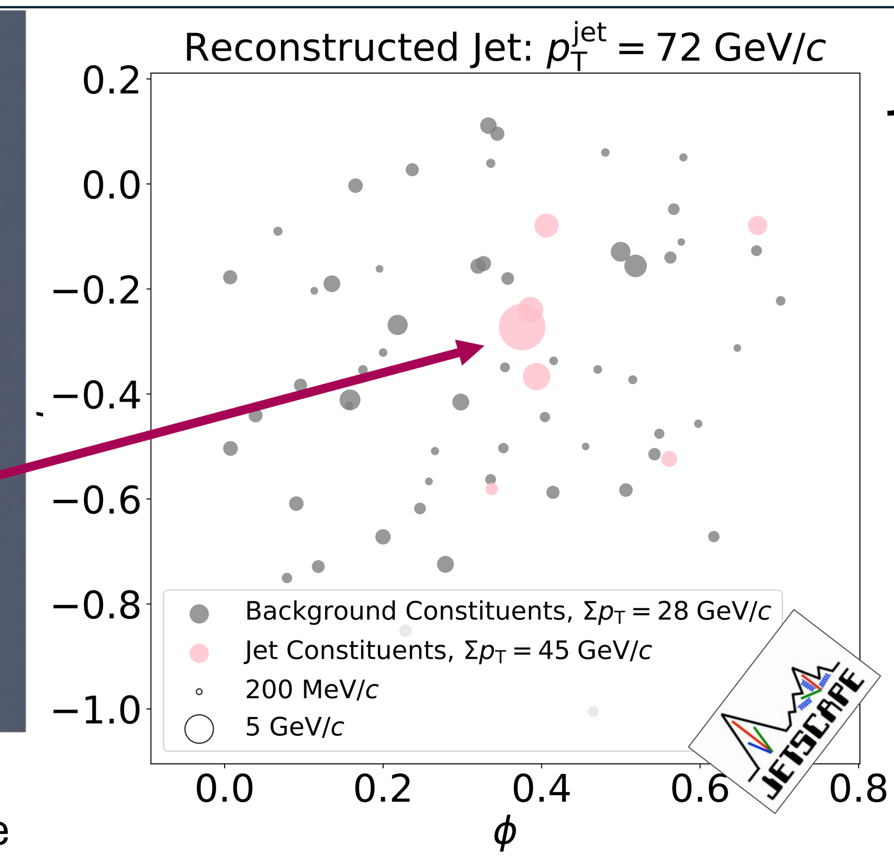


Hard partonic scatterings ("jets") form early in a collision (prior to Quark Gluon Plasma "QGP") formation. They then may traverse and be quenched by the QGP, resulting in columnated sprays of particles which are algorithmically clustered together along with a heavy background of other particles.



Jets: "tomographic probes" of QGP

Measurement resolution limited by background subtraction

Can Neural Networks help?

Motivation

Standard jet background p_T correction is Area Based ("AB"): subtract event median background p_T density (ρ_{bkg}) scaled by jet area:

$$p_T^{corrected} = p_{T.}^{detector} - \rho_{bkg} A_{jet}$$

Results in jet-by-jet residual p_T errors:

$$\delta p_T \equiv p_T^{corr} - p_T^{truth}$$

which are dominated by background density fluctuations. The corrected jet p_T spectrum is statistically corrected on an ensemble level for δp_T to obtain the truth-spectra.

Monte Carlo generators for jets in vacuum (JETSCAPE in this study) are robust.

⇒ Train neural networks (NN) with jet parameters to correct :

$$p_{T.}^{detector} \rightarrow p_T^{corr}$$

⇒ Tighter δp_T distributions

⇒ Better measured p_T^{truth} resolution

However

Jet quenching modifies jet parameters

⇒ May bias NN background corrections

⇒ May bias final jet measurements, but by how much?

Train Neural Networks

- Use FASTJET to simulate realistic Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV/c with hydrodynamically modelled QGP flow and jet quenching
- Embed MC vacuum-jets into backgrounds

Match only the leading processes:

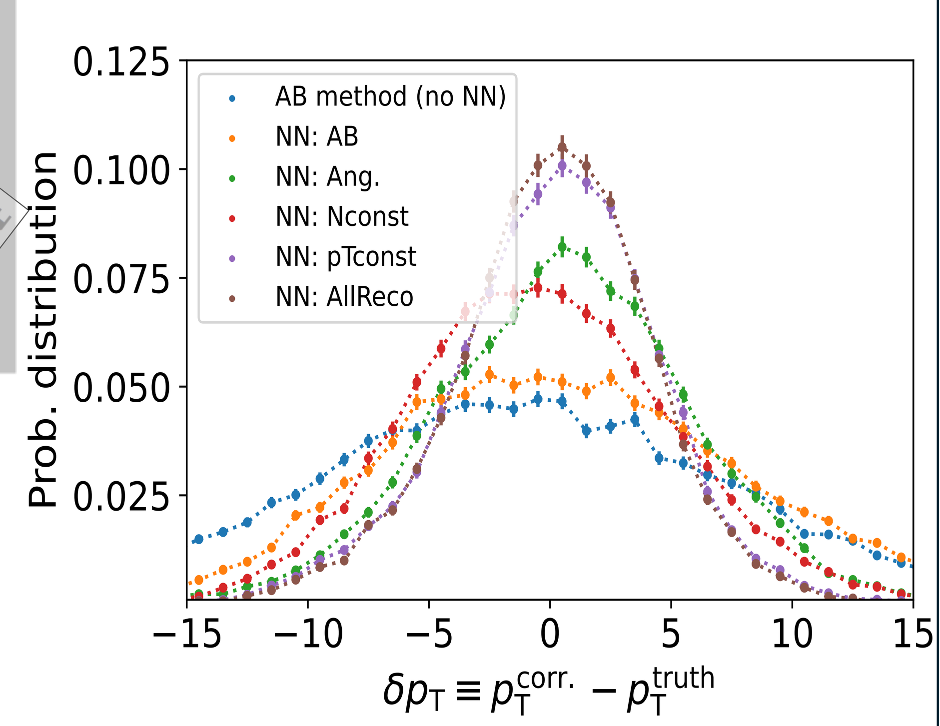
- highest p_T scattered parton (IP) to
- highest p_T "truth jet" (without bkg) geometrically close ($\sqrt{\Delta\eta^2 + \Delta\phi^2} < 0.3$)
- to highest p_T geometrically close reco jet (jet+background)

Label	Additional Training Parameters†
NN_{AB}	(none)
NN_{Ang}	Angularity: $\alpha \equiv \sum_i p_{T,i}\Delta R_i$, where i runs over all constituents, and ΔR_i is the η-ϕ distance from the constituent to the jet axis
NN_{Ncons}	The number of jet constituents
NN_{pTcons}	p_T of the highest-p_T constituents (limited to 10) in the reco jet
$NN_{AllReco}$	All parameters listed in this chart together

†$p_{T,jet}^{truth}$, $p_{T,jet}^{reco}$, A_{jet}, & ρ_{bkg}, are used with each NN

Train neural networks:

- Sequential model, RELU activation functions, 3 dense layers: 100, 50, 50 nodes
- Map measured jet input parameters to truth jet p_T for 5 neural networks



NN generate significantly tighter distributions of δp_T

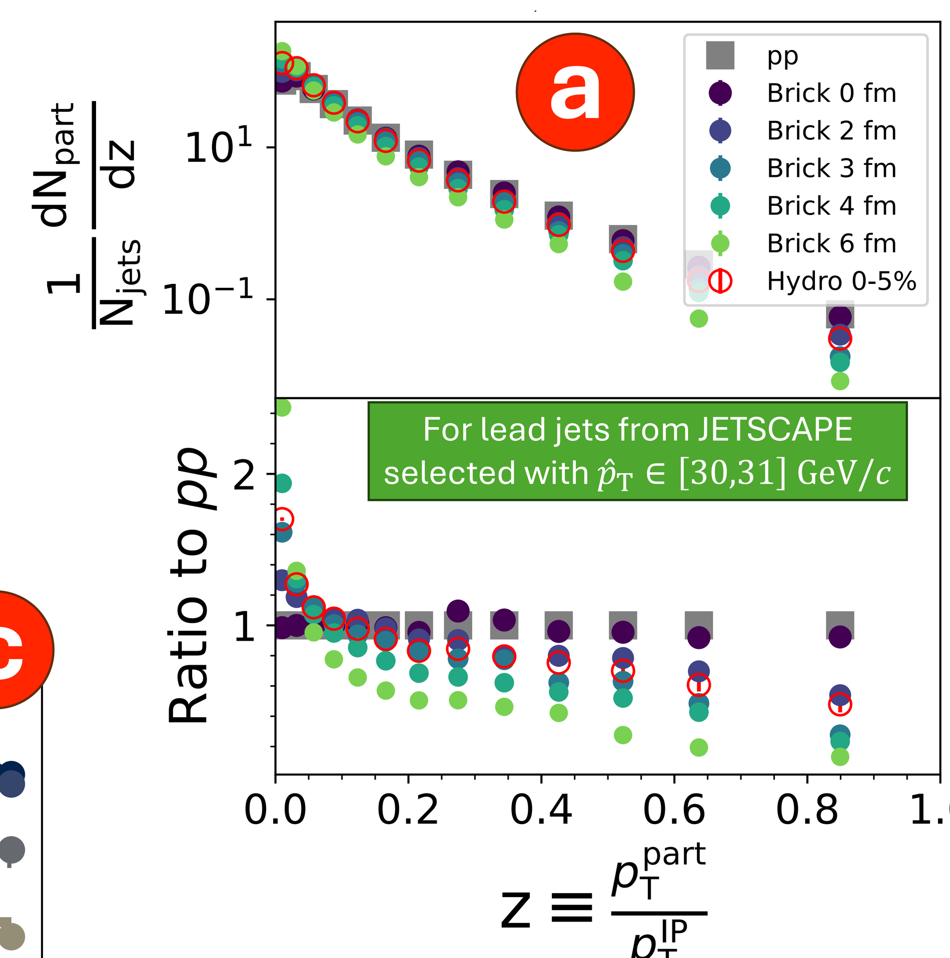
Quench Jets and Test NN Biases

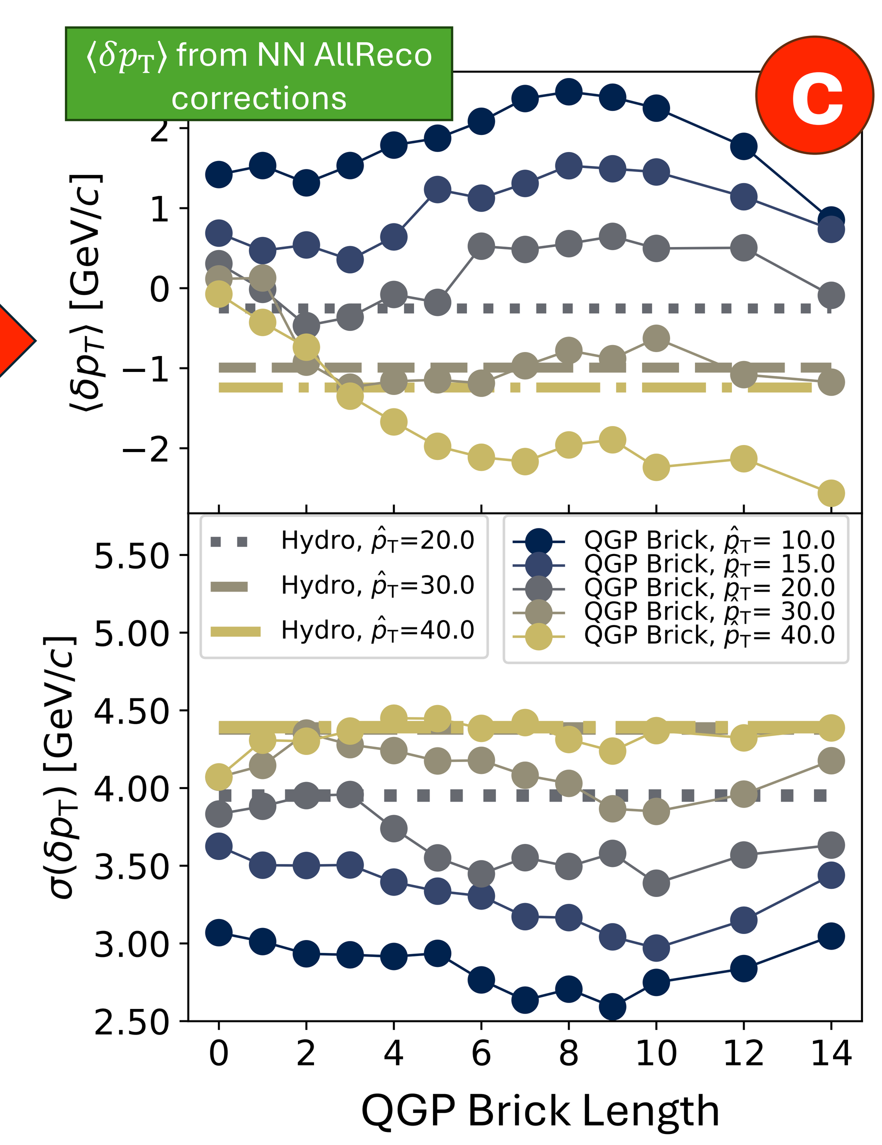
Full JETSCAPE hydro: most accurate simulations available for quenching, but computationally very expensive

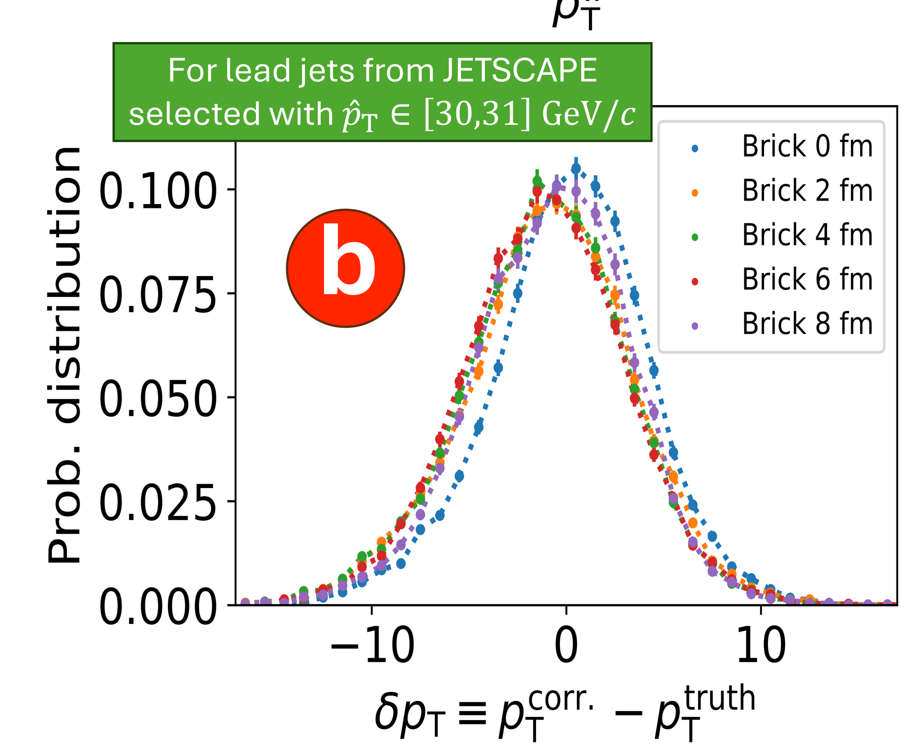
⇒ Compare hydro w/cheaper MC using constant length "brick" QGP by comparing:

- constituent p_T distribution
- biases in NN* values of δp_T

*"NN AllReco" results shown here





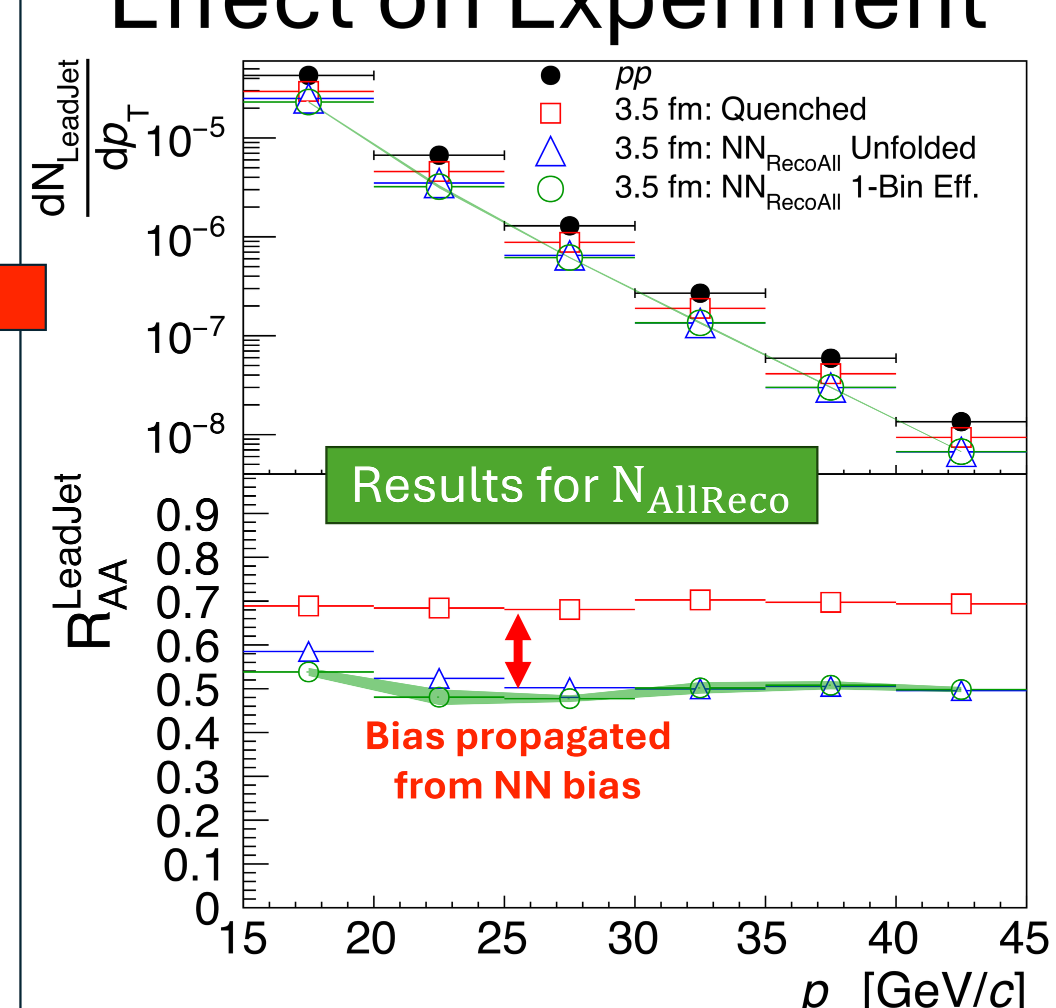


Bias Results

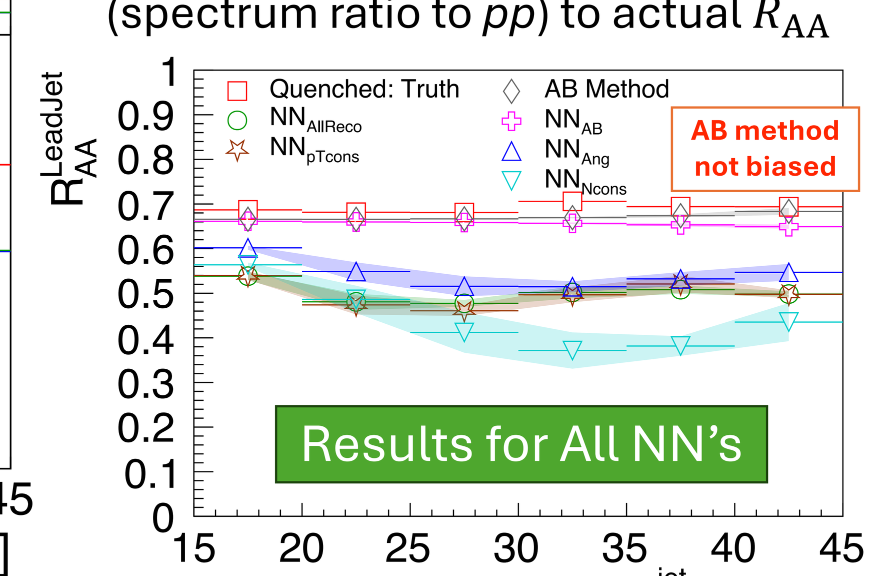
- **(a)** Constituent p_T relative to initiating parton p_T show hydro quenching ≈ 3.5 fm QGP brick
- **(b)** δp_T distributions using $NN_{AllReco}$ (evolve) w.r.t. quenching
- **(c)** Needed: $\langle\delta p_T\rangle \approx 0$ and $\sigma(\delta p_T)$ independent of quenching and $\hat{p}_T$* Result: $\langle\delta p_T\rangle$ and $\sigma(\delta p_T)$ both evolving (are biased). Biases agree with **(a)**: bias in hydro ≈ 3.5 fm QGP brick

*MC parameter for p_T of jets' initiating partons

Effect on Experiment



- Generate full spectra of leading jets in pp and with 3.5 fm QGP bricks
- Embed quenched jets into heavy-ion background
- Use NN to background subtract
- Statistically correct for δp_T for "measurement"
- Compare measured quenching R_{AA} (spectrum ratio to pp) to actual R_{AA}



Conclusions

- Using the best available MC generators for heavy ion collisions, neural networks (NNs) can add significant discrimination to distinguish jets from backgrounds *depending on training data correctness*
- Jet quenching adds significant biases to NN background corrections, which are compounded in spectra unfolding
- Errors in the suppression of the jet p_T spectra ratio (R_{AA}) for leading jets is very significant (up to ~30% for every NN, up to ~47% for NN_{Nconst})*
- Possible to continue investigation by using MC to train NN on quenched jets
  - However, verification via measurement is non-trivial
- Likely better to train ML only on the background (unaffected by jet quenching) and use to compare/reject background combinatorial jets

*except the NN trained only on the background (which mimics the AB method and is unbiased)

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