# Development of unfolding techniques for dijet measurements in sPHENIX

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## Abstract

The quark-gluon plasma (QGP) is a liquid created in high-energy heavy-ion collisions where quarks and gluons become deconfined. This state allows us to examine the emergent properties of quantum chromodynamics (QCD) under extreme conditions. sPHENIX, a new experiment at RHIC, studies the QGP created in Au+Au collisions and started taking data in 2023. Collimated sprays of particles, called jets, may be created in these collisions, typically in back-to-back (dijet) configurations. These dijets are produced prior to the formation of the QGP and interact with it during their development, losing energy in a process called "jet quenching" which probes the nature of the QGP. When these dijets do not pass through the same path-length of QGP, the energy loss will be asymmetric. The dijet momentum imbalance ($x_J$) is defined as the ratio between the sub-leading (second highest energy) jet's energy and the leading (highest energy) jet's energy, and is a useful measure of energy loss. However, dijet measurements are sensitive to the underlying event and detector resolution. To correct for these effects we examine the development and application of Bayesian unfolding techniques on PYTHIA jets embedded into HIJING Au+Au background. Future uses will include implementation on measured dijet distributions in sPHENIX.


## Jet Quenching and Dijet Asymmetry

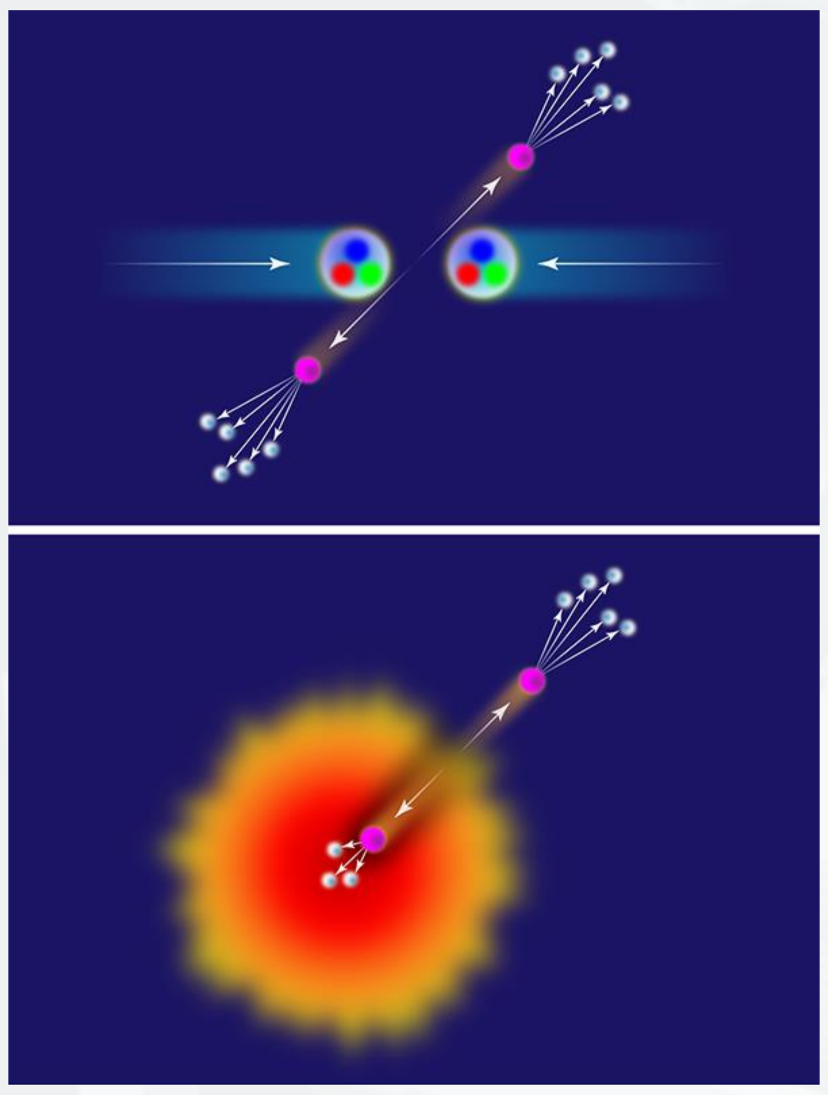

**Figure 1:** (top) A particle collision, quarks represented in red, blue and green. Partons created after the collision in pink and energized hadrons after hadronization in white. (bottom) One jet of particles passes through the Quark Gluon Plasma (shown in red and orange) and loses energy, while the other does not. IC: APS/Alan Stonebraker

- In heavy ion collisions, quarks and gluons can become deconfined, creating a liquid called the Quark Gluon Plasma (QGP)
- Collimated particle sprays called jets can also be created in these collisions in back-to-back configurations
- Jet quenching is observed when jet lose energy as they interact with the QGP
- One measurement to study jet quenching is called dijet momentum balance ($x_J$)
- When one jet interacts more with the QGP than the other, energy is lost to the medium asymmetrically
- Leading jet – highest transverse momentum ($p_{T,1}$)
- Subleading jet – second highest transverse momentum ($p_{T,2}$)
- $x_J = \frac{p_{T,\,\mathrm{subleading}}}{p_{T,\,\mathrm{leading}}}$

## Unfolding Motivation

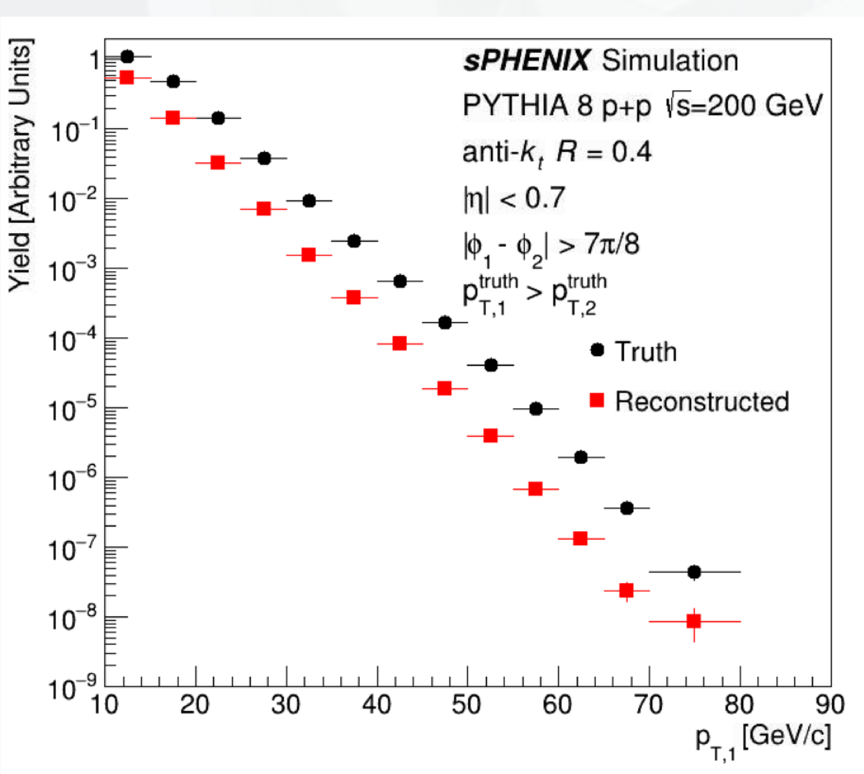


**Figure 2:** Plot showing both truth (simulated collision) and reconstructed (simulated GEANT4 detector response) leading jet spectra from a UE subtracted PYTHIA 8 p+p simulation. Reconstructed jets are not fully corrected for energy scale.

- Truth data simulates p+p collisions using PYTHIA 8
- Reconstructed data uses GEANT4 to simulate detector response
- When jets are reconstructed by detectors with finite energy resolution, kinematics like $p_T$ are "smeared"
- This effect does not affect all jets equally
- Sometimes results in $p_{T,1}$ and $p_{T,2}$ "swapping" when jets are measured
- Can cause misinterpretation of jet measurements, especially $x_J$
- The process of correcting for this smearing is called unfolding
- Unfolding removes detector effects from final results

## Unfolding Process

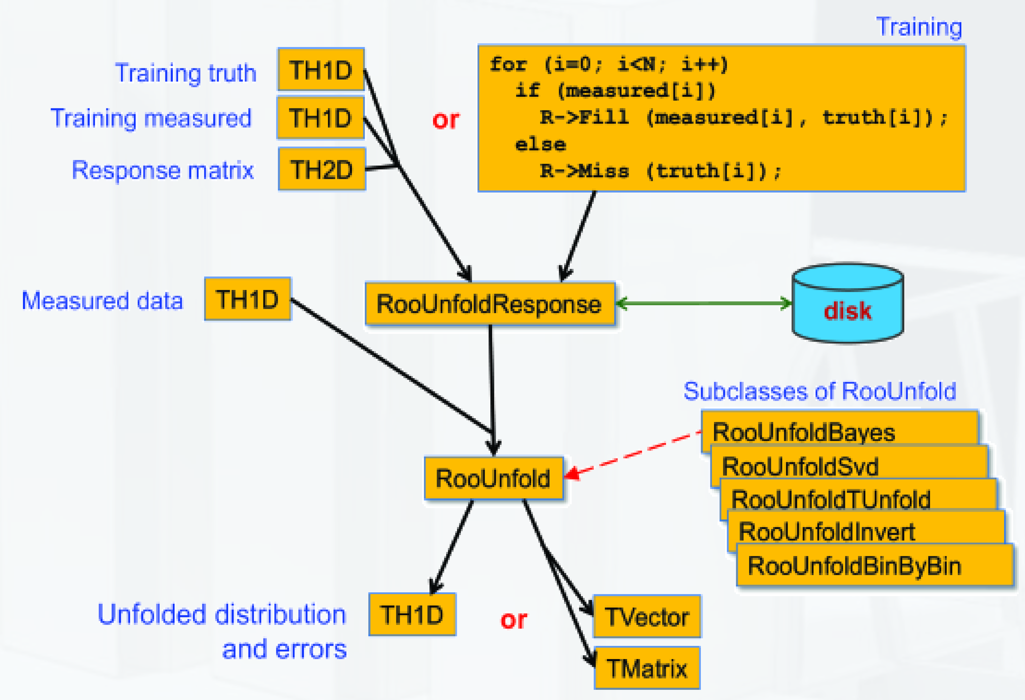


**Figure 3:** Diagram showing the general structure of the RooUnfold classes and how they work together. IC: Tim Adye

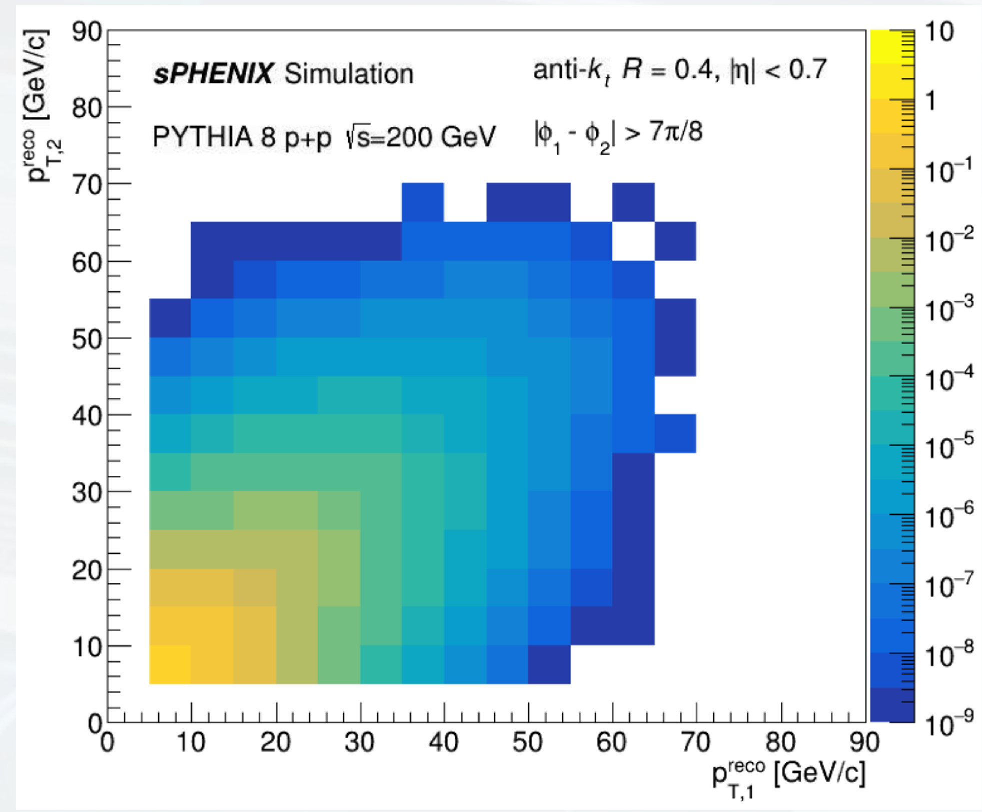


**Figure 4:** A UE subtracted symmetrized $p_{T,\,reco}$ distribution for a response matrix. Data taken from a PYTHIA 8 p+p simulation.

- RooUnfold program is used to unfold
- Response Matrix made up of truth and measured distributions
- For 2D distribution unfolding, a 4D Response Matrix with 4 variables is used ($p_{T,1}^{truth}$, $p_{T,2}^{truth}$, $p_{T,1}^{reco}$, $p_{T,2}^{reco}$)
- Response matrix and $p_T$ distributions symmetrized to account for $p_{T,1}$ and $p_{T,2}$ swapping during measurement
- D'Agostini method encoded in RooUnfoldBayes function with 4 iterations used to unfold
- For 2-Dimensional unfolding "Toys" are used to decrease unfolding time needed
- Unfolding methods tested using a "closure test"
- For closure test half the data is used to produce the measured and truth training distributions
- The other half is used to produce response matrix
- Closure test mimics expected statistical independence of unfolding real data
- Unfolded distribution then plotted against truth and reconstructed distribution
- Ratio between unfolded and truth distributions taken

## Progress

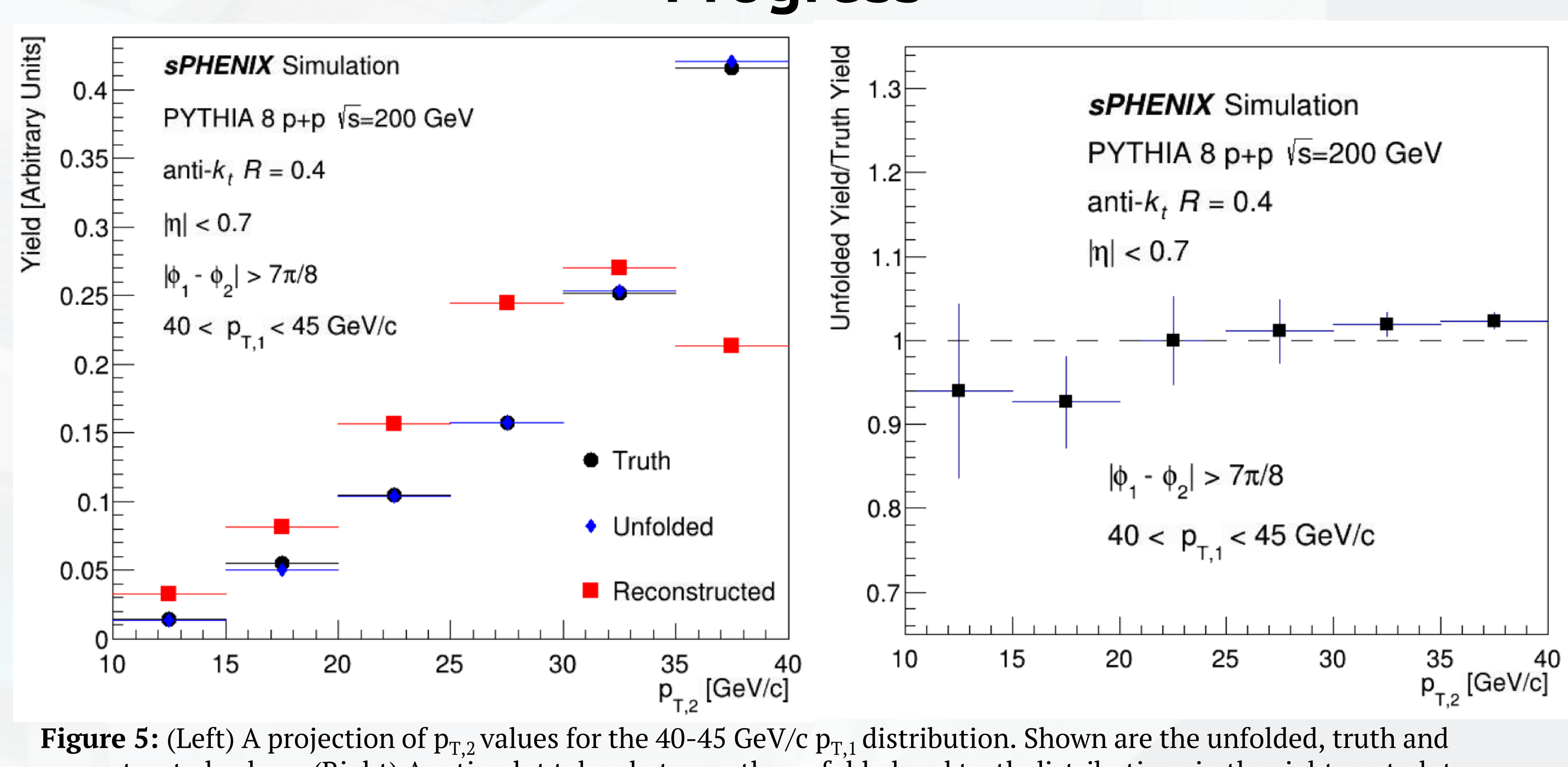


**Figure 5:** (Left) A projection of $p_{T,2}$ values for the 40-45 GeV/c $p_{T,1}$ distribution. Shown are the unfolded, truth and reconstructed values. (Right) A ratio plot taken between the unfolded and truth distributions in the rightmost plot.

- Projection of $p_{T,2}$ values for a $p_{T,1}$ bin
- Analogous to $x_J$ measurement
- Sharp decrease in yield as jets become more asymmetric
- Little agreement between reconstructed and truth distribution
- Large agreement between unfolded and truth distribution
- Ratio is either overlapping unity or near unity for all values
- Proof of concept is complete, next step is to implement on simulated Au+Au data
- Final goal is to create a response matrix to unfold $x_J$ in p+p and Au+Au in sPHENIX


## Acknowledgements

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