Probing the Parton Shower and Hadronization with Novel Jet Substructure Measurements at STAR

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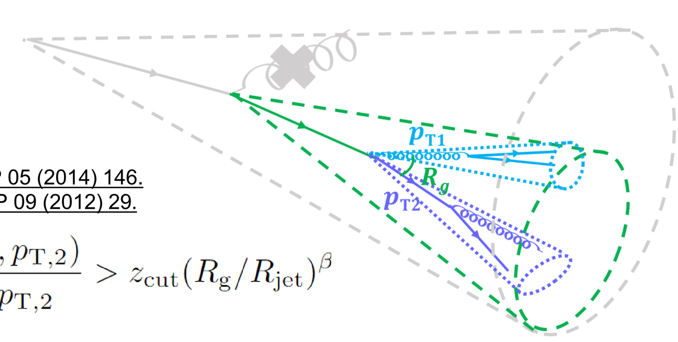
Introduction

Jets are collimated sprays of final-state particles produced from initial high-momentum-transfer partonic scatterings in collisions. Since jets are multi-scale objects that connect asymptotically free partons to confined hadrons, jet substructure measurements in vacuum can provide insight into the **parton shower** and the ensuing **hadronization** processes. We present two novel jet substructure measurements with $\sqrt{s} = 200$ GeV *pp* collision data recorded by the STAR experiment.

Grooming

To enhance perturbative contributions, **SoftDrop grooming** is often used to remove soft wide-angle radiation.



Larkoski, et al. JHEP 05 (2014) 146.
Dasgupta et al. JHEP 09 (2012) 29.

$$z_g = \frac{\min(p_{T,1}, p_{T,2})}{p_{T,1} + p_{T,2}} > z_{cut}(R_g/R_{jet})^{\beta}$$

With **CollinearDrop grooming**, we can study the **soft wide-angle radiation within jets**. This is an interesting region of phase space of the parton shower that deserves more study!

Chien and Stewart JHEP 06 (2020) 64.

We use $(z_{cut\ 1}, \beta_1)$ = **(0,0)** and $(z_{cut\ 2}, \beta_2)$ = **(0.1,0)**: difference in the original and SoftDrop groomed observable. E.g., the CollinearDrop groomed jet mass:

$$\Delta M/M = \frac{M - M_g}{M}$$

Unfolding Correlated Variables

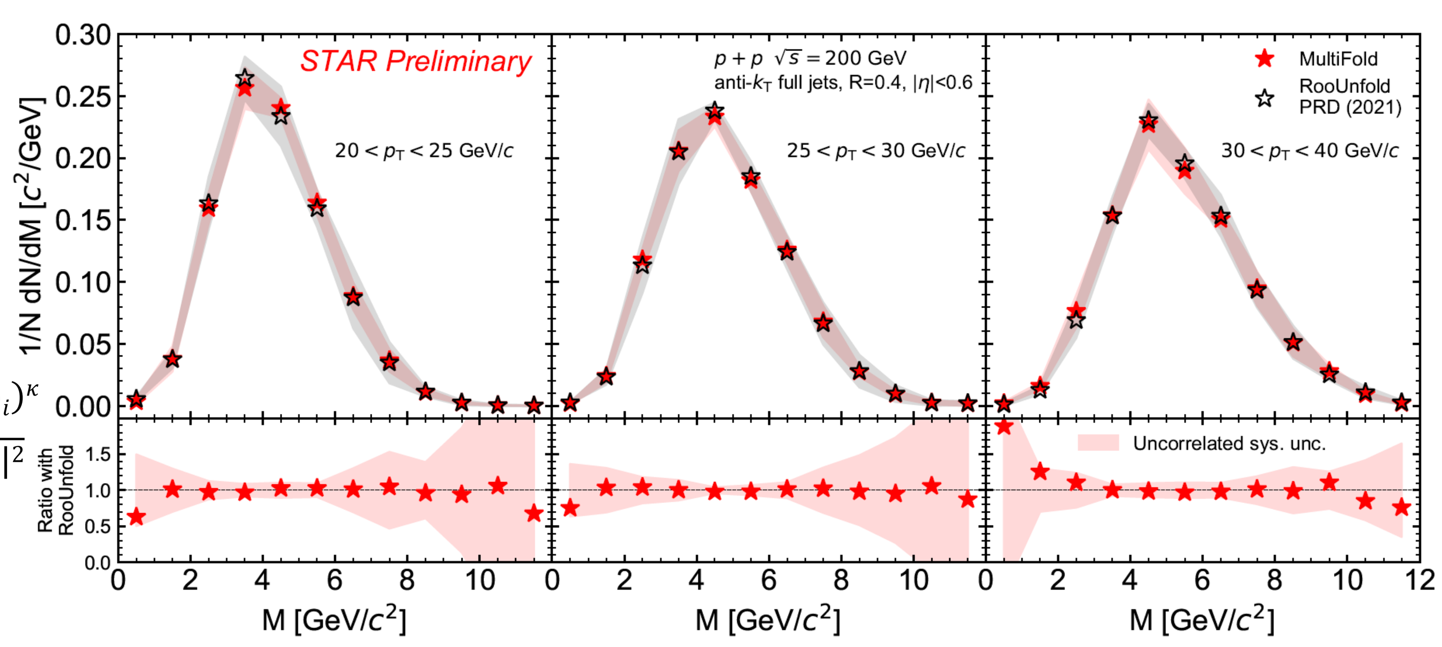
Unfolding methods:

- Iterative Bayesian unfolding (D'Agostini, arXiv:1010.0632 (2010))
- **MultiFold** (Andreassen et al. PRL 124, 182001 (2020))
  - Machine learning driven
  - Unbinned
  - **Simultaneously** unfolds many observables → **Correlation** information is retained!

Unfolded observables:

- p_T : transverse momentum
- Q^{κ} : jet charge $Q^{\kappa} = \frac{1}{(p_{T_{jet}})^{\kappa}} \sum_{i \in jet} q_i \cdot (p_{T_i})^{\kappa}$
- M: jet mass $M = \left|\sum_{i \in jet} p_i\right| = \sqrt{E^2 - |\vec{p}|^2}$
- R_g : groomed jet radius
- z_g : shared momentum fraction
- M_g: groomed jet mass

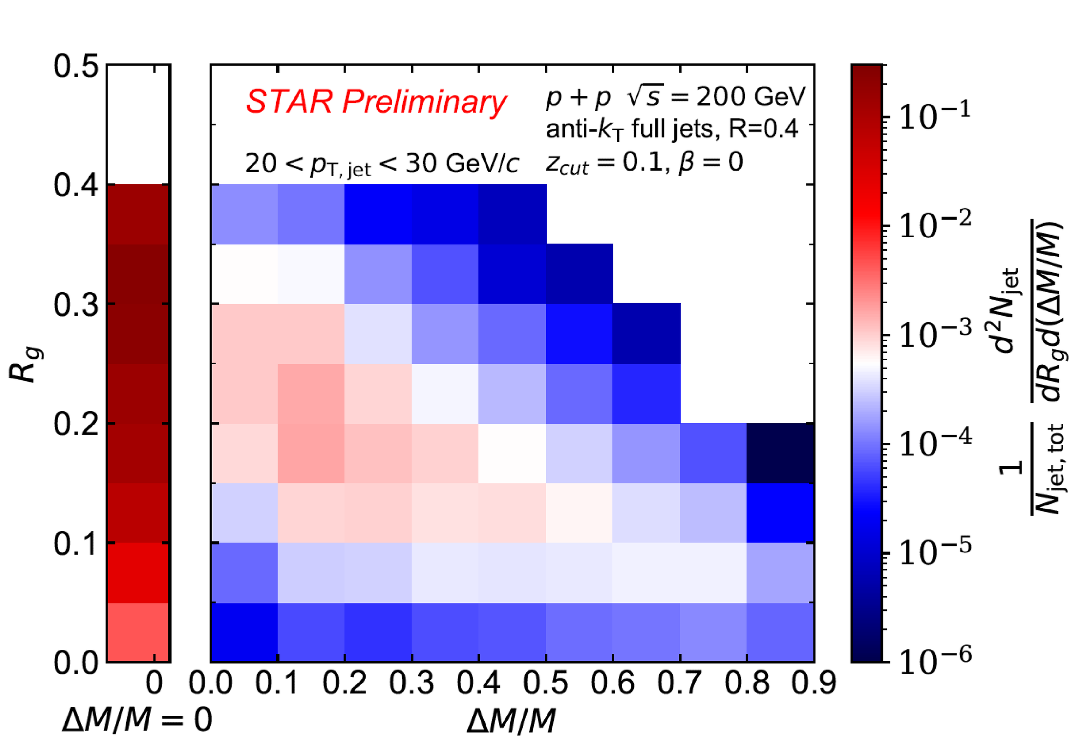
MultiFolded result is consistent with the previously published **RooUnfolded** result! (STAR Collaboration, PRD 104, 052007(2021))

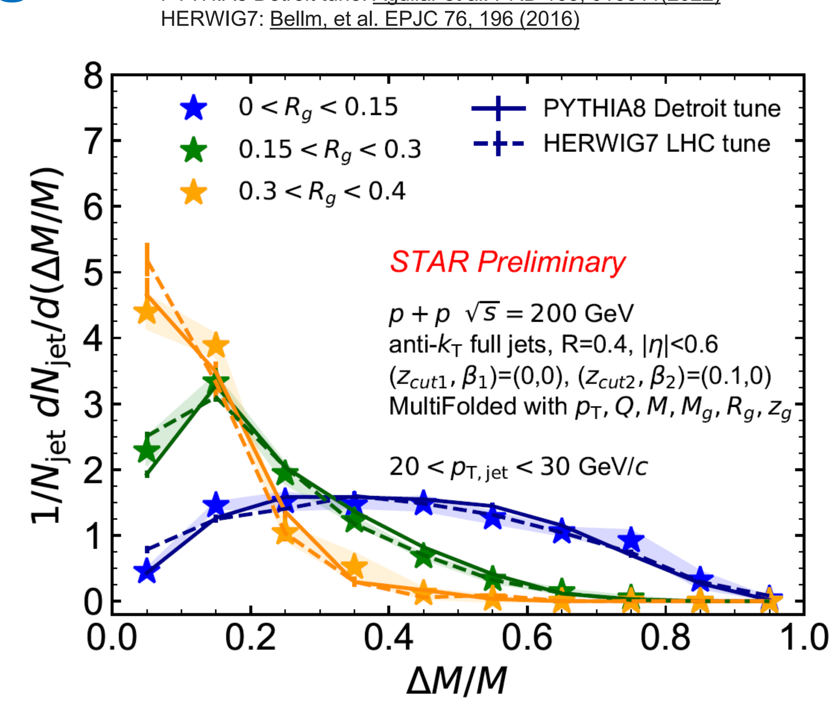


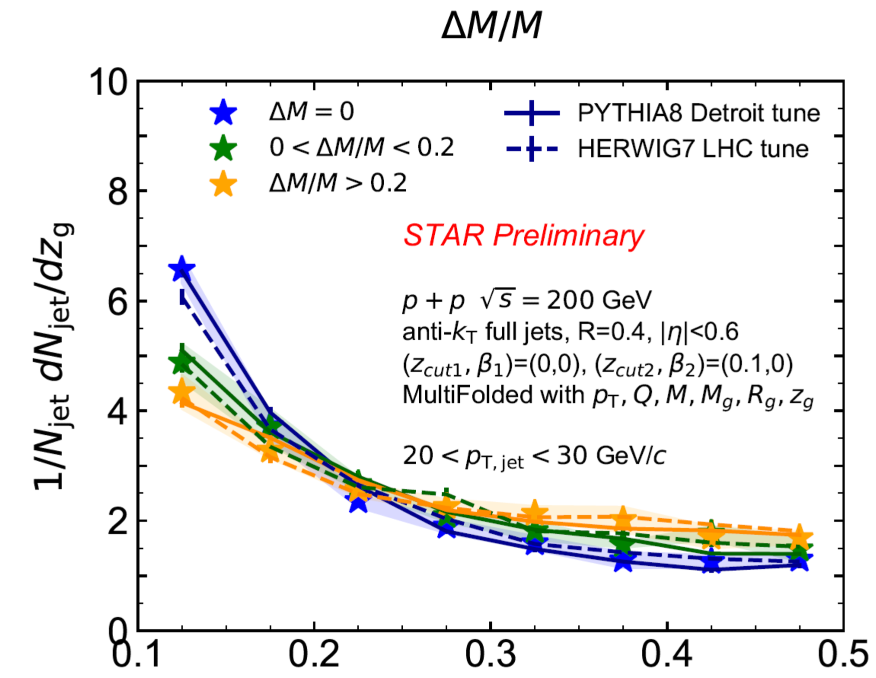
☆ First application of MultiFold on RHIC data!

Results

PYTHIA6 Perugia + STAR tune: Skands, PRD 82, 074018 (2010)
J. K. Adkins, PhD thesis (Kentucky U., 2015)
PYTHIA8 Detroit tune: Aguilar et al. PRD 105, 016011(2022)
HERWIG7: Bellm, et al. EPJC 76, 196 (2016)



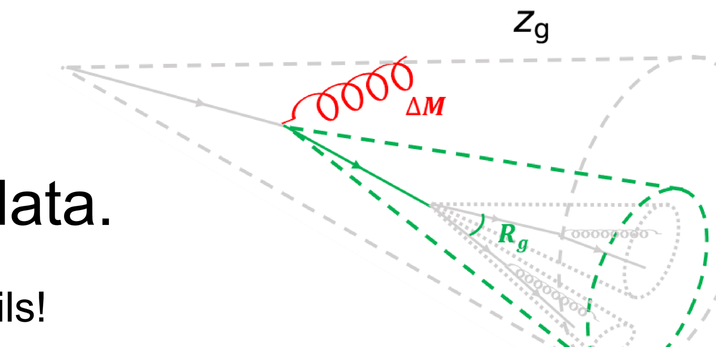




☆ The mean of $\Delta M/M$ distribution is anti-correlated with mean of R_g.
→ consistent with **angular-ordered** parton showers

☆ **Early** soft wide-angle radiation constrains the angular phase space and the momentum imbalance of **later** splittings.

☆ MC models describe the trend of data.



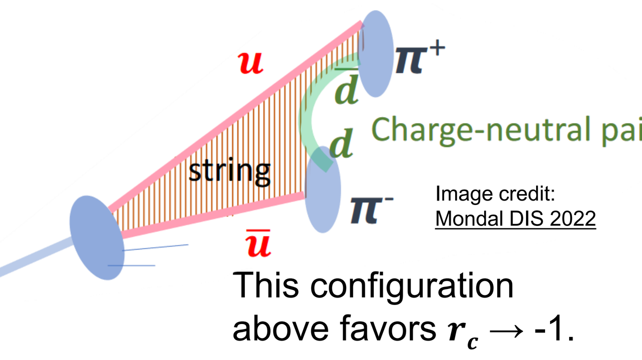
See https://arxiv.org/abs/2307.07718 for more details!

Charge Correlator Ratio

The **charge correlator ratio** r_c probes for evidence of **string-like fragmentation**, by distinguishing the charge signs of leading and subleading charged particles within jets. Chien et al. PRD 105 051502 (2022)

$$r_c = \frac{N_{ss} - N_{os}}{N_{ss} + N_{os}}$$

ss: same-sign track pairs,
os: opposite-sign track pairs



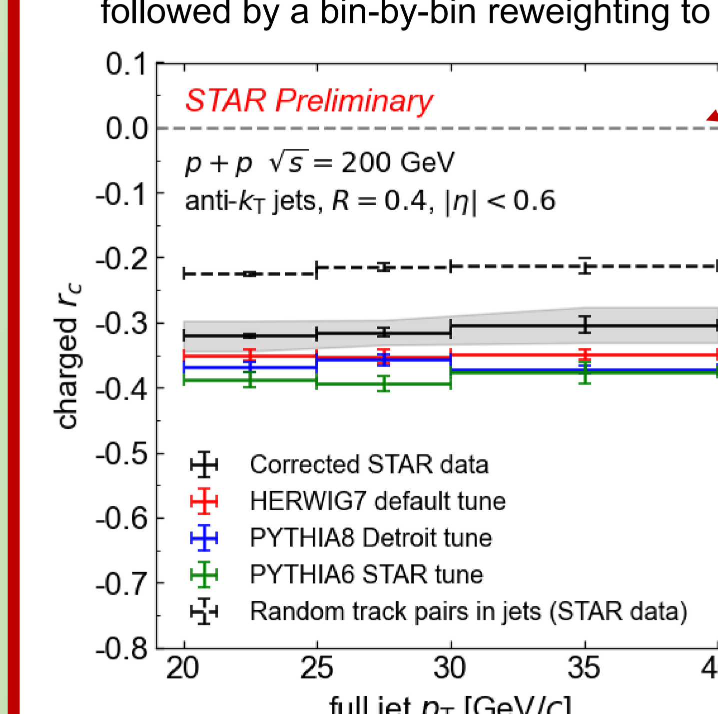
This configuration above favors $r_c \to -1$.

This measurement can also establish a baseline for studying **medium modification of hadronization in the QGP**! The choice of leading dihadrons makes it less susceptible to the background.

Results

NEW @ QM23

To correct for detector effects, we performed a mistagged subtraction to account for incorrectly identifying tracks that are not leading/subleading, followed by a bin-by-bin reweighting to account for the jet energy scale.



Random pairs from a neutrally charged bath: $r_c = 0$

Data show a preference of opposite sign pairs over same sign pairs, in:

- pair of random tracks within a jet;
  Influenced by jet charge ~ 0 on average: $r_c \approx -0.2$
- leading and subleading tracks in jet.
  Additional correlation from fragmentation: $r_c \approx -0.3$

☆ r_c has a **weak dependence on jet p_T**.

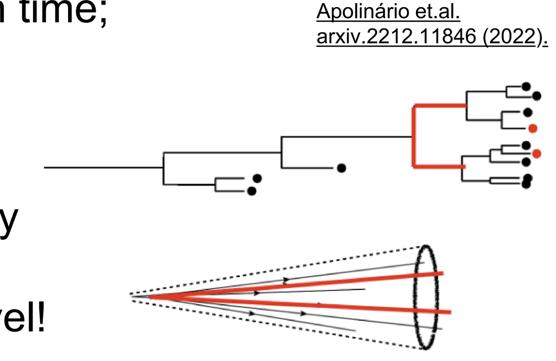
☆ Preference for HERWIG's cluster hadronization, or effect of tune?

Opportunity for tuning of HERWIG to RHIC environment!

Outlook

Study the **transition from perturbative to nonperturbative regime** within jets with

- r_c as a function of formation time;
- r_c measured on subjets.



Using iterative declustering technique, we could potentially connect hadrons back to the resolved splitting at parton level!

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The STAR Collaboration
https://drupal.star.bnl.gov/STAR/presentations