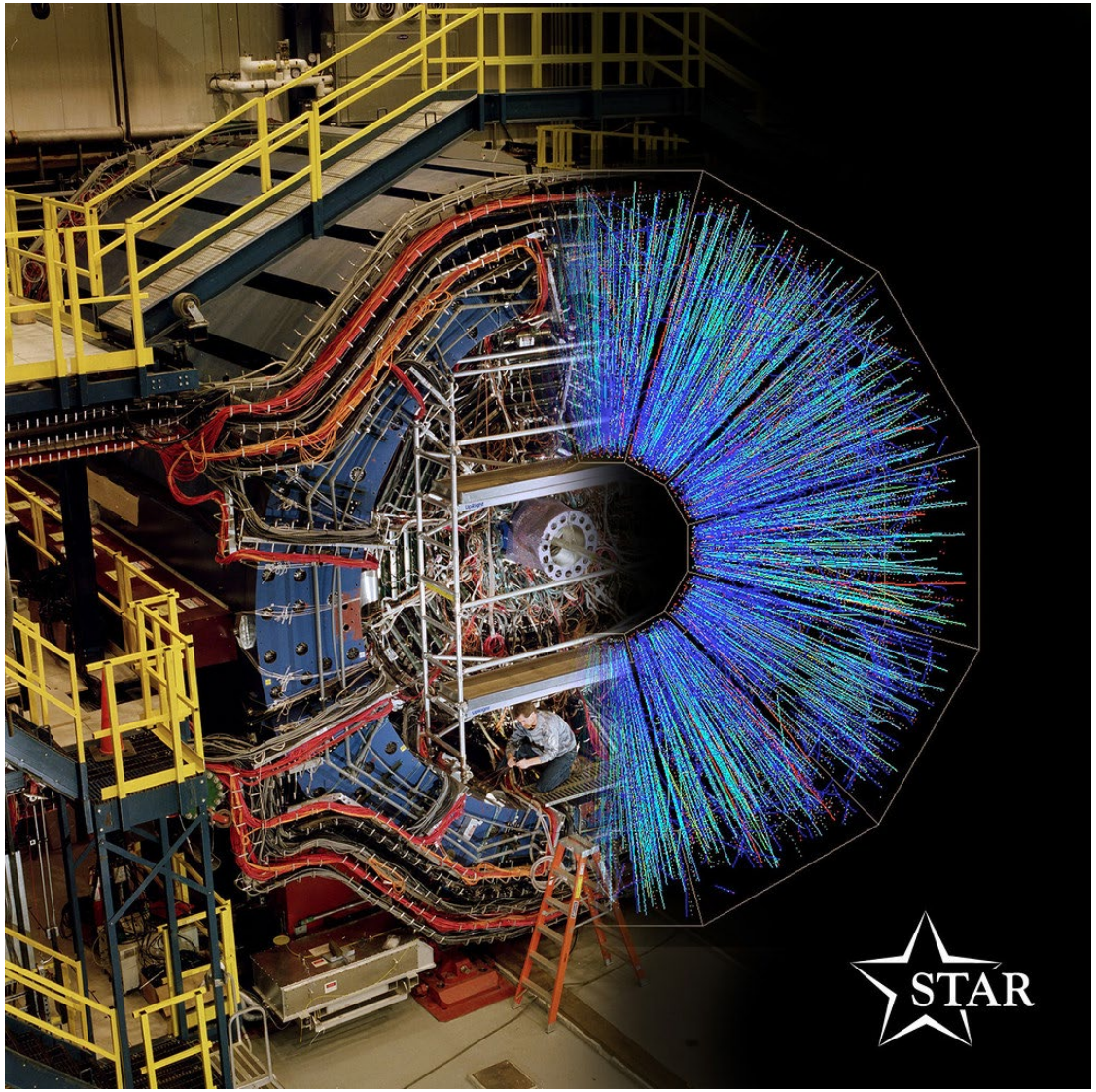
Measurement of Full and Charged Two-Point EECs at STAR

Andrew Tamis (Yale University)
For the STAR Collaboration
Date TBD

Energy Correlators at the Collider Frontier

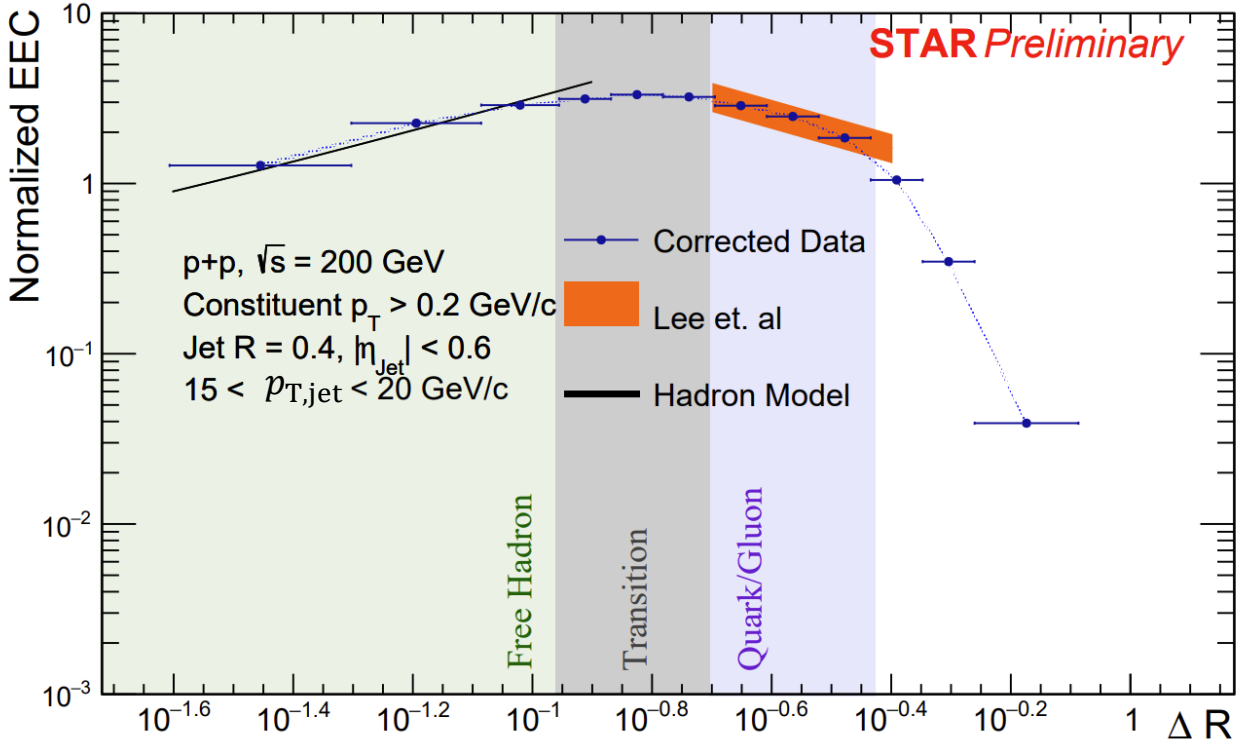
Measurement at STAR



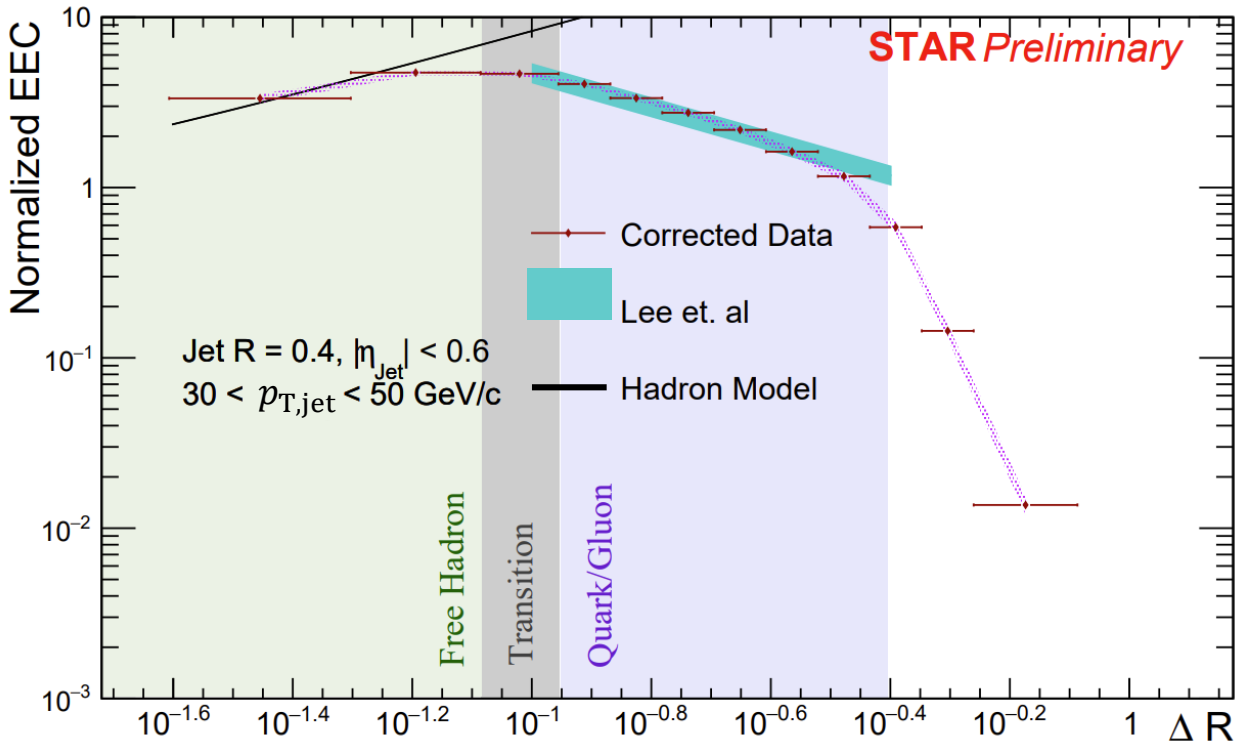
- STAR Time Projection Chamber (TPC) provides excellent charged track resolution
- Barrel Electromagnetic Calorimeter (BEMC) allows for measurement of **full jets**
- BEMC used for trigger in order to obtain jet-rich data sample

Measurement at STAR

15 < Full Jet p_T < 20 GeV/c



30 < Full Jet p_T < 50 GeV/c

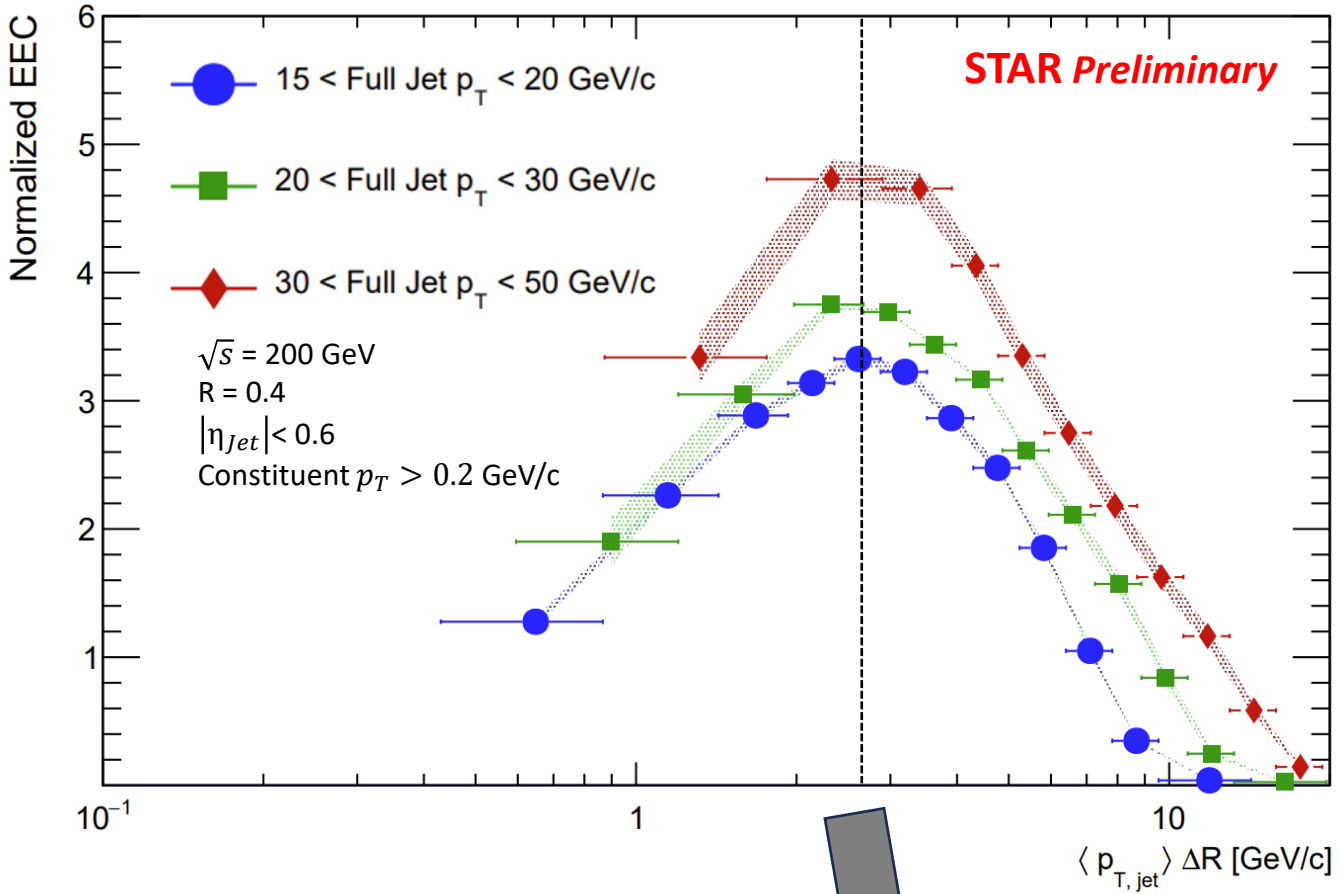


Lee, Mecaj, Moult (2023): arXiv:2205.03414

- Theoretical comparison calculated in the Perturbative Region ($\frac{3\text{GeV}}{{p_T}^{\text{Jet}}_{\text{Low}}} < \Delta R <$ Jet R)
- **Behavior agrees well with theoretical expectations!**
- Low angle behavior compared with toy model of hadrons, assuming uniform energy distribution

p_T-Shifted Distributions

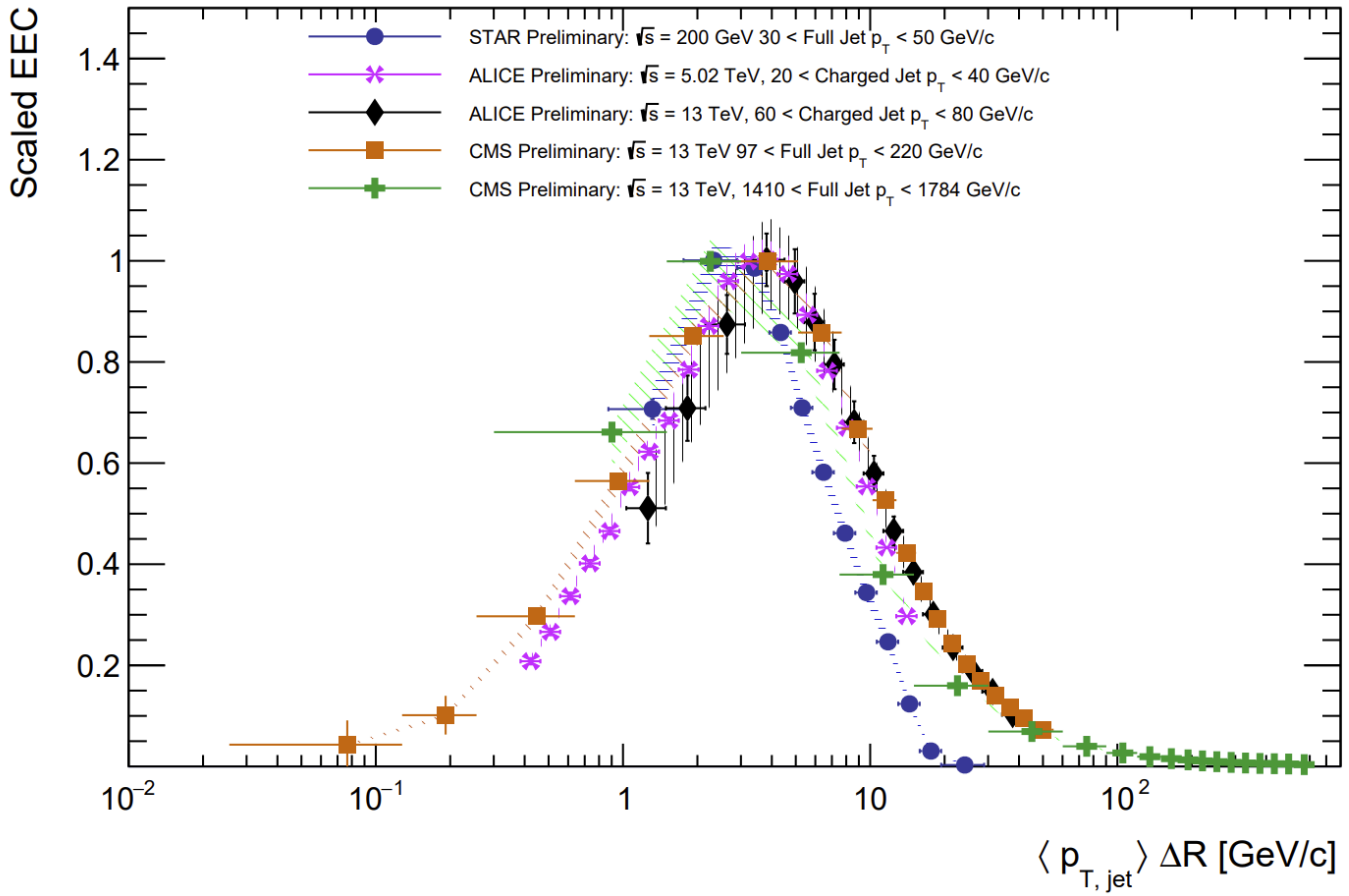
- Shift Corrected Result on x axis by average $p_{\mathrm{T,jet}}$ in a given bin
- As location of transition $\propto \frac{\Lambda_{\mathrm{QCD}}}{p_{\mathrm{T}}^{\mathrm{Jet}}}$, this will collapse it onto a single point
- In this case, average momentum is determined via PYTHIA and applied post-correction



$< p_{T,\mathrm{jet}} > \Delta R_{Turnover} \sim 2 - 3\ GeV$

Comparison with ALICE and CMS Results

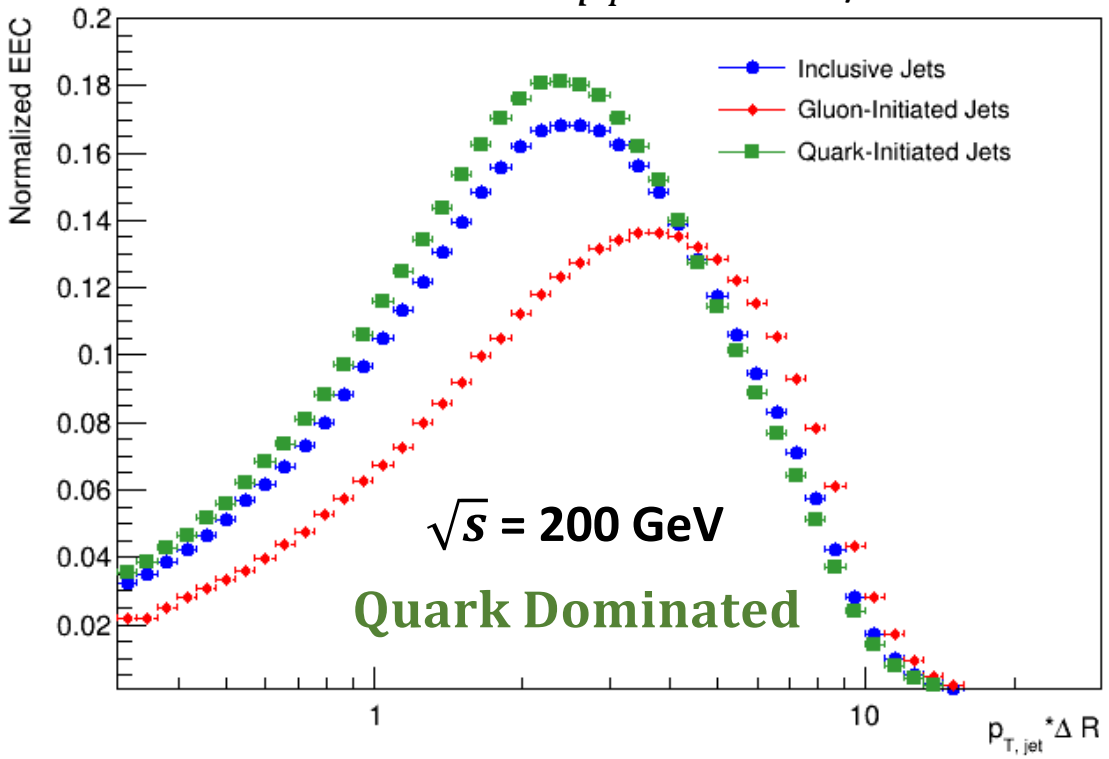
- STAR Result is comparable with both CMS and ALICE results – across a large gap in jet momentum
- EEC scaled to have value at peak be one to more directly compare peak locations
- Quark, gluon fragmentation differences ➡ transition shift



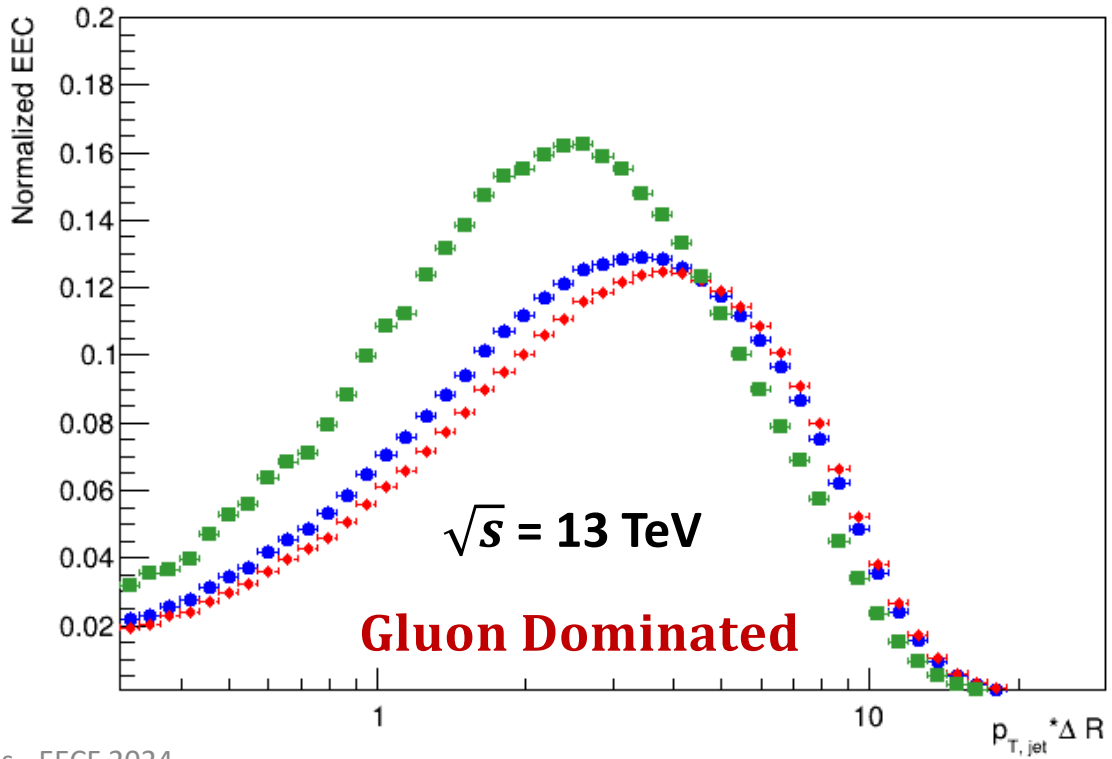
Impact of Quark/Gluon Fraction

- Observed turnover region for ALICE result occurs at larger $< p_{T,\mathrm{jet}} > \Delta R_{Turnover}$
- This is largely due to difference in quark/gluon fraction as gluons fragment to larger angles
- ***Quark-rich environment of STAR is unique place to study EECs***

R = 0.4
$|\eta_{Jet}| < 0.6$
Constituent $p_T > 0.2$ GeV/c



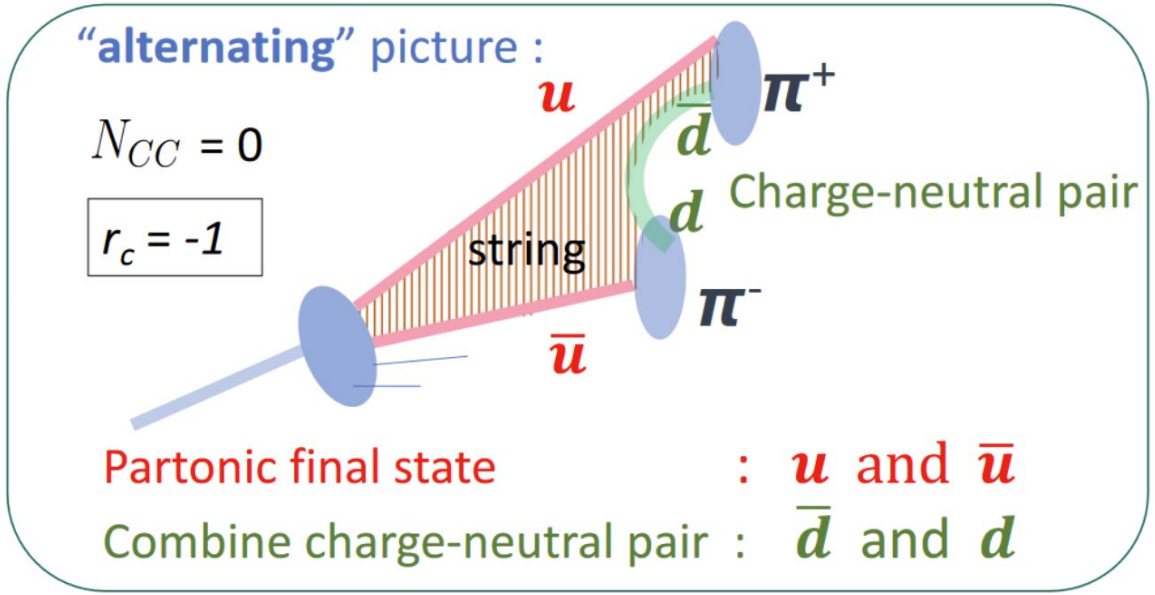
20 GeV/c < $p_{\mathrm{T,jet}}$ < 40 GeV/c
PYTHIA8
Multi-Parton Interactions OFF

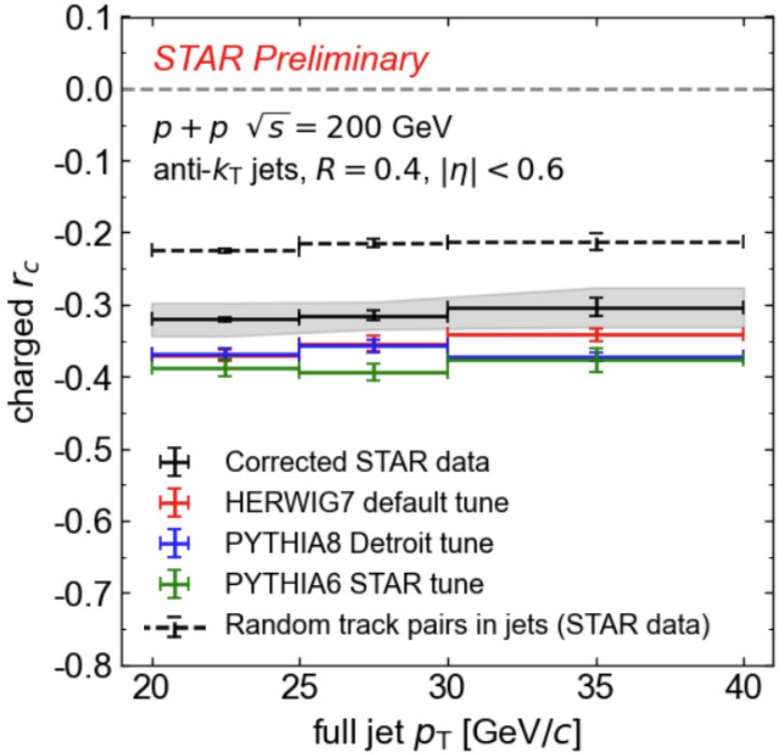


Charge-Dependent Hadronization

- Hadronization may introduce explicit charge dependence dependent on mechanism
- String-Like hadronization used by PYTHIA, while cluster hadronization used by HERWIG
- Studied by several charge dependent observables, such as r_c

Figure: Youqi Song





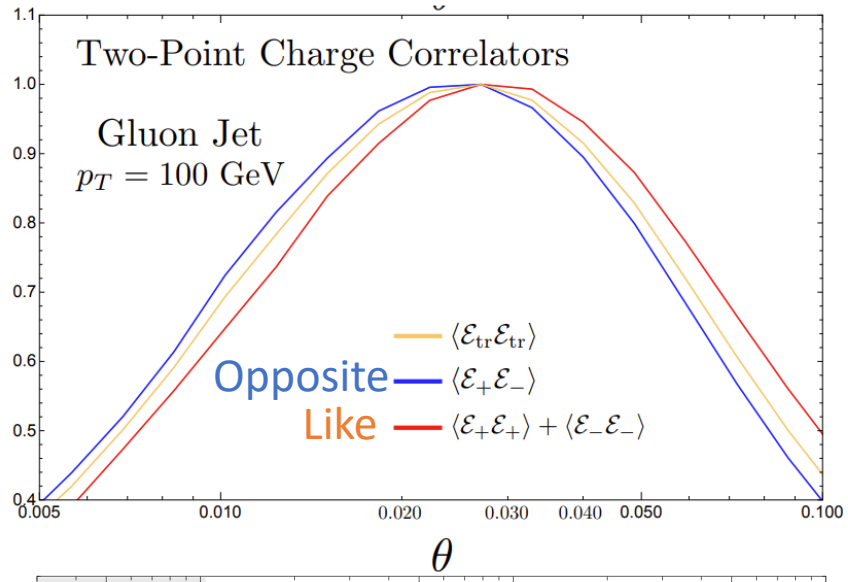
Charged EECs

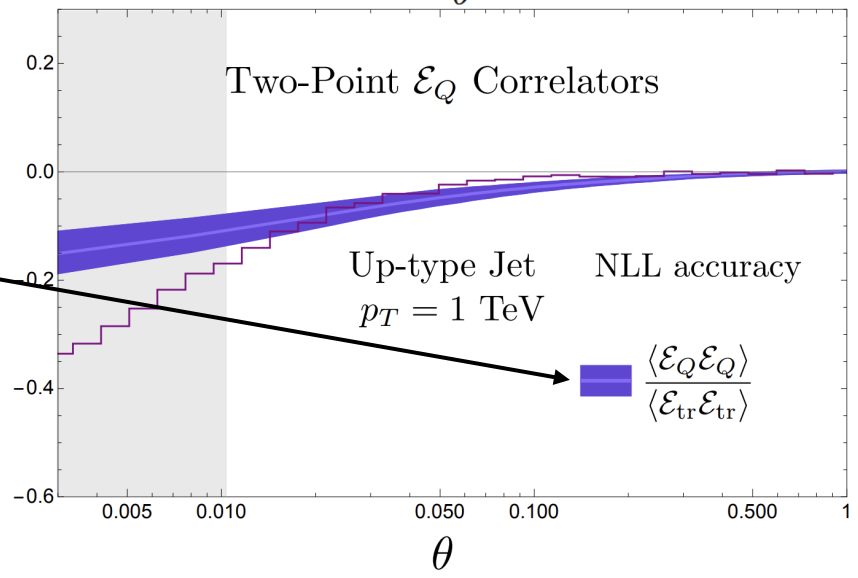
- Can further extend non-perturbative power of EEC by exploring correlation of both angle and charge distribution.

- Replace energy flow operator with some selection on charge (Like or Opposite charge correlations)
  - Or by weighting energy flow operator by charge operator

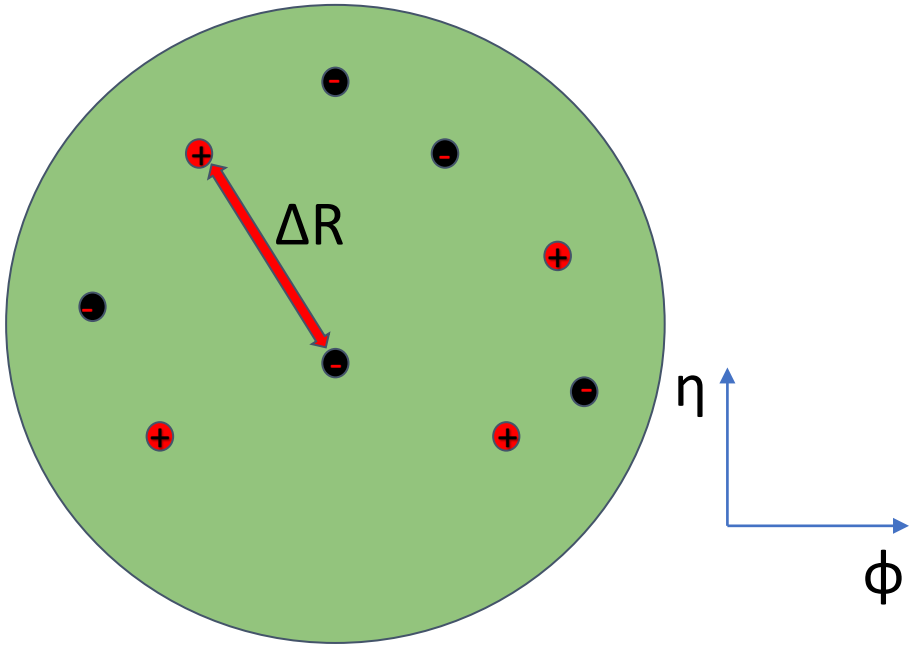
- Seen in Pythia simulations done by Lee and Moult, Transition region shifts on like- and opposite-charge selection

Lee,Moult 2023: arXiv:2308.00746





Charged EEC Experimental Measurement

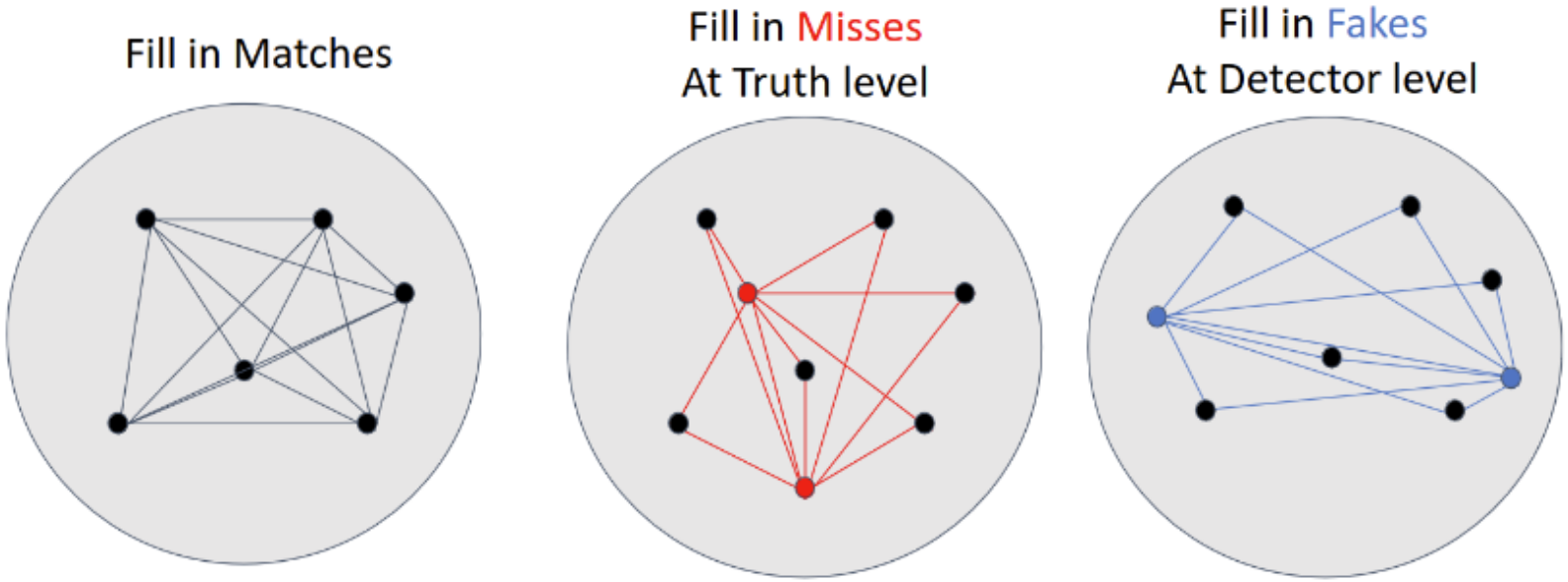


- Experimentally: Build distributions out of like-sign correlations and opposite-sign correlations
- Perform 3D Bayesian unfolding separately to each distribution
- Construct charge-weighted EEC via their difference

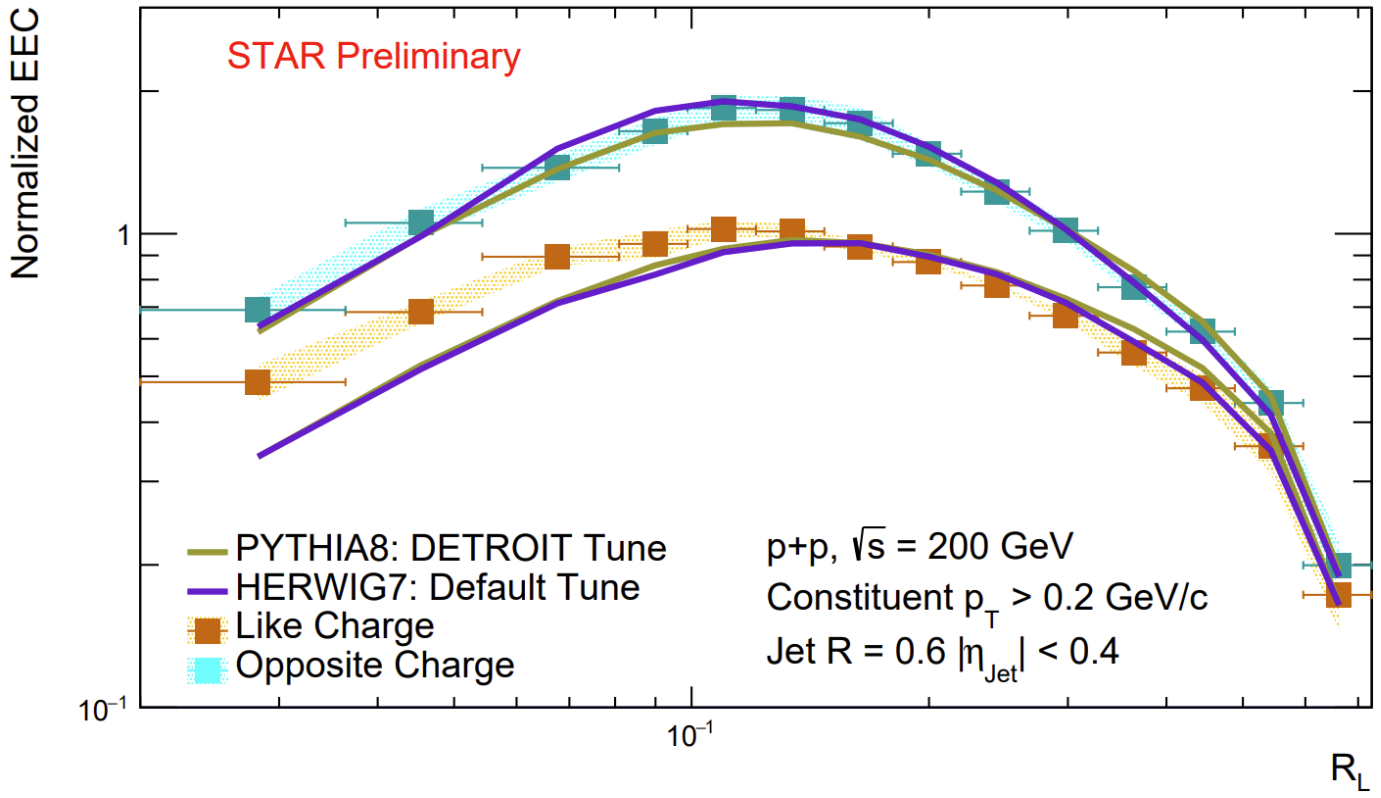
$$\text{Charged EEC} = \frac{d\left(\sum_{Jets}\sum_{i\neq j}\frac{E_i Q_i E_j Q_j}{{p_{T,Jet}}^2}\right)}{d\,(\Delta R)} = \text{EEC}_{++} - \text{EEC}_{+-}$$

3D Unfolding – Method

- Unfold Separately for like-charge and opposite-charge correlations
- Perform matching between particle and detector level
  - Once for Jets (Within Jet Radius) and once for constituents (Within 0.01 in eta-phi)
- Bayesian Unfolding in three variables <u>per correlation</u>
  - $p_{T,jet}$, R_L , $\frac{E_1 E_2}{{p_{T,jet}}^2}$



Like and Opposite charge Distributions

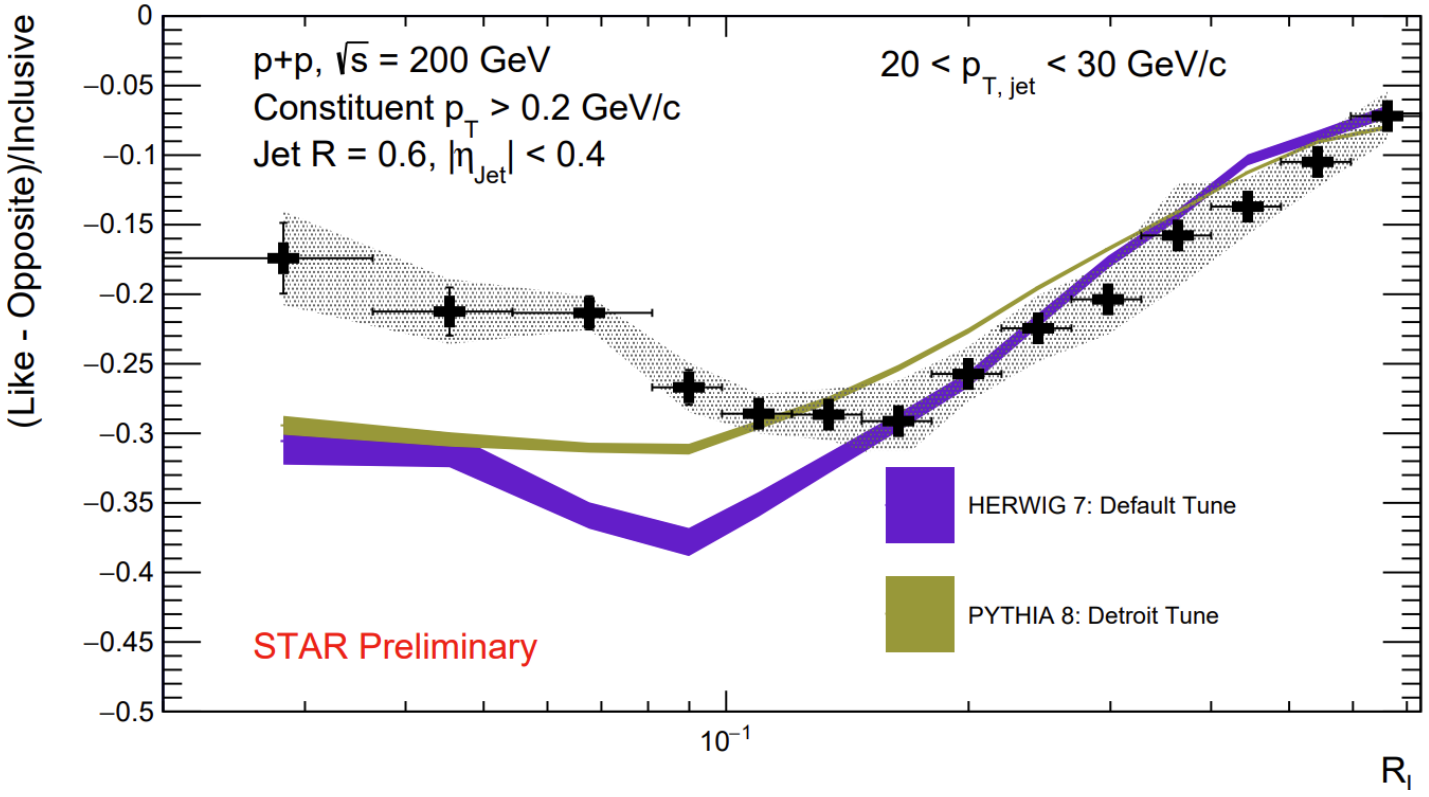


First measurement!

- Both Like and Opposite sign follow expectations in perturbative region
- Excess of like-charge correlations below transition region
- Shift in location of transition region seen in Monte-Carlo, but not resolved in data

Charge Ratio

$$\approx \frac{\langle \mathcal{E}_Q \mathcal{E}_Q \rangle}{\langle \mathcal{E}_{\mathrm{tr}} \mathcal{E}_{\mathrm{tr}} \rangle}$$



First measurement!

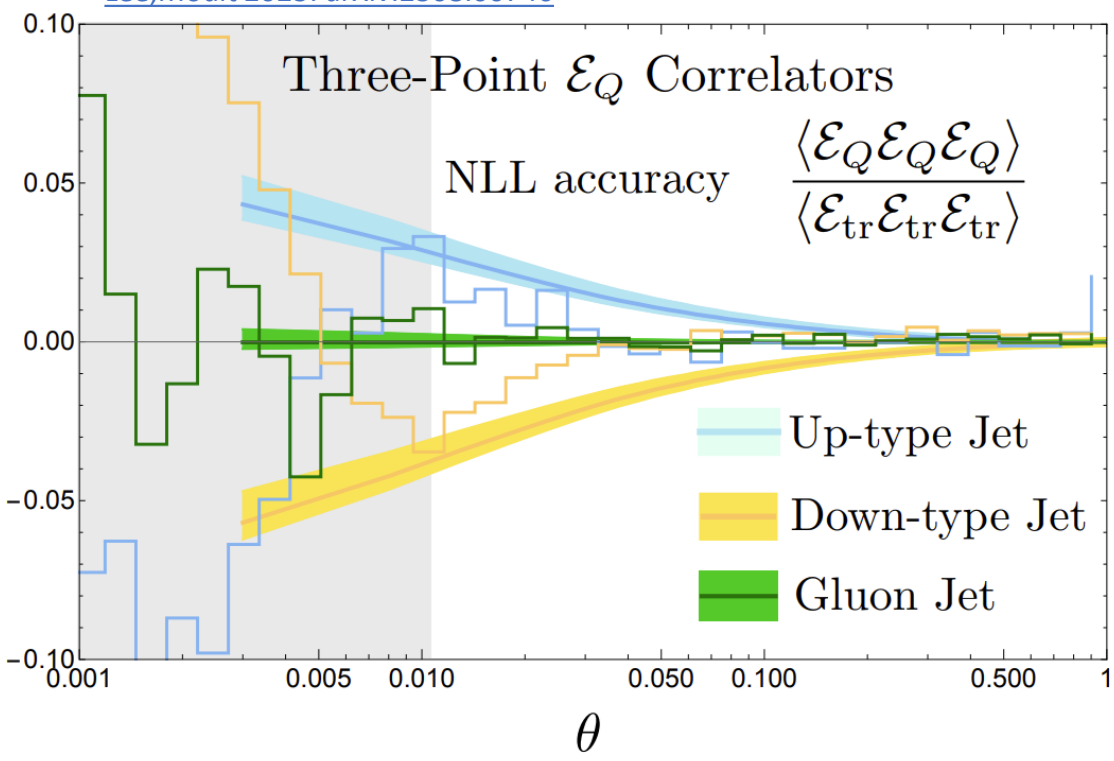
- Cluster hadronization (Herwig) and String hadronization (Pythia) both predict same qualitative behavior
- Both describe scaling of data in perturbative region, but neither describe data below transition region
- Implementation of charge dependence/conservation in hadronization mechanism may not fully capture effects

Extension to Three-Point

- Extension to Three-point charge correlators extremely interesting
  - Charge odd – separates based on initiator charge
  - Identically zero for gluon jets

- Well suited to be measured at STAR energies – high quark fraction with little antiquark cancellation

Lee,Moult 2023: arXiv:2308.00746



Conclusions

- STAR is an extremely useful environment for study of ENCs, and an excellent complement to LHC measurements

- Charged ENCs expand sensitivity of ENCs to non-perturbative effects and the hadronization mechanism
  - Observe tension with current Monte-Carlo models in charge-dependent hadronization

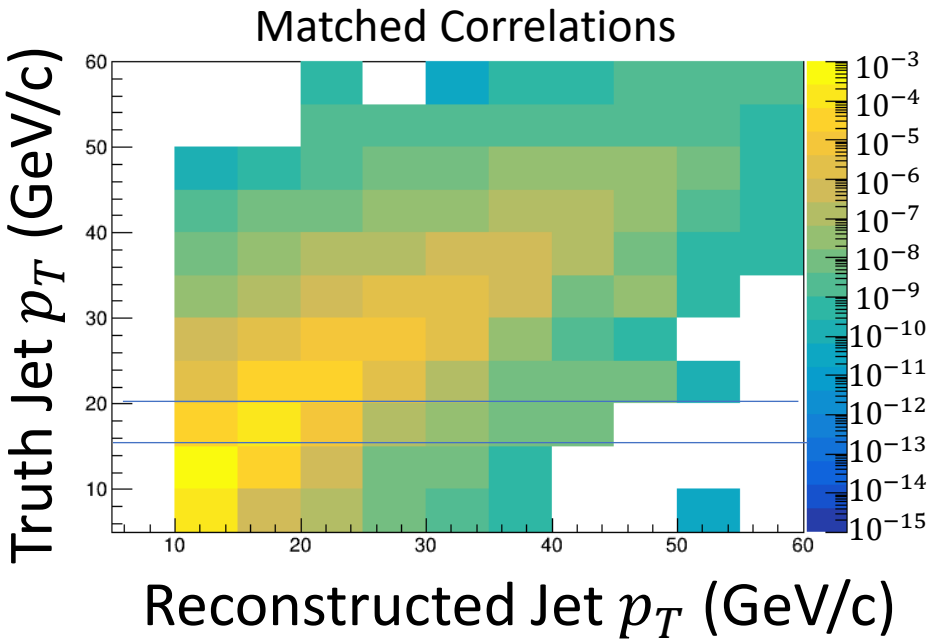
- First measurements of Two-Point Charged EECs shown, with three-point extension in progress

Backup

p_T^{Jet} Correction Method

- Inform correction via use of PYTHIA6 (Truth) and PYTHIA6 + GEANT Embedded in min-bias data (Reconstructed)

- Match jets between Truth and Reconstructed samples within a ΔR of 0.4 and then match constituents inside of jets within a ΔR of 0.02 and form response matrix



$\sqrt{s}$ = 200 GeV
R = 0.4
$|\eta_{Jet}|$< 0.6
Constituent $p_T > 0.2$ GeV/c

PYTHIA 6 + GEANT

- Preliminary results use a correction procedure in which $p_{T,jet}$ is the only variable in which a response matrix is formed
  - Detailed in **arXiv:2309.05761**
  - Planning to expand to full three-dimensional unfolding