p-p, $\bar{p}$-$\bar{p}$, and p-$\bar{p}$ Femtoscopic Correlations in the RHIC Beam Energy Scan in STAR

Andrew Peterson
for the STAR Collaboration

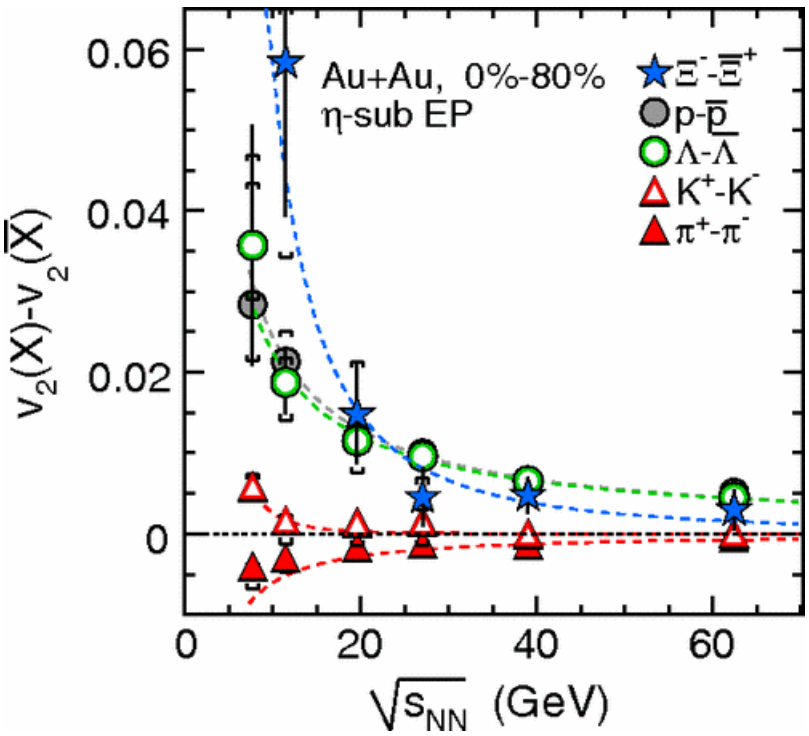
Ohio Section Regional APS Meeting
March 27-28, 2015

Outline

- Motivation
- Femtoscopy Overview

- Detector and Dataset
- Measured Correlation Functions: $C_{lm}(k^*)$
  - $\{p,\bar{p}\}$ pairings at $\sqrt{s_{NN}}$ = 200, 39, and 19.6 GeV

Baryon and Anti-Baryon observables are dramatically different vs collision energy

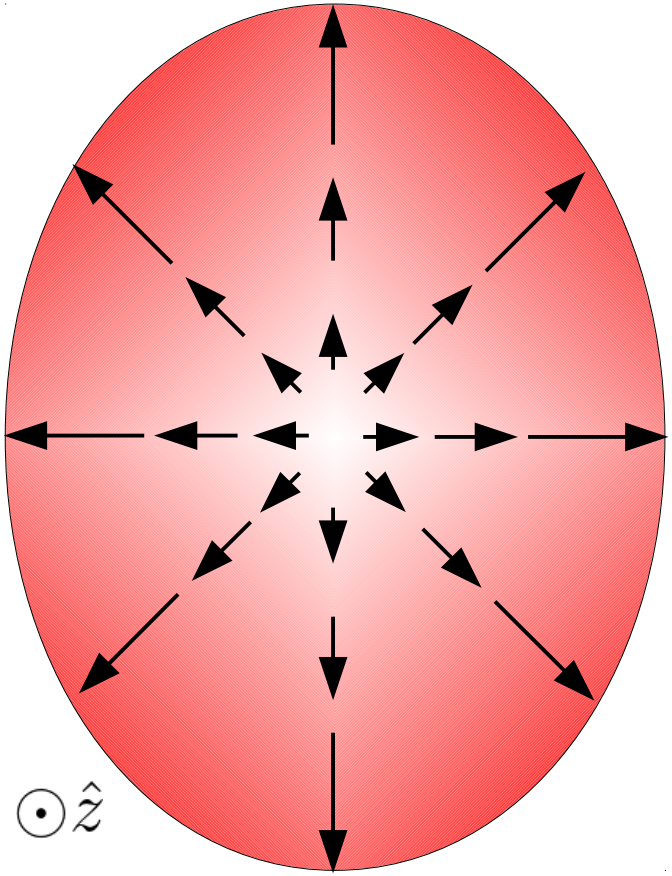


- B and $\overline{B}$ v_2 splitting is a possible sign of partonic DoF turning off
  - phase transition?
- What could Radial Flow do to the v_2 signal?

PhysRevLett.110.142301

Geometric Effects on Radial Flow

Radial Flow Field
in Semi-Central Event



- If B are emitted further out than $\bar{\mathrm{B}}$ in the transverse plane, then with radial flow:

$$v_2(\mathrm{B}) > v_2(\bar{\mathrm{B}})$$

(converse also true)

- What might affect Baryon Emission Geometry?

Do Baryons and Anti-Baryons come from different places in the source?

$$N_{\bar{\mathrm{B}}}(r) = e^{-2\mu_{\mathrm{B}}(r)/T(r)} N_{\mathrm{B}}(r)$$

Unclear: Interplay between $\mu_B(r)$ and $T(r)$

Temperature dependence stronger

- Thermal B-$\bar{B}$ production in center of collision

$$\langle r_B \rangle > \langle r_{\bar{B}} \rangle$$

Steinheimer, Koch, and Bleicher
arXiv:1207.2791

Baryon density dependence stronger

- Annihilation will wipe out $\bar{B}$ in center of source

$$\langle r_B \rangle < \langle r_{\bar{B}} \rangle$$

Heinz, Shen
Private Communication

Contradictory predictions, even in sign, for $\langle r_B \rangle - \langle r_{\bar{B}} \rangle$...

Femtoscopy Overview

- Relative Momentum Correlations between particles are sensitive to Spatial Correlations:

$$\mathcal{R}(\vec{k}^*) \equiv \mathcal{C}(\vec{k}^*) - 1 = \int \mathrm{d}^3 r^* \mathcal{S}_{\vec{k}^*}(\vec{r}^*) \left[|\phi(\vec{r}^*, \vec{k}^*)|^2 - 1 \right]$$

  - * denotes Pair Rest Frame (PRF)
  - Two-Particle Source Function $\mathcal{S}_{\vec{k}^*}(\vec{r}^*)$
  - Two-Particle Wavefunction $\phi(\vec{r}^*, \vec{k}^*)$

- Femtoscopic Measurements: $\mathcal{C}(\vec{k}^*) = \dfrac{\mathcal{N}(\vec{k}^*)}{\mathcal{D}(\vec{k}^*)}$

  - $\mathcal{N}(\vec{k}^*)$ from single events (correlations $\otimes$ phase space)
  - $\mathcal{D}(\vec{k}^*)$ from mixed events (phase space)

Non-Identical Particle Femtoscopy

- The Femtoscopic Source Function is a convolution of Single-Particle Source Functions
  - Often assumed to be a Gaussian in PRF

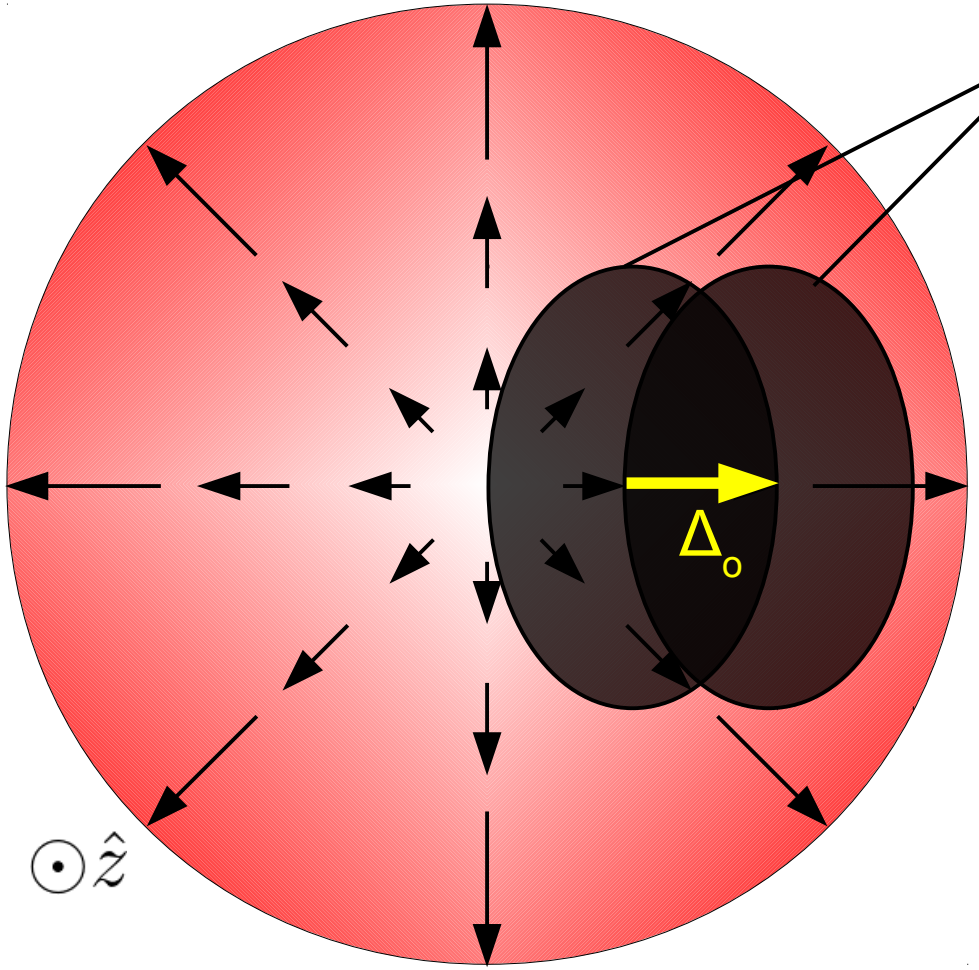
- Non-Identical Species are sensitive to the relative displacement in homogeneity regions

$$S(\vec{r}^{*}) \sim \exp\left[-\frac{(r_o^* - \Delta_o)^2}{4R_o^2} - \frac{r_s^{*2}}{4R_s^2} - \frac{r_l^{*2}}{4R_l^2} \right]$$

  - for symmetric rapidity, event plane insensitive

Non-Identical Particle Femtoscopy

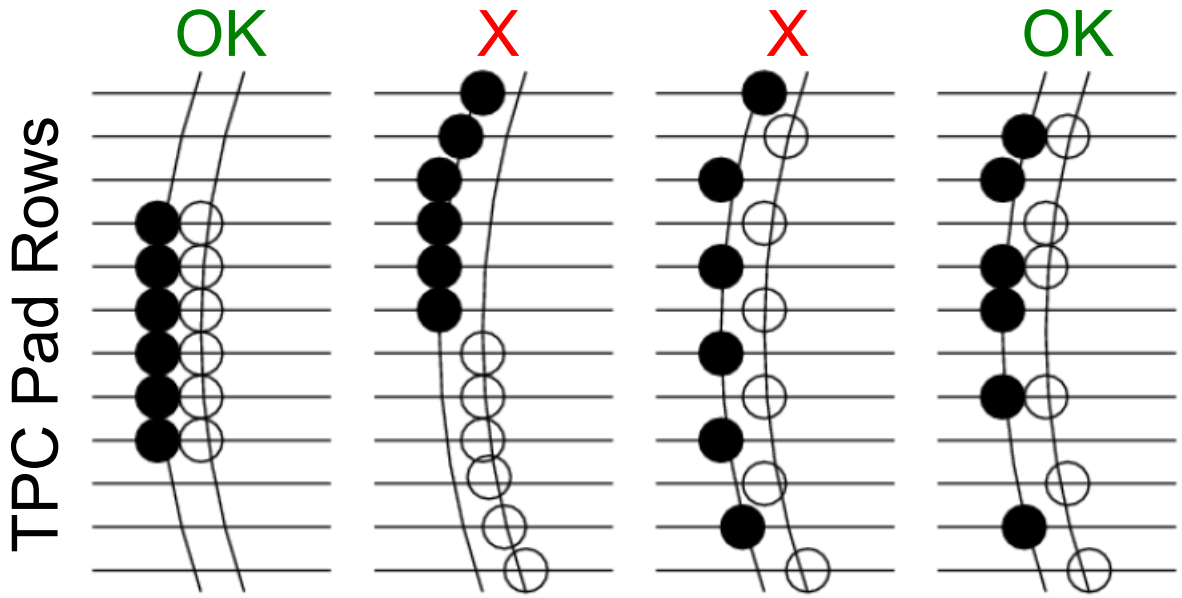
Central Collision w/ Radial Flow



- Measurable Homogeneity Regions
- Relative distributions of B and $\bar{B}$ can be measured versus $\sqrt{s_{NN}}$ via the RHIC Beam Energy Scan
  - Using p and $\bar{p}$ as proxies

Detector, Cuts, and Dataset

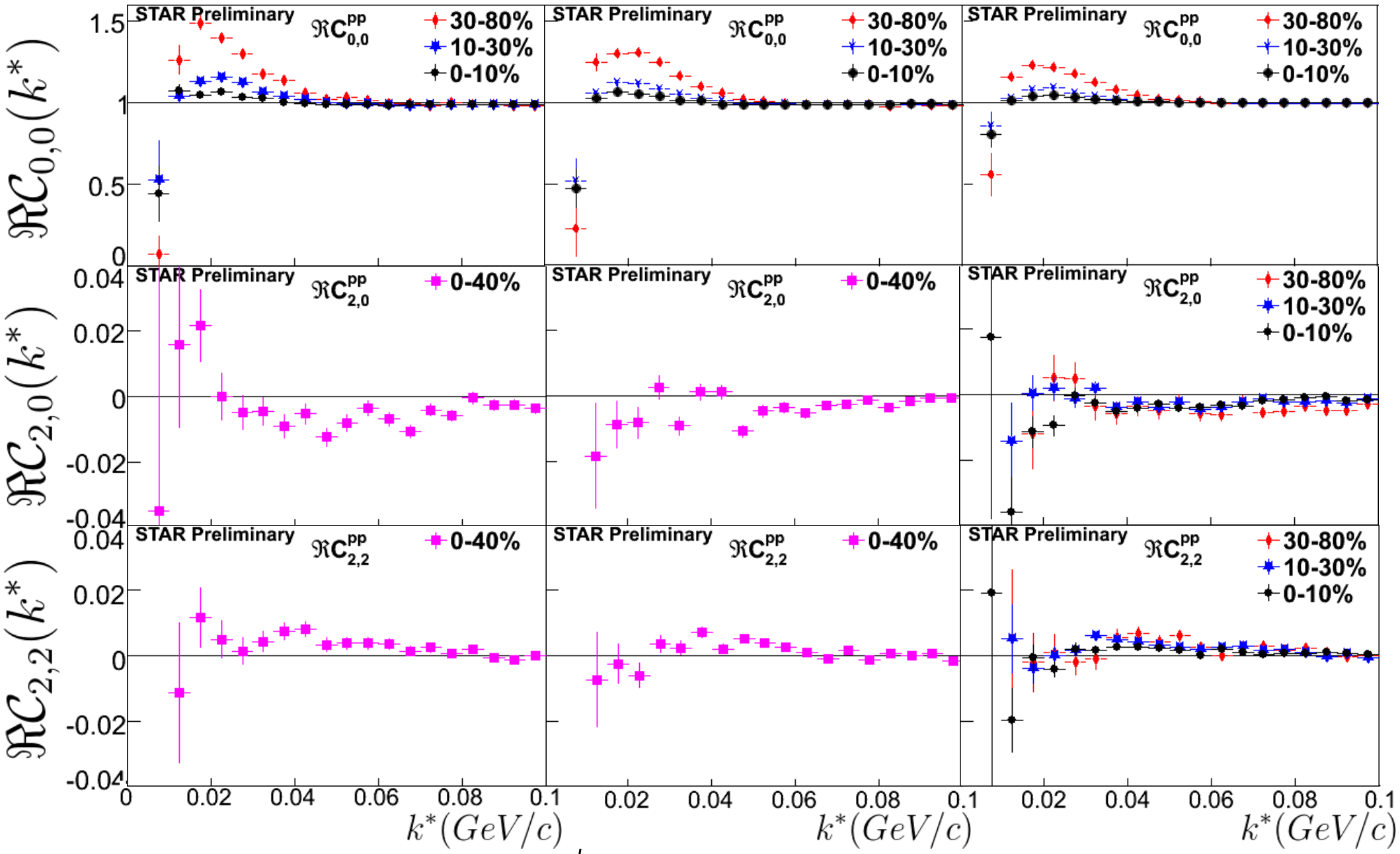
- STAR TPC + ToF
  - PID
  - Full Azimuth
  - $|\eta| < 1$
- Spalled p cut
  - $p_T > 0.4$ GeV/c
- p-$\bar{p}$ only: Anti Di-Electron Pair Cut
- Anti Splitting and Merging Pair Cuts



Phys.Rev. C71 (2005) 044906

- Beam Energy Scan: Au+Au @ $\sqrt{s_{NN}}$ = 7.7 to 200 GeV

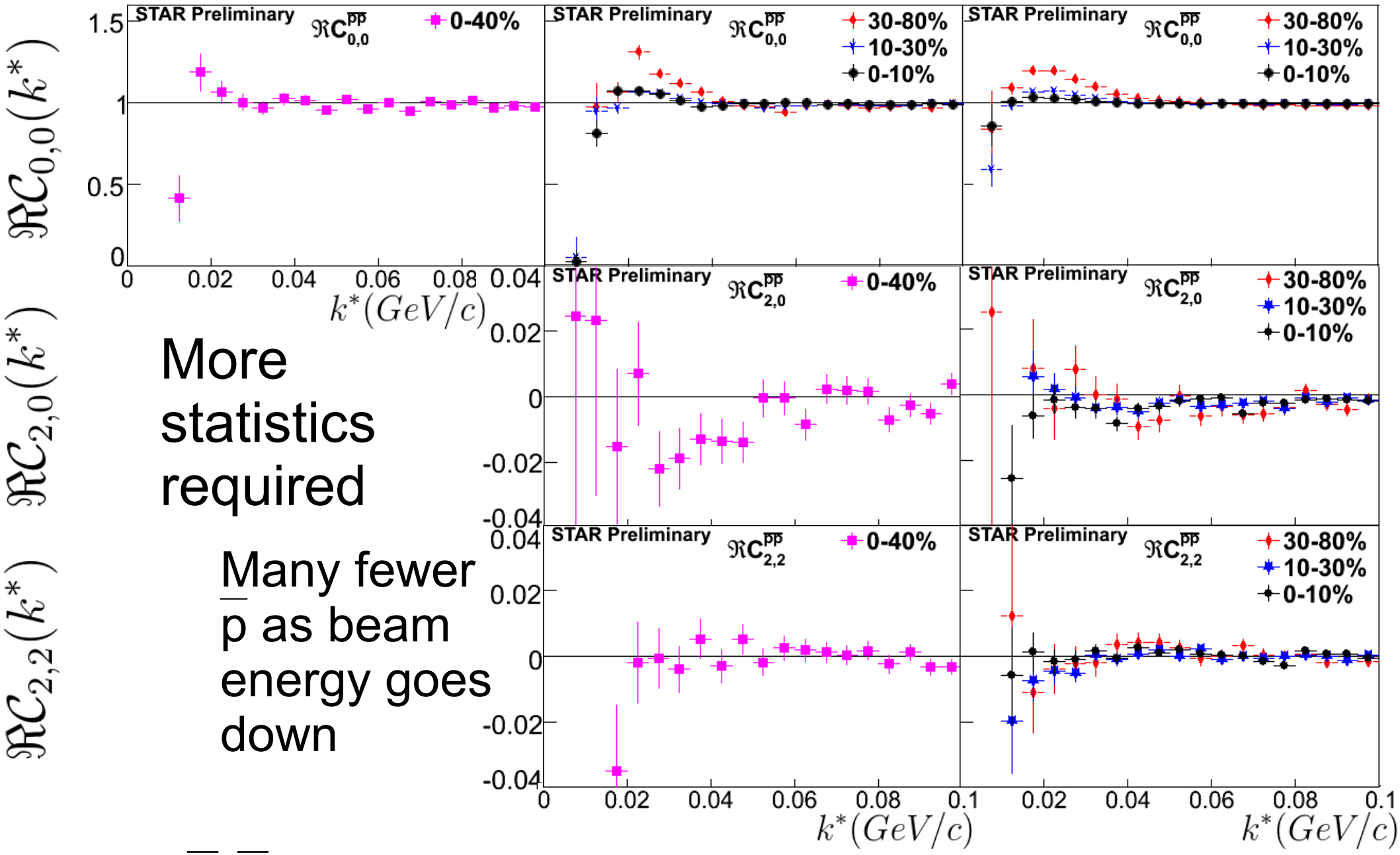
p-p 19.6 GeV 39 GeV 200 GeV



- Centrality and $\sqrt{s_{NN}}$ scaling as expected

$\bar{p}$-$\bar{p}$

19.6 GeV 39 GeV 200 GeV



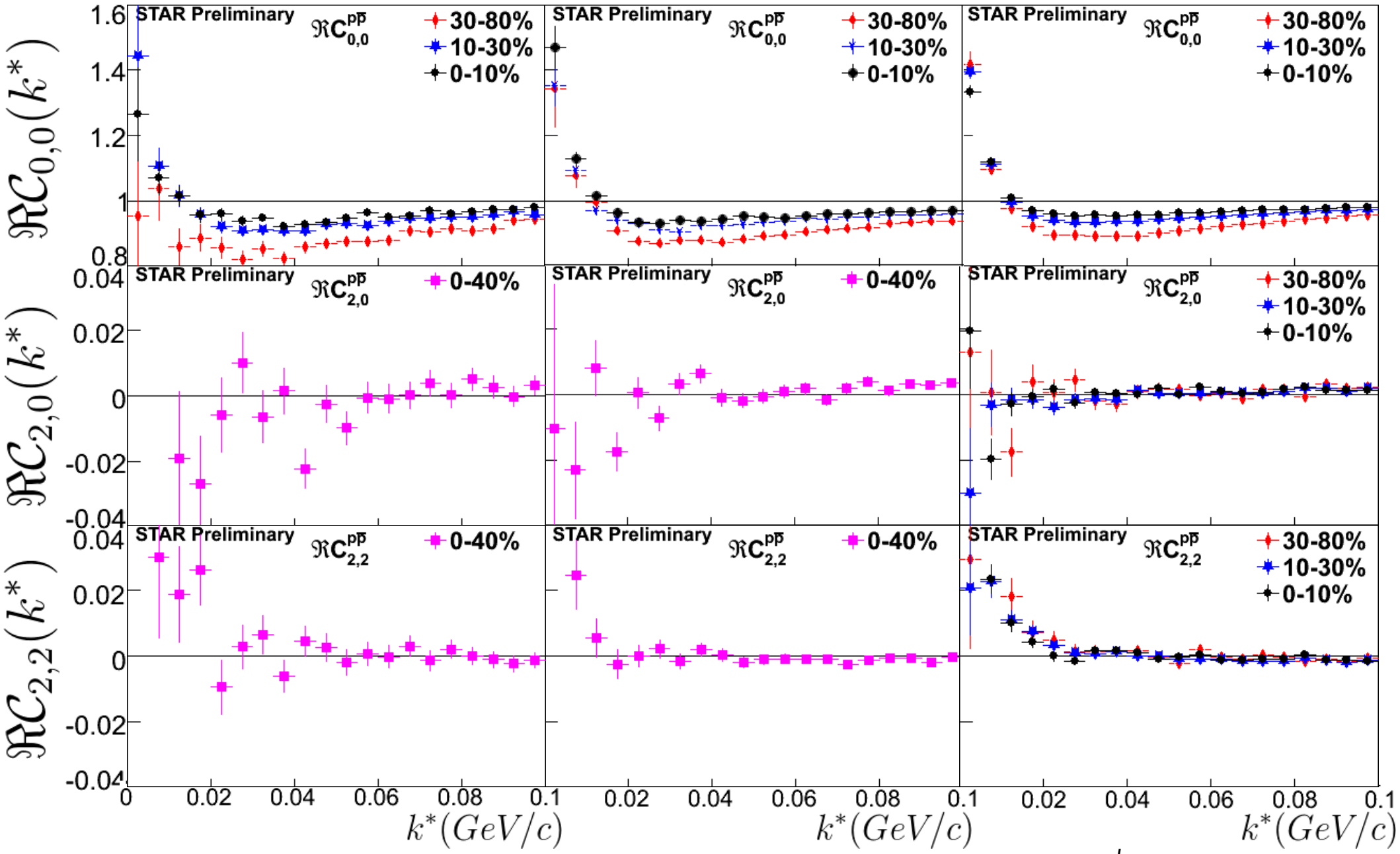
More statistics required

Many fewer $\bar{p}$ as beam energy goes down

- $\bar{p}$-$\bar{p}$ C_{lm}'s nearly identical to p-p C_{lm}'s

p-$\bar{p}$

19.6 GeV 39 GeV 200 GeV

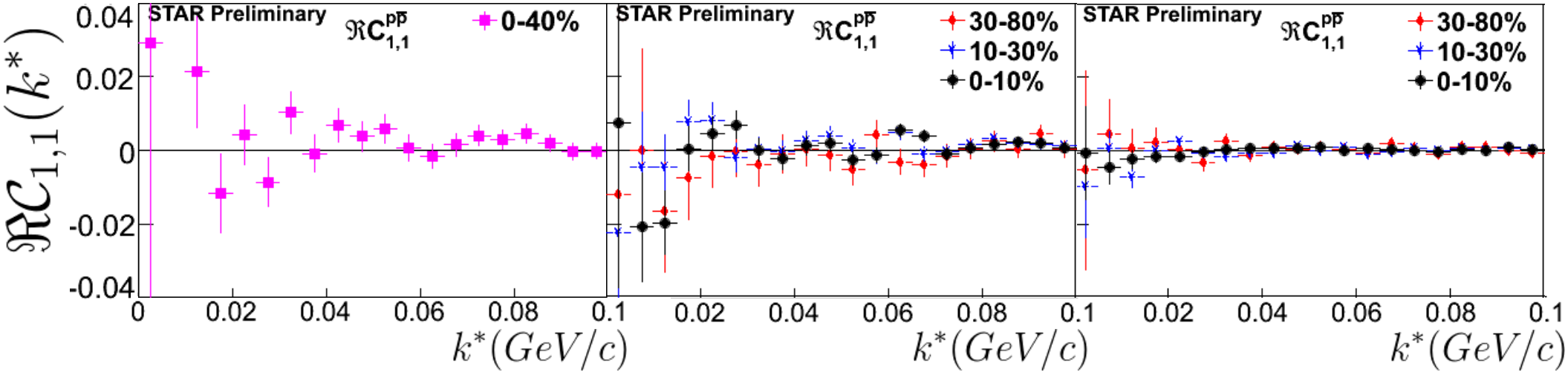


- Similar quadrupole structure across $\sqrt{s_{NN}}$

p-$\bar{p}$

Δ_o Sensitive Harmonic C_{11}

19.6 GeV 39 GeV 200 GeV



- Possible signs of non-zero Δ_o at lower energies
  - $C_{11} \neq 0$ if $\Delta_o \neq 0$
- Need more statistics at 19.6 GeV

Summary and Conclusion

- B and $\overline{B}$ Observables differ vs Collision Energy
  - B/$\overline{B}$ Emission Geometry + Radial Flow?
- Femtoscopy is sensitive to the displacement between particle homogeneity regions

- Femtoscopic Correlation Functions for p-p, p-$\overline{p}$, and $\overline{p}$-$\overline{p}$ at $\sqrt{s_{NN}}$ = 200, 39, and 19.6 GeV shown
- Small hints at non-zero Δ_o seen in p-$\overline{p}$ C_{11}!?
  - Next steps are to fit p-$\overline{p}$ C_{lm}'s for Radii and Δ_o
  - Hopeful for more 19.6 GeV data from next BES

Backup Slides

Flow Coefficients

- Flow Coefficients v_n from Spectra

$$\frac{\mathrm{d}N}{p_T \mathrm{d}p_T \mathrm{d}(\Delta\phi)} = \frac{1}{2\pi}\left[1 + 2\sum_{n\ \mathrm{even}} v_n \cos(n\Delta\phi) + 2\sum_{n\ \mathrm{odd}} v_n \sin(n\Delta\phi)\right]$$

Cuts

PID (p and $\bar{p}$)

- $|p_T| > 0.4$ GeV/c
- $|n\sigma_p| < 2$
- $|y| < 0.7$
- ToF Match
  - $0.4 < |p| < 2.5$ GeV/c
  - $0.8 < m^2 < 0.95$ $(GeV/c^2)^2$

- $Q_p = +1e$ $Q_{\bar{p}} = -1e$
- $NHits_{TPC} \geq 15$
- $DCA_{xy,global} < 2$ cm
- No ToF Match
  - $0.4 < |p| < 0.8$ GeV/c
  - $|n\sigma_e|$ & $|n\sigma_k|$ & $|n\sigma_\pi| > 2$

Pair

- $-0.5 <$ Quality Cut < 0.6
- $6 <$ Average Track Separation < 500 cm
- Fraction of Merged TPC Padrows < 10%
- p-$\bar{p}$ only: Anti Di-Electron Pair Cut