Probing the QGP to Hadron-Gas Phase Transition with Charge, Strange, and Baryon Balance Functions

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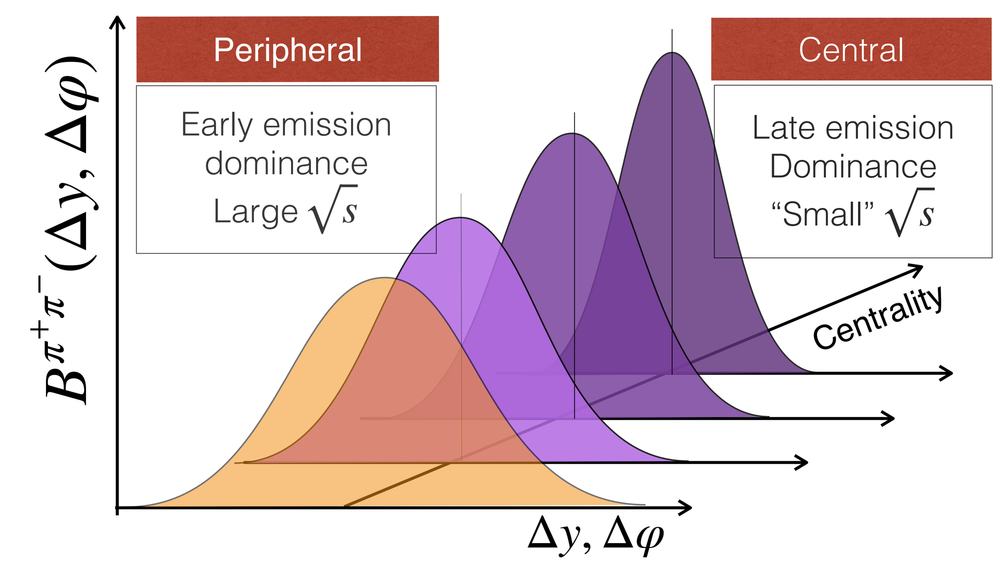


Introduction

Prior Works & Known Properties of Balance Functions (BFs)

- Investigate particle production vs. collision centrality, seek evidence for delayed hadronization/two-stage quark emission w/ π and K BFs [1, 2, 3] Sensitivity to hadron decays, radial flow [4,5], diffusivity of light quarks [6,7], chemical evolution of the hot matter formed in A–A collisions, quantum statistic effects [8],
- Related to net charge fluctuations cumulants κ_2^Q [9].

New Developments - This Work

- Account for a system's net-charge with Unified Balance Functions
- Mixed Species, Baryons and Strangeness
- Multi-particle BFs

Simulations shown performed with PYTHIA 8, pp collisions at selected collisions energies.

Unified Balance Functions [10, 11]

Original BF as Conditional Density

$$B^{+|-}(\vec{p}_1|\vec{p}_2) = \rho_2^{+|-}(\vec{p}_1|\vec{p}_2) - \rho_2^{-|-}(\vec{p}_1|\vec{p}_2) \quad \text{w/} \quad \rho_2^{\alpha|\beta}(y_1|y_2) = \frac{\rho_2^{\alpha\beta}(y_1,y_2)}{\rho_1^{\beta}(y_2)}$$

Integral of BF

$$I^{+-} = \frac{1}{\langle N_1^-\rangle}\int_\Omega d\vec{p}_2 \int_\Omega d\vec{p}_1 B^{+|-}(\vec{p}_1|\vec{p}_2) = \frac{1}{\langle N_1^-\rangle}\left[\langle N_2^{+-}\rangle - \langle N_2^{--}\rangle\right],$$

Unified Balance Functions: Defined for any combination $\alpha\,\beta$ of identified particles in an acceptance Ω.

$$B^{\alpha\bar{\beta}}(y_1,y_2|\Omega) = \frac{1}{\langle N_1^{\bar{\beta}}\rangle}\left[C_2^{\alpha\bar{\beta}}(y_1,y_2) - C_2^{\bar{\alpha}\bar{\beta}}(y_1,y_2)\right]$$

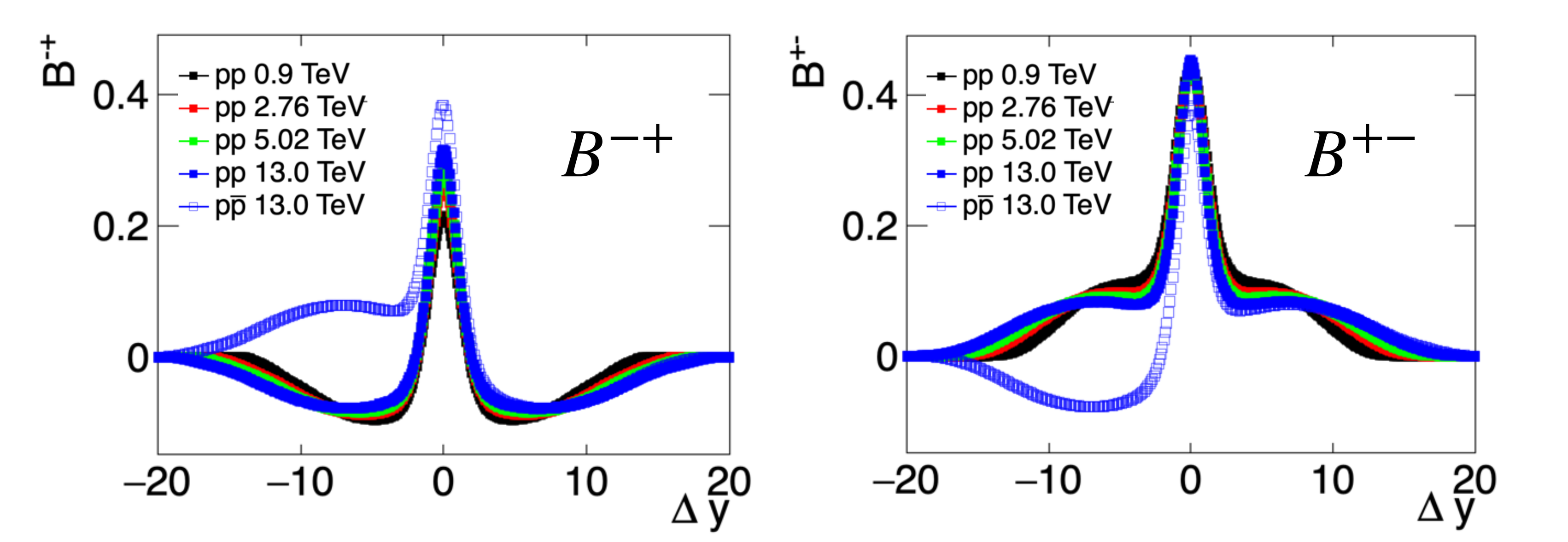
$$\text{w/} \quad C_2^{\alpha|\beta}(\vec{p}_1,\vec{p}_2) = \rho_2^{\alpha\beta}(\vec{p}_1,\vec{p}_2) - \rho_2^{\alpha\bar{\beta}}(\vec{p}_1,\vec{p}_2)$$

Use charge/strangeness densities for particles with $|q| > 1$, $|s| > 1$.

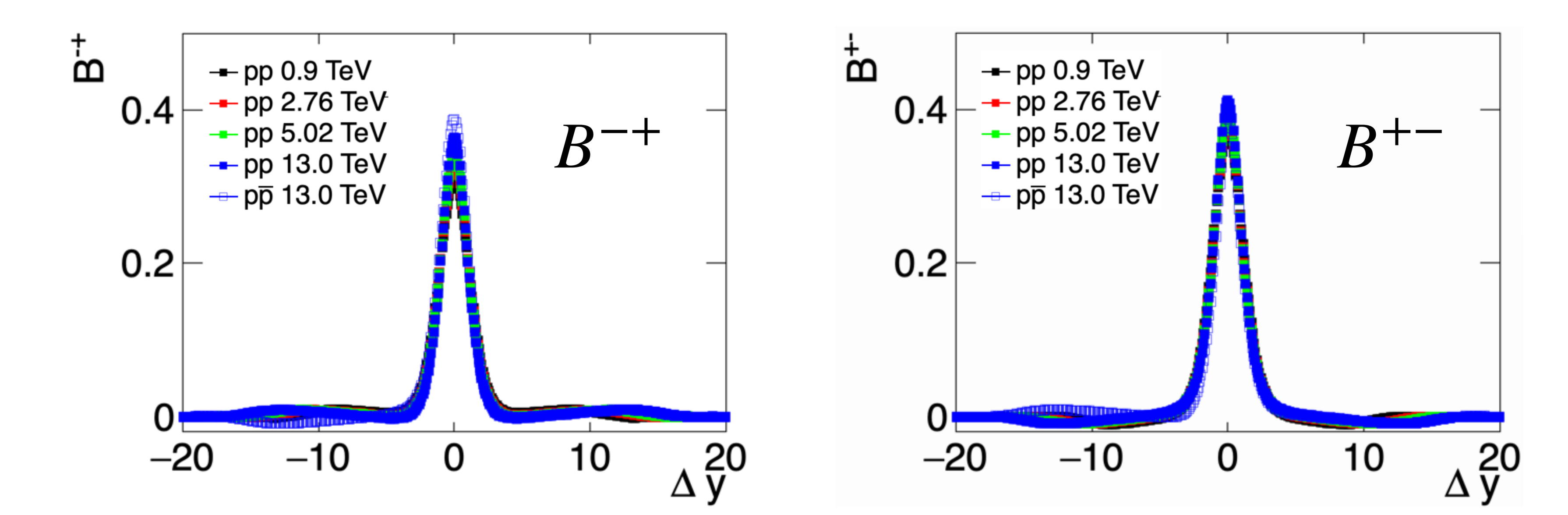
Integral of Unified Balance Functions

$$I^{+-} = \frac{1}{\langle N_1^-\rangle}\int_\Omega d\vec{p}_2 \int_\Omega d\vec{p}_1 B^{+|-}(\vec{p}_1|\vec{p}_2) = 1 \text{ for full acceptance } \Omega.$$

Original BF



Unified Balance Function



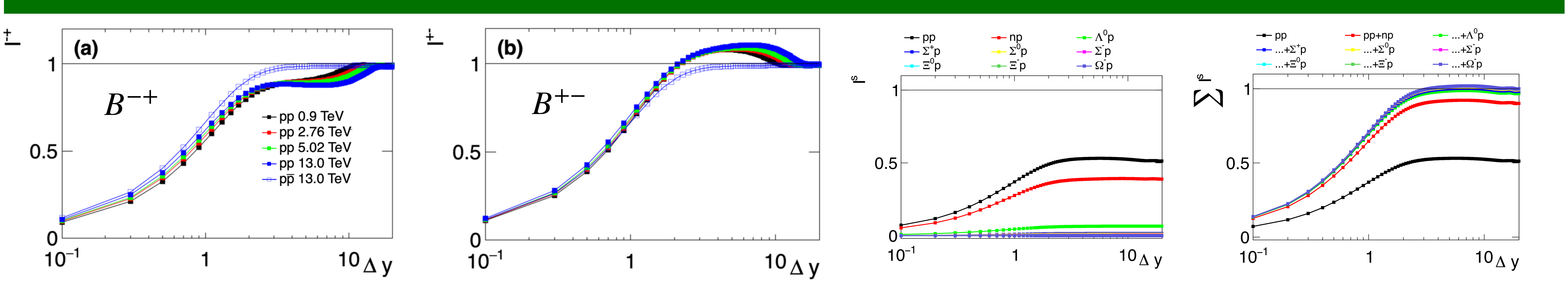
Sum Rule [10, 11]

Example: Assume a pion π^+ is detected at $\vec{p}_2$, then negative particles $\bar{\alpha}$ must also be emitted to balance the charge.

Sum rule: $B^{-|\pi^+}(\vec{p}_1|\vec{p}_2) = \sum_\alpha B^{\alpha|\pi^+}(\vec{p}_1|\vec{p}_2)$

$B^{\alpha|\pi^+}(\vec{p}_1|\vec{p}_2)$ integrates to a fraction of unity in the full acceptance. The fraction is determined by the relative abundances of specific particle production channels.

Probes details of particle production.



Multi-Particle Balance Functions [12]

Balance Functions Extended to 2n particle correlation functions based on n-particle cumulants. Example:

$$B_4^{2(+)2(-)}(\vec{p}_1,\vec{p}_2,\vec{p}_3,\vec{p}_4) = \frac{2}{4!/2!}\frac{\left[6C_4^{++--}(\vec{p}_1,\ldots,\vec{p}_4) - 4C_4^{+---}(\vec{p}_1,\ldots,\vec{p}_4) + C_4^{----}(\vec{p}_1,\ldots,\vec{p}_4)\right]}{\langle N_-(N_- - 1)\rangle}$$

These functions also satisfy sum rules.

Summary

- UBFs defined w/ cumulants, i.e., genuine measures of correlations.
- Generalized for PID, mix species, multi- strange, & charged particles.
- Generalized to multi-particle correlations as combinations of n-particle cumulants.
- Satisfy simple sum rules.
- Study vs. acceptance will enable added sensitivity to particle production, baryon stopping, measuring QGP properties.

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[1] Bass, Danielewicz, Pratt, PRL. 85, 2689 (2000).
[2] Jeon, Pratt, PRC 65, 044902 (2002).
[3] Pratt, McCormack, Ratti, PRC 92, 064905 (2015).
[4] Pruneau, Gavin, Voloshin, NP A 802, 107 (2008).
[5] Bialas, PLB 579, 31 (2004).
[6] Pratt, Plumberg, PRC 102, 044909 (2020),
[7] Pratt, Plumberg, PRC 104, 014906 (2021).
[8] Pratt, Martirosova, PCC 105, 054906 (2022)
[9] Pruneau, PRC 100, 034905 (2019).
[10] Pruneau, Gonzalez, *et al.*, PRC 107, 014902 (2023)
[11] Pruneau, Gonzalez, *et al.*, PRC 107, 054915 (2023)
[12] Pruneau, *et al.*, In preparation.