Multiplicity Fluctuations in Relativistic Heavy Ion Collisions

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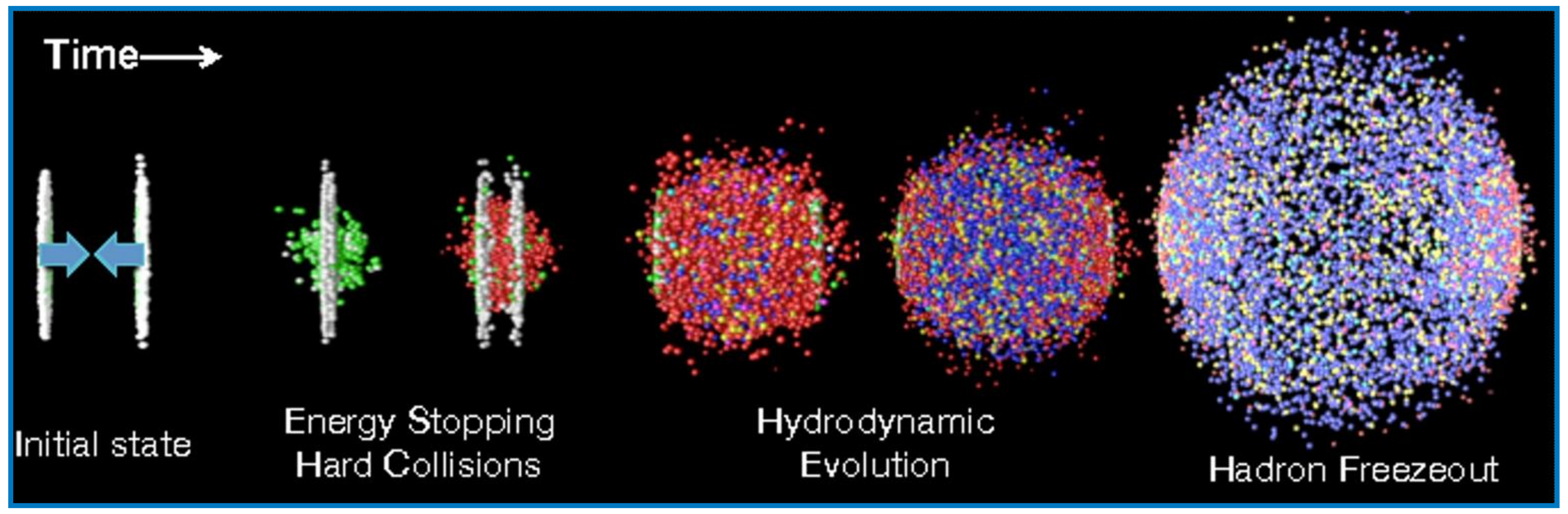
Abstract

Fluctuations in the multiplicity of particles produced in relativistic nuclear collisions influence many multi-particle correlation measurements. In each nuclear collision, the number of produced particles fluctuates because the number of particle sources fluctuates, and the number of particles emerging from each source also fluctuates. Further, we expect that jet and thermal source models of particle production should produce different fluctuation patterns. We search for a method to categorize collision events by the regions of phase space that provide the largest contribution to multiplicity fluctuations. In particular, we seek to develop a method for comparison of different collision systems including proton-proton, proton-nucleus, and nucleus- nucleus collisions.

Heavy Ion Collisions



Particle Distributions

Singles Distribution $\rho_1(\mathbf{p}) = \dfrac{dN}{d^3\mathbf{p}}$

$$\langle N\rangle = \int \rho_1(\mathbf{p})d^3\mathbf{p}$$

Pair Distribution $\rho_2(\mathbf{p}_1,\mathbf{p}_2) = \dfrac{dN}{d^3\mathbf{p}_1 d^3\mathbf{p}_2}$

$$\langle N(N-1)\rangle = \int \rho_2(\mathbf{p}_1,\mathbf{p}_2)d^3\mathbf{p}_1 d^3\mathbf{p}_2$$

Two-Particle Correlations

The Two-Particle Correlation Function

$$r(\mathbf{p}_1,\mathbf{p}_2) = \rho_2(\mathbf{p}_1,\mathbf{p}_2) - \rho_1(\mathbf{p}_1)\rho_1(\mathbf{p}_2)$$

Multiplicity Fluctuations

$$\mathcal{R} = \frac{1}{\langle N\rangle^2}\int r(\mathbf{p}_1,\mathbf{p}_2)d^3\mathbf{p}_1 d^3\mathbf{p}_2 \qquad \mathcal{R} = \frac{\langle N(N-1)\rangle - \langle N\rangle^2}{\langle N\rangle^2}$$

Related Two-Particle Correlations

See poster 313 by **Brendan Koch** about two-particle correlations and partial thermalization.

Transverse Momentum Correlations

$$\mathcal{C} = \frac{1}{\langle N\rangle^2}\int p_{T1}p_{T2}\, r(\mathbf{p}_1,\mathbf{p}_2)d^3\mathbf{p}_1 d^3\mathbf{p}_2$$

Can be used to extract estimates of shear viscosity and shear relaxation time.

Gavin, Moschelli, Zin, Phys. Rev. C94 (2016) no.2, 024921
STAR Phys.Lett.B 704 (2011) 467-473
ALICE Phys. Lett. B 804 (2020) 135375

Correlations of Transverse Momentum Fluctuations

$$\langle \delta p_{T1}\delta p_{T2}\rangle = \frac{1}{\langle N(N-1)\rangle}\int \delta p_{T1}\delta p_{T2}\, r(\mathbf{p}_1,\mathbf{p}_2)d^3\mathbf{p}_1 d^3\mathbf{p}_2$$

$$\delta p_{Ti} = p_{Ti} - \langle p_T\rangle$$

$$\langle p_T\rangle = \frac{\langle P_T\rangle}{\langle N\rangle} \qquad \langle P_T\rangle = \int p_T\, \rho_1(\mathbf{p})d^3\mathbf{p}$$

Can be used to test thermal equilibration.

Gavin, Moschelli, Zin, Phys. Rev. C95 (2017) no.6, 064901
ALICE Eur. Phys. J. C 74 (2014) 10, 3077
STAR Phys. Rev. C 99 (2019) 4, 044918

Momentum-Multiplicity Correlations

$$\mathcal{D} = \frac{1}{\langle N\rangle^2}\int \delta p_{T1}\, r(\vec{p}_1,\vec{p}_2)\, d^3p_1 d^3p_2$$

Gavin, Moschelli, and Zoulfekar Mazloum, *in preparation*, C. Zin *Ph.D. Thesis*

See poster 312 by **Mark Kocherovsky** about the influence of jets on $\mathcal{D}$.

Acknowledgements

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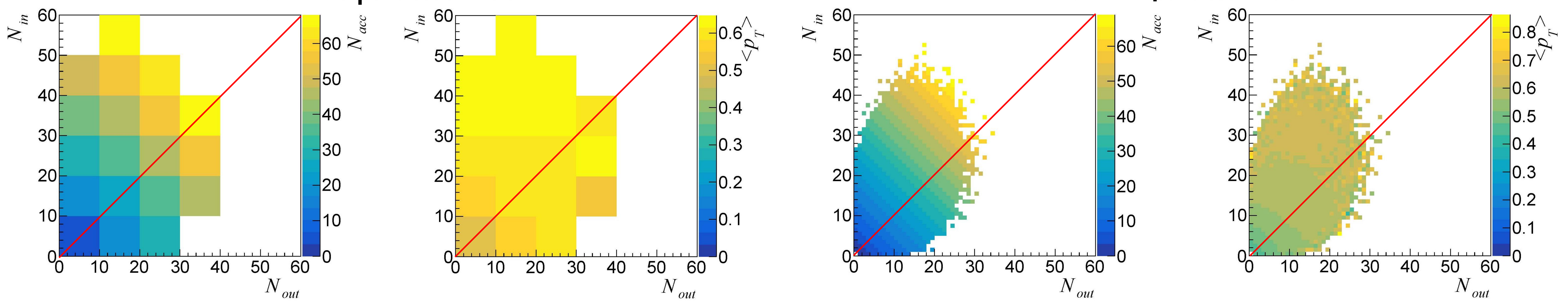
Multiplicity Fluctuations in Proton-Proton Collisions

Bin = 10 particles wide | **Bin = 1 particle wide**



$N_{in} \to |\eta| < 0.5$ $\quad N_{out} \to 0.5 < |\eta| < 0.8$

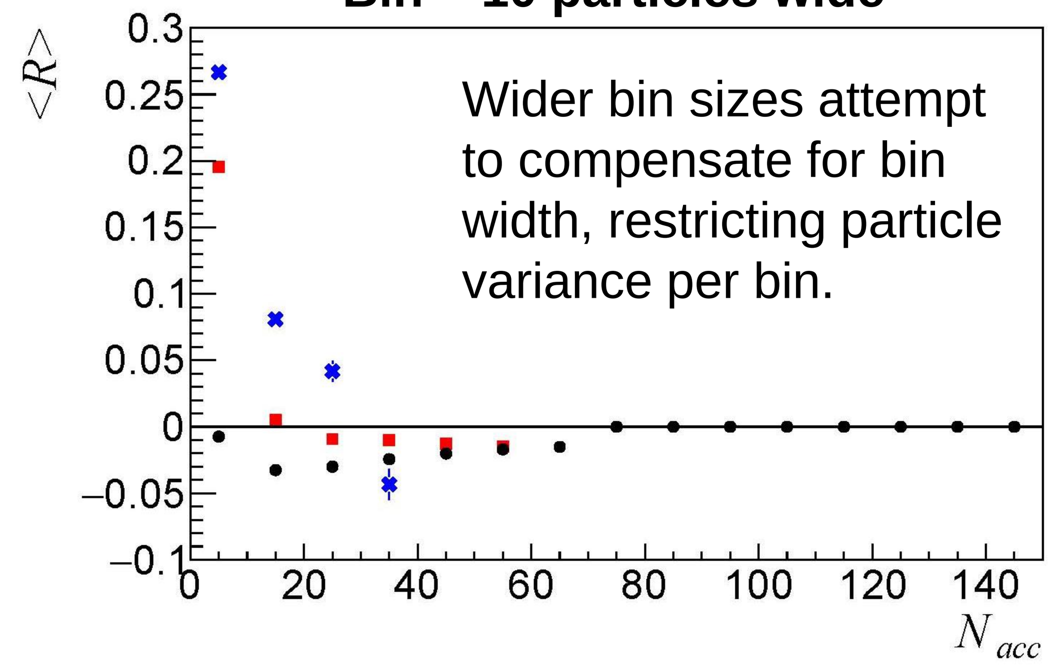
Total multiplicity and total transverse momentum are biased to the mid-rapidity region.

PYTHIA8.2, Comput. Phys.Commun. 191 (2015) 159

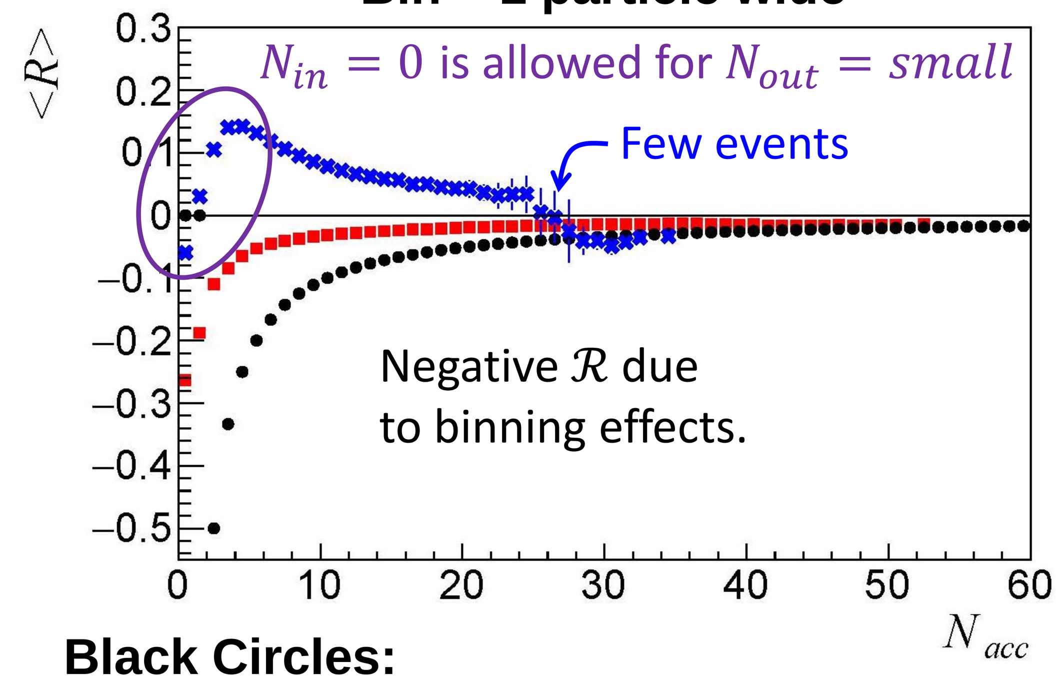
PYTHIA 8.2: pp collisions

- $\sqrt{s} = 2760\ GeV$
- $25M$ min bias events
- $21M$ separated centrality (blue cross) events
- $0.15 < p_T < 2\ GeV$
- Only charged hadrons

Bin = 10 particles wide



Bin = 1 particle wide



Error Estimates:

sub-group method

- 30 groups of 1M events
- Observables calculated in each group
- Values are averaged
- Error bars are standard deviations

$$\mathcal{R} = \frac{Var(N) - \langle N\rangle}{\langle N\rangle^2}$$

$$Var(N) = \langle N^2\rangle - \langle N\rangle^2$$

Multiplicity Binning Effects:

- All two-particle correlations are influenced by $\mathcal{R}$.
- For independent particle production $Var(N) = \langle N\rangle$ then $\mathcal{R} \to 0$
- Narrow bins force $\langle N^2\rangle \to \langle N\rangle^2$ then $\mathcal{R} \to -1/\langle N\rangle$

Black Circles:
- Centrality N_{acc} = particles in $|\eta| < 0.8$
- Calculation with particles in $|\eta| < 0.8$

Red Squares:
- Centrality N_{acc} = particles in $|\eta| < 0.5$
- Calculation with particles in $|\eta| < 0.8$
- Matches ALICE Eur. Phys. J. C 74 (2014) 10, 3077

Blue Crosses:
- Centrality N_{acc} = particles in $0.5 < |\eta| < 0.8$
- Calculation with particles in $|\eta| < 0.5$
- Similar to STAR Phys. Rev. C 99 (2019) 4, 044918