Multiplicity Fluctuations at RHIC

VI-SIM Workshop
May 19 2006

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Charged hadron multiplicities at RHIC

Charged hadron multiplicities at RHIC

- Rich p+p, p+A, A+A dataset on multiplicities
- “Scaling features” of hadron multiplicities in A+A
  - $N_{\text{part}}$ scaling (also in p+A)
  - Limiting fragmentation (also in p+p, p+A, e+e-)
  - Factorization of energy/centrality dependence
  - Universality of total multiplicity in A+A, e+e-, p+p
- Seen over wide range in energy
Global constraints on multiplicity distributions

PHOBOS PRL91,052303 (2003)

PHOBOS nucl-ex/0301017

Centrality dependence of \( \frac{dN}{d\eta} \) shape

\( N_{\text{part}} \) scaling of total \((4-\pi)\) multiplicity
Charged hadron multiplicities at RHIC

• “Global constraints” on average $dN/d\eta$
Charged hadron multiplicities at RHIC

- "Global constraints" on average $dN/d\eta$
- What is the variation of large scale structure from event to event?
- What is the local structure of hadron production?
- Study multiplicity correlations/fluctuations
Search for large scale fluctuations:
I. Multiplicity Fluctuations $\leftrightarrow$ Integral of raw $dN/d\eta$
II. Shape Fluctuation $\leftrightarrow$ $\chi^2$ of single-event $dN/d\eta$ vs average
“Unusual” Events in Au+Au?

**Total Multiplicity Fluctuations**

- Graph showing frequency of events vs. total number of hits for Au+Au 200 GeV and 2M MinBias events.
- 2M 3% central (scaled).

**Shape Fluctuations**

- Graph showing frequency of events vs. $\chi^2$ for Au+Au 200 GeV 0-3% Central events.

**Other Graphs**

- Graph showing fraction of strange events vs. product of beam currents for Au+Au 200 GeV 3% central events.
- Graph showing fraction of strange events vs. product of beam currents for events with unusual shape $\chi^2 > 3$.
Understanding the width of multiplicity distributions

Variance of multiplicity distribution

$\leftrightarrow$

Variance of $N_{\text{part}}$ distribution

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Centrality determination and fluctuations

Recipe

(a) or (b): Select fractional x-section in ‘multiplicity’ $N$

(c) Use MC to translate x-section bin in $N$ to x-section in $N_{\text{part}}$

(d) Find $<N_{\text{part}}>$ and $\sigma(N_{\text{part}})$ for each x-section bin

Requires knowledge of
* trigger efficiency
* fluctuations/resolution in $N$
Fluctuations and centrality cuts

Hijing + Geant

Large variation in $N_{\text{part}}$ even for very fine (3%) x-section bins: 6%

(compare to Poisson multiplicity fluctuations ~ few %)

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Normalized variance vs. participants

Deviation from Poisson
No charge dependence
Forward/backward multiplicity correlations

Particles produced independently:
\[ \sigma^2_C = 1 \]

Particles produced in clusters of size \( K \):

\[ C \rightarrow \sqrt{K} C \]
\[ \sigma^2_C \rightarrow K \sigma^2_C \]

Use variance \( \sigma^2_C \)

* Removes participant fluctuations
* Works for asymmetric bins
Forward/backward multiplicity correlations

Particles produced independently:
\[ \sigma^2_C = 1 \]

Particles produced in clusters of size \( K \):
\[ C \rightarrow \sqrt{K} C \]
\[ \sigma^2_C \rightarrow K \sigma^2_C \]

effective cluster size \( \approx 2 - 2.5 \) for 200 GeV Au+Au
Clusters in p+p

Clusters in Au+Au reminiscent of results from p+\bar{p}


\bar{p} + p  \quad 546 \text{ GeV}
Forward/backward multiplicity correlations

"Clusters" in A+A (and p+p) collisions

PHIOBOS QM'05

"Cluster" in $\Delta\eta, \Delta\phi$ space via 2–particle correlations (pythia p+p @200 GeV, $\eta<3$)

effective cluster size $\approx$ 2-2.5 for 200 GeV Au+Au
“Cluster” in $\Delta \eta, \Delta \phi$ space via 2–particle correlations (PHOBOS $p+p$ @200 GeV, $\eta<3$)

“Cluster” in $\Delta \eta, \Delta \phi$ space via 2–particle correlations (pythia $p+p$ @200 GeV, $\eta<3$)
Connection between $\sigma^2_c$ and K

“Conjecture”

MC p+p $\Delta \eta, \Delta \phi$ correlations $\sim$ p+p $\Delta \eta, \Delta \phi$ correlations

MC $\sigma^2_c$ systematics $\sim$ Au+Au $\sigma^2_c$ systematics

$\Rightarrow$ clusters in Au+Au $\sim$ clusters in p+p
p+p clusters vs $\sqrt{s}$

Origin of p+p clusters?

* Resonances?
* String fragmentation?
* (mini-) Jets?
Correlation length in Au+Au

Au+Au 200 GeV, no magnetic field
\( \Delta \eta < 0.7, \Delta \Phi < \pi/2 \) rad

• Fitting Range
  Blue: \( \delta \eta \leq 0.35 \)
  Red: \( \delta \eta \geq 0.35 \)
• Centrality
  filled circle: 0-70 % (10% interval)
  open circle: 5-65 % (10% interval)

“Different behaviors about the extracted correlation length (\( \xi \)) as a function of number of participants are observed in the different range of the pseudo rapidity gap. The correlation length at the range of large pseudo rapidity gap has a large fluctuation.”

K. Homma and T. Nakamura (QM’05)
Angular correlations in A+A

Cu+Cu MC w/ $v_2$ and $v_1$

Much richer phenomenology in A+A
* study vs $\eta$, $\sqrt{s}$, species, centrality
Angular charge correlations

STAR
200 GeV p+p

Like sign

2-D angular correlation function

Unlike sign

Pythia, 200 GeV p+p, all p_T, all charges

Split sample

2-D angular correlation function
Angular charge correlations

STAR 200 GeV p+p

Like sign

Unlike sign

Subtract

longitudinal charge ordering

gaussian
flat

“Charge Dependent (CD)” correlations
Charge Dependent Correlations

Difference of like-sign and unlike-sign 2-particle correlations:
Charge Dependent Correlations

Difference of like-sign and unlike-sign 2-particle correlations:

Evolution of “cluster” properties/charge correlations

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Summary

- Studies of multiplicity fluctuations and correlations are emerging at RHIC
- Dominated by local correlations structures ("clusters")
- Similarities to pp
  - Cluster-size, correlation length
- Evolution from pp to AA
  - 1D to 2D charge ordering
- Much more to come in AA
Excitation Function: Momentum Spectra

Compilation by NA49
Plot from Claudia Hoehne, QM’05

- Structure in energy dependence of \(<mT>\)
- Reminiscent of Van Hove’s \(T \text{ vs } \varepsilon\) prediction (1982)
- Surprisingly difficult measurement
  - Decay corrections, PID acceptance
Excitation Function: Momentum Fluctuations

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Compilation by STAR
STAR PRC 72 044902 (2005)
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Monotonic energy dependence over measured range
No results near “step” region
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Results from STAR

STAR PRC 68 (2003)

Acceptance: $\Delta y \approx 2$, $\Delta \Phi = 2\pi$

Fluctuations agree with stochastic distributions of **Hadrons**

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Excitation Function: Charge Fluctuations

Plot from Claude Pruneau
RHIC Users meeting workshop ’04
PHENIX: PRL 89 082301 (2002)

NA49, PRC 70 064903 (2004)

Little (no) \( \sqrt{s} \) dependence of charge fluctuations
What have we learned from Charge fluctuations?

Net charge fluctuations
large (~ hadron gas)
Small/no $\sqrt{s}$ dependence

DoF of Medium?

Quark coalescence?
Property of Hadronization?
Diffusion?
Bound states?
Measuring global charge fluctuations

"Clustersize" $\Delta y \approx 2$

Acc. $\approx$ Clustersize $\approx$ Rapidity gap

Acc. $\approx$ Clustersize $<$ Rapidity gap

Acc. $>\text{Clustersize} \ll \text{Rapidity gap}$

SPS

RHIC

LHC

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Extraction of two particle correlation

Normalized correlation function

\[ R_2(y_1, y_2) = \frac{C_2(y_1, y_2)}{\rho_1(y_1) \rho_1(y_2)} = \frac{\rho_2(y_1, y_2)}{\rho_1(y_1) \rho_1(y_2)} \]

- inclusive single particle density
- inclusive two-particle density
- two-particle correlation function

Relation with NBD \( k \)

\[ \frac{1}{k(\delta \eta)} = F_2 - 1 = K_2 = \int_{\delta \eta}^{\eta} C_2(y_1, y_2) dy_1 dy_2 \]
\[ \int_{\delta \eta}^{\eta} \rho_1(y_1) \rho_1(y_2) dy_1 dy_2 \]

Used in E802 : PRC, 44 (1991) 1629

\[ R_2 = R_0 e^{-|y_1 - y_2|/\xi} \quad : \quad \frac{1}{k(\delta \eta)} = F_2 - 1 = \frac{2R_0\xi^2 [\delta \eta / \xi - 1 + e^{-\delta \eta / \xi}]}{\delta \eta^2} \]

Two component model

\[ R_2 = e^{-|y_1 - y_2|/\xi} + b \quad : \quad \frac{1}{k(\delta \eta)} = F_2 - 1 = \frac{2\xi^2 [\delta \eta / \xi - 1 + e^{-\delta \eta / \xi}]}{\delta \eta^2} + \frac{b}{2} \]

\( \xi \): Two particle correlation length

\( b \): Strength of long range correlation
What have we learned from Charge fluctuations?

Net charge fluctuations:
- Large (~ hadron gas)
- Small/no $\sqrt{s}$ dependence

DoF of Medium?

How are hadrons made?
- Quark coalescence?
- Property of Hadronization?
- Diffusion?
- Bound states?
Net Charge Fluctuations and the QGP


• Net Charge/$\Delta y$ Fluctuations $\Leftrightarrow$ Charge/DoF
  – Fluc’s change from 1-2 (QGP) to 4 (Pion Gas)
• Fluctuations frozen b/c charge conservation
  – Diffusion vs Expansion timescale

Note:
* Similar for net baryon number
* Connection to quark number susceptibilities
* Connection to Critical point
Charge Dependent Correlations

Centrality evolution in Au+Au

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