Fluctuations and correlations
Summary QM2004

Harald Appelshäuser, GSI Darmstadt
Mean $p_t$ fluctuations

G. Westfall (STAR)

Now we need a measure....

H. Appelshäuser, QM2004 Oakland
A good measure should be:

- Independent of particular experiment
- Comparable to theory
- Corrected for detector effects (e.g. 2-track resolution)
- Not corrected for "known physics effects" (e.g. HBT, flow, superposition of independent sources etc.)
What we have:

\[ F_{pT} \approx \frac{\Phi_{pT}}{\sigma_{pT, incl.}} \]

\[
\sigma_{pT, dyn}^2 = \frac{2 \Phi_{pT} \sqrt{\Delta p_T^2}}{\langle N \rangle} \\
\Delta p_T^2 = p_T^2 - \frac{2 F_{pT}}{\langle N \rangle} \\
\Delta \sigma_{pT, n} \approx \sqrt{(\Phi_{pT} + \sigma_{pT, incl.})^2 - \sigma_{pT, incl.}^2} \\
\sum_{pT} = \frac{\sigma_{pT}}{p_T} \sqrt{\frac{2 F_{pT}}{\langle N \rangle}} \\
\Sigma_{pT} = \text{sgn}(\sigma_{pT, dyn}) \sqrt{\frac{\sigma_{pT, dyn}^2}{\overline{p_T}}} \\
\Delta \sigma_{pT, n}
\]

J. Mitchell (Plenary)

H. Appelshäuser, QM2004 Oakland
The critical point of QCD

...should show up as a peak in the excitation function (Stephanov, Rajagopal, Shuryak)

H. Sako (CERES)

• No indication for the critical point so far

• Scan between SPS and RHIC

• 20 and 30 GeV/c from NA49

• GSI SIS 300

H. Appelshäuser, QM2004 Oakland
Centrality dependence

G. Westfall & Poster by C. Pruneau

H. Sako

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Centrality dependence

G. Westfall (STAR)

Acceptance matters!

Fluctuation signal is scale dependent

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Scale dependence of $p_t$ correlations

D. Prindle (STAR) Poster

Medium response to minijets?

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Centrality dependence

Traces of thermalization?

S. Gavin

Larger centrality =
Longer lifetime =
Smaller survival probability $S$

$$\langle p_t \rangle = \langle p_t \rangle_0 S + \langle p_t \rangle_e (1-S)$$

$$\langle \delta p_{t1} \delta p_{t2} \rangle = \langle \delta p_{t1} \delta p_{t2} \rangle_0 S^2 + \langle \delta p_{t1} \delta p_{t2} \rangle_e (1-S^2)$$

Deviation in central events due to jets?

Thermalized partons or hadrons?

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Centrality dependence

M. Tannenbaum, J. Mitchell (PHENIX):
This is not flow, these are jets!
Phenomenological, PYTHIA-based model gives good description
What happens to the quenched jets?

H. Appelshäuser, QM2004 Oakland
Other explanations

E. Ferreira, Poster

Data: PHENIX

\[ \langle p_t \rangle \text{ fluctuations by string percolation} \]

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Other explanations

H. Sako (CERES):
Comparison to cascade models

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Charge fluctuations

Charges are more evenly distributed in a QGP

Strongly reduced net charge fluctuations in a small region of phase space

This has not been observed!

Charge (and multiplicity) fluctuations may give insight to the particle production mechanism, thermalization etc.

Charge fluctuations (NA49, CERES, STAR)
Balance functions (NA49, STAR)
Multiplicity fluctuations (NA49, Phobos)

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Charge fluctuations

\[ \nu_{\text{dyn}} \equiv \left( \frac{N_+}{\langle N_+ \rangle} - \frac{N_-}{\langle N_- \rangle} \right)^2 - \left( \frac{1}{\langle N_+ \rangle} + \frac{1}{\langle N_- \rangle} \right) \]

H. Sako (CERES)

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Charge fluctuations

S. Gavin

Common thermal explanation for $p_t$ and charge fluctuations

H. Appelshäuser, QM2004 Oakland
Charge fluctuations

50-70% centrality  S. Westfall (STAR)  0-10% centrality

Consistent with narrowing of balance function:

\[ B(Y|Y) = -\langle N \rangle \nu_{\text{dyn}}/4 \]

Pruneau, Gavin, Voloshin

Consistent with late hadronization plus flow

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Multiplicity fluctuations

K. Wozniak (PHOBOS)

\[ C = \frac{N_1 - N_2}{\sqrt{N_1 + N_2}} \]

For statistical fluctuations
\[ \sigma^2(C) = 1 \]
Independent of multiplicity

Data consistent with Hijing+Geant
Hijing consistent with cluster model k=2 and correlation width \( \Delta \eta = 1 \)
Consistent with STAR nucl-ex/0307007

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Multiplicity fluctuations

158 AGeV/c Pb-Pb

NA49, Poster K. Perl, M. Rybczynski

\[ V(n_) = \langle n_\cdot^2 \rangle - \langle n_\cdot \rangle^2 \]

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Particle ratio fluctuations

Christof Roland (NA49)
Pb-Pb 20, 30, 40, 80, 158 AGeV/c

$\frac{K^+ + K^-}{\pi^+ + \pi^-}$ fluctuations increase towards lower beam energy (new horn?)

$p/\pi$ fluctuations explained by resonance decays

We want more!

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Non-identical particle correlations

A. Kisiel (STAR):
\[ \pi p \text{ in } 130 \text{ GeV } \text{Au-Au} \]
\[ \pi p, \pi K, pK \text{ in } 200 \text{ GeV Au-Au} \]

Significant asymmetry observed

Particles are not emitted from the same space-time region

Consistent with strong x-p-correlations

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More to come...

$\rho\Lambda$

STAR preliminary

$\pi^\pm\Xi$

STAR preliminary

$\rho\Lambda$

STAR Preliminary

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A. Kisiel (STAR)
π HBT: Energy scan at SPS

Pb-Pb central (S. Kniege, NA49)

...from midrapidity to (near) beam rapidity

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$R_{\text{out}}/R_{\text{side}}$ at SPS

S. Kniege, NA49

CERES, NPA714 (2003)

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Coulomb

Purity...
• Purity of pion sample has to be taken into account!

• Partial Coulomb correction adapted by all experiments

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'New' Coulomb treatment affects mainly $R_{out}$ (and $R_{out}/R_{side}$)

200 GeV Au-Au central
(M. Heffner, PHENIX)

H. Appelshäuser, QM2004 Oakland
π HBT at 200 GeV

STAR 200 GeV, S. Bekele, T. Gutierrez

Results consistent so far, needs detailed checks...

H. Appelshäuser, QM2004 Oakland
Azimuthal HBT

Measure HBT-Radii relative to the reaction plane in non-central collisions:

U. Wiedemann a.m.m.

• out-side cross-term
• characteristic oscillations

Heinz, Kolb PLB 542 (2002)

→ spatial anisotropy of the pion source at freeze-out!

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Azimuthal HBT

D. Magestro (STAR)

Source eccentricity:
\[ \varepsilon_{\text{initial}} \equiv \frac{(R_y^2 - R_x^2)}{(R_y^2 + R_x^2)} \]
\[ \varepsilon_{\text{final}} \approx 2R_{s,2}^2 / R_{s,0}^2 \]

...source retains initial orientation!

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Consistency check of lifetime

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**Midcentral (10%-20%)**

-0.05
-0.025
0
0.025
0.05
0.075
0.1
0.125
0.15
0.2

**M. Lisa (ISMD2003)**

Freeze-out eccentricity confirms short lifetime (e.g. from \( R_{\text{long}} \))

HBT parameters are internally consistent

**H. Appelshäuser, QM2004 Oakland**
HBT in pp

Poster M. Gutierrez (STAR)

Results are much smaller than in Au-Au!

$K_t$ dependence is very similar!

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System size dependence

STAR preliminary

• Presumably very different dynamics in p-p and Au-Au
• But the HBT radii look qualitatively the same

Do we believe in coincidences?

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System size dependence

M. Heffner (PHENIX) Au-Au 200 GeV

All radii scale with $N_{\text{part}}^{1/3}$

Consistent with freeze-out at constant density

Not new, but centrality (system size) dependence was never really challenged!

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Universal Pion freeze-out

Mean free path at freeze-out:

\[ \lambda_f = \frac{1}{\rho \cdot \sigma} = \frac{V_f}{\sum_i N_i \cdot \sigma_{\pi,i}} \approx 1 \text{ fm} \]

D. Magestro (STAR)

also in small systems!

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Universal Pion freeze-out

Freeze-out at constant mean free path is counter-intuitive if late stage is dominated by hadronic rescattering: size dependence expected!

In p-p: \( \lambda_f \approx R_{geo} \)

In Au-Au: \( \lambda_f << R_{HBT} < R_{geo} \)

Flow in Au-Au may lead to local freeze-out

But why does it exactly compensate?

Do we believe in coincidences (II)?

CERES (Pb+Au)
NA35 (S+S)
NA49 (p+p)

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New old HBT puzzle

pp and Au-Au data look qualitatively and quantitatively the same (needs confirmation)

Models: Non-trivial dynamics must lead to trivial freeze-out

Study system size dependence
Balance function width

158 AGeV/c

P. Christakoglou (Poster) NA49  G. Westfall (STAR) 200 GeV Au-Au

H. Appelshäuser, QM2004 Oakland
Balance functions

\[ B(\Delta y) = \frac{1}{2} \left\{ \frac{N_{+-}(\Delta y) - N_{++}(\Delta y)}{N_+} + \frac{N_{-+}(\Delta y) - N_{--}(\Delta y)}{N_-} \right\} \]

158 AGeV/c

P. Christakoglou (Poster) NA49

G. Westfall (STAR) 200 GeV Au-Au

H. Appelshäuser, QM2004 Oakland