# Questions on Charged Particle Ratio Fluctuations?

Jamie Nagle, March 31, 2004

I have been trying to understand the theory behind the charged particle ratio fluctuations (Jeon, Koch, hep-ph/0003168) and had a few questions on how to interpret the experimental results from PHENIX (PRL 89, 082301 (2002)).

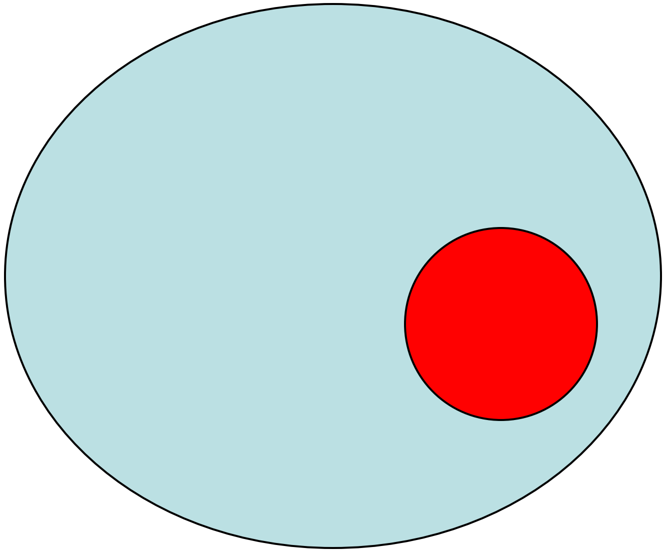
The paper details that one can use the Grand Canonical Ensemble if one assumes thermal equilibrium and that one is only measuring a sub-sample of the entire volume. This assumption seems reasonable, and that the total charge conservation effect is then expected to be relatively small for the PHENIX acceptance.

To Jeon/Koch, uou refer to more details on this in reference 7 (upcoming manuscript). Is this available?

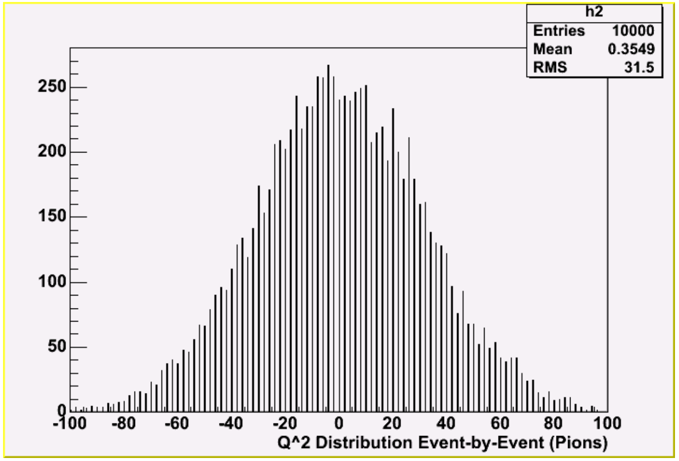
Also you refer to the Bjorken (PRD 27, 140 (1983)) paper to justify entropy conservation. However, now that the RHIC data clearly show that there is no boost invariance, do you have a different justification for entropy conservation?

If there were a gas of just pions, and one randomly picked out 1000 charged pions per event, one would expect just the Poisson statistics result.
In fact, in this case it does not matter at all if the pions that are measured in the detector acceptance all originate from an isolated spatial region (red dot) or are a random sample selected from the entire spatial volume.

$$D = 4 \langle \delta Q^2 \rangle / \langle N_{ch} \rangle$$



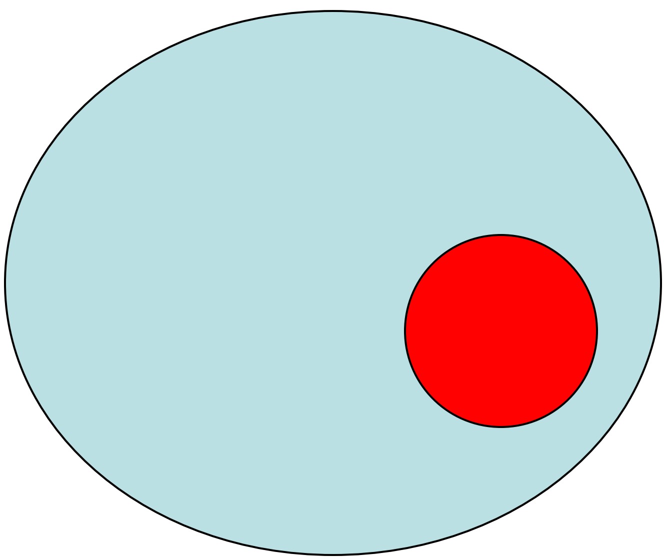
$$D = 4 * (31.5*31.5)/1000 = 3.97$$




The experimental results from PHENIX are close to this limit from the 130 GeV data and nearly indepedent of centrality.

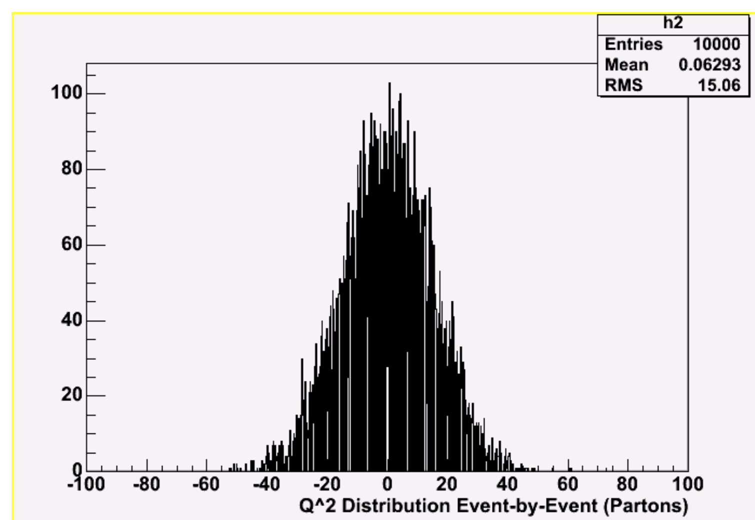
If the system were composed of light quarks and gluons in thermal equilibrium, we would expect a gas of up, anti-up, down, anti-down quarks and gluons. For simplicity I used a ratio of 6:6:6:6:16, based on 3 colors and 2 spins for quarks and 8 colors and 2 spins for gluons.

If I had a volume composed of these objects in thermal equilibrium, and randomly selected 1500 of these objects, the charged particle ratio fluctuations are quite different. According to your entropy equation (20 and 21), these 1500 objects would result in 1000 charged pions.



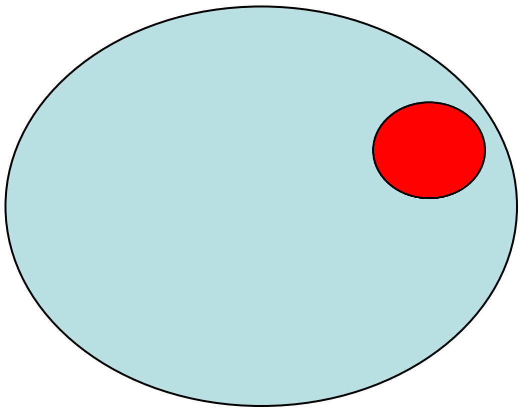
$$D = 4 \langle \delta Q^2 \rangle / \langle N_{ch} \rangle$$

$$D = 4 * (15.1*15.1)/1000 = 0.91$$

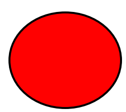



This is the factor of 4 or 80% reduction mentioned in the theory and PHENIX paper from QGP expectations.

So, I was able to reproduce these simple numerical results (good exercise for experimentalists). Now come the questions.



Imagine that my detector perfectly samples all of the particles from the red region. If the red region is exchanging quarks and gluons with the larger volume, then the Grand Canonical Ensemble is reasonable.



At some time, we hypothesize that the red region very quickly decouples from the remaining volume. At this point, the net electric charge of the red region is fixed by the number of quarks and anti-quarks that had fluctuated into the region.

If my detector measures only particles from the red region, it doesn’t even really matter if entropy is not conserved, the net charge of that region in this event cannot change. However, the entropy conservation and your equation (19 and 20) for entropy are critical for normalizing the fluctuations to the mean number of charged pions that are emitted.

$S = 3.6\langle N_g\rangle + 4.2\langle N_u\rangle+4.2\langle N_{ubar}\rangle+4.2\langle N_d\rangle+4.2\langle N_{dbar}\rangle = 3.6 \langle N_\pi\rangle$

One issue I note is that you have assumed massless, non-interacting particles. In this type of transition, the mean energy of the particles is changing and thus there are other factors in the entropy calculation other than just number of particles as bosons and fermions. Isn't that correct? I am not sure how much this might change the results. Is this something you have investigated?

Just as an example, recombination models, which usual are quoted as violating conservation of entropy, would indicate that you would need:

$\langle N_\pi\rangle = 2 \times (\langle Nu\rangle+\langle Nubar\rangle+\langle Nd\rangle+\langle Ndbar\rangle)$

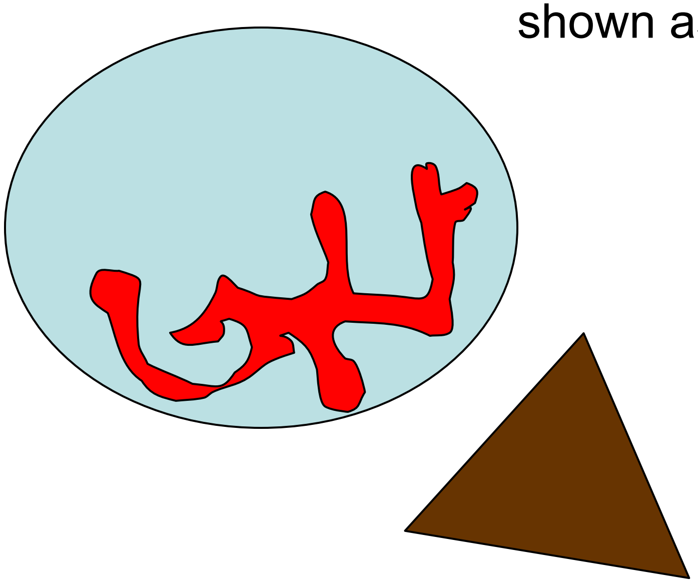
This would not change the charge fluctuations in the red region ($\langle\delta Q^2\rangle$), but would reduce <Nch> by almost a factor of 2. This would in effect, increase the fluctuation variable D by a factor of 2 due to the mis-calculation of the initial entropy.

Again, any suggestions on how to think about the sensitivity of this entropy conserving mapping would be very helpful.

# Freezing in of the charged particle ratio fluctuations?

In the case outlined previously where the red region decouples very quickly, and we then measure everything from the red region (and nothing else), the effect of rescattering (within the red region) in the later stage amongst the pions has almost no effect.  Since the region decouples quickly, there is no heat exchange and entropy is conserved.  Also, the red region has a particular net charge, which cannot change.

However, we do not measure particles from one spatial region.  We measure particles within a given momentum vector region.  In a given event we can still think of the quarks and gluons as coming from a particular red region, just not spatially localized.   The red region below covers all the partons that our detector shown as the brown triangle will sample.



In this case, if the red region very quickly decouples the rest of the blue volume, there is no problem.

However, there is a very good chance for significant rescattering of particles (pions) after hadronization.  Red and blue will mix a lot in this case even in a few fm/c.

In this case, since rescattering is likely to occur between spatially nearest neighbor pions, many of the pion rescattering will occurs between objects in the red region of interest and the blue region. These will change the net charge from that which was set at the partonic level.

In the large pion rescattering limit, one should always return to the D ~ 4 value from the random sampling of pions calculation.

In your paper, you invoke the Bjorken model where rapidity is perfectly correlated with spatial coordinates. Thus, you state that if y(total) >> y(accept) >> 1 then these rescattering effects should be small. I believe there is no evidence for this Bjorken scaling. Your study only including rapidity blurring within the context of rescattering and the Bjorken picture.

In addition, in the PHENIX correlations, we have a low pT cut. Thus, even within our rapidity range, a pion at pT= 120 MeV/c is not included, but a pion at pT = 160 MeV is included. This helps to show that the red region and blue region will have lots of mixing.

What do you really think?

The PHENIX experimental results always give something with D ~ 4 independent of centrality. One could arrive at various conclusions.

1. We never have partonic degrees of freedom and that is why is looks like a pion gas.

2. We form a system with partonic degrees of freedom, but the system stays near equilibrium through hadronization. Thus, the fluctuations are only seeing the later pion gas phase. This is like looking at the CMBR and seeing only the decoupling time of 300,000 years after the big bang.

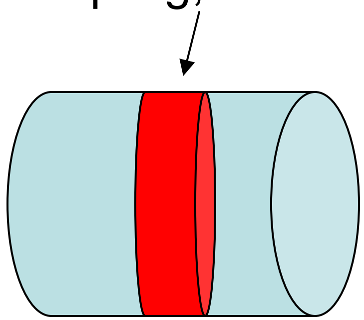
3. We form a system with partonic degrees of freedom, but the entropy calculation is not complete. Correcting this gives agreement with the data. I suspect there is more needed in the entropy calculation, however, it would be a great coincidence that this factor cancels the fractional charge factor for all centralities to give D ~ 4.

4. Our acceptance is just too small.

Can you comment on these scenarios and what else you can suggest.

# Follow up work (after initial email sent)

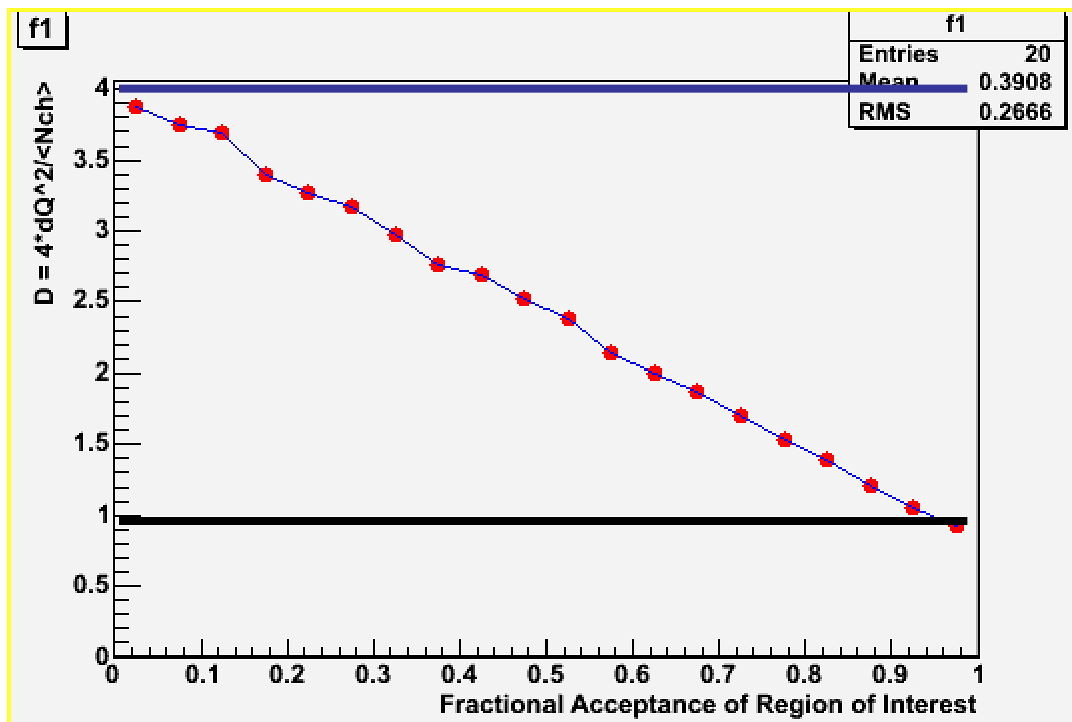
Assume Bjorken picture. Assume Grand Canonical Ensemble fluctuations from one slice to the rest of the cylinder (as the heat bath). Then assume very rapid decoupling, and a detector only measures resulting pions from that (red) slice.



Assume fluctuations amongst quarks, antiquarks and gluons. If one samples pions that come only from the red region, and sample all of them, one gets D ~ 0.9

However, as you measure a smaller fraction of the pions from this region, you start to introduce fluctuations that are Poisson in the unit charged pions.

The plot on the right shows the D value you would measure for a given acceptance fraction (f) of the particles from the red region.



Therefore, my conclusion at this point is that even in the most ideal situation:
(1) Grand Canconical Ensemble for one spatial slice,
(2) Bjorken model for perfect mapping of spatial region onto rapidity region,
(3) No rapidity blurring – only particles from red region are measured,
(4) No final state hadronic re-scattering,
(5) Entropy conservation as calculated by Jeon/Koch,
(6) And a quark-gluon plasma as a non-interacting, massless, uncorrelated gas as calculated by Jeon/Koch

One would only expect D ~ 3.5 due to the limited PHENIX acceptance (one arm only gives you 25% of the rapidity slice red region, and then down further due to inefficiencies, and no tracking below some minimum pT).

It is still interesting that maybe we see something higher than this value, though I have not included any rapidity blurring, hadronic rescattering, error in entropy assumption etc.

Thus, the surprising comparison of our measurement around D ~ 4 and the QGP at D ~ 0.7-0.9, is not correct. Our limited acceptance always Poissonizes the distribution at the unit charge level since we either accept or do not accept pions at the end of the day.