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Measurements and Calculations of $\hat{q}L$ via transverse momentum broadening in RHI collisions using di-hadron correlations

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The renewed interest in analyzing RHIC data on di-hadron correlations as probes of final state transverse momentum broadening as shown at Quark Matter 2018 [1] by theoretical calculations [2] compared to experimental measurements [3, 4] led me to review the quoted theoretical calculations and experimental measurements because the theoretical calculation [2] does not show the correct errors of the PHENIX measurements [3, 5] as published. The above references were checked and fits were performed to the published measurements with the correct errors [3, 5] to determine $\hat{q}L$ from the measured azimuthal broadening to compare with the theoretical calculation [2]. The new fits with the correct errors give values of $\langle\hat{q}L\rangle$ on the order of -1 ± 1 GeV^2, clearly inconsistent with the value of $\hat{q}L = 13$ GeV^2 claimed in the theoretical calculations [2]. One STAR measurement [4], that I had previously analyzed [6], quoted in Ref. [2] gave a value of $\langle\hat{q}L\rangle = 0.86\pm0.87$ GeV^2 also inconsistent with the theoretical claim [2]. As a check I calculated the values of $\hat{q}L$ from a more recent PHENIX measurement with superior errors [7]. The values of $\hat{q}L$ from these measurements also had the interesting effect of being consistent with zero for larger values of associated $p_{Ta} \geq 3$ GeV/c. This effect is well known from all previous measurements of the ratio of the p_{Ta} distributions in Au+Au to p+p for a given trigger p_{Tt} called I_{AA} [4, 7, 8] which remain constant for $p_{Ta} \geq 3$ GeV/c. One possible explanation is that for $p_{Ta} \geq 3$ GeV/c, which is at a fraction $\approx 1\%$ of the $x_E \approx p_{Ta}/p_{Tt}$ distribution, these hard fragments are distributed narrowly around the jet axis so that they are not strongly affected by the medium [9]. Hence, di-jets rather than di-hadrons at RHIC are proposed as an improved azimuthal broadening measurement to determine $\hat{q}L$ and possibly $\hat{q}$.

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1. Introduction

When I was reviewing talks from Quark Matter 2018, a slide (Fig. 1) in a presentation by Miklos Gyulassy [1] drew my attention because it involved a figure from a preprint [10] that I had referenced in my publication on measuring $\hat{q}L$ from di-hadron correlations [6].

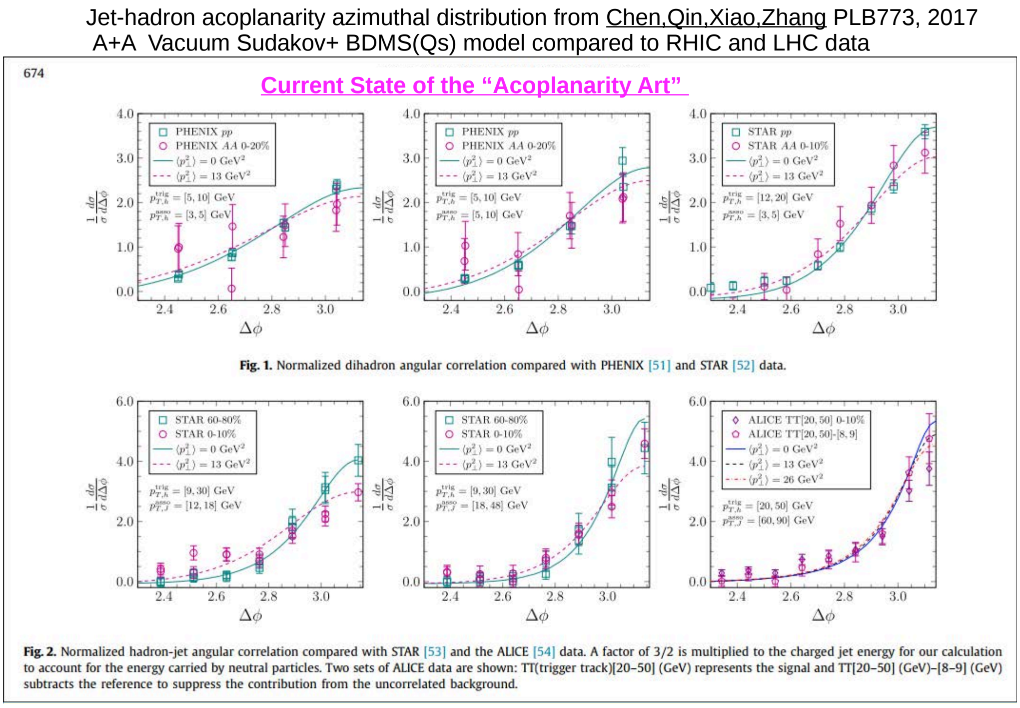

Figure 1: Copy of slide with away-side azimuthal widths (folded) of data said to be from PHENIX, STAR and ALICE, together with calculation from theoretical paper indicated.

I had not paid much attention to that figure previously, but in comparing the two plots labeled PHENIX in Fig. 1, which is reproduced from Refs. [2, 10], to the actual plots from the quoted PHENIX publication [3] in Fig. 2, I realized that the the data in the plots in Fig. 1, from Refs. [2,

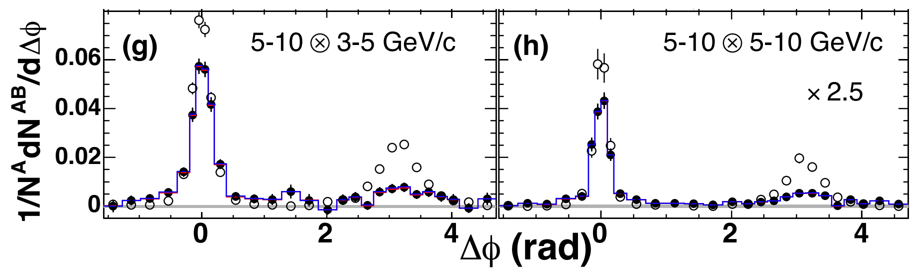

Figure 2: PHENIX azimuthal correlation conditional yield in p+p and 0-20% centrality Au+Au collisions at $\sqrt{s_{NN}}$=200 GeV for trigger $h^{\pm}$ with $p_{Tt} = 5-10$ GeV/c and associated $h^{\pm}$ with $p_{Ta} = 3-5$ GeV/c (g) and $p_{Ta} = 5-10$ GeV/c (h) reproduced from Ref. [3]

10], looked nothing like the measurement shown in Fig. 2 from the quoted PHENIX publication [3]. Notably, in the actual PHENIX data [3], shown in Fig. 2, errors are shown for the same side peaks in p+p and Au+Au, but no errors are shown for the away-side peaks ($\pi/2 < \Delta\phi < 3\pi/2$ radians) for either p+p or Au+Au. However, in Fig. 1 reproduced from Ref. [2] errors are shown for the p+p and Au+Au away-side data which is labelled as PHENIX data from reference [3]. Also in Ref. [2] the data points for both p+p and A+A were rescaled to make them normalize to 1, which were called 'self normalized' data.

To understand this issue, I sent an email to the authors of Reference [10], which had been published in the interim as Ref. [2], and I got a very prompt answer from Bo-Wen Xiao: "I believe that we are correct when we cited the PHENIX data in Ref. [3] . The data are taken from Fig. 1, Panel (g) and (h) in Ref. [3] (Fig. 2 here). We focus on the away side (near π) of these two plots, and plot them in self-normalized manner." When I pressed Bo-Wen, I got the following important additional information:"We used the software called xyscan to get the data points and the error from the figure. Indeed we rescaled the points for both pp and AA data to make them normalize to 1. I am not sure whether the errors are exact or not. But this is the best we could do at that moment."

In my opinion the derived PHENIX data in Fig. 1 and Fig. 3 reproduced from Ref.[2] look nothing like the published PHENIX data in Fig. 2 [3]. Admittedly a listing of the data in Fig. 2 was not available, but shortly thereafter a following publication [5] with the exact same figure did provide a listing [11] [1] of the data points with the errors shown in Fig. 4.

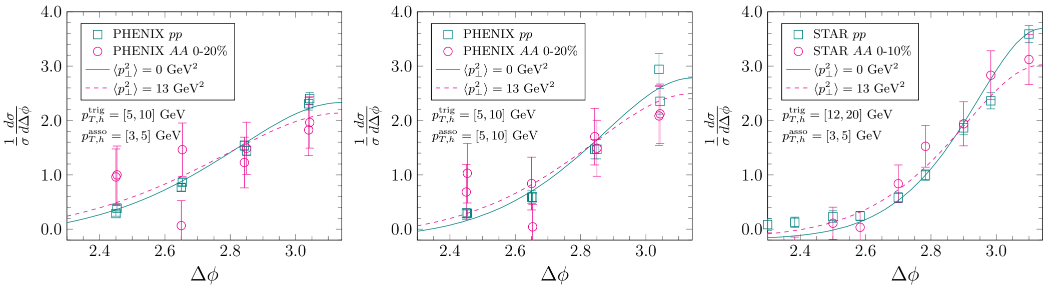

Figure 3: Figure of Normalized dihadron angular correlation compared with PHENIX [3] and STAR [4] data, reproduced from Ref. [2]

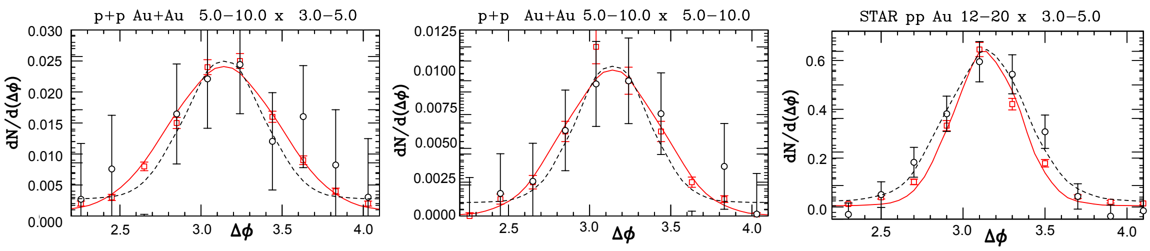

Figure 4: My Gaussian fits to actual dihadron angular correlation measurements of PHENIX [3] plus my previous fit [6] to the STAR data [4].

Given the actual data points for the PHENIX dihadron correlations I first fit the data to Gaussians in $\Delta\phi$ ($\sigma_{\Delta\phi}$) for the trigger side $-\pi/2 \leq \Delta\phi \leq \pi/2$ and $\pi/2 \leq \Delta\phi \leq 3\pi/2$ for the away side shown in Fig. 4 in order to compare the data and fits to Fig. 3. The p+p data are open squares with fits as solid lines. The Au+Au data are open circles with fits as dashed lines. The y axes for the Au+Au data and fits in Fig. 4 are rescaled so that the peaks in the p+p and Au+Au fits lie on top of each other. The STAR data and my fits from Ref. [6] are also shown in Fig. 4.

[1] Ref. [11] verifies that these are the actual data from Fig. 1 of Ref [3] (Fig. 2 here).

The most notable observation about the fits in Fig. 4 is that for both p_{Ta} ranges, the PHENIX Au+Au fits have smaller $\sigma_{\Delta\phi}$ than the p+p fits, which is more convenient to quote in the variable $\langle p^2_{\rm out}\rangle = (p_{Ta}\sin\sigma_{\Delta\phi})^2$ as follows: for PHENIX $p_{Tt} = 5-10$ GeV/c, the values of $\langle p^2_{\rm out}\rangle$ for $p_{Ta} = 3-5$ GeV/c are 0.79 ± 0.64 (GeV/c)^2, χ^2/dof=22/23, for Au+Au 0-20% and 1.54 ± 0.08 (GeV/c)^2 for p+p; and for $p_{Ta} = 5-10$ GeV/c, 2.12 ± 1.13 (GeV/c)^2, χ^2/dof=13/23, for Au+Au and 3.92 ± 0.33 (GeV/c)^2 for p+p. For the STAR Au+Au 00-12%, $p_{Tt} = 12-20$, $p_{Ta} = 3-5$ GeV/c data, the results are the same as in Ref. [6], namely $\langle p^2_{\rm out}\rangle = 0.851\pm0.203$ (GeV/c)^2 for Au+Au and 0.576 ± 0.167 (GeV/c)^2 for p+p.

From these numbers it is obvious [6] that $\langle\hat{q}L\rangle$ (which corresponds to the $\langle p^2_{\perp}\rangle$ on Fig. 3) is negative for the PHENIX data and thus not equal to $\langle\hat{q}L\rangle = 13$ GeV^2 quoted on Fig. 3 reproduced from Ref. [2]. For readers who may not understand this as obvious, a review of the method to calculate $\langle\hat{q}L\rangle$ is presented followed by the calculations of $\langle\hat{q}L\rangle$ from the PHENIX and STAR data in Fig. 4 and some other published PHENIX data, leading to an interesting conclusion.

2. An explanation of why I am so interested in azimuthal broadening in di-hadron calculations and $\hat{q}L$

Azimuthal broadening of di-hadrons was first observed at the CERN ISR in 1976-77 by experiments, notably CCHK [12] trying to determine what was balancing the production of high p_T particles discovered in 1972-73 at the CERN ISR by CCR [13] (Fig. 5a). The variables used by CCHK for the measurements (Fig. 5b,c) were $p_{\rm out} = p_{Ta}\sin(\Delta\phi)$ and $x_E \equiv \frac{p_{Ta}\cos(\Delta\phi)}{p_{Tt}} \approx \frac{p_{Ta}}{p_{Tt}} \equiv x_h$. They found azimuthal broadening: the $\langle p_{\rm out}\rangle$ increased with increasing x_E, which they attributed to transverse momentum k_T of a quark in a nucleon which Fenynam, Field and Fox formalized [14].

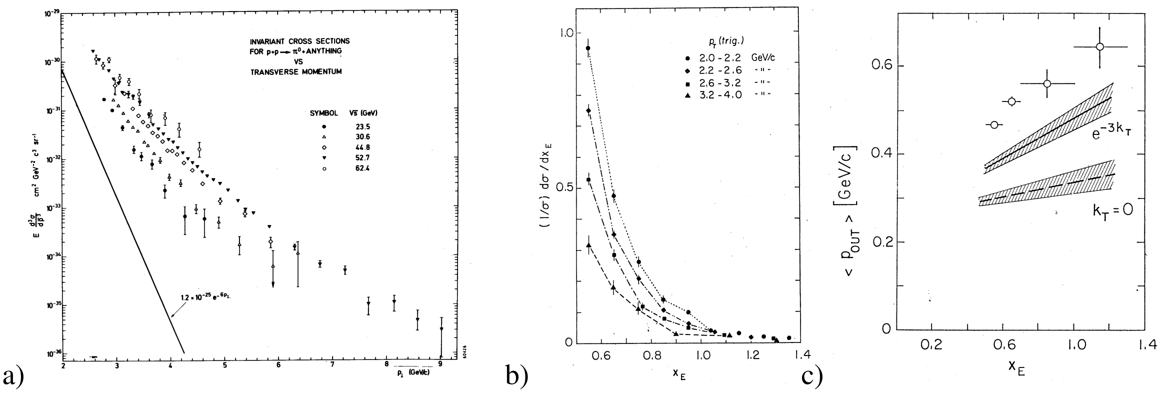

Figure 5: a) CCR [13] discovery of π^0 with a power-law spectrum for $p_T \geq 2$ GeV/c compared to the exponential e^{-6p_T} Cocconi formula for $p_T \leq 2$ GeV/c. b) CCHK [12] measurements of the x_E distribution for a variety of trigger p_{Tt} and c) the $\langle p_{\rm out}\rangle$ as a function of x_E for triggers in the range $2.0 \leq p_{Tt} \leq 3.2$ GeV/c.

2.1 Understanding k_T as formalized by Feynman, Field and Fox [14].

Following the ideas of Levin and Ryskin [15] and CCHK, Feynman, Field and Fox [14] established the formalism for $\overrightarrow{k_T}$, the transverse momentum of a parton in a nucleon. In this formulation (Fig. 6), the net transverse momentum of an outgoing parton pair, where the two $\overrightarrow{k_T}$ add randomly,

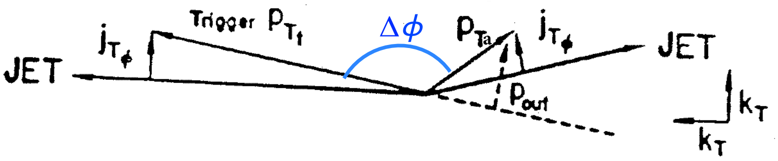

Figure 6: Sketch looking down the beam axis of a di-jet with trigger and away-side fragments p_{Tt} and p_{Ta}

is $\sqrt{2}k_T$, which is composed of two orthogonal components, $\sqrt{2}k_{T_\phi} = k_T$, out of the scattering plane, which makes the jets acoplanar, i.e. not back-to-back in azimuth, and $\sqrt{2}k_{T_x} = k_T$, along the axis of the trigger jet, which makes the jets unequal in energy.

FFF [14] gave the approximate formula to derive k_T from the measurement of $p_{\rm out}$ as a function of x_E:

$$\langle|p_{\rm out}|\rangle^2 = x_E^2[2\langle|k_{T_\phi}|\rangle^2 + \langle|j_{T_\phi}|\rangle^2] + \langle|j_{T_\phi}|\rangle^2 \qquad . \tag{2.1}$$

This formula assumed that $\langle z_{\rm trig}\rangle = 1$ and that the jet energies are equal.

PHENIX [16] computed $\langle k_T^2\rangle$ for di-hadrons as fragments of the original di-jets with possible unequal energies :

$$\sqrt{\langle k_T^2\rangle} = \frac{\hat{x}_h}{\langle z_t\rangle}\sqrt{\frac{\langle p_{\rm out}^2\rangle - (1+x_h^2)\langle j_T^2\rangle/2}{x_h^2}} \tag{2.2}$$

where p_{Tt}, p_{Ta} are the transverse momenta of the trigger and away particles, $x_h \equiv p_{Ta}/p_{Tt}$, $\Delta\phi$ is the azimuthal angle between p_{Tt} and p_{Ta} and $p_{\rm out} \equiv p_{Ta}\sin(\pi - \Delta\phi)$. The di-hadrons are assumed to be fragments of jets with transverse momenta $\hat{p}_{Tt}$ and $\hat{p}_{Ta}$ with ratio $\hat{x}_h \equiv \hat{p}_{Ta}/\hat{p}_{Tt}$. $z_t \simeq p_{Tt}/\hat{p}_{Tt}$ is the fragmentation variable, the fraction of momentum of the trigger particle in the trigger jet. j_T is the jet fragmentation transverse momentum and we have taken $\left\langle j_{Ta\phi}^2\right\rangle = \left\langle j_{Tt\phi}^2\right\rangle = \langle j_T^2\rangle/2$. The variable x_h (which STAR calls z_T) is used as an approximation of the variable $x_E = x_h\cos(\pi - \Delta\phi)$ from the original terminology at the CERN ISR where k_T was discovered and measured [17] more than 40 years ago.

2.2 So where does $\hat{q}L$ come in?

Rolf Baier asked me a a meeting in Paris in 1998 [18] whether we could measure jets at RHIC. I said [19] “Not really, but we probably could do just as well with high p_T hadrons which PHENIX was designed to measure." I was correct for high p_T hadrons since our high p_T suppression discovery paper [20] is the first and so far only regular paper at RHIC to have more than 1000 citations.

2.3 Jet Quenching by coherent LPM radiative energy loss of a partion in the QGP 1997

In 1997, Baier, Dokshitzer, Mueller, Peigne, Schiff [21] also Zakharov [22] said that the energy loss from coherent LPM radiation for hard-scattered partons exiting the QGP would "result in an attenuation of the jet energy and a broadening of the jets" As a parton from hard-scattering in the A+B collision exits through the medium it can radiate a gluon; and both continue traversing the medium. It is important to understand that "Only the gluons radiated outside the cone defining the jet contribute to the energy loss." (Fig. 7). In the angular ordering of QCD [23], the angular cone of any further emission will be restricted to be less than that of the previous emission and will end the energy loss once inside the jet cone. This doesn’t work in the QGP [9], so no energy loss occurs only when all gluons emitted by a parton are inside the jet cone. In addition to other issues this means that defining the jet cone is a BIG ISSUE-watch out for so-called trimming.

3. BDMPSZ-the cone, the energy loss, azimuthal broadening-QGP signature 1997

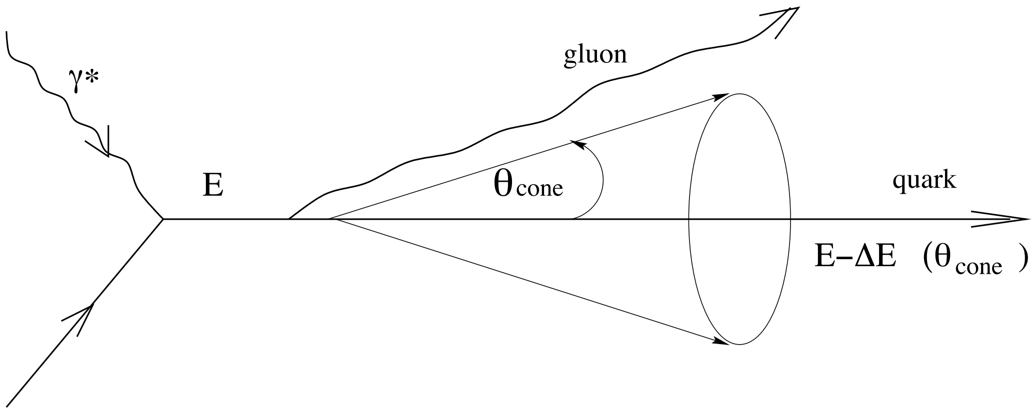

Figure 7: Jet Cone of an outgoing quark with energy E [22]

The BDMPSZ model has two predictions:
(1)The energy loss of the original outgoing parton, $-dE/dx$, per unit length (x) of a medium with total length L, is proportional to the total 4-momentum transfer-squared, $q^2(L)$, with the form:

$$\frac{-dE}{dx} \simeq \alpha_s \langle q^2(L)\rangle = \alpha_s\, \mu^2 L/\lambda_{\rm mfp} = \alpha_s\, \hat{q}\, L \tag{3.1}$$

where μ, is the mean momentum transfer per collision, and the transport coefficient $\hat{q} = \mu^2/\lambda_{\rm mfp}$ is the 4-momentum-transfer-squared to the medium per mean free path, $\lambda_{\rm mfp}$.

(2)Additionally, the accumulated momentum-squared, $\left\langle p^2_{\perp W}\right\rangle$ transverse to the parton from its collisions traversing a length L in the medium is well approximated by[2]

$$\left\langle p^2_{\perp W}\right\rangle \approx \langle q^2(L)\rangle = \hat{q}\, L \qquad \langle \hat{q}L\rangle = \left\langle k_T^2\right\rangle_{AA} - \left\langle k'^2_T\right\rangle_{pp} \tag{3.2}$$

Although only the component of $\left\langle p^2_{\perp W}\right\rangle$ $\perp$ to the scattering plane affects k_T, the azimuthal broadening of the di-jet is caused by the random sum of the azimuthal components $\left\langle p^2_{\perp W}\right\rangle/2$ from each outgoing jet or $\left\langle p^2_{\perp W}\right\rangle = \hat{q}\, L$.

3.1 The key new idea (k'_T) gives elegant solutions

The di-hadron correlations of p_{Ta} with p_{Tt} are measured in p+p and Au+Au collisions. The parent jets in the original Au+Au collision as measured in p+p will both lose energy passing through the medium but the azimuthal angle between the jets should not change unless the medium induces multiple scattering from $\hat{q}$. Thus the calculation of k'_T from the dihadron p+p mesurement to compare with Au+Au measurements with the same di-hadron p_{Tt} and p_{Ta} must use the value of

[2]Ref. [6] had $\langle \hat{q}L\rangle/2 =$ in Eq. 3.2 because I forgot that the di-hadron correlation represents both the trigger and away-side scattered partons.

$\hat{x}_h$ and $\langle z_t \rangle$ of the parent jets in the A+A collision. [$\hat{x}_h \equiv \hat{p}_{Ta}/\hat{p}_{Tt}$, $\langle z_t \rangle \simeq p_{Tt}/\hat{p}_{Tt}$, $x_h \equiv p_{Ta}/p_{Tt}$] The same values of $\hat{x}_h$, and $\langle z_t \rangle$ in Au+Au and p+p in Eqs. 2.2 and 3.2 gives the cool result:

$$\langle \hat{q}L \rangle = \left[\frac{\hat{x}_h}{\langle z_t \rangle}\right]^2 \left[\frac{\left\langle p_{\rm out}^2 \right\rangle_{AA} - \left\langle p_{\rm out}^2 \right\rangle_{pp}}{x_h^2}\right] \tag{3.3}$$

For di-jet measurements, the formula is even simpler:
i) $x_h \equiv \hat{x}_h$ because the trigger and away 'particles' are the jets;
ii) $\langle z_t \rangle \equiv 1$ because the trigger 'particle' is the entire jet not a fragment of the jet;
iii) $\left\langle p_{\rm out}^2 \right\rangle = \hat{p}_{Ta}^2 \sin^2(\pi - \Delta\phi)$. This reduces the formula for di-jets to:

$$\langle \hat{q}L \rangle = \left[\left\langle p_{\rm out}^2 \right\rangle_{AA} - \left\langle p_{\rm out}^2 \right\rangle_{pp}\right] = \hat{p}_{Ta}^2 \left[\left\langle \sin^2(\pi - \Delta\phi) \right\rangle_{AA} - \left\langle \sin^2(\pi - \Delta\phi) \right\rangle_{pp}\right] \tag{3.4}$$

3.2 How to Find $\langle z_t \rangle$, $\hat{x}_h$, and the energy loss of $\hat{p}_{Tt}$ for dihadrons [6]

A) The Bjorken parent-child relation and 'trigger-bias' [24] give $\langle z_t \rangle$. Also, the $\langle z_t \rangle$ as a function of p_{Tt} can be calculated [16, 25]; **B)** the energy loss of the trigger jet from p+p to A+A can be measured by the shift in the trigger hadron p_T spectra [26]; **C)** $\hat{x}_h$ can be measured from the away particle p_{Ta} distribution for a given trigger particle p_{Tt} using Eq. 3.5 [$x_E \approx p_{Ta}/p_{Tt} = x_h$]

$$\left.\frac{dP_\pi}{dx_E}\right|_{p_{T_t}} = N(n-1)\frac{1}{\hat{x}_h}\frac{1}{(1+\frac{x_E}{\hat{x}_h})^n} \quad , \tag{3.5}$$

with the value of $n = 8.10$ (± 0.05) fixed as determined in Ref. [27], where n is the power-law of the inclusive π^0 spectrum and is observed to be the same in p+p and Au+Au collisions in the p_{T_t} range of interest.

Figure 8 shows a fit of Eq. 3.5 to the PHENIX x_E Au+Au 0-20% and p+p distributions in a region with $\langle p_{Tt} \rangle \approx 7.8$ GeV/c, close to the $5 \leq p_{Tt} < 10$ GeV/c region in Fig. 4 with $\langle p_{Tt} \rangle \approx 6.5$ GeV/c. The results are $\hat{x}_h = 0.86 \pm 0.03$ in p+p and $\hat{x}_h = 0.47 \pm 0.07$ Au+Au (dashes). What is more interesting is a fit to Eq. 3.5 for N and $\hat{x}_h$ plus another term of Eq. 3.5 with $\hat{x}_h = 0.86$ fixed at the p+p value, with the normalization $N_p = 0.22 \pm 0.08$ fitted, compared to the $N = 1.5^{+1.4}_{-0.6}$ for the partons that have lost energy. The result is the solid Au+Au curve with a much better χ^2/dof $= 1.4/2$ which is notably parallel to the p+p curve for $x_E \geq 0.4$ ($p_{Ta} \approx p_{Tt} \times x_E = 3.1$ GeV/c).

3.2.1 This effect is well known under a different name

One possible explanation is that in this region for $p_{Ta} \geq 3$ GeV/c, which is at a fraction $\approx 1\%$ of the $dP/dx_E|_{p_{Tt}}$ distribution, these hard fragments are distributed narrowly around the jet axis so that they are not strongly affected by the medium [9]. An unlikely possibility is from tangential parton-parton collisions at the periphery of the A+A overlap region which has probability much smaller than the N_p/N ratio.

Either possibility is consistent with measurements of the ratio of the Au+Au to p+p x_E (or p_{Ta}) distributions for a given p_{Tt} which are called I_{AA} distributions (Fig. 9a [7]). All I_{AA} distributions ever measured show the same effect as in Fig. 9a, they fall in the range $0 < p_{Ta} < 3$ GeV/c and then remain constant. This effect also can be seen in I_{AA} measurements by STAR [4]; and

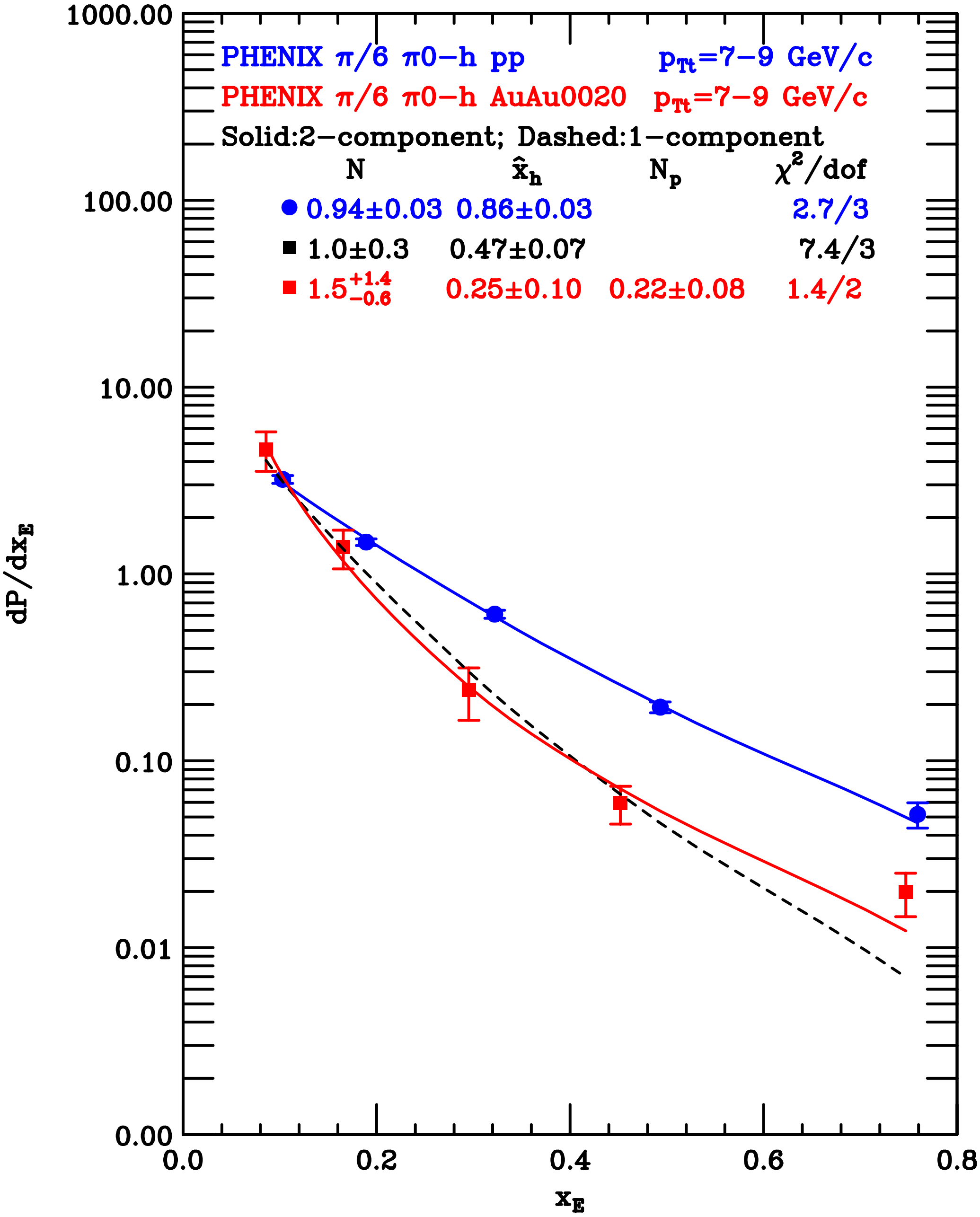

Figure 8: Fits to PHENIX dP/dx_E distributions [7, 28] for π^0-h correlations with $7 \leq p_{Tt} \leq 9$ GeV/c in $\sqrt{s_{NN}}$=200 GeV p+p and Au+Au 0-20% collisions.

in $8 < p_{Tt} < 16$ GeV/c p+p and 0-10% Pb+Pb measurements at $\sqrt{s_{NN}}$=2.76 TeV by ALICE at the LHC [8]. The fact that I_{AA} remains constant above $p_{Ta} \approx 3$ GeV/c means that the ratio of the away-jet to the trigger jet transverse momenta in this region remains equal in A+A and p+p , i.e. no apparent suppression via energy loss in this region. This effect also causes problems in the following calculations of $\langle\hat{q}L\rangle$ from the di-hadron correlations.

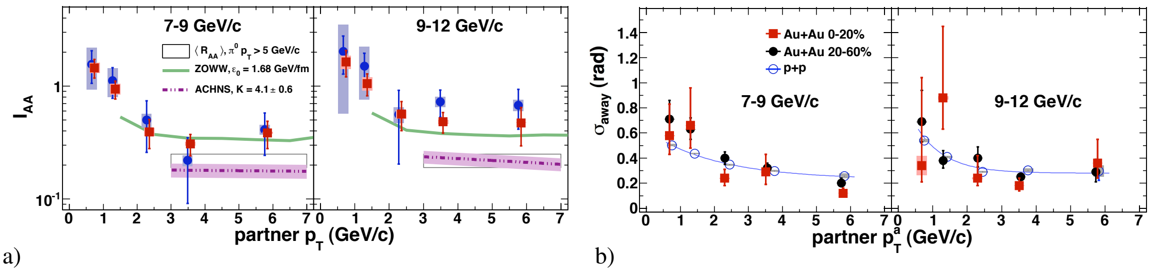

Figure 9: PHENIX [7]: a) $I_{AA} = dP/dx_E|_{AA}/dP/dx_E|_{pp}$ for p_{Tt}=7-9 and 9-12 GeV/c vs. partner p_T (i.e. p_{Ta}) in $\sqrt{s_{NN}}$=200 GeV p+p and Au+Au 0-20% collisions; b) $\sigma_{\rm away}$ for p_{Tt}=7-9 and 9-12 GeV/c vs. partner p_{Ta} for 0-20% and 20-60% centrality as indicated.

4. Calculation of $\langle \hat{q}L \rangle$ from di-hadron azimuthal broadening.

The calculations of $\langle \hat{q}L \rangle$ for the STAR measurement [4] in Fig. 4 as well as for $1.0 \leq p_{Ta} \leq 3$ GeV/c performed in Ref [6] [3] with the values $\hat{x}_h^{pp} = 0.84 \pm 0.04$, $\langle z_t \rangle = 0.80 \pm 0.05$ are given in Table 1.

Table 1: Tabulations for $\hat{q}$–STAR π^0-h [4]

STAR PLB760				
$\sqrt{s_{NN}} = 200$	$\langle p_{Tt} \rangle$	$\langle p_{Ta} \rangle$	$\langle p^2_{\rm out} \rangle$	$\langle \hat{q}L \rangle$
Reaction	GeV/c	GeV/c	(GeV/c)^2	GeV^2
p+p	14.71	1.72	0.263 ± 0.113	
p+p	14.71	3.75	0.576 ± 0.167	
Au+Au 0-12%	14.71	1.72	0.547 ± 0.163	4.21 ± 3.24
Au+Au 0-12%	14.71	3.75	0.851 ± 0.203	0.86 ± 0.87

The value of $\langle \hat{q}L \rangle = 0.86 \pm 0.87$ GeV^2 for the fit to the $3 \leq p_{Ta} \leq 5$ GeV/c STAR data shown in Fig. 4 is consistent with zero and clearly in significant disagreement with the proposed $\langle \hat{q}L \rangle = \langle p_\perp^2 \rangle = 13$ GeV^2 quoted on Fig. 3 [2]. The value of $\langle \hat{q}L \rangle = 4.21 \pm 3.24$ GeV^2 in the lower p_{Ta} bin is closer to the prediction, within 2.7 standard deviations, but also consistent with zero.

The calculations of $\langle \hat{q}L \rangle$ from the fits to the PHENIX data in Fig. 4 with $\hat{x}_h = 0.51 \pm 0.06$ and $\langle z_t \rangle = 0.64 \pm 0.06$ are given in Table 2. The values of $\langle \hat{q}L \rangle = -1.43 \pm 1.29$ and -1.07 ± 0.77 GeV^2 are negative, as noted above, and both consistent with zero but inconsistent with the predicted 13 GeV^2.

Although not discussed in Ref. [2], the PHENIX measurement of I_{AA} [7] shown in Fig. 9a also provided values of $\sigma_{\rm away}$ for Au+Au and p+p plotted clearly (Fig. 9b) so that values of $\hat{q}L$ can be read off practically by inspection. While $\sigma_{\rm away}$ is apparently larger in Au+Au than in p+p for

[3] The sharp-eyed reader will notice that the $\langle \hat{q}L \rangle$ values in Ref. [6] were 8.41 ± 2.66 and 1.71 ± 0.67 GeV^2 for two reasons: first is the $\langle \hat{q}L \rangle /2$ in Eq. 2 there (Eq. 3.2 here), second was a miscalculation of the error which should have been obvious from the errors in $\langle p^2_{\rm out} \rangle$ which are unchanged.

Table 2: Tabulations for $\langle\hat{q}L\rangle$–PHENIX Fig. 4

PHENIX PRC77				
$\sqrt{s_{NN}}$=200	$\langle p_{Tt}\rangle$	$\langle p_{Ta}\rangle$	$\langle p^2_{\rm out}\rangle$	$\langle\hat{q}L\rangle$
Reaction	GeV/c	GeV/c	(GeV/c)^2	GeV^2
p+p	6.46	3.75	1.54 ± 0.08	
p+p	6.46	6.68	3.92 ± 0.33	
Au+Au 0-20%	6.46	3.75	0.79 ± 0.64	-1.43 ± 1.29
Au+Au 0-20%	6.46	6.68	2.12 ± 1.13	-1.07 ± 0.77

$p_{Ta} < 2$ GeV/c it is smaller or equal to the p+p value for $p_{Ta} > 2$ GeV/c, i.e. $\hat{q}L$ consistent with zero. Details for $p_{Tt} = 9-12$ GeV/c are given in Table 3.

Table 3: Tabulations of $\langle\hat{q}L\rangle$-PHENIX 9-12 GeV/c Fig. 9b

PHENIX PRL104				
$\sqrt{s_{NN}}$=200	$\langle p_{Tt}\rangle$	$\langle p_{Ta}\rangle$	$\langle p^2_{\rm out}\rangle$	$\langle\hat{q}L\rangle$
Reaction	GeV/c	GeV/c	(GeV/c)^2	GeV^2
p+p	10.22	1.30	0.319 ± 0.023	
p+p	10.22	2.31	0.491 ± 0.052	
p+p	10.22	3.55	1.256 ± 0.166	
p+p	10.22	5.73	2.884 ± 1.376	
Au+Au 0-20%	10.22	1.30	0.86 ± 0.339	13.3 ± 10.4
Au+Au 0-20%	10.22	2.31	0.299 ± 0.190	-1.5 ± 1.7
Au+Au 0-20%	10.22	3.55	0.394 ± 0.189	-2.9 ± 1.6
Au+Au 0-20%	10.22	5.73	4.08 ± 2.83	1.5 ± 4.0

5. Conclusion

When calculated with fits to the measured distributions in Fig. 4 the values of $\hat{q}L$ (Table 2) are -1.43 ± 1.29 and -1.07 ± 0.77, clearly inconsistent with the calculation of $\hat{q}L = 13$ GeV^2 claimed in Fig. 3 [2], for $p_{Ta} \geq 3$ GeV/c. For values of $p_{Ta} < 3$ GeV/c in Tables 1 and 3, separating the flow background causes the errors in the measurement of $\hat{q}L$ to be too large to obtain reasonable results.

The measurement of $\hat{q}L$ and possibly $\hat{q}$ can be greatly improved by measuring di-jet angular distributions rather than di-hadron distributions. The energy loss of the trigger jets can be determined by the shift in the p_{Tt} spectrum from p+p to A+A the same way as for π^0 [26, 6]. Then a plot of the $\hat{p}_{Ta}$ of the away jets for a given trigger jet with $\hat{p}_{Tt}$ analogous to Fig. 8 and an evaluation of $\Delta E = \alpha_s\hat{q}L^2$ from $\hat{p}_{Tt} - \hat{p}_{Ta}$ and $\hat{q}L$ by Eq. 3.4 as a function of $\hat{p}_{Ta}$ might allow the L dependence to be factored out or determined which would lead to a experimental measurement of $\hat{q}$.

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