Anisotropic flow
S.A. Voloshin

aDepartment of Physics and Astronomy
Wayne State University, Detroit, U.S.A.

Recent experimental results on directed and elliptic flow, theoretical developments, and new techniques for anisotropic flow analysis are reviewed.

1. Introduction. Flow adventures from Monterey to Nantes.

From the point of view of anisotropic flow this conference is quite remarkable. Elliptic flow has been fully recognized as an important observable providing information on the early stages of heavy ion collisions. An increased attention to anisotropic flow in recent years has resulted in a significant improvement in all three components of the field: techniques and methods, analysis and presentation of the data, and theoretical understanding of the underlying physics. For a long time the anisotropic flow measurements suffered large systematic errors related to the so called “non-flow” contribution, the contribution due to the azimuthal correlations not related to the orientation of the reaction plane. At this Quark Matter conference, for the first time, we discuss the results mostly free of this uncertainty, using results obtained with 3-, 4-, and even more particle correlations. Elliptic flow up to $p_t \sim 10 - 12$ GeV/c, the “wiggle” in directed flow, $v_2(p_t)$ for a number of identified particles up to $p_t \sim 3-4$ GeV/c, are only a few other results presented at this conference.

The starting point for many recent developments was the Quark Matter ’95 conference at Monterey. Then, the E877 Collaboration reported the first observation of anisotropic flow in ultra-relativistic nuclear collisions at the BNL AGS [1], the discovery, which M. Gyulassy in his concluding remarks called the “major highlight of the year”. That analyses was done with the use of a new approach [2], the very notations of which, like $v_1$ and $v_2$, are a common language now. The E877 Collaboration also presented the results from the first attempts to perform HBT interferometry of the anisotropic source, one of the important directions in today’s HBT analysis. At the same conference, J.-Y. Ollitrault, foreseeing future precise measurements, emphasized the importance of the understanding and measuring of the non-flow correlations. It was pointed out that flow is a collective phenomena and in order to disentangle it from other contributions to particle azimuthal correlations one has to exploit multi-particle correlations (cumulants).

Anisotropic flow is defined as azimuthal asymmetry in particle distribution with respect to the reaction plane (the plane spanned by the beam direction and the impact parameter). It is called flow for it is a collective phenomena, but it does not necessarily imply hydrodynamic flow. It is commonly characterized using Fourier decomposition of the az-
imuthal distributions [3]. Then the first harmonic Fourier coefficient, \( v_1 \), describes directed flow, and the second harmonic coefficient, \( v_2 \), corresponds to elliptic flow; non-zero higher harmonics can be also present in the distribution.

The two reasons for anisotropic flow are the original asymmetry in the configuration space (non-central collisions!) and rescatterings. In a case of elliptic flow the initial “ellipticity” of the overlap zone is usually characterized by the quantity \( \varepsilon = (\langle y^2 - x^2 \rangle)/(\langle y^2 + x^2 \rangle) \), assuming the reaction plane being the \( xz \)-plane. With the system expansion the spatial anisotropy decreases. This is the reason for the high sensitivity of elliptic flow to the evolution of the system at very early times [4,5], 2–5 fm/c, of the order of the size of the system.

2. Directed flow

Three major results reported at this conference regarding directed flow were: the understanding of the role of momentum conservation [6,7] (due to lack of space I do not discuss it here, for details, see [8]), the use of 3-particle correlations in order to suppress the non-flow contributions [7], and the first results on directed flow of protons close to mid-rapidity [6]. The latter is related to earlier predictions of the so called “wiggle” in the dependence of \( v_1(y) \)[9,10].

Three-particle correlations, discussed in the talk of Borghini et al. [7], relies on the observed strong elliptic flow at mid-rapidity and permits directed flow measurements, which are much less affected by non-flow correlations. If in the usual two-particle correlator

\[
\langle e^{i(\phi_1 - \phi_2)} \rangle \approx v_1^2 + \delta_1, \tag{1}
\]

the non-flow contribution, \( \delta_1 \sim 1/N_{\text{tot}} \), where \( N_{\text{tot}} \) is the total number of particles, then the 3-particle correlation approach gives

\[
\langle e^{i(\phi_1 + \phi_2 - 2\phi_3)} \rangle \approx v_1^2 v_2 + \delta_2. \tag{2}
\]

The relative suppression of the non-flow contribution in Eq. 2 compared to Eq. 1 is of the order of \( 1/(v_2 N_{\text{tot}}) \), which for large elliptic flow could be significant. Mathematically, one can trace that in Eq. 2, the contribution of any correlations projected onto the reaction plane and the plane perpendicular to the reaction plane enter with opposite signs. The non-flow contributions, by definition, are the correlations not dependent on the relative orientation with respect to the reaction plane, and as such just cancel out from the final result.

The so called “wiggle” in directed flow, the three times change in the sign of directed flow in the midrapidity region, had been predicted a few years ago. The origin of this wiggle is somewhat different in different models, but any of the explanations would be very intriguing and interesting. In the “third flow component” picture [9], it results from the expansion of the initially tilted disk of the compressed matter. It appeared that the effect is present only if QGP is produced. Thus the wiggle might be a signature of the QGP production. The second explanation of the wiggle relies on the non-complete stopping of nucleons during the collisions, which results in the correlation of the position of the nucleon in the transverse plane and their rapidity. Combining this with a subsequent radial expansion one gets the wiggle [10]. The first results have been presented by the
NA49 Collaboration [6] (see Fig. 1): One can see a clear indication of the change of sign of directed flow of protons as a function of rapidity for the most peripheral events. It would be extremely interesting to see the analogous results from experiments at RHIC. Detailed model predictions for the energy dependence of directed flow of both pions and baryons would also be very interesting.

3. Elliptic flow

There have been many new results and ideas presented at this conference. I will only briefly mention the most important (from my point of view).

3.1. Comparing the results from different experiments

Anisotropic flow results at this conference have been presented by many collaborations [6,7,11,12,13]. As always in such a case the question appears if these results are consistent. There are obvious difficulties to perform a fair comparison: different collaborations use different centralities. Nevertheless, I would conclude that the data where comparable are consistent (for the figures see the slides of my talk).

The second question often asked during the conference concerns transverse momentum dependence of elliptic flow at different collisions energies. The integrated elliptic flow is higher at RHIC than at SPS. The question is if \( v_2 \) as a function of \( p_t \) become steeper or if the observed increase in integrated flow is mostly due to the increase in mean transverse momentum? To answer this very interesting question is more difficult, as the slope of \( v_2(p_t) \) strongly depends on centrality and one does have to have the same centralities in different experiments for comparison. With the existing data, however, I would conclude that in the central collisions the slope of \( v_2(p_t) \) at SPS energies looks significantly smaller.
than at RHIC; in mid-central collisions the difference is not that large. (I discuss the centrality dependence of \(v_2\) in more detail below.)

### 3.2. Flow and non-flow from multi-particle correlations

Anisotropic flow is a multi-particle phenomena. It means that if one considers many-particle correlations instead of two-particle correlations, the relative contribution of non-flow effects (due to few particle clusters) would decrease. Considering many-particle correlations, one has to subtract the contribution from correlations of the lower-order multiplets and use cumulants instead of simple correlators \[33\]. For example, correlating four particles, one gets \(u_i \equiv e^{i\phi_i}\)

\[
\langle u_{n,1} u_{n,2} u_{n,3} u_{n,4}^* \rangle = v_n^4 + 2 \cdot 2 \cdot v_n^2 \delta_n + 2 \delta_n^2, \tag{3}
\]

where \(\delta_n\) stands for the non-flow contribution to two particle correlator: \(\langle u_{n,1} u_{n,2}^* \rangle = v_n^2 + \delta_n\). Subtracting from the expression (3) twice the square of the two particle correlator, one is left with only the flow contributions

\[
\langle\langle u_{n,1} u_{n,2} u_{n,3} u_{n,4}^* \rangle\rangle \equiv \langle u_{n,1} u_{n,2} u_{n,3} u_{n,4}^* \rangle - 2 \langle u_{n,1} u_{n,2}^* \rangle^2 = -v_n^4, \tag{4}
\]

where the notation \(\langle\langle \ldots \rangle\rangle\) is used to denote the cumulant. A very elegant way of calculating cumulants in flow analysis with the help of the generating function was proposed in \[33\]. The NA49 Collaboration presented elliptic flow results from 4-, 6- and even 8-particle cumulants \[7\]. Remarkably, the results from all higher order cumulants agree well, indicating that even 4-particle cumulants already suppress the non-flow contribution to a negligible level. The use of the multi-particle correlations permits one to measure the non-flow contribution and check its multiplicity dependence. The latter is expected to be roughly inversely proportional to the multiplicity, thus reflecting the small cluster origin of such correlations. Indeed, the result reported by the NA49 Collaboration are in agreement with a \(1/N\) dependence.

The STAR Collaboration presented results from 4-particle correlations at \(\sqrt{s_{NN}} = 130\) GeV and \(\sqrt{s_{NN}} = 200\) GeV \[17\], Fig. 2. Transverse momentum dependence of the non-flow (relative) contribution was also discussed \[15\]. The results are consistent with weak increase in the relative non-flow signal from 15% at low \(p_t\) to about 20% at \(p_t \sim 4\) GeV/c (at \(\sqrt{s_{NN}} = 130\) GeV). Finally, note a possible increase of the relative non-flow contribution with the collision energy, from 7-10% at SPS \[7\] to about 15% at \(\sqrt{s_{NN}} = 130\) GeV and \(\sim 20%\) at \(\sqrt{s_{NN}} = 200\) GeV at RHIC \[15\]. Both effects are consistent with the increase in the contribution from hard processes.

#### 3.2.1. Flow fluctuations

Very good statistics results reported at this conference become sensitive to another effect usually neglected in flow analysis, namely, event-by-event flow fluctuations. The latter can be due to two different reasons: “real” flow fluctuations – fluctuations at fixed impact parameter and fixed multiplicity (see, for example, \[14\]), and impact parameter variations among events from the same centrality bin in a case where flow does not fluctuate at fixed impact parameter. Note that these fluctuations affect any kind of analysis, including the “standard” one based on pair correlations. The reason is that any flow measurement is based on correlations between particles, which are sensitive only
to certain moments of the distribution in $v_2$. In the pair correlation approach with the reaction plane determined from the second harmonic, the correlations are proportional to $v^2$. Averaging over events gives $\langle v^2 \rangle$, which in general is not equal to $\langle v \rangle^2$. The 4-particle cumulant method involves the difference between 4-particle correlations and (twice) the square of the 2-particle correlations. It is usually assumed that this difference comes from non-flow correlations. Note, however, that this difference ($\langle v^4 \rangle - \langle v^2 \rangle^2 \neq 0$) could be due to flow fluctuations. Let us consider an example where the distribution in $v$ is flat from $v = 0$ to $v = v_{\text{max}}$ and there is no non-flow contribution. Then, a simple calculation would lead to the ratio of the flow values from the standard 2-particle correlation method and 4-particle cumulants as large as $\frac{\langle v^2 \rangle}{\langle (2\langle v^2 \rangle - \langle v^4 \rangle)^{1/4} \rangle} = 5^{1/4} \approx 1.5$. Thus comparing any theoretical model with the data one should take into account flow fluctuations if they exist in the model.

**Figure 2.** STAR Preliminary results [17] on centrality dependence of elliptic flow from 4-particle cumulant analysis.

**Figure 3.** PHOBOS preliminary results [13] on pseudorapidity dependence of elliptic flow at $\sqrt{s_{NN}} = 200$ GeV.

### 3.3. Pseudorapidity dependence

The PHOBOS Collaboration is still the only one which reports elliptic flow in a wide pseudorapidity range, Fig. 3. This pseudorapidity dependence is still a challenge for the hydrodynamic models [15], which predicts rather weak pseudorapidity dependence of elliptic flow. As was pointed out at the conference such behavior of $v_2$ in the hydrodynamic model could be related to the boost invariant initial conditions used in the calculations. Note also that PHOBOS results for elliptic flow at $\sqrt{s_{NN}} = 130$ GeV and 200 GeV are very similar, which is in some disagreement with the STAR results.

### 3.4. Elliptic flow at large $p_t$

An obvious interest in elliptic flow at large transverse momenta is due to a possible strong signal as a results of high $p_t$ parton energy loss [19,20]. Shuryak in his recent paper [21] argued that the signal observed by the STAR Collaboration (only elliptic flow results from 2-particle correlations were known at that moment) could be probably too strong.
He has calculated elliptic flow for the limiting case of very strong absorption resulting in predominant surface emission. Using his idea I arrived for the maximum flow values as a function of impact parameter

\[ v_{2,max} = \sin(2\alpha)/(6\alpha), \quad \text{where} \quad \alpha = \arccos(b/(2R)). \]  

Comparing this formula to the STAR data \cite{14} from 4-particle cumulants one finds reasonable agreement.

At this conference, the STAR Collaboration presented the results \cite{15} on \( v_2(p_t) \) up to \( p_t \approx 12 \text{ GeV/c} \) (from 2-particle correlations). It shows that elliptic flow is large at least to \( p_t \approx 6 - 8 \text{ GeV/c} \). Elliptic flow is maximum at \( p_t \sim 3 \text{ GeV/c} \) and probably decreases very slowly up to the highest momentum measured. To discuss reliably any trends in the region of \( p_t > 6 \text{ GeV/c} \), however, requires multi-particle correlation measurements. Model calculations are also needed.

Another interesting fact concerning flow at high \( p_t \) has been reported by the CERES Collaboration \cite{11}. According to their data, the saturation of \( v_2(p_t) \) at SPS energies is quite similar to the one at RHIC, although to make a definite conclusion one needs more carefully comparison.

### 3.5. Baryon and meson elliptic flow

At this conference both the STAR and PHENIX Collaborations presented very interesting results on \( p_t \) dependence of elliptic flow of baryons and mesons. Although the results from both experiments have rather large error-bars, both agree that baryon elliptic flow saturates at higher \( p_t \) and larger \( v_2 \) values than meson elliptic flow. From my point of view it could be due to the (partial) particle production via (constituent) quark coalescence at moderate transverse momentum. Then, in this region:

\[ \frac{d^3n_M}{d^3p_M} \propto \left[ \frac{d^3n_q}{d^3p_q}(p_q \approx p_M/2) \right]^2, \quad \text{and} \quad \frac{d^3n_B}{d^3p_B} \propto \left[ \frac{d^3n_q}{d^3p_q}(p_q \approx p_B/3) \right]^3, \]

resulting in larger saturation values of \( v_2 \) for baryons as well as the saturation point being at higher transverse momentum.

Note that Eq. 6 is valid only in a rather limited region of transverse momentum. At very low momentum probably most hadrons are formed via coalescence. Then their elliptic flow values should be similar to the elliptic flow of constituent quarks (I do not consider here the possible dependence on the mass of the particles). At really high \( p_t \), however, hadrons are formed mostly due to parton fragmentation. There, the elliptic flow of hadrons should be determined by the elliptic flow of the fragmenting partons and there should be no significant difference in baryon and meson flow (due to this mechanism and neglecting the difference in the parton fragmentation functions into baryons/mesons). Note that the coalescence effect, if present, would also lead to an increase of the relative baryon to meson ratio in the same \( p_t \) range.

The centrality dependence of the ratio \( v_{2,baryon}(p_t)/v_{2,meson}(p_t) \) would be extremely interesting. If the effect of baryon flow being larger than meson flow is indeed due to coalescence, one would expect that at higher centralities the crossings would appear at somewhat higher transverse momentum. A detailed comparison of the transverse momentum and centrality dependencies of elliptic flow of baryons/mesons and their yields could also help to understand the nature of both effects.
identified hadrons (−) \( v_2 \)
\( |\eta| < 0.35, \) min. bias, 
R.P. \( |\eta| = 3–4 \)
PHENIX Preliminary

identified hadrons (+) \( v_2 \)
\( |\eta| < 0.35, \) min. bias, 
R.P. \( |\eta| = 3–4 \)
PHENIX Preliminary

PHENIX Preliminary data on elliptic flow of protons/anti-protons and pions.

Figure 4. Upper panels: PHENIX Preliminary data on elliptic flow of protons/anti-protons and pions. Lower panels: STAR preliminary data on elliptic flow of \( \Lambda \)'s and \( K^0 \) and protons and pions.

3.6. Centrality dependence

In the hydrodynamic limit elliptic flow is approximately proportional to the original spatial ellipticity of the nuclear overlapping region \[22,23,24\], \( v_2 \propto \varepsilon \). In the opposite limit, usually called the low density limit \[25,26\], elliptic flow depends also on the particle density in the transverse plane: \( v_2 \propto \varepsilon \frac{dN/dy}{S} \), where \( S \) is the area of the overlapping zone. The comparison of the results on elliptic flow from the point of view of particle density in the transverse plane was first done in \[26\]. In this approach, the transition to deconfinement would lead to some wiggles in \( v_2/\varepsilon \) dependence, (“kinks”) \[27,25,26\].

Fig. 5 shows the recent (\( \sqrt{s_{NN}} = 130 \) GeV) STAR results on elliptic flow from 4-particle cumulants \[14\], preliminary NA49 \[6\] (also from 4-particle cumulants), and E877 results. New measurements at full RHIC energies of \( \sqrt{s_{NN}} = 200 \) GeV reported by STAR \[17\] are also shown. For this Figure I have rescaled down these new data points by a factor of 1.06 to account for the change in mean transverse momentum (in 200 GeV data set the low transverse momentum cutoff is 150 MeV/c compared to 75 MeV in 130 GeV data). Note also that SPS data do not have a low \( p_t \) cutoff. (There are possible systematic errors in Fig. 8 of the order of 10-20% due to uncertainties in centrality measurements. However,
these uncertainties do not alter the general trend). Fig. 5 shows that at high particle densities the data reach hydrodynamical limits. With relatively large error-bars for the most central collisions it is difficult to draw any conclusion about the saturation at the hydrodynamical limit. As for the hydrodynamic limits, they are also somewhat model dependent. In some cases (depending on the latent heat and equation of state) in the model [24] one can observe an almost linear dependence of \( v_2 \) on particle density.

A closer examination of the plot in the region of 7-15 particles/fm\(^2\) shows that there is no scaling in this region. (This is probably related to the use of \( \varepsilon \) calculated using the specific weight according to the number of wounded nucleons. One should also take into account slightly different transverse momentum regions used in different analyses.) Note that the data from both RHIC and SPS results show a rather flat region with some rise at density \( \tilde{15} \text{ fm}^{-2} \). One could speculate that such a behavior could indicate a change in the physics of rescatterings. Noteworthy that the color percolation point discussed by Satz [28] is just in the same region (shown by an arrow in figure). Very interesting that the WA98 Collaboration [29] analyzing the high transverse momentum photon flow also observes a non-smooth behavior at the same place.

Another indication of non smooth flow dependence on the particle density in this region can be seen in the figure showing an elliptic flow excitation function [6]. In this figure both NA49 and NA45 data points show very little increase in the average flow from 40\( \text{A GeV} \) to 160\( \text{A GeV} \) data, while there is a significant increase between highest AGS point and lowest SPS, and between SPS and RHIC.\(^1\)

![Figure 5](image1.png)

**Figure 5.** \( v_2/\varepsilon \) as a function of particle density. The curves are only to indicate the possible structure.

![Figure 6](image2.png)

**Figure 6.** Pion elliptic flow at midrapidity for 25% centrality versus \( \sqrt{s_{NN}} \).

### 3.7. Models

It has been mentioned many times that at RHIC energies the hydrodynamic description of the results is quite successful. However, a few problems, like the description of the

\footnote{In the poster of H. Sako, CERES Collaboration, one can also notice an interesting increase in multiplicity as well as mean transverse momentum fluctuations at beam energy of 40\( \text{A GeV} \).}
pseudorapidity dependence still remain. The hydrodynamic model has been discussed in a separate talk at this conference and many details can be found there.

At this conference there also was presented a model with totally hadronic rescatterings starting at zero time, which also describes many features of the data.

AMPT (A Multi Phase Transport) model also describes the data very well in the so-called “string melting” scenario with quark-quark cross sections of about 5 mb. More detailed examination of the “string melting” scenario reveals that it is nothing else than what one would do in a case of a constituent quark picture. Namely, the number of quarks in the system is calculated as the number of quarks in the final hadrons. The final formation time (after which a quark can interact) is also taken into account. The cross section of 5 mb also does not look unusual - it would be close to the total NN cross section divided by 9. Note that the AMPT model also quite successfully describes the HBT radii. This model definitely deserves further study.

4. Conclusions

I will summarize the most important results just by enumeration:
- the “wiggle” in proton directed flow has been observed at SPS.
- non-flow contribution is better understood and measured both at SPS and RHIC.
- at RHIC $v_2(p_t)$ saturates at values close the ones in the surface emission picture.
- $v_2$ of baryons exceeds $v_2$ of mesons from $p_t$ about 2 GeV/c till at least 3–4 GeV/c.
- At RHIC elliptic flow persists up to $p_t \approx 8 – 12$ GeV/c.
- the saturation of elliptic flow at SPS probably not very different than at RHIC.
- The dependence of elliptic flow on pseudorapidity is rather strong. It drops about 2 times at about $\eta = 3$. (Still a challenge for the hydrodynamic description.)
- $v_2/\varepsilon$ is roughly proportional to particle density in the transverse plane ($dN/dy$)/$S$ reaching the hydrodynamic model predictions in central collisions.

In this summary I also want to mention a few important measurements for the future:
- we have to measure non-flow correlations in $pp$ collisions and compare them to the ones measured in nuclear collisions.
- we need to check for non-flow contribution at high transverse momenta.
- centrality dependence of baryon/meson elliptic flow would be very interesting.
- the collision of lighter system (e.g. Cu+Cu) and (multi)strange particle flow will be very important to understand the origin of the observed collectivity.
- different RHIC collaborations have data taken at $\sqrt{s_{NN}} =20$ GeV. It would be really interesting to analyze these data and compare with SPS results.
- directed flow at RHIC will be probably the next result from RHIC...
- the percolation point region should be looked at in great detail.
- finally, we need a detailed comparison (at a level of a few percent) of the results from different experiments; for that we need the results corresponding to the same centralities.

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REFERENCES

1. Y. Zhang and J. Wessels for the E877 Collaboration, Quark Matter ’95, Nucl. Phys. A590 (1995) 557c.
2. S. Voloshin and Y. Zhang, Z. Phys. C 70, 665 (1996).
3. A. M. Poskanzer and S. A. Voloshin, Phys. Rev. C 58, 1671 (1998).
4. H. Sorge, Phys. Rev. Lett. 78, 2309 (1997).
5. B. Zhang, M. Gyulassy, C.M. Ko, Phys. Lett. B 455 (1999) 45.
6. A. Wetzler for the NA49 Collaboration, this proceedings.
7. N. Borghini, P.M. Dinh, and J.-Y. Ollitrault, this proceedings.
8. N. Borghini, P.M. Dinh, J.-Y. Ollitrault, A.M. Poskanzer, and S.A. Voloshin, Phys. Rev. C66 (2002) 014901.
9. L.P. Csernai, D. Röhrich, PLB 458 (1999) 454; J. Brachmann, S. Soff, A. Dumitru, H. Stöcker, J.A. Maruhn, W. Greiner, D.H. Rischke, Phys.Rev. C61 (2000) 024909. V. Magas, L.P. Chernai, D. Strottman, hep-ph/0202085.
10. R.J.M. Snellings, H. Sorge, S.A. Voloshin, F.Q. Wang, and N. Xu, Phys. Rev. Lett. 84 (2000) 2803.
11. A. Slivova for the CERES Collaboration, this proceedings.
12. S. Esumi for the PHENIX Collaboration, this proceedings.
13. S. Manly for the PHOBOS Collaboration, this proceedings.
14. STAR Collaboration, C. Adler et al., Phys. Rev. C, 66 (2002) 034904.
15. K. Filimonov for the STAR Collaboration, this proceedings.
16. C.E. Aguia, Y. Hama, T. Kodama, and T. Osada, hep-ph/0106266, 2001.
17. L. Ray for the STAR Collaboration, this proceedings.
18. T. Hirano, Phys. Rev. C65, 011901(R), 2001, and this proceedings.
19. R. Snellings, A.M. Poskanzer, and S. Voloshin, nucl-ex/9904003.
20. X. N. Wang, Phys. Rev. C 63 (2001) 054902; M. Gyulassy, I. Vitev, and X. N. Wang, Phys. Rev. Lett. 86, 2537 (2001).
21. E.V. Shuryak, nucl-th/0112042.
22. J.-Y. Ollitrault, Phys. Rev. D 46, 229 (1992).
23. P. Kolb, J. Sollfrank and U. Heinz, Phys. Lett. B 459, 667 (1999); Phys. Rev. C 62, 054909 (2000).
24. D. Teaney, J. Lauret, and E.V. Shuryak, Phys. Rev. Lett. 86, 4783 (2001).
25. H. Heiselberg and A.-M. Levy, Phys. Rev. C 59, 2716 (1999).
26. S.A. Voloshin and A.M. Poskanzer, Phys. Lett. B 474, 27 (2000).
27. H. Sorge, Phys. Rev. Lett. 82, 2048 (1999).
28. H. Satz, this proceedings.
29. S. Bathe for the WA98 Collaboration, this proceedings.
30. Zi-Wei Lin and C.M. Ko, nucl-th/0108039.
31. P. Huovinen, this proceedings.
32. T. Humanic, this proceedings.
33. N. Borghini, P.M. Dinh, and J.-Y. Ollitrault, Phys. Rev. C, 63 (2001) 054906; Phys. Rev. C 64 (2001) 054901.