# The elliptic flow of neutral transverse energy in heavy ion interactions at SPS energies

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The threshold effect in the J/$\psi$ suppression seen in the NA50 data in lead on lead interactions at the CERN SPS [1,2] can't be taken into account by conventional models. Other candidate models [3] use a phase transition, and therefore let suppose that the thermodynamic variables are defined everywhere that is the so-called thermalization. The in-plane elliptic flow, which has been proposed [4] in order to probe the thermalization at these beam energies, is found to be actually present in lead on lead interactions at 158A GeV/$c$, but can't be observed in sulphur on sulphur at 200A GeV/$c$ in the NA38 data [5,6].

## 1. The centrality detectors

The experiment uses three centrality detectors : an ElectroMagnetic Calorimeter (EMC), a Zero Degree Calorimeter (ZDC), and a Multiplicity Detector (MD). All of them are azimutally and evenly segmented, which allows to get the azimutal distribution of the measured quantity, the integral of which is the centrality estimator. They perform a discrete sampling of these periodic functions like the azimutal distribution of the neutral Transverse Energy ($E_T$) for instance. The sixfold EMC whose pseudo rapidity range is [1.1,2.3], and the fourfold ZDC are used in the present analysis. In order to compare different systems, we use the scaled transverse energy, which happens also to be the scaled multiplicity $m = \frac{E_T}{E_{Tknee}} = \frac{M}{M_{max}}$, where $E_{Tknee}$ is the $E_T$ value for central collisions.

## 2. The method

Using the technic of the finite Fourier series and the Discrete Fourier Transform applied to the sampled functions $\frac{dE_T}{d\phi}$ and $\frac{dE_{ZDC}}{d\phi}$, one can get their shapes for each event. From the six numbers provided by the EMC, one gets six coefficients of the corresponding finite Fourier series expansion.

$$\frac{dE_T}{d\phi} = \frac{E_{T(event)}}{2\pi} \left(1 + a_1 \cos\phi + b_1 \sin\phi + a_2 \cos 2\phi + b_2 \sin 2\phi + b_3 \sin 3\phi\right) \tag{1}$$

The first factor, $\frac{E_{T(event)}}{2\pi}$ provides the centrality measurement. The five scaled coefficients, $a_i, b_i$ describe the shape of the azimutal distribution of the transverse energy for the given event. They are related straightforward to those of a polar expansion of the same quantity, from which the directed $(V_1, \phi_1)$ and elliptic $(V_2, \phi_2)$ flow are usually defined [7]. They provide the direction and the magnitude of the directed and the elliptic raw anisotropy of the $E_T$ azimutal distribution. One gets in the same way the shift of the centroid, and then the reaction plane from the ZDC four numbers.

The raw anisotropy measured for one event is the sum of two terms : the intrinsic one, which is the flow, and a statistical fluctuation. The latter can be important due to the finite number of particles reaching the EMC. In order to get rid of the statistical fluctuations, we must deal with samples of events of same multiplicity.

For such an $E_T$ bin, $a_i, b_i$ have centred gaussian distributions. The flow and the fluctuations are independent so that the corresponding variances add to produce the raw effect. Two circumstances allow to measure the statistical fluctuations of the anisotropy magnitude, and hence to remove them. It can be stated, from symmetry arguments, that $b_3$ must have an intrinsic null value in central collisions of spherical nuclei, and at any centrality in the case of symmetric systems. Hence, it originates from purely statistical fluctuations and, in some way, measures them. The ratios

$$R_{i3} = \frac{\langle a_i^2 \rangle + \langle b_i^2 \rangle}{2\langle b_3^2 \rangle} \qquad \text{for} \qquad i = 1, 2 \tag{2}$$

are free of systematic errors and can be written down as

$$R_{i3} = K \cdot m V_i^2 + C_i \qquad \Longrightarrow \qquad \lim_{m \to 0} R_{i3} = R_{i3}|_{m=1} = C_i \tag{3}$$

The constant $C_i$ is got from the central events, and K from $\langle b_3^2(m) \rangle$. If there is no flow at a given order $i$, the corresponding ratio $R_{i3}$ must be independent from the multiplicity.
Conversely, this plot of $R_{i3}$ versus $m$ must exhibit a bump when any flow is present. Of course, such a plot would be efficient when looking for a flow $V_i$, whose centrality depedence is then straitforward to get. The second point is to state if, when present, the elliptic flow is in-plane or out-of-plane. The ZDC provides four numbers, from which we can get the centroid shift due to the bounce of the projectile fragments. This defines the reaction plane. The angular resolutions are good enough to decide, despite the smearing coming from the statistical fluctuations, if the elliptic flow is in plane or out of plane.

## 3. The results

### 3.1. Lead on lead collisions at 158A GeV/$c$

The $R_{23}$ plot (fig.1) shows evidence for an elliptic flow. The shape of the $V_2$ centrality dependence (fig.2) looks like the expected one, but its maximum is lower than calculated.
The angular distribution of the elliptic flow relative to the reaction plane shows clearly that it's in-plane.

### 3.2. Sulphur induced interactions at 200A GeV/$c$

For the sulphur SPS beam induced interactions, the data have been taken by the NA38 collaboration, with a very similar EMC. No centrality dependence of the $R_{23}$ variable can be found in the sulphur on sulphur (fig.3), which obviously shows that there is no elliptic flow. The result is the same for the sulphur on copper data (fig.4). The copper nucleus is a small and spherical one, therefore the system is quite symmetric.

## 4. Conclusion

The in plane elliptic flow is a signal for the thermalization of the medium produced in the initial state. It has been found at the SPS in lead on lead collisions. No elliptic flow can be seen in the sulphur on sulphur data.

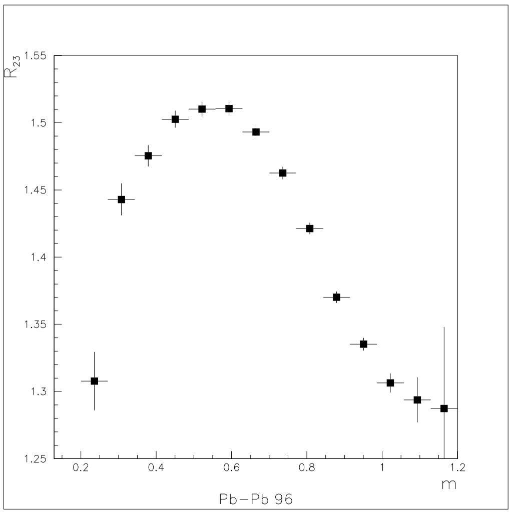


Figure 1. $R_{23}$ vs $m$ for a sample of 6,130,085 events in Pb-Pb ('96 data)

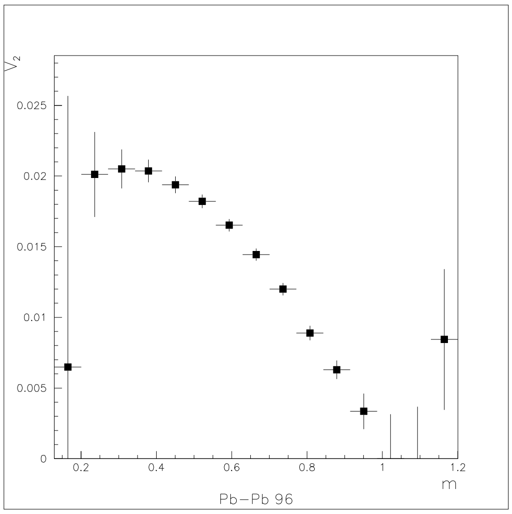


Figure 2. Centrality dependance of the elliptic flow $V_2$ of neutral transverse energy in the rapidity range [1.1,2.3] in Pb-Pb (158A GeV beam).

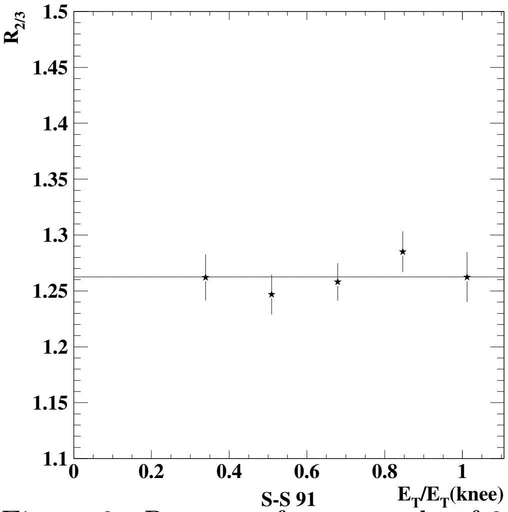


Figure 3. $R_{23}$ vs $m$ for a sample of 81,085 events in S-S ('91 data)

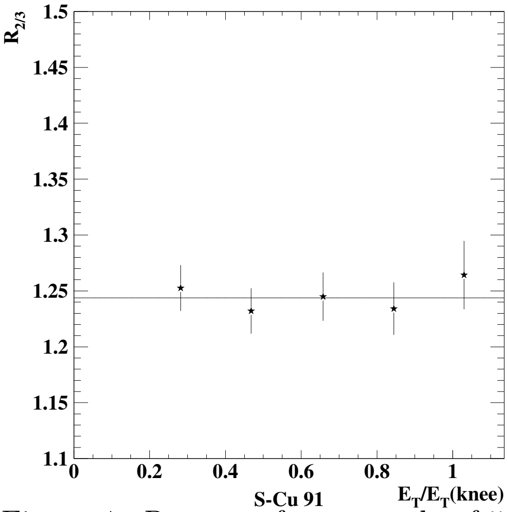


Figure 4. $R_{23}$ vs $m$ for a sample of 56,615 events in S-Cu ('91 data)

## REFERENCES


1. M.C. Abreu et al., Phys. Lett. B 410 (1997) 337
2. M.C. Abreu et al., Phys. Lett. B 450 (1999) 456
3. T. Matsui, H. Satz, Phys. Lett. B 178 (1986) 416
4. J.Y. Ollitrault, Phys. Rev. D 46 (1992) 229
5. I. Chevrot et al., the NA50 Collaboration, Proceedings Moriond'98, March 1998
6. I. Chevrot, Thèse, Université Clermont II, 1998
7. S. Voloshin, Y. Zhang, Z. Phys. C 70 (1996) 665