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Collective Flow Effects in Ne + Pb Collisions at E/A=400 and 800 MeV

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Triple differential cross sections in momentum p, polar angle θ, and azimuthal angle φ with respect to the reaction plane, have been measured at the Saturne synchrotron in Saclay for collisions between neon and lead nuclei at incident energies of 400 and 800 MeV per nucleon, using the pictorial drift chamber (PDC) of the Diogene 4π detector[(1)]. A barrel-shaped set of 30 plastic scintillator slats surrounds the PDC; at least 2 of these must be hit in order to trigger an accepted event. The PDC and trigger acceptances used in this analysis were:

PDC: $20° < \theta < 132°$

	pions	baryons	
	$\eta > 0.66 + 0.77\ y$	$\eta > 0.36 + 0.72\ y$	for $y<0$
	$\eta > 0.66 - 0.63\ y$	$\eta > 0.36 - 0.80\ y$	for $y>0$

TRIGGER: $37° < \theta < 119°$

	pions	baryons	
	$\eta > 0.81 + 0.33\ y$	$\eta > 0.41 + 0.30\ y$	for $y<0$
	$\eta > 0.81 - 0.33\ y$	$\eta > 0.41 - 0.40\ y$	for $y>0$

where η is the transverse momentum divided by the mass and y is the rapidity.

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The experimental results are compared with the intranuclear cascade model (INC)[2]. As shown in Ref.3, the cascade calculation does not reproduce correctly the pseudo-proton multiplicity distributions, $M_{\tilde{p}}$, where pseudo-protons $\tilde{p}$ consist of free protons and protons bound in fragment nuclei. Consequently, the impact parameter selection must be made in a manner independent of the shape of this distribution. Since the cascade does reproduce the integral under the $M_{\tilde{p}}$ distribution, impact parameters were defined by dividing the area under this distribution into five bins of approximately equal cross section, starting with the highest value of $M_{\tilde{p}}$ and corresponding to increasing impact parameter values such that $(b/b_{trig})^2$ = 0.1, 0.3, 0.5, 0.7, and 0.9, where b_{trig} is the maximum impact parameter corresponding to the trigger requirement. Results will be presented only for the first 4 bins, where there is a number of particles per event sufficient to define the reaction plane.

We have used the procedure suggested by Danielewicz and Odyniec[4] to evaluate the azimuthal angle φ of each particle with respect to the (coalescence invariant) impact parameter vector, defined event-by-event as:

$\vec{Q} = \Sigma(Z_i/A_i)(y_i-\langle y\rangle)\vec{p}_{\perp i}$ with $\langle y\rangle = (\Sigma(Z_i/A_i)m_i y_i)/(\Sigma(Z_i/A_i)m_i)$, and where the subindex refers to baryons with mass m_i, rapidity y_i, transverse momentum $\vec{p}_{\perp i}$, atomic number Z_i, and atomic mass A_i. For each particle, the transverse momentum p_x in the reaction plane is calculated as the projection of the transverse momentum in the direction of $\vec{Q}$; autocorrelations are suppressed as in Ref.4. The center of mass rapidity, $\langle y\rangle$, is not known a priori for the asymmetric system described here and is thus calculated for each event. The continuous function $(y_i-\langle y\rangle)$ replaces the weights originally proposed in Ref.4. Triple differential cross sections are obtained by adding particles from all events with a given multiplicity. For each rapidity interval, the average p_x/m is calculated from the projection of the cross section onto the p_x-axis.

Figure 1 shows $\langle p_x/m\rangle$ as a function of rapidity for Ne + Pb at E/A = 800 MeV, for pseudo-protons $\tilde{p}$ emitted in events with multiplicity $M_{\tilde{p}}$ ranging from 13 to 17, which corresponds to $(b/b_{trig})^2$ = 0.3. For the same value of impact parameter, the INC calculations use $M_{\tilde{p}}$ ranging from 19 to 26. The y dependence of $\langle p_x/m\rangle$ is almost linear, especially near the rapidity y_o where $\langle p_x/m\rangle$ is zero. This point can be interpreted as the rapidity of the emitting system, and the

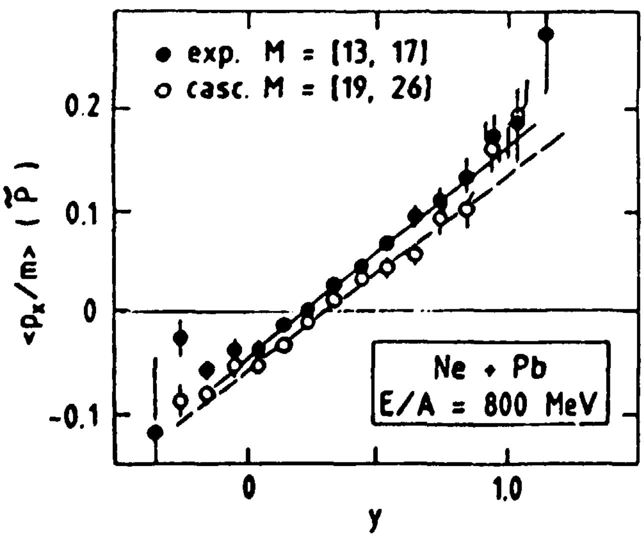

Fig.1 $\langle p_x/m\rangle$ versus rapidity, for pseudo-protons.

slope S at y_o is taken as a measure of the collective particle flow in this reaction.

The flow F is obtained from S as in Ref.4 after correction for effects due to the finite number of particles in each event. The ratio F/S varies between 1.3 and 2.5 . Figure 2 shows the resultant flow obtained from experiment and from the cascade calculation at both incident energies. The flow increases as a function of impact parameter, but the experimental flow is bigger than the INC calculation, and the difference increases at small impact parameters. The experimentally observed flow is bigger at the higher incident energy; this is not true for the INC calculation.

The flow carried by deuterons was found to be slightly bigger than the flow carried by protons. The biggest difference occurred at small impact parameters for 400 MeV per nucleon neon and at large impact parmeters for 800 MeV per nucleon neon. This kind of analysis needs to be pursued with better statistics before more definite conclusions can be drawn.

An example of the flow carried by pions is shown in Fig. 3, where $\langle p_x/m \rangle$ is positive for all values of the rapidity. The statistics are not adequate for a determination of the flow angle from a straight line fit to the data. Instead, the values of p_x/m, averaged over the rapidity, were binned by impact parameter. The results obtained at 800 MeV per nucleon are shown in Fig. 4, where the averaged $\langle p_x/m \rangle$ has been plotted as a function of impact parameter, for both π^+ and π^-. The average value of $\langle p_x/m \rangle$ is always positive and greater for

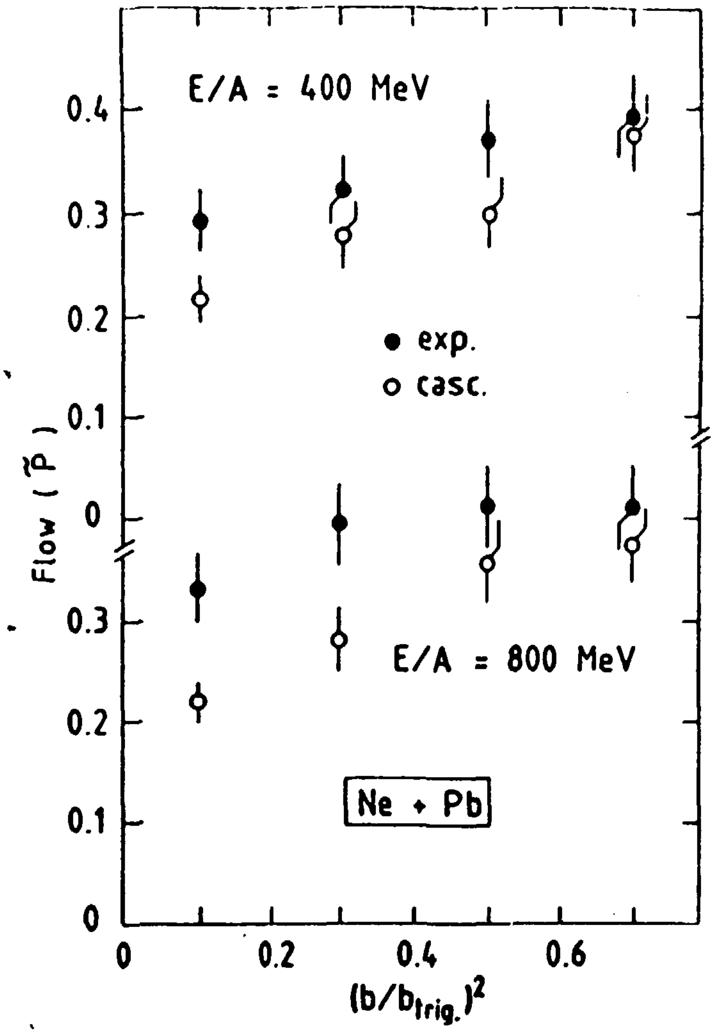

Fig.2 Flow versus impact parameter, for pseudoprotons.

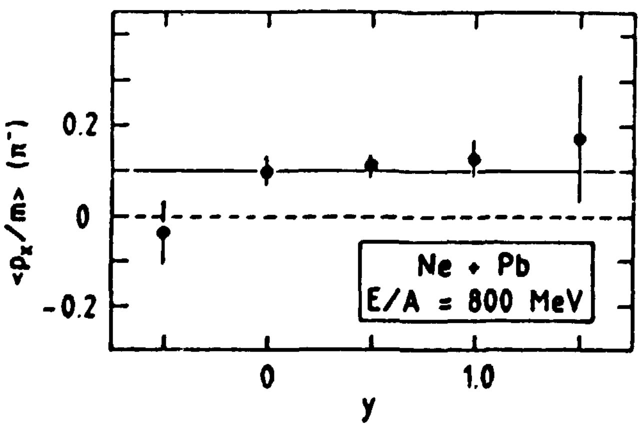

Fig.3 $\langle p_x/m \rangle$ versus rapidity, for π^-.

π^+ than for π^-, especially at intermediate impact parameters. The unidirectionality of the flow is further illustrated by the ratio between the number of pions emitted at positive values and the number emitted at negative values of $<p_x/m>$, which is equal to 1.3 . This property of the pion flow was already observed for π^- emitted in asymmetric collisions[5], but this constitutes the first observation of unidirectional π^+ flow. The unidirectionality can be understood qualitatively as a consequence of preferential absorption, by the heavy target nucleus, of pions emitted in the direction opposite to the impact parameter vector.

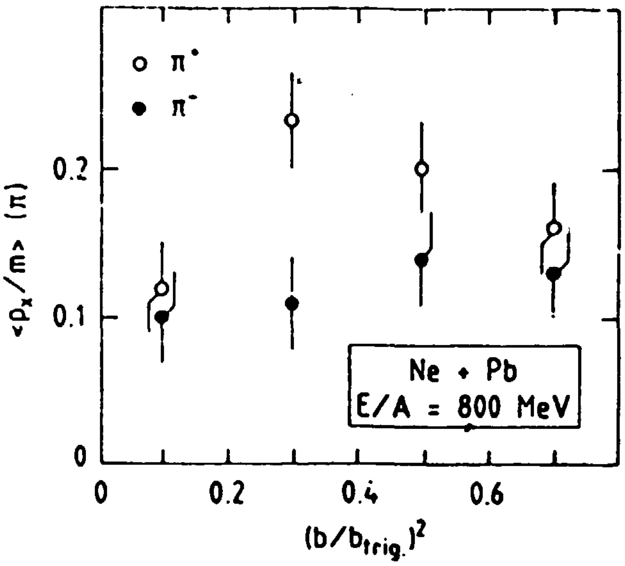

Fig.4 y-averaged $<p_x/m>$ versus impact parameter, for $\pi^{\pm}$.

Flow represents only part of the information contained in the triple differential cross sections. More information can be obtained by removing the acceptance dependence of the data and reconstructing the entire $(p_x/m,y)$ distributions. The result of such a reconstruction is shown in Fig. 5, for pseudo-protons at E/A = 800 MeV per nucleon. The $(p_x/m,y)$ distribution for three cuts in $M_{\tilde{p}}$ has been fitted to a 2-dimensional gaussian distribution tilted at some angle θ_1 from the beam axis. The 1/e-contour of this distribution in the $(p_x/m,y)$ plane is an ellipse with semi-axes σ_1 and σ_2 $(\sigma_1>\sigma_2)$.

A large amount of information can be easily obtained from Fig. 5. The rapidity at the center of each ellipse, which reflects the velocity of the emitting source, increases with increasing impact parameter, in qualitative agreement with a clean cylindrical cut picture of the collision for the asymmetric Ne + Pb system. Also in agreement with such a geometrical model is the fact that the area of the ellipses increases with increasing impact parameter. If the slope of the major axis of the ellipses shown in Fig. 5 is taken to represent a better measure of the flow angle, it can be seen

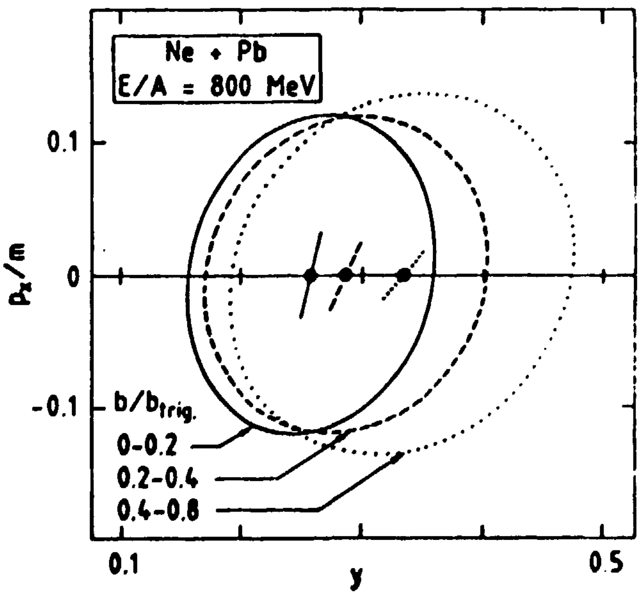

Fig.5 Contour plots in the $(p_x/m,y)$ plane, at the 1/e-level of the maximum, of the 2-dimensional gaussian fit for pseudoprotons and three impact parameters at E/A=800 MeV.

that the "real" flow angle varies from a large value of 75° at small impact parameter to a smaller value of 40° at large impact parameter. This information could not have been deduced from the usual flow measurements, which must yield a value of 0 for purely central collisions due to the symmetry for that case.

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