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CURRENT ANALYSES OF PARTICLE EMISSION IN NE-NUCLEUS COLLISIONS BETWEEN 400 AND 800 MEV PER NUCLEON

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CURRENT ANALYSES OF PARTICLE EMISSION IN NE-NUCLEUS COLLISIONS BETWEEN 400 AND 800 MEV PER NUCLEON.

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ABSTRACT We present preliminary data from neon induced reactions at 400 to 800 Mev per nucleon on various targets ranging from NaF to Pb, measured with the 4Π detector Diogene at Saturne. Multiplicity selected events are studied for their rapidity and transverse energy distribution behaviour. The proton data cannot be understood in terms of emission by a single thermalized source but rather suggest the contribution of a second source which is colder than the fireball. The pions, which cannot be emitted by a cold source, behave qualitatively as expected from a thermal emission process, and might thus be a much better "thermometer" than the protons for the fireball. The production of delta resonances in non peripheral collisions is clearly stated.

The large solid angle detector Diogene [1] has been used at Saturne for a systematic study of neon-nucleus collisions, at beam energies between 200 and 1000 MeV per nucleon, with four different targets C, NaF, Nb and Pb. The detector acceptance ranges from 20 to 132 degrees for the polar angle θ, with a full coverage of the azimuthal angle, and a low momentum cut-off of about 60 MeV/c for pions and 150 A.MeV/c for baryons. It is thus well suited to investigate the participant region. An impact parameter selection is performed by dividing the multiplicity distribution in five bins of roughly equal cross-section. Since the measurements are exclusive, at least within the detector acceptance, many features of the reactions can be studied. Here, we concentrate on double differential cross-section characteristics , for which there is very little published data [2,3,4,5], and present a clear evidence for the formation of Δ resonances in the collisions by studying π^+-p correlations. The data analysis is under way; although the results presented here are preliminary the qualitative features that will be discussed should not be modified by the refinements that are currently being performed.

Double differential cross-sections

In order to present the double-differential cross-sections, (see also ref. 6), we choose variables which are suited to reflect the thermodynamical properties of the system which emits the particles. Let us start from a thermal distribution of particles emitted by a single source. In the source frame the Boltzmann distribution can be expressed with dimensionless quantities [7]:

$$\frac{d^3N}{d^3p} = \frac{N}{4\pi m^3 K} \exp(- \frac{\tau_t ch(y)}{\tau}) \qquad (1)$$

where K depends only on the particle type and the temperature T, $\tau_t = E_t/m$, and $\tau = T / m$; $E_t^2 = m^2+p_t^2$, p_t is the transverse momentum and y the rapidity. With these variables, we can write a cross-section which is invariant by a Lorentz transformation parallel to the beam, as:

$$\frac{1}{\tau_t^2} \frac{d^2N}{d\tau_t dy} = N_{eff}(y).\exp(- \frac{\tau_t}{\tau_{eff}(y)}) \qquad (2)$$

where $N_{eff}(y) = ch(y-y_0).N/2K$ and $\tau_{eff}(y) = \tau/ch(y-y_0)$; y_0 is the rapidity of the source. Thus the distribution $1/\tau_t^2.d^2N/d\tau_t dy$ is simply an exponential defined by the two quantities N_{eff} and τ_{eff} that are related by $N_{eff}.\tau_{eff} = N.\tau/2K$, i.e. the product $N_{eff}.\tau_{eff}$ is constant (independent of y) in the case of emission by a single thermalized source. One should not expect to get this product strictly constant in the experiment since it is not possible to select a single impact parameter. However a fireball [8] calculation of the Ne + Pb reaction at E/A=800 MeV, taking into account the whole range of impact parameters, showed that the overall variation of $N_{eff}.\tau_{eff}$ should be less than one order of magnitude.

This way of analysing the data has clear advantages:

- the exponential fit is a straight line in semi-logarithmic plots, making the comparison with the data straightforward;
- the condition $N_{eff}.\tau_{eff} \sim$ constant is easy to check;

Even if this condition is not fulfilled, the procedure of fitting is convenient provided the fits are reasonably good:

- a fit is rather insensitive to the experimental cuts; indeed, Diogene cuts off most of the particles emitted by the spectators; thus this analysis allows to concentrate efficiently on the participants;
- the $d^2N/d\tau_t dy$ fitted distributions can be integrated analytically over τ_t to get the dN/dy distributions;

- the very large amount of data can be summarized by the y dependence of the two quantities N_{eff} and τ_{eff}.
- the quantity N_{eff} turns out to be extremely sensitive to the temperature: N_{eff} is multiplied by a factor larger than 10^5 when the temperature decreases from 80 to 40 MeV.

As can be seen in Fig. 1, the exponential fit of the data is satisfactory. However, in a few cases especially for peripheral collisions at mid-rapidity for E/A=800 MeV, the data cannot be fitted by an exponential; the curve structure might be attributed to the presence of protons produced in quasi-elastic N-N collisions. At low τ_t, the π^+ also happen to deviate from the exponential due possibly to Coulomb repulsion effects. For central collisions the fits are always satisfactory (typically, $0.7<\chi^2<2.5$); most results will concern the central collisions, which are anyhow the most interesting ones to study the behaviour of hot nuclear matter.

Proton results

The rapidity distributions were obtained by integrating $d^2N/d\tau_t dy$ over τ_t. The average rapidities exhibit very little dependence on the impact parameter. The width of the distribution, which is representative of the temperature in the thermal picture, increases as the collision becomes more central with the symmetric system Ne+NaF. For the Pb target, the distribution becomes narrower for more central collisions. As can be seen in Fig. 2, the distribution varies strongly as a function of incident energy for the NaF target: the mean rapidity follows the centre of mass rapidity of the nucleon-nucleon system; the width increases markedly with the incident energy thus following what one should expect for the fireball. Surprisingly the rapidity distribution varies very little as a function of beam energy for the Pb target: the mean rapidity is slightly above the rapidity of the fireball for central collision in a clean cut geometry; the width increases very slowly with the beam energy. Another surprise comes from the comparison of the Pb and the Nb target (Fig. 3): the distributions are very similar for both systems, but the distribution peaks at smaller rapidity for Nb than for Pb.

The temperature of the fireball is also reflected in the τ_{eff} values; lower temperatures are connected with lower τ_{eff} values. The y dependence of τ_{eff} should be of the $1/ch(y-y_0)$ type. As can be seen in Fig. 4 and 5, the τ_{eff} variation as a function of y has a bell shape (except for high rapidities where the error bars are large and where the data may be affected by systematic errors that are currently being corrected). However the y dependence is much stronger than $1/ch(y-y_0)$. The curves are shifted towards higher T_{eff} values when the beam energy is increased indicating that more energy is pumped into transverse energy (Fig. 4). A similar increase is observed when the collision becomes more central (fig. 5); T_{eff} increases also with the target mass. These two last effects would indicate that the larger the number of participant nucleons, the hotter the fireball; multiple collisions are more likely to occur in a large participant region, leading to a higher conversion of projectile kinetic energy into heat. At 800 MeV per nucleon, the situation is different: T_{eff} is nearly independent of impact parameter and target mass, except for the large rapidities where the data are not so safe.

For the deuterons, the T_{eff} values are about a factor 1.7 to 2 below the proton values. Thermal emission would give a factor of 2 due to the mass difference between the two particle types.

The $N_{eff} \cdot T_{eff}$ product is anything but constant as a function of rapidity (Fig. 6). The large variation of this product (5 to 6 orders of magnitude) would rather suggest that some of the protons (especially in the target rapidity region) might be emitted by a source at a temperature much smaller than the fireball. Do we see some compound nucleus like events ?

Pion results

Pions are subject to strong Coulomb effects. This feature is obvious in the comparison of π^+ and π^- rapidity distributions for peripheral collisions (Fig. 7). The π^+ distributions are much enhanced in the regions of the target and projectile as compared to the π^- ones. Isospin effects show up in the impact parameter dependence of the yields: the π^- are strongly favoured in central collisions, even with the NaF target which is the most isospin symmetrical system. There are 2 reasons for this effect:

- the more central the collision, the larger the fraction of the target (which contains more neutrons that protons) in the participants;
- the production of composites (mainly deuterons) increases with the centrality of the collision, thus increasing the isospin asymmetry of the remaining participants.

For the nearly symmetric system Ne+NaF, the peak position is the same for π^+ and π^- and is at the y_{NN} rapidity (Fig. 8). For the asymmetric systems, the π^- have roughly the same average rapidity as the protons; the π^+ have a markedly larger rapidity. The width of the rapidity distribution is always larger for

π^+; it decreases when the target mass increases which could be interpreted as a decrease of the temperature with heavier targets.

T_{eff}, with the NaF target (Fig. 9), is the same for π^+ and π^-. With the Nb and Pb targets, T_{eff} is larger for π^+ than π^-; this effect could be attributed to Coulomb effects. In all cases, the y dependence of T_{eff} is compatible with a $1/ch(y-y_0)$ distribution, except in the high rapidity region where the results are not safe yet. T_{eff} increases with beam energy, decreases when the target mass is increased and decreases when the collisions becomes more central. These two last features are expected in the thermal picture; they are contradictory to the proton results.

The product $N_{eff} \cdot T_{eff}$ is nearly constant over y for the π^+; it is also constant for π^- in the case of the NaF target (Fig. 10). For the two other targets, its overall variation is at most two orders of magnitude, that is not too far from what one could expect for a thermalized source.

The pion behaviour is much closer to what one expects from the emission by a thermalized system than the behaviour of protons. This is in favour of the assumption that some of the protons are emitted by a cooler source: since real pions do not exist in the projectile and target, their emission requires energy; they thus cannot be emitted by a cool source. The pions would then be a much better thermometer of the fireball than the protons.

Delta resonances

The $\pi^{\pm}$-proton correlations have been investigated by comparing the invariant mass distribution of all "correlated" pairs (the pion and the proton are measured in the same event) to the same invariant mass distribution for uncorrelated pairs (the pion and the proton are from two different events) in order to subtract the large combinatorial background. Only π^+-p correlations show a clear signal (Fig. 11). This is observed unambiguously only with the NaF target (where the multiplicity and hence the combinatorial background are the smallest), and shows up mainly at the highest energy reported here of 800 MeV per nucleon. The event trigger eliminates peripheral collisions in the data acquisition; thus the Δ resonances detected here are produced in non peripheral nucleus-nucleus collisions. This is the first time that such production is measured.

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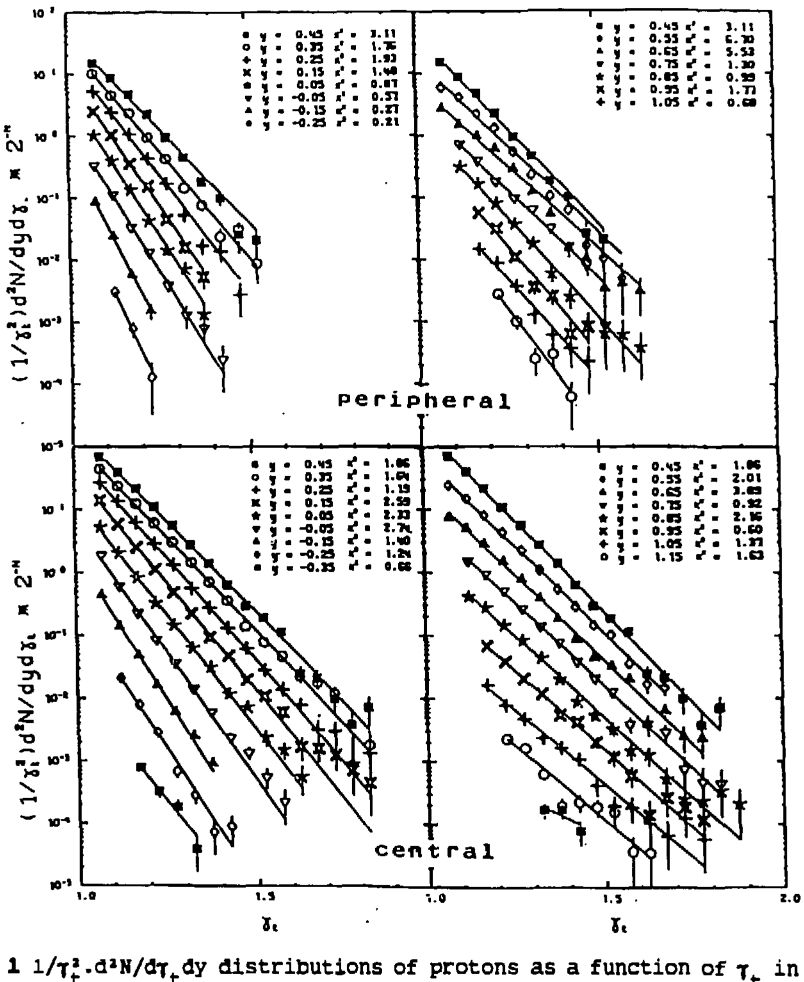

Fig. 1 $1/\gamma_t^2 . d^2N/d\gamma_t dy$ distributions of protons as a function of γ_t in rapidity bins .1 unit wide around the values indicated in the figure. In order to make the plot readable, the rapidity interval is divided into 2 domains; furthermore, the second curve starting from the top has its values divided by 2, and each subsequent curve is divided by a further factor of 2.

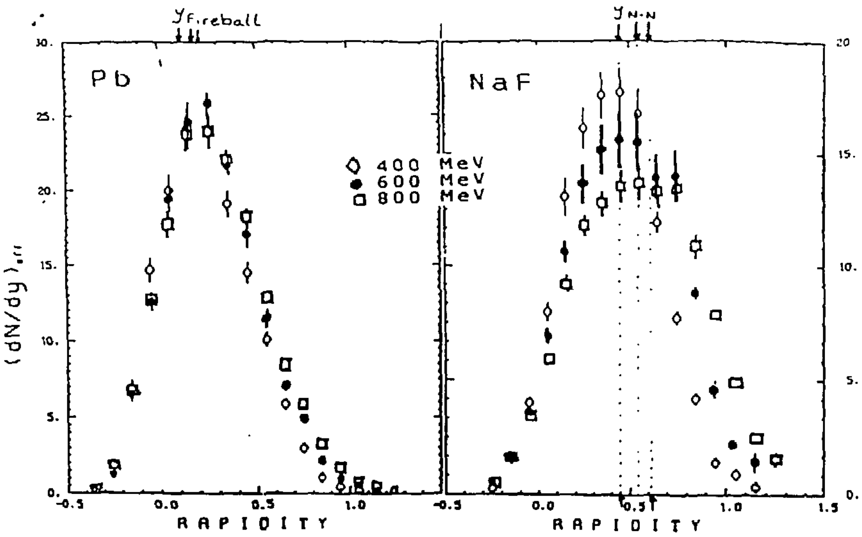

Fig. 2 Rapidity distributions of protons in central collisions of Ne+Pb (left) and Ne+NaF (right) at 3 beam energies per nucleon. On the left figure, the arrows indicate the rapidity of the fireball for central collisions; on the right figure, the arrows indicate the centre of mass rapidity.

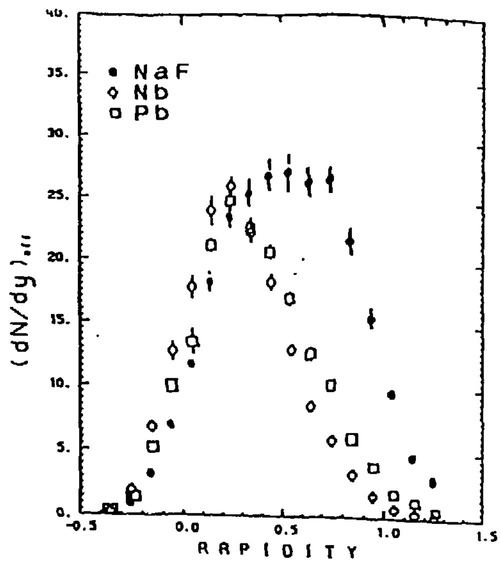

Fig. 3 Rapidity distributions of protons in central collisions of Ne with the three targets NaF, Nb and Pb at E/A=800 MeV.

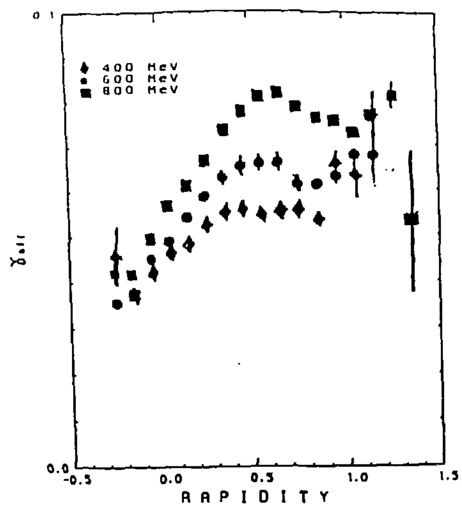

Fig. 4 T_{eff} versus rapidity at three different beam energies, for protons emitted in central collisions of Ne+NaF.

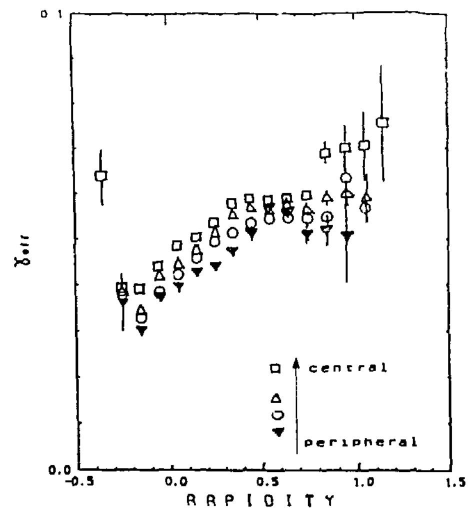

Fig. 5 T_{eff} versus rapidity in different impact parameter bins, for protons emitted in Ne+Pb collisions at E/A=400 MeV.

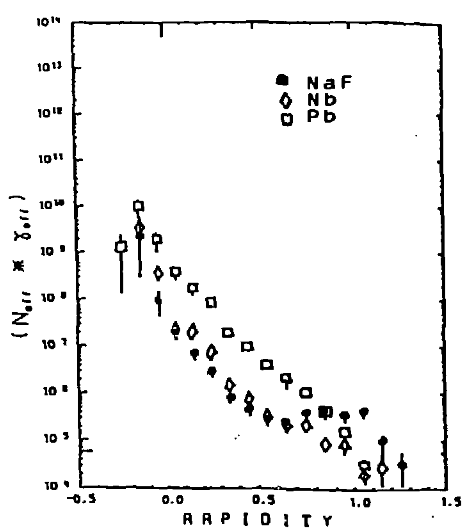

Fig. 6 $N_{eff} \cdot T_{eff}$ product versus rapidity for protons emitted in central collisions of Ne with three different targets at E/A=800 MeV.

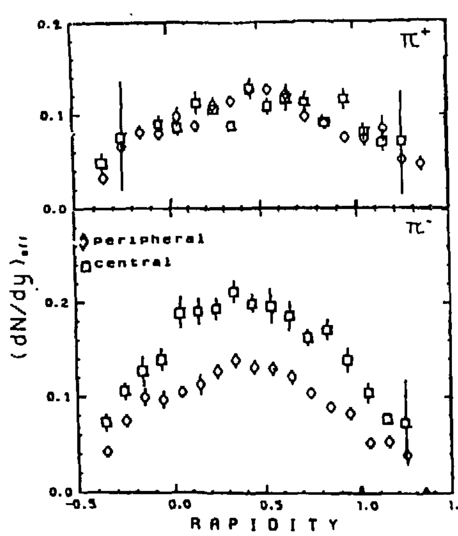

Fig. 7 Rapidity distributions of pions emitted in rather peripheral and rather central collisions of Ne+NaF at E/A=400 MeV.

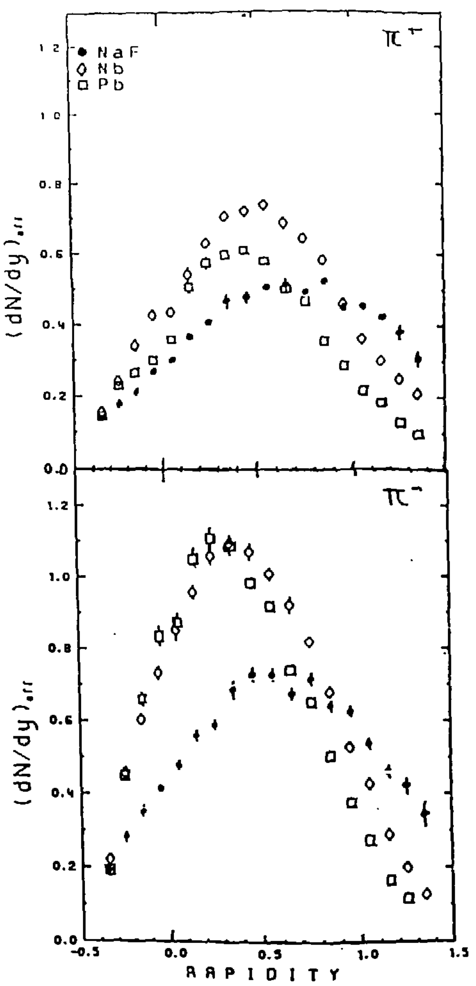

Fig. 8 Rapidity distributions of pions emitted in central collisions of Ne with three different targets at E/A=800 MeV.

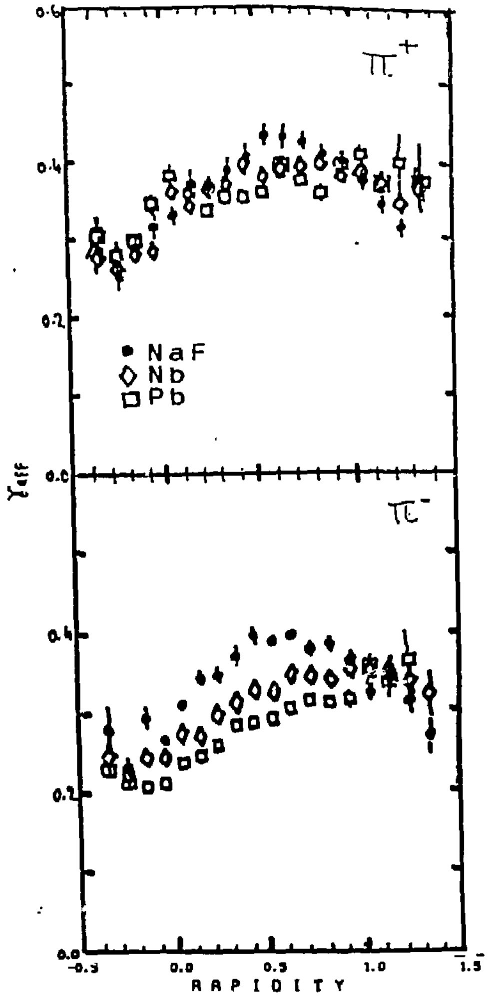

Fig. 9 T_{eff} versus rapidity for pions emitted in central collisions of Ne with three different targets at E/A=800 MeV.

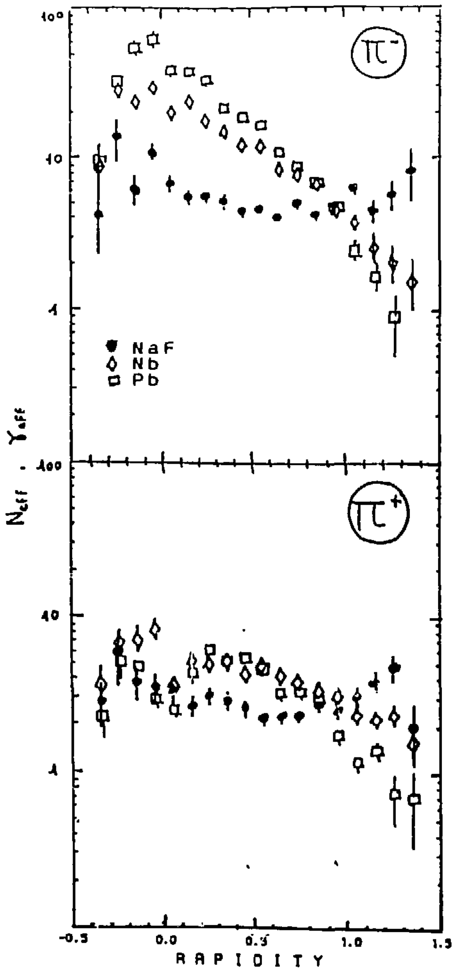

Fig. 10 $N_{eff} \cdot T_{eff}$ product versus rapidity for pions emitted in central collisions of Ne with three different targets at E/A=800 MeV.

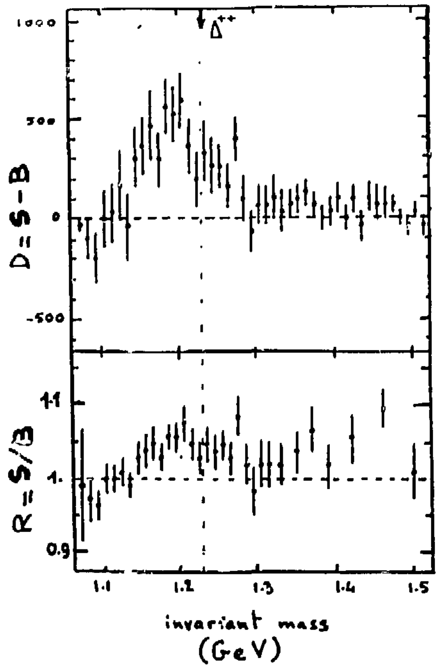

Fig. 11 Invariant mass distribution for π^{+}-p pairs. In order to get rid of the background, two methods have been investigated. In the top figure the "uncorrelated" distribution is subtracted from the "correlated" one. In the bottom figure the correlated distribution is divided by the uncorrelated one.