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Pion Absorption in Excited Nuclear Matter*)

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Abstract

The target dependence and azimuthal correlations of protons and pions are investigated for pA reactions at 4.9, 60 and 200 GeV. The experimental observations can be understood qualitatively under the assumption that pions are absorbed in excited target spectator matter.

1. Introduction

The study of hadron-nucleus interactions offers the possibility to learn about the space-time development of high energy reactions, something which is not possible in elementary particle collisions. The reason is that target nucleons serve as detectors of reaction products at distances and time-scales not accessible with macroscopic detectors. Further interest into results from nucleon-nucleus collisions comes from ultrarelativistic heavy-ion physics: a comparison of nucleus-nucleus with nucleon-nucleus data might reveal deviations from linear scaling and thus indicate interesting, collective effect, like, -ultimately-, the quark-gluon plasma phase transition.

In the present contribution we shall report on a fully electronic ΔE-E measurement of target fragments in an azimuthally complete coverage of a large fraction of the target rapidity range. We shall focus both onto the A-dependence of the proton and pion yields as well as on their azimuthal correlations. The data will be compared both with VENUS 3.07 [1] and RQMD 1.07 [2]. These event generators include rescattering of produced particles. Results concerning $dN/d\eta$ and $dN/dp_\perp$ of protons are contained in the contribution of Kampert et al. to this conference [3].

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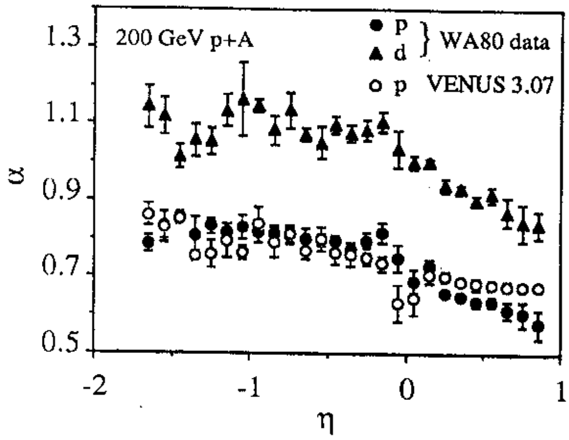

Fig. 1 Target dependence of protons (filled circles) and deuterons (filled triangles) as a function of η. The target dependence is parameterized as $dN/d\eta \propto A^{\alpha(\eta)}$. The open circles show the result of VENUS 3.07 simulations.

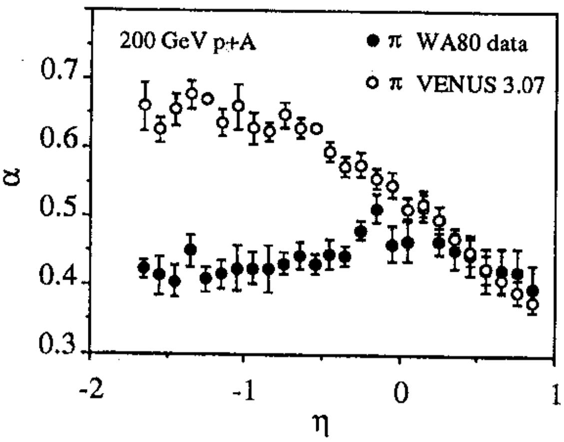

Fig. 2 Target dependence of pions (filled circles) as a function of η. The open circles show the result of VENUS 3.07 simulations.

2. Experimental Setup and Data Reduction

The present data were measured employing the Plastic Ball detector [4]. The Plastic Ball, in its present configuration, is a modular, azimuthally symmetric array of 655 ΔE-E telescopes allowing the identification of light baryons and slow positive pions (E_π<120 MeV) and to measure their energy. Fast, punch-through pions are identfied, but are without energy information.

The data at 4.9 GeV bombarding energy where taken at the BEVALAC. After the completion of the measurements at LBL in 1985 the detector has been moved to CERN and was incorporated into the WA80 experiment [5], where the 60 and 200 GeV data were taken. Thus, a range of bombarding energies, which cannot be made available at a single accelerator, is measured with the same detector. This has the great advantage that systematic uncertainties, which might arise from comparison of data from different apparatus, are minimized. In the CERN setup, the Plastic Ball covers the angular range from 160° to 30° in the laboratory, corresponding to the target fragmentation region for ultrarelativistic projectiles. At the BEVALAC, the coverage was close to 4π. In the present analysis, however, only the region corresponding to the CERN setup was studied. Thus, charged baryons were analyzed, -under minimum bias condition-, in the range $-1.7 \leq \eta \leq 1.0$ and under the requirement that 40 MeV$\leq E_{kin}/A \leq$300 MeV. All events from simulations were subjected to the same cuts in coverage and energy.

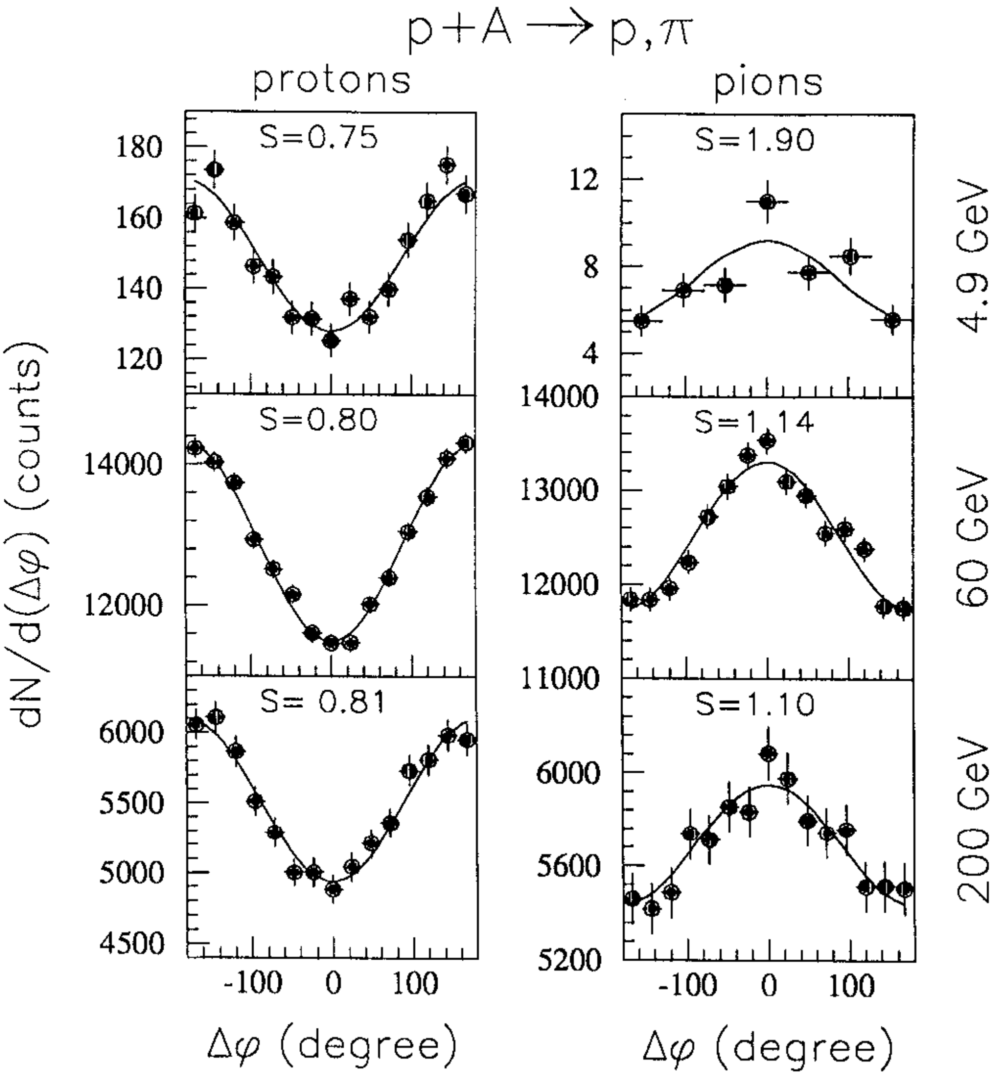

Fig. 3 The correlation function C(Δφ) as described in the text for p+Au collisions at 4.9 (top), 60 (middle) and 200 (bottom) GeV. The left and right hand plots contain C(Δφ) for protons and pions, respectively

3. Results

3.1. Target Dependence of Proton and Pion Yields

We have measured the reaction of protons with Au, Ag, Cu, Al, C at 200 GeV and with Au at 60 and 4.9 GeV. An investigation of the A-dependence of the proton and deuteron yields as a function of η is depicted in Fig. 1, where we show the exponent α from parameterizing the yields as $dN/d\eta(A)=a+bA^{\alpha(\eta)}$. As can be seen, the absolute value and the η-dependence of the proton yield is well reproduced by VENUS 3.07. The distinction between protons and deuterons yields a stronger A-dependence for deuterons, which exceeds $\alpha=1$ for backward angles. Fig. 2 shows the same dependence, but for pions. While the exponent α stays around 0.4 for the data, the simulated pion yields from VENUS exhibit an increasing value of α for decreasing values of η.

3.2. Azimuthal Correlations of Protons and Pions

A possible azimuthal correlation between protons or between pions in the target rapidity range is investigated by constructing the correlation function $C(\Delta\varphi)$ as follows:

$C(\Delta\varphi) := dN/d(\Delta\varphi)$; where

$$\Delta\varphi = \cos^{-1}\left(\frac{\vec{Q}_{back} * \vec{Q}_{for}}{Q_{back} * Q_{for}}\right), \qquad \vec{Q}_{back} := \sum_{y<y_0} \vec{p}_{\perp}{}^{i} \quad \text{and} \quad \vec{Q}_{for} := \sum_{y\geq y_0} \vec{p}_{\perp}{}^{i}$$

y_0 is chosen as 0.2, guided by the idea of a target "fireball" moving with a rapidity y_0. In fact, the target rapdity distribution of protons peaks at this value. Essentially, $C(\Delta\varphi)$ measures whether the particles in the backward and forward hemispheres of the target "fireball" are preferentially emitted back-to-back ($\Delta\varphi=\pm180°$) or side-by-side ($\Delta\varphi=0°$). For the case of pions, where the energy is mostly not measured, $p_\perp$ is replaced by $r_\perp$, the transverse coordinate. Fig. 3 shows the experimental results for the correlation function $C(\Delta\varphi)$ for 4.9 (top), 60 (middle) and 200 (bottom) GeV protons impinging on a Au target. The left and right hand figures contain $C(\Delta\varphi)$ for protons and pions, respectively. The data were fitted assuming $C(\Delta\varphi) \propto 1 + \beta \cos\Delta\varphi$ and the strength of the correlation is quantified as

$$S := \frac{C(0°)}{C(180°)} = \frac{1+\beta}{1-\beta}$$

As can be seen, S is <1 for the protons, while being >1 for pions, meaning that protons are preferentially emitted back-to-back, while pions are emitted side by side. At 4.9 GeV bombarding energy only positive pions with energies below 120 MeV were taken into account.

The same distributions are shown in Fig. 4 for *simulated* p+Au collisions at 200 GeV. The top row shows results from VENUS 3.07, while the bottom row represents RQMD 1.07 simulations. It is observed that VENUS events show for the pions an opposite behavior as compared to the data, while the proton correlation is reproduced. On the other hand, RQMD events seem to reproduce the data both for protons and pions.

3.3. Discussion

Both for the target dependence of the particle yields as well as for the azimuthal correlations a remarkable difference between proton and pions is observed.

We conjecture that the reason for the observed difference between protons and pions comes from pion absorption in the excited target matter:

$$\pi + N \rightarrow \Delta \quad \text{and} \quad \begin{cases} \Delta + N \rightarrow N + N \\ \Delta + \Delta \rightarrow N + N \end{cases}$$

Pions, which might be created via rescattering in the target rapidity are reabsorbed. Thus, the target dependence of the pion yield remains essentially the one from the primary reactions of the projectile with the target nucleons: $dN^{\pi}/d\eta \propto A^{1/3}$

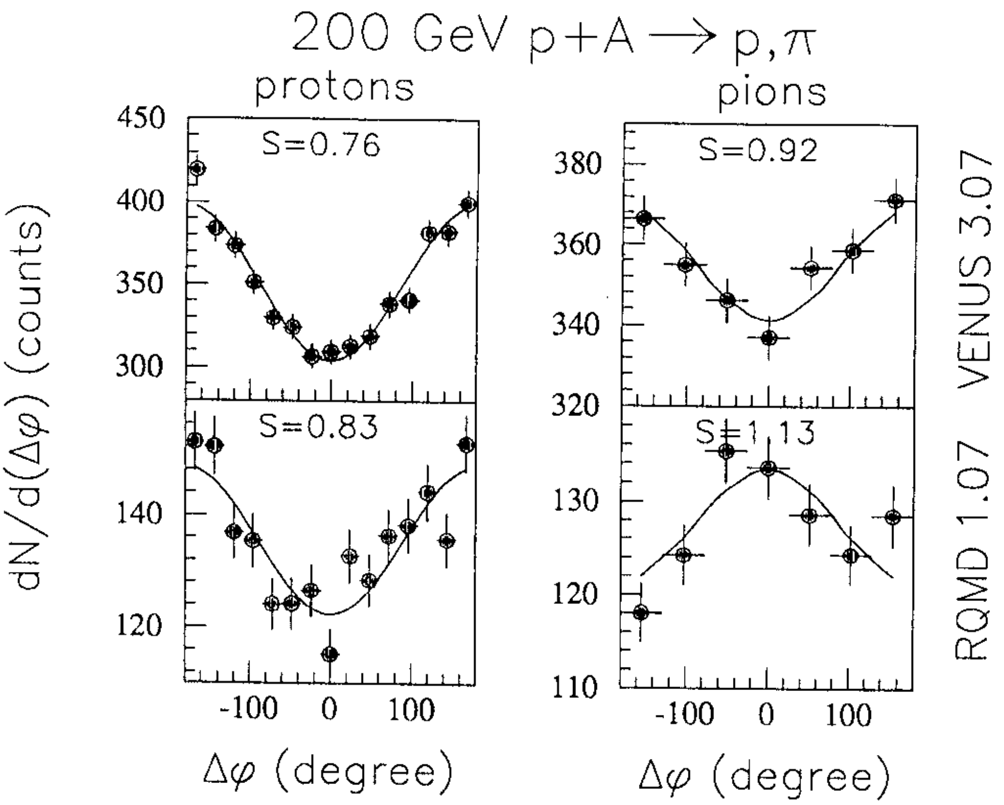

Fig. 4 The correlation function C(Δφ) from simulated p+Au collisions at 200 GeV. The left and right hand plots contain C(Δφ) for protons and pions, respectively; the top and bottom plots are from VENUS and RQMD simulations, respectively.

A second, independent, experimental hint towards pions absorption is contained in the azimuthal correlation: While the back-to-back emission of protons can be understood as resulting from transverse momentum conservation, the pion correlations show, in the data, an opposite behavior. This can be explained based on the picture that pions created in a b≠0 fm collision are absorbed in the target matter on the far side of the impact as depicted schematically in Fig.5. Furthermore, the correlation is strongest for 4.9 GeV, where only slow, positve pions were considered. This might reflect the energy dependence of the absorption cross section.

Interestingly, the RQMD model seems to reproduce the pion correlation. This might be due to the fact that this model uses experimentally measured cross sections for πN reactions, which are, in the low energy region, dominated by the Δ-resonance excitation . VENUS, on the other hand, uses a unique distance d_0 of minimal approach, below which, independent of the energy and rapidity, secondary interaction occur.

4. Summary

We have measured proton-nucleus collisions for various targets and three different bombarding energies (4.9, 60 and 200 GeV). The A-dependence of the proton yield at 200 GeV is well reproduced by VENUS for all η-windows, while disagreement occurs for the pion

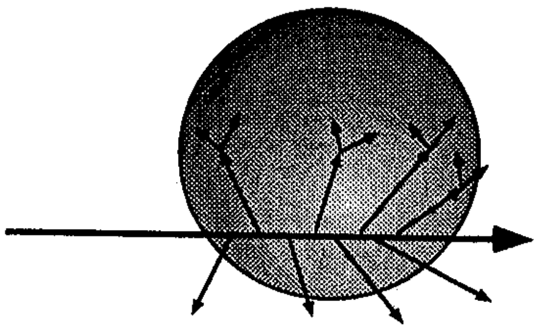

Fig.5 Schematic plot of a non-central pA collisons. Pions created along the path of the incident protons are partially absorbed in the target matter.

yields. Azimuthal correlations between protons exhibit a behavior, i.e. back-to-back emission, which is expected from transverserse momentum conservation. The correlation of pions, on the other hand, indicate side-by-side emission. The observations are in accord with the conjecture that pions are absorbed in excited target spectator matter. This picture is further supported by calculations within the framework of the RQMD model, which includes pion absorption in excited nuclear matter based on experimentally measured cross sections.

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