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 $^{16}\text{O} + \text{Au}$ COLLISIONS AT 200 AGeV**

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Transverse Momentum Distributions of Neutral Pions from Central and Peripheral $^{16}\text{O} + \text{Au}$ Collisions at 200 A GeV

WA80 collaboration

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Abstract

The production of neutral pions by the interaction of 200 A GeV protons and ^{16}O projectiles with a Au target has been studied in the pseudorapidity range $1.5 \leq \eta \leq 2.1$. Transverse momentum spectra have been measured between 0.4 GeV/c and 2.8 GeV/c and their dependence on the centrality of the collision has been investigated. The data show a high degree of similarity to p + p and $\alpha + \alpha$ data from the ISR. The peripheral-collision spectra display a marked change of slope with a hard component starting at about 1.8 GeV/c, in contrast to central-collision data.

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1 Introduction

First results from ultrarelativistic heavy-ion experiments at the CERN SPS [1] have shown that with 200 A GeV ^{16}O projectiles on heavy targets, high energy densities are created, which approach the critical values for a quark gluon phase transition predicted by QCD lattice calculations [2]. One means of studying the properties of the compressed and highly excited reaction zone is the investigation of p_T spectra of produced pions and their dependence on the centrality of the reaction. To distinguish different contributing processes and to provide a reliable basis for comparisons with p + p scattering, a large p_T coverage is required. In particular, data at high p_T values, where hard processes become important and may be calculated by perturbative QCD are of great interest. The present investigation of π^0 spectra has, therefore, concentrated on detailed measurements of p_T spectra up to 2.8 GeV/c and on selections of the data according to the centrality of the reaction. Results presented here cover the full data set of the 1986 $^{16}\text{O} + \text{Au}$ run and extend the subset of data previously published in Ref. [3].

2 Experimental Setup

The experiment has been performed at the CERN SPS using the WA80 setup described in Ref. [4]. The data were obtained by means of an electromagnetic calorimeter (SAPHIR), a uranium scintillator sampling calorimeter located at zero degrees (ZDC), an iron scintillator calorimeter located at mid-rapidity (MIRAC), streamer tube multiplicity arrays (LAM, MIRAM, SAM) and the Plastic Ball located in the target fragmentation region.

The ZDC measures the forward energy distribution ($\eta \geq 6.0$) which is mainly determined by projectile spectators. It has been found [5] that the ZDC energy for $^{16}\text{O} + \text{Au}$ can be related to the number of participants and, hence, is a measure of the centrality of the reaction. The total transverse energy in the ϕ - symmetric pseudorapidity range $2.4 \leq \eta \leq 5.5$ is measured with MIRAC. LAM, MIRAM and the Plastic Ball, together cover 97 % of 4π sr solid angle and provide the total number of charged particles per event. It has been shown that the mean values of the ZDC energy, the total transverse energy, and the number of charged particles are strongly correlated [5,6]. Any of the three quantities can, therefore, be used for event characterization. In our setup the minimum-bias trigger is defined by the requirements that :

- less than 88 % of the total projectile energy is measured by the ZDC (for ^{16}O beams but not for proton beams);
- at least one charged particle is recorded by LAM or MIRAM ($1.2 \leq \eta \leq 4.4$).

The lead-glass detector, SAPHIR, is located at a distance of 342 cm from the target and covers the lab. angle region from 13.7° to 25.9° with respect to the beam axis. It measures photons in the energy range from 0.2 to 20 GeV in about $1/6$ th of the solid angle in the pseudorapidity range from 1.5 to 2.1. Each of the 1278 lead glass modules (SP5) was calibrated with an electron beam at the CERN SPS. The gain stability, monitored during

beam time by a laser reference system, was found to be better than 0.5 %. LAM and an additional streamer tube array in front of SAPHIR serve as charged particle veto detectors with a joint overall detection efficiency of 98 %. The material in front of SAPHIR (streamer tubes, target vacuum chamber, and target) causes photon conversion with a probability of only 6 % for the Au target. As the multiplicity of photons and of charged particles incident on SAPHIR's surface is higher for central $^{16}\text{O} + \text{nucleus}$ collisions than for peripheral ones, the probability of photon misidentification caused by overlapping showers increases for central reactions. Hence the photon reconstruction efficiency drops from 94 % for peripheral to 78 % in central $^{16}\text{O} + \text{Au}$ collisions [3, 7]. This effect was taken into account in the evaluation of the π^0 p_T distributions by a Monte Carlo acceptance calculation.

Neutral pions are identified by their decay photons ($\pi^0 \rightarrow 2\gamma$) and p_T distributions are obtained by performing the following steps:

1. Invariant mass spectra are first accumulated for different bins of $p_T(\gamma, \gamma)$.
2. In order to determine the π^0 -peak area in each invariant mass spectrum, a third order polynomial is fitted to the combinatorial background and subtracted from the spectrum.
3. From this analysis the p_T distribution is then calculated for those neutral pions for which both decay photons were measured.
4. Finally this momentum distribution has to be corrected for the geometrical acceptance, which is obtained from a Monte Carlo calculation.

In going from low to high π^0 transverse momenta the π^0 -peak to background ratio in the invariant mass spectra increases. The possibility that showers from the two decay photons overlap and are observed as one single shower is excluded in the p_T region under consideration due to their minimum opening angle.

3 Results and Discussion

Invariant π^0 cross sections for reactions of protons and ^{16}O projectiles with a Au target at 200 A GeV have been obtained as a function of transverse momentum for different trigger conditions. Fig. 1 shows the minimum-bias data for p + Au and $^{16}\text{O} + \text{Au}$ together with an exponential fit ($1/p_T \, dN/dp_T \sim \exp(-p_T/T)$) to the data in the range 0.8 GeV/c $\leq p_T \leq 2$ GeV/c. At this stage of the analysis no attempt has been made either to fit the whole spectrum within the context of a particular model or to interpret the slope parameter T in terms of a temperature. The slope parameter of the $^{16}\text{O} + \text{Au}$ spectrum ($T = 210 \pm 3$ MeV/c) is larger than the slope parameter of the p + Au data ($T = 196 \pm 4$ MeV/c). To investigate the influence of a possible η -dependence on the π^0 cross section, the solid angle covered by SAPHIR was divided into three η regions. It should be noted that in the p_T range from 0.4 GeV/c to 2.8 GeV/c the relative difference between rapidity and pseudorapidity is less than 0.5 % and thus can be neglected. It was found that the variation of the slope parameter from one to another of the three η regions is less than 0.5 %.

This difference between the $^{16}\text{O} + \text{Au}$ and p + Au spectra is more clearly displayed by plotting the ratios of the spectra (Fig. 2). A similar representation has previously been used by Cronin et al. [8] to discuss the *nuclear enhancement* of p + A compared to p + p data. In that work, a scaling of the minimum-bias cross section ratios with A_{target}^α and a rise of α with p_T was observed for charged pions in the range 0.8 GeV/c $\leq p_T \leq 5$ GeV/c. A similar enhancement, which can be attributed to different projectile masses, is seen in going from p + Au to $^{16}\text{O} + \text{Au}$ reactions. The absolute magnitude of the enhancement depends on the definition of the minimum-bias trigger in the $^{16}\text{O} + \text{Au}$ and p + Au data, respectively.

More insight into the particular mechanism of heavy-ion reactions at high energies can be gained by selecting central and peripheral collisions. Collective effects or the formation of new states of nuclear matter are expected primarily in very central collisions. Data on peripheral collisions may, on the other hand, provide a link to p + A and p + p reactions. For the present data the centrality selection has been achieved by cuts in the ZDC energy. Central events are defined by $0 \% \leq E_{\text{ZDC}}/E_{\text{beam}} \leq 30\%$, corresponding to 37% of the minimum-bias cross section, while peripheral events are defined by $40\% \leq E_{\text{ZDC}}/E_{\text{beam}} \leq 88\%$ corresponding to 54% of the minimum-bias cross section. In Fig. 3 spectra selected for central and peripheral events are displayed. Again, exponential fits are shown for 0.8 GeV/c $\leq p_T \leq 2$ GeV/c together with the data. The following differences between central and peripheral collisions are observed in the data of Fig. 3:

- The decreasing slope parameter of the minimum-bias data for $p_T \leq 0.8$ GeV/c (see Fig. 1) is also indicated in the central-collision but not in the peripheral-collision data. (Similar observations for central-collision data have been made by NA35 for charged pions in the rapidity window $2 < y < 3$ [9].)
- In the intermediate region 0.8 GeV/c $\leq p_T \leq 1.8$ GeV/c the spectra show a well-developed exponential shape with a significantly larger slope parameter for central collisions ($T = 220 \pm 5$ MeV/c) than for peripheral collisions ($T = 189 \pm 5$ MeV/c).
- For $p_T > 1.8$ GeV/c the central-collision spectrum continues with the same slope parameter as at lower p_T , whereas the peripheral-collision spectrum shows a clear deviation from the low- p_T behaviour, towards a much larger slope parameter at higher p_T .

The three regions distinguished above are clearly seen in Fig. 4, where the ratio of the two spectra from Fig. 3 is displayed.

Fig. 5 shows a comparison of the peripheral-collision π^0 spectrum from $^{16}\text{O} + \text{Au}$ at 200 A GeV ($\sqrt{s_{NN}} \cong 19.4$ GeV) with charged-pion spectrum from p + p at $\sqrt{s_{NN}} = 23$ GeV [10]. There is a remarkable agreement in the spectral slope of the data up to the highest p_T of the present experiment. The flattening of the slope in the p + p data beyond $p_T \approx 2$ GeV/c has been interpreted as the onset of hard QCD scattering, which is expected to become important for p_T values of several GeV/c. It, therefore, appears that the hard-scattering component of the elementary p + p interaction survives in peripheral heavy-ion collisions, but in the present p_T range it is strongly obscured by nuclear effects in central collisions. Forthcoming experiments in an extended p_T range are expected to reveal whether the hard component emerges in central collisions at higher p_T values.

A systematic analysis of the relative change of the π^0 pr distributions as a function of the reaction centrality is shown in Fig. 6. Inspired by Ref. [12] $R_{ZDC}(pr)$ is defined as the ratio of the π^0 yield for events in a given E_{ZDC} window to the π^0 yield for minimum-bias events. Both yields are normalized to unity :

$$R_{ZDC}(pr) = \frac{N^{-1} \cdot dN/dpr(E_{ZDC})}{\langle N \rangle^{-1} \cdot \langle dN/dpr \rangle}$$

where $\langle \rangle$ denotes the average over all minimum-bias events. The dip at $pr \approx 700$ MeV/c in the more central-collision data and the following increase up to about 1.8 GeV/c resembles the previously discussed nuclear enhancement in going from p + Au to ^{16}O + Au data. We observe a complementary behaviour in the peripheral-collision data, where a maximum appears at about 700 MeV/c and a dip is seen at about 1.8 GeV/c. It is clear that the complicated pattern observed in the data of Fig. 6 cannot readily be described by a simple nuclear enhancement but requires a detailed treatment of the contributing processes in different pr regions.

The pattern of Fig. 6 is rather similar to results from charged-particle measurements in p + p and α + α experiments at $\sqrt{s_{NN}} = 63$ GeV and $\sqrt{s_{NN}} = 31.2$ GeV, respectively [11,12], where a selection of the data was made according to their associated charged-particle multiplicities. The observed similarity suggests a common underlying mechanism in p + p, α + α and heavy-ion collisions, which causes the characteristic behaviour in different pr regions. Several attempts have been made within hydrodynamical and thermodynamical models [13,14] to describe the development of a hot and dense reaction zone and its connection to measured pr spectra. In Ref. [15] a hydrodynamical model with isentropic expansion of a fireball and a certain freeze-out criterion is applied to our data. The low and intermediate part of the pr spectrum, in particular the changing of the slope with centrality, is well described in this model with an initial energy density of 1.5 - 2 GeV/fm³. The high pr component in the peripheral-collision data is not described in this model, indicating again that it may be due to hard scattering processes. In thermodynamical descriptions [16,17], where the slopes of the pr spectra are considered to be measures of the reaction temperature, different pr regions and slopes are related to the breakup of substructures or to different scattering mechanisms. In particular, rescattering of secondary pions has been considered as the source of the increased cross section at low pr [17]. In the pr region beyond 2 GeV/c, where hard QCD processes become increasingly important, the influence in the entrance channel may be studied by extending the comparison of p + p with heavy-ion data to multiplicity selected spectra covering a large pr range.

4 Conclusions

Transverse momentum distributions of π^0 have been measured for p- and ^{16}O -induced reactions in the pseudorapidity range $1.5 \leq \eta \leq 2.1$. Centrality selection has been achieved by different cuts in the energy of the ZDC. Significant differences between the pr -dependence of central- and peripheral-collision π^0 spectra from ^{16}O + Au reactions have been observed. For $pr \leq 2$ GeV/c the variation is similar to the variation of charged-particle distributions from

p + p and α + α reactions at ISR energies. It is found that over the complete pr range, the shape of the π^0 distribution for peripheral events follows very closely the pion spectra from p + p collisions. A striking feature of the present ^{16}O + Au data is that the change of the slope in the hard-scattering regime ($pr > 2$ GeV/c) is not observed in the data for central collisions.

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References

- [1] *Quark Matter*, Z. Phys. C - Particles and Fields **38** (1988), H. Satz, H. Specht and R. Stock, eds., and references therein
- [2] *Quark matter formation and heavy ion collisions*, proc. Bielefeld Workshop (May 1982) (World Scientific, Singapore, 1982), M. Jacob and H. Satz, eds., and references therein
- [3] R. Albrecht et al., WA80 Collab., Phys. Lett. **B201** (1988) 390
H. Löhner et al., WA80 Collab., Z. Phys. C - Particles and Fields **38** (1988) 97
- [4] H.H. Gutbrod et al., GSI preprint GSI-85-32, August 1985 and
CERN SPSC/85-39/M406
- [5] R. Albrecht et al., WA80 Collab., Phys. Lett. **B199** (1987) 297
- [6] R. Albrecht et al., WA80 Collab., Phys. Lett. **B202** (1988) 596
- [7] P. Beckmann et al., to be submitted to Nucl. Instr. Methods
- [8] J.W. Cronin, H.J. Frisch, M.J. Shochet, J.P. Boymond, P.A. Piroué, R.L. Summer,
Phys. Rev. D **11** (1975) 3105
D. Antreasyan, J.W. Cronin, H.J. Frisch, M.J. Shochet, L. Kluberg, P.A. Piroué,
R.L. Summer, Phys. Rev. D **19** (1979) 764
- [9] H. Ströbele, A. Bamberger, D. Bangert, J. Bartke, H. Bialkowska, R. Bock, R. Brockmann, S.I. Chase, C. de Marco, M. de Palma, I. Derado, V. Eckardt, C. Favucci, J. Fent, D. Ference, P. Freund, M. Gazdzicki, H.J. Gebauer, K. Geissler, C. Guerra, J.W. Harris, W. Heck, T. Humanic, K. Kadij, A. Karabarbounis, R. Keidel, M. Kowalski, W. Krischer, M. Lahanas, S. Margetis, E. Nappi, G. Odyniec, G. Paic, A.D. Panagiotou, A. Petridis, J. Pfennig, F. Posa, K.P. Pretzl, H.G. Pugh, F. Pühlhofer, G. Rai, A. Ranieri, W. Rauch, R. Rennfordt, D. Röhrich, K. Runge, A. Sandoval, D. Schall, N. Schmitz, T. Schouten, L.S. Schroeder, G. Selvaggi, P. Seyboth, J. Seyerlein, E. Skrzypczak, P. Spinelli, R. Stock, H. Ströbele, A. Thomas, M. Ticknell, L. Teitelbaum, G. Vesztergombi, D. Vranic, S. Wenig, NA35 Collab., Z. Phys. C - Particles and Fields **38** (1988) 89
- [10] B. Alper, H. Böttgild, P. Booth, L.J. Carroll, G. Damgaard, G. von Dardel, B. Duff, K.H. Hansen, F. Heymann, J.N. Jackson, G. Jarlskog, L. Jönsson, A. Klovning, L. Leis-tam, E. Lillethun, E. Lohse, G. Lynch, G. Manning, K. Potter, M. Prentice, P. Sharp, S. Sharrock, S. Olgaard-Nielsen, D. Quarrie, J.M. Weiss, Nucl. Phys. **B100** (1975) 237
- [11] M. A. Faessler, Phys. Rep. **115** (1984) 1
- [12] W. Bell, K. Braune, G. Claesson, D. Drijard, M.A. Faessler, H.G. Fischer, H. Frehse, S. Garpman, W. Geist, C. Gruhn, P. Hanke, M. Heiden, W. Herr, P.G. Innocenti, T.J. Ketel, E.E. Kluge, I. Lund, G. Mornacchi, T. Nakada, I. Otterlund, B. Povh, A. Putzer, B. Rensch, E. Stenlund, T.J.M. Symons, M. Szczekowski, R. Szwed, O. Ulla-land, M. Wunsch, Z. Phys. C - Particles and Fields **27** (1985) 191
- [13] M. Kataja, P.V. Ruuskanen, L.D. McLerran, H. von Gersdorff,
Phys. Rev. D **34** (1986) 2755
- [14] M. Danos and J. Rafelski, Phys. Rev. D **27** (1983) 671
- [15] K. S. Lee and U. Heinz, Theoretische Physik Regensburg TPR-88-16, to be published in
Z. Phys. C
- [16] E. V. Shuryak, Phys. Rep. **61** (1980) 71
- [17] E. V. Shuryak, Novosibirsk, preprint 87-142
E. V. Shuryak, Phys. Lett. **B207** (1988) 345

Fig. 1. Invariant π^0 cross sections from collisions of protons and ^{16}O projectiles with a Au target at 200 A GeV measured in the pseudorapidity range $1.5 \leq \eta \leq 2.1$. An exponential function is fitted to the data in the p_T region from 0.8 GeV/c to 2 GeV/c (solid line) and is extrapolated to the full p_T range (dashed line). The slope parameters are $T = 210 \pm 3 \text{ MeV}/c$ for $^{16}\text{O} + \text{Au}$ and $T = 196 \pm 4 \text{ MeV}/c$ for $p + \text{Au}$, respectively.

Fig. 2. Ratio $\sigma(^{16}\text{O} + \text{Au}) / \sigma(p + \text{Au})$ of minimum bias π^0 p_T spectra.

Fig. 3. Invariant π^0 cross sections from collisions of ^{16}O projectiles with a Au target at 200 A GeV measured in the pseudorapidity range $1.5 \leq \eta \leq 2.1$ for different E_{ZDC} windows. The squares correspond to central collisions and the dots to peripheral collisions, as described in the text. An exponential function is fitted to the spectra for $0.8 \text{ GeV}/c \leq p_T \leq 2 \text{ GeV}/c$ and is extrapolated to the full p_T range as a dashed line. The slope parameters are $T = 189 \pm 5 \text{ MeV}/c$ for the peripheral- and $T = 220 \pm 5 \text{ MeV}/c$ for the central-collision data, respectively.

Fig. 4. Ratio of the experimental $\pi^0 p_T$ yields from Fig. 3. Both yields are normalized to unity.

Fig. 5. Comparison of peripheral-collision π^0 spectra from the present $^{16}\text{O} + \text{Au}$ experiment at $\sqrt{s_{NN}} \approx 19.4$ GeV with charged-pion spectra from minimum-bias $p + p$ data at $\sqrt{s_{NN}} = 23$ GeV [10]. (π^- and π^+ data are averaged and plotted as a single set of data points.)

Fig. 6. Ratios $R_{ZDC}(p_T)$ (as defined in the text) of centrality-selected to minimum-bias π^0 spectra in four E_{ZDC} windows for $^{16}\text{O} + \text{Au}$ at 200 A GeV :
a) $60\% \leq E_{ZDC}/E_{beam} < 88\%$ b) $40\% \leq E_{ZDC}/E_{beam} < 60\%$
c) $15\% \leq E_{ZDC}/E_{beam} < 30\%$ d) $0\% \leq E_{ZDC}/E_{beam} < 15\%$
a) corresponds to the most peripheral and d) to the most central collisions.