HIGH p_T π^0 PRODUCTION FROM $\alpha\alpha$ AND αp COLLISIONS AT THE CERN ISR*CERN¹-Oxford²-Rockefeller³ (COR) Collaboration*

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ABSTRACT

The invariant cross-sections for π^0 meson production in alpha-alpha and alpha-proton collisions at the ISR were measured up to transverse momenta of 7 GeV/c and 8 GeV/c, respectively. These measurements are compared with π^0 production in pp collisions at the same values of $\sqrt{s}$ /nucleon, and the variation of the nuclear A-dependence with p_T is determined.

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The discovery of the anomalous nuclear enhancement by Cronin et al. [1] led to much experimental [2-6] and theoretical [7,8] work on the variation of high-energy processes with atomic number. High-energy cross-sections can be parametrized as A^α , where A is the atomic number and the exponent α is naïvely expected from shadowing arguments to be between $2/3$ and 1 depending on the degree of shielding within the nucleus. The result of the experiments referred to above was that α was found to be greater than one at high transverse momentum (p_T) and for some produced particles as high as 1.3. When the ISR was filled with alpha particles in August 1980, a determination of α and its p_T -dependence for the production of high- p_T π^0 's became possible at a value of $\sqrt{s}$ /nucleon twice as high as any previous measurement.

In this paper results are reported from data taken with both alpha-alpha and alpha-proton collisions. The apparatus used is shown in fig. 1. Apart from the addition of four lead scintillator sandwich calorimeters, not used in this measurement, it remained the same as described in refs. [9-11]. It consisted of two lead-glass arrays placed on either side of a superconducting solenoid which contained a barrel hodoscope of scintillation counters, the A counters, surrounding the interaction region. Between the solenoid and the lead-glass there were additional hodoscopes of scintillation counters, the B counters.

Data were collected during alpha-alpha, alpha-proton, and proton-proton runs with $\sqrt{s}$ /nucleon values of 15.5, 22.0 and 31.5 GeV, respectively. These results were compared with proton-proton data taken in June and July 1979 at the same values of $\sqrt{s}$ /nucleon (half the centre-of-mass energy available in the collision of a pair of individual nucleons). Table 1 lists the integrated luminosities collected. During data taking the trigger required an energy deposition greater than a threshold, in either of the lead-glass arrays, corresponding to 3.0 GeV for the alpha-alpha running and 4.0 GeV for the alpha-proton running. The pulse heights of all the lead-glass blocks and the B counters were recorded.

In the analysis, the π^0 production cross-section obtained from alpha-alpha and alpha-proton collisions was divided by the cross-section found in proton-proton collisions at the same value of $\sqrt{s}$ /nucleon. Accordingly, identical cuts were made on all sets of data so that most systematic errors could be expected to cancel. Data from the two independent lead-glass arrays ('inside' and 'outside') were analysed separately to monitor systematic errors and the results were combined at the end. Clusters of energy deposition of at most 3×3 blocks were searched for with the requirement that the block with the maximum energy should not be an edge-block. Corrections to the energy of the clusters were made on an event-by-event basis for the energy lost in the solenoid coil and for the angular dependence of the response of the lead glass. The correction for energy lost in the coil was based on the pulse height measured in the B counters and is described in refs. [12] and [13]. The angular dependence was corrected by using the formula $E_{\text{corrected}} = (1.0 + 0.22\psi)E_{\text{observed}}$, where ψ is the angle (measured in radians) between the normal to the glass and the direction of incidence of the π^0 . This relationship was deduced from test-beam data.

No track information from the drift chambers was used, so the interaction was assumed to have taken place at the centre of the region where the two beams crossed. This assumption added about 2% to the uncertainty in the p_T measurement. However, its effect on the determination of α was minimal since all three sets of data were affected equally. At least two A counters were required to be hit to ensure that the cluster was associated with a real beam-beam interaction.

The rapidity, y , was calculated assuming that each cluster was caused by a π^0 from a nucleon-nucleon collision. For the alpha-alpha and proton-proton data the apparatus was symmetric about $y = 0.0$ and a cut of $|y| < 0.40$ (0.55) for the inside (outside) array was made. For the alpha-proton data the apparatus was not symmetric about $y = 0.0$ and the cuts in y were $-0.05 < y < 0.65$ for the inside and $-0.1 < y < 0.8$ for the outside arrays. The cuts in the azimuthal angle were $|\phi| < 0.32$ and 0.44 for the inside and outside arrays, respectively.

To find the ratio of these cross-sections to those for proton-proton π^0 production, earlier data were analysed with the same cuts. Since the two data sets were taken a year apart, the possibility of a systematic change in the absolute energy scale of the lead-glass arrays had to be taken into account. Such a change in the absolute p_T scale would result in large errors when dividing two rapidly falling cross-sections. To eliminate this time-dependent effect, the following procedure was used. The $\sqrt{s} = 63$ GeV proton-proton data collected in 1980, between the alpha-alpha and alpha-proton runs, were compared with proton-proton data at $\sqrt{s} = 63$ GeV taken in 1979. The comparison was made by fitting the invariant cross-section measured with the new data to the function [14]

$$E \frac{d^3\sigma}{dp^3} = C p_T^{-n} \exp(-15x_T), \quad (1)$$

which is a good representation of the data. The parameters C and n were then fixed and the cross-sections from the old data set were fit to the same formula except that p_T was multiplied by a factor defining the change in the p_T scale. It was found by this method that the old scale had to be multiplied by 1.045 ± 0.002 and 1.007 ± 0.002 for the inside and outside arrays, respectively. Figure 2 shows the ratio of the fit of the earlier $\sqrt{s} = 63$ GeV data with the p_T scale change applied to the data collected a year later at the same energy. The p_T -independence of this ratio demonstrates the consistency of this method. These p_T scale factors were then applied to the $\sqrt{s} = 31$ GeV and $\sqrt{s} = 44$ GeV pp data taken close in time to the $\sqrt{s} = 63$ GeV data.

The proton-proton data at $\sqrt{s} = 31$ GeV and $\sqrt{s} = 44$ GeV were fitted to the formula given in eq. (1) and the alpha-alpha and alpha-proton cross-sections were divided by the resulting function. Since in this experiment only protons and alpha particles were used, we were not able to establish the A^α -dependence. This dependence was therefore assumed and α was determined with the formula $\alpha = \ln(R) / \ln(A_1 A_2)$, where A_1 and A_2 are the atomic numbers of the beam particles and R is the ratio of the cross-sections. Since the alpha-proton and proton-proton data cover different ranges of rapidity, it was also necessary to assume that the invariant cross-section for π^0 production is independent of the y range of the two

measurements. This assumption was checked by repeating the alpha-proton analysis, restricting the rapidity range used to $0.0 < y < 0.4$ (0.55) for the inside (outside) array. This is equivalent to the range of the proton-proton data since the proton-proton data are symmetrical about $y = 0.0$. Since the results obtained using this reduced sample were consistent with those obtained using all the data, the latter were used in the final analysis. The values obtained for R and α are shown in fig. 3.

For the alpha-alpha data the exponent α rises between transverse momenta of 4 and 5 GeV/c. Above $p_T = 5$ GeV/c the data are consistent with $\alpha = 1.3$. However, with the alpha-proton data, no strong p_T -dependence is apparent. The data start at $p_T = 5$ GeV/c and the value of α stays around or below 1.0. An estimate of the systematic error, not shown in fig. 3, was made by changing the p_T scale difference by 0.5%. This value is twice the error obtained from the fit. The effect of this was to change the ratio and the exponent α by only 2.5% and 1%, respectively.

These two results seem to be difficult to reconcile with multiple-scattering type models [8], in which the inclusive cross-section is parametrized as

$$E \frac{d^3\sigma}{dp^3} = kA(1 + \gamma A^{1/3} + \dots) ,$$

where the constant γ is the strength of the second scattering and is predicted to be positive for both alpha-alpha and alpha-proton scattering. Whereas the alpha-alpha data presented here clearly require a positive γ , the alpha-proton data require γ to be zero or even negative.

In conclusion, the atomic number dependence of high- p_T π^0 production in nucleon-nucleus collisions and nucleus-nucleus collisions has been measured at the highest energies to date. The alpha-proton result constitutes an extension in $\sqrt{s}$ by a factor of 2 of the experiment of Cronin et al. where no $\sqrt{s}$ dependence was seen. The result presented in this paper demonstrates that in going from Fermilab energies to ISR energies the anomalous nuclear enhancement observed in nucleon-nucleus collisions is reduced. A very pronounced enhancement is, however, observed in alpha-alpha collisions.

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Table 1

Luminosities collected

Beams	Date	Luminosity (cm^{-2})	$\sqrt{s}$ (GeV)	$\sqrt{s}/\text{nucleon}$ (GeV)
$\alpha\alpha$	1980	6.00×10^{33}	124	15.5
αp	1980	1.38×10^{35}	88	22.0
pp	1980	4.07×10^{34}	63	31.5
pp	1979	1.92×10^{36}	31	15.5
pp	1979	1.63×10^{37}	44	22.0
pp	1979	7.28×10^{35}	63	31.5

Figure captions

- Fig. 1 : A view of the apparatus normal to the beams.
- Fig. 2 : Ratio of the proton-proton cross-section at $\sqrt{s} = 63$ GeV, measured at the time of the alpha-alpha and alpha-proton runs, to the fit of the $\sqrt{s} = 63$ GeV proton-proton data taken earlier with the p_T scale change applied.
- Fig. 3 : The results for R and α obtained with alpha-alpha beams at $\sqrt{s} = 15.5$ GeV/nucleon and with alpha-proton beams at $\sqrt{s} = 22.2$ GeV/nucleon. The systematic uncertainty of 2.5% is not included in the errors.

Fig. 1

Fig. 2

Fig. 3