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INCLUSIVE π^0 PRODUCTION AT VERY LARGE p_T AT THE ISR

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ABSTRACT

Inclusive π^0 production at 90° has been studied at the ISR at $\sqrt{s} = 52.7$ and 62.4 GeV over the p_T range from 7 to 15 GeV/c. The two photons from π^0 decay yielded overlapping electromagnetic showers in the liquid-argon-Pb plate calorimeter detector system. Any direct photon production is included in these measurements. For large values of p_T , the cross-section is observed to decrease with p_T more slowly than the p_T^{-8} behaviour which has been observed at lower values of p_T .

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1. INTRODUCTION

In a previous publication [1] we reported on the inclusive production of neutral pions having transverse momenta p_T of up to ~ 6 GeV/c, with the two decay photons resolved. Here we extend the measurements to higher values of the transverse momentum by studying the π^0 decays when the showers due to the two decay photons have coalesced.

The π^0 's studied were produced from pp collisions at the CERN ISR. π^0 's emerging near 90° c.m. with p_T up to 15 GeV/c were measured at $\sqrt{s} = 62.4$ GeV, while at $\sqrt{s} = 52.7$ GeV, the data sample was smaller and only extended up to $p_T = 11$ GeV/c.

These studies were carried out using a detector system [2] based on liquid-argon-Pb plate calorimeters (17.7 radiation lengths total thickness) of high spatial resolution and large solid angle acceptance. The properties of these calorimeters are well suited to separating the desired signal due to electromagnetic showers from the various backgrounds which are potentially large compared to the signal at large values of p_T .

2. DETECTION APPARATUS

For measuring the π^0 production at very high values of p_T we used the apparatus described in detail in Ref. 2, with a configuration of the detectors as shown in Fig. 1. This detector system provides a large solid angle, covering approximately 3 sr of total fiducial area. It consists of four liquid-argon-Pb plate calorimeters around the intersection region, centred at 90° to the beam directions and at a distance of 0.86 m from the interaction point. The luminosity is monitored by counters which record the beam-beam interactions at small forward angles.

With this configuration the angular resolution of two-shower separation is 3° , so that about 70% of the $\pi^0 \rightarrow \gamma\gamma$ decays at $p_T \sim 6$ GeV/c are not resolved as two separate showers and this percentage grows to $\geq 90\%$ for $p_T \geq 8$ GeV/c. Therefore, the desired π^0 events consist either of single showers representing two overlapping electromagnetic showers, or, less often, of a resolved pair of nearby photons.

The trigger required that both the energy deposited in localized regions in the first two sections of the calorimeter, amounting to a total of ~ 6 radiation lengths, and the total energy deposited in the calorimeter had to exceed thresholds corresponding to a π^0 transverse momentum of about 5 GeV/c. Event read-out was triggered when this trigger signal from a calorimeter was in coincidence either with the beam-beam counters or with the scintillator hodoscopes.

The effective integrated luminosities for the two c.m. energies were $3.30 \times 10^{36} \text{ cm}^{-2}$ at $\sqrt{s} = 52.7 \text{ GeV}$ and $3.62 \times 10^{37} \text{ cm}^{-2}$ at $\sqrt{s} = 62.4 \text{ GeV}$.

3. DATA ANALYSIS

For the p_T range of interest, i.e. $p_T > 7 \text{ GeV/c}$, few of the π^0 's could be identified as resolved pairs of photon showers. In order to include these resolved pairs in our data sample, we defined the π^0 momentum as the sum of the momenta of all showers situated inside a cone with half-angle of 5° around the shower carrying the largest p_T .

It was also necessary to consider contributions to the counting rate from other final-state particles such as unresolved $2\pi^0$ systems, η production, and possible direct photon production. We have corrected our data for accidental overlap of photon showers from two different π^0 's by extrapolating a plot of counting rate versus angular size of the deposited energy to zero angular size. Using a Monte Carlo program, we have shown that the measured η cross-section [3] makes only a small contribution ($< 4\%$) to the counting rate. (The minimum opening angle for $\eta \rightarrow 2\gamma$ decay is greater than our angular resolution). However, we cannot make a subtraction for direct single photon production, since our angular resolution in this arrangement of the apparatus is insufficient to allow us to distinguish overlapping $\pi^0 \rightarrow 2\gamma$ showers from single photon showers. (There are experimental indications [3,4] that direct $\gamma/\pi^0 \lesssim 30\%$ for $p_T \leq 10 \text{ GeV/c}$.)

The linearity and absolute value of the energy (p_T) scale were determined from the ISR data itself using resolved $\eta \rightarrow 2\gamma$ decays with p_T of 5-10 GeV/c.

There were two types of background originating from other than beam-beam interactions. The first type appeared to be caused by particles entering the

calorimeter from upstream interactions of beam particles with residual gas in the ISR vacuum pipe or with ISR components such as vacuum pipe walls or magnet pole tips. This type of background was most clearly characterized by broad transverse shower size and abnormal longitudinal development of the shower in the calorimeter. Also, it showed a strong tendency to occur at azimuthal angles near the plane of the ISR beams (i.e. near the edges of calorimeters Q3 and Q4). By imposing strict requirements on the transverse size and longitudinal development of the showers, this background was reduced to a negligible level.

The second type of background appeared to originate from cosmic rays, since it is much greater in the two calorimeters Q2 and Q3 which are facing upward and which count downward-moving showering particles than in Q1 and Q4 (facing downward). We found that this asymmetry could be removed by requiring the event to contain at least one charged track originating in the interaction diamond in any one of the other three octants. The high statistical accuracy of the data (e.g. ~ 1100 counts in the 9-10 GeV/c bin at $\sqrt{s} = 62.4$ GeV) allowed us to verify that this requirement removed the up-down asymmetry in the data but did not introduce a p_T -dependent bias.

We have also made special runs to directly measure the cosmic-ray background. The results showed that the observed up-down asymmetry was indeed due to cosmic rays, and also that the above charged track requirement was satisfied by only $\sim 10\%$ of the cosmic-ray associated background events. We used data from these special runs to make a cosmic-ray background subtraction.

The efficiency of our reconstruction procedure was estimated by studying the effect of changing the minimum energy requirement in the pattern recognition and from inspection of event displays. A correction determined from a study of untriggered calorimeters was applied for showers which converted late inside the calorimeter and consequently did not satisfy the pattern recognition threshold in the first calorimeter section.

Data were corrected for inefficiencies introduced by the application of the various event selection criteria. Corrections were also made for the variation

of trigger thresholds with the angle of incidence and for the triggering inefficiency of those events where the produced charged particles were not within the acceptance of the beam-beam counters. We also made corrections for the effects of π^0 decays with large $\gamma\gamma$ opening angles, for the finite resolution in p_T , and for the non-linearity in the energy scale caused by energy leakage through the finite depth of the calorimeters.

Table 1 gives typical values of the corrections described above. Most of these correction factors vary little as a function of p_T .

4. RESULTS

Table 2 gives our invariant cross-section results. These are shown in Figs. 2 and 3 together with results from other recent experiments as well as our own results [1] at smaller p_T .

As can be seen from the graphs, our cross-section results for $p_T \geq 6$ GeV/c are consistently lower than those from the CCOR [4] and CERN-Saclay-Zurich [5] experiments. This discrepancy rises from a factor of about 1.5 at $p_T = 7$ GeV/c to a factor of about 4 at the largest values of p_T . The causes for this discrepancy are not known. One possibility is that the photon energy scales in the three experiments differ by $\sim 10\%$ at large p_T , but this is not consistent with the estimated energy accuracy of these experiments. Also, it should be noted that the cross-sections measured by all three groups agree quite well below $p_T = 5$ GeV/c.

Based upon our experiment alone, we observe in Figs. 2 and 3 that the present data (unresolved photons) connect smoothly with the π^0 production data which we previously reported [1] (resolved photons), indicating that single-photon production is not large compared to π^0 production at $p_T \sim 7$ GeV/c.

5. DISCUSSION

Inclusive cross-section data at 90° c.m. are often compared with the expression

$$E \frac{d^3\sigma}{dp^3} = A p_T^{-n} f\left(x_T = \frac{2p_T}{\sqrt{s}}\right).$$

A scaling equation of this type has been found to yield [1,6,7] $n = 8$ for π^0 production data with $2 < p_T < 6$ GeV/c over a wide range of values of $\sqrt{s}$.

We have used the above equation to determine n as a function of X_T from our experimental data (we have interpolated our $\sqrt{s} = 62.4$ data), using the expression

$$n = \log \left(\frac{Ed^3\sigma/dp^3|_1}{Ed^3\sigma/dp^3|_2} \right) / \log \left(\frac{\sqrt{s}_1}{\sqrt{s}_2} \right),$$

where

$$p_T^1 = \frac{X_T \sqrt{s}_1}{2}, \quad p_T^2 = \frac{X_T \sqrt{s}_2}{2}.$$

The results are shown in Fig. 4. The sizes of the error bars in Fig. 4 are dominated by our lower level of accuracy at $\sqrt{s} = 52.7$ GeV (20-30% at the largest values of X_T). We believe that the relative normalization error in cross-sections for the two $\sqrt{s}$ values is not less than 12%. This corresponds to an uncertainty of 0.7 in the value of n , and would result, for example, from a 1% relative shift of photon energy scales between the interspersed runs at the two $\sqrt{s}$ values.

From Fig. 4, one observes that for values of X_T up to 0.25, n is consistent with the value of 8, but for $X_T > 0.25$ (i.e. $p_T \geq 7$ GeV/c) decreases toward a value of 4-5. This behaviour is similar to that reported in Refs. 4 and 5.

QCD theories [8,9] predict n to have a value of 4-6 at high p_T . Since this prediction only applies at asymptotic energies, the energy dependence of the cross-sections must be taken into account. We have attempted to do this in the above analysis, but the QCD theories predict deviations from the scaling form assumed. Consequently, it is not certain that results such as those shown in Fig. 4 establish the QCD-type behaviour.

REFERENCES

- [1] C. Kourkouvelis et al, Study of resolved high p_T neutral pions at the CERN ISR, Phys. Lett. B (in press).
- [2] J. Cobb et al., Nucl. Instrum. Methods 140 (1976) 1977;
J. Cobb et al., Nucl. Instrum. Methods 158 (1979) 93.
- [3] C. Kourkouvelis et al, Inclusive η production at high p_T at the ISR, following Letter.
- [4] A.L.S. Angelis et al., CERN-Columbia-Oxford-Rockefeller Collaboration, Phys. Lett. 79B (1978) 505.
- [5] A.G. Clark et al., CERN-Saclay-Zurich Collaboration, Phys. Lett. 74B (1978) 267.
- [6] M.J. Tannenbaum, Invited talk at meeting at Marseille -- Hadron physics at high energies, 5-9 June 1978.
- [7] F.W. Büsser, et al., Nucl. Phys. B106 (1976) 1.
- [8] R.D. Field, Phys. Rev. Lett. 40 (1978) 997.
- [9] A.P. Contogouris et al., Phys. Rev. D 17 (1978) 2314.

Table 1

Typical correction factors

Correction for	Equivalent counting rate effect
Shower transverse size requirement	0.90 ± 0.02
Reconstruction efficiency	0.88 ± 0.02
Beam-beam or SC requirement	0.92 ± 0.02
Associated track requirement	0.75 ± 0.05
Threshold and efficiency effects	0.75 ± 0.05
Conversion probability	0.97 ± 0.02
Large opening angle π^0 decay	0.97 ± 0.02
Two overlapping π^0	1.15 ± 0.05
Contribution from η	1.04 ± 0.02
Energy resolution, binning	1.10 ± 0.02
Non-linearity in energy scale (1%)	0.90 ± 0.04
Energy scale accuracy ($\pm 2\%$)	1.00 ± 0.18
Other normalization uncertainty	1.00 ± 0.10

Table 2

Invariant cross-section results^{a)}

p_T (GeV/c)	$Ed^3\sigma/dp^3$ ($\text{cm}^2\text{c}^3/\text{GeV}^2$)	
	at $\sqrt{s} = 52.7$ GeV	at $\sqrt{s} = 62.4$ GeV
6.5	$(8.66 \pm 1.77) \times 10^{-35}$	$(1.42 \pm 0.28) \times 10^{-34}$
7.5	$(1.36 \pm 0.15) \times 10^{-35}$	$(2.90 \pm 0.29) \times 10^{-35}$
8.5	$(3.10 \pm 0.43) \times 10^{-36}$	$(8.11 \pm 0.82) \times 10^{-36}$
9.5	$(7.74 \pm 1.55) \times 10^{-37}$	$(2.18 \pm 0.23) \times 10^{-36}$
10.5	-	$(7.81 \pm 0.88) \times 10^{-37}$
11.0	$(7.93 \pm 2.91) \times 10^{-38}$	-
11.5		$(2.25 \pm 0.31) \times 10^{-37}$
12.5		$(6.52 \pm 1.27) \times 10^{-38}$
13.5		$(3.07 \pm 0.77) \times 10^{-38}$
15.0		$(9.22 \pm 2.63) \times 10^{-39}$

a) In addition to the indicated errors, which include $\pm 10\%$ due to uncertainties in corrections which may be p_T -dependent, there is an over-all normalization error of $\sim \pm 20\%$.

Figure captions

Fig. 1 : Arrangement of the detection apparatus. The ISR beam intersection pipe is normal to the plane of the drawing.

Fig. 2 : Invariant cross-section versus p_T at $\sqrt{s} = 52.7$ GeV.

Fig. 3 : Invariant cross-section versus p_T at $\sqrt{s} = 62.4$ GeV.

Fig. 4 : The value of n evaluated as discussed in the text as a function of X_T (the error bars are statistical only). There is an additional common systematic error of ± 0.7 in n , as described in the text. Results from our previous analysis [1] of resolved $\pi^0 \rightarrow 2\gamma$ events at $\sqrt{s} = 62.4$ and 52.7 GeV are also shown.

Fig. 1

Fig. 3

Fig. 4