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STUDY OF RESOLVED HIGH P_T NEUTRAL PIONS AT THE CERN ISR

Fig. 2

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ABSTRACT

The inclusive production of π^0 at large values of p_T in pp collisions at the ISR has been studied. In this experiment the two photons are resolved and separately measured for p_T values of up to 7 GeV/c, giving confidence that the desired signal has been separated from various backgrounds.

1. INTRODUCTION

Inclusive hadronic production of pions at large p_T is an important process for testing constituent models of hadron reactions. At the ISR, π^0 inclusive production in pp collisions at 90° c.m. has been studied in several experiments. In most of these, the two photons from π^0 decay were not detected separately, but instead merged into a single unresolved signal in a photon detector.

In this experiment, we have used liquid-argon - lead-plate calorimeters as photon detectors, in order to achieve both high spatial resolution and large solid angle. We have obtained data in which the two photons from $\pi^0 \rightarrow \gamma\gamma$ decay are resolved for p_T values up to 7 GeV/c. By requiring that the invariant mass of the two detected photons be equal to m_{π^0} , our analysis is then able to exclude contributions from various background sources. (In a subsequent Letter, we report our results for larger values of p_T , up to 16 GeV/c, where the photons from π^0 decay are not resolved.)

2. EXPERIMENTAL ARRANGEMENT

In an earlier paper [1] our detector modules are described in detail, as used in an experiment designed to maximize the solid-angle coverage, with each calorimeter covering about an eighth of the azimuth and positioned 0.8 m from the interaction point. In this experiment, two of the calorimeters, shown in Fig. 1, were placed at 1.6 m from the interaction point, to allow resolution of the $\pi^0 \rightarrow \gamma\gamma$ decays up to higher values of p_T ($p_T \approx 7$ GeV/c). Furthermore, in order to minimize the amount of converting material, the transition radiation detectors, not relevant to this experiment, were removed. With this arrangement, each calorimeter covered a polar angle of 70° to 120° and an azimuth angle of 20° . The angular resolution for separating two showers was 1.5° . The calorimeters were internally subdivided both longitudinally (in the direction of shower development) and transversely, allowing strict selection criteria to be placed on the spatial extent of the electromagnetic shower signal.

3. TRIGGERING REQUIREMENTS

To select π^0 's of large p_T in each calorimeter, we imposed the requirement that the energy deposited in localized regions in the first two sections of the calorimeter (~ 3 radiation lengths each) as well as the total energy deposited, determined by summing over all sections of the calorimeter, exceeded corresponding thresholds. The total energy thresholds were set to correspond to an energy of just below 3 GeV, which essentially imposed an effective trigger threshold of 2.8 GeV in transverse momentum owing to the small polar angle covered by our apparatus.

Event read-out was initiated when the signal from the calorimeter was in coincidence with either a signal from a set of "beam-beam" counters, positioned in such a way as to require that an inelastic pp collision had occurred, or with a coincidence from the SC1 and SC2 scintillation counter hodoscopes.

Data were taken for three c.m. energies; the effective integrated luminosities (after dead-time corrections) for the present data were $0.65 \times 10^{36} \text{ cm}^{-2}$ at $\sqrt{s} = 30.6 \text{ GeV}$, 1×10^{36} at $\sqrt{s} = 52.7 \text{ GeV}$, and 0.98×10^{36} at $\sqrt{s} = 62.4 \text{ GeV}$.

4. DATA ANALYSIS

Each event was required to have at least two reconstructed showers of energy above 400 MeV each, inside a certain fiducial volume. Because no track reconstruction was performed in this run, the proportional chambers used in our electron experiment having been removed, the effective mass, $M_{\gamma\gamma}$, of the photon pair was computed by assuming that the interaction point was at the centre of the 40 cm long interaction diamond. The effect of the assumption was found to be small and has been taken into account in the acceptance calculations.

To avoid losses due to asymmetric decays of the π^0 's we restricted the asymmetry of the photon pair, $\alpha = |E_2 - E_1|/E_{\text{tot}}$ to values smaller than 0.4. The transverse momentum range of the π^0 extended from 3 to 7 GeV/c. The lower limit was imposed by the trigger requirement, as mentioned above. The upper limit was imposed by statistics and by worsening detection efficiency of a separated photon pair.

For a $p_T \gtrsim 5$ GeV/c the photon opening angle becomes smaller and the π^0 's begin to appear as single showers. To study the merging problem in detail, high p_T π^0 's were simulated using the data^{*)}. By running data through the reconstruction program, we estimated directly the number of π^0 's that were reconstructed as resolved showers. This way the reconstruction efficiency for resolved π^0 's of high p_T was directly determined from the data, without resorting to Monte Carlo methods to simulate the showers, and was found to be $97 \pm 3\%$ for $p_T \approx 5$ GeV/c and $87 \pm 4\%$ for $p_T \approx 7$ GeV/c.

In Fig. 2 we show the distribution in effective mass $M_{\gamma\gamma}$ of the photon pairs which satisfied the above selection criteria. The background under the peaks may be due either to wrong γ -pairing when computing $M_{\gamma\gamma}$, or to showers that originate from beam-gas interactions. The background of the first kind was estimated by studying events of the right-hand side and left-hand side of the peaks and was found to be of the order of 5%. The second type of background found under the π^0 peak was presumably due to (upstream) beam-gas interactions. In this case, a single skew shower, caused by a particle entering the calorimeter from the side, was apparently interpreted by the shower-finding computer program as two barely resolved showers. This can result in a peaking at low mass, i.e. under the π^0 peak. Such background showers are expected to have longitudinal and lateral development very different from that of true electromagnetic showers from photons originating in the interaction diamond. We found that this kind of background could be removed by imposing stringent cuts on the fractional energy deposit in the first and second sections of the calorimeter and on the shower radii. The residual background was estimated to be not more than 7%. The validity and efficiency of these cuts were also studied and confirmed using electron shower test data [1], which we obtained at the CERN PS.

The solid angle acceptance for $\pi^0 \rightarrow \gamma\gamma$ events was calculated by means of a Monte Carlo program. The efficiency of our event reconstruction procedure was

*) Similar results were obtained by running the shower Monte Carlo program EGS.

estimated by varying the minimum energy cut and observing its effect on pattern recognition and by inspection of event displays. The absolute energy scale was determined by monitoring the value of the π^0 and η mass peaks. The trigger efficiency was determined by studying showers produced in untriggered modules. A correction estimate was applied for showers which converted late inside the calorimeter, i.e. for showers which did not satisfy the pattern recognition threshold in the first calorimeter section.

A final correction was applied to account for the efficiency of triggering of those events in which the produced charged particles were not within the acceptance of the beam-beam counters or SC1-SC2 hodoscopes. This efficiency was found to be 78% for $\sqrt{s} = 30.6$, 90% for $\sqrt{s} = 52.7$, and 91% for $\sqrt{s} = 62.4$ GeV.

4. RESULTS AND CONCLUSIONS

Figure 3 shows the invariant cross-section for π^0 production as a function of p_T for the rapidity interval of ± 0.4 units for three values of $\sqrt{s}$.

The uncertainty in absolute normalization was estimated to be about 22%. Various sources of this uncertainty are listed in Table 1; the dominant one (17%) arises from a 2% uncertainty in the energy scale (as derived from fitting the π^0 mass). The linearity of the shower energy scale has been checked from calibration runs at the PS with an electron beam and verified by observing that the η , J/ψ , and T masses had the right values. Table 2 gives the cross-section for the three values of $\sqrt{s}$. Our results are in remarkable agreement with those of Clark et al. [2] up to the largest p_T value of their resolved data ($p_T = 4.5$ GeV/c). They are also compatible with preliminary results of the CCOR Collaboration [3].

Previous measurements [4] of the π^0 inclusive cross-section at 90° c.m. have shown that the parametrization:

$$E \frac{d^3\sigma}{dp^3} = A p_T^{-n} (1 - X_T)^m \quad \text{where} \quad X_T = \frac{2p_T}{\sqrt{s}} \quad (1)$$

could fit the data with $n \approx 8$. However, in the above parametrization, the parameters n and m are strongly coupled. In order to determine the value of the parameter n we choose data from pairs of the three $\sqrt{s}$ sets of data that have the same X_T . By dividing the corresponding pairs of invariant cross-sections we divide out the X_T dependence and therefore the dependence on the parameter m . We then multiply each invariant cross-section by the corresponding p_T raised to the n^{th} power.

Figure 4 displays the ratio

$$\left\{ p_T^8 E \frac{d^3\sigma}{dp^3} \right\}_{\sqrt{s}_i} / \left\{ p_T^8 E \frac{d^3\sigma}{dp^3} \right\}_{\sqrt{s}_j}$$

for $i \neq j$ and $\sqrt{s}_i > \sqrt{s}_j$ as a function of X_T . We observe that the power 8 of the transverse momentum describes adequately the experimental data up to a value of X_T of 0.27, i.e. for the ranges of $3 < p_T < 6$ GeV/c and $31 < \sqrt{s} < 63$ GeV.

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Table 1

Uncertainties in cross-section correction factors
for retracted-octant data

Luminosity measurement	$\pm 7\%$
Trigger efficiency plus acceptance calculation	$\pm 10\%$
Reconstruction program efficiency calculation	$\pm 5\%$
Late conversion correction	$\pm 2\%$
Trigger bias correction	$\pm 2\%$
Calorimeter area correction	$\pm 2\%$
Absolute energy calibration ($\pm 2\%$)	$\pm 17\%$
Total	$\pm 22\%$

Table 2

Invariant cross-sections for the reaction $p + p \rightarrow \pi^0 + X$

p_T ^{a)} (GeV/c)		$Ed^3\sigma/dp^3$ ($\text{cm}^2/\text{GeV}^2 \text{ c}^{-3}$)		
p_T range	$\langle p_T \rangle$	$\sqrt{s} = 30.6$	$\sqrt{s} = 52.7$	$\sqrt{s} = 62.4$
3.0-3.1	3.05	$(5.32 \pm 0.76) \times 10^{-32}$	$(2.41 \pm 0.33) \times 10^{-31}$	$(2.68 \pm 0.37) \times 10^{-31}$
3.1-3.2	3.15	$(3.85 \pm 0.56) \times 10^{-32}$	$(1.74 \pm 0.24) \times 10^{-31}$	$(2.02 \pm 0.28) \times 10^{-31}$
3.2-3.3	3.25	$(2.82 \pm 0.41) \times 10^{-32}$	$(1.29 \pm 0.18) \times 10^{-31}$	$(1.59 \pm 0.22) \times 10^{-31}$
3.3-3.4	3.35	$(1.98 \pm 0.30) \times 10^{-32}$	$(9.85 \pm 1.36) \times 10^{-32}$	$(1.15 \pm 0.16) \times 10^{-31}$
3.4-3.5	3.45	$(1.32 \pm 0.21) \times 10^{-32}$	$(7.25 \pm 1.00) \times 10^{-32}$	$(8.74 \pm 1.21) \times 10^{-32}$
3.5-3.6	3.55	$(1.05 \pm 0.17) \times 10^{-32}$	$(5.50 \pm 0.77) \times 10^{-32}$	$(6.63 \pm 0.92) \times 10^{-32}$
3.6-3.7	3.65	$(7.12 \pm 1.20) \times 10^{-33}$	$(4.14 \pm 0.58) \times 10^{-32}$	$(5.25 \pm 0.73) \times 10^{-32}$
3.7-3.8	3.75	$(4.87 \pm 0.87) \times 10^{-33}$	$(3.15 \pm 0.44) \times 10^{-32}$	$(3.73 \pm 0.52) \times 10^{-32}$
3.8-3.9	3.85	$(3.52 \pm 0.67) \times 10^{-33}$	$(2.40 \pm 0.34) \times 10^{-32}$	$(3.02 \pm 0.42) \times 10^{-32}$
3.9-4.0	3.95	$(2.48 \pm 0.51) \times 10^{-33}$	$(1.63 \pm 0.23) \times 10^{-32}$	$(2.26 \pm 0.32) \times 10^{-32}$
4.0-4.2	4.10	$(1.22 \pm 0.25) \times 10^{-33}$	$(1.15 \pm 0.16) \times 10^{-32}$	$(1.57 \pm 0.22) \times 10^{-32}$
4.2-4.4	4.30	$(8.69 \pm 1.96) \times 10^{-34}$	$(7.39 \pm 1.06) \times 10^{-33}$	$(8.68 \pm 1.24) \times 10^{-33}$
4.4-4.6	4.50	$(4.21 \pm 1.16) \times 10^{-34}$	$(4.57 \pm 0.68) \times 10^{-33}$	$(6.26 \pm 0.91) \times 10^{-33}$
4.6-4.8	4.70	$(2.28 \pm 0.81) \times 10^{-34}$	$(2.77 \pm 0.42) \times 10^{-33}$	$(3.62 \pm 0.54) \times 10^{-33}$
4.8-5.0	4.89	$(7.11 \pm 4.22) \times 10^{-35}$	$(1.89 \pm 0.30) \times 10^{-33}$	$(2.38 \pm 0.37) \times 10^{-33}$
5.0-5.4	5.18	$(8.09 \pm 3.25) \times 10^{-35}$	$(1.01 \pm 0.16) \times 10^{-33}$	$(1.63 \pm 0.25) \times 10^{-33}$
5.4-5.8	5.58	$(6.47 \pm 2.76) \times 10^{-35}$	$(3.92 \pm 0.72) \times 10^{-34}$	$(6.35 \pm 1.06) \times 10^{-34}$
5.8-6.2	5.97		$(1.99 \pm 0.43) \times 10^{-34}$	$(2.95 \pm 0.57) \times 10^{-34}$
6.2-6.6	6.37			$(2.25 \pm 0.46) \times 10^{-34}$

a) All p_T values are in the ISR c.m. system.

Figure captions

- Fig. 1 : Apparatus arrangement for retracted-octant runs.
- Fig. 2 : $\gamma\gamma$ invariant mass spectrum for $\sqrt{s} = 63$ GeV.
- Fig. 3 : π^0 invariant cross-section versus p_T . (The error bars include a 10% point-to-point systematic uncertainty.)
- Fig. 4 : Plot of the ratio of the product $p_T^2 E(d^3\sigma/dp^3)$ for all pairs of the three different sets of $\sqrt{s}$ data.

Fig. 1

Fig. 2

Fig. 3

Fig. 4