**High transverse momentum η production in π^-p , π^+p , and
 pp interactions at 280 GeV/c
WA70 – collaboration**

M.Bonesini⁴⁾, E.Bonvin⁵⁾, P.S.L.Booth³⁾, R.Bopp¹⁾, L.J.Carroll³⁾, A.J.Cass³⁾, D.Cavalli⁴⁾,
S.U.Chung¹⁾, G.Costa⁴⁾, M.Donnat¹⁾, P.A.Dorsaz¹⁾, E.Durieux¹⁾, M.E.J.Feliks²⁾, J.R.Fischer¹⁾,
L.Fluri⁵⁾, F.Gianotti⁴⁾, S.Jack²⁾, J.N.Jackson³⁾, M.Kelly³⁾, M.N.Kienzle-Focacci¹⁾, R.Lacock²⁾,
J.G.Lynch²⁾, L.Mandelli⁴⁾, M.Martin¹⁾, L.Mathys¹⁾, A.Maxwell²⁾, M.Mazzanti⁴⁾, P.J.Negus²⁾,
L.Perini^{4,6)}, D.Perrin⁵⁾, G.Polesello⁴⁾, R.Poultney³⁾, W.H.Range³⁾, L.Rosselet¹⁾, S.W.Snow³⁾,
A.S.Thompson²⁾, R.M.Turnbull²⁾, and M.Werlen¹⁾

Abstract

The inclusive cross sections for η production by the interactions of 280 GeV/c momentum π^- , π^+ , and proton beams in hydrogen have been measured. The kinematical range covered is $-0.45 < x_F < 0.45$, and $4.0 < p_T < 7.0$ GeV/c for Feynman x_F and transverse momentum respectively. The η to π^0 cross section ratios are given for the three reactions. The ratio of π^-p to π^+p cross sections for η production in the above kinematic ranges is $1.22 \pm 0.08 \pm 0.11$

-
- 1) University of Geneva, D.P.N.C., CH-1211 GENEVE, Switzerland
2) University of Glasgow, Dept. of Physics and Astronomy, GLASGOW, G12 8QQ, UK
3) University of Liverpool, Dept. of Physics, LIVERPOOL, L69 3BX, UK
4) Dipartimento di Fisica dell'Università e Sezione INFN Milano, I-20133 MILANO, Italy
5) University of Neuchâtel, CH-2000 NEUCHÂTEL, Switzerland
6) CERN, CH-1211 GENEVE 23, Switzerland

1. Introduction

The results on high transverse momentum (p_T) η production presented here have been obtained at CERN in the WA70 experiment which was designed to study prompt photons. It comprises a fine grained electromagnetic calorimeter [1-3] and the CERN Omega spectrometer [4]. The recorded data sample also contains the two-photon decay channel of the η which has a known branching ratio of 0.39 ± 0.01 . In this channel, the acceptance is large and covers the kinematical region $-0.45 < x_F < 0.45$ and $4.0 < p_T < 7.0$ GeV/c for Feynman x_F and transverse momentum respectively. The sensitivities are 3.2, 1.3, and 5.8 pbarn⁻¹ for the π^- , π^+ , and p beams respectively.

Previous experiments [5-7] have measured high p_T π^0 and η production cross sections in pp and $\bar{p}p$ interactions for transverse momenta in the range 2.0 to 11.0 GeV/c and have attributed [7] their production to the fragmentation of quarks and gluons. The absence of differences between pp and $\bar{p}p$ cross sections has been interpreted [7] as evidence that the contribution from the valence quark annihilation diagrams is not dominant. No similar comparison between π^-p and π^+p interactions has been made for the production of high p_T π^0 and η . In addition to the fragmentation production mode, direct production (Higher Twist) is also expected for mesons at a rate of about 10% for both η and π^0 [8]. The η to π^0 cross section ratio should however remain insensitive to the presence of Higher Twist and be of the order of 0.5 [8].

In this paper, the η production cross sections have been determined for π^-p , π^+p , and pp interactions, and are compared with the previously determined π^0 cross sections from this experiment [9,10]. The ratio of the production cross sections for π^- and π^+ interactions is also presented. The statistics obtained here allow a comparison of differential cross sections as a function of p_T and x_F .

The experimental system and the data reduction have been described in detail in references 9,10 and 11; they will be briefly outlined in section 2. The analysis and the results are presented in section 3.

2. Experimental system and selection of events

A 280 GeV/c hadron beam from the CERN SPS, incident on a 1m long liquid hydrogen target, was equipped with two differential Cerenkov counters (CEDAR) set to identify pions. For part of the data taking a toroidal magnet was installed around the beam line in order to deflect the muon beam halo.

The photons were detected by a lead-liquid scintillator calorimeter, divided into three segments in depth (8 radiation lengths each). The charged particles were detected by the Omega spectrometer proportional chambers (33 wire planes, 2mm pitch) inside a magnetic field of 1.1 T, together with drift chamber planes at the downstream end of the Omega magnet, and a large multiwire proportional chamber (BMWPC) in front of the calorimeter. The fiducial area of the calorimeter and of the BMWPC is 4m x 4m. The target was positioned with its downstream end at the centre of the magnet, and the calorimeter was situated 10.9m beyond this.

Data acquisition was triggered by demanding a coincidence between an interaction trigger from beam scintillation counters and a calorimeter trigger [12] which selected events with high p_T electromagnetic showers with a total transverse energy above a threshold of typically 3 GeV/ in one trigger cell. With a beam intensity of 2.0×10^7 particles per 1.6s beam pulse, the interaction trigger rate was about 2.0×10^6 and the acquisition rate 100 events per burst.

Events were filtered both on-line before tape writing and off-line in order to remove spurious triggers such as shower clusters simulating a single high- p_T shower, superimposed interactions from two beam particles, hadron and muon-induced triggers. After the calorimeter shower reconstruction a minimal p_T for the reconstructed trigger shower or for a pair of showers with effective mass smaller than 1.2 GeV was required. These selections are the same as for the π^0 analysis, and are described in more detail in references 9,10. The events were processed to reconstruct charged tracks and the final data sample then required the reconstruction of a vertex inside the target.

3. Analysis and results

3.1 Selection of η candidates

Electromagnetic showers have been distinguished from hadronic showers by requiring that less than 20% of the energy of the shower was deposited in the third calorimeter segment. Electromagnetic shower pairs with an asymmetry $|E_{\gamma_1} - E_{\gamma_2}|/(E_{\gamma_1} + E_{\gamma_2})$ less than 0.8 have been selected. The resulting mass spectrum which has been obtained by combining the trigger shower with all other showers, requiring a minimal p_T of 4.0 GeV/c for each shower pair, is shown in fig. 1; the η mass resolution is $\sigma = 26$ MeV. There was more than one combination in the 0.45-0.65 GeV range for a single event in less than 2% of the cases. The number of η s has been obtained by subtracting the number of combinations found in the two ranges 0.35-0.45 GeV and 0.65-0.75 GeV from the number between 0.45 and 0.65 GeV. This background subtraction (about 50%) has been determined for each p_T - x_F bin.

3.2 Results

The acceptance corrections and the detection efficiencies have been estimated from a Monte Carlo sample where single η s were generated with the same p_T - x_F dependence as observed in π^0 production [9,10]. This procedure showed the same results as a complete event simulation with a LUND Monte Carlo within a 5% accuracy. The resulting invariant cross sections $Ed^3\sigma/dp^3$ corrected for the $\gamma\gamma$ branching ratio of 0.39 are given for the three incident beams in the form of p_T - x_F tables (table 1). The two projected distributions versus x_F and p_T , with their statistical errors are shown in fig.2. The x_F distributions for π^- and π^+ beams are significantly broader and shifted towards positive x_F values, compared with the distribution obtained for protons, which is centred at $x_F = 0$. The systematic uncertainties on the total cross sections have been estimated to be about 15%, due to errors on beam particle identification, gain equalization of the different parts of the calorimeter and energy scale, efficiency corrections, and shape of the background quadratically added. They are reduced to 9% for the ratio of η cross sections in π^-p to π^+p interactions, where the remaining error term comes from the hypothesis on the shape of the background. They are also reduced to 9% for the cross section ratios for η to π^0 production with the same incident beam, for which the remaining error term comes from the uncertainty on the shape of the background for the η , quadratically added to the uncertainties on the acceptances for η and π^0 .

The η/π^0 production cross section ratios versus p_T are shown in fig.3 for the three beams. The π^0 cross sections used in these ratios are slightly different from those published earlier; an additional trigger acceptance correction factor has now been applied to the data, whereas previously it was included in the systematic uncertainty.

Within statistical errors the η/π^0 ratios are p_T -independent . Their values integrated in p_T and x_F with their statistical and systematic errors are the following:

$$\begin{aligned}\eta/\pi^0 \text{ ratio for } pp &: 0.45 \pm 0.02 \pm 0.04 \\ \pi^+ p &: 0.44 \pm 0.03 \pm 0.04 \\ \pi^- p &: 0.48 \pm 0.02 \pm 0.04\end{aligned}$$

The ratio of η production cross sections for $\pi^- p$ and $\pi^+ p$ interactions, averaged over the whole p_T and x_F ranges, is measured to be:

$$\frac{\sigma(\pi^- p \rightarrow \eta X)}{\sigma(\pi^+ p \rightarrow \eta X)} = 1.22 \pm 0.08 \pm 0.11$$

The p_T and x_F dependences of this ratio are shown in fig.4.

3.3 Phenomenological fit

The same phenomenological expression as that used for the π^0 analysis[9] has been fitted to the results of the x_F - p_T tables, using a least squares method:

$$Ed^3\sigma/dp^3 = \frac{C(1-x_D)^m}{(p_T/p_0)^{2n}}$$

with

$$x_D = (x_T^2 + (x_F - x_0)^2)^{1/2}$$

$$x_T = 2p_T/\sqrt{s}$$

$$p_0 = 1 \text{ GeV}/c$$

and where C , x_0 , m , n are free parameters

The values of these parameters are given in table 2, and the results of the fit have been superimposed on the projected distributions in fig. 2 . Only statistical errors have been taken into account.

The slope parameters m and n obtained for the fits on the η samples are consistent with those previously published for the π^0 samples[9] within the systematic errors on the cross sections.

4. Conclusion

The η production cross sections in the transverse momentum and Feynman x_F ranges $4.0 < p_T < 7.0$ GeV/c and $-0.45 < x_F < 0.45$ have been measured for π^-p , π^+p and pp interactions at 280 GeV/c.

The results have been fitted with a phenomenological function. The x_F distributions for π^- and π^+ beams are significantly broader and shifted towards positive x_F values, compared with the distribution obtained for protons, which is centred at $x_F = 0$.

The η to π^0 cross section ratios are constant for the three beams in the range of $4.0 < p_T < 7.0$ GeV/c. These ratios are compatible within statistical errors for incident π^- , π^+ and protons.

The ratio of the η cross section for π^- and π^+ beams remains constant over the kinematical region covered by this experiment, with the value of $1.22 \pm 0.08 \pm 0.11$.

Acknowledgements

It is a pleasure to thank the members of the Omega support group, especially W.Beusch and F.Bourgeois as well as the EA support group for their invaluable assistance throughout the experiment.

We thank J.P.Dufey, who developed the MICE acquisition system, J.Joosten and M.Letheren for their help with MICE, and members of the DD/OC support group who provided the VAX data acquisition system.

We gratefully acknowledge the provision of computing facilities by CERN, CILEA, RAL and University of Geneva as well as financial support from CERN, INFN, the United Kingdom SERC and the Swiss National Foundation.

References

1. M.Bonesini et al., Nucl. Instr. and Meth. A261(1987)471
2. M.Bonesini et al., Nucl. Instr. and Meth. A263(1988)325
3. M.Bonesini et al., Nucl. Instr. and Meth. A270(1988)32
4. W.Beusch: CERN/SPSC 77 – 70, SPSC/T-17 (1977)
5. C.Kourkouvelis et al., Phys. Letter 84B(1979) 277
6. T.Akesson et al., Phys. Letter 158B(1985) 282
7. J.Antille et al., Phys. Letter 194B(1987) 568
8. M.Benayoun et al., Nucl. Phys. B282(1987) 653
9. M.Bonesini et al., Z. Phys. C 37(1987)39
10. M.Bonesini et al., Z. Phys. C 38(1988)371
11. M.Bonesini et al., Z. Phys. C 37(1988)535
12. P.Bené et al., Nucl. Instr. and Meth. A270(1988)21

Table 1: The η invariant cross sections, in pbarn GeV^{-2} .

Each cell contains the value of the cross section corrected for the branching ratio of 0.39 and its statistical error. The systematic error is estimated to be 15%. The limits of each p_T - x_F cell and its weighted mean p_T are given.

a) π^- beam

$p_T =$	4.0	4.5	5.0	5.5	7.0	GeV/c
$\bar{p}_T =$	4.2	4.7	5.2	6.1		GeV/c
$x_F = +0.45$	186.3 $\pm$ 22.3	45.1 $\pm$ 8.5	17.94 $\pm$ 2.9	2.63 $\pm$ 0.48		
+0.30	367.7 $\pm$ 32.1	69.9 $\pm$ 10.9				
+0.15	464.6 $\pm$ 30.1	103.1 $\pm$ 10.6	19.2 $\pm$ 3.3			
+0.00	384.9 $\pm$ 30.0	92.4 $\pm$ 10.4				
-0.15	238.8 $\pm$ 25.4	44.4 $\pm$ 8.5	10.8 $\pm$ 2.4	1.22 $\pm$ 0.44		
-0.30	52.6 $\pm$ 38.9	13.2 $\pm$ 11.2				
-0.45						

b) π^+ beam

$p_T =$	4.0	4.5	5.0	5.5	7.0	GeV/c
$x_F =$	$\bar{p}_T = 4.2$	4.7	5.2	6.1		GeV/c
+0.45	207.4 $\pm$ 29.4	63.6 $\pm$ 10.7	11.3 $\pm$ 3.8	1.34 $\pm$ 0.49		
+0.15	360.3 $\pm$ 31.3	70.5 $\pm$ 10.7				
-0.15	143.5 $\pm$ 25.2	18.0 $\pm$ 7.7	13.0 $\pm$ 3.6			
-0.45						

c) proton beam

$p_T =$	4.0	4.5	5.0	5.5	7.0	GeV/c
$x_F =$	$\bar{p}_T = 4.2$	4.7	5.2	6.1		GeV/c
+0.45	31.5 $\pm$ 8.5	10.9 $\pm$ 2.7	3.6 $\pm$ 1.0	0.85 $\pm$ 0.22		
+0.30	146.7 $\pm$ 15.6	33.0 $\pm$ 5.2				
+0.15	286.7 $\pm$ 17.4	43.4 $\pm$ 5.3	9.3 $\pm$ 1.6			
+0.00	293.1 $\pm$ 19.2	47.8 $\pm$ 6.4				
-0.15	170.8 $\pm$ 17.4	34.2 $\pm$ 5.6	5.5 $\pm$ 1.5	0.34 $\pm$ 0.26		
-0.30	97.6 $\pm$ 26.5	9.9 $\pm$ 7.7				
-0.45						

Table 2: Parameters of the phenomenological fit.

a) π^- beam

	C(mb/GeV ²)	m	n	x ₀
value $\pm$ stat. error	12.0+9.6 -5.3	4.4 $\pm$ 0.4	5.29 $\pm$ 0.23	0.062 $\pm$ 0.010
correlation coefficients	C x ₀ n	-0.355 -0.059 -0.630	0.948 0.071	0.062

b) π^+ beam

	C(mb/GeV ²)	m	n	x ₀
value $\pm$ stat. error	38.2+70.4 -24.1	3.91 $\pm$ 0.68	5.81 $\pm$ 0.41	0.057 $\pm$ 0.021
correlation coefficients	C x ₀ n	0.632 -0.225 0.302	0.927 -0.083	-0.148

c) proton beam

	C(mb/GeV ²)	m	n	x ₀
value $\pm$ stat. error	95.4+109.0 -50.4	5.94 $\pm$ 0.49	5.87 $\pm$ 0.29	-0.020 $\pm$ 0.010
correlation coefficients	C x ₀ n	-0.173 0.478 -0.449	0.957 -0.200	-0.071

Figure captions

1. The $\gamma\gamma$ effective mass spectrum in the η region
2. Cross sections :
 - a. Invariant cross sections for η production for the three beams as a function of p_T , for $-0.45 < x_F < 0.45$ (the error bars are statistical only). The curves show the result of the phenomenological fit.
 - b. Invariant cross sections for η production for the three beams as a function of x_F , for $4.0 < p_T < 7.0$ GeV/c (the error bars are statistical only). The curves show the result of the phenomenological fit.
3. The η/π^0 production cross section ratios for the three beams as a function of p_T (the error bars are statistical only).
 - a. π^- beam
 - b. π^+ beam
 - c. proton beam
4. The η cross section ratios for π^- and π^+ beams $\sigma(\pi^- p \rightarrow \eta X)/\sigma(\pi^+ p \rightarrow \eta X)$ as a function of p_T and x_F (the error bars are statistical only).
 - a. function of x_F
 - b. function of p_T

FIG.1

FIG.2

FIG. 3

FIG. 4