INCLUSIVE PRODUCTION OF π^0 's AND
FEYNMAN SCALING TEST IN
THE FRAGMENTATION REGION AT
THE SppS COLLIDER

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ABSTRACT

The inclusive production of π^0 's has been measured in the nucleon fragmentation region at the SppS Collider at 630 GeV center of mass energy. Average transverse momentum and rapidity distributions compared with lower energy ISR data show no sizable violation of Feynman scaling in the fragmentation region.

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Hadron production at the SppS and Tevatron Colliders has been extensively studied in the central rapidity region by the UA1 [1], UA2 [2], UA4 [3], UA5 [4], CO [5] and CDF [6] experiments. Violation of Feynman scaling [7] has been observed both in particle density [1,2,3] and in the increase of the average transverse momentum $\langle p_t \rangle$ with center of mass energy and particle multiplicity [1,2,5,6]. Data in the intermediate region between fragmentation and central exist from UA4 [3] and UA5 [4], but no measurement has been made in the very forward region.

The aim of the UA7 experiment was to measure the production cross-section and transverse momentum of photons from π^0 's in the fragmentation region at a center of mass energy of 630 GeV at the SppS Collider. In order to compare the beam fragmentation at different incident energies, the rapidity in the mirror system, Y_{lab} has been introduced: $Y_{lab} = (Y_{beam} - Y)$. Y is the rapidity defined in the center of mass and Y_{beam} is 6.5 at SppS.

EXPERIMENTAL SET-UP:

The experimental layout is shown in fig. 1. It uses the small angle elastic scattering and total cross-section measurement system of UA4 [8]. In addition, three cylindrical compact calorimeters have been installed on the $\bar{p}$ outgoing side. A 4" diameter calorimeter, called π^0_1 , was installed in a 'Roman pot' -a movable section of the SPS beam pipe- approaching the nominal beam plane up to 3 cm at a distance of 25 m from the $\bar{p}p$ crossing point. The covered rapidity range of the photon was $-0.6 < Y_{lab} < +0.2$. A 3" diameter calorimeter and another 4" diameter calorimeter, called π^0_2 , were located just outside the beam pipe after a thin wall 8 cm from the beam axis at 12 m from the crossing point. The corresponding rapidity range was $1.1 < Y_{lab} < 1.6$.

The 4" calorimeters were composed of a total of 20 radiation lengths of tungsten plates interspaced by 16 layers of 4" diameter silicon wafers. The 3" calorimeter had a total of 14 radiation lengths of lead plates interspaced by 9 silicon layers 3" in a diameter. The energy resolution of both calorimeter types for electromagnetic showers was $18\%/\sqrt{E(\text{GeV})} + 1.5\%$ and $24\%/\sqrt{E(\text{GeV})} + 4\%$ respectively for the 4" and the 3" calorimeters.

The shower position was obtained by segmenting part of the silicon wafers into x(horizontal), y(vertical) and u(45° oriented) strips. The position resolution of the photon shower center was $(4/\sqrt{E(\text{GeV})} + .05)\text{mm}$ and

$(6/\sqrt{E(\text{GeV})} + .2)\text{mm}$ respectively for the 4" and the 3" calorimeters. For events with two photons in the same detector the position resolution is worse by a factor of 1.5. All types of calorimeters have been tested and calibrated in electron and pion beams at energies ranging from 700 MeV to 150 GeV in order to check the reconstruction algorithm. A detailed description can be found in ref. [9,10].

The trigger was given by the original UA4 trigger system [8] covering 99% of inelastic collisions. It was divided into fully inelastic and diffractive like trigger types:

- i) fully inelastic trigger: $(T2_L + T3_L) \times (T2_R + T3_R) \times E_{\text{cal}}$
- ii) diffractive-like trigger: $(T2_L + T3_L) \times (T2_R + T3_R) \times E_{\text{cal}}$

E_{cal} corresponds to a minimum energy deposition in the calorimeters, which was set to 3 GeV corresponding to a maximum p_t of 50 MeV/c in the calorimeters. A fraction of both triggers without the requirement of minimal energy deposition in the calorimeters and suitably prescaled has been recorded to obtain the absolute normalization. Using UA4 data [11], the cross section corresponding to the minimum bias trigger i) is 40.3 ± 1.2 mb and $7.9 \pm .3$ mb for trigger type ii). The minimum bias sample has also been used to check for eventual trigger biases. A total of about 3 million events has been collected.

DATA ANALYSIS

The following cuts have been applied to the data:

- deposited energy must be greater than 3 GeV,
- shower must start before 4 radiation lengths,
- deposited energy in the first silicon wafer must be less than the energy deposited by a minimum ionising particle. This is in order to reject showers starting in the material in front of the calorimeters - .05 r.l. in front of the 4" calorimeter placed inside the 'Roman pot' and .06 r.l. in front of the two others placed outside the vacuum pipe. The data have been corrected for this loss.

The reconstructed two photon invariant mass is shown for pairs of photons in the same calorimeter (fig. 2a & b). For this configuration the resolving power has been studied by superimposing randomly two showers from different triggers. For showers separated by more than 2 cm, 100% of the original pairs are recognized. This means that only π^0 's with energy greater than 170 GeV could be confused as a single shower in the calorimeters located 12 m from the interaction point. Due to the loss of these π^0 's, the average transverse momenta calculated below have to be corrected by at most

1 MeV/c. The energy limit is such that no photon pair from the same π^0 could be confused with a single shower in the calorimeter placed inside the 'Roman pot'. As can be seen in fig. 2 a & b, for π^0 's reconstructed from a pair of photons in the same calorimeter the background of wrong combinations is low.

For π^0 's reconstructed from showers in different calorimeters, the background has also been estimated by associating randomly two showers from different triggers. Using this technique, the shape of the two photon invariant mass spectra is well reproduced below and above the π^0 mass region. The background from wrong pair association has been estimated using this distribution renormalized to the observed two photon mass spectra outside the π^0 mass region.

To correct the observed distribution for limited acceptance, a Monte-Carlo simulation has been performed by generating the π^0 distributions by:

$$\frac{1}{\sigma} \frac{d\sigma}{dY} = A [1 + \exp(-Y_{lab} + Y_0)/D]^{-1}$$

$$\text{and } \frac{d\sigma}{dp_t} = A' p_t \exp(-p_t / \langle p_t \rangle) \quad (1)$$

$$\text{with } \langle p_t \rangle = \langle p_t \rangle_0 [1 - \exp(C(Y_{lab} + Y_0)^2)]$$

The parameters $C = -.21$, $D = .7$, $Y_0 = 1.7$ have been adjusted to reproduce the experimental data, while the absolute normalization are obtained from the minimum bias trigger T_{MB} data common to the UA4 total cross section measurement [11]. The value $\langle p_t \rangle_0 = 400$ MeV/c has been taken from the UA2 measurement at $Y_{lab} = 6.3$ [2].

Figure 3 shows the corrected p_t distributions for different rapidity intervals for trigger type i). Similar distributions are observed for trigger type ii). Superimposed on the data are exponential fits. The values of the parameters obtained from the fits are given in table 1.a and for trigger type i) and table 1.b for trigger types i) and ii) added together. The dependence of the experimentally obtained slope B to the Monte-Carlo input slope $B_0 = \langle p_t \rangle_0$, is given by $dB/dB_0 = .02$. The sensitivity of the cross-section values to the other Monte-Carlo input parameters C , D , and Y_0 is small. It should be mentioned that there is no difference in the result between the two trigger types.

The longitudinal and transverse size of the beam are respectively equal to 30 cm and .15 mm. The average position of the beam crossing point is taken from the UA2 measurement done at the same time, the angle between the nominal beam plane and the beam itself is taken from beam monitors and is equal to 10 μ rad. The uncertainties on these parameters correspond to an uncertainty on the measured angles of .2 mrad, and have small effect on the p_t and Y distributions.

The average $\langle p_t \rangle$ is shown in fig. 4a together with a compilation of π^+ and π^- data from the ISR [12] in the fragmentation region and UA2 [2] in the central region. Going from ISR to SppS, the data are comparable within the experimental errors up to $Y_{lab} = 0.6$, however they are significantly different for $Y_{lab} > 1.2$.

The rapidity distribution is shown in fig. 4b again together with ISR data. The shape of the distributions are similar as well as the absolute cross-section.

According to Feynman scaling, the cross section integrated over p_t ($d\sigma/dY$) and the average $\langle p_t \rangle$ should be independent of the center of mass energy. In comparison with ISR results, the present experiment verifies that within the experimental errors Feynman scaling holds in the fragmentation region and exclude scaling violation like observed in the central region.

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REFERENCES

1. UA1 Collaboration, G. Arnison et al., Phys. Lett. 118B (1982) 167
and G. Arnison et al., Phys. Lett. 123B (1983) 108
2. UA2 Collaboration, M. Banner et al., Phys. Lett. 122B (1983) 322
and M. Banner et al., Zeit. Phys.C 27 (1985) 329
3. UA4 Collaboration, D. Bernard et al., Phys. Lett. 166B (1987) 459
4. UA5 Collaboration, K. Alpgard et al., Phys. Lett. 107B (1981) 315
and G.J. Alner et al., Zeit. Phys. C33 (1986) 1

5. C0 Collaboration, T. Alexopoulos et al., Phys. Rev. Lett. 60
(1988) 1622
6. CDF Collaboration, F. Abe et al., Phys. Rev. Lett. 61(1988) 1819
7. R.P. Feynman, Phys. Rev. Lett. 23 (1969) 1415
8. UA4 Collaboration, R. Battiston et al., Nucl. Inst. Meth. A238
(1985) 35
9. A. Nakamoto et al., Nucl. Inst. Meth. A238 (1985) 53
A. Nakamoto et al., Nucl. Inst. Meth. A251 (1985) 275
10. J. Bourotte et al., Nucl. Inst. Meth. A274 (1988) 129
11. UA4 Collaboration, M. Bozzo et al., Phys. Lett. 147B (1984) 392
and D. Bernard et al., Phys. Lett. 198B (1987) 583
12. P. Capiluppi et al., Nucl. Phys. B70 (1974) 1
P. Capiluppi et al., Nucl. Phys. B79 (1974) 189
CHLM Collaboration, M.G. Albrow et al., Nucl. Phys. B56 (1973) 333
and M.G. Albrow et al., Nucl. Phys. B73 (1974) 40

Table 1

Table 1.a

y_{lab}	A(mb)	B(MeV)	$\chi^2/d.o.f.$
-.15	.041 $\pm$.010	159. $\pm$ 7.	13.8/8
.25	.062 $\pm$.014	164. $\pm$ 23.	2.5/4
.60	.121 $\pm$.014	281. $\pm$ 72.	.5/2
.95	.231 $\pm$.016	290. $\pm$ 20	11.8/7
1.25	.295 $\pm$.040	352. $\pm$ 19.	6.2/8
1.45	.215 $\pm$.066	368. $\pm$ 23.	5.9/8

Table 1.b

-.15	.041 $\pm$.009	158. $\pm$ 6.	9.2/8
.25	.054 $\pm$.011	161. $\pm$ 22.	2.7/4
.60	.109 $\pm$.014	244. $\pm$ 50.	.6/2
.95	.207 $\pm$.014	301. $\pm$ 20.	10.4/7
1.25	.279 $\pm$.043	420. $\pm$ 52.	2.7/4
1.45	.191 $\pm$.047	367. $\pm$ 18.	5.7/8

Tables 1: Result of an exponential fit to the invariant cross section as a function of p_t . A is the normalization, B is the average $\langle p_t \rangle$ for different rapidity intervals. Table 1.a corresponds to fully inelastic events from trigger type i). In table 1.b, the diffractive like events from trigger type ii) have been added.

FIGURE CAPTIONS:

1. Experimental layout : T are UA4 trigger scintillation hodoscopes, L(ef) and R(ight) means $\bar{p}$ and p outgoing side respectively. The silicon calorimeters were located at 12 m and 25 m from the interaction point.

2. Two photon mass spectra for a) a photon pair in the same 4" calorimeter # 1, b) a pair in the same 4" calorimeter # 2, c) a pair consisting of one photon in 4" calorimeter # 1 and a second photon in the 4" calorimeter # 2. The lines correspond to the Monte Carlo simulation of the background as described in the text.

3. Invariant p_t distribution of the π^0 for different rapidity intervals. The lines represent the best exponential fit to the data.

4. a) Average p_t of the π is given as a function of the rapidity. The full line corresponds to the Monte Carlo simulation as described in the text. The dashed line is the equivalent to the ISR data with $\langle p_t \rangle$ in the central region equal to 330 MeV.

b) Production cross-section of π^0 's as a function of Y together with ISR data.

Fig. 1

Fig. 2

Fig. 3

Fig. 4