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A MEASUREMENT OF THE INCLUSIVE CROSS SECTION OF
CHARGED PIONS AT VERY HIGH TRANSVERSE MOMENTA

CERN-Dortmund-Heidelberg-Warsaw Collaboration

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ABSTRACT

The inclusive cross sections for the production of high transverse momentum π^+ and π^- mesons in proton-proton interactions have been measured at the highest ISR energy $\sqrt{s} = 63$ GeV and at a centre of mass production angle of 50° . The cross sections for π^+ and π^- mesons are compared as a function of transverse momentum. It is shown that the inclusive cross section of π^- mesons decreases faster than the π^+ cross section. Particle ratios $\sigma(\pi^\pm)/\sigma(\text{charged particles})$ are presented as a function of transverse momentum.

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1. INTRODUCTION

The hadronic production of particles with large transverse momentum carries important information on the hard constituent scattering. The p_T and s -dependence of the inclusive cross section as well as the flavour and charge composition of the produced particles can be used to constrain the absolute value, the dimensional scale and the shape of the contributing parton-parton scattering amplitude.

Up to now however, most available experimental data are concentrated in a narrow region around 90° scattering angle. The scarce measurements away from 90° with identified hadrons are confined to relatively small transverse momenta [1]. This situation limits the kinematical range over which parton-parton scattering can be inspected in detail.

We are presently pursuing an experimental program to extend this range using identified charged hadron triggers. Our measurements cover scattering angles between 60° and 6° for p_T values that reach at least half the total available transverse momentum for the larger angles and touch the kinematical limit in the small angle region.

In this paper we present inclusive cross sections for charged pions and particle ratios at 50° scattering angle at the highest ISR energy, $\sqrt{s} = 63$ GeV. The transverse momentum range reaches up to 12 GeV/c, thus decisely extending the p_T range available up to now at any scattering angle for charged hadrons. We show that the ratio between π^+ and π^- production cross sections increases rapidly with transverse momentum. We also show that the fraction of pions in all charged hadrons has a p_T dependence which is very different for positive and negative particles.

The experiment was performed at the SFM spectrometer; the complete event structure of charged tracks has been recorded together with the triggering high p_T hadron. Detailed investigations of jet structure, charge and flavour correlations in high p_T events will be published in subsequent papers.

2. EXPERIMENTAL PROCEDURE AND DATA REDUCTION

The experiment was performed at the CERN-ISR using the Split Field Magnet (SFM) in its upgraded form. The SFM is a spectrometer which detects and momentum analyzes charged particles in the full solid angle. It consists of 70 000 wires of Multi Wire Proportional Chambers (MWPC), an array of scintillation counters for time-of-flight measurements and a set of Cerenkov counters. A more detailed description of the spectrometer can be found in ref. [2]. Fig. 1 shows a top view of the SFM. The shaded area indicates the acceptance of the high P_T trigger telescope.

2.1 The trigger

In order to be sensitive to cross sections of order 10^{-36} cm² a trigger system which works efficiently and essentially dead time free is required. To achieve this goal the MWPC signals have been used in a multi-level decision scheme.

The first level (FAST) uses fast OR (FOR) signals of groups of 256 wires, requiring a six-fold coincidence of "space points" in the region of acceptance to give a track candidate. The decision time is 100 ns, and the reduction factor is 25.

The second level uses chamber memory OR signals (MOR). A MOR is set if at least one of its 16 wires (corresponding to a spatial resolution of 6.4 cm) has been hit. The MOR's are grouped in coincidence matrices to define "roads" by seven-fold coincidences. The coincidence patterns follow the wanted trajectories thus excluding tracks with low magnetic stiffness. The system consists in total of 176 "roads", which are processed and interrogated in parallel. The decision time is 2 μ s, and the reduction factor is 200.

The third level is a PDP 11/20 used as on-line filter computer. The filter computer reads selectively chamber coordinates inside the trigger telescope and performs track finding in the bending plane. If a track candidate has been found, its transverse momentum is estimated [3]. The event is recorded whenever the transverse momentum is above a preset threshold. The decision time is 10 ms, and for a nominal cut off at $P_T = 4$ GeV/c the reduction factor is 50.

2.2 The Cerenkov counters

The threshold Cerenkov counters covering the trigger region allow the separation of pions from particles heavier than pions. The counters were operated at atmospheric pressure and filled with freon 12. Each counter consists of 4 mirrors reflecting light into 4 phototubes.

During the experiment the efficiencies were controlled by examining the pulse height distributions for off-line reconstructed trigger tracks. Efficiencies were found to be stable and, for the momentum range covered by this experiment to be greater than 99.99%.

2.3 Data analysis and background rejection

The data sample analyzed consists of a total of 11×10^6 triggers taken at the highest ISR energy $\sqrt{s} = 63$ GeV and corresponds to an integrated luminosity of $1.6 \times 10^{37} \text{ cm}^{-2}$. The triggering track has been reconstructed using an especially adapted version of the SFM off-line reconstruction program. Only triggers having a clean reconstructable trigger track were retained. The final criterium for a track to be a clean trigger was derived from the track fit, where it is examined whether a track candidate is compatible with a trajectory of a charged particle in the SFM field (confidence level test) and its track parameters (momentum, charge and direction) are determined. In total 32 coordinates were available for the track fit, providing it with a very high rejectivity against background triggers. Background triggers were found to be mainly due to a superposition of track elements from low transverse momentum tracks, or tracks having a kink in the non bending plane.

In order to study remaining background contaminations, events with unphysical high transverse momentum have been selected and analyzed in detail. The following background sources could be isolated:

- (a) Triggers originating from cosmic rays, which in rare cases were even superimposed with a normal inelastic proton-proton interaction.

- (b) Low transverse momentum tracks having a very small kink due to a decay in flight or a nuclear interaction. In rare cases these tracks are accepted by the track fit and fitted with a small effective sagitta thus faking a high transverse momentum track.

Both background sources could be eliminated by appropriate selection criteria.

Triggers due to cosmic rays can be easily recognized, e.g. because there are no additional tracks in the event. If a cosmic ray is superimposed with a normal inelastic proton-proton interaction the event can be excluded due to the fact that either the trigger track can not be fitted to a common vertex, or a track with comparable momentum is found in the backwards prolongation of the trigger track.

Background triggers due to a misinterpretation of a kinking low transverse momentum track can be excluded by accepting only tracks having a confidence level of the track fit greater than 5%.

After application of these criteria the sample was essentially free of background. The estimated residual background contribution to the invariant cross section is smaller than $2 \times 10^{-38} (\text{cm}^2 \text{ GeV}^{-1} \text{ c}^3)$.

2.3 Momentum resolution of the trigger telescope

Given the extreme steepness of the inclusive cross section as a function of the transverse momentum, it is important to measure the momentum of the triggering high transverse momentum particles as precisely as possible.

The momentum resolution in the trigger telescope is

$$dp/p = 0.004 \times p; \quad p \text{ in GeV/c.}$$

This value was determined by computing the momentum uncertainty of each reconstructed track, and has been verified by track simulation. As an independent test a sample of reconstructed cosmic rays accepted by the trigger has been used. The trajectory of these cosmic rays was reconstructed independently in the trigger telescope and in a set of chambers opposite to it. By comparison of these two independent measurements of a single track it was found that the computed momentum uncertainty was correct up to momenta of 50 GeV/c.

2.4 Corrections

Data were corrected for:

- (a) Geometrical acceptance using a Monte-Carlo method which takes into account the distribution of interaction vertices as derived from reconstructed events triggered with a minimum bias trigger. The corrections were computed for every individual ISR run. The geometrical acceptance as a function of transverse momentum is almost constant for $p_T > 4$ GeV/c. Corrections are in the order of 35%.
- (b) Nuclear absorption in the beam tube, in the proportional chambers and in the Cerenkov counter and for losses due to particle decays in flight. The largest correction is due to nuclear absorption, which is found to be 14%.
- (c) Inefficiencies in the on-line and the off-line track finding. The corrections vary with transverse momentum, they are in the order of 20%, where typically 5% are due to the on-line filter efficiency and 15% due to the off-line track finding efficiency. In order to keep corrections for the on-line filter efficiency small, data taken with the on-line filter were only used for the evaluation of the invariant cross section for transverse momenta where its efficiency was greater than 90%. The relative high inefficiency of the off-line track finding is not due to genuine losses, but due to the stringent selection criteria applied in order to keep background contaminations as small as possible. The most important loss of genuine good tracks is due to the fact that only candidates with a track fit confidence level greater than 5% were accepted.

- (d) Smearing due to finite momentum resolution. Given the excellent momentum resolution of the trigger telescope, corrections are rather small. Typical corrections are 2% at $p_T = 5$ GeV/c, and 10% at $p_T = 10$ GeV/c, where the momentum uncertainties are 0.1 GeV/c and 0.4 GeV/c respectively.

3. INCLUSIVE CROSS SECTIONS FOR CHARGED PIONS

Pions were identified by a Cerenkov signal corresponding to the reconstructed trigger track. The absolute cross section was obtained using the information from scintillation monitor counters calibrated using the Van der Meer method [4]. All data presented here were obtained using the same geometrical set up of the apparatus, therefore the relative normalization is independent of the overall normalization uncertainty. Cross section values are averaged over the polar angles accepted by the trigger. Due to the different bending in the magnetic field, the interval of acceptance differs slightly for positive and negative particles. The region of acceptance is displayed in table 1: θ , ϕ and y denote the polar angle, the azimuthal angle and the rapidity respectively. All quantities refer to the centre of mass.

In fig. 2 the invariant cross section for positive and negative pions is plotted as a function of the transverse momentum. The values are given in table 2. The overall uncertainty is estimated to be about 10%. The main sources of systematic errors are the calibration of the monitor counters (5%) and the influence of the distribution of interaction vertices on the geometrical acceptance. The uncertainties given in fig. 2 and table 2 are only statistical. The decrease of statistical uncertainty for cross sections with transverse momentum $p_T > 5$ GeV/c with respect to the lower transverse momentum values is due to the fact that below $p_T = 5$ GeV/c data without on-line filter were used; they represent a smaller integrated luminosity than the data taken with the on-line filter.

The data displayed in fig. 2 show an interesting trend. The cross section for positive pions is higher than for negative ones and decreases less steeply. In order to better illustrate this behaviour, the ratio of

cross sections $\sigma(\pi^+)/\sigma(\pi^-)$ is plotted in fig. 3. It can be clearly seen, that this ratio rises with transverse momentum.

This behaviour is expected in QCD models. It originates from the fact that with higher transverse momentum the contribution from gluons to the cross section dies out and scattered quarks dominate. Since a pion with high transverse momentum is always a leading fragment (trigger bias) of the fragmenting parton it carries in the mean its quantum numbers. Consequently positive pions which are quark fragments originate from u-quarks whereas negative pions are fragments of d-quarks. The increase of the ratio $\sigma(\pi^+)/\sigma(\pi^-)$ reflects the fact, that there are more fast u-(valence) quarks in a proton than there are d-(valence) quarks.

For a quantitative comparison with theoretical predictions the difference in polar angle as indicated in table 1 should be kept in mind. The systematic error on the ratio is estimated to be 10%, originating from the uncertainty in the geometrical acceptance, which is different for positive and negative particles.

4. PARTICLE RATIOS

Since the flavour of a leading jet fragment is believed to reflect in average the flavour of its parent parton it is very interesting to measure the composition of high transverse momentum particles.

In fig. 4 the ratios of the inclusive cross sections $\sigma(\pi^+)/\sigma(\text{positive particles})$ and $\sigma(\pi^-)/\sigma(\text{negative particles})$ are shown, the values are given in table 3. For comparison the measurements of the British Scandinavian Collaboration [5] at lower transverse momentum are included in fig. 4. One observes that the fraction of positive pions rises slowly over this range of transverse momenta and seems to reach a plateau of about 65% at high transverse momenta. The fraction of negative pions rises more rapidly, at 9 GeV/c transverse momentum it is as high as 90%, thus dominating the inclusive cross section.

If we assume that the particles heavier than pions are predominantly K mesons as is suggested by an extrapolation from FNAL measurements [6], this behaviour can be understood when taking into account the quark contents of π^- and K^- mesons. Positive pions ($u\bar{d}$) and positive kaons ($u\bar{s}$) contain the same valence quark. During the fragmentation process either a strange or a non strange antiquark has to be picked up out of the quark sea. Consequently the ratio $\sigma(\pi^+)/\sigma(K^+)$ tends to become constant at high transverse momenta, where the scattering of valence quarks dominates. The plateau value of the ratio $\sigma(\pi^+)/\sigma(K^+)$ is a measure of the strangeness suppression in the sea.

The situation is different when considering π^- and K^- mesons. Negative pions ($d\bar{u}$) contain a valence quark whereas negative kaons ($s\bar{u}$) do not. On the other hand negative kaons can originate from the following sources:

- (a) Sea quark fragmentation.
- (b) Valence quarks can give rise to leading K^- mesons, suppressed however, with respect to π^- mesons.
- (c) Gluon fragmentation.

By inclusive measurements alone one can not distinguish among the different possibilities. It seems however possible that a detailed study of the event structure and the correlations inside the events will enable us to answer the question of the K^- parentage.

5. CONCLUSIONS

The inclusive cross section of charged pions has been measured for very high transverse momenta in an angular region not previously explored. These measurements enabled us to investigate the behaviour of $\sigma(\pi^+)/\sigma(\pi^-)$ at ISR energies, which is of importance in order to verify QCD calculations. Qualitatively the relative π^+ and π^- yields show the

trend expected in QCD models. Also, the measured particle ratios, when confronted with quantitative calculations, will provide strong constraints on the relative importance of quark and gluon scattering in high p_T reactions.

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TABLE CAPTIONS

- Table 1 Acceptance of trigger (centre of mass).
- Table 2 Invariant cross sections for inclusive π^+ and π^- production at $\sqrt{s} = 63$ GeV and $\theta = 50^\circ$.
- Table 3 Ratios of the inclusive cross sections $\sigma(\pi^+)/\sigma(\text{positive particles})$ and $\sigma(\pi^-)/\sigma(\text{negative particles})$.

TABLE 1

Particle	θ min	θ max	$\langle\theta\rangle$	ϕ min	ϕ max	$\langle\phi\rangle$	y min	y max	$\langle y \rangle$
π^+	41.4°	57.6°	49.0°	-10.5°	+10.5°	0.0°	0.60	1.00	0.80
π^-	45.9°	61.2°	52.9°	-10.5°	+10.5°	0.0°	0.52	0.88	0.71

TABLE 2

P_T (GeV/c)	$E \frac{d^3\sigma}{dp^3}$ $\text{cm}^2 \text{ GeV}^{-2} \text{ c}^3$ π^+ mesons	$E \frac{d^3\sigma}{dp^3}$ $\text{cm}^2 \text{ GeV}^{-2} \text{ c}^3$ π^- mesons
3.78	$(3.56 \pm 0.22) \times 10^{-32}$	$(3.02 \pm 0.17) \times 10^{-32}$
4.18	$(1.31 \pm 0.12) \times 10^{-32}$	$(1.15 \pm 0.10) \times 10^{-32}$
4.66	$(4.09 \pm 0.52) \times 10^{-33}$	$(3.96 \pm 0.44) \times 10^{-33}$
5.10	$(1.71 \pm 0.04) \times 10^{-33}$	$(1.33 \pm 0.03) \times 10^{-33}$
5.30	$(1.19 \pm 0.03) \times 10^{-33}$	$(9.41 \pm 0.23) \times 10^{-34}$
5.50	$(7.98 \pm 0.26) \times 10^{-34}$	$(6.13 \pm 0.18) \times 10^{-34}$
5.70	$(5.35 \pm 0.20) \times 10^{-34}$	$(3.86 \pm 0.14) \times 10^{-34}$
5.90	$(3.87 \pm 0.17) \times 10^{-34}$	$(2.65 \pm 0.11) \times 10^{-34}$
6.10	$(2.86 \pm 0.15) \times 10^{-34}$	$(2.00 \pm 0.10) \times 10^{-34}$
6.30	$(1.82 \pm 0.12) \times 10^{-34}$	$(1.34 \pm 0.08) \times 10^{-34}$
6.50	$(1.53 \pm 0.10) \times 10^{-34}$	$(9.60 \pm 0.68) \times 10^{-35}$
6.70	$(8.75 \pm 0.75) \times 10^{-35}$	$(7.08 \pm 0.57) \times 10^{-35}$
6.90	$(6.86 \pm 0.66) \times 10^{-35}$	$(4.11 \pm 0.43) \times 10^{-35}$
7.10	$(5.25 \pm 0.56) \times 10^{-35}$	$(3.76 \pm 0.40) \times 10^{-35}$
7.38	$(3.40 \pm 0.31) \times 10^{-35}$	$(2.45 \pm 0.23) \times 10^{-35}$
7.78	$(2.06 \pm 0.22) \times 10^{-35}$	$(1.11 \pm 0.15) \times 10^{-35}$
8.44	$(7.73 \pm 0.85) \times 10^{-36}$	$(4.95 \pm 0.59) \times 10^{-36}$
9.45	$(2.20 \pm 0.43) \times 10^{-36}$	$(1.08 \pm 0.26) \times 10^{-36}$
10.46	$(4.42 \pm 1.89) \times 10^{-37}$	$(2.10 \pm 1.08) \times 10^{-37}$
11.46	$(2.85 \pm 1.35) \times 10^{-37}$	$(4.28 \pm 4.28) \times 10^{-38}$
12.46	$(6.22 \pm 6.22) \times 10^{-38}$	

TABLE 3

P_T (GeV/c)	$R^+ = \sigma(\pi^+)/\sigma(\text{positive particles})$	$R^- = \sigma(\pi^-)/\sigma(\text{negative particles})$
2.97	0.586 ± 0.025	
3.38	0.608 ± 0.020	0.683 ± 0.025
3.78	0.573 ± 0.030	0.701 ± 0.035
4.10	0.608 ± 0.005	0.728 ± 0.004
4.30	0.622 ± 0.005	0.751 ± 0.005
4.50	0.608 ± 0.006	0.751 ± 0.006
4.78	0.608 ± 0.006	0.771 ± 0.005
5.18	0.623 ± 0.008	0.778 ± 0.007
5.59	0.636 ± 0.011	0.801 ± 0.009
6.07	0.649 ± 0.011	0.801 ± 0.010
6.67	0.624 ± 0.017	0.852 ± 0.010
7.44	0.683 ± 0.020	0.863 ± 0.019
8.44	0.623 ± 0.040	0.906 ± 0.032

FIGURE CAPTIONS

- Fig. 1 A top view of the Split Field Magnet Detector (SFM).
- Fig. 2 The invariant cross sections for inclusive π^+ and π^- production as a function of the transverse momentum ($\sqrt{s} = 63$ GeV, $\theta \approx 50^\circ$).
- Fig. 3 The ratio of the invariant cross sections, $\sigma(\pi^+)/\sigma(\pi^-)$, as a function of the transverse momentum ($\sqrt{s} = 63$ GeV, $\theta \approx 50^\circ$).
- Fig. 4 The ratios of the inclusive cross sections, $\sigma(\pi^+)/\sigma(\text{positive particles})$ and $\sigma(\pi^-)/\sigma(\text{negative particles})$, as a function of the transverse momentum ($\sqrt{s} = 63$ GeV, $\theta \approx 50^\circ$).

Fig. 1

Fig. 2

Fig. 3

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