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TEST OF NUCLEAR EFFECTS IN HADRONIC DIMUON PRODUCTION

NA3 Collaboration

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ABSTRACT

We present the final analysis of the nuclear effects on the cross section of dimuon production, using simultaneously a hydrogen and a platinum target in a 150, 200 and 280 GeV pion beam. For the dimuon mass interval 4.1 to 8.5 GeV, the ratio of the cross sections is in agreement with the Drell-Yan model within a 10% error, mainly due to systematics. The variation of this ratio with the dimuon mass, x_1 , and x_2 is also in good agreement, and no variation with the transverse momentum is observed.

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The low cross section processes lead experimentalists to use heavy nuclear targets instead of hydrogen because of their larger density; on the other hand, the influence of possible nuclear effects has to be well understood.

In the frame work of the Drell-Yan model [1] quark-antiquark annihilations are considered as point-like interactions. In other words, because of the dimensionless nature of the interacting constituents, no shadow effects should be present, in contrast to most of the total cross section. In the latter case it is well known, and experimentally observed, that the cross section is proportional to A^α where A is the atomic number of the target and α is equal to about $2/3$. For hard scattering processes involving point like constituents, a linear dependence with the number of partons is expected (i.e. $\alpha = 1$). This is due to the fact that the point-like constituents of the projectile hadron interact incoherently with a set of partons of the target whose number is directly proportional to the number of nucleons and that the incoming partons interact very rarely with the rest of the nucleus. However, because of the difference in the quark composition of a proton and a neutron, the cross section on a nucleus should be written as :

$$d\sigma(Z,A) = Z d\sigma_p + (A-Z) d\sigma_n$$

where $d\sigma_p$ and $d\sigma_n$ are the differential cross sections on proton and neutron (Z is the number of protons in the nucleus)

In the NA3 experiment, in order to measure the A dependence of the Drell-Yan mechanism, we have used simultaneously two targets, one of liquid hydrogen and one of platinum. The large range between $A = 1$ for hydrogen and $A = 195$ for platinum allows for a good determination of possible deviations from the Drell-Yan predictions.

A general description of the NA3 experiment is given elsewhere [2]. Four sets of data are available in order to measure the nuclear effects : π^- at 150 GeV, 200 GeV and 280 GeV, and π^+ at 200 GeV. Due to our experimental resolution, the dimuon mass interval corresponding to the Drell-Yan continuum lies between 4.1 and 8.5 GeV (between the ψ' and the T).

Our platinum target is 6 cm long. Taking into account the absorption length in the target [3], the effective length is calculated to be 4.6 cm which allows a determination of the effective number of nucleons in the target with a precision of the order of 5%.

The hydrogen target is a cylinder of 30 cm length (50 cm in the 280 GeV run) and 4 cm diameter. The same calculations as above taking also into account the mylar windows give the effective number of nucleons of the hydrogen target at a precision level better than 5%.

For the platinum target, we have to take into account two effects : the reinteractions in the heavy target and the Fermi motion of the nucleons inside the nucleus. The incidence of the first effect has been calculated to be about 3% at 150 GeV and 4% at 280 GeV. The main effect of the Fermi motion is a small change in the shape of the dimuon mass spectra which is less than 5% between 4.1 and 8.5 GeV/c², and is taken into account in the Monte-Carlo calculations.

One experimental problem is to ensure a clean assignment of the target in which the interaction vertex is located. Figure 1 shows the reconstructed position of the dimuon vertex along the beam axis. This distribution indicates a clean separation between the hydrogen and platinum targets. We have also to take into account the different acceptances for the two targets, corresponding to their respective locations in the experiment.

The number of selected events for each energy are given in table 1.

The Drell-Yan model predicts that the cross section for dimuon production in hadron-nucleon collisions depends on the quark composition of the incident and target particles and therefore on their structure functions. Notice that, for the target, the structure function for the "hydrogen nucleon" (100% proton) is not the same as the structure function of the "platinum nucleon" (40% proton and 60% neutron). We define

$$R = \frac{A \sigma(\pi^{\pm} H_2 \rightarrow \mu^+ \mu^-)}{\sigma(\pi^{\pm} P_t \rightarrow \mu^+ \mu^-)}$$

as the ratio of the dimuon cross sections on hydrogen and platinum "per nucleon".

In the framework of the Drell-Yan model, using the structure functions of ref. [4], a complete calculation including valence-sea and sea-sea terms gives for R the following values : 1.47, 1.45 and 1.41 at 150, 200, 280 GeV respectively, for π^- incident particles. Note that these values reflect mainly the relative abundance of u quarks in the targets, and therefore these predictions are not very sensitive to the choice made for the structure functions.

These Drell-Yan predictions can be computed as functions of various parameters and compared to the experimental cross section ratios.

The table 2 summarizes the results for the different energies. The comparison between the experimental and predicted ratio is also indicated for the difference between π^- and π^+ cross sections at 200 GeV. This latter measurement is interesting as, in that case, the possible contribution of hadronic processes to muon pairs production cancels out.

α is extracted from : $A^{1-\alpha} = R_{\text{exp.}}/R_{\text{th.}}$

For the experimental ratio, only statistical errors are quoted but for $R_{\text{exp}}/R_{\text{th}}$ and α systematic errors are included. This systematic error accounts for the uncertainty on the number of nucleons in the targets (7%), the error on the ratio of the acceptances (5%), and the model dependence of the predicted R (5%). Notice also that our results are independent of absolute normalisation problems as our data are taken simultaneously on hydrogen and platinum.

Figure 2 shows the variation of the experimental ratio R with $\sqrt{\tau} = M/\sqrt{s}$, x_1 and x_2 . The agreement between the experimental points and the theoretical predictions (full line) is very satisfactory.

We also show on Fig. 2 the variation of R with transverse momentum of the dimuon. No significant variation is observed up to 4 GeV/c.

In conclusion our data on hydrogen and platinum targets are compatible with the absence of nuclear effects, as expected by the Drell-Yan model, this prediction remaining unchanged by QCD corrections. This is found to be true within our experimental errors in the energy interval 150 to 280 GeV/c. The ratio of the cross sections, divided by the expected ratio, is 1.00 ± 0.10 , or in other words $\alpha = 1.00 \pm 0.02$.

In order to be less sensitive to acceptance corrections and structure function effects, we have performed another measurement using platinum and carbon targets [5] simultaneously. The size of each target has been chosen such as to give the same absorption length for both. To get rid of acceptance problems, the targets have been inverted every 6 hours. In that case the result for α is 0.97 ± 0.05 in good agreement with our previous measurements (the quoted error is statistical only).

Some other experiments have measured α for the dimuon continuum. With incident 400 GeV protons on Be, Cu and Pt targets, the CFS collaboration [6] quoted a result compatible with $\alpha = 1$ ($\alpha = 1.007 \pm 0.018$ (statistical error) ± 0.028 (systematic error)). An early determination of α by the CIP collaboration [7], using π^- at 225 GeV/c on C, Cu and W targets gave $\alpha = 1.12 \pm 0.05$. The consequence of this difference from 1 is to multiply the cross section (per nucleon) of dimuon production by a factor 1.8 and is directly connected to the absolute normalisation factor K as discussed elsewhere [8].

We are very grateful to the members of the SPS operating crew and the Experimental Areas group. In particular we acknowledge the skilful and dedicated collaboration of Mr. N. Doble for providing full operation of the beam line. We finally would like to express our deep gratitude to the engineering and technical staff of our collaboration for the outstanding contribution in the design, construction and operation of our apparatus.

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TABLE 1

Beam Target	150 GeV	200 GeV		280 GeV
	π^-	π^-	π^+	π^-
Hydrogen	535	121	40	741
Platinum	22 321	5 562	2047	18 970

Statistics of $\mu^+\mu^-$ continuum events ($4.1 < M < 8.5 \text{ GeV}/c^2$)

TABLE 2

Particle	R_{th}	R_{exp}	R_{exp}/R_{th}	α
π^- 200 GeV	1.45	1.35 ± 0.13	0.93 ± 0.15	1.02 ± 0.03
π^+ 200 GeV	0.89	1.13 ± 0.19	1.27 ± 0.25	0.95 ± 0.04
$\pi^-\pi^+$ 200 GeV	1.92	1.60 ± 0.34	0.83 ± 0.25	1.03 ± 0.05
π^- 150 GeV	1.47	1.47 ± 0.07	1.00 ± 0.10	1.00 ± 0.02
π^- 280 GeV	1.41	1.40 ± 0.07	0.99 ± 0.10	1.00 ± 0.02

Comparison between the experimental and the predicted ratio
of cross-sections on hydrogen and platinum.

FIGURE CAPTIONS

Fig. 1 Distribution of the reconstructed vertex at 150 GeV for masses greater than 5 GeV/c².

Fig. 2 Hydrogen to platinum cross section ratio (per nucleon) for incident π^- at 150 GeV as functions of P_t , x_1 , x_2 and mass.

Fig. 1

FIG. 2