A-DEPENDENCE OF MUON-PAIR PRODUCTION IN π^- -NUCLEUS INTERACTIONS AT 280 GeV/c

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ABSTRACT

We have measured the relative cross-sections for muon-pair production by 280 GeV/c negative pions on three different targets: carbon, copper, and tungsten. The value of α obtained from the parametrization $\sigma = \text{constant} \cdot A^\alpha$ is $0.94 \pm 0.02 \pm 0.02$, whereas the parametrization $\sigma \sim \sigma_0(Z/A) \cdot A^{\alpha'}$, where $\sigma_0(Z/A)$ is given by the Drell-Yan model, leads to $\alpha' = 0.97 \pm 0.02 \pm 0.02$. This last result is in agreement with the quark additivity rule which is inherent in the Drell-Yan model; no dependence is observed on the transverse momentum of the muon pair.

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Lepton-pair production in hadronic collisions is successfully described by the Drell-Yan mechanism, i.e. quark-antiquark annihilation and subsequent pair production via a virtual photon [1]. For proton-nucleus collisions where there are no valence antiquarks involved (and therefore neutrons and protons behave in the same way), the dependence of the cross-section on the target mass number A is parametrized as $\sigma = \sigma_0 A^\alpha$, the constant σ_0 being the cross-section per nucleon. The picture of an incoherent scattering process between free constituents leading to the quark additivity rule predicts $\alpha = 1$, in very good agreement with experimental results [2]. On the other hand, for pion-nucleus collisions where the main contribution comes from the pion valence antiquark annihilating with nucleon valence quarks, one has to account for the different sources of $u\bar{u}$, $d\bar{d}$, ... quark-antiquark annihilations in different nuclei: in the formal relation $\sigma = \sigma_0 A^\alpha$, σ_0 depends on A and Z (the atomic number), and is interpreted as the average cross-section per nucleon for a given (Z,A) nucleus. Within this last framework, a recent experimental determination [3] finds $\alpha = 0.994 \pm 0.015$, whereas the different approach that ignores the quark content of the interacting hadrons and constrains σ_0 to be a constant has led a previous experiment [4] to the value $\alpha = 1.12 \pm 0.05$. These two results have suggested the measurement presented here, where our experimental data are analysed using both methods.

The experiment was done at the CERN North Area High Intensity Facility [5] with the NA 10 spectrometer shown in fig. 1. The measurement is based on a partial sample of data that were collected in less than a week of running.

The 280 GeV/c unseparated π^- beam (1.1% K^- , 0.04% $\bar{p}$) [6] had a momentum bite of $\pm 10\%$, an intensity of 4×10^8 π^- /burst, and a spot r.m.s. radius of 2.5 mm at the target. It was monitored with an ionization chamber in the beam line and two scintillation-counter telescopes viewing the target at 90° . Three targets of 6 mm radius were interchanged regularly during data taking; their characteristics are summarized in table 1. The absorption lengths were taken from ref. [7].

The target is followed 0.4 m downstream by a 4.8 m long dump. This dump consists of a 4 m long conical tungsten and uranium core surrounded by a conical

graphite ($\rho = 1.9 \text{ g}\cdot\text{cm}^{-3}$) structure, which is a first muon filter and matches the acceptance of the spectrometer. The graphite has a hole of 2 cm diameter and 0.8 m length in front of the tungsten and uranium core. The whole structure is embedded in iron and concrete blocks.

The spectrometer magnet is a toroid of 4 m length and 1.5 m radius, with six 42° air gaps defined by sector-shaped pole pieces. It is pulsed and has a field integral of 3 T·m at a radius of 0.75 m. Upstream and downstream of the magnet there are two scintillation-counter hodoscopes (each consisting of 6 sectors of 32 counters) and 4 multiwire proportional chambers (see fig. 1). All detectors match the six-fold symmetry of the magnet. A 1.2 m thick iron wall in front of R4 acts as a second muon filter. The spectrometer accepts tracks from 39 to 117 mrad (for infinite momentum).

Each hexagonally shaped proportional chamber consists of three planes with 3 mm wire spacing and with wires slanted by 120° from one plane to the next. Each gap width is 6 mm. The cathodes are graphited mylar foils. The 20,000 wires are read out by the RMH delay-line system [8].

A fast coincidence between corresponding elements of the front telescope (R1·R2) selects trajectory segments pointing to the target. An ECL coincidence matrix associates these trajectory segments with the ones downstream of the magnet, defined by counters of the back telescope (R3,R4). This allows a fast measurement of the deflection angle and hence of the transverse momentum p_T of a particle. The final trigger logic performs a rough mass selection $[M \sim (p_{T_1} + p_{T_2})]$, adding the p_T 's of two muons from non-adjacent sectors. In case of ambiguities in segment association, the logics select the highest mass. In order to reduce the trigger rate and enrich the high-mass sample, events with $M < 2.0 \text{ GeV}/c^2$ are rejected, whereas those with $M < 4.5 \text{ GeV}/c^2$ are prescaled. The system is designed to reject accidental triggers originating from halo muons (almost parallel to the beam) or punch-throughs from the dump. A multiplicity condition on R2 (less than 6 hits per sector) rejects accidental triggers produced by showers leaving the dump.

For the present study we have retained only dimuons deflected in the air sectors of the magnet and satisfying the following off-line reconstruction criteria:

- a) The tracks are validated by hits in the trigger counters.
- b) The forward and backward tracks meet within ± 1.6 cm at the mid-plane of the magnet.
- c) The z-coordinate of the reconstructed vertices falls within ± 30 cm of the target centre. Figure 2 displays this distribution for the longest (carbon) target and shows that our trigger rejects muon pairs originating in the beam dump. For mass calculations, the vertices are constrained to the target centre.

As an example fig. 3 shows the opposite-sign dimuon mass plot obtained with the tungsten target, corrected for prescaling, but without corrections for acceptance and inefficiencies. The like-sign dimuons are also displayed (dashed histogram). A mass resolution of 3% FWHM at the J/ψ is achieved.

To eliminate contributions from resonances, the analysis is limited to the mass interval $4.5-8.4$ GeV/c². Table 2 gives the number of events (obtained after subtraction of the like-sign background) and the ratios of the experimental cross-sections per nucleus relative to tungsten. The inefficiencies of the apparatus are the same for each target and cancel out in the cross-section ratios. The composition of the W alloy leads to a 5% correction of the number of events from the W target.

For comparison with ref. [4], we have fitted the data presented in table 2 with the parametrization

$$\sigma_A/\sigma_W = \text{constant} \cdot A^\alpha, \quad (1)$$

applying an acceptance correction which is target-dependent, owing to the differences in target lengths (4% for carbon). This fit yields (with $\chi^2 = 0.18$, d.o.f. = 1):

$$\alpha = 0.94 \pm 0.02,$$

with an additional systematic uncertainty of ± 0.02 . This result differs from the value $\alpha = 1.12 \pm 0.05$ of ref. [4]. The closeness of α to unity confirms the absence of nuclear effects.

Parametrization (1) takes only into account the number of nucleons in the target, whereas, according to the $q\bar{q}$ annihilation model, dimuon production depends on the flavoured quark content of the beam and of the target. Within the framework of the Drell-Yan model, for a given (Z,A) target, the cross-section per average nucleon written with the standard notation is

$$\frac{d^2\sigma_0(Z,A)}{dx_1 dx_2} = K \frac{4\pi\alpha^2}{9sx_1^2 x_2^2} \left[\left(\frac{2}{3}\right)^2 \bar{u}^\pi(x_1) u^T(x_2) + \left(\frac{1}{3}\right)^2 d^\pi(x_1) \bar{d}^T(x_2) \right], \quad (2)$$

where $\bar{u}^\pi(x_1)$, $d^\pi(x_1)$ are the structure functions of the $\bar{u}$ and d quarks in the π^- . In the following we set $\bar{u}^\pi = d^\pi$. The sum $u^T(x_2)$ over the u -flavour structure functions in the target is

$$u^T(x_2) = \frac{Z}{A} u^P(x_2) + \left(1 - \frac{Z}{A}\right) d^P(x_2) + s^P(x_2) \quad (3)$$

with $u^n = d^P$. Taking experimentally determined structure functions^{*)} [9,10] the integration of eq. (2) weighted by the acceptance of our detector predicts a cross-section per nucleus:

$$\sigma_{th}(Z,A) = \sigma_0(Z/A) \cdot A. \quad (4)$$

To test deviations from this model, we parametrize our data according to

$$\sigma_A \sim \sigma_0(Z/A) \cdot A^{\alpha'} \quad (5)$$

and compute α' , with a fit through the three values of σ_A obtained with our targets, as a function of A . The result of the fit is ($\chi^2 = 0.38$, d.o.f. = 1)

$$\alpha' = 0.97 \pm 0.02$$

again with an additional systematic error of ± 0.02 , showing good agreement of our data with ref. [3].

While the p_T dependence of dimuon production is strictly speaking outside the domain of the original Drell-Yan model, we have checked whether $\alpha' \approx 1$ also holds

*) We used: $\bar{u}^\pi(x) = 0.66x^{0.45}(1-x)^{1.04} + 0.25(1-x)^{5.4}$
 $u^P(x) = 2.27x^{0.52}(1-x)^{2.8}$
 $d^P(x) = 1.29x^{0.52}(1-x)^{3.8}$
 $s^P(x) = 0.27(1-x)^{8.0}$

for different p_T values. Dividing the p_T distribution of each target into 3 bins and fitting our data according to formula (5), we find:

$$\begin{aligned}\alpha' &= 0.95 \pm 0.04 \quad \text{for} \quad 0 < p_T < 1 \text{ GeV/c} & (\chi^2 = 0.63, \text{ d.o.f.} = 1) \\ \alpha' &= 0.99 \pm 0.04 \quad \text{for} \quad 1 < p_T < 2 \text{ GeV/c} & (\chi^2 = 0.71, \text{ d.o.f.} = 1) \\ \alpha' &= 0.97 \pm 0.08 \quad \text{for} \quad p_T > 2 \text{ GeV/c} & (\chi^2 = 0.97, \text{ d.o.f.} = 1)\end{aligned}$$

showing that α' is compatible with one and is independent of p_T .

To summarize, we have studied the relative cross-sections for muon-pair production by pions on carbon, copper, and tungsten targets and our conclusions are the following:

- a) The parametrization $\sigma = \sigma_0 A^\alpha$ (with σ_0 constant) gives $\alpha = 0.94 \pm 0.02 \pm 0.02$.
- b) No deviation is found from the quark additivity rule which is inherent in the Drell-Yan model. Such a deviation would be characterized by the departure of α' from unity, where α' is defined by $\sigma = \sigma_0 (Z/A) \cdot A^{\alpha'}$. The experimental value obtained here is $\alpha' = 0.97 \pm 0.02 \pm 0.02$.
- c) Within the experimental errors, the value of α' is independent of the transverse momentum of the virtual photon.

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Table 1

Target properties. The absorption lengths were obtained from the absorption cross-sections of ref. [7]. The so-called W target is actually an alloy consisting of 95% W, 3.5% Ni and 1.5% Fe (weight percentages).

Target	Length (cm)	Density (g · cm ⁻³)	Length/ ℓ_{abs}	Nuclei per cm ² (× 10 ⁻²³)
C	30.0	1.88 ± 0.06	0.48 ± 0.02	22.5 ± 0.5
Cu	9.1	8.85 ± 0.03	0.48 ± 0.02	1.48 ± 0.01
W	6.0	17.90 ± 0.05	0.49 ± 0.03	2.65 ± 0.04

Table 2

Experimental results

Target	Number of events	Integrated π^- flux (× 10 ⁻¹²)	Relative cross-section σ_A/σ_W
C	538 ± 24	3.43 ± 0.06	0.074 ± 0.004 ± 0.003
Cu	305 ± 19	1.48 ± 0.01	0.36 ± 0.03 ± 0.01
W	613 ± 26	2.31 ± 0.02	1.00

Figure captions

- Fig. 1 : Experimental set-up.
- Fig. 2 : Distribution of the z-coordinate of the vertex along the beam for
events obtained with the 30 cm long carbon target.
- Fig. 3 : Muon-pair mass plot for events off the W target.

Fig. 1

Fig. 2

Fig. 3