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DIMUON PRODUCTION IN PROTON-NUCLEON COLLISIONS AT 300 GeV/c

D. Eartly, G. Giacomelli,[*] and K. Pretzl[†]

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[*]Istituto di Fisica, University of Bologna, Bologna, Italy
[†]Max Planck Institute for Physics and Astrophysics, Munich, Germany

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ABSTRACT

In a simple search for muon pairs directly produced in proton-nucleon collisions at 300 GeV performed with two range telescopes, we observed the ψ (3105).

*And Istituto di Fisica, University of Bologna, Bologna, Italy
†And Max Planck Institute for Physics and Astrophysics, Munich, Germany

This note describes the result of a simple test designed to study the direct production of muon pairs in 300-GeV proton-nucleon collisions in a beam dump at the Fermi National Accelerator Laboratory. The reaction studied was

$$p + N \rightarrow \mu + \mu + X \qquad (1)$$

where X was unobserved and the muon energies were measured through their ranges, without determining their sign.[1] We detected symmetric and almost symmetric dimuon combinations, corresponding to dimuons emitted forward or at rest in the c.m. system. These configurations are expected to yield a relative large number of events. The main emphasis of the test was to search for gross structure in the dimuon mass spectrum.

As sketched in Fig. 1, the setup consisted of two symmetric range telescopes, which looked at the front of the Meson Area beam dump, first at an angle of 96 and then at 76 mrad with respect to the primary beam.

Each telescope consisted of six 5-in. × 5-in. × 0.25-in. scintillation counters interspersed in steel blocks. A seventh counter (S) was added to one arm before the last measurements. The scintillators were suspended in air-light guides viewed by 56-AVP photomultipliers. The light guides of alternate counters were rotated by 90°. The photomultiplier divider bases (current pumped zeners) were capable of high-average currents. In each arm (α or β) the counters were placed in sequential two-fold coincidences:

$\alpha_2 = C_1C_2$, $\alpha_3 = \alpha_2C_3$, $\alpha_4 = \alpha_3C_4$, $\alpha_5 = \alpha_4C_5$, $\alpha_6 = \alpha_5C_6$, $\alpha_7 = \alpha_5S$, $\beta_2 = C_7C_8$, $\beta_3 = \beta_2C_9$, etc. For the original configuration each coincidence accepted muons with a momentum larger than 16.9, 19.6, 22.3, 25.0, 30.4, and 38.6 GeV. For some runs the first two absorber blocks were removed and in others S was moved behind the last iron block.

The counter combinations of the two range telescopes were placed in two-fold coincidences; the symmetric combinations were: $\alpha_2\beta_2$, $\alpha_3\beta_3$, $\alpha_4\beta_4$, $\alpha_5\beta_5$, $\alpha_6\beta_6$. Also a number of asymmetric combinations were recorded ($\alpha_2\beta_3$, $\alpha_3\beta_2$, $\alpha_2\beta_4$, $\alpha_4\beta_2$, $\alpha_3\beta_4$, $\alpha_4\beta_3$, $\alpha_3\beta_5$, $\alpha_4\beta_5$, $\alpha_4\beta_6$, $\alpha_5\beta_6$, $\alpha_6\beta_5$, and $\alpha_7\beta_5$). This redundance allowed checks to be performed like the comparison of the $\alpha_2\beta_3$ and $\alpha_3\beta_2$ rates, etc. Two random rates [$(\alpha_3\beta_3)_R$ and $(\alpha_4\beta_4)_R$] were also continuously recorded.

The telescopes covered the dimuon mass ($m_{\mu\mu}^2 \approx p_\alpha p_\beta\, \theta_{\mu\mu}^2$) ranges of $2.5 \lesssim m_{\mu\mu} \lesssim 5.2$ GeV and $3.2 < m_{\mu\mu} < 7.4$ GeV in the 76-mrad and 96-mrad configurations respectively.

We tested the equipment with the beam impinging on the standard beryllium target, located approximately 4 meters in front of the beam dump. The counter gains were cross checked with a Co^{60} source. With the target in place we found very high singles rates, very high rates for single muon production and also for apparent double muon coincidences. Many of these events were due to pion decays in the 4-meter distance between the production target and the beam dump and to randoms which varied considerably depending on intensity and RF bucket populations.

With the target removed, singles rates dropped typically an order of magnitude. The single arm coincidence rates and the dimuon rates dropped by one to two orders of magnitude. Thus counter gains had to be rechecked. Typical randoms varied from 1% to 30% depending on intensity and RF structure. These target-out runs were made in few short runs, each of 1/4 to 3 hours duration. We were able to vary the beam intensities from less than 3×10^{9} to 10^{12} protons per pulse.

Figure 2 shows two integral dimuon spectra corrected for geometrical efficiencies, obtained in the 76-mrad configuration with some iron removed. One of the spectra was obtained with a beryllium target in the primary beam, while the other was obtained without any target. Both spectra show a structure at 3.1 GeV. The structure is present in all the other spectra which have been taken at different periods and at incident beam intensities differing by 3 orders of magnitude. This indicates independence from random rates and from the number of protons in each RF bucket. This structure is consistent with the recently discovered ψ(3105).[2,3,4]

Clearly a measurement of the type described in this note does not have any problem with event rate, but suffers from a large number of systematic uncertainties. Our poor energy resolution and the small number of counters used did not allow us to properly differentiate the integral spectra of Fig. 2. The absolute normalization of the dimuon cross section is made difficult by multiple scattering effects, by beam normalization for low intensities, by the inprecise knowledge of acceptance, and by the fact that we measure only a specific configuration. The order of magnitude yield of events in the 3.1-GeV structure is about one event per 10^8 proton interactions, corresponding to a production cross section of the order of $\gtrsim 10^{-33}$ cm^2.* This is only a rough order of magnitude. The graph of Fig. 2 does not show indications for the 3.7 and 4.15 states, because either their production cross section or their $\mu^+\mu^-$ branching ratios are smaller than those of the 3.1-GeV state.

Figure 3 shows two dimuon spectra obtained in the 96-mrad configuration, with and without the first absorber. The spectra may suggest a structure at $m_{\mu\mu}^2 \simeq 36$ GeV^2 at the level of about one event per 10^9 proton interactions. The effect was found to persist, independent of beam intensity over two orders of magnitude. Thus if the effect were real, it is unlikely to result from accidental effects. On the other hand, since the break in these spectra is associated with $\alpha\beta$ correlations which always involve β_5 (Fig. 3a) the question of systematic effects arise. In all cases, the counter efficiencies had been plateaued and it was established that all correlations peaked at about the same power supply voltage. The structure seemed to persist when 5 ft of iron was removed from each arm (Fig. 3b).

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*This quoted value of the production cross section assumes $\Gamma_{\mu\mu} \simeq 0.1$.

The smallness of the cross section, the small number of counters available, and the nature of the environment with its high background rate do not allow us to reach a definite conclusion on this structure.

We conclude that we have observed the $\psi(3105) \rightarrow \mu\mu$ at a level of about 1 event in 10^8 proton interactions and that if other structures in the $\mu\mu$ mass spectrum exist they are produced with cross sections at least 10 times smaller.

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FIGURE CAPTIONS

Fig. 1 Layout of the two range telescopes in the 96-mrad configuration.

Fig. 2 Integral dimuon spectra taken with the telescopes in the 76-mrad configuration and (a) with the Meson Area target in place and (b) with the target.

Fig. 3 Integral dimuon spectra taken without the Meson Area target, with the telescopes in the 96-mrad configuration and with (a) the telescopes as in Fig. 1 and (b) removing 5 ft of iron at the front of each arm. The yields are over an order of magnitude smaller than those of Fig. 2.

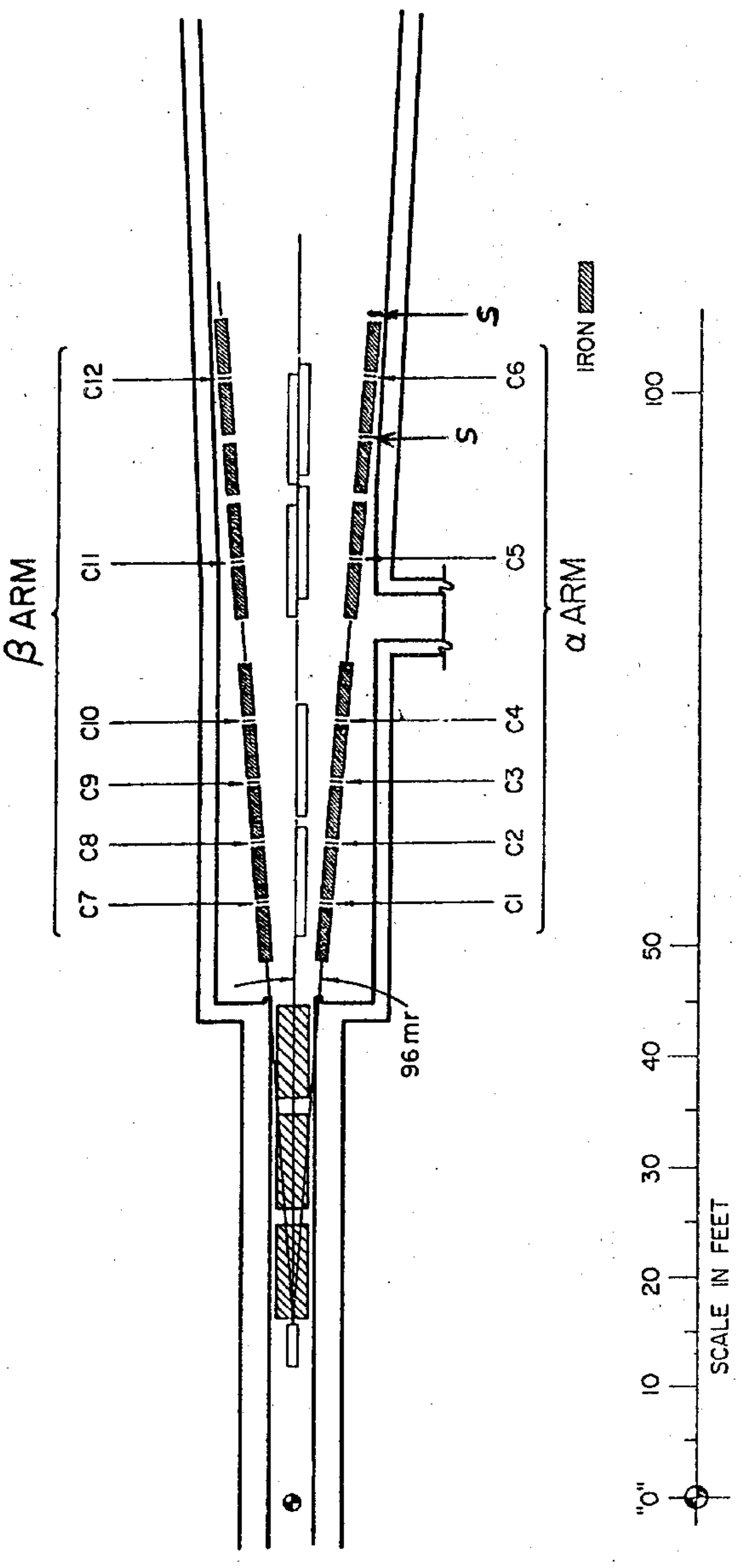
β ARM
C7
C8
C9
C10
C11
C12
α ARM
C1
C2
C3
C4
C5
C6
S
S
IRON
96 mr
"0"
10
20
30
40
50
100
SCALE IN FEET

Fig. 1

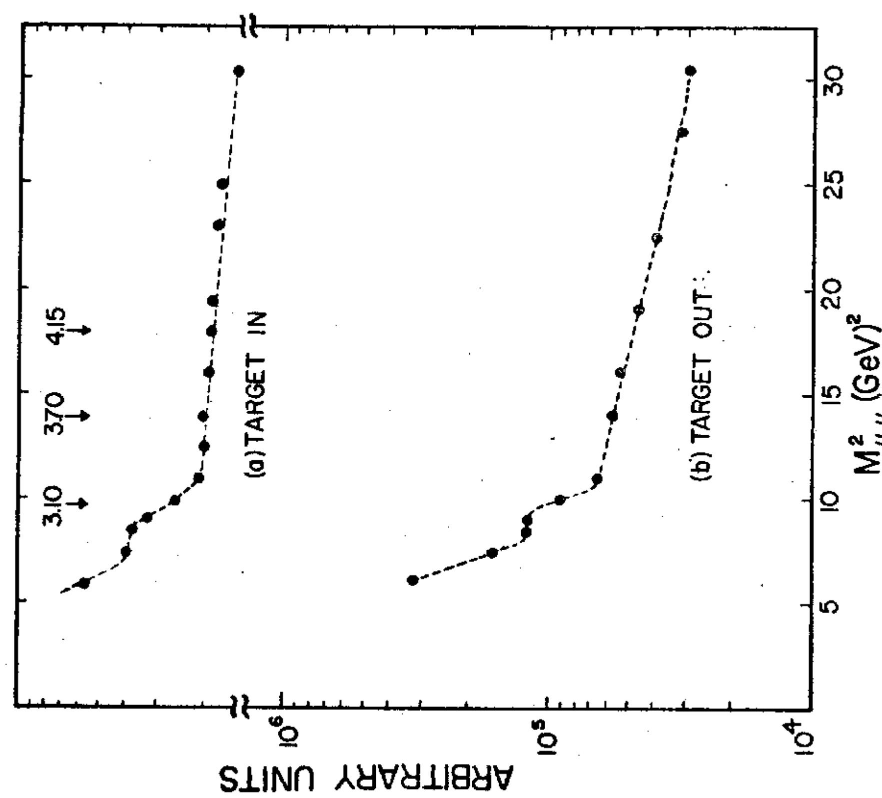
ARBITRARY UNITS
10^4
10^5
10^6
$M^2_{\mu\mu}$ (GeV)^2
5
10
15
20
25
30
3.10
3.70
4.15
(a) TARGET IN
(b) TARGET OUT

FIG. 2

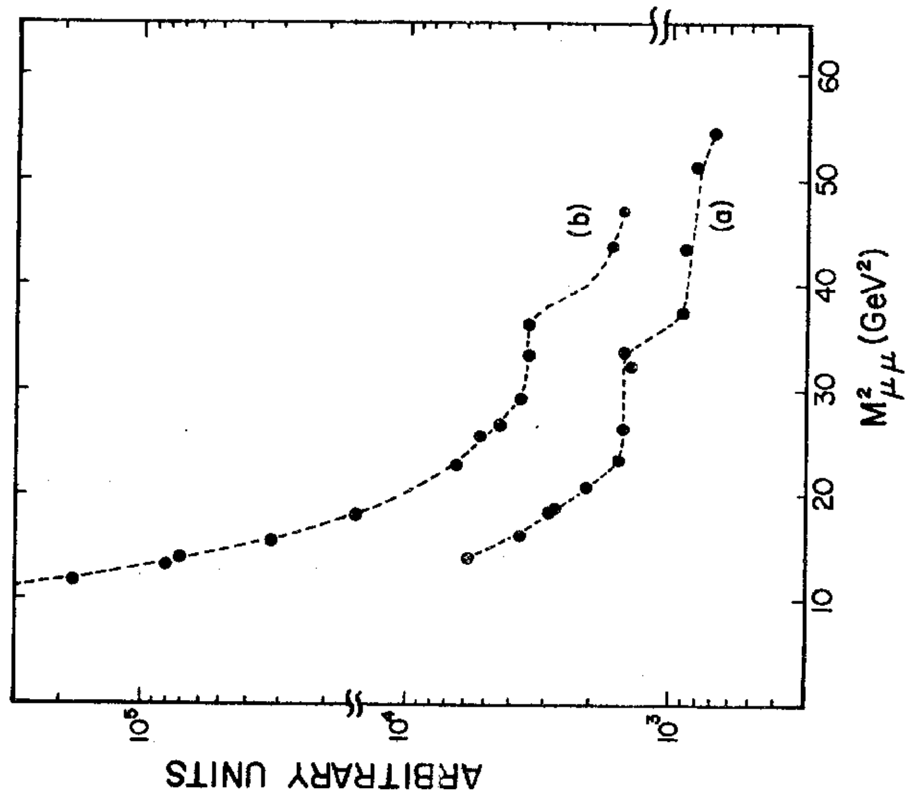
ARBITRARY UNITS
10^3
10^4
10^5
$M^2_{\mu\mu}$ (GeV^2)
10
20
30
40
50
60
(a)
(b)

FIG. 3