Dimuon Production in Proton-Nucleon Collisions at 300 GeV/c

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In a simple search for muon pairs directly produced in proton-nucleon collisions at 300 GeV performed with two range telescopes looking at a beam dump, we observe the ψ(3.1 GeV) and have an indication for a structure around $m_{\mu\mu}^2 = 36$ GeV^2.

This Letter describes the result of a simple experiment 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.[1] The reaction studied was

$$p + N \to \mu + \mu + X, \qquad (1)$$

where X was unobserved and the muon energies were measured through their ranges, without determining their sign.[2] We detected symmetric and almost symmetric dimuon combinations, corresponding to dimuons emitted at rest in the c.m. system. The main emphasis of the experiment 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 mrad and then at 76 mrad with respect to the primary beam.

Each telescope consisted of six 5-in. $\times$5-in.

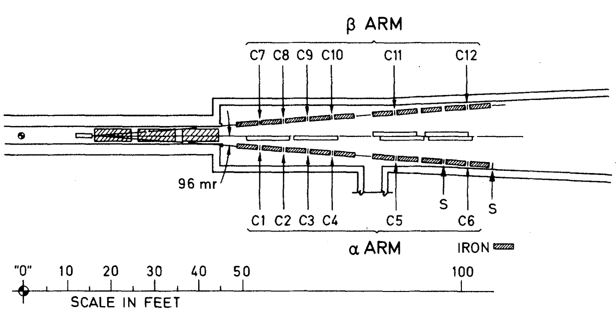

FIG. 1. Layout of the two range telescopes in the 96-mrad configuration. The scale starts at the location of the beryllium target. The two range telescopes look at the front end of the beam dump.

$\times$0.25-in. scintillation counters interspersed in steel blocks. The scintillators were suspended in air-light guides viewed by 56 AVP photomultipliers. The light guides of alternate counters were rotated by 90°. In each arm (α or β) the counters were placed in sequential twofold 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, 30.5, and 38.6 GeV. For some runs the first two absorber blocks were removed and in others an additional counter S was moved behind the last iron block.

The counter combinations of the two range telescopes were placed in twofold coincidences; the symmetric combinations were $\alpha_2\beta_2$, $\alpha_3\beta_3$, $\alpha_4\beta_4$, $\alpha_5\beta_5$, and $\alpha_6\beta_6$. Also a number of asymmetric combinations were recorded.

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

The accidental dimuon spectrum due to π decay was investigated by having for some special runs the proton beam impinge on the standard beryllium target located approximately 4 m in front of the beam dump. The rf-bucket population was continuously monitored and accidentals were measured. The accidentals yielded a smooth, monotonic mass spectrum. We were able to vary the beam intensity from less than 3×10^9 to 10^{12} protons per pulse. Typical randoms varied from 1% to 30% depending on beam intensity and rf structure.

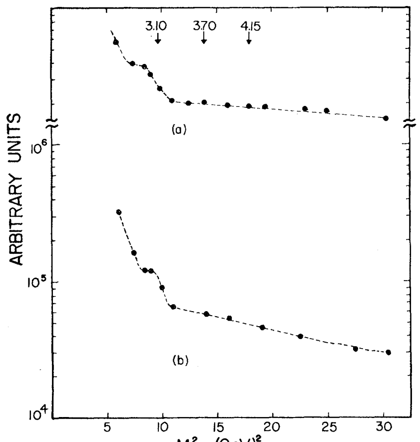

FIG. 2. Integral dimuon spectra taken with the telescopes looking at the beam dump in the 76-mrad configuration and, spectrum *a*, with the meson-area Be target in place and, spectrum *b* without the target.

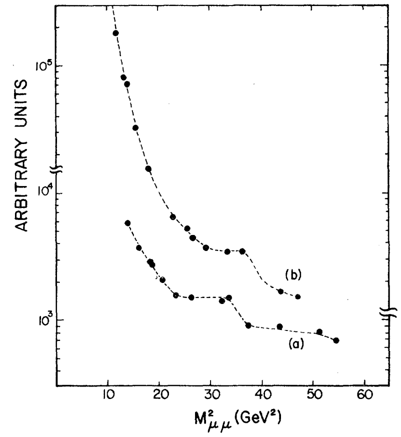

FIG. 3. Integral dimuon spectra taken without the meson-area target, with the telescopes in the 96-mrad configuration and, spectrum *a*, with the telescopes as in Fig. 1 and, spectrum *b*, with 5 ft of iron removed from the front of each arm. The yields are over an order of magnitude smaller than those of Fig. 2.

Figure 2 shows two integral dimuon spectra corrected for relative 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 with the beam dump only. 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 three 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(3.1 GeV).[3-6] The order-of-magnitude yield of events into the spectrometer acceptance in the 3.1-GeV structure is about 1 event per 10^8 proton interactions.

The graph of Fig. 2 does not show indications for the 3.7 and 4.15 states, because either their production cross sections 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 suggest a structure at $m_{\mu\mu}^2 \simeq 36$ GeV^2 at the level of about 1 event per 2×10^9 proton interactions. The effect persisted independently of beam intensity over two orders of magnitude. Therefore 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. 3(a)] the question of systematic effects arises. The structure seemed to persist when 5 ft of iron was removed from each arm [Fig. 3(b)]. Clearly a measurement of the type described here has no problem with event rate, but suffers from a large number of systematic uncertainties.

The absolute mass scale in Figs. 2 and 3 has been corrected for multiple-scattering effects. The error in the mass values has been estimated to be ± 200 MeV at $m_{\mu\mu}^2 = 36$ GeV^2. The largest contribution to this error arises from the uncertainty in the range-energy relation. The mass resolution comes out to be approximately of the same value.

The absolute normalization of the dimuon cross section is made difficult by multiple-scattering effects, by beam normalizations, by unknown acceptance, and by the nature of the environment with its high background.

We conclude that we observe $\psi(3.1 \text{ GeV}) \to \mu + \mu$ and have an indication for a structure around $m_{\mu\mu}^2 = 36$ GeV^2. A dilepton state of mass 6.2 GeV has been predicted by Iwasaki as an exotic state of charmed quarks ($c\bar{c}c\bar{c}$).[7] A structure in the e^+e^- mass spectrum at 6.0 GeV produced in 400-GeV pN collisions has been reported by Hom *et al.*[8]

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Systematics of Isospin Mixing in Proton Elastic Scattering from Light Nuclei*

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The effects of isospin mixing observed by isospin-forbidden resonant proton scattering from the stable, self-conjugate, even-even nuclei exhibit a simple dependence on target mass number A. Furthermore, for $A=8n+4$, n integral, the mixing is systematically a factor of 5 larger than for $A=8n$. The relation between this behavior and the trends of other relevant nuclear properties is discussed.

The total isospin quantum number T of a nuclear state would be unique if the nuclear Hamiltonian were identical for neutrons and protons.[1] Isospin mixing in nuclear states can be determined by measuring deviations from isospin conservation rules. In this Letter we show that isospin mixing in light nuclei, as evidenced by the reduced widths γ_p^2 in proton isospin-forbidden elastic scattering from the self-conjugate ($N=Z$) nuclei with Z even, shows a very simple dependence on target mass number A. Moreover, we find that γ_p^2 is systematically about a factor of 5 larger for the $A=8n+4$ targets (^{12}C, ^{20}Ne, ^{28}Si, ^{36}Ar) than for $A=8n$ targets (^{8}Be, ^{16}O, ^{24}Mg, ^{32}S, ^{40}Ca). Indications of this periodic behavior had been noted previously[2,3] on the basis of less complete data. The isospin-forbidden α decays of excited $T=2$ states of the same nuclei exhibit a periodic behavior to a limited extent.[4]

Proton elastic scattering from self-conjugate target nuclei through $T=\frac{3}{2}$ resonances is isospin forbidden; it can occur by isovector ($\Delta T=1$) or isotensor ($\Delta T=2$) interactions. We measured elastic-scattering excitation functions at four backward angles over the lowest $T=\frac{3}{2}$ resonances for ^{24}Mg, ^{28}Si, and ^{32}S targets, using methods described previously.[2,5] Typical target thicknesses corresponded to a mean energy loss of 300 eV, and the high-resolution system[6] produced an incident beam spread with full width at half-maximum of ~ 650 eV. Representative excitation functions are shown in Fig. 1. Polarized-beam data with thicker targets and a beam resolution of about 1.5 keV were also accumulated near each resonance.

For each target nucleus the high-resolution excitation functions were analyzed[5] in terms of spin-flip and spin-nonflip helicity amplitudes.[7] With the use of the polarized-beam data only two real parameters were required to fit the off-resonance data at each angle. The $T=\frac{3}{2}$ resonance was ascribed a Breit-Wigner energy dependence with the resonance energy, the width Γ, and the proton elastic-scattering partial width Γ_p as parameters. The ratio Γ_p/Γ was constrained to be

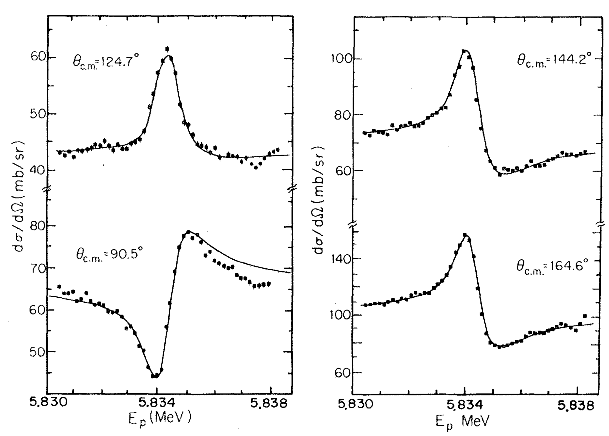

FIG. 1. High-resolution excitation functions over the lowest $T=\frac{3}{2}$ resonance observed in $^{28}Si(p,p)^{28}Si$. The target was enriched SiO (mean energy loss 250 eV) on a C foil. The solid lines are fits for total width $\Gamma=360$ eV, $\Gamma_p/\Gamma=0.82$, and an energy-resolution function with $\Delta=650$ eV and $\xi=80$ eV, as discussed in the text.