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Search for Narrow Two-body Enhancements at Fermilab*

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ABSTRACT

A search has been made in neutron-beryllium interactions for neutral narrow enhancements produced at Feynman $x \geq 0.2$. Upper limits are presented for production cross sections times branching ratio into the 2-body channels $\pi^+\pi^-$, π^+K^-, pK^- and $p\bar{p}$ for masses in the interval 2 GeV $\lesssim m \lesssim$ 4 GeV. Comparisons are made with ψ production observed in the same experiment.

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Mounting evidence from hadronic[1/], electromagnetic[2/] and weak[3/] interaction experiments indicates that new quantum numbers are being excited in hadrons. Mesons and baryons explicitly possessing these new quantum numbers are predicted to have masses $\gtrsim$ 1.5 GeV.[4/] The lowest mass states will presumably decay weakly and have small decay widths.

Our experiment has searched for the inclusive production of such long lived states in neutron induced reactions at Fermilab. Two-body decay channels were analyzed for resonances produced with Feynman $x \geq 0.2$ and with $p_\perp \leq 1.0$ GeV/c, for example by associated production. This forward geometry has potentially smaller backgrounds from uncorrelated large $p_\perp$ secondaries than experiments at $x \sim 0$.

The spectrometer is shown schematically in fig. 1. The neutron beam is incident from the left onto a beryllium target just upstream of counter S_1. Charged secondaries are reconstructed using eleven 1mm and 2mm spacing proportional chamber planes upstream and between 2-BM109 dipole magnets. These are followed by fourteen planes of magnetostrictive wire spark chambers. Both upstream and downstream arms contain x, y and rotated u,v planes. The magnet apperture is 8" vertically and 24" horizontally.

Produced particles were analyzed by a low pressure N_2 threshold Cerenkov counter divided optically into two cells, and instrumented with RCA 31000M phototubes. Cerenkov pressure curves, using 300 GeV/c diffracted protons down the neutral beam line, confirmed that the two cells had equal efficiencies to within 10% and predicted a maximum of ~4.5 photoelectrons for π threshold set at 20 GeV/c. This choice of threshold allowed pions to be distinguished from kaons and protons since typical particle momenta were ~45-50 GeV/c. The detailed particle selection criteria were as follows. Particles producing light in the Cerenkov and having momenta between 22 GeV/c $\lesssim$ p $\lesssim$ 130 GeV/c were classified as pions. Particles yielding no light in the Cerenkov were classified as kaons between 25 GeV/c $\lesssim$ p $\lesssim$ 80 GeV/c and/or as protons between 25 GeV/c $\lesssim$ p $\lesssim$ 140 GeV/c. Muons were identified by a 10-foot range requirement in steel.

The neutron beam, produced at ~1mr from 300 GeV/c pBe interactions in the meson laboratory target, peaked at ~240 GeV/c and had $\lesssim$1% K_L^o contamination above 100 GeV/c[5]. Photons in the neutral beam were removed with a lead absorber of ~9 r.ℓ. The neutron flux was continuously monitored using a 1.7% converter-counter telescope placed downstream of the spectrometer.

To obtain a mass selective trigger we utilize the technique of "point to parallel focusing" often used in K° experiments[6]; thus, the required transverse momentum "kick" from the dipole was approximately one half the 2-body mass. This geometry provided the optimal invariant mass resolution for a forward spectrometer, and the large magnetic field strongly defocused low transverse momentum secondaries. The parallelism trigger required $\geq$ 1 track on each side of the beam line plus "parallel logic", using hodoscope elements on H_1 and H_2, to accept particles within ±10 mr of the beam direction. This trigger resulted in a mass bite of Δm ~ 600 MeV for the spectrometer and necessitated 4 mass (magnet) settings to survey the mass interval ~2 GeV to ~4 GeV.

Tracks were reconstructed starting downstream of the dipoles using hodoscopes H_1 and H_2 to establish roads. Downstream line segments were then extrapolated through the magnet creating roads in the proportional chambers. Finally, a fit was made constraining the tracks to originate from a common vertex. Accepted high mass pairs were required to satisfy the experimental trigger independent of additional background tracks in the events.

Running was divided into two basic modes: "hadronic", using the parallel 2-body trigger (and for part of the data a semi-inclusive trigger requiring a multiplicity of two in H_1 and H_2), and "2μ", requiring two penetrating particles in addition to the parallel trigger. Hadronic data were obtained with ~ 2×10^6 n/pulse incident on a 3.75 cm Be target, the 2μ data with ~ 4×10^6 n/pulse on a 7.25 cm two piece Be target. These targets were clearly resolved in the reconstructed vertex distributions.

The mass distribution of the 2μ data near 3 GeV is shown in Fig. 2. A two bin enhancement is observed at the ψ mass; the 2μ continuum is primarily from hadronic decays before the iron absorber. To obtain the ψ cross section we assume an isotropic decay distribution in the ψ rest frame and take the production model:

$$\frac{d^2\sigma}{dx\,dp_\perp^2} \approx f(x)\, e^{-ap_\perp^2}$$

with f(x) constant near x = 0: [7] (1)

$$f(x) = \begin{cases} 1.0 \text{ for } x < 0.35 \\ e^{-5(x-0.35)} \text{ for } x \geq 0.35 \end{cases}$$

The resulting ψ cross section times branching ratio into 2μ for $x \geq 0.2$ is 3.6 ± 2.0 nb/nucleon for $a = 1$ GeV^{-2} [8] in agreement with the results of references 7 and 9. The cross section is ~10% larger if

$f(x) = e^{-5x}$ for all $x \geq 0$. To obtain the cross section/nucleon we have taken the cross section/nucleus to have a linear dependence on atomic number[9/].

The invariant mass distributions for the 2-body hadronic channels $\pi^+\pi^-, \pi^+K^-$, pK^- and $p\bar{p}$ are shown in Fig. 3. Data from the lowest mass (magnet) setting and the three higher mass settings are plotted separately; the former indicates the mass bite of the spectrometer. The relative normalization of these data is arbitrary. Additionally, some overlap does exist in these data since protons and kaons are indistinguishable below 70 GeV/c.

These mass spectra are compared to smoothed distributions, for example generated with randomized tracks from different events, to search for $\gtrsim$ 4 standard deviation enhancements. One such enhancement is observed in the π^+K^- mass distribution at $m_{\pi k} = 2.29 \pm 0.03$ GeV with a width consistent with the experimental mass resolution, $\delta m_{FWHM} \approx 0.01m$ [10/]. Assuming the production model of eqn. (1) with a = 3 GeV^{-2} we obtain a cross section times branching ratio of 65 ± 26 nb/nucleon for $x \gtrsim 0.2$. This corresponds to a production cross section of ~36 $\sigma_{\psi \to \mu\mu}$ [8/]. We note that this "4σ" enhancement has a purely statistical probability of ~3% [11/]. Additional data are now being taken to increase our sensitivity in the 2.3 GeV mass region.

In the absence of enhancements, cross section times branching ratio upper limits for $x \gtrsim 0.2$ are calculated corresponding to a "4σ" effect. These results, shown in Fig. 4, incorporate the experimental mass resolution, and include corrections for two track reconstruction inefficiencies (~13%), losses from secondary interactions and decays of particles, Cerenkov efficiencies, losses from vertex cuts and χ^2 cuts on track reconstruction (~5%), trigger bias losses for data obtained with the H_1,H_2 multiplicity cut (50 ± 10%), and neutron beam attenuation before the monitor. The upper limits are at the level of $\gtrsim$ 20 $\sigma_{\psi \to \mu\mu}$.

An evaluation of our sensitivity to the production of narrow resonances can be obtained by scaling these cross sections for all Feynman x, a multiplicative factor of ~3 in the model of eqn. (1). With the exception of one possible π^+K^- enhancement, we observe no narrow resonances with a cross section times branching ratio of $\gtrsim$ 0.1 μb.

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8) For comparison with our hadronic data the $\psi \rightarrow \mu\mu$ cross section is 1.8 ± 1.0 nb/nucleon with $a = 3\ GeV^{-2}$ in eqn. (1).

9) B. Knapp et al., Phys. Rev. Lett. 34, 1044 (1975); I. Gaines, Proc. of the 2nd International Vanderbilt High Energy Physics Conf. (1976).

10) Cerenkov momentum and geometrical cuts, as well as the thinner target used in the hadronic data result in improved mass resolution with respect to the 2μ data.

11) This corresponds to a probability of occurrence of $6.34 \times 10^{-3}\%$ times ~500 data bins.

FIGURE CAPTIONS

1) Plan view of the spectrometer.

2) $\mu^+\mu^-$ mass distribution near the ψ . The smooth curve is a polynomial fit to the data plus a gaussian for the ψ .

3) $\pi^-\pi^+$, $\bar{p}p$, K^-p and $K^-\pi^+$ mass distributions from the lowest mass settings a), c), e) and g) and the three higher mass settings b), d), f) and h) of the spectrometer.

4) "4σ" upper limits for the inclusive production of narrow resonances in the channels $\pi^-\pi^+$, $K^-\pi^+$, $\bar{p}p$ and K^-p.

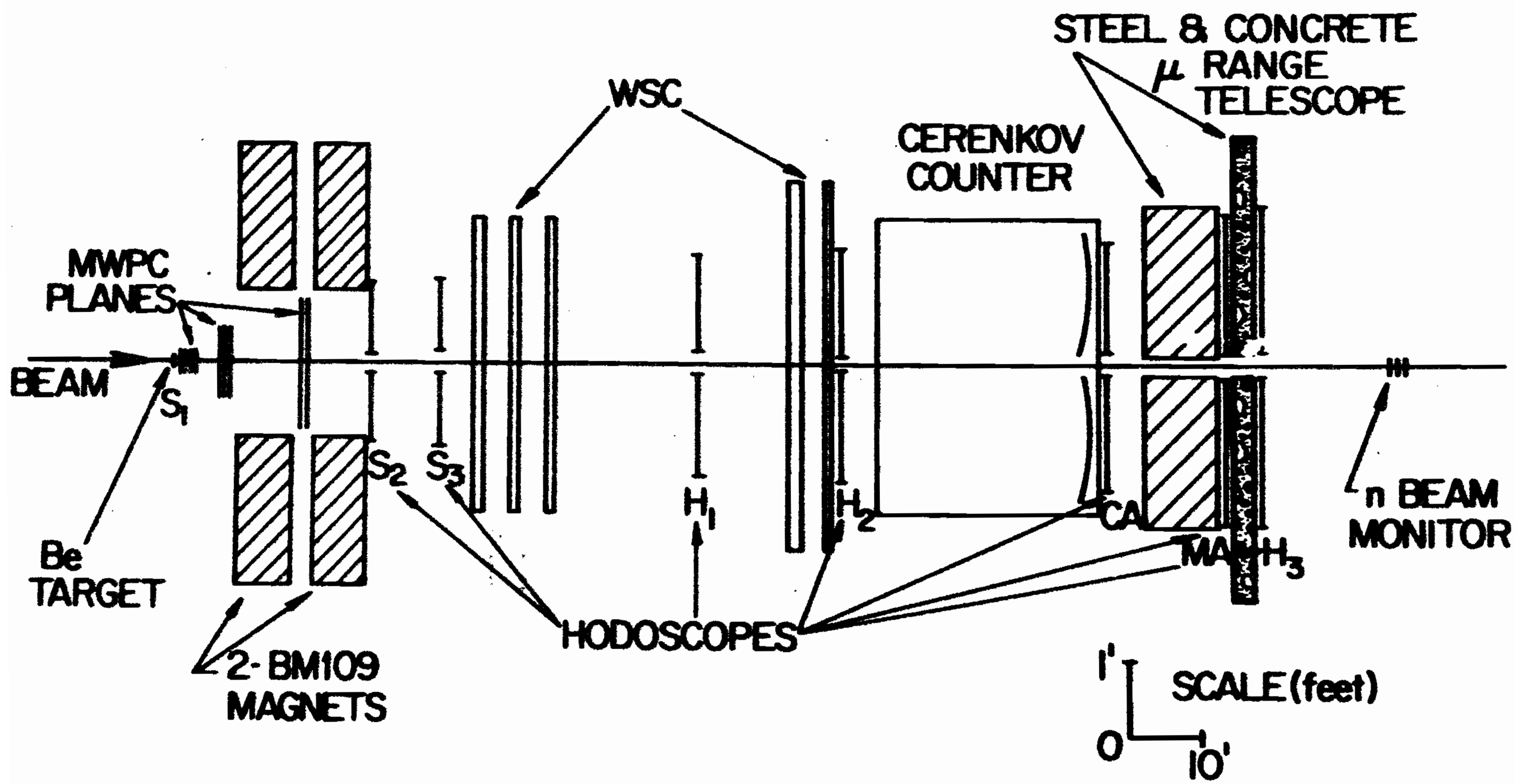

STEEL & CONCRETE
μ RANGE
TELESCOPE
WSC
CERENKOV
COUNTER
MWPC
PLANES
BEAM
S1
Be
TARGET
2-BM109
MAGNETS
S2
S3
H1
H2
CA
MA
H3
HODOSCOPES
n BEAM
MONITOR
1'
SCALE (feet)
0
10'

Fig. 1

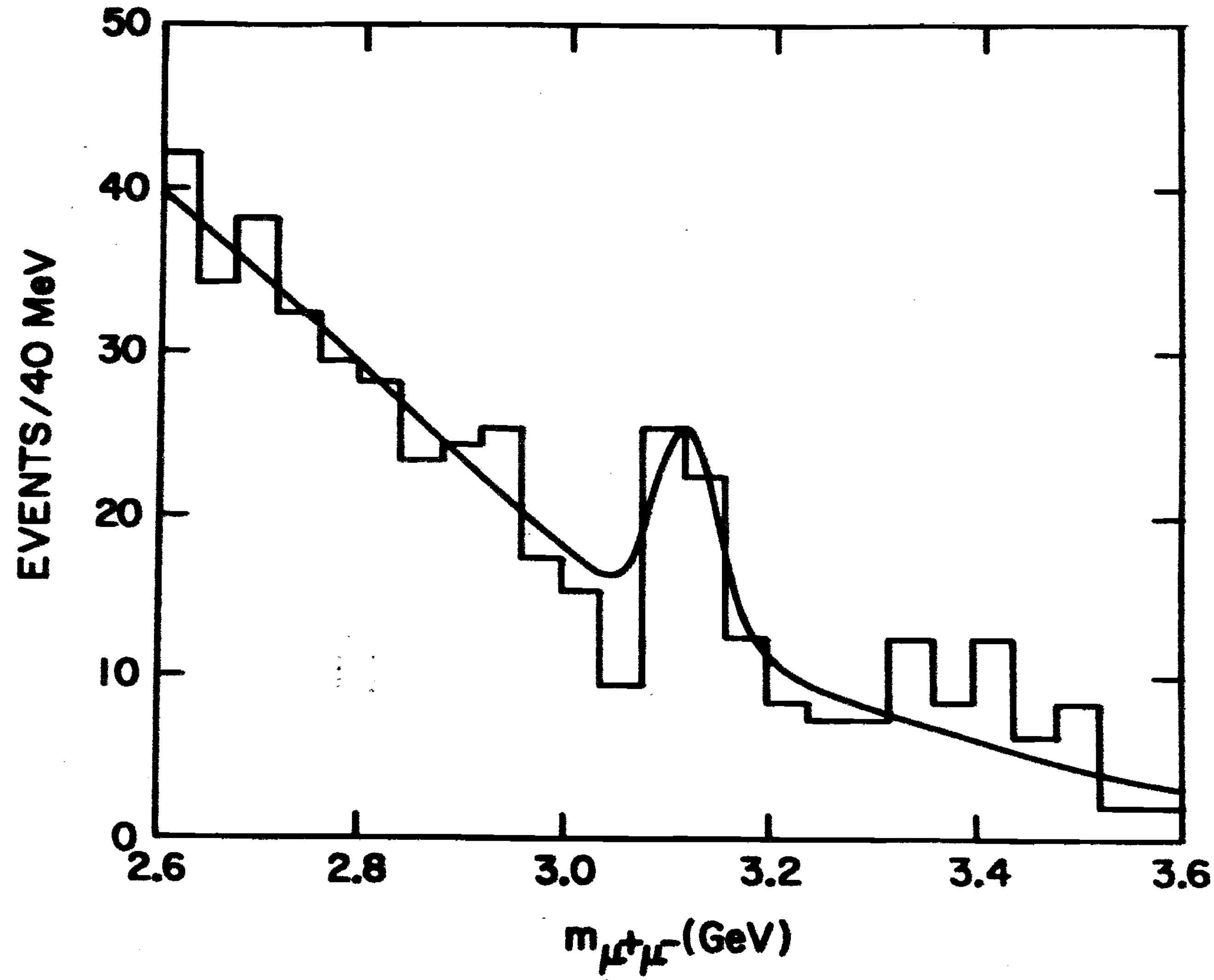
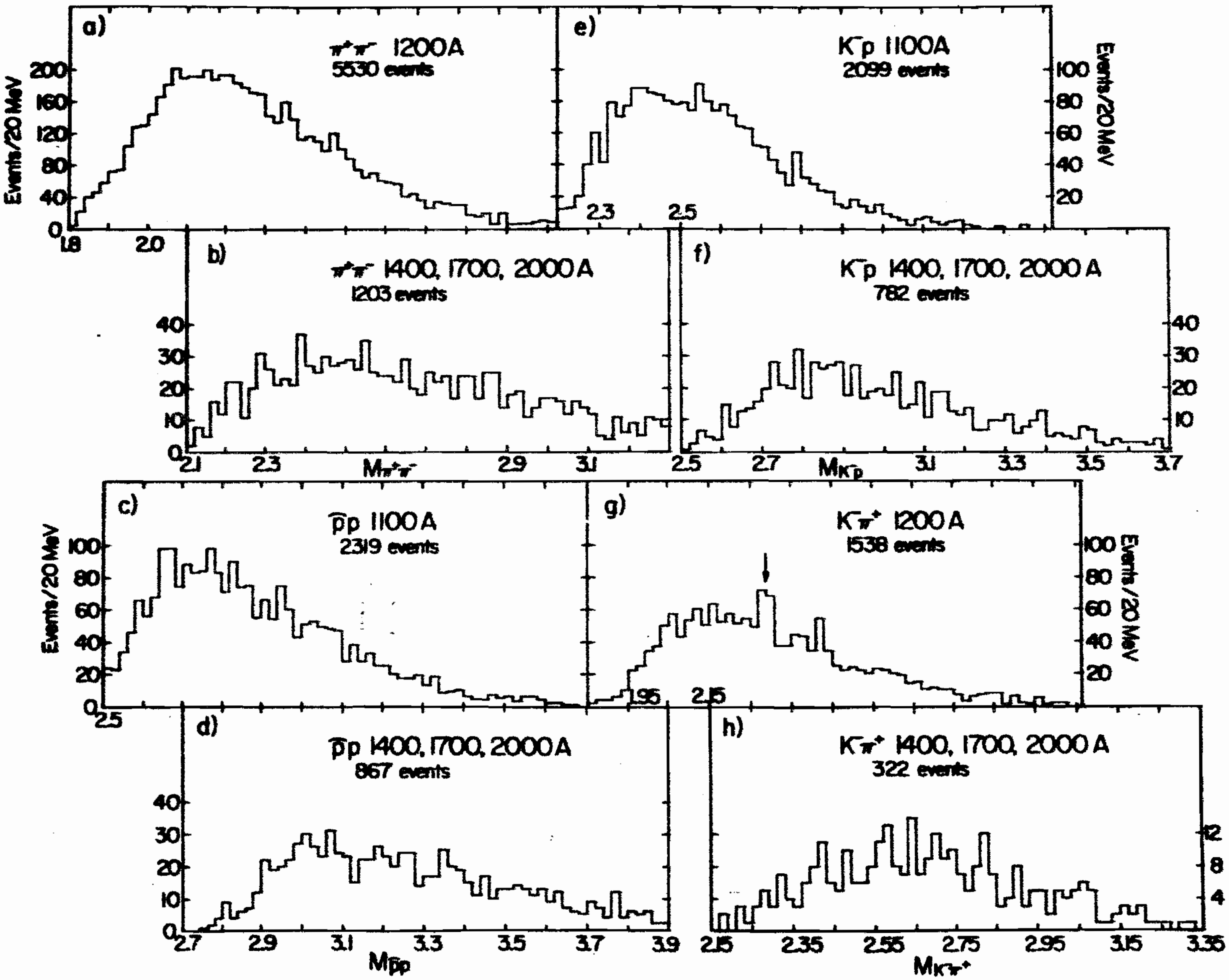


Fig. 2



a)
π⁺π⁻ 1200A
5530 events
Events/20 MeV
M_π⁺π⁻
b)
π⁺π⁻ 1400, 1700, 2000 A
1203 events
c)
p̄p 1100 A
2319 events
d)
p̄p 1400, 1700, 2000 A
867 events
M_p̄p
e)
K⁻p 1100A
2099 events
f)
K⁻p 1400, 1700, 2000 A
782 events
M_K⁻p
g)
K⁻π⁺ 1200 A
1538 events
h)
K⁻π⁺ 1400, 1700, 2000 A
322 events
M_K⁻π⁺

Fig. 3

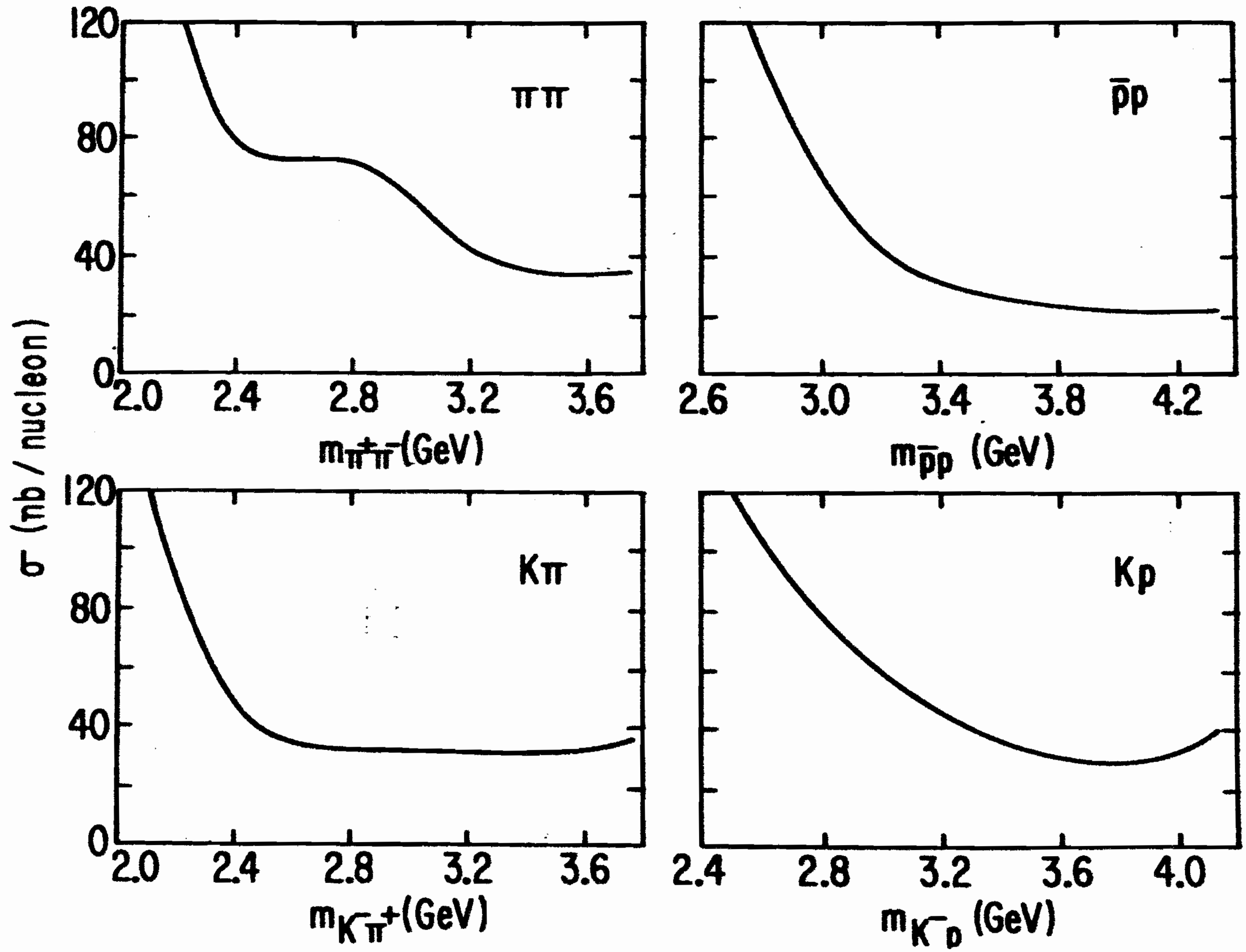

ππ
p̄p
Kπ
Kp
σ (nb / nucleon)
120
80
40
0
2.0
2.4
2.8
3.2
3.6
$m_{\pi^+\pi^-}$ (GeV)
2.6
3.0
3.4
3.8
4.2
$m_{\bar{p}p}$ (GeV)
$m_{K^-\pi^+}$ (GeV)
4.0
m_{K^-p} (GeV)

Fig. 4