

A SEARCH FOR NEW PARTICLES IN
 PROTON-NUCLEUS COLLISIONS AT 400 GeV/c*

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ABSTRACT

We report preliminary results from a search for new particles produced in proton-nucleus collisions at 400 GeV/c. A double-arm spectrometer is used to detect two-body final states where each spectrometer arm has the capability of uniquely identifying π^\pm , K^\pm , p , \bar{p} , μ^\pm , and ϕ . The J/ψ is measured in the $\mu^+\mu^-$ mode.

This is a preliminary report on a search for narrow resonances (X) decaying into two hadrons, h_1 and h_2 , produced in the reaction

$$pN \rightarrow X + \text{anything}$$

$$\quad \searrow$$

$$\quad \quad \rightarrow h_1 h_2$$

at 400 GeV/c. The results presented are from the first data-taking run in November-December, 1975, of the FNAL/Michigan/Purdue double-arm spectrometer system installed in the M2 beam line at FNAL. Our experiment (E-357) is one of several performed at FNAL^{1,2} to search for new particles resulting from the possible existence of a new quantum number, charm³. If the J/ψ particle⁴ is a $c\bar{c}$ bound state, a new family of hadrons, some of which should decay into $K\pi$, K^-p , or $\bar{p}K^+$ with a significantly large branching ratio, is expected. Thus far, except for a bump in the $K^-\pi^+$ mass spectrum observed by MSU/OSU/Carleton², the results of charmed particle searches have been negative^{1,5,6}.

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The plan view of our symmetric, double-arm spectrometer system is shown in Fig. 1. Each arm contains 16 planes of drift chambers, 20 scintillation counters, 3 Cherenkov counters, a BM-109 dipole magnet which bends vertically, and 6 feet of steel plus 18" of concrete to identify μ^\pm . Unambiguous identification of π , K, and p and \bar{p} is obtained for momenta between 7 and 20 GeV/c, and separation of p and \bar{p} from π and K is obtained up to 40 GeV/c. In addition, we detect $\varphi \rightarrow K^+K^-$, $K_S^0 \rightarrow \pi^+\pi^-$, and $\Lambda^0 \rightarrow p\pi^-$ when their decay products go into a single arm of the spectrometer system. Thus, we can identify $X \rightarrow \pi\pi$, πK , πp , KK , Kp , pp , $\varphi\pi$, φK , and φp in all possible charge states except those with a π^0 . The mass acceptance of the system for unambiguously defined particles is $1.5 \leq M_x \leq 4.0 \text{ GeV}/c^2$ with the rapidity acceptance of $X \rightarrow h_1 h_2$ events confined to $y_{\text{cm}} = 0$. The mass resolution varies linearly with M_x ; at $M_x = 3 \text{ GeV}/c^2$, $\sigma_m \approx 7 \text{ MeV}/c^2$.

The 400 GeV/c diffracted proton beam was incident on a 10% interaction length CH_2 target divided into seven segments separated by 4" along the beam axis. The trigger for $X \rightarrow h_1 h_2$ was simply a coincidence between the two spectrometer arm signals, each of which, by the coincidence between signals from suitable sets of intra-arm scintillation counters, signified that a charged particle with momentum greater than 7 GeV/c had traversed the arm. For our typical incident flux of 5×10^7 protons per ~ 0.8 sec spill, the two arm coincidence rate was 250/spill. However, due to computer-induced deadtime, the number of events actually recorded on magnetic tape was ~ 80 /spill. During the November-December, 1975, run, approximately 7.7 million triggers were recorded, with $\sim 33\%$ having reconstructable tracks in both arms.

The observation of $\varphi \rightarrow K^+K^-$, where both the K^+ and K^- go into the same arm, provides an excellent test of our apparatus and reconstruction procedures. As shown in Fig. 2, the $\varphi \rightarrow K^+K^-$ signal appears as a sharp peak in the K^+K^- mass spectrum with a width consistent with our calculated mass resolution. We estimate the ratio of φ plus anything in the other arm to π^- plus anything in the other arm to be about 10^{-2} for $p_\perp \geq 1.4 \text{ GeV}/c$. Since the branching ratio for $\varphi \rightarrow \mu^+\mu^-$ is 2.5×10^{-4} , it is clear that φ production contributes little to the observed prompt μ to π ratio of $\sim 10^{-4}$ at large p_\perp .

Muon pair data were accumulated simultaneously with the hadron pair data in order to experimentally verify the mass scale, mass resolution, and sensitivity of the experiment with the J/ψ particle. Our J/ψ statistics are limited since the beam rate was optimized for hadron running. The hadron trigger rate saturated the data recording capability at $\sim 0.5 \times 10^9$ ppp. No special attempt was made to improve J/ψ statistics at the expense of the hadron data by running with only a μ -pair trigger. The μ -pair effective mass spectrum representing the data taken in November and December is presented in Fig. 3. The J/ψ signal is a sharp peak centered at a mass of $3.095 \text{ GeV}/c^2$. From these data we determine experimentally that our mass resolution is $\sigma_m \sim 7 \text{ MeV}/c^2$. Assuming a linear dependence on atomic number, isotropic J/ψ decays, and a momentum dependence given by

$$E \frac{d^3\sigma}{dp^3} \propto (1 - |x|)^{4.3} e^{-1.6p_{\perp}},$$

we calculate that $\sigma_{J/\psi \rightarrow \mu\mu}^B = (9 \pm 3)\text{nb/nucleon}$ at 400 GeV/c, in agreement with Snyder et al.⁷ who obtained $(11 \pm 3)\text{nb/nucleon}$ at 400 GeV/c under the same assumptions.

Convinced by our $\phi \rightarrow K^+K^-$ and $J/\psi \rightarrow \mu^+\mu^-$ signals that we understand the apparatus well, we have investigated the hadron-pair mass spectra. In Figs. 4-8 we show the mass spectra for five of the twenty-one possible combinations of charged π 's, charged K's, and p and \bar{p} : specifically, $\pi^+\pi^-$, $K^-\pi^+$, π^-K^+ , K^-p , and $\bar{p}K^+$. Clear, narrow peaks in the $K^-\pi^+$ or K^-p and $\bar{p}K^+$ mass spectra would be indications for charmed particles. None of the mass spectra, including those not presented, show any statistically significant narrow structure at the 4 standard deviation level. Since all of these data were collected simultaneously, the $K^-\pi^+$ data may be compared with the π^-K^+ data and the K^-p with the $\bar{p}K^+$ data. In doing this, we find that none of the tantalizing, but nevertheless statistically insignificant, peaks in the $K^-\pi^+$ and K^-p spectra coincide with similarly tantalizing peaks in their respective conjugate spectra. Thus, at this early stage of our experiment we see no evidence for massive narrow resonances decaying into two hadrons.

It is clear from this experiment and others^{1,2,5,6} that charmed particles are not easily observable in hadronic effective mass spectra. To obtain upper limits on the cross sections times branching ratio into two hadrons, $\sigma_c B_{h_1 h_2}$, it is necessary to make assumptions about the production mechanism for charmed particles. If we assume that charmed particles are produced with the same momentum dependence as the J/ψ particle, we can calculate upper limits for $\sigma_c B_{h_1 h_2}$ directly in units of $\sigma_{J/\psi \rightarrow \mu\mu}^B$. For the data shown in Figs. 5-8, $\sigma_c B_{h_1 h_2}$ ranges from 10 to 40 times $\sigma_{J/\psi \rightarrow \mu\mu}^B$ at $M_x = 2.3 \text{ GeV}/c^2$ and 4 to 8 times $\sigma_{J/\psi \rightarrow \mu\mu}^B$ at $M_x = 3.0 \text{ GeV}/c^2$. Here we have used the criterion that a 4 standard deviation peak in a 20 MeV/ c^2 wide mass bin would have been a positive indication of a narrow resonance. These upper limits are set primarily by the large physical hadronic background. If we take our calculated value of $(9 \pm 3)\text{nb/nucleon}$ for $\sigma_{J/\psi \rightarrow \mu\mu}^B$, then the level of sensitivity of our particle search is of the order of 100 nb/nucleon for $\sigma_c B_{h_1 h_2}$.

Our experimental run at FNAL is now less than one-half complete. In the remainder of the run we should be able to at least double the amount of data. The anomalous lepton production observed in several diverse experiments suggests a possible signature for events containing new particles. Therefore, we have proposed an additional experiment at FNAL to search for narrow resonances in two-body hadron mass spectra for events containing a prompt muon. Only minor modifications to our present apparatus are required. This new proposal has been approved, and we hope to start taking data as early as this summer.

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PRESENT E-357 LAYOUT
FNAL/MICHIGAN/PURDUE

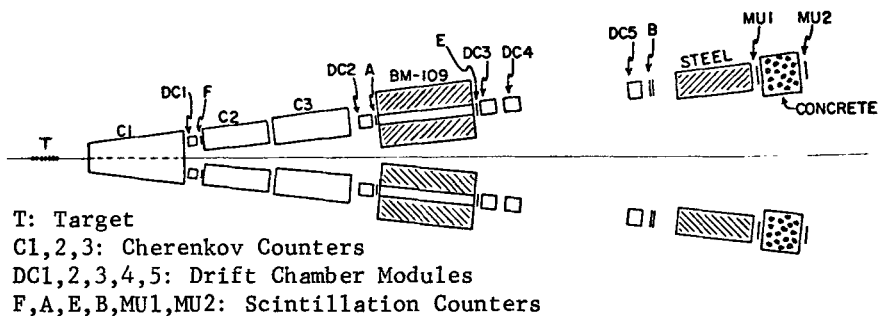


Fig. 1. Plan view of the double-arm spectrometer system.

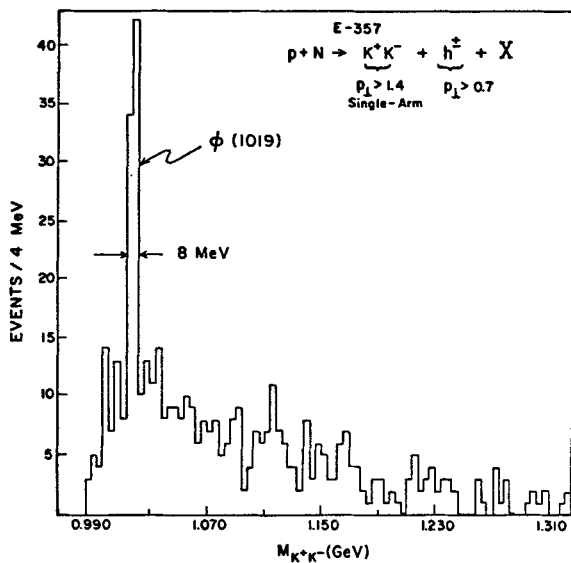


Fig. 2. K^+K^- effective mass spectrum for events in which both the K^+ and K^- go into a single spectrometer arm.

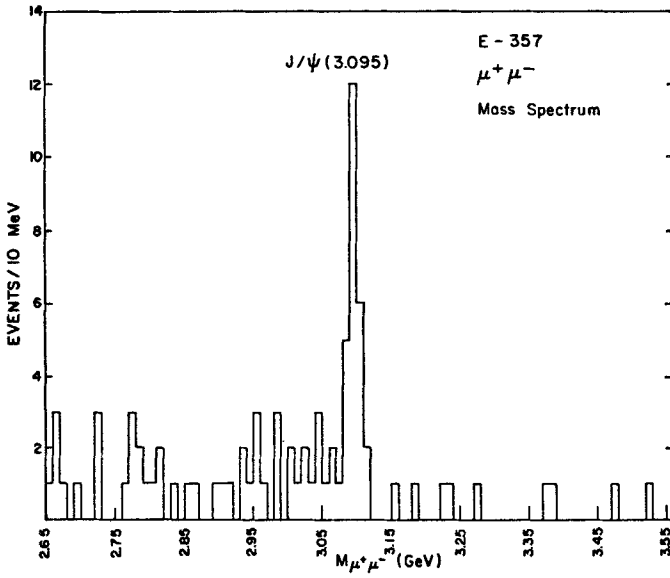


Fig. 3. $\mu^+\mu^-$ effective mass spectrum.

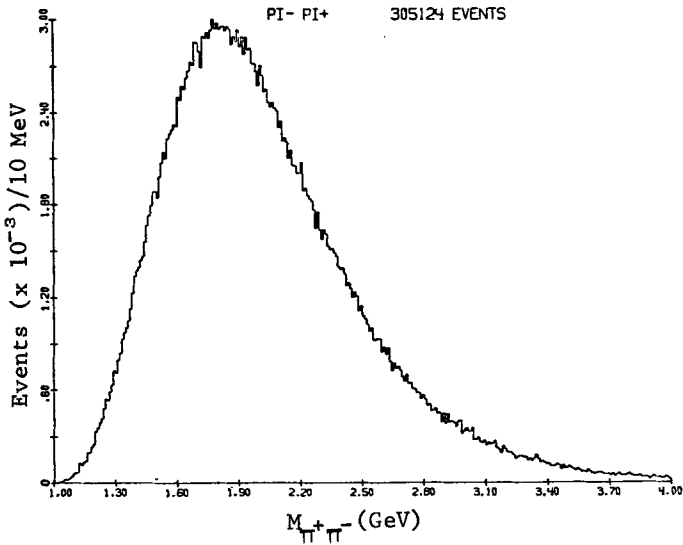


Fig. 4. $\pi^+\pi^-$ effective mass spectrum.

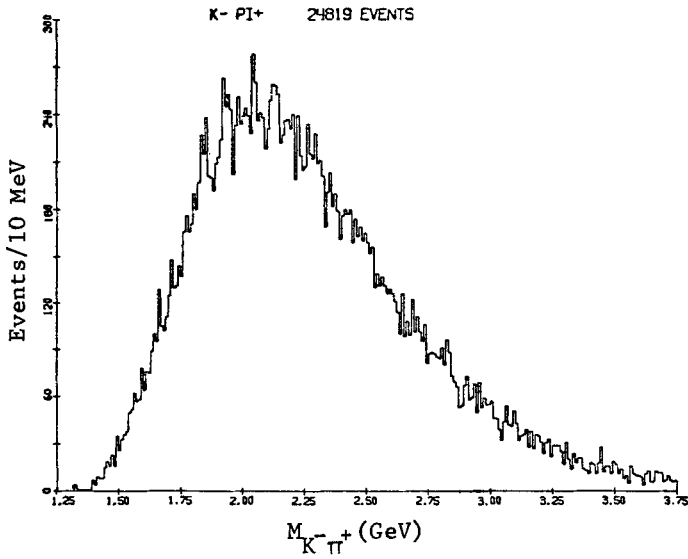


Fig. 5. $K^- \pi^+$ effective mass spectrum.

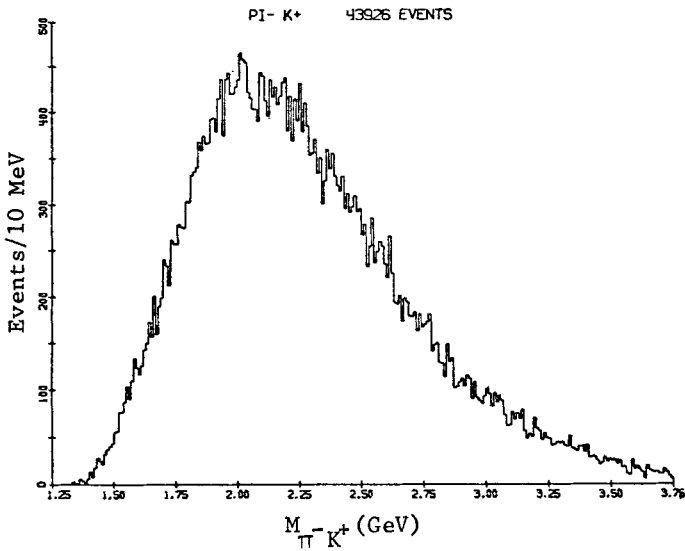


Fig. 6. $\pi^- K^+$ effective mass spectrum.

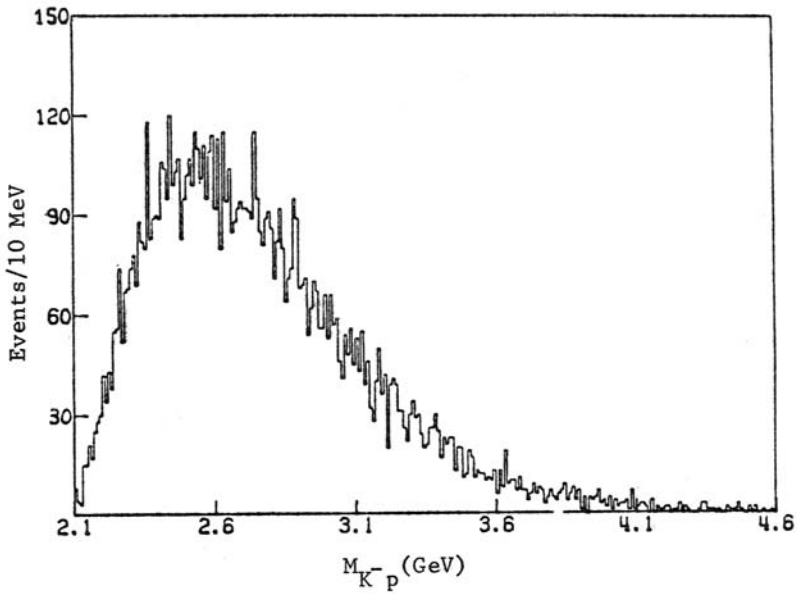


Fig. 7. K^-p effective mass spectrum.

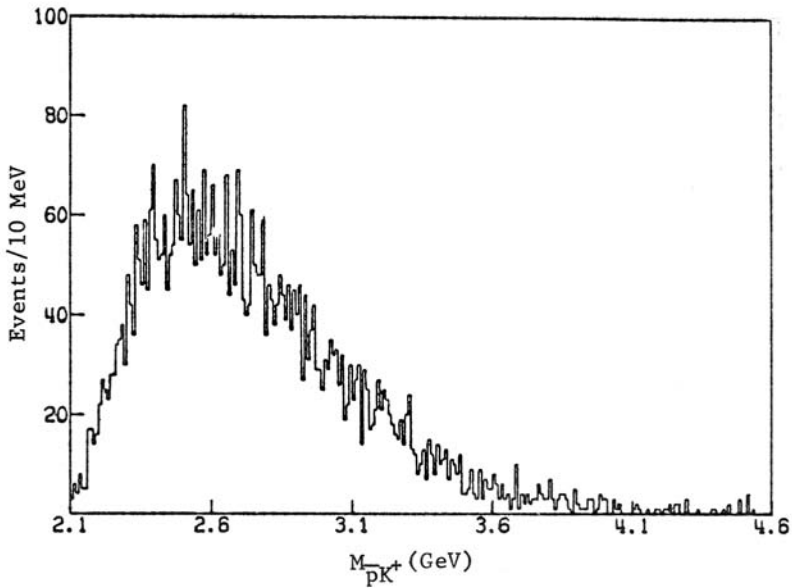


Fig. 8. $\bar{p}K^+$ effective mass spectrum.