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Presented by J. Dowd

ABSTRACT

This paper describes an experiment that will search for J$^{PC}$ hybrid mesons at the Brookhaven MPS-II facility. Such explicitly exotic states are allowed in QCD, and are predicted to be in an accessible mass region by several models. The experiment will investigate the production of exotics in the reaction $\pi^- p \rightarrow \pi^- f_1 p$. Expected rates and experimental sensitivity to possible hybrid states are discussed.

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This paper describes an experiment that will search for J^PC hybrid mesons at the Brookhaven MPS-II facility. Such explicitly exotic states are allowed in QCD, and are predicted to be in an accessible mass region by several models. The experiment will investigate the production of exotics in the reaction \( \pi^- p \rightarrow \pi^- f_1 p \). Expected rates and experimental sensitivity to possible hybrid states are discussed.

INTRODUCTION

Gluonic degrees of freedom in QCD are expected to give rise to two new spectroscopies in the same mass region as conventional q-qbar mesons. Glueball and hybrid spectra with states in the mass range 700 to 3000 MeV are predicted by several models. Experimentally, the unambiguous identification of glueball states is difficult. The quantum numbers of the lowest lying states are expected to be non-exotic (e.g. 0^{++}, 0^{-+}, 2^{++}), and thus these states are expected to mix with ordinary q-qbar mesons.

The experimental signature for the production and identification of possible hybrid states may be more promising. Hybrids are color singlet states consisting of a q-qbar color octet and a gluon. Models for the hybrids predict masses for the lowest lying states that are somewhat higher than that of the lowest lying glueballs, but the low lying hybrid states in these models are expected to be J^PC exotic. Sum rule and flux tube models predict that the J^PC of the lowest lying hybrid state is the manifestly exotic 1^{-+}.

A flux tube model due to Isgur and Kokoski makes several predictions that can be exploited to provide an experimental signature for hybrid production and identification. In this model the gluon component of the hybrid is essentially an excitation of the string. The cross section for hybrid production is expected to be substantially the same as that of ordinary mesons, but the decay of the hybrid to a pair of L=0 mesons is suppressed. The gluon spin is picked up as the orbital angular momentum of one of the decay mesons. This selection rule favors decay channels that have not been studied in high statistics experiments. For example, Isgur...
predicts that the $J^{PC} = 1^-$ hybrid $X(1900)$ should decay to $\pi\eta$ and $\pi\eta'$ final states.

**EXPERIMENTAL SETUP**

This experiment will take data with the MPS-II and a 12 GeV/c separated pion beam to search for the hybrid state produced in the $b_1$ exchange process (See Figs.1 and 2):

$$\pi^-(12\text{ GeV/c}) + p \rightarrow X^-(1900) + p$$
$$\rightarrow \pi^- f_1(1285)$$  \hspace{1cm} (1)

The $f_1(1285)$ in reaction (1) is to be detected through the decay mode:

$$f_1(1285) \rightarrow \pi^- a_0(980)$$
$$\rightarrow K^+ K^0$$
$$\rightarrow \pi^- \pi^+$$  \hspace{1cm} (2)

One potential source of background for reaction (1) is the diffractive dissociation of the pion beam into $K\bar{K}\pi\pi$. In order to suppress this process relative to $b_1$ exchange, the experiment is designed to detect recoil protons with $-t > 0.3$ GeV$^2$. For $-t > 0.3$ GeV$^2$ the recoil proton has a laboratory momentum greater than 600 MeV/c, and a laboratory angle of greater than 55 degrees with respect to the beam. A cylindrical proportional-wire chamber is being constructed to detect the recoil proton. The chamber consists of four independent cylindrical gaps of diameter 19.4, 23.4, 27.4, and 31.4 mm respectively. The chamber length is 60 cm and the cell size is 12.5 mm.

The layout of the apparatus is shown in figure 3 and is similar to that of our previous experiment (E771) where we studied $K\bar{K}\pi\pi$ final states.

The trigger will consist of three major elements: a RAM trigger (TRAM) for the detection of the downstream Kaon, a multiplicity increase component (TMULT) for $K_{short}$ detection, and a cylindrical PWC track requirement (TCYL). In addition, the beam particle is required to be uniquely identified (TBEAM). TRAM requires a coincidence between the appropriate wire clusters of proportional chambers P0 and P2, the hodoscope elements of H1, H2 and TOF, and no signal from the corresponding cell of segmented Cerenkov counter C1. TMULT requires a multiplicity of 3 in PWC P1 and a multiplicity of 5 in PWC P2. TCYL requires a multiplicity of one in the cylindrical PWC. Several versions of a track reconstructing cylindrical PWC trigger - differing in the sophistication of their tracking requirements - are currently under study.

**ACCEPTANCE AND SENSITIVITY**

The acceptance for reaction (1) in the MPS gradually increases with momentum. On the other hand, the $b_1$ exchange process which we wish to study falls off as $P_{lab}^{-2}$, where $P_{lab}$ is the beam momentum. The product of
these two factors shows a broad maximum of approximately 7% centered around 12 GeV/c.

We anticipate an 800 hour data taking run, with 2.5 x 10^6 pions /spill. Using a 60 cm LH2 target, a 7% acceptance, and a 50% "contingency" factor, we obtain an integrated pion flux of 2.6 x 10^{12} and a visible sensitivity (cross section x branching ratio) of 240 events/nanobarn. Our estimates for the branching ratios are:

\[ B(\pi^- \rightarrow \pi^+ \pi^-) = 1/3 \]
\[ B(\pi^+ \rightarrow a_0^+ \pi^-) = 1/3 \]
\[ B(a_0^+ \rightarrow K^+ K^0) = 1/3 \]
\[ B(K^0 \rightarrow \pi^+ \pi^-) = 1/3 \]

In addition, we have to add the effect of the t-cut, \(-t > 0.3\text{GeV}^2\). For this purpose, we assumed that the b1 exchange process for reaction (1) has a t-dependence of \((t-t_{\text{min}})^{8.5}\). Monte Carlo events generated with this slope show that about 1/3 of the events lie in the region with \(-t > 0.3\text{GeV}\).

Thus the final "branching ratio" for the process in our experiment is approximately 1/240, yielding an expected sensitivity for reaction (1):

\[ n_\sigma = 1 \text{ event/nb} \]

**HYBRID SIGNAL TO BACKGROUND**

We can estimate the background (i.e. non-hybrid production of the \(f_1 \pi \pi\) final state) starting from our own \(K \bar{K} \pi p\) data on the process \(\pi^- p \rightarrow f_1 n\). We observed approximately 4750 events satisfying this hypothesis at 8 GeV/c. In order to estimate \(f_1 \pi^- p\) events at 12 GeV/c, we assume that the energy dependence is \(P_{\text{lab}}^{-2}\), and that the ratio of \(f_1 \pi\) to \(f_1\) is approximately 1:1. Finally, the product of (acceptance x flux) for this experiment is larger than our previous experiment by a factor of 4.5. This results in an estimate of 9500 \(f_1 \pi\) events. To this must be added non-\(f_1\) background events. Non-\(f_1\) background in \(\pi^- p \rightarrow f_1 n\) at 8 GeV/c is small, i.e. approximately 1/4 in our previous data. However, a diffractive channel such as \(f_1 \pi^- p\) is expected to be accompanied by a much higher non-\(f_1\) background, resulting from pion dissociation into \(K \bar{K} \pi \pi\). The only known diffractive production of a \(f_1 \pi\) system comes from \(\pi^-\) nucleon collisions at 200 GeV/c where an approximately 50% non-\(f_1\) background is observed in the \(\eta \pi^+ \pi^-\) system. We will assume that this higher non-\(f_1\) background applies to this experiment and thus estimate 9500 events from this source.

The total non-hybrid background is estimated to be 19,000 events. Let us assume that a hybrid resonance is centered at 1900 MeV with a full width of 200 MeV. A Monte Carlo estimate shows that approximately 1/4 of the background events should be in this region, so that one can anticipate a \(X^-\) background of 4700 events with a statistical error of 70 events. A 4 sigma hybrid signal would correspond to 280 events, i.e. (cross section x branching ratio) = 1 nb. Thus the minimum production cross-section for \(X^-\) which will give us a 4 sigma signal is 0.24 mb. This may be compared with representative 2-body resonance production cross sections at 12 GeV/c:

\[ \pi^- p \rightarrow a_2^-(1320) n \quad 110 \text{ mb} \]
We can conclude therefore that if a $J^{PC} = 1^{-+}$ resonance is not observed at 0.24 $\mu$b level, it is probably not produced at cross sections typical of hadrons in the 1.5 GeV mass range, contrary to the expectations of Isgur et. al.

**ANGULAR DISTRIBUTIONS**

A $f_1 \pi$ state with $f_1 \rightarrow KK\pi$ is an enormously complex system requiring variables in 7 dimensions. It is therefore imperative that a full partial-wave analysis be performed on the $f_1 \pi$ system to do justice to the information contained in the mass spectrum. In particular the interference effects among the various $J^{P}$ states are expected to be crucial in picking out small $J^{P}$ waves. Nevertheless, we have performed a simple two-dimensional study of the angular distributions resulting from the final acceptance of our apparatus. For this purpose we have ignored the 5-dimensional space spanned by the decay $f_1 \rightarrow KK\pi$. (The $f_1$ has a higher laboratory momentum in this experiment than in our previous MPS experiment, and we found the acceptance excellent with all major waves detected correctly without acceptance correction.) We are thus left with the angles $\theta$ and $\phi$ for the orientation of the $f_1$ in the $f_1 \pi$ Jackson frame. A Monte Carlo calculation shows that the accepted $\cos \theta$ vs $\phi$ distribution is essentially flat. For $J^{PC} = 1^{-+}$ both S and D waves are allowed, while for $J^{PC} = 1^{++}$ only P waves are allowed. The S, D and P waves are easily distinguished owing to their very different functional forms. We estimate that a full partial-wave analysis program will be able to detect a signal as low as 10% of the total events in a given mass region, if, in particular, the signal wave interferes with the background waves.

**SUMMARY**

We expect, under reasonable assumptions, a total of approximately 19,000 events for reaction (1) in a 800 hour run at the MPS-II. A 250 event $X$ resonance signal would represent a 4-sigma signal and correspond to a production cross section of approximately 250 nb, which is a factor of approximately 200 time smaller than typical hadron cross sections at 12 GeV/c.

The Jackson angle acceptance of the apparatus is well behaved, and Monte Carlo studies show that a $J^{PC} = 1^{-+}$ resonance coupling via S and D waves to $f_1 \pi$ exhibit angular distributions vastly different from the diffractive background, a $J^{PC} = 1^{++}$ P-wave $f_1 \pi$ system.

**REFERENCES**