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Letter of Intent to FNAL
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Search for Primakoff Production of Hybrid Mesons.

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Summary:

Availability of high energy, intense beams at FNAL, as well as development of new detectors and data acquisition techniques, provide a motivation for a new generation Primakoff experiment. The physics goal is to improve on previous experiments by several orders of magnitude, and, in particular, to search with high sensitivity for production of hybrid mesons in the Coulomb field of heavy nuclei.

This is a Letter of Intent to perform the experiment in conjunction with E781. The modifications to the spectrometer are minimal and relatively inexpensive, and our setup, debugging and running time will not represent a major disruption of the E781 efforts. We expect to be joined by several physicists who have already expressed an interest, and we are confident that we will be able to attract others to this experiment, once approval is granted, and provide adequate manpower to prepare, perform and analyze the experiment.

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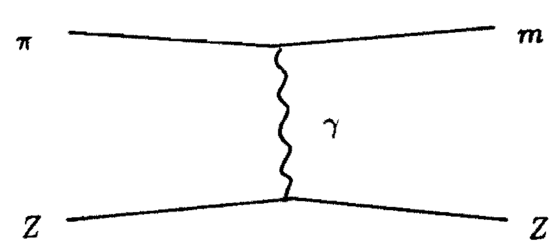
In the past, the one-photon exchange mechanism ('Coulomb' or 'Primakoff' production) has been used in meson spectroscopy mainly for measurements of radiative and two-photon widths of known mesons (π^0, η, ρ, A_2 etc.); this is the 'Primakoff effect' [1]. The production mechanism, being electromagnetic (see Fig. 1), is characterized by extremely low values of momentum transfer: $|t| < m^4/p^2$

Figure 1: Figure 1:



where m is the mass of the produced meson, and p is the laboratory beam momentum. This means that the after an appropriate cut, the data sample will contain very small

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contamination from other processes, and this purity (see examples on Fig. 2) improves with increasing beam momentum. At the same time, the total Coulomb production of a given state increases logarithmically with p. These features, together with

- availability of intense, high energy beams at FNAL
- development of silicon detectors with high position resolution
- development of modern data acquisition and data-processing techniques

make it possible to design a new-generation experiment which would result in a significant improvement over previous Primakoff studies. Rather then continuing exploration of 'classical' issues such as verifying the Z-dependence and p-dependence of the effect, or measuring the radiative widths of known mesons with better precision, we intend to perform a high sensitivity study of meson states with masses up to 3 GeV (through an appropriate trigger, we will exclude the bulk of large cross section processes such as the Coulomb production of ρ and A_1).

Of particular interest is a search for Primakoff production of hybrid mesons. As a specific example we will discuss the search for an isovector $J^{PC} = 1^{-+}$ meson[2] $\tilde{\rho}$. The quantum numbers of this state are exotic in the sense of the traditional $q\bar{q}$ quark model. States of this kind are expected to exist in the hadron spectrum of the elementary particles, especially in the form of a system composed of a gluon and a $(q\bar{q})$ color octet. Such hybrid mesons have been discussed on the basis of a variety of QCD-inspired models[3]. Although there is uncertainty concerning the widths and specific decay channels for hybrids, most models predict these mesons to have masses in the range of 1.5–2 GeV. There is general consensus that $\tilde{\rho}$ will have a branching width into $\rho\pi$ that is of the order of 1–10 MeV, and a substantially larger rate into more complex channels[4] such as $b_1(1235)\pi$ or $f_1(1285)\pi$. The presence of a 1–10 MeV width into the $\rho\pi$ channel assures, through vector-dominance arguments, a width of $\tilde{\rho}$ into $\pi\gamma$ at a level of 3–30 keV. This means that such a state could be observed in a Primakoff experiment[5].

Previous search conducted for objects such as $\tilde{\rho}$ have met with mixed success. The results of Alde et al, although very interesting, are somewhat controversial[6], and have yet to be confirmed. Earlier studies published by Fermilab experiment E272[7] were limited in scope because E272 was designed for low-mass spectroscopy, and therefore the sensitivity to masses in excess of 1.5 GeV was rather poor. The data in the $\eta\pi$ and $\rho\pi$ modes did not yield any effect, and could only be used to set upper limits on the branching rate of the hybrid meson into the $\pi\gamma$ mode[8]. This result is not surprising because the width of the vector hybrid into the above channels is expected to be rather small (several percent of the total width). These upper limits were not very restrictive for masses beyond 1.5 GeV. The only decay mode to which E272 could be anticipated to be sensitive was the $f_1(1285)\pi$ channel, and in fact, the data[9] show a tantalizing enhancement at ~ 1.6 GeV in this state (see Fig. 3); the limited statistics and acceptance did not allow any definite conclusion.

In addition to searching for hybrid mesons, the experiment will yield valuable data on "ordinary" meson spectrocopy. Obviously, not all possible hybrid, multi-quark or glue states are expected to have manifestly exotic quantum numbers. The 'crypto-exotic' states will have to be disentagled from the $q\bar{q}$ mesons by systematic observations and classifications of different production and decay modes. As a specific example of an issue opened by the previous Primakoff experiment, we note the discrepancy in the mass and width values of the $b_1(1235)$ meson:

$M = 1233 \pm 10,\ \Gamma = 150 \pm 10$ MeV (world average)[10]
$M = 1271 \pm 11,\ \Gamma = 232 \pm 29$ MeV (E272)[7].

This may indicate the observation of more than one state in strong or Primakoff production or both; the new data will enable a detailed Partial Wave Analysis which should settle this question. Another important byproduct of our experiment will be a remeasurement of the pion polarizability (by analyzing the reaction $\pi Z \rightarrow \pi\gamma Z$ in terms of a Compton effect on a pion). An urgent need for this has been stressed in a recent analysis of chiral perturbation theory in QCD[11].

The experiment will be state-of-the-art, but relatively straightforward: it will involve:

- an intense (about $5 * 10^6$ per sec) π^- beam at highest possible energy ($\sim$ 600 GeV/c), with a thin ($\sim 1\%$ interaction length) Pb target
- a magnetic spectrometer with dP_T of about 1.5 GeV/c providing precise measurement of charged particles (for beam and fast secondaries, we will use Silicon Strip Detectors)
- adequate measurement of high energy photons from π^0 and η decays (e.g. using a Liquid Argon Calorimeter).

Instead of building a dedicated spectrometer, an economical approach to performing the experiment would be in conjunction with an existing or approved FNAL experiment. A good possibility appears to be experiment E781: it is a large-x spectrometer designed for study of charmed hyperons, and it could be adapted for our purpose by:

1) upgrading the beam Si system to enable faster readout.
2) enclosing the target in a veto-box to reject any incoherent interactions.
3) using the E781 counters and computer hardware to develop an appropriate hardware and software trigger for the Primakoff experiment.

We have studied the acceptance and the angular and energy resolution of the E781 spectrometer, and we found them suitable for the Primakoff experiment. We have also discussed this possibility with E781 principals, and we did not find any reason why this approach should not be feasible; in fact, our proposal has their full support. The upgrading of the readout can be used by both experiments. The changes 2) and 3) imply the necessity of separate runs (note that running in one mode can be used for de-bugging of the other). Our running requirements are relatively modest: we estimate that 2 weeks of good data taking would represent an improvement over E272 of more than two orders of magnitude for $m < 1.5$ GeV , with even more dramatic improvement in the higher mass region where E272 acceptance was poor. As an example, we would obtain several thousand events in a specific final state such as $\pi^+\pi^+\pi^-\gamma\gamma$ for a meson with $m = 1.6$ GeV, $\Gamma_{\pi\gamma} = 10$ keV, and branching ratio into $f_1(1285)\pi$ of 0.4. Desirability of more data would depend on the results obtained.

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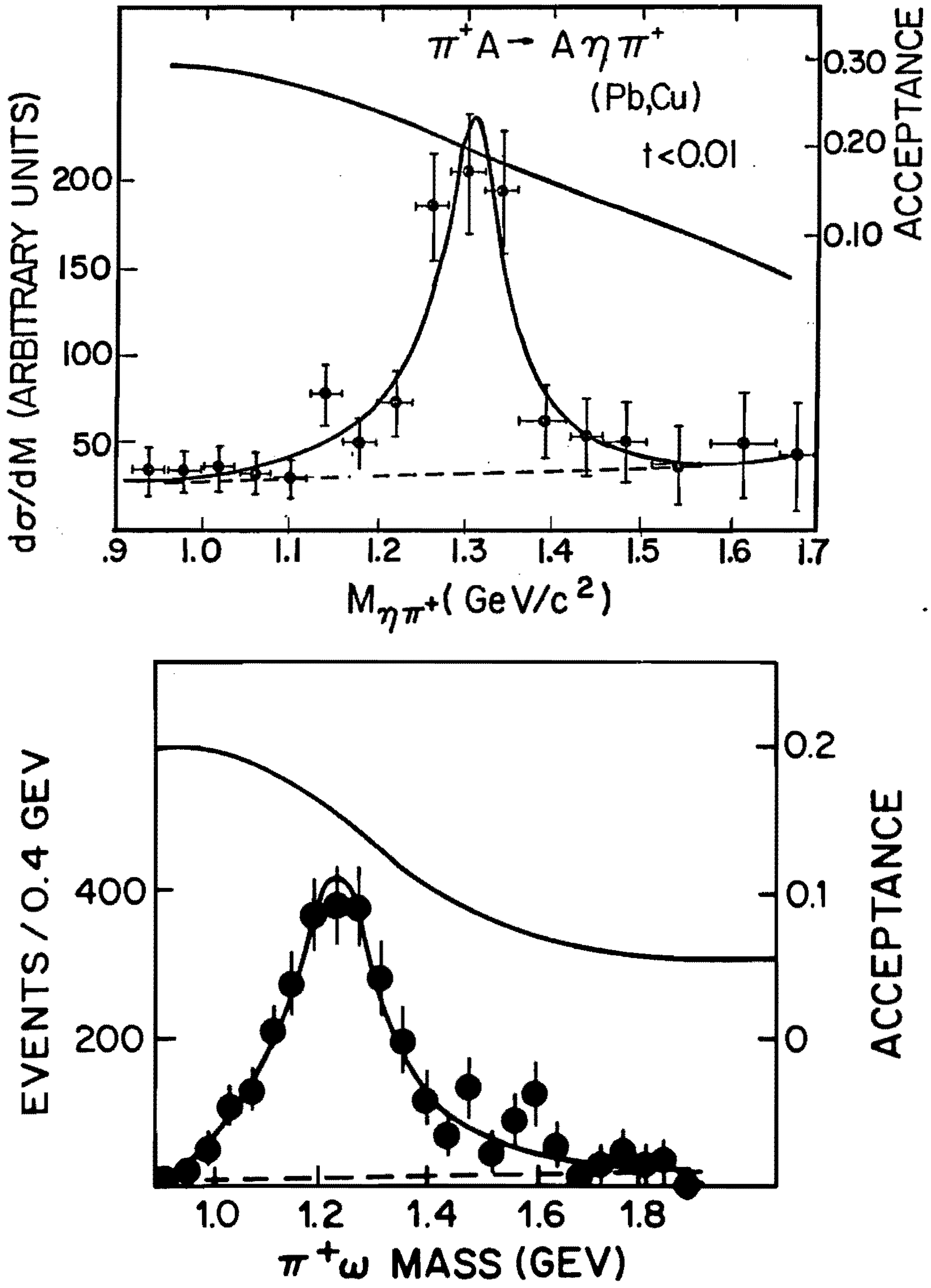

Figure 2: Examples of Primakoff production of $a_2(1320)$ and $b_1(1235)$ from E272[7].

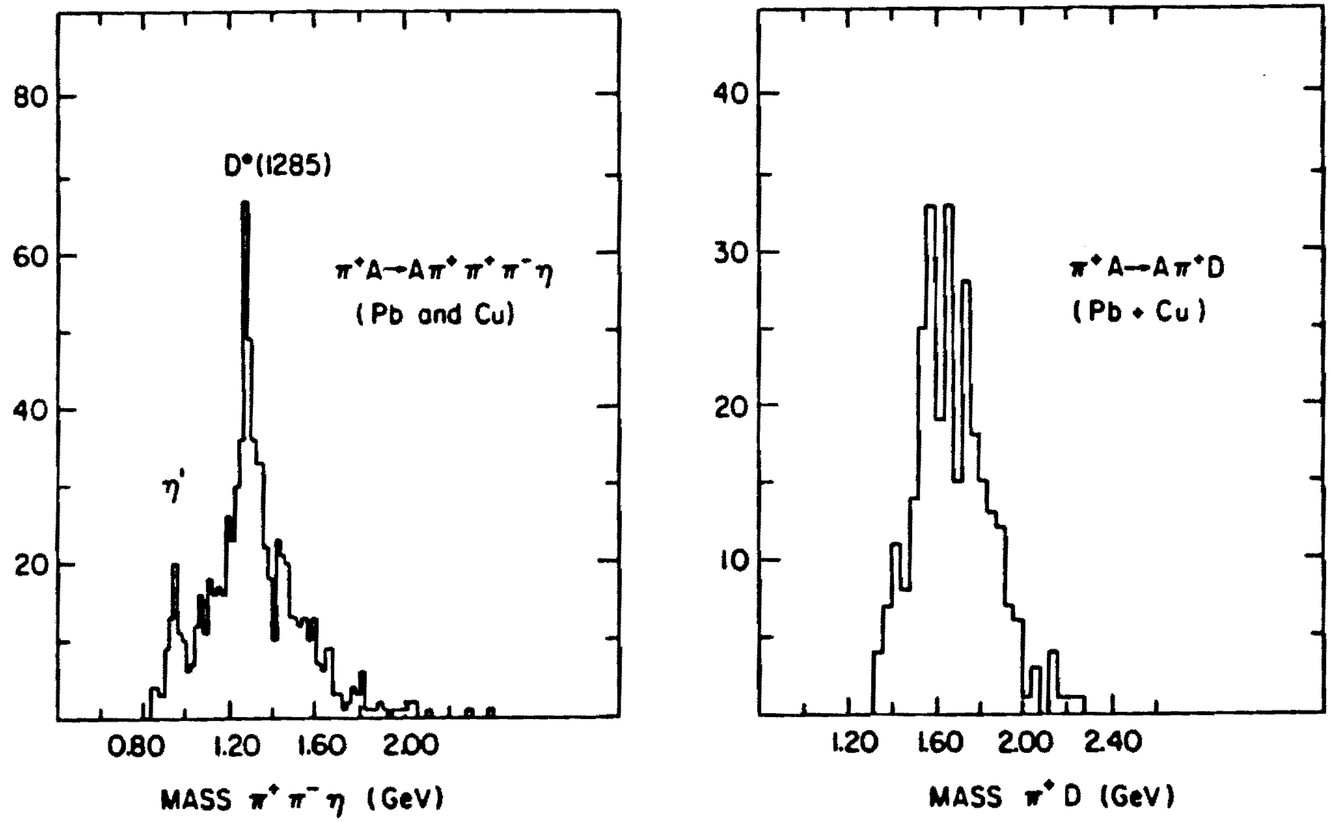

Figure 3. Distributions in $\pi^+\pi^-\eta$ and π^+D mass for coherent production of $\pi^+\pi^+\pi^-\eta$ systems on Pb and Cu targets in $\pi^+ A$ collisions at 200 GeV/c.