411

Proposal to Search for Pion Produced Particles Decaying Under Prompt Emission of One or More Muons

FNAL Proposal #________

(NU Proposal #365A)

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PROPOSAL TO SEARCH FOR PION PRODUCED PARTICLES DECAYING UNDER PROMPT EMISSIONS OF ONE OR MORE MUONS

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Summary

We propose a search for the production of new particles which promptly decay emitting one or more muons. The apparatus for this experiment consists of two spectrometers. One will detect slow recoiling protons. The other will be an iron spectrometer for the measurement of angles and momenta of fast ($p \gtrsim 20$ GeV/c) muons. Among the processes that will be investigated are:

(1) The production of pairs of particles such as charmed mesons, D, produced in reactions $\pi^- + p \to D + \bar{D} + p$ or $\pi^- + p \to D + \bar{D} + \text{hadrons} + p$, where at least one D decays under muon emission.

(2) The production of particles, W^-, produced singly in reactions $\pi^- + p \to W^- + p$ or $\pi^- + p \to W^- + p + \text{hadrons}$, where the W^- decays under muon emission, for example $W \to \mu\nu$ or $W \to \mu X$.

(3) The production of particles, X, produced in reactions $\pi^- + p \to X^- + p$ where the X^- decays under emission of at least one vector meson, V, which in turn decays into a muon pair.

The unique features of the experiment are:

(1) Use of a missing mass technique to obtain the spectrum of masses $D\bar{D}$, $D\bar{D}$ + hadrons, W^-, W + hadrons, or X^-. This technique allows a rapid mass scan, with one apparatus setting, for masses up to ~ 7 GeV, and with good resolution, $\Delta M^2 \sim \pm 1\ \text{GeV}^2$.

(2) Use of a double missing mass technique (muon angles and momenta are measured) to determine the nature of the intermediate state from which the muon (or muons) originate. This permits distinguishing between many very different kinds of new phenomena involving muon emission regardless of detailed production hypotheses.

(3) Excellent sensitivity. Cross sections for the above reactions in the nanobarn region are probed.

(4) Test data exist which have determined background levels and have shown the feasibility of the experiment.

(5) Most of the apparatus exists.

We are requesting 200 hours in a 200 GeV π^- beam with a flux of up to 10^7 π^-/pulse. In addition we need approximately 150 hours of parasitic time for apparatus testing and calibration.

Table of Contents

I) Foreword

This is one of several proposals* addressing themselves to the question of the existence of particles which decay under emission of one or more muons. Common features of these proposals are the use of the same apparatus and the possibility of concurrent running. The physics goals, however, vary.

This program has been submitted previously.** It is resubmitted at the request of FNAL, broken up into several parts.

The technical discussion is abridged in the present document. It is assumed that the reader has access to the earlier material some of which has been reproduced and submitted with the new proposals for ease of reference.

* NU Proposals 365A, 365B, 359D, 359E.

** FNAL Proposal 359, FNAL Proposal 365, Addendum to Proposal 365 of 12/20/74, Progress report and request for additional accelerator time for E365 of 3/18/75.

II. Introduction

This proposal discusses a measurement of reaction

$$\pi^- + p \rightarrow p + n\mu + \text{anything}$$

where n = 1, 2, ... These processes will be detected in an apparatus consisting of two spectrometers. One is a large acceptance spectrometer sensitive to slow recoiling protons emitted at large angles. The other is an iron spectrometer which detects fast ($p_\mu \geq 20$ GeV/c) muons emitted in the forward direction ($\Delta\theta \sim \pm 50$ mr).

The proposed measurement provides a novel method to search for new phenomena associated with the production of muons. Its scope is very general, based on kinematical requirements and the fact that direct muon production exists, rather than special models which usually inspire search experiments. Specifically, the experiment is capable of detecting: charmed particles, heavy leptons, vector bosons, etc.

Additional unique features of this experiment are:

(1) Capability to accept very high beam rates (up to 10^7 pions/pulse).

(2) Excellent sensitivity (nanobarn region).

(3) Capability to use various incident particles ($\pi^\pm$, $K^\pm$, $p^\pm$. See also Proposal NU365B).

(4) Test data exist. Their results are discussed in Section V.

III. The Technique

In previous communications with FNAL and PAC we have discussed, at great length, the physics we are pursuing. We will not repeat the discussion here. Rather we will briefly describe three types of reactions that are probed by the experiment. These examples will exhibit the special features of our technique.

(1) The first type of particle, which we call W^-, is one which can be produced single in reactions

$$\pi^- p \rightarrow W^- p, \quad W^- \searrow \mu\nu, \text{ or more general } \mu + \text{anything} \tag{1}$$

or

$$\pi^- p \rightarrow W^- hp, \quad W^- \searrow \mu + \text{anything} \tag{2}$$

(Here h stands for one or more hadrons.) The signature for reactions (1) and (2) will be a recoil proton in coincidence with the μ from the W decay. The missing mass spectrum from the inclusive reaction

$$\pi^- p \rightarrow X^- p \tag{3}$$

will show a peak at $M_{X^-} = M_{W^-}$ from reaction (1) for events in which a forward μ is detected in coincidence with the recoil proton. The sensitivity of the experiment, compared to a simple missing mass experiment, is increased by at least a factor of about 10^4 (see E365 material) by requiring the forward muon. Thus, an object with width comparable to the resolution ($\delta M^2 \approx \pm 1$ GeV^2) and $\sigma B = 7$ nb will be observed as a 5 standard deviation effect.

Moreover, measurement of muon momentum and angle in the reaction determines a second missing mass, M'_X, of objects recoiling against the $p\mu$ system. For example, the decay $W \rightarrow \mu\nu$ results in $M'_X = 0$. Background, on the other hand, such as a π decay, almost always results in a second missing mass only slightly smaller than the first missing mass.

Reaction (2) may not give a peak in the X^- missing mass spectrum, but it also will not give μp coincidence events for $M_{X^-} < M_{W^-}$. It should therefore show up as an onset of events with $M_{X^-} > M_{W^-}$. This threshold effect should be wider than a peak produced by reaction 1.

(2) The second kind of particle which we call T^-, is produced singly in the reaction

$$\pi^- p \rightarrow T^- p \qquad (4)$$
$$T^- \rightarrow H^- V^o$$
$$V^o \rightarrow \mu^+ \mu^-$$

T decays into a bound state H^- and a meson V^o which in turn decays into two μ's. Again, the double missing mass technique will be used to measure the H^- mass, with the V^o mass also determined.

(3) The third type of particle, D, is produced in pairs. Charmed mesons are the most obvious candidates. They may be produced in reactions

$$\pi^- p \rightarrow D\bar{D}p \rightarrow \mu + \text{anything} + p \qquad (5)$$

$$\rightarrow 2\mu + \text{anything} + p \qquad (6)$$

or

$$\pi^- p \rightarrow D\bar{D}\ H\ p \rightarrow \mu + \text{anything} + p \qquad (7)$$

$$\rightarrow 2\mu + \text{anything} + p \qquad (8)$$

Here either one or both charmed mesons decay leptonically or semileptonically.

Usually one thinks of the missing mass technique as being used to measure only particles produced in a two body final state such as reactions (1) and (2) discussed previously. However, the missing mass technique is also well suited for detecing pairs of particles produced in reactions (5) through (8). One expects that the missing mass spectrum from these reactions will contain a narrow peak at $\sim 2M_D$. This expectation is based on the emperical observation that in many reactions such as

$$\pi^- p \rightarrow \rho\ x\ p$$

and

$$\pi^- p \rightarrow K_S^o X\ p$$

There is a large peak in the missing mass spectrum at the lowest kinematically allowed mass region. If the only source of direct muon production were from reactions (5) through (8) the missing mass spectrum taken with one or more μ's in coincidence with the recoil proton would be extremely clean, i.e. no events at all below the $D\bar{D}$ mass threshold $M_X- = 2M_D$ and a dramatic rise above this threhold.

The double missing mass approach yields two important results: for reaction 5, for example/ near threshold the second missing mass M_X' must be larger than $\sqrt{2}\ M_D$. This may be significant to distinguish charmed pair reactions from reactions of type (1) and (2). In addition this leads to an additional factor ~ 3 in background rejection.

Reactions (6) and (8), in which two muons are emitted, while reduced in rate by the muonic branching ratio, will have a background reduced by an additional factor $\gg 10^3$ (see also the discussion in Section V). Therefore, the reduction in background may far exceed the reduction in signal.

IV. Apparatus

The apparatus used in the measurements to date is shown in Fig. 1 which is self explanatory. It is essentially the same one used in E365. For a complete description see the reference material cited in Section I. Changes anticipated for future data taking are slight modifications of the spark chamber arrangement in the region behind the magnetized iron so that the tracking efficiency will be close to 100% and more easily determined.

The apparatus has already been tested in a beam of 10^7 protons per pulse and worked very well. The trigger rate for 10^7 π's per pulse is $\sim$ 10 per pulse. The apparatus is capable of recording $\sim$ 150 events per pulse so that dead time will not be a limitation.

V. Results to Date

E-365 was allowed to accumulate about 30 hours of data with a 200 GeV π^- beam of $\sim 6 \times 10^5$ π's/pulse corresponding to a total π flux of $\sim 10^{10}$. The results of this run are shown in Fig. 2. (For additional details see the reference material cited in Section I). In this plot two enhancements appear. One at low mass and one in the $17 \leq M^2 \leq 21$ GeV^2 region. At present we believe that the broad enhancement in the $0 \leq M^2 \leq 13$ GeV^2 region is due to low mass diffractive production in

$$\pi^- p \rightarrow X^- p \rightarrow \text{(hadrons) } p$$

followed by π and K muonic decays in flight and/or hadrons producing μ's by direct production in the hadron absorber. We are at present still investigating this effect. The enhancement in the $17 \leq M^2 \leq 21$ GeV^2 region, although of limited statistical significance, is very interesting in that it appears most strongly when cuts on the detected μ are made which are expected to be effective in rejecting π and K decay backgrounds. Such a cut rejects little of the signal expected from D^- or W^- type decays.

In the proposed experiment the effect in the $17 \leq M^2 \leq 21$ GeV^2 region is expected to appear as more than a 10 standard deviation effect.

At present we also have detected 4 events from the reaction

$$\pi^- p \rightarrow X^- p \rightarrow \mu\mu\ X' p$$

Two of these events have M_X^2 in the 15 to 20 GeV^2 range. The calculated background from π and K decays and single μ's produced in the beam dump is less than .01 events. In the proposed experiment we expect to accumulate more than 60 of these 2μ events. The 2μ events will be essentially free from backgrounds and will, when combined with the 1μ data, allow a determination of the average semi leptonic branching ratio for the D and $\bar{D}$.

VI. Scheduling, FNAL Requirements

The main physics objective is to collect at least 30 times as much data as is shown in Fig. 2. This would require an integrated π flux of 3×10^{11}. With 5×10^6 π's per pulse and 600 pulses per hour this would require 100 hours. An additional 100 hours will be used for more limited studies at other beam energies (70 hours) and for setup and calibration purposes (30 hours). A flux of 5×10^6 π^-/pulse at 200 GeV can be achieved in the M2 beam line if 10^{13} protons per pulse are supplied to the meson target at 400 GeV.

Consequently we are asking for 200 hours of beam time in the M2 line of the meson laboratory. In addition we would expect approximately 2 weeks of parasitic beam use for timing and similar purposes.

The equipment required from FNAL is identical to that supplied for E365. It includes the existing H_2 target and cooler, and the necessary PREP - electronics.

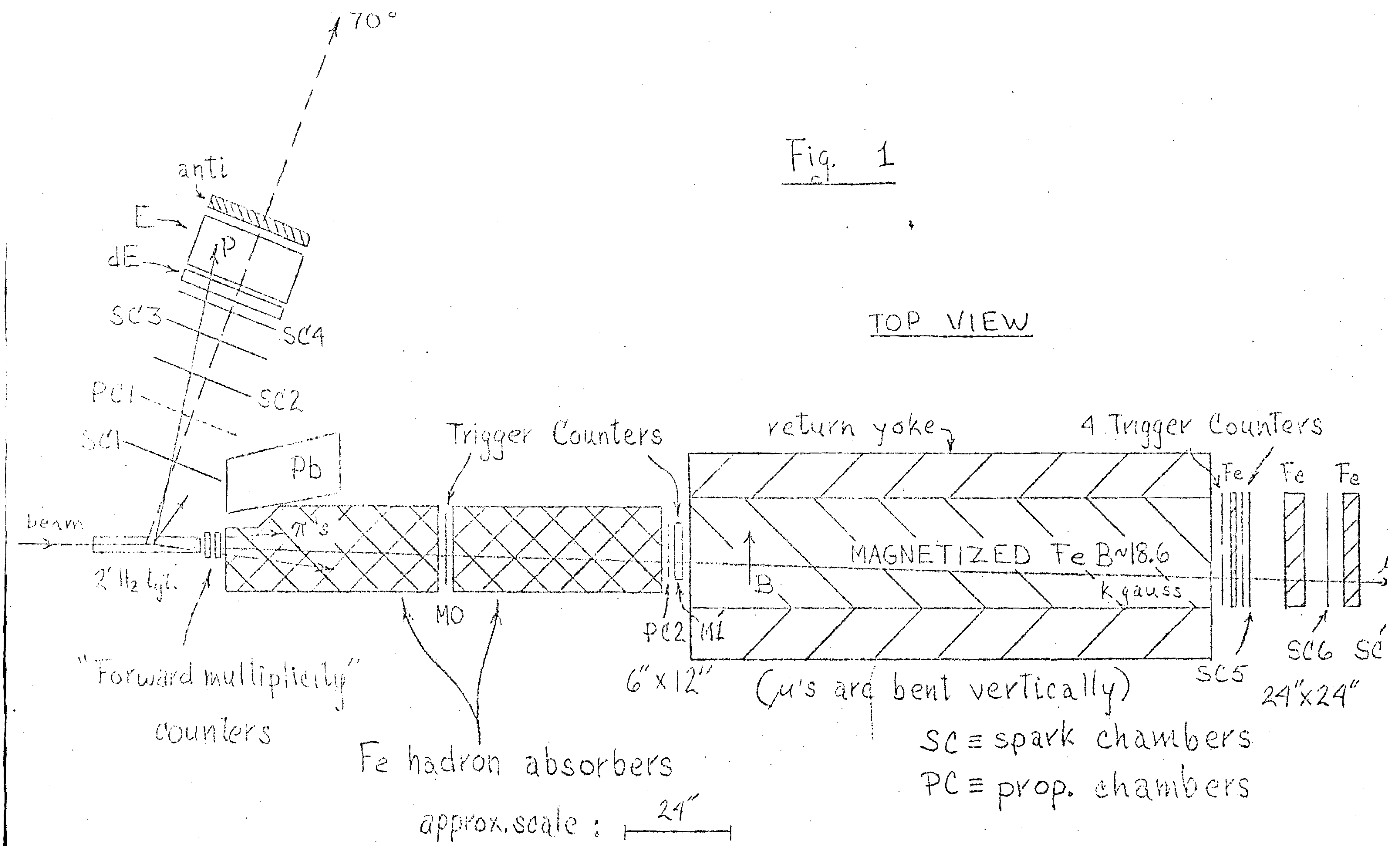
Figure Captions

Fig. 1. Layout of the p and μ detectors.

Fig. 2. Cross section $d\sigma/dtdM_X^2$ for $\pi^- p \to X^- p \to \mu X' p$ vs. M_X^2 for $P_{\perp\mu}^2 \geq .1\ GeV^2$, $16 \leq P_\mu \leq 100$ GeV and $.1 \leq |t_p| < 0.4\ GeV^2$. A 100% μ detection efficiency is assumed. The solid line is drawn as a "guide".

Fig. 1

TOP VIEW



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