PROPOSAL NO. 384

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PROPOSAL TO STUDY π^-p INTERACTIONS AT HIGHEST ENERGY IN THE FERMILAB 15' BUBBLE CHAMBER

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SUMMARY

This is a proposal to study hadronic physics with 300,000 pictures in the Fermilab 15-foot bubble chamber filled with hydrogen and exposed to a π^- beam at the highest practicable energy ($\geq$ 250 GeV). The objectives of the experiment are (i) to search for charm particles, (ii) to investigate cluster formation in events containing more than one strange particle, (iii) to study inclusive production of strange particles, (iv) to study inclusive processes involving photons, and (v) to measure parameters of diffraction dissociation.

Negative pions are chosen because they allow the study of direct meson interactions and secondly because the identification of particles in the final state is easier since the beam does not introduce strangeness or baryon number. The highest energy is desired so as to allow for the highest mass of products.

We expect to analyze the film beginning with a first pass scan for double V events, using the effective mass of the two V's as a "trigger" to reduce background for charmed particles. This process will reduce the amount of measurement and will produce preliminary physics results on the first 3 subjects mentioned above in about six months from the conclusion of the run. The second pass scan will concentrate on finding four-prongs and six-prongs, measuring them on an automatic device and getting preliminary physics results in about a year. The full extent of the experiment will take 2 - 3 years.

PHYSICS JUSTIFICATION

The Fermilab 15-foot bubble chamber is a unique particle detector. Its large volume coupled with 4π solid angle detection makes it an excellent piece of apparatus for studying strange particles and neutral pions. The physics that we are proposing utilizes these characteristics. As outlined in the summary we have five principal areas of interest.

(i) Search for Charm Particles

Theoretical developments[1] both in the study of spontaneously broken gauge theories and in the experimental observation[2] of neutral currents point in the direction of a unified, renormalizable theory of weak interactions. However, in order to accomodate the absence of a strangeness-changing neutral current without conflicting with such a beautiful theory, some new degrees of freedom have to be introduced. One possibility involves a fourth "charm" quark,[3] implying the existence of a new spectrum of hadron states of non-zero charm quantum numbers. The discovery of the ψ(J) also stimulates the search for charm since it could be the charm quark-anti charm quark state.[4]

Charm was first proposed in 1964 for symmetry reasons.[3] To the SU(3) group of quarks u, d, and s, was added the c quark forming a basic SU(4) representation. In such a scheme these four quarks correspond to the four observed leptons in weak interactions. In most models of charm there are many "charmed" particles, mesons and baryons, with a lifetime of $\lesssim 10^{-13}$ seconds and mass between 2 and 10 GeV.[5] The existence of these particles may be indicated for instance by the observation of narrow peaks in mass spectra of hadrons involving a strange particle or new long lived particles. Table I lists some charm states as predicted in the model by Gaillard, Lee and Rosner.[5]

Our method of search can be discussed in two parts: (a) if the lifetime $\tau > 10^{-13}$ seconds and (b) if $\tau < 10^{-13}$ seconds.

For part (a) with $\tau > 10^{-13}$ seconds one might expect to see D^0's move away from the production vertex before decaying. We believe that this part of the search is less likely to yield anything significant because earlier 30" bubble chamber experiments have not reported such events.

For part (b) with $\tau < 10^{-13}$ our approach is to isolate those events with observed double strangeness. We will measure and fit these V's to locate the K's and Λ's. The $K\bar{K}$, $K\Lambda$, $\Lambda\bar{\Lambda}$, etc., events which are produced with effective mass within a few hundred MeV of threshold will be assumed to be normal associated production of a small cluster of strangeness and consequently not to involve charm. We assume that charm-anticharm decay would give a large effective mass for the strange antistrange system since charm involves masses above 2 GeV. Figure 1 shows data from 205 GeV/c π^- interactions in the 30" bubble chamber. All 23 double strangeness events found were within 600 MeV of threshold. Figures 2, 3 and 4 give the inclusive production cross section for K_s^0, Λ and $\bar{\Lambda}$ in the 30" 205 GeV π^- experiment. In the 15' bubble chamber higher values (higher momentum) can be observed. From these data we believe that our "trigger", that is effective strange-antistrange particle mass more than

Charmed 0^- Mesons

$C = 1$	D^+	$c\bar{d}$	$T=\frac{1}{2}, T_z=\begin{cases}\frac{1}{2}\\ -\frac{1}{2}\end{cases}$	;	$S = 0$
	D^0	$c\bar{u}$			
	F^+	$c\bar{s}$	$T = 0$	;	$S = +1$

Charmed 1^- Mesons

$C = 1$	D^{*+}
	D^{*0}
	F^{*+}

Charmed $1/2^+$ Baryon States

	Label	Quark Content	Isospin	Strangeness
$C = 1$	C_1^{++}	cuu	$T = 1,\ T_z = \begin{cases}1\\0\\-1\end{cases}$	$S = 0$
	C_1^+	$c(ud)_{sym}$		
	C_1^0	cdd		
	C_0^+	$c(ud)_{anti}$	$T = 0$	0
	S^+	$c(su)_{sym}$	$T = \frac{1}{2},\ T_z = \begin{cases}\frac{1}{2}\\ -\frac{1}{2}\end{cases}$	-1
	S^0	$c(sd)_{sym}$		
	A^+	$c(su)_{anti}$	$T = \frac{1}{2},\ T_z = \begin{cases}\frac{1}{2}\\ -\frac{1}{2}\end{cases}$	-1
	A^0	$c(sd)_{anti}$		
	T^0	css	$T = 0$	-2
$C = 2$	X_u^{++}	ccu	$T = \frac{1}{2},\ T_z = \begin{cases}\frac{1}{2}\\ -\frac{1}{2}\end{cases}$	0
	X_d^+	ccd		
	X_s^+	ccs	$T = 0$	-1

Table I

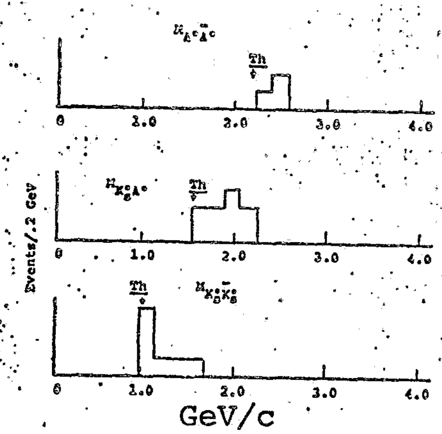

Figure 1. Effective masses of strange-antistrange particles from Experiment #137, 205 GeV/c π^-p.

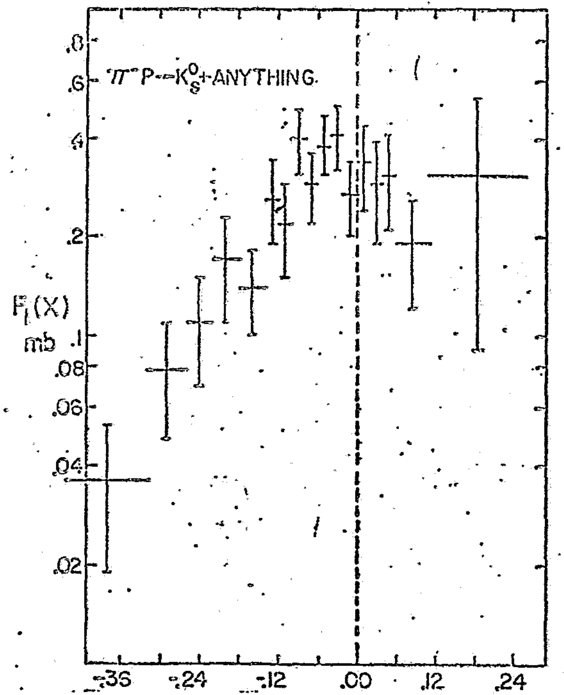

Fig. 2 Inclusive K^0_s production in 205 GeV/c π^- interactions.

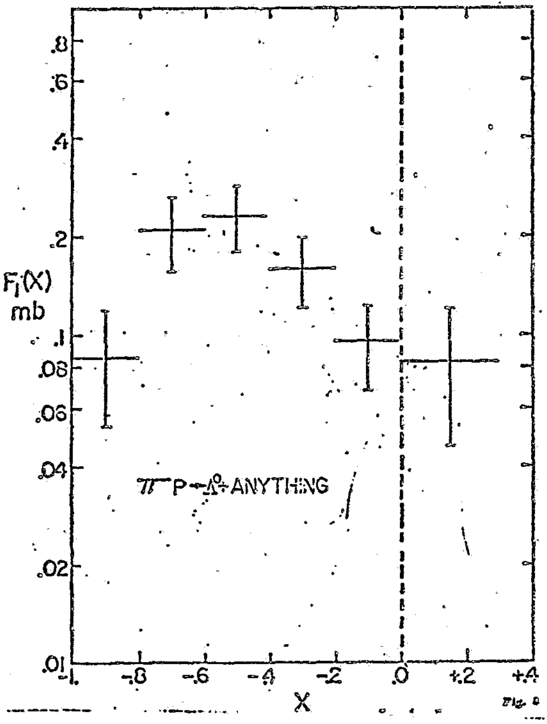

Fig. 3 Inclusive Λ production in 205 GeV/c π^- interactions.

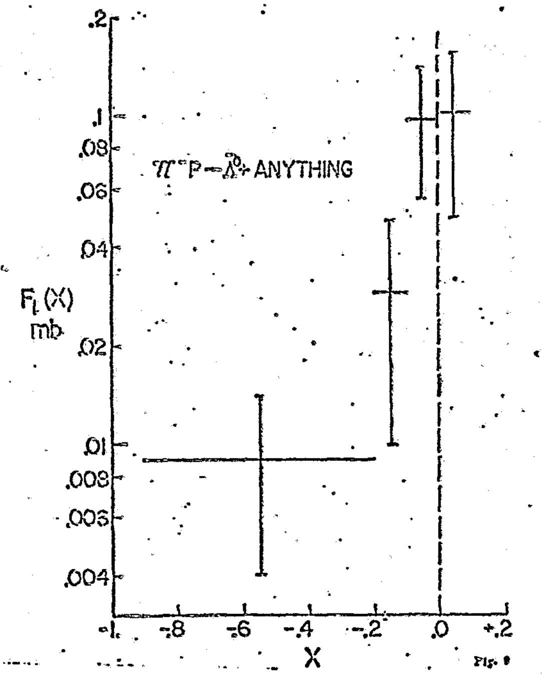

Fig. 4. Inclusive $\bar{\Lambda}$ production in 205 GeV/c π^- interactions.

a few hundred MeV above threshold, will reduce the large number of possible mass combinations ($K\pi$, $K\pi\pi$, ..., $\Lambda\pi$, $\Lambda\pi\pi$, etc.) coming from normal associated production and thus improve the signal to noise by an order of magnitude. For example double arm counter experiments looking at $K\pi$ necessarily have a very large background of normal associated production events. The < 10% double strangeness events remaining in our experiment will be studied in detail for charm.

We note that with the bubble chamber we can "see" many of the possible decay modes for charm. Some representative charmed particle production reactions which would fall into this search system would be:[5]

(1) Fragmentation of the proton vertex:

$$p \rightarrow D^-(C_0^{+}\pi^+) \rightarrow (\pi^-K^0) \begin{Bmatrix} \pi^+\Lambda \\ \bar{K}^0 p \end{Bmatrix} \pi^+$$

$$\rightarrow D^- C_0^{++} \quad (\pi^-K^0) \quad (D^+n)\pi^+ \rightarrow (\pi^-K^0) \quad (\pi^+\bar{K}^0 n)\pi^+$$

$$\rightarrow D^-D^+p \qquad (\pi^-K^0) \quad (\pi^+\bar{K}^0)p$$

(2) Central region:

$$\pi^-p \rightarrow D^+D^- \rightarrow (\pi^+\bar{K}^0) \quad (\pi^-K^0)$$

$$\rightarrow C_0^{+}C_0^{-} \rightarrow \begin{Bmatrix} \pi^+\Lambda \\ \bar{K}^0 p \end{Bmatrix} \begin{Bmatrix} \pi^-\bar{\Lambda} \\ K^0\bar{p} \end{Bmatrix}$$

(3) Fragmentation of the π^- vertex:

$$\pi^- \to D^+ D^- \pi^- \to (\pi^+ \bar{K}^0)\ (\pi^- K^0)\pi^-$$

Of course many effective mass combinations may be consistent with a single charmed meson or baryon and these will also be studied. The reactions given above will allow the discovery of two of them in the same reaction.

The proposed experiment (with 200,000 interactions in the fiducial volume) is sensitive at the level of 8 evts/μb or to a few μbarn for charm when branching ratios and effeciencies are considered. Some theoretical models predict cross-sections of about this size.[6]

(ii) Cluster Formation in Events Involving Strange Particles

A systematic study of the correlations between particles produced in the final states of high energy hadron collisions may provide important information for the understanding of the dynamics of hadron interactions. For instance, various clustering effects were observed in correlation measurements at CERN-ISR[7,8] and Fermilab.[9] These experiments show that the observation of one particle makes it more probable to find another one in the same region of phase space than would be expected from measured single-particle yields. A tentative conclusion from these results has been that clusters of particles are produced, with energies of a few GeV and zero for most of the quantum numbers. If this conclusion is correct, then such clusters can be studied very effectively in the 15' bubble chamber. It is not clear whether the observed clustering effects are due to the production and decay of well-defined objects or are merely a kind of phenomenological description of the production mechanism.

If we define a cluster containing heavy particles (kaons, hyperons, and their antiparticles) as a heavy cluster, it was suggested[10] that by studying the formation, decay, and the associated pion multiplicity of heavy clusters, one may find qualitative answers to the following problems. The argument is that if clusters are indeed well-defined objects, one expects that their formation and decay properties are independent of each other, or that some factorization property holds. Thus one may investigate in particular: (i) the short range correlation among heavy particles from the decay of the same cluster and also long range correlations among them from different clusters, (ii) the correlation length, the decay isotropy of the heavy clusters, (iii) the flow of conserved quantum numbers in phase space, and (iv) the associated pion multiplicities. This kind of analysis can be done with the 15' bubble chamber at FNAL. (For pp collisions, such an analysis may also be done with the split-field-magnet system at CERN-ISR).

(iii) Inclusive Strange Particle Production

Inclusive strange particle distributions will be automatic from the two studies mentioned above. Apart from obtaining reasonably unbiased inclusive K_s, Λ, and $\bar{\Lambda}$ distributions, we can investigate in detail any anomalies found in these distributions. The strange particle production vs. multiplicity can also be studied. We expect of the order of 30,000 events in this category.

One of the crucial tests to Muller-Regge theory is the validity of factorization, that is the independence of secondary spectra from the identity of the incident projectile. For instance, the inclusive spectrum

$\frac{1}{\sigma}\frac{d\sigma_a}{dy_a}$ obtained from $\pi^- p \rightarrow a$ + anything, can be compared with those obtainable from $pp \rightarrow a$ + anything for $a = \pi^o$, K_s^o, Λ^o, etc.

(iv) Inclusive Photon Production

The mean conversion probability for $\gamma \rightarrow e^+e^-$ in the 15' bubble chamber is .15 and thus .0225 for converting both photons from a π^o. With this conversion probability we can determine to a much better accuracy the π^o production vs. charged multiplicity.[11] At present there appear to be roughly equal numbers of π^-, π^+ and π^o in each event. This can be studied in much more detail. The various moments of the π^o multiplicity can be measured also. It is not necessary to measure the full sample of film for this study.

(v) Diffraction Dissociation

Since the 15' bubble chamber provides a large potential length for the recoil protons to stop and for the strange particles to decay, it results in two unique features for the study of pion excitation.

(1) Observation of a stopping recoil proton yields a better

measurement on the values of M, hence it provides better data for the Triple-Regge limit analysis of the pion excitation.

(2) Observation of strange particles in the forward jet in association with a stopping recoil proton provides us a chance to study the dynamics of the fragmentation of the excited pion, e.g. we may ask whether the excited pion fragments into clusters, resonances, or merely into completely uncorrelated particles. We can also study the nature of quantum number conservation among clusters. Figure 5 shows the data from the 205 GeV/c $\pi^- p$ experiment in the 30" bubble chamber.[12]

In addition we hope to measure on SAMM and PEPR all 4 and 6 prong events with a stopping proton but no associated gammas or V's to obtain the two channels:

(a) $\pi^- p \rightarrow \pi^- \pi^+ \pi^- p$

(b) $\rightarrow \pi^- \pi^+ \pi^- \pi^+ \pi^- p$

We believe these channels will be dominated by diffraction dissociation. We can provide information on the position and width of the A_1 and study its production mechanism vs. energy. This will also give a clean sample of 5 pion dissociation.

Experimental Conditions

In this section we describe our requirements for the beam and bubble chamber operating conditions.

(i) Beam

We would like a 250 GeV or greater, π^- beam with approximately four tracks per photo. In order to ensure an approximately constant beam intensity the "Walker Kicker Magnet" should be present. Also we would like to use the N-5 Cerenkov counter and proportional wire chamber tagging system to ensure that our beam tracks have not previously scattered and that our K^- and $\bar{p}$ contamination is identified.

(ii) Bubble Chamber

We request the "bare" 15-foot chamber filled with H_2. We would like to run the chamber at full magnetic field (30 Kg) in order to reduce our experimental errors. We expect measurement errors to be the order of 300μ. Since we wish to measure this film with automatic measuring devices (SAMM or PEPR) it will be necessary both to delay the flash about 5 - 6 msec. to allow the bubbles to grow sufficiently and to monitor the details of film quality very closely. Because we are proposing a high statistics experiment, multipulsing the chamber may be desirable provided acceptable picture quality can be obtained on pulses after the first one.

(iii) Scope of the Experiment

(1) Projected Number of Events

We are requesting 300,000 pictures from the 15' hydrogen bubble chamber. Assuming 4 beam tracks per picture, and that the π^-p cross-section at 350 GeV/c is ~ 24mb we expect a total of ~ 200,000 primary interactions to take place in our fiducial volume, yielding an experimental size of 8 events per μb. We expect these events to be divided as follows:

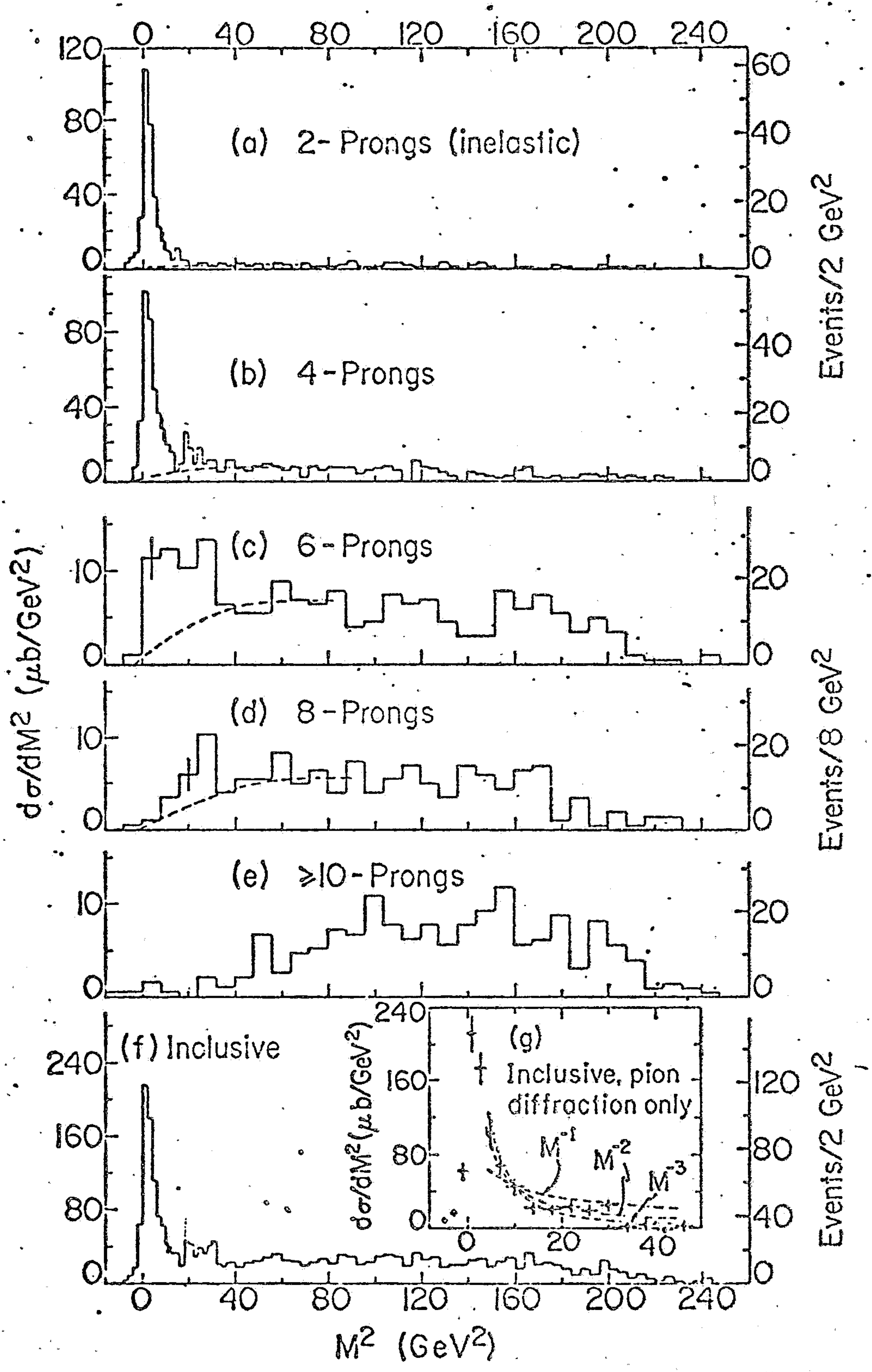

Fig. 5

Missing mass in $\pi^-+p\to p+M$ in Experiment #137, 205 GeV/cπ^-p.

(a) Events with no γ-conversion or visible neutral strangeness = 70,000

(b) Events with obvious e^+e^- pairs only= 35,000

(c) Events with at least one possible candidate for neutral strangeness = 95,000

200,000

(d) Events with at least two possible candidates for neutral strange particles = 35,000

(e) Events with two or more definite neutral strange particles = 4,000

(f) Events with an identified proton (either stopping or by ionization = 45,000

(g) Events with 4 and 6 prongs but no γ or neutral decays = 25,000

These projections are based on data from the 250 GeV/c π^- engineering exposure in the 15' chamber.

(2) Analysis Procedure

An initial scanning pass will look only for the major interaction vertex and all V's (strange neutral decays) and A's (neutral decays ambiguous between V's and gamma's). A small sample of film will also be scanned for G (gamma rays). We estimate that this scan will take 10 machine years (about 8 months if each lab contributes 5 scanning shifts per day). A first measurement pass will concentrate on events with at least two possible strange particle candidates (category d). The estimated measuring time is 9 machine years (about 8 months). Preliminary results on charm and heavy clusters can be obtained during the analysis by measuring the 4,000 unambiguous double V events (category e).

The second pass will search for four and six-prong events without γ or V's. (25,000 expected) and events with an identifiable proton (45,000 expected) which will take about 5 machine years or about 4 months. Predigitizing the four and six-prong events for the SAMM and PEPR and measurement of identified protons could be done during this pass, for which the time is estimated to be about 10 machine years (8 months).

(3) Measuring and Scanning Equipment:

At Fermilab large magnification (60x) MOMM scanning-measuring machines will be available for use on this film plus Micrometrics with magnification 25x. At FSU three Micrometric-type scanning-measuring machines will be assigned to this experiment. These machines, currently being used on 15-foot chamber film with a maximum magnification of 25x, will be converted to 60x by the time the film from this experiment is available. At the University of Maryland three Micrometric scanning-measuring machines will be available. In addition, the semi-automatic measuring machine SAMM at Fermilab and PEPR at the University of Maryland will be used to automatically measure four and six prong events.

(4) Staff:

This experiment is to be performed as a collaboration between Fermilab, the Florida State University, and the University of Maryland. Of the physicists listed on the cover page of this proposal, this will be the major experimental effort of at least eight of them. There will also be at least two graduate students who will devote most of their efforts to this experiment. Each laboratory will provide at least 5 FTE scanner-measurers.

FOOTNOTES AND REFERENCES

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