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Scientific Spokesman:

R. M. Edelstein
Department of Physics
Carnegie-Mellon University
Pittsburgh, Pennsylvania 15213

FTS/Off-net: 412 - 644-3311
621-2600

# HADRONIC INTERACTIONS IN COMPLEX NUCLEI

R. M. Edelstein
D. R. Green
H. J. Halpern
J. S. Russ

Carnegie-Mellon University
Pittsburgh, Pennsylvania 15213

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Experimental Proposal to

Fermi National Accelerator Laboratory

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## Summary

We propose to study several types of hadronic interactions in complex nuclei using the Multiparticle Spectrometer Facility in M6 West at FNAL. Broadly speaking, these experiments are for the purpose of learning about the following:

A) Diffraction dissociation, through the use of the unique filter of coherent hadron dissociation.

B) The interaction of high energy hadronic systems in nuclear matter, including production, absorption, and cascade.

C) Manifestly incoherent beam dissociation reactions such as those with charge exchange.

D) Details of nuclear models for coherent and incoherent scattering.

The MPS facility is a magnetic spectrometer with proportional wire chambers, wire spark chambers and Cerenkov counters for particle detection. It will be used first to perform approved experiment E110/260. We propose this experiment for a time when it is expected that the spectrometer as well as beam detection equipment will be functioning. Modest revisions of the apparatus are required in the form of Pb-Scintillator sandwich counters 1) downstream of the spectrometer for $\pi^0$ detection and 2) surrounding the target for $\pi^0$ and nuclear breakup detection.

For running time we request

800 hours data taking
200 hours testing.

A minimum of 6 calendar months is needed for setting up, testing and running.

# HADRONIC INTERACTIONS IN COMPLEX NUCLEI

## I. Introduction

We propose to study several types of hadronic interactions in complex nuclei using the Multiparticle Spectrometer Facility in M6 West at FNAL. Broadly speaking, these experiments are for the purpose of learning about the following:

A) Diffraction dissociation, through the use of the unique filter of coherent hadron dissociation.

B) The interaction of high energy hadronic systems in nuclear matter, including production, absorption, and cascade.

C) Manifestly incoherent beam dissociation reactions such as those with charge exchange.

D) Details of nuclear models for coherent and incoherent scattering.

Our interest in this work derives in part from earlier experiments we have done at the AGS in which 1) diffraction dissociation was first observed[1,2,3] in the reactions $B+p \to B+\rho\lambda^*$ (where $B=p$, $\pi^-$, $K^-$, $\bar{p}$), and 2) high statistics investigations were made[4,5] of the coherent dissociation reactions $p+A \to (p\pi^+\pi^-)+A$, $p+A \to (p\pi^0)+A$ and $\pi^\mp + A \to (\pi^+\pi^-\pi^\mp)+A$, where A represents a nuclear target.

### A. Coherent Diffraction Dissociation

1. Importance of the coherent filter. In the process

$$\text{hadron} + A \to \text{hadron system} + A,$$

wherein the nuclear target A remains in its ground state, the diffraction dissociation reaction (Pomeranchuk exchange) is enhanced at small momentum

transfer relative to other exchange processes because of the following:

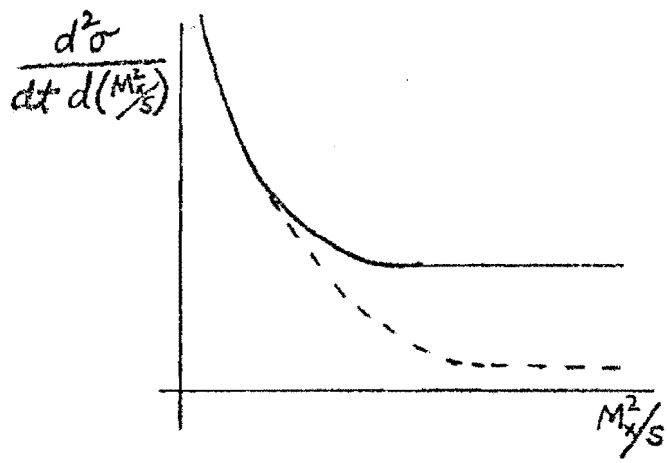
1) I spin exchange is either greatly reduced or, when I=0 for the nucleus, strictly forbidden (except for Coulomb effects).

2) For analogous reasons, in that nuclear ground state spins are small or zero and also because the coherence condition restricts scattering to small momentum transfer, the non-flip amplitude is greatly enhanced relative to spin flip amplitude (referring to the nuclear vertex).

One can readily understand the importance of this filtering, in spite of working at very high energies, in terms of the following plot. Here we show qualitatively the invariant cross section at small fixed t for the inclusive reaction

$$a+b \rightarrow x+b$$

plotted against the scaling variable $M_x^2/s$.




It has recently been shown[6,7] that Feynman scaling is approximately correct for small t and $M^2/s \lesssim 0.2$. (Note that for all our discussions s is computed for the beam-nucleon system, not beam-nucleus).

Therefore, such a curve remains essentially fixed independent of s. Its shape depends on the values $\alpha_i(t)$ appropriate to the trajectories which are exchanged.[8] The case shown here for $t \approx 0$ is an incoherent sum of Pomeronchuk exchange, $\alpha(0)=1$, amd normal Regge exchange, $\alpha(0) \approx 0.5$, which yield $(M^2/s)^{-1}$ and $(M^2/s)^0$ dependence, respectively. (Lower lying trajectories give contributions which rise with $M^2/s$). The dashed curve represents the effect of imposing the coherence condition in order to reduce non-Pomeron exchange. (The curve is normalized to give the same diffractive component.) <u>It is clear that independent of energy one is now able to study diffraction dissociation relatively free of non-diffractive background over a broader range of values for $(M^2/s)$ than is possible in scattering off protons</u>.

2. <u>Features of Diffraction Dissociation to be studied</u>. The coherent dissociation channels which will be stressed in this experiment are

$$p+A \rightarrow p\pi^+\pi^- +A$$
$$p2\pi^+2\pi^- +A$$
$$p3\pi^+3\pi^- +A$$
$$\text{etc.}$$

$$\text{and } \pi^-+A \rightarrow \pi^-\pi^+\pi^- +A$$
$$\pi^-2\pi^+2\pi^- +A$$
$$\pi^-3\pi^+3\pi^- +A$$

Similar reactions involving lower flux beams of $K^-$, $\pi^+$, and $\bar{p}$ will be studied less extensively in order to extend the range of dissociating particle type,

thus testing for factorization or possible differences in the dissociated systems, and to compare particle/antiparticle reactions. There are no plans at present to measure neutral dissociation products with high precision. (There will be crude neutral detection as discussed later). However, such a capability would enhance this experiment and would be used if it existed at the time of the experiment. We will investigate the possibility of contributing to the development of such a capability.

There are a number of features of the coherently produced diffractive signal which we want to study:

1) Mass spectra for low multiplicity. As in the past one is still interested in studying the diffractive mass spectra for enhancements and possible resonances. So far the gross features of these spectra from nuclear target work have been relatively dull. In $\pi^- \to (3\pi)^-$ one has seen the broad $A_1$ enhancement,[9,5] and in $\mathcal{N} \to \mathcal{N}\pi$, $\mathcal{N}\pi\pi$ one has seen both the broad enhancement at ~1410 MeV (lower for $\mathcal{N}\pi$ and higher for $\mathcal{N}\pi\pi$), and as well, an amount of coherent $\mathcal{N}^*(1690)$ production.[10] Future bump hunting if fruitful at all will likely be more so in the lower multiplicity channels.

2) Partial Wave Analyses. Analyses such as the Illinois scheme are a very important tool in probing the substructure of low multiplicity systems. Our data on $\pi \to 3\pi$ are being studied with this technique,[4] and it has been shown that the $(3\pi)^-$ signal includes a substantial amount of $A_2$ production which may very well be due to Pomeranchuk exchange. If true this would violate the simple orbital angular momentum exchange rule

$\Delta\pi = (-1)^J$. It will be very interesting to do these analyses for higher energy data in order to decide whether $A_2$ production follows the same energy dependence as other diffractive signals or if, for example, it is due to $f^o$ exchange. More generally one wants to study the energy dependence of other partial waves as well. Also, hopefully, similar analyses will be done on the $p\pi^+\pi^-$ system.

3) Mass spectra and multiplicities. As noted earlier, it has recently been shown at NAL with fairly good precision that the inclusive diffractive signal scales. Specifically, for the reaction $p+d \rightarrow x+d$ it was found that

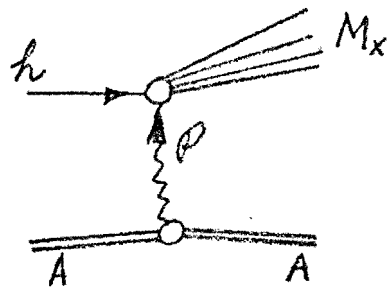
$$\int \frac{d^2\sigma}{dt\ d(M_x^2/s)}\ dt = f(M_x^2/s) \quad .$$

Furthermore, the data are reasonably well fit by the function

$$f(M^2/s) \propto (M^2/s)^{-1}$$

Cast in terms of the triple Regge model, such behavior shows that the triple Pomeron vertex dominates in inelastic diffraction scattering. This discovery represents a very significant advancement in our understanding of diffraction dissociation. In our experiment we expect to be able to check their result with much higher statistics and in a way which is essentially free of nuclear form factor effects. The logical next step is to study the details of the forward system: (a) the mass dependence of the particle multiplicities, (b) the submasses present such as $\rho^o$ or $\Delta^{++}$, (c) rapidity distributions and possible correlations, and (d) decay angular distributions.

Note that for best understanding of these data in terms of hadron-nucleon scattering one will want to concentrate on the light nuclear targets to stay relatively free of nuclear rescattering questions. From a simple Pomeron exchange picture as in the figure below, one will be studying the charged particle multiplicities in Pomeron-nucleon scattering at center of mass energy $M_x$.




Recent bubble chamber evidence from NAL shows the charged particle multiplicity for the diffracted hadron to be similar to that observed in hadron-p scattering at similar center of mass energies.

It is important to note that since the coherence condition limits the data to small $t$ and since $t_{min} \approx (M_x^2/s)^2\, m_\rho^2$, the accessible mass range is limited. For example, considering the form factor for carbon, $t_{min} \leq .04\,(\mathrm{GeV}/c)^2$, $M_x^2/s \leq 0.2$ and, therefore, at 200 GeV $M_x \lesssim 9$ GeV. Nevertheless, observe that this value of $M_x^2/s$ is much larger than the value $M_x^2/s < 0.1$ which can be comfortably studied in hadron-proton scattering.

It should also be emphasized that the multiplicity distributions discussed here are <u>exclusive</u> charged particle distributions and not <u>inclusive</u> as is more familiar. This is because extra <u>non-observed</u> neutrals would destroy the coherence condition.

4) Dissociation of different projectiles. It should be re-emphasized that the use of several beams in this experiment allows one to compare particle/antiparticle behavior and to test for factorization. It is as important to study the diffractive signal for several particle beams, employing all the techniques we have discussed, as it is to measure the corresponding total and elastic cross sections.

## B. Hadron-Nucleus Interactions

1. Total cross sections for hadron systems on nucleons. Nuclear targets provide a unique opportunity to study the interaction of unstable particles with nucleons. Among other studies total cross sections have been measured for $(3\pi)^-\mathcal{N}$, $(5\pi)^-\mathcal{N}$, $(p\pi^+\pi^-)\mathcal{N}$, and $(p\bar{\pi})\mathcal{N}$ scattering[5,9,10] through comparison of the nuclear target yields to a Glauber model with nuclear absorption. Remarkably the cross sections for a multiparticle system on a nucleon are much smaller than anticipated, and for the most part are very similar to the cross sections of the parent particles. This has been interpreted as possibly due to continued coherence of the hadron system after production. These cross sections can be calculated through comparison of nuclear models to both coherent production data and incoherent data. By this means one will be able to measure absorption cross sections as a function of various kinematic variables, most particularly $M_x$ and multiplicity. Since the interaction of the hadron system and subsequent nuclear hadrons is also part of the picture of diffraction scattering, the reabsorption cross section is a very important element in our understanding

of this process.

While the foregoing discussion deals with production and nuclear absorption as distinct time-ordered processes, there has been concern for some time that the simple picture may be far from accurate. This problem has been discussed most recently by Gottfried.[11] An obvious consequence of the independence between successive events in the nucleus is the cascading of ever higher multiplicities with atomic weight. But, on the contrary, even at cosmic ray energies the observed multiplicities in emulsions, for example, while larger than those for hydrogen are not remarkably so, thus contradicting the cascade model. While the coherent yield vs. multiplicity should produce some insight into this problem, theoretical ideas about the interaction in nuclear matter can also be tested with incoherent scattering. We intend to take extensive data on incoherent production, and with $\pi^0$ multiplicity tagging, for several targets and beam energies.

## C. Incoherent But Exclusive Scattering

A separate set of data will be taken to study incoherent scattering in the absence (or near absence) of extra $\pi^0$'s. These samples will be further subdivided into data with zero charge exchange to the forward system and with single charge exchange. The former will be a mixture of coherent and incoherent events, but taken with a triggering scheme in which nuclear breakup is not suppressed and therefore with a much larger ratio of incoherent/coherent scattering than in the "coherent" sample. The CEX sample is manifestly incoherent and includes such reactions as $\pi^- + A \rightarrow \rho^0 + A'$, and $p + A \rightarrow \Delta^{++} + A'$.

The purpose of these data is to check the Glauber model for incoherent scattering both for its own sake and as an aid in understanding the small incoherent background under the forward coherent peak. While the latter is a relatively small problem, it is nevertheless a very knotty one since the incoherent scattering at $t_{min}$ is affected in an undetermined amount by the Pauli effect, final state interactions, and scattering from nuclear clusters.

## II. Experimental Layout

The overall technique is indicated in Fig. 1. It involves what is by now a classical magnetic spectrometer scheme. The secondary beam which is required is of high quality, modest intensity, and with Cerenkov counter particle tagging. The targets to be used are Be, C, Aℓ, Ca, Ti, Cu, Aℊ, Ta, Pb, and U and will be surrounded by a set of Pb-scintillator sandwich counters to form a veto box. The veto box will reject particles of all sorts from nuclear breakup (n, p, $\gamma$, etc.) and $\gamma$'s from $\pi^o$ decay. The latter is used particularly for triggering on coherent dissociation events and also for tagging in the incoherent trigger. Downstream is indicated the NAL Multiparticle Spectrometer facility which has been described in detail in approved proposals 110 and 260. Basically, all particle trajectories from an event which are accepted by the aperture of this system are completely determined by multiwire proportional chambers placed upstream of the magnet and magnetostrictive spark chambers downstream of the magnet. There are $\gamma$ detecting hodoscopes in the downstream region for vetoing in the coherent and the ($\pi^o$ free) incoherent triggers and for measuring high momentum $\pi^o$ multiplicities

in the inclusive sample. Particle types are tagged by two segmented Cerenkov counters.

Coherent events are identified statistically by their steep t-dependence in the forward direction, and not on an event by event basis. The most stringent resolution requirements are imposed by low multiplicity coherent events in heavy targets like Pb for which the forward t slope is ~500$(\mathrm{GeV/c})^{-2}$. Therefore, $\delta p_T$ the absolute uncertainty in $p_T$ (not its relative error) requires most precise measurement, $\delta p_T \sim 25$ MeV/c. This in turn implies very accurate measurement of entrance and exit angles to the target; at 200 GeV $\delta\theta \sim 0.1$ mr for each particle, a number which is achievable in this system. At low mass the above angle precision is more than adequate for good resolution. For higher masses where downstream momentum resolution becomes important, the mass resolution is still excellent, at least for the higher multiplicities. (See below for details).

The longitudinal momentum resolution of the spectrometer is ~1% for 3 particles having a total momentum of 200 GeV/c. For this case, assuming the beam momentum is much better known, the error in nuclear missing mass is 2 GeV. While this helps discriminate against extra high momentum pions, it does not help with nuclear breakup rejection. Nevertheless, the incoherent background under a forward coherent peak should be limited to <10%, and be more like 1% for low masses and heavy elements.

With these considerations in mind we now discuss the experimental set-up in more detail.

Beam

The momentum resolution required of the beam is $\frac{\delta p}{p} \lesssim 0.1\%$, and the

entrance angle requirement at the target is $\delta\theta \simeq 0.1$ mr. This precision is consistent with current plans for the area and adequate beam detection equipment should already have been installed. These include the spectrometer system from E69 for momentum measurement and the PWC system for incident angle measurement (to $\delta\theta = 0.06$ mr) in E110/260. A 2 cm spot size can be tolerated but the entrance and exit holes in the veto box will be minimal, 3 cm DIA downstream, for a $\lesssim 5$ mm beam diameter. We expect that the latter size can be achieved. Currently beam tagging of particle type is provided by a single DISC counter which is used in experiments E69 and E96. We will provide additional Cerenkov counter tagging so that three particle types ($\pi$,K,p) can be run simultaneously if necessary. However, it is likely that full beam detection will exist by the time we run.

Because of the finite resolving time of the downstream spark chambers high fluxes cannot be tolerated in a high statistics, high precision experiment because of the large number of spurious tracks and sparks per event. The flux level at which one can operate depends on the capability of the chambers to sustain many sparks and of the reconstruction program to find all the tracks. To minimize the multiple beam effect there will be dead timing of events with $\geq 2$ beam particles. Nevertheless, to be conservative we plan for $2.5 \times 10^5$ particles per pulse in a 1 sec spill.

Target

The list of target elements already noted have atomic weights A of 9, 12, 27, 40, 48, 64, 108, 181, 207, and 238. The full complement will be used only for high counting rate situations. All targets will have

.1-.2 radiation lengths thickness in order to keep multiple scattering and $\delta$ rays to a low level. Inevitably then one is forced to lower data taking rates with heavy elements because the nuclear cross section increases slowly with A due to absorption and $L_{Rad}$ decreases with A.

The target is surrounded by the veto box which covers all of $4\pi$ solid angle except for entrance and exit ports for the beam and the downstream hadron system. While this box sounds very similar to the one in E110/260, it is likely that a distinct one will be provided for this experiment. An important problem which must be solved in this experiment, especially for high multiplicities, is the $\delta$ rays originating in the target which count in the veto box. Especially for high multiplicity events this could be a $\gtrsim$25% effect. Care must be taken to minimize $\delta$ counts in the box while maximizing detection of low energy nucleons and $\gamma$'s through selection of Pb and scintillator thicknesses and counter thresholds.

Downstream of the veto box is a 1/32" thick dE/dx counter for triggering on more than one charged particle from the target. Since the trigger will be loose, potentially there are many triggers from interactions downstream of the target in the chambers, etc. This is especially troublesome since the veto box cannot help to minimize this rate. Such a counter was used very effectively in our BNL coherent experiment to clean up the trigger sample.

Spectrometer

The Multiparticle Spectrometer for E110/260 has been designed with great care for the very concerns which affect this experiment, excellent

resolution, large acceptance for high multiplicity events, and the ability to sustain many sparks with high efficiency. A drawing, taken from proposal E110/260 is shown in Fig. 1.

The angle resolution upstream of the magnet is determined essentially by geometry in the PWC's. Currently the plan is to stagger high pressure chambers so as to achieve ~.1 mm resolution at each station which over 1 m spacing yields 0.14 mr resolution consistent with the most stringent needs of this experiment. It should be noted that the final fit to an event will include the vertex point which constraint causes a considerable improvement in overall angular resolution.

The angular resolution downstream of the magnet should be comparable to upstream considering the redundancy, spacing of chambers ($\gtrsim$2m), and inherent resolution ($\lesssim$300μ). Therefore, with a bending power of $\Delta p_T$ = 1 GeV/c in the magnet ~1% overall momentum resolution can be achieved for the downstream system. Thus longitudinal momentum balance will not be a very useful aid in reducing background.

The spectrometer includes two segmented atmospheric pressure Cerenkov counters. These will be used to good advantage in nucleon and kaon induced events where $p/\pi$ and $K/\pi$ separation must be achieved. They will also be used to tag kaon and nucleon pairs among the more copious pions in the downstream ensemble to the extent that the rates and Cerenkov efficiencies allow.

$\pi^o$ Detection

We describe here the minimal $\pi^o$ detection system which is needed particularly to reduce the background triggers in high charged multiplicity coherent events, and to measure $\pi^o$ multiplicities in particle production

data. These are hodoscope arrays of three layer sandwiches, scintillator-Pb-scintillator, which 1) line the upstream vertical surface of the magnet and 2) form a single large plane as the last element of the spectrometer; the latter array is 2m × 4m with each element 0.5m × 0.5m. These modules will be OR-ed into the trigger to veto on $\gamma$'s and neutrons which convert in the Pb but not on charged particles. We feel that to improve on this scheme one must build an elaborate system at the end of the spectrometer with good position and energy measurement for the $\gamma$ rays while maintaining this system for triggering. Then one can study high multiplicity events $\lesssim 10$ particles with both charged and neutral detection most particularly in the coherent sample.

Mass Resolution and Acceptance

Figure 2 taken from proposal E110 (amended), shows the mass resolution and acceptance of the spectrometer for 2, 4 and $6\pi$ systems up to 5 GeV, for 50 and 100 GeV beams and for a 24" vertical gap in the magnet except where noted. Their Monte Carlo calculation assumes a phase space distribution of the decay products. Note that the acceptance improves with beam energy while resolution gets worse. Also, at a given mass the resolution improves with multiplicity. From these curves it is seen that bump hunting is possible at least for higher multiplicities out to the highest effective mass one expects to attain in the diffractive signal.

We plan to have two different geometries to stress low and high multiplicities. The former type of run will be done with the "standard" upstream system shown in Fig. 1. The geometry for the latter or "short"

running mode will be with the target assembly placed at the upstream magnet end guard and with one PWC assembly just downstream of the target as before and another in the magnet, as noted in Fig. 1. On the basis of a simple calculation, the resolution in $p_T$ and $M_X$ should not be degraded greatly, so that in this configuration the high multiplicity resolutions are comparable to low multiplicity resolutions in the standard mode.

Currently there are also plans to line the magnet aperture with PWC detectors in order to give some momentum measurement of particles which hit the walls of the magnet aperture. This development may allow the short geometry to lengthen again and its exact layout must depend on further Monte Carlo studies.

## III. Running Schemes

The standard trigger for a coherent event is a coincidence of

1) Beam with particle tagging
2) Veto box anti
3) Pulse height counter threshold
4) Track multiplicity (T) selection in PWC's upstream and downstream of the magnet, e.g. $2 \leq T \leq 4$ for 3 fold only
5) Veto on downstream neutral detectors
6) Downstream beam anticoincidence.

Incoherent events with no downstream $\pi^0$'s will have the same trigger but with the veto box condition removed. For particle production events with

the possibility of downstream $\pi^0$'s the downstream veto is also removed. All counter information will, of course, be latched into the data storage so the veto information will be available for later data processing. For most running it is expected that coherent events will not be spark chamber trigger limited. Also the non-coherent data need not be of the same statistical quality as the coherent. Therefore, these three types will be mixed together with the non-coherent triggers pre-scaled to a level such that the running time is affected negligibly. For example, in carbon where coherent data is more copious, the non-coherent triggers will be 20% of the total. In Pb they may be 80%.

For diagnostic purposes special triggers will also be mixed randomly with the data trigger. These include the following: 1) triggering on the beam for a live check of chamber alignment, field calibration, etc.; 2) Triggering on beam + downstream Cerenkov counters only, or downstream beam anti-coincidence. This trigger is for the purpose of checking the efficiency of those elements of the trigger, including non-redundant PWC's, which cannot be checked with live data.

Finally, periodically there will be special diagnostic runs for background, and for calibration.

## IV. Time Estimates

Basically data will be taken at two beam energies, 100 and 200 GeV and for both positive and negative beams. There will be some additional running at 50 GeV. The estimated fluxes on target for these beams are given in Table 1. Note that an upper limit has been taken of $2.5 \times 10^5$/pulse total flux in order to keep spurious tracks in the system to an adequately low level. In our AGS experiment beams of $>10^5$/pulse lead to too many tracks in the upstream detectors, however, with the improved resolving time of PWC detectors this upper limit is quite conservative. Again, in the AGS experiment a data taking run of 100 hrs netted $2 \times 10^5$ coherent $p\pi^+\pi^-$ events total for 9 targets. This includes time for special runs, target changes, aborted runs, etc. Based on this experience, on the increased maximum flux and acceptance of this system and on an assumed energy independence of the cross sections, we estimate 75 hours of running to obtain comparable statistics in 10 elements in the 3 body final state with additional data on higher multiplicities. This situation exists for p, $\pi^+$ and $\pi^-$ beams at 100 GeV and p and $\pi^-$ at 200 GeV with the "standard" configuration for the upstream detectors. Implicit in our calculation is a maximum of 20% dead time for the system, and the expectation of 1/6 yield of coherent events for the coherent trigger. Since the higher charged multiplicities in this experiment have more unwanted $\pi^\circ$'s in the background, it is crucial that downstream $\gamma$ rejection be highly efficient.

A suggested allotment of running time is listed in Table 2. In addition to the runs noted above, there is running 1) at 100 GeV on $K^-$ and $\bar{P}$ beams 2) on all these beams using the "short" upstream system to study high multiplicities and 3) runs at 50 GeV and "short" geometry primarily to study the energy dependence of the non-coherent particle yields. These runs are for

a reduced number of targets as noted.

In calculating the coherent yield vs. multiplicity a number of very simple assumptions have been made:

1) The average charged multiplicity in the forward system is the same as for the "diffractive" signal in pp scattering at the same $M_x$ as determined from NAL bubble chamber data.[12] The charged multiplicities are Poisson distributed with this mean.

2) $\pi^\circ$ multiplicities are also Poisson distributed with a mean value $\bar{n}_o = \frac{1}{2}(\bar{n}_+ + \bar{n}_-)$ which is independent of the charged multiplicity.[13] Both these assumptions are reasonably consistent with data, and are quite adequate for rate calculations.

3) The absorption cross sections in nuclei are independent of $M_x$ and multiplicity. There is no data on this latter feature for the higher multiplicities. However, any cascading tends to increase the higher multiplicity yields as if absorption had decreased. In that sense this is a conservative estimate of yields.

4) The inclusive diffractive signal follows the form

$$\frac{d^2\sigma}{dt\, d(M_x^2/s)} \propto e^{Bt} \left( M_x^2/s \right)^{-1}$$

where $e^{Bt}$ is the nuclear form factor near t = 0 (the t slope is increased to account for the elemental t slope in hadron-nucleon scattering at high mass).

Table 3 gives the relative yields in carbon, B = 60, $(\mathrm{GeV/c})^{-2}$, for the $\pi^\circ$ free diffractive signal vs. $M_x^2$ and charged multiplicity. Spectrometer acceptance has not been folded in. Decreasing yields with $M_x^2$ are due to the

explicit $M_x^2$ dependence, the $t_{min}$ effect, and the decreasing probability of no $\pi^\circ$ emission. This can be compensated to a point by summing data over larger $M^2/s$ bins at higher values. The range of values in the table for $M^2/s$ is very broad on the other hand. Significant data can be taken at least for the range $M_x^2/s < 0.1 (M_x^2 < 40)$ and for charged multiplicities up to 9.

The loose triggers in which downstream $\gamma$'s and veto box signals are tagged but do not veto the event will be interleaved with tight "coherent" triggers, as already noted. Information on this type of data need not be as precise as for coherent data, therefore, with a negligible perturbation of the running time ample inclusive charged particle data and exclusive incoherent data (no extra $\pi^\circ$'s) will be obtained.

Total Running Time

The total good data taking time requested is 800 hours. An additional 200 hours is required for testing at low intensity. Assuming 100 data taking hours/week this amounts to 10 weeks. Two additional calendar months should be adequate for set up time. The minimum calendar time this experiment need occupy the experimental floor is six months. Because of sharing the beam with other users this time will likely stretch to 9 months.

## V. Group Resources

Group Personnel

At present the group consists of three faculty, Edelstein, Russ and Green, and one research associate, Halpern, with a second post doc currently being hired. For the present, we regard five as the steady state size of

the group. Typically the group includes three to four post qualifying students plus one or two pre-qualifying. There are two technicians.

Shops

The physics department maintains excellent machine and electronics shops, and there are additional shop facilities in other areas of the campus from which we can draw as needed.

Computing

The group maintains an on-line software system centered around the DEC PDP7 and including 2 DEC tapes, 3 tape drives, disc, scope readout, and line printer. At present this system is kept on campus since in the current work at BNL there is adequate on-site computing support. While it appears that the on-site support at the spectrometer facility should be more than adequate, we are prepared to bring this system to the lab if it is required.

Large scale data processing is done on the Univac 1108 at CMU. The combined High Energy Groups, two experimental groups + theoreticians, have an arrangement with the University whereby we may use up to 1/2 the running time on this machine. Since we have yet to approach this limit the arrangement has been very stable for ~5 years and can be expected to remain so.

Time Scale

The group is currently fully committed to its work at Brookhaven. Most immediately we are helping to build their multiparticle spectrometer facility, MPS, and will perform one of the first experiments on it. Therefore, our schedule mates well with the expected schedule for E110/260. We point out that, while no experiment is cheap or easy, our experiment could be mounted in the spectrometer with minimal effort at a somewhat earlier time

should the E110/260 group decide to take a break in their running schedule. Our runs at Brookhaven on coherent dissociation were done in this fashion on the Lindenbaum/Ozaki spectrometer and the interleaving of efforts was very successful.

Funding

The combined High Energy Groups at CMU have been supported by the AEC since the beginning of the synchrocyclotron laboratory about 25 years ago. In recent years our group has had adequate support; we have been encouraged to expect continued financial health to the extent that one can plan.

## VI. Comparison of MPS and the Chicago Cyclotron Apparatus

We have compared the relative advantages of the Multiparticle Spectrometer facility with those of the Chicago cyclotron muon spectrometer. In our view they are as follows:

1) Aperture. While the cyclotron magnet aperture is much larger than in MPS 4' x ~13' as compared to 2.' x 4', the maximum useable solid angle subtended at a target just upstream of the magnet is almost the same in the two cases, since in the MPS the distance along the beam is much shorter. The comparison is also similar when the upstream detector systems are stretched out to improve the measurement capabilities. Therefore, both systems have excellent acceptance capabilities for high multiplicity events. However, this is accomplised much more economically in MPS since chamber sizes are smaller in this condensed system. It is also a factor leading to improved spacial resolution in the MPS downstream system.

2) Bending power. The cyclotron magnet has a bending power of $\Delta P_T$ = 2 GeV/c as compared to an expected ~1 GeV/c for MPS. However, as we have

discussed, for this experiment it is upstream angle measurement which primarily effects the precision in transverse momentum and mass determination. Longitudinal momentum balance is not at all helpful in either case for removing nuclear breakup events from the coherent signal.

3) Upstream angle resolution. This crucial requirement will be met adequately by the MPS facility as it is now being constructed. It is not met by the current upstream PWC's at the cyclotron. There the angular resolution is ~1 mr as compared to ~0.1 mr for MPS. If t slopes of 500 $(GeV/c)^{-2}$ are to be seen at 200 GeV (for coherent Pb scattering), clearly a new upstream system would have to be built.

4) $\pi^{\circ}$ Detection. Neither system as yet has Pb-scintillator hodo scopes in the downstream system which are required for $\pi^{\circ}$ rejection in triggering the high charged multiplicity events. (The downstream calorimeters in E260 may, in fact, serve our purpose.)

5) MPS will have two segmented Cerenkov counters for downstream particle identification. These would have to be built for the cyclotron and they would be enormous in order to match the magnet aperture.

6) Beam Quality. The present hadron beam in M6 is excellent in resolution, spot size and angular dispersion. Presumably a hadron beam of adequate quality can be constructed in the neutrino area, and with adequate detection equipment. One advantage, however, in the meson lab is that by the time this experiment runs the beam will be fully instrumented and it will not have to be shared in so many incompatible ways as in the neutrino area. At least from the experimenter's point of view this is a great advantage.

7) Time Scale before Running. Running this experiment in MPS is clearly some time away. In the light of the amount of building and re-arrangement that would have to be done at the cyclotron, and considering the amount of muon data still to be taken, it is also clear that the waiting time for the cyclotron system is similarly long.

Over all, we consider the MPS system to be better suited to this experiment than the cyclotron system. It was designed with precisely this type of experiment in mind, and it can accommodate it with only modest revisions. Yet this experiment is quite distinct from those contemplated by the E110/260 group. It complements the current effort well.

## VII. Future Refinements

Two possible improvements on this experiment are the following:

1) Improved high quality neutral detection downstream of the spectrometer with precise angle and energy measurements, as mentioned above.

2) Coherent production with detection of the recoil nucleus. Such a scheme works only for light nuclei like d and He. We have debated pursuing this direction at an early date, but have concluded that this more refined technique has a much more limited scope both in versatility and statistics. Nevertheless, it has some distinct advantages since with complete detection of angles, mass, and energy of the recoil ion inclusive experiments with the downstream detection of the spectrometer become feasible. It becomes a very attractive second generation coherent experiment.

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TABLE 1. Beam Fluxes for 300 GeV External Beam

| Beam Momentum | $\pi$ | K | P |
|---|---|---|---|
| +50 | $1.8 \times 10^5$ | $2.5 \times 10^4$ | $4.5 \times 10^4$ |
| -50 | $2.4 \times 10^5$ | $1.2 \times 10^4$ | $3 \times 10^3$ |
| +100 | $1.2 \times 10^5$ | $2 \times 10^4$ | $1.2 \times 10^5$ |
| -100 | $2.4 \times 10^5$ | $6 \times 10^3$ | $1.2 \times 10^3$ |
| +200 | - | - | $2.5 \times 10^5$ |
| -200 | $2.5 \times 10^5$ | - | - |

Table 2. Running Plan

| Beam Momentum (GeV/c) | Particle Type | Hours | Upstream Configuration | Number of Targets* |
|---|---|---|---|---|
| +100 | $p, \pi^+$ | 75 | Standard | 10 |
| | | 50 | Short | 5 |
| +200 | $p$ | 75 | Standard | 10 |
| | | 50 | Short | 5 |
| -100 | $\pi^-$ | 75 | Standard | 10 |
| | | 50 | Short | 5 |
| | $K^-, \bar{p}$ | 50 | Standard | 3 |
| | | 50 | Short | 3 |
| -200 | $\pi^-$ | 75 | Standard | 10 |
| | | 50 | Short | 5 |
| +50 | $p, \pi^+$ | 50 | Short | 3 |
| -50 | $\pi^-$ | 50 | Short | 3 |

*For 10 targets read the full complement listed in text

For 5 targets read C, Aℓ, Cu, Ag, Pb

For 3 targets read C, Cu, Pb

Table 3. Relative Coherent Yields* in Carbon

at 200 GeV/c

| $M_x^2$ $(GeV)^2$ | $M_x^2/s$ | $-t_{min}$ $(GeV/c)^2$ | $\bar{n}_c$ | Exclusive Charged Multiplicity 3 | 5 | 7 | 9 | 11 |
|---|---|---|---|---|---|---|---|---|
| 4 | 0.01 | $1.0\times 0^{-4}$ | 2.0 | 6.7 | 1.3 | .13 | .007 | |
| 10 | 0.026 | $6.3\times10^{-4}$ | 3.0 | 1.8 | .83 | .18 | .022 | .002 |
| 25 | 0.066 | $3.9\times10^{-3}$ | 4.0 | .32 | .26 | .10 | .022 | .003 |
| 50 | 0.13 | $1.6\times10^{-2}$ | 5.0 | .034 | .042 | .025 | .009 | .002 |
| 75 | 0.20 | $3.6\times10^{-2}$ | 5.2 | .006 | .008 | .005 | .002 | |

* $\frac{d^2\sigma}{dt\, d(M^2/s)} \propto (M^2/s)^{-1}\, e^{Bt}\, e^{-\bar{n}_o}\left(e^{-\bar{n}_c} \times \bar{n}_c^{\,n_c}/n_c!\right)$, where $\bar{n}_o = 1/2\ \bar{n}_c$,

$B = 60(GeV/c)^{-2}$, $S = 376\ GeV^2$, $\bar{n}_c$ is taken from Ref. 12.

Plan View – Multiparticle Spectrometer with Nuclear Targets

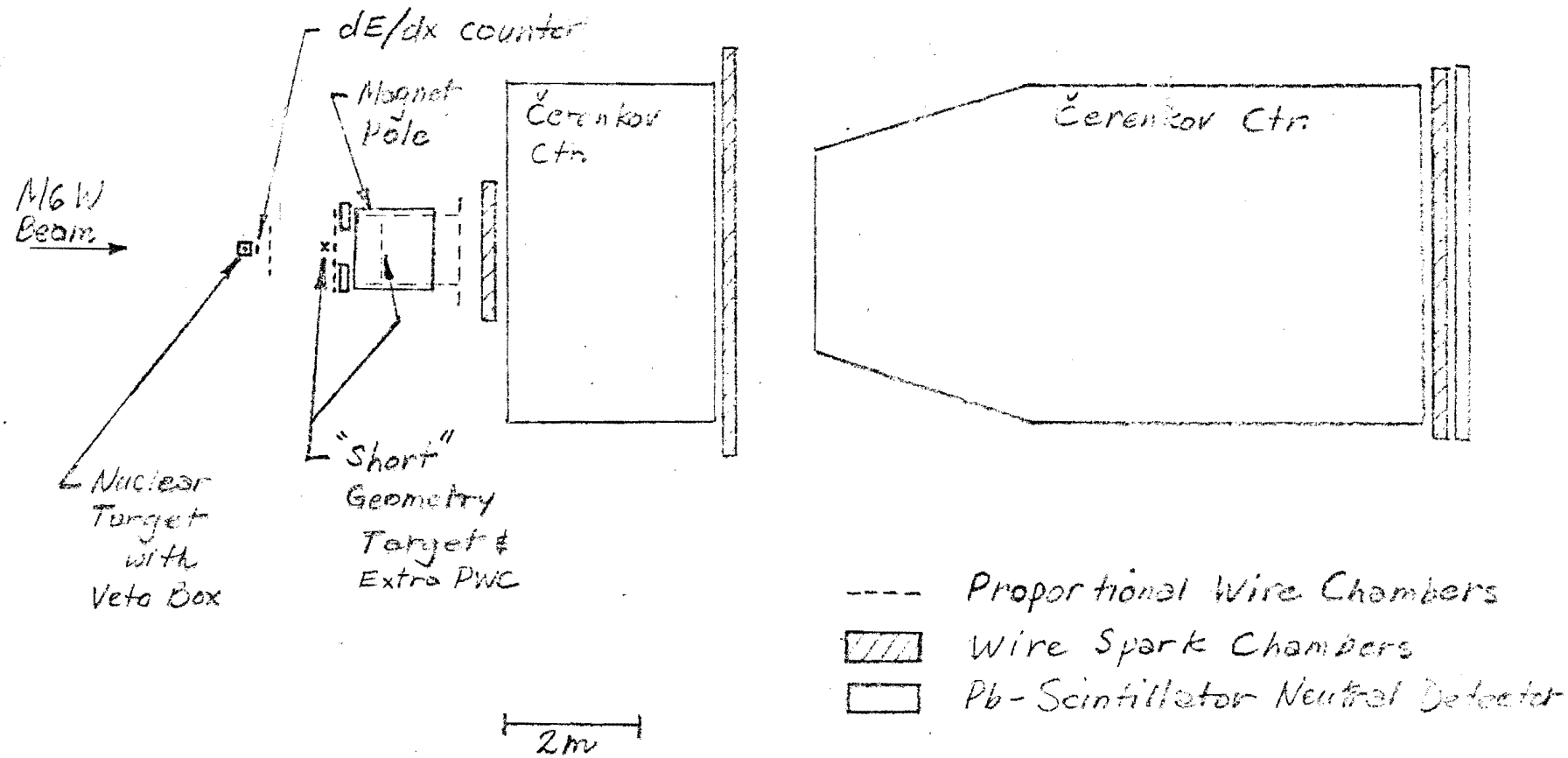


Fig. 1

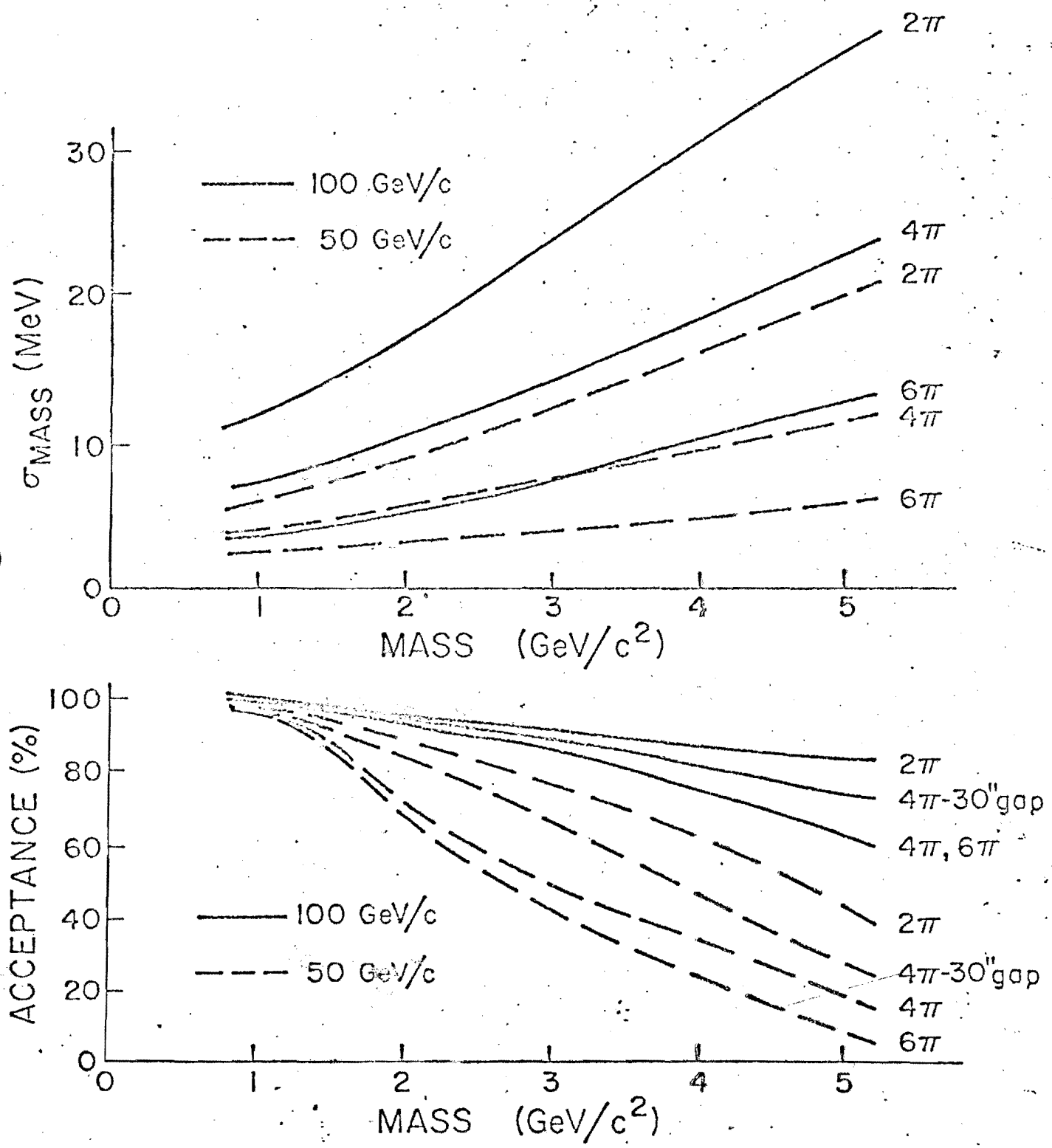


Fig. 2

Figure A2. Mass resolutions and acceptances at 50 and 100 GeV/c incident momenta.

E110/260