NAL PROPOSAL No. 292

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MULTIPARTICLE PRODUCTION IN NUCLEI BY PROTONS OF SEVERAL HUNDRED GeV

Bucharest-CERN-Cornell Collaboration

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15 October 1973

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

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1. SUMMARY

We propose to study the multiplicity and angular distributions of particles produced in collisions of protons with heavy nuclei at NAL energies. Data on this type of process are very scarce and mainly serve to show that conventional strong-interaction models are inconsistent with observation.

As targets we intend to use very thin wires and foils of appropriate materials like Au and stainless steel; the wires will be embedded in nuclear emulsion and the foils will be sandwiched between emulsion pellicles. The extremely high spatial resolution of the emulsion makes it relatively easy to observe and measure the fast particles in the projectile system, and the geometry of the experiment is such as to allow the simultaneous observation of all the slow particles emitted from the target nucleus.

We thus expect to be able to obtain detailed information on the fate of the projectile system as function of the atomic number A of the target, and on the excitation of the target nucleus (as determined from observation of the tracks of evaporated particles and knock-ons).

The design and preparation of the equipment will be carried out at CERN, as will the processing of the emulsions. The exposures will be made at NAL. Scanning and measurements are planned to take place in Bucharest.

2. PHYSICS

Why study nuclear production?

Let τ be some characteristic collision time in the c.o.m. system of a high-energy pp collision. In the laboratory frame τ is dilated to $\tau' \equiv (s/4m_N^2)^{1/2}\,\tau$. In conventional hydrogen experiments we cannot make observations on the system during such microscopic time intervals; all we can do is wait for "ever" and measure S-matrix elements. If the pp collision occurs in a nucleus, however, the newly born state resulting from this first encounter will interact with one or more downstream nucleons provided s is large enough so that $\tau' > \lambda$, where λ is the mean free path of a typical hadron in nuclear matter (λ = 2 to 3 fm). For s > 400 $(\mathrm{GeV/c})^2$, this covers a large range of characteristic times ($\tau \lesssim m_N^{-1}$). Therefore, the nuclear process is very sensitive to the space-time structure of pp production amplitudes, and provides fundamental information that cannot be obtained by other known means.

That the nucleus is a powerful and unique device for studying short-time hadronic interactions has already been established in the coherent-production experiments carried out at electron synchrotrons and CERN. The processes most extensively studied were photoproduction of vector mesons and pionic production of 3π and 5π systems$^{1)}$. These experiments gave a surprisingly simple result: the cross-section on nucleons of these multi-boson systems (i.e. ρ^0, 3π, 5π) does not differ appreciably from $\sigma_{\pi N}$. There is little doubt that this is a crucial fact that a reputable theory of hadronic dynamics must explain.

Here we propose to study not a particularly simple set of channels, as in coherent production, but global characteristics of the totality of channels. In particular, we wish to investigate the multiplicity and pseudo-rapidity distributions of relativistic secondaries (i.e. essentially pions) produced in high-energy p-nucleus collisions.

Bird's-eye view of present data

One might have expected nuclear multiple production to be a complex phenomenon, but it is astonishingly simple. A superficial glance at the nuclear data would not distinguish them from hydrogen: multiplicities of relativistic secondaries in nuclei (per nuclear interaction - not per nucleon!) differ but little from those obtained in hydrogen, and the inclusive pion rapidity distributions in hydrogen and complex nuclei are indistinguishable for at least half of the full rapidity range. These facts have been clearly established in a 200-GeV/c emulsion exposure at NAL carried out by a large collaboration$^{2)}$. Numerous cosmic-ray experiments have revealed similar features though, of course, with less precision$^{3)}$. Fig. 1 shows the multiplicity ratio$^{4)}$

$$R_{Em}(p_{inc}) = \frac{\text{Mean number of relativistic tracks from emulsion nucleus}}{\text{Mean charged multiplicity from pp collision}}$$

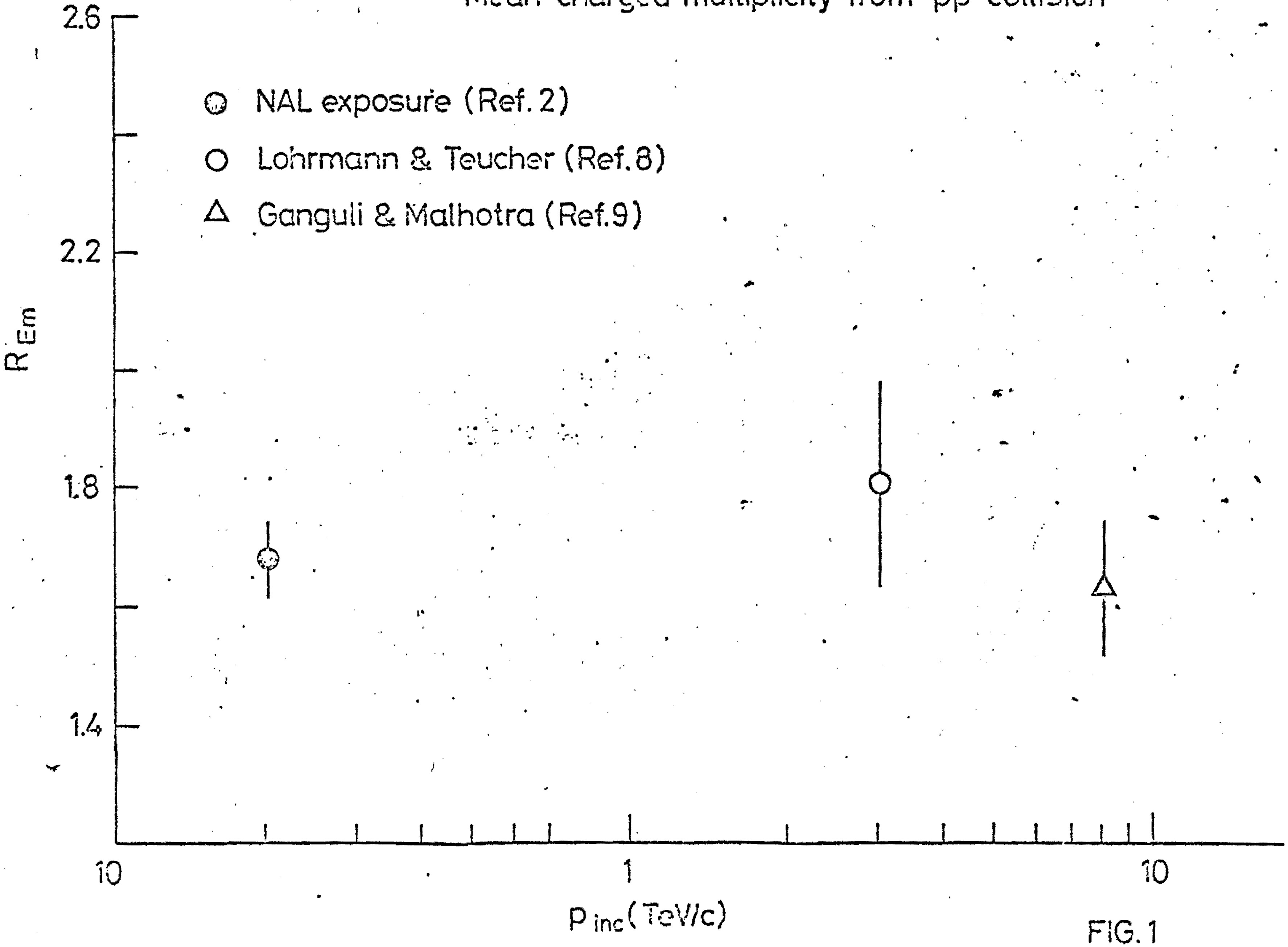


FIG. 1

$$R_A(s) = \frac{\text{Mean no. of relativistic tracks produced from nucleus A}}{\text{Mean pp charge multiplicity}}$$

for "emulsion nuclei" (R_{Em}), plotted as function of p_{inc}. As we see, $R_{Em} \simeq 1.7$ for 10 TeV/c $\gtrsim p_{inc} \gtrsim$ 200 GeV/c. Here it must be borne in mind that the mean A in an emulsion is about 70.

The distribution of the (pseudo) rapidity (log tan θ) determined in the 200-GeV/c NAL exposure is shown in Fig. 2 as a dashed histogram, and compared to the same distribution measured in a 200-GeV/c HBC experiment. Note that in the entire projectile hemisphere (i.e., to the left of the pp c.o.m. designated by C in Fig. 2) there is no discernible difference between hydrogen and emulsion.

One other well-established fact is that the nuclear response reaches an asymptotic form at very low energies. Fig. 3 shows the integral multiplicity distribution for evaporation and knock-out protons from emulsions at 200 GeV/c; there is essentially no change from the world data below PS energies. Amongst other things, this gives one confidence that nuclear dynamics plays no significant role in the process.

It is natural to ask for the precise A dependence of $R_A(s)$; obviously an emulsion only provides a very crude measure of this variation. Here there are only two pieces of information: (i) measurements of R_A in C by the questionable Echo-Lake experiment$^{5)}$, as shown in Fig. 4, and (ii) an exceedingly poor statistics (8 events!) measurement at 200 GeV/c in an emulsion loaded with tungsten pellets$^{6)}$. In short, the A dependence of R_A is very poorly known, and nothing whatsoever is known about the multiplicity or rapidity distributions as a function of A.

Theoretical significance of the data

The small and virtually constant value of R_{Em} provides a formidable hurdle for all the fashionable theories of the basic pp collision$^{7)}$. Obviously a conventional cascade must be avoided at all costs, for it would lead to a catastrophic growth of $R_A(s)$ with both A and s.

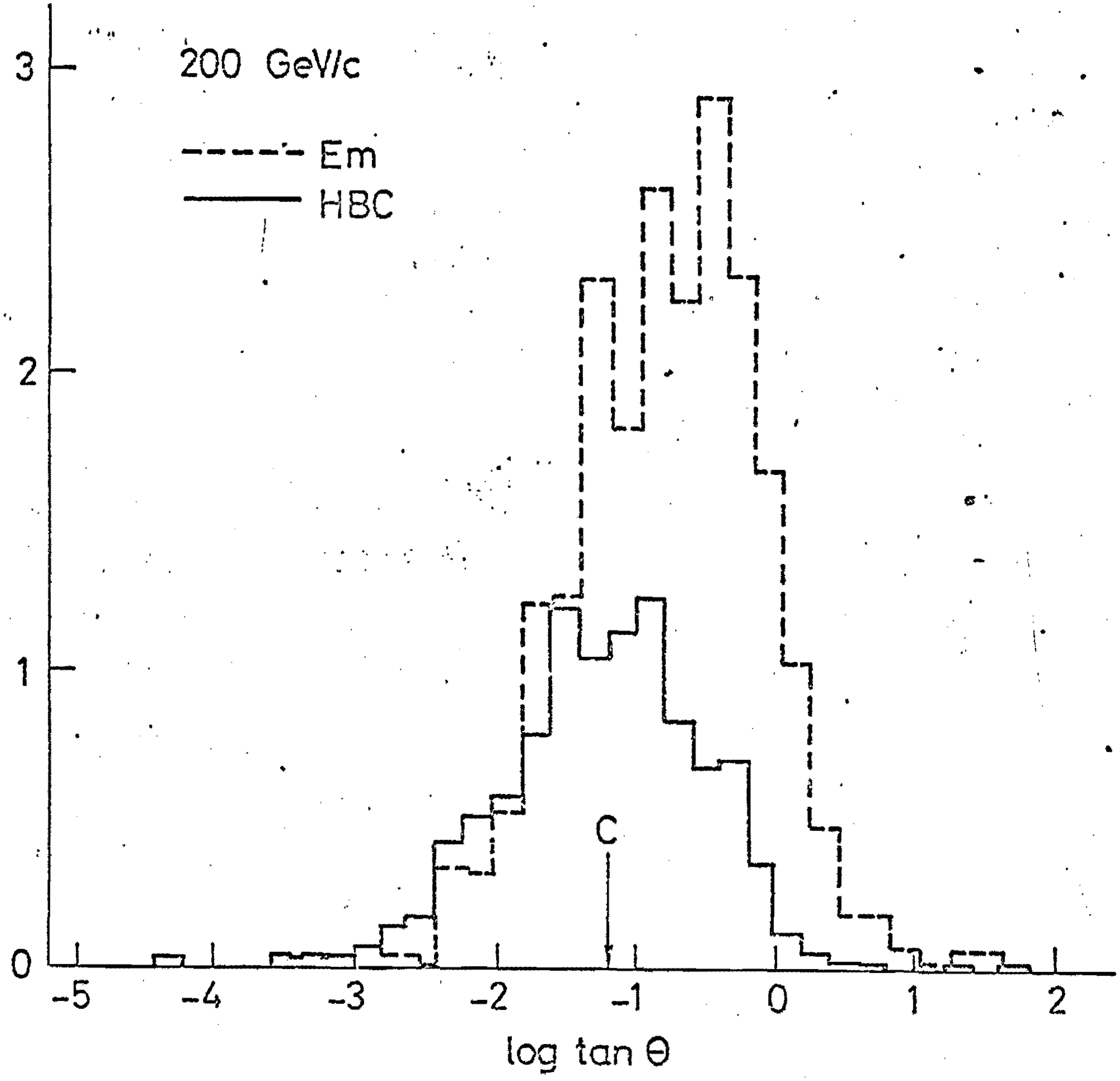


FIG. 2

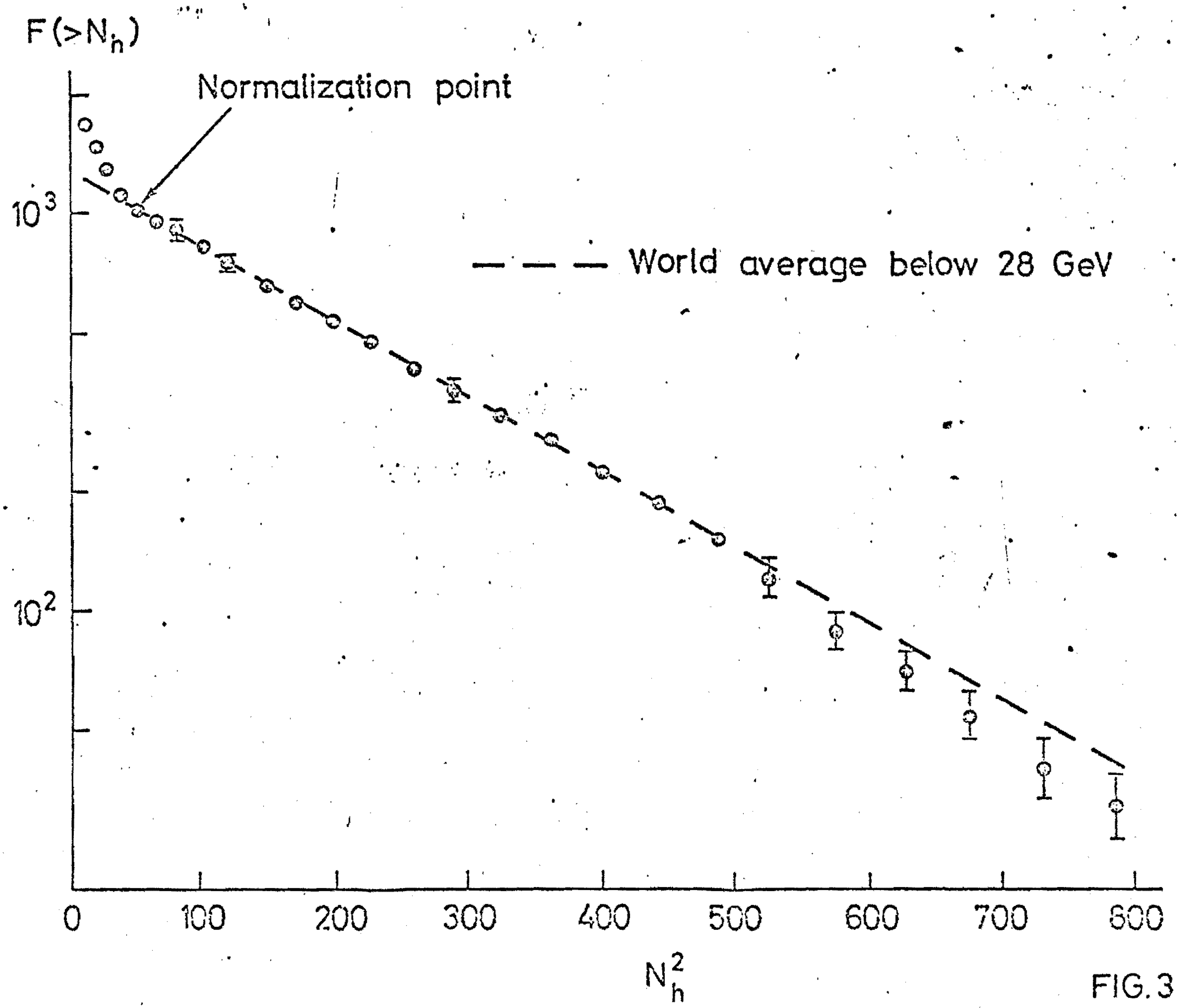

F(>N_h)
Normalization point
10^3
10^2
World average below 28 GeV
0
100
200
300
400
500
600
700
800
N_h^2

FIG. 3

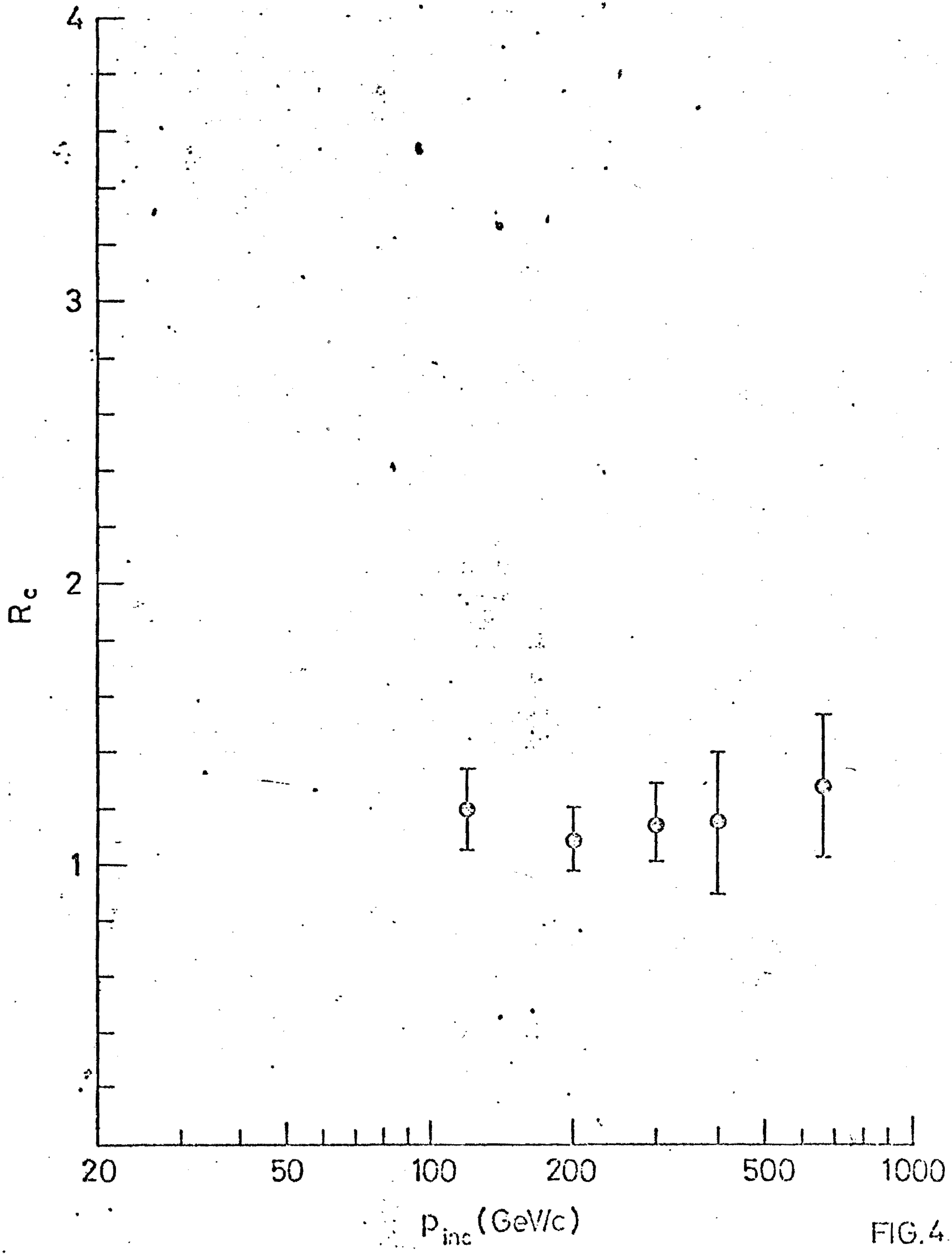


FIG.4

The popular short-range-order (SRO) view of multiple production, so successful with the qualitative features of the ISR data, would, at first sight, lead to the conclusion that $R_A(s) \to 1$ as $s \to \infty$. It should be noted, however, that SRO is merely a picture in momentum space of the finally observed state, and does not provide a dynamical description of the space-time development of the process. The multiperipheral model is the only known dynamical scheme that displays SRO, and yet when applied to nuclear production it appears to lead to catastrophically large values of R_A.

It is almost certain that the nuclear process shows that at short times hadronic interactions cannot be described by the particle degrees of freedom manifested by the asymptotic state, but that a description in terms of collective variables (e.g. field strengths, the stress tensor) is more appropriate7). A more detailed knowledge of nuclear production phenomena would provide essential guidance in the search for such a description.

3. EXPERIMENTAL METHOD

Requirements

The experiment should provide measurements of the following quantities:

i) The number of relativistic particles emitted in each event. More than half of these will be emitted into a narrow forward cone of half-angle $\lesssim 5^{\circ}$. Thus, very high spatial resolution is required.

ii) The angular distribution of the relativistic particles. Here, too, one needs very high spatial resolution.

iii) The excitation energy of the target nucleus, as estimated from the numbers and types of non-relativistic particles emitted from the interaction.

Ideally, one would aim at obtaining 1000 events for each type of target nucleus and for each primary energy; we consider it realistic to plan for two primary momenta (200 and maximum NAL momentum) and up to four target elements.

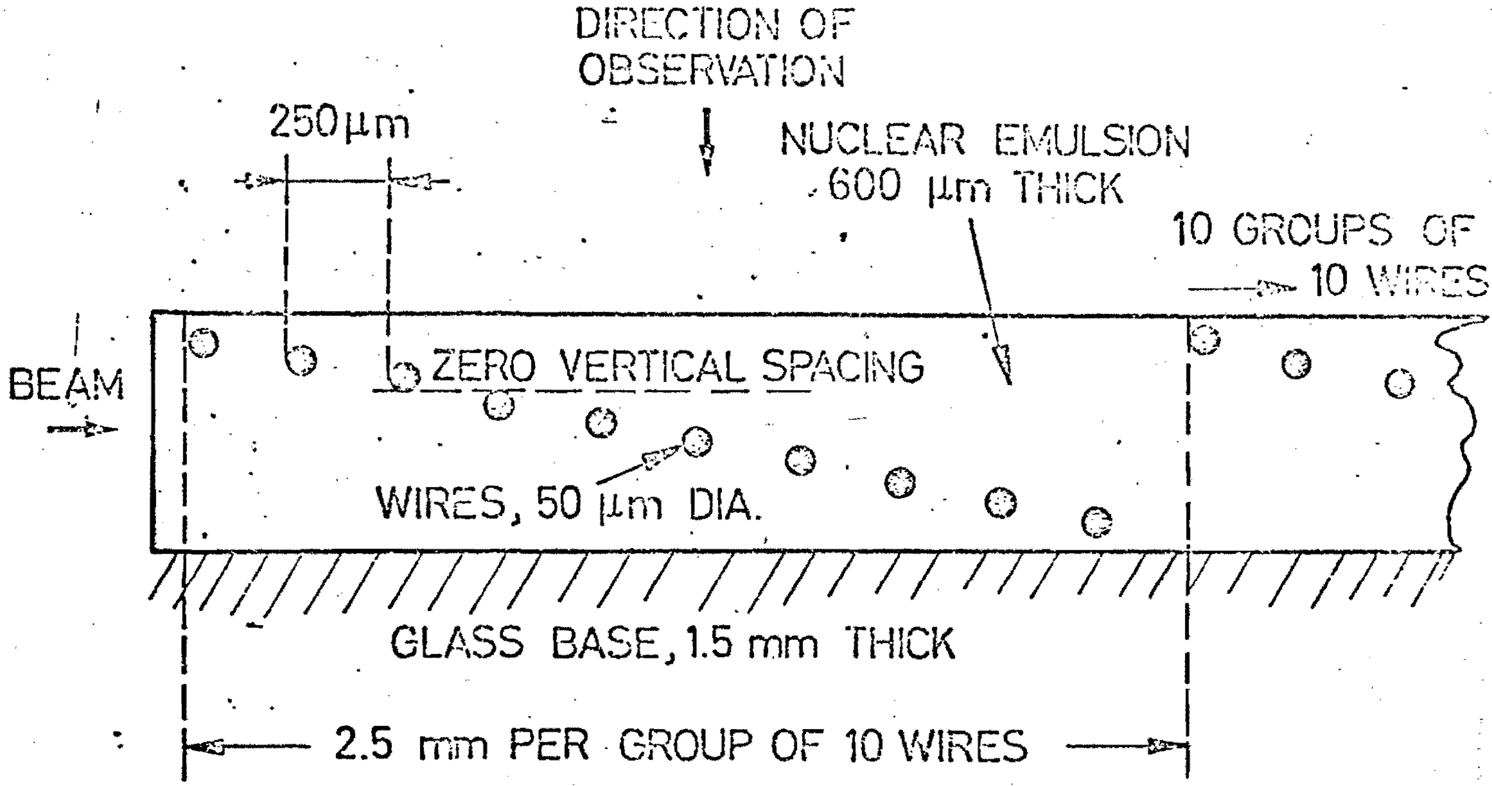
Proposed methods

We want to obtain results on a reasonable time scale; taking this into account we are satisfied that the best method available at present is the following:-

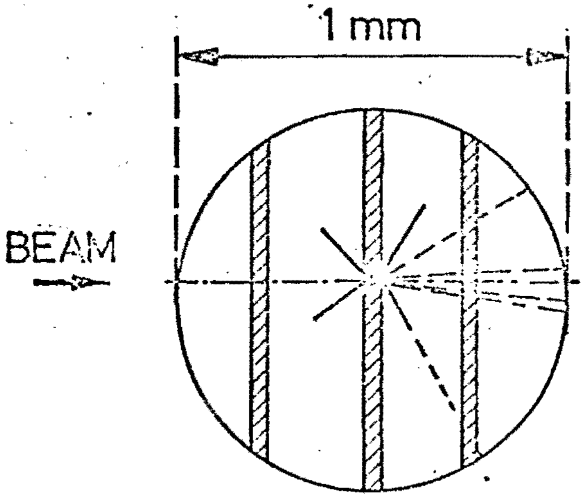
> As target material we use arrays of fine (diameter 50 μm) wires embedded in nuclear emulsion which serves as detector of the charged particles. The proposed arrangement is shown in Fig. 5. The beam particles will traverse a 50-μm wire every 3 mm. Looked at from above, the wires will be spaced 250 μm apart to allow observation of the tracks. Scanning, by searching for events along the wires, should be rather easy and quick. However, the technology of embedding wires in emulsion will need some development work (see below).

The next best method, which we wish to employ concurrently, is the following:-

> Emulsions covered with thin foils of target material are exposed at a convenient angle to the beam (Fig. 6). After processing, the emulsions are scanned for interactions in the foil and these are geometrically reconstructed to confirm the point of origin. With this method scanning and analysis are more difficult and time-consuming than in the case of wire loading, there may be some loss of low-multiplicity events, and the estimate of the excitation energy is less precise as only a fraction of the evaporation tracks is observable. However, the technology does not present any problems and target materials may be obtainable more easily in the form of foils than as wires with suitable mechanical properties.



SECTION THROUGH WIRE-LOADED PLATE, NORMAL TO WIRES.



APPEARANCE OF INTERACTION IN WIRE AT LOW MAGNIFICATION USED IN SCANNING

FIG. 5

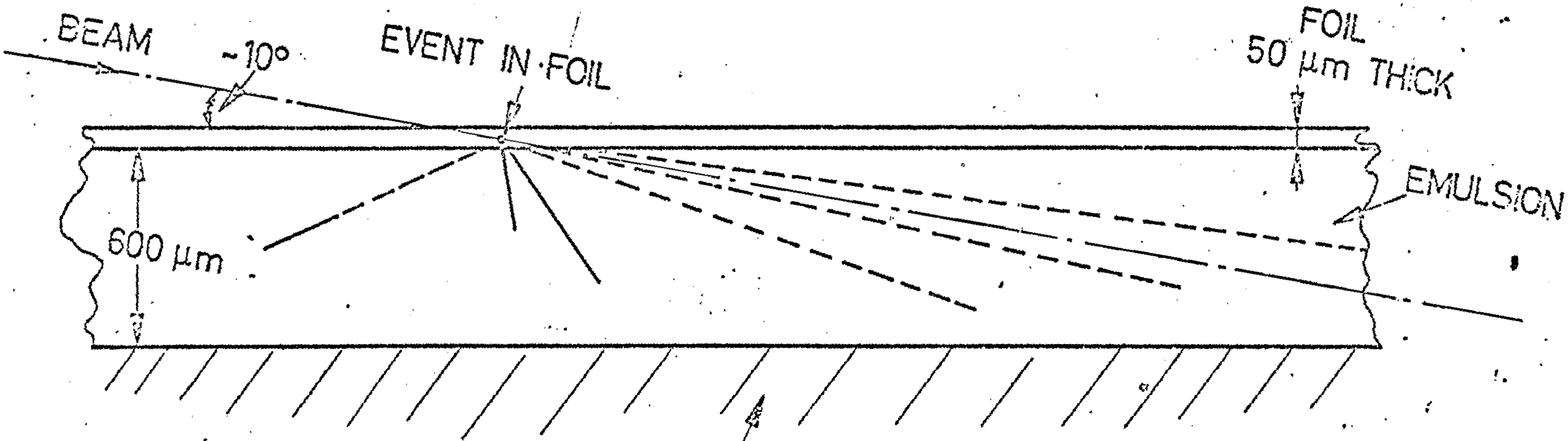


FIG.6 : SECTION THROUGH PART OF FOIL-COVERED PLATE

Technology of wire loading

Wire loading was first proposed and tried in 1951 [10,11], but the technology will have to be revived, tested and developed somewhat further in order to achieve the geometry and event rates required in the present experiment.

In the early work, the number of wires and thus the amount of material presented to the beam was relatively small. In our case, we shall have to design and build jigs and fixtures to hold large numbers of closely spaced wires in place while the emulsion solidifies around them. The techniques, though similar in principle to those employed in making wire chambers, will need to go through the usual procedure of designing, testing, refining and retesting, but the fund of knowledge and experience available at CERN should make this process a rapid one.

It is almost certain that wire-loaded emulsions will need special processing methods[11] - these, too, will have to be revived and tested.

Event numbers and quantity of emulsion required

In nuclear emulsions, a beam intensity with which one can work comfortably is 2×10^4 particles per cm^2 normal to the beam. If we have wires 20 cm long and 50 μm in diameter, each wire will then be traversed by 2000 tracks. To obtain about 1000 events, 1000 wires will be needed if Au is the target material, 1600 wires if it is steel. If we embed 100 wires in each emulsion of dimensions 20 cm × 5 cm, we shall need stacks of 15 pellicles for each exposure.

If foil-covered emulsion is used, as shown in Fig. 6, a beam with 2×10^4 particles per cm^2 will produce about 7.5 events per cm^2 of (inclined) emulsion surface with 50-μm steel foil; about 10 events per cm^2 with 50-μm Au foil.

In either case, there is no problem at all in obtaining adequate numbers of events with very brief exposures.

Why emulsions?

An electronics experiment to provide the data required at multiplicities ranging between about 5 and 50 in a narrow forward cone would be orders of magnitude more complex and expensive than what we are proposing here if, indeed, it can be done at all. It would certainly require much more time.

One might contemplate an hydrogen-bubble-chamber experiment with solid targets. Work is now in progress on the development of computer programs capable of reconstructing high-multiplicity events in large bubble chambers, but up to now it has not been found possible to reconstruct very-high-energy high-multiplicity events reliably, mainly because of confusion between the tracks12). Furthermore, one will not be able to use thick targets for it is essential to see the tracks of slow evaporated particles in order to estimate the excitation of the target nucleus. Most evaporated protons have ranges of the order of 100 μm or less in materials like gold or tungsten, so event rates in acceptable target foils will be low: even if one were to allow as much as 20 beam tracks per picture (unlikely to be possible) one would need about 500,000 pictures for the experiment.

4. HOW LONG WILL IT TAKE?

If approval is given quickly, one of us (AJH) could start technical development and preparations at CERN and at Ilford Limited, London before the end of November. One might hope that an adequate team for the preparation of the experiment can be assembled at CERN in January 1974. If progress is satisfactory, a reasonable level of priority is accorded to the work in the specialized workshops at CERN, and there are no scheduling problems at NAL, exposures could start as early as April 1974. First results should thus become available in Autumn 1974.

5. FACILITIES REQUIRED

At CERN

Precision mechanical work, of a kind similar to the construction of small wire chambers, will have to be carried out in the CERN specialist workshops, and the help of an expert designer will be needed.

The existing dark rooms in NP Division are adequate. The emulsion-processing technician, at present on detachment to the PIO, will be needed full-time as soon as practical work starts. Space will be needed for two physicists (Paid Associates).

A small amount of computer time will be needed for the analysis of the experiment.

At NAL

A low-intensity proton beam of large cross-sectional area will be needed, to provide about 2×10^4 protons per cm^2 normal to the beam. Past experience at CERN suggests that the total beam occupation time will not exceed two hours for each of three exposures. Some beam-monitoring equipment will be needed, as well as technical assistance with setting up and surveying.

At Bucharest

A major part of the team of scanners and technicians, as well as the full facilities of the Bucharest group, will be employed in the collection and analysis of the data.

6. COST TO CERN (All in Swiss Francs)

Materials		
2 ℓ Ilford K5 emulsion	10,000	
Workshops and materials	15,000	
Stores	2,000	
	27,000	
Travel		
4 × 1 week London (Ilford)	5,000	
3 × 1 week NAL	8,000	
	13,000	
Paid Associates		
2 Associates, 4 months each	35,000	
Total direct cost - NP: 40,000 + 25% contingency		50,000
Associates budget:		35,000

CERN salaries and overheads not included.

7. REFERENCES

1. These coherent multipion production phenomena are reviewed in W. Beusch, Acta Physica Polonica, B3, 679 (1972), and the photoproduction by K. Gottfried, Proceedings International Symposium Photon and Electron Interaction, Cornell University, 1971.

2. Barcelona-Batavia-Belgrade-Bucharest-Lund-Lyon-McGill-Nancy-Ottawa-Paris-Quebec-Rome-Strasbourg-Valencia Collaboration, paper submitted to the Aix-en-Provence Conference, September, 1973.

3. For a summary of cosmic ray data, see K. Gottfried, CERN TH 1735 (1973).

4. The numerator is the so-called shower-track multiplicity corresponding to secondaries with $v/c > 0.7$, while the denominator is obtained from the NAL-ISR compilation of M. Antinucci et al., Nuovo Cimento Letters 6, 13 (1973). In comparing with the cosmic-ray data the latter's formula for n_{ch} was used to extrapolate (see Ref. 3).

5. L.W. Jones et al., Proceedings of 11th International Conference Cosmic Rays, Budapest, 1969. There is also a bit of emulsion data on R_c at cosmic ray energies; see Ref. 3.

6. J.R. Florian et al., University of Washington, preprint (1973).

7. For a summary of interpretations of the data, see Ref. 3.

8. E. Lohrmann and M.W. Teucher, Nuovo Cimento 25, 957 (1962).

9. S.N. Ganguli and P.K. Malhotra, private communication.

10. G. Meulemans, G. Occhialini and A. M. Vincent, Nuovo Cimento 8, 341 (1951)

11. M. Danysz and G. Yekutieli, Phil. Mag. (7), 42, 1185 (1951).

12. We are indebted to Dr. Y. Goldschmidt-Clermont, Dr. G. Kellner and Dr. E. Quercigh for discussions on this point.

Addendum to Proposal:

MULTIPARTICLE PRODUCTION IN NUCLEI BY PROTONS OF SEVERAL HUNDRED GeV

1. In each exposure, we would need a total of about 10^7 protons distributed over a rectangular cross section of 10 cm x 20 cm. Dr. Herz has recently done a rough exposure of this type at CERN with a total beam occupation time of 10 minutes. The reason we have given 2 hours as the upper limit of beam occupation time for each of the three exposures is that a lot of time often goes into adjusting the beam, setting up stands, leveling the emulsion holders, and returning the beam back to its original small image.

2. The set-up would consist of a simple leveled stand or platform on which the emulsion stacks are placed, lined up, of course, with respect to the beam. The most convenient way of tuning the beam to the right cross section and intensity would probably be to do it with a suitable counter telescope or, if available at NAL, a beam-profile analyzer incorporating multi-wire proportional chambers. Of course, it can also be done with emulsions, but not as quickly. However, we cannot really say how we intend to set up and monitor the beam until we know what facilities we can borrow at NAL: this is the sort of thing that Dr. Herz intends to work out in face-to-face discussions with the people directly concerned.

3. Dr. Herz intends to handle the exposures himself, but he would also like to have assistance from the NAL staff in setting up the beam (presumably with NAL electronics), and he presumes that NAL could supply the level table.