EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN/ISRC/69-6
13 February 1969

INTERSECTING STORAGE RINGS COMMITTEE

PROPOSAL FOR A DETAILED INVESTIGATION OF LOW-MOMENTUM PARTICLES EMITTED AT LARGE ANGLES FROM pp COLLISIONS AT THE ISR

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1. INTRODUCTION

Most theoretical models of multiple particle production in very-high-energy proton-proton collisions predict that slow particles are emitted at large angles to the line of flight in the centre-of-momentum system of the colliding protons. Experimental data obtained at present-day accelerators are consistent with this prediction[1)] but detailed information is lacking. We propose to make a study of the production rates of π^+, π^-, K^+, K^-, p and $\bar{p}$, their angular distributions at large angles, and their momentum distributions below about 200 MeV/c (for pions). The experiment is intended to provide reliable and precise information in this region of secondary-particle momenta and angles for which data are very scarce at present. We hope that it will contribute a significant test of theories of particle production.

We have chosen the nuclear-emulsion technique because we are sure that it is the best available for this experiment. Because we propose to concentrate initially on particles which come to rest in the emulsion, the efficiency of identification will be very high, based on observation of the event (decay, star, etc.) at the end of the range, together with an estimate of the rate of change of energy loss with range. Momenta will be derived from measurements of range, and it will be possible to reject with almost 100% efficiency particles not coming from the interaction region. Finally it is important to note that for the present purpose the emulsion technique becomes more effective with decreasing particle momentum, down to a very low lower limit (about 25 MeV/c for pions) whilst the opposite is generally the case for electronic techniques.

2. PHYSICS AND AIMS OF THE EXPERIMENT

Following the recent resurgence of interest in many-body collisions of hadrons[2)], there now exist a number of models all of which appear to be sufficiently flexible to be capable of describing the data available. Even the oldest, and most intuitive, of these, the "fire-ball" model, provides predictions consistent with the known facts of multiple pion production, and we have used it freely in making rough estimates of expected distributions at the ISR (see section 3 below). A second model, much used in predicting particle fluxes at accelerators, is the thermodynamic model of Hagedorn and Ranft[5)]. Thirdly there is the multiperipheral model[6,7)] which is still at an early stage of development.

It is now important to provide reliable data against which models can be tested, data on the basis of which it will also be possible to make refinements to them. It seems desirable to cover the whole spectrum of particles emitted from the ISR including, in particular, the part with very small longitudinal momentum in the centre-of-momentum system, emitted at large angles with respect to the colliding beams at the ISR, with which this proposal is concerned.

The general features of the momentum distribution of the particles we wish to investigate are easily established without recourse to models: it is well known from experiments that the distribution of transverse momenta rises rapidly from zero at zero transverse momentum to a maximum in the region between 200 and 400 MeV/c; it is clear that the momentum distribution of particles with very small longitudinal momenta will be similar. In the experiment proposed we expect to obtain detailed and precise data in this region. The results obtained, and in particular the cross-sections are sensitive to the distribution of the longitudinal components of momentum in the centre-of-momentum system, and this experiment, together with others carried out at higher momenta (and smaller production angles) should allow complete longitudinal-momentum distributions to be established. The experiment is complementary also to counter/spark-chamber experiments in which the particle fluxes at large angles, but higher momenta, are to be investigated.

One of the aims of the experiment is the measurement of absolute fluxes, making it possible to determine absolute cross-sections once the luminosity is known. These results should not only be useful to test theories, but also in the design of later experiments and in the normalization of relative distributions obtained by other methods.

For completeness we should like to mention that we are aware of the possibility of the production of "new" objects such as monopoles. We propose to organize the scanning in such a way that tracks with unusual properties are reported to physicists for inspection.

3. ESTIMATES OF FLUX TO BE EXPECTED

To obtain an order-of-magnitude estimate of absolute fluxes to be expected around 90° (~ 1570 mrad), we employed program ISRPRO by Andersson and Daum 8). Fig. 1 shows the momentum distributions obtained for pions, kaons, protons and antiprotons. Note that these curves are "pure predictions" 5). Also in Fig. 1 we have plotted the momentum distribution of pions predicted by Friedländer on the basis of the fireball model 9).

The number of interactions per second assumed in these calculations is 1.6×10^5, the design value which may not be reached until some time after startup. For estimation purposes we shall take the pion fluxes produced with this interaction rate to be 10^4 $(\mathrm{GeV}/c)^{-1}$ sr^{-1} s^{-1}, and the fluxes of K^+, K^-, p and $\bar{p}$ to be of the order of 10^3 $(\mathrm{GeV}/c)^{-1}$ sr^{-1} s^{-1} at 1570 mrad (90°), considering momenta below 300 MeV/c only.

To see what this means in terms of an emulsion exposure, let us make the following rough assumptions:

(i) Most of the intensity of the ISR is contained in beams of widths $w_1 = w_2 = 7.5$ cm, a few cm high. Thus the total length of the interaction region is 60 cm; 75% of the interactions will take place in the central 30 cm of this.

(ii) There are produced 10^4 particles $(\mathrm{GeV}/c)^{-1}$ sr^{-1} s^{-1}.

(iii) An emulsion stack is placed at a distance of 100 cm from the interaction region, with an area 30 cm×10 cm facing the beams (see Fig. 2). It subtends a solid angle of about 3×10^{-2} sr at the interaction region.

The useful momentum region we can accept will certainly be more than 100 MeV/c wide. Assuming that the width is 100 MeV/c we find that slow pions will enter the stack at the rate of 30 s^{-1} each for π^- and π^+, and that the other particles considered (K^+, K^-, p, $\bar{p}$) should be coming in at the rate of about 3 s^{-1} each.

For each type of pion alone, a 1-hour exposure would thus produce 3.6 tracks per mm^2 -- an acceptable density for emulsion work.

In the table below we give the estimated total numbers of measurable particles in the stack (2/3 of the number entering) and the number entering each mm^2 of stack surface for two ISR conditions: the design rate of 1.6×10^5 interactions per second, and 10^4 interactions per second.

N_{int} (s^{-1})	Exposure time (h)	π^+ or π^-		other particles		all particles	
		mm^{-2}	total	mm^{-2}	total	mm^{-2}	total
1.6×10^5	1	3.6	7.2×10^4	0.36	7.1×10^3	8.6	1.7×10^5
1.6×10^5	5	18	3.6×10^5	1.8	3.6×10^4	43	8.5×10^5
10^4	1	0.23	4.6×10^3	0.023	4.6×10^2	0.54	10^4
10^4	10	2.3	4.6×10^4	0.23	4.6×10^3	5.4	10^5

The numbers given in this table show that the experiment is entirely feasible unless background is so high that exposures are limited to considerably less than one hour (at 1.6×10^5 interactions per second).

4. BACKGROUND

In general, the rates at which the various types of background will be generated is proportional to the beam current in the rings, whilst the rate at which beam-beam interactions take place is proportional to the product of these currents. Because of this there will be a minimum value of beam current below which useful exposures are not possible. In order to make it possible to plan the experiment and to decide when, in the development period of ISR operations, the first exposures should take place, it is thus most important to obtain detailed and reliable information about the production of background radiation and about its effects in emulsion.

Two types of background will affect the experiment. The first of these is due to particles produced in beam-gas interactions in the interaction region. If such particles have momenta in the range under investigation, they cannot be distinguished from those originating in beam-beam interactions. The second type of background is the general radiation which makes scanning and measurement more and more difficult as its density increases; it will be due to particles and photons produced in beam-gas interactions outside the interaction region and in interactions of the beam halo with the walls of the vacuum chamber and other obstacles. In addition there will be radioactivity in the area.

We have found it possible to make some estimates of the intensity of the radiation caused by beam-gas interactions in the interaction region. The results suggest that this type of background will not be a major problem. On the other hand, we do not have adequate information on the limitations to the exposures due to the second, general, type of background. These limitations, which will affect all emulsion experiments at the ISR, must be investigated in detail with the aid of emulsion exposures at the PS: conclusions arrived at without such tests would be pure speculation. Further below we return to the subject of these tests.

To estimate the background due to beam-gas interactions in the interaction region, we have used the results of fireball-model calculations made by Friedländer9) on pion production in beam-beam and beam-gas (hydrogen) interactions. We have assumed that the gas pressure in the interaction region is 3×10^{-11} Torr, and that the composition is 97% H_2 plus 3% CO10); pressures as low as 6×10^{-11} Torr have already been reached.

Our use of the fireball model does not, of course, imply any prejudice in favour of this model or against any other. We do not pretend to know whether fireballs are real or just a convenient aid to calculations.

We have also made a rough estimate of the flux of background protons due to evaporation of nuclei of carbon and oxygen.

The full design intensity of the proton current in each of the rings is 20A or 1.25×10^{20} protons s^{-1}, corresponding to 4×10^{14} protons circulating. This current will give rise to 1.6×10^{5} beam-beam interactions per second in each of the interaction regions.

Making the assumptions stated above, we calculate the following interaction rates for events in the interaction region giving background particles which are not distinguishable from particles emitted in beam-beam interactions:

Interactions with hydrogen: $1.35 \times 10^{3}\ \mathrm{s}^{-1}$
Interactions with CO($\approx N_2$): $1.9 \times 10^{2}\ \mathrm{s}^{-1}$

Taking account of these rates, of the angular distributions expected from the fireball model[9)], and of the multiplicities in beam-beam and beam-hydrogen collisions, one finds that the background flux of pions at 90° will be less that 10^{-3} of the total, giving a flux in the emulsion of the order of 5×10^{-2} pions (+ and –) per second, to be compared with 60 pions per second from beam-beam interactions.

Evaporation of carbon and oxygen nuclei will produce protons in the energy range between 4 MeV and 30 MeV (85 to 240 MeV/c) which are indistinguishable from slow protons produced in beam-beam interactions. A rough estimate shows that even if the partial pressure of CO is only 3% of the total ($\sim 9 \times 10^{-13}$ Torr), the flux of such protons may well be greater than that of protons from beam-beam collisions. The background of slow protons from evaporation might thus make it difficult to obtain reliable data on the proton flux. A subtraction experiment may be needed unless the proportion of complex nuclei in the residual gas can be reduced.

5. EXPERIMENTAL ARRANGEMENT

As we wish to detect particles with very low momenta, it is essential to have as little material as possible between the interaction region and the entrance face of the emulsion stack. The magnitude of this practical installation problem becomes clear when one realizes that a pion of 20 MeV/c has a residual range of 80μ in nuclear emulsion, about 50μ in steel.

The simplest solution will probably be to install a large and extremely thin window in the vacuum tank. Such a window may not be strong enough to support atmospheric pressure with adequate safety, so that the outside may have to be kept at a low-grade vacuum. To introduce a stack into such a low vacuum, 0.1 Torr for example, does not present special problems.

We thus envisage the installation of an extremely thin large window, separating the ultra-high vacuum in the interaction region (3×10^{-11} Torr) from a rough-vacuum chamber ($\sim 10^{-1}$ Torr) furnished with air locks and some type of mechanism to transport stacks rapidly between a shielded region and the exposure position.

This arrangement could be installed in one of the "low-quality" interaction regions.

As it will take some considerable time to design, build and install the equipment, it is urgent that a decision on whether it should be done be made soon.

6. PRELIMINARY WORK AND PREPARATIONS

To prepare the experiment before start-up of the ISR, the work set out in this section will have to be done during the next two years.

a) Study of background flux to be expected

This involves experimental work, with emulsions, at the PS, as well as some theoretical work to apply the data obtained to expected ISR conditions. Such a study would occupy a small group of competent emulsion workers for three to twelve months.

b) Design and construction of experimental set-up

This is an engineering project which should be attacked in collaboration with ISR engineers. It must be started as soon as possible.

c) Training of a team, or teams, of microscopists

The best type of training would be an experiment involving the same methods of scanning and measurement. Such an experiment, with some scientific interest in its own right, would be a measurement of the momentum spectrum of low-momentum pions at the SC. We propose to carry out such a measurement during the year preceding the ISR experiment.

7. RELATION TO OTHER EXPERIMENTS PROPOSED FOR THE ISR

All emulsion experiments at the ISR are likely to suffer from similar background problems. Thus, even though the scientific aims and the experimental set-ups may be different, all would benefit from a thorough study of background. The results of such an investigation would also be useful in the design of experiments in which other techniques are employed.

Because of the requirement of a thin window, the experimental set-up for the experiment we propose is rather different from that needed for other emulsion experiments. However, all of them would probably need a means of transporting emulsion stacks between a shielded region and the place of exposure, and all of them will need the same general facilities for emulsion handling and processing.

8. MANPOWER REQUIREMENTS

The experiment proposed here does not require a large staff of physicists. The exact number will depend on the number of laboratories over which the work of scanning and analysis is to be distributed.

The rate at which results will be accumulated once the irradiation at the ISR has taken place is proportional to the number of microscopists. In this context it is useful to note that the total number of full-time microscopists working on the Λ^0-magnetic-moment experiment is 36 at present. The majority of the microscopists would, of course, work at collaborating laboratories, not at CERN.

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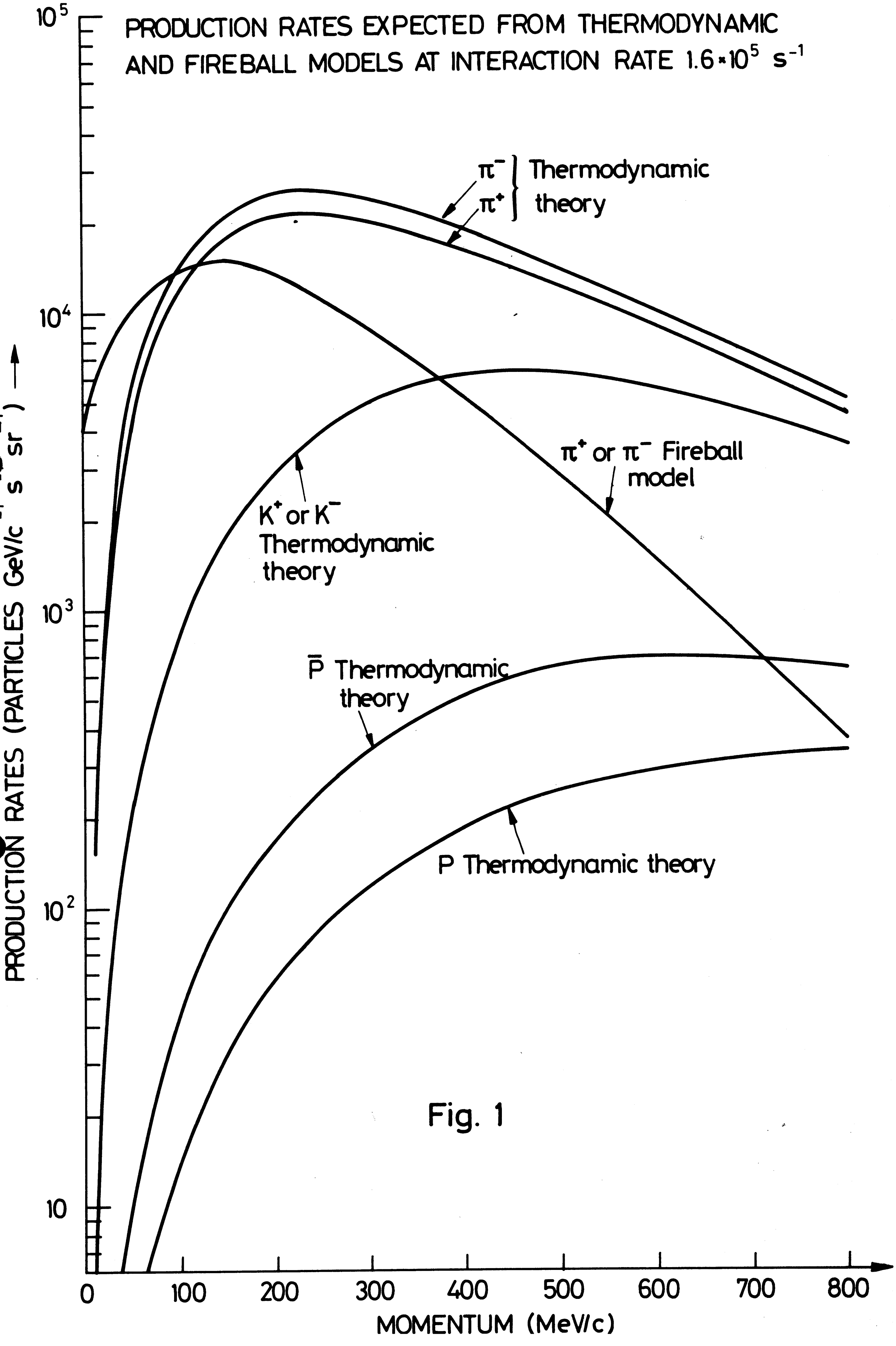

PRODUCTION RATES EXPECTED FROM THERMODYNAMIC AND FIREBALL MODELS AT INTERACTION RATE $1.6 \times 10^5\ s^{-1}$

Fig. 1

FIG. 2