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THE STUDY OF $\bar{p}p$ INTERACTIONS AT 50, 100, 150 AND 200 GeV/c BY MEANS OF A RAPID CYCLING BUBBLE CHAMBER

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Abstract.-

If a rapid cycling bubble chamber would be made available at the SPS as presently under discussion, we would be interested in studying $\bar{p}N$ interactions at high energy. As a first step we propose to carry out $\bar{p}p$ experiments at 50, 100, 150 and 200 GeV/c. The motivation of this proposal is exposed below.

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I. INTRODUCTION

Recently new data have been reported on total $\bar{p}p$ cross sections at 50, 100, 150 and 200 GeV/c incident momentum[1]. We propose to complete these investigations by studying $\bar{p}N$ reactions at the same momenta by means of a hybrid bubble chamber - counter type experiment. The present letter of intent is based on the hypothesis that a rapid cycling bubble chamber (R C B C) coupled to a downstream device allowing the identification of secondary particles will be available at the S P S. The advantages offered by the possible additional presence of a γ-detector are also discussed. The bubble chamber would not only be used as a vertex-detector but would also constitute an essential part of the global particle identification and measurement set-up. The properties of the R C B C - I S I S combination have been considered previously by Allison et al.[2]. The availability of a vertex-detector like the one described in reference (2) appears to be a very powerful tool for studying the physics of high multiplicity final states as will be discussed below.

As a first step of the proposed study of $\bar{p}N$ interactions, we would be interested in collecting 50,000 $\bar{p}p$ interactions at each of the following momenta : 50, 100, 150 and 200 GeV/c. As shown below, this will lead to statistics sufficient for the physics which we forsee to study. In the future we intend to complete this systematic study of $\bar{p}N$ interactions by investigating the properties of $\bar{p}d$ reactions in the 100—300 GeV/c region.

II. MOTIVATION FOR USING A VERTEX-DETECTOR FOR THE STUDY OF VERY HIGH ENERGY INTERACTIONS

The primary aim of the present proposal is the study of high multiplicity events induced by high energy antiprotons. Therefore in order to avoid tedious pattern recognition problems, a vertex-detector with a nearly 100 % detection efficiency for charged particles will be particularly suitable for analysing multiprong events in which secondary particle interactions and decays could occur relatively frequently close to the primary vertex. The use of a visual technique has the inherent disadvantage of not allowing a complete on-line analysis of the data. This however is not a great incovenience, in view of the complexity of the pattern recognition problems with which non visual automatic techniques would have to deal. A rapid cycling bubble chamber would allow us to determine the space coordinates of the primary vertex with a precision of 50 μ, which is essential for the optimised use of downstream devices as recent F N A L hybrid experiments have shown. In addition, the R C B C will offer the usual isotropic detection, measurement and identification power for low momentum (≤ 1 GeV/c) particles. In the study of interactions in hydrogen this feature will permit the detection of low momentum transfer diffractive processes. When analysing interactions on deuterium the study of reactions with quasi - free neutrons will be improved through the observation of spectator protons.

III. MAIN PHYSICS INTERESTS

a). Topological cross sections

The proposed experiment will allow us to measure the topological cross sections (σ_n) and also the statistical moments of the charged multiplicity distributions as a function of incident momentum. Because of the I S I S system, the annihilation topological cross section can also be obtained. Indeed as part of the $\bar{p}p \rightarrow \bar{p}\, n\, m\, M$ (where M denotes a meson in the final state) and the $\bar{p}p \rightarrow \bar{n}\, p\, m\, M$ cross sections can be measured, an estimate of the cross section of $\bar{p}p \rightarrow \bar{n}\, n\, m\, M$ can be obtained, assuming, for instance, factorization. Thus by a subtraction procedure one can obtain estimates of the annihilation topological cross sections. The comparison of the topological cross sections for $\bar{p}p$ with the pp results (see Table I) may be of interest in understanding the mechanisms involved in those interactions.

b). Exclusive reactions

Recent $\pi^- p$ and pp bare bubble chamber experiments at 205 GeV/c[3,4] have shown that the fitting of four constraint events can be carried out. The R C B C - I S I S systems represents however a large improvement over the 30" B.C. This would be even more the case if an external γ detector would be added to the system. Therefore we intend to study fitted 4C and possibly 1C low multiplicity events. For such topologies it should be possible to make a systematic comparison of $\bar{p}p$ and pp exclusive reactions.

c). Single particle distributions and correlations in inclusive reactions

The combined advantages of the RCBC and ISIS will allow a study of various single particle distributions as those observed for instance in the following inclusive reactions :

$$\begin{aligned} \bar{p}p &\to \bar{p}X \\ &\to \pi^{\pm}X \\ &\to K^{\pm}X \\ &\to \Delta^{++}X \\ &\to VX \end{aligned}$$

where V stands for the decay of a strange particle. The importance of quantum number exchanged in the t channel can be stressed by comparing these reactions with pp interactions. Such a comparison should be of particular interest in the study of inclusive K_s^o production, whose cross section is known to behave very differently for $\bar{p}p$ and pp interactions below 10 GeV/c incident momentum.

The measurement and identification of the outgoing particles will permit the study of two particle correlations between all pairs of charged particles using various kinematical variables.

d). Diffraction dissociation

Diffraction dissociation of both beam and target particles can be studied in this experiment. In particular, $\bar{p}$ diffraction dissociation can be investigated in the reaction

$$\bar{p}p \to pX$$

for laboratory momenta of the proton up to 1.3 GeV/c, removing two-prong elastic events by a kinematic fitting procedure(*). The mass distribution of

(*) Elastic scattering events could be studied as a check of the results of counter experiments where systematic effects are of a different nature.

of the "X" system will be studied for the various topologies. An estimate of the total diffractive inelastic cross section can be obtained and compared with the ISR data for the events with values of the Feynman variable $x < -0.9$, where the non-diffractive background is known to be small[5]. The energy dependence of the cross section will be compared to the data of pp experiments.

e). Annihilation channels

The ISIS device should allow the identification of charged secondaries of momenta between 5 and 100 GeV/c. The latter momenta will be determined with good precision (about 10 % momentum resolution for 150 GeV/c charged particles). The identification and anti selection of fast secondary antiprotons by ISIS and of slow protons by the bubble chamber, will provide a means of obtaining an enriched sample of annihilation events. An estimate of the annihilation cross section in the 50 – 200 GeV/c range can be made assuming that the cross section is falling with energy ($\sqrt{S}$) according to $S^{-0.6}$ as extrapolated from low energy data[6]. One thus obtains an annihilation cross section of about 6 and 3 mb at 50 and 200 GeV/c respectively. The validity of these estimates are confirmed by the known difference between $\bar{p}p$ and pp total cross sections. In a 50,000 interaction sample one hence expects about 6700 and 3200 annihilation events at 50 and 200 GeV/c respectively (see Table II). The proposed experimental set-up will allow us to detect annihilation channels with strange particles in the final state.

f). Non-annihilation channels

The properties of non-annihilation channels can be compared to those of pp interactions. Moreover a search for baryonic and mesonic resonances will be carried out. The search for bosonic resonances is of great interest because recent ISR data suggest that they are produced abundantly in very high energy reactions[7]. In particular the search for the $\phi \to K^+K^-$ resonance will be interesting in connection with the e^+e^- production observed in recent ISR experiments[8].

IV. GAMMA DETECTION

The hybrid system proposed in reference 2, does not include explicitely gamma detectors. It recognizes, however, their importance and stresses the ample possibilities offered by their apparatus for useful gamma detection. Gamma detectors are foreseen also in the proposed FNAL "improved 30" BC hybrid system"(13). If fast forward π^0's could be detected and measured, the scope of our proposed experiment could be considerably extended. Inclusive π^0 spectra and two-particle correlations including π^0's could be studied. Moreover, events with a single fast π^0 could be included in the 4 constraints class : a γ-veto could also be put to obtain an enriched "conventional" 4C events. Finally, production of narrow resonances like ω^0 and η^0 could be studied. In particular the 2γ decay of η^0 could be detected with good efficiency.

We consider it important, therefore, that the possibility of equiping the RCBC-ISIS system with a forward gamma detector, of a type similar to that proposed for use with BEBC and a TST(14) be studied. By putting a detector $1.5 \times 1.5 m^2$ wide, about 9 m from the center of the chamber, γ's emitted at $\pm 5°$ could be measured. If magnets and wire chambers were used behind ISIS for measurements of particles with momenta > 50 GeV/c the gamma detector design would become more complicated, but still feasible (see for instance ref.13). Possibly the set-up could be complemented by detectors for charged (or neutral) particles emitted at large angles.

V. THE EXPOSURE

Table II shows, in the hypothesis that $\bar{p}p$ topological cross sections have the same branching ratios as pp ones (see Table I), the number of interactions of the various kinds we would get in a sample of 50,000 pp interactions at 50,100 and 200 GeV/c. Since a separated $\bar{p}$ beam may not be available at the highest momenta (above 100 GeV/c) to keep the number of pictures, and of bubble chamber expansions, to a reasonable level we will have to use an enriched beam, of the type proposed by Neale(15) (the content of $\bar{p}$ in a ~ 200 GeV/c non-enriched negative beam is $\leq 1\%$).

The most promising of the schemes proposed by Neale seems to be that using $\bar{p}$'s from $\bar{\Lambda}^0$ decays (target halo beam). The fraction of $\bar{p}$'s in the secondary beam would be, in this case, at the bubble chamber, 25 ± 50%, depending on the beam design. The yield would be, again at the bubble chamber, one $\bar{p}$ per 10^{10} primary protons on the target. The total flux of negative particles would then be 2 or 4 depending on the beam design. The primary proton energy should be 300 GeV for $\bar{p}$'s up to 150 GeV/c and 400 GeV/c for $\bar{p}$'s of 200 GeV/c. For the fraction of $\bar{p}$'s present in the secondary beam we shall use, in the following, the lower of the two values given by Neale, or 1 $\bar{p}$ every 4 particles. If the 10^{13} ppp extracted proton beam (E P B) is spilled out during a ~ 700 – 900 ms flat - top, this would supply the ~ 4 particles (1 antiproton) per ms that the R C B C requires. With a 50 cm fiducial length in the chamber and a cross section of ~ 40 mb, this flux would yield one interaction every 4 expansions and one $\bar{p}$ interaction every 16 expansions, i.e. every machine pulse (the R C B C can operate at 15 Hz). The total intensity used by the bubble chamber would be 15×10^{10} protons, a negligible fraction of the total. In practice, the B C beam could be produced by interposing on the E P B line, which takes the beam to another "main user", a rotating target which would intercept the E P B 15 times per second, each time for 1 ms.

The secondary beam line should be equipped with a Cerenkov for tagging antiprotons, hence allowing a triggering of events to be photographed. The exact trigger to be chosen will depend on the quality of the beam and on the equipment available with the R C B C - I S I S system. The triggers we consider at present are :

1). Interaction trigger : Wire chambers, or counter hodoscopes, placed before and after the chamber, would detect the disappareance, or displacement from its undisturbed path, of a $\bar{p}$ primary. This might require some computation from the on - line computer, but with our flux (~ 4 particles/ms) there should be enough time for it. (Or, the trigger could be made by hardware logic).

2). Multiplicity trigger : The wire chamber or counter hodoscope placed behind the bubble chamber could supply the trigger whenever it is hit by a given number of particles.

3). γ - trigger : If a γ - detector is employed, the signal from it could be used to trigger the flash.

4). If a slow - particle detector is used, a signal from that could also be used as a trigger.

Using a combination of the above triggers in coincidence with the tagging of the primary, we would be sure to get most of the $\bar{p}$ interactions that occur in the chamber. The triggering system can also be used to flag a specific type of interaction. The main loss would be small angle elastic scatterings and part of the two pronged events.

It seems possible, therefore, to obtain at each energy the required sample of ~ 50,000 interactions with ~ 100,000 pictures in 50,000 machine pulses and 800,000 R C B C expansions.

VI. CONCLUSIONS

The results already obtained at F N A L with the 30" bubble chamber have shown that interesting experimental material can be investigated with such an instrument. The R B C B as described in reference 2 represents, however, a large improvement over the 30" bubble chamber. The physical interests discussed above show that many new aspects of high energy $\bar{p}$ interactions can be investigated with the R C B C coupled with the downstream I S I S device. The number of interactions listed in Table II for each topology is sufficient to carry out an interesting physics program. The detection and measurement of fast, forward π^o's would considerably extend the scope of the experiment.

The experiment can be carried out in an entirely parasitic way, if an enriched beam scheme will be implemented and will require a total exposure to ~ 200,000 machine pulses.

The four proposing laboratories could handle in a reasonable time the 50,000 interactions at each of the four momenta that we request. Two of the proposing groups are at present carrying out a hybrid experiment at F N A L with the 30" B C. A third group is involved in experiments on high energy interactions in Mirabelle and introduced a proposal to study antiproton interactions in B E B C at 70 GeV/c incident momentum[16].

TABLE I

TOPOLOGICAL CROSS SECTIONS IN pp COLLISIONS

Prong Number	Cross section (mb) 50 GeV/c (9)	102 GeV/c (10)	205 GeV/c (11)	303 GeV/c (12)
2 elastic	6.9 ± 0.2	7.0 ± 0.4	6.8 ± 0.3	7.2 ± 0.4
2 inelastic	5.97 ± 0.88	4.5 ± 0.4	3.49 ± 0.87	1.78 ± 0.56
4	9.40 ± 0.47	7.9 ± 0.3	5.55 ± 0.28	4.84 ± 0.30
6	7.99 ± 0.43	7.5 ± 0.3	6.94 ± 0.31	5.71 ± 0.34
8	5.02 ± 0.33	5.8 ± 0.2	5.78 ± 0.28	5.40 ± 0.33
10	2.03 ± 0.20	3.7 ± 0.2	4.41 ± 0.25	4.72 ± 0.32
12	0.48 ± 0.10	1.6 ± 0.1	3.43 ± 0.22	4.19 ± 0.30
14	0.20 ± 0.06	0.62 ± 0.07	1.70 ± 0.16	2.17 ± 0.21
16	0.01 ± 0.02	0.21 ± 0.04	0.87 ± 0.11	1.39 ± 0.17
18	–	0.05 ± 0.02	0.30 ± 0.07	0.87 ± 0.14
20	–	0.016 ± 0.011	0.17 ± 0.05	0.51 ± 0.11
22	–	–	0.05 ± 0.03	0.07 ± 0.06
24	–	–	–	0.10 ± 0.05
26	–	–	–	0.05 ± 0.03
total inelastic	31.1 ± 1.2	31.9 ± 0.7	32.7 ± 1.2	31.8 ± 1.3
total	38.0 ± 1.0	38.9 ± 0.8	39.5 ± 1.1	39.0 ± 1.0

TABLE II

ESTIMATED NUMBER OF $\bar{p}p$ EVENTS OBTAINED FROM 100 K PICTURES (4 PRIMARIES/PICTURE) USING THE RCBC WITH A FIDUCIAL REGION OF ABOUT 50cm, AN ENRICHED BEAM, TAGGING OF THE PRIMARY AND TRIGGERING (see Text)

Prong Number	Estimated number of events at 50 GeV/c	100 GeV/c	200 GeV/c
0	600	370	230
2 elastic	9000	9000	8600
2 inelastic	7800	5800	4400
4	12000	10000	7000
6	10400	9600	8800
8	6400	7400	7300
10	2600	4700	5500
12	600	2000	4300
14	260	800	2100
16	12	270	1100
18	–	60	370
20	–	25	220
22	–	–	60
total inelastic	41000	41000	41500
total annihilation	6700	4600	3200
total	50000	50000	50000

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