NAL PROPOSAL No. 267

Scientific Spokesman:

D.R.O. Morrison
CERN
1211 Geneva 23
Switzerland

PROPOSAL TO STUDY 100 GeV/c NEGATIVE PARTICLE INTERACTIONS IN THE NAL 15 FOOT BUBBLE CHAMBER

Aachen-Bonn-CERN-Cracow-London-Vienna-Warsaw Collaboration

November 1973

CERN/D.Ph.II/DROM/ef
11.2.1974

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SUMMARY

A request is made for photographs of 100 GeV/c negative particles in the 15 foot NAL hydrogen bubble chamber. The main aim of the experiment is to study exclusive reactions. This would greatly extend our experimental knowledge of reaction mechanisms, in particular of diffraction dissociation.

SPOKESMAN FOR THE COLLABORATION: D.R.O. Morrison

SPOKESMEN FOR THE GROUPS: G. Otter (Aachen), K. Böckmann (Bonn), D.R.O. Morrison (CERN), K. Zalewski (Cracow), P. Dornan (London), M. Markytan (Vienna) and R. Sosnowski (Warsaw).

CONTENTS

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1. MOTIVATION

Recently our knowledge of the reaction mechanism of inelastic high energy collisions has been greatly extended by the study of inclusive reactions. However, very few exclusive reactions have been or are being studied above 40 GeV/c. We feel that the next great advance will come from a systematic study of exclusive reactions and this is the main purpose of the experiment we propose.

A large bubble chamber is an excellent instrument to study exclusive reactions since the vertex region of the interaction can be clearly seen and accurate measurements can be made on the charged secondaries and on a substantial fraction of the neutral secondaries (e.g. neutrons, π^o's, K^o, Λ). With the NAL 15 foot chamber, 4-constraint reactions should be easily identified kinematically, but such reactions are few in number and, from isospin considerations, have small cross sections at high multiplicities. One-constraint reactions are however more numerous and tend to have higher cross sections. Our aim is to obtain good samples of both 4C and 1C reactions - this will allow us to cover all multiplicities. Results from NAL and ISR have shown that diffraction dissociation does not occur only in 3 and 4-body reactions, but also in higher multiplicities up to $\gtrsim$ 10. Thus we would like to study diffraction dissociation in the reactions:

$\pi^- p \rightarrow p\pi^o\pi^-$	$\pi^- p \rightarrow n\pi^+\pi^-$
$\rightarrow p\pi^+\pi^-\pi^-$	
$\rightarrow p\pi^+\pi^-\pi^-\pi^o$	$\rightarrow n\pi^+\pi^-\pi^+\pi^-$
$\rightarrow p\pi^+\pi^-\pi^+\pi^-$	
$\rightarrow p\pi^+\pi^-\pi^+\pi^-\pi^-\pi^o$	$\rightarrow n\pi^+\pi^-\pi^+\pi^-\pi^+\pi^-$
$\vdots$	$\vdots$

where we would study not only the pion dissociating into 3π, 5π, 7π, ... but also the proton dissociating into $p\pi^o$, $n\pi^+$, $p\pi^+\pi^-$, $p\pi^+\pi^-\pi^o$, $n\pi^+\pi^-\pi^+$, ...

Our choice of 100 GeV/c is motivated by the fact that this is an energy at which one can still identify a substantial fraction of one constraint reactions in the "bare" 15-foot chamber. This fraction would be greatly increased if the momentum of the fastest outgoing secondaries would be measured downstream of the chamber (see sect.2.2).

The choice of a negative beam (mainly π^-, some K^- and $\bar{p}$) as projectiles is made to study the interactions of non-identical hadrons. This provides considerable additional information to what is learned from proton-proton interactions (e.g. a forward lambda particle would suggest baryon exchange in meson-proton reactions, but in pp reactions it would be difficult to determine whether the lambda came from the projectile or target proton).

While exclusive reactions are the most exciting subject, we would measure all charged and neutral secondaries of all events to study also inclusive reactions, correlations, events of large transverse momentum.

A particular advantage of our Collaboration is that the ERASME system is working at one laboratory and being developed at two other laboratories. It is a system designed especially for BEBC and therefore will be immediately useful for the 15-foot chamber. As explained in sect. 3.4, it should be possible to use this system to identify one constraint events with a missing neutron, by calculating the direction of this neutron while the event is still on the scanning + measuring table and thus allowing a search for an interaction of this neutron. The neutron interaction could thus be immediately measured.

We are very interested in the energy variation of the various exclusive and inclusive processes. Our Collaboration has already made extensive measurements of meson-proton reactions at lower energies (π^+p at 8,16 and 23 GeV/c, π^-p at 16 GeV/c, K^-p at 10 and 16 GeV/c) which would be immediately available for the new types of analysis that we expect to make with 100 GeV/c film. Also the CERN group is at present working on photographs of 100 GeV/c π^-p interactions in the NAL 30-inch chamber.

2. EXPERIMENTAL CONDITIONS

In this section we want to specify our requirements and assumptions about beam and chamber and present the scanning and measuring techniques.

2.1 Beam

We request accelerated protons of 300 GeV/c momentum in order to obtain in the secondary negative beam a useful fraction of kaons and antiprotons. We assume that there will be a system of Čerenkovs and hodoscopes in the beam allowing us to tag the individual particles and thus make use of the K^- and $\bar{p}$ contamination, which we expect to be of about 2% and 0.5%, respectively. For the 100 GeV/c pion beam we assume a momentum resolution $\Delta p/p$ of $\leqslant 0.2\%$ and an angular resolution (using wire planes in the beam line) of $\Delta\theta \leqslant 0.2$ mrad.

2.2 Chamber and Downstream Apparatus

This request is essentially for a "bare" chamber but the experiment would be considerably helped if additional equipment were available downstream - in particular a measurement of the momentum of fast secondaries would increase the fraction of one-constraint exclusive reactions which can be studied.

In the estimate of experimental errors, the following constants were assumed:

Magnetic Field....	30 kG
Setting Error...	300μ .

2.3 Scanning and Measuring

The Collaboration has a large scanning and measuring capacity and is preparing systems for measuring BEBC film. In particular CERN has the ERASME system working - this was specifically constructed for BEBC and is immediately usable for the 15 foot NAL chamber. It has a measuring capacity of $\gtrsim$ 200 K photographs/year.

Other groups in the Collaboration are constructing similar systems.

A particular advantage of the ERASME system is that the geometry is calculated on-line. We propose to use this facility to calculate the direction and momentum of the missing mass. The operator will then be instructed to scan carefully along, and near, this direction. If the missing mass was a single particle, e.g. a neutron or K^o, then the measurement of any observed interaction, e.g. a proton recoil, could be instantly added and calculated. The effect of this would be to convert a possible 1-constraint fit into a relatively sure 4-constraint fit.

It is intended that we scan for and measure all types of events, i.e. all multiplicities, decays, electron pairs etc.

3. DATA EXPECTED

Quite detailed studies have already been made of the kind and quality of data expected from large bubble chambers [1,2]. We give below some results of calculations done specifically for 100 GeV/c pions interacting in the 15 foot NAL chamber.

3.1 Accuracy of momentum measurements

With the setting error and magnetic field specified above and an average track length of fast particles (> 10 GeV/c) of $\sim$ 2.5 m, the error in 1/p is $\sim 1.5\ 10^{-4}\ \mathrm{GeV}^{-1}$, which implies a momentum resolution $(\frac{\Delta p}{p} = p \cdot \Delta\frac{1}{p})$ of 15 MeV/c for a track of 10 GeV/c and 1.5 GeV/c for 100 GeV/c.

The resolution in the azimuthal angle is $\sim$ 0.15 mrad not taking into account the uncertainty in the beam direction which is of the order of 0.2 mrad.

3.2 Slow protons

Protons will be trapped in the chamber up to about 800 MeV/c and hence their momentum can be determined by range within 1 MeV/c. Calculations of the missing mass against a slow proton and of its error show that the resolution is bad for proton momenta below 300 MeV/c ($|t| < 0.1$) but is at an acceptable level above that and for MM > 1 GeV.

3.3 Kinematic Fitting

The quality of 4 constraint fits depends on how well one can veto against slow additional neutrals. The most restrictive check against neutrals comes from the transverse momentum balance. Formulated in terms of χ^2 this reads as [3]

$$\chi^2 = \left(\frac{p_{T,O}}{\Delta p_T}\right)^2$$

where $p_{T,O}$ is the transverse momentum of an undetected neutral and Δp_T is essentially given by $p\Delta\Theta$ of the track with highest momentum, which is $\lesssim$ 25 MeV/c in our case. It follows that events with neutrals having p_T < 65 MeV/c will fit the 4C hypothesis with a confidence level > 1%. How much bias this actually means for a specific channel depends on the ratio of cross sections of final states differing by one π^o (see sect. 4.3). In any case we expect less than 10% bias in the 4C channels even in the bare chamber. Measurement of electron pairs and neutral interactions should both reduce this contamination and allow it to be studied and corrected for.

The situation is worse for 1C fits, as in certain parts of phase space the error in the missing mass becomes so large that it is not sure whether it is possible to discriminate by kinematic fitting - this is particularly so for very slow and very fast neutrals. By measurement of interactions of neutral particles and of gamma conversions we will check the quality of the 1C fits obtained in the various regions of phase space and deduce criteria that will enable us to employ also the events in which no neutral interaction or gamma conversions are observed.

This is the solution which would be adopted with a bare chamber. However the problem could be better resolved if a measurement of the momentum of the fastest outgoing particle were made with a downstream spectrometer. If such a measurement had a precision of $\sim$ 100 MeV/c, then there should be almost no ambiguities between (one π^o) and (two π^o) events or between n and (n + π^o) events.

3.4 Neutron Detection

If the interaction of a secondary neutron can be measured, then it is possible to convert a 1C fit into a 3C or 4C fit. Also, the detection of neutrons allows a check on the efficiency of the 1C fits. We would use the ERASME system to calculate on-line the direction of the missing neutral and scan only in this region.

One-constraint events giving a low momentum neutron are difficult to fit kinematically, but up to 1 GeV/c the neutron-proton cross section is mainly elastic so that measurement of the momentum and angle of the recoil proton yields complete information about the 4-momentum of the reaction. In practice the recoil proton has to have a momentum of > 150 MeV/c to be measurable. Cross sections and reaction probabilities in the 15 foot chamber assuming a potential path length of 6 feet, are listed in table I. It may be seen that a good sample of 1C events can be converted into 4C events. As the neutron momentum increases, the cross section for elastic scattering decreases, but kinematic fitting becomes more reliable. Also observation of the direction of inelastic neutron interactions can convert a 1C fit into a 3C fit.

In this section we have considered especially the case of the missing neutral being a neutron. However if the missing neutral were another hadron, e.g. K^o or Λ, the same technique involving ERASME, would apply.

3.5 Gamma Conversion

One advantage of big bubble chambers is the increased conversion probability for gamma rays. This has three main uses:

1. determination of 1C events with a missing π^o,
2. by finding the number of gammas associated with events fitted as four-constraint, the contamination of the 4C sample can be determined,
3. from the numbers of events with 0,1,2,3,... gammas converting into electron pairs, the distribution of events with 0,1,2,3,... π^o's can be determined.

For events in the upstream half of the chamber, we assume a mean path length of gammas in the chamber of 3 metres which gives a mean conversion probability of 0.3. Final states with one π^o will have,

no	visible	gamma	in 49%	of	the	events
one	"	gamma	" 42%	"	"	"
two	"	gammas	" 9%	"	"	"

The efficiency for reconstructing individual π^o's is somewhat less than 9% since very soft gammas may be undetectable or unmeasurable.

The technique of using ERASME to establish at the measuring table, the direction of the missing momentum can be useful also here. If the missing neutral particle is a π^o, then in a good fraction of the events (≈ 40%), one of the gammas emitted will have almost the same direction as the π^o, if the direction of break-up of the π^o is approximately along the line-of-flight of the π^o - and this fraction is quite large since the Q-value, and therefore the transverse momentum is small. This technique can be used statistically and for some individual events, to confirm the 1C hypothesis suggested by kinematic fitting.

4. PHYSICS

Bubble chamber experiments yield highly differential data allowing many different approaches in their analysis. For the sake of systematics we split the discussion of the physics that we expect to study into 3 fields:

1. exclusive studies
2. inclusive studies
3. cross sections and multiplicities.

The analyses proposed here should be considered as a minimum programme as it has always been our experience in working on bubble chamber data that an appreciable part, and often the most interesting part, of the work was on subjects that were not considered or foreseen before the photographs were taken.

Estimates of the event rates are based on 100 K photographs containing 400 K events for most types of reactions. Where fitted reactions are considered a smaller fiducial region is taken, corresponding to 250 K events or 10 events/μb.

4.1 Exclusive Studies

One field of activity with exclusive reactions will consist in repeating analyses made of inclusive reactions to investigate how inclusive results are built up from the individual exclusive channels and to whether the results obtained are general ones or derive from characteristics of only certain exclusive channels. For example, some results [4] on charge transfer ΔQ, between forward and backward hemispheres at $\gtrsim$ 10 GeV/c seem surprising and, if confirmed at 100 GeV/c, should be studied as functions of the multiplicity of the exclusive channels. Results on correlations and clusters obtained from inclusive reactions and from various charged multiplicities, need study in terms of the "true" (i.e. charged + neutral) multiplicity since the effects of adding together events of different "true" multiplicities does create correlations.

We particularly wish to study diffraction dissociation effects in different multiplicities, both single diffraction dissociation, SDD and double diffraction dissociation, DDD. The reasons for this have recently been described in ref. 5. We now consider the various channels in more detail.

$p\pi^+\pi^-\pi^-$

At 200 GeV/c this channel has been reported [6] to be almost purely diffractive with a cross section of 500μb. The number of events then expected at 100 GeV/c is $\gtrsim$ 5000. This number is just large enough to allow a partial wave analysis of the 3π state which would then be compared with lower energy results (5-40 GeV/c). It would be of great interest to see whether the average spin continued to increase with the mass of the 3π system and whether the detailed partial wave structure has changed or not.

$p\pi^+\pi^+\pi^-\pi^-\pi^-$

The investigation of this channel will probably have the same importance for diffraction dissociation at 100 GeV/c as the channel $p\pi^+\pi^-\pi^-$ has between 5 and 20 GeV/c. We hope to get completely new information about SDD into higher mass states ($\pi \to 5\pi$, $p \to p4\pi$) and about the existence, cross section and properties of DDD [$\pi^- p \to (3\pi)^- (p\pi\pi)^+$], as well as about non-diffractive mechanisms of multiparticle production. If our present knowledge about DD is correct, we may expect to see in addition to the A_3 at 1640 MeV, a ($f\pi$) state, also an A_4, at around 2100 MeV as a ($g\pi + \rho'\pi$) state and possibly an A_5 at around 2400 MeV if there is a $J^P = 4^+$ recurrence on the exchange-degenerate ρ-f trajectory.

It will be interesting to see whether diffractively produced ($A_2\rho$) systems occur. A_3 and most likely A_4 will show up in the final state $p\pi^+\pi^-\pi^-$ as well and can be studied in two different modes.

It is not clear how diffractively produced baryon states will look New peaks in the mass spectrum similar to $N^*(1470)$ or $N^*(1700)$ above a broad background could reveal interesting structure in the baryon spectrum.

It is not easy to estimate the cross section for this channel since the contributing reaction mechanisms are not well known. The cross section at 16 GeV/c is 180μb. As the total 6 prong cross section is still growing at 16 GeV/c and the multiplicity distribution at 100 GeV/c peaks at 6 prongs, we expect a value around 150μb corresponding to 1500 events. The channel with an additional π^0 is expected to have a cross section about twice as big so that bias due to incorrect fits will be about 5 to 10%.

$p\pi^-\pi^0$

$p\pi^+\pi^-\pi^-\pi^0$

The probability of having both γ's converted is ∿ 10%. This leaves us with a rather low number of fits, namely ∿ 100 for $p\pi^-\pi^0$ and 150-200 for $p\pi^+\pi^-\pi^-\pi^0$. Biases in these channels come from final states with $2\pi^0$'s for which the probability of having two and only two converted gammas coming from the same π^0 is also ∿ 10%. Therefore the purity of the sample depends on the transverse momentum fit suggesting a 5 to 15% contamination. However these numbers are lower limits and the use of kinematic fitting and of events with one gamma, as described in sect. 3.5, is expected to give a larger sample.

These channels are particularly interesting for comparing the SDD and DDD reactions $\pi^- p \rightarrow \pi^- (p\pi^o)$ and $\pi^- p \rightarrow (3\pi)^- (p\pi^o)$.

$n\pi^+\pi^-$ and $n\pi^+\pi^+\pi^-\pi^-$

From measurement of secondary elastic np scatters, one expects the following number of fits; 450 to 550 for $n\pi^+\pi^-$ and 400-500 for $n\pi^+\pi^+\pi^-\pi^-$. Again these numbers are lower limits and considerably more are expected from kinematic fitting.

The SDD and DDD reactions $\pi^- p \rightarrow \pi^- (n\pi^+)$ and $\pi^- p \rightarrow (3\pi)^- (n\pi^+)$ can be compared with one another and with the results for the corresponding π^o channels. However the sample with neutrons is larger and probably cleaner than in the π^o case. Moreover the neutron polarization can be determined from secondary scattering, yielding information about spin-parity and helicity structure of diffractively produced baryon states.

Similar studies will be made with higher multiplicities.

Energy dependence of all cross sections for quasi two-body reactions, channel cross sections, for fixed mass intervals etc. will be studied using lower energy data as this yields valuable information on reaction mechanisms.

4.2 Inclusive Studies

Single particle spectra can be measured for charged pions, for neutral pions via the γ-spectra, for protons in a region limited by $p_{LAB} \lesssim 1.5$ GeV/c and for K^o and Λ. For incident pions these spectra and other integrated information like charge distributions will be known by then. We hope to measure at least part of these spectra also for incident K^- ($\sim$ 7000 events on 100 kpx) and for $\bar{p}$ ($\sim$ 3500 events) and to compare them with the spectra of pion and proton induced reactions.

Single particle spectra are input to studies of two and more particle correlations. With the amount of detailed and complete information in bubble chamber data we expect many new and relevant results about multiparticle production. We list some of today's problems which we would like to study:

1. detailed studies of particle systems recoiling against individual particles (p, K^o, Λ, leading π^-) and other particle systems (Δ^{++}, forward or backward going groups of charged particles). This includes measuring the missing mass spectrum against slow protons [6]. Particle multiplicities are known functions of the total energy available. It is important to check whether the same dependence holds also for subsystems of events,

2. events with secondaries of high transverse momentum can be studied in detail without angular restrictions and can be compared to "normal" events in an unbiased way,

3. investigation of high multiplicity events ($\gtrsim$ 6 particles) especially to study clustering effects. Since the total rapidity range for pions at 100 GeV/c is 9.25 and the present estimates for the short range correlation length are about 2, possible structures in rapidity distributions should be well detected.

4.3 Cross Sections and Multiplicities

Obvious numbers to determine are total cross sections for single particle production of pions (π^+, π^-, π^o) and of strange particles (K^o, Λ, $\bar{\Lambda}$, $\Sigma^{\pm}$). The charged multiplicity distribution and its variation with energy will certainly be known from other experiments by the time these data become available. What will be new, however, is the possibility of determining not charged but "true" multiplicity distributions via multiplicities of converted gammas in hydrogen (assuming that all gammas are coming from π^o's). With x being the mean conversion probability for gammas in the chamber and P_n the probability of having n π^o's in a final state, the gamma-multiplicity is given by the sum of binomial distributions:

$$P(n_\gamma) = \sum_n P_n \frac{(2n)!}{(2n-n_\gamma)!(n_\gamma)!} x^{n_\gamma} (1-x)^{2n-n_\gamma}$$

This formula can be fitted to the experimental distribution with the P_n as parameters. Performing such an analysis for each charged topology separately yields almost complete information about channel cross sections. This is of relevance to all models of particle production which up to now can only be checked against integrated data like charged multiplicities or correlations of the type $<n_o>/n_{ch}$.

5. REQUEST

Our proposal is for 100,000 photographs of 100 GeV/c negative particles in the 15-foot NAL hydrogen bubble chamber which would give about 400,000 measurable interactions. We request that there be Čerenkovs and hodoscopes in the beam so that incident K^- and $\bar{p}$ particles can be identified - the fraction of such particles could be increased if the protons incident on the target were of the highest possible energy. As we particularly wish to study exclusive reactions, a good angular resolution of the beam track is essential and it would be a great improvement if the momentum of the fastest secondary could be measured accurately in a downstream spectrometer. We would be prepared to measure these photographs as soon as available, and we intend to make this our main experiment in 1975/1976. If, as we hope, we can finish measuring the film in late 1975 or early 1976, then we would be interested in an extension of the experiment.

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TABLE 1

Detection probability of neutrons from measurable np elastic scatters.

Neutron			σ	Reaction probability %	p_p>150MeV efficiency %	Total detection probability %
momentum MeV/c	m.c. energy MeV	kin.en. MeV	mb			
200	1887	21	350	100	43.5	43.5
300	1900	47	130	78	74.5	58
400	1917	82	70	42	85.5	36
500	1938	125	50	30	90.5	27
600	1962	175	40	24	93	22
700	1989	232	35	21	95	20
800	2019	295	32	18	96	17
900	2049	362	32	18	97	17
1000	2082	433	32	18	97	17