HADRONIC FINAL STATES IN ν AND $\bar{\nu}$ EXPERIMENTS

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Abstract

An overview is presented of the experimental possibilities of the study of fragmentation in the BEBC bubble chamber, exposed to neutrino and antineutrino beams. Comparisons are made with other techniques: muon-hadron and electron-positron experiments. Possible improvements of BEBC are discussed that will improve our knowledge of the fragmentation.

1. INTRODUCTION

In the past, fragmentation processes have been studied in the BEBC bubble chamber, filled with H_2 and D_2 and using both ν_μ and $\bar{\nu}_\mu$ as test particles. Since the study of fragmentation by the counter experiments in the same beam line has been restricted to subjects like dimuon search, and no definite plans for the continuation of these studies exist at the moment, the present discussion will be confined to BEBC. The features and possibilities of the bubble chamber and its filling liquids will be analyzed; a comparison will be made with other techniques like muon-hadron and e^+e^- experiments.

For a continuation of the BEBC program in the second half of this decade, a number of experimental improvements have been suggested:

1. Construction of a forward spectrometer;
2. Construction of a calorimeter inside BEBC;
3. Implementation of methods of holographic photography;
4. Increase of statistics of the present experiments.

The impact of such improvements will be discussed in the coming sections.

2. THE STUDY OF FRAGMENTATION

The quantities important for the study of the fragmentation process are: fragmentation functions and their integrals in dependence of the parameters W and Q^2, Feynman x distributions etc. In the present bubble chamber experiments, the measured quantities have to be corrected for the energy of the invisible neutral particles, for measurement errors and, in the case of deuterium, for the uncertainty due to Fermi motion. The corrections are generally made by means of Monte Carlo calculations in which the uncertainties are incorporated. The computations result in smearing factors which have to be applied to the measured data. It is the uncertainty of these factors, rather than their size which contributes to the systematical uncertainty of the final result. Fig. 1a shows the fragmentation function for negative hadrons (the leading charge) in the $\bar{\nu}$ interaction. The smearing functions are shown for hydrogen and deuterium in figs. 1b and 1c. Under the present conditions the detection probability for γ's in BEBC amounts to nearly 20%. The Monte Carlo program utilizes this value.

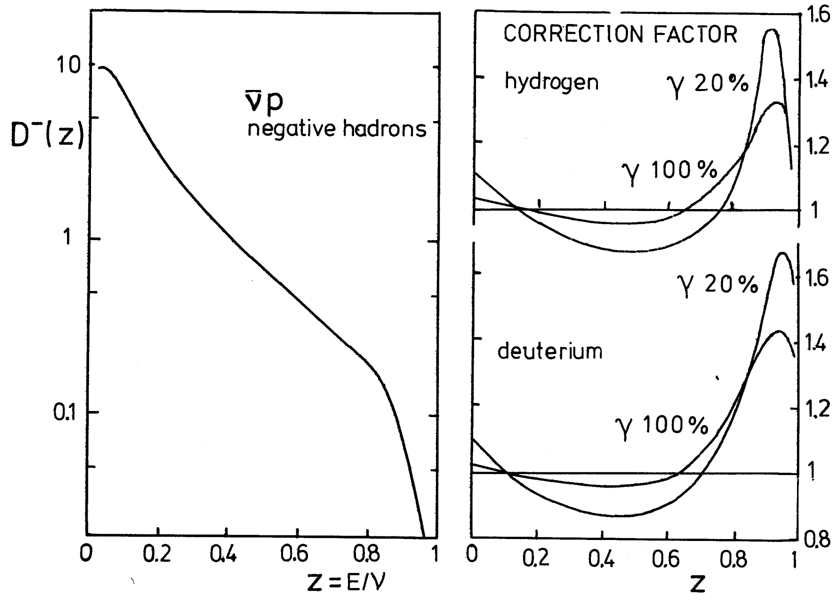

Fig. 1 Fragmentation function of negative hadrons in $\bar{\nu}p$ interactions (left).
Smearing functions for hydrogen and deuterium (right).

The resulting curves show values in the neighbourhood of 1 in the region of small and medium values of the fragmentation parameter $z = E_h/\nu$, but show large fluctuations in the region of high z. It must be noted that the values of the smearing function are strongly dependent upon the distribution under study, so that large fluctuations indeed give rise to important uncertainties. The measurement of the fragmentation function in the high z region is of great importance, for instance for the study of higher twist effects.

If fragmentation functions of positive particles are measured, the identification of protons plays a significant role. Protons may be reliably identified in the bubble chamber by means of a bubble density estimate for momenta up to 1 GeV/c. For higher momenta again corrections have to be applied for the underestimate of the proton energy if this particle is mistaken for a pion. The smearing curves show larger deviations from 1 in the low z region than the ones displayed in figs. 1b and 1c.

Fig. 1c shows larger smearing factors than fig. 1b because of the Fermi motion in the deuteron. The difference, however, is not very large due to the predominance of the energy uncertainty over the Fermi motion. The high peak in the curves is due to measurement errors rather than to energy uncertainty: For an event with a particle with high z, nearly all energy is visible. However, measurement errors of the muon and the fast particle lead to a transverse momentum non-balance which, by the energy correction algorithm, is translated into a positive energy correction.

Figs. 1b and 1c also show the results of a 100% detection efficiency for γ's. This would be the approximate situation if an internal photon calorimeter were installed in BEBC. The figures, indeed, show smearing factors much closer to 1 for both hydrogen and deuterium, over a large region of z. The high peak at the end of the interval is not dramatically reduced, since it is not caused by energy mismeasurement. It should be pointed out that the presented curves have been calculated with the present energy correction algorithm (Bonn method). It is conceivable that in presence of the calorimeter more powerful algorithms may be designed which may disentangle the energy loss from the transverse momentum measurement error. However, in this case a new uncertainty will take over as the most important one: the uncertainty due to neutrons and undetected neutral strange particles. Then, real progress may only be obtained by a reduction of the depth of the fiducial volume that will decrease the measurement errors. The smearing factor could be considerably flatter in that case. This reduction would come in addition to the one caused by the calorimeter itself and could appreciably reduce the number of useful events by ca. 40%.

3. THE EXPERIMENTAL PROGRAM

We now turn to the experimental program of possible future BEBC experiments. The question has to be answered which problems in fragmentation are best answered by neutrino experiments employing the bubble chamber technique. For this purpose we shall divide the fragmentation process into three phases:

1. The primordial stage;
2. The quark-gluon fragmentation;
3. The decay of resonances.

4. THE PRIMORDIAL COLLISION

There are specific problems of the lepton-quark primordial collision that can be studied better in $\nu/\bar{\nu}$-hadron interactions than in μ-hadron or in e^+- e^- interactions. This is due to the fact that a) ν and $\bar{\nu}$ test on the flavour of the accelerated quark, b) the u and d quark participate at equal footing in $\bar{\nu}$ and ν experiments and c) that there are two diquark systems (uu and ud) in hydrogen and three in deuterium (uu, ud and dd) left over after the collision. As an example, fig. 2 shows Bjorken x distributions of Λ production in ν and $\bar{\nu}$ interactions. The bubble chamber is specifically suited for the study of neutral strange particles, for which it has a nearly unbiased acceptance and therefore yields an optimal detection possibility of the strange flavour. Figs. 2a and 2b show a difference in x-distribution which indicates a larger contribution of the quark sea to the Λ production by antineutrinos than by neutrinos. Indeed, the $\bar{\nu}$ may react with an $\bar{s}$ quark of the sea; the remaining s quark may have the right colour to combine with a ud-diquark to produce a Λ hyperon.

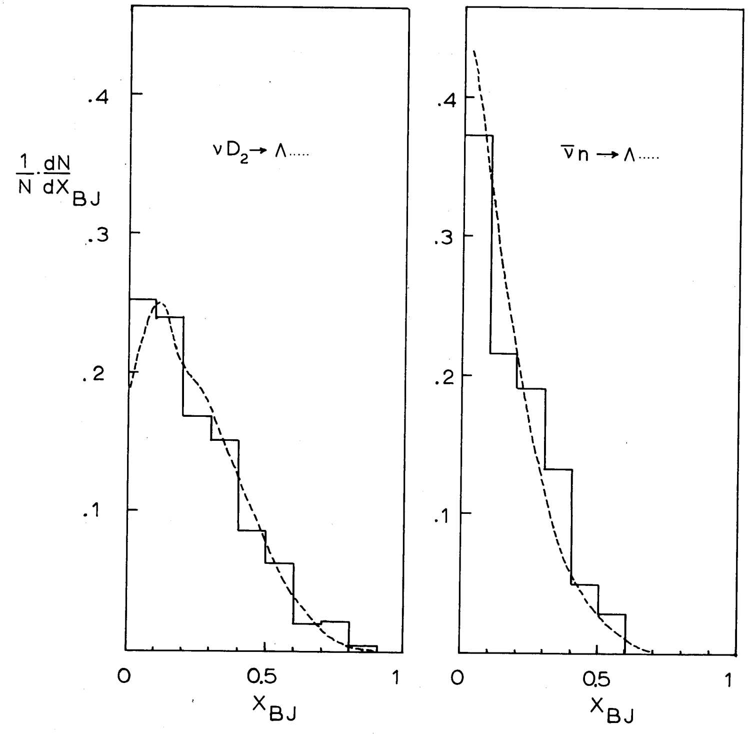

Fig. 2 x-distributions of $\bar{\nu}$ and ν-neutron events with Λ production.

In the present experiments 3% of all charged current events show a Λ decay, 5% a K° decay. It is clear that for a continued study of strange particle production the experiments need higher statistics, independent of further technical improvement of the bubble chamber.

Also charmed particles occurring in the final state of a neutrino interaction point directly to the primordial collision. Probably, the charmed quark is too heavy to allow the creation of $c\bar{c}$ quark pairs in the course of the fragmentation of the colour string. In $\nu/\bar{\nu}$ reactions the charm production mechanism may be studied as well as the type of particle produced: D, D*, F, Λ_c, Σ_c etc.

For the detection of charmed particles in BEBC, the application of holographic methods is highly needed. A hydrogen run in BEBC with 40,000 charged current events would yield 260 detectable charmed particles if the spacial resolution were 100 μm. With a resolution of 50 μm the number would be increased to 1000. The experiment could yield information about the like-sign muon problem, inclusive reactions, x-distributions and fragmentation functions. It cannot be foreseen, however, which fraction of the data can be fully evaluated, for instance by 3-constraint fitting. Part of the events will be lost by the presence of too many neutral particles. It is clear that holography in BEBC combined with an internal calorimeter would considerably improve the situation.

5. THE QUARK-GLUON FRAGMENTATION

For the measurement of fragmentation functions of different particles, especially for the search for mass dependence of the fragmentation functions, particles must be individually identified in the bubble chamber. Proton-pion separation is limited to momenta below 1 GeV/c, as indicated before. Pion-kaon separation is nearly impossible under the present conditions.
The detection of neutral strange particles facilitates the study of a limited number of processes. Fig. 3 shows the fragmentation functions and the Feynman x distributions of K^{*+} and K^{*-} produced in ν-deuterium interactions.

The availability of a calorimeter in BEBC would open up new possibilities for the study of fragmentation. Particles like η, ω and π^0 could be identified by individual γ-detection. The identification of protons would become possible by kinematical fitting in a far greater percentage of the cases if most neutral outgoing particles can be detected. According to an analysis made by J. Schneps it will also become possible to recognize most of the rescattering events in deuterium (events where both baryons are involved in the reaction) by making use of a kinematical algorithm. This algorithm works best with a maximum amount of information about neutral particles.

A special problem is the identification of neutrons for which the calorimeter only yields very limited facilities. At a limited rate, neutrons can be detected by secondary interactions in the chamber. Also the neutron energy may be measured for a fraction of the events. Fig. 4 shows the result of a Monte Carlo calculation, showing the secondary interaction rates for n, K^0 and $\bar{n}$ as a function of particle momentum, as being produced in charged current $\bar{\nu}n$ interactions. The vertical scale and the

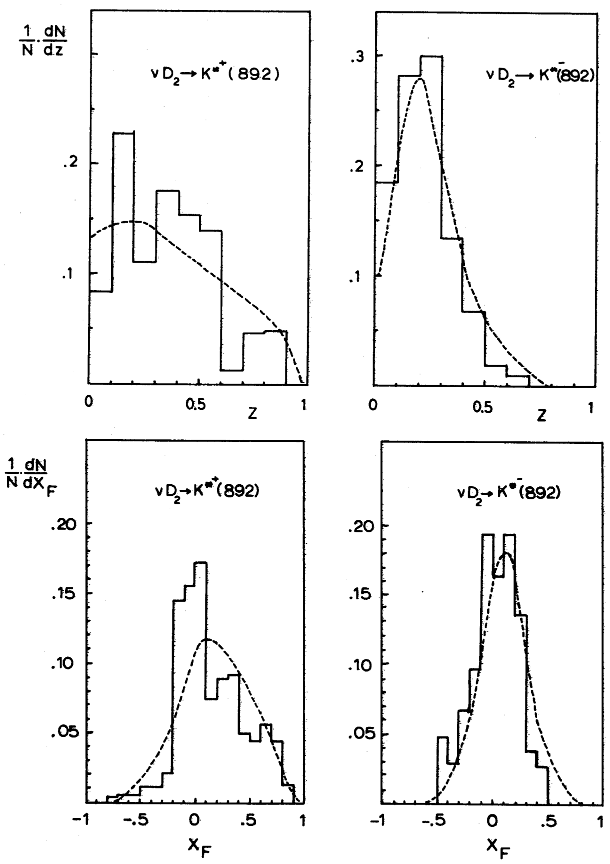

Fig. 3 Fragmentation functions and x Feynman distributions for K*(892) in ν interactions.

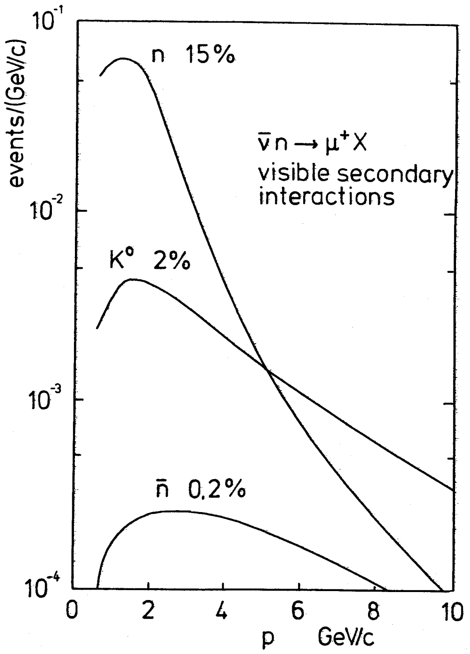

Fig. 4 Fraction of charged current $\bar{\nu}n$ events with a secondary interaction in BEBC as a function of particle momentum.
Percentages refer to integrated values.

integral values show fractions of the charged current events in the $\bar{\nu}n$ channel. It becomes clear from the figure, that neutron detection is possible for neutrons of a few GeV/c. At higher momenta there is a strong n-K° ambiguity. Antineutrons may never be detected in this way.

Among the problems to be investigated with the bubble chamber are the study of charge flow in the fragmentation process, soft gluon effects (transverse momentum balance in the colour string) and the polarization of hyperons. For most of the problems a better particle identification and a better determination of total and individual energies would be desirable.

A number of problems in fragmentation can better be investigated in μ-nucleon and e^+e^- collisions. Here higher hadronic centre of mass energies and Q^2 values are needed than can be obtained in $\nu/\bar{\nu}$ interactions at the present beam energies. Among these problems is the question of correlation in rapidity between $K\bar{K}$, $B\bar{B}$ and $\Lambda\bar{K}$ pairs. A long range of rapidity must be available to find these correlations. Also first and higher order QCD effects in fragmentation (hard gluon effects) will only be important at higher hadronic energies than can be obtained in neutrino experiments with sufficient statistics. The same is true for hard gluon jets that probably are very rare at the present energies.

For the study of this part of the program, a bubble chamber would have to be equipped with good tools for the identification of particles going forward in the hadronic centre of mass. For this purpose a forward spectrometer would be appropriate. As being pointed out, however, the specific problems on hand can better be studied at higher centre of mass energies, the need of a forward spectrometer in BEBC is therefore strongly reduced.

6. RESONANCE DECAY

An important problem in the study of fragmentation processes is the distinction between particles that are directly created in the quark-gluon fragmentation and those that originate from directly produced resonances. As discussed in the previous section, the detection is possible of both K° and K* (= $K^\circ\pi$). In this way the ratio can be measured between vector meson and pseudoscalar meson production in the fragmentation process. With the present methods, identification is possible of Δ^{++}, Δ°, Y*, K* and ρ°. More possibilities would exist if more γ's can be identified.

7. THE FERMILAB PROGRAM

Fermilab has higher energy, the bubble chamber will be equipped with holography and possibly with a calorimeter. However, the statistics is low and there seems not to be a real competition with the CERN program.

8. CONCLUSIONS

1. $\nu/\bar{\nu}$ experiments in BEBC yield interesting results, mainly by the disentangling of the primordial process.
   BEBC has good detection facilities; the ability of particle identification is limited.
2. Of the possible improvements of BEBC, the construction of an internal γ-calorimeter and the implementation of holographic equipment seem most rewarding.

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