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DIRECT DETECTION OF SHORT-LIVED PARTICLES FROM NEUTRINO INTERACTIONS IN NUCLEAR EMULSIONS INSIDE THE 15-FOOT BUBBLE CHAMBER

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Summary
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We propose a systematic search for and analysis of short-lived particles produced by neutrino interactions in nuclear emulsions inside the 15-foot bubble chamber. With 20 liters of cryogenically suitable NIKFI BR2 emulsions, and a wide band neutrino exposure with 3×10^{18} protons on target, approximately 1,000 emulsion neutrino interactions will be obtained. This experiment can be performed parasitically with the bubble chamber neutrino research program. We plan to exploit fully the bubble chamber track precision, particle identification (including EMI) and momentum analysis capabilities, for locating the interactions inside the emulsion stacks, assisting in searches for particle decays and in analyzing masses, decay modes, lifetimes and other properties of charmed baryons, charmed bosons or other species of new particles. The range of particle lifetimes we plan to explore directly in this experiment extends from 10^{-11} to 10^{-15} seconds.

Summary prepared by
L. Voyvodic, May, 1977

PHYSICS MOTIVATION

Increasing evidence from high energy neutrino experiments, using both electronic spectrometers and large bubblè chambers, indicate appreciable production of new families of heavy hadrons, and possibly of heavy leptons, which are expected to have relatively short lifetimes in the region of 10^{-13} seconds. Direct observation of the production and decay of such short-lived particles in nuclear emulsion should provide especially convincing evidence for the existence of such particles and permit a more detailed analysis of the properties associated with charm and other new quantum numbers[1]. However, attempts at such emulsion experiments have so far had only limited success. In Fermilab experiment E-247, only one candidate event has been observed in 28 neutrino interactions located in the emulsions from reconstruction of tracks observed in optical spark chambers[2,3]. In a similar 1976 Serpukhov experiment, no short-lived candidates appeared in 8 neutrino interactions located in emulsions from spark chamber track reconstructions[4]. Both of these preliminary experiments appear to have suffered particularly from difficulties in obtaining sufficiently precise space coordinates for locating neutrino interactions inside the emulsion pellicles.

The main feature of the experiment proposed here is the use of nuclear emulsion as a high resolution track sensitive target inside a very powerful and precise multi-particle spectrometer, the 15-foot bubble chamber. With sufficient cryogenically sensitive emulsions ($\sim$20 liters of NIKFI BR2 pellicles[5,6,7]), a parasitic exposure during the next major run of the chamber with wide band neutrino (ν and $\bar{\nu}$) beams is expected to produce $\sim$1,000 interactions in emulsion.

By exploiting existing methods and accumulated experience in bubble chamber and nuclear emulsion experimental techniques, we propose to locate these interactions in the emulsions and carry out a systematic search for produced particles with decay lengths between 1 micron and 1 centimeter. Studies to determine mass, lifetime, cecay modes and other such properties will be made for all observed particles decaying with lifetimes between $\sim 10^{-15}$ and $\sim 10^{-11}$ seconds. In this experiment we anticipate up to 100 such events representing the decay of a variety of charmed baryon and meson states such as C_0^+, D^+, F^+, etc. This number is based on current estimates of 1 to 2% of neutrino interactions producing dileptons through charm production, and 5 to 10% for producing charmed particles which subsequently decay via hadronic modes.

We expect to follow this exploratory investigation with a later major experiment using larger amounts of emulsions and optimized chamber conditions, which will be aimed at full analysis of $\sim$10,000 interactions of high energy neutrinos in nuclear emulsions.

BUBBLE CHAMBER

Figure 1 shows the general features of the proposed installation of nuclear emulsions in the 15-foot chamber. Two sets of emulsion containers and support brackets are shown, one above and one below the hadron beam plane and nose-cone, so as to spread $\geq$20 liters of emulsion with small thickness in the beam direction. The support brackets, with mirrors for observing any upstream tracks entering the emulsions, are to be welded to the nose-cone flange. Before chamber cooldown, the emulsion assemblies will be lowered through the 16 inch central camera port opening and bolted securely to the support brackets. The assemblies will be removed immediately after warm-up, following a chamber cryogenic operating period which may extend up to three months in duration.

It is important that the emulsion assemblies and supports product negligible amounts of spurious boiling or other distortions in the normal bubble chamber photographs. We plan to work closely with 15-foot chamber personnel to eliminate sharp edges and cracks, install effective scotchlite reflectors on all assembly surfaces, and orient the assemblies so as to minimize interference with fluid motion during the chamber expansion cycle.

For good connections between bubble and emulsion tracks, the stack locations above and below the nose-cone opening shown in Figure 1 also have advantages over the use of emulsions inside the nose-cone as suggested earlier[7]. Bubble track displacement and distortions due to liquid motion, magnetic field uniformity, and ability to use mirrors for seeing charged particle tracks entering the emulsion stacks upstream, are all considerably better in the locations shown. In particular, bubble tracks are expected to have small ($\leq$1mm) net vertical displacements for the locations shown in Figure 1, whereas fluid motion within the nose-cone may have relatively large horizontal as well as vertical components. Thus we do not expect, for the emulsion stack locations shown in Figure 1, any noticeable turbulence in the chamber during expansions, which would significantly degrade the accuracy of the track reconstruction.

It is expected that all six camera positions for the 15-foot chamber will offer good views of the emulsion assemblies and outgoing particle tracks. Scanning for neutrino interactions can be carried out quickly on a single view, e.g., from a fourth camera or from copies of one view of the normal neutrino pictures. For those frames showing neutrino-emulsion interaction candidates, plus a comparable number of frames with straight-through muons or upstream interactions (which are extremely important for calibrating the emulsion coordinates and track ionization), copies will be made of the two additional views, plus EMI data, from the prime user of the bubble chamber epxosure. Alternately, we can use the other complete set of three "hadron" cameras if this is preferred by the Laboratory.

NUCLEAR EMULSIONS

Based on our previous emulsion experience, including experiments with tagged events in exposures at Fermilab and at Serpukhov, we are planning the following:

1. Use of NIKFI BR2 emulsion pellicles, 600 microns thick x 5cm x 20cm, stacked in 2 liter modules, each 5cm in the beam direction and 20cm x 20cm across. (Typically, BR2 pellicle stacks 10 x 10 x 20cm have been used in Serpukhov exposures and in Fermilab experiments E183, 328, 329, 421, 463.)

2. To ensure suitable emulsion sensitivity for prolonged cryogenic exposures, additional tests will be made at IHEP and at ITEP. Our estimate at the present time is that the sensitized BR2 pellicles for this experiment will show relativistic particle tracks with 20 to 22 grains/100 microns after several months at liquid hydrogen temperatures.

3. To ensure precise location of individual pellicles and emulsion modules with respect to the external container fiducials, other cryogenic tests on emulsion shrinkage and on mounting techniques will be carried out at Fermilab. The aim here is to establish the relative coordinate systems with an accuracy of ≤ 50 microns at room temperature and ≤ 100 microns at cryogenic temperatures.

4. The two emulsion assemblies shown in Figure 1 are each expected to consist of five of the precision 2 liter modules, mounted side-by-side in a welded stainless steel container and sealed in a helium atmosphere.

LOCATION OF EMULSION INTERACTIONS

Each bubble chamber track emerging from an apparent neutrino interaction event in an emulsion stack can be reconstructed in space with conventional three-view measurements and programs, using chamber based fiducials. In addition to kinematic data on each outgoing particle, a first approximation estimate of the emulsion interaction vertex location can be obtained from predictions of the extrapolated interaction region for all such tracks in the event. By including additional film measurements of fiducial marks on the emulsion stack container, and of corresponding points on bubbles at the beginning of each track, more precise connection will be made between the bubble track and emulsion track for each particle, and the best estimate derived for the primary intersection vertex by using all the bubble chamber track information.

Preliminary tests have been made with hadronic interactions in 15-foot chamber photographs, simulating neutrino events in our proposed emulsion stacks. A sample of 300 GeV pp interactions, previously analyzed for experiment E343, were re-measured without the beam track and without track points for distances within $\gtrsim$ 5cm of the vertex. After spatial reconstruction, tracks in each event were paired in all combinations, and examined for predictions of the extrapolated vertex location. For each pair of reconstructed tracks, values are shown in Figure 2 for the opening angle θ_{open}, and for discrepancies between predicted and originally measured interaction vertex space coordinates. Mean values for vertex prediction accuracy from the individual pairs data in Figure 2 are $\Delta X \approx \pm$ 6.7mm, $\Delta Y \approx \pm$ 0.5mm and $\Delta Z \approx \pm$ 1.2mm in the beam, horizontal and vertical directions respectively. (From νp interactions in E45, the estimated mean opening angle is $<\theta_{open}> \approx 260$ mrad, and six track pairs can typically be expected from an interaction.)

By using information from all the tracks, rather than individual pairs, and by measuring corresponding points and emulsion container fiducials, final mean values for accuracy of vertex location for neutrino interactions in this experiment are expected to be about one-third those listed above, when depth in the emulsion is limited to about 5 centimeters. Thus the expected average scan volume per event amounts to $\lesssim 3mm^3$, with a corresponding scanning time of less than one hour.

For events which are not readily located in emulsion by the predicted vertex method, a second effort will be made by connecting each bubble track with its corresponding track at the front surface of the emulsion. Preliminary estimates of spatial accuracy for this method is $\sim\pm 0.2$mm at the emulsion, perhaps somewhat better in the horizontal coordinate. (To take advantage of improved stereo accuracy in the horizontal direction and to be less sensitive to vertical fluid and bubble displacements, additional studies will be made on whether the emulsion pellicales should be oriented vertically but still parallel to the beam direction.)

EVENT RATES AND BACKGROUNDS

Based on calculated and observed event rates in E53A, we estimate for 400 GeV protons and wide band neutrino beam the production, at the 15-foot chamber, of

$$0.8 \text{ events}/10^{13} \text{ protons}/20 \text{ tons},$$

or

$$17 \text{ events}/10^{18} \text{ protons/liter emulsion.}$$

Assuming an effective exposure of 3 x 10^{18} protons for the neutrino and anti-neutrino bubble chamber experiments with deuterium, scheduled for Spring of 1978, the anticipated production rate is ≈50 neutrino events/liter, or ≈1,000 events/20liters emulsion.

We estimate that integrated background fluxes up to 10^5 particles/ cm^2 are tolerable for this experiment. The most serious source for exceeding this limit is N1 muon beam operation during the neutrino emulsion exposure. Backgrounds due to possible operation of the N3/N5 hadron beams during this period appear to be less severe. Vertical cosmic ray muon backgrounds of $\sim 10^3/cm^2$/day may pose a limitation on the exposure duration for vertically oriented emulsions. Neutrino beam associated tracks from upstream interactions are expected to be infrequent but very useful for calibrating emulsion coordinates, and also track ionization as a function of exposure time. Single incoming tracks, chiefly muons, are estimated to produce a total background of ∿30 tracks/cm^2 for an exposure of 3 x 10^{18} protons. Multiple incoming tracks, due to neutrino interactions just upstream in the chamber walls and magnet coils, are estimated to be only one tenth as frequent as the single tracks, and to contribute only a minor background of <10 tracks/cm^2 in the emulsions.

SEARCH FOR SHORT-LIVED PARTICLES

After locating the interaction vertex, the search for short-lived particles will consist of three phases.

The first phase is the conventional scanning and examination of the clear region of emulsion near the vertex, typically covering decay lengths of 10 to 300 microns, for either charged or neutral particles. This rapid examination can be made at the same time as the primary vertex is located.

For shorter-lived particles, precise track measurements and extrapolations near the vertex can be made in the second search phase, in order to spot candidates within 10 to $\sim$0.3 microns.

For longer-liver particles, which are difficult to find directly in emulsions, the third phase is based on following back into the emulsion any bubble chamber tracks which have not already been satisfactorily linked to the primary vertex, to converted electron pairs, to strange particle decays, etc. The main goal of this method is to detect decay lengths from $\sim$300 to 10^4 microns.

The time of flight τ measured in the rest frame of a decay particle, is given by $\tau = d/c\eta$, where d is the observed decay length, c the velocity of light and $\eta = \beta\gamma$ reflects the relativistic dilation. For heavy particles and wide band neutrino specrtum $\eta \sim 3$ and $\tau \sim 10^{-15}d$ seconds, where d is in microns. The three search phases are thus expected to cover direct tests of production and decay of short-lived particles over the range of lifetimes from $\sim 10^{-15}$ to 10^{-11} seconds.

For the analysis of each decay candidate, full use will be made of both bubble chamber and emulsion information on kinematics and identification of particles at the production and decay vertices.

The major effort will focus on identification of the decay particle in terms of charmed baryons and charmed bosons , and on searching for the existence of new particle species.

LOGISTICS AND COSTS

The collaboration for this experiment is modelled on, and overlaps with, several previous Fermilab collaborations, particularly for the US-USSR 15-foot chamber experiment, E180, on $\bar{\nu}$-Ne interactions, and the US-Polish tagged emulsion experiment, E382, on deep inelastic collisions and charm search with muons.

The emulsions will be prepared in the USSR and final preparations and mounting made at Fermilab prior to the 15-foot chamber ν-D_2 and $\bar{\nu}$-D_2 runs, expected to start in March, 1978.

Bubble chamber scanning, and reconstruction of tracks emerging from the emulsion stacks, will be carried out during the chamber running period and as soon as film is available. Film copies of all emulsion interaction frames, plus EMI data, will also be provided for additional reconstruction tests in the USSR.

After exposure, the emulsion stacks will be processed in the USSR. One-half the emulsions will be analyzed there, the other half sent to Fermilab for analysis by the US and Polish groups.

Initial results from this experiment are expected to be reported by December, 1978.

The main cost of this experiment to Fermilab will be for the bubble chamber photographs and copies.

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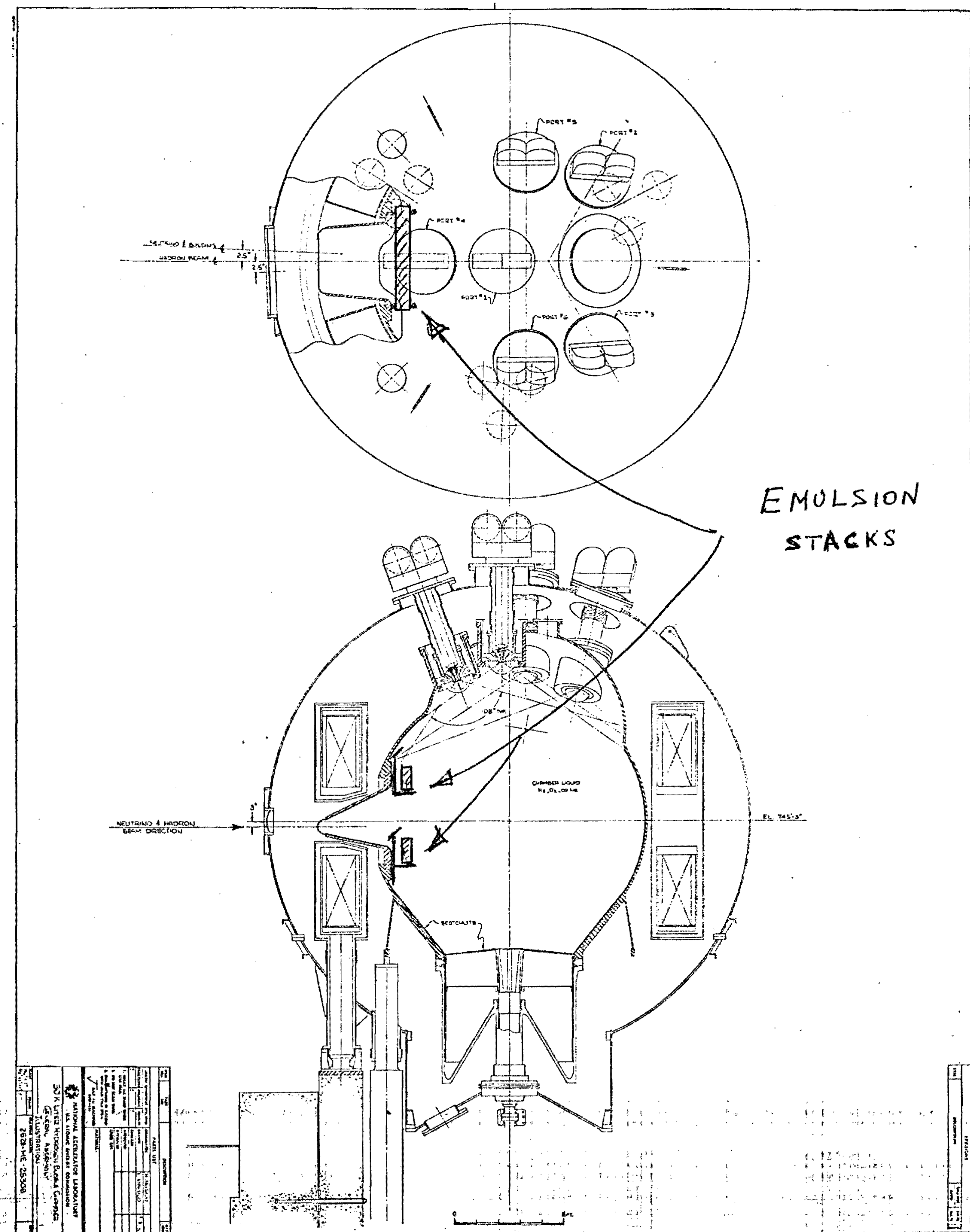
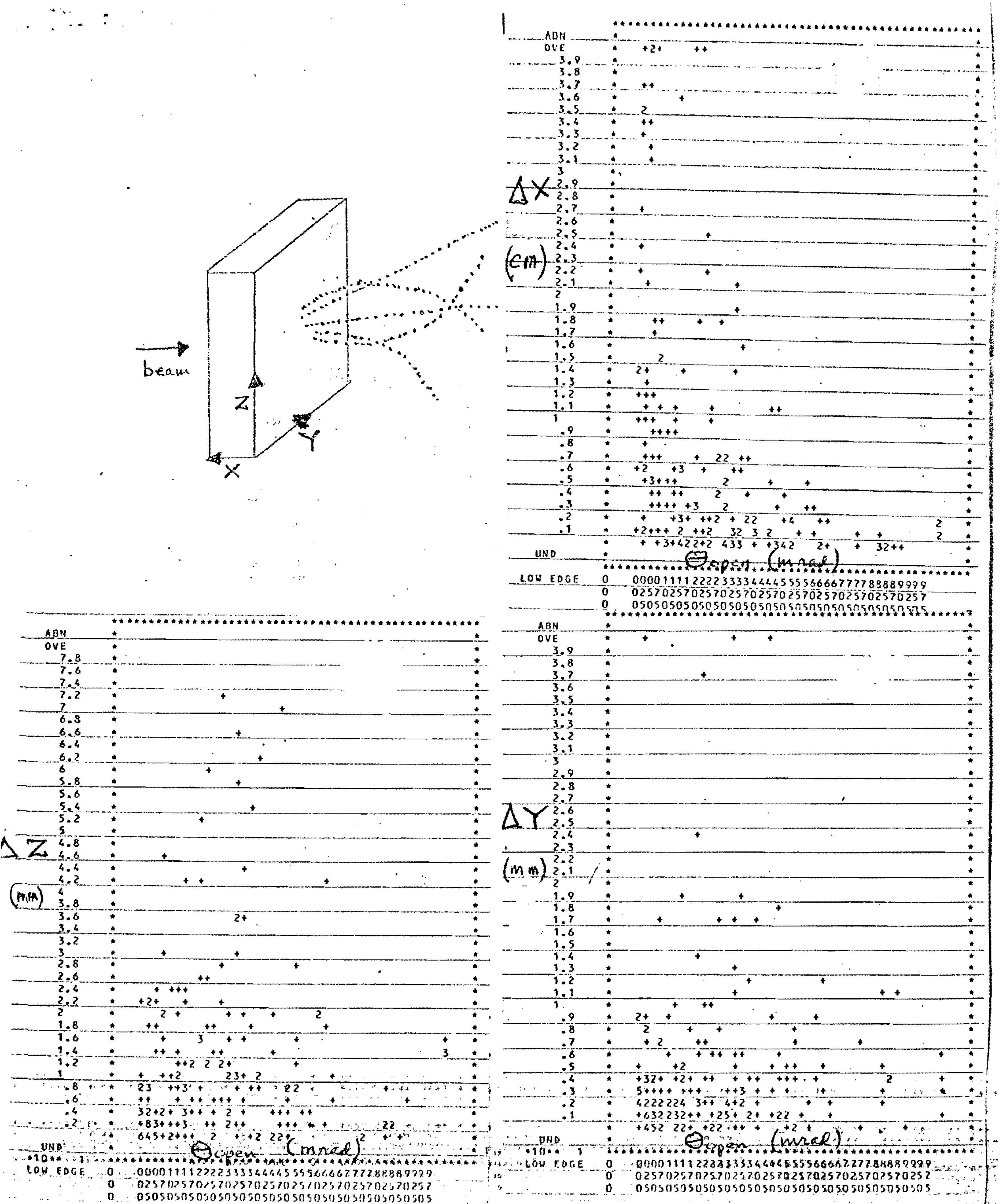

EMULSION
STACKS
PORT #5
PORT #2
PORT #4
PORT #1
PORT #6
PORT #3
NEUTRINO & HADRON
BEAM DIRECTION
CHAMBER LIQUID
SCOTCHLITE
NATIONAL ACCELERATOR LABORATORY
U.S. ATOMIC ENERGY COMMISSION
30 K LITER HYDROGEN BUBBLE CHAMBER
GENERAL ASSEMBLY

Fig. 1


beam
Z
Y
X
ΔX
(cm)
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(mm)
ΔZ
(mm)
θopen (mrad)
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LOW EDGE
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Fig. 2