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"Equipment Proposal for Bevalac Experiments"

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A. SUMMARY

A large Multiple Sampling Ionization Chamber (MUSIC) has been developed as a part of the Heavy Ion Spectrometer System (HISS). This facility is being used for the study of relativistic nuclear collisions at the Bevalac of Lawrence Berkeley Laboratory.

We have measured for MUSIC a single-event resolution of 15% for Fe beam and a charge resolution better than 0.5 units of charge for a Ne beam. These results indicate that a charge resolution of one unit from $Z = 7$ to $Z = 100$ should be achieved with the present detector.

B. REPORT

MUSIC (Multiple Sampling Ionization Chamber)¹ is a large ionization chamber which can multiple-sample the energy loss of nuclear fragments. Its construction was initially funded largely by a DOE grant to UCD. MUSIC uses time projection chamber (TPC) electronics so that large multiplicities from a single event can be handled. This is done by measuring as a function of time the electrons from the ionization tracks as they reach the sampling electrodes after drifting down in the uniform electric field. The multiple sampling (along the track) of each ion track provides an energy loss distribution which should allow a charge separation of $\Delta z \cong 1$ from about Carbon to Uranium (and beyond). (Lighter fragments can be identified in the HISS TOF scintillator wall.)

In 1980-81 we constructed a prototype MUSIC whose active volume (1m x 1m x 0.5) was 6 times smaller than the new unit. Due to curtailment of Bevalac running on July 3, 1981, we were only able to make a few tests. The results (see Appendix A for more details) showed that in Argon + CH₄ the detection of light nuclei such as carbon nuclei was difficult due to the small signal-to-noise ratio (from the preamps and the environment, even though all possible precautions of shielding were taken). One promising development that will help in this regard is that CF₄ has been shown to be a good gas for ionization chambers.² With a drift velocity of 12 cm/ μ sec at $E/p=1$ ($E/p=1$ means 760 V/cm at atmospheric pressure), it is one of the fastest gases available. It has in addition three times the energy loss per cm as Argon, so the lighter ions $Z \gtrsim 6$ can be separated from the noise.

One encouraging thing we did learn with an argon beam was that the energy loss resolution was considerably better than predicted by the Vavilov theory.

On an single anode cell we measure $\approx 15\%$ vs. the $\approx 22\%$ FWHM predicted by the theory. The reason for this is that the high energy δ rays (produced by the ion) do not deposit all their energy in the dE/dx cell but actually lose only a small fraction of their energy in each cell. In addition, as they diverge from the ion track, they reach separations such that their charge tracks are not integrated in with the ion's charge track. Thus we measured a much narrower and nearly symmetric energy loss distribution without the long Vavilov tail. The Vavilov distribution correctly gives the energy lost by the ion, but not that deposited in the cell.

The construction of the new MUSIC was completed in July 1982. The active volume, as defined by the field cage of $2 \times 1 \times 1.6$ m, is shown in Fig. 1. This is housed inside a large stainless steel tank 2.9 m in diameter. The tank has removable end caps which can cover the thin end windows and allow evacuation of the vessel before filling with gas. This is necessary in order to achieve the required gas purities (< 5 ppm of O_2). The field cage and windows have been constructed at the Crocker Nuclear Laboratory (CNL) shop and were installed in the tank at LBL in mid July for tests in beam and the first experiments at HISS at the end of July 1982. For this run, the entrance and exit window for the particles consisted of two compounded polypropylene-aluminum-mylar foils which are separated by a gas-filled 1.5 cm gap. A clean gas (Ar) was purged through this gap, in order to maintain the high gas purity in the detector volume. The anode structure is mounted 2 cm below the Frisch Grid and is operated at positive voltage (750 volts). Connections to the anodes are brought to the outside. The anode consists of independent right and left halves, each of which for the tests described contained 60×2 cm and 4×6 cm divisions. The 128 preamplifiers are mounted outside the tank, 64 on each side. See Appendix B for pictures of the present MUSIC detector.

Figure 1. The MUSIC Detector.

Figure 2 presents data obtained during the last half of 1982 corresponding to tests done with a 600 MeV per nucleon Fe beam. The 2-dimensional plot (Fig. 2a) shows the anode wire number (y-axis) as a function of the drift time of the electron cloud (zero drift time would correspond to an event passing near the bottom of the MUSIC box). For this test, the Fe beam was sent through the right part of the anode structure at about the vertical center of the detector, which corresponds to a drift time of about 10 microsec, as observed in Fig. 2a. No events are observed on the left 64 anodes which are displayed above the right. A pulser was turned on about 40 microsec after the event and shows signals in all 128 wires. This picture was obtained on line. The off-line analysis using the powerful program LULU³ has just started. Figure 2b is the same event of Fig. 2a but in a succession of pulse height vs. drift time displays (only wires 0 through 20 are shown). Anode wires 0 and 16 sampled 6 cm of Argon gas rather than 2 cm for the others, so their signals sizes are about 3 times larger. The energy lost by the Fe ion on each cell was obtained from the peak value for each display such as in Fig. 2b, corrected by the relative gain and baseline offset of the individual channels. Figure 2c is the energy loss histogram for this single event. It includes 31 anode wires for which a calibration for their relative gain and offset was available. The observed gaussian shape and about 15% FWHM resolution are the expected results in agreement with those for our prototype tests (Appendix A). Each of the individual iron events analyzed (more than 600) have the above 15% FWHM resolution. We cannot report however an average energy loss spectrum for the iron run because of a not fully understood event to event variation in the average energy loss obtained. Part of this variation is due to the fact that only the peak value for the amplifier output signal rather than the area could be extracted in the Fe run

Fig. 2 - One event in the MUSIC detector corresponding to an 800-A MeV Fe ion. See text.

FREQUENCY
7.467
7.156
6.844
6.533
6.222
5.911
5.600
5.289
4.978
4.667
4.356
4.044
3.733
3.422
3.111
2.800
2.489
2.178
1.867
1.556
1.244
0.9333
0.6222
0.3111

0.000

99.9
ΔE (arbitrary units)

200.

to characterize the energy loss. For the Neon run described next, the electronics was modified to allow area extraction.

Figure 3 shows a preliminary average energy loss distribution for the Neon beam run in December 1982. Because of the low charge ($Z=10$), the sampling cell size was increased to 8 cm by connecting sets of 4 consecutive anode wires in parallel to the charge sensitive preamplifiers. Each ion track was sampled 16 times. The average in Fig. 3 is based on 14 preamplifiers for which the relative gain is known. The observed 7% FWHM resolution (3.5% FWHM charge resolution) is consistent with the measured individual track resolution of 27% FWHM. The noise contribution to the latter is estimated to be 17%, mainly due to the increased input capacitance (4 times the normal single anode wire configuration). Assuming $Z=10$ for the peak in Fig. 3, the threshold for the present analysis is close to 9.

We have just finished the relative calibration and determination of the offsets using a pulser into the input of the individual preamplifiers. We have done this to better than 1%. Effects in the charged coupling device (CCD) electronics such as the leakage current variation (which changes the offset) and variation of time bucket number per event have been studied. The variation in amplitude due to that in the leakage current is less than 2% for a time interval of 30 μ sec.

In summary, we have designed, built and successfully tested a large multiple sampling ionization chamber. We have measured for this detector a single event resolution of 15% for 1.8 GeV for nucleon Fe beam and a charge resolution better than 0.5 units of charge for a ~ 0.5 GeV per nucleon Ne beam. These results indicate that a charge resolution of one unit from $Z = 7$ to $Z = 100$ should be achieved with the present detector.

In collaboration with the HISS group A at LBL, we plan to take more data in 1983-84, this time on line with the drift chambers (which were not used during the July 1982 run) and a trigger that will allow us to identify the incident ion, in this way truly calibrating the MUSIC detector. The measured energy loss resolution for a single Fe ion event of $\sim 15\%$ as reported above, should allow us to get a FWHM $\Delta Z/Z$ charge distribution of $15\% / (2\sqrt{64}) \sim 1\%$.

Figure 3: Energy loss spectrum for a Neon beam (average over 14 samples). For reference, the arrows show the expected energy losses for $Z=9$ and 11 .

References

1. C.R. Gruhn, H. Crawford, D. Greiner, and J.J. Symons, LBL Internal Report, 1979.
2. L.G. Christophorov et al., Nucl. Instr. and Meth. 163:141 (1979).
3. H. Crawford and P. Lindstrom, LBL-16171, 1983.

Appendix A

The Prototype MUSIC Box¹

The UC Davis group constructed, debugged, and tested the prototype MUSIC box. This chamber, which is operated at standard temperature and pressure, is used to measure energy loss (dE/dx) of fragments that pass through it. Depending on the anode configuration (no. of elements, etc.) it can achieve resolutions in charge of less than one unit ($6 < Z < 100$) for all particles having energies between 50 and 2000 MeV/nucleon.

The MUSIC box samples dE/dx many (25-50) times along the ionization track in the detector and employs a statistical method for accurate extraction of energy loss and eventually charge information. Figure A-1 shows one of the designs we tested. The box presents an area $1\text{ m} \times 1\text{ m}$ to the scattered beam of particles and is 0.5 m thick. It is divided into left and right halves which have independent arrays of sensing anodes at the bottom. This is to improve the capability for high multiplicity events. The particles traverse the 50 cm thick chamber perpendicular to a vertical electric field. Electrons along the ionization path drift downward in the field and are collected on anode wires or plates at the bottom of the chamber. These run nearly perpendicular to the particle track and each wire samples the charge of a segment of the track. The charge segments arriving at each anode wire are sampled every ≈ 100 ns via charge-coupled devices so that a time projection of the charge cloud is obtained thus allowing the vertical distance of the track centroid to be located accurately, and to allow its separation from the tracks formed by other fragments from the same event. Using Time Projection Chamber (TPC) electronics developed at LBL² the signals are digitized and sent to a computer. Software to calculate the maximum likelihood for a particular energy loss and hence charge is being developed.

Figure A-1. Multiple sampling ionization chamber (MUSIC).

A large vacuum tank to contain and evacuate the MUSIC box for subsequent loading with the counting gas was also constructed. This is necessary, particularly if expensive gases such as Xe are used. Xe has three-times the energy loss per cm that Ar has, and its use allows (in the case of 1 cm samples) one to go as low as $Z \approx 6$ before the thermal noise of the preamplifiers on each sense anode anode limits the resolution.

Figure A-2 shows the charge resolution, dZ , which is expected for 50 1 cm cells. The Vavilov width is the dominating factor here. For small Z the electronic noise, assumed here to have a σ_e of 424 electrons, and the statistics of ion pair production, σ_s , play an appreciable role. In tests we found the electronic noise to be about a factor of two larger than the latter, largely due to input capacity, which can be reduced somewhat in later designs and modifications. The statistical width due to σ_s is small for $Z \gtrsim 6$.

Figure A-2. Charge resolution dZ (FWHM) vs β for various Z .

For low Z at large β one needs a fairly large number of cells in order to obtain small dZ . (dE/dx is in the Vavilov or Landau region.) For large Z dE/dx is not in this region and one does not need a large number of cells but one does need total length to achieve good charge resolution.

Note that argon is better for medium z at the highest β , while xenon is superior for the highest $z \approx 100$.

In the June 1981 runs in the Bevalac we tested two different anode configurations: one with the wire anodes and one using plates. The latter should provide better (faster) collection time which should allow better separation of tracks in the case of events which have high multiplicities.

Figure A-3. Pulse height spectra for carbon and argon ions through argon-20% CH_4 for various anode plate sizes. "3 x 2 cm" corresponds to 3 plates each 2 cm wide. All spectra have approximately the same gain.

Figure A-3 shows some pulse height spectra taken with a carbon beam and with an argon beam on various collection plates as indicated. With Ar gas one can barely resolve the carbon peak. Xe gas would give a factor of three more in pulse height. Better preamps will be tried. The resolution observed for Ar averaged about 15% as compared to the 19% expected from Landau prediction. One needs only about 13 such samples to obtain $dZ = 0.5$ for an argon ion.

We also measured electron drift time in a field of ≈ 90 V/cm and the resulting drift velocity is ~ 6 cm/ μsec , as expected at this field strength in 20% CH_4 , 80% Ar drift gas. However we need to calibrate our high voltage meter before any conclusions are drawn. In addition our oxygen analyzer did not function correctly and due to the press of circumstances we were not able to obtain a good measure of O_2 content of the chamber gas or to have time for more flushings. This must be at or below a few ppm for good drift velocity and collection efficiency.

Figure A-4. Drift in collection time for ionization signals. This pattern is consistent with a particle entering the chamber with a slight upward angle. Each "bucket" = 100 nano-seconds. The sequence begins with the pulse height histogram in the upper left hand corner. This initial signal is from an anode collection plate very near the wall where the beam first enters the chamber. One may also note how much wider the pulse width of a real ionization signal is in comparison to a pulser signal. This is due to the intrinsic drift width of the ionization cloud.

The time read-out of the charge-coupled devices (CCD), which sample the charge reaching the sense plates, was obtained for a few events. One of the things we have to work on is faster software. We did not have the proper software to handle the large word size of each event. A given event with n fragments through the box, where each anode has, say, 10 charge buckets in time (which gives vertical position) has about $N \times 10 \times n$ pieces of information to be digitized and read, where N = number of samples and n = number of fragments. Figure A-4 (top) shows time spectra for the charge from an argon ion arriving at several of the 2 cm collecting plates. This can be compared with spectrum due to the pulser whose shape is determined by the time constants of the shaping amplifier which feeds the CCD's.

References to Appendix A

1. F.P. Brady et al., UCD-CNL 194 (1982).
2. S.B. Sidman, S. Olson and R. Jared, LBL-15676, 1983.

Appendix B

The following pictures, taken in July 1982, correspond to the final MUSIC box detector.

The first picture shows the High Voltage Field Cage that sits over the anode structure (not shown) of MUSIC and defines the active volume (2m x 1m x 1.6m). At the top of the field cage is a stainless steel cathode-corona hat. The field is established by a mylar curtain festooned with Copper strips interconnected by resistors. Undergrad Mike Shaw is to the right of the cage. Design: Sann, Rothrock, Goodart, Barasch.

In the second picture, graduate student C. Tull supports one of the two beam windows that define the active cross section of the MUSIC Chamber. Design: Sann.

The last picture shows the whole MUSIC Chamber assembly being craned through the wooden roof of the HISS cave. The stainless steel "wine barrel" provides atmosphere isolation for the detector proper. The end bells prevent collapse of the beam windows during evacuation and purging. Note the beginnings of a gas system hanging on the stand. Design of outer assembly: Sann, Grulick, Rothrock, Reimers, Porter, Barasch.

C. STAFFING

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D. PRESENTATIONS

1. E.F. Barasch, F.P. Brady, C.M. Castaneda, J. Drummond, J.L. Romero, C.D. Goodart, R. Rothrock, H. Crawford, R.C. Jared, D.E. Greiner, P.J. Lindstrom, S.B. Sidman, and H. Sann, A Prototype Multiple Sampling Ionization Chamber, Bulletin American Physical Society 26 (1981) 1158.
2. H. Sann et al., LBL Annual Report, 1982.
3. F. Paul Brady, G. Barasch, C. Castaneda, B. Christie, J. Romero, C. Tull, F. Bieser, H. Crawford, M. Flores, D. Greiner, P. Lindstrom, J. Porter and H. Sann, Using MUSIC to Study Relativistic Nuclear Collisions, International Topical Meeting on "High Energy Nuclear Physics", Sixth International Balaton Topical Conference, Balatonfüred, Hungary, 6-11 June 1983.

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