

The Response of Ionization Chambers to Relativistic Heavy Nuclei

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ABSTRACT

As part of a recent calibration at the LBL Bevalac for the Heavy Nuclei Experiment on HEAO-3, we have compared the response of a set of laboratory ionization chambers to beams of ^{26}Fe , ^{36}Kr , ^{54}Xe , ^{67}Ho , and ^{79}Au nuclei at maximum energies ranging from 1666 MeV/amu for Fe to 1049 MeV/amu for Au. The response of these chambers shows a significant deviation from the expected energy dependence, but only a slight deviation from Z^2 scaling.

1. Introduction

Gas filled ionization chambers were used on the Heavy Nuclei Experiment (HNE) on HEAO-3 (Binns et al., 1981). The response of such chambers is expected to be proportional to the energy deposited by the particle traversing them. At low energies this energy deposit is simply the ionization energy loss, while at high energies energetic knockon electrons are able to escape from the chamber, reducing the energy deposit.

To first order the ionization energy loss scales as the square of the particle charge Z , however at high Z this assumption breaks down. A more complete expression is given by Ahlen (1980, 1982), and predicts an energy loss rising slightly faster than Z^2 . Such effects are important when identifying ultraheavy elements.

We have performed two calibrations of ion chambers at the LBL Bevalac using beams ranging from ^{25}Mn to ^{79}Au . The first, in 1982, was done with a prototype of the HNE ion chamber module which was essentially identical to that used in flight. Thus those data, reported in Garrard et al., 1983, are directly applicable to our flight experience at the energies calibrated. The second calibration, in 1984, used lab chambers which were made of thinner and more uniform materials, permitting better resolution and better knowledge of the beam energy in each ion chamber, at the cost of less direct relevance to the flight data. Figure 1 is a schematic drawing of the 1984 detector.

Particles entering the 1984 detector traversed $\sim 0.1 \text{ g cm}^{-2}$ of mylar in the upstream window, rather than the $\sim 1 \text{ g cm}^{-2}$ of aluminum honeycomb in the flight prototype; thus the energy loss in the window is much smaller and more uniform. Also, in the 1984 calibration the beam energy was measured with a magnetic spectrometer after being degraded to the calibration energy, rather than being calculated from an energy loss model.

The lab ion chambers had aluminized mylar electrodes (0.8 mg cm^{-2}) rather than aluminum screenwire (10 mil diameter, 62.5 mil spacing); thus the production and absorption of knockons is much more uniform. A Monte Carlo model of knockon

production correctly predicts the degradation in resolution caused by non-uniform production of knockons in the screen wire electrodes. This resolution degradation in the flight chambers tends to mask the relatively subtle deviations from Z^2 scaling.

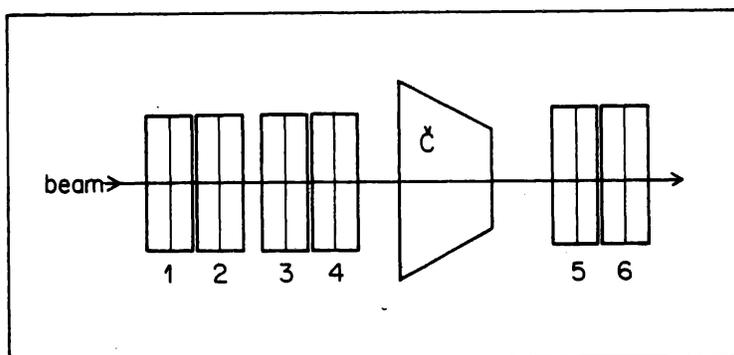


Figure 1. Schematic drawing of the 1984 detector, showing the six ion chambers.

In 1982 the ultraheavy capabilities of the Bevalac were new and we calibrated only on beams of ~ 1700 MeV/amu ^{25}Mn and ~ 1000 MeV/amu ^{79}Au . The 1984 calibration used beams of ^{26}Fe , ^{36}Kr , ^{54}Xe , ^{67}Ho , and ^{79}Au at maximum energies ranging from 1666 MeV/amu for Fe to 1049 MeV/amu for Au.

2. Results of the 1984 Calibration

Figure 2 shows the response of chambers 1, 5, and 6 to ^{26}Fe nuclei as a function of the energy at the midplane of the appropriate chamber, and compares their signals to the calculated dE/dx , arbitrarily normalized at 500 MeV/amu (requiring 27.9 eV per ion pair in the P-10 gas used (90% argon, 10% methane)). It is apparent that the signals fall below that predicted by dE/dx at energies above 700 MeV/amu. This loss of signal is somewhat surprising since at these energies we would expect knockons escaping from the exit window to be in equilibrium with those arriving from above, particularly for chambers 5 and 6 which have ~ 2 g cm^{-2} of upstream material. However, some of the decrease in observed signal may be due to knockons escaping from the sides of the chambers.

By interpolating to a particular energy we can construct a plot of signal versus Z at that energy. At low energies, the heaviest nuclei have an effective charge, $Z_{\text{eff}} = Z[1 - \exp(-130\beta Z^{-2/3})]$, due to electron capture (Pierce and Blann, 1968). Figure 3 shows the pulse heights, scaled down by Z_{eff}^2 , at four energies for $Z = 26-79$, using ion chambers 1, 5, and 6. The uranium data have not been included because the charge state in the magnetic spectrometer was uncertain for those beams whose energy had been degraded significantly. The straight lines represent a linear fit to the data, and it is apparent that there is a small negative non- Z^2 effect. The charge of an ^{82}Pb nucleus would be underestimated by about 0.5 charge units at these energies, in contrast with the charge overestimate of +3 charge units observed in the calibration of the flight chambers.

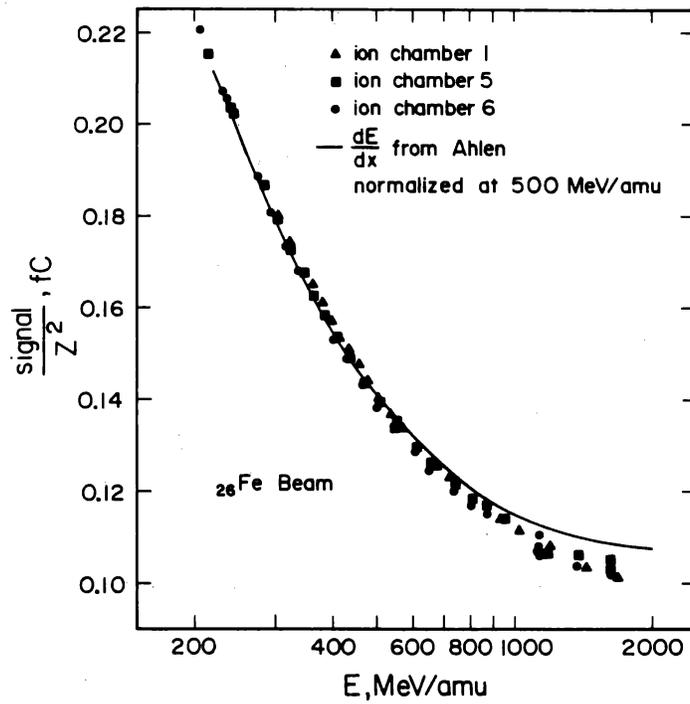


Figure 2. The response of chambers 1, 5, and 6 to ^{26}Fe nuclei as a function of energy.

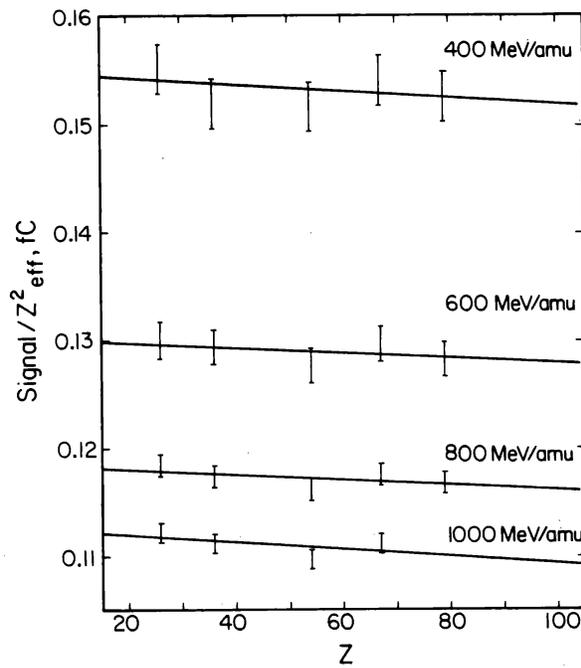


Figure 3. Response of chambers 1, 5, and 6 at four energies, scaled by Z^2_{eff} .

3. Conclusions

Although the non- Z^2 effects in these chambers differ from those observed in the prototype flight chambers, the assumption of Z^2 scaling is still not seriously in error. We also note that our published abundances above charge 50 have used primarily the Čerenkov detector to assign charges, and are unaffected by small non- Z^2 effects in the ion chambers.

Since the two calibrations differ, the ionization response to energy loss must be sensitive to details of the mass distribution above, below, and within the chambers. As a result we have used the flight data to directly determine both the energy dependence and effective non- Z^2 correction (Jones et al., (1985, OG 4.1-8) and Newport et al., (1985, OG 4.4-5)).

4. Acknowledgements

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