MASS RESOLUTION OPTIMIZATION IN A LARGE ISOTOPIC COMPOSITION EXPERIMENT

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ABSTRACT

A range-energy experiment has been built which will measure the isotopic composition of galactic cosmic rays. Recent experiments have shown an enrichment of neutron rich isotopes, ^{22}Ne and (^{25}Mg + ^{26}Mg) in particular, when compared to the solar composition. A high statistics measurement of these and other neutron-rich isotopes in the galactic flux will yield valuable information as to the source of these particles.

The 1.0 m^2-sr instrument will use a Cherenkov radiation detector (n = 1.5) to measure the particle velocity. The range of the particles will be measured by a passive nitrocellulose stack. Two scintillation counters and two gas drift chambers will be used to determine the nuclear charge and trajectory of the particles.

A computer simulation of the experiment has been used to estimate the instrument resolution. The Cherenkov detector light collection efficiency, ε_d, has been calculated. Absorption of light in the radiator has been considered in order to determine the optimum Cherenkov medium thickness, $x \cong 2.5$ cm. The computer projections also show that the Cherenkov radiator must have a uniform response to within 0.5% to achieve a mass resolution of $\delta A \leqslant 0.3$ amu. The experiment is expected to determine the isotopic composition for the elements neon through argon in the energy range 300-800 MeV per nucleon.

1. Introduction: Recent observations of the isotopic composition of galactic cosmic rays (1) have shown an overabundance of neutron-rich isotopes when compared with the solar composition. A discussion of the possible models which could cause this phenomena is given in Woosley and Weaver, 1981. Measurements of the galactic flux would conceivably show which processes dominate in the production of these particles.

A Large Isotopic Composition Experiment (2) (ALICE) has been designed to measure the isotopic composition of cosmic rays in the energy range 300-800 MeV per nucleon. ALICE will yield measurements for the elements Ne, Z = 10, through Ar, Z = 18.

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The 1.0 m^2-sr instrument relies upon 5 active detectors to measure the particle nuclear charge, velocity and trajectory. A passive cellulose nitrate (CN) stack is used to determine the particle range. This parameter is used to determine the particle mass.

A computer simulation has been used to determine the energy losses (3) of the incident cosmic rays within the detectors for given Z and A. The energy losses are used to project the uncertainties in particle energy and range. A mass resolution of less than 0.3 amu is the design goal of the experiment.

2. Detector Complement: The experiment employs 3 distinct types of detectors for the active measurements. A schematic diagram of the instrument is shown in Figure 1.

Two gas drift chambers (4) determine the particle trajectory. The chambers are filled with a gas mixture (Ar: 90 percent, CH_4: 10 percent) and will each contain 6 groups of parallel wires. Three groups are set along the x-axis and 3 along the y-axis thus creating a cartesian coordinate system approximately 20 cm deep. The electron drift velocity, (V_d = 40.3 mm/μs), together with the difference in arrival times of the sense wire signals determines the track position. The single wire resolution of this hodoscope is ~ 200 μm.

A knowledge of the particle trajectory enables us to relate a particular event in the active chambers to the track left in the CN range stack. The particle incident angle is also found for use in cosine corrections to the path lengths through the detectors.

The remaining 3 active detectors have the same basic interior design which is shown in Figure 2. The chamber interiors are coated with a diffusely reflecting Barium Sulfate ($BaSO_4$) paint which has a reflectivity of 95 percent in the visible light region. This high reflectivity effectively reduces losses due to absorbtion by the chamber walls.

Scintillation light is produced in commercial PS-10. The 2 scintillation counters each contain a 1-cm thick sheet of PS-10 which covers the entire lower surface of the chamber interior. Sixteen equally spaced photomultiplier (PM) tubes, set 4 to a side, produce an active detection area of 2236 cm^2. Although light will be lost through absorbtion by the PS-10 and the chamber walls, a light collection efficiency, ε_d, of 49 percent is expected. A fast trigger is provided by four 2-inch PM tubes on each scintillation chamber. A coincidence between the S1 and the S2 signals trigger the instrument. This feature will collimate the particle beam, effectively minimizing the number of false events.

Pilot 425 (n = 1.5) will be used in the Cherenkov detector. Since the Cherenkov radiation is emitted primarily in the ultraviolet region, the Cherenkov material is doped with an ultraviolet-to-blue wave shifting compound to enhance the number of photons with wave lengths within the sensitivity limits of the PM tubes. The detector utilizes 24 PM tubes with an effective detection area of 3354 cm^2. The flight PM tubes have been selected for optimal resolution which we have determined corresponds to those PM tubes with the highest quantum efficiency and, hence, "gain". A sample of 86 PM tubes were tested out of which the best 24 PM tubes were selected. The Cherenkov material will have a thickness X = 2.5 cm.

The passive range stack is composed of several hundred layers of 0.03 g/cm^2 nitrocellulose sheets with a total depth of about 15 g/cm^2. After the flight, the range stack will be recovered and the sheets individually etched. Computer scanning methods will be used to produce a 3-dimensional view of the particle tracks in the range stack.

Lastly, an anti-coincidence counter is located below the range stack so that incident cosmic rays which do not stop in the stack are flagged. This feature will produce a measurement of iron secondaries in addition to the isotopic measurements.

The payload is to be elevated by balloon to an atmospheric depth of 4 g/cm^2 with a flight duration of 24 hours. A Fall 1985 launch is planned.

3. Calculated Resolution: ALICE must measure the particle mass to within 0.3 amu for the data to be useful. We may assume that the charge error, δZ, and errors associated with the trajectory, $\delta \cos \phi$, are much smaller than the uncertainties associated with the measured range and velocity, δR and $\delta \beta$, respectively.

The range of the particle is related to Z, A, and β through the equation:

$$R = \frac{A}{Z^2} f(\beta)$$

where $f(\beta)$, the velocity dependence, may be determined from proton range energy relations (3).

This relation yields a formula for the mass resolution:

$$\frac{\delta A}{A} = \left\{ \left(\frac{\delta R}{R}\right)^2 + \left(\frac{1}{f(\beta)} \frac{\partial f(\beta)}{\partial \beta} \delta\beta\right)^2 \right\}^{1/2}$$

A computer simulation of the experiment has been used to estimate the instrument resolution.

Figure 3 depicts the mass error for the isotopes ^{20}Ne and ^{40}Ar, respectively. The particles are assumed to be vertically incident and the effects of delta rays and residual scintillations have not been included in this calculation. Residual scintillations are ~ 1/10 of the size of the saturated Cherenkov signal in Pilot 425. The effect of residual scintillations is similar to an increase of the index of refraction. Delta rays also mask the particle signal. The contribution of delta rays to the total Cherenkov signal has been studied (5). The combined effect of residual scintillations and delta rays is about 15% of the saturated signal. Near threshold, ~ 320 MeV/n, where the effect of delta rays is most significant, the mass error will be larger than depicted. For energies above 330 MeV/n in the Cherenkov medium, fluctuations in the delta ray signal are less than a 1σ deviation of the particle Cherenkov signal. Therefore, the mass error curves will approach those in Figure 3 at energies above 435 MeV/n and 490 MeV/n at the top of the atmosphere for ^{20}Ne and ^{40}Ar, respectively.

As of this writing, the ALICE stack has been assembled and calibration of the instrument is underway.

References

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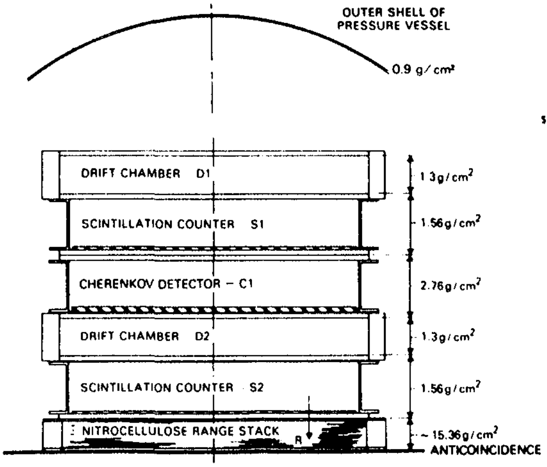

Fig. 1. ALICE schematic diagram

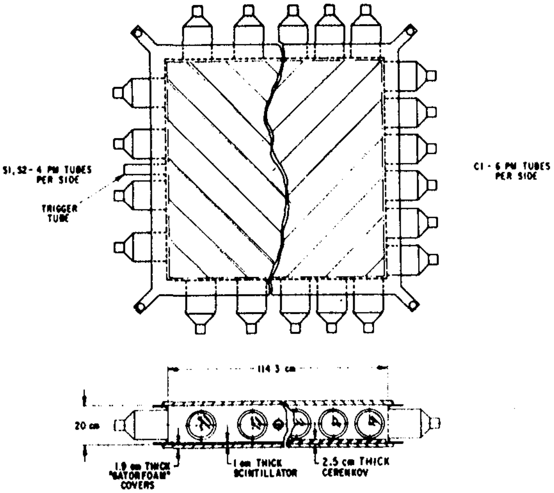

Fig. 2. Cherenkov and Scintillation Chamber Photomultiplier Tube Placement

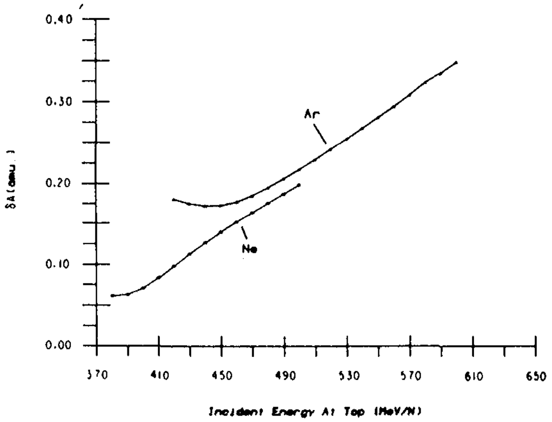

Fig. 3. Mass Uncertainties for ^{20}Ne and ^{40}Ar.