# MULTIPLE SCATTERING EFFECTS IN dE/dx-E INSTRUMENTS FOR ISOTOPIC COMPOSITION STUDIES

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1. **Introduction**. The development of cosmic ray telescopes capable of separating individual isotopes of heavy elements using the dE/dx-vs.-E technique depended critically on the incorporation of precise trajectory sensing elements into these systems. In typical implementations the particle trajectory is derived from a set of position measurements made prior to a particle's entering the first energy loss detector. The use of the trajectory obtained in this way to correct energy loss signals for the actual pathlengths through the detectors depends on the assumption that the particle trajectory is a straight line. In order to resolve iron isotopes the angle of incidence, θ, of the particle track (measured from the normal to the detector surfaces) must be known rather accurately.

When the angle of the cosmic ray's track through the ΔE detectors must be known with this high precision, the effects of multiple Coulomb scattering in the trajectory sensor, in the material between it and the ΔE detector, and in the ΔE detector itself must be taken into account. For example, when iron nuclei at 200 MeV/amu pass through a 1 g/cm² thick layer of silicon, multiple scattering causes a distribution of the effective angles of the particle tracks through this layer. This distribution, while centered on the angle at which the particles enter the layer, has an rms spread of approximately 0.11°. For iron particles traversing the layer at an angle of 30° this would lead to an uncertainty in the calculated mass of slightly more than 0.1 amu. These effects become increasingly more severe when one considers measurements of nuclei of lower energy, or when absorbing materials of higher atomic number are used.

In this paper we discuss an alternative approach to particle trajectory determination which can provide a significant reduction in the pathlength uncertainty in the energy loss detectors which is caused by multiple scattering. This approach involves the measurement of the locations of the points at which the particle enters and exits the detector and approximating the trajectory by a straight line between these two points, rather than by a straight line through two points along the particle's track before it entered the detector. In Section 2 the pathlength errors which result from these two approximations are compared. In Section 3 one practical implementaton of the new approach is described, and practical issues which limit its general applicability are mentioned.

2. **Comparison of Pathlength Uncertainties**. Figure 1 schematically shows the track of a heavy nucleus through a layer of material (such as a ΔE detector), with the scattering greatly exaggerated. Also shown are the approximations to this path which are obtained by using straight lines

through: a) points measured along the trajectory before entry into the detector, and b) the points at which the particle entered and exited the detector. Analyses by others [1] have shown that in case (a) the relative uncertainty in the pathlength through the detector is given by·

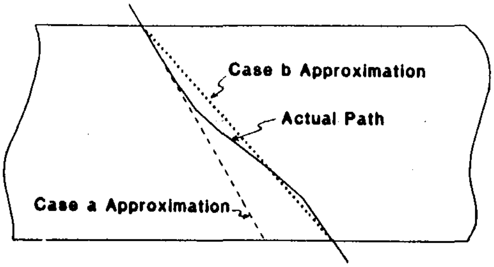

Figure 1.

$$\frac{\sigma_{\sec\Theta}}{\sec\Theta} = \frac{1}{\sqrt{6}} \cdot \tan\Theta \cdot \sqrt{X}\ \sigma_{\Theta}$$

where $\theta$ is the nominal angle of the particle's track (measured from the detector normal), X is the detector thickness in g/cm², and $\sigma_\theta$ is the rms angle of deflection over a pathlength of 1 g/cm². (Throughout this discussion we neglect the effects of particle slowing in the layer. Zumberge [2] has analyzed such effects, and the application of his approach to the cases considered here makes no qualitative changes in our results.)

For case (b) we have carried out a formal analysis in which the detector is subdivided into a large number of thin sublayers and the scatterings in each layer are treated as independent Gaussian random variables and their effects on the pathlength and on the point of exit from the detector are compounded. This analysis, carried out to first order in $\sigma_\theta$, shows that the approximate trajectory (b) (see Fig. 1) agrees exactly with the true pathlength. The reason for this agreement is illustrated in Figure 2, in which we compare two paths - one involving a single scatter and the other a straight line agreeing with the first at its end points. The lenghts of the three segments shown are related by:

$$c = \sqrt{[\ a^2 + b^2 + 2ab \cdot \cos(\delta\Theta)\ ]}$$

which for small values of $\delta\theta$ reduces to:

$$c \simeq a + b - \frac{1}{2}\left(\frac{ab}{a+b}\right) \cdot (\delta\Theta)^2$$

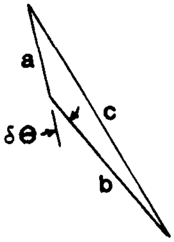

Figure 2.

That is, the difference in the two pathlengths is second order in $\delta\theta$. When more than one deflection of the particle's trajectory is considered, their combined effects also produce pathlength differences, but these all involve products of the individual scattering angles and therefore again only yield second order or higher effects.

In order to carry out a quantitative comparison between the pathlength errors in cases (a) and (b) we have chosen to perform Monte

Carlo calculations, rather than to extend our calculation for case (b) to second order. In addition, we have incorporated the effects of ionization energy loss in the Monte Carlo calculation, calculating the rms scattering angle in each sublayer using the actual value of the particle's velocity in that layer. In Figure 3 we compare our results for the two cases. Also shown, on the right hand abscissa, is a scale indicating the approximate contribution of these pathlength errors to the mass resolution for the measurement of iron isotopic composition. It can be seen that the determination of particle trajectories from the entry and exit points contributes negligibly to the mass resolution, while the use of a trajectory extrapolated from outside the detector leads to a mass error which, at large angles, could be the dominant source of mass uncertainty for measurements of iron isotopes.

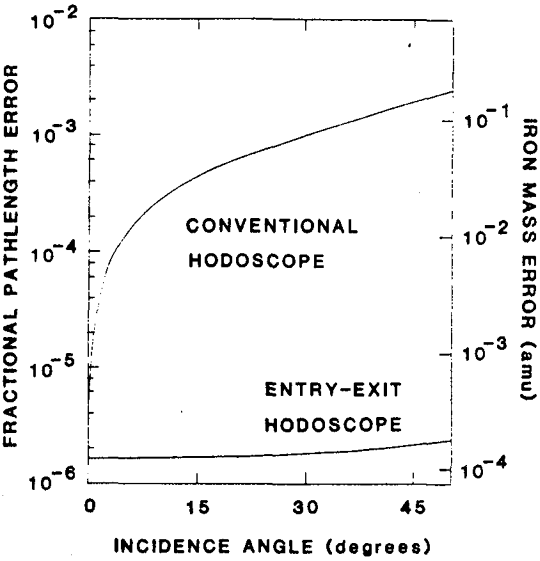

Figure 3.

An additional source of pathlength uncertainty, which occurs when the trajectory is only measured before entry into the ΔE detector stack, results from scattering in any material (such as previous ΔE detectors) between the trajectory measurement and the measurement of ΔE which is being used for mass determination. For the same amount of material, these scatterings contribute a factor $\sqrt{3}$ more to the pathlength uncertainty than do scatterings in the ΔE detector itself [1]. Normally the best mass resolution is obtained from ΔE measurements made close to a particle's end-of-range, but multiple scattering effects may significantly degrade such measurements in systems where several other thick detectors must be penetrated subsequent to the trajectory measurement. These resolution-degrading effects should become noticeable for high-Z, high-argle events in the next generation of cosmic ray composition experiments utilizing silicon solid state detectors.

3. Practical Applications. The above considerations were based on the assumption that the locations of discrete points along a particle's track can be measured exactly. Under most practical conditions the errors made in measuring the locations of these points will dominate the multiple scattering error in case (b). If two orthogonal coordinates are each measured with an uncertainty $\sigma_x$ at two faces of a detector of thickness $\Delta z$, the resulting uncertainty in the pathlength between these points is:

$$\frac{\sigma_{\sec\Theta}}{\sec\Theta} = \frac{1}{\sqrt{2}} \cdot \sin(2\Theta) \cdot \frac{\sigma_x}{\Delta z}$$

The difficulty in implementing a practical entry-and-exit trajectory system stems mostly from the fact that the ratio $\sigma_x/\Delta z$ must be $\lesssim 10^{-3}$ to achieve the pathlength accuracy required to resolve heavy isotopes. In solid state detector telescopes one typically has $\Delta z \lesssim 5$ mm, requiring $\sigma_x \lesssim 5$ µm. While this tracking accuracy is, in principle, achievable, it is far beyond the level of presently practical systems.

Systems employing gas ionization detectors for the ΔE measurement are more amenable to the implementation of an entry-exit trajectory system because the low gas density dictates that the detectors be relatively thick. We are in the process of constructing such a system in which a ΔE detector consists of 30 cm of gas at a pressure of 10 atm (~0.5 g/cm²). We are incorporating a pair of single-wire proportional counters, one at the front of the ΔE detector and one at the back, in the same gas volume as the ΔE detector, to provide a determination of the entry and exit coordinates from combined measurements of drift time (to determine the distance of the particle track from the wire) and charge division (to determine the position along the wire). The large lever arm provided by the ΔE detector thickness (30 cm) makes it possible to derive a sufficiently accurate trajectory from position measurements made with a precision rather typical of gas-phase position sensitive detectors (~ 0.3 mm rms). While our present system uses P-10 gas (90% Ar, 10% $CH_4$) as the ionization medium, the entry-exit trajectory system should permit the use of heavier gases (such as Xe) to provide additional stopping power without introducing additional pathlength uncertainty. If a conventional trajectory system were used, the use of Xe instead of Ar would increase the multiple scattering induced pathlength uncertainty by a factor ~ 4, thereby severely restricting the solid angle over which satisfactory mass resolution could be attained (cf. Fig. 3).

4. Conclusions. Trajectory systems which provide the coordinates of a particle's track as it enters and exits each energy loss detector could, in principle, eliminate the contribution of multiple scattering to the mass error in dE/dx-E particle identifiers. The implementation of such systems appears most practical in systems using gaseous energy loss media. A detector system which can be used to experimentally test these results is now being developed.

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## References

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