Computer Animation of Extended Air Showers Interacting with the Milagro Water Cherenkov Detector

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We employ advanced computer animation to visualize the interaction of Extensive Air Showers (EAS) with the Milagro water reservoir. The animations help conceptualize the evolution of the EAS particle front as it hits a large volume of water and converts to Cherenkov photons. Expected effects such as refraction and curvature are easily seen, as well as a number of novel behaviors. A simple model that explains the observed dynamics of the shower front will be presented.

Due to the difficulty of presenting animations on a poster, we will be demonstrating the movies with a portable computer system during the poster session. What follows is a simple model to explain the dynamics observed in these animations. We look forward to demonstrating the animations for you during the poster session.

The Bowl-Ring Model of Cherenkov Light Emission

Particles entering a large Cherenkov detector such as Milagro do not emit light in just the classic Cherenkov ring. When the particles first enter the water, they do emit their light in the classic ring pattern, however, as the particles slow they suffer large deflections due to multiple scattering and the ring of emitted Cherenkov light is deflected through a large angle. For a shower core consisting of many particles hitting together, a bowl and ring structure of Cherenkov light is emitted as can be seen in the still frame to the left. As the particles of the core enter the pond they are all emitting light in the same Cherenkov ring. But as the core penetrates into the pond the particles suffer large random deflections due to multiple scattering so that the Cherenkov rings for the different particles are no longer coincident. The spherical shell or bowl structure is the addition of many Cherenkov rings emitted from roughly the same place but in different orientations.

For a single particle entering the pond, the probability distribution of Cherenkov light emission is described by the same bowl-ring distribution seen in the core. This probability distribution is shown in the diagram to the right. The light is initially emitted into the ring, but due to multiple scattering the later Cherenkov light is emitted into the bowl structure. This Cherenkov light emission pattern leads to several interesting effects when an Extensive Air Shower (EAS) interacts with a ground level Cherenkov detector.

To explain the observed effects we will use a toy model of the full EAS. Our toy model will consist simply of a plane of uniformly distributed particles. If our toy shower is vertically incident on the pond, each particle will emit light in bowl-ring distribution as shown in the diagram to the right. There are several features of the diagram to note in particular. First is the bifurcation of the shower front as seen in Cherenkov light. The first front travels at the speed of light in water and is formed by the bottom of the Cherenkov bowls. The second front is caused by the Cherenkov rings and travels at (cos θ) times the speed of light in water. Also note that there is a lot of light that is not involved in either of the two shower fronts. This “late light” is caused by the incoherent addition of the Cherenkov bowls that occurs behind the first shower front.

If we now turn our attention to a toy shower that impacts the pond at an angle, other important effects can be observed. In the diagram at right the dual Cherenkov front and the late light effects can still be seen. Although the first shower front is unaffected, the second shower front shows significant broadening over the vertical example. This broadening of the shower front is because the Cherenkov rings are emitted perpendicular to the direction of the original particle, not parallel to the refracted Cherenkov light front. This suggests that the width of the second shower front should be angle dependent. Also note the different refraction angles of the two Cherenkov fronts due to the difference in propagation speeds.

The pair of still images to the left are from Monte Carlo generated movies that model the propagation of the toy shower through the pond. Close scrutiny of the upper image reveals shower front bifurcation, dual refraction angles, late light, and broadening of the second shower front. In the lower image multiple scattering has been removed to show just the second shower front and the angle dependent broadening.

Selected Stills:

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