Computer Simulations of Nonimaging Concentrators
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Abstract
A new type of detector has been proposed for inclusion in the Pierre Auger Observatory to study the origins of ultra high energy cosmic rays by measuring the Cherenkov radiation they emit when they enter the atmosphere. This detector requires a concentrator to focus the Cherenkov radiation into a photomultiplier tube. Simulations of concentrators consisting of two cone segments sitting on top of each other were carried out to determine if they would be a suitable compromise between highly efficient but expensive compound parabolic concentrators (CPCs) and simple but inefficient conical concentrators. The simulations calculated the path of photons as they reflected inside the concentrators and calculated the acceptance angle for each configuration. By varying the location at which the two sections come together and the angle of the bottom section it was determined that certain combinations of these parameters will result in better optical performance and a shorter height than a simple cone. This demonstrates that a concentrator consisting of two cone segments sitting on top of each other is a viable alternative to the more common but ill suited CPCs and conical concentrators.

Background
The Pierre Auger Observatory (PAO) is an ongoing experiment to determine the origin of ultra high energy cosmic rays (UHECRs). These cosmic rays are protons or atomic nuclei with energies on the order of 1 to 10 Joules. Nothing in the known universe can create particles with energies this high so discovering their origin could lead to new knowledge of high energy physics or the universe in general. UHECRs travel at nearly the speed of light in a vacuum. Their speeds are greater than light in the atmosphere, causing them to give off Cherenkov radiation, a “sonic boom” of light. By measuring the Cherenkov a cosmic ray’s energy and direction of travel can be determined. A proposed addition to the PAO is a new type of detector has been proposed for inclusion in the Pierre Auger Observatory to study the origins of ultra high energy cosmic rays by measuring the Cherenkov radiation they emit when they enter the atmosphere. This detector requires a concentrator to focus the Cherenkov radiation into a photomultiplier tube. Simulations of concentrators consisting of two cone segments sitting on top of each other were carried out to determine if they would be a suitable compromise between highly efficient but expensive compound parabolic concentrators (CPCs) and simple but inefficient conical concentrators. The simulations calculated the path of photons as they reflected inside the concentrators and calculated the acceptance angle for each configuration. By varying the location at which the two sections come together and the angle of the bottom section it was determined that certain combinations of these parameters will result in better optical performance and a shorter height than a simple cone. This demonstrates that a concentrator consisting of two cone segments sitting on top of each other is a viable alternative to the more common but ill suited CPCs and conical concentrators.

Methods/Intermediate Results
To create a two stage concentrator from a simple cone, a bend was created. See Figure 1 for illustrations of the effects of changing the bend location, bend angle, and height scale on the geometry of the concentrator. The radius of the bottom aperture was held constant through all modifications because the PMT it will attach to has a fixed radius. In the first set of simulations two properties were held constant and the third was swept over a range of values. The results of these simulations showed that increasing the height was ineffective at improving performance and the third was swept over a range of values.  The results of these simulations.  For certain combinations of bend angle and location the falloff was less than that of a simple cone. The acceptance was also affected, decreasing with any modification to the simple cone. To create a concentrator with the desired performance, an acceptance angle of 40 degrees and a falloff width of 5 degrees, a simple cone with a 50 degree acceptance angle and 5 degree falloff width was chosen as the starting cone. By changing the initial cone based on the results of the first simulation, a concentrator that comes very close to the desired performance was developed.

Discussion
It has been shown that concentrators that are composed of two cone sections on top of each other can have very similar performance to simple cones but are much shorter, making them easier to work with out in the field. For an acceptance angle of 40 degrees and a falloff width of 5 degrees a simple cone would be too tall to be practical but a two stage concentrator is an acceptable height. Because they perform well and have a simple geometry, two stage concentrators are a good solution for focusing light into a PMT for the Cherenkov radiation detector. Now that the program is written and the process is developed, it would be easy to design a new concentrator if the desired performance changed sometime in the future.

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