Quartz-based Cherenkov Calorimeter Simulation

Summary: As experiments designed to search for new physics reach higher and higher energies, detector strategies need to be developed to manage the increased radiation. Rare physics processes require not only high energies, but also extremely high luminosities, which therefore require very fast readout circuitry.

Existing scintillators face two major limitations to contemporary applications: They are not radiation-tolerant - they darken when exposed to radiation. Since the light they generate is proportional to the energy of the particle that traverses it, a darkening scintillator requires continual recalibration of the detector.

The second major limitation is that many have slow emission times, or decay times. When the particle hits the scintillator, it may take 20 - 200 ns for the scintillator to stop scintillating. At the Large Hadron Collider, collisions are designed to occur every 25 ns, and the experiments there are facing a real challenge known as pile-up. Pile-up occurs when a previous event is still being read out by detector electronics when another event occurs, so there is leakage from one event into the next and into the next and so on. The challenge then becomes distinguishing the signals between events.

We propose using quartz cubes as the active medium for a calorimeter, reading out the quartz using a SiPM as the photodetector, and placing layers of tungsten or iron as absorber material between layers of quartz (see Fig. 1).

Quartz is extremely radiation tolerant - the forward calorimeter in the CMS detector at CERN uses quartz fibers to transmit light because of this fact. They are performing well even after several years of running. This makes quartz an ideal material for high radiation environments.

Cherenkov radiation occurs when a high energy particle enters a different medium with a velocity greater than c/n, where c is the speed of light and n is the index of refraction of the medium.

The advantage of using Cherenkov radiation as the source for our photodetectors is that the Cherenkov mechanism is on the order of tens of picoseconds, therefore light is generated only as long as the particle is passing through the medium. This makes Cherenkov radiation the ideal mechanism for high-luminosity experiments.

We have developed a simulation of this detector, modeling the true quantum efficiency as a function of wavelength for a standard Hamamatsu SiPM with peak efficiency around 400 nm, in order to gauge the SiPMs ability to measure the Cherenkov photons generated.

We have and will present data on the detector response to pions, electrons, and muons (see Fig. 2) for a detector with 1 cm quartz cubes, 45 cubes x 45 cubes in XY, and 80 cubes deep in Z. The Z-axis alternates an XY layer of quartz cubes and a layer of tungsten absorber, as well as a simulation with iron absorbers.

This is a highly segmented “digital” calorimeter that can be used to track particles, as an ECAL, and at the same time as an HCAL, which holds serious promise for the future.

Our plan is to use machine learning algorithms to tag particles, by training the reconstruction algorithms with this simulation data. By doing this, an extremely efficient experimental program could be established and run with minimal overhead to get physicists the data they need to do the analyses for new physics.

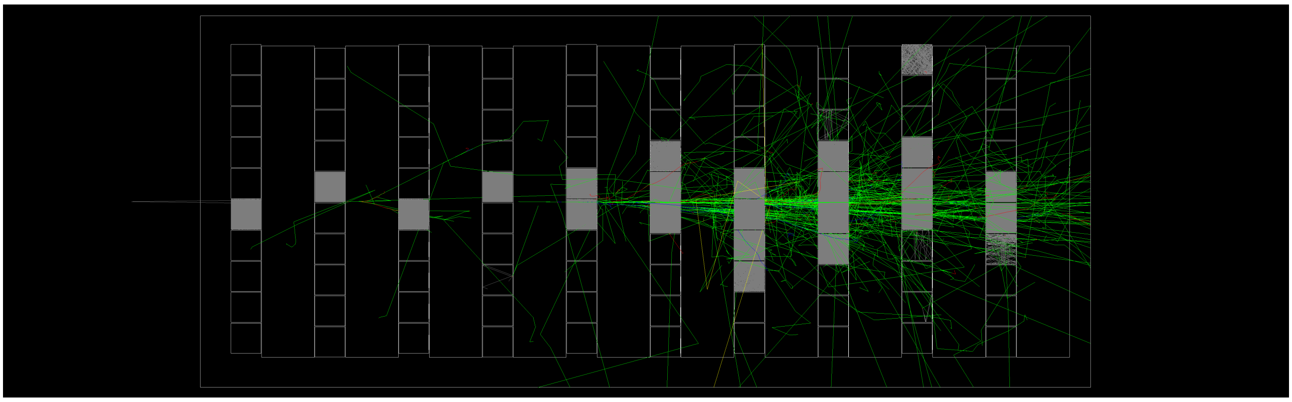

Fig. 1: Visualization of a pion traversing the calorimeter simulation in GEANT4 with alternating layers of quartz and iron.

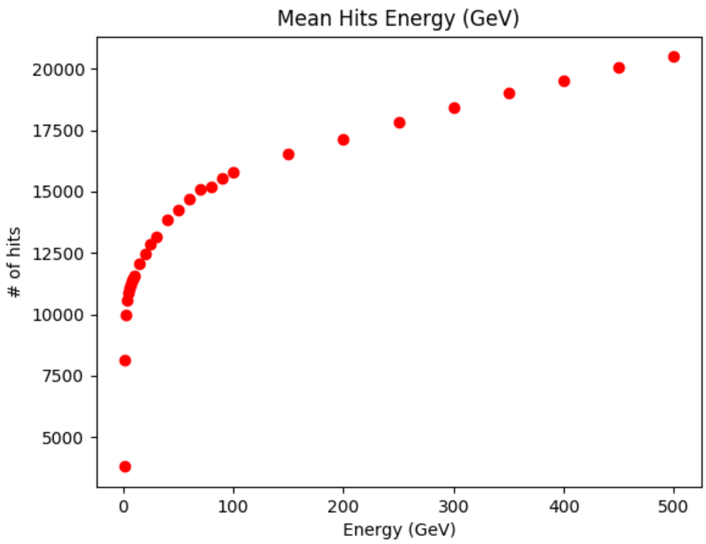

Fig. 2: Plot of average # of SiPM hits vs. Energy for muons through a quartz/tungsten calorimeter, simulated in GEANT4. Total of 10,000 events for each energy.

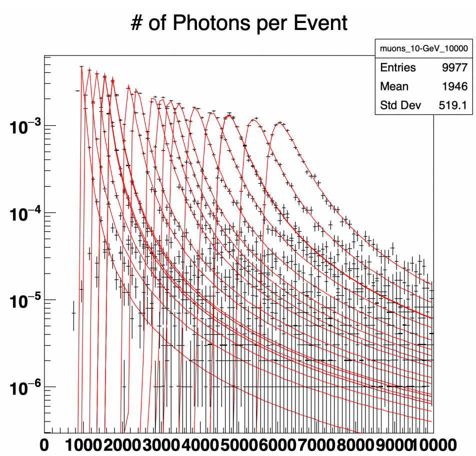

Fig. 3: Landau fits to detector responses to get MPV for Fig. 2 plot. 10,000 events per energy.