GEM TN-92-212

Preliminary GEANT Simulation Results on the Forward Quartz-Fiber Calorimeter

R. Carey, S. T. Dye, J. P. Miller - Boston University
D. R. Winn - Fairfield University

November 11, 1992

Abstract:

Preliminary simulation results on the performance of a quartz fiber/lead (tungsten) calorimeter, a candidate technology in the GEM detector's forward region, are presented. Results suggest that the design is promising and may be appropriate for the physics at very large $|\eta|$.

November 12, 1992 GEM-TN-92-212

Preliminary GEANT Simulation Results on the Forward Quartz-Fiber Calorimeter

R. Carey, S. Dye, J. Miller and D. Winn

Abstract

Preliminary simulation results on the performance of a quartz fiber/lead (tungsten) calorimeter, a candidate technology in the GEM detector's forward region, are presented. Results suggest that the design is promising and may be appropriate for the physics at very large $|\eta|$.

1 Geometry

Our calorimeter was a cube. Particles were incident on the center of one of the faces. For electrons it measured 18.5 cm on a side and for pions 184.5 cm, to make sure the showers were reasonably well contained. The absorber material was lead or tungsten. The fiber had a 0.16 cm radius with .925 cm spacing (9% packing). A few simulations were made with 0.10 cm radius fiber with 0.46 cm spacing (15% packing). The fiber had an index of refraction n=1.46, and the cladding, n=1.41. Cerenkov photons were kept if they were emitted within the total internal reflection angle in the fiber and were travelling in the +z direction, and were otherwise discarded. We assumed a light yield scaled from 200 photons/cm in water, and we ignored issues of wavelength and PMT efficiency.

For a given incident angle, the point of incidence was moved randomly over a single cell consisting of one fiber plus surrounding absorber.

2 Preliminary results

For 100 GeV incident electrons:

- In lead, we obtained 32% rms resolution at incident angles of 6 degrees to 15 degrees to the fiber. (Larger angles were not investigated.) This

improved to 9% for 0.1 cm radius fiber, 0.46 cm spacing. The resolution rose to 67% and 100% at angles of 2 degrees and 0 degrees respectively. The corresponding numbers for the closer spacing were 22% and 54%.

- There were about 2700 photons arriving at the fiber end for 100 GeV showers. This number rose sharply to 3500 photons as the incident angle neared 0 degrees. For the closer spacing case, we obtained 5000 and 5600.

- In tungsten, there was about 30% less light (1700 photons) than in lead for 100 GeV electrons incident at more than 4 degrees. The energy resolution (RMS) was about 53%, rising to 140% at 0 degrees. The number of photons again rose sharply at exactly 0 degrees, this time to 2700.

- A large contribution to the resolution came from the spacing between fibers, which was wide compared with the lateral spread of the em shower, in both lead and tungsten. We attribute the relatively poor performance in tungsten to its higher density and shorter radiation length, which has an effect similar to increasing the fiber spacing.

- The photon-weighted average shower position was found for each event. In the direction transverse to the original particle trajectory, the error in the photon-weighted average position of showers on an event-by-event basis is 0.52 cm at 0 degrees incidence.This is quite conservative since it includes the contribution from the one-cell variation in incident position.

For 100 GeV incident pions:

- In lead, for incident angles larger than 4 degrees, about 20% less light was produced than for 100 GeV electrons.

- The resolution in the case of pions deteriorated from 18% at 10 degrees to 32 % at exactly 0 degrees. The same number of photons were produced at both angles, in direct contrast to the electron case at the same angles. The corresponding numbers for the closer fiber spacing were 12% and 20%.

- 25% of the cerenkov photons came from pions, 3% were from protons, and the remainder were from electrons and positrons. About the same numbers were obtained for the closer spacing.

- The resolution deteriorated from 18% to 25% at 10 degrees when the fiber spacing was increased by 33%.

- In tungsten, pions incident at 4 or more degrees produced 25% fewer photons than for incident electrons. The resolutions for the tungsten case were 28% and 57%, at 10 and 0 degrees respectively. Once again the number of photons was the same at both angles. 27% of the cerenkov light came from pions plus 3% from protons, and the remainder from electrons and positrons.

- Again, the photon-weighted average position was found for each event. The histogram of the averages had a sigma of 0.62 cm in the direction transverse to the incident trajectory, including, once again, a contribution from the spread of incident positions over one cell. This indicates good position resolution transverse to the shower.

3 Summary

In summary, the energy and transverse position resolution, and the pulse height stability vs. angle for hadrons was good, and the responses to hadrons and electrons/positrons were comparable. For electrons, the energy resolution was worse, the pulse height rose and the position resolution deteriorated as the incident angle approached (less than 2 degrees) 0 degrees. These effects can be alleviated by using smaller diameter fibers and a smaller spacing between fibers. Note by comparison the fibers used in NA38 and GEM test beams had 1 mm diameters, a factor of 3.2(10) in diameter(area) smaller, and with similar packing fractions, 3.2 times closer fiber spacings in NA38, explaining the superior resolutions. It may be possible to alleviate the small-angle effects by wiggling the fibers (like the accordeon technique) or by helically wound bundles of small diameter fibers (like braided wire) serving as a single fiber. Studies are under way to examine the effects of these changes.

3.1 Salient Points

- Response: The photon yield, about 20-30/GeV at 9% packing, is similar to other measurements and predictions: assuming 25% quantum efficiency, 6-8 p.e./GeV at 9% packing fraction in this Monte Carlo, compared to 16 p.e./GeV at 20% packing fraction measured at CERN, and 5.4 p.e./GeV at 6.8% packing fraction measured by GEM at BNL. The Monte Carlo and data are within 25% of each other scaling by the packing fractions, a remarkably encouraging early agreement.

- Compensation: The e/pi = 1.33 in this Monte Carlo at 100 GeV (9% packing fraction), compared with CERN prediction of e/proton = 1.1 at 10% packing (with different fiber spacing and diameter) and measurement of e/proton of about 1 at 5-10% packing. The general trend of the possibility of approximate compensation (e/pi<1.3) in quartz fiber calorimeters is confirmed by this study.

- Energy Resolution: For beam-fiber angles above 6 and below 15 degrees (with large 3.2 mm dia. fibers) the energy resolution, assuming $1/\sqrt{E}$ scaling, is 10% or less at 1 TeV, the minimal benchmark to obtain 10% E_t resolution for E_t = 100 GeV at η of 3. This generally confirms the pioneering CERN work, both Monte Carlo ($225\%/\sqrt{E}$) and measurement (6.4 TeV 32S heavy ions in a 90 cm long hadron module, after leakage corrections). The MC studies clearly indicate that resolution will improve with finer fibers more closely spaced, extending adequate resolution to small angles of fibers to the beam (<2 degrees).

- Beam-fiber angular response: The MC results of responses for beam-fiber angles of 15→ 0 degrees confirm the GEM prototype measurements taken at 9 degrees. (5-6 p.e./GeV, 25% energy resolution at 10 GeV for 6.8% packing fraction). Furthermore this Monte Carlo indicates that large light yields persist below 5 degrees, giving confidence that a 1-2 degree calorimeter can be constructed. The degradation of resolution below 5-10 degrees is clearly more associated with fiber diameter and crude spacing more than a falling light yield. This observation extends the CERN work towards a viable forward quartz fiber calorimeter.

- Position and Angular Response: The position resolution indicated by this MC is sufficient to calculate E_t at 100 GeV E_t to 10%. Since $E_t = E_{cal} \sin\theta$, good transverse position resolution of the forward calorimeter is also necessary for precision E_t measurements. At η of 3, the distance to the beam center of a calorimeter at 5 meters is 5 m x tan(5.7°) = 50 cm. The position resolution at 100 GeV is 5-6 mm for hadrons and electrons. The fractional angular error is therefore approximately: position error/distance to beam, 6 mm/50 cm = 1.2% at η of 3. E_t is given by $E_t = E_{cal} \sin\theta = E_{cal}\theta$. Adding the fractional errors in energy at 1 TeV [$x sin(5.7^0) = 100 GeV E_t$] of 10% and in angle of 1.2% in quadrature gives an E_t fractional error of 10%. Note that in general the position resolution should scale as $1/\sqrt{E}$, and would be 3 times better at 1 TeV than the MC 6 mm result quoted at 100 GeV. Redoing this calulation at η of 4.5 using 2 mm position error gives a fractional error in the angle of 2 mm/11 cm = 2%. Because of the boost, the energy is 4.5 TeV for 100 GeV E_t, and the energy resolution is about 5%. This gives an E_t error of less than 6% at 100 GeV at $\eta = 4.5$. At η of 5, the angular error is 3% and the energy error is 4% . [Note:the above is assuming z = 5 m for the calorimeter face.] Although this back-of-envelope calculation is done for single particles, jets should be similar or better. These MC results indicating good position resolution confirm the viabilty of quartz fiber calorimeters as an E_t measurement tool.

- Radiation Hardness: Recent studies at CERN by NA38 (P. Gorodetsky) confirm that quartz fiber operate at exposures of electrons up to Grad. the actual Cerenkov yield and ring diamtere ($\frac{1}{n}$ is monitored during the exposure to a 1 MeV electron beam. The yield drops by 10% at 3 Grad.

- Conclusion: Monte Cralo studies and data on quartz fiber calorimeters indicate sufficient performance to justify study as a technology for froward calorimetery.