Quartz Fiber Technique for CMS Forward Calorimeter

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CMS-HF Collaboration

- Hungary
  - ATOMKI
  - KFKI-RMKI
- Spain
  - CIEMAT
- Turkey
  - Cukurova University
  - Middle East Technical University
- Russia
  - ITEP
  - Moscow State University
- USA
  - Boston University, Boston
  - Fairfield University, Fairfield
  - University of Iowa, Iowa City
  - University of Nebraska, Lincoln
  - Texas Tech University, Lubbock
Experimental Technique

- Light is generated by Cherenkov effect in quartz fibers

\[ \frac{d^2N}{dx d\lambda} = 2\pi \alpha Z^2 (\sin^2 \theta / \lambda^2) = 2\pi \alpha Z^2 / \lambda^2 [1 - 1/\beta^2 n^2] \]

- Sensitive to relativistic charged particles
  \[ \beta_{\text{min}} = 1/n \]

- Amount of collected light depends on the angle between the particle path and the fiber axis

- Signals are readout with PMTs
Features of QF Calorimeter

- Very fast signals (< 10 ns)
- Radiation resistant (quartz and copper)
- Insensitive to neutrons and activation products below threshold
- Short and narrow showers ($\rho_M$)
- Reliable operation with limited maintenance
- Simplicity of mechanics; (fibers embedded in absorber)
- Low light yield (~ 0.5 pe/GeV)
Beam Test Results

Hadronic Prototype (1995)

- 135 cm (~8.5 $\lambda_t$) deep
- 5 cm by 5 cm towers (10)
- 300 $\mu$m core dia QQ fibers
- Hexagonal matrix (2.3 mm) (1.5%)
- R329 and XP2020 PMTs
- Fiber bundles in the back

Electromagnetic Prototype (1996)

- 34 cm (22 $\chi_0$) deep
- 5 cm by 5 cm towers (12)
- 300 $\mu$m core dia QQ+QP fibers
- Hexagonal matrix (2.3 mm) (1.5%)
- Fiber ends are mirrored
- XP2020 and XP2020Q PMTs
- Fiber bundles in front (long)
Absorber is made out of stacked 2 mm thick copper plates with electrochemically etched grooves.

Towers are made by bundling fibers, e.g. 625 fibers/ (5 cm by 5 cm) tower.

Each tower is readout by a single PMT.

Fibers are nominally at zero degree to beam.
Energy Linearity to Electrons

Linearity of the prototypes were tested with electrons from 8 - 250 GeV and found to be within ±1 % (XP2020).
Electromagnetic Energy Resolution

QFCAL energy resolution for electrons as a function of electron energy with XP2020 (0.53 pe/GeV) and XP2020Q (0.87 pe/GeV) readout PMTs.
QFCAL energy resolution for electrons as a function of electron energy with XP2020 (0.53 pe/GeV) and XP2020Q (0.87 pe/GeV) readout PMTs.
Calorimeter response as a function of impact point to 150 GeV electrons (magnified scan) is non-uniform to ±1% level. Non-uniformity period corresponds to the Cu plate thickness.
Signal distribution for 80 GeV electrons entering the detector at angles 0 (top) and 6 (bottom) degrees. QFCAL does not show a channeling effect.
Attenuation curves for the calorimeter were measured with XP2020 (glass window) and XP2020Q (quartz window) PMTs. UV component is more strongly attenuated than the visible.
Typical electron signal (in GeV, glass PMT) in the "hadronic" module, with a Gaussian fit.
Signal distributions for 12, 100 and 350 GeV pions.
Response to pions

Calorimeter response to pions as a function of pion beam energy.

Response $\sim 0.33$ P.E./GeV/\% p.f.
The non-compensation of Čerenkov calorimeters leads to large \( e/\pi \) ratios.
The calorimeter response to positive and negative hadrons, and electrons as a function of particle energy.
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Hadronic energy resolution as a function of energy. The circles represent raw data, the triangles the contribution of fluctuations in the number of photoelectrons and the squares the contribution from other sources.
Lateral containment of 80 GeV pion (top) and the electron showers (bottom). Shown are the total signals measured in three calorimeter towers as a function of distance between the outer edge of this row and the beam.
Longitudinal Shower Profile

Average longitudinal profile of the Cherenkov component of 50 and 150 GeV pion showers in iron.
Pulse Shape

Time structure of a typical EM shower in the QFCAL before (top) and after (bottom) the mirrors were removed. (10 m fast cable)

375 GeV π
Fiber Bundle Arrangement
Quartz Fiber Radiation Damage
Hadron fluence, $E > 100$ KeV, $(\text{cm}^{-2})$ and radiation dose (Gy) in and around HF for 10 years of LHC operation. (1 Gy = 100 rad)
Estimated dose rate in $\mu$Sv/hr around the HF due to induced radioactivity after 60 days of running and a day of cool down at an average luminosity of $5 \times 10^{33}$ cm$^{-2}$ sec$^{-1}$ (1 Sv=100 rem)
HF Activation
(60 Days Running + 1 Day Cooldown)

- PMTs: 2.2 - 2.5 μSv/hr
- Fiber bundles: 15 μSv/hr
- Electronics: 0.08 - 0.02 μSv/hr

- CERN Limits
  - Radiation Controlled Area: < 10 μSv/hr
  - Surveyed Area: < 1 μSv/hr
  - Public Area: < 0.1 μSv/hr
  - H2 Beamline: ~40 μSv/hr
Conclusions

- The detector can be made intrinsically radiation hard at the required level
- The detector, for all practical purposes, is sensitive to the electromagnetic shower components
- It is based on Cherenkov radiation and is extremely fast
- The effects of induced radioactivity and neutron flux to a great extent are eliminated from the signal
- Neutron production is considerably reduced (high-Z vs low-Z)
- The detector can be relatively short
- The detector can be made perfectly hermetic