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RESULTS FROM THE FIRST TILE-HCAL PROTOTYPE

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The performance of a hadronic scintillator tile calorimeter prototype with various photodetector readout is discussed.

1 Introduction

The physics goals at a linear collider impose high demands on calorimetry. For excellent separation of WW jets from ZZ jets, which plays a key role in Higgs boson studies, a jet-energy resolution of $\sigma_E/E \sim 0.3/\sqrt{E}$ is required[1]. This can be achieved by combining the potentials of particle flow approach[2] with high granularity in transverse and longitudinal directions for both electromagnetic (ECAL) and hadronic (HCAL) calorimeters. A sub-group of the CALICE collaboration[a] has developed the analog option based on a sampling structure with scintillating tiles read out by wavelength-shifting (WLS) fibers coupled to different photodetectors. A small prototype, called the MiniCal, was built in order to test the performance of a ~100-channel device in a test beam, studying uniformity, stability, performance of different photodetectors, system calibration, monitoring and MC simulation of the shower development.

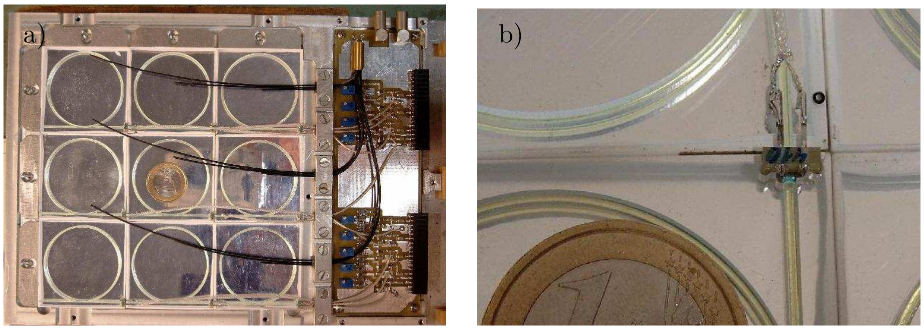

Figure 1: a) An open cassette housing 9 tiles with 1-loop groove WLS fiber and SiPM readout. b) Zoom to the SiPM connection on tile.

[a]The institute members of the group are: DESY, Hamburg, ITEP, LPI, MEPHI, Prague.

2 The MiniCal structure

The MiniCal structure consists of 27 layers of 2 cm thick steel plates stacked with 0.9 cm gaps, of which 11 are equipped with thin-walled aluminum cassettes, each housing nine 5×5 cm^2 wide and 0.5 cm thick scintillator tiles (Fig.1a). The scintillation light is extracted from the tile via WLS fibers. The material in the MiniCal at normal incidence amounts to $1.15X_0$ per layer. The total active area contains 97% of a 6 GeV e^+ shower. The light yield optimization of the tile-fiber system is described in reference[3] and leads to ~200 photons per MIP at the photodetector input. Multi-anode photomultipliers (MAPM), silicon photomultipliers (SiPM) or avalanche photodiodes (APD) record the photons. The 16-channel MAPMs (Hamamatsu H6568) are placed outside the MiniCal, connected via 60 cm long WLS fibers. They are operated with gains of $\sim 10^6$. The 3×3 mm^2 APDs are operated in proportional mode with gains of ~ 100 and are also connected outside the cassettes, more details are given in reference[3]. The SiPMs[4,5] are silicon based photodetectors operated in a limited Geiger mode with an intrinsic gain of 10^6. Their active area of 1 mm^2 is divided into pixels (1024 for the type used in the MiniCal). Given the small size and large signal, they are mounted directly on tile as shown in Fig.1b. The calibration of the energy deposited in the MiniCal in units of MIPs is performed with a 3 GeV e^+ beam by placing all cassettes outside the absorber plates and steering the beam at the tile center.

3 Performance of the MiniCal

In each channel, we fit the calibration spectrum with a Gaussian for the pedestal, a Gaussian for the MIP peak and a Landau tail to parameterize sampling fluctuations. The distance between signal peak and pedestal position provides an ADC calibration in MIPs. The average S/N ratios for SiPM, MAPM, and APD setups are respectively 30, 15, and 9.5, while the MIP-pedestal separability is for each setup $S/\sigma_{MIP} = 3.7$, 3.2, and 5.4, where σ_{MIP} denote the Gaussian width of the signal peak. The latter number is understood from the higher quantum efficiency of APDs. Monitoring the calibration versus temperature and high-voltage fluctuations reproducibility within 2% is achieved. A 2% systematic uncertainty due to tile inhomogeneity is introduced by calibrating with a very narrow beam, as it is estimated performing an eight-point scan around the tile center in 1 cm steps.

For the readout with SiPMs a calibration in photoelectrons (pe) is needed to correct for the nonlinearity introduced by the finite number of pixels. This calibration was performed for over 100 tiles both with the positron beam in the MiniCal and with a Ru^{106}-source. An average of 25 ± 4 pixels/MIP is found, in

excellent agreement for both procedures.
After calibration the energy deposited in all tiles of 11 layers is summed event-by-event for beam energies from 1 to 6 GeV. The energy sums are well represented by Gaussian shapes. Fig. 2a shows the preliminary result for the measured energy versus beam energy. The two measurement sets are in good agreement with each other and with the simulation. Deviations from linearity are less than 2%. SiPM values before nonlinearity correction are also shown. An overall 3% deviation from linearity is obtained for SiPM readout when changing the beam impact point on the central tile. Since in these configurations energy sharing among various tiles is different this is a good test for the reliability of SiPM nonlinearity correction. The MiniCal geometry has been

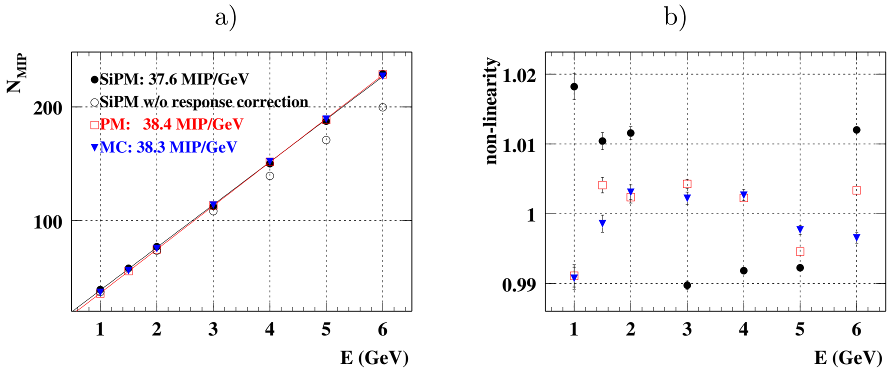

Figure 2: a) linearity curve for SiPM with and without response function correction, MAPM (squares) and MC prediction. b) deviation of the points from linear behavior.

implemented into a GEANT4 simulation. Besides geometry and material specification, also Poissonian fluctuation of pe statistics, efficiencies and calibration uncertainties are taken into account. The simulated longitudinal shower profile of a 3 GeV e^+ is in reasonable agreement with the measurement as shown in Fig. 3a for SiPM data. Similar results are obtained for MAPM data. Fig. 3b shows the preliminary energy resolution of the MiniCal with MAPM and SiPM readout in comparison to MC. The fit function is the quadratic sum of stochastic and constant term, though the sensitivity to the constant term is rather limited in this energy range. The SiPM and MAPM results are in very good agreement both yielding a stochastic term of $\sim 21\%/\sqrt{E}$ and a constant term of $\sim 2\%$ in agreement with simulation. The MC includes the beam energy spread ranging from 6% at 1 GeV to 2% at 3-6 GeV.

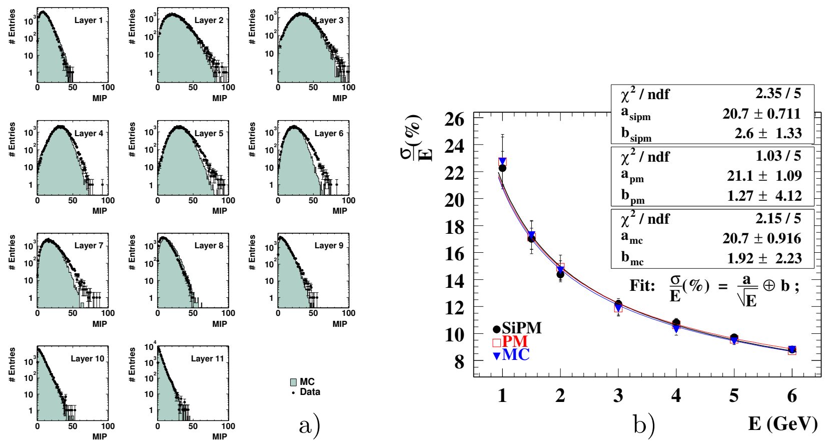

Figure 3: a) Data to MC comparison of the electromagnetic longitudinal shower shape (SiPM). b) Energy resolution for SiPM, MAPM and MC prediction.

4 Conclusion

A new calorimeter concept for a linear collider detector has been developed, which allows unprecedented longitudinal and transverse granularity. The SiPM has been established for the readout of single scintillator tiles. A first calorimeter prototype equipped with 99 SiPM, has been successfully operated in an e^+ test beam. A reliable calibration procedure for all tiles is established and a monitoring system proves the detector to be rather stable. The non-linear response of the SiPM is corrected to better than 2% with a unique function for all photodetectors. A detailed MC simulation has been developed to interpret the test beam data, which correctly models the SiPM response. The MiniCal operation has provided valuable experience for the design, construction and operation of a physics prototype, which will be tested next year together with an electromagnetic calorimeter prototype in hadron beams for further studies on hadronic shower reconstruction and separation.

References

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