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CALORIMETER FOR THE INTERNATIONAL LINEAR COLLIDER[1]

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The requirements on calorimetry for the e^+e^- International Linear Collider are formulated. Recent R&D results for the hadron calorimeter from CALICE collaboration are given.

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1 Introduction

The physics at electron–positron linear collider (ILC) with the collision energy in the centre-of-mass system between $90 - 800$ GeV is dominated by final states containing many jets. Among them, production of heavy bosons W, Z and probably Higgses followed by hadron and lepton decays is the most important. The resolution of calorimeters in the energy range of the future ILC is mediocre. More promising method called "particle energy flow" (PEF) [1–3] relies on precision measurements of charged tracks in the tracker and photons in the fine grained electromagnetic calorimeter (ECAL). These particles represent about 90% of an event energy. The remaining 10% of energy with large fluctuations, of course, must be separated from charged track deposits in the fine grain hadron calorimeter (HCAL). The goal is to reach the energy resolution for jets $\sigma/E \sim 30\%/\sqrt{E}$. To profit from the PEF new effective software algorithms are as important as new detectors.

Based on the above considerations, R&D program for calorimeters was formulated by CALICE Collaboration [4]. The main task of the R&D program is to choose a proper technology and optimize the calorimeter design. A prototype of the calorimeter (1 m^3) is being built [5] and will be tested in beams in 2006. The results of the tests will help to optimize the simulation and reconstruction software.

2 The ECAL design

The requirement of ECAL is to identify photons down to energies of several hundreds MeV without collecting fake ones. To optimize the separation between photons, electrons and hadrons, the calorimeter should be far from the interaction point, dense and highly granular with large ratio of interaction λ_I over radiation X_0 lengths. The comparison for iron, copper, tungsten and lead

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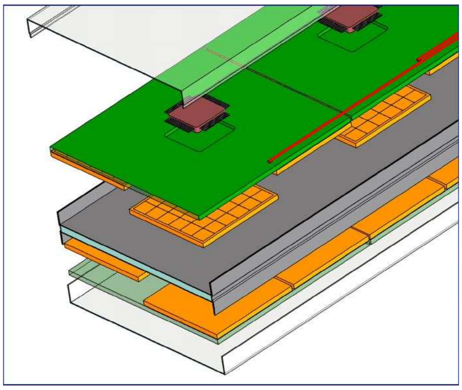

Fig. 1. A double slab 150 cm long of ECAL detector. Si diodes are arranged in arrays of 6×6 pads. They are supported by an H profile made of tungsten–carbon–epoxy molding in the middle. Above the sensors, chips of front-end electronics are placed on a PCB. The double slab is protected from bottom and top by aluminum U shaped covers.

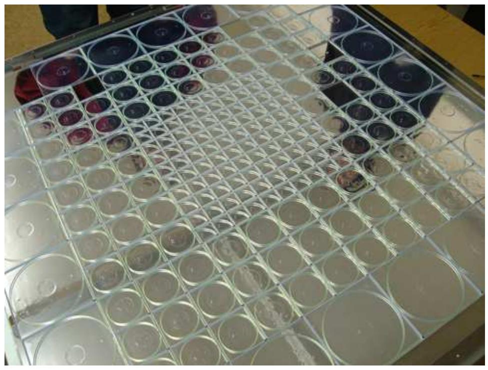

Fig. 2. A 1 m^2 plane of scintillator tiles with WLS fibres in grooves and SiPMs as photo-detectors placed in tiles at the end of the WLS fibre. In the inner part 100 cells of 3×3 cm^2 square tiles are surrounded by 3 rows of 6×6 cm^2 tiles and 12×12 cm^2 tiles on the perimeter.

as materials for the absorber makes tungsten the best radiator for a compact detector. To reach the transversal size close to Molière radius $\rho_M \sim 1$ cm the obvious solution is to use silicon diodes as sensing detectors. This solution is proposed in [6] and called a Si-W calorimeter (see Fig. 1). By using 30 thin layers of sampling (0.4 X_0) followed by 10 coarser ones (1.2 X_0), the calorimeter is only 19 cm thick and has an energy resolution close to $10\%/\sqrt{E}$. The sensing pad size of 1 cm^2 is made on 4" Si wafers 0.5 mm thick of high resistivity of 5 kΩ.cm. They are delivered by INP Moscow and IP AS CR Prague. Because of large pad area and higher noise they are AC coupled to the front-end electronics mounted above pads. The front-end chip for the prototype is directly derived from a chip developed for the OPERA experiment. It has 18 channels and reads 36-channel Si wafer. It works with switchable gain 1 or 10, has dual shaper and track and hold. Its dynamic range is 12 bit. 1000 chips were produced in 2004 needed for 9720 channels of the ECAL prototype. The prototype will be finished in 2005.

3 The HCAL design

The primary role of the hadron calorimetry is to isolate and measure the energy of neutral hadrons. The calorimeter must be able to follow tracks of charged hadrons from the tracker. Therefore, the spatial resolution is of primary importance. From the point of view of the measured energy in a calorimeter cell we speak about a digital calorimeter (cells hit by particles are counted) or an analog calorimeter (energy lost by particles is measured).

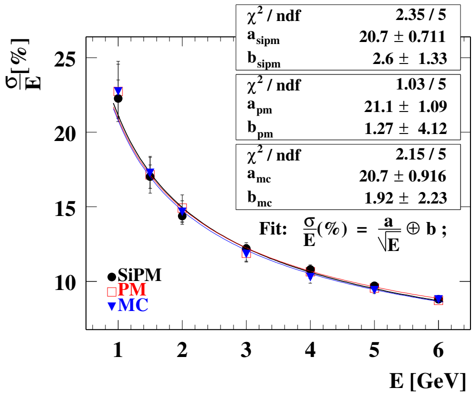

Fig. 3. Measured energy resolution for SiPMs with (solid points), MAPM (squares) and MC prediction (triangles).

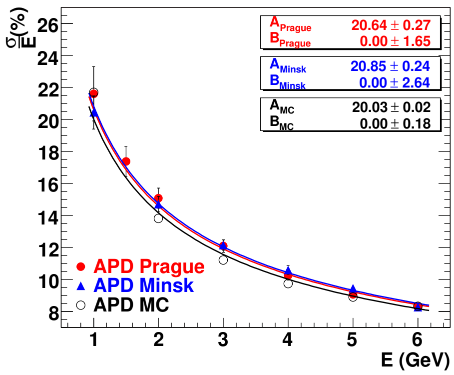

Fig. 4. Energy resolution measured for APDs with Prague (squares) and Minsk (triangles) preamplifier, and MC prediction (open points).

3.1 The tileHCAL

An example of an analog calorimeter is tileHCAL [7]. The scintillation light produced in plastic scintillator tiles enters the wavelength shifting (WLS) fibre placed inside the tile and is re-emitted as green light at around 500 nm wavelength. About 5% of emitted light is captured in the double clad WLS fibre and guided to sensitive photo-detectors. Different types of photo-detectors were studied for optimal photo-cathode efficiency, gain and large signal to noise ratio:

- avalanche photo-diodes (APD); they have large $\sim 80\%$ quantum efficiency of the photo-cathode for green light, relatively small gain of 100–400 and need sensitive preamplifier
- silicon photomultipliers arrays (SiPM) [8]; they have comparable characteristics to photo-multipliers but operate at ~ 50 V. Unfortunately, they are not linear in the response
- multi-anode photomultiplier arrays (MAPM); they can be used as a reference at test as they cannot be operated at high magnetic fields

Actual R&D studies started in autumn 2001 and have come already to concrete results based on tests with the first prototype – MiniCal – a tile calorimeter of size $20 \times 20 \times 80$ cm^3 consisting of 2 cm thick stainless-steel plates stacked with 0.9 cm gaps. Gaps were equipped with thin-walled aluminum cassettes, each housing nine $5 \times 5 \times 0.5$ cm^3 scintillating tiles.

The best light yield (LY) was obtained with the Bicron BC-408 scintillator viewed by a Y11(300) double clad WLS-fibre from Kuraray. The LY is 1.5–1.7 higher with two fibre loops in the groove in the tile with respect to the simpler configuration with fibre on the tile side. Russian polystyrole based scintillator BASF 130 from Vladimir company which will be used in the next prototype gives LY about $\sim 70\%$ of BC-408. The optimal fibre wrap was a special super-reflector foil from 3M. Fibres were read by Hamamatsu H6568 MAPMs with 4×4 channels, 1 mm^2 SiPM diodes produced by MEPHI-PULSAR Moscow and by 3 mm^2 APDs S 8664-55 spec. from Hamamatsu. The analog signal from photodetectors was sent to a LeCroy 2249A 10-bit charge sensitive ADCs and read out via CAMAC. The calibration was performed by using the peak position of a MIP with respect to the pedestal. Since each of 99 channels was calibrated, different LY in the tile as well as different photo-detector responses, preamplifier gains and ADC conversions were accounted for. The energy deposition were summed over all tiles in 10 layers for each positron beam energy 1–6 GeV at DESY. A linear fit was performed to the data to extract the slope parameter in units of MIP/GeV. The slopes for the three photo-detectors agree at the 2% level. The energy resolution for the SiPMs and MAPMs [9] is plotted in Fig. 3 and for APDs [10] in Fig. 4.

The goal is to go to tiles $3 \times 3 \times 0.5$ cm^3 with photo-detectors directly inserted inside the scintillator tile and coupled to the WLS fibre. This favours small sized SiPMs. The currently accepted geometry for the active plane of the 1 m^3 prototype is shown in Fig. 2. Tiles with SiPMs are soldered on a large PCB. There will be 38 detecting layers produced in 2005-6 for the 1 m^3 prototype which will be tested with Si-W ECAL in beams.

4 Conclusions

To finalize the design of a calorimeter for ILC considerable effort is needed both on the technical and software sides. The electromagnetic calorimeter as a sandwich of W and Si appears to be adequate from the point of view of physics, it remains to be fully proved technologically. For the hadron part a choice has to be made between two possibilities – analog or digital calorimeter.

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