R&D Program for TESLA Hadron Calorimeter

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The determination of energy and angles of jets can be significantly improved with a calorimeter optimized for identification, separation and assembling of the clusters of produced neutral particles being not visible for the tracker system. The base line Tile–HCAL version of the TESLA Hadron Calorimeter is described. The program for R&D studies of small scintillator tiles with waveleght shifter fibre readout and coupling to suitable photodetectors (PD) is outlined. In a second phase a complete system test with cosmic muons (MIPs) is foreseen with up to 64 calorimeter cells in operation covering all envisaged tiles sizes. As a next step a real prototype Tile-HCAL with 860–1000 cells is proposed to test the separation of clusters within jets and their individual energy reconstruction. Such a prototype HCAL will be used in electron and hadron test beams at DESY and CERN for all available energies.

1. Introduction

The requirements of the physics program at TESLA [1] determine the desired calorimeter performance.

Energy and angles of particles and jets will be measured and reconstructed with the EFLOW technique [2]. According to this method all charged tracks are measured in the tracker system, the calorimeters (ECAL and HCAL) serve for the identification, separation and reconstruction of all cell clusters with the objective to measure directly all neutral particles as gamma's, neutrons and kaons. This requires, apart from studies for optimization of the hardware in addition extensive software developments with sophisticated reconstruction tools [2].

At the present level of hardware studies still two basic solutions for the HCAL are considered, an analogue read out sandwich sampling calorimeter with stainless steel radiator plates interleaved with layers of small scintillating tiles in the following named Tile–HCAL, as the baseline option, and a digital calorimeter with similar radiator structure where the tile plates are replaced by thin gas chambers with much smaller cells $\sim 1 \times 1$ cm^2 being read out in a binary mode [1].

In the following the R&D program of the baseline Tile–HCAL is discussed.

The basic detector elements of the Tile–HCAL are scintillator tiles of fairly quadratic shapes inserted in the supporting stainless steel radiator structure. Wave length shifter (WLS) fibres couple to these tiles, collect and absorb the blue scintillation light produced by the showering particles and reemit a significant fraction of this absorbed light now shifted to longer wave lengths.

Optical, clear plastic fibres guide this WLS light to appropriate PD's.

To keep the HCAL compact, the PD's have to be placed outside the calorimeter volume e.g. in the small gap between the barrel and endcap sections. In front of the PD's the clear fibres from individual tiles are bundled towards lightmixers building the calorimeter cells. In the proposed Tile–HCAL version the tile sizes vary from $\sim 5 \times 5$ cm^2, representing the bulk of the HCAL volume, to $\sim 15 \times 15$ cm^2 in the rear quarter of HCAL. The sum of the signals from three to nine individual tiles along the particle direction represents the HCAL cells which define the granularity for reconstruction. With the proposed longitudinal module segmentation in 9 (barrel) to 11 (endcaps) cell layers, a total number of ~200000 cells is expected (for more details see [3]).

The calorimeter performance has been studied in detailed MC simulations of such a structure. The energy resolution achievable is estimated to dE/E = $40\%/\sqrt{(E)}\%$ + 5% (see [4], page 4,5). How this compares to various existing or proposed calorimeters is shown in ([4], page 2).

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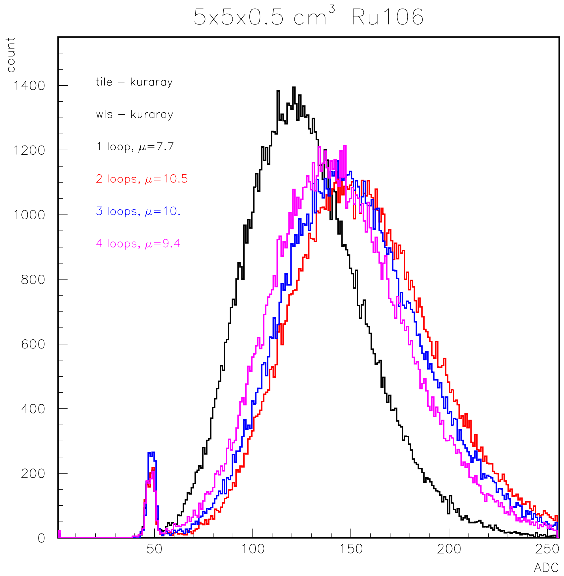

Figure 1: Light yield of various plastic scintillator tiles of 5×5 cm^2 size, μ is the average number of photoelectrons detected.

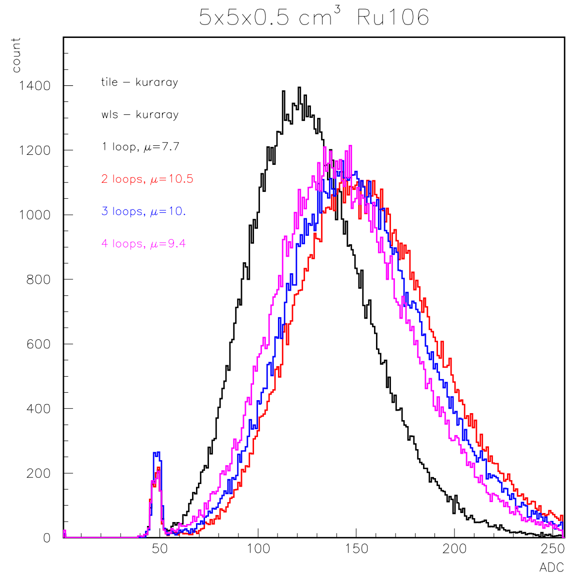

Figure 2: Light yield with different numbers of coupled wavelength shifter loops, μ is the average number of photoelectrons detected.

The constant term dominates the resolution at larger particle energies only, which do not contribute significantly to the total energy (see [2]).

This term can be reduced to ~2% when software compensation is applied [5], which corrects for the calorimeter cell response being different for electromagnetic and hadronic sub-showers.

2. The Tile–HCAL study program

2.1. Hardware R&D for individual components

Additional technological R&D is needed to choose and optimize the appropriate components of the Tile–HCAL. All relevant materials are studied:

(a) Plastic scintillator tiles from 6 different producers are investigated to optimize the light yield, work on improvement for two Russian scintillator products has been initiated,

(b) 6 different types of double clad wavelength shifter fibres from 2 producers are studied,

(c) tile–fibre couplings in loops of 1-3 winding are tested and optimized and compared with simple straight fibre readout without grooves,

(d) various tile/fibre wrappings and some optical contact media are investigated,

(e) several clear optical readout fibres with long attenuation length will be compared, and

(f) a special design of light mixers for fibre bundling in front of the PD's is needed.

Some activities have started, Figure 1 shows e.g., the results of light yield measurements for 5 scintillators, cut in 5×5 cm^2 tiles and readout with WLS-fibres from Kuraray Y11(200). Indicated is the mean number of photoelectrons seen by a photomultiplier with a photocathode conversion efficiency of 11%. The BC-408 scintillator shows nearly twice the light yield of the others, corresponding to about ~96 photons collected from a 5 mm thick tile by a crossing MIP. The light collected for various numbers of WLS fibre loops coupled to a SCSN-81 scintillator tile is shown in Figure 2, saturation is observed for 2 loops already. With a BC-408 scintillator ~153 photons can be collected in this way. More results will be available soon.

The strong magnetic field requires either PD's insensitive to the magnetic field or conventional photomultipliers (PM's) placed outside the field.

As a first conclusion, enough light is produced to favour the choice of relatively cheap Avalanche Photo Diodes (APD's). For the first tests single APD's with 3×3 and 5×5 mm^2 window were used. Our requirements have initiated (together with MPI-Munich) the production and investigation of new integrated 32 pixel APD-array prototypes with 1.4×1.4 mm^2 pixel size. Outside the field volume standard Multi-Anode PM's could be used with 64 anode pixels of 2×2 mm^2.

2.2. System test in a test-array

It is expected that up to summer 2002 the optimal detector materials and components will be found and their interplay optimized. Then a system test could follow with a 'Minical' with 27 layers of absorbers/tile plates allowing to study up to 167 tiles summed in up to 55 calorimeter cells. The investigations will include:

(a) light yield fluctuations in the large sample of tiles and cells,

(b) long term stability and aging of the tile–fibre–reflector assembly. If WLS loops and clear readout fibres with tight bending will be used it may happen that they develop cracks in core and cladding,

(c) gain fluctuations and signal/noise performance of the PD's connected to appropriate preamplifiers,

(d) study of the cell gain stabilization achievable with LED-photodiode monitoring,

(e) precision achievable in absolute cell energy calibration with cosmic MIPs,

(f) performance of the device in strong magnetic fields, this is needed in particular to address the question of channeling of produced low energetic secondary electrons in the gap between the boundaries of the absorber and tile plates. If slightly varying sandwich gaps can not be avoided it is important to measure how such channeling effects deteriorate the expected energy resolution.

Such a 'Minical' has a depth of $\sim 30X_0$ and lateral dimensions of $\sim 4 \times 4R_{\mathrm{Moliere}}$ and fits in a 1 Tesla solenoid magnet available in a DESY electron test beam.

2.3. The prototype HCAL for beam studies

A sketch of the proposed prototype with real stainless-steel structure and tile sizes is shown on page 8 of [4].

The overall size of the module is $100 \times 100 \times 106$ cm^3 and encloses 860 (later probably 1340 cells) combined from $\sim$3000 (later $\sim$5000) individual tiles with sizes increasing in depth from 5×5 to 15×15 cm^2, representing the present favoured granularity. Further MC simulation studies will help to find the optimal cell sizes everywhere.

The table in [4], page 7 shows the transverse shower losses for 3 different sizes of equipped prototype volume for 2 pion energies. To avoid larger lateral leakage as still observed for the 860 cell volume an additional surrounding skin of larger cells (e.g. up to $20\times20\times20$ cm^3) should be inserted into the prototype structure closing the inner shower core.

Also a layer of large size tiles has to be added behind the prototype to tag or measure punch-through fractions of late developped showers.

The measurements of the noise level, signal-noise separation, absolute calibration precision and the calorimeter cell inhomogeneities are needed as input to more realistic simulation studies. Finally the cluster patterns of individual particles—from various energies and angle as measured in the beamtests—will be overlaid to simulate a realistic jet cluster picture for EFLOW reconstruction studies.

3. Status of programme and time scale

A proposal describing the amount of work on hardware and software simulation in detail is submitted to the Physics Research Committee at DESY ([6]) by Institutes from Germany (DESY), Russia (ITEP, LPI-Moscow), Prague and Tashkent. Other collaborators are highly welcome. An encouraging answer from this commity is expected in November 2001.

The selection of optimal material and components could a accomplished end of I/2002, the Minical could be operational in II/2002. The studies on the components could be carried out up to end of 2002, when the stainless-steel prototype structure will be available for module stabilty tests and the installation of complete tile—fibre readout plates. End of 2003 the prototype could be fully equipped with PD's, preamplifiers, ADC's and DAQ electronics, tested and calibrated with cosmic muons and first beam tests with electrons at DESY could be made.

In spring 2004 the prototype can be transported to CERN where beam tests in electron and hadron beams can start.

References

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