PROCEEDINGS OF SCIENCE

Molière radius measurement using a compact prototype of LumiCal in a test set-up

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The FCAL collaboration has performed a design study for luminometers at future electron-positron colliders. Compact sampling calorimeters with precisely positioned silicon sensors and a fast readout will reach the necessary performance even in the presence of background from beamstrahlung and two-photon processes. A prototype calorimeter has been built with special focus on ultra-thin fully instrumented sensor planes to ensure a very small effective Molière radius. Preliminary results of measurements in a 5 GeV electron beam are presented.

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1. Introduction

Two concepts of future e^+e^- linear collider experiments are currently considered, the ILC [1] and CLIC [2]. In both cases, at very forward angles, a system of high precision and radiation-hard calorimeter detectors (LumiCal and BeamCal) is foreseen. These extend the calorimeter solid-angle coverage to almost 4π. The LumiCal is designed to measure the luminosity with a precision of better than 10^{-3} at 500 GeV centre-of-mass energy and $3\text{x}10^{-3}$ at 1 TeV centre-of-mass energy at the ILC, and with a precision of 10^{-2} at CLIC up to 3 TeV. The BeamCal will tag electrons and positrons that are only slightly deflected in peripheral scattering events, will perform a bunch-by-bunch estimate of the luminosity and, supplemented by a pair monitor, will assist beam tuning when included in a fast feedback system [3]. The layout of the forward region of the ILD detector at the ILC is presented in Figure 1.

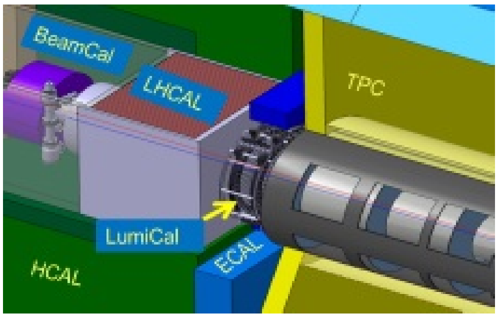

Figure 1: *The very forward region of the ILD detector. LumiCal, BeamCal and LH-CAL are carried by the support tube for the final focusing quadrupole QD0 and the beam-pipe. TPC denotes the central tracking chamber, ECAL the e.m. calorimeter and HCAL the hadron calorimeter.*

The LumiCal and BeamCal are designed as cylindrical sensor-tungsten sandwich electromagnetic calorimeters. In the ILC detector design, both consist of 30 tungsten layers of 3.5 mm thickness, each corresponding to one radiation length, interspersed with sensor layers placed in the one millimeter gap between absorber plates. One of the stringent requirements for the LumiCal prototype is the compactness. For LumiCal, silicon pad sensors are envisaged. For BeamCal, due to its lower polar-angle range, high radiation-tolerance is required and therefor, GaAs sensors are under development. Other sensor technologies, including silicon diodes, sapphire and silicon carbide, are also under consideration. In this paper, results from tests in an electron beam of the first LumiCal prototype with ultra-thin sensor layers are reported. The design of the thin sensor layers and the experimental set-up at the test beam are described. Preliminary results of the transverse electromagnetic shower development (the effective Molière radius) of this very compact LumiCal prototype are presented.

2. Design of thin LumiCal sensor layers

The first LumiCal ultra-thin module prototype was successfully built and tested in a multilayer configuration at the DESY-II ring with a beam of secondary electrons with energies between 1 and 6 GeV. The LumiCal sensor layer prototype, developed for this study, achieved a total thickness of 650μm (Figure 2). The LumiCal sensor [4] is made from a *N-type* silicon, with a thickness of 320μm. It is shaped as a ring segment of 30° subdivided into four sectors. Each sector is segmented in the radial direction with 64 pads of 1.8 mm pitch.

Figure 2: *Thin LumiCal module assembly, photo and cross section (not to scale).*

For the module assembly, the LumiCal silicon sensor was glued with epoxy to a 120μm thick front-end board made of flexible Kapton-copper foil, and then ultrasonic wire bonding was used to connect conductive traces on the fan-out to the sensor pads. The high voltage was supplied by a 70μm thick Kapton-copper foil, glued on the back side of the sensor with conductive glue. In order to have a good mechanical stability it was decided to use a carbon fibre envelope. The total thickness of the envelope is about 650μm, with the part supporting the sensor thinned down to about 120μm (see Figure 2). The mechanical structure was designed and produced to maintain uniformity in composition and thickness for all three glued layers between different LumiCal detector module components.

3. Test beam set-up

The LumiCal module prototype has been operated in extensive test beam campaigns in 2015 and 2016 at DESY in different energy ranges. Eight ultra-thin modules were assembled for the 2016 test beam including one assembled using TAB technology [5, 6].

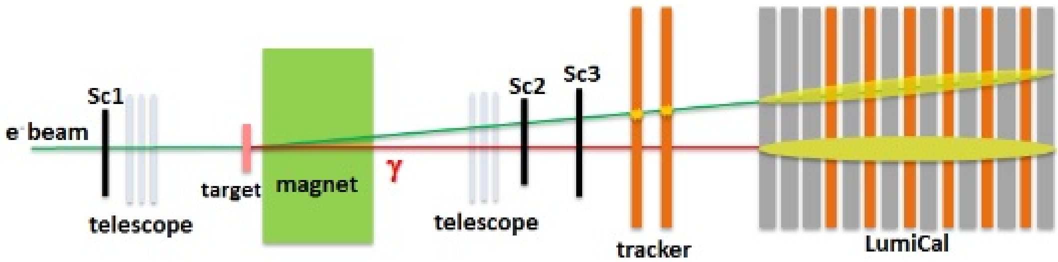

Figure 3: *Test-beam setup, simplified view (not to scale).*

For the first time, the concept of tracking detectors in front of the LumiCal detector as a tool for electron and photon identification in linear collider experiments has been tested. A schematic view of the DESY setup is presented in Figure 3. Bremsstrahlung photons are produced by the electron beam hitting a copper target installed upstream close to a dipole magnet. The magnetic field was chosen to allow both photons and electrons to travel within the acceptance of the second telescope arm and arrive to LumiCal with a separation large enough to be resolved by the calorimeter. For triggering such events with low energy photons, all scintillator counters (Sc1, Sc2 and Sc3) are used in coincidence. A telescope composed of six layers of MIMOSA-26 chips arranged in two arms of three sensors on each side of the magnet aided the track reconstruction. The LumiCal prototype was prepared using two LumiCal modules denoted as "tracker " in Figure 3 and six detector planes always separated by one absorber tungsten layer as shown in Figure 4. A crucial requirement of the measurements was to connect all 256 pads from each sensor layer to the front-end board. In order to be able to read out all pads of a sensor the APV25 chip [7] was chosen. A mechanical structure [8] (Figure 5) allows for the installation of the tungsten absorber layers and the active sensor layers with a precision better than 50μm.

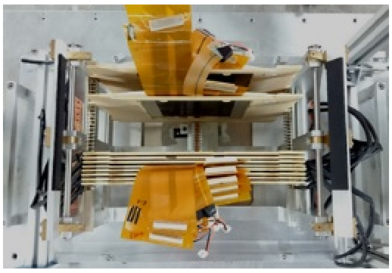

Figure 4: *Top view on the assembled LumiCal prototype*

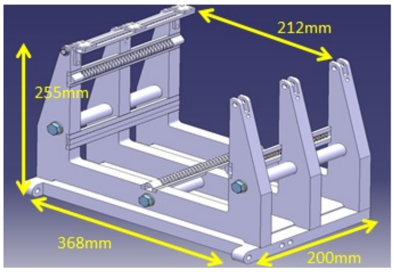

Figure 5: *Dimensions of the mechanical frame for the positioning of sensor and absorber planes.*

4. Results

The focus of the on-going analysis of the test beam data is on electromagnetic shower development in the longitudinal and transverse direction, as well as on the electron/photon separation.

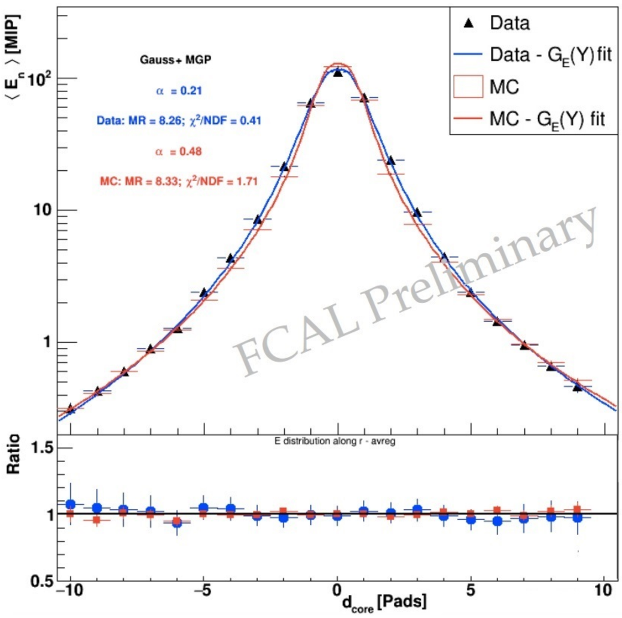

Figure 6: *The transverse shower profile <E_m>, as a function of d_{core} in units of pads, from beam-test data and the MC simulation, after symmetry corrections and fit. The lower part of the figure shows the ratio of the distributions to the fitted function, for the data (blue) and the MC (red).*

As an example, in Figure 6, the preliminary result on the transverse e.m. shower profile for an electron energy of 5 GeV is shown. The different steps of the analysis are described in detail in [9]. The measurements are in good agreement with Monte Carlo simulations: the preliminary result obtained for the effective Molière radius is R_M = 8.26 mm for experimental data and R_M= 8.33 mm for the simulation.

5. Conclusions

The first LumiCal ultra-thin module prototype was prepared and tested in an electron beam. Using new technology and expertise, the FCAL collaboration succeeded to develop, produce and test sensor layers for LumiCal with a thickness well below 1 mm (650 μm). This allows for the construction of a calorimeter prototype of an unprecedented compactness. The transverse electromagnetic shower was investigated, and the effective Molière radius for 5 GeV electons was found to be 8.3mm, in good agreement with Monte Carlo simulations.

Acknowledgement

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References

[1] H. Abramowicz et al., *The International Linear Collider Technical Design Report – Volume 4: Detectors*, arXiv:1306.6329 [physics.ins-det].

[2] M. Aicheler et al., *A Multi-TeV Linear Collider Based on CLIC Technology: CLIC Conceptual Design Report*, Tech. Rep. CERN-2012-007, Geneva, (2012).

[3] Ch. Grah and A. Sapronov, *Beam parameter determination using beamstrahlung photons and incoherent pairs*, JINST 3 (2008) 10004.

[4] J. Blocki et al., *Silicon sensors prototype for the LumiCal*, Eudet-Memo-2009-07 (2009).

[5] J. R. Lutz, L. Arnold, J. Baudot, D. Bonnet, J. P. Coffin, M. Germain, C. Gojak, F. Jundt, C. E. Kuhn, C. Suire, et al., *TAB Bonded SSD Module for the STAR and ALICE Trackers*, Proceedings of 5th Conference on Electronics for LHC Experiments, Snowmass, CO, USA, 20-24 Sep 1999, pp.147 (CERN-1999-009). CERN-ALI-99-47.

[6] M. Bregant, O. Borysov, L. Bosisio, P. Camerini, G. Contin, F. Faleschini, E. Fragiacomo, N. Grion, G.-V. Margagliotti, S. Piano, I. Rachevskaia, et al., *Assembly and validation of the ALICE silicon microstrip detector*,. Nucl. Instr. and Meth. A 570 (2007) 312.

[7] M.J. French et al., *Design and results from the APV25, a deep sub-micron CMOS front-end chip for the CMS tracker*, Nucl. Instrum. Meth. A 466 (2001) 359.

[8] F.-X. Nuiry, *Collected documents on the FCAL-AIDA precision mechanical infrastructure and tungsten plates.*, https://edms.cern.ch/document/1475879/.

[9] H. Abramowicz et al., *Measurement of shower development and its Molière radius with a four plane LumiCal test set-up*, Eur. Phys. J. C 78 (2018) 135.