R&D with Very Forward Calorimeters for Linear Colliders

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***Abstract*—The luminosity of the International Linear Collider will be measured by counting Bhabha scattering events, recognized by coincident detection of two low angle electrons in two calorimeters located symmetrically on both sides of the interaction point. The calorimeters are designed as sampling calorimeters with tungsten absorber disks interspersed with silicon sensors. For a precise measurement of the polar angle, it is essential to achieve a small Molière radius. The design thus foresees ultra-thin sensors that allow 1 mm spacing between the absorbers. In 2014, a first multi-layer prototype of the calorimeter was tested in a beam of 5 GeV electrons and muons at CERN. Excellent performance of the sensors was demonstrated. The development of electron showers has been measured and compared to simulations. Good agreement is found. In the next step, different connectivity schemes have been explored allowing to reach sensor module thickness below 1 mm. Eight thin sensor layers, fully equipped with front-end electronics, have been succesfully tested in a 5 GeV electron beam at DESY. In parallel, the development of a novel ultra-low power SoC type front-end ASIC called FLAME has been started. Prototypes of its two main blocks have been designed, fabricated, and partially tested.**

I. Introduction

In future linear collider detectors, the forward region is instrumented with low angle calorimeters, LumiCal for precise luminosity measurement and BeamCal for beam parameter monitoring and electron tagging [1]. Both calorimeters are centered around the axis of the outgoing beams. LumiCal and BeamCal consist of 3.5 mm thick tungsten plates interspersed with segmented sensor layers [1]. All detectors in the very forward region have to tackle relatively high occupancy, requiring dedicated front-end electronics. The forward region layout foreseen for the ILD detector is shown in Fig. 1.

Prototype sensor planes have previously been built for LumiCal and BeamCal with dedicated frontend electronics and ADC ASICs. Because of high expected energy depositions in the LumiCal, standard 320 μm thick silicon sensors were selected as a compromise between the capacitance and the amount of generated charge. The sensors were succesfully tested in electron beams of several GeV in 2011 [2]. In the next step a first multilayer prototype of the LumiCal detector was built [3] and studies with 5 GeV electrons and muons performed at CERN in 2014. The tests proved the functionality of the LumiCal design, however one of the main goals i.e., the compactness of the detector - reflected by its small Molière radius, has not yet been reached. To achieve this goal a very thin detector module is needed. In the last years the FCAL R&D has been focused on this goal.

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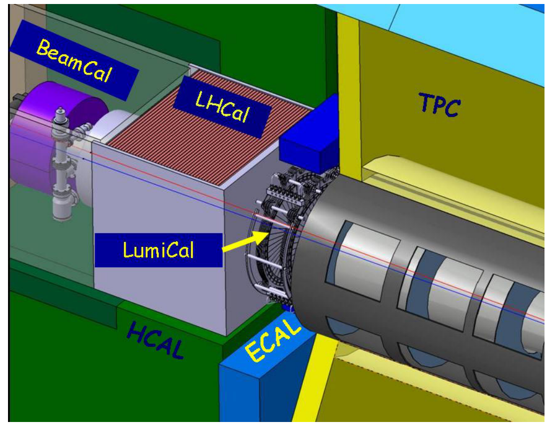

Fig. 1. The very forward region of the ILD detector. LumiCal, BeamCal and LHCAL are carried by the support tube for the final focusing quadrupole QD0 and the beampipe.

In section two we report briefly on the design and preliminary beam-test results obtained with the first multilayer LumiCal prototype. Then in section 3 the current R&D on the development of a very compact LumiCal prototype is described.

II. First Multilayer LumiCal prototype

The first multilayer prototype of a LumiCal detector, shown in Fig. 2(top), comprises a precise mechanical frame, tungsten absorber planes of very good flatness, and detector planes, as shown in Fig. 2(bottom)), containing sensors and dedicated readout electronics [3]. The mechanical frame is designed to install up to 30 tungsten absorbers and sensor layers with a precision of a few tens of micrometers. The first 4-plane prototype has been successfully commissioned and operated in test beam conditions at CERN. A secondary beam with muons, hadrons and electrons with 5 GeV/c momentum was used. Different configurations of absorber and sensor layers were used to study the shower development in the detector stack. Fig. 3 shows the deposited energy per plane as a function of the shower depth. Each detector layer corresponds approximately to one radiation length. As can be seen, for 5 GeV electrons, the measured shower maximum is obtained after six radiation lenghts. The simulations using Geant4 are in good agrement with the measurement. Detailed analyses, taking into account also the transverse shower development, are still ongoing.

III. R&D on compact LumiCal prototype

A. Thin sensor modules

For a precise polar angle measurement in the presence of background, it is essential to achieve a small Molière radius

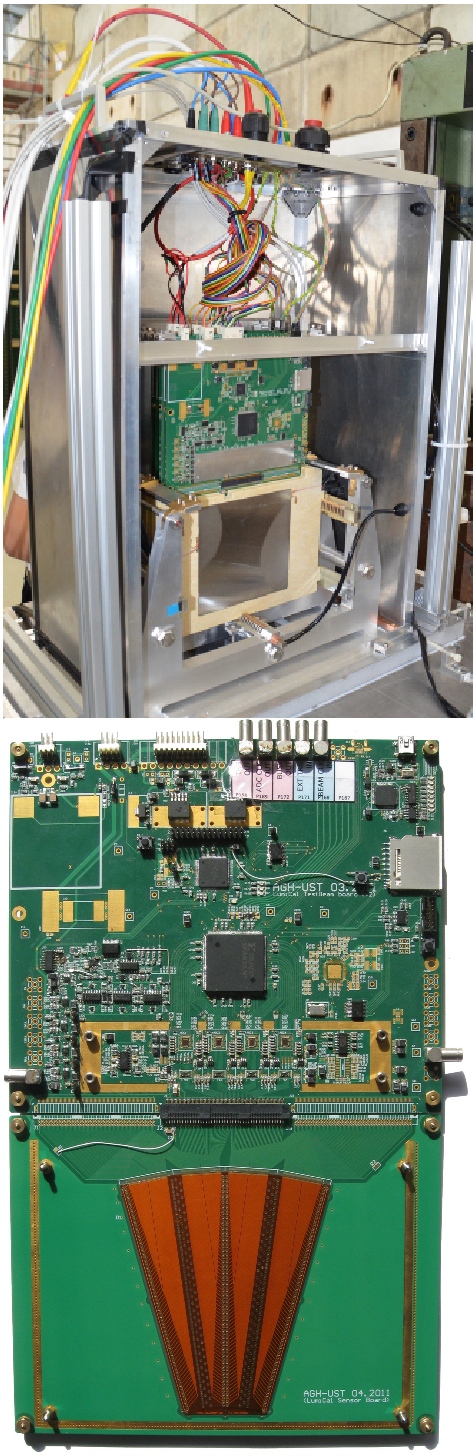

Fig. 2. Top: Prototype of LumiCal detector; Bottom: Single detector module.

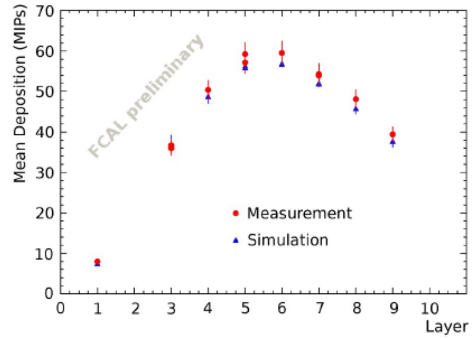

Fig. 3. Preliminary beam-test measurement of shower development in the LumiCal prototype compared to simulations.

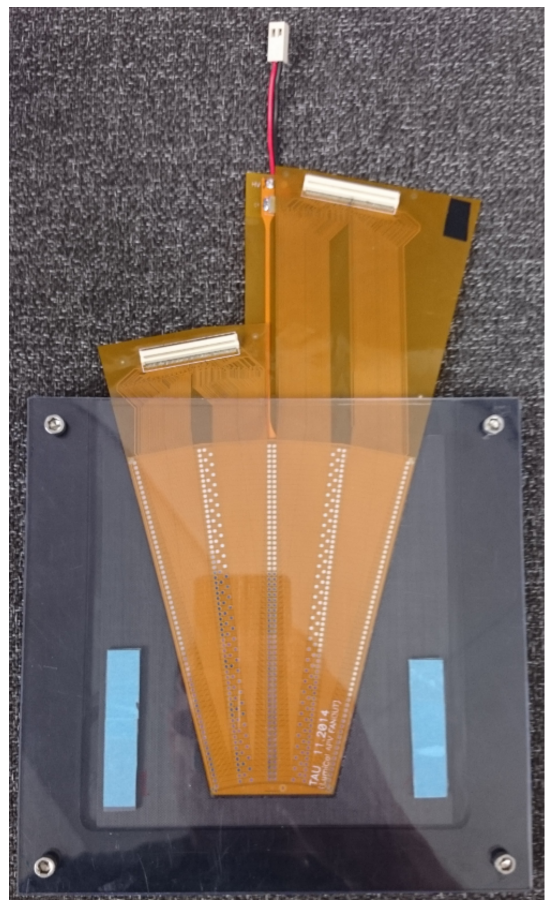

Fig. 4. Ultra-thin sensor module. Module contains the sensor with readout and HV kapton foils placed on carbon fiber envelope.

of the detector. The design thus foresees 1 mm spacing between the absorbers. Recently, novel ultra-thin sensor modules, shown in Fig. 4, were developed. The kapton read out foil with two 130-pin connectors was built to read signals from the sensor pads. Furthermore, a thin kapton foil for the supply of the bias voltage was developed. Finally, a carbon fiber envelope was designed to mechanically support the sensor and the two kapton foils.

Eight ultra-thin sensor modules have been already built and integrated in the LumiCal detector prototype, as seen in Fig. 5. In the configuration shown the two first sensor modules on the left side are mounted in front of the calorimeter to measure the trajectory of the incoming particle, while the next six modules are interspersed with tungsten plates working as calorimeter. To readout the sensor planes currently an external ASD chip based readout electronics is used. The performance of the above tracker-calorimeter configuration has been investigated in a 5 GeV/c electron beam at DESY in 2016. The data analysis is under way.

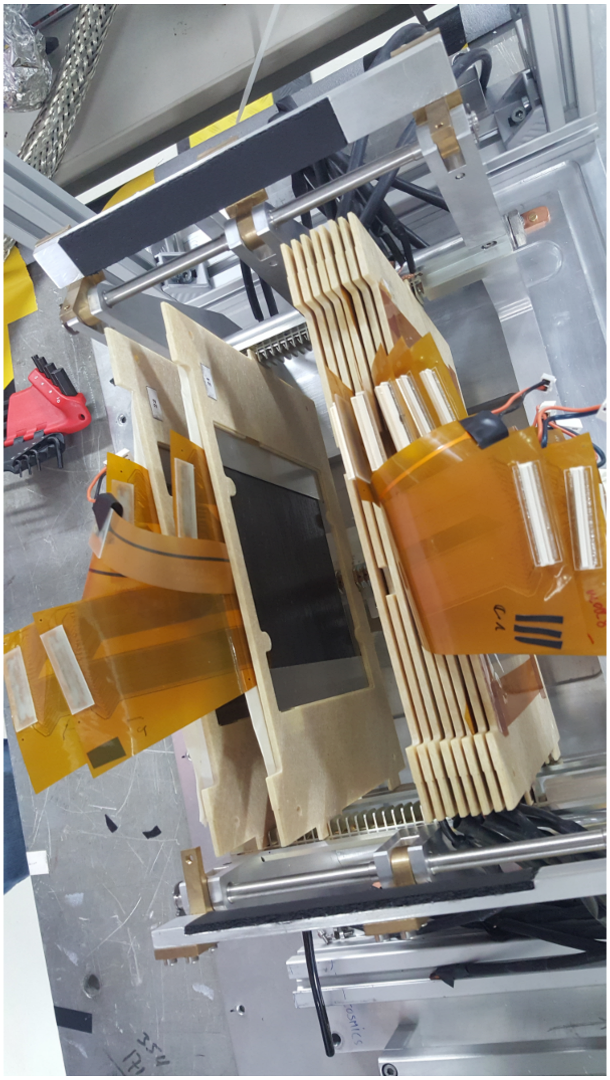

Fig. 5. Setup with ultra-thin sensor modules. Two first modules (left side) are used as tracker and next six interspersed with tungsten plates are used as LumiCal detector.

B. Novel front-end electronics

In parallel to the thin sensor module development the design of a dedicated new front-end ASIC for LumiCal has been started in CMOS 130 nm technology. The architecture of a ultra-low power SoC (System on Chip) type ASIC, called FLAME (FcaL Asic for Multiplane rEadout), is shown in Fig. 6. FLAME is a 16-channel readout ASIC comprising a

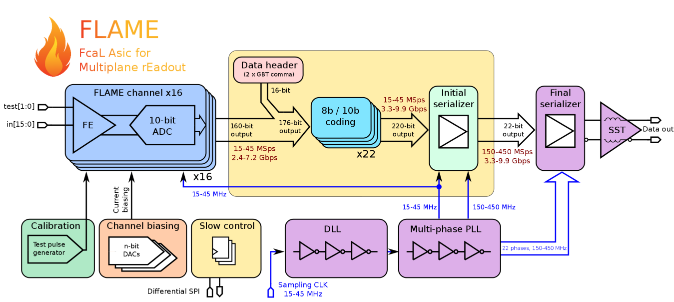

Fig. 6. Block diagram of FLAME readout ASIC.

front-end and an ADC in each channel, followed by a very fast serialization and data transmission. Depending on the ADC sampling frequency the output data stream may change from few Gbps up to 10 Gbps. FLAME will contain all necessary building blocks (e.g. PLL, DLL, DACs) and interfaces (e.g. slow control). Such a complex architecture, comprising all functionalities, is needed to develop a very compact readout board.

To verify the basic concepts of the novel FLAME architecture, prototypes of two main blocks were first designed and fabricated. In Fig. 7(left) the layout of an 8-channel ASIC comprising front-end and ADC in each channel is shown. The main front-end features are: variable gain allowing operation in calibration and physics mode, preamplifier working with sensor capacitances up to about 50 pF, fully differential CR-RC shaper with 50 ns peaking time, and power consumption of about 1 mW. The main ADC features are: SAR fully differential architecture, variable sampling frequency up to 50 MSps, dynamic implementation of analog and digital blocks resulting in a lack of static power dissipation, ultra-low power scaling with sampling frequency ($< 1mW@50MSps$). In Fig. 7(right) the layout of a very fast serializer containing

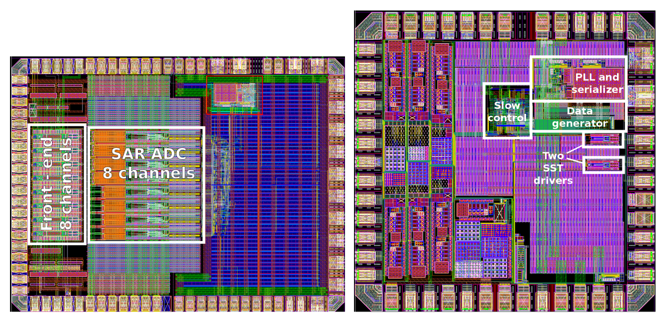

Fig. 7. Left: Layout of 8-channel front-and and ADC ASIC; Right: Layout of very fast serializer ASIC.

SST (Source-Series Terminated) data interface is shown. It serializes data from 16 channels and sends it out up to a rate of 10 Gbps.

The measurements of the prototype ASICs have just been started. In Fig. 8 an example pulse shape observed at the differentail front-end output is shown, together with CR-RC shaper fit. The development of the setup is ongoing. In

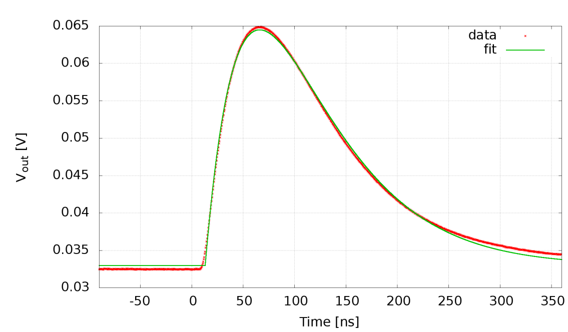

Fig. 8. Pulse shape measured at the front-end output of the 8-channel front-end ASIC.

Fig. 9 an example eye diagram at 5 Gbps measured at the output of serializer ASIC is shown. Although the measurement confirms the basic functionality, also for this ASIC a test setup expansion is needed to allow also the measurement of the bit error rate.

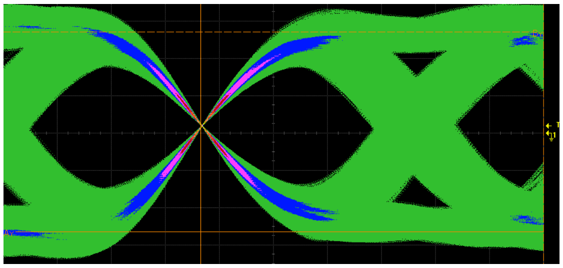

Fig. 9. Eye diagram measured of fast serializer ASIC measured at 5 Gbps.

IV. Conclusion

Recent results of R&D on Forward Calorimeters for Linear Colliders are presented. A multilayer prototype of the LumiCal calorimeter was built and experimentally verified in an electron beam. The longitudinal shower development profile was measured. Geant4 simulations are found in good agreement with the measurement. The R&D on a new, very compact calorimeter prototype has been started. A very thin ($< 1mm$) sensor module has been designed and fabricated, and already used in test-beam. The development of an ultra-low power, SoC type front-end ASIC called FLAME has been started. Prototypes of its two main blocks have been designed, fabricated, and their basic functionality has been verified.

Acknowledgment

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