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

Veta GHENESCU
Institute of Space Science, Bucharest, ROMANIA

[on behalf of the FCAL Collaboration]
Overview

- Forward region in LC Experiments
- Thin LumiCal module design
- LumiCal prototype performance in test-beam
  - Test-beam setup
  - Results
- Conclusions
Forward region in LC Experiments

- **LumiCal**: precision integrated luminosity measurements;
- **BeamCal**: instant luminosity measurement;

<table>
<thead>
<tr>
<th>Parameters</th>
<th>ILC (ILD)</th>
<th>CLIC_ILD</th>
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</thead>
<tbody>
<tr>
<td>LumiCal</td>
<td>geometrical acceptance [mrad]</td>
<td>31 - 77</td>
</tr>
<tr>
<td></td>
<td>fiducial acceptance [mrad]</td>
<td>41 - 67</td>
</tr>
<tr>
<td></td>
<td>number of layers (W + Si)</td>
<td>30</td>
</tr>
<tr>
<td>BeamCal</td>
<td>geometrical acceptance [mrad]</td>
<td>5 - 40</td>
</tr>
<tr>
<td></td>
<td>number of layers (W + sensor)</td>
<td>30</td>
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</tbody>
</table>

The silicon sensor prototype was produced by Hamamatsu in the technology based on:
- 6-inch *N*-type bulk wafer;
- Radially segmented – 64 pads with 1.8 mm pitch;
- 4 azimuthal sectors in one tile, each 7.5 degrees;
- 320 μm thickness;
Thin LumiCal Module

Araldite epoxy and ultrasonic wire bonding

Conductive glue

Kapton-copper fanout

LumiCal Silicon sensor

High voltage kapton

Araldite epoxy

Carbon fiber support

Kapton Fan out: 120µm

Kapton HV: 70µm

Sensor: 320µm

Envelope: 120µm

Glue: 10-20µm

~650µm
Test beam infrastructure @ DESY:

- Electrons $1 - 5 \text{ GeV}$ energy;
- Data taken in August 2016 at 21 beam line area;
- EUDET telescope – 6 MIMOSA planes;
- Dipole magnet $1 - 13 \text{ kGs}$ for $e/\gamma$ separation;
- DAQ framework provided:
  - EUDAQ (software);
  - Trigger Logic Unit (hardware);

DUT

Goals:

- Performance of the compact LumiCal prototype;
- $e/\gamma$ identification with tracking detector in front of LumiCal;
- Electromagnetic shower development study;
- Moliere radius measurement;
DUT (LumiCal multi-layer prototype):

- First **sub-millimeter LumiCal** detector module (~ 650 μm);
- 8 silicon sensors with **256 equipped channels**;
- **APV-25** hybrid front-end chip;
- 2 silicon sensor planes used as tracker;
- **Si sensors** always separated by one absorber layer;
- **3.5 mm** thick tungsten absorber layer;
Results

Preliminary results on deposited energy distribution in calorimeter for different $e^-$ energy

Energy deposited distribution in LumiCal prototype for different beam energy

Average total energy deposited in LumiCal prototype as a function of beam energy
The function used to describe the average transverse energy profile of the shower is:

$$F_E(r) = A_C e^{-\left(\frac{r}{R_C}\right)^2} + A_T \frac{2r^\alpha R_T^2}{(r^2 + R_T^2)^2}$$

where: $r$ is the distance from the shower center; $A_C; A_T; R_C; R_T; \alpha$ are the fit parameters.

- The fitting range corresponds to the area connected to readout.
- The parameters of $F_E(r)$ are fixed by both test-beam data and MC simulation.
- The Molière radius, $R_M$, is a characteristic constant of a stack of materials. By definition, it is the radius of a cylinder with axis coinciding with the shower axis, containing on average 90% of the energy deposition of the shower.
- The Molière radius, $R_M$, can be found from the equation:

$$0.9 = \int_0^{2\pi} d\phi \int_0^{R_M} F_E(r) \ r dr$$
Results – transverse electromagnetic shower – TB2014

In 2014, at CERN PS area, took place a testbeam experiment. The Moliere radius has been determined [Eur. Phys. J. C (2018) 78:135]: \( R_M = 24.0 \pm 0.6 \) (stat.) \( \pm 1.5 \) (syst.) mm, using a parametrization of the shower shape.

\[
\frac{1}{R_M} = \frac{1}{E_S} \sum w_j E_{cj} X_{0j} = \sum \frac{w_j}{R_{Mj}}
\]

The shower transverse profile \( < Em > \), as a function of \( d_{core} \) in units of pads. The ratio of the distributions to the fitted function, for the data and the MC.
Results – transverse electromagnetic shower – TB2016

The shower transverse profile $\langle E_m \rangle$, as a function of $d_{\text{core}}$ in units of pads, for different beam energy. The ratio of the distributions to the fitted function for testbeam data.

$R_M = 8.30, \chi^2/\text{NDF}=1.05$

$R_M = 9.26, \chi^2/\text{NDF}=0.87$

$R_M = 12.25, \chi^2/\text{NDF}=0.79$
Results – transverse electromagnetic shower

**TB2016**

- Data
- MC
- MC - $G_E(Y)$ fit
- $\chi^2$/NDF = 0.41
- $R_M = 24.0; \chi^2$/NDF = 1.3

**TB2014 & TB2016**

- MC 16: $\alpha = 1.40$
Conclusions

- Thin LumiCal module with submillimeter thickness was developed and produced. Its geometry meets requirements of LumiCal conceptual design.

- The LumiCal prototype with eight thin modules and existing mechanical structure was assembled and tested with beam. Data analysis is in progress.

- The LumiCal prototype demonstrates good linear response to the beam of 1 GeV – 5 GeV.

- The preliminary results on effective Molière radius calculation give $R_M$ around 8.3mm for 5 GeV $e^-$ and are in good agreement with MC simulations.

- Major components developed by FCAL Collaboration can be operated as a system in the future LC experiments.
THANK YOU FOR YOUR ATTENTION
Acknowledgements:

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