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New electromagnetic calorimeter for GPD measurements at COMPASS

SPIN-Praha-2010
OUTLINE

1. Introduction
2. AMPD
4. Tests in 2010
5. ECAL0 matrix prototype (3x3)
6. Conclusions and Outlook
INTRODUCTION(1)

An entirely new calorimeter ECAL0 covering larger photon angles is under development at the JINR Dubna.

The electromagnetic calorimeter ECAL0 will supplement the COMPASS spectrometer for the GPD studies. The main tasks of the ECAL0 are the following:
- together with the ECAL1 and ECAL2, to ensure a hermeticity of the setup for photons from DVCS,
- to help in reduction of a background,
- to enlarge the kinematic domain of the DVCS registered by COMPASS.
For these purposes the ECAL0 should detect photons in the solid angle not covered by the ECAL1 and ECAL2.
The impact of ECAL0 shows the projected improvement in the uncertainty of the measurement of the t-slope parameter $B(x_B)$ at large $x_B$ values.
INTRODUCTION (3)

Module:
- size is 12x12 cm² (cell size is 4x4 cm²)
- 9 light collection system (fibers, light guides – Winston cones)
- 9 AMPDs (MAPD-3A,3B,3N)
- LED-PIN system
- Thermo stabilization systems (Peltier, electronics)
- 9 Amplifiers
- 9 SADC(MSADC) channels
- Power supply

The maximal geometrical size of the ECAL0 is 2.2 x 2.2 m² with an aperture of 0.5 x 0.5 m² and a distance from the centre of the target of 2.7 m

Total: 248 9-towers modules
2232 Channels (SADC, MSADC)
The weight is about 6-7 tonn

Optimization of the overall ECAL0 size and also of its aperture will result from several compromises, among which are the tracking requirements. A small aperture will guarantee good hermiticity between ECAL0 and ECAL1.
Preliminary requirements for ECAL0:

1. Photon energy range 0.2- 30GeV
2. Granularity 4x4 – 6x6cm²
3. The required energy resolution is about 10.0%/√E (GeV) or better ?
4. Taking into account the space limitation in the target region, the total length of the calorimeter should be about 50 cm.
5. Photodetector should be insensitive to magnetic field


Aims: module prototypes , new AMPD, thermal stability, housing design
The required energy resolution of the ECAL0 module

ECAL acceptances

Energy resolution vs number of layers sampling

Energy resolution vs number of layers

Energy resolution vs incidence angle of $\gamma$
The new technique of the light collection and detection is proposed using a photodiode AMPD (Avalanche-Multipixel Photo Diode). The AMPD is a novel photodetector with a multipixel intrinsic structure on the common silicon substrate.

The first metal-resistor-semiconductor (MRS APD) has been proposed by A. Gasanov, V. Golovin, Z. Sadygov, N. Yusipov (Russian patent #1702881, from 10/11/1989).
Since 1989 many GM APD structures were developed by different developers:

- CPTA/Photonique (Moscow/Geneva) ~1000 pixels/mm²
- Zecotek (Singapur, Dubna) up to 40000 pixels/mm²
- MEPhI/Pulsar (Moscow) ~1000 pixels/mm²
- Hamamatsu Photonics (Hamamatsu, Japan) up to 1600 pixels/mm²
- SensL (Cork, Ireland)
- RMD (Boston)
- MPI Semiconductor Laboratory (Munich, Germany)
- FBK-irst (Trento, Italy)

Each producer invented their own name for this device: MRS APD, AMPD, SiPM, SSPM, SPM, G-APD …

However, all developers, except Zecotek, produce the APMD’s with a number of pixels not more than one thousand per square millimeter. Zecotek can produce AMPD’s with a much higher density of pixels, for example, MAPD-3A,3N(3x3 mm²) have 135000 and MAPD-3B has 360000 pixels.

This is very important, because it allows to cover the wide range of photon energies (even more than 30 GeV), assuming that 1 GeV photon produces up to two thousand photoelectrons.
Main AMPDs features:
- high density of pixels 15 Kpix/mm$^2$ MAPD-3A, 40 Kpix/mm$^2$ MAPD-3B;
- size for both - 3x3 mm$^2$;
- work at low bias voltage (<100 V);
- PDE $\sim$12 % (520 nm) (Photon Detection Efficiency);
- gain $\sim$2x$10^4$ MAPD-3A; $\sim 10^4$ MAPD-3B;
- temperature dependences $\sim 3$-$4\%$/°C;
- insensitive to magnetic fields up to 15 T;
- compact, rugged and show no aging *;
- tolerate accidental illumination;
- radiation hardness ($>10^{12}$ p/cm$^2$);
- capacitance $\sim$ 300pF

Problems: recovery time?
Double LED pulses were used to measure the cell recovery time. The ~10 ns LED signal have to saturate the AMPD response (~200 000 photons/pulse)
<table>
<thead>
<tr>
<th>Type</th>
<th>MAPD-3a</th>
<th>MAPD-3B</th>
<th>MAPD-3N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size, mm$^2$</td>
<td>3x3</td>
<td>3x3</td>
<td>3x3</td>
</tr>
<tr>
<td>Pitch (pixel size) μ</td>
<td>8(3)</td>
<td>5(2)</td>
<td>8(5)</td>
</tr>
<tr>
<td>Number of pixels</td>
<td>~135000</td>
<td>~360000</td>
<td>~135000</td>
</tr>
<tr>
<td>Bias voltage</td>
<td>~66.5</td>
<td>~70</td>
<td>~90</td>
</tr>
<tr>
<td>Gain, $x10^4$</td>
<td>2</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>PDE, %($\lambda$~520nm)</td>
<td>12</td>
<td>10</td>
<td>25</td>
</tr>
</tbody>
</table>

**New Zecotek MAPD**

![Graph showing PDE vs. wavelength for MAPD-3N1 and MAPD-3A(5)]

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AMPD(6)

MAPD-3A
Pulse shape:
Rise Time = 3 ns
FWHM = 25 ns
Fall Time = 80 ns

MAPD-3B
G=10000
t=15 °C

MAPD-3A
G_{pix} = 2.0 \times 10^4
T = 15 °C

MAPD-3N
G_{pix} = 3.6 \times 10^4
T = 15 °C

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Summary of the beam test 2008 at T9 (1)

Total length ~660 mm

Photodectors: MAPD-3A (PMT)

- 64 fibers, 4 bundles
- Optical head with Peltier cooler with fan (working point $15^\circ \pm 0.2^\circ$)
- Calibration – LED controlled by Pin Diode

144 fibers, 9 bundles

<table>
<thead>
<tr>
<th>Technology</th>
<th>Shashlyk (LHCb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scintillator</td>
<td>PSM - 115 2.5% p-terphenyl 0.01% POPOP, 66 layers</td>
</tr>
<tr>
<td>Absorber</td>
<td>Lead, 66 layers</td>
</tr>
<tr>
<td>Pb / Sc plates thickness, mm</td>
<td>2 / 4</td>
</tr>
<tr>
<td>Pb/Sc plates dimensions, cm</td>
<td>12.12x12.12 (4.0x4.0)</td>
</tr>
<tr>
<td>Moliere radius, cm</td>
<td>3.5</td>
</tr>
<tr>
<td>Radiation length, cm</td>
<td>1.64</td>
</tr>
<tr>
<td>Total thickness, cm</td>
<td>42 (25 X0)</td>
</tr>
</tbody>
</table>
Summary of the beam test 2008 at T9 (2)
Summary of the beam test 2008 at T9 (3)

The tests of the thermal stabilization
Beam tests: CERN, T9 in 2009 (1)

ECAL0 module length 350 mm, without head readout. Last one has taken about 70 mm space

Total length ~430mm

<table>
<thead>
<tr>
<th>Technology</th>
<th>Shashlyk</th>
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<tbody>
<tr>
<td>Scintillator</td>
<td>PSM - 115 2.5% p-terphenyl 0.01% POPOP, 40 layers</td>
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<tr>
<td>Absorber</td>
<td>Lead, 40 layers</td>
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<tr>
<td>Pb/Sc plates thickness, mm</td>
<td>2 / 4</td>
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<tr>
<td>Pb/Sc plates dimensions, cm</td>
<td>12.12x12.12</td>
</tr>
<tr>
<td>Moliere radius, cm</td>
<td>3,5</td>
</tr>
<tr>
<td>Radiation length, cm</td>
<td>1.64</td>
</tr>
<tr>
<td>Total thickness, cm</td>
<td>25.2cm (15 X0)</td>
</tr>
</tbody>
</table>

**FEE – fast preamplifier, G=37**

**DAQ – SADC JINR 100 MHz, 128 samples, 14 bit, 16 ch**

**Calibration – LED controlled by Pin Diode**

**Temperature stabilisation - Peltier cooler with fan (working point 15º ± 0.2º)**

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Beam tests: CERN, T9 in 2009 (2)

9-tower ECAL0-MAPD-3B, 4 GeV/c

σ/E=6%

Nphe\textsubscript{2009}/Nphe\textsubscript{2008}=1.35 \quad σ/E\textsubscript{2009}=σ/E\textsubscript{2008}

σ/E=10%
Beam tests: DESY, Test Beam 21 in 2009

The energy resolution (left) versus the electron beam energy and the time resolution (right) at 4 GeV for the short module with MAPD-3B.

Fit function:
\[
\frac{\sigma E}{E} = \sqrt{a} + \frac{b}{E} + \frac{c}{E^2}
\]

Fit parameters:
- \(a = 10.14 \pm 0.16\)
- \(b = 2.78 \pm 0.20\)
- \(c = 3.70 \pm 0.13\)
Positive Hadron beam 4 GeV at T9 Intensity I=6k/.5 s

$\Delta_{\text{MAPD-3B}} = 14.6\%,$

$\Delta_{\text{MAPD-3A}} \sim 5\%$, the same as 2008
Tests in COMPASS experimental area:
- ECAL0 module prototype (9 towers, MAPD-3A, MAPD-3B)
- Upstream RPD, 50 cm away from beam line.
- $\mu^+$ beam, spill $\sim 3 \times 10^8 \mu^+/\text{spill}$
- Count rate $\sim 10^5 \mu^+/\text{spill}$ (13x13 cm$^2$ scintillator upstream of the module)
Beam tests: CERN, COMPASS in 2009 (2)

\[ \Delta_{\text{MAPD-3A}} = 0.21\% \]
Beam tests: CERN, COMPASS in 2009 (3)

$\Delta_{\text{MAPD-3B}} = 1.6\%$

Mean $= 3429.6$

Mean $= 240.8$

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Long-term test: 10 MAPDs were irradiated by LED pulses with f=1 MHz and amplitude $\sim 10^4$ph.e at T$\sim 30$ °C during 2 months. No changes in gain and dark current were observed.
I. Beam test: at COMPASS

Three types of AMPD’s will be tested simultaneously in COMPASS for final choice. (Possible locations of module:
-upstream polarized target;
-distance from beam-line 24 cm away from beam line).

II. Long–term stability of AMPDs (few months) tests at T ~70°C: gain, dark current etc.

In 2010 the JINR/Dubna team, with the help of other Compass institutions, will construct a small prototype of the calorimeter ECAL0 consisting of a matrix of 3 x 3 modules and geometrically compatible with a location behind the RPD.
Size of Sc(Pb) tiles is 4x4(12x12)cm, 
thickness -1.5(.8) mm.

On the way to a complete design of ECAL0 module in 2010

<table>
<thead>
<tr>
<th>Technology</th>
<th>Shashlyk</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scintillator</td>
<td>Polystyrene Kharkov</td>
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<tr>
<td>Absorber</td>
<td>Lead</td>
</tr>
<tr>
<td>Number of layers</td>
<td>109</td>
</tr>
<tr>
<td>Sc / Pb plates thickness, mm</td>
<td>1.5/0.8</td>
</tr>
<tr>
<td>Pb/Sc plates dimension, cm</td>
<td>12.0x12.0/4.0x4.0</td>
</tr>
<tr>
<td>Moliere radius, cm</td>
<td>3.5</td>
</tr>
<tr>
<td>Radiation length, cm</td>
<td>1.64</td>
</tr>
<tr>
<td>Number of tower</td>
<td>9</td>
</tr>
<tr>
<td>Fiber</td>
<td>KYRARAY Y11(150 or175)*</td>
</tr>
<tr>
<td>Number of fibers per tower</td>
<td>16</td>
</tr>
<tr>
<td>Diam. of bundle, mm</td>
<td>6.5</td>
</tr>
<tr>
<td>Light guide</td>
<td>Winston cone glued to photodetector</td>
</tr>
<tr>
<td>Photodetector</td>
<td>MAPD-Zecotek(type will be defined)</td>
</tr>
<tr>
<td>Total thickness, cm</td>
<td>25.2(~ 15 X0)</td>
</tr>
<tr>
<td>ADC</td>
<td>MSADC</td>
</tr>
<tr>
<td>Thermostabilization</td>
<td>Peltier cooler</td>
</tr>
</tbody>
</table>
ECAL0 matrix prototype

Under the member state contract with JINR the production line was setup for NICA electromagnetic calorimeter at Kharkov

Status of the production:
1. The press-form drawings (for scintillators) are prepared for press-forms production at Kharkov. Now the drawing are in Kharkov. We plan to finish press-forms production in August.
2. The Press-form drawings for lead are prepared. The production is started. We plan to finish press-forms production in August.
3. The press-form drawings for top- and end- caps, light guides (Winston cone) are prepared, and in Kharkov now. They are under preparation for production.
4. System of thermostabilization, preamplifiers(with shapers) will be made at JINR, scintillator and lead plates will be produced in Kharkov in late 2010.

Assembling a matrix 3x3 modules will be made at JINR. Tests of ECAL0 3x3 matrix prototype will start at CERN in 2011.
Conclusions and outlook (1)

1. New EM calorimeter ECAL0 is essentially improve quality GPD measurements at COMPASS: acceptance, background, exclusive reactions, hermiticity
2. Main requirements for ECAL0 are defined: sizes, granularity, energy resolution, type of photo-detector
3. Hardware tests in 2007-2009:
   - module design is defined;
   - both type of AMPDs are OK;
   - temperature stabilization system is preliminary designed;
   - measured module characteristics meet with ECAL0 requirements
4. In 2010 hardware tests will be finished:
   - Long-term stability tests
   - Three types of AMPD’s will be tested simultaneously at COMPASS for final choice.
5. The production will start in October-November 2010.
6. The preparation on ECAL0 prototype matrix is in progress, projected date to finish end of 2010
7. Tests of ECAL0 3x3 matrix prototype will start at CERN in 2011
Thank You for Your attention
Linearity of AMPD is determined by its total number of pixels. In the case of uniform illumination:

\[ N_{\text{fired cells}} = N_{\text{total}} \cdot \left(1 - e^{-\frac{N_{\text{photon}} \cdot \text{PDE}}{N_{\text{total}}}} \right) \]

This equation is correct for time length of light pulses which are shorter than pixel recovery time and for an “ideal” AMPD (no cross-talk and no after-pulsing).

(B. Dolgoshein, TRD05, Bari)
Time resolution of ECAL0 prototype (MAPD-3B) (time difference between S2 and central tower signals)
Tests of AMPDs

Long-term stability

The long-term stability of 10 EG&G APDs was tested by operating them for a week close to breakdown voltage at a temperature of 85°C. This is a standard method to obtain data on the lifetime of semiconductor devices. The mean time to failure (MTTF) is then calculated by [4.3]:

$$\frac{E(T_2-T_1)}{k_B \times T_2 \times T_1}$$

with $E = 0.53$ eV and $k_B$ the Boltzmann constant.

Failure is defined as having occurred if the dark current is doubled. Since no APD failed the result for 22°C is:

Long-term (few months) tests with 10 MAPDs at $T \sim 70^0C$:
gain, dark current etc.
Test bench is in preparation.
The special temperature chamber is delivered under preparation (LCT-1035C)
The test will start in August with MAPD-3A, 3B

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