Application of Multi-Pixel Photon Counter to Positron Emission Tomography

Erika Garutti, Martin Göttlich
DESY

Hans-Christian Schultz-Coulon, Alexander Tadday
University of Heidelberg

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Multi-Pixel Photon Counter
(Hamamatsu)

Multiple avalanche-photodiode pixels operated in Geiger mode.

<table>
<thead>
<tr>
<th># Pixel (size [mm²])</th>
<th>Bias</th>
<th>Dark rate &gt; 0.5 Pixel</th>
<th>Dark rate &gt; 1.5 Pixel</th>
<th>Gain (10^5)</th>
<th>Time resolution FWHM</th>
</tr>
</thead>
<tbody>
<tr>
<td>3600 (3x3)</td>
<td>70 V</td>
<td>3.2-3.3 MHz</td>
<td>320-330 kHz</td>
<td>7.4-7.5</td>
<td>100 ps</td>
</tr>
</tbody>
</table>

Problem: Saturation. Pixel recovery time: 4 ns.
Scintillator r/o using MPPCs

Study energy and time resolution:

<table>
<thead>
<tr>
<th>MPPC</th>
<th>LFS</th>
<th>3x3x15 mm³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Na-22</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ρ [g/cm³]</th>
<th>refr. index</th>
<th>decay time [ns]</th>
<th>LY [1/MeV]</th>
<th>radiation length [mm]</th>
<th>peak emission [nm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.4</td>
<td>1.84</td>
<td>40</td>
<td>25k</td>
<td>11.4</td>
<td>420</td>
</tr>
</tbody>
</table>

Emission process in scintillators (R = mean number of photons):

GEANT4 simulation (energy resolution 11% FWHM):

(see NIM A 564 (2006) 185-189)
Energy and Time Resolution

Energy resolution:

- 11 % FWHM
- ~1500 pixels

Time resolution:

- 475 ps FWHM
- 5 p.e.
- 1500 pixels

Leading edge triggering.

Resolution limited by noise jitter.

→ ARC triggering
A first Prototype - Overview

Multi-channel read out:

Rotation stage (MICOS)

Module

Submodule

16 r/o channels

~3 cm

~1 cm

2x2 MPPC array

+ 4 crystals

Pixel size: 3x3 mm²

(HAMAMATSU)

SiPM Integrated Read Out Chip

(for CALICE AHCAL)

Future plans: two crystal layers for DOI information.
Simulation Studies

GEANT4 Application for Emission Tomography: GATE

- Energy and time resolution tuned to the single crystal measurements.
- Pixel size 3x3mm²
- Rotation
- 2 point sources: (-5,5)mm and (5,5)mm, radii 0.5 mm

Image reconstruction:

![Graph showing sinogram S [mm] vs. yield, with ideal and granularity lines.](image1)

![Graph showing pixel height [a.u.] vs. x [mm], with 2.6 mm FWHM.](image2)
SPIROC ASIC

SPIROC test board:

Developed by the Orsay Micro Electronic Group Associated for the CALICE collaboration (SiPM based AHCAL for the ILC).

- ASIC chip with 0.35 \( \mu \)m SiGe technology
- time jitter (LED light on MPPC): 100 ps FWHM

Time jitter measurement using two testboards:

15% FWHM

Threshold too high

RMS 2.8 ns
Crystal Homogeneity

Channel 1 (same crystal):

- Lutetium Fine Silicate from LPI Moscow
- 100 crystals tested (exchanging the crystals under red light)
- Within experimental precision the crystals are homogeneous.
- Homogeneity sufficient for our application.

Channel 2 (different crystals):

- Time resolution:
  - 2%
  - 5%
  - 3%
Submodule Energy Resolution

- 2x2 MPPC devices 3x3 mm², 3600 pixels each
- at 25° and 68.8 V: Gain $7.5 \times 10^5$, 0.5 p.e. th. dark rate 4 MHz
- common cathode -> anode r/o -> positive signal

- best results with 3m reflective foil and optical grease
- use intrinsic radioactivity of LFS to check alignment
- improve: alignment, reflection, bias
Summary and Outlook

• Application of MPPCs to PET very promising
• Prototype will be a proof of principles
• LaBr$_3$:Ce (3% energy resolution, decay time 20 ns, high LY)
• Smaller pixel size (1x1mm$^2$): 0.7 mm spatial resolution
• Larger MPPC/SiPM arrays
Additional Material
Linearity & Saturation

Linearity checked in the energy region of interest.

Long signal $\rightarrow$ large effective number of pixels.
Technical Details

r/o circuit:
PET – Basic Concept

Tracer (FDG)

Annihilation (E = 511 keV)

LOR

Coincidence Finder

PMT crystals

Sinogram

Image Reconstruction
Integration along all LORs at fixed $\phi$
Back Projection
(Analytic 2D image reconstruction)

Linear superposition of back projections:

\[ \int_{\Delta} f(x,y) \]

Integrate over all possible projection angles.

Introduces 1/r blurring of the image resulting in poor spatial resolution.

-> Filtering which suppresses long distances and thus enhances pixel-to-pixel contrast.
Filtering (FBP)

Filter sinogram with **ramp-filter** before backprojection: Fourier transformation into frequency space, apply ramp-filter and transform back to spatial domain.

(Two sources with $d=1\text{mm}$ each.)
Experimental Setup I

Two back-to-back crystal-MPPC gamma detectors.

**MPPC:**
- 3x3 mm²
- 3600 pixels

**Crystals:**
- Lutetium Fine Silicate
- 3x3x15 mm³

**Source:**
- Na-22

**Measurement:**
- Energy and time resolution.
Experimental Setup II

Features: select coincidences in a small time window, allows low thresholds (-1 mV, about 4 pixels), synchronization between energy and time measurement
Gain Calibration

Attenuated light on MPPC:

Fourier-analysis of spectrum gives number of channels (charge) per photon.