TOF with LYSO + G-APD

J. Va’vra, SLAC

SuperB Workshop at Frascati, 2011
Content

- Start counter resolution in CRT
- SLAC results with small LYSO + G-APD
- SLAC results with small scintillator + G-APD
- SLAC results with large LYSO + G-APD
- Fermilab results with a tiny LYSO + G-APD
- Pisa results with with a tiny LYSO + G-APD
### Crystals for HEP Calorimeters

<table>
<thead>
<tr>
<th>Crystal</th>
<th>NaI(Tl)</th>
<th>CsI(Tl)</th>
<th>CsI</th>
<th>BaF₂</th>
<th>BGO</th>
<th>LYSO(Ce)</th>
<th>PWO</th>
<th>PbF₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density (g/cm²)</td>
<td>3.67</td>
<td>4.51</td>
<td>4.51</td>
<td>4.89</td>
<td>7.13</td>
<td>7.40</td>
<td>8.3</td>
<td>7.77</td>
</tr>
<tr>
<td>Melting Point (°C)</td>
<td>651</td>
<td>621</td>
<td>621</td>
<td>1280</td>
<td>1050</td>
<td>2050</td>
<td>1123</td>
<td>824</td>
</tr>
<tr>
<td>Radiation Length (cm)</td>
<td>2.59</td>
<td>1.86</td>
<td>1.86</td>
<td>2.03</td>
<td>1.12</td>
<td>1.14</td>
<td>0.89</td>
<td>0.93</td>
</tr>
<tr>
<td>Molière Radius (cm)</td>
<td>4.13</td>
<td>3.57</td>
<td>3.57</td>
<td>3.10</td>
<td>2.23</td>
<td>2.07</td>
<td>2.00</td>
<td>2.21</td>
</tr>
<tr>
<td>Interaction Length (cm)</td>
<td>42.9</td>
<td>39.3</td>
<td>39.3</td>
<td>30.7</td>
<td>22.8</td>
<td>20.9</td>
<td>20.7</td>
<td>21.0</td>
</tr>
<tr>
<td>Refractive Index a</td>
<td>1.85</td>
<td>1.79</td>
<td>1.95</td>
<td>1.50</td>
<td>2.15</td>
<td>1.82</td>
<td>2.20</td>
<td>1.82</td>
</tr>
<tr>
<td>Hygroscopicity</td>
<td>Yes</td>
<td>Slight</td>
<td>Slight</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Luminescence b (nm) (at peak)</td>
<td>410</td>
<td>550</td>
<td>420</td>
<td>310</td>
<td>300</td>
<td>220</td>
<td>480</td>
<td>402</td>
</tr>
<tr>
<td>Decay Time c (ns)</td>
<td>245</td>
<td>1220</td>
<td>30</td>
<td>6</td>
<td>650</td>
<td>0.9</td>
<td>300</td>
<td>40</td>
</tr>
<tr>
<td>Light Yield d/e (%)</td>
<td>100</td>
<td>165</td>
<td>3.6</td>
<td>1.1</td>
<td>36</td>
<td>4.1</td>
<td>21</td>
<td>85</td>
</tr>
<tr>
<td>d(LY)/dT f (%)/ °C</td>
<td>-0.2</td>
<td>0.4</td>
<td>-1.4</td>
<td>-1.9</td>
<td>-0.9</td>
<td>-0.2</td>
<td>-2.5</td>
<td>?</td>
</tr>
</tbody>
</table>

- a: at peak of emission; b: up/down row: slow/fast component; c: QE of readout device taken out.

### Logic of using LYSO for TOF?

- It is not as fast as CsI or PWO, but it has much larger light yield compared to the two (almost as high as NaI(Tl)). If one could “parasit” on the forward EMC calorimeter and achieve a good timing, why not? A cheap simple way...

3/1/2011  
J. Va'vra, Forward TOF with LYSO
SLAC CRT setup

Cosmic Ray Telescope (CRT):
(described in SLAC-PUB-13873 (2010):

- $T1*T2*S1*Q_{tz\_counter}$ rate $\sim 5k/24$ hours $\Leftrightarrow E_{\mu\text{on}} > 1.6$ GeV
- Can accumulated more than 150k triggers/month.

3/1/2011  J. Va’vra, Forward TOF with LYSO
Double-quartz counter performance in CRT

Form a difference between two pairs of pads:
\[ \Delta T = \frac{\text{Pad}_1 + \text{Pad}_2}{2} - \frac{\text{Pad}_3 + \text{Pad}_4}{2} \]

CRT:
\[ \sigma \sim 103 \text{ ps/}\sqrt{2} \]
\[ \sim 73 \text{ ps} \]

(Integrated over a CRT run lasting several months)

- The start counter gives a resolution consistently of about 70-75 ps in a long CRT run, averaged over all CRT track angles, temperature drifts, etc.

4-pad MCP-PMT & 2 quartz bars:

The same counter in the ESA test beam lasting a few hours and measured relative to an accelerator start pulse:

\[ \sigma \sim 42 \text{ ps} \]
SLAC tests with small LYSO

Small LYSO + MCP-PMT (sum of 4 pixels):

- **LYSO 1**
  \[ \sigma \sim \sqrt{\sigma_{\text{LYSO}}^2 - \sigma_{\text{Quartz}}^2} \]
  \[ \sim \sqrt{128^2 - 70^2} \]
  \[ \sim 107 \text{ ps} \]

- **LYSO 2**
  \[ \sigma \sim \sqrt{\sigma_{\text{LYSO}}^2 - \sigma_{\text{Quartz}}^2} \]
  \[ \sim \sqrt{174^2 - 70^2} \]
  \[ \sim 159 \text{ ps} \]

Small LYSO + G-APD (4x4 array):

- **LYSO 1**
  \[ \sigma \sim \sqrt{\sigma_{\text{LYSO}}^2 - \sigma_{\text{Quartz}}^2} \]
  \[ \sim \sqrt{128^2 - 70^2} \]
  \[ \sim 107 \text{ ps} \]

- **LYSO 2**
  \[ \sigma \sim \sqrt{\sigma_{\text{LYSO}}^2 - \sigma_{\text{Quartz}}^2} \]
  \[ \sim \sqrt{174^2 - 70^2} \]
  \[ \sim 159 \text{ ps} \]

**Corrections & cuts:** \( k_z \) & ADC corrections, cuts on Spot & ADC & Energy

3/1/2011
J. Va’vra, Forward TOF with LYSO
SLAC tests with small LYSO

Scintillator + MCP-PMT (4x4 array):

![Image of small LYSO setup]

Time difference between scintillator and Start counter:

\[ \sigma \sim \sqrt{\sigma_{\text{scintillator}}^2 - \sigma_{\text{Start}}^2} \]

\[ < \sqrt{(154^2 - 70^2)} \]

\[ < 136 \text{ ps} \]

Full size LYSO + G-APD (4x4 array):

![Image of full size LYSO setup]

Time difference between LYSO and Start counter:

\[ \sigma \sim \sqrt{\sigma_{\text{LYSO}}^2 - \sigma_{\text{START}}^2} \]

\[ \sim \sqrt{230^2 - 70^2} \]

\[ \sim 220 \text{ ps} \]

Corrections & cuts: \( k_z \) & ADC corrections, cuts on Spot & ADC & Energy

3/1/2011  J. Va’vra, Forward TOF with LYSO
SLAC tests with full size LYSO

Full size LYSO + G-APD (single 3x3mm² MPPC S10362-33-025C):

Plan to run it in CRT in April

σ ~ ?

To be done before CRT shutdown for FDIRC tests

3/1/2011  J. Va‘vra, Forward TOF with LYSO
The first LYSO tests had more simple electronics.

3/1/2011 J. Va'vra, Forward TOF with LYSO
Their aim: to develop a fast PET detector using LYSO.

Co$^{60}$ source and trigger on back-to-back γ’s.

3mm x 3mm Hamamatsu G-APDs.

Very tiny LYSO crystal of 3mm x 3mm x 7mm.

The DRS4 waveform digitizer to analyze data (5 GHz sampling).

With a PiLas laser diode they obtained a resolution of $\sigma \sim 39$ps for a signal of $\sim$25 pe’s.

With a Co$^{60}$ source they obtained $\sigma \sim 155$ps (their best resolution).
For a development of a fast PET detector using LYSO.

3mm x 3mm FBK G-APDs (the same G-APDs as Padova is using presently).

Noise rate: 1-3MHz for threshold of 1-2 pe’s, and 3-4kHz for threshold of 3-4 pe’s.

The best resolution was obtained with a very tiny LYSO crystal of 3mm x 3mm x 10mm. He compared this result with other small crystal sizes.

With a Na$^{22}$ source, the best resolution obtained was $\sigma \sim 107$ ps.
## Conclusion

### Results so far:

<table>
<thead>
<tr>
<th>Test</th>
<th>Radiator</th>
<th>Detector</th>
<th>Particle</th>
<th>Resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>SLAC</td>
<td>Small LYSO 17mm x 17mm x 17mm</td>
<td>MCP-PMT</td>
<td>CRT μ’s</td>
<td>109 &amp; 159 ps</td>
</tr>
<tr>
<td>SLAC</td>
<td>Small LYSO 17mm x 17mm x 17mm</td>
<td>G-APD array</td>
<td>CRT μ’s</td>
<td>~ 140 ps</td>
</tr>
<tr>
<td>SLAC</td>
<td>Small scint. 17mm x 17mm x 17mm</td>
<td>G-APD array</td>
<td>CRT μ’s</td>
<td>~ 136 ps</td>
</tr>
<tr>
<td>SLAC</td>
<td>Long LYSO 25mm x 25mm x 200mm</td>
<td>G-APD array</td>
<td>CRT μ’s</td>
<td>~ 220 ps</td>
</tr>
<tr>
<td>Fermilab</td>
<td>Tiny LYSO 3mm x 3mm x 7mm</td>
<td>3mm² G-APD</td>
<td>γ’s from Co⁶⁰</td>
<td>~ 155 ps</td>
</tr>
<tr>
<td>Pisa</td>
<td>Tiny LYSO 3mm x 3mm x 10mm</td>
<td>3mm² G-APD</td>
<td>2γ’s from Na²²</td>
<td>~ 107 ps</td>
</tr>
</tbody>
</table>

### Still one more test is planned in CRT, but things do not look hopeful to me that we can achieve σ ~ 100ps. But would like to go at it once more.