A LYSO calorimeter for the SuperB factory

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Outline

- Motivations for a LYSO calorimeter development
- LYSO crystal main characteristic
- Matrix prototype
- Beam test at CERN
- Beam Test at Frascati
- Conclusions
Motivations

- R&D project devoted to the development of an electromagnetic calorimeter for a high intensity flavor factory
- Optimizations and studies are sometimes explicitly based on SuperB
  - high luminosity asymmetric e+e- collider
  - Center of mass energy 10.58 MeV, Y (4S) resonance
- Despite this aspect, the developed detector may still have an application in several other environments
Calorimetry at b-factories

- Both b-factory experiments of the last decade (BABAR and Belle) use the same kind of electromagnetic calorimeter
  - CsI(Tl) crystals calorimeter
- Main CsI(Tl) characteristic is the very high light yield which means very good performances even at low energy (few GeV)
  - BABAR resolution \( \frac{\sigma(E)}{E} = \frac{2.30}{\sqrt[4]{E(GeV)}} \oplus 1.35\% \)
- How are CsI(Tl) performances in an environment with a luminosity a factor 100 higher?
Asymmetric machine $\rightarrow$ asymmetric detector

After 10 years with a Luminosity $\sim 10^{34}\text{cm}^{-2}\text{s}^{-1}$:

- "Barrel" EMC:
  - Small radiation damage
- "Forward" EMC:
  - High radiation damage

In the hypothesis to have a machine running for 10 years at $10^{36}\text{cm}^{-2}\text{s}^{-1}$:

- "Barrel" could sustain this rates and radiation damage is not an issue
- "Forward" need a detector faster, with finer granularity and with an higher radiation hardness
<table>
<thead>
<tr>
<th>Crystal</th>
<th>NaI(Tl)</th>
<th>CsI(Tl)</th>
<th>CsI</th>
<th>PWO</th>
<th>LYSO (Ce)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density (g/cm³)</td>
<td>3.67</td>
<td>4.51</td>
<td>4.51</td>
<td>8.3</td>
<td>7.1</td>
</tr>
<tr>
<td>Melting Point (°C)</td>
<td>651</td>
<td>621</td>
<td>621</td>
<td>1123</td>
<td>2050</td>
</tr>
<tr>
<td>Radiation Length (cm)</td>
<td>2.59</td>
<td>1.85</td>
<td>1.85</td>
<td>0.9</td>
<td>1.14</td>
</tr>
<tr>
<td>Molière Radius (cm)</td>
<td>4.8</td>
<td>3.57</td>
<td>3.57</td>
<td>2.0</td>
<td>2.2</td>
</tr>
<tr>
<td>Hygroscopicity</td>
<td>yes</td>
<td>slight</td>
<td>slight</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>Luminescence (nm)</td>
<td>410</td>
<td>560</td>
<td>420/310</td>
<td>560/420</td>
<td>420</td>
</tr>
<tr>
<td>Decay Time (ns)</td>
<td>230</td>
<td>1250</td>
<td>35/6</td>
<td>30/10</td>
<td>45!</td>
</tr>
<tr>
<td>Light Output (%)</td>
<td>100</td>
<td>165</td>
<td>3.6/1.1</td>
<td>0.3/0.08</td>
<td>80</td>
</tr>
<tr>
<td>d(LO)/dT (%/°C)</td>
<td>~0</td>
<td>0.3</td>
<td>-0.6</td>
<td>-1.9</td>
<td>-0.3</td>
</tr>
<tr>
<td>Radiation Damage</td>
<td>Yes</td>
<td>10%/krad</td>
<td>2%/krad</td>
<td>Small</td>
<td>Small</td>
</tr>
</tbody>
</table>

LYSO Crystals meets all the requirements
R&D campaign started in 2010 with laboratory and beam tests

\[ \text{Lu}_2(1-x)\text{Y}_{2x}\text{SiO}_5 \]
LYSO Characterization

- Radiation damage on this type crystals has been measured in 2007
  - LY loss ~12% after 1 Mrad

- Luminescence peak between 420 and 440 nm (depends on producer)
- Small differences in sensors QE (<2%)

J. Chen, R. Mao, L. Zhang, R. Zhu
IEEE Transaction on Nuclear Science, V54N4 2007

R. Zhu, EMC SuperB Meeting April 2011
A 5x5 matrix of LYSO crystal was built in order to perform beam tests

- 3 different LYSO producer
  - Saint-Gobain (SG) 12 crystals
  - SIPAT 10 crystals
  - SICCAS 3 crystals
- Crystal are 20cm long (~17.4X₀)
- Glass fiber alveolar structure

Before beam tests all crystals have been studied in laboratory
Light Output uniformity

- Light output non-uniformity related to Ce concentration along crystal
- Significant non-uniformity impacts on energy resolution
- Uniformization with 15mm black band painted on the opposite side of readout
  - Pro: Fast and reversible
  - Con: ~30% of light loss

R. Zhu, EMC SuperB Meeting February 2011
Readout Electronics

- **Sensor:**
  - 5x5 mm² Hamamatsu S8664 APD

- **Very Front-End:**
  - Custom made board with commercial Cremat CSP (1.4V/pC)

- **Shaping Amplifier:**
  - Custom VME board with commercial Cremat Shaper (100ns)

- **DAQ:**
  - Caen V1720 250MHz differential digitalizer
Beam Test @ CERN

- October 2010
- Beam Test at CERN PS : 1-4GeV
  - T10 line, about 12m far from beam pipe
- Trigger with two scintillator fingers
- Cherenkov threshold detector (e/π separation)
- 5 Temperature sensors
Beam Test @ CERN

- High number of muon and π in the beam
  - MIP deposit at 1 GeV along crystal ~198 MeV
- Used to extract temperature correction factor for APDs: -2.8%/°C
- Also intercalibration coefficients evaluated with MIP

![Graph showing temperature correction factor](image)
- Sum over all crystals over threshold
  - Threshold: $3 \sigma_{ch}$
  - $\sigma_{ch} \sim 800\text{KeV}$
- Energy distribution fitted with crystal-ball function

- We were able to collect data only at 3 energy (1, 1.5 and 2 GeV)
- Electron statistics inside beam too low at higher energy
Beam Test Facility @ LNF.
- 50-500 MeV
- 50Hz with 1-10^9 e⁻/spill

Higher gain in read out chain wrt CERN test beam (~3)

Silicon beam telescope:
- Single-side 228μm strip pitch
- 2 planes x-y
- Active area 8.75x8.75 cm²

Data:
- 5 energies: from 487 MeV to 99 MeV
- 3 different positions
Strong correlation between energy and beam profile
- Larger size at low energy
- Selection on position to perform energy resolution measurement
Ex: 487 MeV total reconstructed energy

- Deposited energy, 487 MeV
  - FWHM/2.355 = (105.5 ± 1.1)
  - $\frac{\sigma_E}{E} = (2.920 ± 0.031)\%$
  - Without position selection

- Deposited energy, 487 MeV
  - FWHM/2.355 = (85.0 ± 2.4)
  - $\frac{\sigma_E}{E} = (2.332 ± 0.066)\%$
  - With position selection

Channel intercalibration
- RMS minimization (e⁻ events)
- Cosmic muons
Results (I)

- Beam energy spread is not precisely known (estimation ~1%@500MeV)
  - MC test by changing the beam spread
  - Beam spread is not constant with energy

Null constant term c

- Due to the fact that beam spread is not constant with energy

\[
\frac{\sigma E}{E} (\%) = \frac{a}{\sqrt{E (\text{GeV})}} + \frac{b}{E (\text{GeV})} + c
\]

\[\chi^2 / \text{ndf} = 15.65 / 2\]
- a: 1.528 ± 0.05653
- b: 0.5228 ± 0.03897
- c: 1.002e-06 ± 0.4767
Beam spread extraction

- Extract BS directly from data using multi particle events
  - Assume difference in resolution between N e- with energy E and 1 e- with energy NxE is due to different beam energy spread
  - Obtain beam spread and matrix resolution from minimization

![Graph showing beam spread extraction](image)

\[ \sigma_E = \frac{1.1\%}{\sqrt{E(\text{GeV})}} + \frac{0.4\%}{E(\text{GeV})} + 1.2\% \]
Conclusions

- R&D started with the main purpose of developing a new calorimeter for a high intensity flavor factory
  - Fast response
  - High granularity
  - Radiation hardness
- First calorimetric measurement with LYSO crystal
- Two beam tests
  - CERN: tested the response of the matrix at energy between 1 and 2 GeV
  - Frascati: measured the energy resolution at energy below 500MeV

\[
\frac{\sigma_{E}}{E} = \frac{1.1\%}{\sqrt{E(\text{GeV})}} \oplus \frac{0.4\%}{E(\text{GeV})} \oplus 1.2\%
\]
SuperB detector

Drift Chamber
FDIRC (PID)
Silicon Vertex Detector
Backward EMC
IFR (PID)
EM Calorimeter
Baseline Design
Design Options
Forward PID

e^+ e^−
SuperB Story

- R&D project started on 2005
- Italian Government approval in December 2010
  - First founding ~250M€
- Site selection in May 2011
  - Tor Vergata University campus (near Rome)
- Cabibbo Lab start-up signed in October 2011
- Detailed costing by Accelerator management during 2012
- November 2012: Costing review by Italian Ministry of education university and research commission
- December 2012: Project was closed
  - The Minister pointed out that the importance and quality of the program were out of discussion, but that the economic conditions of the country and the limits foreseen by the National Research Plan were incompatible with the estimated cost of the project.
Geometry and Mechanics

- **General Layout**
  - 20 rings of crystal arranged in 4 groups of 5 layers each
  - Each group of 5 layers arranged in modules 5x5

- **Crystal dimensions**
  - Approx 2x2 front face and 2.5x2.5 back face
  - 20cm long (~17.5X₀)

- **Two mechanical structure prototypes (5x5 matrix) made by RIBA (Faenza, Italy)**
  - Beam Test
  - Mechanical test
LYSO Characterization with PMT

- 12 LYSO crystals (Saint Gobain)
- Light Output and uniformity studies with a $^{60}\text{Co}$ source (2 $\gamma$: 1.17 e 1.33 MeV)

\[
\frac{LY}{LY_{\text{mean}}} = 1 + \frac{\delta(\%)}{100} \cdot \left( \frac{x}{x_{\text{mid}}} - 1 \right)
\]

- Delta value smaller than with APD
- Difference due to the different active surface
  - PMT cover 100% of crystal face
  - APD cover ~6% of crystal face