A LYSO CALORIMETER
FOR THE SUPERB FACTORY

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The SuperB factory

Flavor physics at the SuperB factory, after BaBar/Belle, would be a complement to LHC to study New Physics beyond the Standard Model in the $b$, $c$ and $\tau$ sector.

The SuperB factory will run at a luminosity of $10^{36}\text{cm}^{-2}\text{s}^{-1}$ to collect an integrated luminosity of 50-75ab$^{-1}$.

The machine is an asymmetric $e^+e^-$ collider employing the new “crab waist” colliding scheme, with very low emittance. Longitudinally polarized beam at 80% can be obtained. Luminosity related bckg in the forward region will be high and is one of key study ongoing in the “collaboration”.

CDR detector for the SuperB is based on BaBar with re-optimization TDR phase has been approved for two years.
ELECTROMAGNETIC CALORIMETER

BABAR calorimeter

BARREL: OK
- no radiation damage
- can support SuperB rates
- shielding against bckg (radiative Bhabha’s) is crucial

NEW FORWARD EMC is needed (subject of this talk):
- radiation damage
- not good for high rates at SuperB
  - finer granularity
  - faster crystals, shorter decay time
- good Light Yield

Intensive R&D effort in Italy (Perugia, Roma) and Caltech is ongoing for the design, development and construction of a LYSO calorimeter.

There is a proposal for a Backward EMC (not present in BaBar) made of Pb and scintillator.
<table>
<thead>
<tr>
<th>Crystal</th>
<th>NaI(Tl)</th>
<th>CsI(Tl)</th>
<th>CsI</th>
<th>BaF$_2$</th>
<th>BGO</th>
<th>PbWO$_4$</th>
<th>LSO(Ce)</th>
<th>GSO(Ce)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density (g/cm$^3$)</td>
<td>3.67</td>
<td>4.51</td>
<td>4.51</td>
<td>4.89</td>
<td>7.13</td>
<td>8.3</td>
<td>7.40</td>
<td>6.71</td>
</tr>
<tr>
<td>Melting Point (°C)</td>
<td>651</td>
<td>621</td>
<td>621</td>
<td>1280</td>
<td>1050</td>
<td>1123</td>
<td>2050</td>
<td>1950</td>
</tr>
<tr>
<td>Radiation Length (cm)</td>
<td>2.59</td>
<td>1.85</td>
<td>1.85</td>
<td>2.06</td>
<td>1.12</td>
<td>0.9</td>
<td>1.14</td>
<td>1.37</td>
</tr>
<tr>
<td>Molière Radius (cm)</td>
<td>4.8</td>
<td>3.5</td>
<td>3.5</td>
<td>3.4</td>
<td>2.3</td>
<td>2.0</td>
<td>2.3</td>
<td>2.37</td>
</tr>
<tr>
<td>Interaction Length (cm)</td>
<td>41.4</td>
<td>37.0</td>
<td>37.0</td>
<td>29.9</td>
<td>21.8</td>
<td>18</td>
<td>21</td>
<td>22</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>2.2</td>
<td>1.82</td>
<td>1.85</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)</td>
<td>410</td>
<td>560</td>
<td>420</td>
<td>300</td>
<td>480</td>
<td>560</td>
<td>420</td>
<td>440</td>
</tr>
<tr>
<td>(at peak)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Decay Time $^b$ (ns)</td>
<td>230</td>
<td>1300</td>
<td>35</td>
<td>630</td>
<td>300</td>
<td>50</td>
<td>40</td>
<td>60</td>
</tr>
<tr>
<td>Light Yield $^b,c$ (%)</td>
<td>100</td>
<td>45</td>
<td>5.6</td>
<td>21</td>
<td>13</td>
<td>0.1</td>
<td>75</td>
<td>30</td>
</tr>
<tr>
<td>d(LY)/dT $^b$ (%/ °C)</td>
<td>~0</td>
<td>0.3</td>
<td>-0.6</td>
<td>-2</td>
<td>-1.6</td>
<td>-1.9</td>
<td>-0.3</td>
<td>-0.1</td>
</tr>
</tbody>
</table>

**Experiment**

<table>
<thead>
<tr>
<th>Crystal Ball</th>
<th>CLEO CLEO</th>
<th>BABAR BABAR</th>
<th>KTeV, E787 KTeV, E787</th>
<th>TAPS (L*) TAPS (L*)</th>
<th>L3 BELLE L3 BELLE</th>
<th>CMS ALICE CMS ALICE</th>
<th>PANDA? (BTeV) PANDA? (BTeV)</th>
<th>SuperB? SuperB?</th>
</tr>
</thead>
</table>

*a. at peak of emission; b. up/low row: slow/fast component; c. measured with bi-alkali PMT*
CRYSTAL STUDY

More than one producer:
- St. Gobain (good quality, very expensive)
- SIPAT (quality is growing, approaching preliminary specs)
- SICCAS (starting to produce LYSO following our requests)

Tested also after irradiation, no change is observed.

LY is about a factor of 6 more than BGO.

Consistent with the measurement done using APD's.

LIYUAN ZHANG talk
CRYSTAL STUDY: St. Gobain production for Test Beam

12 crystals are under test in Italy:

- Metrology to check dimensions (requested ± 100 μm)
- Light yield measurement (using a Co source)

LY (1.17MeV) = 1027 p-e/MeV
LY (1.33MeV) = 986 p-e/MeV

Crystals are bare, apply a factor 2.3 with respect to measurement with Tyvek, in agreement with previous measured crystals (1900-2000 p-e/MeV)
GEOMETRY DESCRIPTION AND MECHANICS

General layout:

20 rings of crystals arranged in 4 groups of 5 layers each.
Each group of 5 layers arranged in modules 5 crystals wide.
The number of modules in a ring is multiple of 2x3.

Module prototype for Beam test October 2010

Solid doughnut or two halves is still under discussion

Mechanical structure prototype has been built by RIBA (Faenza, Italy).
Two possible readout are under study: PiN diodes (as in the Barrel) and APD’s.

- PiN would require intermediate step with PMT during uniformity measurements
- APD’s strong temperature dependence

- Neutron induced signal see talk of R.Y. Zhu

- Towers of 25 crystals for the forward => 4 towers per trigger link
- Towers of 12 crystals for the Barrel => 6 towers per trigger link

<table>
<thead>
<tr>
<th>MeV</th>
<th>% Low Range MeV</th>
<th>% High Range MeV</th>
<th>% Range selected MeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>6.87</td>
<td>219.73</td>
<td>6.87</td>
</tr>
<tr>
<td>10</td>
<td>0.69</td>
<td>21.97</td>
<td>0.69</td>
</tr>
<tr>
<td>100</td>
<td>0.07</td>
<td>2.20</td>
<td>0.07</td>
</tr>
<tr>
<td>200</td>
<td>0.03</td>
<td>1.10</td>
<td>0.03</td>
</tr>
<tr>
<td>800</td>
<td>OVF</td>
<td>0.73</td>
<td>0.73</td>
</tr>
<tr>
<td>1000</td>
<td>OVF</td>
<td>0.22</td>
<td>0.22</td>
</tr>
<tr>
<td>9000</td>
<td>OVF</td>
<td>OVF</td>
<td>OVF</td>
</tr>
</tbody>
</table>

- charge preamplifier + 2 ranges gain (x1, x32)
- 12 bit digitalization + 1 bit range
- special range for calibration
MC PERFORMANCE STUDIES

Fundamental point for the optimization of the detector:

1. Resolution study as function of space between crystals and modules
   - Mechanical structure (very useful during design phase of the prototype module)

2. Detailed study of the effect of the material in front of the calorimeter for a possible PID forward detector

Resolution as function of the position for showers away from edge of the forward EMC

Resolution as function of the position for showers in the transition region between barrel and forward EMC

Resolution as function of the quartz thickness

Quartz
3. Clustering algorithm for pattern recognition in case of overlapping events

**MC PERFORMANCE STUDIES cont’d**

- Maximum Energy or Seed Crystal
  - $\delta X \leq 1$
  - $\delta X \leq 2$

**Graphs:**
- Fraction of Measured Energy
  - No Clustering
  - Clustering
  - $5 \times 5$ Crystal Matrix
  - $3 \times 3$ Crystal Matrix

- Two plots showing FWHM vs seed energy threshold for different energies (1 GeV $\gamma$, 100 MeV $\gamma$) with $\delta X = 1$ and $\delta X = 2$.
4. Background study (radiative Bhabha events) is one of the most important, it has implications on:
   - Electronics (shaping time, integration, pile up)

Most of the clusters are coming from neutrons, very few from electrons and photons.
Physics study $B^+ \rightarrow K^+ \nu \nu$

Example for the optimization of the detector:

**FWD**

*Full Sim*

$B^+ \rightarrow K^+ (K_s \pi) \nu \nu$

signal MC

**B**

$\rightarrow$ 

**K**

$\nu \nu$

**BARREL**

Full Sim

$B^+ \rightarrow K^+ \nu \nu$

signal MC

**Fast Sim**

$B^+ \rightarrow K^+ \nu \nu$

signal MC

**FWD EMC**

shows expected shape for signal MC

In the barrel a more detailed study of the bckg is needed to obtain good performance.

$E_{\text{extra}} =$ neutral energy after all tag side tracks and neutral cluster have been accounted for.
1 LYSO crystal (2x2x20cm) with two different sensors
- 1 Photodiode PiN Hamamatsu S2744-08 (1x2cm)
- 2 APD Hamamatsu S8664-55 (0.5x0.5cm each)
- same APD used by CMS
- one e- and two e- peaks are evident
- fits are made with the sum of two CrystalBall function
- beam position is measured by a fibrometer (resolution ~cm)
Put under test matrix of 5x5 LYSO crystals + external ring of CsI crystals (CLEO)

5 channels of the new electronics are under production and will be tested in June:
• test OK 😊 assembly up to 25 channels for October TB
• VFE to be modified 😠 recover and use 5 channels + 20 channels with APD’s and CMS DAQ
• C1/C2 Cerenkov counters, CERN setup: the detectors are provided by CERN in the beam line, two channels, electron/pion separation, radout via ADC VME system. DAQ system integrated with beam telescope and new electronics channels. @LNF we do not have/need external particle identification.

• S1/S2: two 10cm x 10cm x 1cm plastic scintillators, to be used in the trigger and to synchronize the two independent DAQ systems, @LNF and @CERN

• Beam telescope (2 X-Y planes, Fermi sensors, single sided detectors, they are nearly 10x10 cm^2, 50 micron strips, 225 micron pitch, 384 strips per wafer, 400 micron silicon) ready.
- Studies for a new LYSO calorimeter for the SuperB factory have been developed

- Different aspects are under/have been investigation/investigated:
  - **LYSO characterization** (LY, uniformity, Ce doping)
  - **performance studies**: well advanced detailed study (occupancy and background, material in front of the endcap…) are on going
  - **mechanics**: developing analysis for the whole structure, prototype structure for the BT is ready
  - **electronics**: readout is under investigation (APD’s, PiN), electronics is under development and will be photodetector independent, first prototype will be ready for test in June, October 2010 Beam Test
  - **Beam Test** organization is on going

  October 2010 at CERN (up to 3.5 GeV)

  November 2010 at BTF (50 – 500 MeV)