IFR Detector  R&D status

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On behalf of the ferrara SuperB group

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Detection Technique

Scintillator bars + WLS fibers readout on both ends by Geiger mode APDs

- **Scintillator:**
  - 4 cm scintillator bars coated with TiO$_2$
  - Light collection through **WLS fibers**
  - Fibers housed in a surface groove or in a embedded hole

- **WLS fibers:**
  - $\phi = 1$mm type Y11(200/300) (Kuraray) or BCF92 (Saint Gobain), Attenuation length $\lambda \approx 3.5m$, trapping efficiency $\varepsilon \approx 5.5\%$

- **Photodetectors:**
  - Multi Pixel Photon Counters (Hamamatsu), Silicon Photo Multiplier (IRST Trento-Italy):
    - Gain $>10^5$, DE $\approx 40\%$ (@ 500 nm, MPPC) (DE = Q.E x Fill factor x Avalanche probability)
    - < 1ns risetime
    - Low bias voltage (35V SiPM, 70V MPPC)
    - Dark current rate @ room temperature: 100s of kHz @ 0.5 phe, few 10s of kHz @ 1.5 phe, few kHz @ 2.5 phe
detector layout options…

- 2 layouts: time readout, double coord. readout

- Time readout: the azimuthal coord $\phi$ by the hit bar and polar coord $\theta$ by the arrival time of the signal

- Double coord readout: two layers of orthogonal (1.0 cm) scintillating bars provide directly the $\phi$ and $\theta$ coordinates.

- Easier from the point of view of electronics but more complicated for the mechanics
readout options…

• Waiting for simulations of background neutron flux on the detector…

• In the most pessimistic case we have to bring all the photosensors out of the detector:
  – 4m of WLS fiber + 10m of clear fibers
  – Factor ~3 less in number of p.e., to be recovered keeping the same time resolution:
    • Increasing the number of WLS fibers, from 1 to 4, on 2x2 mm$^2$ SiPM
    • Increasing the fiber’s diameter from 1.0 to 1.2 (ordered from Kuraray, expected 2-nd half of Feb.)
    • Playing with fibers position and/or scintillator coating to maximize the light collection
Detector R&D activities in Ferrara
Cosmic ray test setup

Trigger = S1 x S2

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Cosmic ray test setup
Detection efficiency and timing studies for “on detector readout”
Module prototype

Surface groove

Scintillator wrapped with aluminum foil and black tape

1.5 cm x 2.0 cm scintillator

Fibers: - kuraray T11-300 ppm
- St.Gobain BCF92

Embedded hole
Light yield

Efficiency ~ 98% @ 1.5 phe
~96% @ 2.5 phe

ADC spectra for a kuraray T11-300 fiber about 4 m long in an embedded hole

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Light yield

**fiber kuraray**

**Efficiency** 97.7% @ 1.5 phe
94.4% @ 2.5 phe

ADC spectra for a kuraray T11-300 fiber about 4 m long in a **surface groove**

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Time resolution Saint-Gobain fiber

Distance ~200 cm
sigma 1.3 ns

Distance ~200 cm
sigma 1.8 ns

Distance ~50 cm
sigma 1.15+-0.03 ns

Distance ~350 cm
sigma 1.84+-0.05 ns
• 1.0 cm scintillator and Saint-Gobain fiber on a surface groove

• Low light yield at the far end (~ 4 m)

• Detection efficiency less than 73% @ 1.5 phe

Eff = 72.7%
The MPPC modules comes with (unknown) FE electronics

For the SiPM devices a prototype amplifier has been developed based on commercial Texas Instrument THS4303 fast amplifier

The idea is to preserve as much as possible the very fast leading edge of the SiPM signal (~ 200psec) to minimize the time spread
Latest studies for “out of detector readout”
• In this case we have to bring the light signal out of the detector, in a lower radiation region
• we have considered 10m of clear fiber
  \[ \lambda_{\text{att}} = 10 \text{ m} \rightarrow \sim \text{factor 3 less number of p.e.} \]

• Several measurements are ongoing:
  – 4 WLS fibers/scintillator on 2x2 mm\(^2\) SiPM (Hamamatsu 3x3 mm\(^2\) ordered)
  – Various FE amplifiers
  – Kuraray and Saint-Gobain fibers
• two 1cm scintillators “sandwiched”
Some picture of the last setup

- Scintillators with PMTs as fast trigger
- 2 5-cm long 2-cm high scintillators with different combinations of fibers.
- 4 fibers readout by 2x2 mm² SiPM
- 1 fiber readout by 1x1 mm² SiPM/MPPC
4 fibers kuraray OR saint gobain

8 fibers kuraray AND saint gobain

Two sandwiched scintillators 1cm thick
In some more detail…

- We tried many combinations of FE amplifiers (for complete description see Roberto Malaguti’s talk) with different gain/BW combinations:
  - Texas instruments
  - Analog device

- Various fiber’s length: 3, 4, 5 m of both, Bicron and Kuraray

- SiPM with active area 2x2 mm\(^2\)
  (waiting for Hamamatsu 3x3 mm\(^2\))

- We concentrated our efforts (for the moment) on the optimization of the time resolution

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So.. Let’s start from the trigger

- The trigger is given by the coincidence of two scintillators: S1, S2, to select vertical cosmics.

- The reference time \( T_0 \) is given by scintillator S2. S1 has a time spread of \( \sim 0.66 \) with respect to S2.

- The \( T_0 \) time spread is then about 0.4 - 0.5 nsec so the actual time resolution is expected to be roughly 0.1 nsec lower.
• Our best results (for the moment) have been obtained with Saint-Gobain fibers

• 1.5 and 2.5 phe thresholds

• we tried with CF discriminator but no clear improvement was seen

• A Fan In / Out was taken out but results are better with it (it filters some high frequency noise? See next slides)
If we plot the time distribution of the 1.5 phe corresponding to 2.5 hit (Tbest) we obtain a promising 1.2 nsec resolution.
• Time resolution is limited by a clear ~1 nsec “multipeak structure” ....

• This regularity is suspect and might be due to ~1 GHz noise (mobile phone - wireless??) summing up to the signal...

• Intrinsic discrete (phe) signal structure would give closer peaks (< 0.5 nsec)

• Also SiPM multiple hit structure is present but peaks time distance is > 1.0 nsec (see next slide)

• better shielding / grounding
A sample of signals…..

This peculiar signal shape is related to the external light signal…..

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# Summary of results

<table>
<thead>
<tr>
<th>Type of electronics</th>
<th>Time resolution (ns)</th>
<th>Efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>bicron 3m</td>
<td>bicron 5m</td>
</tr>
<tr>
<td>old</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.5 phe</td>
<td>-</td>
<td>1.3/1.5</td>
</tr>
<tr>
<td>new fast</td>
<td>2.5 phe</td>
<td>1.2/1.3</td>
</tr>
<tr>
<td>new fast FIFO</td>
<td>2.5 phe</td>
<td>1.1</td>
</tr>
<tr>
<td>1.5 phe</td>
<td>1.0</td>
<td>1.25</td>
</tr>
<tr>
<td>best T</td>
<td>0.9</td>
<td>1.2</td>
</tr>
<tr>
<td>C.F.</td>
<td>1.1</td>
<td>1.3</td>
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<tr>
<td>new slow no FIFO</td>
<td>2.5 phe</td>
<td>1.2</td>
</tr>
<tr>
<td>1.5 phe</td>
<td>1.15</td>
<td>-</td>
</tr>
<tr>
<td>best T</td>
<td>1.1</td>
<td>W. Baldini, INFN sez. di Ferrara</td>
</tr>
</tbody>
</table>
Efficiencies...

- With this new setup also efficiency studies are ongoing...
- We just implemented a CAEN ADC (V792) instead of a LeCroy 1182 which had some problems...
- For the moment efficiencies are calculated only through the TDC and are rather low: ~ 80%
- With the V792 we will have more informations on the signal and will help to investigate...
Radiation effects....
Damage comparison

Damage effect ... almost the same for protons and neutrons

proton irradiation

$\text{Current after 1 hour (}\mu\text{A})$

$60\text{Co }\gamma\text{-ray irradiation}$

irradiated dose (Gy)

Damage effect ...

1~2 orders larger with protons than $\gamma$-ray irradiation

$2.3 \times 10^5$ p/mm$^2$/s (130 Gy/h)

$I_{\text{leak}} @ (V_{\text{op}}, 1.4 \times 10^8 \text{ p/mm}^2) =

2.8 \times 10^8$

$p/\text{mm}^2$

before irradiation

$1.4 \times 10^8$

$p/\text{mm}^2$

Bias Voltage

$4.2 \times 10^5$ n/mm$^2$/s

$I_{\text{leak}} @ (V_{\text{op}}, 1.0 \times 10^8 \text{ n/mm}^2) = 8.5 \mu\text{A}$

Current (\muA)

100 pixel MPPC

$1 \times 10^8$

$n/\text{mm}^2$

before irradiation

Neutron irradiation
VERY Rough background estimate

- Flux $\sim 1.6 \times 10^9$ n/s over $4\pi$, from bending magnets (d $\sim$10-12 m from IP) @ $L = 7\times10^{33}$ cm$^{-2}$ s$^{-1}$

- $\rightarrow \sim 1.3$ neutrons / sec * mm$^2$ $\rightarrow \sim 250$ n/sec*mm$^2$ (2 sources and a factor 100 in luminosity)

- Damage begins around $10^8$ neutrons, this means a lifetime $10^8 / 250 = 4 \times 10^5$ sec…

- Of course this is a very rough estimate, more precise simulations needed….
Next steps

- Measurements with the “2cm” thick scintillator (just started, no results yet)
- More realistic conditions (4.0 cm large instead of 1.5 cm)
- Measurements with 4 x 1.2 mm WLS and 1.5 mm clear fibers
- Repeat measurements with hamamatsu 3x3 MPPC (better Detection efficiency)
SPARE SLIDES
APDs vs Geiger mode APDs

**APD:**
- For BaBar R&D was considered the model RMD #S0223:
  - $G > 1000$
  - QE=65% (>530 nm)
  - 5ns risetime
  - High bias voltage (1850V) → difficult to stabilize
  - G very sensitive to V and T variations
  - Hamamatsu APDs have lower gain (few 100), bias voltage 400-500 V

Geiger mode APDs:

**MPPC (Hamamatsu), SiPM (FBK- IRST)**
- $G > 10^5$
- DE ≈ 40% (530nm) (DE = Q.E \times Fill \; factor \times Avalanche \; probability)
- ∼ 1ns risetime
- ≈ 10 times less sensitive to V and T variations
- Low bias voltage (30-70V)
- Dark current rate @ room temperature:
  - $100s \; of \; kHz \; \text{thr} = 0.5 \; phe$
  - $10s \; of \; kHz \; \text{if thr} = 1.5 \; phe$
Dear Eugenio,

I pulled some numbers of neutron rates at BaBar and compared them to LHC CMS projected rates. They are similar! The technique to estimate BaBar rates was as follows:

1. Use two neutron counter rates on opposite side of BaBar.
2. Calibrate them with a Pu237 neutron source to correct their efficiency.
3. Assume, naively I should say, that the there is a single source coming from radiative Bhabhas striking some region between Q3 & Q4. Its position was worked out from the two counter rates assuming assuming the spherical propagation.
4. Using this spherical model, I estimate a rate of $1.6 \times 10^9$ Hz going into 4pi for a BaBar luminosity of $7 \times 10^33$.
5. From there I can estimate rates at various detector faces in BaBar and compare them to the CMS rates.

I have no way to verify that these rates are correct. However, Chris O'Grady told me that a rate of DCM FPGA resets was consistent with my flux estimate on the DCM face, if he uses some LHC R&D data.

6. Finally, Roberto Fasso from SLAC radiation group calculated energy spectra of these neutrons at BaBar using Fluke program. Assuming 4-9 electrons striking Cu or Fe flange, they are typically 1-2 MeV neutrons.

I include his simulated spectrum.

7. Finally I compare BaBar rates with the LHC EMC estimated rates in the region of main tracking detectors. I include the numbers from their internal note. The rates are similar within a factor of 10.

8. Last but not necessarily the least. Every neutron ends its life with a few Gammas of a few MeV. That is a final additional background.

I think the way to proceed is to estimate the neutron flux at the likely major source, which is, according to Mike's picture, about 10 lb isotope from IR (the first major bend). It will be shielded, of course. However, not along the beam line pointing back to BaBar. This will act as a port hole in a nuclear reactor fuming neutrons back. So one should estimate the rate there assuming a spherical radiation of neutrons, and calculate what will be coming into BaBar assuming spherical geometry.

Jerry