New FDIRC for SuperB

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Content

• **SuperB detector**
• **Lessons from the FDIRC prototype: What timing resolution do we need to correct the chromatic error?**
• **Design of the new FDIRC for SuperB**
• **Simulation with Mathematica**
• **MC simulation**
• **Expected performance**
• **Conclusion**
Super-B detector

New Focusing DIRC (FDIRC)

Nominal design

Option

Cluster counting in new DCH ??

Forward TOF or Forward Aerogel RICH ??

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BaBar DIRC ---> SuperB FDIRC

- Long-term accumulated experience

DIRC proved to be a very reliable detector at BaBar. We all learned to like it.

Prototype verified the focusing concept, use of highly pixilated detectors, developed MC methods, and established that the chromatic error can be corrected by timing.

3D imaging (x, y & time), 25x smaller volume and 10x faster than BaBar DIRC.
Lessons from FDIRC prototype:

- New fast highly pixilated detectors
- 10x better timing resolution than D IRC
- Correction of the chromatic error
- Methods to design the optics
- Ring aberration
Focusing DIRC prototype photon detectors

C. Field et al., Nucl.Inst.&Meth., A 553 (2005) 96

1) Burle 85011-501 MCP-PMT (64 pixels, 6x6mm pad, \(\sigma_{TTS} \sim 50-70\)ps)

2) H-8500 MaPMT (64 pixels, 6x6mm pad, \(\sigma_{TTS} \sim 140\)ps)

3) H-9500 Flat Panel MaPMT (256 pixels, 3x12mm pad, \(\sigma_{TTS} \sim 220\)ps)

Timing resolutions were obtained using a fast laser diode in bench tests with single photons on pad center, and with the CFD electronics used on the FDIRC prototype.
Cherenkov ring in pixel and time domain


• Both domains can be used to determine $\theta_c$.
• FDIRC uses time to resolve the forward-backward ambiguity, do chromatic corrections, reject the background; it will be used for PID in a likelihood analysis, etc.
Color tagging by measurement of photon propagation time

\[ v_{\text{group}} = \frac{c}{n_{\text{group}}} = \frac{c}{[n_{\text{phase}} - \lambda \frac{dn_{\text{phase}}}{d\lambda}]} \]

\[ t = \frac{\text{TOP}}{v_{\text{group}}} = \frac{L}{v_{\text{group}}} = \frac{L [n_{\text{phase}} - \lambda \frac{dn_{\text{phase}}}{d\lambda}]}{c} = \text{Time-Of-Propagation} \]

\[ \frac{dt}{L} = \frac{d\text{TOP}}{L} = \frac{\lambda}{c} \frac{d\lambda}{d\lambda^2} - \frac{d^2n}{d\lambda^2} \]

\( dt \) is pulse dispersion in time, length \( L \), wavelength bandwidth \( d\lambda \), refraction index \( n(\lambda) \)

- We have determined in Fused Silica: \( \frac{dt}{L} = \frac{d\text{TOP}}{L} \sim 40\text{ps/meter} \).
- **Our goal is to measure the color of the Cherenkov photon by timing!**
FDIRC prototype is the 1-st RICH detector to correct the chromatic error by timing


Because Cherenkov angle correlates with time-of-propagation (TOP), one can correct the Cherenkov ring chromatic broadening by time. To be able to do the chromatic correction, one needs a single photon resolution of ~200ps.

Tagging color by time in 5m-long DIRC bar:

Cherenkov angle production controlled by \( n_{\text{phase}} \) (\( \cos \theta_c = 1/(n_{\text{phase}} \beta) \)):

\[ \theta_c \text{ (red)} < \theta_c \text{ (blue)} \]

Propagation of photons is controlled by \( n_{\text{group}} \) (\( v_{\text{group}} = c_0/n_{\text{group}} = c_0/[n_{\text{phase}} - \lambda \times dn_{\text{phase}}/d\lambda] \)):

\[ v_{\text{group}} \text{(red)} > v_{\text{group}} \text{(blue)} \]

Excel calculation: Data from the prototype: Result with 3 mm pixels:

\[ \Delta \text{TOP} / L_{\text{path}} = (\text{TOP}_{\text{measured}} - \text{TOP}_{\text{expected}}) / L_{\text{path}} \text{ [ns/m]} \]

Consistent with expectation

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Summary of error contributions to $\theta_c$


- Chromatic smearing: $\sim 3-4$ mrad
- Pixel size ($\sim 6\text{mm} \times 6\text{mm}$ pixel size): $\sim 5.5$ mrad
- Optical aberrations: 0 mrad (at ring center) to 9 mrad (in outer wings of Cherenkov ring)

Total $\theta_c$ resolution: $\sim 9.6$ mrad
Optical aberration in FDIRC prototype


- Vary the beam position (z is a distance from the bar end):

Overlay of two plots on top of each other (z_s=0 & z_q=-2000cm):

Cherenkov ring resolution is worse for photons in the wing

Overlay of two plots on top of each other (z_s=0 & z_q=-100cm):

- The optical aberration (kaleidoscopic pattern) is due to bar/mirror acting on pieces of ring, as determined by Mathematica-based ray tracing.
- Non-focusing (no mirror) DIRC has a similar aberration due to a bar alone.

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New FDIRC for SuperB

**Design aim:**
1. ~10x better timing resolution than BaBar DIRC.
2. ~25x smaller volume than BaBar DIRC.
3. Highly pixilated detector (16-32k pixels/system).
4. Avoid water as optical coupling medium.
5. FDIRC measures photons in 3D (x, y and time), which allows the chromatic error correction.
6. \( \theta_c \) resolution, based on pixels alone, is about the same as in the BaBar DIRC.
7. Time, however, plays a role to determine \( \theta_c \) even in FDIRC, and will be included in the final PID likelihood hypothesis.
8. Electronics design should be conservative using TDC/ADC concept.

**Important condition:**
Use the existing BaBar bar boxes without significant changes.
FDIRC for SuperB: optics design

J. Va’vra, SLAC-PUB-13763, 2009

- Optics of the detector camera was designed by ray tracing. Then various things were checked by a Mathematica ray tracing program. Finally a full check by a MC simulation.
- We have to live with the existing bar box, which includes the old wedge, which has two complications: (a) it has a 6 mrad inclined angle at the bottom, intended to do a simple focusing, and (b) it is not long enough to bring all rays onto the cylindrical mirror, thus not all rays would be focused. Therefore, we have added a New Wedge outside the box.
- Cylindrical mirror radius is 120 cm.
- Double-folded mirror optics allows a good access to photon detectors.
- Will measure the timing resolution for a single photon to 150-200ps.
- Focusing in y only \(\Rightarrow\) would like to use small pixels in y, and large pixels in x-direction.

5/4/2010 J. Va’vra, RICH 2010, Cassis, France
Ray tracing & MC simulation

J. Va’vra, Simulation with Mathematica, SLAC-PUB-13464 & SLAC-PUB-13763,

Ray tracing: Geant 4 model:

Old wedge New wedge FBLOCK
FDIRC photon detectors

Typical pixilation of H-9500 and H-8500 (multi-anode PMT)

- **H-8500**: (a) Preferred by medical community, (b) much smaller price than H-9500, (c) smaller TTS spread ($\sigma \sim 140\text{ps}$), (d) available with “enhanced” QE ($\sim 24\%$), (e) Hamamatsu “strongly” recommends this tube to keep a reasonable delivery schedule of large quantities

- **H-9500**: Better Cherenkov angle resolution
Single electron timing response
J. Va’vra et al., SLAC-PUB-12236, 2007

- H-8500 has a better TTS resolution than H-9500.
- Both are good enough to do the chromatic corrections.
Hamamatsu H-8500 & H9500 Flat panel MaPMTs

Hamamatsu data

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Photocathode: Bi-alkali QE at 420nm</strong></td>
<td>20 % (-&gt; 24%) *</td>
</tr>
<tr>
<td>Geometrical collection efficiency CE of the 1-st dynode</td>
<td>75% (-&gt; 80%) *</td>
</tr>
<tr>
<td>Geometrical packing efficiency (dead space around boundary)</td>
<td>89%</td>
</tr>
<tr>
<td>PDE = Total fraction of “in time” photoelectrons detected</td>
<td>~ 13% (-&gt; 16-17%) *</td>
</tr>
<tr>
<td>Photocathode uniformity</td>
<td>1:1.5 to 1:2.5</td>
</tr>
<tr>
<td>Number of dynodes</td>
<td>12</td>
</tr>
<tr>
<td>Total average gain @ -1kV</td>
<td>~10⁶</td>
</tr>
<tr>
<td>Fraction of photoelectrons arriving “in time”</td>
<td>~95%</td>
</tr>
<tr>
<td>σ&lt;sub&gt;TTS&lt;/sub&gt; - single electron transit time spread</td>
<td>~ 140-150 ps</td>
</tr>
<tr>
<td>Matrix of pixels (H8500 &amp; H9500)</td>
<td>8 x 8 &amp; 16 x 16</td>
</tr>
<tr>
<td>Number of pixels (H8500 &amp; H9500)</td>
<td>64 &amp; 256</td>
</tr>
<tr>
<td>Pixel size (H8500 &amp; H9500)</td>
<td>5.8 x 5.8 &amp; 2.9 x 2.9 [mm²]</td>
</tr>
</tbody>
</table>

* - now available with a Super QE (24%) and better collection efficiency (80%)

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Detector matrix on the camera

J. Va’vra, SuperB workshop, Annecy, 2010

Detector precision is determined by a holding screw (H-8500):

- Number of H-8500 detectors: 48 = 8 x 6 per camera.
- Total number of detectors: 576 = 48 x 12 per entire system.
- Total number of pixels (H-8500): 18,432 = 12 x 48 x 32 per entire system.
H-8500 sensitivity to magnetic field

- **DIRC PMT tube** was much more sensitive to magnetic field (~1 Gauss is a very visible effect).
- **H-8500**: edge pixels are more sensitive than center pixels:
  - up to ~20% amplitude loss at ~20 Gauss; up to ~60% amplitude loss at ~50 Gauss
- **We will need a magnetic shield, but it may not need to be as massive as in BaBar**

5/4/2010

J. Va'vra, RICH 2010, Cassis, France
Present FDIRC predicted performance
Doug Roberts, SuperB workshop, Annecy, 2010

Table 1: FDIRC performance simulation by Geant 4 MC.

<table>
<thead>
<tr>
<th>Design</th>
<th>Option</th>
<th>$\theta_c$ resolution [mrad]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>FDIRC with 3 mm x 12 mm pixels with a micro-wedge</td>
<td>8.1</td>
</tr>
<tr>
<td>2</td>
<td>FDIRC with 3 mm x 12 mm pixels &amp; no micro-wedge</td>
<td>8.8</td>
</tr>
<tr>
<td>3</td>
<td>FDIRC with 6 mm x 12 mm pixels with a micro-wedge</td>
<td>9.0</td>
</tr>
<tr>
<td>4</td>
<td>FDIRC with 6 mm x 12 mm pixels &amp; no micro-wedge</td>
<td>9.6</td>
</tr>
</tbody>
</table>

• The most conservative decision, which is a design #4, would give the same performance as the BaBar DIRC (~9.6 mrad for di-muons).
• However, one should point out that FDIRC will correct out the chromatic error by timing, which would reduce the error by 0.5-1 mrad.
FDIRC in FullSim
Doug Roberts, SuperB workshop, Annecy, 2010

MC model:

Ring image at 4 GeV/c with 3mm x 3mm pixels:

- Rings are not circles!
We are handling the problem presently as follows (J.V.):

a) MC-based assignments of $k_x$, $k_y$, $k_z$,
    $\text{TOP}_{\text{direct}}$ & $\text{TOP}_{\text{indirect}}$ for each pixel, and
    for tracks with $\theta_{\text{dip}} = 90^\circ$ and $z = z_{\text{middle}}$.

b) $\cos \theta_c = \frac{k_{\text{track}} \cdot k_{\text{pixel}}}{|k_{\text{track}}| |k_{\text{pixel}}|}$ for any track direction
    (this procedure is used presently in the FDIRC prototype running in the
    CRT test, and works OK)

A full FDIRC model implemented in MC. A full analysis is yet to be worked out.

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FDIRC MC simulation: chromatic corrections
D. Roberts, SuperB workshop, Annecy, 2010

Solution with the micro-wedge in:

3mm x 12mm pixels (H-9500):

6mm x 12mm pixels (H-8500):

- According to this simulation, we could gain ~0.4-0.8 mrad in $\theta_c$ resolution if we do the chromatic correction by timing.
- Results consistent with the FDIRC prototype beam test and MC results.
Expected number of photoelectrons

• Based on this, expect $N_{pe} \sim 20$ pe/ring at $\theta_{dip} = 90^\circ$ and in the middle of the z-acceptance.
• This is for H-8500 MaPMT “enhanced” QE (24% peak), and proper packing efficiency and geometrical collection efficiency.
FDIRC mechanical design
Massimo Benettoni, mechanical engineer from Padova U., Italy

• 1 camera per bar box
• 12 cameras to read the entire FDIRC
• ~25x smaller total camera volume than what we had in BaBar DIRC
**FDIRC TDC/ADC electronics**

Christophe Beigbeder, electrical engineer from Orsay lab, France

**Overall concept:**

- FDIRC electronics is split in two parts:
  - one directly mounted on the PMT receiving signals and processing it with TDC/ADC
  - the other one concentrates and pack all the channels to send data to the DAQ

- Goals:
  - Max rate capability: ~2.5 MHz/pixel.
  - Double hit resolving time: ~50 ns.
  - \( \sigma_{\text{Electronics}} \approx 100 \text{ ps} \), which allows to obtain \( \sigma_{\text{Final}} \approx 170-200 \text{ ps (H-8500).} \)
Conclusion

- **SuperB barrel FDIRC** has been designed with a camera made of solid Fused Silica. We are eagerly waiting for the SuperB approval to be able to proceed with the prototype.

- The detector will have ~10x **better timing resolution** and ~25x **smaller volume** compared to BaBar DIRC. This will be our main defense against the background at ~100x higher luminosities compared to BaBar (having quartz material, instead of water, also helps against the neutron background).

- **We generate the ring using the pixels only.** However, with a single photon resolution of ~170-200ps, FDIRC will correct the chromatic error over most of the bar length.

- **Time** plays a role to determine $\theta_c$ even in FDIRC, and will be included in the final PID likelihood hypothesis.