Light Yield & Uniformity Measurements of different Scintillator Tiles and Studies of 4th Generation Hamamatsu MPPCs

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Outline

- Introduction
- Measurement setup
- Test of hexagonal and square tiles with different readout sites
- Gain and dark current measurements of new S14160 MPPCs
- Read out of ATLAS tiles with MPPCs
- Conclusions and outlook
The SiD ECAL uses hexagonal silicon pixels motivated by higher pixel yields from a wafer.

A hexagon is a better approximation to a circle than a square,
- As for squares larger arrays can be constructed with hexagons without gaps
- But at the module edges, we have to deal with half hexagons

For EM showers, we expect a better performance for hexagonal cells than for square cells since the first ring around a center tile consists of 6 not 8 tiles and the second ring consists of 12 rather than 16 tiles
- Better S/N since the energy of less cells is summed

We started to test the performance of hexagonal tiles with 3 different readout schemes wrt to that of square tiles

We started to test the 4th generation MPPCs from Hamamatsu, which should have lower noise and afterpulsing

We started to check upon the performance of ATLAS TileCal tiles with SiPM readout interesting for future hadron collider hadron calorimeters

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Measurement Setup

- Work in black box
- Use MIP of electrons from $^{90}\text{Sr}$ source
- MPPC is loosely coupled to tile
- Trigger on second tile
- Record 50k waveforms
Signal Recording

- Take 50k waveforms in a run

Trigger signal
Tile signal

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Tile Layouts

- Our machine shop produced 9 hexagonal-shaped tiles (a=1.86 cm) and 9 square-shape tiles (3 cm × 3 cm), which have the same area, thickness 3 mm.

- Scintillator material is from St Gobain (Bicron) BC404.

- We use 3 different readout schemes
  - Via Y11 fiber inserted into a groove located in the middle of the tile
  - Via a dimple in the center
  - Via coupling to a corner/side

<table>
<thead>
<tr>
<th></th>
<th>BC-400</th>
<th>BC-404</th>
<th>BC-408</th>
<th>BC-412</th>
<th>BC-416</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light Output, % Anthracene</td>
<td>0.05</td>
<td>0.08</td>
<td>0.04</td>
<td>0.00</td>
<td>0.08</td>
</tr>
<tr>
<td>Rise Time, ns</td>
<td>0.9</td>
<td>0.7</td>
<td>0.9</td>
<td>1.0</td>
<td>0.4</td>
</tr>
<tr>
<td>Decay Time, ns</td>
<td>2.4</td>
<td>1.8</td>
<td>2.1</td>
<td>3.3</td>
<td>4.0</td>
</tr>
<tr>
<td>Pulse Width, FWHM, ns</td>
<td>2.7</td>
<td>2.2</td>
<td>3.5</td>
<td>4.2</td>
<td>5.3</td>
</tr>
<tr>
<td>Light Attenuation Length, cm³</td>
<td>160</td>
<td>140</td>
<td>210</td>
<td>210</td>
<td>210</td>
</tr>
<tr>
<td>Wavelength of Max. Emission, nm</td>
<td>423</td>
<td>408</td>
<td>425</td>
<td>434</td>
<td>434</td>
</tr>
<tr>
<td>No. of H Atoms per cm³, ( \times 10^{22} )</td>
<td>5.23</td>
<td>5.21</td>
<td>5.23</td>
<td>5.23</td>
<td>5.25</td>
</tr>
<tr>
<td>No. of C Atoms per cm³, ( \times 10^{22} )</td>
<td>4.74</td>
<td>4.74</td>
<td>4.74</td>
<td>4.74</td>
<td>4.73</td>
</tr>
<tr>
<td>Ratio H:C Atoms</td>
<td>1.103</td>
<td>1.1</td>
<td>1.104</td>
<td>1.104</td>
<td>1.11</td>
</tr>
<tr>
<td>No. of Electrons per cm³, ( \times 10^{23} )</td>
<td>3.37</td>
<td>3.37</td>
<td>3.37</td>
<td>3.37</td>
<td>3.37</td>
</tr>
</tbody>
</table>

Principal uses/applications
- General purpose
- Fast counting
- TOF counters, large area
- Large area
- Large area, economy

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Tiles on top and bottom are wrapped with 2 layers of Tyvec paper

Use 2 layers of Teflon tape on sides

Readout hole in Tyvec is 1 mm

Green fiber is Y11 from Kuraray

For readout we use the Hamamatsu MPPC S13360-3025 as well as 4th generation MPPCs: S14160-1315, S14160-1310, S14160-3015 and S14160-3010
Comparison of the 3 Readout Schemes

- Hexagonal tiles read out with 3x3mm² MPPC
- For side and center readout, use 1 mm hole, fiber is at a corner also 1 mm
- Measure center position of tile
  - For readout with fiber
  - For readout on the tile center
  - For readout on the tile side
- Measure high light yields

SiPM’s mounted on the side

(\text{pe})_{\text{most probable}} = 9.6

SiPM’s mounted in the center

(\text{pe})_{\text{most probable}} = 7.1

SiPM read out with fiber

(\text{pe})_{\text{most probable}} = 16.0

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Rewrap tile due to rather non-uniform behavior

Center point is used for normalization

Except for light yield at fiber end all other point have a mean light yield of \((101.7 \pm 1.0)\%\) wrt center LY

Uniformity within \(\sim \pm 10\%\) except for value value at the fiber end (~20% higher)
Center point sees ~1.2 times more light wrt average

Excluding light yield at tile center, tile center, all other mean light yield is (86.2 ±2.4)% wrt center LY

Uniformity within ±6% except for value at the center

Need to enlarge dimple!
Mean value of fitted Gaussian for each position is divided by the light yield measured at center position.

- Note the increase in the number of PE's in the right most bin near MPPC.

Excluding point near MPPC, average relative light yield is (94.6±1.5)%

- Uniformity within ~±7% except for value at the readout side.

- Position at readout position is enhanced by 1.48 wrt average value.

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Uniformity of Square Tile with Fiber Readout

- Mean value of fitted Gaussian for each position is divided by the light yield measured at the center position.
- Most probable light yield at the center position $(pe)_{\text{most probable}} = 19.4 \text{ pe}$.
- Average relative light yield is $(78.2 \pm 1.2)\%$ determined from upper and lower row.
- Uniformity is within $\pm 7\%$.
- Right-hand side of middle row is $\sim 15-20\%$ higher.
Uniformity of Square Tile with MPPC on Side

- Mean value of fitted Gaussian for each position is divided by the light yield measured at the center position.
- Most probable light yield at the center position \((pe)_{\text{most probable}} = 7.91\) pe.
- Average relative light yield is \((86.7 \pm 3.2)\%\).
- Tile is uniform within ±13% (cause is probably non-homogeneous wrapping).
We received 8 MPPCs from Hamamatsu (2 of each type).

<table>
<thead>
<tr>
<th>MPPC</th>
<th>S14160-1310</th>
<th>S14160-3010</th>
<th>S14160-1315</th>
<th>S14160-3015</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sens. area</td>
<td>1.3 x 1.3 mm²</td>
<td>3 x 3 mm²</td>
<td>1.3 x 1.3 mm²</td>
<td>3 x 3 mm²</td>
</tr>
<tr>
<td>Pixel size</td>
<td>10 µm</td>
<td>10 µm</td>
<td>15 µm</td>
<td>15 µm</td>
</tr>
<tr>
<td># pixels</td>
<td>16675</td>
<td>90000</td>
<td>7296</td>
<td>40000</td>
</tr>
<tr>
<td>$V_b$</td>
<td>~43.4</td>
<td>43.1</td>
<td>41.6</td>
<td>42.5</td>
</tr>
<tr>
<td>Dark rate</td>
<td>120 kHz</td>
<td>700 kHz</td>
<td>120 kHz</td>
<td>700 kHz</td>
</tr>
<tr>
<td>gain</td>
<td>$1.8 \times 10^5$</td>
<td>$1.8 \times 10^5$</td>
<td>$3.6 \times 10^5$</td>
<td>$3.6 \times 10^5$</td>
</tr>
<tr>
<td>C at $V_{op}$</td>
<td>100 pF</td>
<td>530 pF</td>
<td>100 pF</td>
<td>530 pF</td>
</tr>
</tbody>
</table>

- Photodetection efficiency is highest for green light from Y11 fiber.
- BC404 has maximum wavelength at 408 nm.
- Photon detection efficiency of 10 µm pixel is about half of that of the 15 µm pixel sensors.

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Experience with S14160 MPPCs

- Waveform of S14160-1315 sensor at $V_b = 43.33$ V and $T = 25^\circ$C
- Clearly see individual photoelectrons
- Solder joints are rather touchy in 3 S14160-13 sensors, solder pads detached from sensor
- Our electronics engineer could fix two S14160-1310 sensors
- Waveform looks similar as that of the unbroken sensor s14160-1315

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Gain versus Reverse Bias Voltage

- Use $^{90}$Sr source on hexagonal tile read out with fiber and an S14160 sensor
- Determine peak of photoelectron distribution
- Determine gain from the distance between two adjacent photoelectron peaks
- Gain can be fitted with linear dependence, slope = $0.002/V$
- Deviations from line may come from small temperature fluctuations

Slope corresponds to $0.002/V$
- At nominal $V_b = 43.4$ V: $G = 1.8 \times 10^5$
- Breakdown voltage $V_{break} = 38.5$ V
Four all 4 S14160 sensors the gain depends linearly on $V_b$ on 40-50 V range

- S14160-1310: slope = 0.00106/V, $V_b = 38.5$ V
- S14160-3010: slope = 0.0005/V, $V_b = 38.5$ V
- S14160-1315: slope = 0.002/V, $V_b = 38.5$ V
- S14160-3015: slope = 0.0011/V, $V_b = 37.5$ V
Determine dark current from minimum of the waveform without source.

Dark current increases rapidly with increased reversed bias voltage.

Fit is second-order polynomial.

We measured dark currents of the other S14160 sensors, but analysis is not yet finished.
The ATLAS Tile Calorimeter is a sandwich of scintillating tiles read out by wavelength-shifting fibers and PMTs and steel absorber plates.

ATLAS use 3 tile sizes:
- Small: 12x26 cm²
- Medium: 14.5x30 cm²
- Big: 18.5x35 cm²

Tiles are slightly tapered.

A Y11 fiber is coupled by air gap to the tile.

A bundle of fibers is read out by PMT.

Some tiles have a hole to shoot $^{137}$Cs source through.
ATLAS Tile Uniformity Measurements

- Place tile a table that has arrangement of holes in a grid allows source to be held in a number of different locations on the tile.

- At each location extract photoelectron (PE) spectra by taking minimum of each of 50,000 triggered waveforms and plotting spectra that are fitted to a Landau distribution after subtracting the position of the pedestal.
Uniformity of ATLAS Small Tiles

- Plot the most probable value of the fitted Landau distribution normalized to the value at the center position.

- Note that the most probable value increases closer to where the fiber is located (i.e. see more PE peaks on average).

- MIP peak is around 3-4 photoelectrons.

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Uniformity of ATLAS Small Tiles

- Plot the most probable value of the fitted Landau distribution normalized to the value at the center position.

- Note that the most probable value increases closer to where the fiber is located (i.e. see more PE peaks on average).

- MIP peak is around 3-4 photoelectrons.

- Note that the hole in the tile has a large affect on the light collection.
Uniformity of ATLAS Medium & Large Tiles

- Except for positions with a hole, light yield is rather uniform for all tiles (~±15%).
- We measured uniformity of three tiles of each size, and the uniformity of other tiles agrees with the results shown.
- Light yield of all tiles is large enough to read out the TileCal with MPPCs.
Conclusions and Outlook

- Performance of hexagonal tiles looks promising
  - Readout with fiber gives highest light yield, uniformity within 10% except near sensor
  - Tiles with center/side readout need larger dimple, uniformity within 6-7% except near sensor

- Performance of square tiles with fiber (side) readout looks fine
  - Uniformity is within ±7% (±13%) except for position close to MPPC
  - Need sufficiently large dimple for center and side readout

- First test of 4th generation MPPCs, 14160 series
  - Gain of S14160 sensors is linear with $V_b$ between 40 and 50 V
  - Dark current increases rapidly with $V_b$
  - Both fixed S14160-1310 MPPCs work fine

- Different-size ATLAS tiles with present fiber couplings can be read out with MPPCs
  - MIP peak produces enough photoelectrons

- Do more performance studies of hexagonal/square tiles (wrapping, RO location)

- Do further studies with new MPPCs (afterpulsing, linearity, noise, T dependence)

- Plan to read out fiber bundle of ATLAS tiles with MPCC arrays

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Backup Slides
Determine dark current from integral of waveform without the source (I-V curves) and plot rms.

Fit is second-order polynomial.