Tests of SiPM's/MPPC's

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(Representing many...)

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Overview

Bench test results, SiPM Generic R&D

(beam test results covered by Paul Rubinov, Calorimetry and Muon Detection: Session 1 on Monday)

- Hamamatsu off-the-shelf S10362-11 series
  Operational experience & checking vendor specs
  Fermilab, Wayne State, Notre Dame, Indiana

- FACTOR Project: SiPM development
  Collaboration with ITC-IRST (Trento, Italy)
  INFN Sections of Trieste, Udine, Messina
  also work at Fermilab SiDET
  Proposal submitted to INFN - Group V in Sept. 2006; foreseen duration: 3 yrs (07 –09)

In ~context of muon detector/tail catcher: WLS + MINOS
4.1 cm x 1 cm scint.

Optically read-out radiation detectors in HEP
(e.g., calorimeters, muon counters) and space experiments
(e.g., time-of-flight)
## Hamamatsu Device

- **Off-the-shelf: S10362-11 series**

<table>
<thead>
<tr>
<th>Active Area</th>
<th>1 mm x 1 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number Pixels</td>
<td>1600</td>
</tr>
<tr>
<td></td>
<td>400</td>
</tr>
<tr>
<td></td>
<td>100</td>
</tr>
<tr>
<td>Pixel Size</td>
<td>25 μm x 25 μm</td>
</tr>
<tr>
<td></td>
<td>50 μm x 50 μm</td>
</tr>
<tr>
<td></td>
<td>100 μm x 100 μm</td>
</tr>
<tr>
<td>Fill Factor</td>
<td>31%</td>
</tr>
<tr>
<td></td>
<td>62%</td>
</tr>
<tr>
<td></td>
<td>78%</td>
</tr>
</tbody>
</table>

- Calorimetry
- MIP Detection
Testing MPPC's with Scintillator Strips

Fermilab: Paul Rubinov, Adam Para, Gene Fisk
Notre Dame: Barry Baumbaugh, Mike McKenna, Mitch Wayne

- Two scintillator strips with 1.2-mm WLS fiber
- Single paddle with PMT placed above; trigger = paddle + one strip

- No momentum filter
- Wide-angle acceptance
- Not 100% efficient
Testing MPPC's with Scintillator Strips

At Notre Dame  Clear individual photo peaks, self-calibrating

Two strips w/ WLS fiber, HPK MPPC, plastic holder assembly + front-end card & connectors

28 May 2008
Hamamatsu MPPC
100 pixels 100µ X 100µ

5mv/pe at nominal bias voltage for a 100 pixel device

HV=70.0, LED on, 66ns gate

ADC counts
Testing MPPC's with Scintillator Strips

- Hamamatsu 100-pixel MPPC, no temp control, $V_{bias} = 69.8$ V
- Shaping high-gain amps with $t_{shape} \sim 15$ ns (FWHM for pulses $\sim 35$ ns)
- Read-out peak voltage

Self-trigger, calibrate mV/pe:

Gain = 8.8 mV/pe
Testing MPPC's with Scintillator Strips

- Cosmic ray signal

Gain = 8.8 mV/pe
Light yield (most prob.) = 15.9 pe
Efficiency above 4.5 pe = 95%

- ~same light yield other channel, 3 x more gain
Pulsed LED Calibration of Hamamatsu MPPC's

Wayne State: S. Gollapini, K. Gunthoti, P. Karchin, A. Gutierrez

- Measure gain as a function of bias voltage
- Compare methods: resolved photopeaks vs. Poisson analysis

**Method**

- Use fast (13.6 ns) light pulses form LED
- Record pulse charge distribution from 10x LeCroy amp and LeCroy QVT, using 75 ns wide gate

Example pulse charge spectrum, 100 μm device
Manufacturer's gain: 100 μm device

2.36 \times 10^6 \text{ @ 70.27 V}

\begin{align*}
G & = \frac{(0.025 \text{ pC/channel}) \times (\text{no. channels between peaks})}{1.6 \times 10^{-19} \text{ C}}.
\end{align*}

RB = 69.7V 50 μm device

Manufacturer's gain: 7.5 \times 10^5 \text{ @ 69.65 V}

Poisson analysis

\langle G \rangle = \frac{\sigma^2}{\langle Q \rangle e}

\langle N_{pc} \rangle = \frac{\langle Q \rangle}{\langle G \rangle e} \sim 24
Conclusions

- gain measured with resolved photopeaks agrees with manufacturer’s measurement
- Poisson-measured gain somewhat larger than resolved photopeak-measured gain – may be due to electronics noise broadening of pulse charge distributions
- Only 100 micron devices can resolve photopeaks with the conventional electronics used
- Bias voltages in a large system must be (individually?) controlled to accuracy ~0.1 v or better!
Temperature Behavior of Hamamatsu MPPC's

Indiana: Greg Pauley, Paul Smith, RvK

- Signal from pulsed green LED
- Canberra Model 241 amplifier, Ortec MCA with 50 ns gate
- Temp. studies: device mounted on Peltier module with heat sink, temp. readout at device

![Ham100U Photospectrum w/ Temperature](image)

- 100 μm, 100 pixels
- 50 μm, 400 pixels: similar behavior
- 25 μm, 1600 pixels: no photopeaks
Temperature Behavior of Hamamatsu MPPC's

- Average gain of three 100 μm, 100 pixel devices @ 20 deg. C is found to be $2.52 \times 10^6$

- Variation of various properties with temperature:

- Cooling not necessary for dark rate; but stable temp. needed (and bias voltage stability to ~0.05 – 0.10 V)
Hamamatsu MPPC's: Different Amplifiers

Notre Dame: B. Baumbaugh, M. McKenna, M. Wayne, R. Ruchti

<table>
<thead>
<tr>
<th>Noise level</th>
<th>LeCroy Discriminator and counter</th>
<th>Hamamatsu Board with integrated amplifier and discriminator</th>
</tr>
</thead>
<tbody>
<tr>
<td>One and above</td>
<td>800 KHz</td>
<td>760 KHz</td>
</tr>
<tr>
<td>Two and above</td>
<td>75 KHz</td>
<td>75 KHz</td>
</tr>
<tr>
<td>Three and above</td>
<td>8.5 KHz</td>
<td>8.5 KHz</td>
</tr>
<tr>
<td>Four and above</td>
<td>1000 Hertz</td>
<td>900 Hertz</td>
</tr>
</tbody>
</table>
FACTOR Project: SiPM Development

U. Udine & INFN Trieste: D. Cauz, A. Driutti, G. Pauletta

SiPM Development

- Comparative device characterization (ISRT, Hamamatsu, Formitech)
- Development (in collaboration with IRST)
- Optimization of packaging & (fast!) preamplification
- Irradiation studies
  - so far on 24 SiPM's: FBK-irst, Hamamatsu Photonique, Formitech
  - X-rays @ INFN Legnaro Labs (50 – 500 krad)
  - neutrons @ IJS reactor, Ljubljana (~4.8 x 10^{10} n/cm^2)

Application Studies

- Large area muon counters (FNAL)
- Calorimetry with optical readout (FNAL/CERN/Frascati)
- Scintillator-based fine-grained hodoscopes (CERN)
Examples of temperature sensitivity of dynamic characteristics

\[ y = 0.0719x + 27.472 \]

**IRST_D1, VBD vs T**

**IRST_D1, VBD vs T**
Examples of dark count studies

**IRST_D1, Dark count**

- **Overvoltage, V**: 0 to 6
- **Dark count, MHz**: 0 to 10

**Temp – sensitivity**
Measured in “climatic” chamber (temp. & hum control)

**IRST_D1, Dark count (room T)**

- **Overvoltage, V**: 0 to 6
- **Dark count, MHz**: 0 to 6

**Dark count reduction**
(dark count rate vs overvoltage for different 1mm² IRST prototypes)

G.Pauletta LCWS08
Bench Tests of Custom IRST SiPM for Muon Application

U. Udine & INFN Trieste @ FNAL: D. Cauz, A. Driutti, G. Pauletta

Current Inventory:
100 SiPMs have been developed by IRST to specs. They were and packaged (T018) with photocathode protected by epoxy(glob-top)

Tests
Of 21 devices tested at SiDet (Aug 2008), 20 show:
• Low operating voltage (~30V)
• Relatively large operating range (5V)
• very uniform characteristics

p.e./mip
Using cosmics and ad hoc coupling: ~20 p.e./mip from T956 scint. Bar read out by wls fiber.
**Bench Tests of Custom IRST SiPM for Muon Application**

**p.e./mip**
Preliminary measurement (using cosmics) to determine the number of photoelectrons per mip in T956 scintillator bars.

With the improved fill–factor of these SiPMs (44%) we obtain ~20 p.e./mip despite less than optimal SiPM to wls fiber coupling.

Coupling is being optimized
Bench Tests of Custom IRST SiPM for Muon Application

- Breakdown voltage $\sim 30.5 \pm 0.2$ V
- Operating range $\sim 30.5 - 34.5$ V
- Current at 4 V over breakdown voltage ranges from 2 to 5 $\mu$A

$I$-$V$ Curves at Room Temperature
Dark count vs. discr. thresh. was also measured as a function of temp. and of voltage above operating threshold.

Each of the above curves represents the dark count rate as a function of the counting discriminator threshold. Different curves correspond to different bias voltages.
Summary

- Hamamatsu off-the-shelf S10362-11 series
  
  Bench test results consistent with vendors specs.
  
  In situ gain calibration from p.e. peaks possible but requires well regulated PS and temp stability
  
  Temperature variation of dark counts, gain, pulse height threshold
  
  Tested with variety of amplifier, pulse-shaping/speed important

  100 μm, 100 pixels appears adequate for scint./WLS + MIPs

  Cooling not necessary, but bias voltage and temp. stability and control important (or monitoring + correction)

- FACTOR Project: SiPM development

  Already showing promising developmental devices, similar bench tests
  
  Lower bias voltages, higher p.e. signal

  Lots more to come!