First evaluation of the prototype 19-modules camera for the Large Size Telescope of the CTA

Tsutomu Nagayoshi for the CTA-Japan Consortium
Saitama Univ, Max-Planck-Institute for Physics
Cherenkov Telescope Array (CTA)

- Extend the accessible energy coverage from 20 GeV to 300 TeV
- Improve flux sensitivity up to factor of 10
- Survey capability through a wider field of view
- Two sites (North: La Palma (Spain), South: Paranal (Chile))

<table>
<thead>
<tr>
<th>Telescope Type</th>
<th>North La Palma</th>
<th>South Paranal</th>
<th>FOV [deg]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large Size Telescope (LST)</td>
<td>4</td>
<td>4</td>
<td>4.5</td>
</tr>
<tr>
<td>Medium Size Telescope (MST)</td>
<td>15</td>
<td>25</td>
<td>~ 8.0</td>
</tr>
<tr>
<td>Small Size Telescope (SST)</td>
<td>-</td>
<td>70</td>
<td>9 - 10</td>
</tr>
</tbody>
</table>
Large Sized Telescope (LST)

- Improving CTA sensitivity in 20 - 200 GeV

- The main requirements for LST
  - Low energy threshold : 20 GeV
  - Fast repositioning speed : < 20 sec/180 deg

- Large discovery potential
  - pulsars, distant AGNs, GRBs

- LST-1 construction is ongoing (North)

CTA Observatory
LST camera

- 1855 PMT pixels and 0.1 deg/pixel (50 mm)
- The minimum camera unit is the so-called “PMT module”

LST camera
FoV: 4.5 deg
1855 pixels
256 PMT modules
Power consumption: 7 kW

PMT module
Seven PMTs
Power consumption: 3 W/ch
PMT module

- Seven PMTs
  - Photon/Electron conversion
- Seven Light guides
  - Reducing dead space
- Readout board
  - A/D conversion
- Slow control board
  - Controlling and monitoring PMTs
- Backplane board
  - Ethernet and power connector
The issues of low energy observations

- Dim Cherenkov emission
  - High QE PMTs

- ~ 300 MHz Night Sky Background (NSB)
  - GHz sampling speed

- Trigger threshold
  - Low afterpulsing probability PMTs

LST requires
- high QE and low afterpulsing PMTs
- GHz sampling readout boards

Cherenkov pulse
~ a few ns

NSB

Threshold [p.e.]

Trigger rate [Hz]

Afterpulsing

cosmic ray (index~1.7)

Afterpulse: dummy pulse generated in PMT
PMT unit

- The PMTs for the first LST have been developed by HAMAMATSU Photonics
- Superbialkali surface ~ 40 % QE
- Quality control was done at ICRR (Japan)
  - nominal voltage distribution (gain : $4 \cdot 10^4$) is narrower than 20 %
  - average pulse width : 2.7 ns
  - average afterpulsing probability : 0.003 %
  - 1988 PMTs work well and meet the requirements (total 2015 PMTs)
LST adopted the analog memory ASIC “DRS4”
- Sampling signal with GHz speed and digitising with MHz speed
  - GHz sampling speed
  - low power consumption
Integration test using Mini Camera

- The Mini Camera system consists of 19 PMT modules (1/14 scale copy of the final LST camera)

- Aims of Mini Camera test:
  - Test mechanics
  - Construct camera control system
    - Module control
    - Trigger propagation system
  - Evaluate total noise level
Mini Camera setup

- First mini camera setup was constructed at ICRR (Japan)
- 1.5 m x 2.0 m x 1.5 m dark box
- A spherical mirror and a diffuser are used to make the light intensity homogeneous (±15%)
- Data is sent via Ethernet
- A module control program was developed
Monitoring display
Single phe response of PMT modules

- Measured with low light intensity
- Single phe peak clearly visible
  - Single phe: \(68.78 \pm 0.03\) [ADC counts]
  - Noise level (total): \(15.15 \pm 0.16\) [ADC counts]
- \(S/N = 4.59 \pm 0.05\)

- Averaged 133 PMT’s
- Nominal high voltage (PMT gain \(4 \cdot 10^4\))
- Charge integration over 5 slices (~5 ns)
All camera elements were shipped to Tenerife, located next to La Palma.

The PMT module assembly and the final integration test using the Mini Camera system are ongoing at Tenerife.

Camera installation will be performed on September 2017.

First Light of LST-1 on November 2017!
Summary

- LST will archive 20 GeV energy threshold and improve the sensitivity of CTA between 20 and 200 GeV

- LST camera has been designed for the lowest energies:
  - PMTs have high QE and low afterpulsing probability
  - Readout board has a low power consumption and GHz sampling speed

- The QCs of each part of the PMT module have been carried out

- We performed the integration test using the Mini Camera system
  - The module control program was developed
  - The trigger system was confirmed to work
  - S/N > 4

- Now we are focusing on the first light of LST-1 on Nov 2017!
Back up
Afterpulsing

- Generated by the positive ions which are generated by the ionisation of residual gas (ion feedback)
- The delay time is a few hundred ns to a few us
- Peak amplitude is 4 - 5 phe

[Diagram of Cherenkov Telescope Array with labels for photocathode, focusing electrode, dynode, anode, positive ion, residual gas, primary pulse, and afterpulses with 100 ns marker]
**Setup of PMT QC**

- **Automatic operation**
  - control light intensity
  - control HV
  - DAQ
  - Analysis
  - Access to MySQL

- **Measured items**
  - Operation HV
  - Pulse width
  - Afterpulsing probability

- **6 PMTs/50min**
- trigger rate: ~ 300Hz
- control light intensity
- reference PMT

MySQL data base

control apply voltage
The DRS4 readout system is based on an array of 1024 capacitors for each channel.

Sampling signal with GHz speed and digitising with MHz speed.

The memory depth is enhanced to 4096 capacitors by cascading four channels, and total memory depth archive ~ 4 us (1GHz sampling speed).
Baseline correction

- Each capacitor of each DRS4 channel has its own offset value
- The dependency of the baseline on the time lapse to the last reading of capacitor (capacitor needs time to release charge).
- After correction, the standard deviation is ~ 0.03 phe /slice

\[ 0.03 \text{ phe} / \text{slic} \]

\[ 0.20 \text{ phe} / \text{slic} \]

\[ [0](\delta T)^{[1]} \]
Communication with camera

- **Computer**
  - Module configuration
  - Command
  - PMT status
  - Data

- **Ethernet Switch**
  - X 19

- **Mini Camera**
  - Module x 19
Noise level of Mini Camera

- Nominal high voltage (PMT gain ~ 4e4)
- Charge integration over 5 slices (~5 ns)
Charge resolution

Fractional Charge resolution \( \alpha_q / Q \) (p.e)

- HighGain
- LowGain
- CTA Requirement
- CTA Goal
- Poissonian limit

Preliminary