The SST-1M telescope proposed for the Cherenkov Telescope Array and its calibration strategy

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cta cherenkov telescope array

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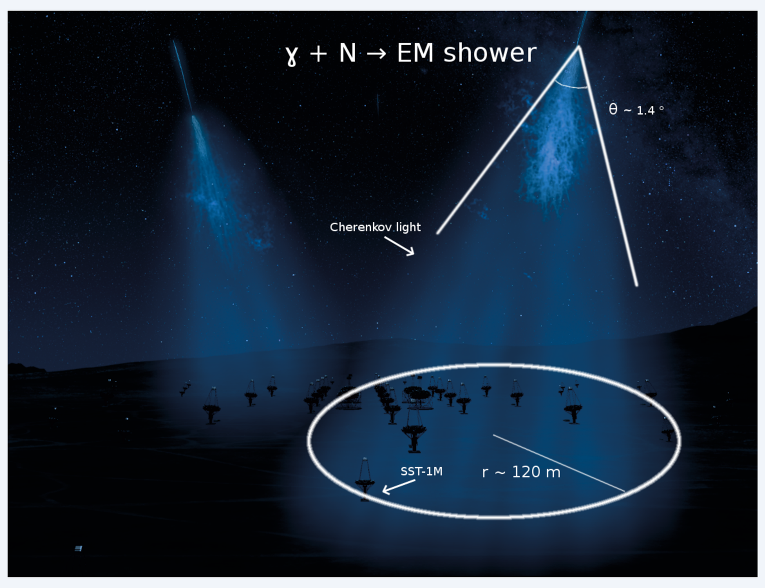
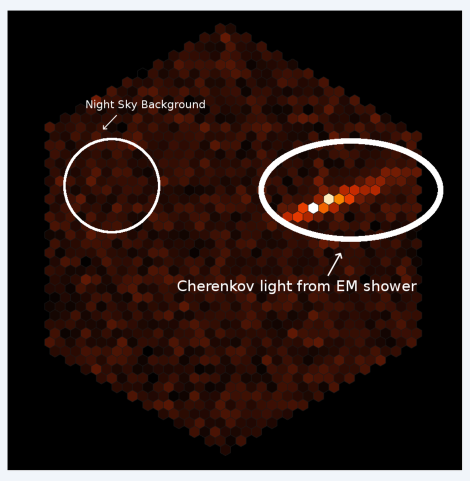
Introduction

There is a strong liaison between neutrino and gamma-ray astronomy, which have in common the sources, as well sources of cosmic rays in hadronic acceleration scenarios. Gamma-rays are detected with high statistics and can help identify the sources of which IceCube is seeing a diffuse flux.

CTA will comprise a sub-array of up to 70 small sized telescopes (SSTs) in the southern array. The SST-1M project, a 4 m-diameter Davies-Cotton telescope with 9 degrees FoV and a 1296 pixels SiPM camera, is designed to meet the requirements in the energy range above 3 TeV. This innovative camera is described as well as its calibration strategy.

Gamma ray detection with CTA



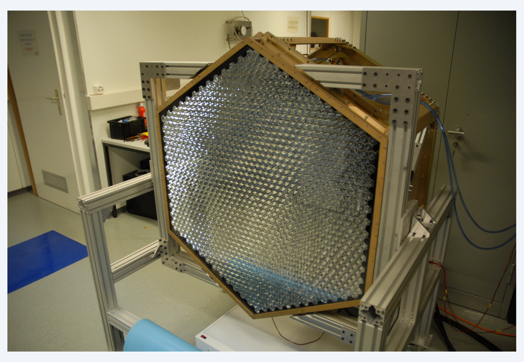


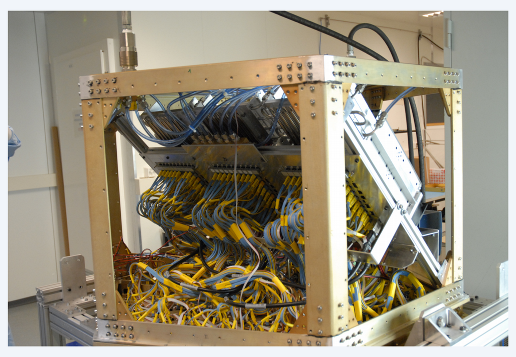
20 TeV simulated gamma ray event with CORSIKA [4] and CARE [5]. The Cherenkov light produced by secondaries is collected by the camera.

- CTA will comprise one array located in the northern hemisphere (La Palma) and one in the southern hemisphere (Chile).
- The arrays will be composed of small, medium and large sized telescopes, for a total of more than 100 telescopes. Each size is dedicated to an energy range.
- CTA will detect gamma rays from 20 GeV up to 300 TeV.
- 10 percent energy resolution and 1 arcmin angular resolution CTA will allow to resolve many cosmic ray sources and could look for spectral features such as dark matter annihilation.

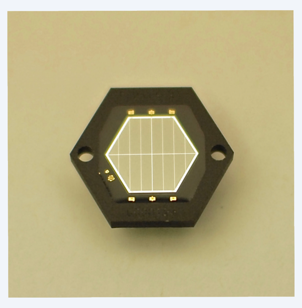
The SST-1M project

The SST-1M 4-m diameter Davies-Cotton with 9° FoV telescope prototype in Krakow

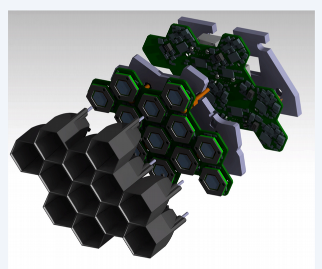




The SST-1M camera with its 1296 hexagonal pixels, front-end electronics and digital readout DigiCam fully assembled at the University of Geneva



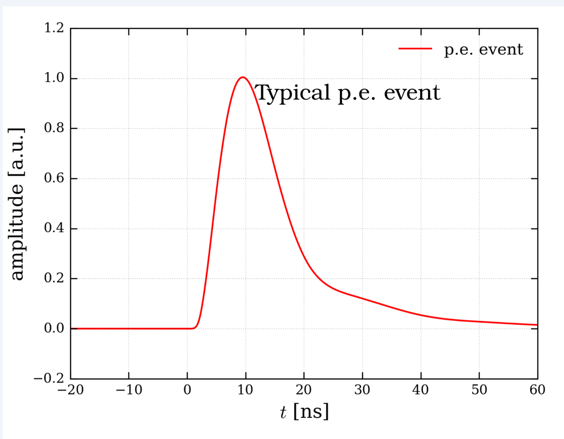
4 chanel hexagonal SiPM S10943-3739(X) from Hamamatsu



12 pixels module with : cones, sensors, per-amplifier board and slow control board

- The SST-1M project [1] is one of the proposed small sized telescope for CTA.
- SST-1M telescope follows a 4 m single mirror diameter Davies-Cotton design. Allowing a 9° field-of-view.
- Its photo-detection plane is composed of 1296 hexagonal SiPM sensors coupled with light funnel, the preamplifier board and the slow control board.
- Hexagonal SiPMs were developed in collaboration with Hamamatsu to reduce dead space.
- The slow control board allows to retrieve high-voltage and temperature for each sensors to adjust operational voltage via a compensation loop.
- The trigger and readout system is performed by DigiCam.

Event reconstruction chain



Crosstalk
NSB/Dark count
Amplification
Electronic Noise
Gain smearing
Digitization

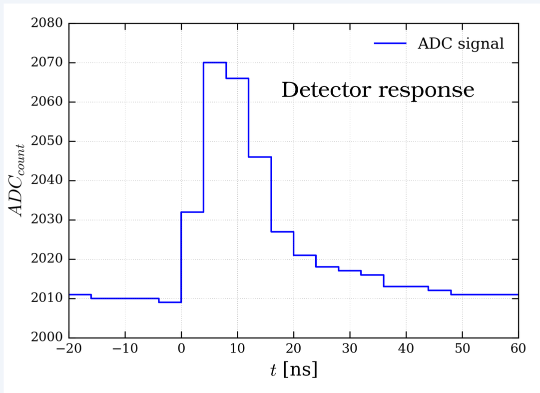


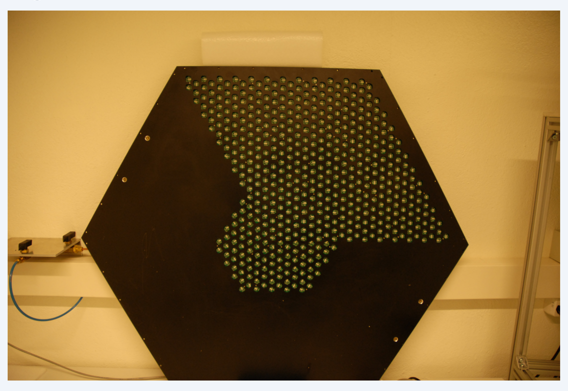
Photo-electron reconstruction

Full CTA array reconstruction. Gamma ray energy and direction determination

Camera Test Setup CTS

The first camera prototype of the SST-1M project [1] is undergoing calibration tests at the University of Geneva. Calibration is performed using a dedicated LED board mounted on front of the camera.

The camera test setup is composed of pulsed and continuous LEDs allowing to emulate signal and background events. It is used to study the charge resolution for various NSBs. An analysis python framework DigiCamCommissioning [6] relying on CTApipe [3] tools is developed for the calibration of SST-1M cameras and could be used for other CTA SiPM cameras. Gain, baseline, electronic noise, optical crosstalk and SiPM gain smearing are extracted using novels PDFs of SiPM response in good agreement with data.

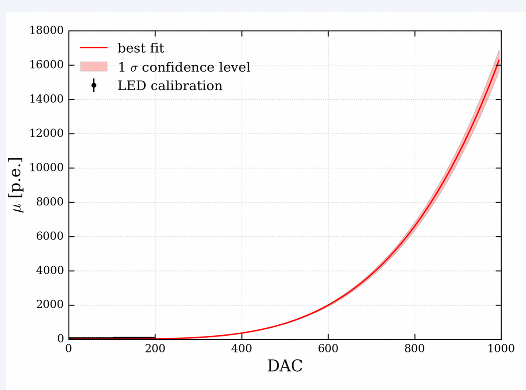


CTS LED board covers one third of the camera

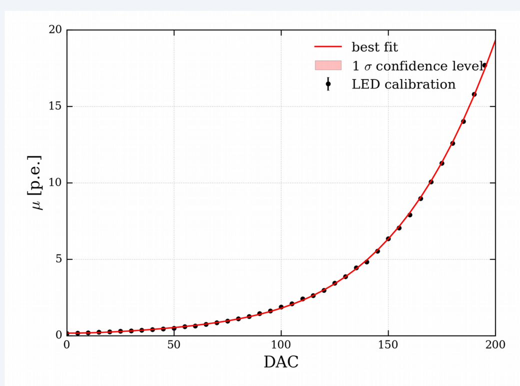
Parameters extraction

$$f(ADC) = A\sum_{n=0}^{\infty} P(n|\mu,\mu_{XT}) \left[\frac{1}{\sqrt{2\pi}\sigma_n} e^{-\left(\frac{x-B-n\cdot G}{\sqrt{2}\sigma_n}\right)^2}\right]$$

$$\sigma_n = \sqrt{\sigma_e^2 + n\sigma_1^2 + \frac{1}{12}}$$



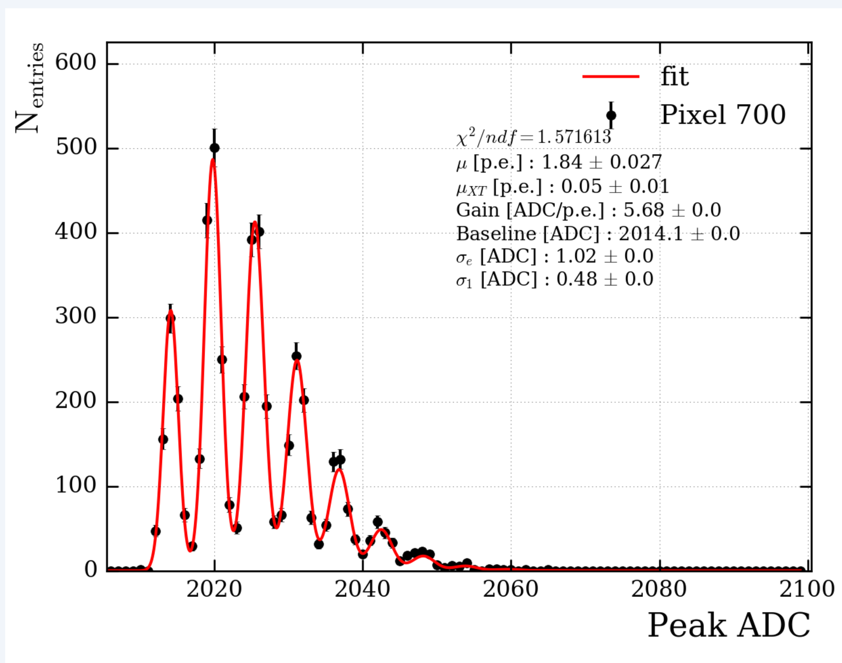
Extrapolated LED calibration curve up to 16000 p.e.



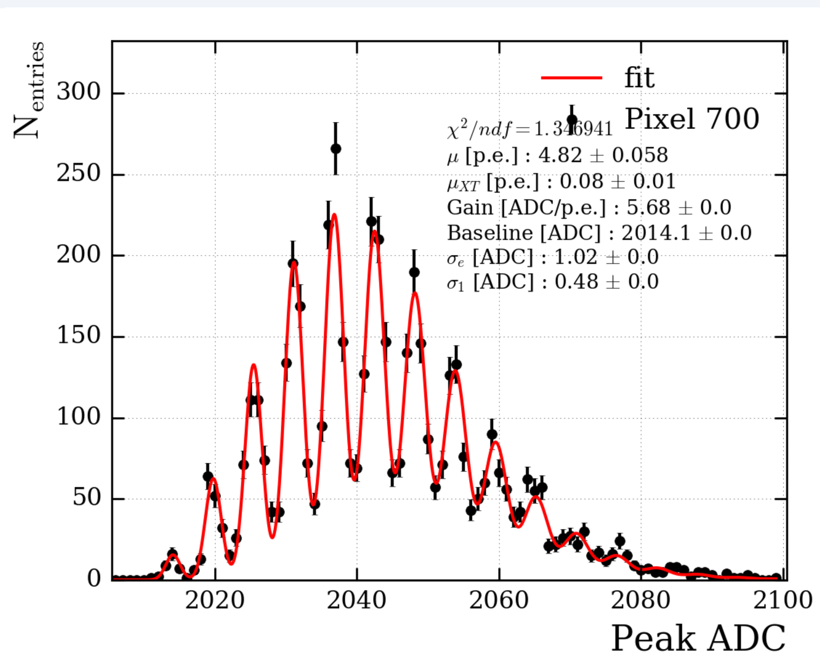
LED calibration curve for various DAC level

Optical crosstalk μ_{XT} measurements and LED board calibration

- Optical crosstalk occurs when a SiPM cell avalanche produces a photon that triggers a secondary cell.
- Crosstalk is described as a Poisson branching process with a Generalized Poisson distribution $P(n|\mu,\mu_{XT})$ [2].
- The mean number of p.e. μ allows to calibrate CTS LEDs.



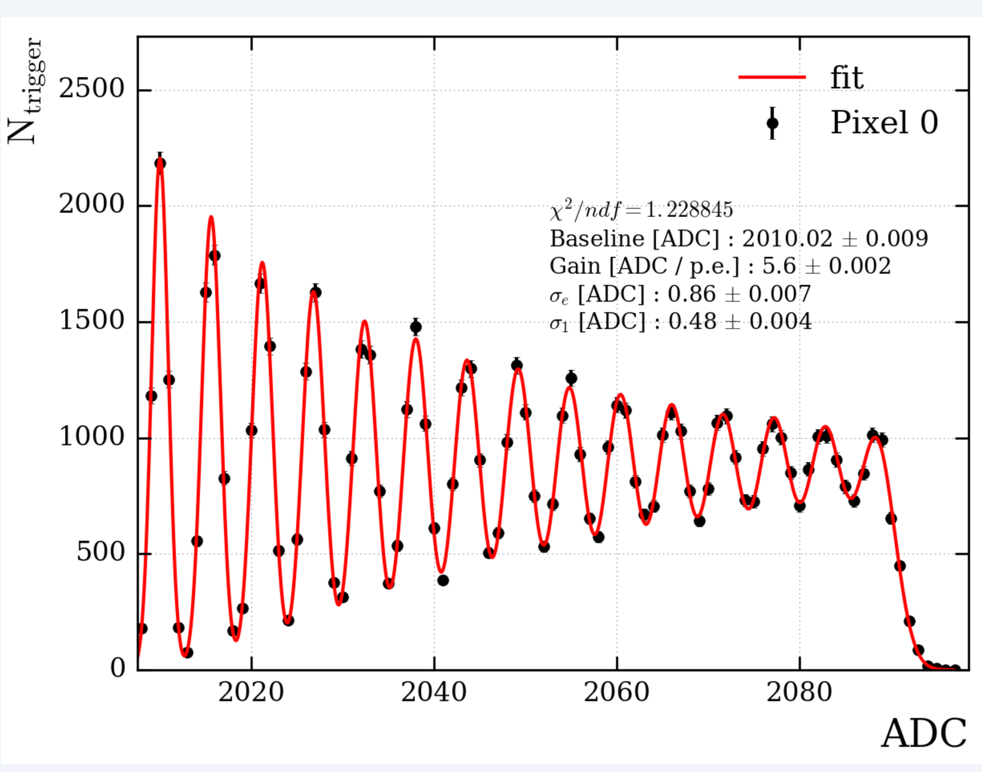
1.84 [p.e.] signal form the Camera Test Setup LEDs with determination of calibration parameters



4.82 [p.e.] signal form the Camera Test Setup LEDs with determination of calibration parameters

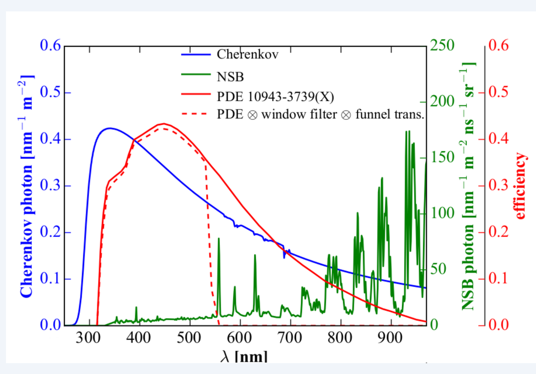
Gain G and SiPM gain smearing σ_1

- The distances between p.e. peaks gives the gain.
- The SiPM gain smearing represents the charge spread produced in an avalanche.
- Data from various light levels is accumulated to extract gain and SiPM gain smearing at high precision.

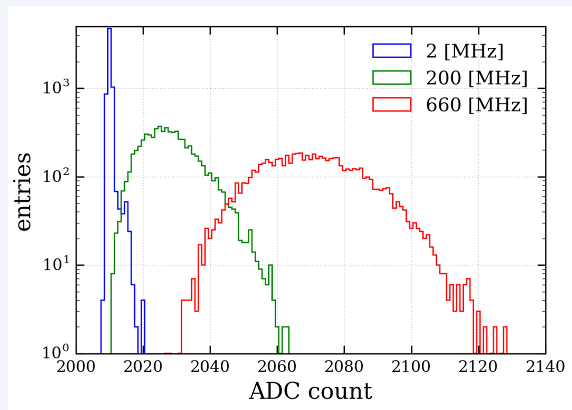


Dark count and NSB

- Dark count is a thermal noise measured in the absence of light (3 MHz).
- The Night Sky Background is the light pulses from the night sky (expected NSB rate for SST-1M [22, 660] MHz).
- Dark count and NSB induce random pulses of light in the readout window and a baseline shift due to the (DC coupled sensors).
- On going work on NSB and dark count integration to the event distribution.



Cherenkov light and NSB spectrum together with the photo-detection efficiency of the sensors. In order to maximize signal-to-noise ratio an entrance window is used



References

[1] M. Heller et al., An innovative silicon photomultiplier digitizing camera for gamma-ray astronomy, July 2016.
[2] S. Vinogradov, Analytical models of probability distribution and excess noise factor of Solid State Photomultiplier signals with crosstalk, March 2012
[3] https://github.com/cta-observatory/ctapipe
[4] D. Heck et al., CORSIKA : A Monte-Carlo code to simulate extensive air showers, 1998
[5] http://www.gtlib.gatech.edu/pub/IACT/GrOptics.git/
[6] https://github.com/cta-observatory/DigiCamCommissioning