R & D Studies for Very High Energy Gamma-Ray Astrophysics at Energies Greater than 10 TeV

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Abstract

In spite of more than 100 discoveries of TeV gamma-ray sources by the current imaging atmospheric Cherenkov telescope (IACT) arrays, Galactic cosmic ray accelerators up to the "knee" energies ($\sim$ PeV) still remain unclear. PeV Explorer (or PeX) is a future project of a relatively small IACT array, optimized to detect gamma rays of energies greater than 10 TeV and aiming to explore Galactic accelerators up to PeV energies. We present the status of our hardware R & D studies for this project and some extension plans.

1. PeV Explorer (PeX)

The "TenTen" concept has been proposed to explore the origin of Galactic cosmic rays up to the *knee* as well as various astrophysical phenomena in the > 10 TeV energy gamma-ray regime [1]. It is a future project for an array of 30–50 imaging atmospheric Cherenkov telescopes (IACTs) of a relatively small aperture (3–5 m diameter) and aims to achieve a 10 km^2 effective area for gamma rays with energies greater than 10 TeV. "PeV Explorer" or "PeX" is one cell of TenTen consisting of 4 or 5 IACTs as shown in Figure 1

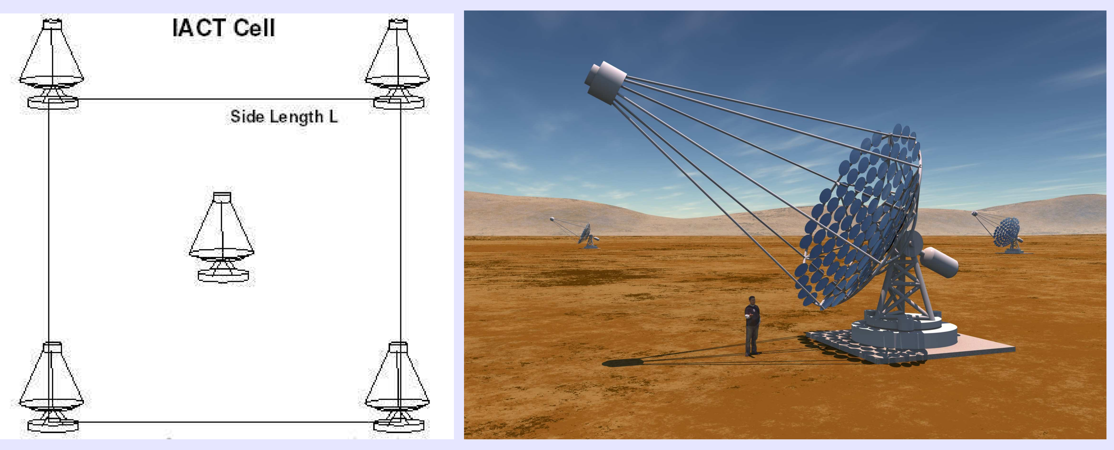

Figure 1: *Left: schematic view of PeV Explorer (PeX) as one IACT cell of TenTen. Right: an artist's impression of TenTen IACTs.*

2. Concept of a Sparse IACT Array

The concept of this IACT array is based on the simulation study by Plyasheshnikov et al. (2000) [2], which showed that the effective area of the array can cost-effectively be expanded by placing telescopes with larger spacing ($\gtrsim 300$ m) and equipping imaging cameras of a larger field of view (FoV) such as $\sim 8°$. This relation is schematically shown in Figure 2. The optimum array configuration must be determined using simulations so that the effective area per cost is maximized as a function of telescope spacing, aperture, and FoV. Sea-level sites are ideal for TenTen given the high energy focus. The SST (Small Size Telescope) array of CTA [3] is also a similar concept, and may realize the goal of a > 10 TeV array.

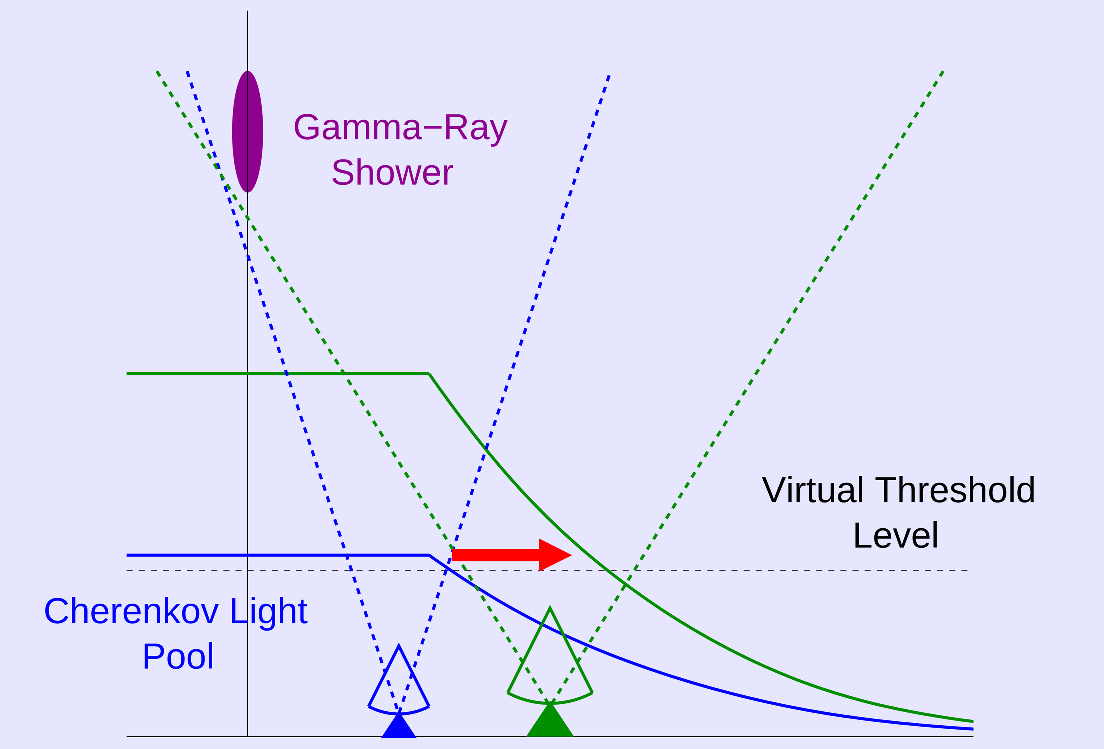

Figure 2: *Schematic view showing a new concept of a sparse IACT array. Cherenkov photons emitted from the gamma-ray shower (upper-left ellipse) make a light pool on the ground (blue solid line), which has a plateau area up to a radius of ~ 100 m surrounded by a wider skirt area. In the existing IACT arrays, telescopes have been placed within the plateau area and triggered when the number of Cherenkov photons collected by the telescope exceeds the virtual threshold level (black dashed line). The effective area can be expanded by detecting photons in the skirt area as shown by the red arrow, requiring a larger aperture (more photons are collected as shown by the green light pool) and a larger FoV (green dashed line).*

3. An Extension Plan

The optimum array telescope spacing of TenTen/PeX depends on the physics target of interest, which may demand a wide range of telescope spacings. We can avoid this risk in array optimization by constructing the array with movable telescopes like ALMA. An example demonstrating flexibility of this "Mobile Telescope Array" is shown in Figure 3. We can get a better sensitivity with a sparse IACT array especially at high energies (this is based on the TenTen concept). In contrast, a dense IACT array gives better angular and energy resolutions as well as a lower energy threshold.

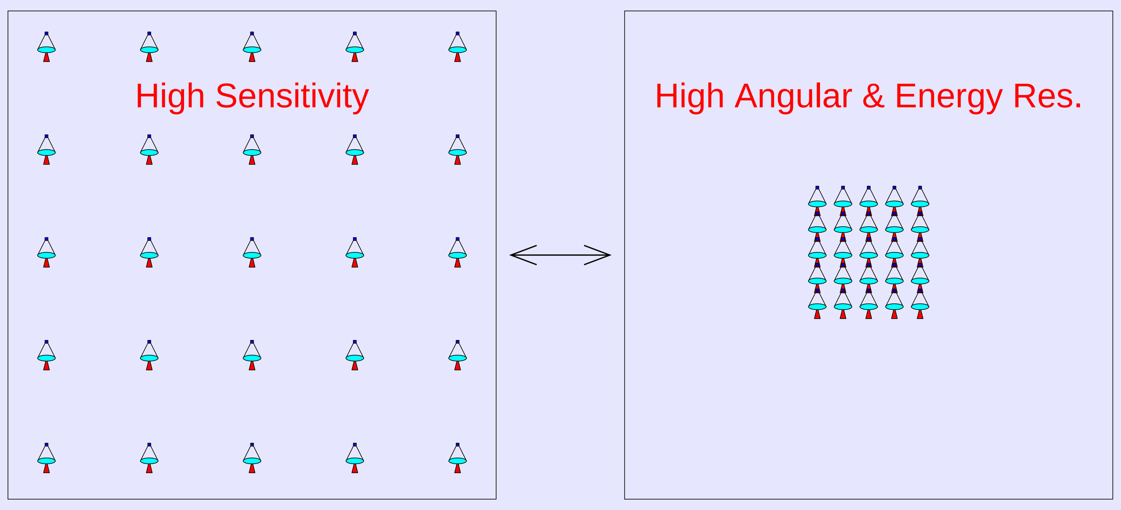

Figure 3: *Two major configurations of the "Mobile Telescope Array" considered as an extension plan of TenTen.*

4. Hardware R & D

4.1 Analog Memory Cell (AMC)

It is desirable to make movable telescopes run on their own local power supply, independent of cumbersome cables. We first started with developing a low power consumption electronics system with an ASIC implementing analog memory cell (AMC) circuits which sample voltages of a Cherenkov signal pulse with a speed of ~ 1 GHz. We plan to optimize the system performance in terms of power consumption and cost by developing our own ASIC. The circuit diagram has been developed on the basis of previous work on readout of hybrid avalanche photo detectors (HAPDs). Some prototype AMC chips have been made with the 0.25 μm process of United Microelectronics Corporation (UMC). We selected 75 fF and 400 fF capacitors in order to control various parameters within acceptable levels and to compare with the previous work. Performance of the prototype chips has been investigated with a test board shown in Figure 4.

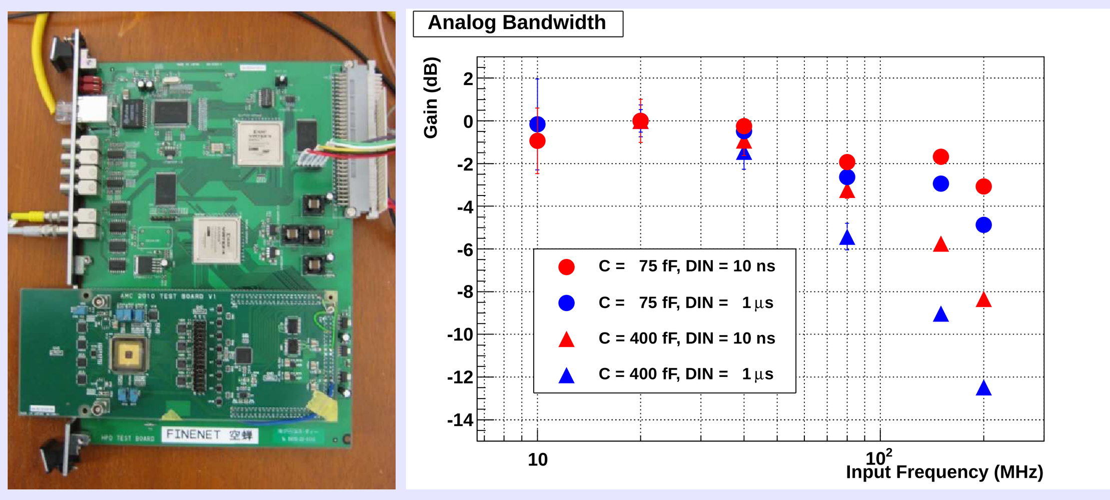

Figure 4: *Left: test setup of a prototype AMC board. The AMC board at the bottom is connected to the module for readout. The AMC ASIC chip is located in the left-hand side of the AMC board. Right: result of analog bandwidth measurements of the AMC board.*

4.2 Automatic Calibration System of Telescope Pointing

The pointing of each mobile telescope has to be calibrated every time after moving. This work can be a time-consuming burden if done manually, especially in an array of 30–50 telescopes. Therefore, some automatic calibration system must be prepared at least for rough measurements of axis directions. We have tested a GPS compass board with two GPS antennas (Figure 5), which can measure the direction of the line connecting the two antennas using the real time kinematic (RTK) technique. The azimuth and elevation directions are measured and read out from the compass board every 100 ms and their accuracy can be improved by averaging accumulated data. We confirmed that the accuracy better than 1 arcmin is achieved by accumulating data for 100 minutes in the case that the distance between the antennas is 4.5 m and this compass system can be used in rough measurements before fine tuning with a CCD camera.

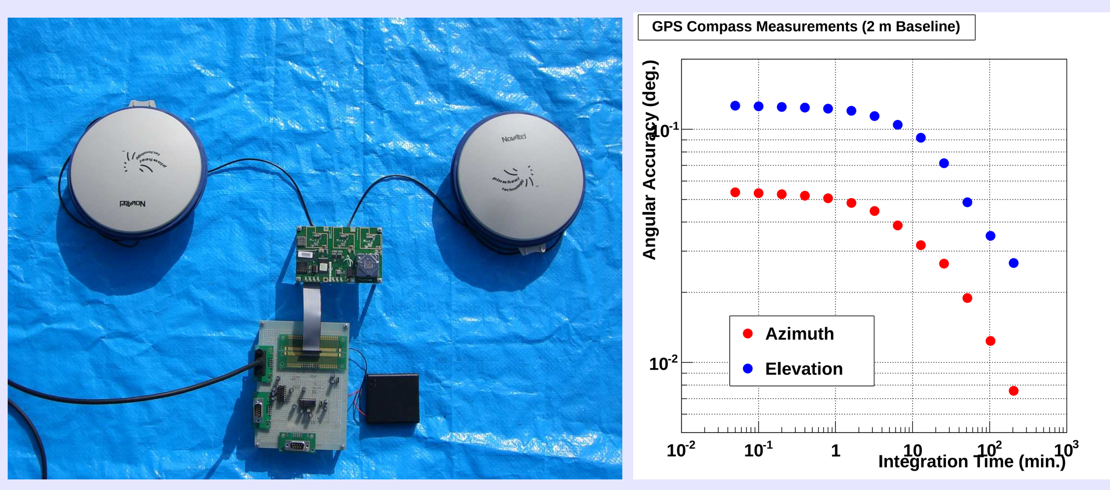

Figure 5: *Left: GPS compass board (Hemisphere Crescent Vector OEM) and GPS antennas (Novatel GPS-701-GG) used for test measurements. Right: accuracies of direction measurements as a function of the integration time.*

5. Future Plan

We have obtained a used Cherenkov telescope with a 3 m aperture, which was already repaired except the mirrors (we plan to recoat them within a couple of years), and installed at the Akeno Observatory of ICRR (Figure 6). This telescope can be utilized as a test bench for any future IACT array project including CTA. The electronics system under development will be installed in this telescope together with an imaging camera of ~ 32 photomultiplier tubes and a simple triggering system. We plan to do some test observations with this system, at least a part of which will be powered by the lithium-ion battery and demonstrated as the first battery-powered IACT system.

Figure 6: *3 m diameter Cherenkov telescope installed at the Akeno Observatory of ICRR.*

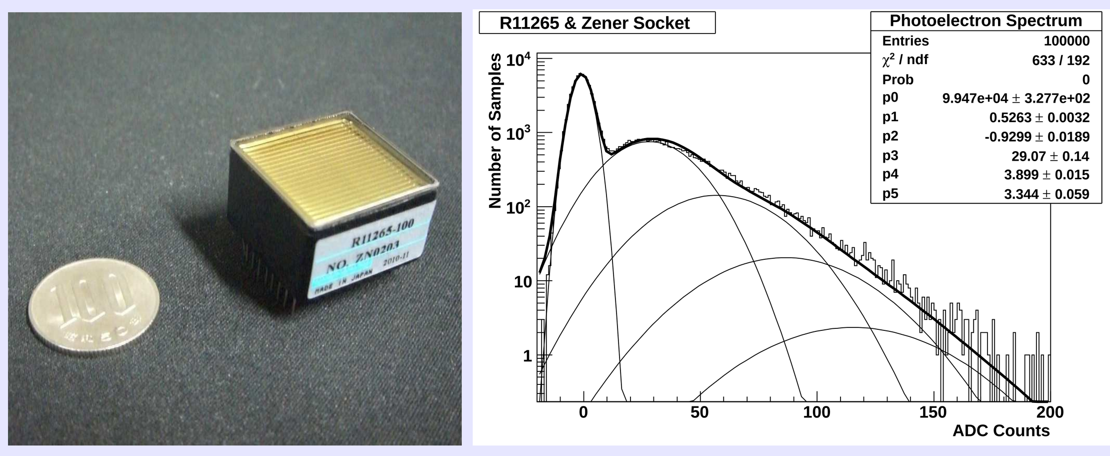

Figure 7: *Left: Hamamatsu R11265 PMT (1 inch square, super bialkali photocathode, 12 stage metal channel dynode) planned to be used for test observations. Right: photoelectron spectrum of a R11265 PMT measured with a Zener socket, illuminated by a blue LED. The fitted model is a convolution of Poisson and Gaussian distributions.*

6. Summary

We are developing instruments for the future projects of VHE gamma-ray astrophysics at energies $\gtrsim 10$ TeV. The prototypes of the AMC ASIC chips for a low power consumption electronics system and the GPS compass system automatically calibrating telescope pointing have been made and tested. These are necessary for the mobile telescopes but can also be utilized effectively in the smaller array of PeV Explorer.

Acknowledgments

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