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Updates of the surface detector array of the TAx4 experiment

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The TAx4 experiment plans to realize an Ultra High Energy Cosmic Rays (UHECR) detection area four times larger than that of the TA experiment. TAx4 will include five hundreds new surface detectors (SD) spaced at 2.08 km and two new fluorescence detectors (FD), which provides hybrid observation of UHECRs. We deployed 257 SDs in 2019 and completed building 2 FD stations in 2020, all operating stably. The data acquisition of the SDs is made via six communication towers, and inter-tower triggers have been recently implemented.

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1. Introduction

The Telescope Array (TA) experiment [1] has been observing ultrahigh-energy cosmic rays (UHECRs) using a surface detector (SD) array [2] and fluorescence detector (FD) stations [3–5] since 2008 in Utah, USA. The TA experiment is the largest UHECR observatory in the northern hemisphere. The TA experiment extended additional SDs and FDs to lower and higher energies. The extension to lower and higher energies were named the TA Low Energy extension (TALE) and TAx4 experiment, respectively. Those detectors enable us to observe approximately five orders of magnitude of energies greater than $10^{15.3}$ eV.

Some evidence of anisotropies in the arrival directions [6, 7] and energy spectra [8–11] were reported by the TA experiment at the highest energies. The TAx4 experiment plans to accelerate the pace of collecting UHECRs at the highest energies by extending SDs and FDs so that we provide events to confirm the evidence.

The spacing of the extended additional SDs is 2.08 km. We call the additional SDs TAx4 SDs here. The spacing is larger than the TA SDs for realizing a larger detection area at the highest energies. Fig. 1 shows the sites of the TA detectors. Two layers of a 1.2 cm thick plastic scintillator cover three m^2 area inside a stainless-steel box of the TAx4 SD. This design is the same as the TA SDs. The fields of view of the TAx4 FDs cover the sites of the TAx4 SDs for detecting the SD and FD hybrid events.

The combined coverage of the TA and TAx4 SDs is expected to be approximately 2800 km^2. The 507 TA SDs cover approximately 700 km^2 and additional 500 TAx4 SDs are planned to cover approximately 2100 km^2. The 257 TAx4 SDs were deployed in 2019 and are stably running. The north and south TAx4 FD stations have been running since 2018 and 2020.

2. Performance of the TAx4 SD array

We evaluated the performance of the TAx4 SD array using MC simulations before deploying the SDs [12]. The obtained angular resolution was 2.2 deg. and energy resolution was 25% above 57 EeV. A reasonable agreement between the data and simulations of geometrical parameters was obtained. The energy spectrum measured by the TAx4 SDs is consistent with the TA SDs [13].

3. Updates on the trigger system

The TAx4 SD array is divided into six sub-arrays, and a communication tower was constructed in each sub-array for the data acquisition. The data collected by each SD is transferred to each communication tower in each sub-array. The data acquisition (DAQ) of the TAx4 SDs was running independently before October 2022. Implementation of inter-tower triggers is needed to obtain UHECR events around the boundary between sub-arrays. We implemented an inter-tower trigger software to the DAQ program, which runs afterward. Fig. 2 shows the time sequence of the DAQ at the SD, a non-central tower, and a central tower. There are 3 Levels (Level-0, Level-1, and Level-2) of triggers in the DAQ of the TAx4 SDs. All the Level-1 trigger times are sent to the central tower, and the Level-2 trigger is judged at the central tower for inter-tower triggers.

The Level-1 trigger rate of each SD is approximately 20 Hz. The total data size of the Level-1 trigger times corresponds to approximately several tens of Kbytes per second. The wireless

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communication data rate is more than approximately 30 Mbps [14], which is well enough for the data transfer of all the Level-1 trigger times. Fig. 3 shows the Level-2 trigger rates before and after the implementation of inter-tower triggers. The Level-2 triggers are judged with the data from other communication towers for inter-tower triggers, so the trigger rate is twice larger than before. The increase in the trigger rate is consistent with the increase in the Level-1 trigger times.

4. Future prospects

Comparison between data and MC simulations after implementing the inter-tower triggers is ongoing. If reasonable agreement is obtained, several anisotropies reported in the arrival directions and energy spectra by the TA experiment will be tested with the boundary-triggered events in the future.

References

[1] H. Kawai et al., *Telescope Array Experiment*, *Nuclear Physics B: Proceedings Supplements* **175–176** (2008) 221.

[2] T. Abu-Zayyad et al., *The surface detector array of the Telescope Array experiment*, *Nuclear Instruments and Methods in Physics Research Section A* **689** (2012) 87.

[3] H. Tokuno et al., *On site calibration for new fluorescence detectors of the telescope array experiment*, *Nuclear Instruments and Methods in Physics Research Section A* **601** (2009) 364.

[4] H. Tokuno et al., *New air fluorescence detectors employed in the Telescope Array experiment*, *Nuclear Instruments and Methods in Physics Research Section A* **676** (2012) 54.

[5] R.U. Abbasi et al., *Measurement of the flux of ultrahigh energy cosmic rays from monocular observations by the high resolution fly's eye experiment*, *Phys. Rev. Lett.* **92** (2004) 151101.

[6] R.U. Abbasi et al., *Indications of Intermediate-scale Anisotropy of Cosmic Rays with Energy Greater Than 57 EeV in the Northern Sky Measured with the Surface Detector of the Telescope Array Experiment*, *ApJ.* **790** (2014) L21.

[7] R.U. Abbasi et al. (The Telescope Array Collaboration), *Indications of a Cosmic Ray Source in the Perseus-Pisces Supercluster*, 2110.14827.

[8] R.U. Abbasi et al., *Search for Anisotropy in the Ultra High Energy Cosmic Ray Spectrum using the Telescope Array Surface Detector*, 1707.04967.

[9] R.U. Abbasi et al., *Evidence for Declination Dependence of Ultrahigh Energy Cosmic Ray Spectrum in the Northern Hemisphere*, 1801.07820.

[10] R.U. Abbasi et al., *Evidence of Intermediate-scale Energy Spectrum Anisotropy of Cosmic Rays* $E \geq 10^{19.2}$ *eV with the Telescope Array Surface Detector*, *ApJ.* **862** (2018) 91.

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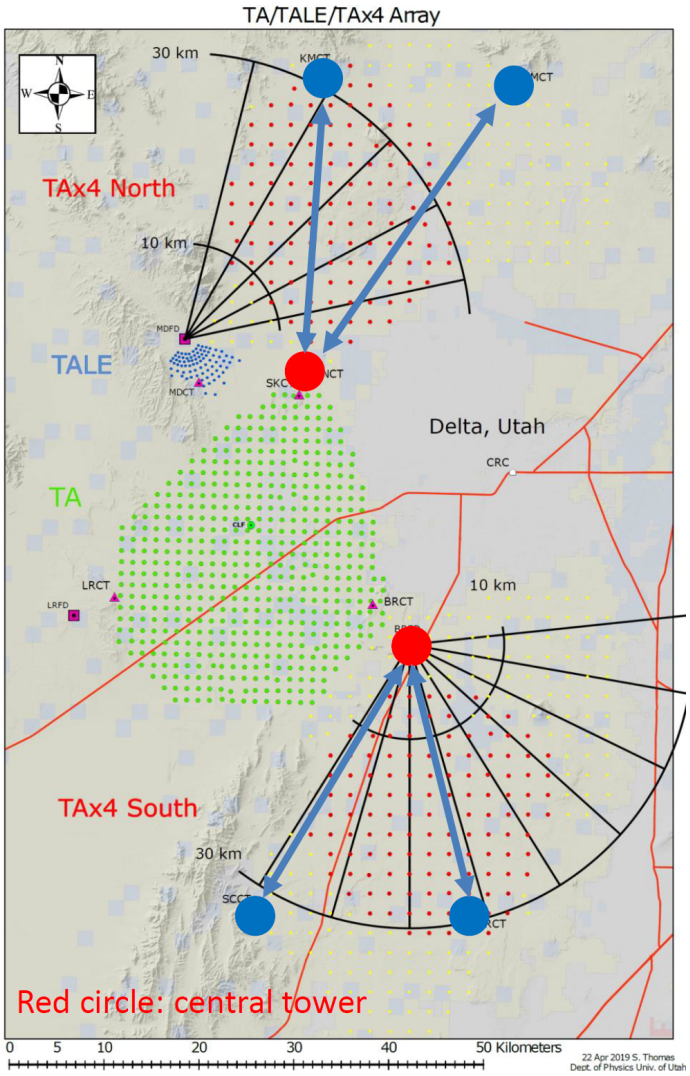

Figure 1: Schematic view of wireless communications for the inter-tower triggers. Large red circles: locations of the central towers. Large blue circles: locations of communication towers that are not central. Blue arrows: wireless communications that are used for the inter-tower triggers. Small red circles in the northeast and southeast: locations of deployed TAx4 SDs. Small yellow ciecles: locations for the future deployment of the TAx4 SDs Small green circles: locations of the TA SDs. Small blue circles: locations of the TALE SDs [15]. The two fan shapes drawn with black lines are the fields of view of the TAx4 FDs.

[11] R.U. Abbasi et al. (The Telescope Array Collaboration), *Evidence for a Supergalactic Structure of Magnetic Deflection Multiplets of Ultra-High Energy Cosmic Rays*, *ApJ.* **899** (2020) 86.

[12] T. Abu-Zayyad et al. (The Telescope Array Collaboration), *Surface detectors of the TAx4 experiment*, *Nuclear Instruments and Methods in Physics Research Section A* **1019** (2021) 165726.

[13] K. Fujisue for the Telescope Array collaboration, *Measurement of the ultra high cosmic ray*

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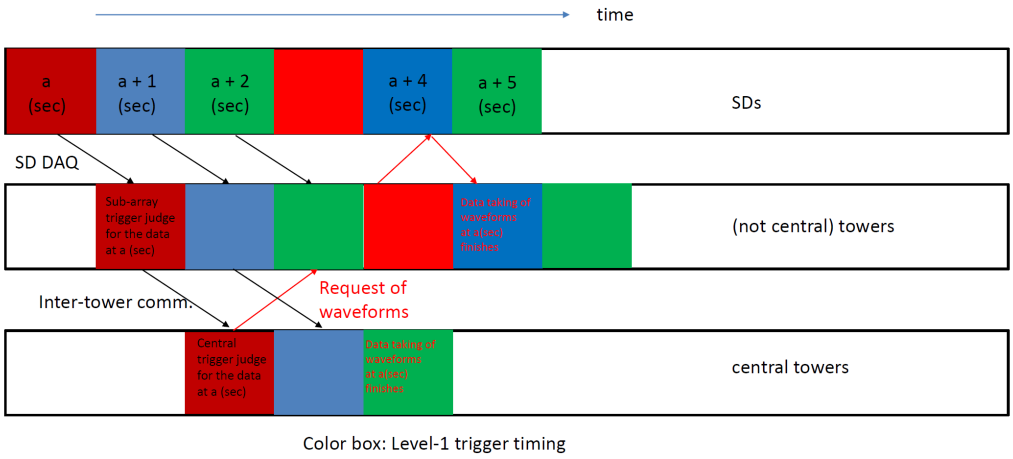

Figure 2: Time sequence of the data acquisition including inter-tower triggers. Boxes with different colors denote Level-1 trigger times collected at different seconds.

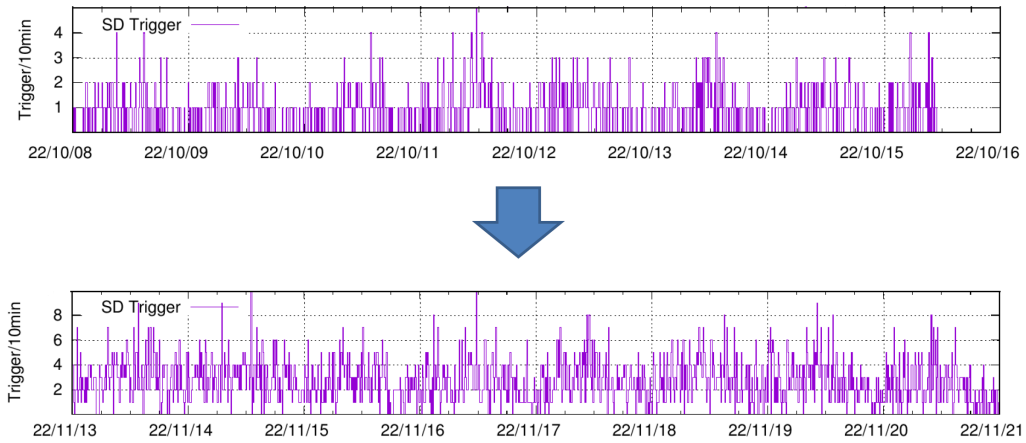

Figure 3: Updates of the Level-2 trigger rates at the north central tower before and after implementing inter-tower triggers.

energy spectrum with the TAx4 SD array, in *38th International Cosmic Ray Conference (ICRC 2023)*, 2023.

[14] T. Nonaka et al. on behalf of the Telescope Array Collaboration, *Long distance network link for TA×4 expansion*, in *36th International Cosmic Ray Conference (ICRC 2019)*, 2019.

[15] A. Iwasaki and S. Ogio on behalf of the Telescope Array Collaboration, *The status of the TALE surface detector array and TALE infill project*, in *37th International Cosmic Ray Conference (ICRC 2021)*, 2021.

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