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The status of the TALE surface detector array and a TALE infill project

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Routine hybrid observations of the surface detectors (SD) in conjunction with the fluorescence detectors (FD) of the Telescope Array Low-energy Extension (TALE) began in November 2018. In this presentation, we will describe the simulation studies of detector aperture and resolution of the TALE SD, and report on the latest observation results other than the energy spectrum. We are also in the process of expanding the experiment by 50 SDs, with even smaller nearest-neighbor spacing, in order lower the energy threshold to match that of the Cherenkov-dominated events seen by the FD. Details of the upgrade and expected performance of this new extension will be discussed.

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1. TALE hybrid observations

The TALE SD array consists of 80 detector units. The spacing of 40 SDs in the distance range of 3 km from the TALE FD station and the spacing of the other 40 SDs which are located in the range from 3 km to 5 km from the TALE-FD station is 600 m. In the connecting area between the TALE SD array and the TA SD array, 23 planned locations for additional SDs are prepared with 1.2 km spacing for further expansion in the future.

TALE SD holds the same basic design as TA SD based on its satisfactory performance in operation for more than 10 years. Each SD has a plastic scintillation counter of 3 m^2 in size, and transmits SD data via a wireless LAN module. Moreover each detector is powered by a solar panel and a battery. The output signals from PMTs are digitized by a 12 bit FADC with a 50 MHz sampling rate on the CPU board. Signal greater than approximately 0.3 MIPs are stored in a memory buffer on the CPU board as Level-0 trigger data. The stored waveform is 2.56μs. long (128 FADC bins). Signals greater than 3.0 MIPs are stored as a Level-1 trigger data, which are sent to a single-board computer, called "host PC", which controls trigger decision and data acquisition processes. The local trigger rates are about 750 Hz for Level-0 and about 20 Hz for Level-1. From the Level-1 trigger time tables of all the SDs, an air shower event trigger is generated when any five SDs are coincident with in $\pm 4\mu$s. We call this trigger the Level-2 trigger, and the current Level-2 triggering rate is 30 events/min. Routine operation started in September 2019.

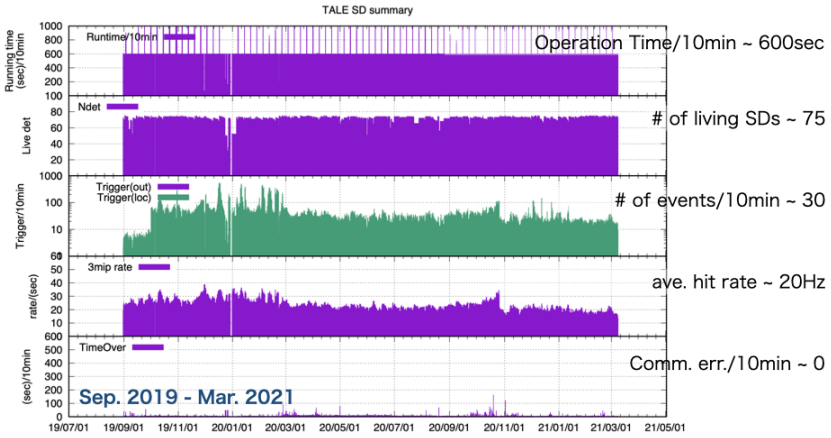

Figure 1: Operation status of the TALE SD array from September 2019.

TALE FD station located at TA Middle Drum (MD) site has ten FD telescopes, which observe $31 - 59^\circ$ in elevation, above the field of view of the original TA FD MD station. The TALE FD station was completed in the fall of 2013, and has been taking data in monocular mode since that time.

The hybrid trigger condition on the TALE FD DAQ system is very simple, which is the number of hit PMTs > 5 and the event duration > 500 ns. The hybrid triggering rate is about 0.05 Hz. With the Level-2 or the hybrid trigger trigger the host PC requests each SD to transfer waveform data within $\pm 32\mu$s from the trigger timing, and the host PC corrects waveform data.

The routine hybrid operation started in October 2018, and he number of hybrid events reached 70,000 at February 2020, as shown in Fig. 2 After a suspension due to the COVID-19 pandemic, hybrid operations resumed in December 2020.

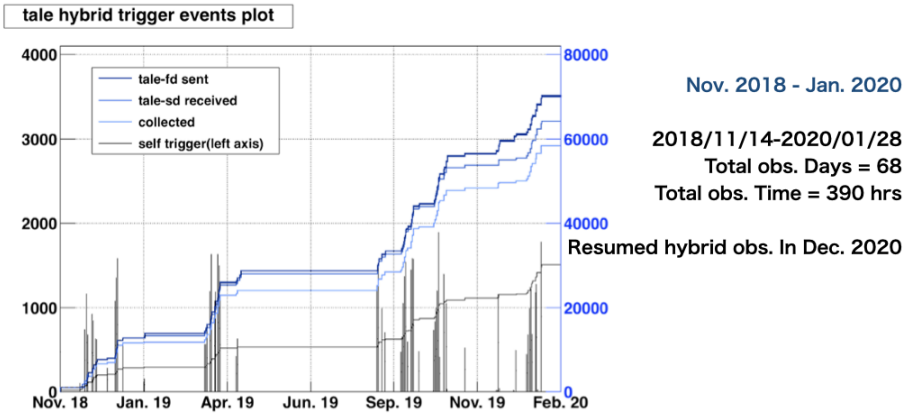

Figure 2: The cumulative number of events with the TALE hybrid trigger.

2. Extension of TALE hybrid

Additionally installing TALE infill surface detectors covering very wide energy range. The expected stereo coverage is from 10^{15} eV to 10^{18} eV, that is from "knee" to "ankle". We will additionally install 54 SDs with 100m and 200m spacing near the TALE FD station within 2km, covering 0.32 km^2. Fig 3 shows a layout of the TALE–infill SDs with TALE FD station and TALE SDs.

Fig. 4are expected triggering efficiency of the TALE-infill SD array and of the TALE-infill hybrid. Based on Monte Carlo studies, we expect 10 % efficiency at 10^{**} eV for the infill SD array and at at 10^{**} eV for the hybrid trigger operation. From these values, the expected mode energy of the infill SD array is $10^{15.3}$ eV, and for theTALE-infill hybrid it will be reached to $10^{15.8}$ eV.

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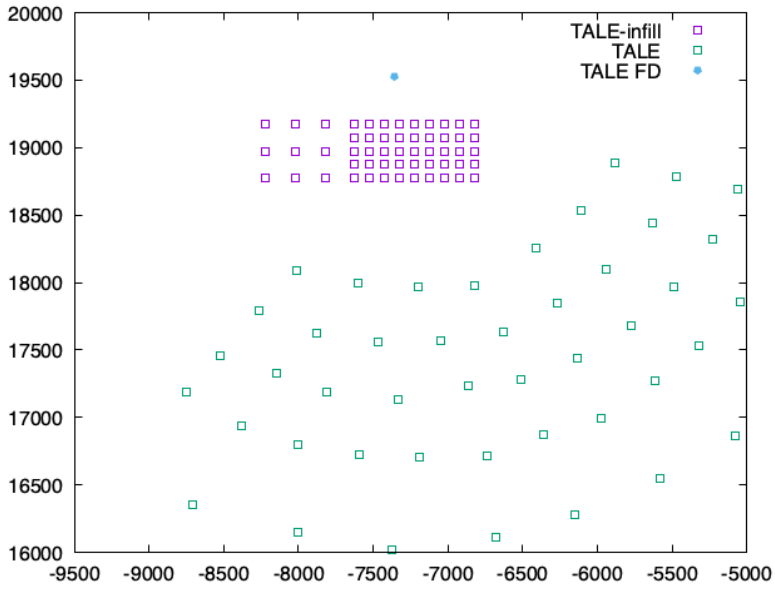

Figure 3: The layout of TALE infill SDs. Purple squares denote the planned locations of 54 SDs for the infill array. The array controlled with a host PC at the TALE FD station indicated with the filled circle.

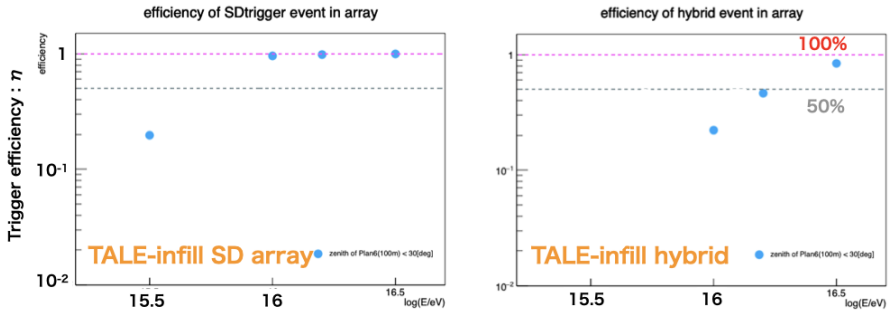

Figure 4: The triggering efficiencies of the TALE-infill SD array and the TALE-infill hybrid operation.

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