TALE surface detector array and TALE hybrid system

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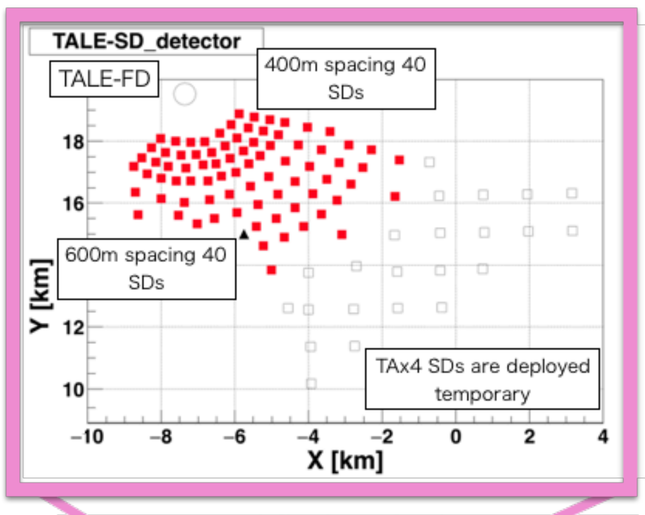
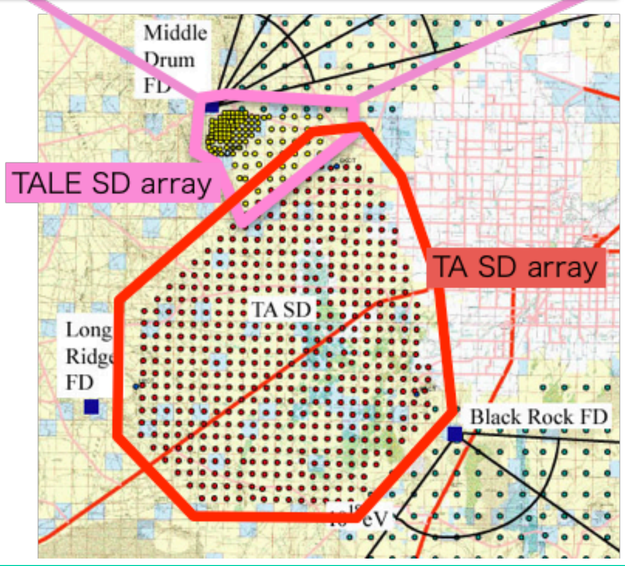
The Telescope Array Low-energy Extension (TALE) experiment is a hybrid air shower detector for observation of air showers produced by very high energy cosmic rays above $10^{16.5}$ eV. TALE is located at the north part of the Telescope Array (TA) experiment site in the western desert of Utah, USA. TALE has a surface detector (SD) array made up of 103 scintillation counters, including 40 with 400 m spacing, 36 with 600 m spacing and 27 with 1.2 km spacing, and a Fluorescence Detector (FD) station consisting of ten FD telescopes located at the Telescope Array Middle Drum FD station, which is made up of 14 telescopes. TALE-FD has been operational since 2013. The deployment and construction of the 103 SDs was completed in 2018, and to date about 80% of the array is in operation with a full triggering and DAQ system. Moreover, the hybrid triggering system was implemented in September 2018. Here we report an overview of the experiment, its capabilities and the technical details of the TALE SD array and the hybrid operations.

Telescope Array Low Energy extension (TALE) experiment





Low energy extension of TA sensitivity down to 10^{16}eV, with

- FDs observing higher elevation,
- Densely-arrayed SDs.

Precise measurement of the composition

⇦FD + SD hybrid measurement

TALE-FD : 10 telescopes (Sep. 2013 ~)

elevation : 31° ~59° , azimuthal : 114°

TALE-SD array : 80 SDs (Feb. 2018 ~)

Expected specifications of TALE hybrid

Threshold energy E : logE = 16.0

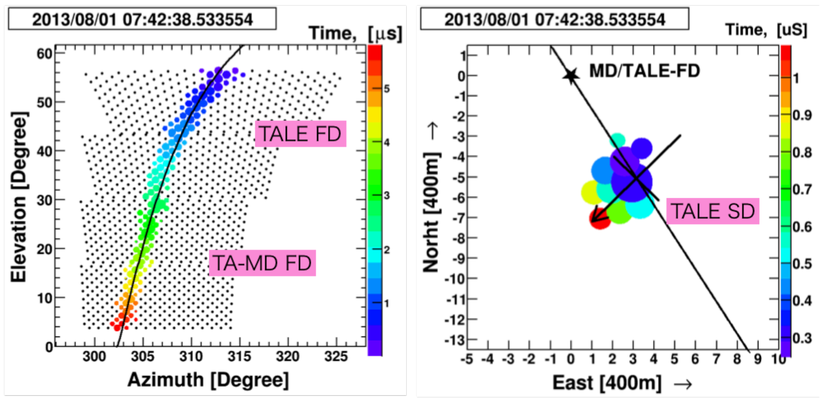
Event rate : ~ 5,000 events/year

$\Delta\theta$ = 1.0° (FD mono : 5.3°)

ΔXmax = 20 g/cm^2 (FD mono : 60 g/cm^2)

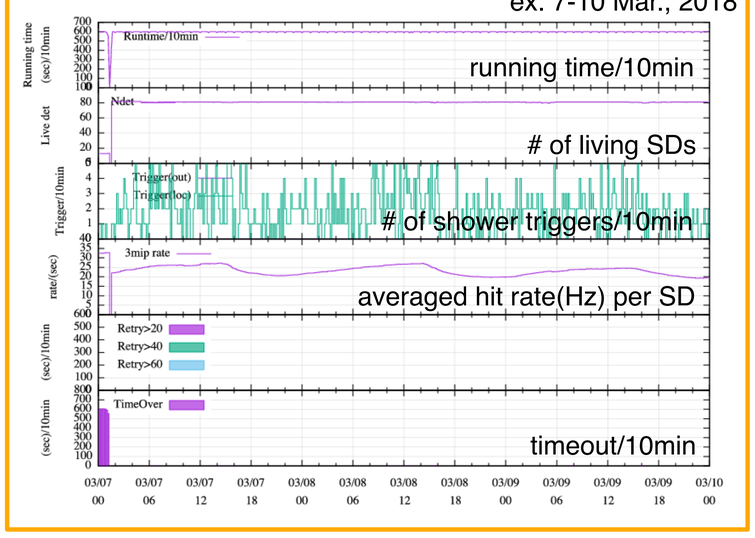
Deployment of the communication tower(2012) and TALE SDs(2018)

TALE hybrid event



Operation of TALE-SD array

Monitoring SD array condition (weekly)



Triggering condition

Level 0 (temporally hold WF): > 0.3MIP

Level 1 (SD hit): > 3MIP

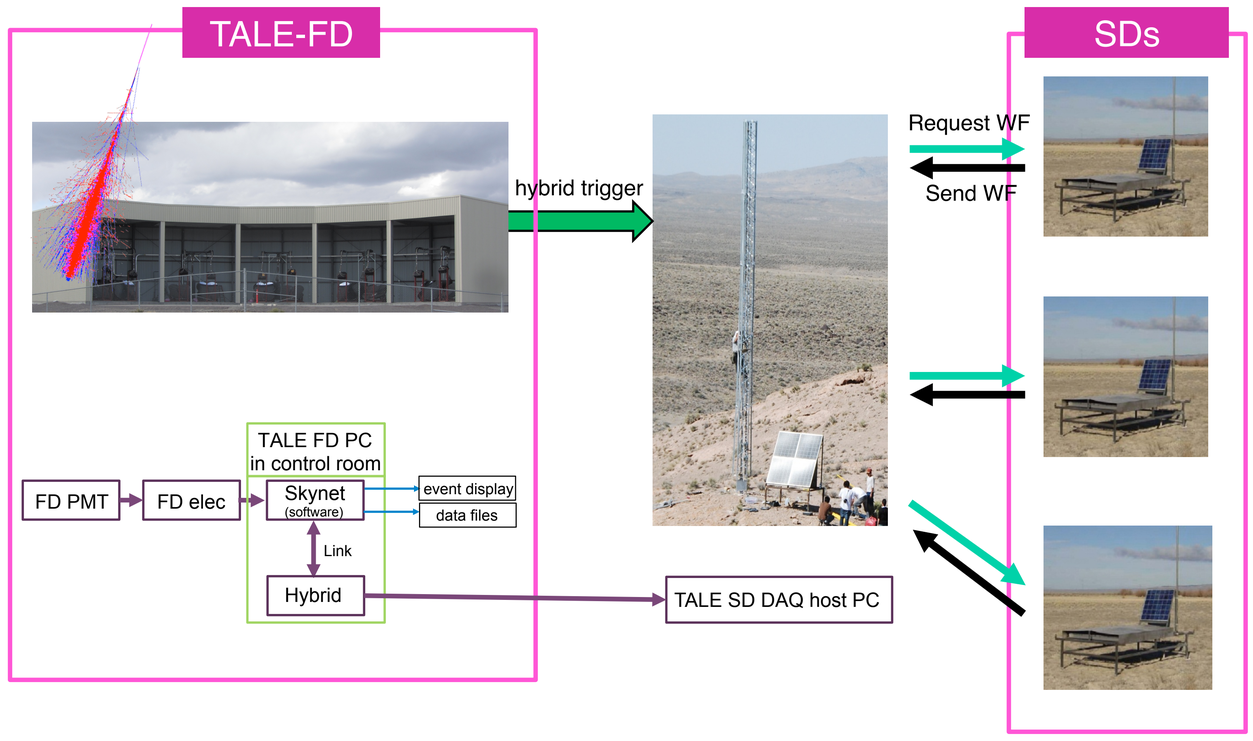
Level 2 (start DAQ process): # of hits > 5 in 8 us

Averaged triggering rate

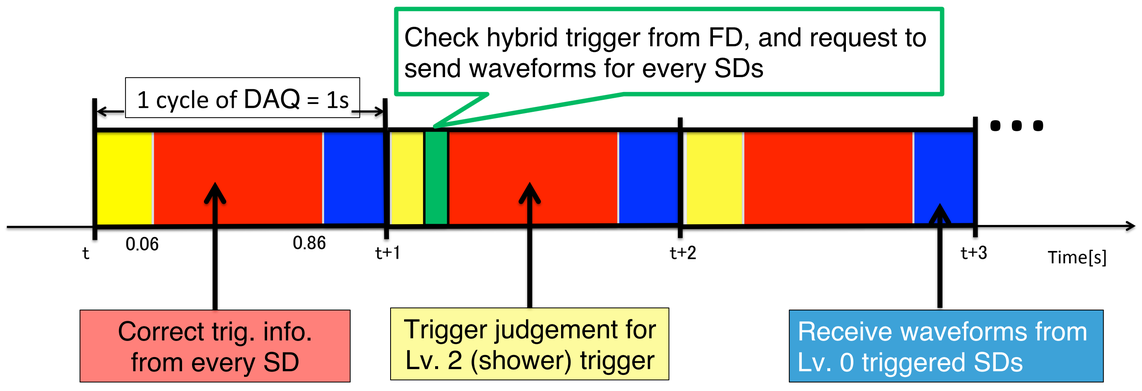
Level 1 (SD hit): 15 Hz > 3MIP

Level 2 (start DAQ process):9/hr

TALE Hybrid trigger system



TALE triggering cycle



Sample Data

TALE-FD

y2018m09d18.hybtrig.log

```
11:34:53.007 Trig connection closed
11:35:20.741 filter: tid 6014 prescale trigger 1537270519.722193
11:35:20.741 Trigger @ 1537270519.722193 #e1 0 13fb0511
11:35:20.741 Trig connected
11:35:22.723 Trig sent '11 5 fb 13'
11:35:32.723 Trig connection closed
```

SD DAQ Host PC@Tower

MD091811.Y2018

```
#T 000113ed 180918 113522 1714 322 0
#A 0 0 0 0
#C 0 0 0 0
L 5401 fffed824 0 321 0 019 2faef29 0 0 0 0
04
FD TRIG DATA RECV
a = 0
a = 1
fd_tmp_time[0]=13fb0511
```

MD091811.H2018

```
#End1pps
#T 000113ed 180918 113522 1714 322 0
FD TRIG DATA RECV RECV DATA[0] = 13fb0511 319 722193
FD trigger judge start 13fb0511
#e1 0 13fb0511
#End1pps
#T 000113ee 180918 113523 1821 323 0
waveform collect done timebin=319 usec=722193 13fb0511
#End1pps
```

Hybrid trigger information, “13fb0511” means:

13f(HEX)=319(DEC) in sec,

b0511(HEX)=722193(DEC) in usec, so then

“13fb0511”=319.722193 s

Current hybrid trigger rate ~ 0.026 Hz

Summary

TALE is an extension project of the TA experiment to lower the energy threshold down to $10^{16.5}$ eV. The constructions of the TALE FD station and the TALE SD array has been finished. Moreover, the implementation of a hybrid triggering system has been finished in September, 2018. The expected threshold energy of hybrid observation is 10^{16} eV,and the mode energy is $10^{17.3}$ eV. The expected number of hybrid events is about 5000 per year. The hybrid analysis developed for TA hybrid events will be applied, and this will be improve the Xmax resolution to be 20 g/cm^2, comparing with the monocular Xmax resolution of 60 g/cm^2.