TALE hybrid

Shoichi OGIO (Osaka City University) for the Telescope Array collaboration

- TA and TALE
- TALE FD monocular spectrum
- TALE SD array
- Hybrid trigger, SD DAQ sequence
- Event reconstruction for real and MC data
- Future plan: lower energy
Telescope Array collaboration

147 collaborators from 36 institutes in 6 countries


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Telescope Array (TA)

Millard county, Utah, USA, about 1400m a.s.l.

Surface Detector (SD) array:
507 scintillation detectors, 3m², 1.2km spacing
Total coverage ~ 700 km²
Fluorescence Detectors (FDs) in 3 stations
In total, 38 telescopes
observing the sky above the array
Operation from 2008

Middle Drum
5.2m² x 14
refurbished HiRes-I

Surface Detector (SD)
3 m² plastic scintillator
2 layers

Black Rock Mesa &
Long Ridge
6.8m² x 12 x 2
newly designed for TA
TALE FD

TALE FD station and TA MD are very close together
10 FDs in the TALE station
Elevation: 30°-57° (higher elevation than MD)
Azimuthal: 114°

Refurbished HiRes FDs
Mirror: same as TA FD (MD)
Elec.: 10 MHz 8bit FADC

Installed in Nov. 2012
Operation from Sep. 2013
Hybrid trigger out Sep. 2018
### TALE-FD mono spectrum (2 yrs)


![Energy spectrum graph](image)

**Breakpoint**
- Break point $17.04 \pm 0.03$
- Break point $16.22 \pm 0.02$

**Slope**
- Slope: $-3.12 \pm 0.01$  
- Slope: $-2.92 \pm 0.01$  
- Slope: $-3.19 \pm 0.02$

**Fit**
- $\chi^2 / \text{ndf} = 31.6 / 39$

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*Figure 20: TALE cosmic rays energy spectrum measured with 22 months of data. A mixed primary composition given by the TXF is assumed. The gray band indicates the size of the systematic uncertainties.*

*Figure 22: A comparison of the spectrum obtained with different compositions.*

*With respect to the energy spectrum for the case of pure iron composition assumption, note that composition measurements by other experiments, e.g. [48, 49], exclude the possibility of iron dominated flux at energies below $10^{16}$ eV. The spectrum is included in the plot simply to demonstrate the extreme case of all heavy primaries.*

*Figure 23: A comparison of the current result with some recent results from other experiments.*

*We note that qualitatively the spectra are in agreement. The difference in normalization is within the systematics of the energy scales of the different experiments. In particular, we note that a 6.5% downward shift in the IceTop energy scale, results in a spectrum that lies on top of the TALE spectrum for energies below $10^{17}$ eV.*

*Figure 24: A comparison of the current result with some recent results from TA Fluorescence [55] and surface detector [56] measurements.*

*We note that above $10^{17}$ eV there is excellent agreement between the different results, demonstrating that the TALE spectrum can be seen as an extension of the measurements in the ultra-high energy regime down to lower energies.*
Compared to recent measurements

Figure 23: TALE cosmic rays energy spectrum plotted along with measurements by Yakutsk [50], TUNKA [51, 52], Kaskade-Grande [53], and IceTop [54].

Figure 24: TALE cosmic rays energy spectrum plotted along with measurements by TA using the FD’s at Black Rock and Long Ridge sites [55], and by the TA surface detector [56], also shown is the Auger spectrum [57] with a 10% energy scaling applied to make it agree with the TA SD flux.
Exposure depends on composition

arXiv: 1803.01288

TALE Energy spectrum (Monocular)

- blue: iron
- green: H4a + HiRes/MIA
- black: TXF
  (a mixed model which reproduces TALE-FD Xmax, used for previous page)
- red: proton
FD monocular $\rightarrow$ FD + SD hybrid

$\Delta X_{\text{max}}$:
FD mono: 40 g/cm$^2$
$\rightarrow$ FD + SD hybrid: 20 g/cm$^2$
TALE hybrid

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: 30°~57°, azimuthal: 114°
TALE-SD array: 80 SDs (Feb. 2018 ~)
TALE-hybrid started running from Sep. 2018

Expected specifications of TALE hybrid
Threshold energy $E : \log E = 16.0$
Event rate: ~5,000 events/year
$\Delta \theta = 1.0^\circ$ (FD mono: 5.3°)
$\Delta X_{\text{max}} = 20$ g/cm$^2$ (FD mono: 40 g/cm$^2$)
TALE SD array

New PMT (Hamamatsu R8619)
• QE ~ 20% @ 500nm (TA: ~10%)
• Linear range max @ ~ 50mA (TA: ~ 25mA)
• Photo-cathode uniformity

→ reduce total length of WLSF ~ 33% of TA
TALE SD array

80 SDs covering 30km²
Running from Feb. 2018
# of living SD ~ 80
DAQ bug fixed at Apr. 2018

Triggering conditions:
Storing waveform in SD: > 0.3 MIP (750Hz/SD)
Hit: > 3 MIPs (20Hz/SD)
Air shower event: 5 hit SDs in 8us window
(3/10min)

Status plot (Jan. 2018 -)
**TALE Hybrid**

Hybrid triggering condition: DAQ installed Sep. 2018

- # of hit PMT > 5 &
- Event duration > 500 ns

Hybrid triggering rate ~ 0.05Hz

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**Central DAQ Host PC**

① FD event trigger

② Request SDs to record waveform with FD event time info.

③ request

④ send waveform > 0.3 MIP

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**DAQ sequence (time chart) in the host PC**

Check hybrid triggers from the TALE FD, and request all the SDs to send waveforms

Correct Level 1 trigger info. from all the SDs

Level 2 trigger decision

Correct waveforms from Level 0 triggered SDs
Hybrid triggering condition: DAQ installed Sep. 2018
- # of hit PMT > 5 &
- Event duration > 500 ns
Hybrid triggering rate ~ 0.05Hz

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
**TALE Hybrid**

Hybrid triggering condition: DAQ installed Sep. 2018
- # of hit PMT > 5 &
- Event duration > 500 ns

Hybrid triggering rate ~ 0.05Hz

1. FD event trigger
2. Request SDs to record waveform with FD event time info.
3. Request
4. Send waveform > 0.3 MIP

Central DAQ
Host PC

**DAQ sequence (time chart) in the host PC**

Check hybrid triggers from the TALE FD, and request all the SDs to send waveforms

Correct Lv. 1 trigger info. from all the SDs
L. 2 trigger decision
Correct waveforms from L. 0 triggered SDs
TALE Hybrid: real event sample

Real hybrid event samples in Nov. 7, 2018

2018/11/07 10:01:30.122752

2018/11/07 11:46:15.622352
TALE Hybrid: real event sample

Real hybrid event samples in Nov. 7, 2018

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<th>Zen.[deg]</th>
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<th>CoreX[km]</th>
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<table>
<thead>
<tr>
<th>Xmax[g/cm²]</th>
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<td>823</td>
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## Results

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<th>Zen.[deg]</th>
<th>Azi.[deg]</th>
<th>Rp[km]</th>
<th>$\psi$ [deg]</th>
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<th>CoreY[km]</th>
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<th>$E_0$ [eV]</th>
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<td>2.35</td>
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# TALE Hybrid: MC event sample

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<th>Rp [km]</th>
<th>$\psi$ [deg]</th>
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<th>CoreY [km]</th>
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TALE Hybrid: MC event sample

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<th>Zen.[deg]</th>
<th>Azi.[deg]</th>
<th>Rp[km]</th>
<th>$\psi$ [deg]</th>
<th>CoreX[km]</th>
<th>CoreY[km]</th>
<th>$X_{\text{max}}$ [g/cm$^2$]</th>
<th>$E_0$ [eV]</th>
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<td>15.04</td>
<td>x</td>
<td>x</td>
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TALE future plan: lower energy

Additionally install 50 SDs with 200m spacing near the TALE FD station (< 2km), to archive lower the threshold energy:

for SD, $E_{\text{mode}} = 10^{15.5} \text{ eV}$

for FD-SD hybrid, $E_{\text{mode}} = 10^{16.3} \text{ eV}$

1.5M$ for 5yrs approved by JSPS in 2019
Summary

TALE hybrid in operation since 2018
• 80 SDs with 400 m, 600 m spacing in stalled in Feb. 2018
• SD event rate is 0.005 Hz
• Hybrid rate is 0.05 Hz

Go down lower energy with additional 50 SDs
• approved by JSPS for 1.5 M$