



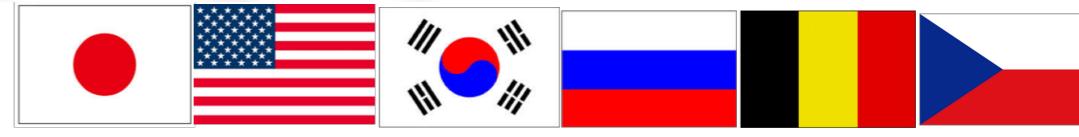
TALE hybrid

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:

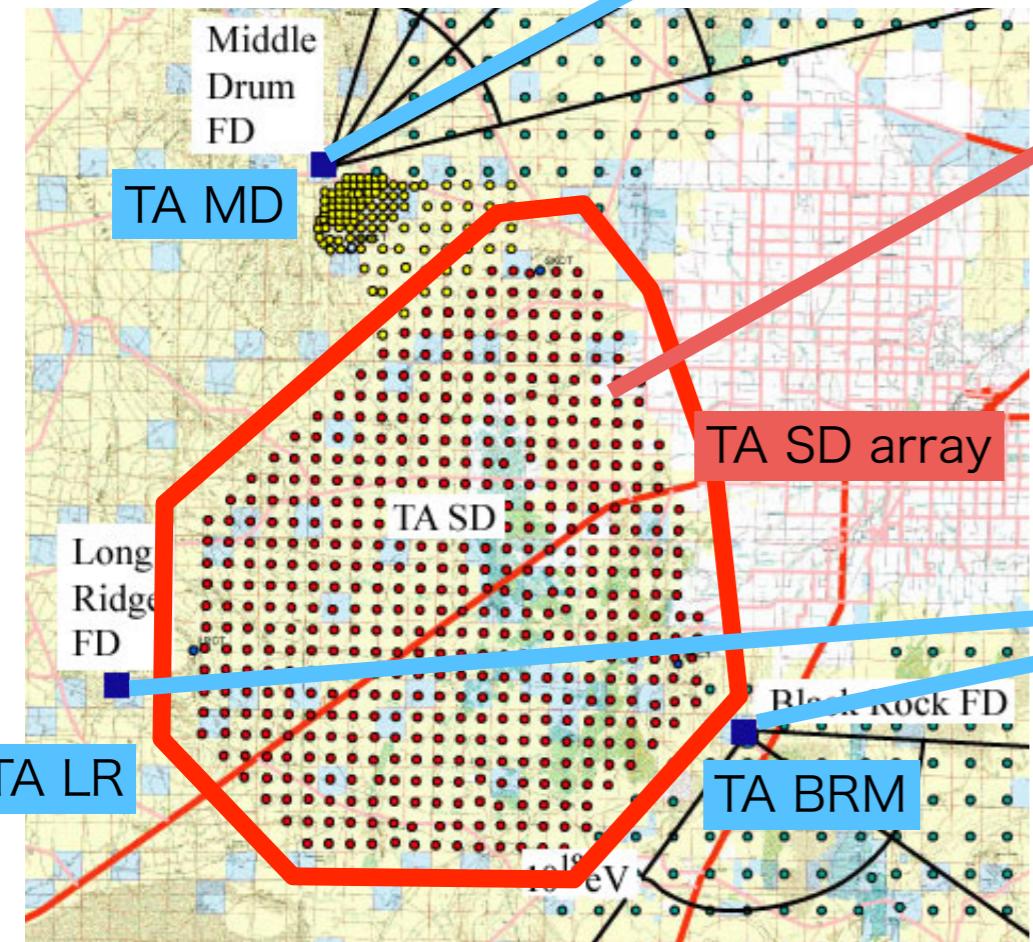
507 scintillation detectors, 3m^2 , 1.2km spacing

Total coverage $\sim 700 \text{ km}^2$

Fluorescence Detectors (FDs) in 3 stations

In total, 38 telescopes
observing the sky above the array

Operation from 2008



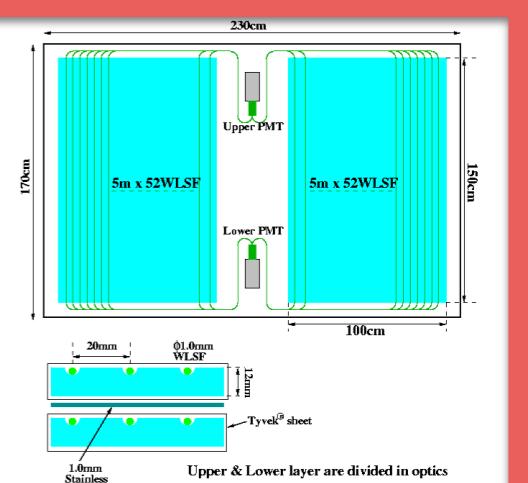
Middle Drum

$5.2\text{m}^2 \times 14$

refurbished HiRes-I

Surface Detector (SD)

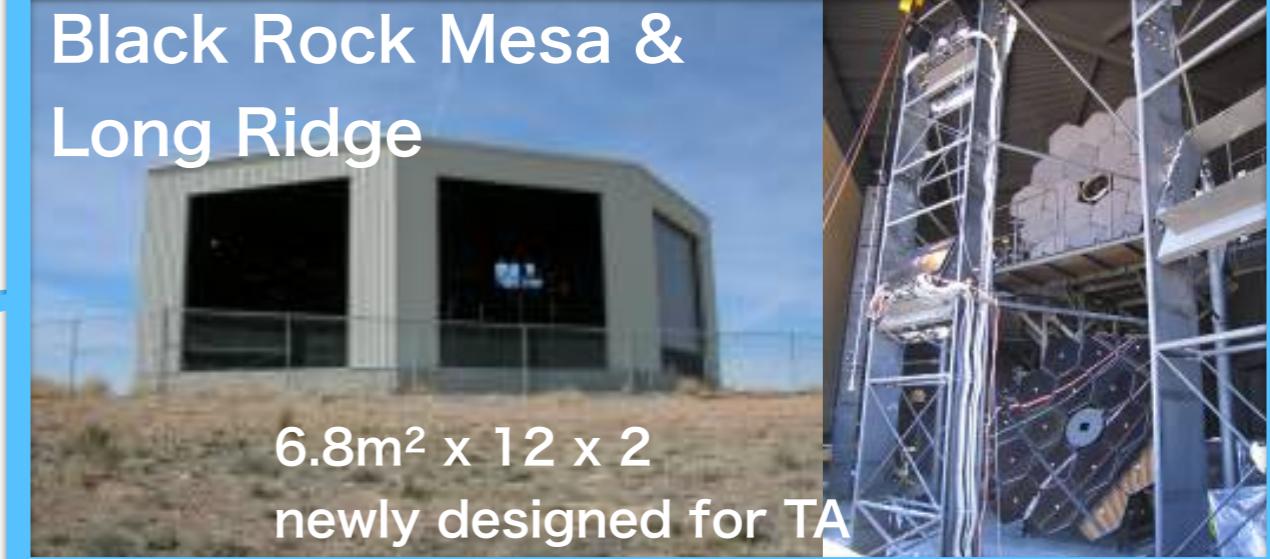
3 m^2 plastic scintillator
2 layers



Black Rock Mesa & Long Ridge

$6.8\text{m}^2 \times 12 \times 2$

newly designed for TA



TALE FD

TALE FD station and TA MD are very close together

10 FDs in the TALE station

Elevation: $30^\circ\text{-}57^\circ$ (higher elevation than MD)

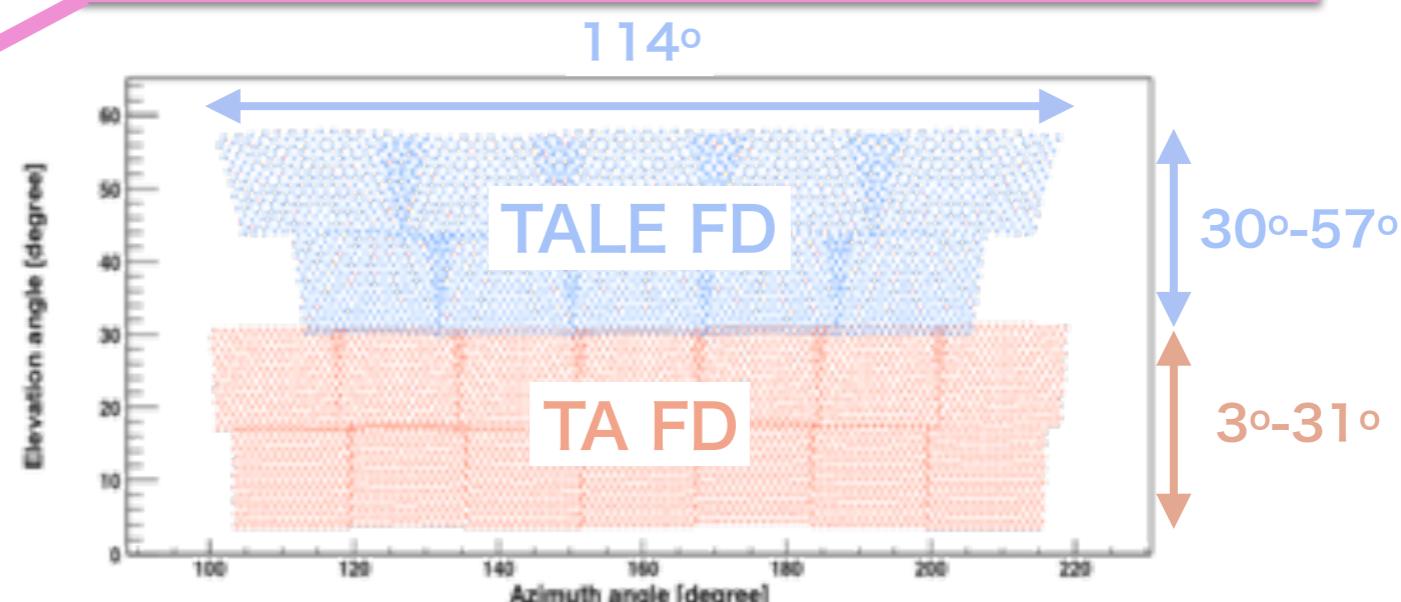
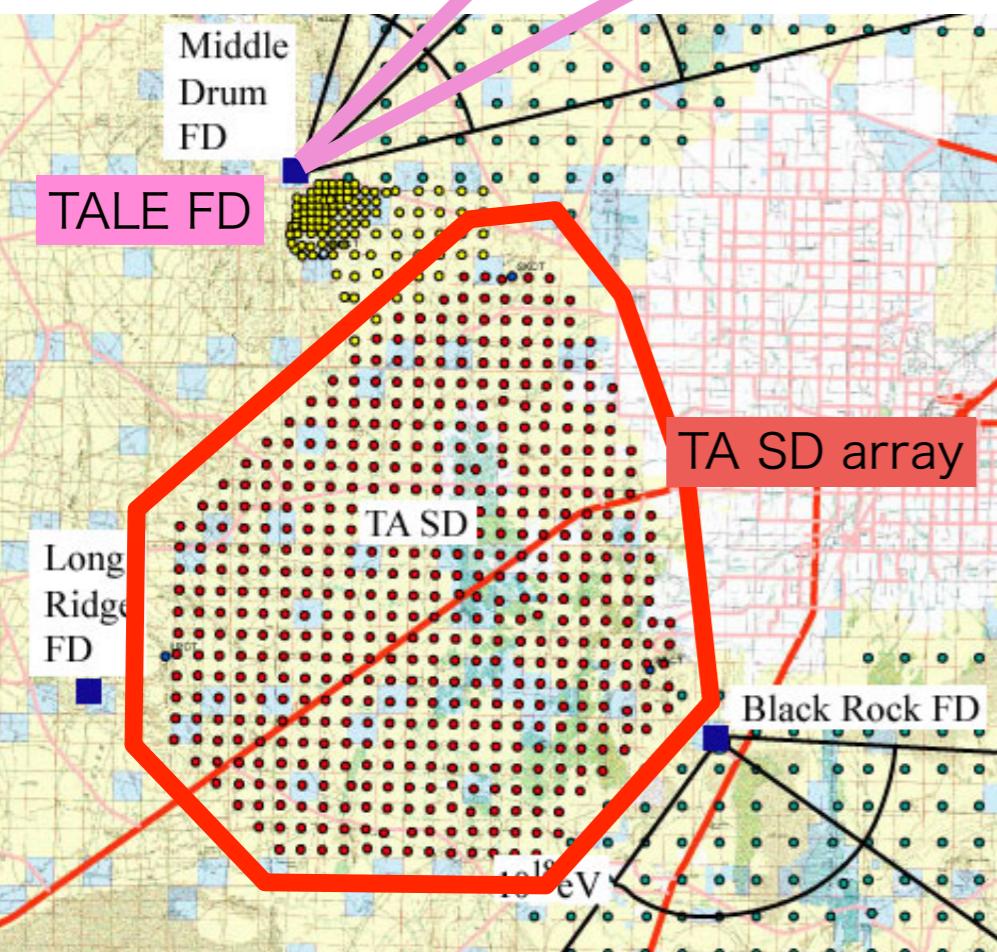
Azimuthal: 114°



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

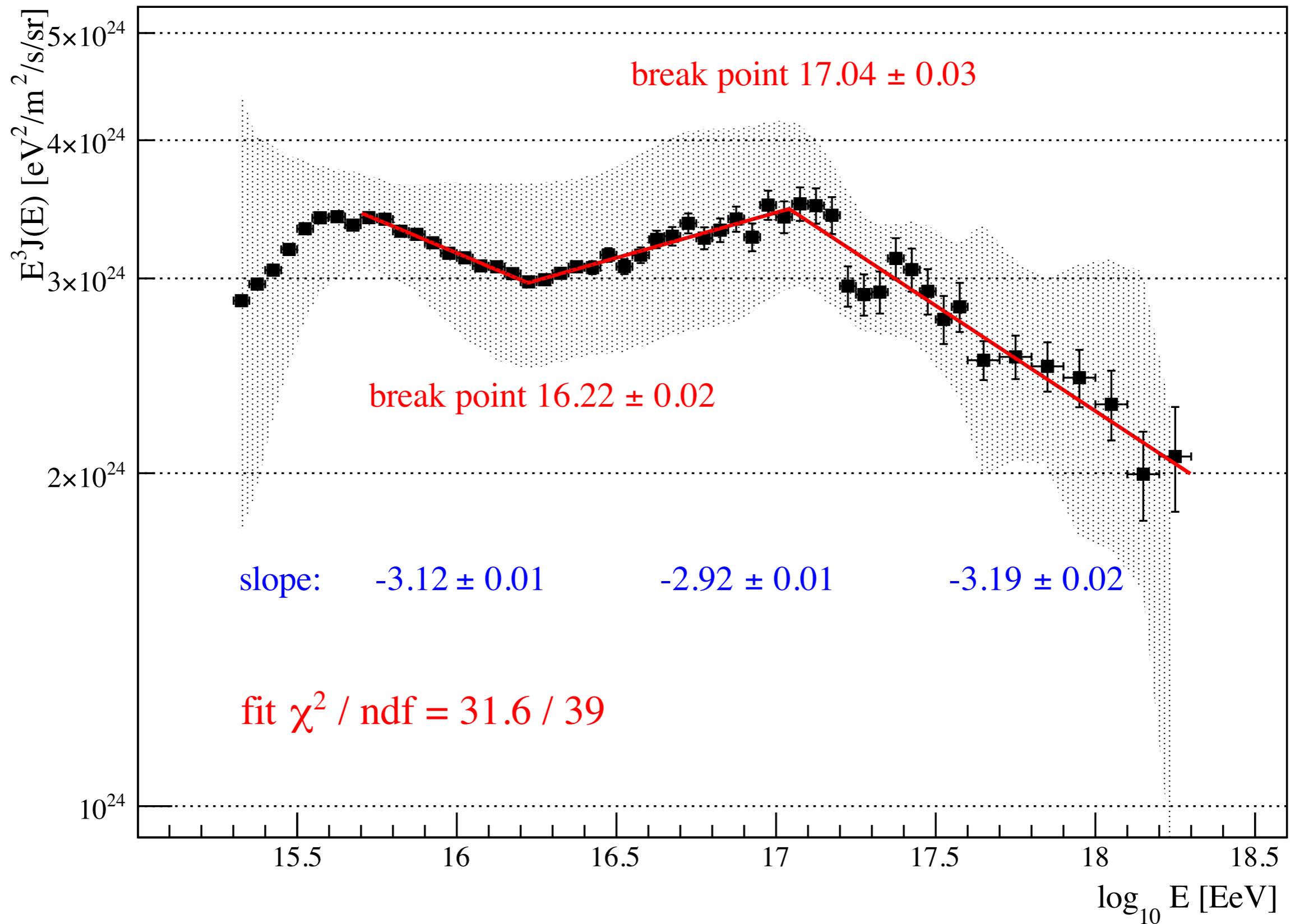


TALE-FD mono spectrum(2yrs)

Data: Jun. 2014 - Mar. 2016

Ap. J., 865, 74(2018)

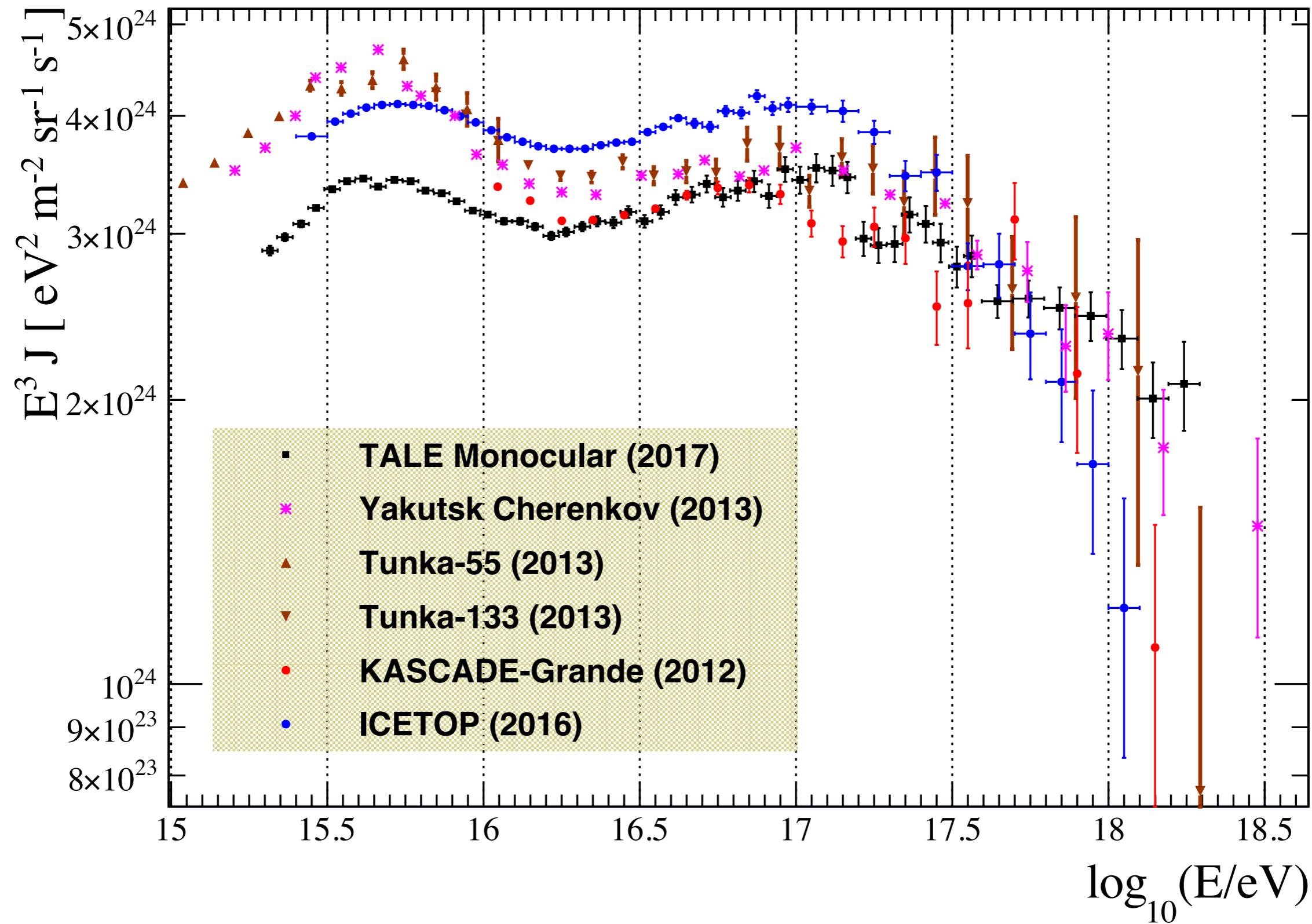
arXiv: 1803.01288



Compared to recent measurements

Ap. J., 865, 74(2018)

arXiv: 1803.01288

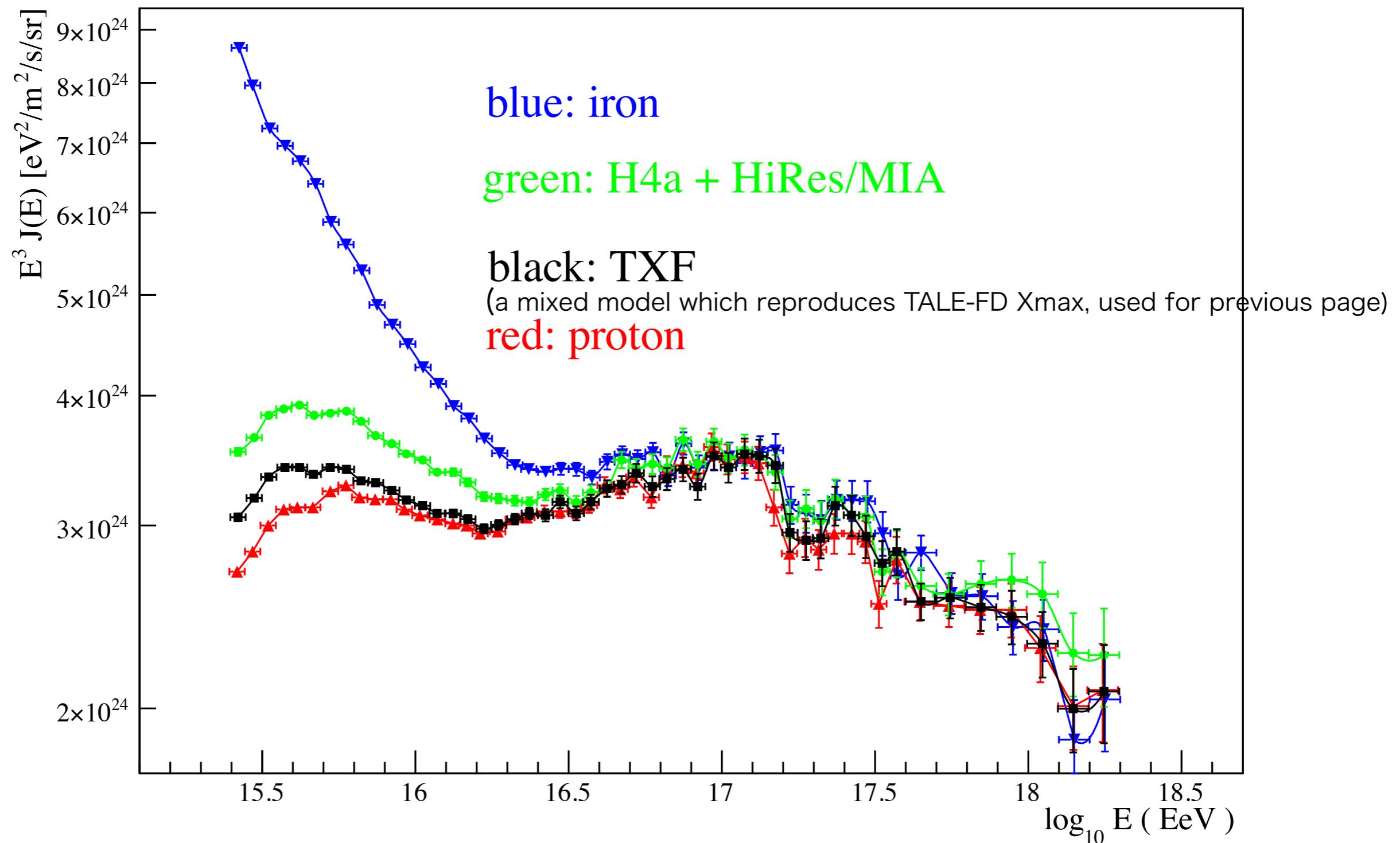


Exposure depends on composition

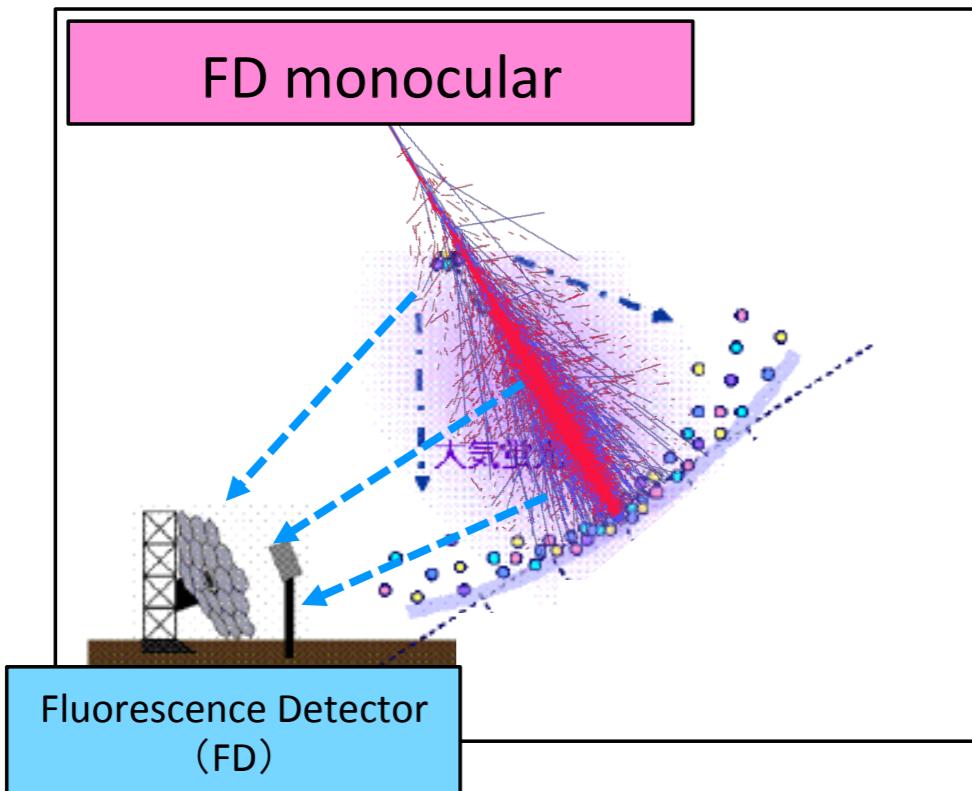
Ap. J., 865, 74(2018)

arXiv: 1803.01288

TALE Energy spectrum (Monocular)



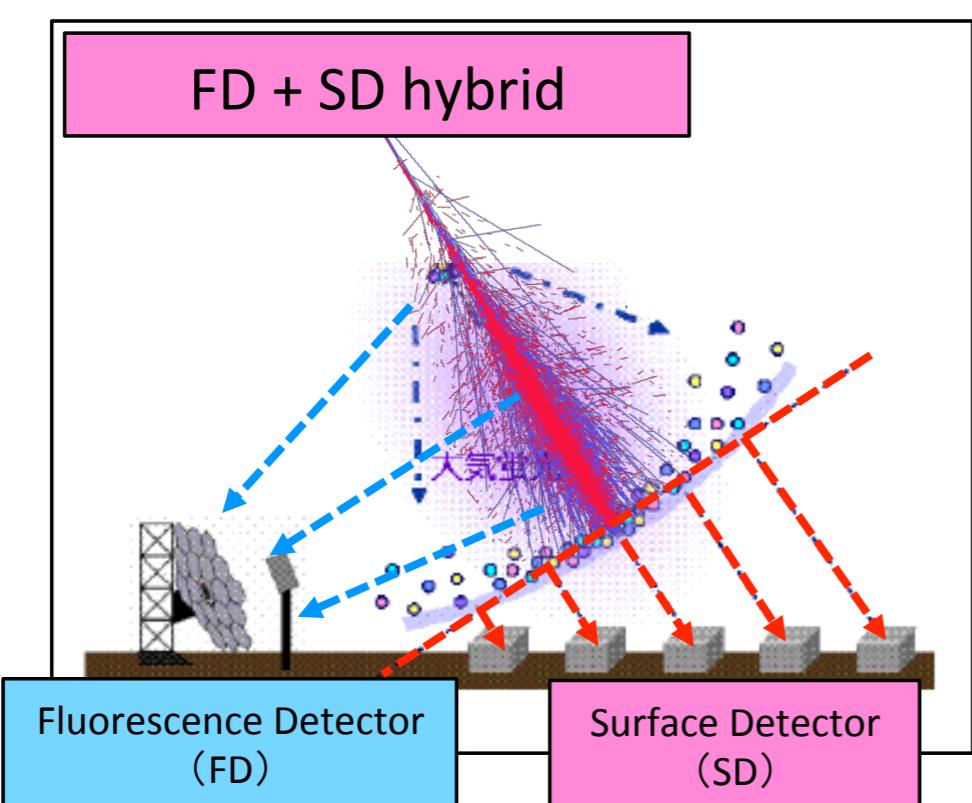
FD monocular → FD + SD hybrid



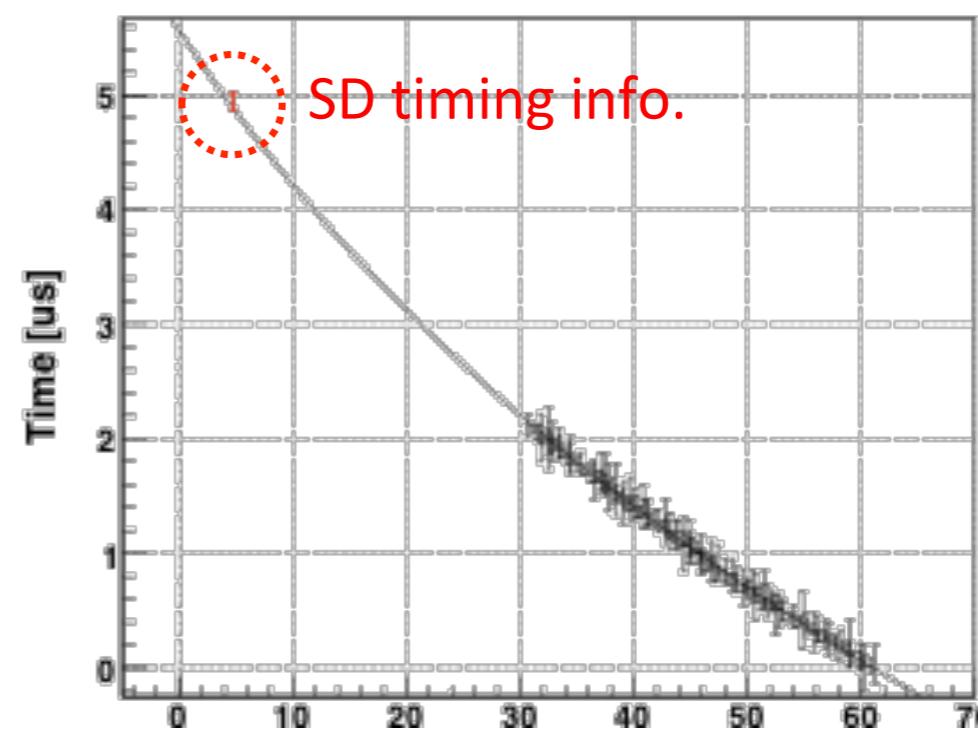
ΔX_{\max} :

FD mono : 40 g/cm^2

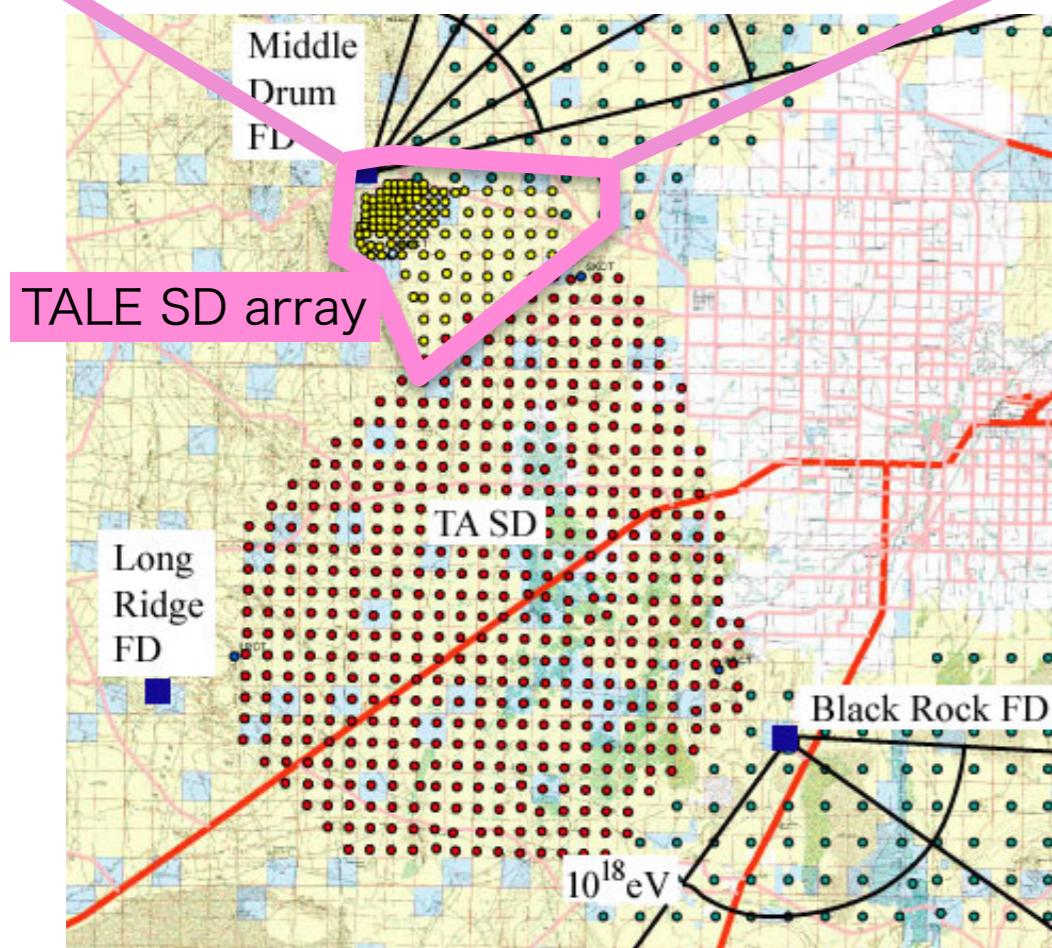
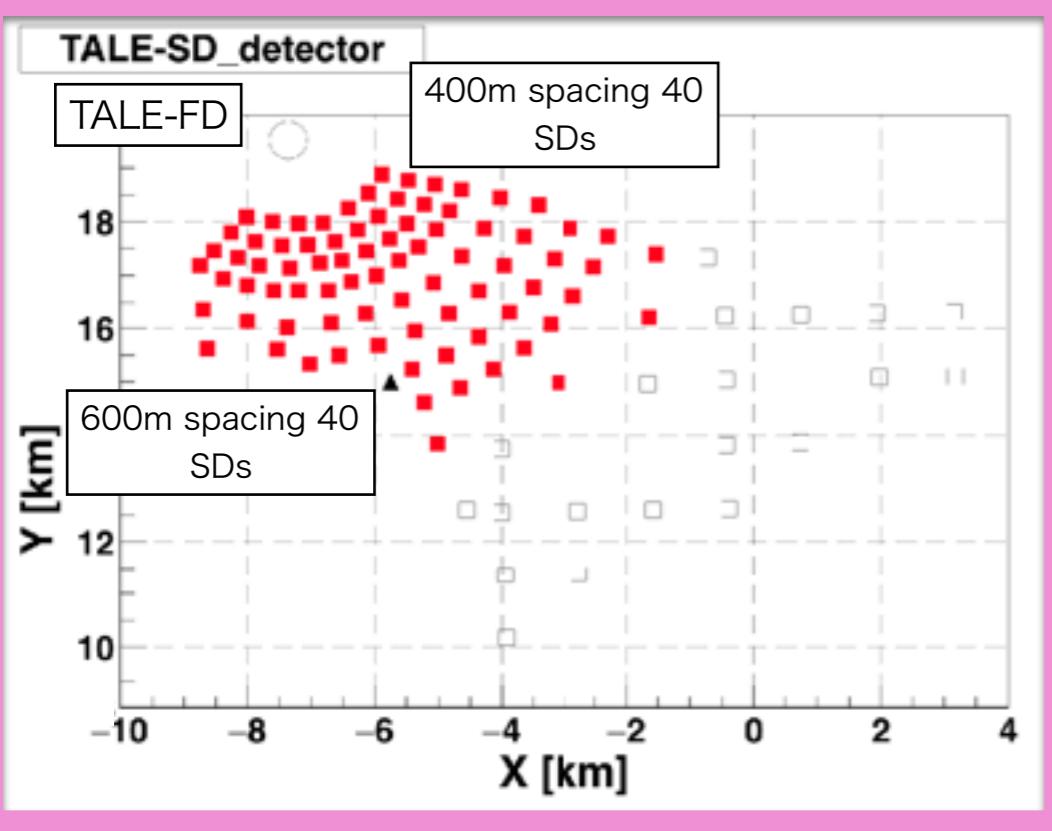
→ FD+SD hybrid : 20 g/cm^2



time vs angle fit



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 : $30^\circ\sim57^\circ$, azimuthal : 114°
TALE-SD array : 80 SDs (Feb. 2018 ~)
TALE-hybrid started running from Sep. 2018

Expected specifications of TALE hybrid

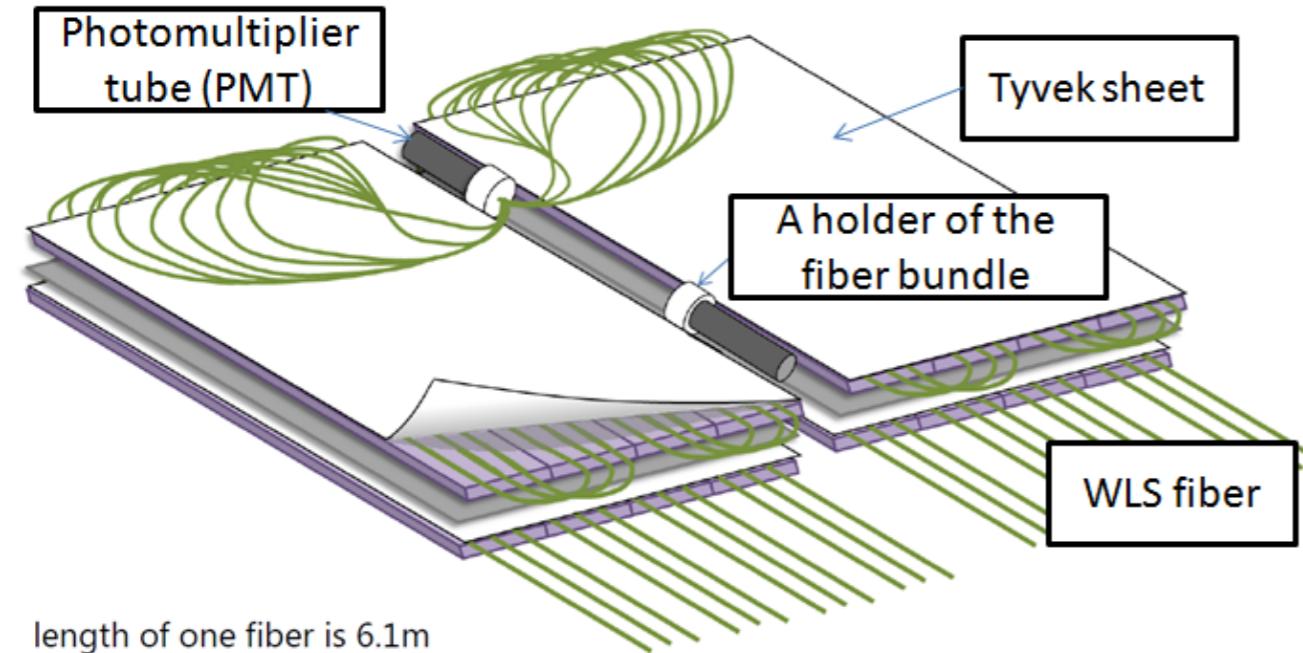
Threshold energy E : $\log E = 16.0$

Event rate : ~5,000 events/year

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

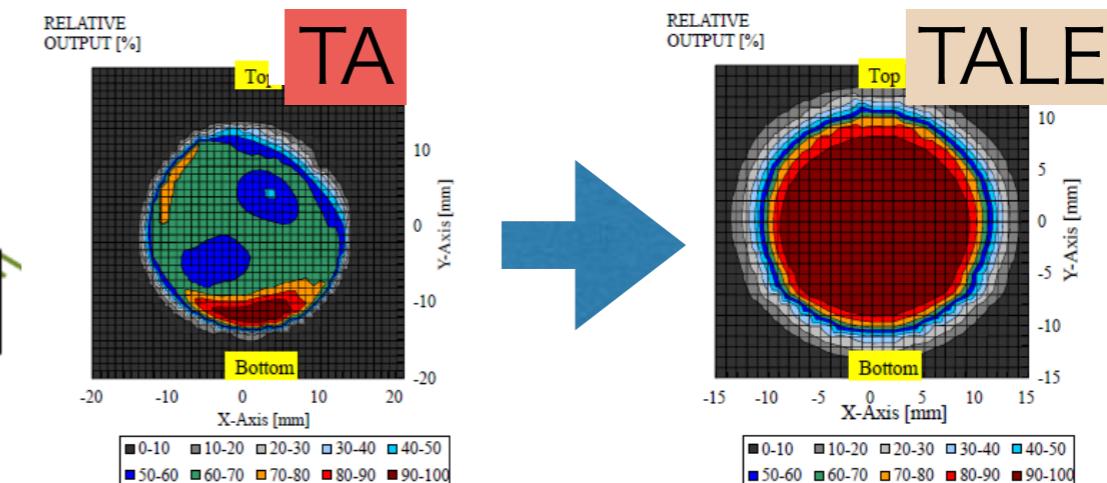
$\Delta X_{\max} = 20 \text{ g/cm}^2$ (FD mono : 40 g/cm^2)

TALE SD array

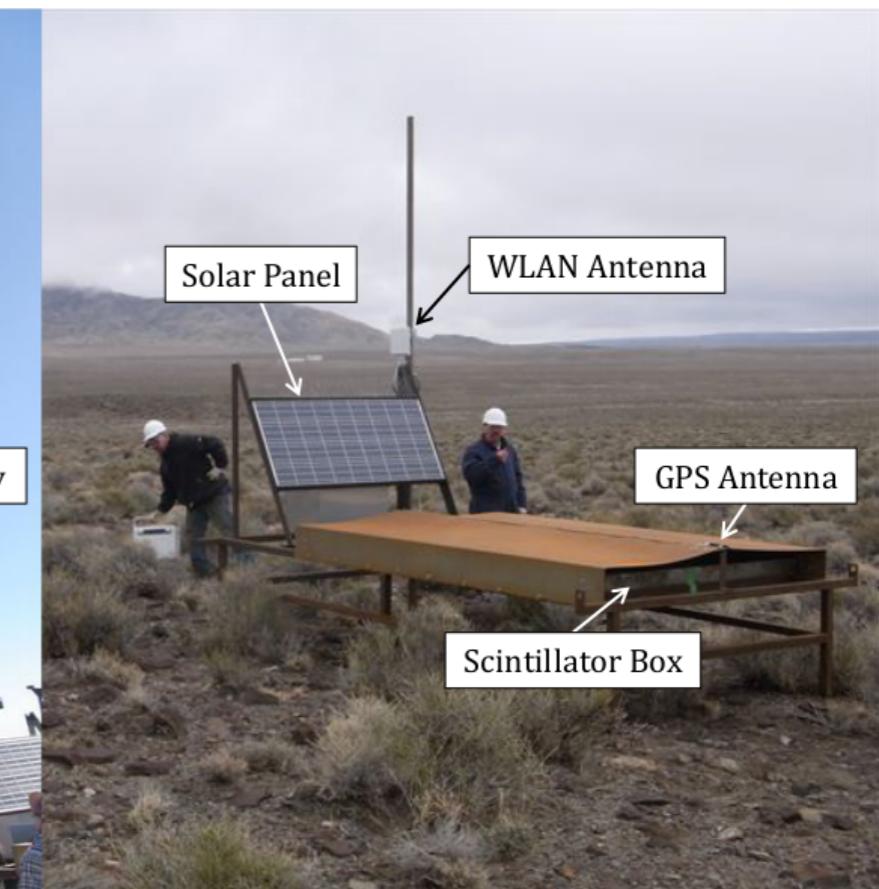
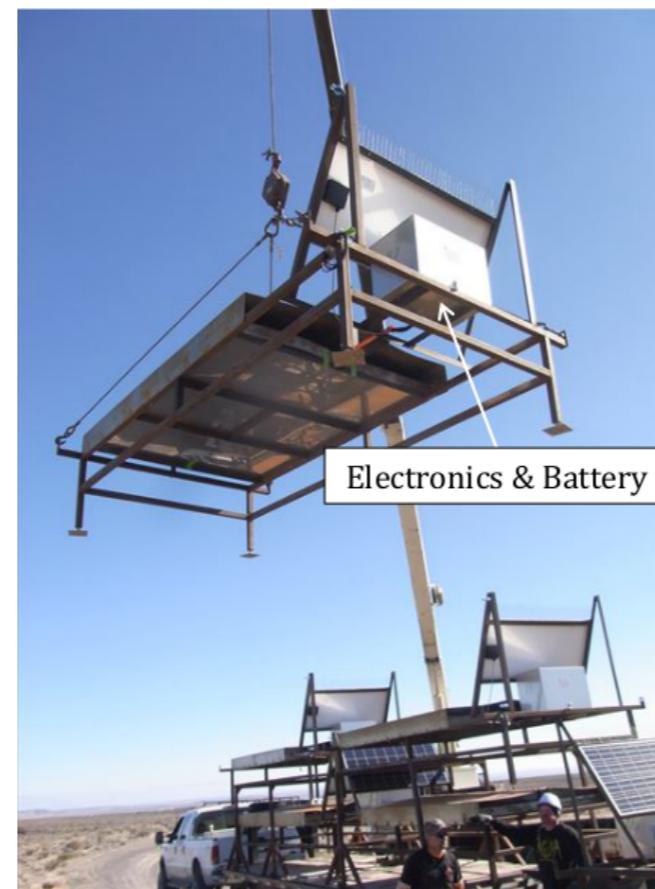
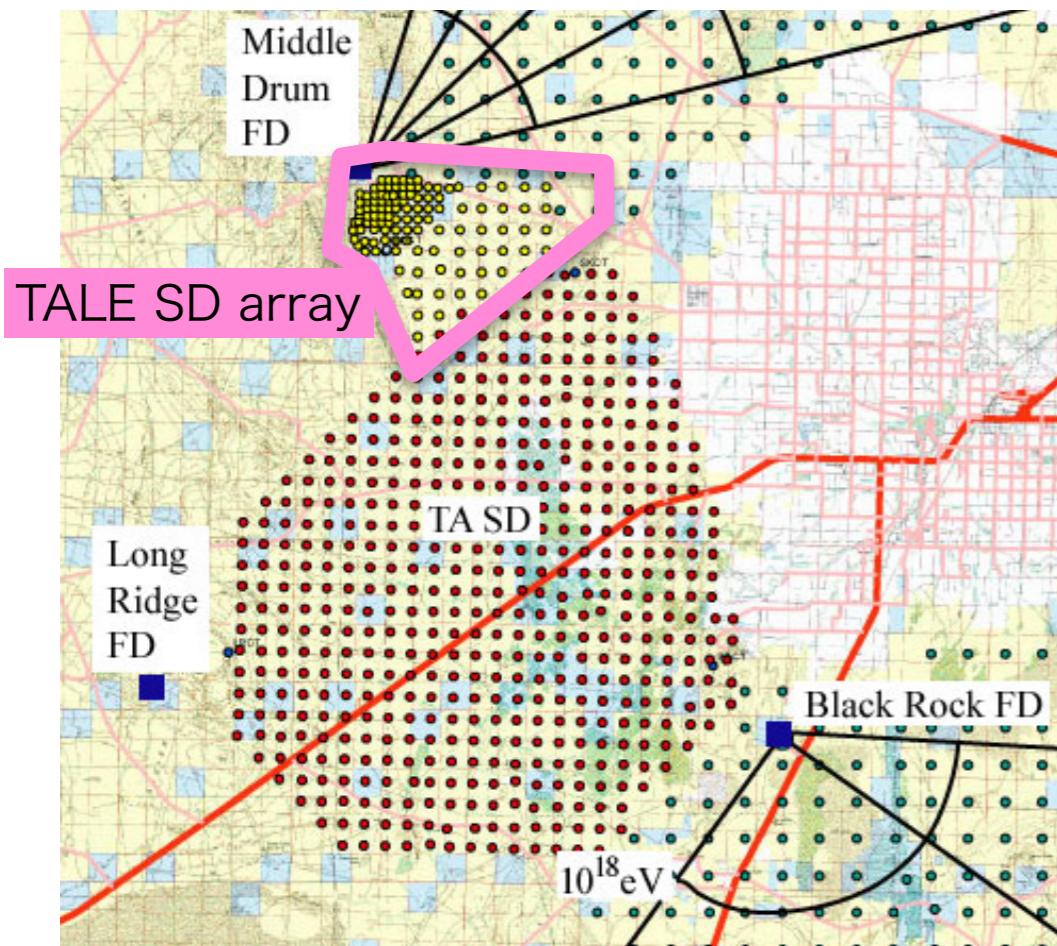


New PMT(Hamamatsu R8619)

- 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

Status plot (Jan. 2018 -)

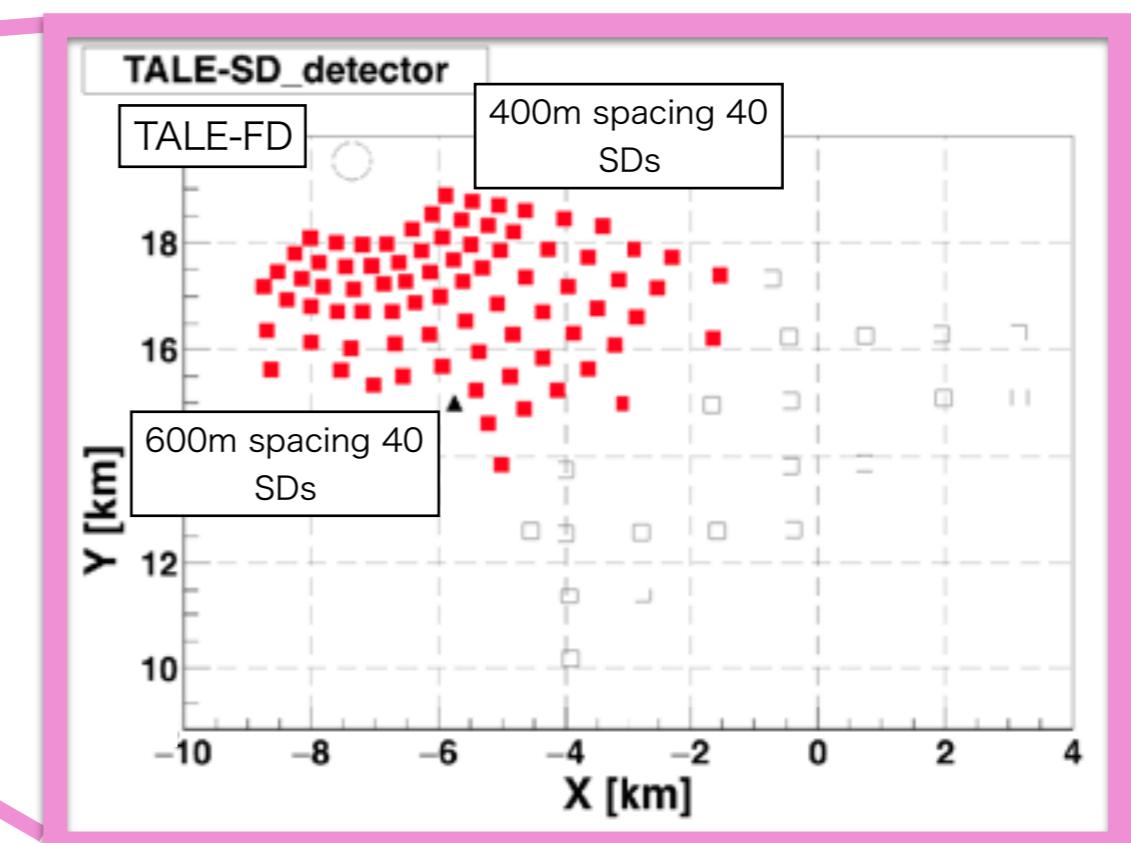
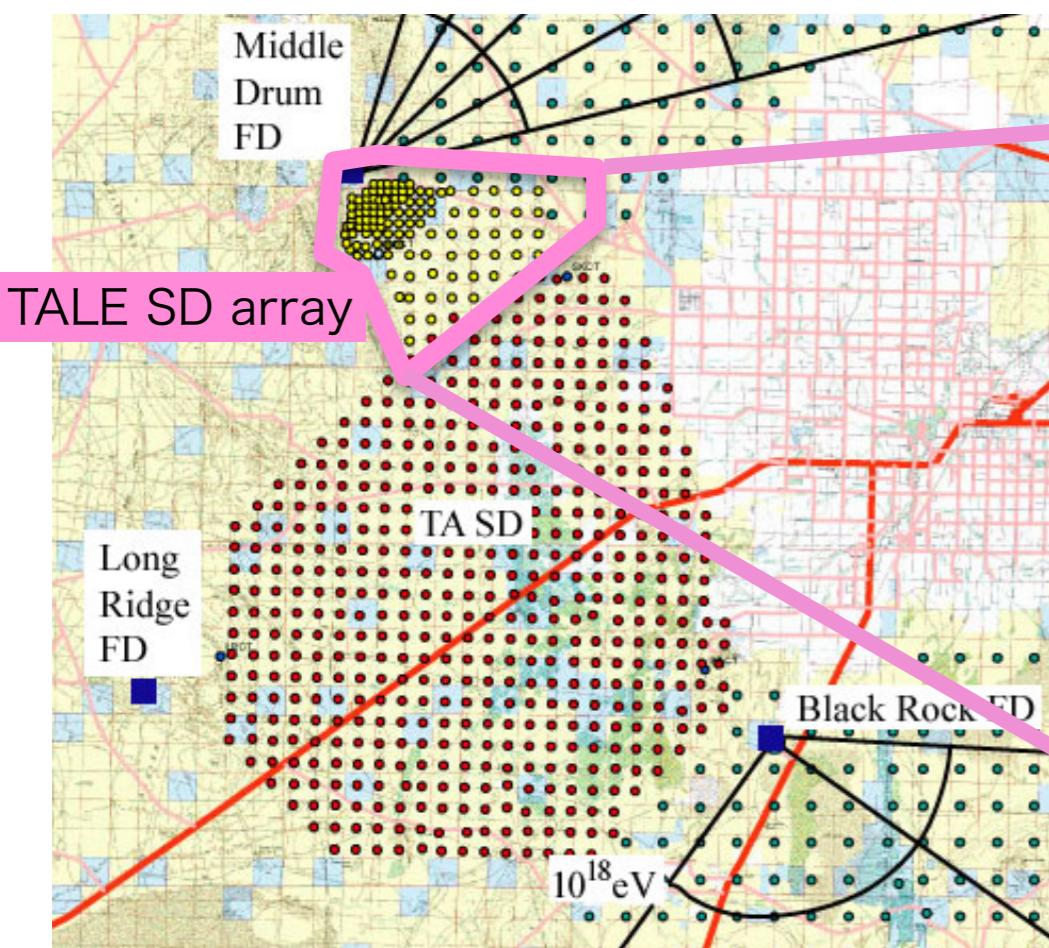
DAQ bug fixed at Apr. 2018

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)



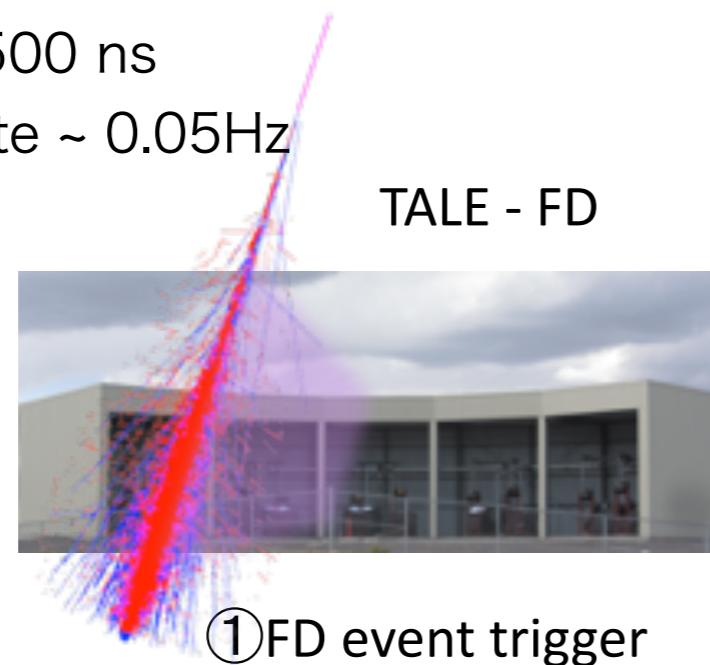
TALE Hybrid

Hybrid DAQ installed Sep. 2018

Hybrid triggering condition: DAQ installed Sep. 2018

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

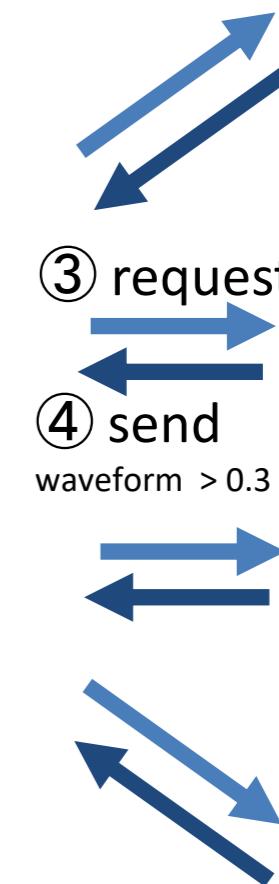
Hybrid triggering rate ~ 0.05Hz



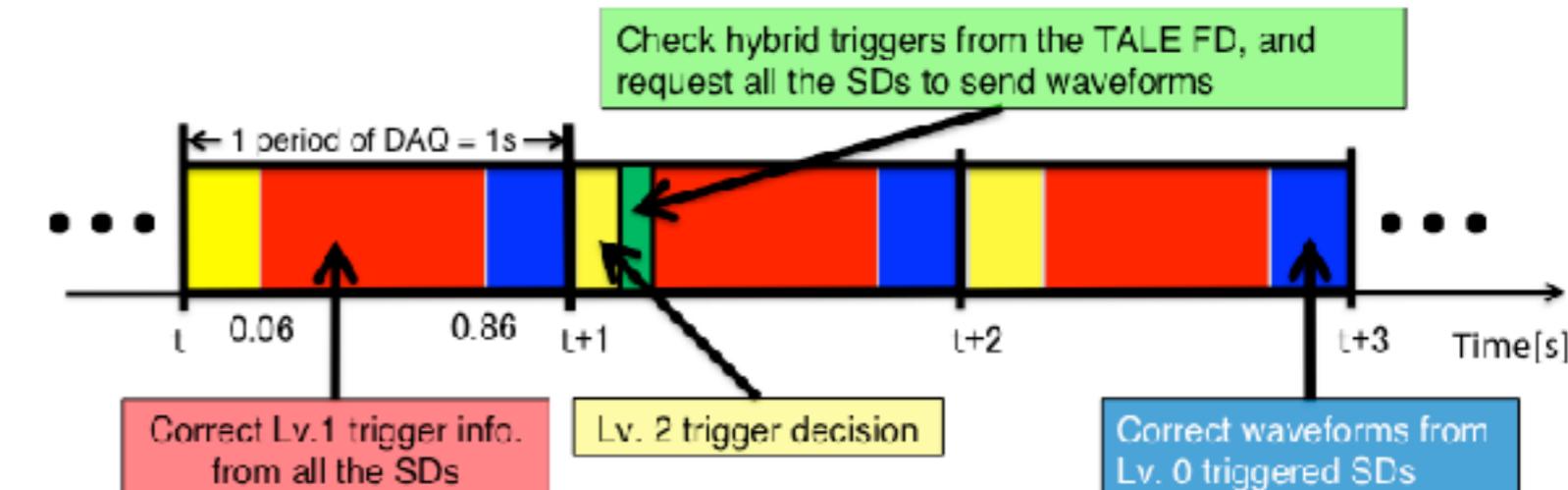
① FD event trigger

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

Central DAQ
Host PC



DAQ sequence(time chart) in the host PC



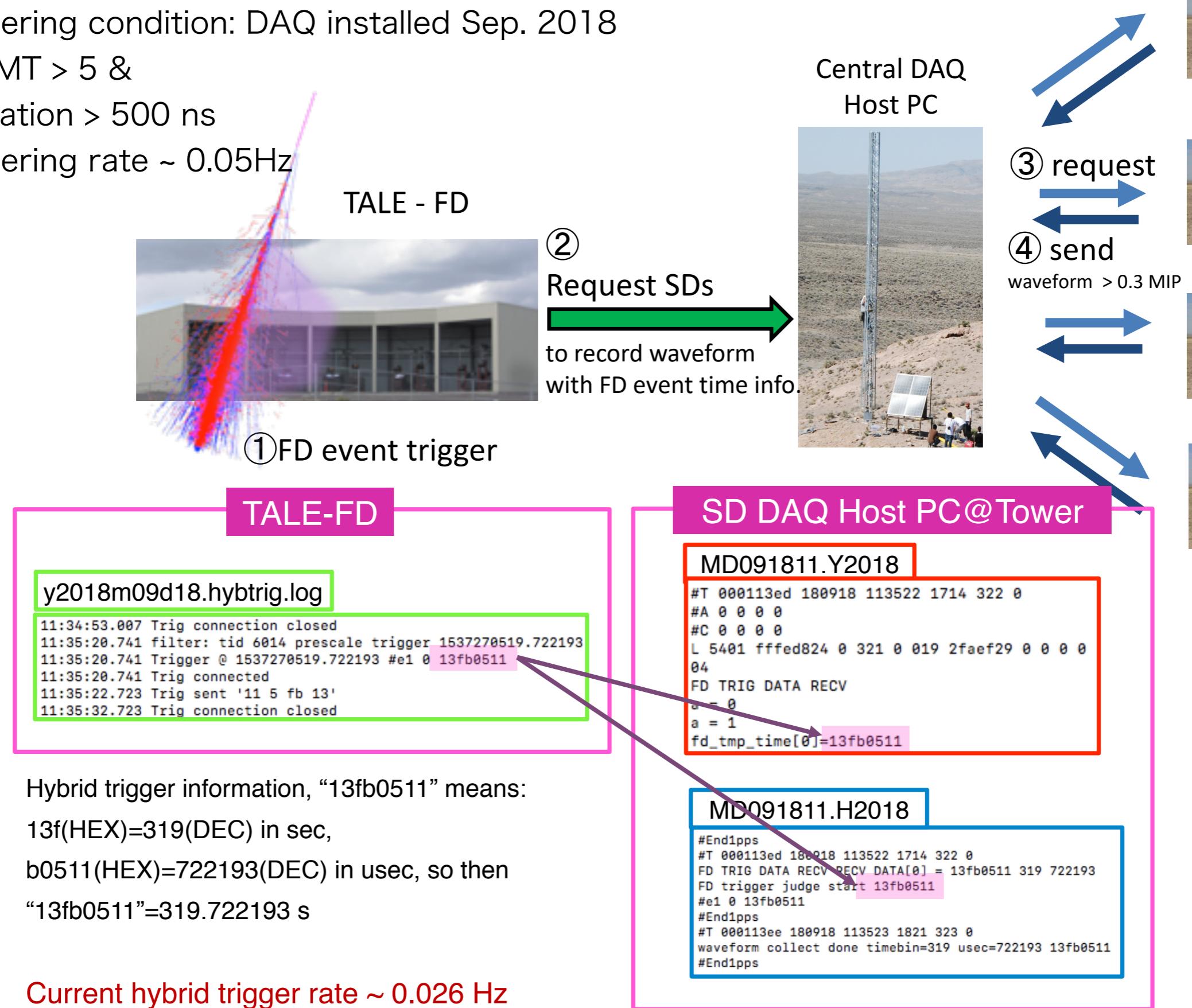
TALE Hybrid

Hybrid DAQ installed Sep. 2018

Hybrid triggering condition: DAQ installed Sep. 2018

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

Hybrid triggering rate ~ 0.05Hz



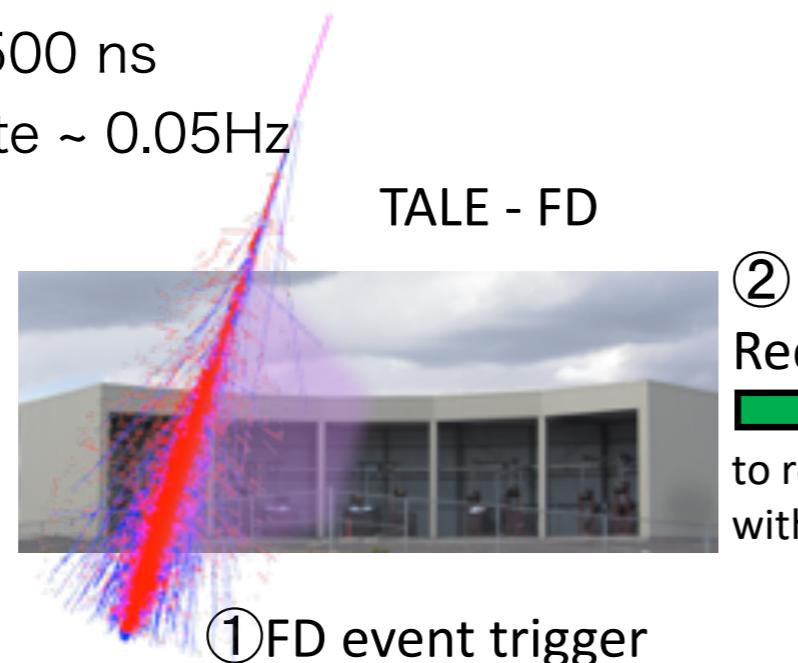
TALE Hybrid

Hybrid DAQ installed Sep. 2018

Hybrid triggering condition: DAQ installed Sep. 2018

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

Hybrid triggering rate ~ 0.05Hz

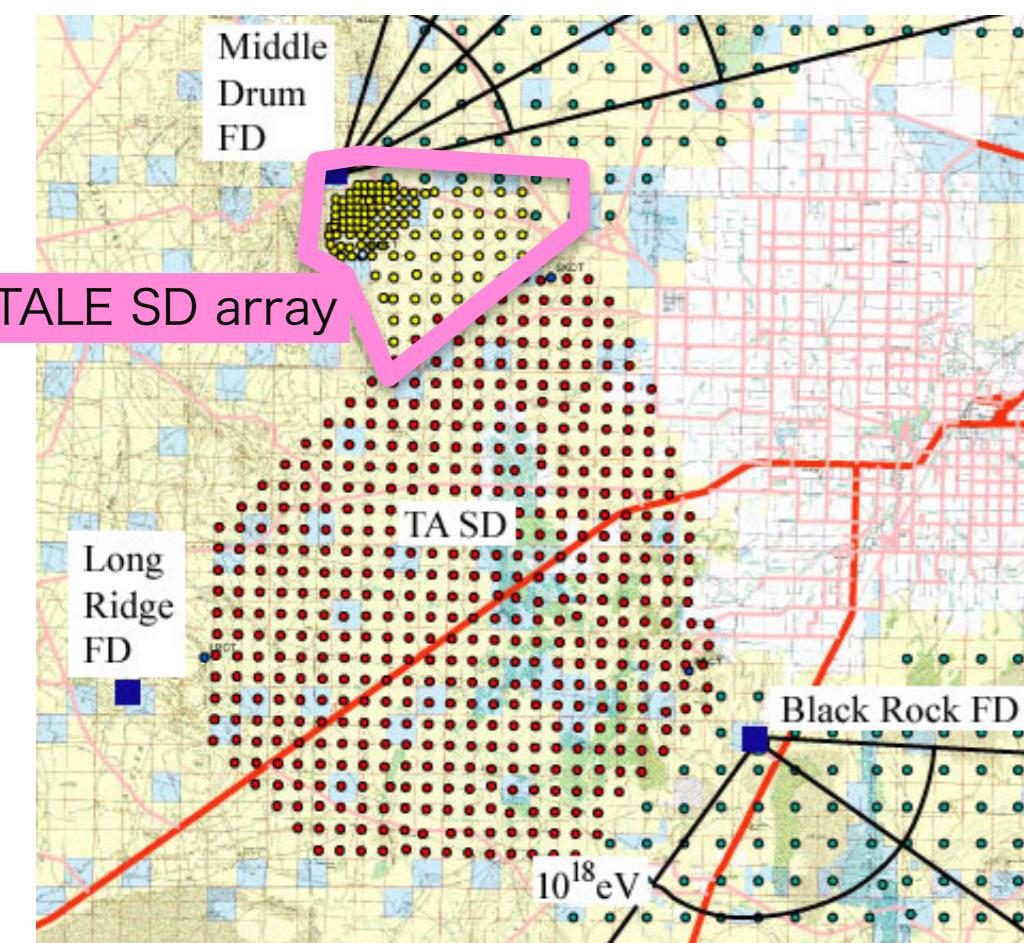
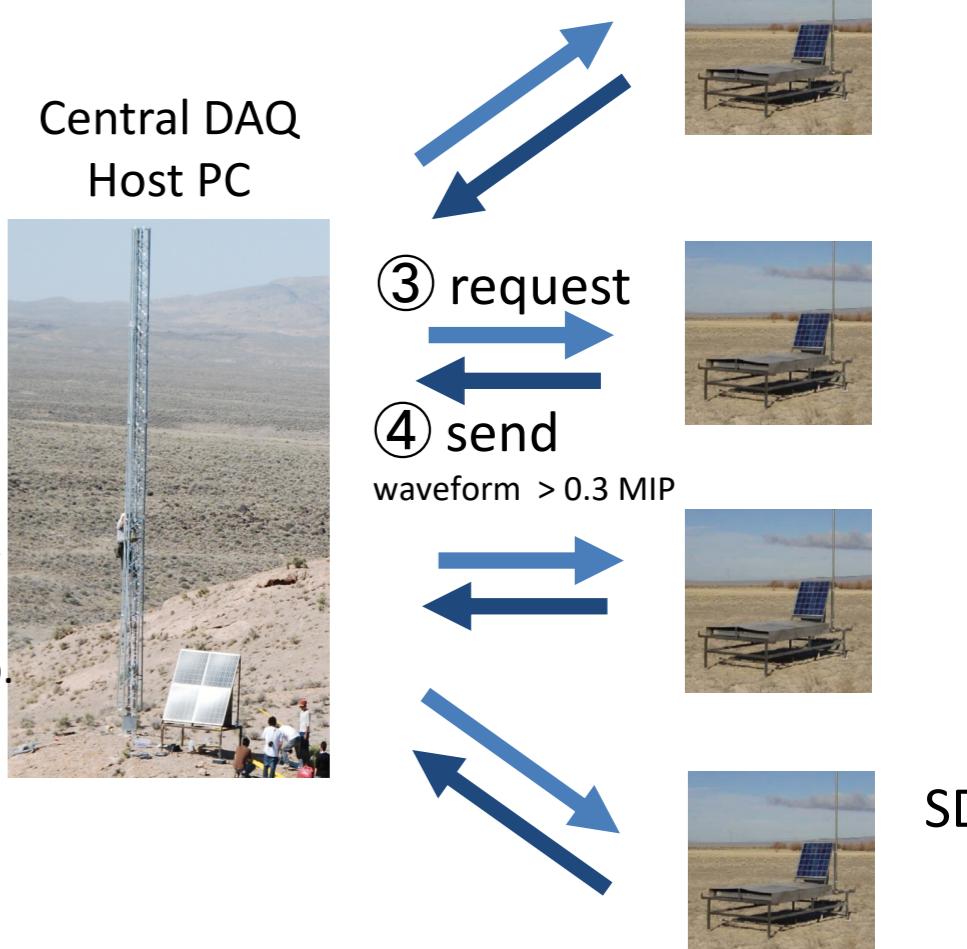


TALE - FD

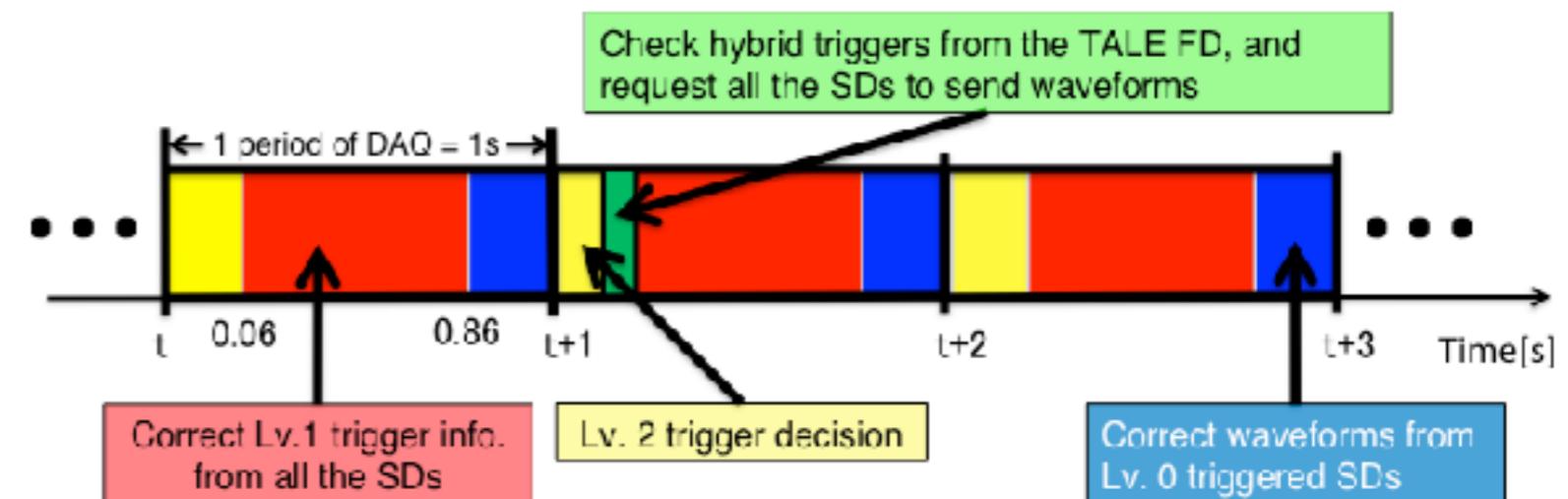
2

Request SDs

 to record waveform
with FD event time info

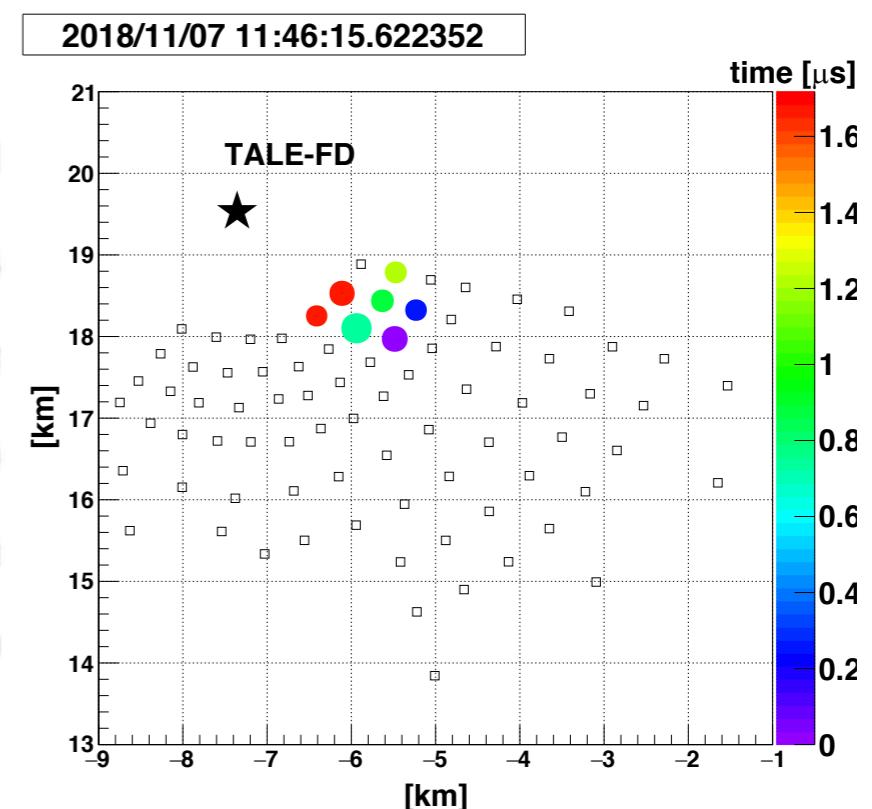
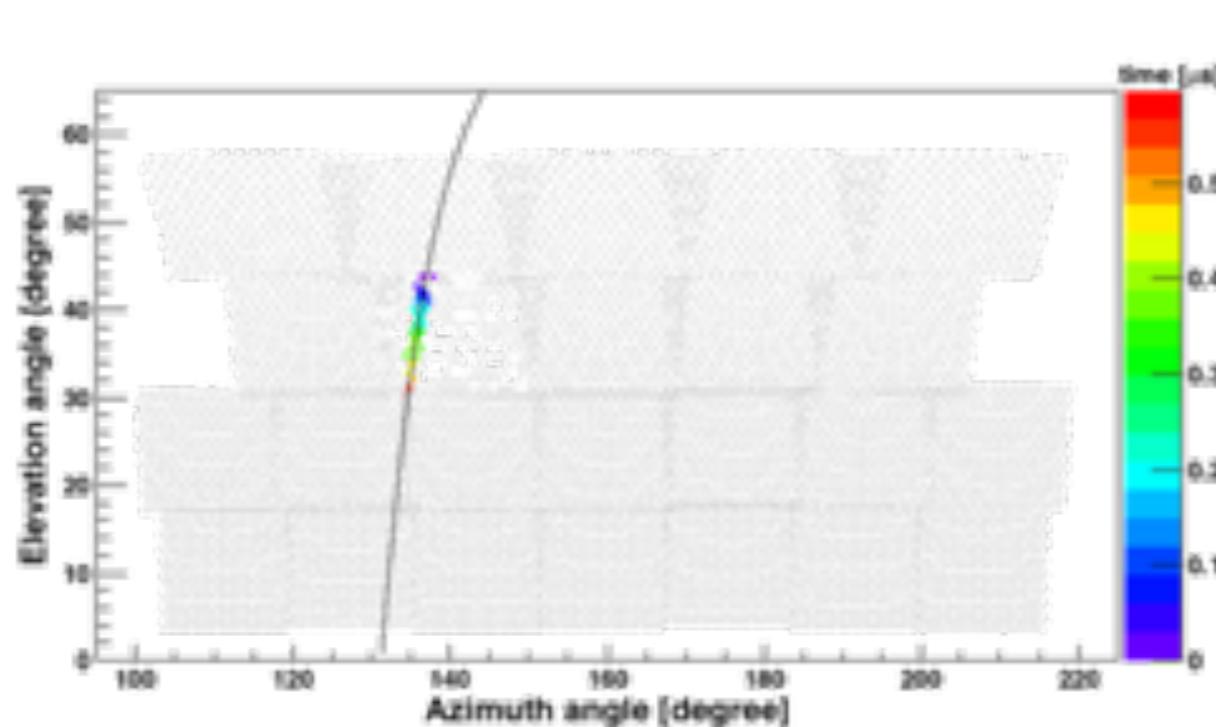
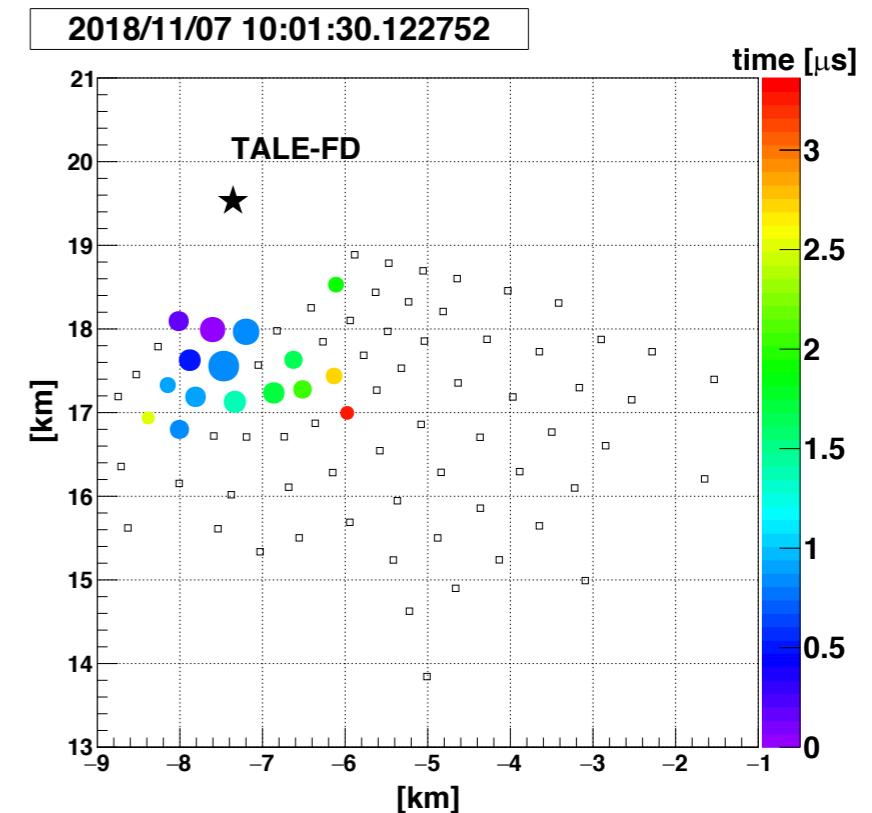
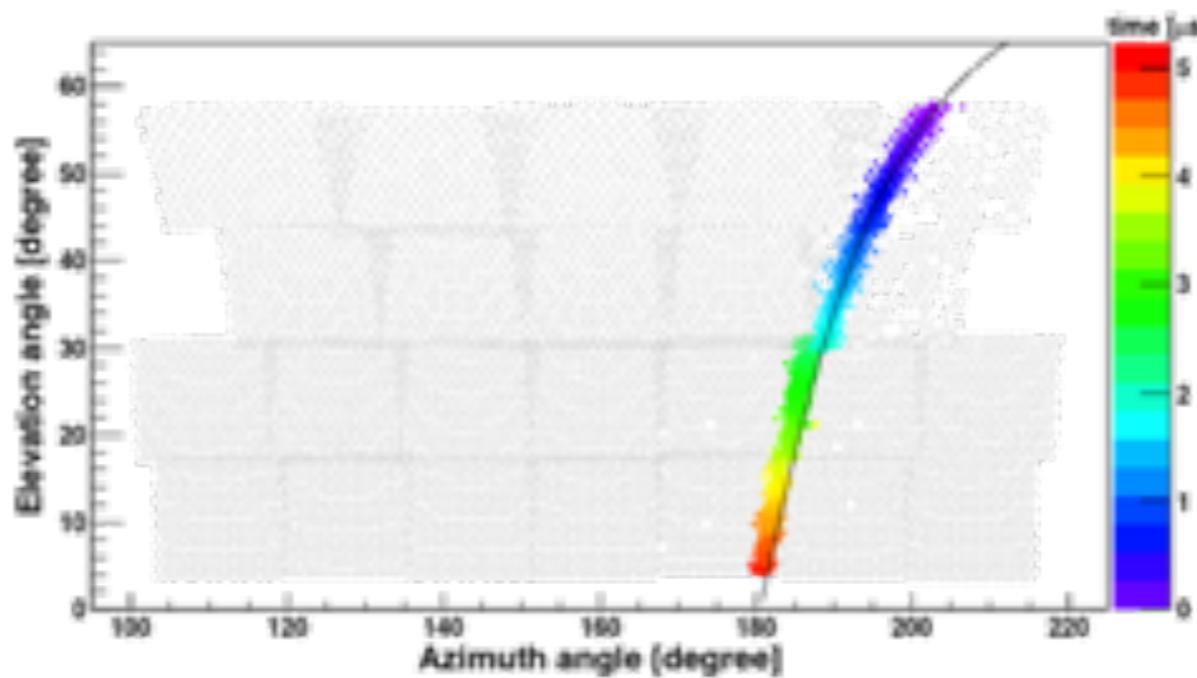


DAQ sequence(time chart) in the host PC



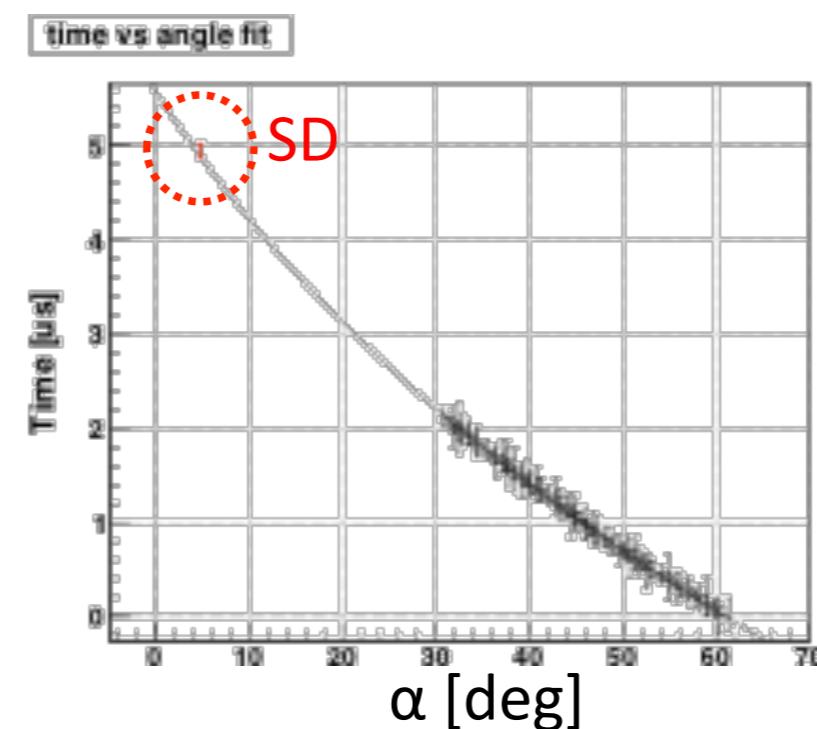
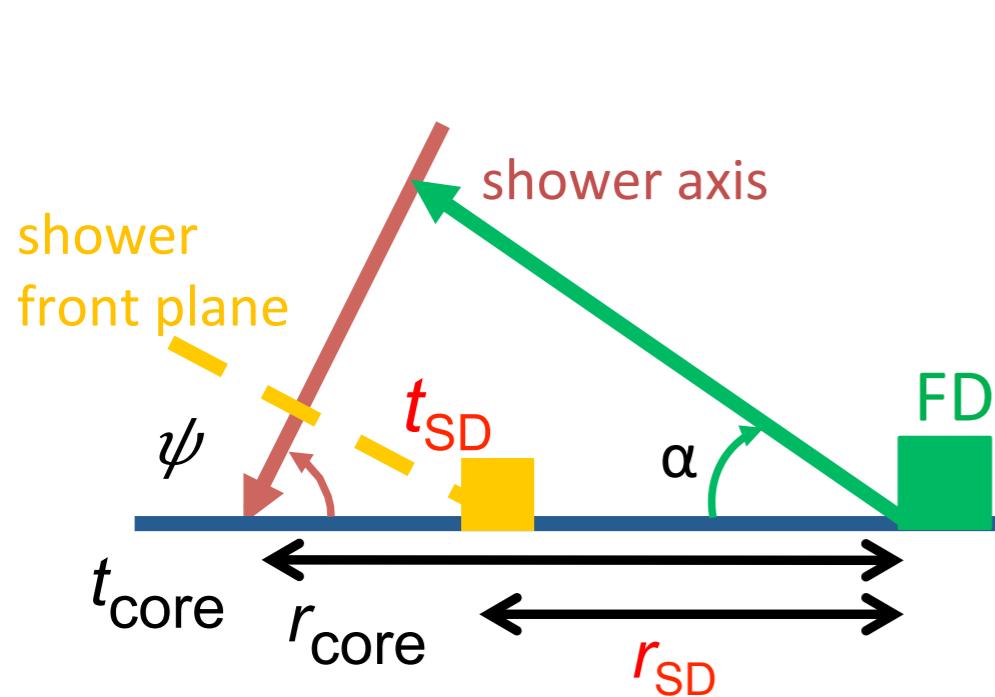
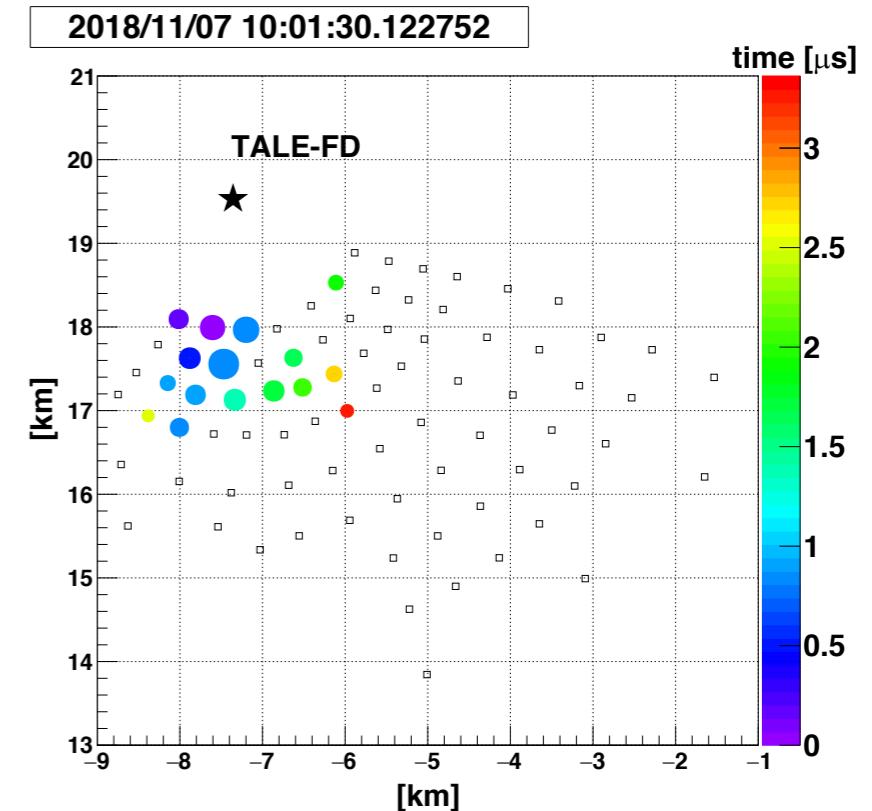
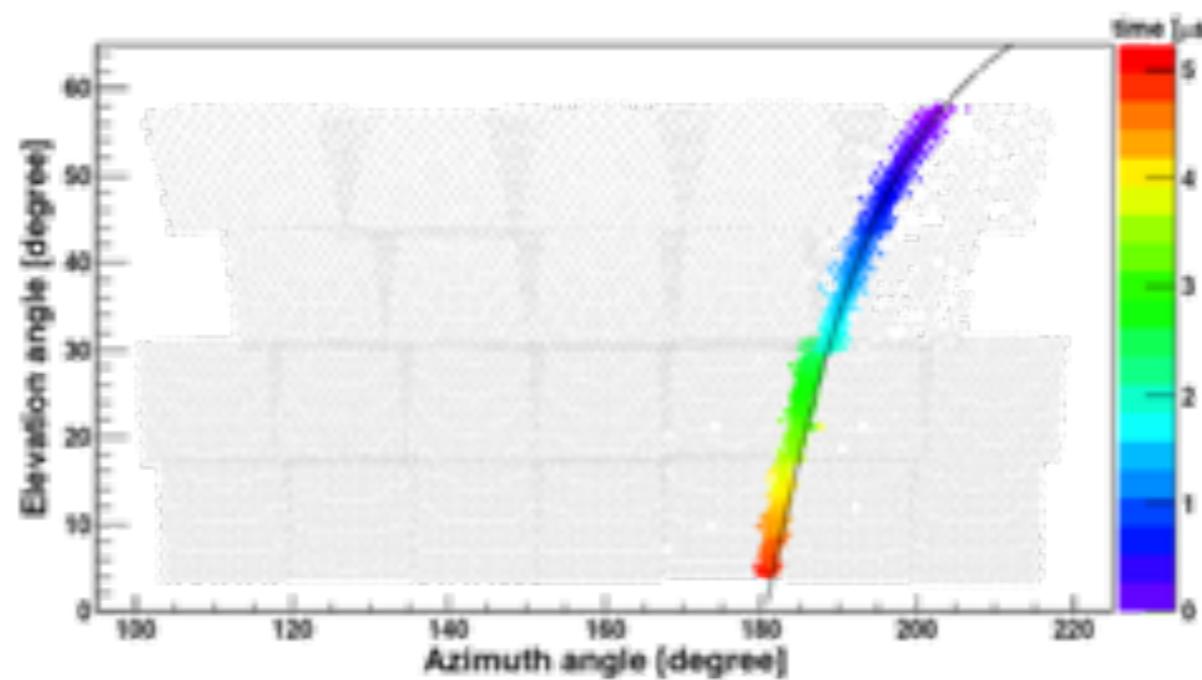
TALE Hybrid: real event sample

Real hybrid event samples in Nov. 7, 2018



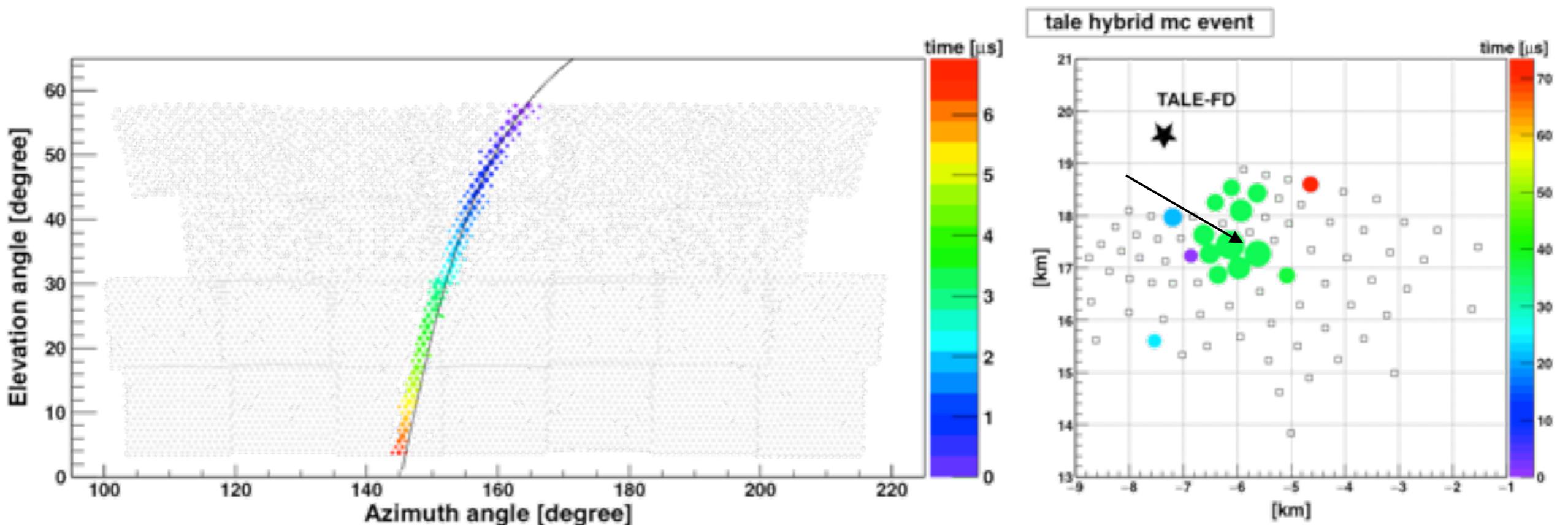
TALE Hybrid: real event sample

Real hybrid event samples in Nov. 7, 2018



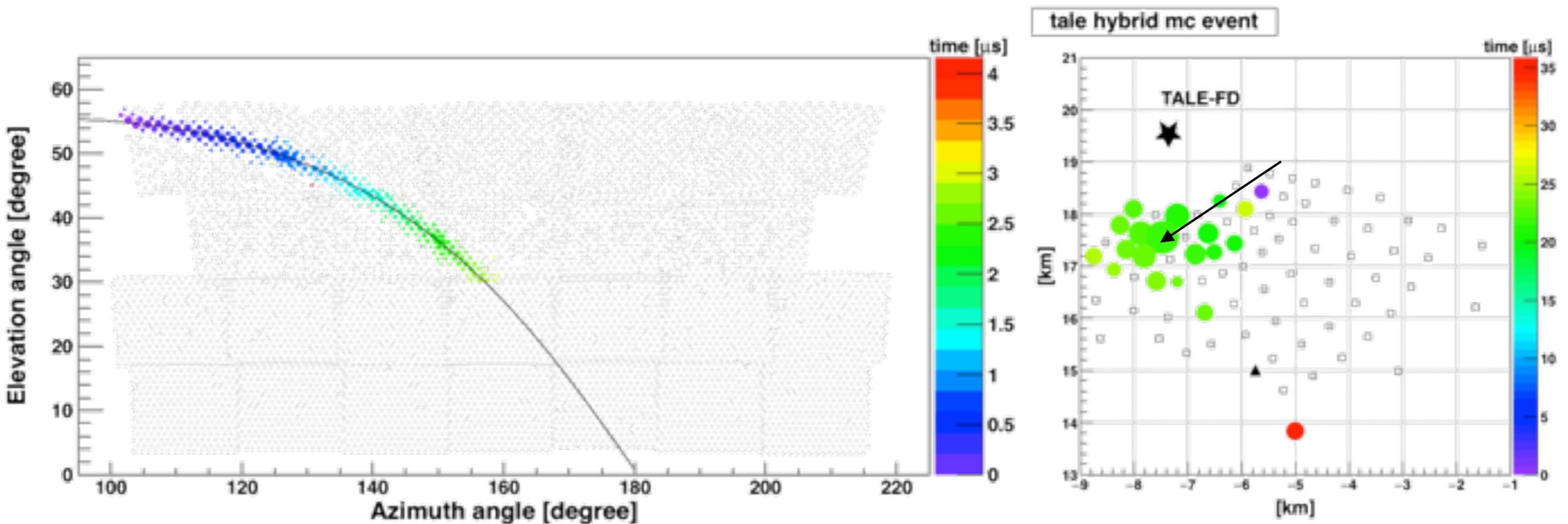
Zen.[deg]	Azi.[deg]
23.6	-33.5
CoreX[km]	CoreY[km]
7.33	17.63
Xmax[g/cm ²]	E[eV]
823	$10^{17.94}$

TALE Hybrid: MC event sample



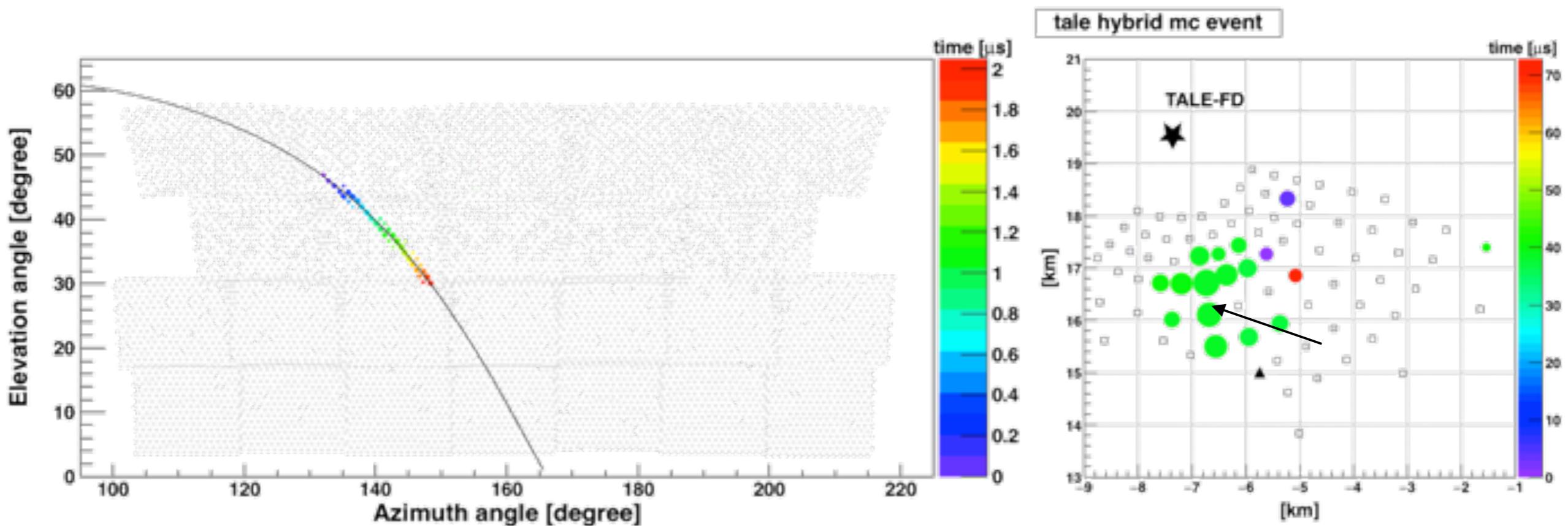
Results	Zen.[deg]	Azi.[deg]	Rp[km]	ψ [deg]	CoreX[km]	CoreY[km]	X_{lmax} [g/cm ²]	E_0 [eV]
thrown	21.6	-65.8	2.33	71.6	-5.86	17.51	734	$10^{17.89}$
hybrid	21.7	-66.3	2.32	71.8	-5.89	17.50	737	$10^{17.83}$
mono	20.5	-68.7	2.35	73.3	-5.88	17.49	725	$10^{17.83}$

TALE Hybrid: MC event sample



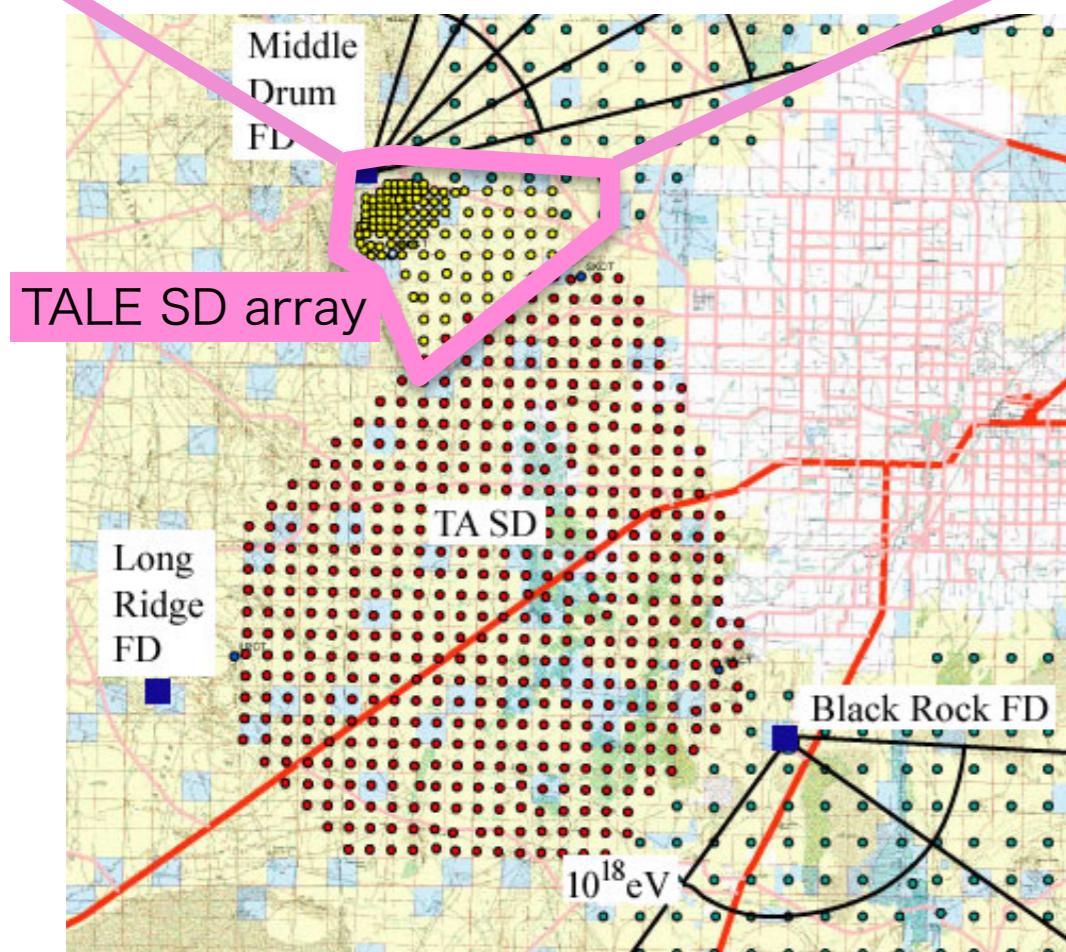
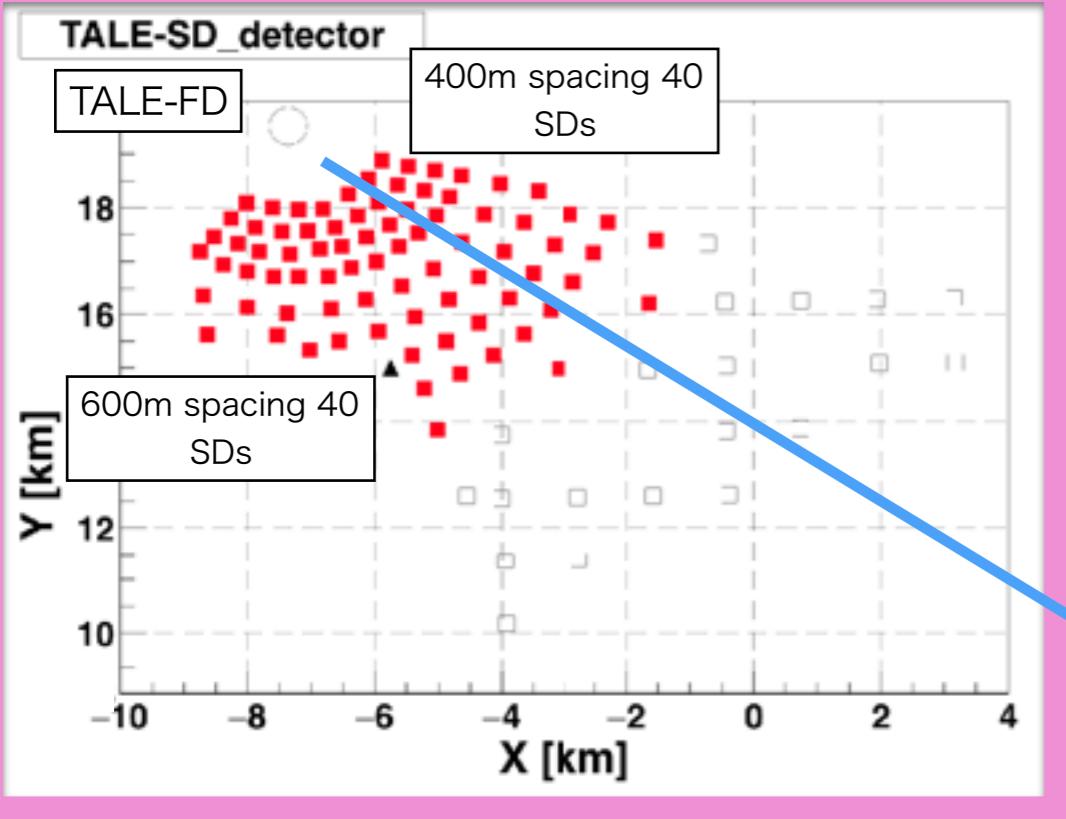
Results	Zen.[deg]	Azi.[deg]	Rp[km]	ψ [deg]	CoreX[km]	CoreY[km]	X_{lmax} [g/cm ²]	E ₀ [eV]
thrown	40.7	52.7	1.78	67.3	-7.46	17.51	781	$10^{17.94}$
hybrid	41.8	51.1	1.74	65.0	-7.51	17.51	789	$10^{17.89}$
mono	38.2	61.4	1.85	72.6	-7.51	17.52	743	$10^{17.85}$

TALE Hybrid: MC event sample

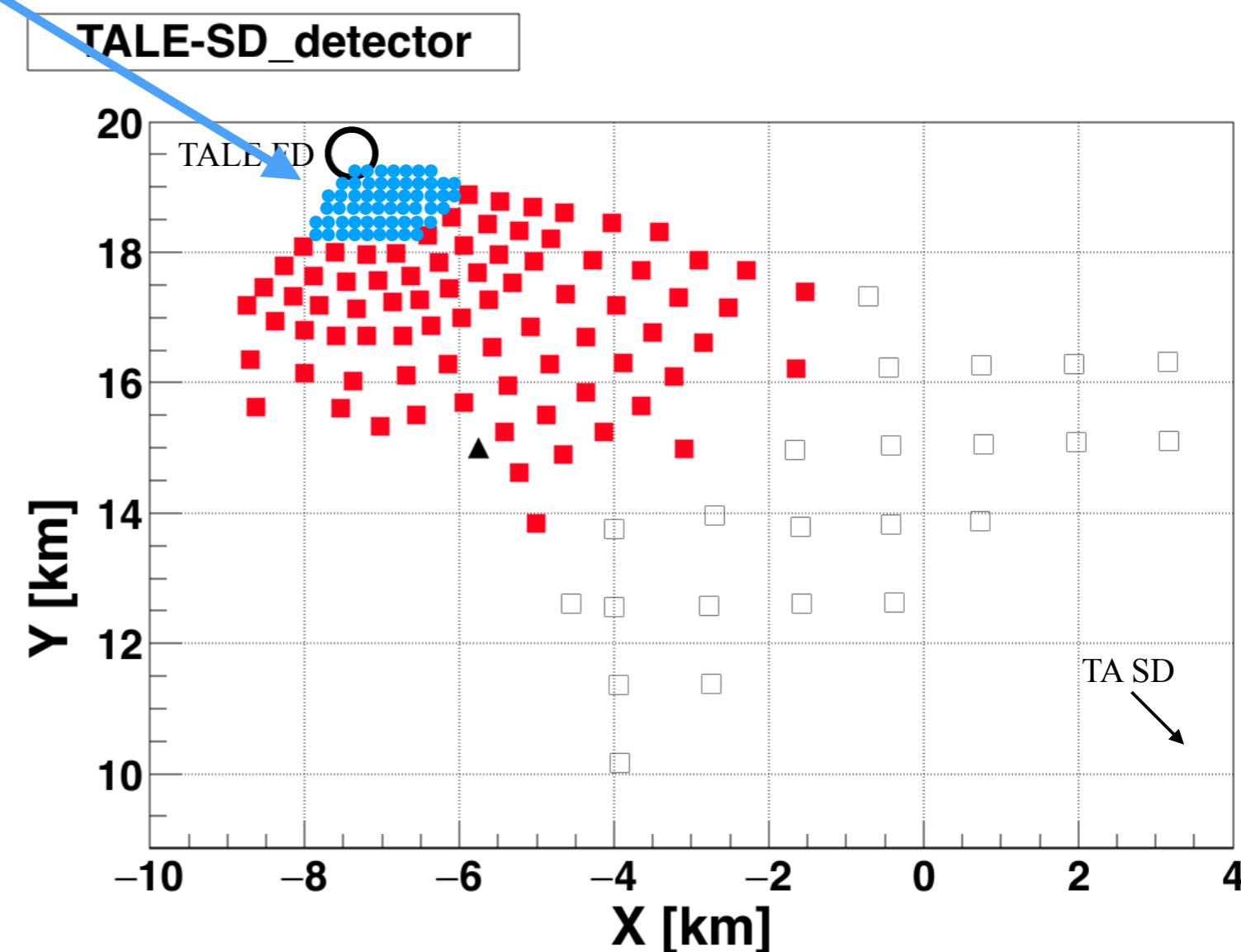


Results	Zen.[deg]	Azi.[deg]	Rp[km]	ψ [deg]	CoreX[km]	CoreY[km]	$X_{\downarrow max}$ [g/cm ²]	E ₀ [eV]
thrown	33.0	112.4	3.03	109.3	-6.66	16.46	689	$10^{17.88}$
hybrid	32.1	109.1	3.14	106.9	-6.68	16.38	676	$10^{17.82}$
mono	52.1	142.0	3.35	136.2	-6.35	15.04	x	x

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, $E_{mode} = 10^{15.5}$ eV
for FD-SD hybrid, $E_{mode} = 10^{16.3}$ 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\$