The TA × 4 experiment

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Outline

- Motivation of the TA × 4 Experiment
- Design of the TA × 4 Surface Detector (SD) Array
- Design of TA × 4 SDs
- Construction of the SDs
- Performance of the SDs
- Future Prospects
- Summary
Indications of anisotropy: hotspot observed by the TA experiment

- TA experiment 5 years observation, 72 events with $E > 57$ EeV
- Max. local significance: $5.1 \sigma$
  - Observed: 19 events, Expected from isotropy: 4.5 events in the direction
- Chance probability to exceed the local significance $5.1 \sigma$: $3.4 \sigma$
- First observation of anisotropy at the highest energies with high significance

Arrival directions of $E > 57$ EeV cosmic rays

Significance map

Equatorial coordinate

20 degrees oversampling from each event

The TA × 4 Experiment

- 500 SDs, 2.08 km spacing for
- 4 × TA SD detection area (~3000 km²) combined with TA SD
  - accepted by Japan in April 2015
  - first 100 SDs arrived at Utah in spring 2016
  - Applied to build 2 FD station (4+8 HiRes Telescopes) to US NSF
    - accepted in 2016

→ Take 19 years TA SD data

Take 16.3 years SD and FD hybrid data
Design of the TA × 4 SD array

- E > 57 EeV: reconstruction efficiency > 95%
- Angular resolution: 2.2°
- Energy resolution: ~25%
Design of TA × 4 SDs

- 2 layers 3 m² 1.2 cm thick plastic scintillators
  → Calibration of signals using single muon
- DAQ with 2.4 GHz wireless communication
- 6 new communication towers
Design of TA × 4 SDs

PMT: Hamamatsu R8619
(PMTs in TA SD: ET9124)

- Quantum efficiency ~20% at 500 nm (~10% ET9124)
- Pulse linearity ~50 mA (25 mA ET9124)
- Position dependence of the output signal on the photo cathode < ~10%

→Change of the arrangement of wavelength shifting fibers
Total length of fibers ~33% of TA SD
Construction of 173 TA × 4 SDs

- 100 scintillator boxes were assembled in Meisei company (Japan) in winter 2015
- 73 scintillator boxes were assembled in Akeno Observatory (Japan) in summer 2016
- 3 supervisors + 6-7 company people/students/staffs
- 4-5 scintillator boxes were assembled per day.

Fibers are assembled

polishing fibers

2016/10/14
Calibration using single muon

Number of photo electrons corresponding to the single muon peak of each layer of SD:

$19.0 \pm 3.3$

All data points are inside of the distribution of TA SD ($24.6 \pm 7.2$)

Mean value of the Gaussian obtained by fitting ADC distribution of pedestal run

Typical charge ADC distribution obtained by taking coincidence of 2 layers of the SD

Relative single peak of sampled scintillators before the assembly (1 sample per (50/100))

16 scintillators are used for 1 SD
Linearity of PMTs were measured with 2 LEDs inside of SDs
Y-axis: Non-linearity of output current from PMTs
X-axis: Output current from PMTs
(1 count $\sim$ 0.01 mA)

Linearity of all assembled PMTs was checked.
Non-linearity < 10% for ADC val. of SD elec. < 4095

Typical non-linearity of PMTs

SD electronics
Max. ADC value
Position Dependence of the Signals

5 SDs measured
15 cm × 15 cm trigger probes
8 positions are measured at the same time
Position Dependence of the Signals

- Max. difference from the average: $\sim 20\%$
- Main source of the position dependence: decay length in the WLS fibers
  $\rightarrow$ Max. difference from the average of (up + low) signals: $\sim 15\%$
Future Prospects

- Transportation of scintillator boxes, mass production of electronics
- Assembly and deployment of SDs
- Construction of FDs
Future Prospects

Assumption:
The hotspot comes from 1 source with 10 deg. Gaussian $\sigma$.
Oversampling 20° radius circle

$N_{\text{total}}$: 305 events, 21 TA SD equivalent years
$N_{\text{BG}}$: 244 events isotropic background
$N_{\text{source}}$: 61 events (21 events and 40 events for 2 separated sources)

Assumption:
The hotspot comes from 2 separated sources with $1\sigma=10$ deg. and with $1\sigma=5$ deg..
Oversampling 15° radius circle
**Future Prospects**

- **Energy spectrum**: more detailed spectrum shape at the highest energies with \( \sim 21 \) TA SD equivalent years data
- **Composition**: \( X_{\text{max}} \) using SDFD hybrid events with high statistics will be also provided.
Summary

• Construction of TA × 4 SDs and FDs was funded.
• 173 scintillator boxes of SDs were already assembled.
• Number of photo electrons corresponding to the single muon peak is $19.0 \pm 3.3$. The plastic scintillators determines the fluctuation.
• In the range of SD electronics, non-linearity of all PMTs <10%.
• Preliminary max. position dependence of up+low signals < ~15%
• First 100 scintillator boxes arrived at Utah in spring 2016.
• 2 FD stations will be also constructed in the near future.
Back Up
## Schedule of TA×4

<table>
<thead>
<tr>
<th>JFY</th>
<th>construction or observation</th>
<th>surface detector (SD)</th>
<th>hybrid (HYB)</th>
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<tr>
<td></td>
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<td>TA SD (=1) (=1)</td>
<td>additional SD (=3)</td>
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<tr>
<td>2019</td>
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<tr>
<td>total</td>
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</table>

JFY: Japanese Fiscal Year that starts in April
Examples of Energy Spectra

w/o E resolution

With E resolution

\[ \Delta \ln(E) = 0.3 \]
Expected significance of the hotspot considering energy resolution effect
Efficiency for the energy spectrum analysis

- Number of good SDs $\geq 4$
- Zenith Angle $< 45$ degree
- LDF (only) Chi2/Dof $< 10$
- Pointing direction uncertainty $< 8$ degrees
- Sigma_S800/S800 $< 0.26$

- 50% reconstruction efficiency, 3.2 degree angular, and 27% energy resolution, $E > 32$ EeV (spectrum cuts)
Resolution

• Ta sd: $E > 57 \text{ EeV}$ 1-1.7 deg
• 15-20% energy resol.
TAX4 SD arrangement of fibers

• 2 layers of 1.2 cm thick plastic scintillators
• The distance b/w fibers: 2 cm → 4 cm
  → Number of photons from fibers ~1/2 of TA SDs
  No problem in efficiency
• Length of fibers: 5 m → 6.1 m
  Arrangement of fibers is changed
• Total length of fibers
  5 m × (208 + spare) → 6.1m × 56
  ~33% of TA SD
Connection of the surface of TAx4 SD PMT with fibers

- Holder of the fiber bundle: transparent → white
  ~9% more number of photons
- Size of the fiber bundle is smaller.
  Diameter: ~20 mm → 8.7 mm
- Optical grease (Optseal: Shin-etsu Chemical Co. Ltd.) is used
その他R&D

鳥の被害対策: バードスパイク, ケーブル保護チューブの検討

エレクトロニクス用リブートタイマー CN101A
全SDに設置予定、週に一度自動リブート

現在TA実験の
SDアレイで試験中
→SDへのアクセスを軽減