The TA × 4 experiment

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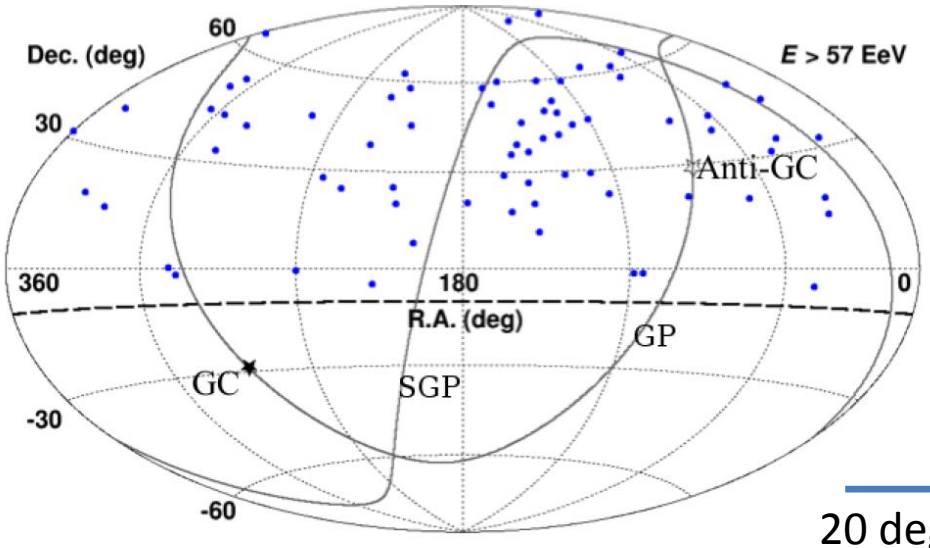
Outline

- 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

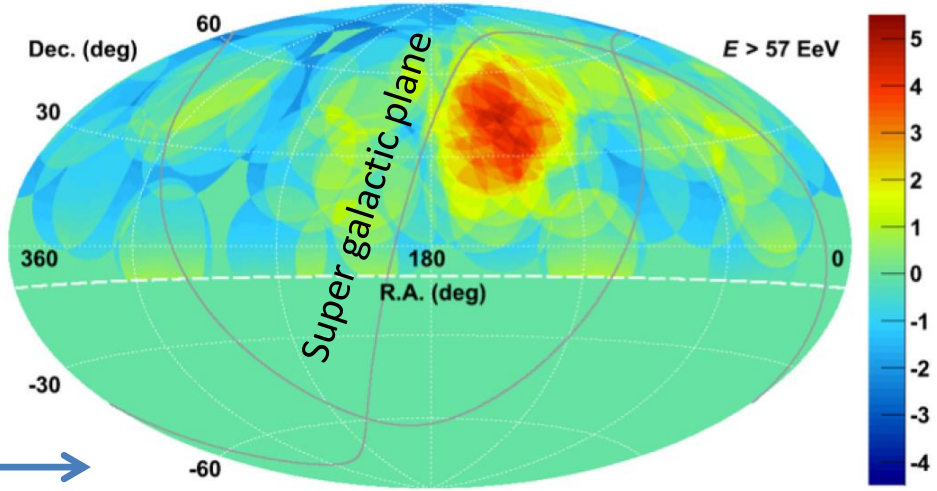
Arrival directions of E > 57 EeV cosmic rays



Equatorial coordinate

20 degrees oversampling from each event

Significance map

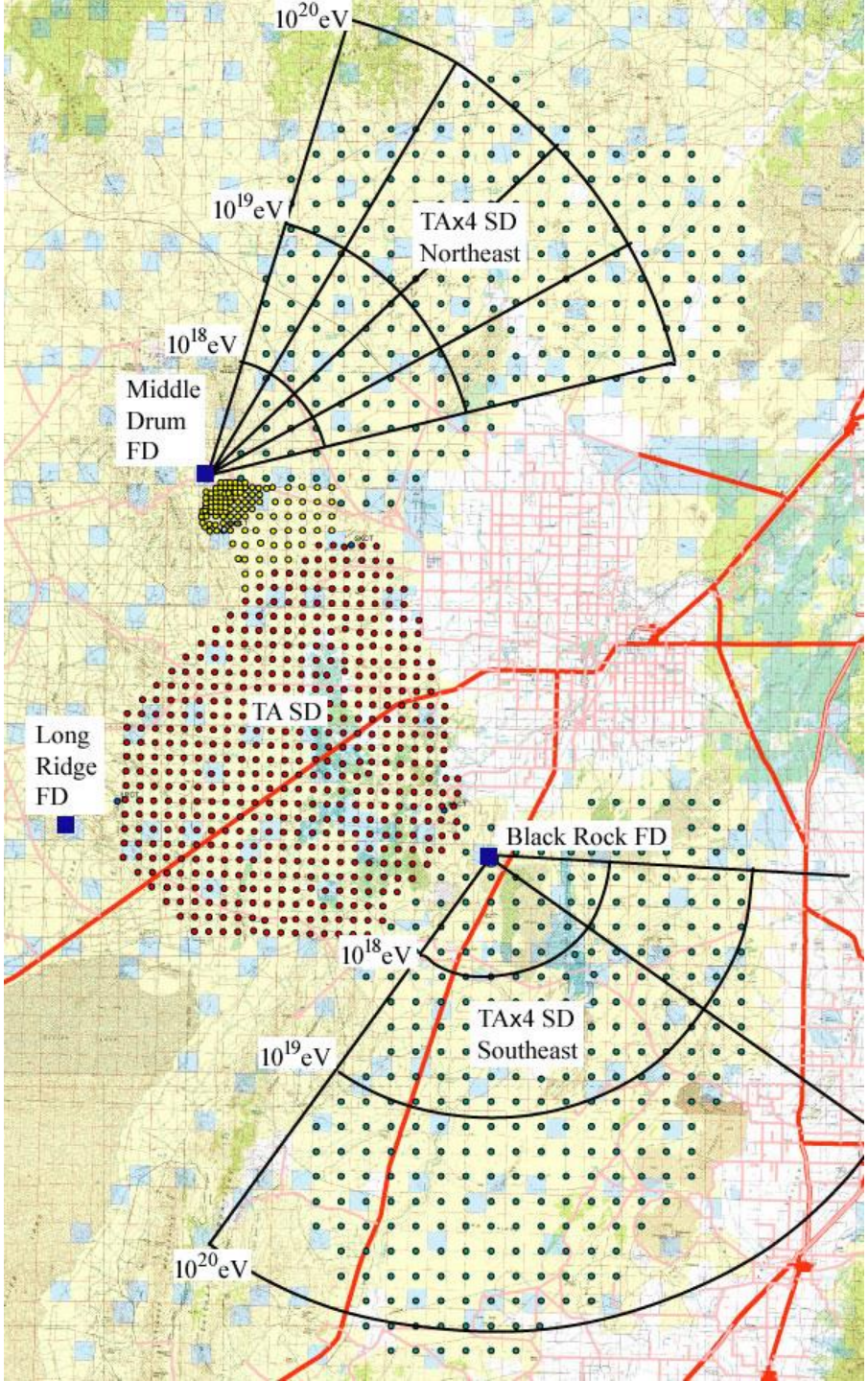


Equatorial coordinate

ApJ 720, L21 (2014)

- TA experiment 5 years observation, 72 events with E > 57 EeV
- Max. local significance: 5.1 σ

  Observed: 19 events, Expected from isotropy: 4.5 events in the direction
- Chance probability to exceed the local significance 5.1 σ: **3.4 σ**
- **First** observation of **anisotropy** at the highest energies with high significance



The TA × 4 Experiment

500 SDs, **2.08 km** spacing for

4 × TA SD detection area (~3000 km^2)

combined with TA SD

accepted by Japan in April 2015

first 100 SDs arrived at Utah

in spring 2016

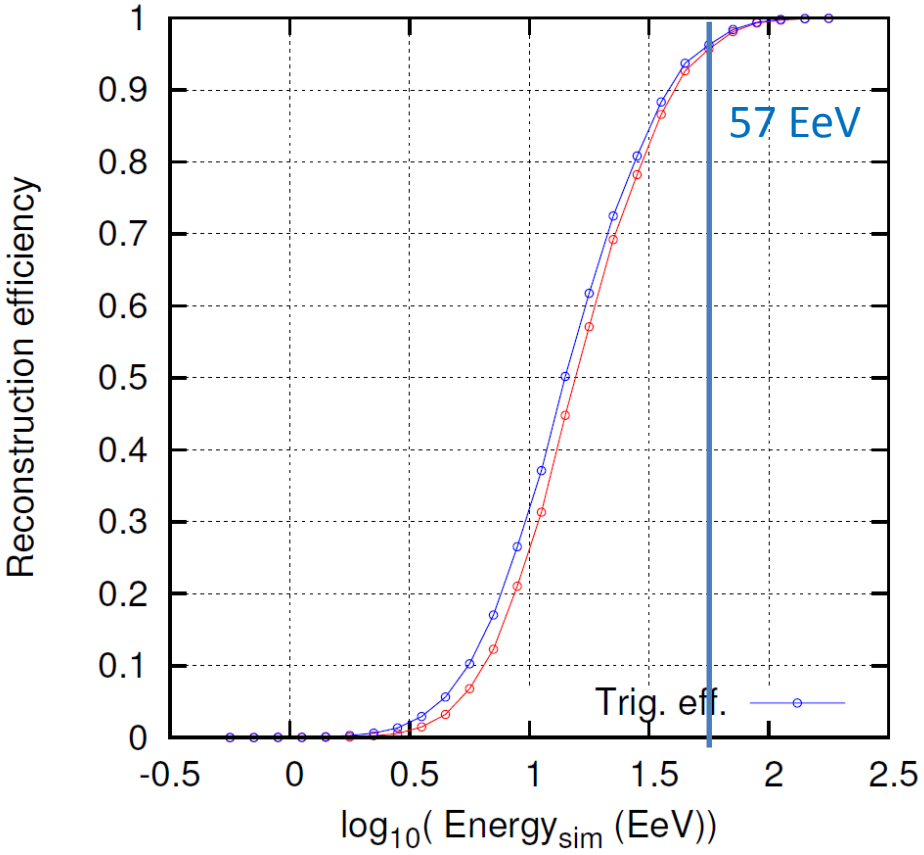
Applied to build 2 FD station (4+8 HiRes Telescopes) to US NSF

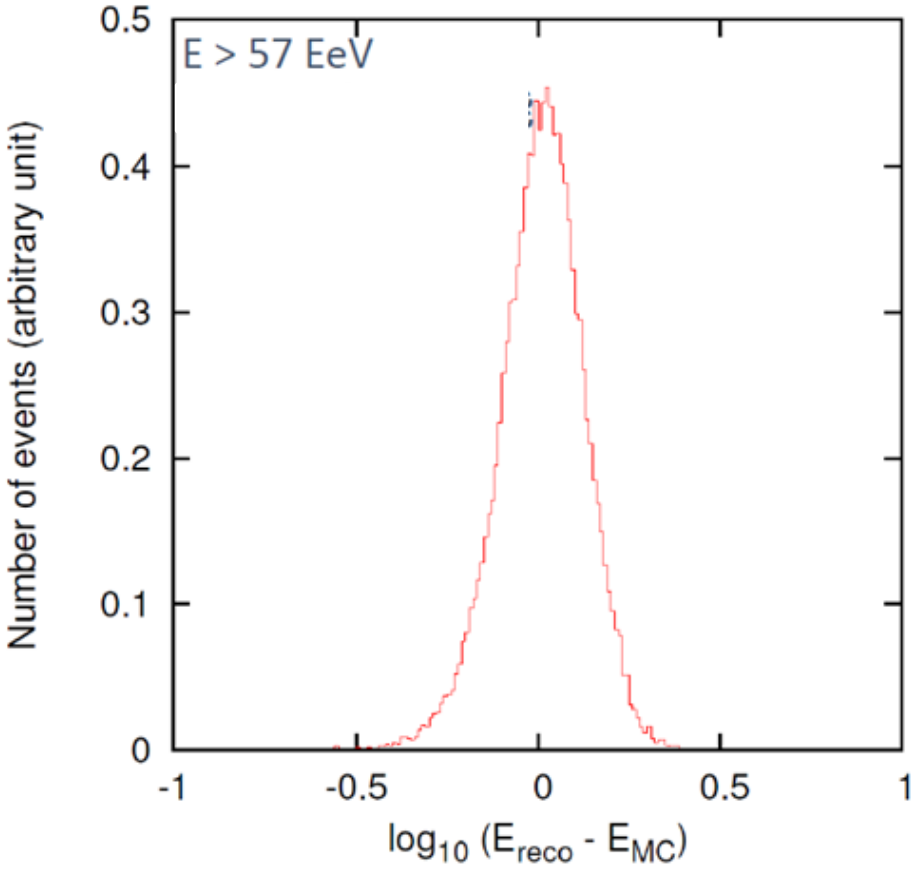
accepted in 2016

→ **Take 19 years TA SD data**

Take 16.3 years SD and FD hybrid data

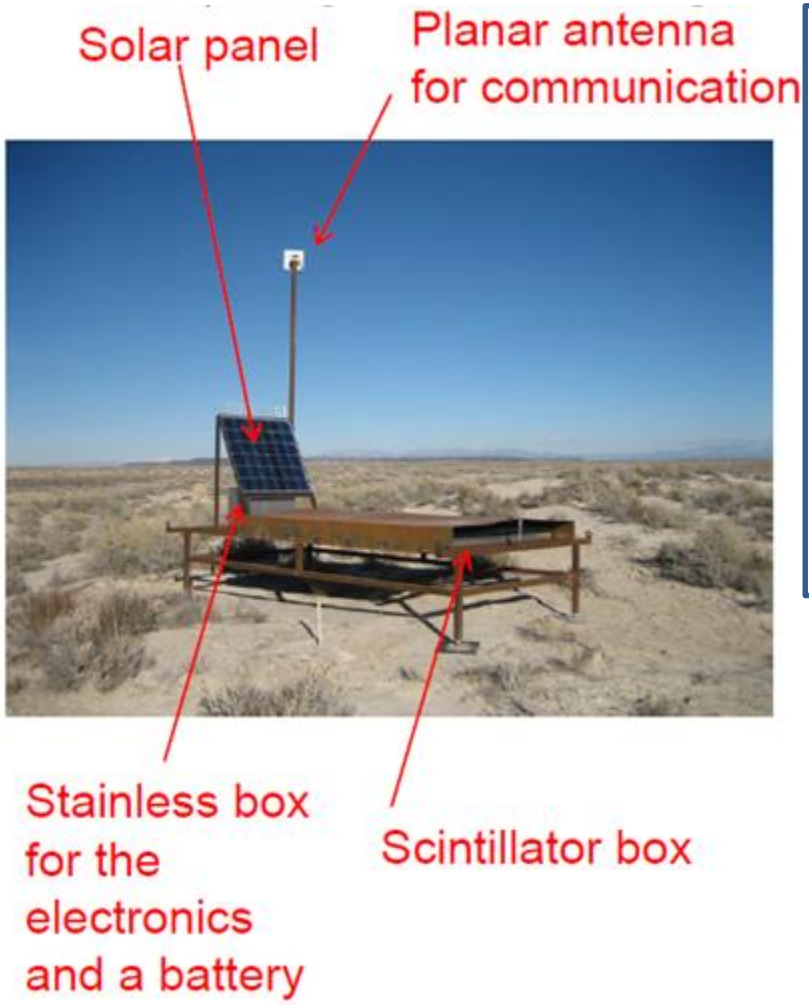
Design of the TA × 4 SD array

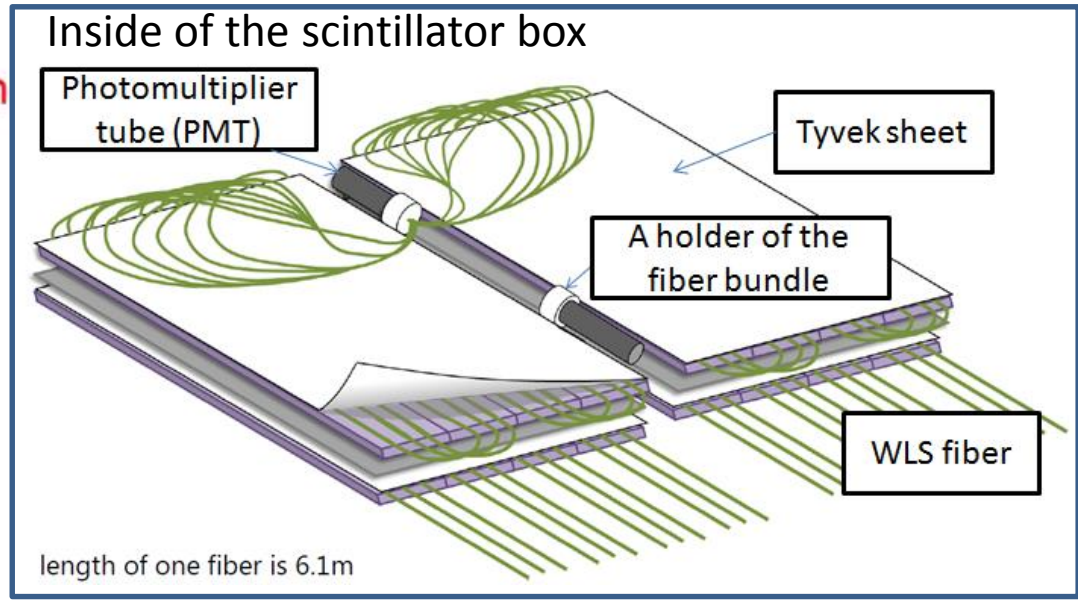




- E > 57 EeV: reconstruction efficiency > 95%
- Angular resolution: 2.2˚
- Energy resolution: ～25%

Design of TA × 4 SDs



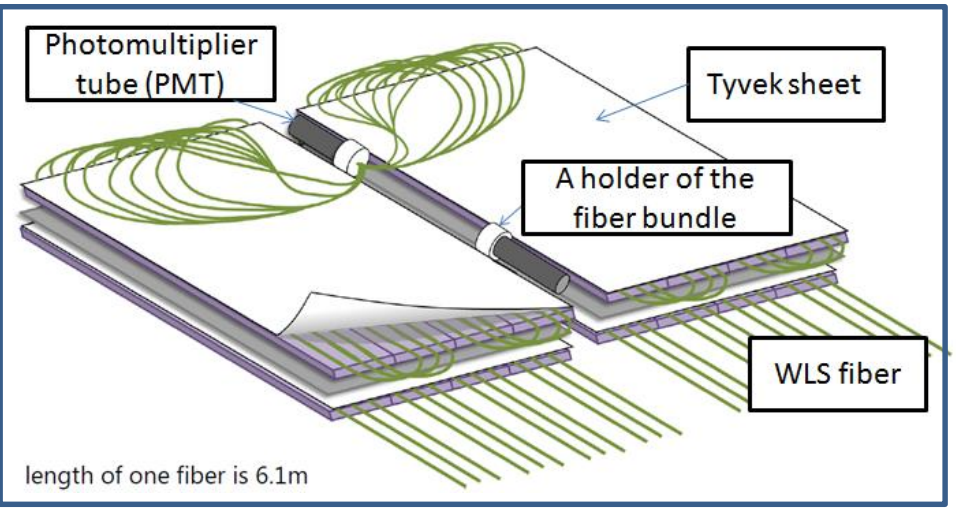


- 2 layers 3 m^2 1.2 cm thick plastic scintillators

→ Calibration of signals using single muon

- DAQ with 2.4 GHz wireless communication
- 6 new communication towers

Design of TA × 4 SDs



Optical grease
(Optseal: Shin-etsu Chemical Co. Ltd.)
b/w fibers and PMT

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

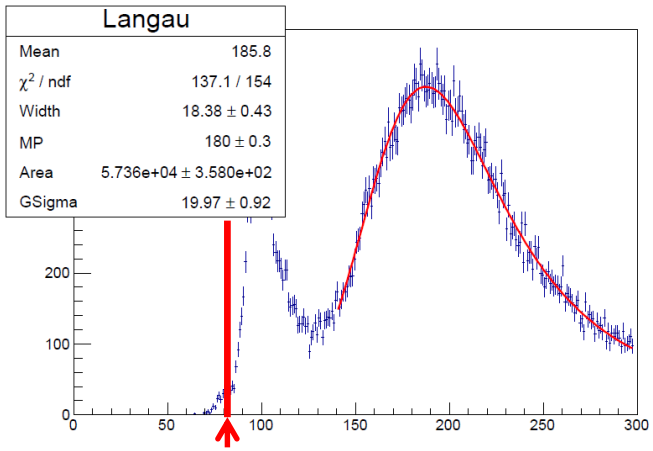
Construction of 173 TA × 4 SDs

Fibers are assembled

polishing fibers

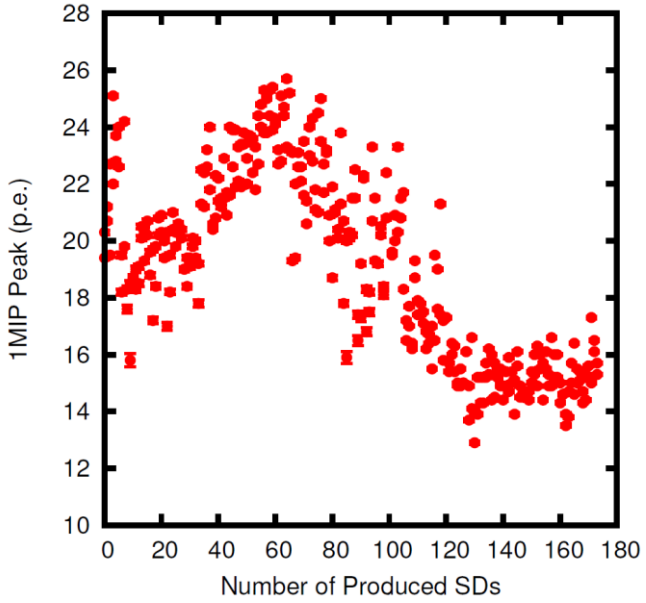
- 100 scintillator boxes were assembled in Meisei company (Japan) in winter 2015
- 73 scintillator boxes were assembled in Akeno Observatory (Japan) in summer 2016
- 3 supervisors + 6-7 company people/students/staffs
- 4-5 scintillator boxes were assembled per day.

Calibration using single muon

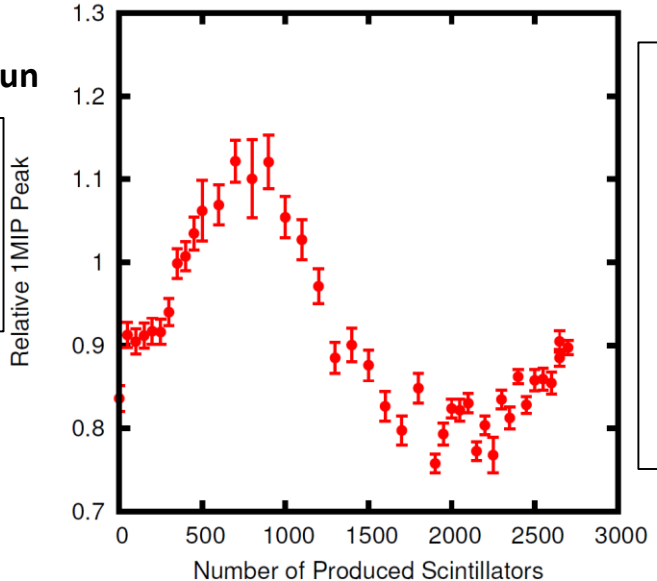


Mean value of the Gaussian
obtained by fitting ADC distribution of **pedestal run**

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



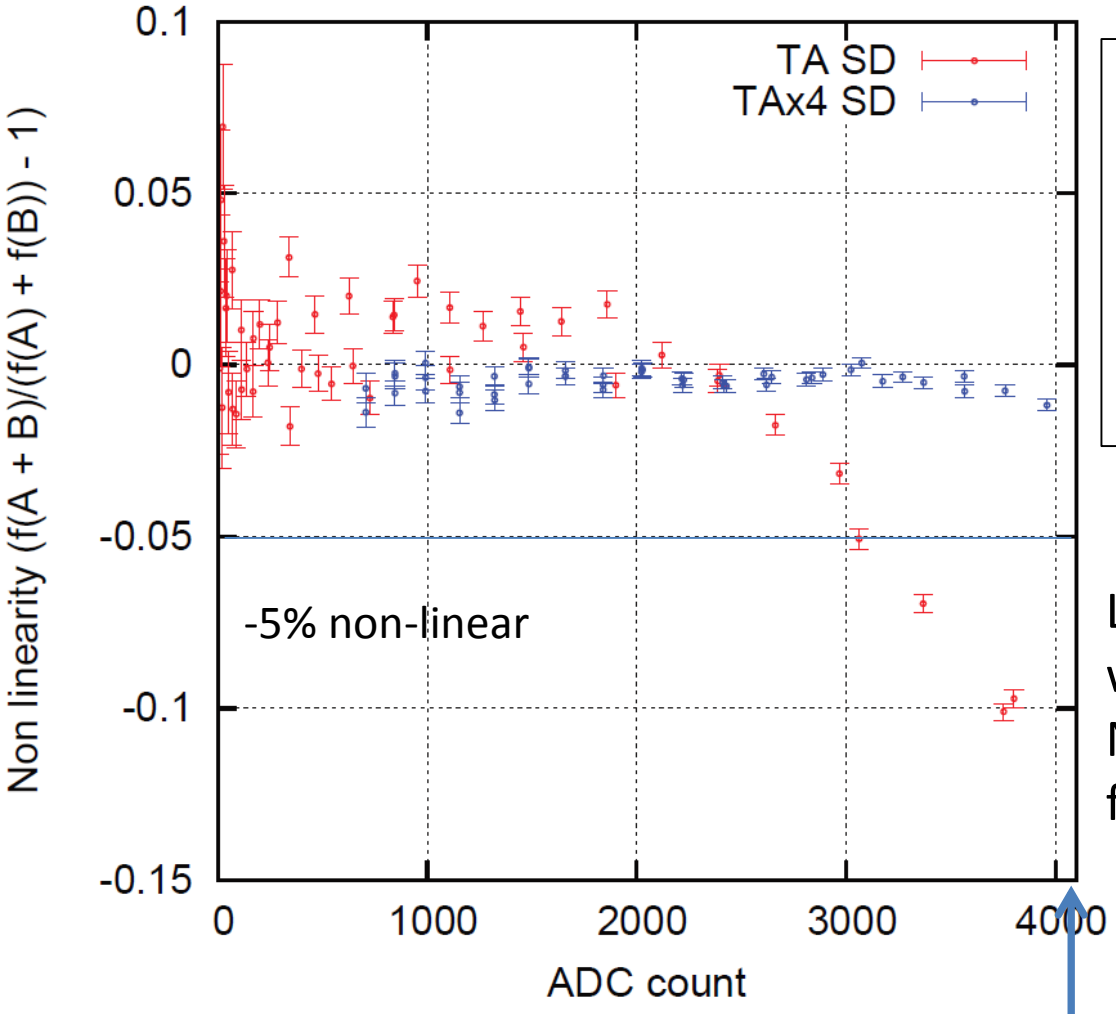
Number of photo electrons corresponding to the single muon peak of each layer of SD :
19.0±3.3
All data points are inside of the distribution of TA SD (24.6±7.2)



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

16 scintillators are used for 1 SD

Linearity of PMTs



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～0.01 mA)

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

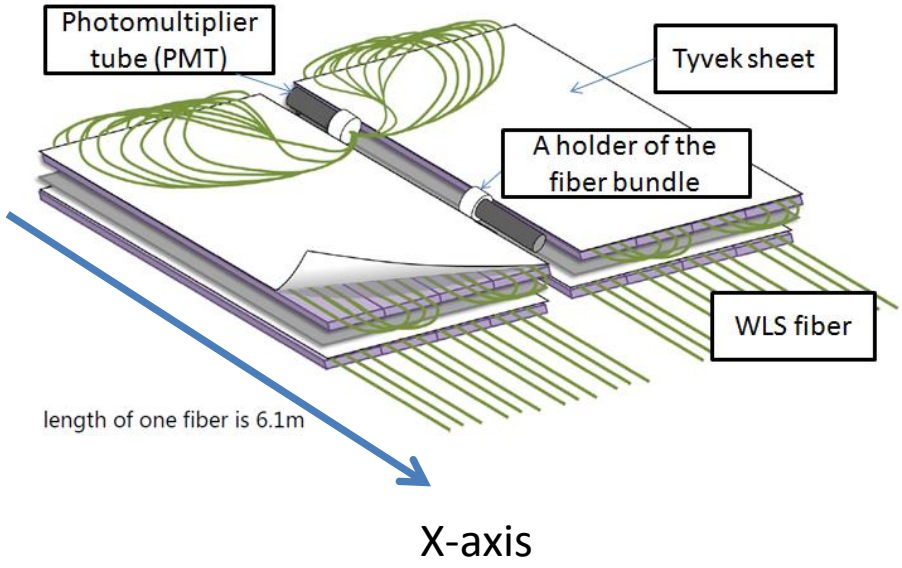
Typical non-linearity of PMTs

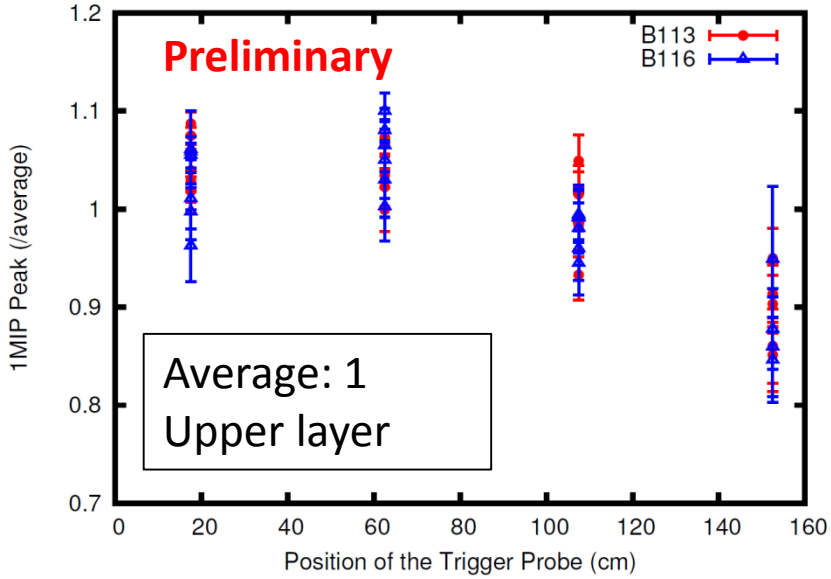
SD electronics
Max. ADC value

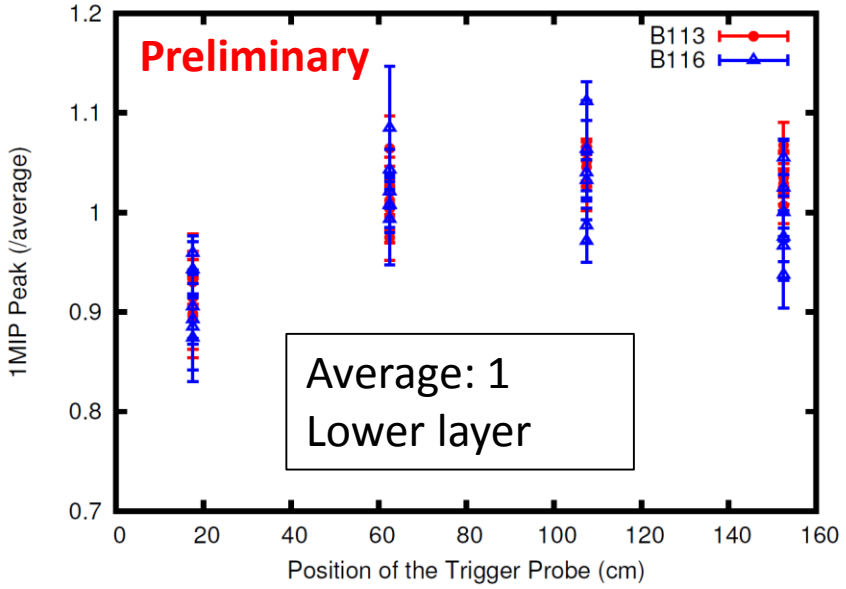
Position Dependence of the Signals

5 SDs measured
15 cm × 15 cm trigger probes
8 positions are measured at the same time

Position Dependence of the Signals







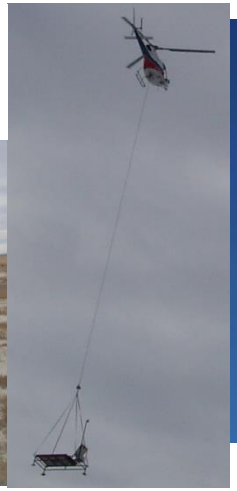
- Max. difference from the average: ~20%
- Main source of the position dependence: decay length in the WLS fibers
  → Max. difference from the average of (up + low) signals: ~15%

Future Prospects

May 2016

May 2016

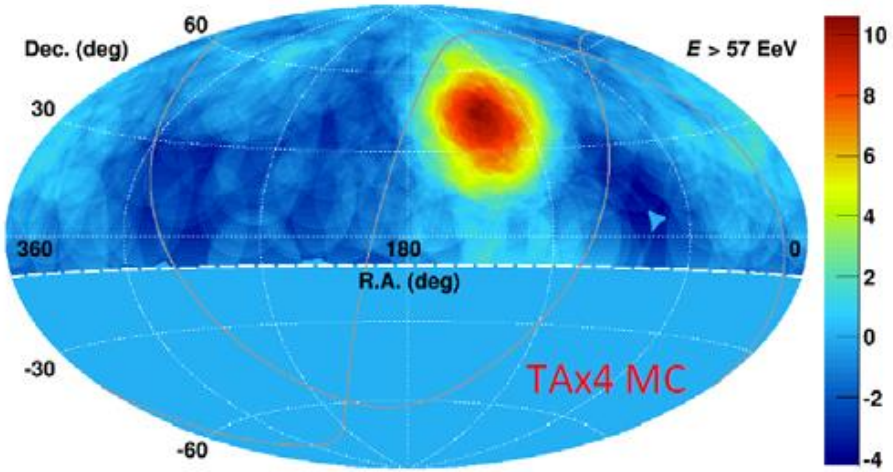
Pictures in 2011



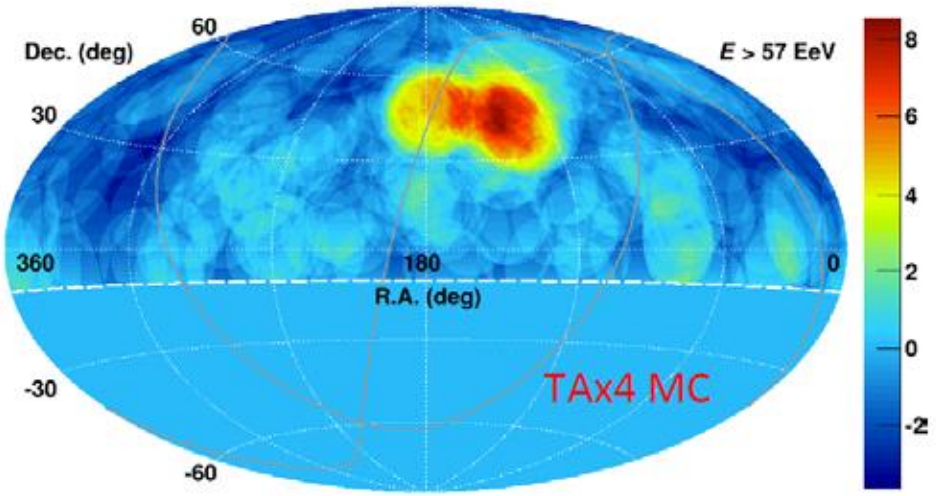
picture in 2004

- 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 σ.
Oversampling 20° radius circle

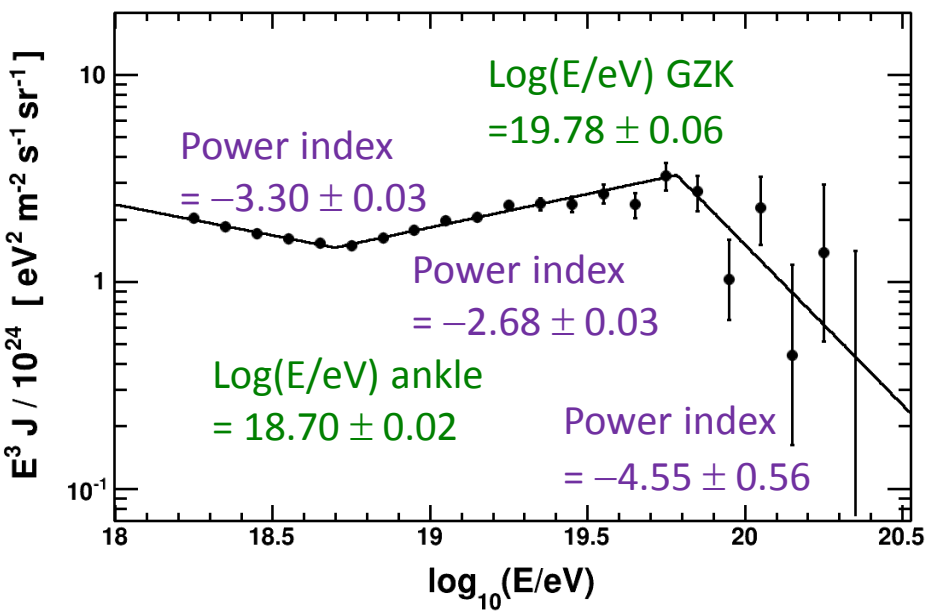


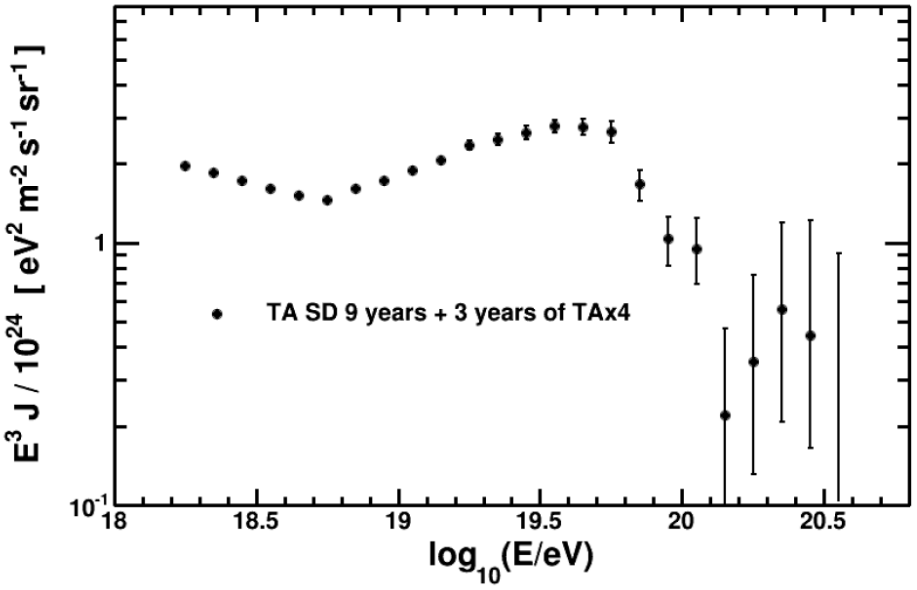
Assumption:
The hotspot comes from 2 separated sources with 1σ=10 deg. and with 1σ=5 deg..
Oversampling 15° radius circle

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

Future Prospects

TA SD energy spectrum (7 years data)





- Energy spectrum: more detailed spectrum shape at the highest energies with ～21 TA SD equivalent years data
- Composition: Xmax 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±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

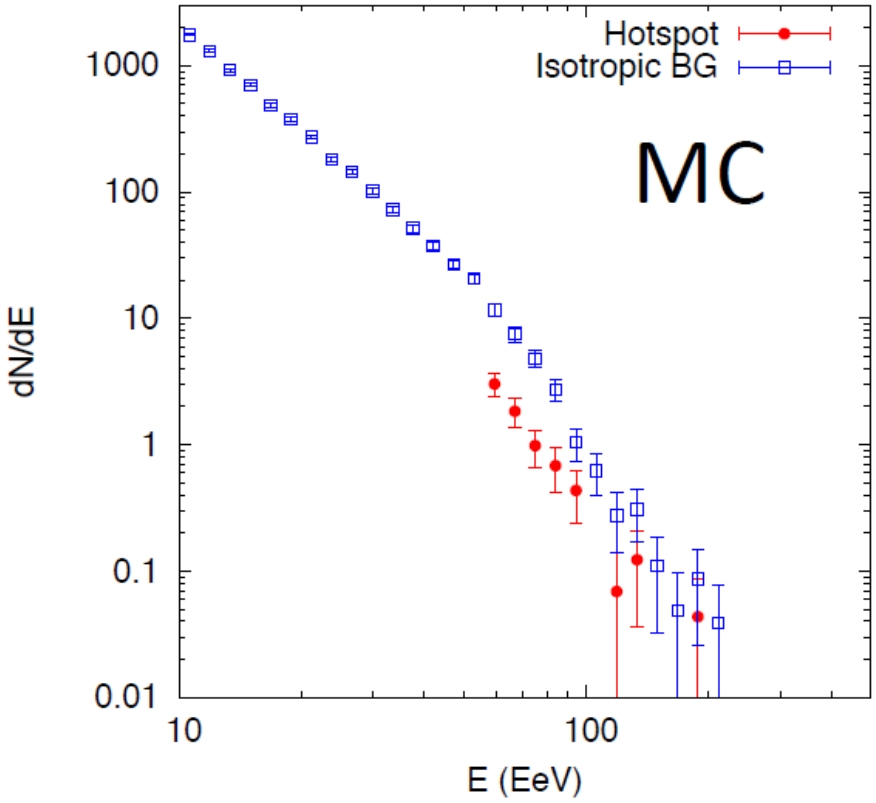
Schedule of TA×4

JFY	construction or observation	surface detector (SD)		hybrid (HYB)	
		TA SD (=1) (=1)	additional SD (=3)	TA HYB (=1)	additional HYB (=3)
2008-2014	observation	7	0	7	0
2015	construction	1	0	1	0
2016	construction	1	0	1	0
2017	construction/(2/3) observation(1/3)	1	1	1	0.3
2018	observation	1	3	1	2
2019	observation	1	3	1	2
subtotal		12	7	12	4.3
total		19		16.3	

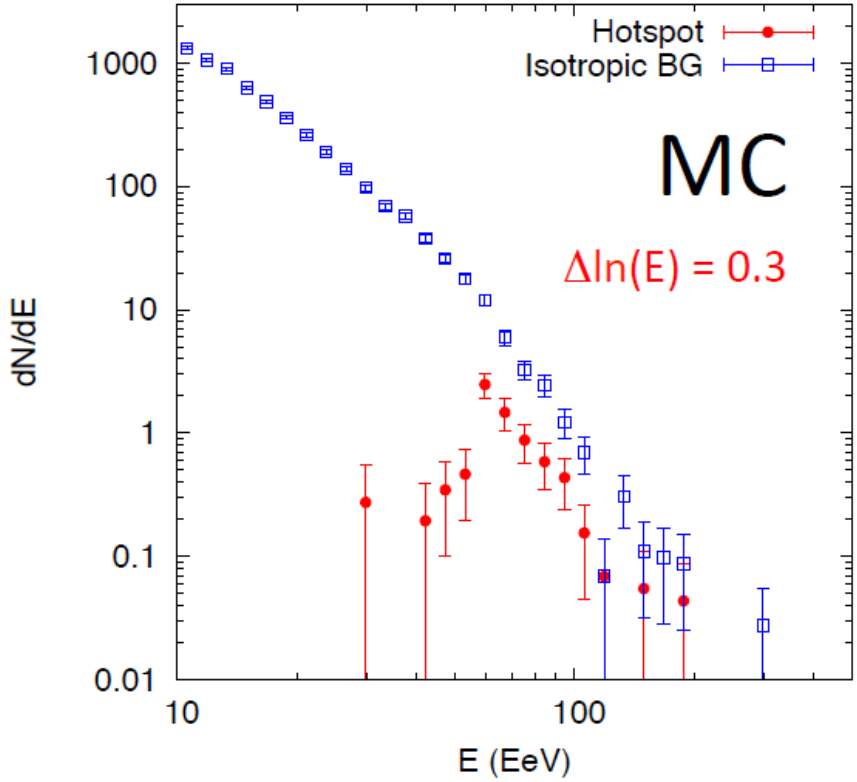
JFY: Japanese Fiscal Year that starts in April

Examples of Energy Spectra

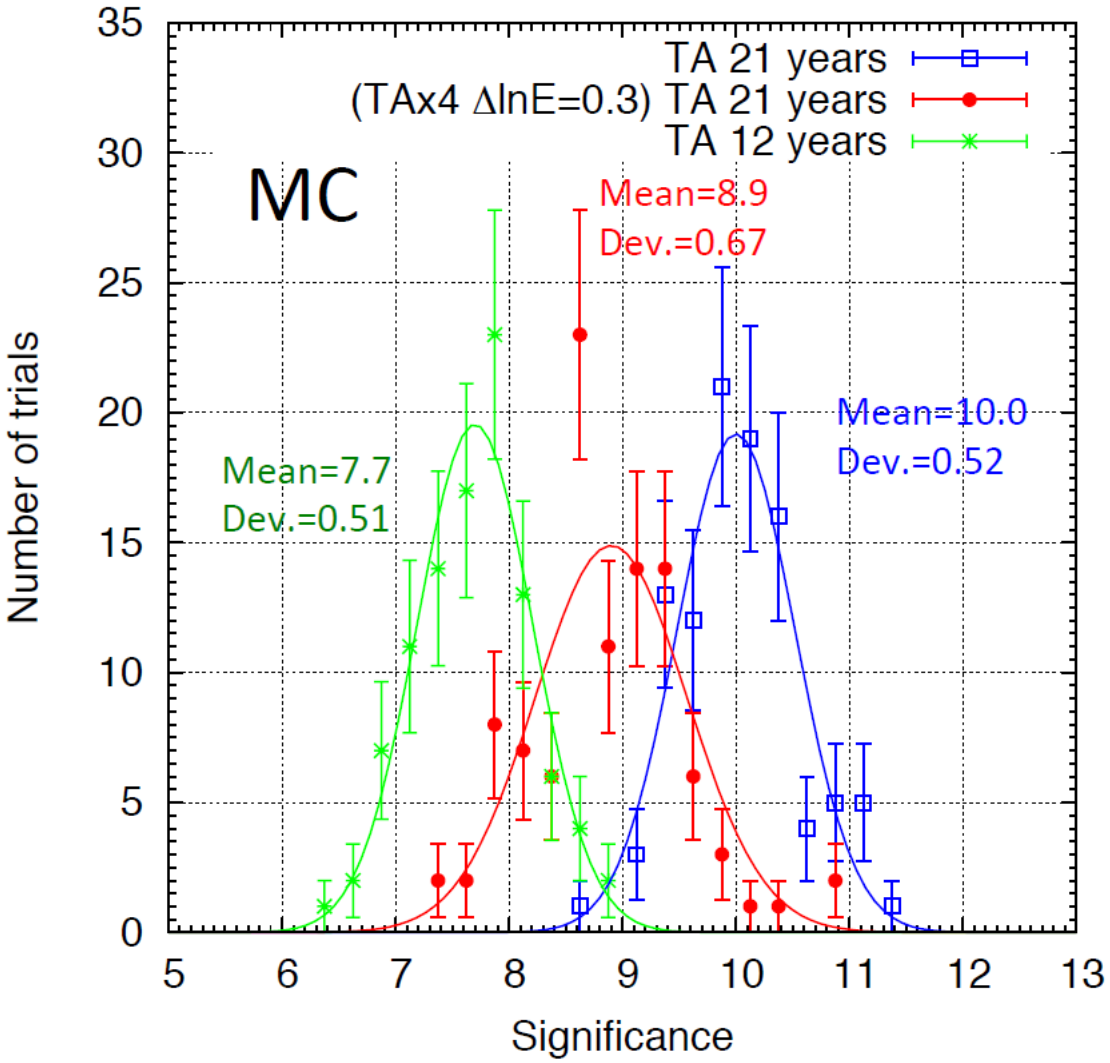
w/o E resolution



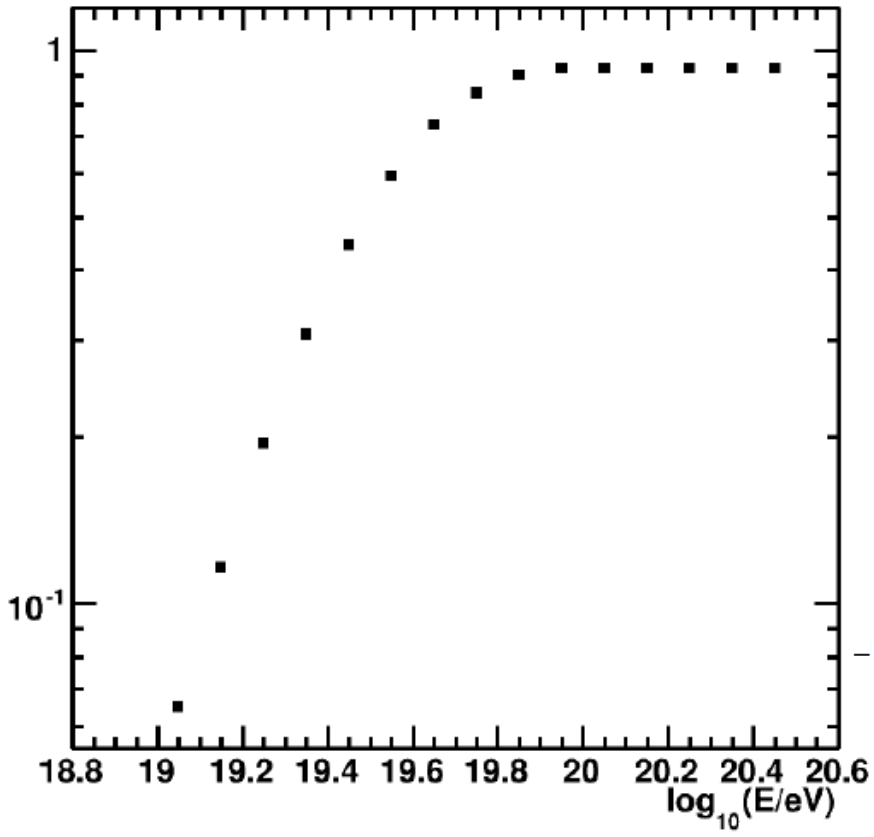
with E resolution



Expected significance of the hotspot considering energy resolution effect



Efficiency for the energy spectrum analysis



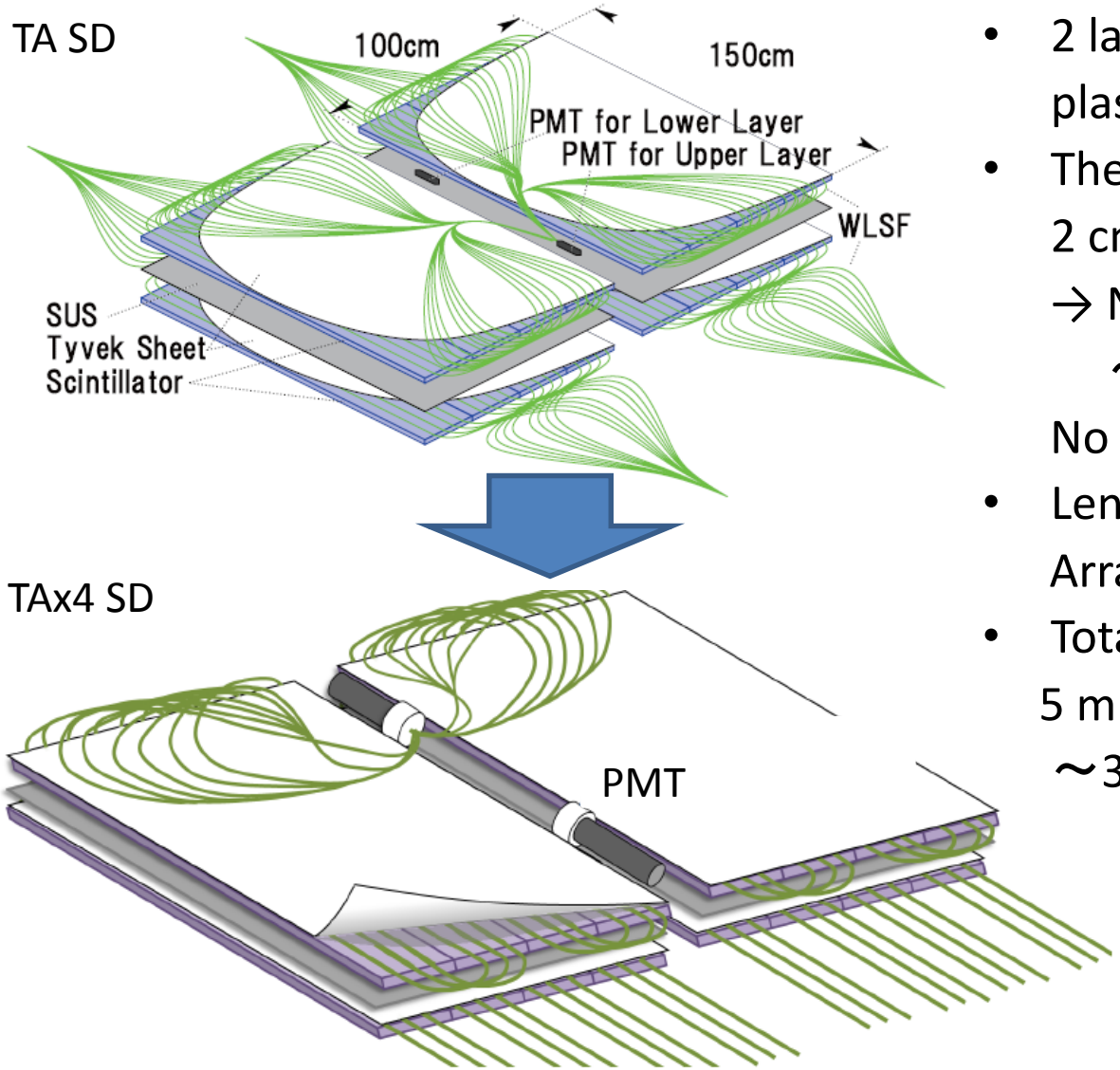
- Number of good SDs >=4
- Zenith Angle < 45 degree
- LDF (only) Chi2/Dof < 10
- Pointing direction uncertainty < 8 degrees
- Sigma_S800/S800 < 0.26

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

Resolution

- Ta sd: E > 57 EeV 1-1.7 deg
- 15-20% energy resol.

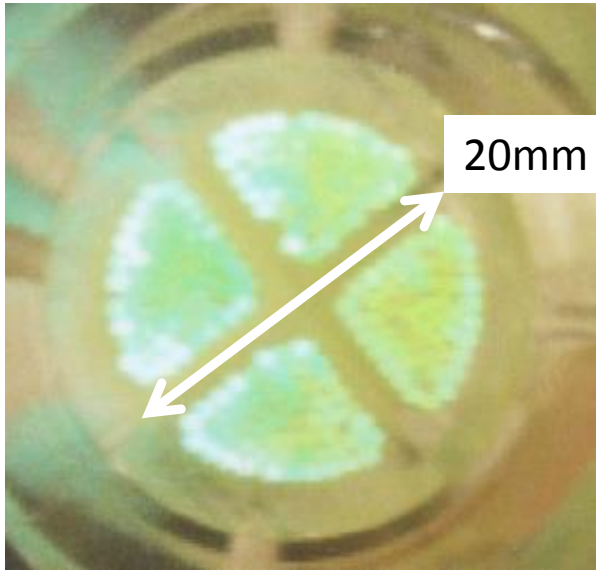
TAx4 SD arrangement of fibers



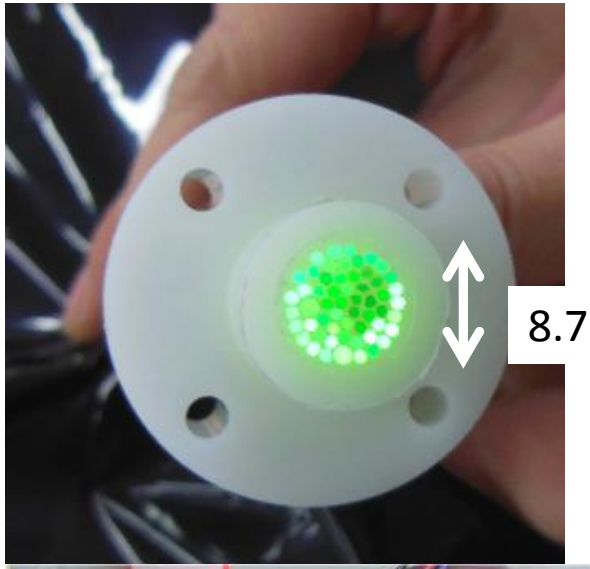
- 2 layers of 1.2 cm thick plastic scintillators
- The distance b/w fibers:
  2 cm → 4 cm
  → Number of photons from fibers
  ～1/2 of TA SDs
  No problem in efficiency
- Length of fibers: 5 m → 6.1 m
  Arrangement of fibers is changed
- Total length of fibers
  5 m × (208 + spare)→ 6.1m × 56
  ～33% of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

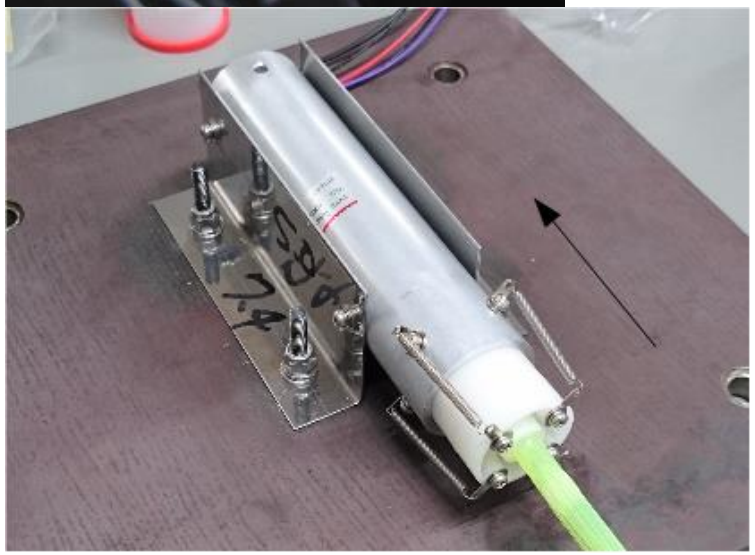
Connection of the surface of TAx4 SD PMT with fibers

TA SD



TAx4 SD





- Holder of the fiber bundle: transparent→white
  ～9% more number of photons
- Size of the fiber bundle is smaller.
  Diameter: ～20 mm→ 8.7mm
- 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