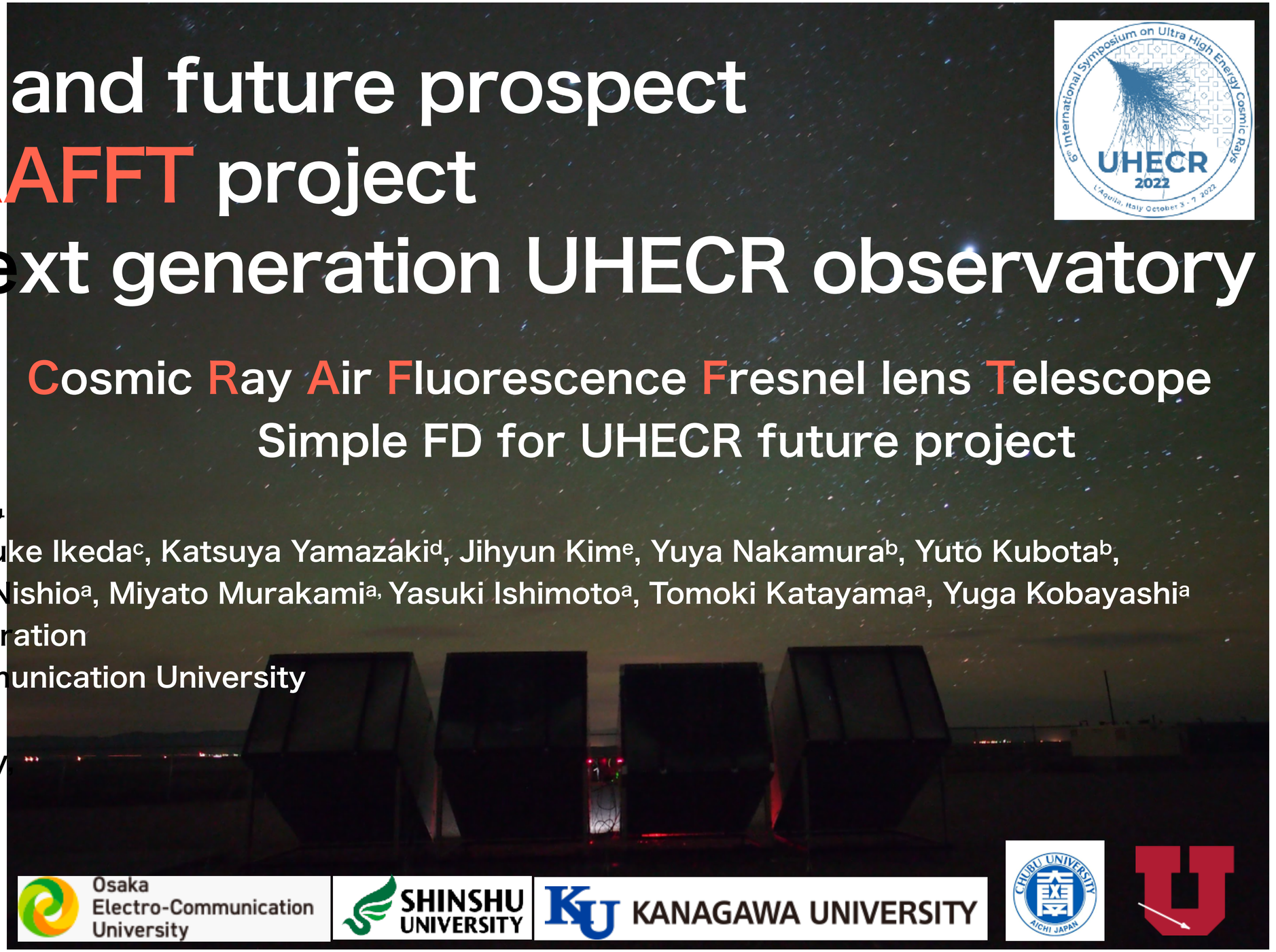
Progress and future prospect of the CRAFFT project for the next generation UHECR observatory



Cosmic Ray Air Fluorescence Fresnel lens Telescope
Simple FD for UHECR future project

Yuichiro Tameda[a],

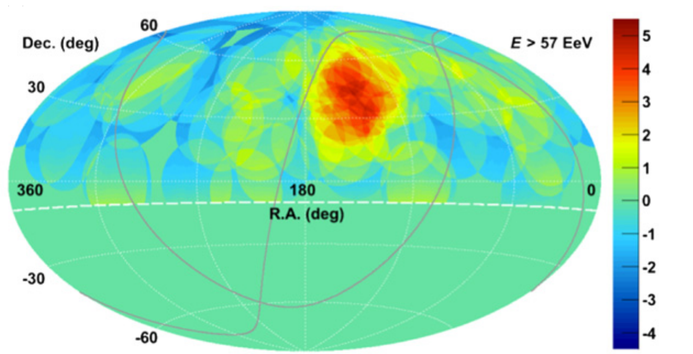
Takayuki Tomida[b], Daisuke Ikeda[c], Katsuya Yamazaki[d], Jihyun Kim[e], Yuya Nakamura[b], Yuto Kubota[b], Norimichi Shibata[a], Eiji Nishio[a], Miyato Murakami[a], Yasuki Ishimoto[a], Tomoki Katayama[a], Yuga Kobayashi[a]

For the CRAFFT collaboration

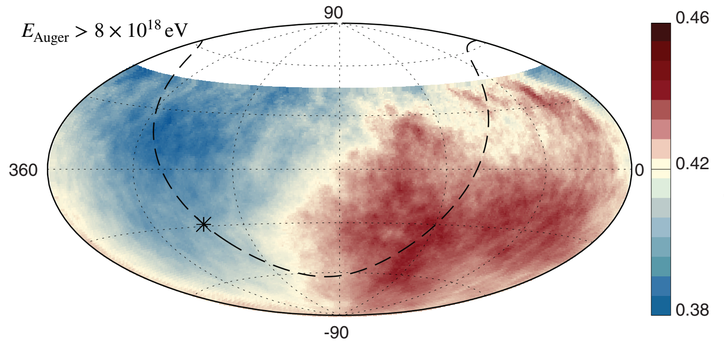
(a) Osaka Electro-Communication University
(b) Shinshu University
(c) Kanagawa University
(d) Chubu university
(e) University of Utah

Current status of UHECR

- Indication of UHECR anisotropy
  - TA reported Hotspot in the arrival direction of UHECRs (>57EeV)
  - Auger reported dipole structure (>8EeV)



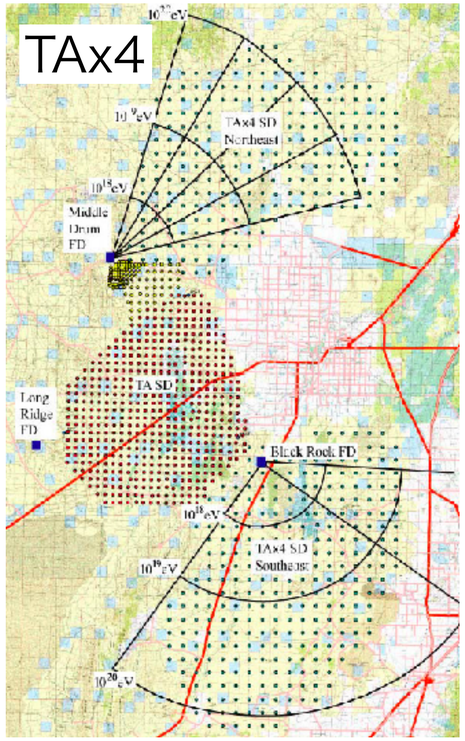
- Can we identify the source of UHECRs ?

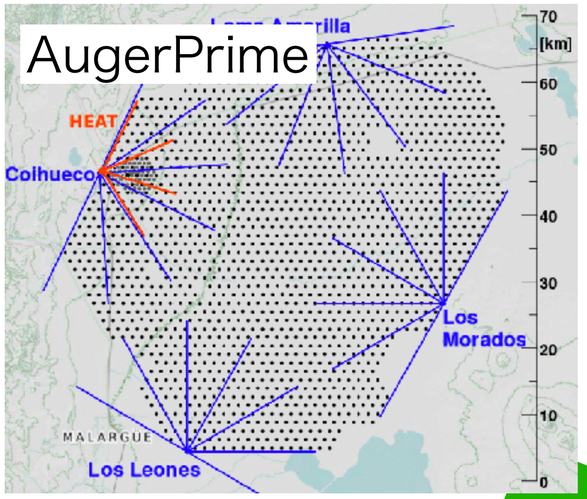


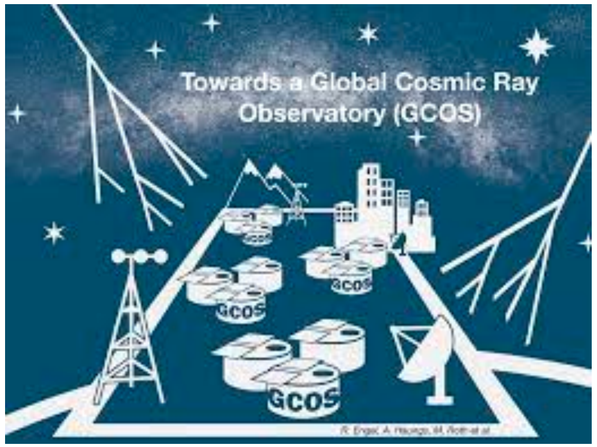
- Extension of detection area for much more statistics
- Mass composition for propagation of UHECR
- All sky survey

Future projects of UHECR

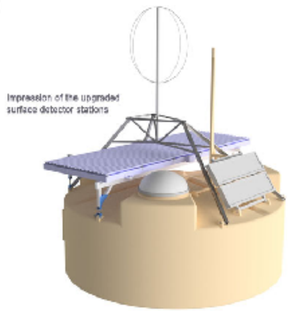
Ongoing project



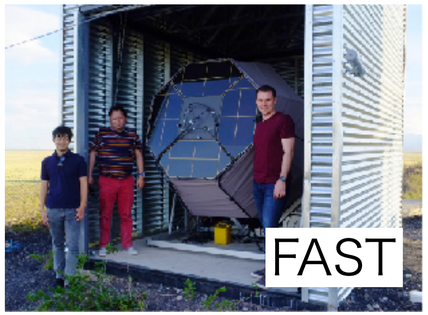


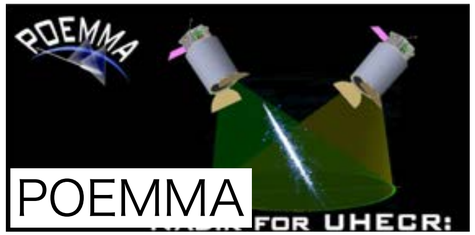


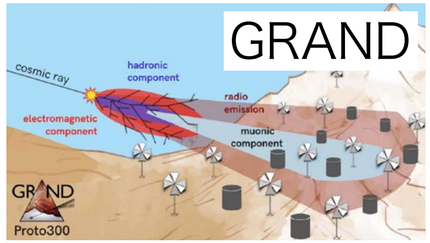
SD



FD

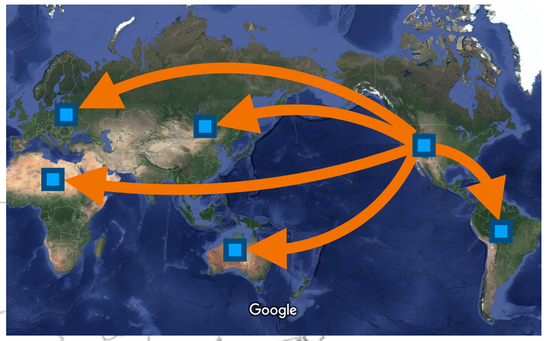






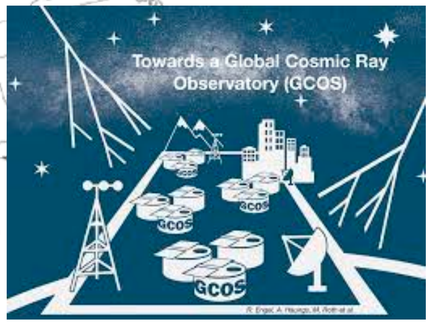
Concept of CRAFFT project

- Extension of detection area for much more statistics
  - Development of cost effective detectors
  - Operation with less man power
    - automation system and maintenance free
  - Low environment impact
    - Less detector density (wide spacing)
- Mass composition for propagation of UHECR
  - Mass composition sensitive detector (ex. FD)
- All sky survey
  - Observation at multi location
    - Easy to construct or transport
- Fluorescence detector (FD) is one of the successful detector for UHECR observation.
- Cost-effective FD can be a solution to realize the next generation observatory for UHECRs.
- CRAFFT project has developed a simple FD to realize huge array of 360° view FD Station



Can be distributed to the world

400,000 km²
FD Array



Roadmap of CRAFFT project

Phase 1

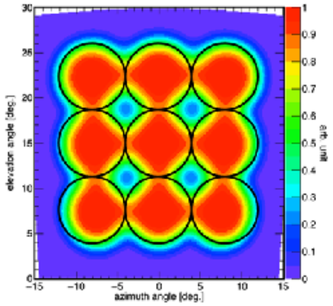
Confirmation of the concept of detectors

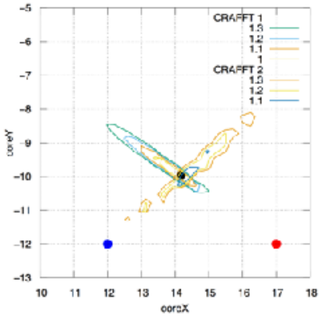
Succeeded to observe UHECR air showers with prototype detector with a 8 inc. PMT

Phase 1.5

Optimization of detector design

Planning to use 5 inc. PMT to improve reconstruction accuracy, and extend F.O.V. per detector.
Reconstruction by waveform fitting.
Automatic DAQ system.

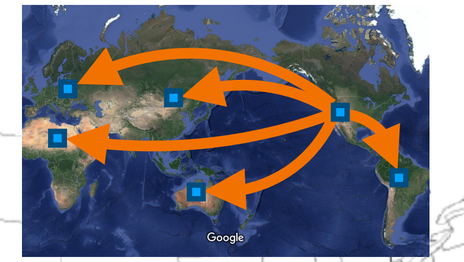




Phase 2

Confirmation of the concept of observation

Stable observation
Deploy optimized CRAFFT at TA site
Steteo obs. Wide area network



Can be distributed to the world

Phase 3

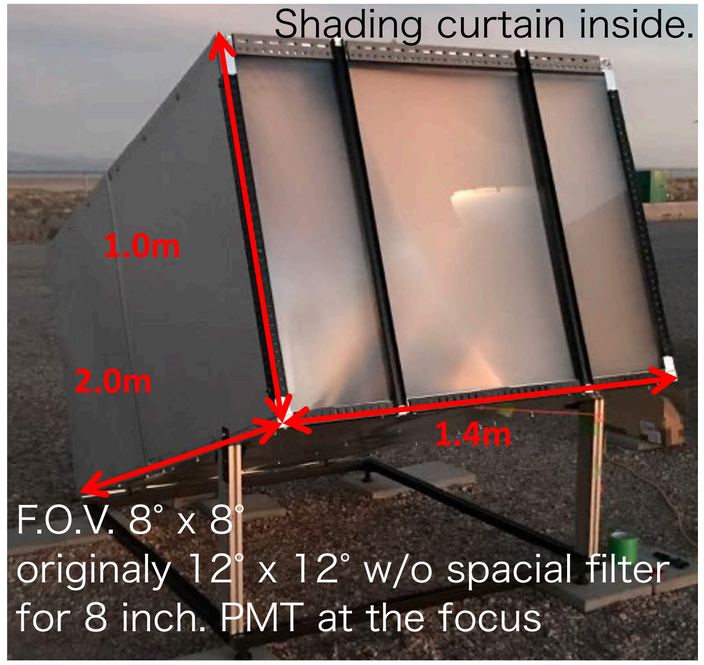
Large scale deployment

Array of 360° FD Station
20km spacing
500 station ~ 10 TA×4
400,000 km²

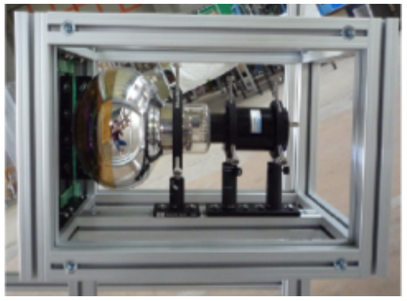
400,000 km²
FD Array

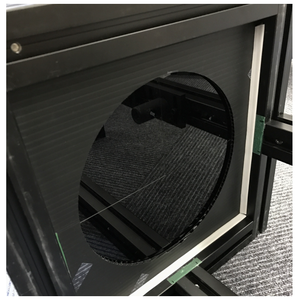
Phase 1

Prototype of CRAFFT



Appearance of CRAFFT detector.





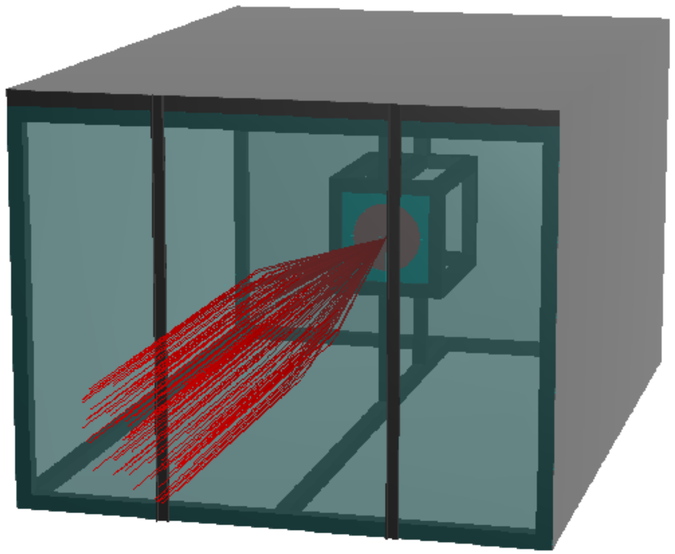
8 in. PMT with UV transmitting filter.
8° spacial filter for test observation.

- CRAFFT :
  Cosmic Ray Air Fluorescence Fresnel lens Telescope
  - Simple structure FD for cost reduction
- All of the equipment can be inside the package of CRAFFT
  - Deployed on the ground directly w/o container
  - Easy to transport
- Efficient light condenser due to no obstacles between lens and focus.
- Easy to expand the F.O.V. per telescope by additional pixels at the focus
- Mass composition sensitive detector

Phase 1

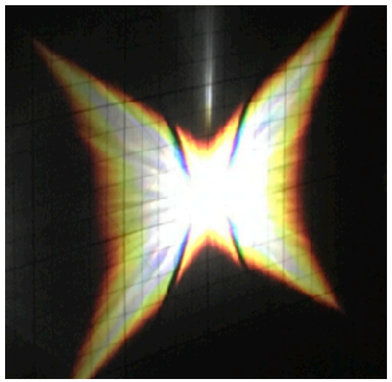
Detector performance

- Detector simulation to understand our detector
- Spot shape is reproduced well.
- Waveform is well reproduced.

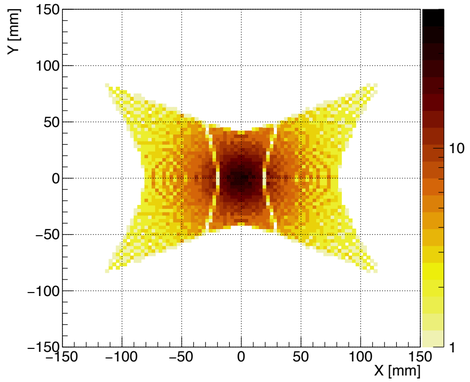


Ray trace simulation

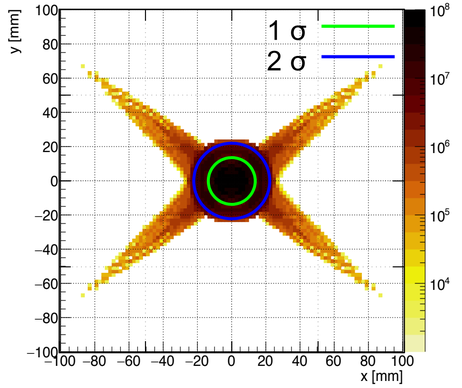
(ROBSAT : A. Okumura 2016)



Unique spot shape of fresnel lens at focal plane

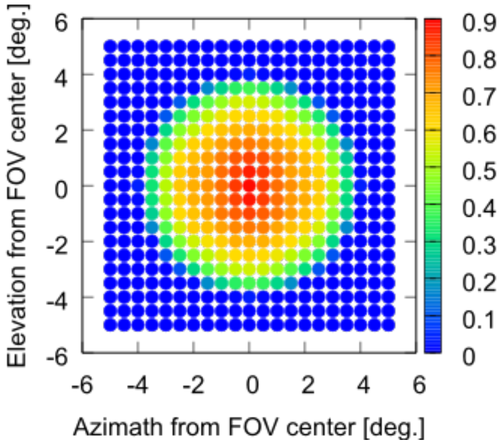


Shape of simulated spot shows good agreement.

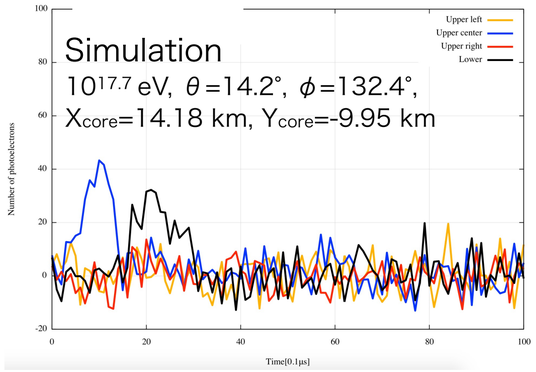


Spot size (95%) : 44 mm

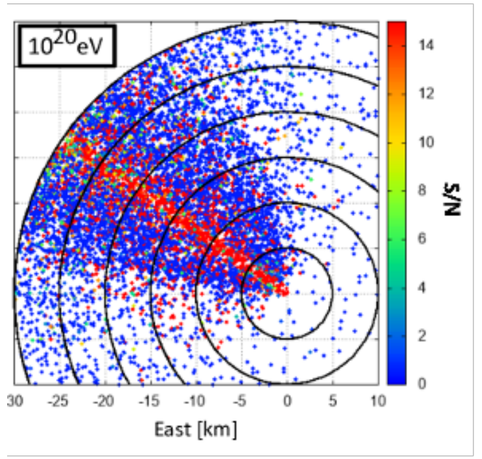
λ = 280 ~ 400 nm, F = 1100 mm



Angular dependence of light collective efficiency.



Simulated waveform with parameters reconstructed by TA FD.



Detection efficiency.

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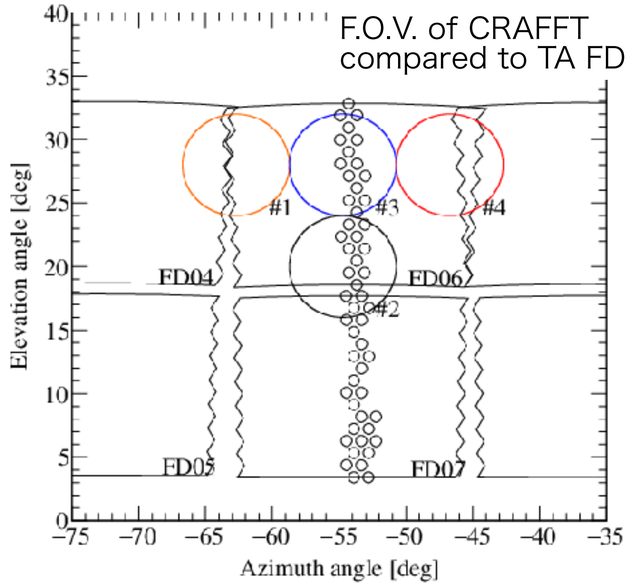
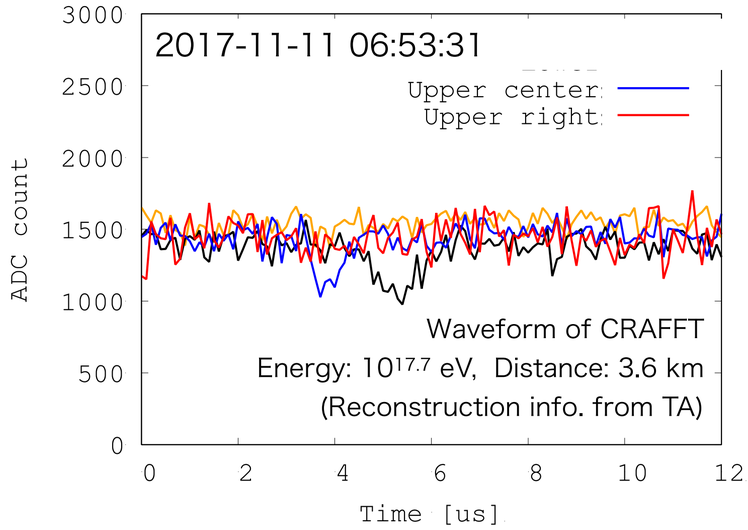
Phase 1

Detection of UHECR air showers

- Test observation at TA FD site
- Deployed four CRAFFT detectors @ TA BR
- Period : 2017 Nov. 9 ~ Nov. 23
- Obs. time : 63.5 h (10 nights)
- 10 obvious air shower events
  - Expected events / month : ~8 events (above 10^{17} eV)
- Triggered by TA FD triggering timing
  - # of recorded events : 556,255





Y. Tameda, et al., Progress of Theoretical and Experimental Physics, 2019, (2019) 043F01

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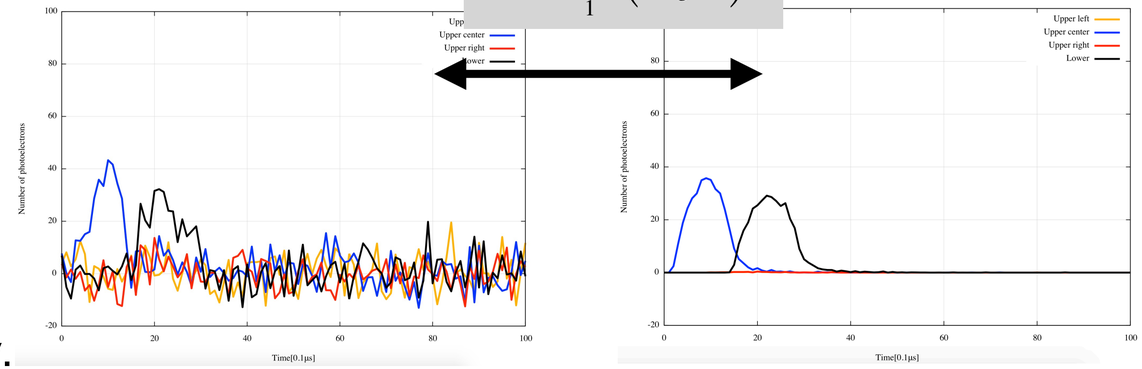
Phase 1.5

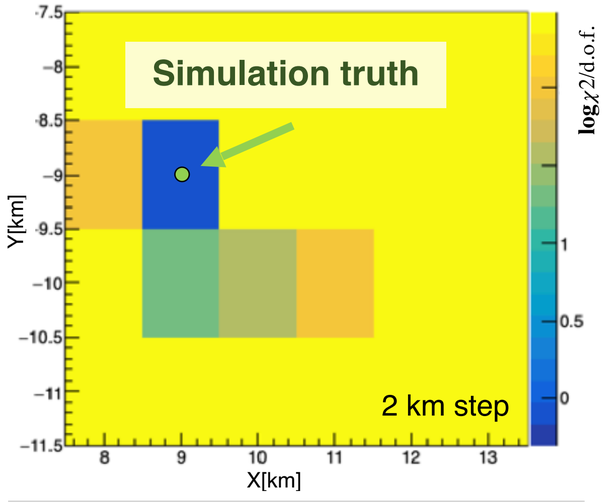
Reconstruction by waveform fitting

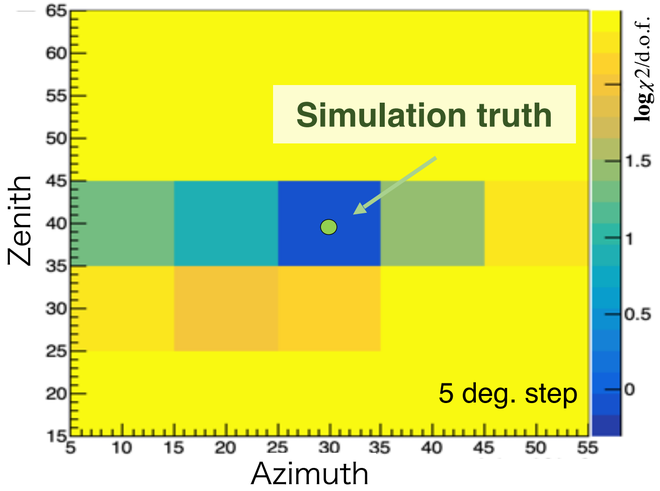
- Disable to determine SDP with single pixel telescope
- Using time information recorded with FADC (80 MHz)
- Least chi square fit for six parameters
  - Zenith, azimuth, Core(x, y), Energy, $X_{\max}$
- We tried to fit with 5 parameters of geometry and energy.
  - Even mono analysis, geometry and energy can be determined.
  - Efficient algorithm and 6 parameter fitting is under study.

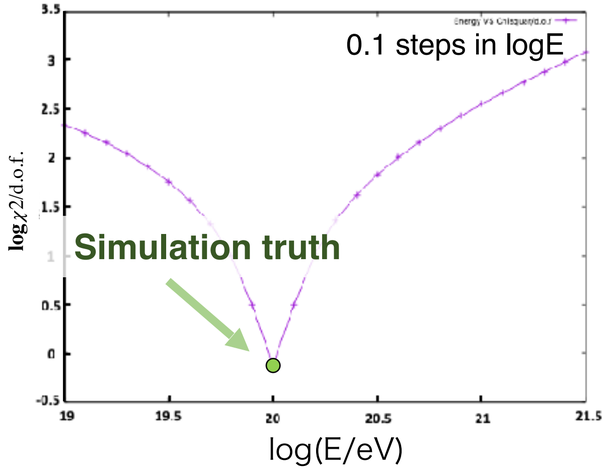
Least chi square fit

$$\chi^2 = \sum_1^n \left(\frac{x_i - \mu_i}{\sigma} \right)^2$$









Reconstruction accuracy @ 10^{20} eV

4 parameters fitting by grid search

Direction : ± 3 deg

Core position : ±200 m

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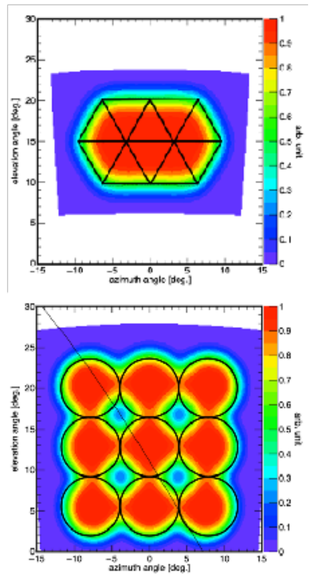
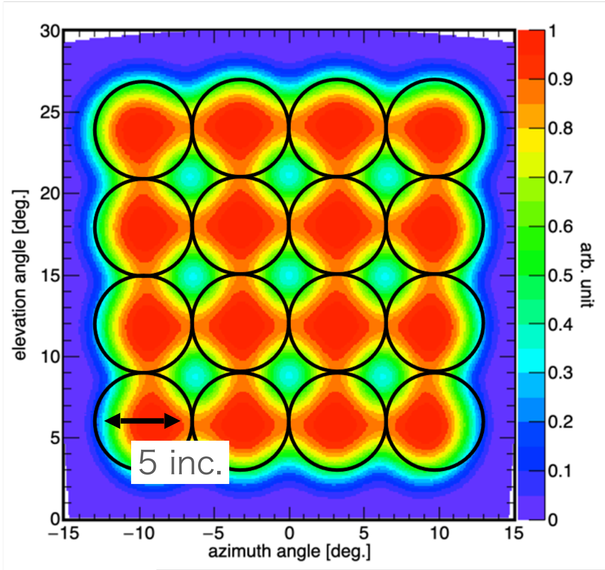
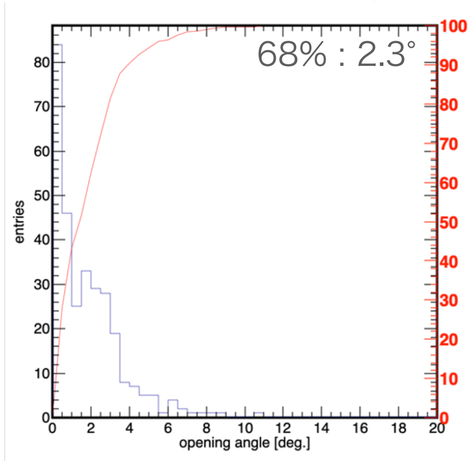
Phase 1.5

Optimization of detector configuration

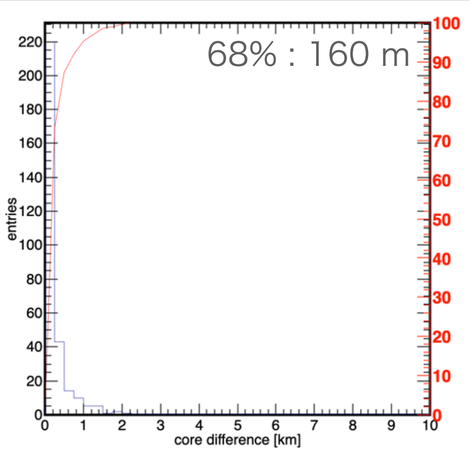
- We need to optimize detector configuration to improve reconstruction accuracy and expand F.O.V. per detector.
  - Multi pixel
  - Cost should be kept low.
- We tried various configuration
  - Evaluating the accuracy of reconstruction accuracy of waveform fitting.
- New configuration for the next plan
  - 4 x 4 matrix of 5 inc. PMT
  - F.O.V corresponds to four TA FDs.
  - Direction : 2.3°
  - Core position: 160 m







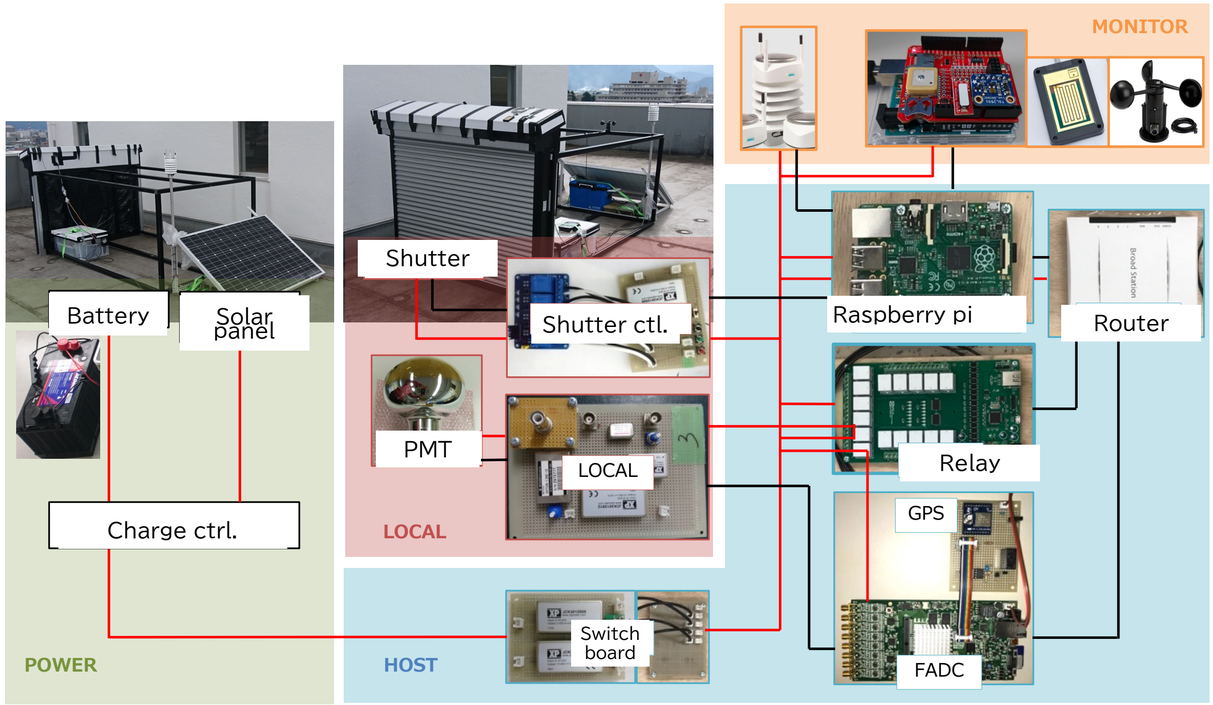
Open angle



Core difference

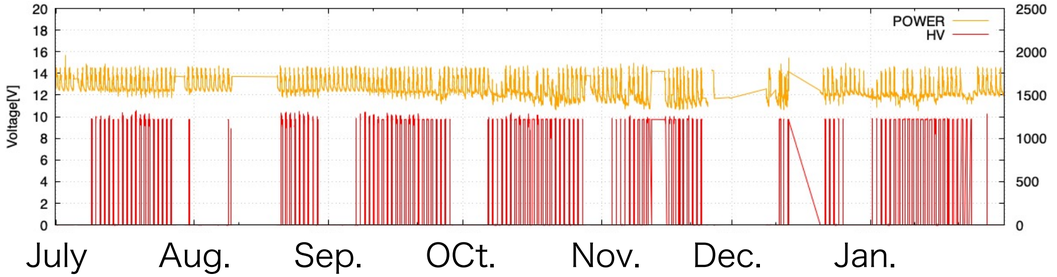
Phase 1.5

Automation of operation system

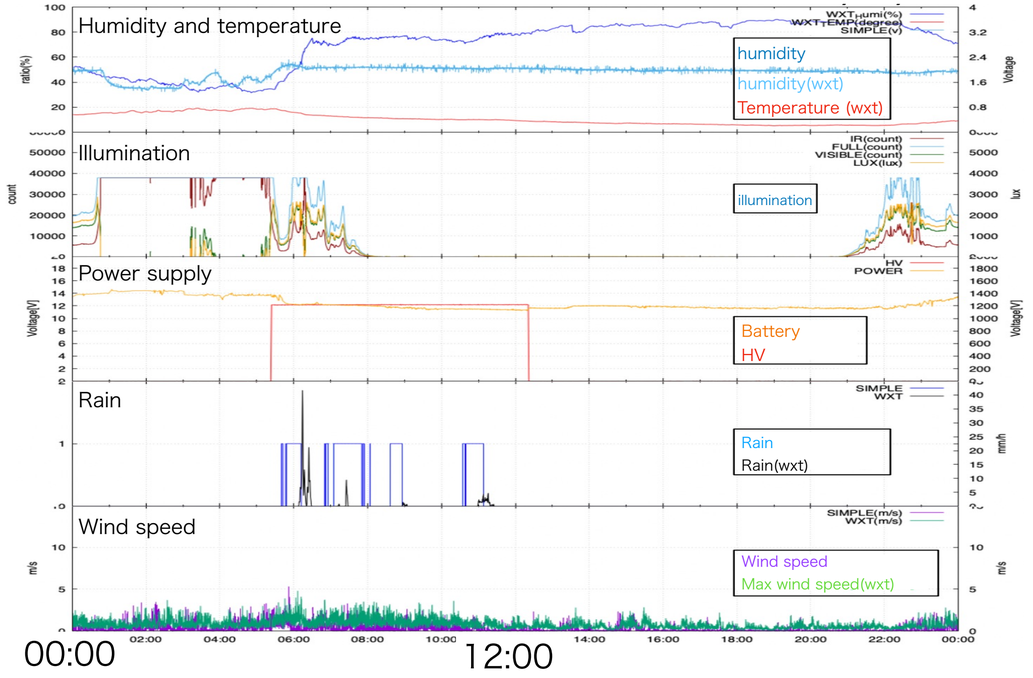


- Development of automation system
  - Essential part for cost reduction of operation
  - Manual operation is not realistic from the point of view of the number of stations and man power.
  - Shutter operation, DAQ process starts automatically.
  - Environment monitor is important to judge starting operation or not.
  - A.I. with CCD camera for cloud monitoring will be powerful.

Long term operation test



Environmental monitor



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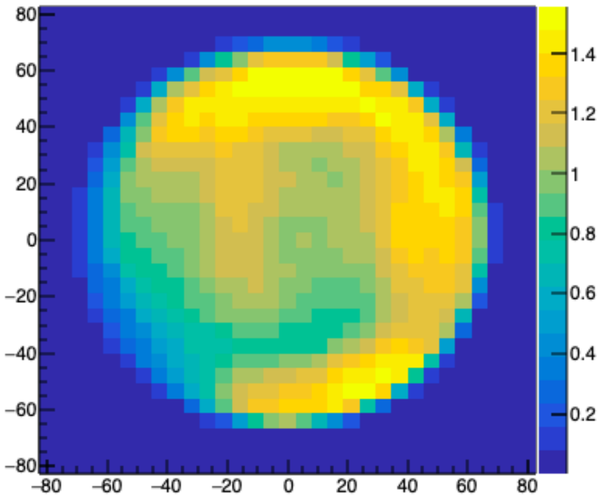
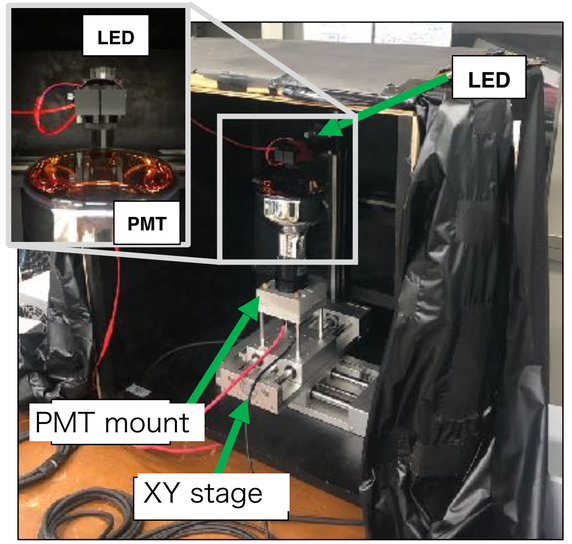
Phase 1.5

Calibration of detector components

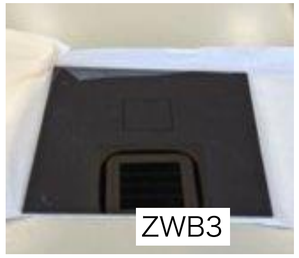
- Measurement of PMT gain uniformity
  - R877-100 (Hamamatsu)
    - Size of PMT change to 5 inc.
  - Light source : UV LED (λ=375 nm)

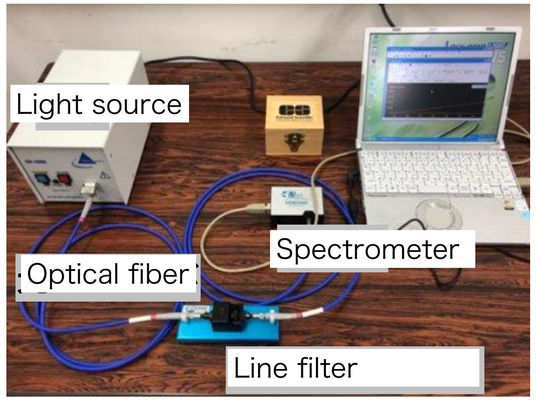


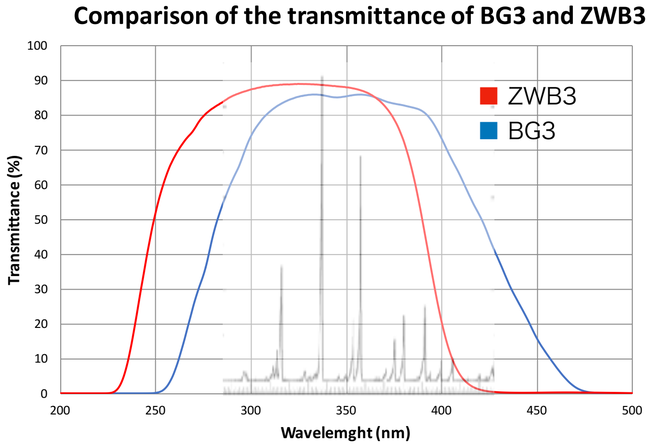
Gain map of R877-100
Normalized with the center of the window



- Measurement of wavelength dependence of the transmittance of UV filter
  - ZWB3(Haian Subei Optical Glass Factory)
  - Cost is much lower then before
  - No difference in quality



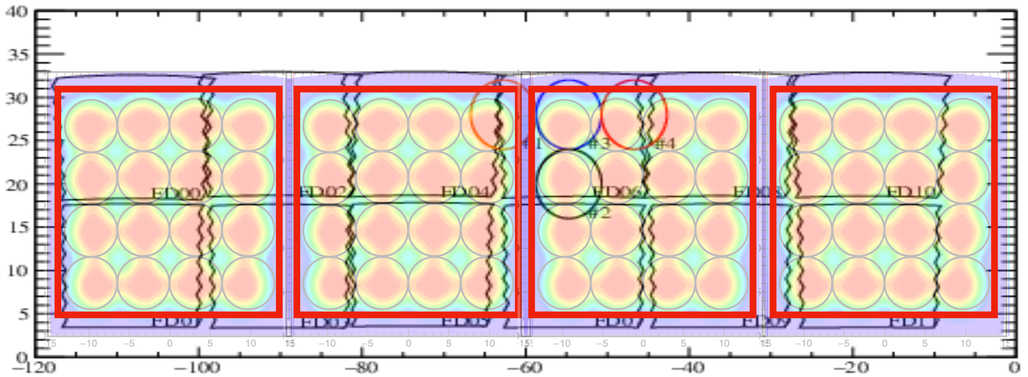


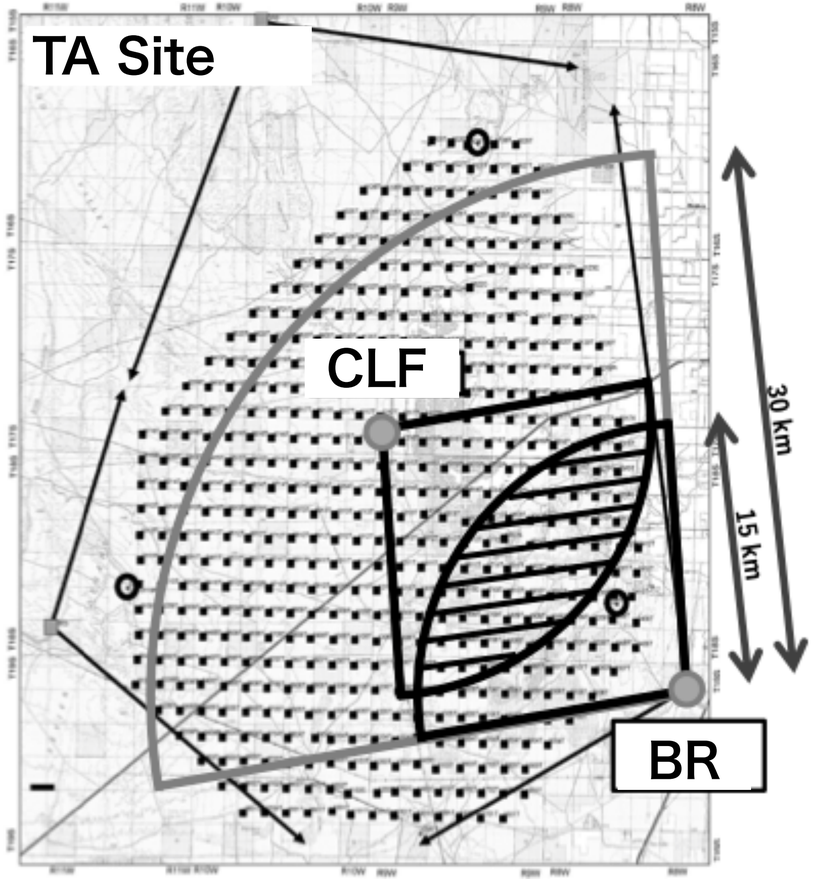


Phase 2

Next observation plan

- New configuration CRAFFT detector at BR
  - Four telescopes cover F.O.V. of TA FD @ BR
- Stable observation with automation system.
- Trigger electronics
- Efficient algorithm for 6 parameter fitting
- Stereo or multi-station observation





Summary

- **CRAFFT** (**C**osmic **R**ay **A**ir **F**luorescence **F**resnel lens **T**elescope)
  - Developing a **simple structure FD**
  - Deployed four CRAFFT detectors at TA FD site.
  - Test observation : 2017 Nov. 9 ~ Nov. 23 (10 nights, 63.5 h)
  - **Succeed to detect 10 UHECR air shower events !!**
- Air shower reconstruction by waveform fitting seems to work even in monocular mode.
- Optimization of detector configuration for better accuracy of reconstruction and extension of the F.O.V. per detector.
- Future prospect
  - We are planning stable observation at TA site.
  - We are preparing automation system, new component for the new configuration.
  - Our goal is to realize **a next generation huge observatory for UHECR observation**.

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