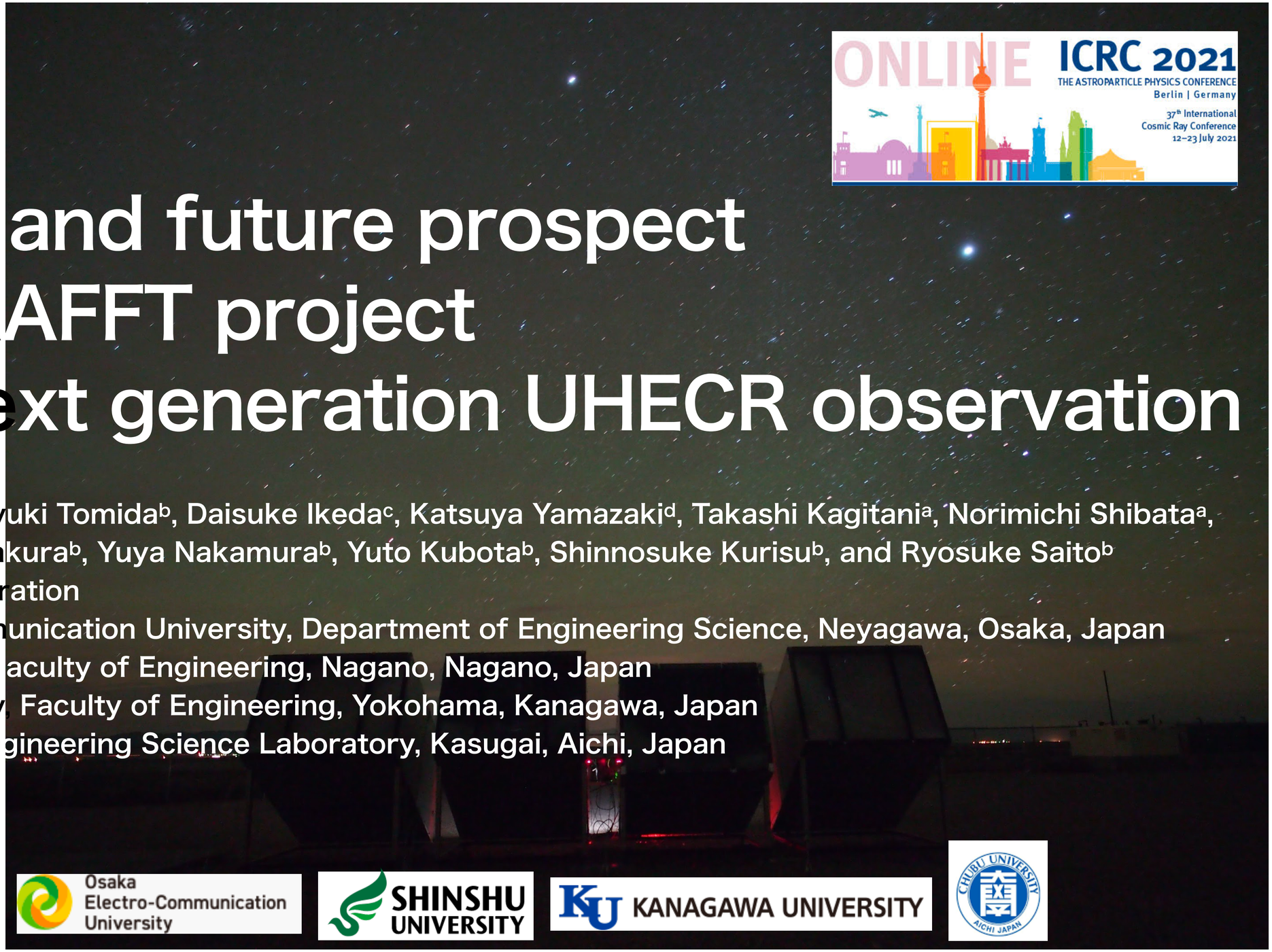

Progress and future prospect of the CRAFFT project for the next generation UHECR observation

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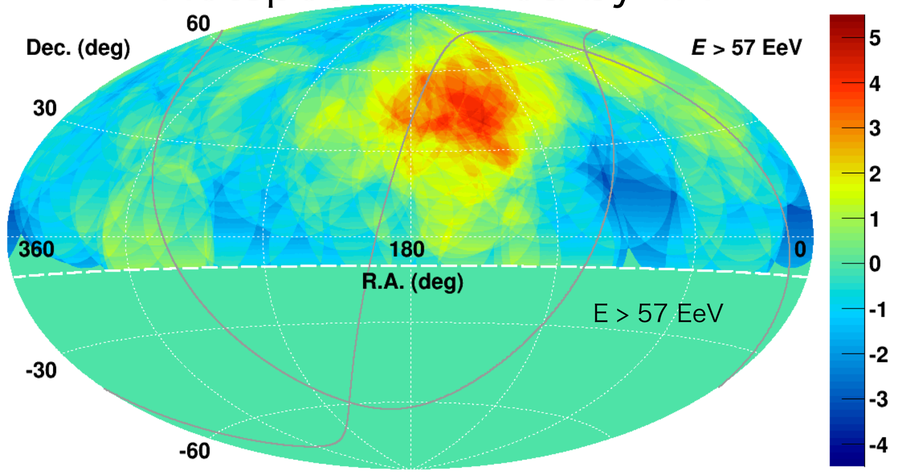
For the CRAFFT collaboration
(a) Osaka Electro-Communication University, Department of Engineering Science, Neyagawa, Osaka, Japan
(b) Shinshu University, aculty of Engineering, Nagano, Nagano, Japan
(c) Kanagawa University, Faculty of Engineering, Yokohama, Kanagawa, Japan
(d) Chubu university, Engineering Science Laboratory, Kasugai, Aichi, Japan

The present situation of UHECR observation

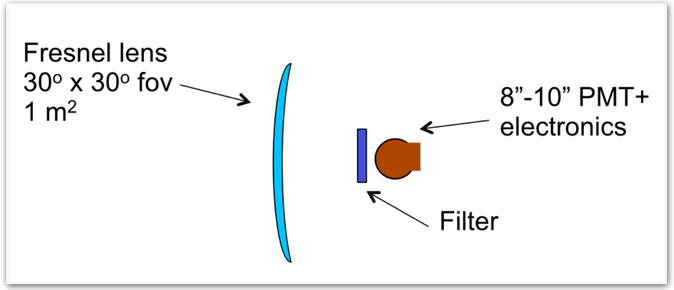
- TA reported hotspot (5σ)
  - Intermediate scale anisotropy of the arrival direction of UHECRs ($E > 57\,\mathrm{EeV}$)
- Is hotspot related to the population of UHECR sources ?
- What should we do to clarify UHECR sources ?
  - Extension of detection area for larger statistics.
- Can UHECRs propagate straight ?
  - Observation of $X_{\max}$.
- Solution :
  - Huge observatory using fluorescence detector(FD).
  - However, Cost of FDs in use are high :(

Hotspot observed by TA

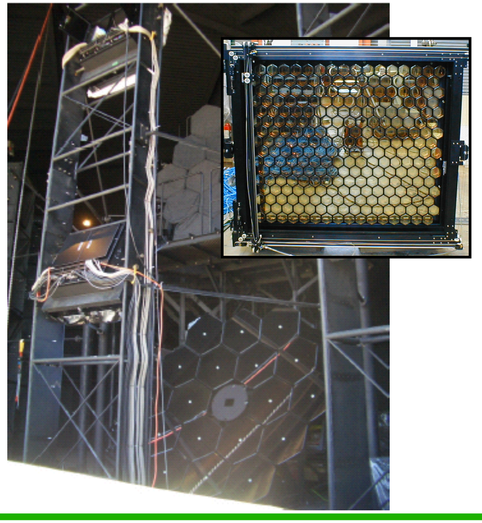


K. Kawata et al. ICRC2017

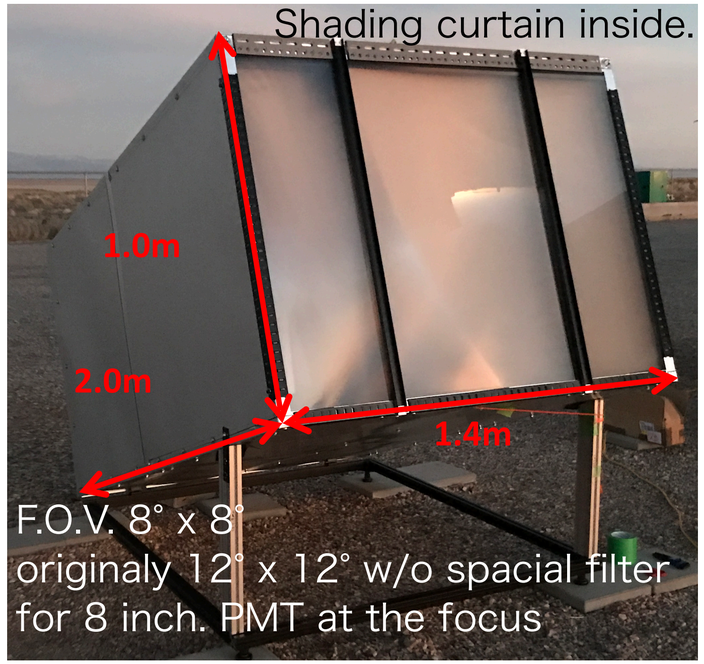
Proposed concept of simple structured FD.



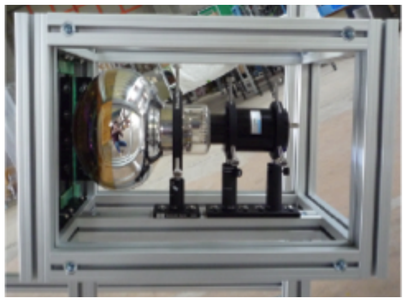
P. Privitera, et.al.UHECR(2012)

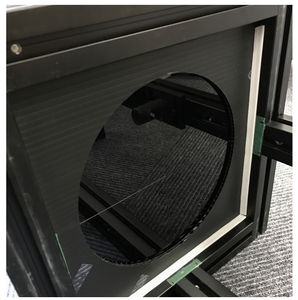


Cosmic Ray Air Fluorescence Fresnel lens Telescope



Appearance of CRAFFT detector.

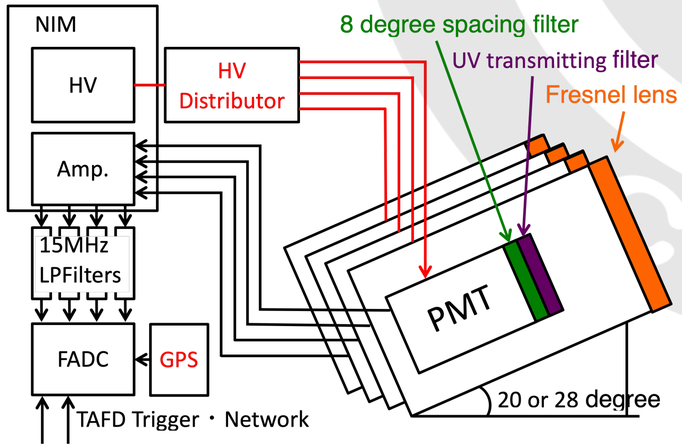




8 in. PMT with UV transmitting filter.
8° spacial filter for test observation.

Single pixel Fresnel lens telescope

- Simple structure, without container
- Easy to deploy
- No obstacle between lens and focus
- Necessity of multiple observation for geometrical determination
- Worse S/N compared to multi pixels.



Component	Product	Specification	Cost/FD
Structure	MIWA	Aluminum frame	950
Fresnel lens	NTKJ, CF1200-B	1m², f=1.2m	370
UV trans. filter	Hoya, UL330	~90%,300-360nm	3,000
PMT	Hamamatsu, R5921	8 inch	2,000
FADC	TokushuDenshiKairo, Cosmo-Z	80MHz, 12bit	290
Amplifier	Lecroy, 612AM		1,000
HV	CAEN, N1470AR	8kV, 3mA	1,600
		Total ($) :	9210

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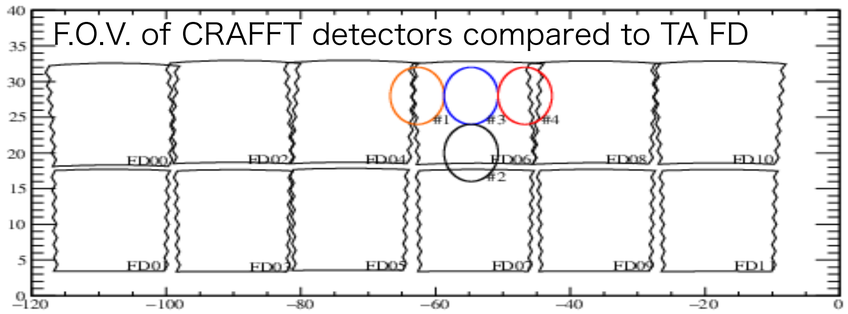
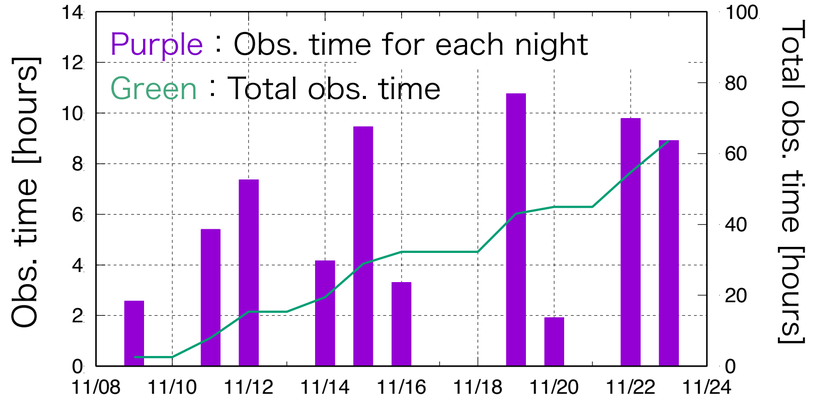
Test Observation at TA FD site

- Test observation at TA FD site
- 2017 Nov. 9 ~ Nov. 23
- Obs. time : 63.5 h (10 nights)
- Expected events / month : ∼8 events (above 10^{17} eV)
- Triggered by TA FD triggering timing
- # of recorded events : 556,255





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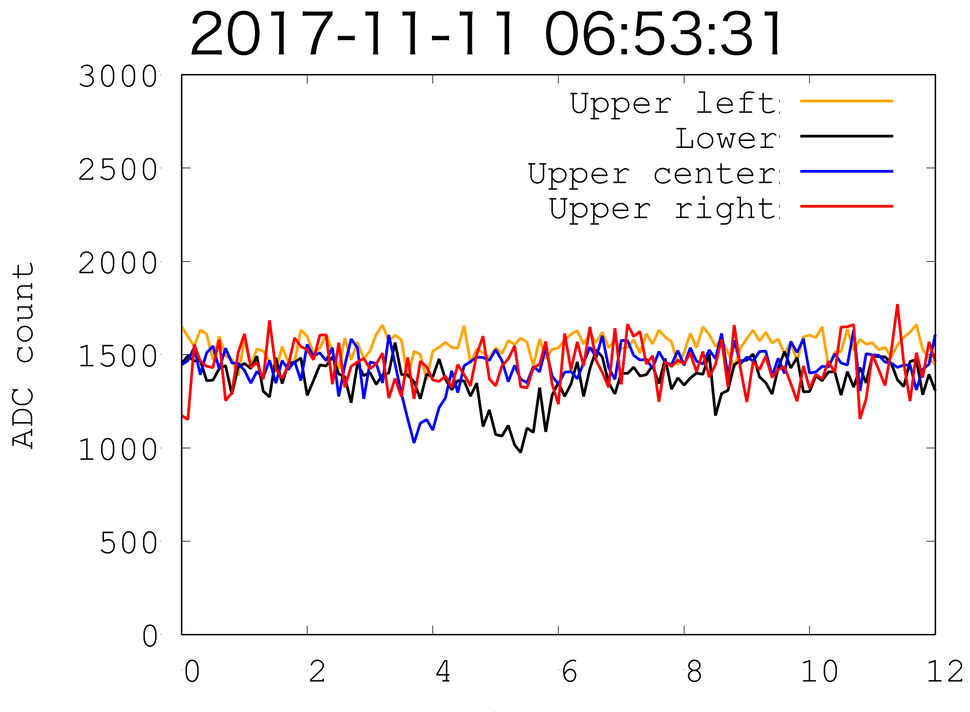
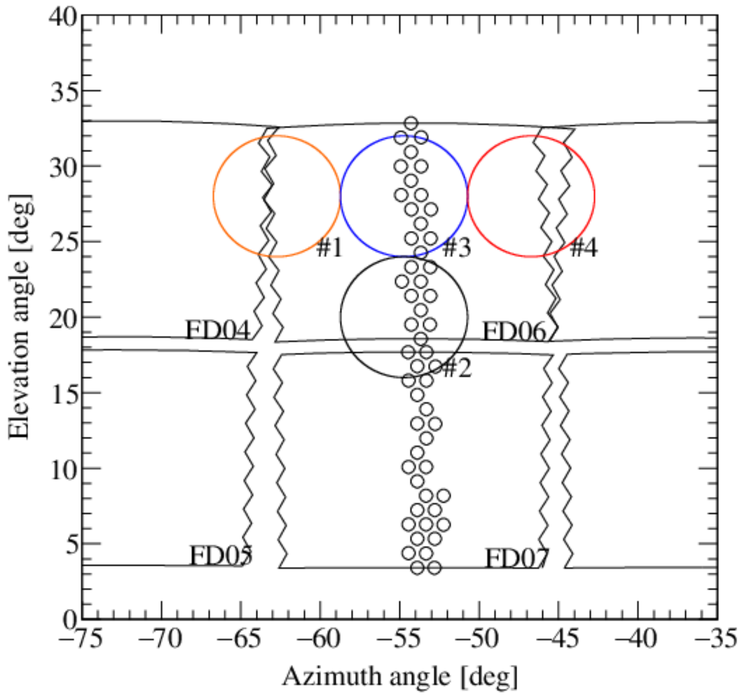
Air shower event observed by CRAFFT

10 obvious air shower events were detected.



Waveform of CRAFFT

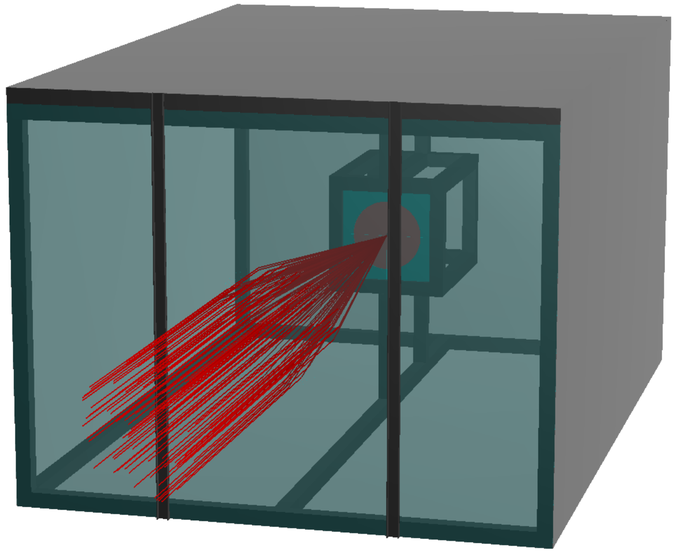


Event display of TA FD
with CRAFFT F.O.V.

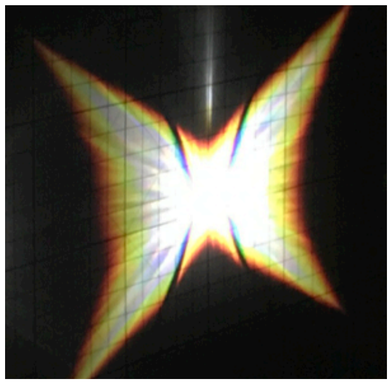
Energy: $10^{17.7}$ eV, Distance: 3.6 km (by TA FD)

Detector simulation

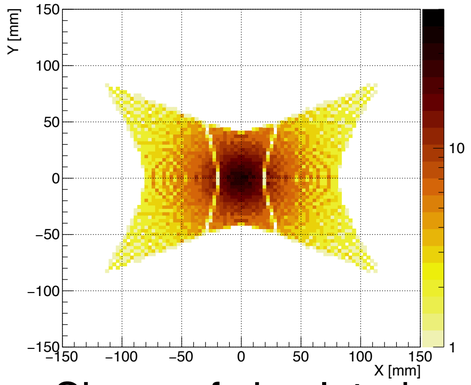
- Detector simulation to understand our detector
- Spot shape is reproduced well.
- Waveform is well reproduced.



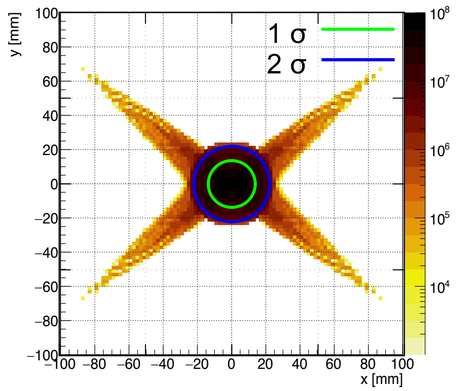
Ray trace simulation
(ROBSAT : A. Okumura 2016)



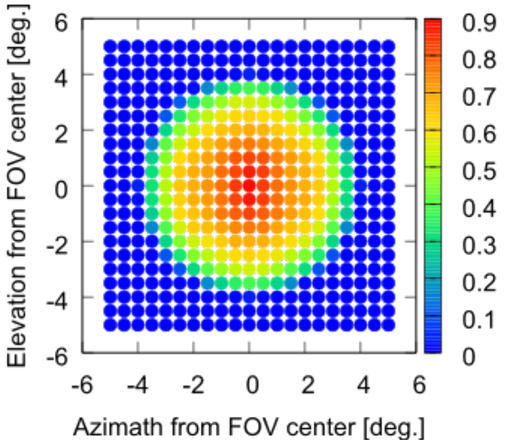
Unique spot shape of fresnel lens at focal plane



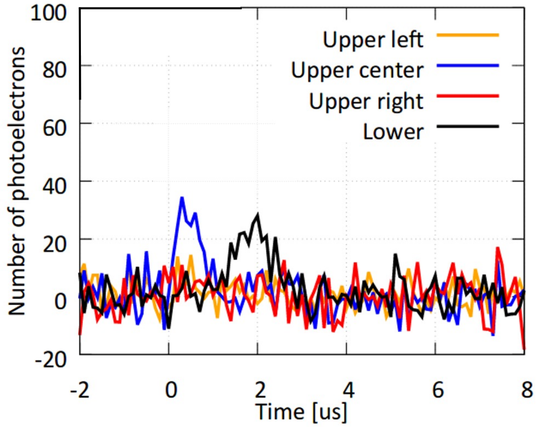
Shape of simulated spot shows good agreement.



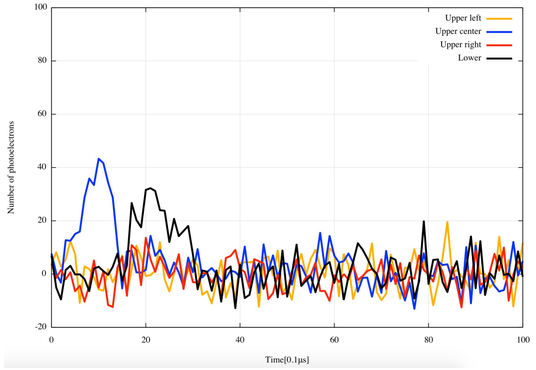
Spot size (95%) : 44 mm
λ = 280 ~ 400 nm, F = 1100 mm



Angular dependence of light collective efficiency.



Observed waveform.



Simulated waveform with parameters reconstructed by TA FD.

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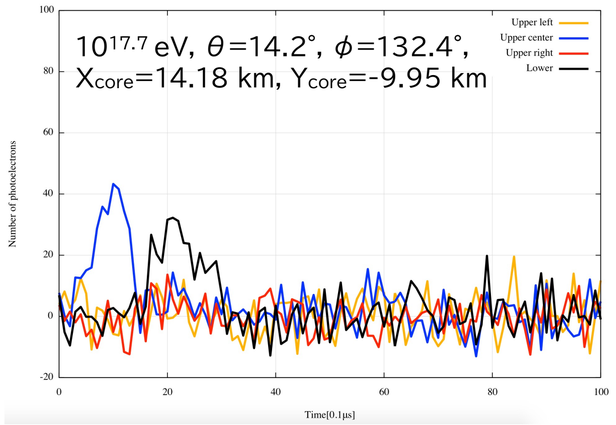
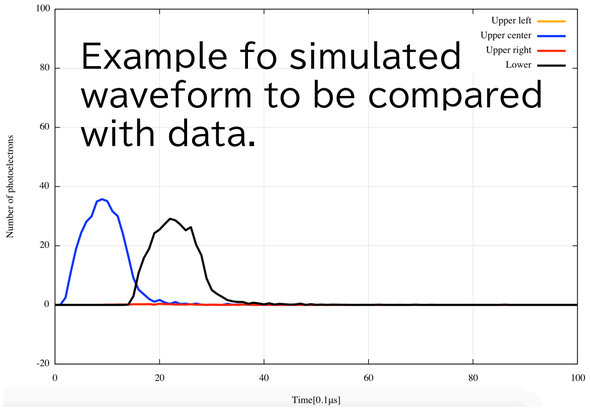
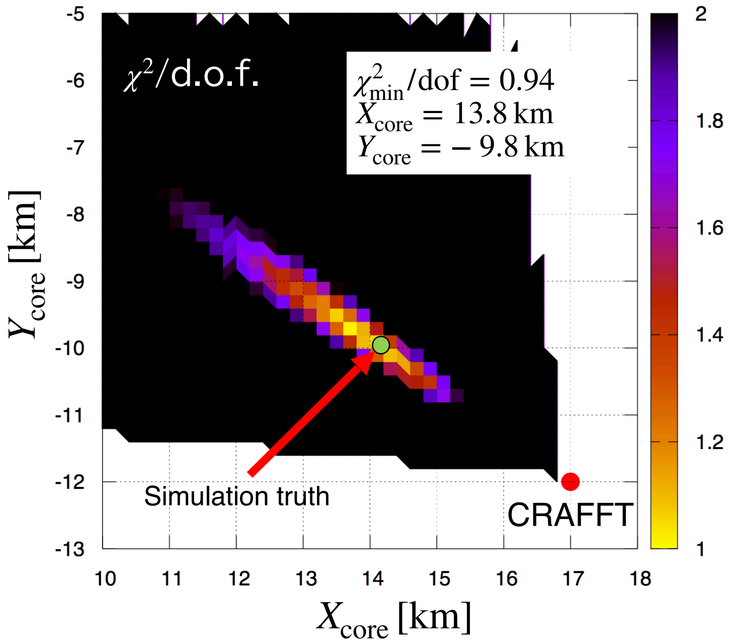
Shower geometry reconstruction

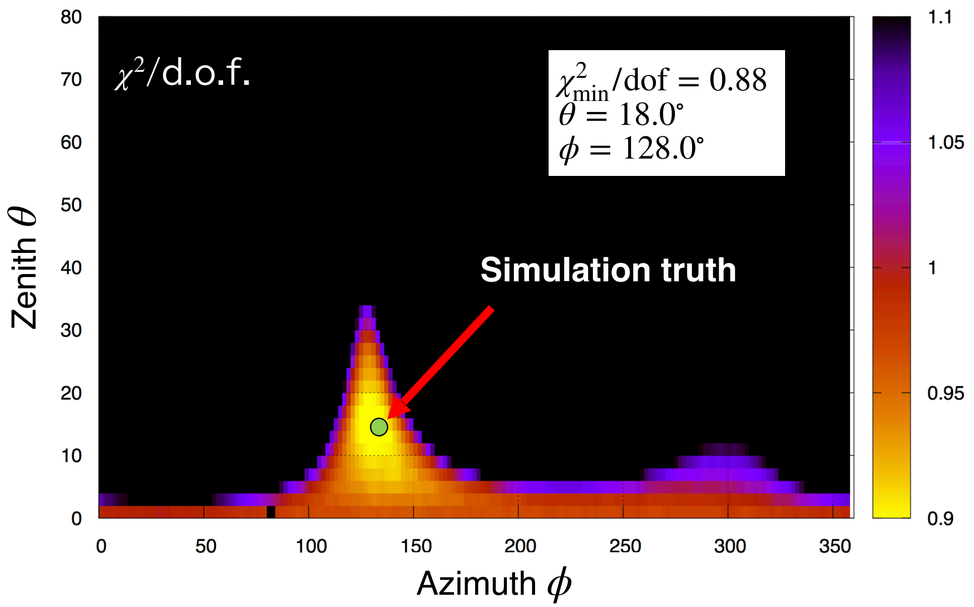


Simulated waveform based on the shower parameters reconstructed by TA FD with night sky background noise.



- Shower detector plane cannot be determined by single pixel detectors.
- Waveform recored by FADC (80 MHz) is only available.
- Least square fit using waveform data and simulated waveform.
- Parameters are Energy, $X_{\max}$, zenith, azimuth, X_{core}, and Y_{core}
- At least, 4 parameter fitting works to reconstruct shower geometry even with monocular measurment. (Energy and $X_{\max}$ are fixed here)



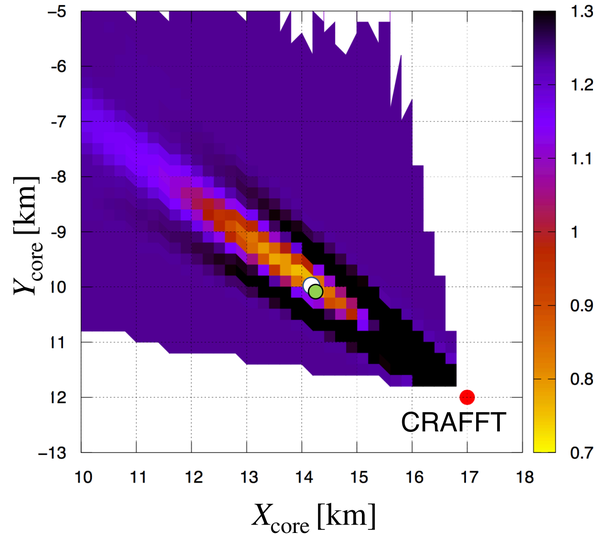


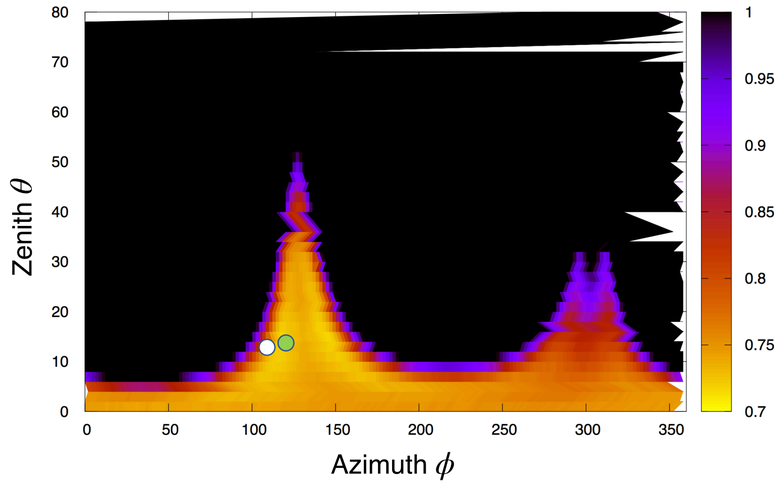
Reconstruction by waveform fitting

- Example of geometry reconstruction

	TA FD	Waveform fitting
Zenith	14.2°	14°
Azimuth	132.4°	146°
Xcore	14.18 km	14.25 km
Ycore	-9.95 km	-10.15 km
χ^2min / d.o.f.		0.71

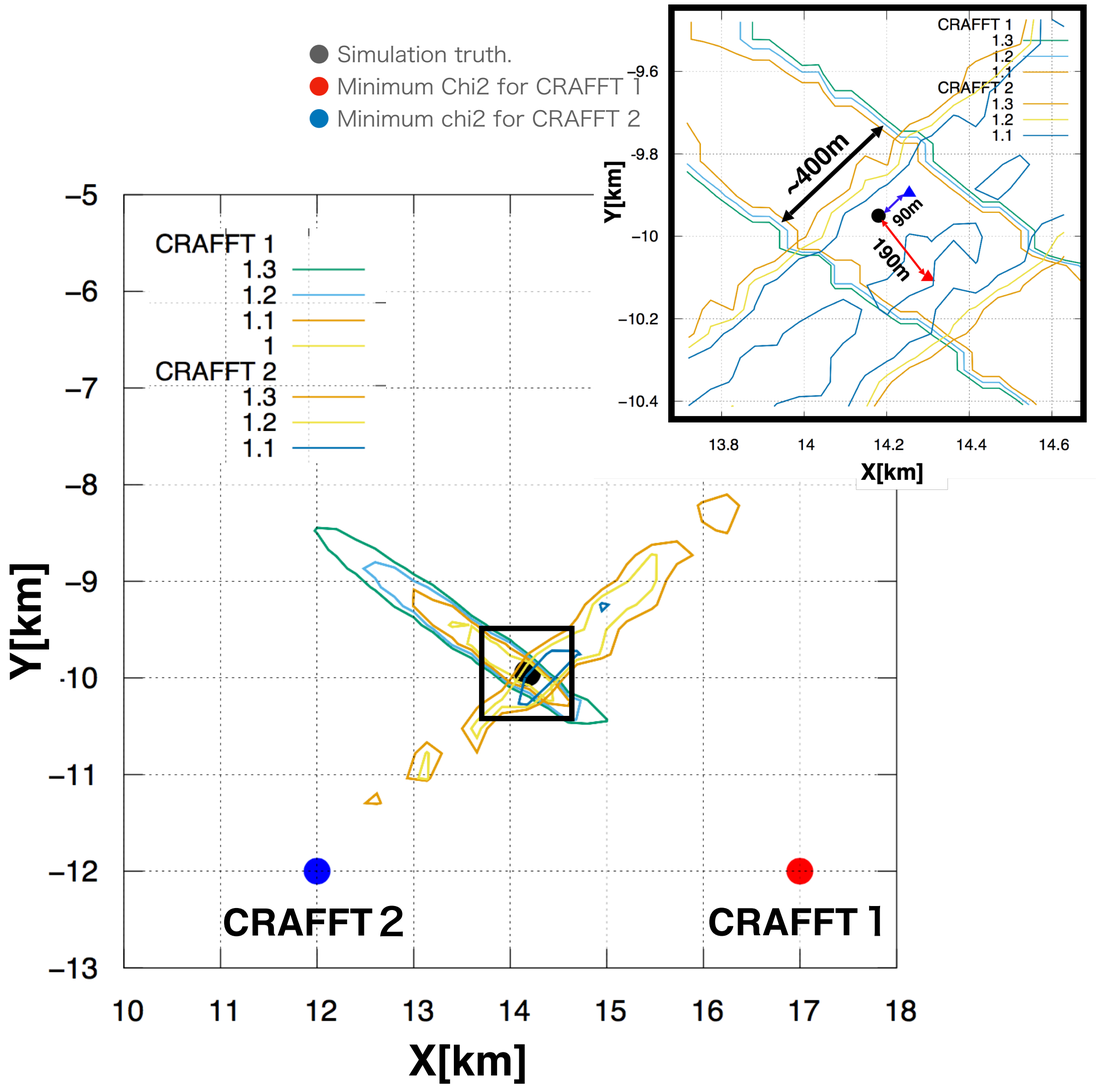
- Energy and Xmax are fixed.
- Core diff. = 210 m, opening angle = 3.3°
- PMT gain and uniformity are not been calibrated.
- For more precise reconstruction
  - Stereo reconstruction.
  - Optimization of detector configuration.





Shower geometry reconstruction

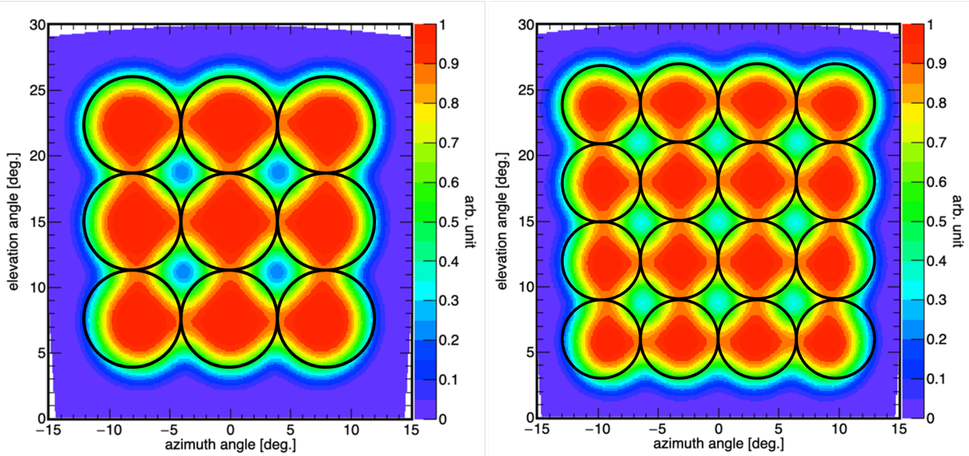
- Proper initial value is important to fit with 6 parameters
- Stereo measurement should be must.
- Stereo measurement can improve accuracy of shower reconstruction as well as traditional FD.
- It is also effective to constrain initial values of fitting parameters.



Optimization of detector configuration

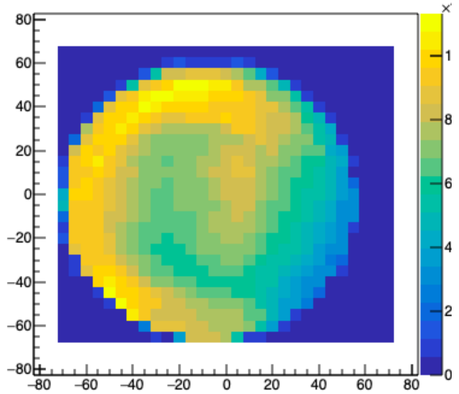
- Number of pixels of the 1st prototype is one.
  - Total signal strength and timing is available.
  - Worse S/N than traditional FD.
  - No spatial resolution in F.O.V.
- Optimizing detector configuration
  - To Improve reconstruction accuracy.
  - To extend F.O.V. per detector.
  - Considering 5 inc. PMT.
  - Number of pixels.
  - Arrangement of pixels.
- Importance of PMT calibration
  - CRAFFT is sensitive with uniformity of PMT gain.

Y. Kubota, ICRC2021



Example of PMT arrangement.
Winstone cone is also considered in right fig.

5 inc. PMT
(Hamamatsu)



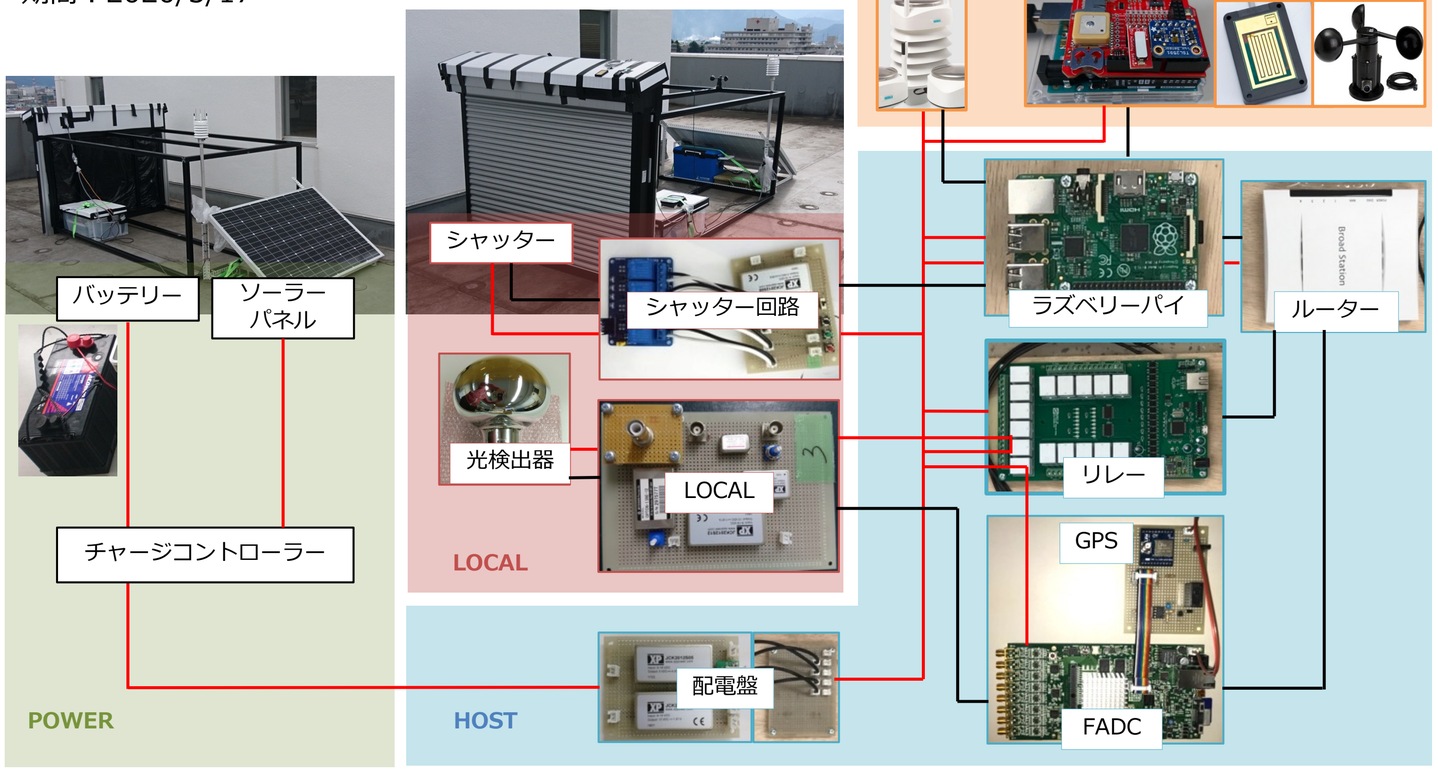
Example of measured
gain uniformity of R877.

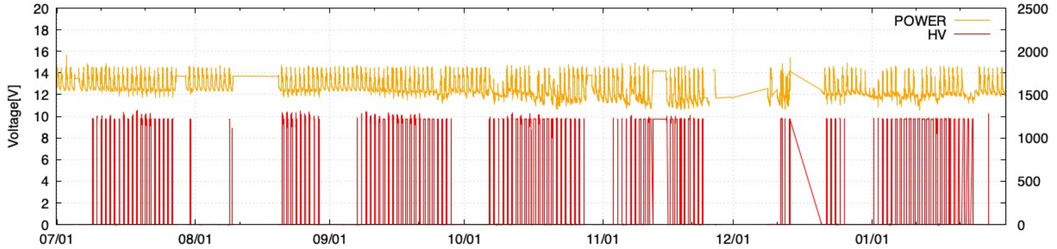
Automation of operation system

- Endurance test is on

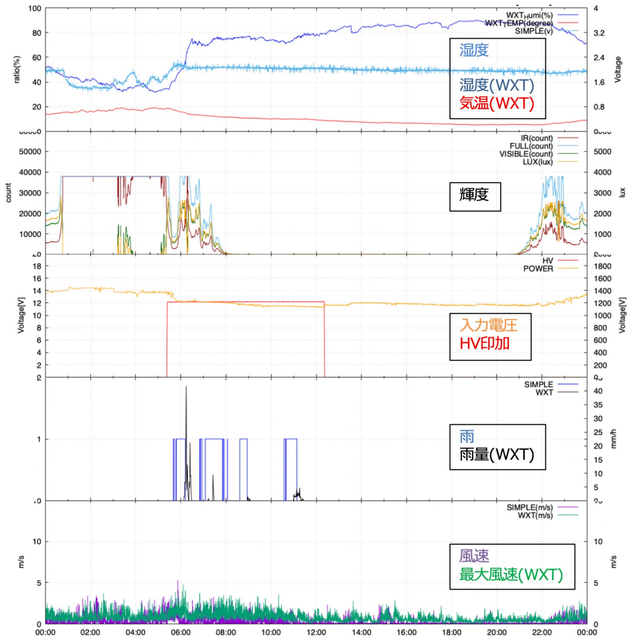
T. Tomida, ICRC2021

場所：信州大学屋上
期間：2020/3/17～





連続稼働試験： 観測時間にHVに印加



環境モニター

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Future prospect

Phase 1

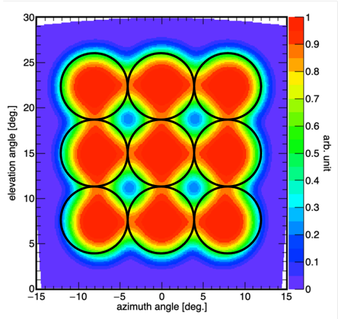
Confirmation of the concept of detectors

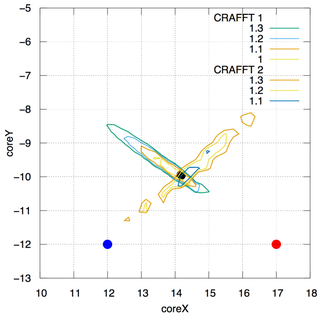
Succeeded to observe UHECR air showers
with prototype detector with a 8 inc. PMT

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.

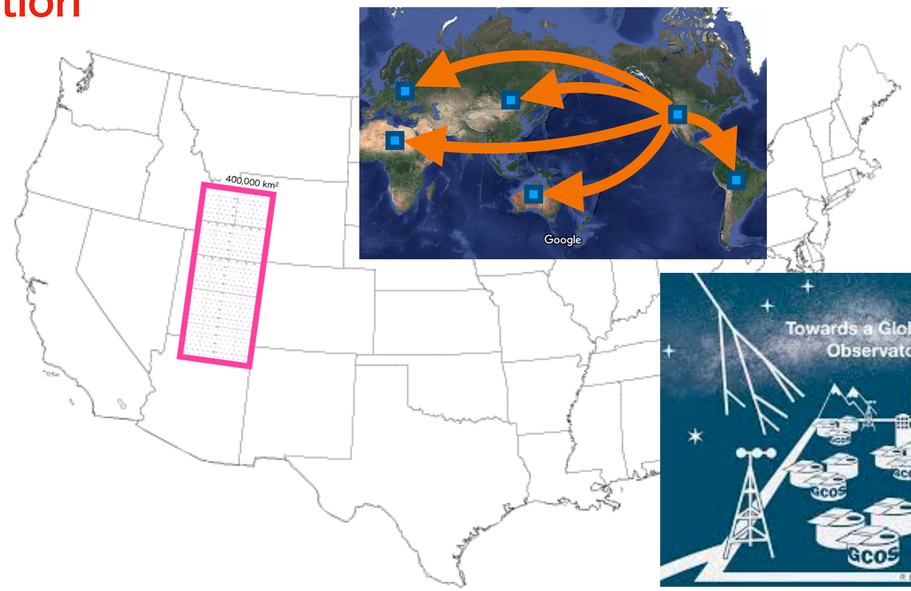




Phase 2

Confirmation of the concept of observation

Stereo observation
Deploy 6 + 6 CRAFFT at TA site
Wide area network



Phase 3

Large scale deployment

Array of 360° FD Station
20km spacing
500 station ~ 10 TA×4
400,000 km²
$150M

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Summary

- **CRAFFT** (**C**osmic **R**ay **A**ir **F**luorescence **F**resnel lens **T**elescope)
  - Developing a low cost FD using Fresnel lens and single pixel
  - 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 !!**
- Detector simulation reproduce data well.
- 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.
- Automation DAQ system is under endurance test.
- Future prospect
  - We are planning stereo observation at TA site.
  - Our goal is to realize a next generation huge observatory for UHECR observation.