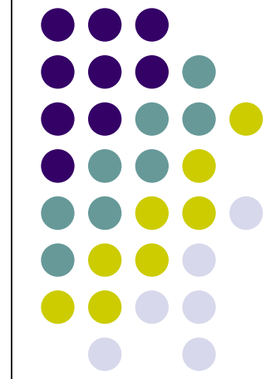
Telescope Array Project

ICRR N. Sakurai
for TA collaboration



1. **Motivation**
2. **Telescope Array**
3. **Current status**
4. **Future plan**
5. **Summary**

TA collaboration

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近畿大	千川･賀来
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高知大	中村
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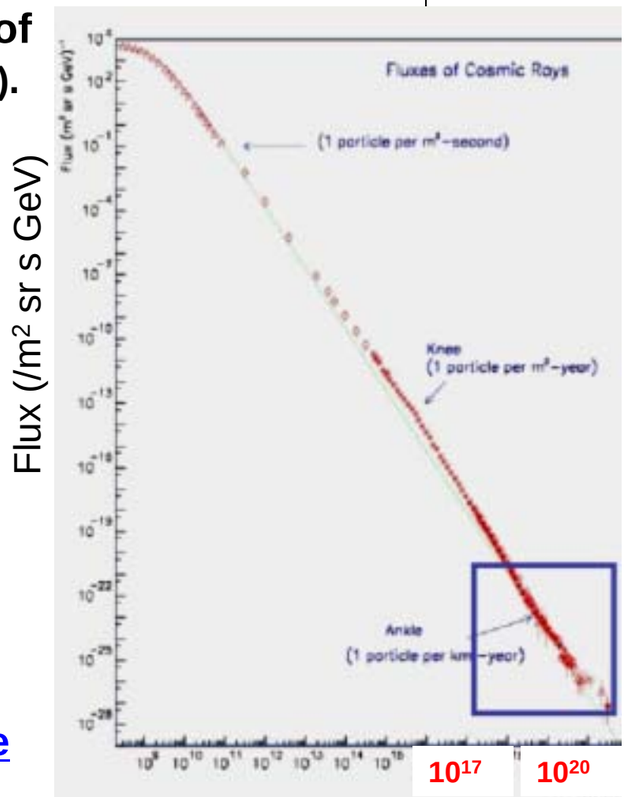
1. Motivation

☐ Highest energy cosmic ray

- **Understanding the nature and the origin of extremely high energy cosmic rays (E>10^{19}eV).**
  - Energy spectrum
  - Arrival direction distribution
  - Chemical composition
- **Super GZK particle : E>10^{20}eV**
  - **Bottom up scenarios**
    - **AGN / GRBs / Galactic clusters etc.**

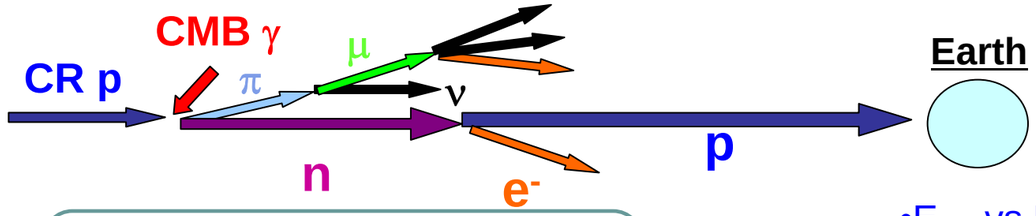
      → **Hadronic primaries are predicted**
  - **Top-Down scenarios**
    - **Topological defects**
    - **Super heavy dark matter**
    - **Z-burst**

      → **Gamma ray + nucleon primaries are predicted.**



GZK cutoff

The propagation through intergalactic space affects the spectrum due to the interaction between cosmic rays and CMB photons.



γ(CMB) + p(E>5x10^{19}eV)

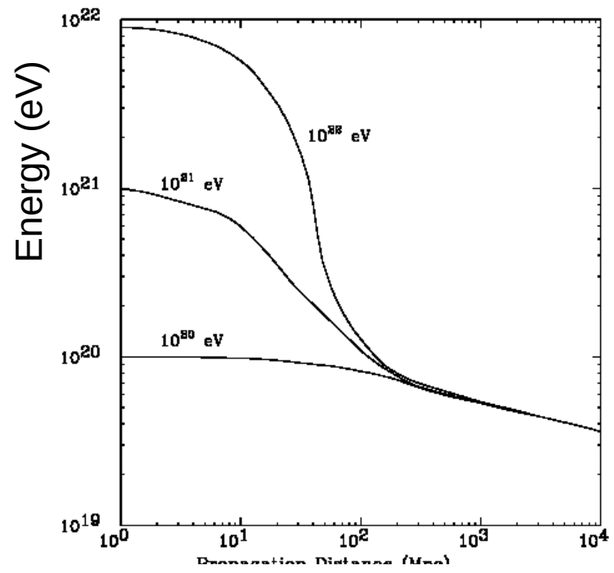
→Δ(1232)→π^0 + p or π^+ + n

If the highest energy CR are produced in distant extragalactic sources, a cutoff appear around 10^{20}eV.(GZK cutoff)

But, as I will show later, AGASA has observed 11 events above 10^{20}eV.

- No GZK cutoff?
- GZK cutoff + another component E>10^{20}eV?

- E_{CR} vs Propagation distance

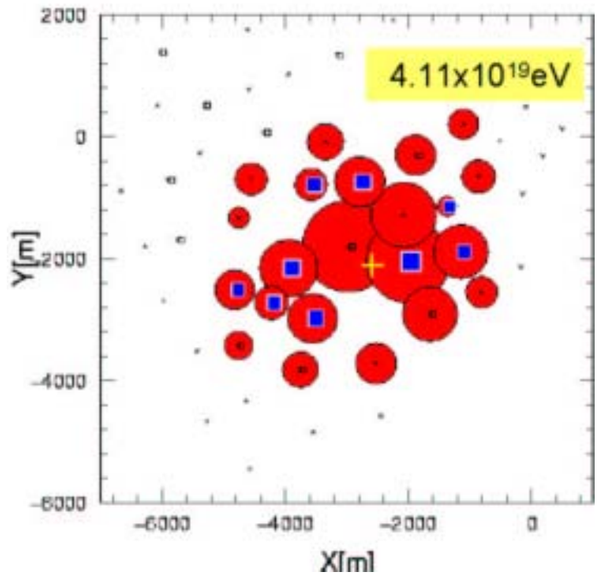


AGASA ~ Ground array

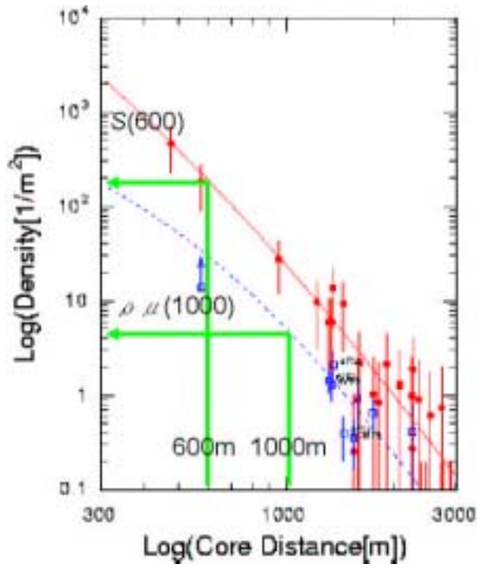
- Akeno, Yamanashi pref. Japan
  - Coordinates: 35°47'N, 138°47'E
- Altitude: 900m asl. (920g/cm^2)
- 111 scintillation detectors (1km mesh)
  - Size:2.2m^2 x 5cm
- 27 muon detectors
  - Size:2.8 ~10m^2
  - Fe/concrete absorber + prop. counters
- Operation: 1990~2004
  - (~95% live ratio)

AGASA event sample

Hit pattern

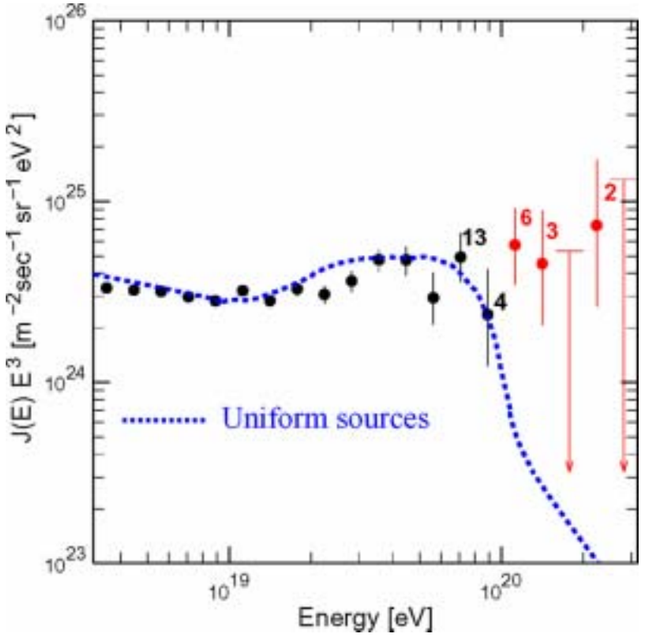


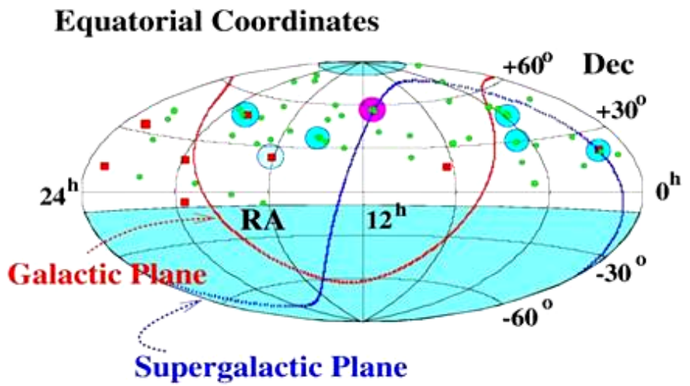
Lateral distribution of density



- Energy estimator : Charged particle density at 600m (**S(600)**)
- Event direction : Timing distribution of detectors.

AGASA results





- **11 super-GZK events**
  - Expected = 1.9 events
    (GZK assumed, uniform source)
- Small scale anisotropy
  - Event clustering
    >4x10^{19}eV within 2.5 °
  - **1 triplet** (◯) and **6 doublets** (◯) are observed.

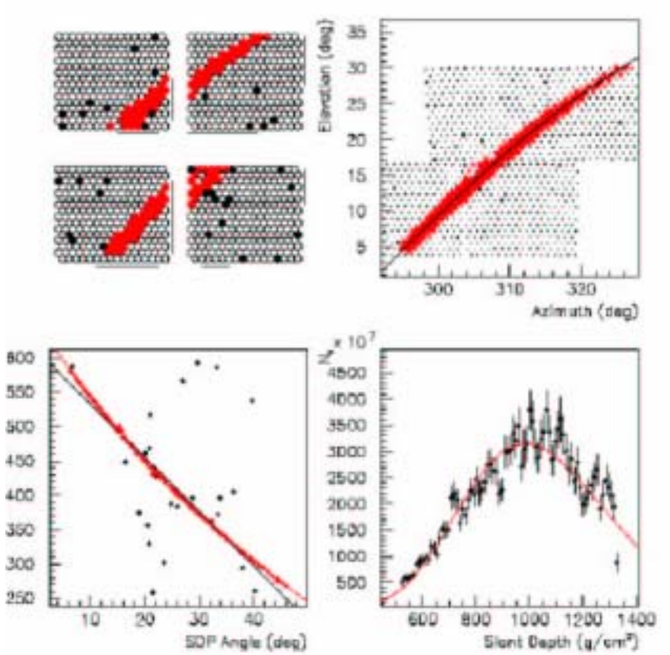
Hires ~ Air fluorescence

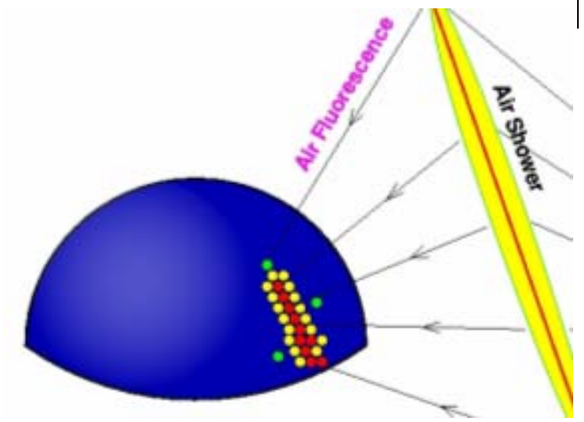
~13km

- Hires I : 21 mirrors
  - **FOV :** 360°(azimuth), 3° ~15° (elevation)
  - June 1997 ~
- Hires II : 42 mirrors
  - **FOV :** 360°(azimuth), 3° ~31° (elevation)
  - October 1999 ~

Hires event sample

5.2x10^{19}eV @Hires II





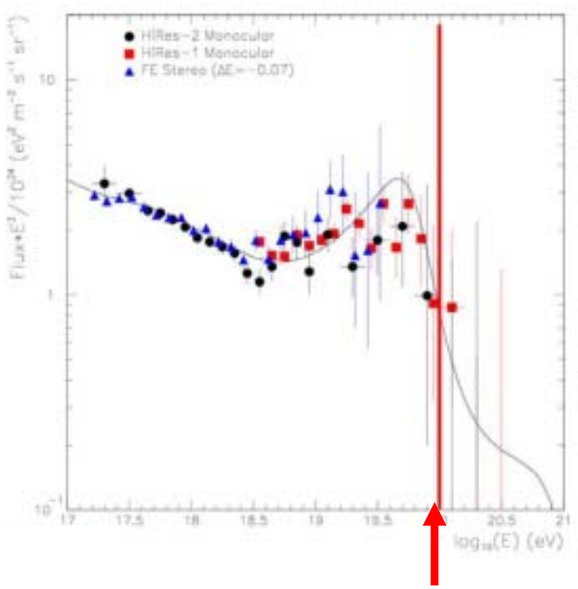
- Geometry fit by shower image and timing distribution.
- Fit by Gaissar-Hillas function
  - Fluorescence yield
  - Absorption correction
  - Cherenkov light subtraction

→Obtain direction, X_{max} and energy.

Hires results

- HiresI,II mono spectrum

D.Bergman et al. ICRC2003

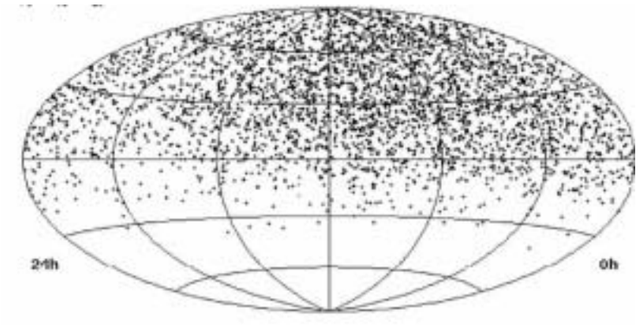


- **Hires - II mono**
- **Hires - I mono**
- **Fly's Eye stereo**

10^{20}eV

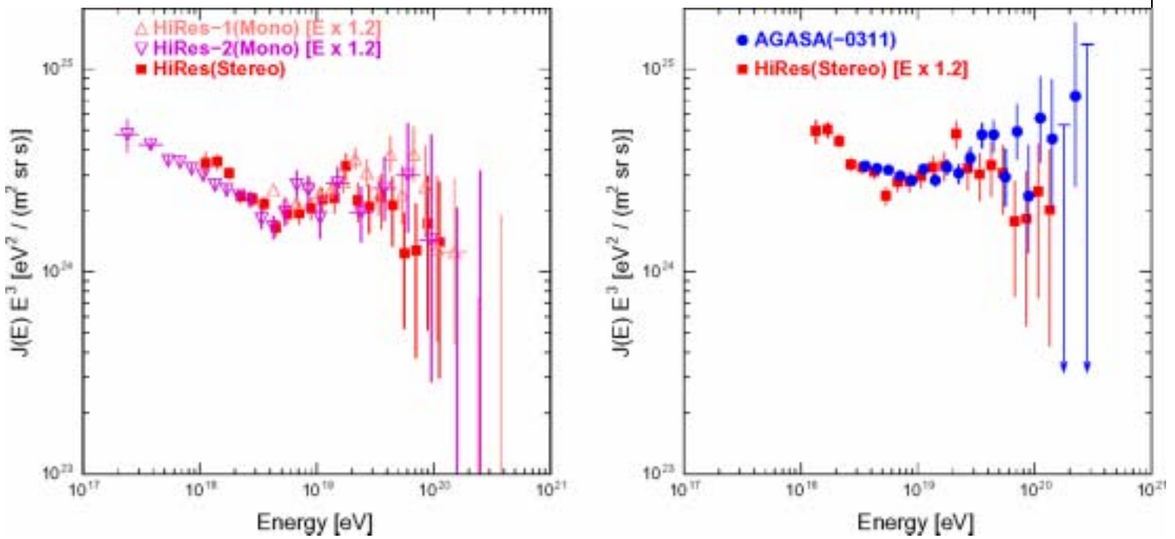
- Stereo event direction ($E>10^{19}$eV)

C.Finley et al. ICRC2003



- Monocular spectra
  - **2 events** above 10^{20}eV
  - Consistent with the existence of GZK cutoff.
- No significant clustering seen in direction distribution.

Comparison



Hires (mono) + 20% **Hires (stereo)**

Hires (stereo) + 20% **AGASA**

20% = Systematic error of energy calculation

We need direct comparison of these methods.

→ Telescope Array project

2. Telescope Array

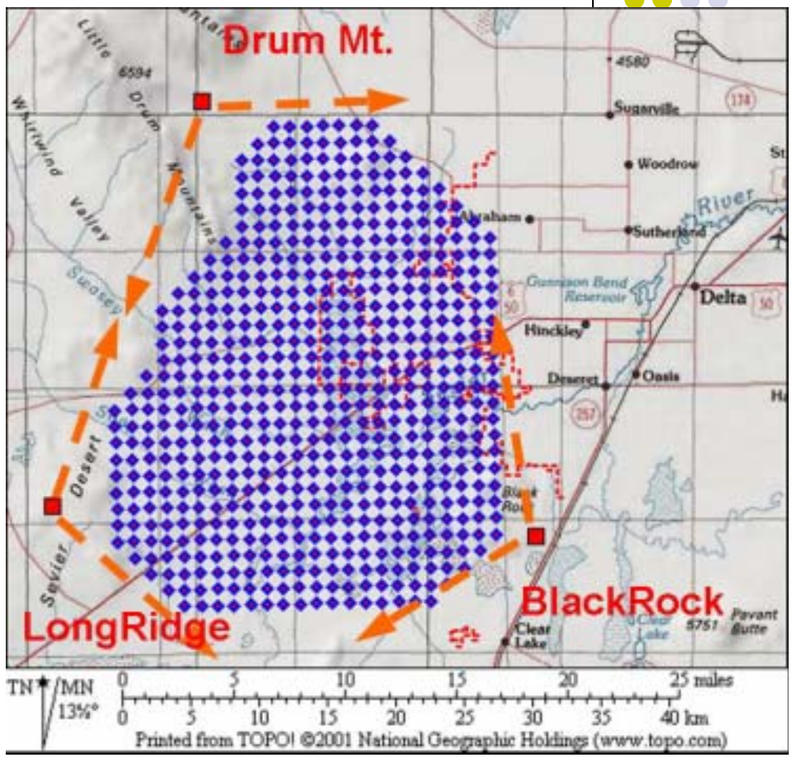
☐ Concept of TA

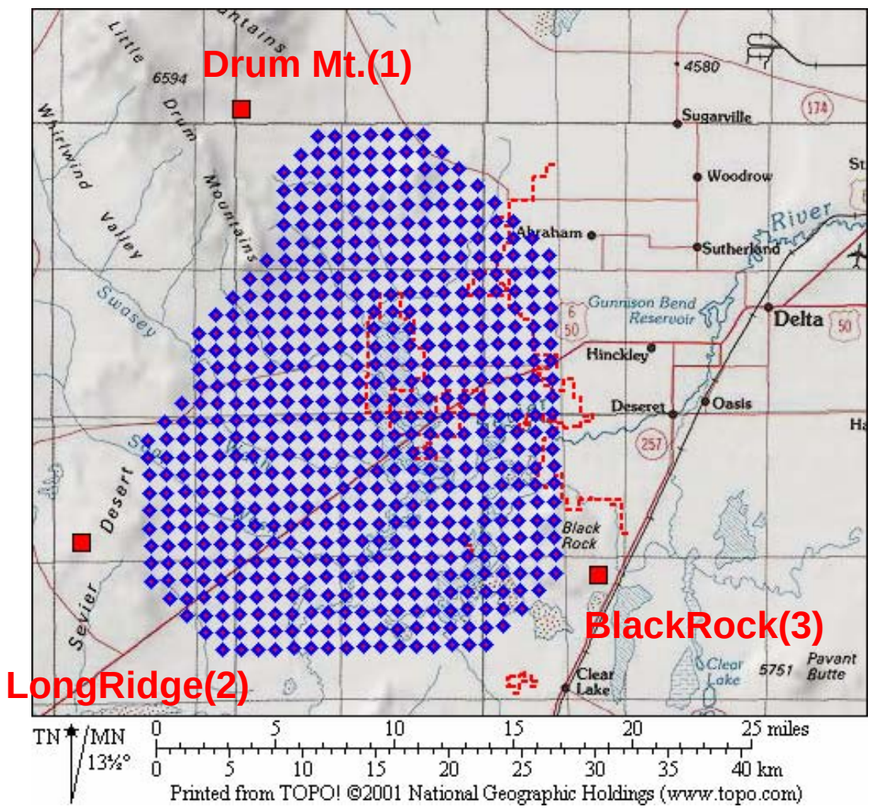
- Hybrid detector : ground array + fluorescence telescopes
  - **<u>Ground array</u>** : Stable observation (Duty factor >90%)
    (SD) Simple and cheap detector
    Acceptance does not depend on the energy so much.
    Energy scale essentially depends on simulation.
    → Energy spectrum shape and cluster search

  - **<u>Telescope</u>** : Only dark & clear night. (Duty factor < 10%)
    (FD) Energy can be calculated using only observable quantities.
    Primary particle identification using X_{max}
    Atmospheric monitoring } are needed.
    Fluorescence yield measurement
    → Absolute energy scale and chemical composition study.

TA site

- West desert in Utah, USA
- 576 plastic scintilation counters in ~1.2km mesh.
  → **AGASA x 9 acceptance**
- 3 fluorescence telescopes
  → **AGASA x 3 acceptance**





FD(DrumMt.)
39 ° 28 ′ 21.1 ″ N
112 ° 59 ′ 36.4 ″ W 1604m

FD(LongRidge)
39 ° 12 ′ 30.3 ″ N
113 ° 07 ′ 19.5 ″ W 1550m

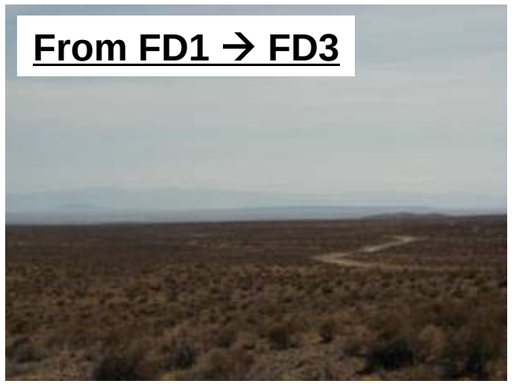
HR(LongRidge)
39 ° 13 ′ 33.8 ″ N
113 ° 04 ′ 23.0 ″ W 1613m

Center
39 ° 17 ′ 52.1 ″ N
112 ° 54 ′ 21.4 ″ W 1371m

FD(BlackRock)
39 ° 11 ′ 12.4 ″ N
112 ° 42 ′ 41.2 ″ W 1403m

Site survey (2003/10/28~29)

From FD1 → FD3



Overlooking of SD site

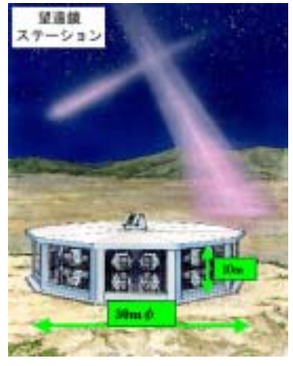
Around FD3

Road to site

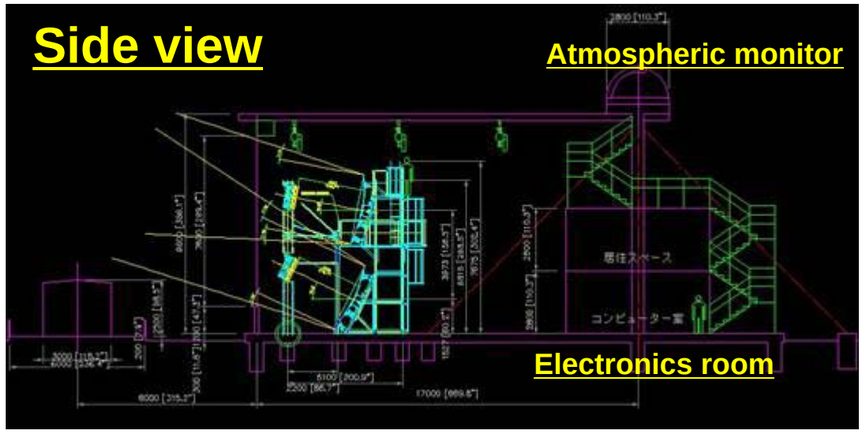
Fluorescence detector (FD)

- **Mirror : 3mΦ** spherical
- **FOV :** 18.0 ° azim., 15.5 ° elev.
- **Camera : 16x16 PMTs**
- **PMT :** R6234
  - 60mm hexagonal, 1 ° FOV
  - HV ~ 800V, Gain ~ 10^4

- Design of FD station
  - 12 ~ 14 telescopes/station.
    - → **~120 ° azim./station**
      ~34 ° elev./station
  - Laser & telescope for atmospheric monitor set in the roof of each station.

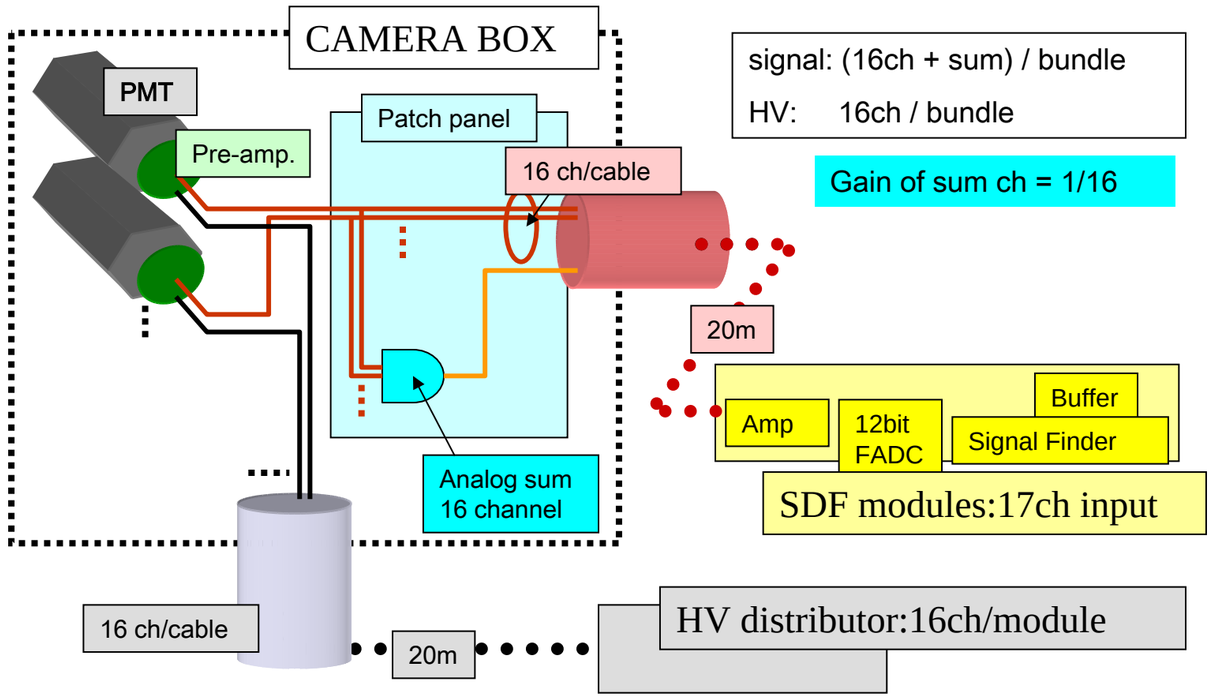


Side view



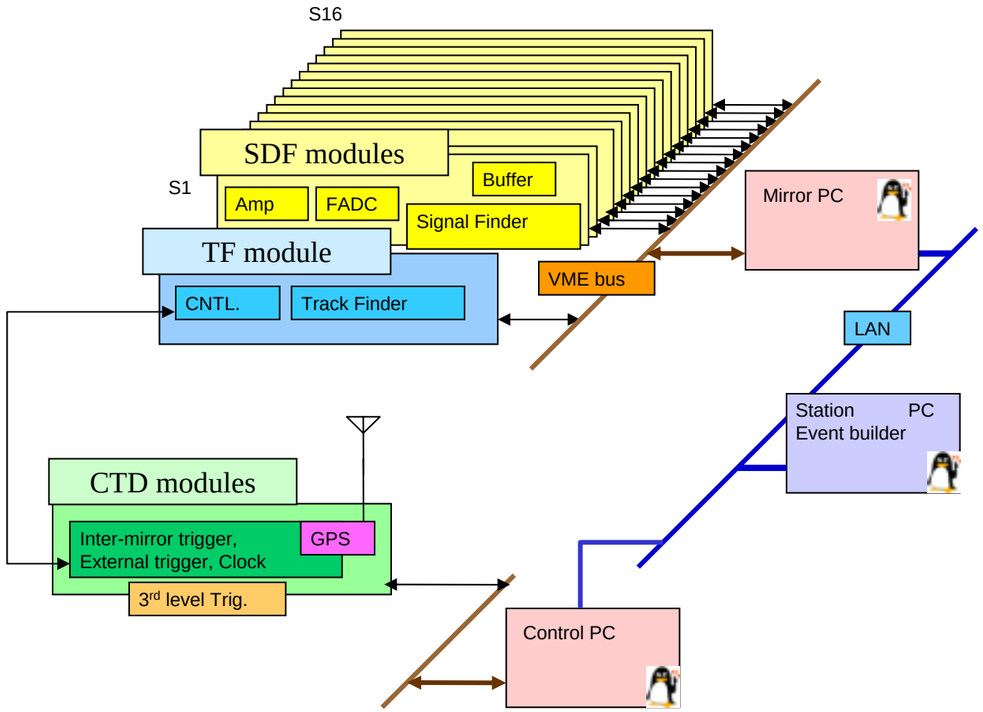
FD electronics (1/2)

- Front-end electronics



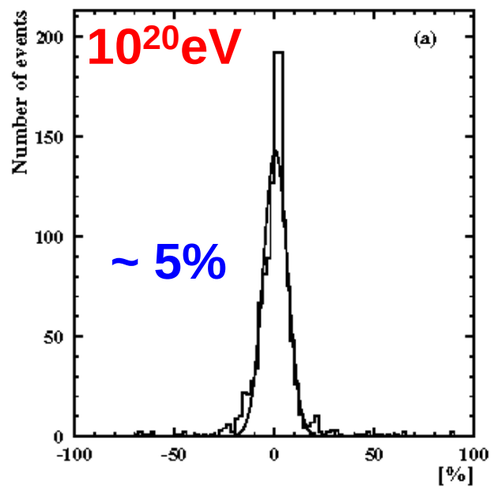
FD electronics (2/2)

- Telescope DAQ



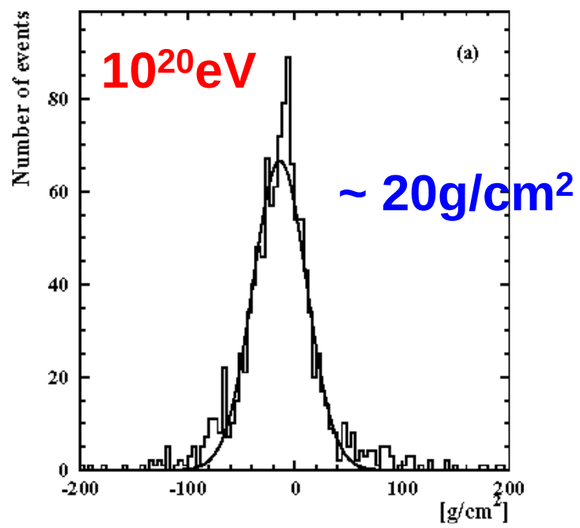
FD resolutions(1/2)

- Energy resolution



~9.5% @E=$10^{18.5}$eV
~5% @E>10^{19}eV

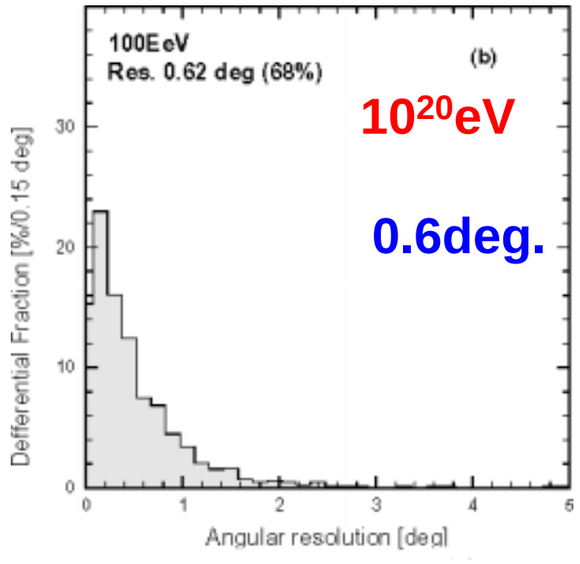
- Xmax resolution



30g/cm^2 @E=$10^{18.5}$eV
20g/cm^2 @E>10^{19}eV

FD resolutions(2/2)

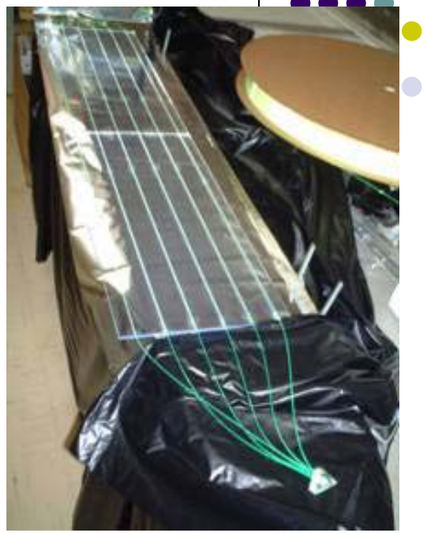
- Angular resolution

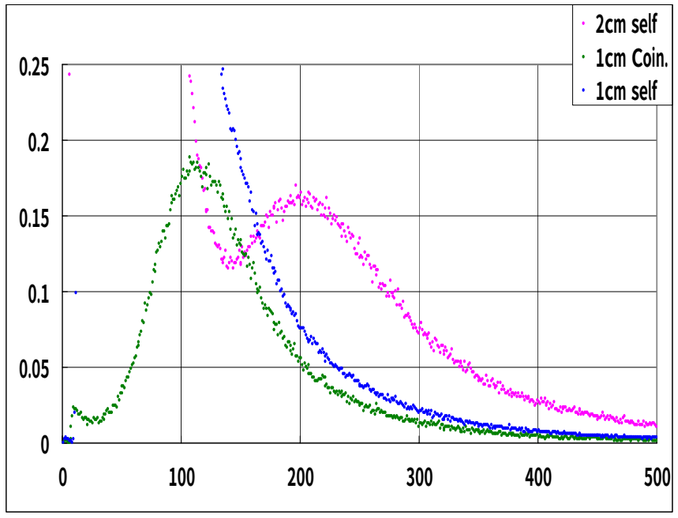


0.7degree @E=$10^{18.5}$eV
Almost constant

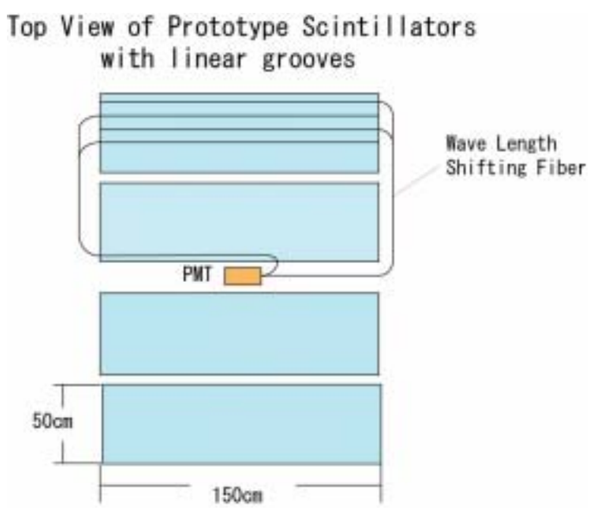
Surface detector (SD)

- **3m²** area x 2cm thick plastic scintillator + WLSF + PMT

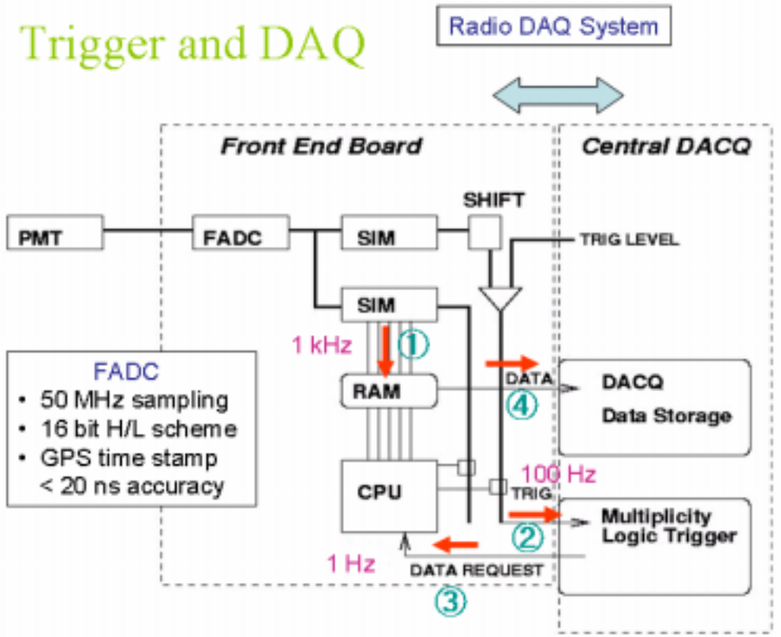


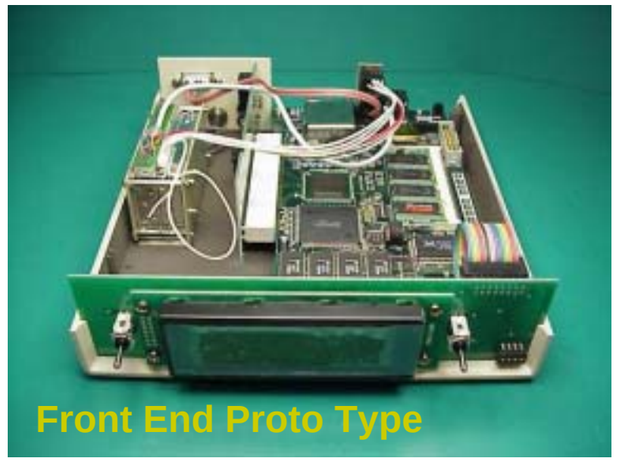


Pulse height distribution of thin Scintillator



Electronics for SD





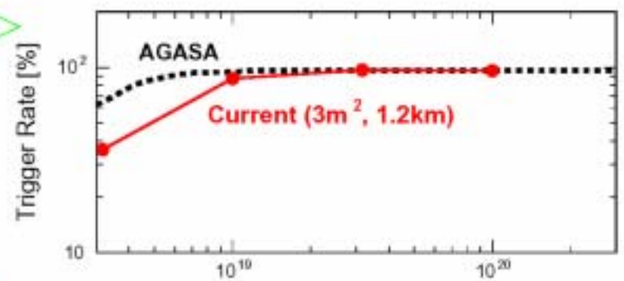
Power : Solar sell + battery system
Communication + DAQ : Wireless LAN
Time : GPS (ΔT_{rel}<20nsec)

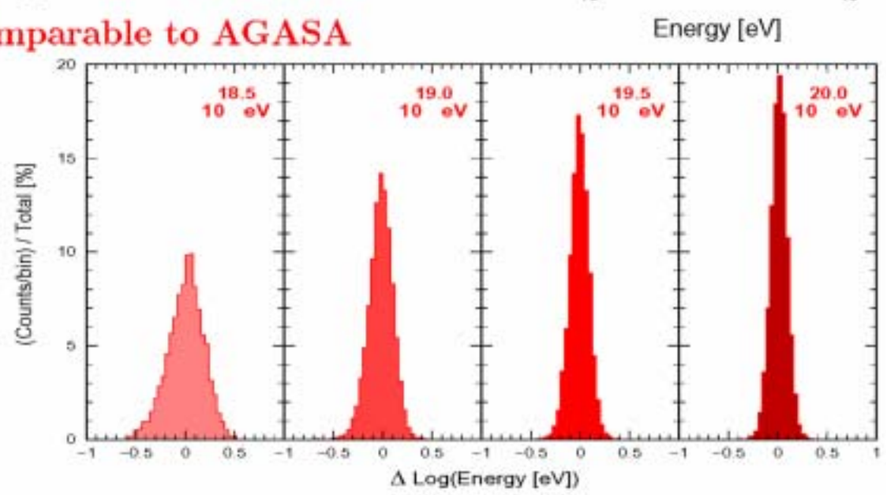
SD performance(1/2)

Very preliminary estimation

< TA-SD Performance >

- Detection Efficiency ⇒
  Constant above 10^{19}eV
- Energy Resolution ⇓
  Comparable to AGASA

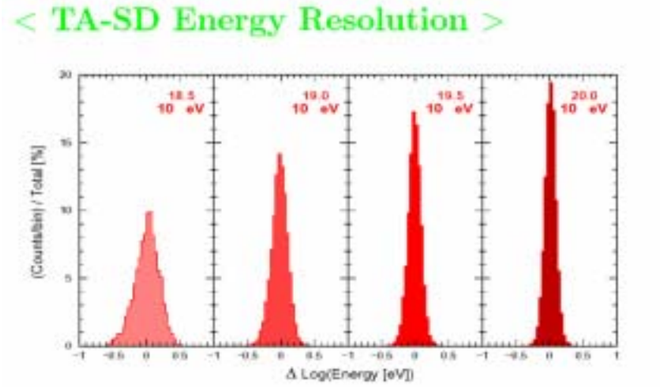




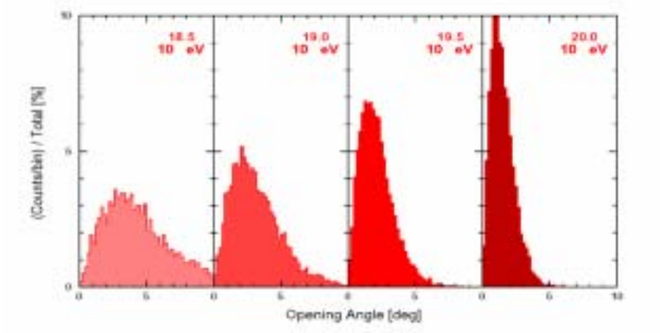
SD performance(2/2)

Very preliminary estimation

< TA-SD Energy Resolution >



< TA-SD ArrivalDirection Resolution >



Expectation (1/2)

•**Expected number of super-GZK events**

	Aperture (km^2sr)	Relative aperture	Angular resolution (degree)	# of events/year	
				$>10^{19}$eV	$>10^{20}$eV
AGASA	162	=1	1.6	100	1
Surface det.	1371	8.5	1.0	700	9
Fluorescence detector*	610	4.1	0.6	300	4
Hybrid observation*	165	1.0	0.4	80	1

Assumption: * = Duty factor 10%

If AGASA spectrum is correct, we can determine the existence of GZK cutoff at about 8 sigma level.

Expectation (2/2)

- **Expected event rate for clusters**

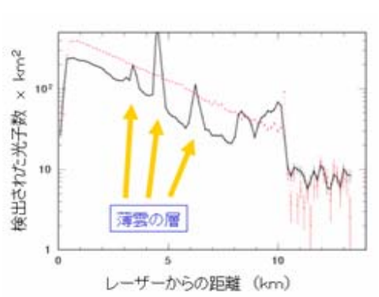
	AGASA 11yr	TA surface array AGASA x 10, 3yrs
Angular resolution	1.6deg.	1.0 deg.
Signal	8	80
Noise	1.6	6

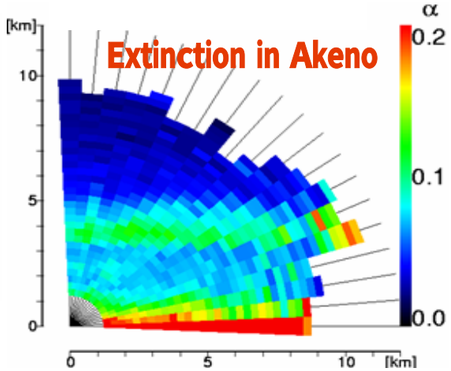
3. Current status

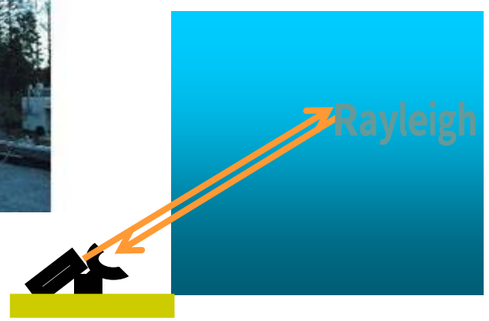
☐ Atmospheric monitoring

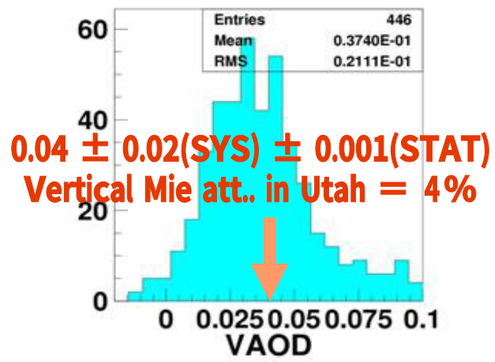
Back scattering LIDER :
Relative meas., difference picture.

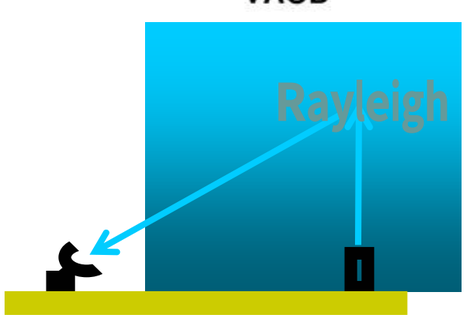
Side scattering monitor :
Abs. measurement Integral picture.



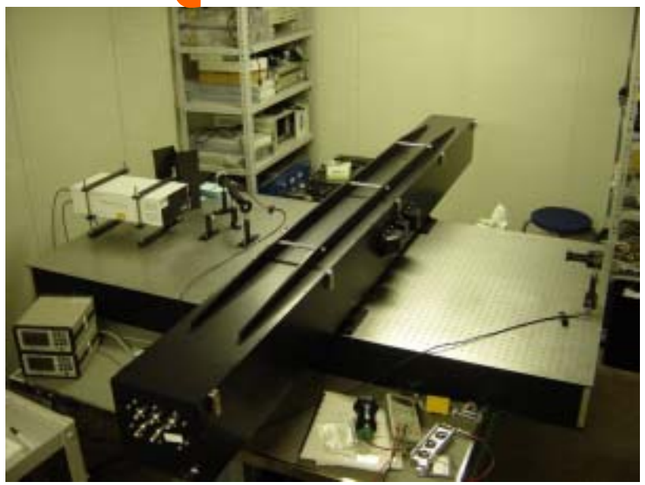


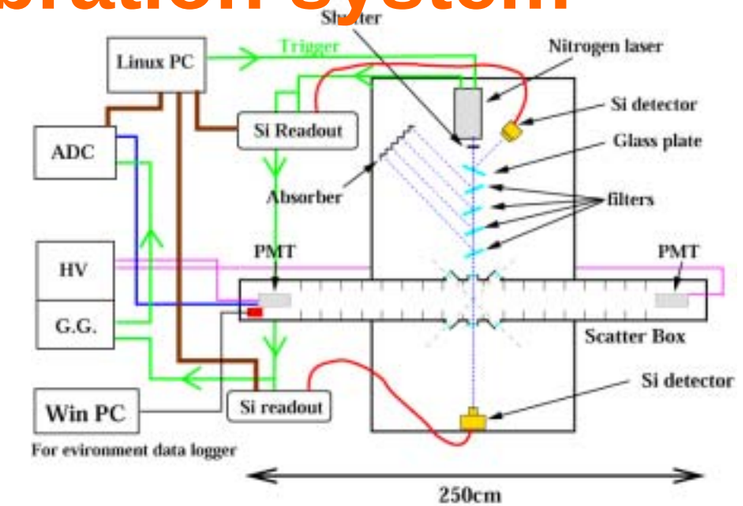






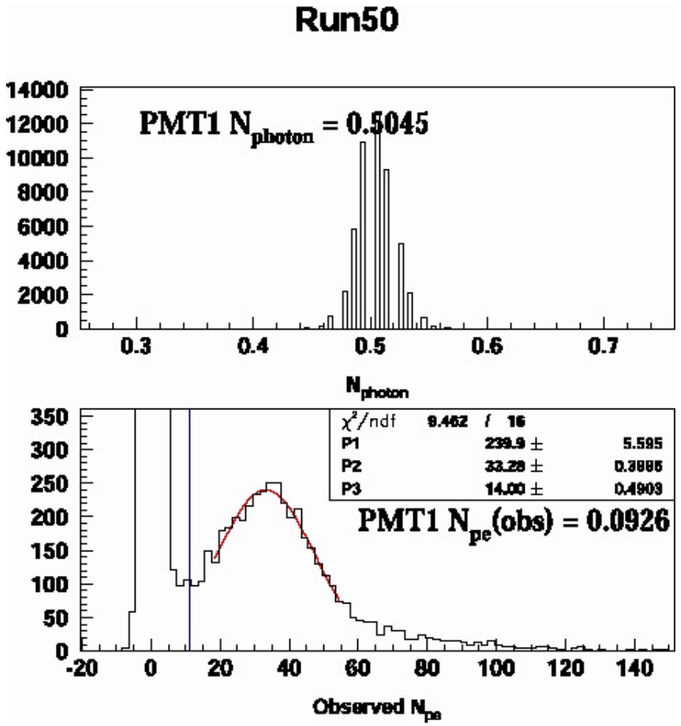
Q.E.&C.E. calibration system





- Light source: N_2 laser (lambda=337.1nm)
- Black box is filled with pure N_2 gas.
- # of scattering photon is easily calculated.
  (Pure rayleigh scattering)
- Laser energy is measured by Si energy probe preciously.

Q.E.&C.E. calibration of PMT



# of photon from Si det.

$N_{photon}=0.50\pm0.03$

# of P.E. from PMT.

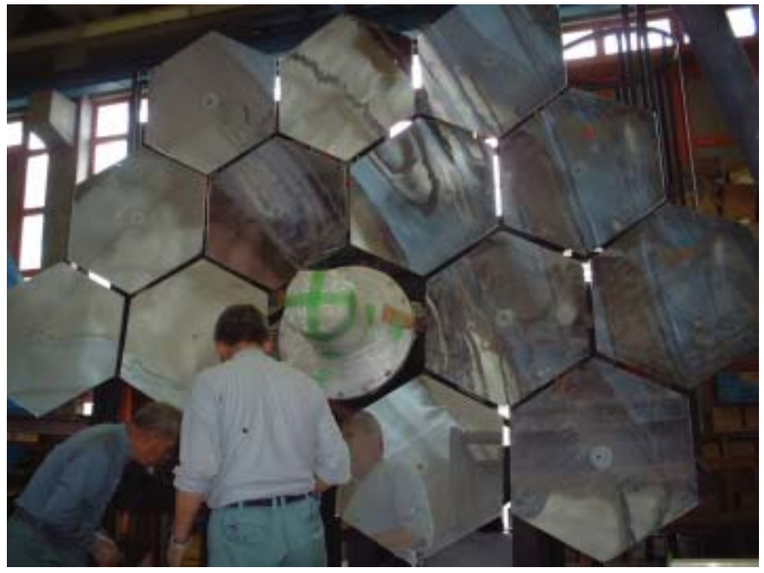
$N_{pe}=0.093\pm0.01$

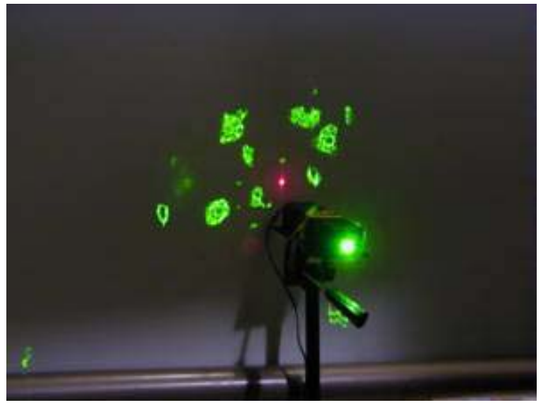
Q.E.×C.E=0.18±0.02

(Data provided by HPK：
Q.E.×C.E.=0.19±0.03)

AKENO test telescope

- We built 1 telescope at AKENO observatory.
  - Test of construction
  - Alignment method (body, mirror)
  - Camera box test
  - Cabling test

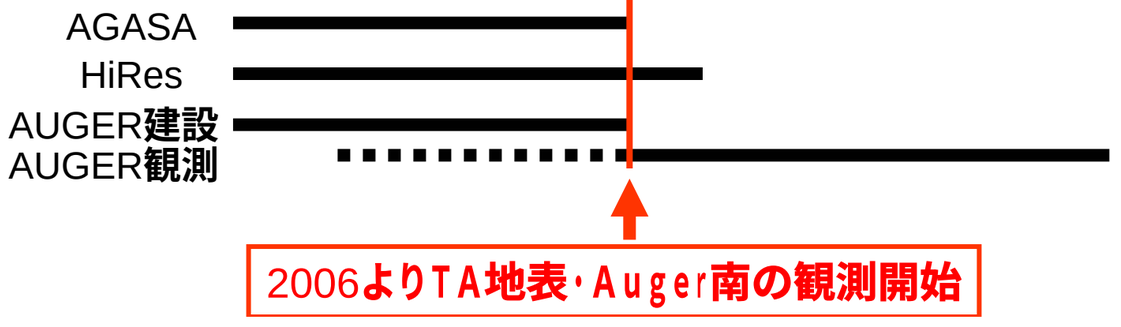




4. Future plan

年次計画 (2004 – 2009)

項　　目	2004	2005	2006	2007	2008	2009
サイト整備						
望遠鏡の現地試験						
望遠鏡の製作						
望遠鏡の設置						
地表検出器の現地試験						
地表検出器の製作						
地表検出器の設置						
AGASA との同時計測による較正						
地表検出器定常観測						
ハイブリッド定常観測						



5. Summary

- There are 2 different results on highest energy cosmic ray.
  - AGASA :11 events above 10^{20}eV.
    7 clusters in direction distribution.
  - HIRES : Energy spectrum is consistent with existence of GZK-cutoff.
    No clusters are found in direction distribution.
- To study the difference between ground array method and air fluorescence method, we are constructing hybrid detector (Telescope Array: TA) now.
  - Site: The western desert of Utah, USA
  - 576 plastic scintillation detectors
  - 3 telescope stations

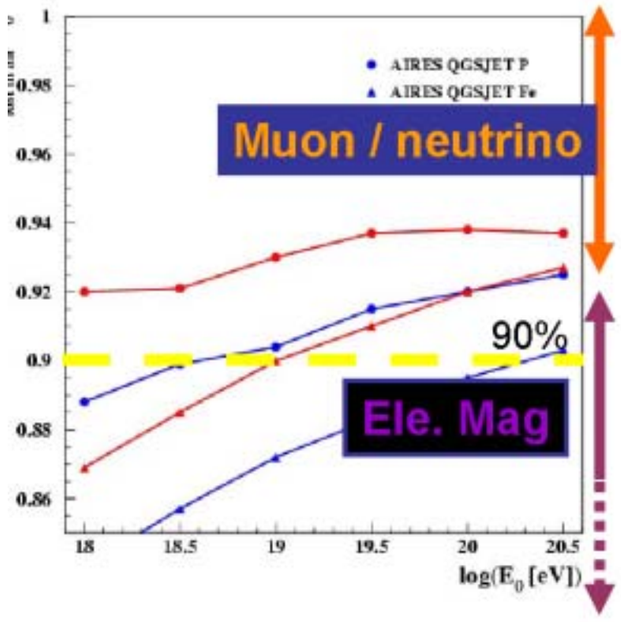
- Site is almost ready. Now we are working to fix the precise positions of particle detectors.
- Prototype of electronics are ready in this Spring.
  - We will built a small engineering array in AKENO.
- Calibration systems are developing now.
  - Atmospheric monitoring system using laser is ready.
  - Absolute/relative calibration of PMT is almost ready.
  - Mirror/filter calibration system is designing now.
  - ……..

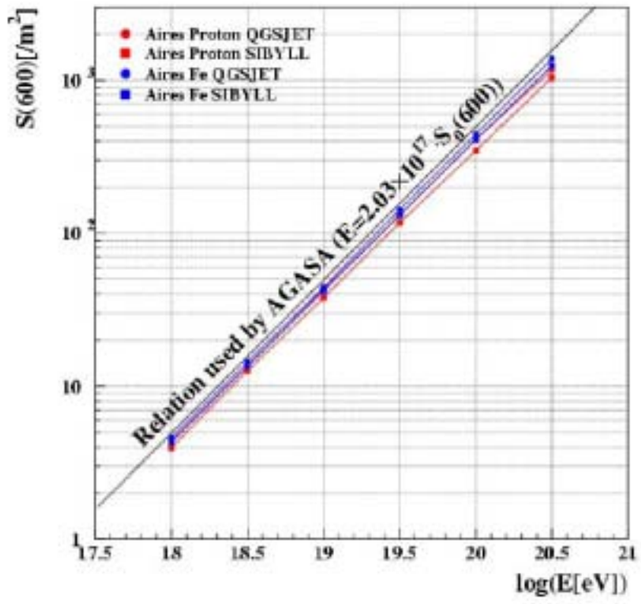
There are so many things to do.
If you are interested in highest energy in the universe, please come and work together.

Energy conversion

AIRES + QGSJET98 / SIBYLL for p & F

Energy dispersion in atmosphere





- **90% primary energy carried by EM component**
  - primary particle & model ~a few % dependence
- S(600) depending less on primary particle / model

End-to-end calibration (LINAC)

- First calibration of telescope using real shower
- Beam energy and # of electron can be measured precisely.
- Atmospheric condition does not affect so much.
  (Light path is not so long.)

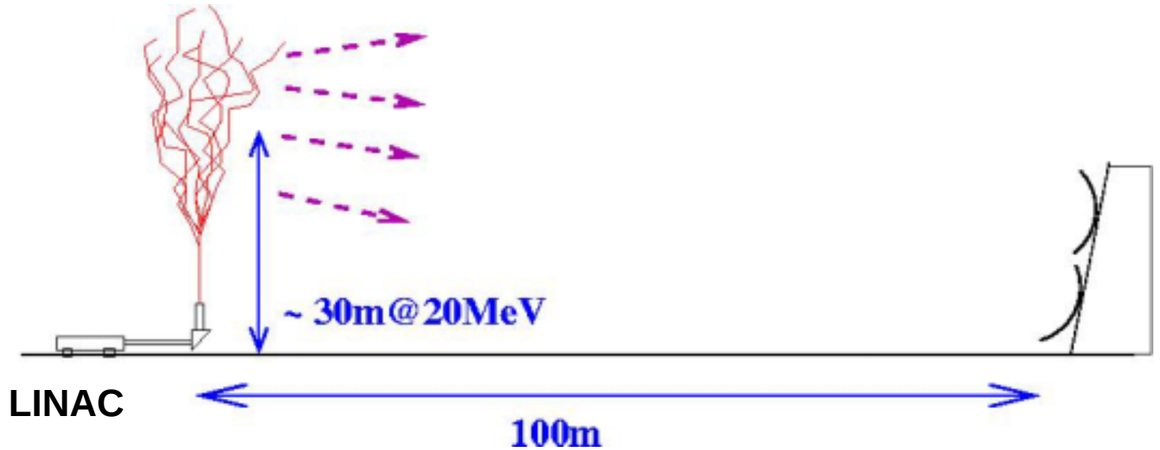
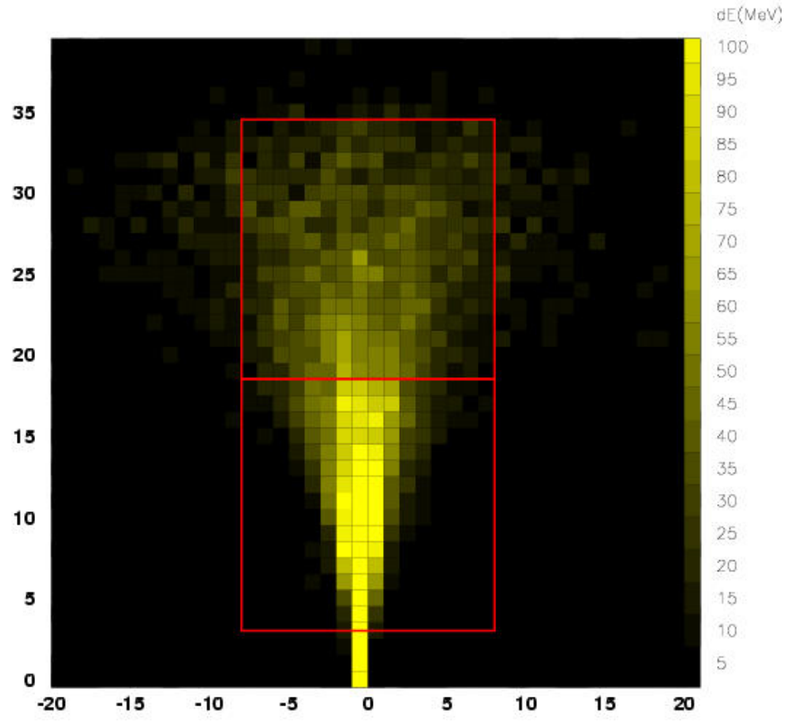


Image of LINAC shower

- 20MeV electron beam
- 1000 electrons are displayed in the right figure.
- Red squares show the field of view of 2 cameras.
- Each pixel size corresponds to the FOV of single PMT.
- dE in FOV in two cameras is about 70% of total energy.



Merit of LINAC calibration

- Systematic error of energy scale is checked directly.
  - For cross check, monochromatic laser (energy calibrated) is shot toward sky.
- Simulation can be easily done using GEANT.
- Trigger and geometry reconstruction efficiency may be measured by this system.

Problems of LINAC calibration

- It isn't understood whether it doesn't violate radiation protection law.
- Is there a suitable place to built LINAC near the telescope station?
- No people, No money.