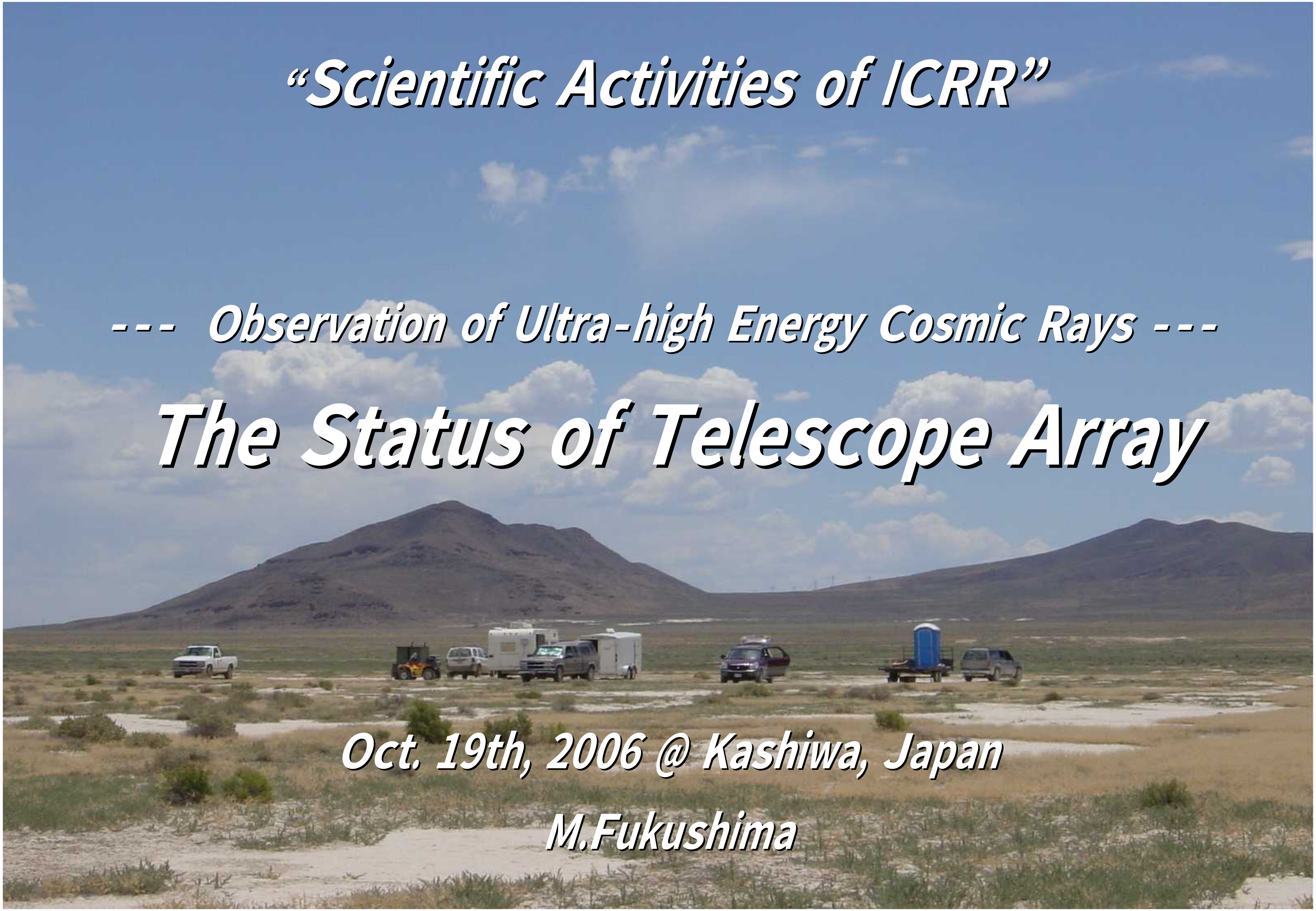

"Scientific Activities of ICRR"
--- Observation of Ultra-high Energy Cosmic Rays ---
The Status of Telescope Array
Oct. 19th, 2006 @ Kashiwa, Japan
M.Fukushima

Telescope Array (TA)

Originally planned as a large array of fluorescence telescopes to identify the origin of super-GZK ($E > 10^{20}$eV) cosmic rays (ICRR review in 2000).

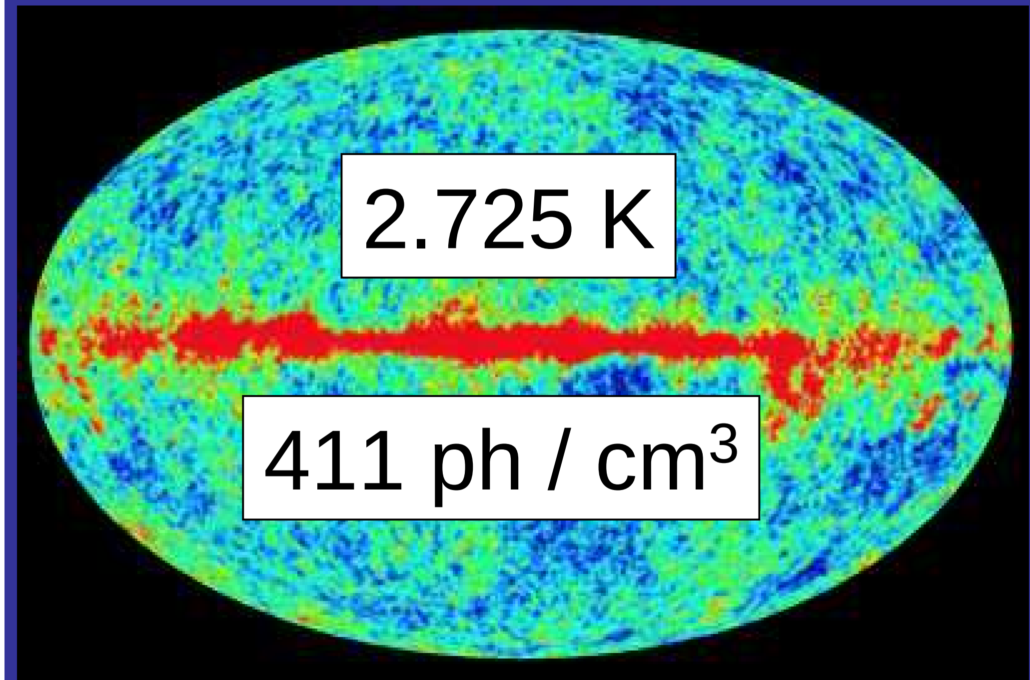
HiRes monocular spectrum suggested existence of GZK cutoff (27^{th} ICRC @ Hamburg in 2001).

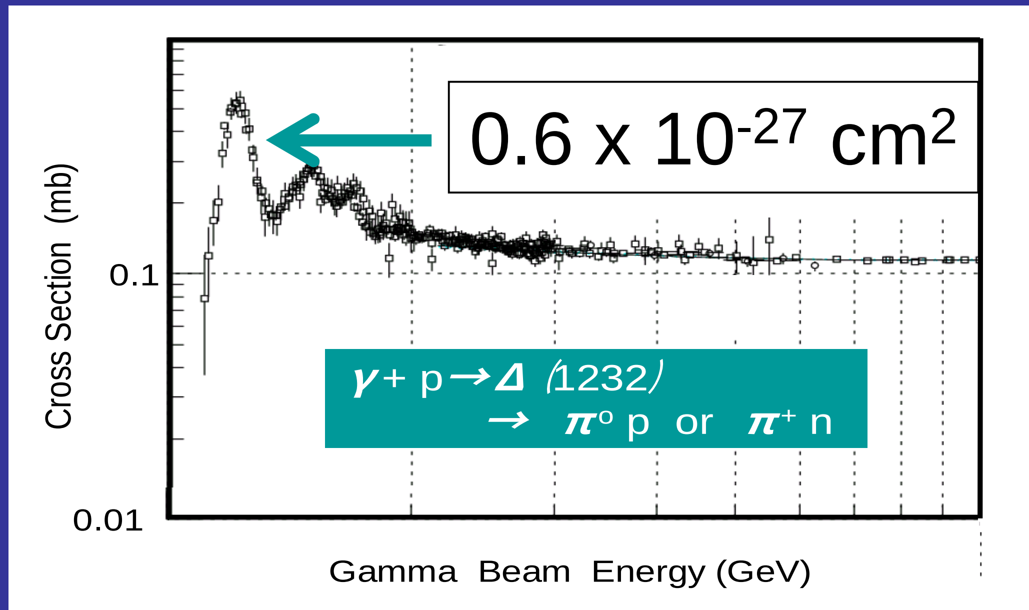
Physics? Method? Statistics?

Critical look at systematics of SD (AGASA) and FD (HiRes) measurements became imperative.

Phase-1 TA financed in 2003 as SD / FD hybrid detector.

Mechanism of GZK Cutoff

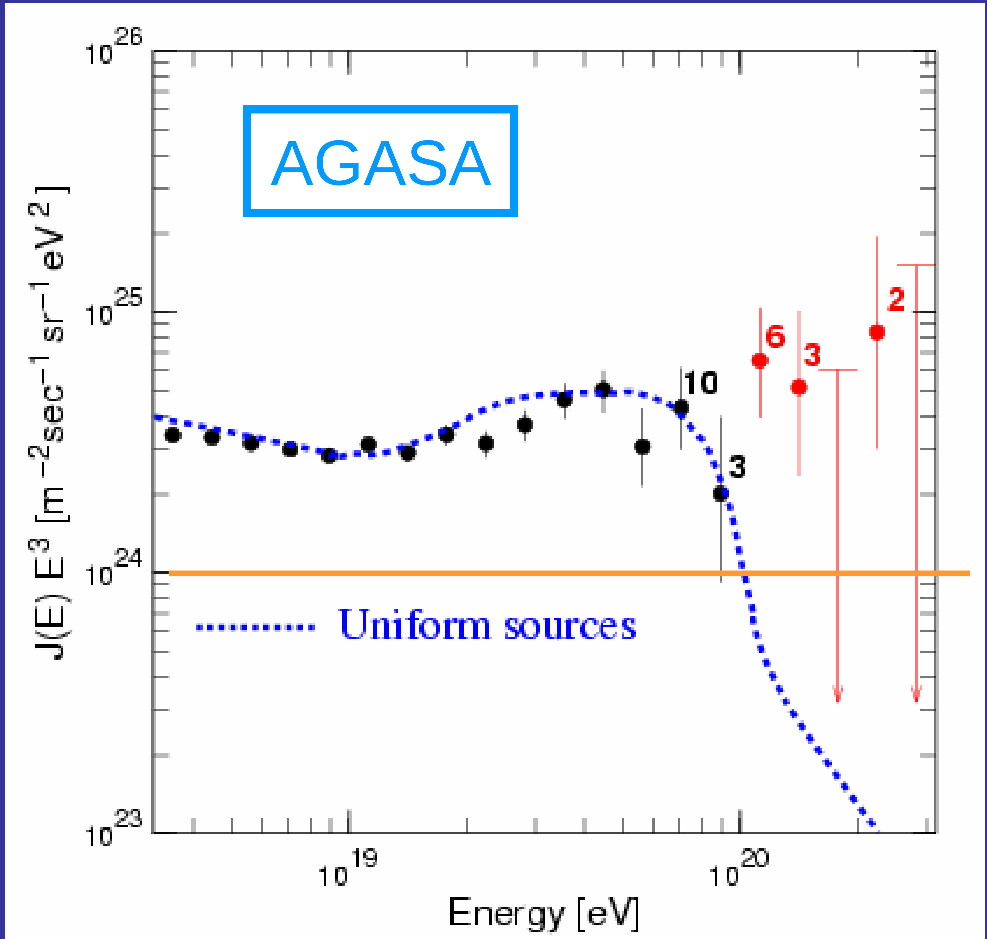




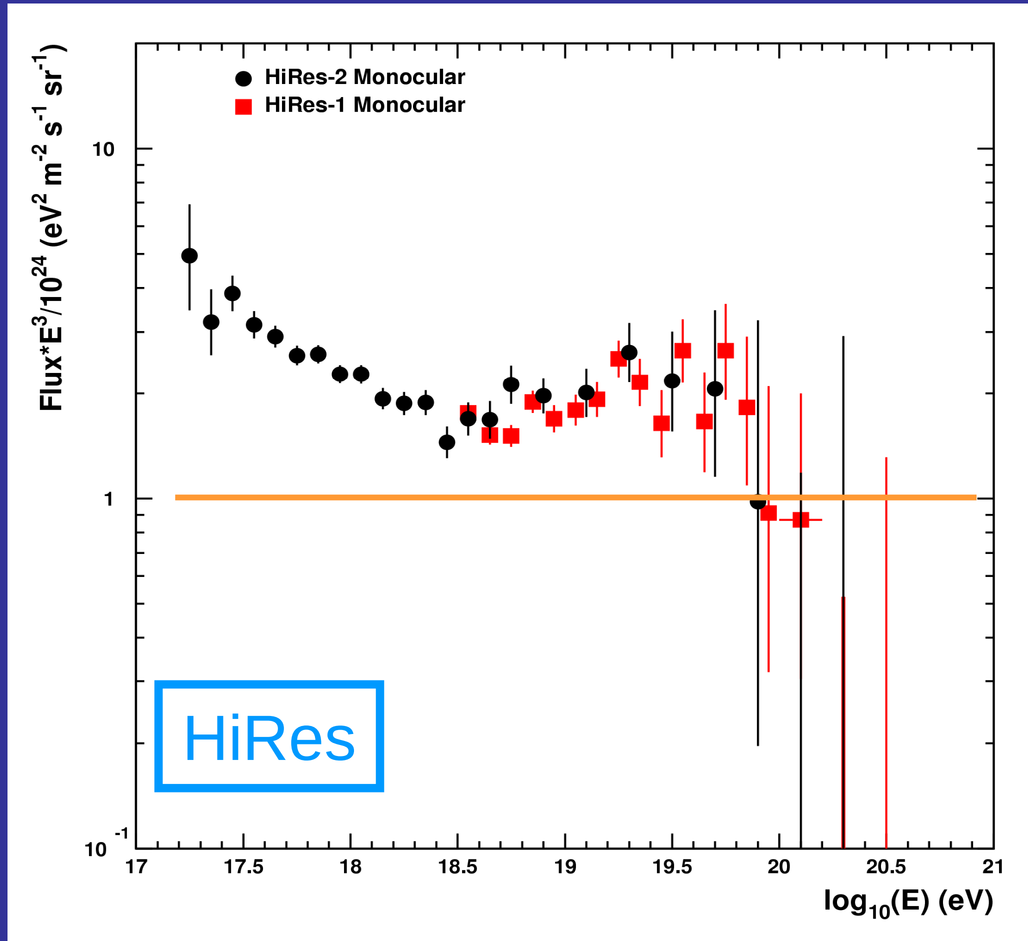
The super-GZK Cosmic Rays must call for a New Physics.

Energy Spectra by AGASA and HiRes (mono)

Ground Array (plastic scintillator)



Fluorescence Telescope



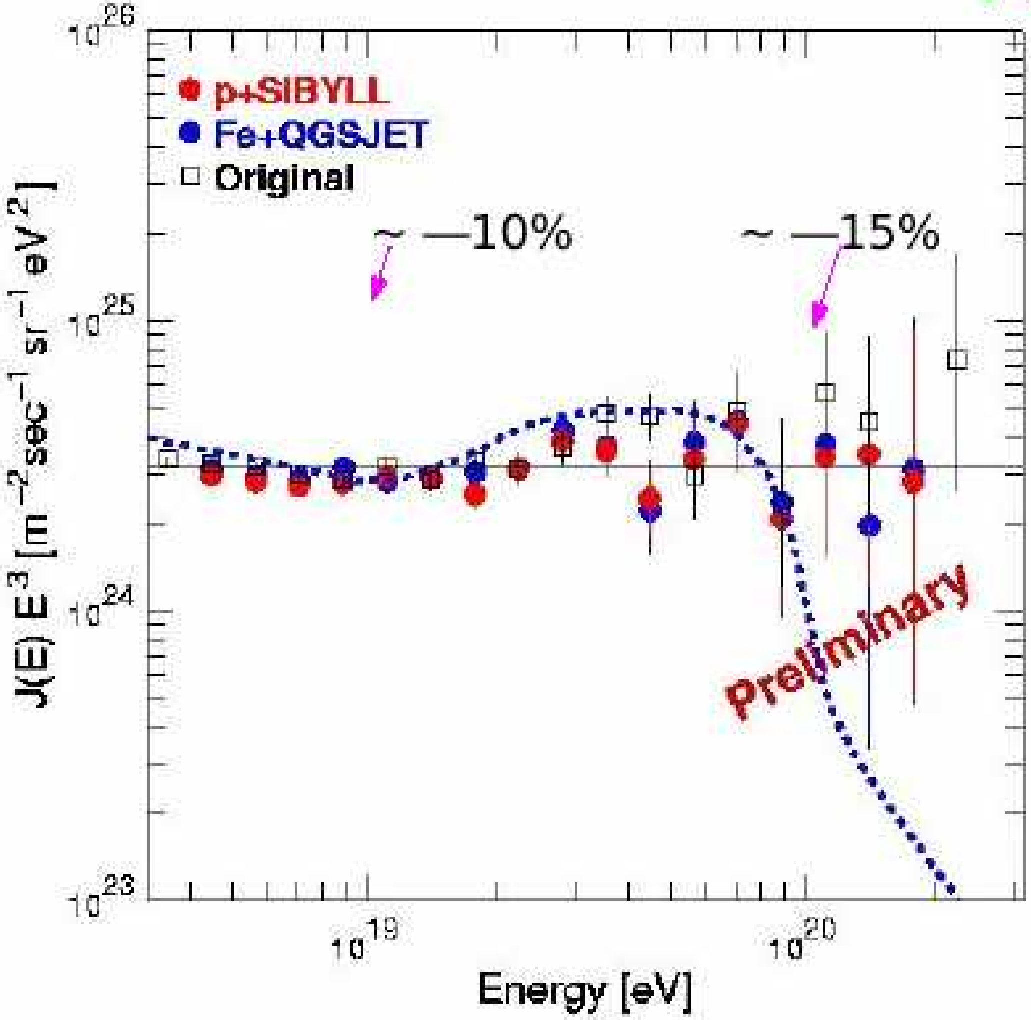
AGASA: stopped in Jan, 2004
Auger: 1st result in Aug. 2005
HiRes: stopped in Apr. 2006

TA: will start DAQ in April 2007
Auger-South: will be completed in 2007

AGASA

Spectrum (MC-derived vs standard)

PRELIMINARY

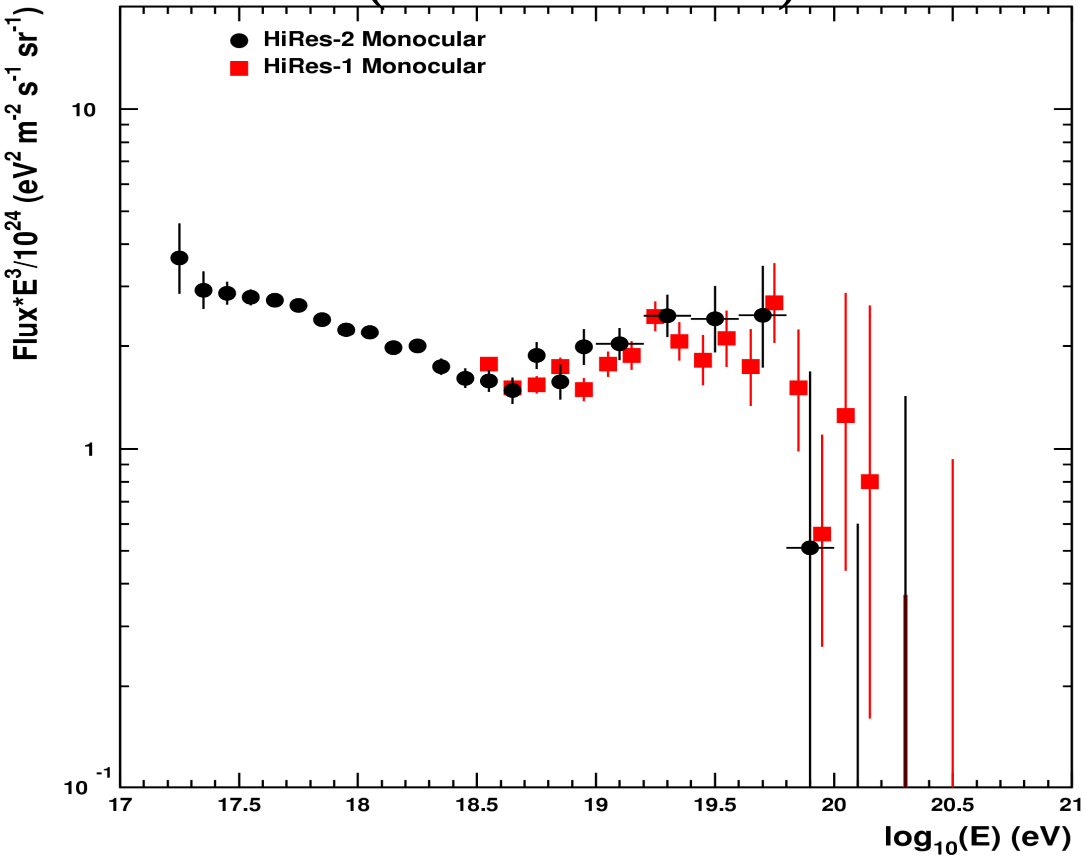


- For two MC-extremes (p+SIBYLL vs Fe+QGSJET)
  - Limited model dependence
  - 5 or 6 events above 10^{20}eV with Fe+QGSJET or p+SIYBLL
  - MC-derived spectrum showing smaller fluxes likely energy-scale shift ~10—15% in use of *S*(600)
  - Less-featured spectrum shape: $-\gamma=2.95\pm0.08$ χ^2/dof=8.5/11

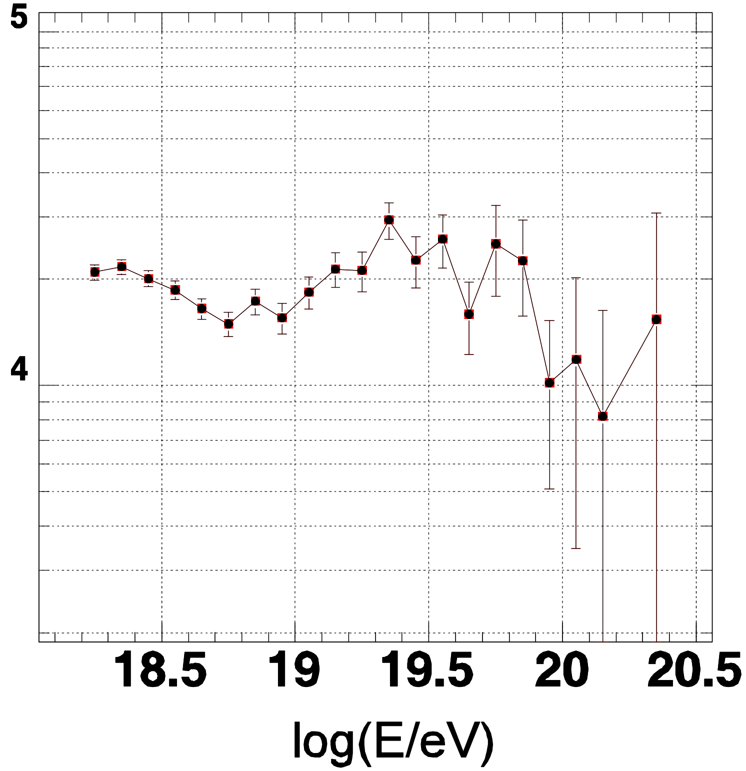
SHINOZAKI @WeiHai, 2006

HiRes

Most recent Mono spectrum (with cloud cuts)



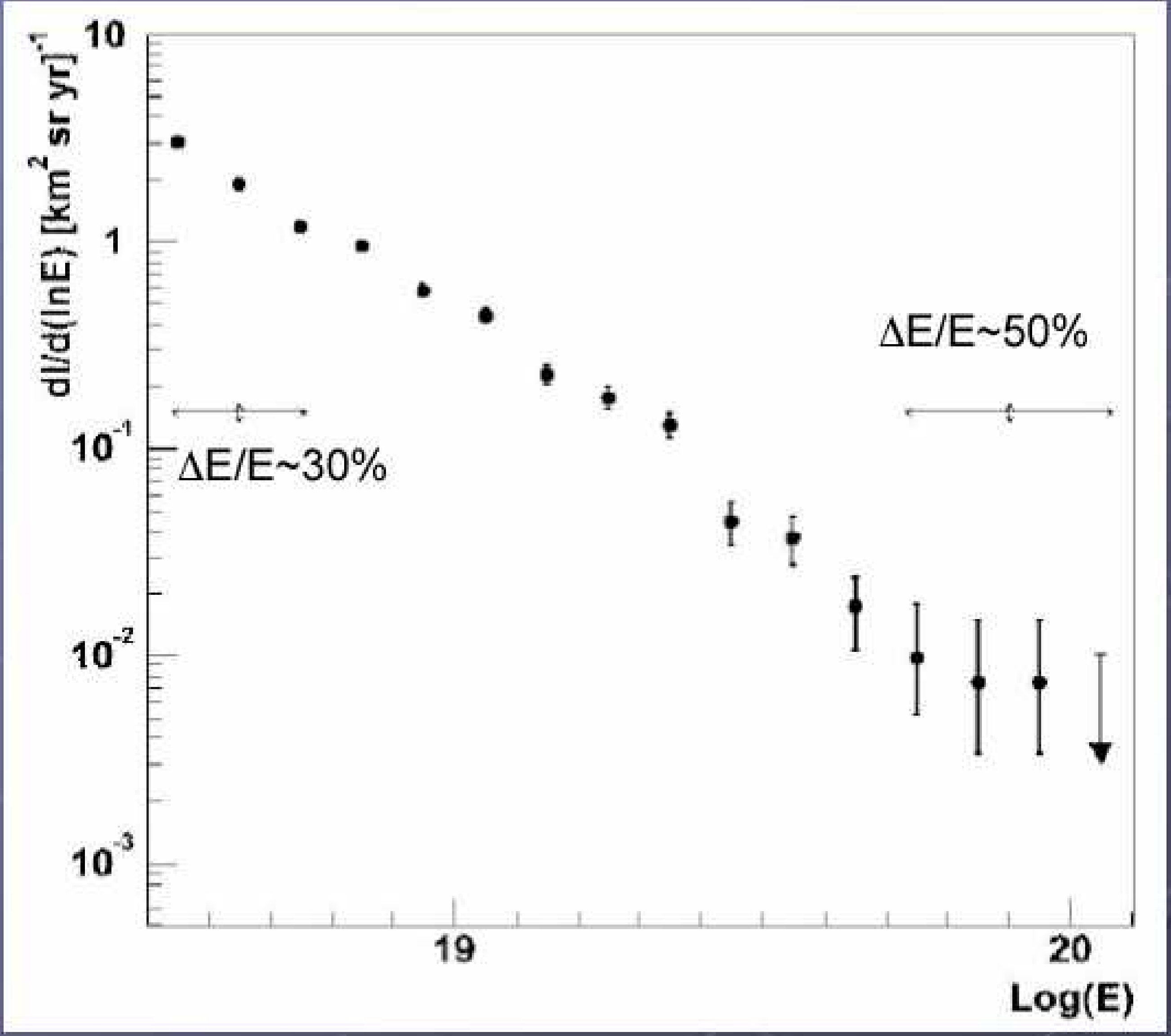
New "fully efficient" stereo Spectrum - no cloud cuts



SOKOLSKY @WeiHai, 2006

AUGER

SPECTRUM

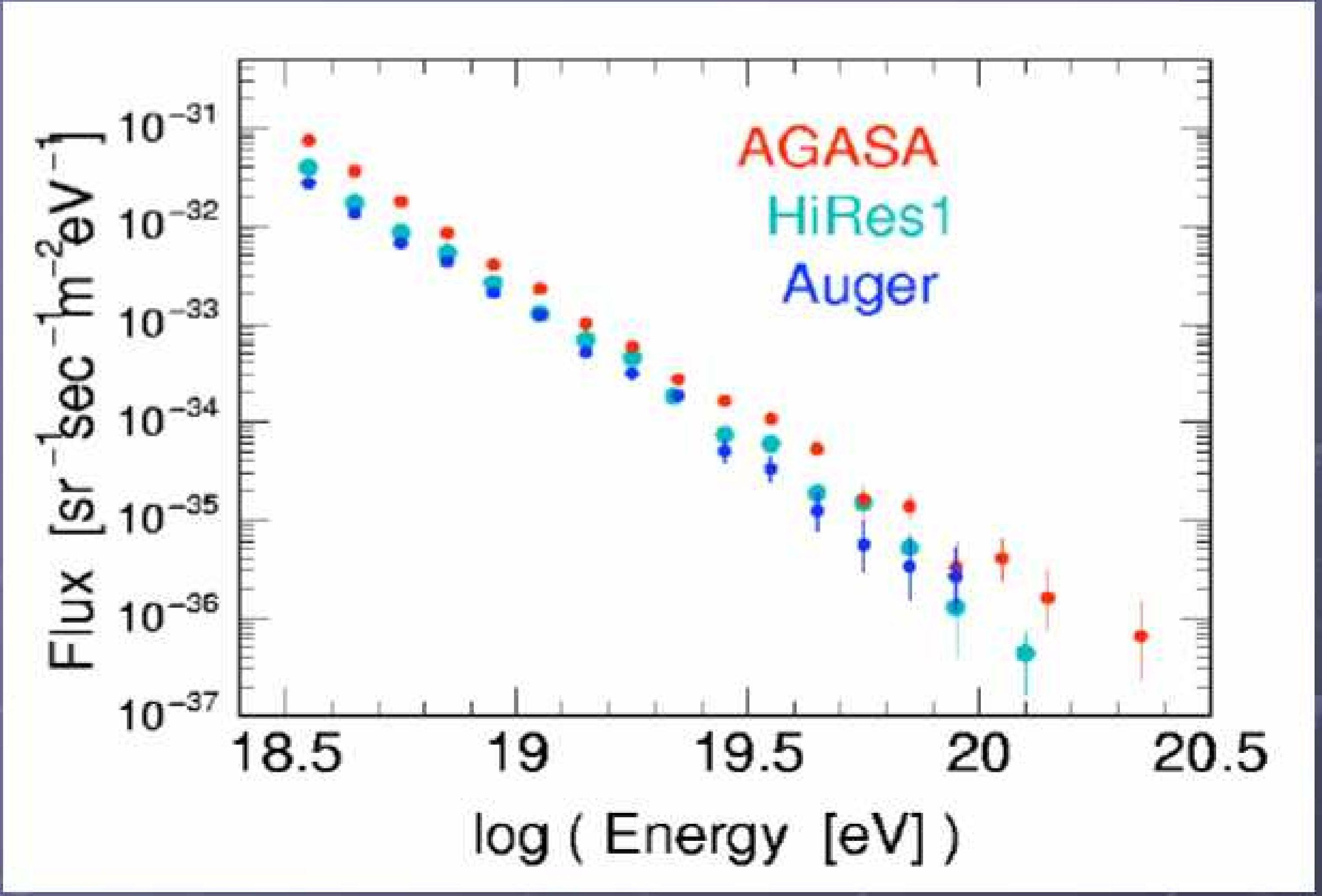


ZAVRTANIK
@WeiHai, 2006

AUGER

SPECTRUM

Comparison with HiRes1, AGASA



1) M. Takeda *et al.* Astroparticle Physics 19, 447 (2003)
2) R.U. Abbasi *et al.* Phys Lett B (to be published)

ZAVRTANIK
@WeiHai, 2006

No conclusion reached on GZK.

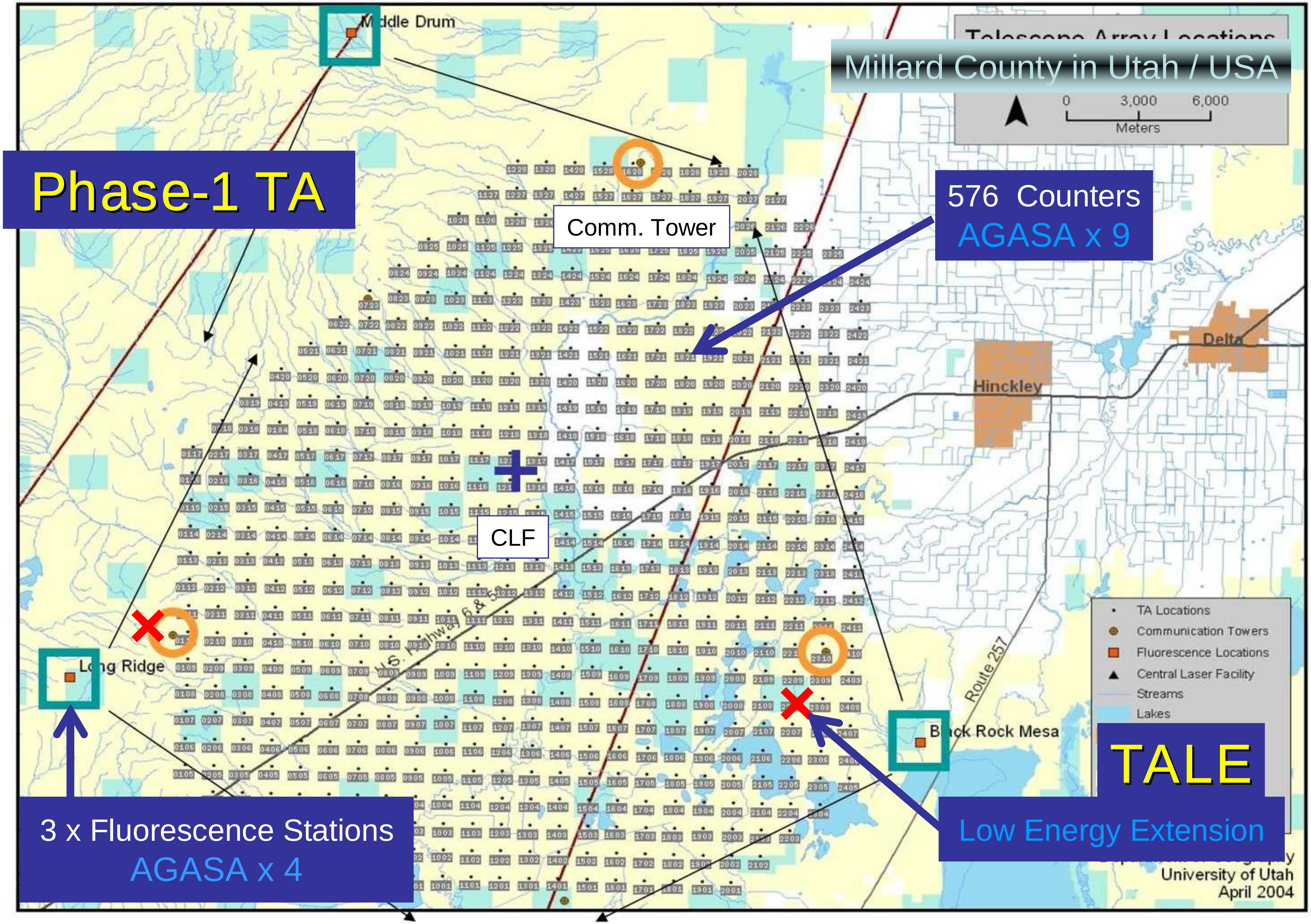
Energy Scale is in question.

But it may not be the only cause of Discrepancies.

Even after energy rescaling, # of events with $E > 10^{20}$ eV differs among experiments.

AGASA: stopped in Jan, 2004
Auger: 1st result in Aug. 2005
HiRes: stopped in Apr. 2006

ph-1 TA: will start DAQ in April 2007
Auger-South: will be completed in 2007

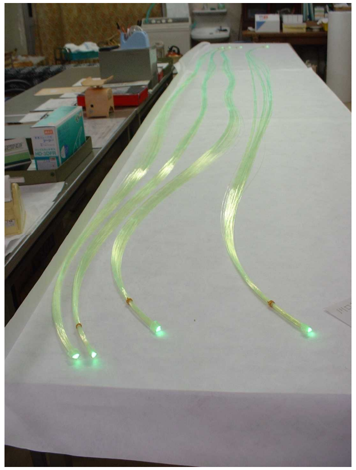


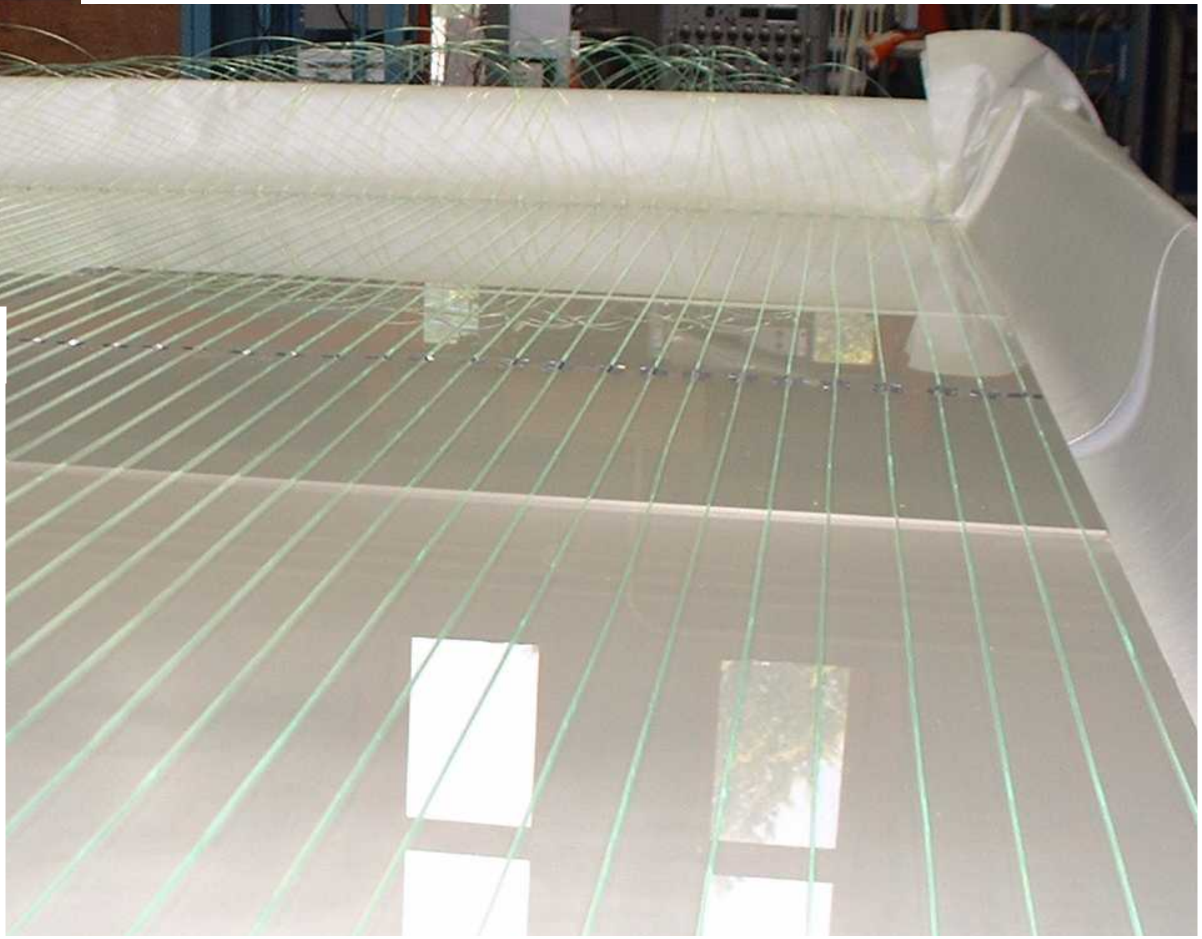
Phase-1 TA
Millard County in Utah / USA
0 3,000 6,000
Meters
576 Counters
AGASA x 9
Comm. Tower
CLF
Middle Drum
Long Ridge
Black Rock Mesa
Hinckley
Delta
Route 257
U.S. Highway 6 & 50
TA Locations
Communication Towers
Fluorescence Locations
Central Laser Facility
Streams
Lakes
TALE
Low Energy Extension
3 x Fluorescence Stations
AGASA x 4
University of Utah
April 2004

Plastic Scintillator

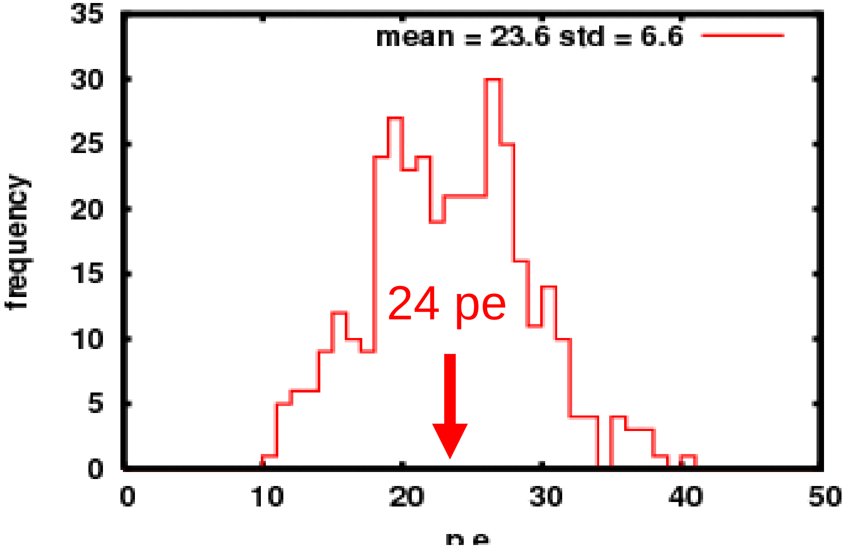
$3\ m^2$, 12 mm t

WLSF readout, 2 layers overlaid



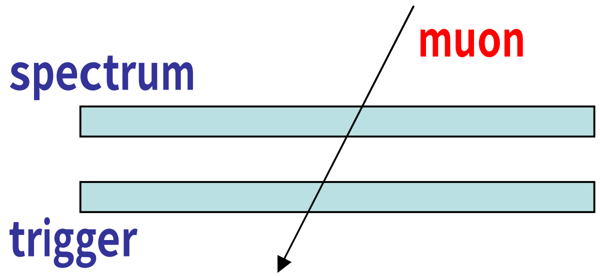


1 MIP photo-electron distribution

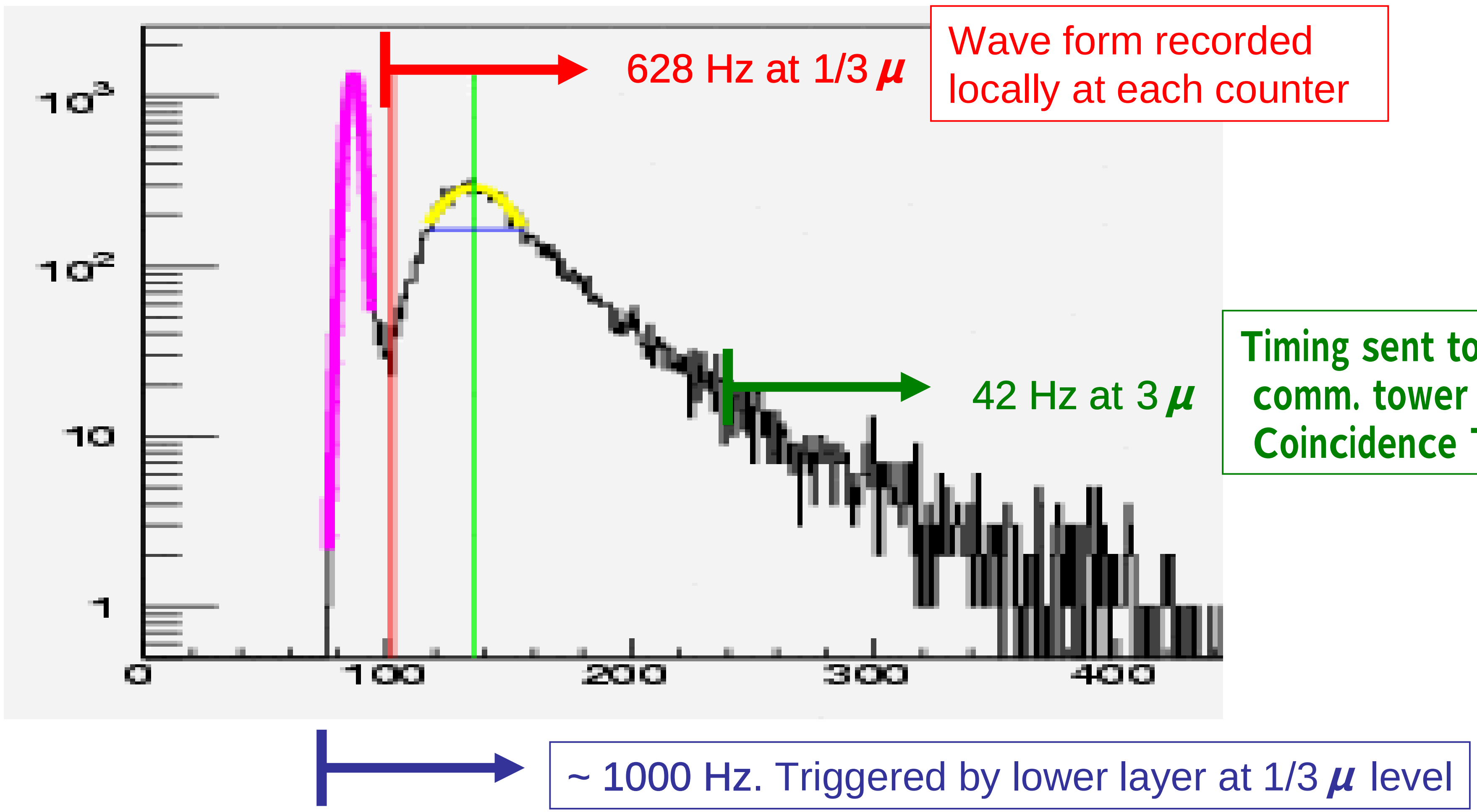


- 50 MHz, 12 bit FADC
- GPS time stamp (~20ns)
- Wireless LAN modem
- Solar panel + charge controller
- Battery
- Slow control

Spectrum and Rate for Cosmic Muon



Integrated over 12 time bins (240ns)



Why Plastic Scintillator ?

- Conserve AGASA energy scale and check
- Sample electromagnetic shower (~90% of Eprimary)
  >>> less dependent on
  - primary composition
  - hadronic interaction @EHE

may vary over GZK energy

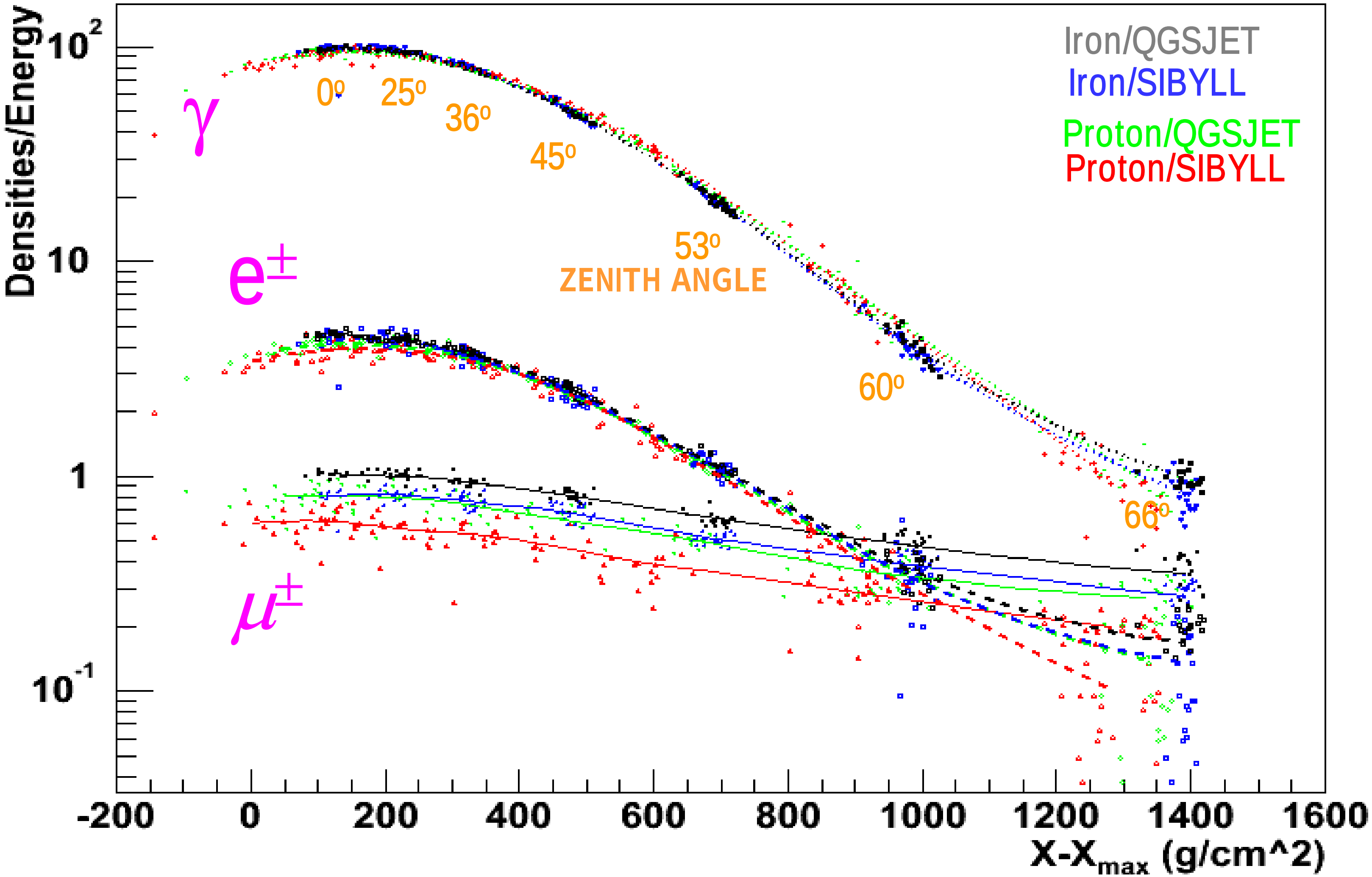
Why Two Layers ?

- trigger and calibration by muon
- wider dynamic range (PMT Gain H/L)
  linear upto 60 / 360 MIPs in 20 ns

S(600) for 3 x 10^{20}eV

AUGER

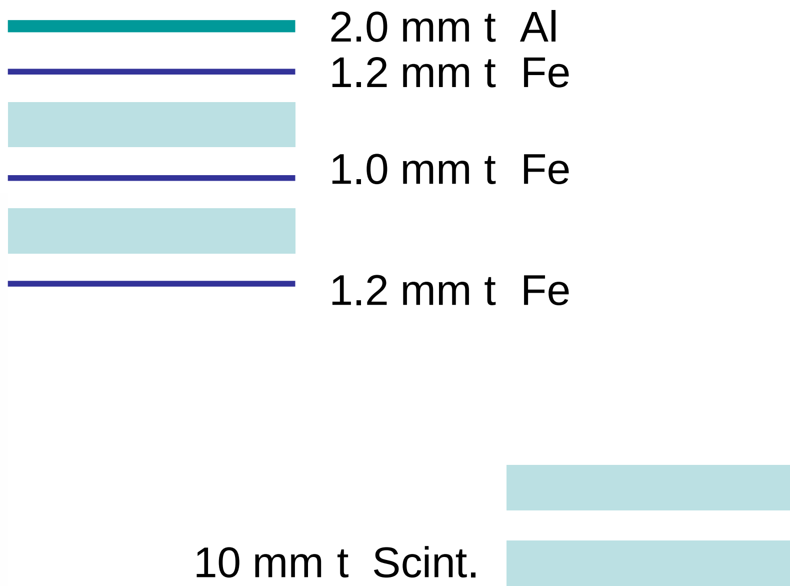
Particle density at 540m from shower core vs X - Xmax

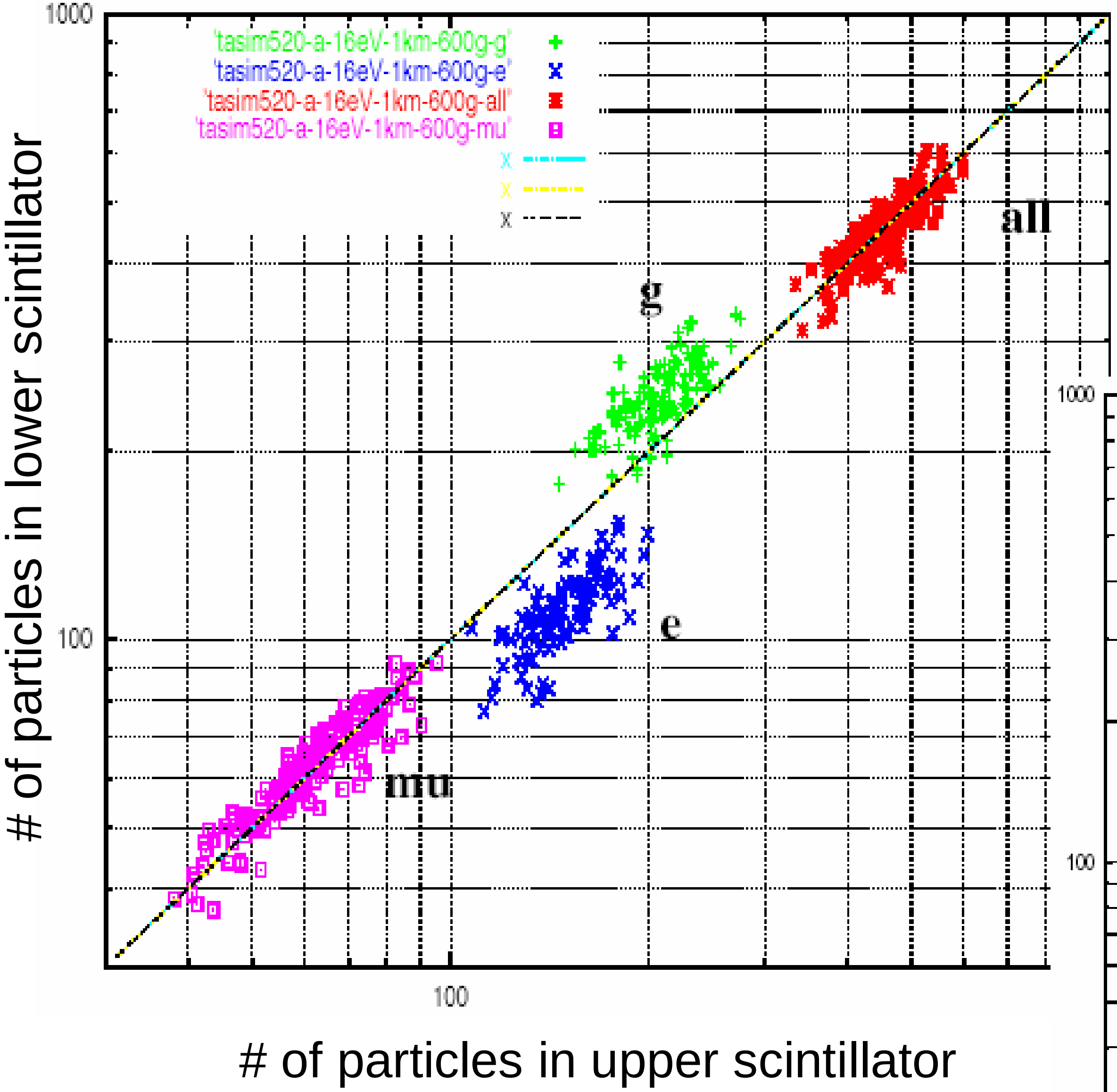


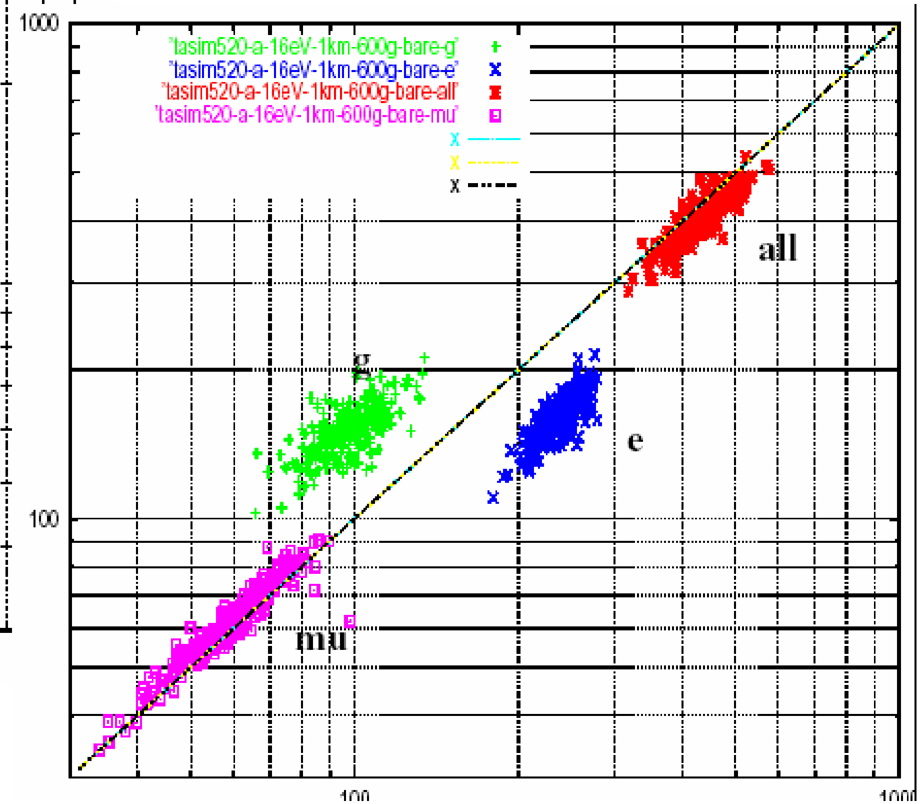
ARISAKA
GAP 2004-037

Expected Signals from e, γ, μ

by GEANT for 10^{16}eV proton shower @ 600 g/cm^2 and 1 km away from core








80% of SDs & 3 towers on federal land.
Took 2.5 years for getting permission from BLM office.
Surveys of endangered animals and plants, cultural resources and historical sites, and numerous other administrative works done by U of Utah colleagues.
First comm. tower built on Sept.15th + 16th
First 50 counters will be deployed today (Sept 19).
516 counters will be in the field by next February.

SDs waiting for Deployment near Delta Cosmic Ray Center

TEST DEPLOYMENT in Dec. 2004

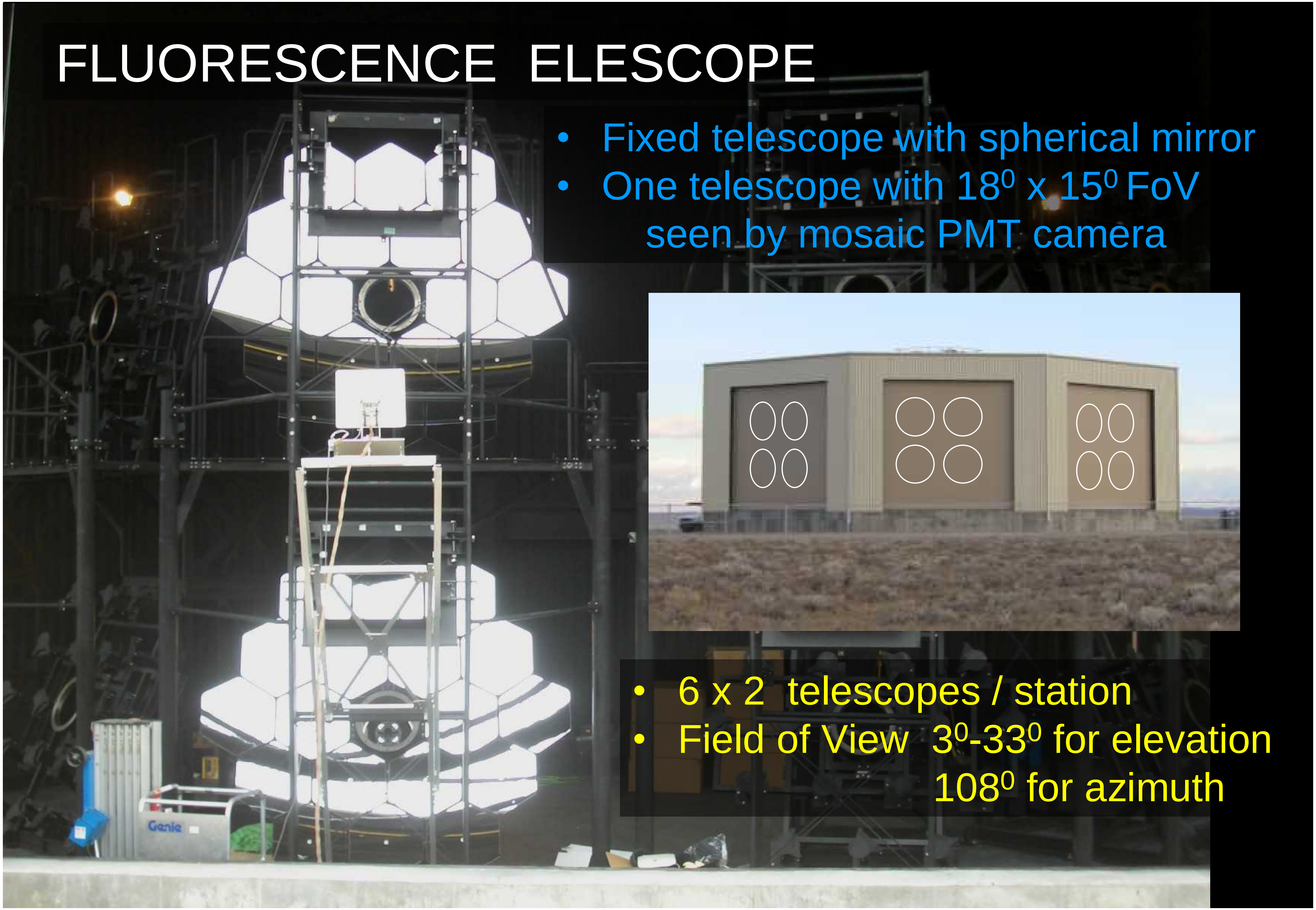
From Delta to staging area (~30km)

18 SDs at the staging area

18 SDs deployed in 3 hours

FLUORESCENCE ELESCOPE

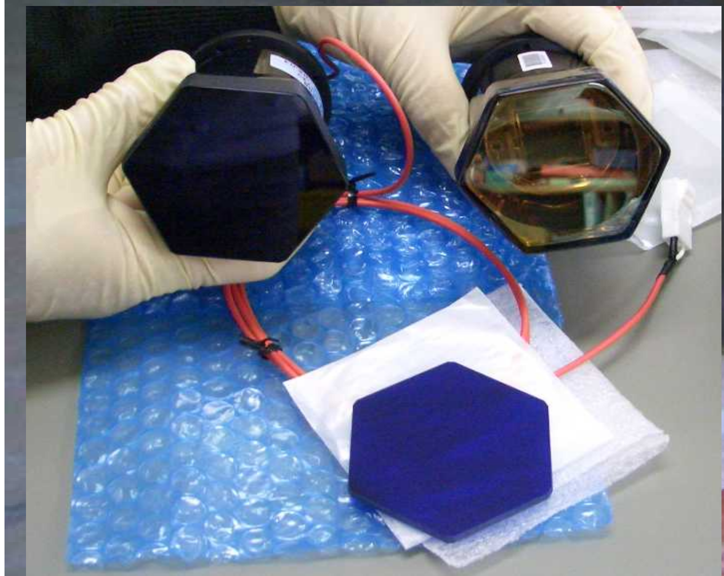
- Fixed telescope with spherical mirror
- One telescope with 18^0 x 15^0 FoV seen by mosaic PMT camera



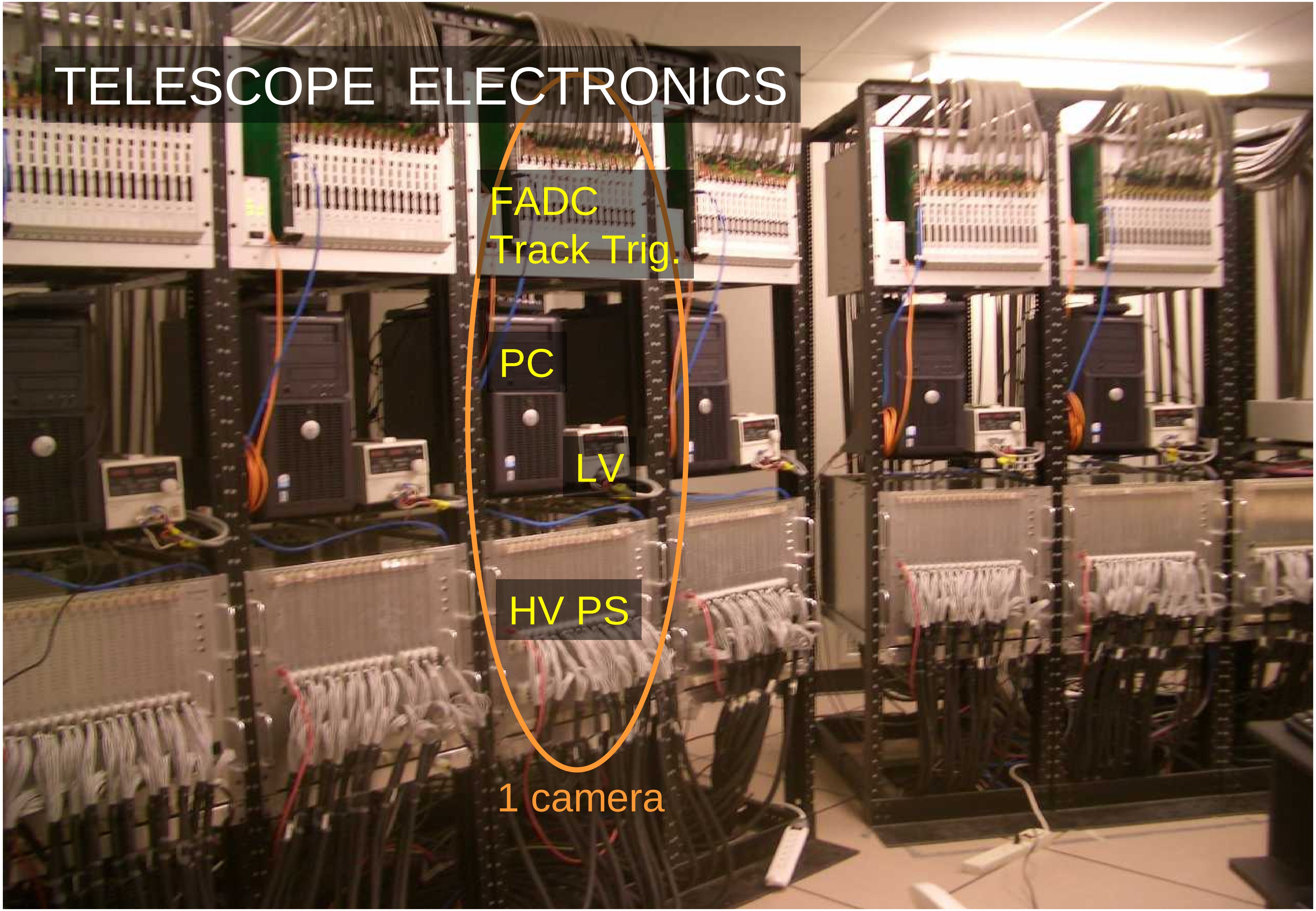
- 6 x 2 telescopes / station
- Field of View 3^0-33^0 for elevation
  108^0 for azimuth

TELESCOPE CAMERA

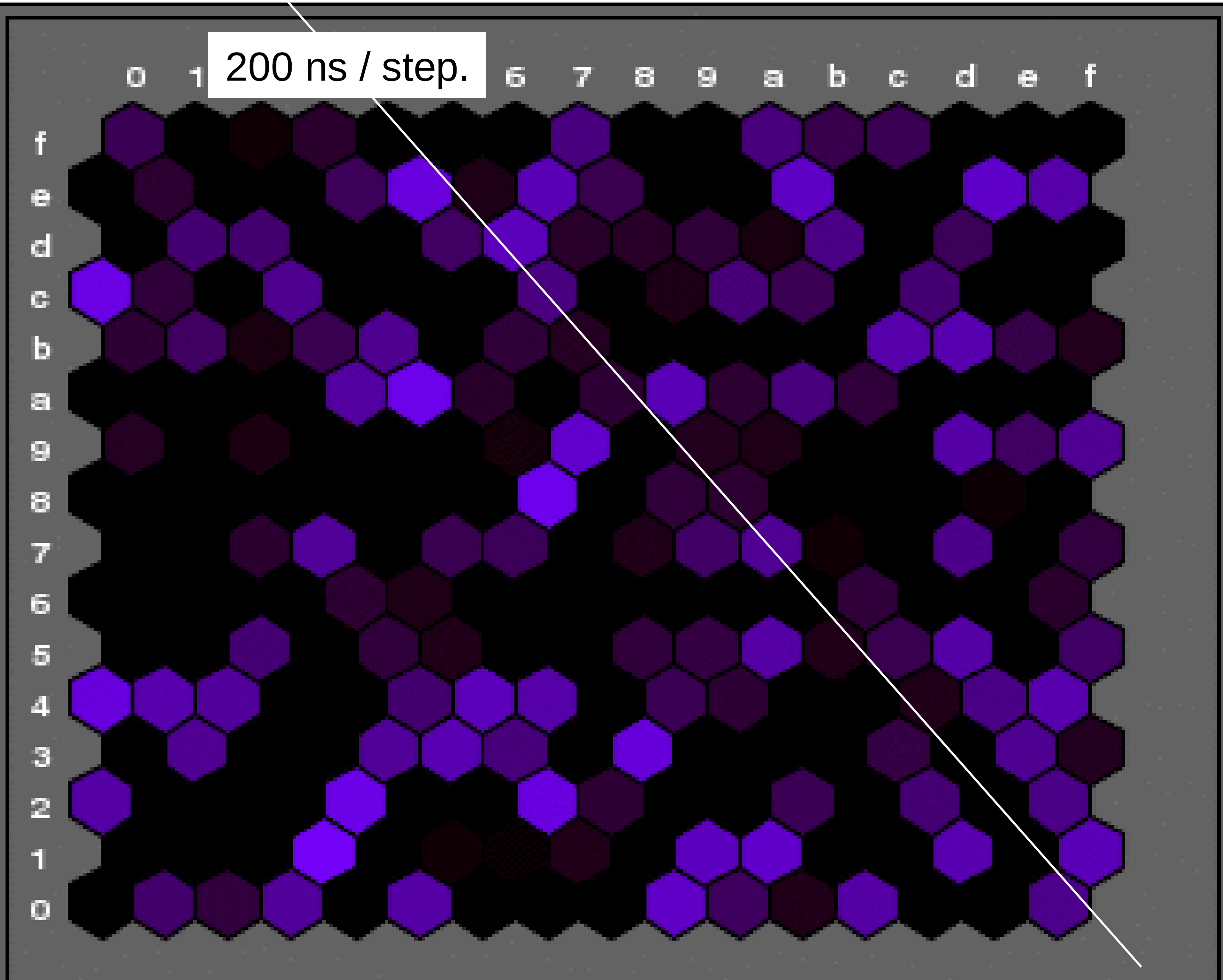
- 16 x 16 PMT array
- BG3 glass filter (UV transparent)
- Pre-amplifier (x 50)



1. 3 PMTs: absolutely calibrated
   by standard UV light source (self develop.)
   & PMT gain monitored by YAP + ^{241}Am.
2. All 256 PMTs: relatively adjusted in situ
   by diffused light (Xenon flasher)
3. XY-mapping by UV-LED scanner


TELESCOPE ELECTRONICS
FADC
Track Trig.
PC
LV
HV PS
1 camera

One of the first events of TA: 2005/07/12, 2:52 am, Utah.



top / bottom & left / right of camera view reversed.

Spherical Mirror (3.3m ϕ) , 1^0 pixel PMT

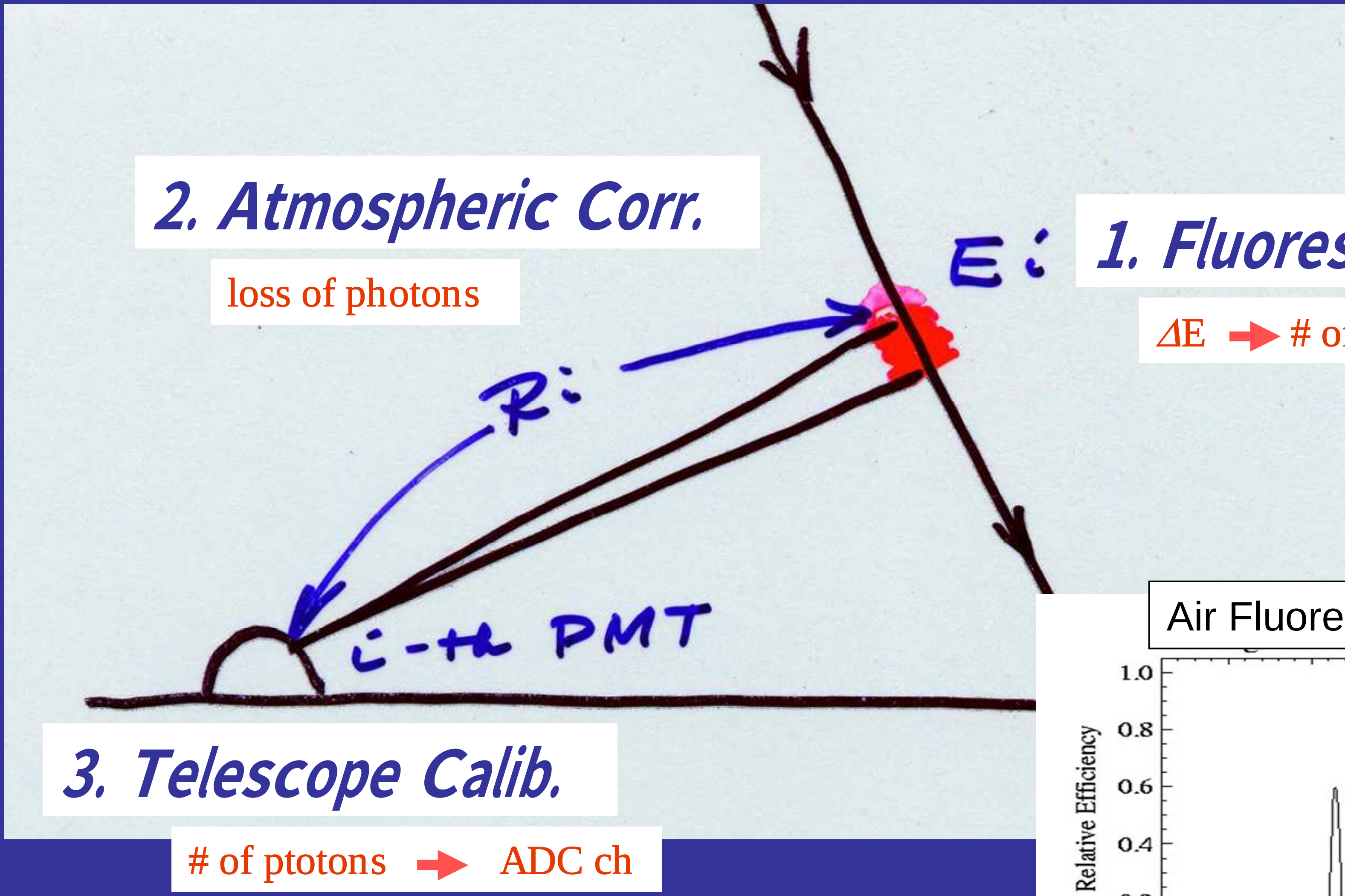
- Conserve HiRes optics (30% more light than HiRes)
- Simple in Optics & Mechanics
- “Sandwich” configuration for stereo meas..
  - less than 20 km to the nearest FD station
  - always tagged by the SD

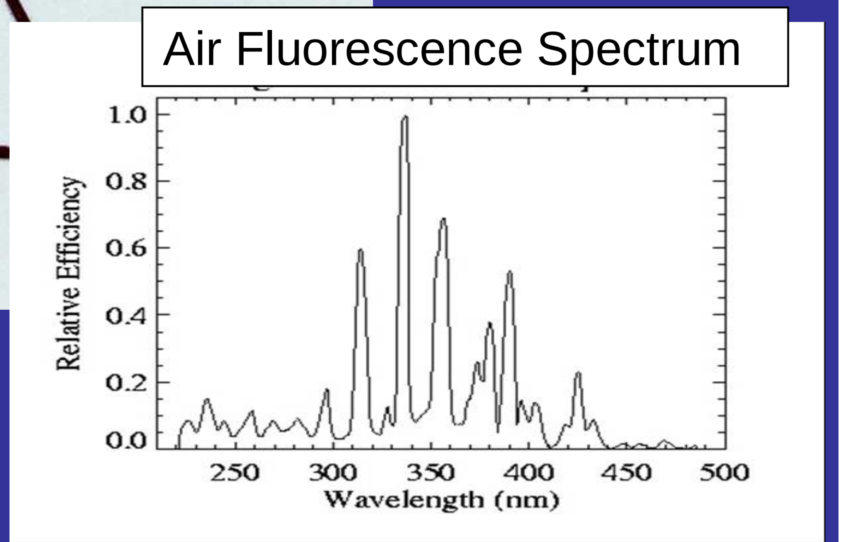
-HV, DC coupled, 40MHz,12-bit sampling

- No wave form distortion
- Direct night sky BG measurement
- “FD as a lidar”
- ~ms baseline update
- 5 contiguous PMTs for “track” trigger

- 1st FD station: 8 / 12 telescopes completed
- 2nd station: to be ready by March, 2007
- 3rd station: transfer of HiRes. Ready by June, 2007.

FD is a Total Absorption Calorimetry for absolute energy measurement





Energy Deposit =

1. Fluorescence Efficiency
2. x Rayleigh and Mie Scattering Loss
3. x Obscuration (by camera and supporting structures)
4. x Mirror Area and Reflectivity
5. x Transparency of Camera Window (UV transp. lucite)
6. x Transmittance of BG3 Filter (against Night Sky bg)
7. x PMT Gap
8. x PMT Quantum Efficiency
9. x PMT (dinode) Collection Efficiency
10. x PMT Gain
11. x Preamplifier Gain
12. x Cable Attenuation
13. x Shaper/Amplifier Gain
14. x FADC Conversion Gain
15. x FADC Count

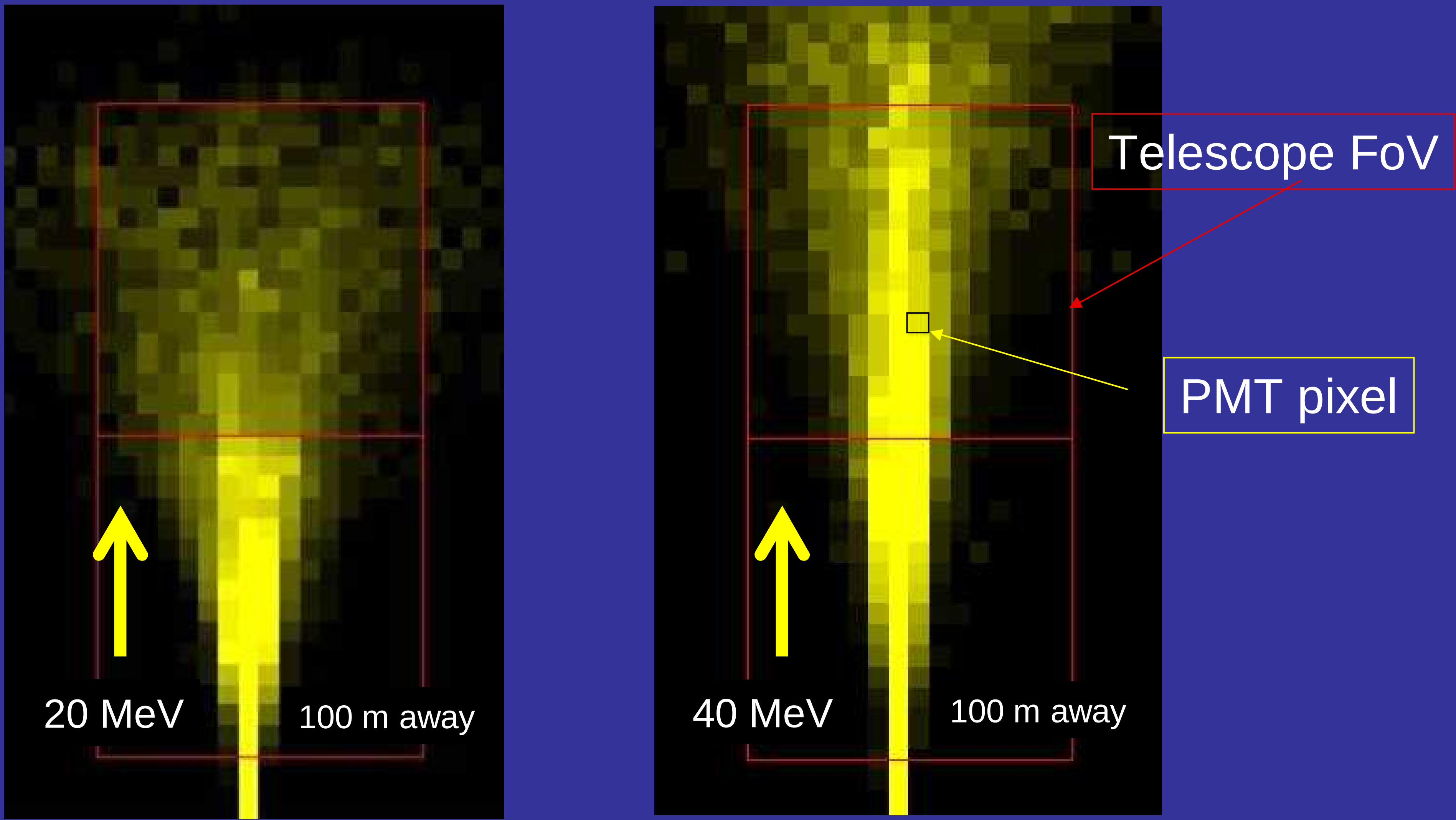
5%? x SQRT(15) ~ 20% ???

Piece to Piece Calibration is needed.
We also have Xe flasher, YAP and LED but….

Energy Deposit → FADC count

Direct End to End Calibration is wanted.

Inject Electron Linac Beam (10 - 40 MeV) into the Sky



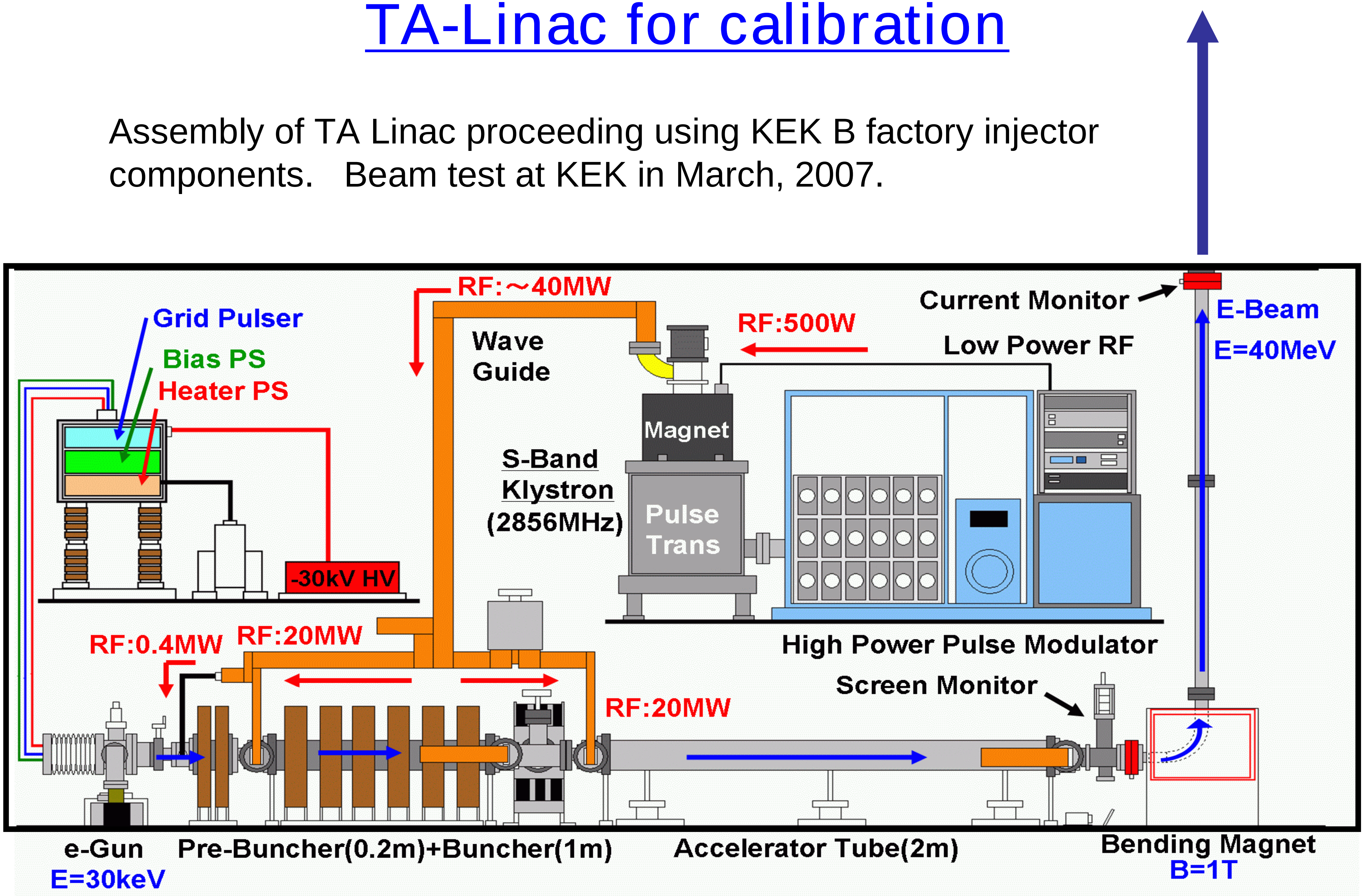
20 MeV / particle x 10^9 ppp = 2 x 10^{16} eV total energy deposit.

➡ Absolutely calibrated Light Source!!

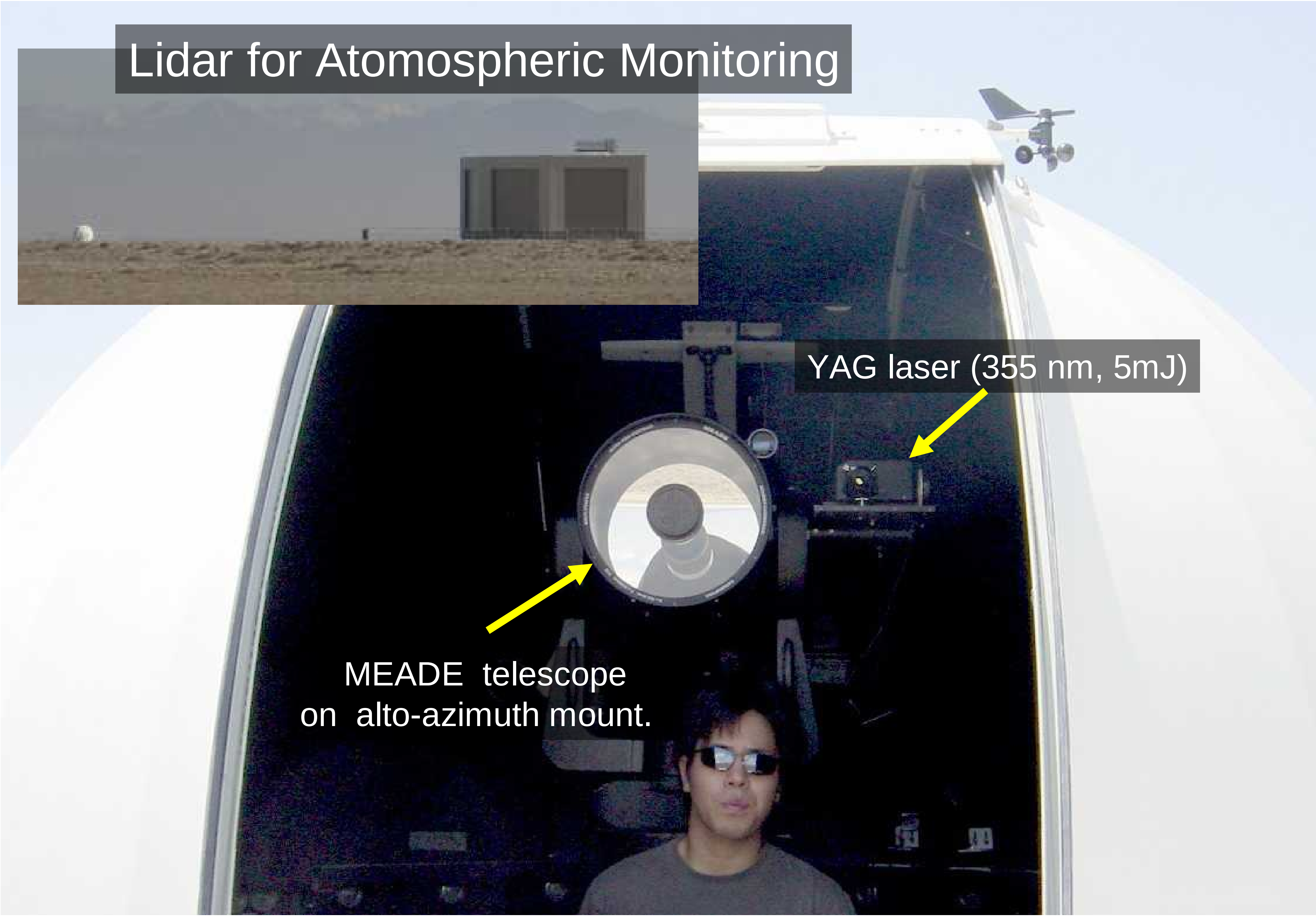
From Energy deposit to ADC ch.

TA-Linac for calibration

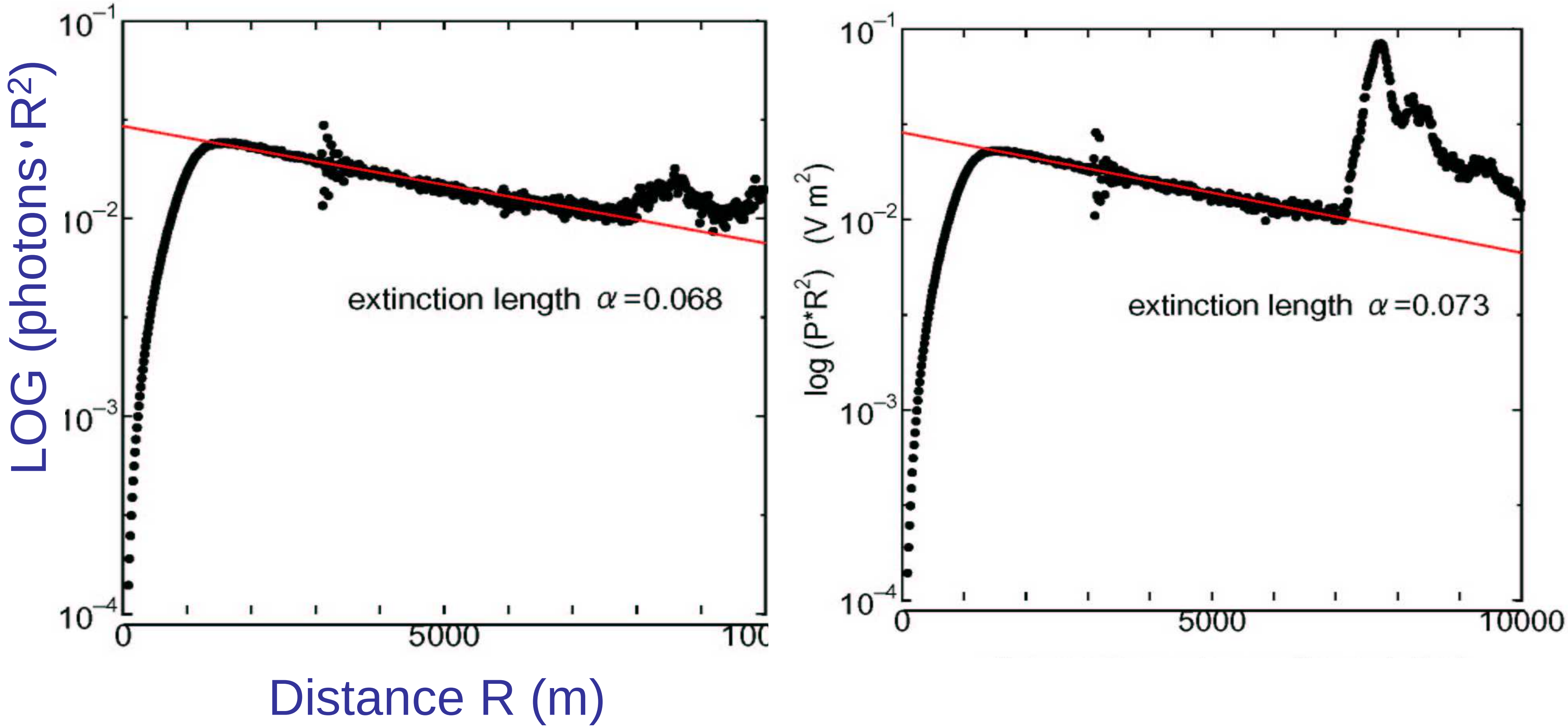
Assembly of TA Linac proceeding using KEK B factory injector components.   Beam test at KEK in March, 2007.



Lidar for Atomospheric Monitoring



Lidar Observation at the BRM station



Performance of TA

	AGASA			
Total Acceptance		1,550	km^2 sr	
SD Acceptance	140 km^2 sr	1,200	km^2 sr	
FD Acceptance (stereo)		290	km^2 sr	
FD Acceptance (mono)	FD →	470	km^2 sr	
Hybrid Acceptance		120	km^2 sr	
Energy Resolution	25 %	25	%	or better
Energy Scale Uncertainty	18 %	10	%	
SD Angular Resolution	2^0	2.0	degree	or better
FD Angular Resolution (stereo)	→	0.6	degree	
Hybrid Angular Resolution		0.5	degree	
FD Xmax Resolution (stereo)	→	17	$g\ cm^{-2}$	

Table 1: Projected Performance of TA. The values are estimated at 10^{20} eV. The total acceptance is the summation of the SD and the monocular FD acceptances. The energy resolution is derived from the SD and the energy scale uncertainty is from the FD.

of Events per Year

		$E > 10^{19}$eV	$E > 10^{20}$eV
Total (SD + FD)		831	13.7
SD only	SPECTRUM	643	10.6
FD stereo	X -check	155	2.6
Hybrid (SD × FD)	Calibration	64	1.1

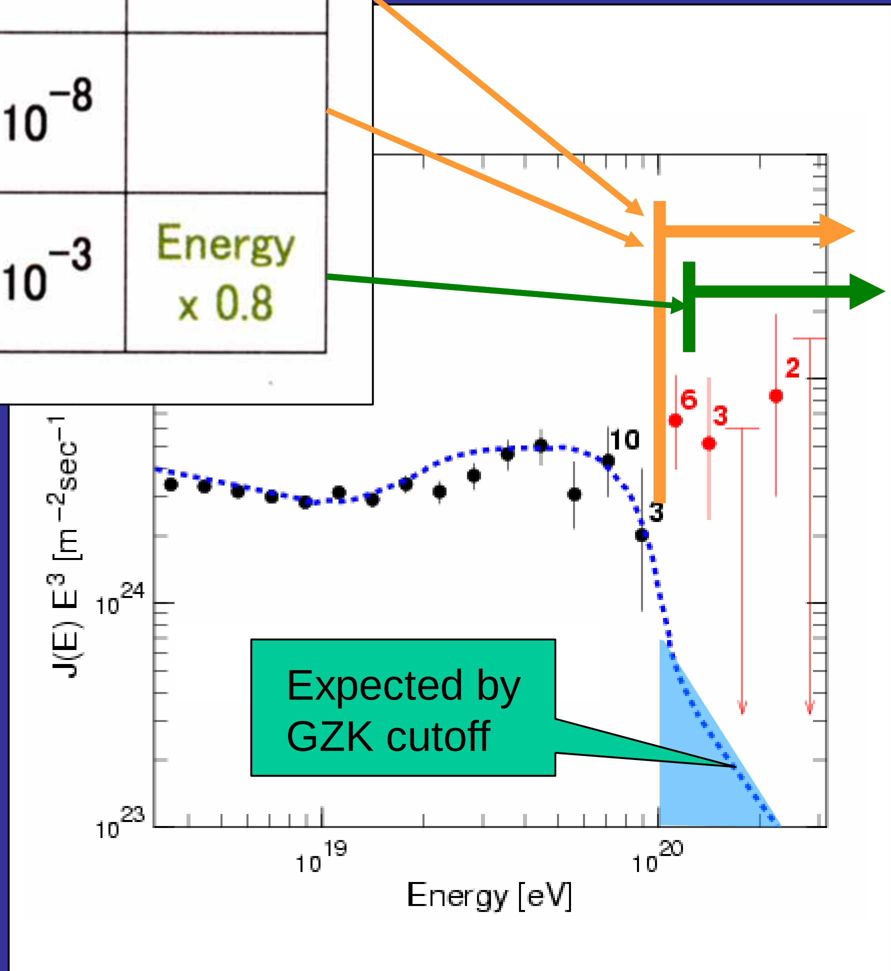
Table 2: The number of events expected in one year of TA operation. The AGASA flux is used for the estimation.

Cumulated # of Events

year	AGASA	HiRes	TA	Auger
2004	121	77	0	0
2005	-	87	0	120
2006	-	90	0	570
2007	-	-	56	1050
2008	-	-	138	1530
2009	-	-	221	2010
2010	-	-	303	2490

Table 3: The cumulated number of events with $E > 10^{19.5}$eV collected by each experiment. The numbers are for AGASA with $\theta < 45°$, HiRes monocular observation, TA/SD with $\theta < 45°$ and southern Auger/SD with $\theta < 60°$ (7000 km^2 sr). The AGASA flux was used for estimating the number of events for TA and Auger. It should be noted that the number of events observed by Auger in 2005 was 32 as opposed to 120 estimated by using the AGASA flux and shown in the Table.

Exp.	Years	#EVENT $E > 10^{20}$eV Observed	Expected by GZK	Poisson Prob.	
AGASA	13	11	2.8 or less	1.6×10^{-4}	
TA	3	26.4	6.7 or less	1.2×10^{-8}	
		12.0	4.3 or less	1.7×10^{-3}	Energy x 0.8

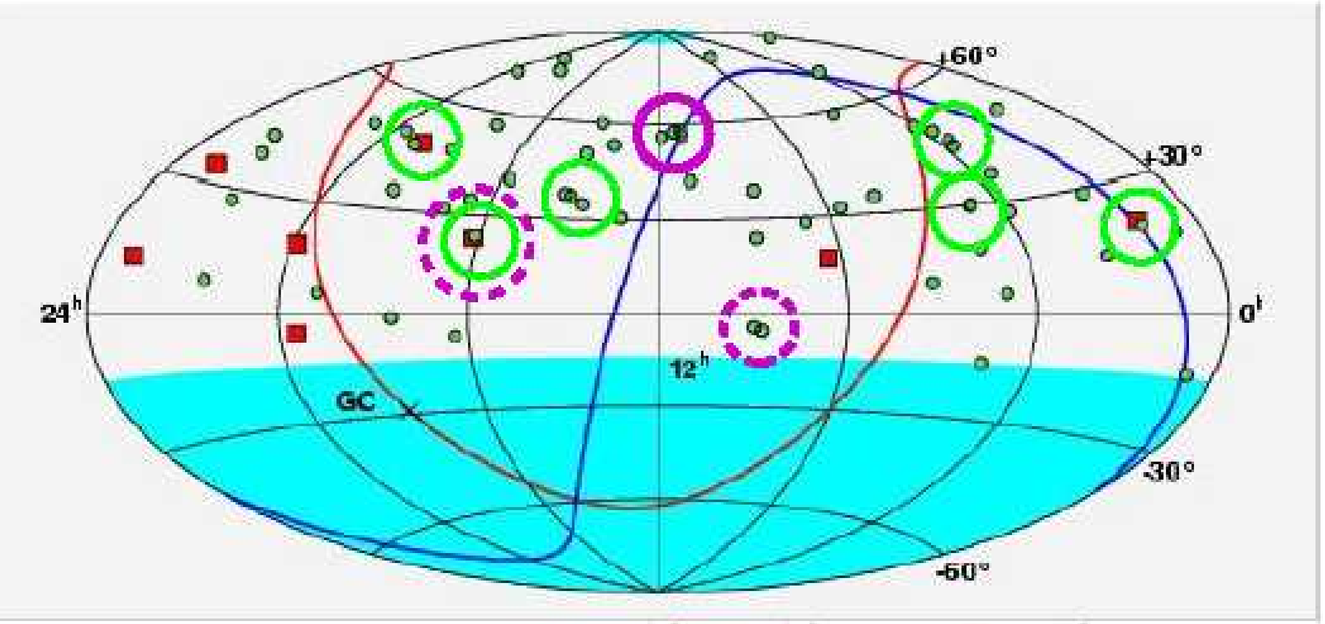


Result of TA by spring 2010

- AGASA flux
- AGASA Energy x 1 or x 0.8
- TA = SD (516 ctrs) + FD mono

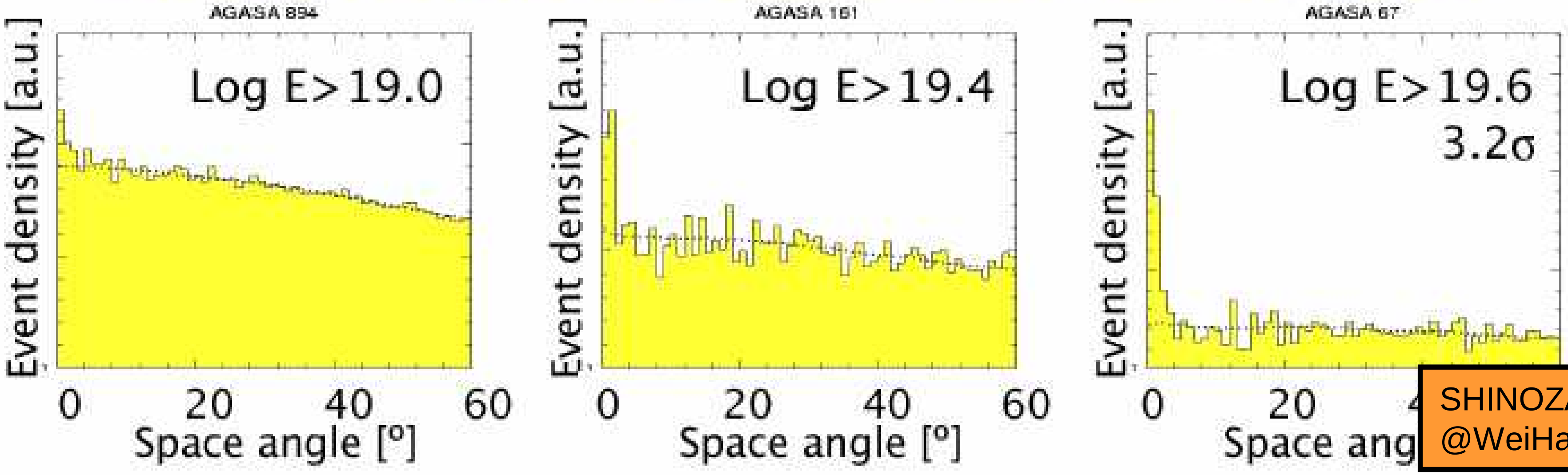
AGASA

(>4x10^{19}eV; θ<50º)



●:4x10^{19} – 10^{20}eV ■:> 10^{20}eV

Space angle distribution of events



SHINOZAKI
@WeiHai, 2006

SUMMARY

- Phase-1 TA approved in 2003: 10 x AGASA + FD
- NSF budget approved in 2006: infra + FD + TALE

    TALE: low energy extension of TA

- Start data taking with 516 SDs & 3 FDs next spring.

    516 SDs = 90% of proposal, 3rd FD by HiRes transfer

- Confirm super-GZK and cluster in the North by 2010.
- Understand SD systematics.
- Establish stereo FD method and energy calibration.

Future: Integrated Giant Ground Detector (> 100 AGASA)

Telescope Array Collaboration

80 physicists
From Japan, USA and Korea

H.Kawai [a], T.Nunomura [a], N.Sakurai [a], S.Yoshida [a],
H.Yoshii [b], K.Tanaka [c], F.Cohen [d], M.Fukushima [d], N.Hayashida [d], M.Ohnishi [d], H.Ohoka [d],
S.Ozawa [d], H.Sagawa [d], T.Shibata [d], H.Shimodaira [d], M.Takeda [d], A.Taketa [d], M.Takita [d],
H.Tokuno [d], R.Torii [d], S.Udo [d], H.Fujii [e], T.Matsuda [e], M.Tanaka [e], H.Yamaoka [e], K.Hibino [f],
T.Benno [g], M.Chikawa [g], T.Nakamura [h], K.Kadota [j], Y.Uchihori [k], Y.Hayashi [l], S.Kawakami [l],
K.Matsumoto [l], Y.Matsumoto [l], T.Matsuyama [l], S.Ogio [l], A.Ohshima [l], T.Okuda [l],
D.R.Bergman [m], G.Hughes [m], S.Stratton [m], G.B.Thomson [m], N.Inoue [n], Y.Wada [n],
K.Kasahara [o], M.Fukuda [p], T.Iguchi [p], F.Kakimoto [p], R.Minagawa [p], Y.Tameda [p],
Y.Tsunesada [p], J.W.Belz [qs], J.A.J.Matthews [r], T.Abu-Zayyad [s], R.Cady [s], Z.Cao [s],
C.C.H.Jui [s], K.Martens [s], J.N.Matthews [s], J.D.Smith [s], P.Sokolsky [s], R.W.Springer [s],
S.B.Thomas [s], L.R.Wiencke [s], T.Doyle [t], M.J.Taylor [t], V.B.Wickwar [t], T.D.Wilkerson [t],
K.Hashimoto [u], K.Honda [u], T.Ishii [u], T.Kanbe [u],S.J.Baek [v], J.E.Kim [v], K.S.Kim [v], S.Nam [v],
I.H.Park [v], J.Yang [v], B.G.Cheon [w], Y.Unno [w], Y.H.Yun [w], I.S.Cho [x], Y.J.Kwon [x]

(a) Chiba University (b) Ehime University (c) Hiroshima City University
(d) ICRR, University of Tokyo, (e) Institute of Particle and Nuclear Studies, KEK
(f) Kanagawa University (g) Kinki University (h) Kochi University (j) Musashi Institute of Technology
(k) National Institute of Radiological Sciences (l) Osaka City University (m) Rutgers University
(n) Saitama University (o) Shibaura Institute of Technology (p) Tokyo Institute of Technology
(q) University of Montana (r) University of New Mexico (s) University of Utah
(t) Utah State University (u) Yamanashi University (v) Ewha Womans University
(w) Chonnam University (x) Yonsei University