Recent results from Telescope Array

CosPA 2013 Cosmic Rays 11/14

Takeshi Okuda (Ritsumeikan University)
for Telescope Array Collaboration

Outline

- Recent Physics Result
  - Energy Spectrum
  - Mass Composition
  - Photon Limit
  - Anisotropy
- Experiment for Extended Energy Region
  - TA Low Energy Extension
  - TA High Energy Extension
- TA Affiliate Experiment

Telescope Array Collaboration

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T. Nonaka[h], A. No[illegible], A. Oshima[j],
S. Ozawa[r], I. H. Pa[illegible]. Sakurai[j],
A. L. Sampson[a], L[illegible], T. Shirahama[m],
J. D. Smith[a], P. So[illegible]Takamura[e],
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~120 collaborators in 5 countries
Japan, USA, Korea, Russia, Belgium

Telescope Array Site

Utah State in USA
39.3N, 112.9W, Alt 1400[m]

Surface Detector (SD)

Telecommunication Tower

Fluorescence Detector (FD)

MDFD

SKCT

32.4km

CLF

27.6km

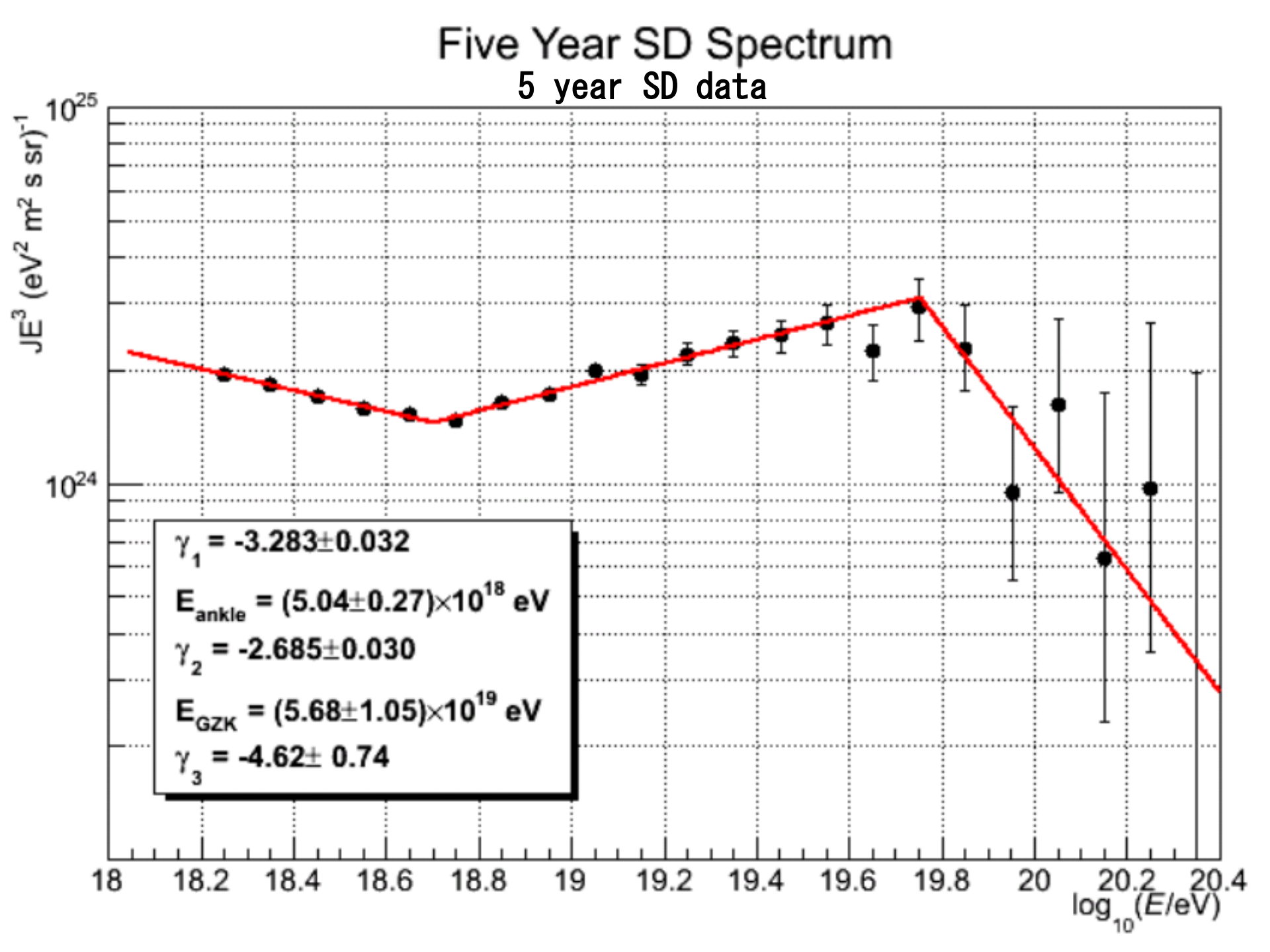
LRFD

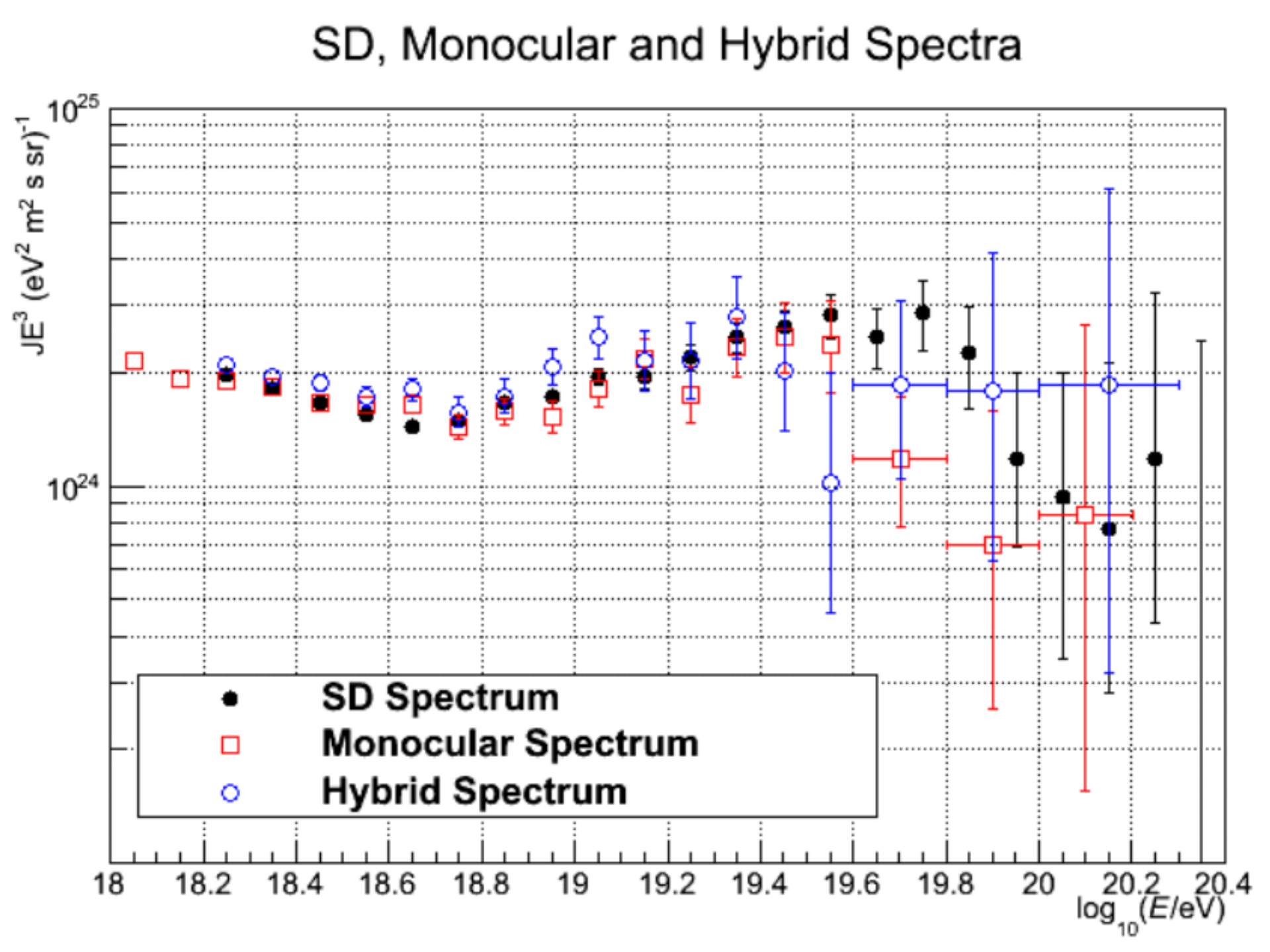
LRCT

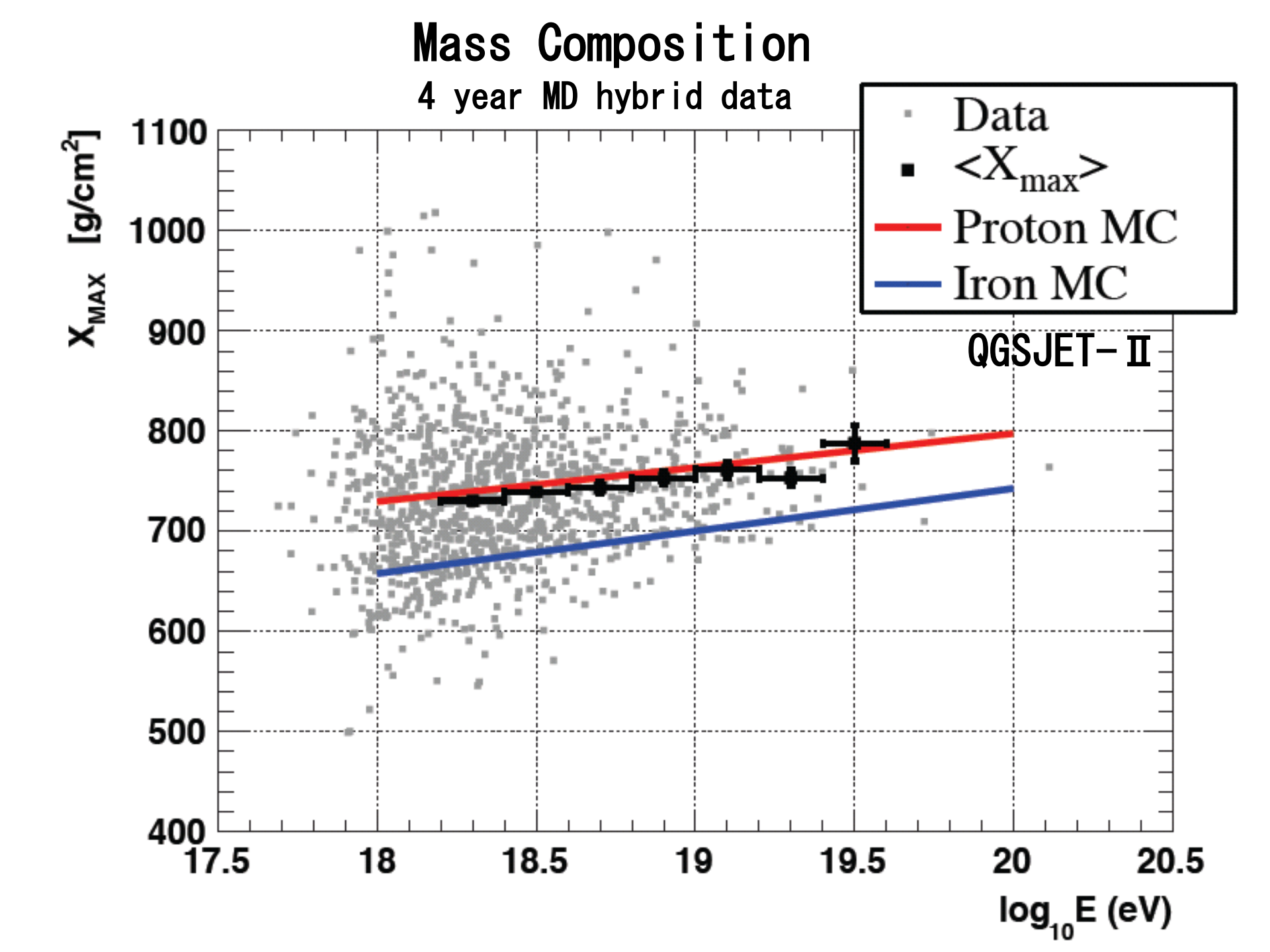
BRCT

507 SDs

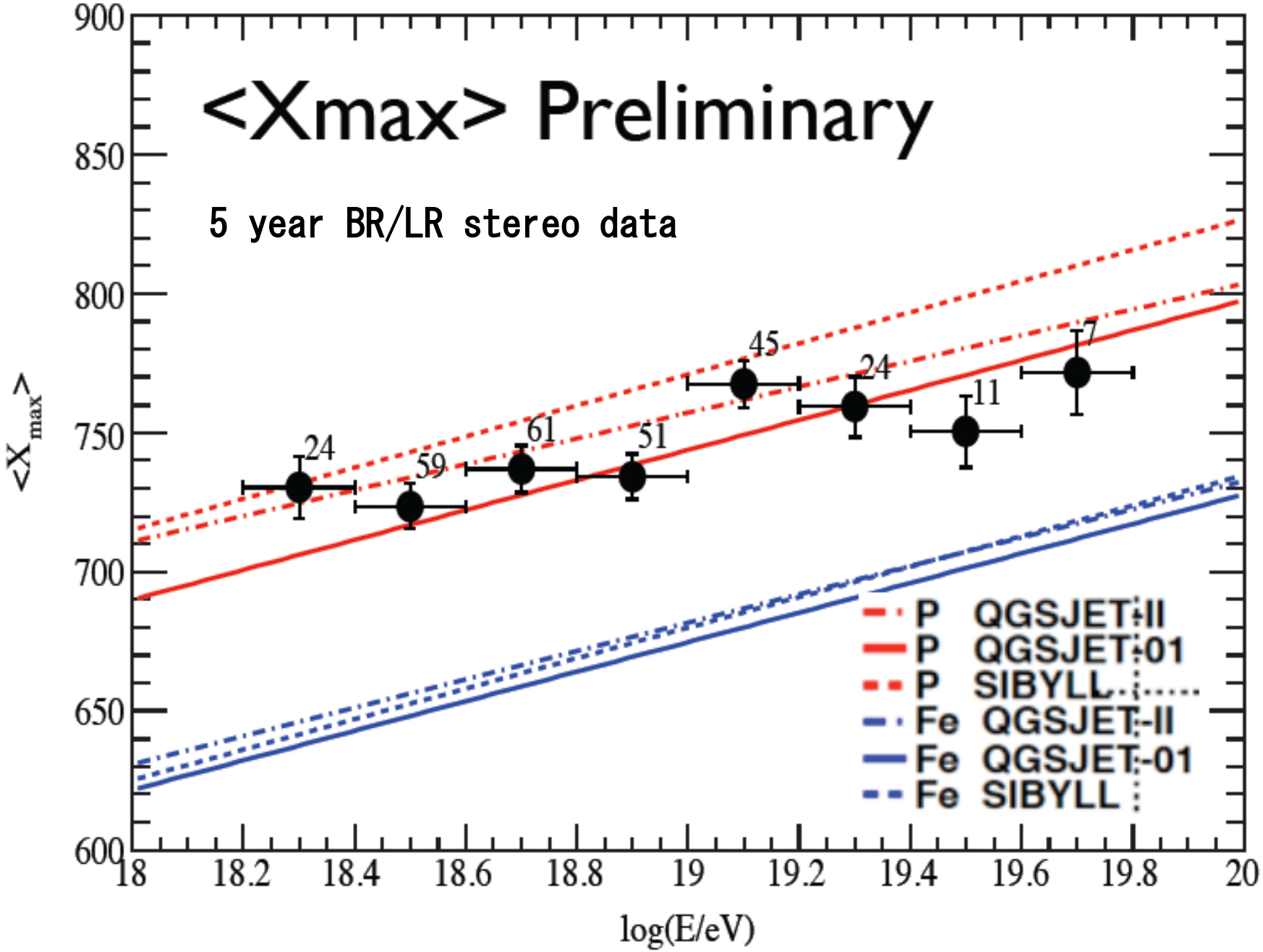
BRFD


Five Year SD Spectrum
5 year SD data
JE^3 (eV^2 m^2 s sr)$^{-1}$
10^{25}
10^{24}
γ_1 = -3.283±0.032
E_{ankle} = (5.04±0.27)×10^{18} eV
γ_2 = -2.685±0.030
E_{GZK} = (5.68±1.05)×10^{19} eV
γ_3 = -4.62± 0.74
18
18.2
18.4
18.6
18.8
19
19.2
19.4
19.6
19.8
20
20.2
20.4
$\log_{10}(E/eV)$

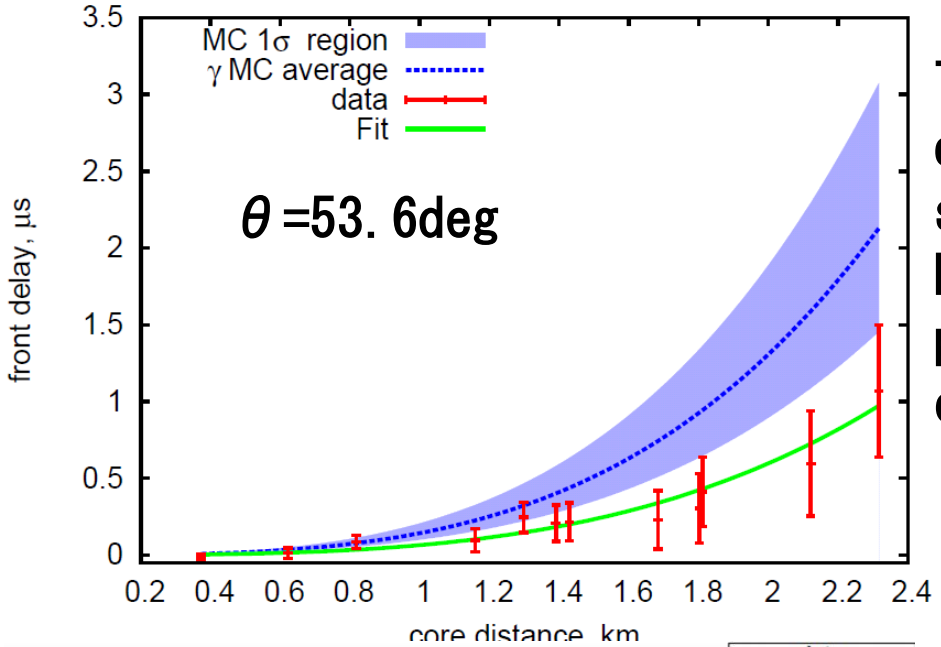

SD, Monocular and Hybrid Spectra
JE^3 (eV^2 m^2 s sr)$^{-1}$
10^{25}
10^{24}
SD Spectrum
Monocular Spectrum
Hybrid Spectrum
18
18.2
18.4
18.6
18.8
19
19.2
19.4
19.6
19.8
20
20.2
20.4
$\log_{10}(E/\mathrm{eV})$


Mass Composition
4 year MD hybrid data
Data
<X_max>
Proton MC
Iron MC
QGSJET-II
X_MAX [g/cm²]
1100
1000
900
800
700
600
500
400
17.5
18
18.5
19
19.5
20
20.5
log10E (eV)

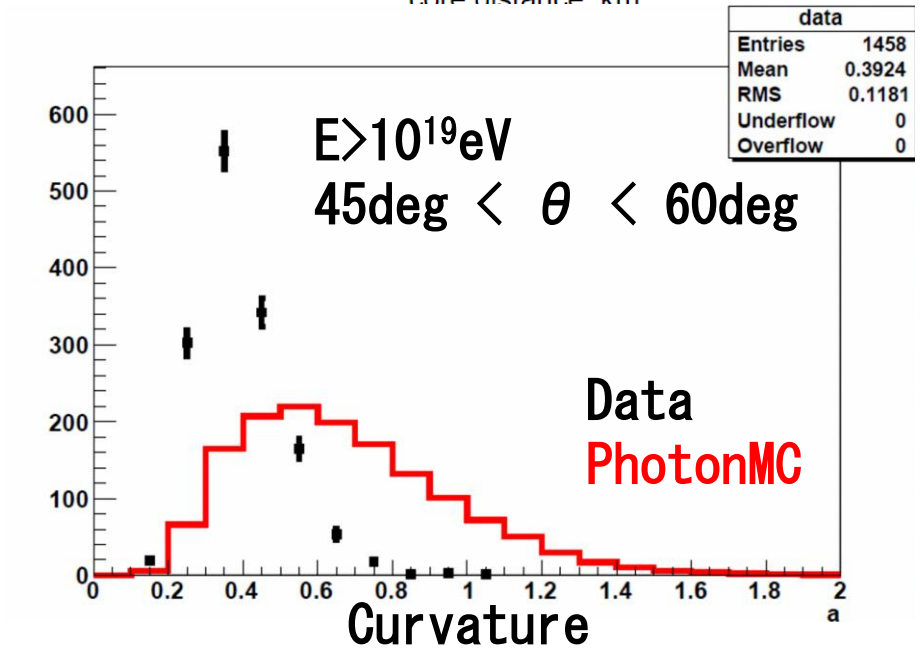
Mass Composition

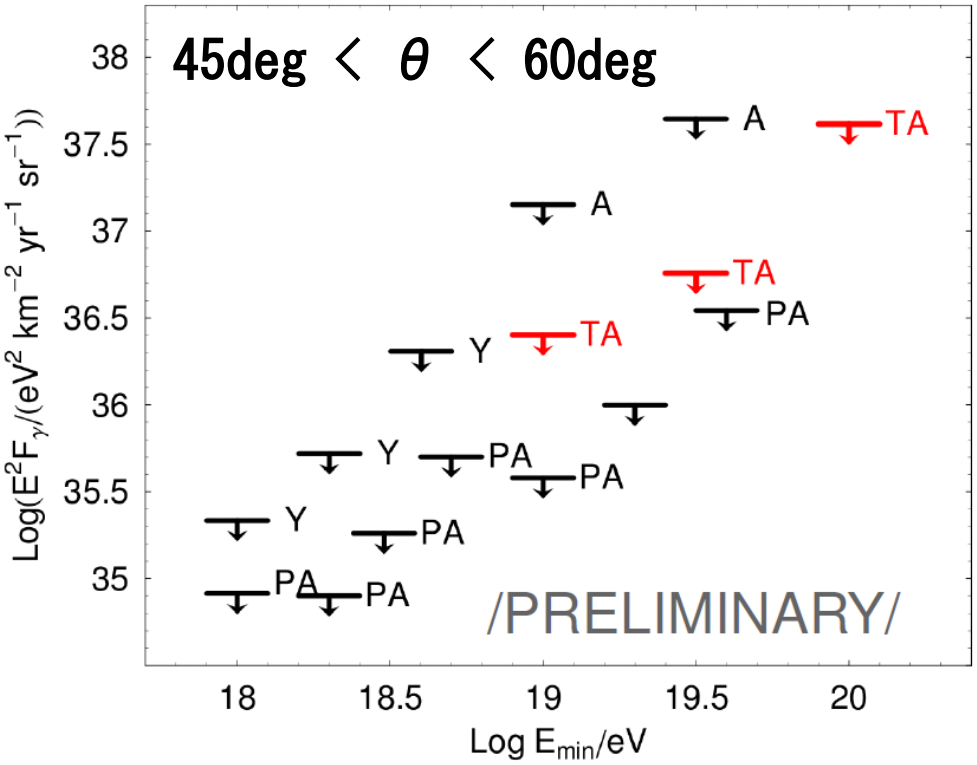


Photon Upper Limit



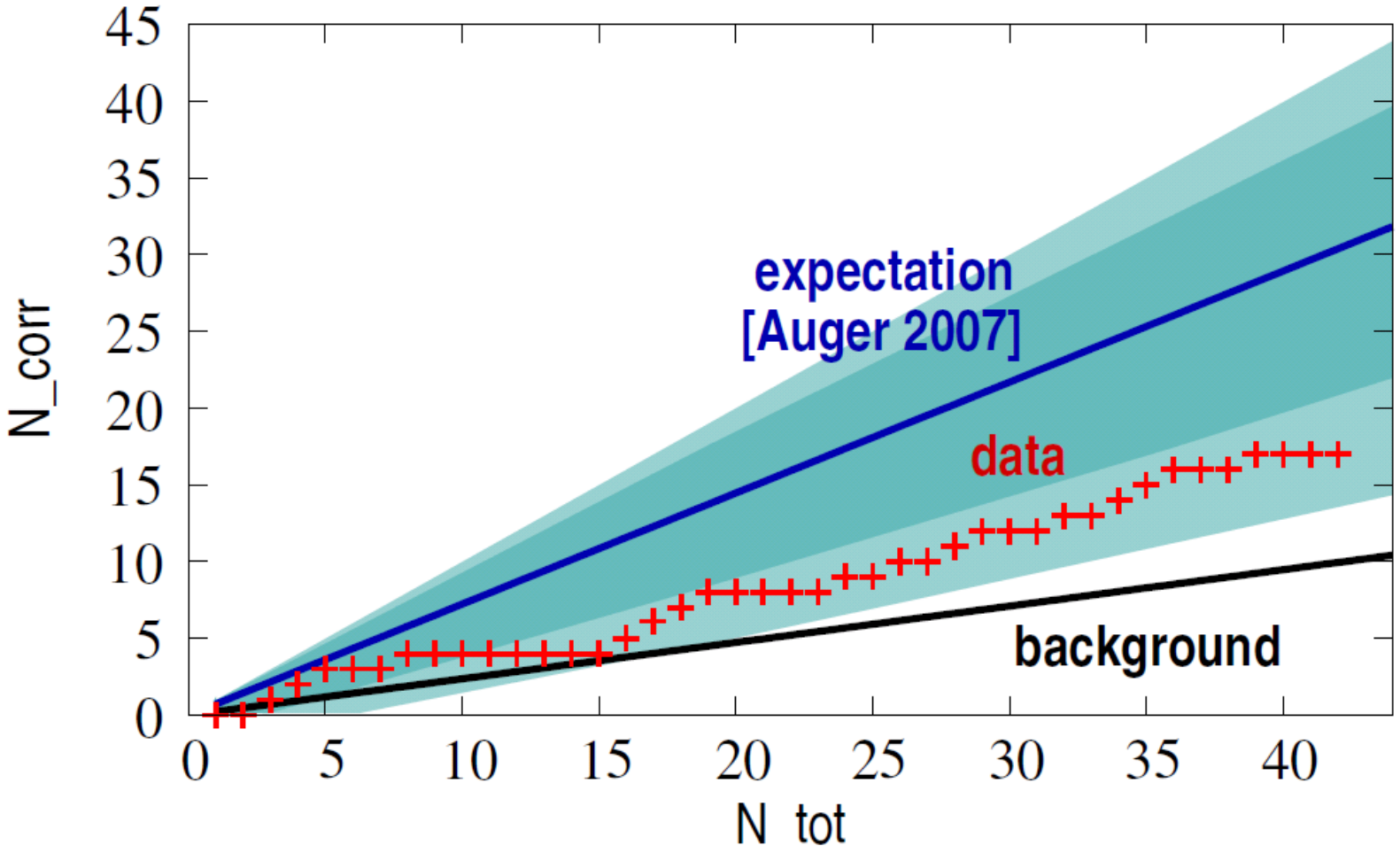
The photon likelihood of the observed shower is evaluated by shower front curvature by SD.
For 5 years SD data, we got the photon upper limit for which estimated energy is more than 10^{19}eV.





Anisotropy (Nearby AGN)

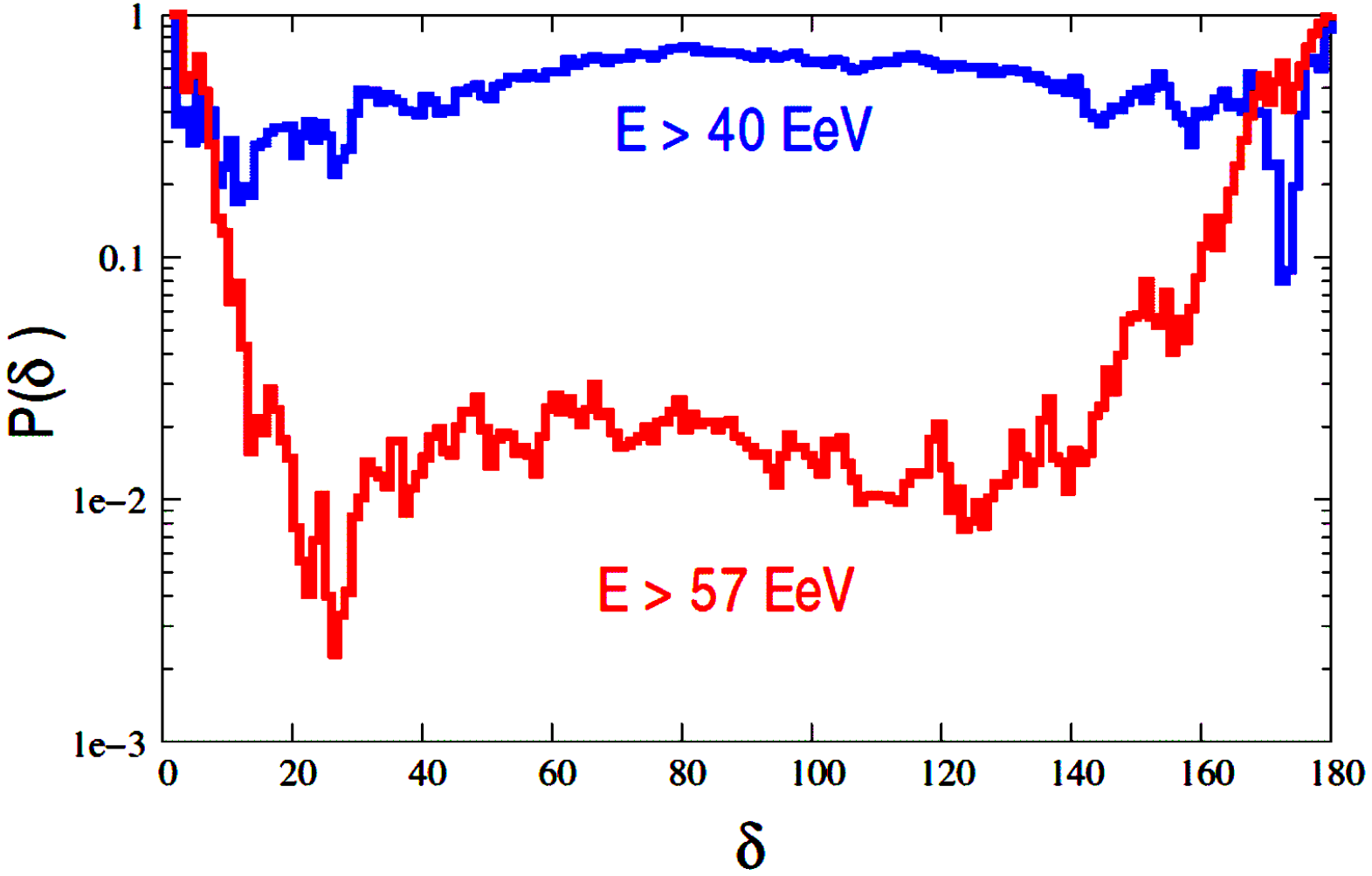
AGNs are from VCV 2006 catalog, cut by z ($0 < z \leqq 0.18$).
There are 465 AGN in our field of view.
Primary Energy $>$ 57EeV, Angular Separation $<$ 3.1° .



17 events correlate out of 42 events.
This probability is 0.014 from chance correlation.

Anisotropy (Auto-correlation)

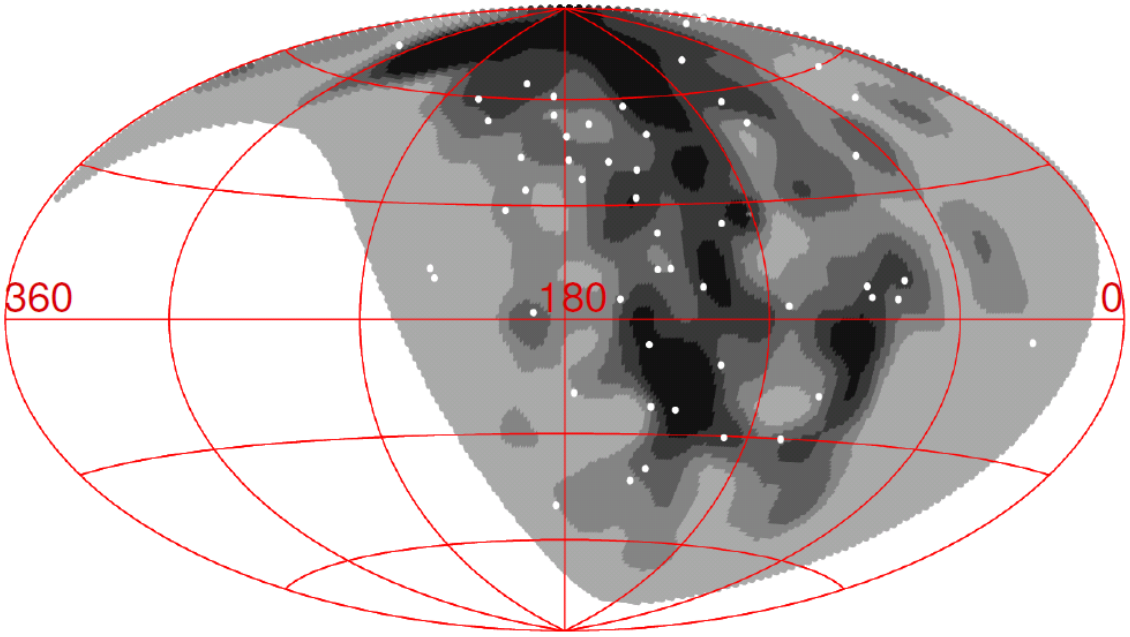
AGASA reported clustering within 2.5° for energy > 40EeV.
TA found no clustering within 2.5° .
Extended search for larger angles δ and higher energy.



Anisotropy (LSS)

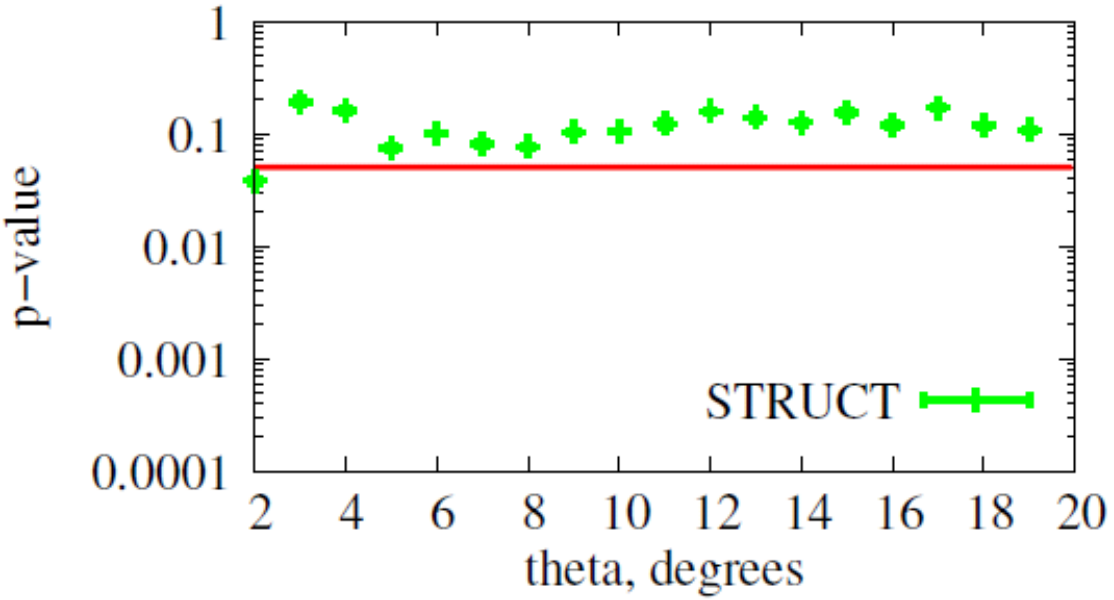
Composition measured by TA is consistent with proton.

Data (white point) and Model distribution (shaded region) from LSS within 100Mpc.



E > 57 EeV

When deflection angle θ set to 6° , p-value of isotropy is 0.001 .



Physics Summary

Significance of the five-year SD spectrum suppression is 5.7σ.

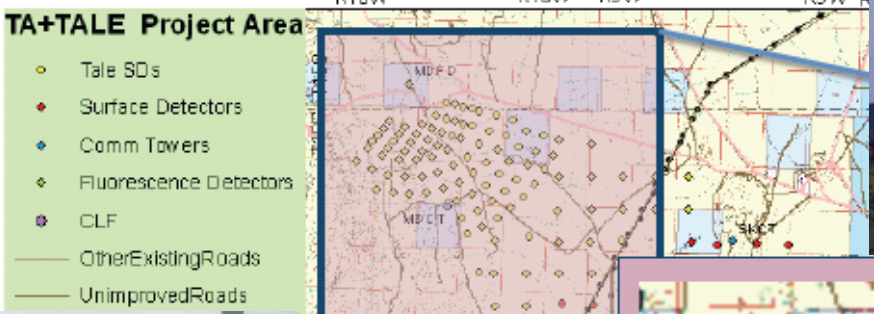
Mass composition is consistent with proton.

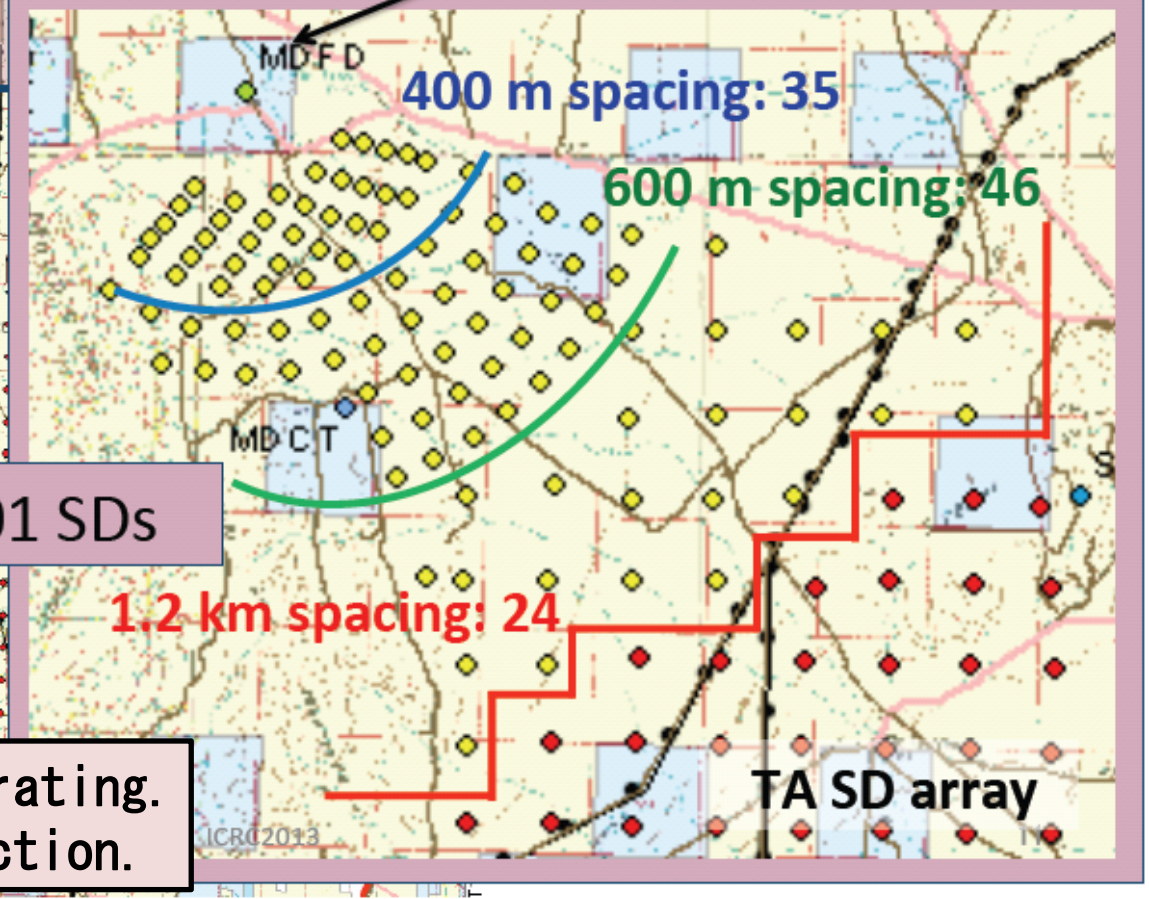
Arrival direction at high energy seems inconsistent with isotropic distribution.

To Extended and Affiliate Experiment

TA Low Energy Extension (TALE)

Basically it uses same method as TA, relatively specific for hybrid observation. The observing energy range is down to 10^{17}eV (LHC).

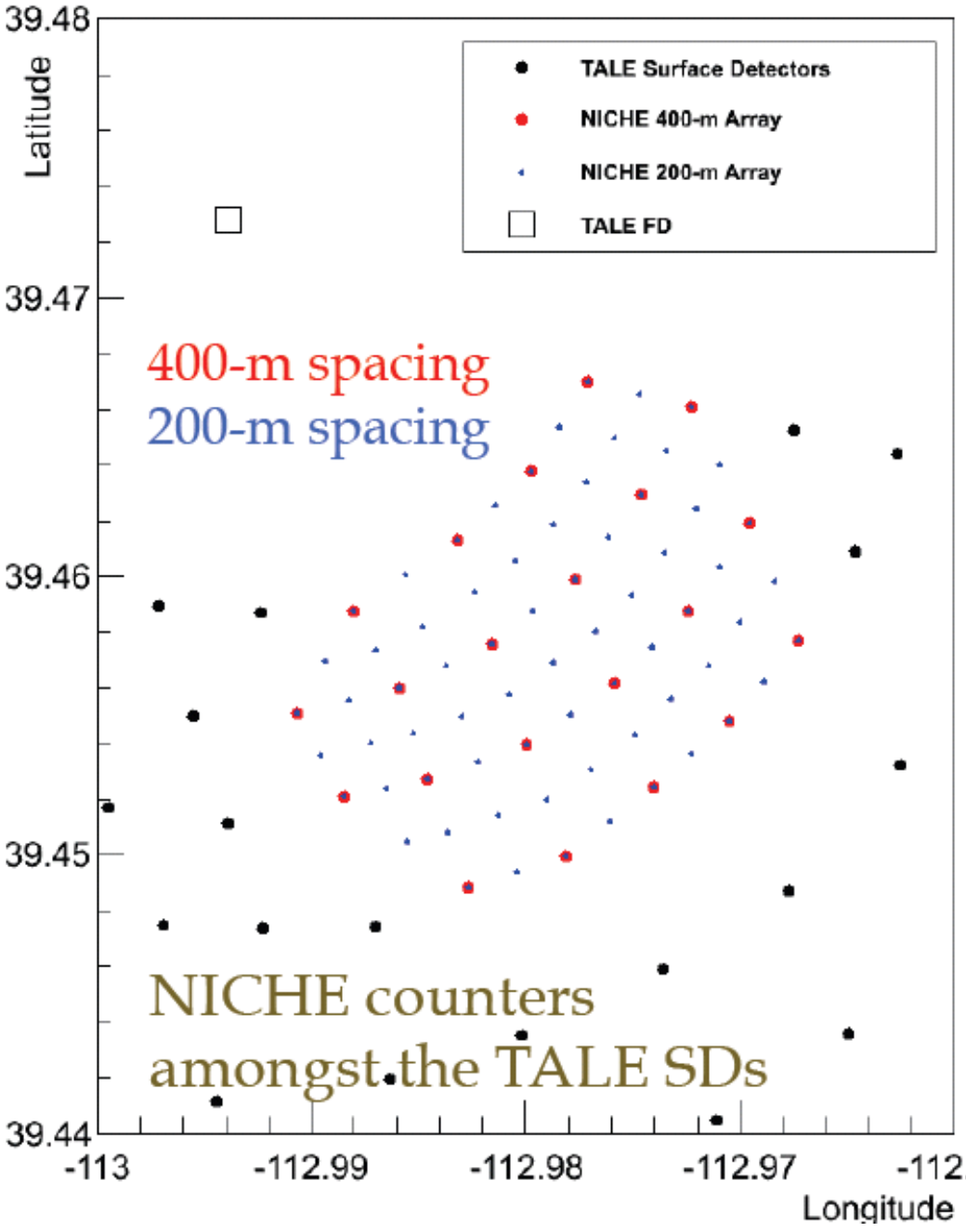




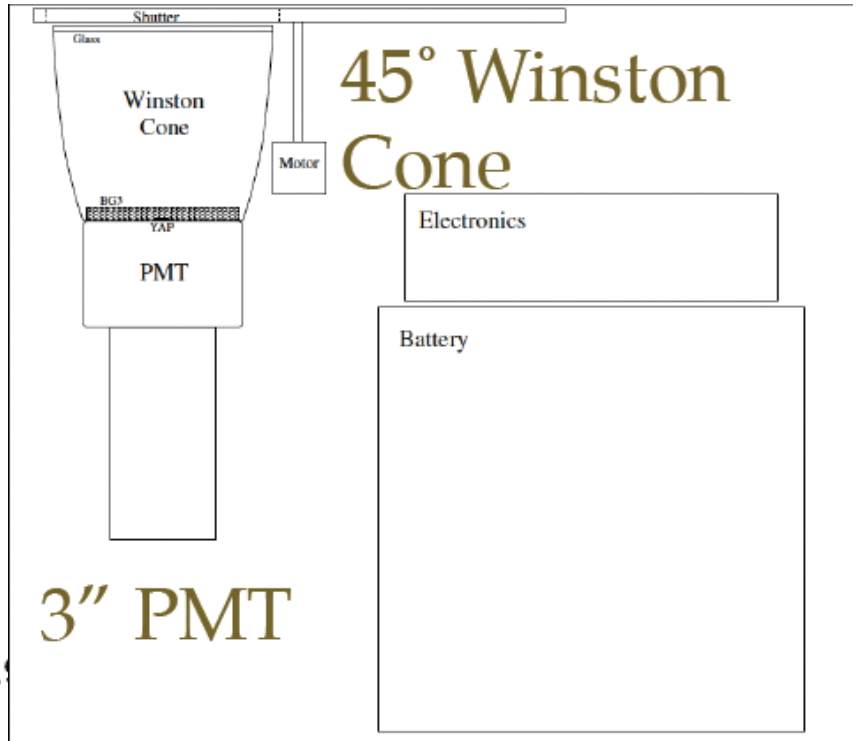
Additionally install 101 SDs

Partially installed and operating.
Now, proposing full construction.

Non-Imaging CHErenkov array (NICHE)



This is the plan of low energy extension for TALE, whose energy range down to 10^{16}eV for 200m spacing. The main purpose is composition study by Cherenkov pulse-width, working with TALE.

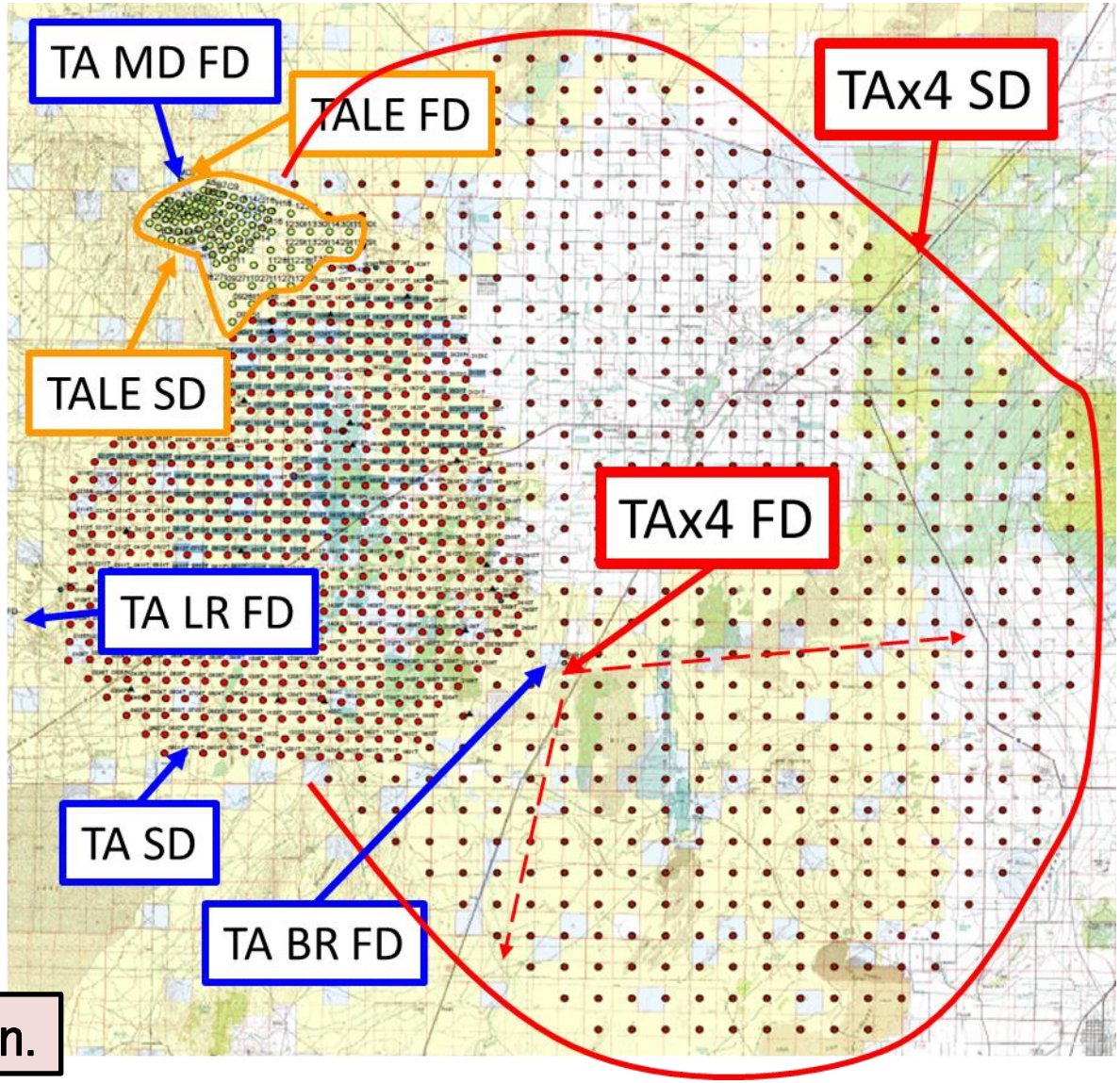


TA High Energy Extension (TAx4)

Basically it uses same method as TA, with a FD and 3 times larger coverage area by SDs. SD full area can not be covered by FD field of view.

This experiment is mainly for anisotropy study,

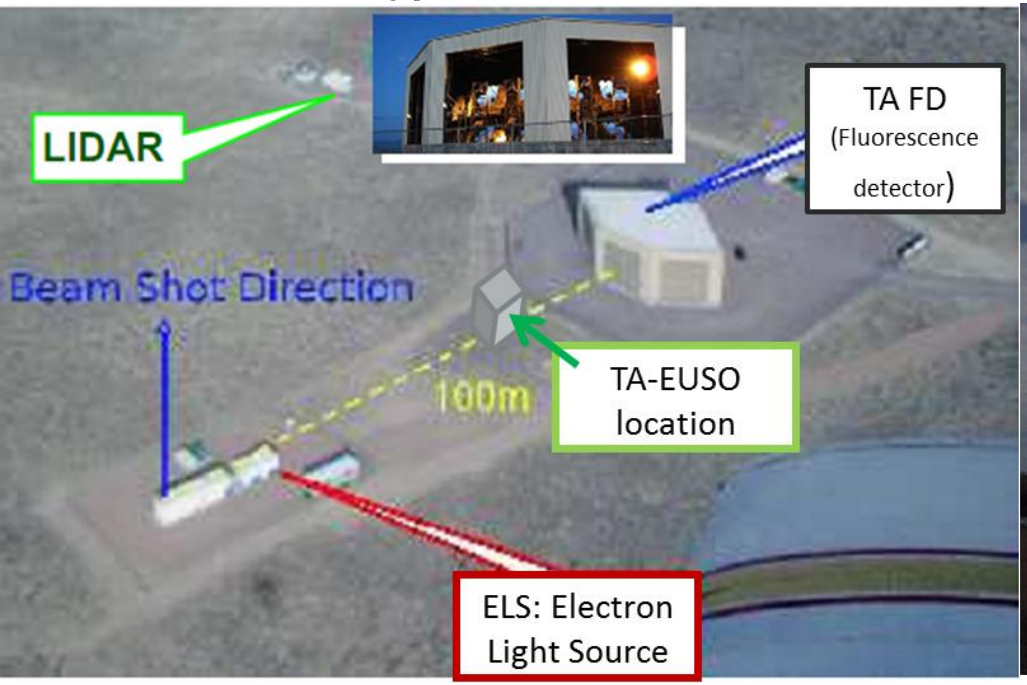
This is for detecting more cosmic rays which have energy over GZK. If they are proton, their source is within 50Mpc. From our current result of the inconsistency with isotropy at high energy region, we are halfway to catching a clue?



Now, proposing construction.

TA Affiliate Experiment

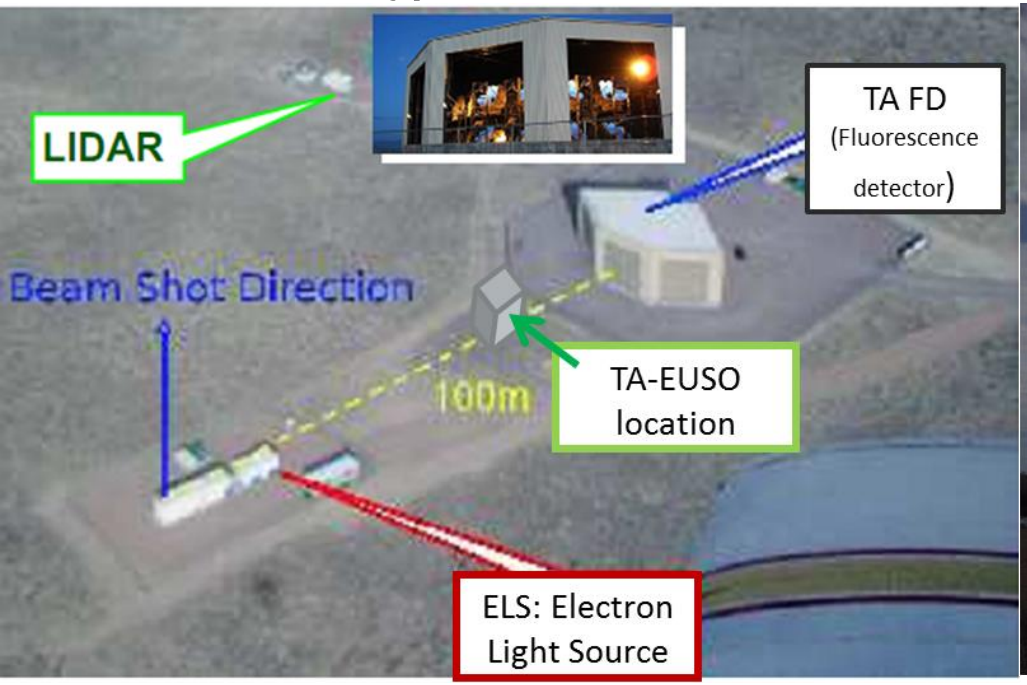
Prototype EUSO at TA



TARA

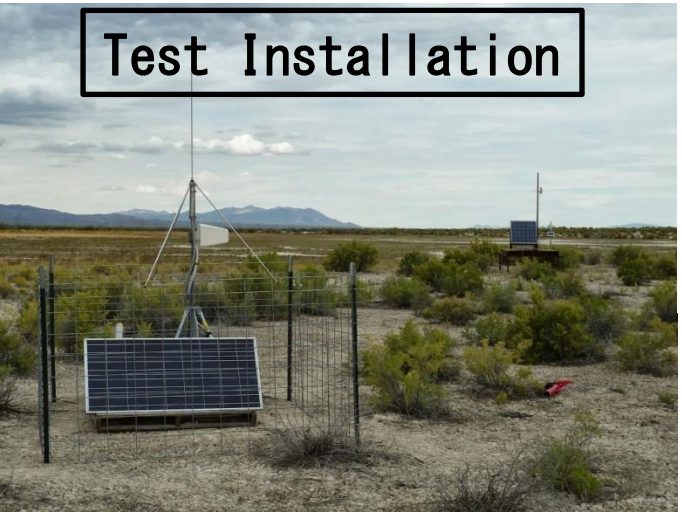
TA Affiliate Experiment

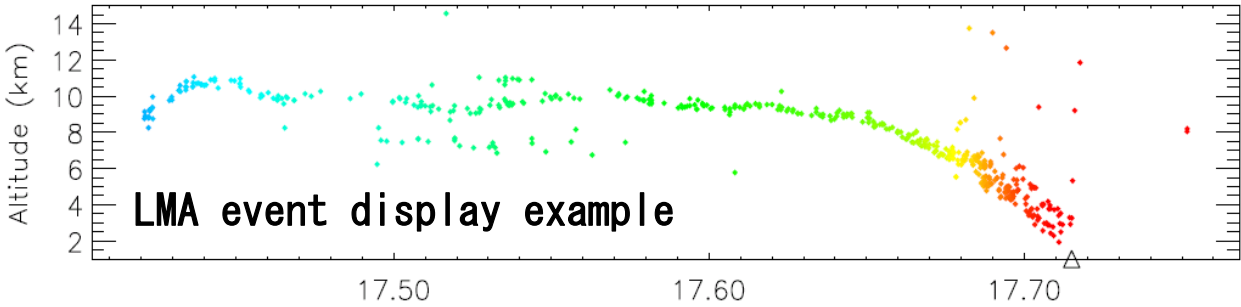
Prototype EUSO at TA



TARA

TA Lightning Mapping Array (TALMA)





LMA can measure the origin of sferics in the lightning process with high resolution of time and position.

Why TA try to install LMA?

Because TASD observed the bursts of shower like events, which are correlated with lightning.

From five years TASD data, there are 10 bursts of shower trigger. The burst criteria is 3 shower trigger in 1 millisecond. The chance expectation for five years is less than 10^{-4}.

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Some events in 5 bursts pass the reconstruction.

	date	time	usec	X[m]	Y[m]
AS	101004	165842	930565	11356	-7425
AS	101004	165842	930612	10478	-7368
AS	101004	165842	930835	11142	-8159
AS	110727	080615	124319	3447	1952
AS	110727	080615	124543	2897	2232
AS	110916	194056	567481	-3210	-9285
AS	110916	194056	567566	-3524	-9413
AS	120706	014911	184219	9847	-10702
AS	120706	014911	184307	7635	-9674
AS	120907	015545	380684	-8636	1254
AS	120907	015545	380755	-9857	-337
AS	120907	015545	380881	-9450	-961

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From five years TASD data, there are 10 bursts of shower trigger. The burst criteria is 3 shower trigger in 1 millisecond. The chance expectation for five years is less than 10^{-4}.

Some events in 5 bursts pass the reconstruction.
These bursts are selected only by timing, but their core position is very close.
In addition, these reconstructed shower front is very curved compared with normal shower. They seems start shower development at low sky.

	date	time	usec	X[m]	Y[m]
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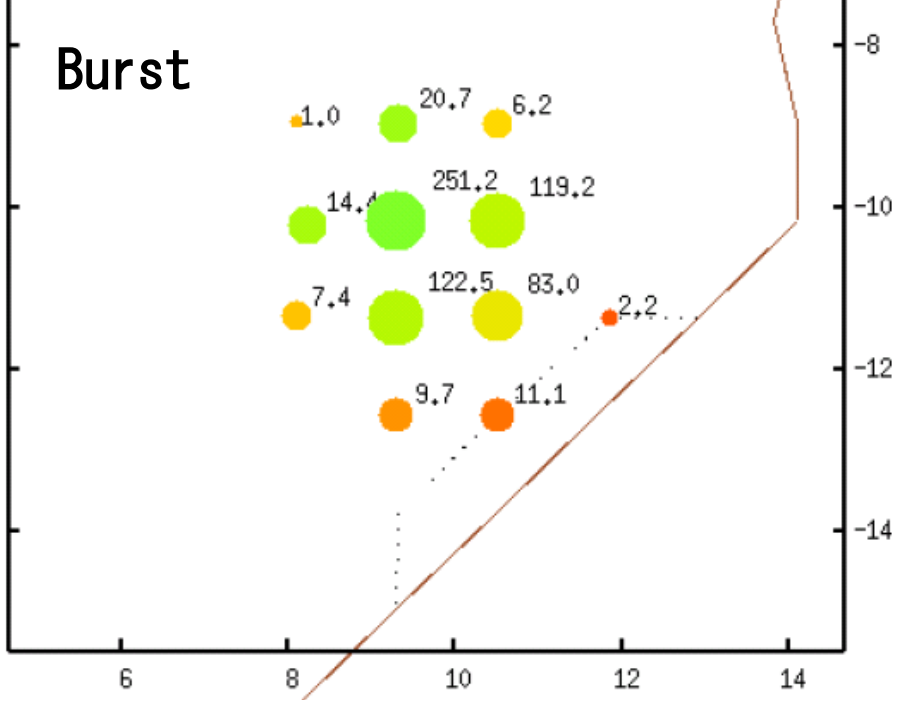
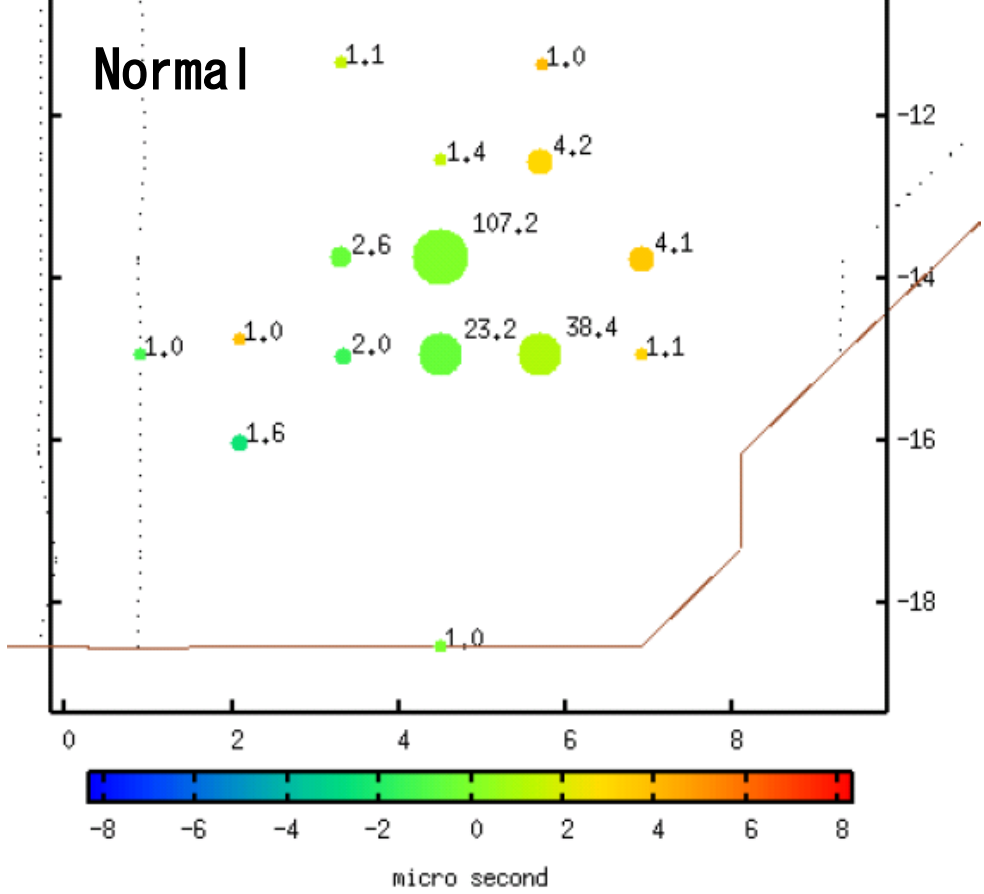
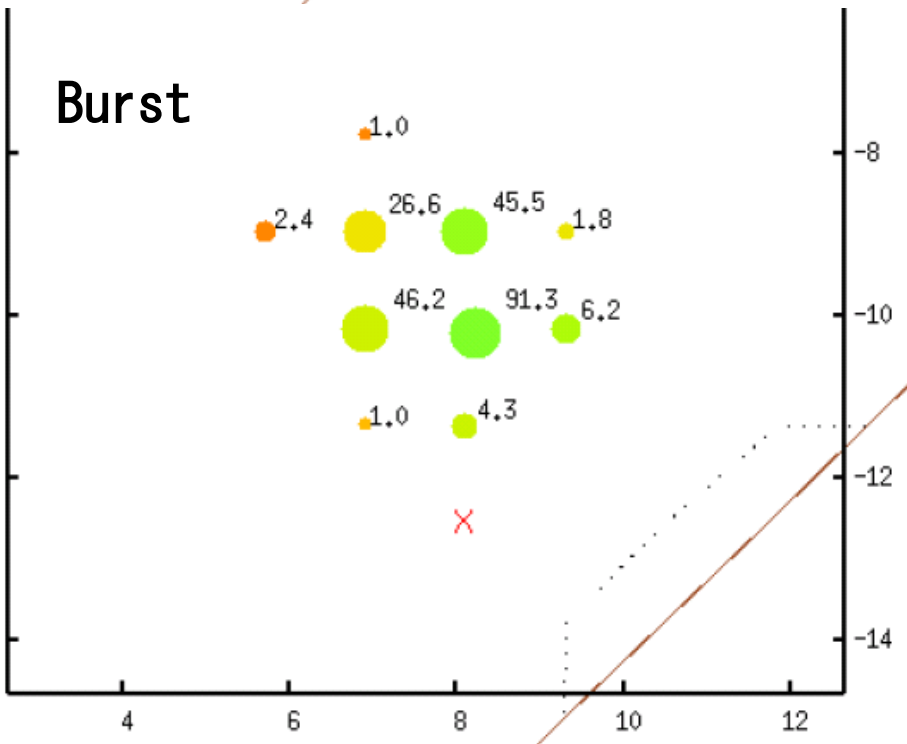
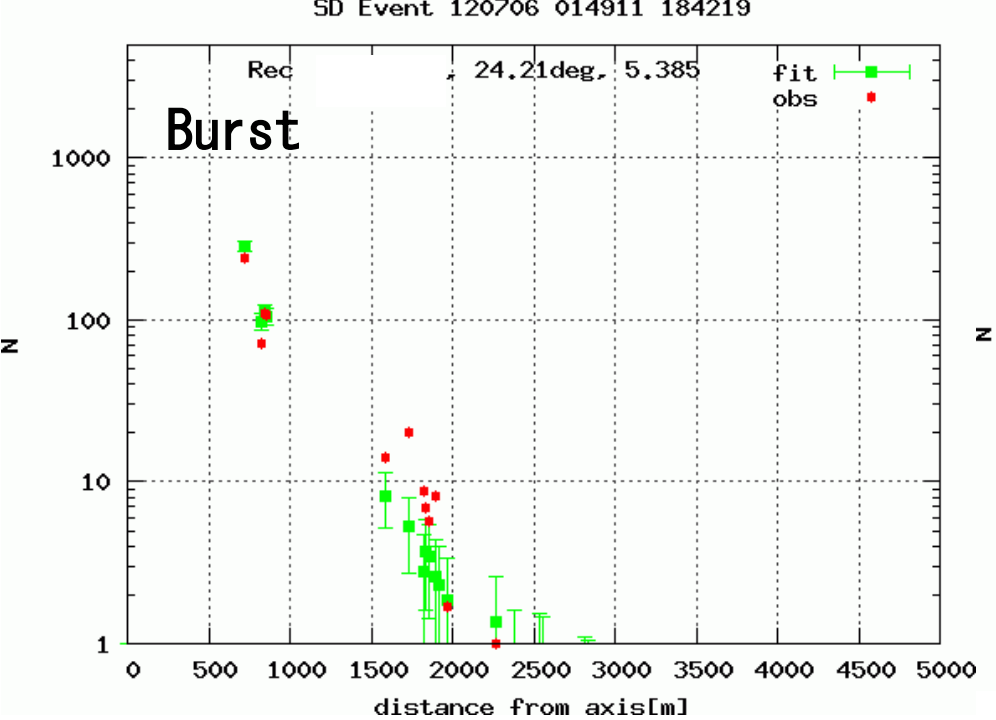


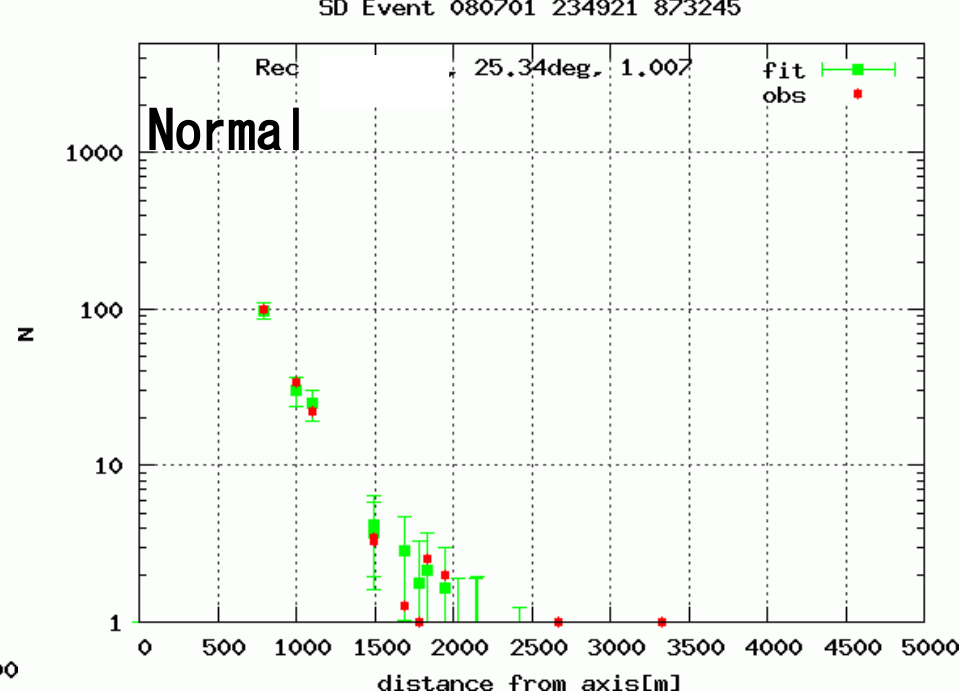


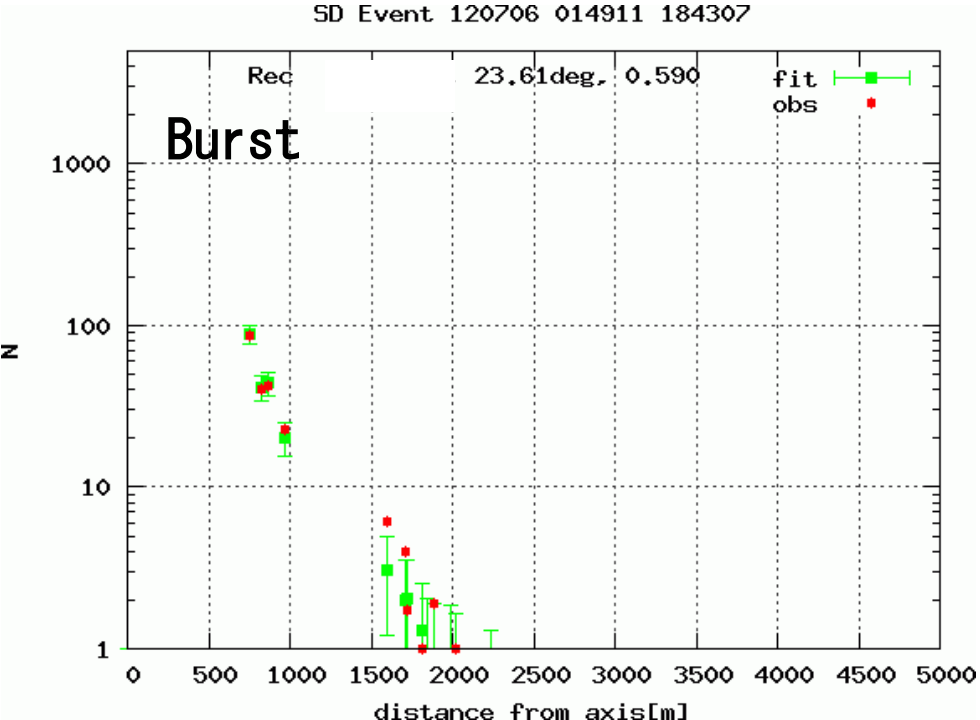


Particle Hit Map

Left plots are burst events. Right plot is a typical (normal) event whose zenith angle is almost same as left two events and its shower size is middle of left two events.

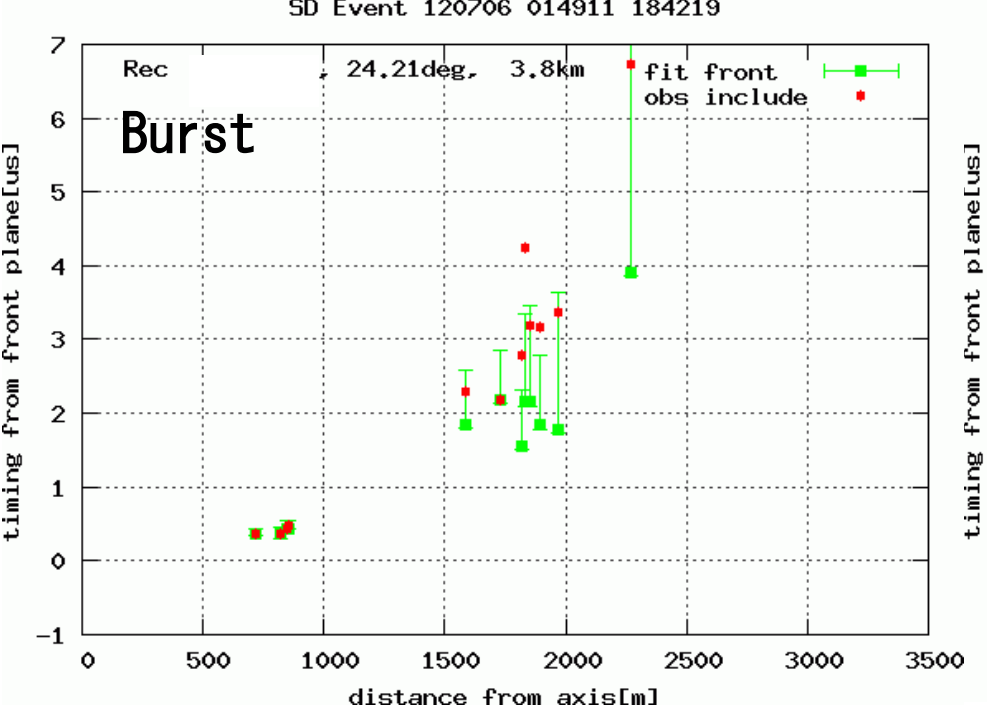


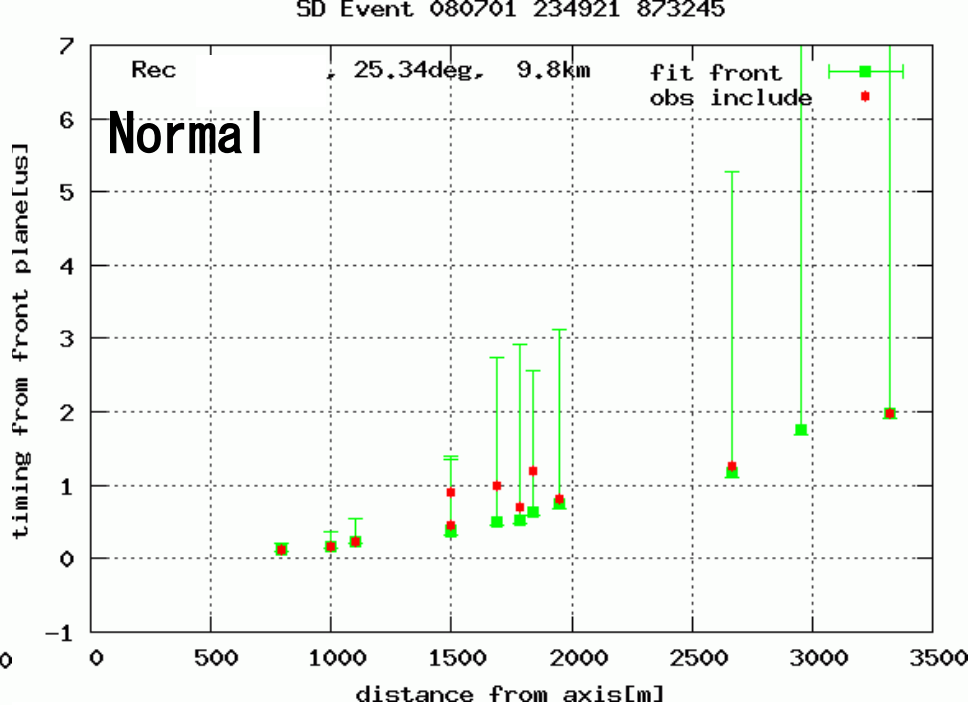


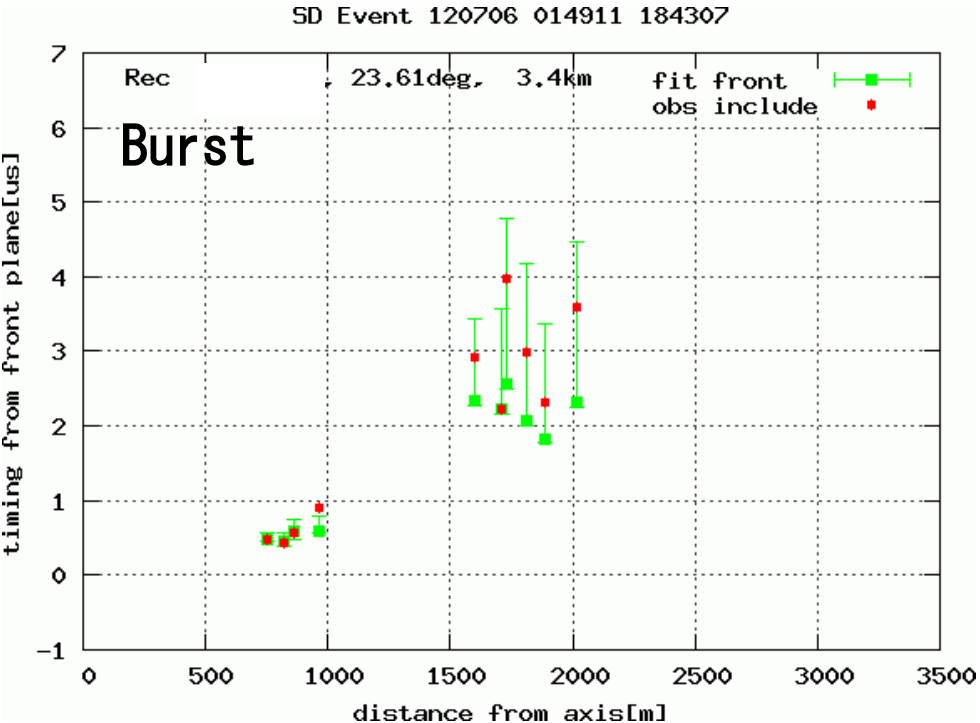


Lateral Number of Particle

Left plots are burst events. Right plot is a typical (normal) event whose zenith angle is almost same as left two events and its shower size is middle of left two events.



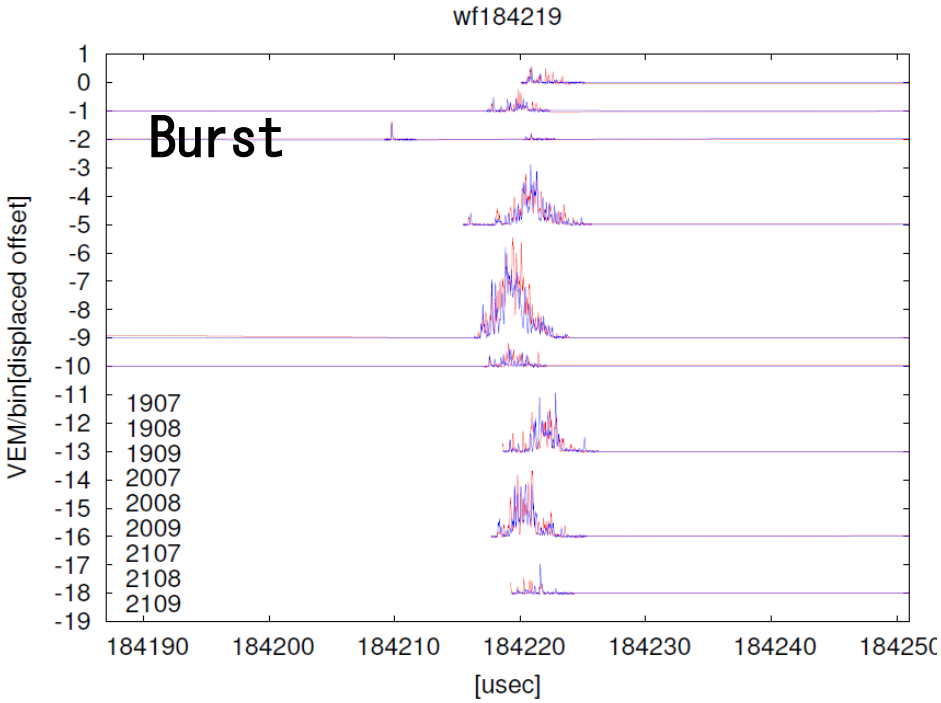


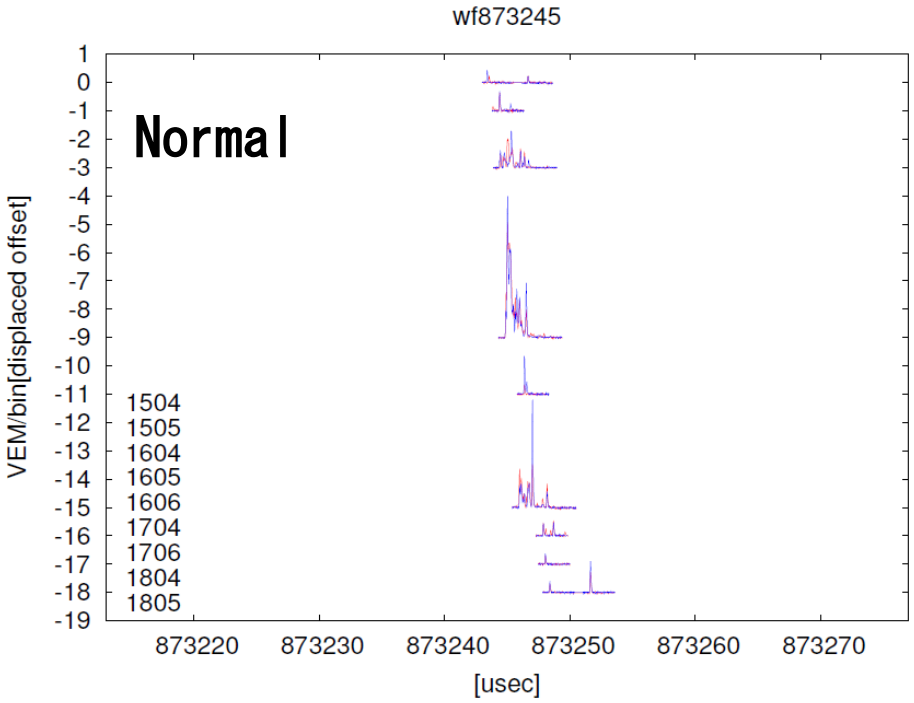


Lateral Arrival Timing

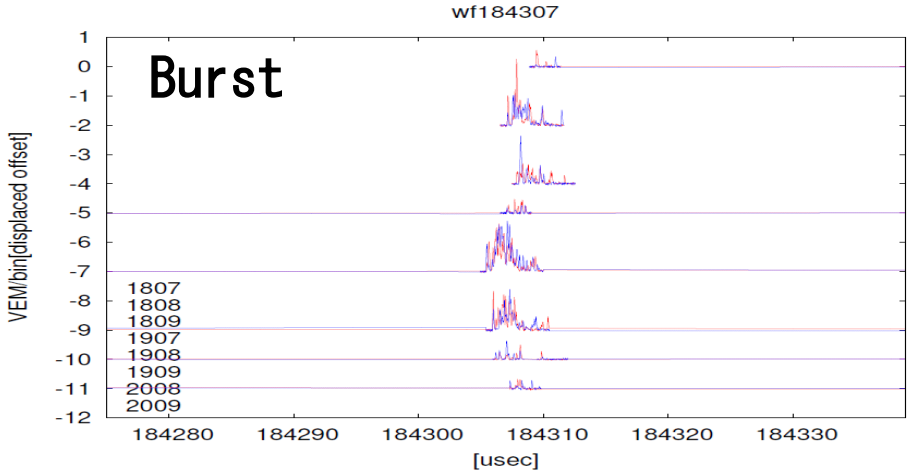
Left plots are burst events. Right plot is a typical (normal) event whose zenith angle is almost same as left two events and its shower size is middle of left two events.

Left plots' shower front is much more curved than Right plot.





Waveforms



Left plots are burst events.
Right plot is a typical (normal) event whose zenith angle is almost same as left two events and its shower size is middle of left two events.

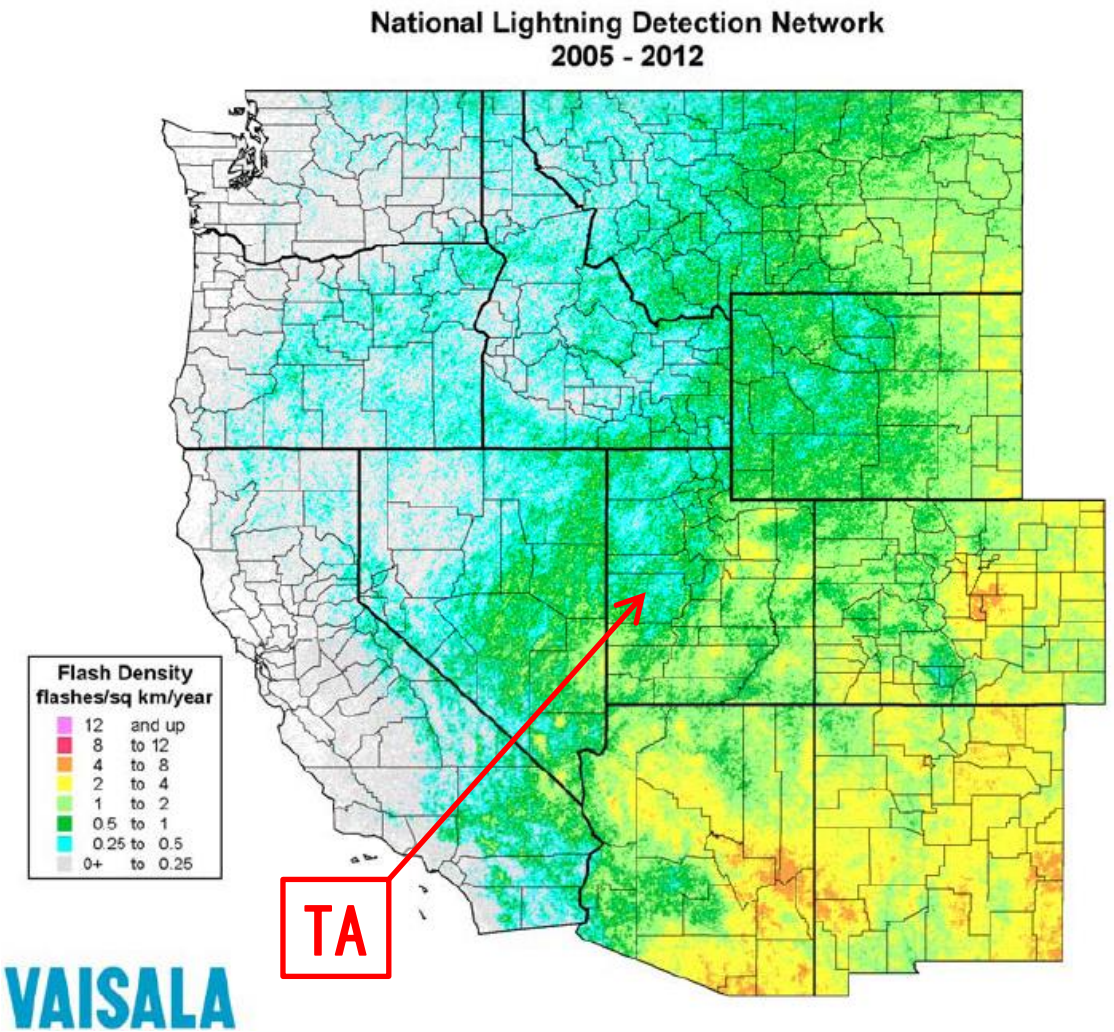
Left plots' waveforms have less sharp rising edge than Right plot.

Correlation with Lightning Data from NLDN.

National Lightning Detection Network detects lightning by VLF. The lighting list contains lightning time, 2D coordinates, peak current and flag which indicates whether intracloud lightning or cloud-ground lightning.

<u>NLDN is somewhat inefficient for intracloud lightning</u>.

I defined “synchronized” lightning is the time difference within ±1[ms] from burst.
I defined “related” lightning is the time difference within ±200[ms] from burst excecpt for synchronized lightning.



AS	date	time	usec	X[m]	Y[m]	H[m]
LG	date	time	usec	X[m]	Y[m]	Flag
AS	101004	165842	930565	11356	-7425	3963
AS	101004	165842	930612	10478	-7368	4400
AS	101004	165842	930835	11142	-8159	3270
LG	101004	165842	930608	12480	-5068	C
LG	101004	165842	934058	10619	-8069	G
AS	110727	080615	124319	3447	1952	4070
AS	110727	080615	124543	2897	2232	3070
LG	110727	080615	124303	3653	2285	C
LG	110727	080615	130887	3084	1996	G
AS	110916	194056	567481	-3210	-9285	3253
AS	110916	194056	567566	-3524	-9413	3134
AS	120706	014911	184219	9847	-10702	3770
AS	120706	014911	184307	7635	-9674	3361
LG	120706	014911	184122	8997	-9670	C
AS	120907	015545	380684	-8636	1254	4446
AS	120907	015545	380755	-9857	-337	4805
AS	120907	015545	380881	-9450	-961	3361
LG	120907	015545	380675	-8942	668	C
LG	120907	015545	390411	-9635	-1952	G
LG	120907	015545	409370	-8608	-1653	G

Correlation with Lightning Data from NLDN.

There are 4 correlations in 5 reconstructed bursts.
This is good correlation with considering NLDN detection efficiency.

AS line shows TASD event.
LG line shows NLDN event.

AS	date	time	usec	X[m]	Y[m]	H[m]
LG	date	time	usec	X[m]	Y[m]	Flag
AS	101004	165842	930565	11356	-7425	3963
AS	101004	165842	930612	10478	-7368	4400
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Correlation with Lightning Data from NLDN.

There are 4 correlations in 5 reconstructed bursts.
This is good correlation with considering NLDN detection efficiency.

AS line shows TASD event.
LG line shows NLDN event.

These correlations are taken only by timing, but the locations of bursts and lightning are also correlated very well.

AS / LG	date	time	usec	X[m]	Y[m]	H[m] / Flag
AS	101004	165842	930565	11356	-7425	3963
AS	101004	165842	930612	10478	-7368	4400
AS	101004	165842	930835	11142	-8159	3270
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LG	120907	015545	409370	-8608	-1653	G

Correlation with Lightning Data from NLDN.

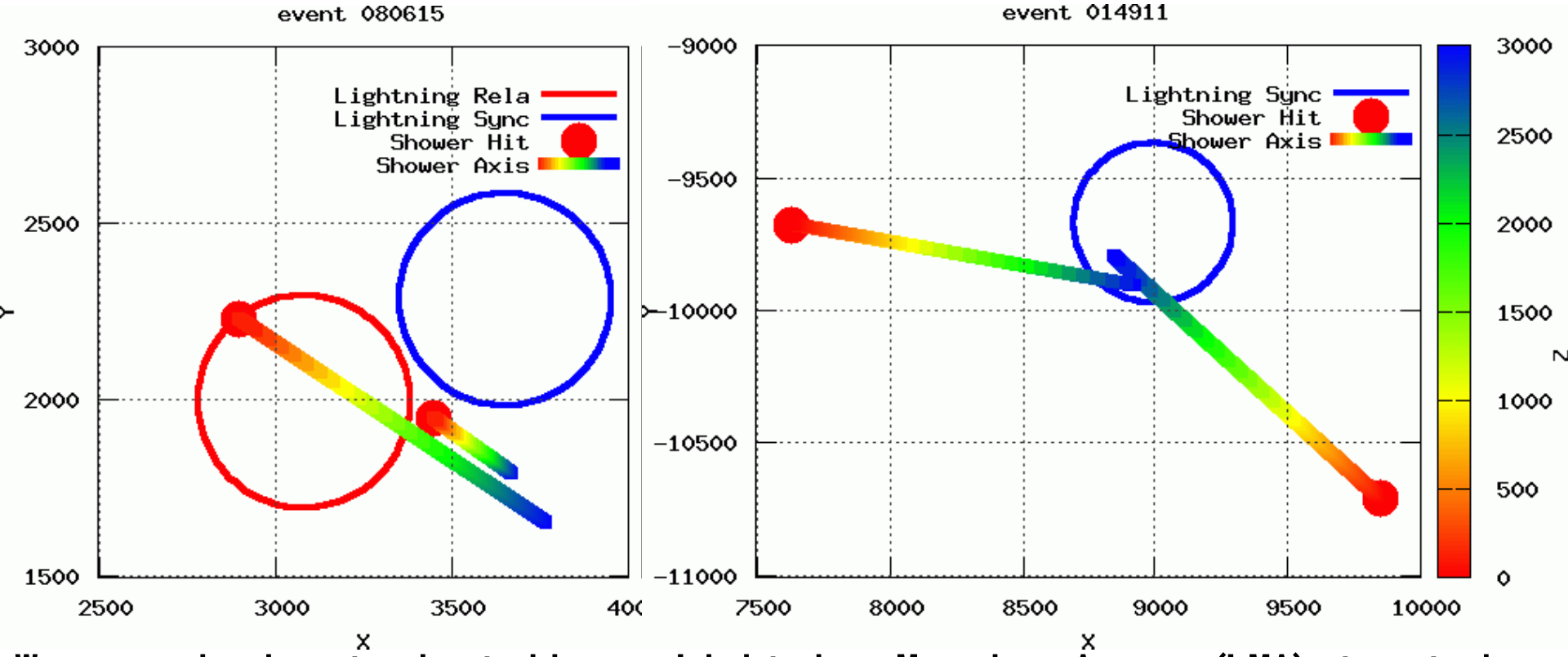
There are 4 correlations in 5 reconstructed bursts.
This is good correlation with considering NLDN detection efficiency.

AS line shows TASD event.
LG line shows NLDN event.

79% of the NLDN lightning data have flag “G(cloud-ground)”.
However, all synchronized 4 lightning strokes have flag “C(intracloud)”. And all related subsequent strokes have flag “G(cloud-ground)”.

High Energy Radiation Shower Geometry with Lightning

Color shows the height from ground up to 3000m.
Red point shows shower core hit position.
Circle shows lightning position with 300m radius.
I set “Synchronized(intracloud)” lightning at 3000m,
and “Related(cloud-ground)” lightning at 0m.



We are planing to install our Lightning Mapping Array (LMA) to study more detail correlation between high energy radiation and lightning.

We need fund for TALMA.

Summary

Some Extended Experiments
and
Some Affiliate Experiments
are planned and going on.

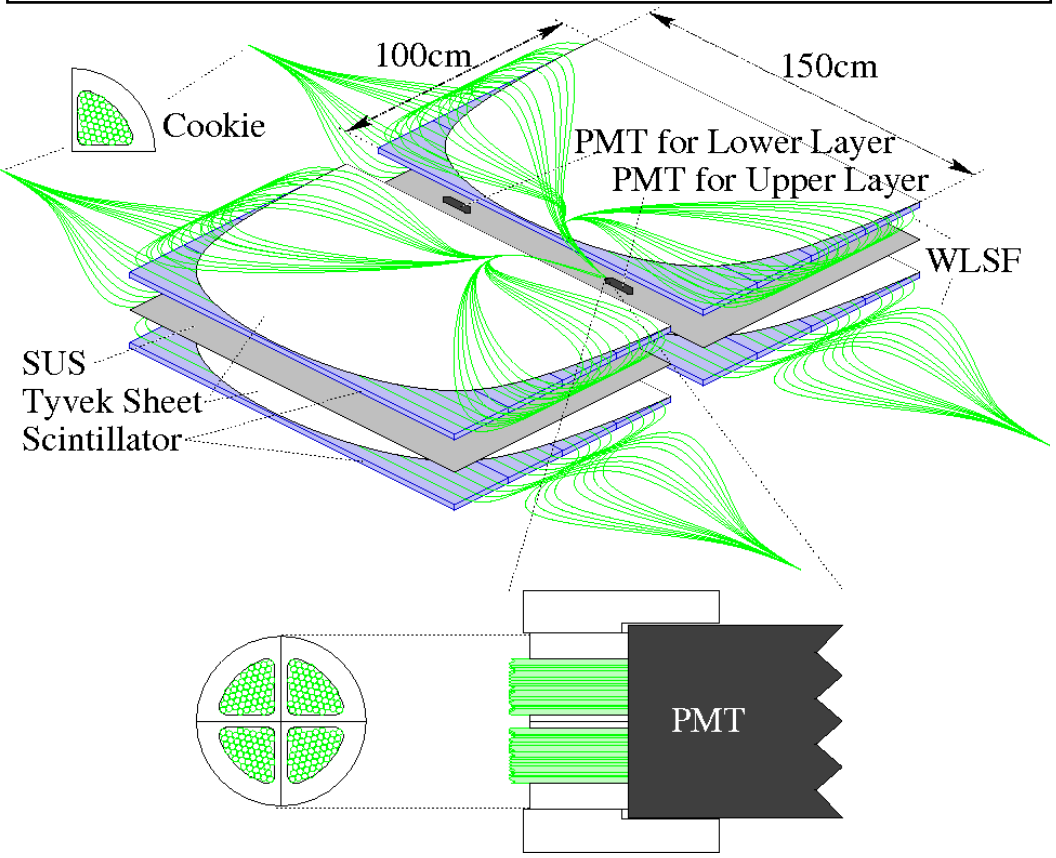
End

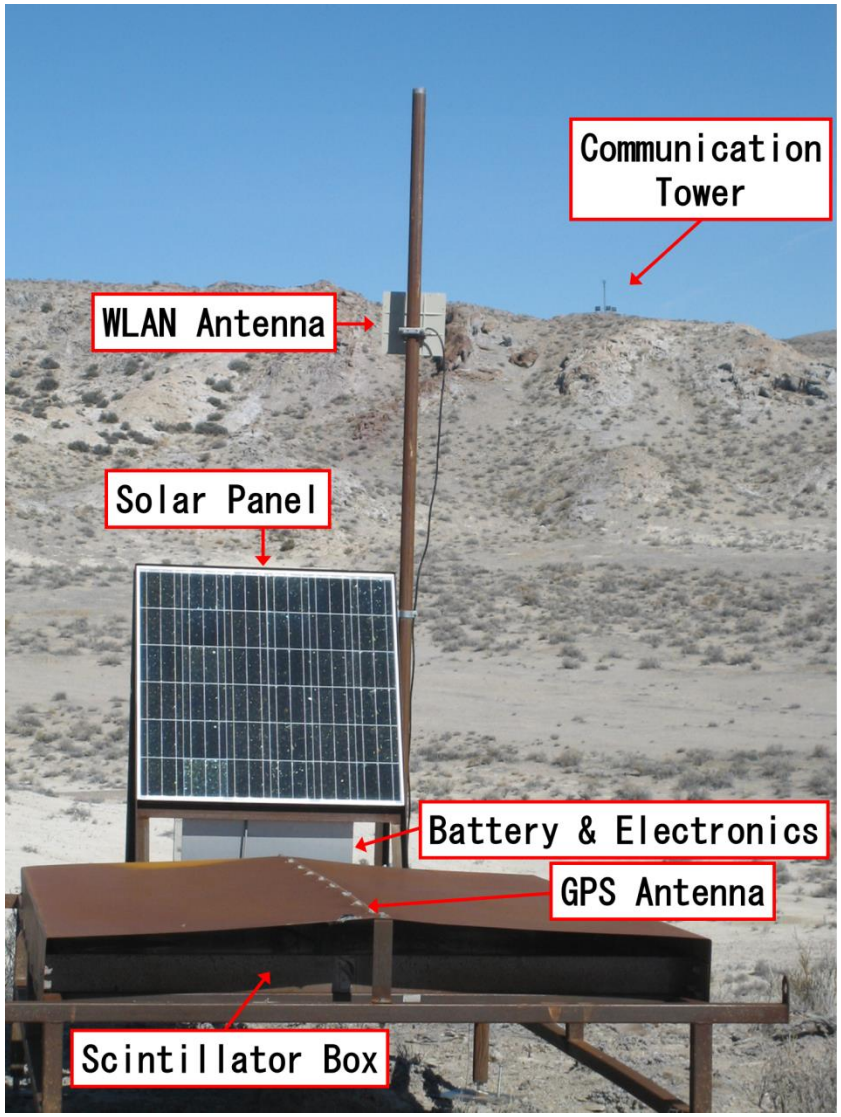
Thank You

Backup

Surface Detector

Particle Detection Part:
2 layers of $3m^2 \times 1.2cm$ plastic scintillators.
104 Wave Length Shifting Fibers for each layer.

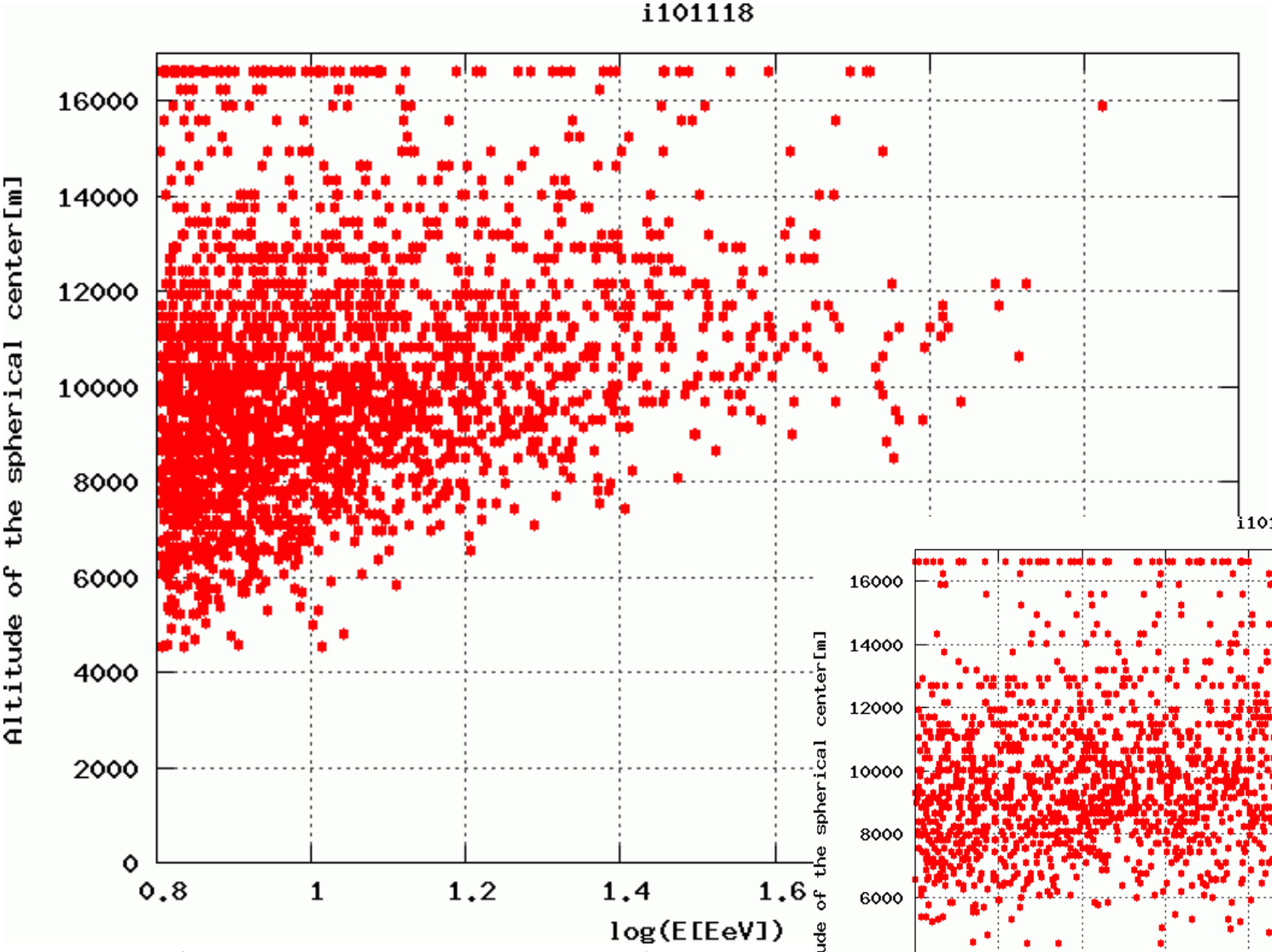


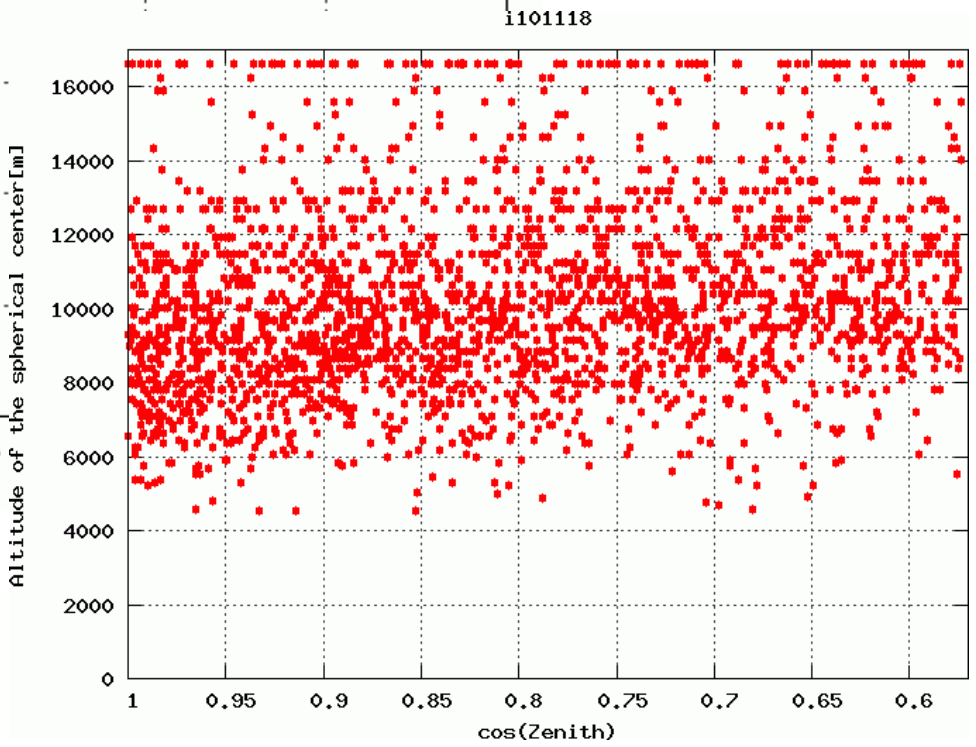


Electronics:
50MHz FADC
Charge Controller
GPS
Wireless LAN

Data Acquisition:
Shower Trigger is generated by adjacent 3SDs whose signal is over 3MIPs in 8μs.
Waveforms for all SD within 32μs from shower trigger time.

Scatter plot of H with Energy or Zenith (080511-100907)





Events (E>6.36EeV && Zen<55deg) with H (the altitude of the spherical center for shower front) less than 6000 are very few.