Telescope Array Experiment

S.Udo, Knagawa univ.
For the Telescope Array collaboration

2011/12/17 共同利用成果発表会

共同利用研究課題

整理番号	研究代表者	研究課題	配分額 (円)		
			研究費	旅費	合計
G07	多米田 裕一郎	ラジコンヘリコプターによる TA 大気蛍光望遠鏡キャリブレーション	60,000	140,000	200,000
G09	芝田 達伸	小型電子加速器による 空気シャワーエネルギーの絶対較正の研究	1,000,000	400,000	1,400,000
G13	千川 道幸	絶対光量測定による 新型大気モニタ装置の開発	500,000	400,000	900,000
G14	池田 大輔	最高エネルギー宇宙線の 電波的観測の研究	500,000	200,000	700,000
G17	常定 芳基	宇宙線望遠鏡実験による低エネルギー領域における 宇宙線原子核組成の研究	0	200,000	200,000
G29	佐川 宏行	宇宙線望遠鏡による 極高エネルギー宇宙線の研究	0	1,000,000	1,000,000
G32	荻尾 彰一	電子加速器を使った 大気マイクロ波の検出	300,000	600,000	900,000
G34	野中 敏幸	TA 実験サイトでの超高エネルギー 宇宙線観測のための新型検出器の開発	0	200,000	200,000
		合計	2,360,000	3,140,000	5,500,000

The TA Collaboration

T.Abu-Zayyad[1], R.Aida[2], M.Allen[1], R.Anderseon[1], R.Azuma[3], E.Barcikowski[1], J.W.Belz[1], D.R.Bergman[1], S.A.Blake[1], R.Cady[1], B.G.Cheon[4], J.Chiba[5], M.Chikawa[6], E.J.Cho[4], W.R.Cho[7], H.Fujii[8], T.Fujii[9], T.Fukuda[3], M.Fukushima[10,20], D.Gorbunov[11], W.Hanlon[1], K.Hayashi[3], Y.Hayashi[9], N.Hayashida[12], K.Hibino[12], K.Hiyama[10], K.Honda[2], T.Iguchi[3], D.Ikeda[9], K.Ikuta[2], N.Inoue[13], T.Ishii[2], R.Ishimori[3], D.Ivanov[1,14], S.Iwamoto[2], C.C.H.Jui[1], K.Kadota[15], F.Kakimoto[3], O.Kalashev[11], T.Kanbe[2], K.Kasahara[16], H.Kawai[17], S.Kawakami[9], S.Kawana[13], E.Kido[10], H.B.Kim[4], H.K.Kim[7], J.H.Kim[4], J.H.Kim[18], K.Kitamoto[6], K.Kobayashi[5], Y.Kobayashi[3], Y.Kondo[10], K.Kuramoto[9], V.Kuzmin[11], Y.J.Kwon[7], S.I.Lim[21], S.Machida[3], K.Martens[20], J.Martineau[1], T.Matsuda[8], T.Matsuura[3], T.Matsuyama[9], J.N.Matthews[1], I.Myers[1], M.Minamino[9], K.Miyata[5], H.Miyauchi[9], Y.Murano[3], T.Nakamura[21], S.W.Nam[19], T.Nonaka[10], S.Ogio[9], M.Ohnishi[10], H.Ohoka[10], K.Oki[10], D.Oku2, T.Okuda[9], A.Oshima[9], S.Ozawa[16], I.H.Park[19], M.S.Pshirkov[22], D.Rodriguez[1], S.Y.Roh[18], G.Rubtsov[11], D.Ryu[18], H.Sagawa[10], N.Sakurai[9], A.L.Sampson[1], L.M.Scott[14], P.D.Shah[1], F.Shibata[2], T.Shibata[10], H.Shimodaira[10], B.K.Shin[4], J.I.Shin[7], T.Shirahama[13], J.D.Smith[1], P.Sokolsky[1], T.J.Sonley[1], R.W.Springer[1], B.T.Stokes[1], S.R.Stratton[1,14], T.Stroman[1], S.Suzuki[8], Y.Takahashi[10], M.Takeda[10], A.Taketa[23], M.Takita[10], Y.Tameda[10], H.Tanaka[9], K.Tanaka[24], M.Tanaka[8], S.B.Thomas[1], G.B.Thomson[5], P.Tinyakov[11,22], I.Tkachev[11], H.Tokuno[3], T.Tomida[2], S.Troitsky[11], Y.Tsunesada[3], K.Tsutsumi[3], Y.Tsuyuguchi[2], Y.Uchihori[25], S.Udo[12], H.Ukai[2], G.Vasiloff[1], Y.Wada[13], T.Wong[1], M.Wood[1], Y.Yamakawa[10], H.Yamaoka[8], K.Yamazaki[9], J.Yang[19], S.Yoshida[17], H.Yoshii[26],R.Zollinger[1], Z.Zundel[1]

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2 University of Yamanashi, Interdisciplinary Graduate School of Medicine and Engineering
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4 Hanyang University
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6 Kinki University
7 Yonsei University
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9 Osaka City University
10 Institute for Cosmic Ray Research, University of Tokyo
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12 Kanagawa University
13 Saitama University
14 Rutgers University
15 Tokyo City University
16 Waseda University, Advanced Research Institute for Science and Engineering
17 Chiba University
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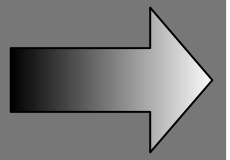
20 University of Tokyo, Institute for the Physics and Mathematics of the Universe
21 Kochi University
22 University Libre de Bruxelles
23 Earthquake Research Institute, University of Tokyo
24 Hiroshima City University
25 National Institute of Radiological Science
26 Ehime University

The TA Collaboration

Spokes Person election was held on Dec. 4, 2011

Old

M. Fukushima (ICRR)
P. Sokolsky (Univ. of Utah)



NEW

H. Sagawa (ICRR)
G. Thomson (Univ. of Utah)

- The Term of a co-spokesperson is 3 years, renewable for one term.
- No two co-spokespersons will be elected from one country.
- Eligible voters are TA members in the most recent publication list.
- There is no quorum requirement. A Simple Plurality is used for the Decision.
- Voting is held during the TA general meeting. Absentee voting is allowed.

Telescope Array Experiment

Millard county, Utah, USA
39.1° N, 122.9° W
~1400 m a.s.l.

Surface Detector Array (SD)

Scintillation counter : 507

3 m² x 1.2cm x 2 layers

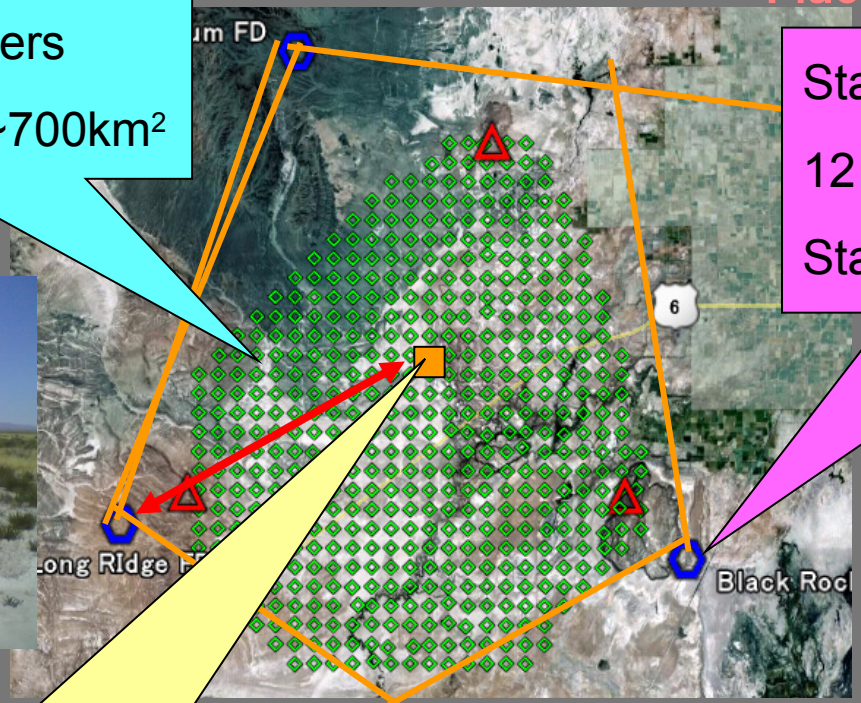
1.2 km separation, ~700km²

Fluorescence Detector (FD)

Stations : 3

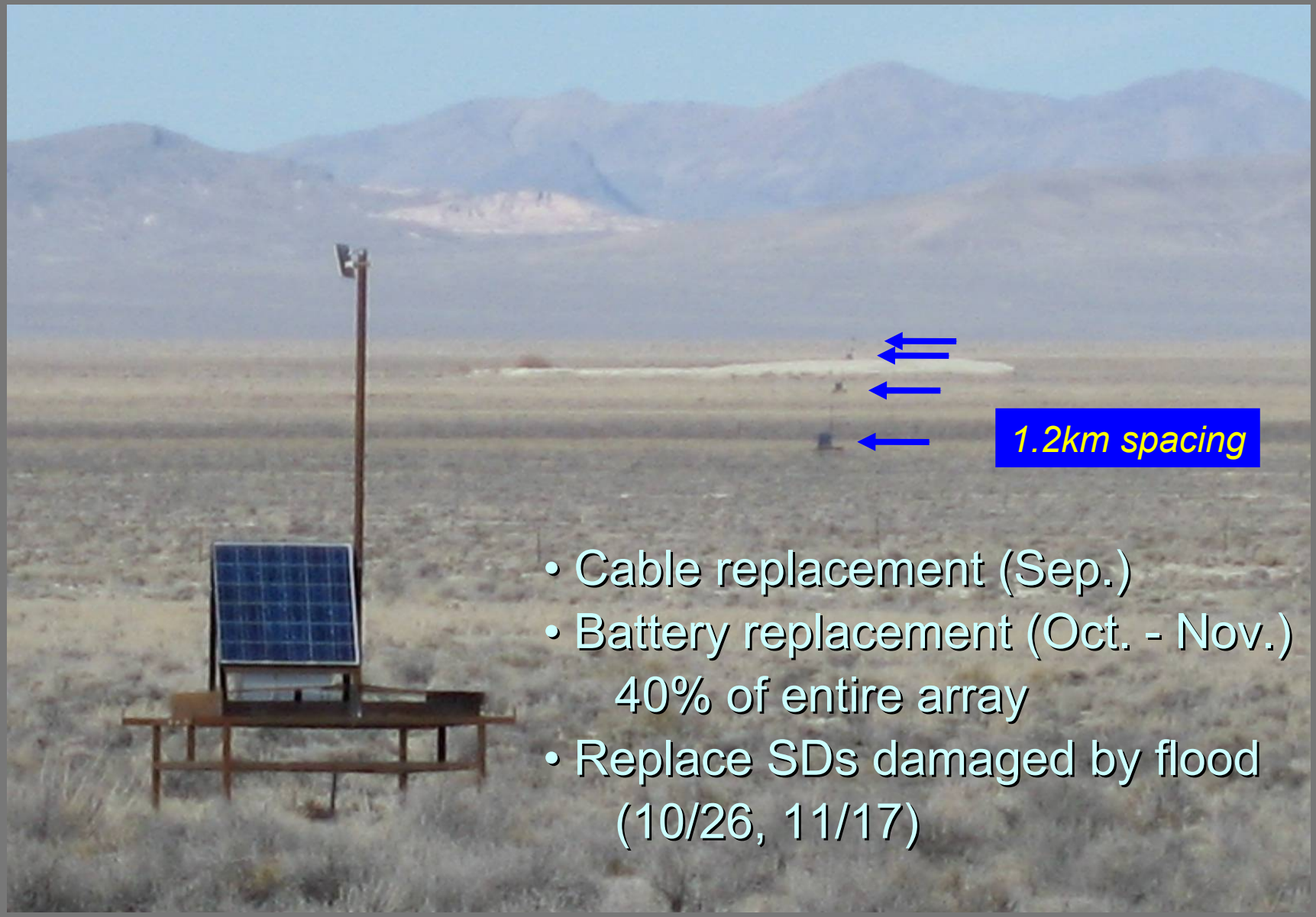
12 (14) Telescopes / station

Station FOV : 3° - 33° x 108°



Central Laser
(~20 km away from 3 FD stations)

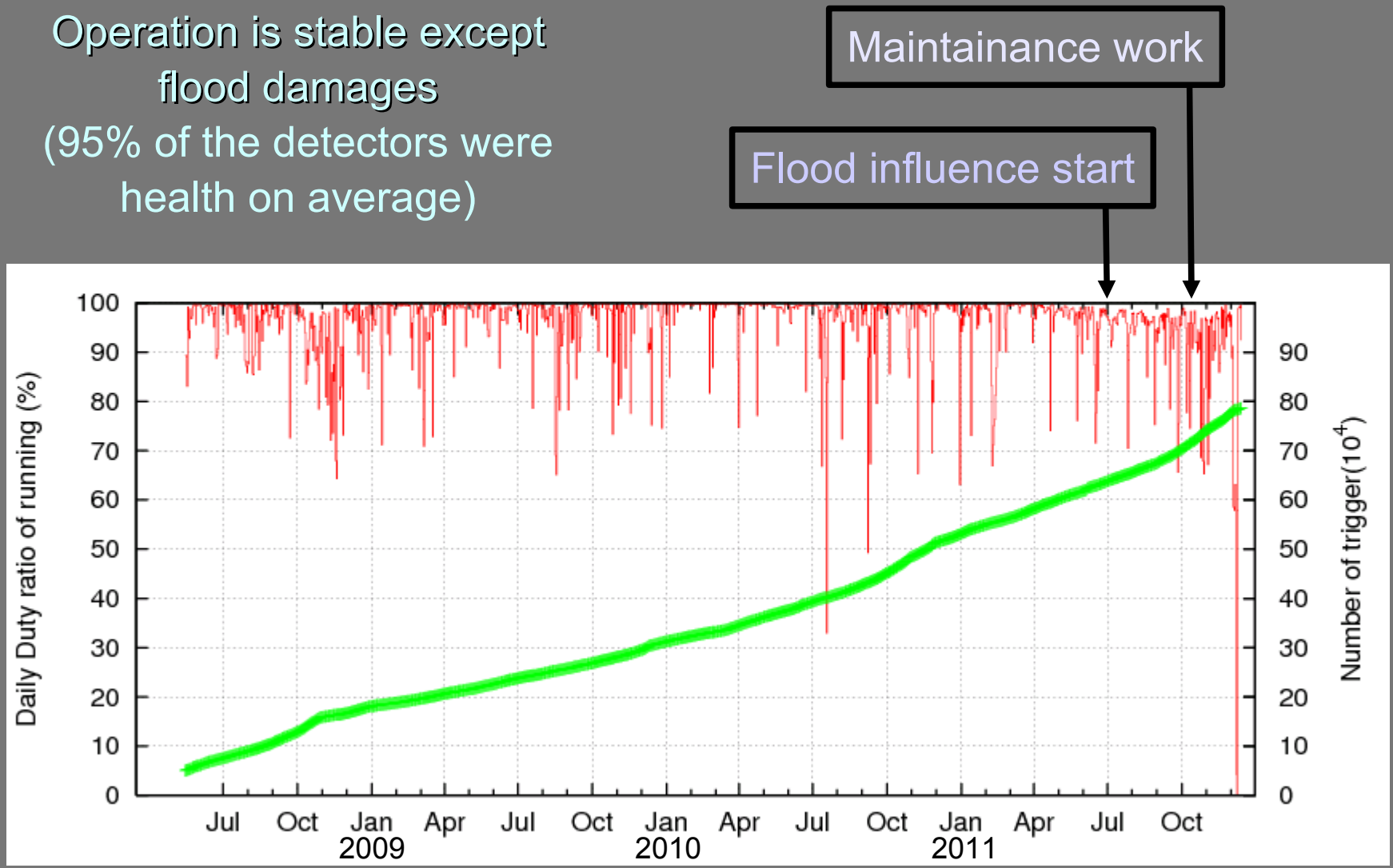
Status : SD



- Cable replacement (Sep.)
- Battery replacement (Oct. - Nov.)
  40% of entire array
- Replace SDs damaged by flood
  (10/26, 11/17)

Status : SD - Observavion

Operation is stable except flood damages
(95% of the detectors were health on average)

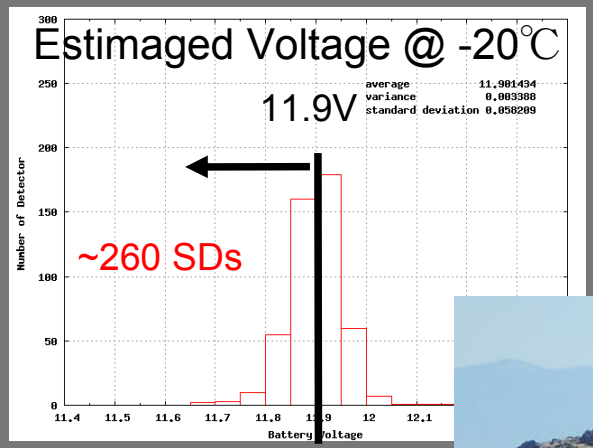


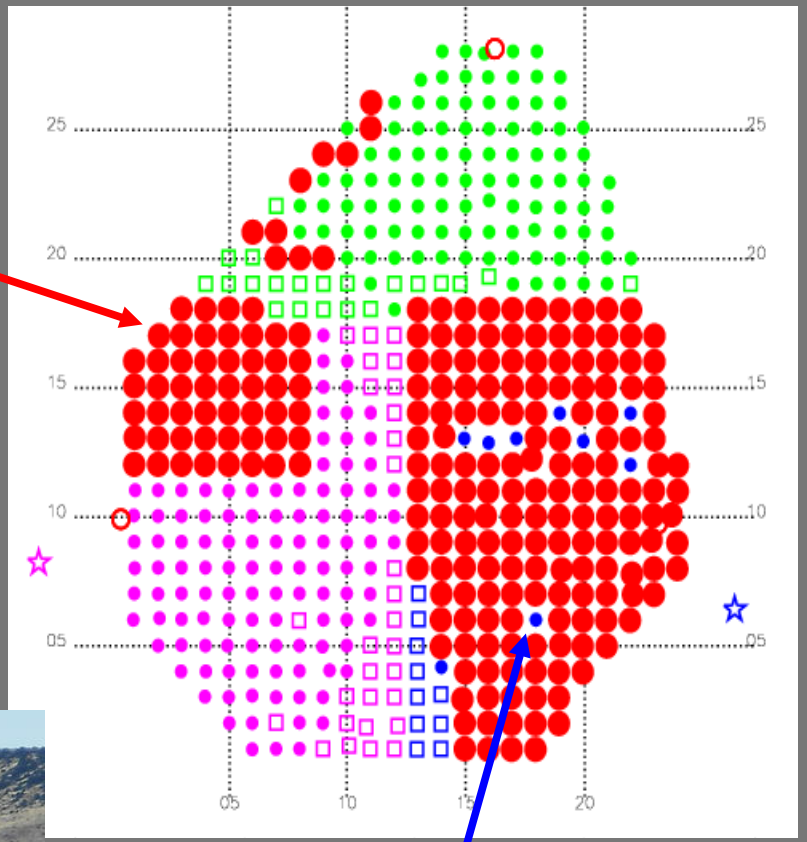
Status : SD - Maintenance

Battery Replacement

- Most of BR array : 153
- North of LR array : 47
- North West of SK array : 24

total : 224





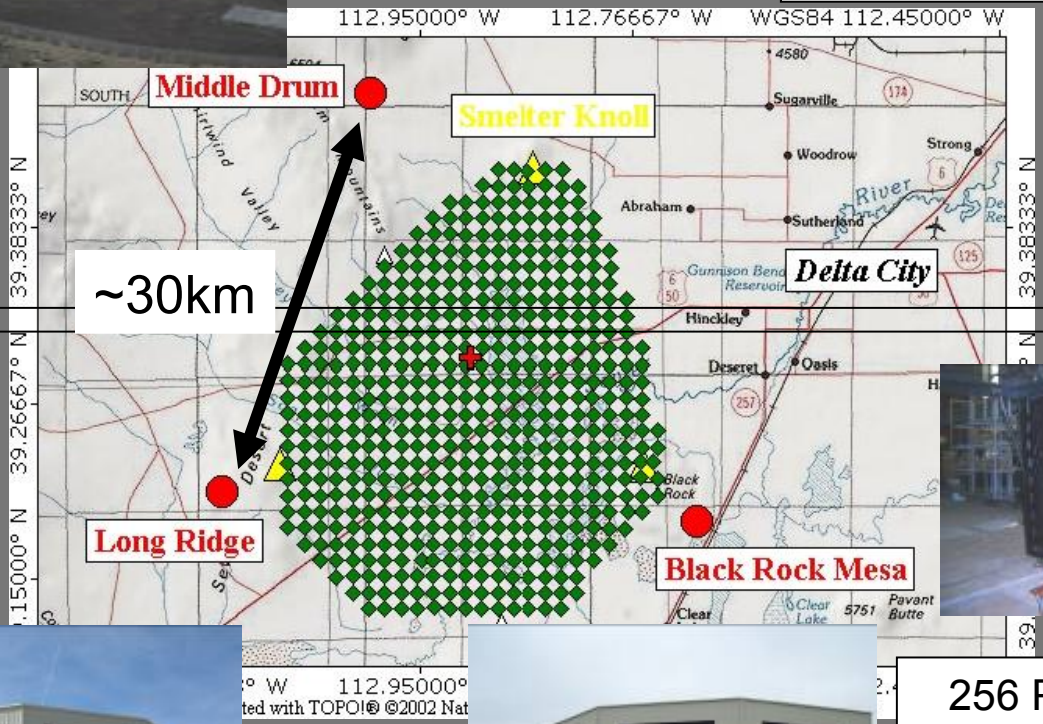
Replacement of “Sunken” SDs

9 SDs were damaged by flood water

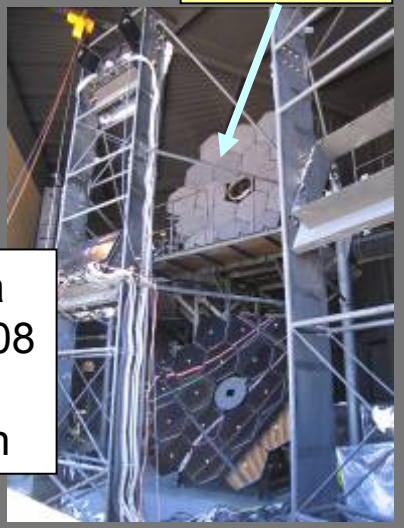
(2 SDs are still in water)

Status : FD

14 cameras/station
256 PMTs/camera
from HiRes

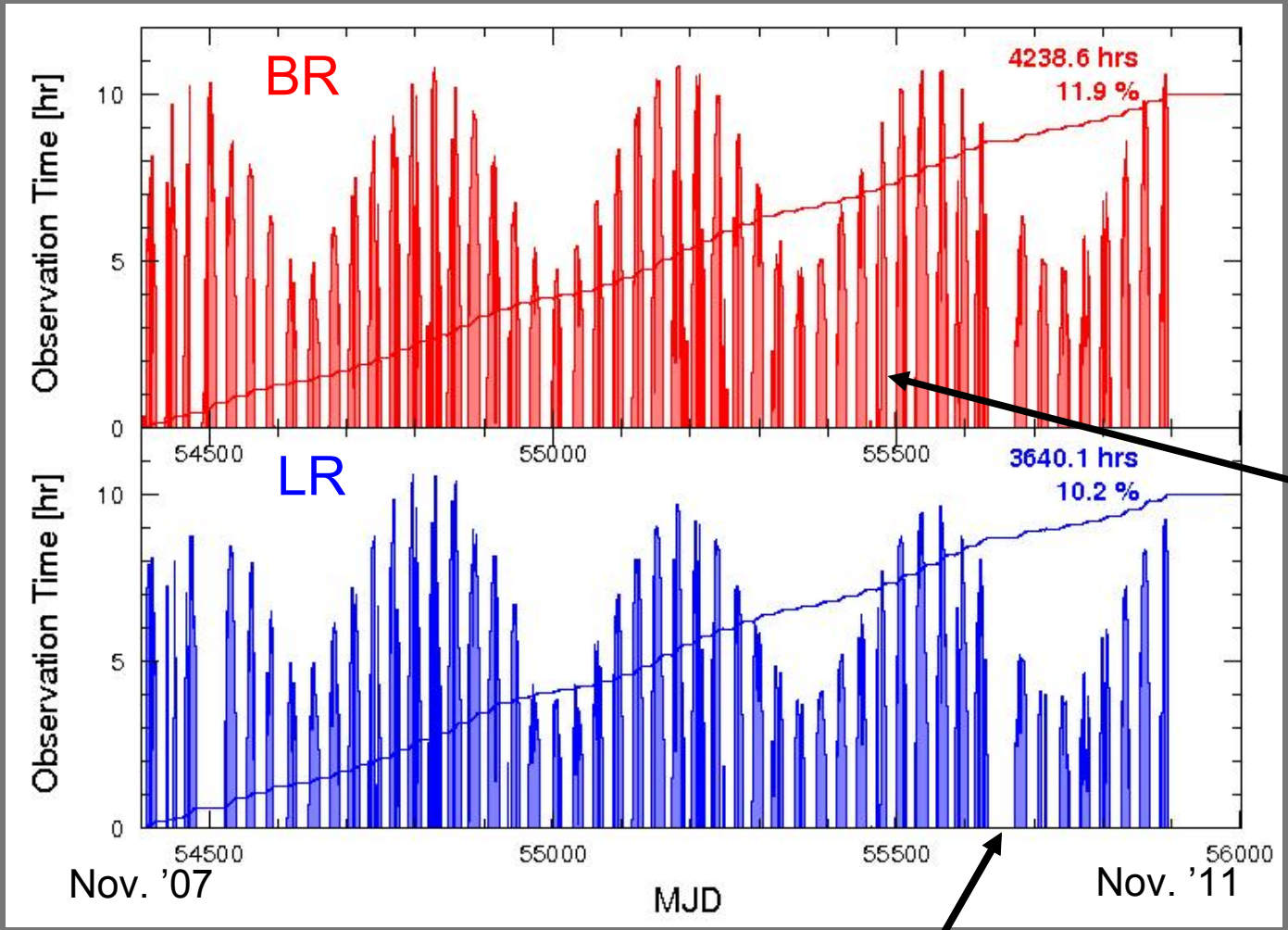


6.8 m²



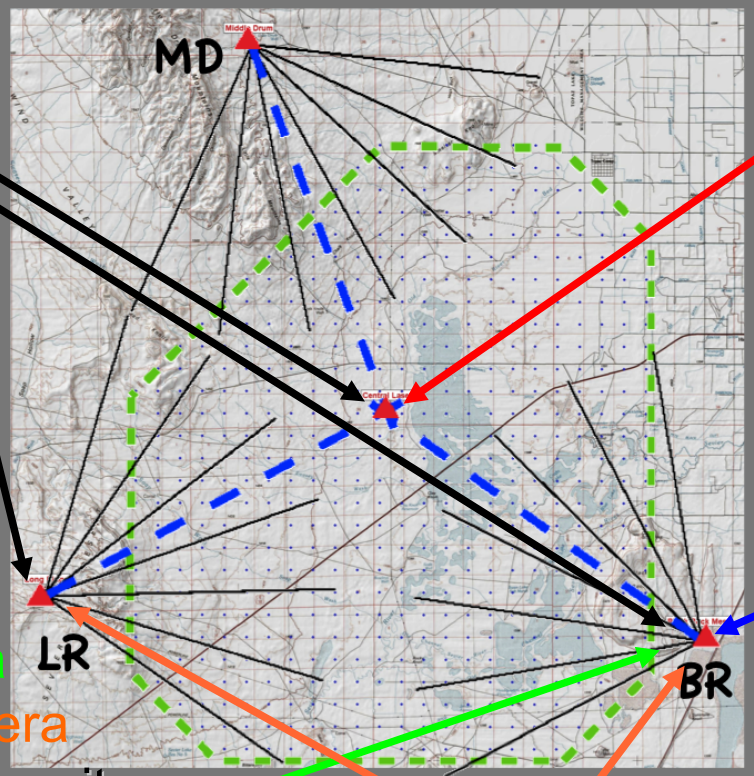
256 PMTs/camera
HAMAMATSU R9508
FOV~15x18deg
12 cameras/station

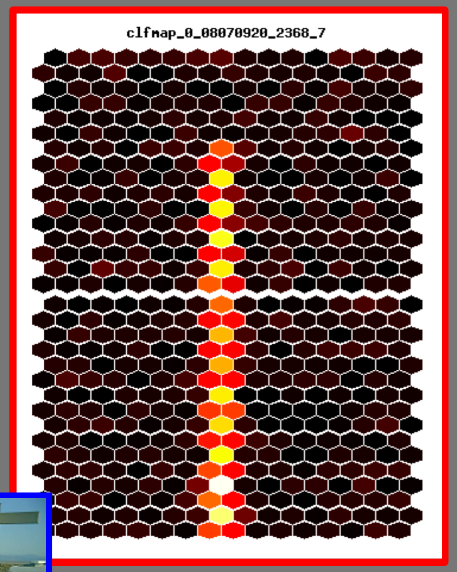
Status : FD - Observation



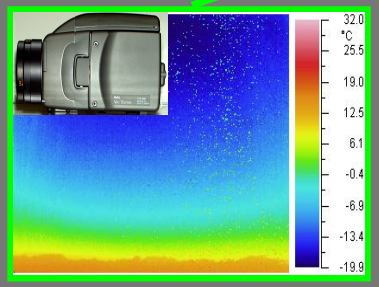
- Full operation since Nov '07
- Long Ridge remote operation since May '09
- Hybrid trig. since Oct. '10

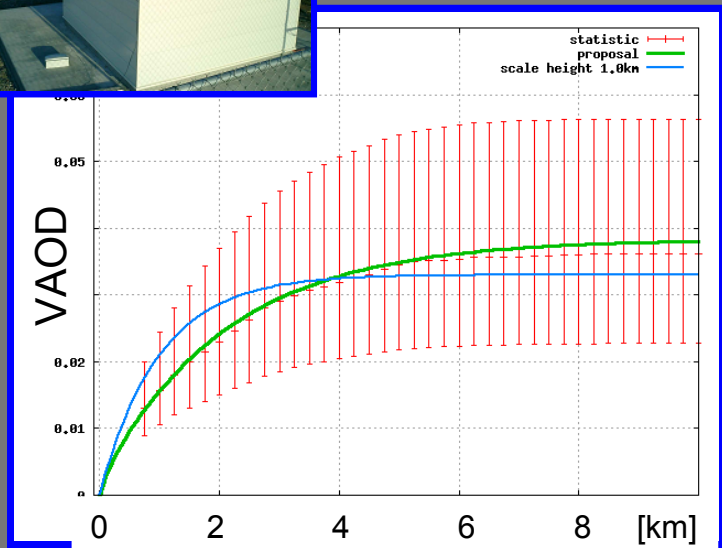
Status : FD - Atm. Monitor





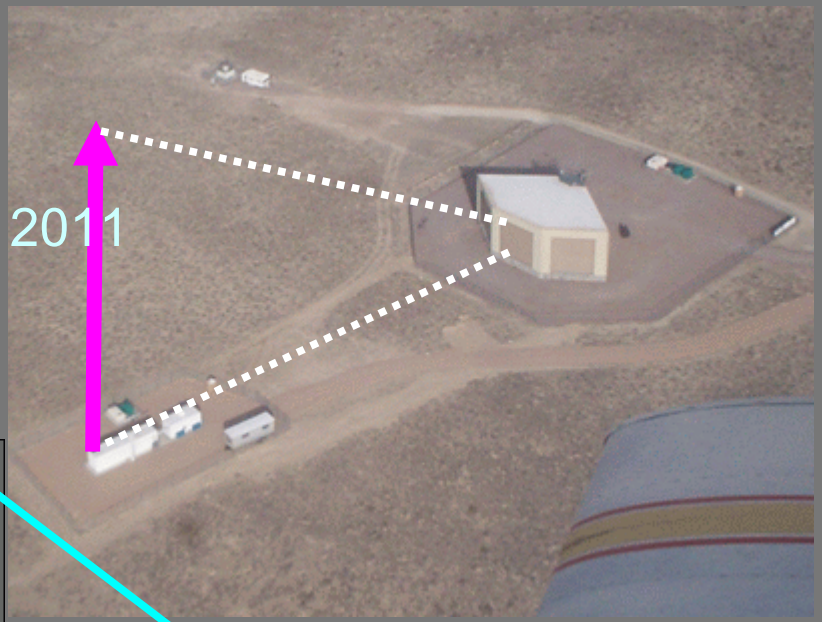
- CLF
- LIDAR
- IR camera
- CCD camera
- Weather monitor

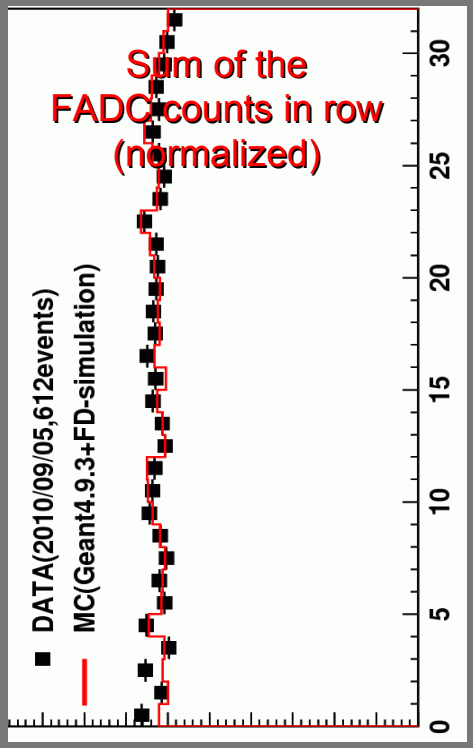


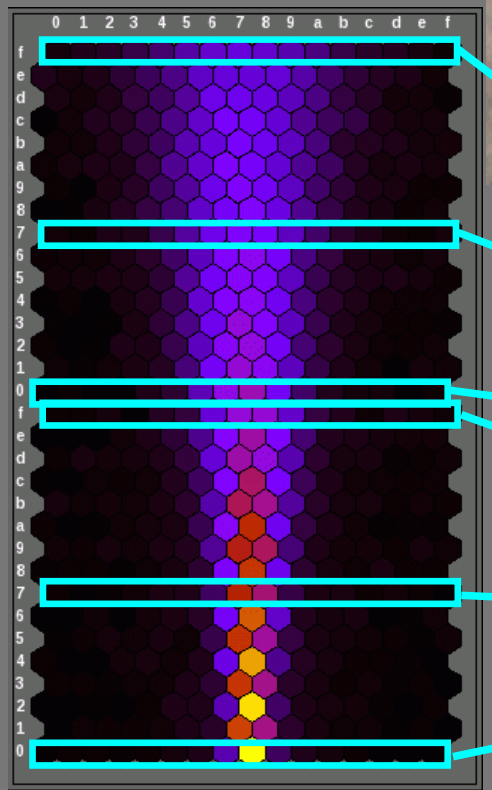


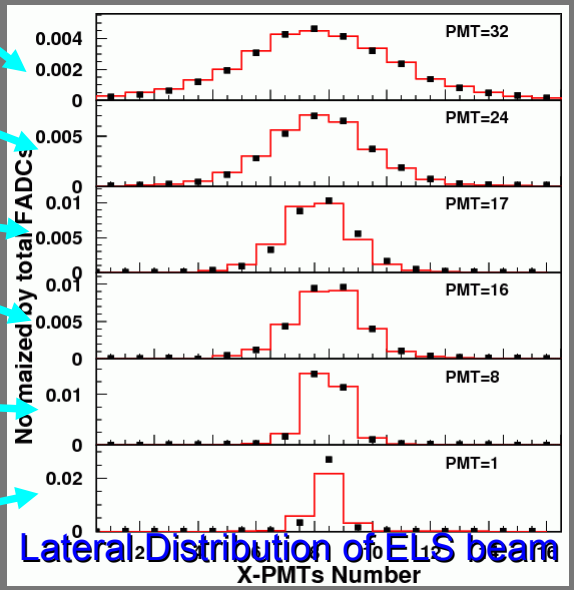
Status : FD - ELS

- 40 MeV, 10^9 electrons
- First shot in Sep. 2010,
  Operation was also performed in Nov. 2011
  (some troubles in Mar. - Nov. 2011)
- Analysis, Calibration is ongoing





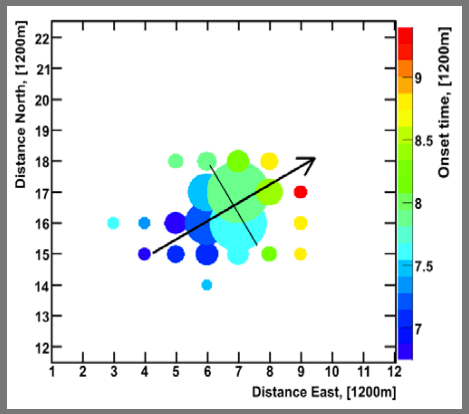


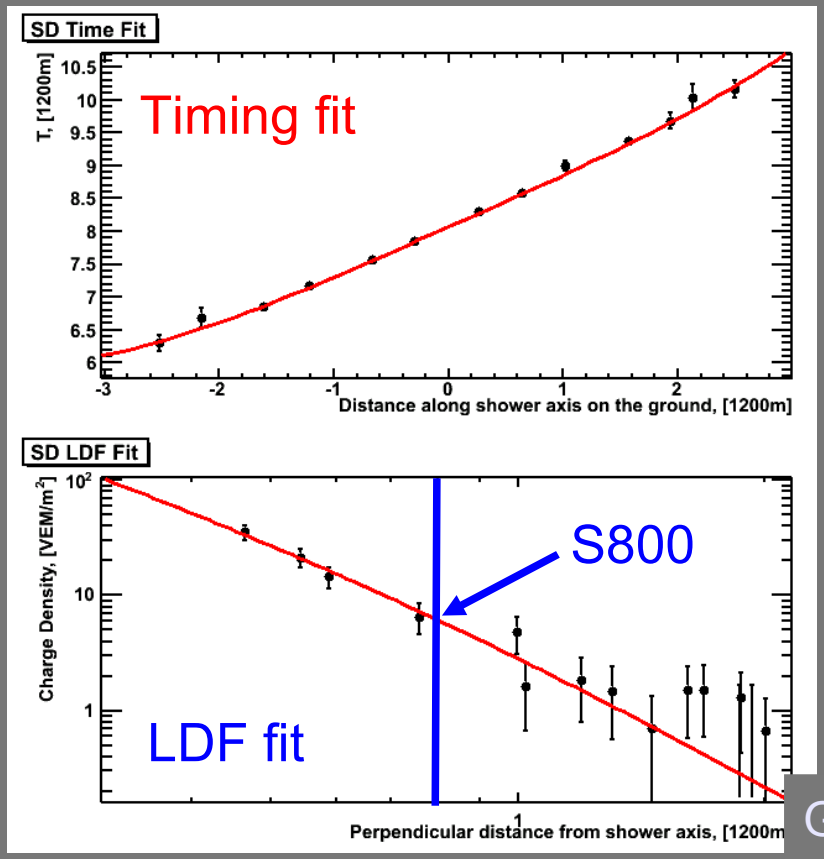


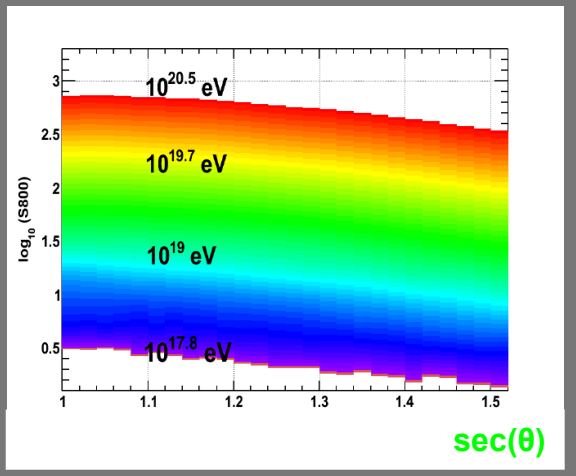
Lateral Distribution of ELS beam

Analysis : SD

Event Reconstruction







Data set

- 08/05/11 – 11/05/01
- Zenith angle cut : 45°
- Boundary ≧1.2km
- Energy is scaled to FD energy scale (1/1.27)
- Angular resolution < 1.5° (E>10^{19}eV)

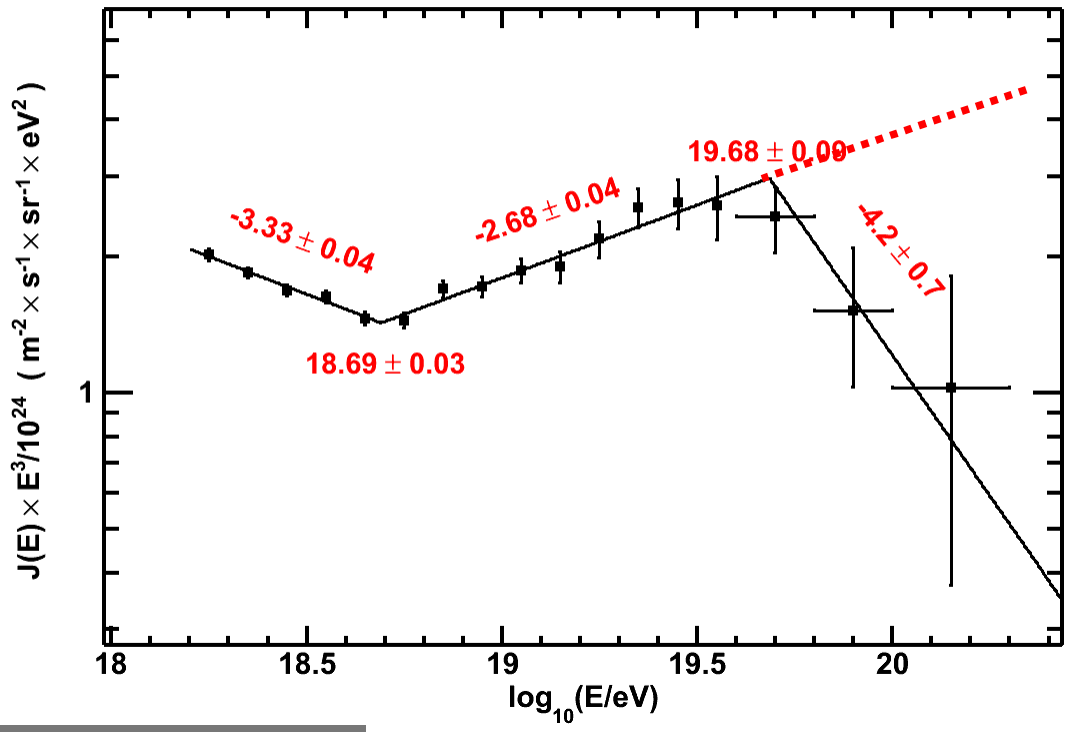
Geometry : Timing fit

Energy E_{SD}(MC) :

Primary estimated by S(800)

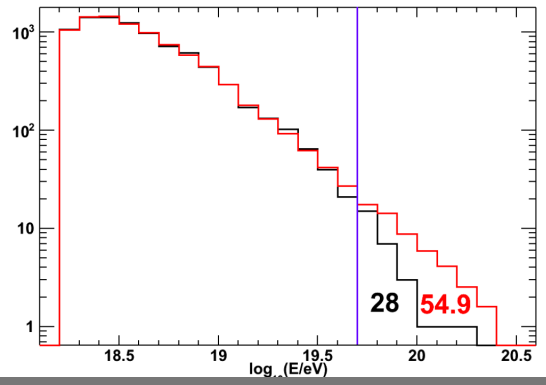
Zenith angle dependence

Analysis : SD - Spectrum



3 years data,
10,997 events

- Assume no GZK cutoff and extend the broken power law fit beyond the break
- Apply this extended flux formula to the actual TA SD exposure, find the number of expected events and compare it to the number of events observed in $\log_{10}$E bins after $10^{19.7}$eV bin:
  - N_{EXPECT} = 54.9
  - $N_{OBSERVE}$ = 28



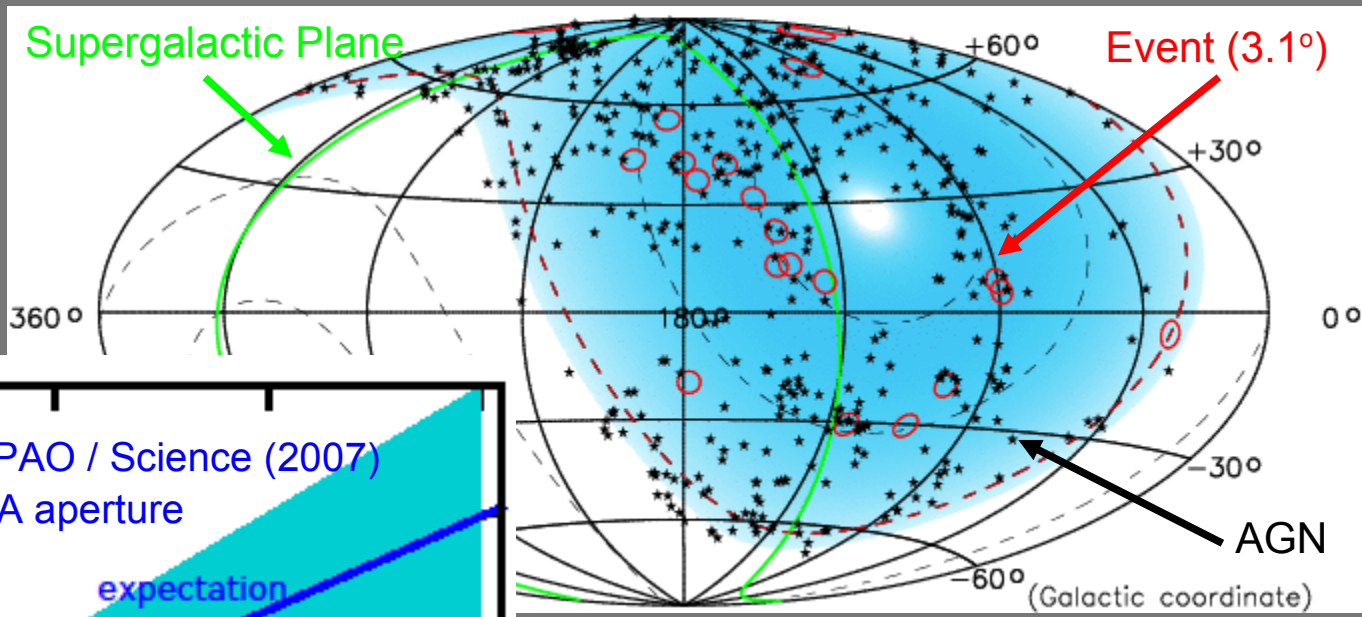
$$\mathrm{PROB} = \sum_{i=0}^{28} \mathrm{Poisson}(\mu = 54.9; i) = 4.75 \times 10^{-5}$$

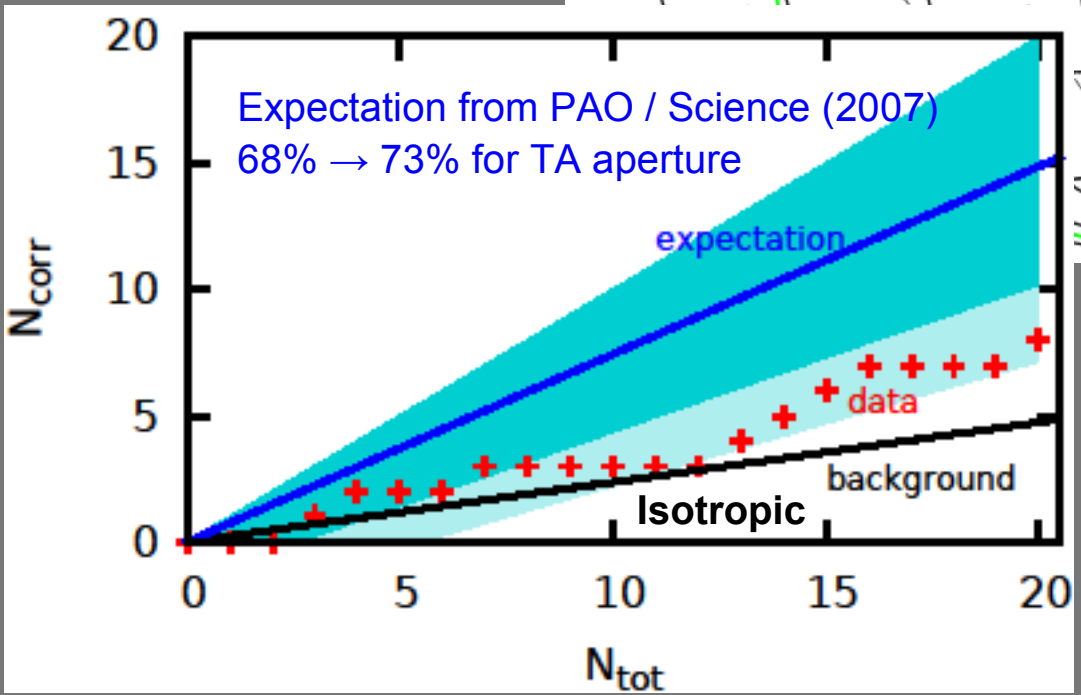
(3.9σ)

Analysis : SD - Anisotropy - AGN Correlation

In Veron AGN 12th in Zmax=0.018, there are 295 AGNs in our view

Skymap for event E > 57EeV, Z<45°



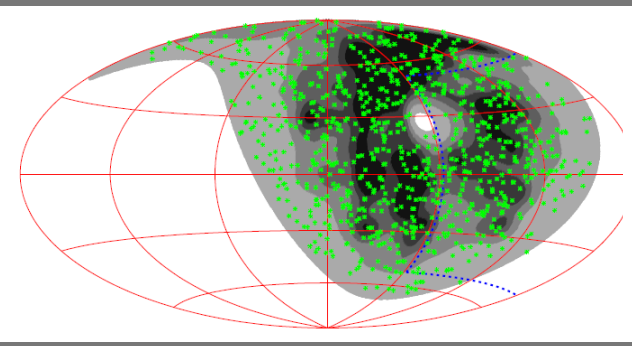


8 of 20 correlated (4.8 for isotropic)

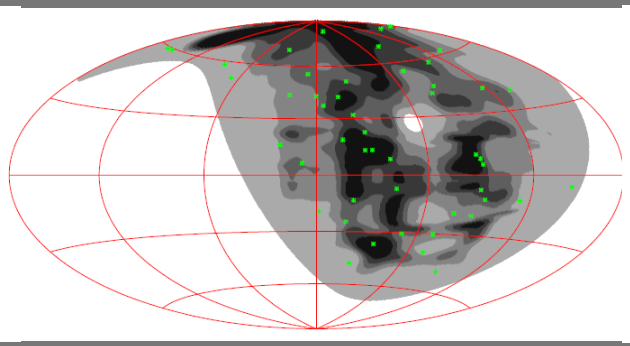
No significant correlation with AGNs (consistente with isotropic), but still within 2σ.

Analysis : SD - Anisotropy - LSS

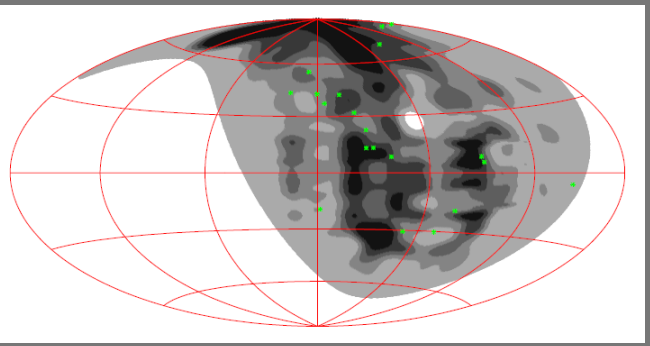
(2 Mass XSCz catalogue)



LSS + GMF
Eth=10EeV

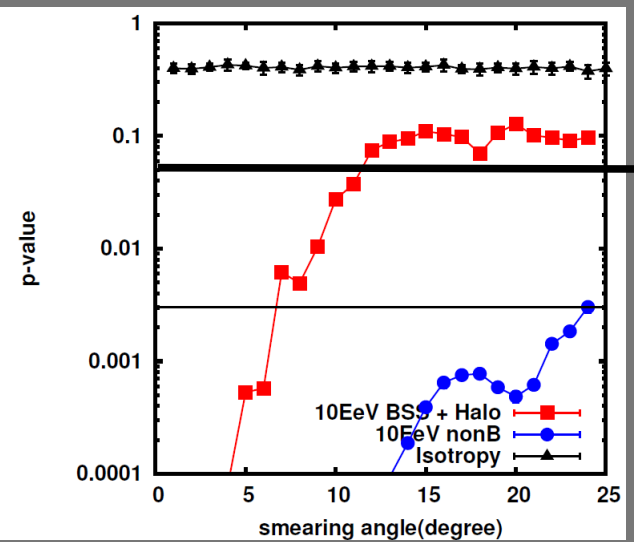


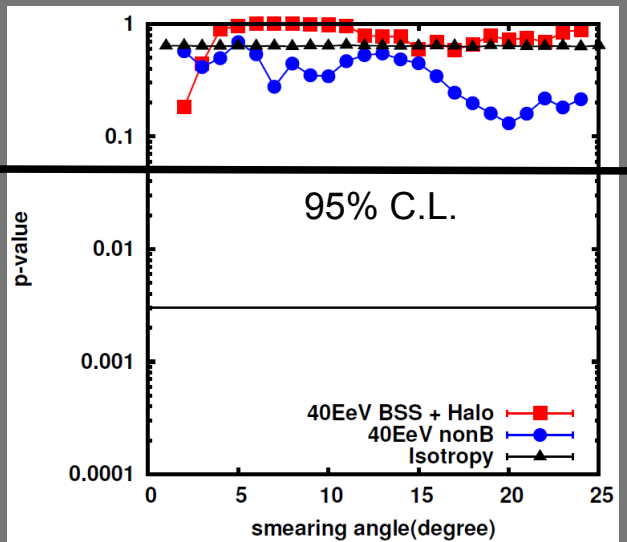
LSS + GMF
Eth=40EeV

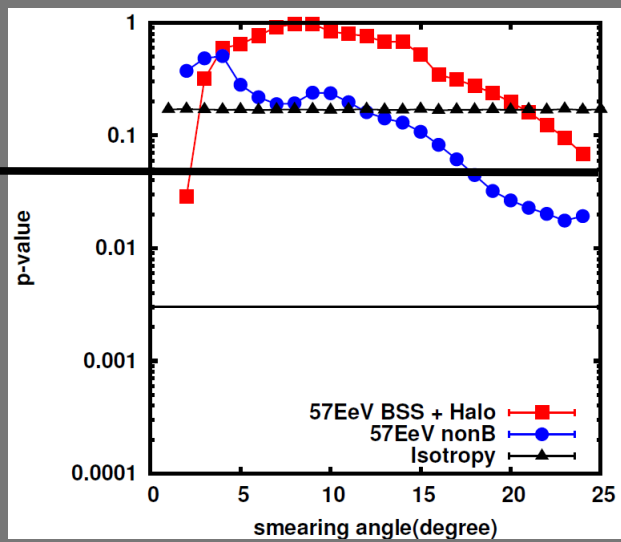


LSS + GMF
Eth=57EeV

Compatible with **Isotropy** and **LSS + GMF (Disk+Halo)** model







Analysis : FD

Monocular Mode

Use only 1 FD station
Geometry reconstruction by Timing Fit
High statistics

Hybrid Mode

FD(s) and Surface detector(SD)
Timing fit using FD + SD
Arrival direction < 1°

Stereo Mode

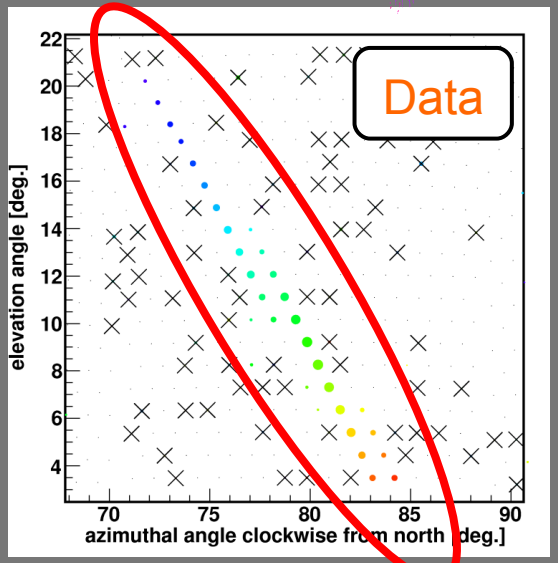
Use 2 FD stations
Intersection of 2 SDPs
Less biases for Xmax

Inverse Monte Carlo

Changing Nmax and Xmax, search for optimum solution with comparing Data/MC

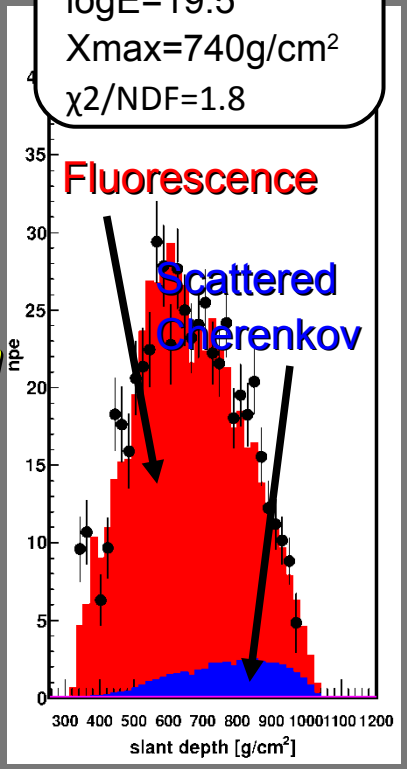
Simulation (GH)

Geometry information



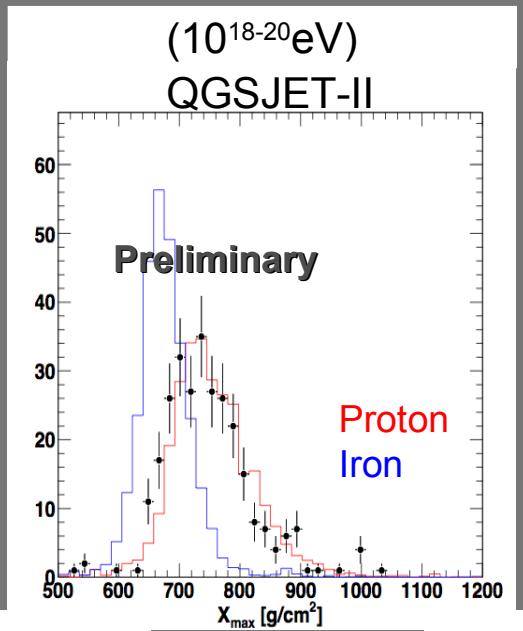
Iteration

Profile Fit
logE=19.5
Xmax=740g/cm^2
χ2/NDF=1.8



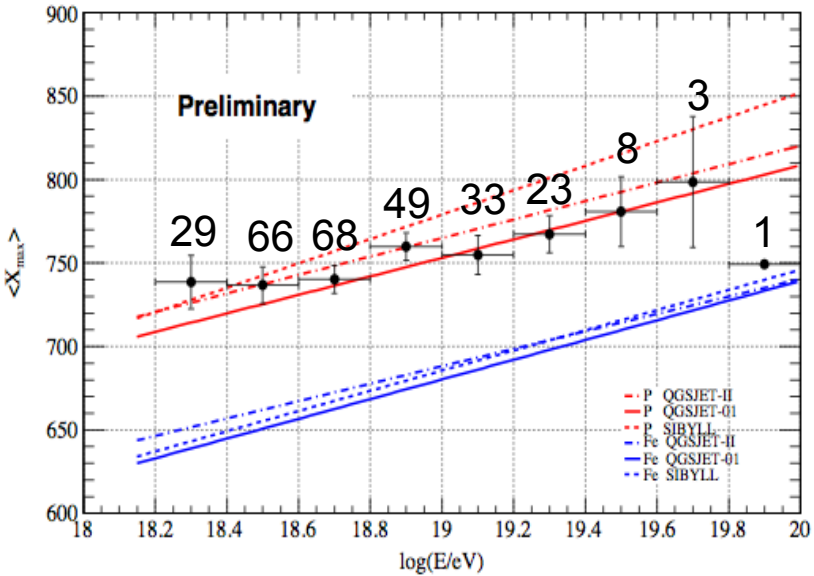
Analysis : FD - Composition

Use Xmax distribution
to distinguish
the primary perticle

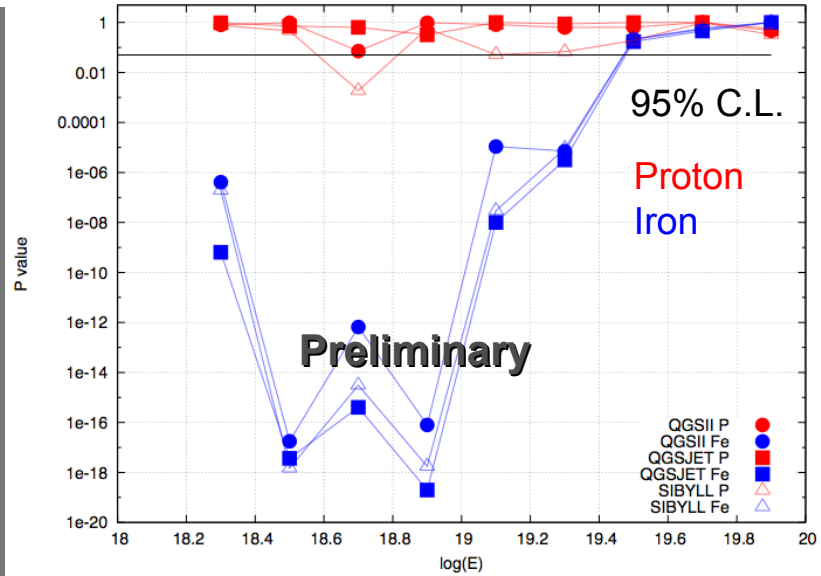


Data set
2007/Nov – 2010/Sep

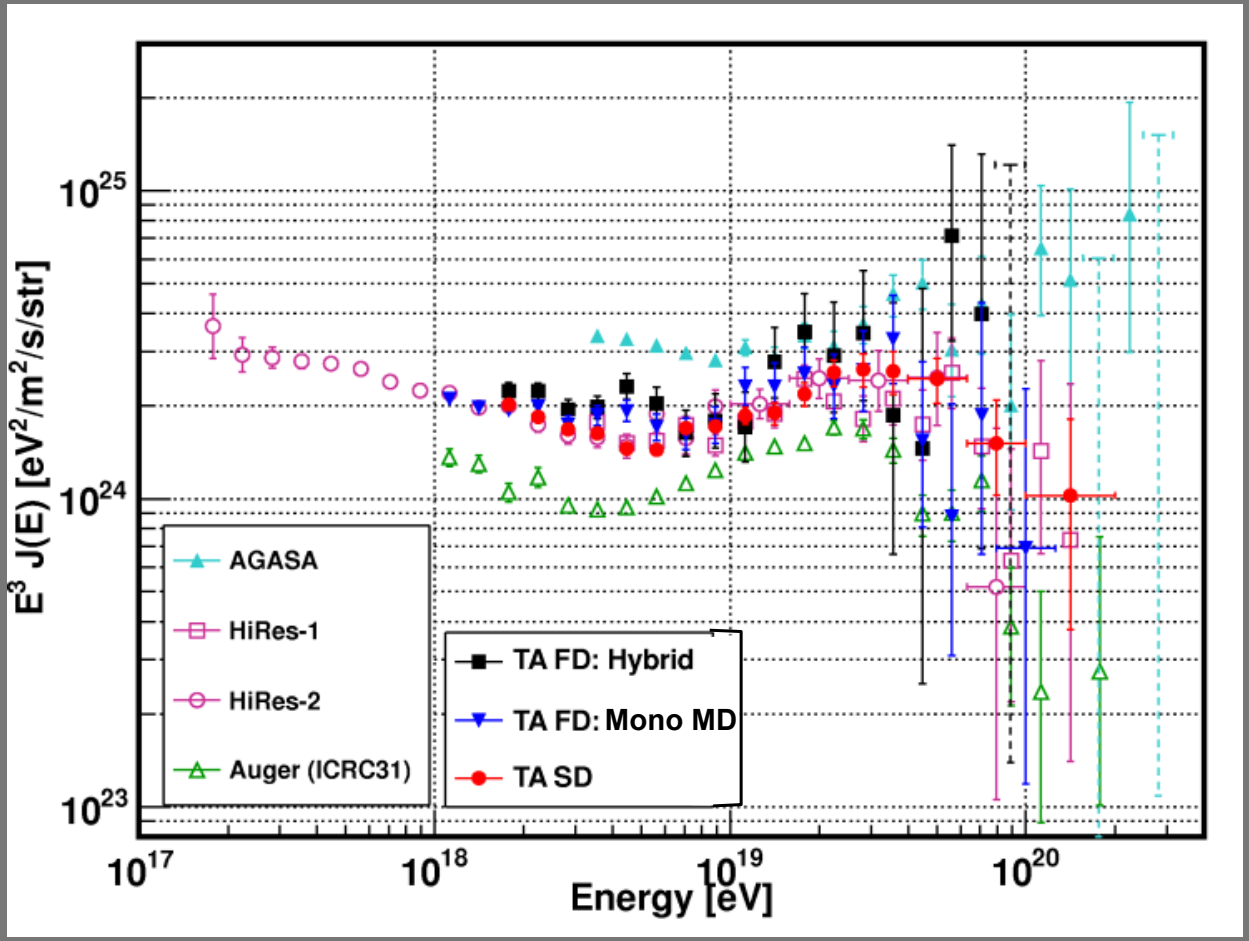
Energy vs <Xmax>



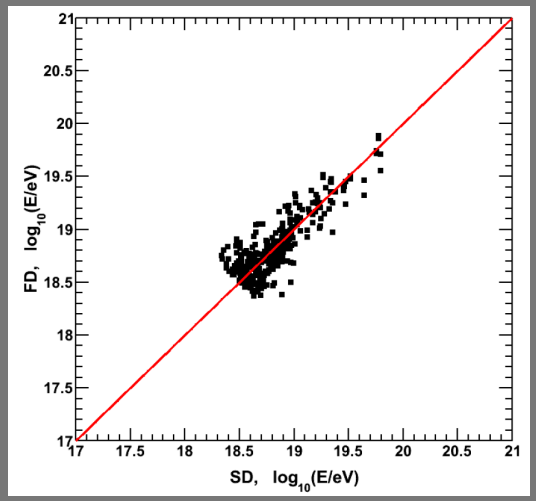
KS Test



Analysis : FD/SD - Spectra



- TA spectra are consistent with HiRes.
- -20% AGASA
- +20% Auger
- 9% difference from the FLY (Kakimoto et al. in TA/Nagano et al./AirFly)
- ~22% total systematic uncertainty in both TA & Auger



* Energy Scale
Set SD energy scale to FD using Hybrid events, 27% renormalization

TALE (TA Low Energy Extension)

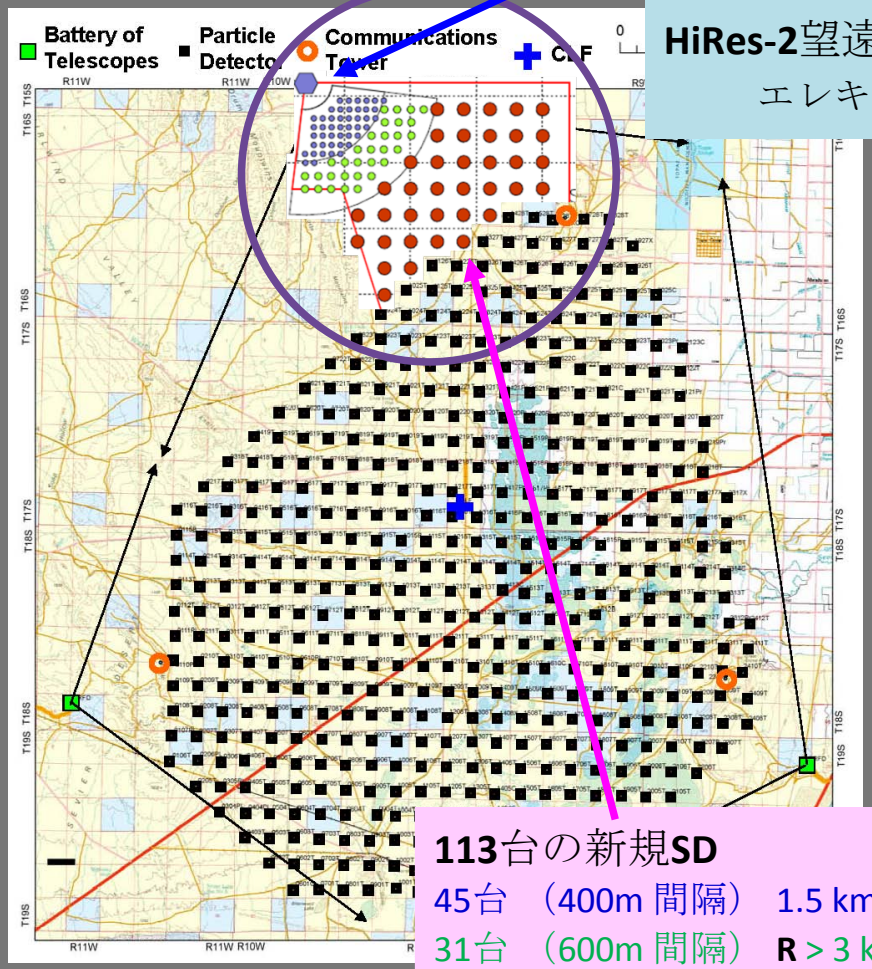
エネルギー範囲
$10^{16.5}$ eV - 10^{19} eV

~$10^{17.3}$eV : 2nd knee

- 系外宇宙線への遷移?
  （重い原子核 →proton?)
- 空気シャワーと**LHCf**との比較
  @10^{17} eV
- **10^{17}～10^{18} eV**の異方性?
  銀河系起源?

~$10^{18.5}$ eV : ankle

- 系外宇宙線への遷移?
- 電子陽電子対生成?

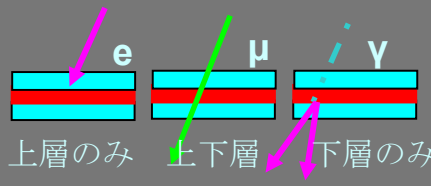


14望遠鏡**@MD**サイト
31°～59° （仰角）
HiRes-2望遠鏡の移設
エレキ：再調整

113台の新規**SD**
45台 （400m 間隔） 1.5 km<**R**< 3 km
31台 （600m 間隔） **R** > 3 km
37台 （1200m 間隔） TA SDアレイとの接続

TA実験サイトでの超高エネルギー宇宙線観測のための新型検出器の開発

粒子種識別の模式図

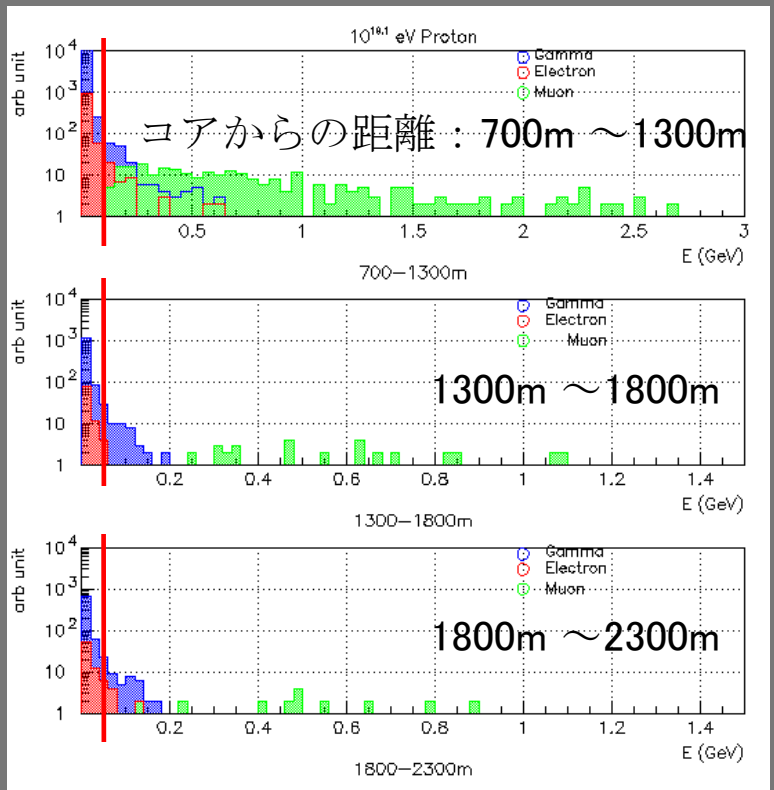


e, μ, γの弁別能力をもつシャワー測定、
核種判別能力の向上
空気シャワー粒子分布測定

- 方法：　鉛をはさむことによる改善を試みる。
- 価格、手間：　筐体の素材やアセンブリ方法の検討を平行して行う。
- 現状：　現在は鉛の手配とシュミレーションによる効果の評価を行っている。

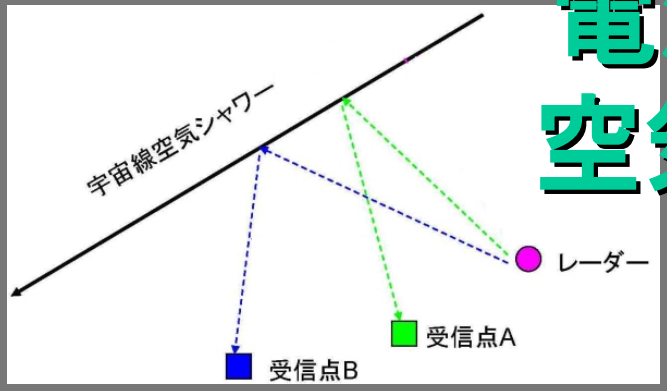
Ex: 鉛 2.0cm
@50MeV
Gamma → 上下層 **coincidence　1%**
(SUS 1mm→9%)
Electron→ 上下層 **coincidence　15%**
(SUS 1mm→96%)
μ粒子とelectron の弁別向上
コア近傍は高エネルギー電磁成分が多い

シャワー粒子のエネルギー分布
青: γ　赤: 電子　緑: μ　（横軸リニア）



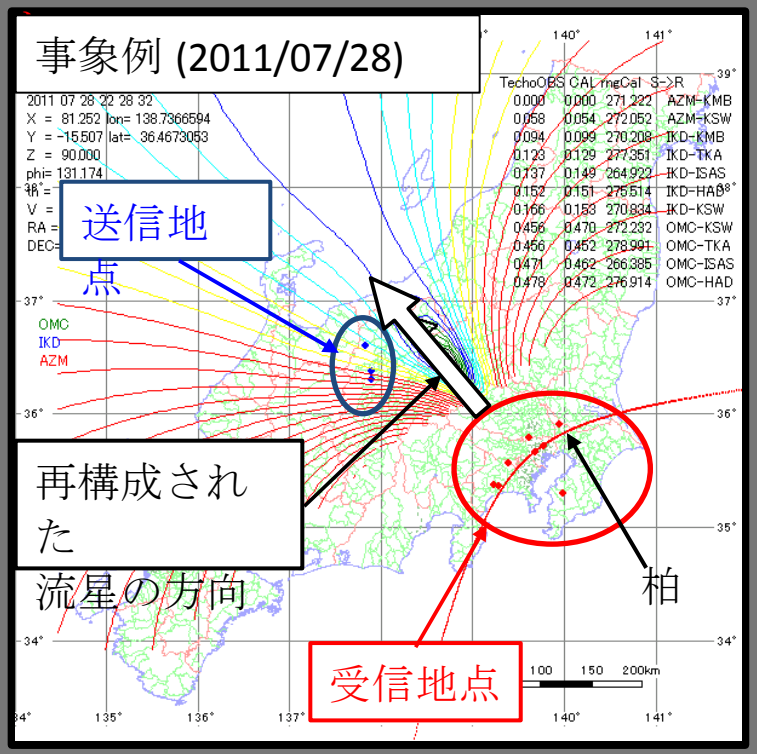
電波エコーによる空気シャワー観測

Telescope Array RAdar project



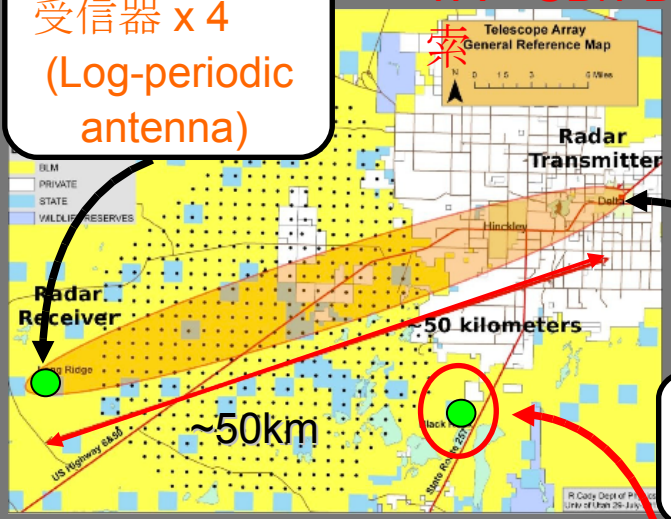
50MHz帯の電波を送信し、空気シャワー通過後に形成される電子柱における反射を受信

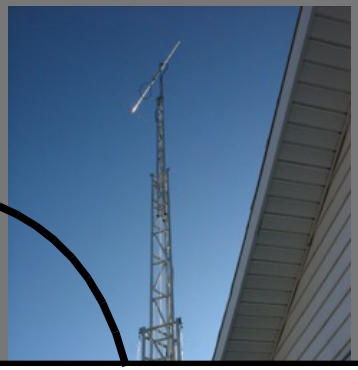
多地点同時流星観測プロジェクト



TAのSD/FDとの同期事象探

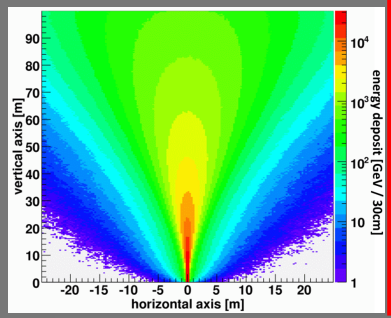
受信器 x 4 (Log-periodic antenna)

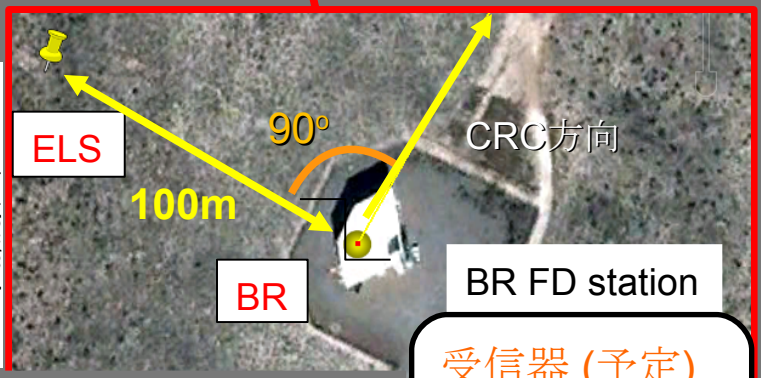




送信器 (6m Yagi)
Power: 2kW -> 40kW

ELSを用いた観測手法の実証





受信器 (予定)
(Log-periodic antenna x 2)

期待されるS/N : ~30 / 1000shots

来春現地にて試験予

電子加速器を使った大気マイクロ波の検出

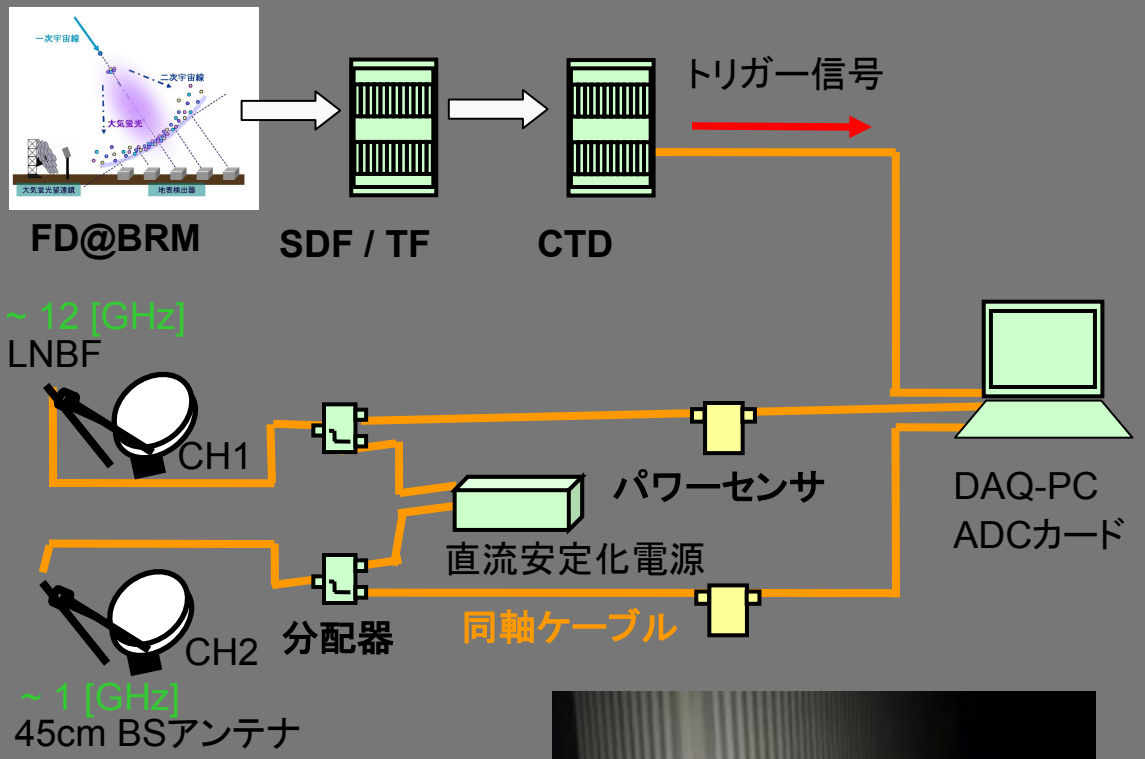
空気シャワーからのマイクロ波放射の探査 (Monostatic)

- 大阪市大にて、空気シャワーアレイとの同期観測

  → 2011年7月～　観測継続中
- TAのFDとの同期観測

  → 2011年10月
- 甲南大にて、1.2m径パラボラx12基の電波望遠鏡アレイ

  → 試験運転中

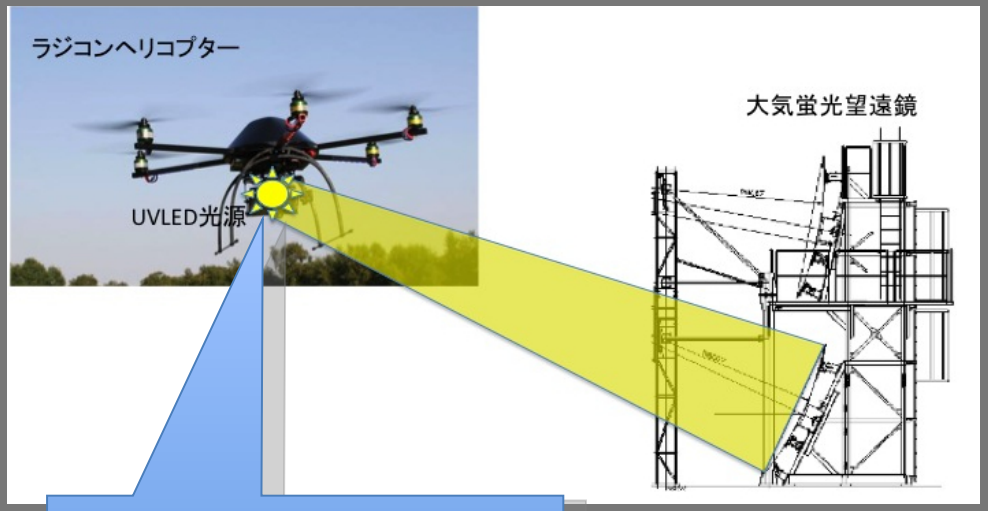


作業ログ@Delta

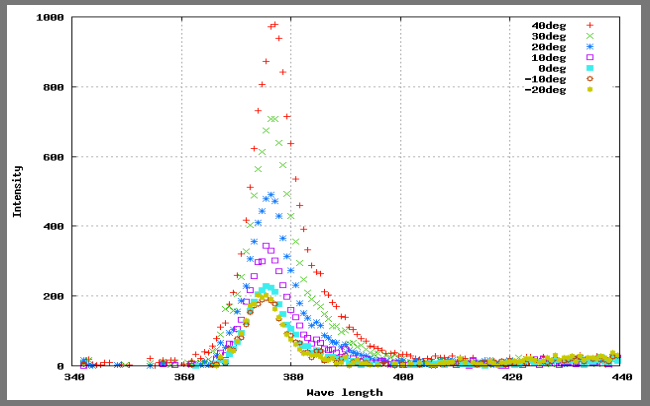
- 10/21-27 BRMに電波観測装置をインストール
- 10/28 BRMにてFDとの同期観測を実施

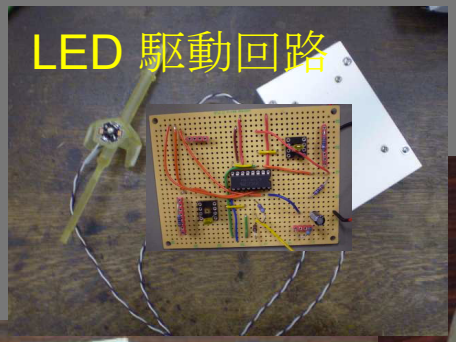
→ 4時間分、22013イベントのデータ収集

ラジコンヘリコプターによる TA大気蛍光望遠鏡キャリブレーション



温度依存性 -20 ~ 40 度





Future Plans ...

Step 1 : Swap the detector(s), PAO and TA

Solve the discrepancy of

- Energy Scale
- Mass Composition

Step 2 : Larger Experiment

possibly involve PAO, etc...

Aim the “Cosmic Ray Astronomy”

- Point Sources
- Anisotropy, GMF

Summary

- *3.5 years fully, stable operation*
- *Energy Spectrum*
  - *Consistent with HiRes*
  - *$E_{SD} / E_{FD} = 1.27$*
  - *Ankle at $10^{18.7}$ eV*
  - *Cut-off at $10^{19.7}$ eV : 3.9σ*
- *Mass Composition*
  - *Proton dominant up to $10^{19.4}$ eV*
- *Anisotropy*
  - *Compatible with both isotropy and LSS correlation hypothesis*
  - *No significance for clustering, AGN correlation*

New calibrations (ELS, Helicopter light source)
and R&D (New SD, Bistatic/Monostatic Radar) are progressing

UHECR 2012

- CERN
- Feb.13(Mon) - 16(Thr), 2012

http://2012.uhecr.org/

- Discuss the highlights and challenges of UHECR observations
- Prepare for a next-generation ground based giant detector
- Evaluate the complementarity of ground and space based observations
- Identify technological challenges and related R&D works