Summary of Results from the Telescope Array Experiment

PDF file of this presentation already posted at http://www.physics.utah.edu/~jui/TA-highlight-icrc2015-post.pdf

[1375] Charles Jui

For the Telescope Array Collaboration

International Cosmic Ray Conference

Aug. 4, 2015 The Hague, Netherlands

Telescope Array Collaboration

RU Abbasi[1], M Abe[13], T Abu-Zayyad[1], M Allen[1], R Anderson[1], R Azuma[2], E Barcikowski[1], JW Belz[1], DR Bergman[1], SA Blake[1], R Cady[1], MJ Chae[3], BG Cheon[4], J Chiba[5], M Chikawa[6], WR Cho[7], T Fujii[8], M Fukushima[8,9], T Goto[10], W Hanlon[1], Y Hayashi[10], N Hayashida[11], K Hibino[11], K Honda[12],D Ikeda[8], N Inoue[13], T Ishii[12], R Ishimori[2], H Ito[14], D Ivanov[1], CCH Jui[1], K Kadota[16], F Kakimoto[2], O Kalashev[17], K Kasahara[18], H Kawai[19], S Kawakami[10], S Kawana[13], K Kawata[8], E Kido[8], HB Kim[4], JH Kim[1], JH Kim[25], S Kitamura[2], Y Kitamura[2], V Kuzmin[17], YJ Kwon[7], J Lan[1], SI Lim[3], JP Lundquist[1], K Machida[12], K Martens[9], T Matsuda[20], T Matsuyama[10], JN Matthews[1], M Minamino[10], K Mukai[12], I Myers[1], K Nagasawa[13], S Nagataki[14],T Nakamura[21], T Nonaka[8], A Nozato[6], S Ogio[10], J Ogura[2], M Ohnishi[8], H Ohoka[8], K Oki[8], T Okuda[22], M Ono[14], A Oshima[10], S Ozawa[18], IH Park[23], MS Pshirkov[24], DC Rodriguez[1], G Rubtsov[17], D Ryu[25], H Sagawa[8], N Sakurai[10], AL Sampson[1], LM Scott[15], PD Shah[1], F Shibata[12], T Shibata[8], H Shimodaira[8], BK Shin[4], JD Smith[1], P Sokolsky[1], RW Springer[1], BT Stokes[1], SR Stratton[1,15], TA Stroman[1], T Suzawa[13], M Takamura[5], M Takeda[8], R Takeishi[8], A Taketa[26], M Takita[8], Y Tameda[11], H Tanaka[10], K Tanaka[27], M Tanaka[20], SB Thomas[1], GB Thomson[1], P Tinyakov[17,24], I Tkachev[17], H Tokuno[2], T Tomida[28], S Troitsky[17], Y Tsunesada[2], K Tsutsumi[2], Y Uchihori[29], S Udo[11], F Urban[24], G Vasiloff[1], T Wong[1], R Yamane[10], H Yamaoka[20], K Yamazaki[10], J Yang[3], K Yashiro[5], Y Yoneda[10], S Yoshida[19], H Yoshii[30], R Zollinger[1], Z Zundel[1]

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USA, Japan, Korea, Russia, Belgium

TA Detectors

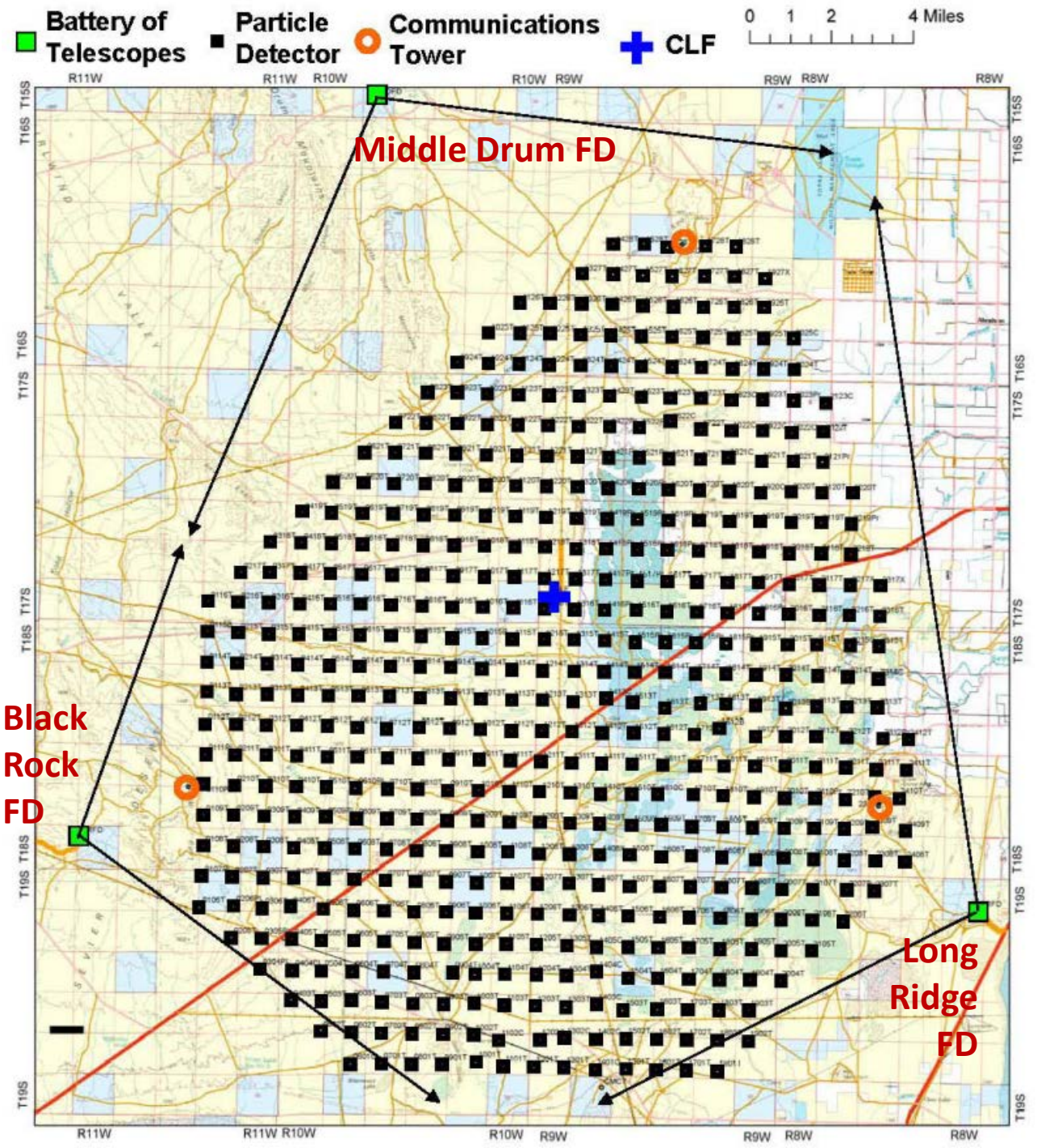
507 scintillation counters surface detector (SD)

Area: ~700 km^2.

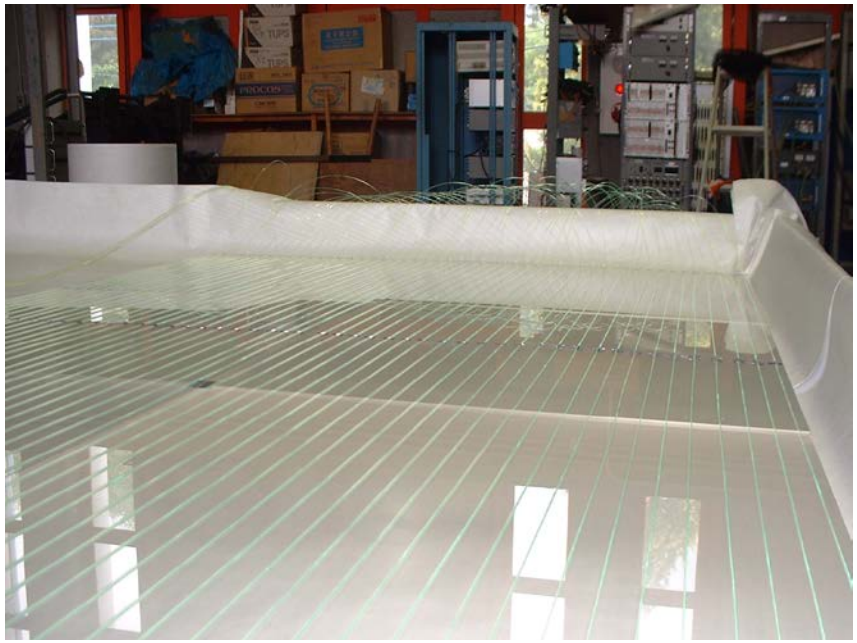
3 fluorescence detector (FD) stations

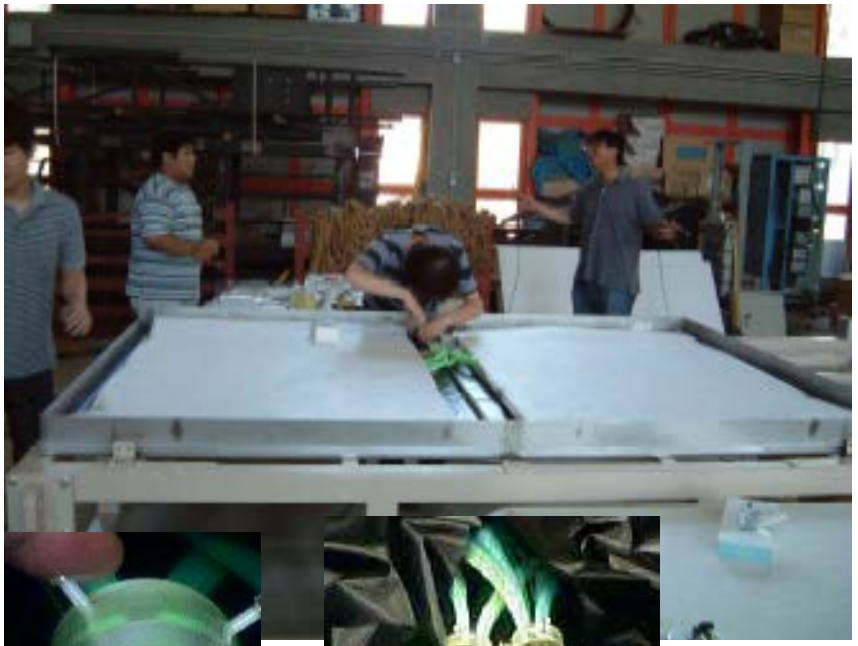
Located at the corners of the SD array

In operation since Mar 2008

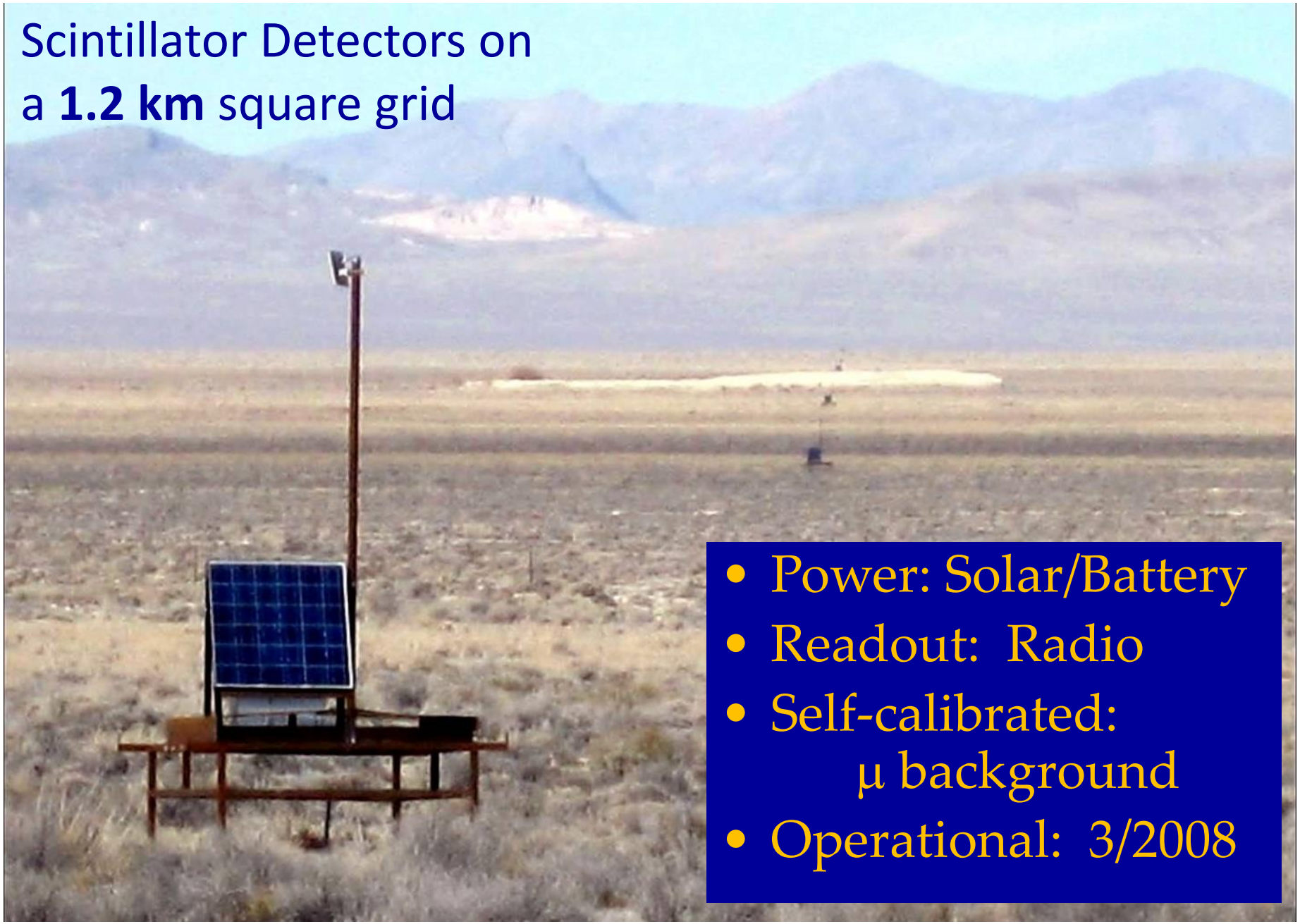


Scintillation Counters





Pre-assembled in Japan, Final Assby/testing in Delta: **2 layers**, **1.25 cm** scintillator, **3m^2** area


Scintillator Detectors on
a **1.2 km** square grid
• Power: Solar/Battery
• Readout: Radio
• Self-calibrated:
μ background
• Operational: 3/2008

TA Fluorescence Detectors

Refurbished from HiRes-I

Observations since ~10/2007

Middle Drum

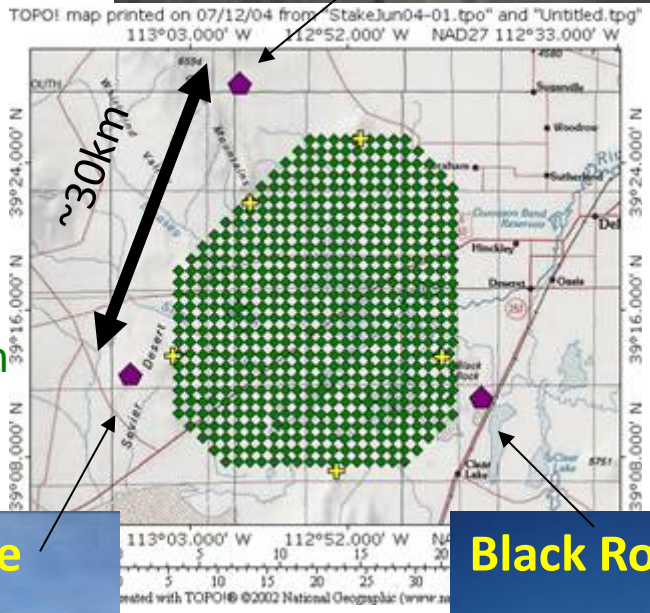
14 telescopes@station
256 PMTs/camera

5.2 m^2

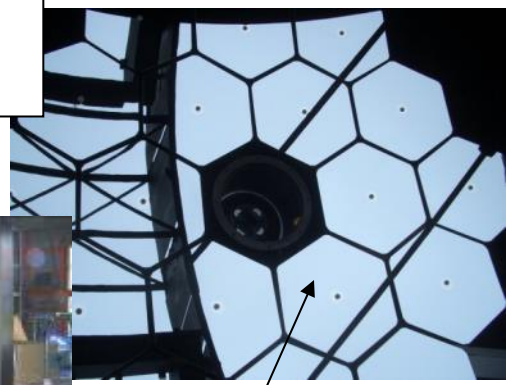
1° pixels

New FDs

Observation since ~11/2007



12 telescopes/station
256 PMTs/camera
Hamamatsu R9508
FOV~15x18deg



6.8 m^2

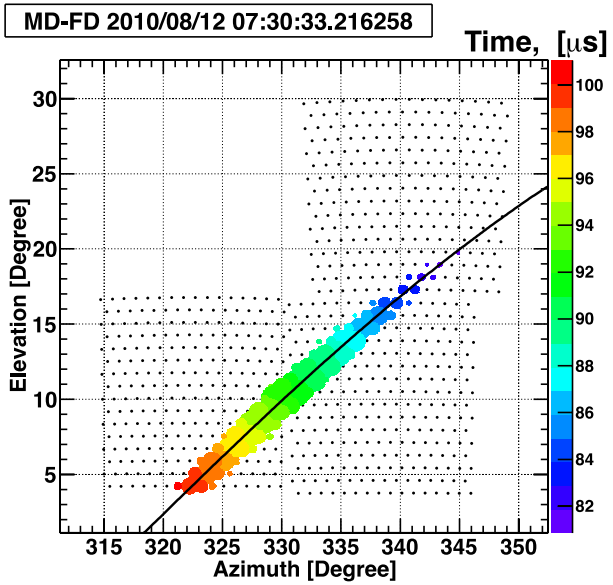
Long Ridge

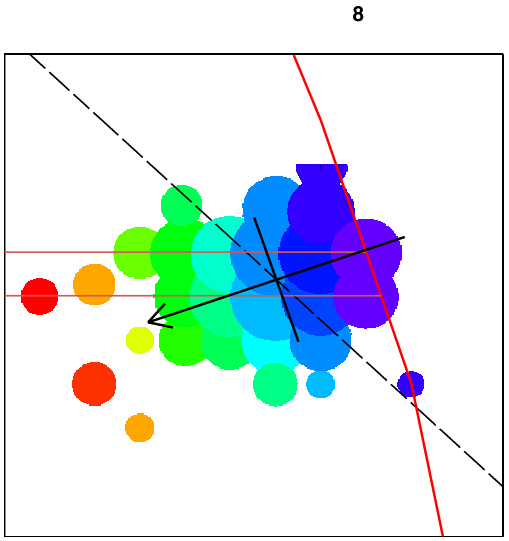
Black Rock Mesa

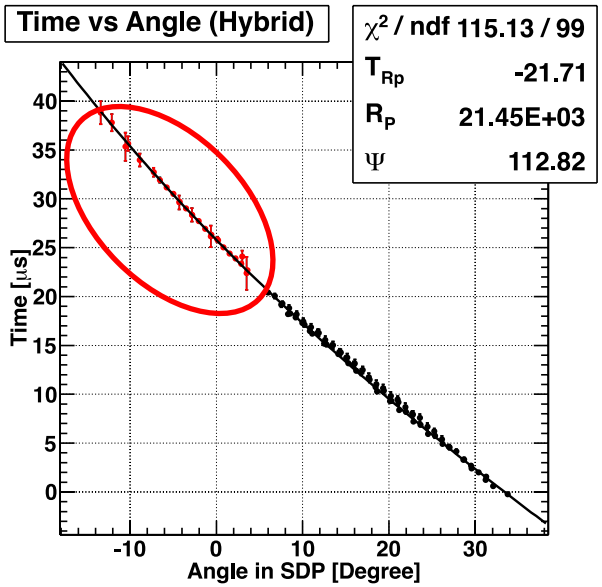
~1 m^2

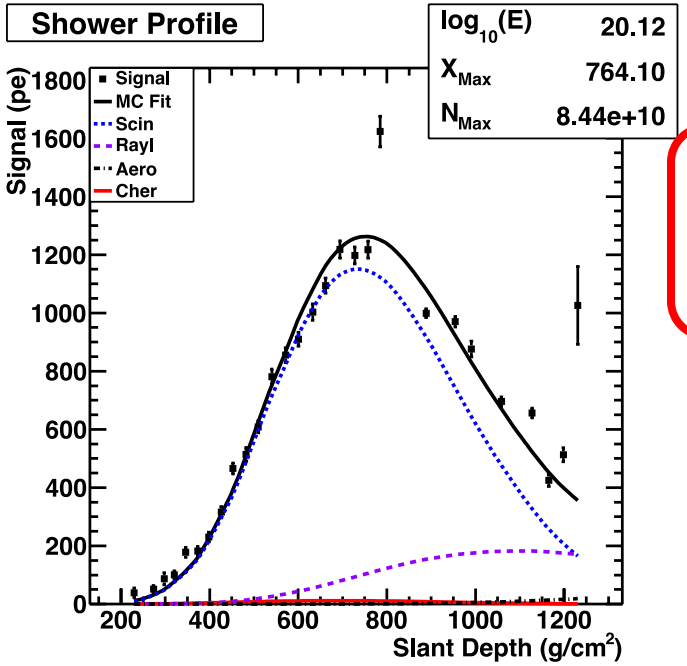
Observation since ~6/2007

High Energy Hybrid Event









Energy: 1.3 × 10^{20} eV

Zenith Angle: 55.7°

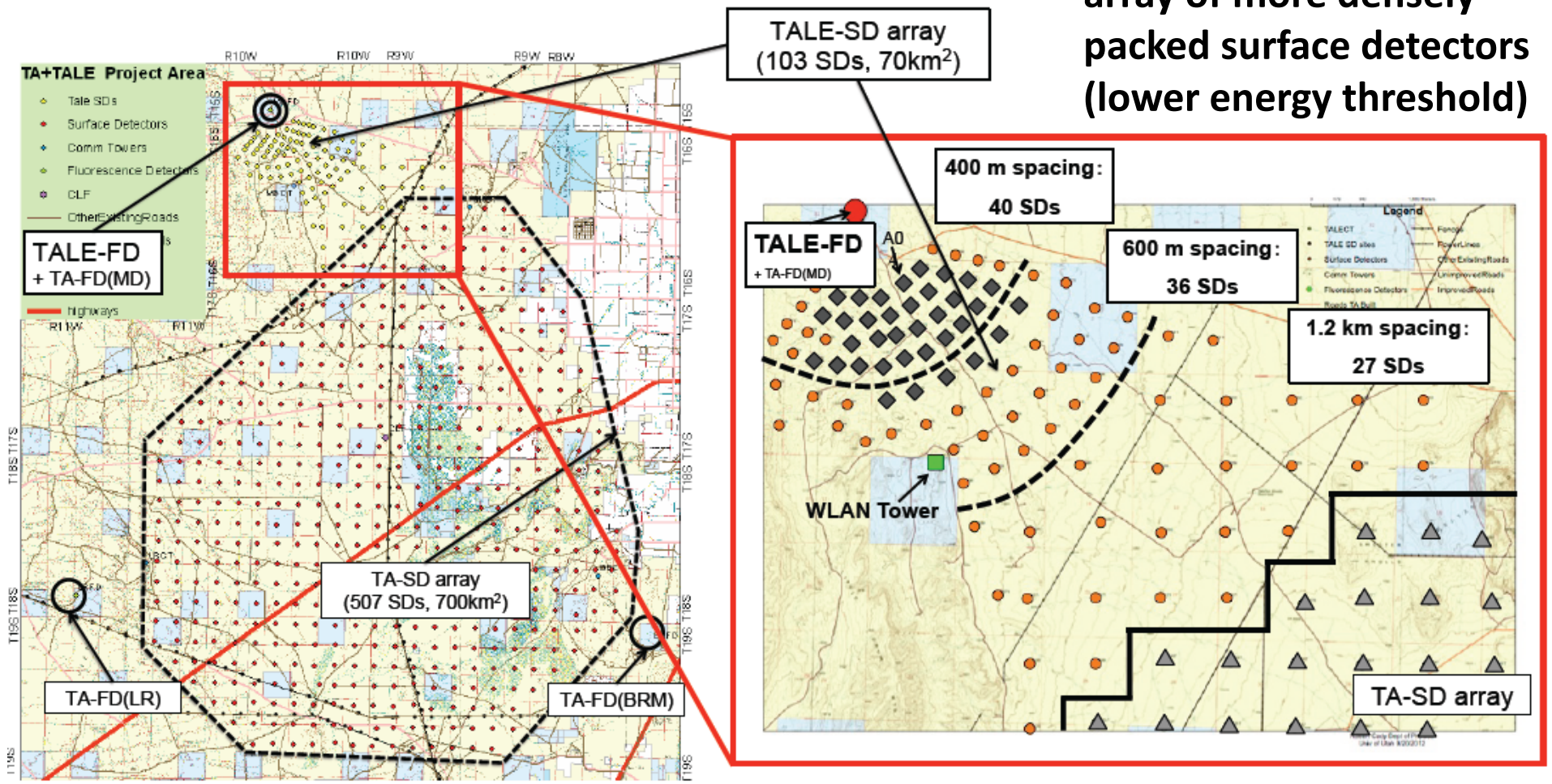
Surface array constrains geometry fit via extra timing & core information

TA Low Energy Extension (TALE)

10 new telescopes to look higher in the sky (31-59^o) to see shower development to much lower energies

[859- PoS 637] Poster 1 CR Track: CRIN Board #: 148
Presented by Shoichi OGIO on 30 Jul 2015
at 15:30

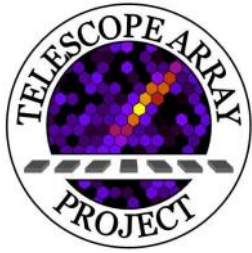
Infill surface detector array of more densely packed surface detectors (lower energy threshold)



All 10 Telescopes installed and in operation since fall 2013

First 35 scintillation surface detectors deployed, 16 are instrumented and operational

TALE SD array now funded from Japan!!!



TA Energy Spectrum Results

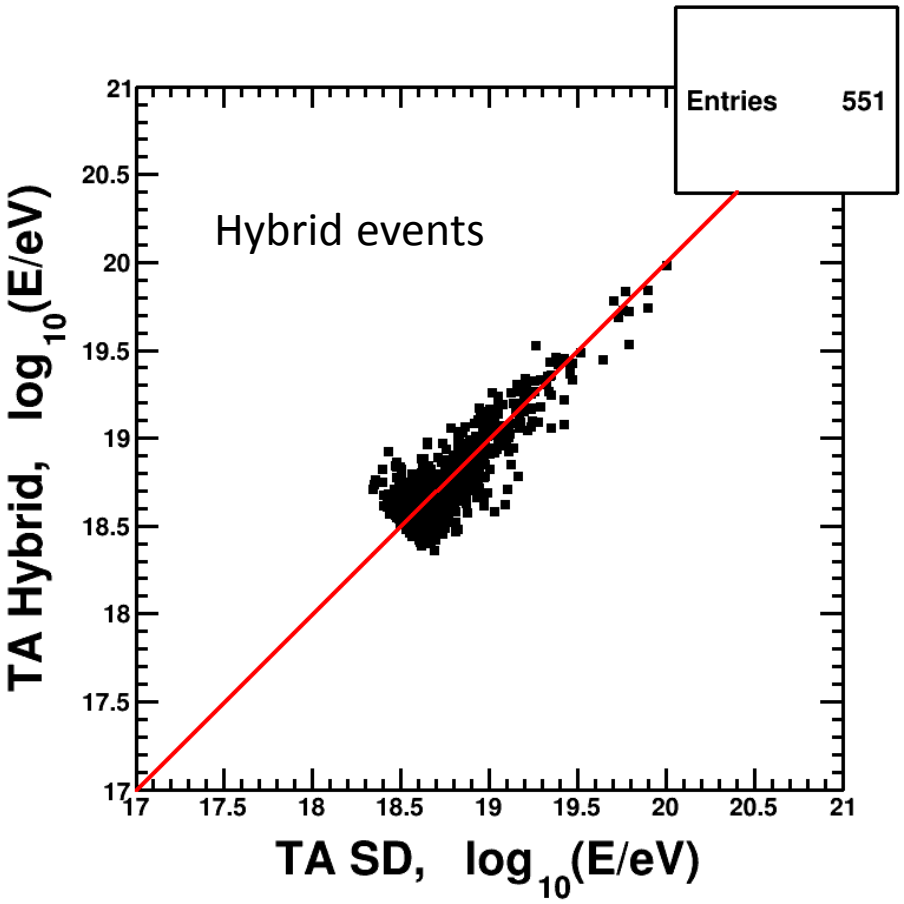
Previously presented at this conference

[847 – PoS 349] Parallel CR17 EAS spec Track: CREX

Presented by Dmitri IVANOV

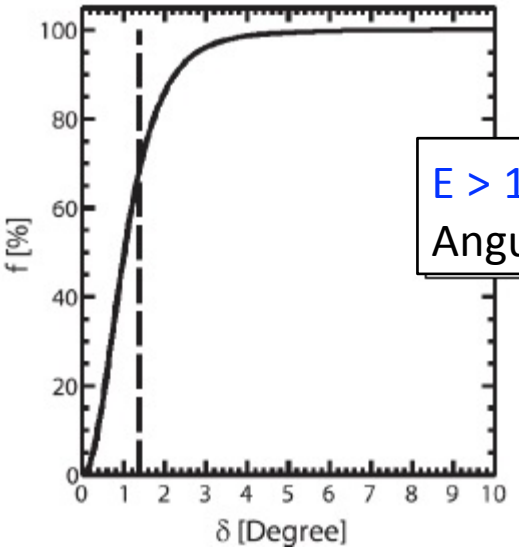
on 4 Aug 2015 at 15:00

Energy Scale Check and resolution

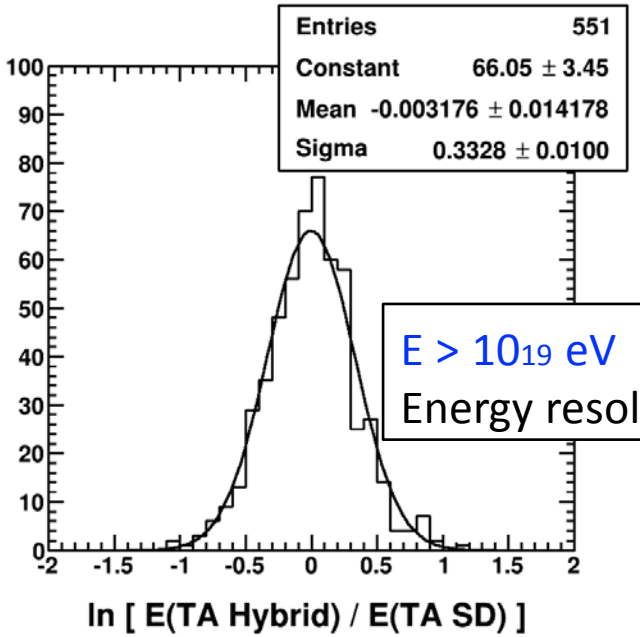


(scaled to FD energy)

$$EEssss = EE'ssss/1.27$$

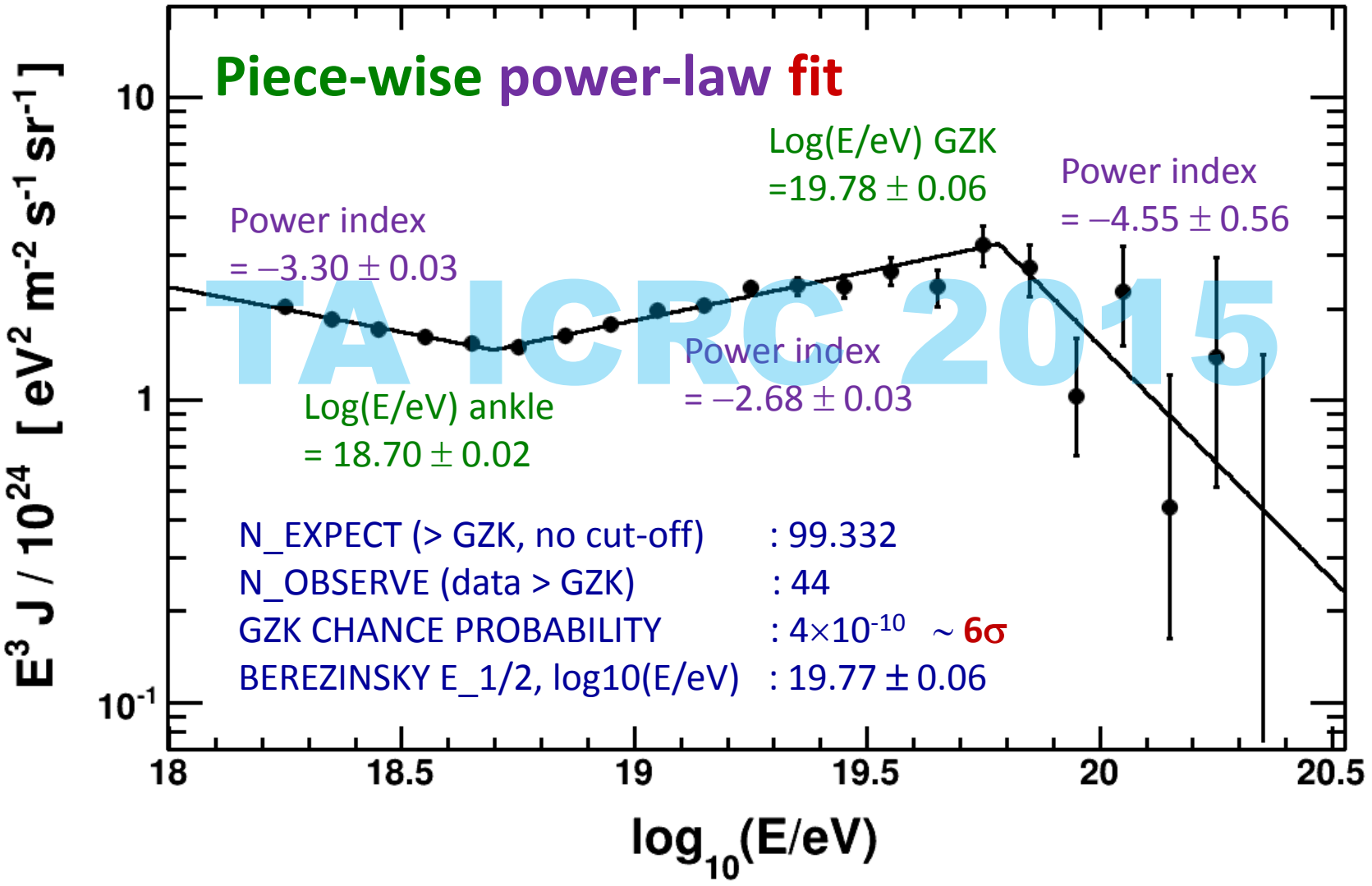


$E > 10^{19}$ eV
Angular resolution = 1.4°



$E > 10^{19}$ eV
Energy resolution < 20%

7 year TA SD spectrum



Previously Pubilshed: **4 year TA surface detector spectrum**
Astrophysical Journal Letters 768 L1 (2013)

Fitting the UHE Spectrum with TA

[299 - PoS 258]
CR17 EAS spec , Presented by Eiji KIDO
on 4 Aug 2015 at 15:15

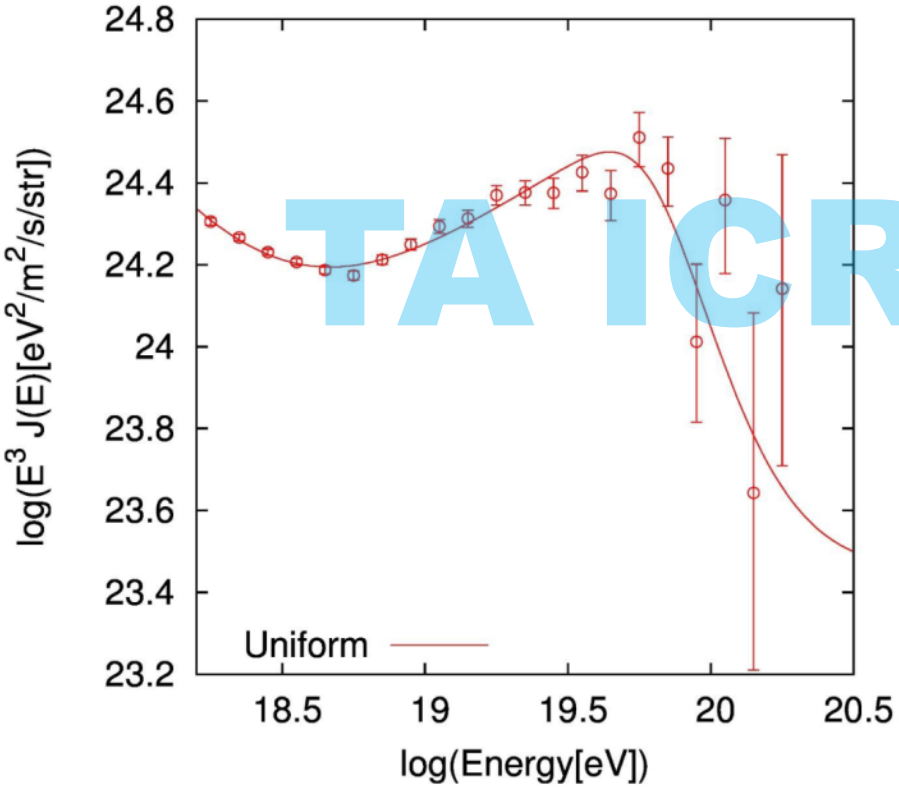
Fitting parameters:

Power law at the source, E^{-p}

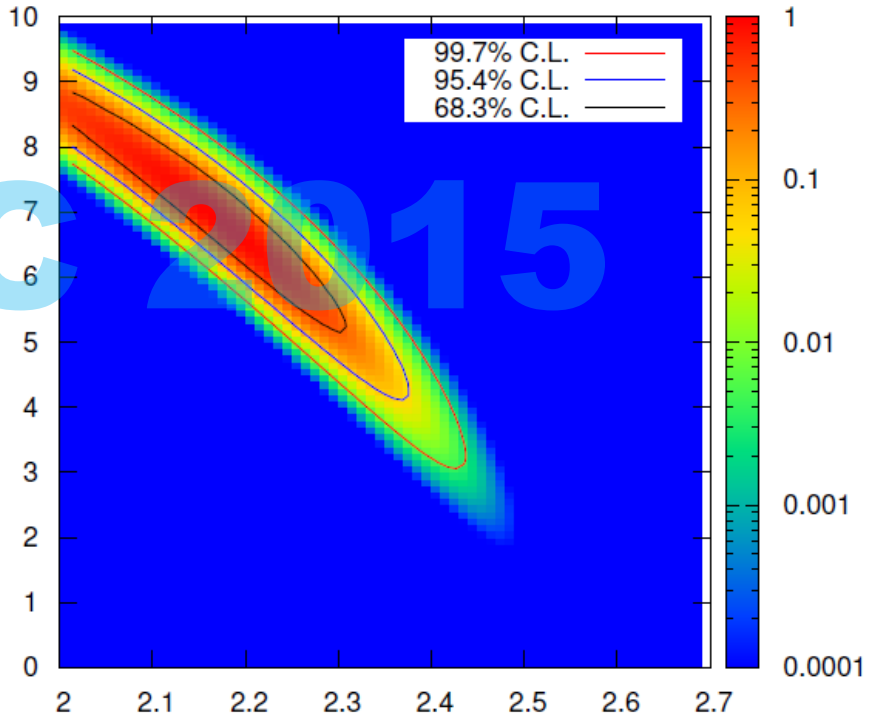
Evolution of the sources, $(1+z)^{m}$

$$p = 2.18^{+0.08}_{-0.14}, \quad m = 6.8^{+1.6}_{-1.1};$$

(stat. + sys.)

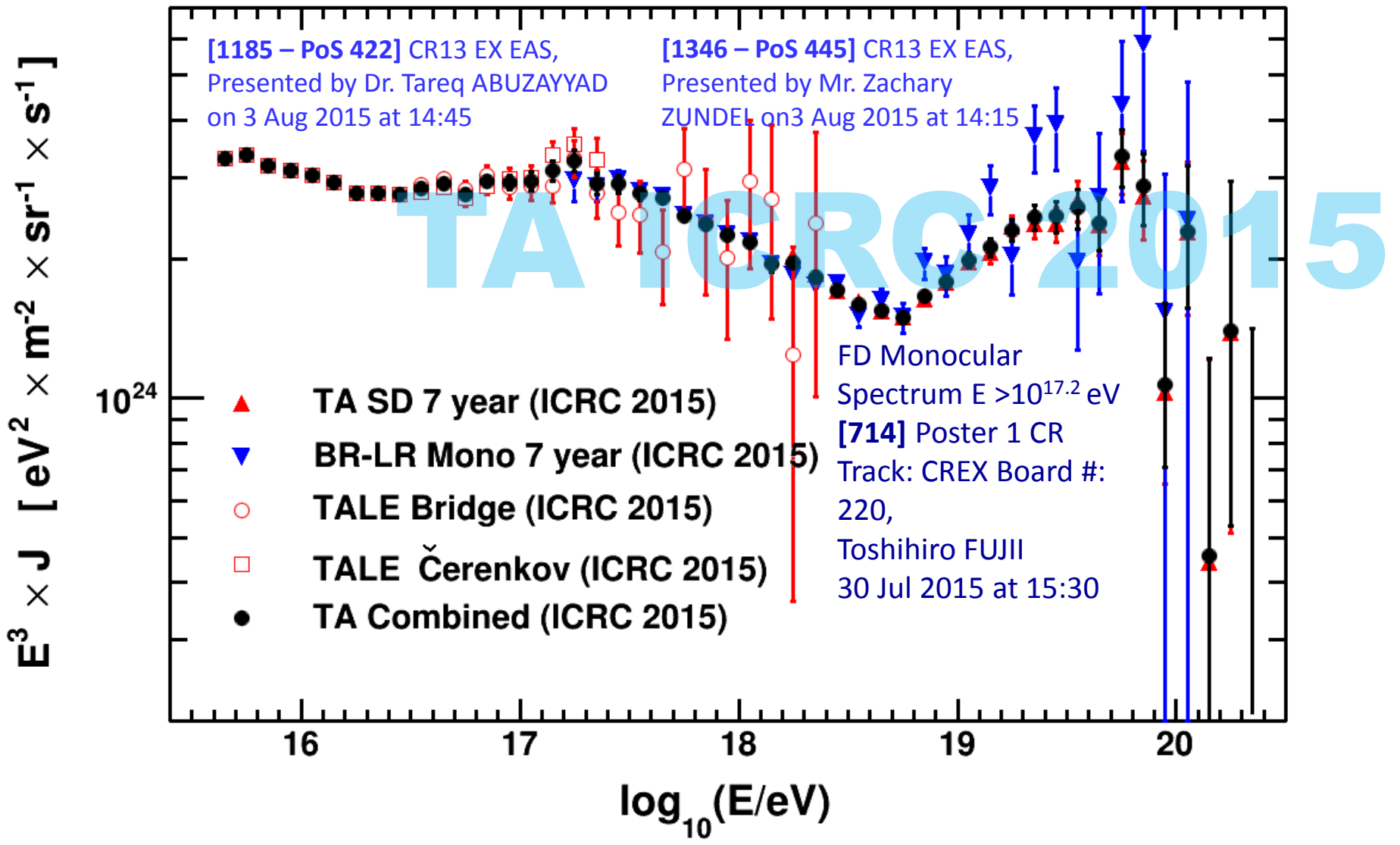


m

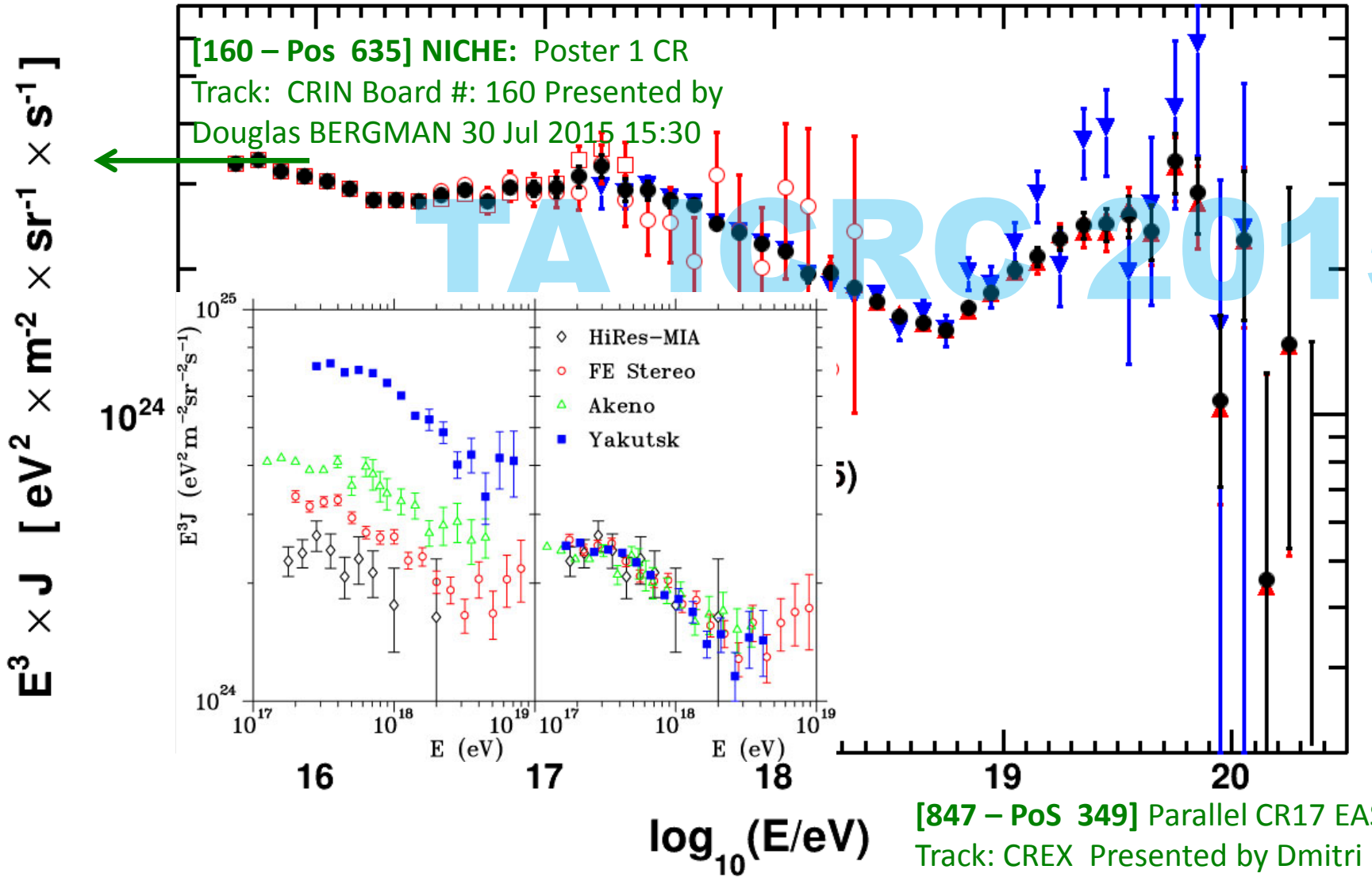


p

Combined TA Energy Spectrum

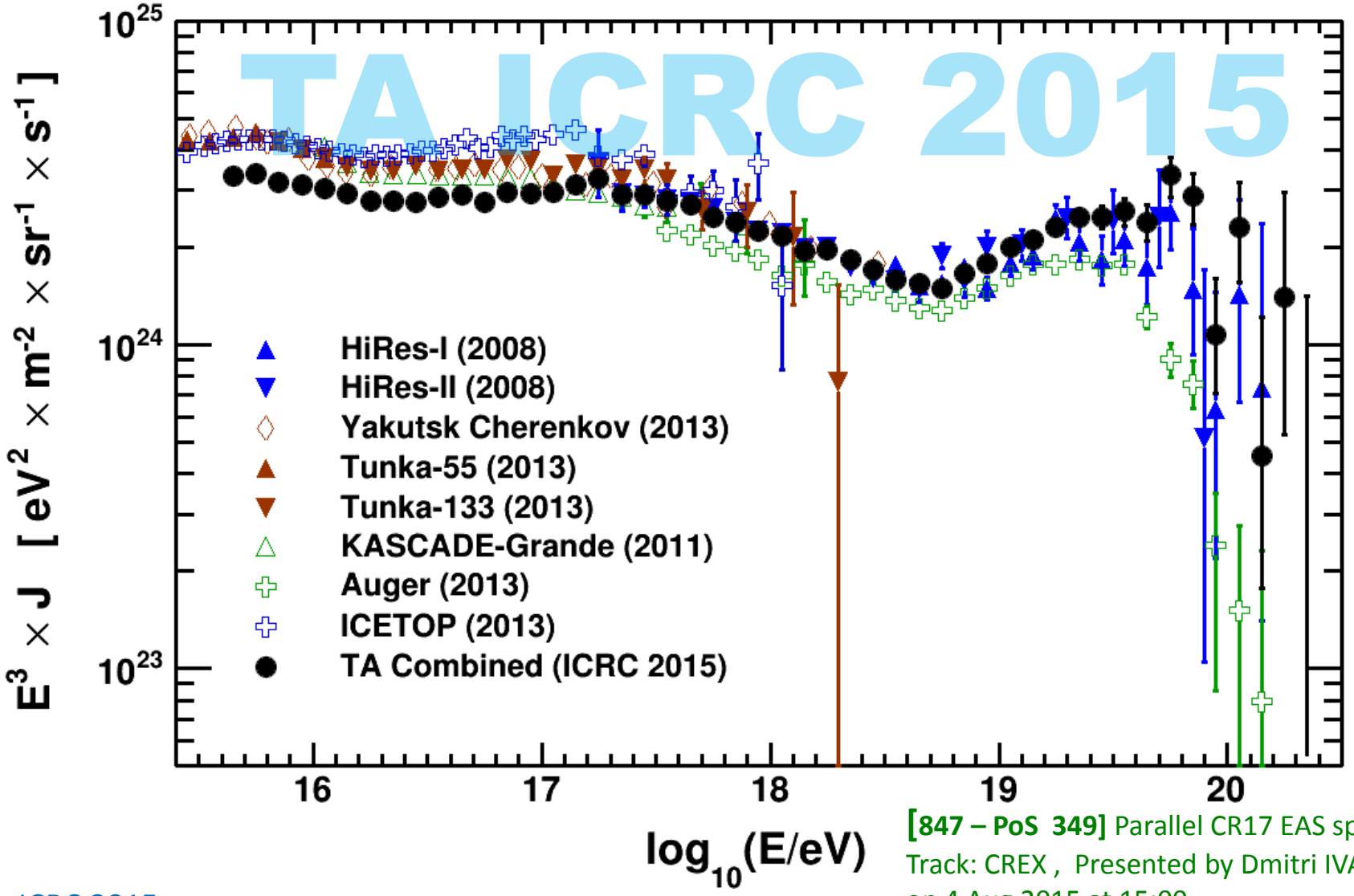


Combined TA Energy Spectrum

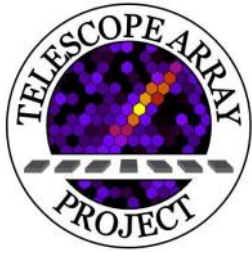


[847 – PoS 349] Parallel CR17 EAS spec
Track: CREX Presented by Dmitri IVANOV
on 4 Aug 2015 at 15:00

Comparison with other Measurements



[847 – PoS 349] Parallel CR17 EAS spec
Track: CREX , Presented by Dmitri IVANOV
on 4 Aug 2015 at 15:00



TA Composition Results

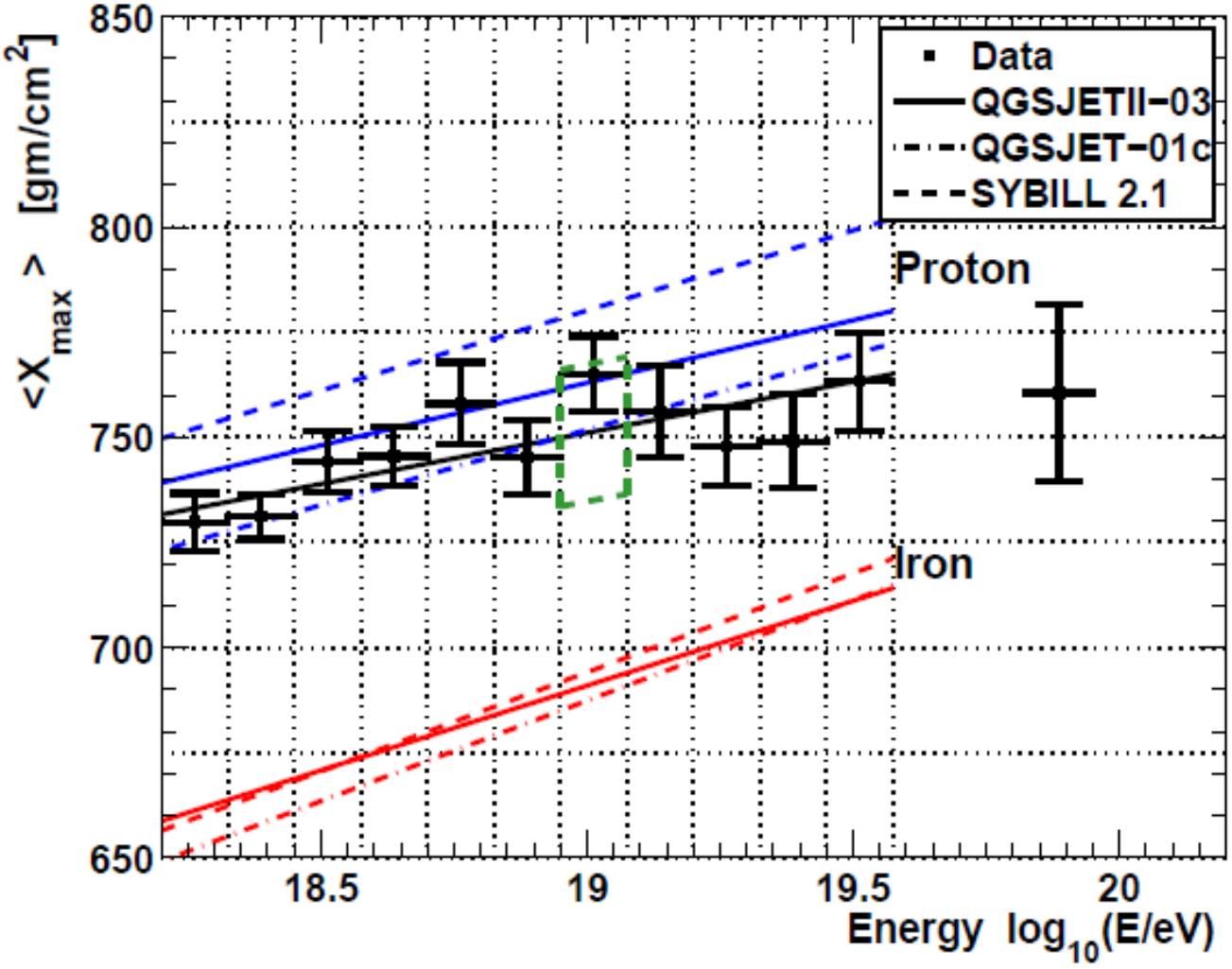
Previously presented at this conference

[863 – PoS 351] Parallel CR07 EAS mass

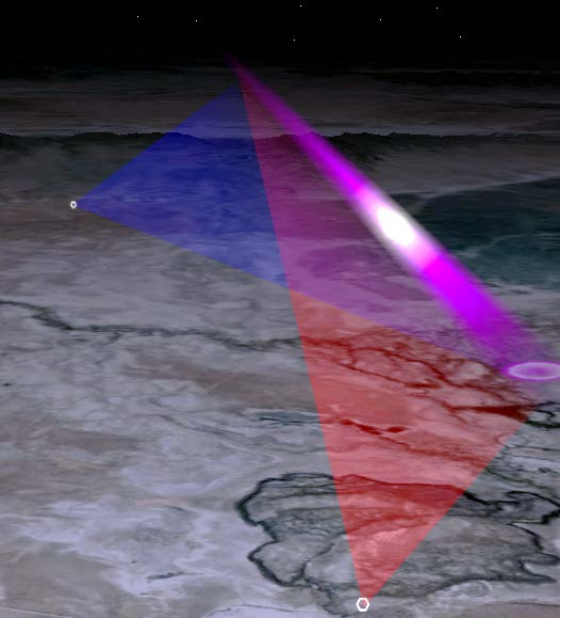
Track: CREX Presented by John BELZ

on 31 Jul 2015 at 14:30

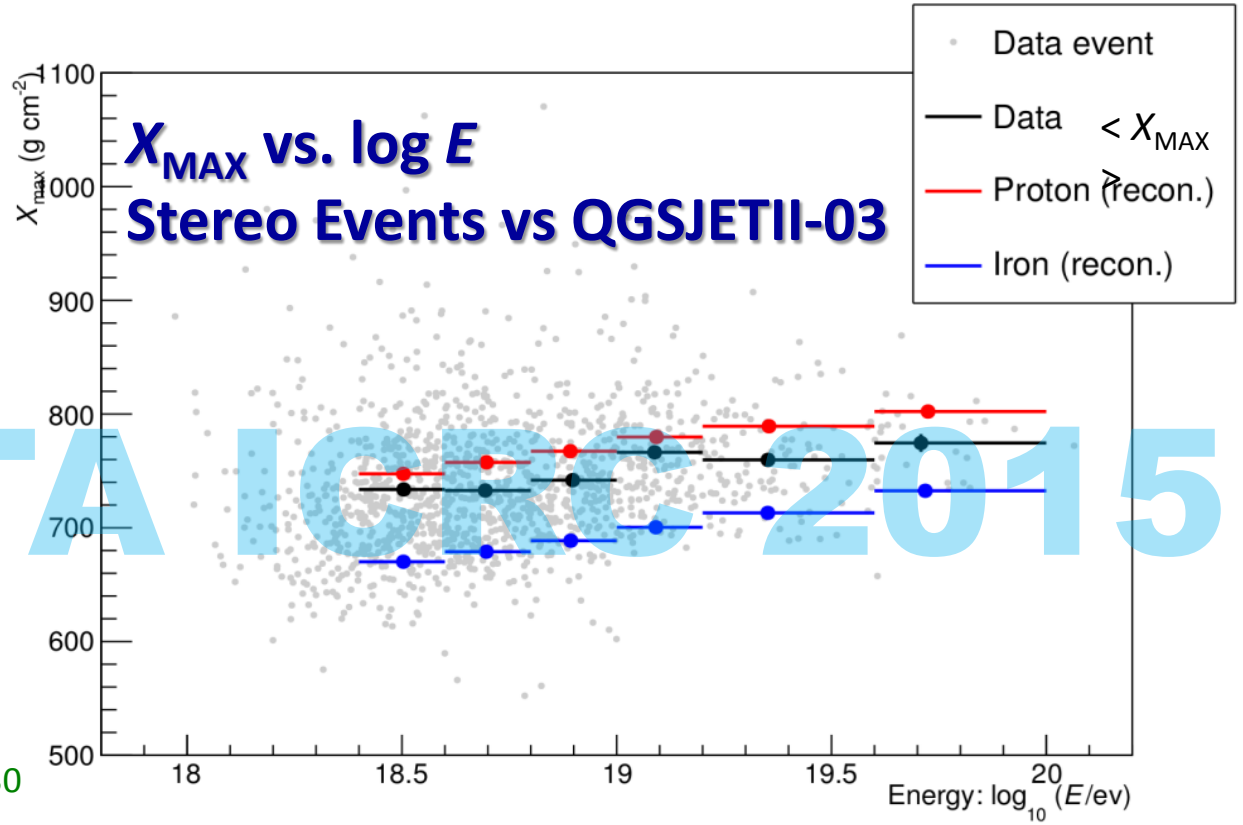
Published Hybrid Composition (MD)



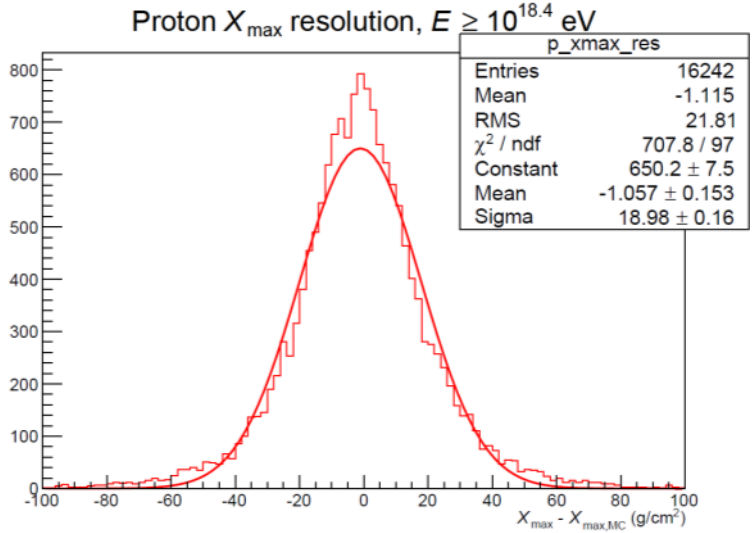
R. Abbasi *et al.* (TA Collaboration) Astropart Phys. (2014) **11** 004

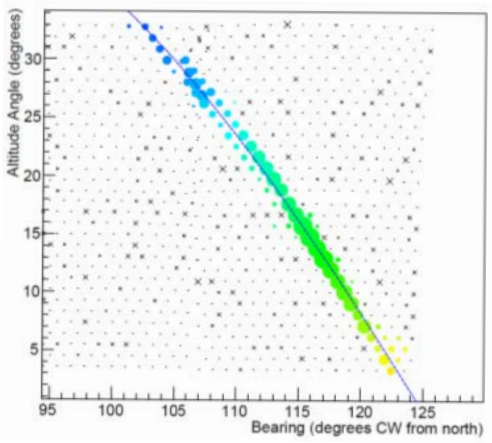


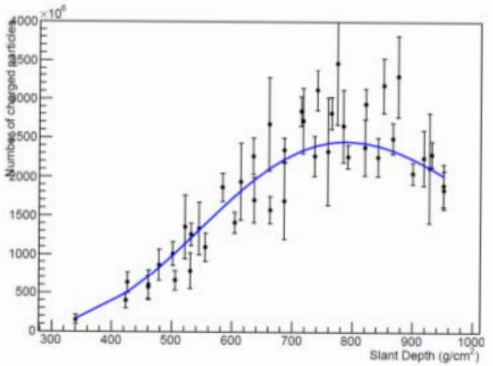
X_{MAX} vs. log E
Stereo Events vs QGSJETII-03



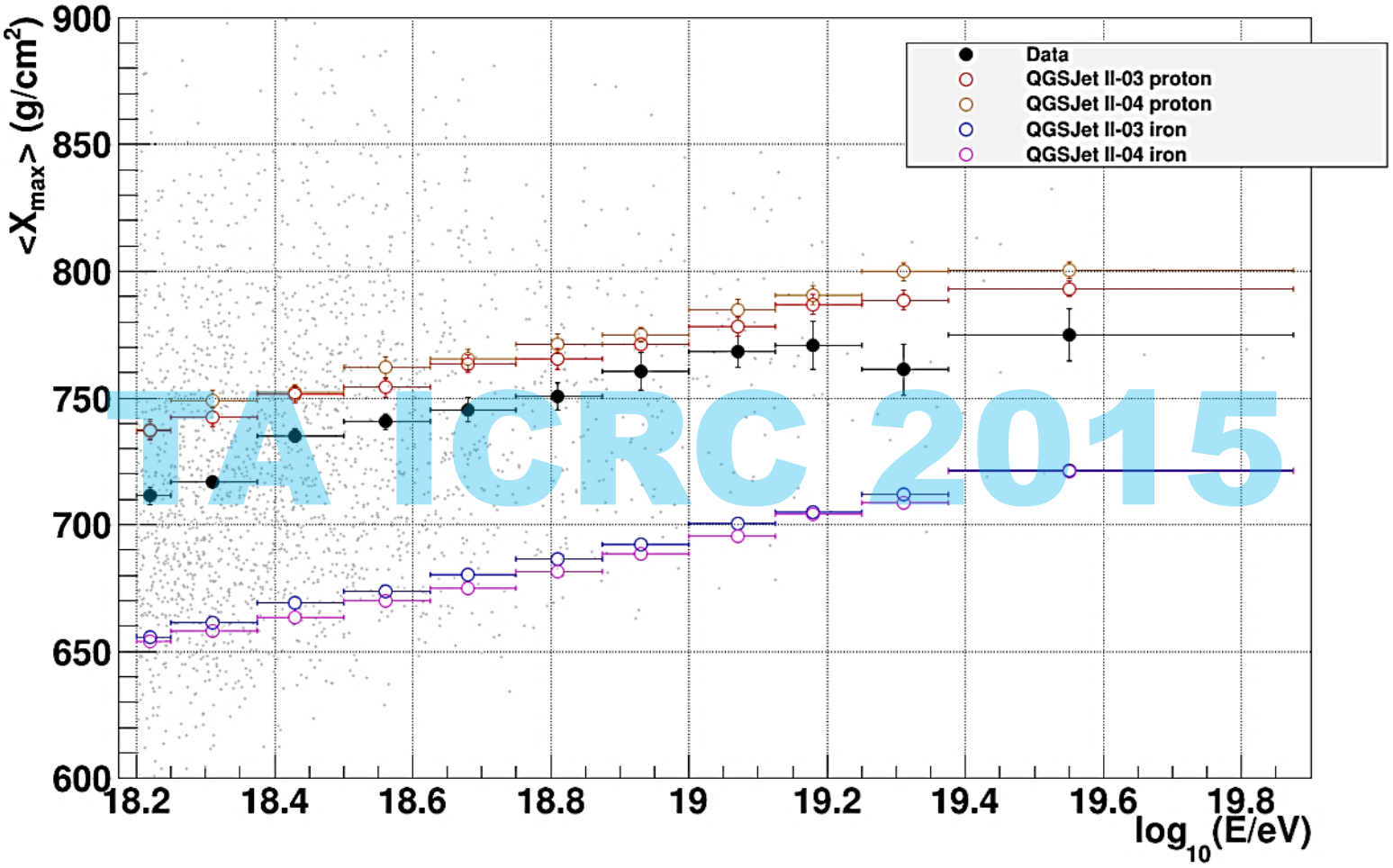
[905 – PoS 361] Poster 1 CR Track:
CREX Board #: 229
Presented by Dr. Thomas STROMAN,
Dr. Yuichiro TAMEDA on 30 Jul 2015 at 15:30







X_{MAX} vs. logE for hybrid events from Black Rock and Long Ridge FD

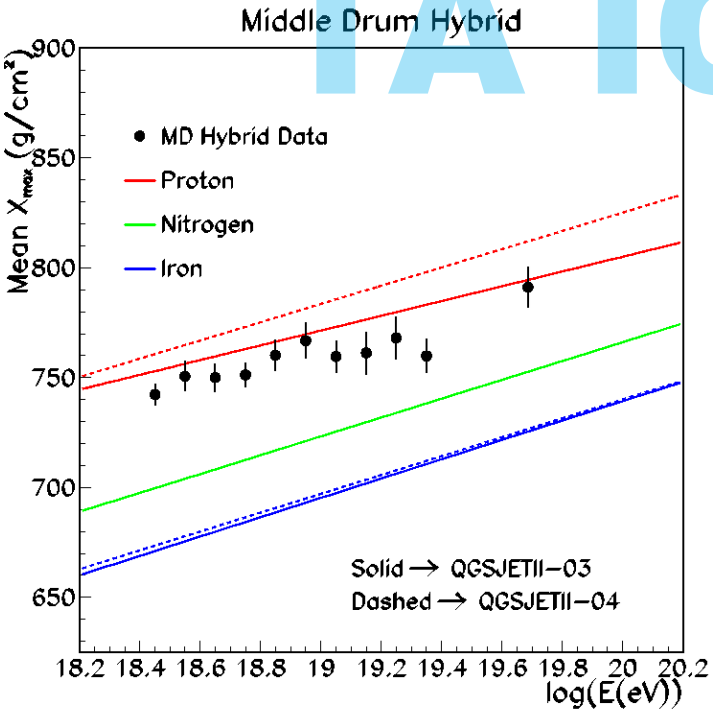


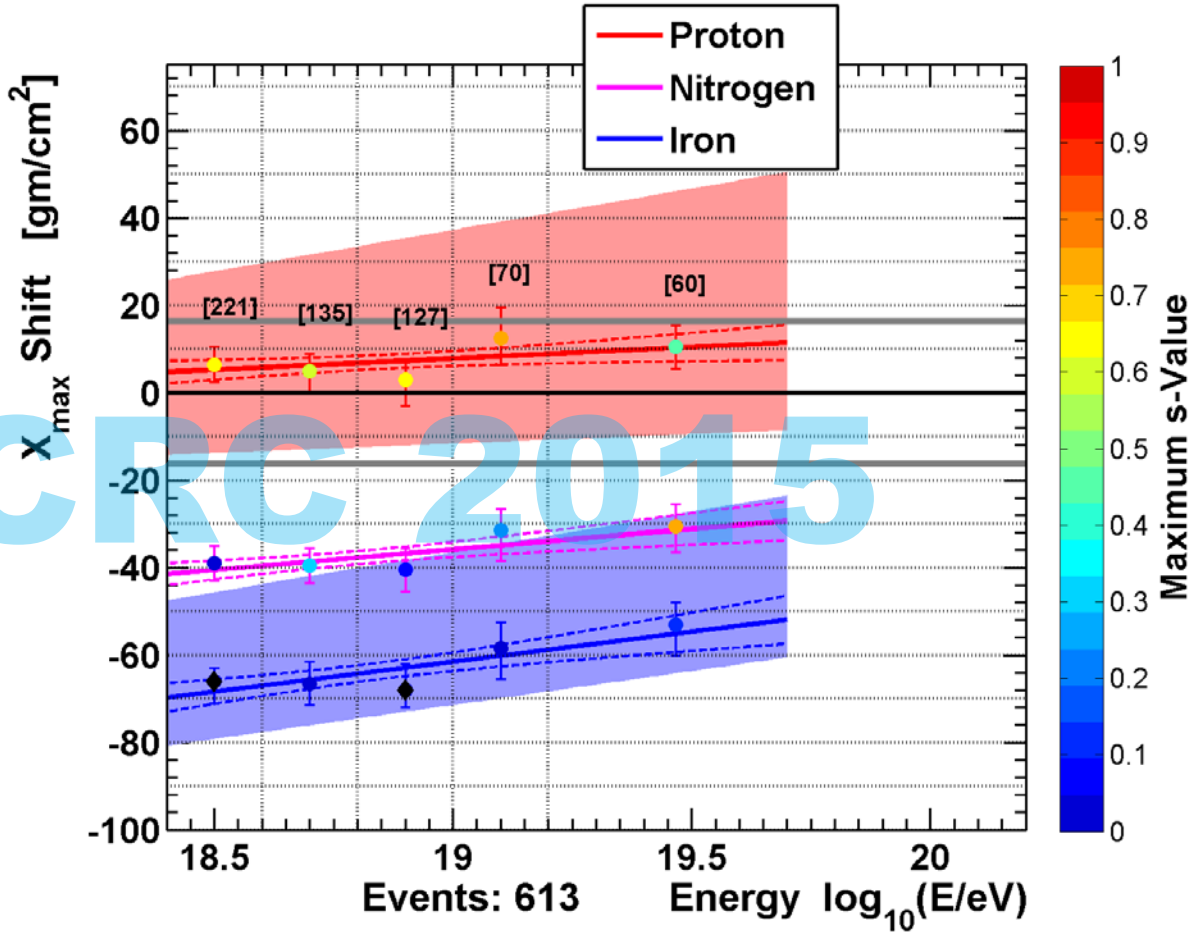
[906 –PoS 362] Poster 1 CR Track: CREX Board #: 230
Presented by Daisuke IKEDA, Dr. William HANLON
on 30 Jul 2015 at 15:30

MD Hybrid

[1332 – PoS 441] Poster 1 CR
Track:CREX Board #: 247 Presented by Mr. Jon Paul LUNDQUIST
on 30 Jul 2015 at 15:30

Standard mean vs log(E) plot





"Shift Plot"

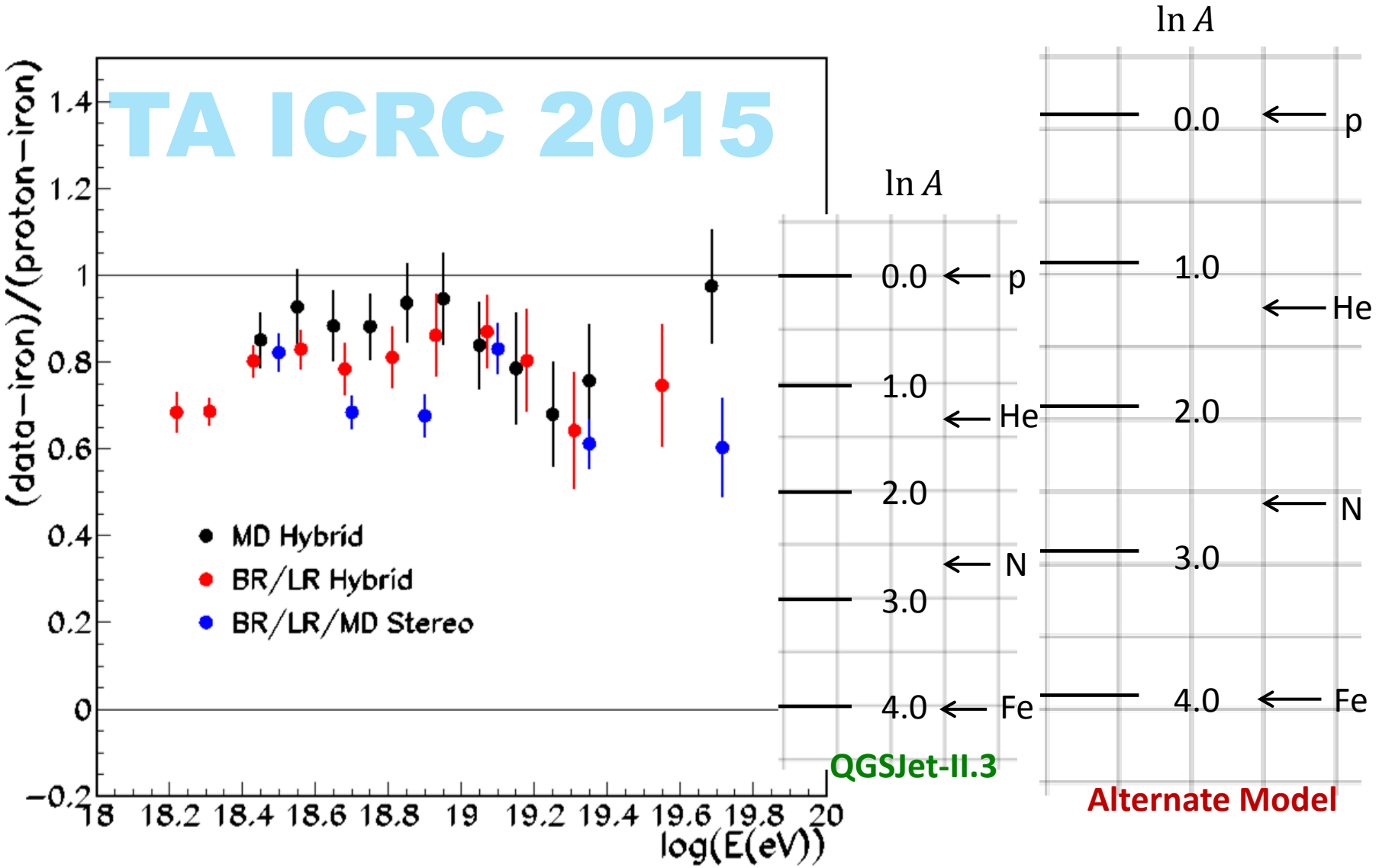
Plot ΔX_{max} required to maximize data/MC agreement (QGSJETII-03).

Standard statistical test on shifted distribution (points)

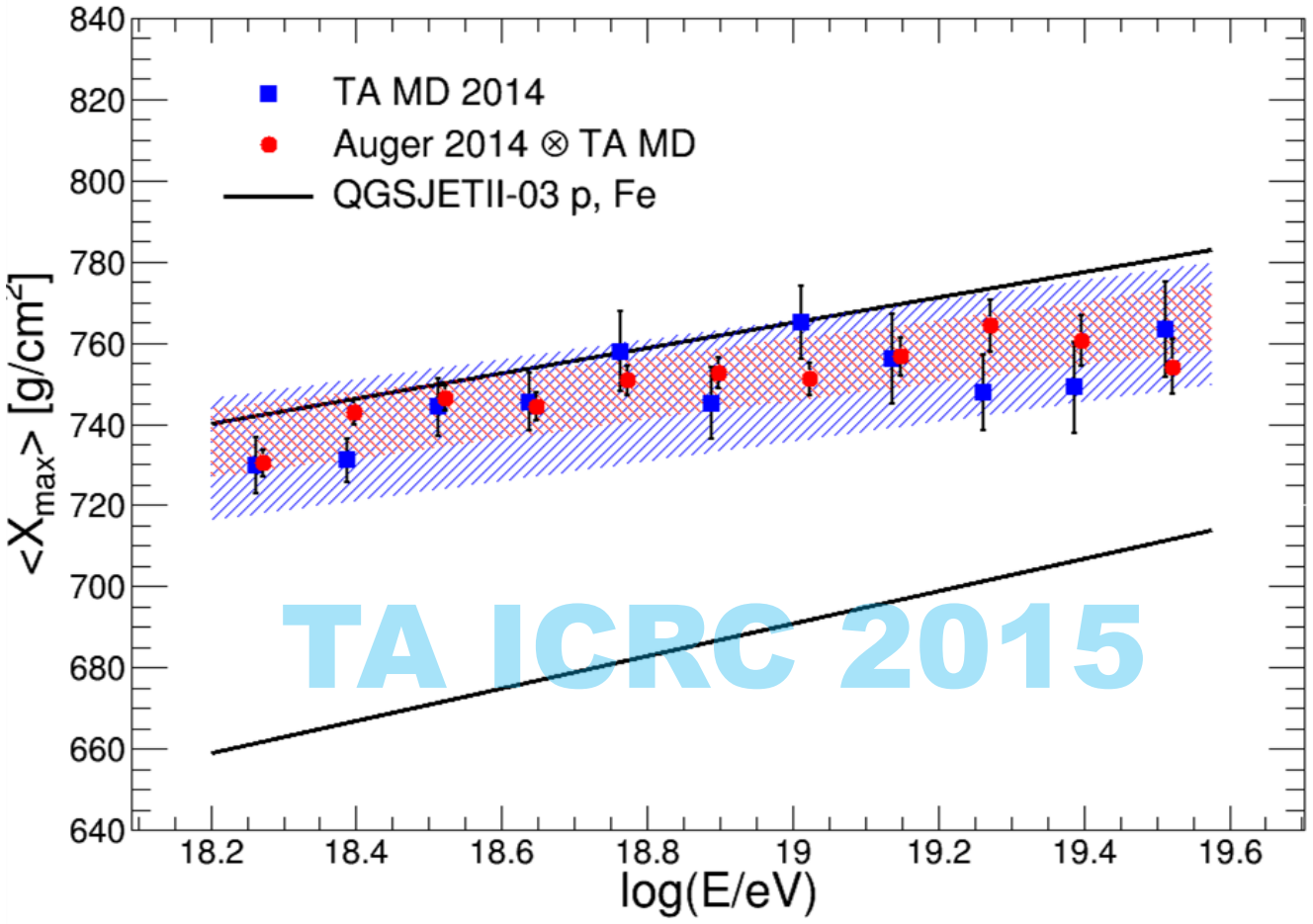
Pink, blue bands for other hadronic models

16 g/cm^2 systematic uncertainty

TA data compared to QGSJet-II.3



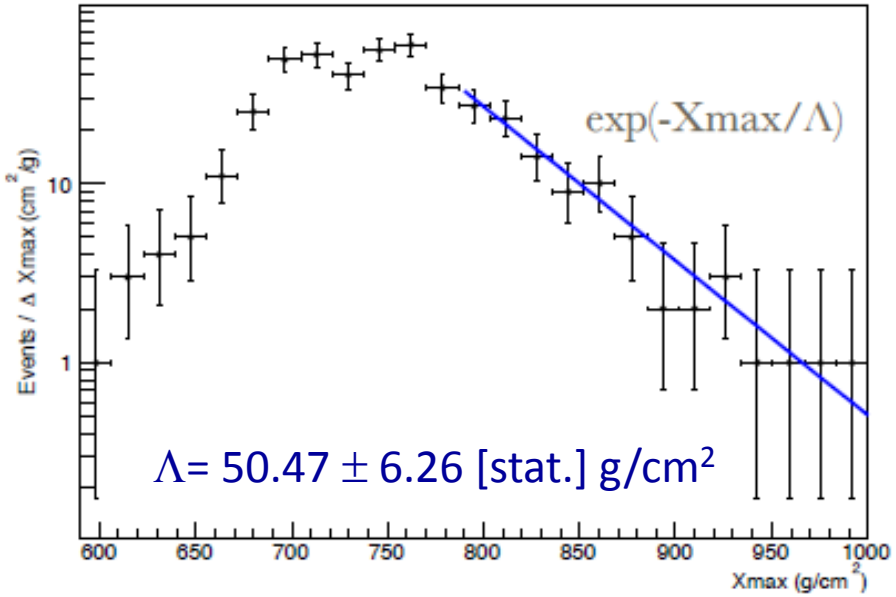
Meta-analysis: Composition WG



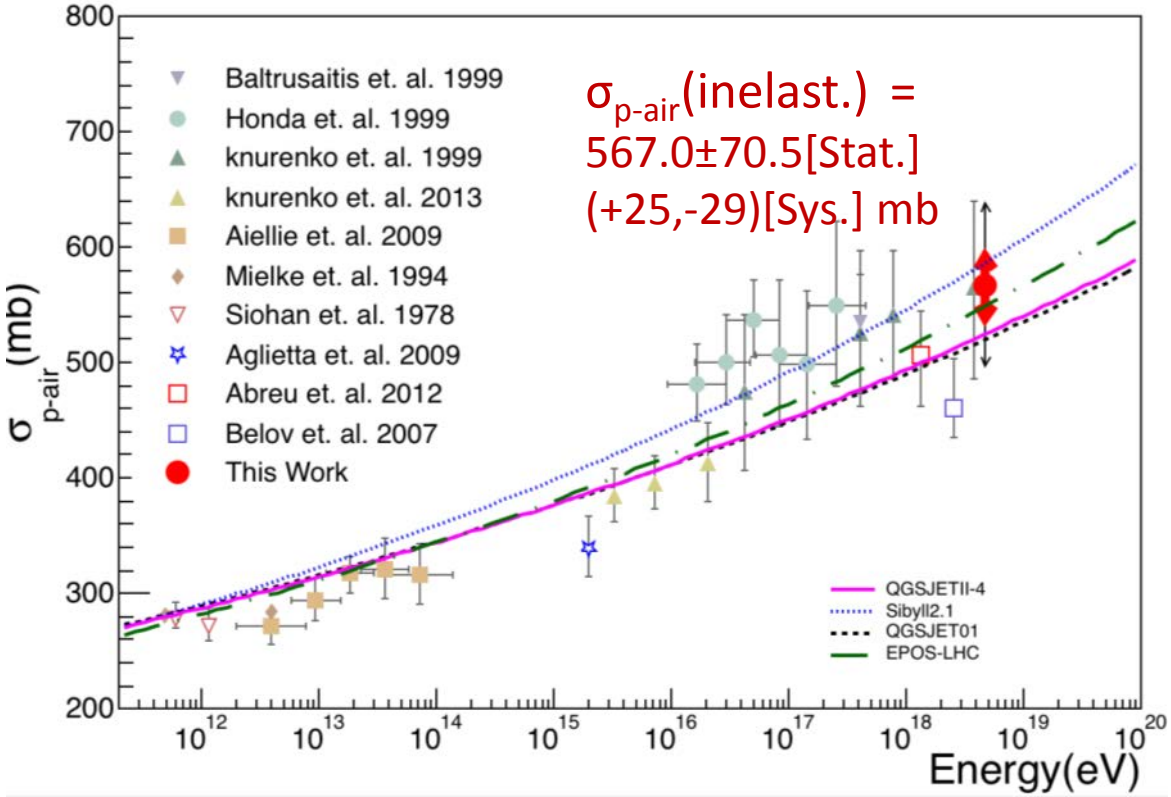
[618 - PoS 307]
Parallel CR07 EAS mass
Track: CREX, Presented by
Michael UNGER
on 31 Jul 2015 at 14:00
Unger et al, PoS 307

TA data cannot distinguish between mix and QGSJETII-03 protons at this level of systematic uncertainty.

TA Measurement of $\sigma_{p\text{-}air}$ (inelast.)



[1095 – PoS 402] Parallel CR14 Hadr Int Track: CREX Presented by Dr. Rasha ABBASI & John Belz on 3 Aug 2015 at 14:15



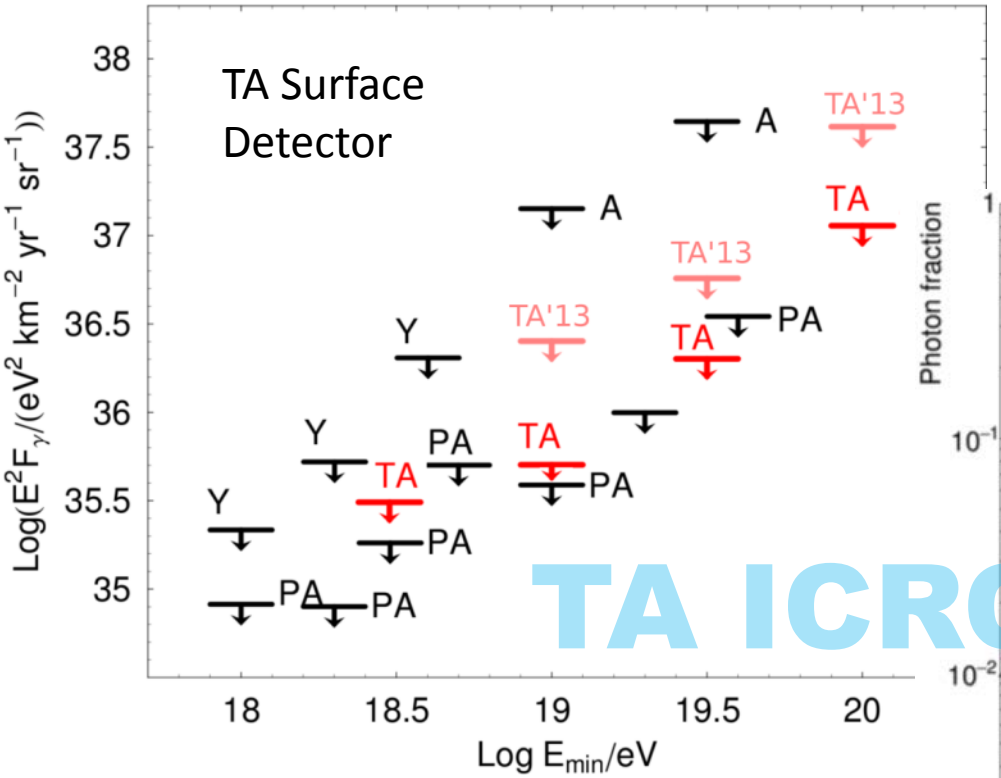
$\sigma_{p\text{-}air}$(inelast.) = 567.0±70.5[Stat.] (+25,-29)[Sys.] mb

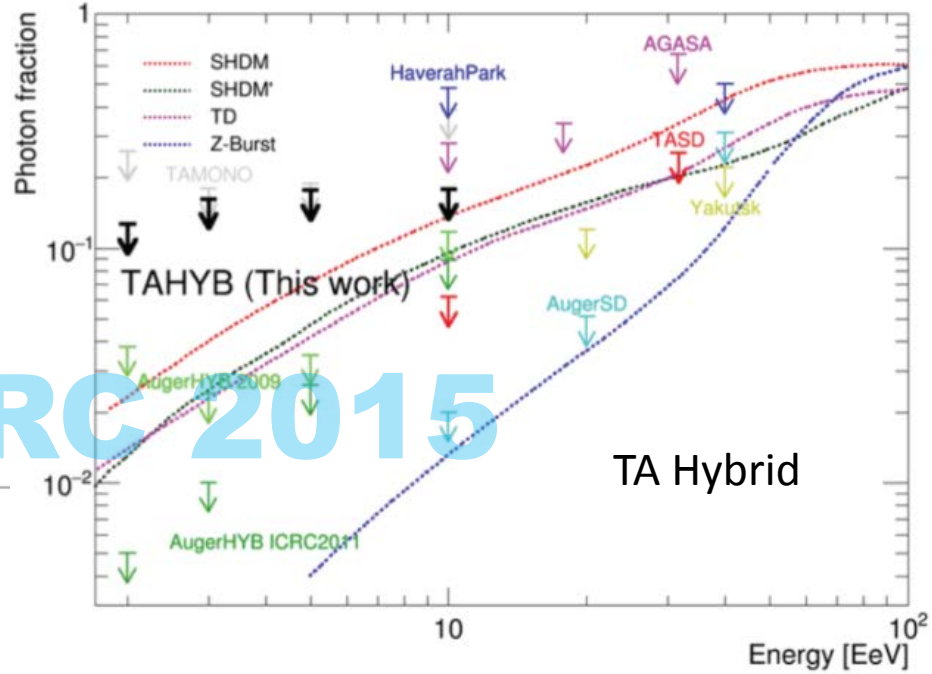
Systematic source	Systematic (mb)
Model Dependence	±17
20%Helium	+18
Gamma<1%*	– 23
Total	(+25,-29)

R. Abbasi et. al. (TA collaboration) Accepted for publication by Phys. Rev. D. **Aug 2, 2015**

Photon Limits

[781 – PoS 331] CR07 EAS mass Track: CREX
Presented by Grigory RUBTSOV
on 31 Jul 2015 at 15:00





AGASA, Astrophys. J. **571**, L117 (2002)
Yakutsk, Phys. Rev. **D82**, 041101 (2010)
Auger, Astropart. Phys. **29**, 243 (2008); Astropart. Phys. **31**, 399-406 (2009)

[883 – PoS 352] Poster 1 CR Track: CREX
Board #: 227 , Presented by Katsuya YAMAZAKI
on 30 Jul 2015 at 15:30

TA Anisotropy Results

Previously presented at this conference

[765 – PoS 326] Parallel CR03 Aniso Track: CREX

Presented by Peter TINYAKOV, Hiroyuki SAGAWA, Igor TKACHEV et al. on 30 Jul 2015 at 14:45

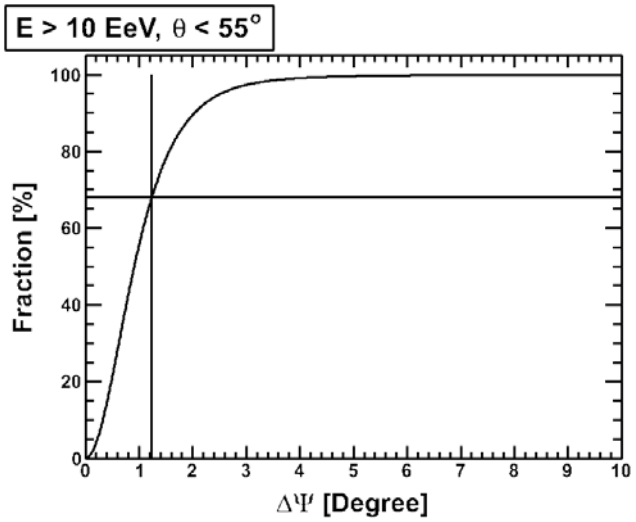
[414 - PoS 276]

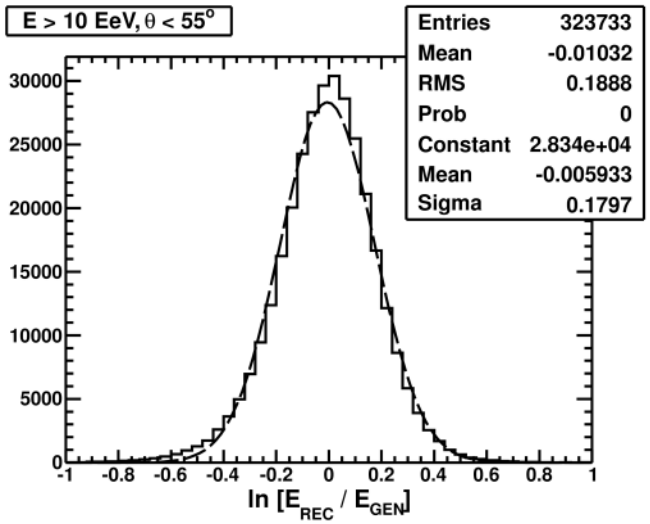
Parallel CR03 Aniso Track: CREX Presented by Kazumasa KAWATA on

30 Jul 2015 at 15:00

Anisotropy Analysis: ICRC 2015

- SD data from period **12.05.2008 — 11.05.2015 (full 7 years)**
- Zenith angle up to 55°, loose border cut
- Geometrical acceptance; exposure 8600 km^2 yr sr
- **2996** above **10 EeV**
- **210** above **40 EeV**
- **83** above **57 EeV**
- Angular resolution: better than 1.5°
- Energy resolution: 20%





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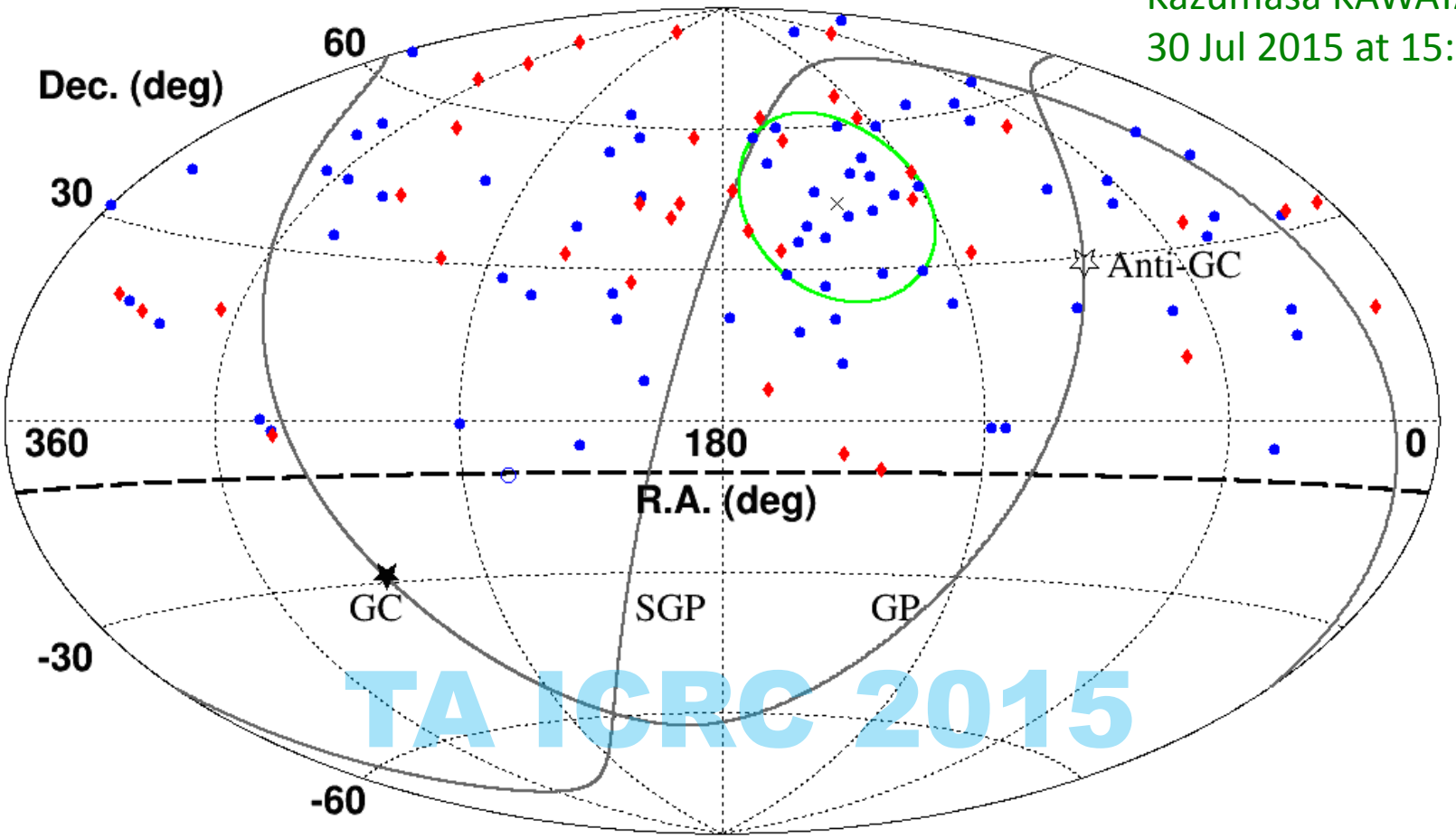
Hot Spot update: 7 years

[414 - PoS 276]
Parallel CR03 Aniso
Track: CREX Presented by
Kazumasa KAWATA on
30 Jul 2015 at 15:00

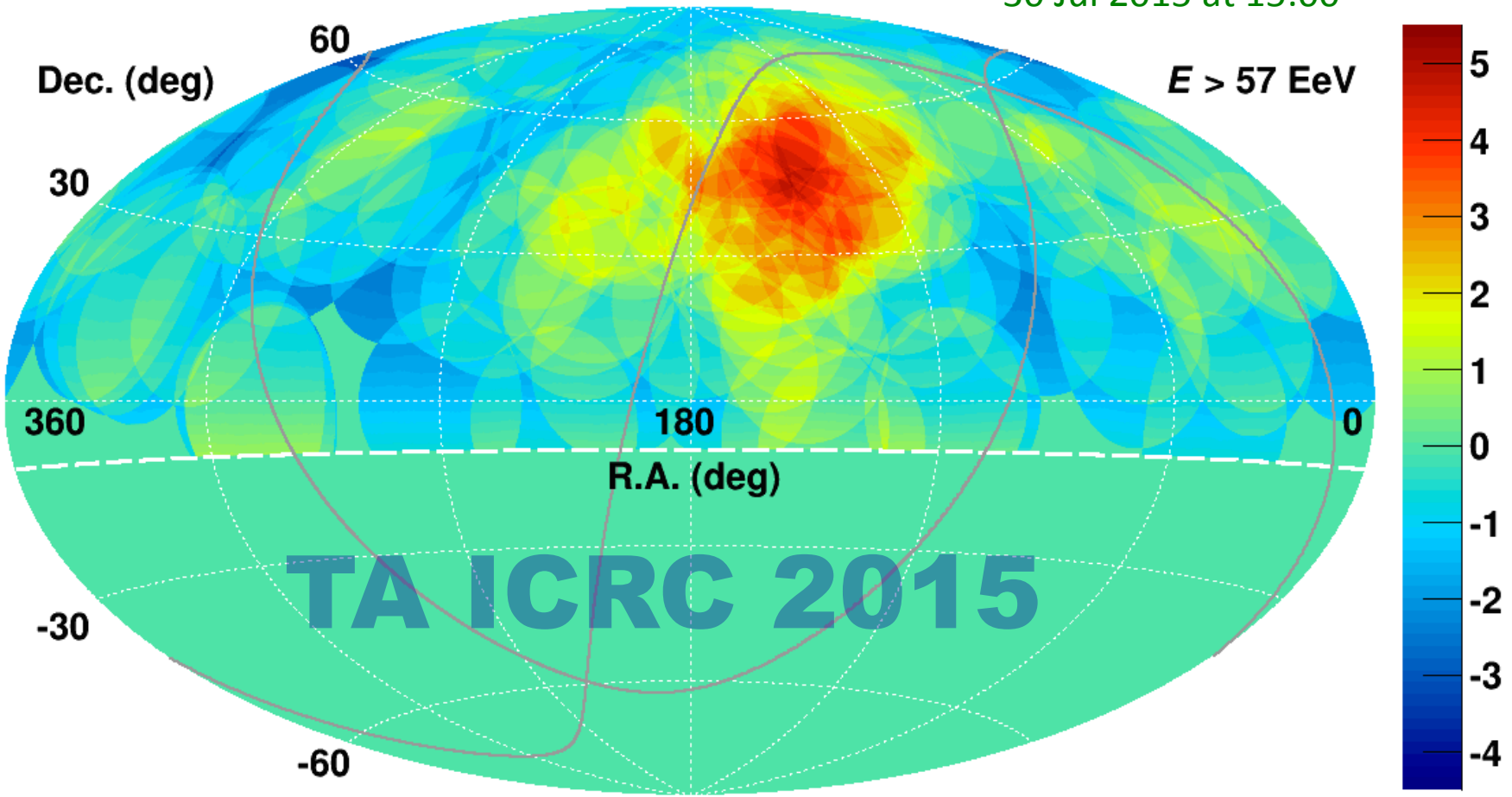


First 5-year data (72 events) -- ApJ 790 L21 (2014)
New 2-year data (37 events)
Total (2008 May 11 – 2015 May 11) 109 events

Period	Total	Signal	B.G.	Chance Prob.
6-th Year	15	3	0.94	7%
7-th Year	22	1	1.37	74%
6th + 7th	37	4	2.31	20%

7 Year Excess Map

[414 - PoS 276] Parallel CR03 Aniso Track: CREX Presented by Kazumasa KAWATA on 30 Jul 2015 at 15:00



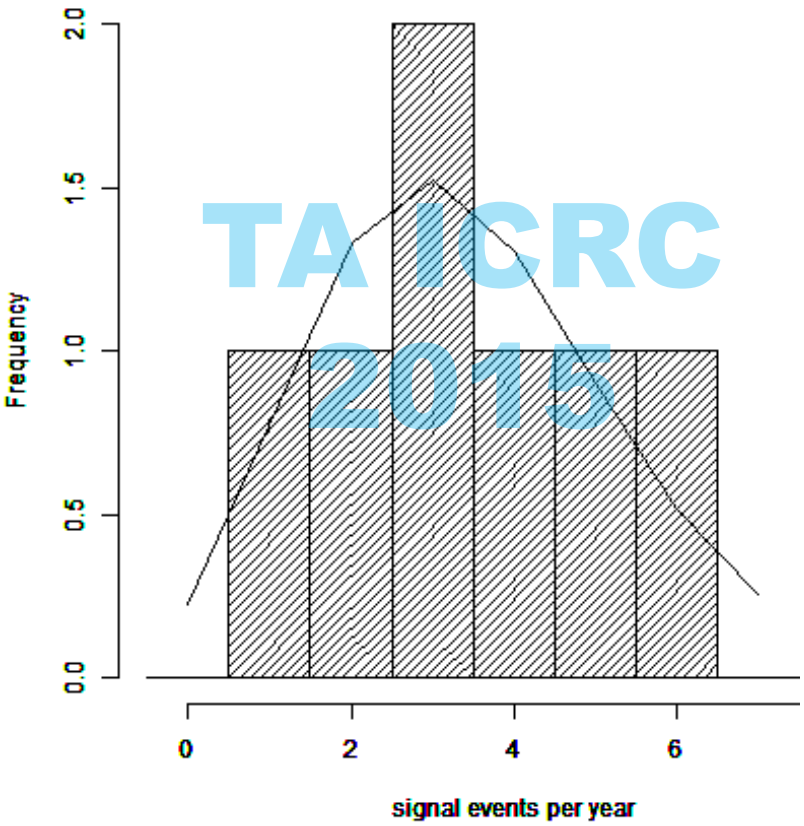
Max significance **5.1**σ (N_{SIG} = 24, N_{BG}=6.88) for 7 years
Centered at R.A=148.4°, Dec.=44.5° (shifted from SGP by 17°)
Global Excess Chance Probability: 3.7×10^{-4} : 3.4σ (~ same as first 5 years)

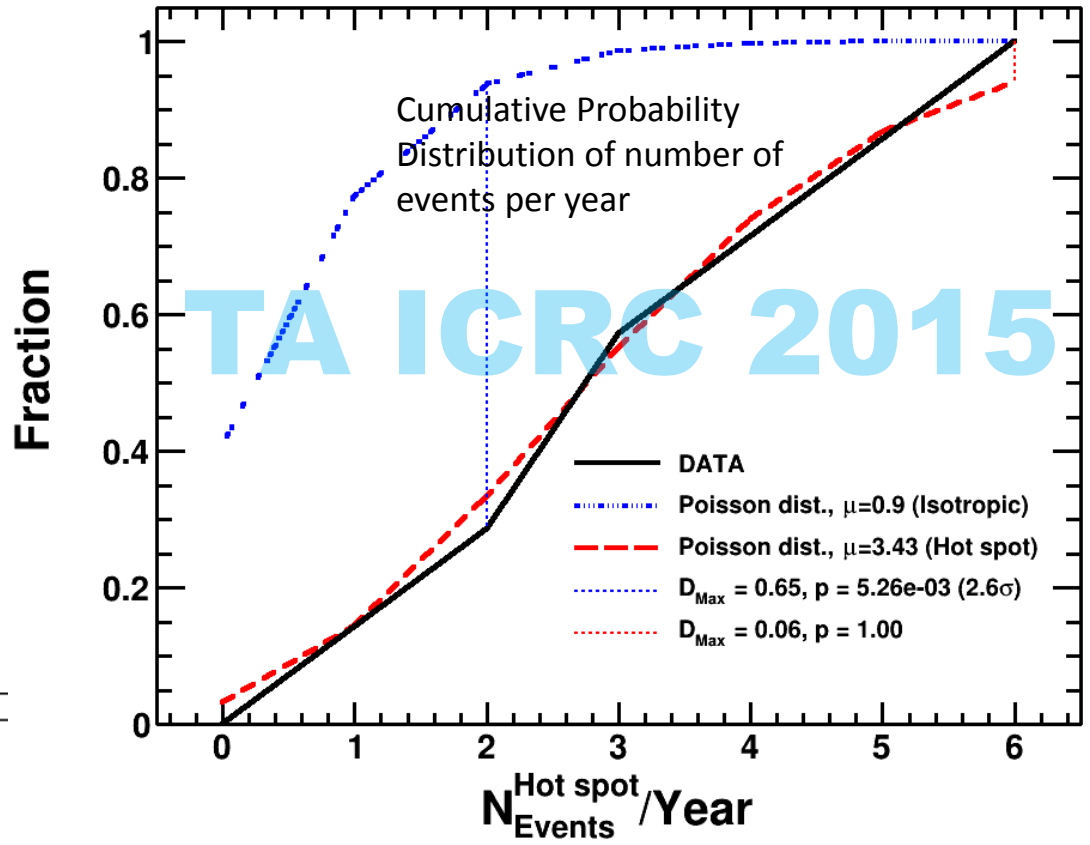
Consistent with Fluctuation

[414 - PoS 276] Parallel CR03 Aniso Track: CREX
Presented by Kazumasa KAWATA on
30 Jul 2015 at 15:00

K.S. Test shows data is consistent with fluctuation for hotspot
(Poisson: average = 3.43 per year, no time variation),

but inconsistent with chance excess from isotropic distribution (Poisson: average = 0.9 per year) at ~ 2.6σ





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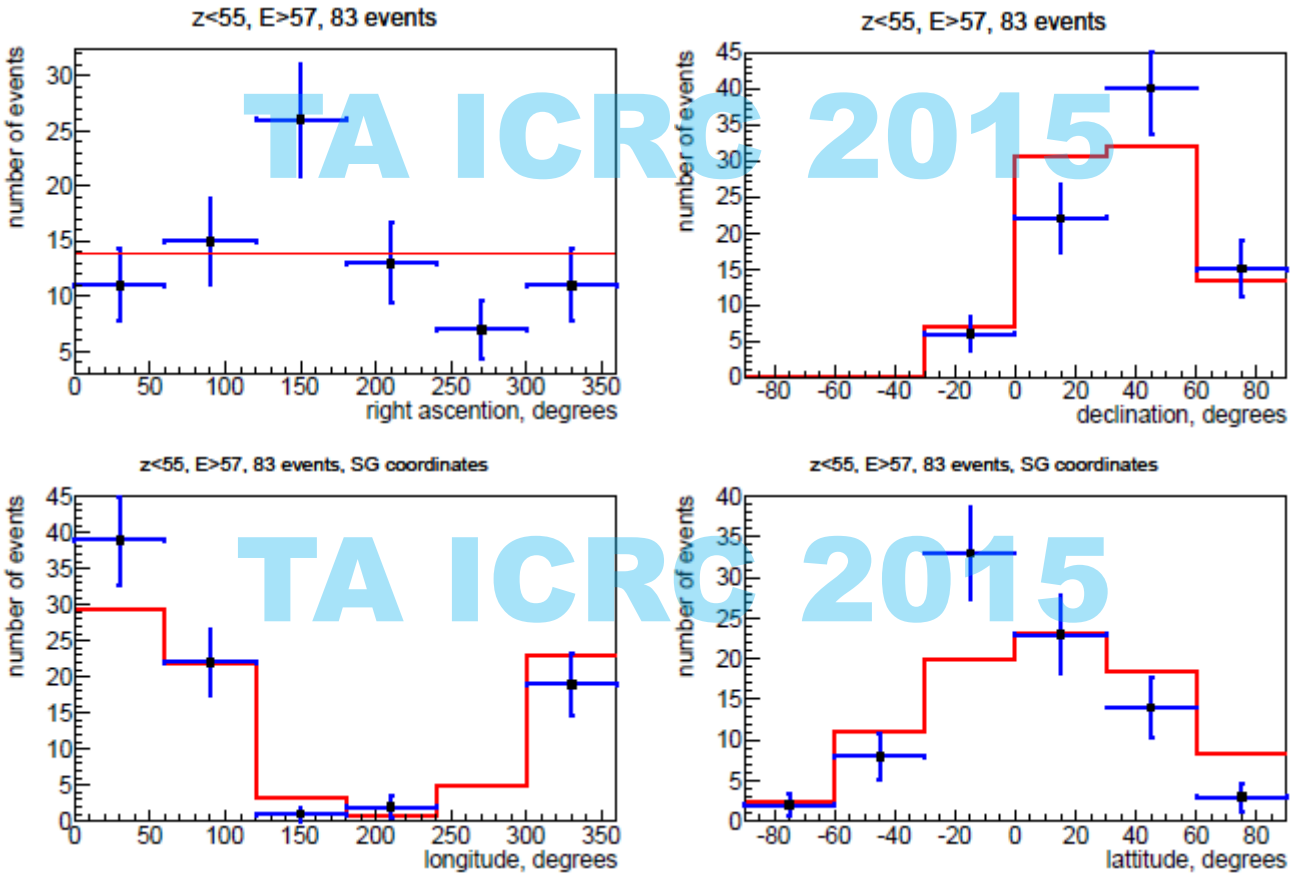
Global Distributions

Low energy sets: E > 10 EeV and E > 40 EeV are compatible with isotropy; the smallest KS p-value is 0.12.

E > 57 EeV

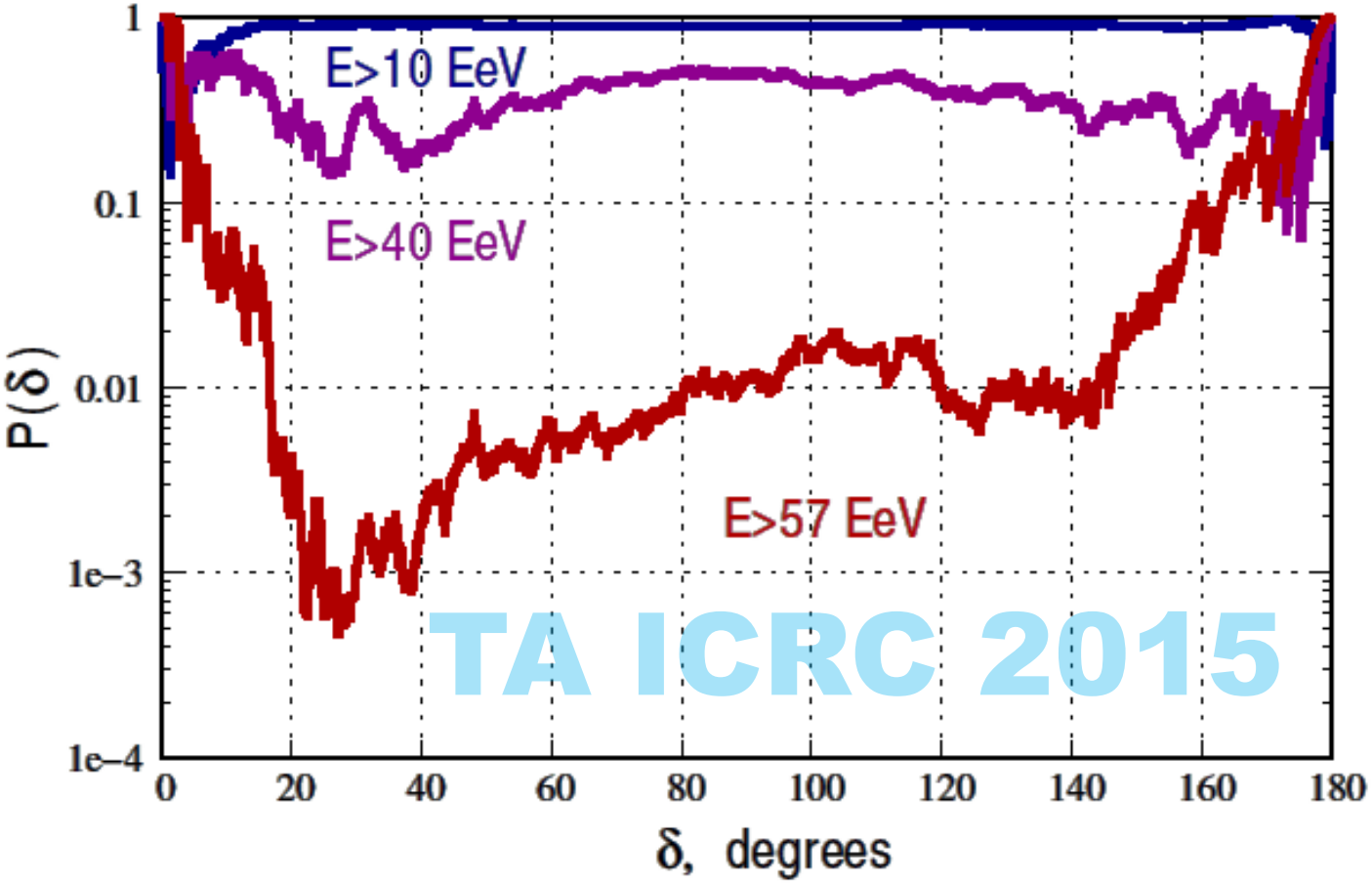
KS p-values

Frame	Long.	Lat.
Equatorial	0.07	0.04
Supergalactic	0.01	0.03



[765 – Pos 326]
Parallel CR03 Aniso,
Presented by
Peter TINYAKOV,
Hiroyuki SAGAWA,
Igor TKACHEV on
30 Jul 2015 at 14:45

Autocorrelation



For each angular bin:

1. Count number of pairs of events at in the bin at separation δ
2. Chance Probability is given by the fraction of isotropic MC sets (with equal statistics) with as many or more than the number of pairs seen in data

Compatible with isotropy at E > 10 EeV and E > 40 EeV,
Tension with isotropy at E>57 EeV

[765 – Pos 326]
Parallel CR03 Aniso,
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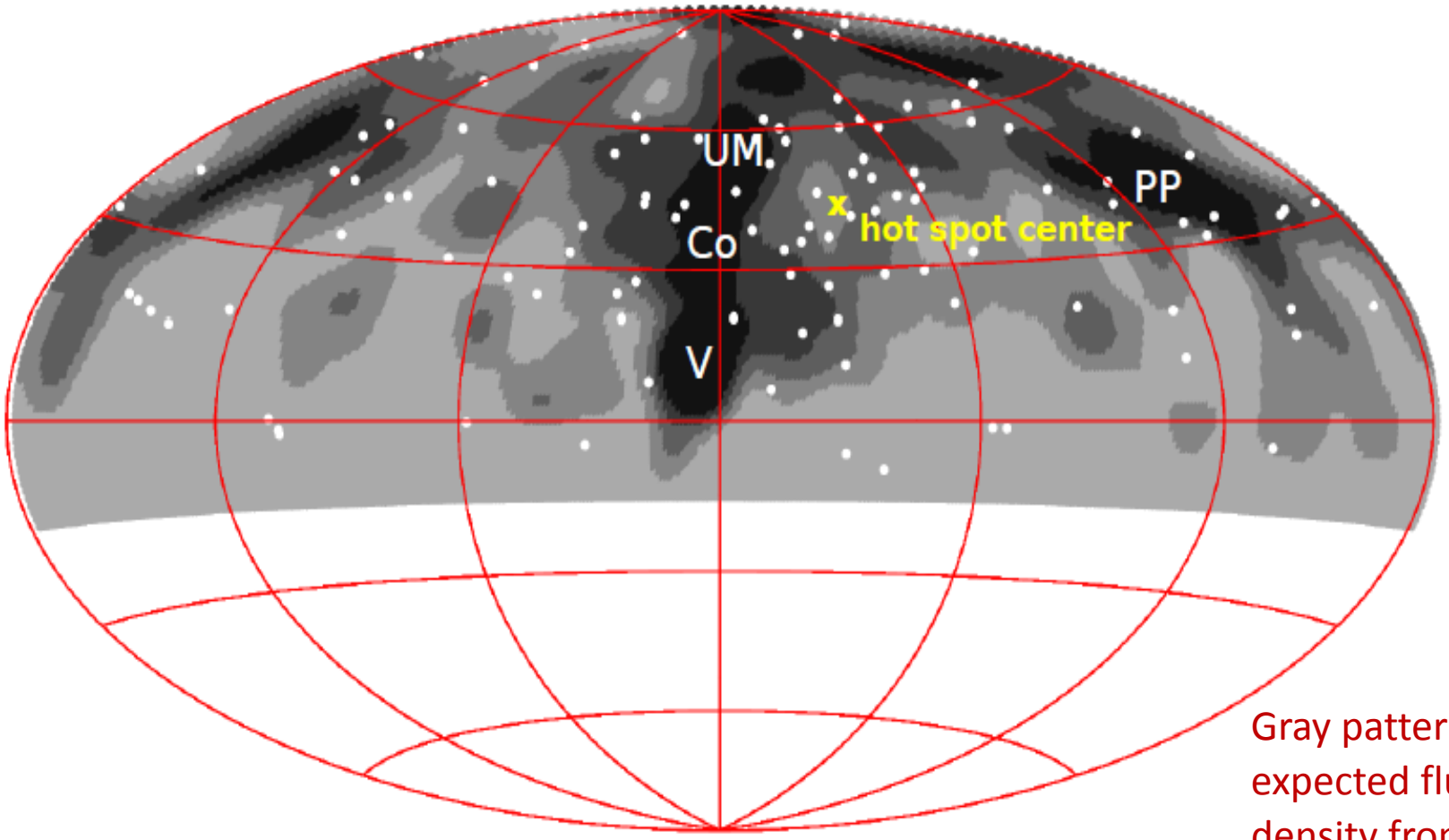
30 Jul 2015 at
14:45

Correlation with Large-Scale Structure (LSS)



Equatorial coordinates. Darker color represents larger flux.
UM — Ursa Major; Co — Coma; V — Virgo; PP — Perseus-Pisces

Gray patterns: expected flux density from proton (E=57 EeV) LSS 2MASS Galaxy Redshift catalog (XSCz)

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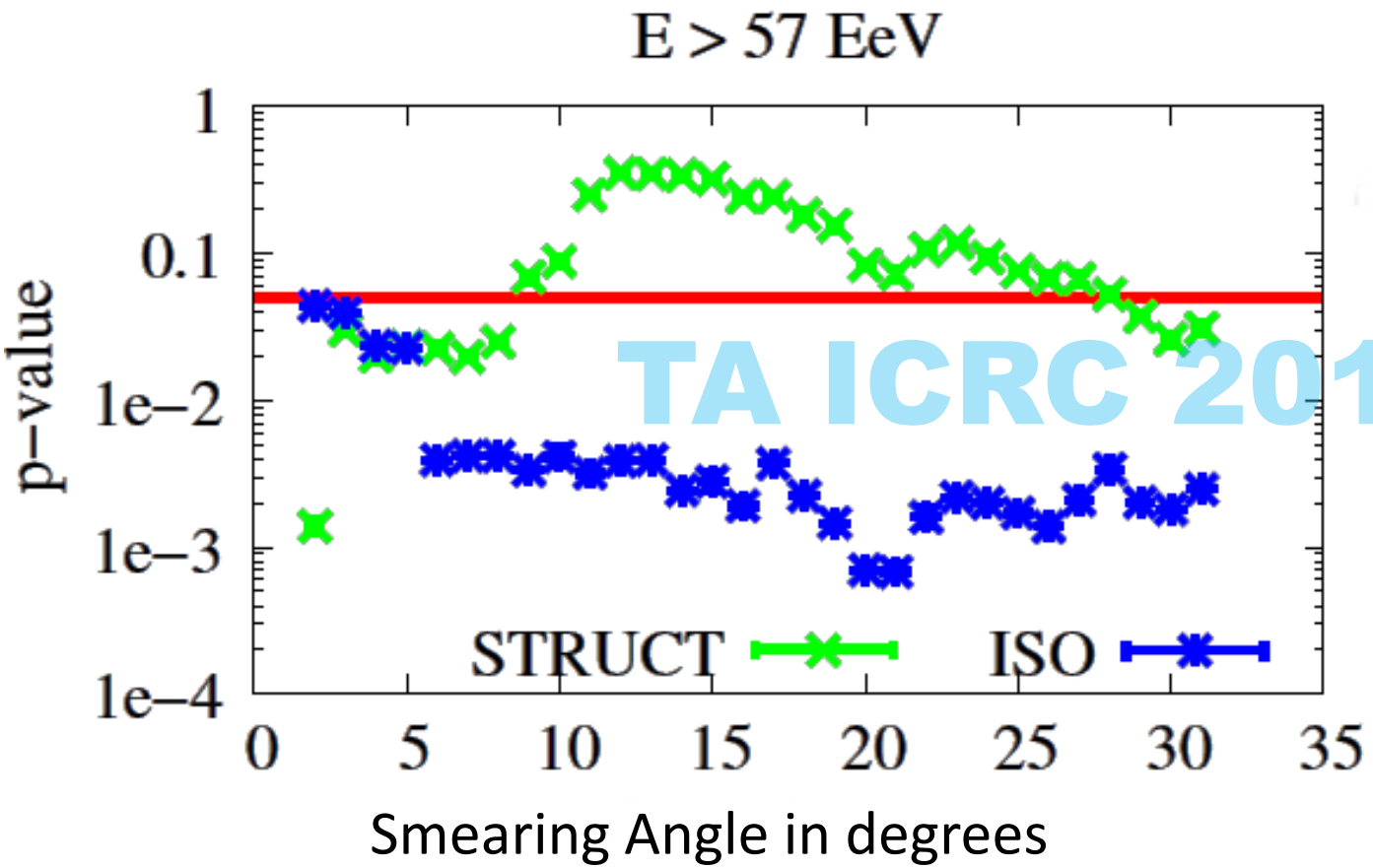
LSS Correlation (continued)

1D Kolmogorov-Smirnov p values comparing expected flux distribution (gray map from previous page) vs. simulation:

Marginally Incompatible with isotropic source simulation

Compatible with LSS source simulation



[765 – Pos 326]
Parallel CR03 Aniso,
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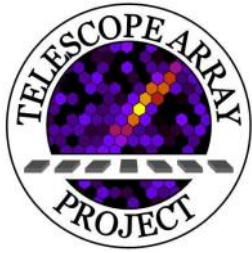
Peter TINYAKOV,
Hiroyuki SAGAWA,
Igor TKACHEV on
30 Jul 2015 at 14:45

Cannot distinguish between LSS and isotropic simulations for E>10 EeV and E>40 EeV

Summary

- TA has measured the energy spectrum, composition and arrival direction of UHE cosmic rays
- New TA Low Energy Extension (TALE) is coming on line. TALE surface detector array has now been funded by Gov't of Japan.
- TA and TALE has measured energy spectrum between 6×10^{15} eV to over 10^{20} eV and have observed spectral features
- The spectrum and composition of UHE cosmic rays measured by TA remain compatible with a single light component at above the ankle (~6×10^{18} eV).
- We have reported a hot spot seen in the direction of Ursa Major with 3.4σ signficance
- **Much more data are needed!**



The Future of TA

To be presented at this conference

[1022 – PoS 657] Parallel CR 19 Future IN Track: CRIN

Presented by Dr. Hiroyuki SAGAWA

on 5 Aug 2015 at 11:15

TA×4 project

Quadruple TA SD (~3000 km^2)

- **500** scintillator SDs
- **2.08 km** spacing

2 FD stations

Proposals

- **SD: approved** in Japan in April 2015
- FD: submit in US in October 2015

Get 19 TA years of SD data by 2020

- Get 16.3 (current) TA years of hybrid data