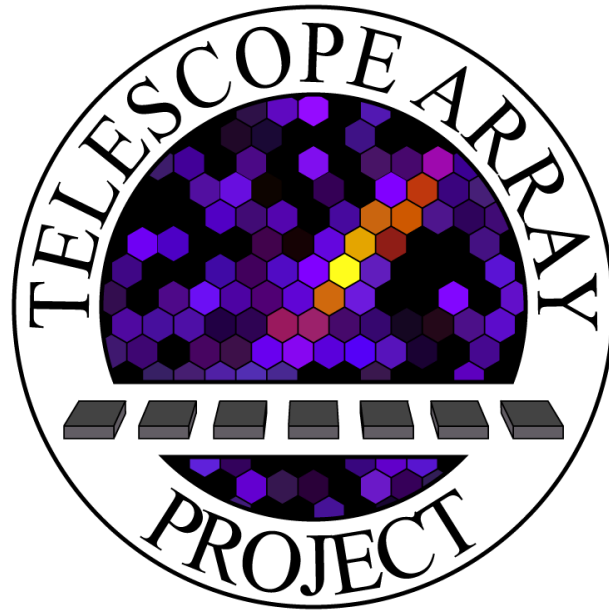# High Energy Spectrum Measured by the Telescope Array Experiment

Dmitri Ivanov
University of Utah
UHECR-2014, Springdale, UT

Outline

- Telescope Array Experiment

- Surface Detector Spectrum

- Fluorescence Mono and Hybrid Spectra

- Comparison with HiRes and Auger
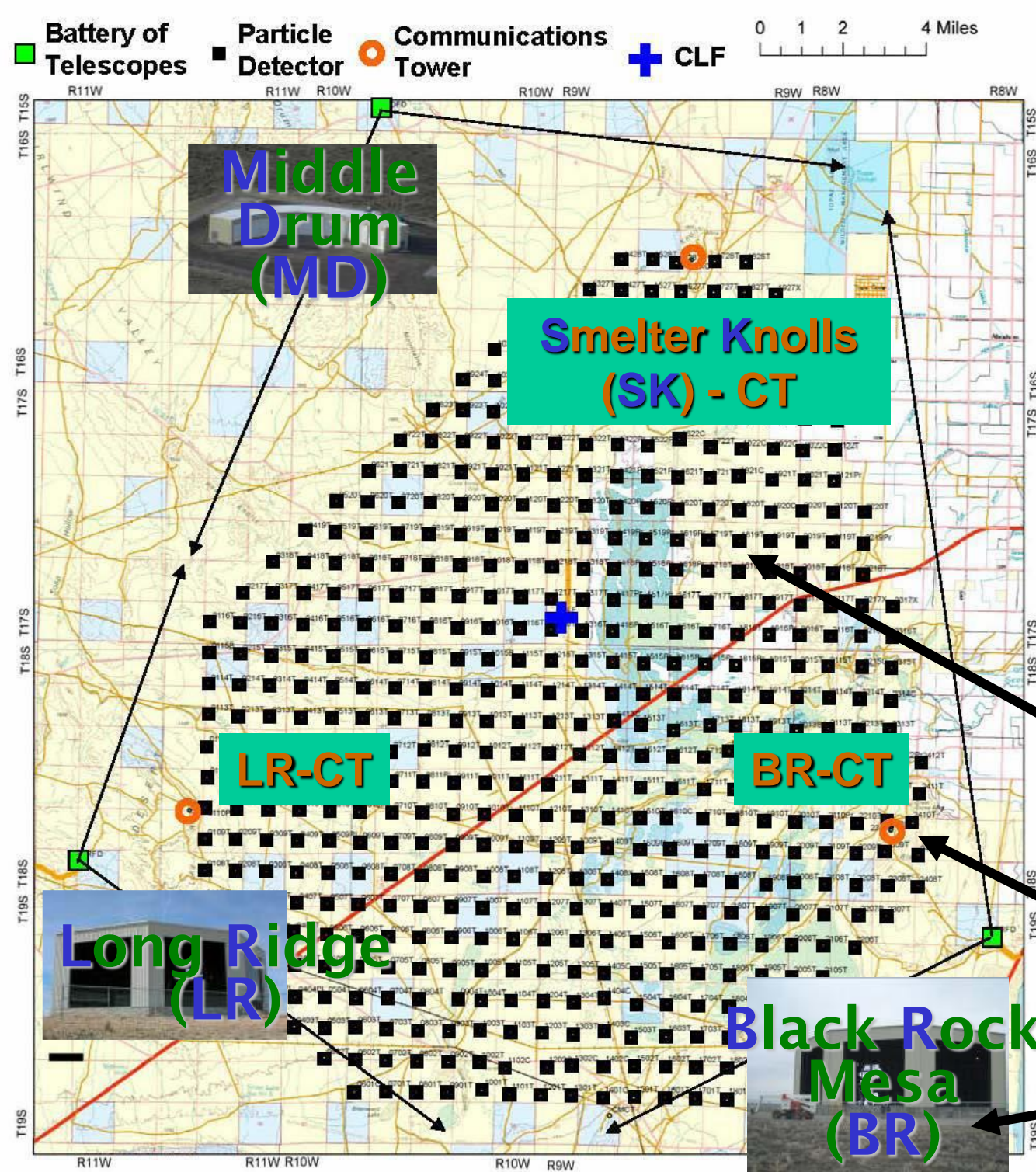
- Conclusions

Telescope Array

Hybrid detector

Millard County, UT
39.3° N , 112.9° W, Alt. 1400m
~880g/cm²
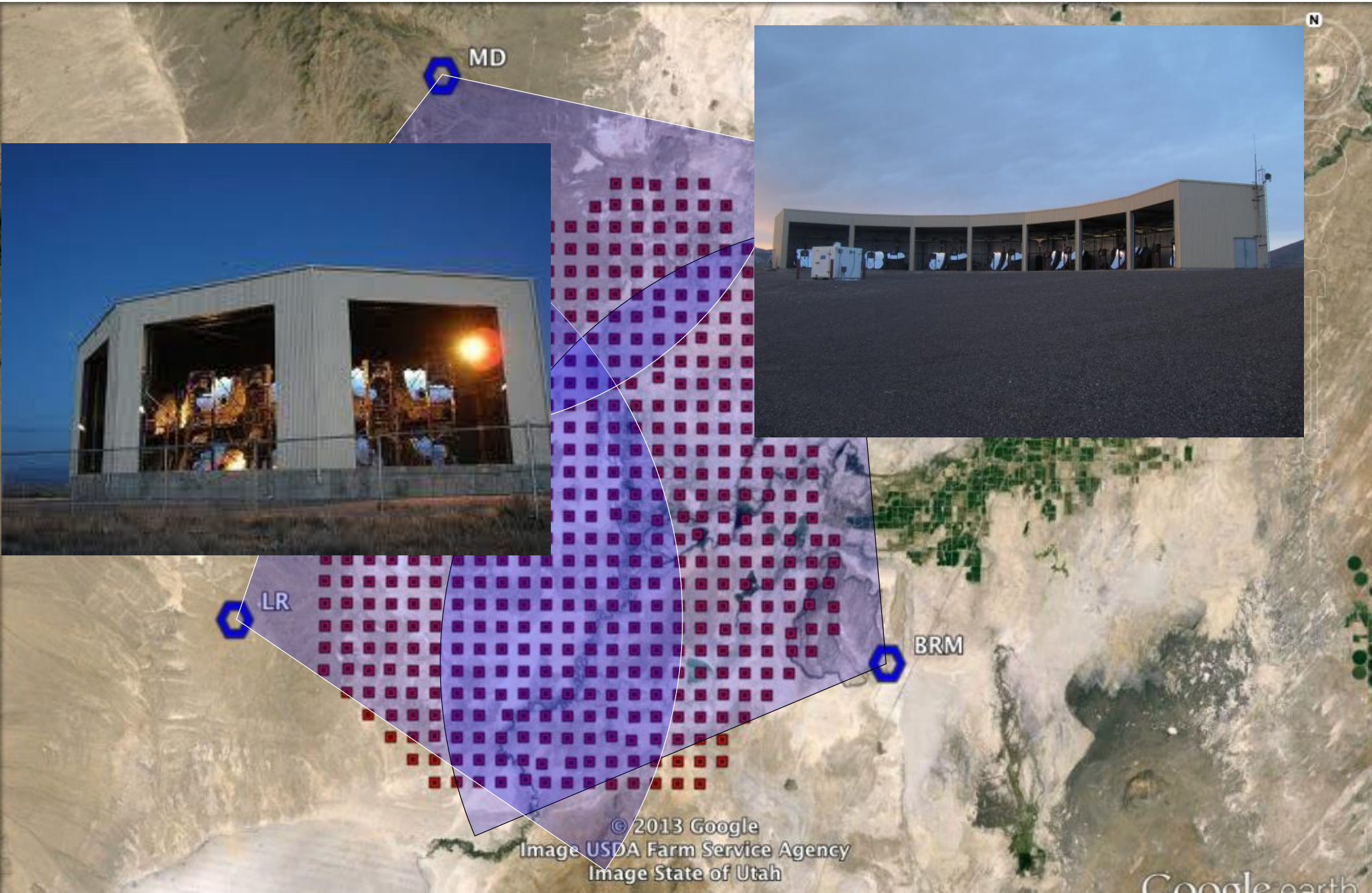
507 Surface Detector (SD) counters, 1.2km apart, cover 680km²

3 Communication Towers (CT): BR,LR,SK

3 Fluorescence Detectors (FD): BR,LR,MD

Battery of Telescopes · Particle Detector ○ Communications Tower ✚ CLF

0 1 2 4 Miles

Middle Drum (MD)

Smelter Knolls (SK) - CT

LR-CT

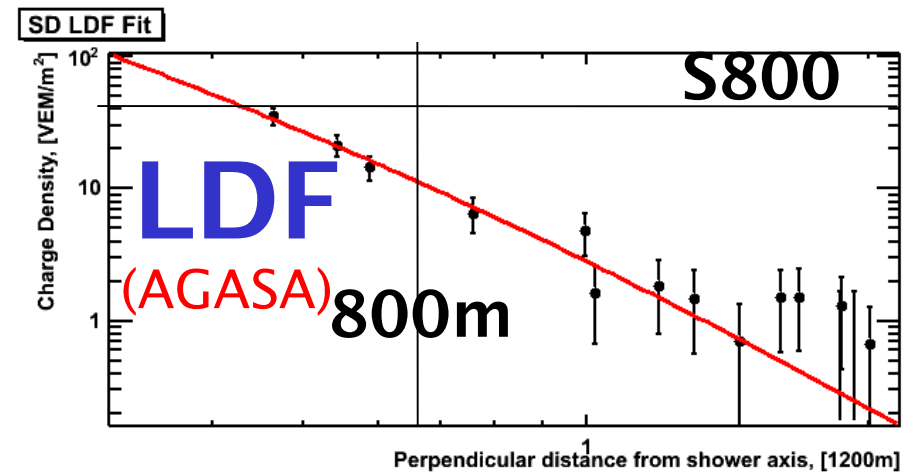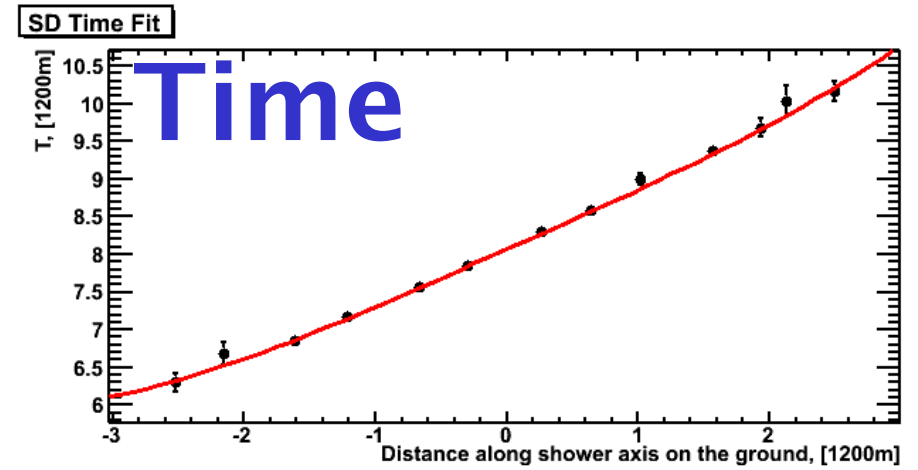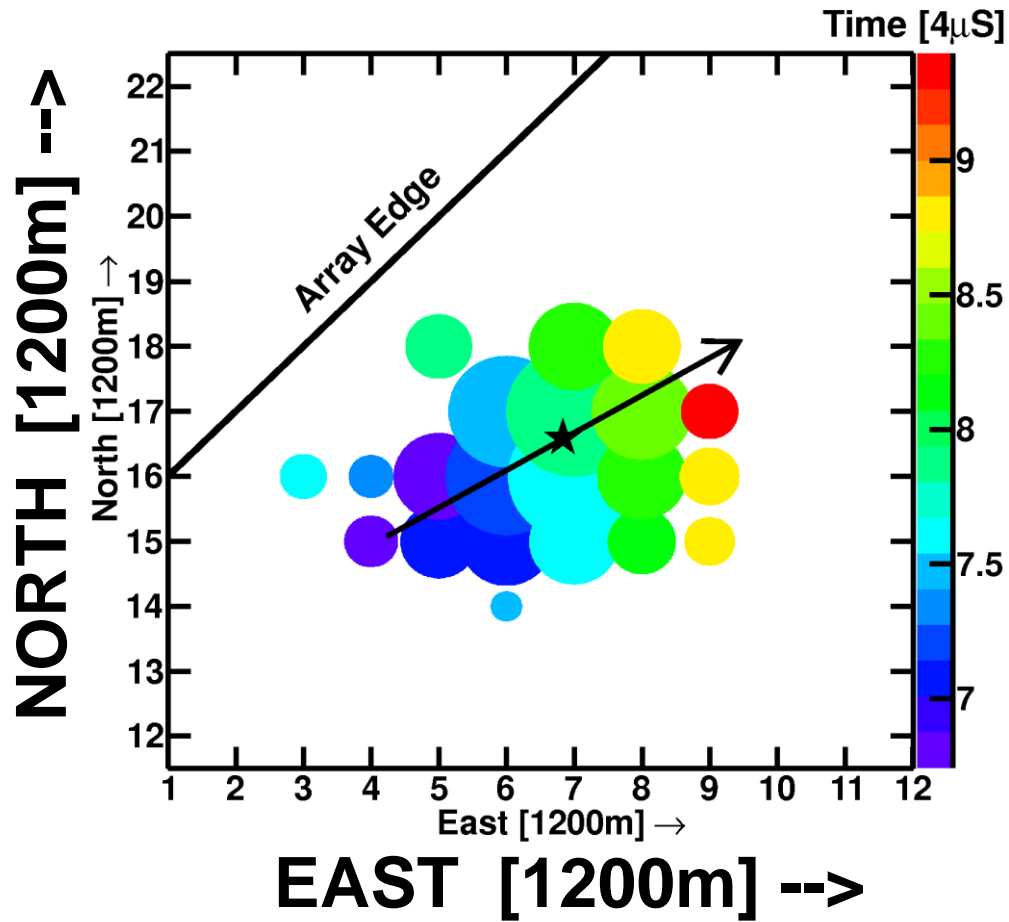BR-CT

Long Ridge (LR)

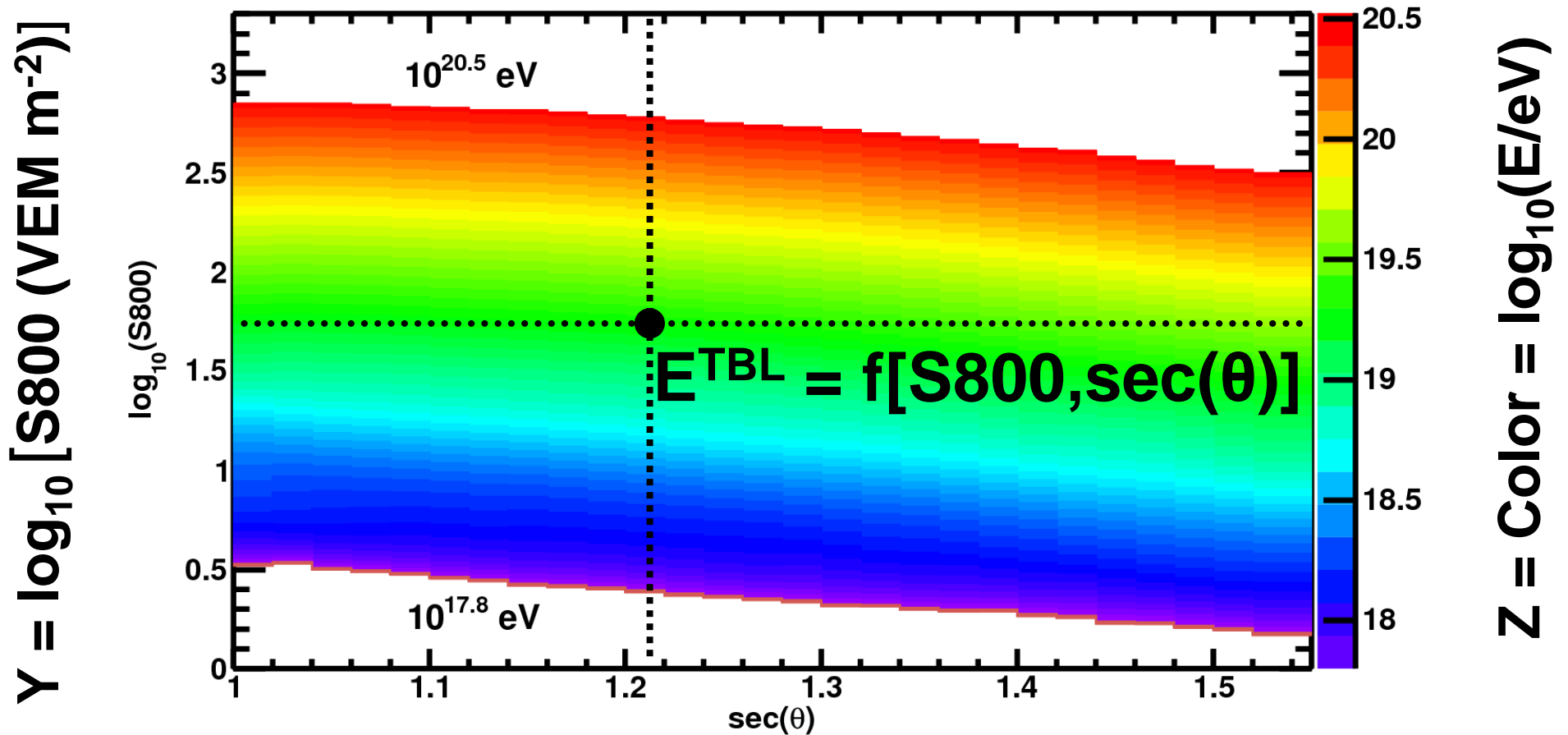Black Rock Mesa (BR)

TA FD

TA Surface Detector

- Powered by solar cells; radio readout.

- In operation since March, 2008.

- Self-calibration using single muons.

- Energy deposited by cosmic ray shower particles is measured in **VEM** units (**V**ertical **E**quivalent **M**uon = energy deposited by a vertical minimum ionizing muon)


2004 12 22

Surface Detector Event

SD Energy 1/2

Y = log$_{10}$ [S800 (VEM m^{-2})]

X = Secant of zenith angle

Z = Color = log$_{10}$(E/eV^{-2})

Inside figure:
- $10^{20.5}$ eV
- $10^{17.8}$ eV
- $E^{TBL} = f[S800, sec(\theta)]$
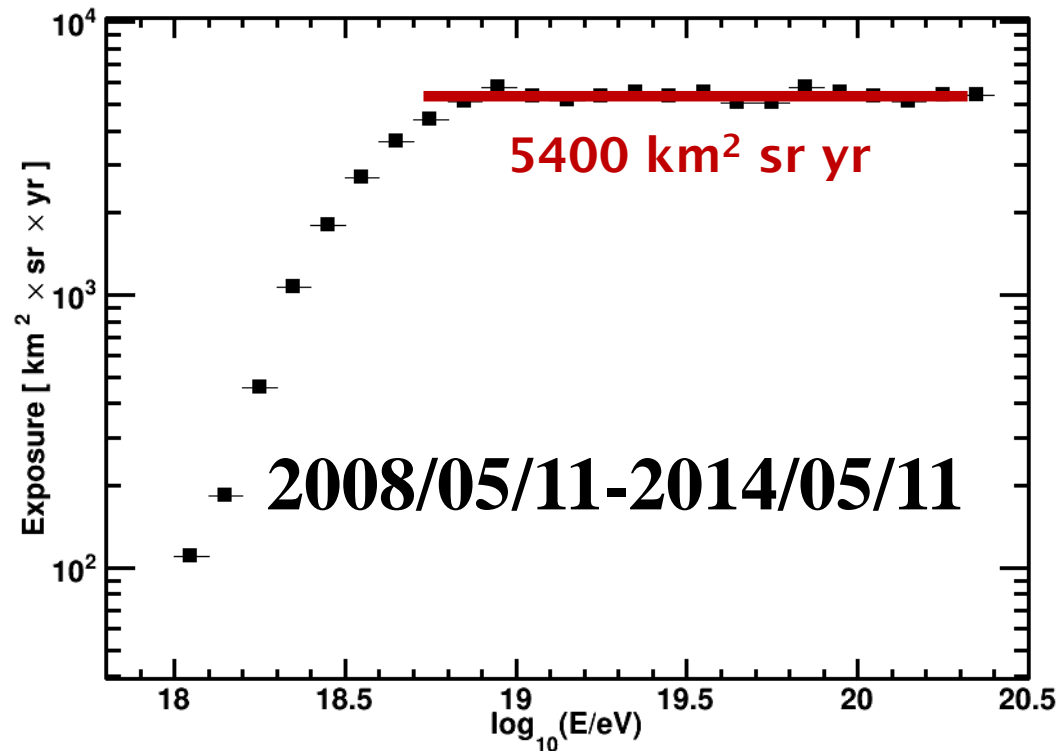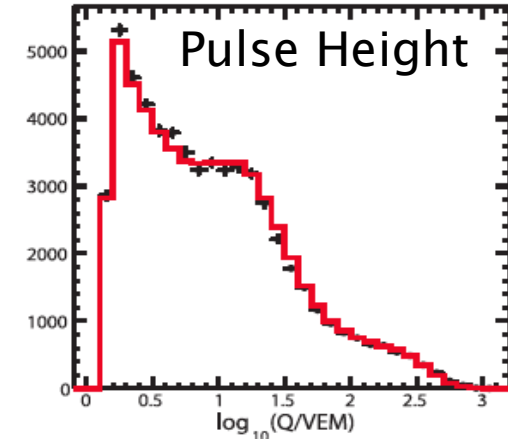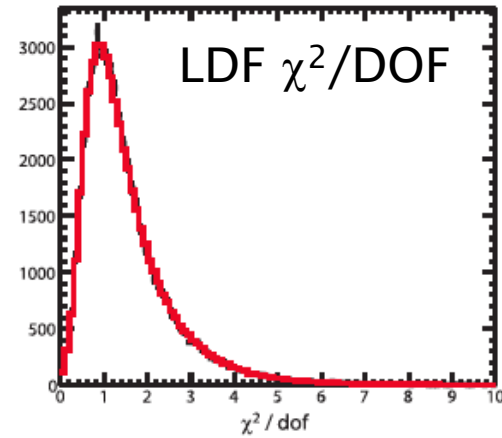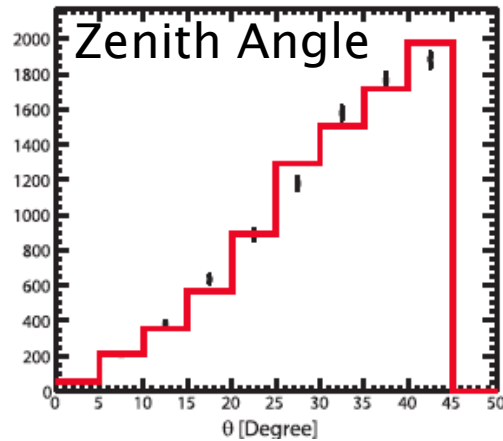- log$_{10}$(S800)
- sec(θ)

- A look-up table made from the Monte-Carlo
- Event energy (E^{TBL}) = function of *reconstructed* S800 and sec(θ)
- Energy reconstruction ⟵⟶ interpolation between S800 vs sec(θ) contours of constant values of E^{TBL}
- The overall energy scale locked to the fluorescence detector

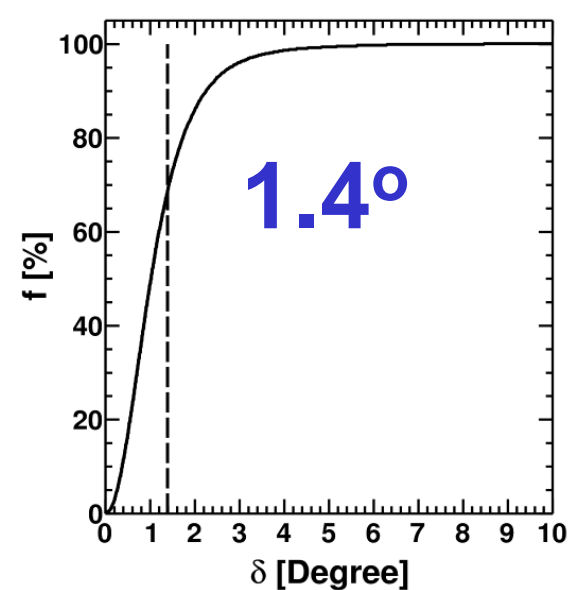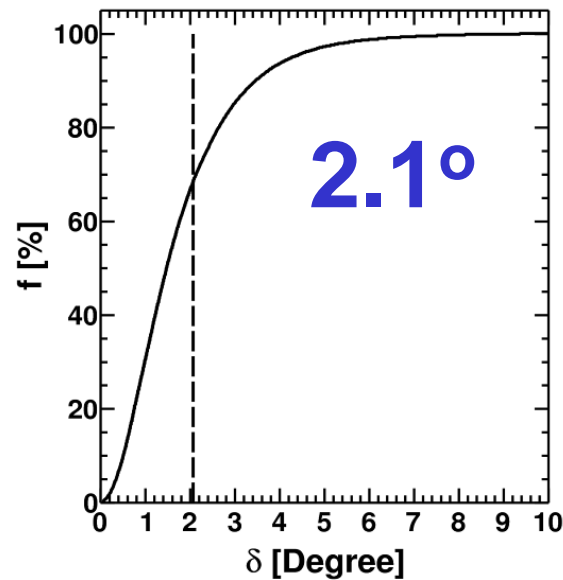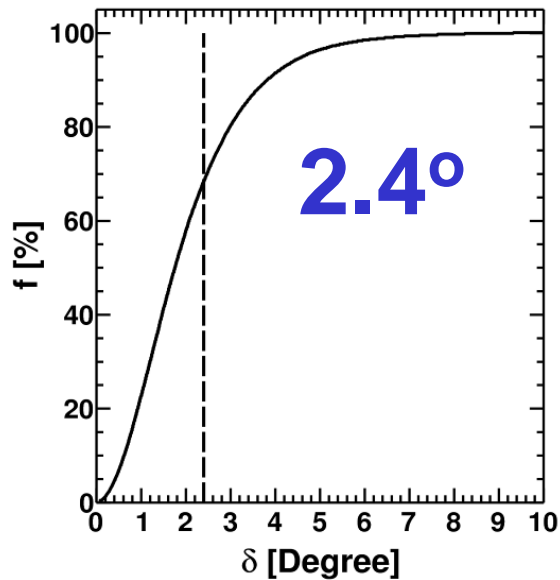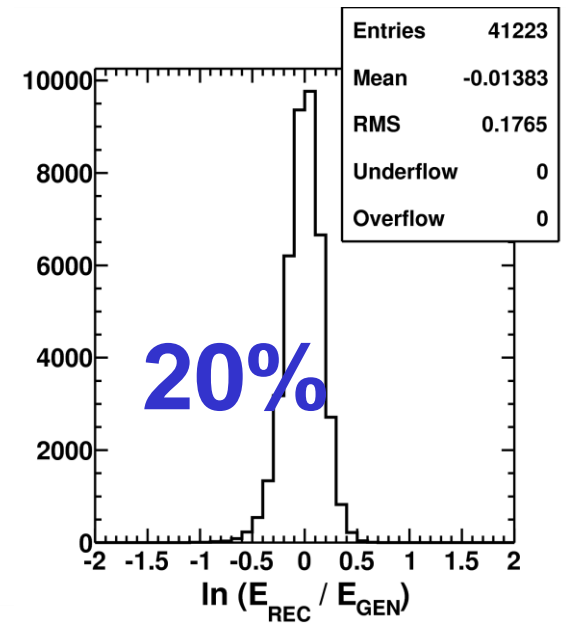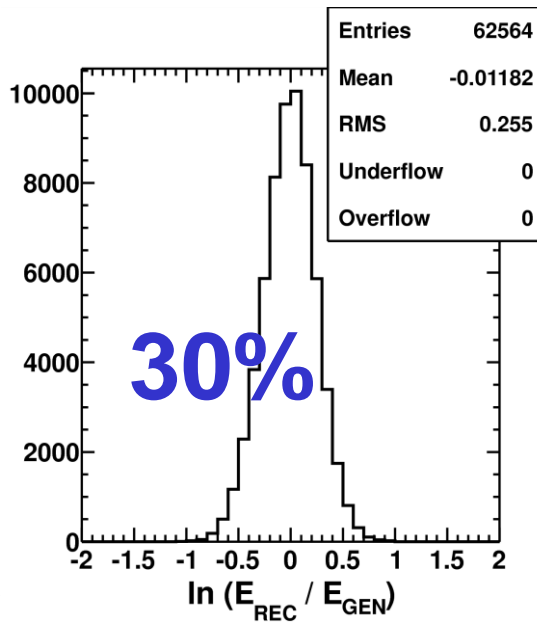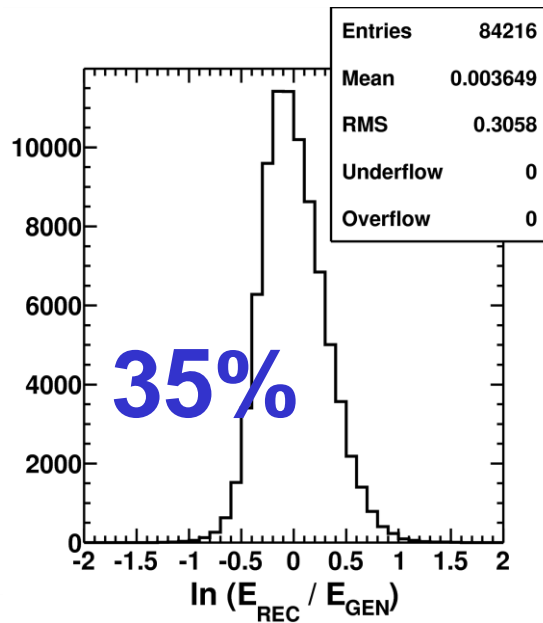# SD Energy 2/2: Energy Scale Set to FD
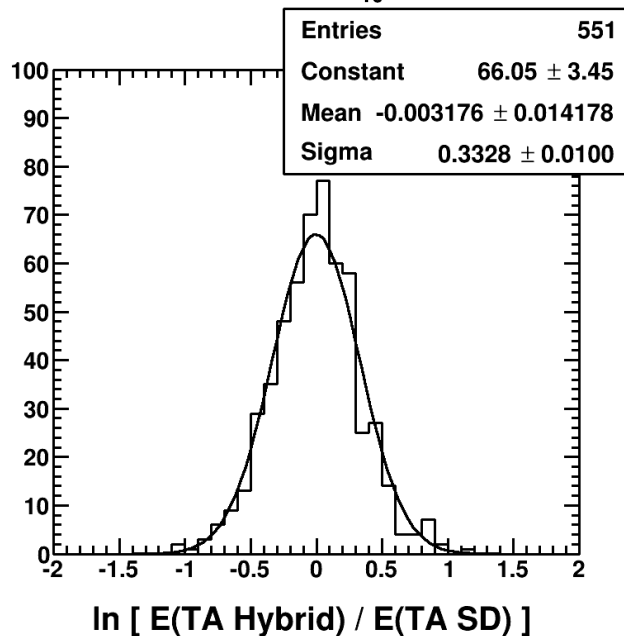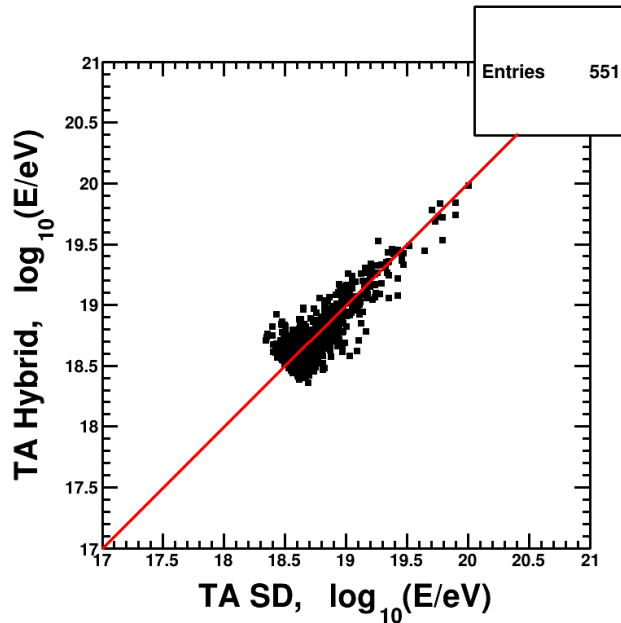
- Energy scale locked to the FD to reduce the systematic due to the model
- Use events well reconstructed separately by SD and FD in hybrid mode:
  - SD ∩ [BR U LR U MD Hybrid]

  - $E^{FINAL} = E^{TBL} / 1.27$
- TOP figure: E^{FINAL} vs E^{FD} scatter plot
- BOTTOM figure: histogram of E^{FINAL} / E^{FD} ratio
- 2008/05/11-2013/05/04

# Exposure from Monte Carlo

SD Resolution from Monte Carlo

Entries	84216
Mean	0.003649
RMS	0.3058
Underflow	0
Overflow	0

35%

$\ln (E_{REC} / E_{GEN})$

Entries	62564
Mean	-0.01182
RMS	0.255
Underflow	0
Overflow	0

30%

$\ln (E_{REC} / E_{GEN})$

Entries	41223
Mean	-0.01383
RMS	0.1765
Underflow	0
Overflow	0

20%

$\ln (E_{REC} / E_{GEN})$

2.4°

δ [Degree]

2.1°

δ [Degree]

1.4°

δ [Degree]

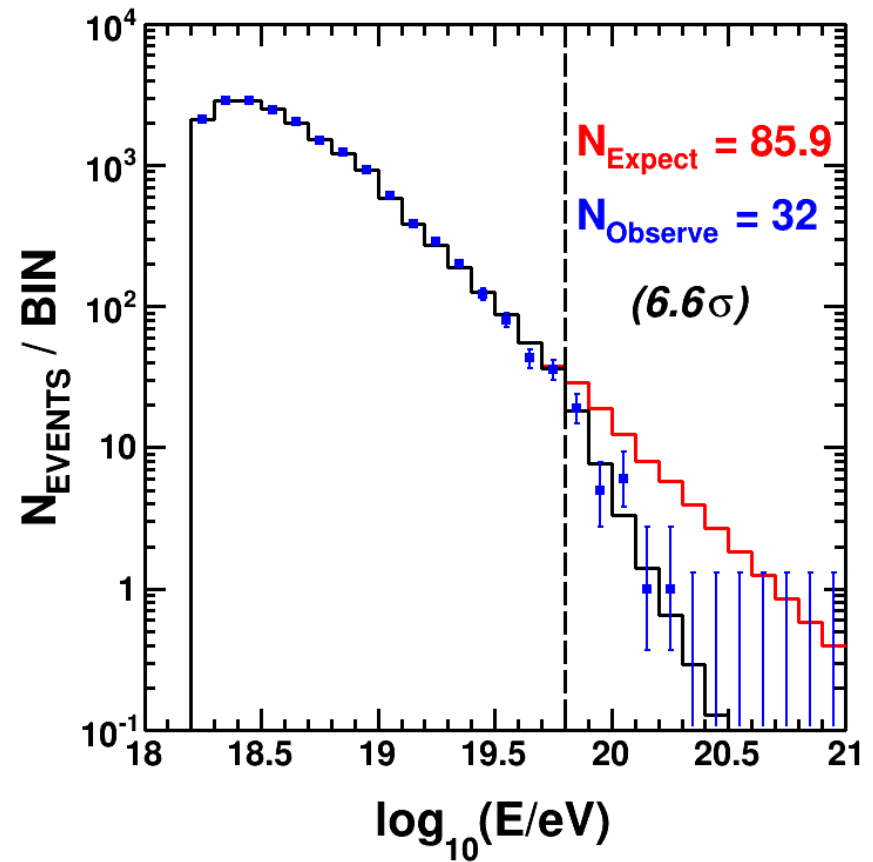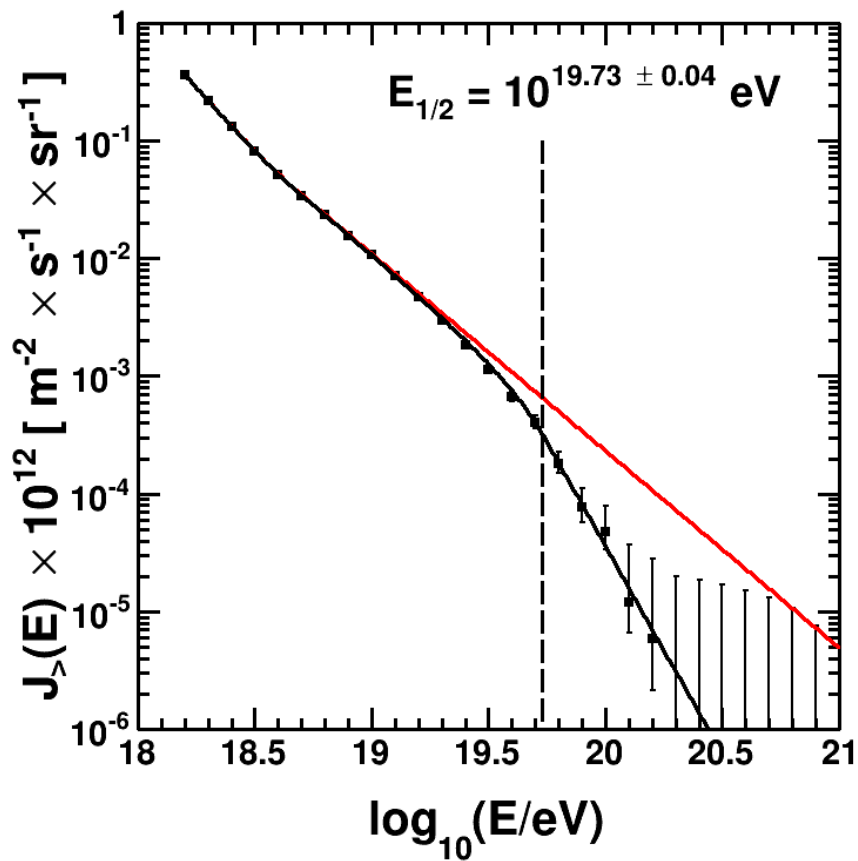$10^{18} - 10^{18.5}$ eV $10^{18.5} - 10^{19.0}$ eV $10^{19.0} - 10^{20.5}$ eV

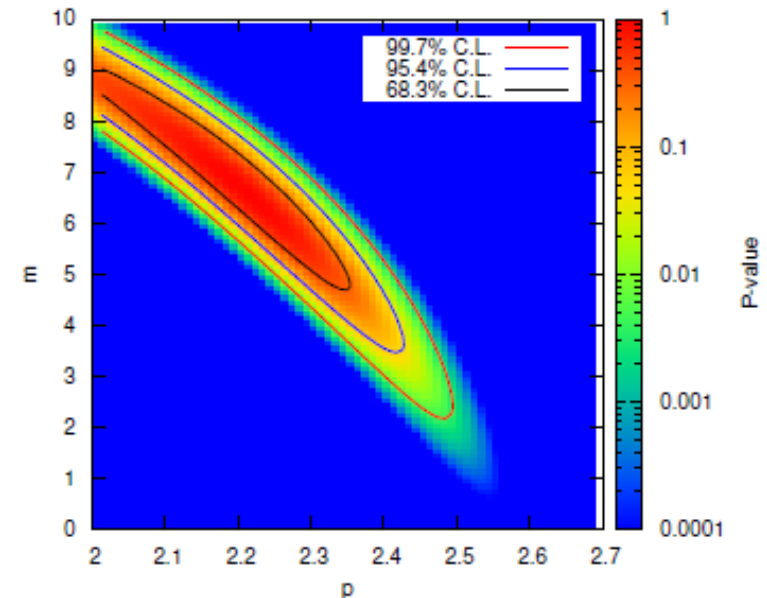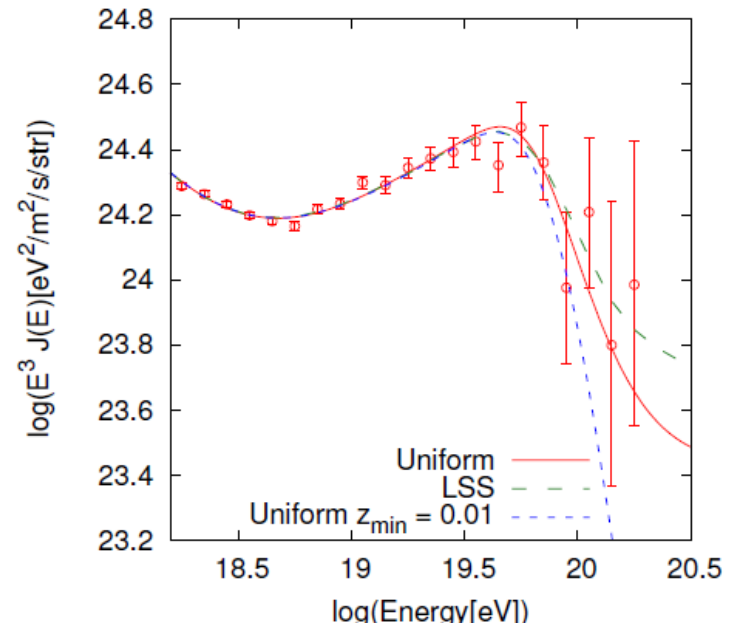# SD Spectrum

2008/05/11-2014/05/11
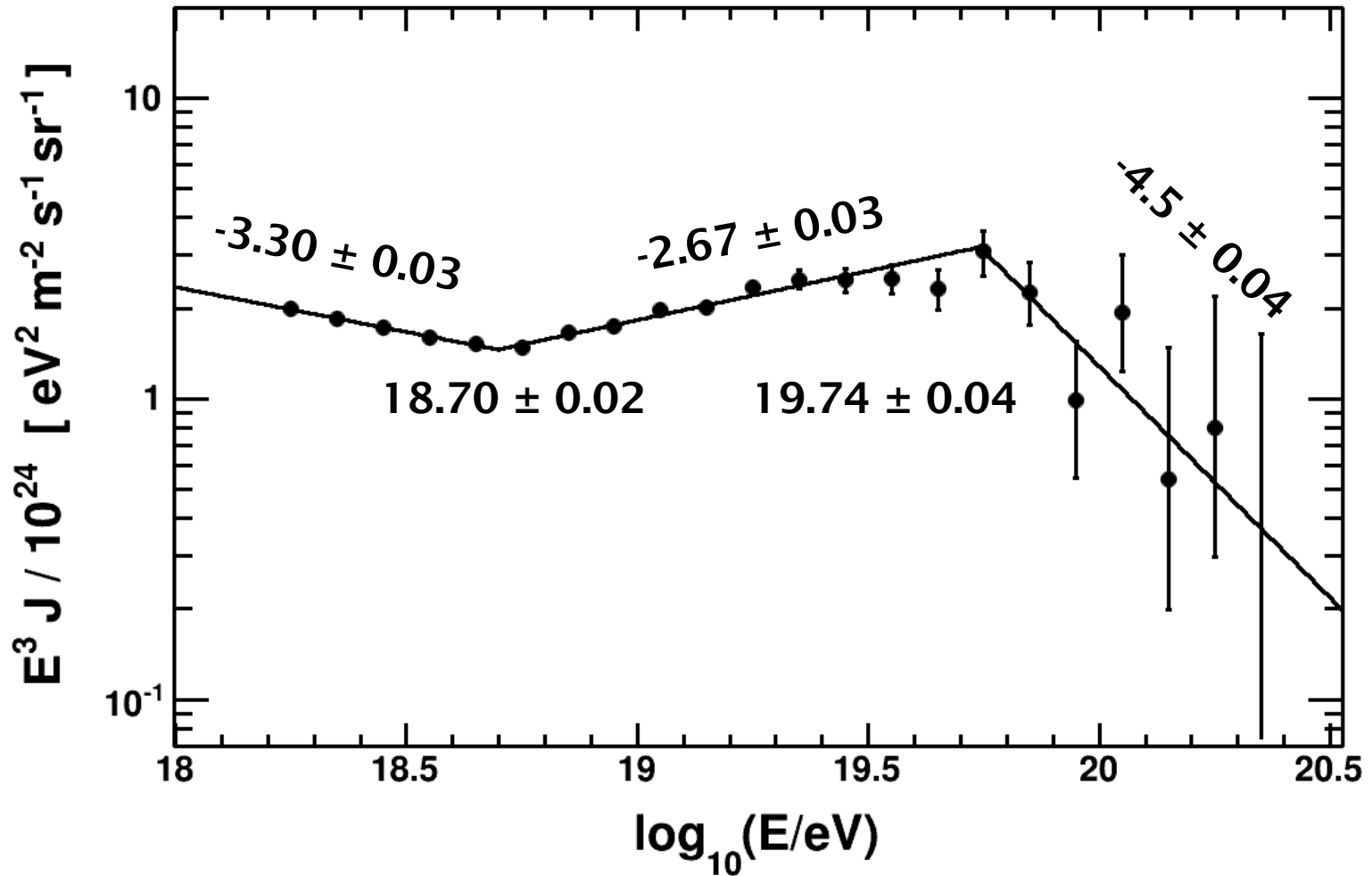
GZK Cutoff

Fit spectrum to energy-loss model
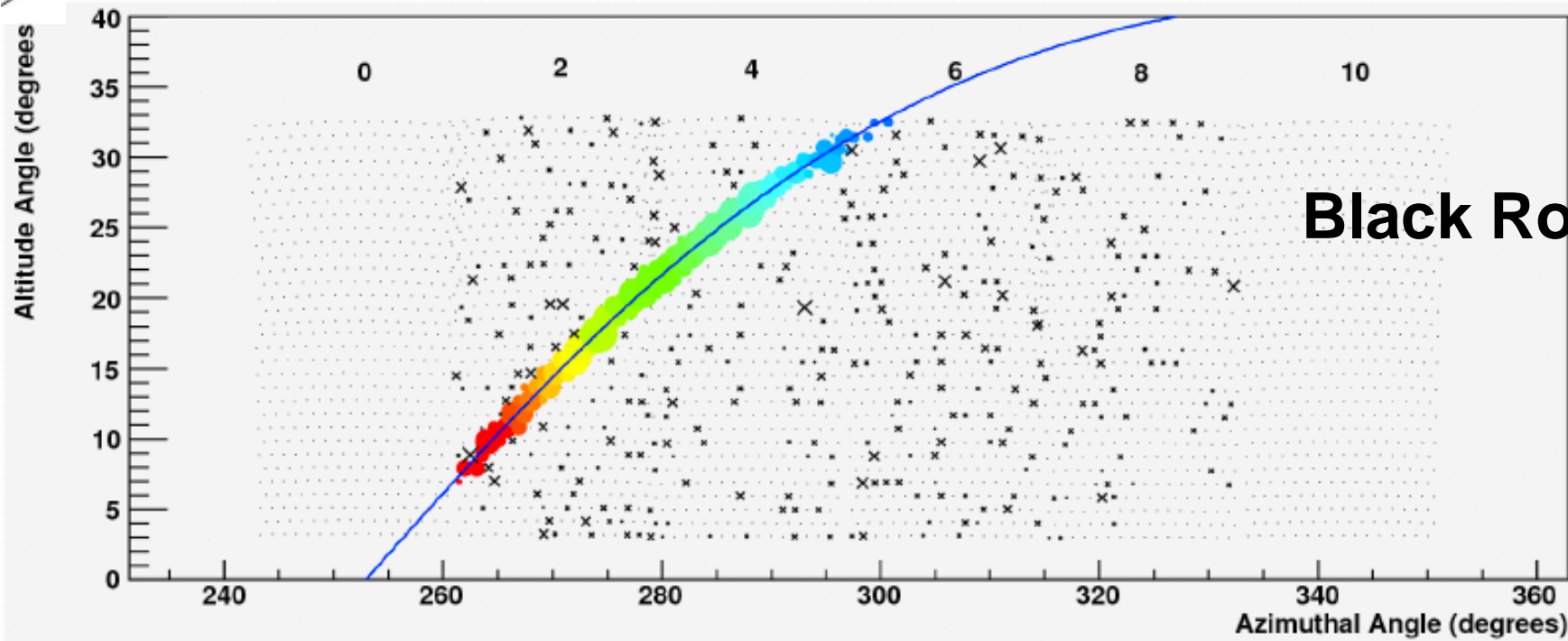
Inputs:

1. Pion photoproduction and e+e- pair production;
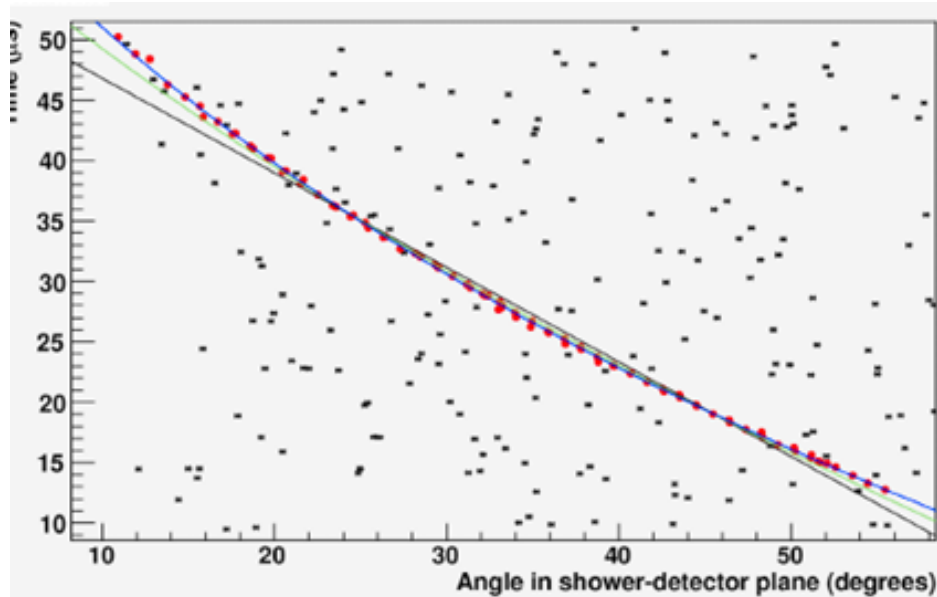
2. Hubble expansion.

Fitting parameters:

1. Power law at the source, E^{-p}
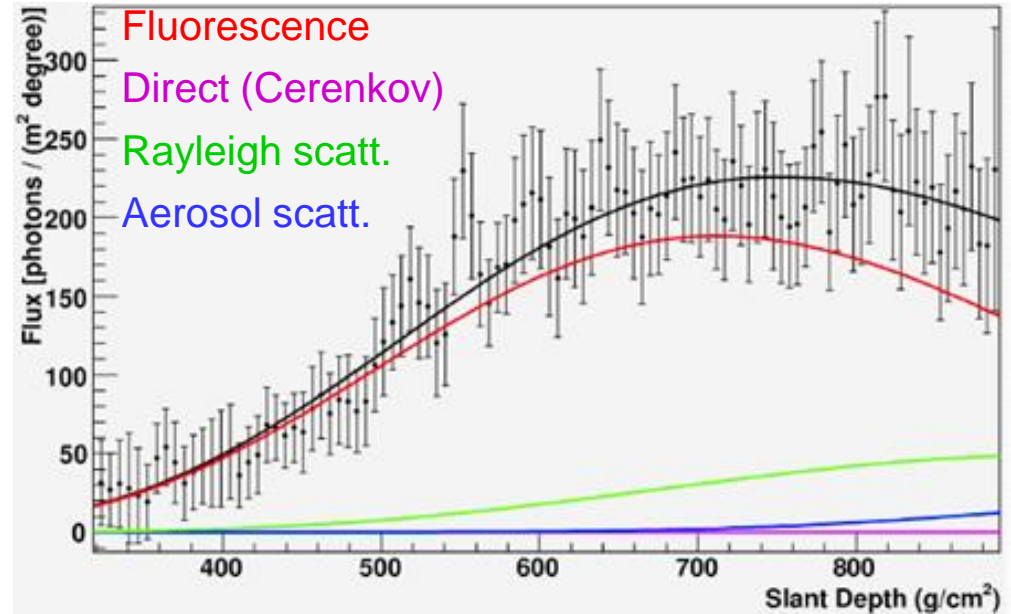
2. Evolution of the sources, $(1+z)^{m}$
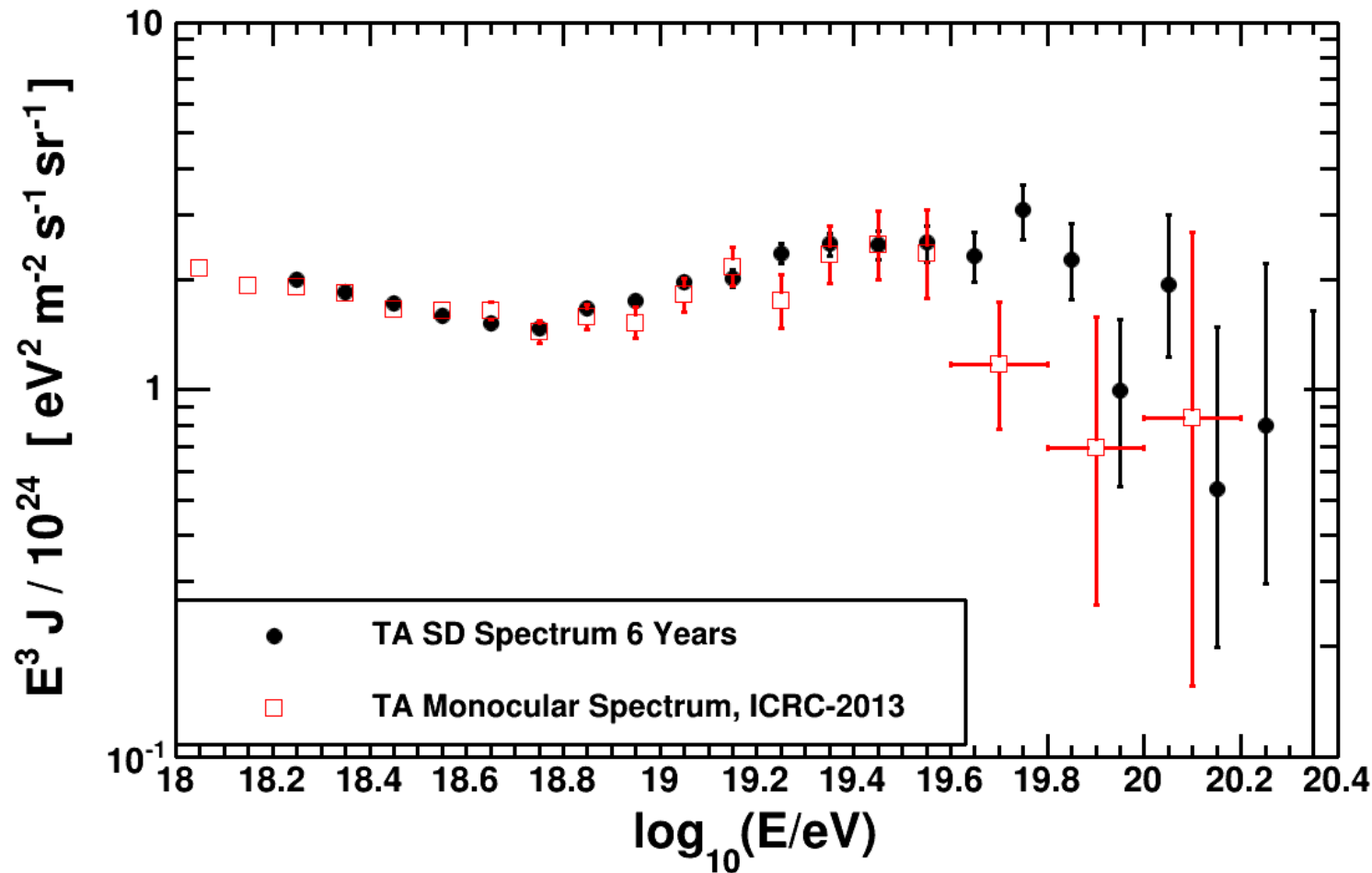
Fluorescence Mono Analysis

Black Rock Mesa

Time fit

Profile fit

Fluorescence
Direct (Cerenkov)
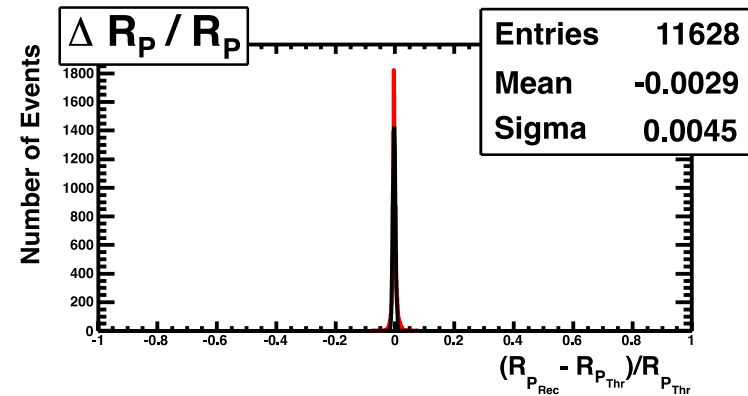Rayleigh scatt.
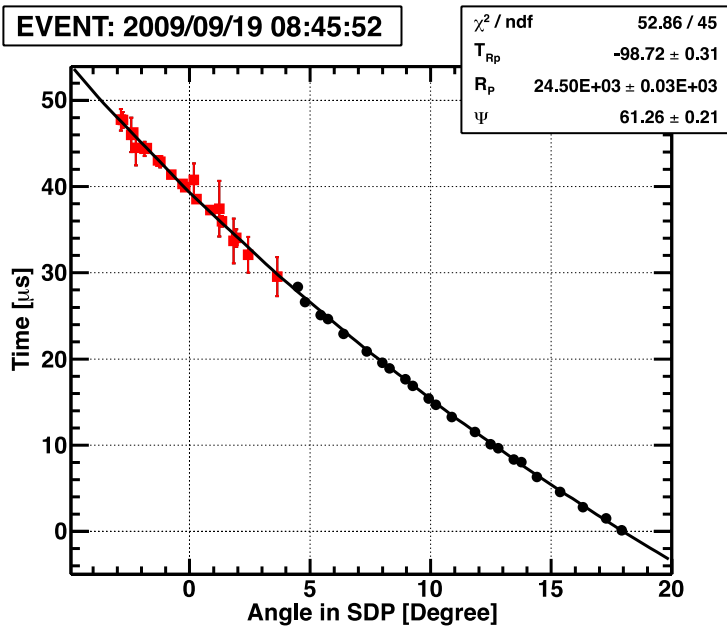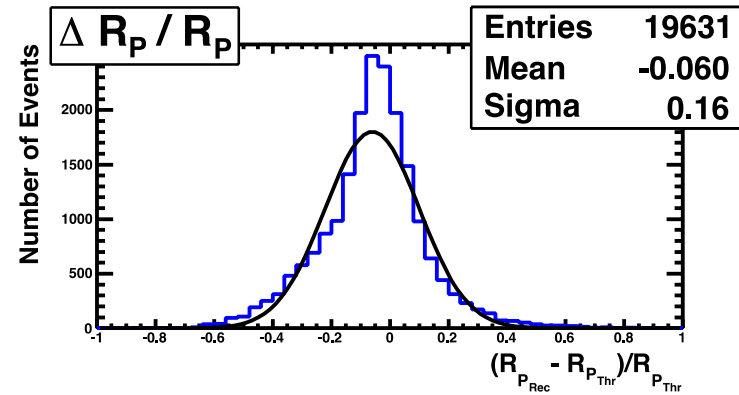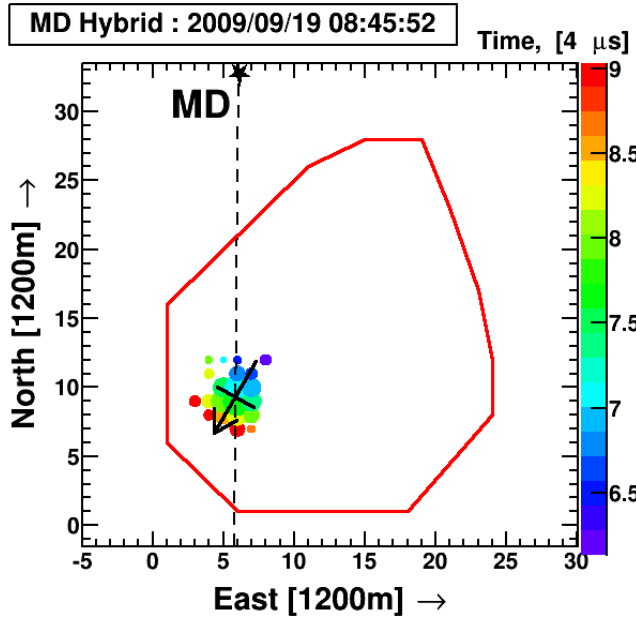Aerosol scatt.

Combined Fluorescence Mono

Combined mono spectrum:
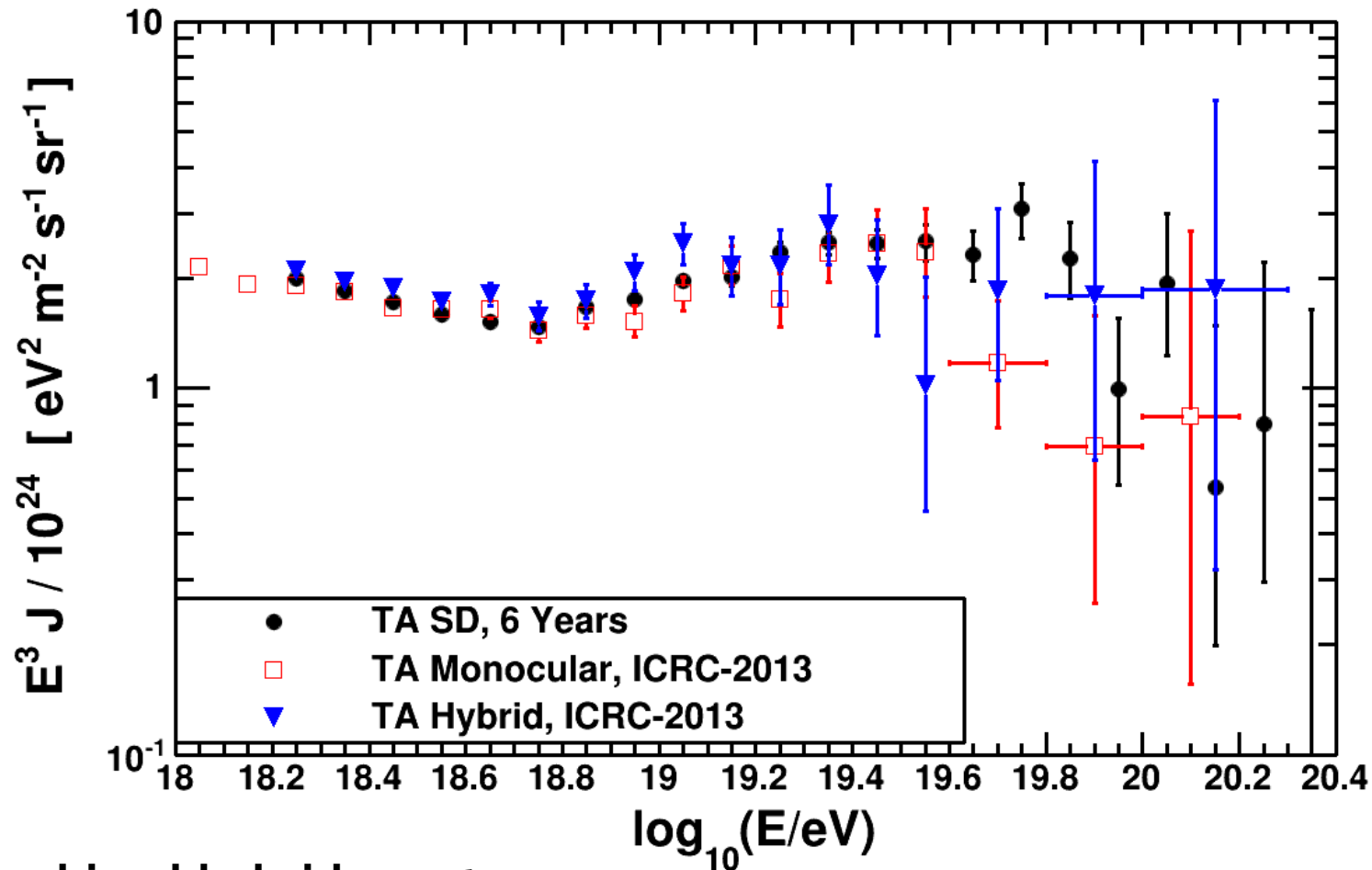**3 years of Middle Drum, APP 39 (2012) 109**
3.5 years of Black Rock / Long Ridge, APP 48 (2013) 16
Use geometric mean of energies, account for the overlaps in the exposure

Hybrid analysis

Combined Hybrid Spectrum

Combined hybrid spectrum:
4 years of Middle Drum Hybrid, submitted to APP
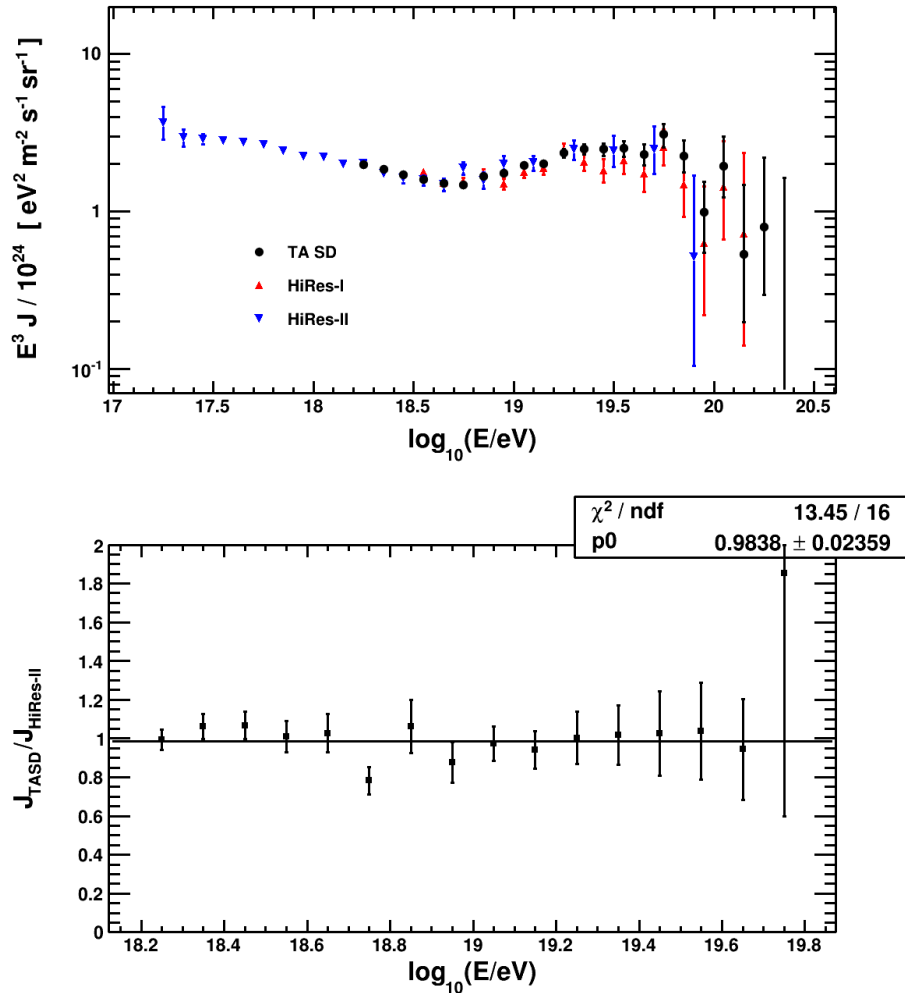**4 years of Black Rock / Long Ridge, APP 61 (2014) 93**

Next

Compare with other experiments:
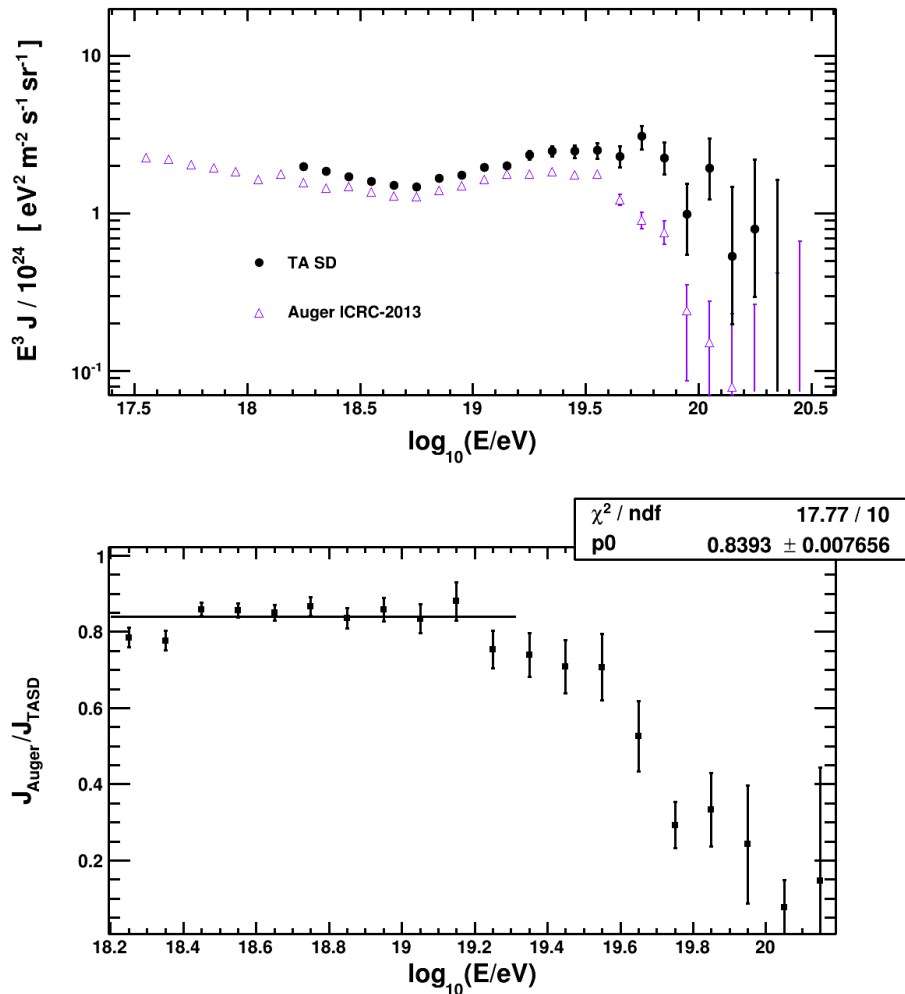HiRes-II, HiRes-II (PRL-2008)
Pierre Auger combined (ICRC-2013)

TA SD and HiRes

- Different experiments using different techniques

- Looking at the same sky

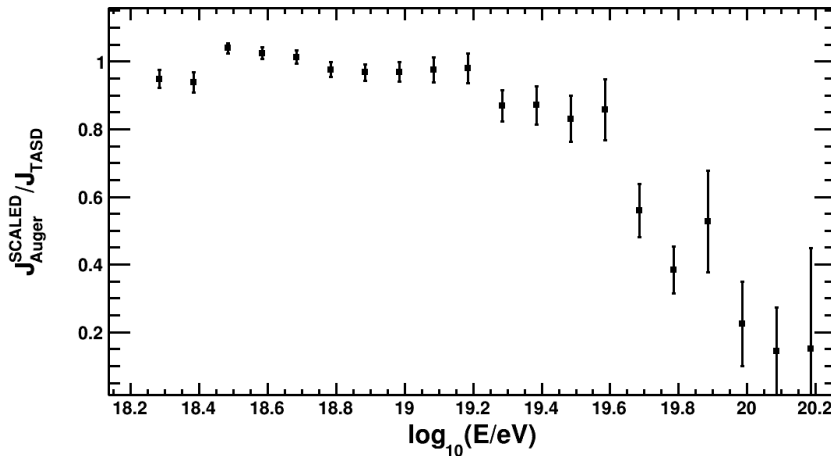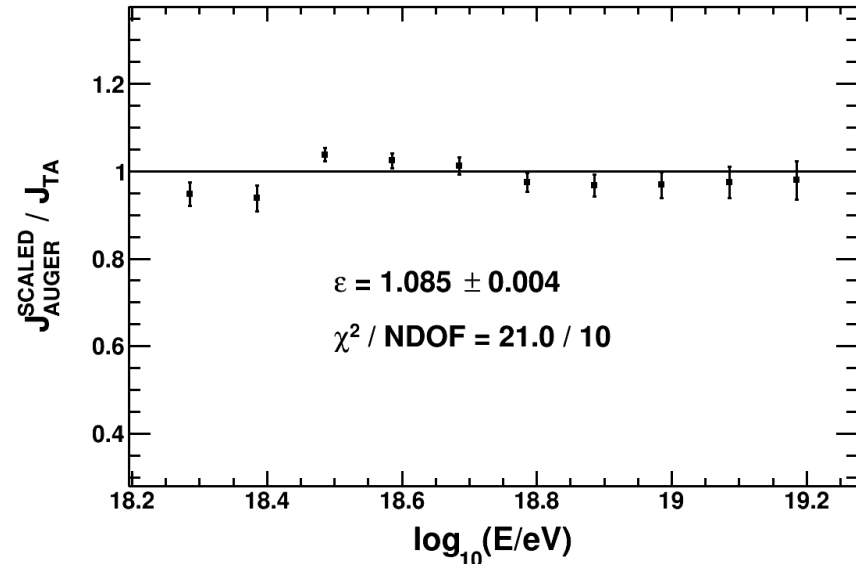- Agreement in overall shape
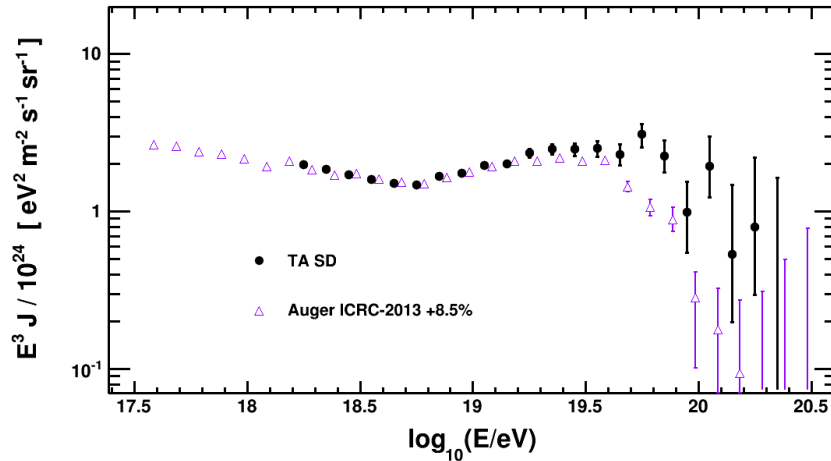
- Same energy scale

TA SD and Pierre Auger

- Similar experiments but looking at different parts of sky

- Auger flux 16% lower than TA in the flat ratio region

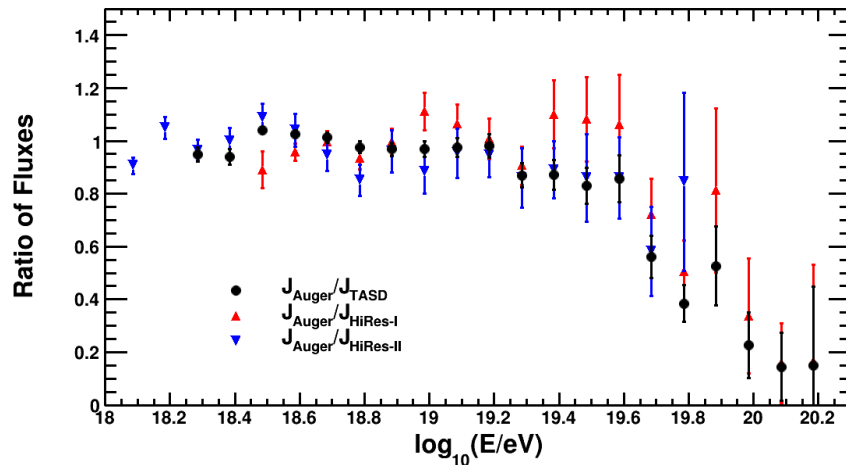- Large differences at the highest energies
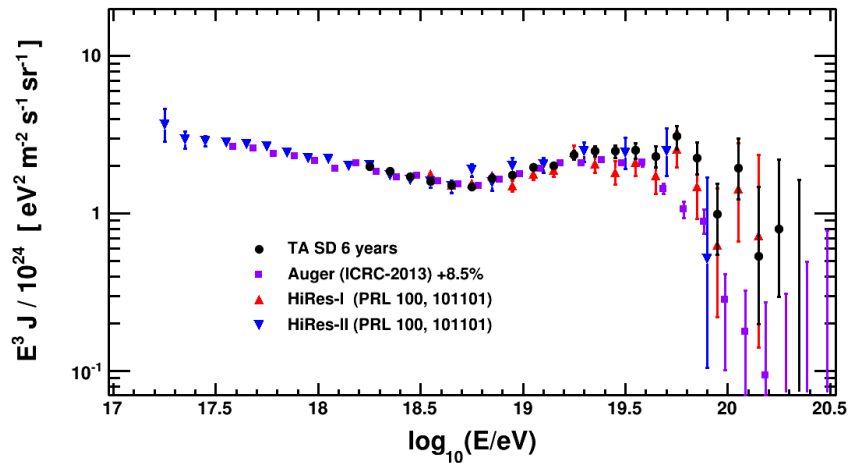
TA SD and Pierre Auger

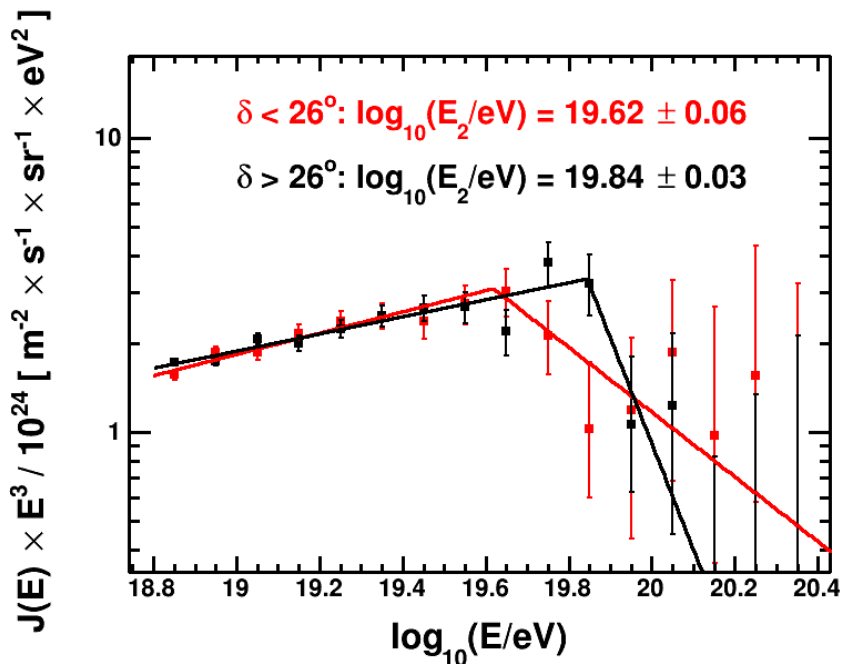Auger energy scale increased by 8.5%

55% difference in the 2nd break point measured by TA($10^{19.73}$eV) and Auger ($10^{19.54}$ eV)

TA SD, Pierre Auger, and HiRes

- Similar feature seen at the highest energies when Auger spectrum is compared to HiRes

Declination dependence of TA spectrum

- Auger and TA sensitive to different parts of the sky

  - TA: delta > -16° (zenith angle < 55)

  - Auger: delta < 26°

- Hint for the declination dependence in TA data (~3σ)

Conclusion

- SD Spectrum updated to 6 years of data, 2008/05/11-2014/05/11

- Energy scale result is unchanged after including more hybrid events into comparison

- TA Mono, Hybrid, and SD spectra all agree

- Fits the simple proton propagation model

- Agree with HiRes, discrepancy with Auger at the highest energies

- Hint of the declination dependence of the second break point

Thank You

Backup