The cosmic ray anisotropy measured by the ARGO-YBJ experiment and the status of the LHASSO project

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and the LHAASO collaboration

Cosmic Ray Anisotropy Workshop 2011, 28-29 October, University of Wisconsin Pyle Center

Outline

- Motivation
- Analysis method
- The results of the ARGO-YBJ experiment
- The status of the LHAASO project

Motivation

- The cosmic ray anisotropy is important in understanding the origin of cosmic rays and Galactic magnetic fields.

- Many ground experiments have detected large-scale anisotropy of galactic cosmic rays, while different spatial patterns are obtained by the ASr and the Milagro experiments. The two experiments conclude differently on whether the anisotropy is correlated with solar activities.

- ARGO-YBJ has the largest data sample in the similar energy range. A measurement with the highest significance is expected.

- The difference between background estimation methods, equal zenith angle method for ASr and direct integral method for Milagro, are investigated.

Analysis method

- The intensity of CR as a function of arrival direction can be solved by minimizing the following X^2.

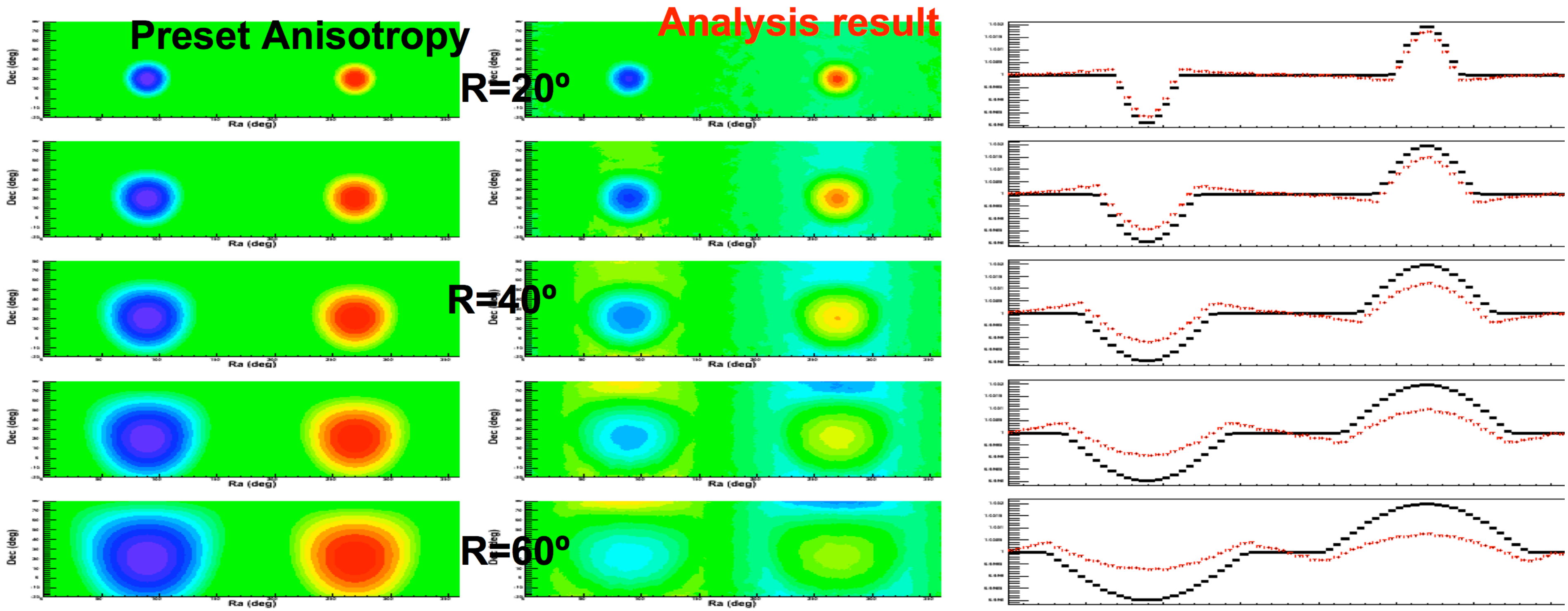
$$\chi^2 = \sum_{m,n,l} \left(\left\{ \frac{N_{\rm obs}(m,n,l)}{I(i,j)} - \frac{\sum_{l' \neq l} [N_{\rm obs}(m,n,l')/I(i',j')]}{\sum_{l' \neq l} 1} \right\}^2 \times \left\{ \frac{N_{\rm obs}(m,n,l)}{I^2(i,j)} + \frac{\sum_{l' \neq l} [N_{\rm obs}(m,n,l')/I^2(i',j')]}{\left(\sum_{l' \neq l} 1\right)^2} \right\}^{-1} \right)$$

ASγ experiment, ApJ, 633:1005–1012 (2005)

- Iteration procedure is very important to find the global minimum.

Why global fitting?

- The equal-zenith angle method, equal-declination angle method (time swapping, direct integral) may underestimate the anisotropy, depending on the scales. A toy MC simulation is used to test this method. Some artificial small structures may be produced.



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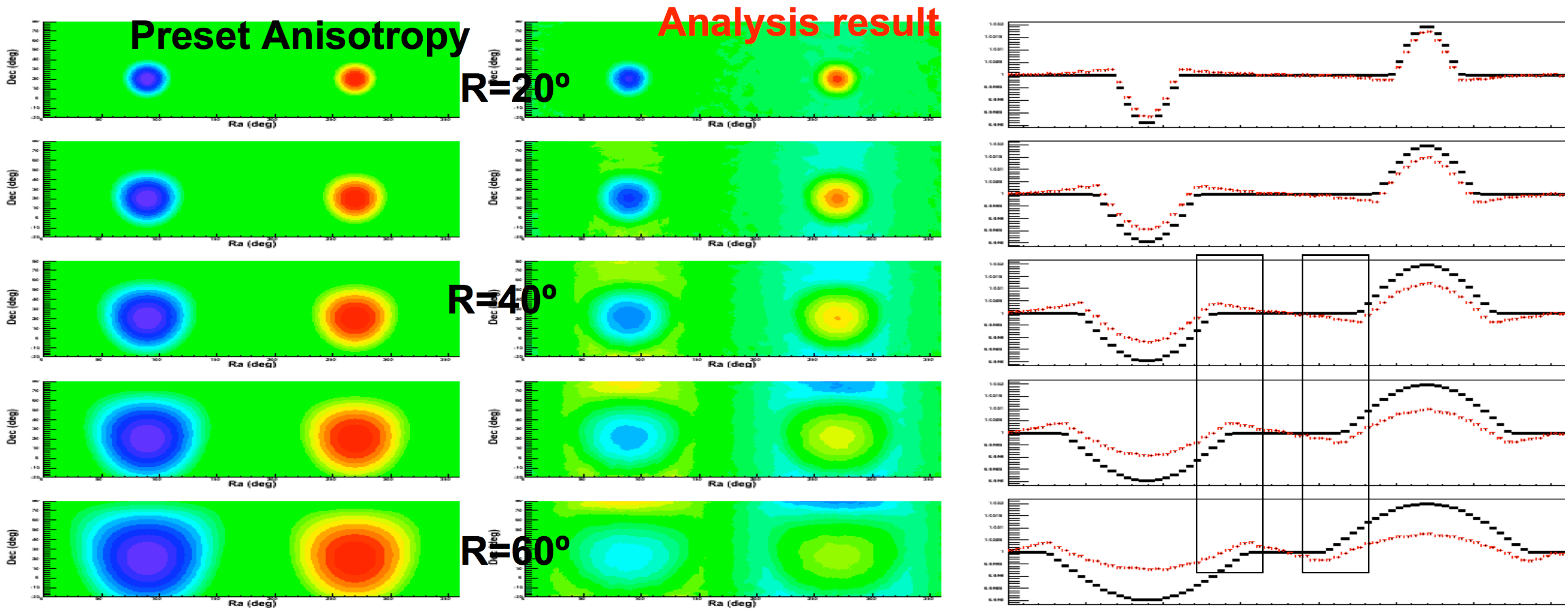

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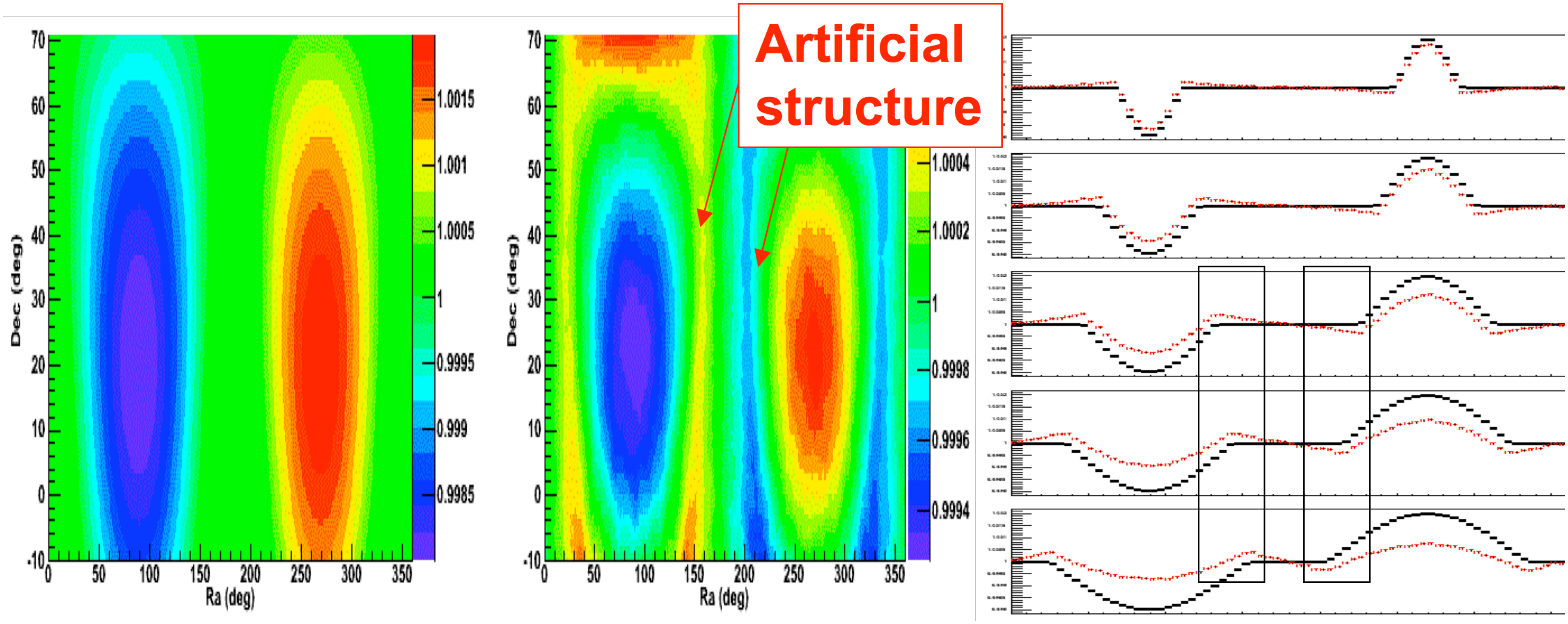
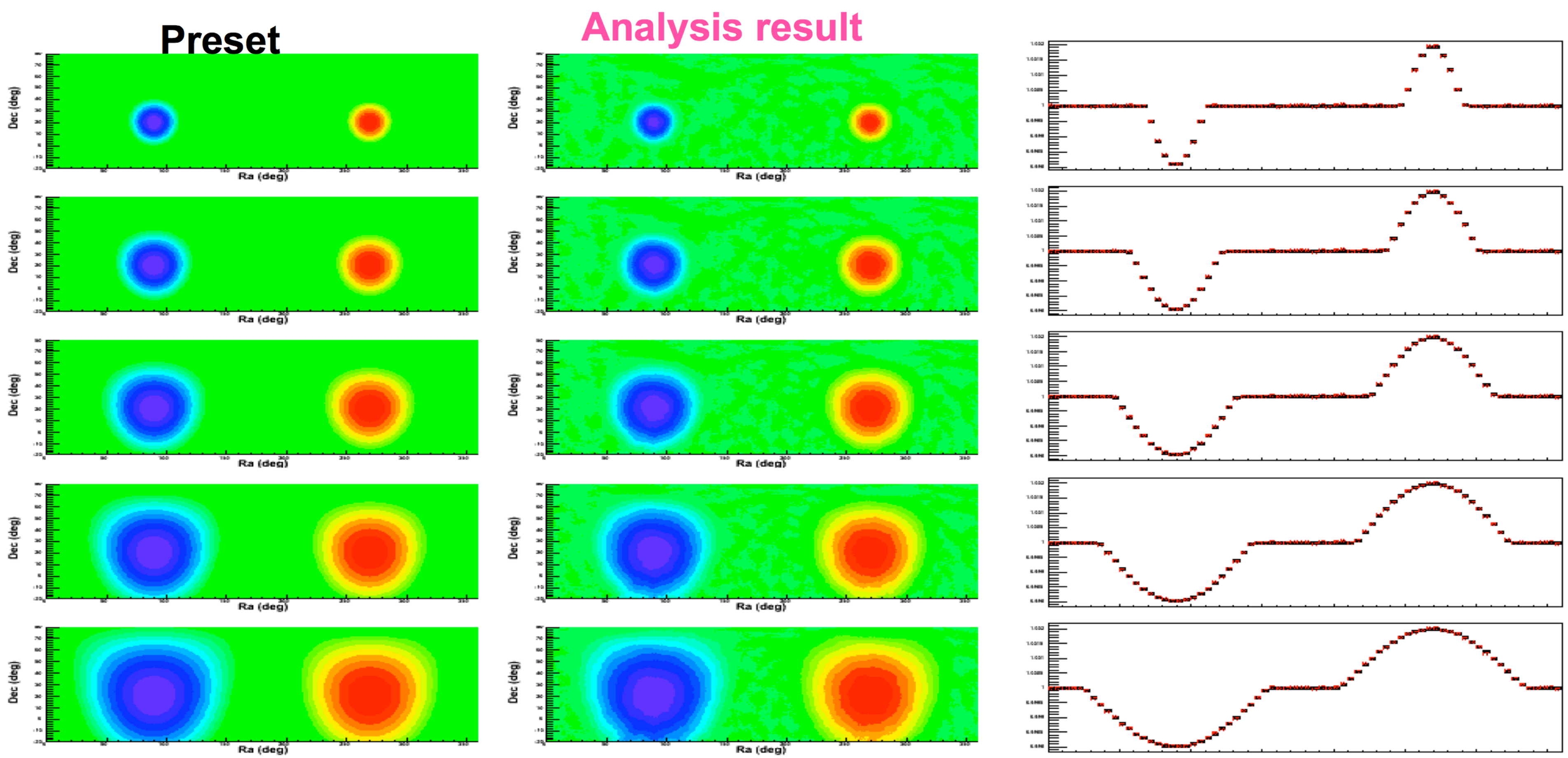


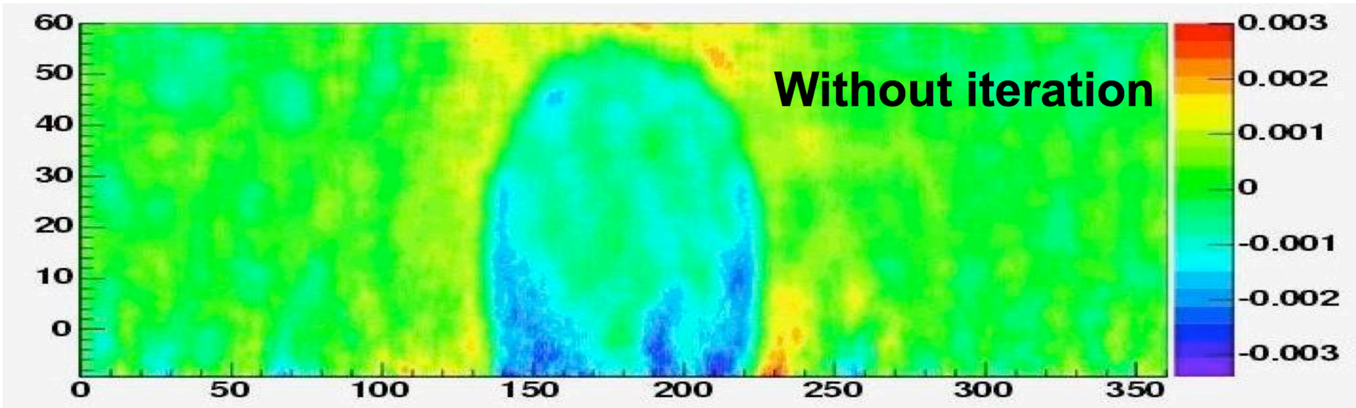
Global fitting based on direct integral method

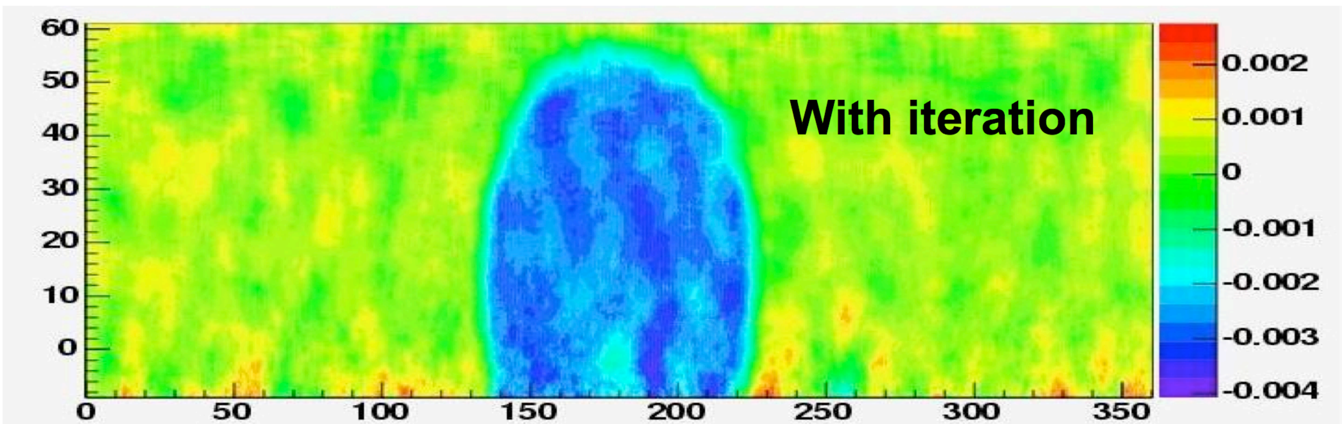
- Global fitting method could effectively reproduce the primary anisotropy for all scales.



Global fitting based on equal zenith angle method

- **A deficit of 0.3% at Dec= 10º, Ra=180º within a cone of 45º is generated in isotropy cosmic ray sky.**
- **The situation is the same as that of the direct integral method.**





Comments

- **The “anisotropy” estimated without iteration, either by “direct integral method” or by “equal zenith angle method”, could be fooling.**

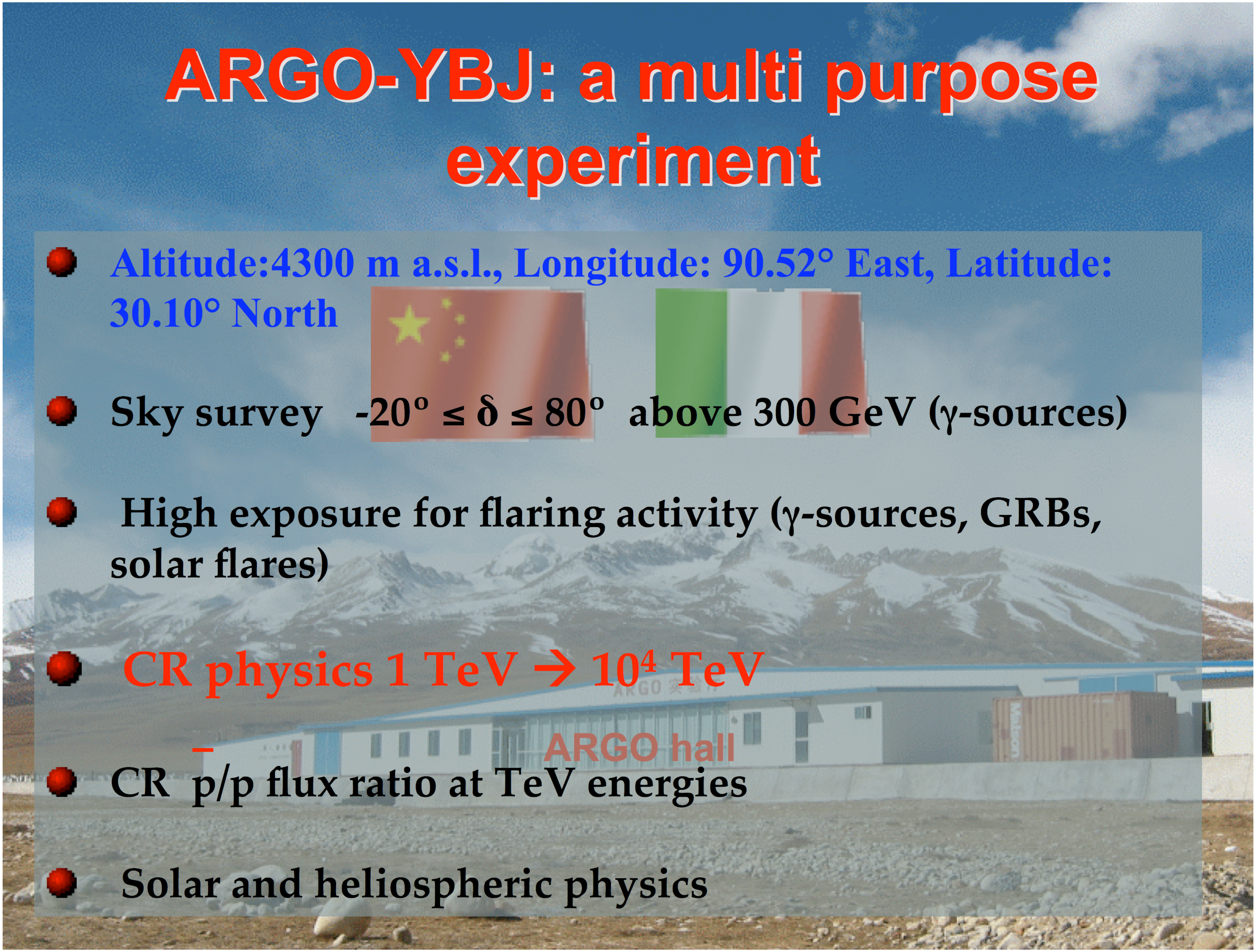
- **The situation may be even worse with short integral time (e.g. 2h or 4h) using “direct integral method” .**

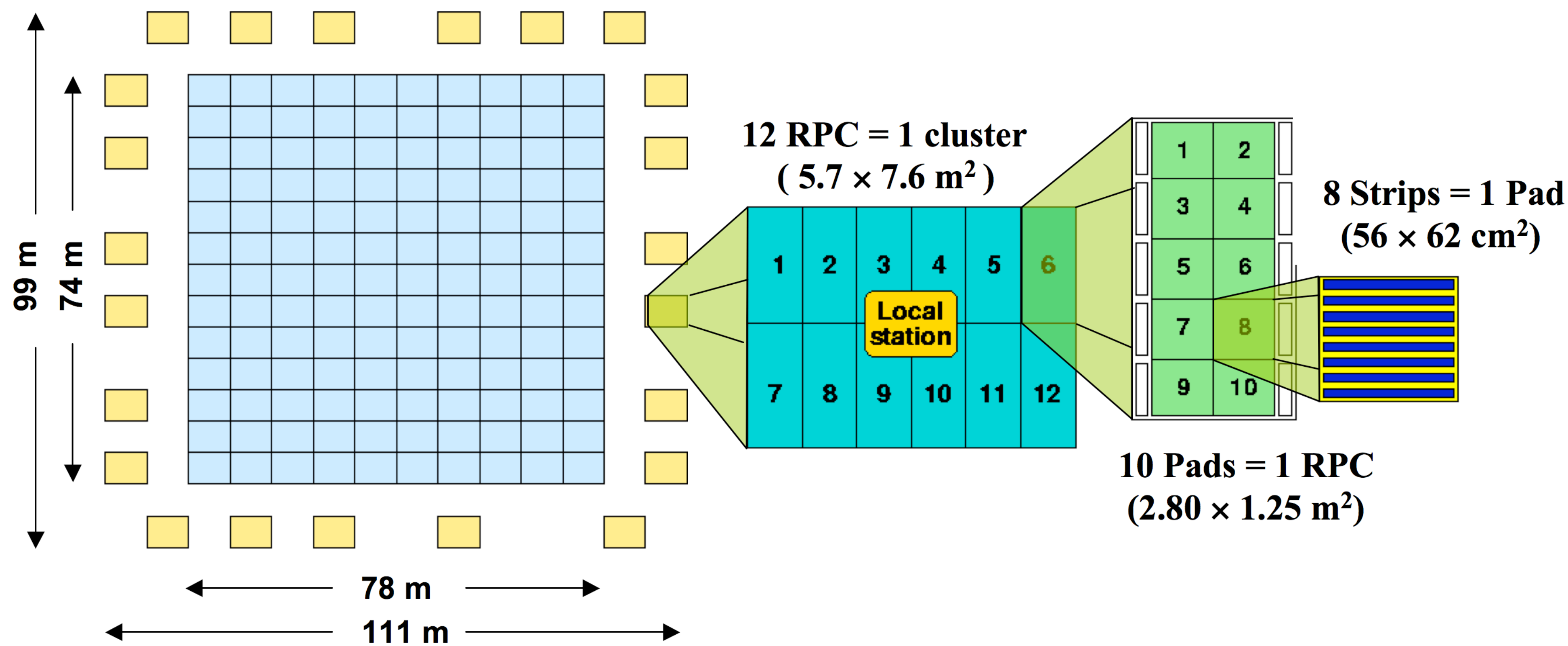
- **Sufficient iteration guarantees to correctly reproduce the anisotropy put in artificially, without any fake structures at small scales.**

ARGO-YBJ: a multi purpose experiment

ARGO-YBJ: a multi purpose experiment

- Altitude:4300 m a.s.l., Longitude: 90.52° East, Latitude: 30.10° North
- Sky survey $-20^o \leq \delta \leq 80^o$ above 300 GeV (γ-sources)
- High exposure for flaring activity (γ-sources, GRBs, solar flares)
- CR physics 1 TeV → 10^4 TeV
- CR $\bar{p}/p$ flux ratio at TeV energies
- Solar and heliospheric physics



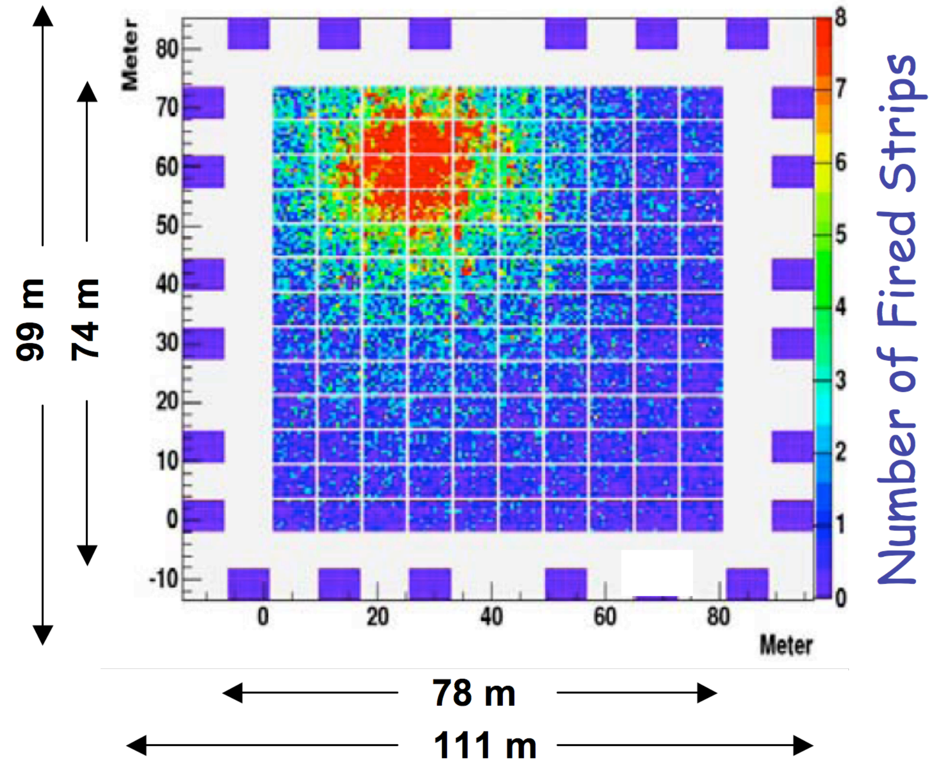


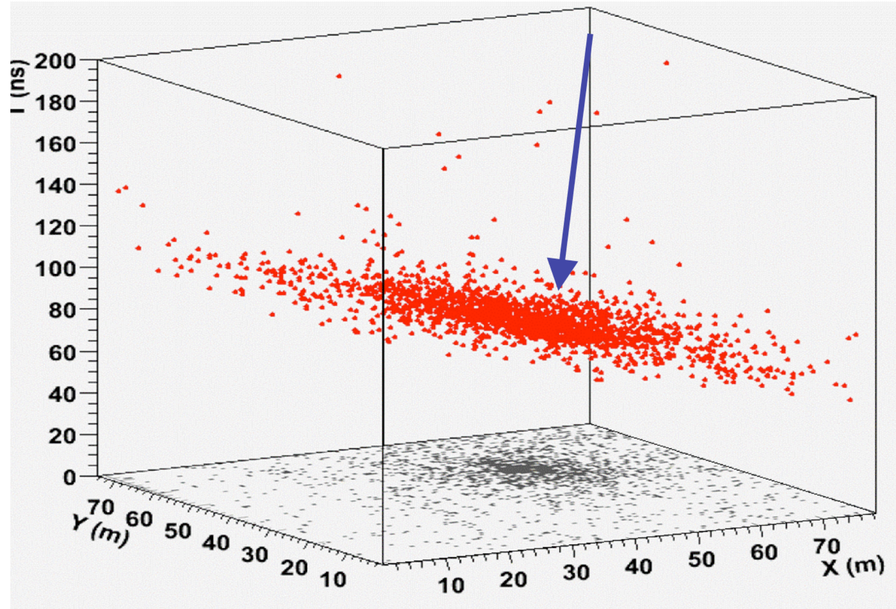
✓ Layer of Resistive Plate Chambers (RPC)

✓ Active area : central carpet ~ 5600 m^2
sampling guard-ring ~ 1000 m^2

✓ Data taking : since July 2006 with the central carpet
since November 2007 with the carpet + guard-ring

Analog charge read-out is working
→ dynamical range up to ~ 10^4 TeV





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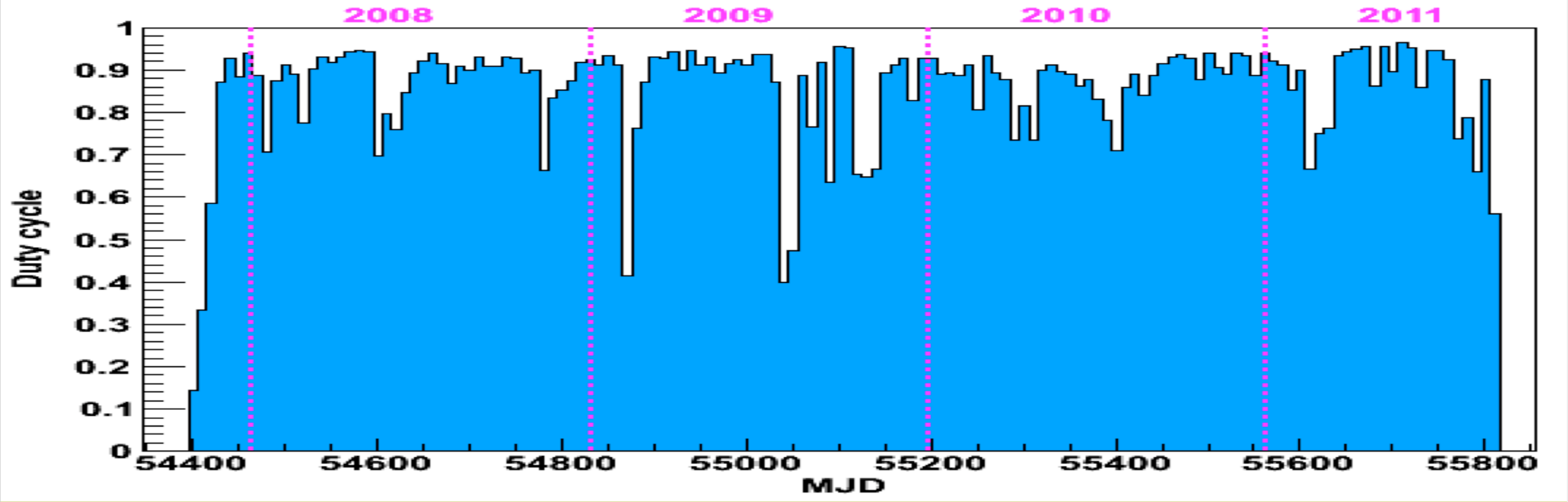
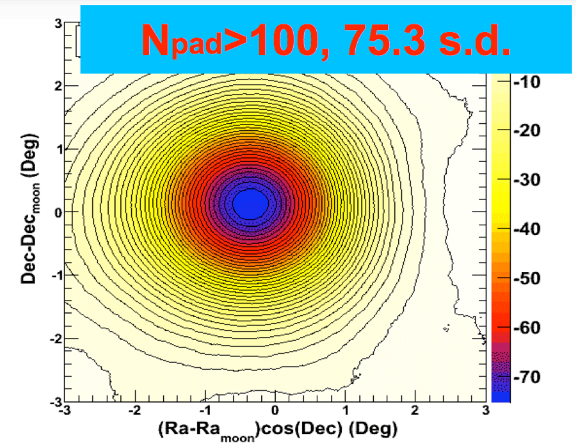
Current status

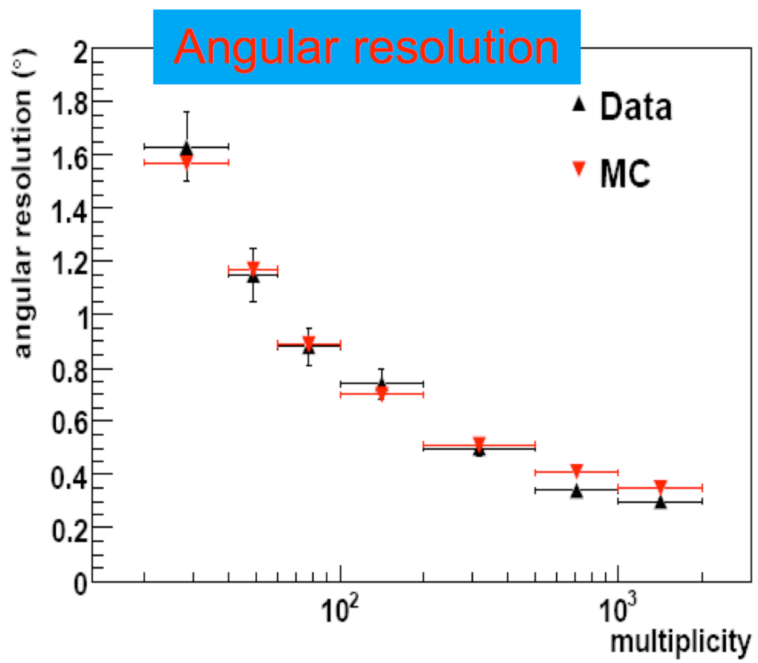
- Operation since July 2006 , Stable data taking since November 2007 with final configuration
- The average duty cycle ~ 85%, dead time 4%,
- Trigger rate ~3.5kz
- 3.5×10^{11} events collected
- 220 GB/day transferred to IHEP/CNAF data centres

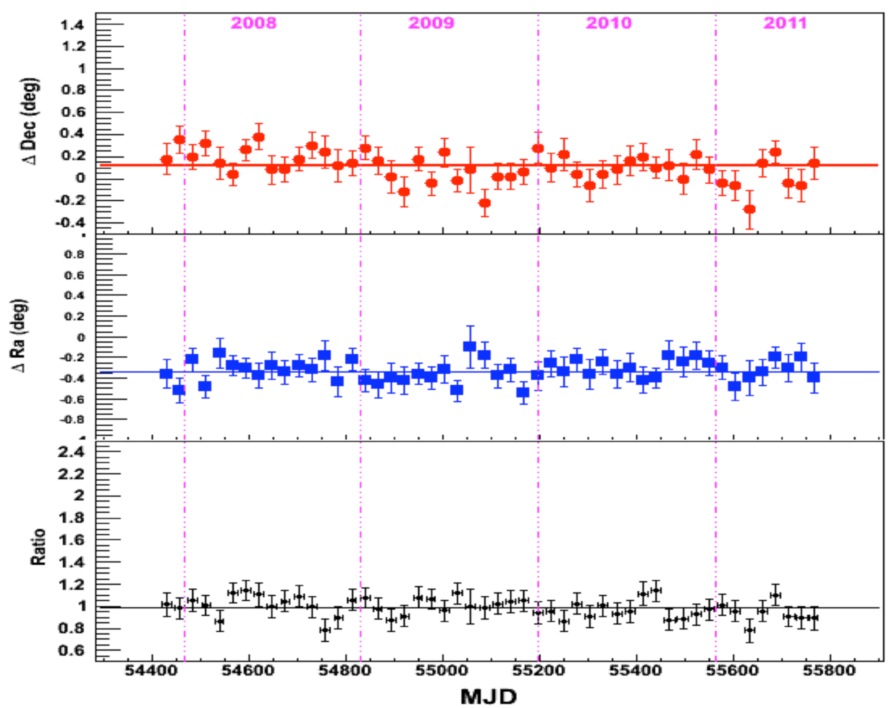


Moon shadow analysis

- Moon shadow: A nature tool to determine the performance of detector:
  - Pointing accuracy,
  - Angular resolution,
  - Absolute energy: ~13%
  - long-term stability

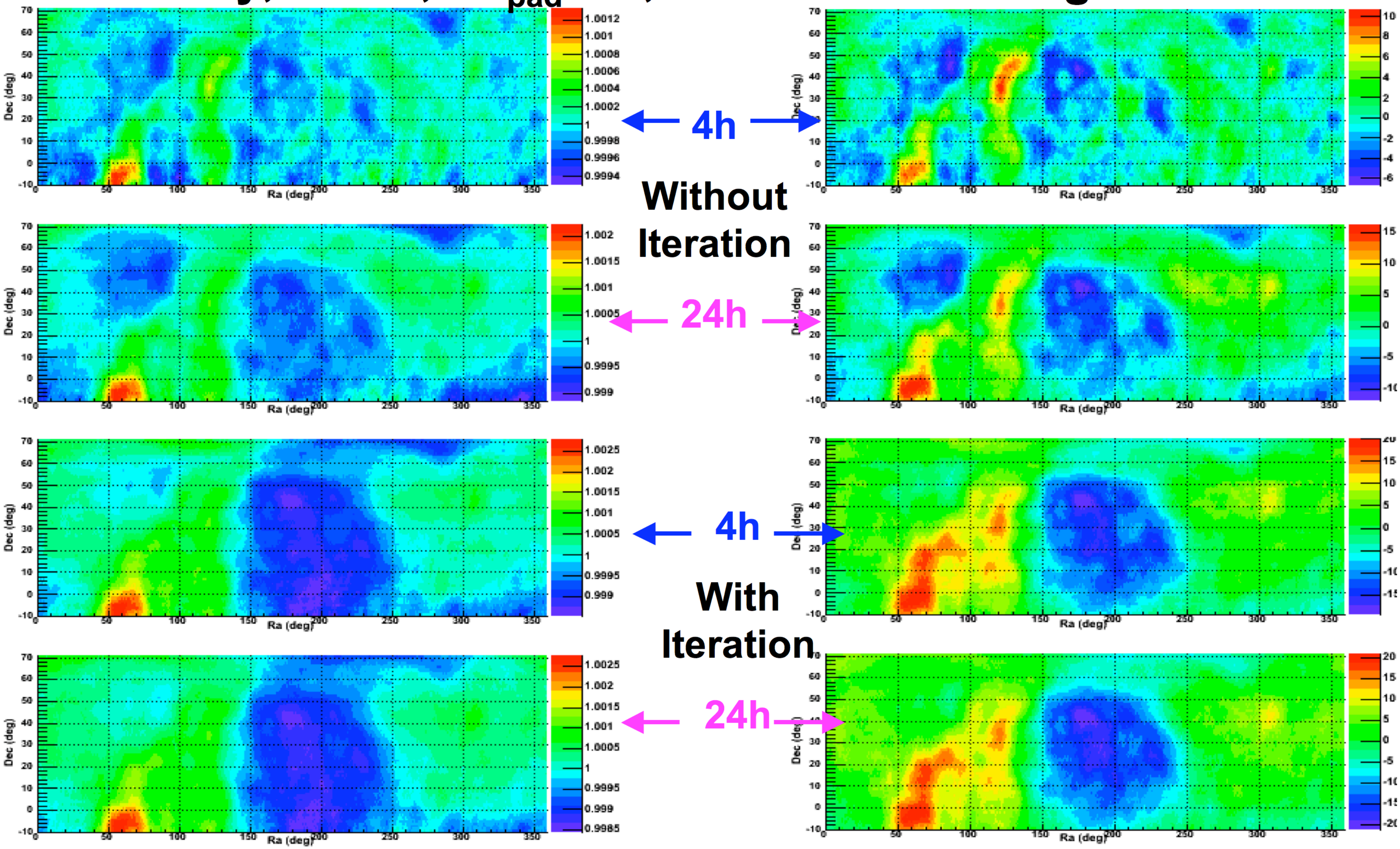






Direct integral method for data 2008

Intensity, R=5º, N_{pad}>40, **significance**



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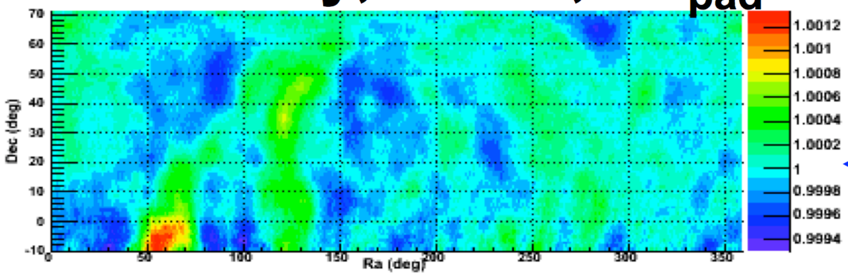
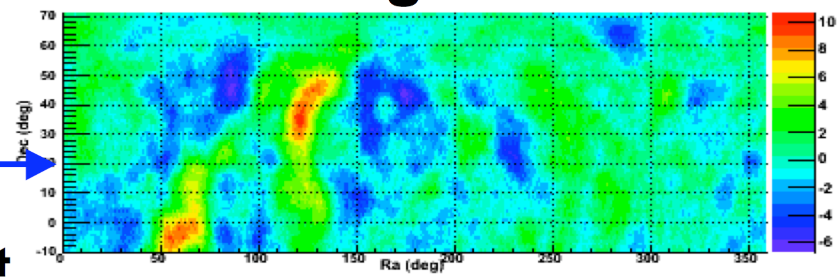
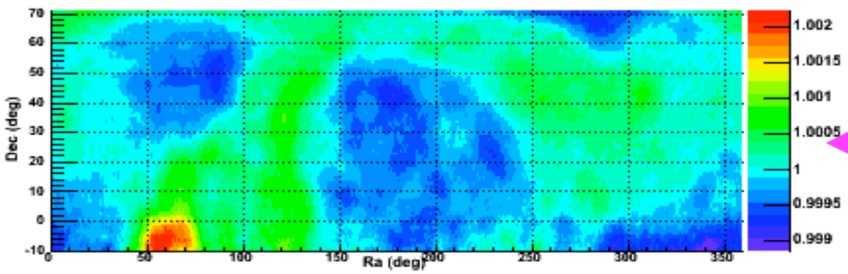


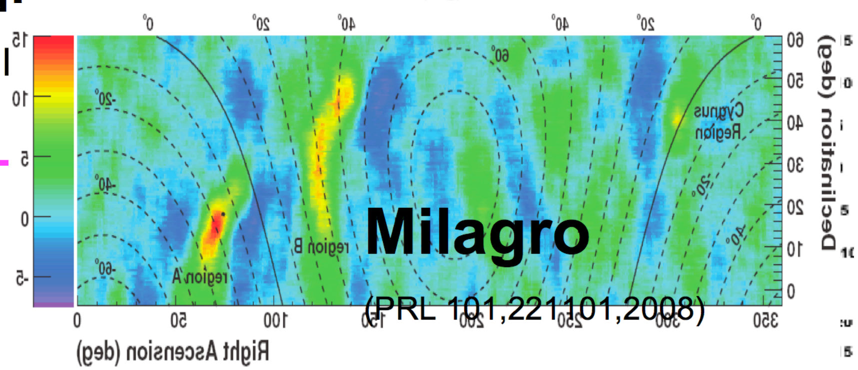
4h



Without Iteration

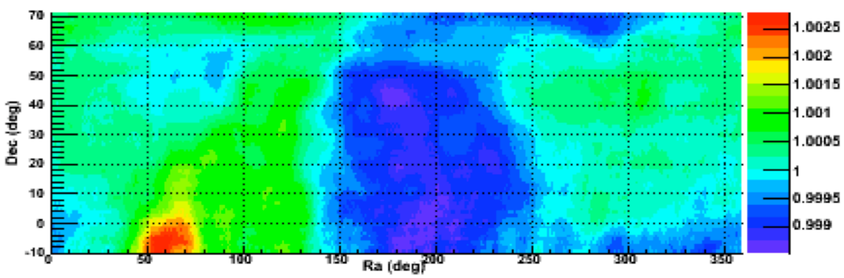


24h



Milagro

(PRL 101,221101,2008)



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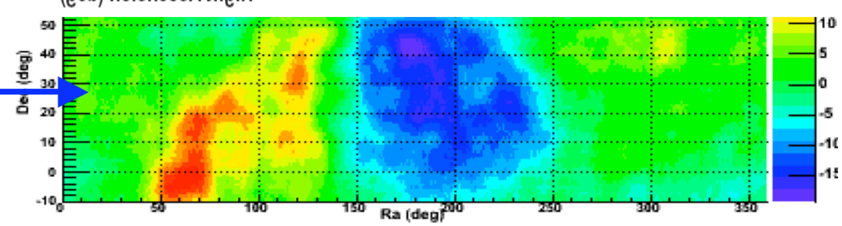
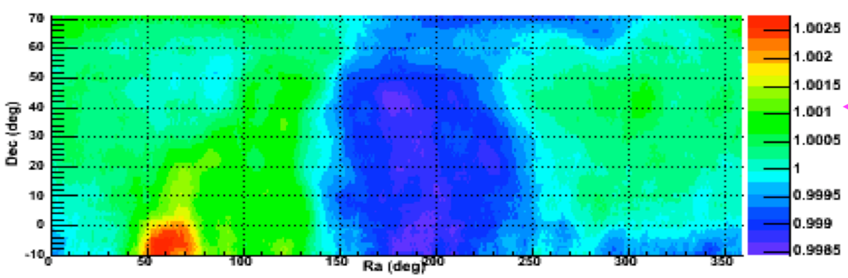


With Iteration



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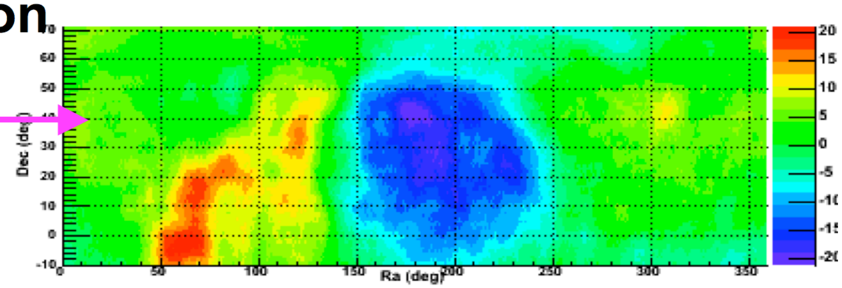
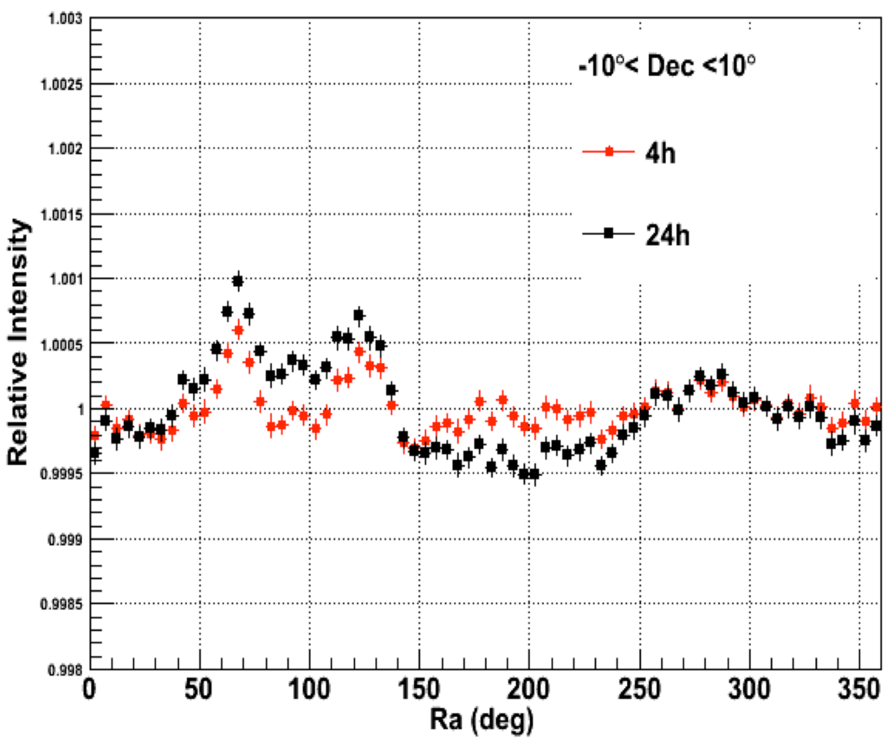
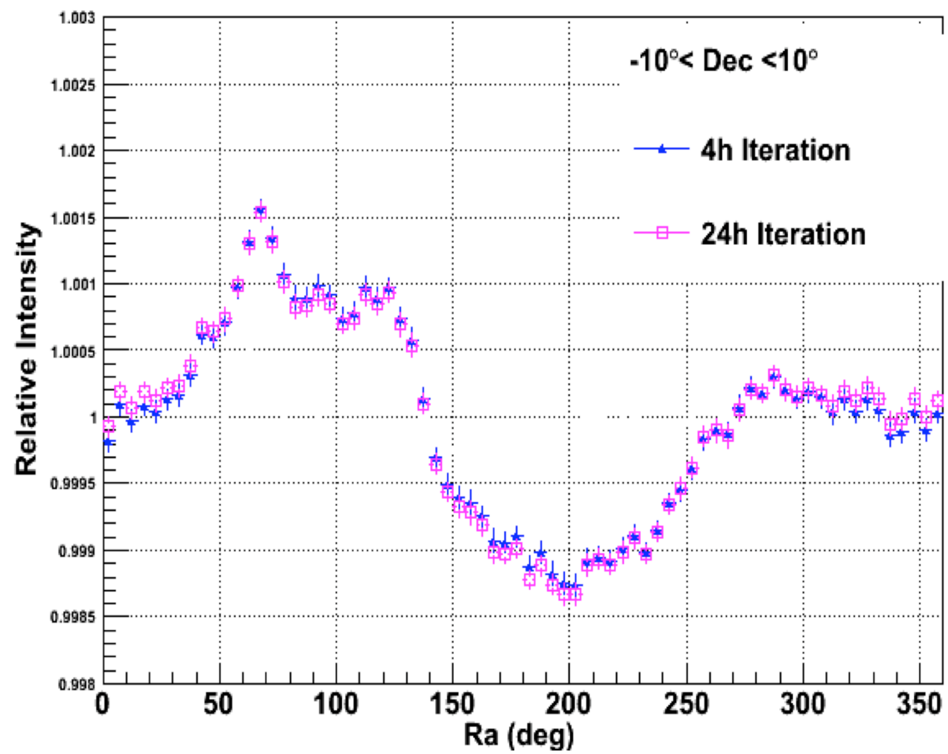


- With iteration, the results using 4h and 24h are the same.
- The effects of the iteration on amplitudes and structure are expected just like what is seen in toy MC.





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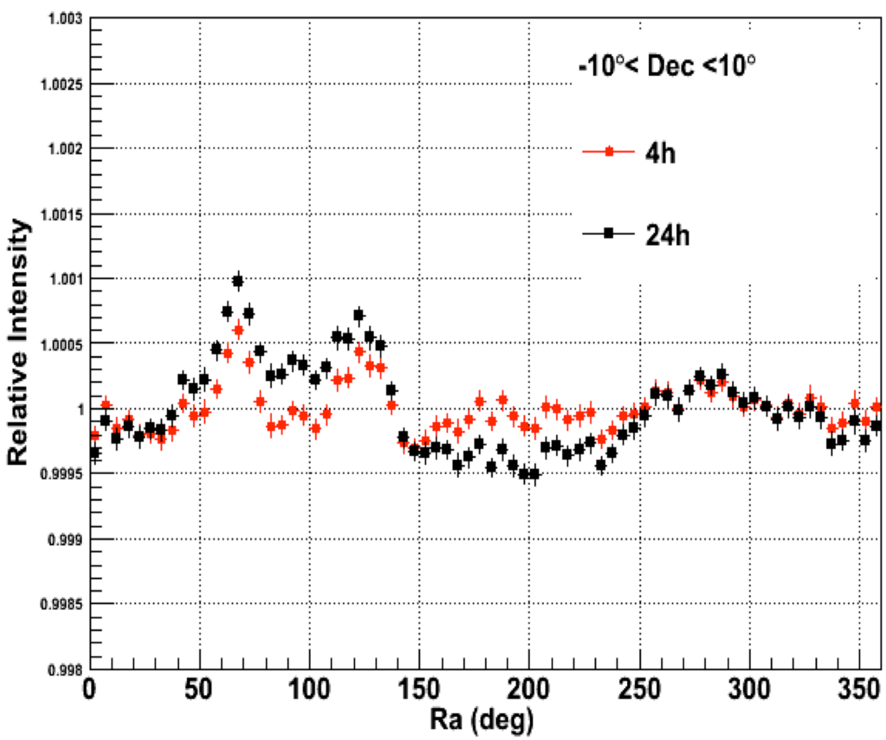

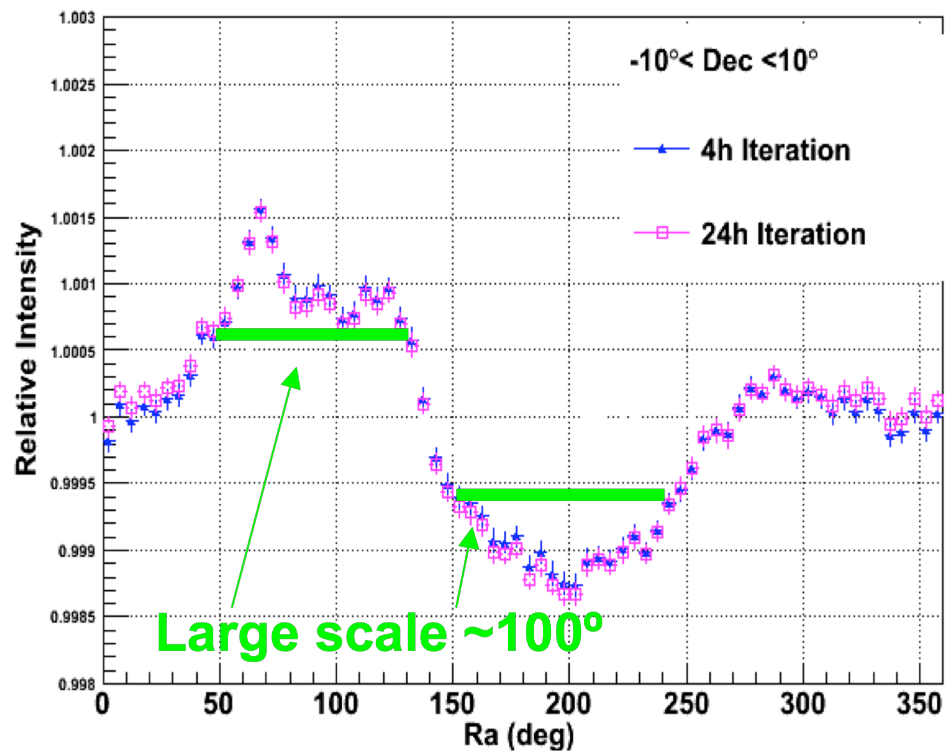

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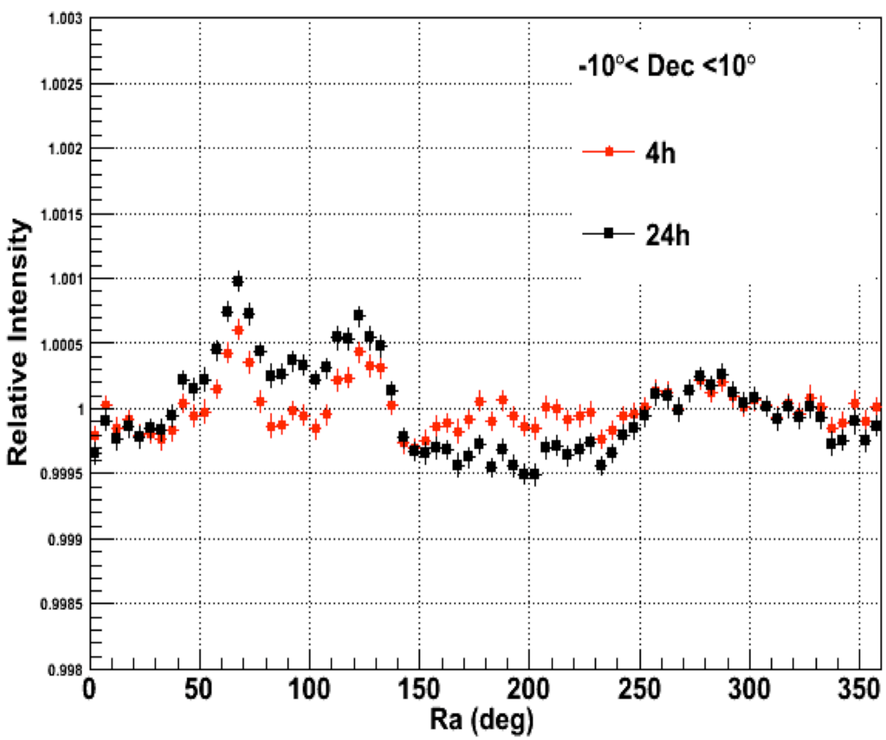

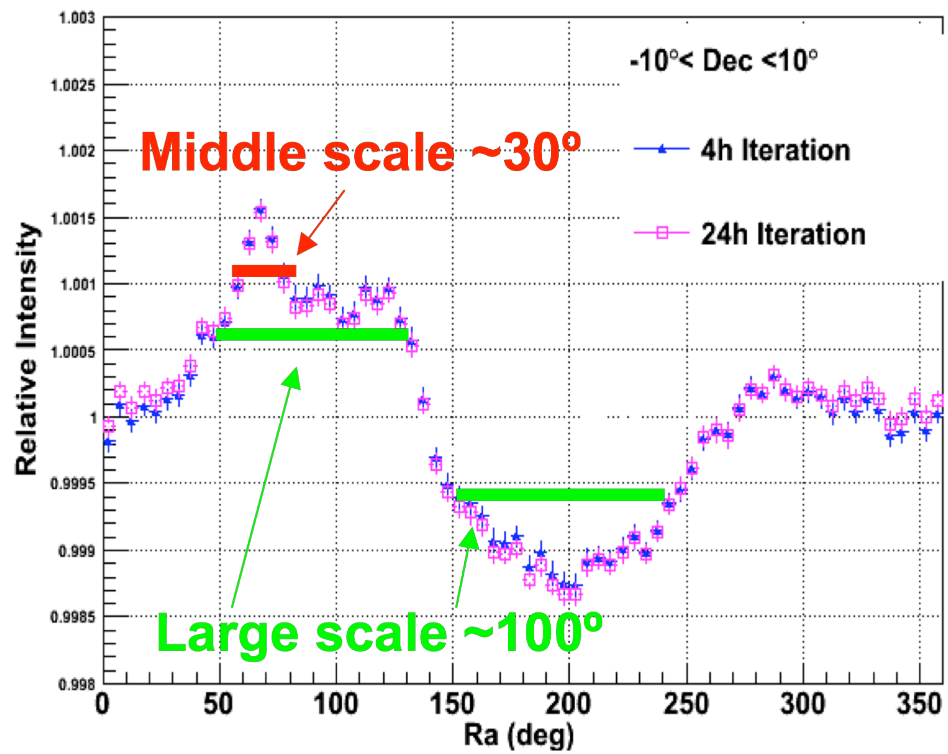

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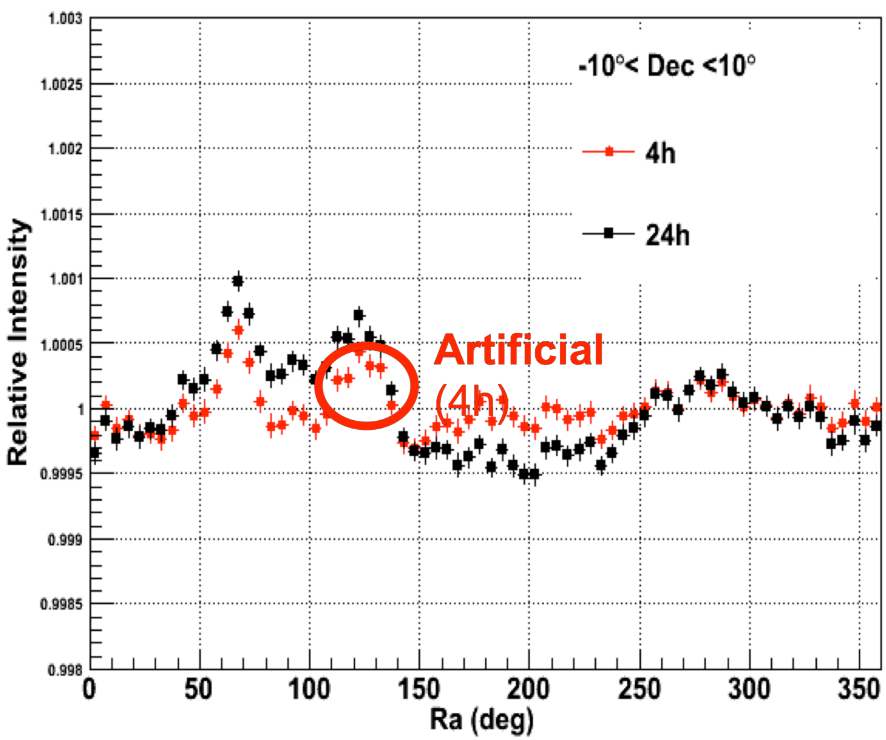
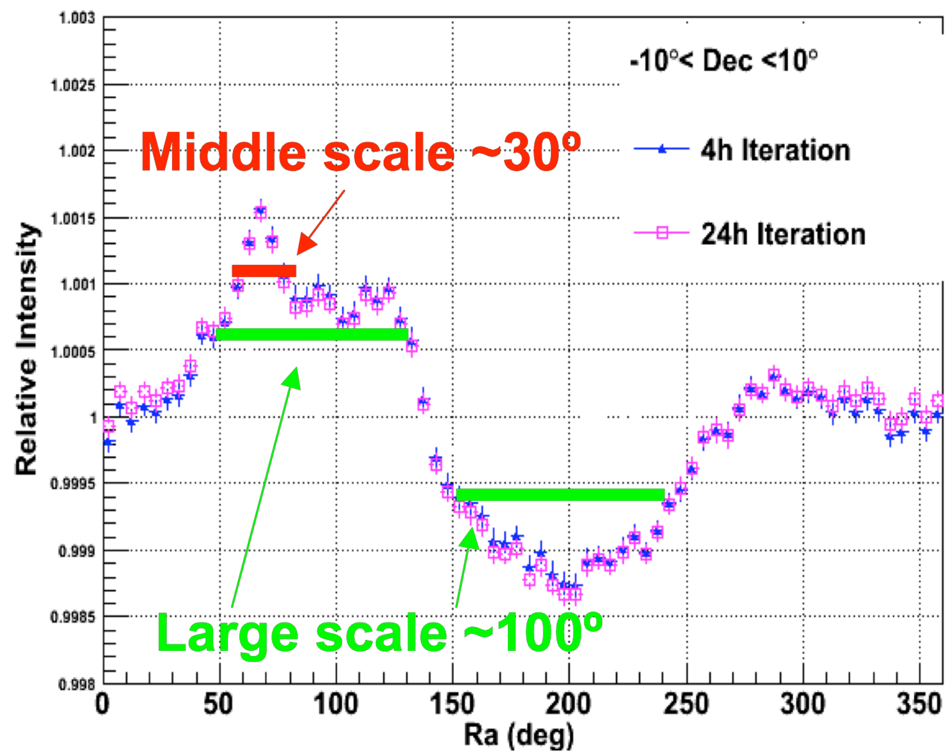
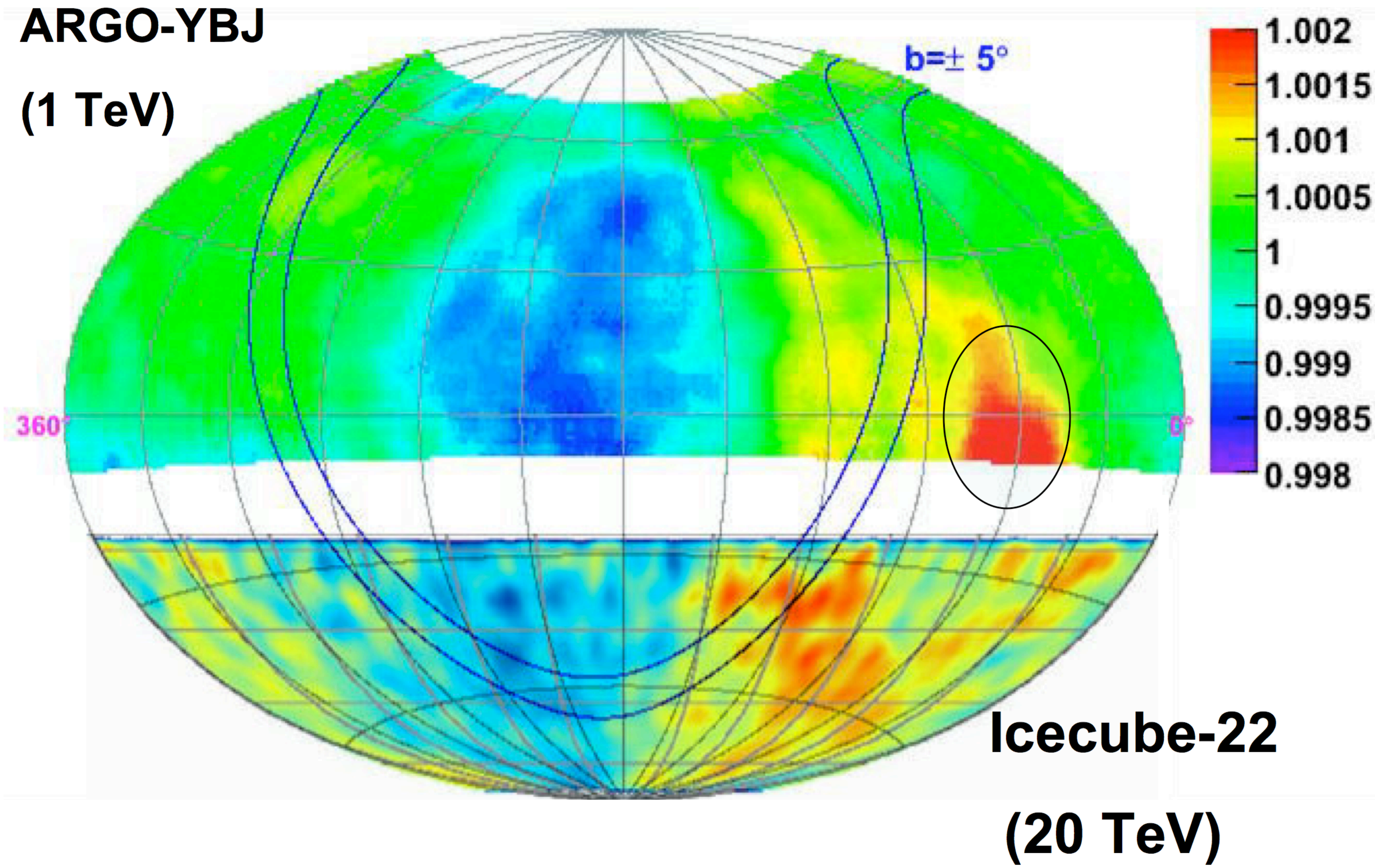


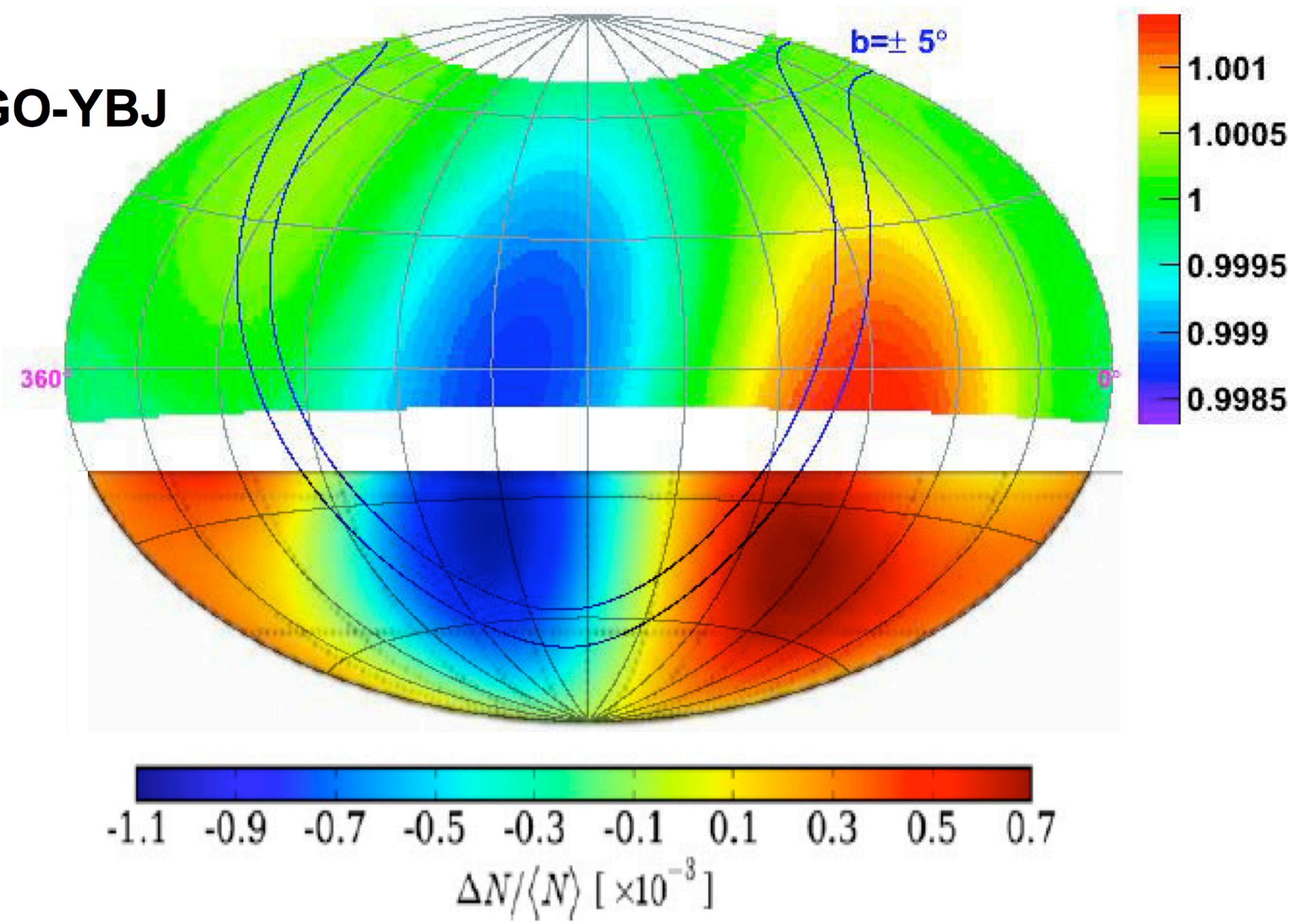


Comparison with Icecube experiment



Dipole + quadrupole fit

ARGO-YBJ



Icecube ApJ, 740:16 (2011)

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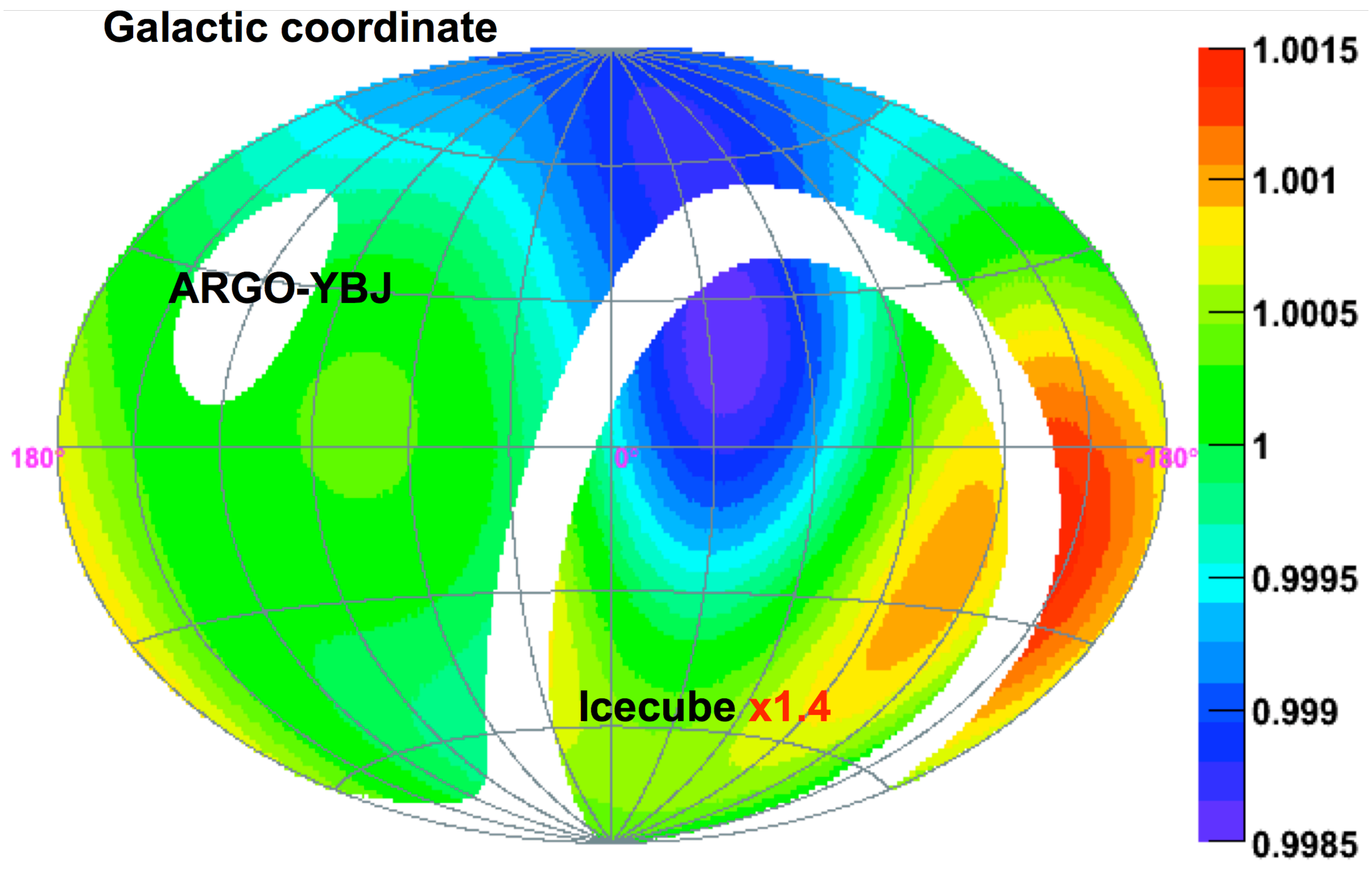

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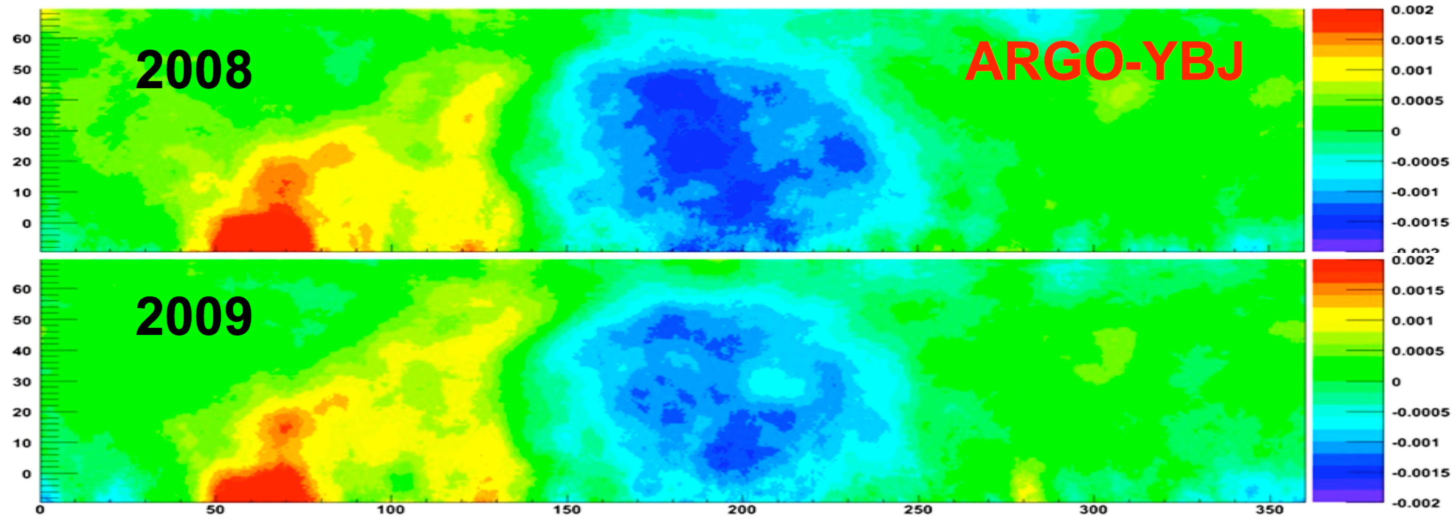
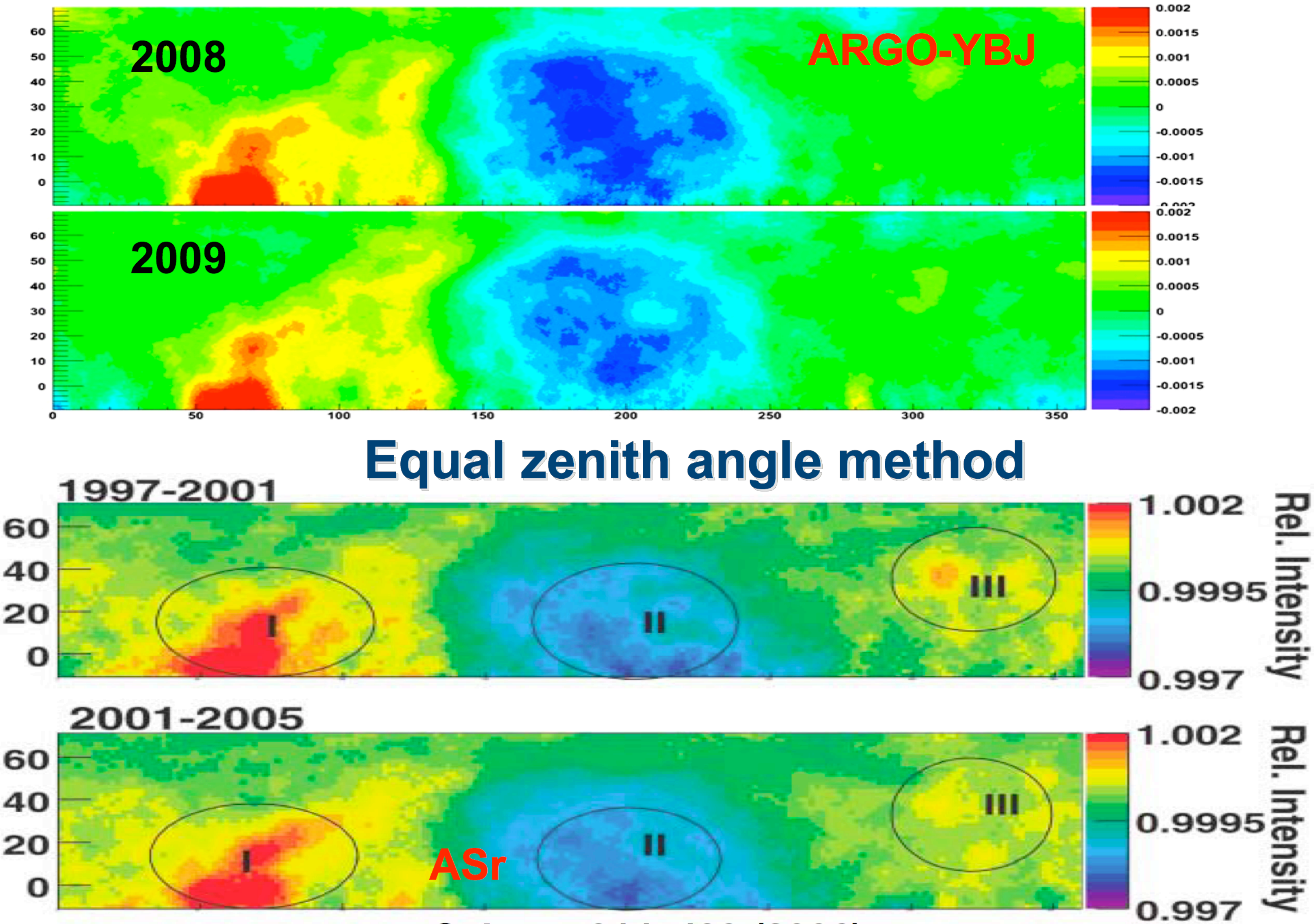
Comparison with ASr experiment



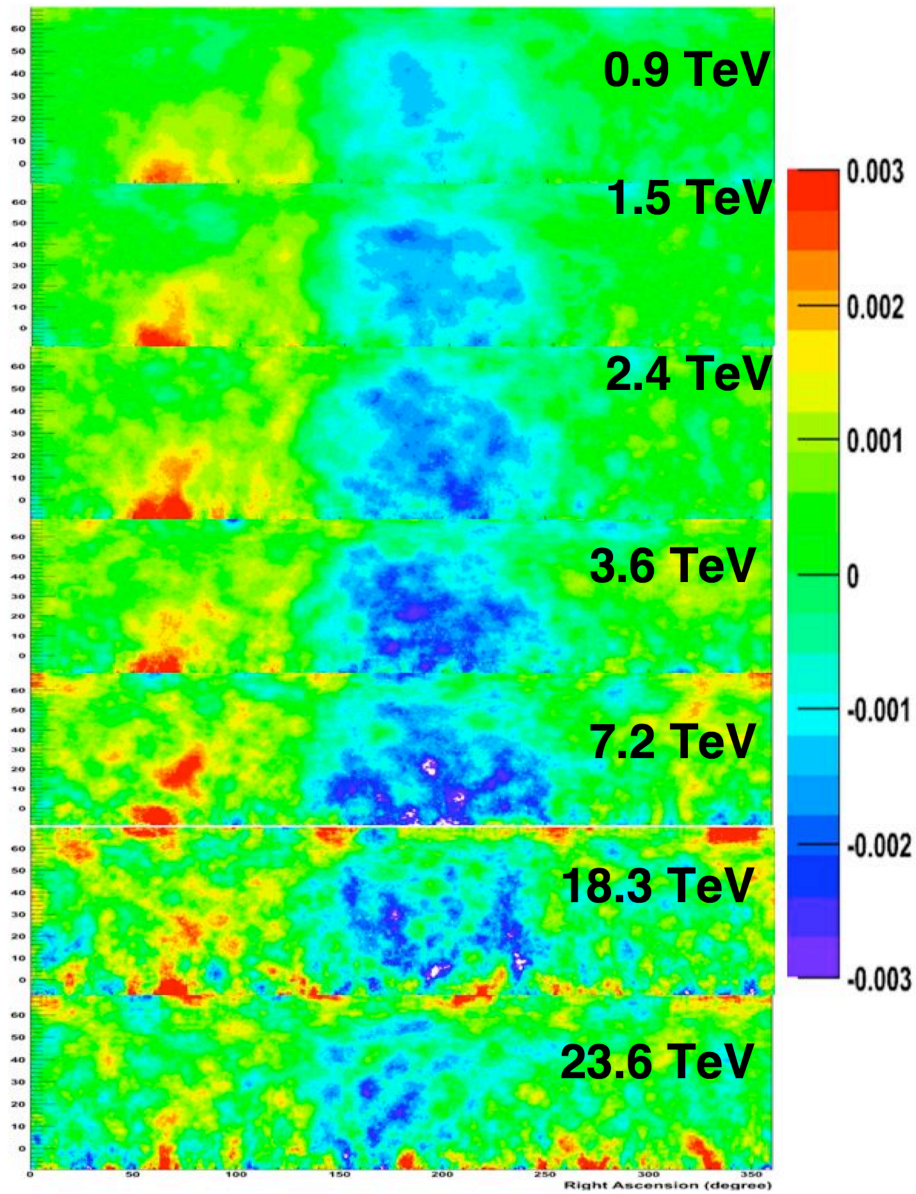
Equal zenith angle method

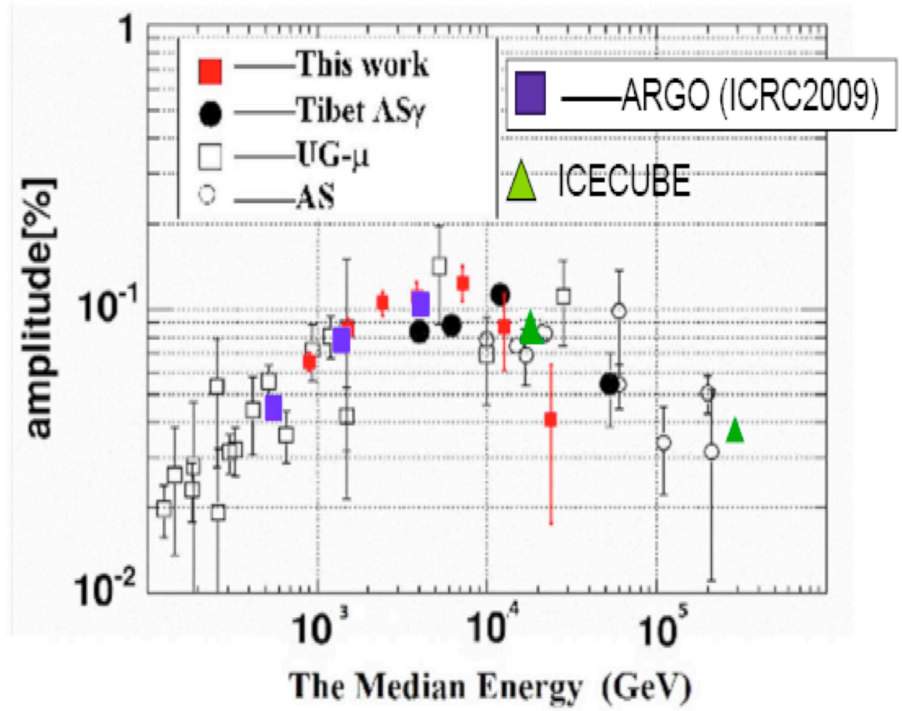
Comparison with ASr experiment



Science 314, 439 (2006)

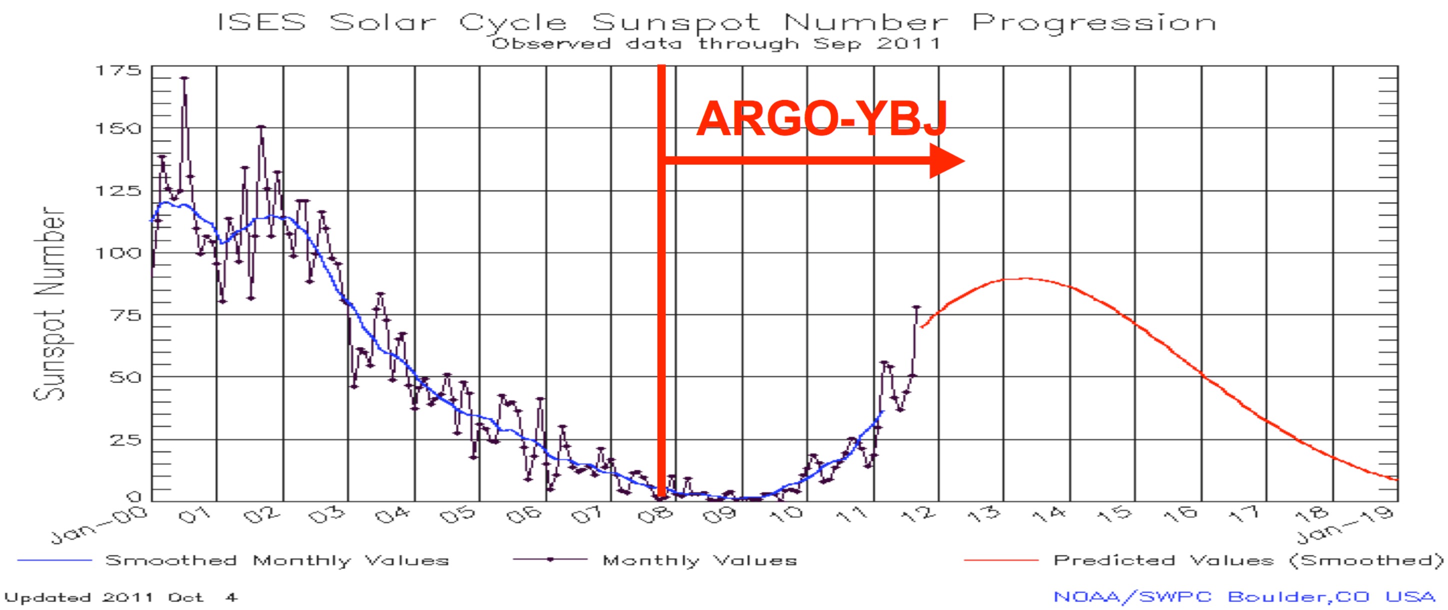
Large scale CR anisotropy vs energy





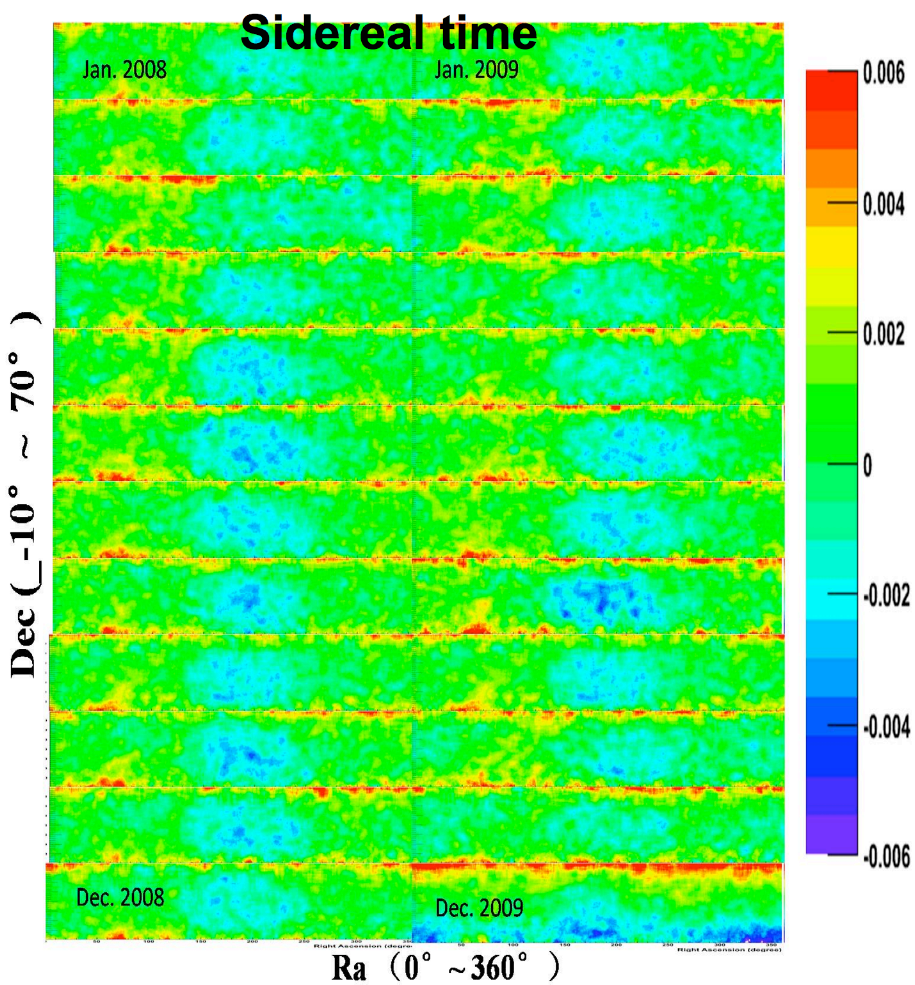
The amplitude of the anisotropy increases with energy below ~10TeV and decreases at higher energies.

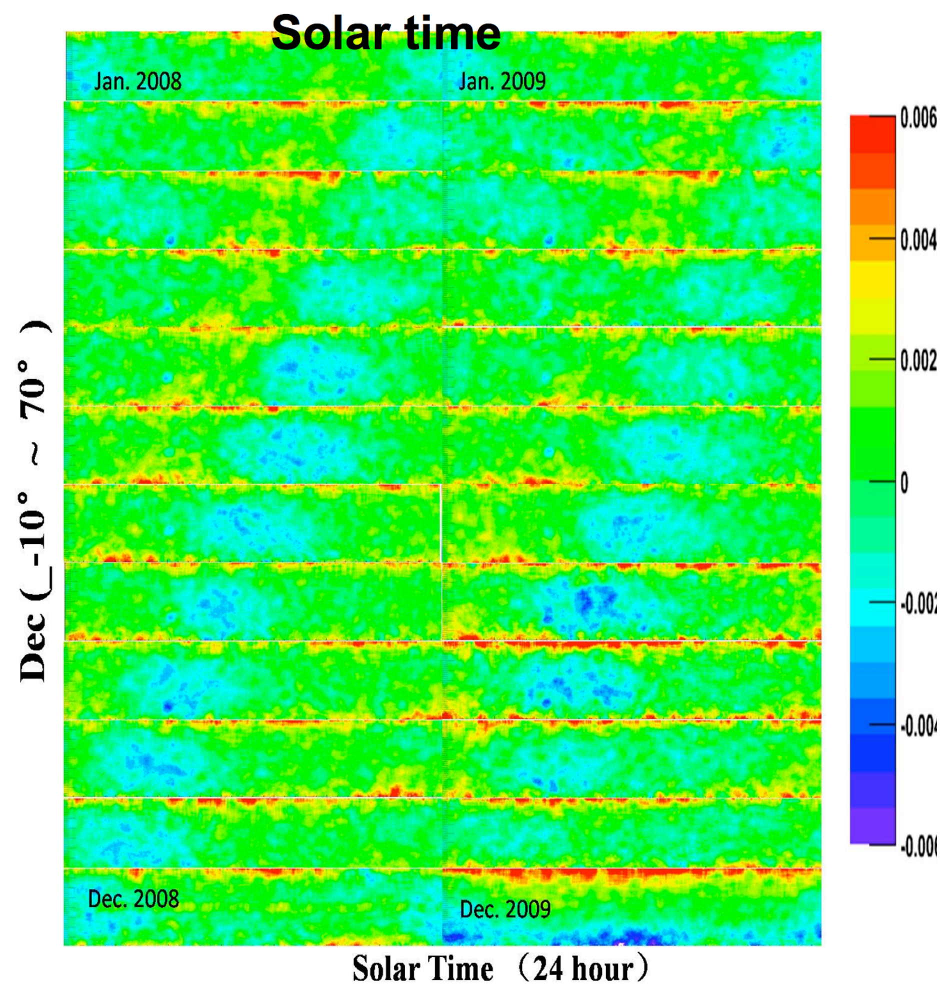
Yearly variation



- **ARGO-YBJ observation time starts from Nov. 2007, during which period the solar activity is from minimum to maximum.**
- **With a low energy threshold, ARGO-YBJ can measure the possible variation of Cosmic ray anisotropy around 1 TeV due to the solar activity.**
- **Data analysis of the time evolution of the anisotropy is in process.**

Two dimensions anisotropy monthly variation at solar time and sidereal time period. Sidereal time anisotropy is dominant.





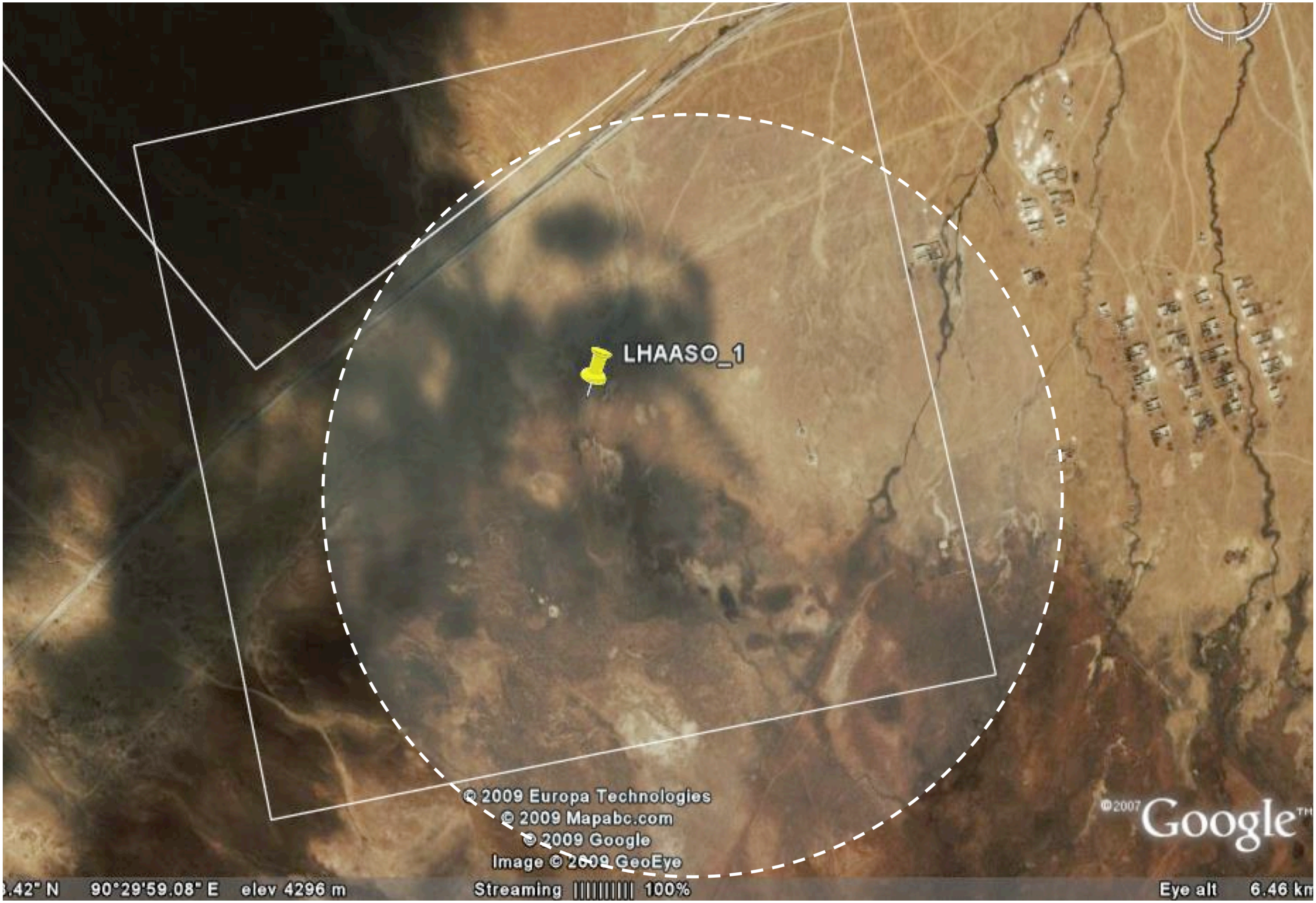
Comments

- Large scale anisotropy has been observed by many experiments. Both Galactic and heliosphere magnetic field have been introduced to interpret the anisotropy, loss-cone and tail-in. Its origination is still under debate.

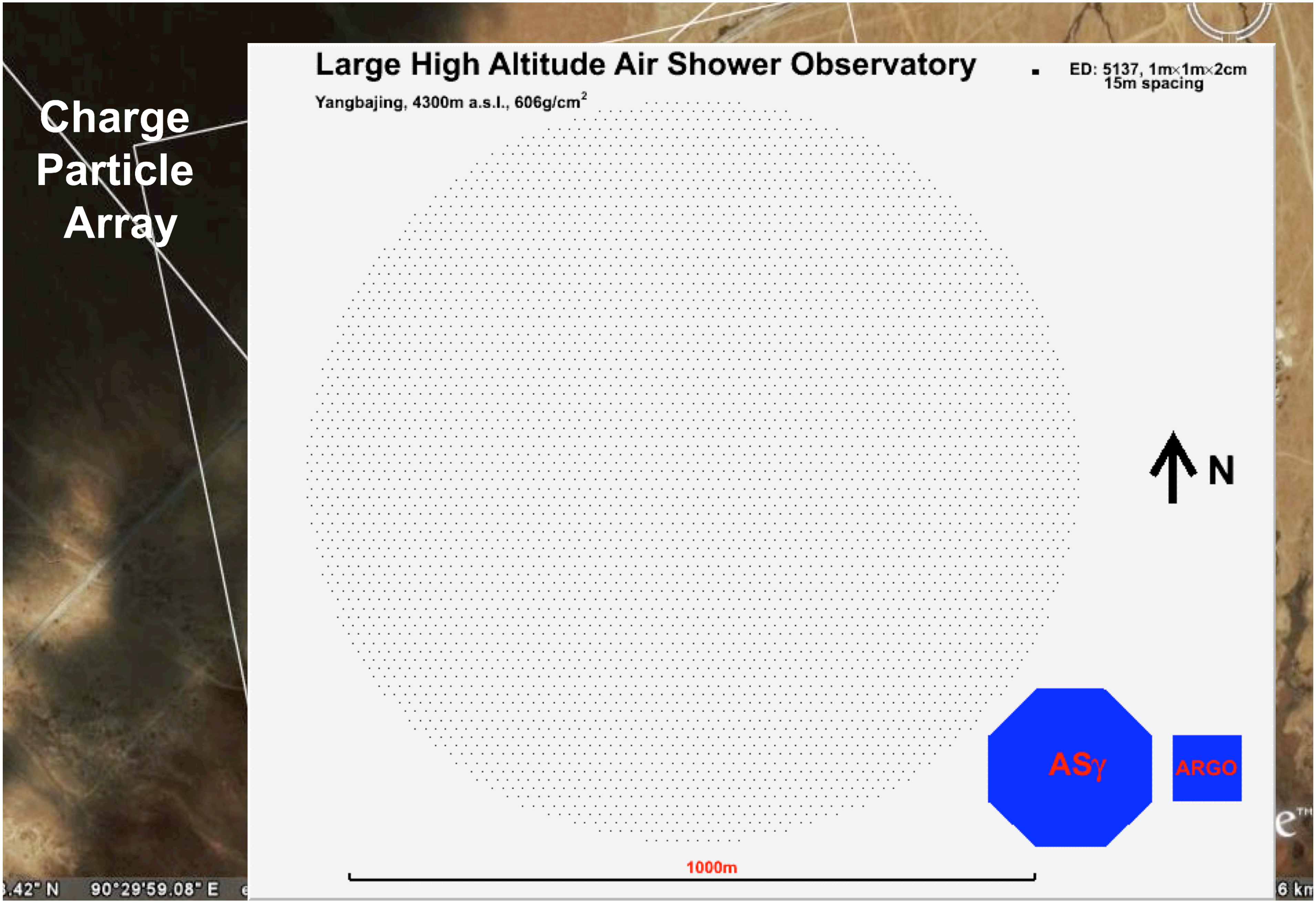
LHAASO Project: γastronomy and origin of CR

Large High Altitude Air Shower Observatory

LHAASO Project: γastronomy and origin of CR



LHAASO Project: γastronomy and origin of CR



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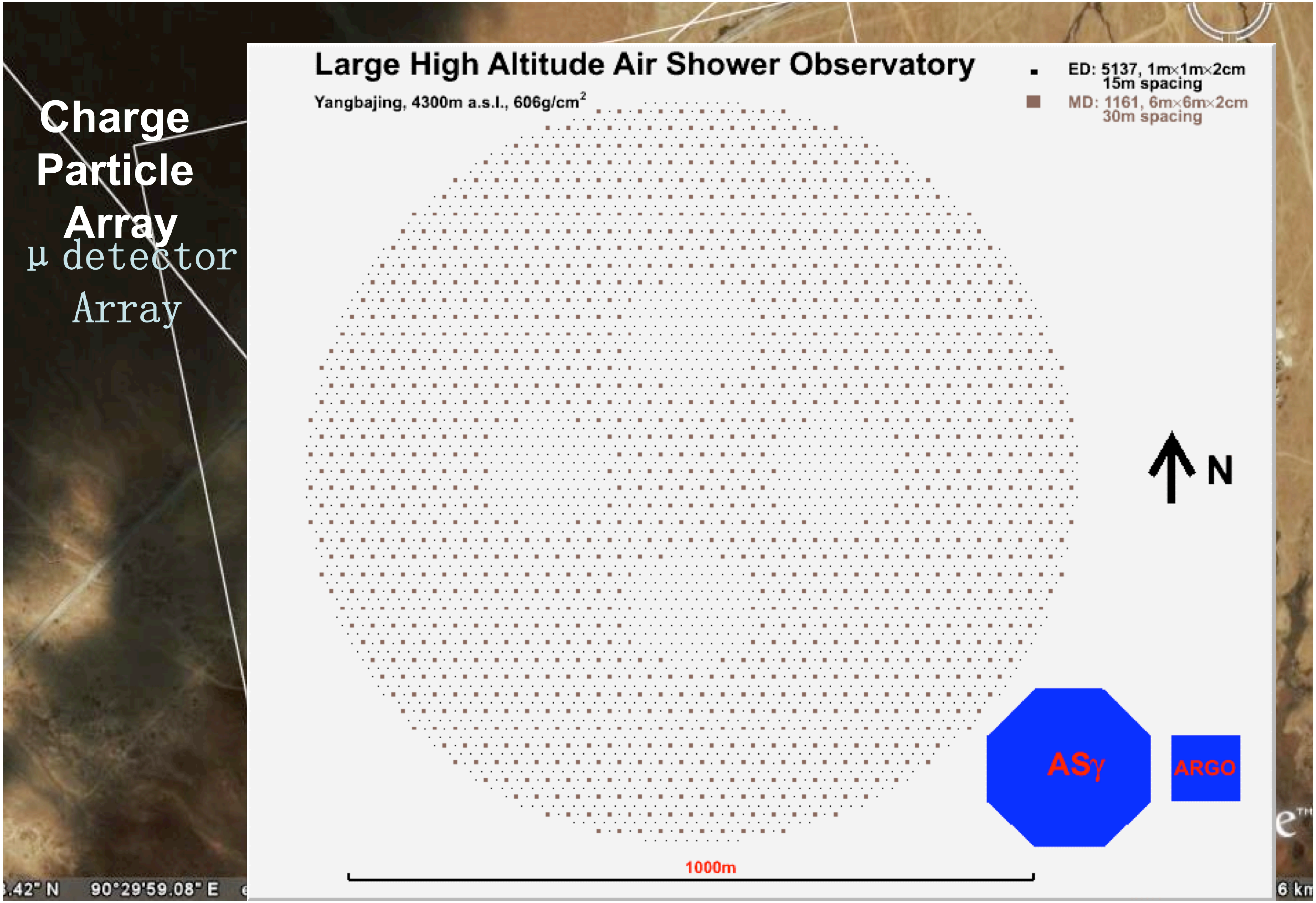
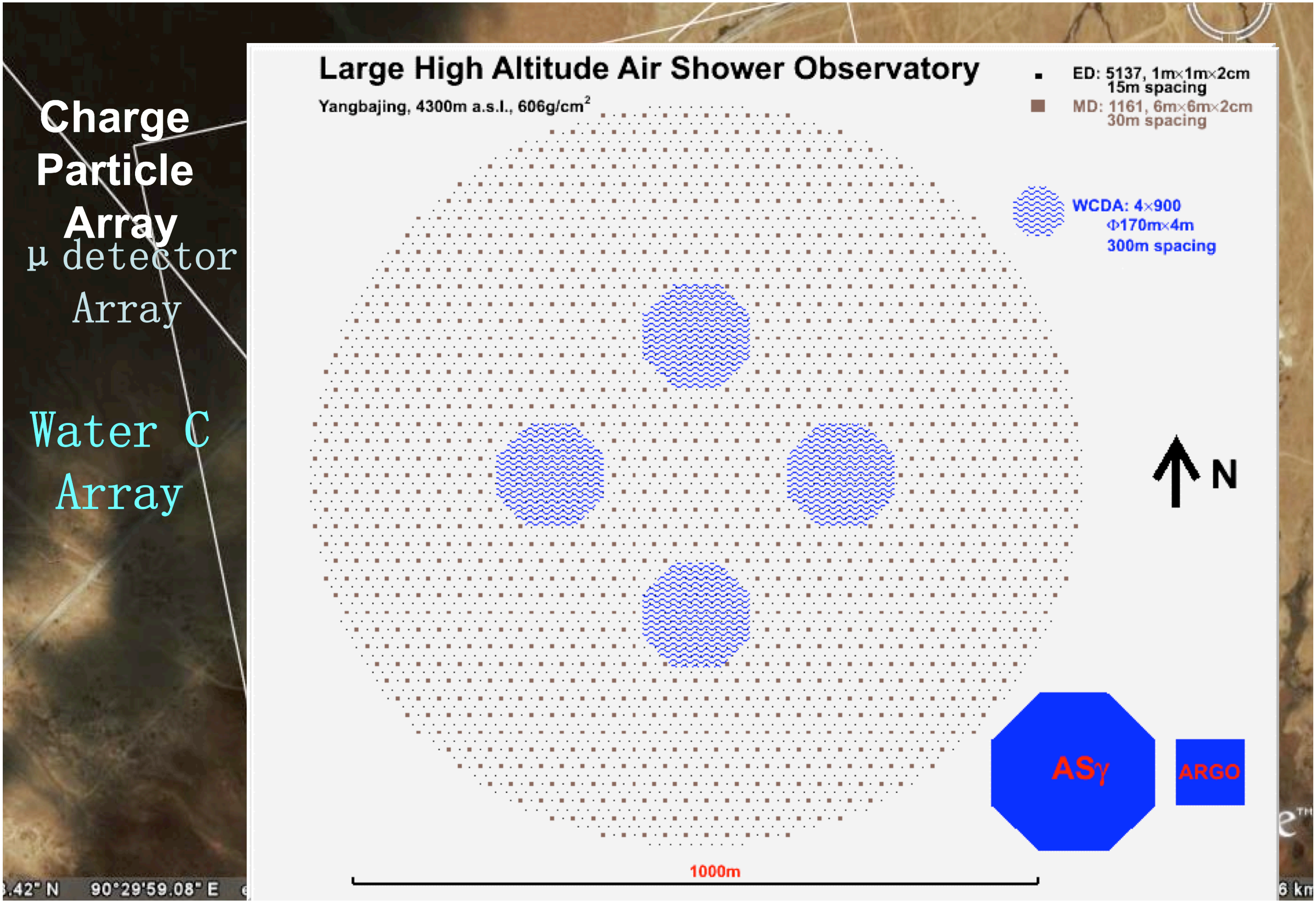
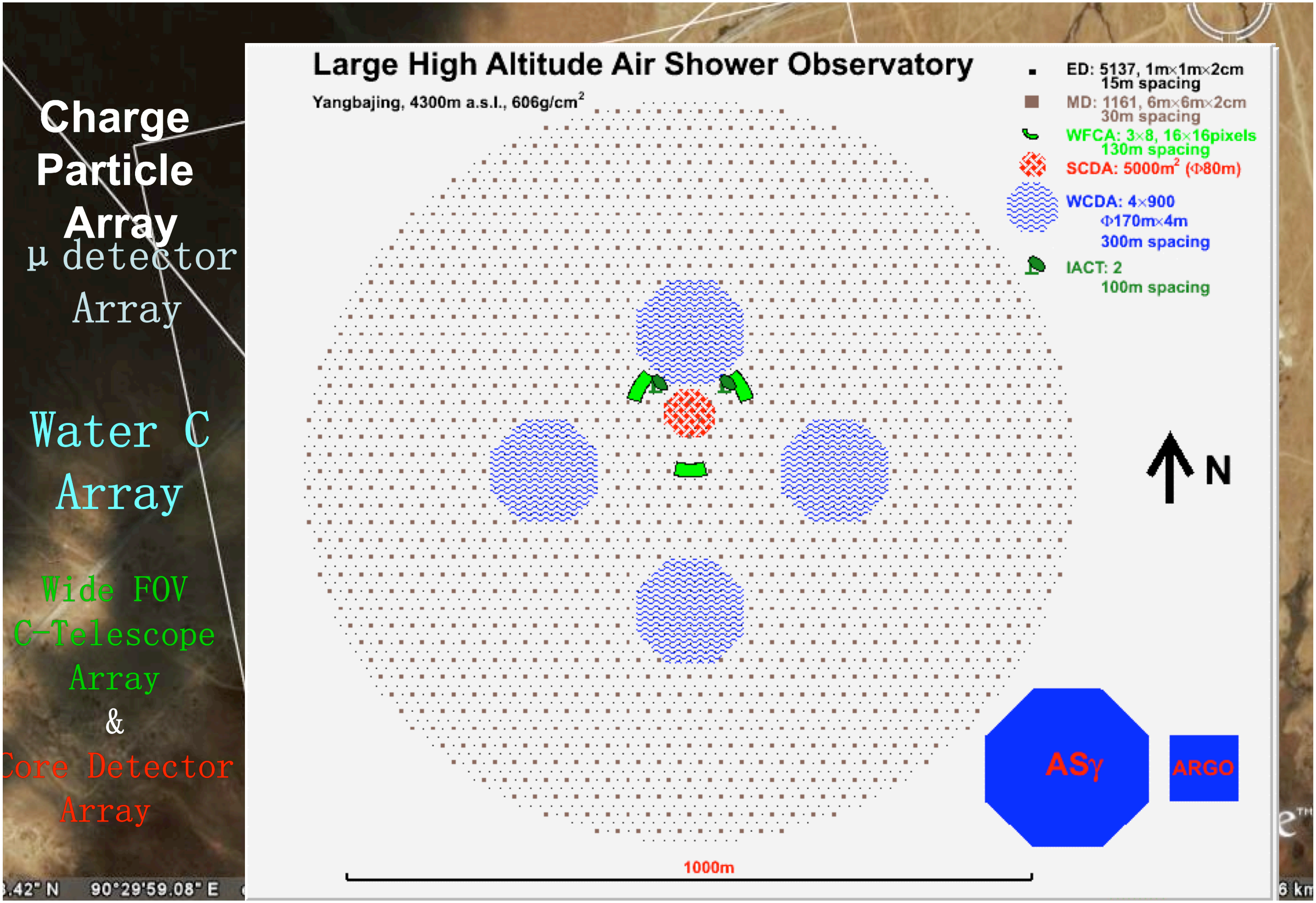


LHAASO Project: γastronomy and origin of CR



LHAASO Project: γastronomy and origin of CR



Physics Goals

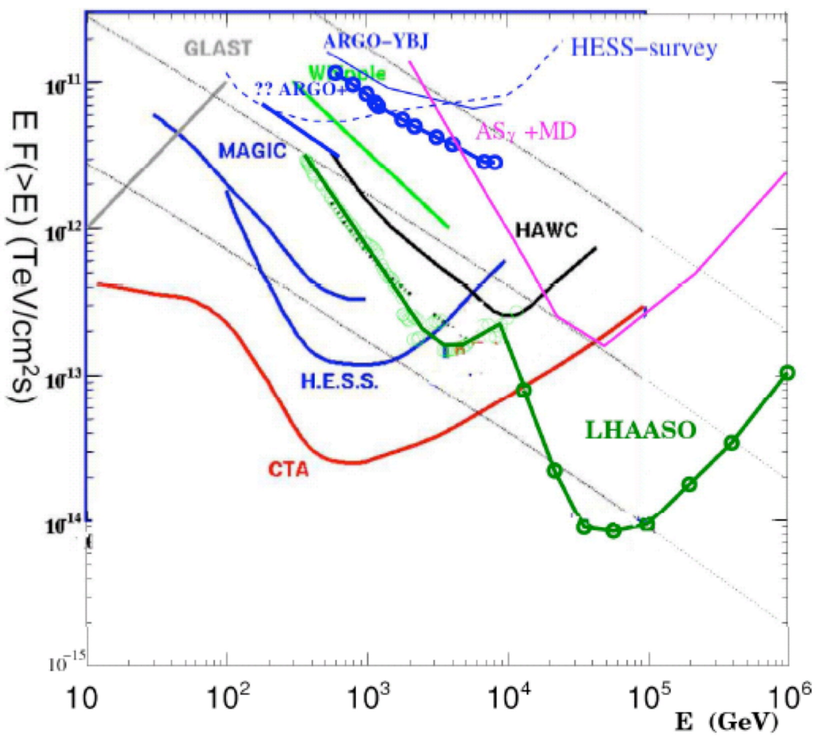
- VHE Gamma astronomy (100 GeV–100 TeV)
  - Sky survey for extragalactic sources, especially for AGN flares (<30 TeV);}
  - GRB detection (<30 TeV);
  - Deep observation for galactic sources (>30 TeV).

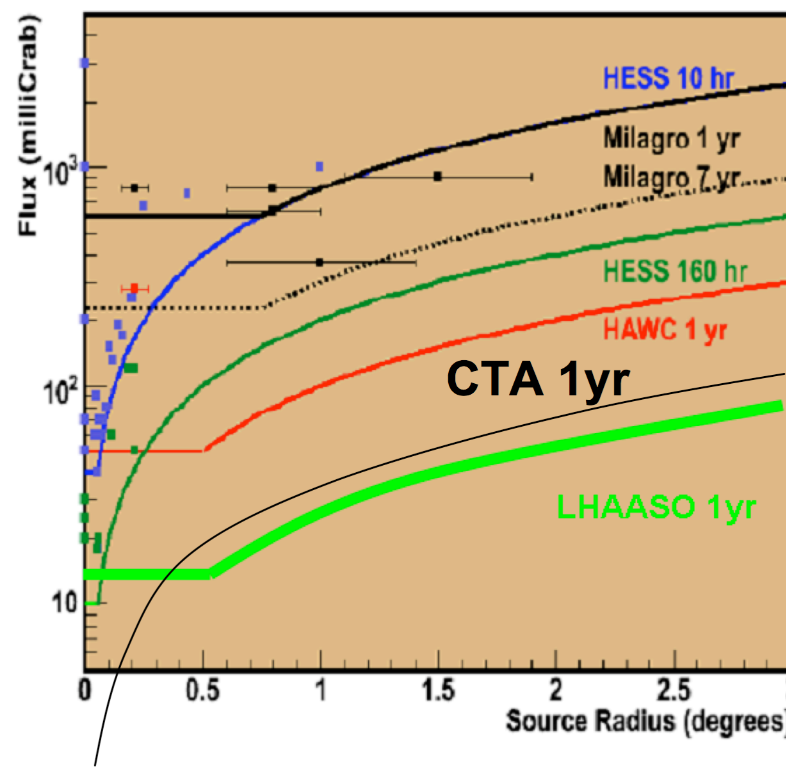
  }
- Cosmic ray physics (50 TeV–1 EeV)
  - Primary spectrum & mass before the knee(50 TeV–1 PeV);
  - Primary spectrum & mass at the knee(1 PeV–100 PeV);
  - Primary spectrum at the second knee(100 PeV–1 EeV).

}
- Other physics:}
  - Anisotropy of cosmic rays;}
  - Solar magnetic field & storm;}
  - Dark matter.

Sensitivity on γAstronomy

- **Survey the northern sky for γsources above 100GeV (>90% of area is never surveyed at a sensitivity of 0.03I_{Crab} at 3 TeV, 0.01 I_{crab} at 50 TeV)**

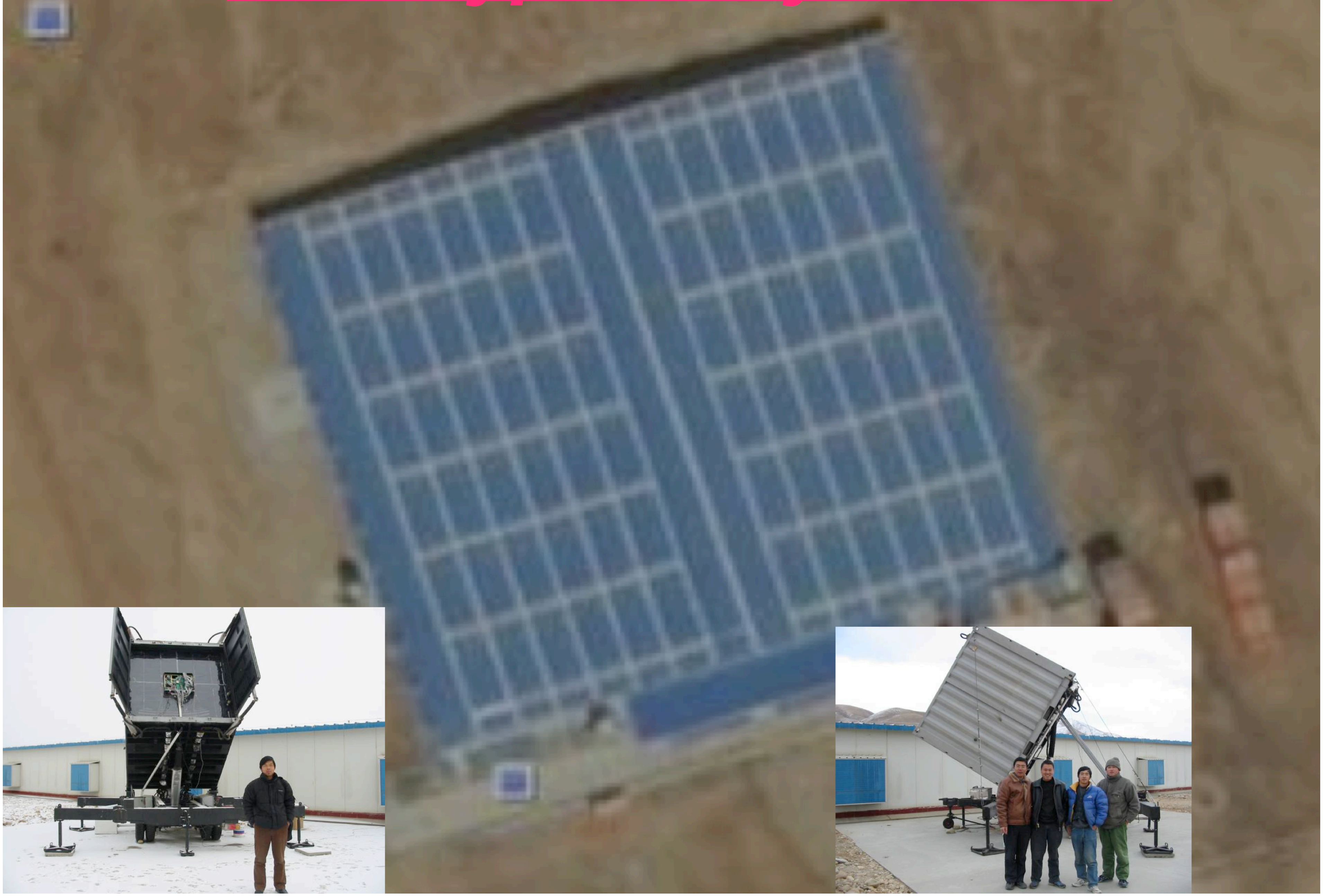




Current status

- **Engineering Array of KM2A at YBJ**
  - The array consists of 42 scintillators
  - Taking data since 2010 with trigger rate 50 Hz
- **Engineering Array of WCDA at YBJ**
  - The array consists of 9 EDs and 1 MD;
  - A water purifier and circulating system;
  - Taking data now
- **Engineering Array of WFCTA at YBJ**
  - Two wide field of view Cerekov telescope, one with tracking system
  - Taking data since 2008

Prototype array on site



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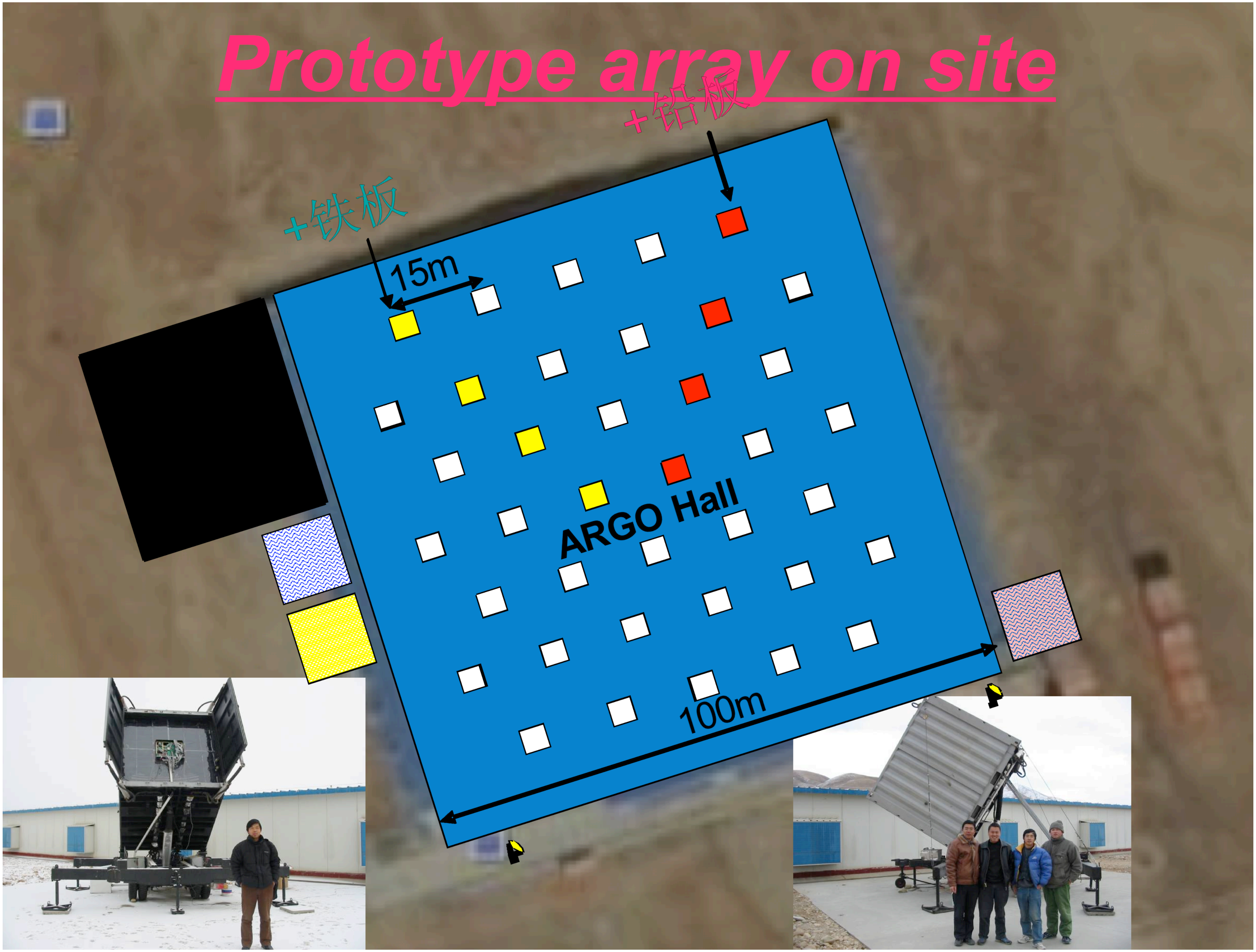

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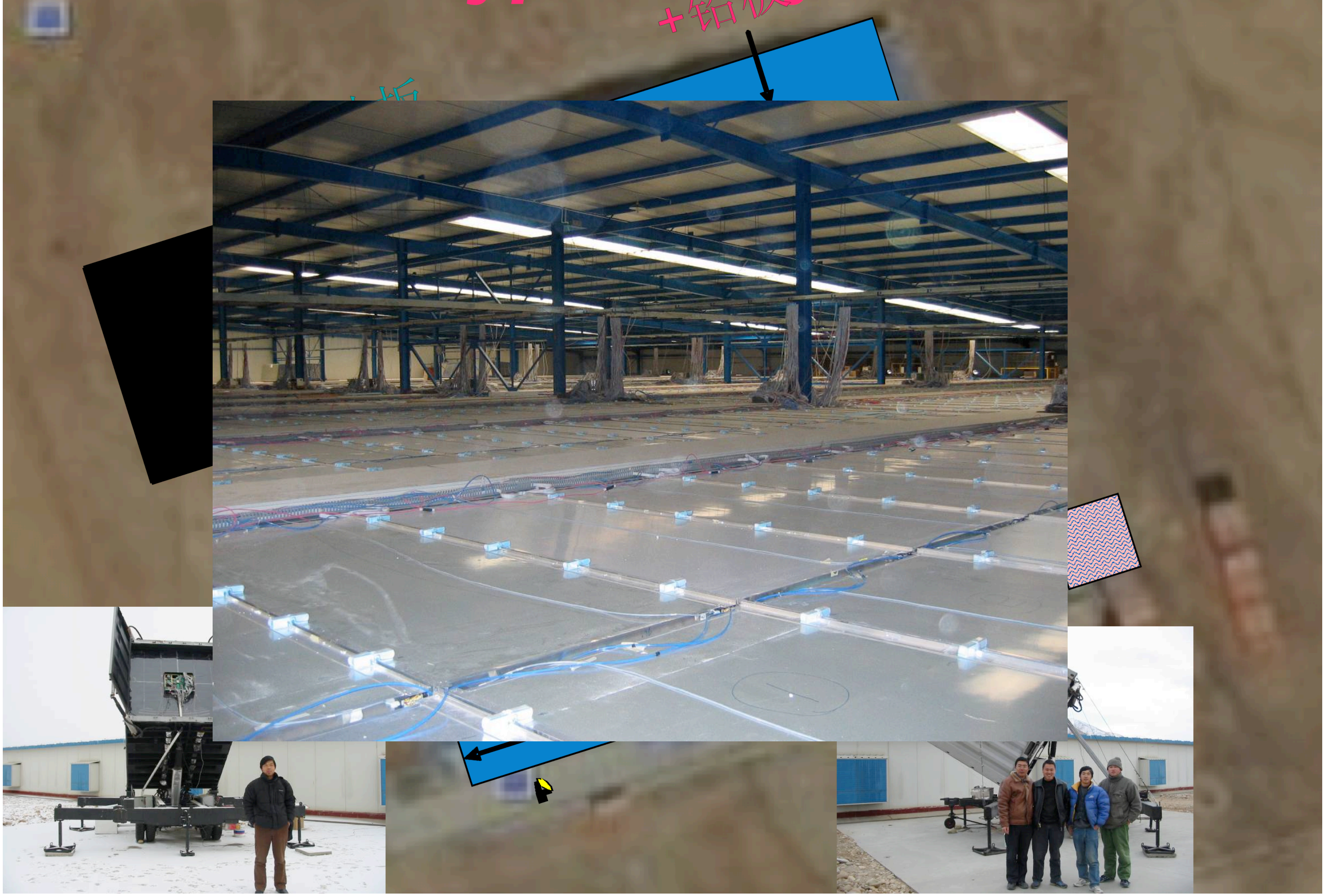

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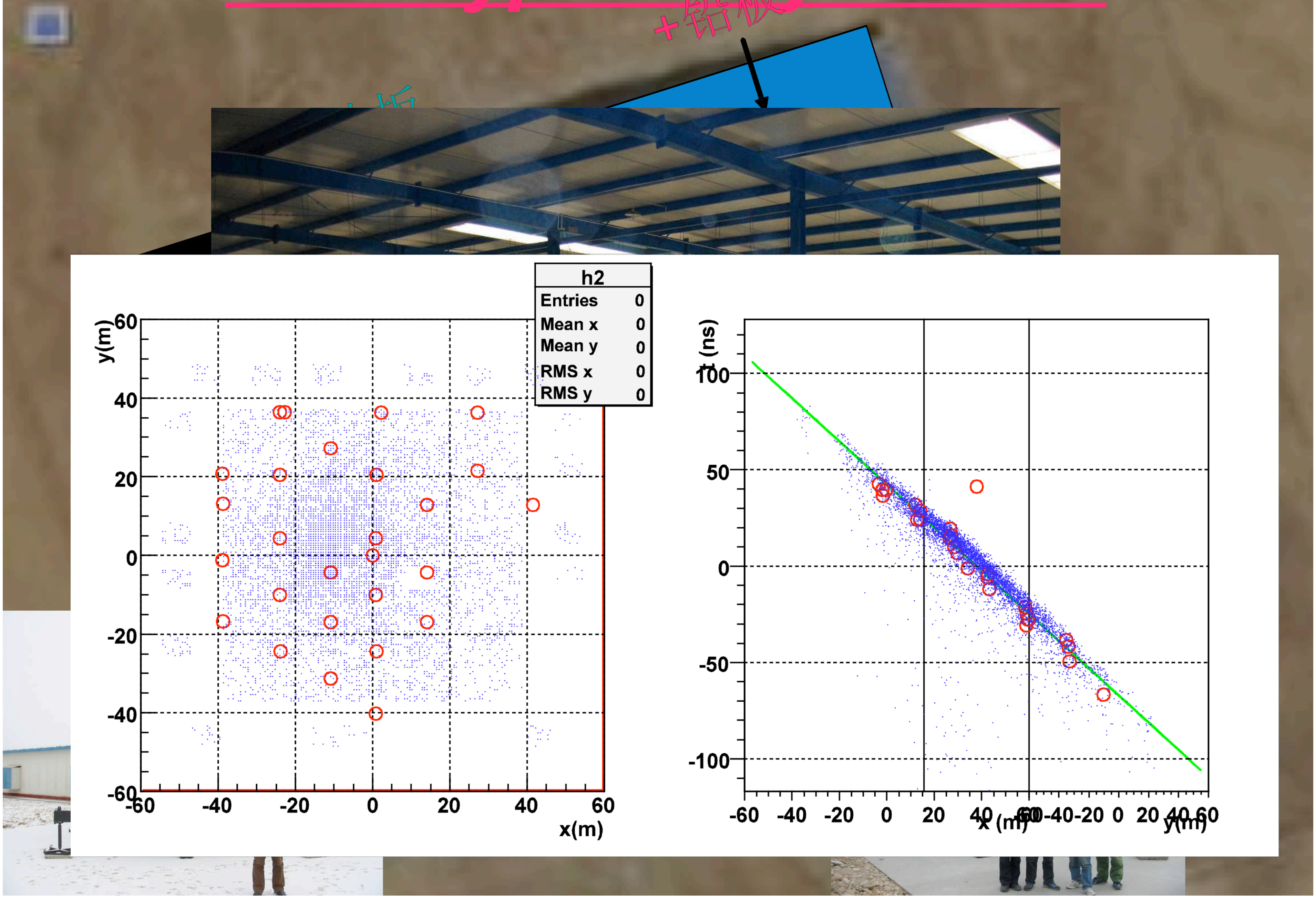
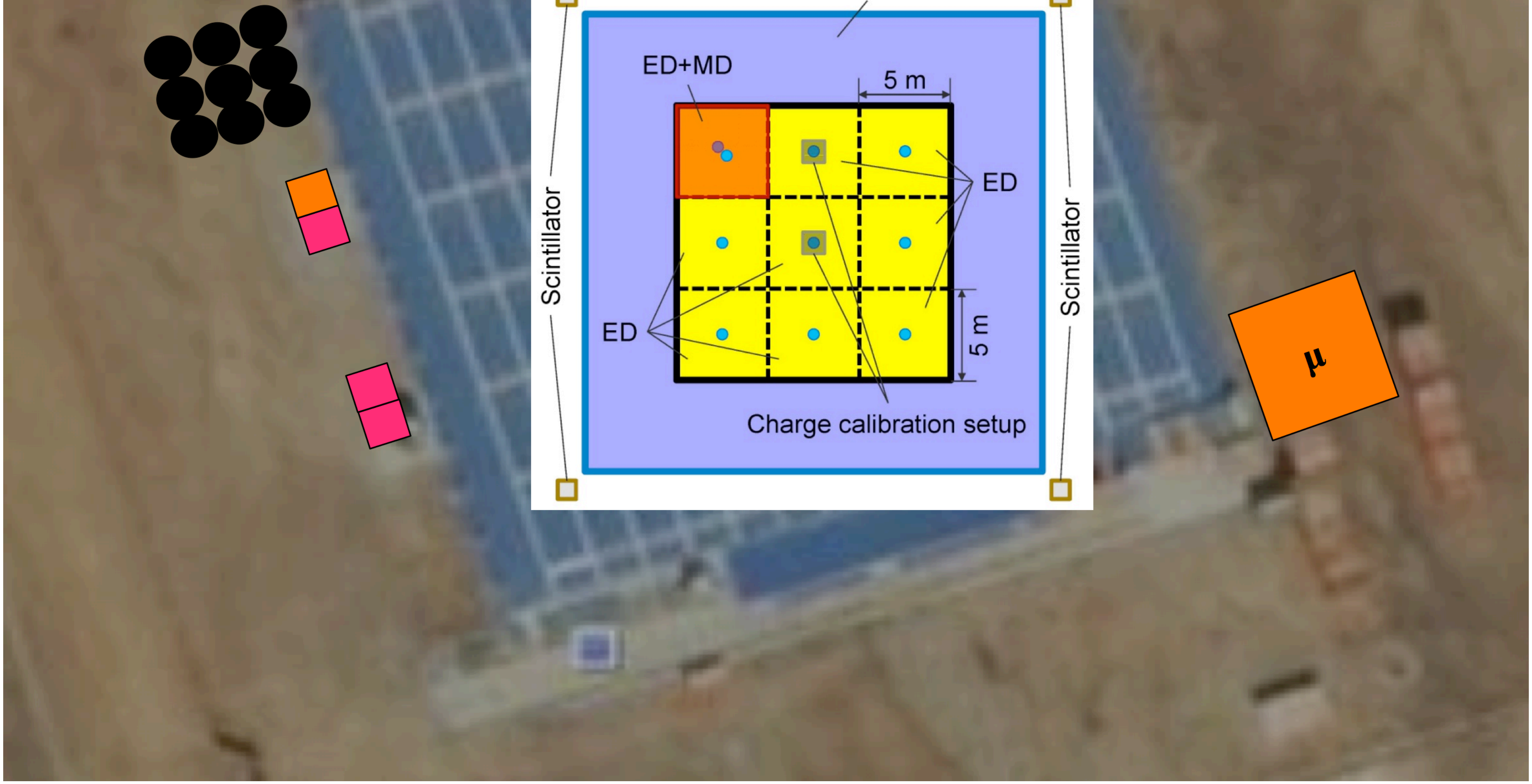


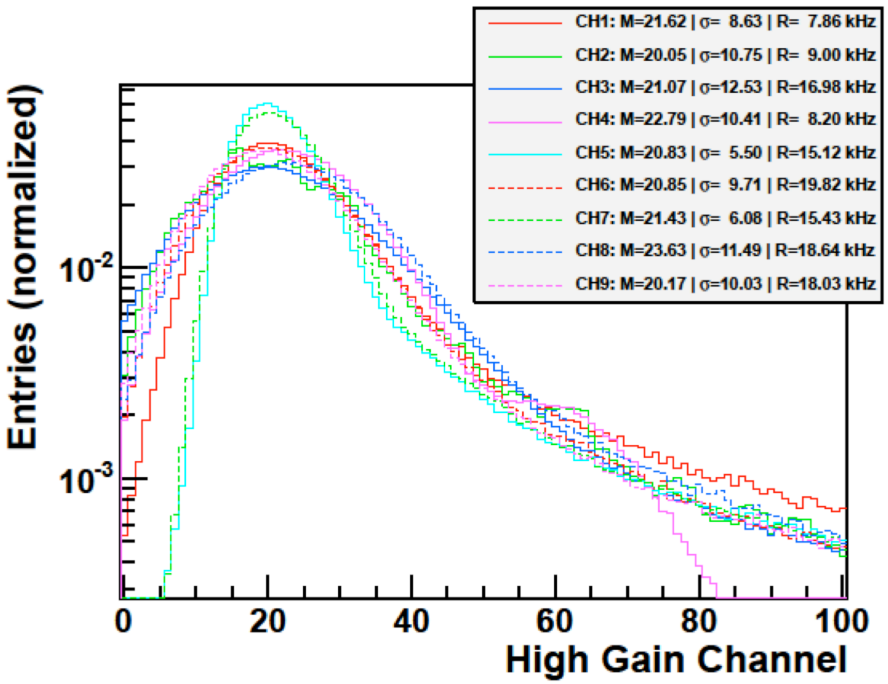
Prototype of WCD at YBJ site

- 1% engineering array near the ARGO detector

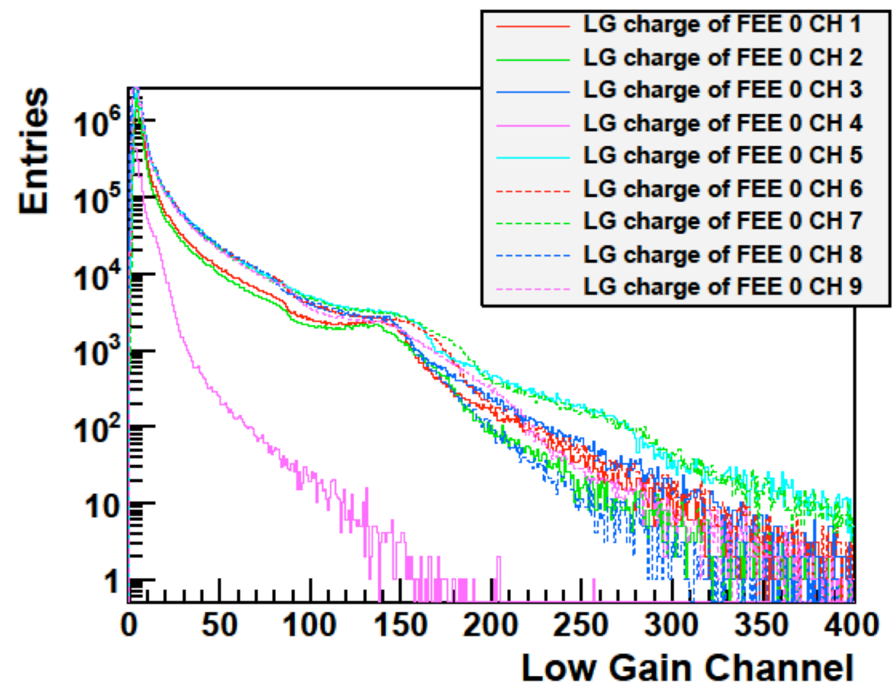


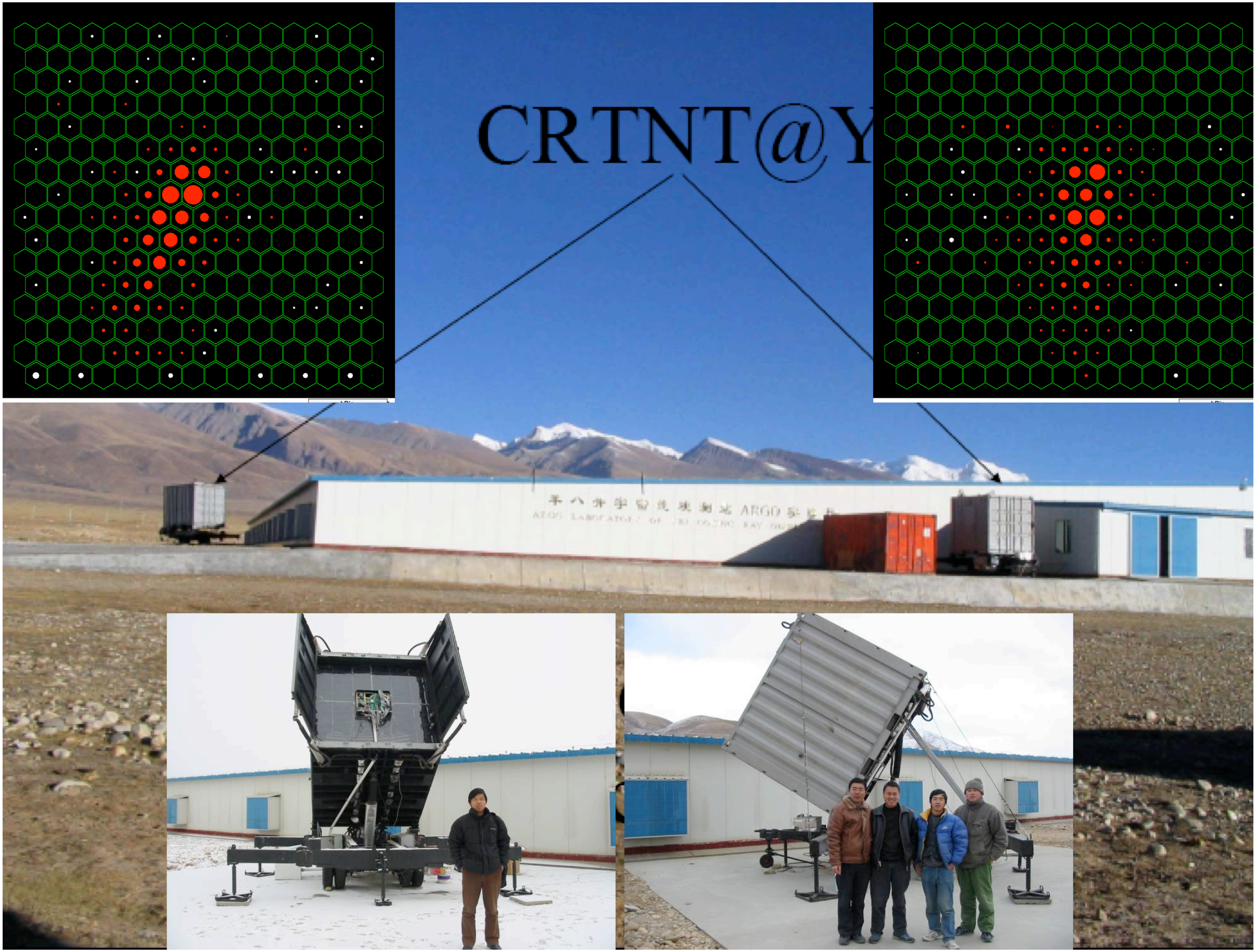
Prototype of WCD at YBJ site

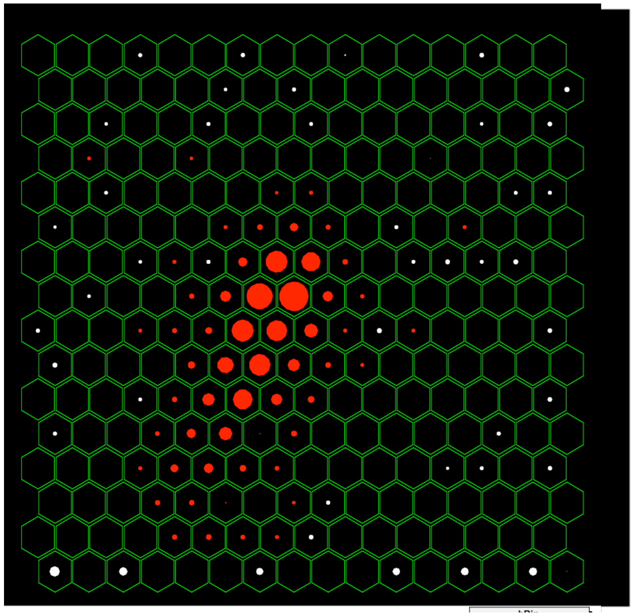
First Test Results

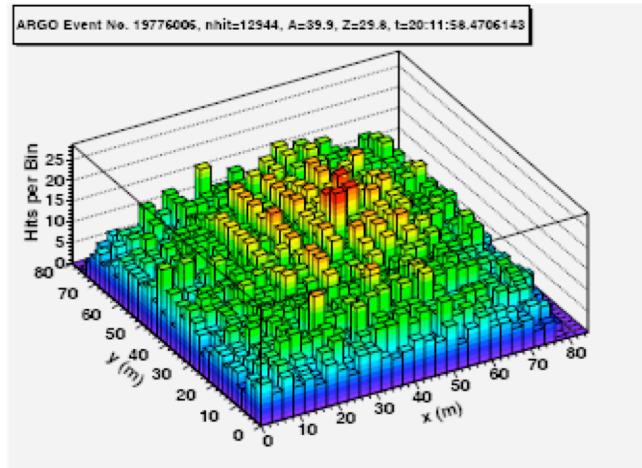


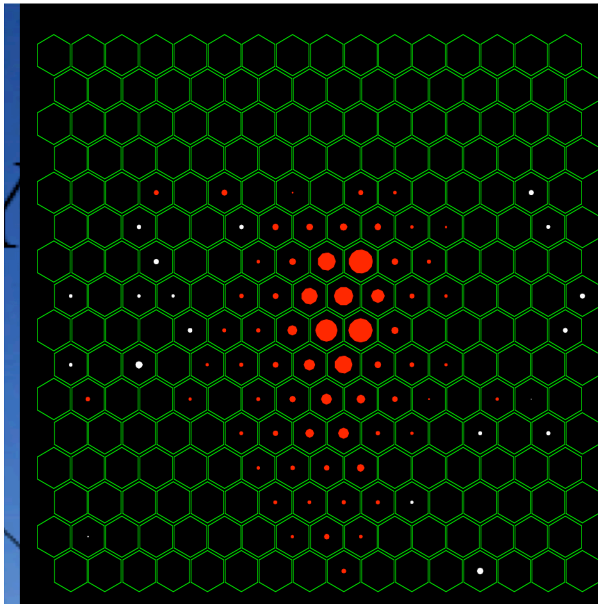
- 9 PMTs:
  - CH1, CH2: with charge calibration covers (shading pad);
  - CH4: not immersed into the water;
- Water depth
  - 30 cm above the photo cathodes.

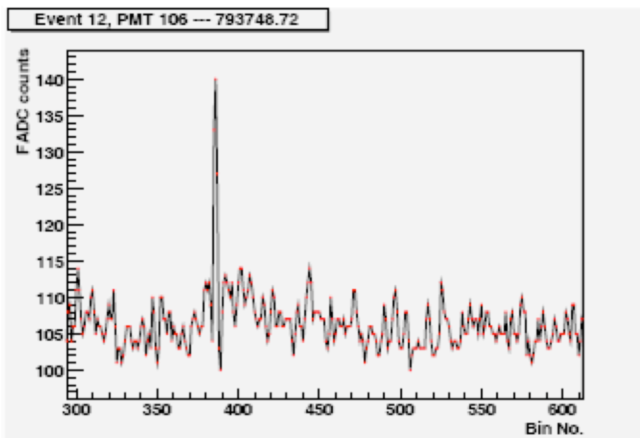


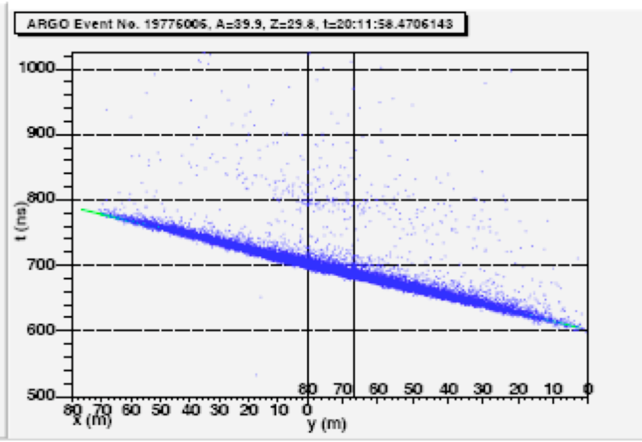

CRTNT@Y

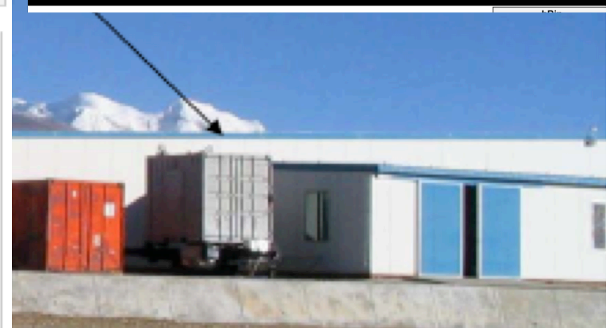


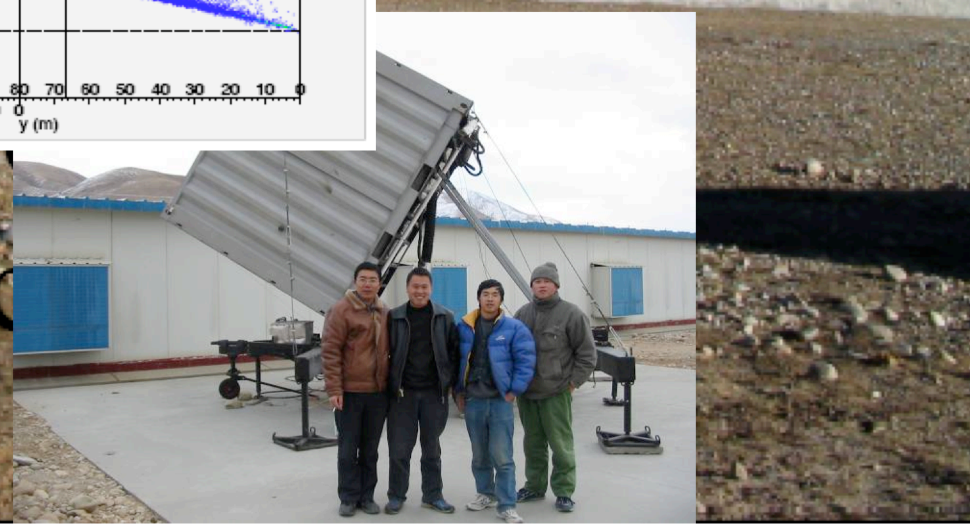

ARGO Event No. 19776006, nhit=12944, A=39.9, Z=29.8, t=20:11:58.4706143
Hits per Bin
y (m)
x (m)




Event 12, PMT 106 --- 793748.72
FADC counts
Bin No.


ARGO Event No. 19776006, A=39.9, Z=29.8, t=20:11:58.4706143
t (ns)
x (m)
y (m)





CR Energy Spectrum

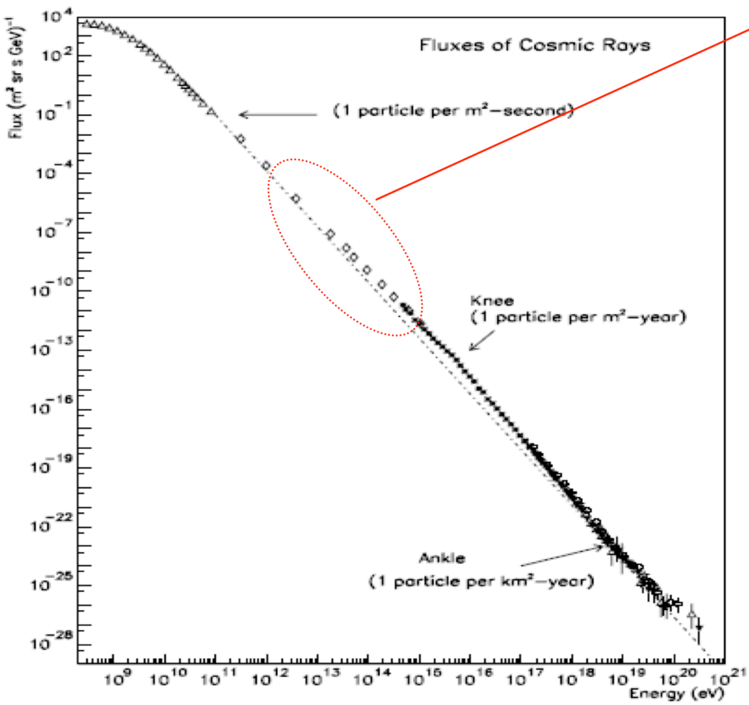
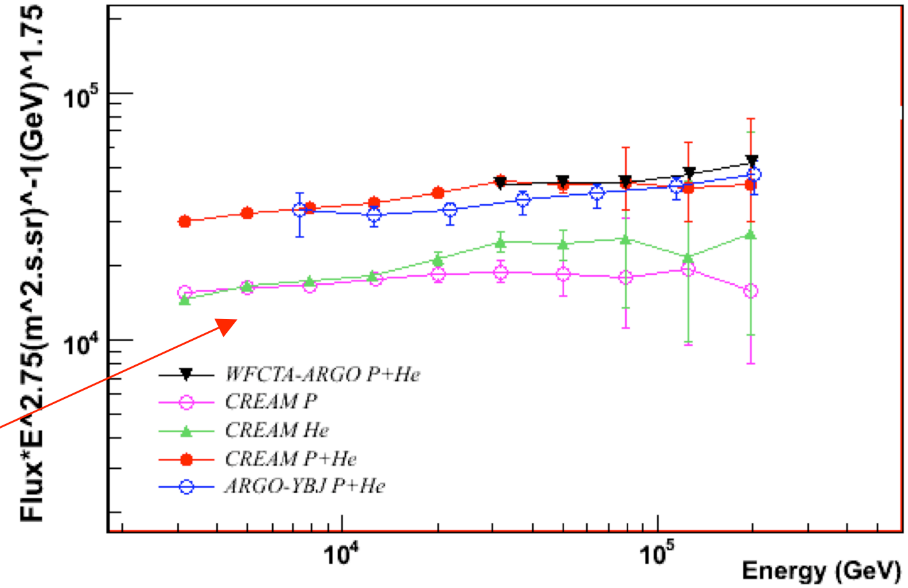
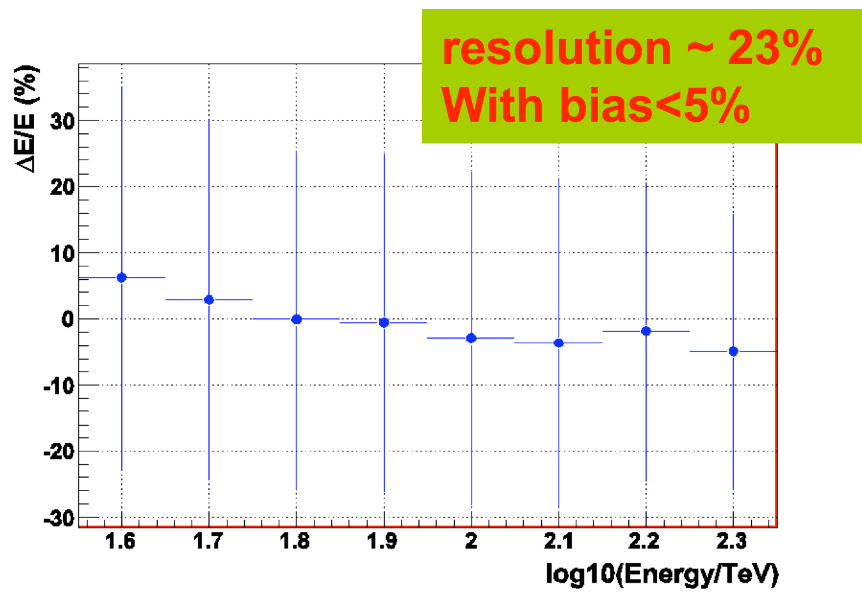


Figure 1. The all particle spectrum of cosmic rays – prepared by the author for Cronin *et al.* (1997).



- WFCTA-ARGO data agree with CREAM and ARGO-YBJ results



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Prospects of LHAASO project for cosmic ray anisotropy studies

- Accurate measurement of the anisotropy with a wide energy range from 100 GeV to 10 PeV.
- Measure the anisotropy of different composition: Proton/He, Fe,γ.
- Study short time variation: yearly, monthly, daily.

Summary

- **The large-scale anisotropy of CRs observed by ARGO-YBJ experiment is consistent with that of the ASr experiment.**

- **The amplitude of the anisotropy increases with energy below ~10TeV and decreases at higher energies.**

- **The monthly and yearly variation of anisotropy is ongoing……**

- **The LHAASO project may bring us interesting results on short time variation.**

Thanks for your attention!