Measurement of interplanetary magnetic field in short period using the cosmic-ray Sun shadow measured by LHAASO

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on behalf of the LHAASO collaboration

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Outline

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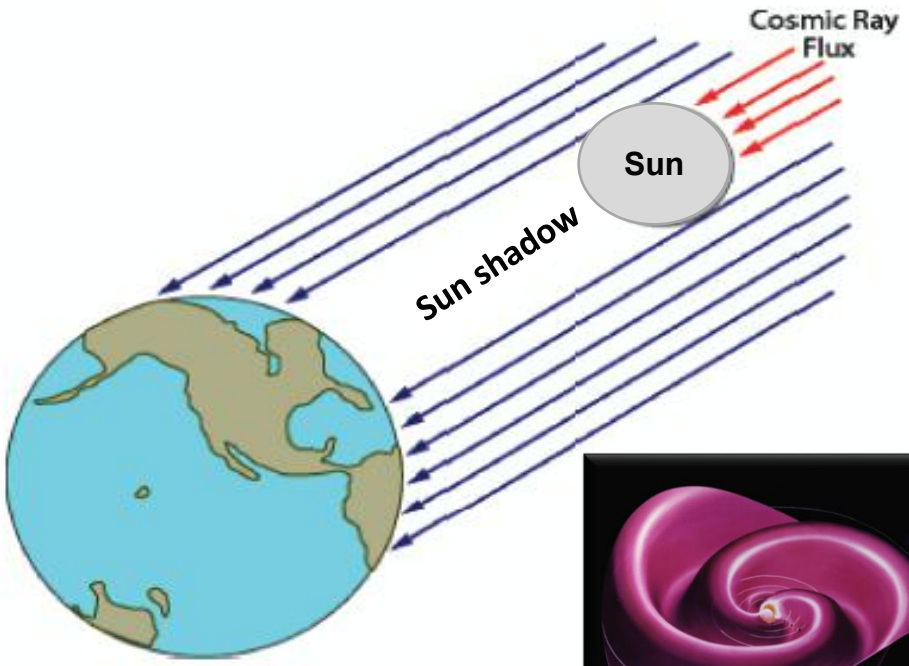
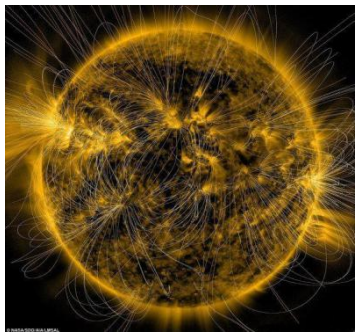
1.Introduction

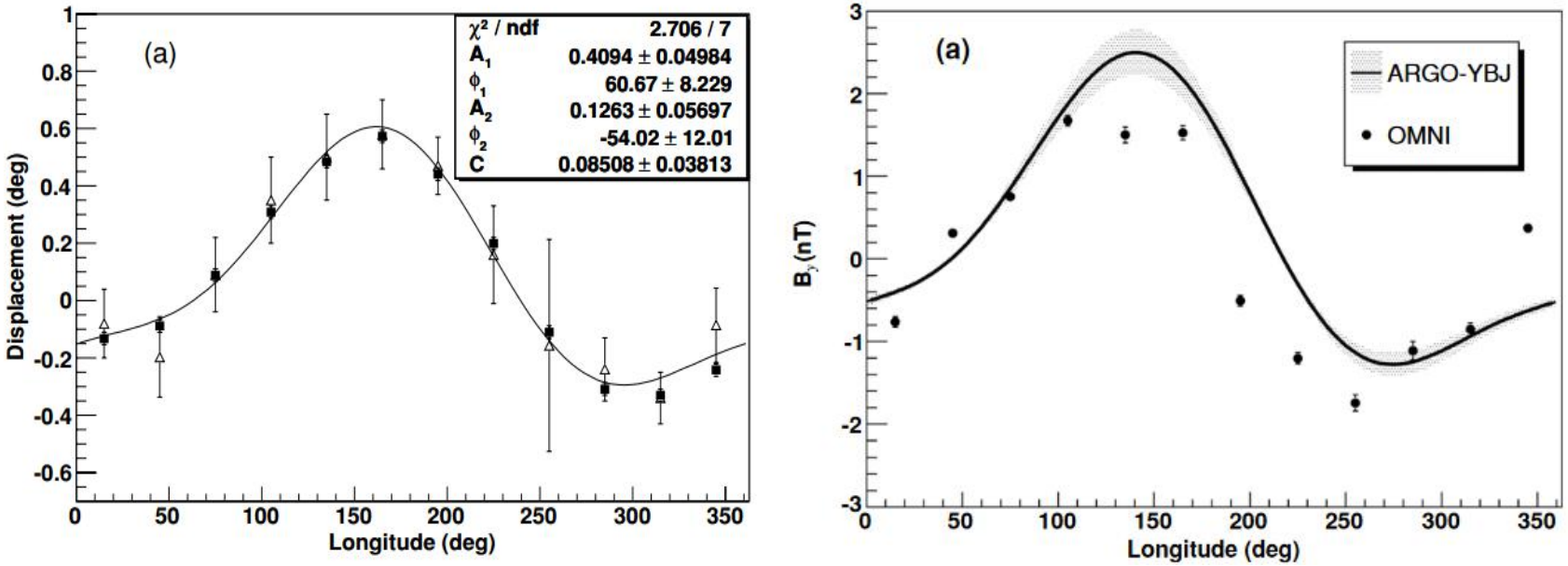
Sun shadow





A probe to detect the Solar-terrestrial magnetic field.

ARGO-YBJ's Sun shadow



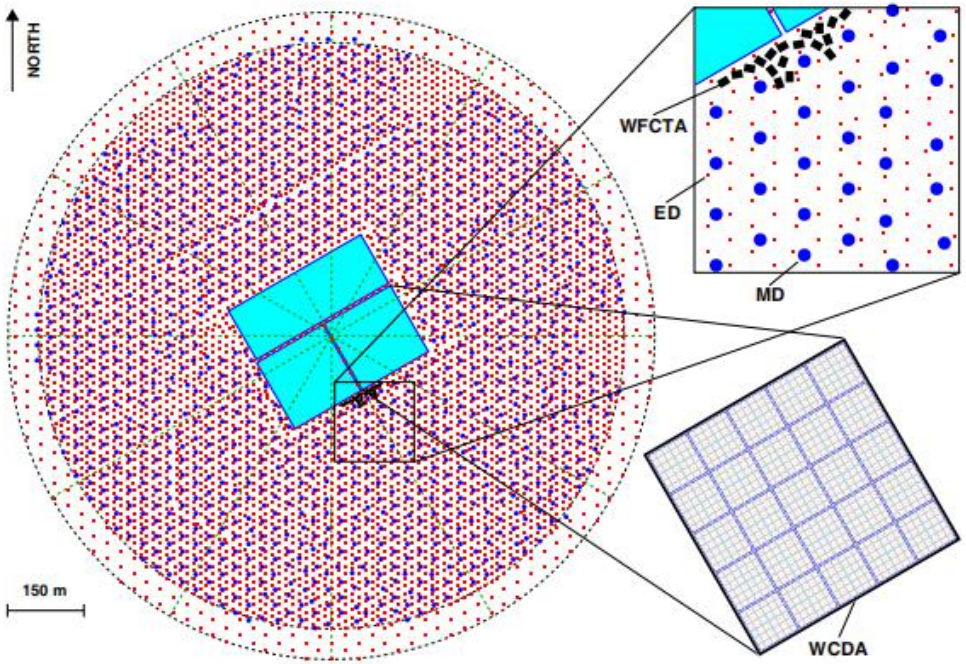
ApJ, 729:113 (2011)

ARGO-YBJ estimated the structure of the IMF 1.6 days ahead at 5TeV by folding ~1 year's data!

2.WCDA-1's Sun shadow

LHAASO-WCDA-1：

LHAASO at 4410m altitude on Haizi Mountain, China

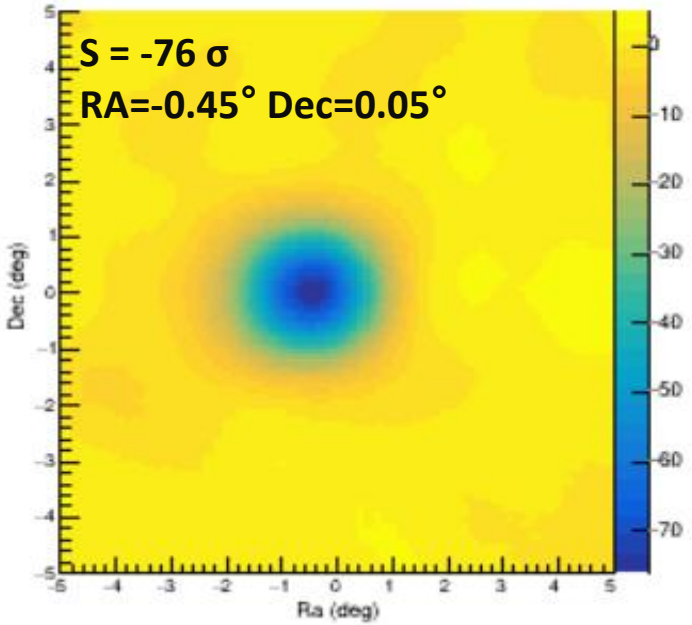


Water Cherenkov Detector Array

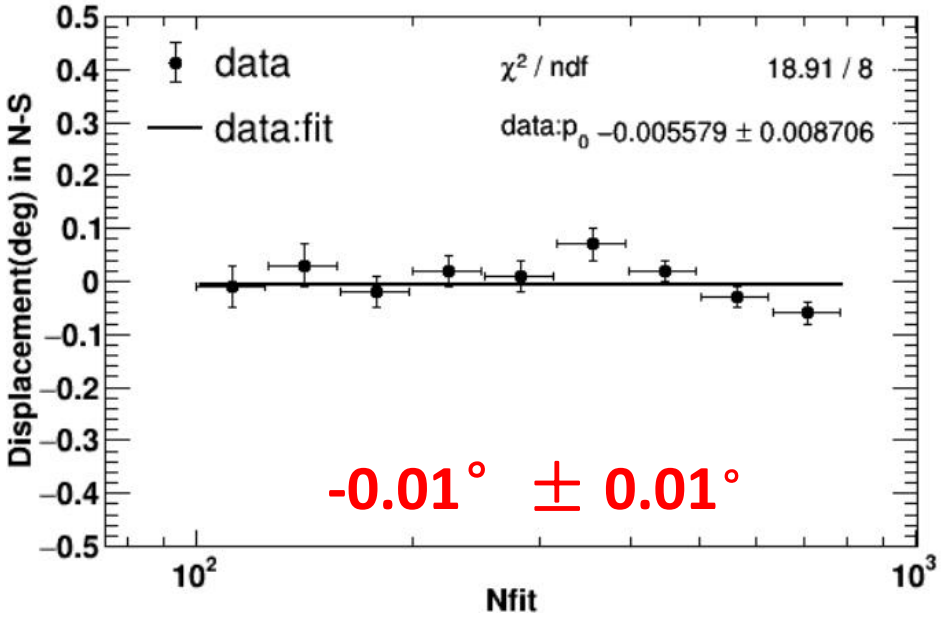
- **Observation time：**
  Apr 2019~ Mar 2020
  ~70σ Sun shadow
- **Data selection:**
  CR2210（20190727-0822）
  Nfit：100-800（6.2TeV）
- **Background estimation method:**
  Direct integration method

Moon shadow

Significance map

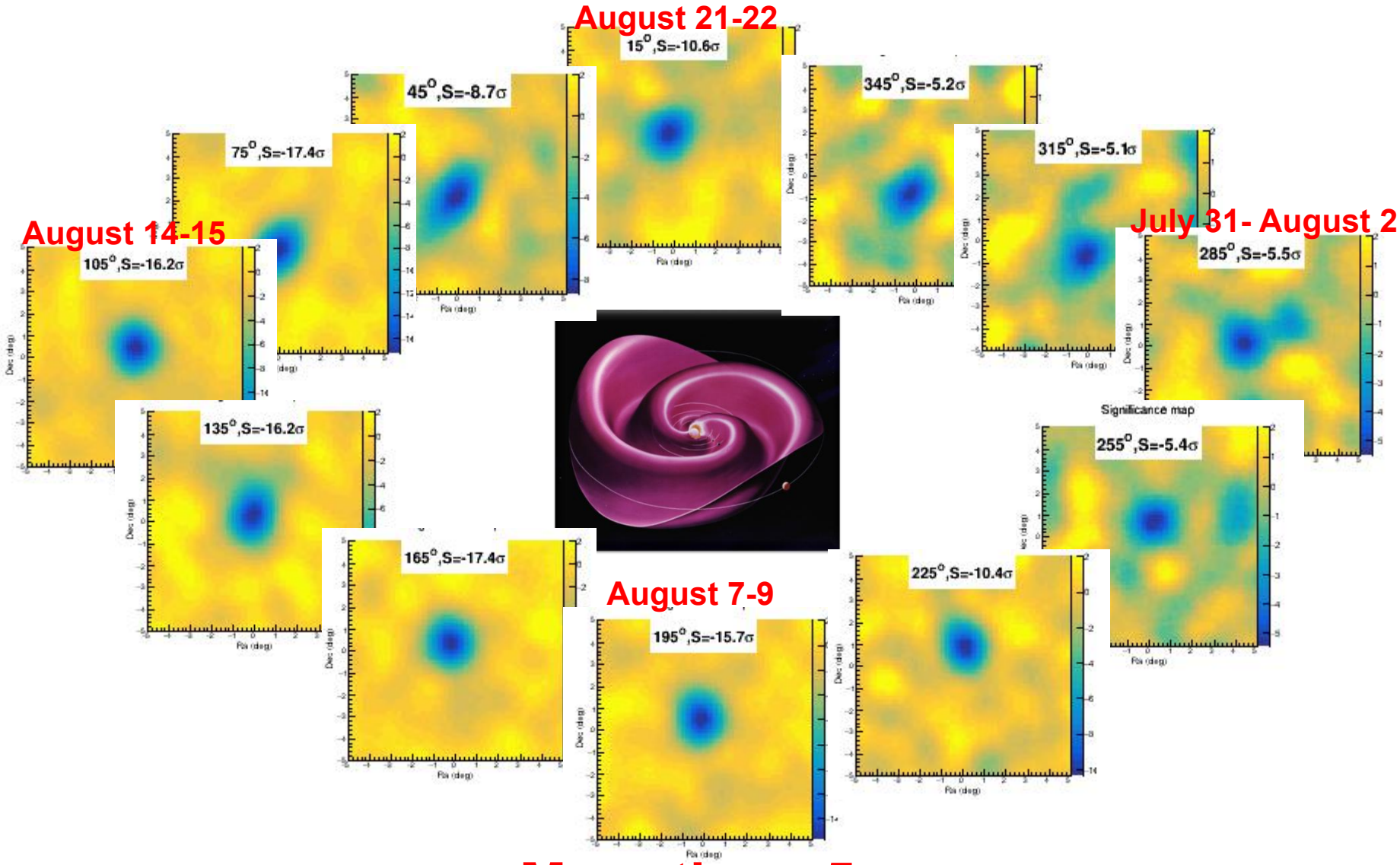


Pointing accuracy



WCDA-1 has good pointing accuracy in N-S !

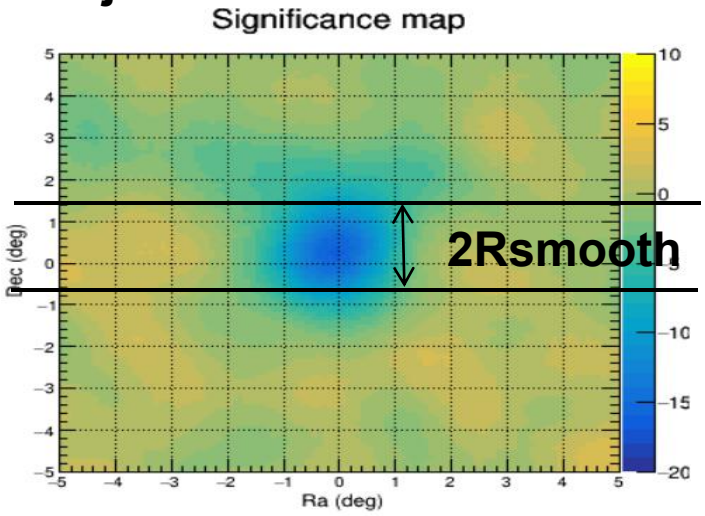
Sun shadow & rotation of IMF



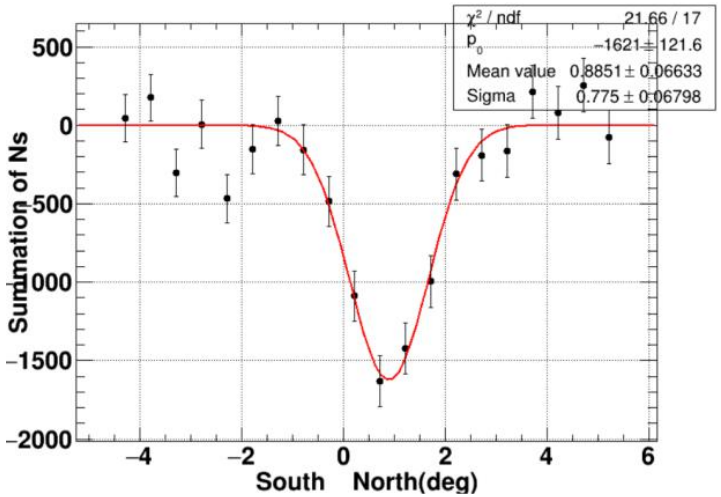
More than~5σ

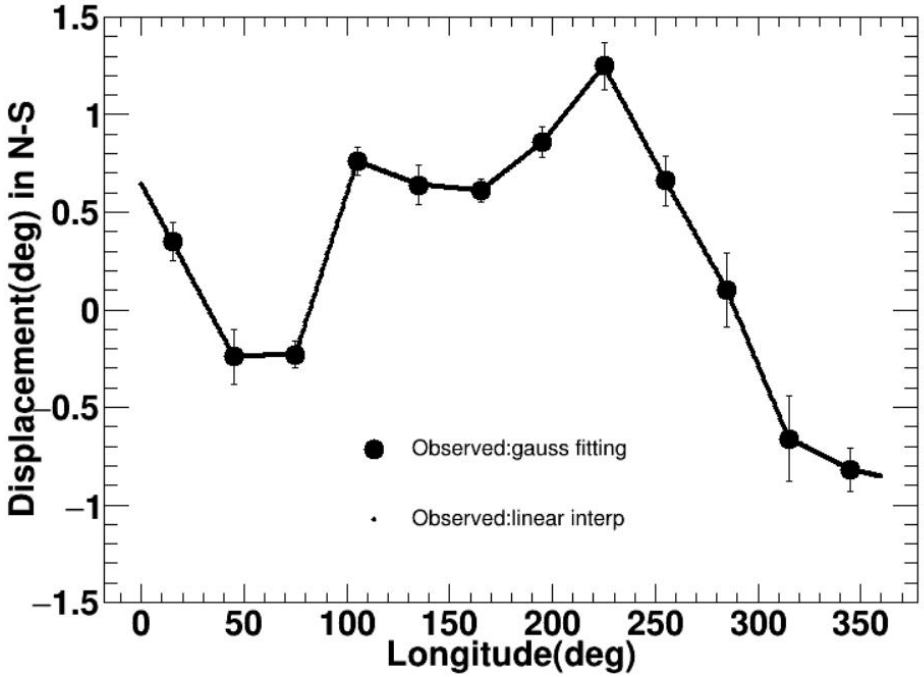
Displacement in N-S

Projection



Gaussian fitting





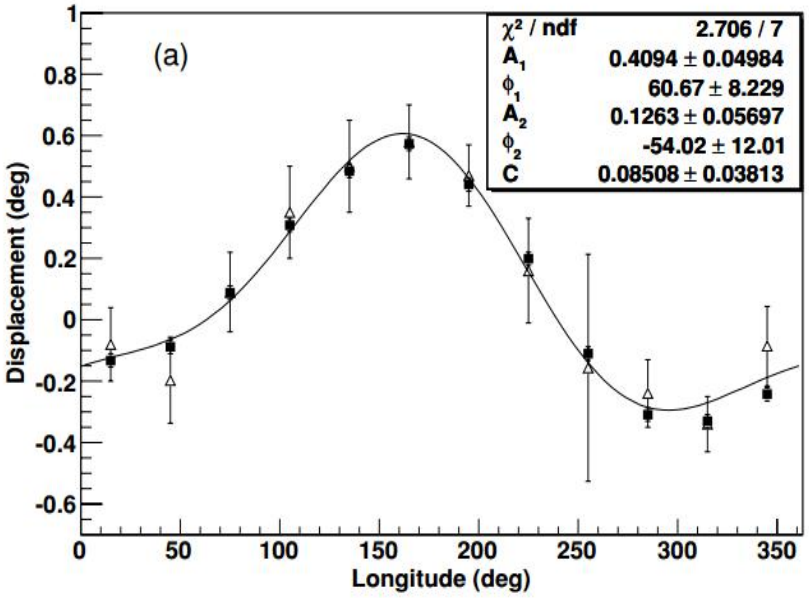
Method

IMF：parker model

$$Bx = -B(\psi_{ss})\left(\frac{b}{r}\right)^2$$

$$Bz = 0$$

$$By = B(\psi_{ss})\left(\frac{\omega}{v}\right)(r-b)\left(\frac{b}{r}\right)^2$$



ApJ, 729:113 (2011)

Divide into two parameters by ARGO

$$Bx = -B_0 \times \mathrm{f}(\psi - \delta)\left(\frac{b}{r}\right)^2$$

$$By = B_0 \times \mathrm{f}(\psi - \delta)\left(\frac{\omega}{v}\right)(r-b)\left(\frac{b}{r}\right)^2$$

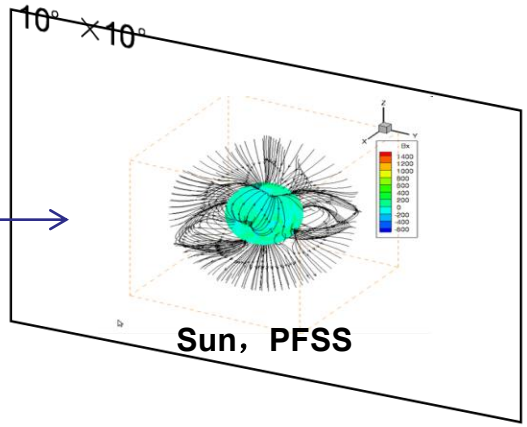
size **shift of longitude**

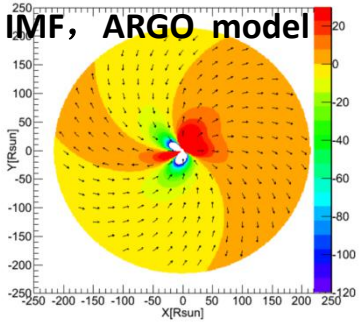
3.Simulation of Sun shadow

Simulation strategy

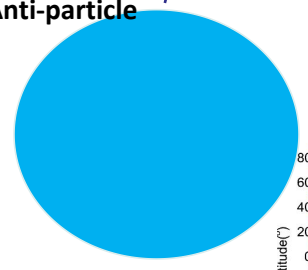
Back forward method

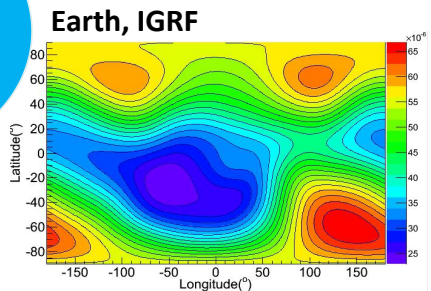
tracing the anti-particle from earth to Sun.





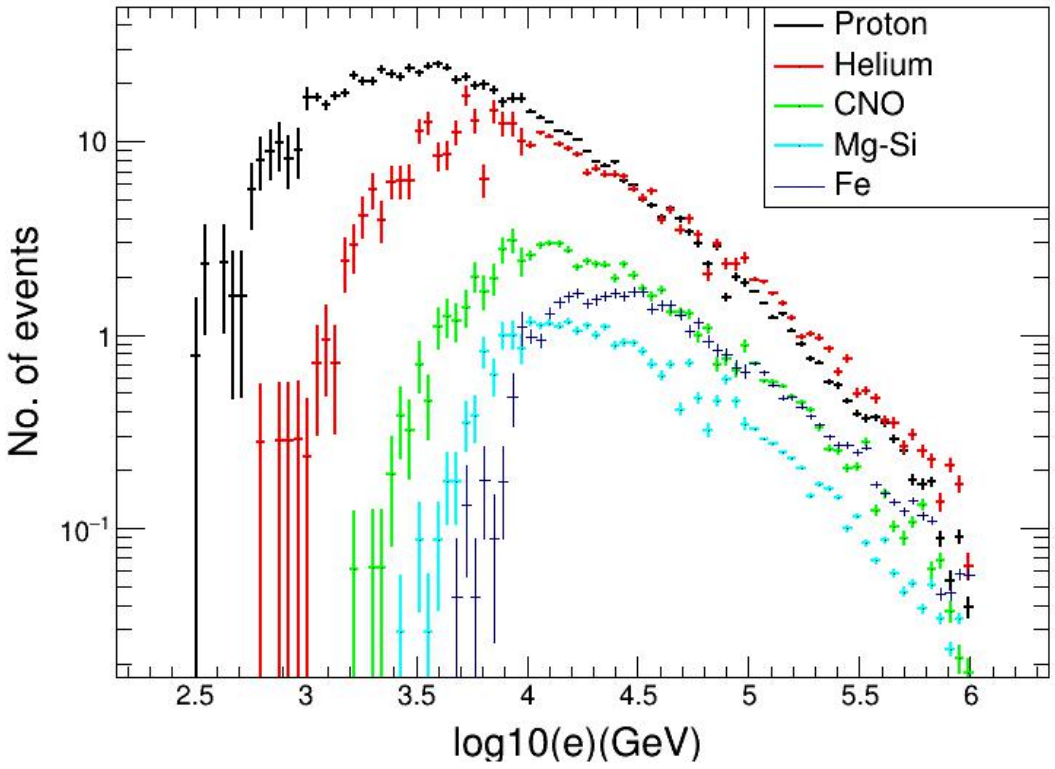
Anti-particle





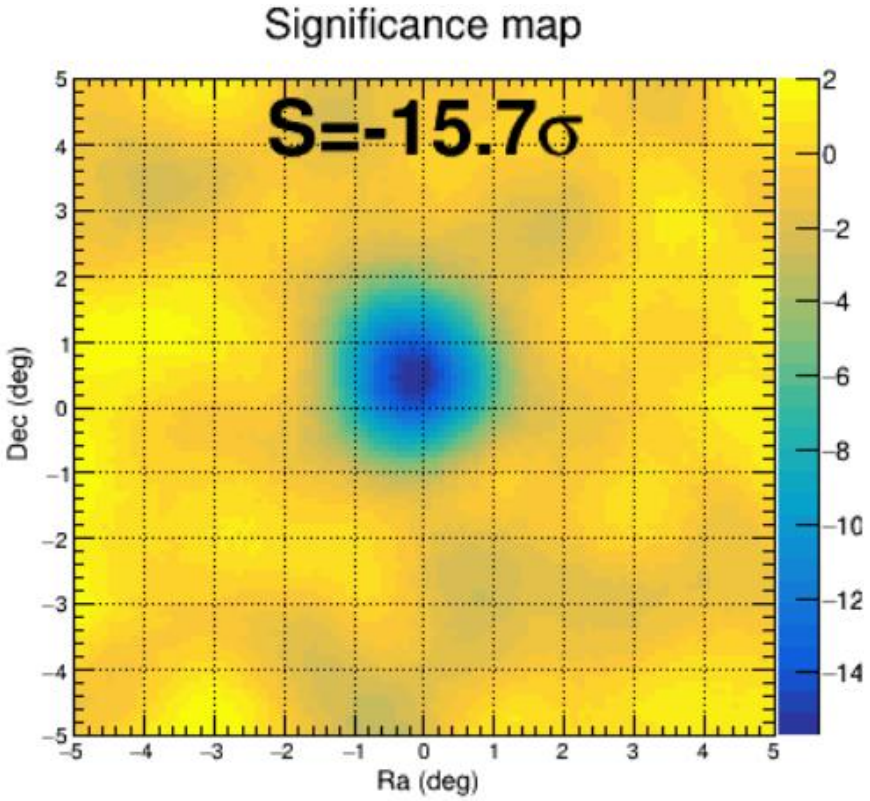
Simulation of the cosmic ray

- **Corsika + G4WCDA - > Noise&digitization -> Reconstruction:**

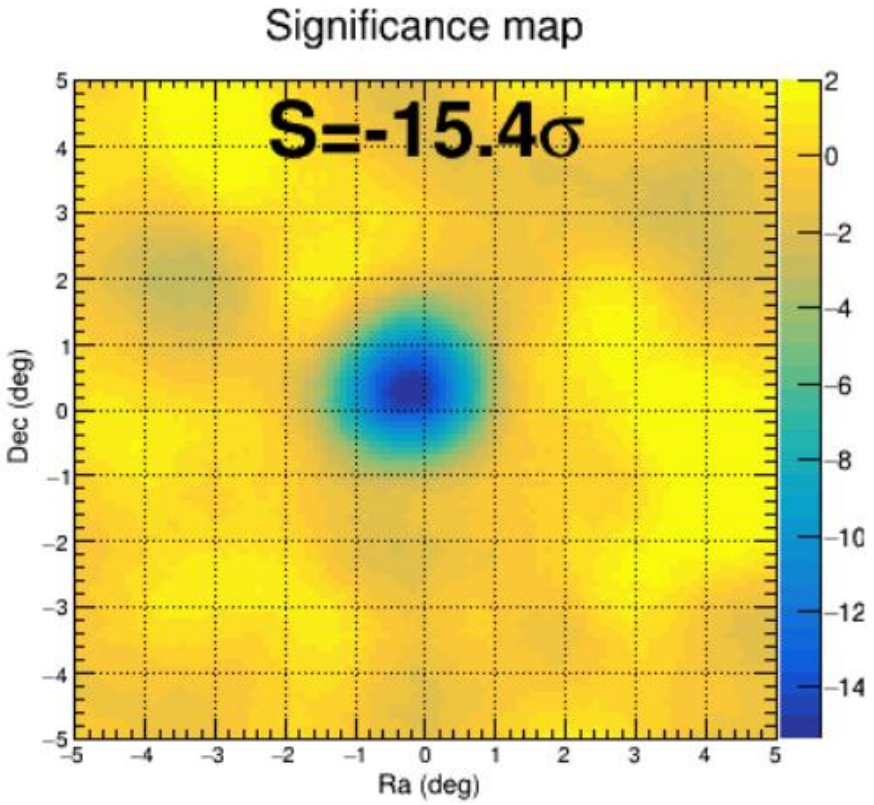


Simulation of Sun shadow

Data

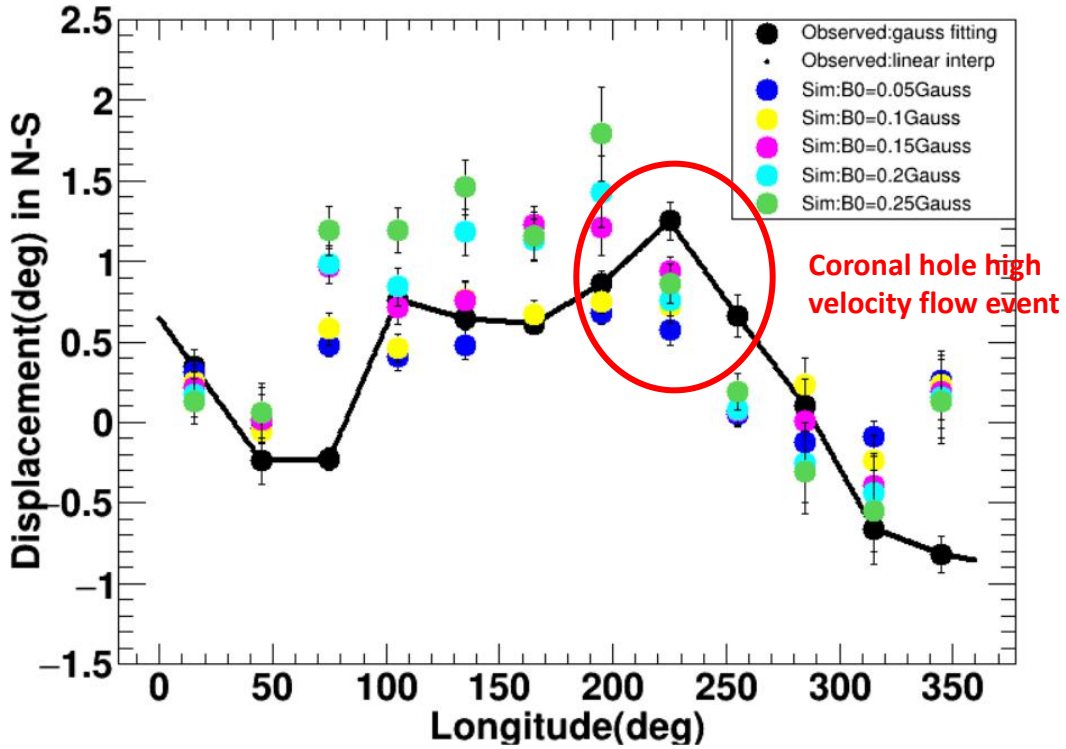


Sim



B0=0.1Gauss，δ=0°

Comparison between data and simulation



- **Fitting method：**

$$\chi^2 = \sum_{i=1}^{12} \frac{\left(D^i_{sim}(B_0,\delta) - D^i_{obs}\right)^2}{\sigma^2_{total}}$$

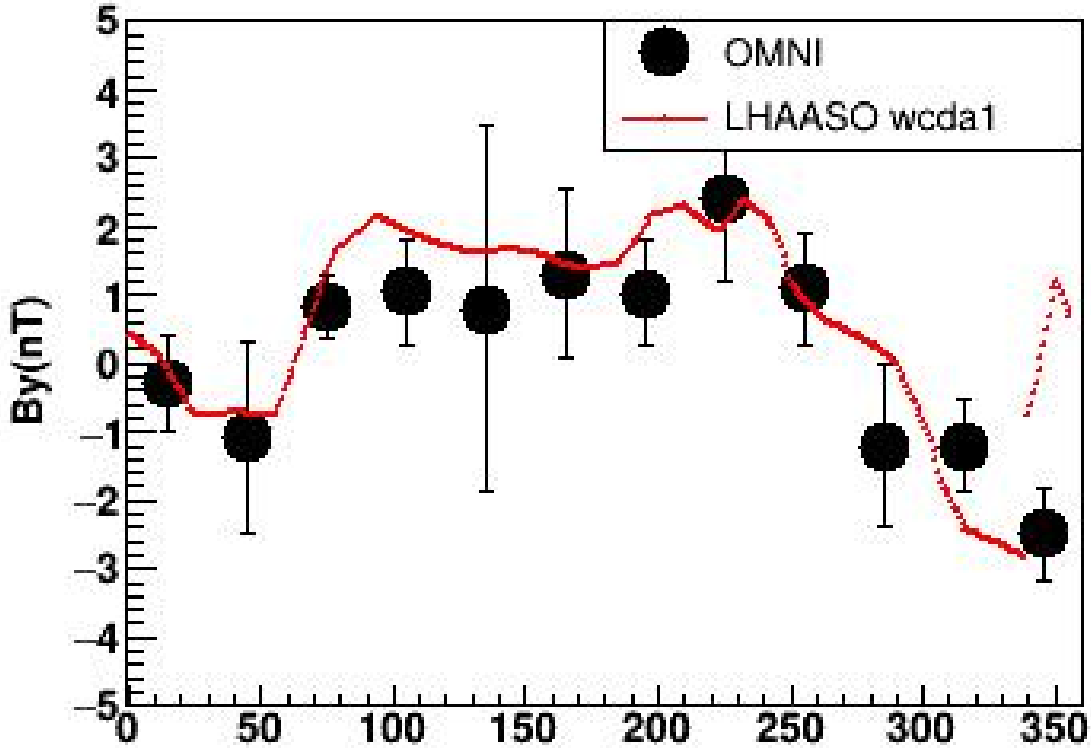
- **Fitting result:**

χ2 = 4.25

δ = 44.98°

B0 = 0.20Gauss

4. Results of the IMF



August 22, 2019 **July 27, 2019**

The structures of results are in agreement with ONMI's at 1AU.

This is the first time to measure the IMF using Sun shadow in a short period !

5. Summary

- From our analysis：

（1）We have constructed a complete data analysis and simulation program of Sun shadow.

（2）We measured the structures of By of the IMF in CR2220 by WCDA-1's Sun shadow preliminarily.

- In the future:

（1）The results of this work will be further explored.

（2）Learning more about the stable and eruptible MF by WCDA and KM2A(LHAASO).