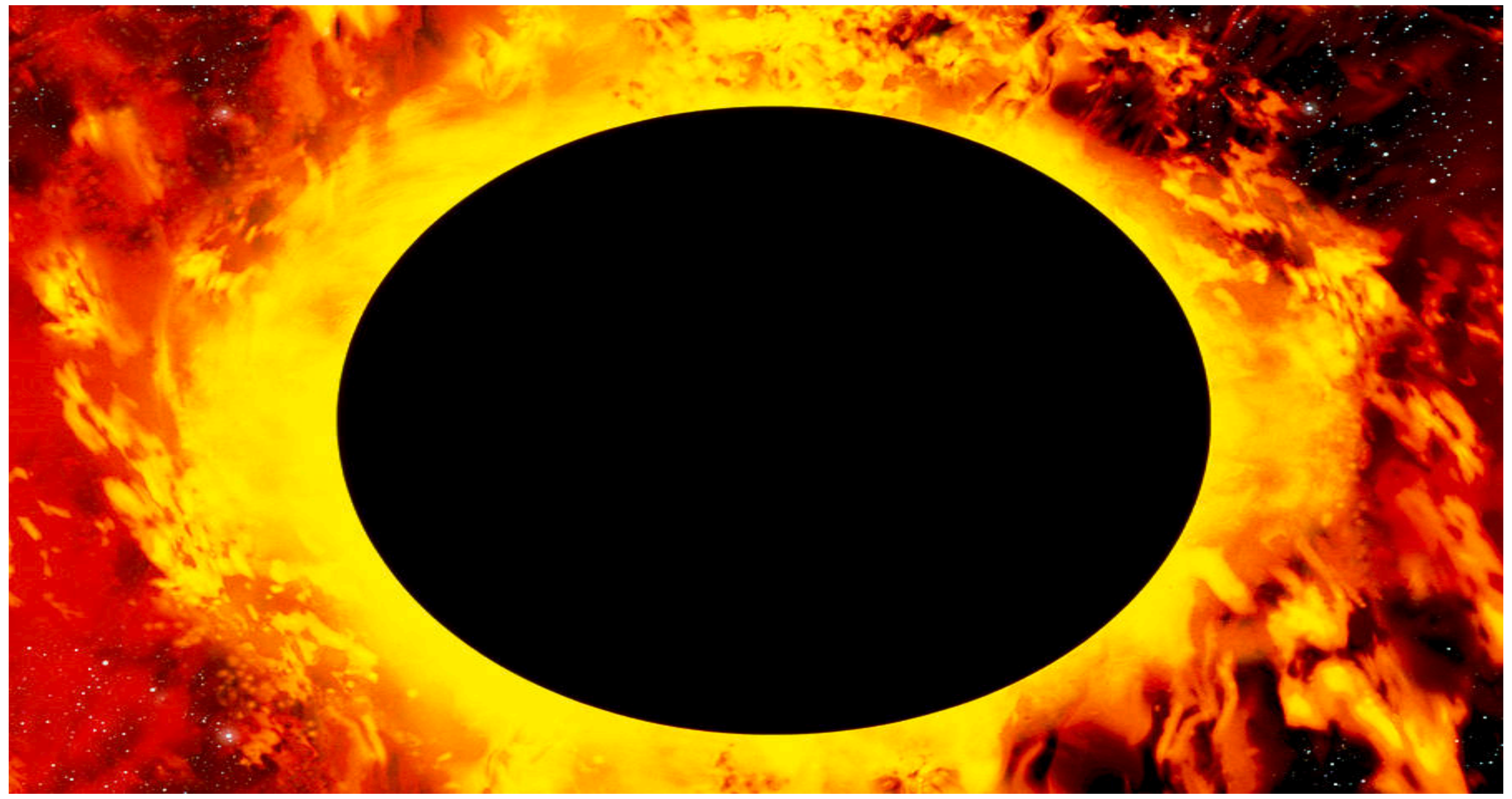
LHAASO measurements on VHE gamma-ray emissions from the Sun



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TeVPA 2023

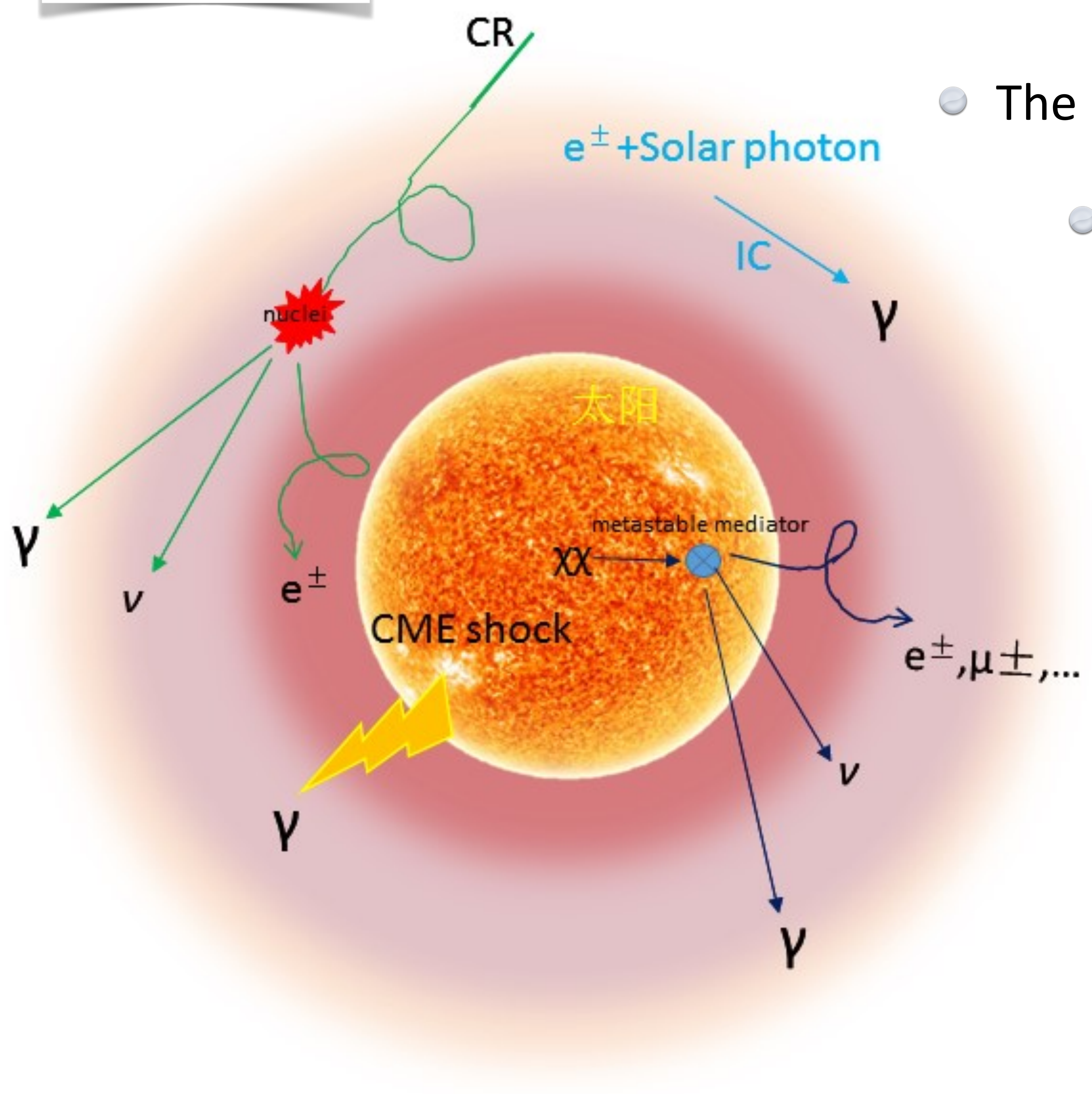
Napoli ,Italy

Outline

- Why solar disk gamma-ray
- LHAASO-WCDA experiment
- Background estimation and results
- Summary

See related Talks by Jung-Tsung Li;Elena Orlando; E. Puzzoni;Kenny C.Y.Ng

1.Why solar disk gamma-ray



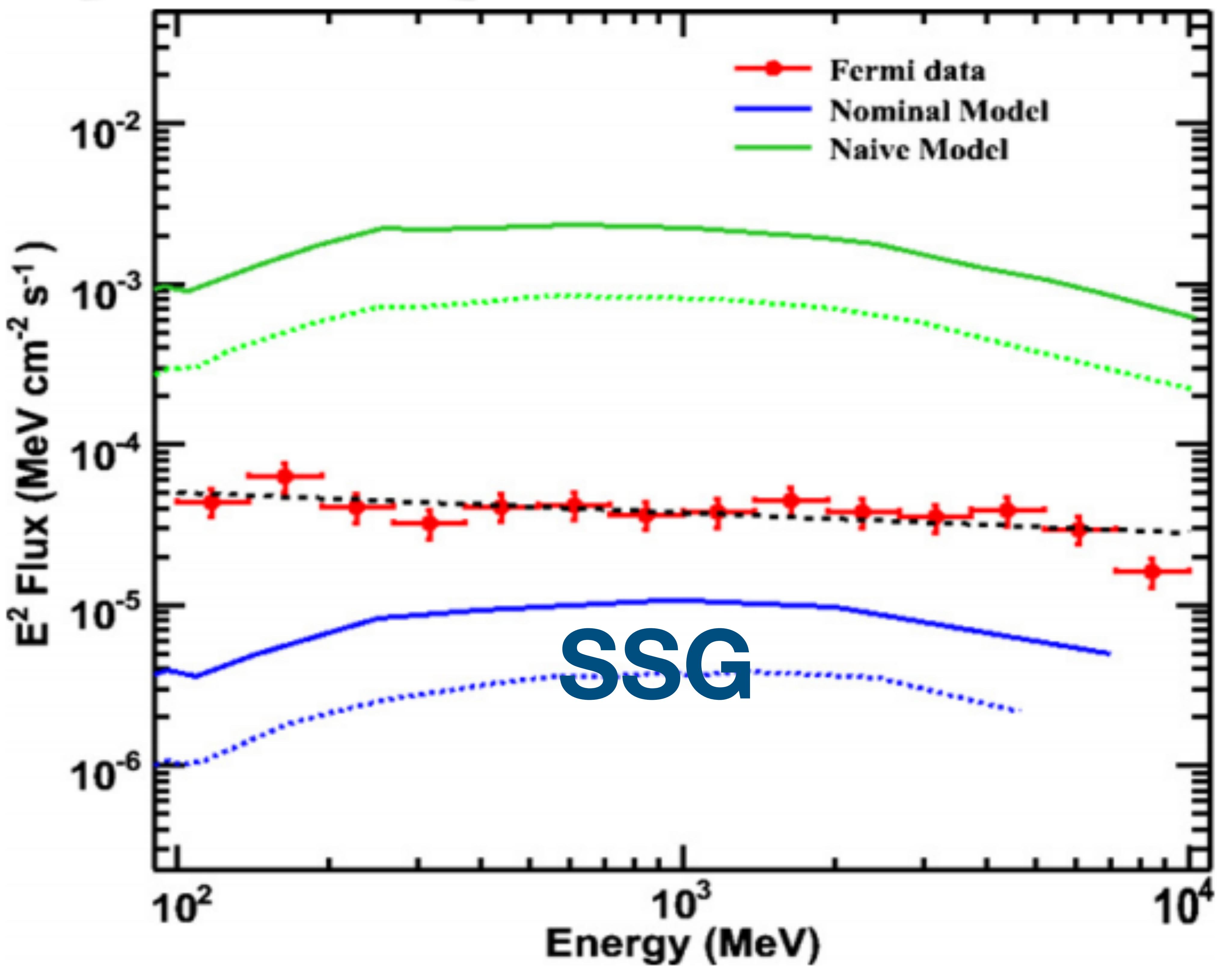
- The highest-energy gamma-ray observed from a flare is ＜10GeV
  - Dark matter annihilation (no observation result)
    - **High energy gamma-rays from the solar region are produced mainly by two distinct process:**

(1)One is produced by IC of cosmic-ray electrons on solar photons, denoted as "**IC component**"

(2)The other is from the hadronic interaction of cosmic rays with solar atmosphere (photosphere and chromosphere) ,denoted as "**Solar disk component**"

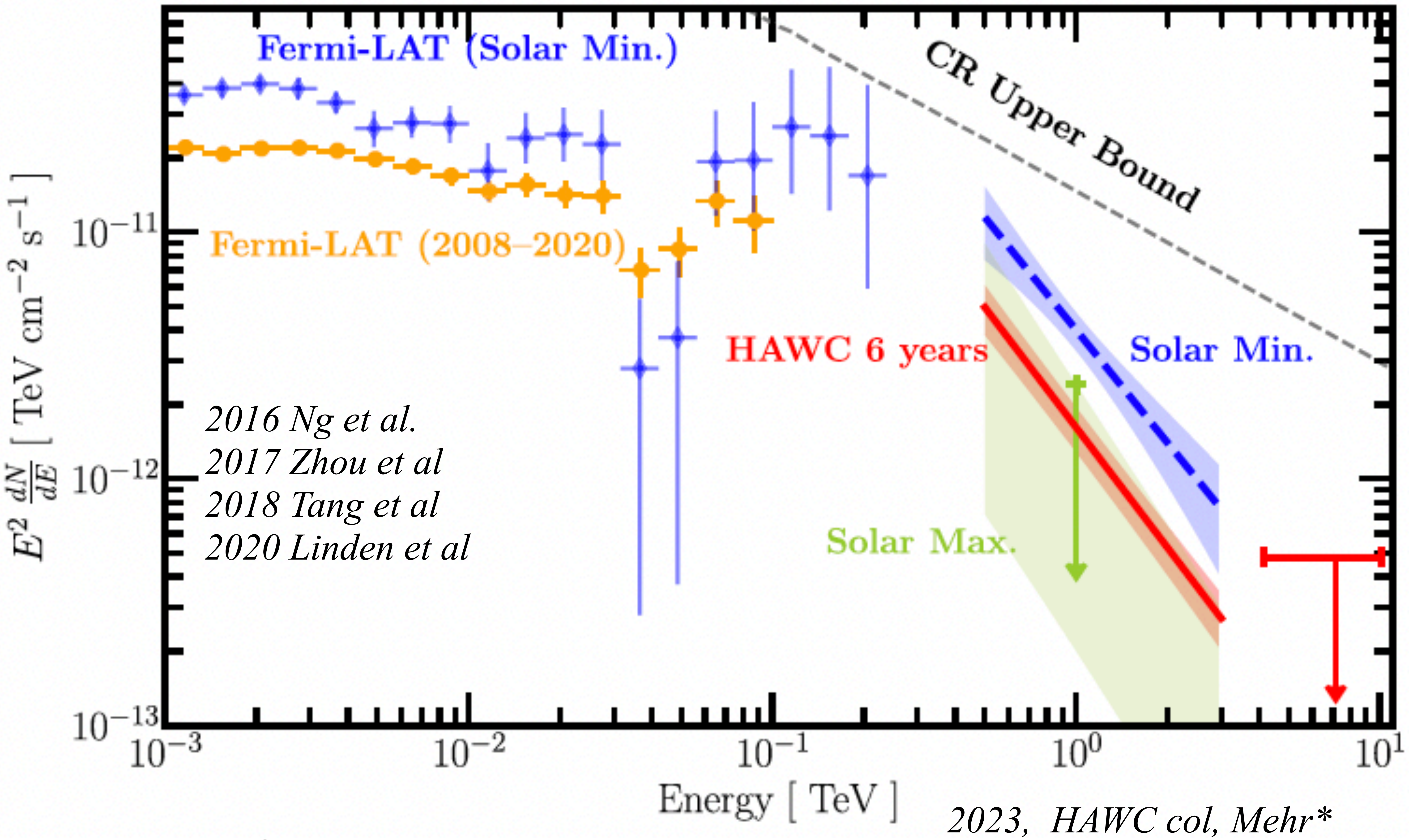
—Point like
—steady γ-ray source
—can be detected on the earth

1.Why solar disk gamma-ray



2011, Abdo et al. Fermi

1.5y data collection
Energy : 0.1-10 GeV
Spectral index:**≈2.11±0.73 (power law)**

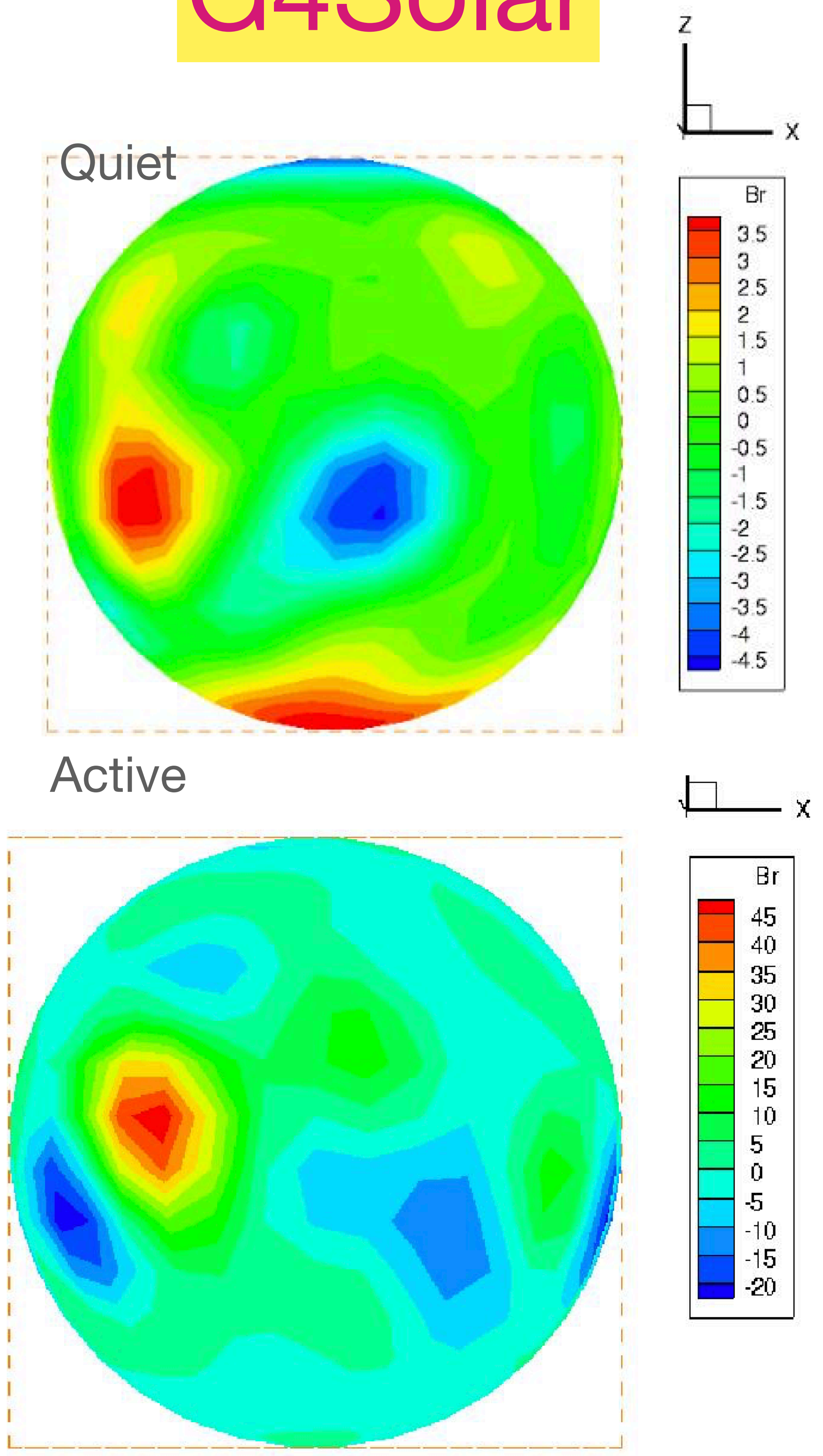


*2023, HAWC col, Mehr**

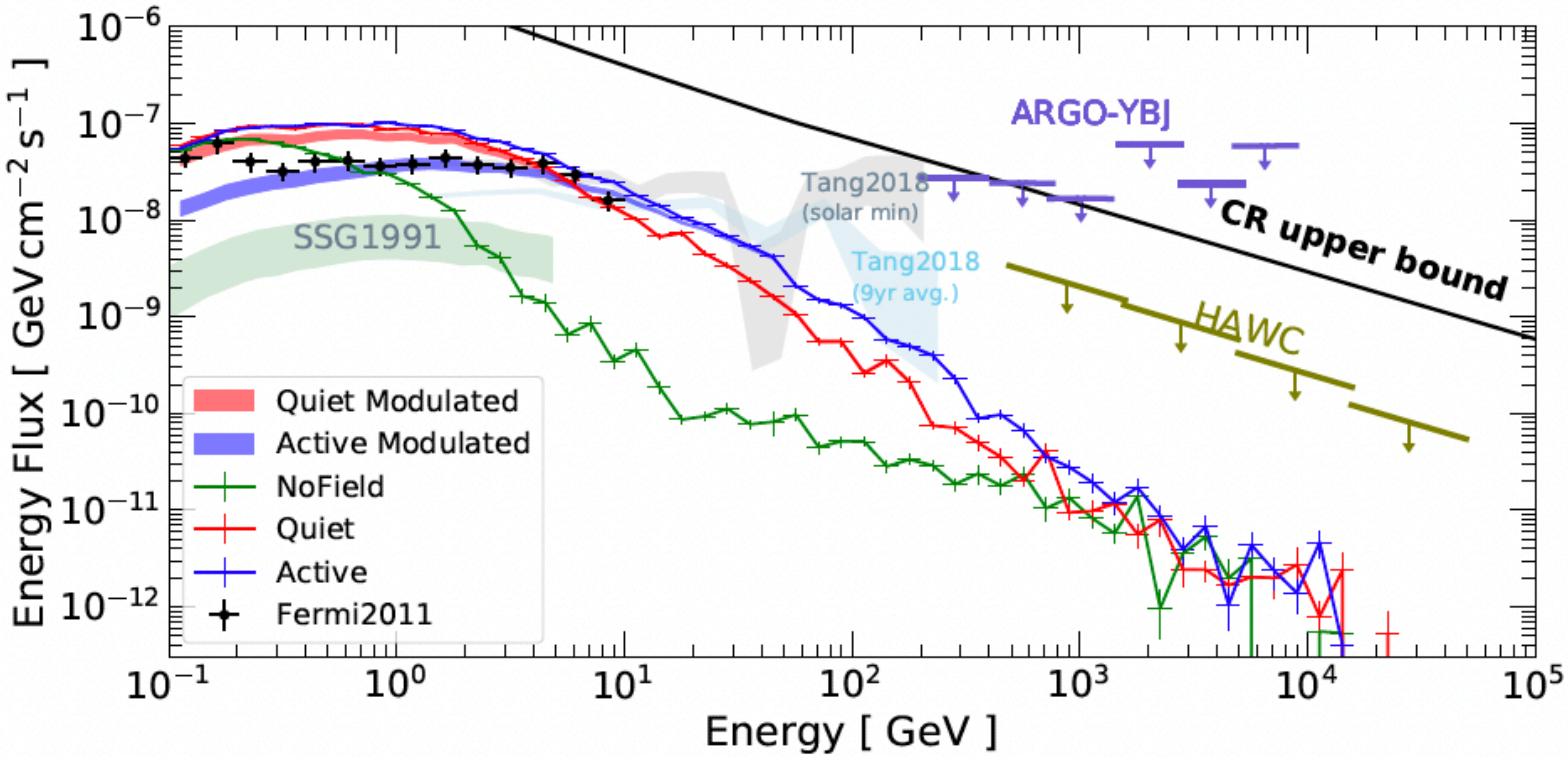
HAWC 's observation around 1TeV:
—solar min: index=-3.52±0.14
—solar max:index=-3.9±0.4

1.Why solar disk gamma-ray

G4Solar



PFSS model of coronal magnetic field



2020, Zhe Li , Kenny C.Y.Ng and Songzhan Chen, et al

Low energy gamma-ray production enhanced by coronal magnetic filed; but no finding on anti-correlation, will do more on the simulation.

2.LHAASO-WCDA experiment

Detection principle:

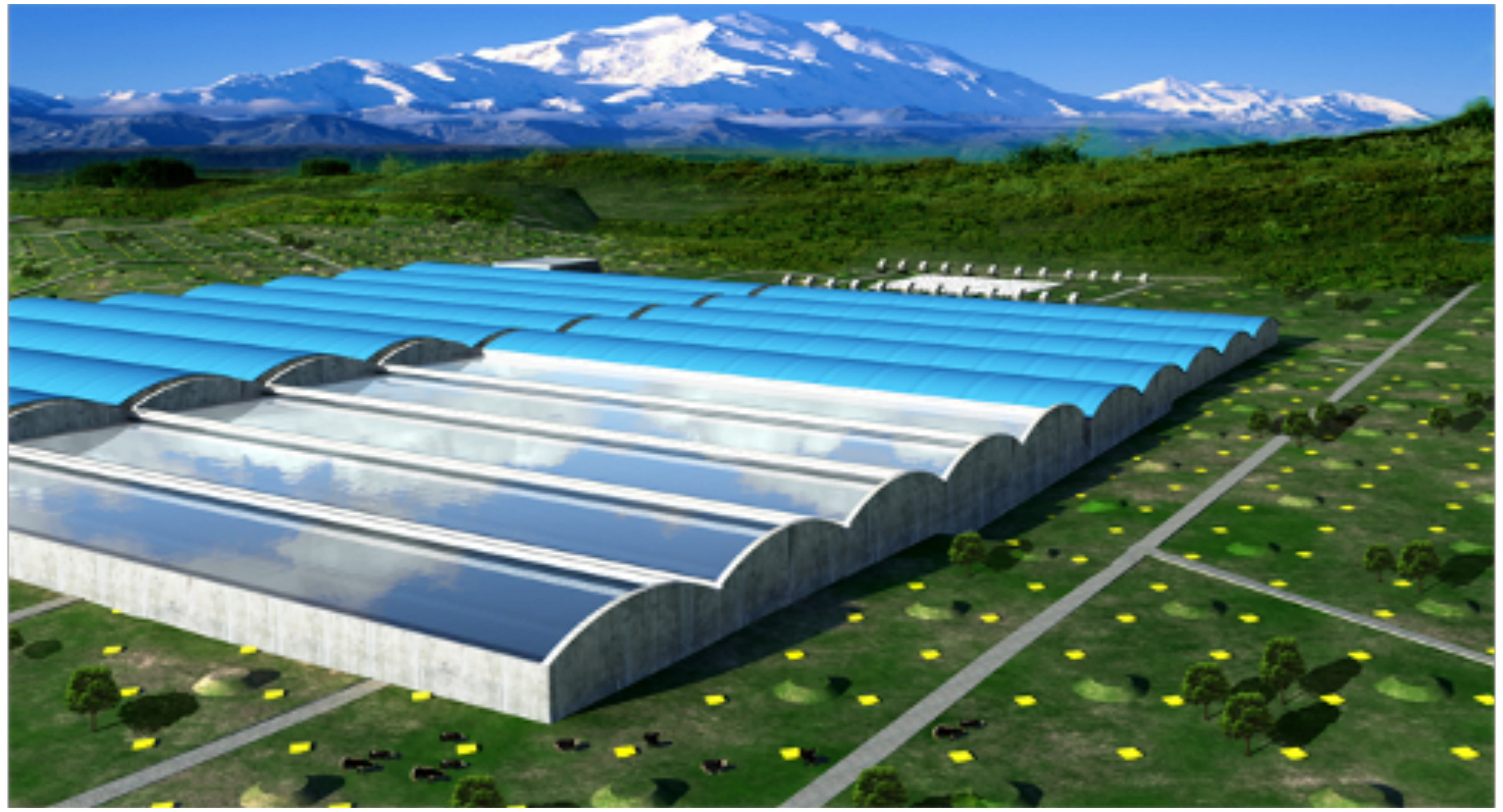
Water Cherenkov light produced by secondary particles of cosmic ray and gamma-ray showers.

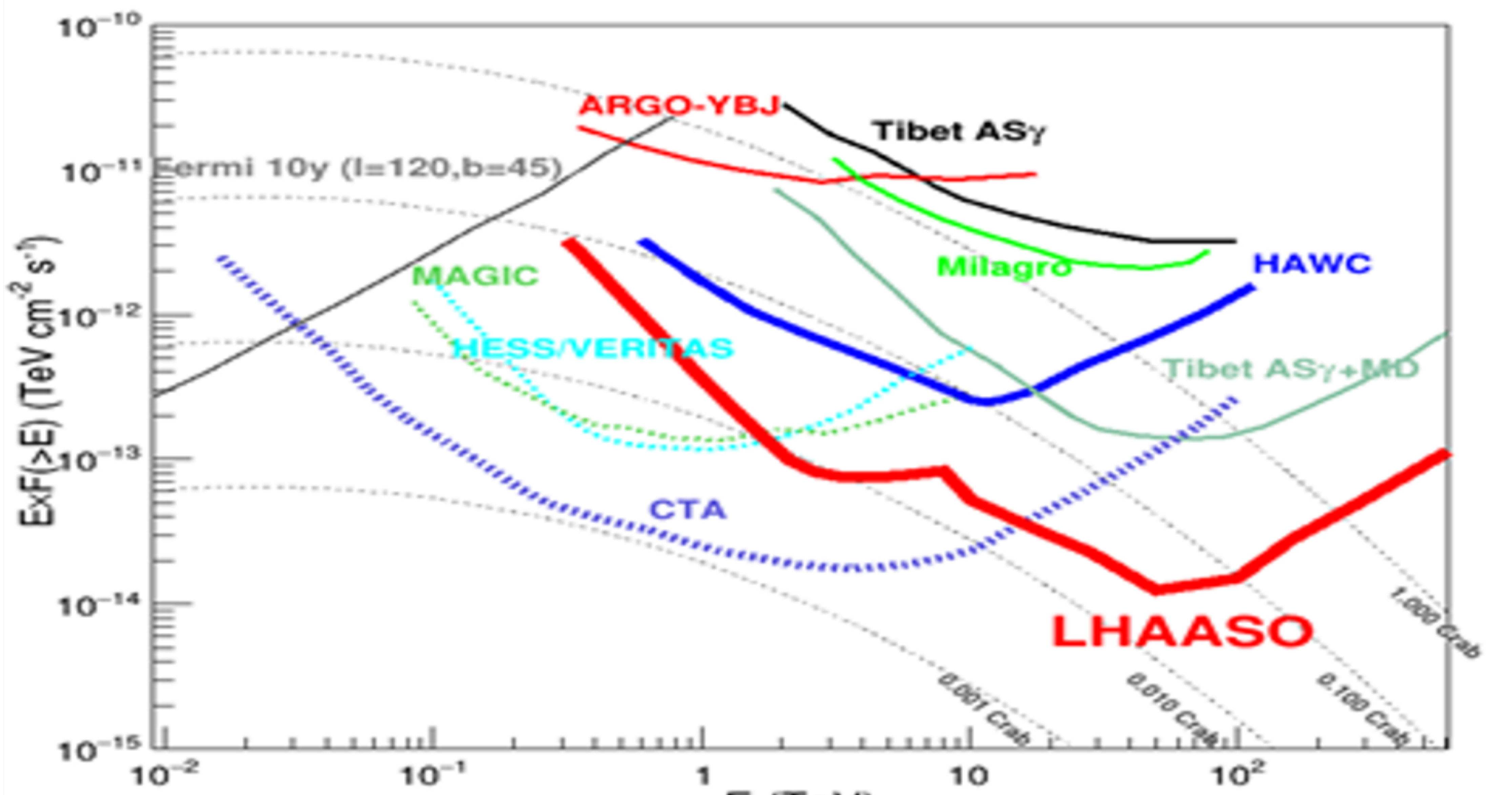
structure:

- 78,000 square meters, ~6 football pitchs;
- The effective water depth is 4m(350,000 tons);
- 5m×5m/unit, 3,120 units in total;
- 8/20 inch PMT and 1.5/3 inch PMT;

physical science:

(1) VHE gamma-ray astronomy;
(2) extra Galactic source survery;
(3) Full-sky scanning of time-varying sources;



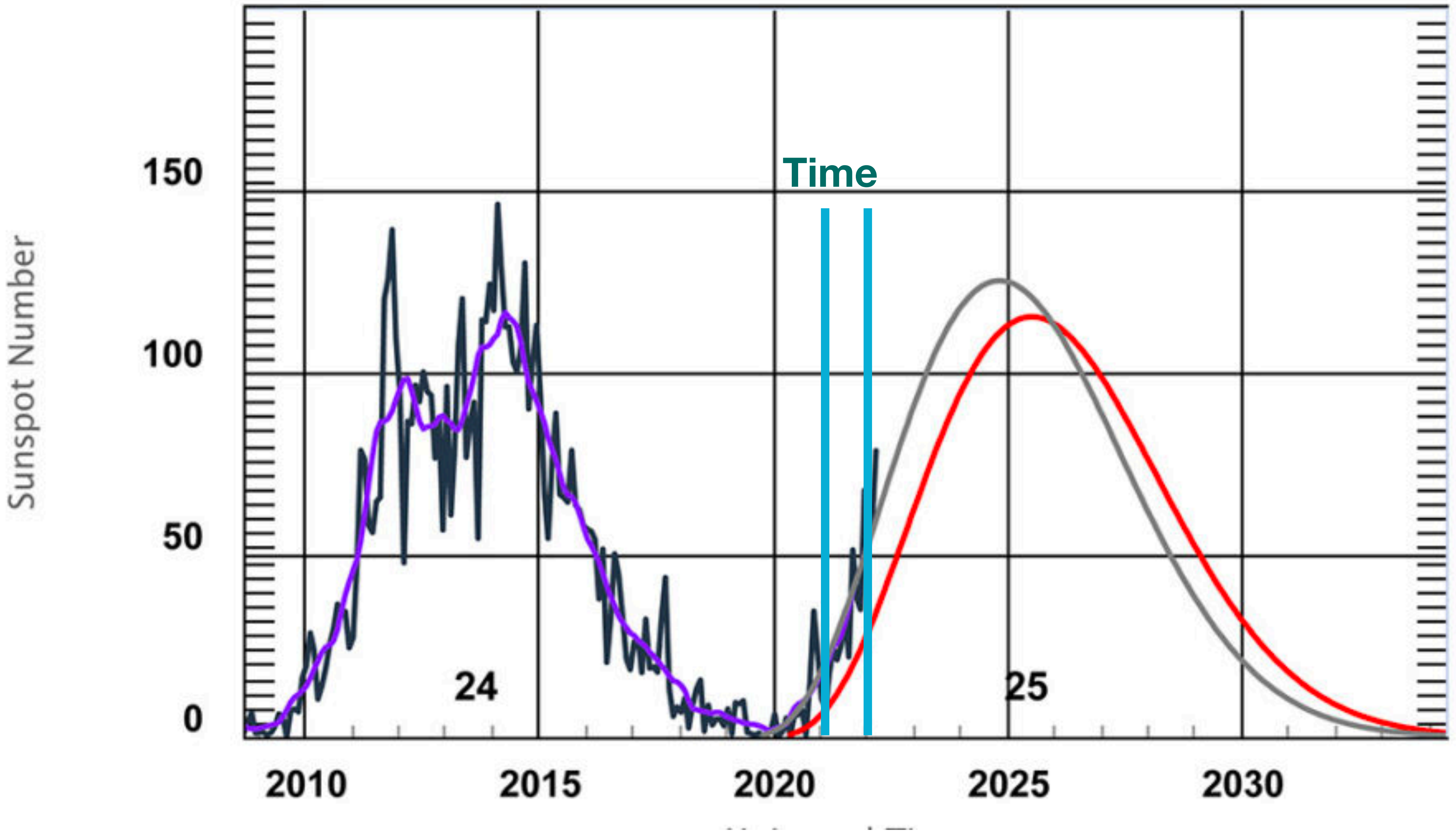


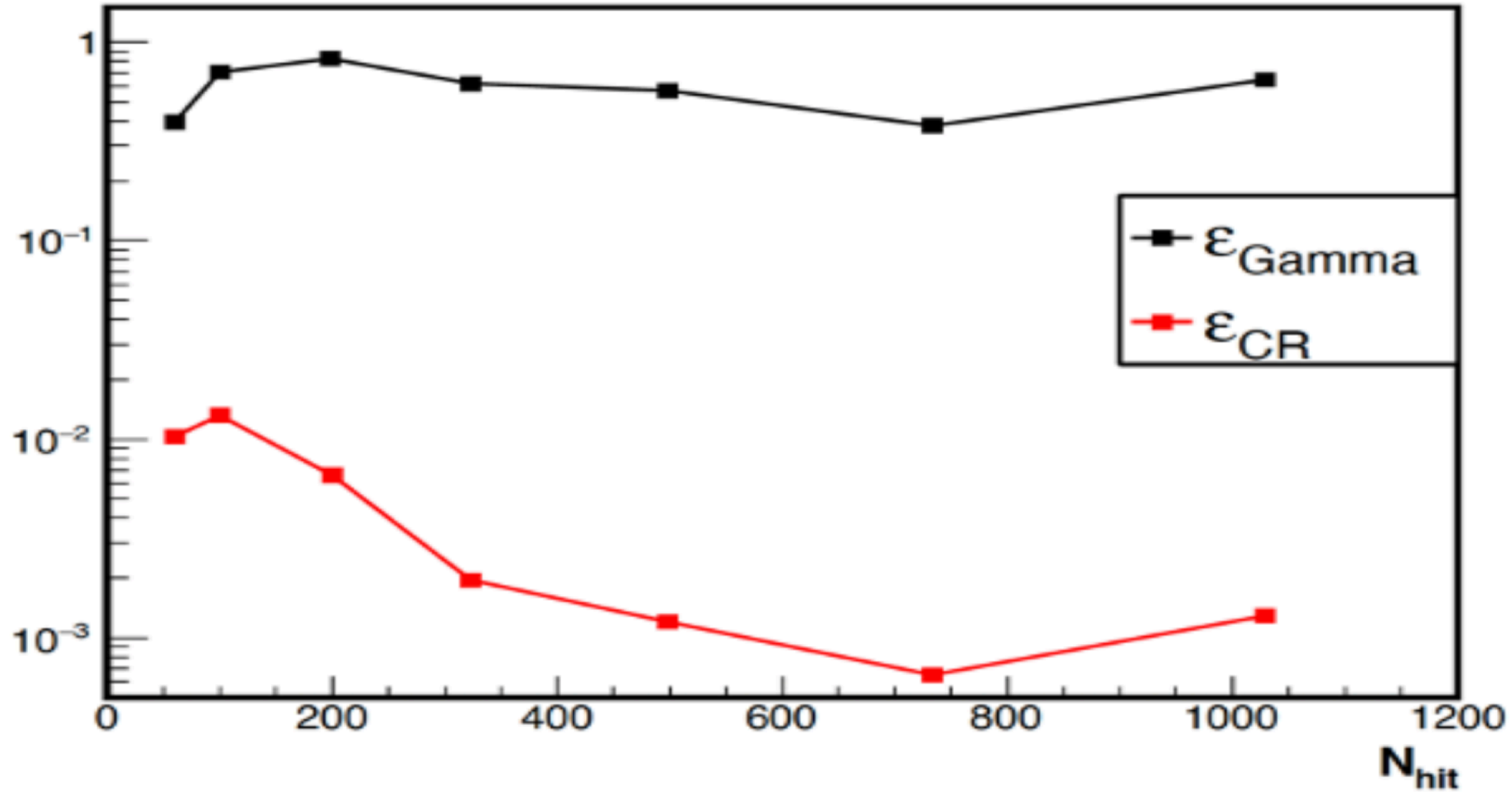
2.LHAASO-WCDA experiment

——Full-WCDA array data : 1 Apr 2021— 31Dec 2021

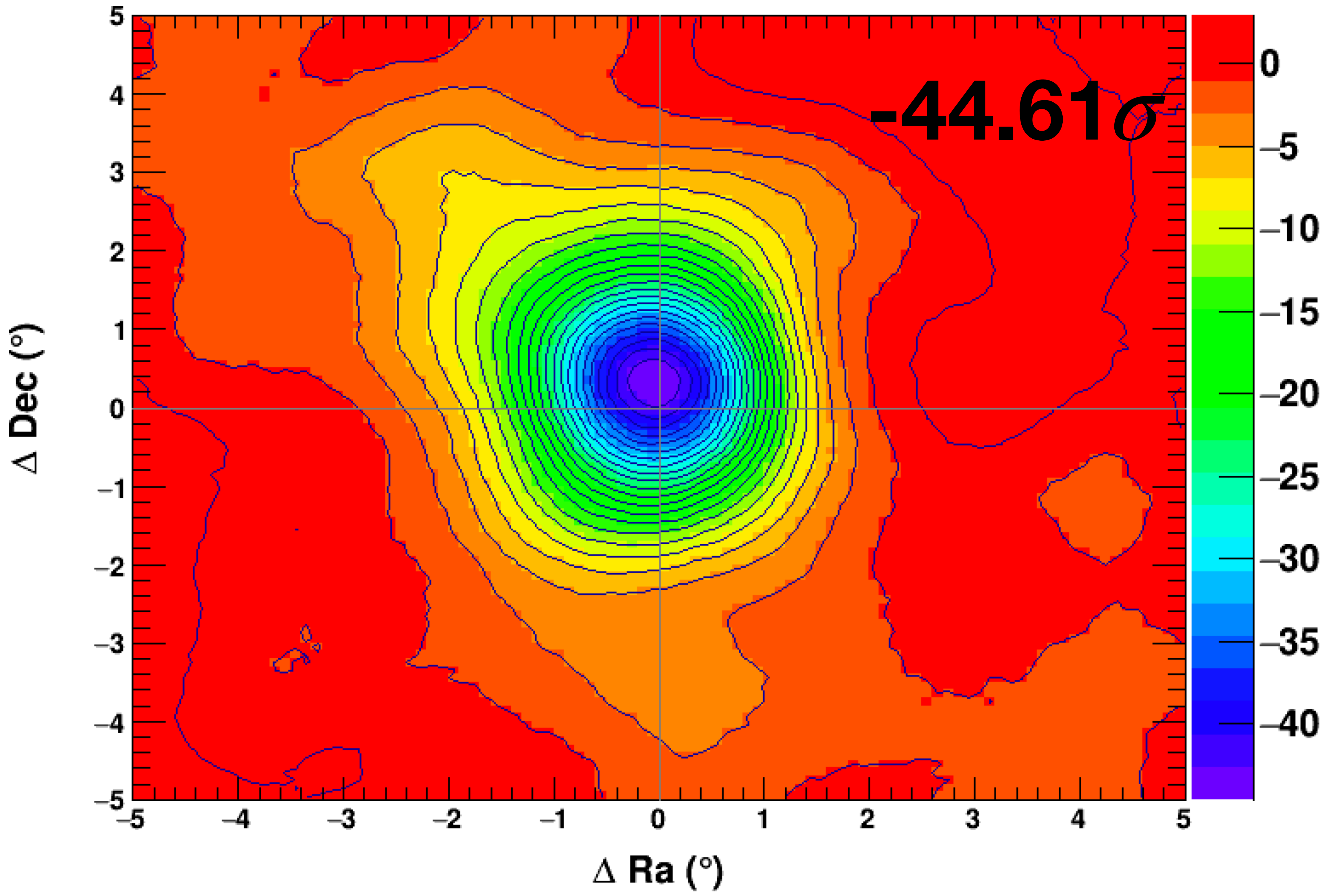
——7 Nhit bins: 60-100,100-200,200-300,300-500,500-800,800-2000,>2000

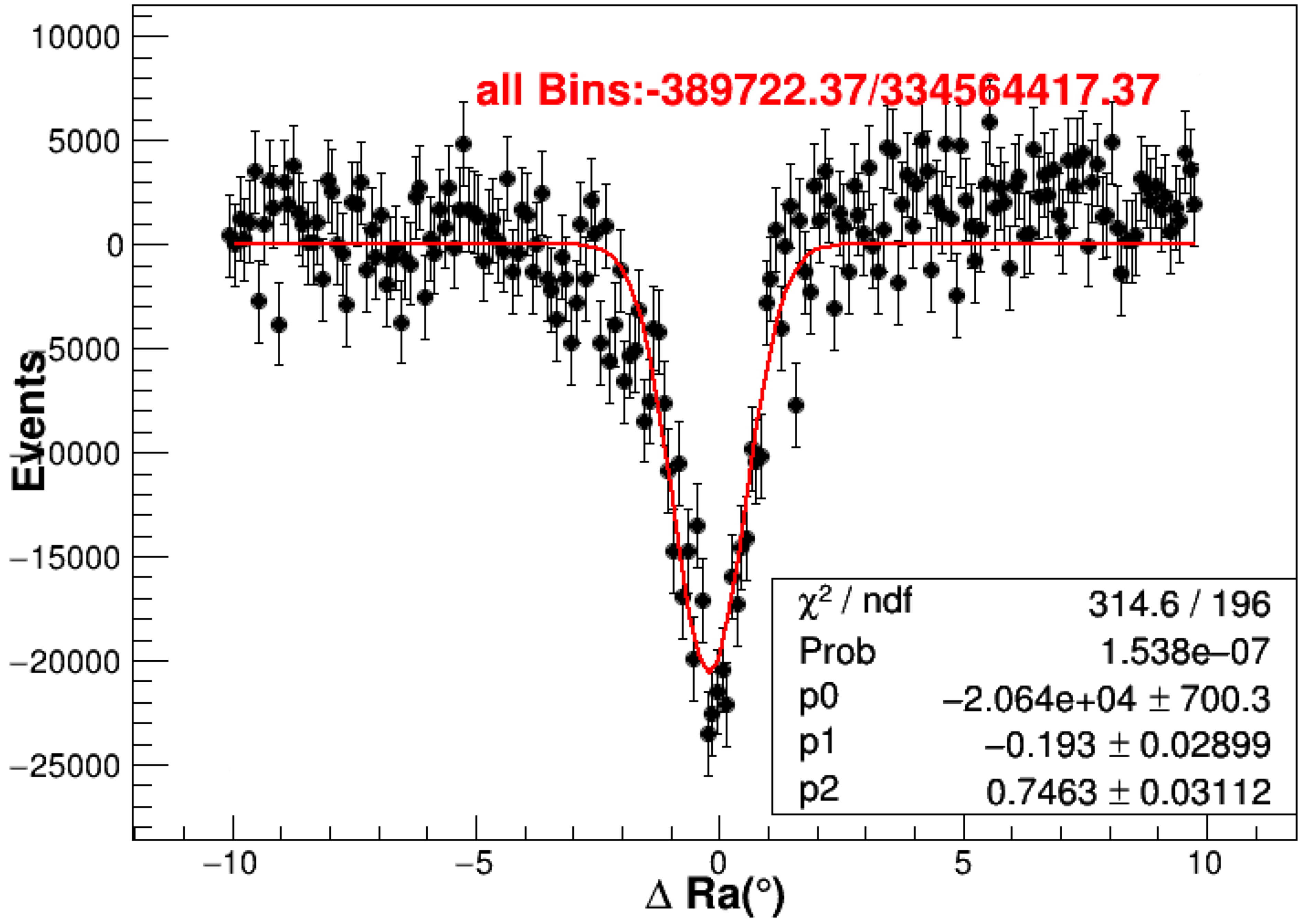
—— the median energy (TeV) roughly around: 0.92, 1.45, 2.52, 4.18, 7.83, 15.88





The Sun shadow map, before g/p cut



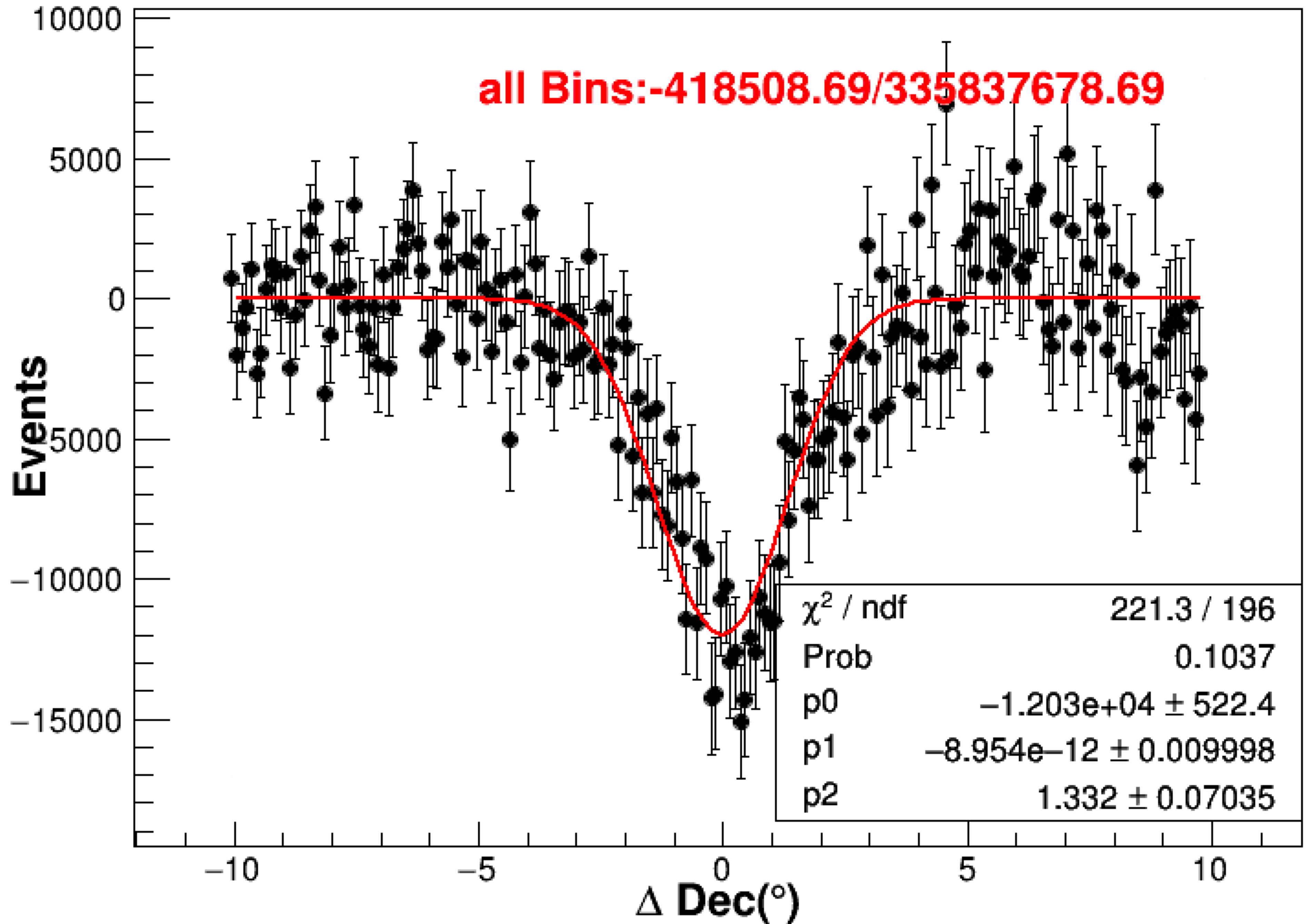


Shadow center:

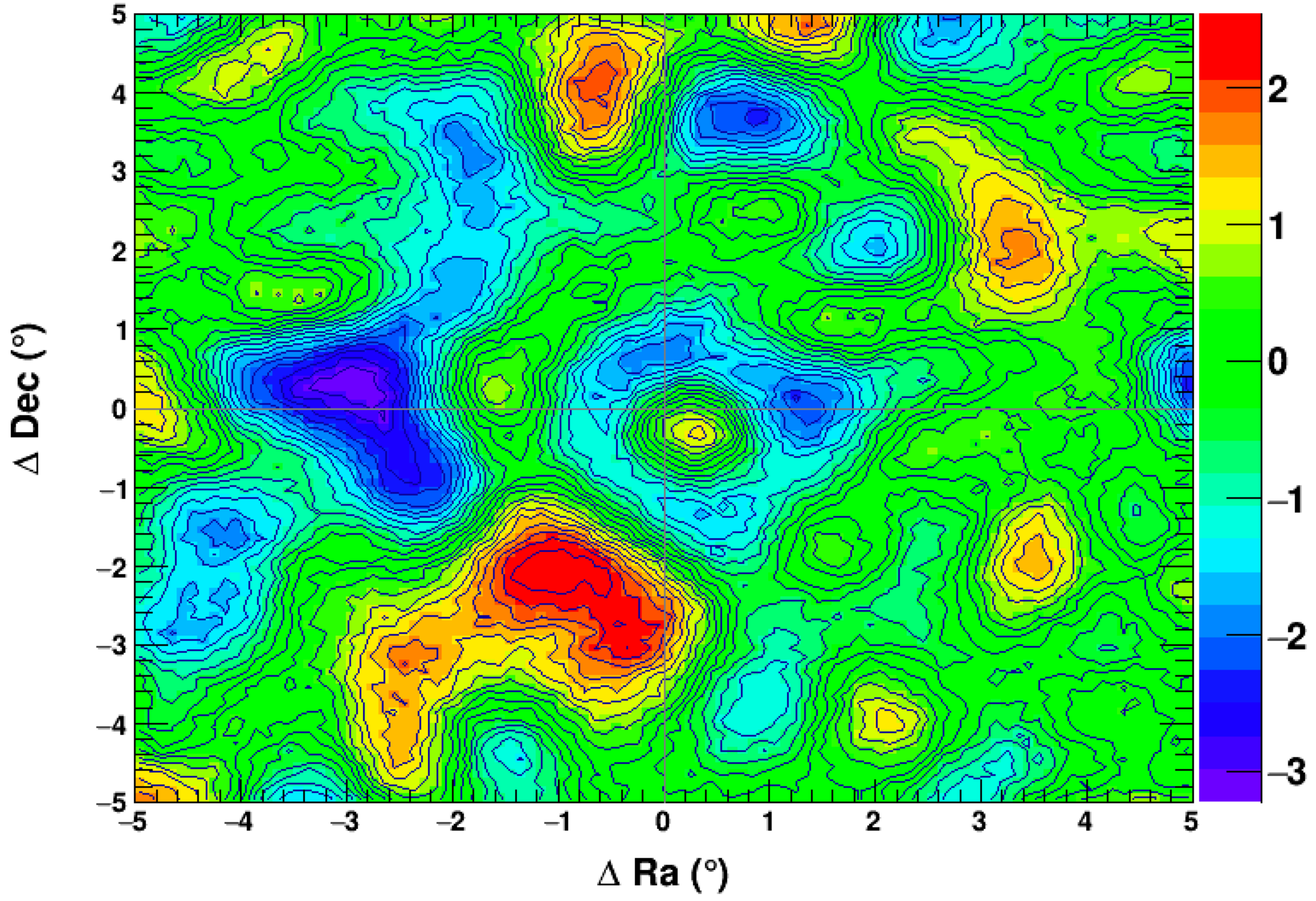
$\Delta Ra = -0.122 \pm 0.025$

$\Delta Dec = 0.191 \pm 0.03$

Spatial extension: 0.787 ± 0.022 (disk included)

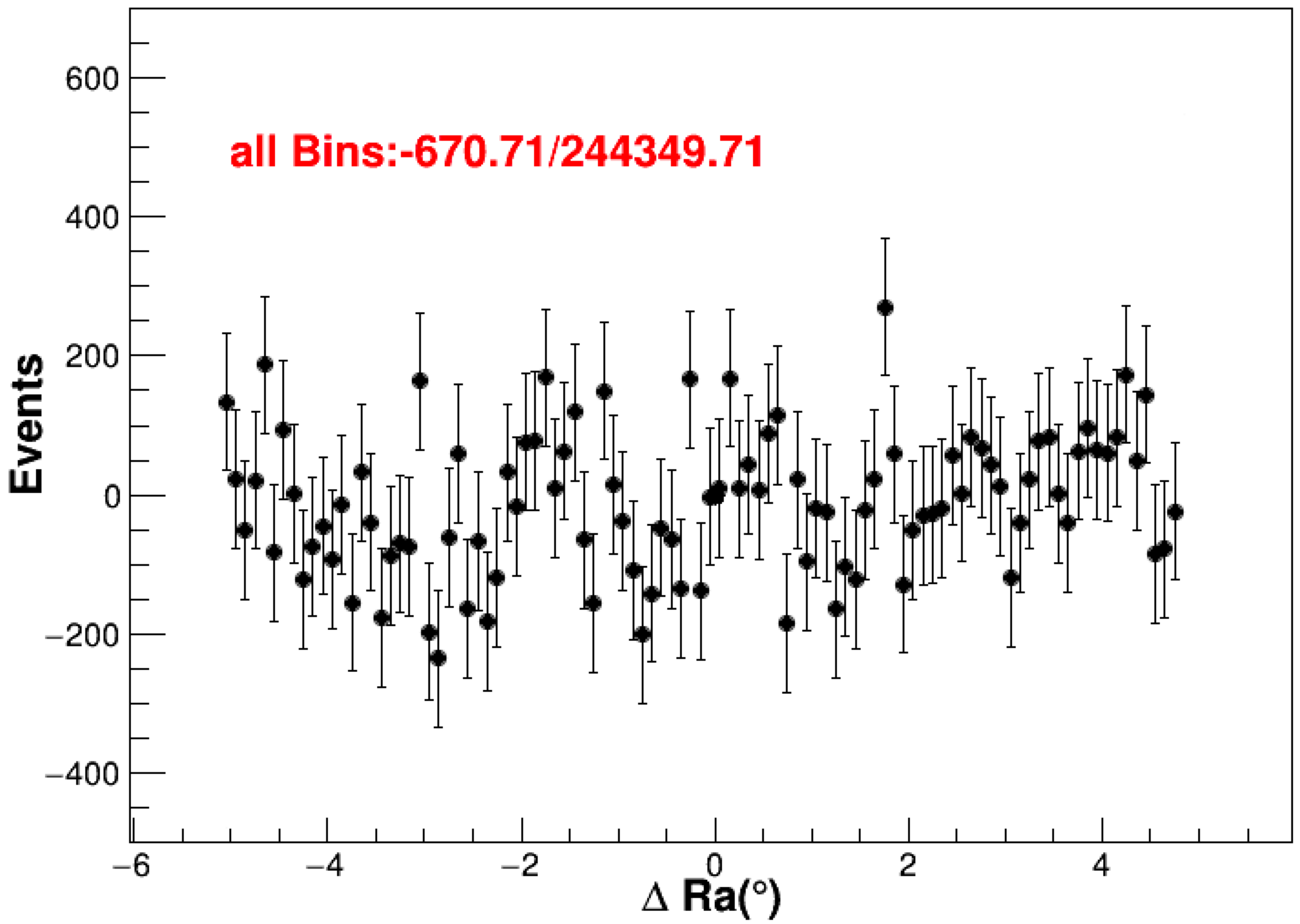


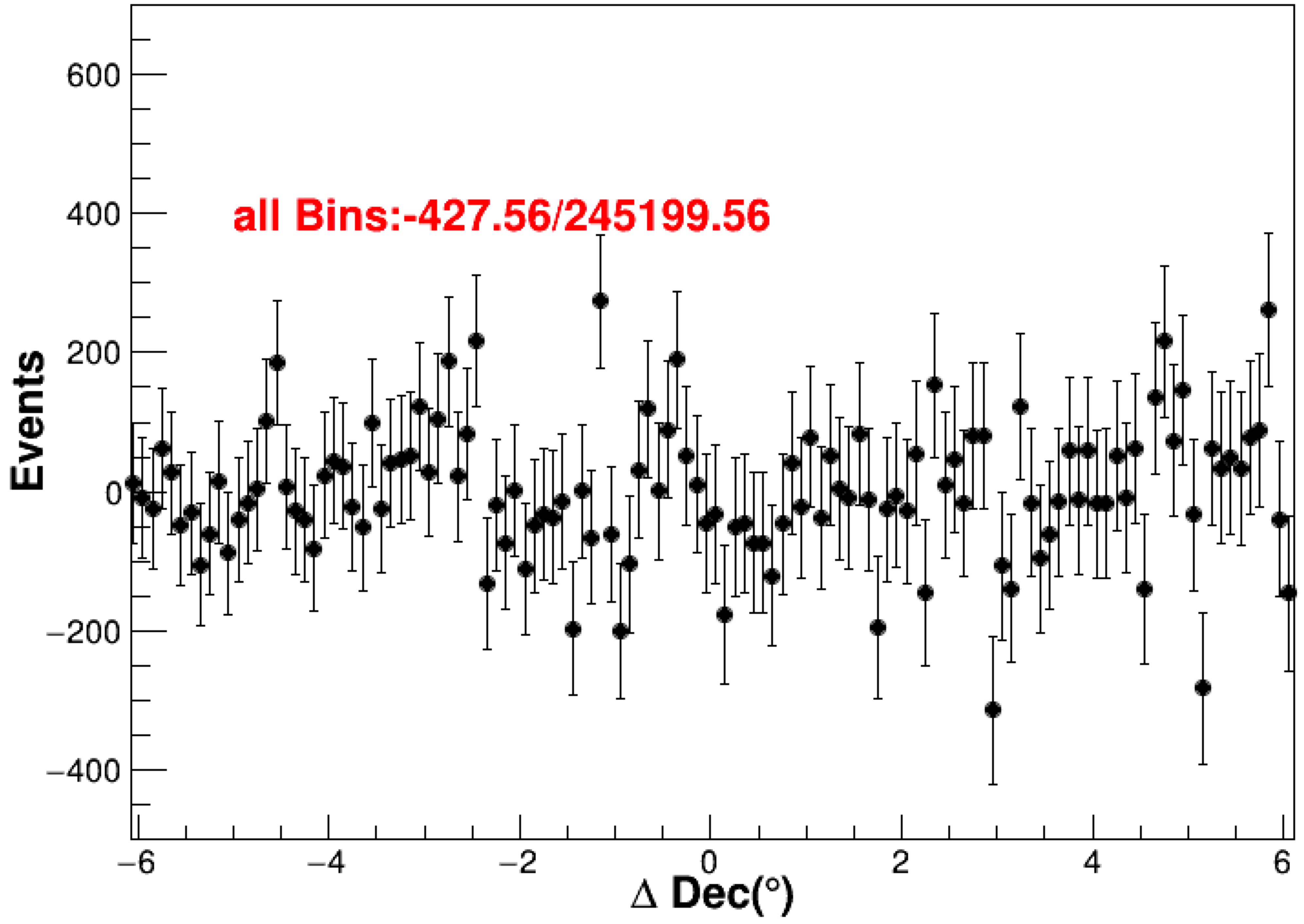
The post-cut data map around the Sun



Even after the gamma/hadron separation,
it is still cosmic-ray dominated.

We must accurately subtract the contribution of cosmic ray events of the Sun shadow.

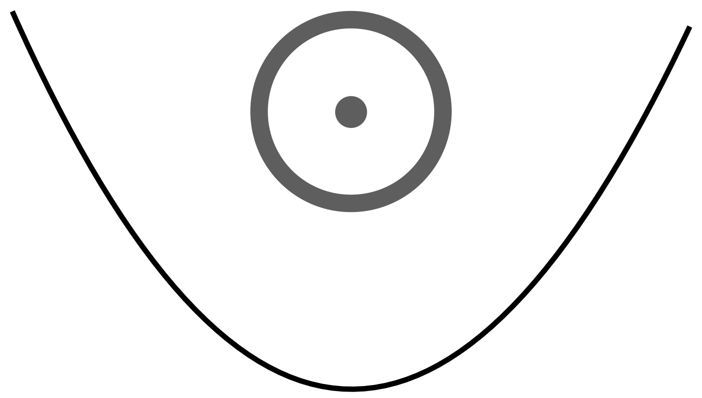




3. Background estimation and results

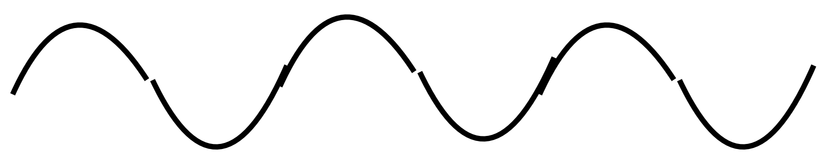
The potential Sun shadow component should be subtracted.

$N_{on,CR}$



Sun shadow formed by blocked cosmic rays

$N_{b,CR}$



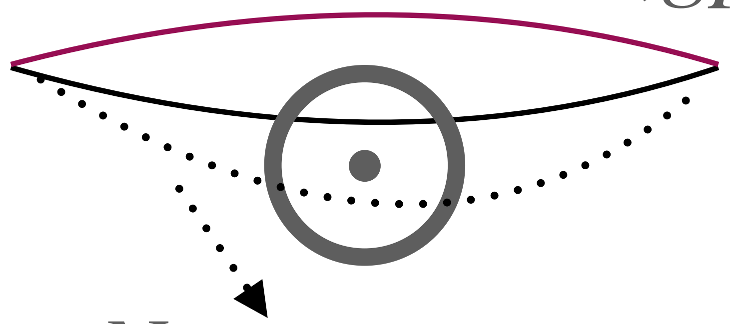
Estimated Background at off-sun region

(All CRs)

(Before gamma/hadron(g/p) cut)

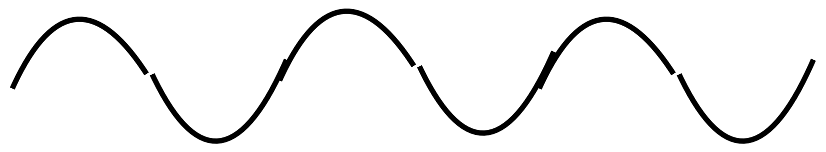
$$N_{\odot,CR} = N_{on,CR} - N_{b,CR}$$

$N_{\odot,gp}$ $N_{on,gp}$



Residual events (blocked CRs+gamma-rays)

$N_{b,gp}$



Estimated Background after g/p cut at off-sun region

(All CRs)

(post g/p cut)

$$N_{\odot,gp} = N_{on,gp} - \underbrace{N_{b,gp} - N_{shadow,gp}}_{N'_{b,gp}}$$

Background estimation and results

Method 1

A method was developed by Mehr et al(HAWC col), PRL,2023:131, 051201

Define the fractional parameter:

$$\Delta I = \frac{N_{on,CR}}{N_{b,CR}} - 1$$

The background can be rescaled:

$$N'_{b,gp} = N_{b,gp} + \Delta I N_{b,gp}$$

$$N_{\odot,gp} = N_{on,gp} - N'_{b,gp}$$

Method2

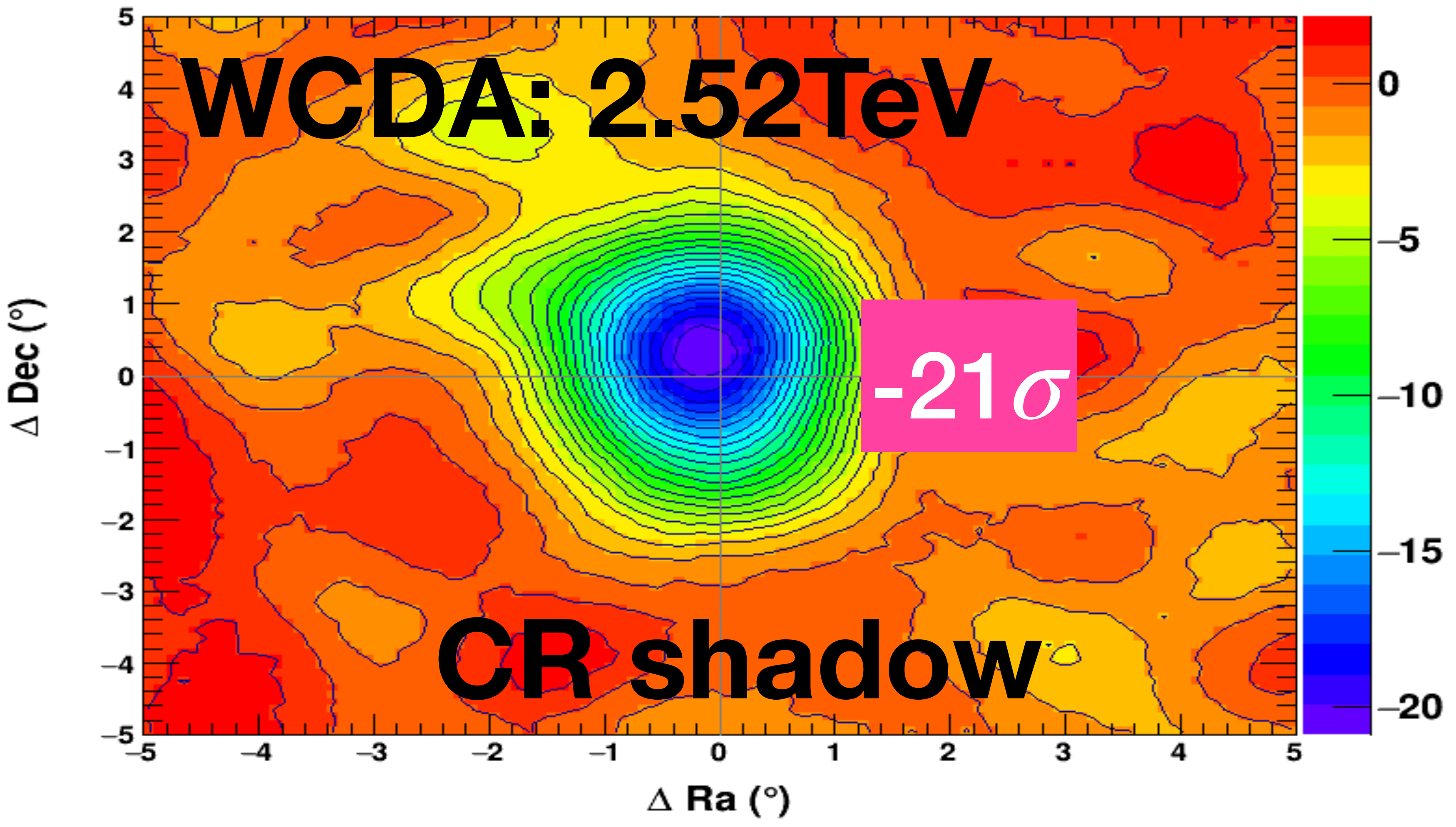
$$N'_{b,gp} = N_{b,gp} + \frac{N_{on,CR} - N_{b,CR}}{N_{b,CR}} N_{b,gp}$$

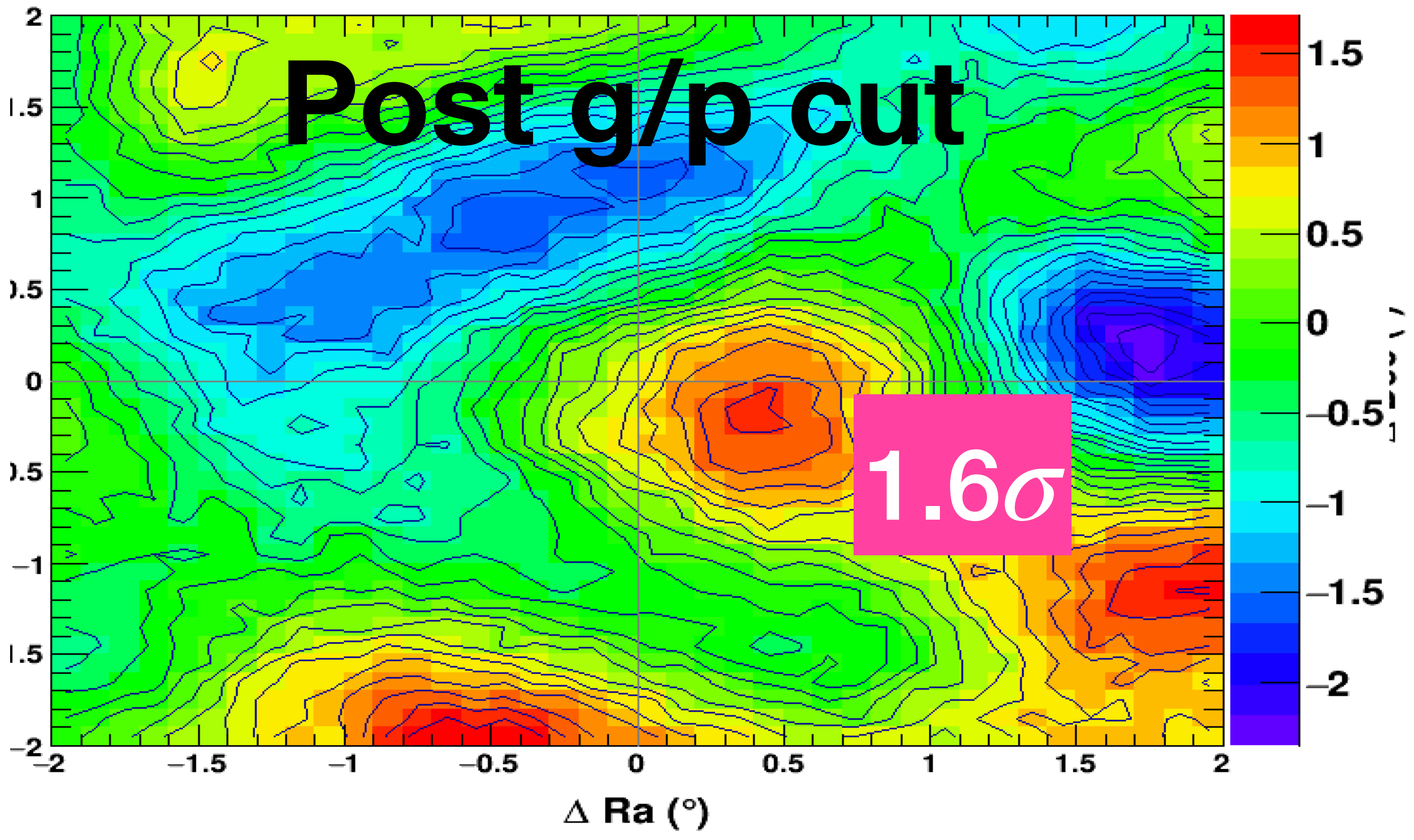
Then: $N'_{b,gp} = \varepsilon_{CR} N_{on,CR}$

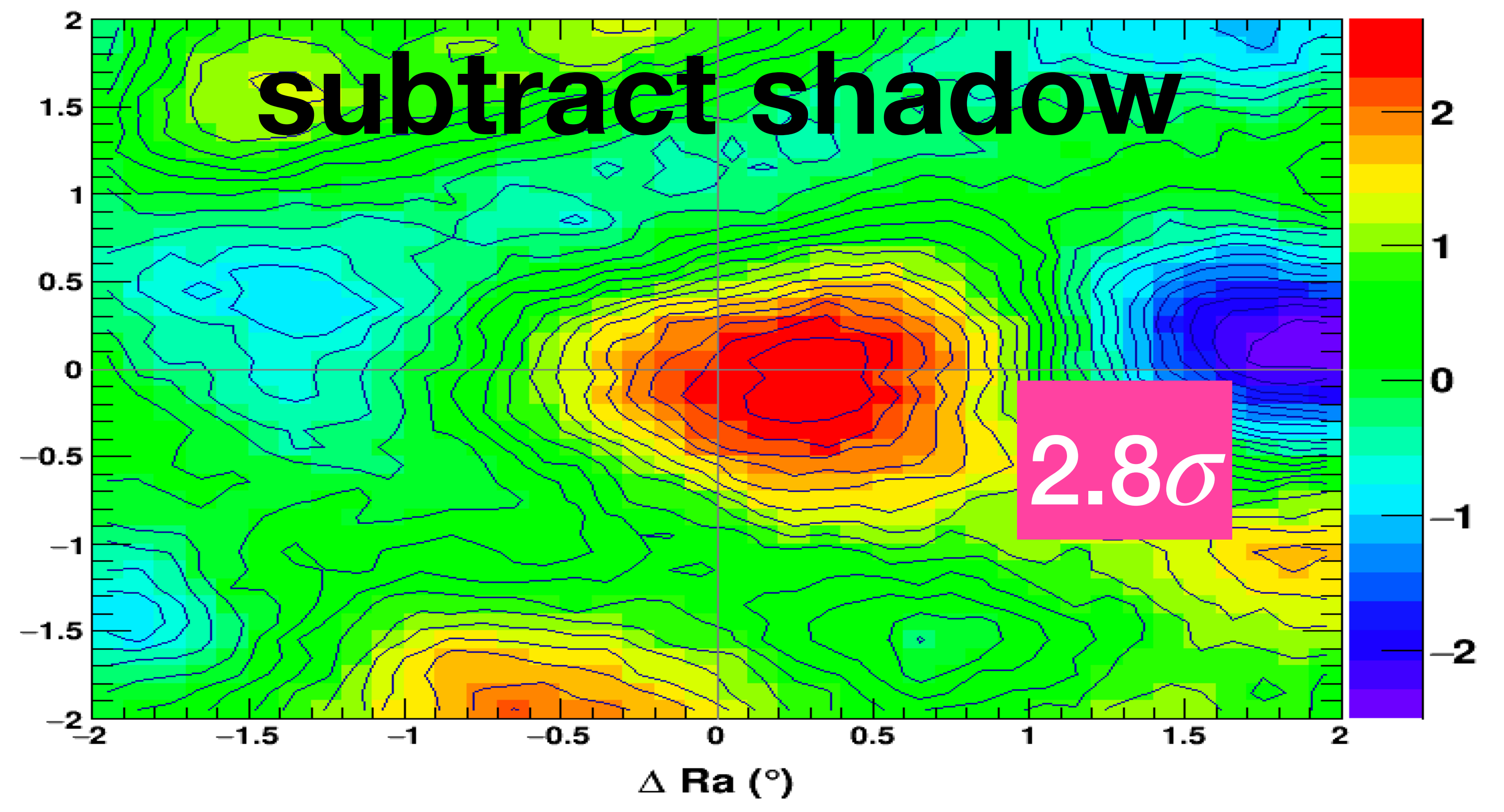
ε_{CR} *Has to be accurately estimated!*

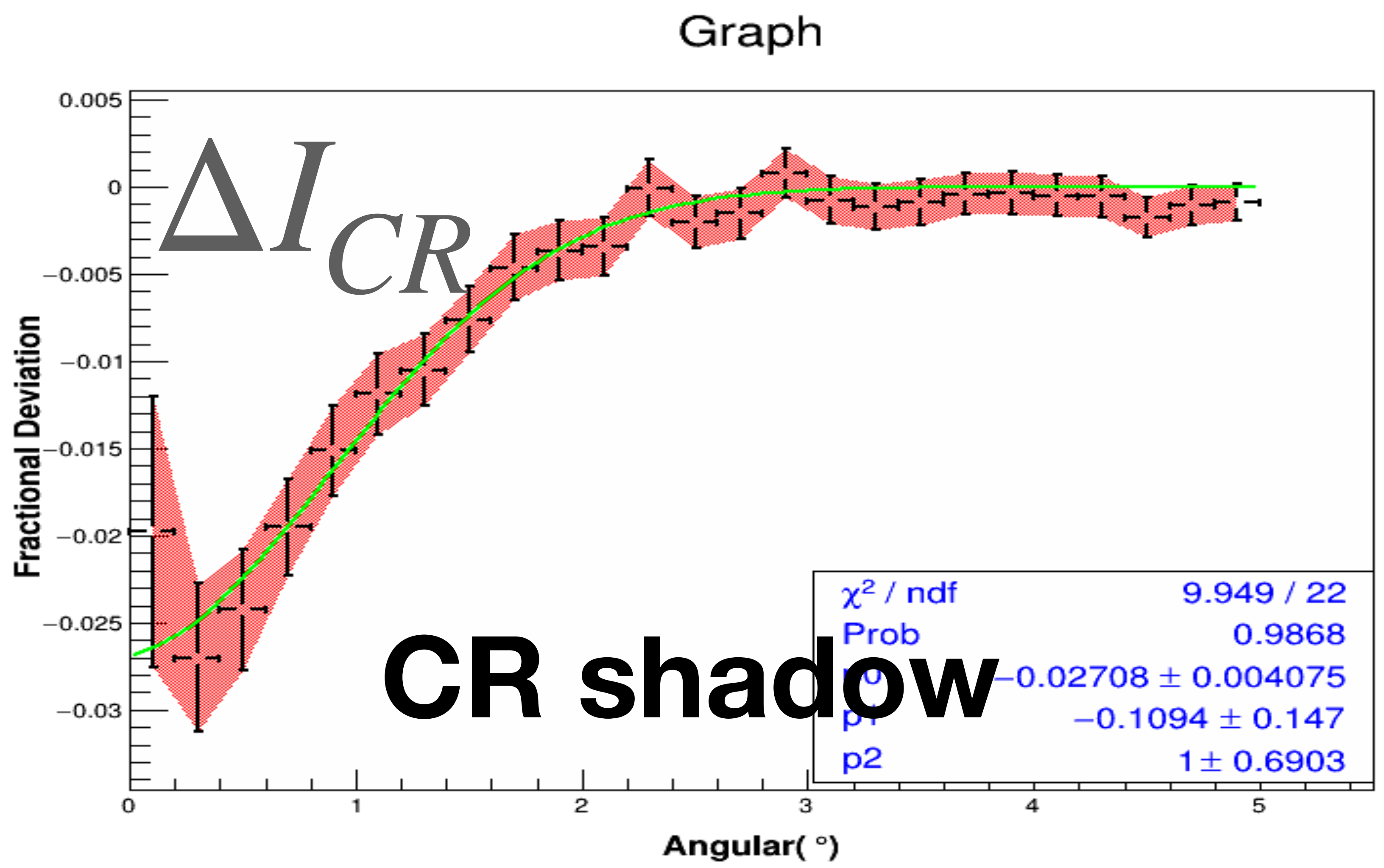
Features for M2: an overall averaged ε_{CR} for all pixels at Sun region, which is more globally.

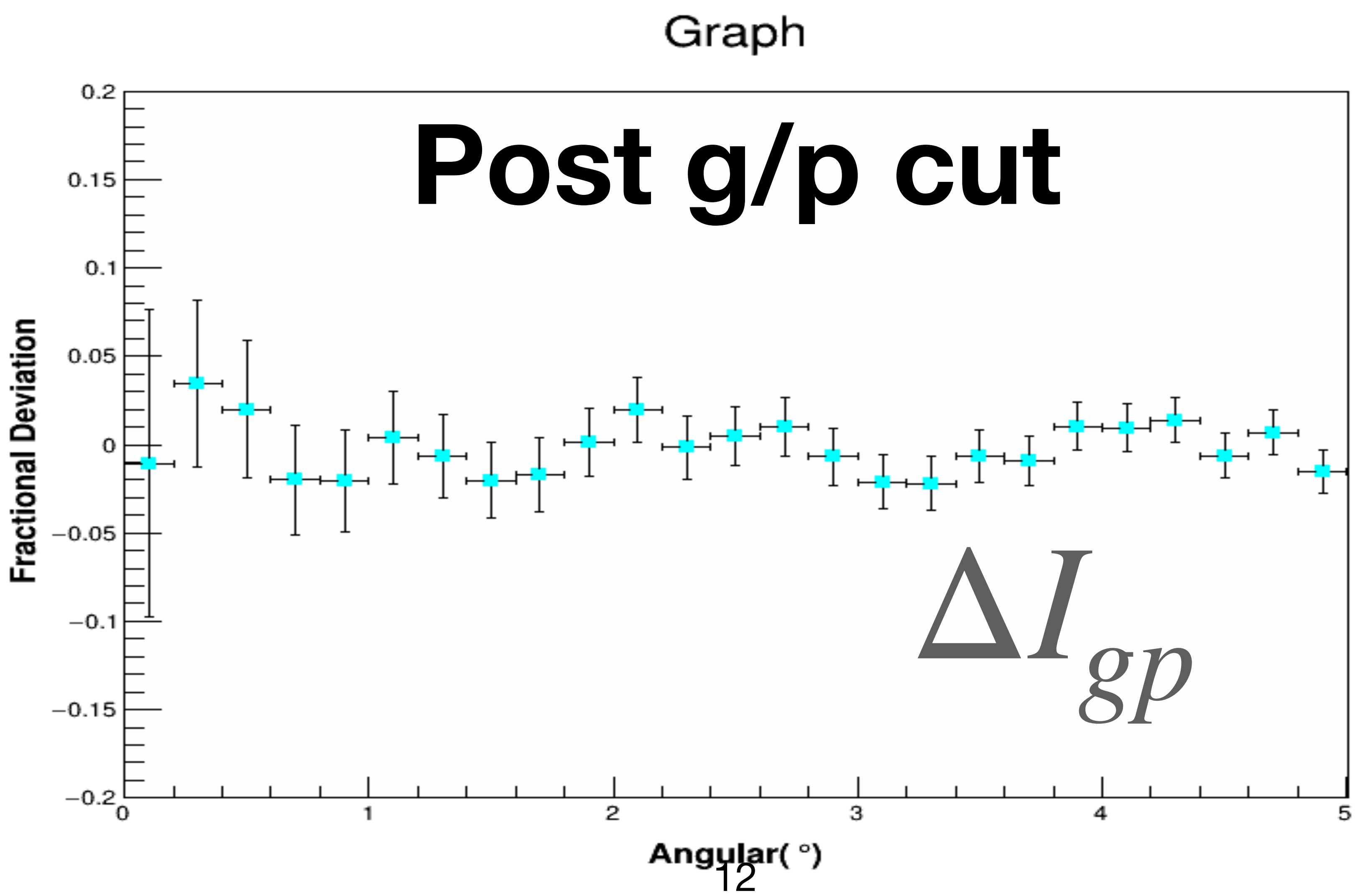
Background estimation and results

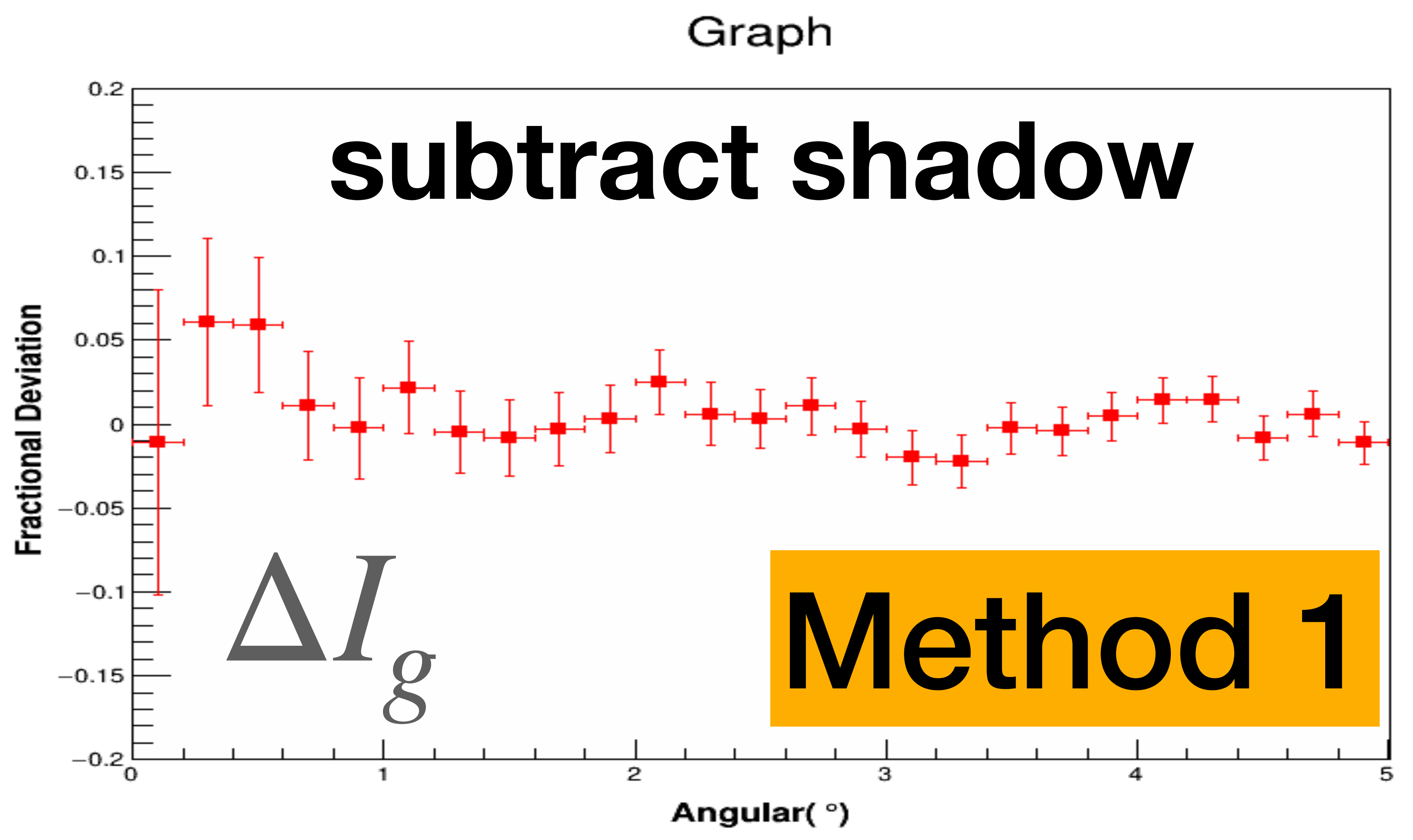




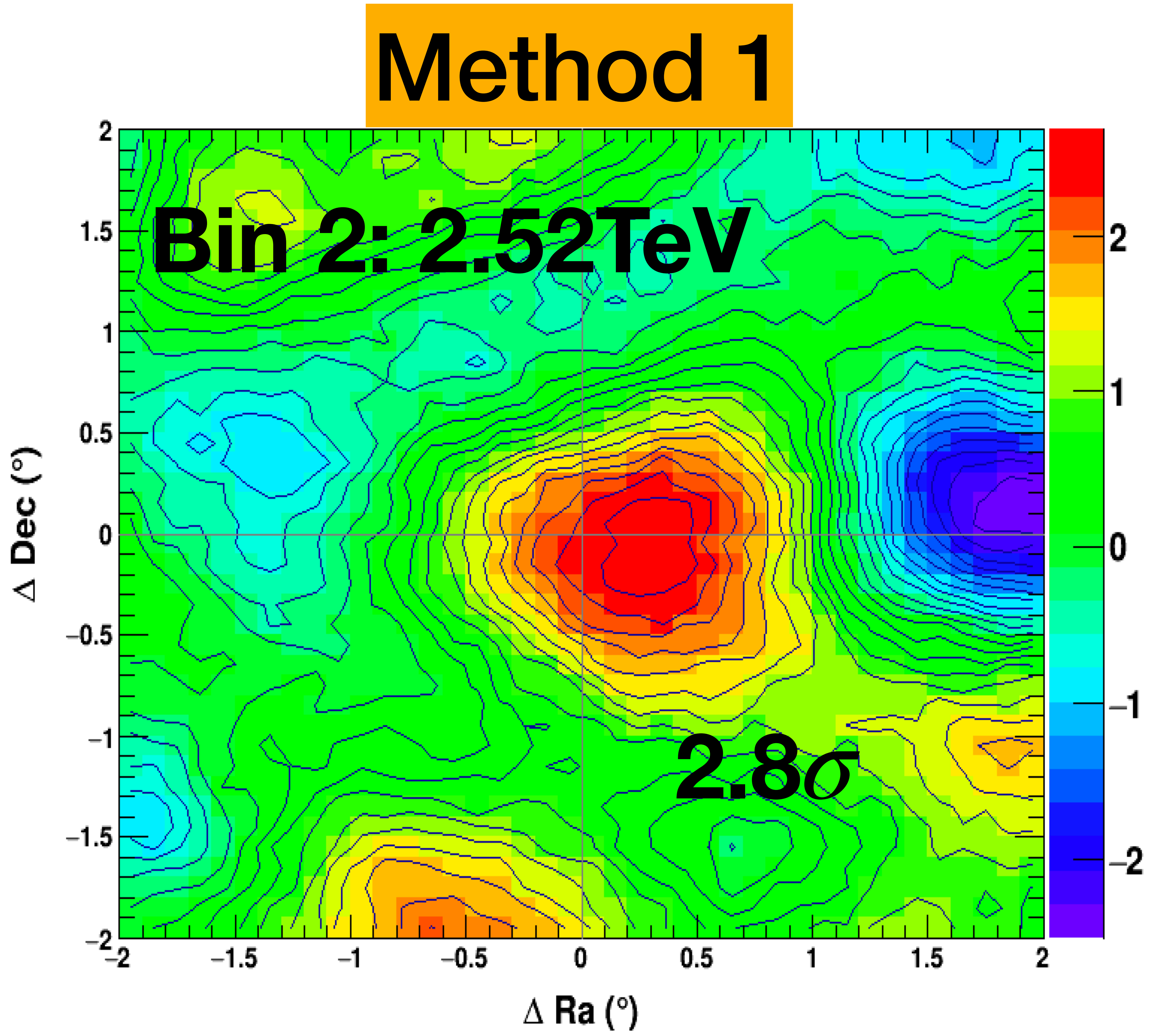


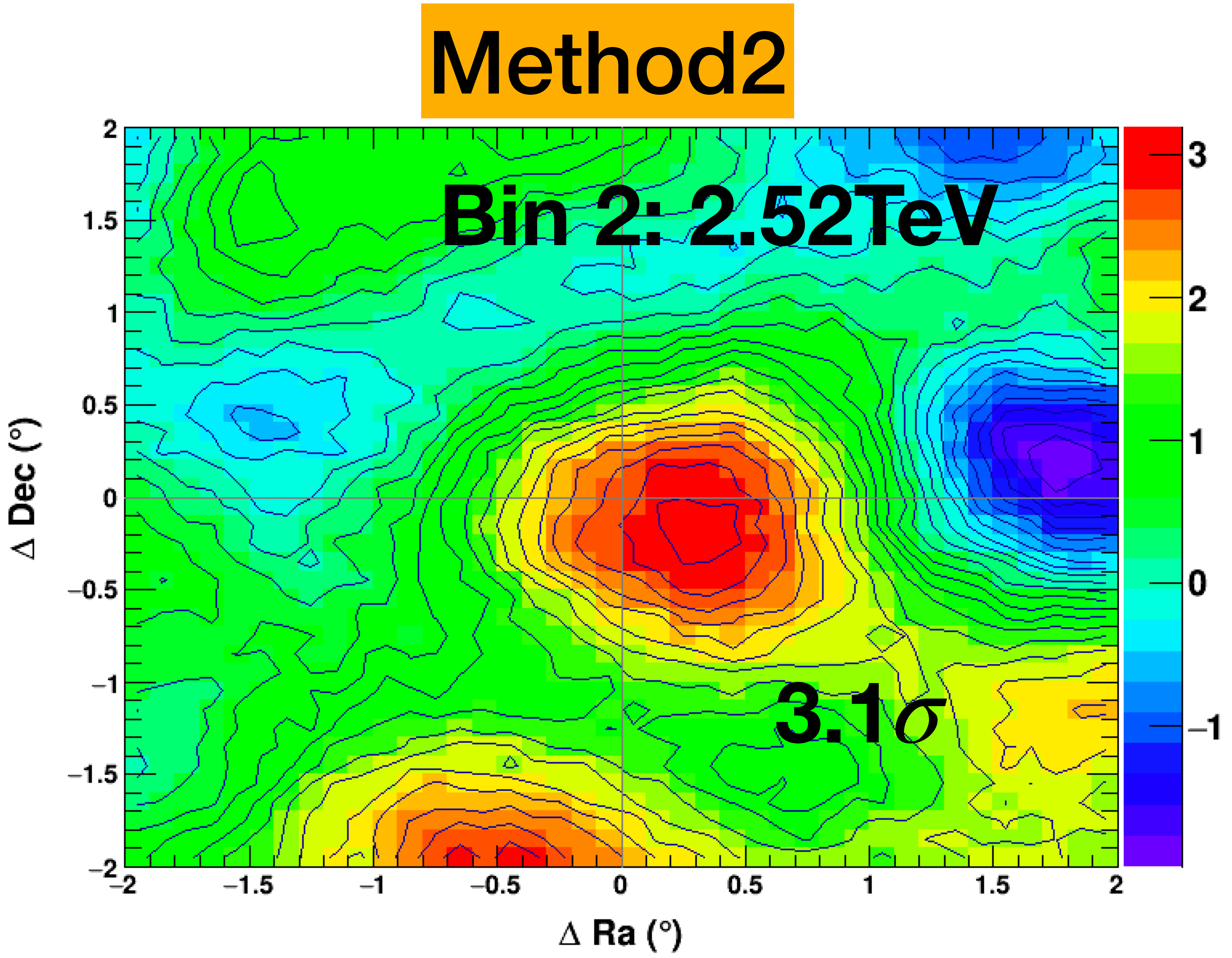






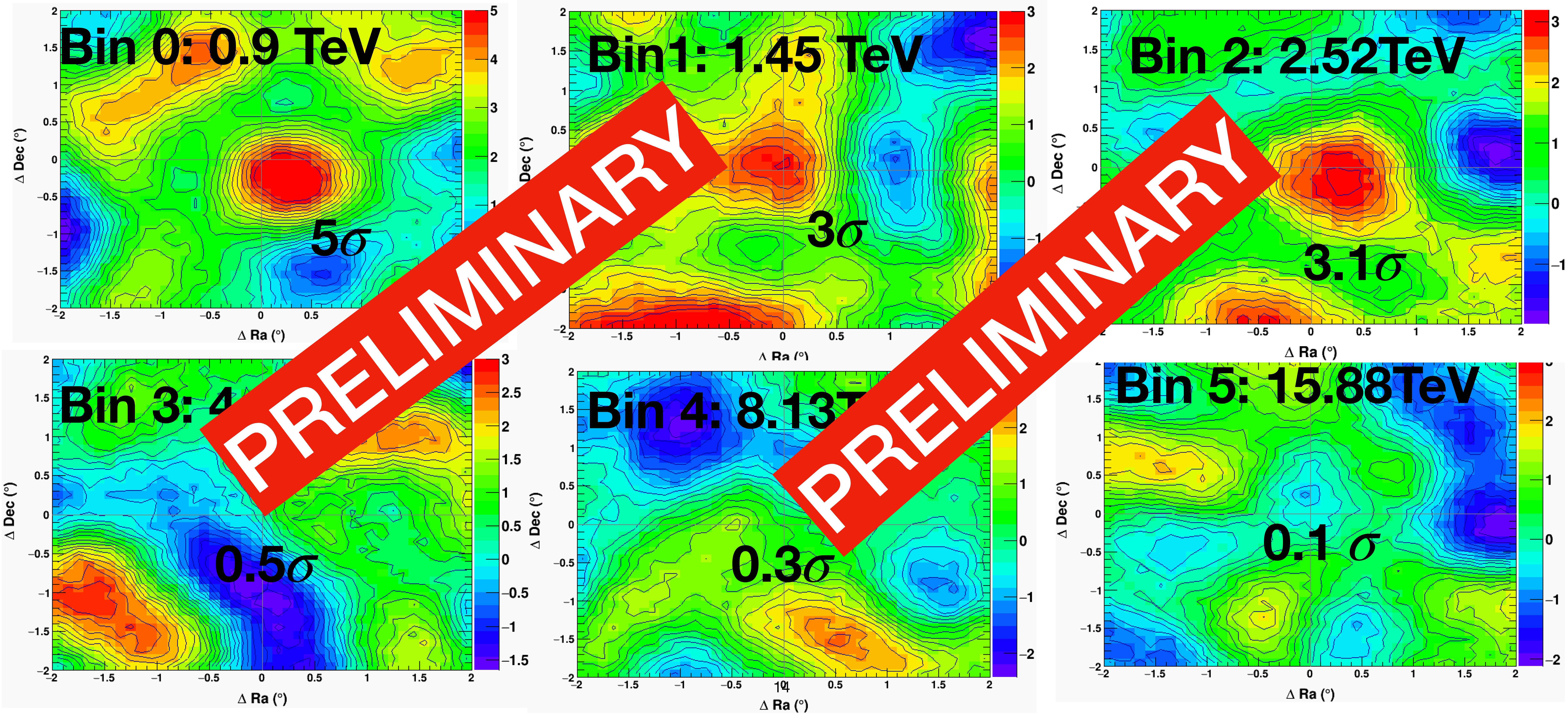
Background estimation and results

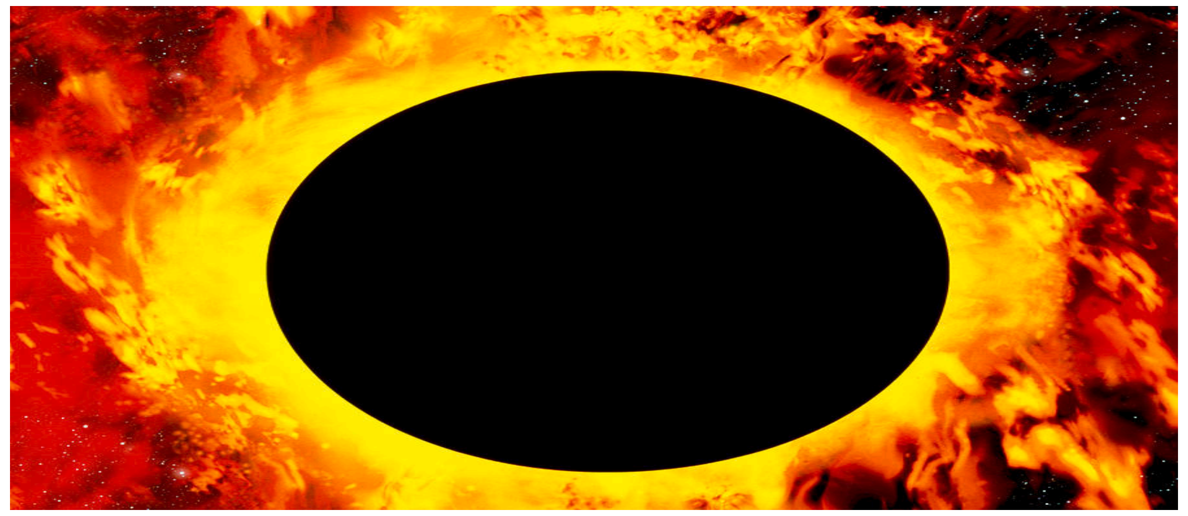




Which one is better or more accurate? We need a further test by observing the moon.

Background estimation and results





Summary

✦ To observe the solar disk gamma-ray, the Sun shadow effect should be accurately estimated;

✦ we need to finalise the background estimation method and do more further testing;

✦ With excellent sensitivity, it is promising to observe the Sun by LHAASO;

Thank you!

Backup

KM2A after subtract the Sun Shadow