

HAWC Observations of Gamma rays from the Quiescent Sun

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TeVPA 2022

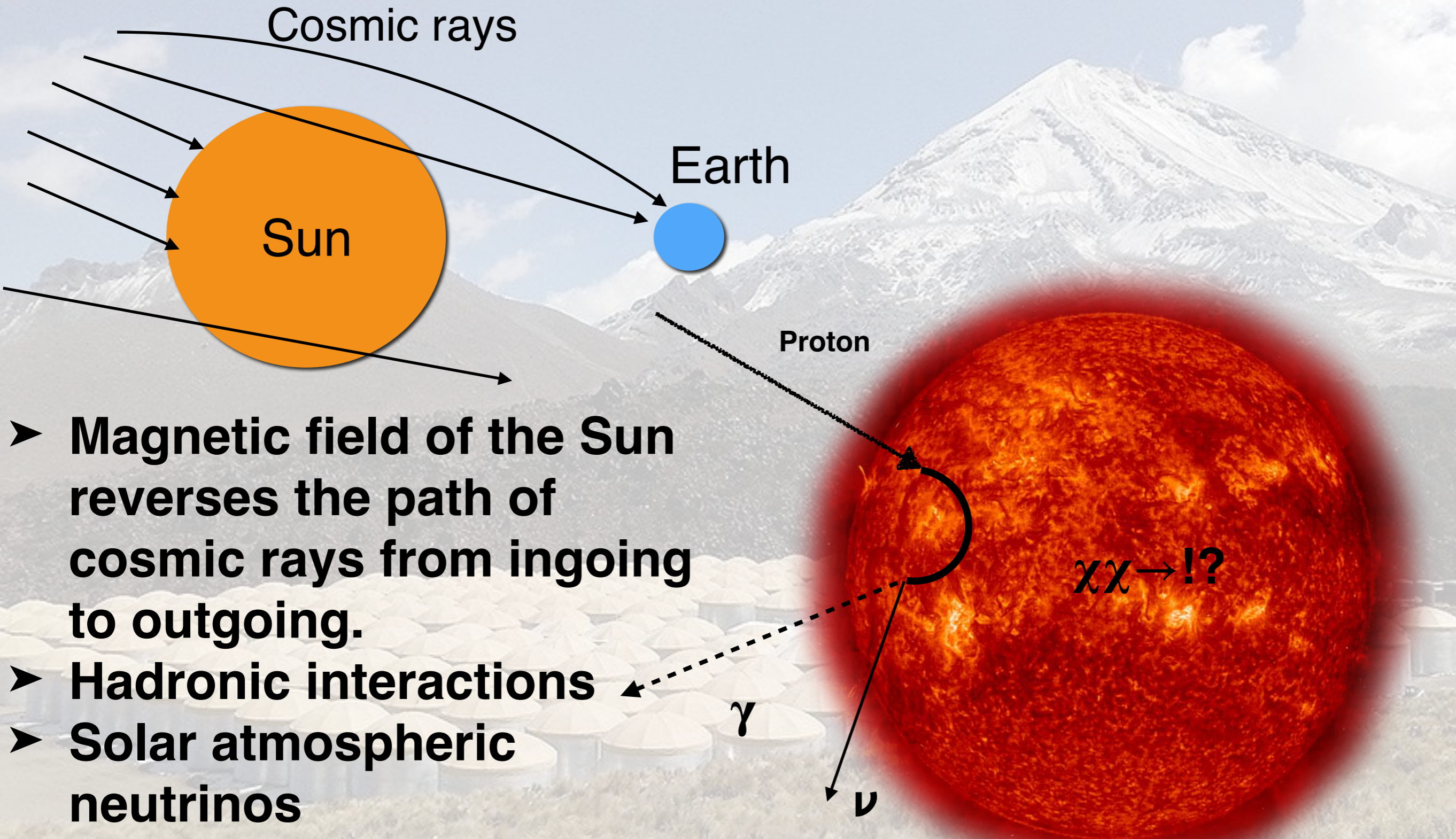


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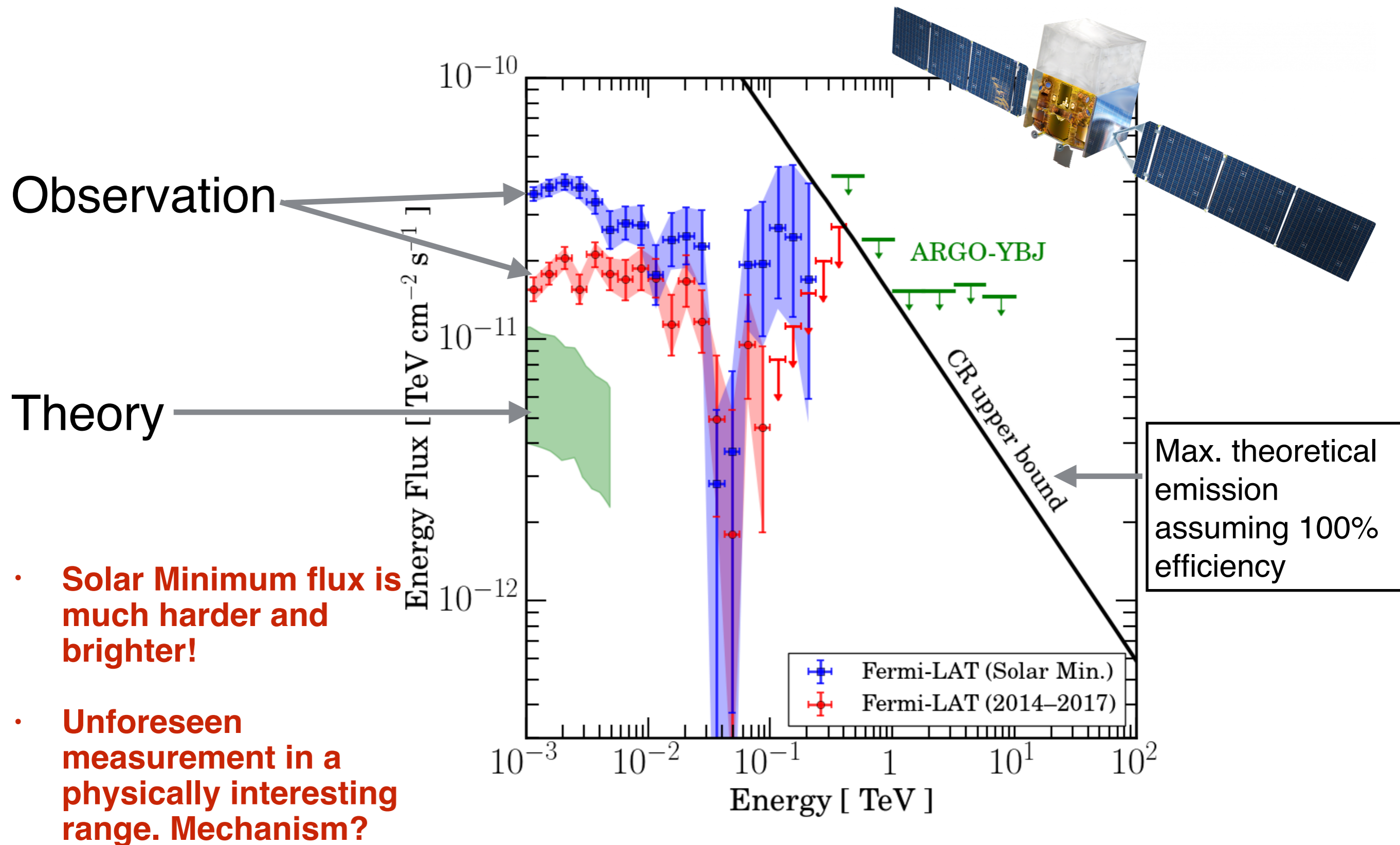
**Collaborators: HAWC + A. Peter, T. Linden,
J. Beacom, B. Zhou, K. Ng**



Cosmic-ray interactions with the Sun's atmosphere produce γ rays and neutrinos



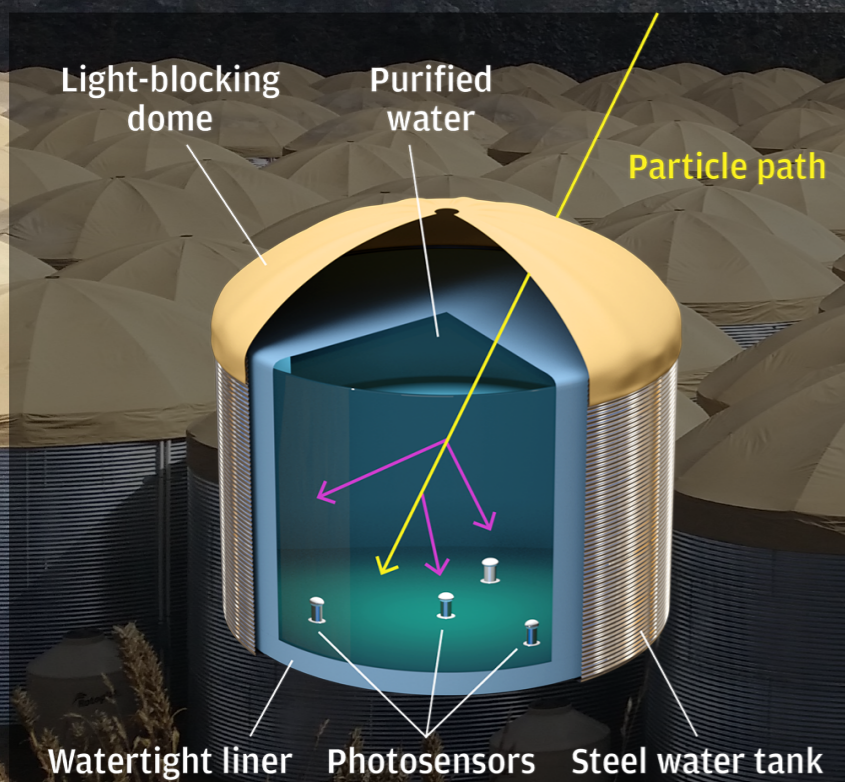
Solar Disk at GeV: Brighter than expected!



High Altitude Water Cherenkov Observatory

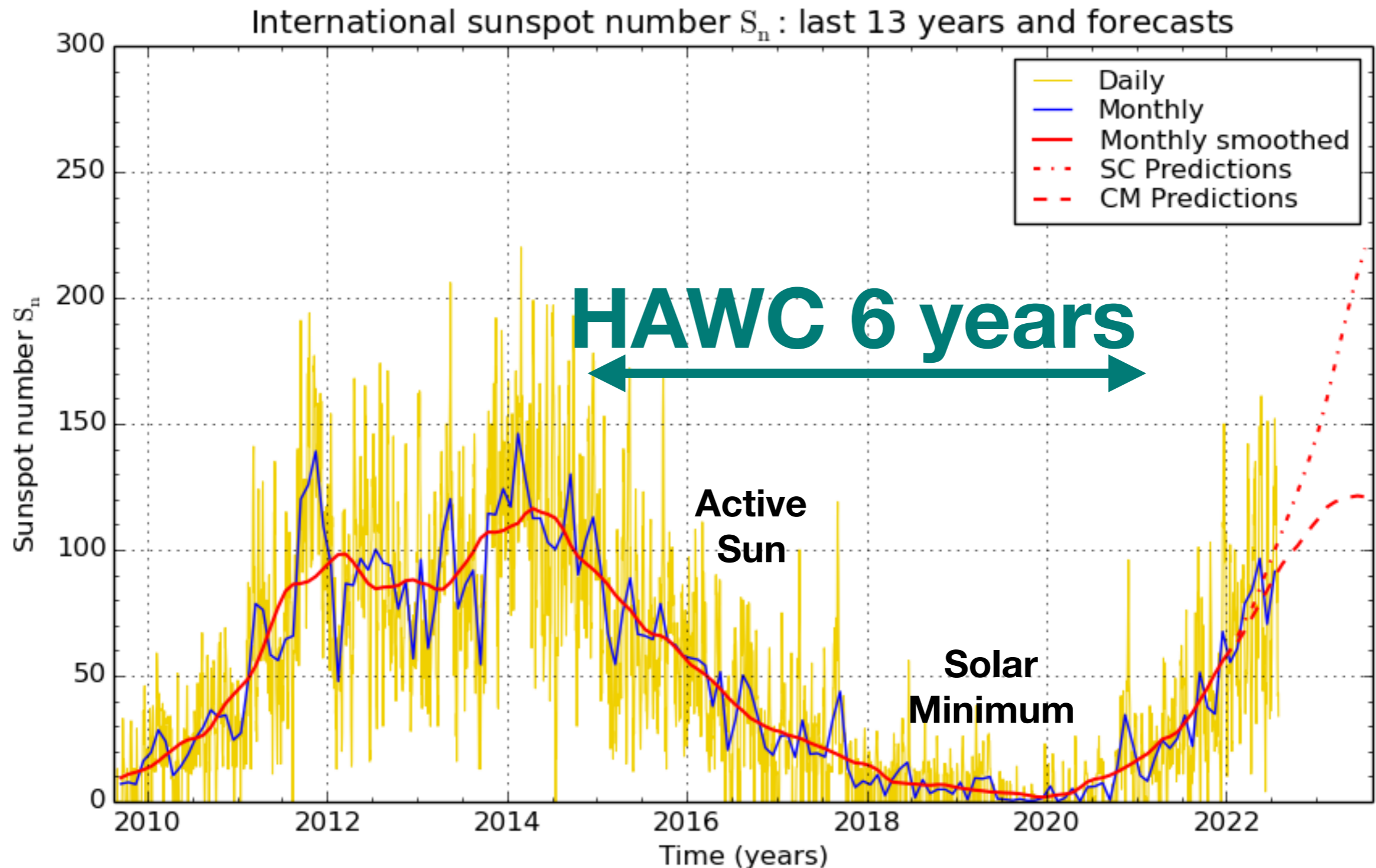
- 300 water tanks with 4 PMTs each (plus 350 Outriggers)

- Area 22,000 m² (100,000m²)
- Trigger rate of 25 kHz
- 300 GeV to > 100 TeV
- 2/3 sky daily coverage

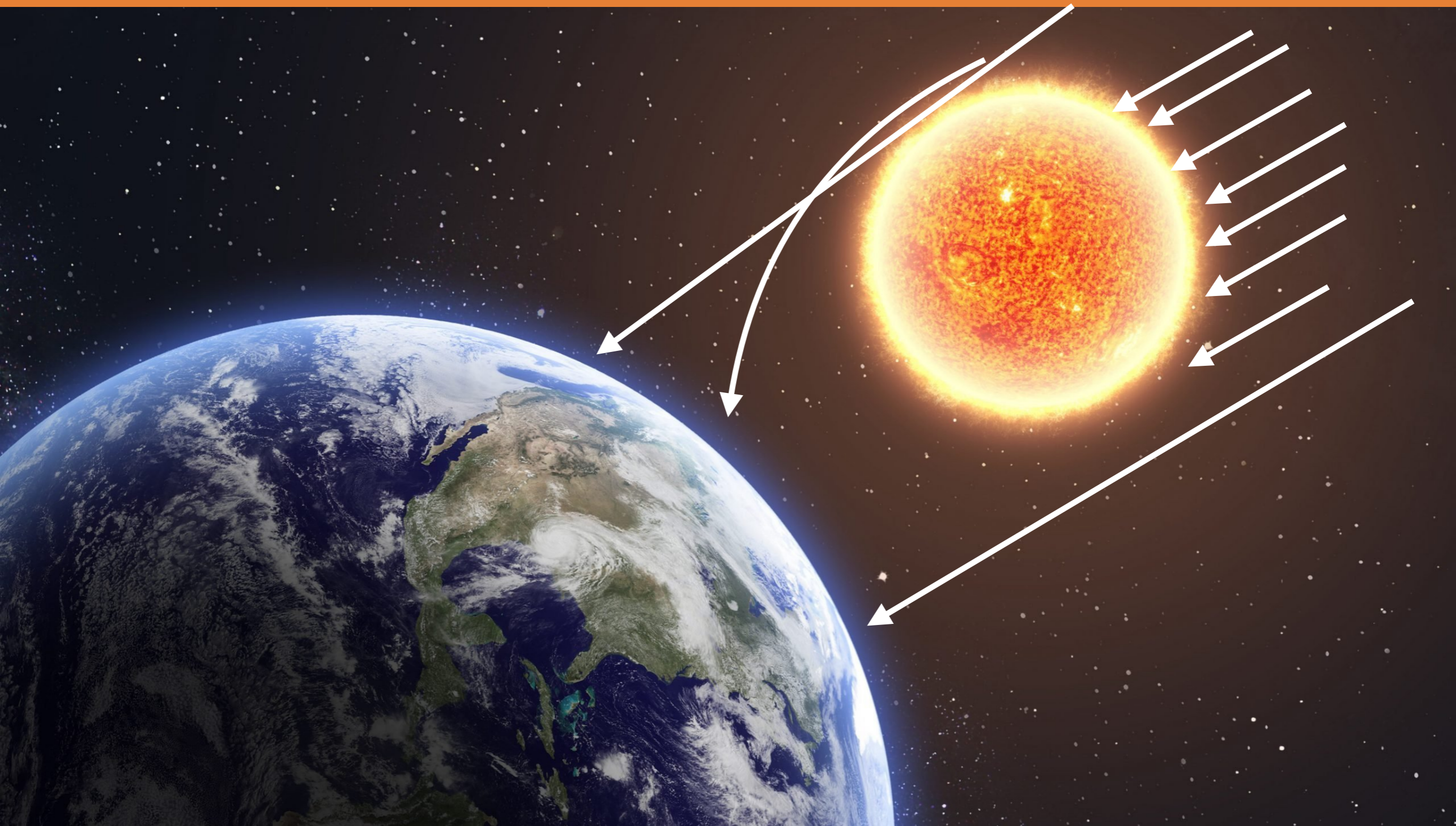


One of the few TeV gamma-ray instruments taking data from the Sun

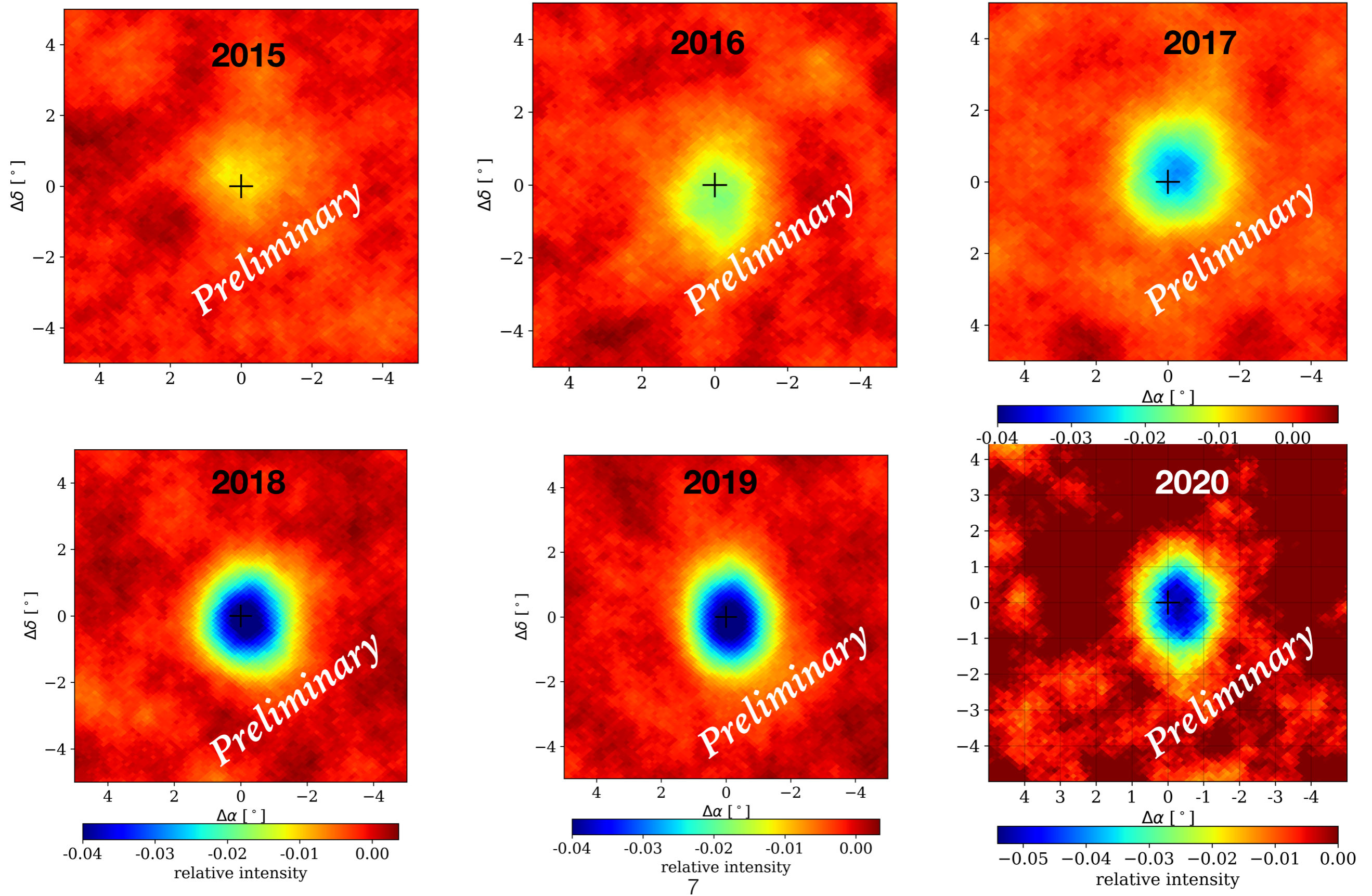
Solar Cycle



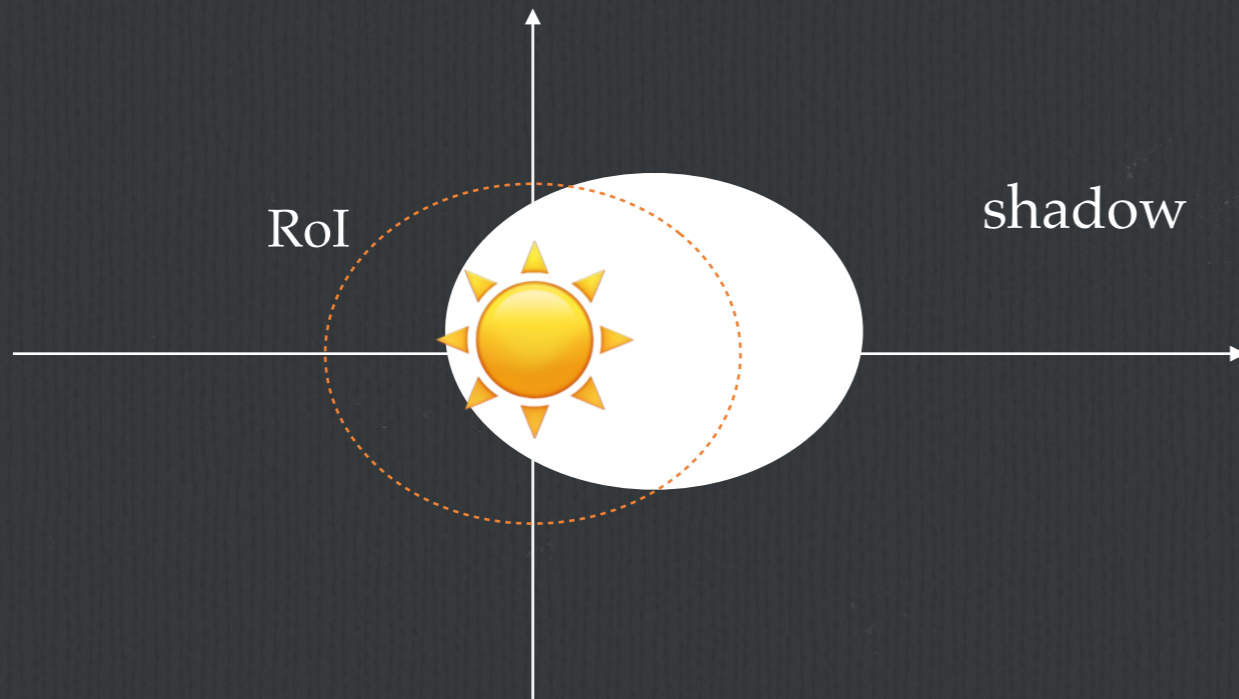
THE SOLAR COSMIC RAY SHADOW



Variation of the Sun shadow with Solar cycle

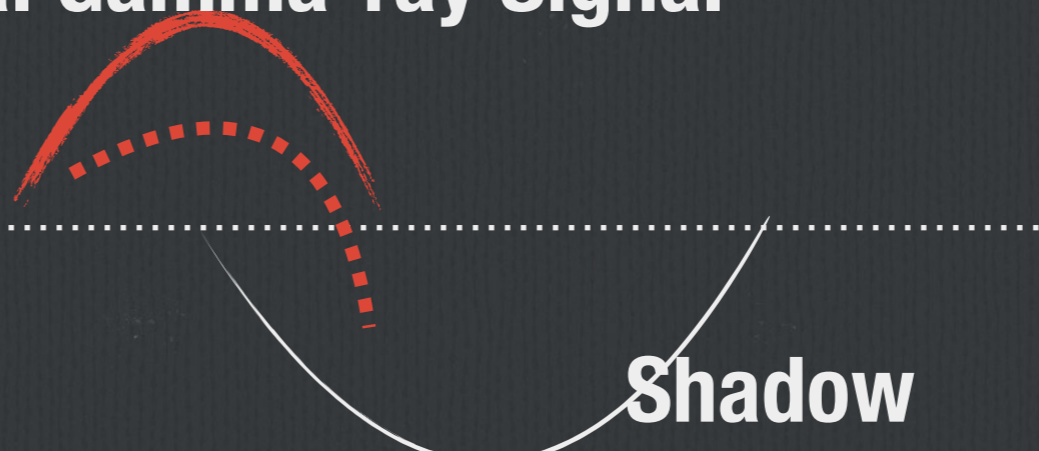


Sun shadow is a nuisance *source*



Potential Gamma-ray Signal

Background

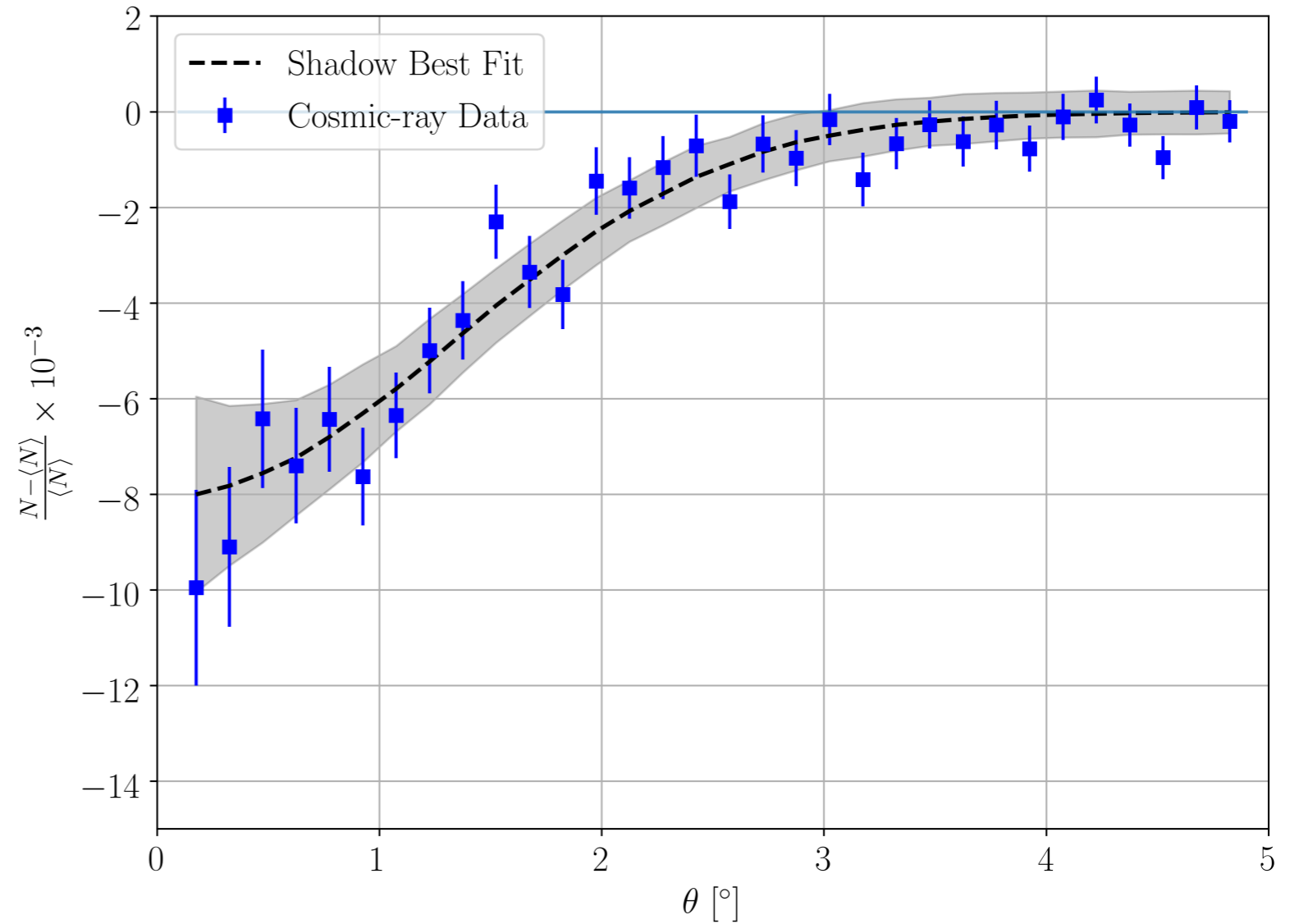
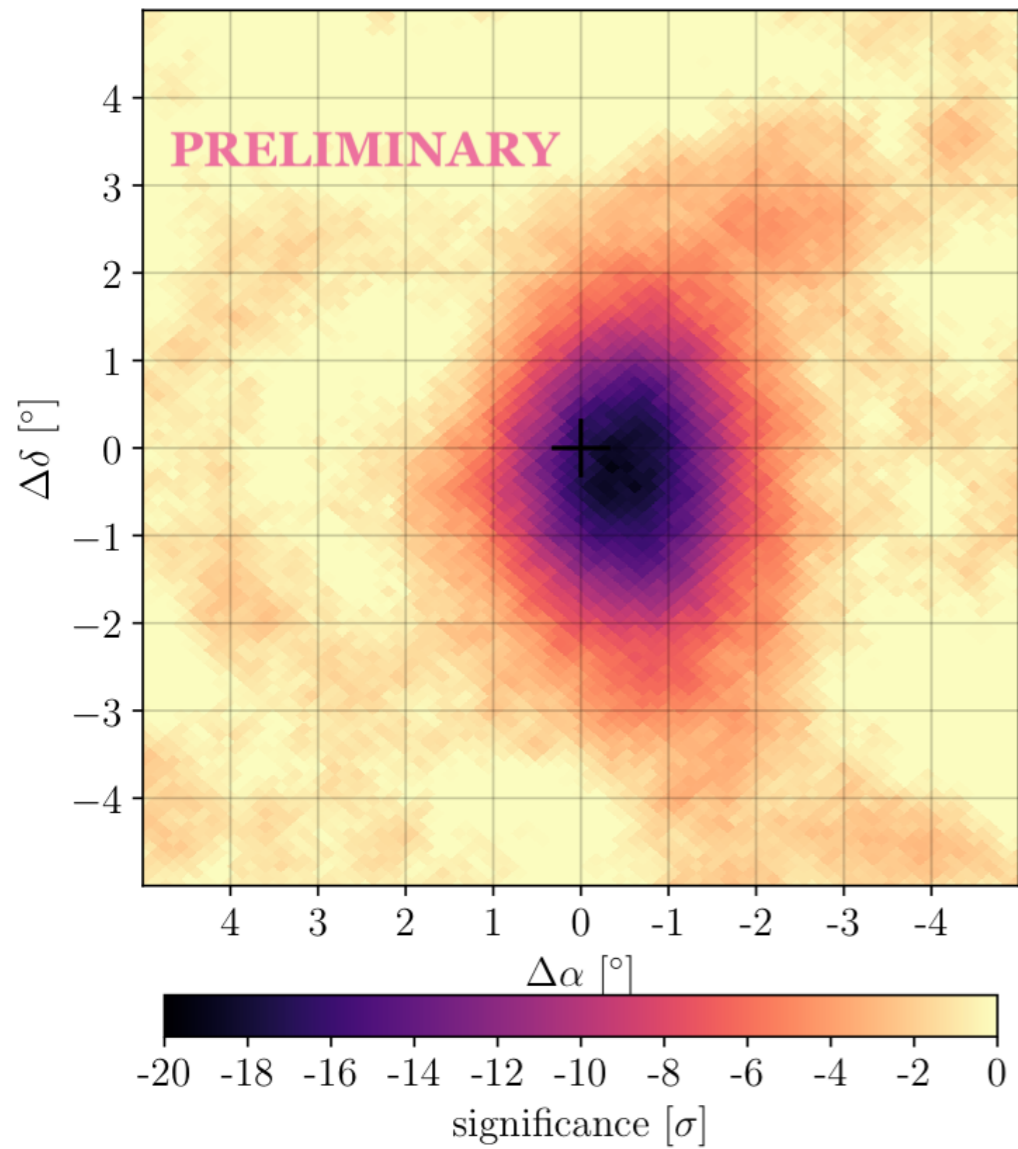


Shadow

- Source contamination by a “negative” source
- Fortunately, this “negative” source is entirely made up of hadrons ⁸ and if we know it’s shape and amplitude we can subtract it from the data.

Analysis Method

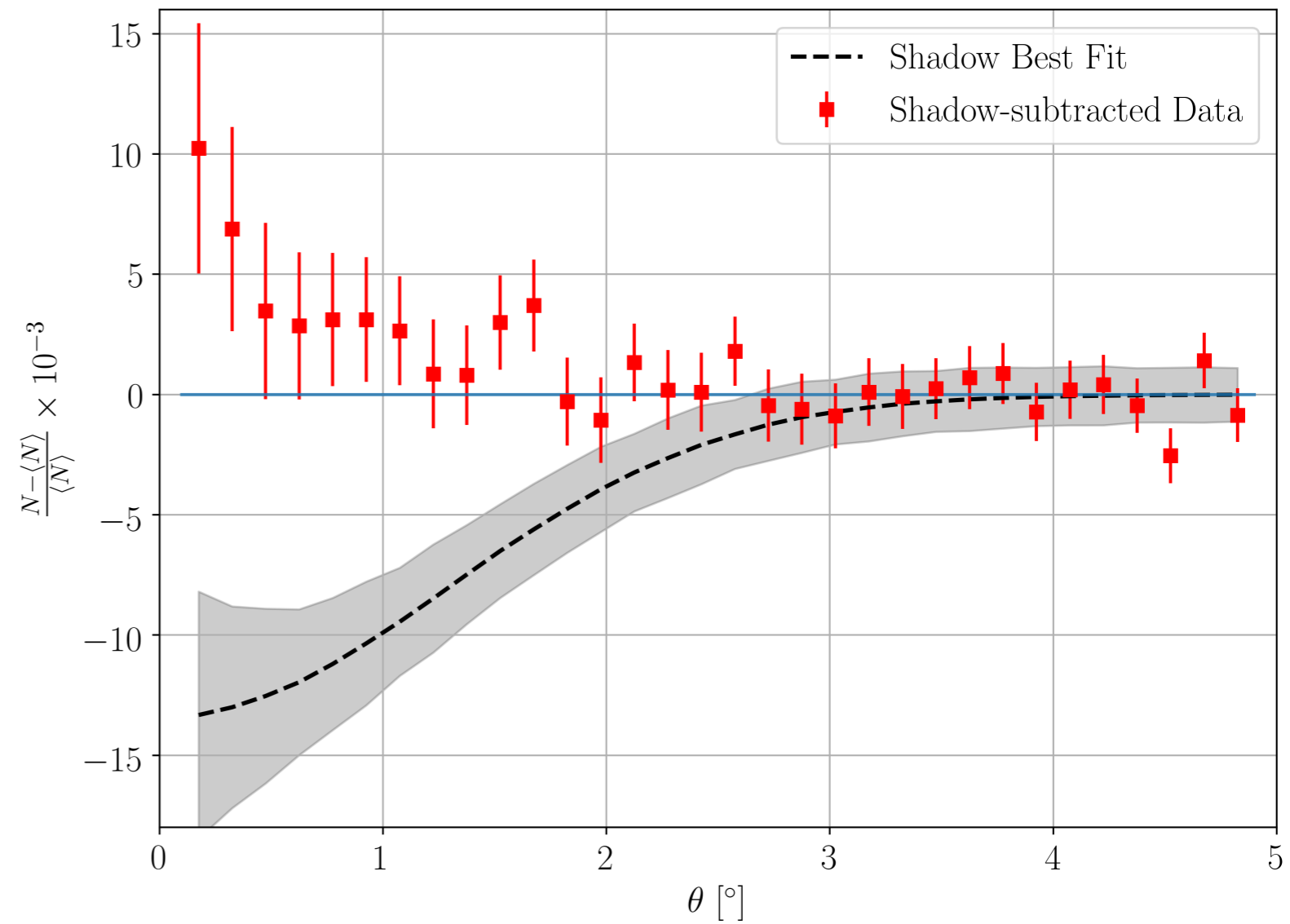
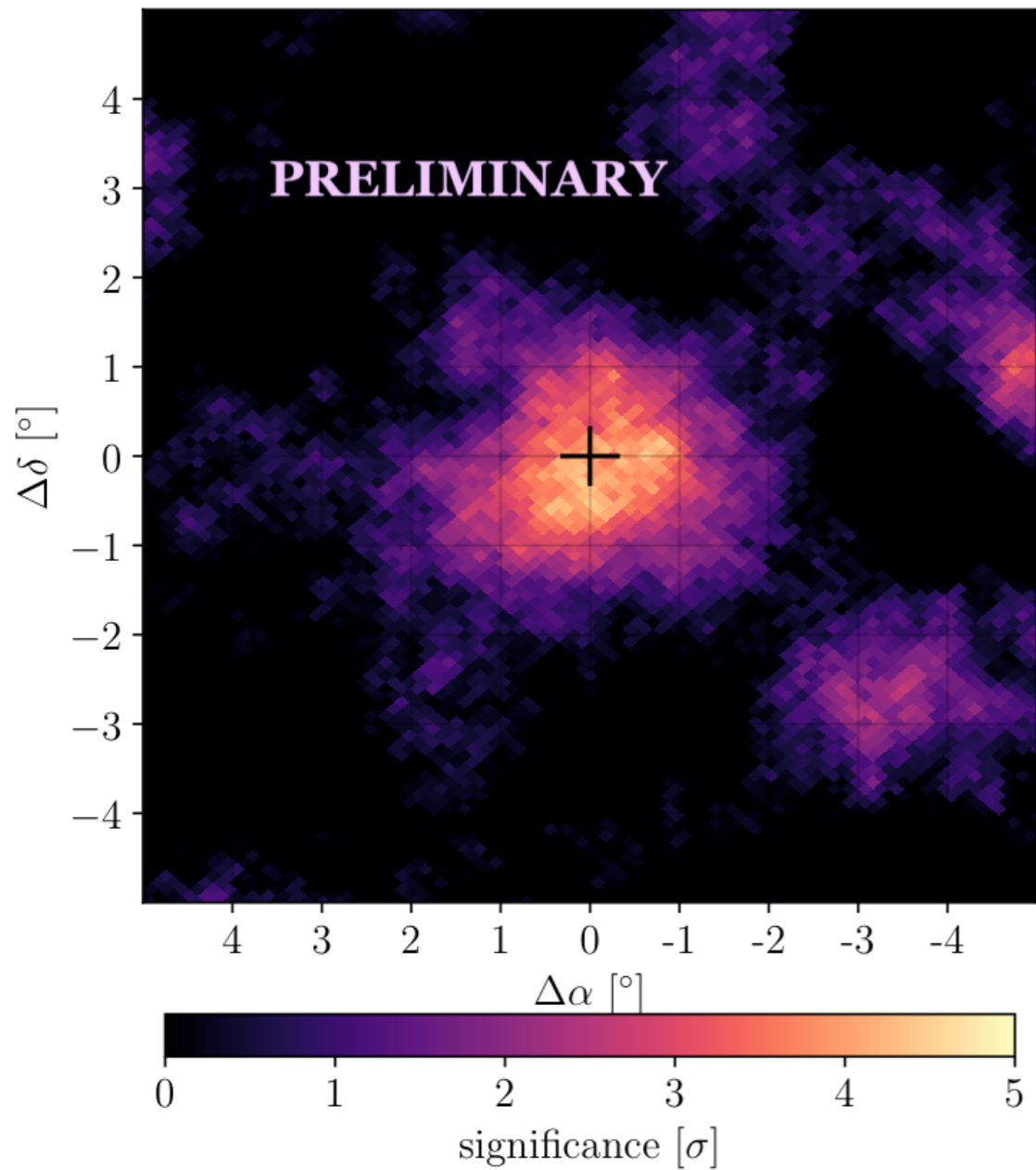
Measured CR Shadow: Quantity of interest is relative deficit wrt to bkg



(Nov 2014— Jan 2021)

Analysis Method

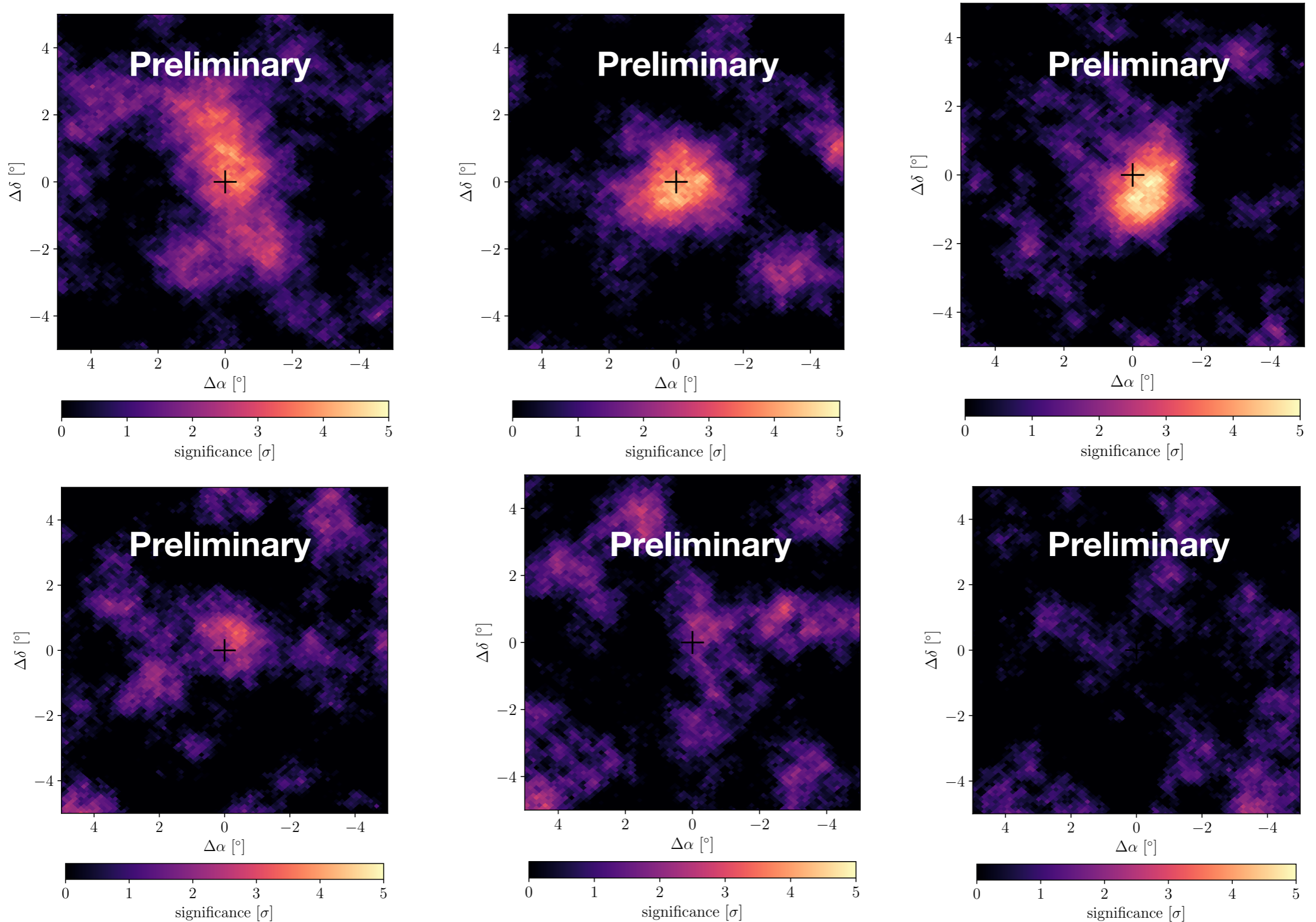
Subtract the CR shadow profile from the raw gamma maps
The subtraction is done in relative counts space.



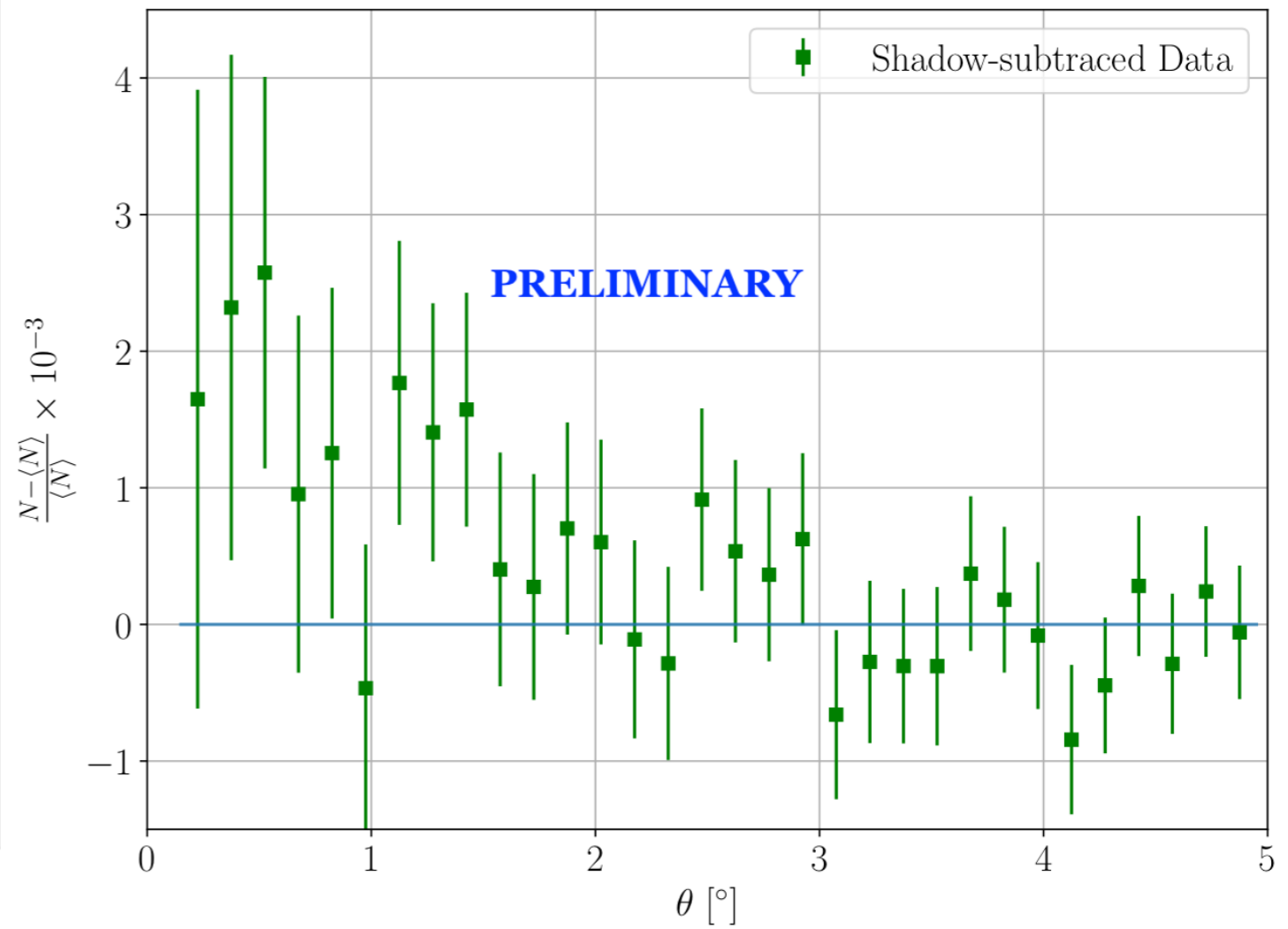
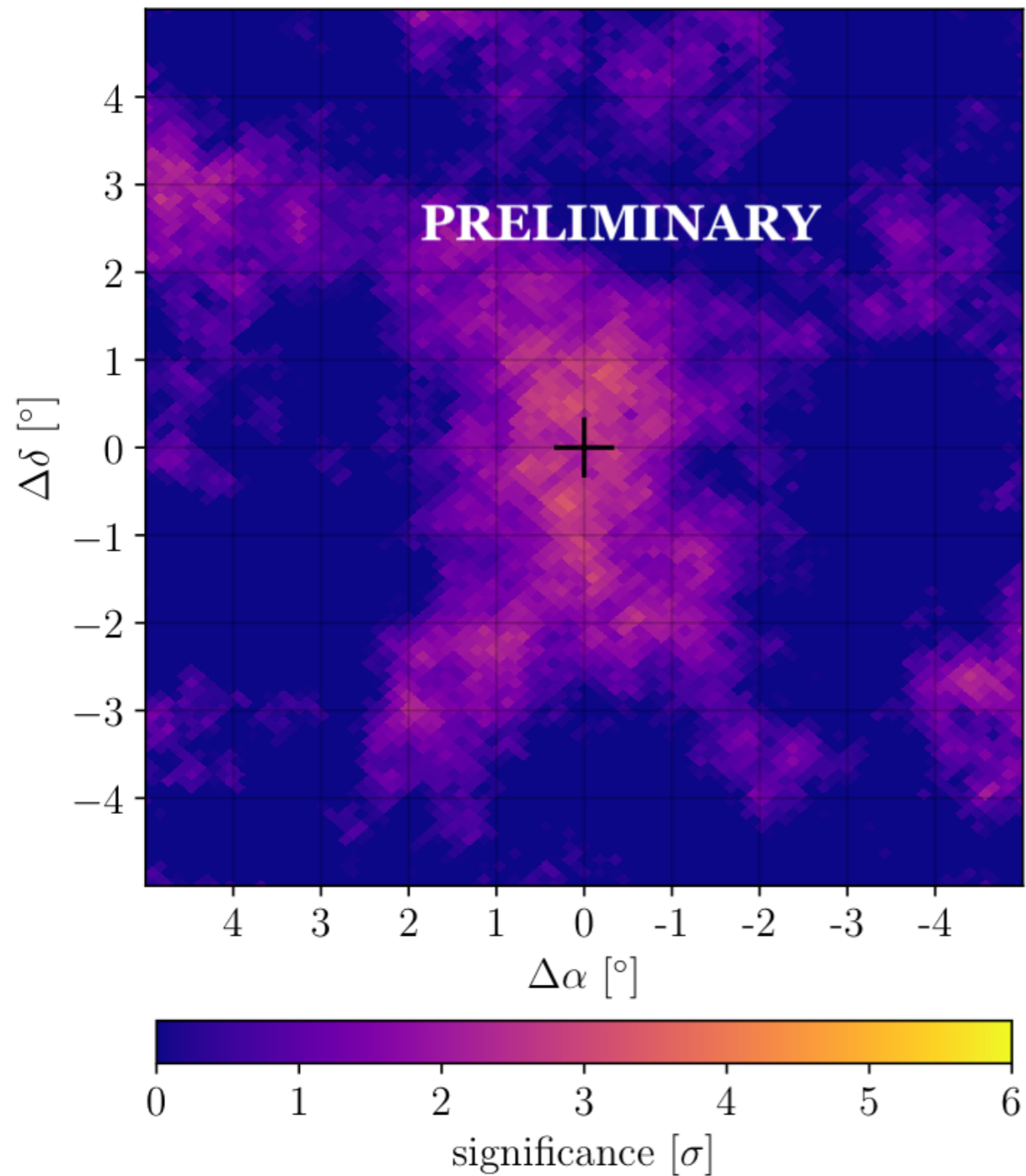
(Nov 2014— Jan 2021)

Shadow Subtracted Maps: Bins 2-7

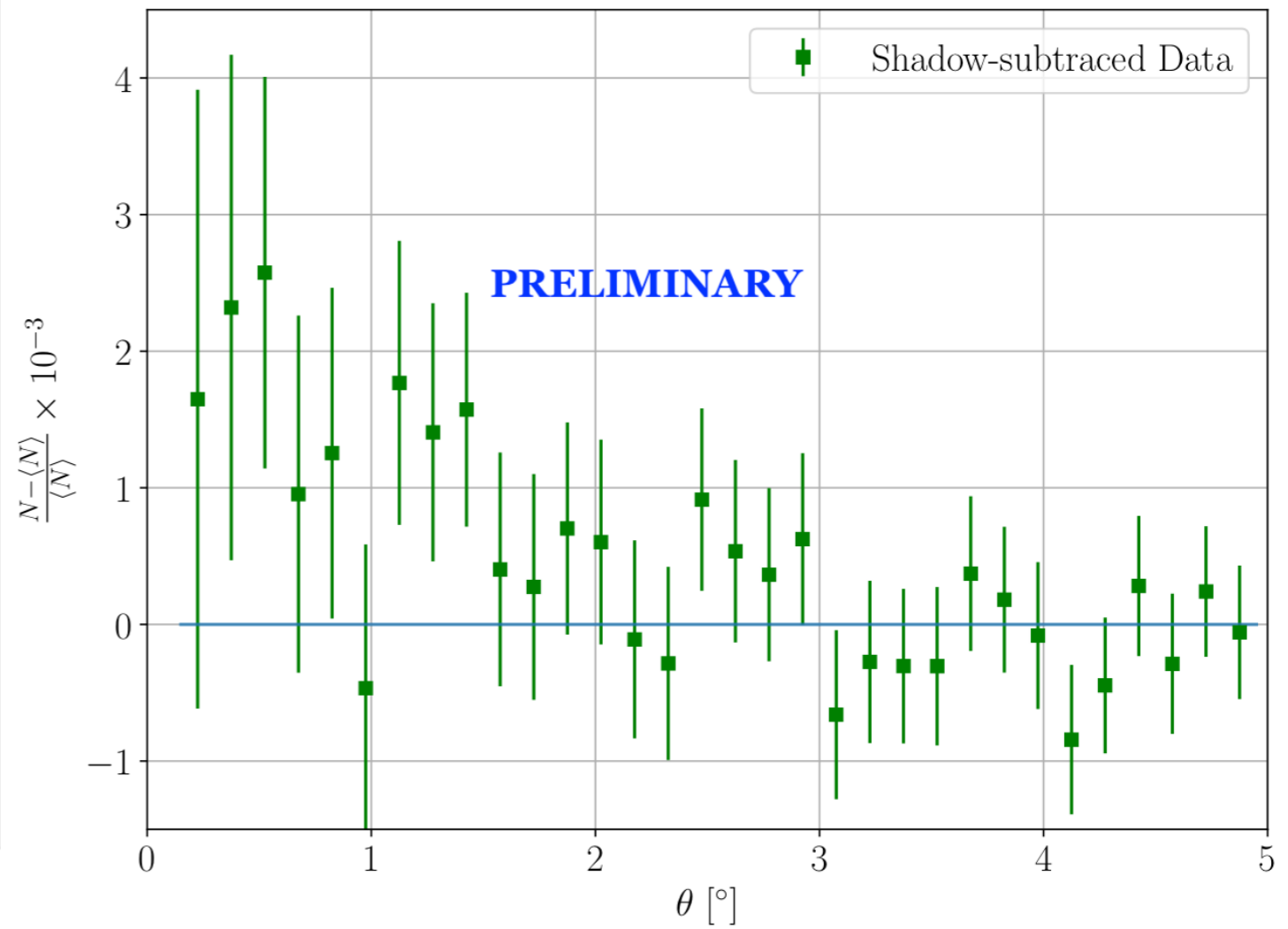
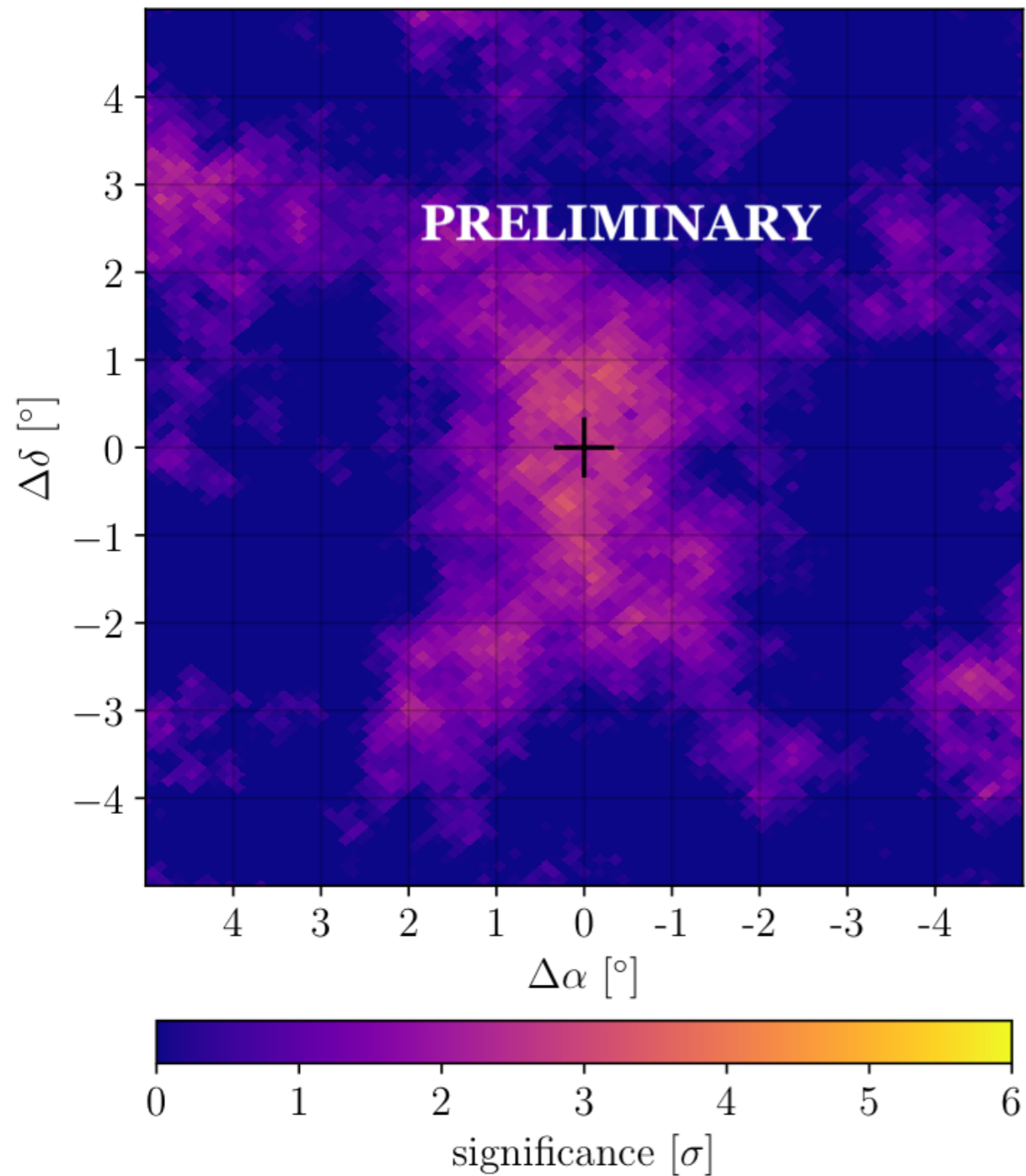
Bins correlate with energy



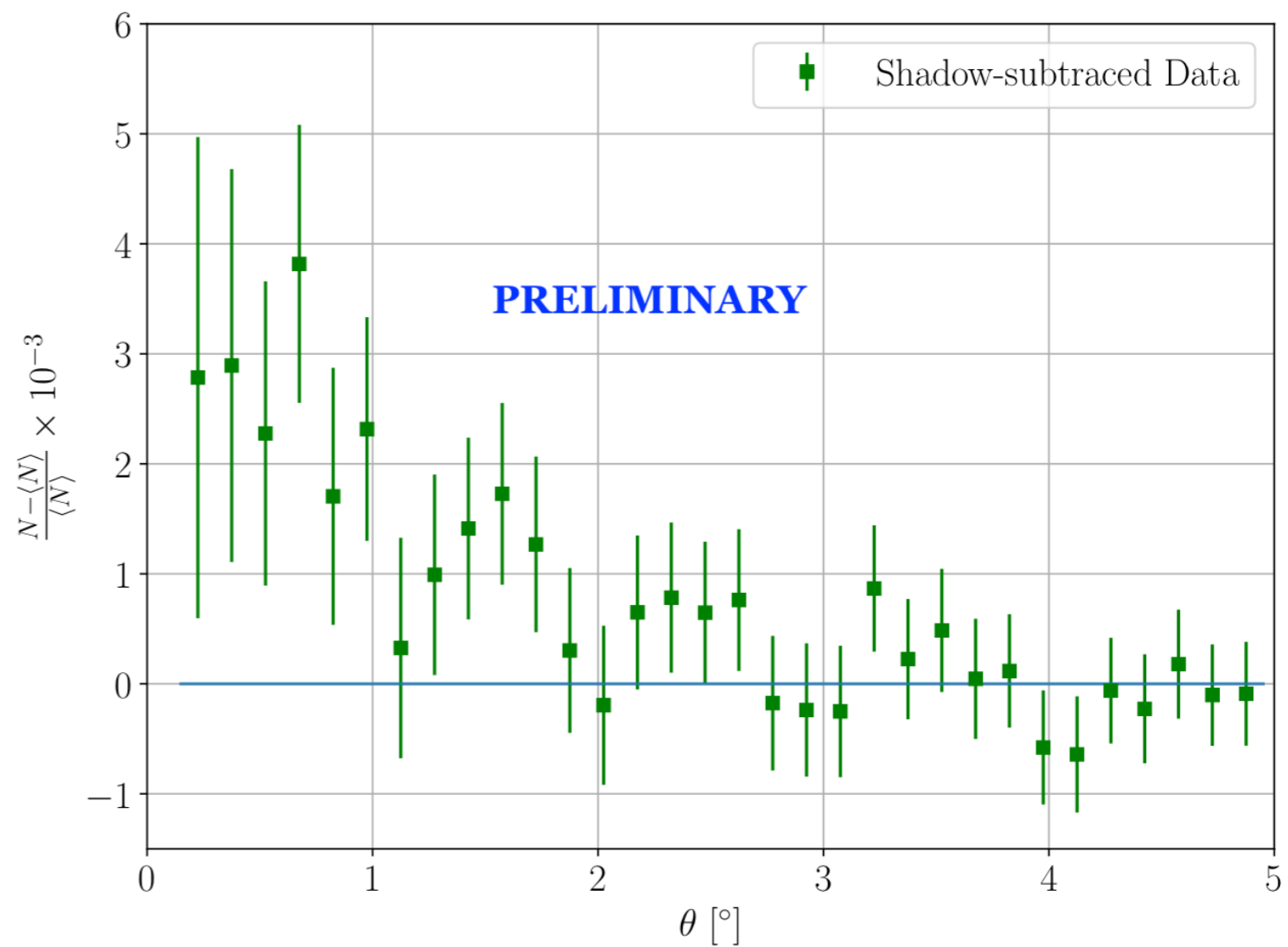
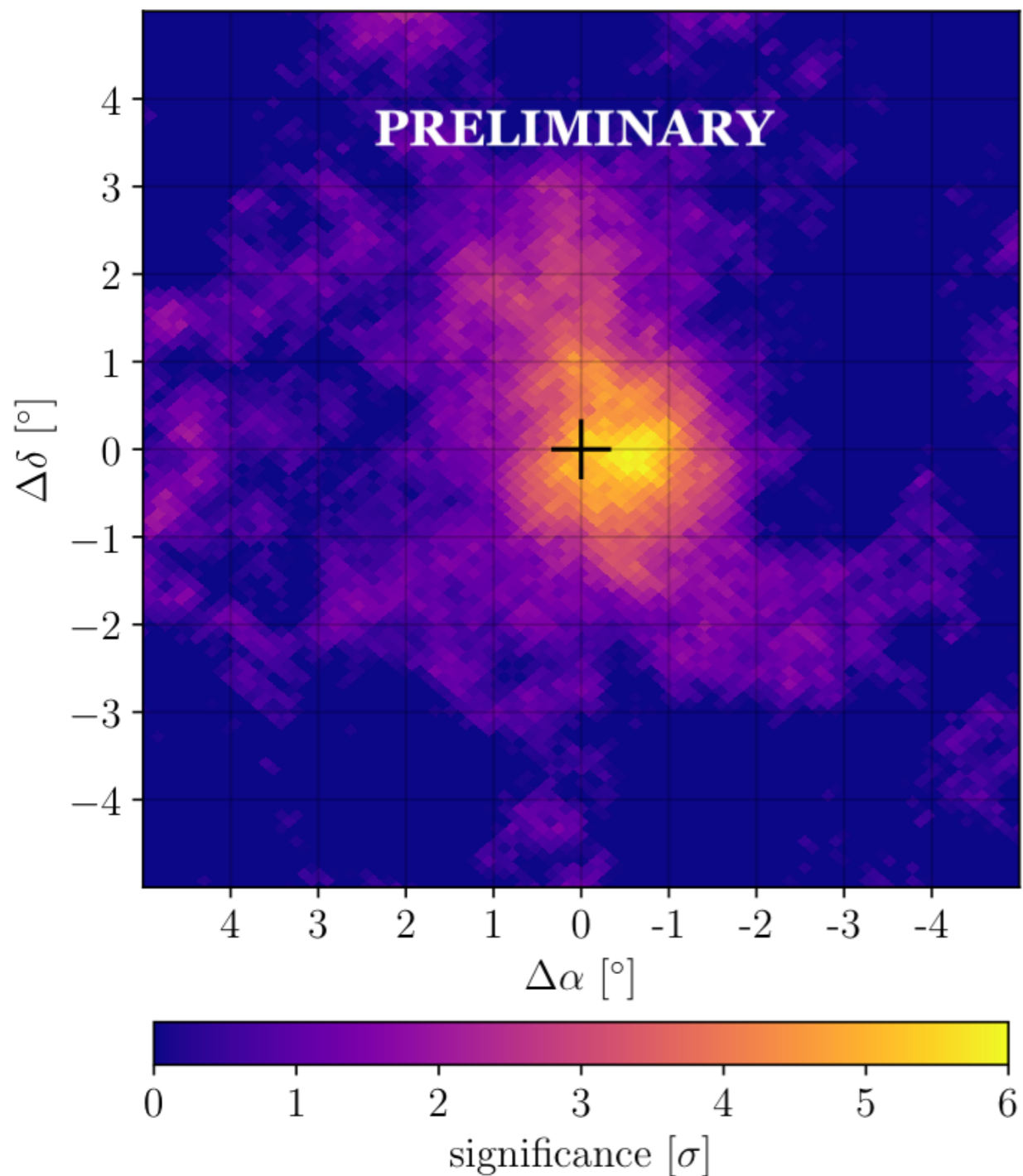
Solar Maximum (2014-2017)



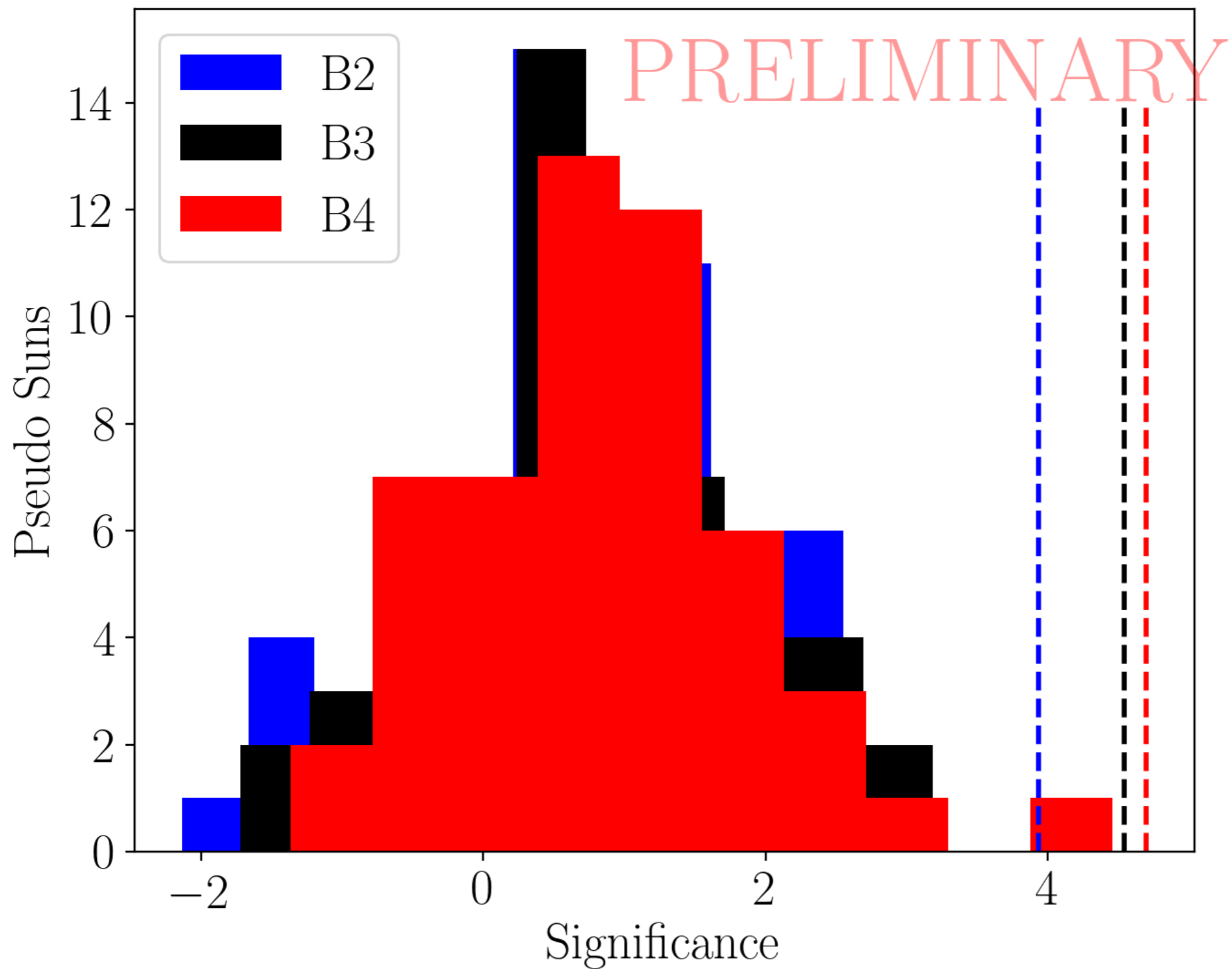
Solar Maximum (2015-2017)



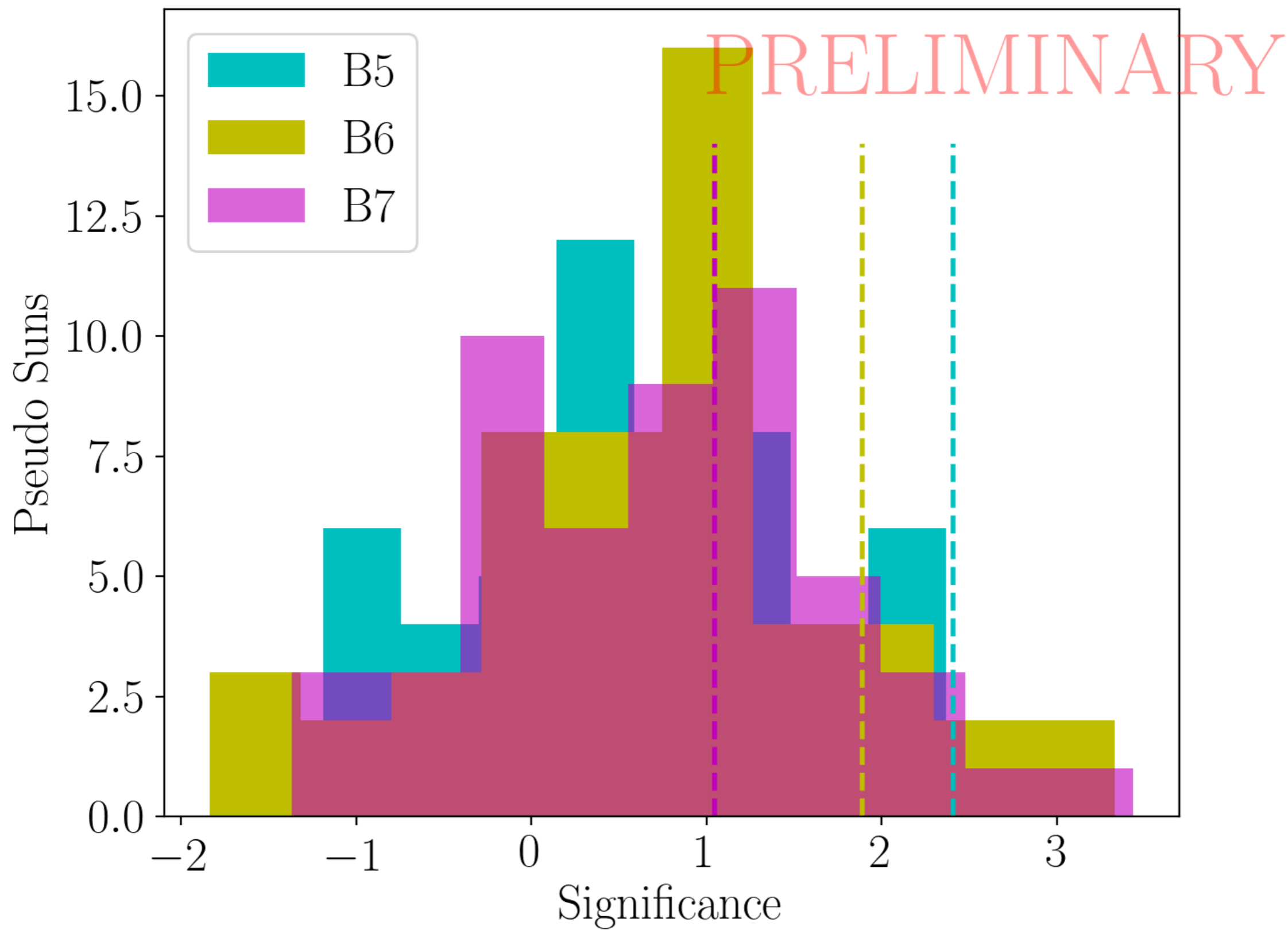
Solar Minimum (2018-2020)



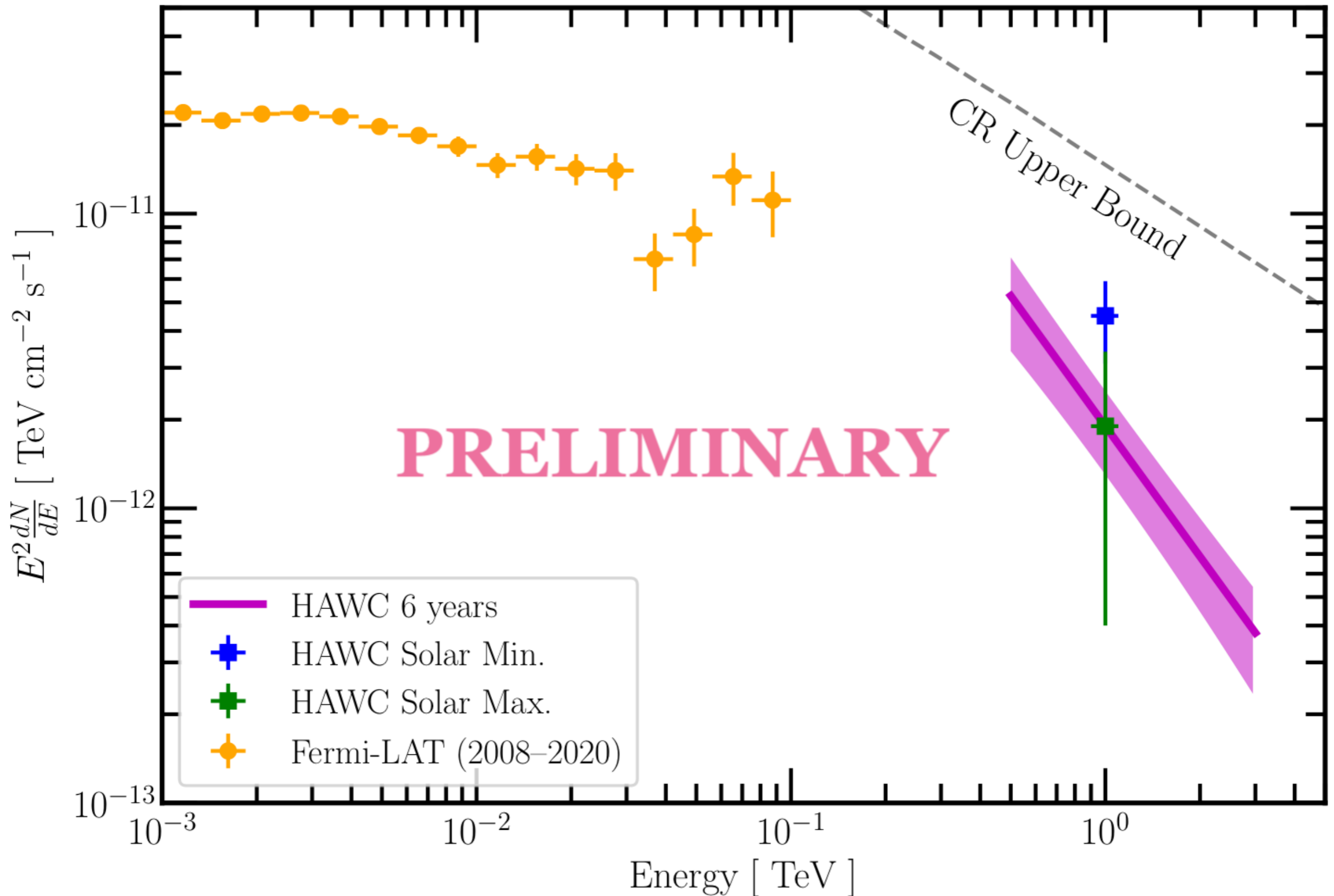
Cross-checks on Off-Sun Regions



Cross-checks on Off-Sun Regions



The First TeV Solar Gamma-ray Spectrum

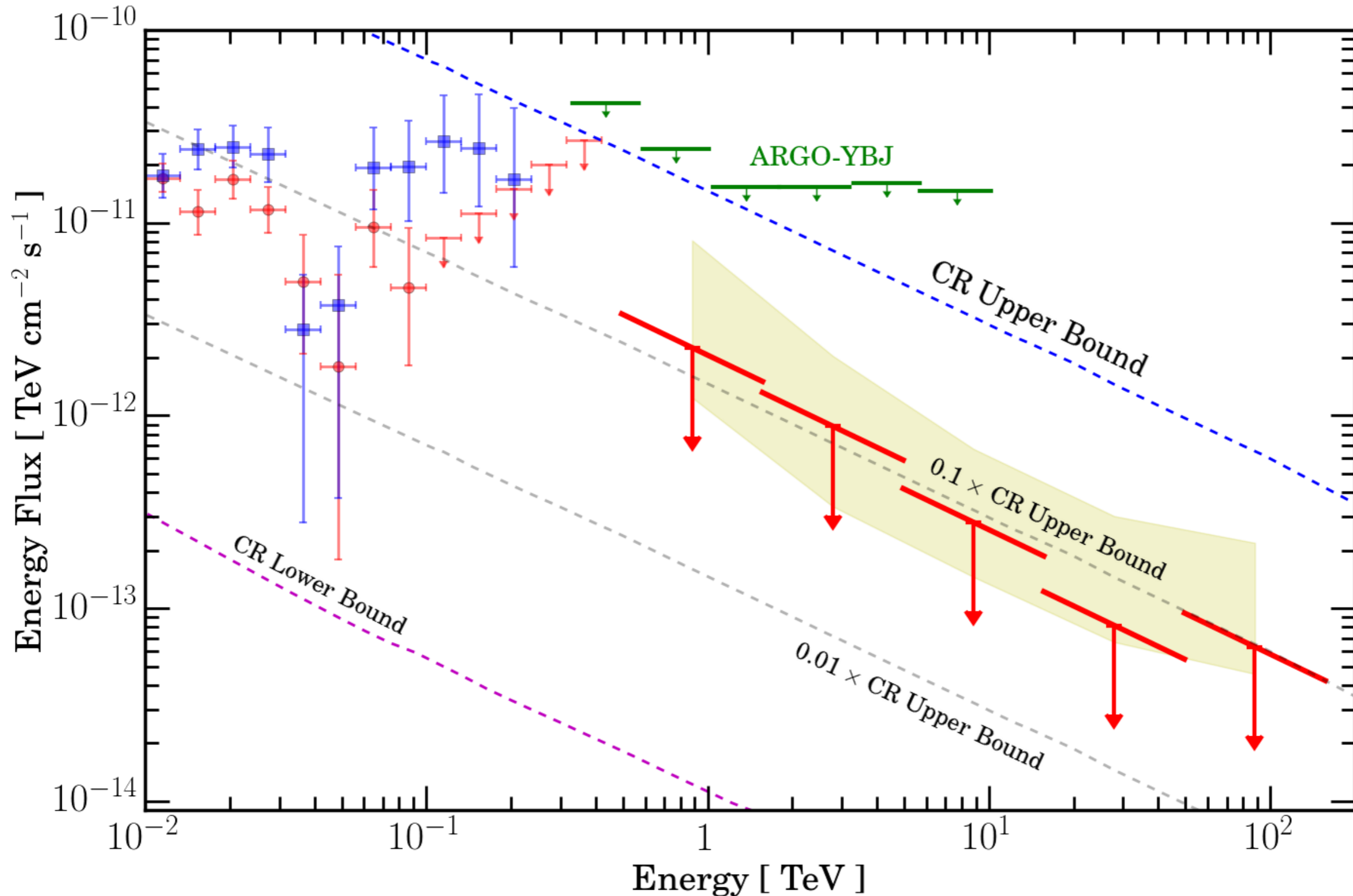


Summary

- **We have observed the first $\sim 6\sigma$ evidence of steady gamma rays from the Sun!**
- **Robust signal verified by extensive cross-checks on the moon and off-Sun regions**
- **The flux also shows clear time-dependence with the solar cycle**
- **The measured spectrum is much softer compared to Fermi observations and likely points towards a cut-off energy for the CR mirroring in photosphere.**
- **Challenges for theory: Flux, modulation, spectrum, morphology and now the highest energy observation**

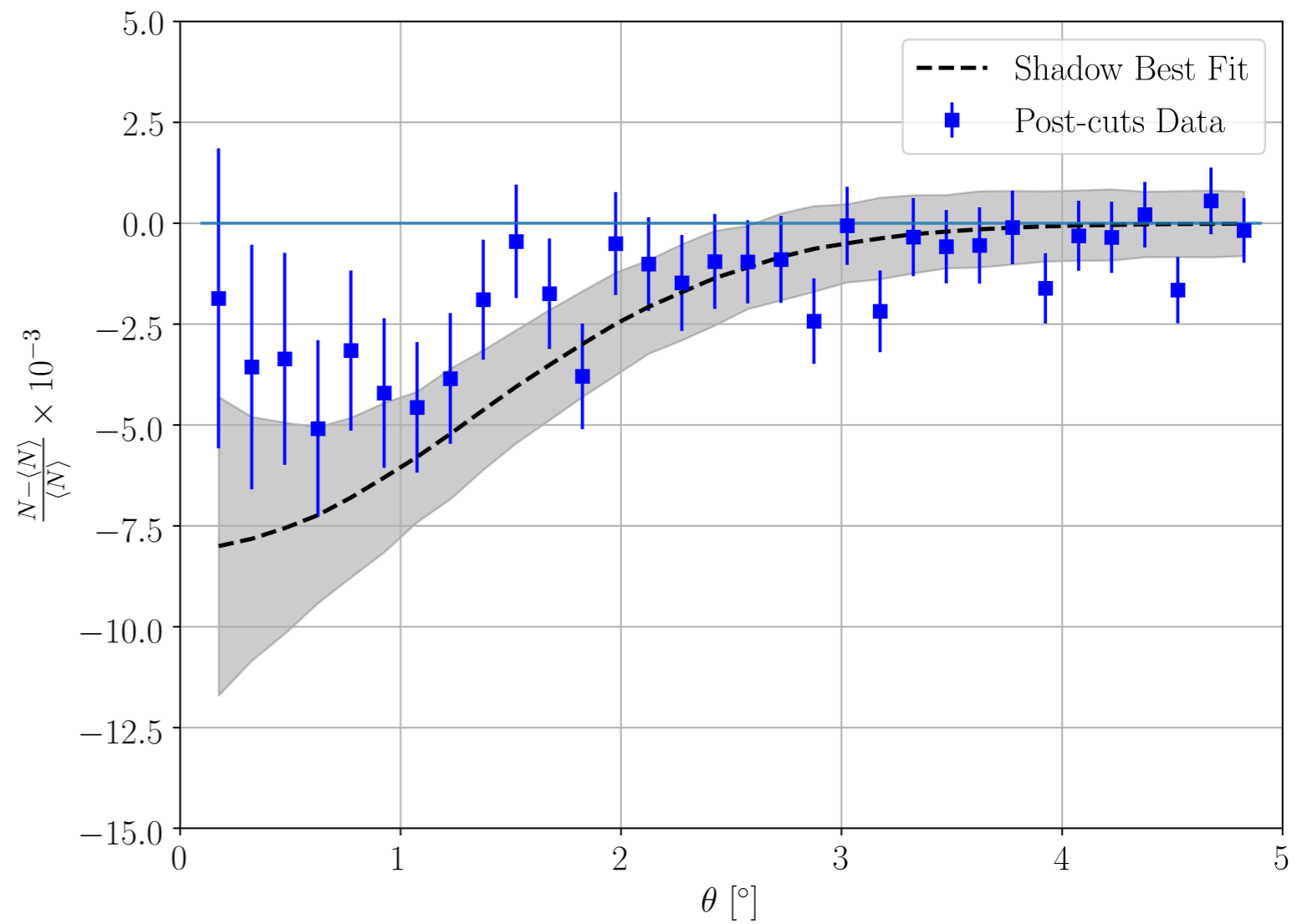
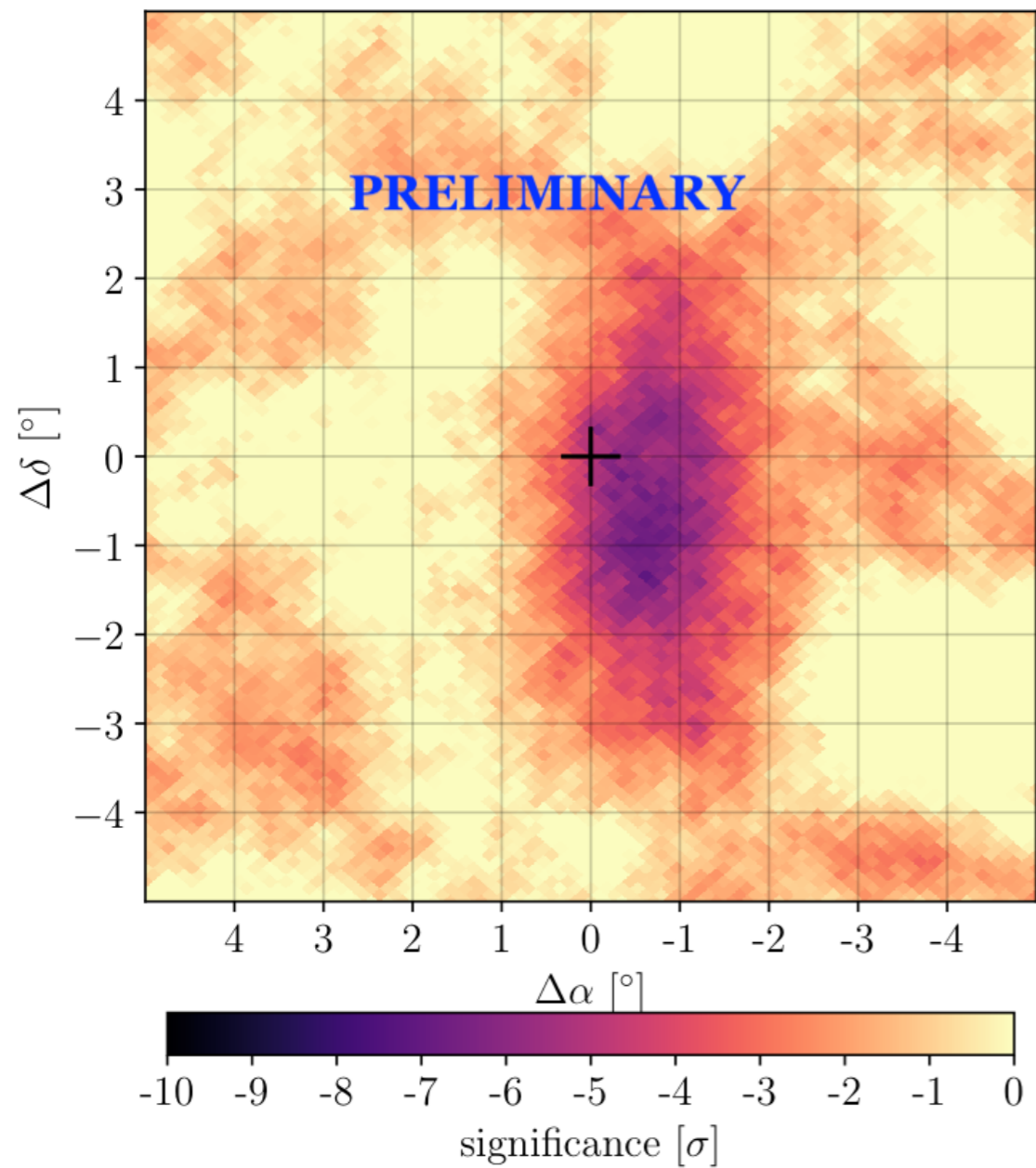
Back Up

First Results from HAWC



Analysis Method: Step 2

Raw data after gamma-hadron cuts: Remember it is still dominated by CRs



(Nov 2014— Jan 2021)