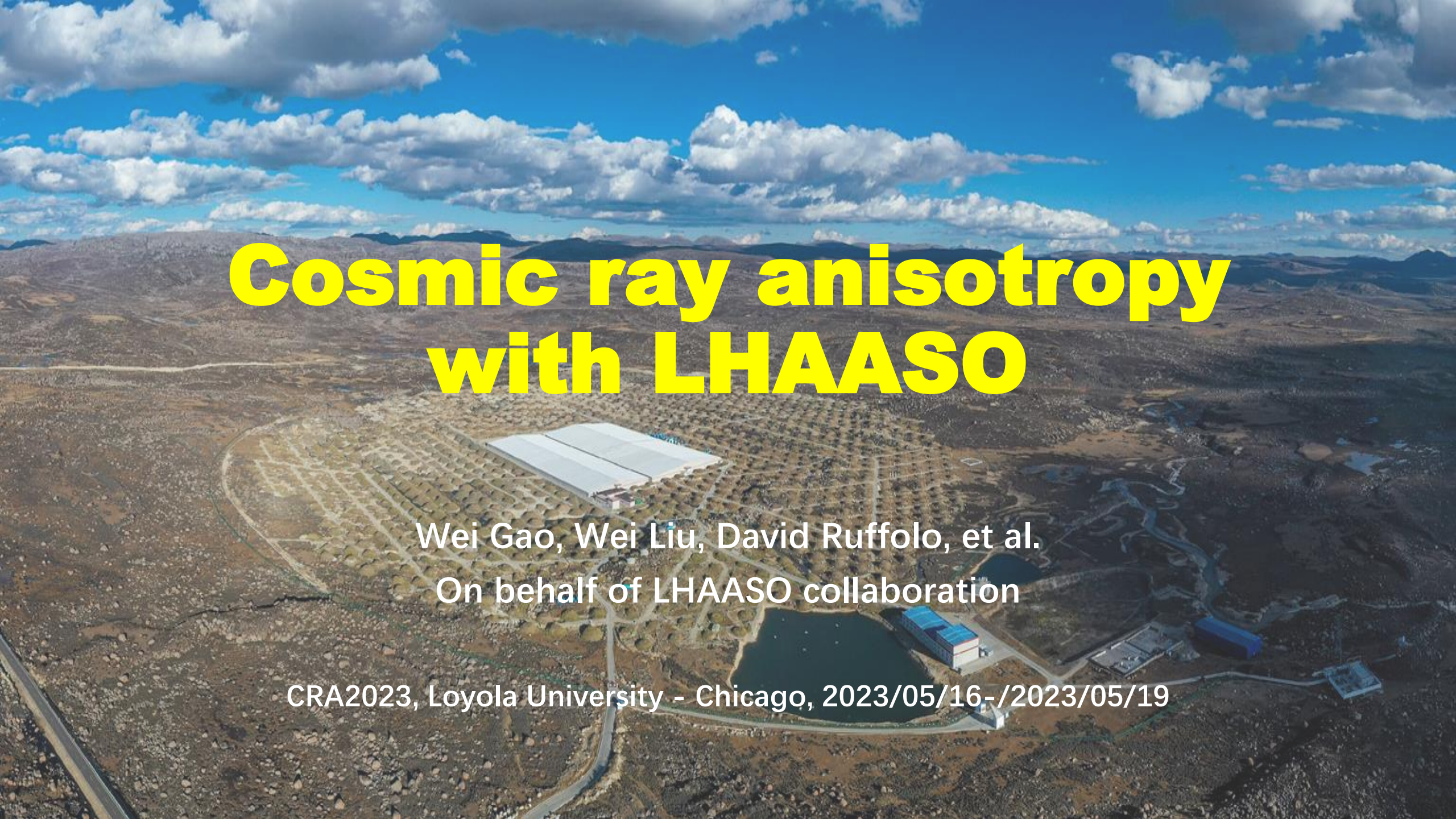


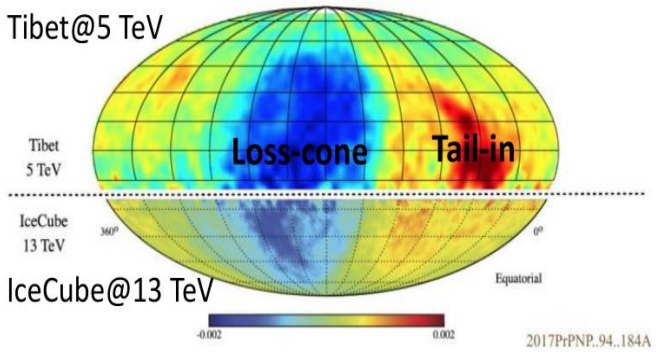
Cosmic ray anisotropy with LHAASO

Wei Gao, Wei Liu, David Ruffolo, et al.
On behalf of LHAASO collaboration

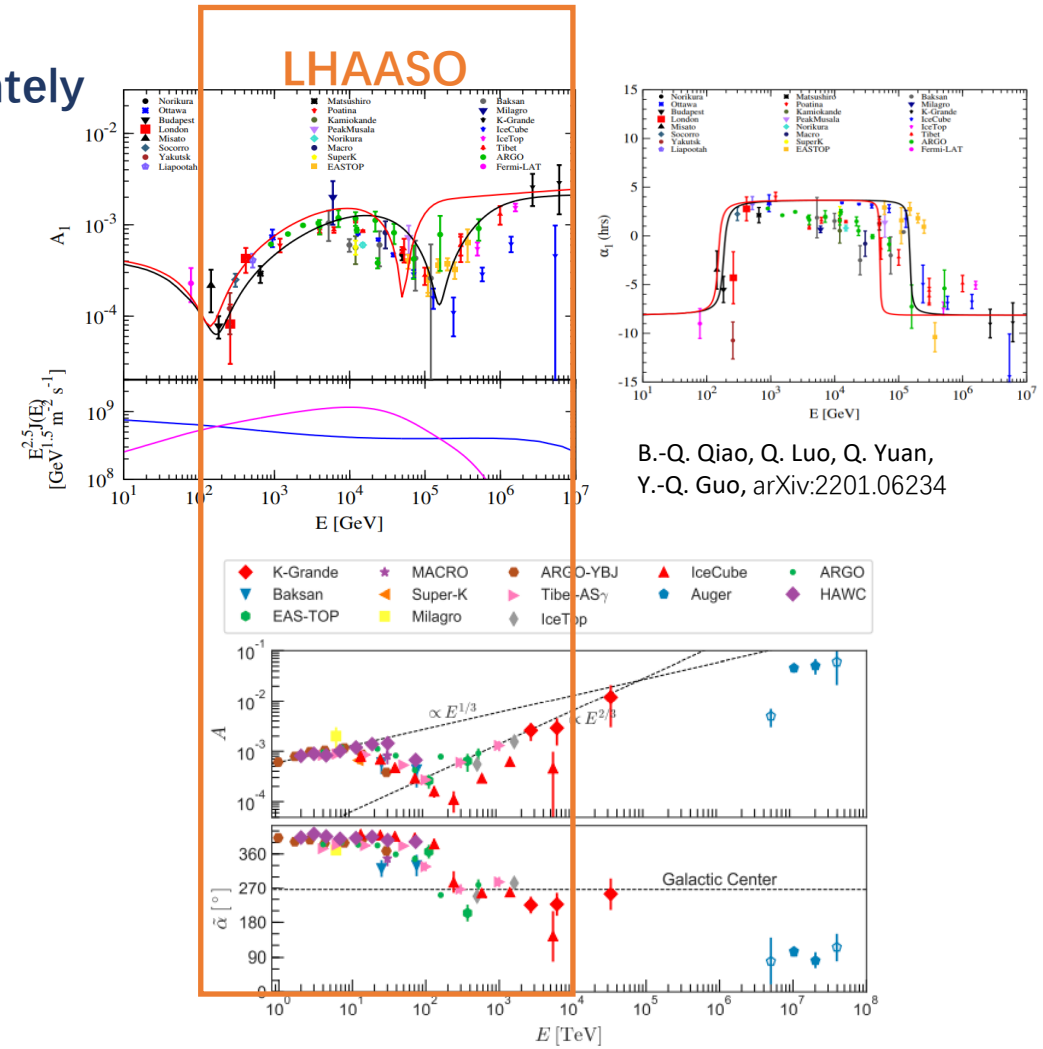
CRA2023, Loyola University - Chicago, 2023/05/16-/2023/05/19

Cosmic ray anisotropy

- Arrival direction is approximately isotropic, but still anisotropic
- amplitude~10^{-4}–10^{-2}
- evolve with energy



M. Ahlers, P. Mertsch, Progress in Particle and Nuclear Physics 94 (2017) 184–216



Julia Becker Tjus et al., Physics Reports, 872(2020) 1–98

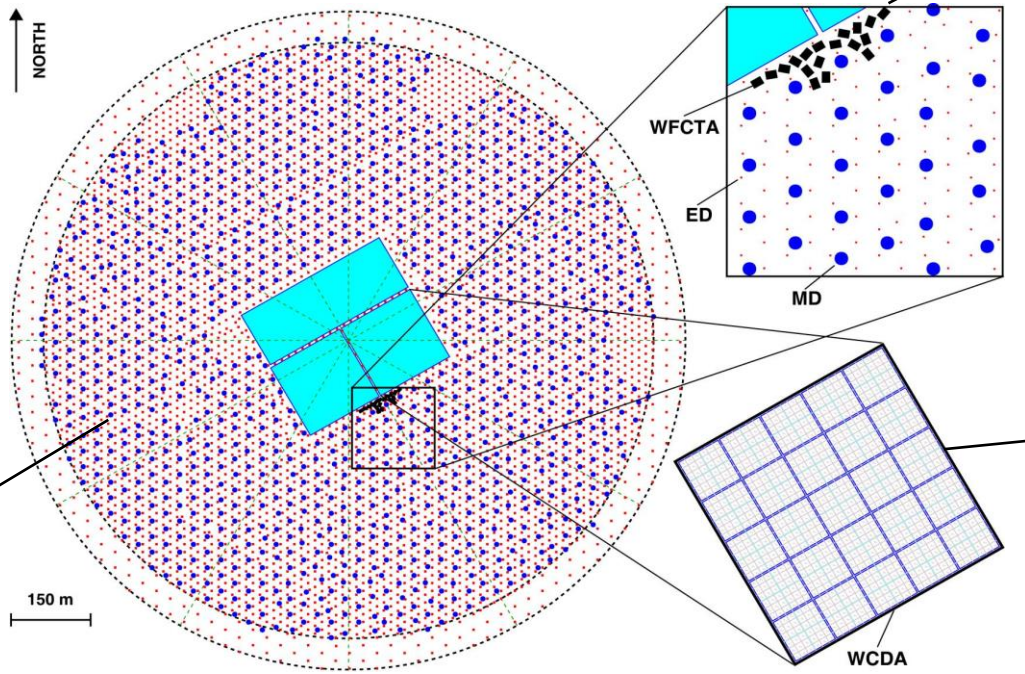
B.-Q. Qiao, Q. Luo, Q. Yuan, Y.-Q. Guo, arXiv:2201.06234

- Origins of anisotropy are still confused
- Local magnetic
- Local source
- .....

LHAASO

- 29°21’ 31” N, 100°08’15” E
- 4410m a.s.l.
- ~600g/cm
- Multi variable measurements
- Completed on July 2021

18WFCTs

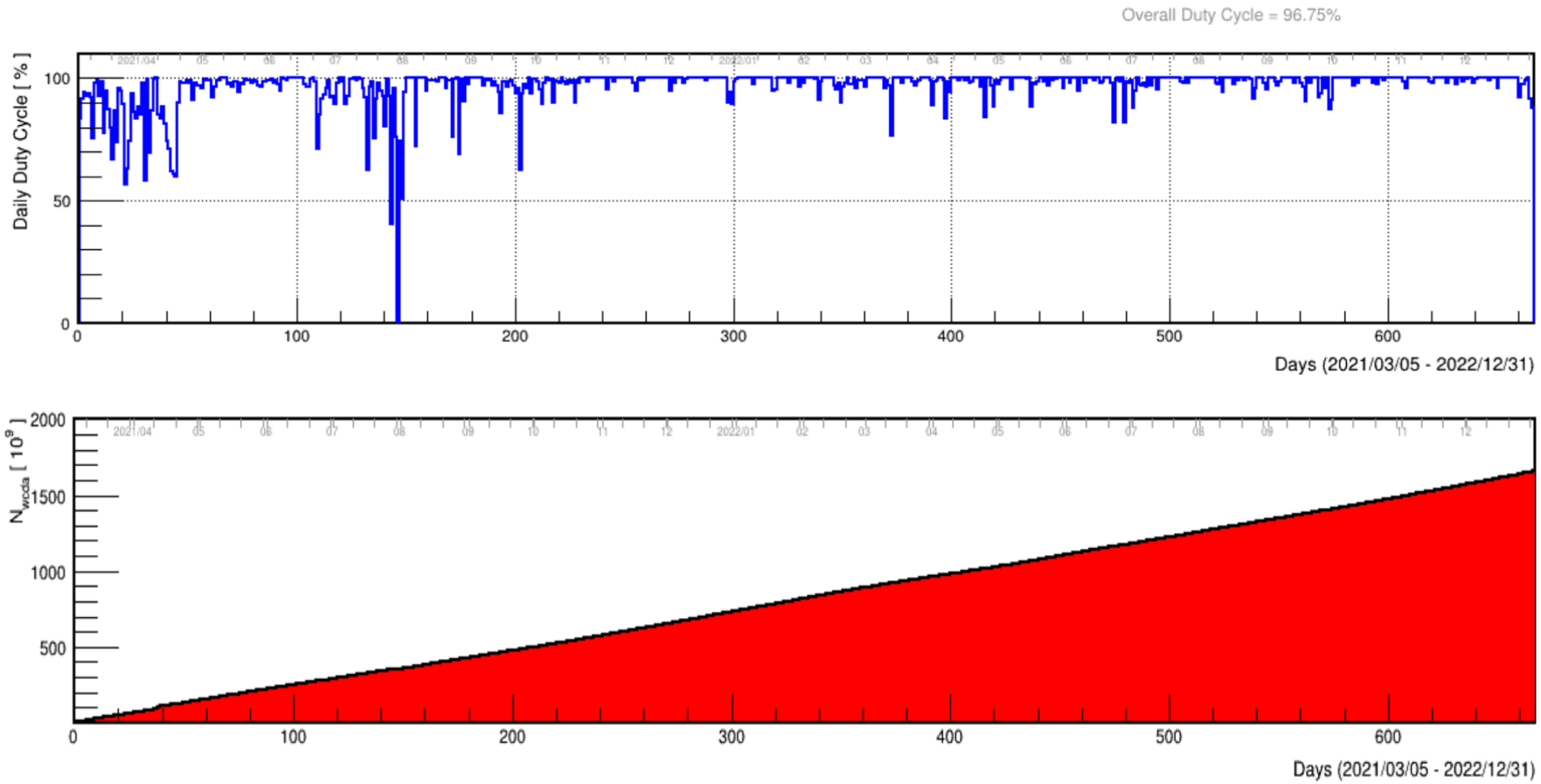


KM2A $(1.3km^2)$
ED:5216 MD:1188

WCDA $(78000m^2)$
3water pools, 3120cells

Status of WCDA

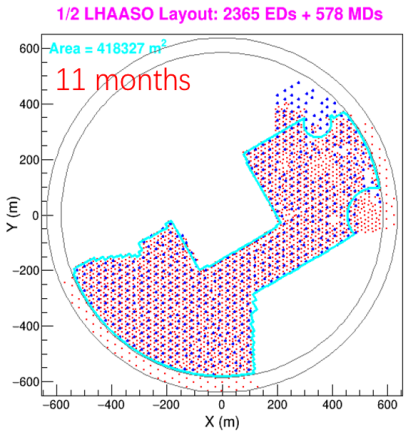
- **WCDA full array mode: ~ 35kHz**
- **2021/03/05-2022/12/31: 96% duty cycle**



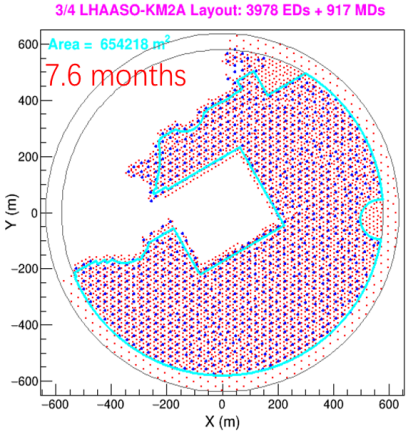
Status of KM2A

- KM2A full array: ~ 2.5kHz
- The average duty cycle of Full-KM2A is 96.8%, nearly 100% for most of the time.

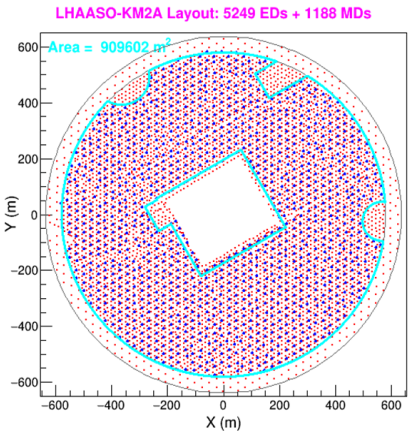
½ KM2A → ¾ KM2A → Full-KM2A



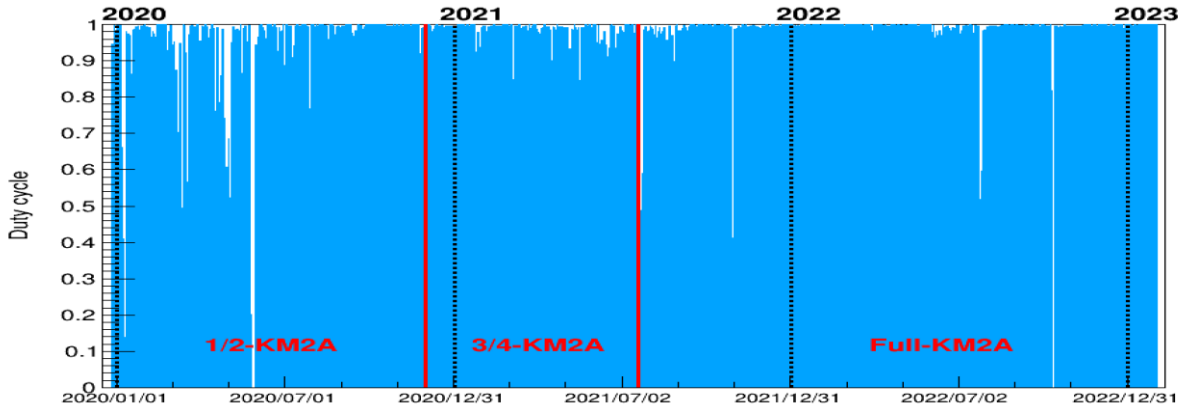
2019-12-27—2020-11-30

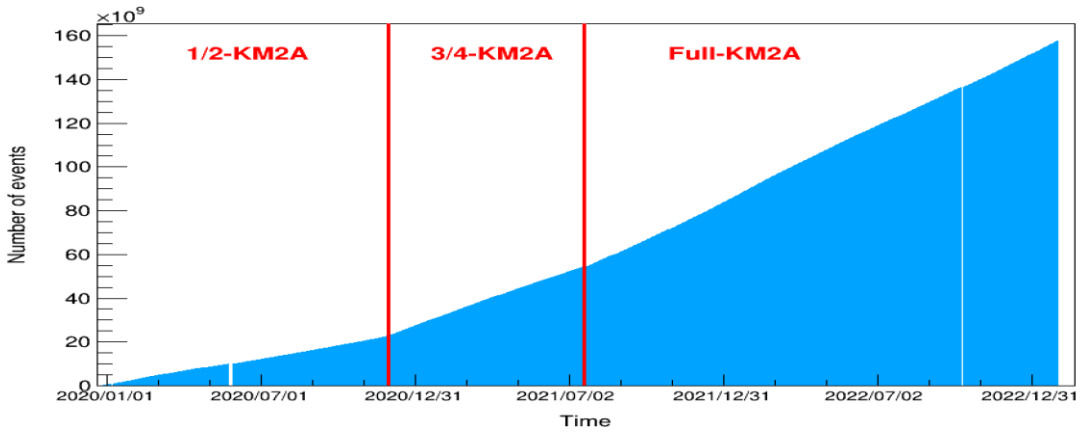


2020-12-01—2021-07-19



2021-07-20—



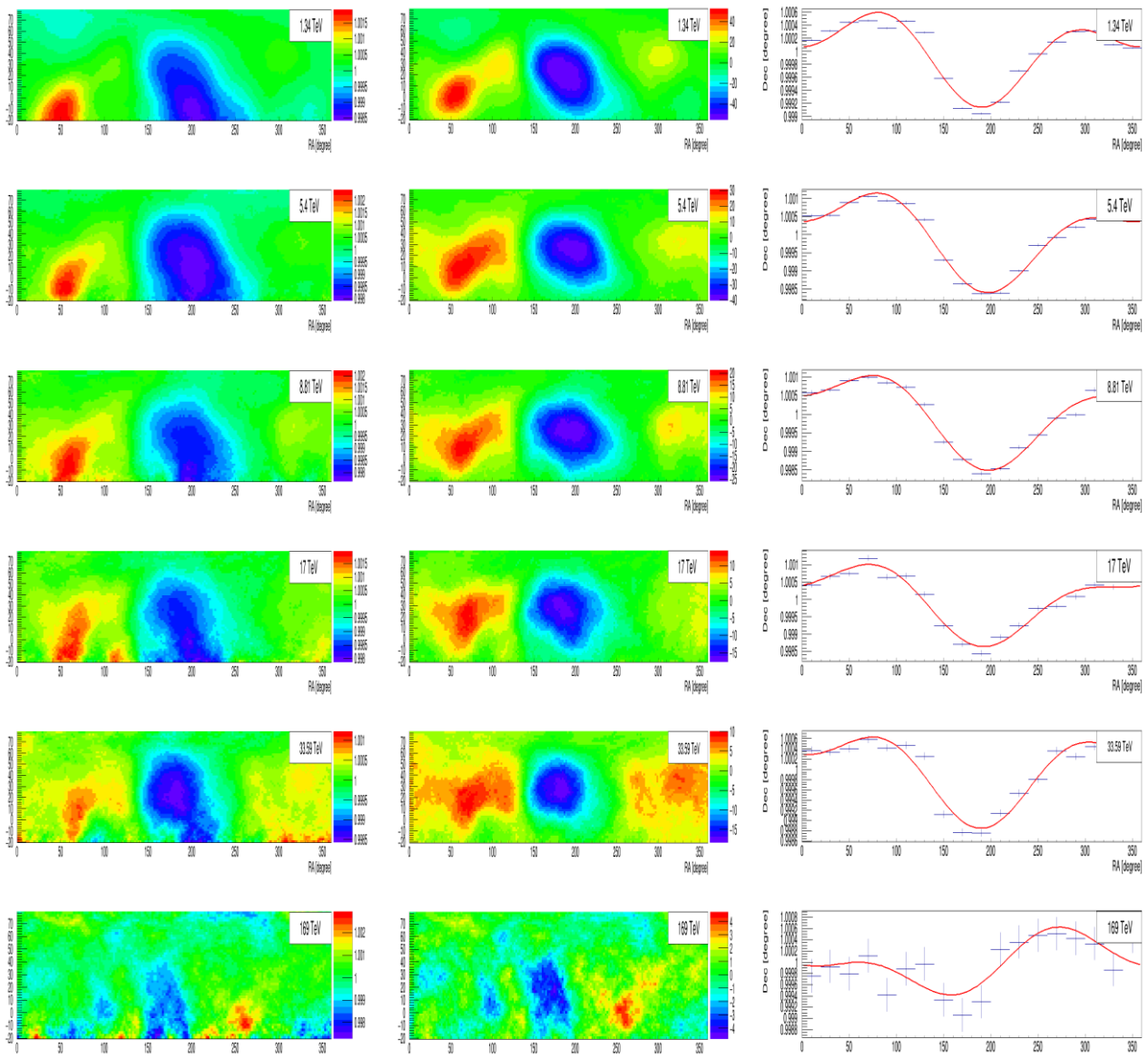


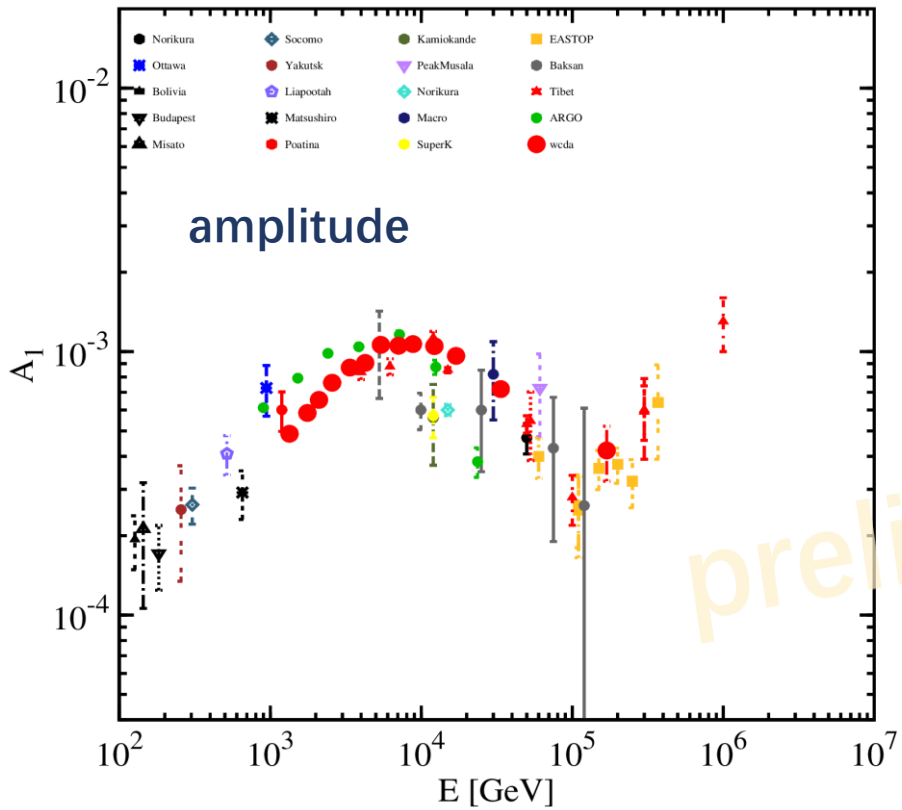
Anisotropy with WCDA

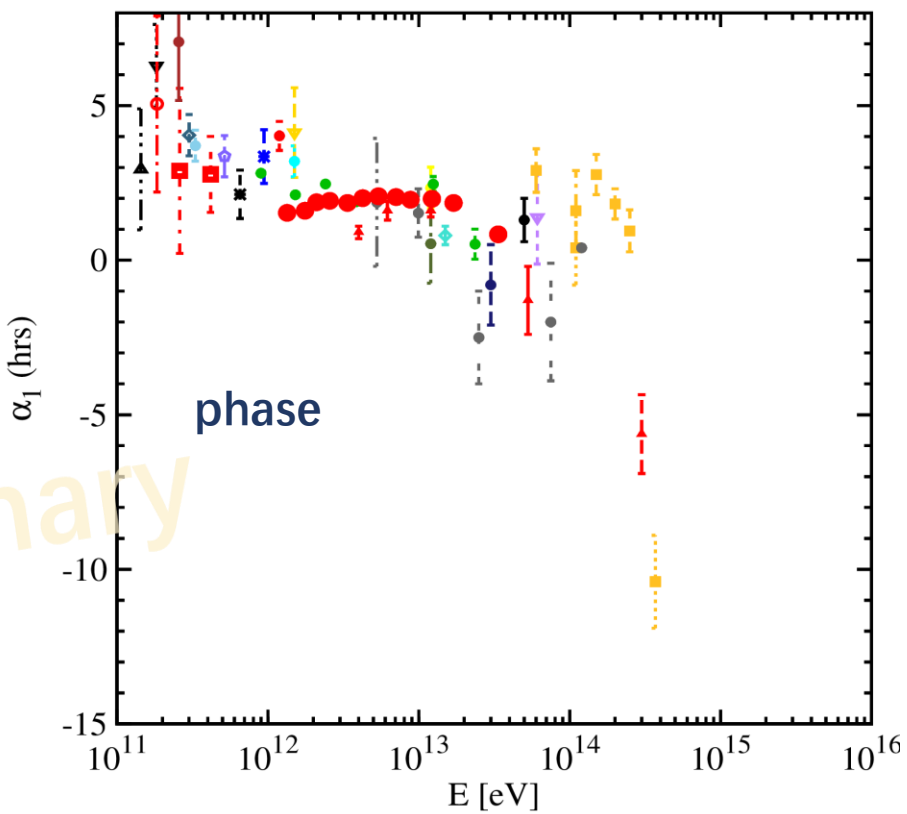
- By Wei Liu et al.
- 2021.09.01-2022.08.31 (one year)
- Zenith 0°<θ<50°
- TeV ~ hundred TeV

Energy (TeV)	nhit
1.3	60-80
1.8	80-100
2.1	100-125
2.6	125-160
3.4	160-200
4.3	200-250
5.4	250-320
7.1	320-400
8.8	400-500
12.2	500-630
17.0	630-800
33.6	800-2000
169.0	2000-3200

- pattern does not vary with energy <100 TeV
- Above 100 TeV, significance is not enough

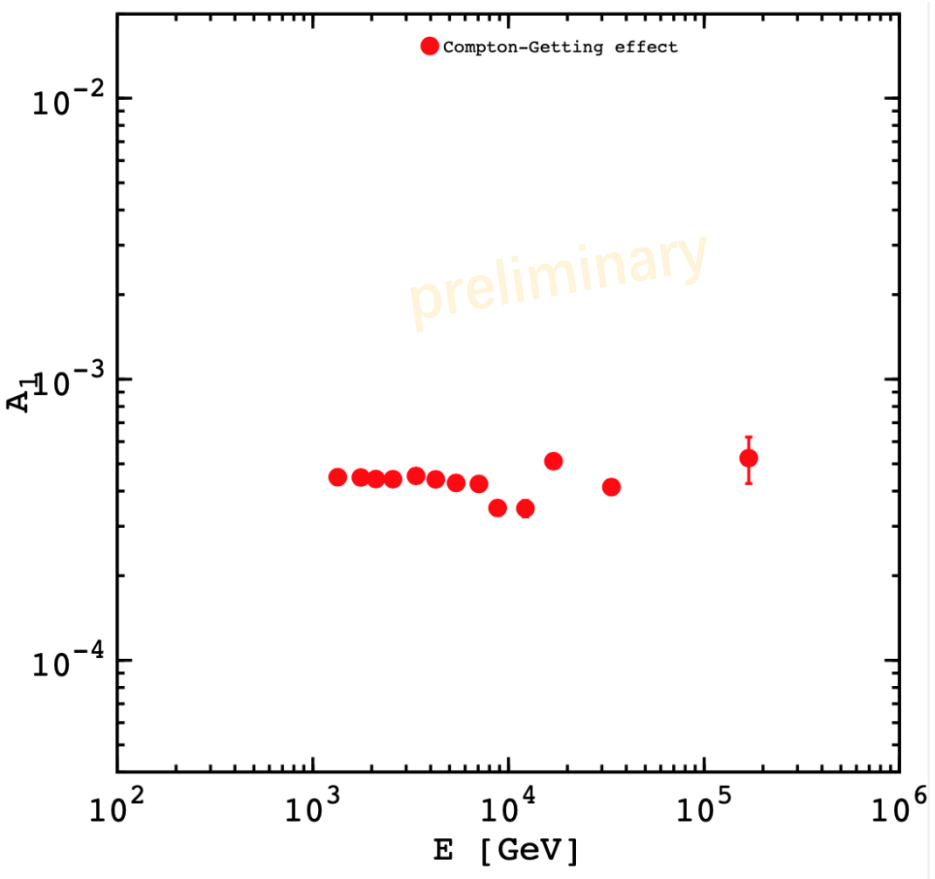


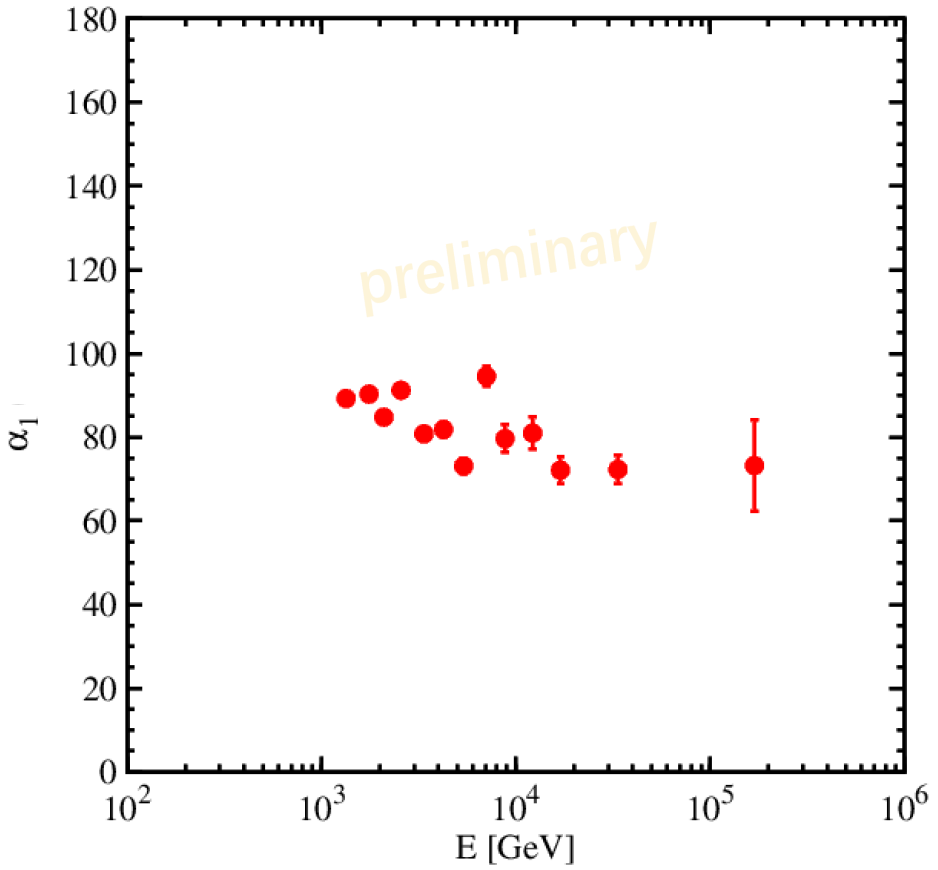




solar anisotropy-WCDA

- **Expect: amplitude 0.0004, phase 6 hour**

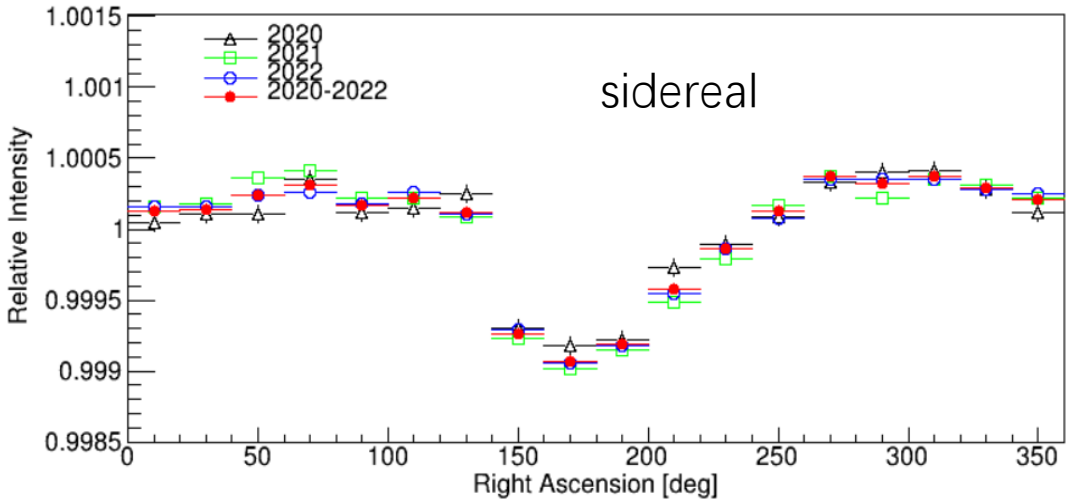




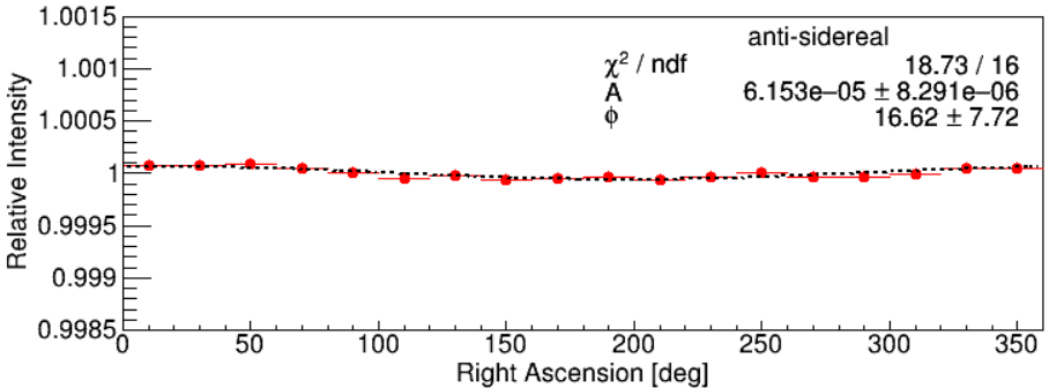
Anisotropy with KM2A

- By Wei Gao et al.
- 2020.01.01-2022.12.31
- Zenith 0°<θ<40°
- Dozens TeV ~ PeV

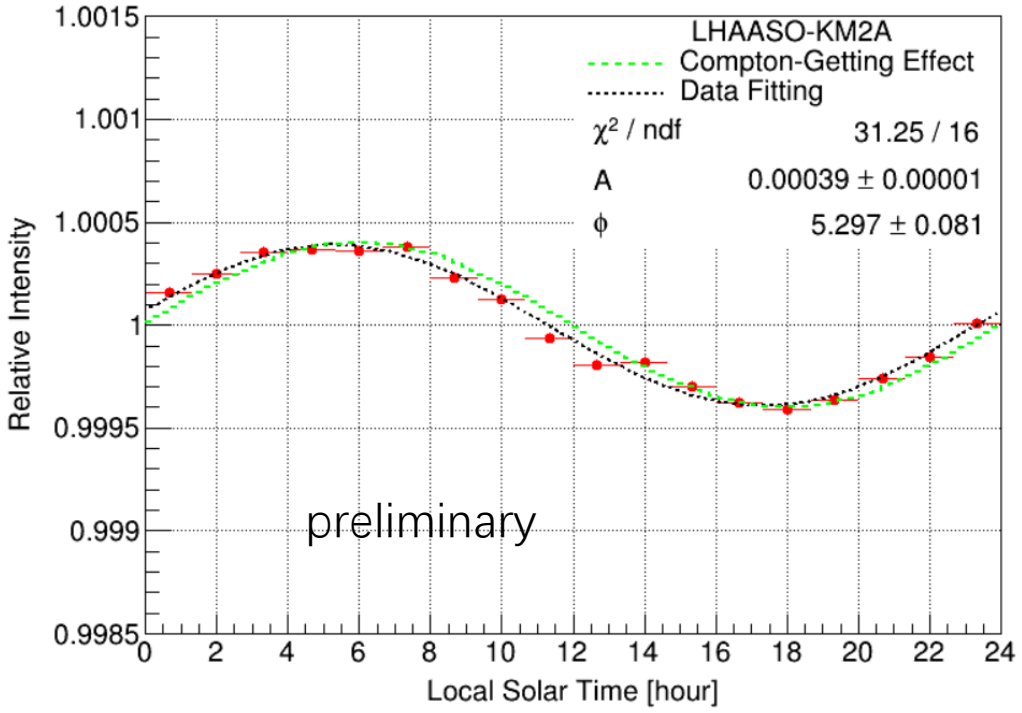
KM2A	half	three	Full	Total
Time	335 days	231 days	501 days	1097 days
Used events	3.89×10^9	5.98×10^9	19.23×10^9	29.09×10^9



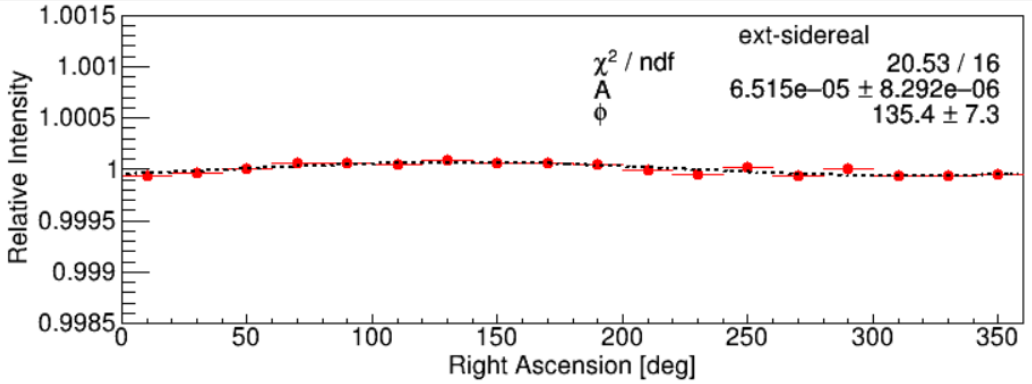
anti-sidereal



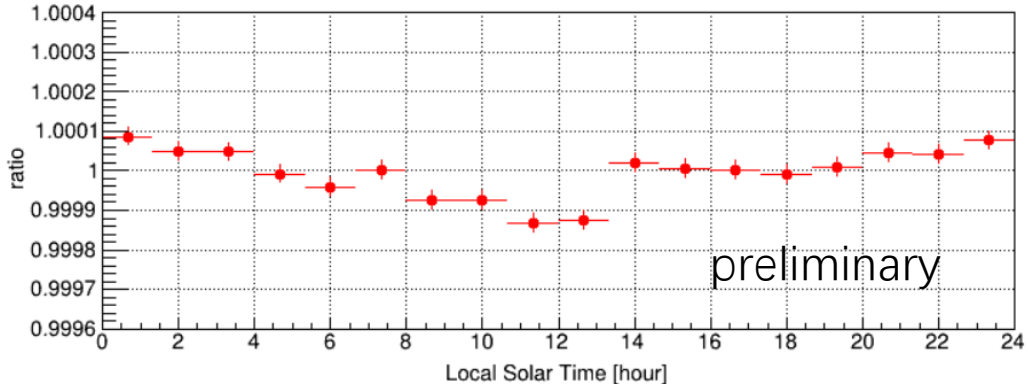
Solar anisotropy with km2a



ext-sidereal

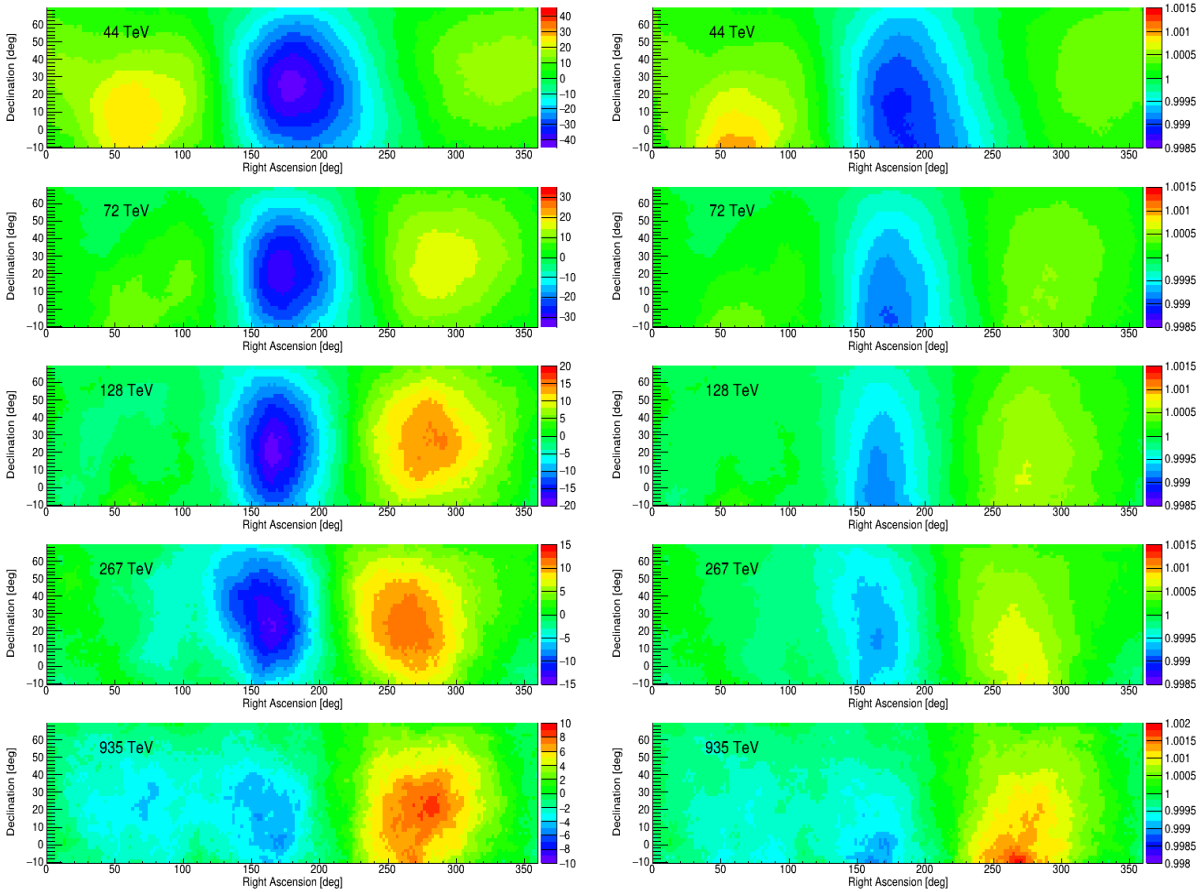


Ratio of the data with expected CG effect

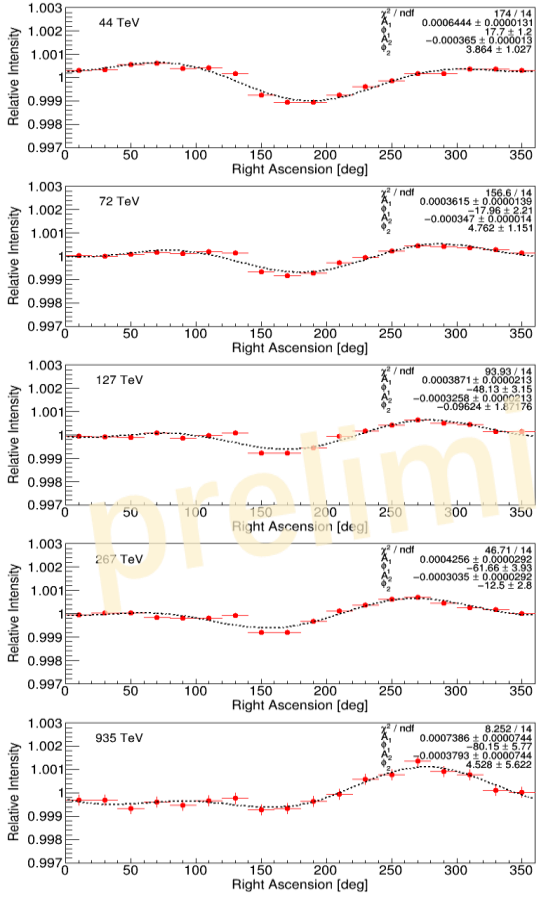


- **1D profile fitted with:**

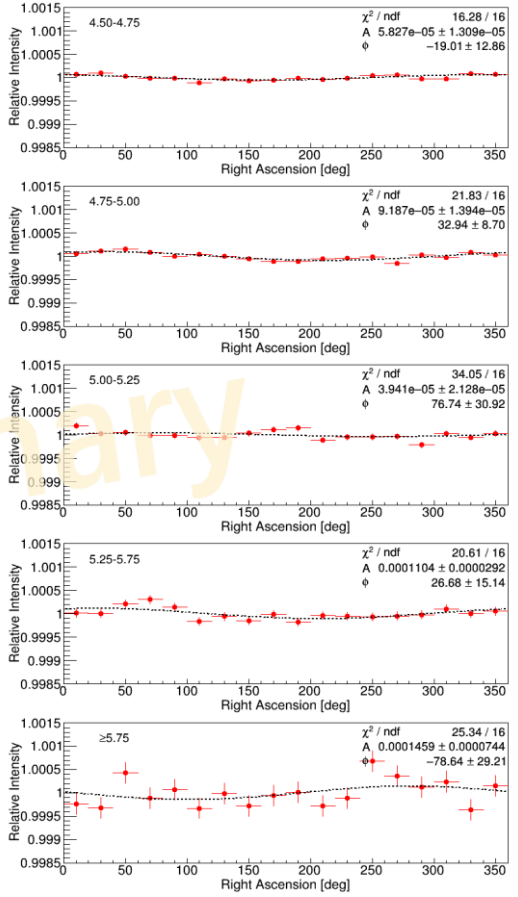
$$1 + \sum_{n=1}^{2} A_n \cos \frac{2\pi n(r.a. - \phi_n)}{360}$$



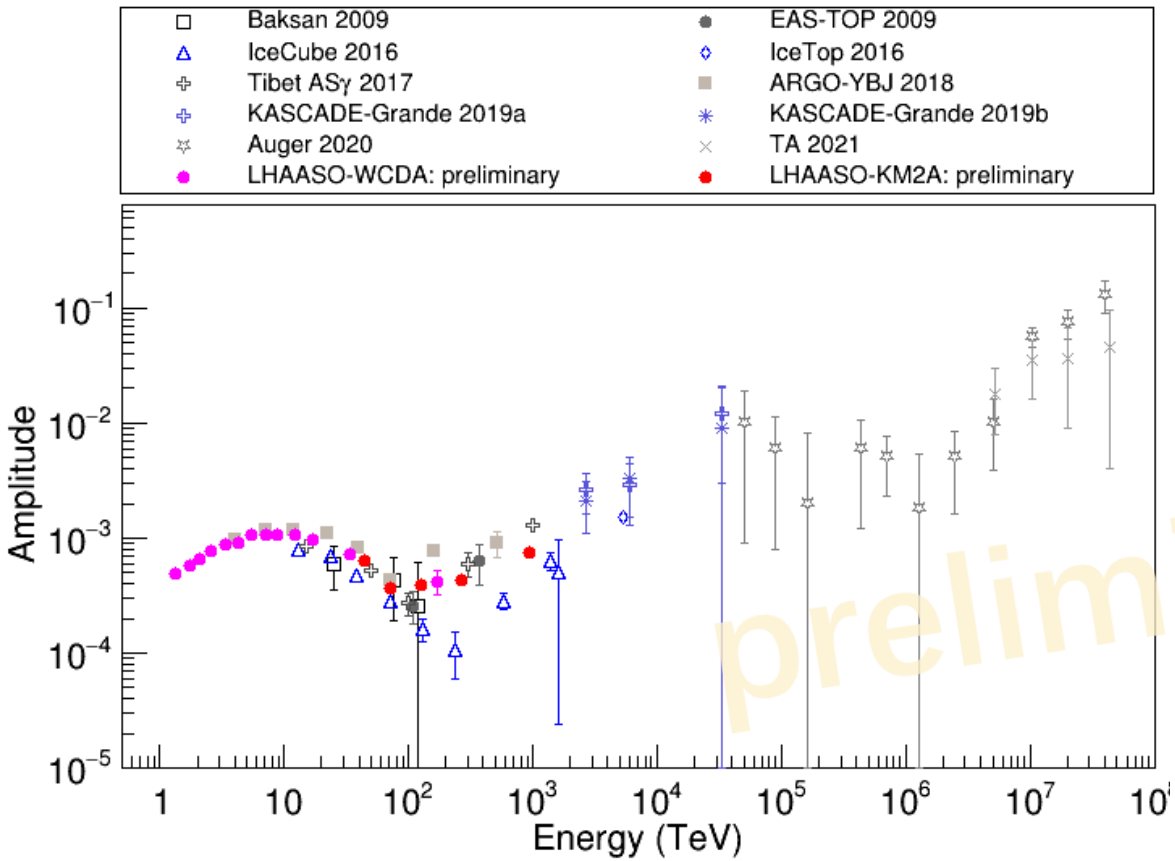
Sidereal

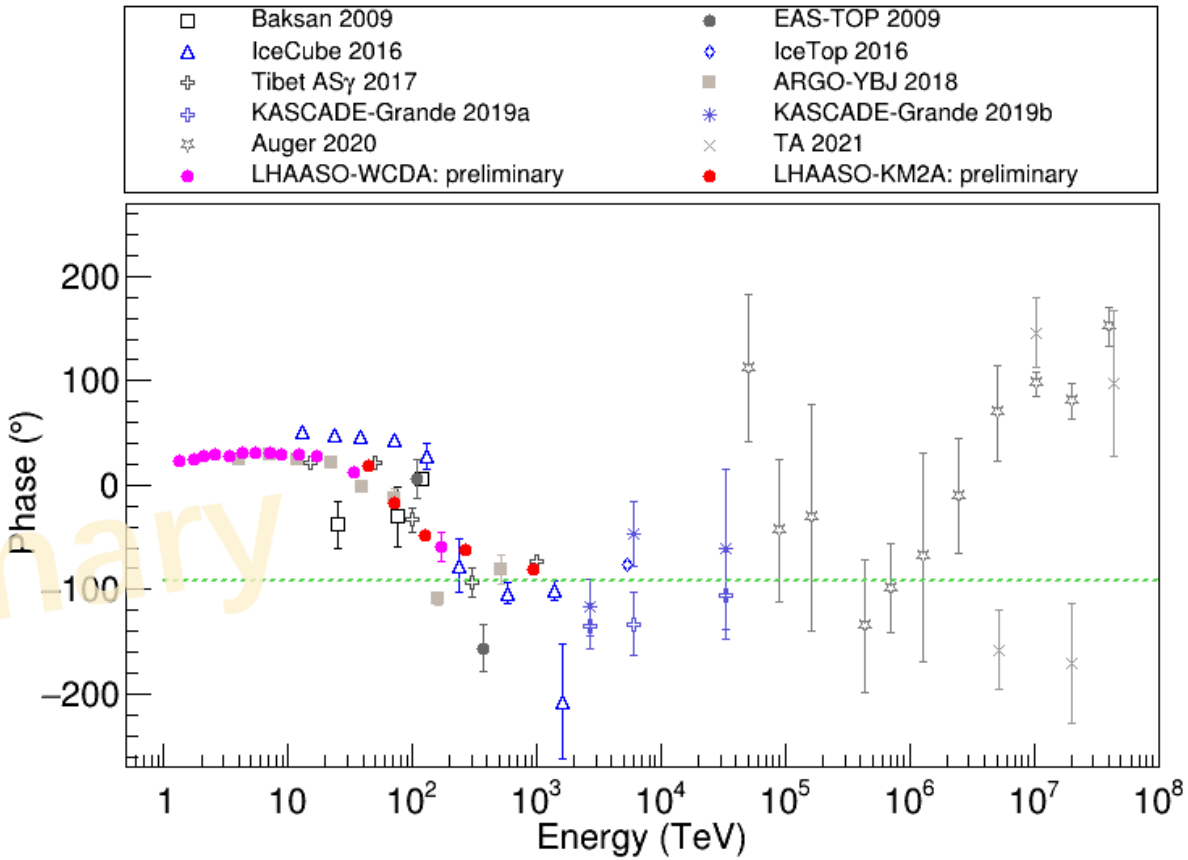


anti-sidereal



Dipole anisotropy VS energy

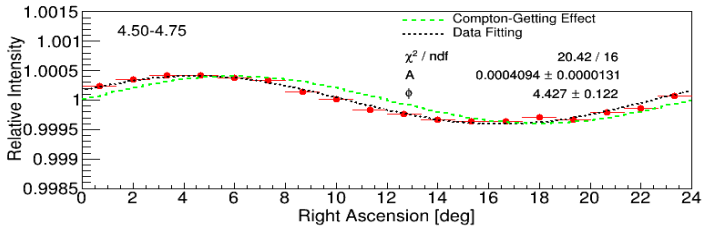


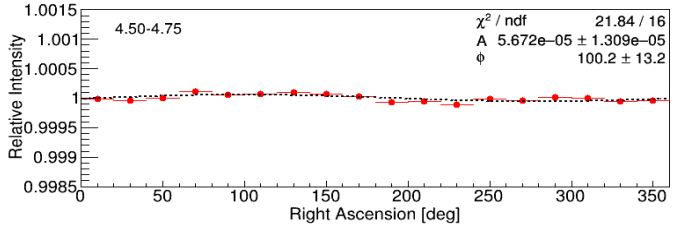


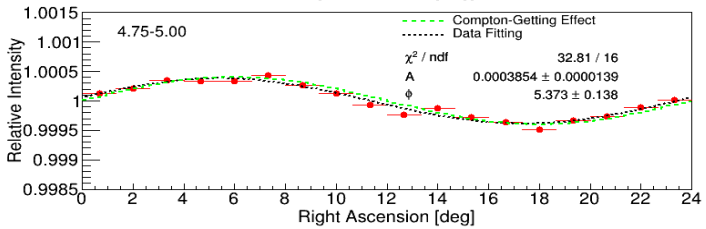
Solar anisotropy

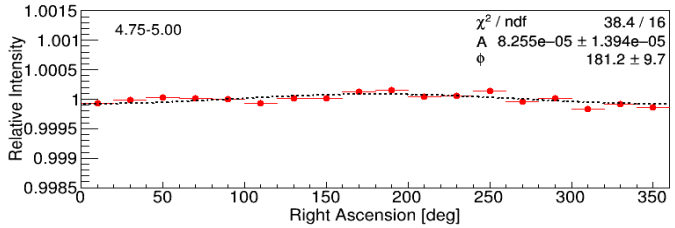
Solar

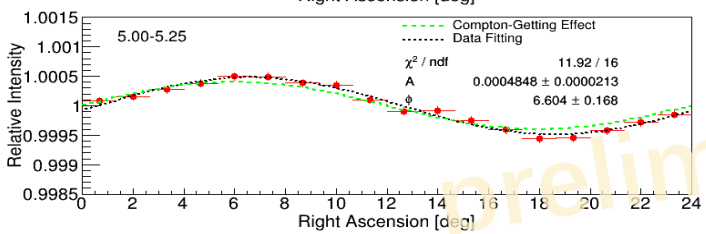
ext-sidereal

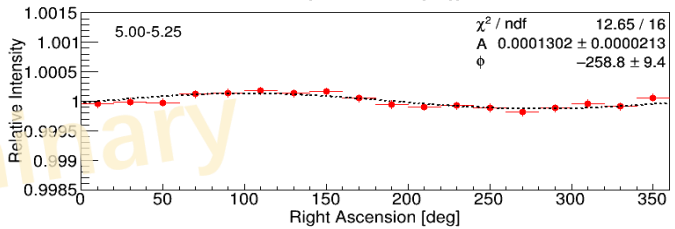


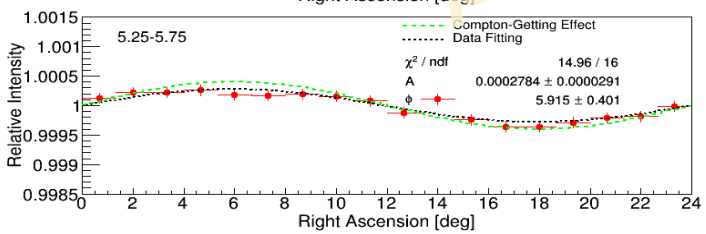


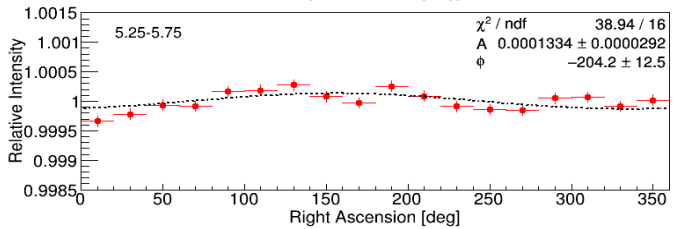


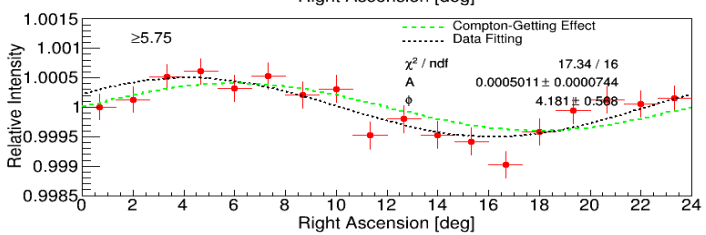


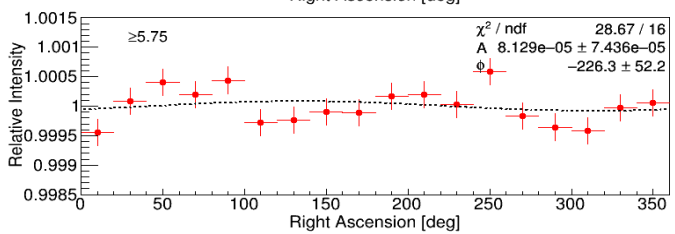


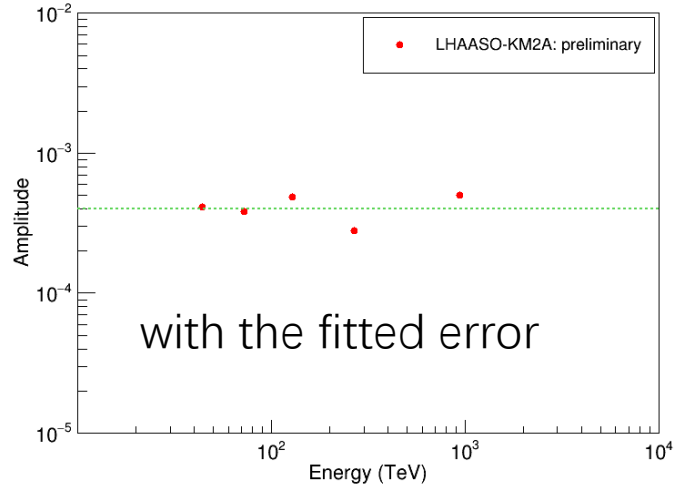


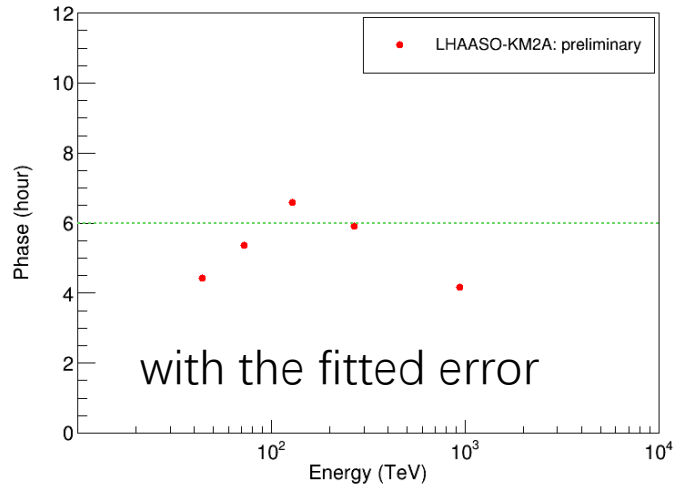










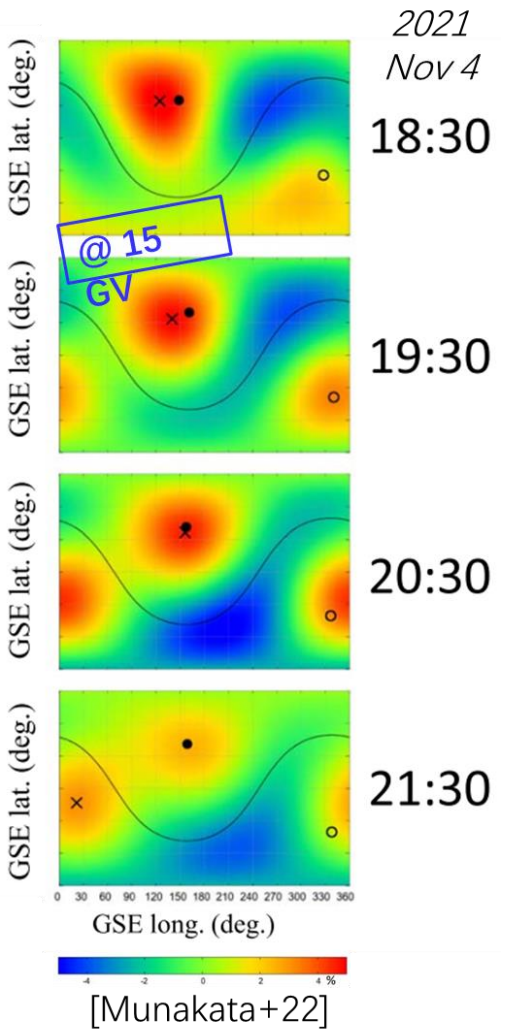


Hourly anisotropy-WCDA

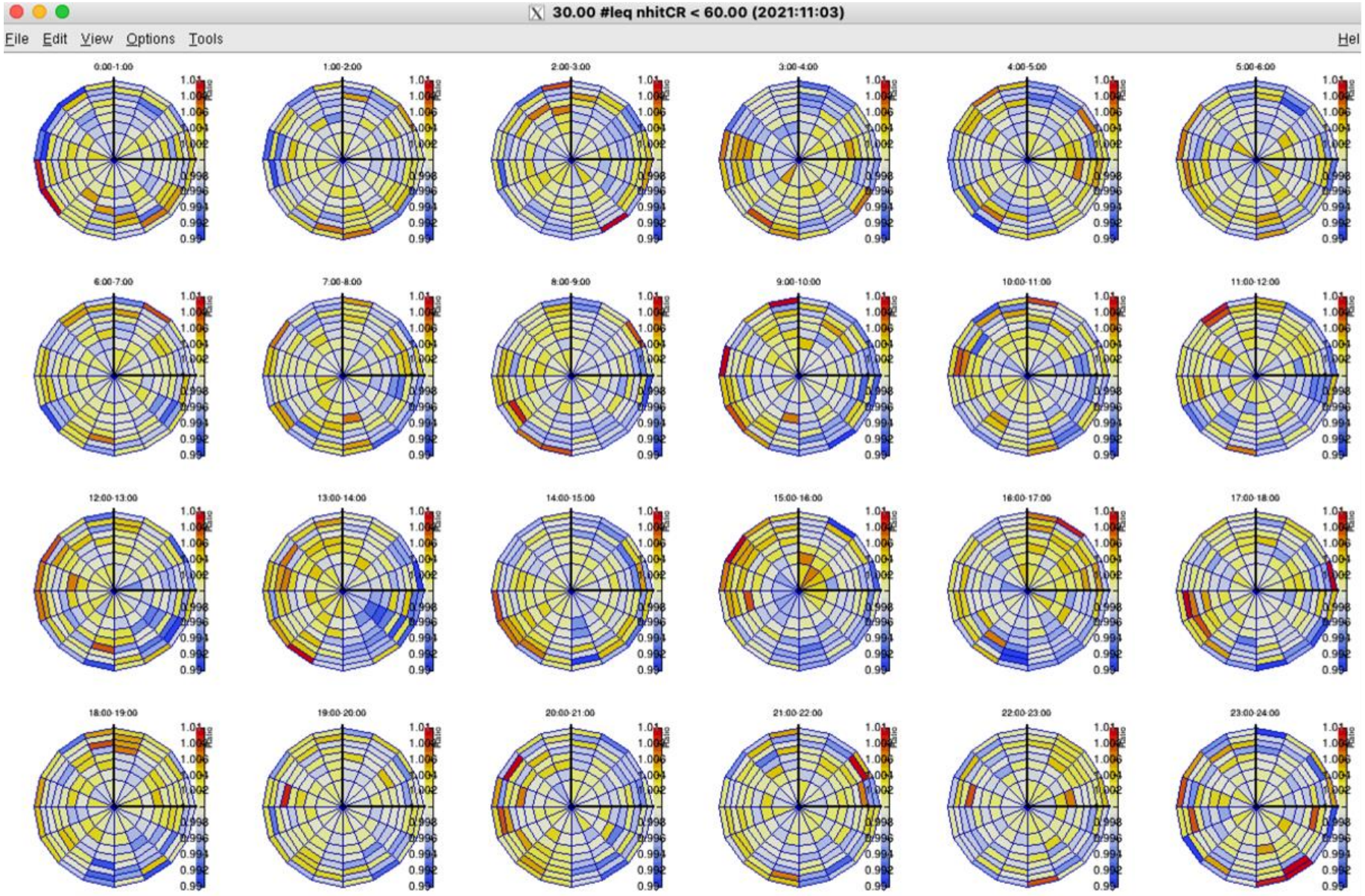
- **By David Ruffolo et al.**

- **In a given hour, anisotropy includes**
  - Only part of sky (using zenith < 45)
  - Sidereal diurnal anisotropy
  - Solar diurnal anisotropy
  - **Any transient effects**

- **look for a transient anisotropy due to the interplanetary coronal mass ejection passage on 2021 November 4-5, starting with 30 < Nhit < 60 (low energies, includes some particles at <100 GeV).**

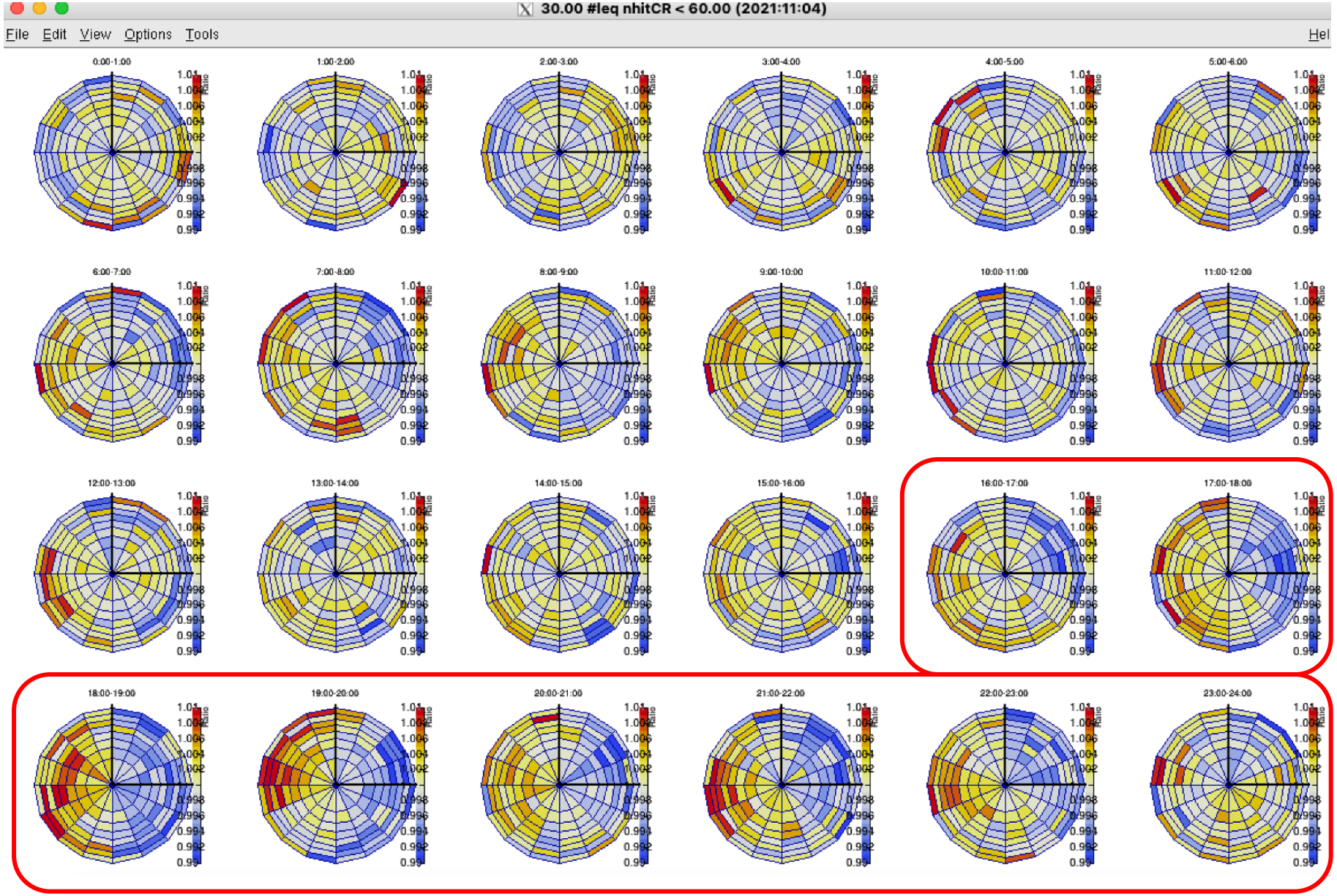


Hourly zenith-centered sky maps on 3th November 2021



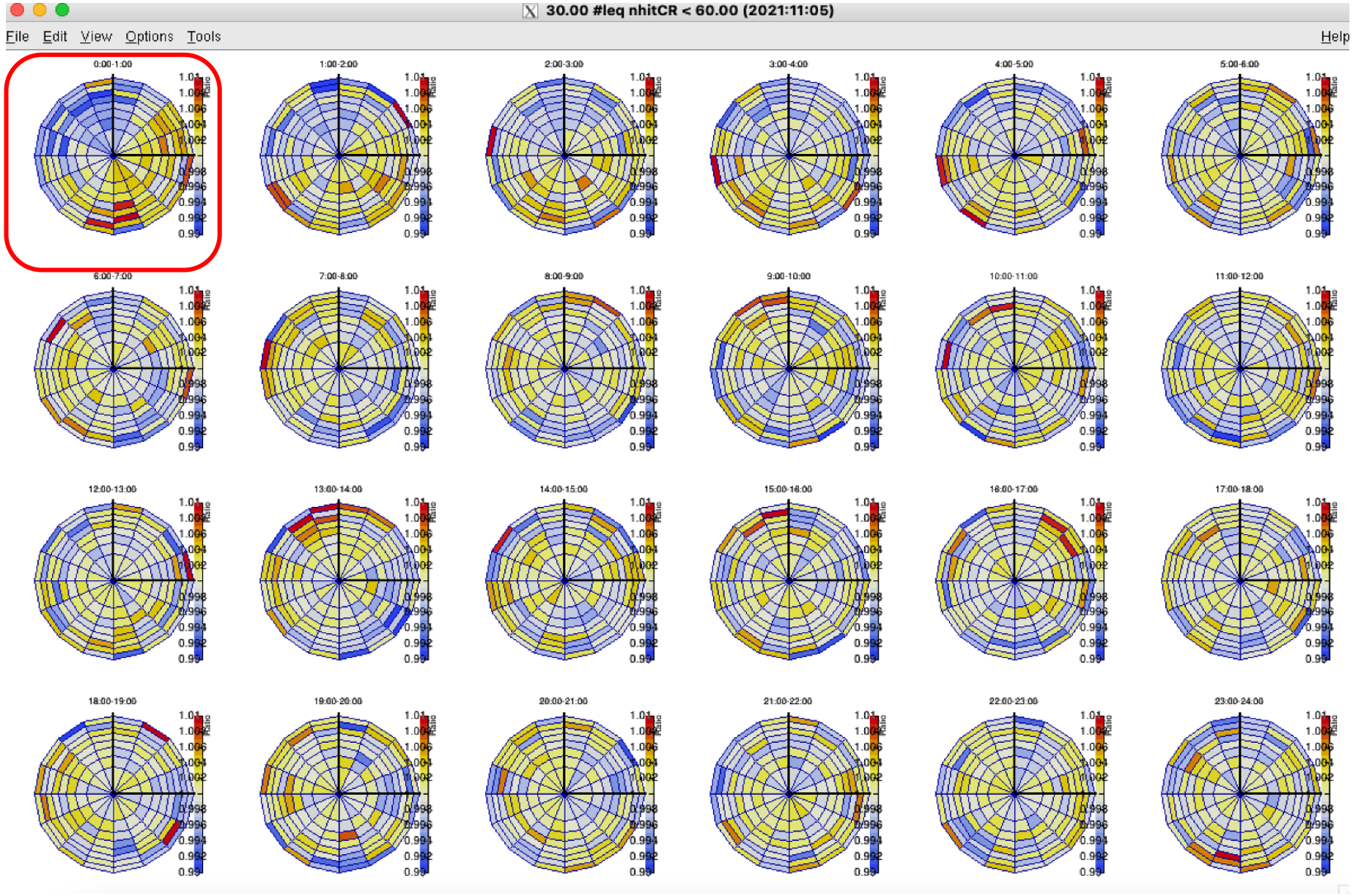
The day before strong anisotropy

Hourly zenith-centered sky maps on 4th November 2021



Start of ICME passage

Hourly zenith-centered sky maps on 5th November 2021



End of ICME passage

• Conclusion

---the all particle anisotropy was observed from TeV to nearly PeV with LHAASO, the preliminary results consistent with others.

---the solar anisotropy approximating the Compton effect was observed, while the stability between individual energy intervals have more large deviation.

---see evidence for enhanced anisotropy at the time of ICME passage (2021 November ICME event), for an data sample that includes cosmic rays of <100 GeV.

• Further works

---optimize the data selection, update the results, extend the all particle anisotropy energy range to higher energy and lower energy

---unify the energy standards of WCDA and KM2A

---more works for the hourly anisotropy at low energy (<TeV)

---more works for the dipole anisotropy due to Compton-Getting effect

supplement

Qudrapole anisotropy VS energy