

Long-term observation of UHE emission from Crab Nebula with LHAASO

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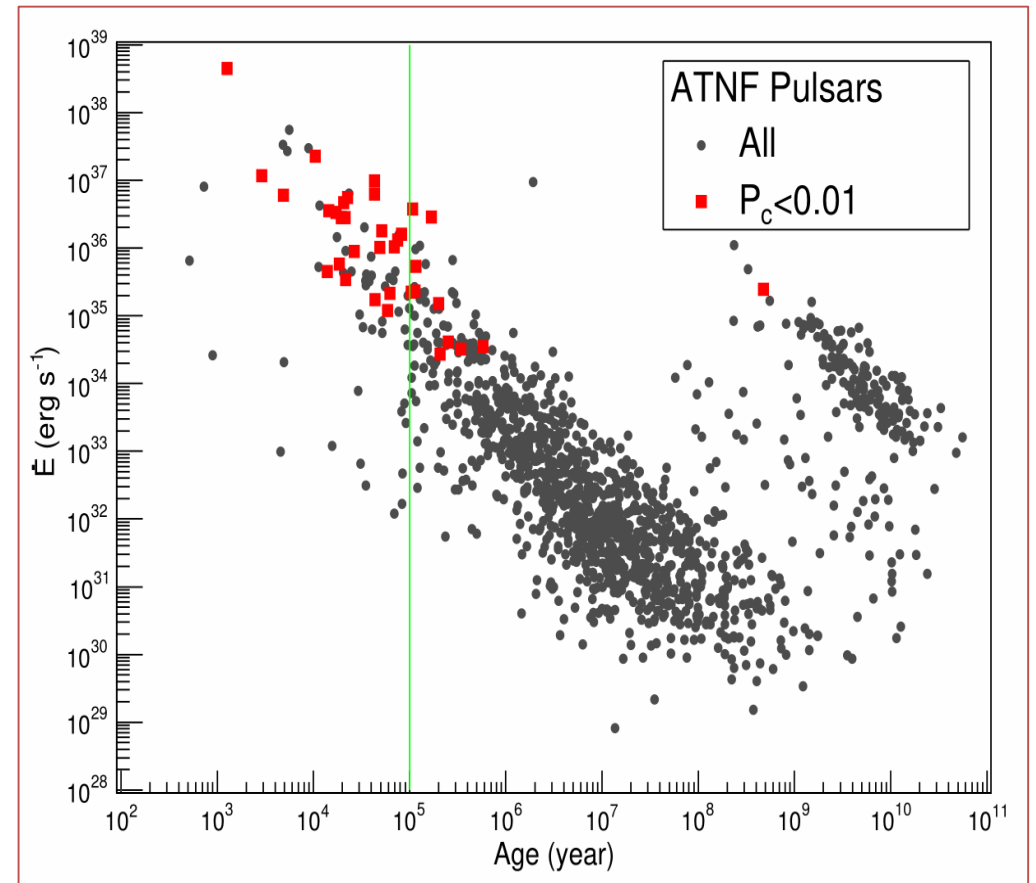
on behalf of the LHAASO collaboration

Institute of High Energy Physics(IHEP),CAS

The 2nd LHAASO symposium@Hong Kong (March 22, 2025)

PWNs are dominate sources at VHE and UHE

- **35** 1st LHAASO sources associate with pulsars.
- **22 out of 35** sources with UHE emission.



LHAASO coll. 2024

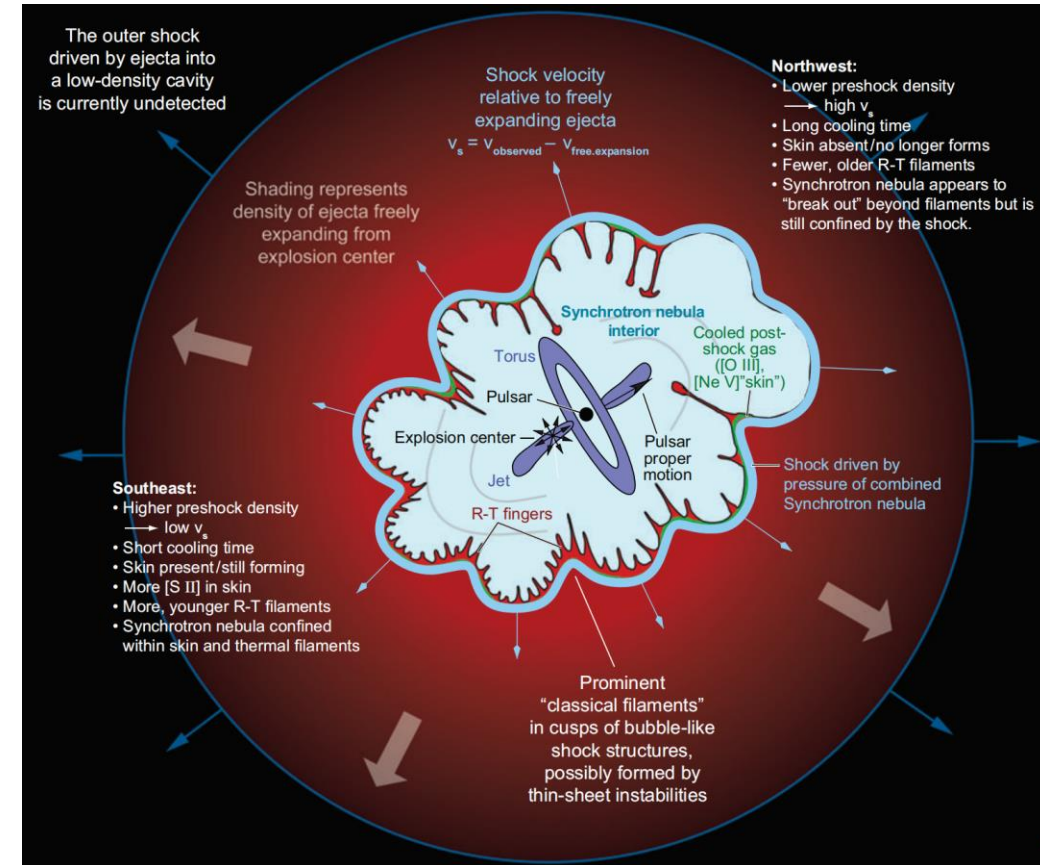
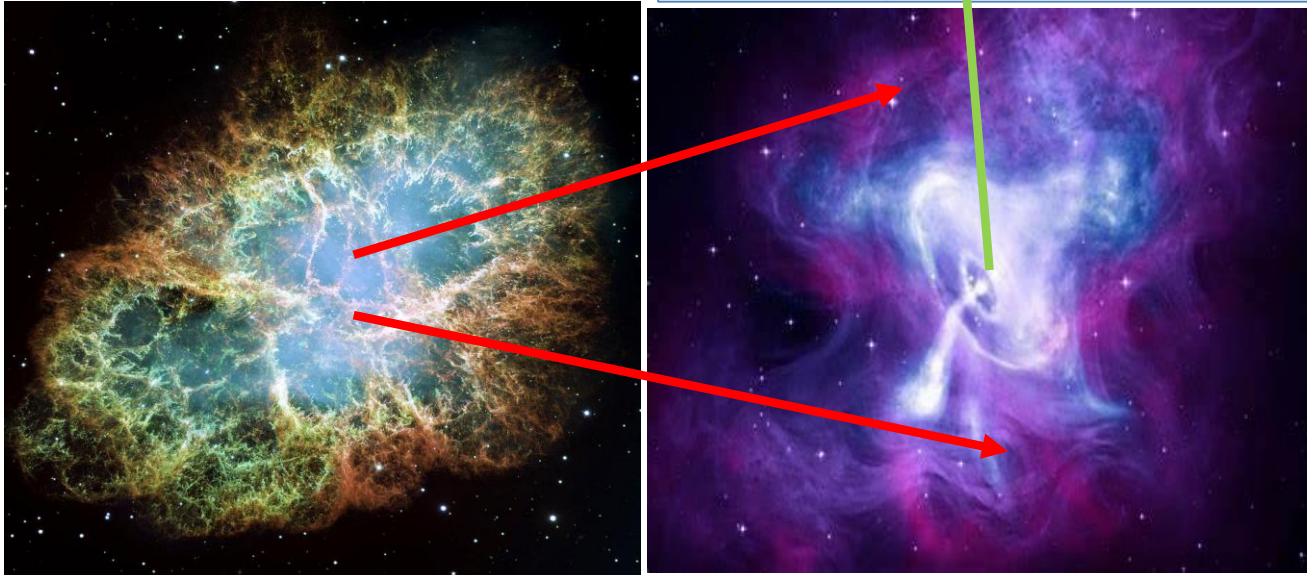
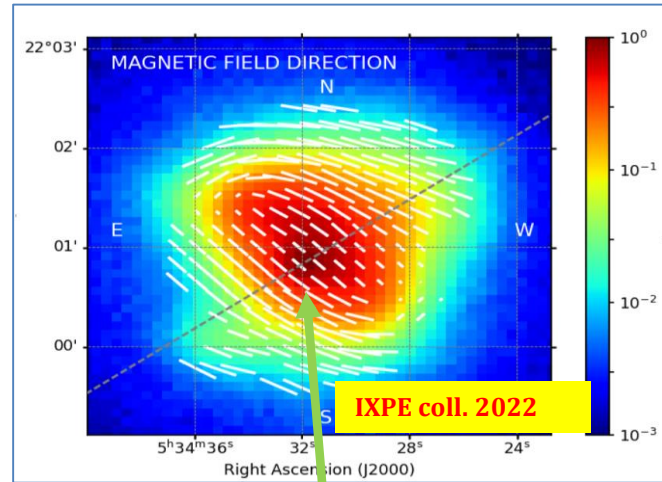
Crab Nebula: a unique case to explore PWN

- The age and structure of Crab nebula is well measured.

SN@July,4th,1054

出於冥井下戊子客星別出子端門內近井星 四月丙午東井下
 客星沒 五月癸酉端門內客星沒壬午客星如字在南斗天箭旁
 昭宗乾寧三年有客星三一大二小在屋危間人合作相相隨東行
 狀如蘭經三日而二小星沒其大星後沒虛危齊分也 光化三年
 正月客星出中垣宿者旁大如桃光射宿者者不見 天復
 二年正月客星如桃在紫宮華蓋下漸行至御史丁卯有流星起交
 星不動 己巳客星在在守之至明年猶不去占將相

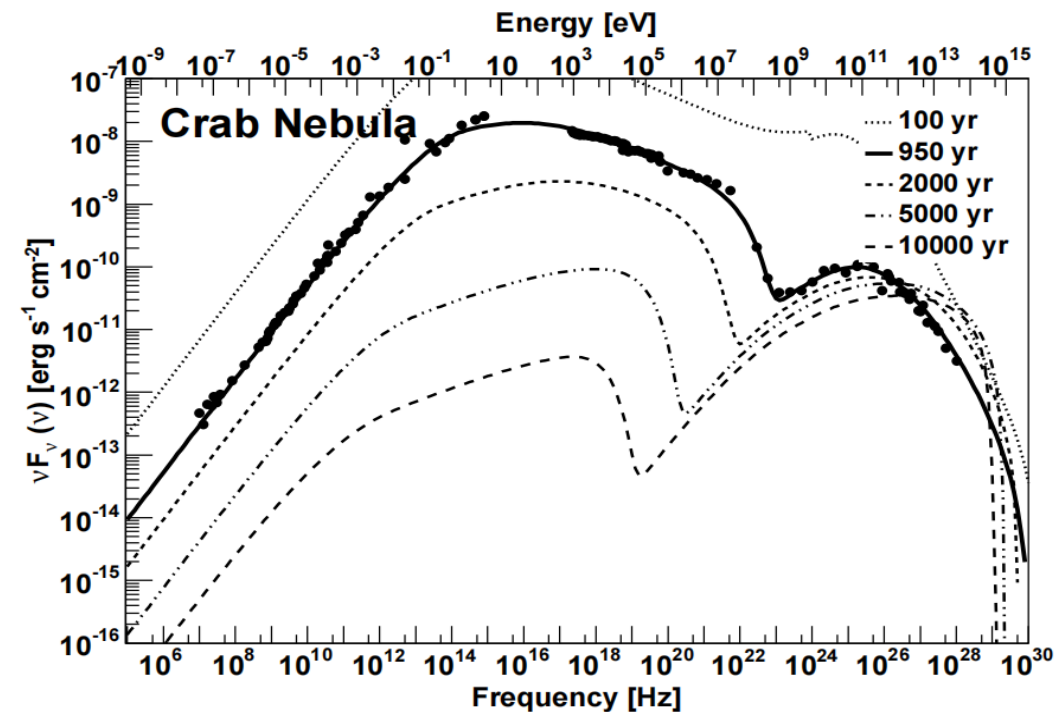
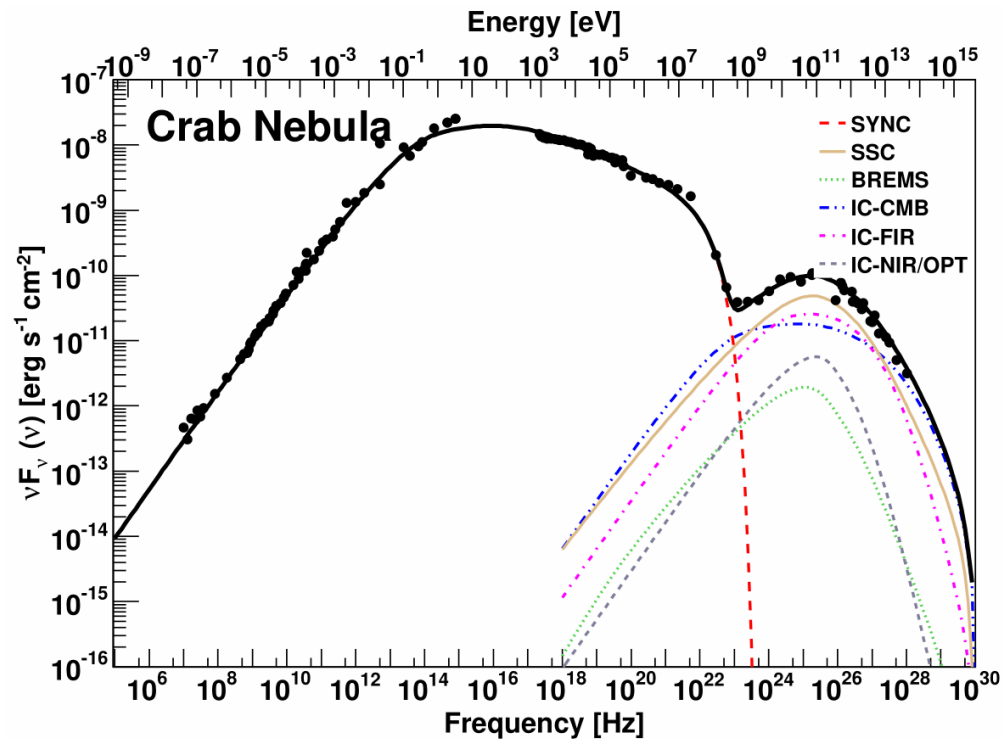
元年五月客星犯帝座
 具宗三朝客星見 建隆二年十二月己酉客星出天
 界微有若禁二年正月辛未西南行人氏宿二月癸丑
 半與國八年二月甲辰客星出大微垣端門東近星
 卿臣失禮克端拱二年七月丁亥客星出北河星西北
 指西南海化元年正月辛巳客星出於宿宿行至張
 丁度乃不見占云有土功又云有使來景德二年八月
 丁微天搭倒字字然如粉絮稍入垣內歷御女畢蓋凡
 日有犯天曆年莊穆皇后前三年三月乙巳客星出東
 行四年正月丁丑客星見南斗魁前占曰有赦令其年
 壬大赦天禧五年四月丙辰客星出軒轅前星西北大
 行轅大星入太微垣操右執法犯次將歷屏星西北九
 湖沒占曰周雅之分大臣憂
 十六月乙巳客星出東北方近濁木星太微有若禁至
 日而沒至和元年五月己丑客星出天關東南可數寸



Hester 2008

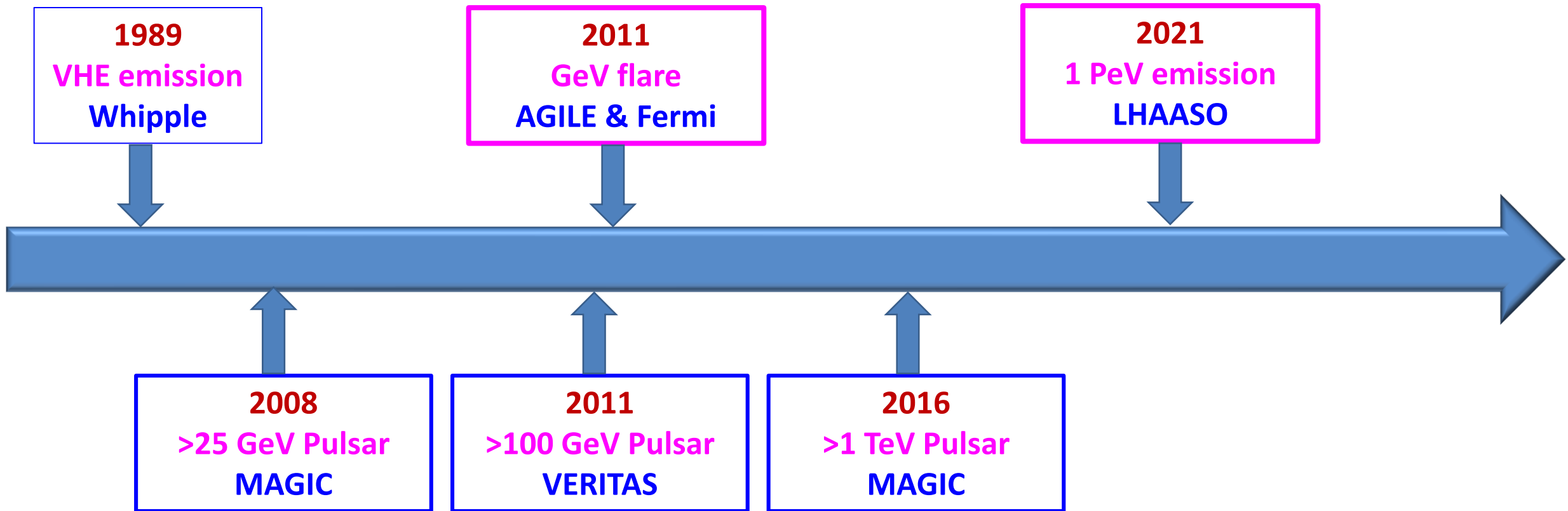
The Standard paradigm of PWN

- Relativistic wind (e^\pm) from central pulsar.
- e^\pm accelerated at terminal shock.



Torres et al. 2014

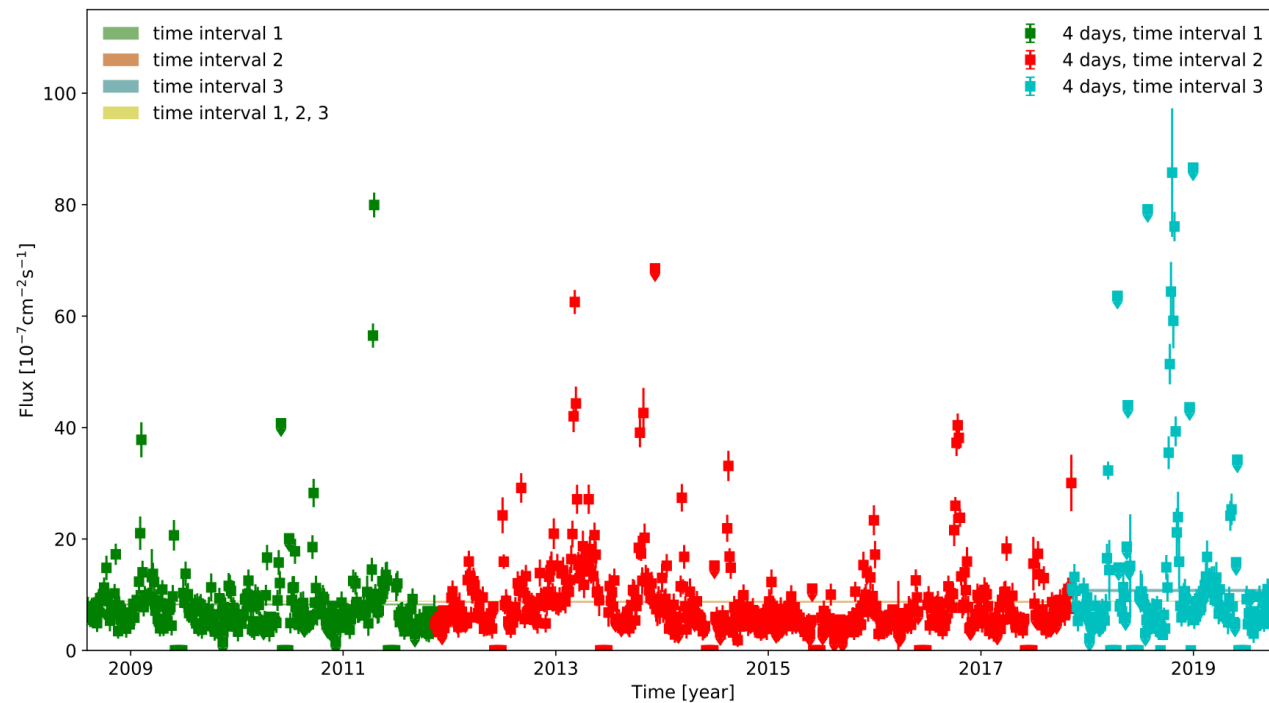
Surprise discoveries from Crab



Unexpected results always come from what we think we know!

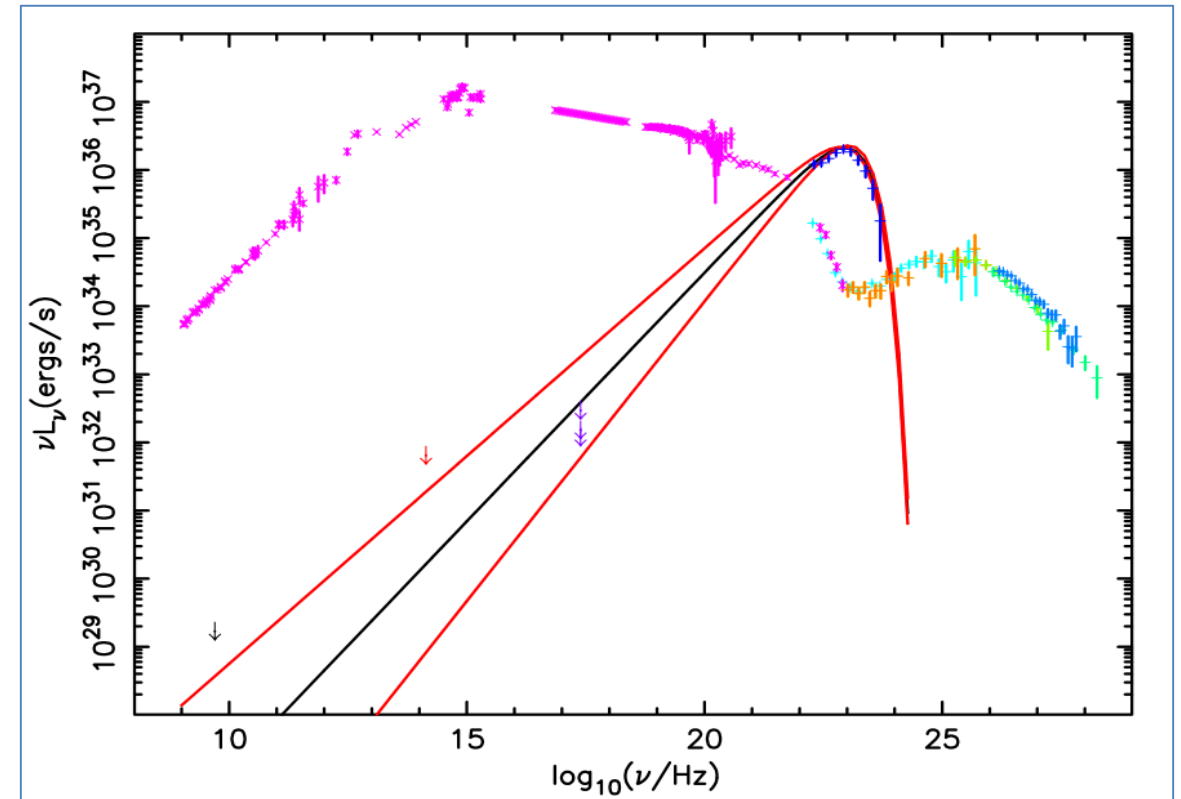
Crab flares

- Flare rate: once per 1.5 years
- Flux enhance factor: up to 30
- Timescale: day to month



Huang et al. 2021

2011 April flare



Weisskopf et al. 2013

Questions about flares

■ Where does the flare emission come from?

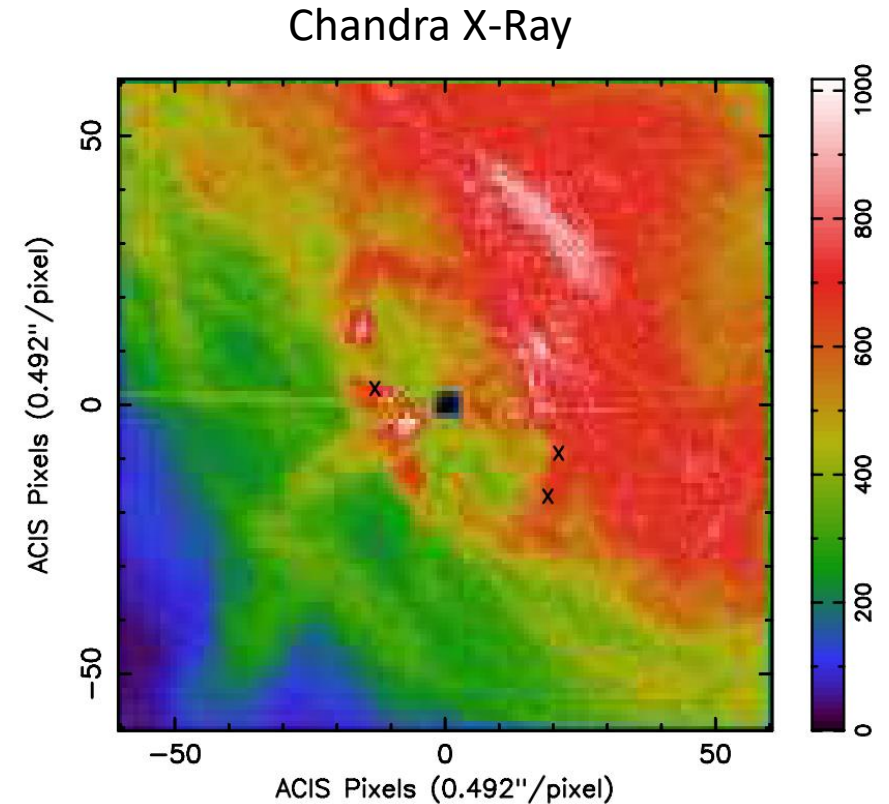
- Inner knot region? **No direct evidence**

■ What produces the flux variations?

- Turbulence?
- High energy fluctuation?

■ How were the emitting particles accelerated?

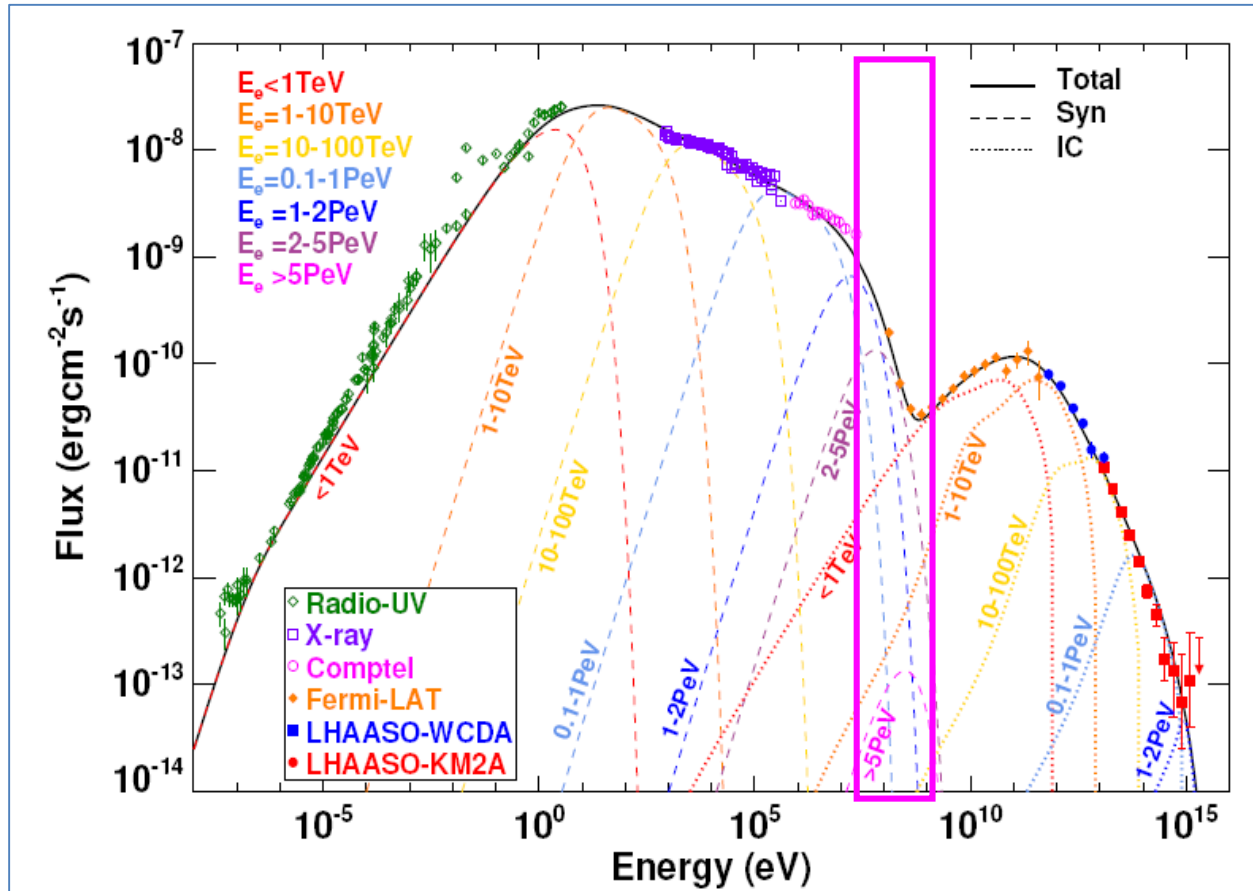
- Magnetic reconnection?
- Terminal shock?



Weisskopf et al 2013

More multiwavelength observations are needed!

Where is the IC component of the flare



LHAASO coll. 2021

■ Synchrotron radiation

$$- E_{\text{syn}} \sim B \cdot E_e^2$$

■ Same region

$$- B \sim 0.1 \text{ mG}, E_e \sim 1\text{-}5 \text{ PeV}, E_\gamma \sim \text{PeV}$$

■ Different region

$$- B \sim x10, E_e \sim x0.3, E_\gamma \sim x0.2$$

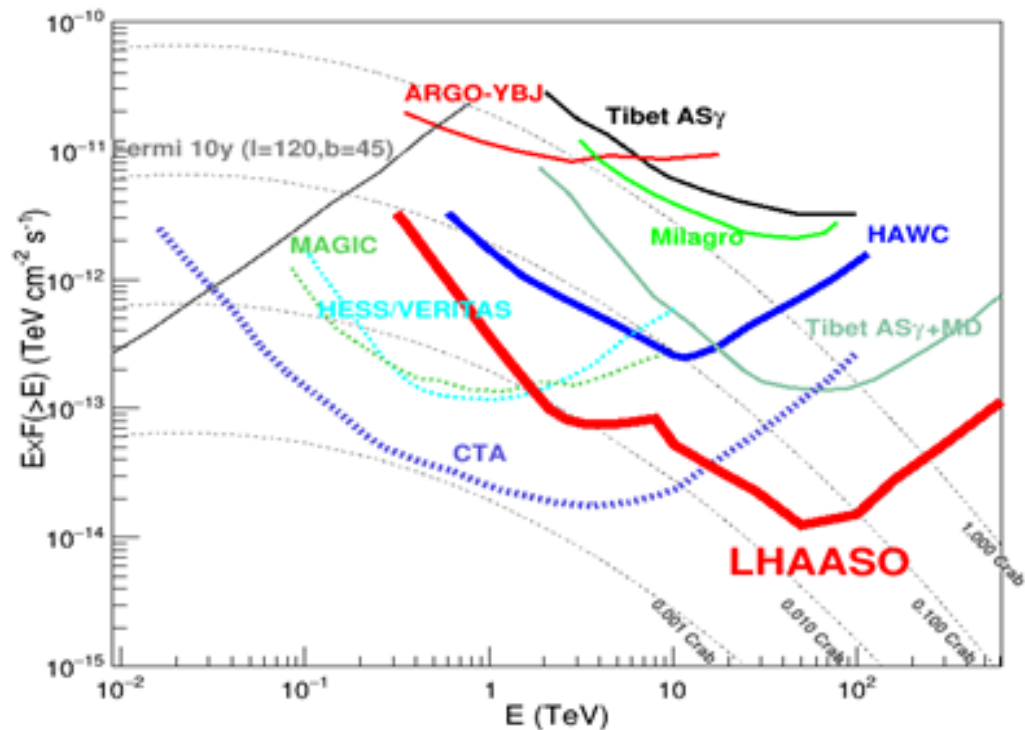
$$- B \sim x100, E_e \sim x0.1, E_\gamma \sim x0.05$$

$$E_e \simeq 2.15 (E_\gamma / 1 \text{ PeV})^{0.77} \text{ PeV}$$

We need to monitor UHE for potential changes!

LHAASO detectors

- ◆ 78000m² WCDA for 0.1-20 TeV γ -rays
- ◆ 1.3 km² KM2A for 4-10000 TeV γ -rays

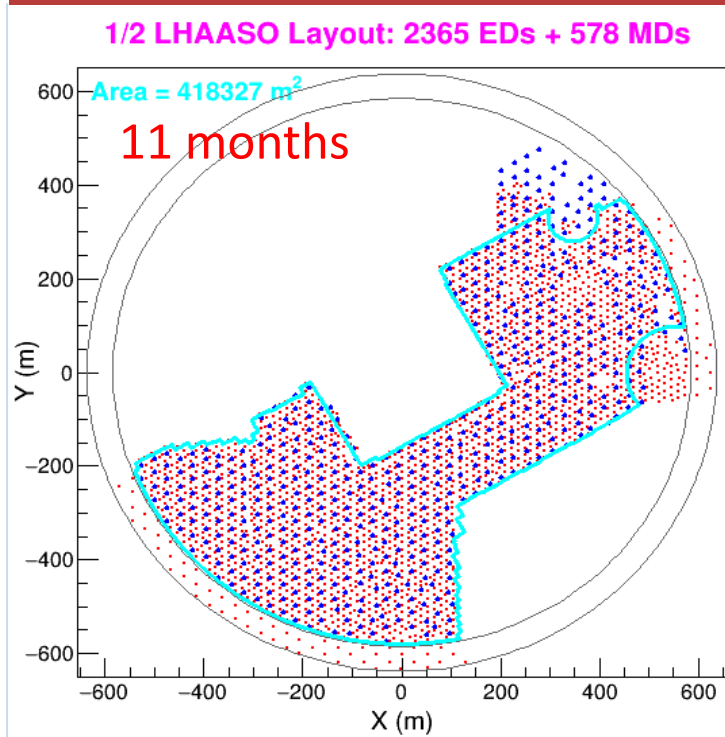


LHAASO @4410 m

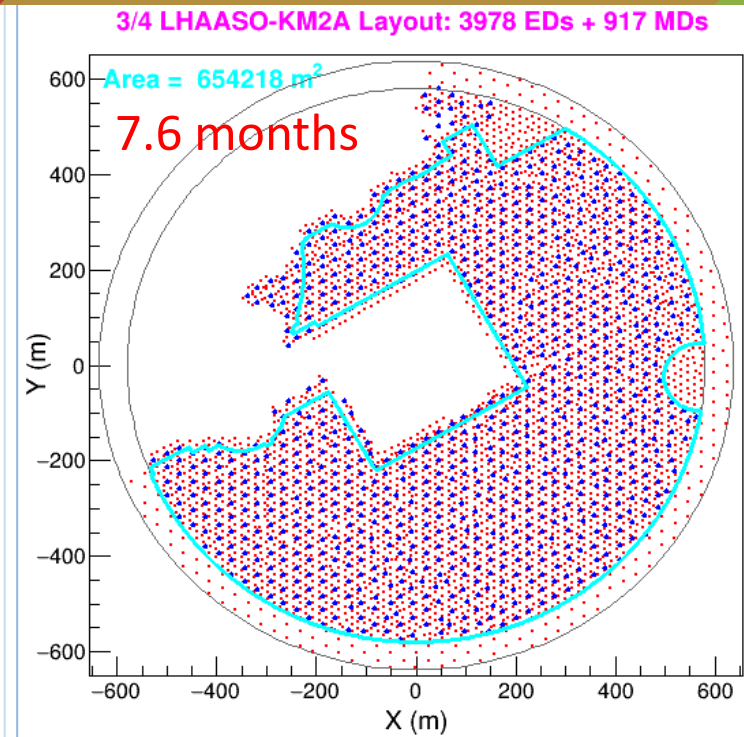


Evolution of the KM2A Array

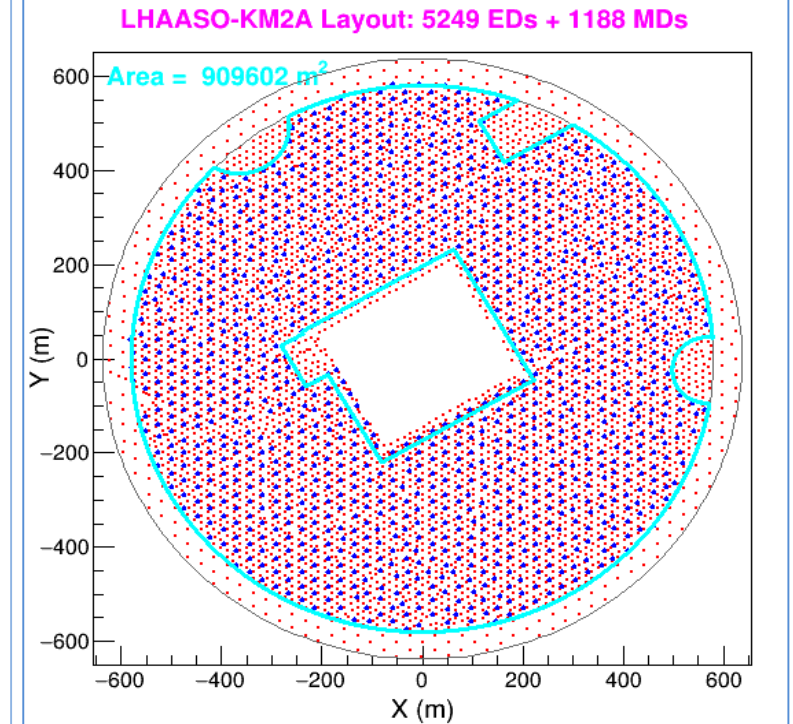
1/2 KM2A



3/4 KM2A



Full-KM2A



2019-12-27—2020-11-30

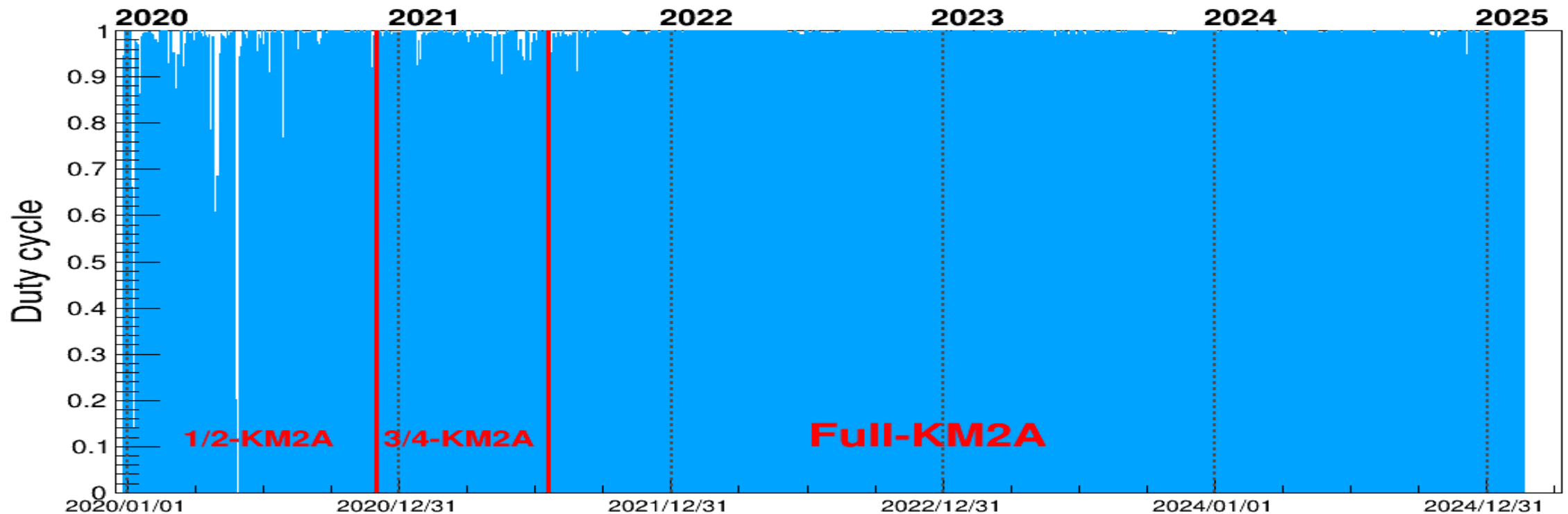
2020-12-01—2021-07-19

2021-07-20—>

Only events with core located inside blue lines region are used.

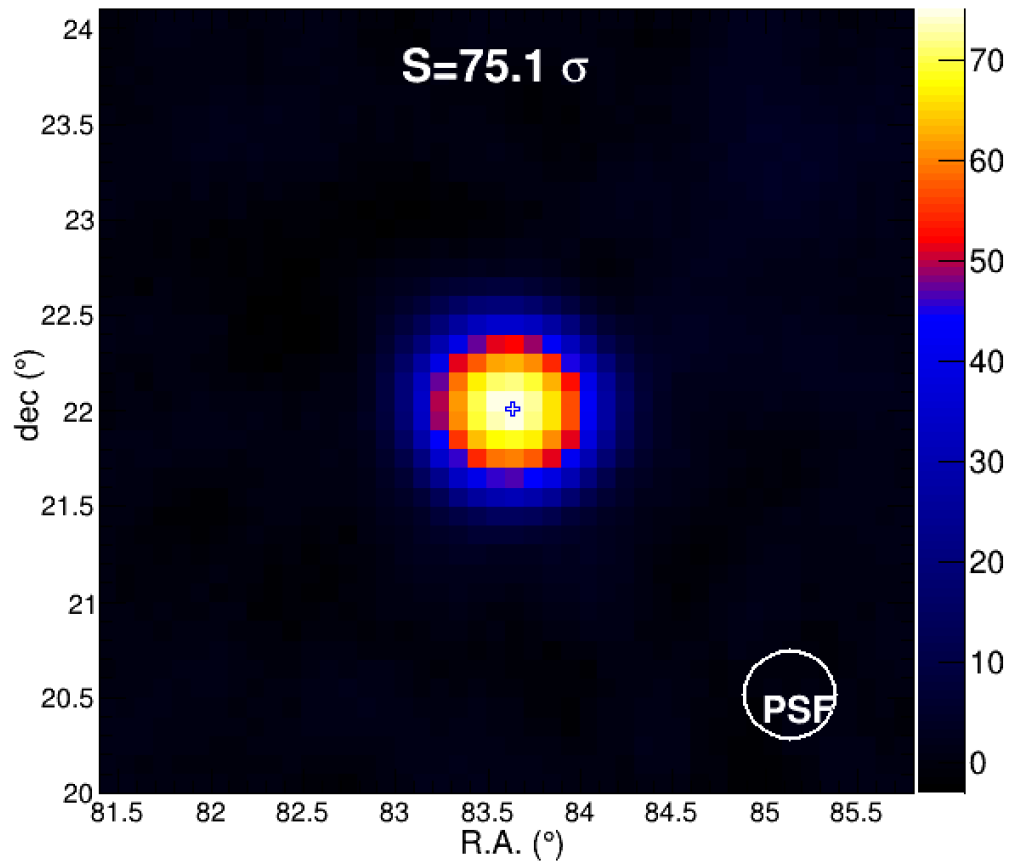
LHAASO-KM2A data

- From 2019-12 to 2024-12
- Effective data: **1700+ days**
- Crab Nebula observation: **13000+ hours**

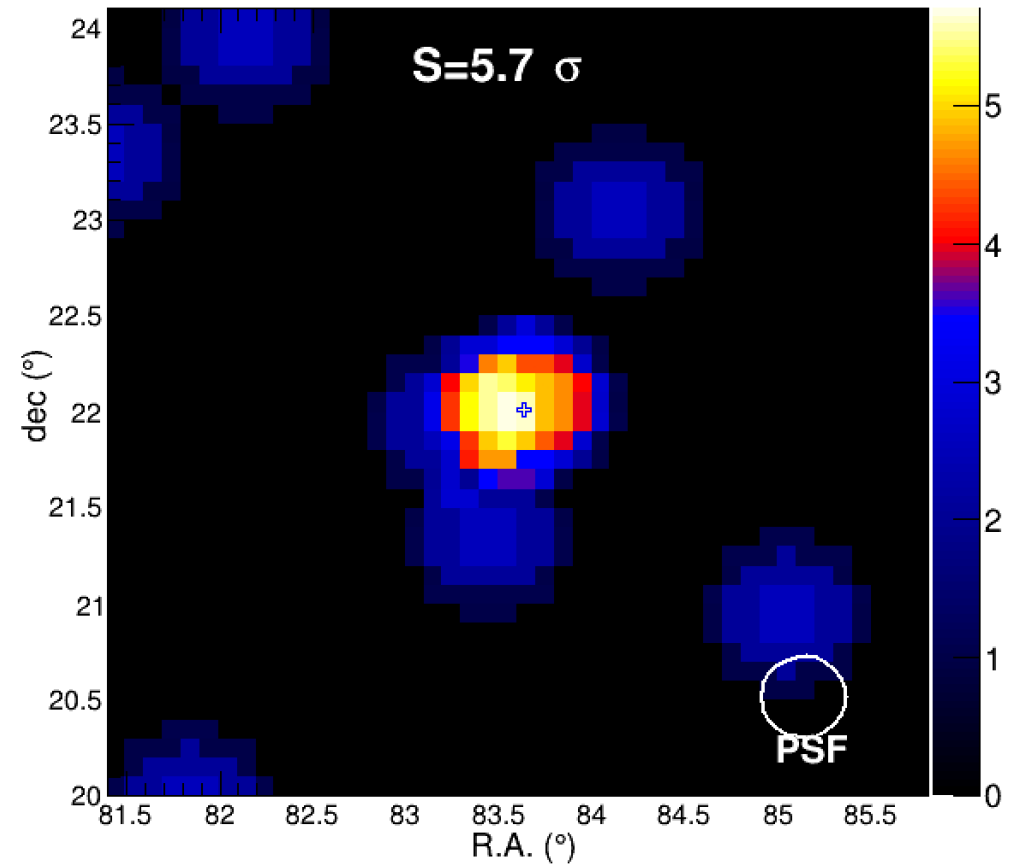


Significance maps around Crab

>100 TeV

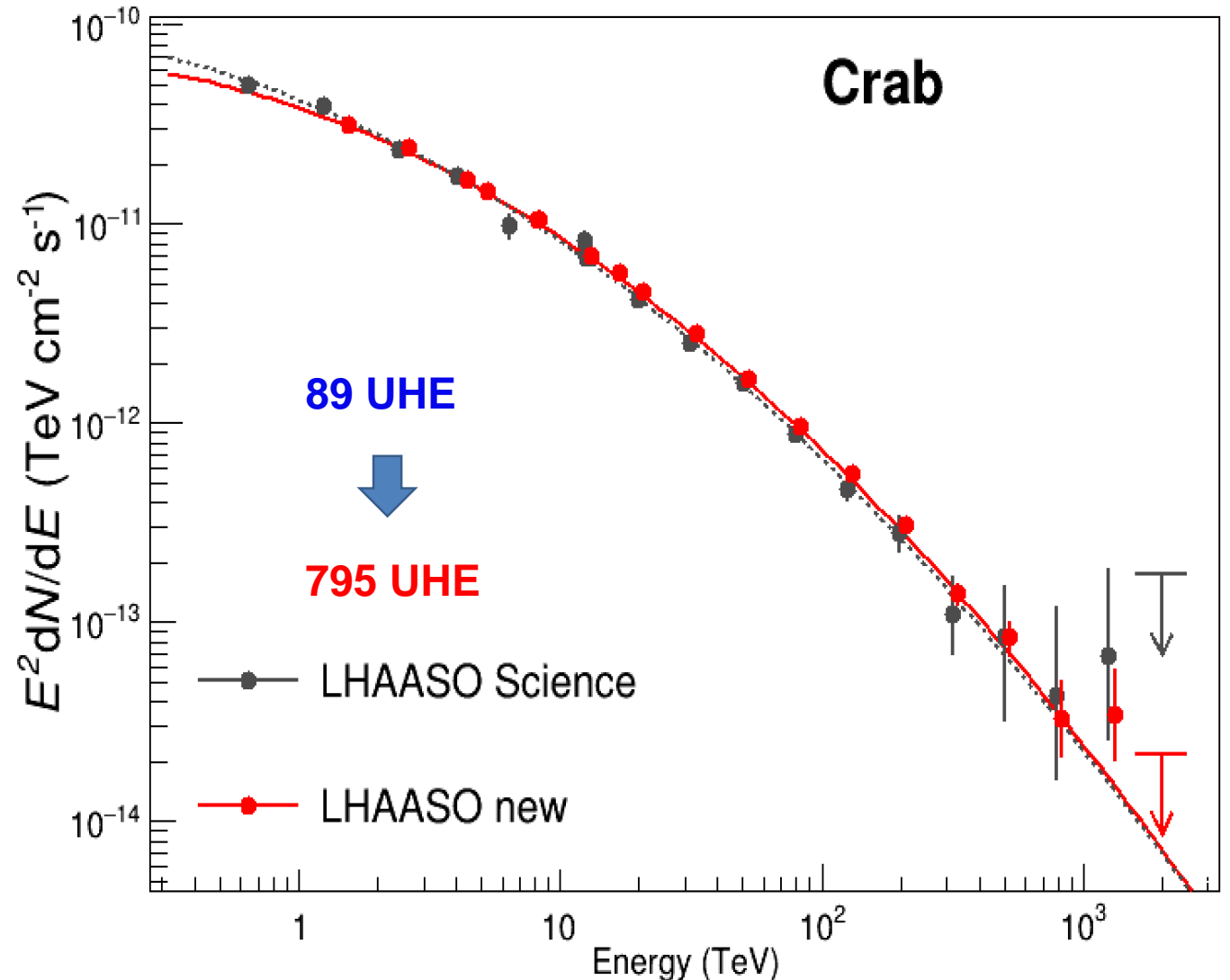


>1 PeV
4 photons



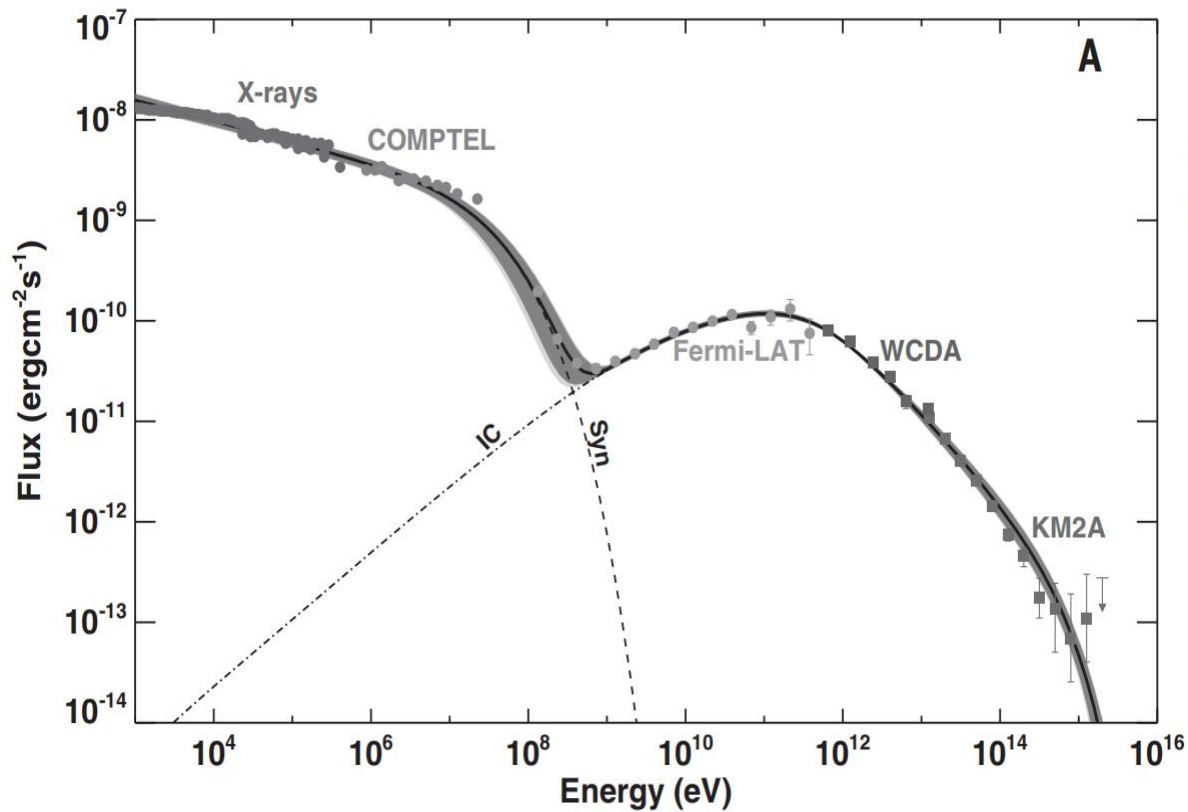
Updated SED

- The Data enlarged by **9**
- The SED is consistent with previous measurement
- Following the log-parabola function well

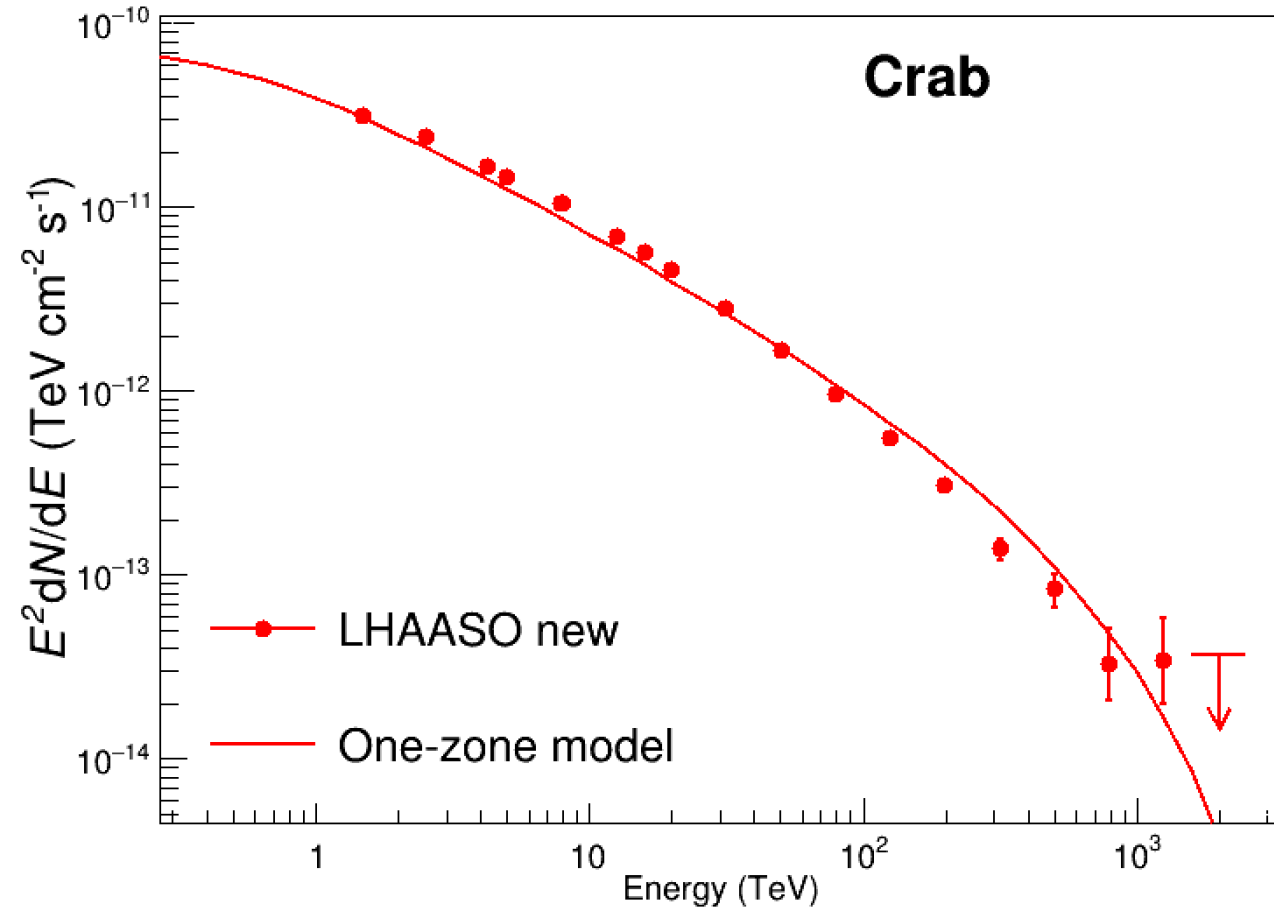


SED vs One zone model

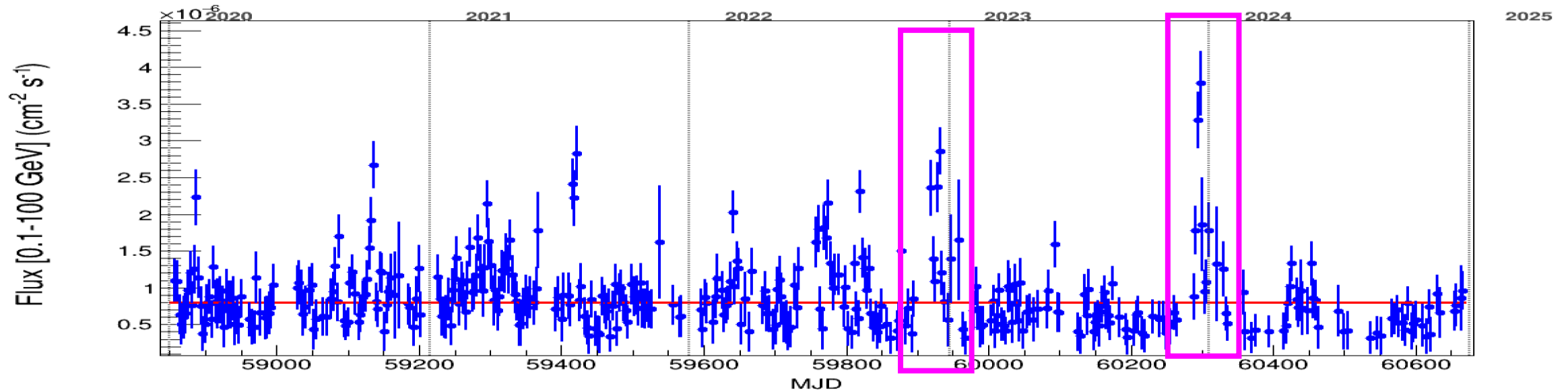
- The situation is similar



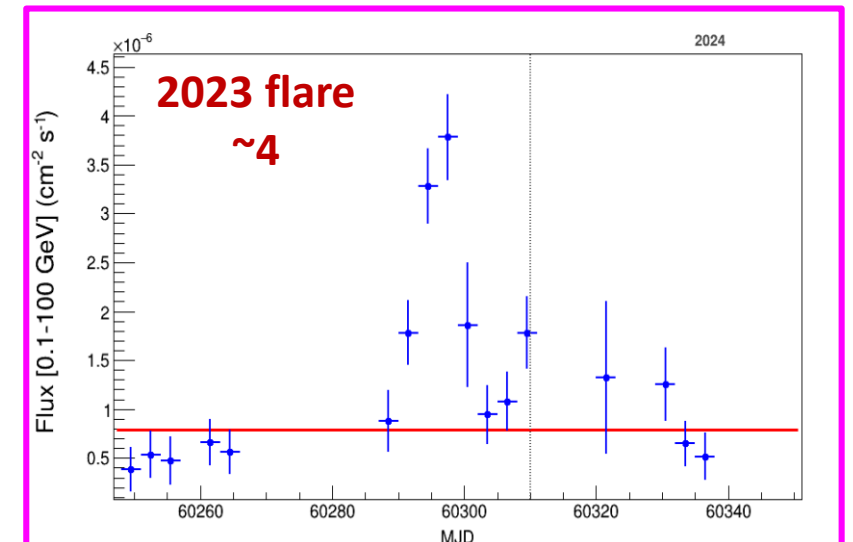
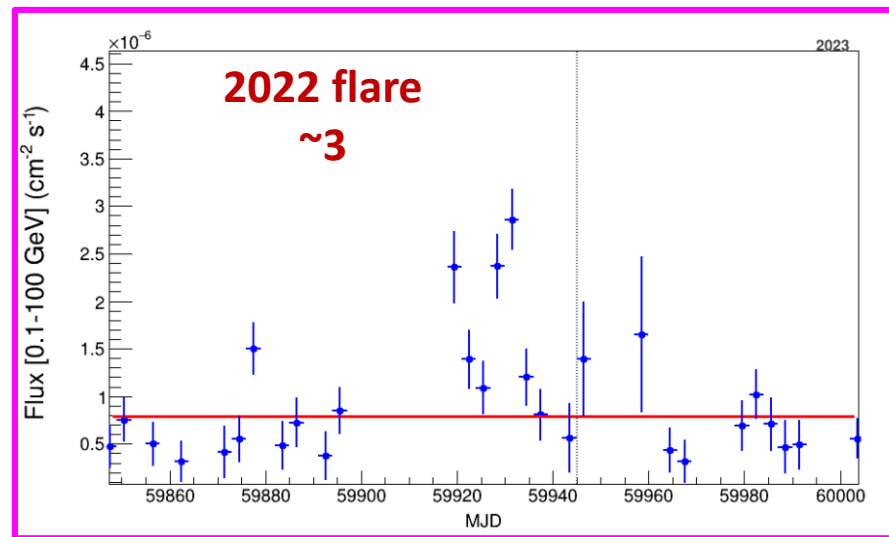
LHAASO coll. 2021



>0.1 GeV Light curve: Fermi-LAT

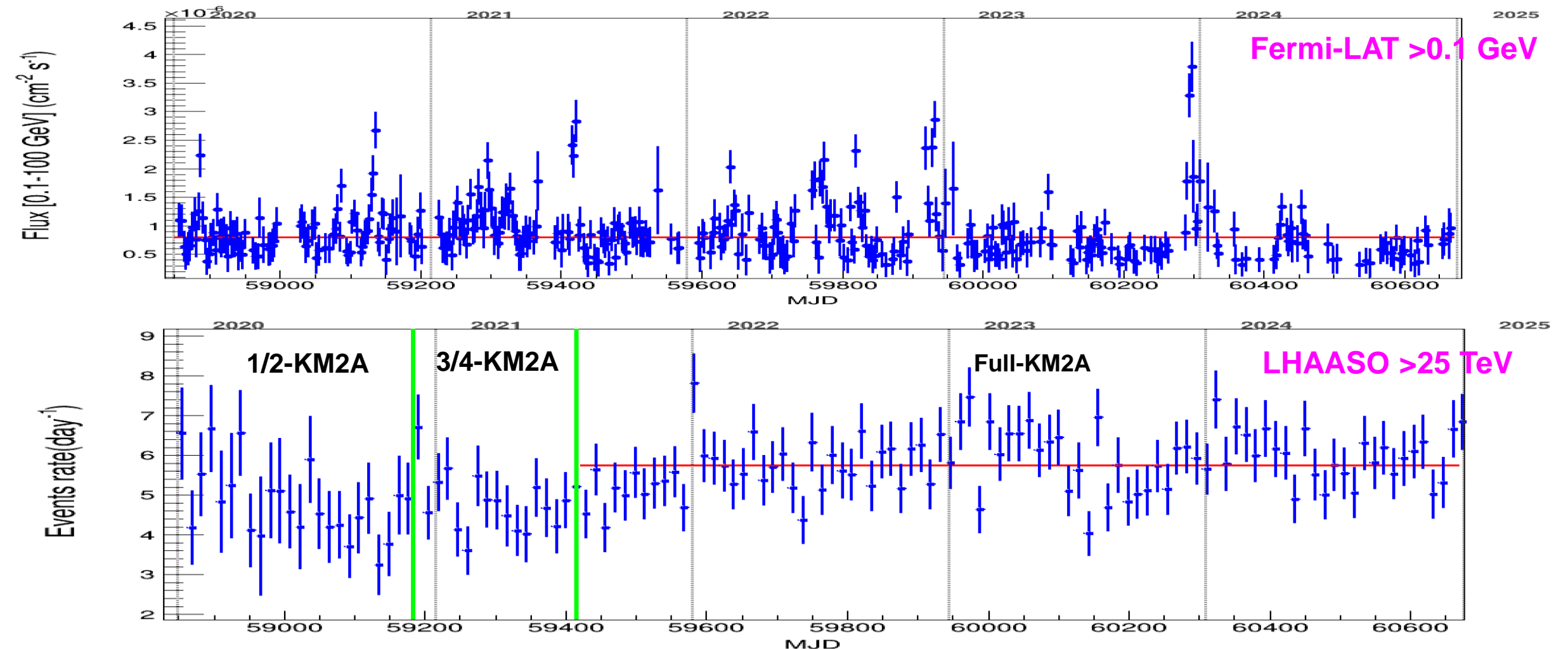


The flares is weak
comparing to others!
The SED is similar
with other flares!



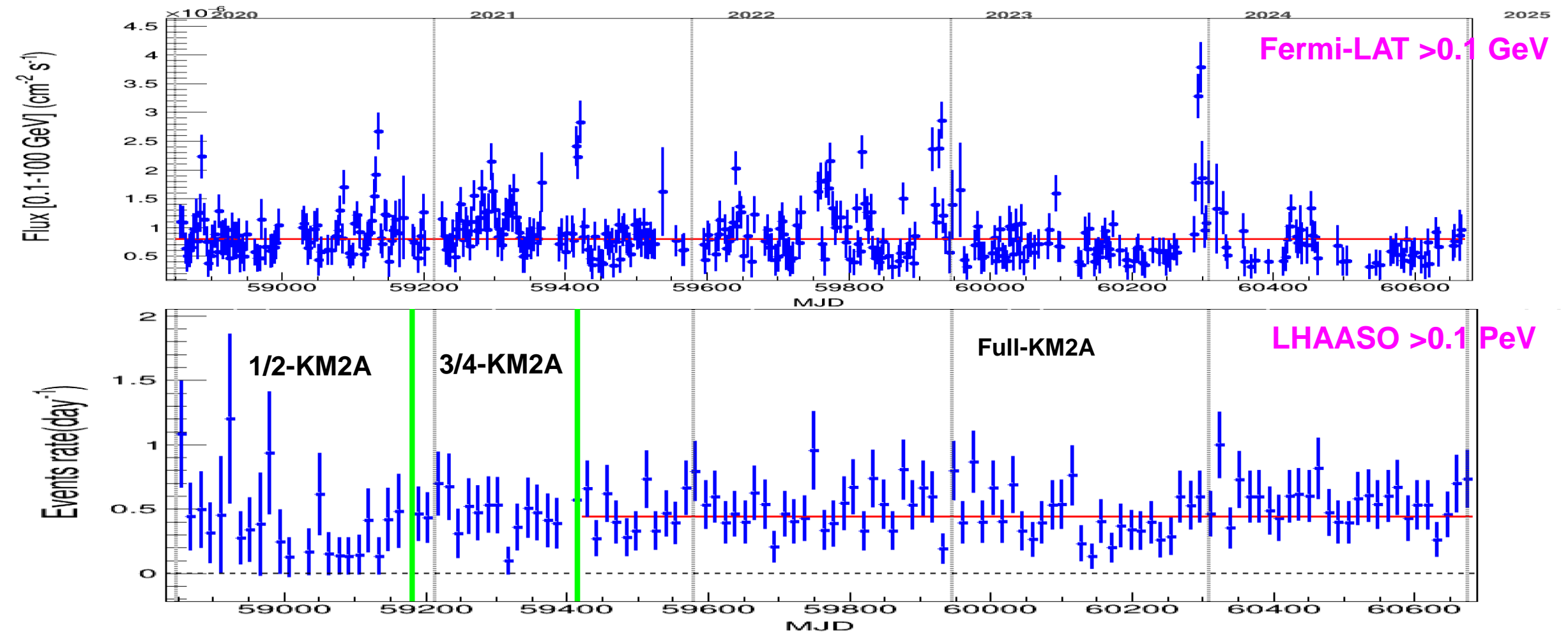
>25 TeV Light curve: LHAASO

- 5.7 events per day. No significant flare is detected up to now.



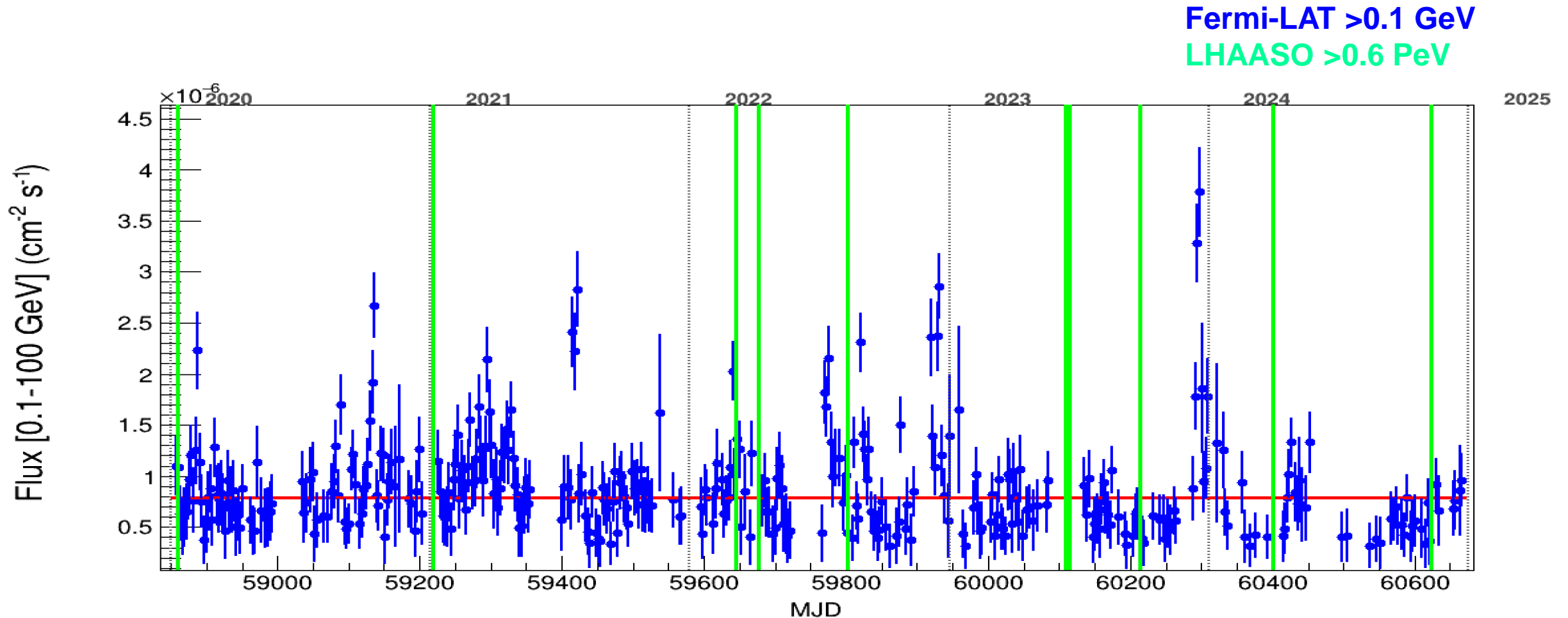
UHE Light curve: LHAASO

- 0.44 UHE events per day. No significant flare is detected up to now.



Top 10 photons Vs Fermi-LAT

- No significant correlation is found



Ability for flare detecting

- **>25 TeV, Icrab ~ 5.7 events per day**
 - 1 day: 3σ ~ **2.5 Icrab** flare
 - 7 days: 3σ ~ **1.5 Icrab** flare
- **>100 TeV, Icrab ~ 0.44 events per day**
 - 1 day: 3σ ~ **9 Icrab** flare
 - 7 days: 3σ ~ **3 Icrab** flare

A fast conclusion:

Similar flux enhancement at >25 TeV as GeV flare can be excluded.

The PeV photons is not due to GeV flare

This is consistent with that the magnetic field for flares is larger.

Summary

- **The PeV gamma-ray signal from Crab Nebula is significantly detected (5.7 sigma). They are not correlated with GeV flares.**
- **The maximum energy photon increases from 1.1PeV to 1.4 PeV.**
- **The updated SED is consist with previous result but with much better accuracy at UHE band. Lop-parabola SED function is favoured.**
- **No >25TeV flux change during the GeV flares is found. This can give some information.**

More LHAASO results can be found from:

<http://english.ihep.cas.cn/lhaaso/>

All the data for LHAASO papers can be found from:

<https://www.nhepsdc.cn/resource/astro/lhaaso?ignoreheadh>


<https://www.nhepsdc.cn/resource/astro/lhaaso?ignorehead>

Data for paper "Constraints on ultra heavy dark matter properties from dwarf spheroidal galaxies with LHAASO observations"

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Keywords: LHAASO WCDA Dark matter


Abstract: Data for paper "Constraints on ultra heavy dark matter properties from dwarf spheroidal galaxies w...  1

Data for paper "Stringent Tests of Lorentz Invariance Violation from LHAASO Observations of GRB 221009A"

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Keywords: LHAASO GRB Gamma-Ray

Abstract: Data for paper "Stringent Tests of Lorentz Invariance Violation from LHAASO Observations of GRB ...  1

Data for Paper "Measurements of all-particle energy spectrum and mean logarithmic mass of cosmic rays from 0.3 to 30 PeV with LHAASO-KM2A"

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Thank you!