Observation of Cygnus Region with LHAASO

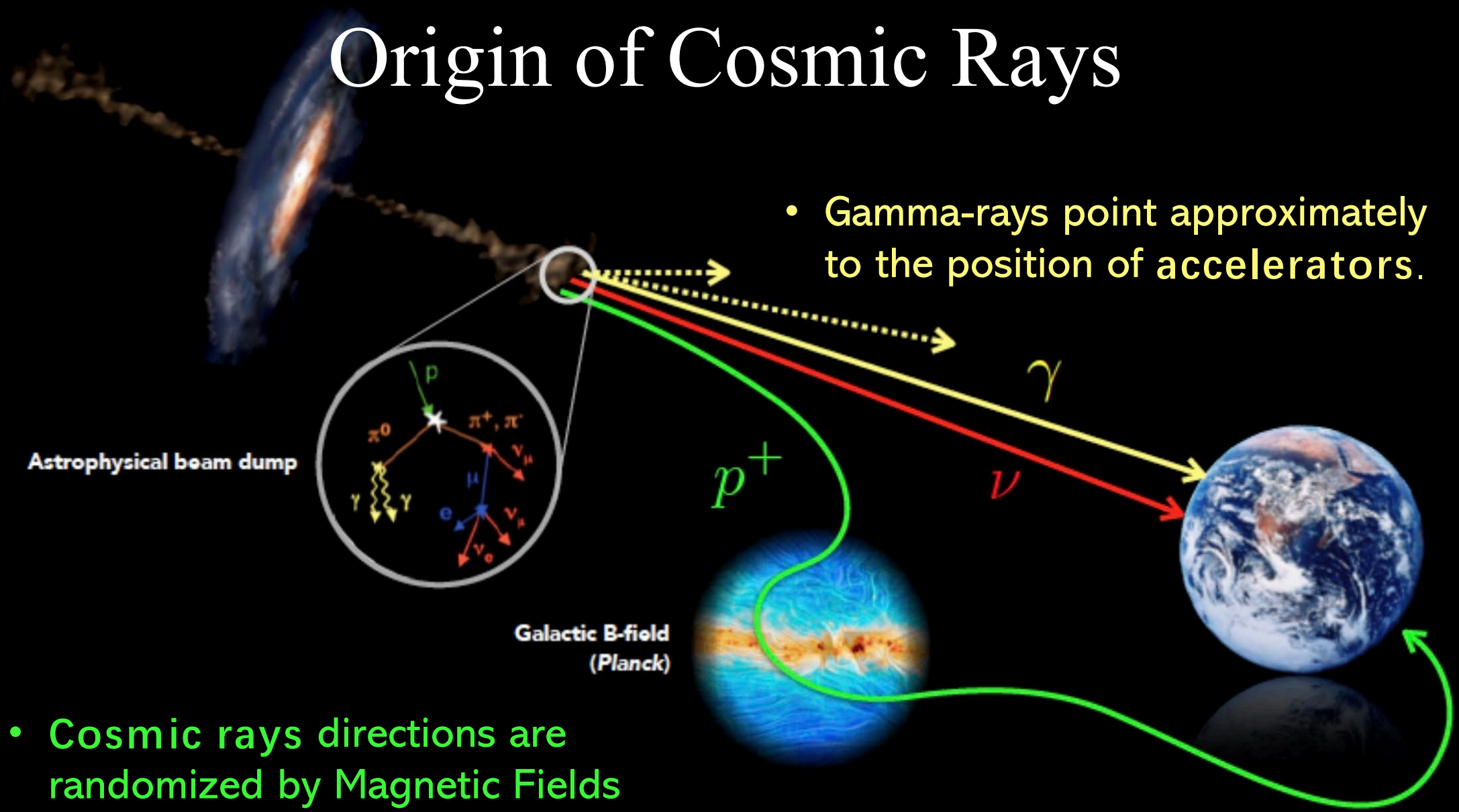
Cong Li

On behalf of LHAASO Collaboration

2024.4.17

Institute of High Energy Physics(IHEP),CAS

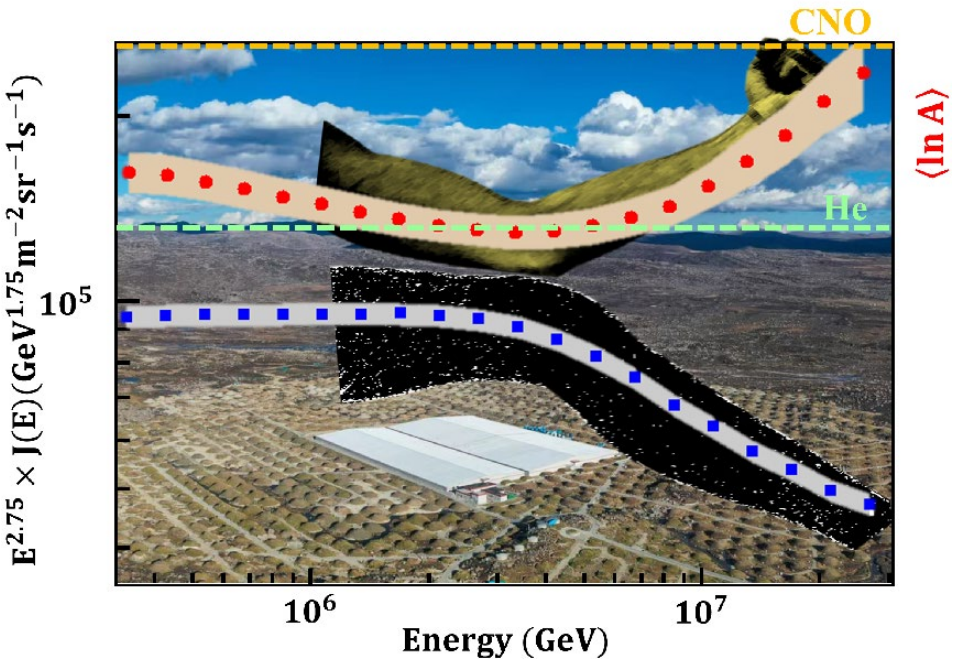
Origin of Cosmic Rays

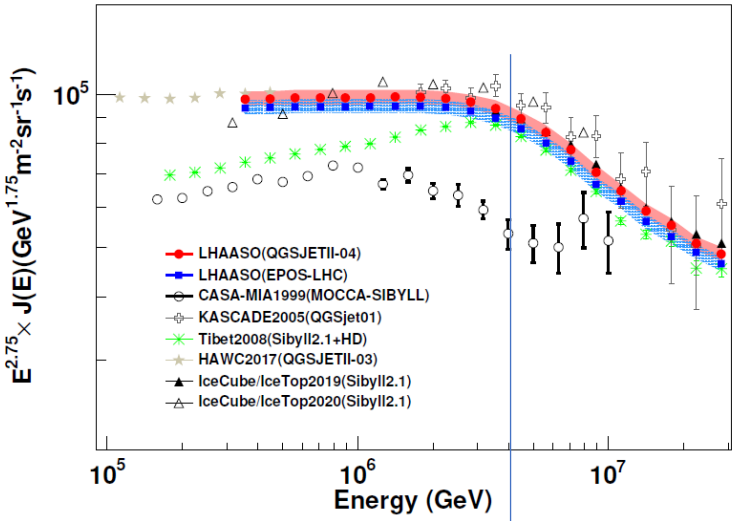


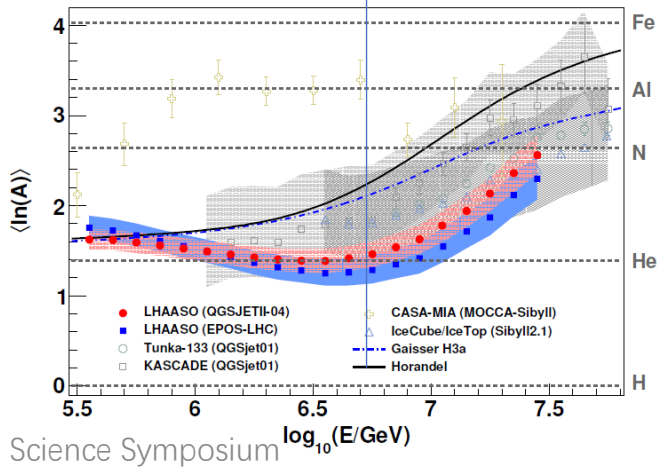
- Gamma-rays point approximately to the position of accelerators.

- Cosmic rays directions are randomized by Magnetic Fields in the Universe.

All-particle energy spectrum & composition by LHAASO



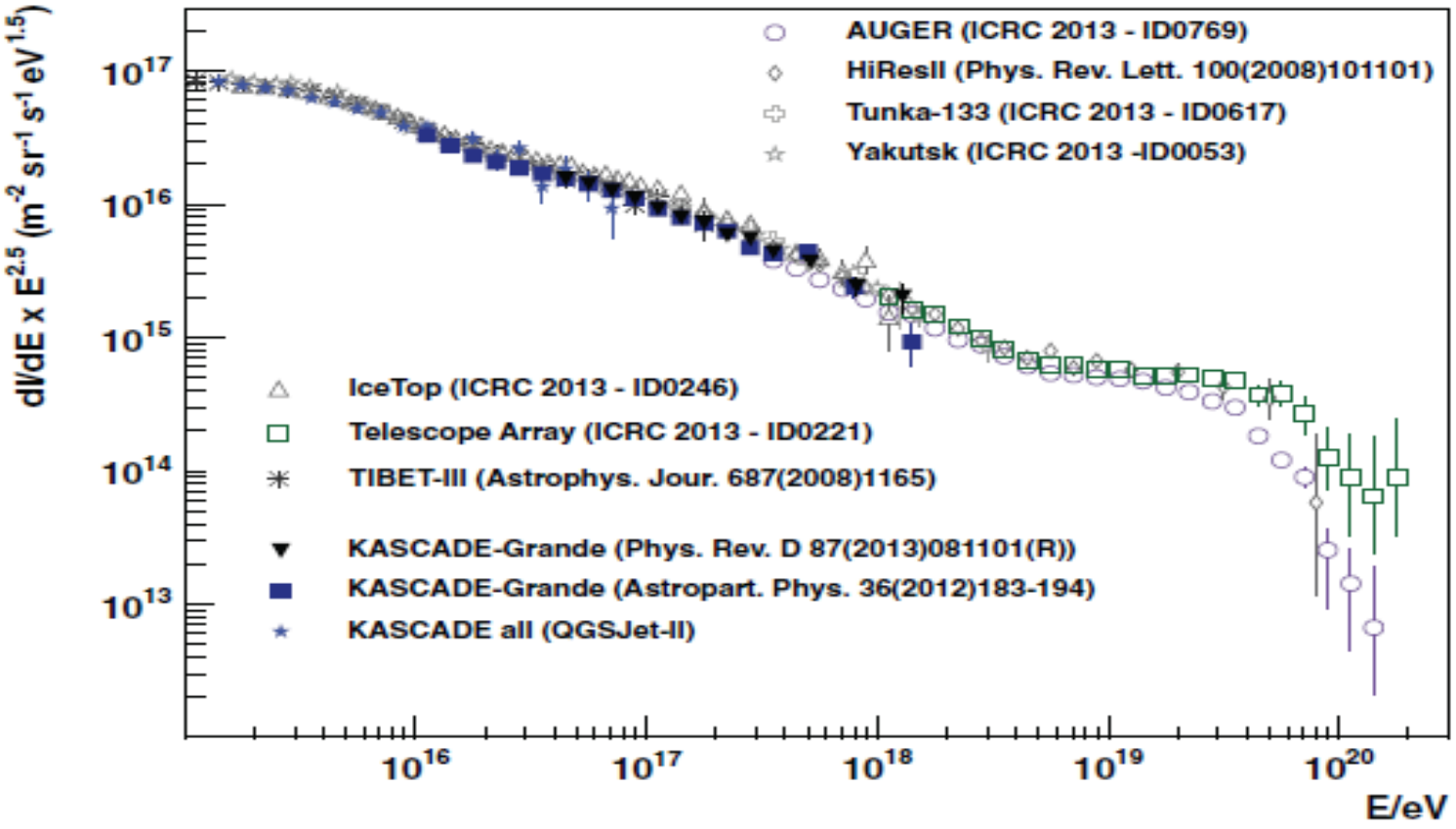




- The large statistics and rather small systematic uncertainty indicate the "knee" is dominated by light component rather than medium-heavy component.

PhysRevLett.132.131002

There is still no clue about the origins of CRs between the "knee" and the "ankle"



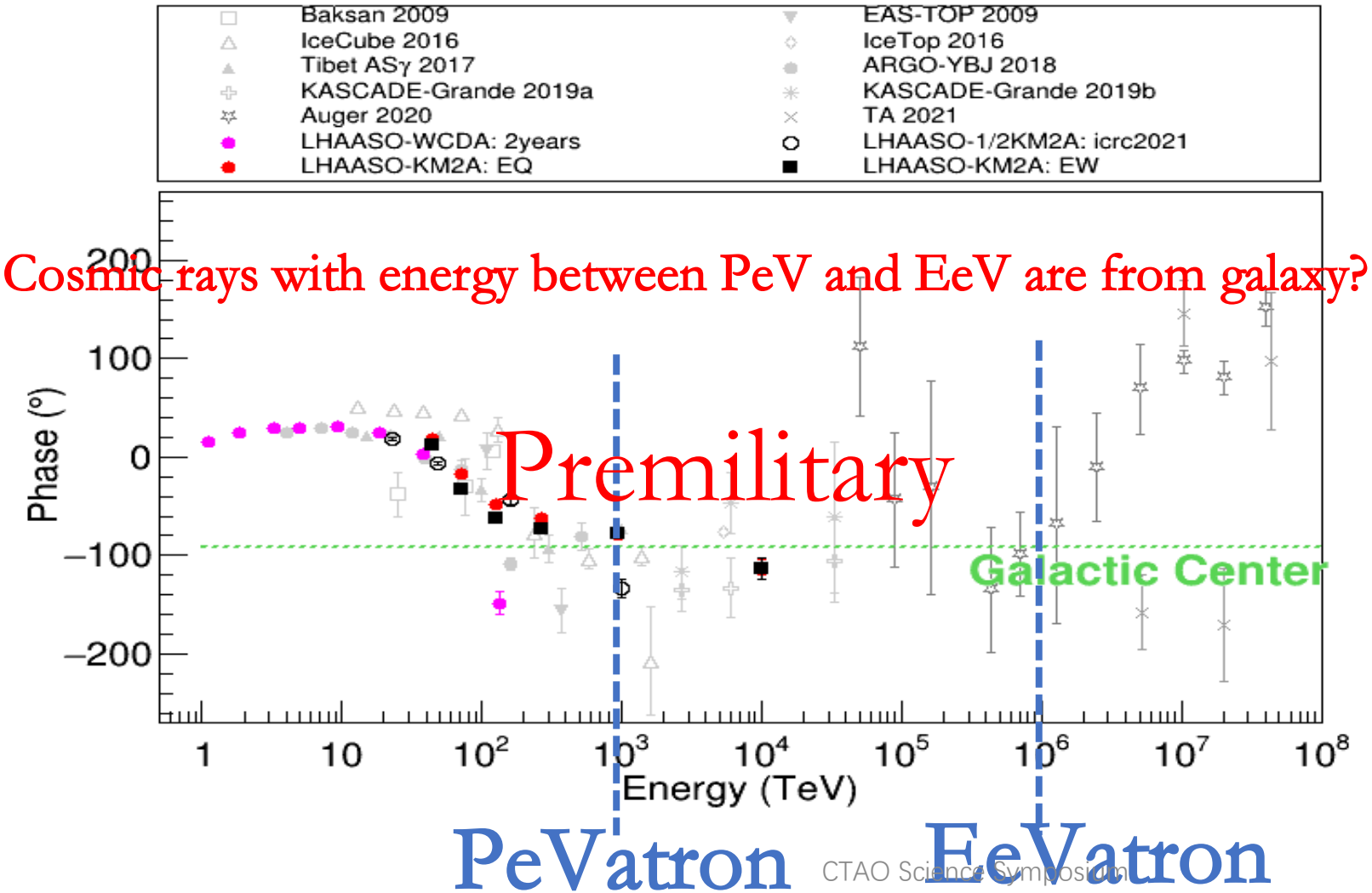
Galactic sources

???

Extragalactic sources

Physics Procedia 61 (2015) 425-434.arXiv:1910.03721v1

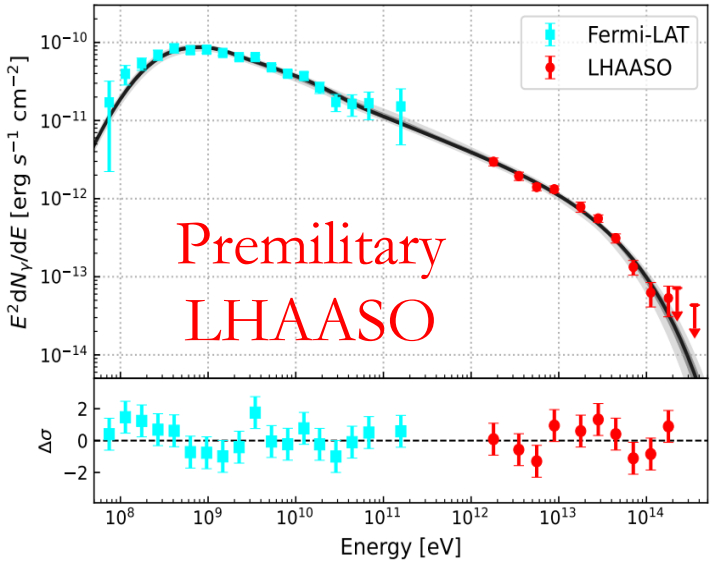
Cosmic ray anisotropy



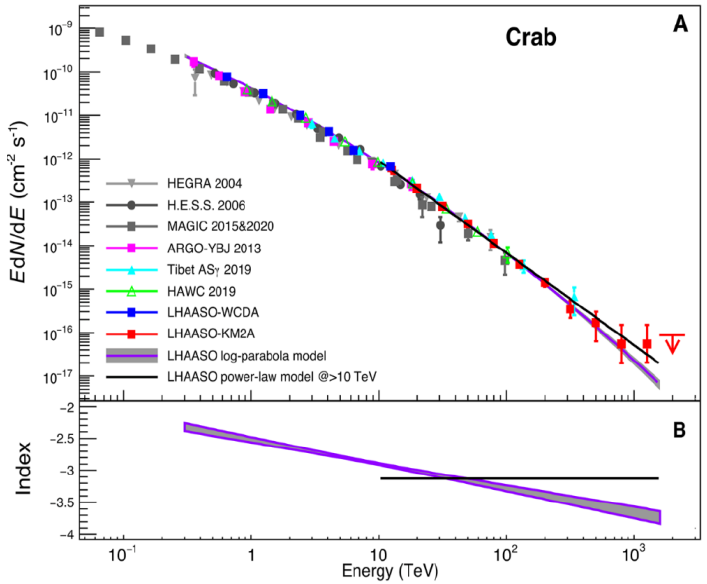
- There might be sources in our galaxy accelerating particles to PeV or even up to EeV from the measurement of CRs at earth.

Possible Source Candidates

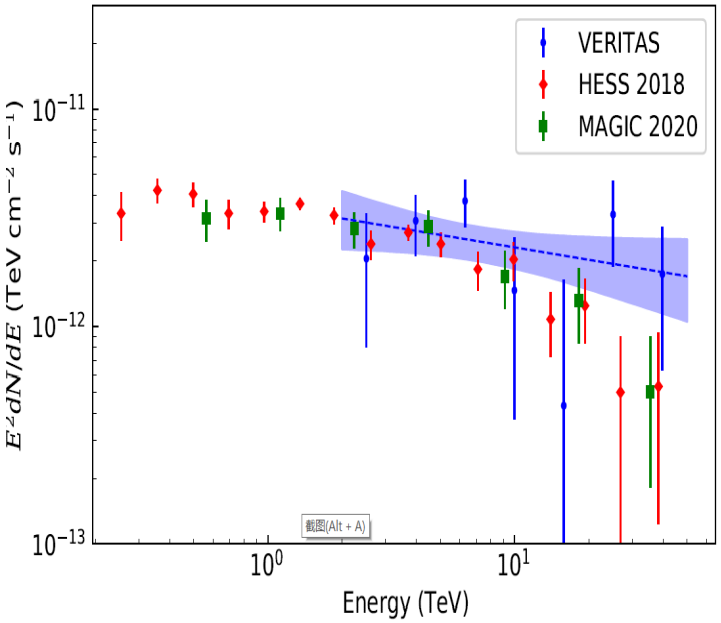
W51C



Crab



G.C.



...

SNR?

PWN?

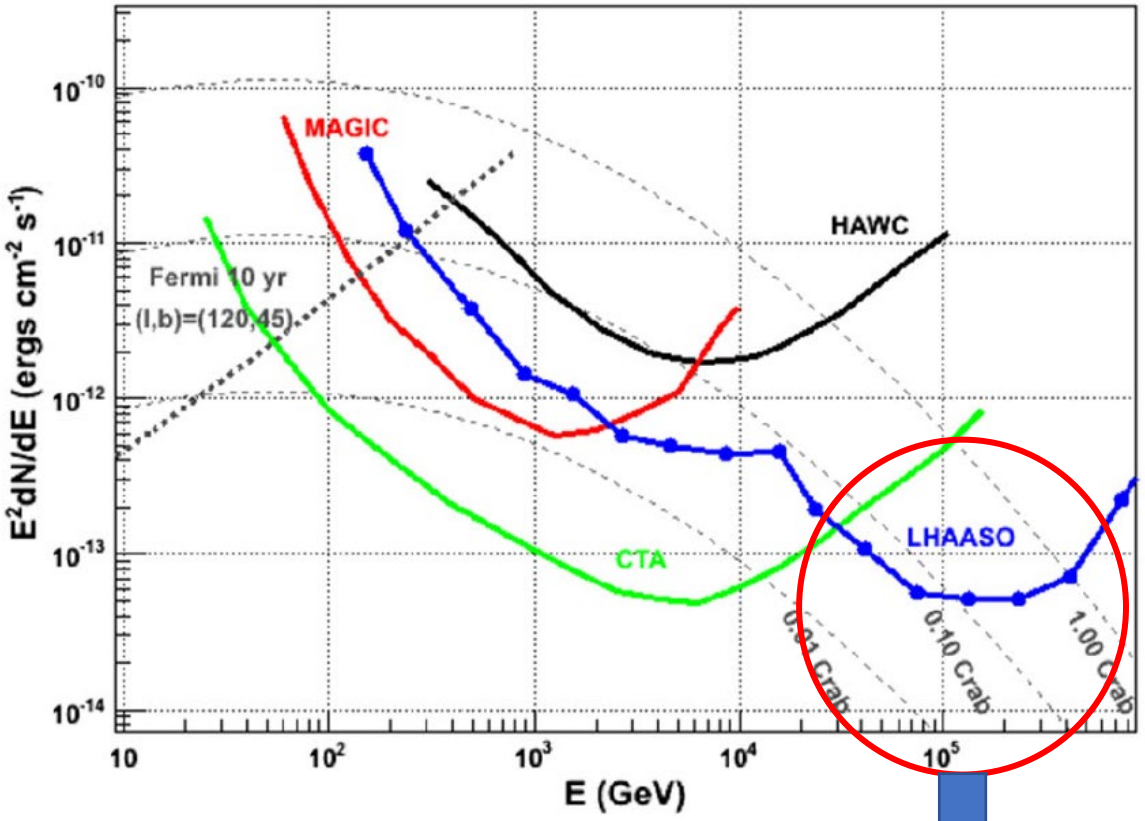
Other sources?

Many types of sources have the potential to accelerate particles to 1 PeV and above

A&A 671, A12 (2023)
Science 10.1126/science.abg5137 (2021).
The Astrophysical Journal, 913:115 (11pp), 2021 Jun


Location: 29°21′ 27.6"N 100°08′ 19.6"E
Altitude: 4410m a.s.l

LHAASO sensitivity



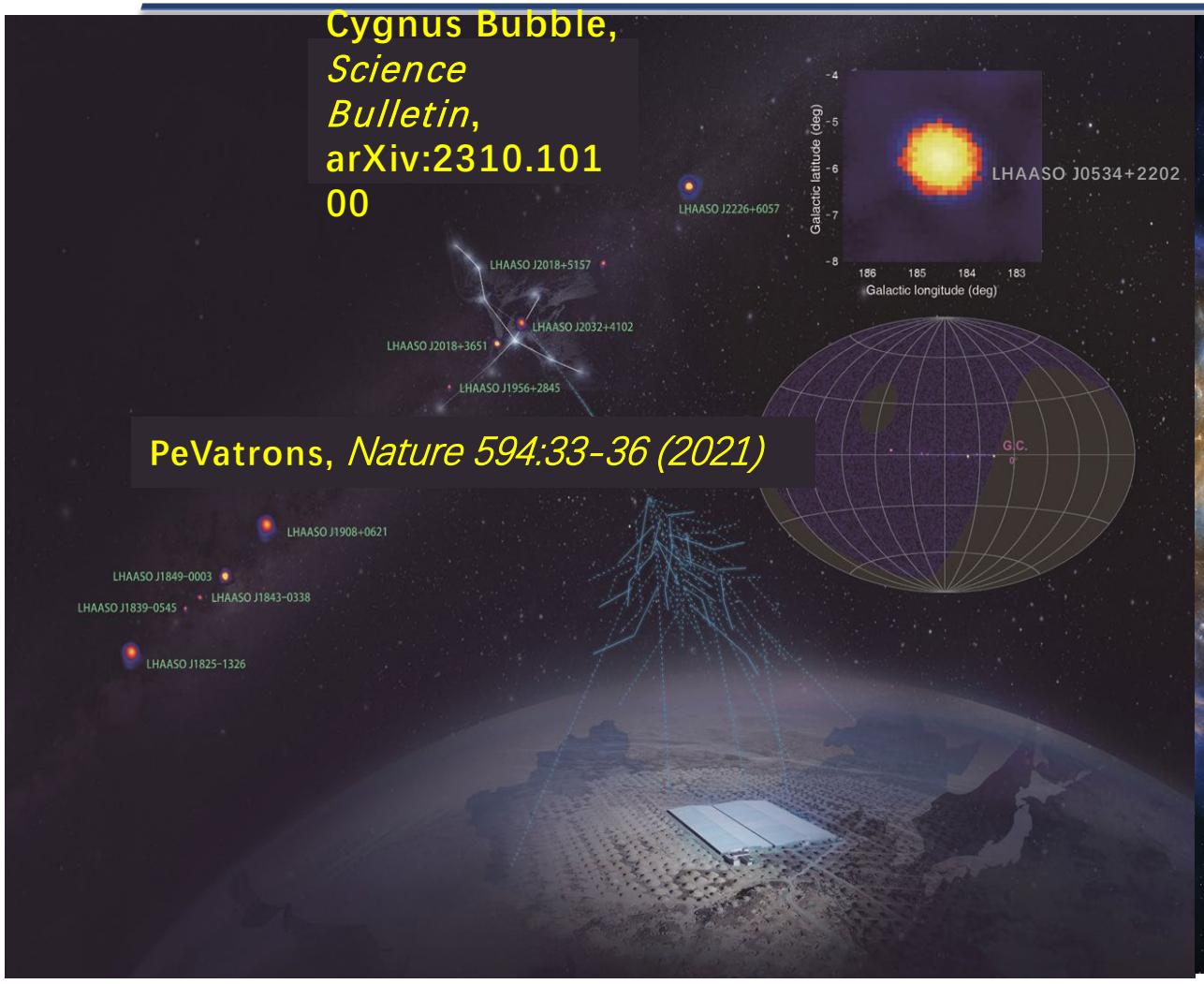
- **High sensitivity:** ~1% Crab@3TeV@100TeV;
- **Wide energy range:** sub-TeV to 10 PeV;
- **Large FOV**:~1.8 sr

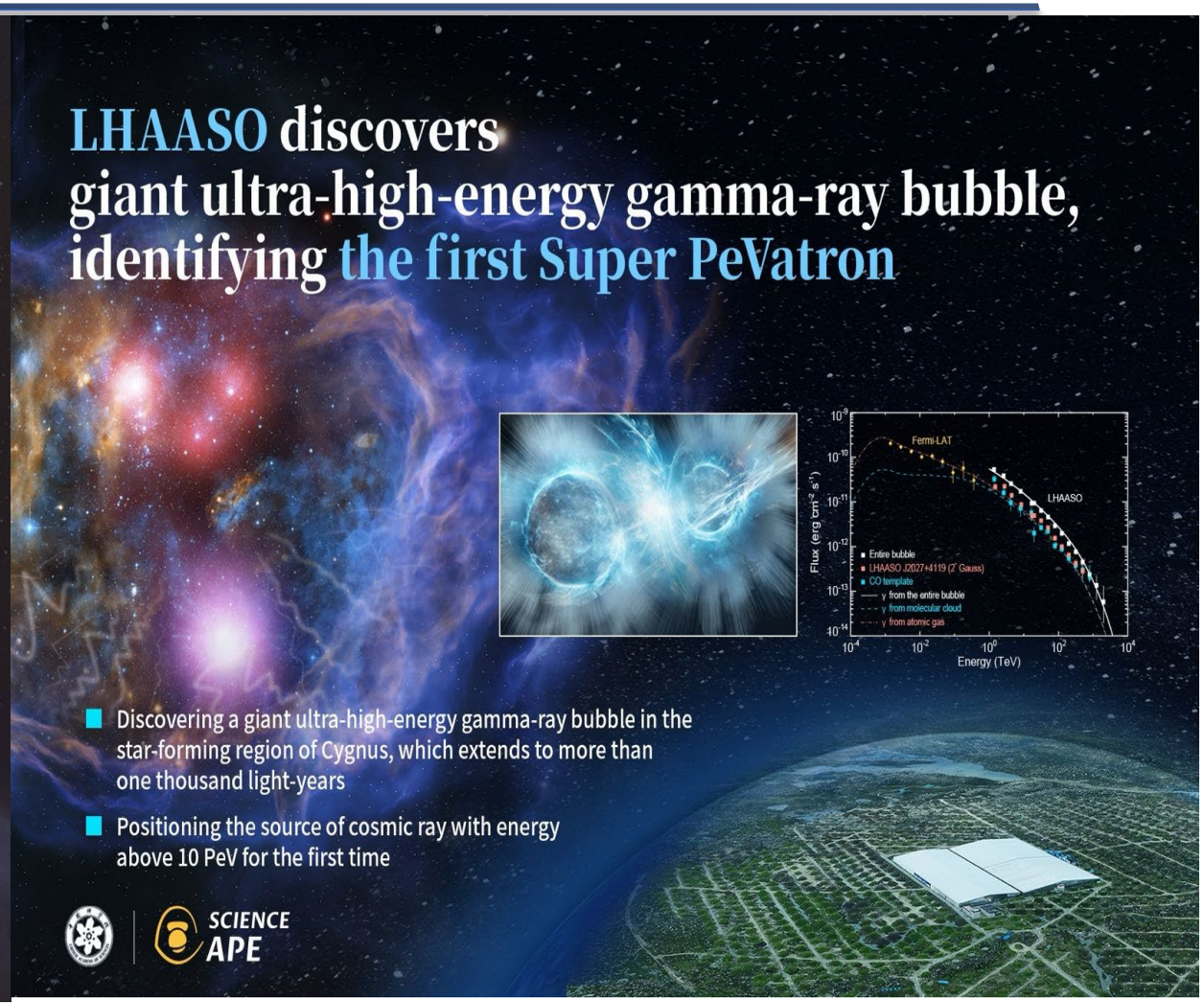
The most sensitive gamma ray detector to explore this highest energy range

The 1st CR-Source Candidate by LHAASO

Cygnus Bubble, *Science Bulletin*, arXiv:2310.10100

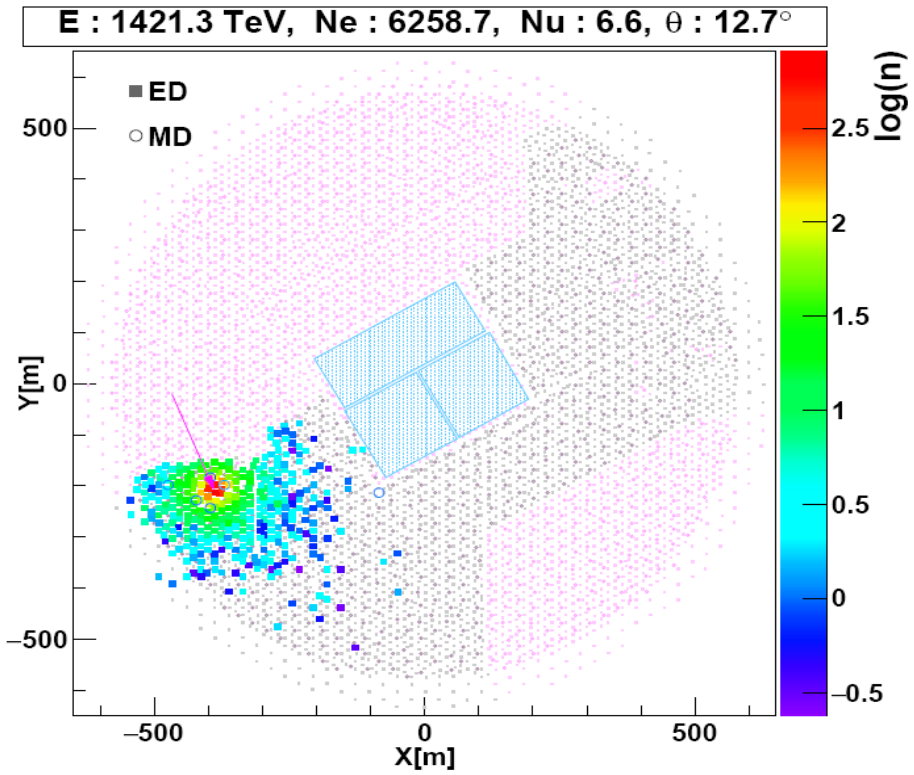
PeVatrons, *Nature 594:33-36 (2021)*



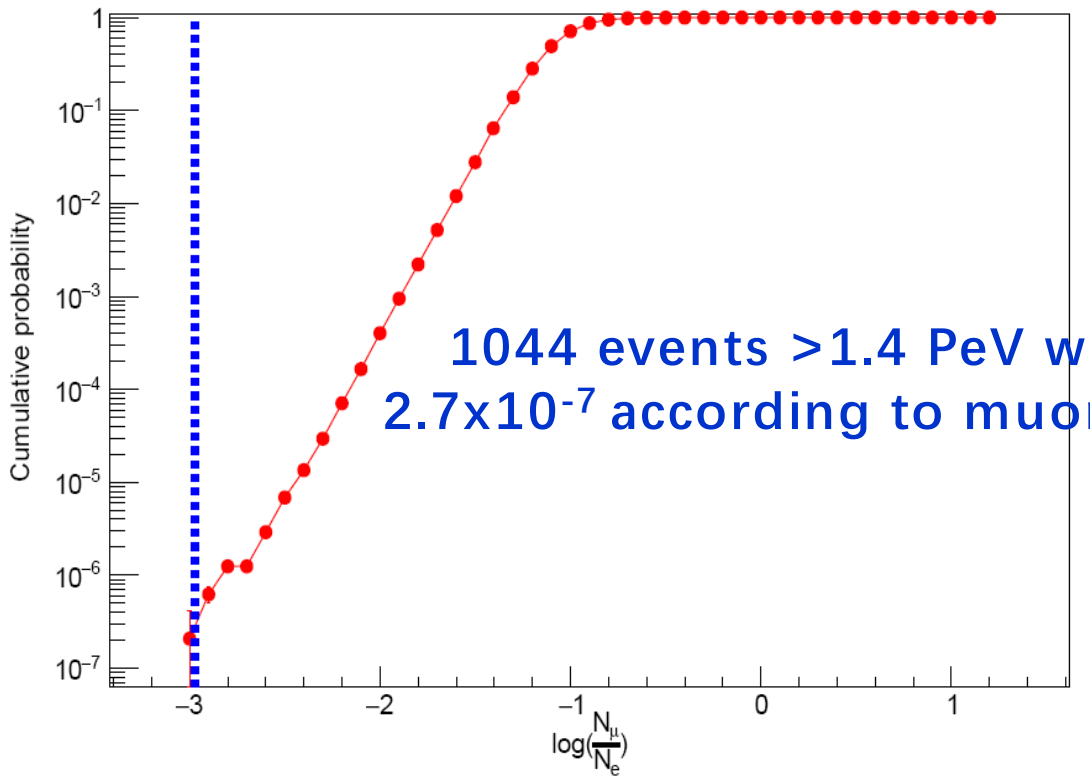


The PeV Photon from Cygnus region

- 1.42±0.13 PeV from the Cygnus region
- Chance probility due to cosmic ray background 0.028% .



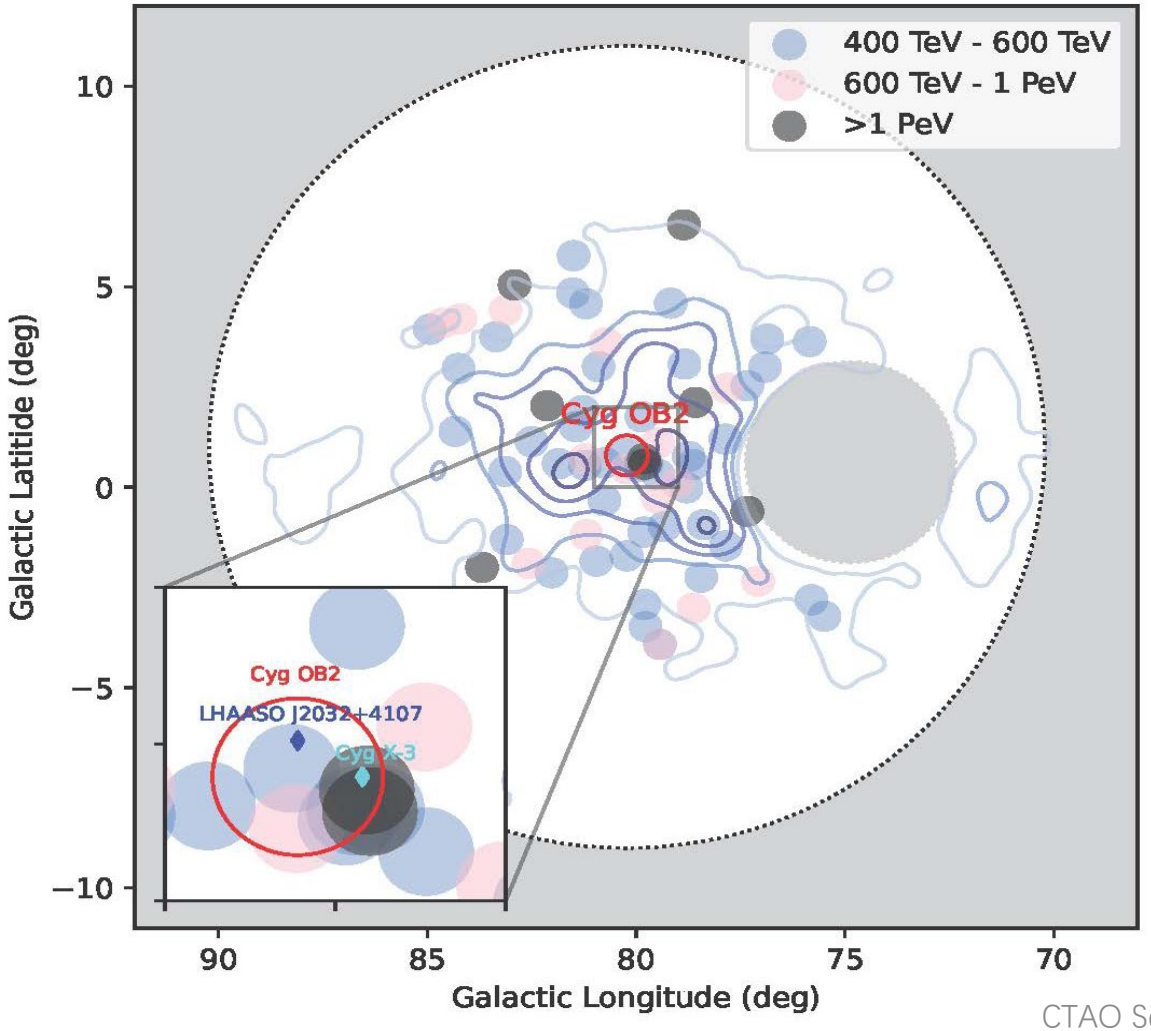
Nature 594:33-36 (2021)



1044 events >1.4 PeV within 1°

2.7×10^{-7} according to muon-conter

A Bubble of UHE γ's centered at a complex core

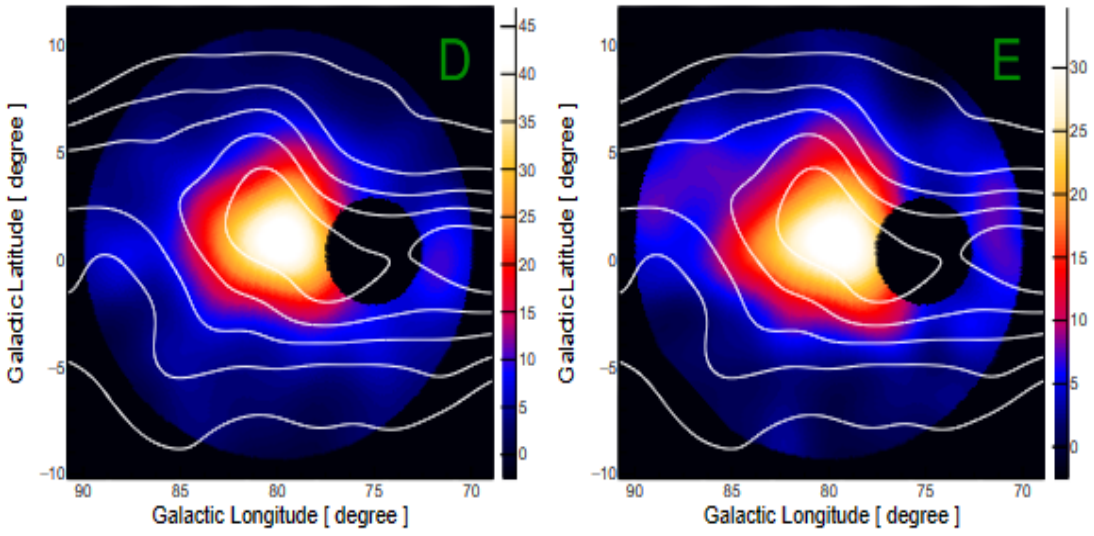


Energy (TeV)	Ne	Nu	Theta (deg)	Dr (m)
1087	5904	13	19.4	143
1188	5480	14	34.4	73
1208	6939	13	14.2	131
1350	6938	8	27.1	43
1379	6469	9	17.4	52
1421	6258	7	12.7	57
1784	6665	13	18.0	41
2481	13815	29	33.0	99

- The UHE photos are dispersed distributed, and are not correlated with any small scale sources.

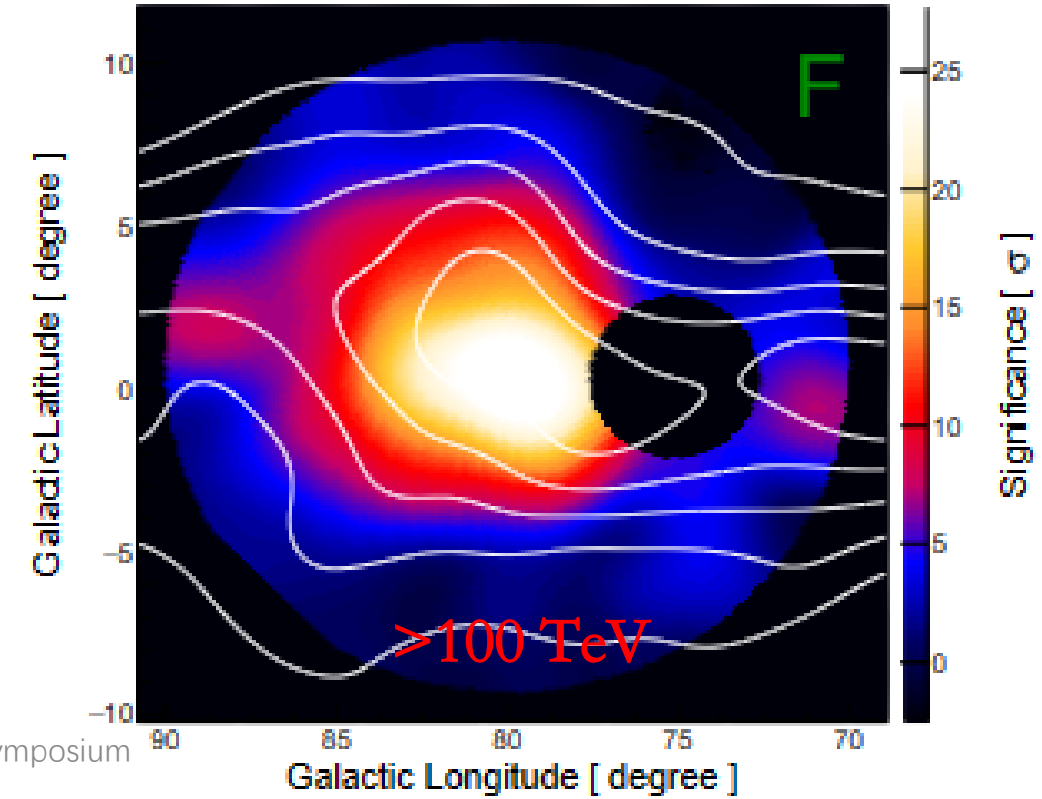
Association with HI gas distribution over ~200 pc

- The significance map is smoothed with a Gaussian kernel=1.0°
- The contour is from HI4PI 21-cm line survey



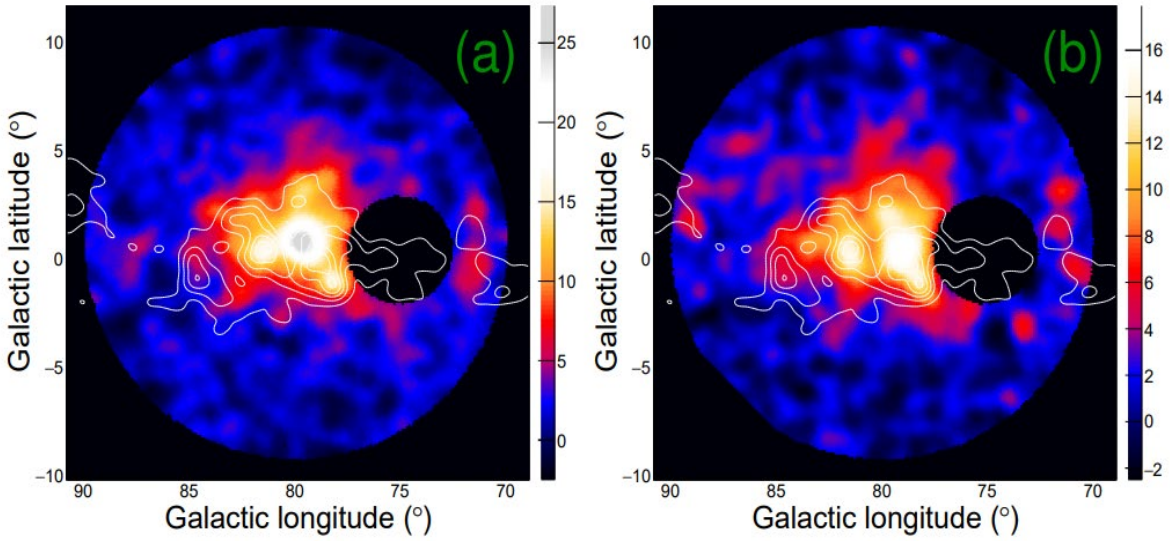
1-20TeV 25-100TeV

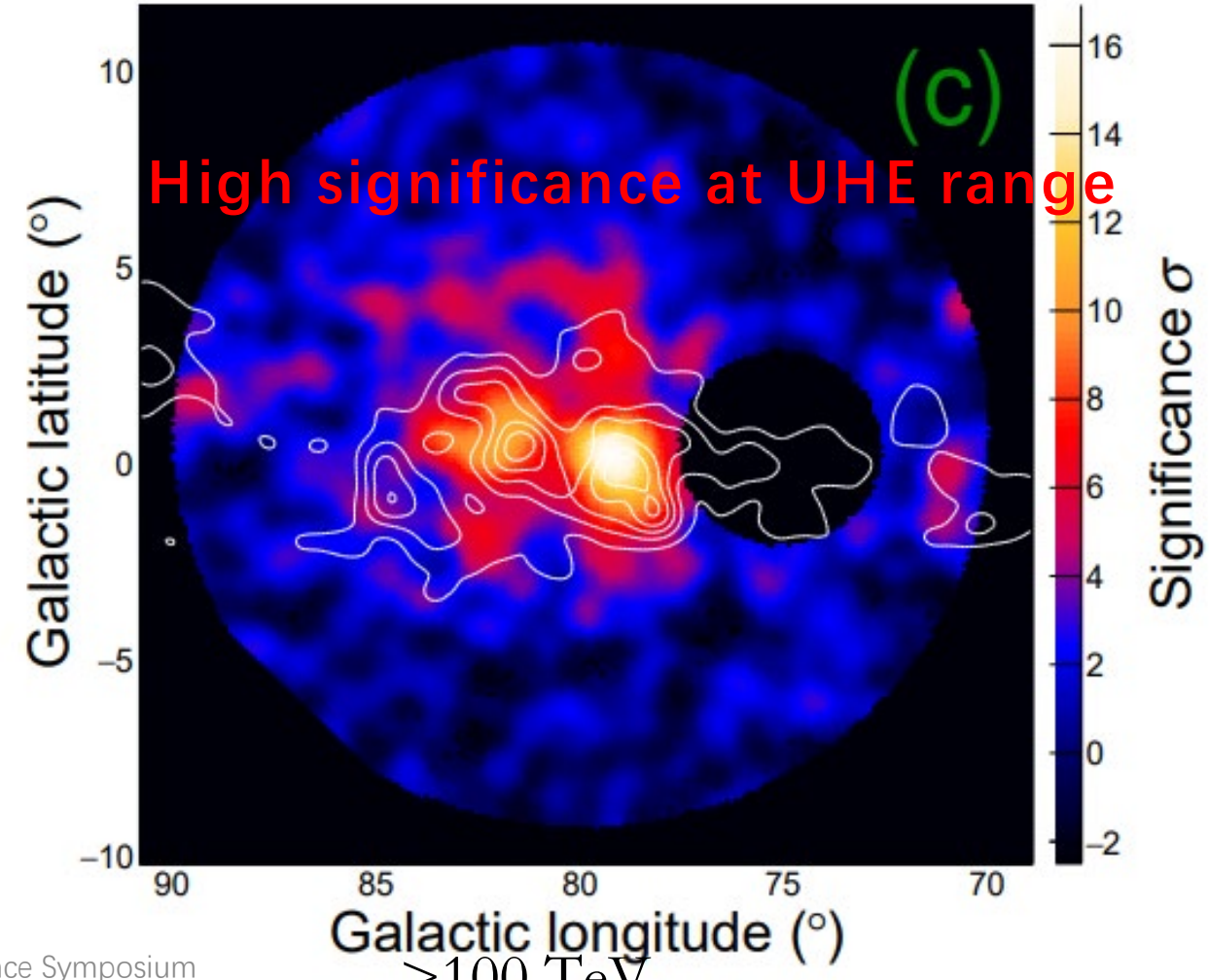
- Clear correlation with gas distribution indicating a hadronic origin of photons in the Bubble
- The signal is elongated along the disk and extends to 10°



Association with molecular cloud

- The contour is from CfA galactic CO survey
- The significance map is smoothed with a Gaussian kernel of $\sigma=0.3^{\circ}$



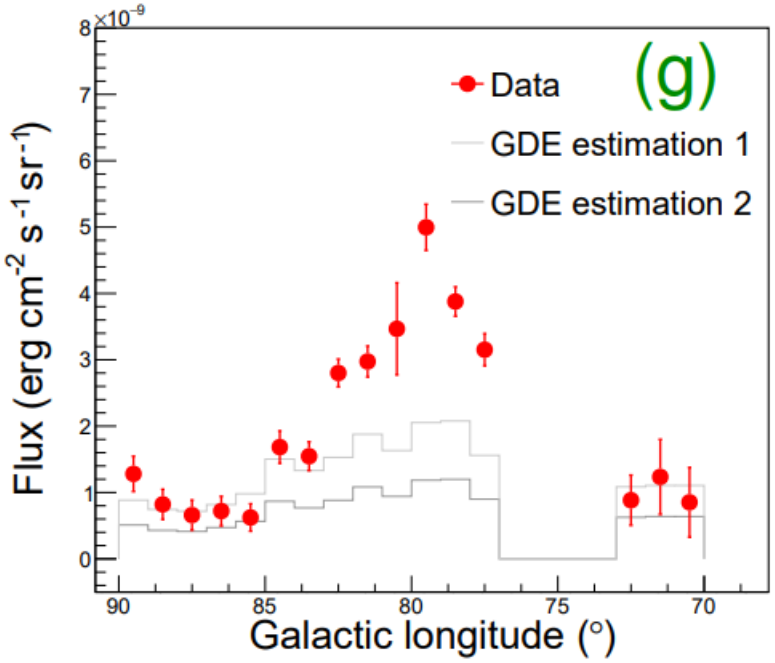


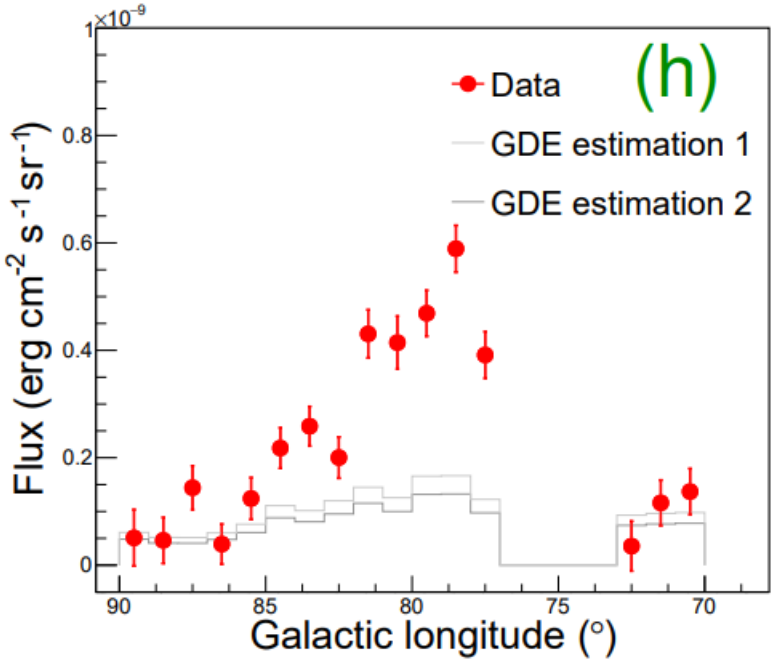
>100 TeV

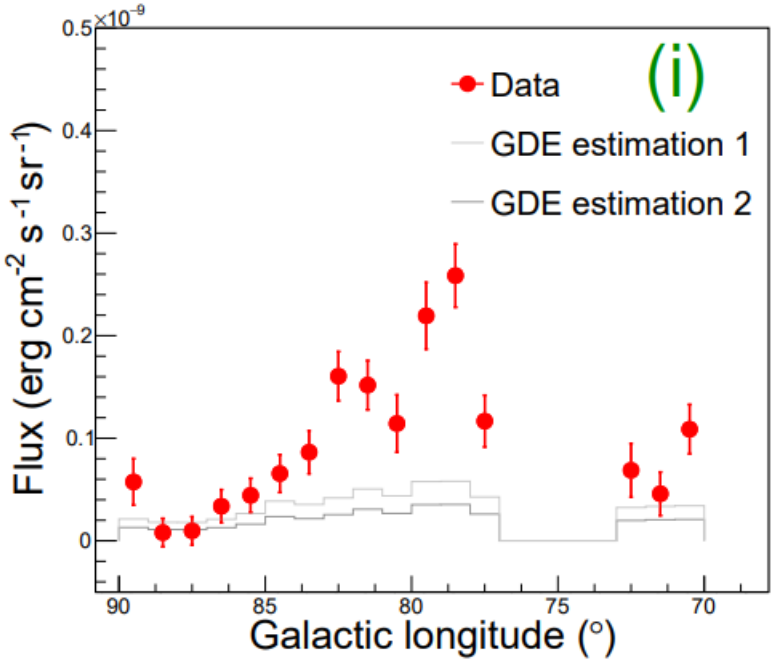
Radial profile of the extended emission

$$F_\gamma = w_{CR} \times N_{HI+H2}$$

- A very sharp distribution of gamma ray emission towards the center agree with CR propagation scenario and rule out a significant contribution from GDE.

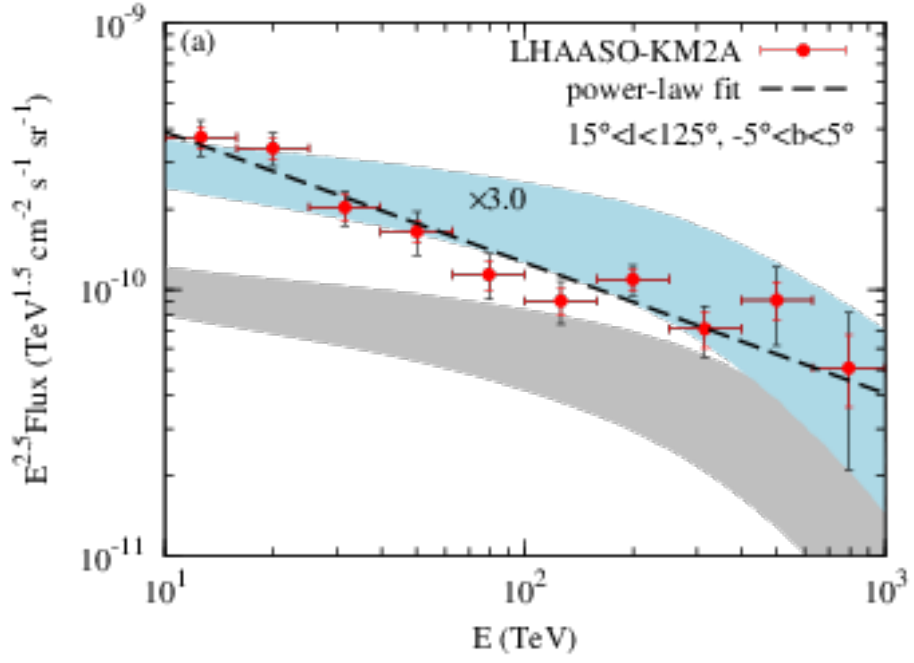


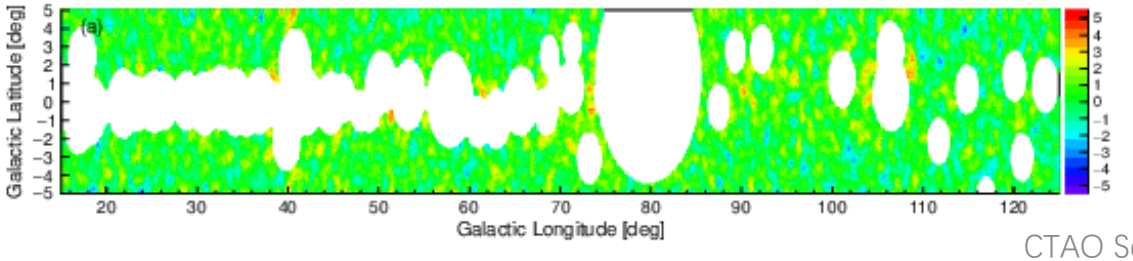




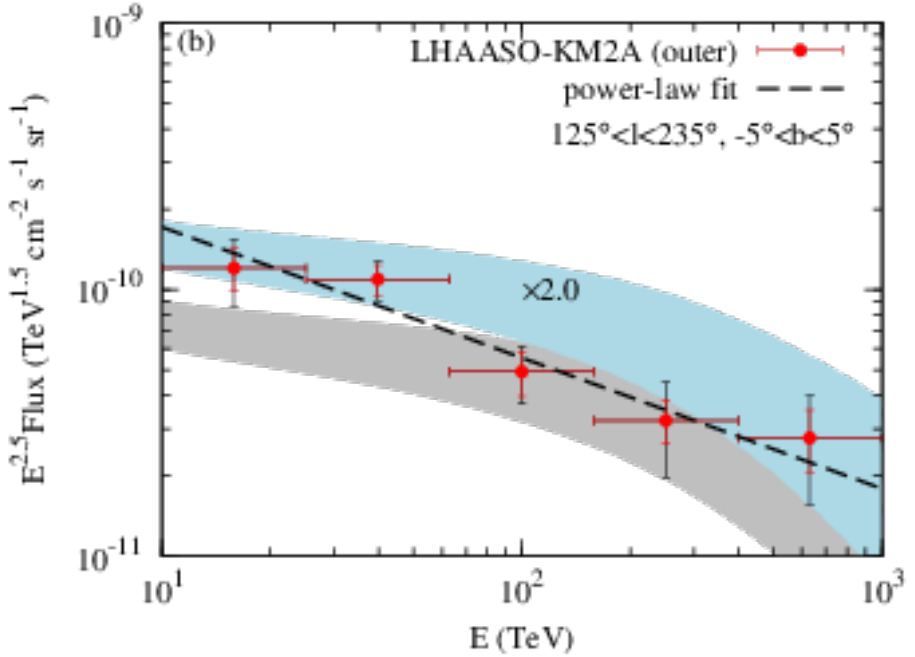
LHAASO measured the Galactic Diffuse Emission

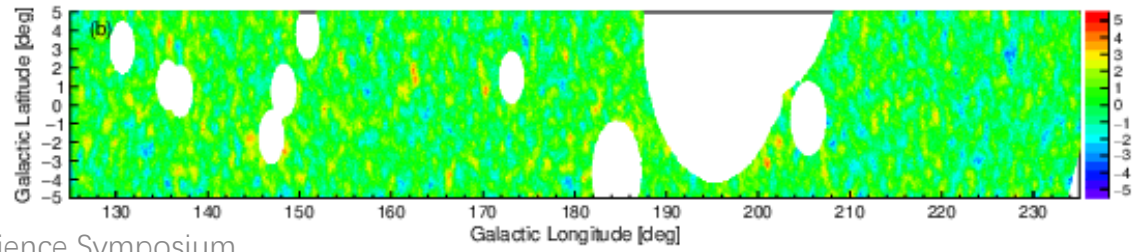
Inner Galactic Region





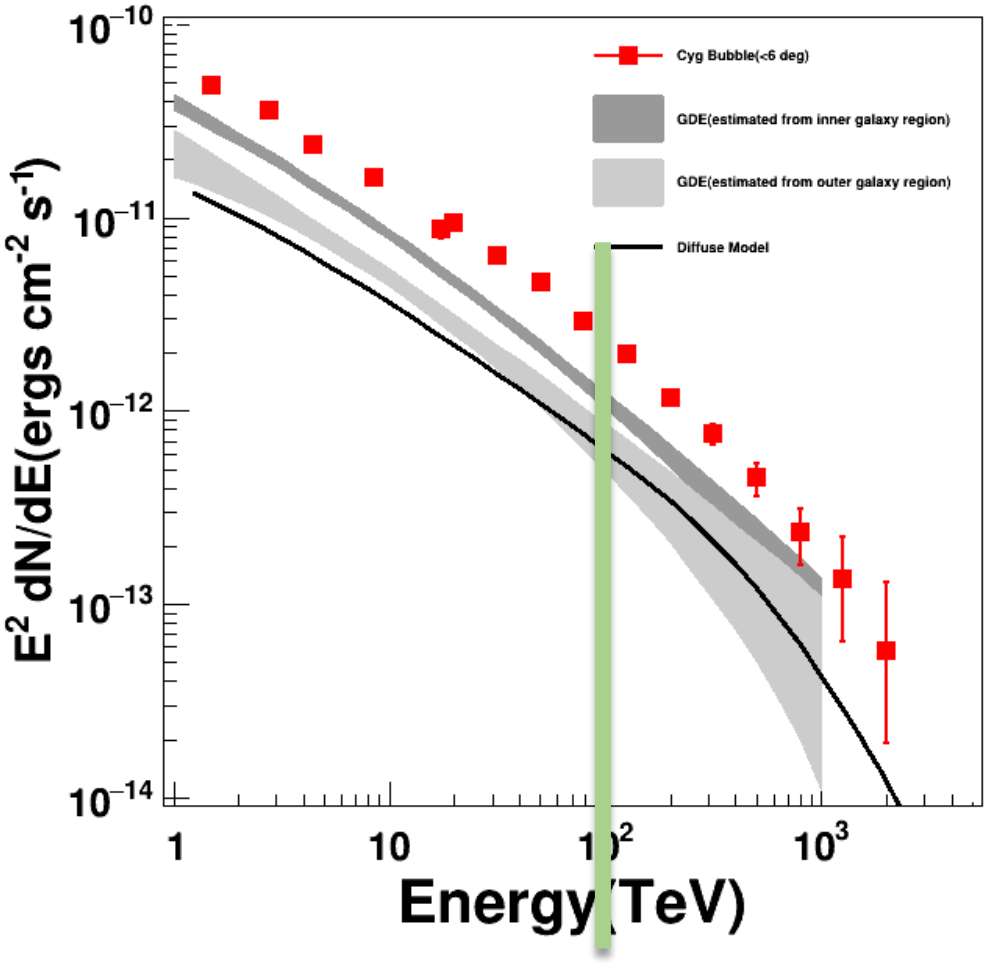
Outer Galactic Region





PhysRevLett.131.151001

Energy spectrum



Energy Bin	Non	Nb
400TeV-630TeV	42	6.8
630TeV-1PeV	14	1.9
1PeV-1.6PeV	6	0.6
1.6PeV-2.5PeV	2	0.2

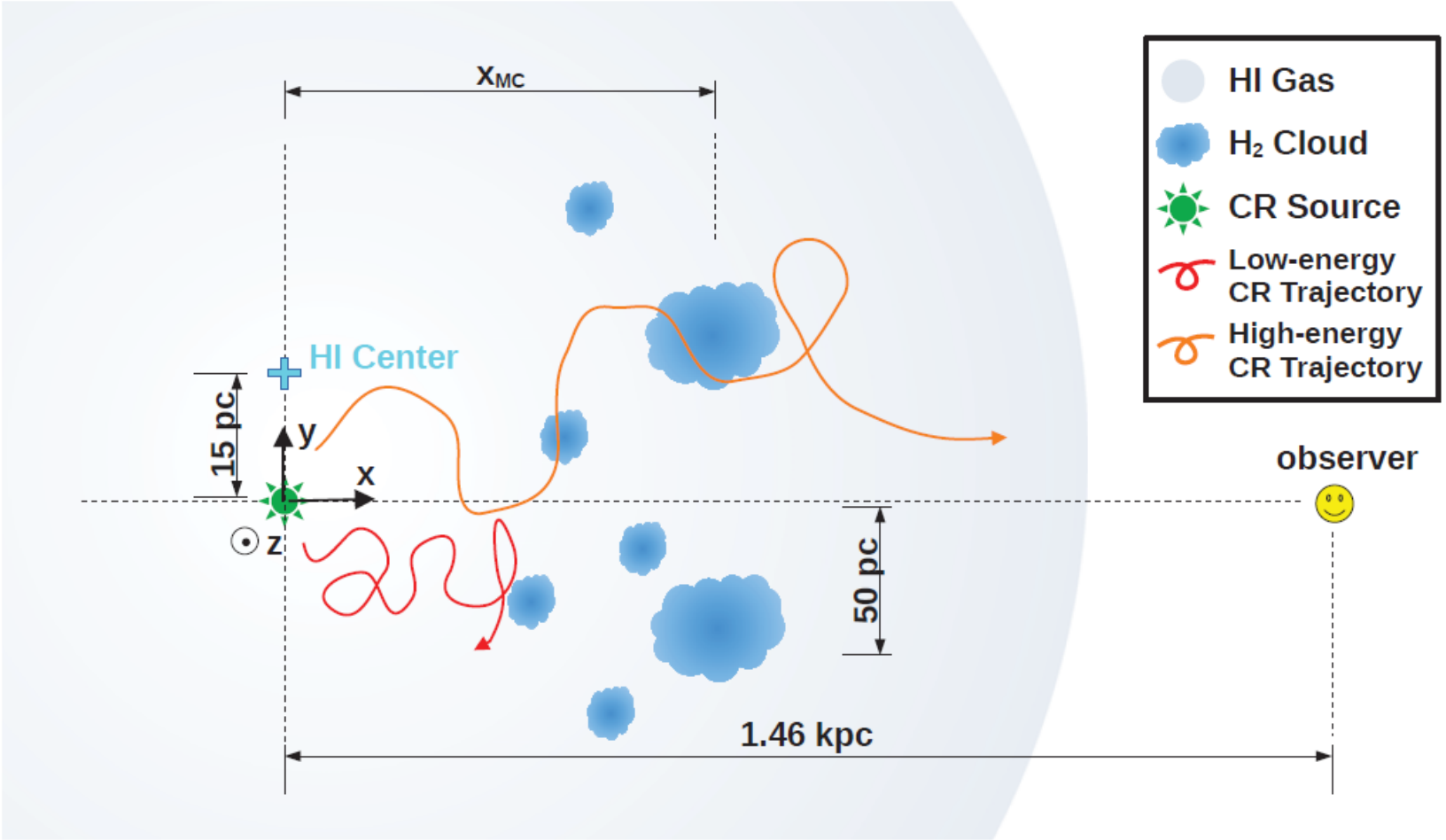
Almost background free

◆ The spectrum can extend beyond PeV without a cut-off at least up to 2PeV, which shows a slightly softening feature.

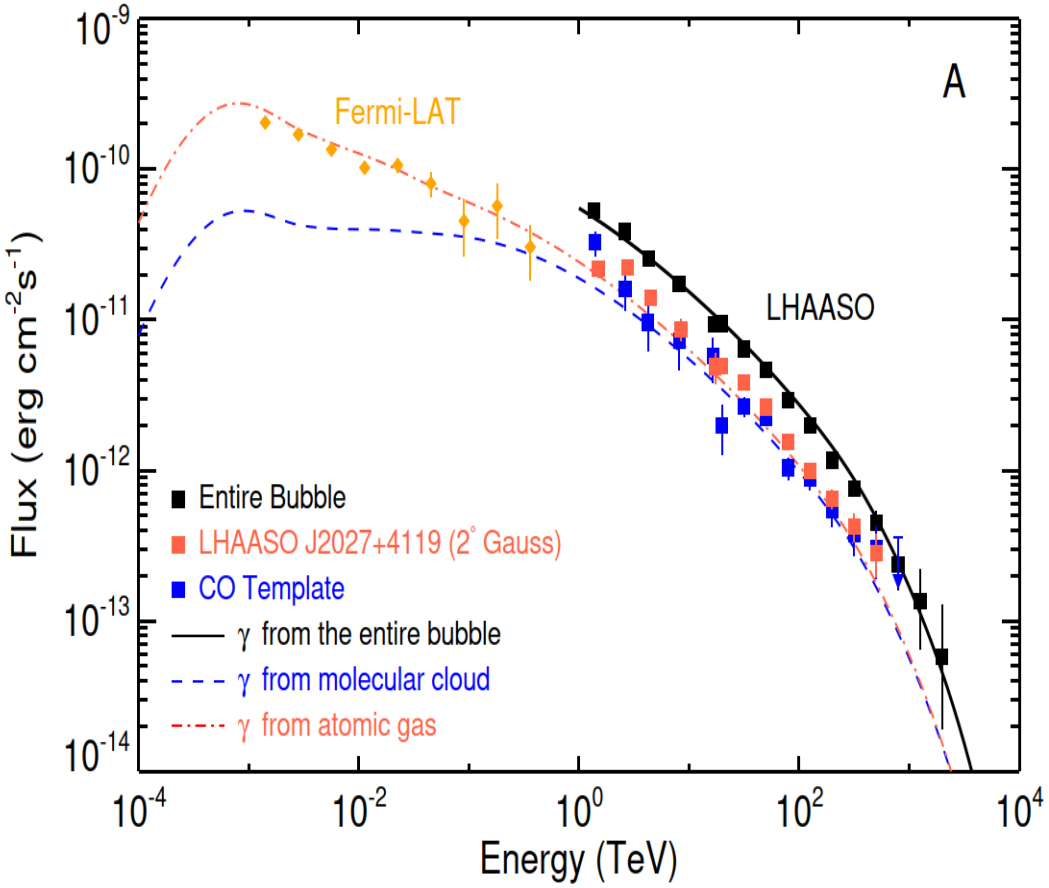
It is definitely a PeVatron, or even a Super-PeVatron

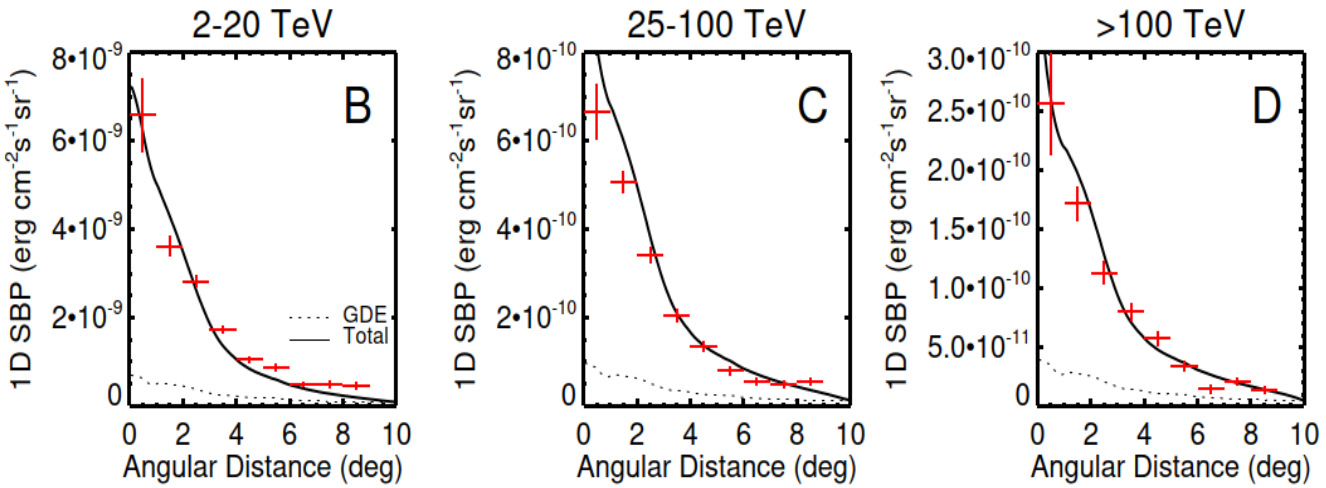
HE Protons injection from the core region

- High energy cosmic rays escape from the accelerator in the core
- Diffusing through the H1 gas and producing γ's in p-p collisions
- Hitting on clampy molecular clouds making hot-spots
- Slow diffusion ~1%DC in ISM



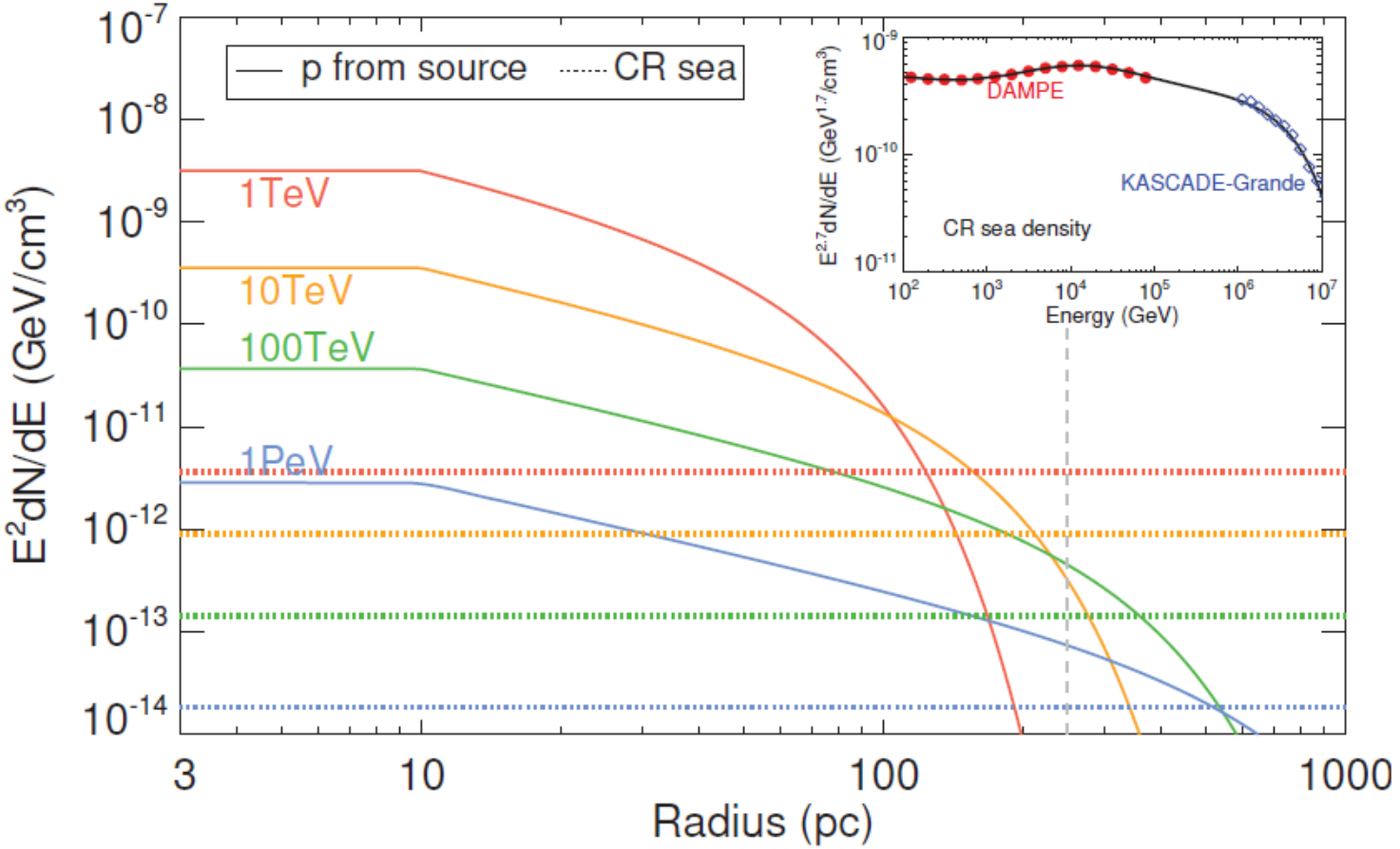
Fitting results





- The energy spectrum and morphology can be fitted well if we assume a PeV cosmic ray accelerator at the center of Cygnus region.

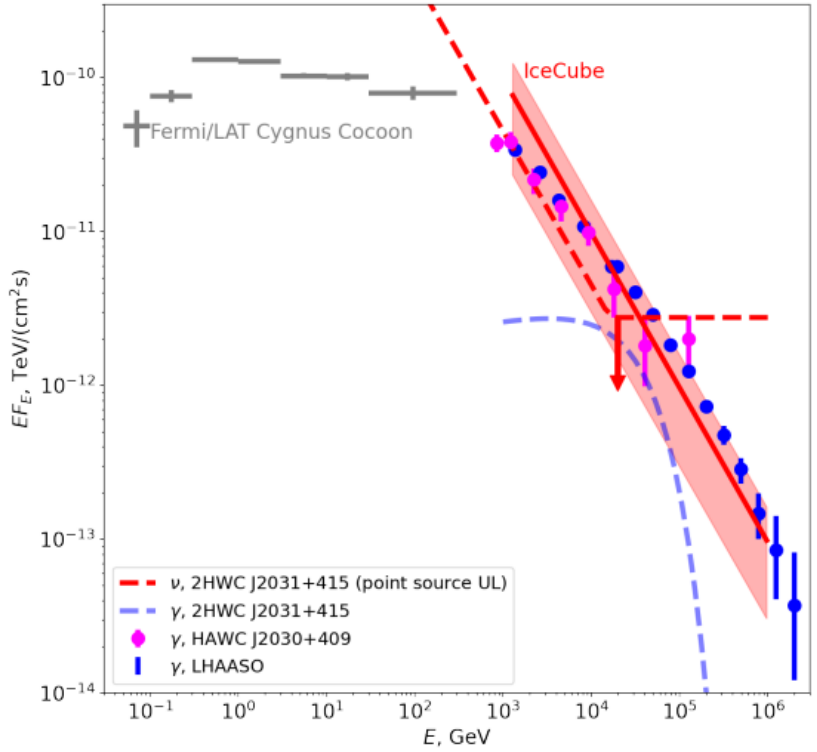
Energy-dependent cosmic ray bubble?



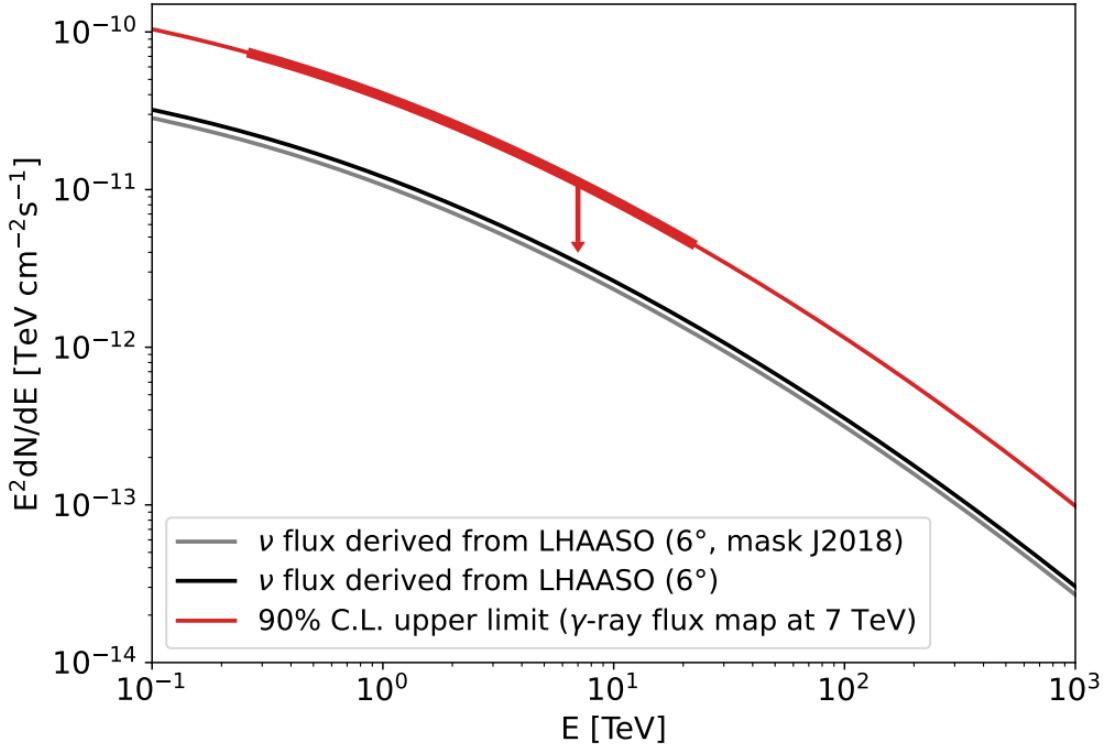
- There is a large cosmic ray bubble , which implies a rather small propagation ecoefficiency around the source.
- The size of bubble depends on the level of diffuse gamma.

Neutrino from Cygnus region?

The sensitivity of neutrino detector seems not enough now.



arXiv:2311.13711v1



arXiv.2402.17352

Conclusion

- A large scale extended emission from Cygnus direction is detected with spectrum beyond PeV, which implies a **Super-PeVatron**.

- CR interact with atomic gas and clampy molecular clouds on the way diffuse out very slowly forming the bubble and hot-spots

- The observation implies a large cosmic ray bubble extending hundreds of pc as the 1st candidate of the origin of cosmic rays beyond the knee