LHAASO
高海拔宇宙线观测站

Observations with LHAASO-1/2 and the Construction Status

Zhen Cao **for LHAASO Coll.**

Institute of High Energy Physics, Beijing

Multimessenger high energy astrophysics in the era of LHAASO, Rome, July 2020

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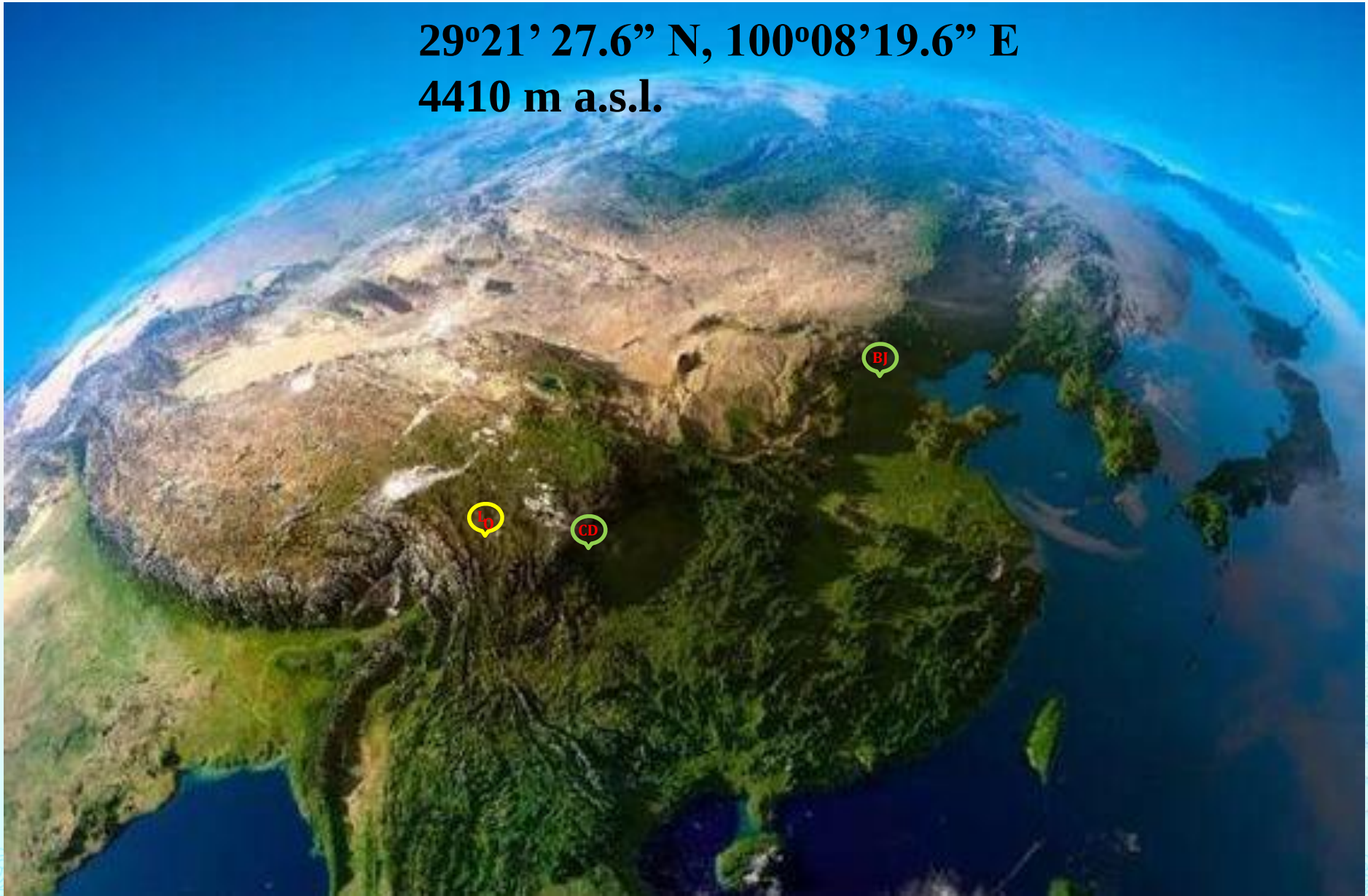
Content

- **Brief Introduction of LHAASO**
- **Construction Status and Observational Results**
- **Prospects**
- **Summary**

Where is LHAASO in the World



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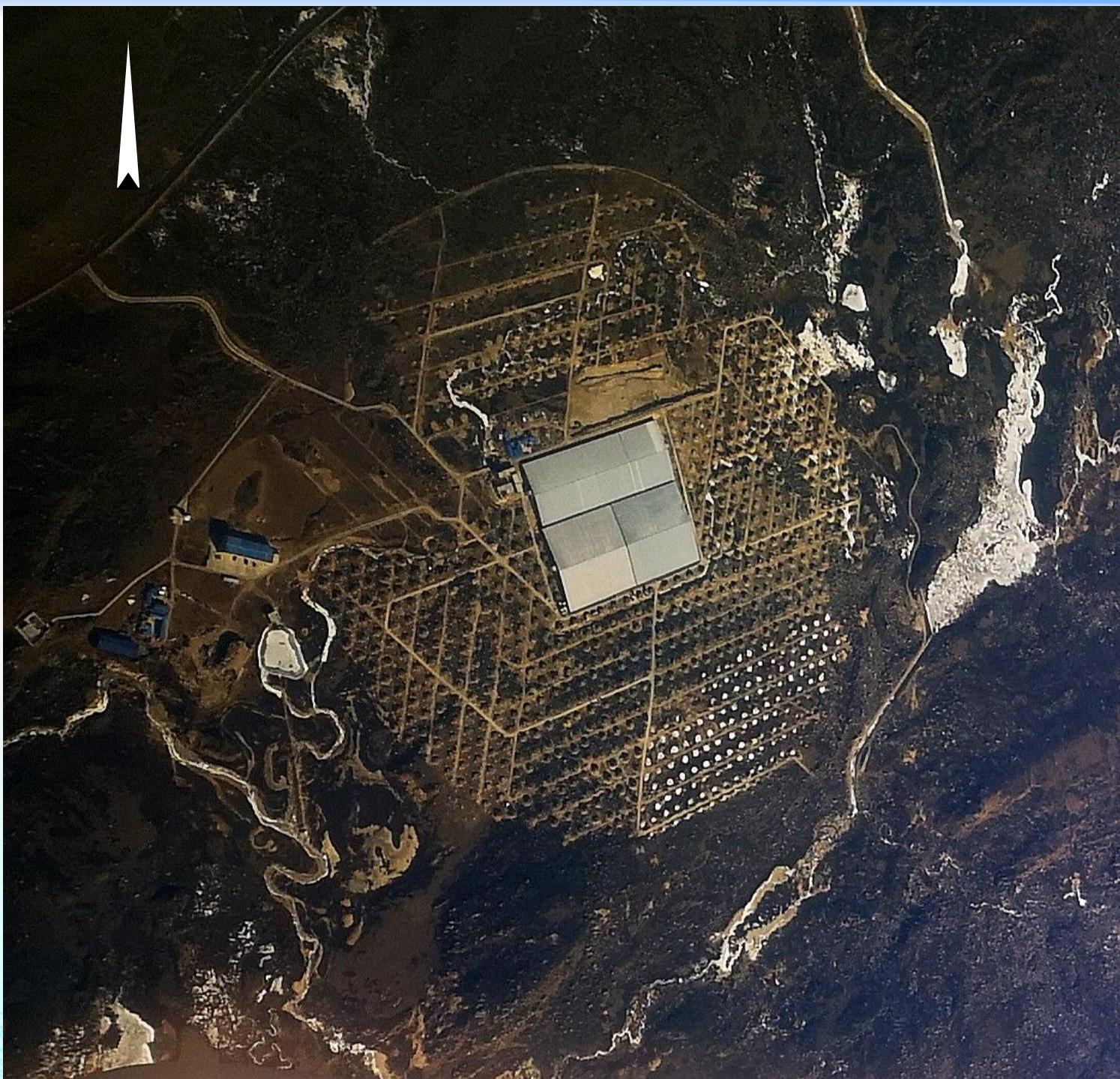
2019-12-24

Air View of LHAASO



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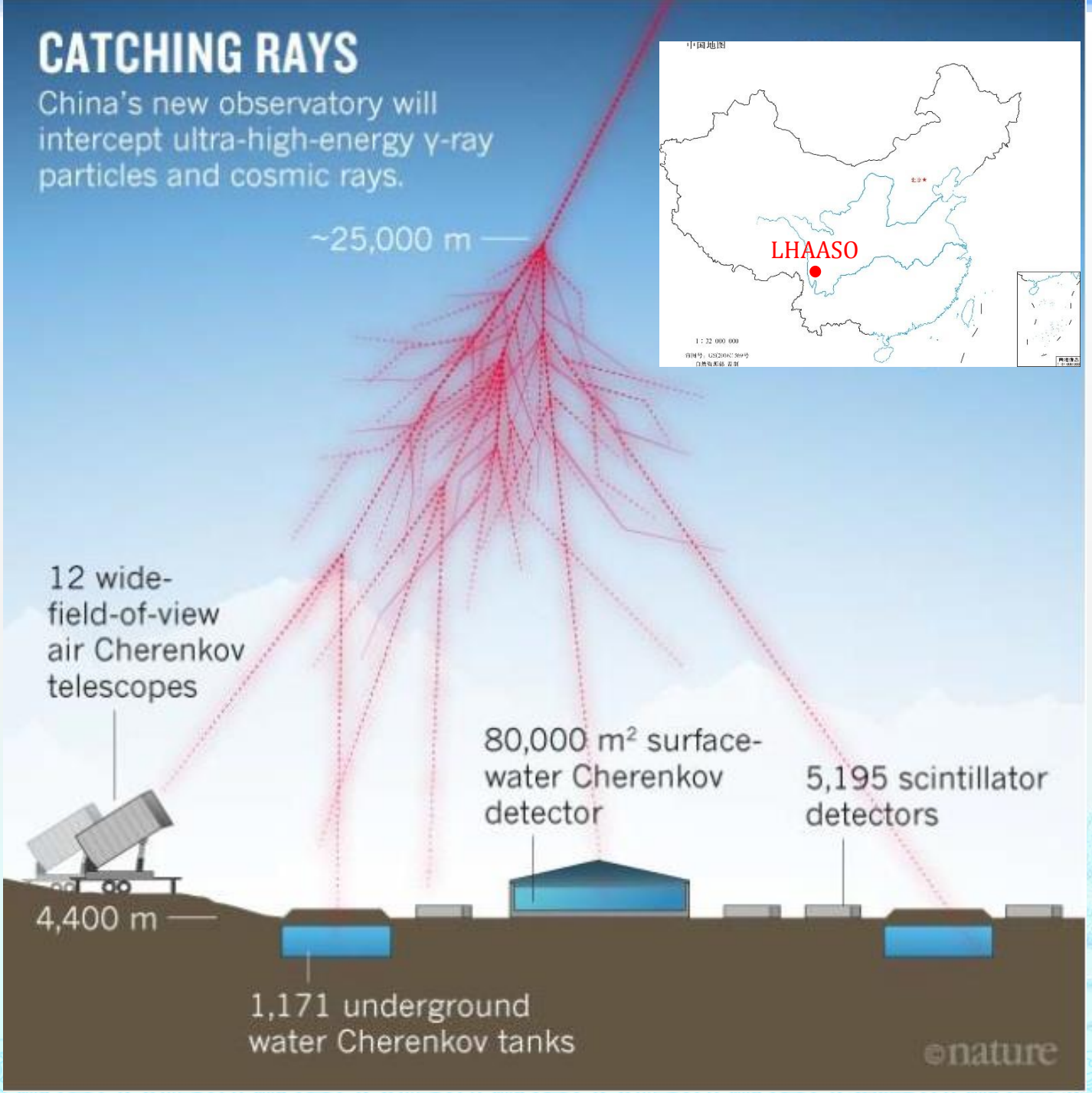
LHAASO

in the eyes of reporters from Nature



LHAASO Collaboration

Scientists: 210

Institutions: 24

The LHAASO Collaboration Zhen Cao

V. Alekseenko [22], Q. An [4], Axikegu [17], L.X. Bai [18], Y.W. Bao [13], D. Bastieri [8], X.J. Bi [1,2,3], Zhe Cao [4], Zhen Cao [1,2,3], J. Chang [14], J.F. Chang [1,3], X.C. Chang [1,3], S.P. Chao [15,1], B.M. Chen [11,1], N. Cheng [1,3], Y.D. Cheng [1,3], J. Chen [18], L. Chen [1,3], M.L. Chen [1,3], M.J. Chen [1,3], Q.H. Chen [17], S.H. Chen [1,3], S.Z. Chen [1,3], T.L. Chen [19], X.L. Chen [1,3], Y. Chen [13], S.W. Cui [11], X.H. Cui [6], Y.D. Cui [9], B.Z. Dai [20], H.L. Dai [1,3], Z.G. Dai [13], Danzengluobu[19], J. Fang [20], J.H. Fan [8], Y.Z. Fan [14], C.F Feng [15], L. Feng [14], S.H. Feng [1,3], Y.L. Feng [14,1], B. Gao [1,3], Q. Gao [19], W. Gao [15], M.M. Ge [20], L.S. Geng [1,3], G.H. Gong [5], Q.B. Gou [1,3], M.H. Gu [1,3], Y.Q. Guo [1,3], Y.Y. Guo [1,3], Y.A. Han [12], H.H. He [1,2,3], J.C. He [1,3], M. Heller [23], S.L. He [8], Y. He [17], C. Hou [1,3], D.H. Huang [17], Q.L. Huang [1,3], W.H. Huang [15], X.T. Huang [15], H.B. Hu [1,2,3], S. Hu [18], H.Y. Jia [17], K. Jiang [4], F. Ji [1,3], C. Jin [1,3], X.L. Ji [1,3], K. Levochkin [22], E.W. Liang [10], Y.F Liang [10], Cheng Li [4], Cong Li [1,3], F. Li [1,3], H. Li [11], H.B. Li [1,3], H.C. Li [1,3], H.M. Li [5], H.T. Li [7], J. Li [1,3], K. Li [1,3], W.L. Li [15], X. Li [17,1], X.R. Li [1,3], Y. Li [18], Z. Li [1,3], B. Liu [13], C. Liu [1,3], D. Liu [15], H.D. Liu [12], H. Liu [17], J. Liu [1,3], J.Y. Liu [1,3], M.Y. Liu [19], R.Y. Liu [13], S.M. Liu [14], W. Liu [1,3], Y.N. Liu [5], Z.X. Liu [18], W.J. Long [17], R. Lu [20], H.K. Lv [1,3], L.L. Ma [1,3], J.R. Mao [21], A. Masood [17], X.H. Ma [1,3], W. Mitthumsiri [24], T. Montaruli [23], Y.C. Nan [15,1], P. Pattarakijwanich [24], Z.Y. Pei [8], B.Q. Qiao [14,1], M.Y. Qi [1,3], D. Ruffolo [24], V. Rulev [22], A. Sáiz [24], L. Shao [11], O. Shchegolev [22], X.D. Sheng [1,3], J.R. Shi [1,3], Y. Stenkin [22], V. Stepanov [22], Z.B. Sun [7], B.X. Tan [9], Z.B. Tang [4], W.W. Tian [6], D.D. Volpe [23], C. Wang [7], H. Wang [17], H.G. Wang [8], J.C. Wang [21], L.Y. Wang [1,3], W. Wang [9], X.G. Wang [10], X.Y. Wang [13], X.J. Wang [1,3], Y.D. Wang [1,3], Y.J. Wang [1,3], Y.N. Wang [17], Y.P. Wang [1,3], Z. Wang [1,3], Z.H. Wang [18], Z.X. Wang [16], D.M. Wei [14], J.J. Wei [14], T. Wen [20], C.Y. Wu [1,3], H.R. Wu [1,3], S. Wu [1,3], W.X. Wu [17], X.F. Wu [14], G.M. Xiang [16,1], G. Xiao [1,3], G.G. Xin [1,3], Y. Xing [16], L. Xue [15], X.R. Yao [7], D.H. Yan [21], C.W. Yang [18], F.F. Yang [1,3], L.L. Yang [9], M.J. Yang [1,3], R.Z. Yang [4], S.B. Yang [20], Y.H. Yao [18,1], Z.G. Yao [1,3], Y.M. Ye [5], L.Q. Yin [1,3], N. Yin [15], X.H. You [1,3], Z.Y. You [1,3], Q. Yuan [14], Y.H. Yu [15], Z.J. Jiang [20], H.D. Zeng [14], T.X. Zeng [1,3], W. Zeng [20], Z.K. Zeng [1,3], M. Zha [1,3], B.B. Zhang [13], H.M. Zhang [13], H.Y. Zhang [15], J.L. Zhang [6], J.W. Zhang [18], L. Zhang [20], P.F. Zhang [20], P.P. Zhang [11], S.R. Zhang [11], S.S. Zhang [1,3], X. Zhang [13], X.P. Zhang [1,3], Yi Zhang [1,3], Yong Zhang [1,3], Y.F.g Zhang [17], B. Zhao [17,1], J. Zhao [1,3], L. Zhao [4], L.Z. Zhao [11], F. Zheng [7], Y. Zheng [17], J.N. Zhou [16], P. Zhou [13], R. Zhou [18], X.X. Zhou [17], C.G. Zhu [15], F.R. Zhu [17], H. Zhu [6], K.J. Zhu [1,3], X. Zuo [1,3],

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list of institutions waiting : Adelaide U., Australia

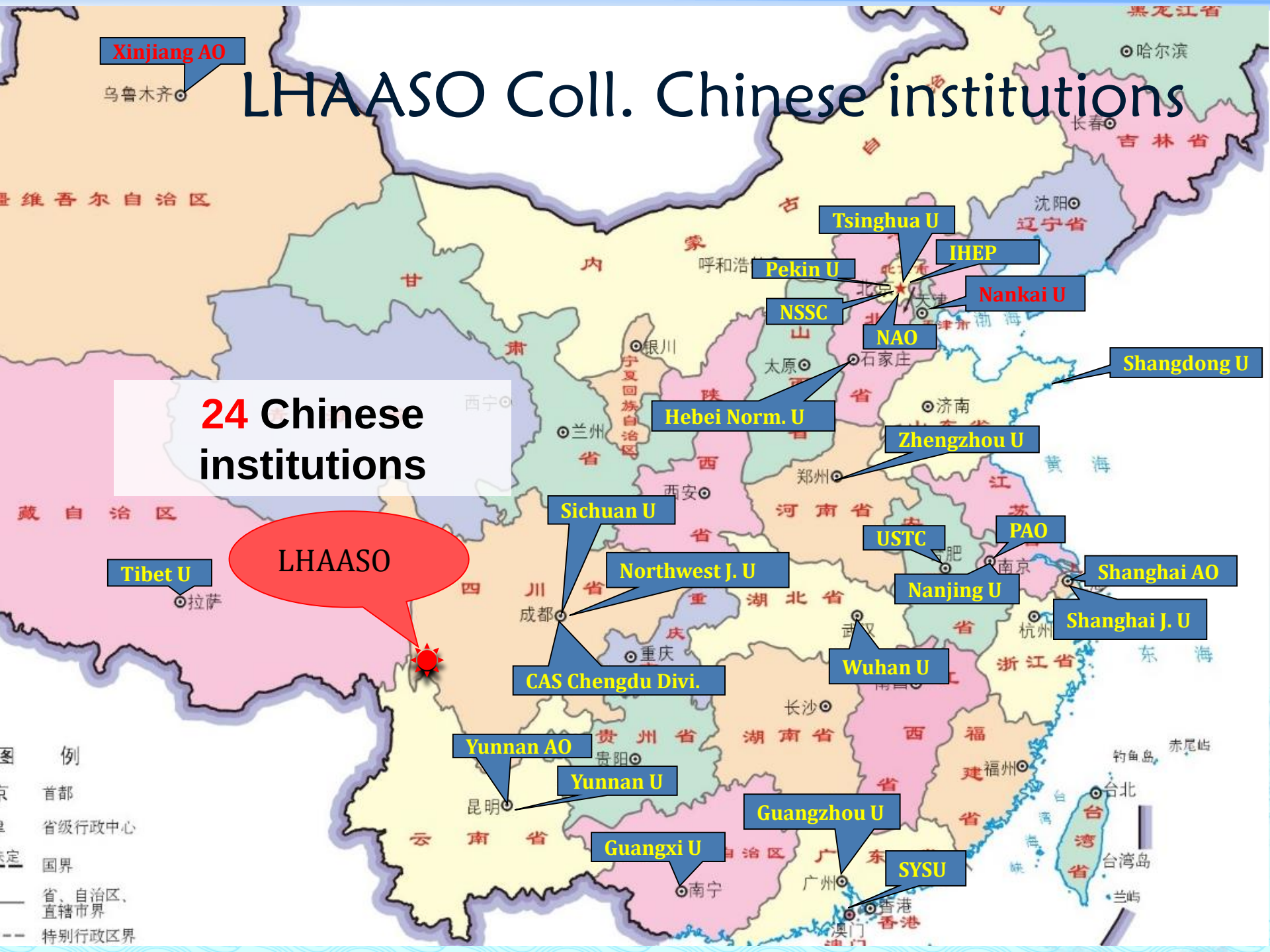
for membership: APS, France

Nankai U., China

Xinjiang Observatory, China

LHAASO Collaboration (by country)

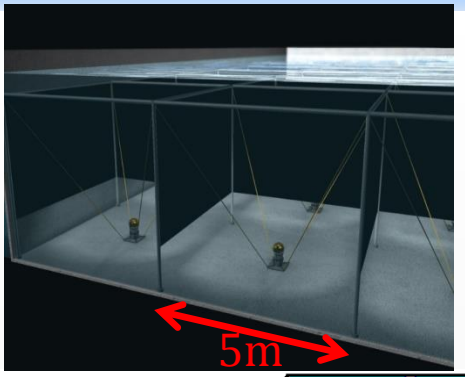
LHAASO Coll. Chinese institutions

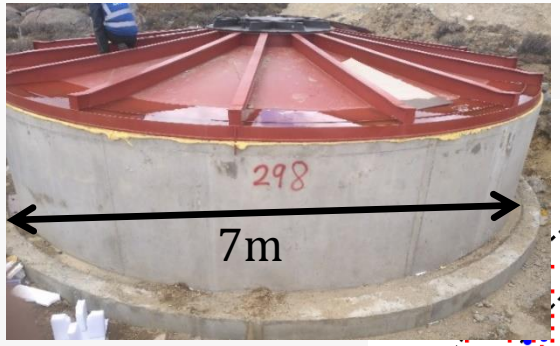


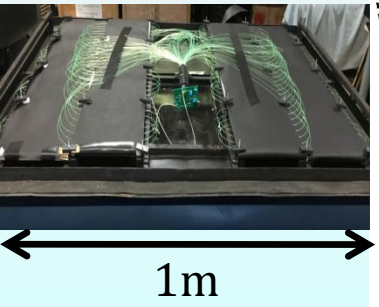
LHAASO
高海拔宇宙线观测站

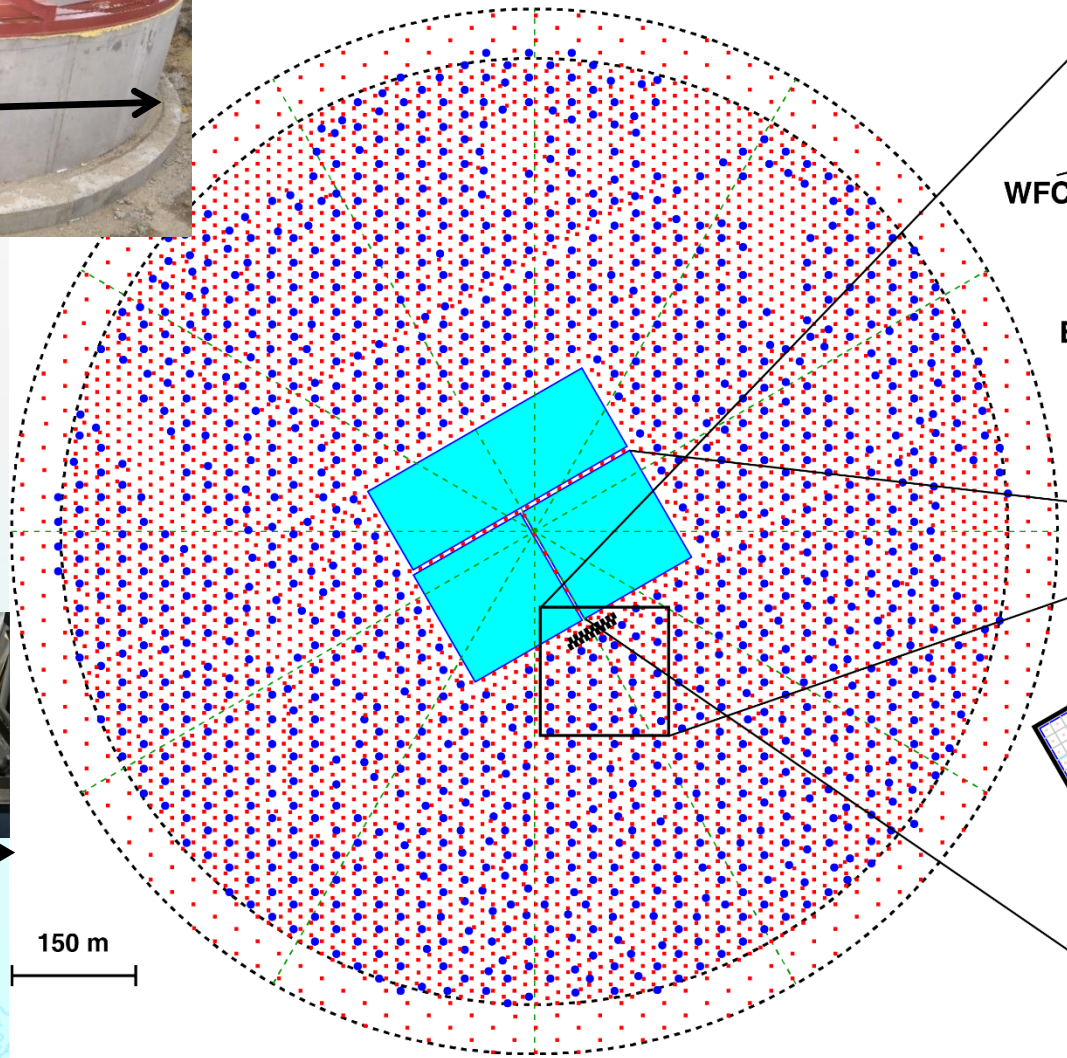
- Brief Introduction of LHAASO
- **Construction Status and Observational Results**
  - **Scintillator-Muon Counter Array (KM2A)**
  - **Water Cherenkov Detector Array (WCDA)**
  - **Wide FoV Cherenkov Telescope Array (WFCTA)**
- Prospects:
- Summary

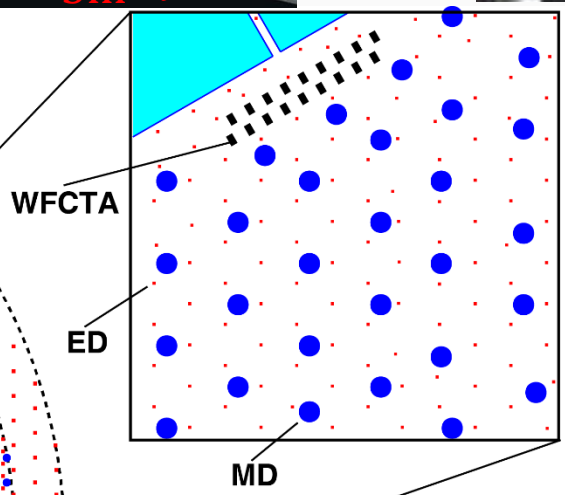
Detector Layout in LHAASO

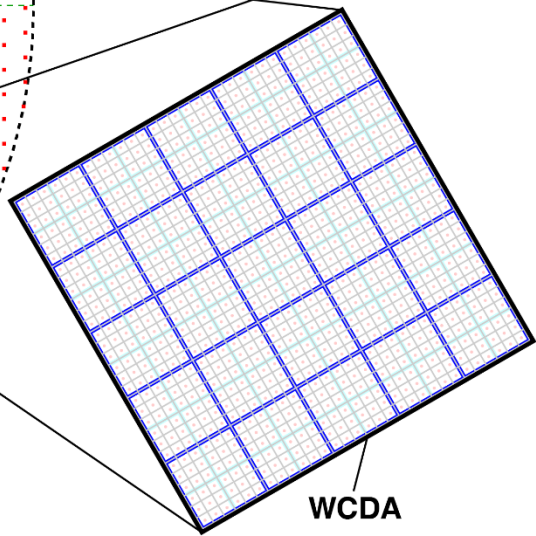












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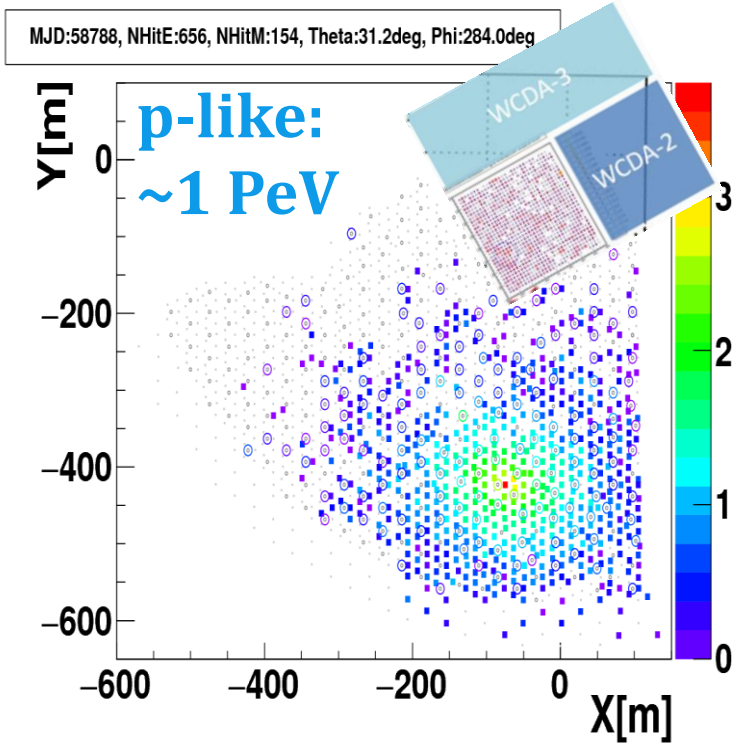
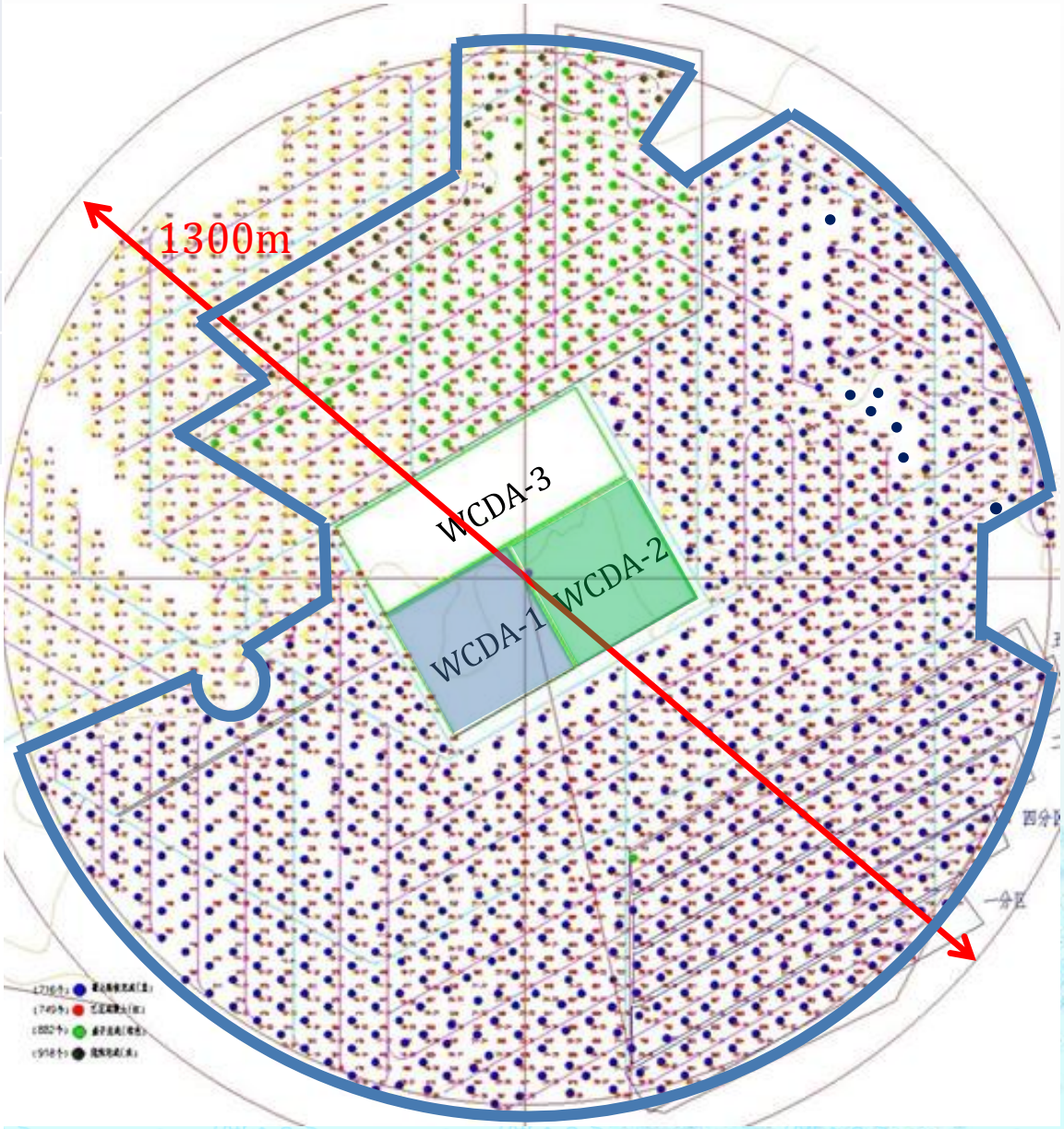
Western view

Eastern view

LHAASO bird view in Oct. 2019

2019- 12- 12	Muon Counter	Scintillator Detector
operating	594	2514
2010-09-31		
operating	**915**	**3948**
Percentage of designed sensitivity	**88%**	

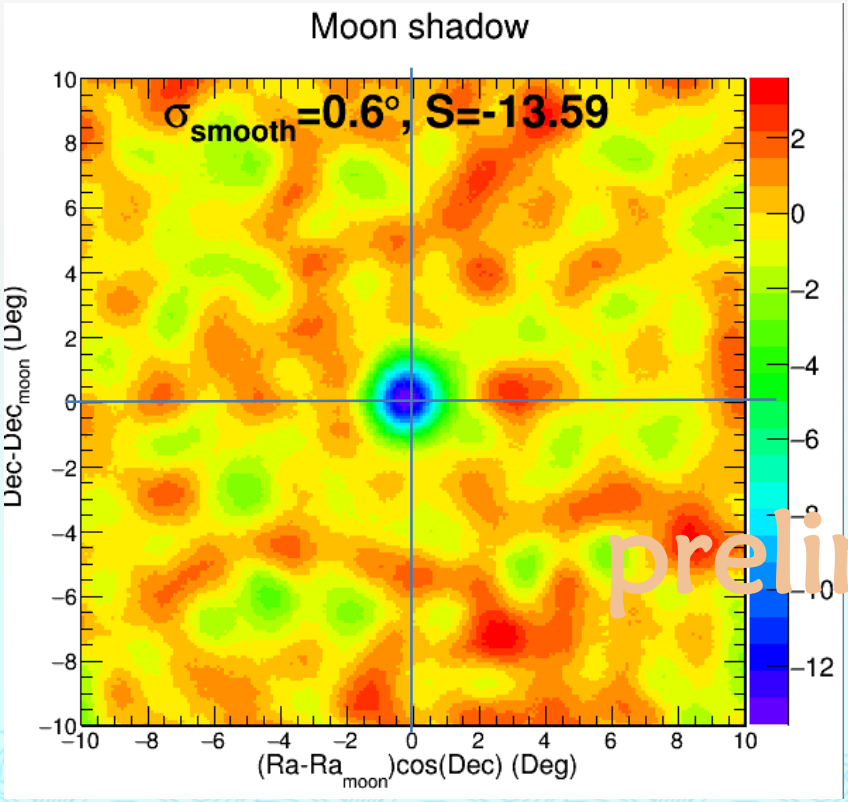




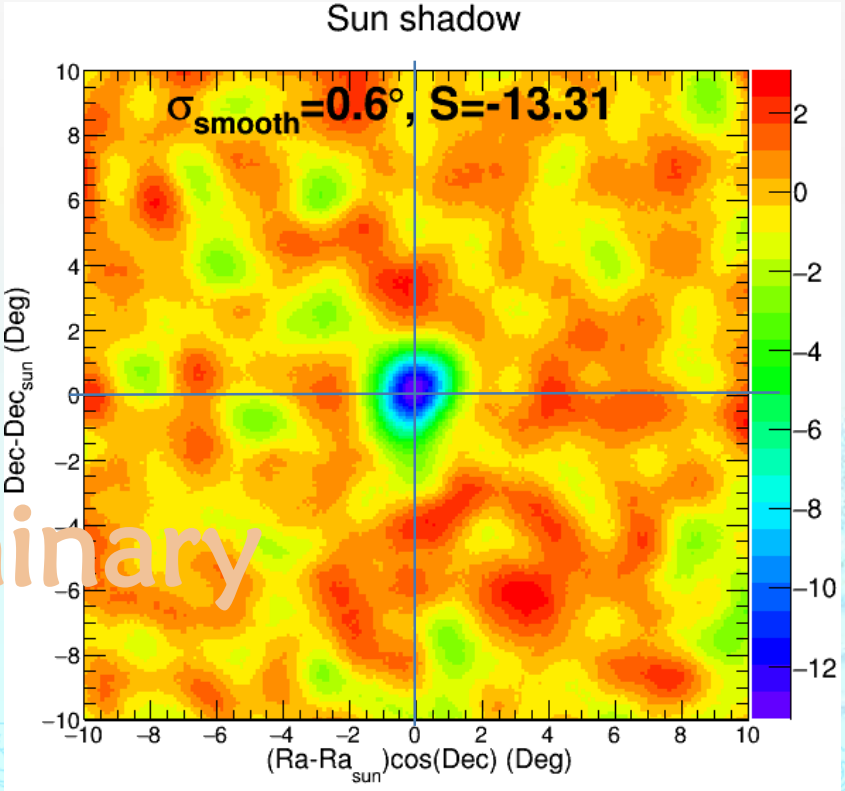
Data: from 2019-07-20 to 2019-10-30

White Rabbit Synchronized TDCs

Moon shadow: -13.6 σ
R.A.=-0.10 Dec=0.10



Sun shadow: -13.3 σ
R.A.=0.00 Dec=0.00



preliminary

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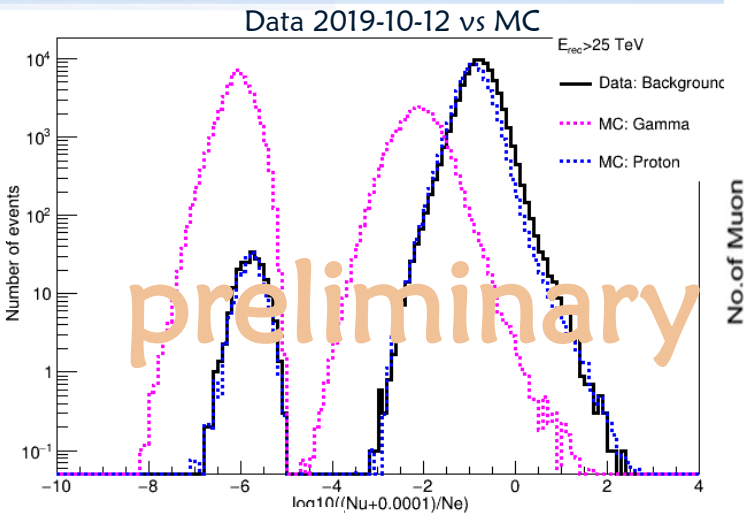
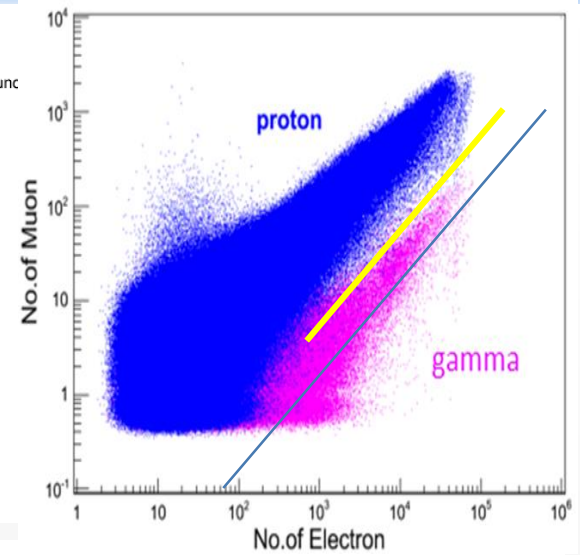
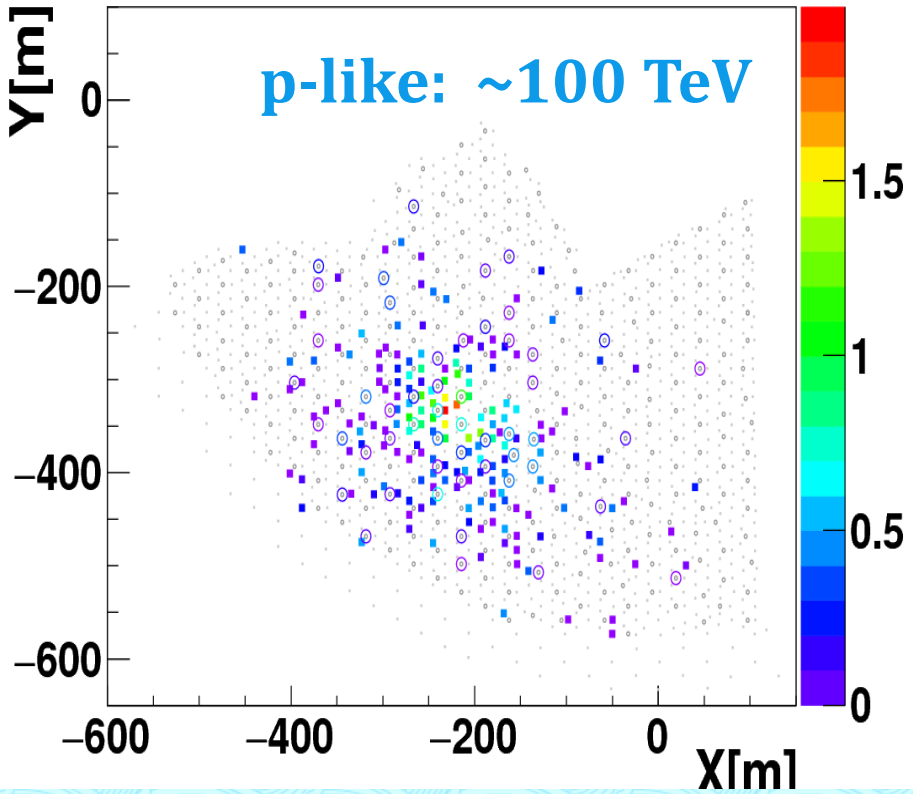
γ/proton Separation: μ-content

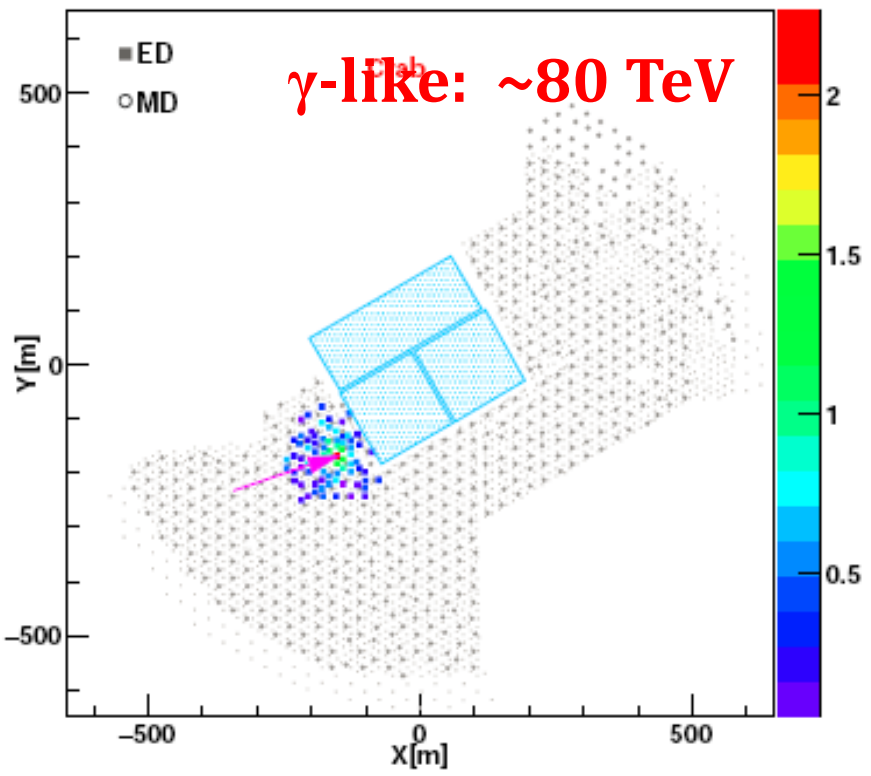




MJD:58788, NHitE:216, NHitM:51, Theta:29.4deg, Phi:333.8deg

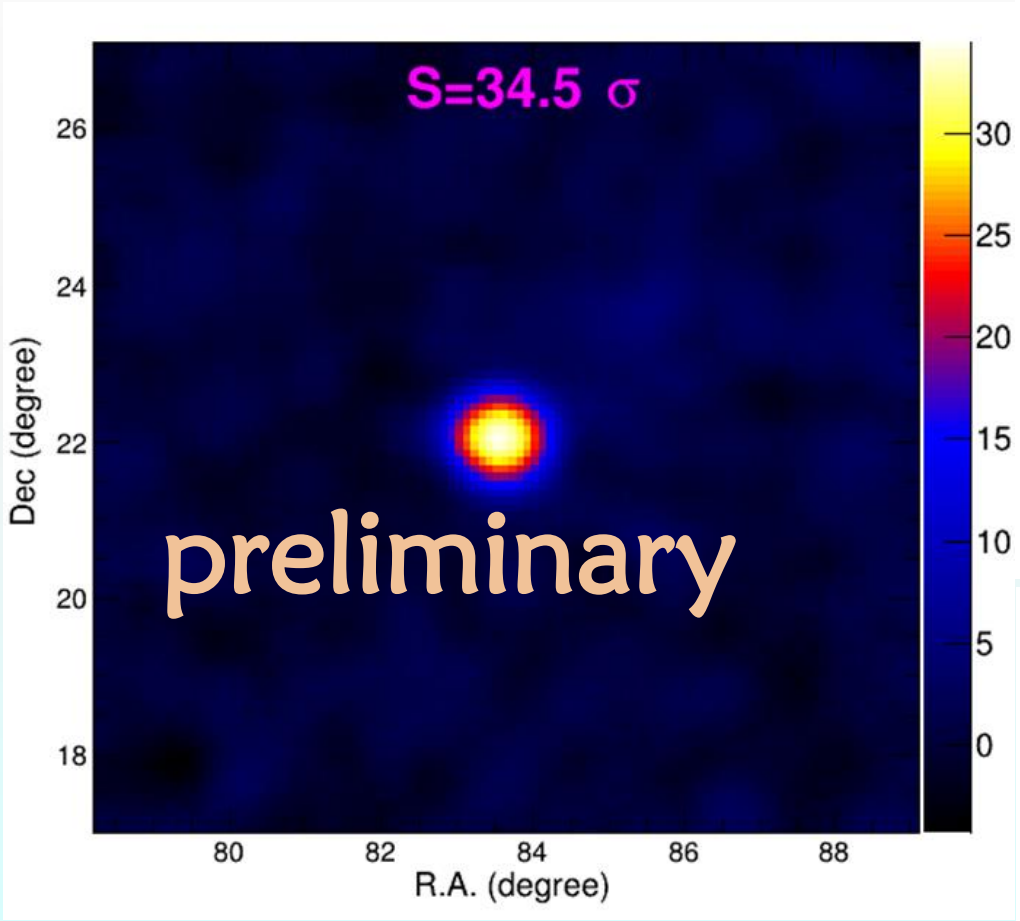


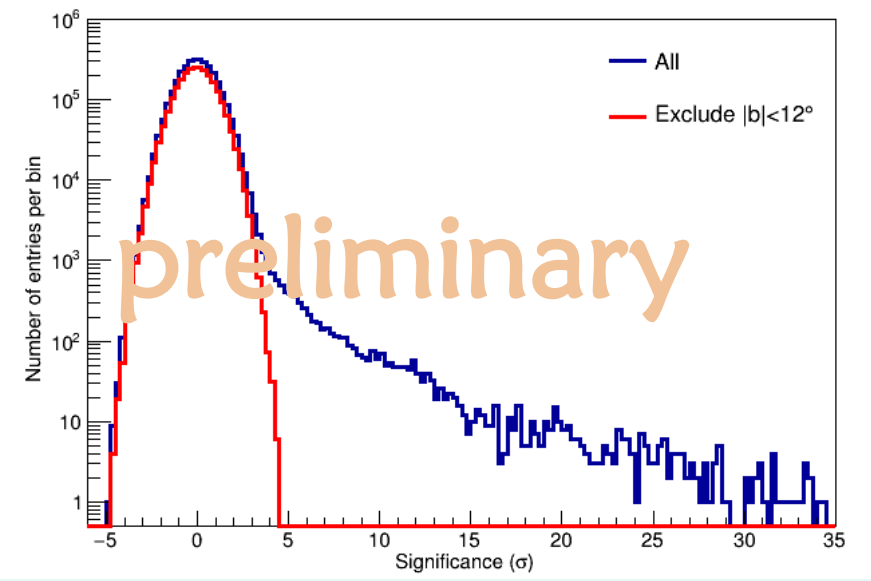
MJD : 58908.57, Ne : 465.8, Nu : 0.0, E_{hlt}: 99.0TeV, E_{pe}: 80.9TeV

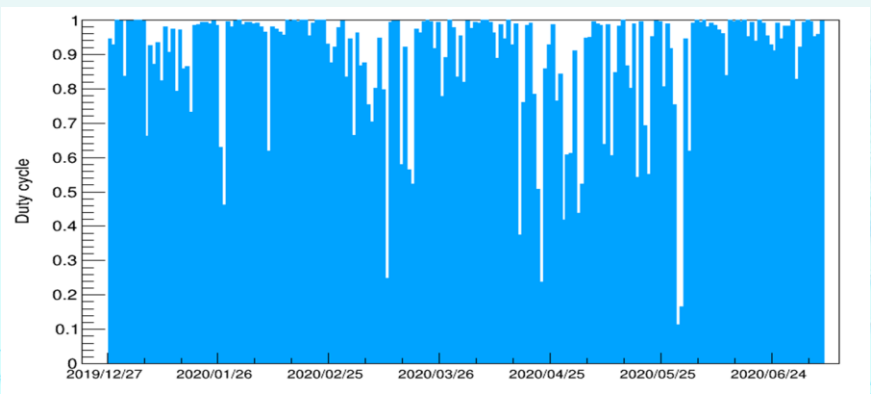


Standard Candle

- 2019-09-11 to 2020-07-07
- Pointing accuracy: ~0.1°
- Angular resolution: 0.26°
- Significance: 35 σ at 25 TeV







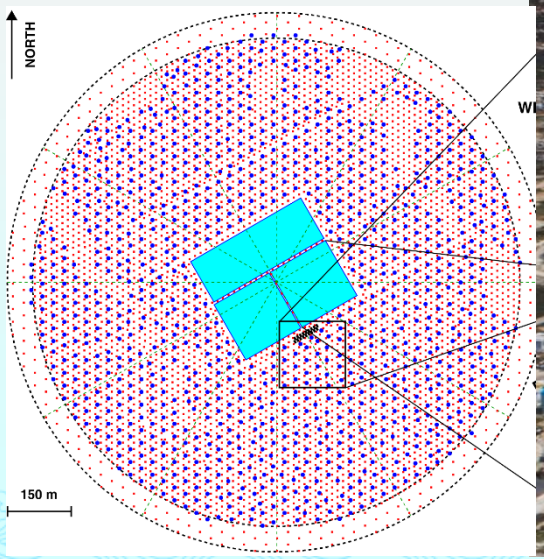
Water Cherenkov Detector Array

3 Arrays

1: 22,500 m^2 8”PMTs

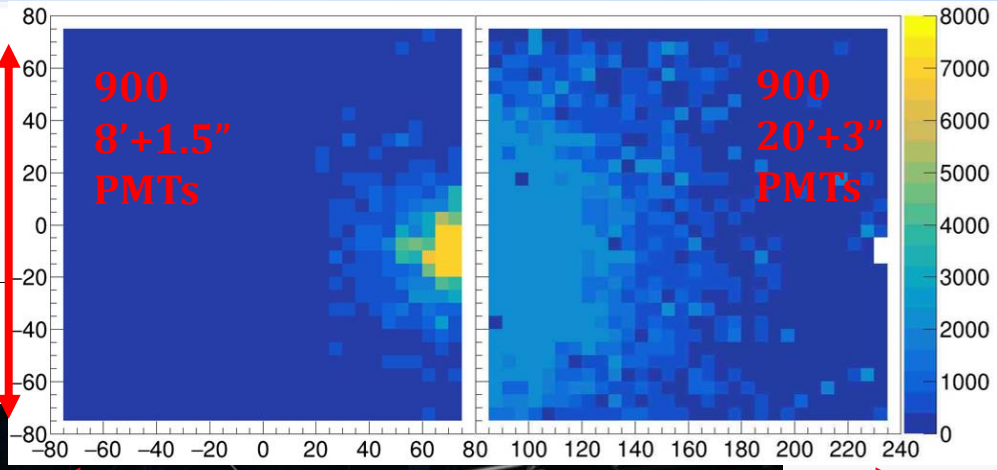
2: 22,500 m^2 20”PMTs

3: 33,000 m^2 20”PMTs

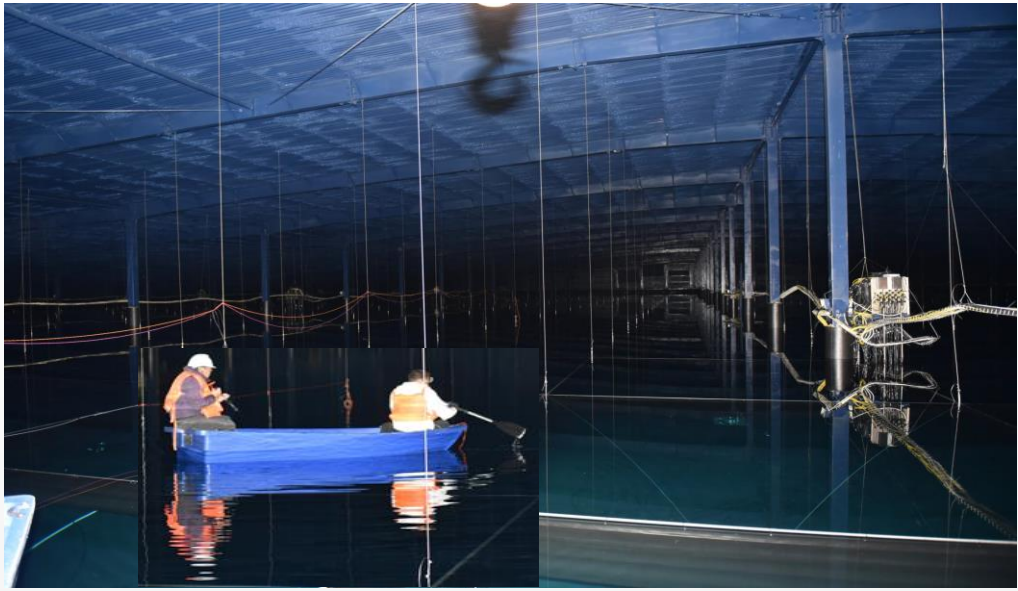


Inside WCDA-3

- WCDA-1 started operating April 2019
- WCDA-1 started operating January 2020

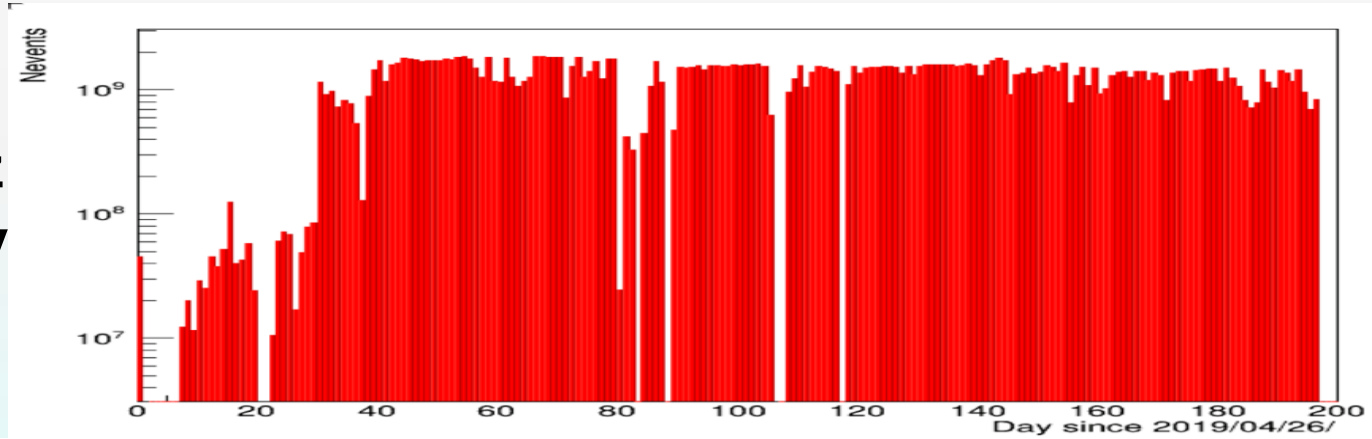


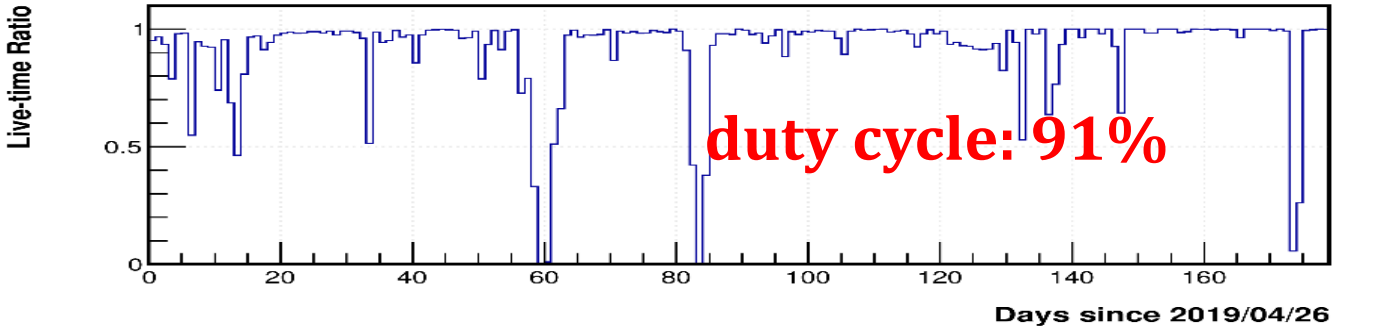
WCDA-1 in operation since 2019-4



- Detector: 22.5kHz/ch
- Event rate: 18 kHz
- Water atten. Length: ~15m

Trigger rate：
~20k Hz
1.7B event/day





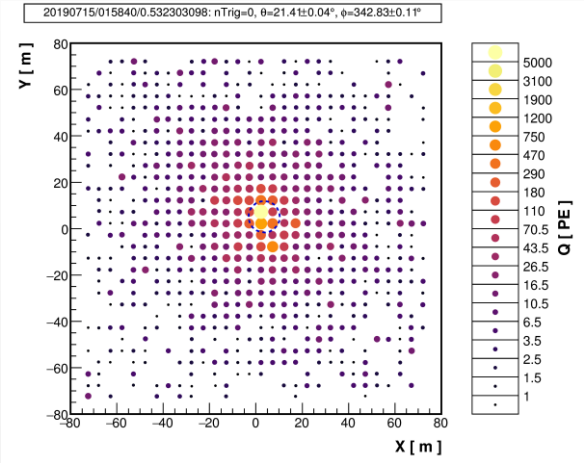
2019-04-26 to 2019-11-10, $3x10^{11}$ events collected

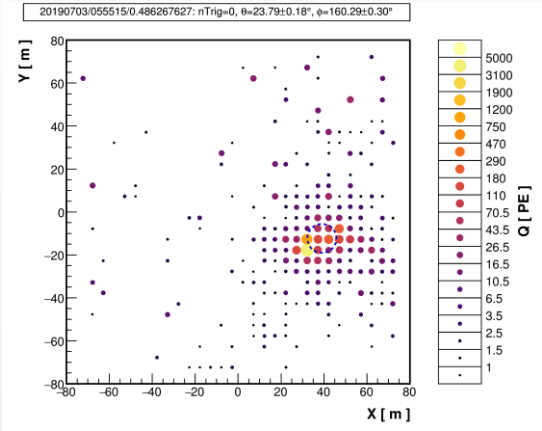
Pure Gamma Event Set!

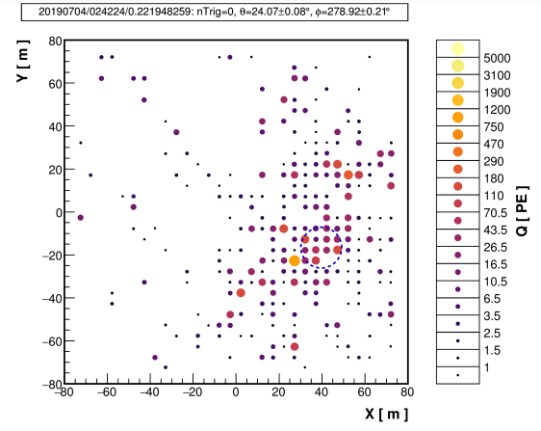
γ-like, N_{hit}=236

hadron-like, N_{hit}=261

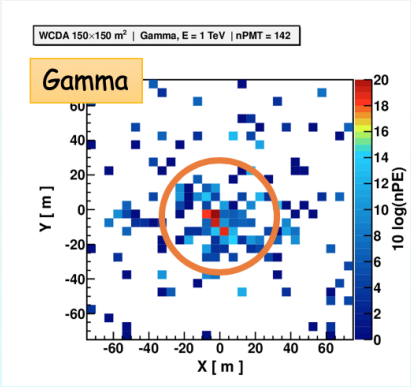
Data

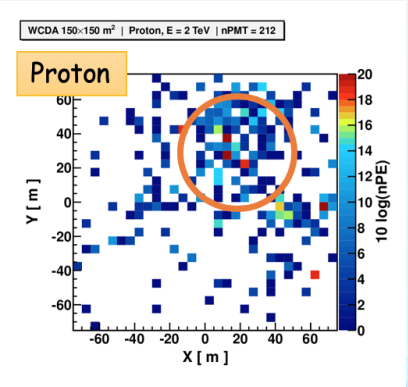






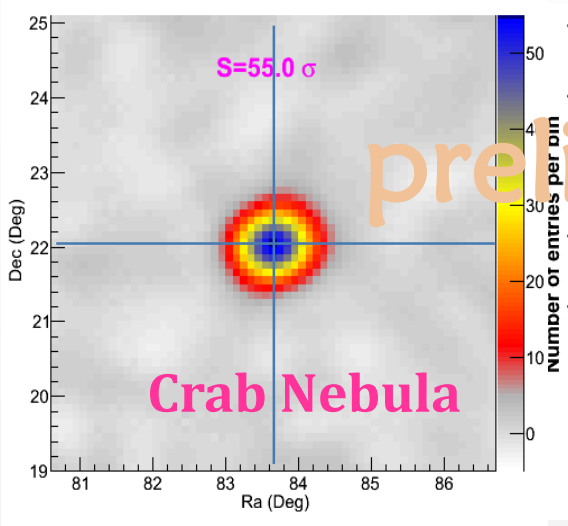
MC

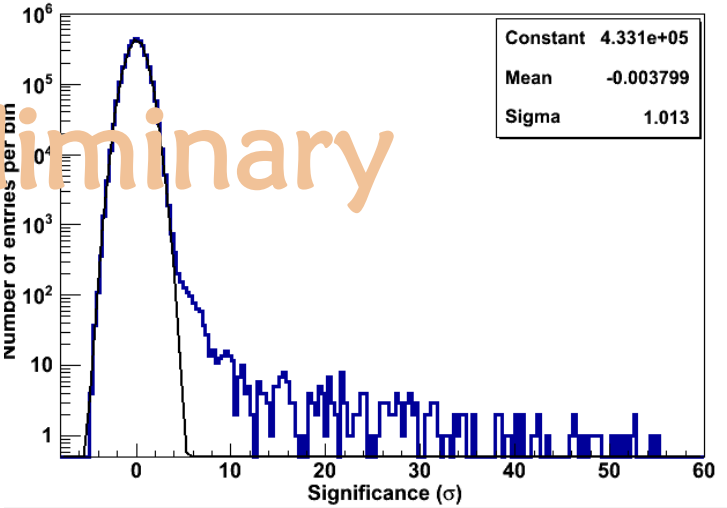


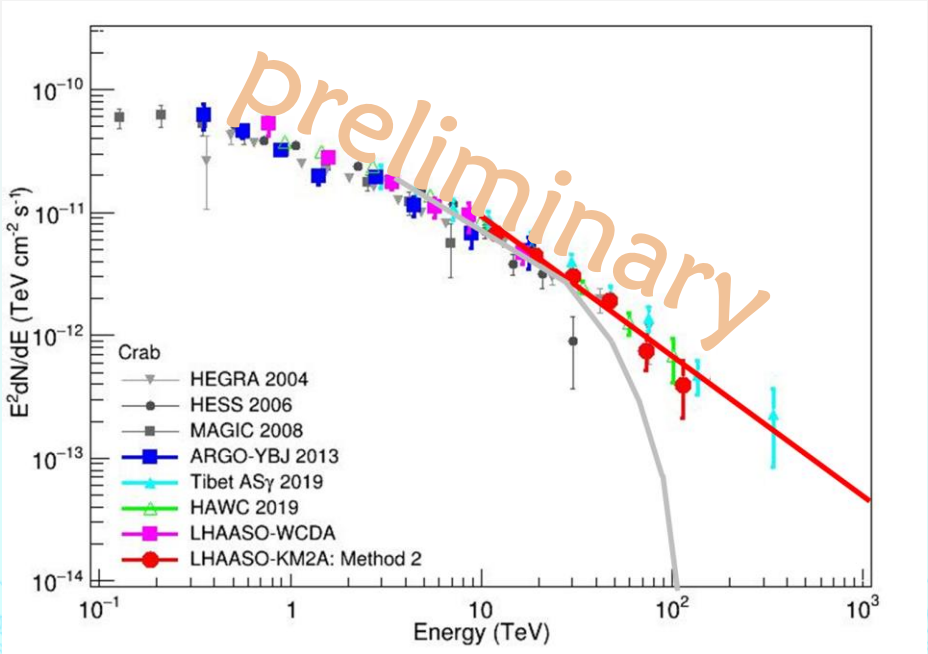


Standard Candle for WCDA & KM2A

- Up to 2019-11-04
- Crab 55 σ (E>1 TeV) implying 70 σ/yr by WCDA-1
- Pointing error <0.1˚



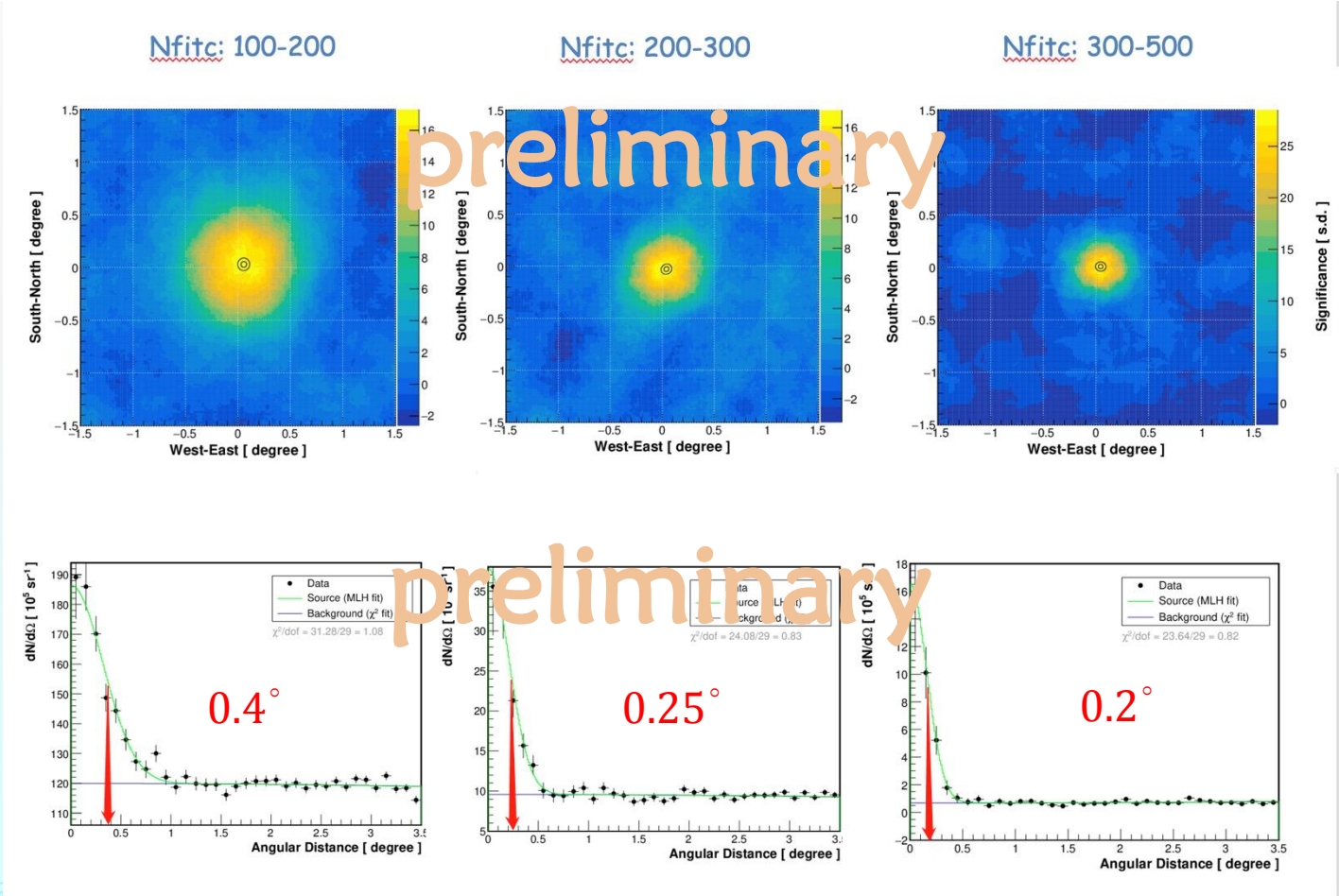




- Not only for the Crab Nebula
- All sources have clear power law spectra in UHE region
- no indication of cut-off
- Posting challenges to models with limits of accelerating power of galactic sources

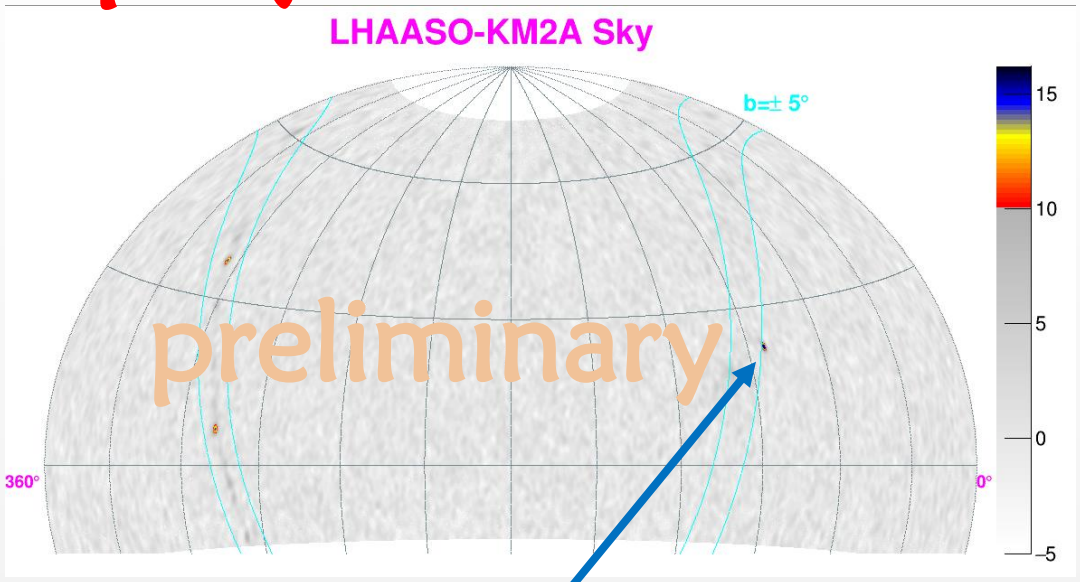
Pointing and Resolution

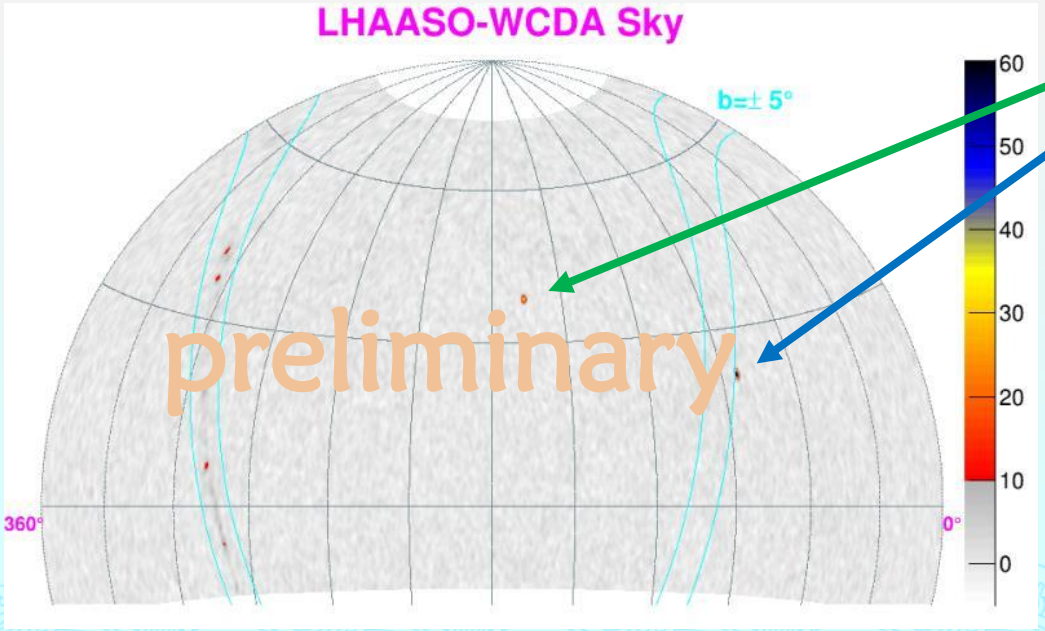
- Pointing accuracy is already good, though we still found the orientation of WCDA-1 29.45° towards west instead of 30.00° that results in an even better pointing



Sky Map by LHAASO

Below 10TeV by WCDA
Sensitivity: 60 mC.U.
PSF： 0.26°
Survey for 300 days：
6 sources >10σ



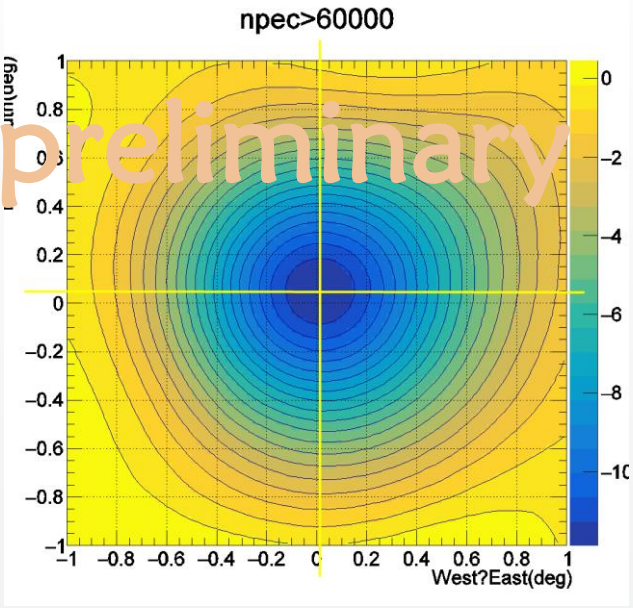


Mkr 421
Crab Nebula

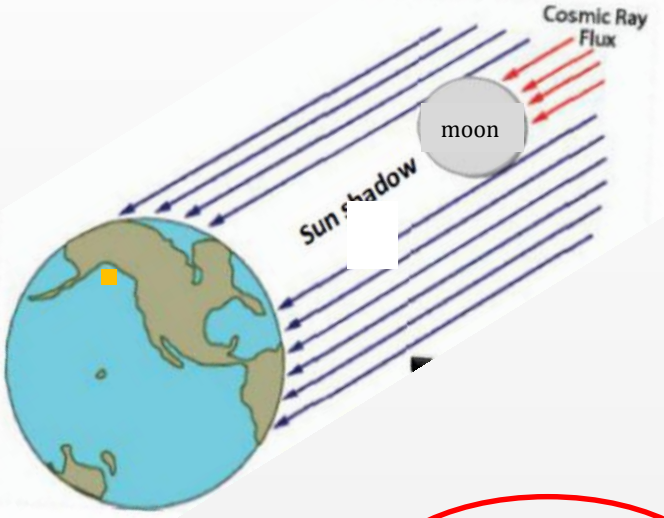
above 100TeV by KM2A
Sensitivity: 0.1C.U.
PSF： 0.26°
Survey for 173 days：
3 sources >10σ

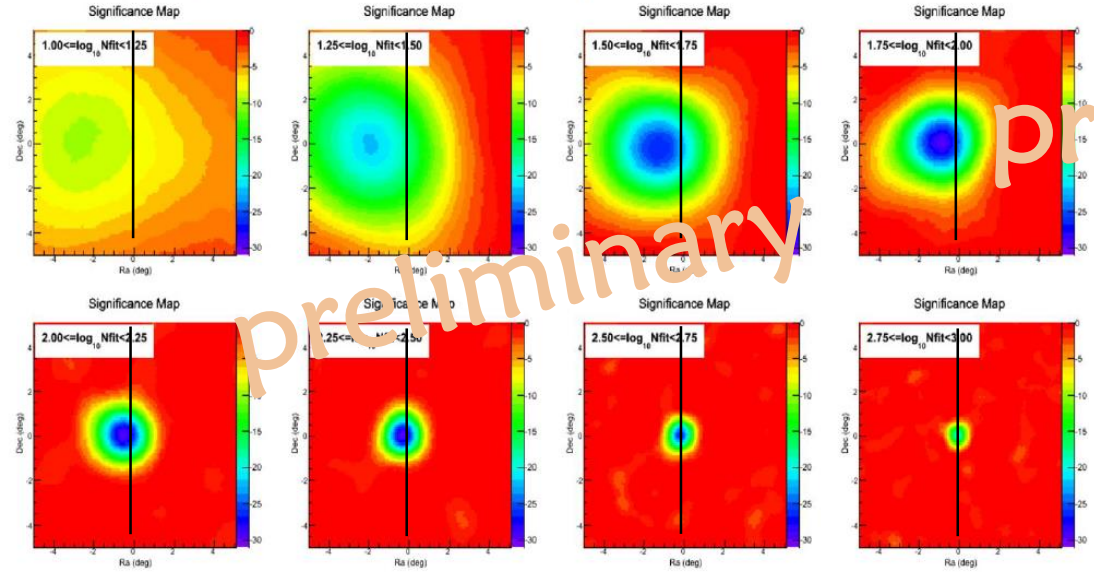
Deflection of the Moon shadow in CRs

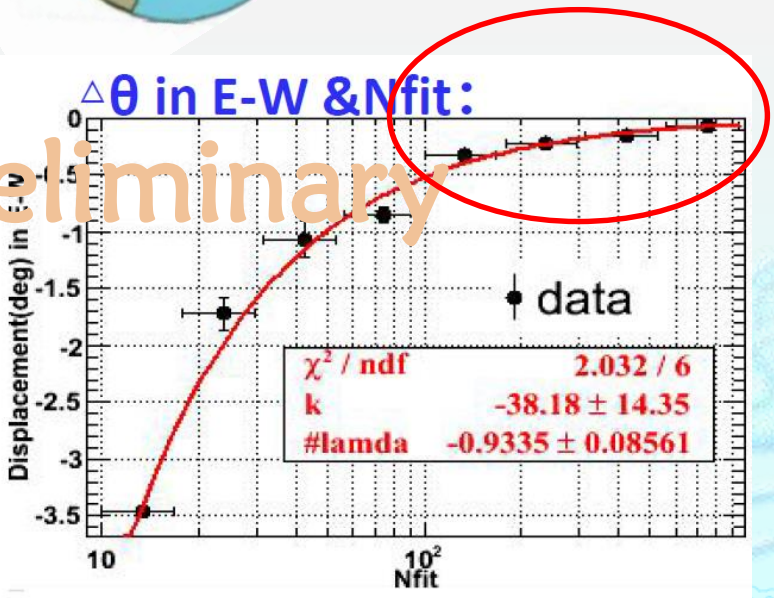
Geo Magnetic Spectrometer



E > 50 TeV
Moon shadow
Pointing
Error: ~0.03°
statistical error
dominates







Energy Scale in HE Shower Measurements

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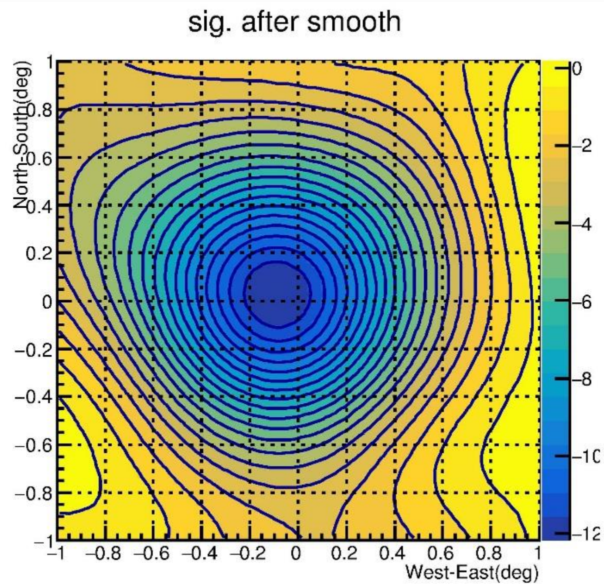
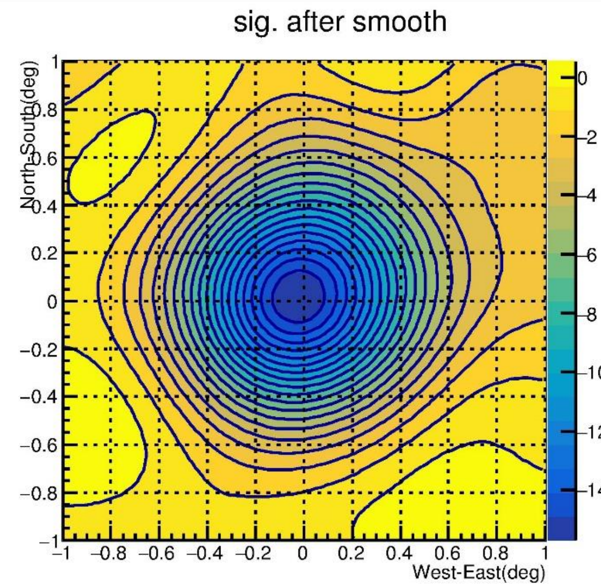
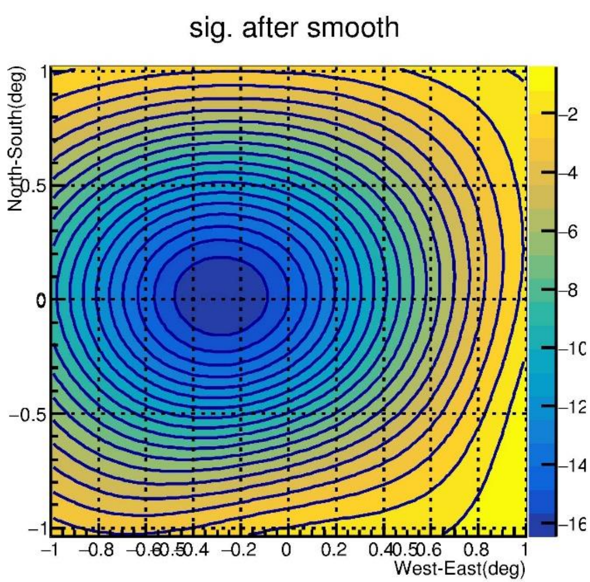
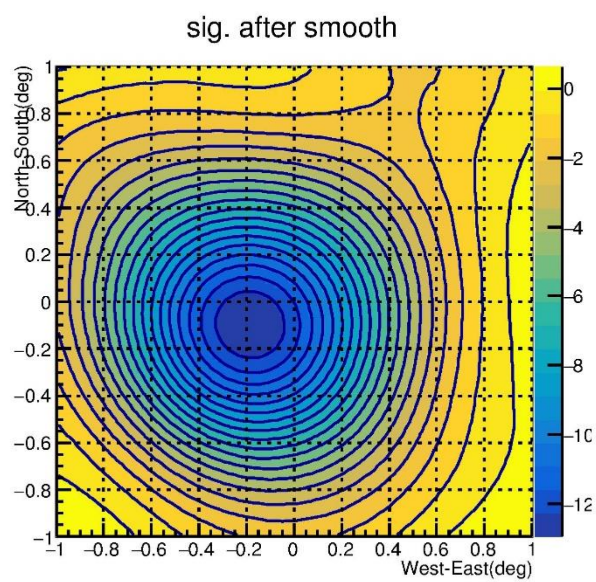
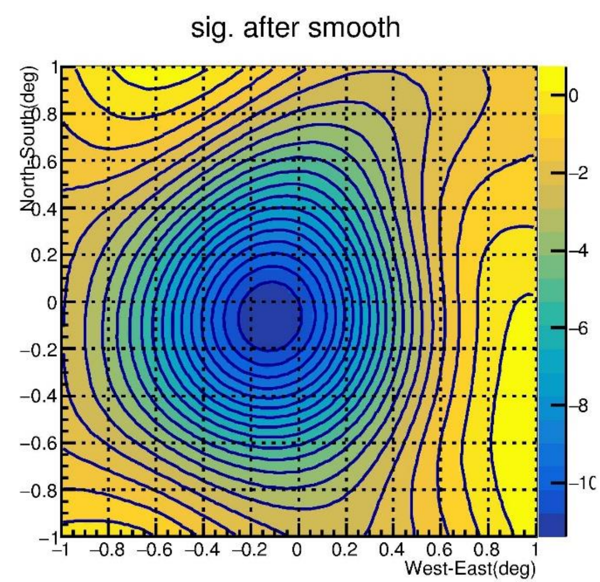
Moon Shadows at 10 TeV and above









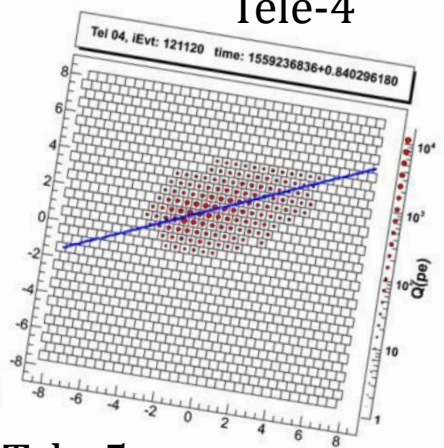


6 telescopes
As the WFCTA
1st-stage are
operating

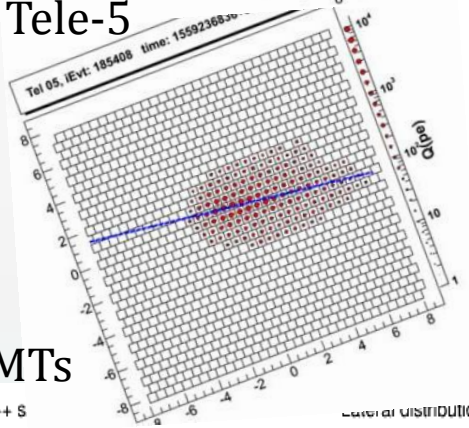
16 telescopes
by the end of
2020

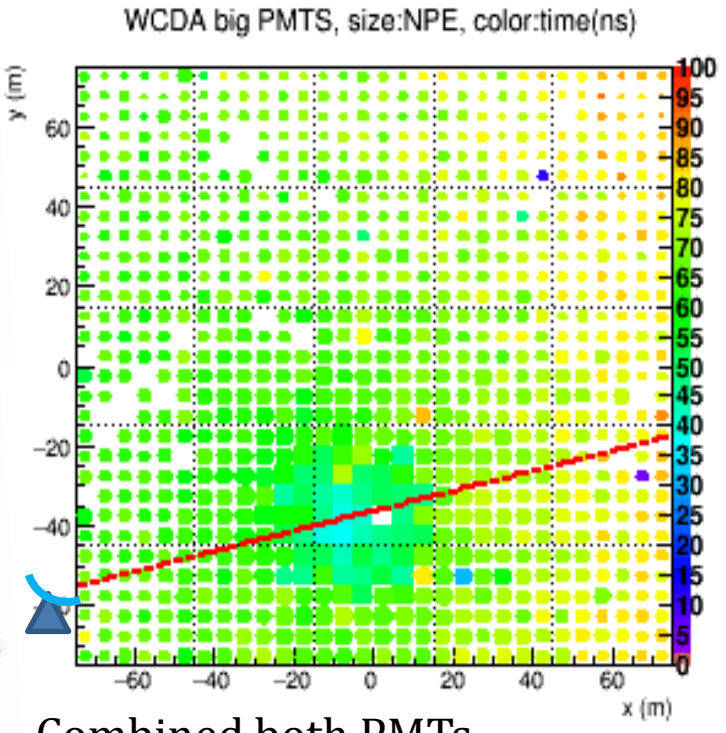
An event registered both by water pond and two telescopes

Tele-4

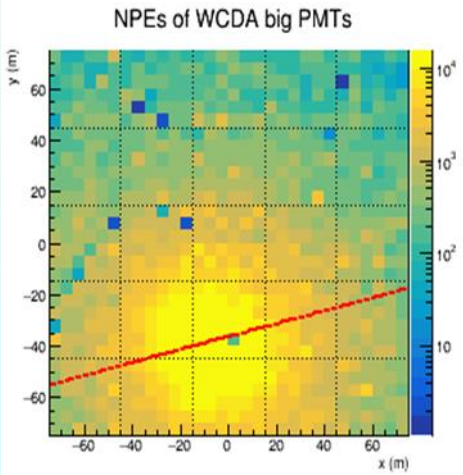


Tele-5

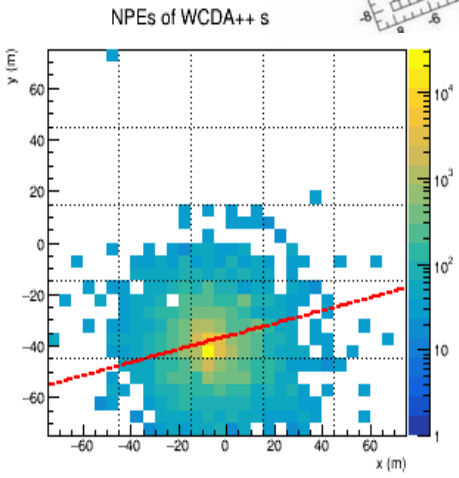




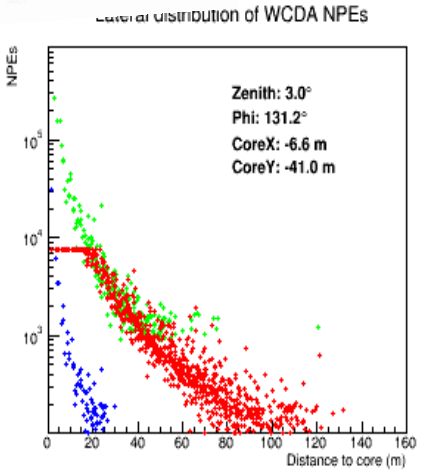
8” PMTs

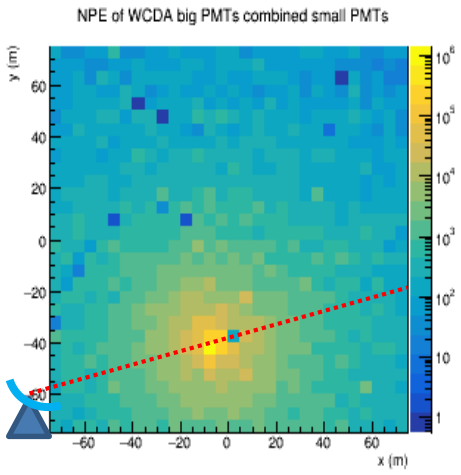


1.5” PMTs



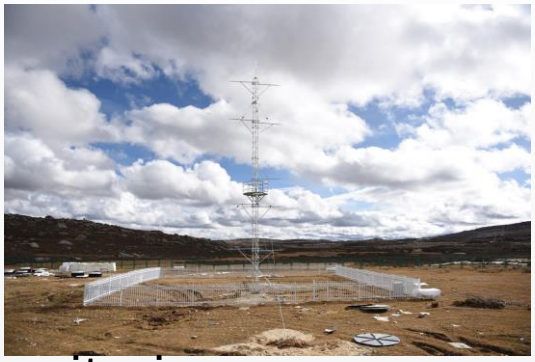
Combined both PMTs

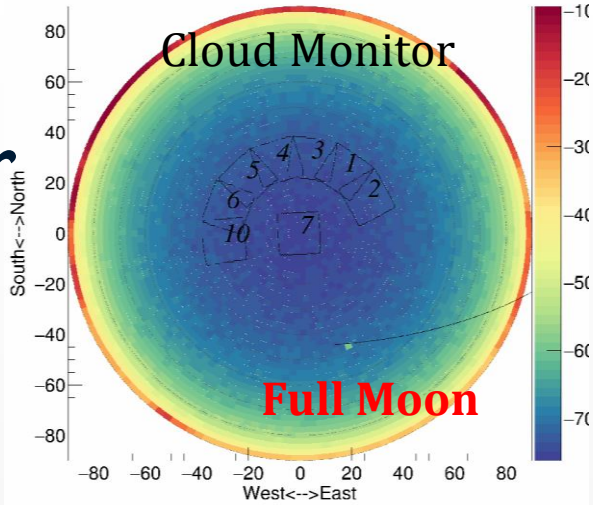




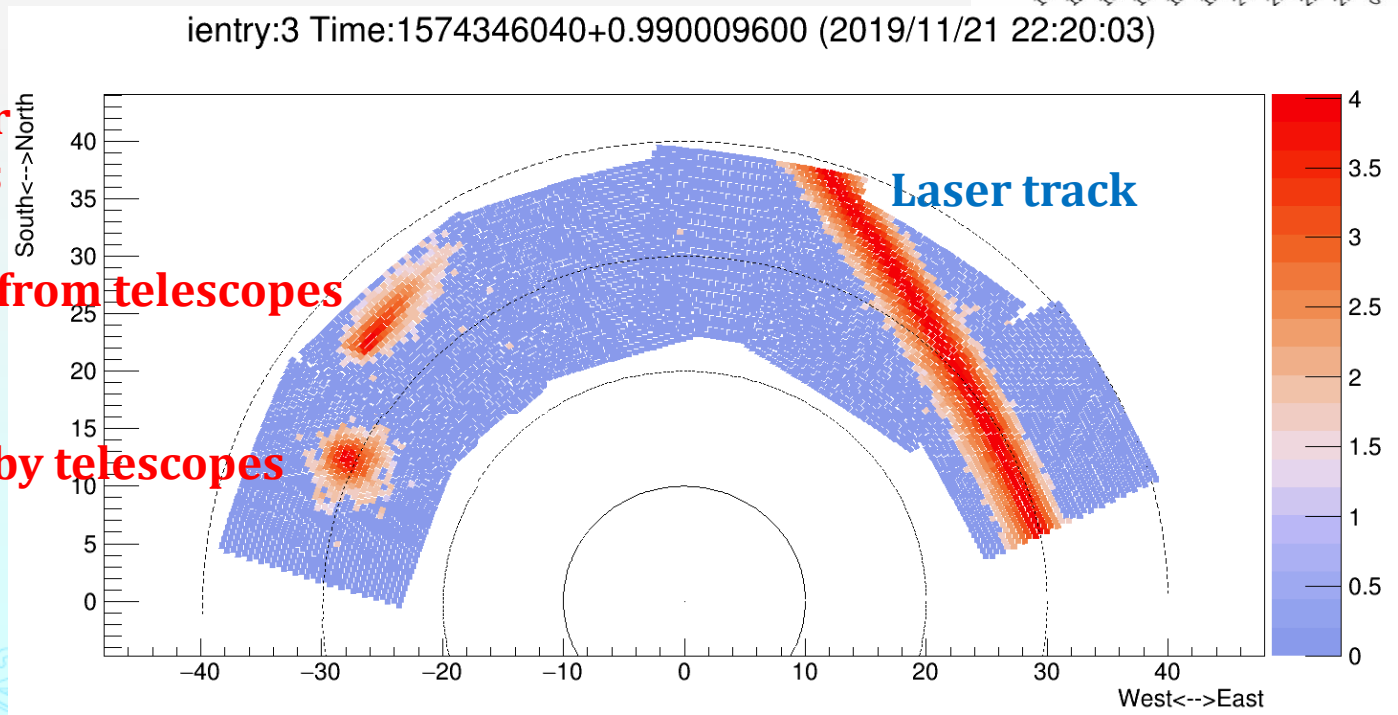
Operation & Atmosphere Monitor

- 2B events collected in 40 Nights
- LIDAR
- All-sky Cloud Monitor
- Full-scale meteorological monitoring on atmospheric condition

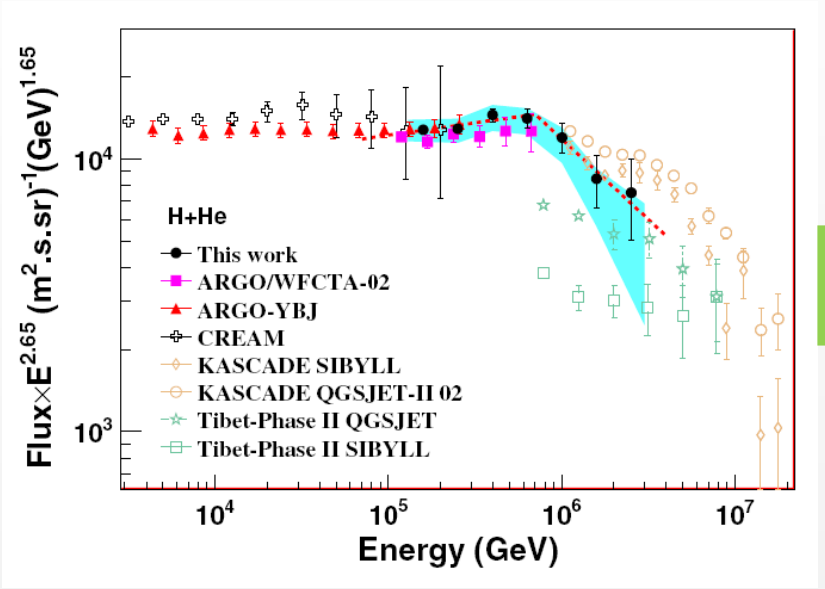


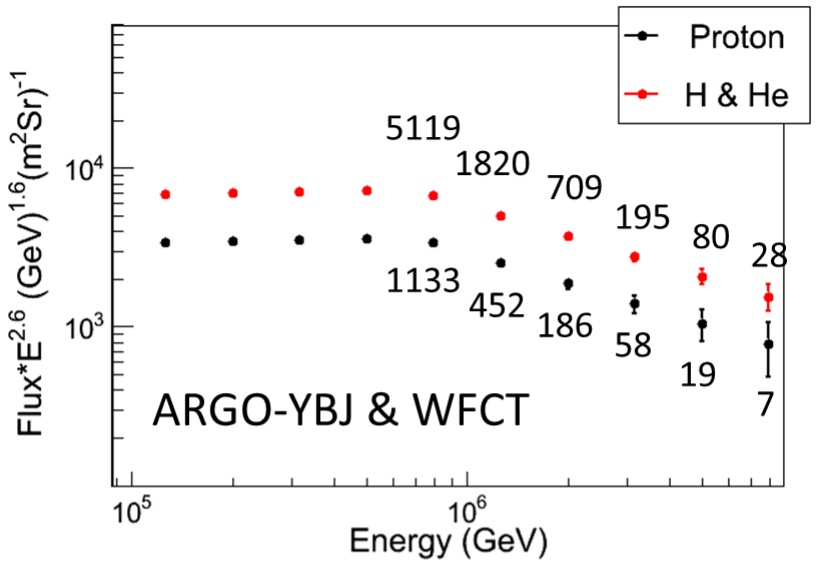


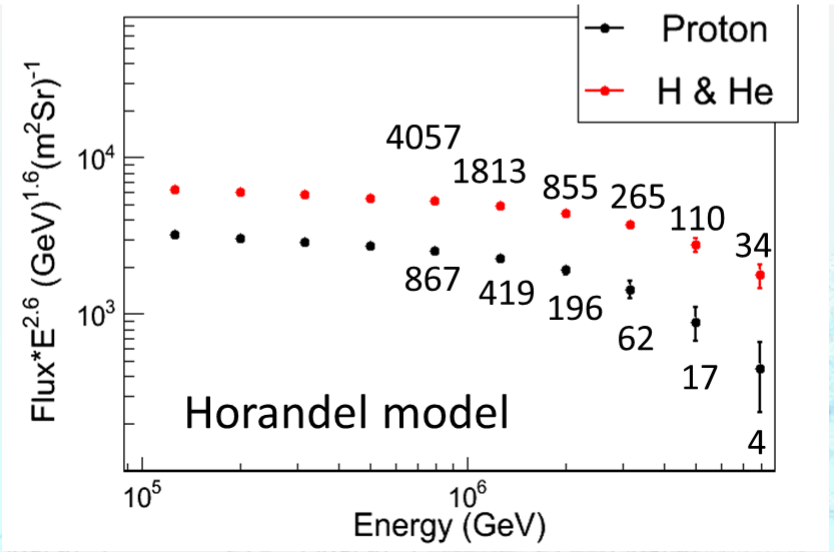
CR Shower images



Number of good events expected in the hybrid observation with C-telescopes and WCDA or KM2A







PHYSICAL REVIEW D 92, 092005 (2015)

From 2019.10.16 to 2020.3.15, the exposure time with good weather has been

2.52×10^6 s = 700 hours

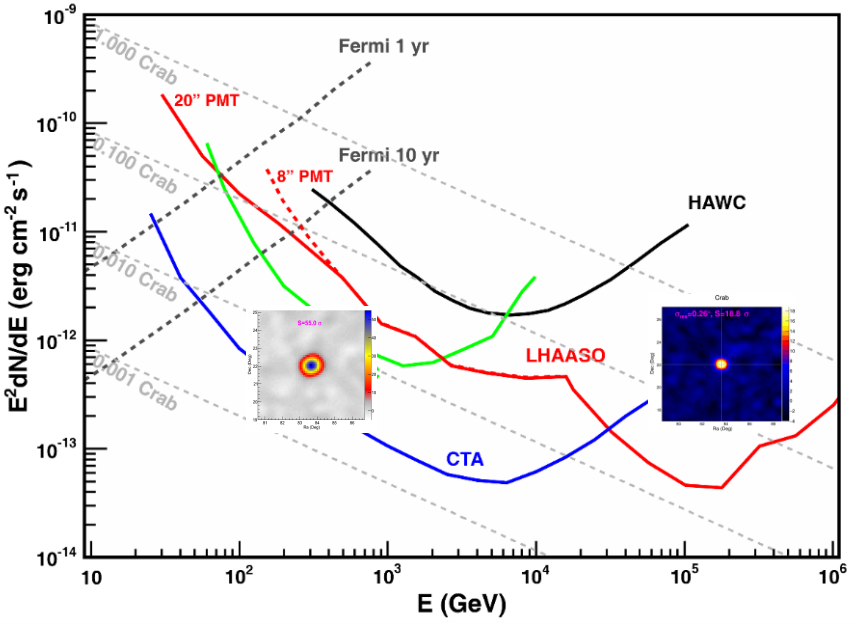
by now.

LHAASO
高海拔宇宙线观测站

- Brief Introduction of LHAASO
- Construction Status and Observational Results
- **Prospects:**
  - **CR**
  - **γ-astronomy**
- Summary

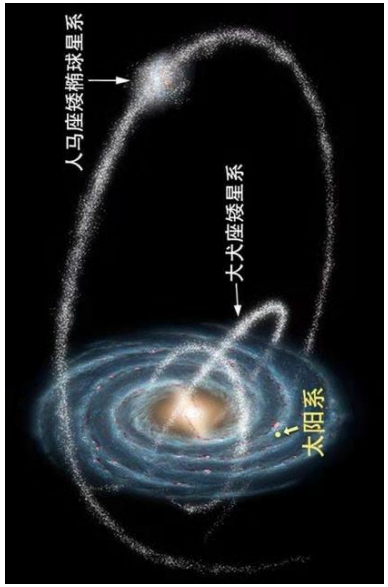
Physics Topics

- **Gamma Ray Astronomy**
- **Charged CR Spectra**
- **New Physics Frontier**

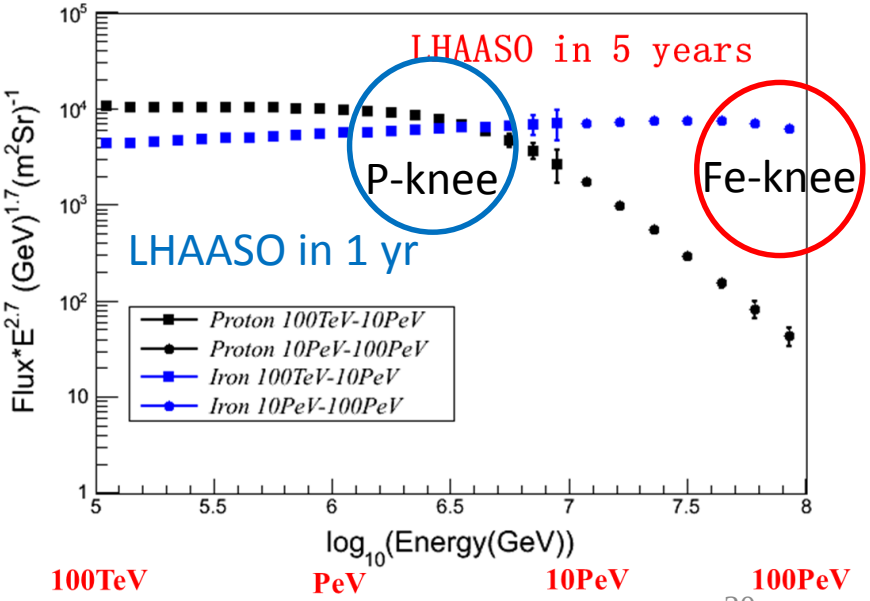


Pevatron searching

DM searching

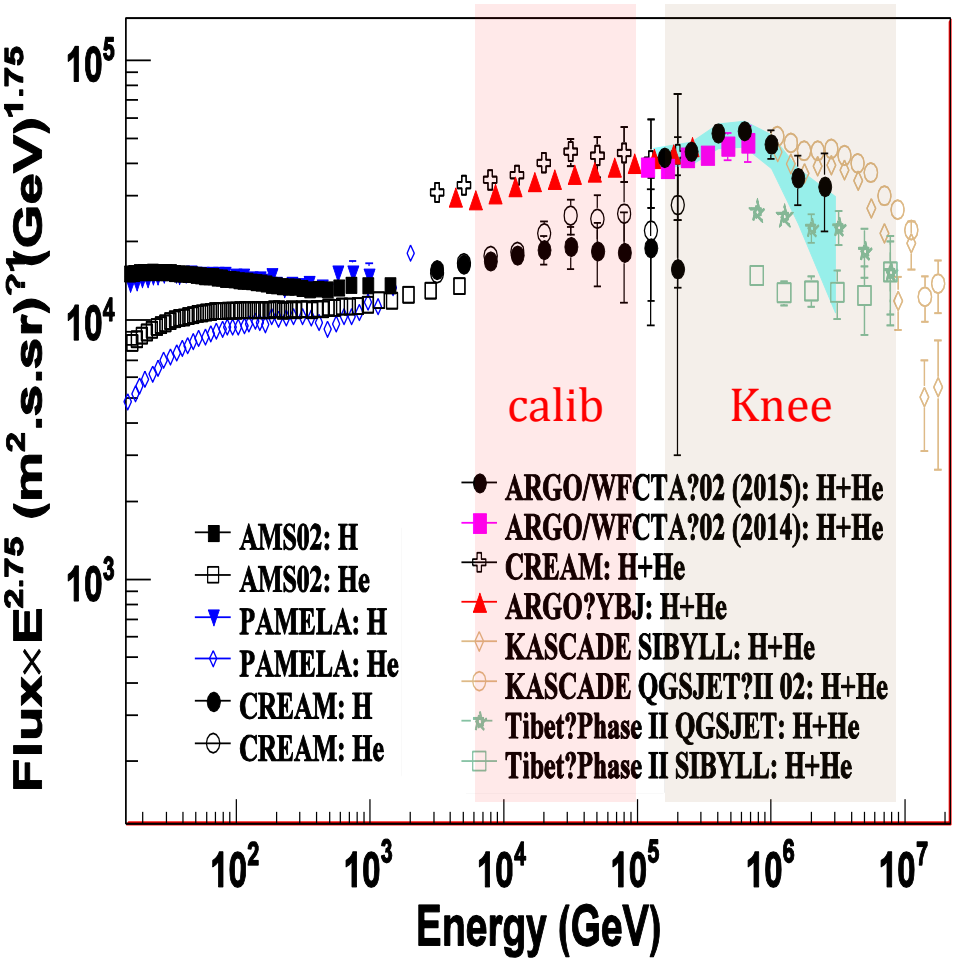


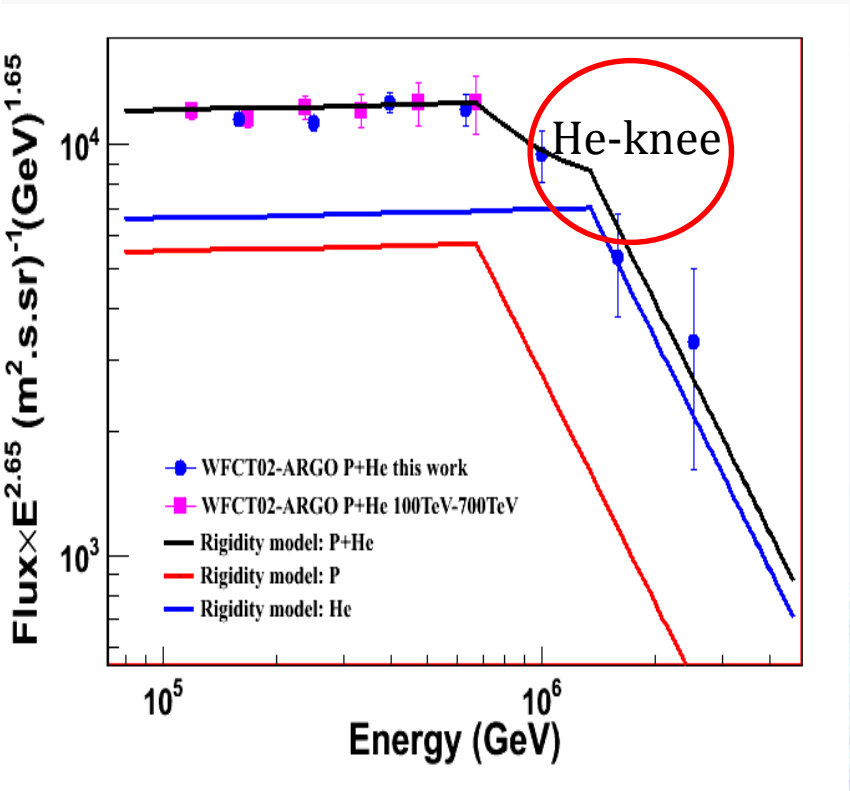
GRB searching



Cosmic Ray Physics: Charged Nuclei knees of spectra of individual species

Using only two parameters, at ARGO-YBJ: E_{knee}-700 TeV, Phys.Rev.D 92092005 (2015)

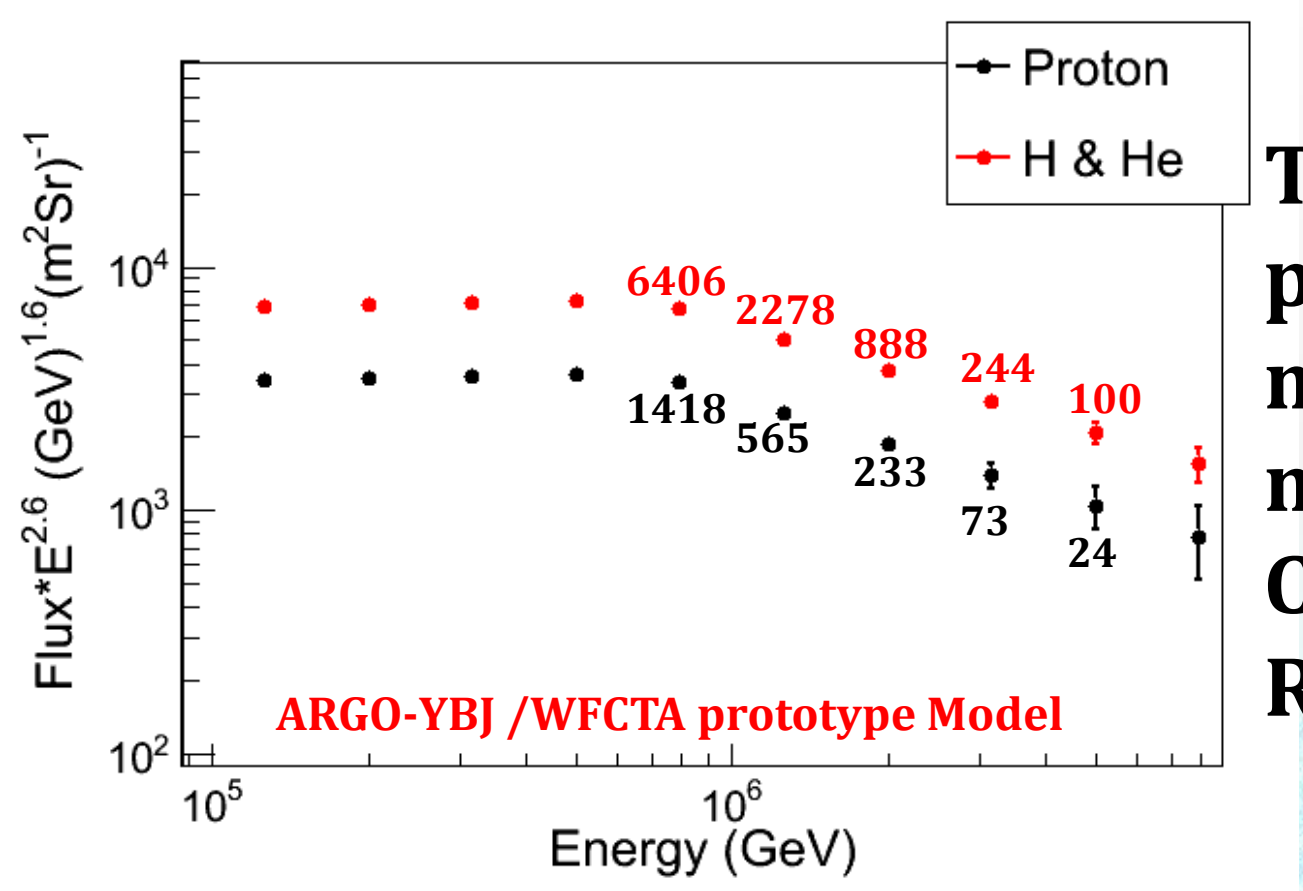




Proton spectrum with Rigidity model and H:He=1:1.2

Number of good events expected in the hybrid observation with C-telescopes and WCDA or KM2A

3.1×10^6 s of exposure time is expected before the monsoon in **2020**



The era of precision measure-ment of Cosmic Rays!

pure H and H + He knees will be accurately measured using ¼ LHAASO in 2020

LHAASO
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Gamma Ray Astronomy with LHAASO

1. Extragalactic transient phenomena
2. multi messenger astronomy
3. PeVatrons and the origins of galactic CRs

Many Topics in Astroparticle Physics

LHAASO
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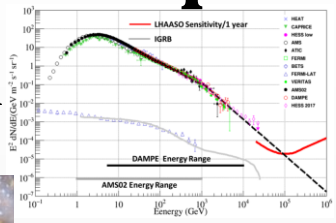
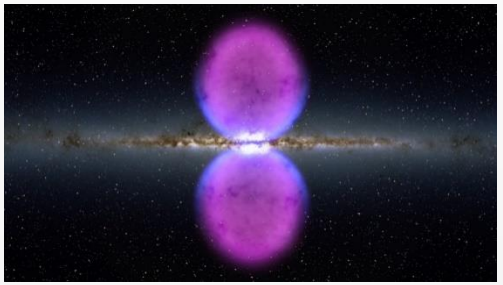
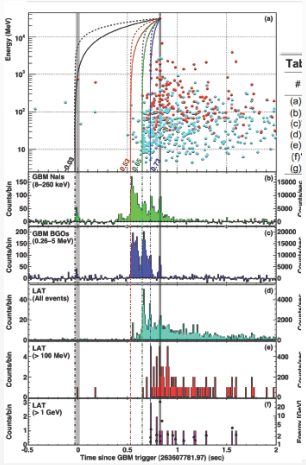
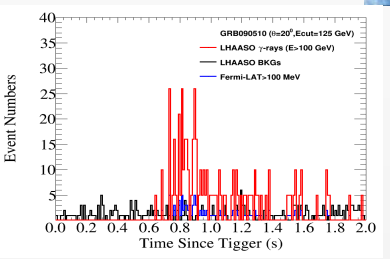
e+e- spectrum



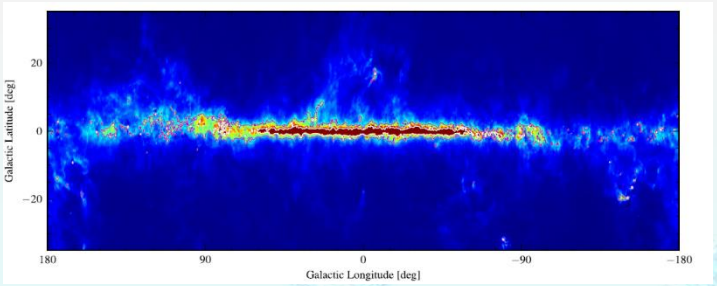
FERMI Bubble



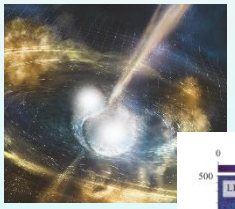


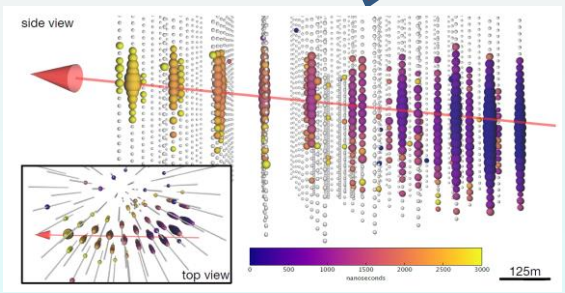


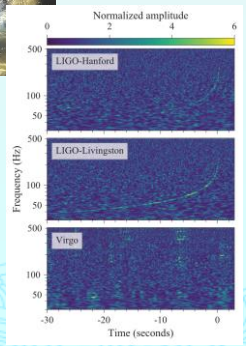
GRB 090501



GW170817







Diffuse γ Background

IC-170922A

LHAASO on AGN flares

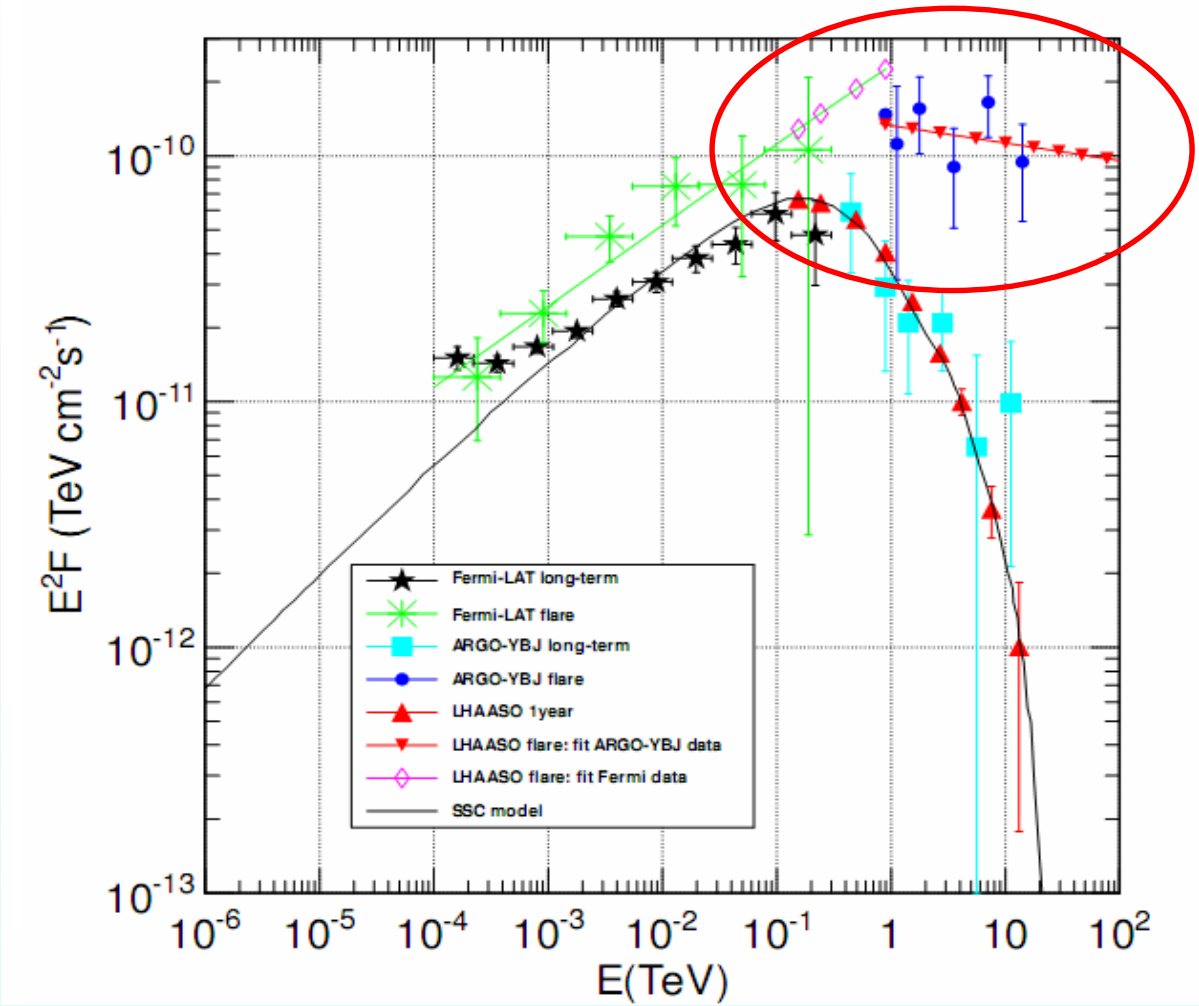
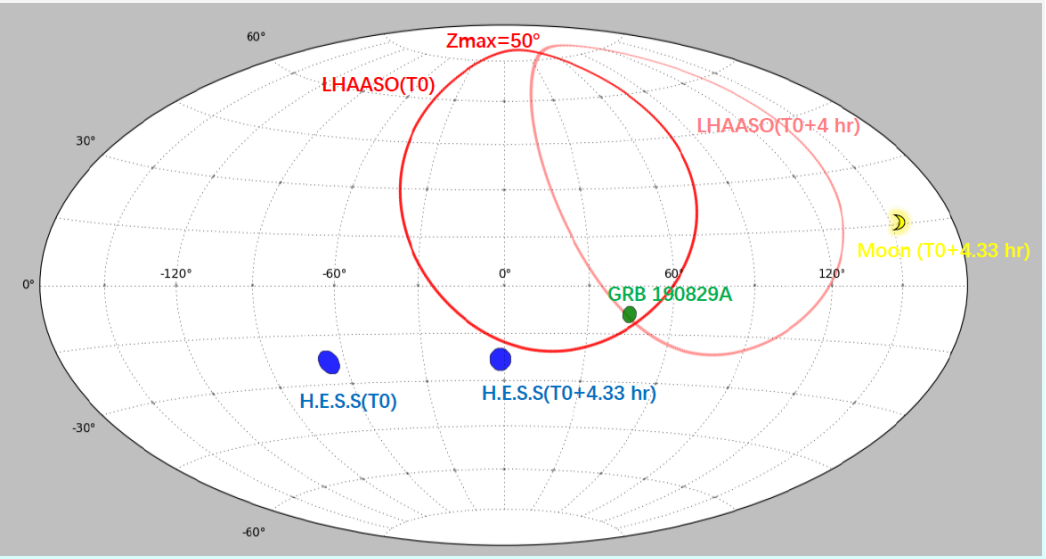
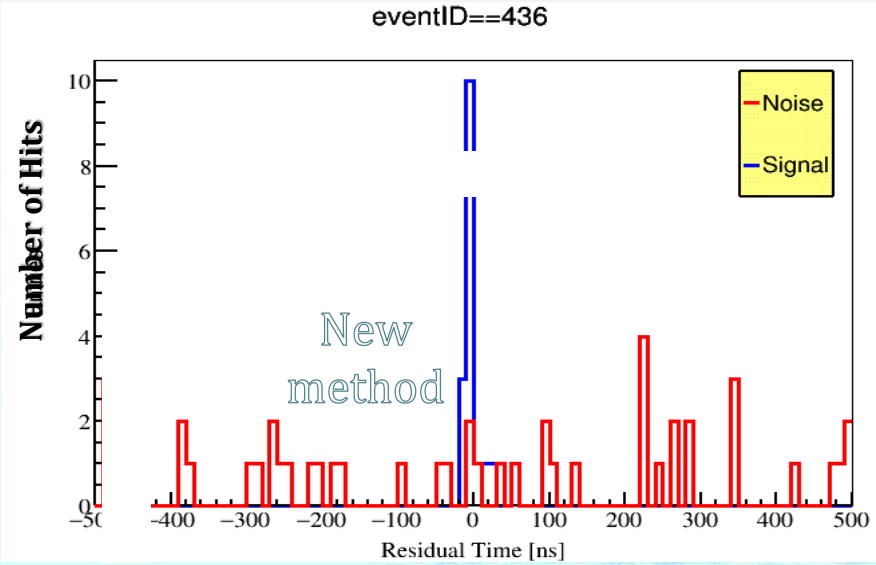


Figure 16: Expectation of the LHAASO project on Mrk501 [57], compared with the measurement of Fermi-LAT, ARGO-YBJ[27].

GRB Search

- Develop a new method to search for GRBs
- Set up GRBs Monitor software
- Fulfill the analysis of GRB190829A
- 36 GRB follow-ups (Since June 2019)
  the statistic analysis is on the way.



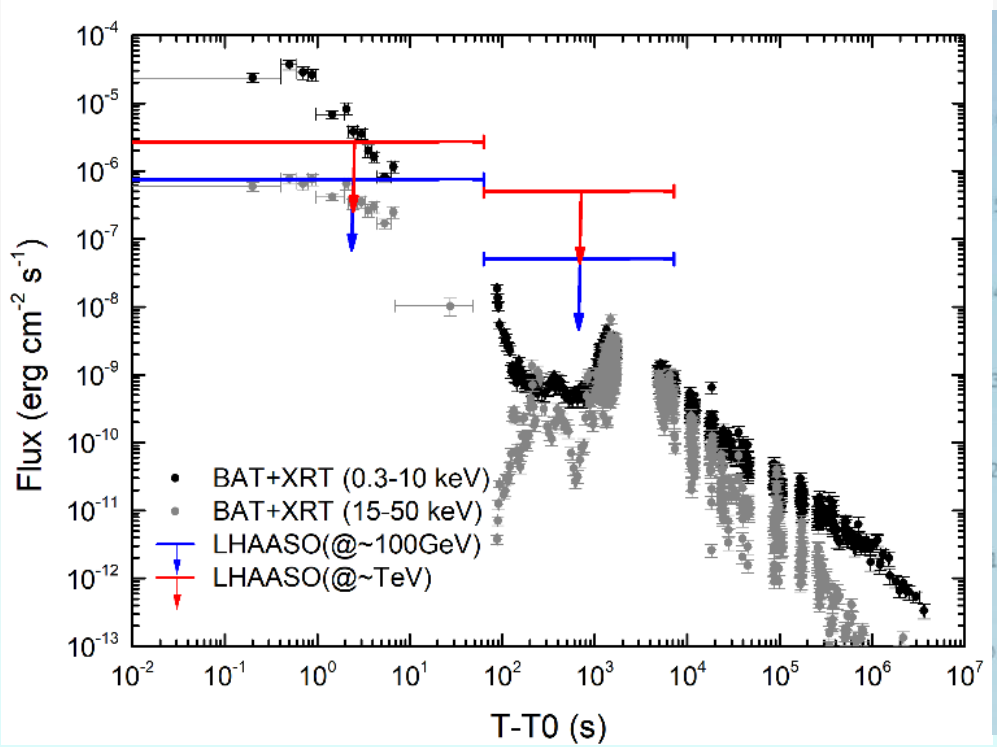


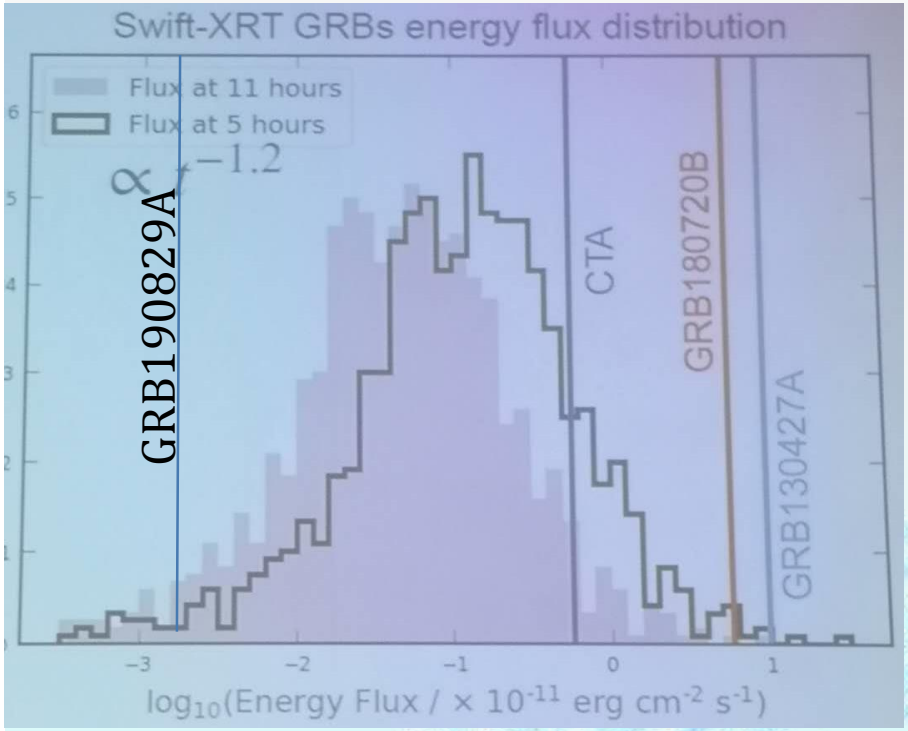
GRB190829A @ LHAASO-WCDA1

Residual Time [ns]

GRB190829A

- LHAASO has to wait for next burst…

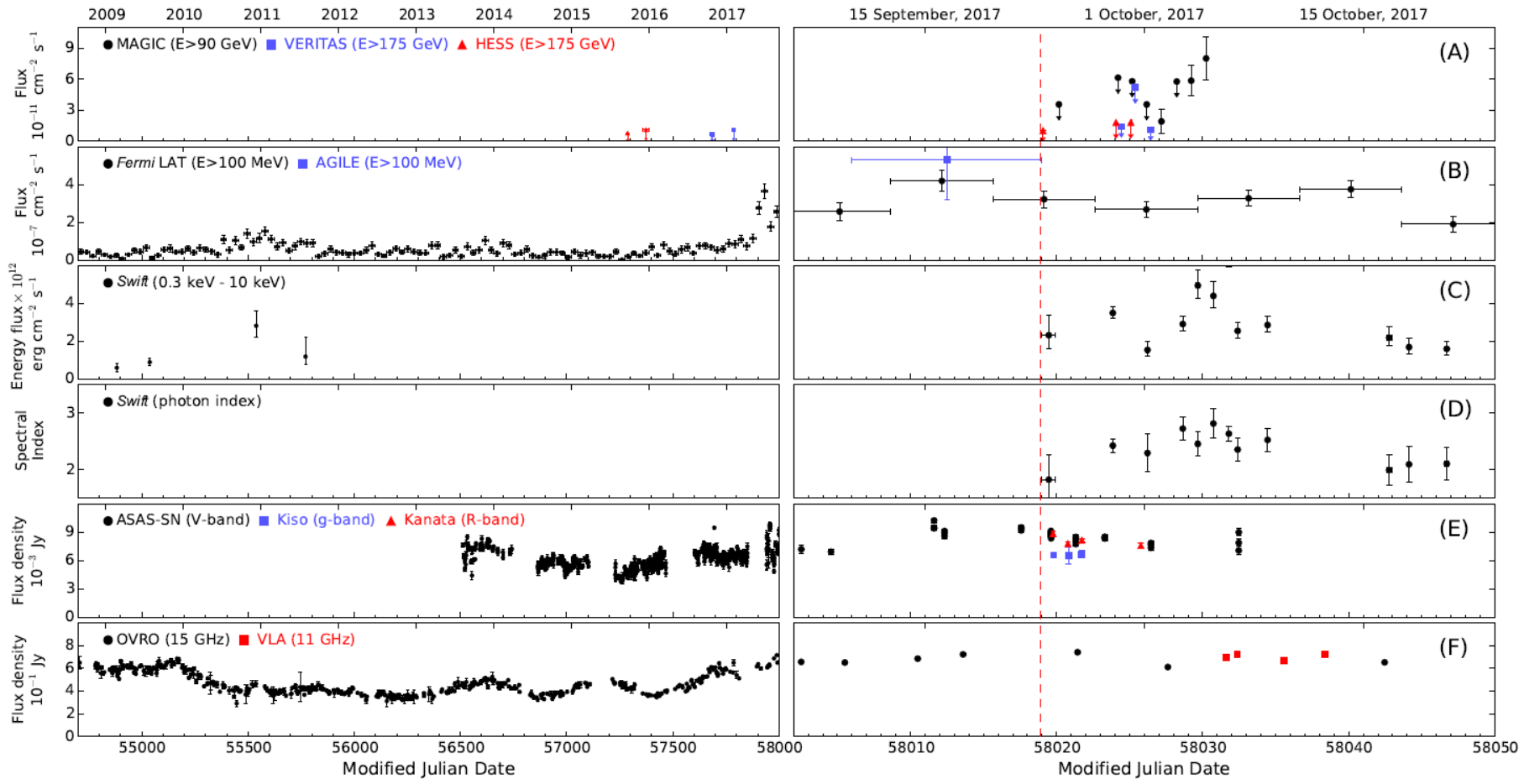




IC-170922A/TXS 0506+056: Multi-Messenger Astronomy

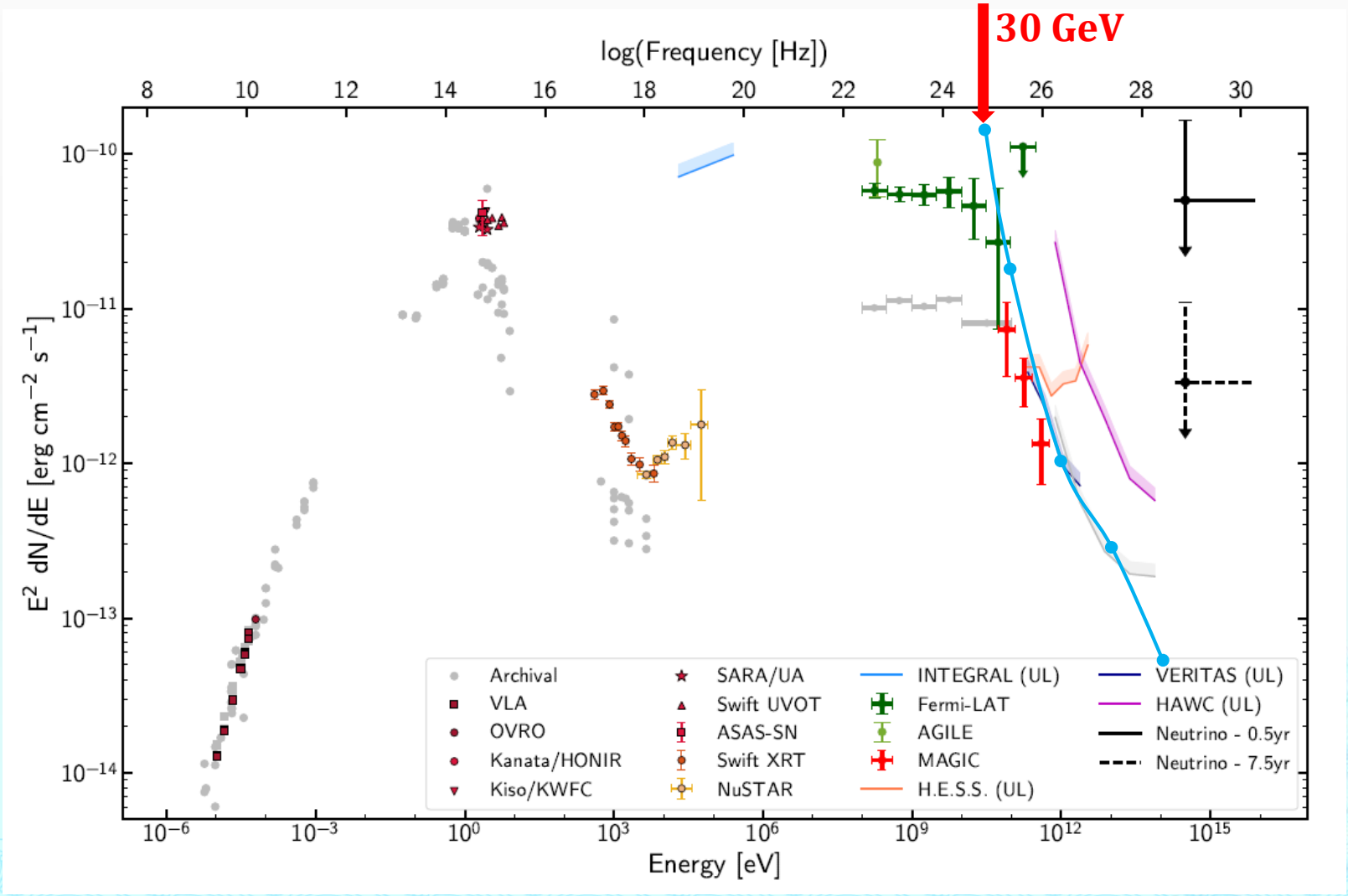
An example

arXiv:1807.08816
Science 361, eaat1378 (2018)



IC-170922A/TXS 0506+056： SED

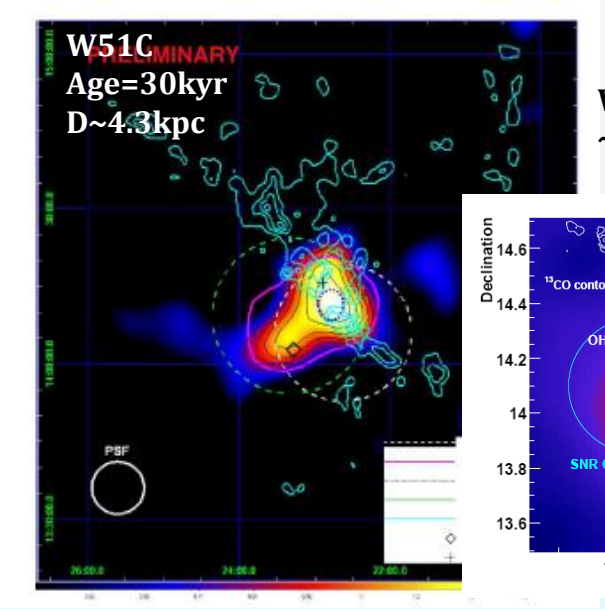
arXiv:1807.08816
Science 361, eaat1378 (2018)



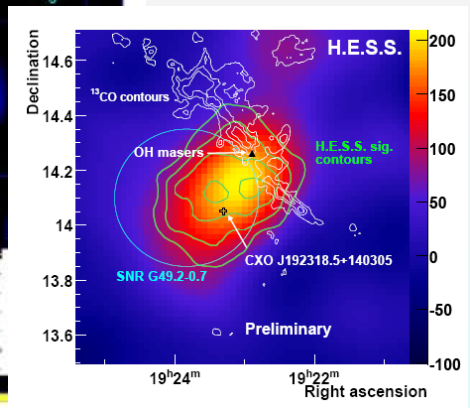
Central scientific target of LHAASO : Identifying Galactic Cosmic Ray Origins

SNRs: for example W51C:

a "mixed-morphology" type of SNR, shocked atomic and molecular gases show the interaction between shock and molecular.

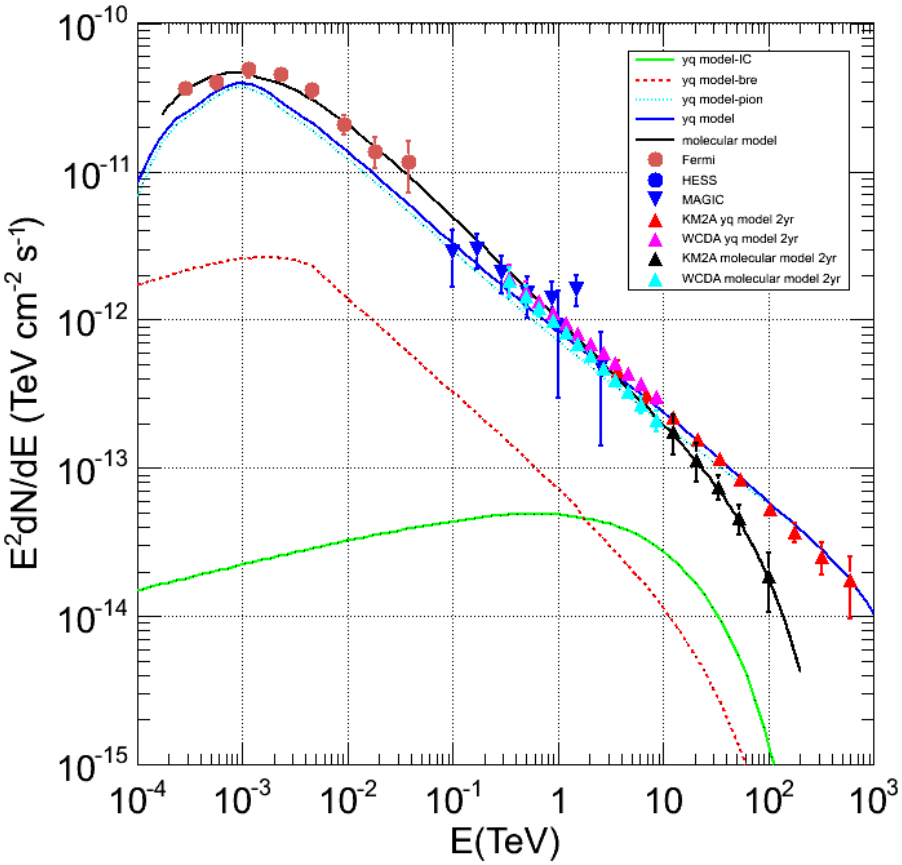


W51C
~3%Crab



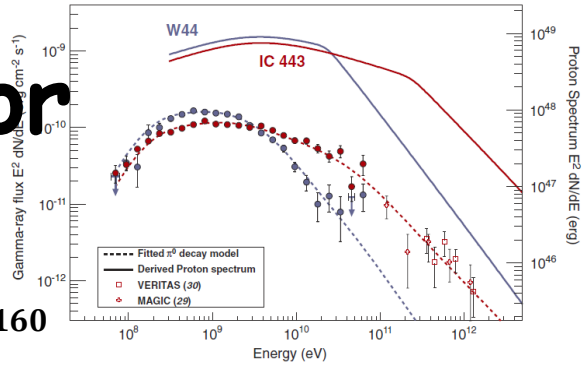
reference~ APJ, 761:133(2012) && Mon.Not.R.Astron.Soc, 421,935-942(2012)

GeV&TeV~ dominated by π^0 decay



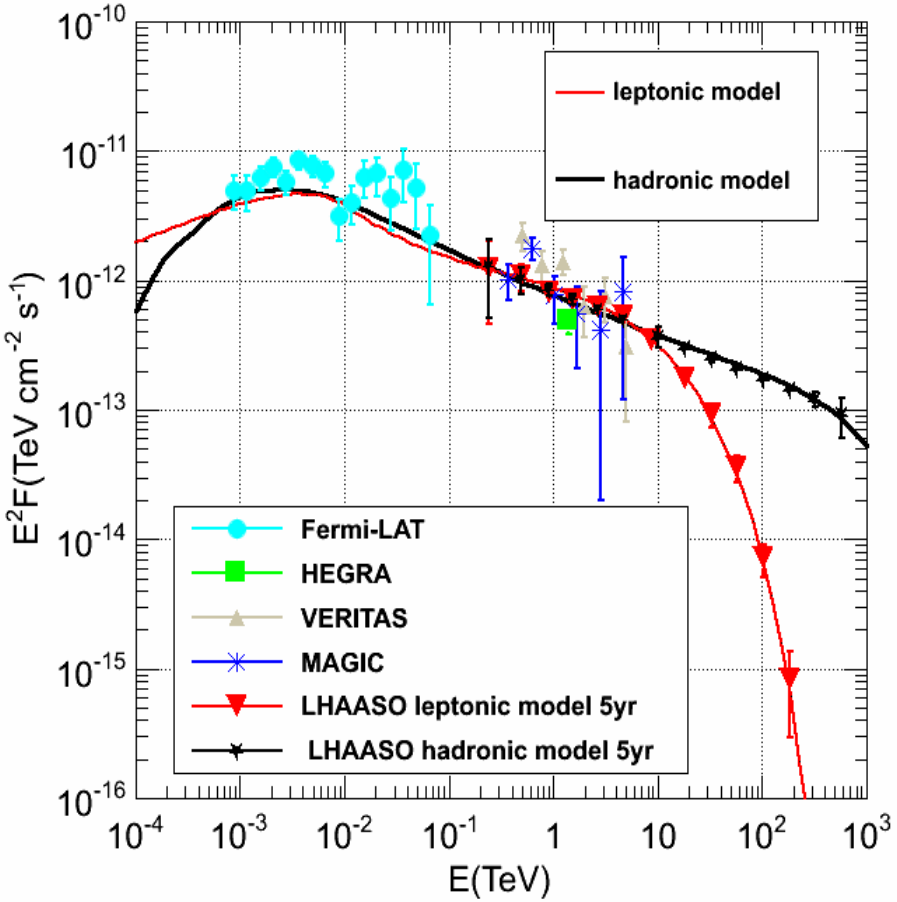
Pevatron CR Accelerator

Characteristic signatures of π^0 decay: at highest energy by LHAASO

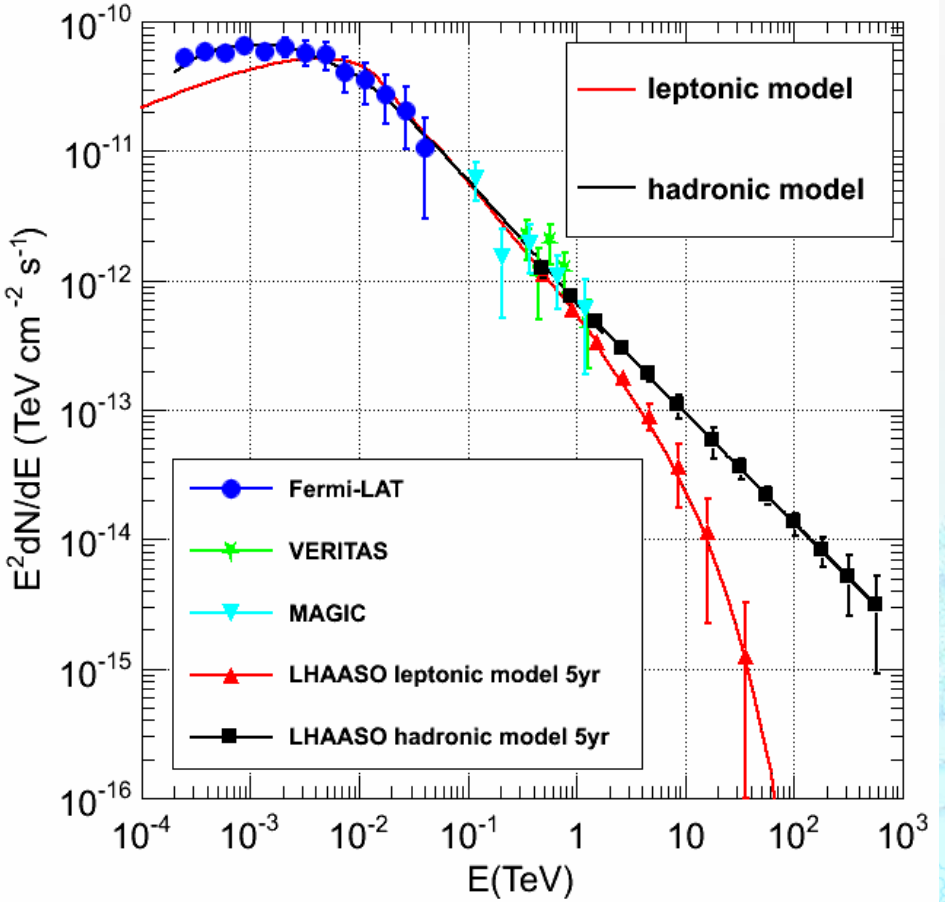


10.1126/science.1231160

Cassionpeia A Historical SNRs

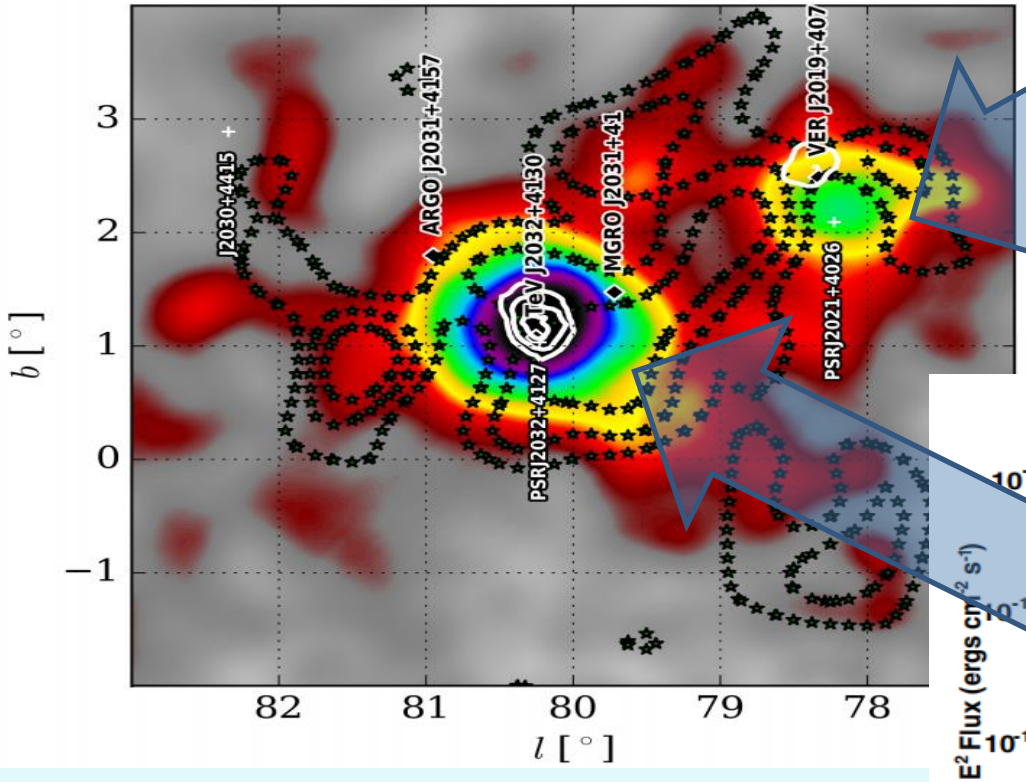


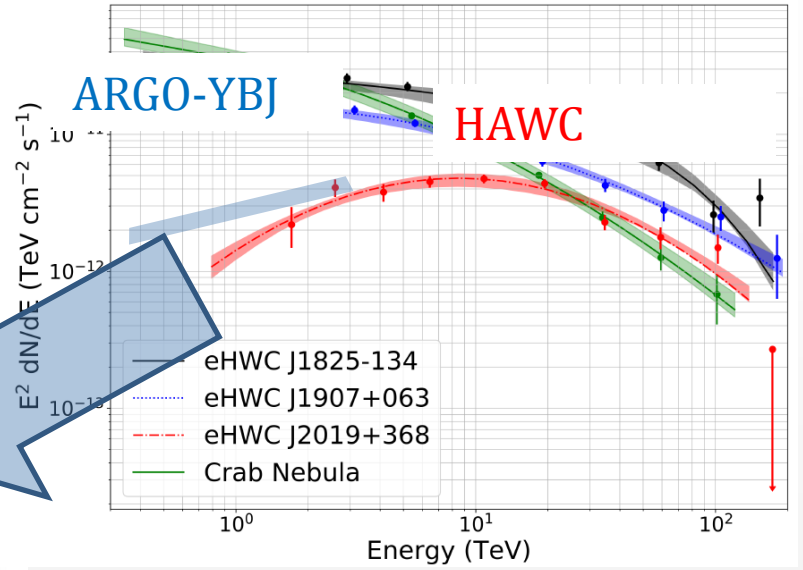
IC443 interacting with molecular clouds

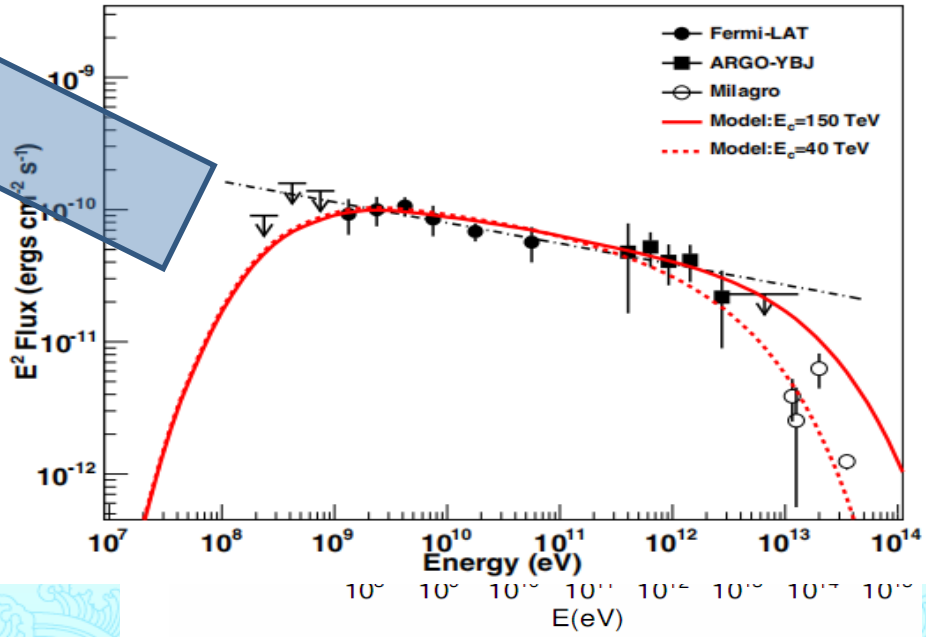


Broad Objects: Cygnus region

The 1st VHE supper-bubble by ARGO-YBJ







Quite puzzling object:

Strong Cut-off above 100 TeV?

Morphological study?

Multi-wavelength?

Summary

- ¼-LHAASO has been turned on for scientific operation since April 26，2019
- ½-LHAASO has been operated for 173 days, and will continue for 80 days
- ¾-LHAASO will be turned on for phase-II operation with 88% designed sensitivity by the end of Sept. 2020
- The entire array will be built up in 2021
- LHAASO observatory for gamma ray astronomy and CR phys.
  - Unique for UHE (>0.1PeV) γ–astronomy: full with **PeVatrons in Milky Way** which are generating **super-PeV photons**
  - No indication of cut-off for most galactic sources: **opening the UHE γ–astronomy era**
  - Evidences of hadronic origin of γ's are expected
  - Wide SED measurements covering a range of **0.1-1000 TeV** by LHAASO
  - Wide FOV monitoring for transient phenomena below 1 TeV
  - Precision measurements of E-spectra of CR species
- Big potential of discovery of Galactic CR origins, stay tuned …