LHAASO

高海拔宇宙线观测站

LHAASO

—— 开启超高能 γ-天文学 及后续发展

曹臻

高能物理研究所

紫金山天文台Colloquium, 南京，2023-03

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LHAASO:

AN INTERNATIONAL COLLABORATION AND AN INSTRUMENT

Bird’s eye view of LHAASO， 2021-08

- Location： 29º21’ 27.6” N , 100º08’19.6” E
- Altitude: 4410 m
- 2021-07 completed built and in operation

Multi-Messenger Collaboration Network

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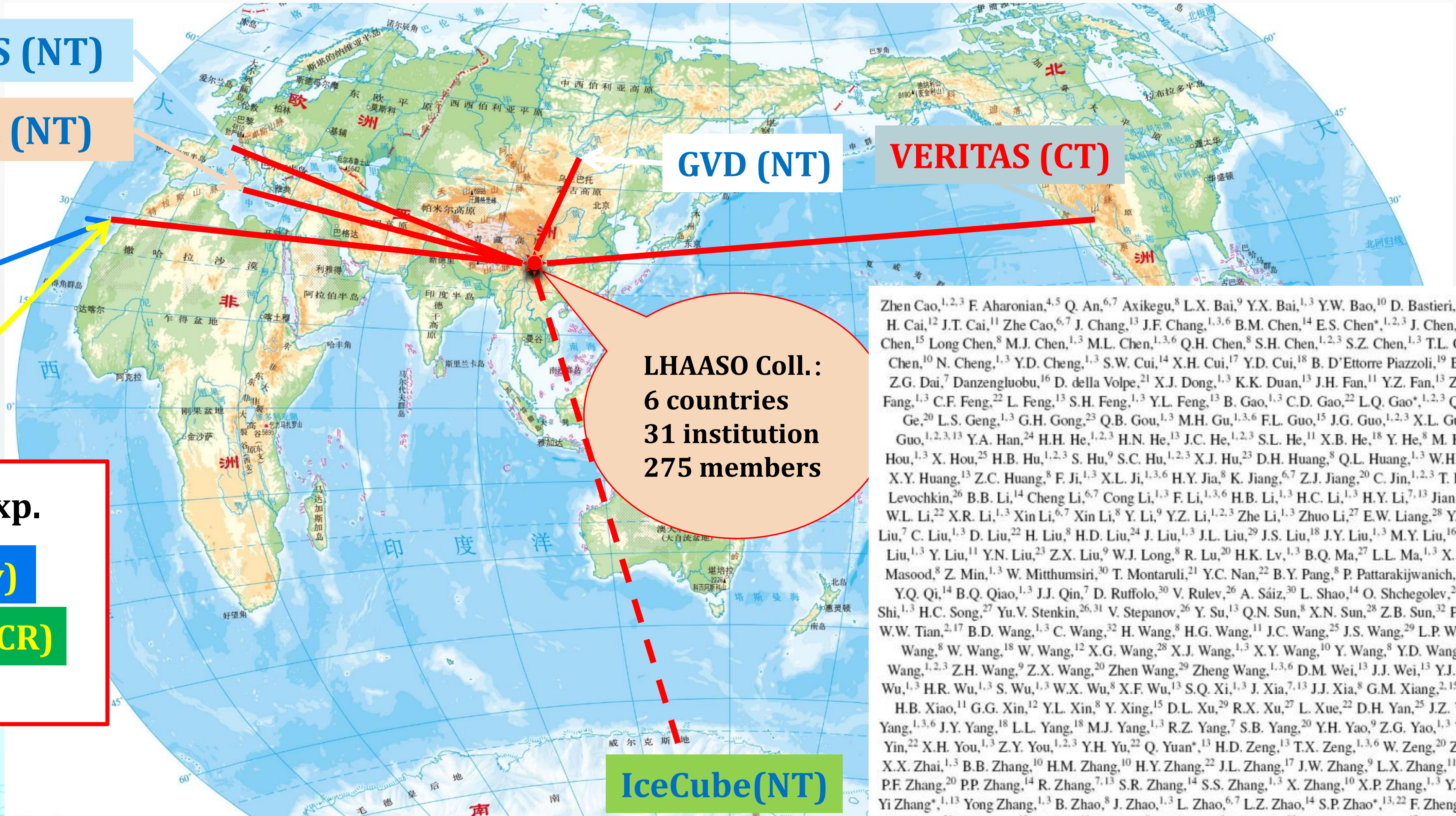

Space borne Exp.

- eROSITA(X-ray)
- DAMPE(γ-ray, CR)

Zhen Cao,[1,2,3] F. Aharonian,[4,5] Q. An,[6,7] Axikegu,[8] L.X. Bai,[9] Y.X. Bai,[1,3] Y.W. Bao,[10] D. Bastieri,[11] X.J. Bi*,[1,2,3] Y.J. Bi,[1,3] H. Cai,[12] J.T. Cai,[11] Zhe Cao,[6,7] J. Chang,[13] J.F. Chang,[1,3,6] B.M. Chen,[14] E.S. Chen*,[1,2,3] J. Chen,[9] Liang Chen,[1,2,3] Liang Chen,[15] Long Chen,[8] M.J. Chen,[1,3] M.L. Chen,[1,3,6] Q.H. Chen,[8] S.H. Chen,[1,2,3] S.Z. Chen,[1,3] T.L. Chen,[16] X.L. Chen,[1,2,3] Y. Chen,[10] N. Cheng,[1,3] Y.D. Cheng,[1,3] S.W. Cui,[14] X.H. Cui,[17] Y.D. Cui,[18] B. D'Ettorre Piazzoli,[19] B.Z. Dai,[20] H.L. Dai,[1,3,6] Z.G. Dai,[7] Danzengluobu,[16] D. della Volpe,[21] X.J. Dong,[1,3] K.K. Duan,[13] J.H. Fan,[11] Y.Z. Fan,[13] Z.X. Fan,[1,3] J. Fang,[20] K. Fang,[1,3] C.F. Feng,[22] L. Feng,[13] S.H. Feng,[1,3] Y.L. Feng,[13] B. Gao,[1,3] C.D. Gao,[22] L.Q. Gao*,[1,2,3] Q. Gao,[16] W. Gao,[22] M.M. Ge,[20] L.S. Geng,[1,3] G.H. Gong,[23] Q.B. Gou,[1,3] M.H. Gu,[1,3,6] F.L. Guo,[15] J.G. Guo,[1,2,3] X.L. Guo,[8] Y.Q. Guo,[1,3] Y.Y. Guo,[1,2,3,13] Y.A. Han,[24] H.H. He,[1,2,3] H.N. He,[13] J.C. He,[1,2,3] S.L. He,[11] X.B. He,[18] Y. He,[8] M. Heller,[21] Y.K. Hor,[18] C. Hou,[1,3] X. Hou,[25] H.B. Hu,[1,2,3] S. Hu,[9] S.C. Hu,[1,2,3] X.J. Hu,[23] D.H. Huang,[8] Q.L. Huang,[1,3] W.H. Huang,[22] X.T. Huang,[22] X.Y. Huang,[13] Z.C. Huang,[8] F. Ji,[1,3] X.L. Ji,[1,3,6] H.Y. Jia,[8] K. Jiang,[6,7] Z.J. Jiang,[20] C. Jin,[1,2,3] T. Ke,[1,3] D. Kuleshov,[26] K. Levochkin,[26] B.B. Li,[14] Cheng Li,[6,7] Cong Li,[1,3] F. Li,[1,3,6] H.B. Li,[1,3] H.C. Li,[1,3] H.Y. Li,[7,13] Jian Li,[7] Jie Li,[1,3,6] K. Li,[1,3] W.L. Li,[22] X.R. Li,[1,3] Xin Li,[6,7] Xin Li,[8] Y. Li,[9] Y.Z. Li,[1,2,3] Zhe Li,[1,3] Zhuo Li,[27] E.W. Liang,[28] Y.F. Liang,[28] S.J. Lin,[18] B. Liu,[7] C. Liu,[1,3] D. Liu,[22] H. Liu,[8] H.D. Liu,[24] J. Liu,[1,3] J.L. Liu,[29] J.S. Liu,[18] J.Y. Liu,[1,3] M.Y. Liu,[16] R.Y. Liu,[10] S.M. Liu,[8] W. Liu,[1,3] Y. Liu,[11] Y.N. Liu,[23] Z.X. Liu,[9] W.J. Long,[8] R. Lu,[20] H.K. Lv,[1,3] B.Q. Ma,[27] L.L. Ma,[1,3] X.H. Ma,[1,3] J.R. Mao,[25] A. Masood,[8] Z. Min,[1,3] W. Mitthumsiri,[30] T. Montaruli,[21] Y.C. Nan,[22] B.Y. Pang,[8] P. Pattarakijwanich,[30] Z.Y. Pei,[11] M.Y. Qi,[1,3] Y.Q. Qi,[14] B.Q. Qiao,[1,3] J.J. Qin,[7] D. Ruffolo,[30] V. Rulev,[26] A. Sáiz,[30] L. Shao,[14] O. Shchegolev,[26,31] X.D. Sheng,[1,3] J.R. Shi,[1,3] H.C. Song,[27] Yu.V. Stenkin,[26,31] V. Stepanov,[26] Y. Su,[13] Q.N. Sun,[8] X.N. Sun,[28] Z.B. Sun,[32] P.H.T. Tam,[18] Z.B. Tang,[6,7] W.W. Tian,[2,17] B.D. Wang,[1,3] C. Wang,[32] H. Wang,[8] H.G. Wang,[11] J.C. Wang,[25] J.S. Wang,[29] L.P. Wang,[22] L.Y. Wang,[1,3] R.N. Wang,[8] W. Wang,[18] W. Wang,[12] X.G. Wang,[28] X.J. Wang,[1,3] X.Y. Wang,[10] Y. Wang,[8] Y.D. Wang,[1,3] Y.J. Wang,[1,3] Y.P. Wang,[1,2,3] Z.H. Wang,[9] Z.X. Wang,[20] Zhen Wang,[29] Zheng Wang,[1,3,6] D.M. Wei,[13] J.J. Wei,[13] Y.J. Wei,[1,2,3] T. Wen,[20] C.Y. Wu,[1,3] H.R. Wu,[1,3] S. Wu,[1,3] W.X. Wu,[8] X.F. Wu,[13] S.Q. Xi,[1,3] J. Xia,[7,13] J.J. Xia,[8] G.M. Xiang,[2,15] D.X. Xiao,[16] G. Xiao,[1,3] H.B. Xiao,[11] G.G. Xin,[12] Y.L. Xin,[8] Y. Xing,[15] D.L. Xu,[29] R.X. Xu,[27] L. Xue,[22] D.H. Yan,[25] J.Z. Yan,[13] C.W. Yang,[9] F.F. Yang,[1,3,6] J.Y. Yang,[18] L.L. Yang,[18] M.J. Yang,[1,3] R.Z. Yang,[7] S.B. Yang,[20] Y.H. Yao,[9] Z.G. Yao,[1,3] Y.M. Ye,[23] L.Q. Yin,[1,3] N. Yin,[22] X.H. You,[1,3] Z.Y. You,[1,2,3] Y.H. Yu,[22] Q. Yuan*,[13] H.D. Zeng,[13] T.X. Zeng,[1,3,6] W. Zeng,[20] Z.K. Zeng,[1,2,3] M. Zha,[1,3] X.X. Zhai,[1,3] B.B. Zhang,[10] H.M. Zhang,[10] H.Y. Zhang,[22] J.L. Zhang,[17] J.W. Zhang,[9] L.X. Zhang,[11] Li Zhang,[20] Lu Zhang,[14] P.F. Zhang,[20] P.P. Zhang,[14] R. Zhang,[7,13] S.R. Zhang,[14] S.S. Zhang,[1,3] X. Zhang,[10] X.P. Zhang,[1,3] Y.F. Zhang,[8] Y.L. Zhang,[1,3] Yi Zhang*,[1,13] Yong Zhang,[1,3] B. Zhao,[8] J. Zhao,[1,3] L. Zhao,[6,7] L.Z. Zhao,[14] S.P. Zhao*,[13,22] F. Zheng,[32] Y. Zheng,[8] B. Zhou,[1,3] H. Zhou,[29] J.N. Zhou,[15] P. Zhou,[10] R. Zhou,[9] X.X. Zhou,[8] C.G. Zhu,[22] F.R. Zhu,[8] H. Zhu,[17] K.J. Zhu,[1,2,3,6] and X. Zuo[1,3]

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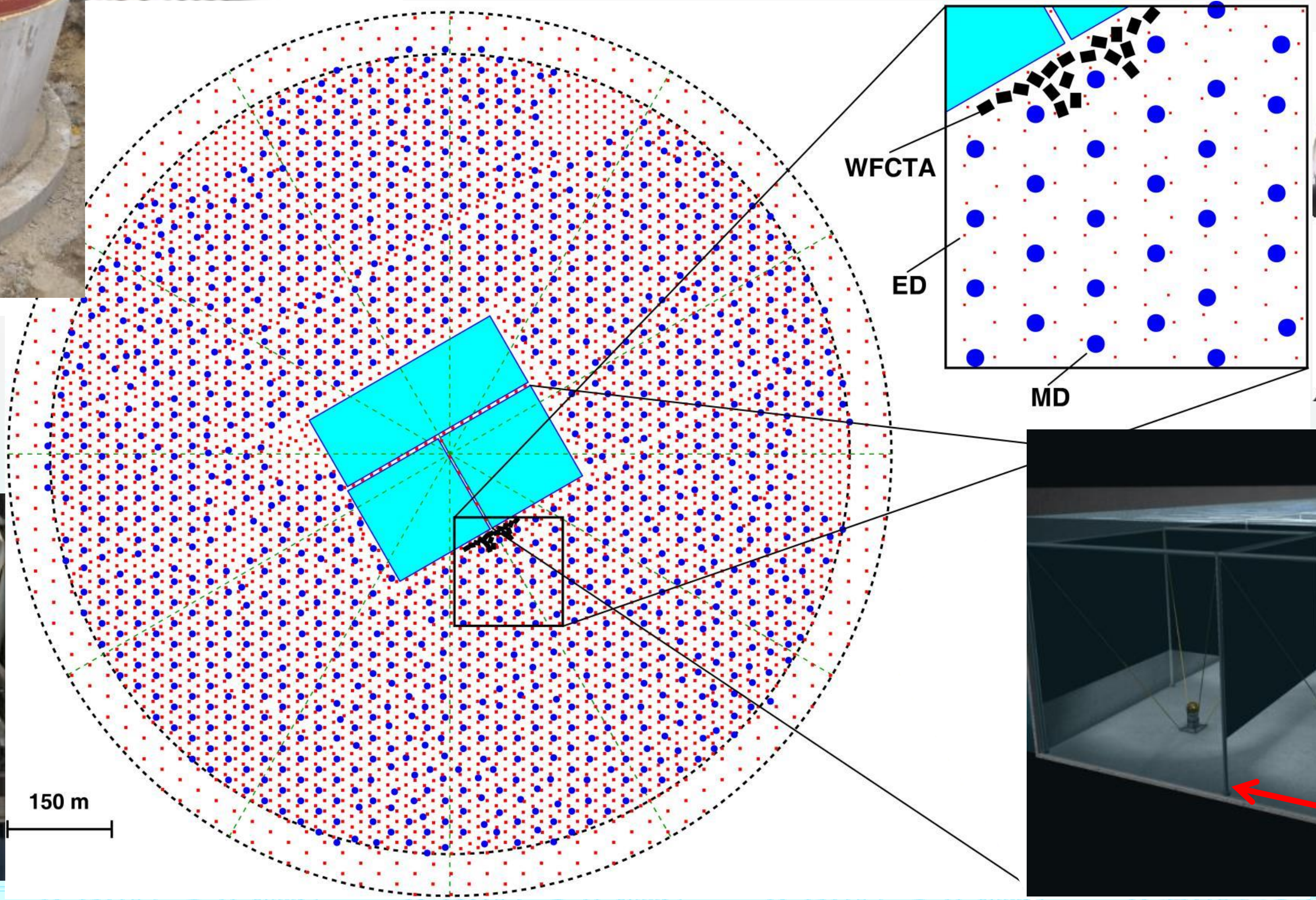
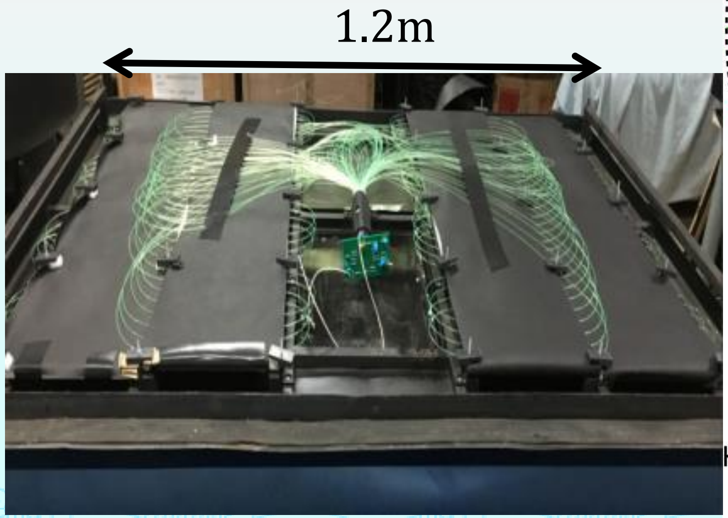
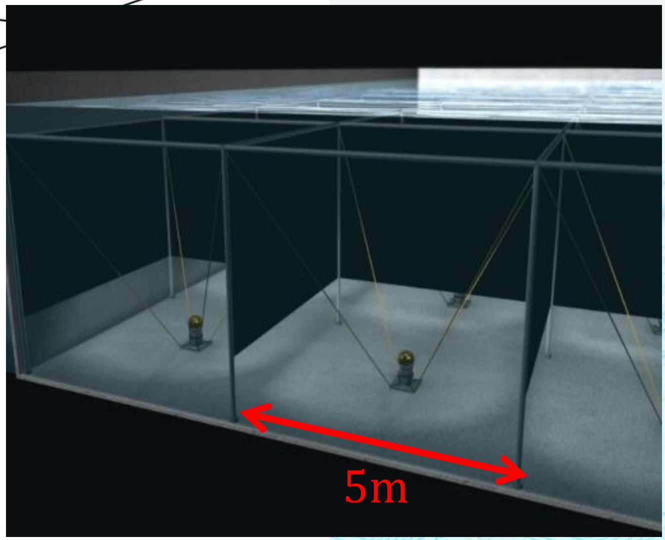
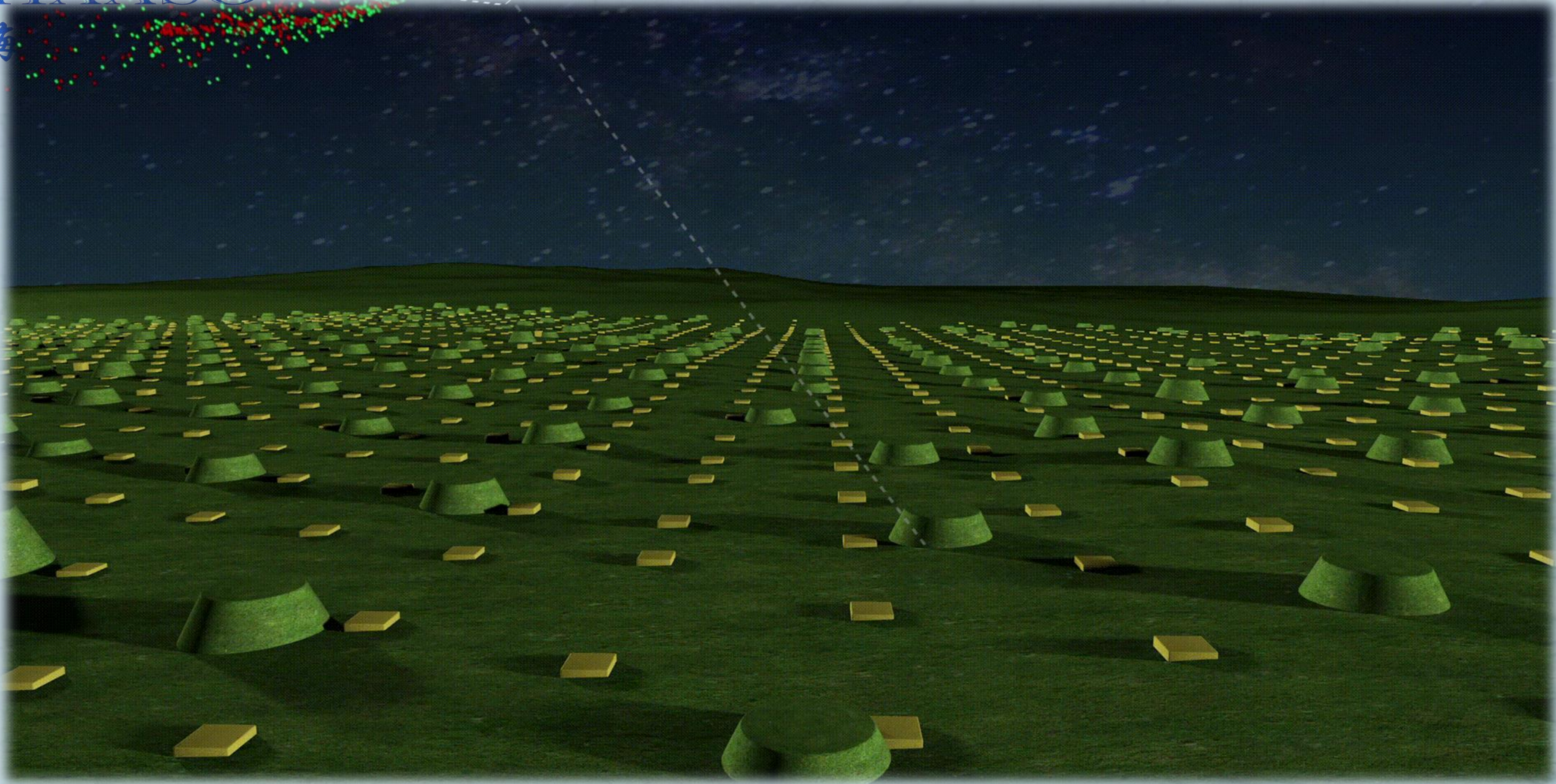
LHAASO Layout







Enter the atmosphere, cascade interaction generates a "shower of particles" which last few nanoseconds



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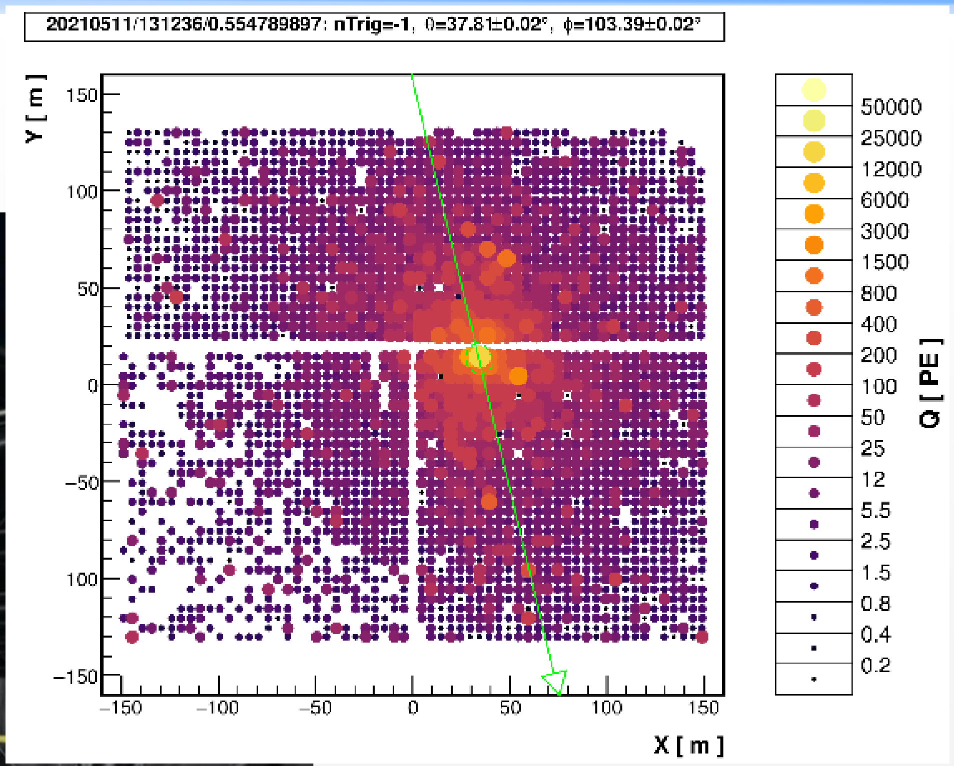
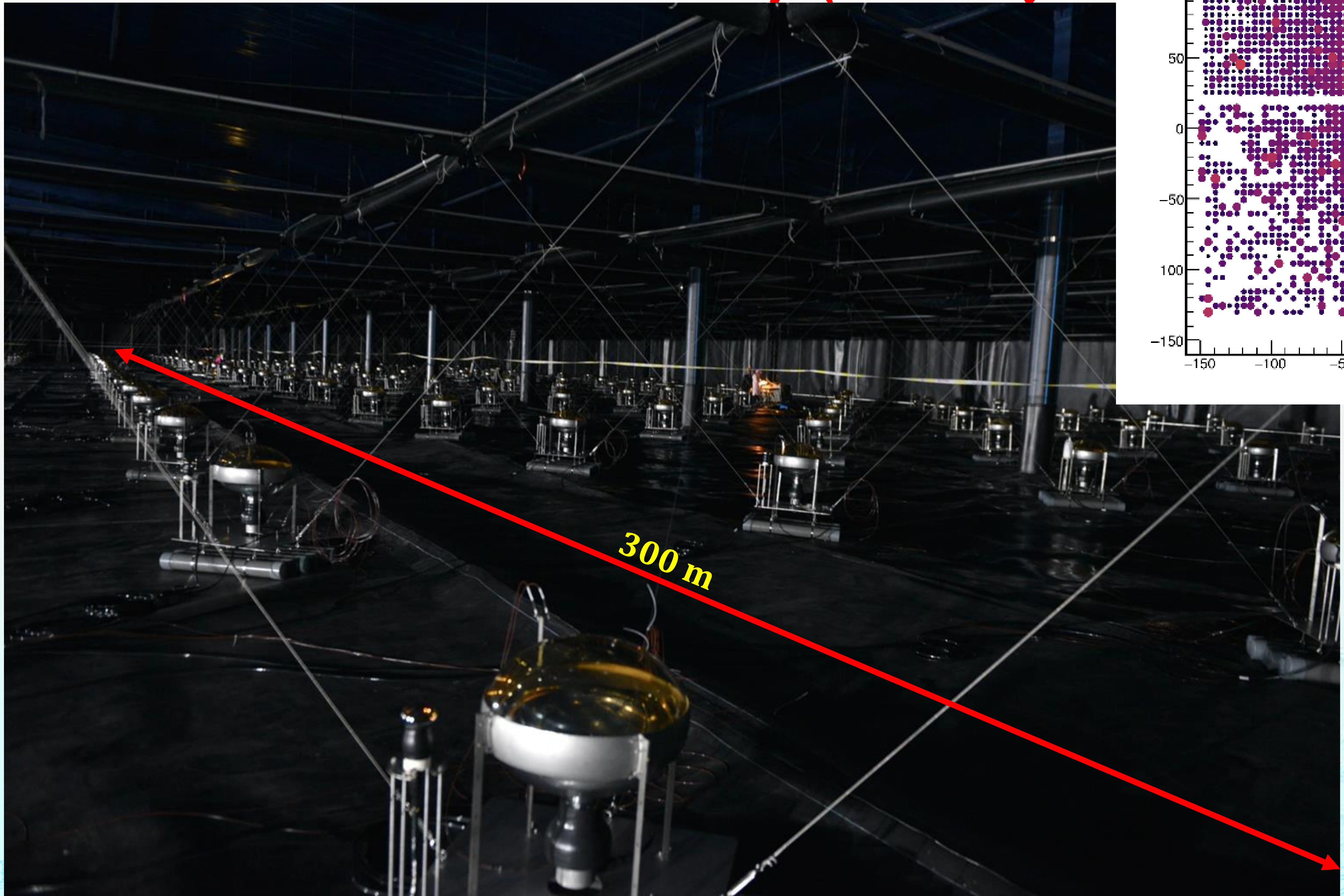
Water Cherenkov Detector Array (WCDA)





- **Area：**
  78,000 m^2
- **Detector units：**
  3120
- **Energy Range：**
  0.1-10 TeV

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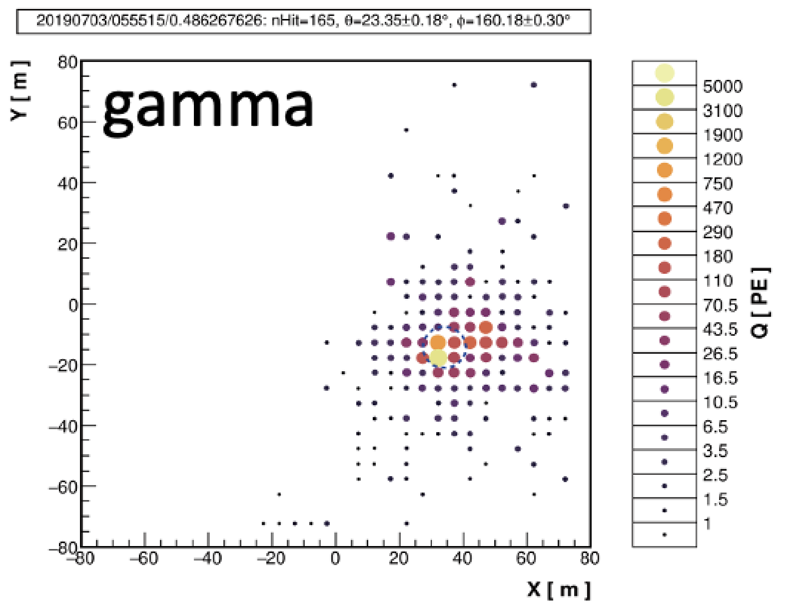
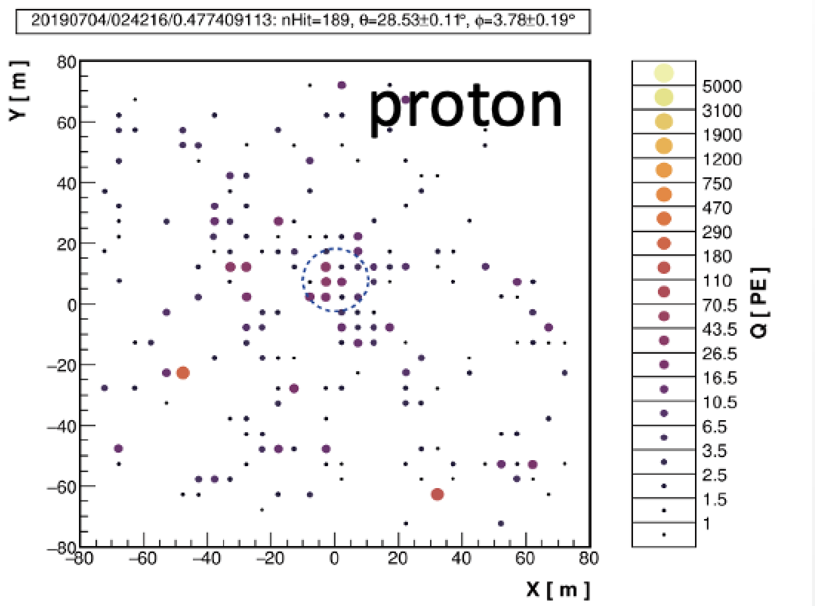
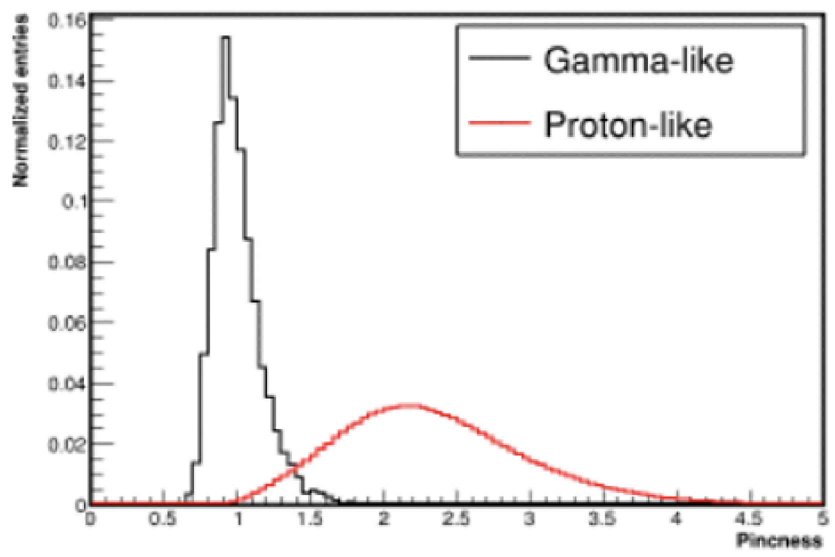
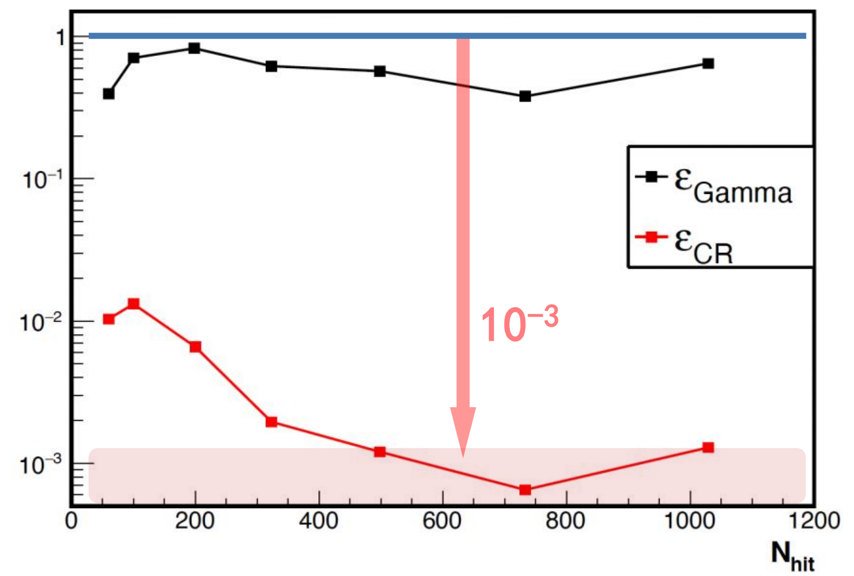
CR Background rejection in WCDA





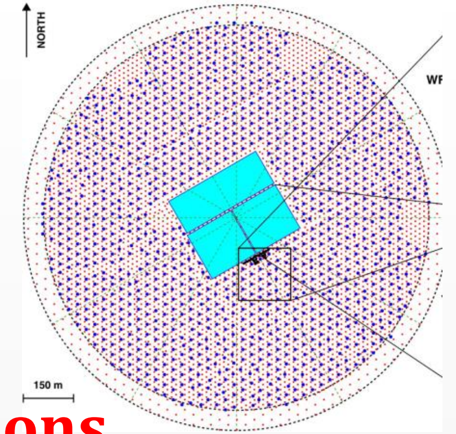




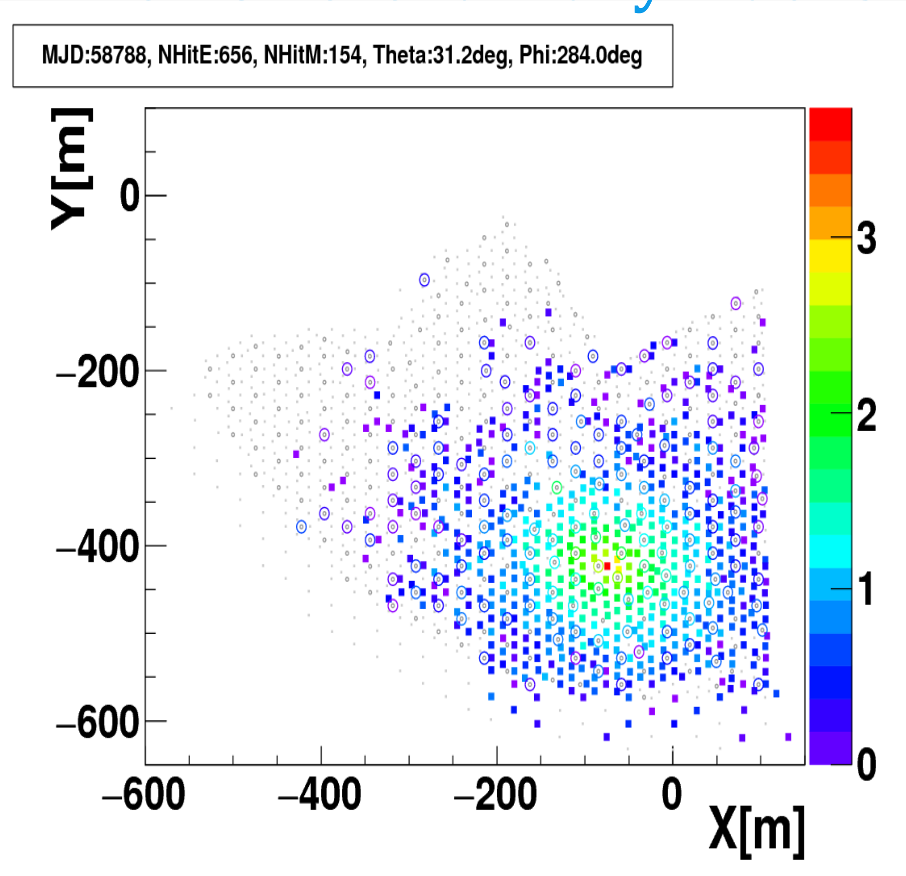
KM2A

Selection of γ–rays out of CR background

Active Area for Muons vs. Array Area: 4%

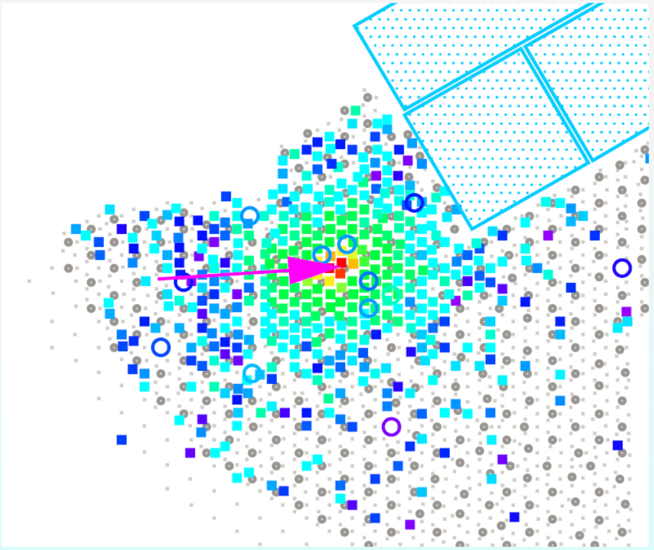


~1 PeV CR event: many muons



~ 1 PeV γ–ray event： very few muons

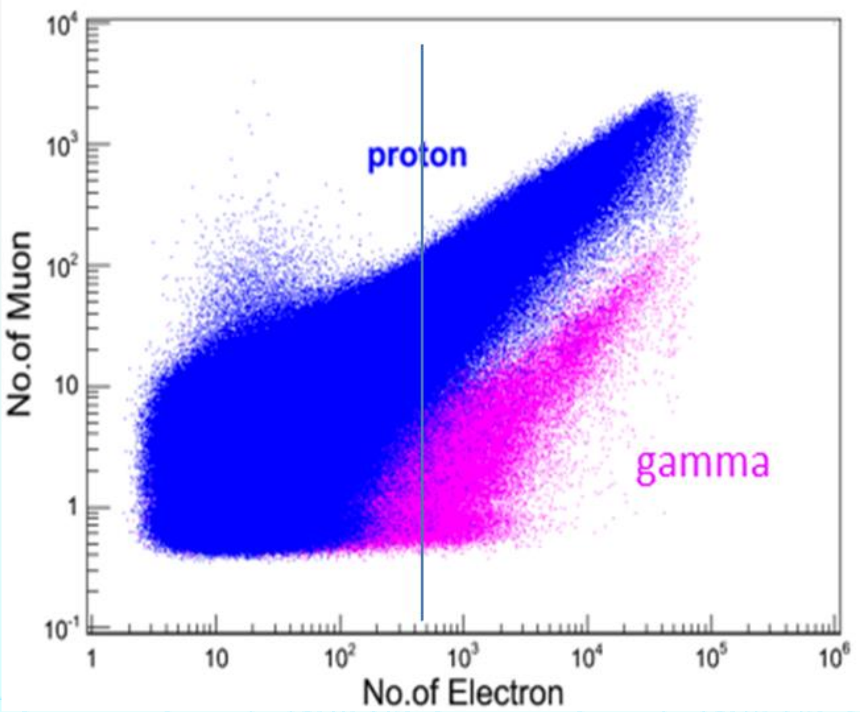
~1 PeV from the Crab

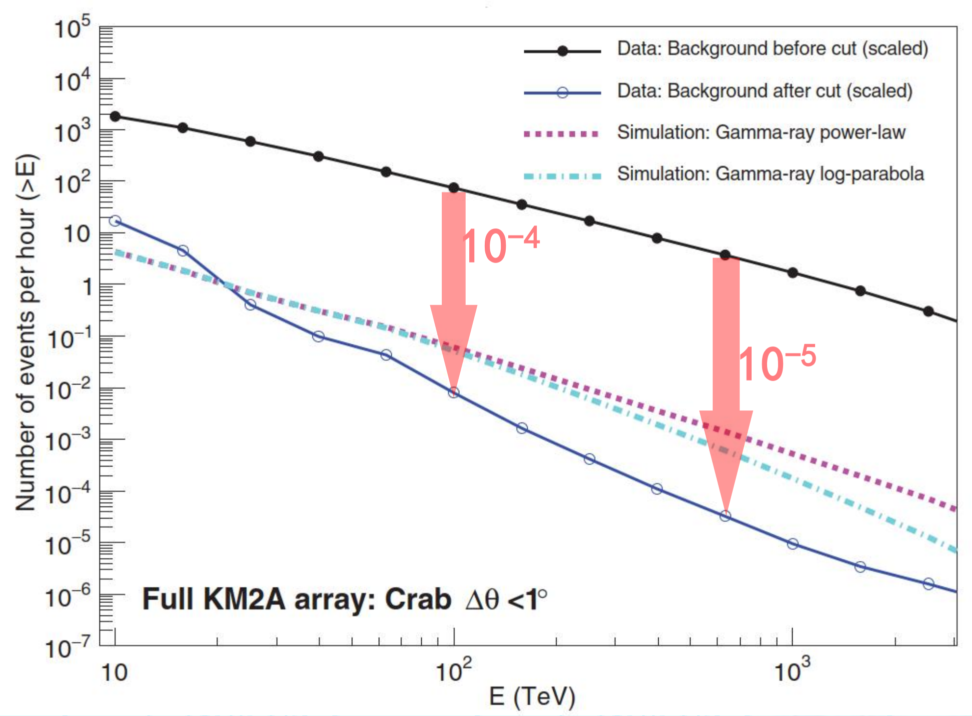


- Area：
  1.3 km^2
- Detectors：
  5242 ED
  1188 MD
- Energy Range：
  0.01-10 PeV

CR background Rejection Power

- Counting number of measured muons in a shower
- Cutting on ratio N_{μ}/N_e<**1/230**
- BG-free ($N_{\gamma}>10N_{CR}$) Photon Counting for showers E>100 TeV from the Crab



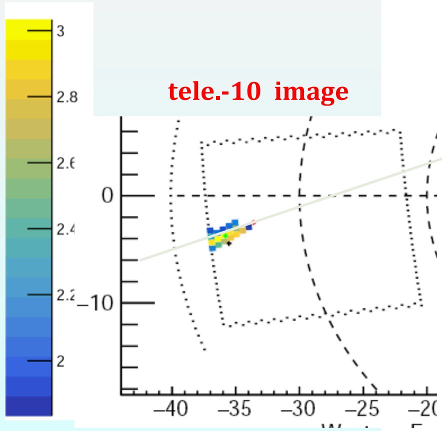


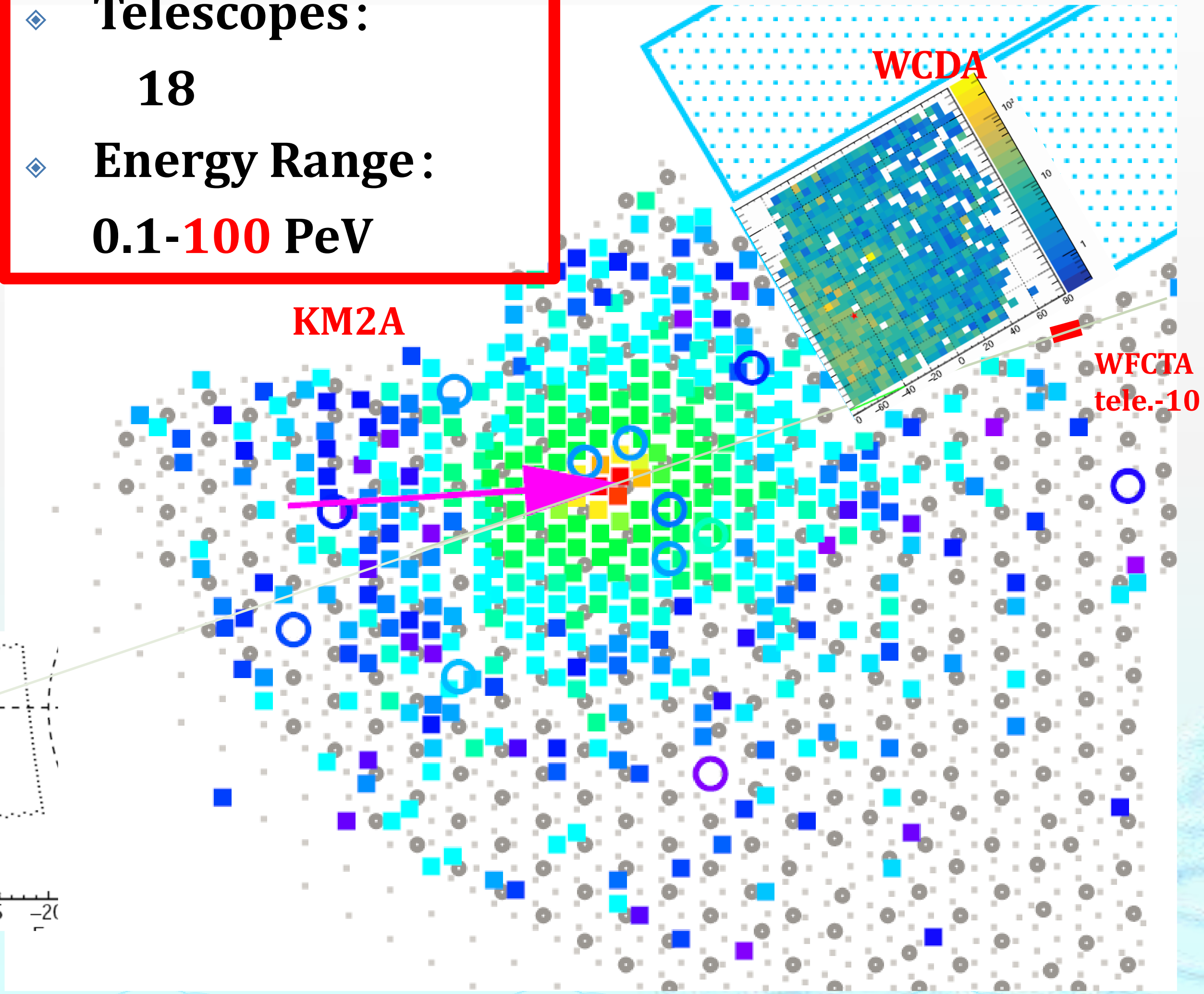
Wide FoV C-Telescope Array (WFCTA)

Cross-checking inside Collaboration

- **Telescopes:**
  18
- **Energy Range:**
  0.1-100 PeV

- WFCTA measured the event simultaneously
  L/W~2.6, N_{pe}~9100 in 11 pixels
- Energy: 0.9±0.2 PeV
- KM2A measured the event
  $N_{particle}$~4574 in 395 EDs
- Energy: 0.9±0.1 PeV
- Chance probability: <0.1%
  N_{μ}~15 in 11 MDs



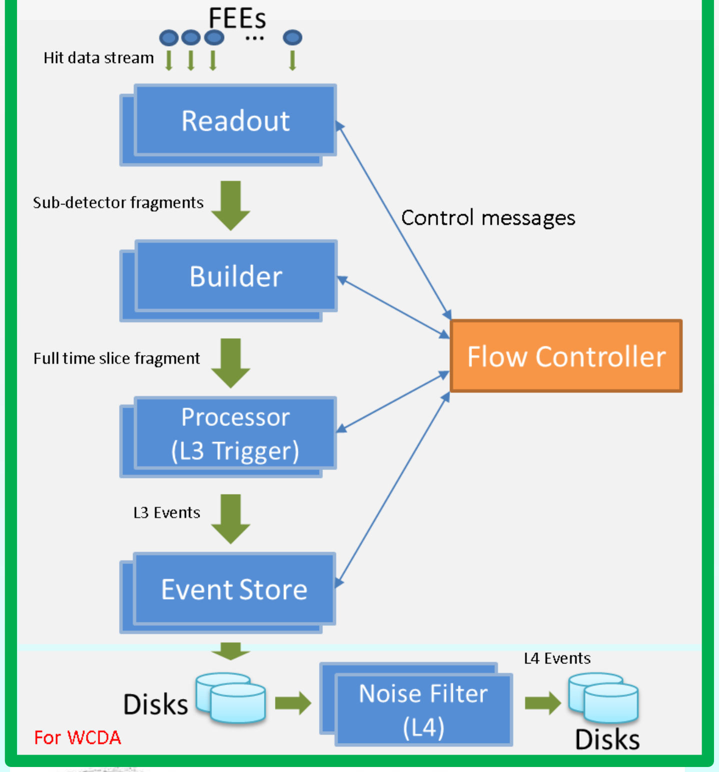


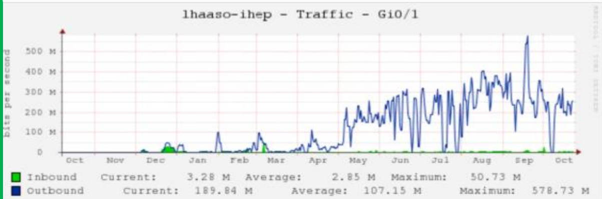
On-site Computing

`trigger-less' Data Acquisition

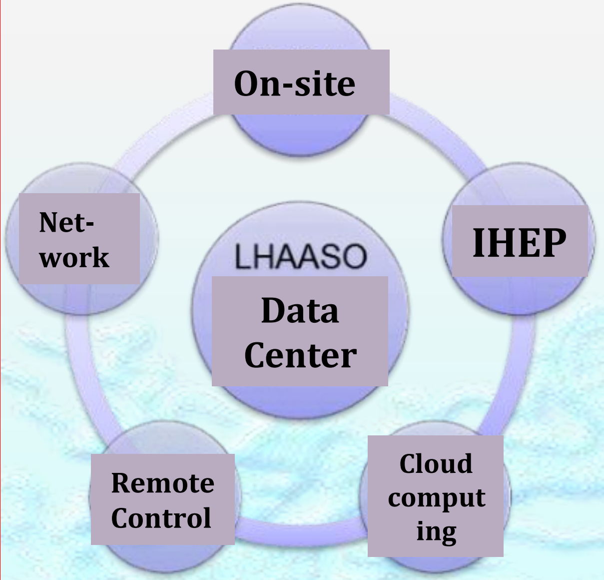
4 GB/s

Zero `dead time'





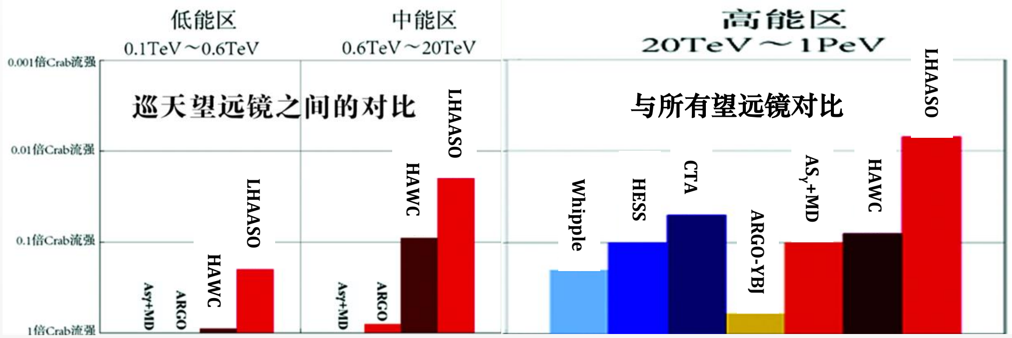
- Full functional computing room
- # of CPU Cores: **~10,000**
- Temp Storage: **2.5 PByte**
- Data Band Width: **2.4 Gbit/sec**

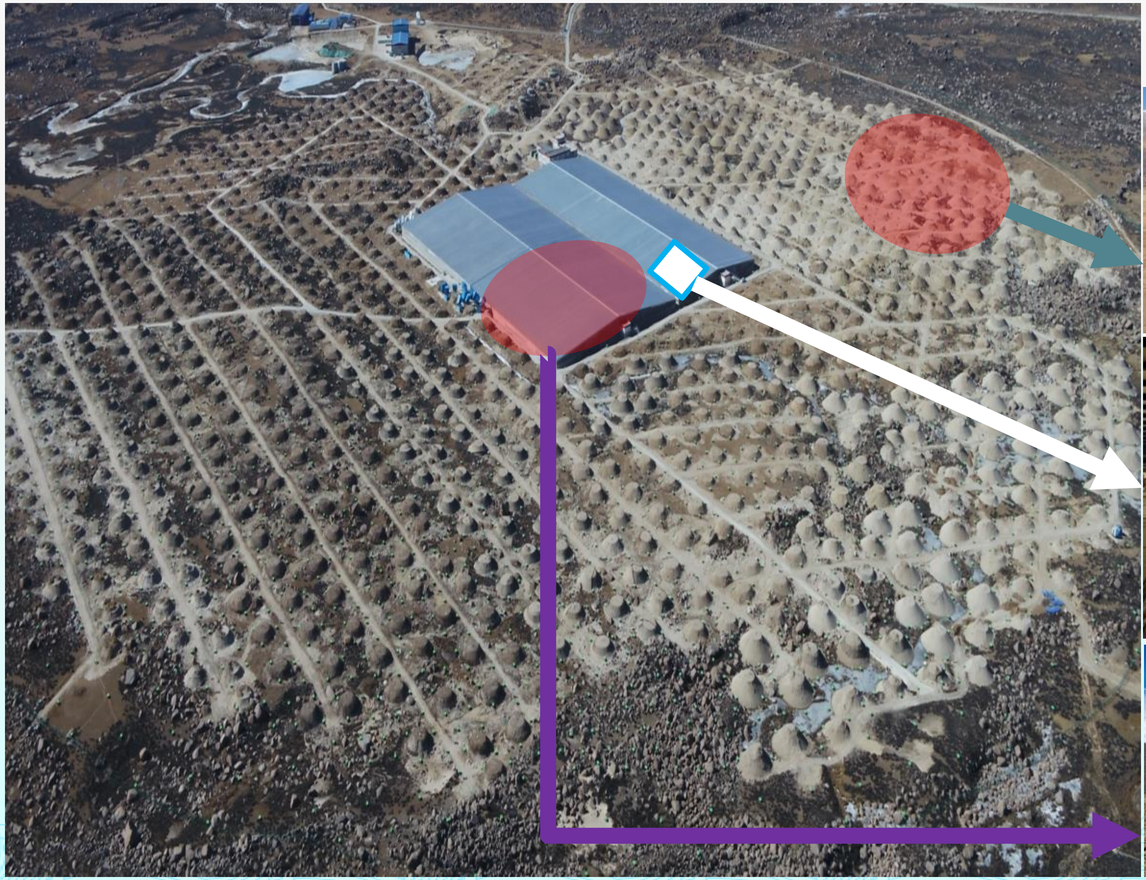


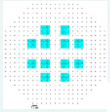
On-site Facility

高海拔宇宙线实验“四代同堂”

LHAASO在宇宙线和伽马天文研究中占据了显著的领先地位，其两大主力设备（一平方公里探测器阵列和水切伦科夫探测器阵列）与上一代装置相比，性能指标都有了跨代提升。



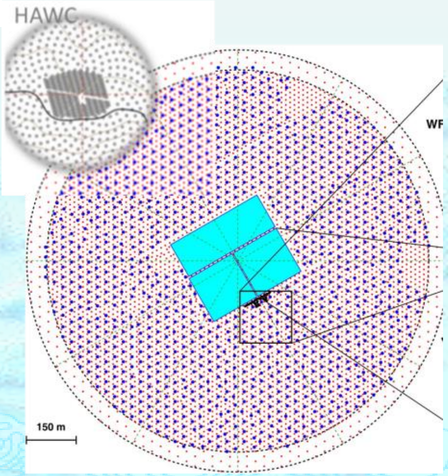




羊八井ASγ

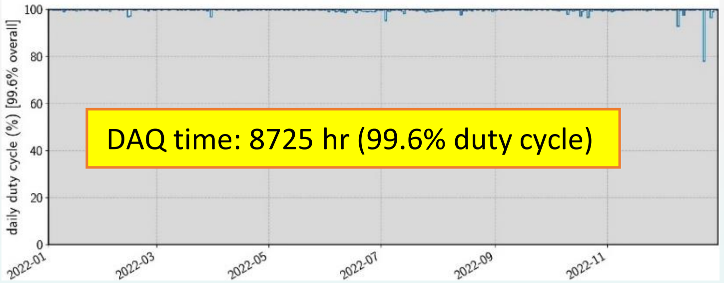
羊八井
ARGO-YBJ

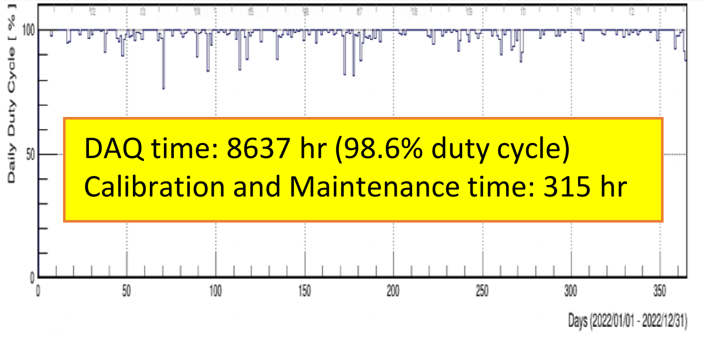
墨西哥、美国
HAWC

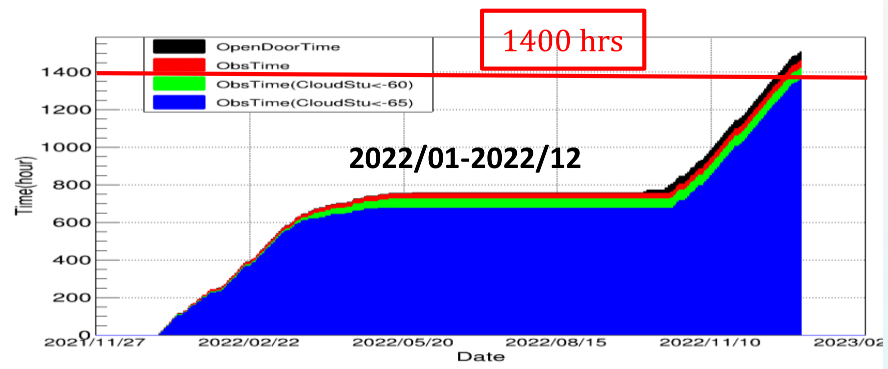


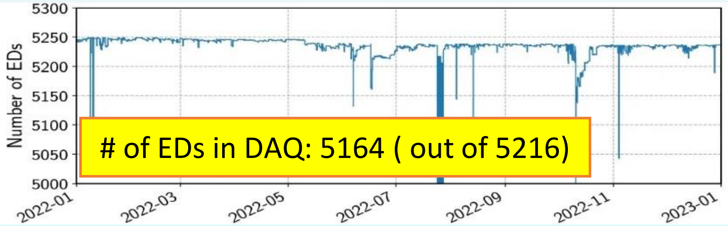
Super Stable & Fruitful Operation

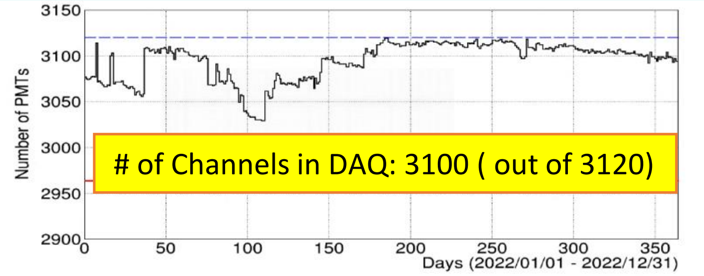


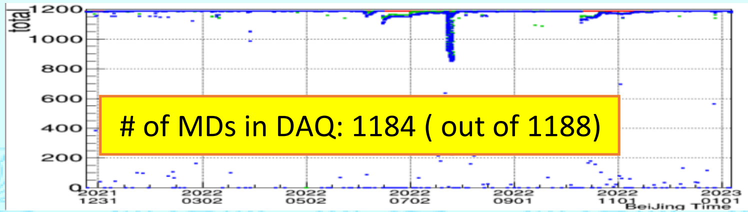












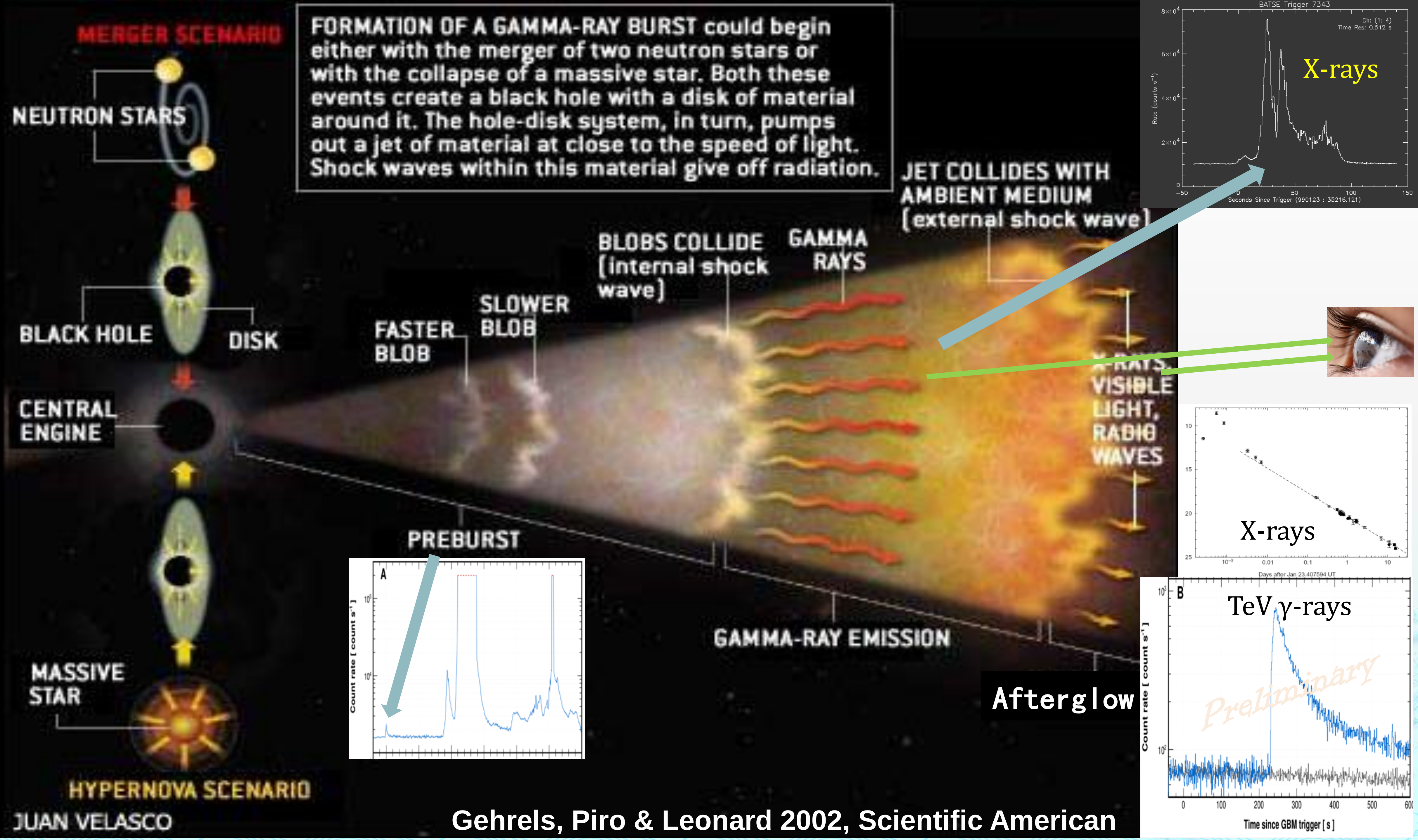
Reconstruction and Analysis

- Data procession
  - # of events: 1 trillion LE、70 billion HE、70 million hybrid
  - Amount: 11 PB
- Simulation
  - # of events: 1 billion LE、0.7 billion HE、150 million hybrid
  - Amount: 4 PB
- # of jobs: 10M for data, 50M for simulation

ACHIEVEMENTS IN GAMMA ASTRONOMY

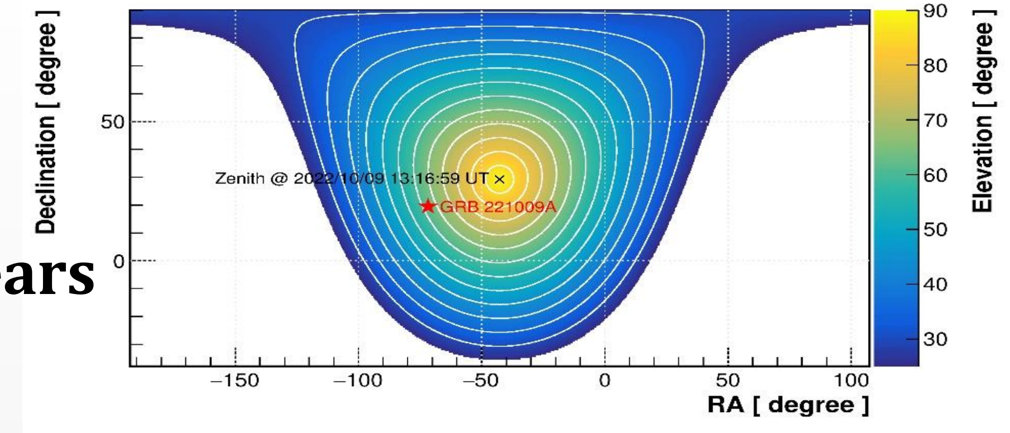
I. GRB221009A
II. The Crab
III. PeVatrons
IV. New TeV Catalog
V. New Physics Exploring: LIV, DM…

GRB model



Gehrels, Piro & Leonard 2002, Scientific American

GRB221009A

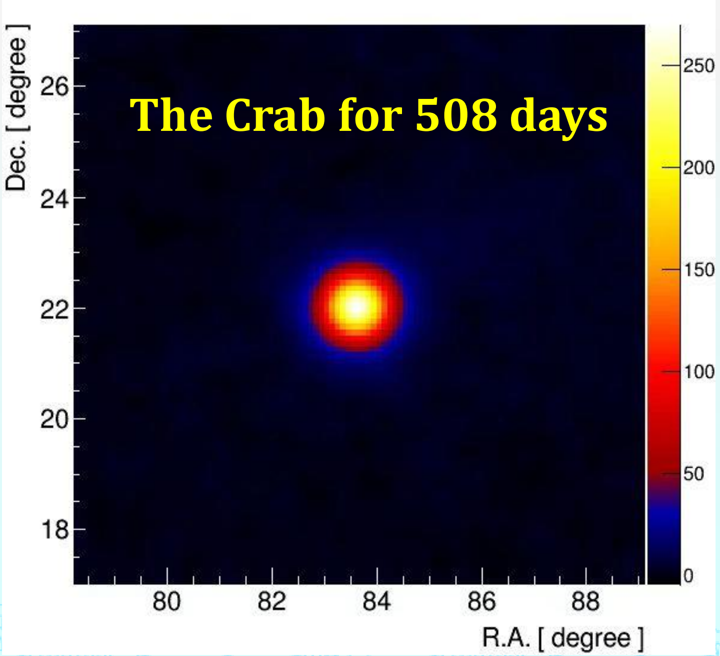


LHAASO observed the brightest GRB in last 60 years

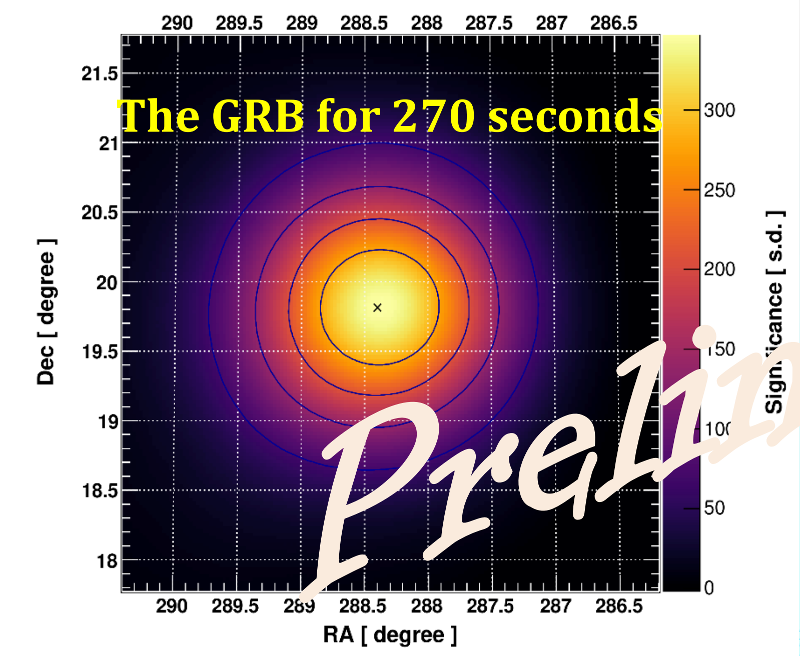
1. >64,000 photons recorded above 200 GeV
2. Significance >300 σ
3. Photon energy: E_{max} ~ 18 TeV

GCN 32677 on Oct. 10th, 2022

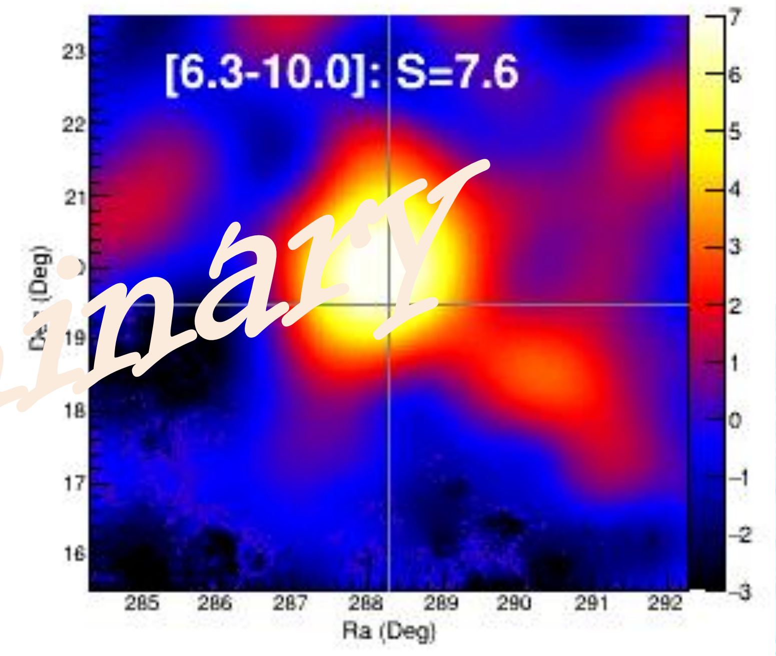
Photon energy E: 1 TeV



0.5 TeV

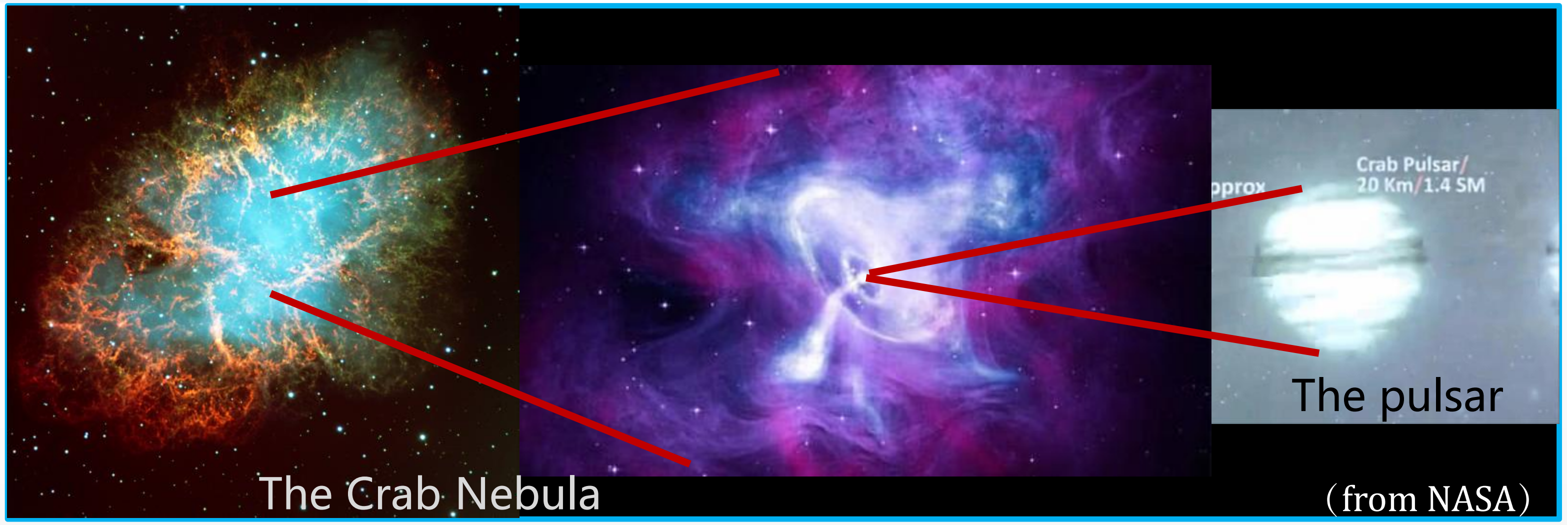


8 TeV



Many things we could learn from the enormous flux of photons

4. Precision measurement of the light curve of the afterglow
   - In both rising and decaying phases
5. Time sliding spectra of GRB photons up to 7 TeV by LHAASO-WCDA
   - The shape of spectra may tell something about the evolution of the jet
6. IC peak observed ?
   - Combined analysis with HXMT and LAT(available only in a very limited time window)
7. Fast variability of flux at a scale of 10^{17} cm (~ the external shock)?
   - Should be highly unexpected !
8. The highest energy photons measured by LHAASO-KM2A
   - New physics frontier exploring

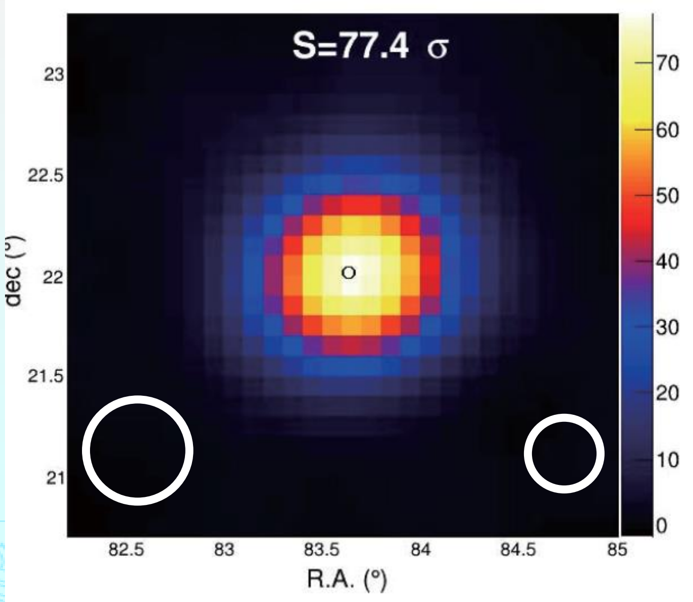


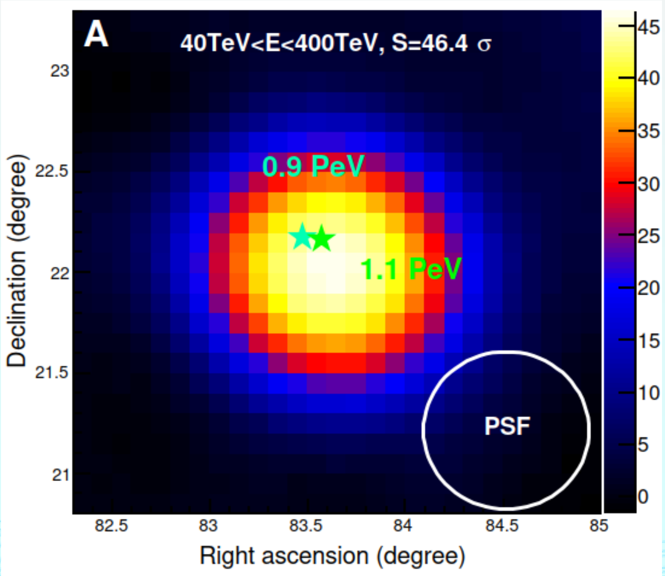
The coverage of 3.5 orders of magnitudes of energy

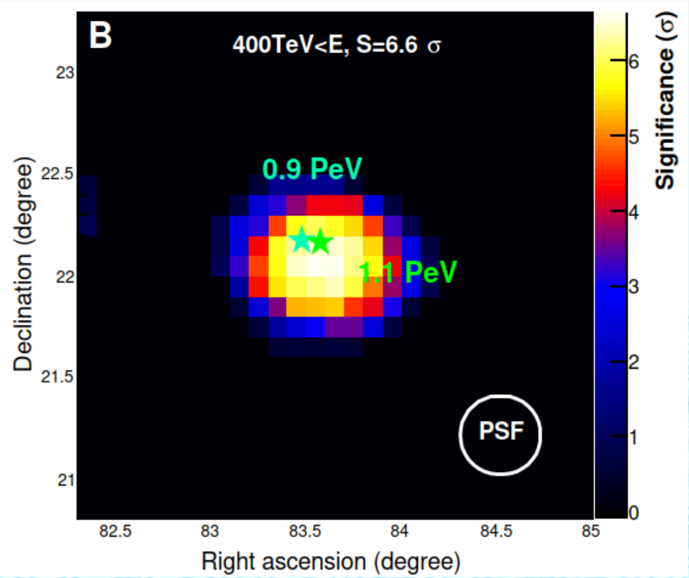
0.5 - 12 TeV　　　　40-400 TeV　　　　0.4-1.2 PeV

PSF: 0.22°　　　　0.26°　　　　0.15°

Pointing accuracy: 0.01°



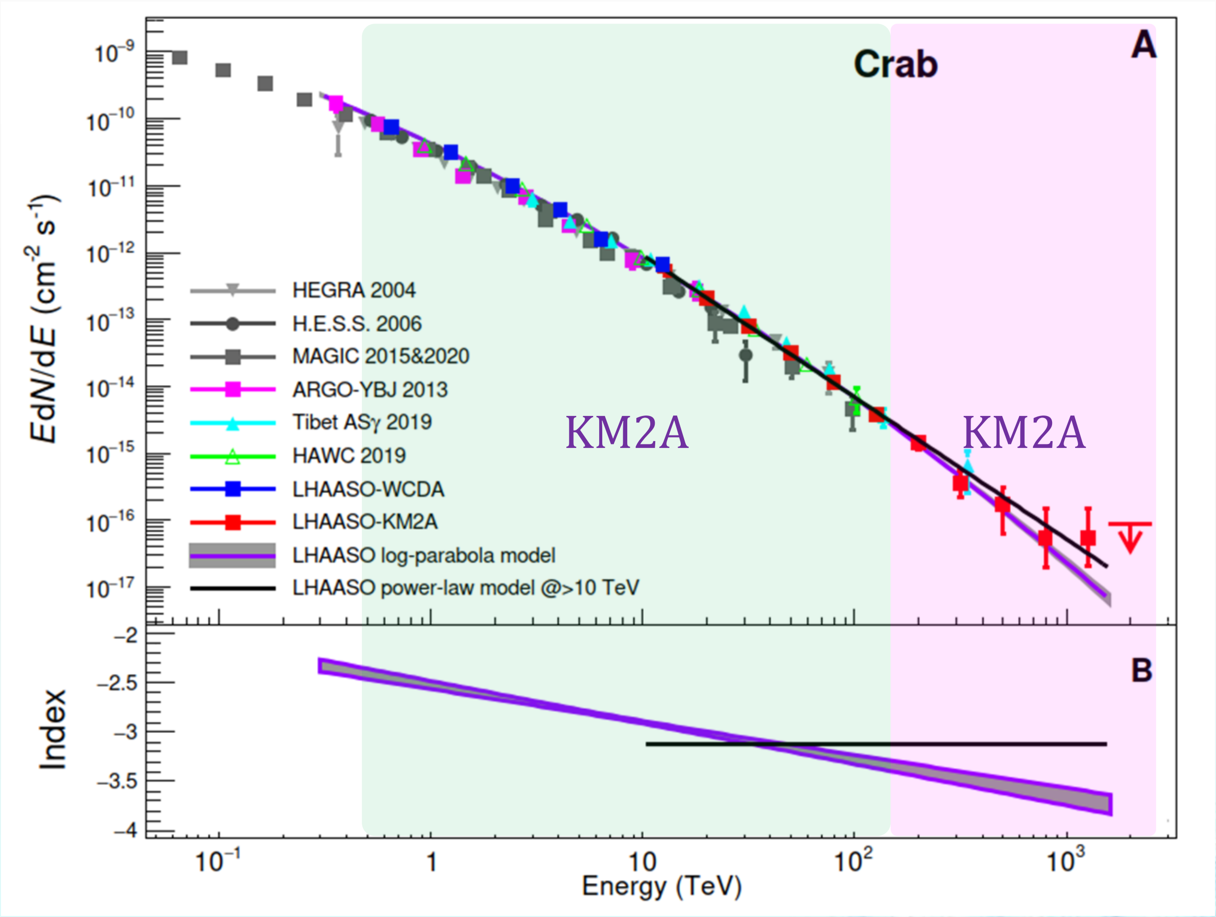




SED of the Crab: “standard Candle”& PeVatron

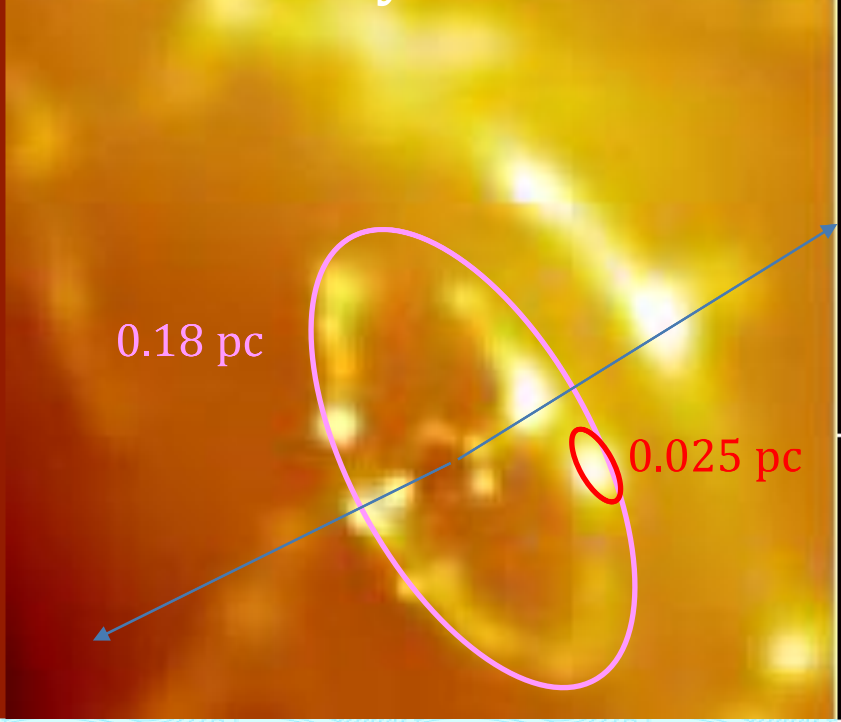
LHAASO, Science, Science, 373, 425 (2021)

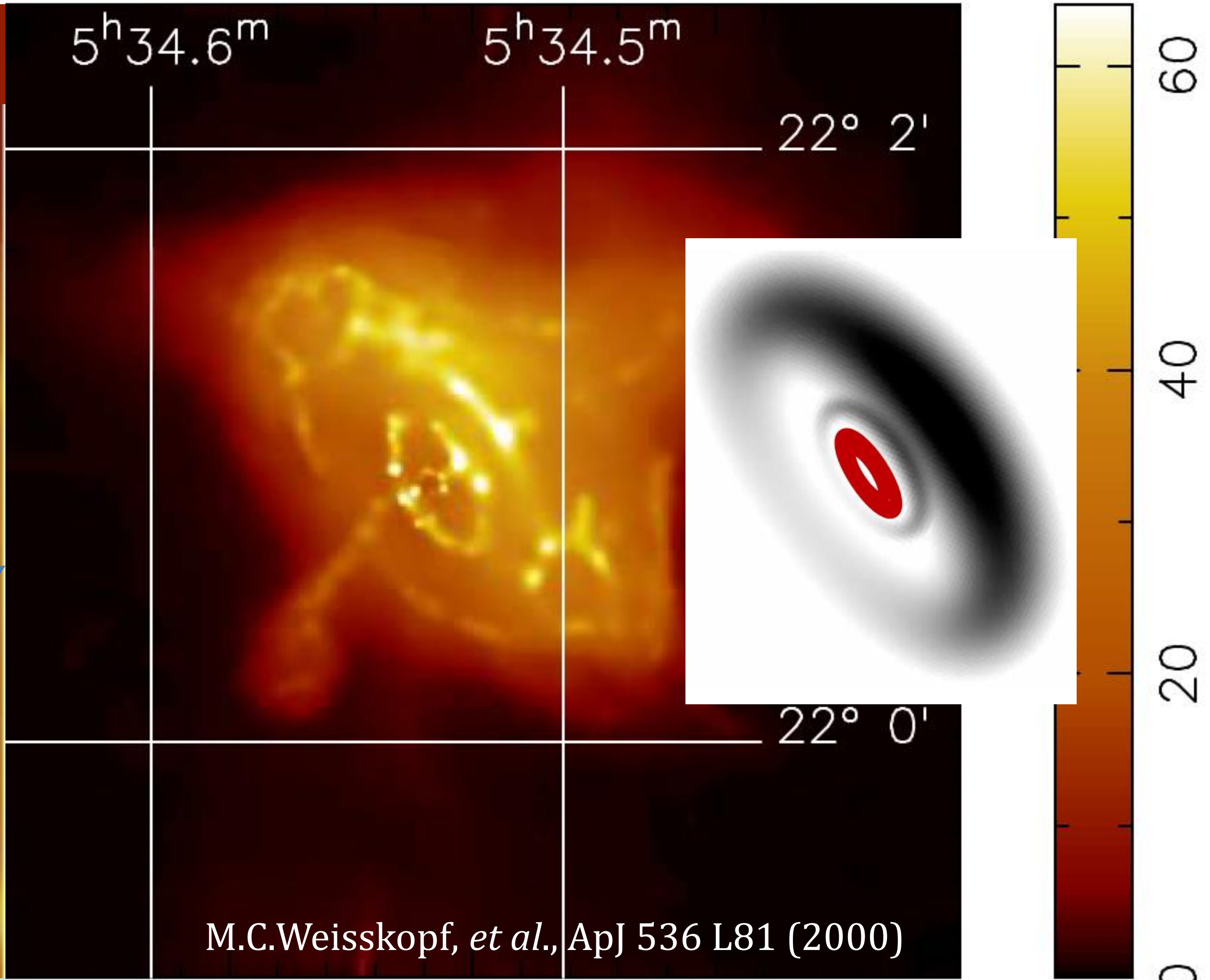
- **LHAASO:**
  - **Covering 3.5 decades of energy**
  - **Agreeing with other experiments below 100 TeV**
  - **Self cross-checking between WCDA & KM2A**
- **LHAASO-KM2A:**
  - **Unique UHE SED**
  - **A PeVatron without ambiguity**
- **Clear origin: a well-known PWN**
- **An extreme e-accelerator:**
  - **2.3 PeV electrons**
  - **in ~0.025 pc core region**
  - **accelerating efficiency of 15% (1000× better than SNR shock waves)**



Extreme Electron Accelerator

- Chandra has observed many knots in between the pulsar and the inner ring
- They are apparently in the region that ~PeV photons may be emitted by electrons



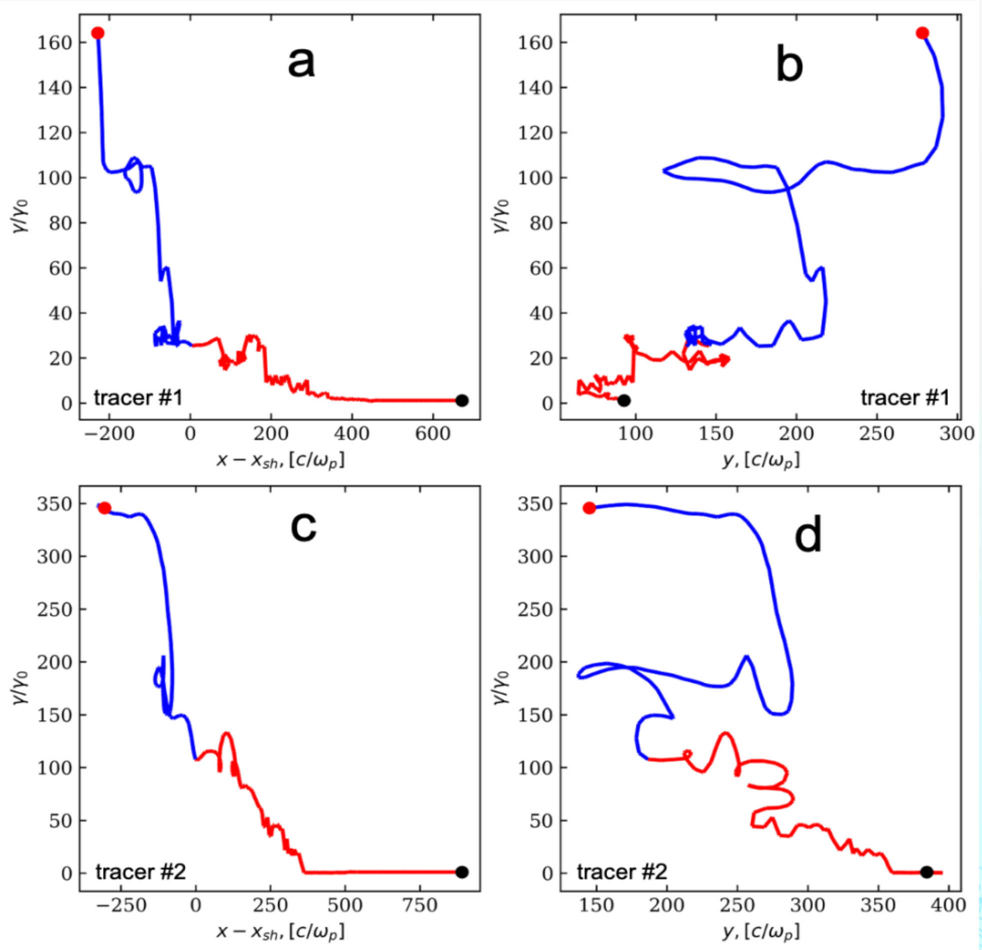


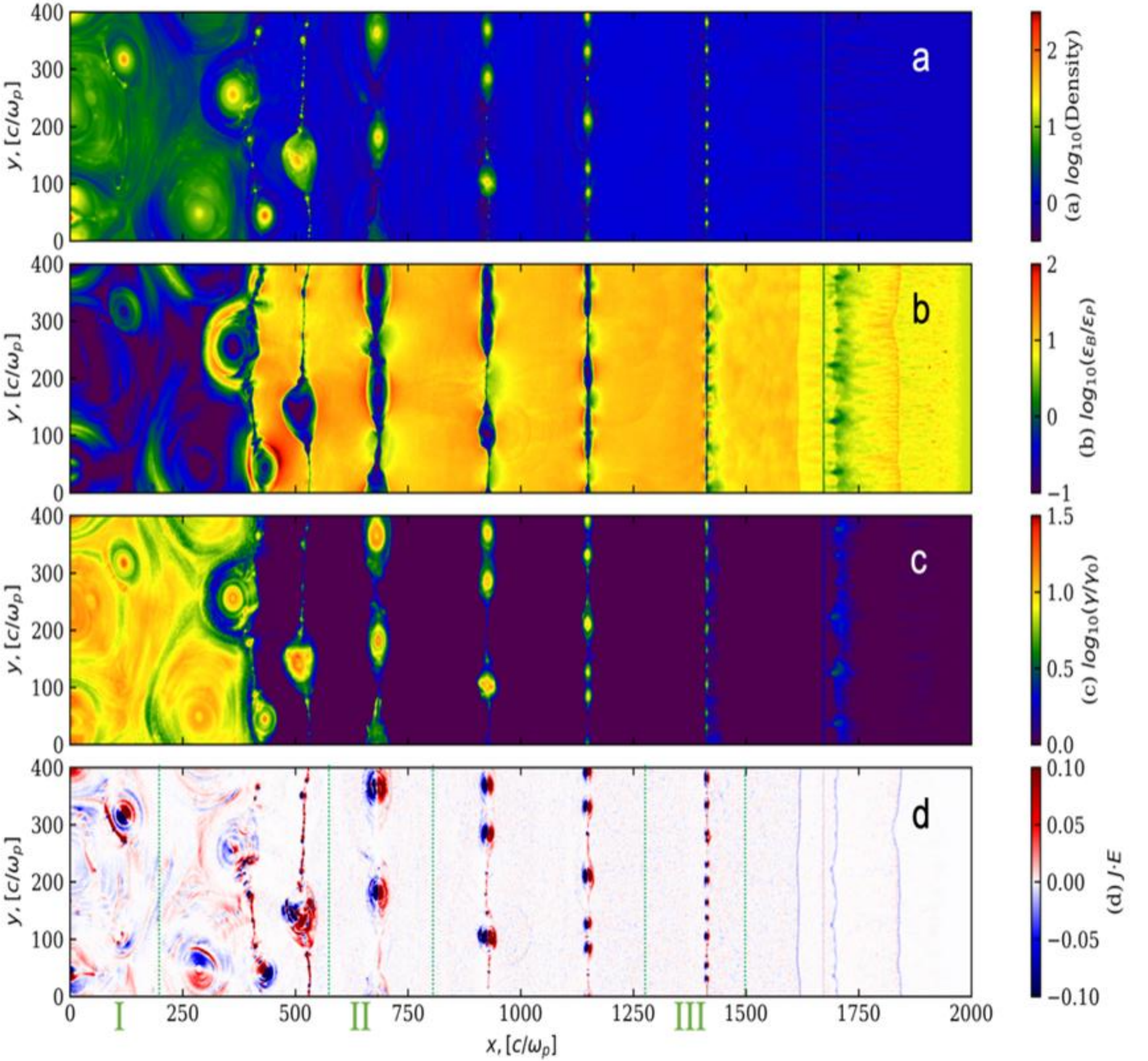
M.C.Weisskopf, *et al.*, ApJ 536 L81 (2000)

磁重联电流片、
终端激波面

MHD PIC Simulation

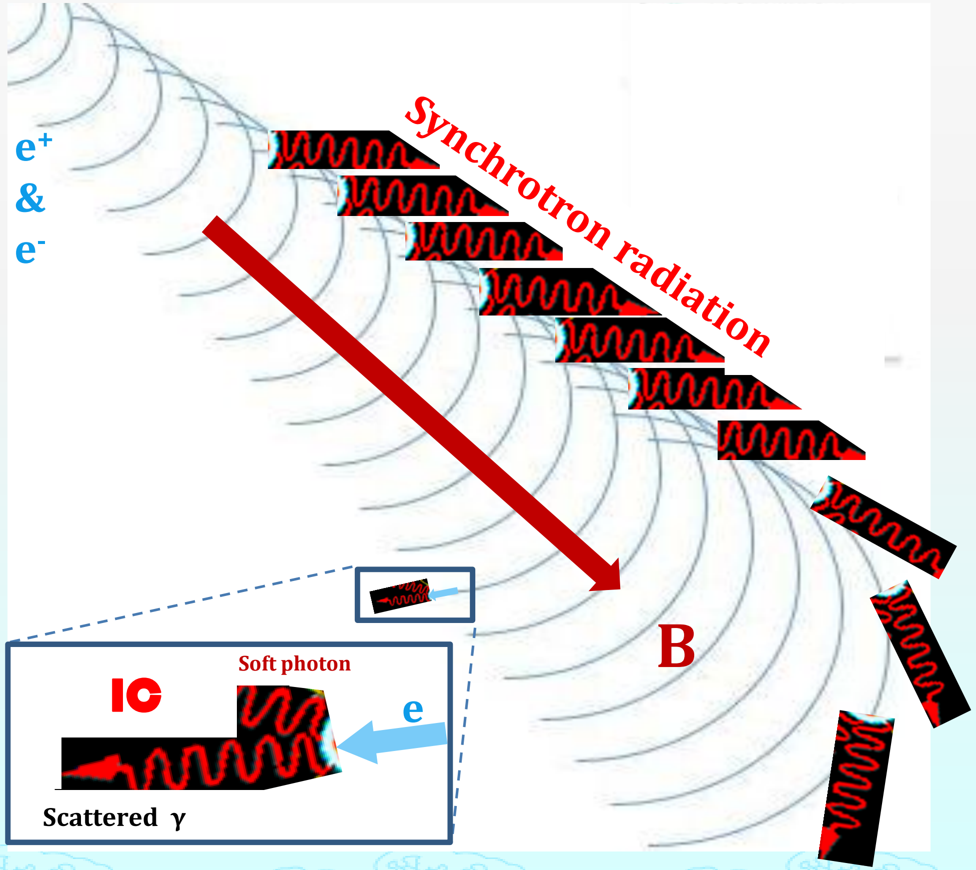
Yingchao Lu et al., ApJ 908, 2, 147 (2021)



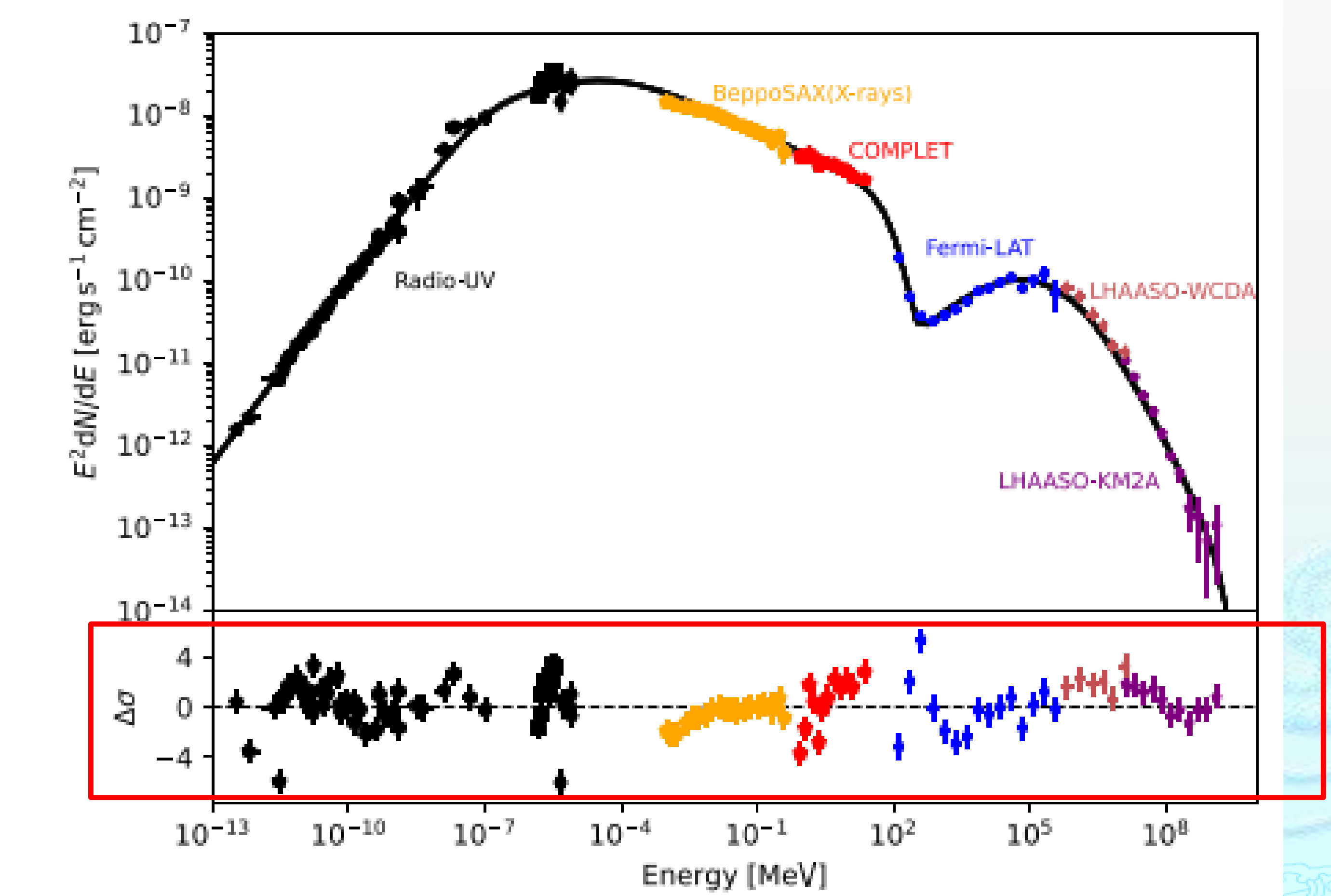


"Extreme Electron PeVatron"

- One-zone Leptonic Model： non-negligible fact, however...
- It is hardly to be recognized as a "reasonably good fitting"
- Too simple?



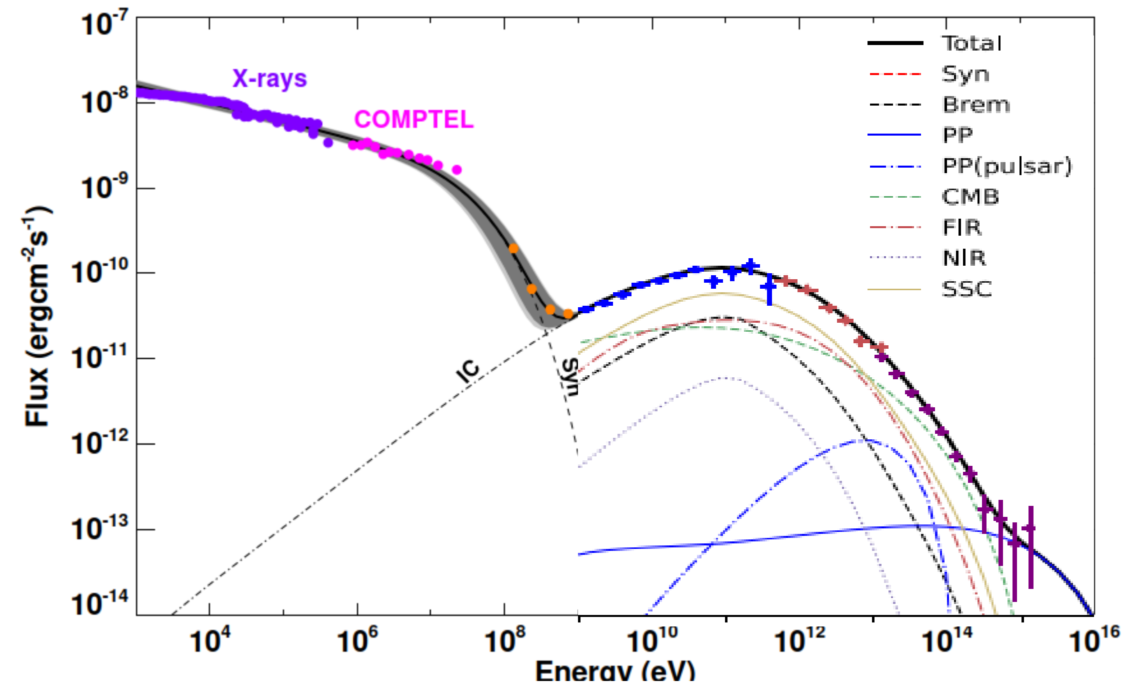
L. Nie et al., ApJ, **924** 42 (2022), arXiv:2201.03796

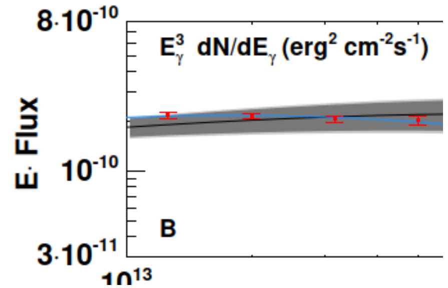


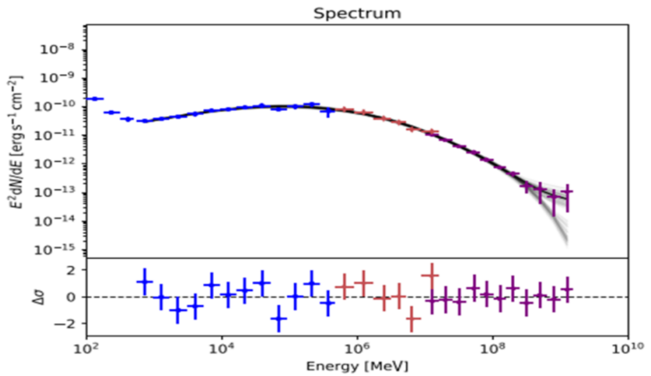
SED of the Crab: EEA or Super-PeVatron

LHAASO, Science, DOI10.1126/science.abg5137, 2021

- Perfect interpretation of one-zone electronic origin up to 50TeV
- Reasonable extension up to 1 PeV, with a deviation of 4 σ
- Can not rule out proton origin of photons ~1.1 PeV, yet
- Accelerator boosting protons to few PeV to 30 PeV nearly perfectly explain the LHAASO data
- 这将是首次发现超过“膝”能量的宇宙线源，存在于银河系内，并且不是SNR，而是PWN！
- 2-3年之内可望敲定！







L. Nie et al., ApJ, 7, 96(2022)

Discovery in KM2A Survey

Our Galaxy is full of PeVatrons

LHAASO, Nature, 594, p.33-36, 2021

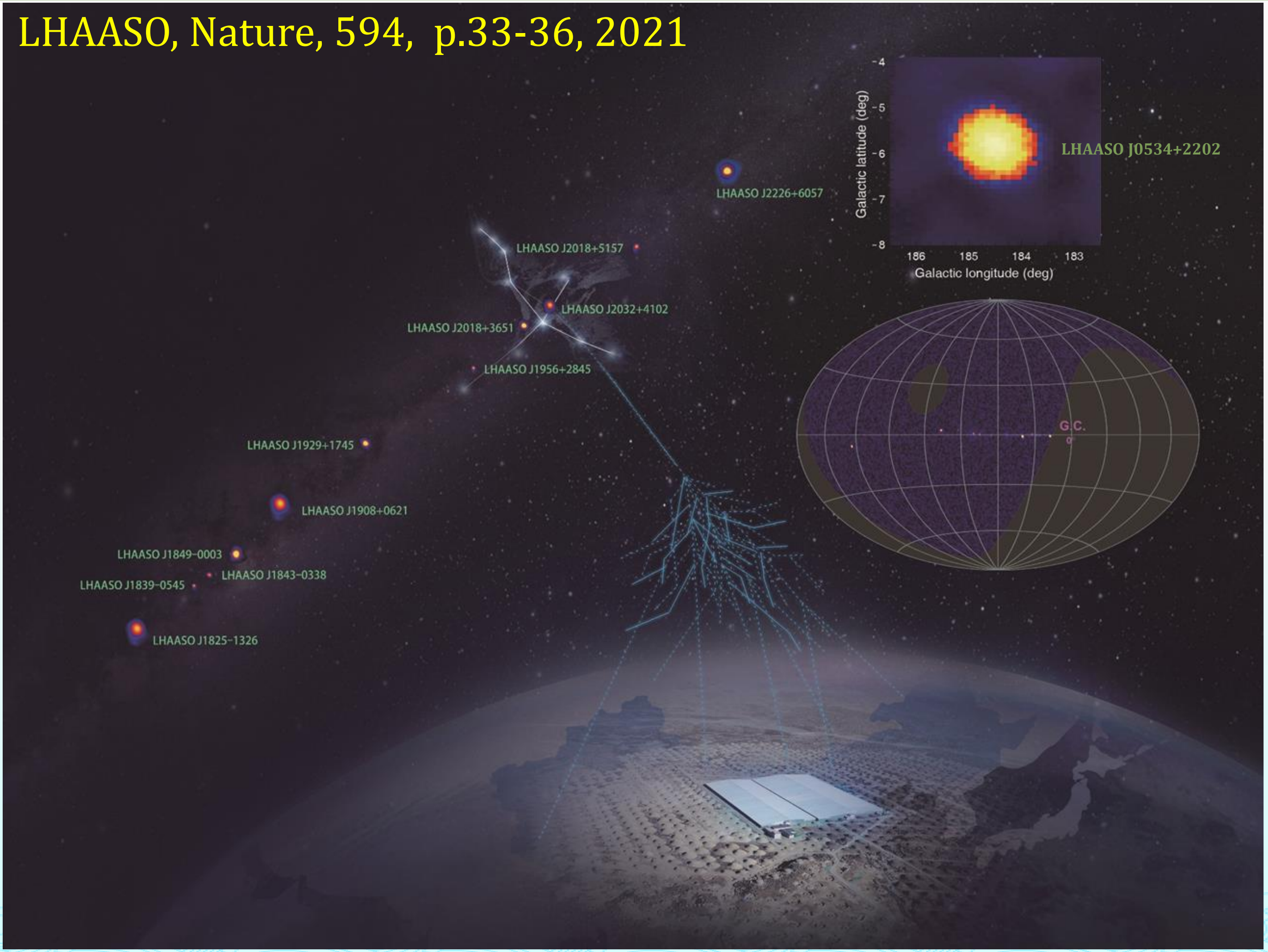


Table 1 | UHE γ-ray sources

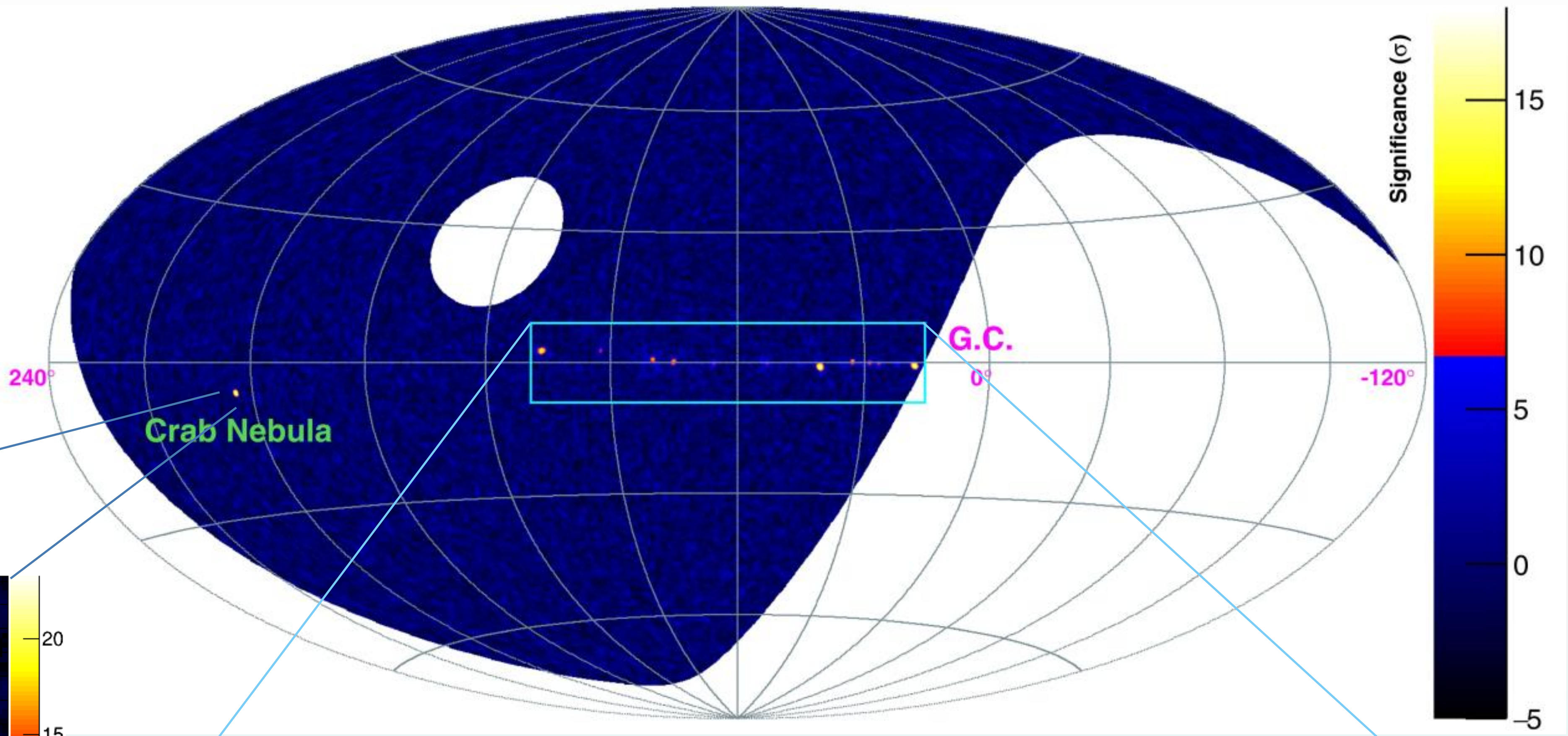
Source name	RA (°)	dec. (°)	Significance above 100 TeV (×σ)	E_{max} (PeV)	Flux at 100 TeV (CU)
LHAASO J0534+2202	83.55	22.05	17.8	0.88 ± 0.11	1.00(0.14)
LHAASO J1825-1326	276.45	−13.45	16.4	0.42 ± 0.16	3.57(0.52)
LHAASO J1839-0545	279.95	−5.75	7.7	0.21 ± 0.05	0.70(0.18)
LHAASO J1843-0338	280.75	−3.65	8.5	$0.26 -0.10^{+0.16}$	0.73(0.17)
LHAASO J1849-0003	282.35	−0.05	10.4	0.35 ± 0.07	0.74(0.15)
LHAASO J1908+0621	287.05	6.35	17.2	0.44 ± 0.05	1.36(0.18)
LHAASO J1929+1745	292.25	17.75	7.4	$0.71 -0.07^{+0.16}$	0.38(0.09)
LHAASO J1956+2845	299.05	28.75	7.4	0.42 ± 0.03	0.41(0.09)
LHAASO J2018+3651	304.75	36.85	10.4	0.27 ± 0.02	0.50(0.10)
LHAASO J2032+4102	308.05	41.05	10.5	1.42 ± 0.13	0.54(0.10)
LHAASO J2108+5157	317.15	51.95	8.3	0.43 ± 0.05	0.38(0.09)
LHAASO J2226+6057	336.75	60.95	13.6	0.57 ± 0.19	1.05(0.16)

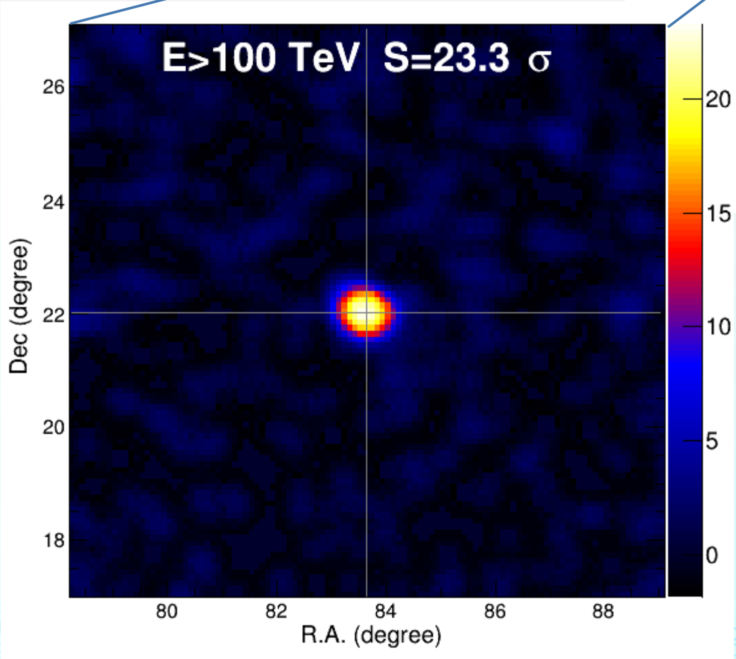
12 PeVatrons are discovered

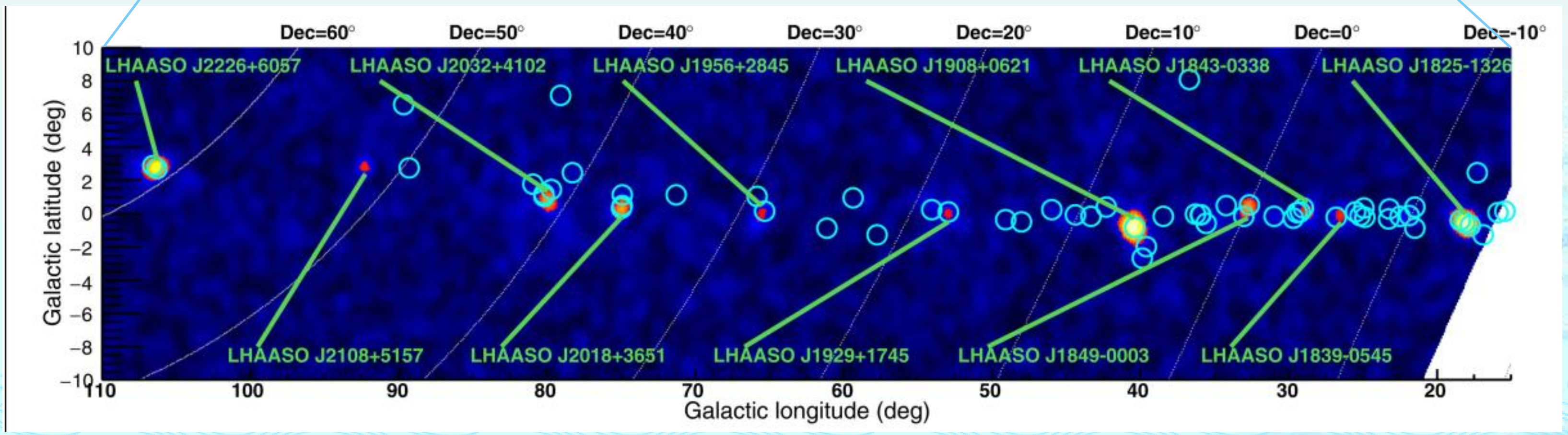
- ◆High Standard： significance >7σ
- ◆BG-free： Cosmic Ray background rejection rate $<10^{-4}$
- ◆High Statistics： 530 UHE photons
- ◆Multiple Type of Sources

LHAASO
高海拔宇宙线观测站

UHE γ–ray (0.1-1 PeV) Sky Map







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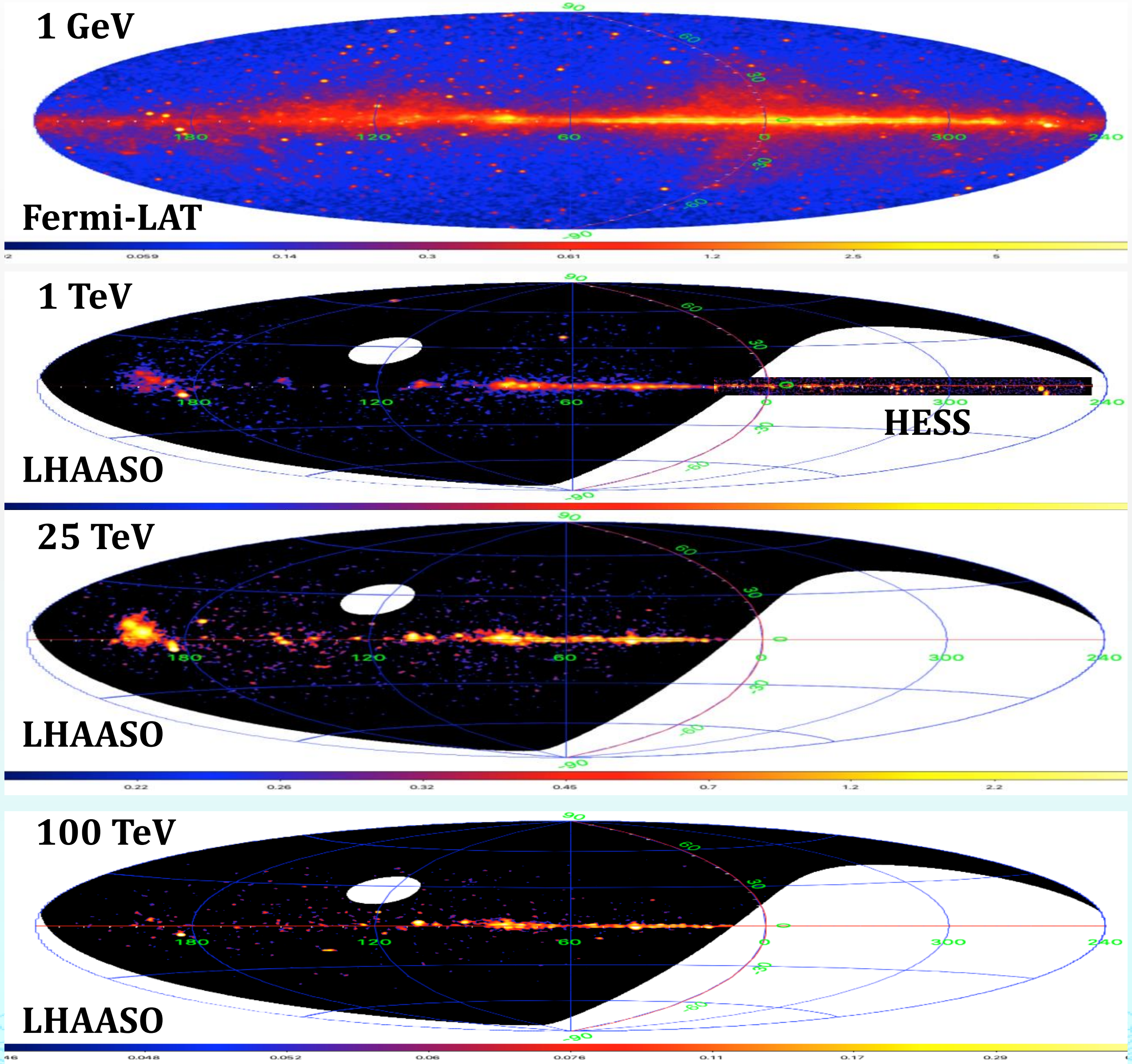
γ-ray sky map

- 1 GeV
- 1 TeV
- 25 TeV
- 100 TeV



Ver-1 LHAASO Catalog is ready to be published

- 100+ sources have been detected with tens of new sources discovered
- Diffuse γ-rays in our galaxy is mapped
- Sky maps of the entire northern hemisphere are available up to 100 TeV and above

LHAASO
高海拔宇宙线观测站

Exploring Lorentz Invariance Violation

In the superluminal LIV

$$\gamma \rightarrow e^- e^+$$

$$\alpha_0 \leq \frac{4m_e^2}{E_\gamma^2 - 4m_e^2},$$

$$E_{LIV}^{(1)} \geq 9.57 \times 10^{23} \mathrm{eV} \left(\frac{E_\gamma}{\mathrm{TeV}}\right)^3,$$

$$E_{LIV}^{(2)} \geq 9.78 \times 10^{17} \mathrm{eV} \left(\frac{E_\gamma}{\mathrm{TeV}}\right)^2.$$

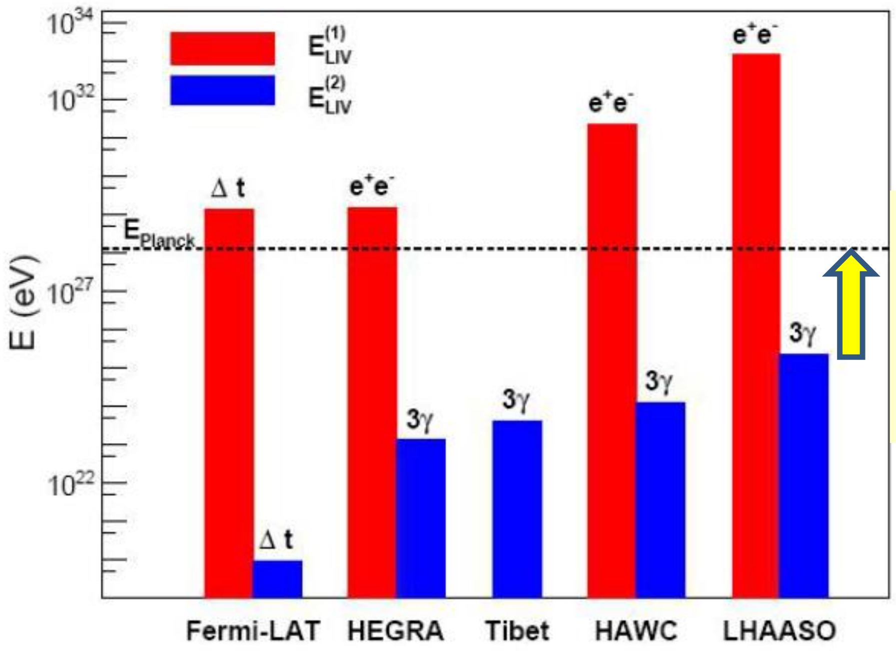
$$\gamma \rightarrow 3\gamma$$

$$\Gamma_{\gamma\rightarrow 3\gamma} = 5 \times 10^{-14} \frac{E_\gamma^{19}}{m_e^8 E_{LIV}^{(2)10}},$$

$$E_{LIV}^{(2)} > 3.33 \times 10^{19} \mathrm{eV} \left(\frac{L}{\mathrm{kpc}}\right)^{0.1} \left(\frac{E_\gamma}{\mathrm{TeV}}\right)^{1.9}.$$

New CLs method

Source	L (kpc)	E_{max} (PeV)	$E_{cut}^{95\%}$ (PeV)
J0534+2202	2.0	0.88	$0.75^{+0.043}_{-0.043}$
J2032+4102	1.4	1.42	$1.14^{+0.06}_{-0.06}$

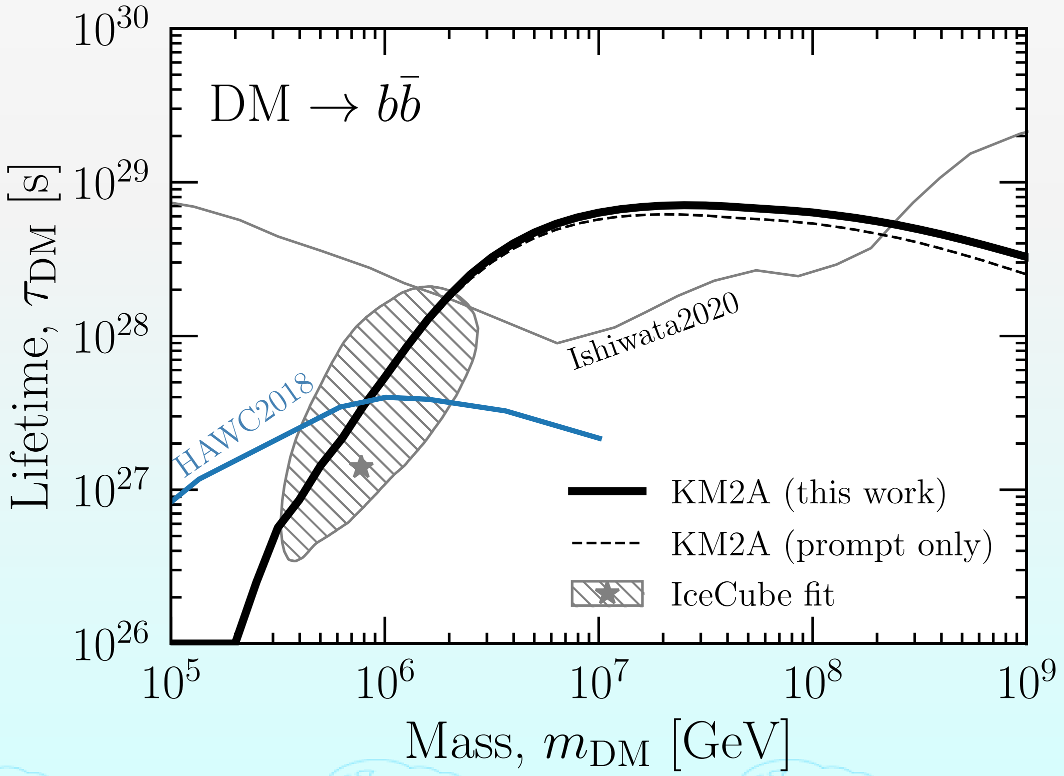


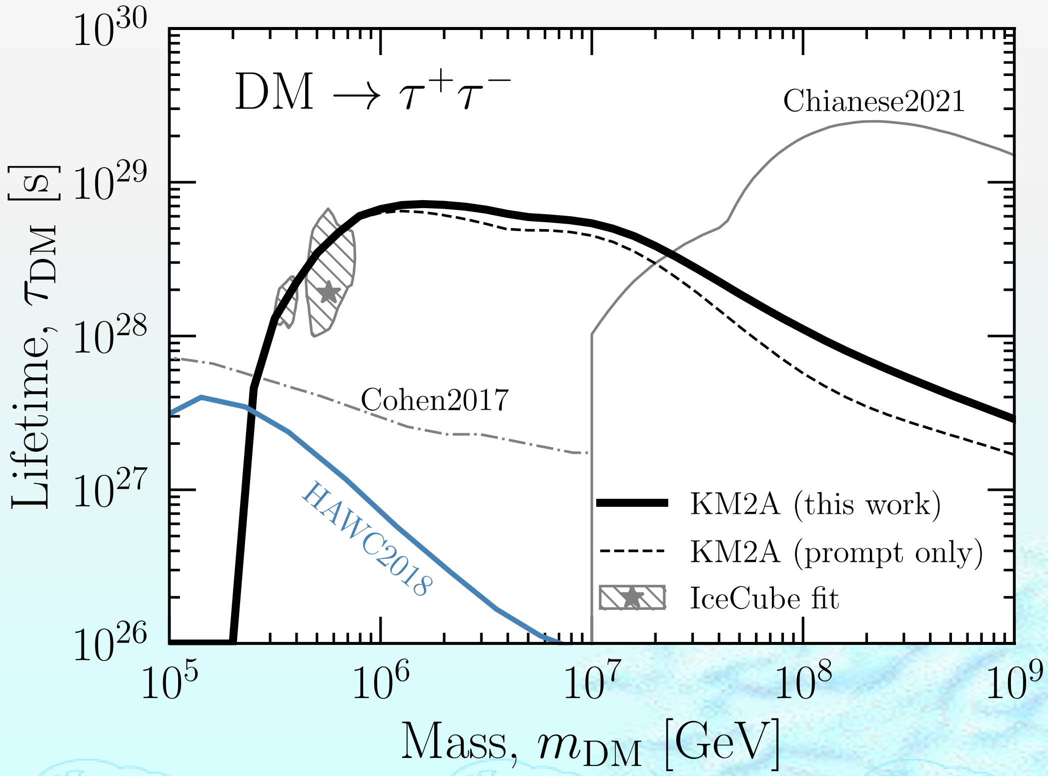
3 orders of magnitudes below the Planck-scale

LHAASO Coll., Phys.Rev.Lett. 128 (2022) 5, 051102, Phys.Rev.Lett. 126 (2022) 051102

Massive DM Search

- Diffuse γ-ray flux from high galactic latitudes are observed using ½ KM2A with negative signal, thus sets limits on DM decay rate: the most strict limits above m_{DM}>1 PeV





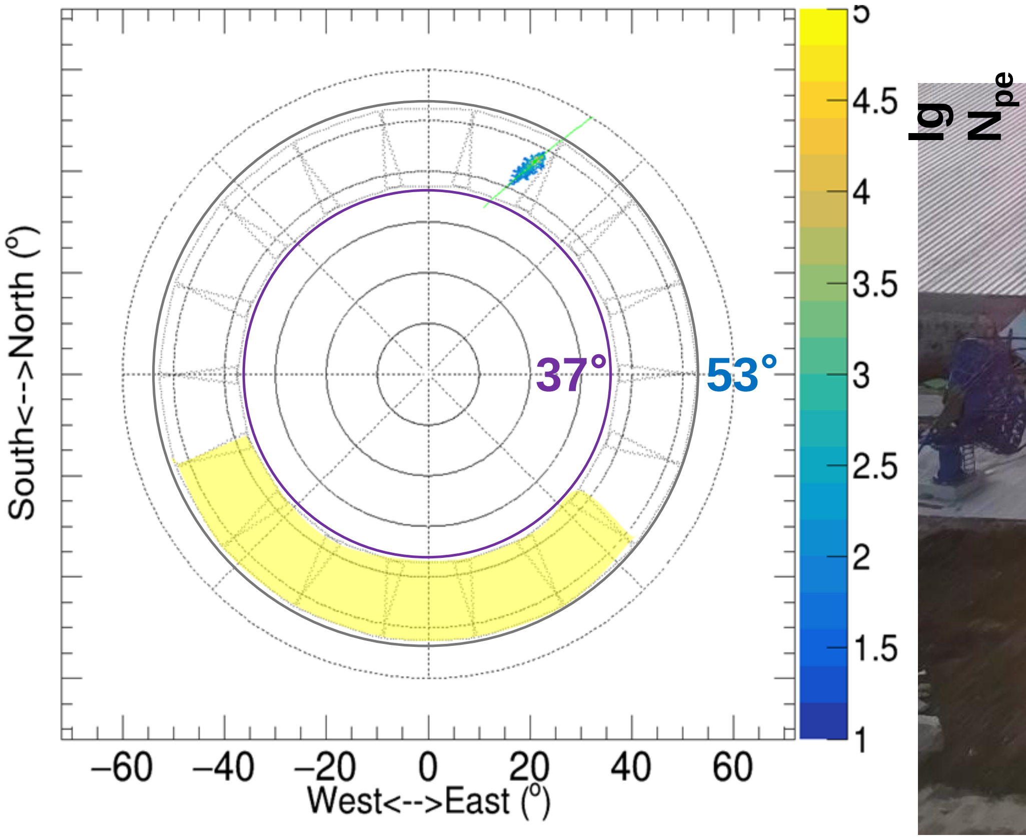
COSMIC RAY PHYSICS

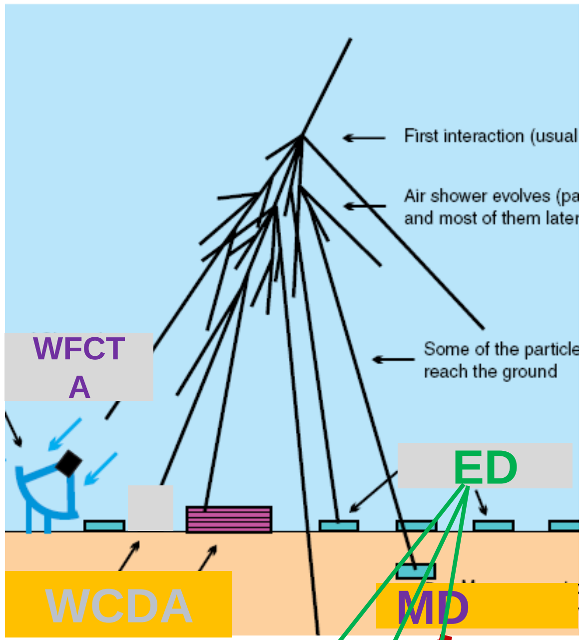
I. Expectation of Spectra measurements
II. Morphological Details
III. Multi-messenger Astronomy

Charged Cosmic Rays

- Measuring **AS front** by WCDA or ED array (0.2°)
- Measuring **E-flux** near core by WCDA (2m)
- Measuring **μ–content** by MD array (1-10^4 each)
- Measuring $\mathbf{X_{max}}$ by WFCTA (40 g/cm^2)
- Measuring AS **Energy** by WFCTA (15%)

- Calibrate **E-scale** using moon shadow by WCDA at **6 <E<30 TeV**
- **ΔE/E** currently 30% dominated by Statistics and **<10%** in 4 yrs
- Propagating the **E-scale** to **WFCTA** by using commonly triggered CRs

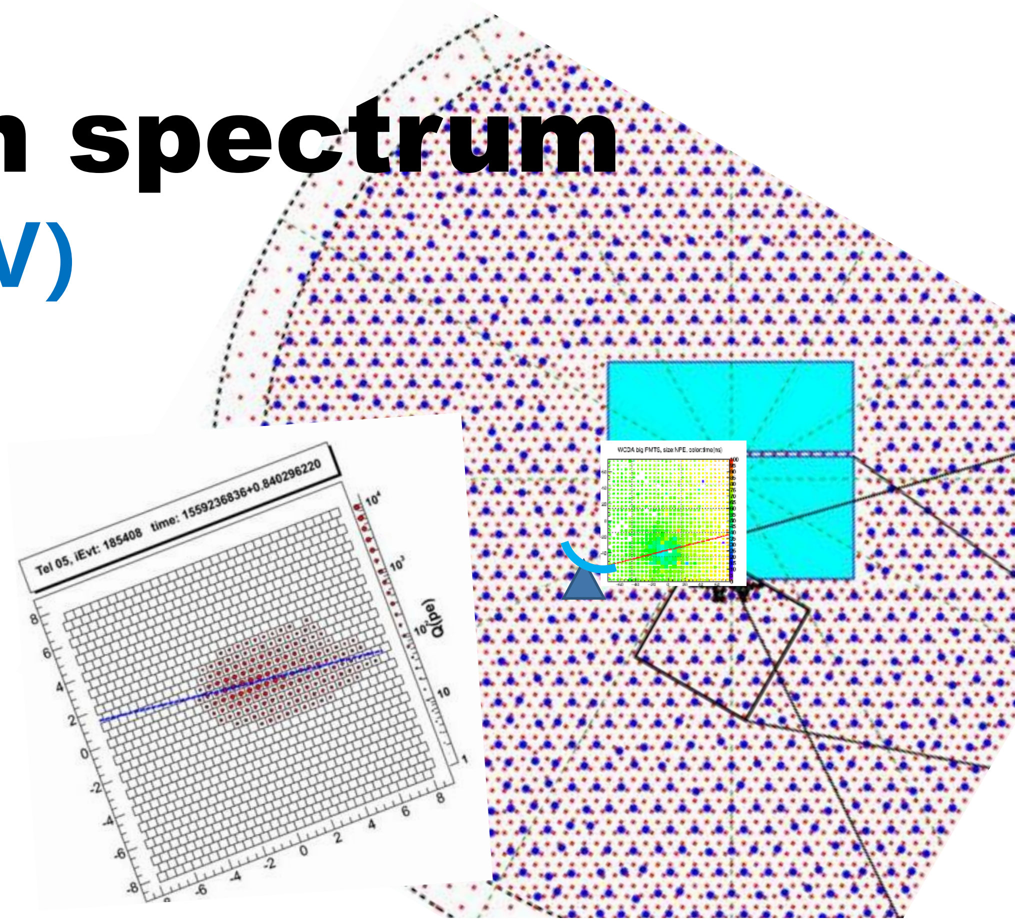


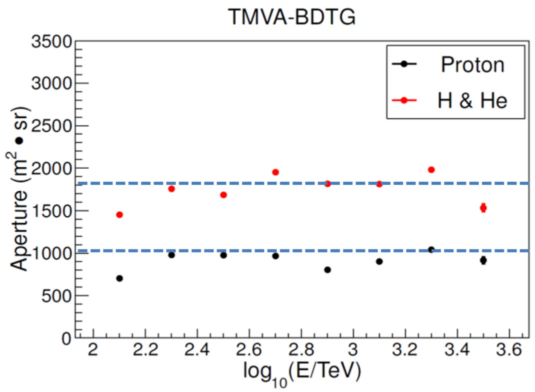


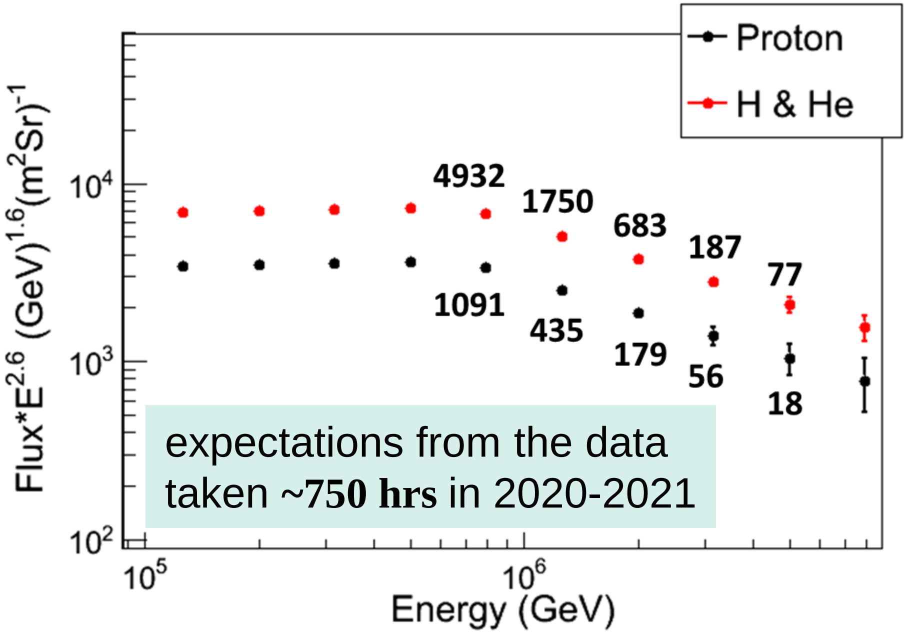
The knee of Proton spectrum

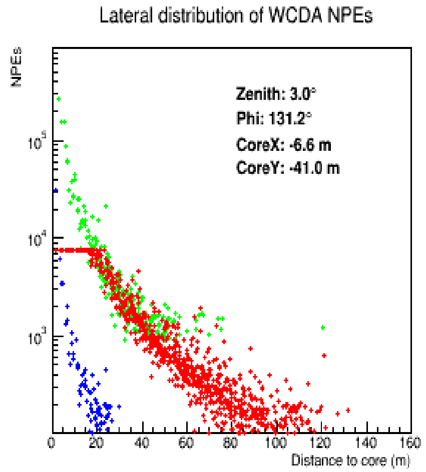
(E_b~0.7 PeV)

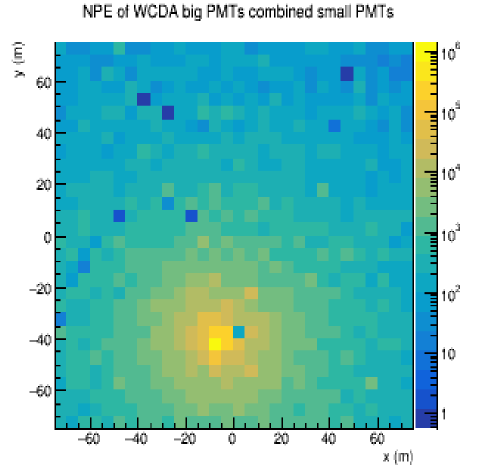
- Coincident events by **WCDA** and **6 telescopes (phase I)**
- Shower cores in **WCDA-1**
- Selecting pure **proton** showers by 4 parameters: aperture of **1000** m² sr
- **H+He** showers: aperture of **1800** m² sr







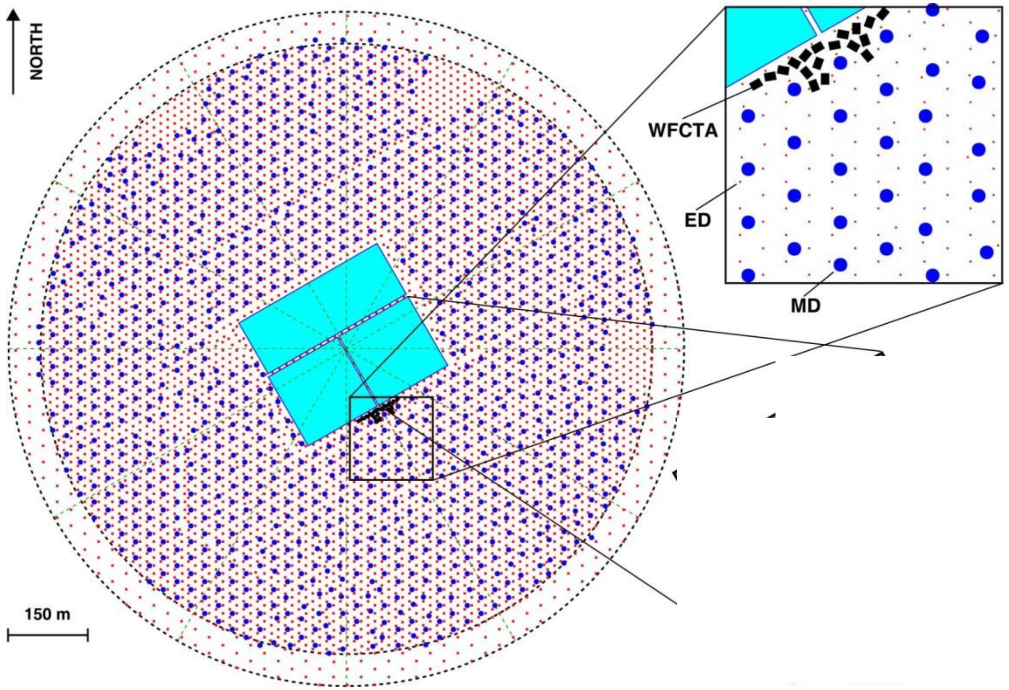


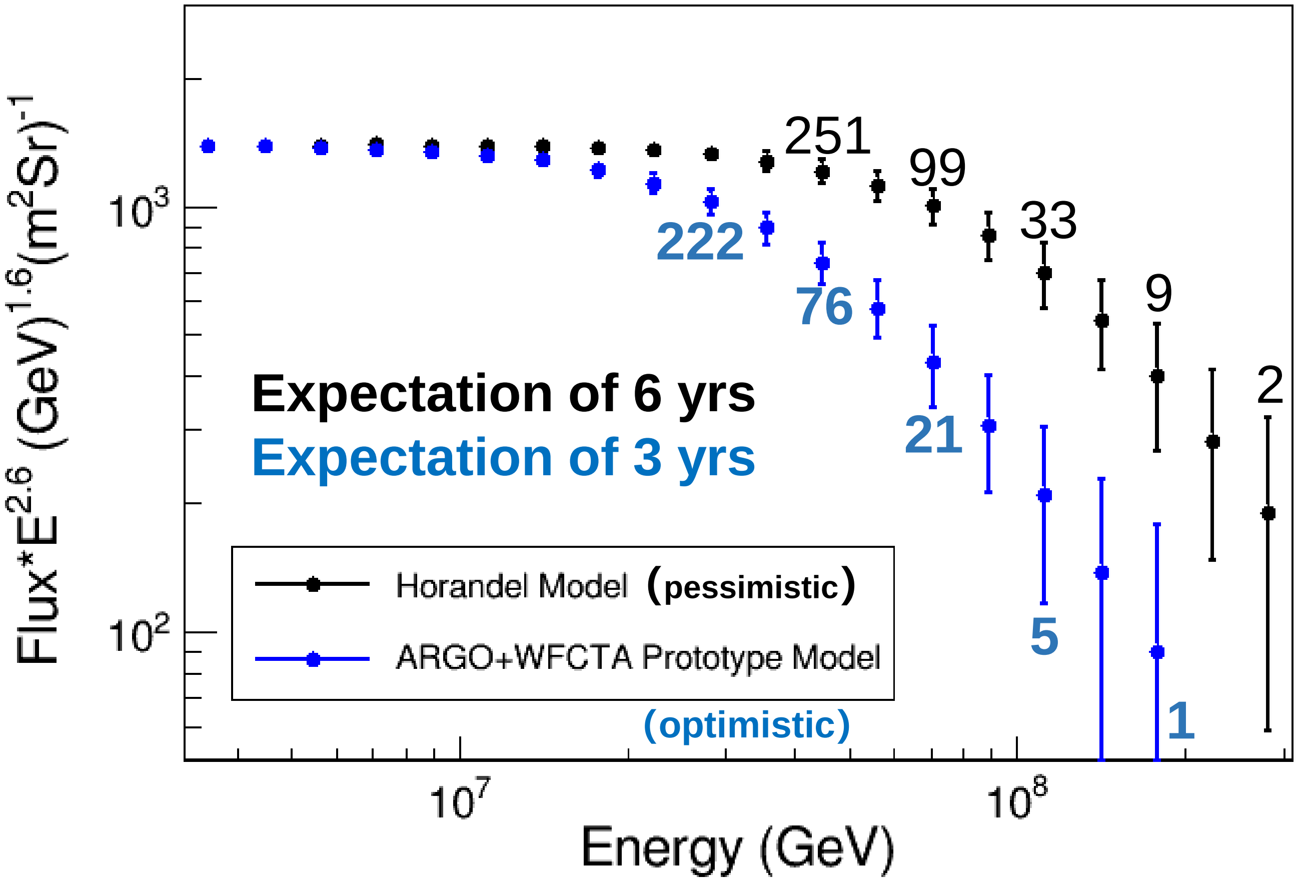


The knee of Fe spectrum

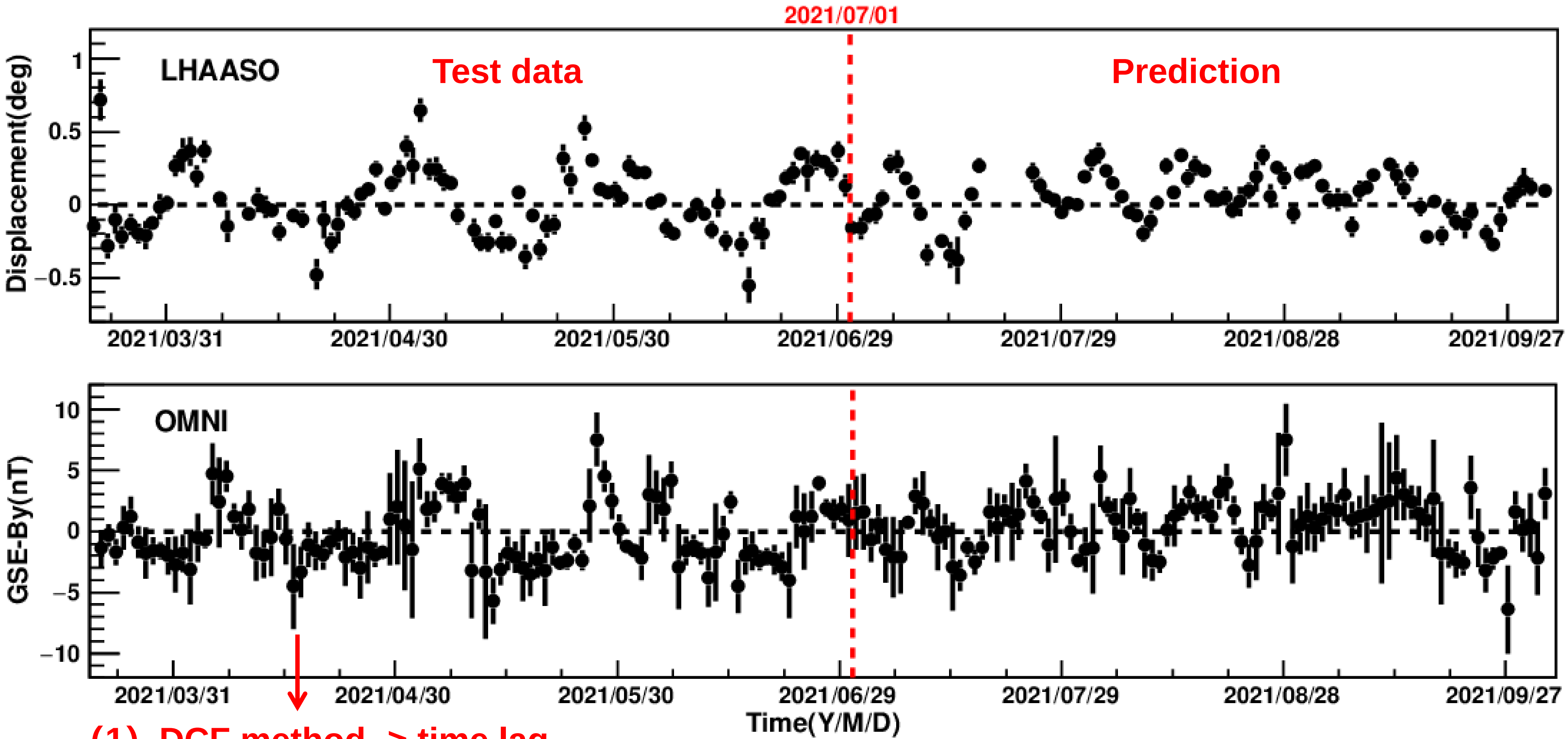
(E_b~24 or 50PeV)

- **Coincident events by both WFCTA and full KM2A (phase-II)**
- **Shower cores are in 1 km²**
- **Incline shower with depth of 840 g/cm²**





假设检验与关联分析 vs. 预测与关联

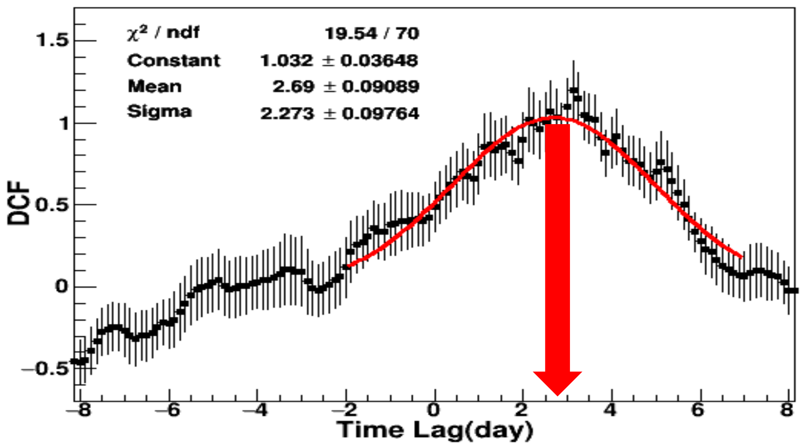


(1) DCF method -> time lag

(2) Cross-correlation -> prediction

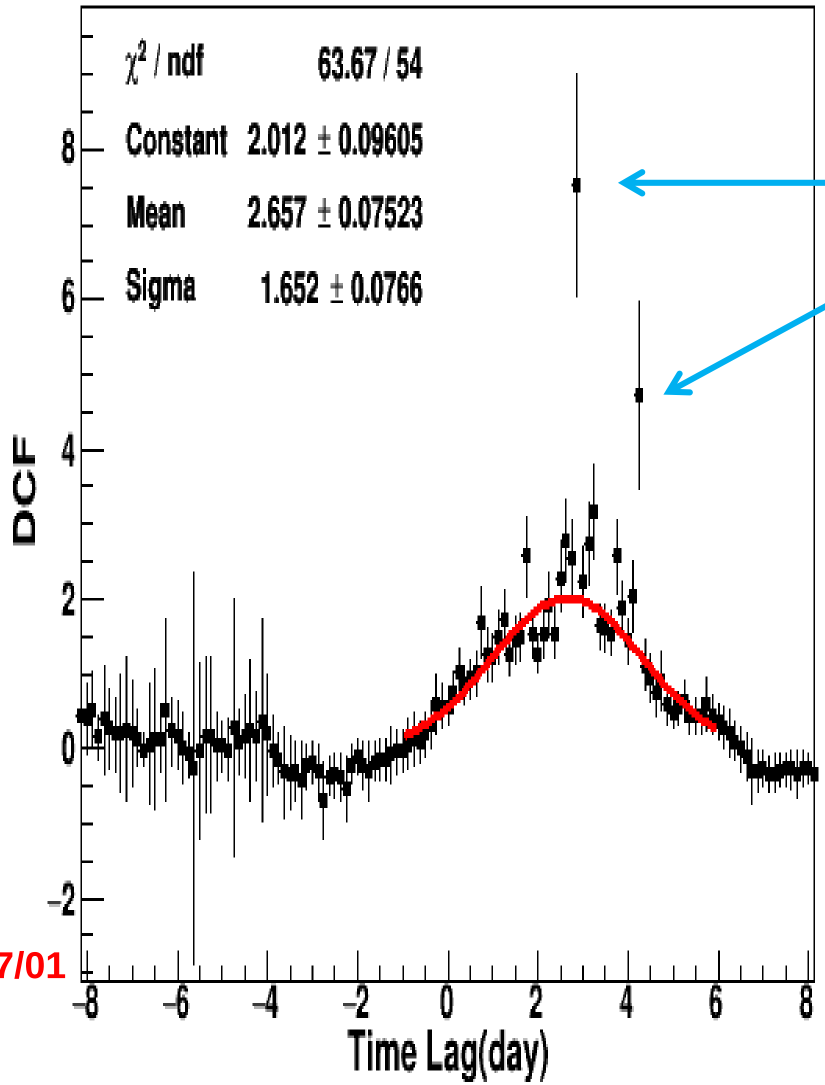
(1) Time lag

Result：DCF vs. time la



Before 07/01

After 07/01



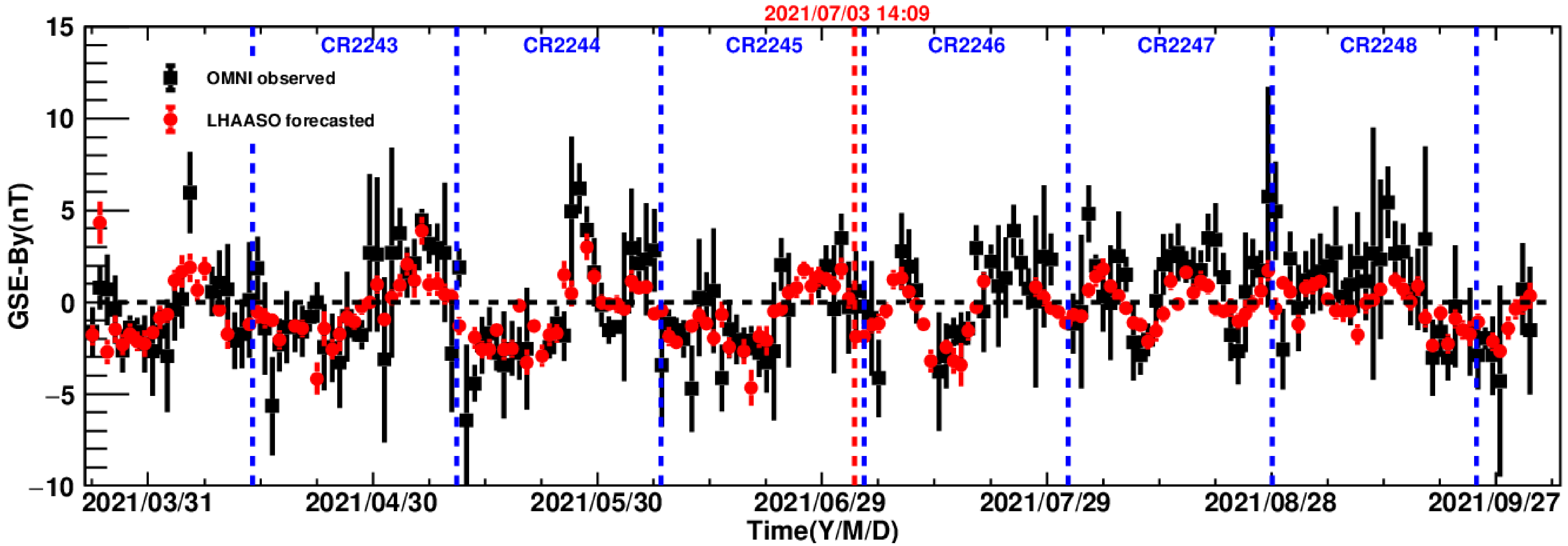
OMNI 数据观测误差太大所致

Sun shadow's displacement is observed 2.7 ± 0.1 days prior to the OMNI-B_y

Time lag is stable during two periods for Test & Prediction

(3) Corrington Rotation Period

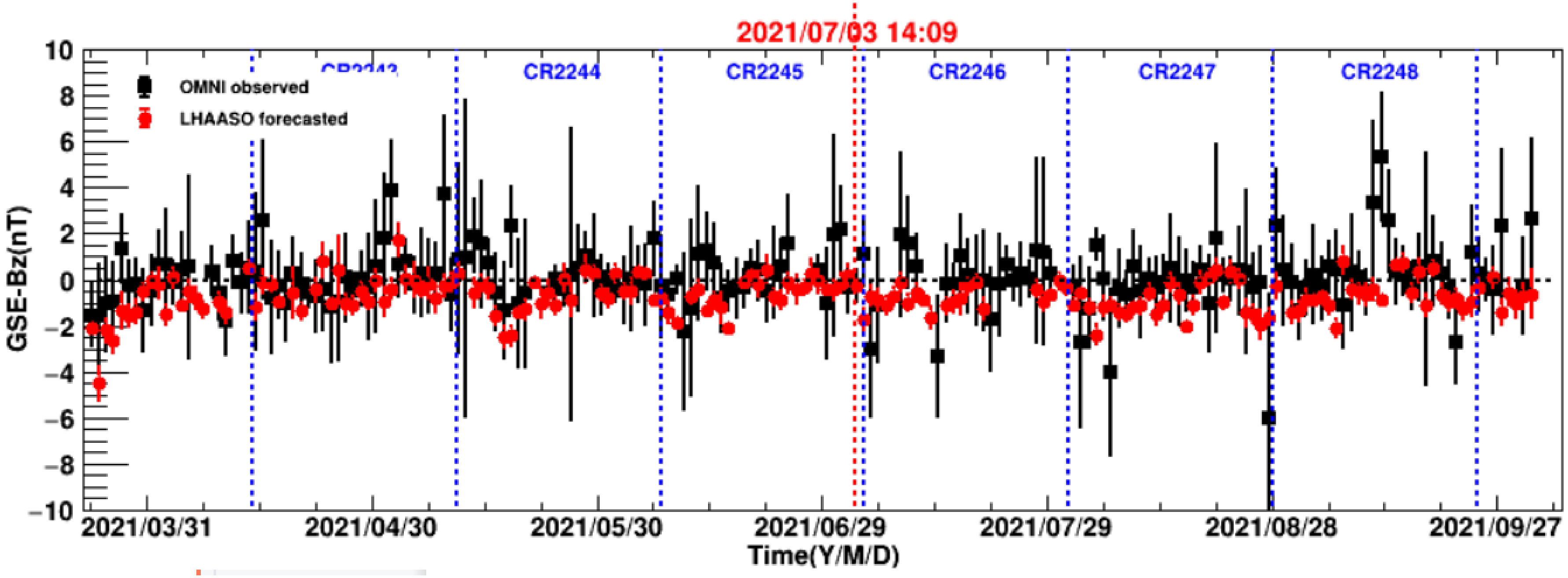
1. IMF-By at 1AU from OMNI
2. Switching between 2-sector to 4-sector on July 1st



B_z预测

- 南向磁场(Bz<0)会引起日影东偏(Displacement>0)，反相关
- 在利用Displacement和已有预测公式来预测Bz时，给Displacement加负号：

$$\hat{B}_z = (-0.77 \pm 0.16) + (7.68 \pm 0.67) \times (-D_{ew})$$



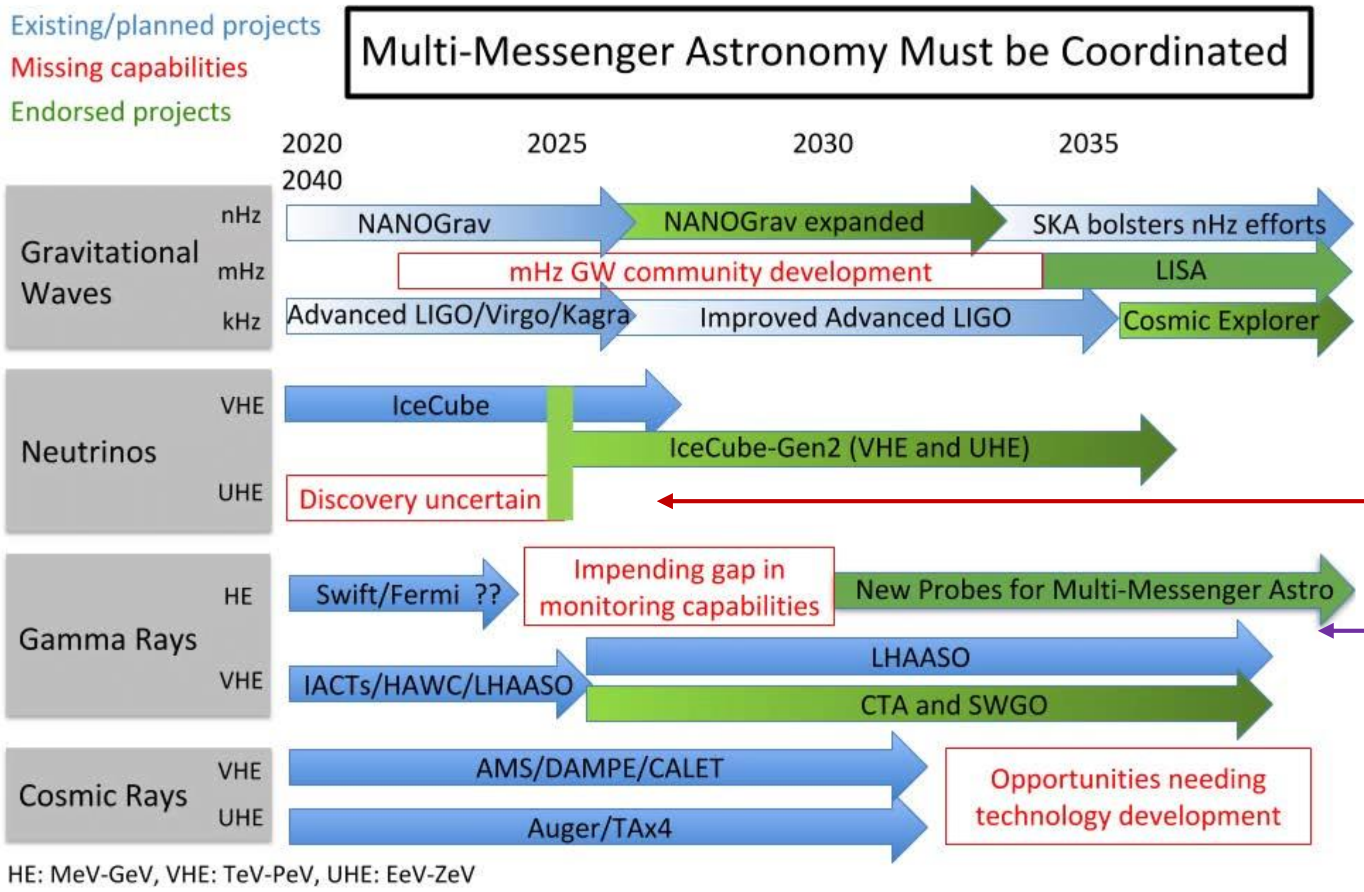
长期平均：LHAASO磁场结果比OMNI结果小0.85nT，GMF effect

LOOKING OUT FOR FUTURE

I. UHE γ-Astro.: identifying CR-sources
II. Multi-messenger Astro.: ν-Astronomy

美国天文和天体物理的十年规划报告（ASTRO2020）：

多信使项目的发展情况 和 LHAASO的国际地位



蓝色：存在的实验
绿色：计划的项目
红色：尚缺失的能力

现在对超高能中微子信使观测缺失
实施IceCube-Gen2，保持领导地位

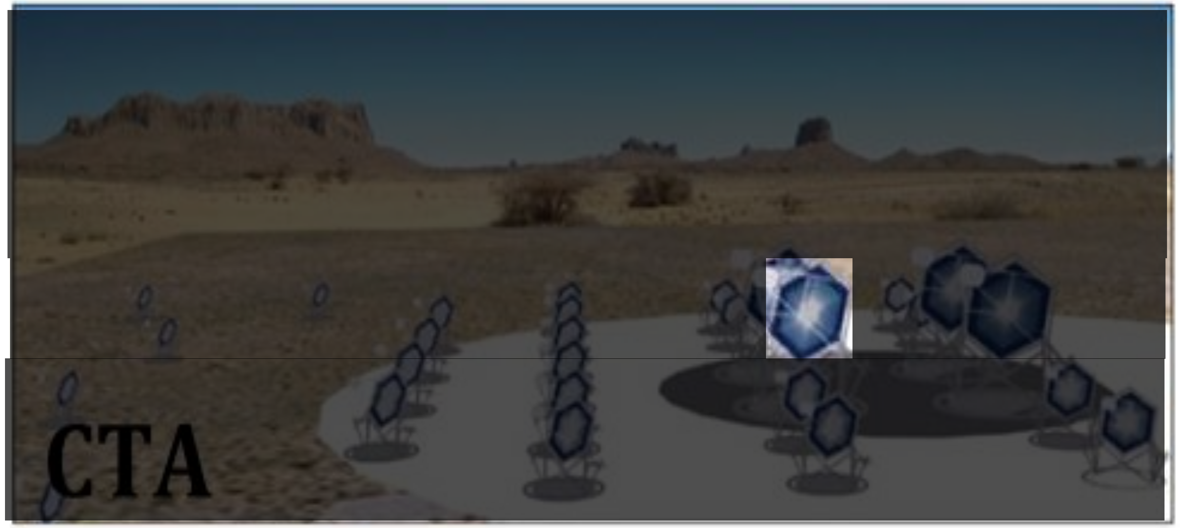
在未来至少15年里，LHAASO一家独大的局面将由CTA的建成而改变；
SWGO具有重大意义：我们已经正式加入，目标是 4 X LHAASO in Peru/Chili

2020年代伽马天文学研究的“国际分工”

- 中国的LHAASO：巡天普查、**精确测量能谱**
- 欧洲的CTA：定点观测、**精确测量光源内部结构**

2004年，欧洲科学家提出CTA计划

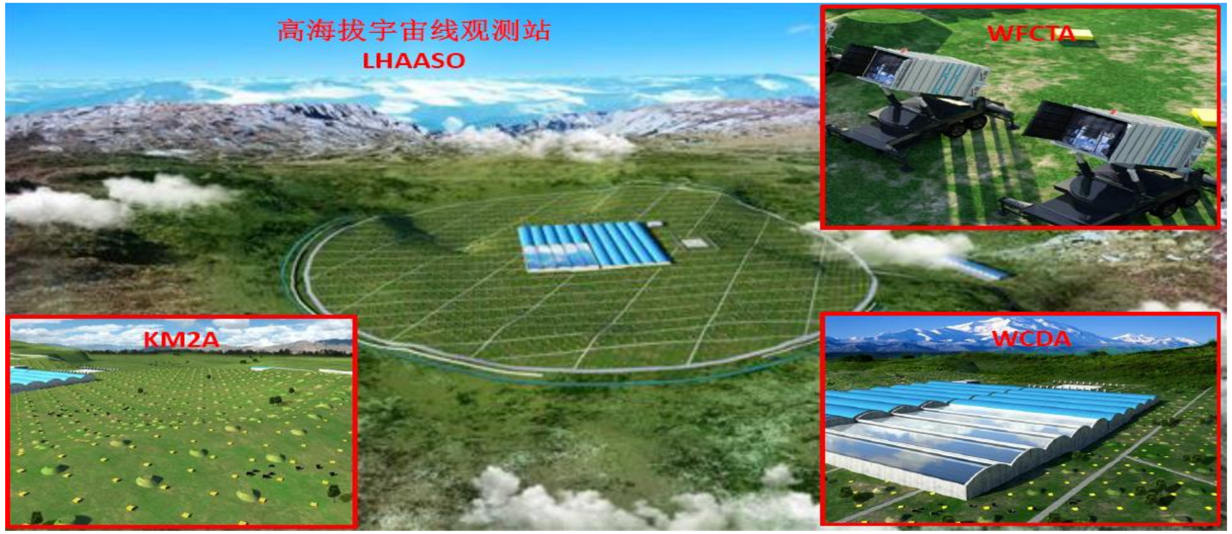
建设10平方公里**百台**望远镜阵列



2021年，一台LST！

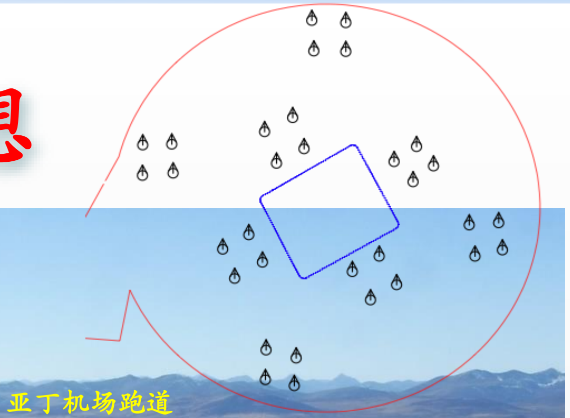
2009年，中国科学家提出LHAASO计划

建设1平方公里地面探测器阵列



2021年7月，全阵列建成，
2021年10月，工艺验收，投入运行！

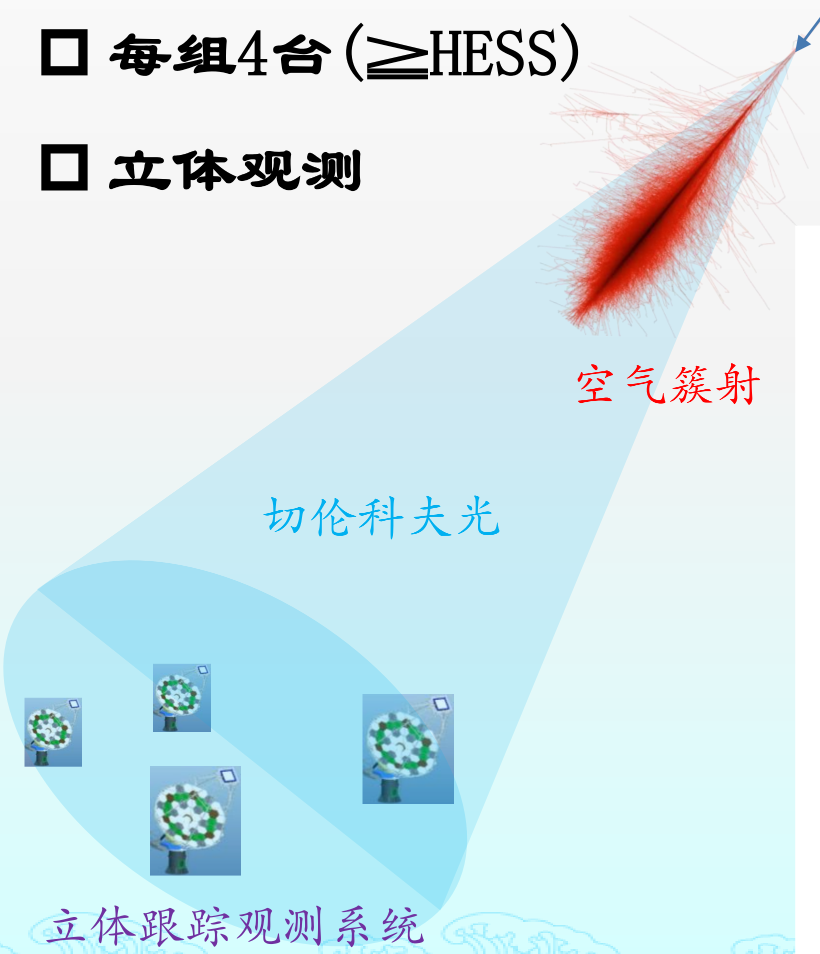
LACT 设计的核心思想



- 32台成像C-望远镜：ϕ6 m （@HESS）
  ~ ϕ12 m （@LACT）
- 分8组覆盖1km²面积： 8×HESS 升级换代

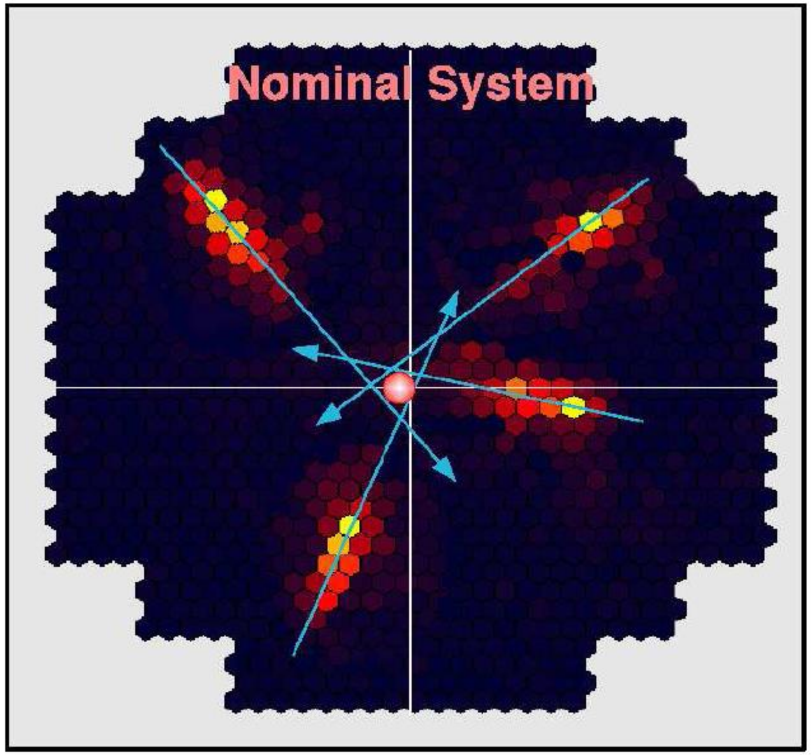
大型超高能伽马源立体跟踪观测设备（LACT）

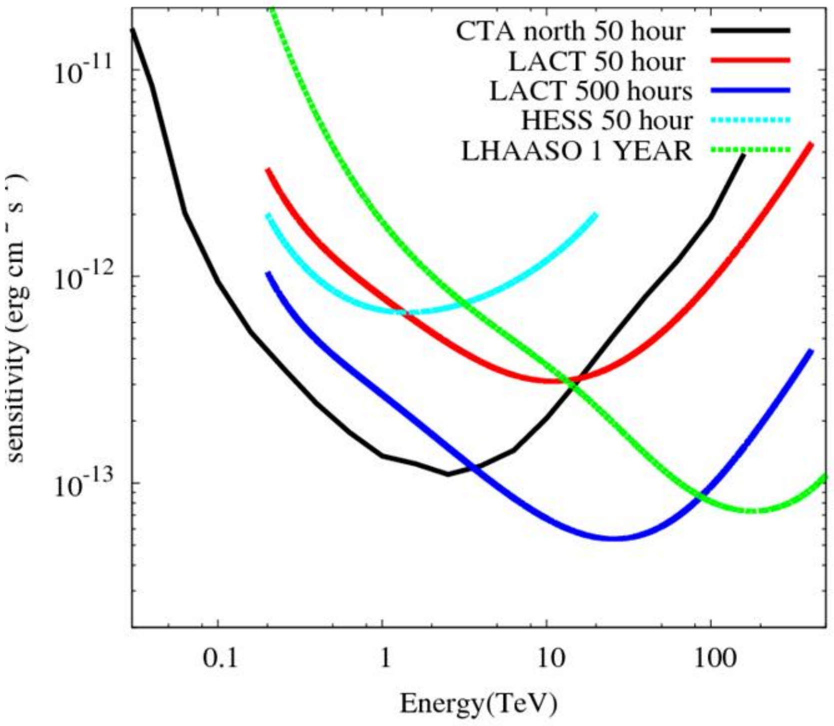
- ☐ 分8组
- ☐ 每组4台（≥HESS）
- ☐ 立体观测



➢ **LACT总体性能指标：**

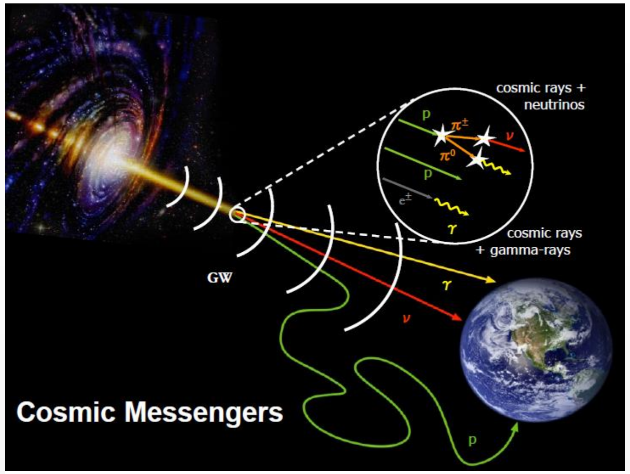
角分辨率 @5TeV	灵敏度 @10TeV	能量分辨率
<0.06°	<3% Crab	<15%

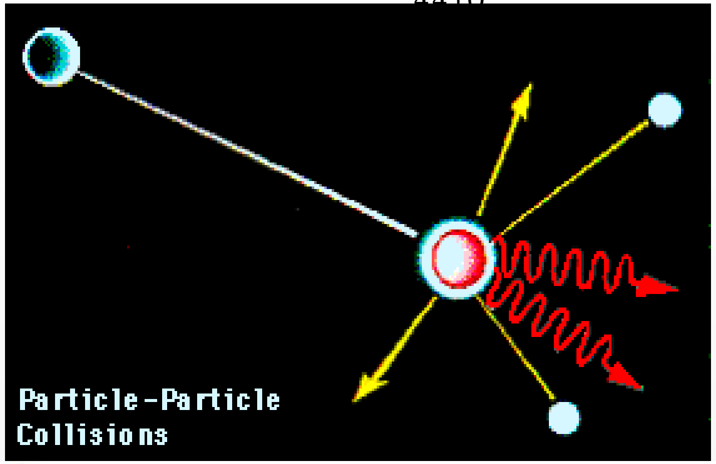




高能中微子望远镜

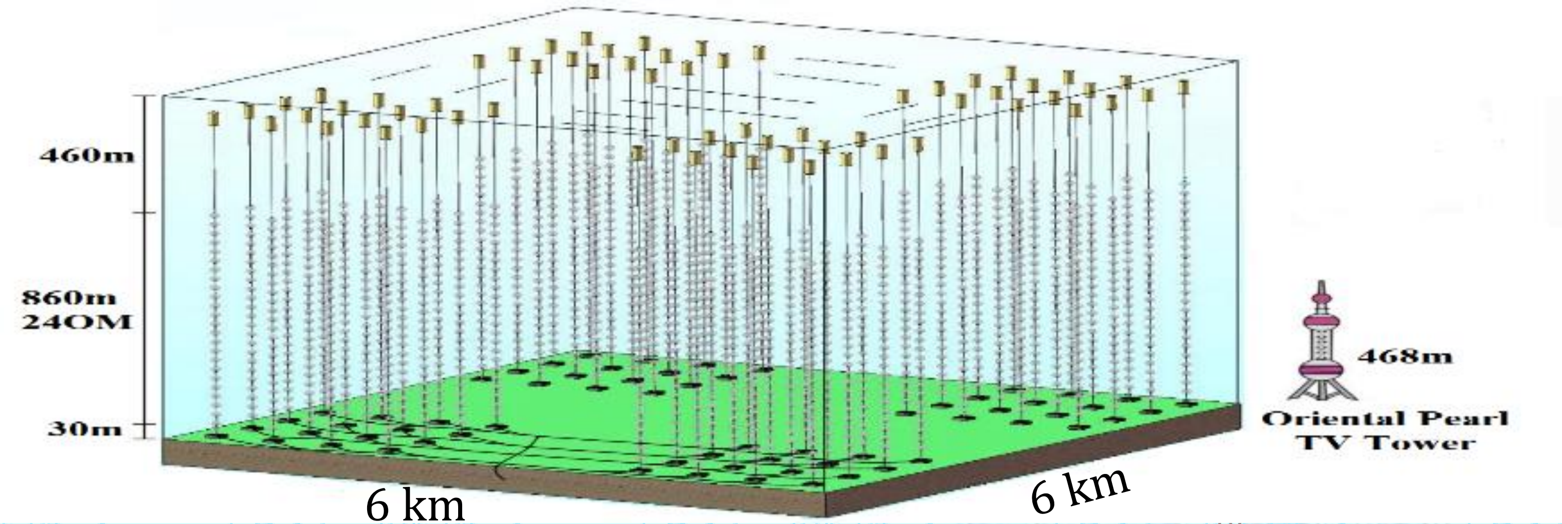
- 宇宙线源发出的高能伽马光子，必然存在相伴生的中微子
- 一锤定音，高能宇宙线起源问题的最后一块拼图！





$$p+p \longrightarrow p+n+\pi^0+\pi^{\pm}+\ldots \longrightarrow \begin{cases} \pi^+ \longrightarrow \mu^+ + \nu_\mu; \quad \mu^+ \longrightarrow e^+ + \bar{\nu}_\mu + \nu_e \\ \pi^- \longrightarrow \mu^- + \bar{\nu}_\mu; \quad \mu^- \longrightarrow e^- + \nu_\mu + \bar{\nu}_e \\ n \longrightarrow p + e^- + \nu_e \end{cases}$$

- 利用贝加尔湖或南海的优势，占领中微子学科领域的制高点
- 建设 >30 km³ 中微子望远镜，超越IceCube-Gen2，实现探测单源灵敏度



LHAASO
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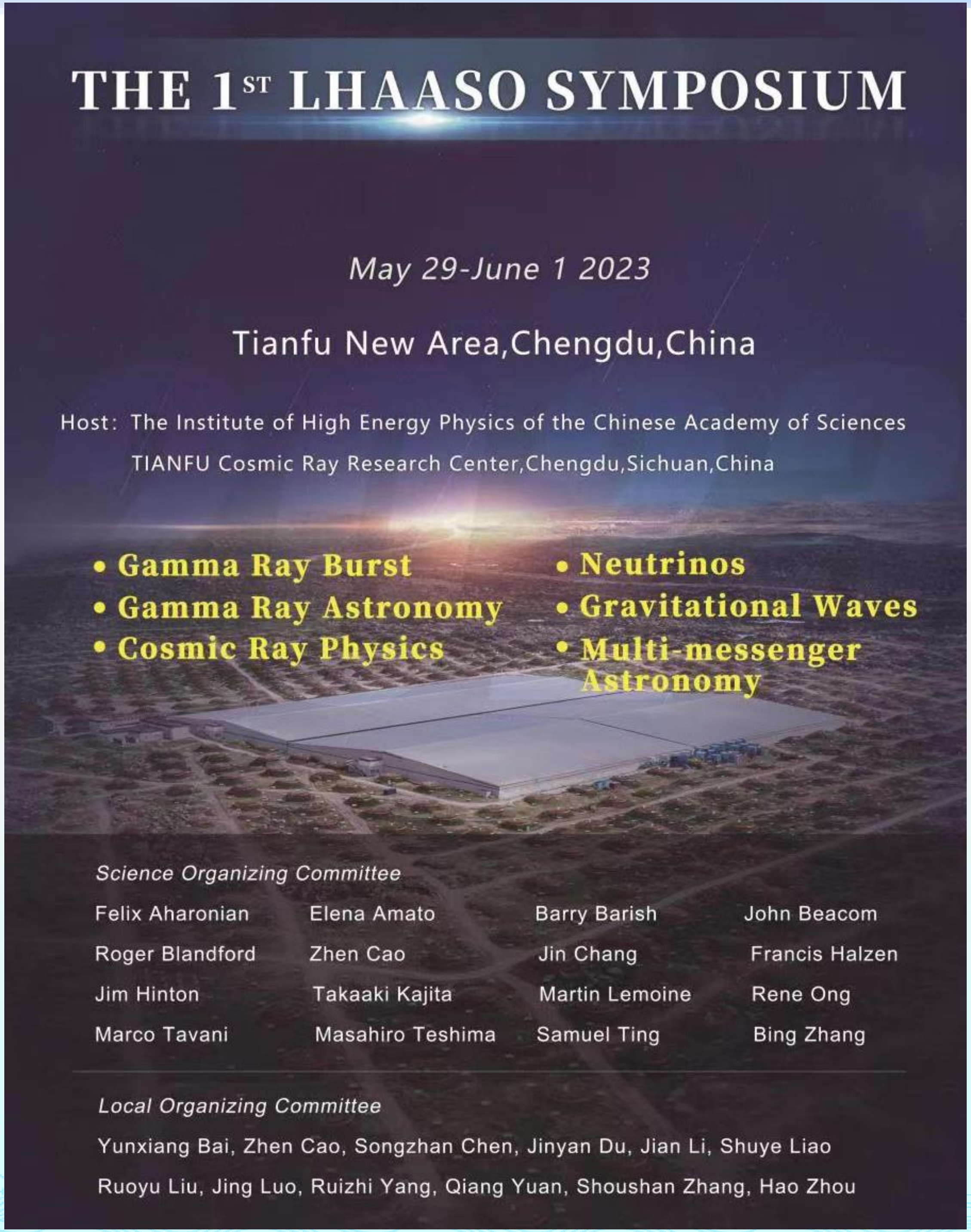
Conclusion

- LHAASO's operation has been super stable since July 2021
- Open-up "UHE (>0.1 PeV) Astronomy"
  1. The brightest GRB detected with 64k photons: many records are set
  2. The Crab: extreme e-PeVatron emitting 1.1 PeV γ posing challenges
  3. 12 PeVatrons are discovered in our galaxy as Ver-0 LHAASO Catalog
  4. Cygnus X is the first candidate of CR origin
  5. Catalog Ver-1 is ready to publish with tens of new sources discovered
- Fundamental physics frontier exploring: e.g. LIV, DM, ALP ...
- Precision Measurements of individual species CRs around knees will be measured at first time
- Lookout for future:
  1. PSF~0.05° for identifying CR origins by LACT
  2. ν-telescope with the sensitivity for single-PeVatron: 30 km^3 in LB or SCS

LHAASO
高海拔宇宙线观测站



Thanks for your attention!