
# Upgrading Plan towards Multi-messenger Observation with LHAASO and Construction Status

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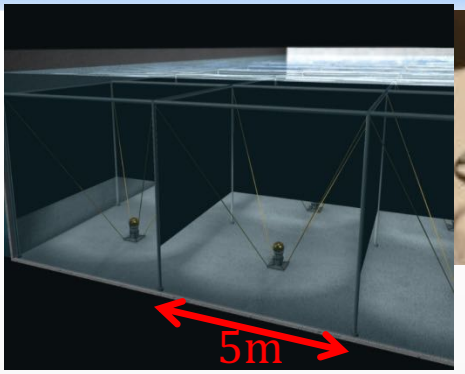
LHAASO
高海拔宇宙线观测站

# Content

- LHAASO Experiment
- Performances and Prospects for Gamma Ray Astronomy
- Upgrading for Enhancement at Low Energy
- Prospects for Multi-messenger Exploring
- Construction Status
- Summary

# Detector Layout in LHAASO

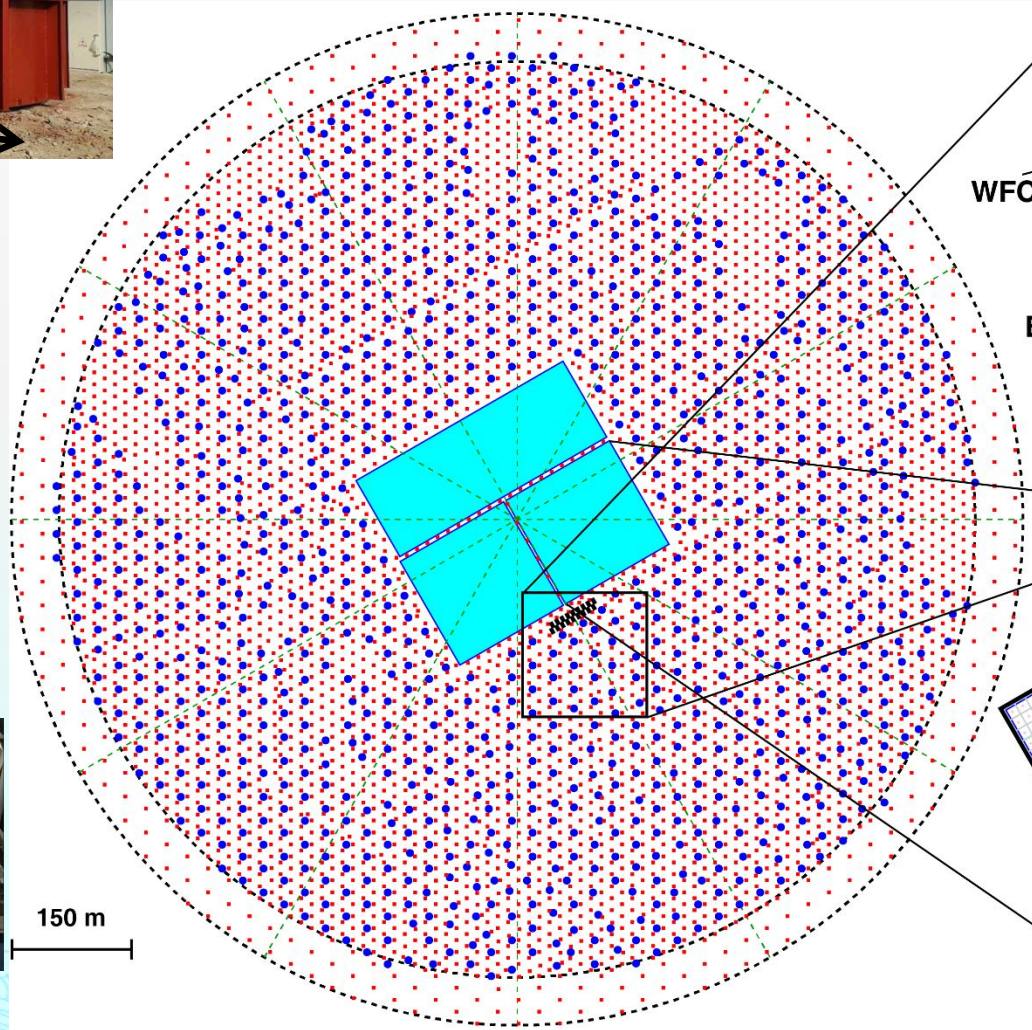


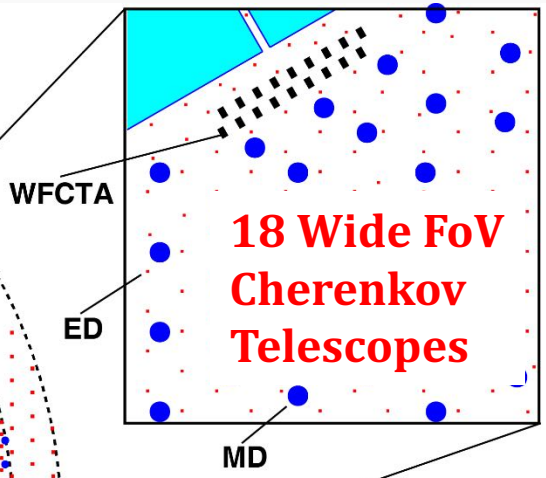


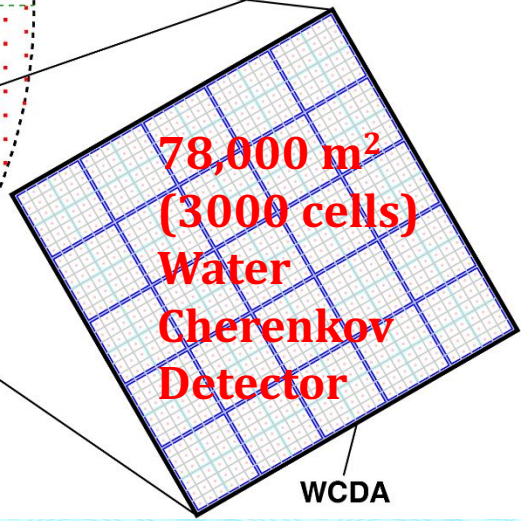


**1171 muon counters**
**30 m spacing**

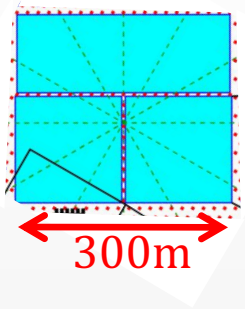
**5195 Scintillator counters**
**15 m spacing**

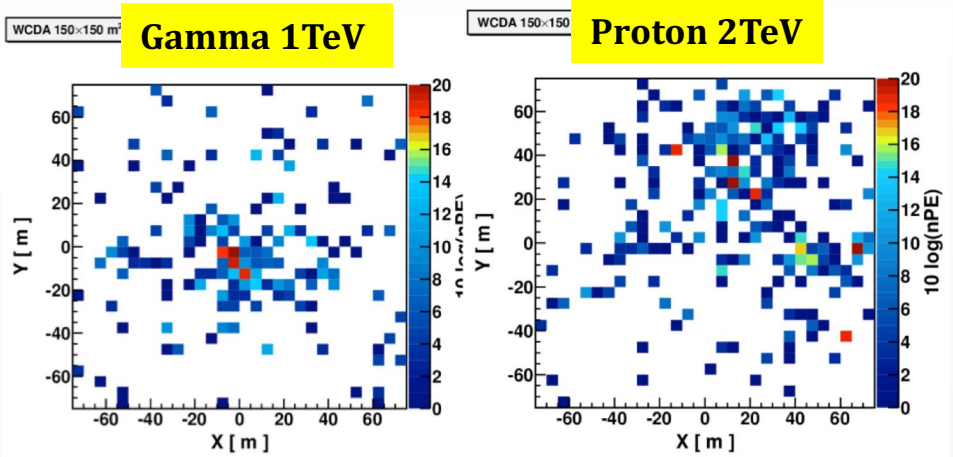



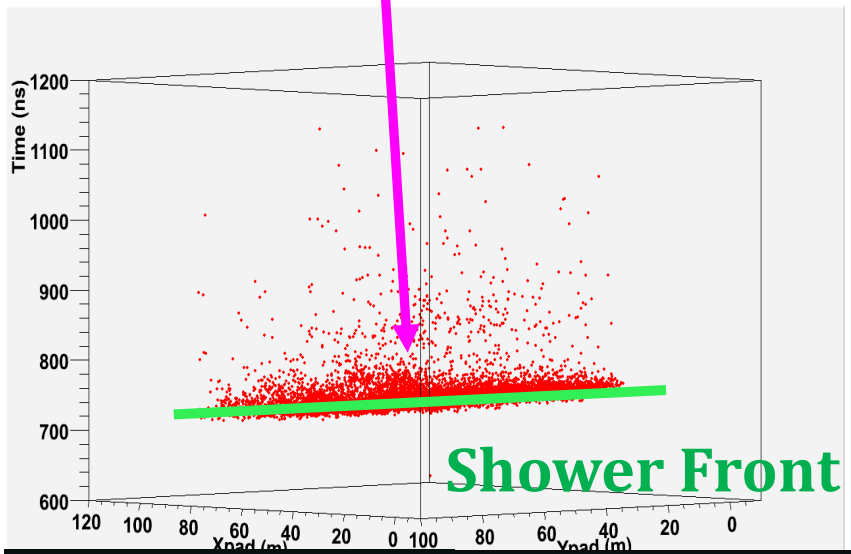



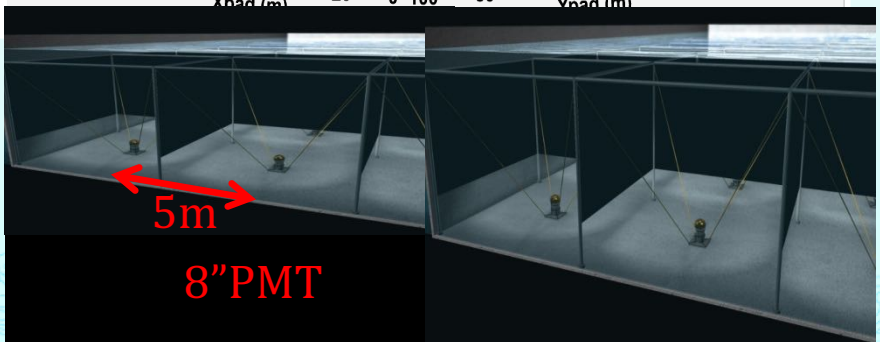
# 3 Pools

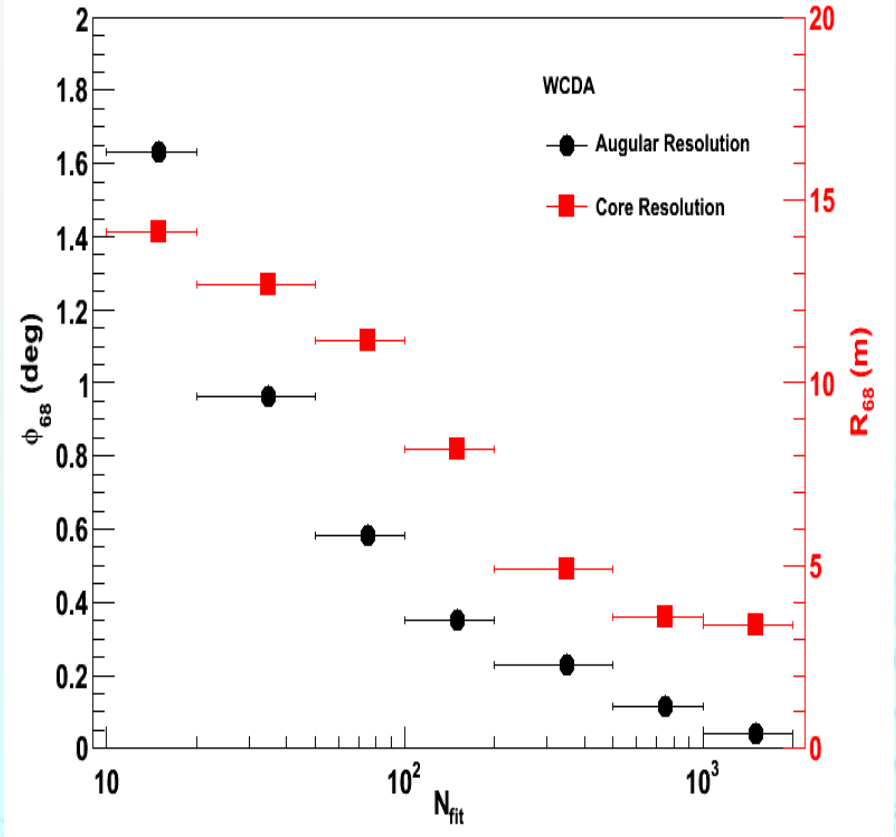



- Measuring shower direction and location
- Catching far muon signals in showers for γ/p



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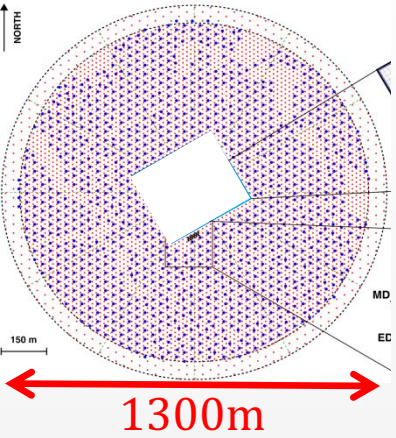
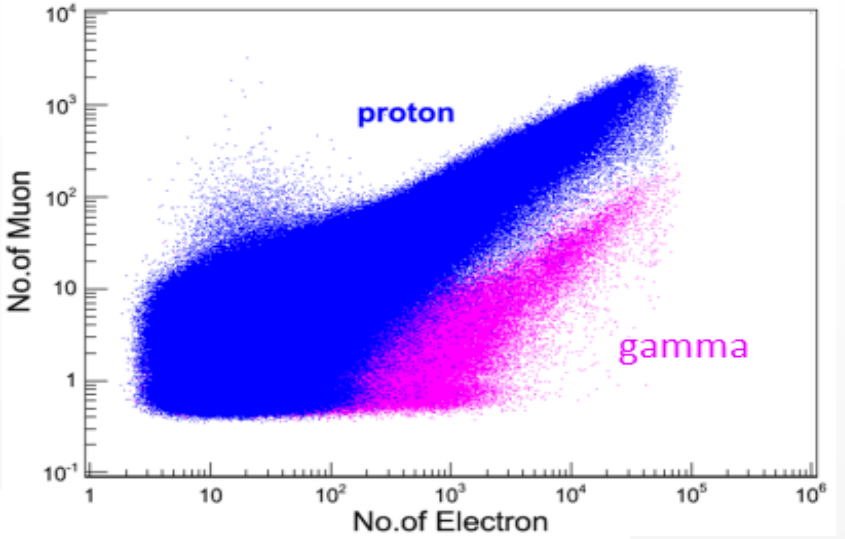
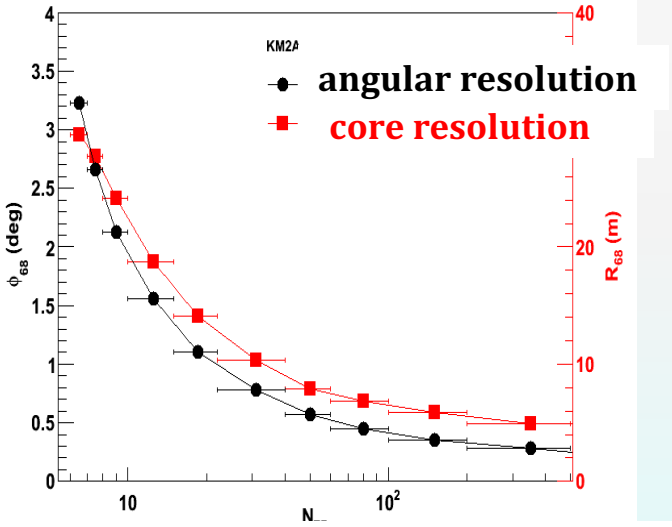
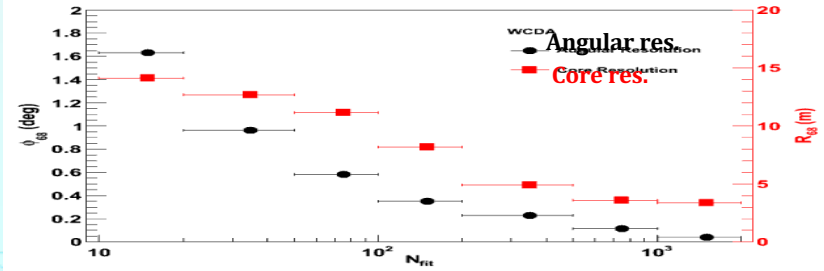



# An Array of Scin. +MDs

- Measuring shower direction and location
- Measuring μ–content with the largest MD array ever
- Clean γ selection

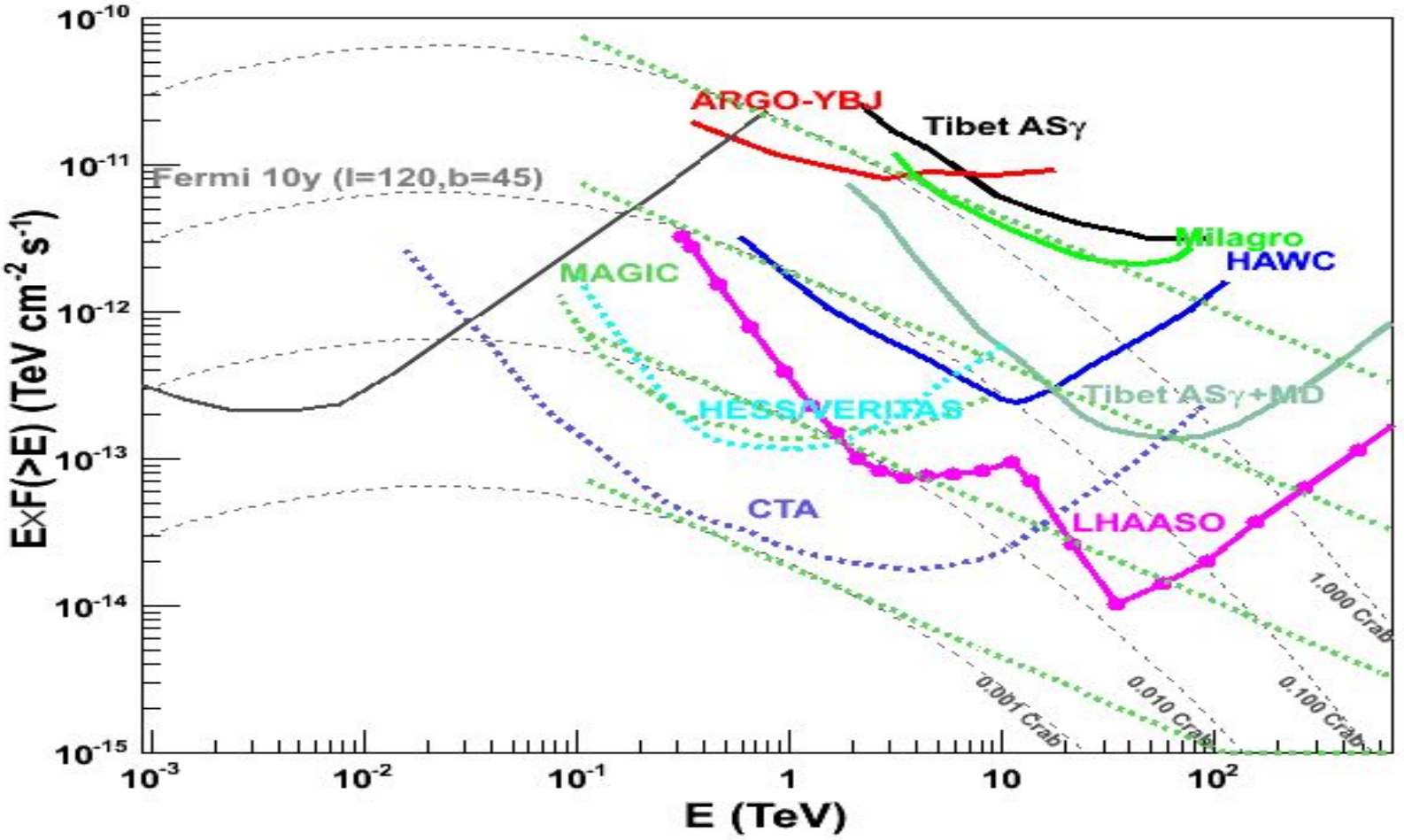


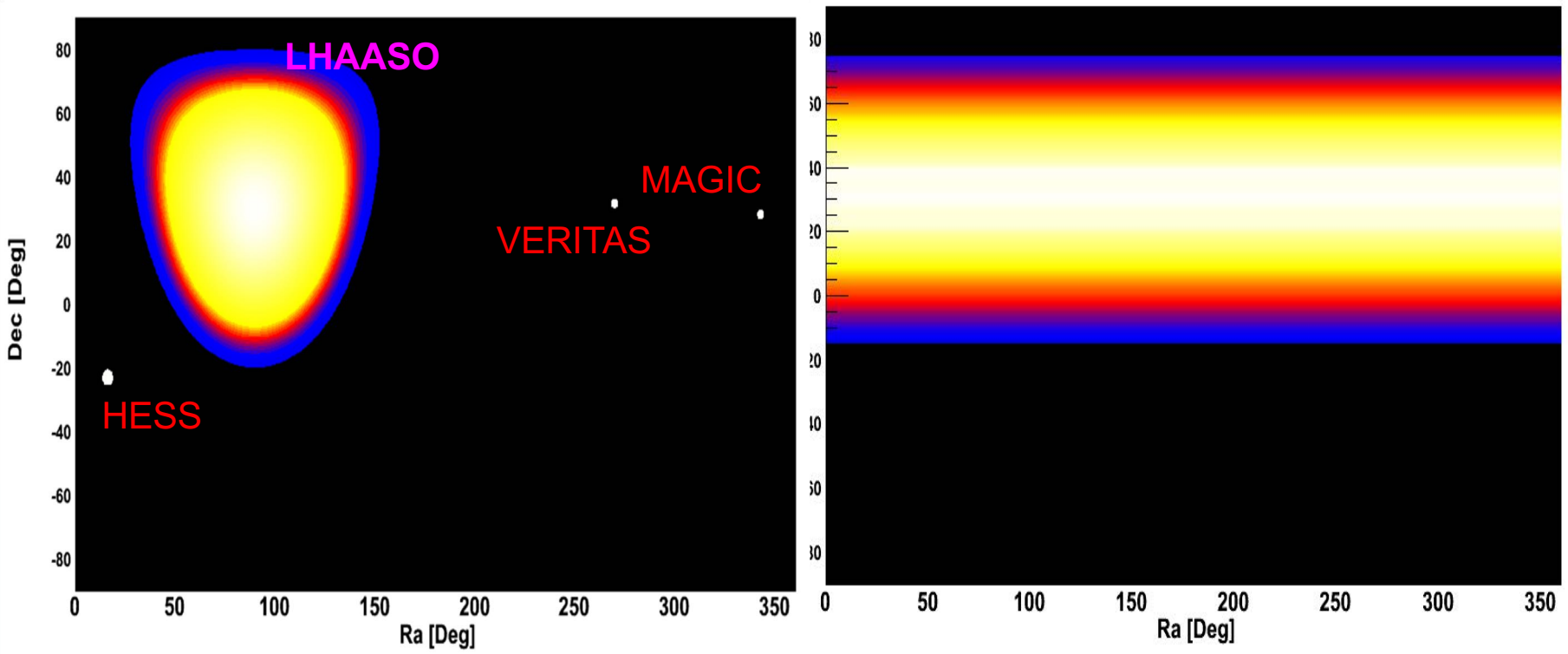
# Sensitivity to gamma ray sources

- **Integral: 1% Crab unit @3TeV & 50TeV**



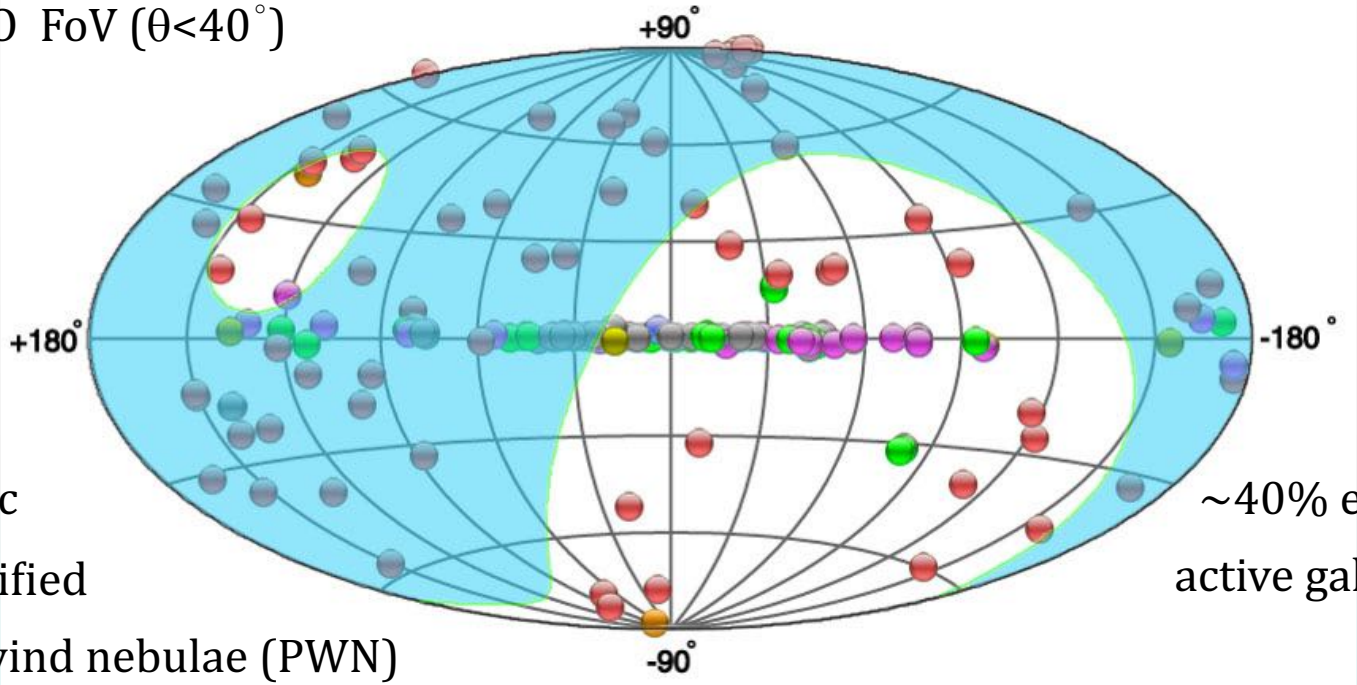
# Wide FOV gamma ray astronomy

- High sensitivity
- Wide FoV:
  - 1/7 of the sky at any moment
  - 60% of the sky in every day (24 hrs)



# Survey over **300 GeV-1 PeV** for pevatrons

208 sources in TeV bend
119 in LHAASO FoV (θ<40°)




~60% Galactic

~1/3 unidentified

~1/3 pulsar wind nebulae (PWN)

~40% extragalactic

active galactic nuclei

~1/3 supernova remnants, compact binary systems and massive star clusters

**LHAASO FoV (θ< 40°)**

# Survey expectations for extragalactic sources by LHAASO

~40% of them are AGNs

Table 1. Number of BL Lacs for 1 year and 4 year observation.

| EBL model | No. for 1 yr survey (LHAASO) | No. for 4 yr survey (LHAASO) |
|---|---|---|
| K06 | 33 | 38 |
| F08 | 39 | 44 |
| F10 | 34 | 43 |
| D11 | 38 | 44 |
| G12 | 40 | 44 |

Considering the fact that more than half of the 2LAC BL Lacs do not have redshift measurements, and there are unclassified AGNs in 2LAC catalog and unassociated sources in Fermi source catalog, the total number of detectable AGNs may be significantly increased.

Yi Zhao et al, *Int. J. Mod.* Phys. D 25, 1650006 (2016)

# LHAASO on AGN flares

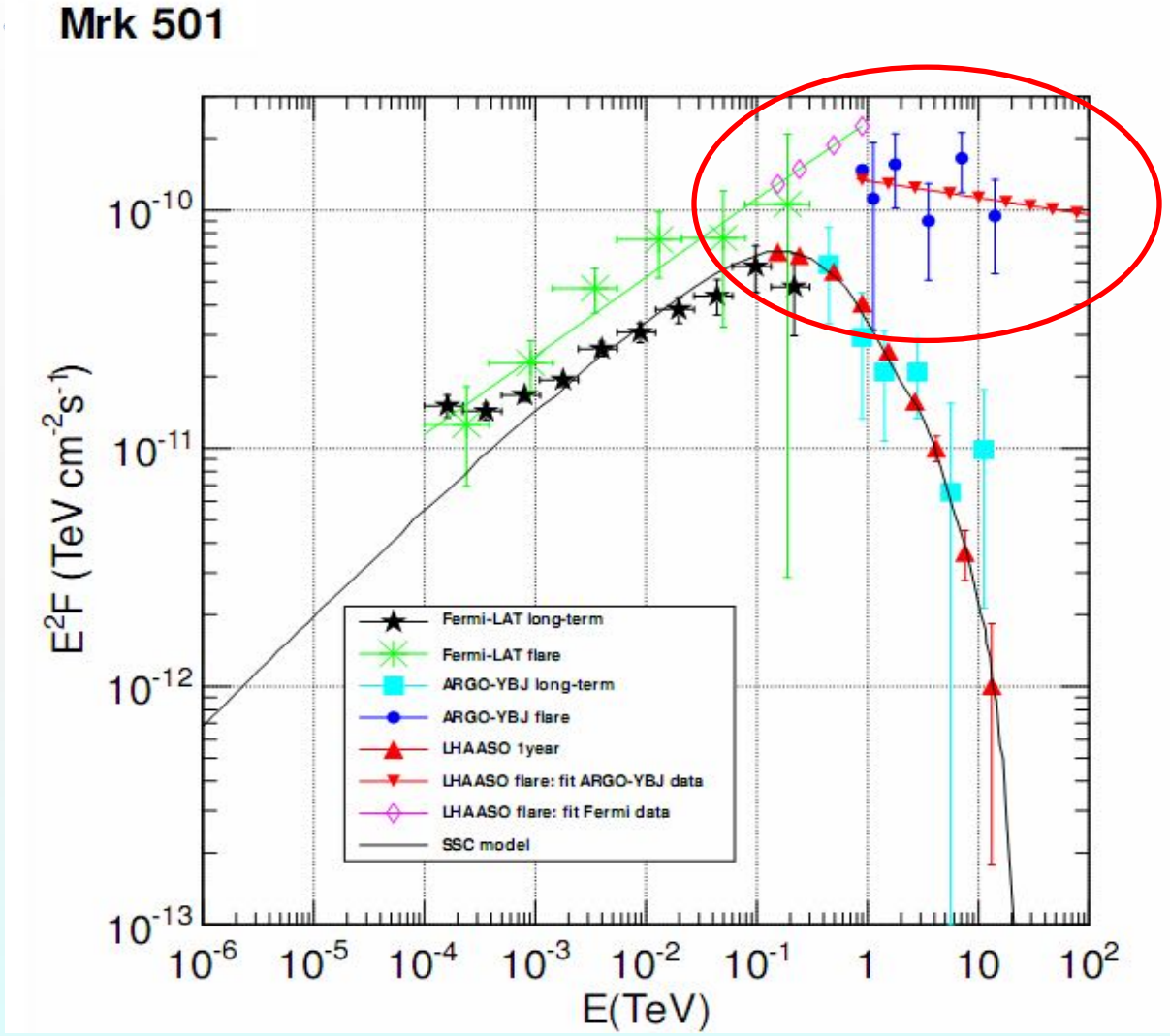



Figure 16: Expectation of the LHAASO project on Mrk501 [57], compared with the measurement of Fermi-LAT, ARGO-YBJ[27].

LHAASO
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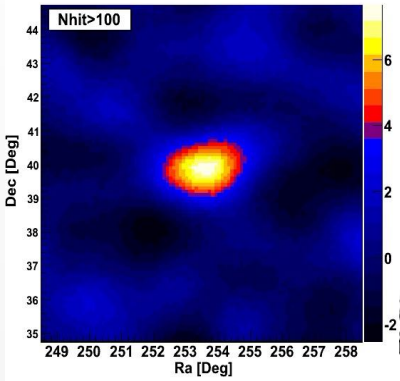
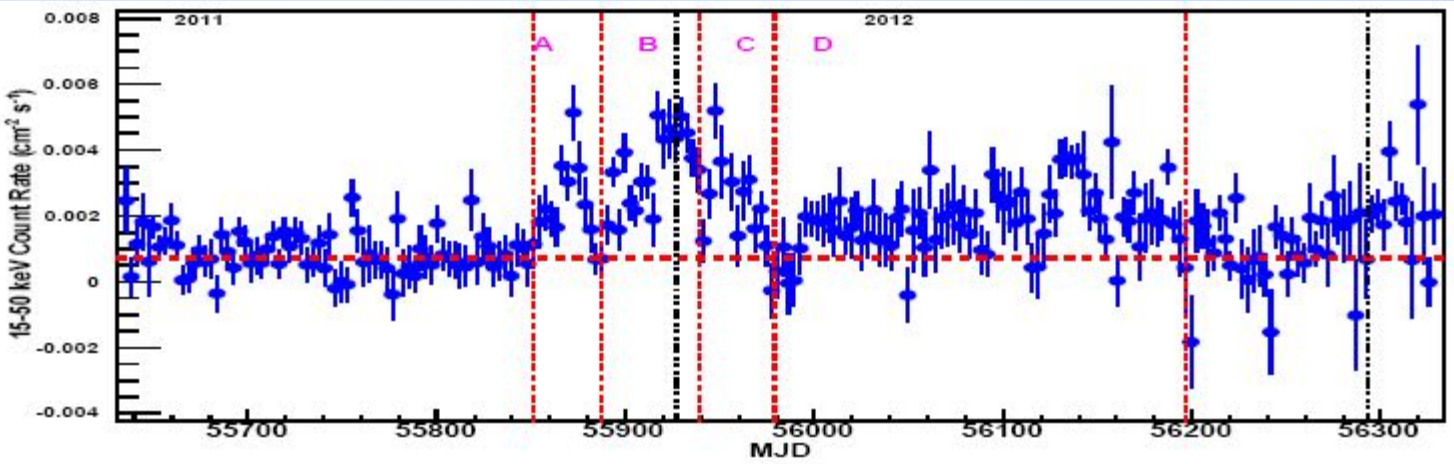


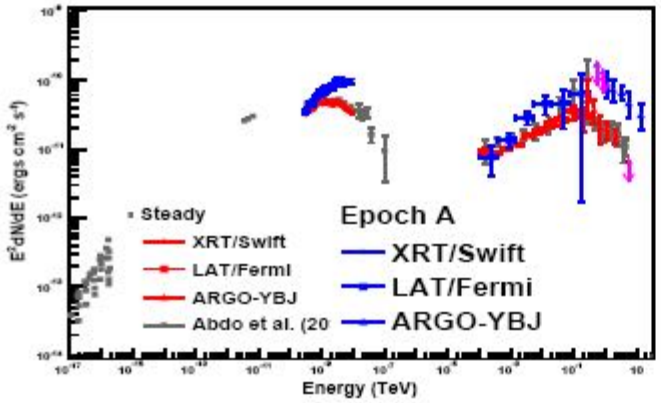

3: Three day-averaged light curve of Mrk 501 at 15–50 keV measured by BAT/*Swift*. The vertical dashed lines icate the four epochs analyzed in this paper. All the errors are statistical at 1 $\sigma$.

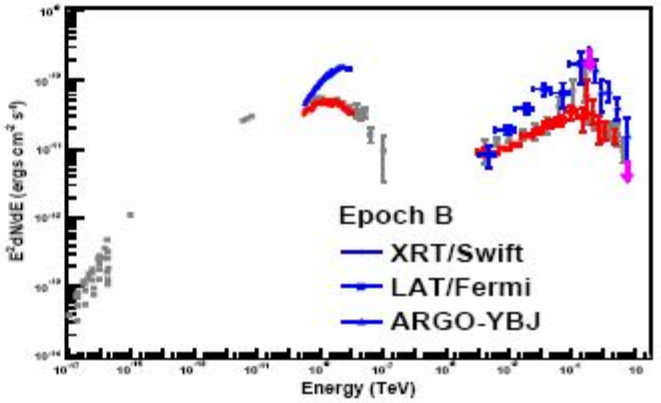
**2011flare of Mrk501**
**S=7.7σ**
**ARGO-YBJ as a example**

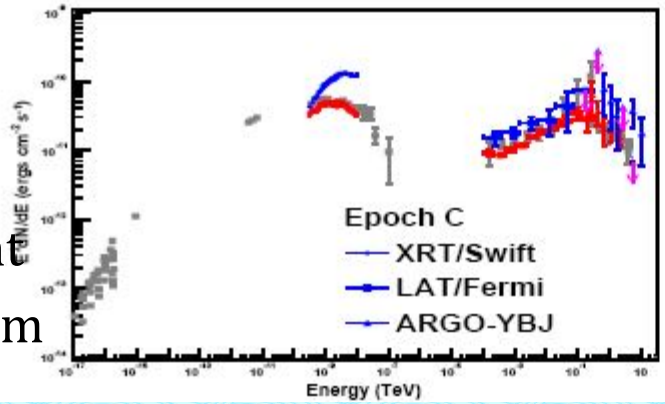
The evolution of the Spectrum during flares

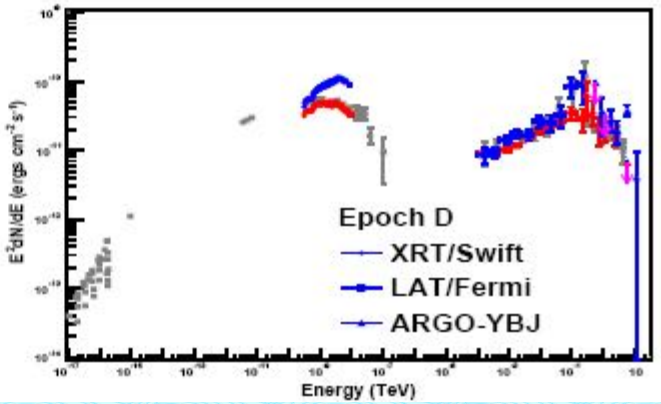
IGMF measurement

Emitting Mechanism



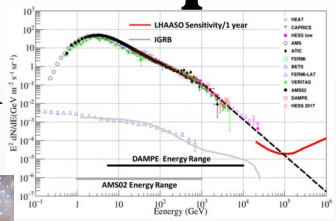



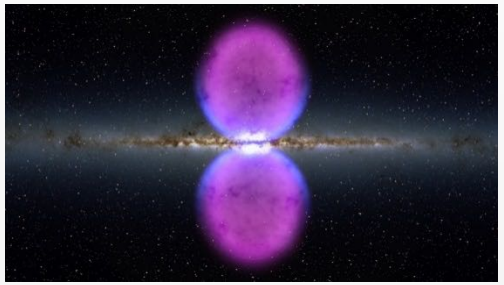



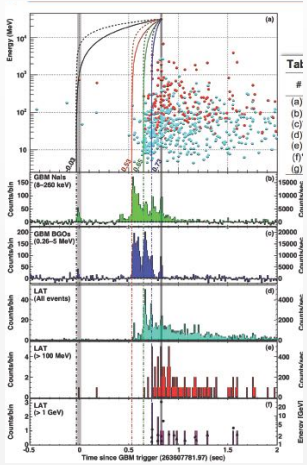
# Many Topics in Astroparticle Physics

e+e- spectrum

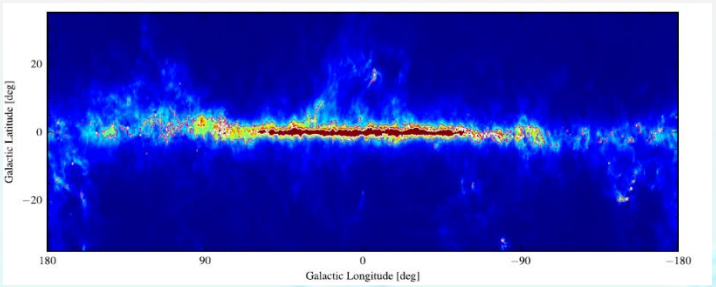


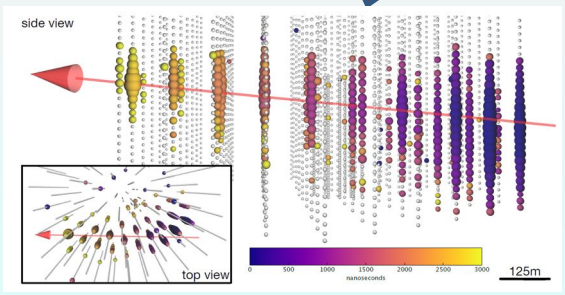



FERMI Bobble

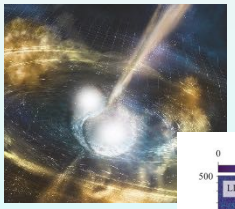


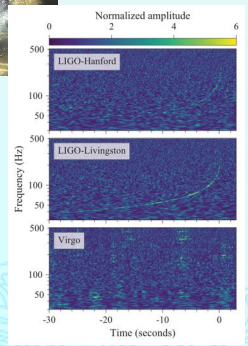

GRB 090501




GW170817



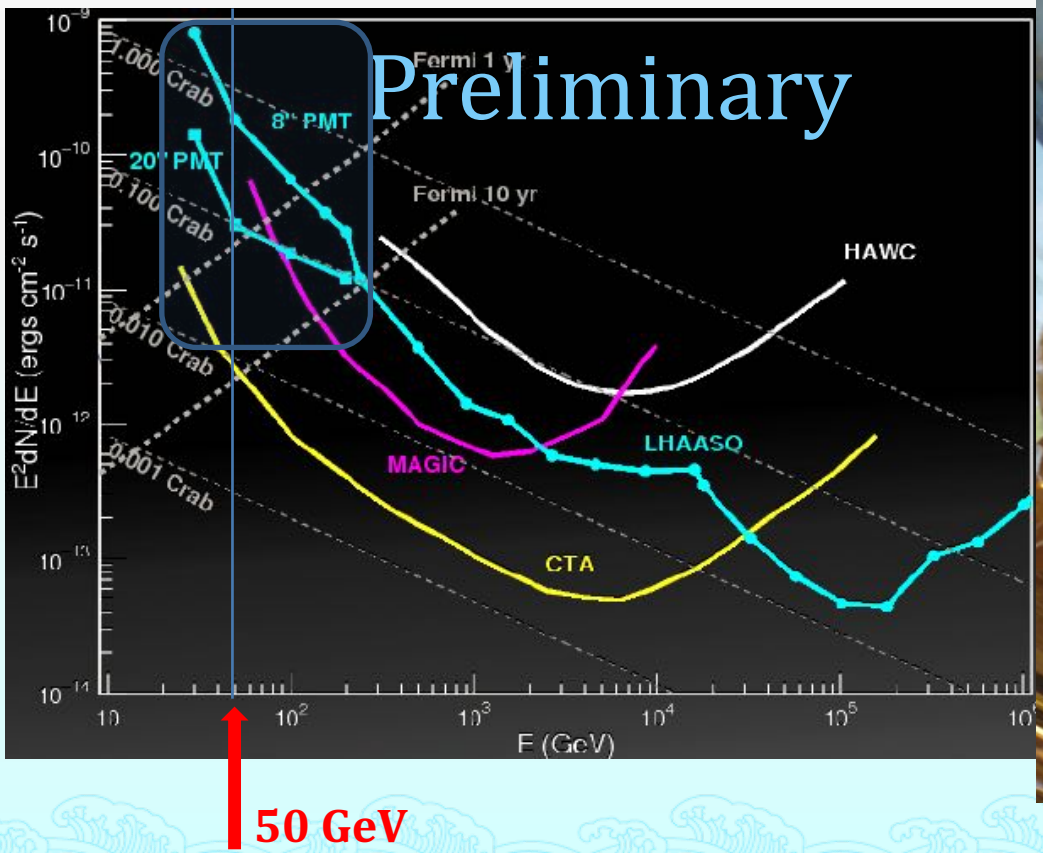


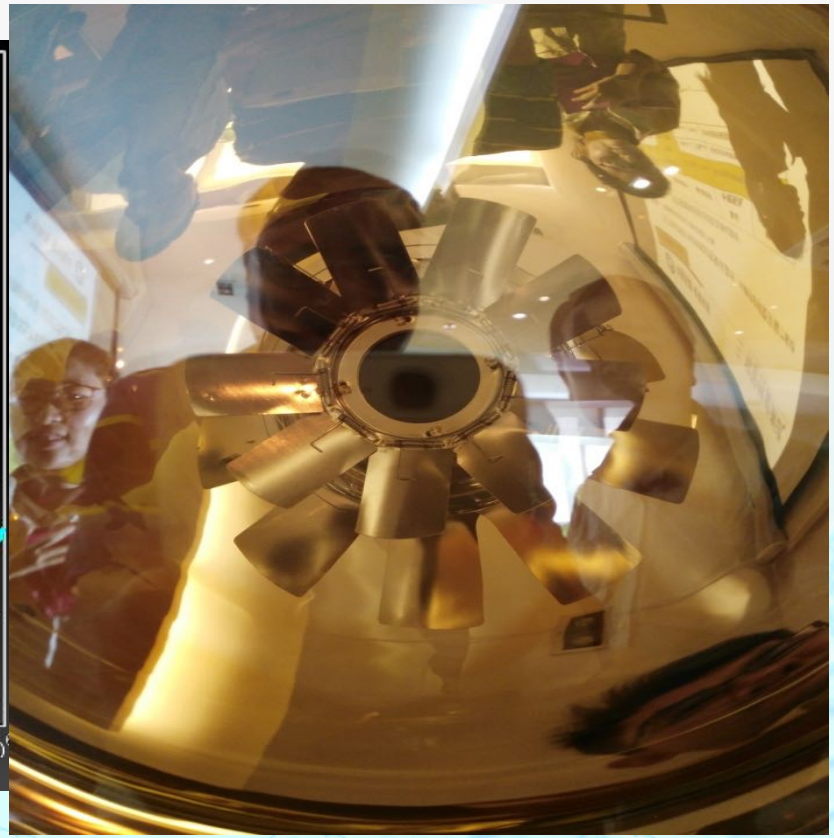

Diffuse γ Background

IC-170922A

# Enhancement of the sensitivity below 100 GeV

- 20” PMTs with special PE collecting design in #2 and #3 ponds of WCDA
- Transient Phenomena： GRB、AGN-flares、N-N merge gravitational wave events …



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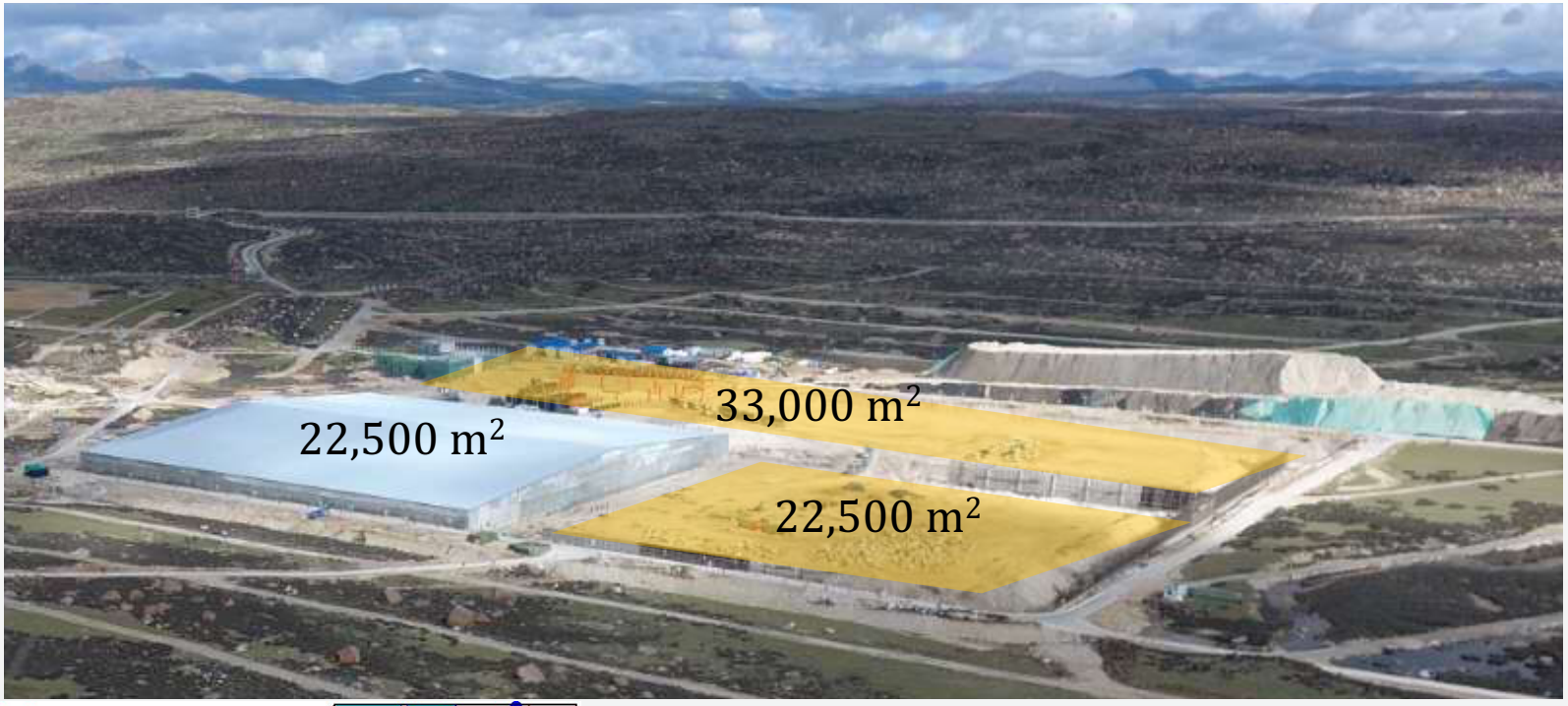
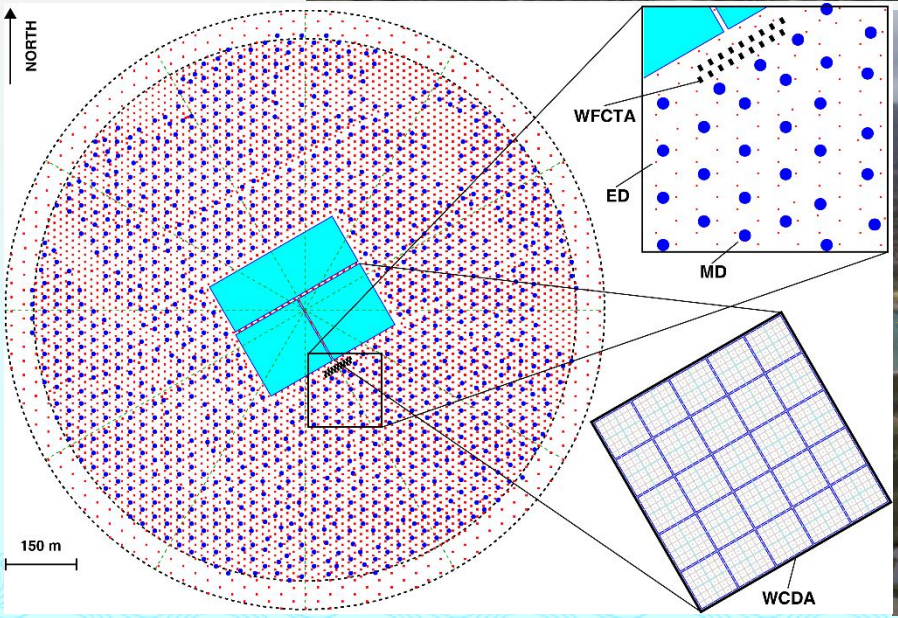
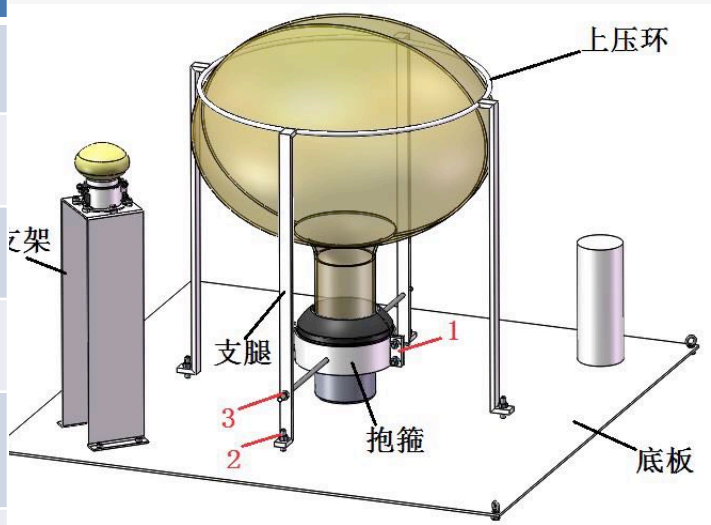


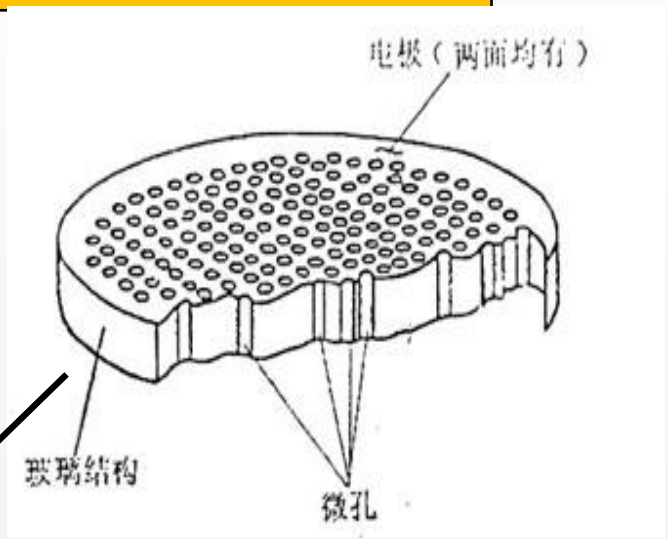

# # of Channels & Specifications

- 2,287cells in #2 and #3 ponds（5500m²）
- Configuration: 20” PMT+3” PMT per cell

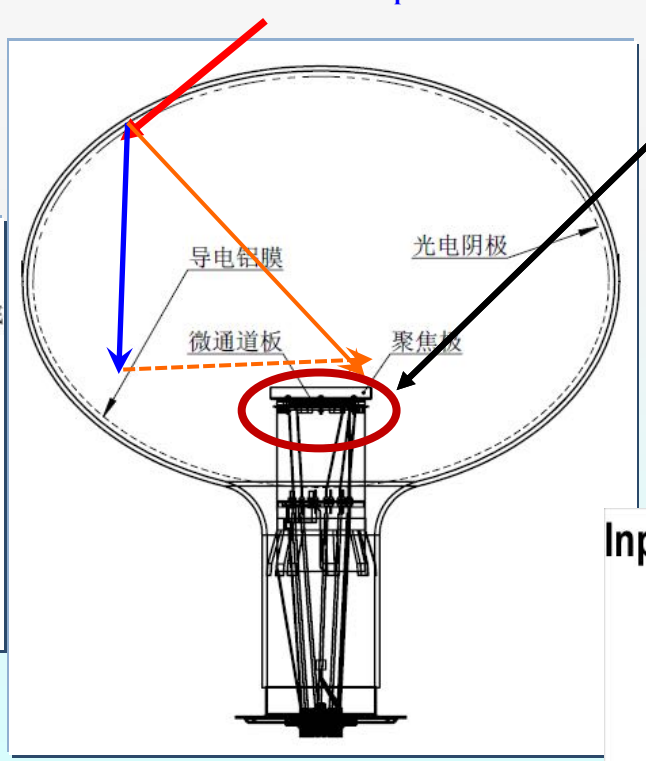
| | 20in PMT （GDB-6203） | 3in PcellMT （XP72B22） |
|---|---|---|
| TTS | ~6ns | ~4ns |
| CTTD | ~2ns | |
| Rise time | ~3ns | ~4ns |
| Linearity | >=2000PE. | >400PE(anode) |
| Dark noise rate | <=10KHz | <1KHz |
| Gain | 5*10**7 | 3*10**6 |
| After Pulse ratio | <1% | <5% |
| Stages | 2 | 10 |



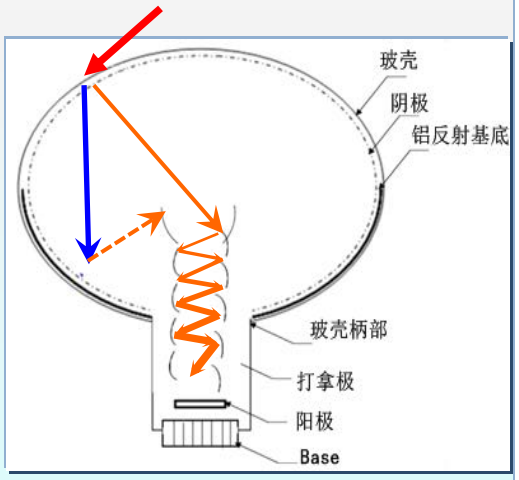
# MCP-PMT

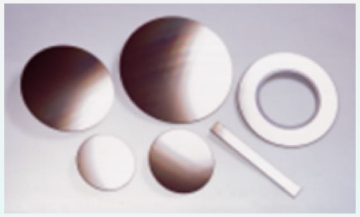


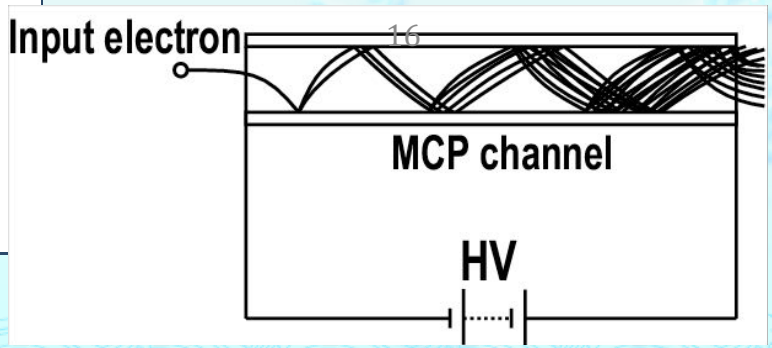

## MCP works as dynodes




## Conventional Dynodes



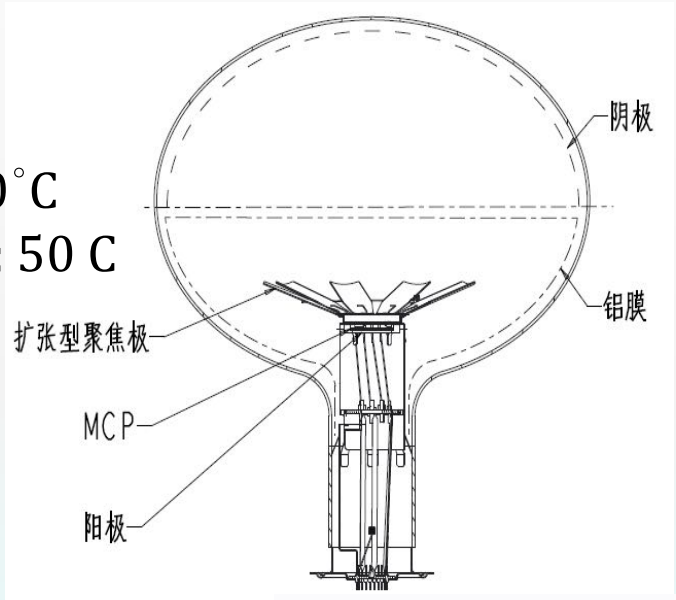


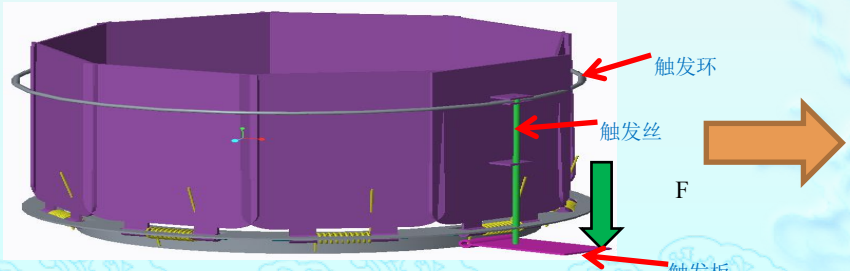
# JUNO's MCP-PMT vs. LHAASO's

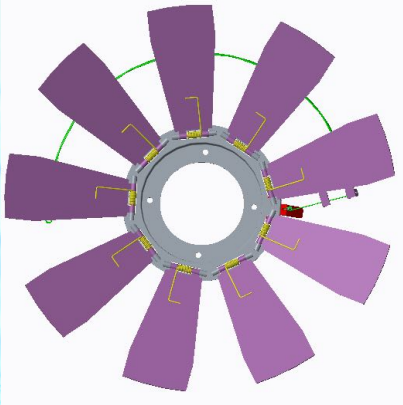
- North Night-Vision Ltd. is producing 15,000 PMTs for JUNO Experiment in 2.5 yr
- Gain: $10^7$

improvements:

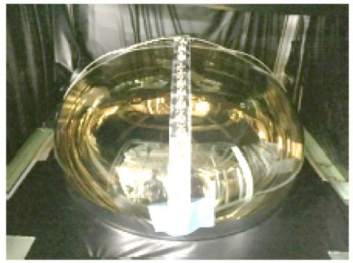
- TTS<7ns, CTTD<2ns
- Noise rate <10KHz @ ~10°C
- Total exposure in lifetime: 50 C (JUNO needs only 5 C)
- Working Current: 200uA



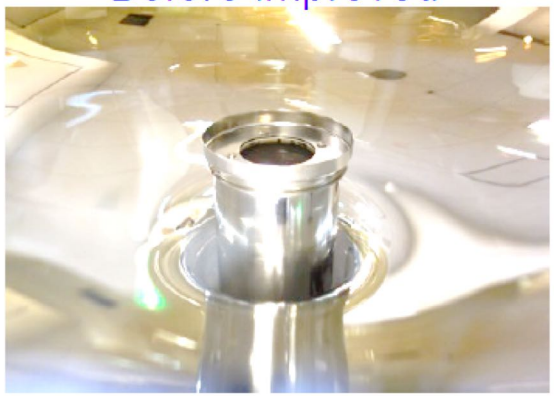



# TTS improvement

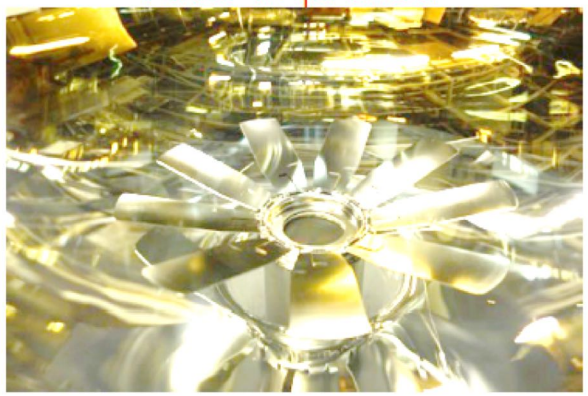


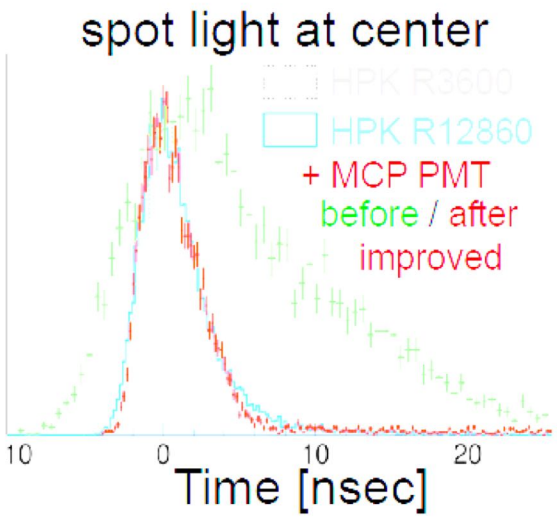
Scanned injected position
from center to edge

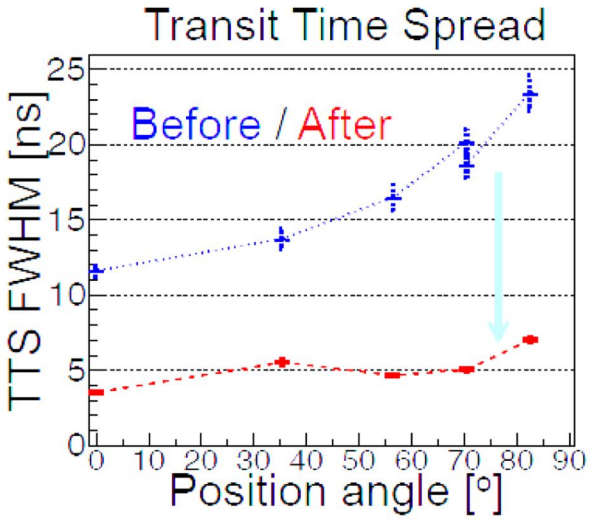
Before improved

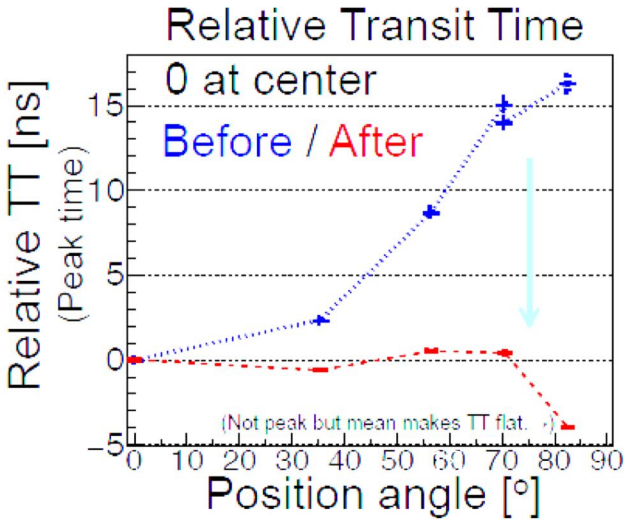


After improved

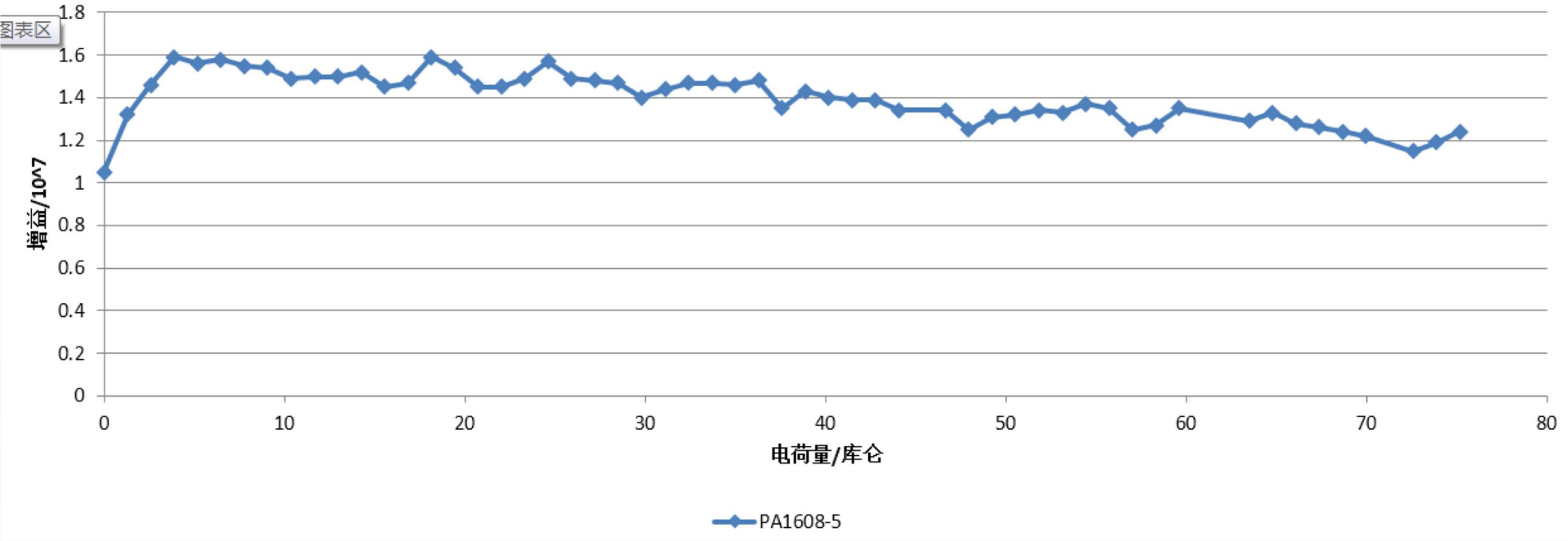




# Long Term Stability Testing

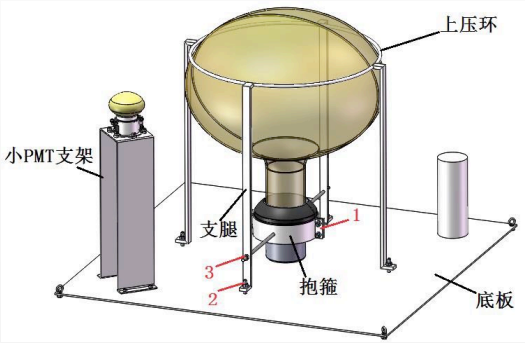


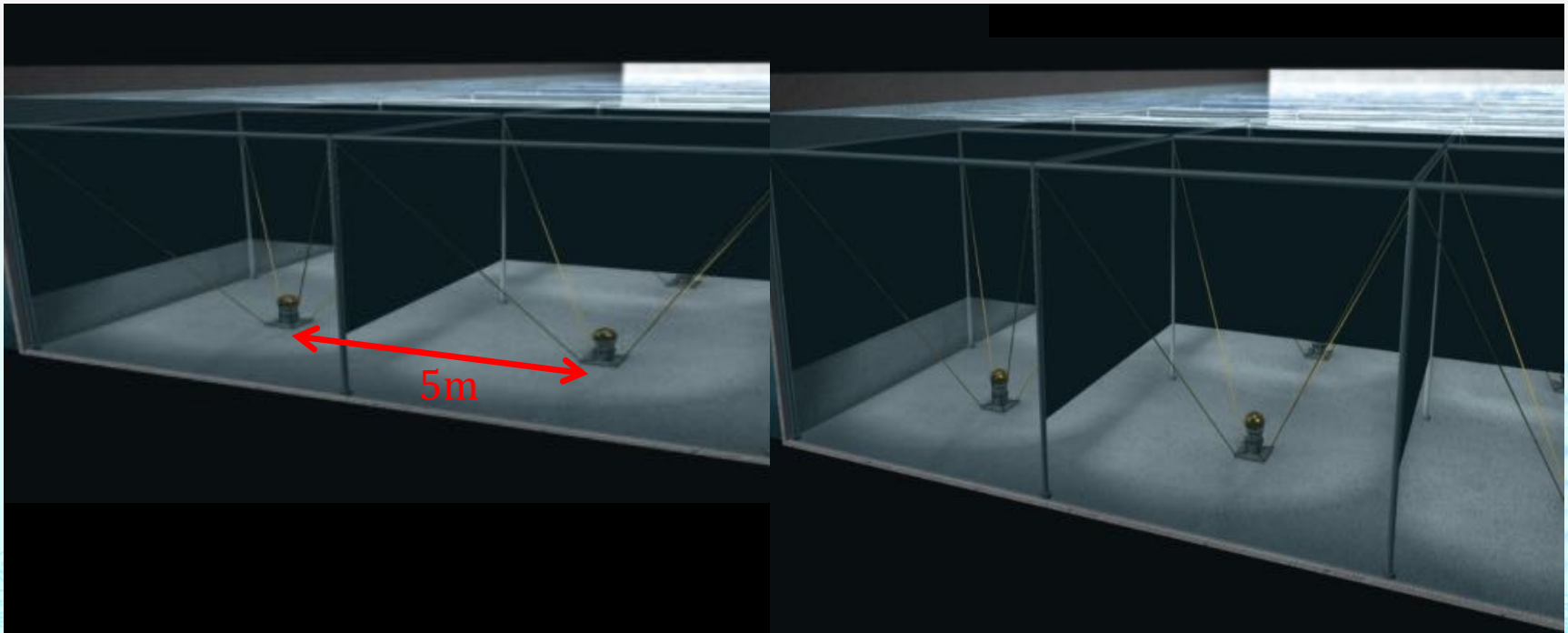

Up to 75 C exposure, gain reduction of 15%, it can be recovered by cranking HV up by only a few volts

# Improvements

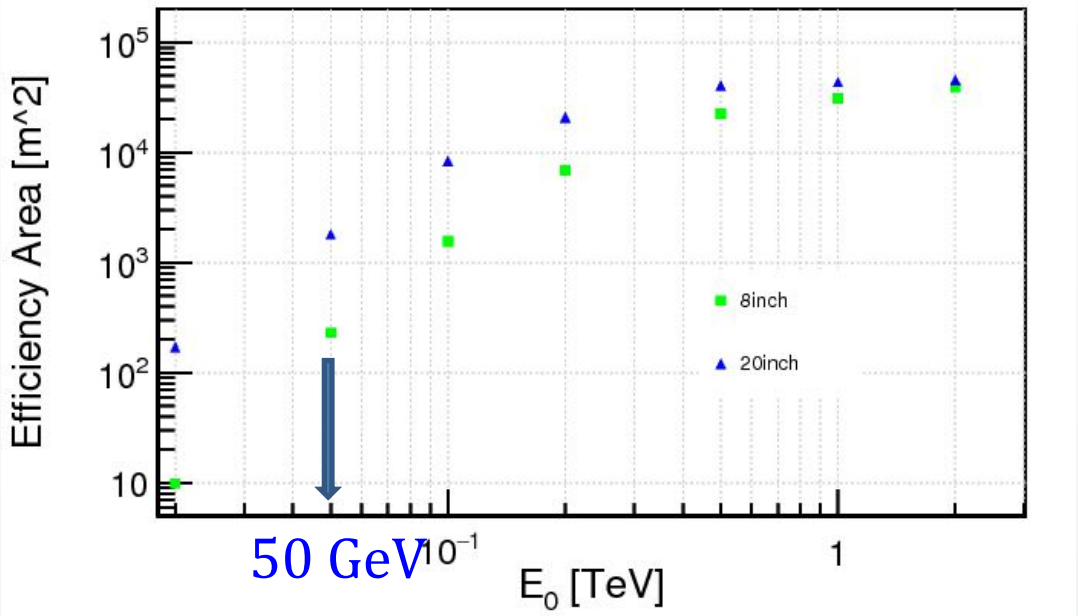
8”vs. 20”

in the same volume of cell



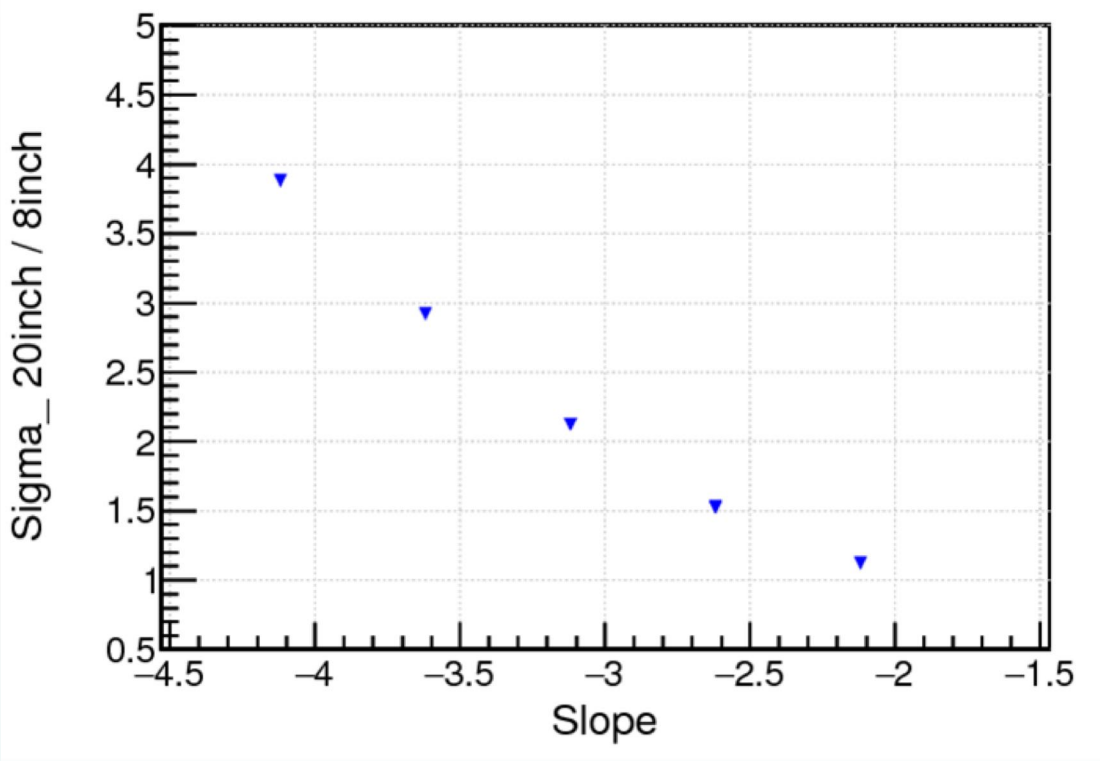



# Efficiency and Effective Area



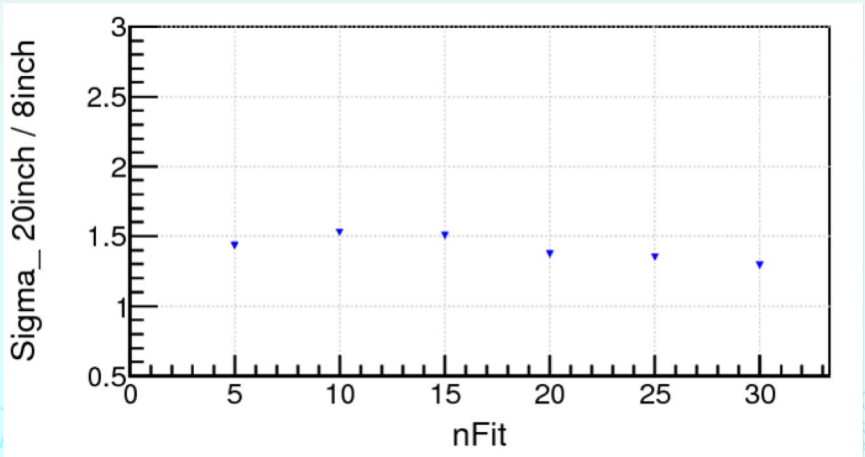

| E (GeV) | 8inch ($m^2$) | 20inch ($m^2$) | Ratio 20/8 |
|---|---|---|---|
| 20 | 9.8 | 171.4 | 17.5 |
| 50 | 230.2 | 1807.4 | 7.9 |
| 100 | 1560.9 | 8373.6 | 5.4 |
| 200 | 6847.3 | 20836.4 | 3.0 |
| 500 | 22675.8 | 40588.0 | 1.8 |
| 1000 | 31109.1 | 43827.2 | 1.4 |
| 2000 | 39154.6 | 45454.4 | 1.2 |

# Sensitivity Boosting




For soft spectrum, could be **4×**

GW170817 or IC170922A both have soft spectra



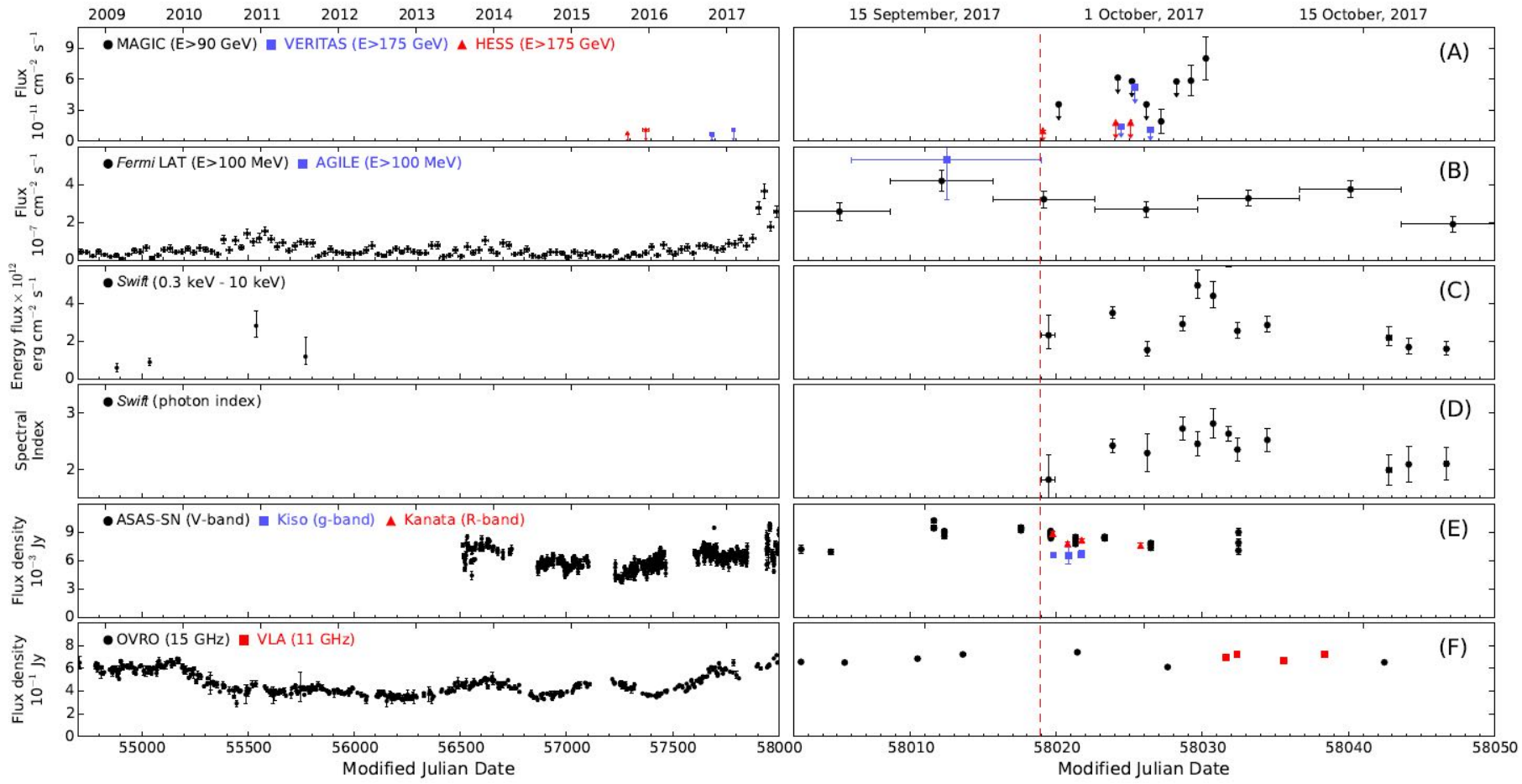

For Crab-like hard spectrum~$E^{-2.62}$

❖ About **1.5×**

# IC-170922A/TXS 0506+056: Multi-Wavelength Observation

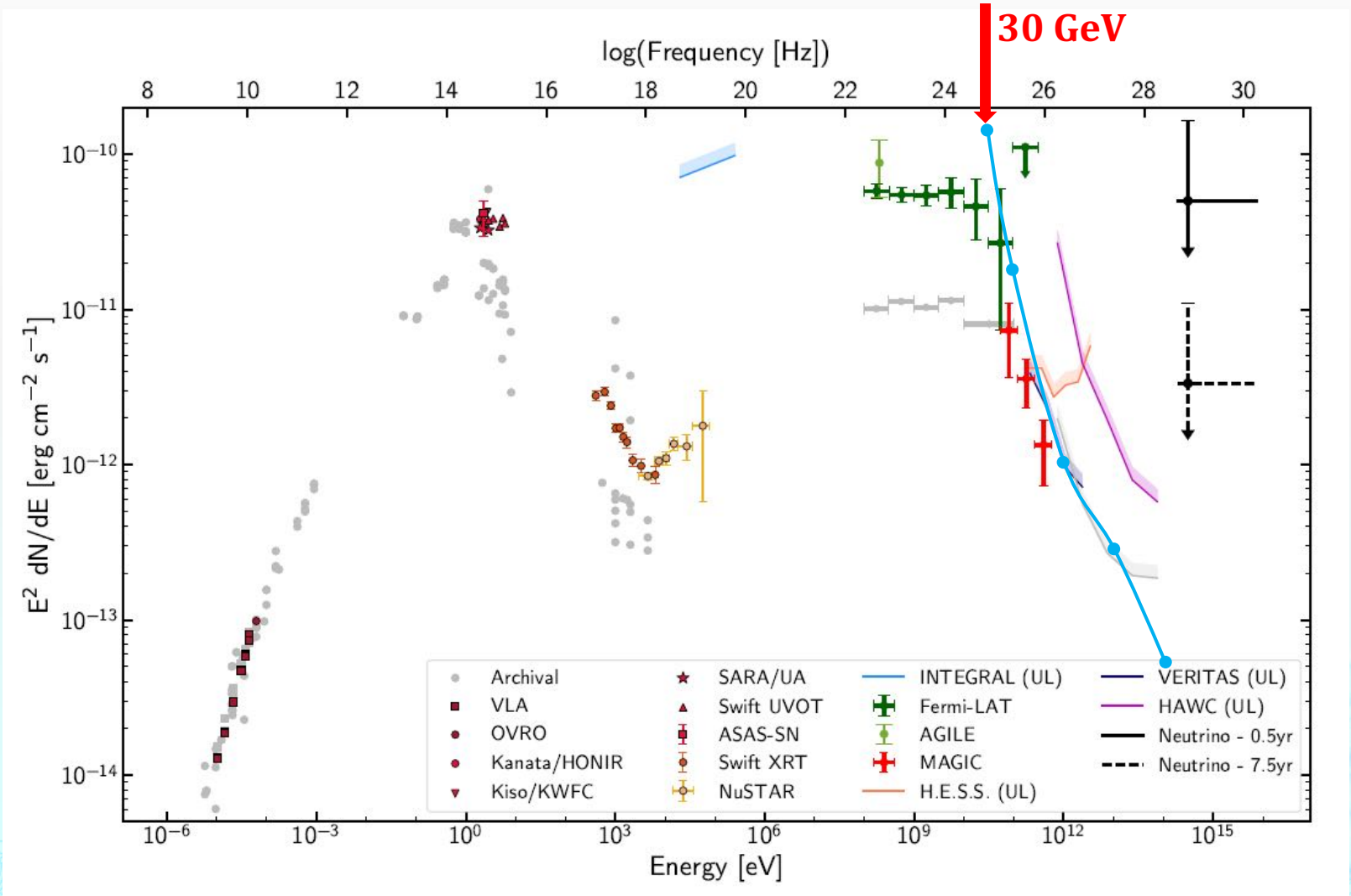
**An example**

arXiv:1807.08816
Science 361, eaat1378 (2018)



# IC-170922A/TXS 0506+056 : SED

arXiv:1807.08816
Science 361, eaat1378 (2018)



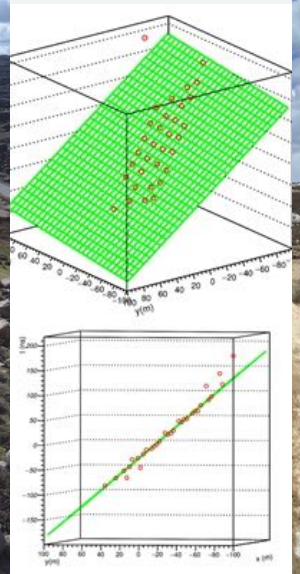
# Construction Status of LHAASO

- Liner

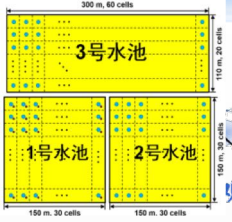
1st WR Fan-less switch

- 2018/02/04, first 33 scintillator detectors deployed.

The 1st LHAASO event



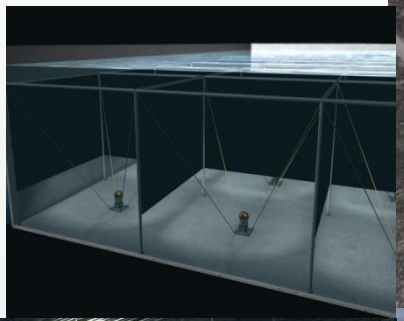
**1st muon detector**

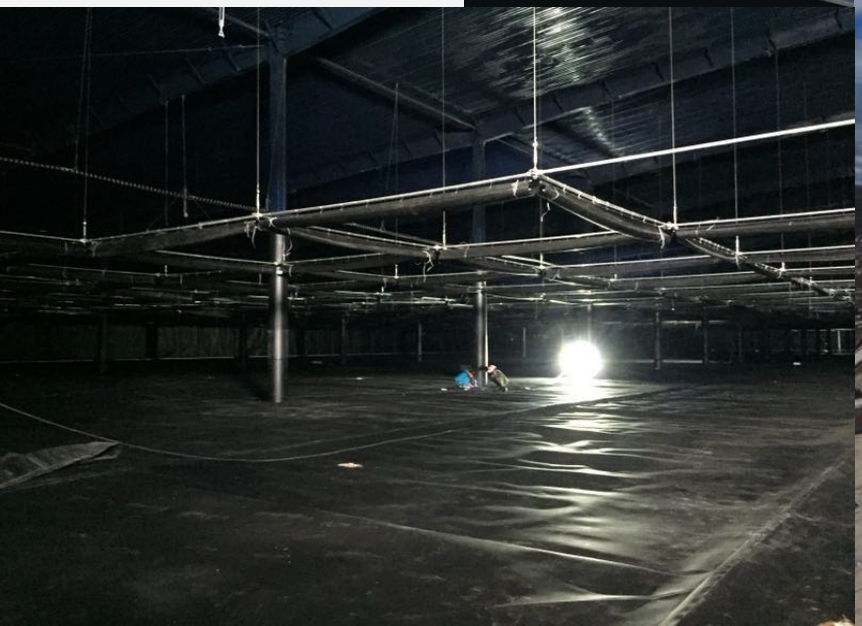



# Construction

- #1 pool（150X150 $m^2$）is built
- 2018/04, #2 & #3 pools were started simultaneously

Installation Inside the pond





1st water pool

LHAASO
高海拔宇宙线观测站

Water purification & recycling system for 0.45M tons

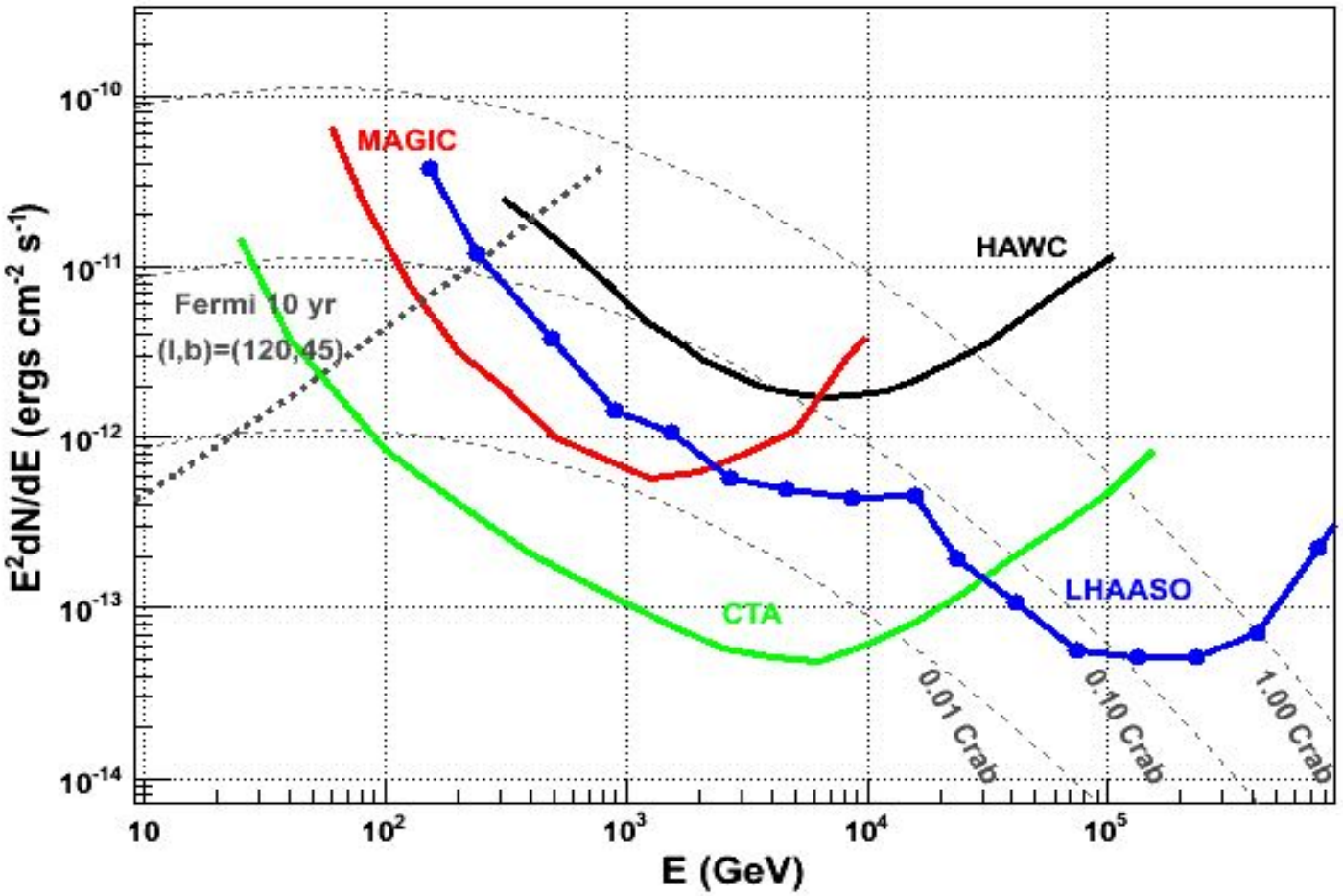
# Summary

- LHAASO observatory for gamma ray astronomy
  - Unique on 10 TeV gamma ray monitoring
  - Window for evidences of hadronic origin of cosmic rays
  - Wide FOV monitoring for transient phenomena
- 20” PMTs in #2-3 pond will enhance the low energy sensitivity for extragalactic phenomena, particularly for the multi-messenger observation
- Detector construction started June 2017 and infrastructure May 2016. ¼ of the array will be turned on for scientific operation early next spring and the construction will be finished in 2021

# Sensitivity to gamma ray sources

- **Differential sensitivity:**

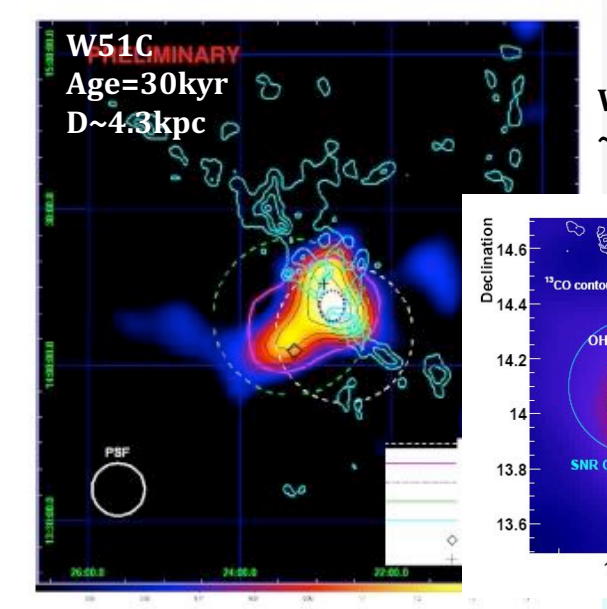
**2% crab in TeV range & 1 crab at 500TeV**



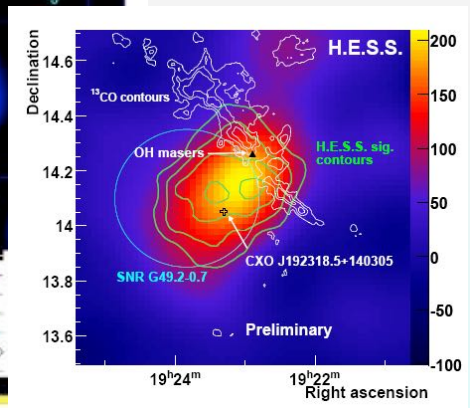
# Central scientific target of LHAASO : Identifying Galactic Cosmic Ray Origins

SNRs: for example W51C:

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

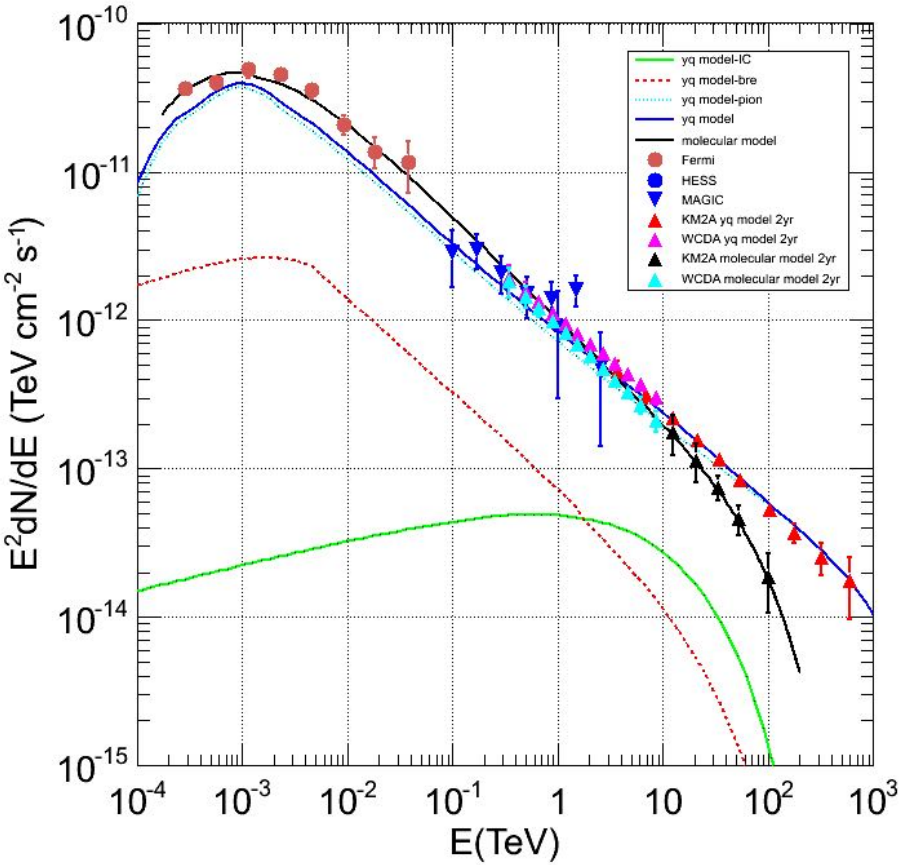



W51C
~3%Crab

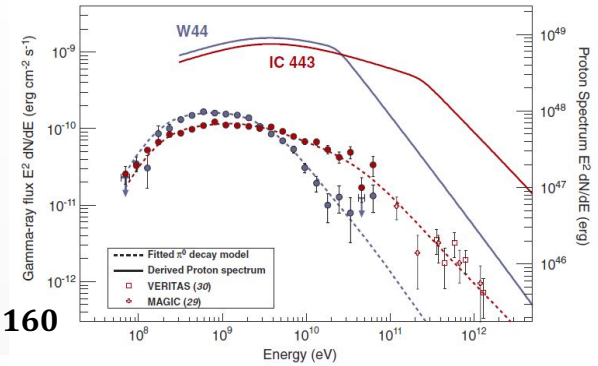



*reference~ APJ, 761:133(2012) && Mon.Not.R.Astron.Soc, 421,935-942(2012)*

**GeV&TeV~ dominated by $\pi^0$ decay**



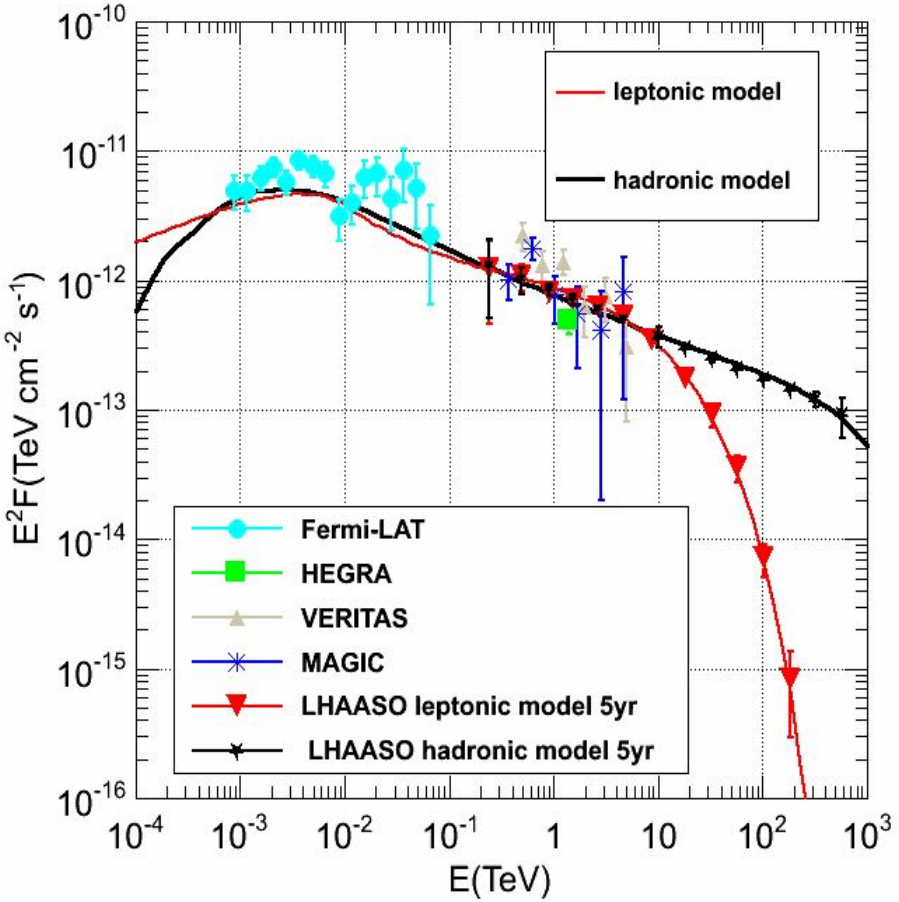
# Hadronic vs. Leptonic



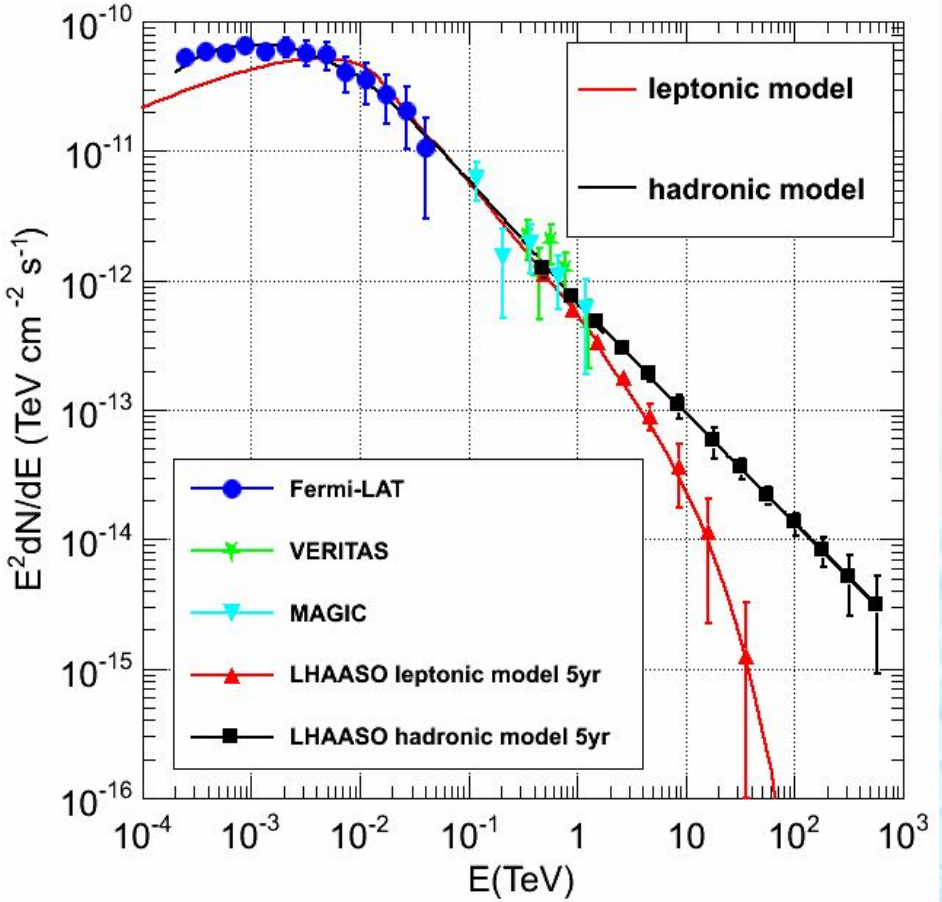

**Characteristic signatures of $\pi^0$ decay: at highest energy by LHAASO**

10.1126/science.1231160

**Cassionpeia A** Historical SNRs

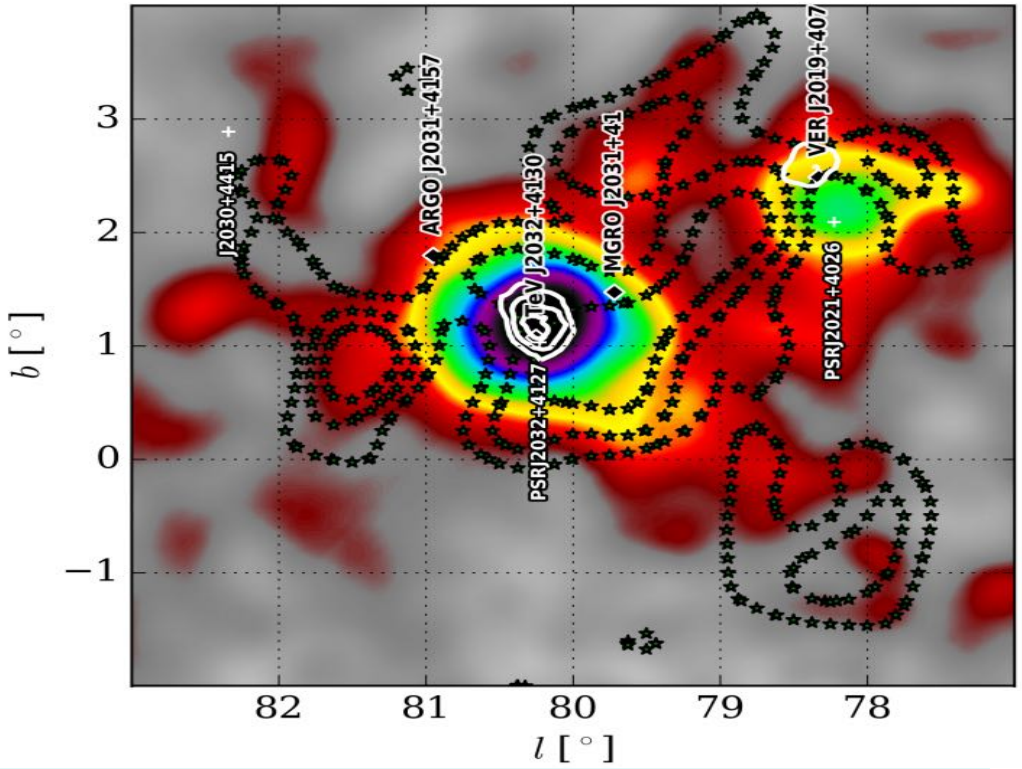


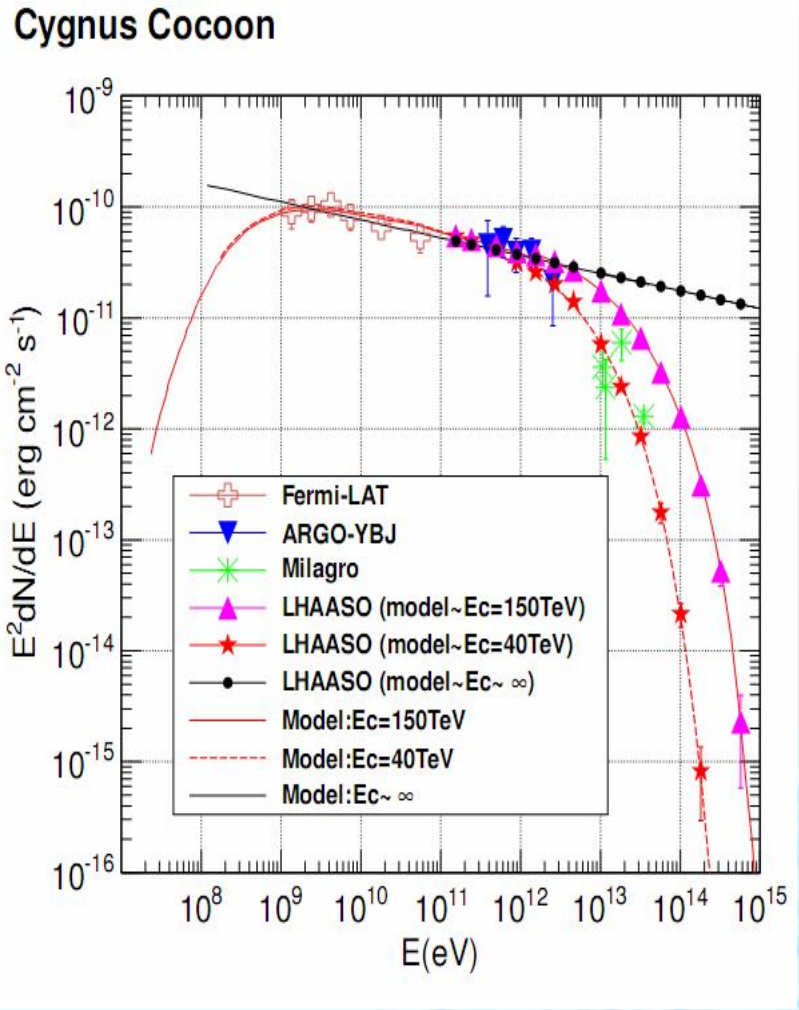

**IC443** interacting with molecular clouds



# Broad Objects: Cygnus region

The 1st VHE supper-bubble by ARGO-YBJ




Overlapping sources？ Morphological study？ Multi-wavelength？

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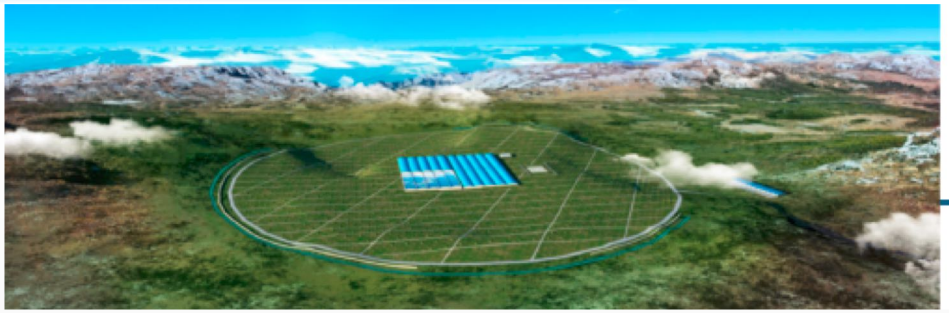
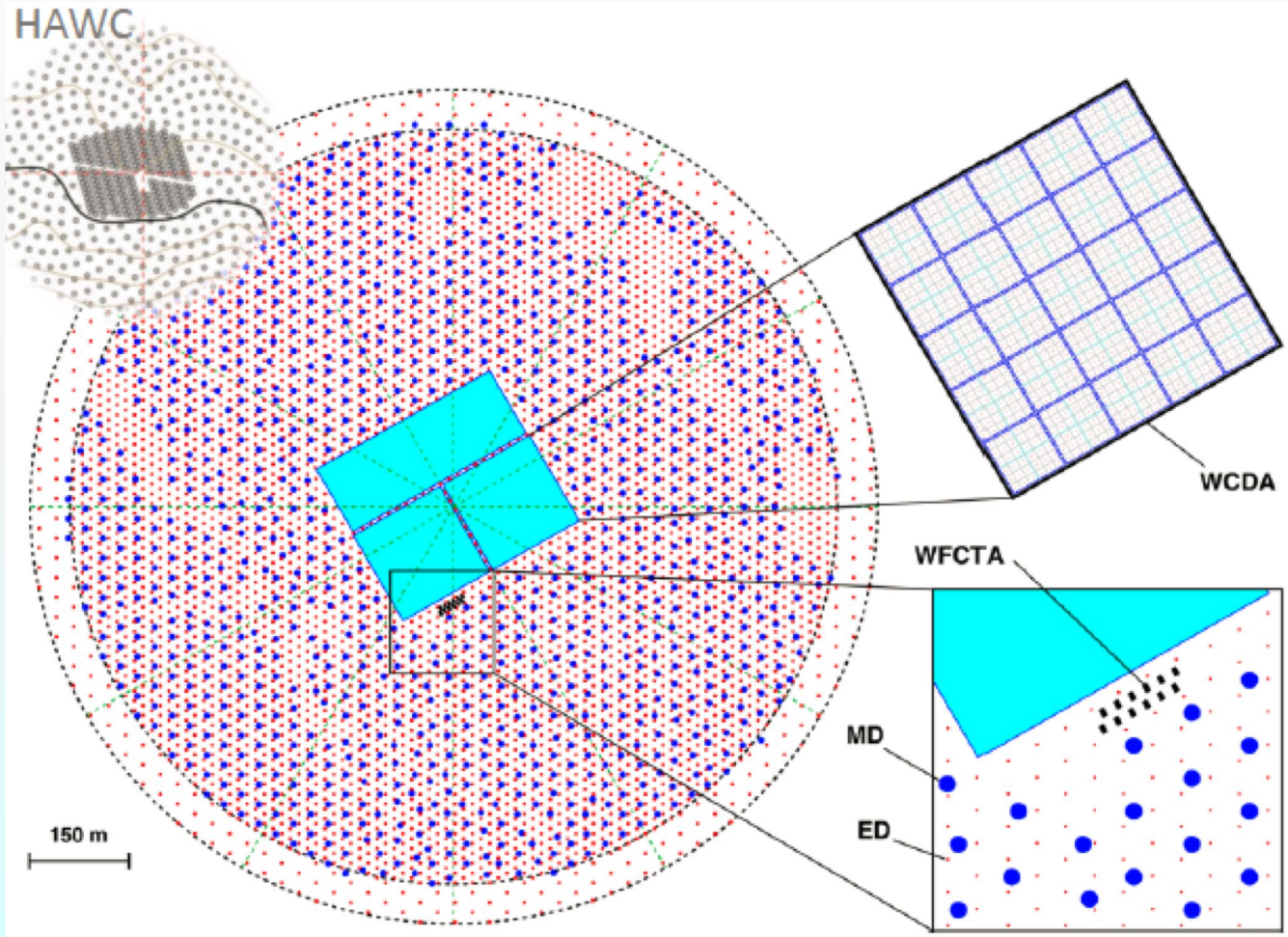


# LHAASO

Sichuan, China, 4410 m asl




**5195 Scintillators**
- 1 $m^2$ each
- 15 m spacing

**1171 Muon Detectors**
- 36 $m^2$ each
- 30 m spacing

**3000 Water Cherenkov Cells**
- 25 $m^2$ each

**12 Wide Field Cherenkov Telescopes**

LHAASO
高海拔宇宙线观测站

# PMT的动态范围考虑

| PMT | 输出 | 电子学路数与量程 | 光阴极面积比 |
|---|---|---|---|
| 8-in PMT | 阳极 | 1-133PE | 1.00 ~18cm |
| | 打拿极 | 30-4,000PE | |
| 20-in PMT | 阳极输出：1-2000PE 相对于8”(1-320PE) | 1-133PE | 6.53 ~46cm |
| | | 30-2,000PE | |
| 3-in PMT | 阳极输出：1-200 相对于8”(7-1,000PE) | (10mV-2V) | 0.766 ~7cm |
| | 打拿极输出：1-100（与阳极X30？30-3000PE） 相对于8”(210-21,000PE) | (20mV-2V) | |

1，如果只用20in PMT，动态范围只为原先的十分之一左右；
2，增加3in PMT，动态范围可以增加约5倍。