LHAASO
高海拔宇宙线观测站

Status of LHAASO

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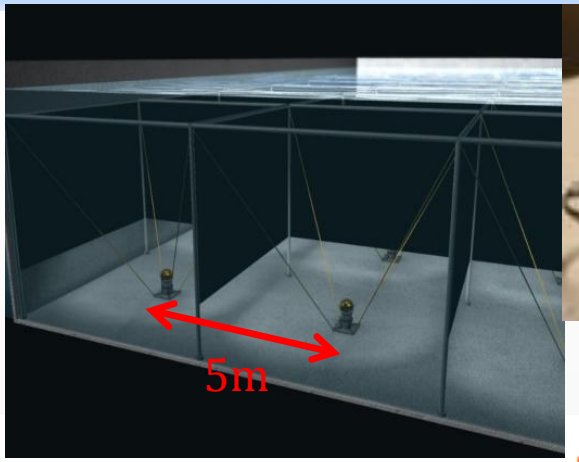
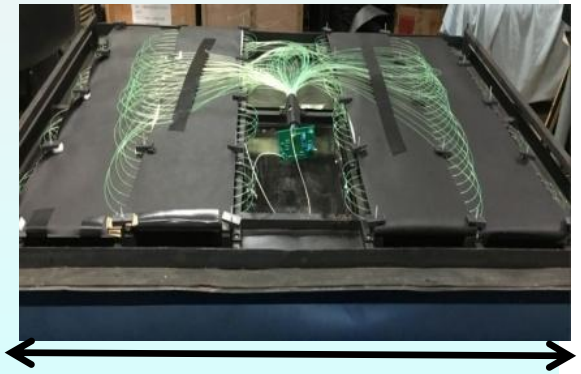
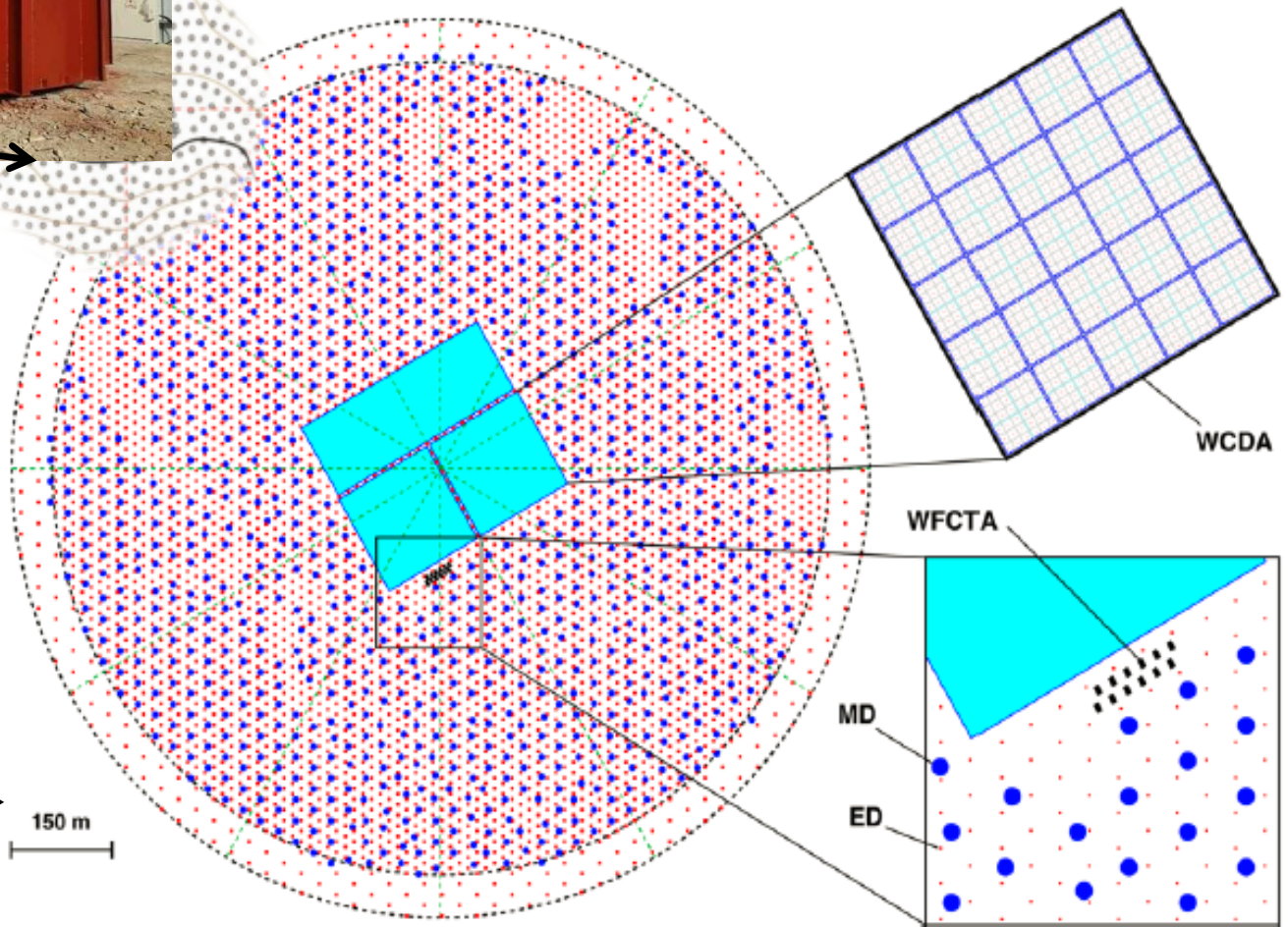
Content

- LHAASO Detector Arrays
- γ-ray detection (WCDA, Scin.+MD Array)
  - Survey for New VHE γ-sources
  - Enhancement at low energy (<100GeV) for transient phenomena
- Hunting for CR sources
- Knees of Spectra of Protons and Irons
- Construction Status
- Summary

Detector Layout in LHAASO







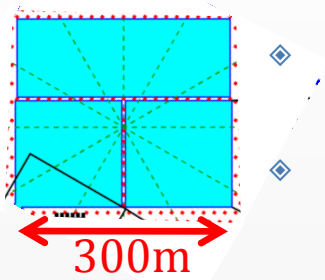
5195 Scintillators
- 1 m^2 each
- 15 m spacing

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

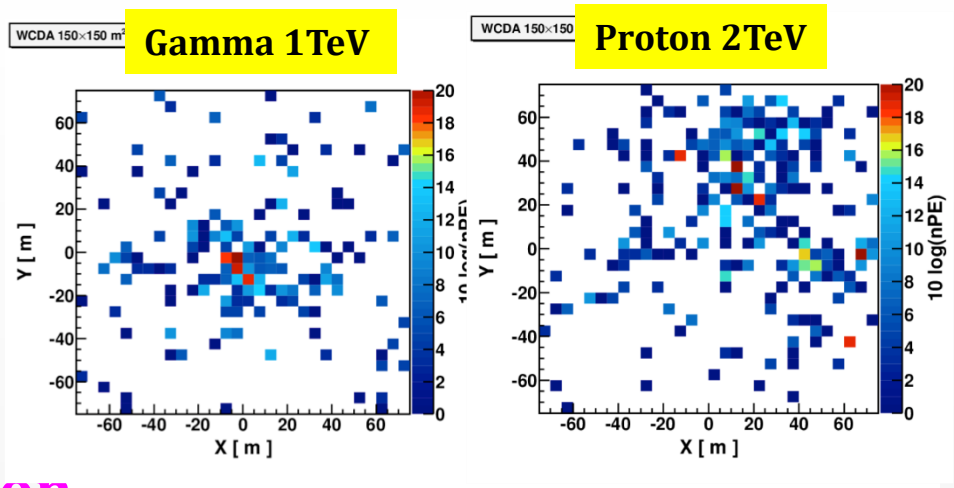
3000 Water Cherenkov Cells
- 25 m^2 each

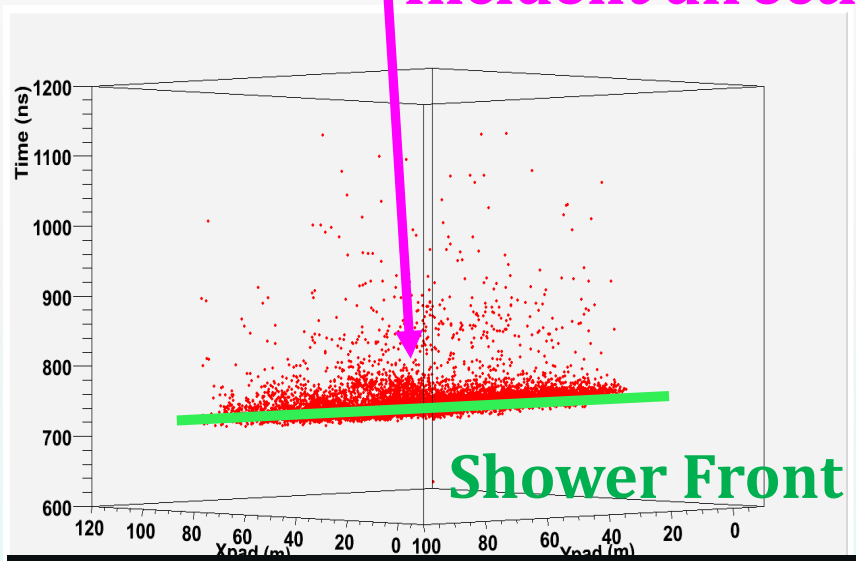
12 Wide Field Cherenkov Telescopes

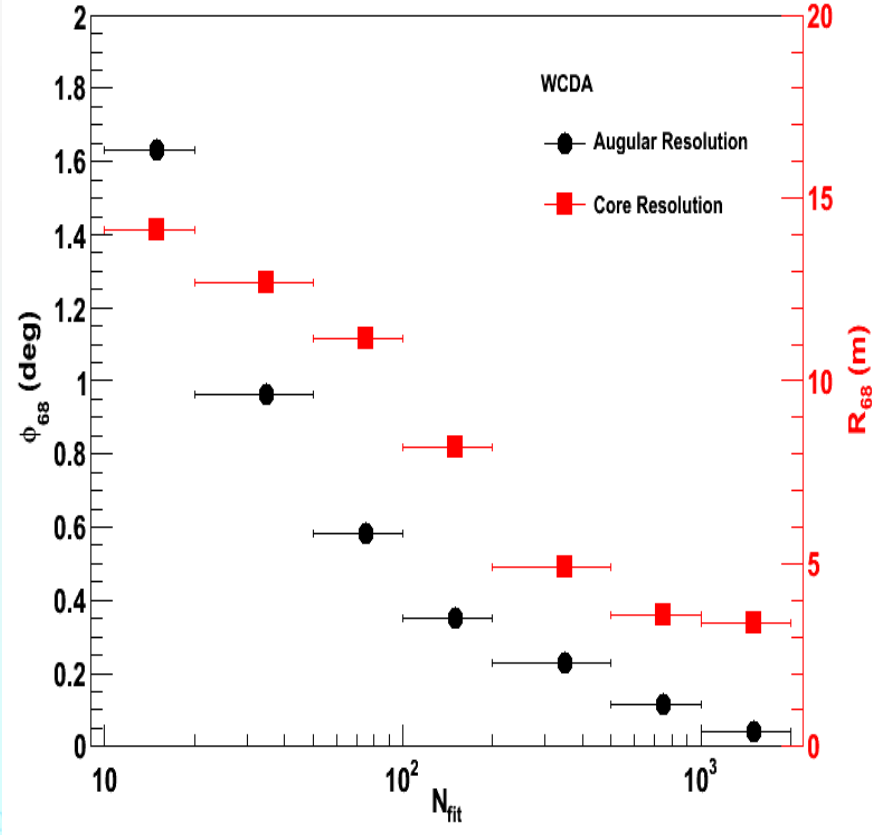
3 Pools



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







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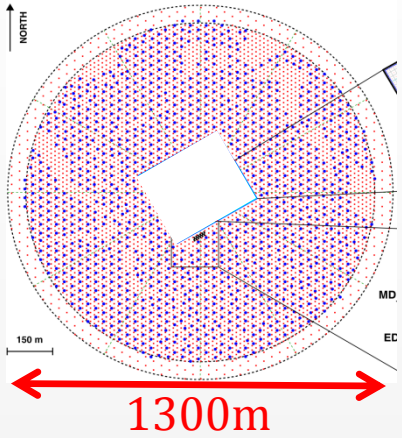
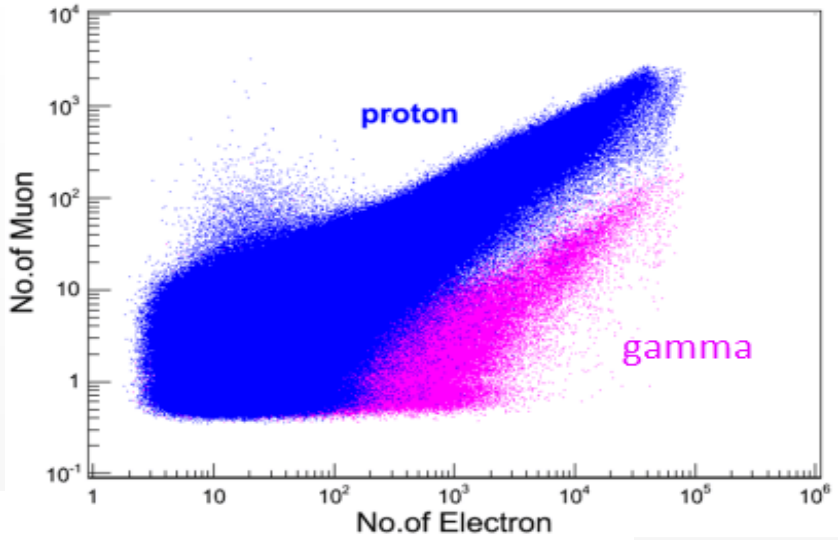
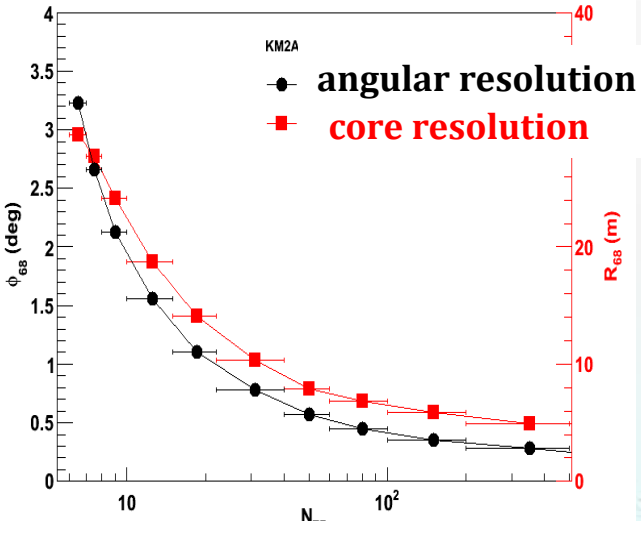
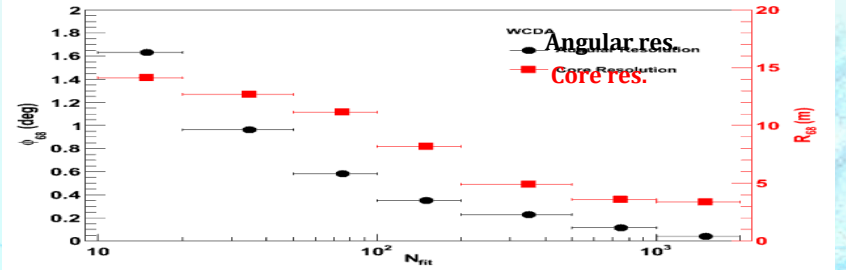


An Array of Scin. +MDs

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

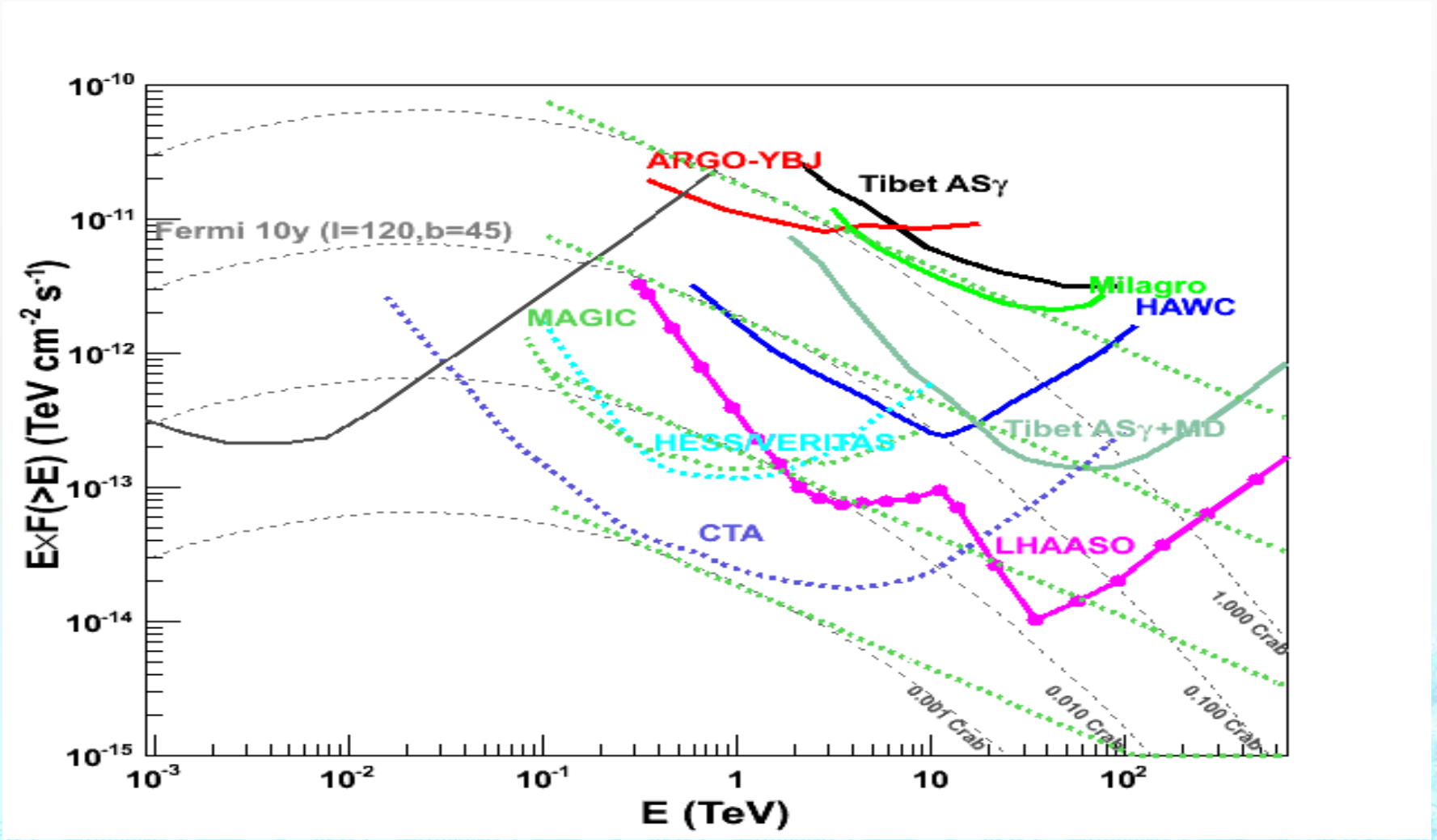






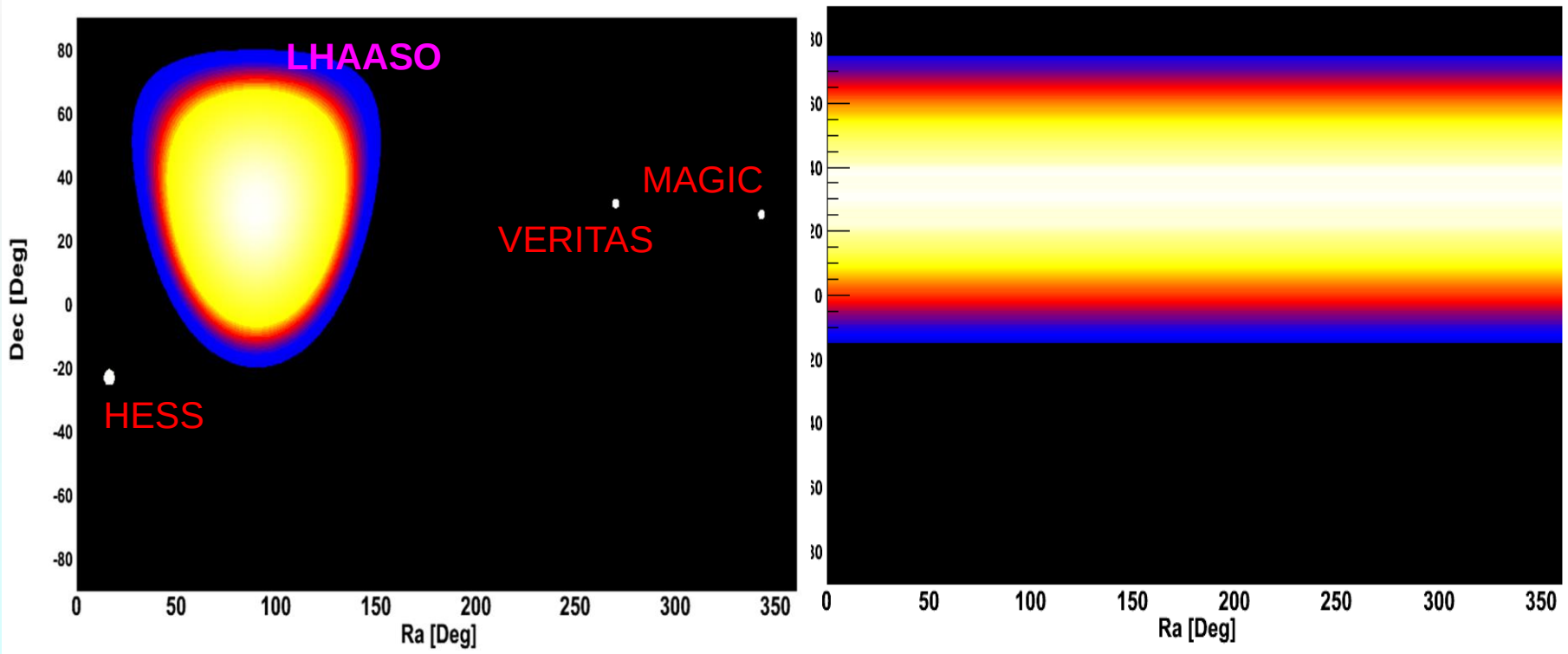
Sensitivity to gamma ray sources

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



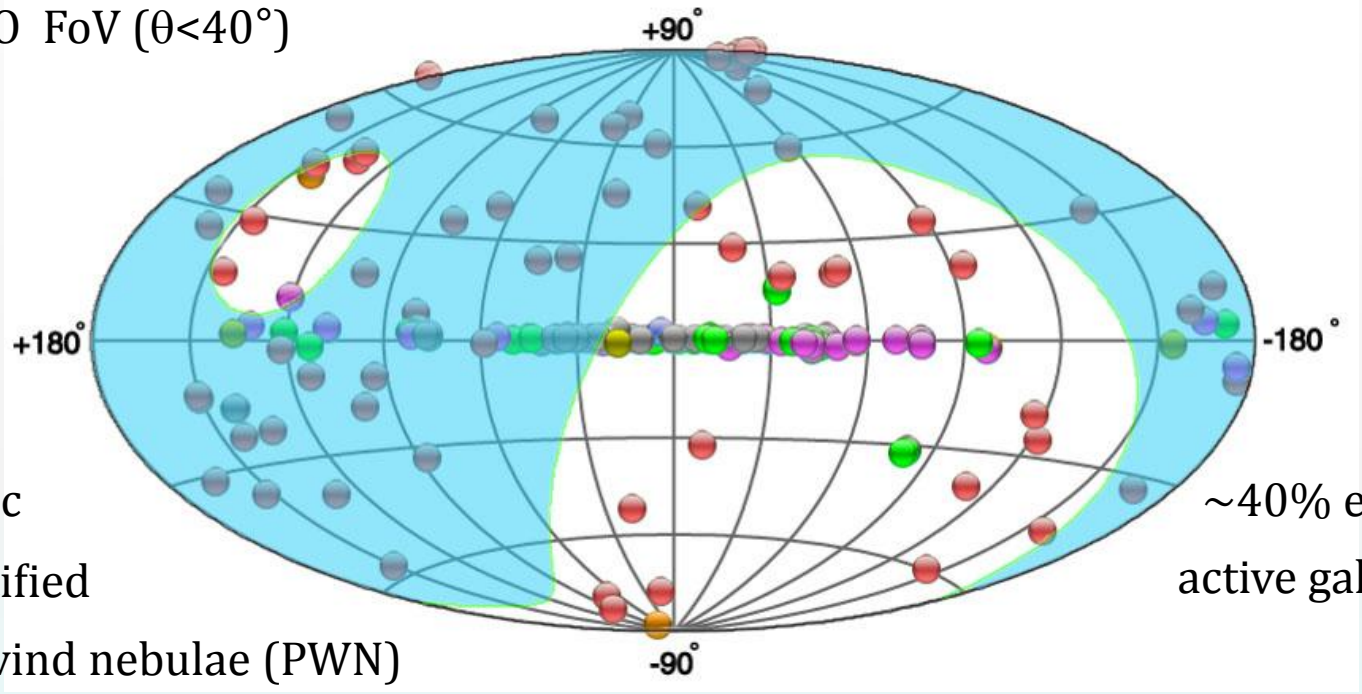
Wide FOV gamma ray astronomy

- **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

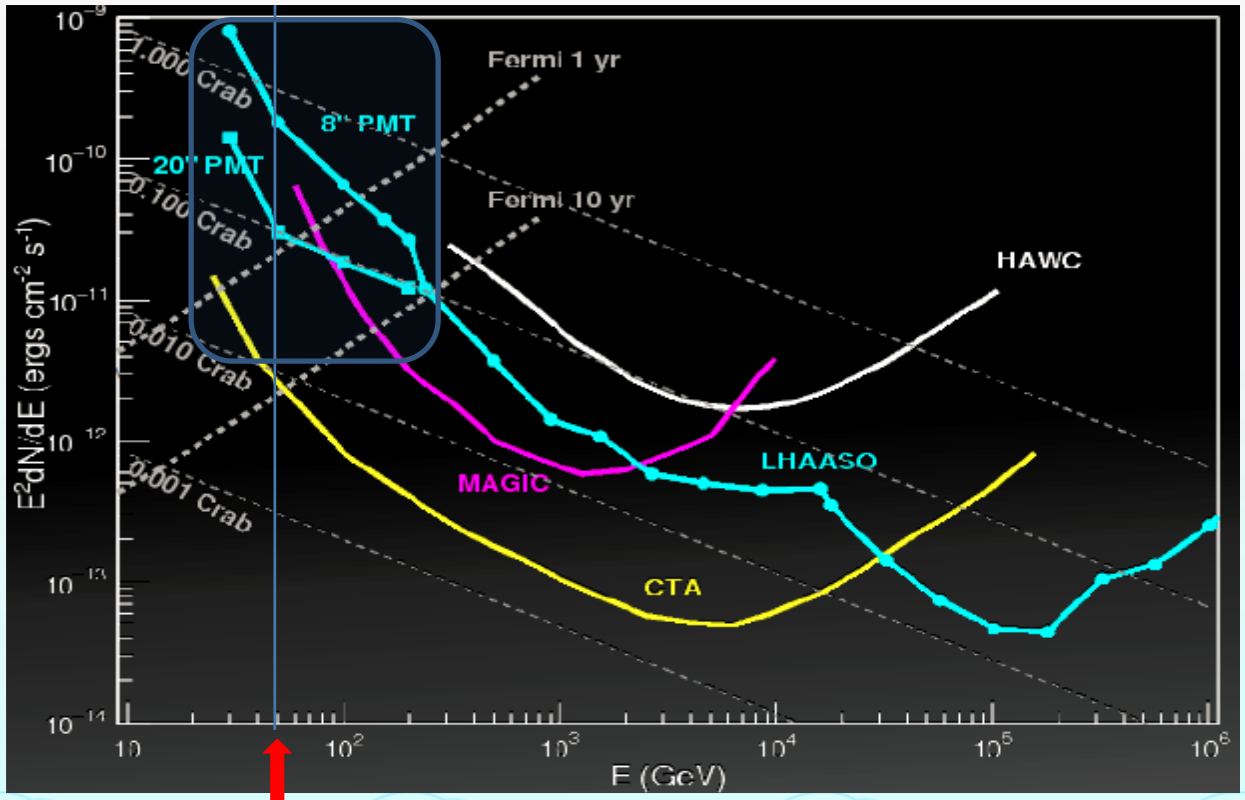
Considering the fact that more than half of the 2LAC BL Lacs do not have redshift measurements, and there are unclassified AGNs in 2LAC catalog and unassociated sources in Fermi source catalog, the total number of detectable AGNs may be significantly increased.

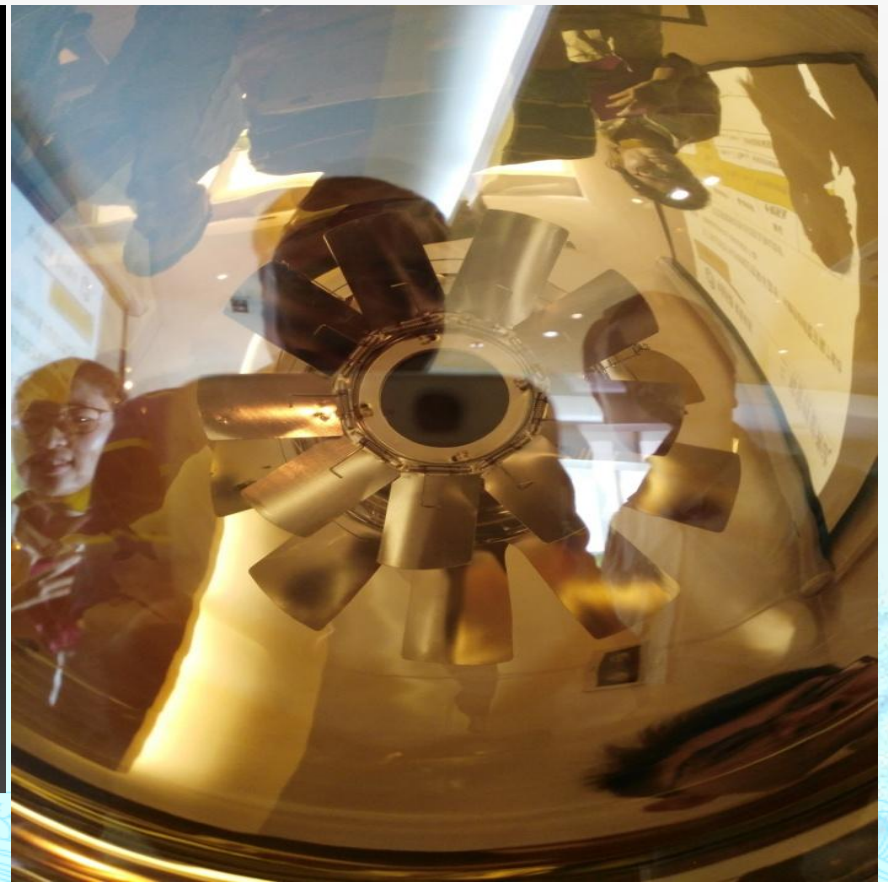
Yi Zhao et al, *Int. J. Mod.* Phys. D 25, 1650006 (2016)

Enhancement of the sensitivity below 100 GeV

See M.J. Chen's talk

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





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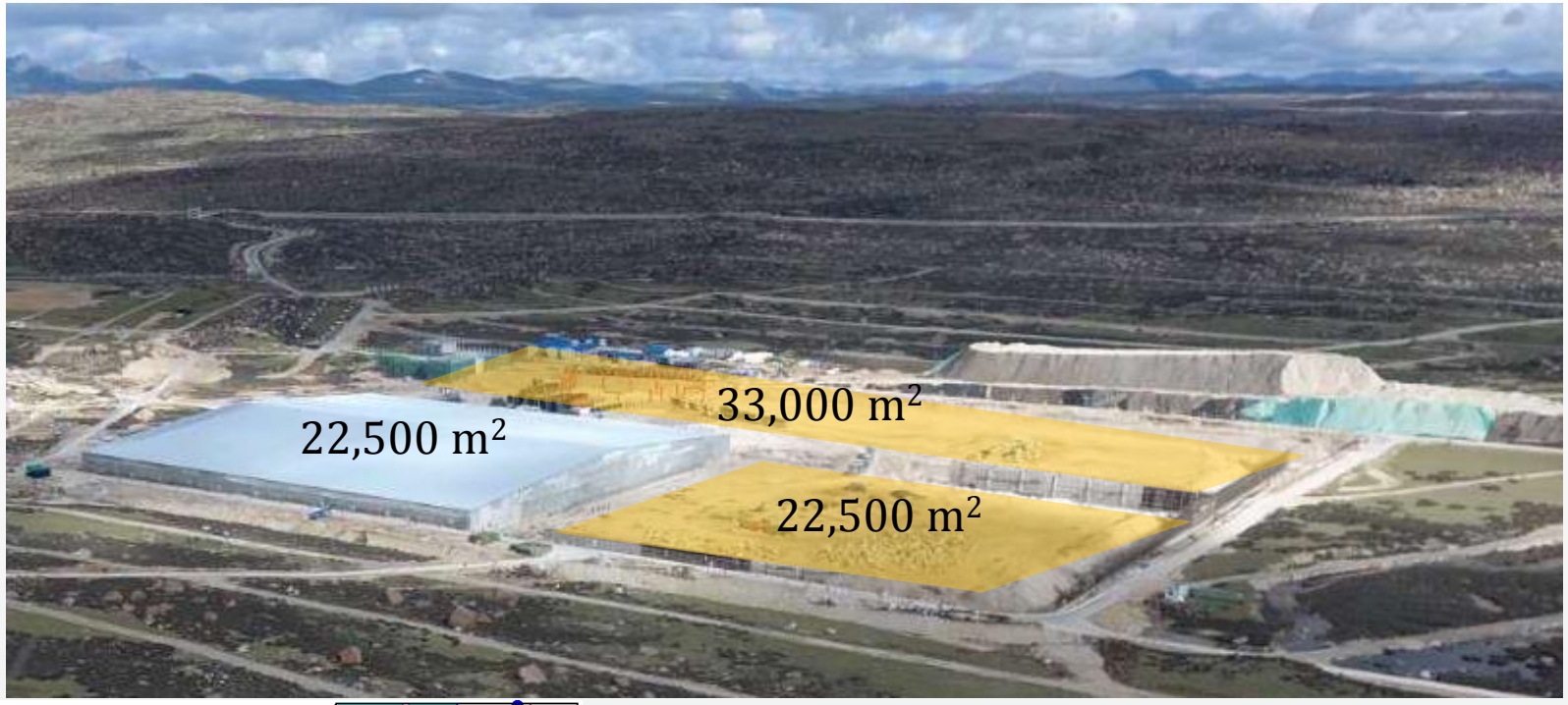
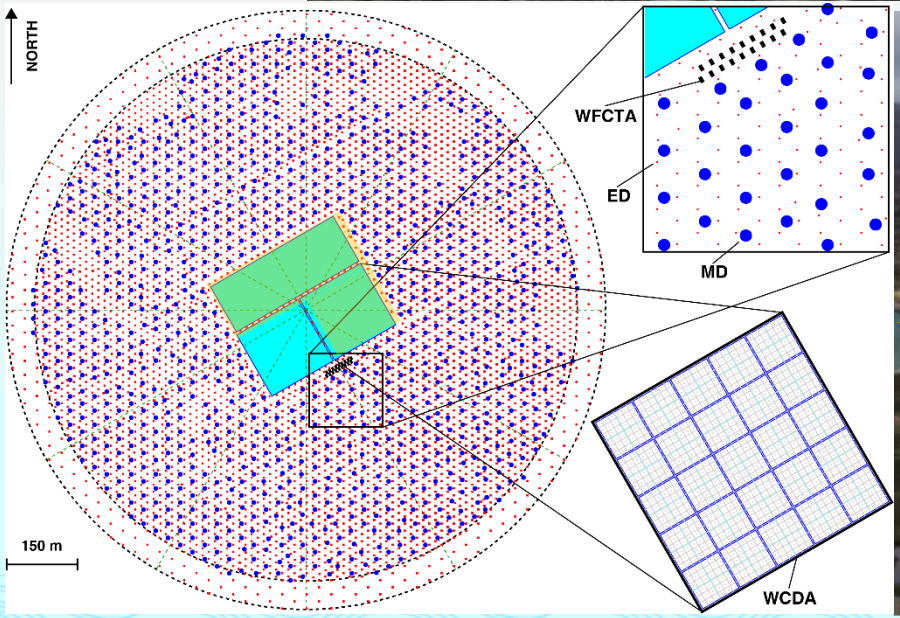




LHAASO on AGN flares

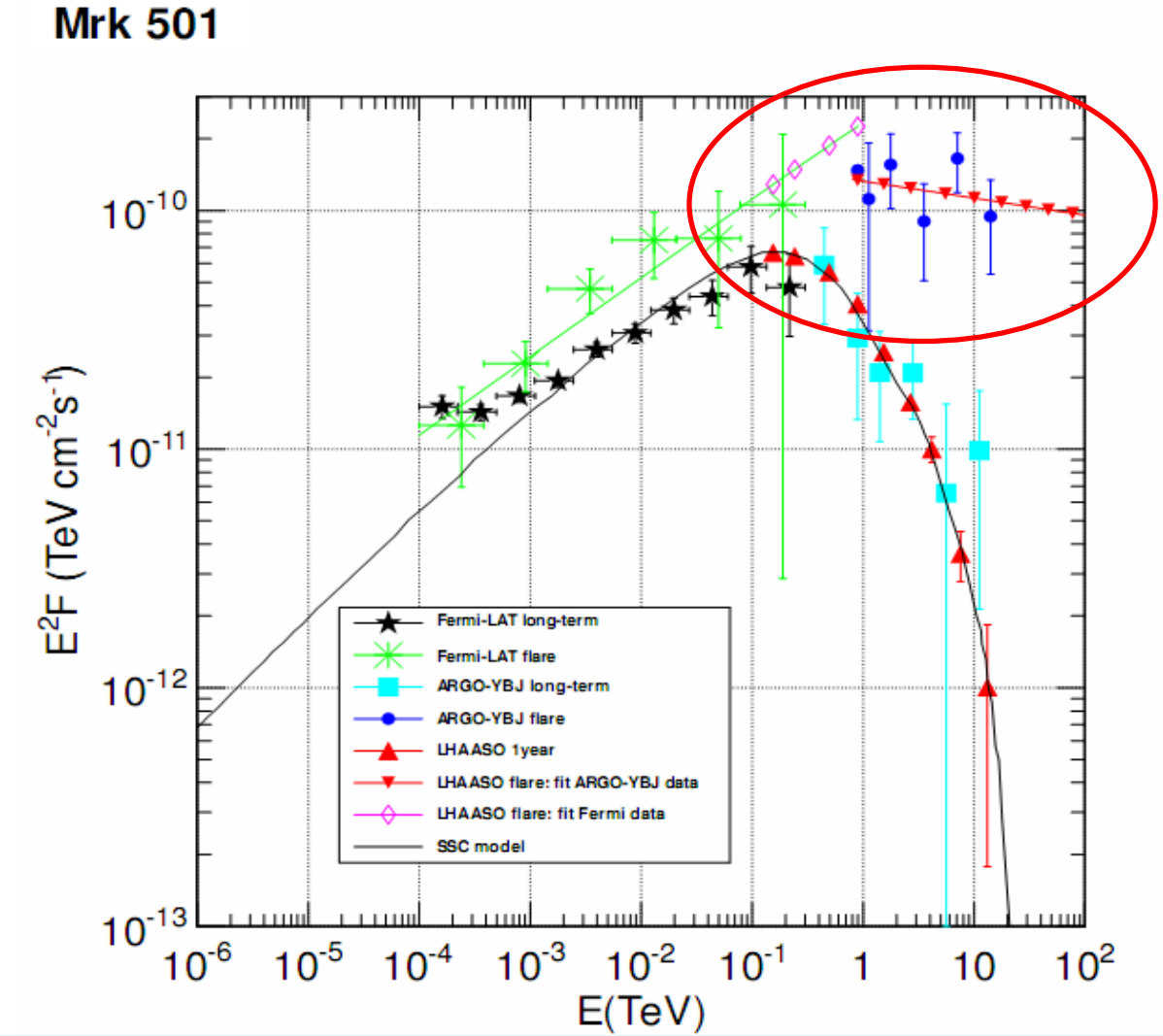
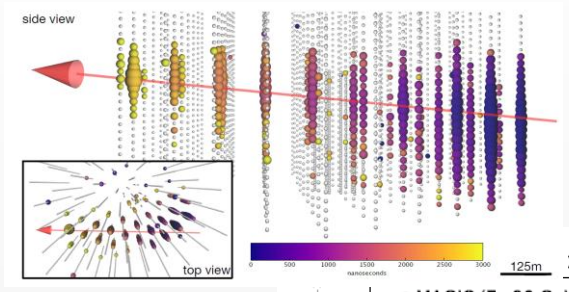
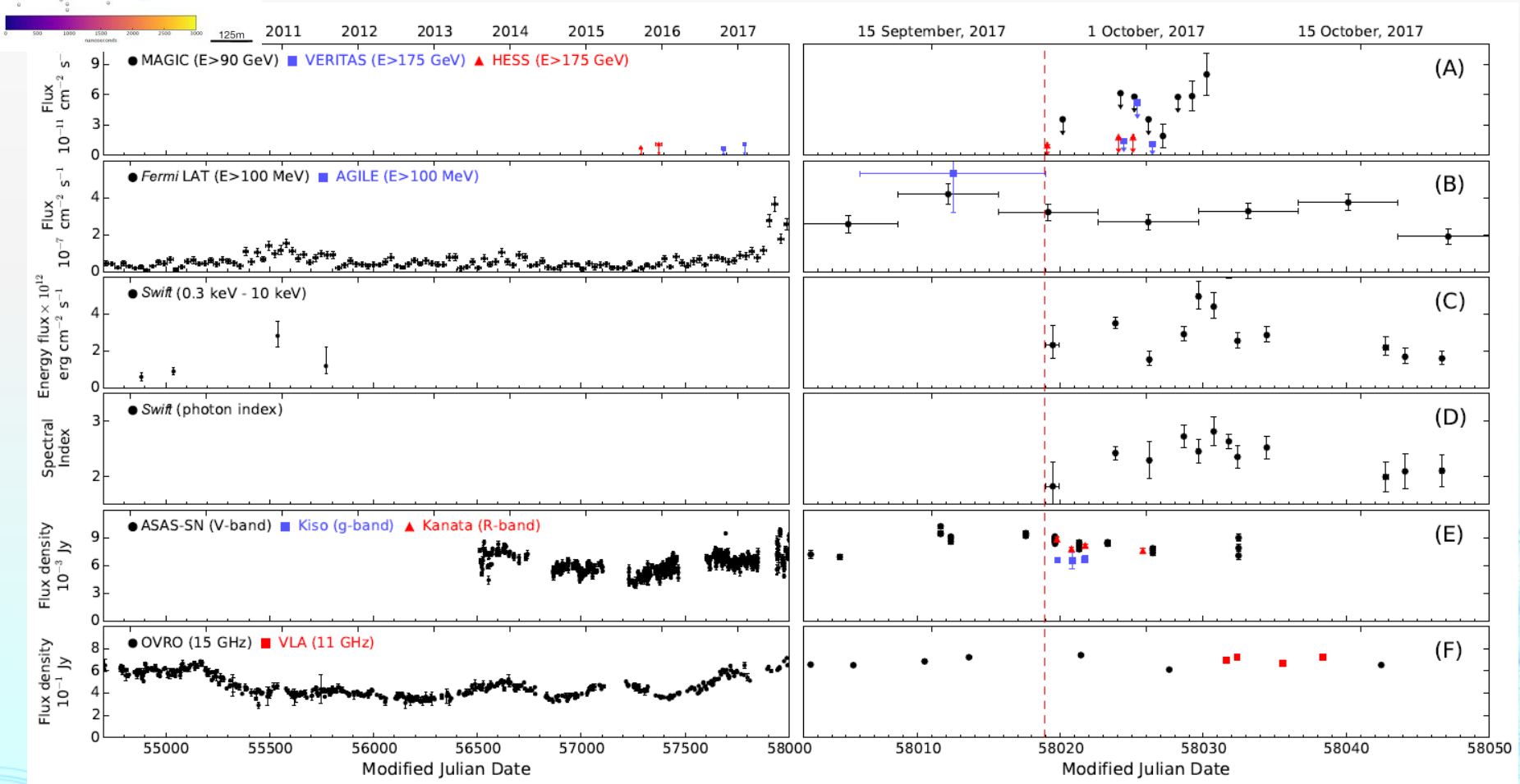


Figure 16: Expectation of the LHAASO project on Mrk501 [57], compared with the measurement of Fermi-LAT, ARGO-YBJ[27].

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

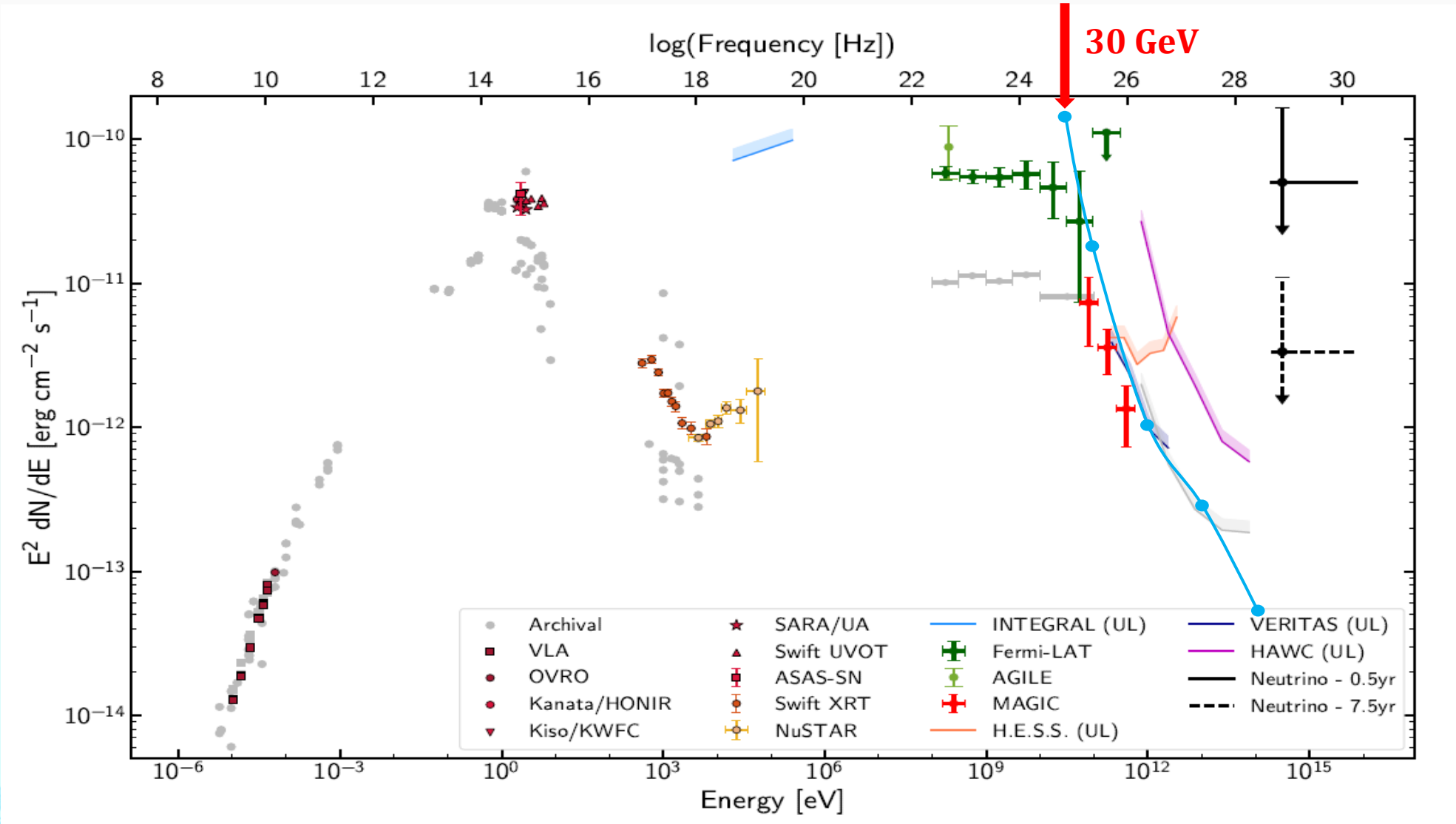


arXiv:1807.08816
Science 361, eaat1378 (2018)



IC-170922A/TXS 0506+056 : SED

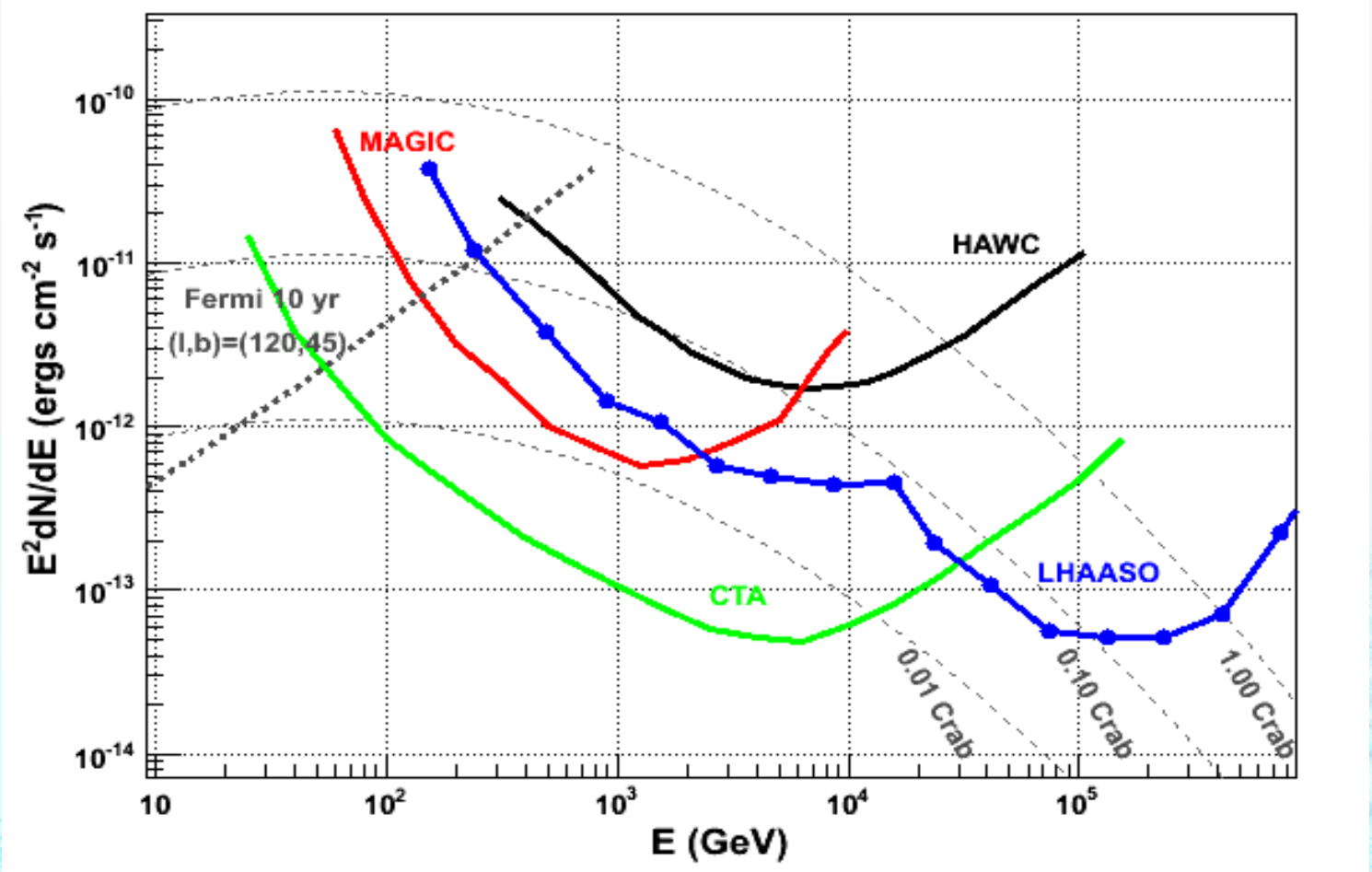
arXiv:1807.08816
Science 361, eaat1378 (2018)



Sensitivity to gamma ray sources

- **Differential sensitivity:**

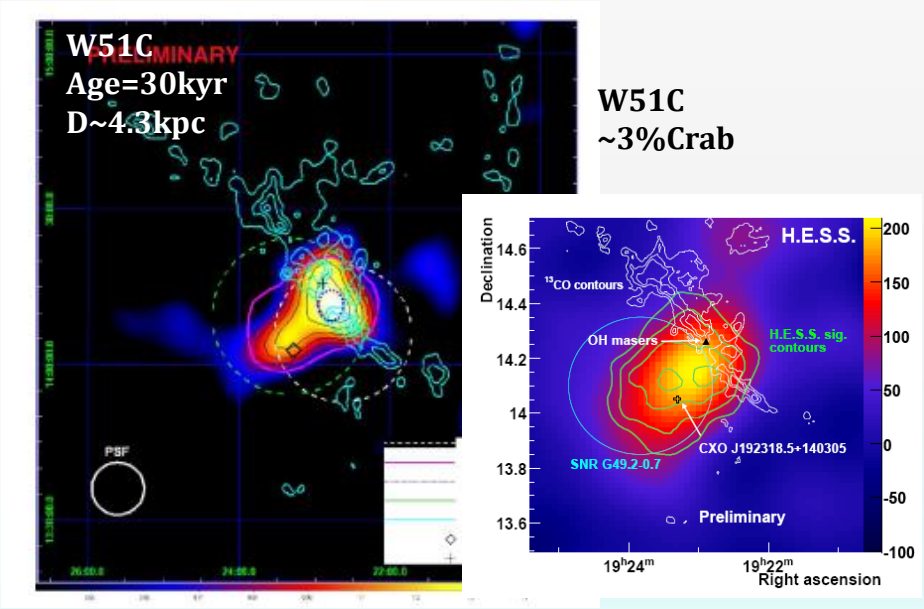
2% crab in TeV range & 1 crab at 500TeV



Central scientific target of LHAASO : Identifying Galactic Cosmic Ray Origins

SNRs: for example W51C:

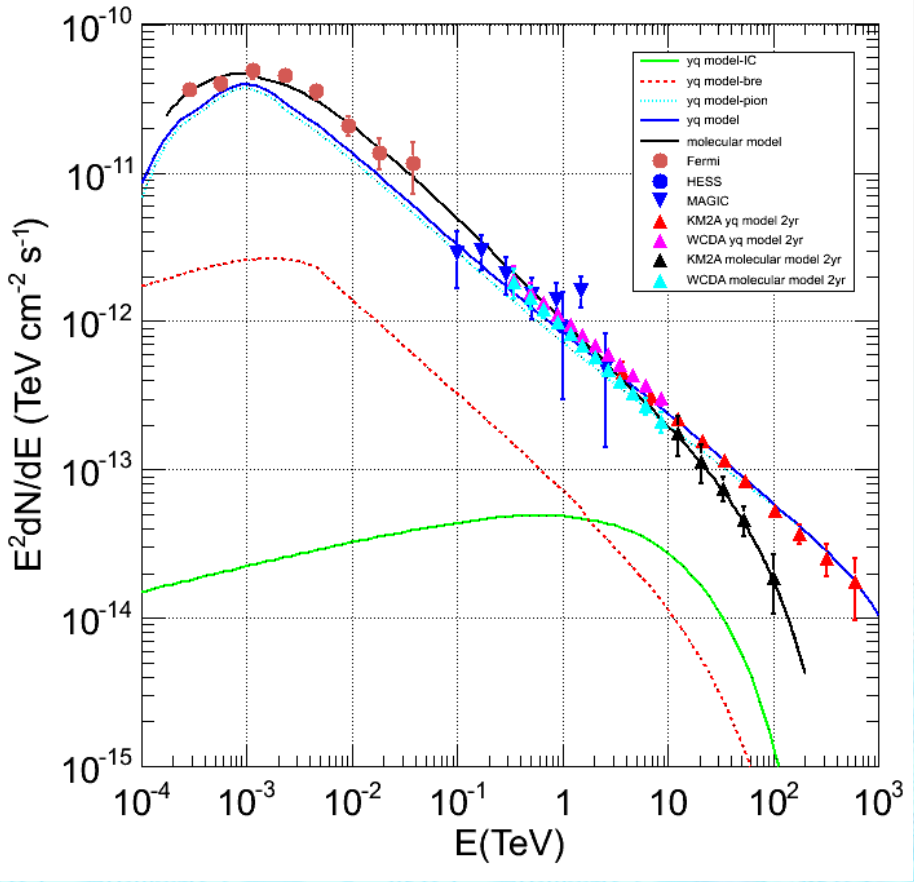
a "mixed-morphology" type of SNR, shocked atomic and molecular gases show the interaction between shock and molecular.



W51C
~3%Crab

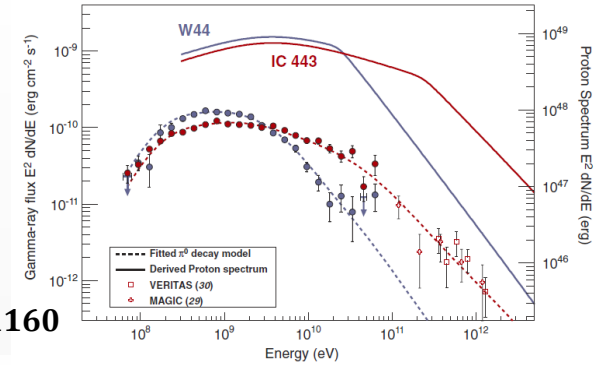
reference~ APJ, 761:133(2012) && Mon.Not.R.Astron.Soc, 421,935-942(2012)

GeV&TeV~ dominated by π^0 decay



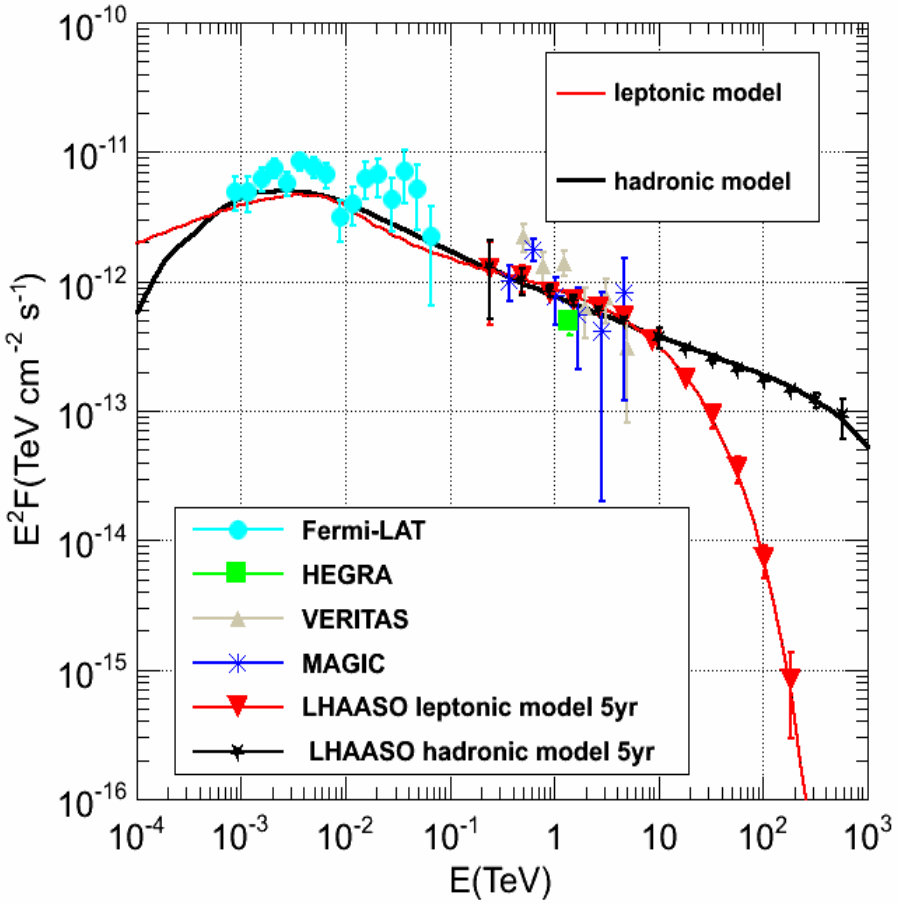
Hadronic vs. Leptonic

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

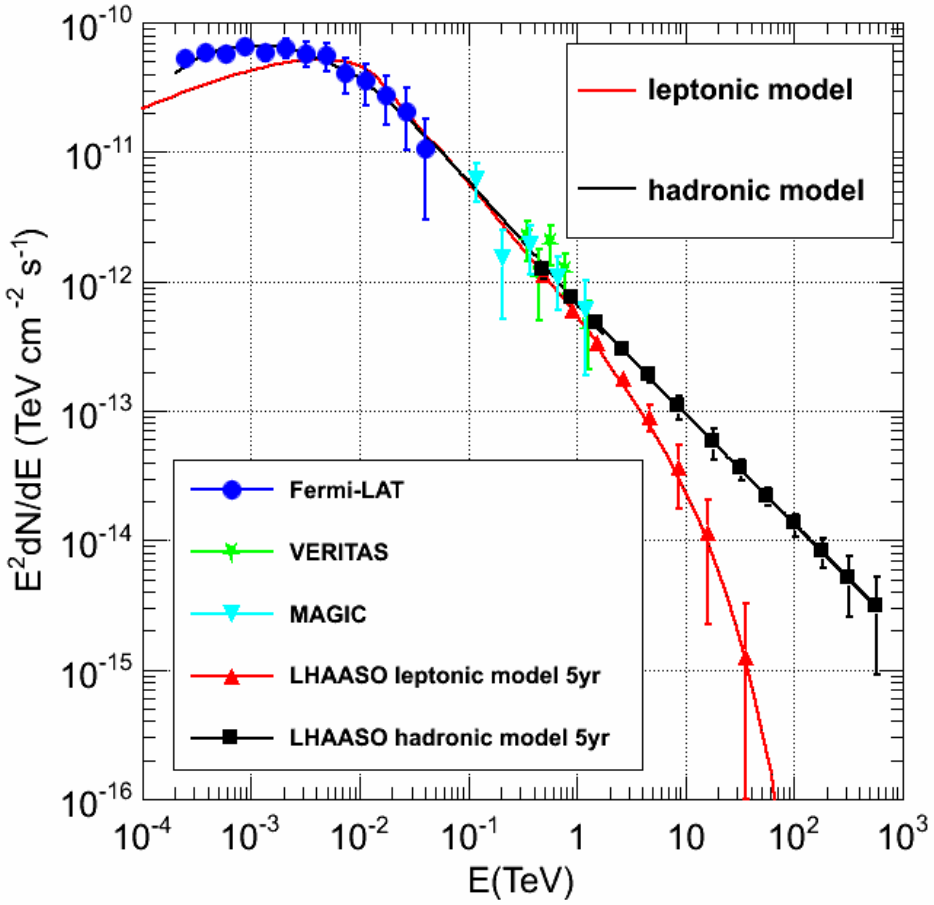


10.1126/science.1231160

Cassiopeia A Historical SNRs

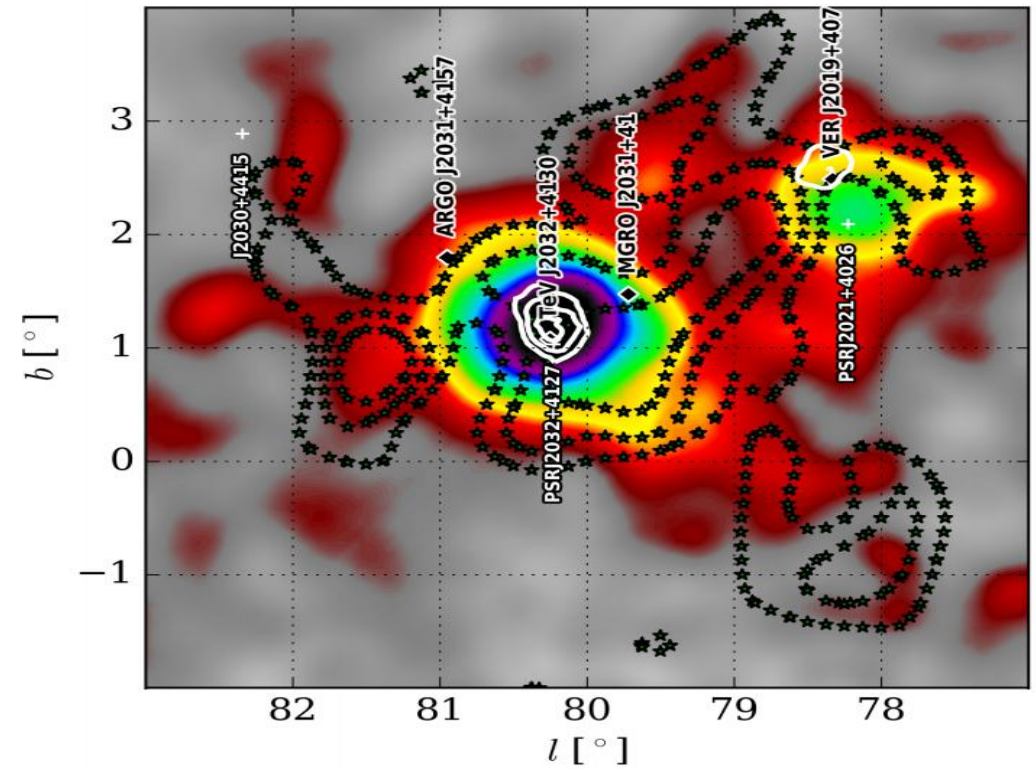


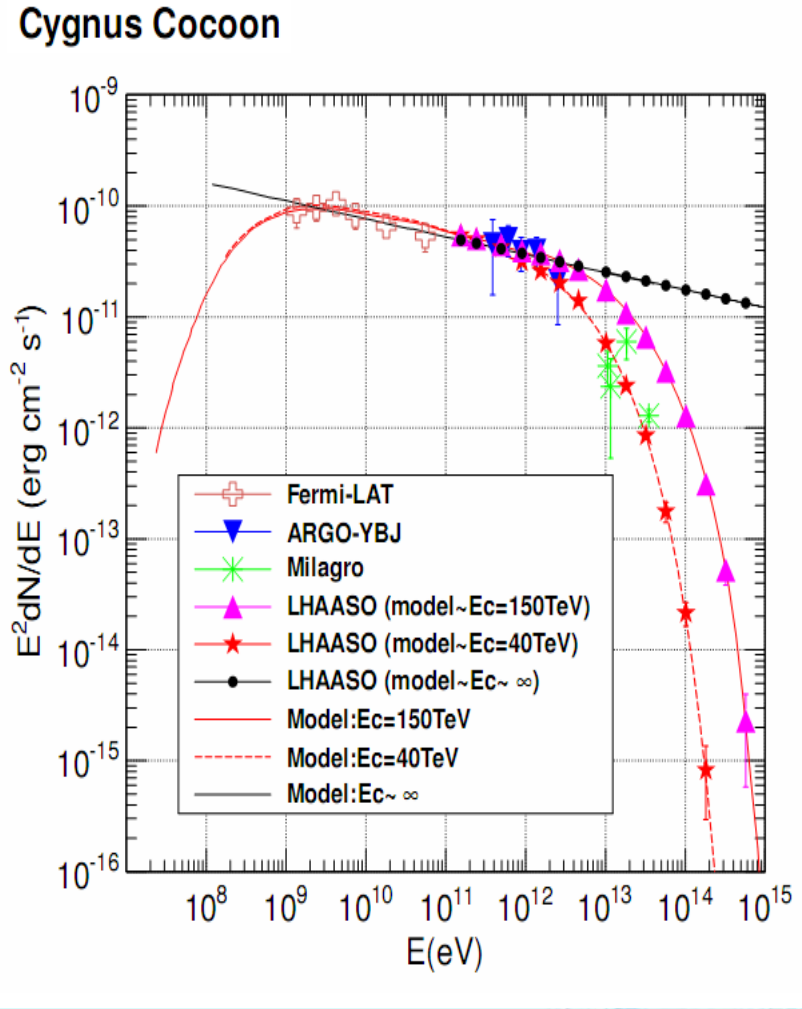
IC443 interacting with molecular clouds



Broad Objects: Cygnus region

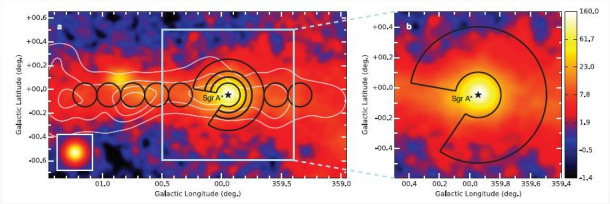
The 1st VHE supper-bubble by ARGO-YBJ





Overlapping sources？Morphological study？Multi-wavelength？

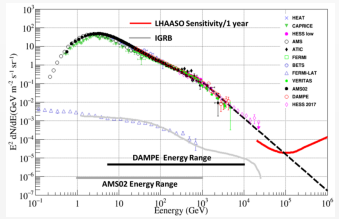
Many Topics in Astroparticle Physics



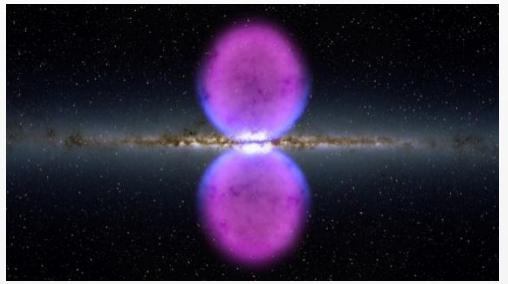
See S.Z. Chen's talk

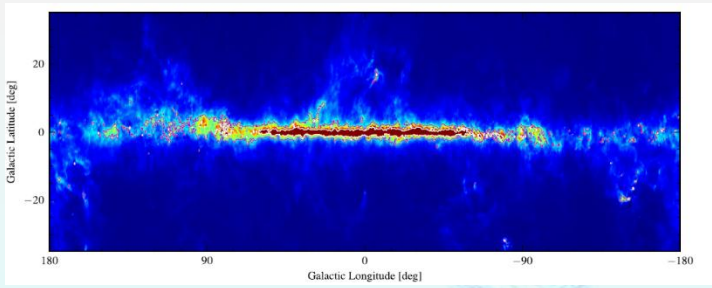
Galactic Center

e+e- spectrum

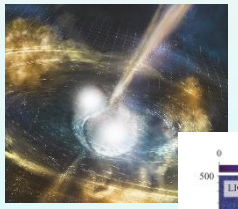


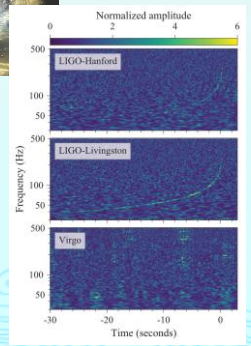
FERMI Bobble





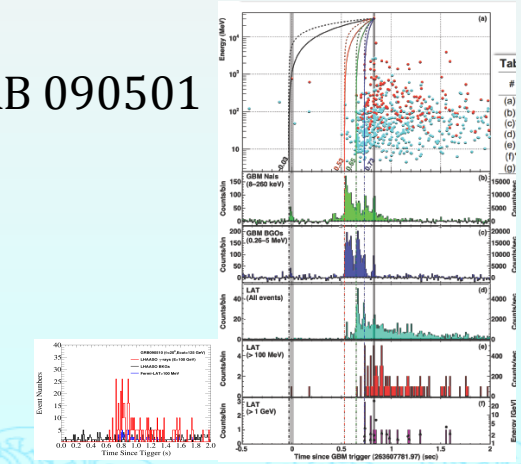
GW170817





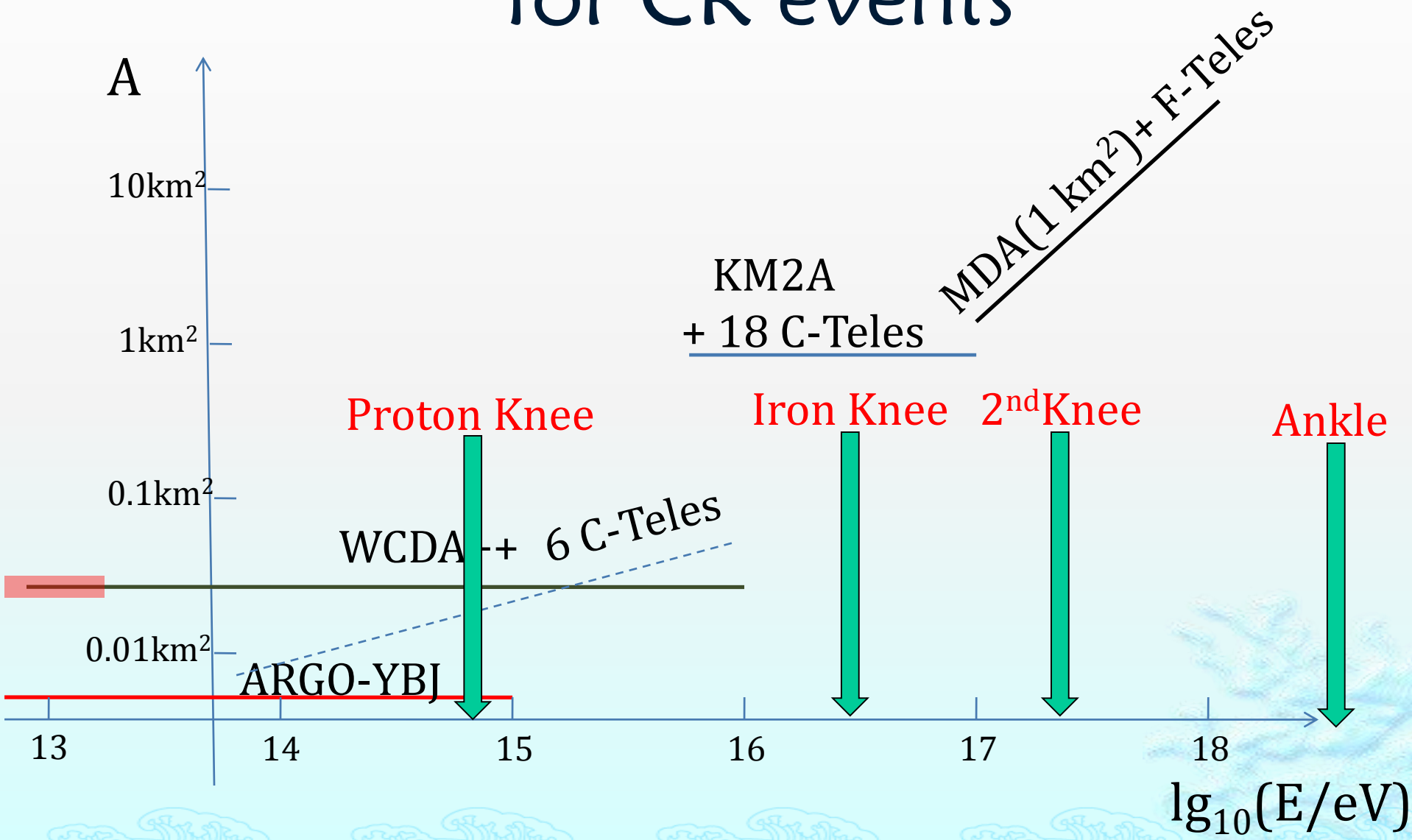
Diffuse γ Background

GRB 090501

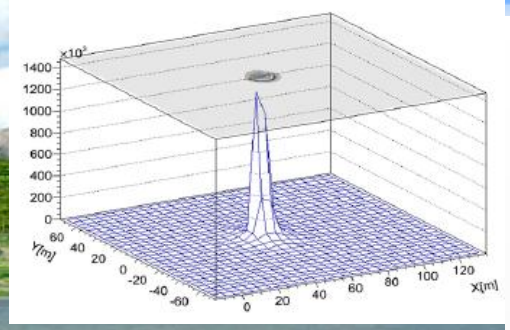


Aperture of LHAASO for CR events

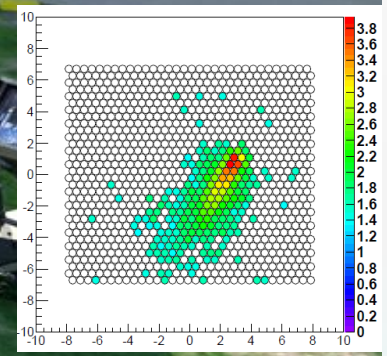
See L.L. Ma's talk

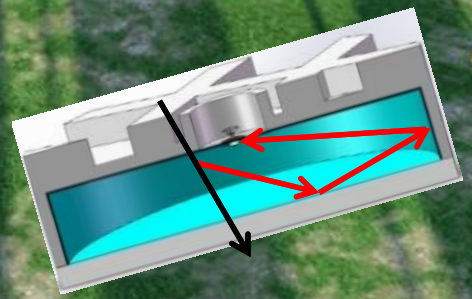


Prospects of P, He knees
from 100TeV to 10PeV



- **WCDA**
  - Core reconstruction: 3m
  - Arrival direction reconstruction: 0.3°
  - Energy flux near the core
- **WFCTA**
  - SIZE (total PE in image)
  - Width, Length
  - Distance between arrival directions to the image center
- **KM2A**
  - Total Muon number

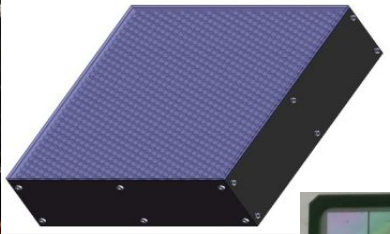
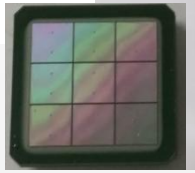


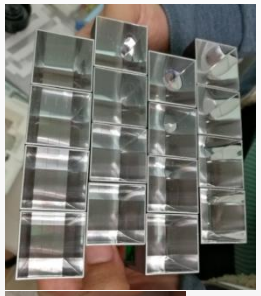
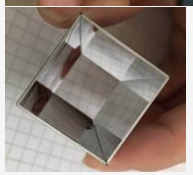


Wide FoV C-Telescope Array

Fully portable telescopes allow reconfiguring the array for CR detection in 3 energy ranges



- Movable telescope housing
- Rotating from 0° to 90° in elevation

- 5 m^2 spherical aluminized mirror
- Reflectivity of 85%

- 32×32 SiPM array
- FoV of 16°×16°
- 0.5° pixel
- 1-4000 PE nonlinearity less than 5%

- 4×4 20μm SiPM sub-cluster
- 50 MHz FADC
- Temperature-compensation power supply
- T-stamp from WR network

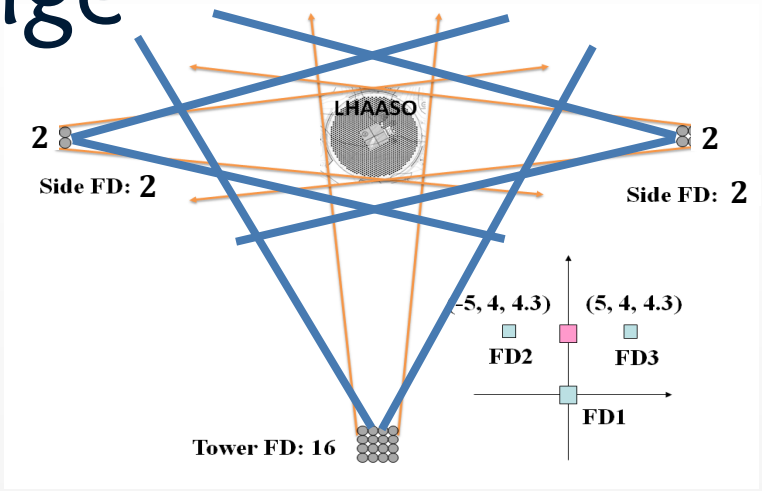
- Aluminized Winston cones
- Cut-off angle 30° with efficiency of 93%
- Filter transmission of 92% in 310－550 nm

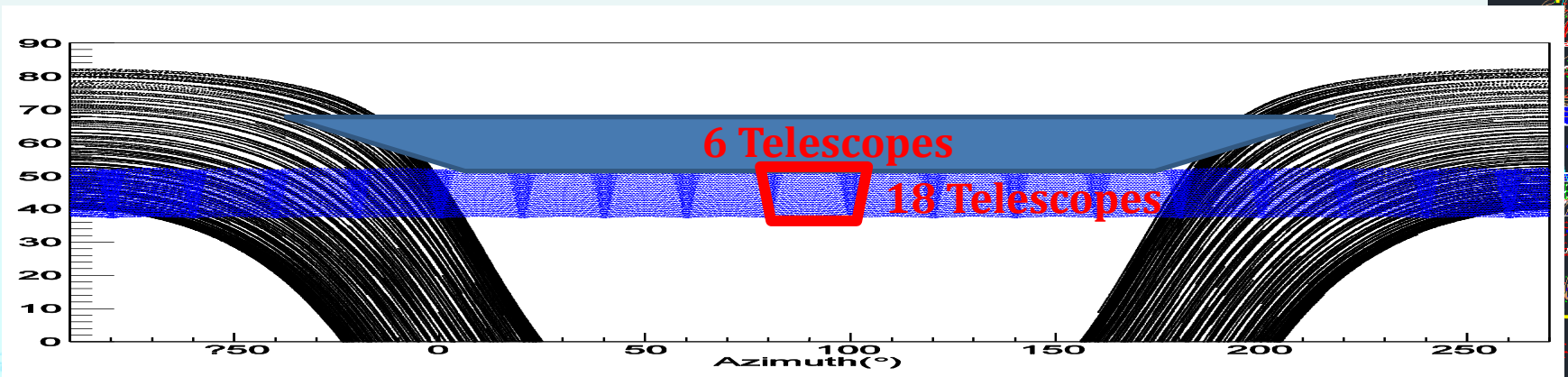
Elevation of 60 toward North
with full-moon duty cycle >30% above 100 TeV

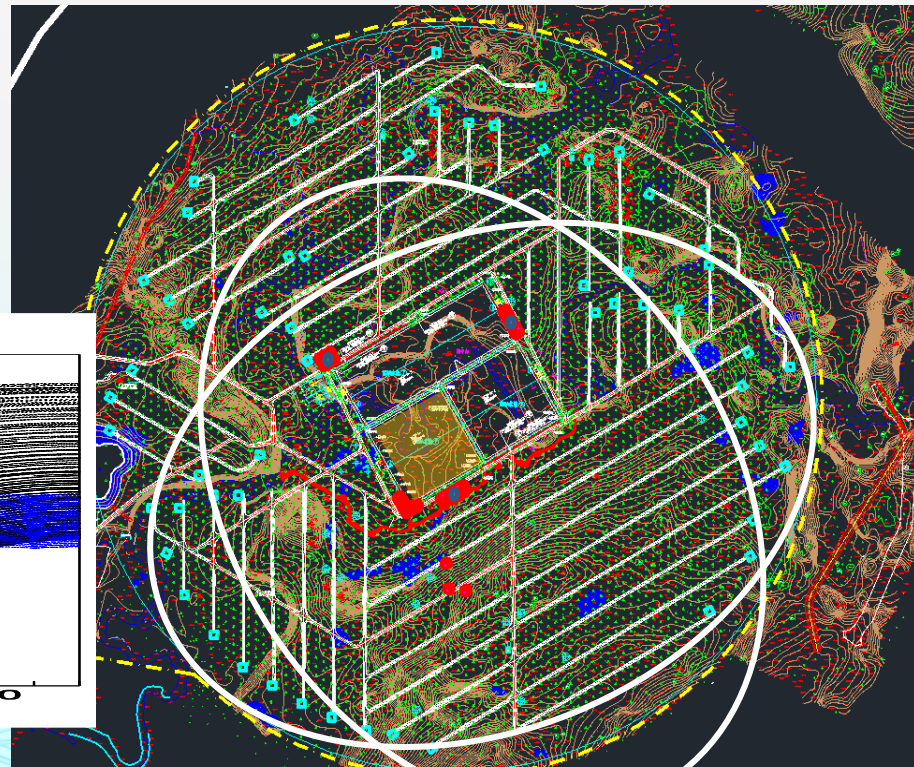
See S.S. Zhang's talk

Layout for Three Energy Range

- **0.1-10 PeV in 2019**
  - pure proton and pure Helium spectra
  - 6 C-Tel's (60 in elevation) + 1st pool
- **1- 100 PeV in 2021**
  - Pure iron or heavy nuclei (MgAlSi+Fe) spectra
  - 18 C-Tel's (45 in elevation)+ Scin.+ MD array
- **>100 PeV in 2023**
  - 2nd knee
  - 20 F-tel's + MD array

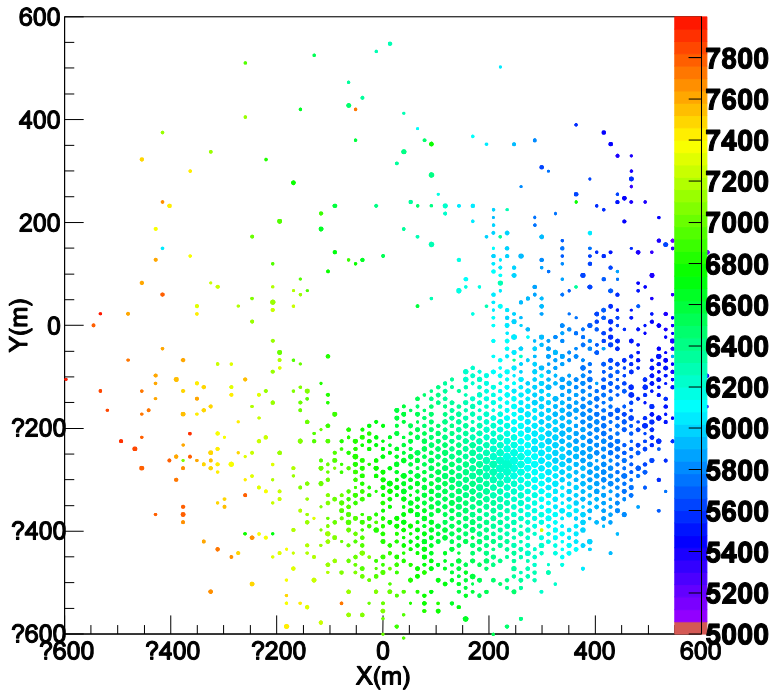


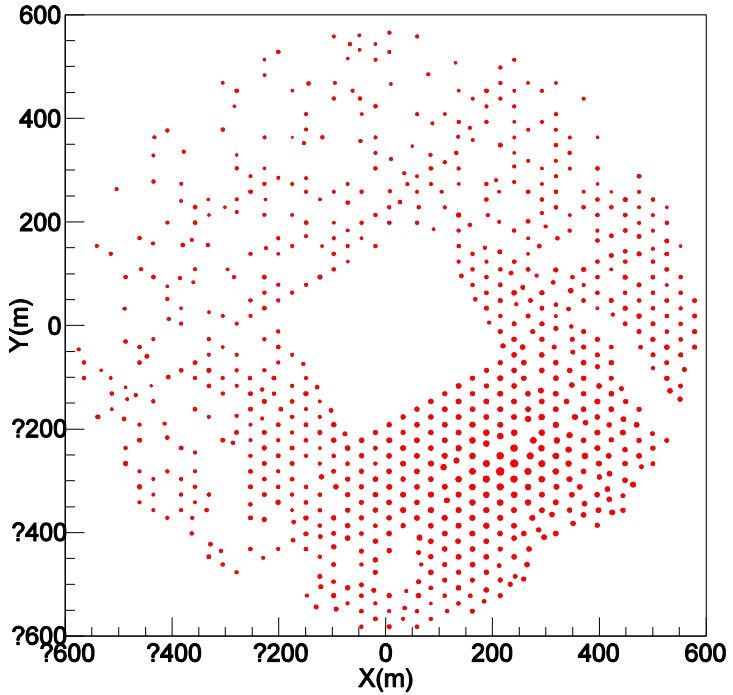


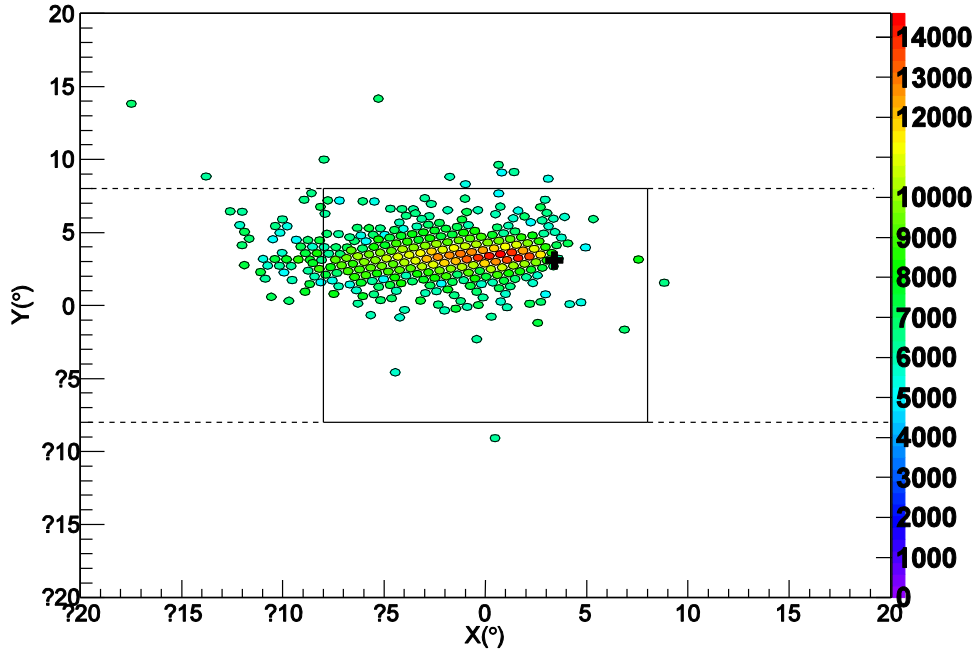


An event at 21 PeV

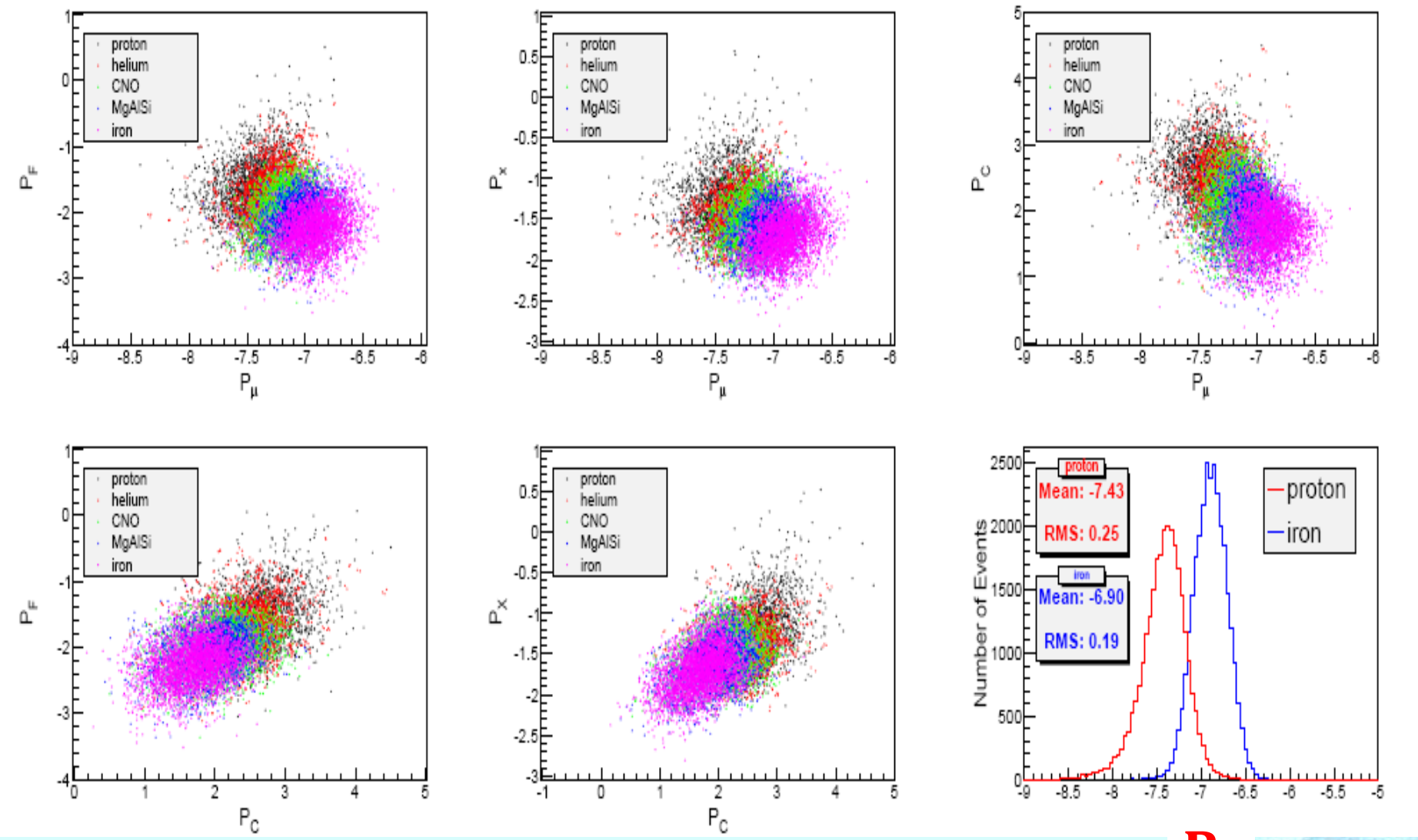
Zenith angle : 45°
Rp: 200 m







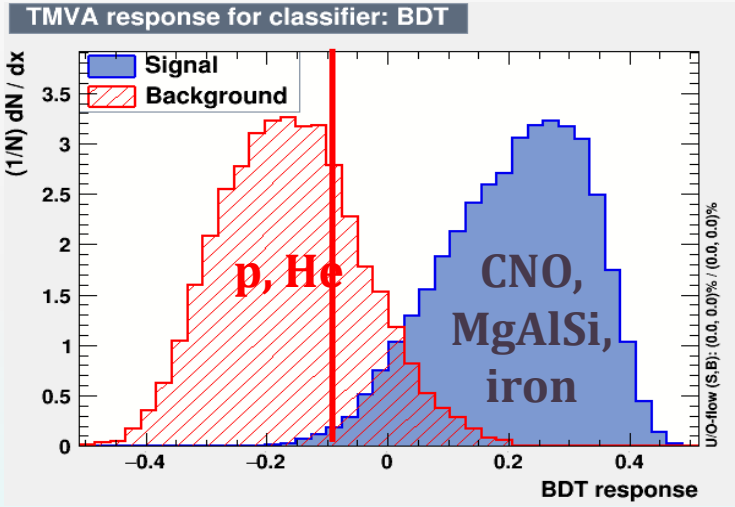
Multi-parameter analysis



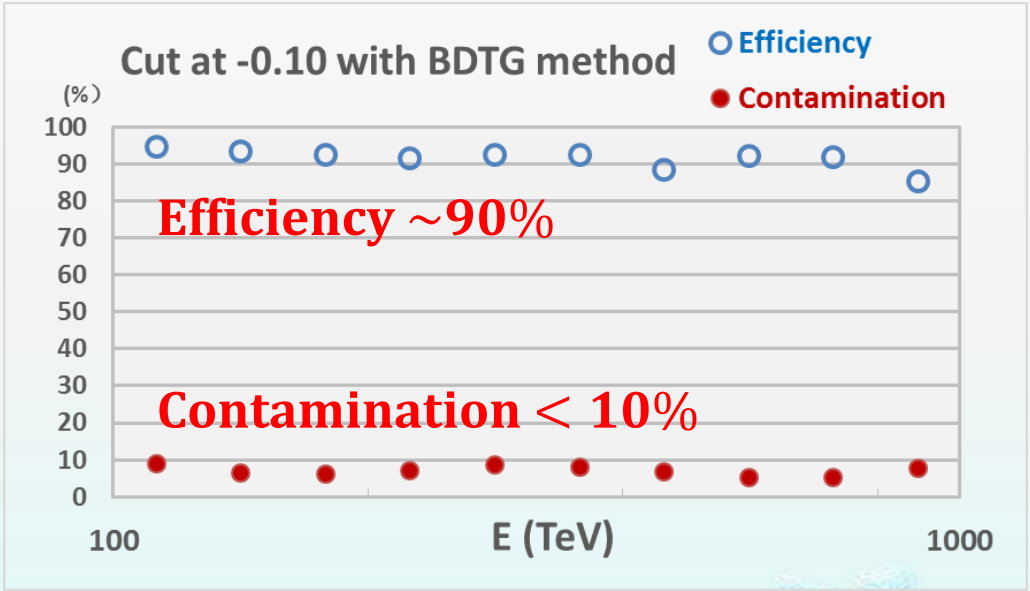
P_μ

MVA method for p,He / heavy separation

With the Multi-Variate Analysis methods (e.g. neural networks and boosted decision trees), good separations for p/iron and p+He/heavy nuclides identification can be obtained.

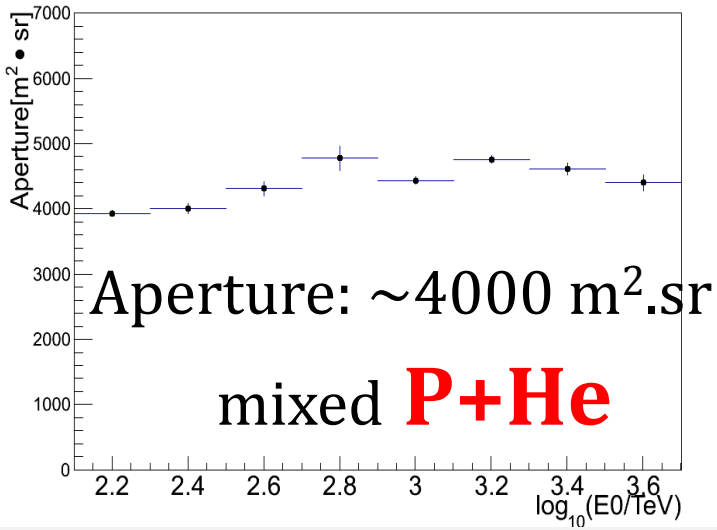


Separation of light (p+He) and heavy nuclei by the BDT (Boost Decision Trees) method.



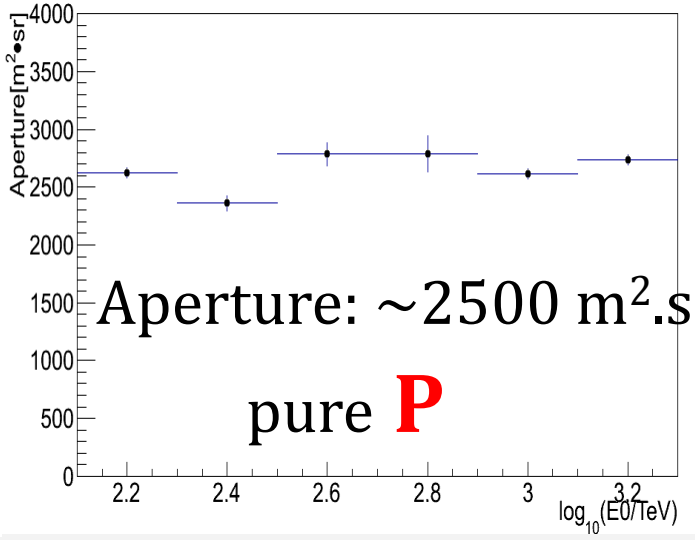
The contamination is calculated based on the Hörandel model.

Apertures and E-resolution



Aperture: ~4000 m^2.sr

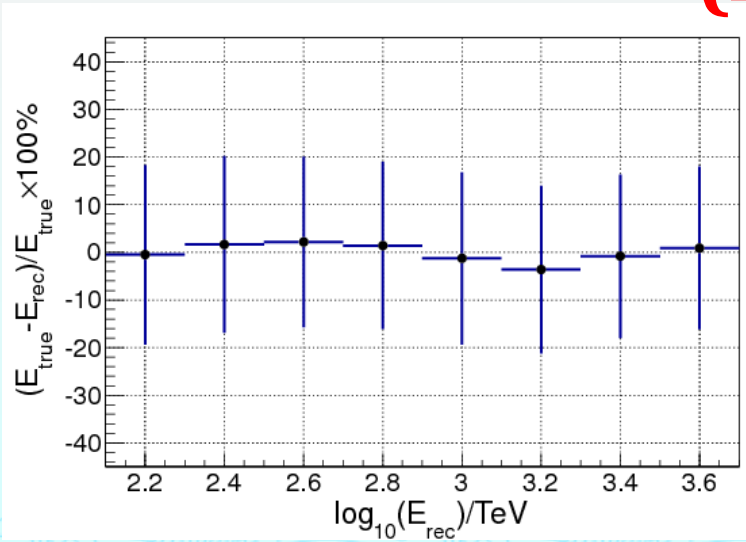
mixed **P+He**

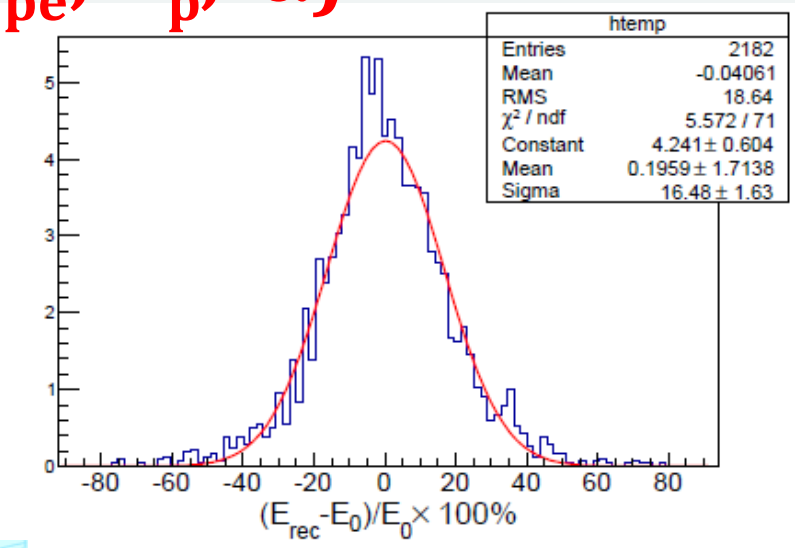


Aperture: ~2500 m^2.sr

pure **P**

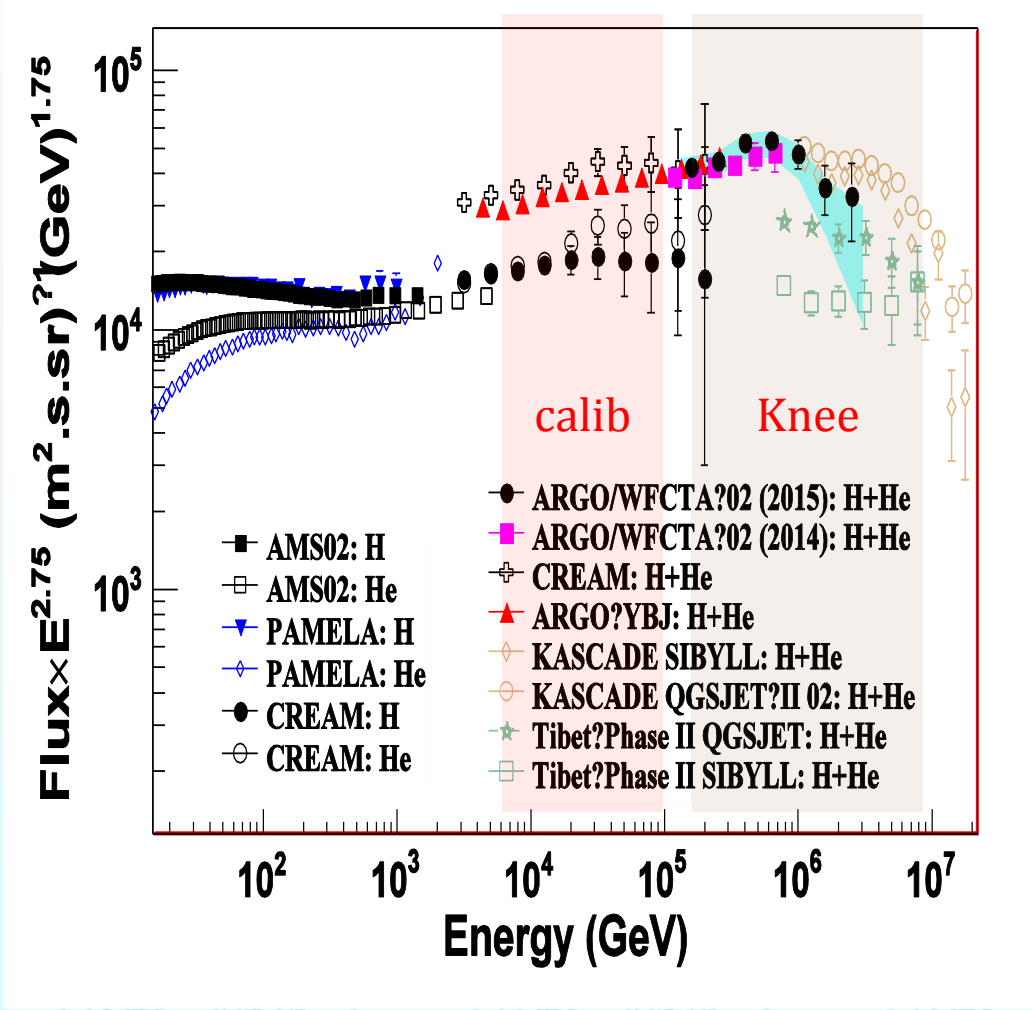
$E = E(\Sigma N_{pe}; R_p, \alpha)$

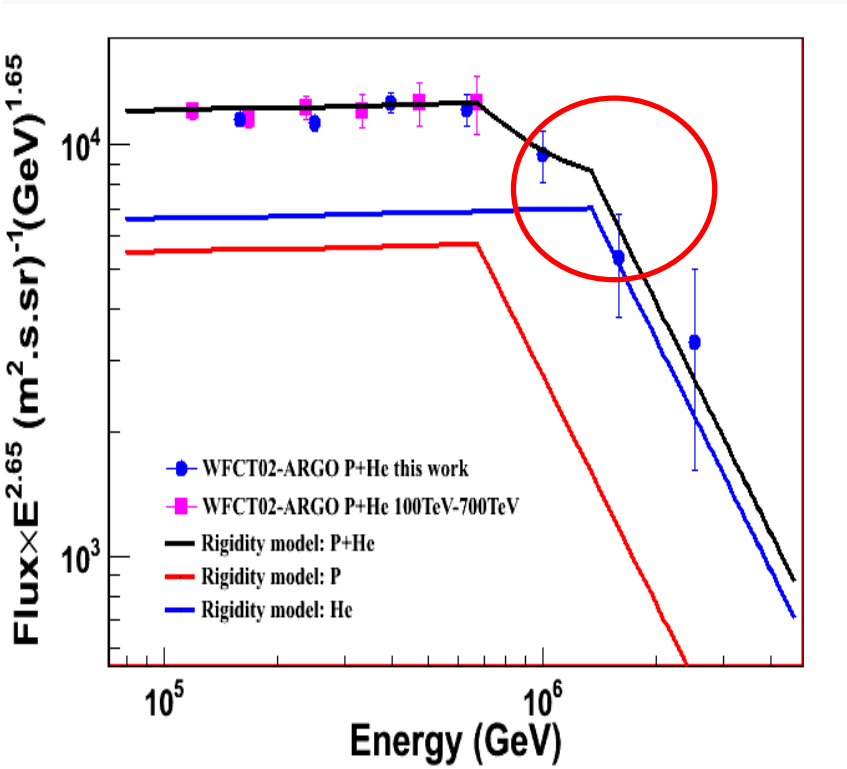




Cosmic Ray Physics: Charged Nuclei knees of spectra of individual species

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

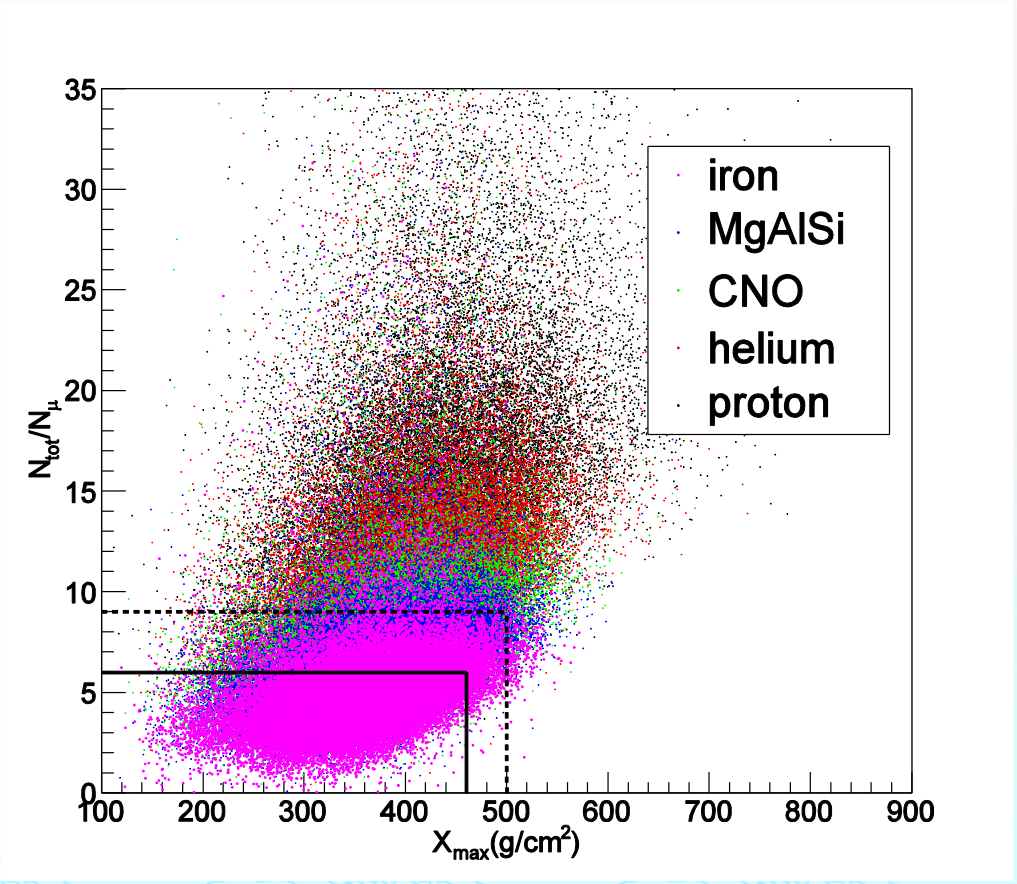


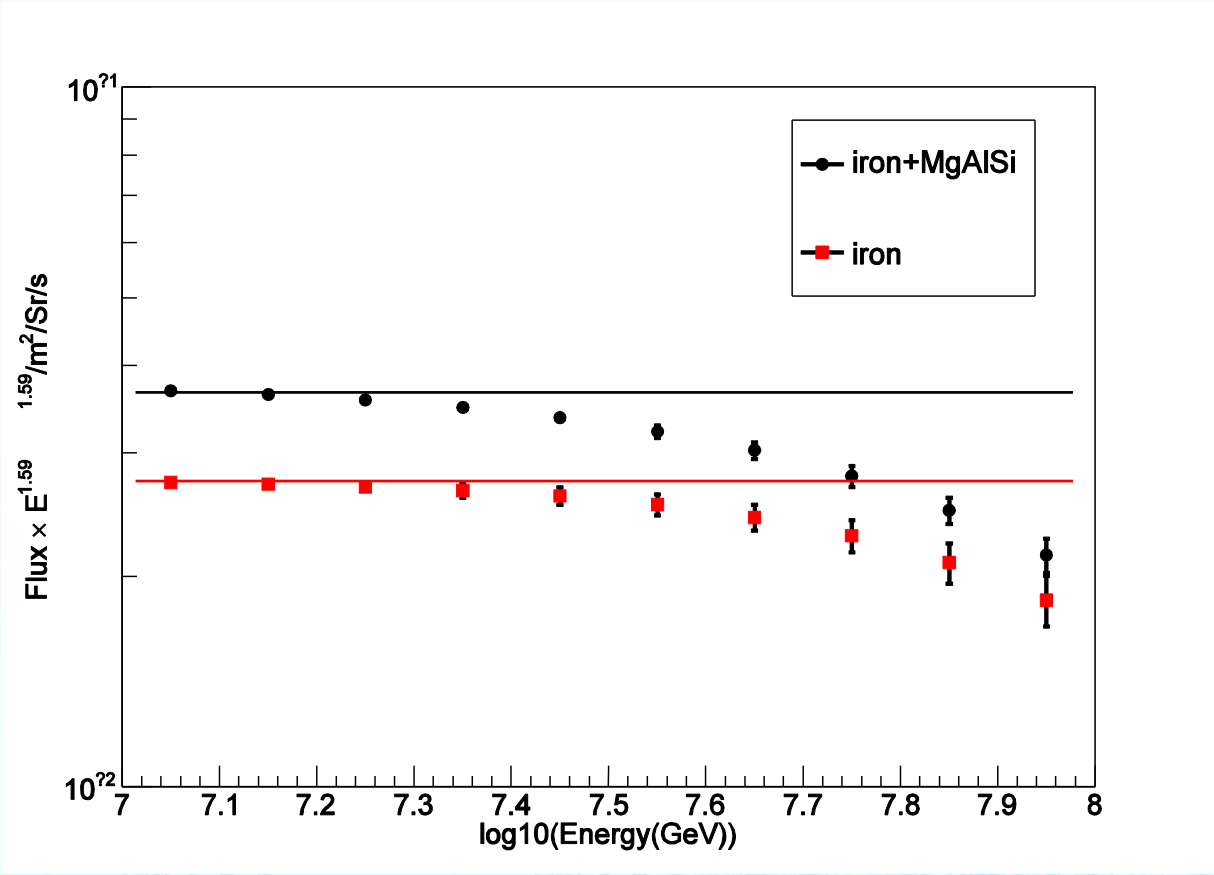


Proton spectrum with Rigidity model and H:He=1:1.2

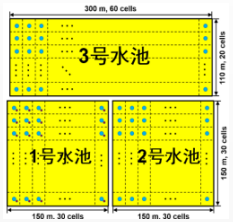
Iron knee above 10 PeV

- Two variables: H_{max} (or vertical X_{max}) and μ-content





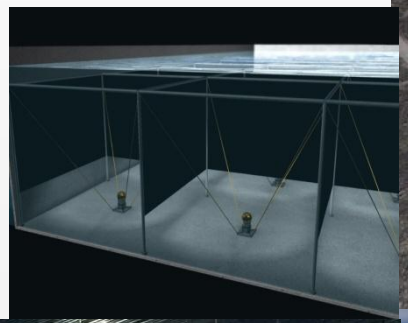
Construction

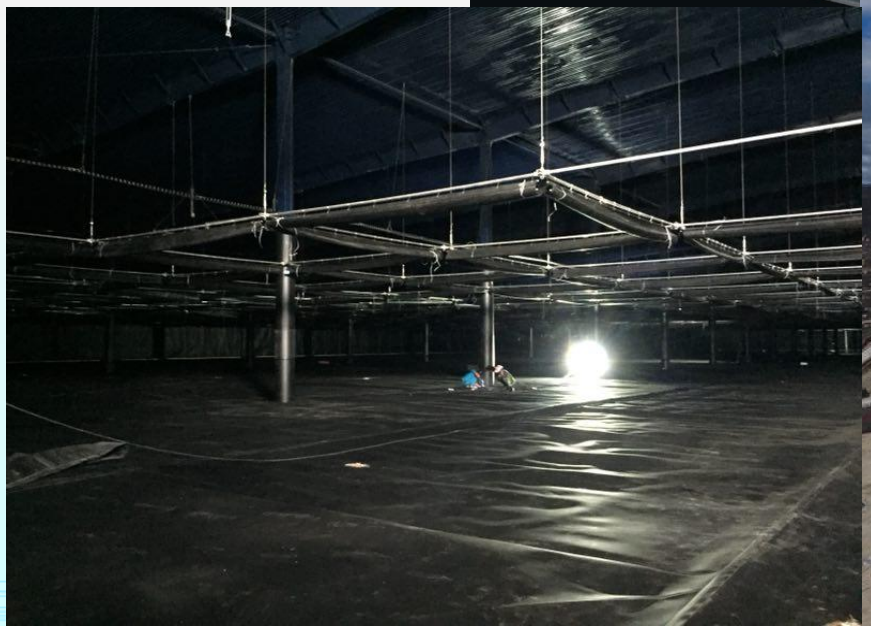


- #1 pool（150X150 m^2）is built
- 2018/04, #2 & #3 pools are started simultaneously

1st water pool

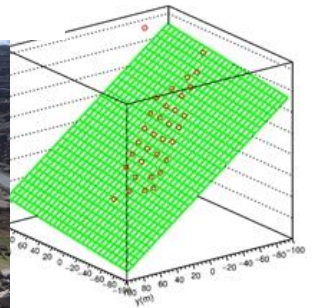
Installation Inside the pond

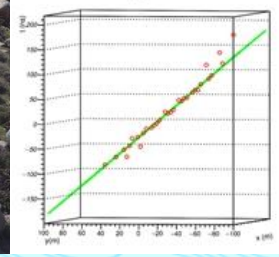


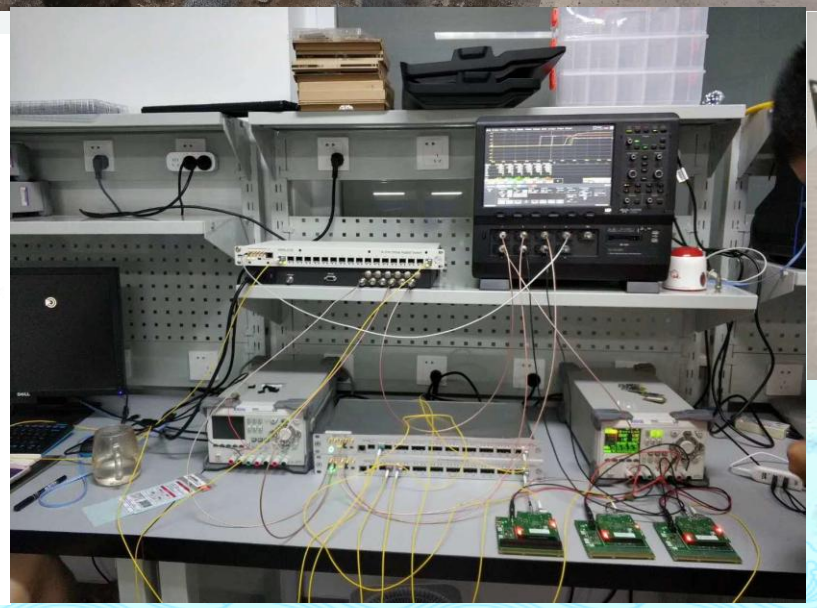


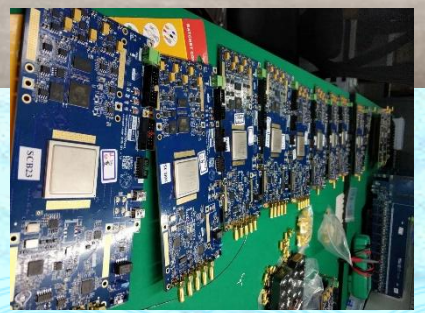
Construction: EDs and WR Switches

- 2018/02/04, first 33 scintillator detectors deployed.
  The 1st LHAASO event









Construction of LHAASO-1/4

A few muon detectors are covered

1st muon detector

➢ Liner

LHAASO
高海拔宇宙线观测站

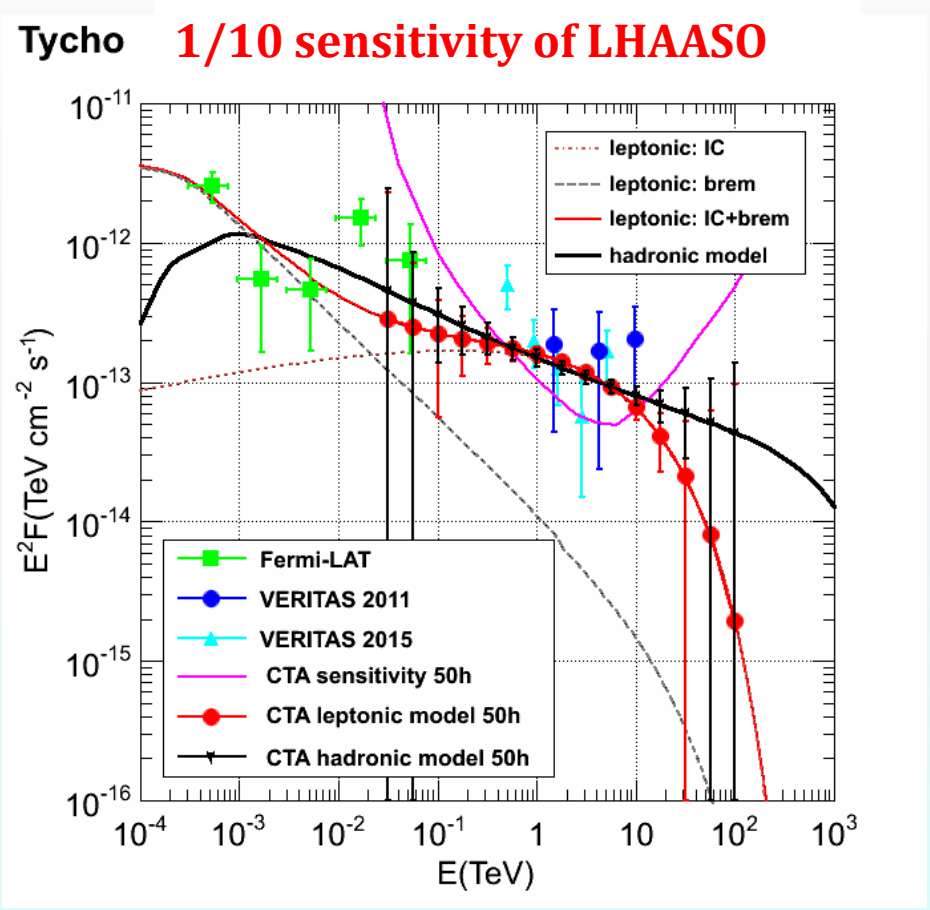
Water purification & recycling system for 0.45M tons

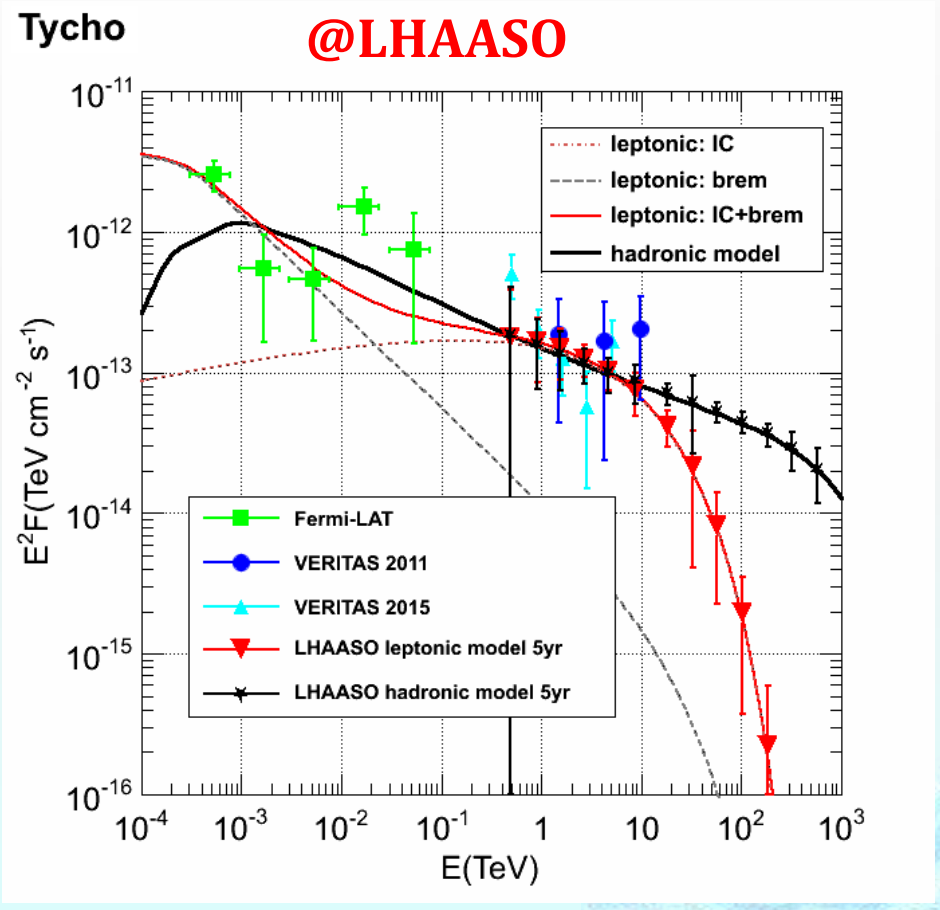
Summary

- LHAASO observatory for gamma ray astronomy
  - Unique on 10 TeV gamma ray monitoring
  - Window for evidences of hadronic origin of cosmic rays
- Detector construction started June 2017 and infrastructure May 2016. ¼ of the array will be turned on for scientific operation next spring and the construction will be finished in 2021
- 20” PMTs in #2-3 pond will enhance the low energy sensitivity for extragalactic phenomena
- LHAASO has been funded mainly by China with 20+ institutions joining the collaboration

GCR signature @ the highest energies

A LHAASO-like sensitivity is mandatory

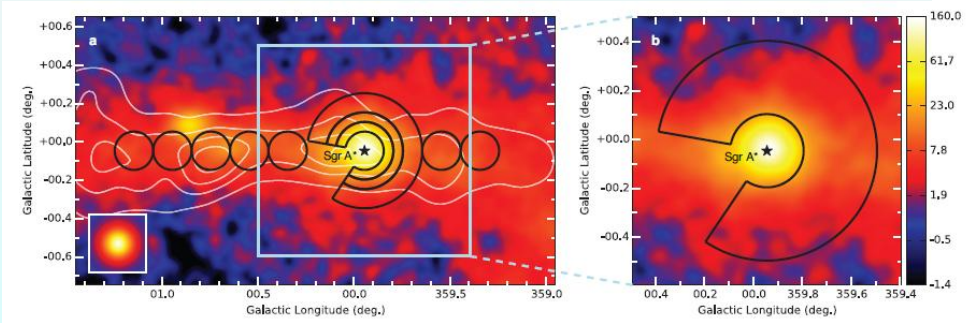


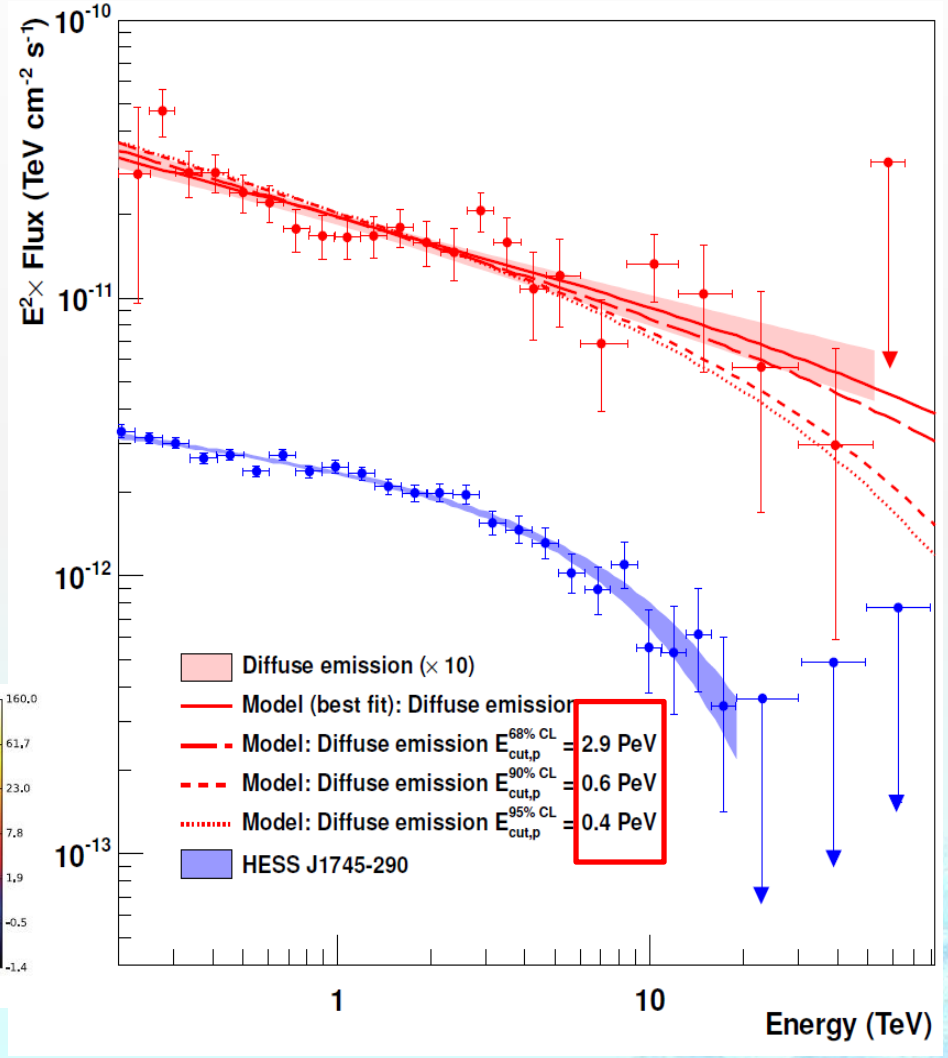


A Pevatron ?

Nature 531 (2016) 476

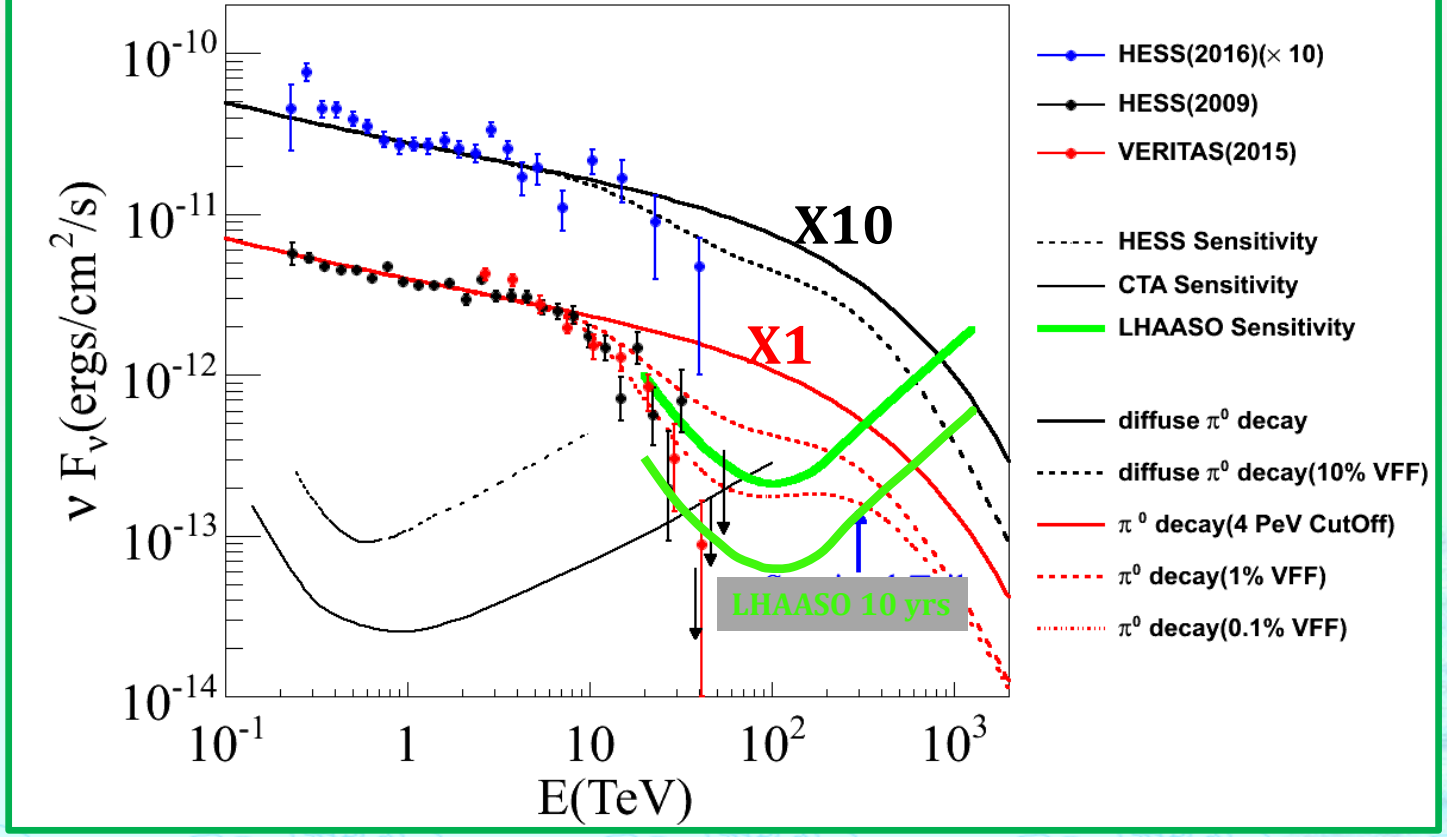
- At G.C. very dense gas density meaning strong absorption
- Models show that the p-spectrum should have a cut-off energy higher than 0.4 PeV





What LHAASO Can Do at G.C.?

LHAASO is not at the right latitude. However, a observation at 100 TeV could be very crucial for the radiation mechanism and acceleration models.



Y. Guo et al., astro-ph/1604.08301

LHAASO on AGNs

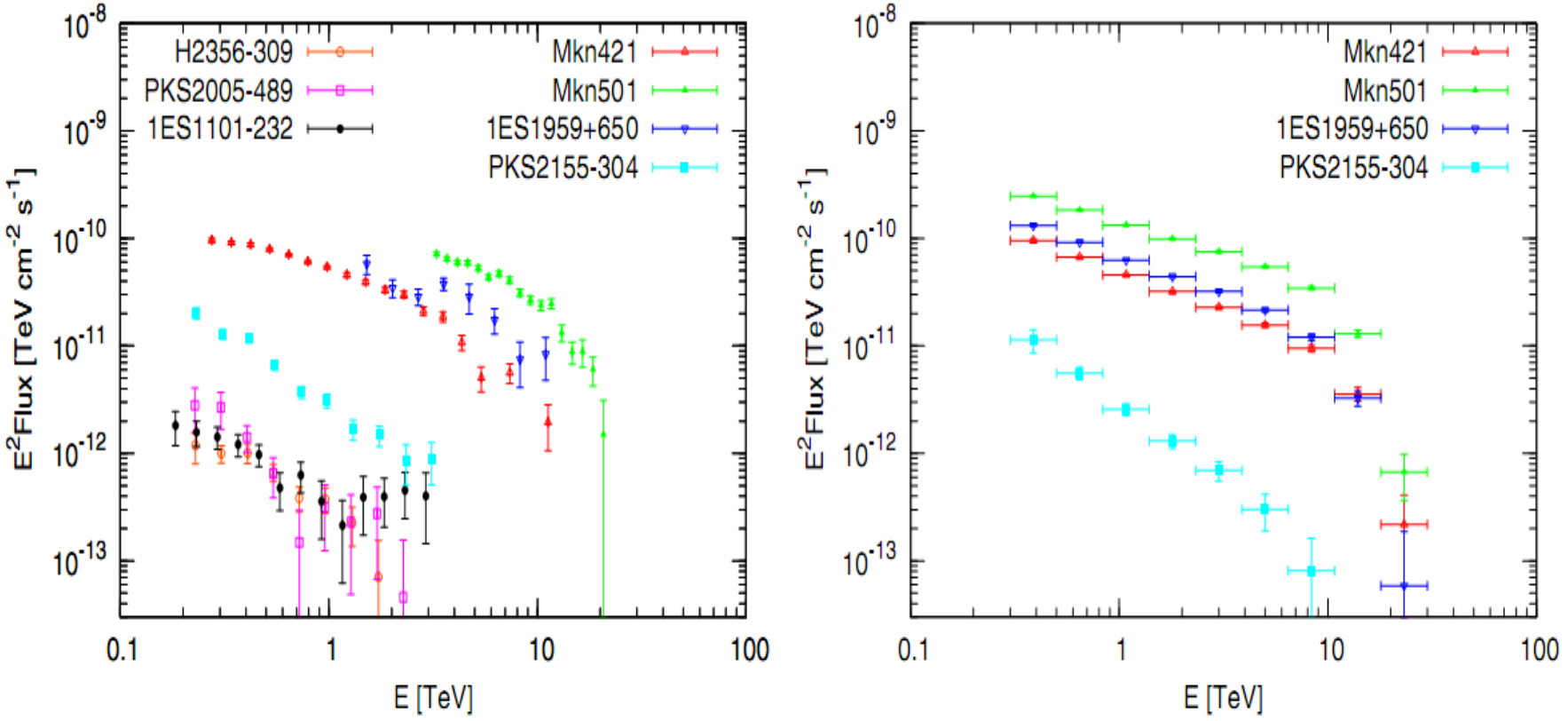
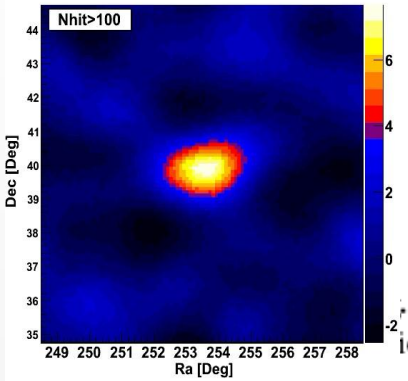
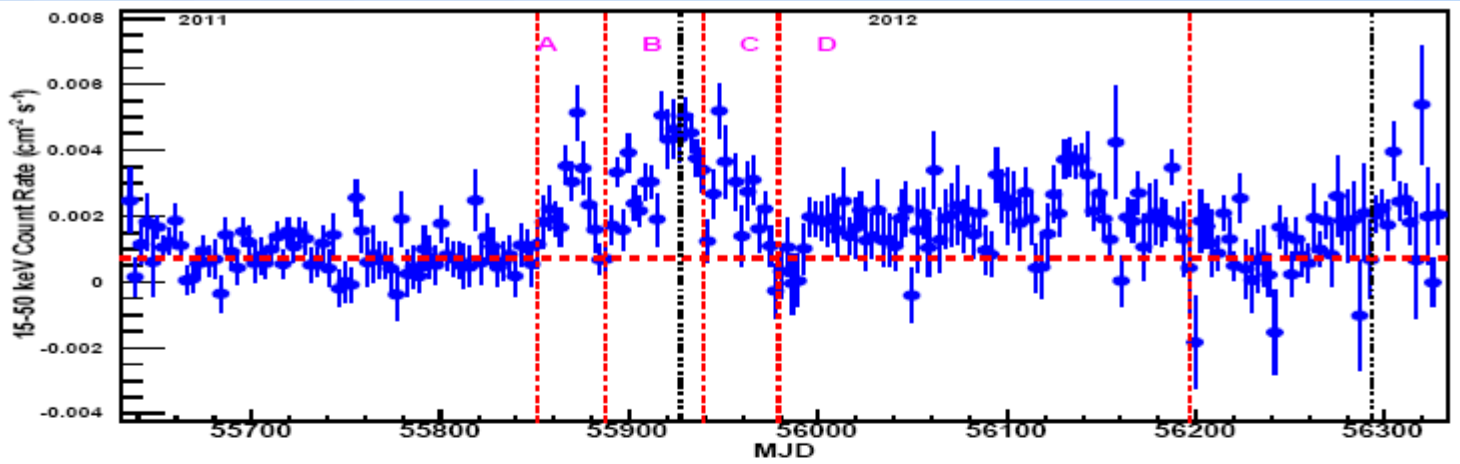


Fig. 6. Left panel: Energy spectra of 7 AGNs observed by past or current IACTs. Right panel: Simulated energy spectra of 4 of the 7 AGNs by LHAASO–WCDA.





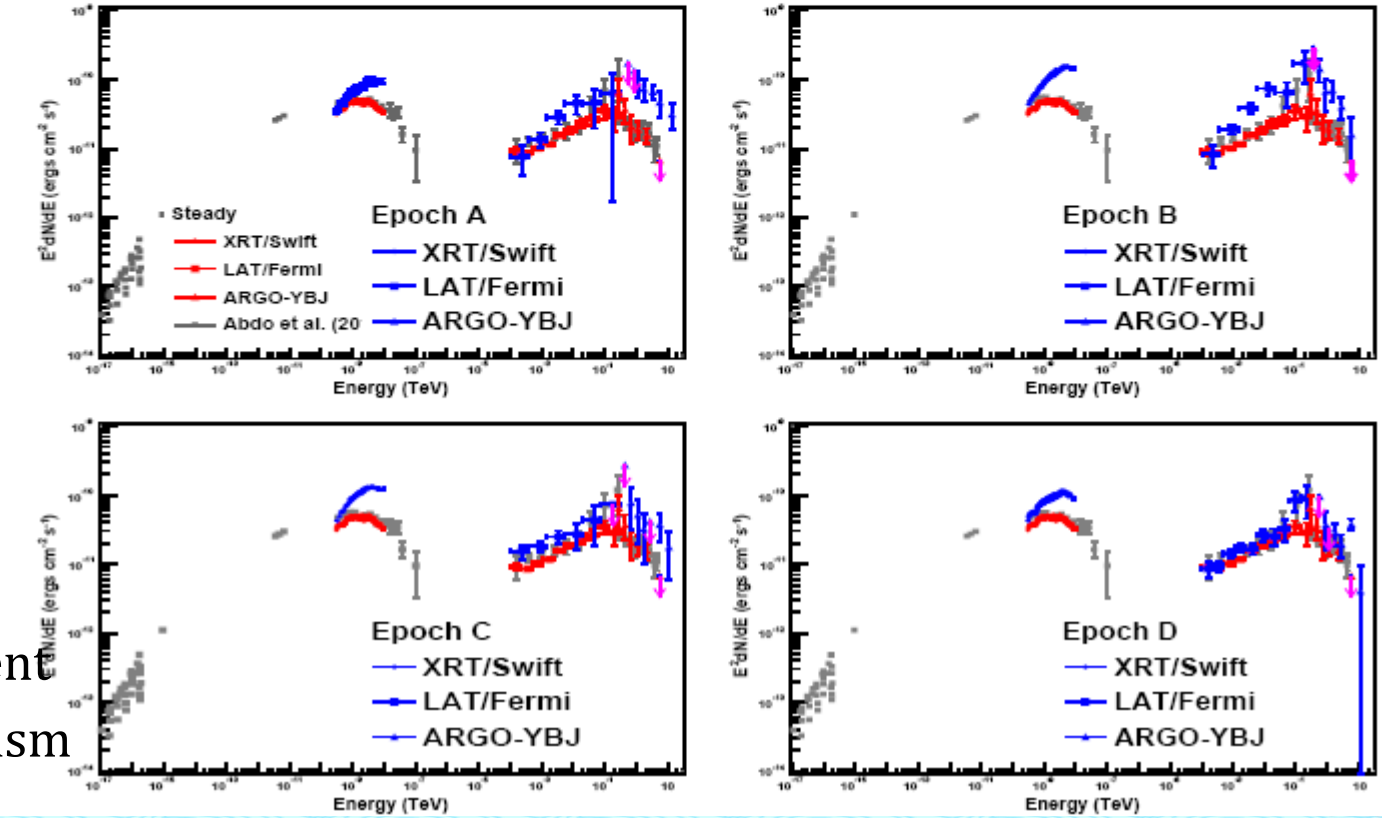
. 3: Three day-averaged light curve of Mrk 501 at 15−50 keV measured by BAT/*Swift*. The vertical dashed lines icate the four epochs analyzed in this paper. All the errors are statistical at 1 σ.

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

The evolution of the Spectrum during flares

IGMF measurement

Emitting Mechanism



LHAASO
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QG-Related Limits from GRB 090510

Abdo et al, Nature 462, 331 (2010)

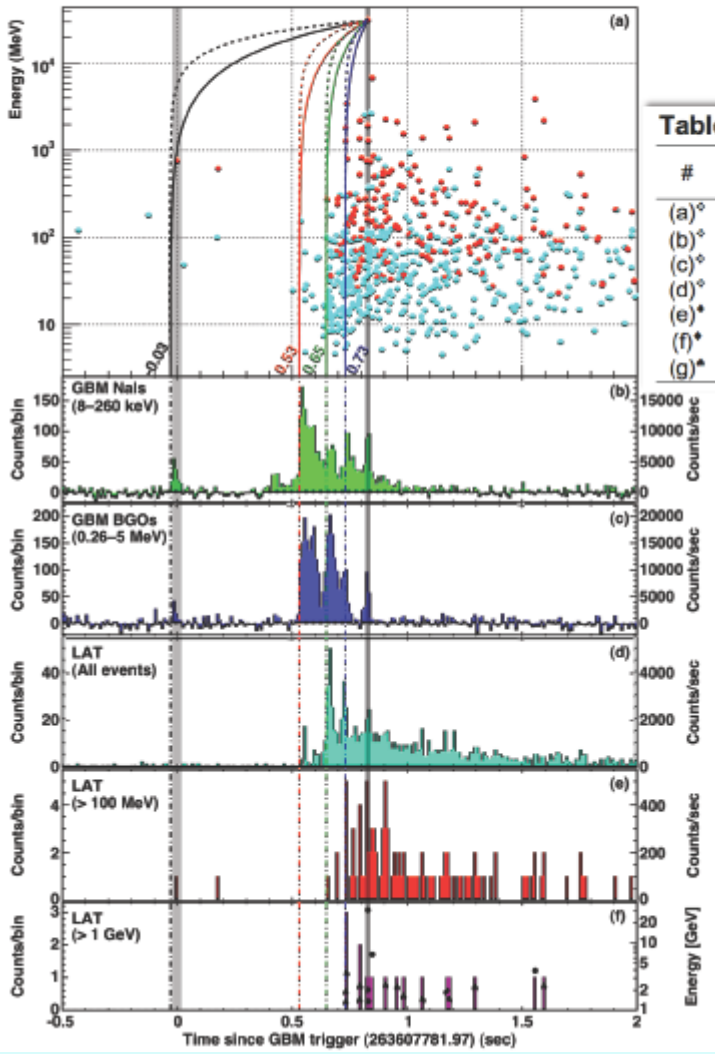


Table 2 | Limits on Lorentz Invariance Violation

#	$t_{start}-T_0$ (ms)	Limit on $\|\Delta t\|$ (ms)	Reasoning for choice of t_{start} or limit on Δt or $\|\Delta t/\Delta E\|$	E_l† (MeV)	Valid for s_n*	Lower limit on $M_{QG,1}/M_{Planck}$
(a)°	−30	< 859	start of any < 1 MeV emission	0.1	1	> 1.19
(b)°	530	< 299	start of main < 1 MeV emission	0.1	1	> 3.42
(c)°	*648*	< 181	start of main > 0.1 GeV emission	100	1	> 5.63
(d)°	730	< 99	start of > 1 GeV emission	1000	1	> 10.0
(e)•	—	< 10	association with < 1 MeV spike	0.1	±1	> 102
(f)•	—	< 19	If 0.75 GeV† γ-ray from 1st spike	0.1	−1	> 1.33
(g)•	$\|\Delta t/\Delta E\|$ < 30 ms/GeV		lag analysis of > 1 GeV spikes	—	±1	> 1.22

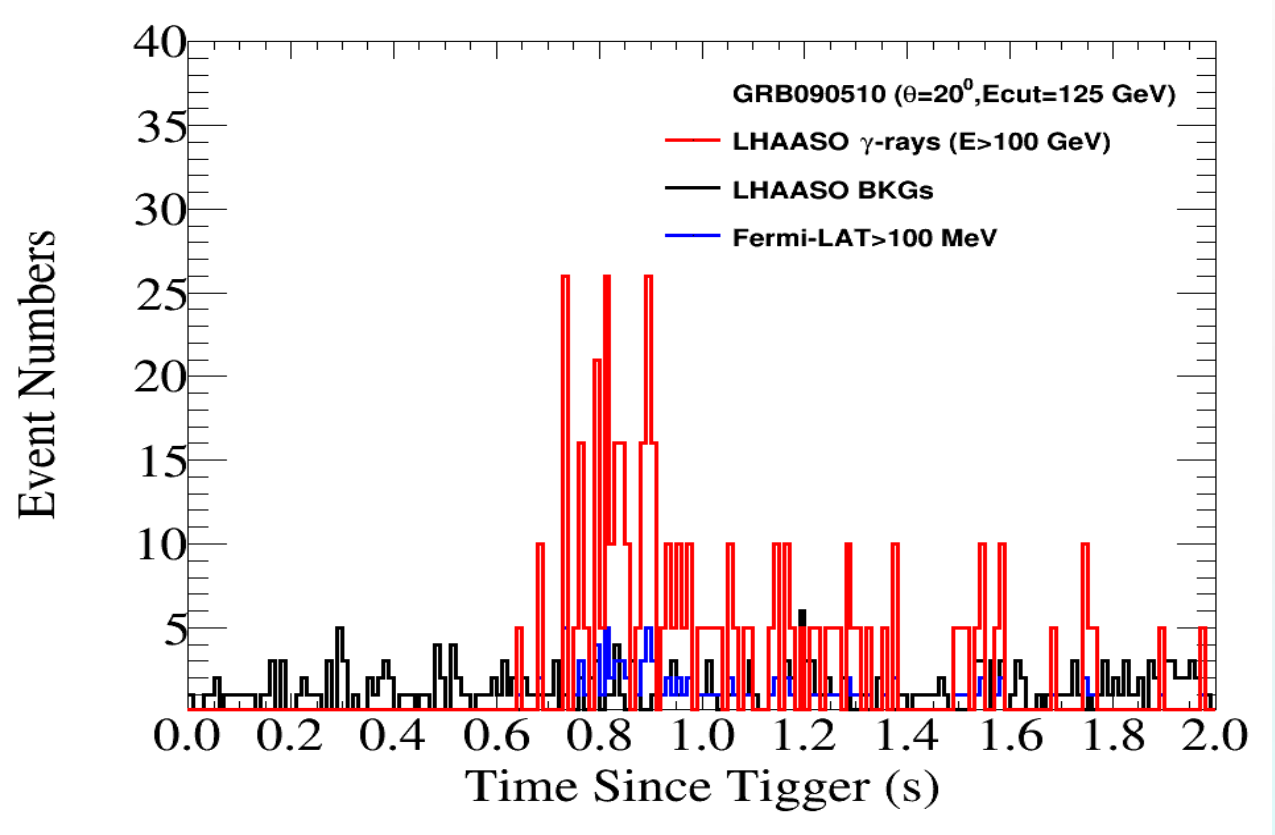
X10

X10

With the assumption that the HE photons are not emitted *before* the LE photons

$M_{QG} > 1.2\ M_{Planck}$

GRB with 100GeV photons such as GRB090510

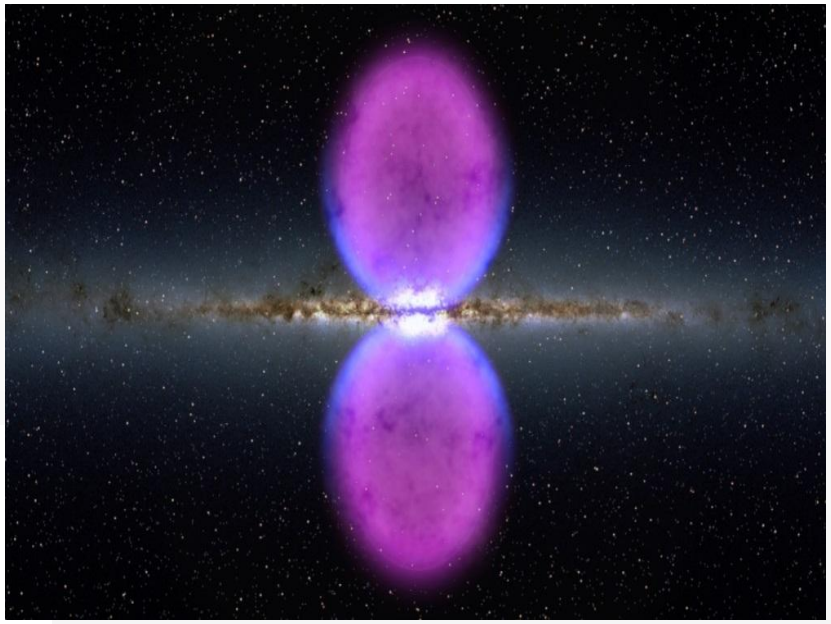


LHAASO：
~500 photons are expected at 100GeV

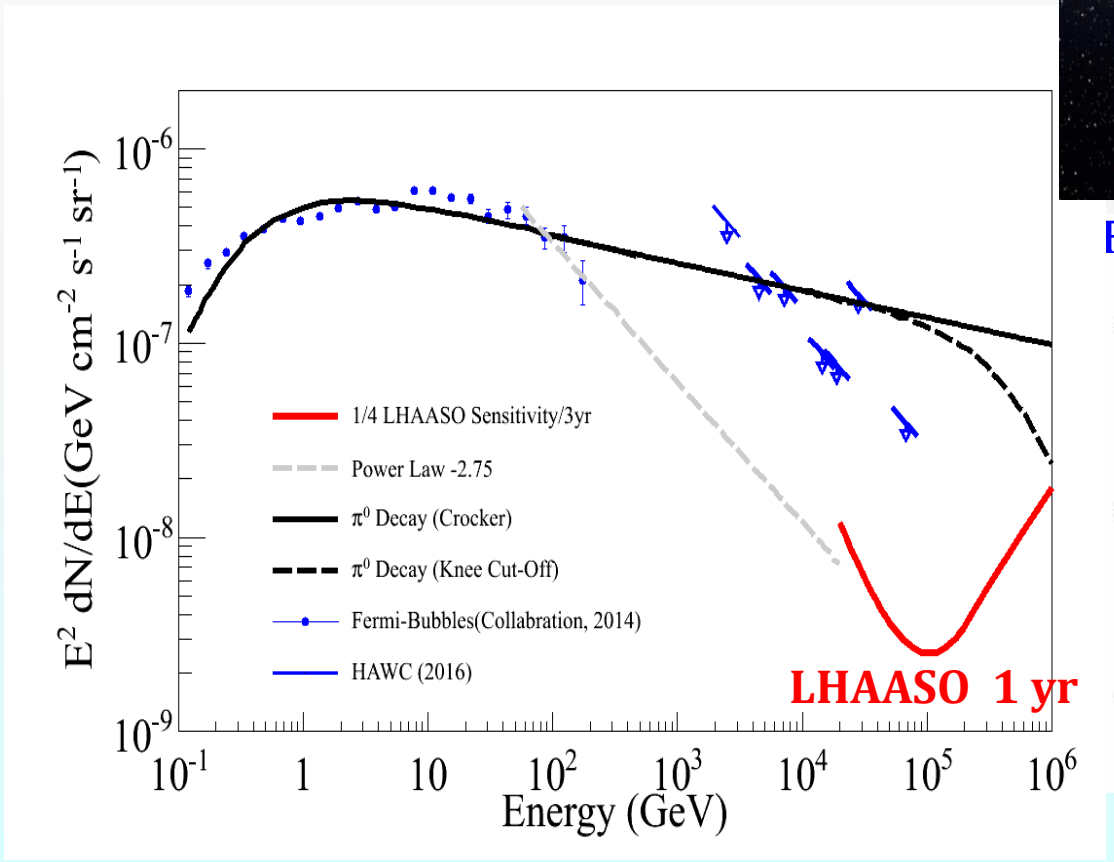
Fermi Bubbles

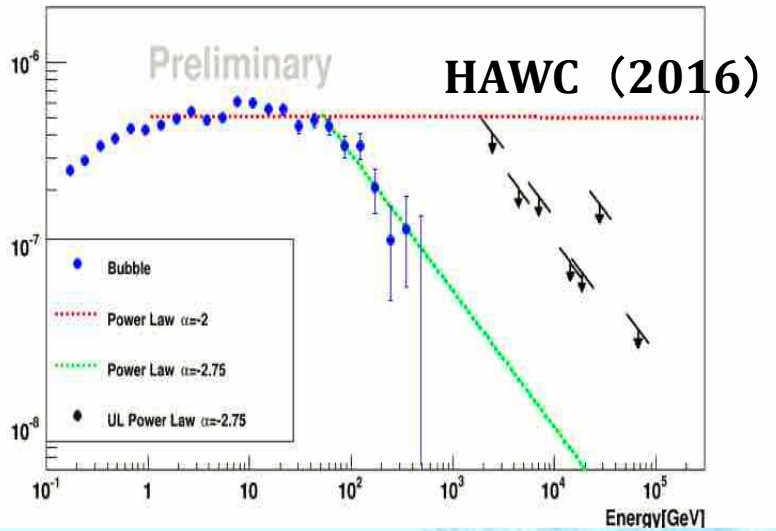
$E^2 \frac{dN}{dE}$

$10^{37\text{-}38}$ erg/s



Fermi-LAT（2014）

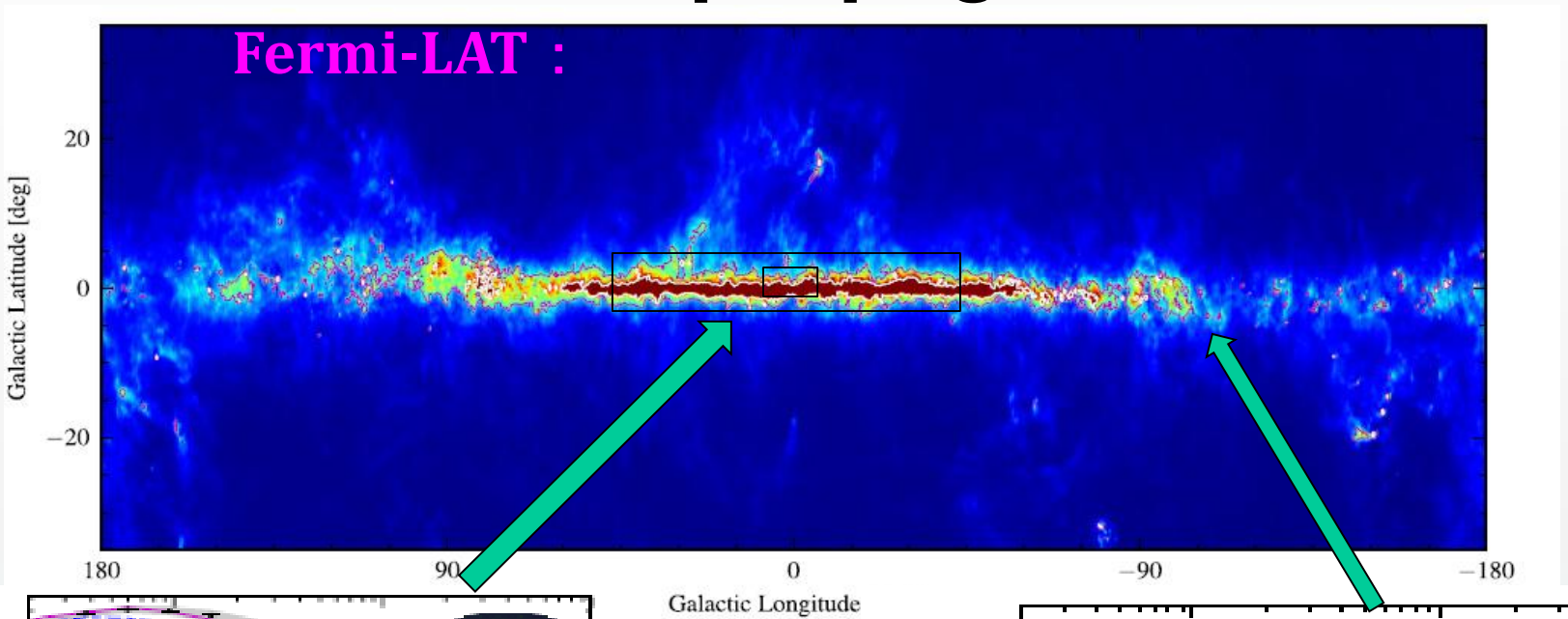


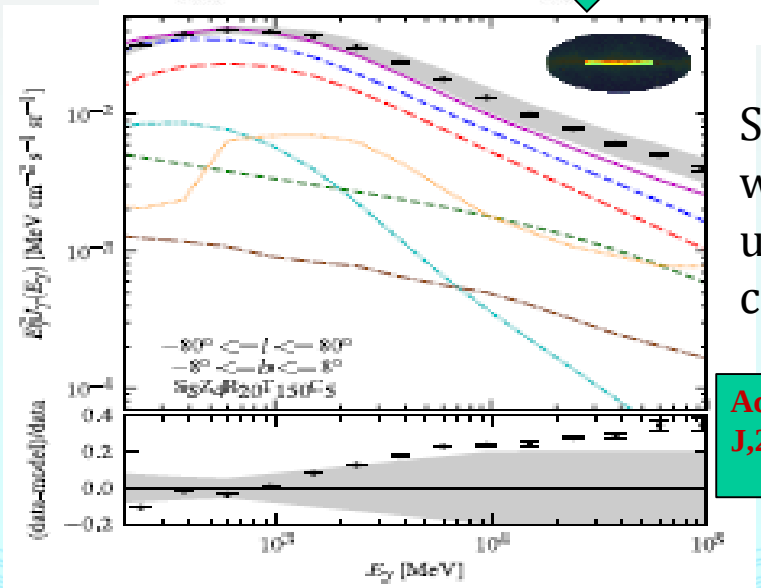


HAWC（2016）

100TeV

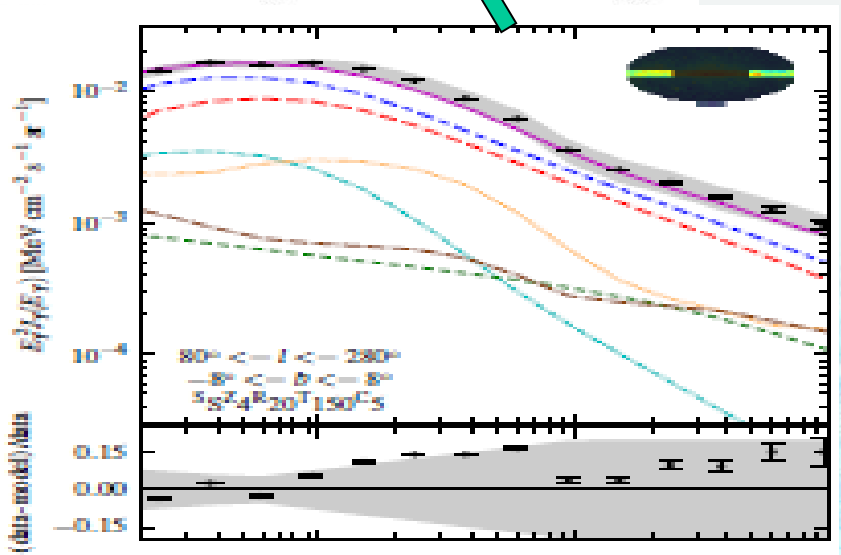
Diffuse GeV gammas: test on the propagation models





Some excess with unknown components

Ackermann,Ap J,2012,750,3

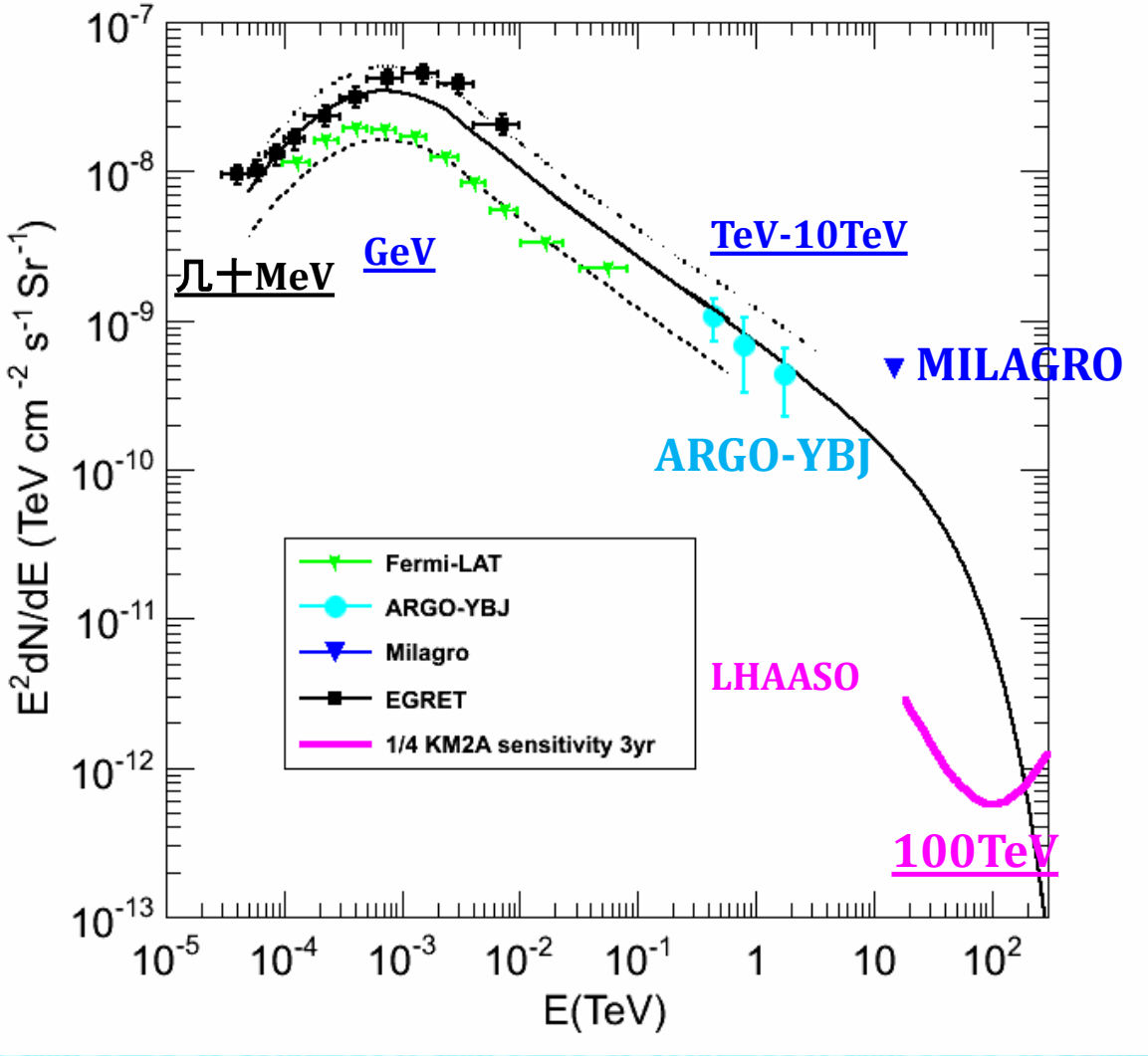


LHAASO: 100TeV Diffuse Gammas in the Galactic Disk

No data yet in the range around 100TeV

Trace the PeV CRs in the Galaxy and find their ESD

Potential of finding something new



新物理

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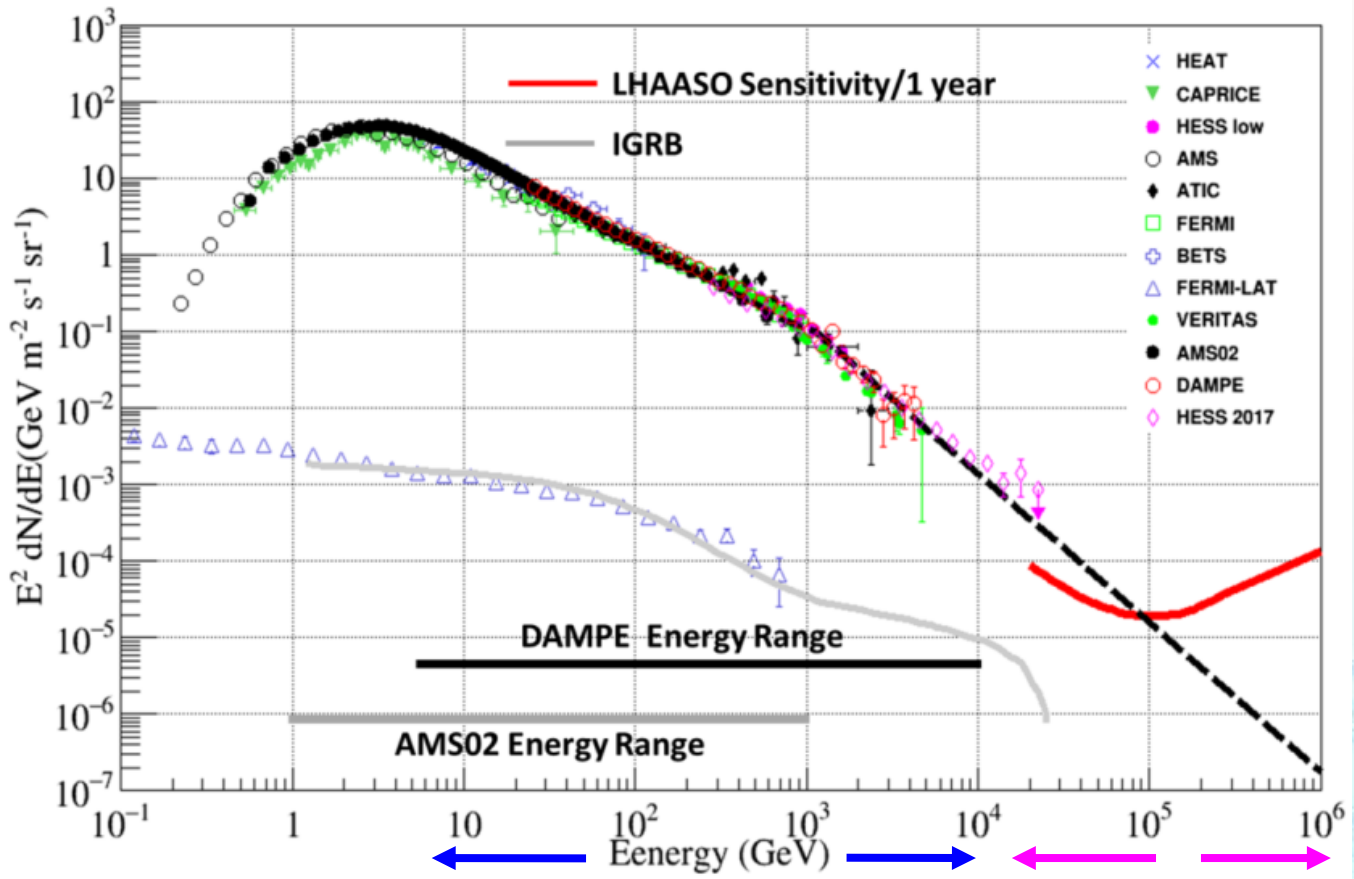
Electron Spectrum
LHAASO: above10TeV

After AMS02 and DAMPE, potential hot spot for DM searching



DAMPE
10GeV-10TeV

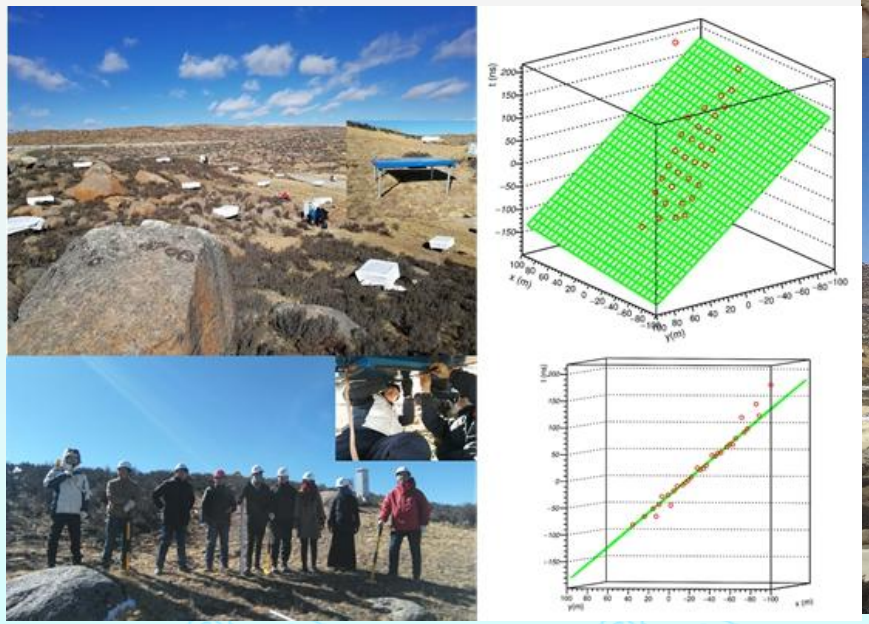
LHAASO 1yr
>10TeV

Construction of LHAASO

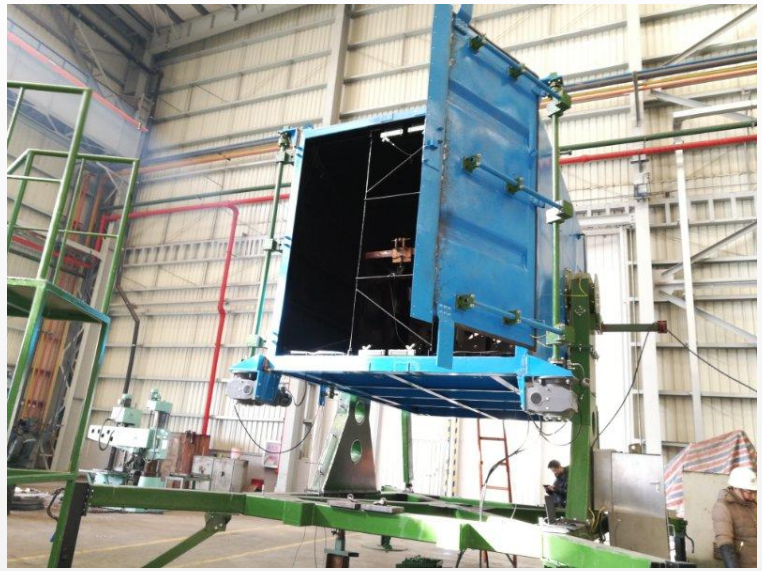
- #1 pool（150X150 m^2）is build up.
- 2018/01/31 covered, internal installation
- 2018/04, #2 & #3 pools are started simultaneously

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

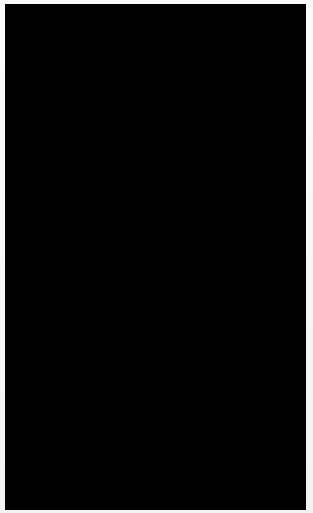
  The 1st LHAASO event



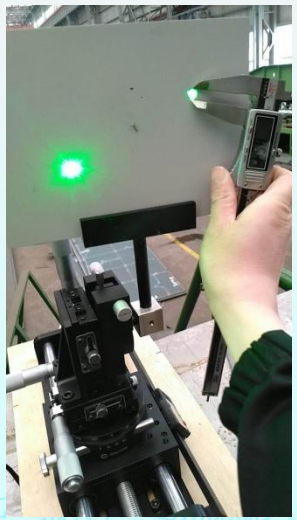
Construction



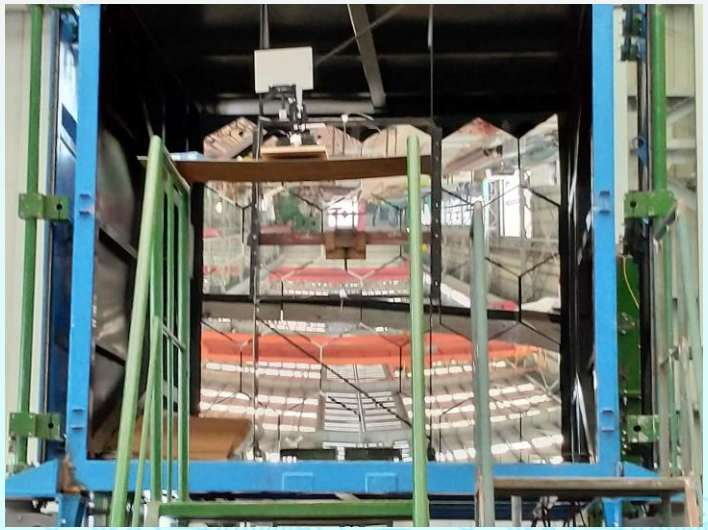
1st fan-less WR switch

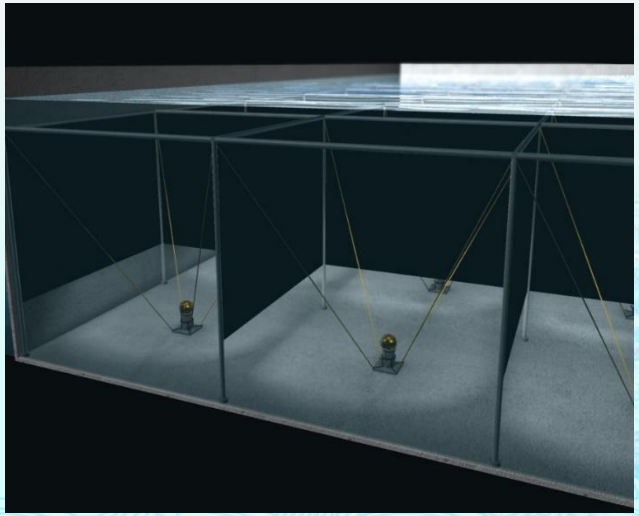


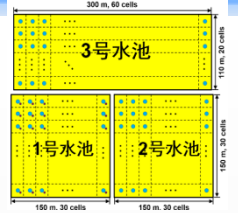
Spot size of 6 mm



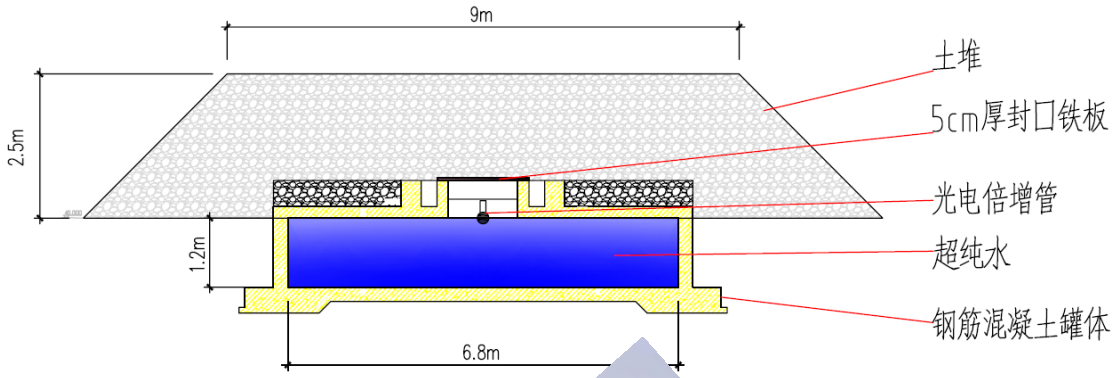
1st telescope







MD Progresses



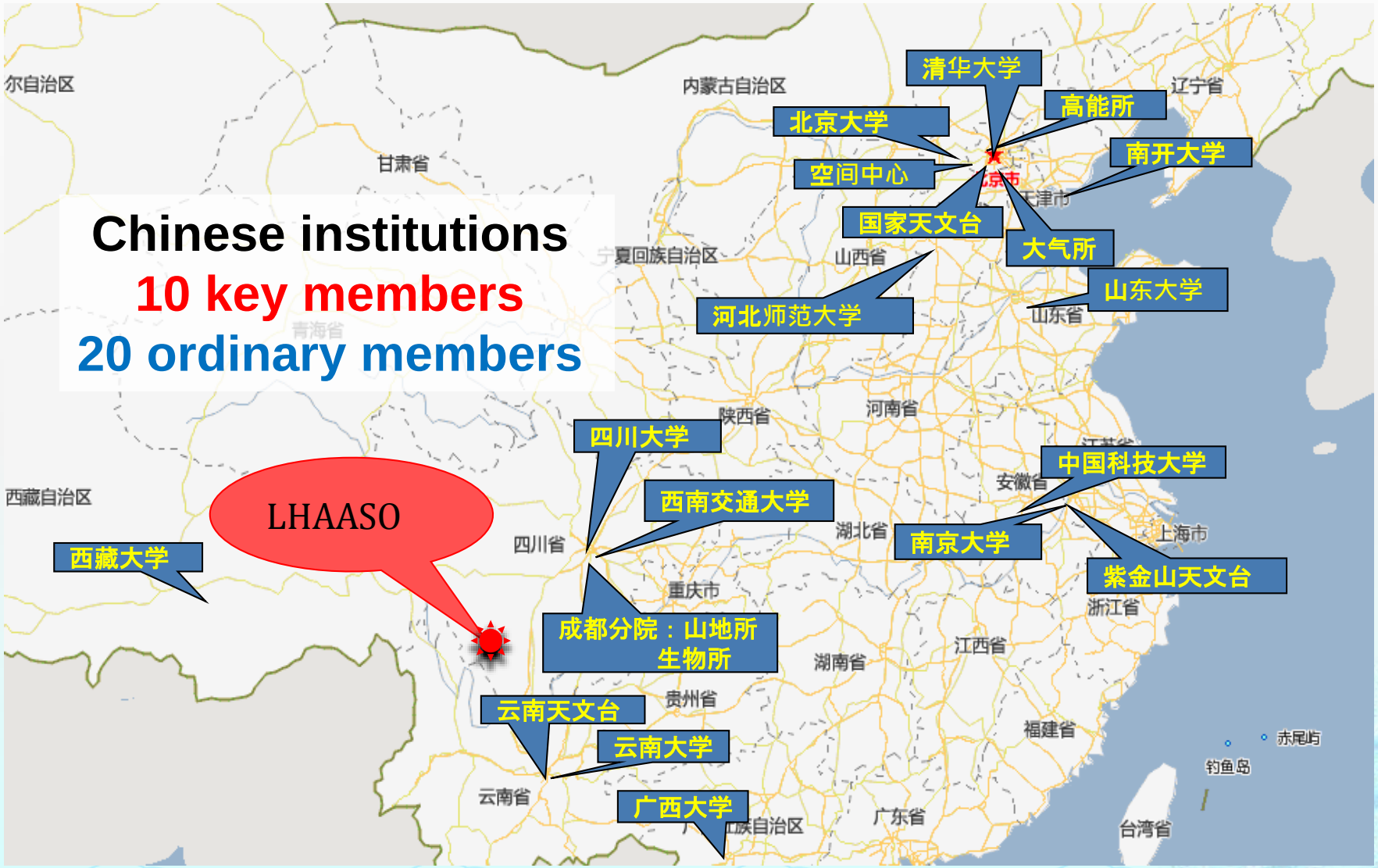
MD Deploying Schedule:

First tank in May

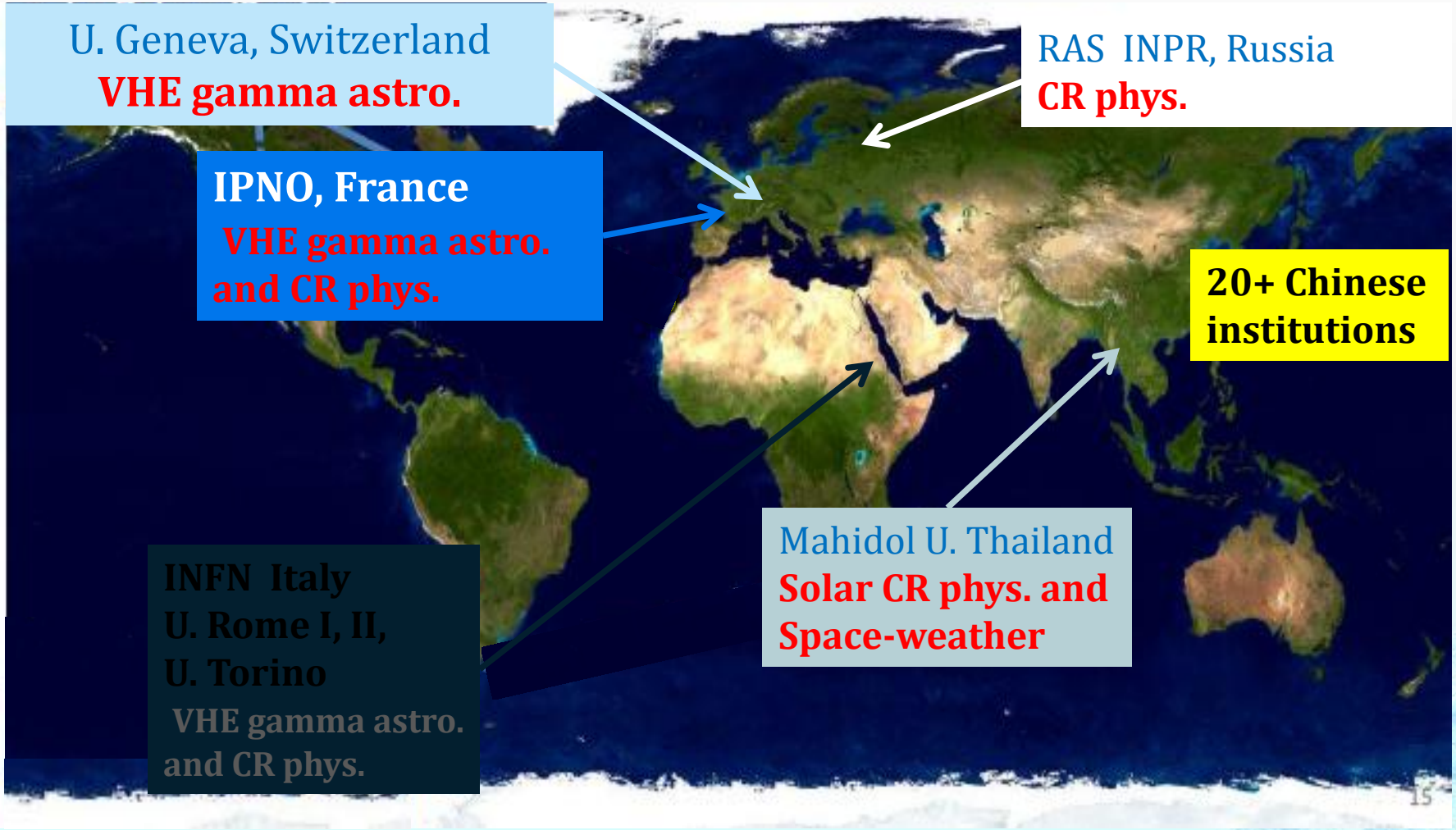
1, in 2018, 300 MDs
2, in 2019, 415 MDs
3, in 2020, 456 MDs

➢ Liner

LHAASO Collaboration



LHAASO Collaboration (growing)



LHAASO
高海拔宇宙线观测站

Welcome to join LHAASO Coll. !

LHAASO picture of the year 2017-11-17 20:00

Motivation

A Fundamental Question in the New entury

The Eleven Questions

Status and Perspective of Astroparticle Physics in Europe

The basic questions

Recommendations for the evolution of the field over the next decade were formulated by addressing a set of basic questions:

1) What is the Universe made of? In particular: What is dark matter?
2) Do protons have a finite life time?
3) What are the properties of neutrinos? What is their role in cosmic evolution?
4) What do neutrinos tell us about the interior of the Sun and the Earth, and about Supernova explosions?
5) What is the origin of cosmic rays ? What is the view of the sky at extreme energies ?
6) Can we detect gravitational waves ? What will they tell us about violent cosmic processes and about the nature of gravity?

An answer to any of these questions would mark a major break-through in understanding the Universe and would open an entirely new field of research on its own.

11. Is a New Theory of Light and Matter Needed at the Highest Energies?

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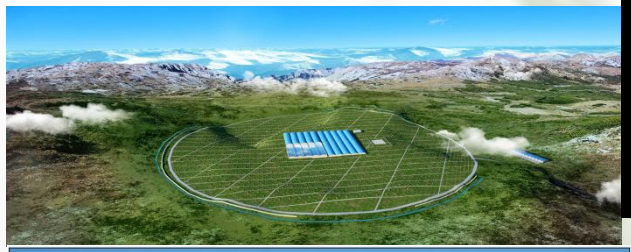
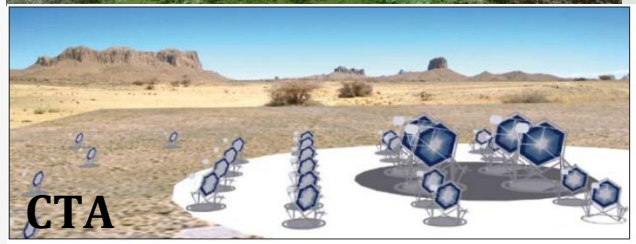
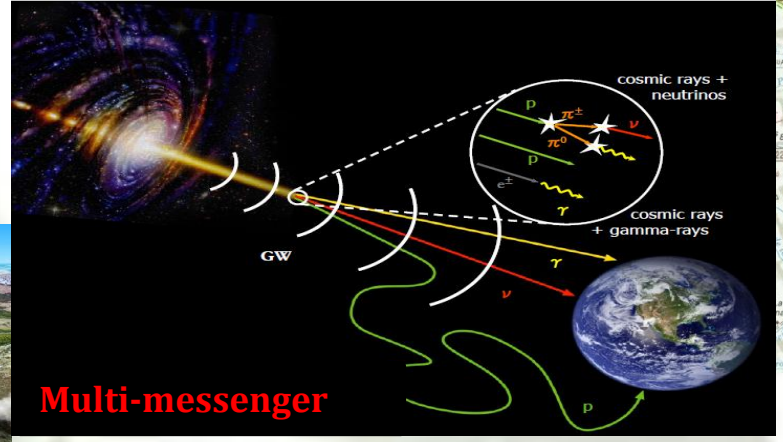




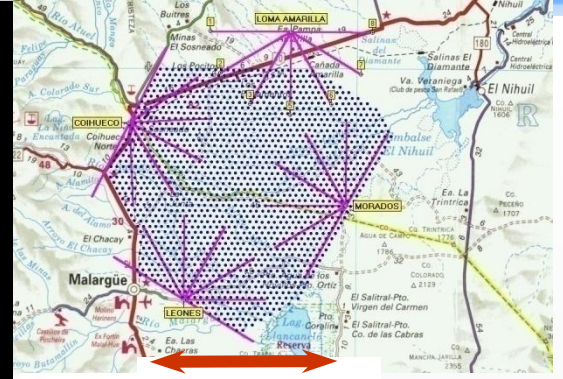
VHEγ Astronomy

LHAASO

CTA



The question

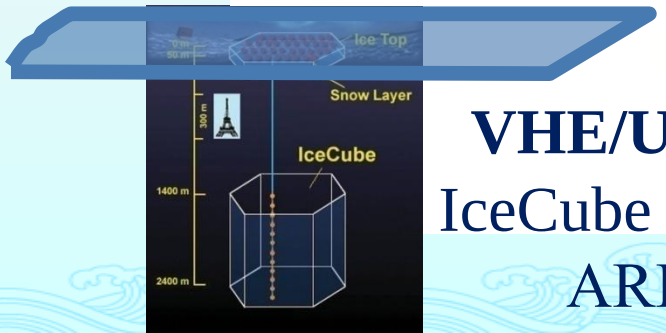


EHE CR Astronomy

TA, AUGER

JEM-EUSO

5km



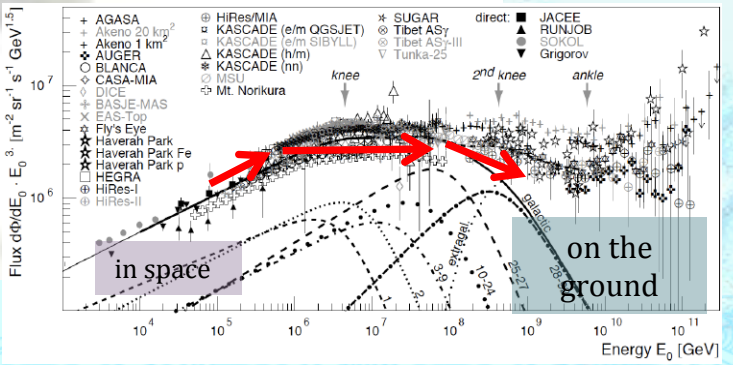
VHE/UHE Neutrinos

IceCube Gen2, KM3net

ARIANA ……

CR Features: knees

AMS02,Iss-CREAM,DAMPE,LHAASO……

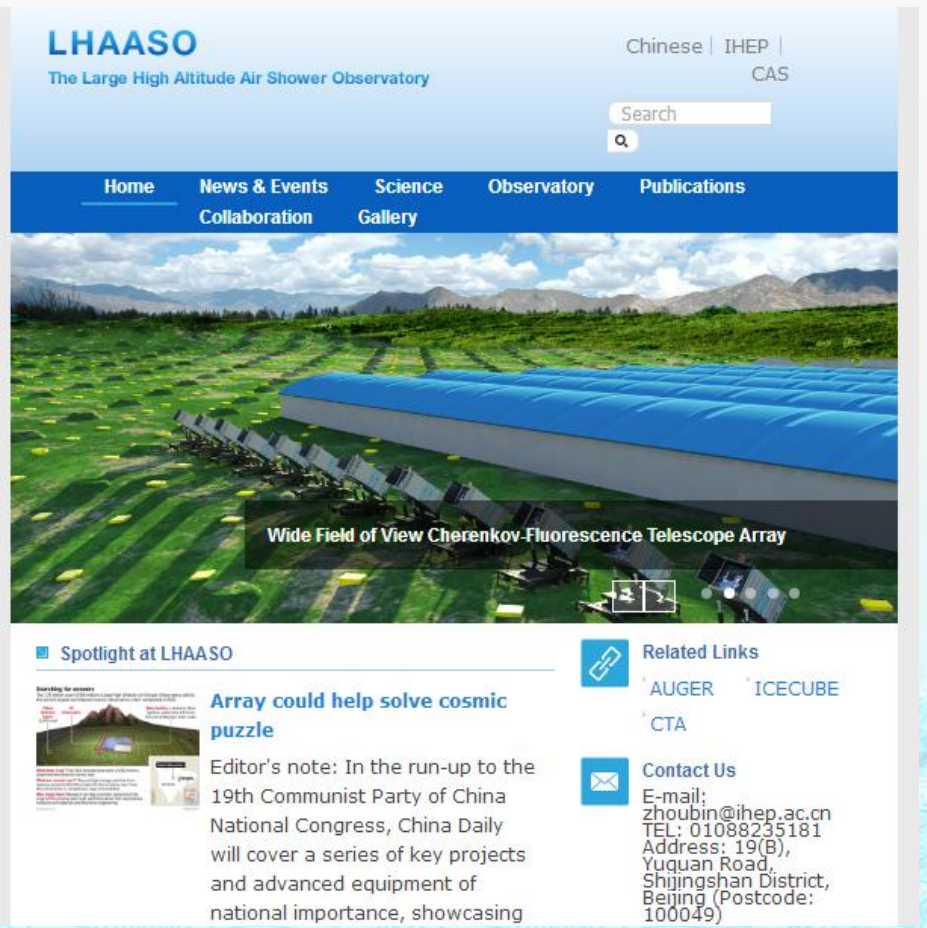


Large High Altitude Air Shower Observatory

LHAASO

- General info is available at the web sites

http://ihep.cas.cn/lhaaso （Chin）　　http://english.ihep.cas.cn/lhaaso （Eng）



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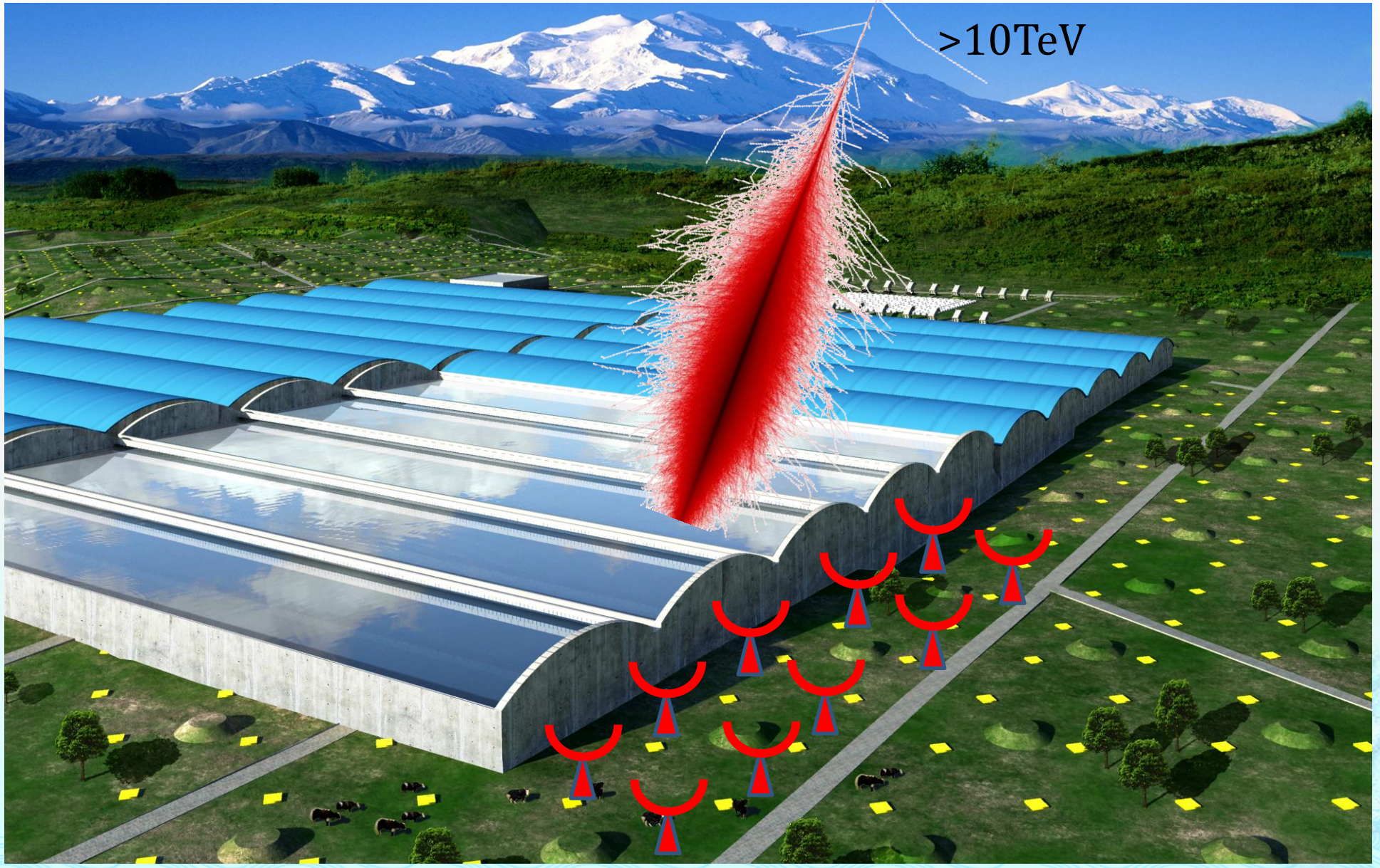
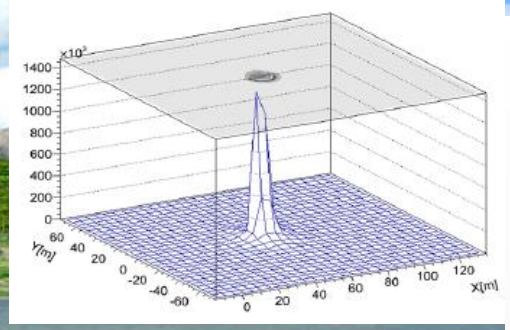
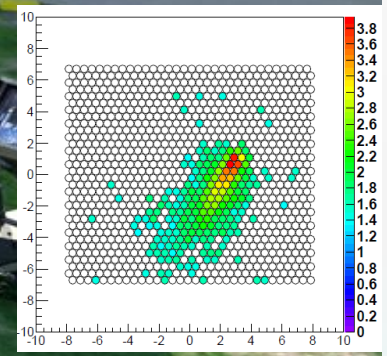
Hybrid Measurements of Showers

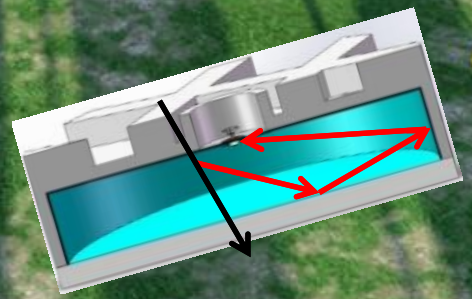


Prospects of P, He knees
from 100TeV to 10PeV

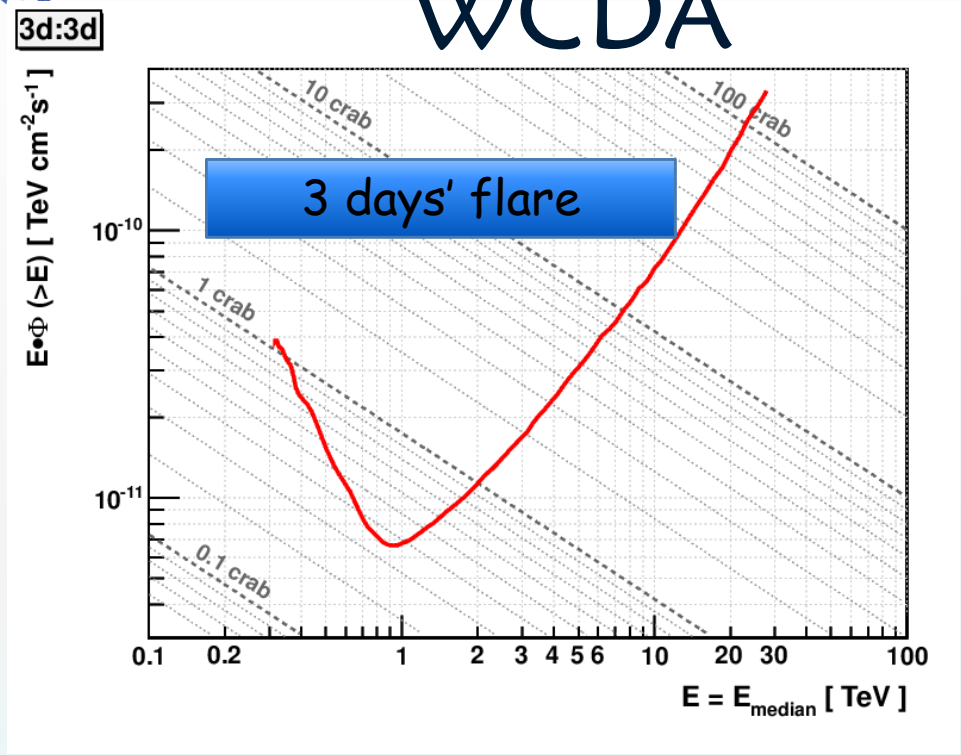


- **WCDA**
  - Core reconstruction: 3m
  - Arrival direction reconstruction: 0.3°
  - Energy flux near the core
- **WFCTA**
  - SIZE (total PE in image)
  - Width, Length
  - Distance between arrival directions to the image center
- **KM2A**
  - Total Muon number





Sensitivity to Flares / GRBs WCDA

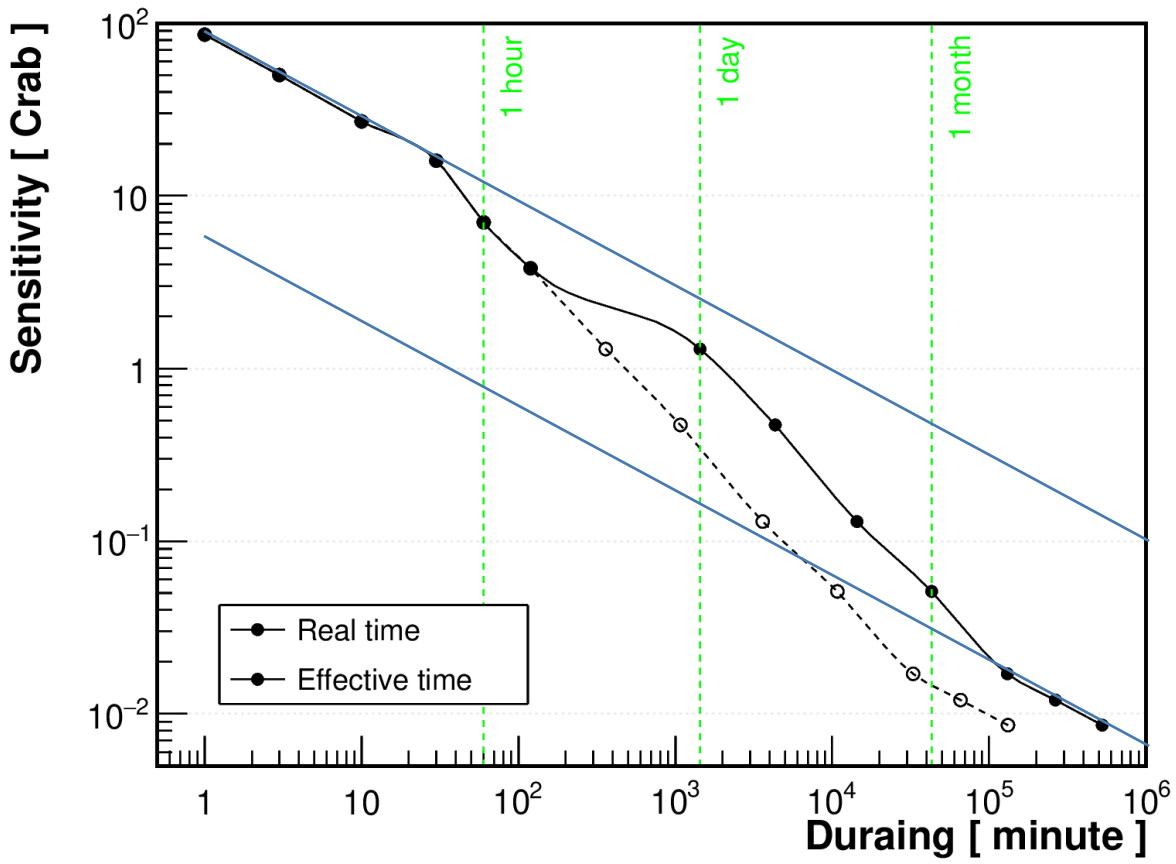


- Requirements:
  - 30 events;
  - 5 s.d.;
  - Calculation based on a power law spectrum (λ=-2.62).
- Partly limited by statistics.

Duration	Sensitivity (Crab)
1 year	0.0066
6 months	0.0094
3 months	0.013
1 month	0.039
10 days	0.10
3 days	0.36
1 day	1.0
2 hours	3.5
1 hour	5.4
30 minutes	13
10 minutes	67
3 minutes	410
1 minute	2100

Yzg's vs. simple sqrt(T)

Duration	Sensitivity (Crab)	Sqrt(T) S(yr)
1 year	0.0086	0.0086
6 months	0.012	0.012
3 months	0.017	0.017
1 month	0.051	0.030
10 days	0.13	0.052
3 days	0.47	0.095
1 day	1.3	0.16
2 hours	3.8	0.57
1 hour	7.0	0.80
30 minutes	17	1.14
10 minutes	27	2.0
3 minutes	50	3.6
1 minute	86	6.2



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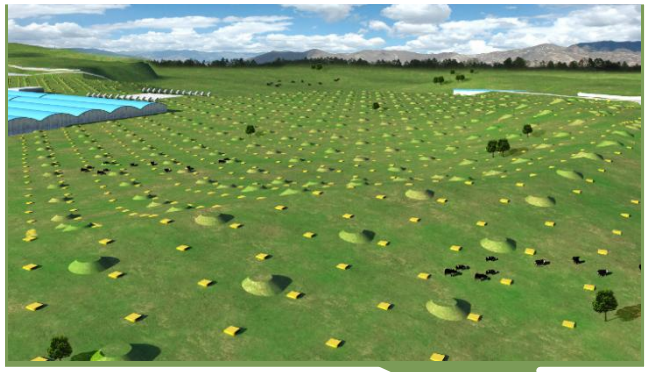
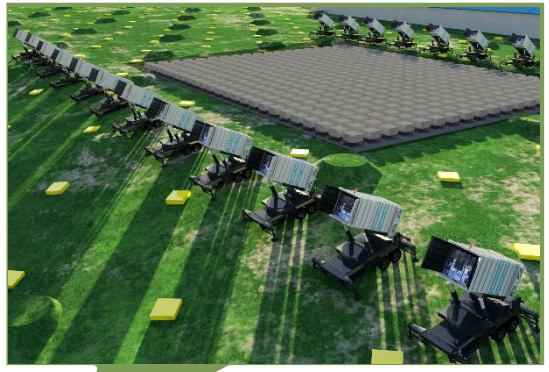
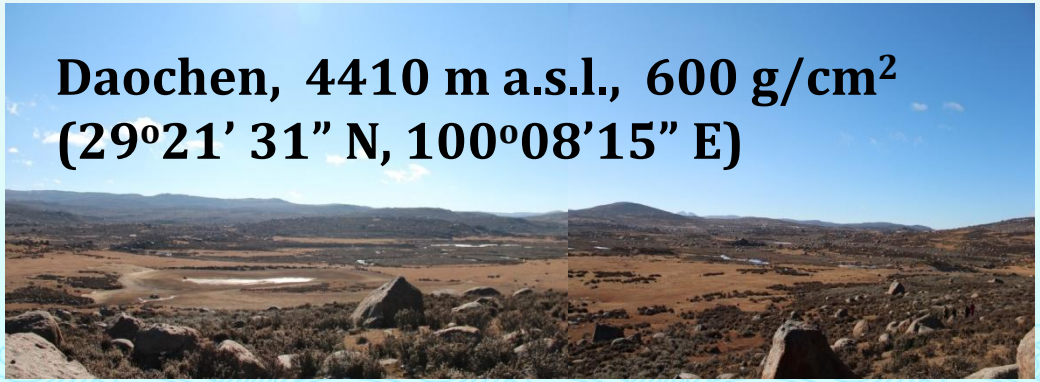


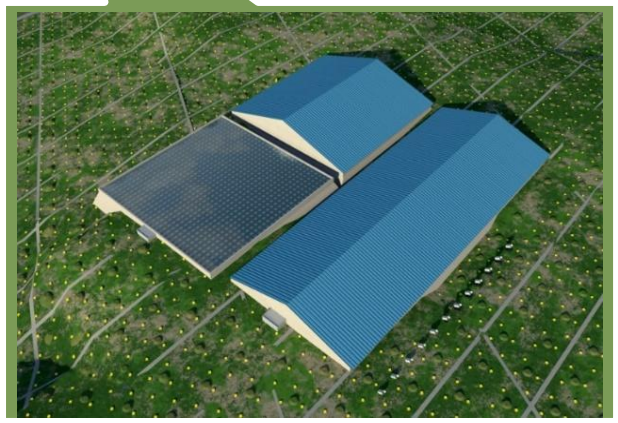


KM2A:
- 5195 Scin's: 1 m^2, 15m spacing
- 1171 MDs: 36 m^2, 30m spacing

WFCTA:
18 Cherenkov telescopes (1024 pixels/telescope)

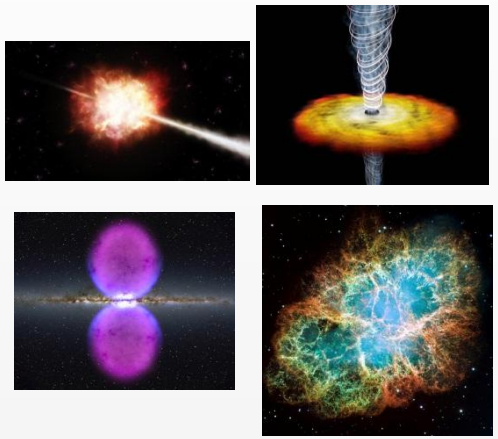
WCDA:
3120 cells (25m^2/cell)

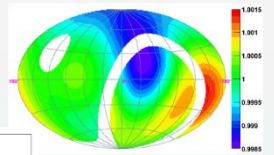


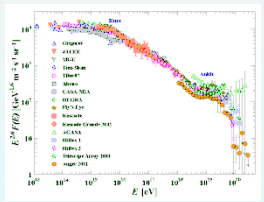


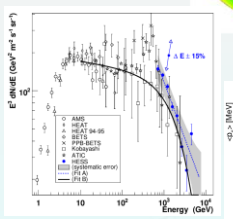
Physics of LHAASO

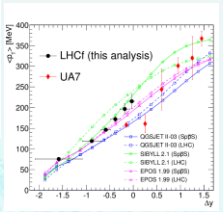
- VHE gamma sky survey (100 GeV-1 PeV):
  - Galactic sources;
  - Extragalactic sources & flares;
  - VHE emission from Gamma Ray Bursts;
  - Diffused Gamma rays.
- Spectrum measurement at the high end:
  - Nature of the acceleration: leptonic or hadronic;
  - Origin of cosmic rays – 100 years' mystery.
- Cosmic rays
  - Spectra of CR Species;
  - Anisotropy of VHE cosmic rays;
  - Cosmic electrons / positrons;
- Miscellaneous:
  - Gamma rays from dark matter;
  - Sun storm & IMF.

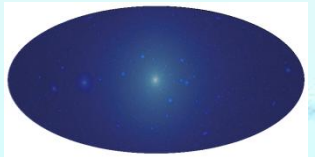


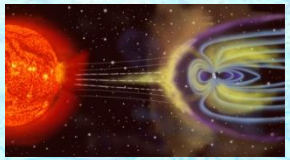












LHAASO survey sensitivity vs. other experiments and projects