The Large High Altitude Air Shower Observatory LHAASO: Science goals and expected performances

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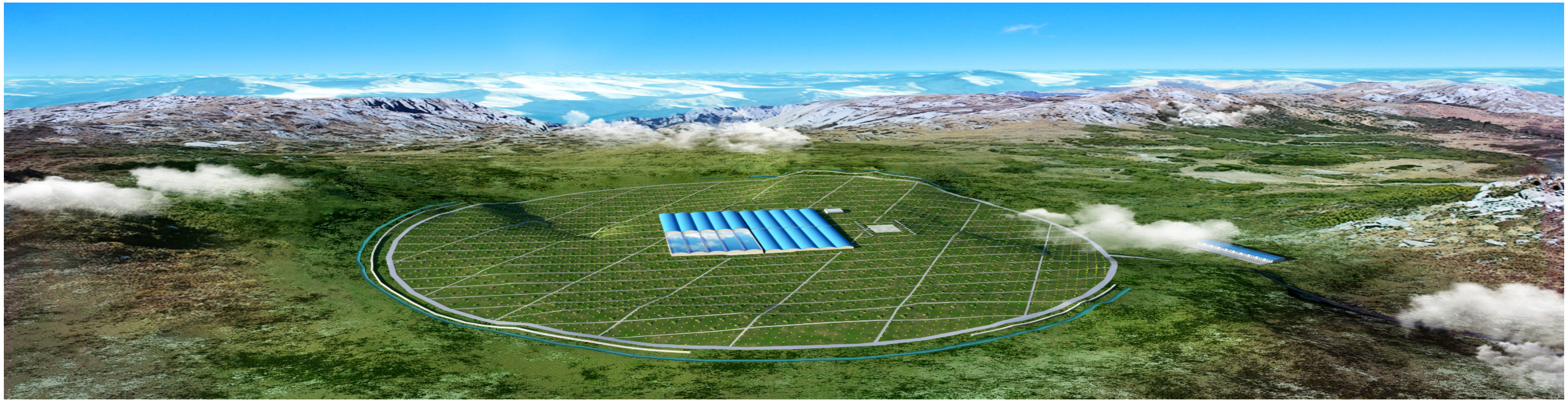
Outline

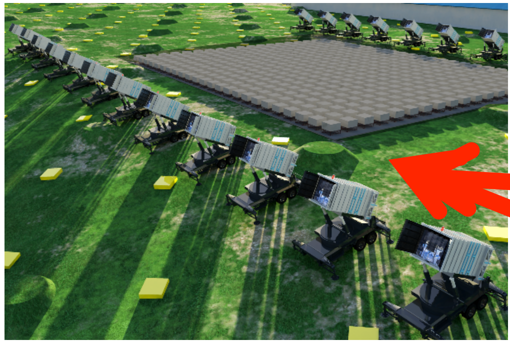
- LHAASO project
- Science case
- Detectors and observatory site
- Status of the project
- Conclusions

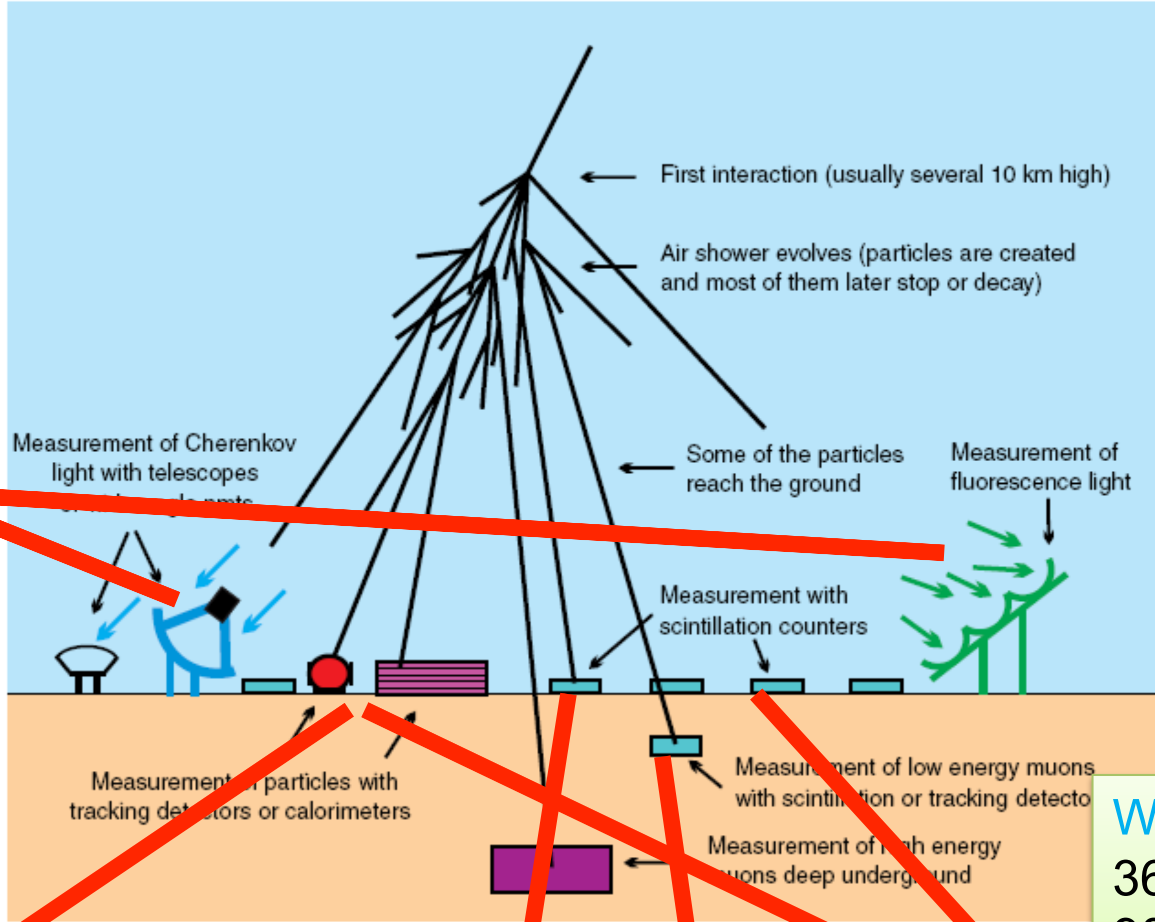
LHAASO Project



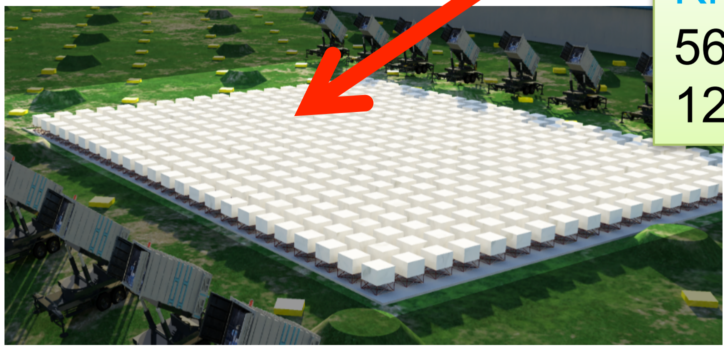
Hybrid detection of Extensive Air Showers by LHAASO

WFCTA:
24 telescopes
1024 pixels each

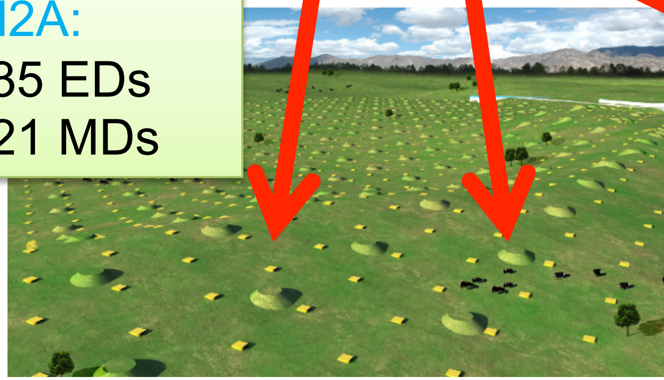




SCDA:
452 detectors



KM2A:
5635 EDs
1221 MDs



WCDA:
3600 cells
90,000 m^2

Science case for LHAASO

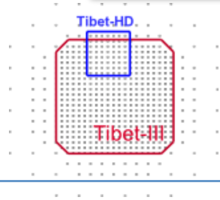
- Survey of the gamma sky above 100 GeV
  - Observation of extended sources
  - Observation of transient sources
  - Observation at very high energies (above 30 TeV)
- Search for cosmic-ray origin among galactic gamma-ray sources
  - Visibility for hadronic origin and charged particle acceleration
- Measurement of cosmic rays above 30 TeV
  - Bridge between direct and indirect measurements
  - Unprecedented statistics for anisotropy studies in the knee region
- New Physics and other studies
  - Dark matter
  - Quantum gravity

VHE (TeV) gamma instrumentation history

IACTs are typically 10× better in sensitivity, gained from the lower energy threshold (stat.)

Whipple
(0.2 Crab)

1980



Tibet-ASγ
(1.5 Crab)

Crab detected!

1989

HEGRA, CANGAROO, CAT … 0.04 Crab

2001

Milagro
(0.9 Crab)

H.E.S.S.
(0.008 Crab)

2004

VERITAS
(0.008 Crab)

2007

ARGO-YBJ
(0.6 Crab)

MAGIC
(0.02 Crab)

2009

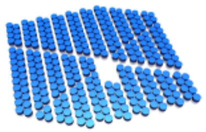
~150 Sources observed

2014

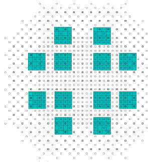
10 years delay!

~10 Sources

2015

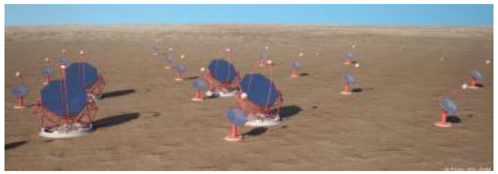


HAWC
0.06 Crab

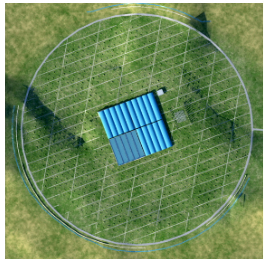


ASγ+MD
0.06 Crab

CTA
(0.001 Crab)

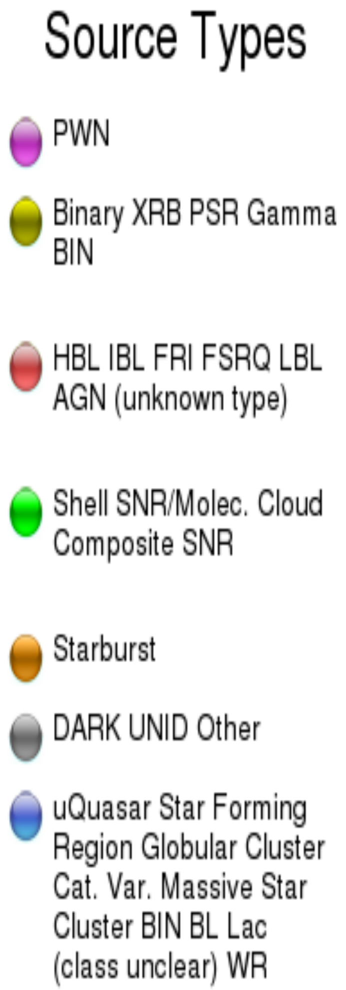


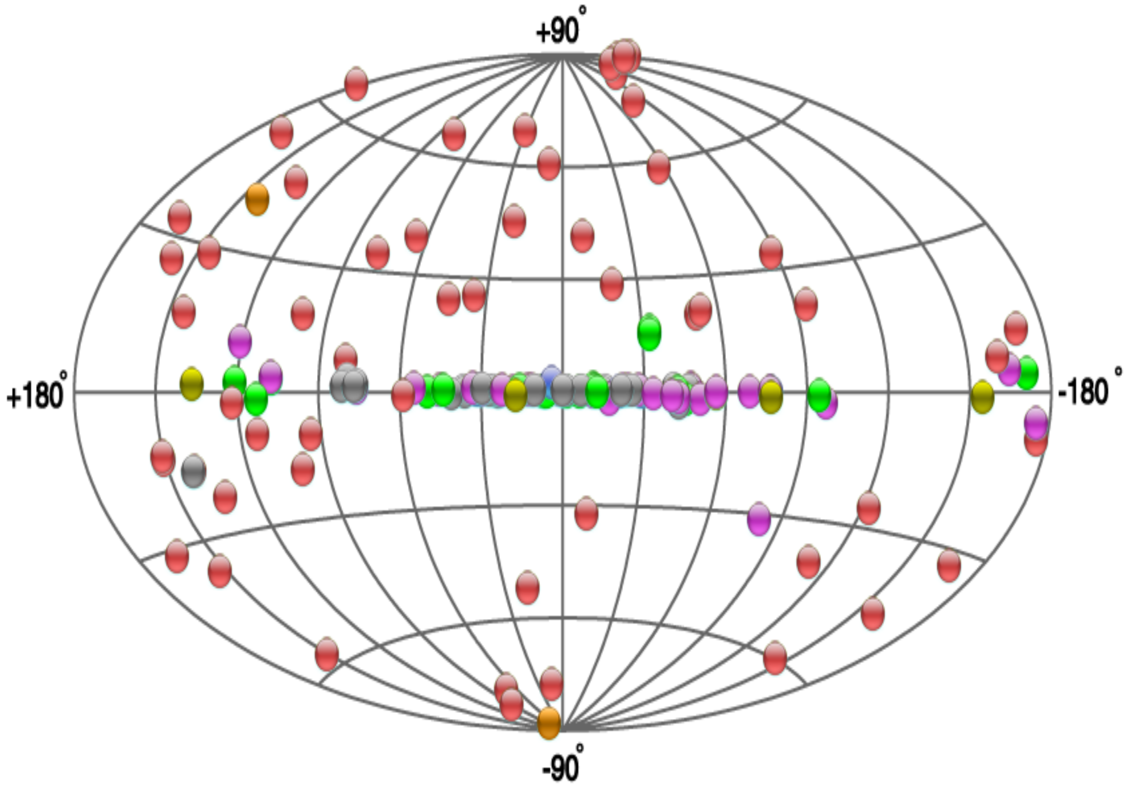
2018
?



LHAASO
(0.01
Crab)

VHE gamma Astronomy status





State of the art

~ 150 sources observed above 1 TeV

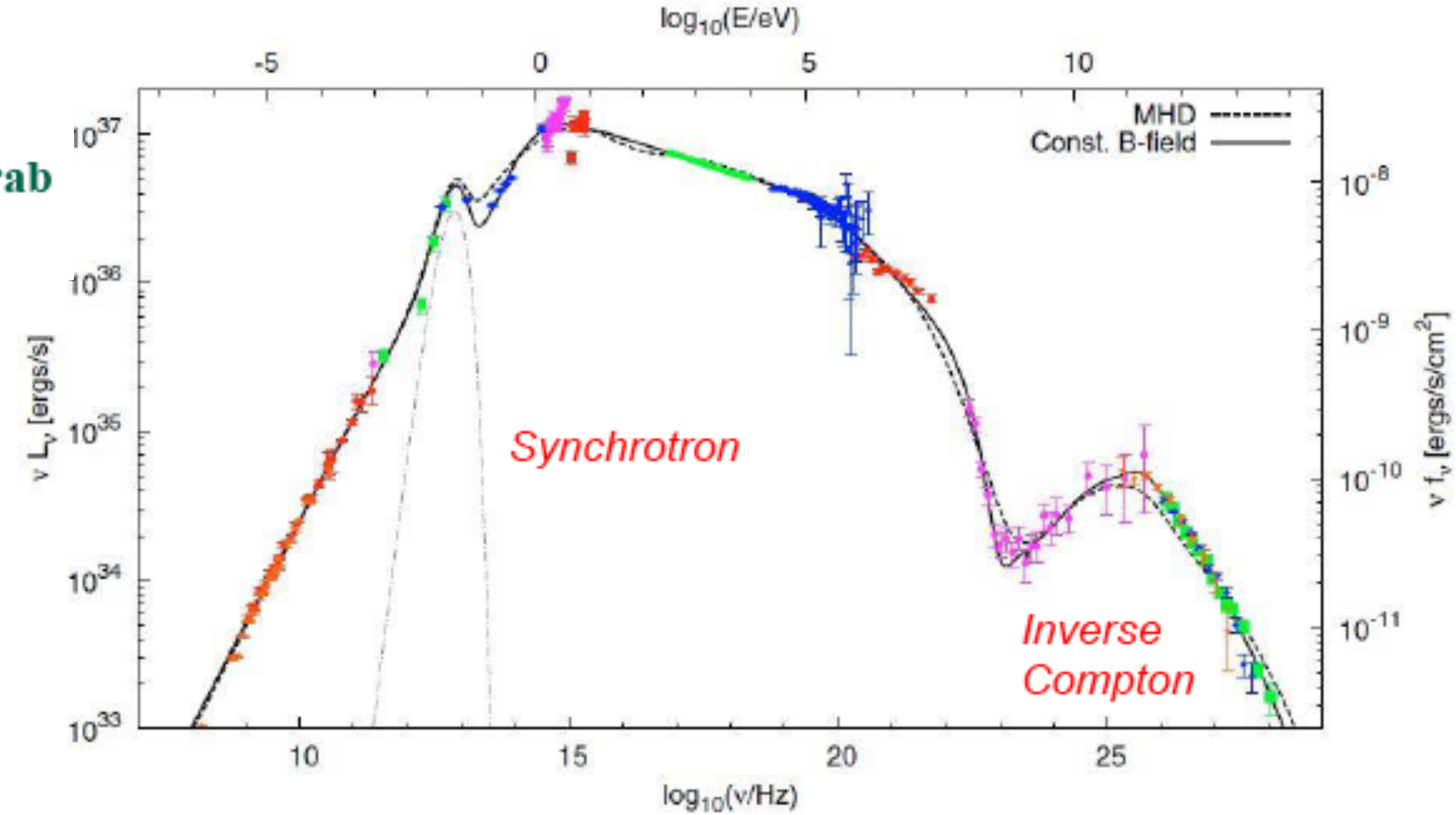
< 10 sources observed above 30 TeV:

Crab Nebula
VELA -X
MGRO J2031+41
MGRO J2019+37
MGRO J1908+06
SNR RX J1713.7-3946 ....

No photons detected above 100 TeV

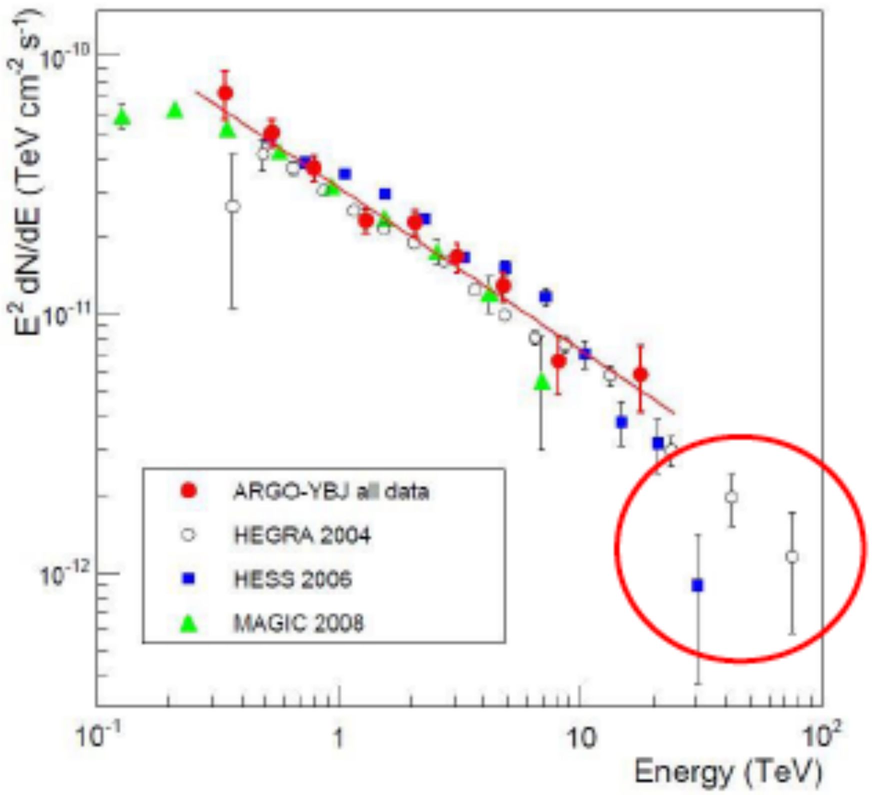
Crab Nebula

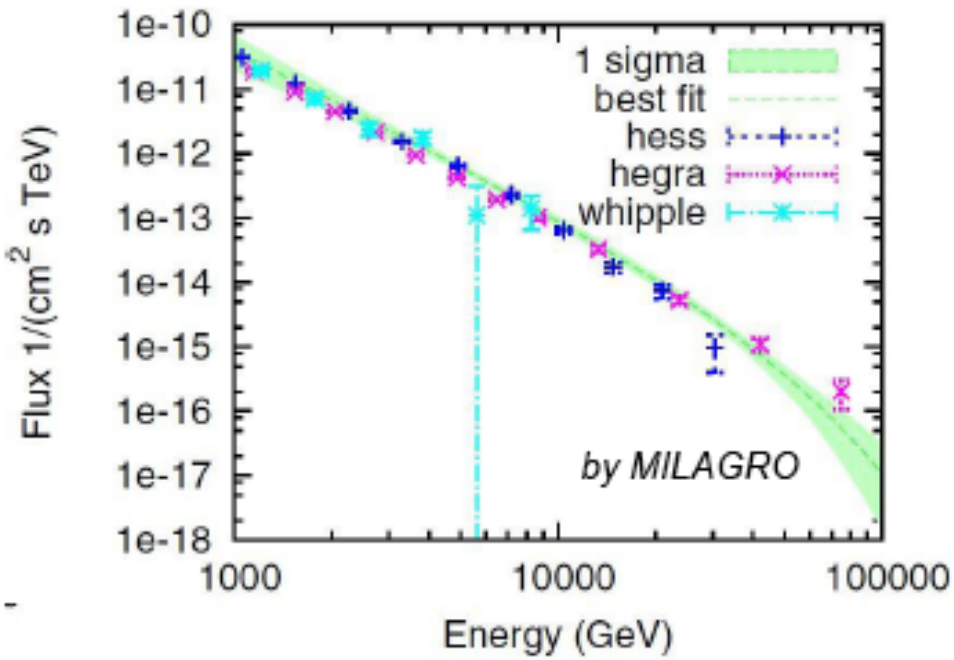
Standard Candle Crab Nebula



- *Leptonic emission*
- *Electron energy up to 10^{15} eV*

TeV Crab Nebula data

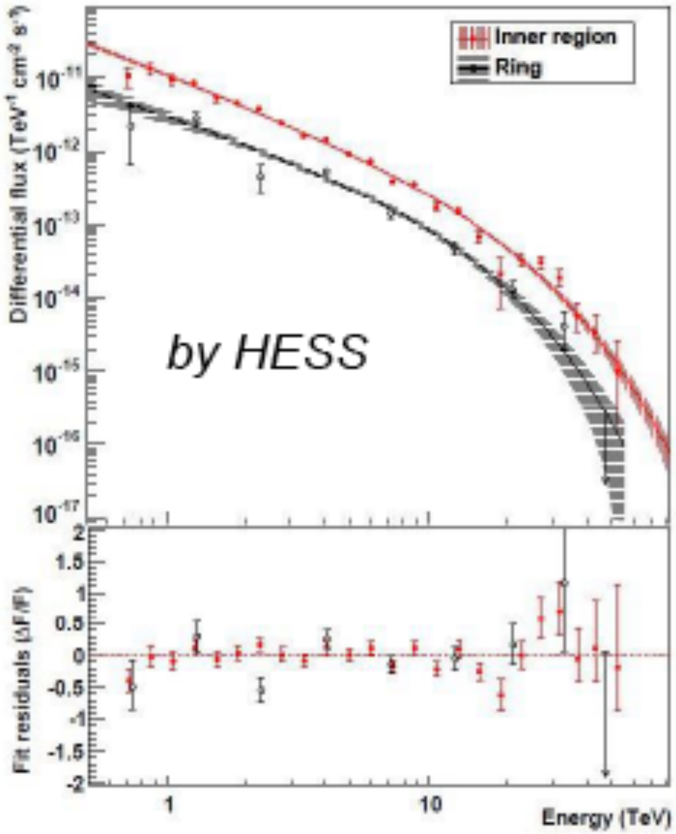




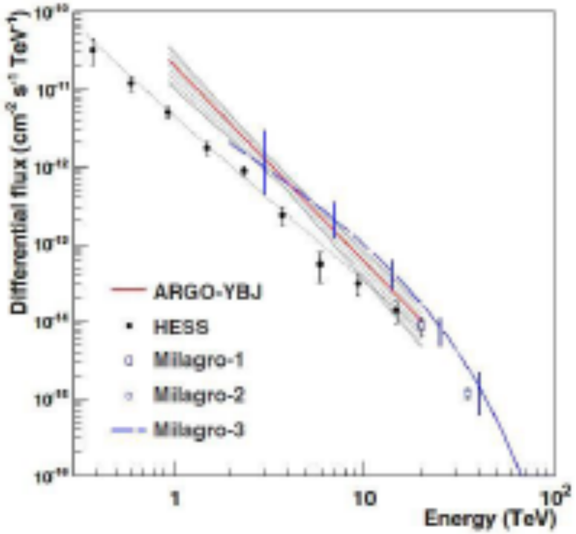
Above 30 TeV: few data and large error bars
GeV Flares observed
Is there an IC component above 10 TeV ?

Other Pulsar Wind Nebulae

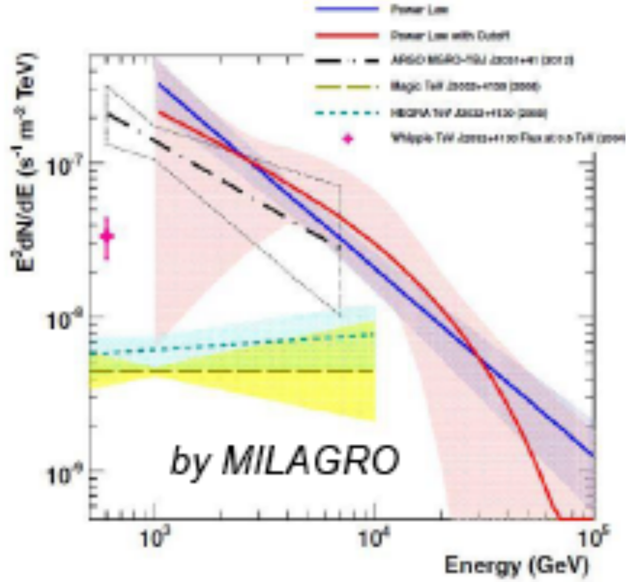
VELA -X

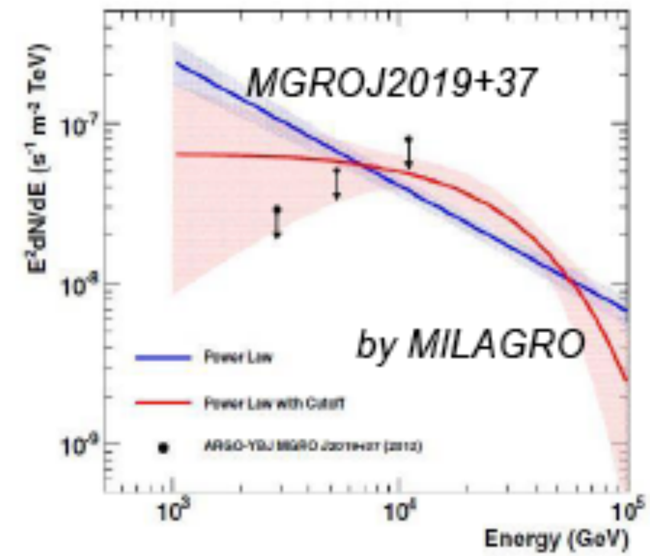


MGROJ1908+06



MGROJ2031+41



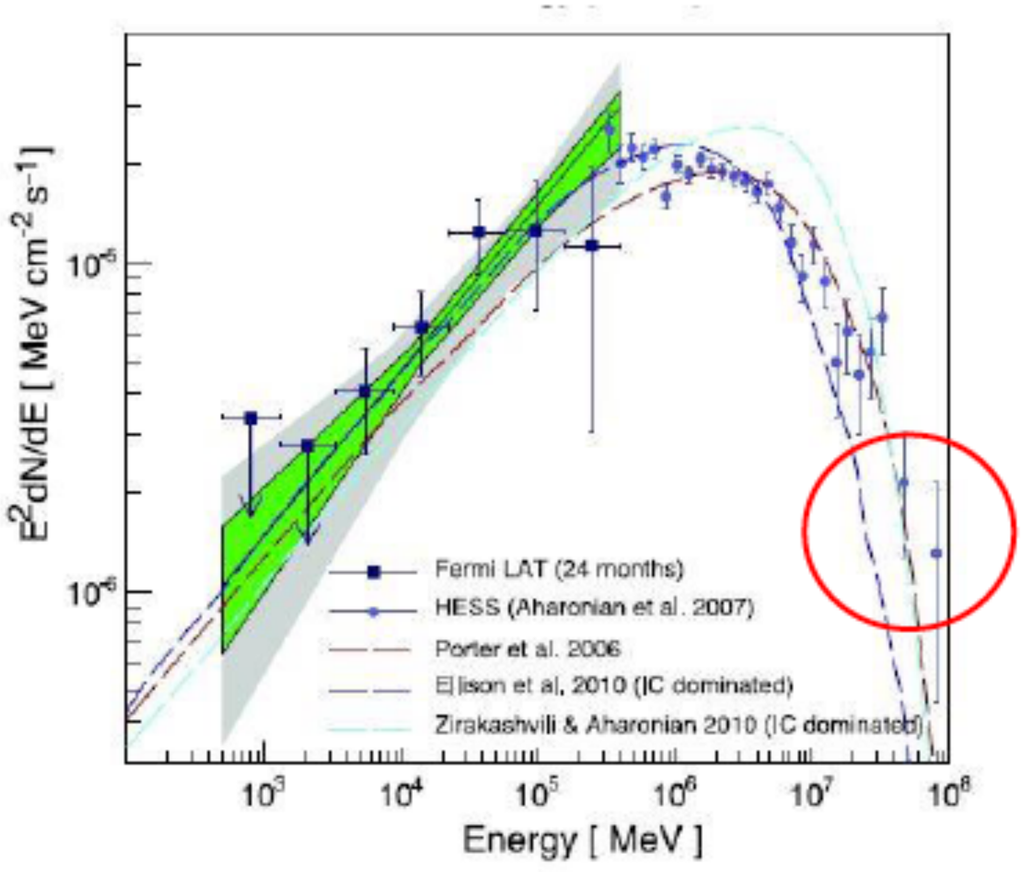


Data above 30 TeV are very scarce

=> LHAASO

SNR RX J1713.7-3946

the only SNR data above 30 TeV



The measurement of SNR spectrum above 30 TeV is very important !

=> LHAASO

Searching for CR sources

It is generally believed that cosmic rays of energy at least to the knee (~3 10^{15} eV) are accelerated in our Galaxy.

SNRs are the favorite sites for the acceleration of Galactic Cosmic Rays.

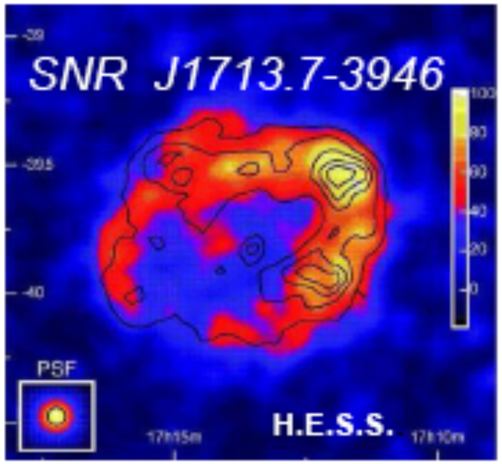
SN explosions could supply the total energy of Galactic CR if one assume that 10% of the SN kinetic energy is converted into CR motion.

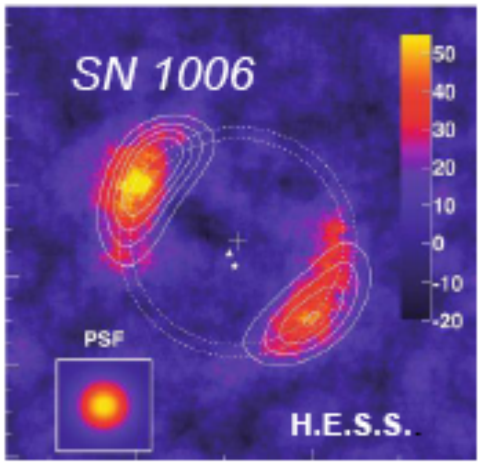
Diffusive Shock Acceleration (DSA) mechanism in young (< few 10^3 years) expanding SN shells can generate a power law spectrum of relativistic particles.

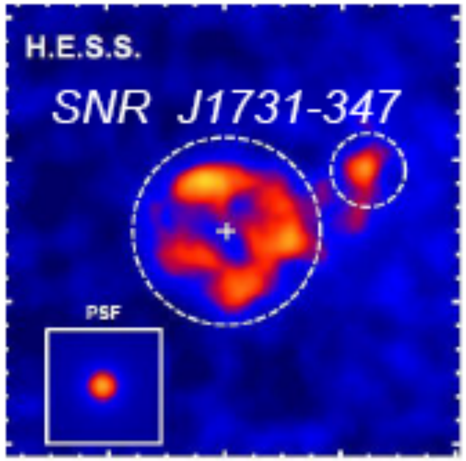
Searching for CR sources

Gamma rays up to a few TeV have been observed from ~10 SNRs.

The emission regions matches well the expanding shells or Molecular Clouds nearby.
=> Particles are effectively accelerated in the SNR shocks.

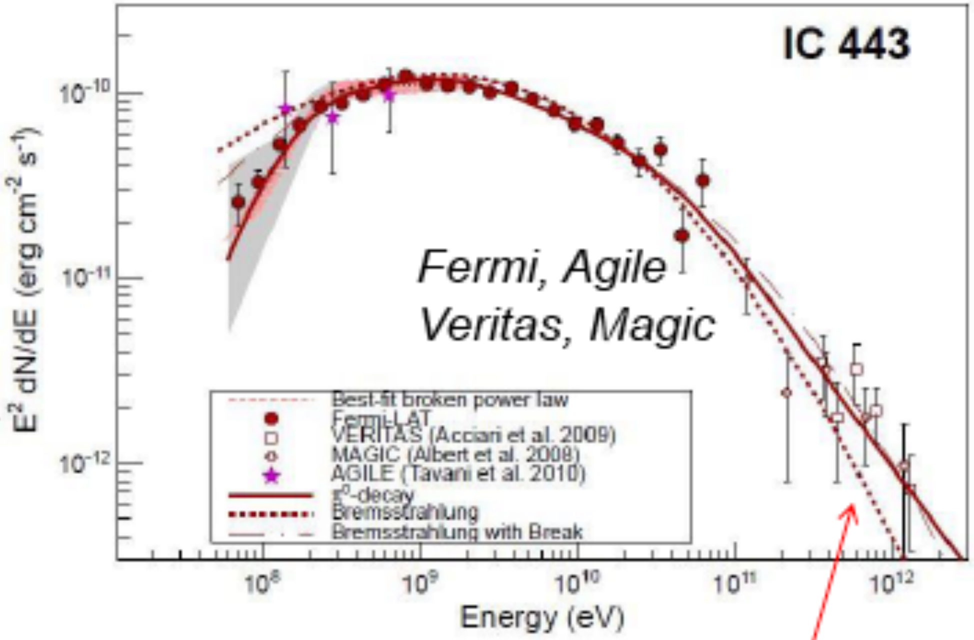


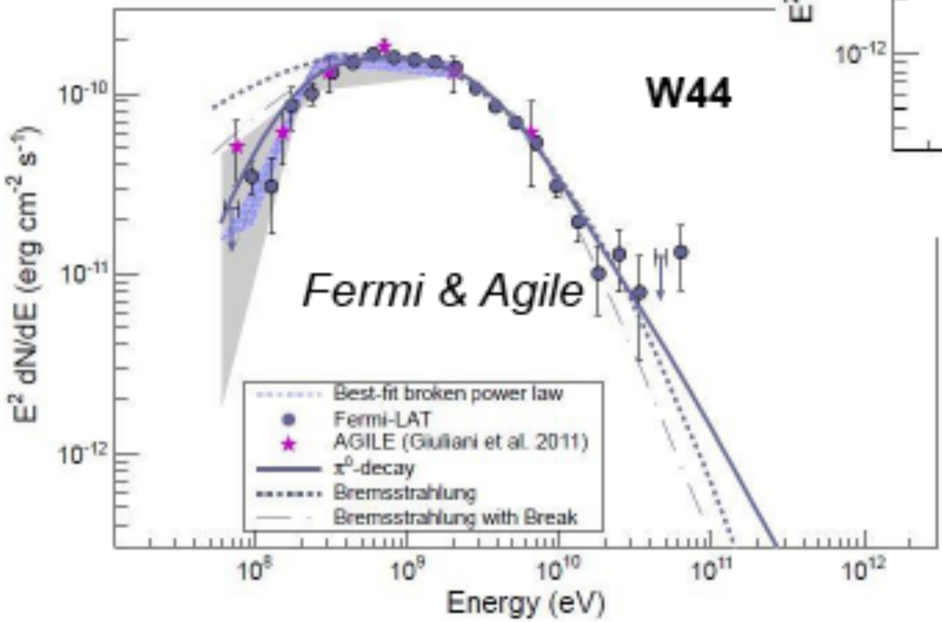




Possible observations of Pevatrons

Gamma ray spectra multiplied by E^2





Hadrons are accelerated up to a few tens of TeV

Spectra are very soft !

The relative contribution of protons and electrons to the observed flux is still unclear.
The proton energy doesn't seem to reach the Cosmic-Ray knee.

Searching for CR sources

Each SNR is individual and has a unique behavior.

In general one expects a combination of leptonic and hadronic emission.

A power law spectrum reaching 100 TeV without a cutoff is a very strong indication for the hadronic origin of the emission.

Inverse Compton is suppressed by the Klein Nishina effect.

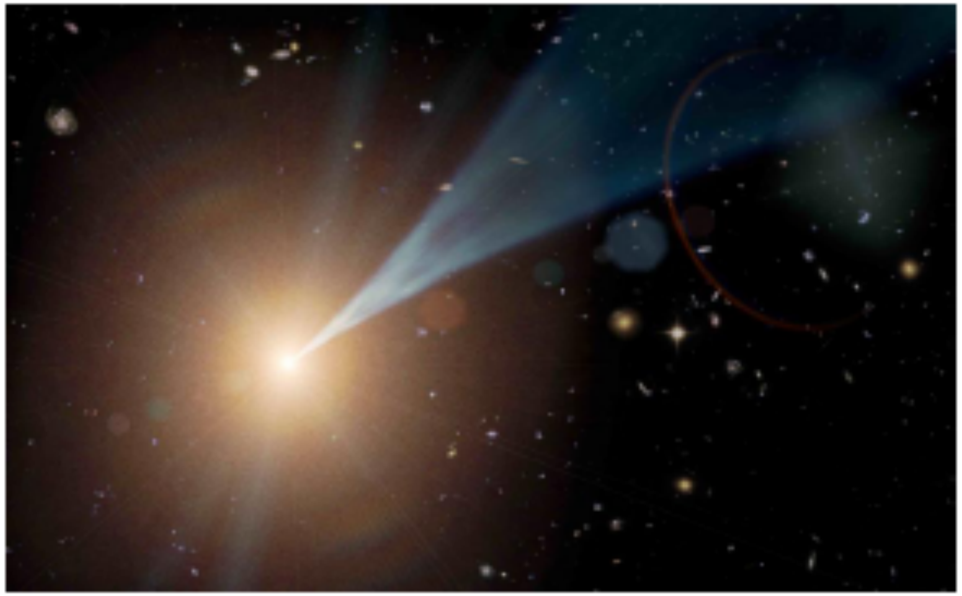
Photons of few hundreds of TeV are a clear signature of acceleration of 10^{15} eV protons.

Gamma ray astronomy above 30 TeV can allow to discover Pevatrons => LHAASO

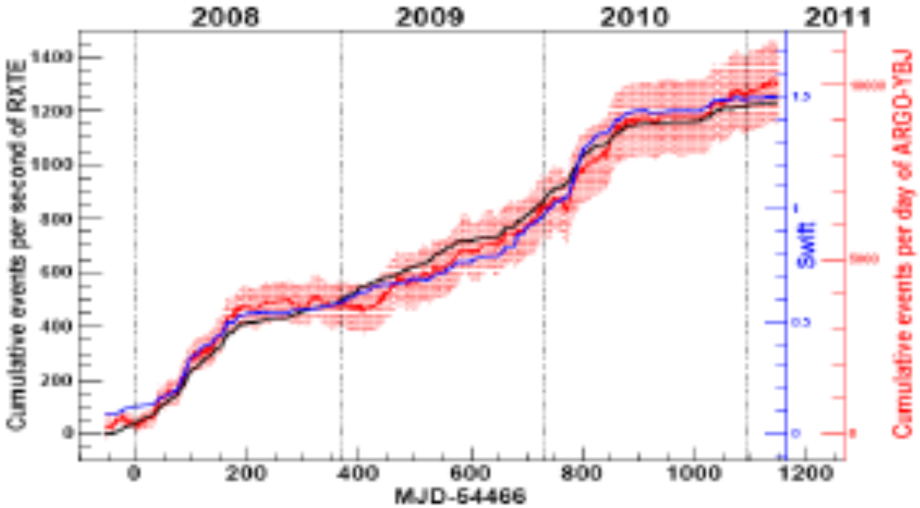
Study of source variability

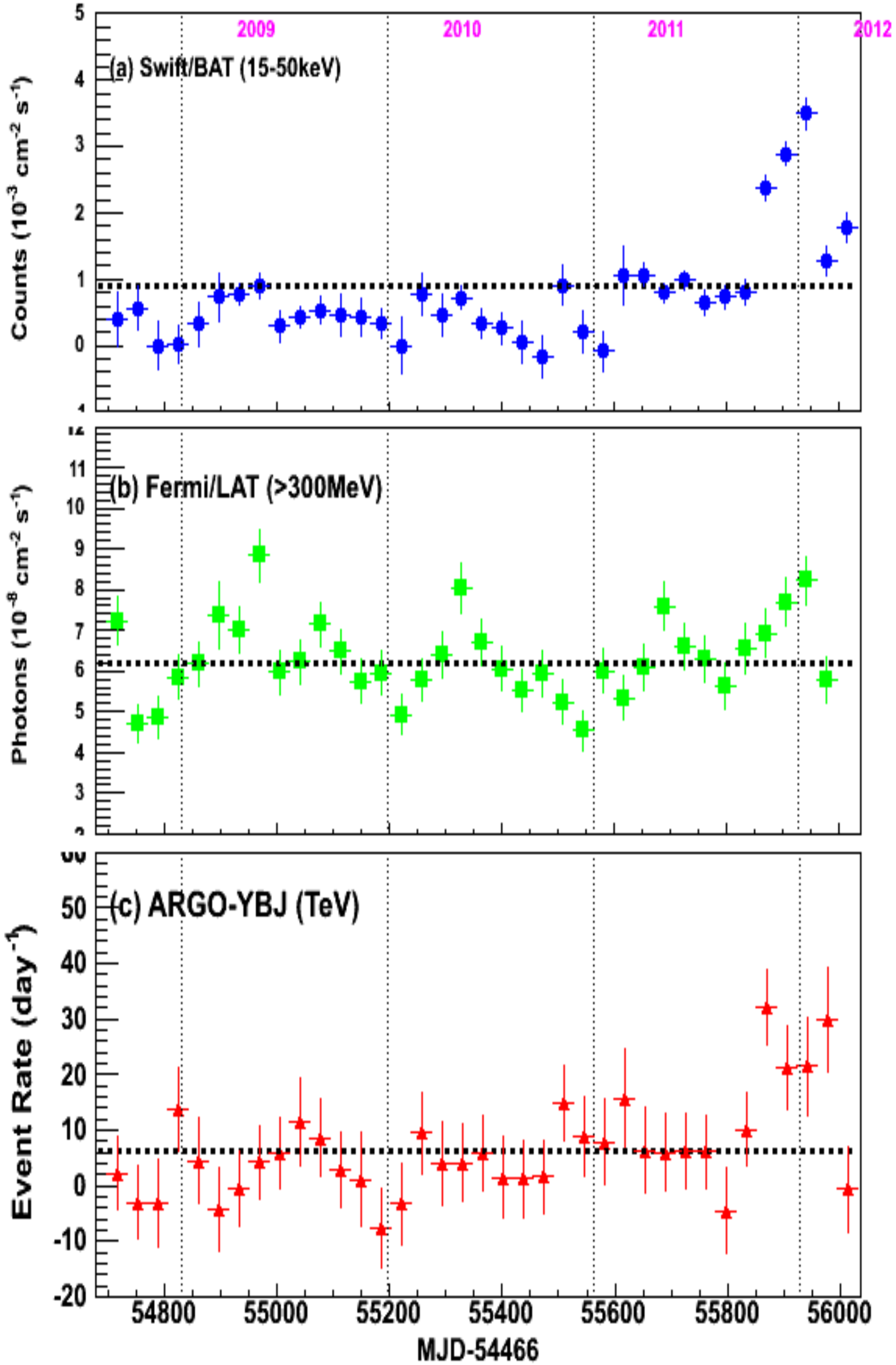
- The TeV blazars show variability of flux where the period varies from minutes to several months.
- Probing variability yields strong constrains on geometry, dynamics, emission processes.
- Different models will predict different correlations between low and high energy components.
- Thus, **long-term continuous multi-wavelength observations, especially at X-ray and TeV band,** are crucial to understand the emission mechanisms and underline processes of the outbursts.

Transient sources: Mrk421



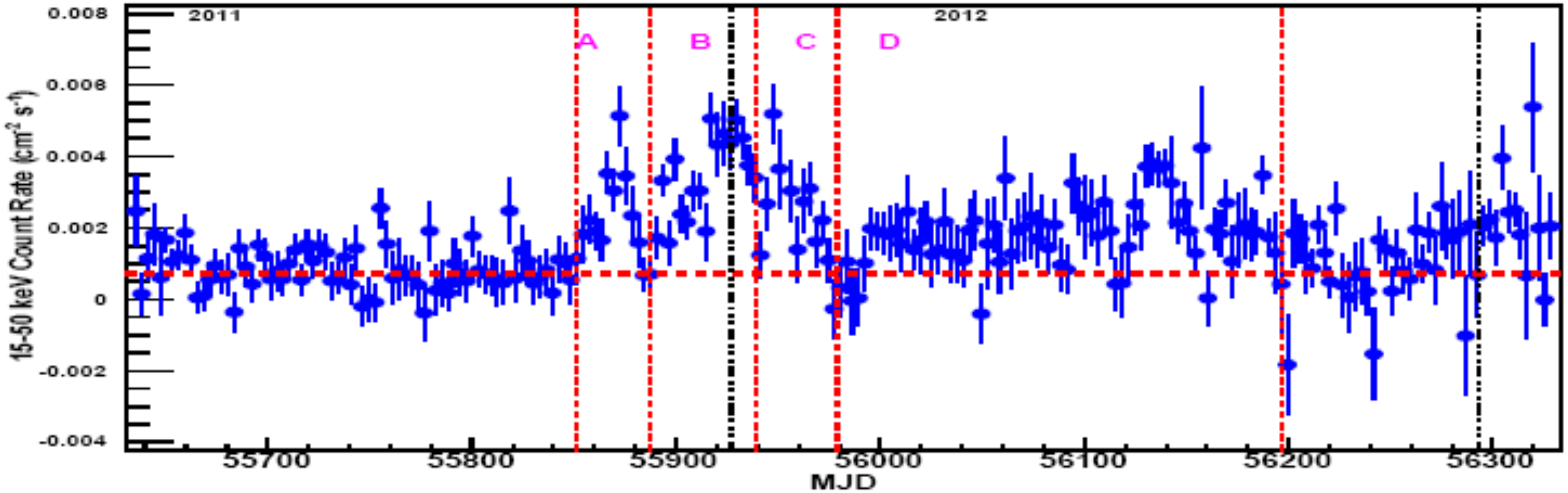
Transient AGNs：Mrk421





Transient sources: Mrk501

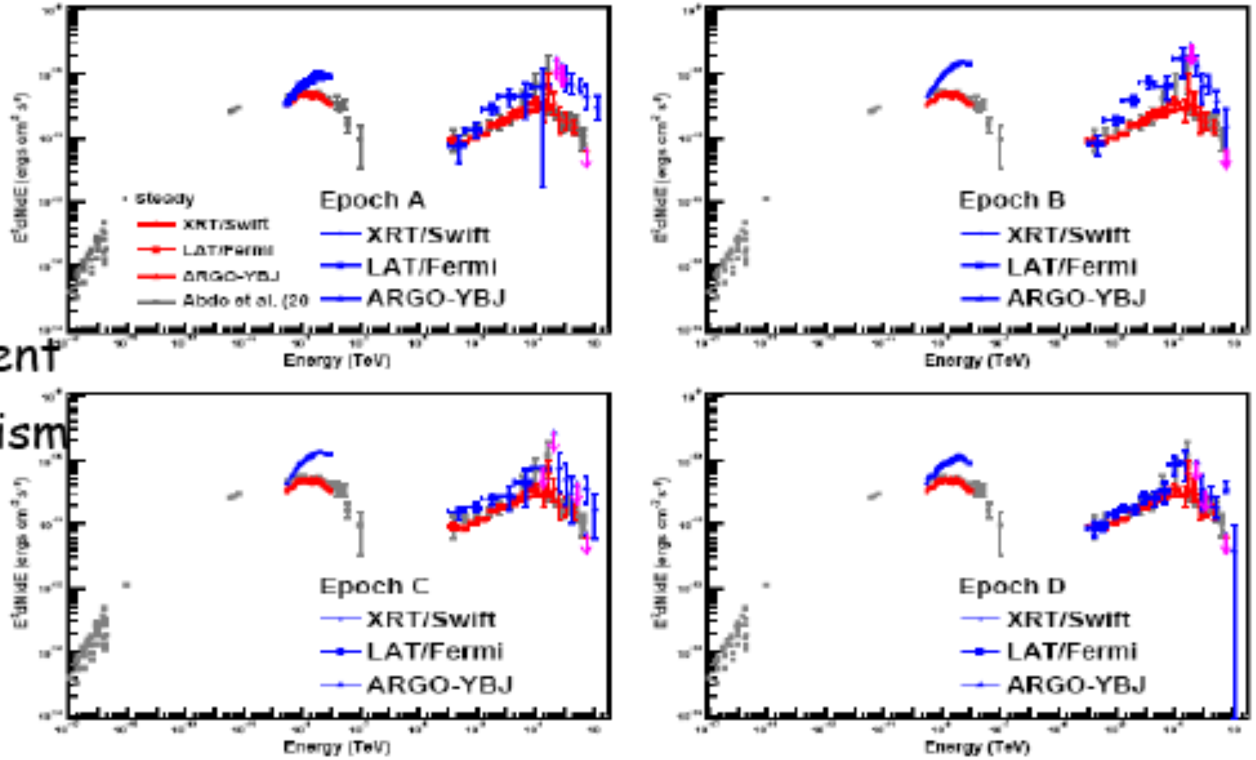
2011 flare of Mrk501 BAT/Swift



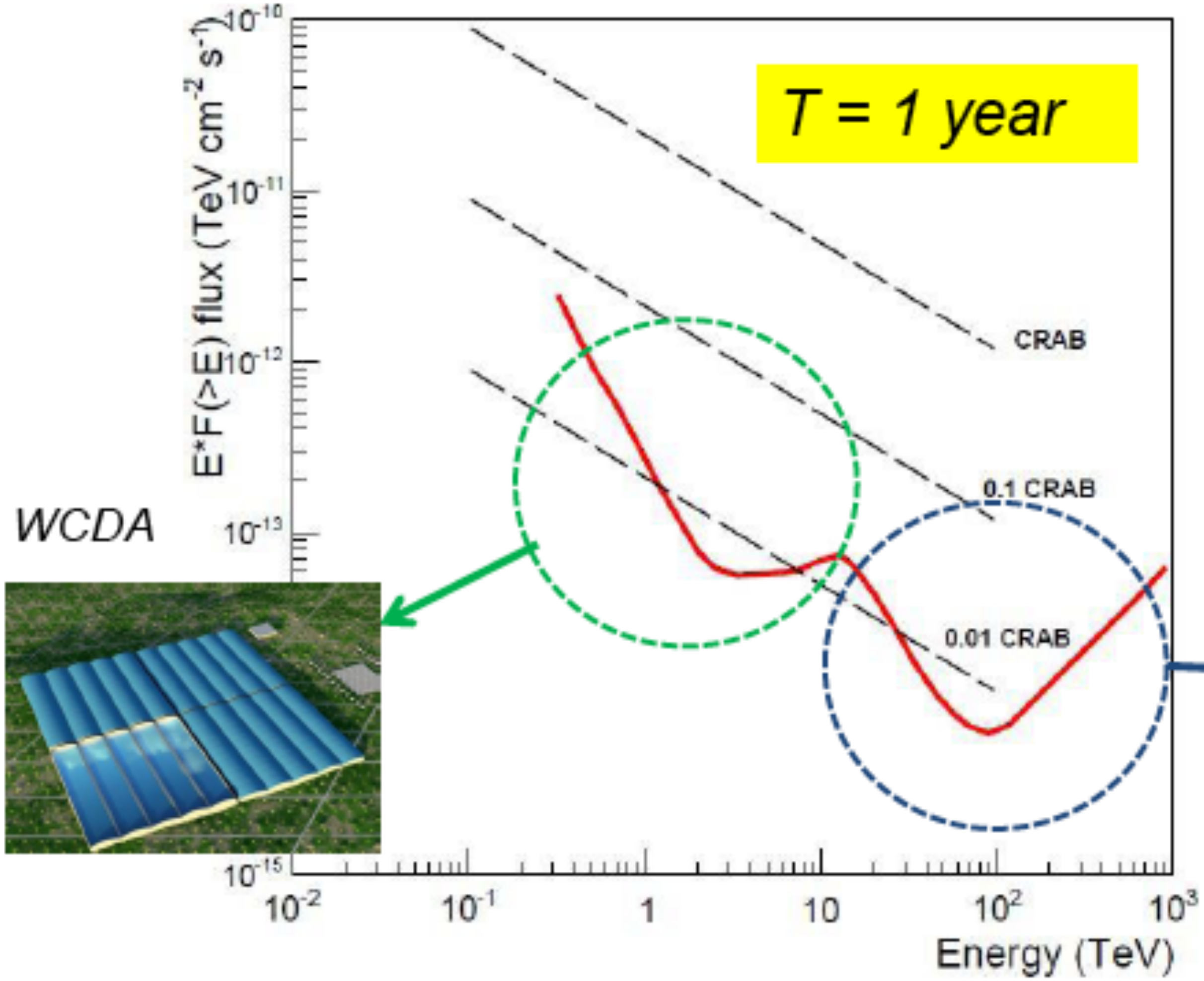
The evolution of the Spectrum during flares

IGMF measurement

Emitting Mechanism



LHAASO performances for gamma measurements



WCDA

Angular resolution:

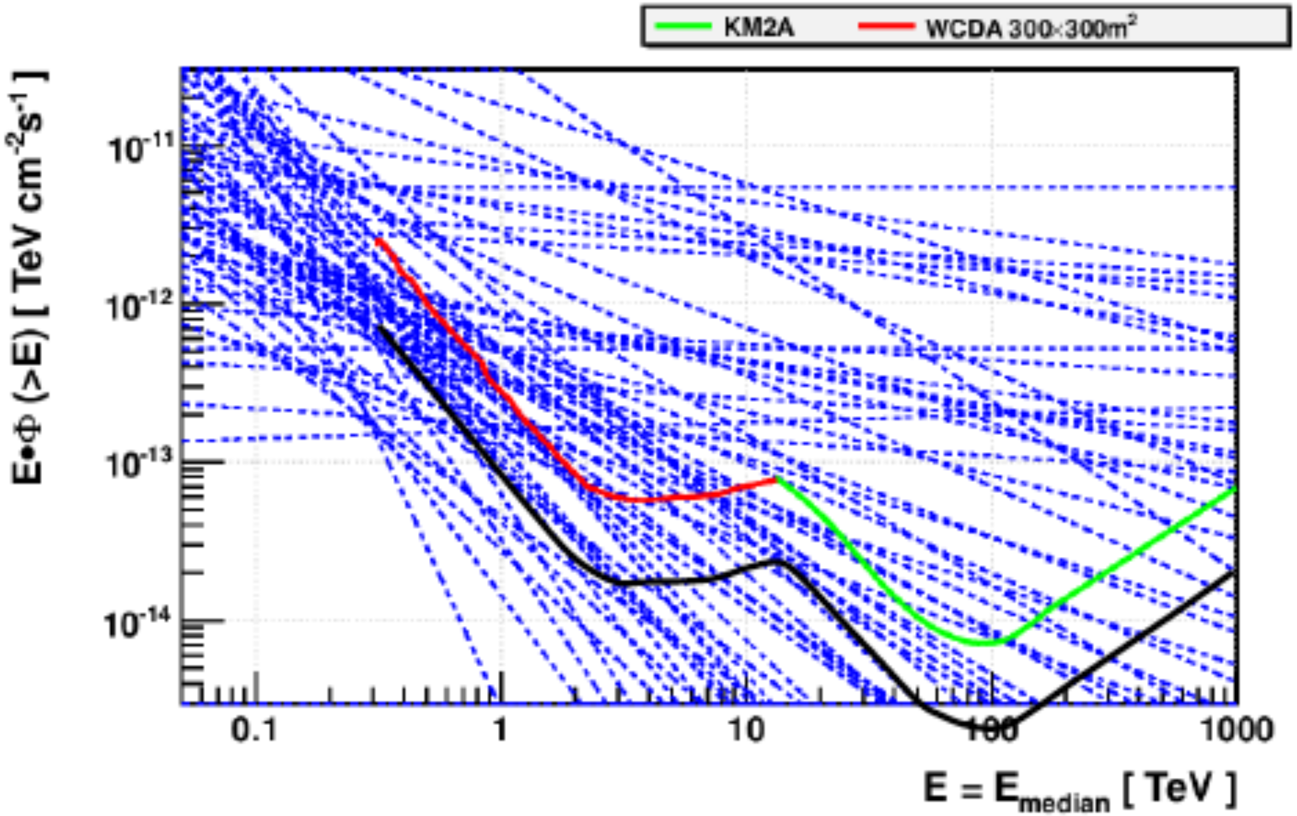
30 TeV ~ 0.4°
100 TeV ~ 0.3°

Energy resolution:

30 TeV ~ 30%
100 TeV ~ 20%

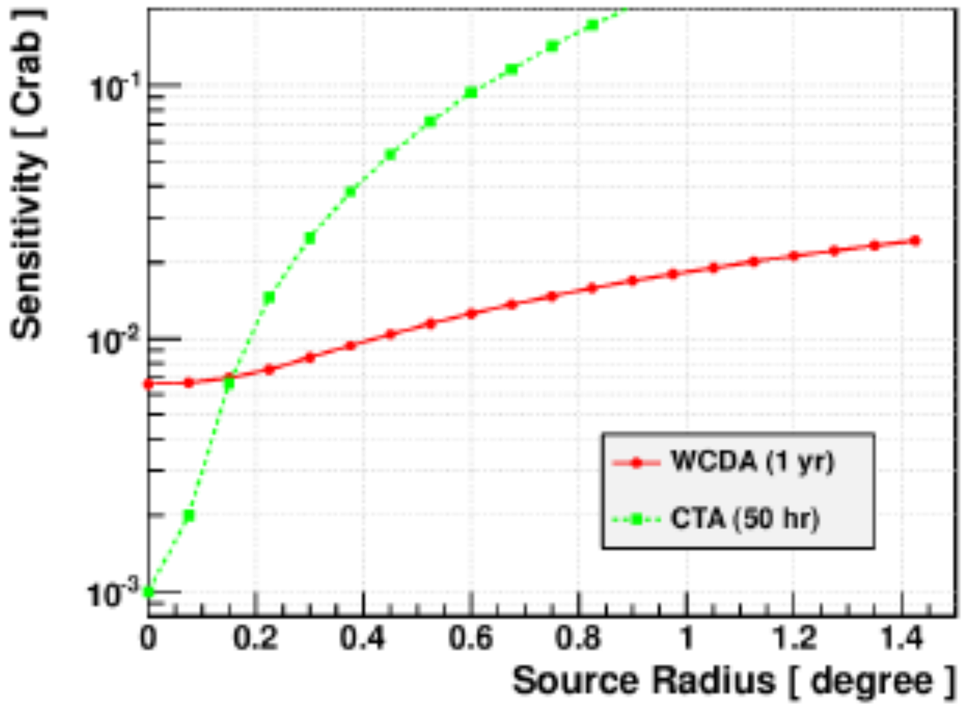
KM2A

LHAASO sensitivity to TeV sources



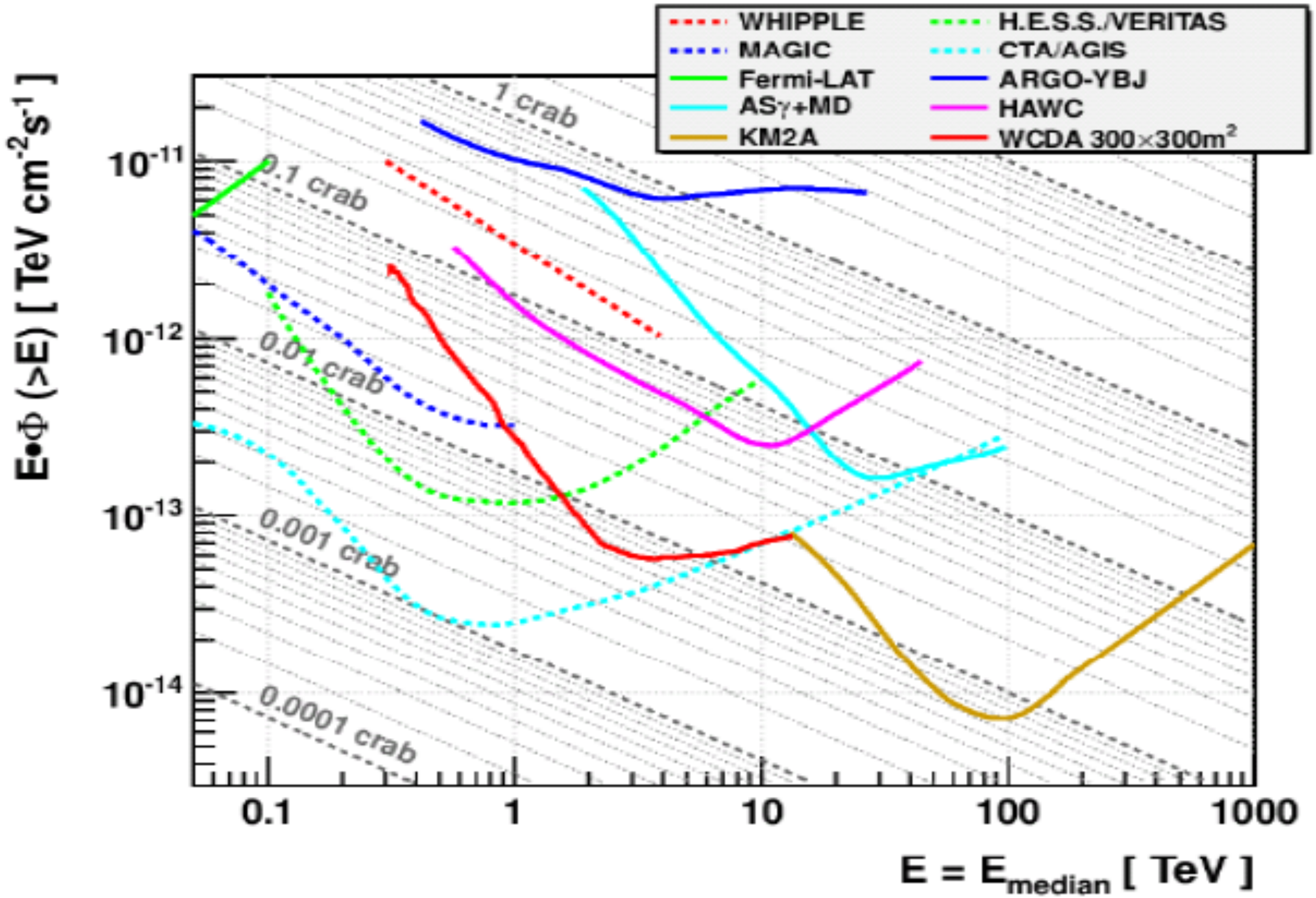
67 of 148 known TeVCat sources are in the LHAASO FOV.
For a very simple estimation, the EBL absorption and the spectrum cut-off is ignored.
80% of these sources can be detected by LHAASO in 1-2 year's operation.

LHAASO sensitivity to extended sources



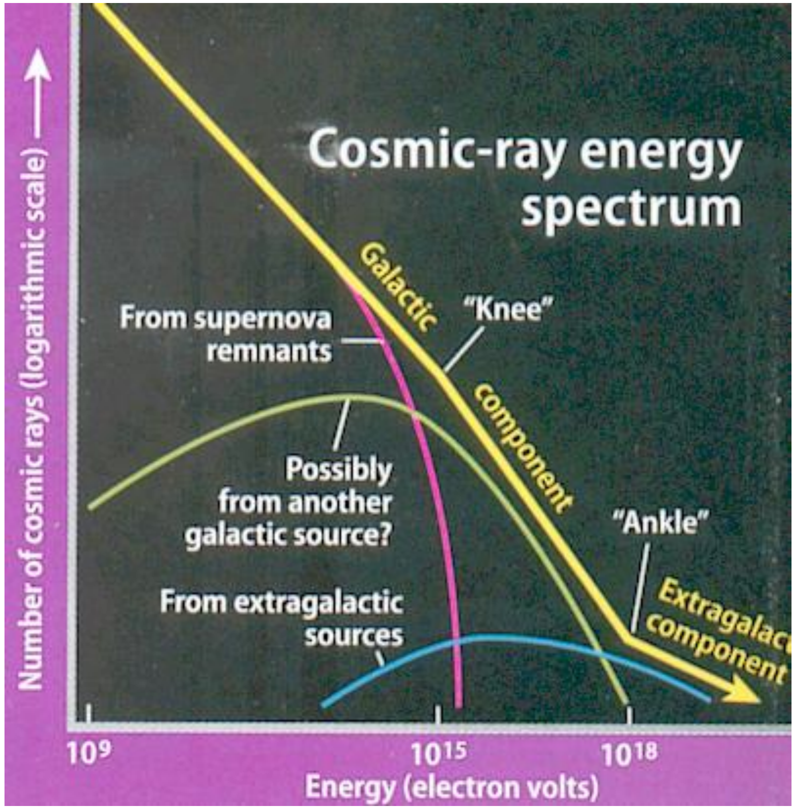
Sensitivity of LHAASO WCDA to extended sources as a function of size.
(The angular bin is optimized for the WCDA only.)

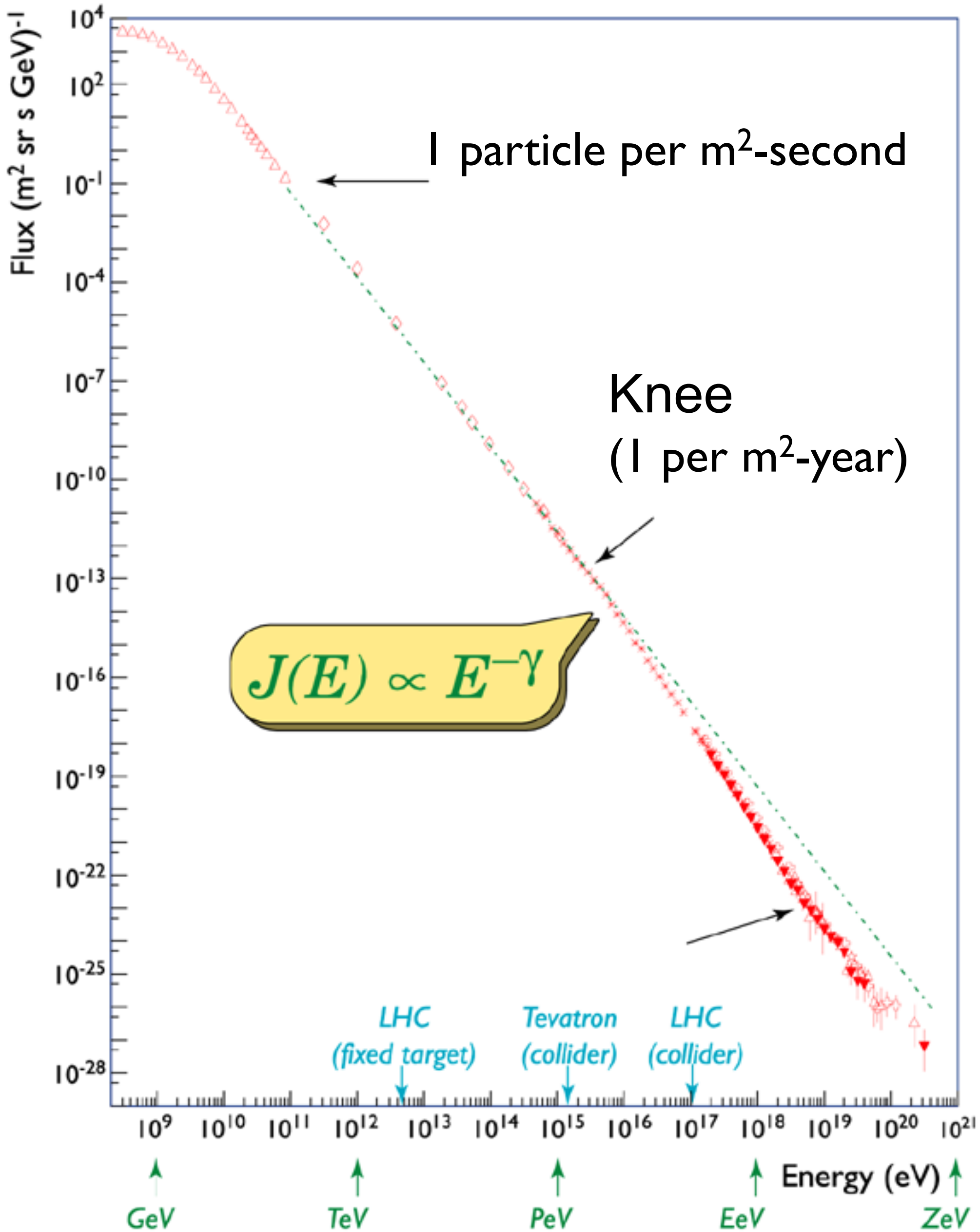
LHAASO sensitivity



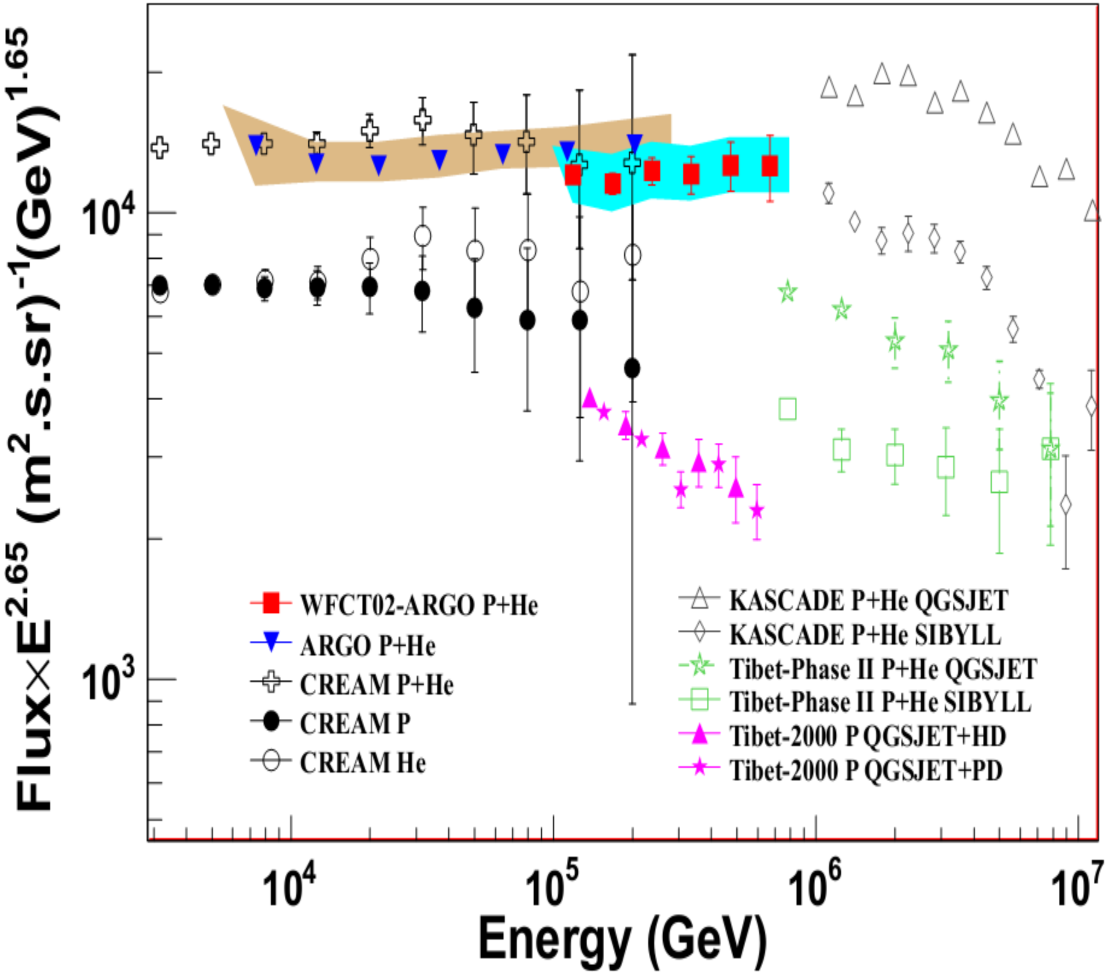
LHAASO science: Cosmic Rays

Measurement of Cosmic Rays above 30 TeV.

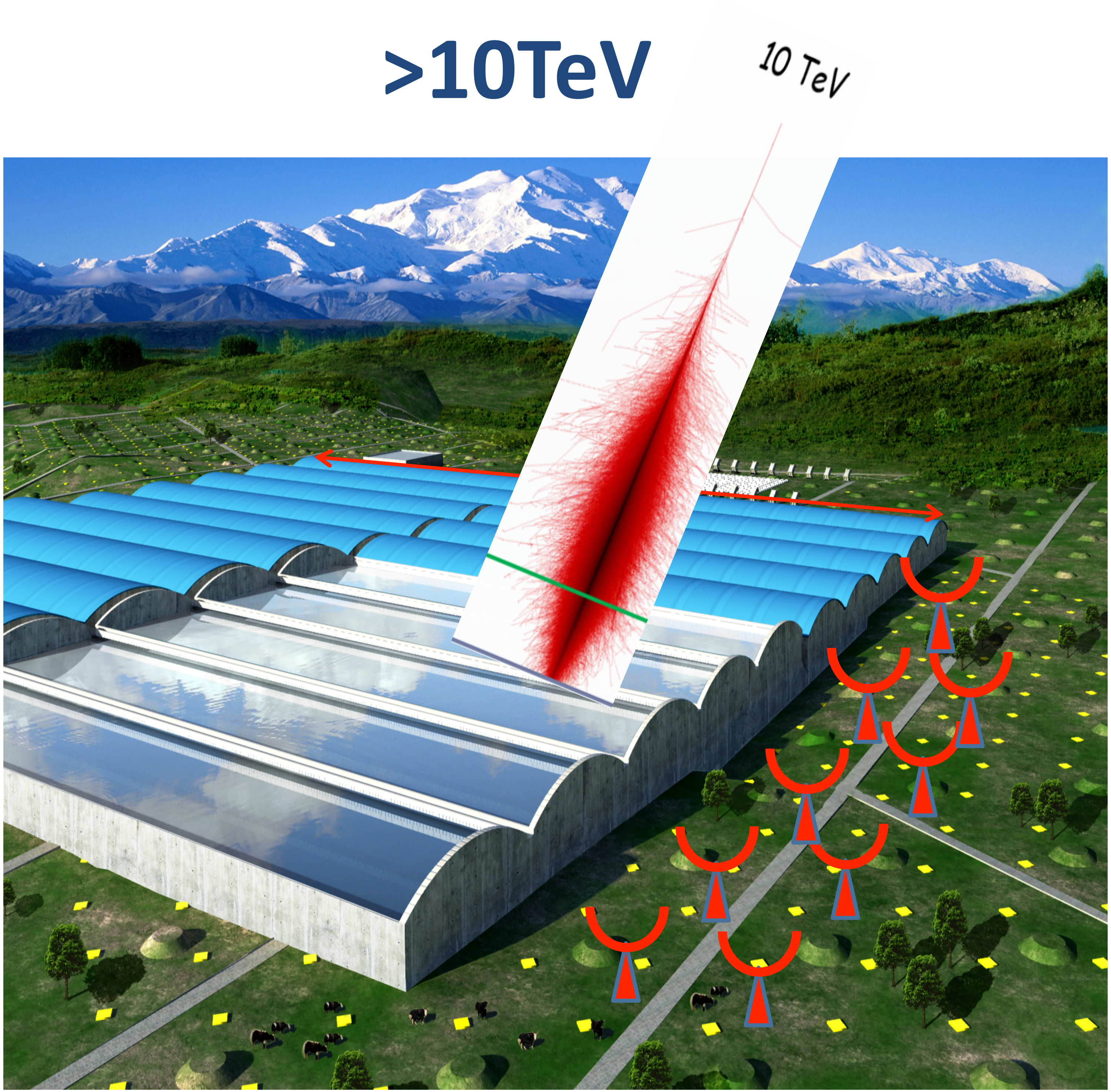




CR measurement with WFCTA prototype



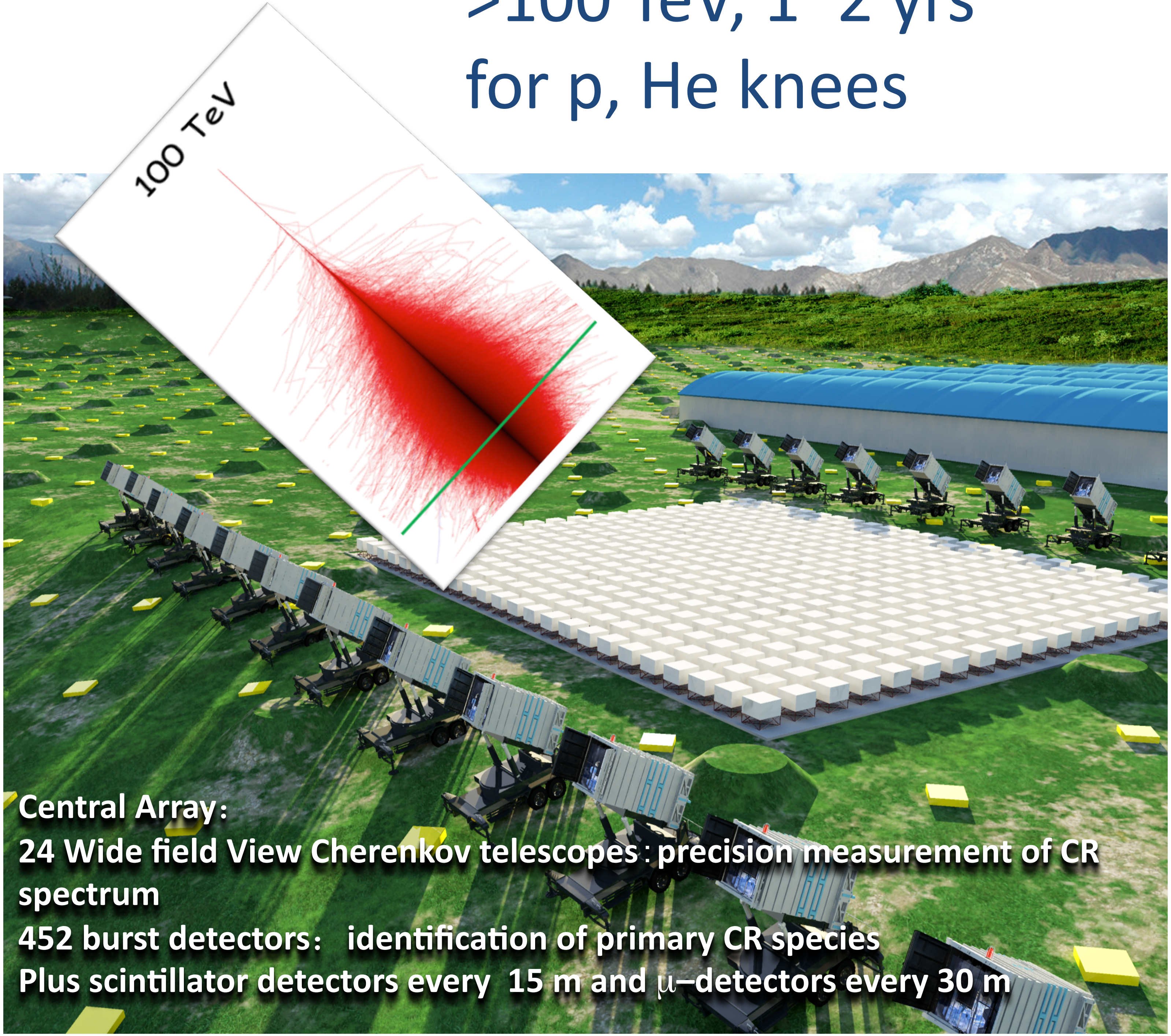
>10TeV



WFCTA + WCDA

E-Scale
Calibration for 1 yr, with moon shadow

>100 TeV, 1~2 yrs for p, He knees

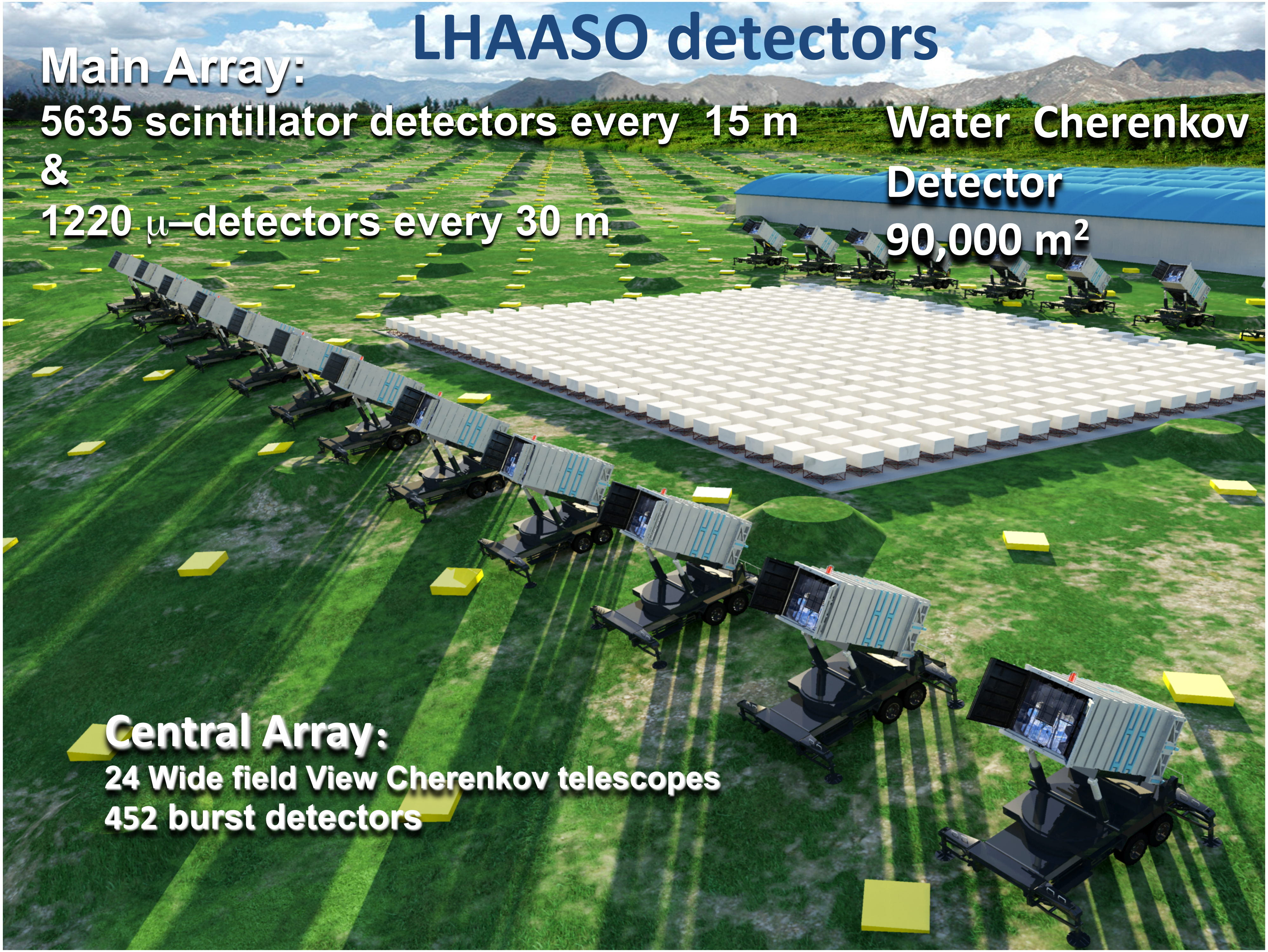


Central Array：

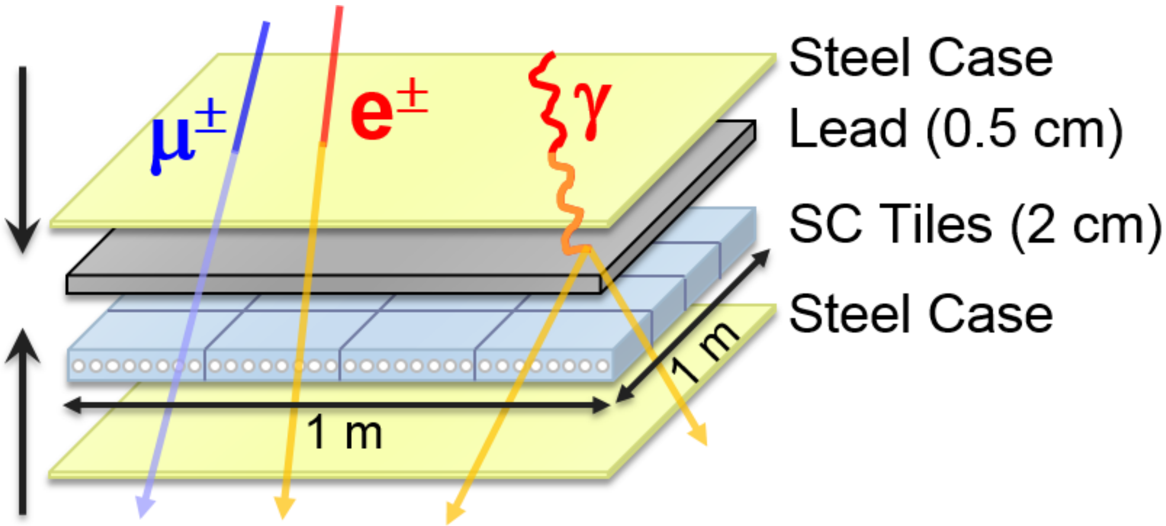
24 Wide field View Cherenkov telescopes：precision measurement of CR spectrum

452 burst detectors： identification of primary CR species

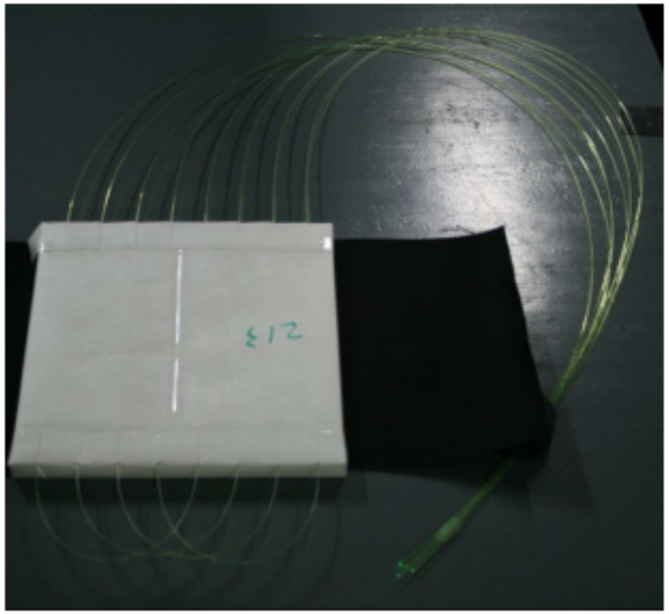
Plus scintillator detectors every 15 m and μ–detectors every 30 m


LHAASO detectors
Main Array:
5635 scintillator detectors every 15 m
&
1220 μ–detectors every 30 m
Water Cherenkov
Detector
90,000 m²
Central Array:
24 Wide field View Cherenkov telescopes
452 burst detectors

Electromagnetic Particle Detector (ED KM2A)



Each ED detector consists of 16 units, which are placed in one 1.6 m x 1.02 m x 0.08 m steel and waterproof box.

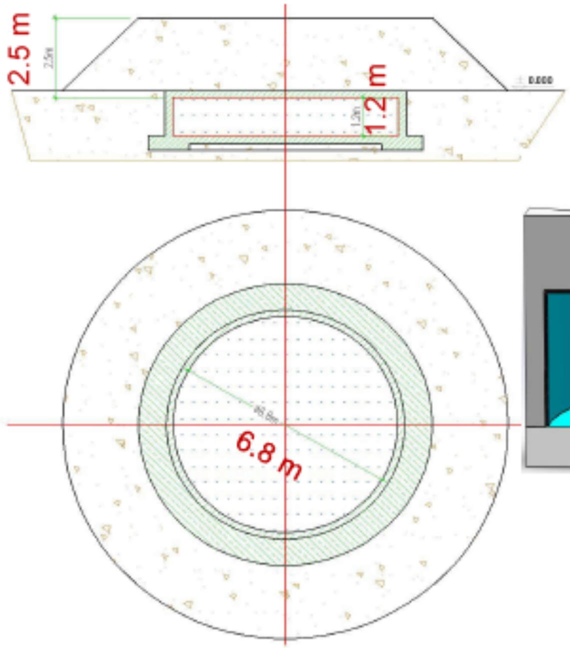


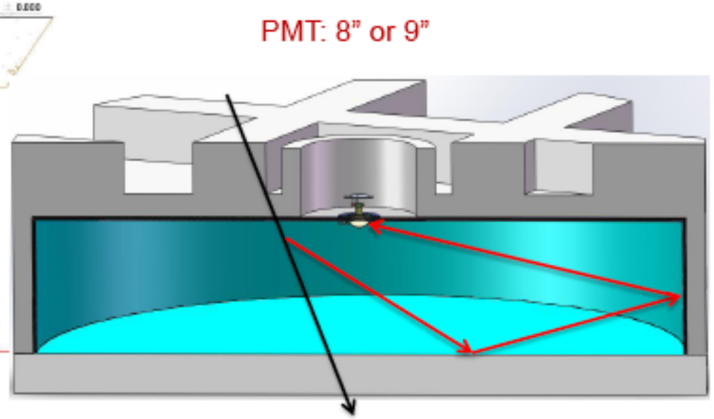
ED KM2A specifications

Item	Value
Effective area	1 m^2
Thickness of tiles	2 cm
Number of WLS fibers	8/tile×16 tile
Detection efficiency (> 5 MeV)	>95%
Dynamic range	1-10,000 particles
Time resolution	<2 ns
Particle counting resolution	25% @ 1 particle 5% @ 10,000 particles
Aging	>10 years
Spacing	15 m
Total number of detectors	5635

Muon Detector (KM2A MD)

7.2m diameter concrete tank with a sealed, reflecting liner containing 49 tons of purified water. Layer of 2.5m of dirt to absorb the electromagnetic component of the showers. 9” PMTs under study from HZC Photonics (Hainan, China).

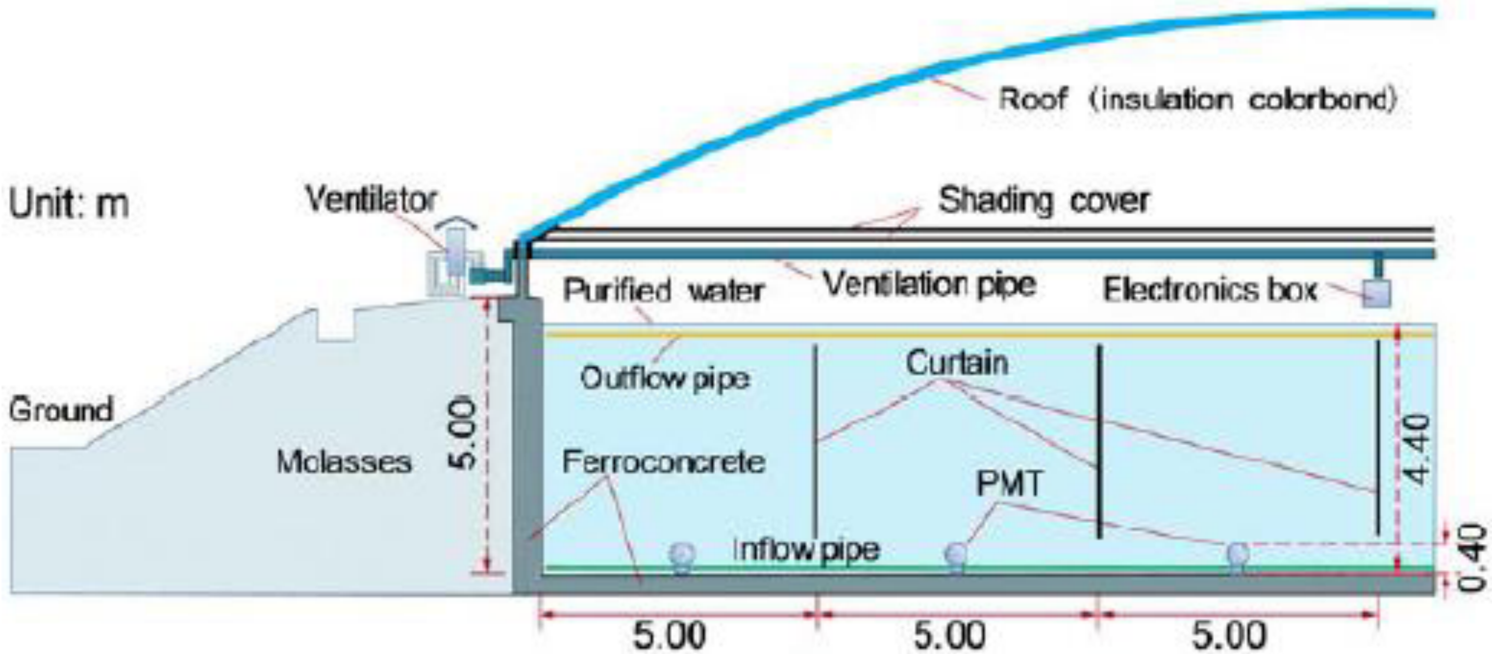


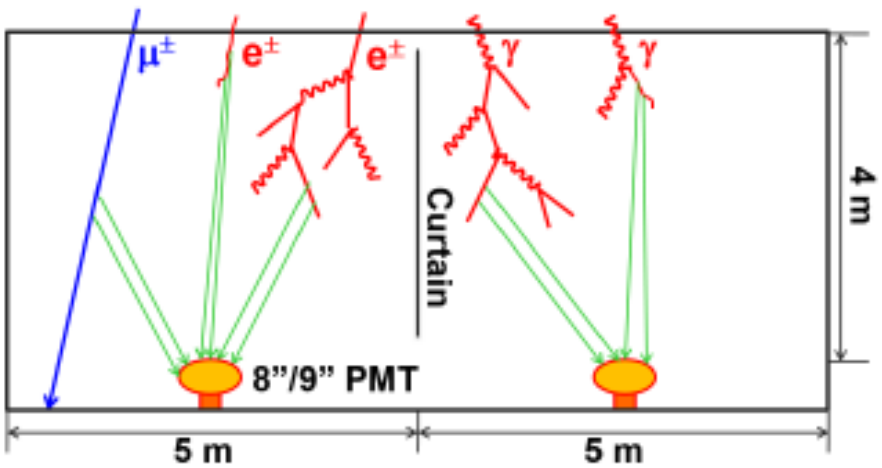


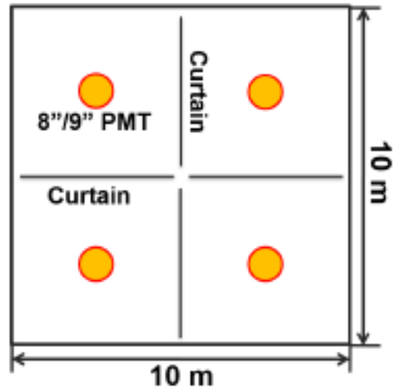
KM2A MD specifications

Item	Value
Area	36 m^2
Depth	1.2 m
Molasses overburden	2.5 m
Water transparency (att. len.)	> 30 m (400 nm)
Reflection coefficient	>95%
Time resolution	<10 ns
Particle counting resolution	25% @ 1 particle 5% @ 10,000 particles
Aging	>10 years
Spacing	30 m
Total number of detectors	1221

Water Cherenkov Detector Array (WCDA)



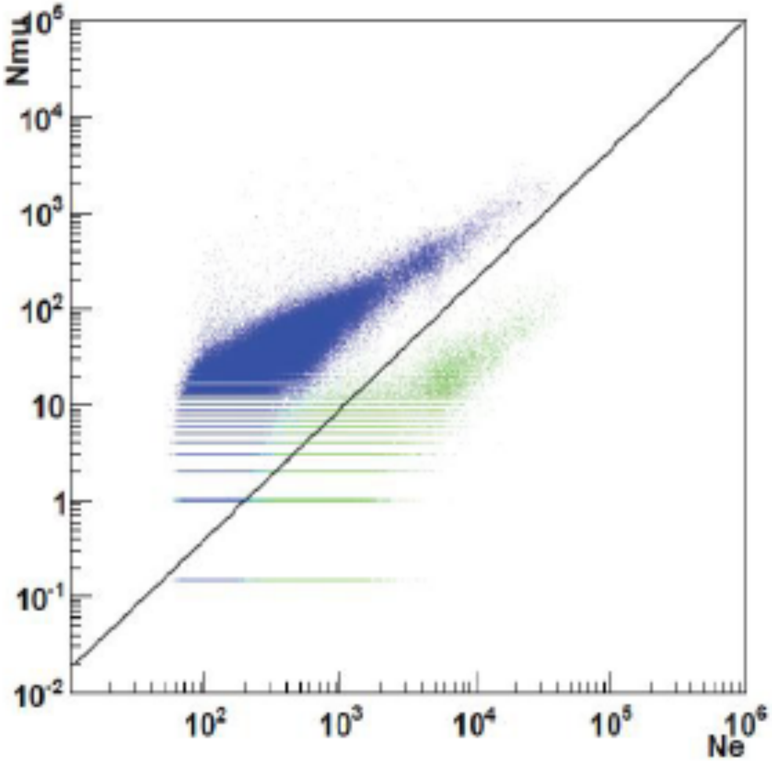




WCDA specifications

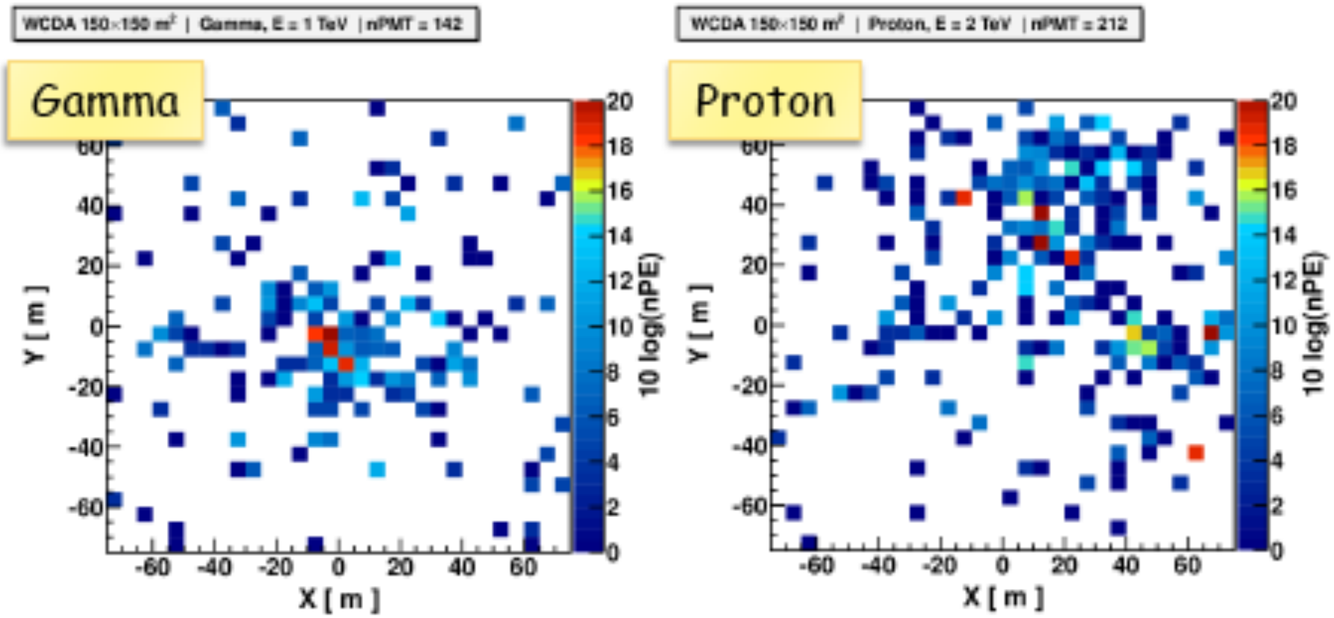
Item	Value
Cell area	25 m^2
Effective water depth	4 m
Water transparency	> 20 m (400 nm)
Precision of time measurement	0.5 ns
Dynamic range	1-4000 PEs
Time resolution	<2 ns
Charge resolution	40% @ 1 PE 5% @ 4000 PEs
Accuracy of charge calibration	<2%
Accuracy of time calibration	<0.2 ns
Total area	90,000 m^2
Total cells	3600

Gamma/proton discrimination – KM2A



nHit	log_{10}(E) GeV	Q-factor
20-30	3.60	2.67
30-45	3.87	5.62
45-65	4.12	11.9
65-90	4.35	20.7
90-120	4.55	46.4
120-180	4.76	86.6
180-260	5.03	backgroud free
260-360	5.28	backgroud free
360-500	5.53	backgroud free
500-700	5.82	backgroud free
700-1000	6.11	backgroud free

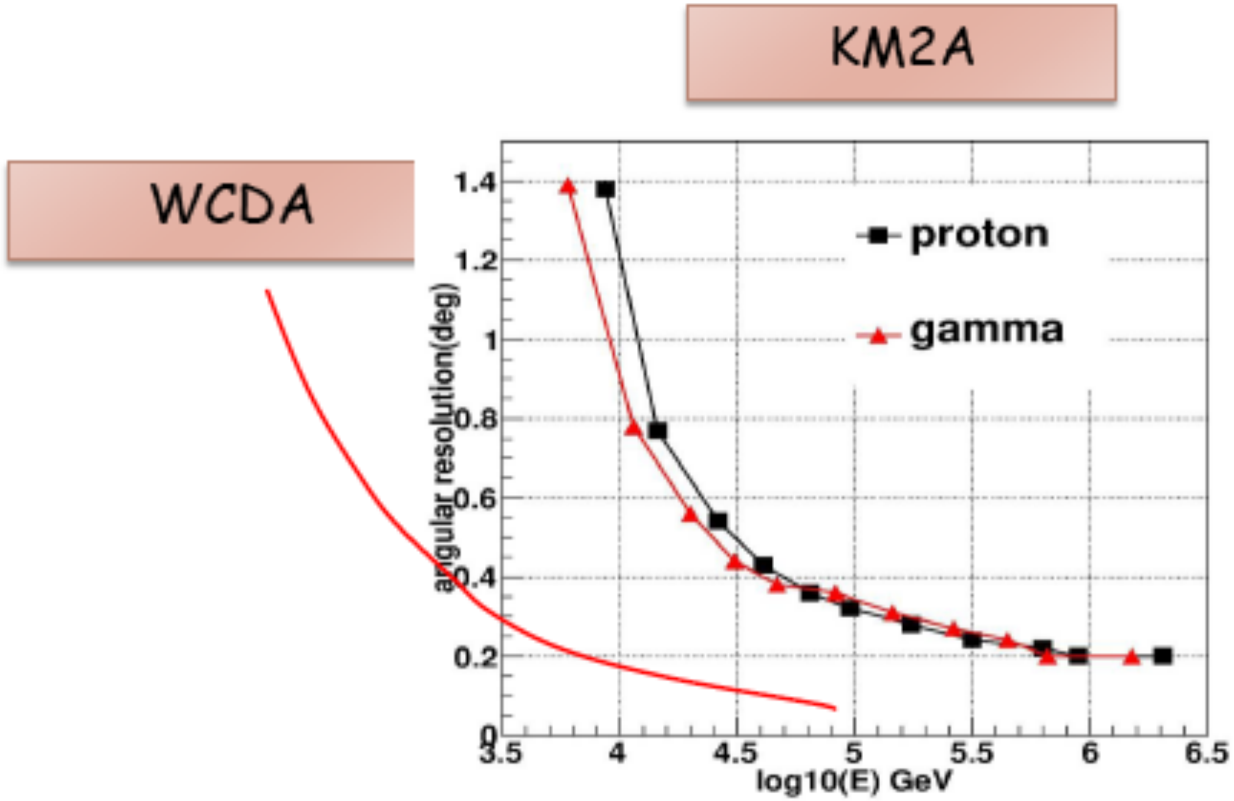
Gamma/proton discrimination – WCDA



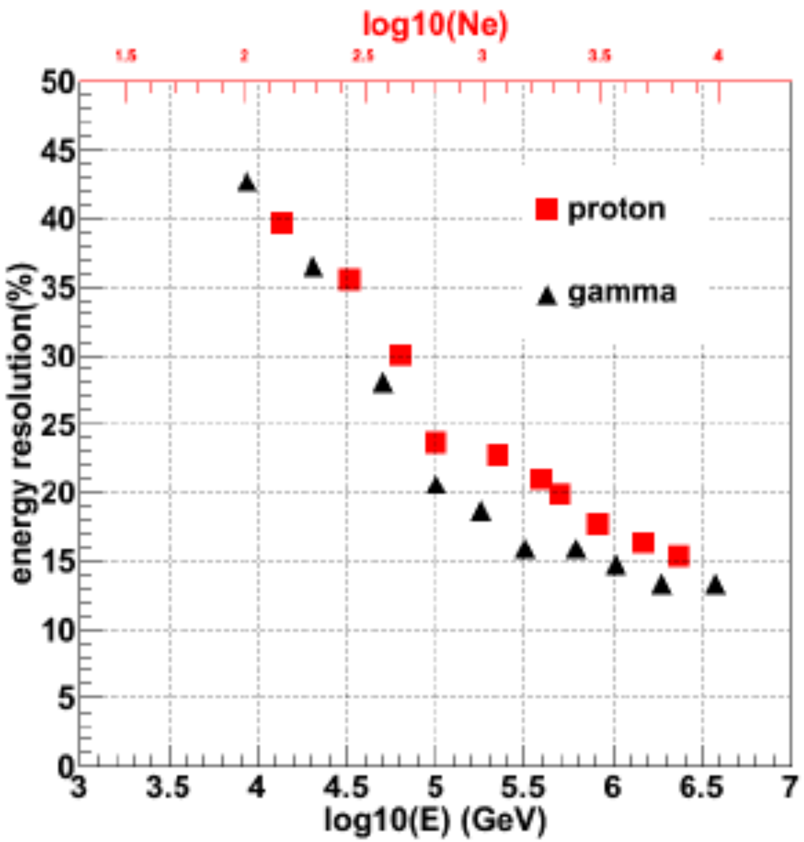
Brightest “sub-core”:
Signal of the brightest PMT outside the shower core region (e.g., 45 m).

“Compactness” can be employed to reject cosmic ray background efficiently.

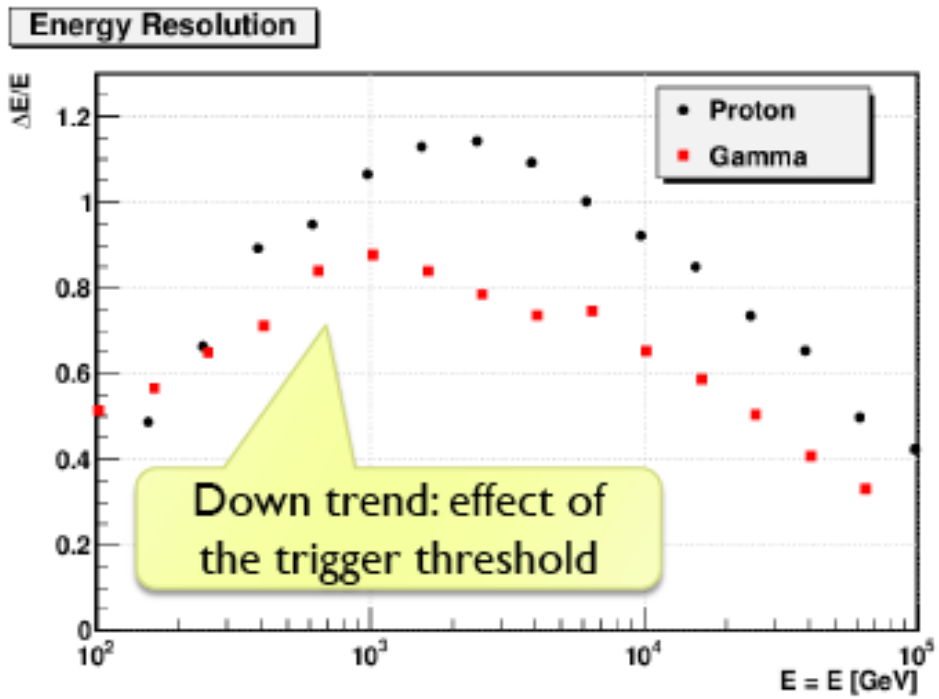
Angular resolution



Energy resolution



KM2A



WCDA

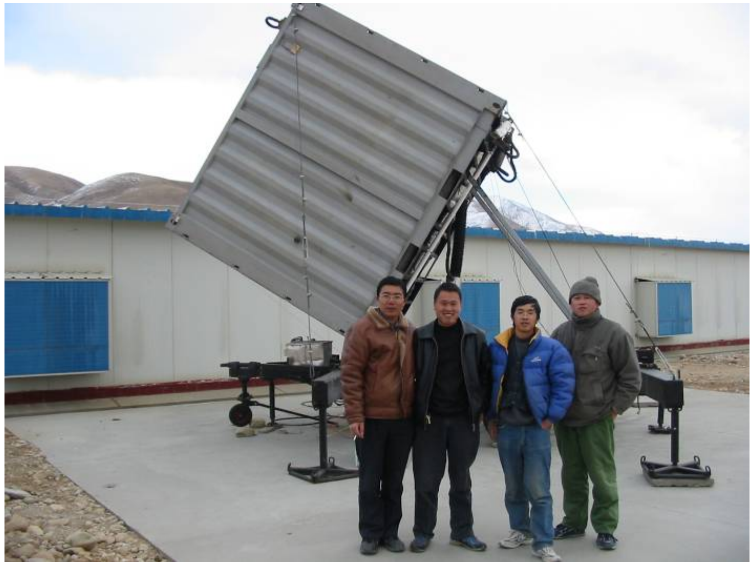
WFCTA telescopes

Spherical mirrors and a camera composed of PMTs.

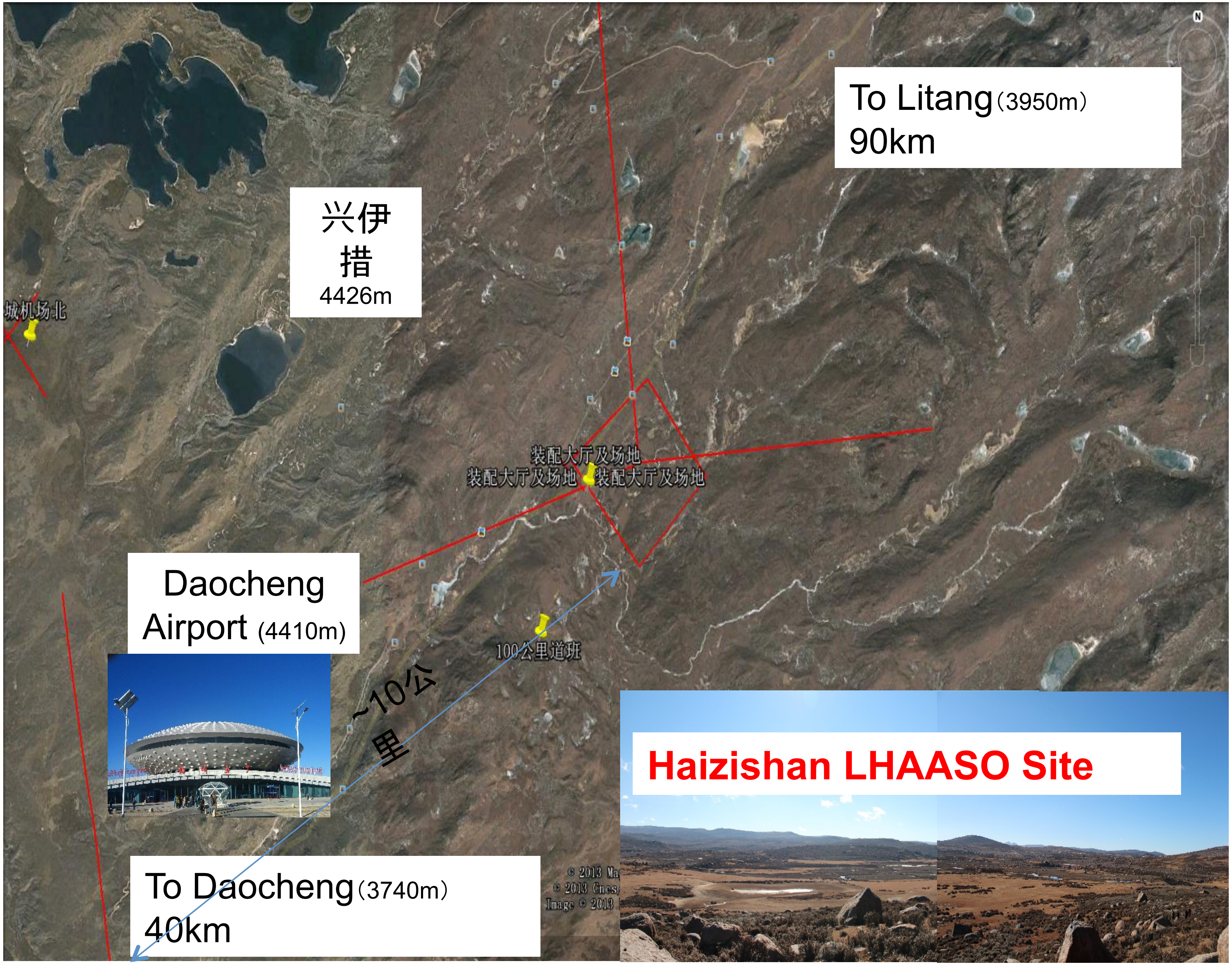
Total FOV of 14°x16°

Two prototype telescopes taking data on ARGO-YBJ site.

Prototype detectors on ARGO-YBJ site



LHAASO site in Sichuan



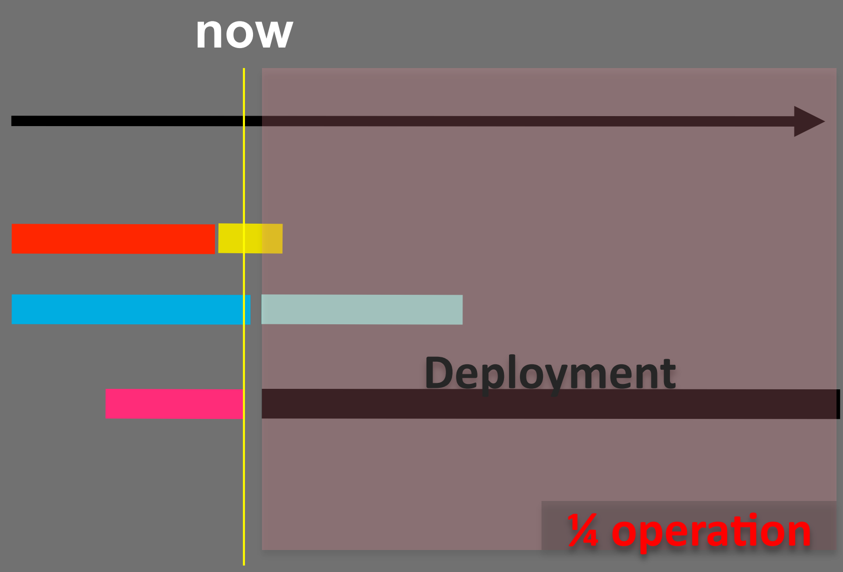
Geological survey is done

and

Civil Construction Design starts

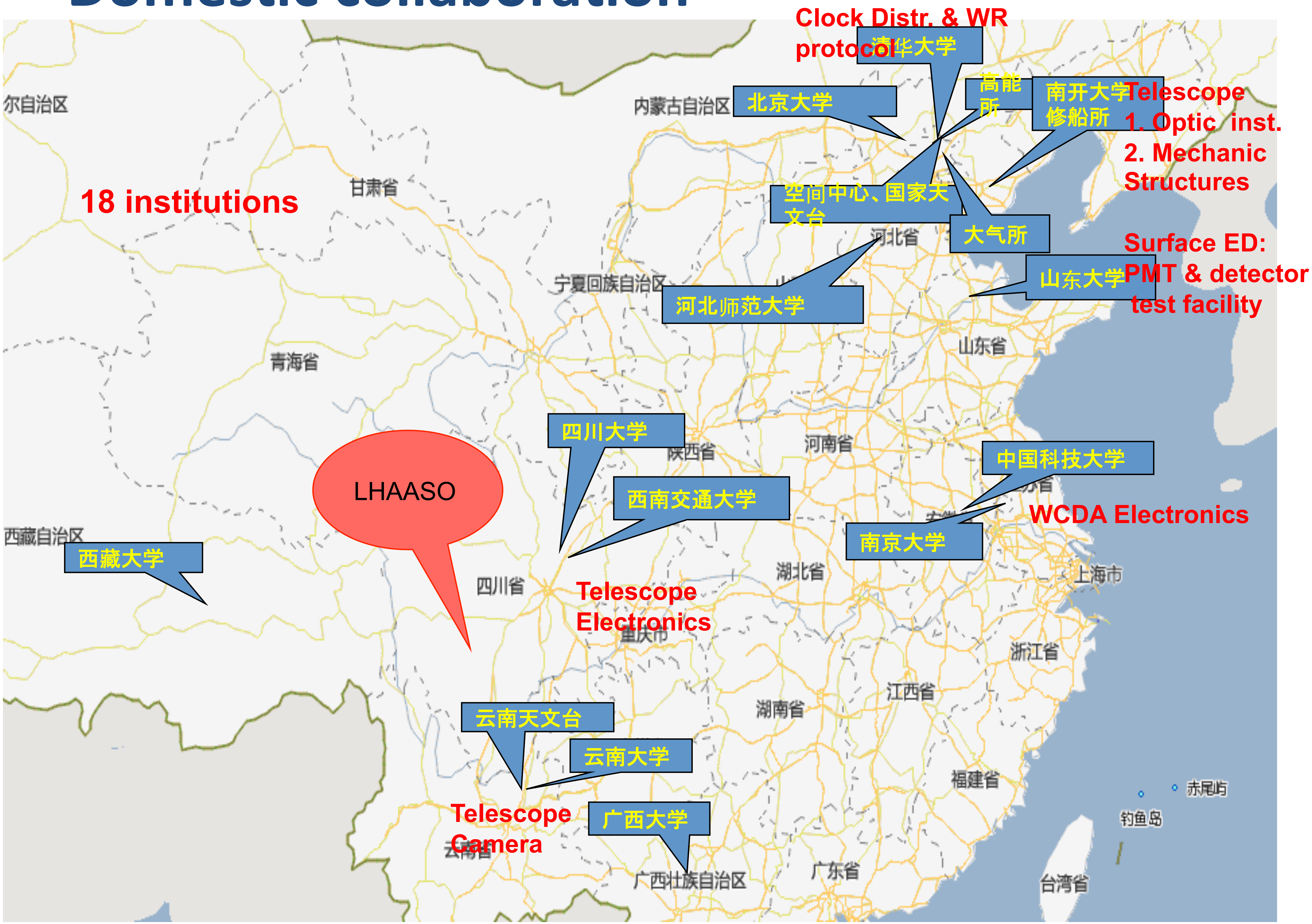
Schedule

- Detector R/D： 1.5yr
- Electronics R/D: 2 yr
- Production: 1.5 yr
- DAQ R/D 0.5 yr
- Deployment: 4 yr
- 1%prototype Oper: 1 yr
- ¼ operation： 2 yr



	LHAASO construction（month）
Civil construction	24
Detector production	36
Deployment	36
¼ operation	28
Full operation	2

Domestic collaboration



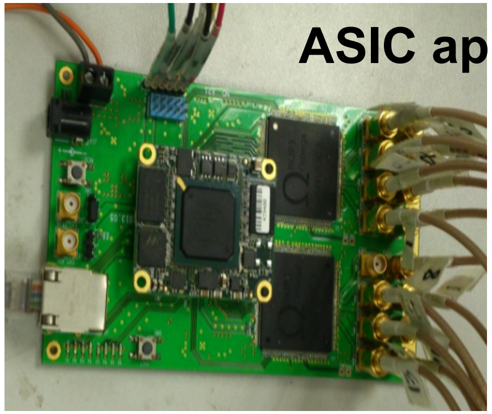
International collaboration

- Collaboration with IPN-Orsay and OMEGA

  CAS project for the China-France collaboration: 1.1 M CNY

  2 PhD students funded by CSC (China)

  T.S. visiting professor of CAS



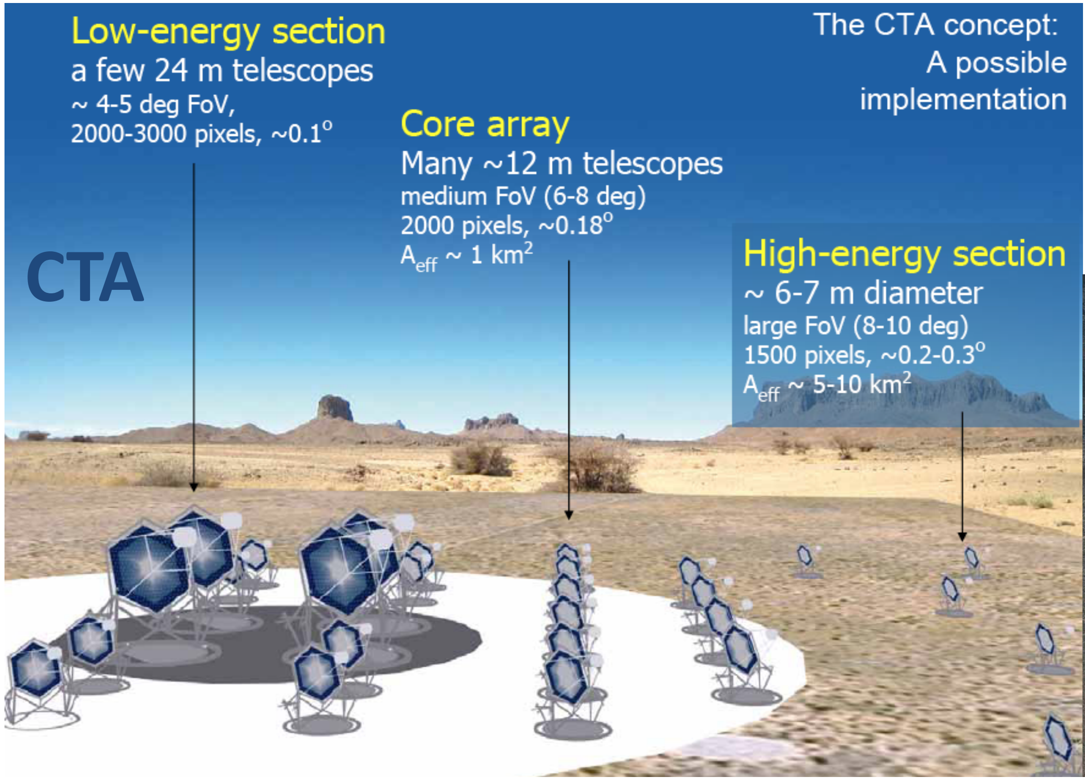
ASIC appl.

- Italian colleagues are proposing for gamma Astronomy with LHAASO (submitted to INFN)

- Collaboration with Russian colleagues for neutron detectors

- Collaboration with Thailand solar CR group

LHAASO complementary to CTA and HAWC



HAWC

Mexico, 4200m a.s.l.

<u>LHAASO:</u>
Continuous, wide field of view survey
Study of extended sources
Higher energies than CTA (CR origin)
Source variability monitoring
<u>CTA:</u>
Detailed source morphology and spectroscopy studies

HAWC and LHAASO are at about the same latitude (28°N) but opposite sides of the globe. Together they provide continuous survey of the Northern hemisphere !

Conclusions

- LHAASO observatory
  - Unique at >10 TeV gamma monitoring
  - Window for evidence of Galactic CR Pevatrons
  - Provides also crucial CR data in the region of knees.
- LHAASO has been selected for funding in China.
- The site is approved and civil construction starts this year.
- Domestic collaboration: 18 institutions
- International collaboration is growing.