Gamma Ray Astronomy with LHAASO

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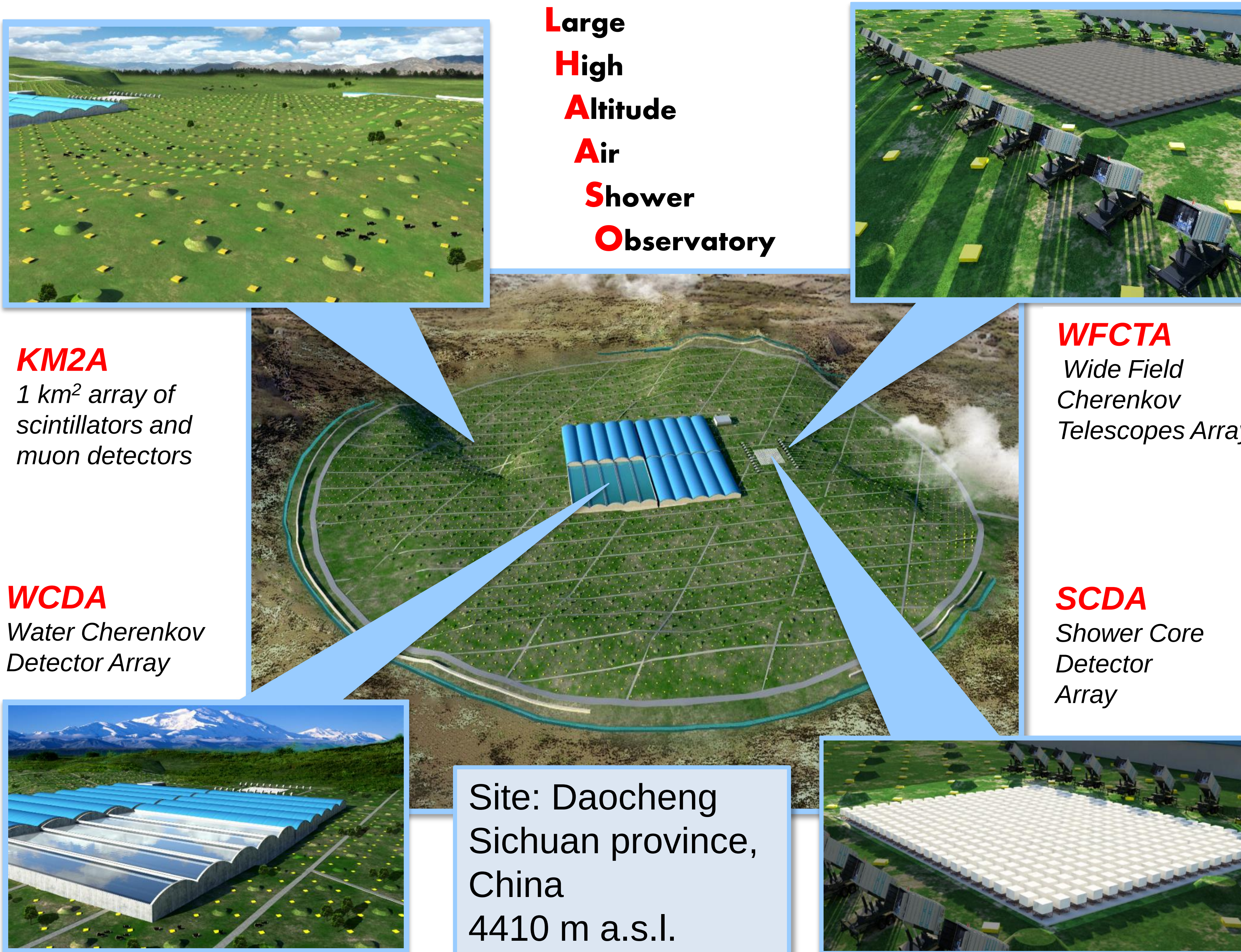
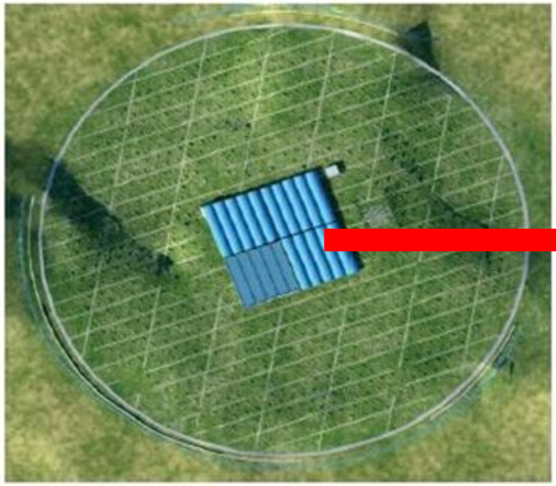
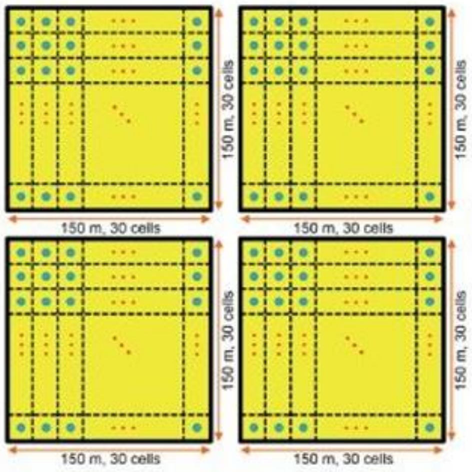
INAF – INFN, Turin

TAUP 2015 – Torino
September 7-11


Large
High
Altitude
Air
Shower
Observatory
KM2A
1 km² array of scintillators and muon detectors
WCDA
Water Cherenkov Detector Array
WFCTA
Wide Field Cherenkov Telescopes Array
SCDA
Shower Core Detector Array
Site: Daocheng Sichuan province, China
4410 m a.s.l.

WCDA: water Cherenkov pool - 300 × 300 m^2

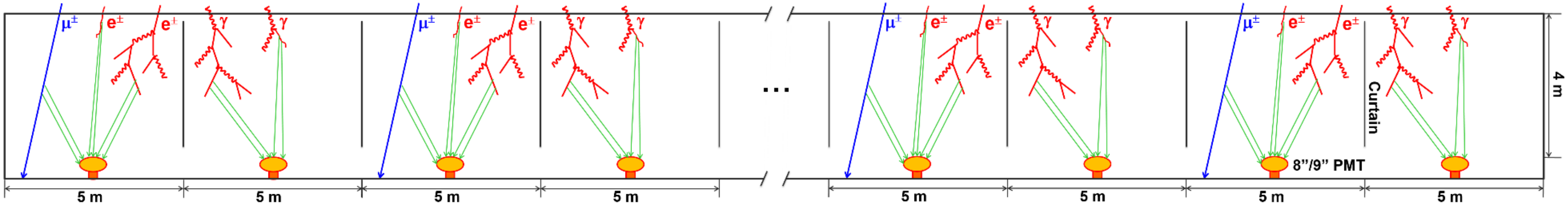


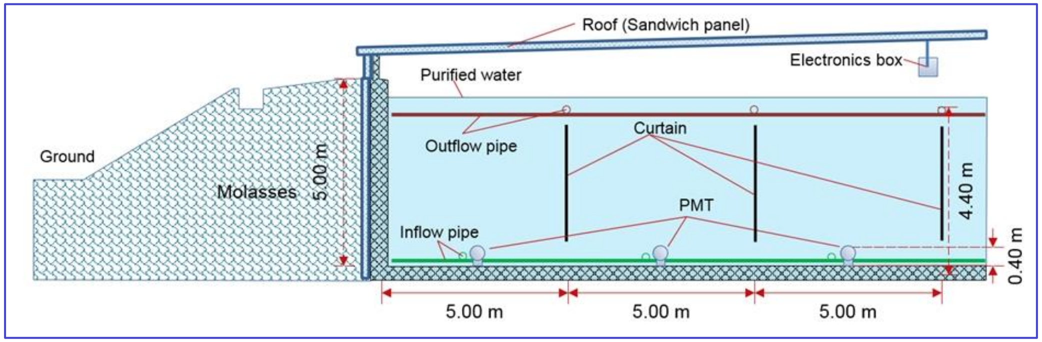


4 pools 150 × 150 m^2 divided in cells 5 × 5 m^2

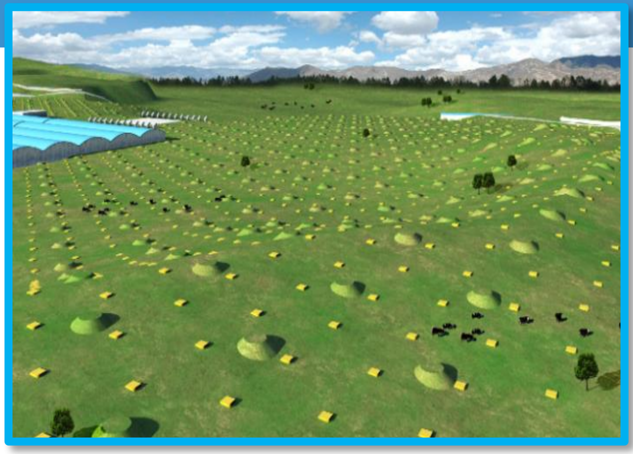
Water depth = 4 m

Total area ~4 × HAWC

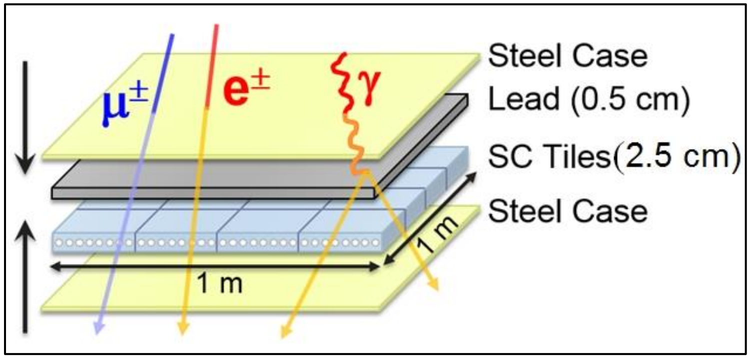




KM2A: a grid of detectors covering ~1 km^2

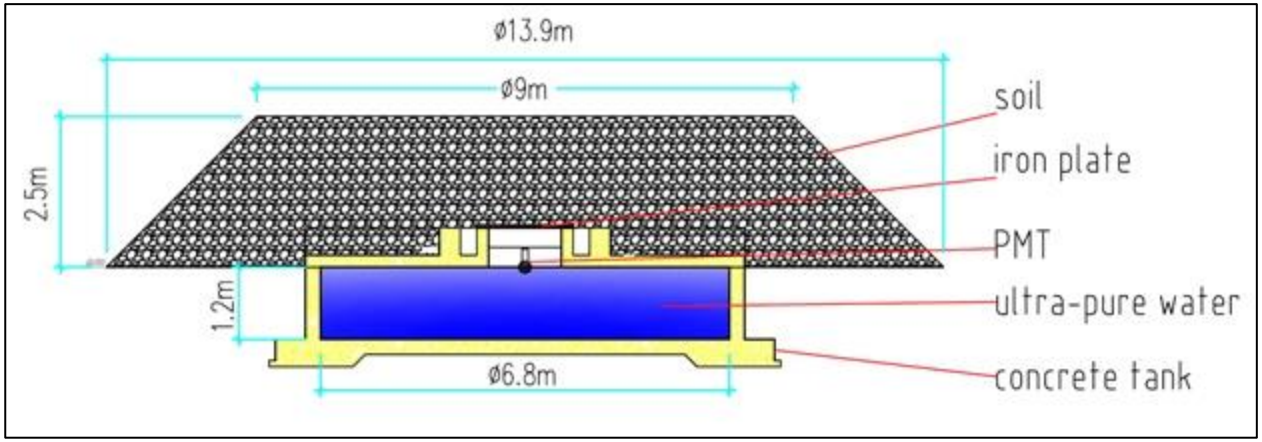


5200 electromagnetic particle detectors (ED)



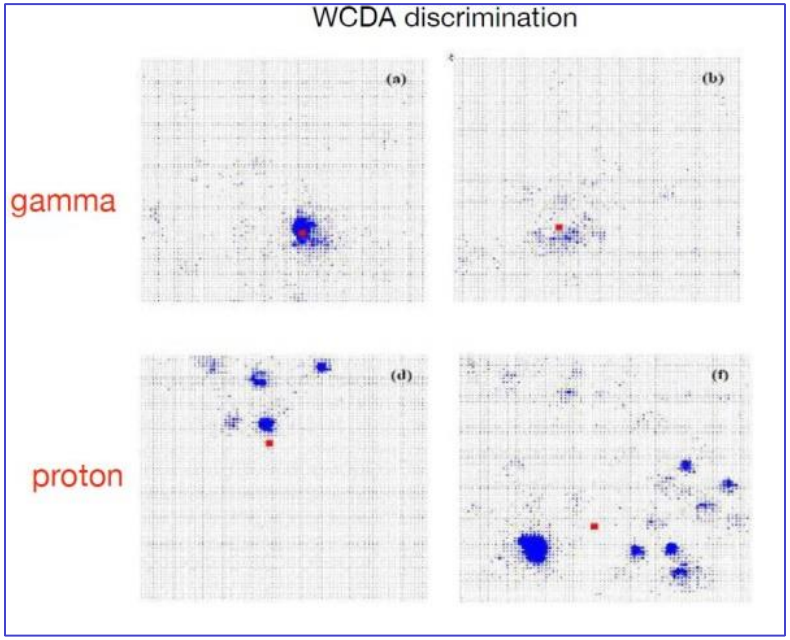
Detector area = 1 m^2
Spacing = 15 m

1170 water Cherenkov μ detectors (MD)



Detector area = 36 m^2
Water depth = 1.2 m
Depth = 2.5 m
Spacing = 30 m

Gamma-hadron discrimination with WCDA

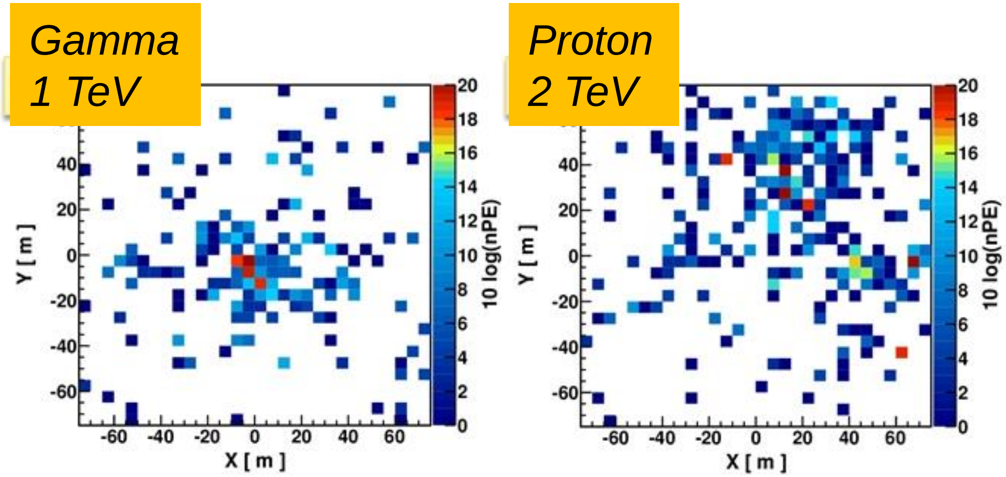


"HAWC tecnique" to identify hadrons

Cut on the **Compactness** parameter

$$C = N_{PMT} / PE_{MAX40}$$

N_{PMT} is the number of PMTs with a signal. PE_{MAX40} is the number of photo-electrons in the PMT with the largest signal outside a radius of 45 meters from the reconstructed shower core



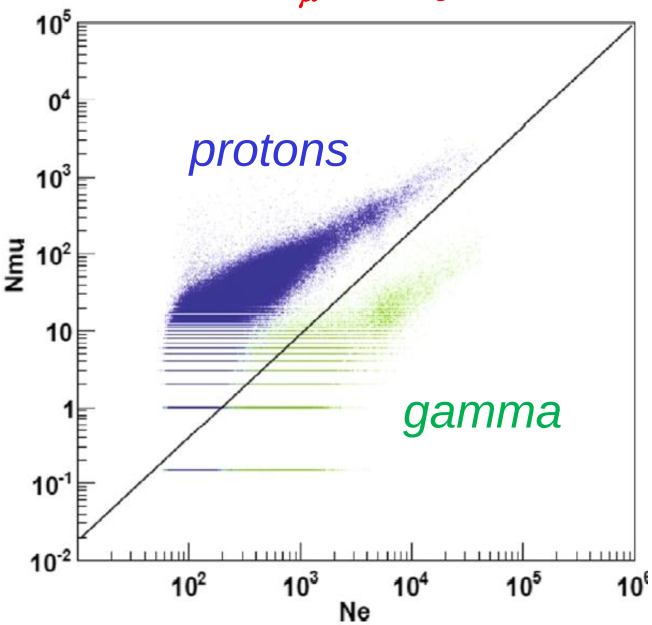
Q factor

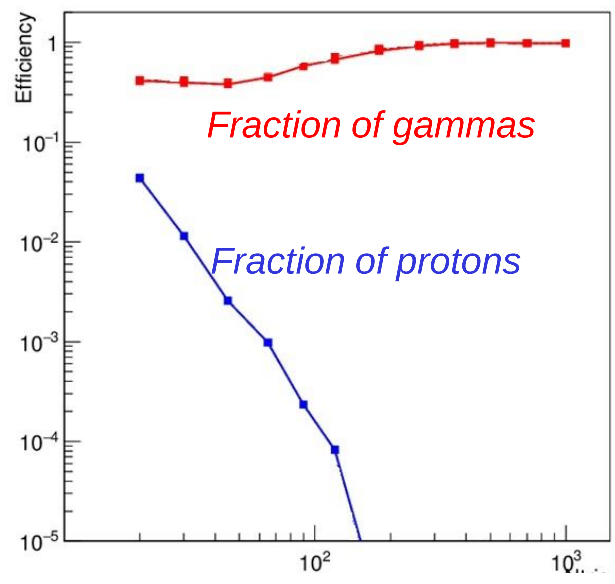
E = 1 TeV	Q ~ 7
E = 5 TeV	Q ~ 22
E = 30 TeV	Q ~ 10

Gamma-hadron discrimination with KM2A

Simulation of one-year Crab Nebula data

N_μ vs N_e





Q factor

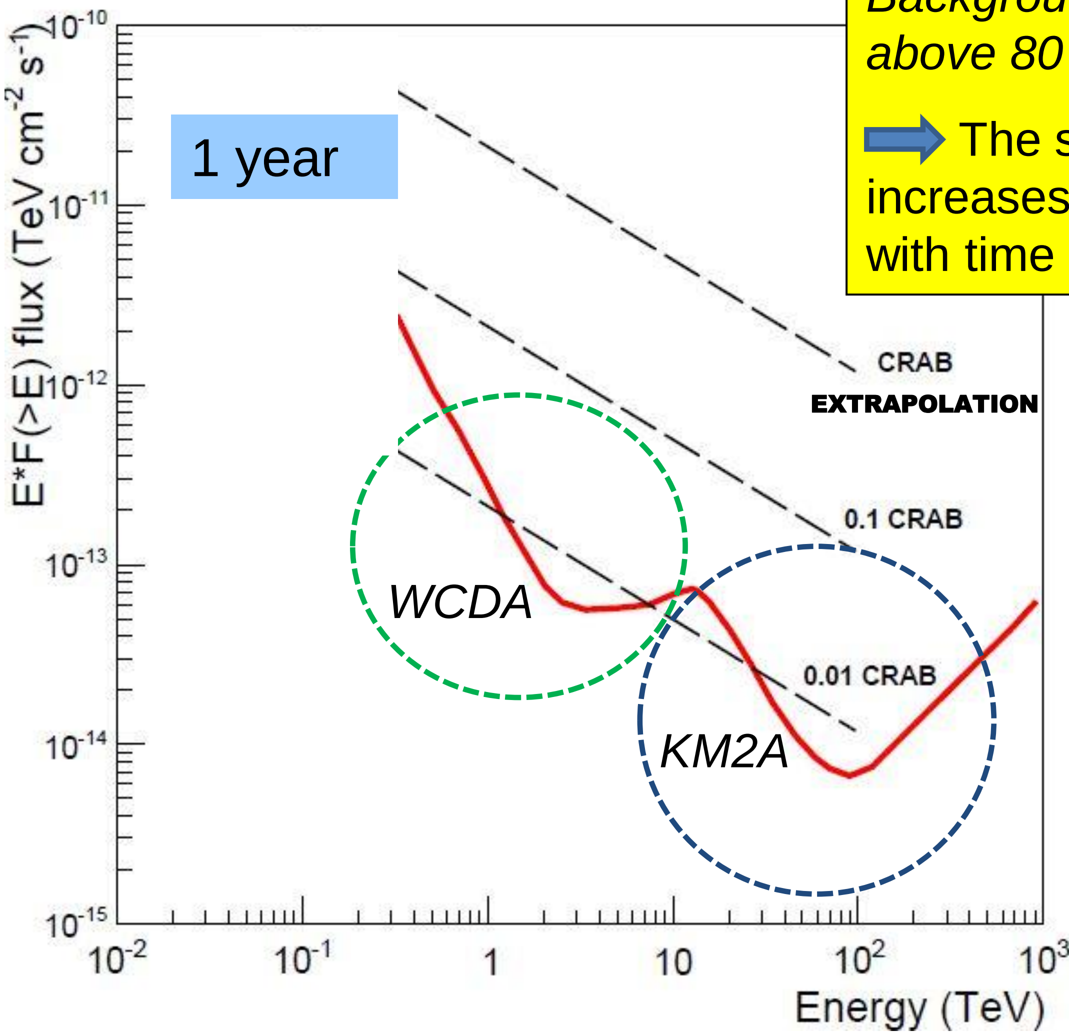
E = 10 TeV Q ~ 4
E = 30 TeV Q ~ 13
E = 80 TeV Q ~ 60

E > 80 TeV
background free

One-year LHAASO integral sensitivity for a Crab-like gamma ray source

WCDA

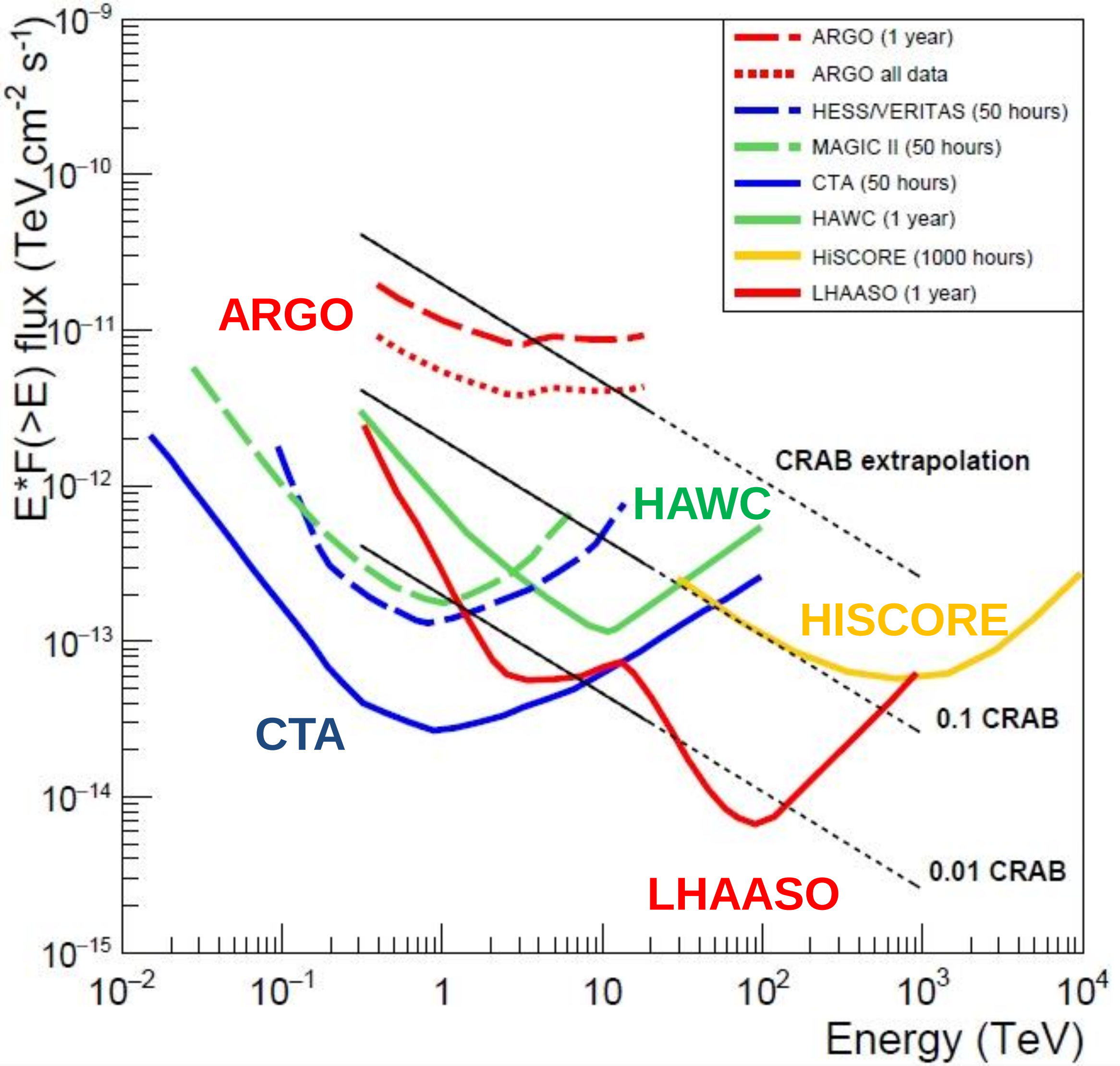
KM2A



Background free above 80 TeV

➡ The sensitivity increases linearly with time

Integral sensitivity for a Crab like source



T = 1 year for EAS arrays

T = 50 hours for IACTs

1 year for EAS arrays means ~1500-2200 hours of observation for each source in the visible declination band (about 4-6 hours per day)

Sky survey

LHAASO latitude: 29° North

Events with zenith angle < 40°

-11° < declination < 69°

Istantaneous FOV: Ω = 2.2 sr ~18% of the whole sky

24 hours FOV: Ω = 7.0 sr ~ 56% of the whole sky

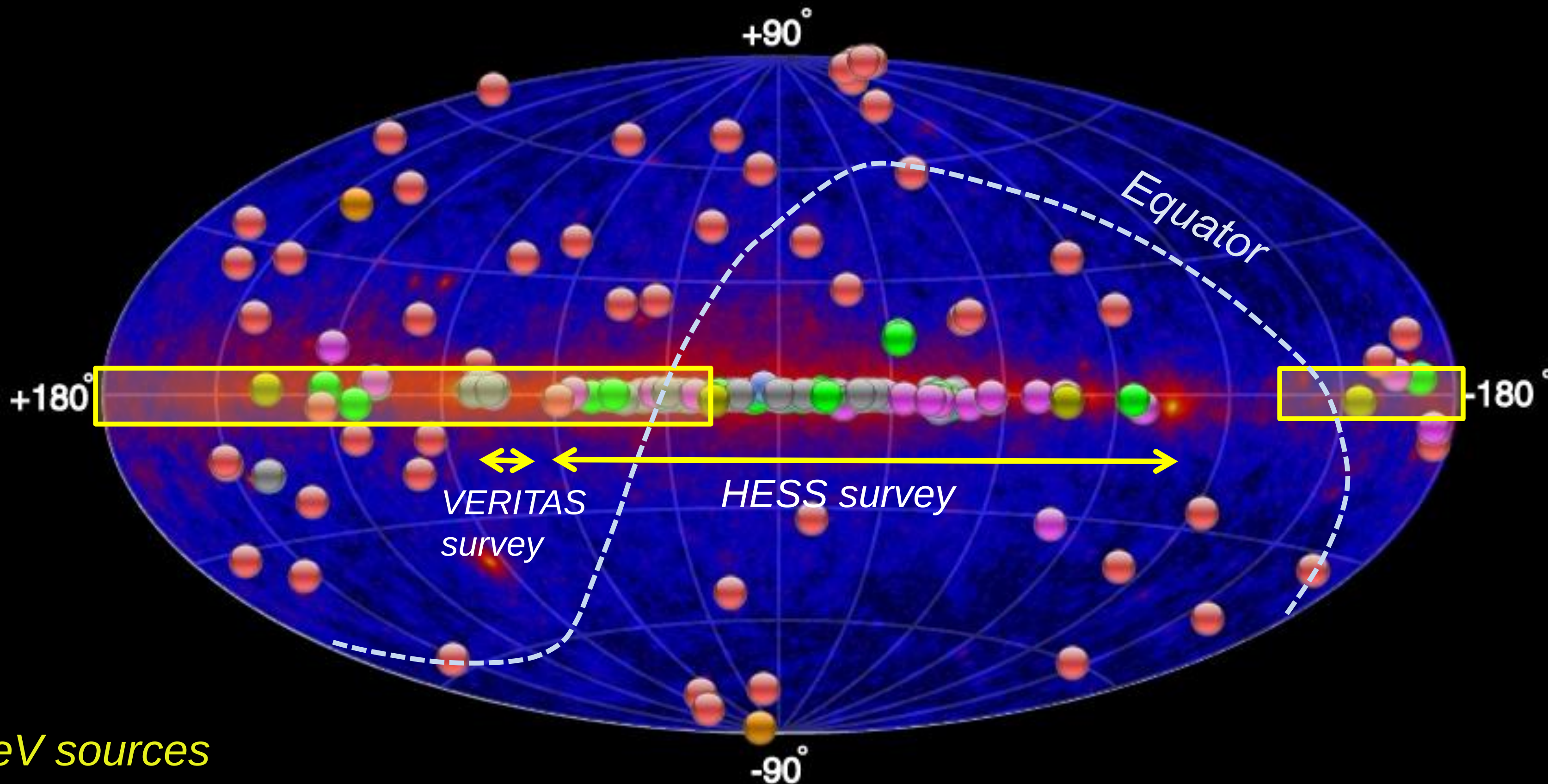
Most of the sources in the 24h FOV are visible for 4-6 hours per day, depending on the declination

In one year LHAASO can survey the Northen sky at ~1 TeV and ~100 TeV at a level of percent of the Crab flux.

Galactic plane in the LHAASO FOV

Zenith angle < 40°

Visible Galactic Plane: l = 20° – 225°



TeV sources from TeVCat

HESS survey:	*l = 250°– 60°*	*|b| < 3.5°*
VERITAS survey:	*l = 67°– 82°*	*-1° < b < 4°*

Gamma ray astronomy above 30 TeV

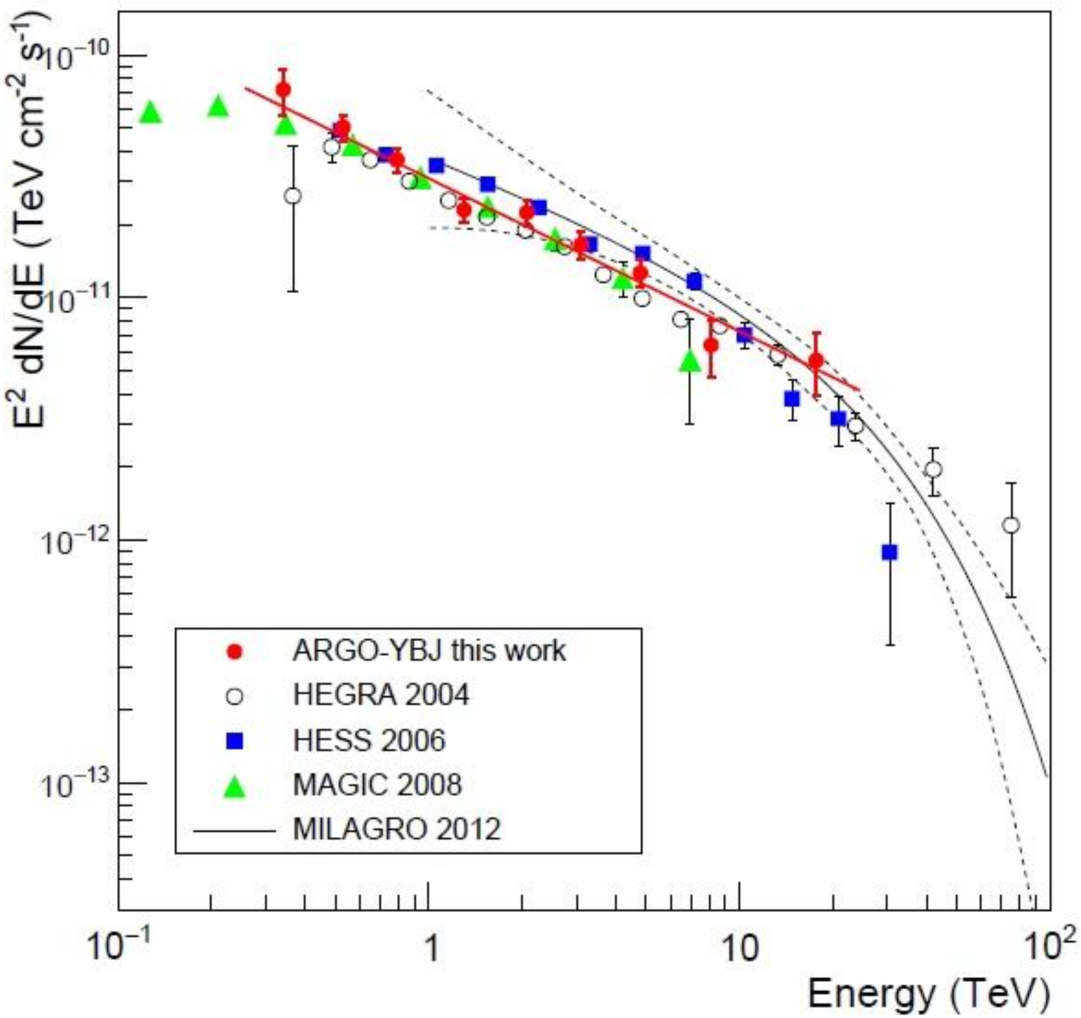
About 160 TeV sources have been detected so far

Only 6 sources have data above 30 TeV:

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

The data above 30 TeV are scarce and have large errors

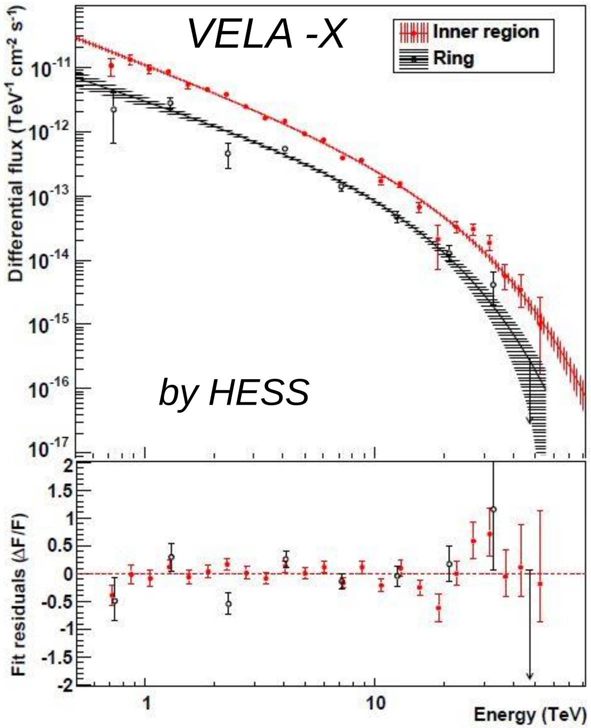
Crab Nebula

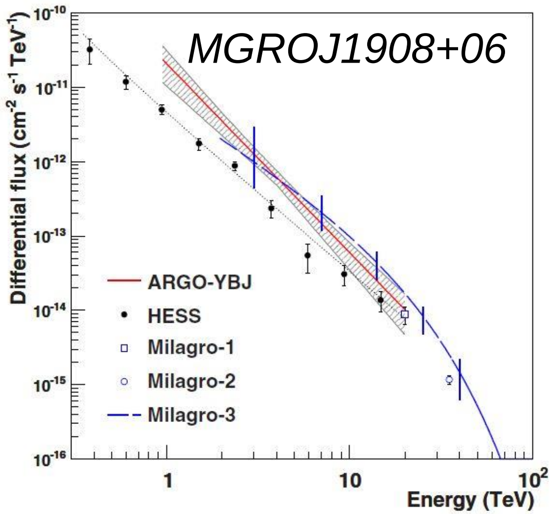


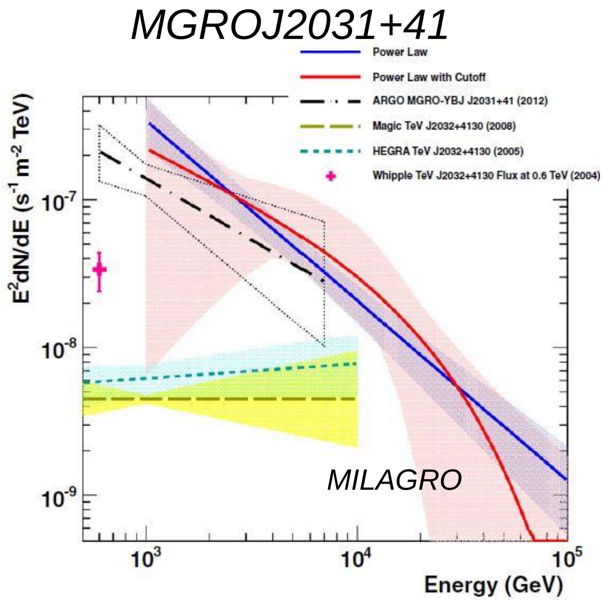
Above 30 TeV
few data and large errors

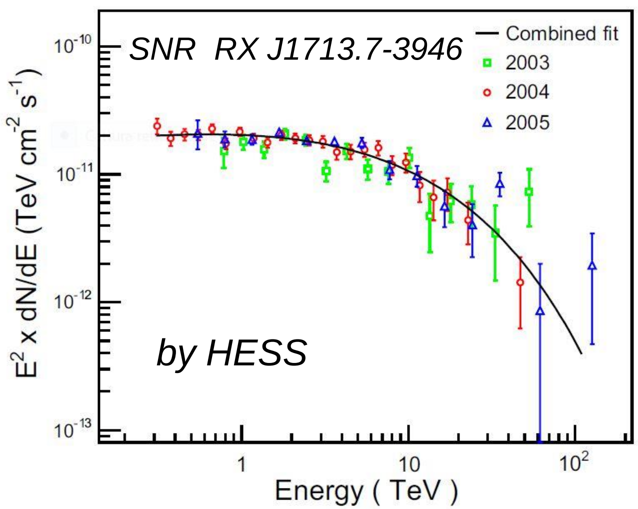
Crab GeV flares:
an Inverse Compton component above 10 TeV does exist?

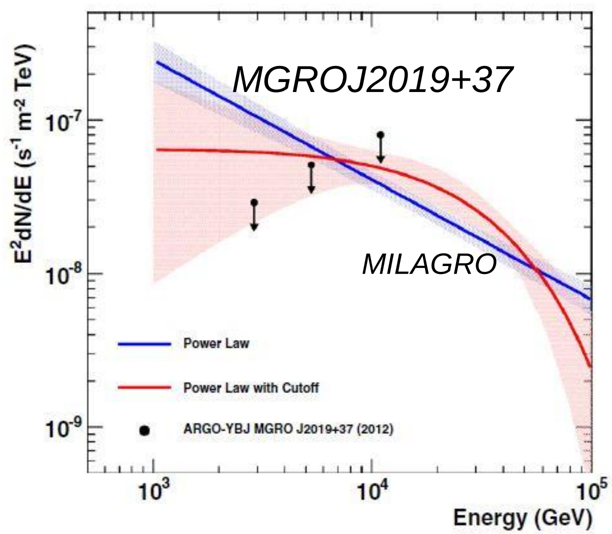
Sources with data above 30 TeV











Very few data above 30 TeV

Searching for cosmic ray sources

Supernova Remnants are the favorite sites for the acceleration of Galactic cosmic rays

Particles are effectively accelerated in SNR shocks, but the relative contribution of protons and electrons to the observed flux is still unclear

Leptonic emission

- Inverse Compton (IC) scattering of electrons on low energy photons:
- Bremsstrahlung

Hadronic emission

- π^0 decay from proton/nuclei interactions with the ambient nuclei

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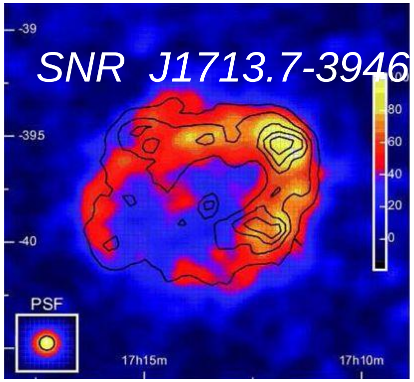
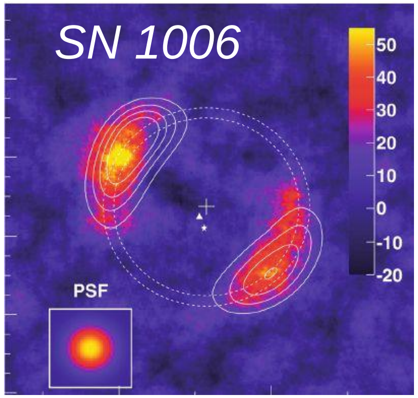
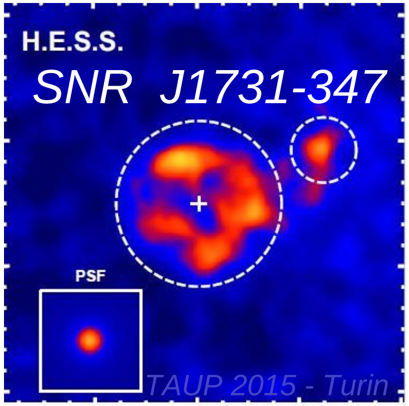






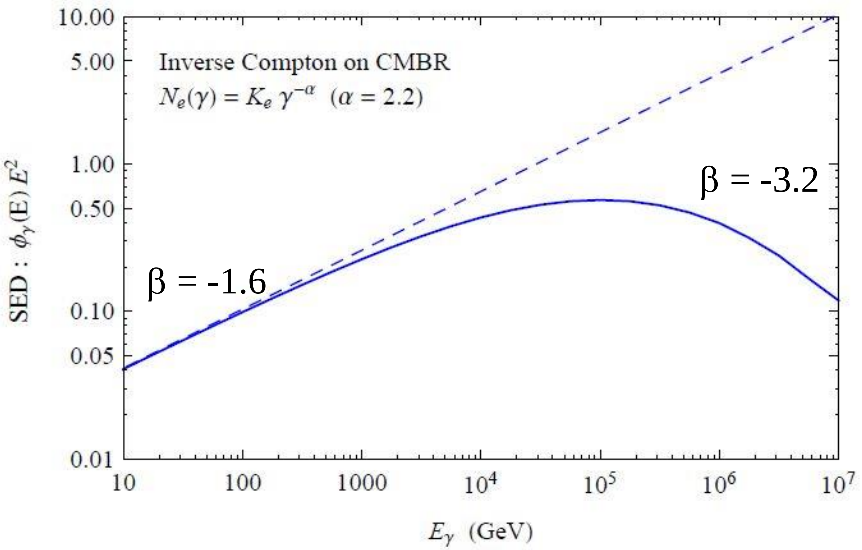
Inverse Compton scattering

1) Thomson regime

$E_e \, \varepsilon << 4 \, m_e^2$ (ε = seed photon energy)

Costant cross section: Thomson cross section

Electron spectrum $E^{-\alpha}$ $\longrightarrow$ Gamma ray spectrum $E^{-\beta}$, $\beta=(\alpha+1)/2$



2) Klein-Nishina regime

The cross section decreases

Photon index $\beta = \alpha+1$

In case of CMB seed photons, the KN regime starts below 100 TeV

Hadronic interactions

$$\mathbf{pp} \longrightarrow \pi^0 + \text{other particles} \qquad\qquad \pi^0 \longrightarrow \mathbf{2}\,\gamma$$

- The gamma ray spectrum is simmetric around $m_\pi/2$ = 67.5 MeV in a log-log scale (π^0 bump)
- Above a few GeV has the same slope of the parents protons
- There is no suppression at high energy as IC, unless the parent proton spectrum has a cutoff
- The emission depends on the environment *gas density*
  In SNR the gas density can range from ~ 0.01 cm^{-3} up to ~1000 cm^{-3} in case of *Molecular Clouds*

Gamma ray astronomy above 30 TeV

Each SNR is individual and has a unique behaviour.

In general one expects a combination of leptonic and hadronic emission and the relative contributions depend on many factors.

In this complex scenario, one thing is clear:

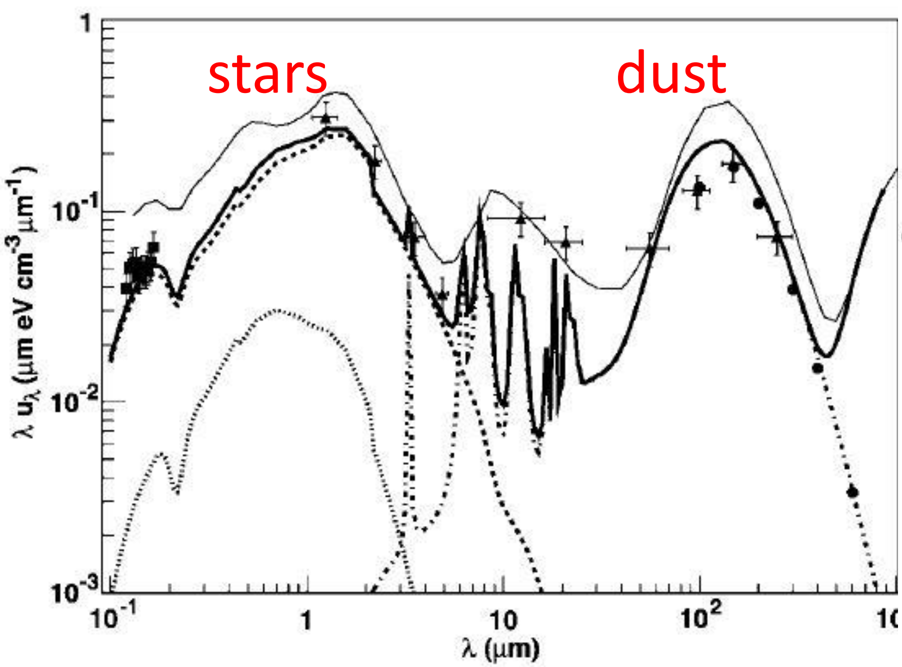
- A power law spectrum reaching 100 TeV without a cutoff is a very strong indication of the hadronic origin of the emission
- Photons of few hundreds of TeV are a clear signature of acceleration of 10^{15} eV protons

Gamma ray astronomy above 30 TeV could give the definitive answer to the question whether the SNRs are the long sought Pevatrons

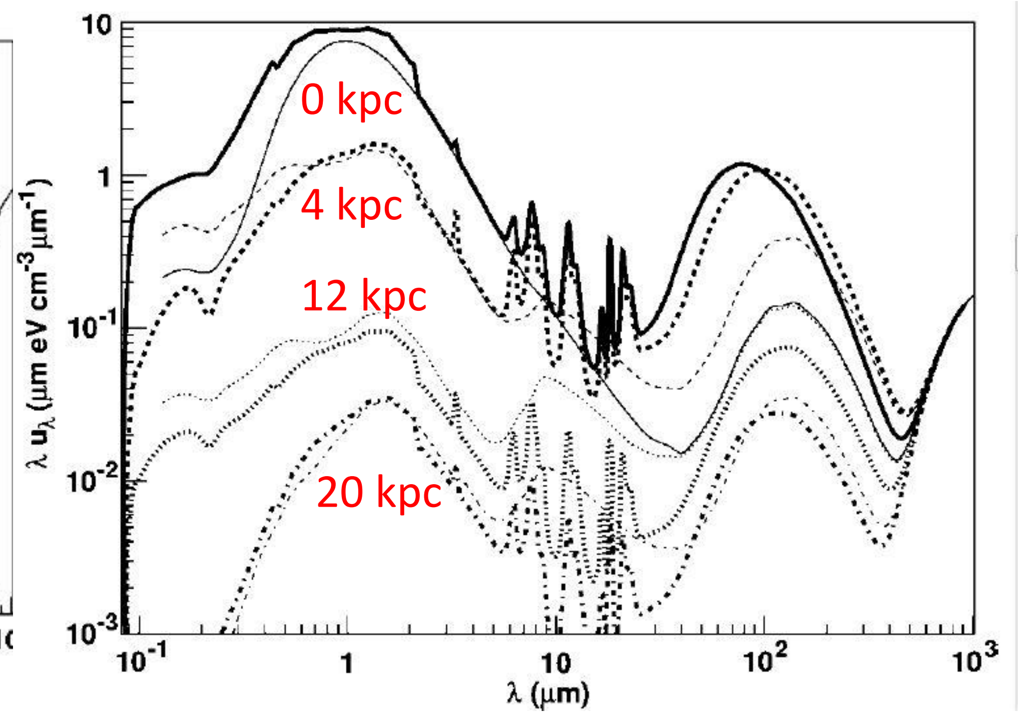
Gamma ray absorption in the Galaxy

Pair production $\gamma + \gamma \longrightarrow e^+ e^-$

Local radiation field



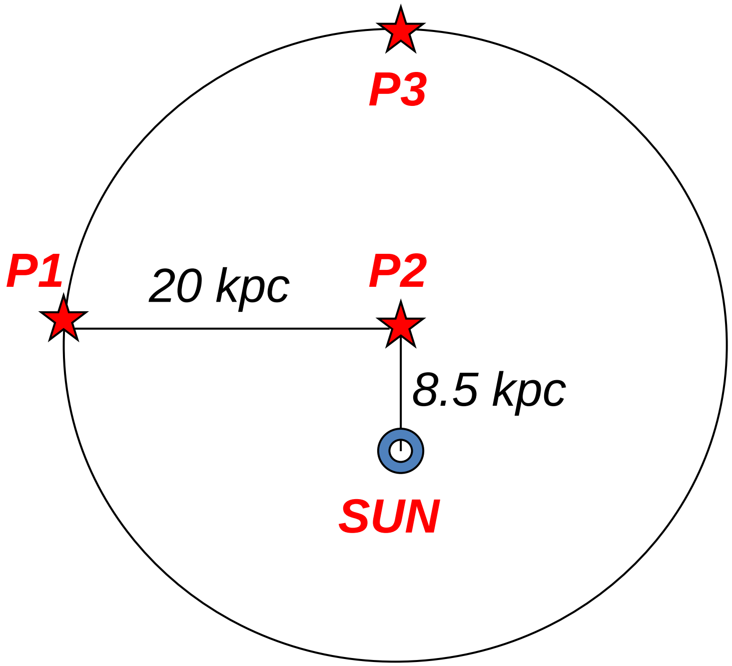
Radiation field for different distances from the galactic center

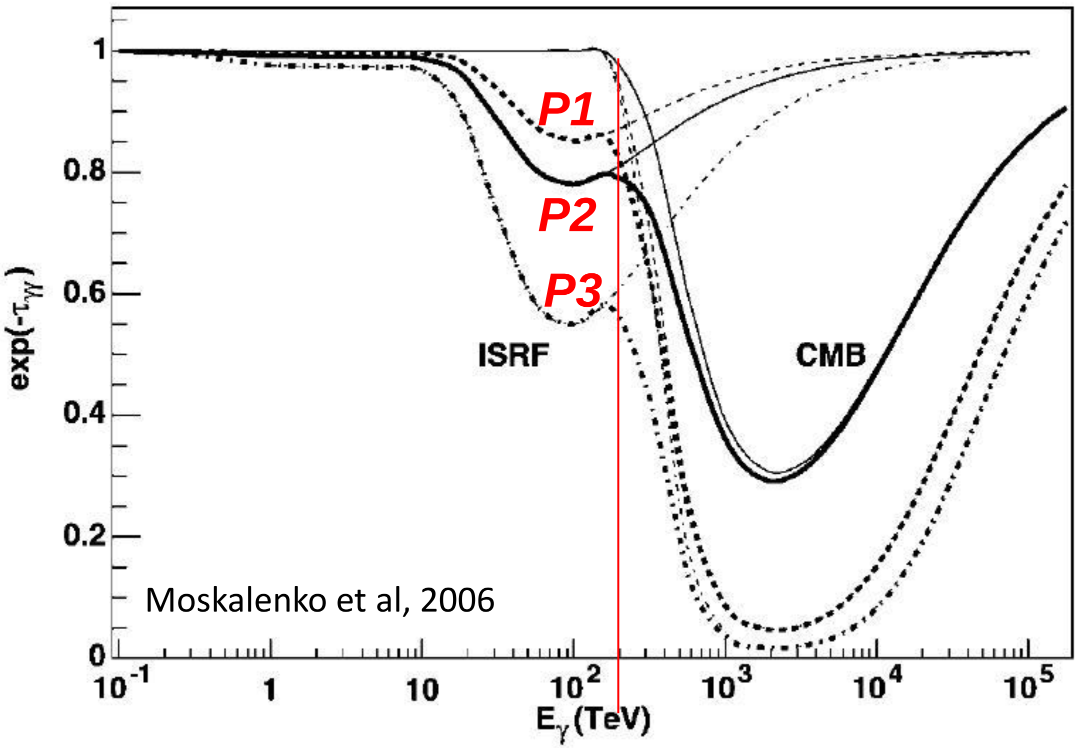


Moskalenko et al, 2006 ApJL 640, 155

Gamma ray absorption in the Galaxy

3 source positions
in the Galaxy





Low attenuation up to ~200 TeV for P1 and P2

TeV sources in the LHAASO FOV

From TeVCat :

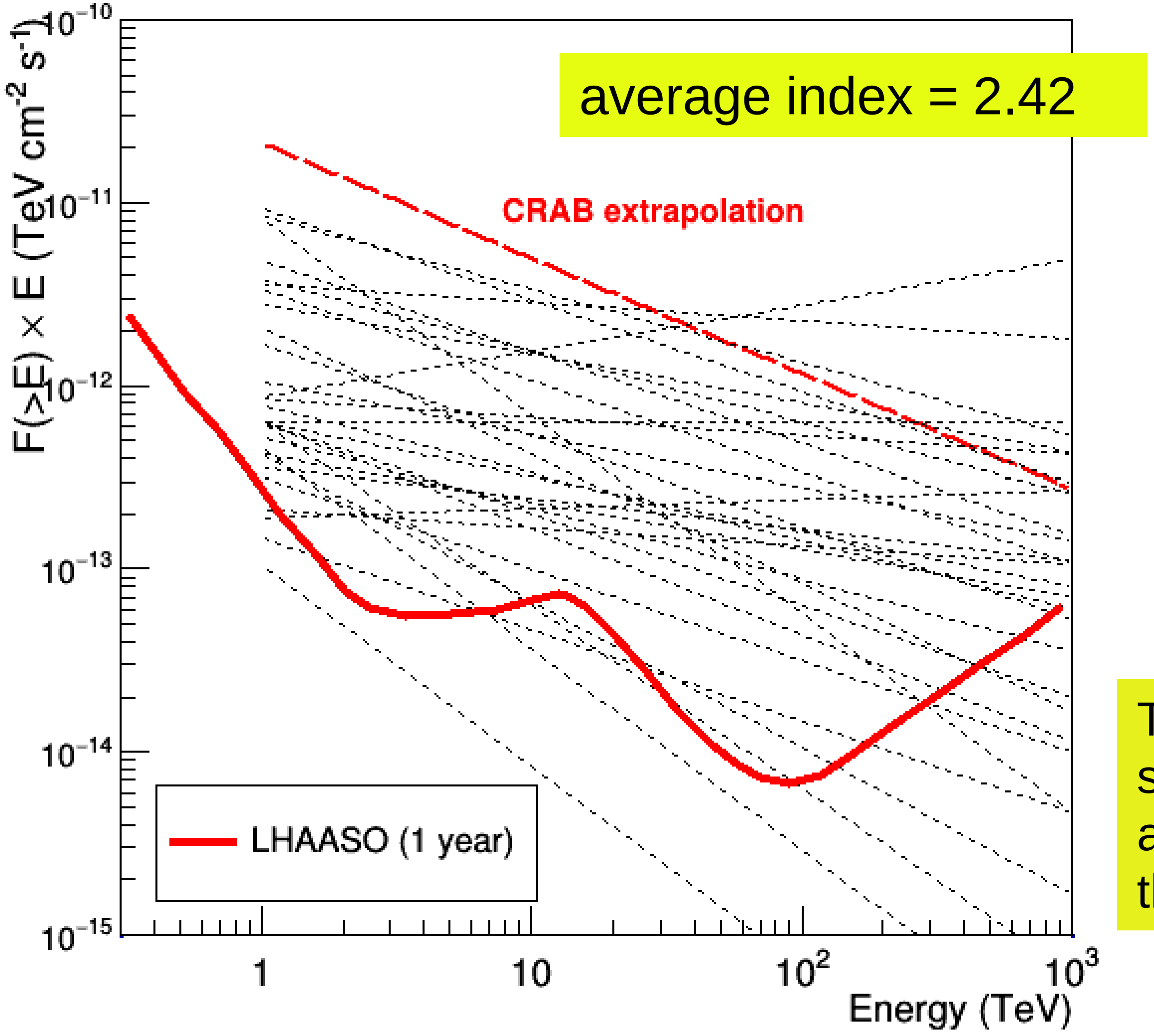
71 sources culminating at zenith angle < 40°

- 31 galactic →
- 40 extragalactic

13	Unidentified
9	Pulsar Wind Nebulae
6	Shell Supernova Remnant
2	Binary System
1	Massive Star Cluster

70% of Galactic sources are extended

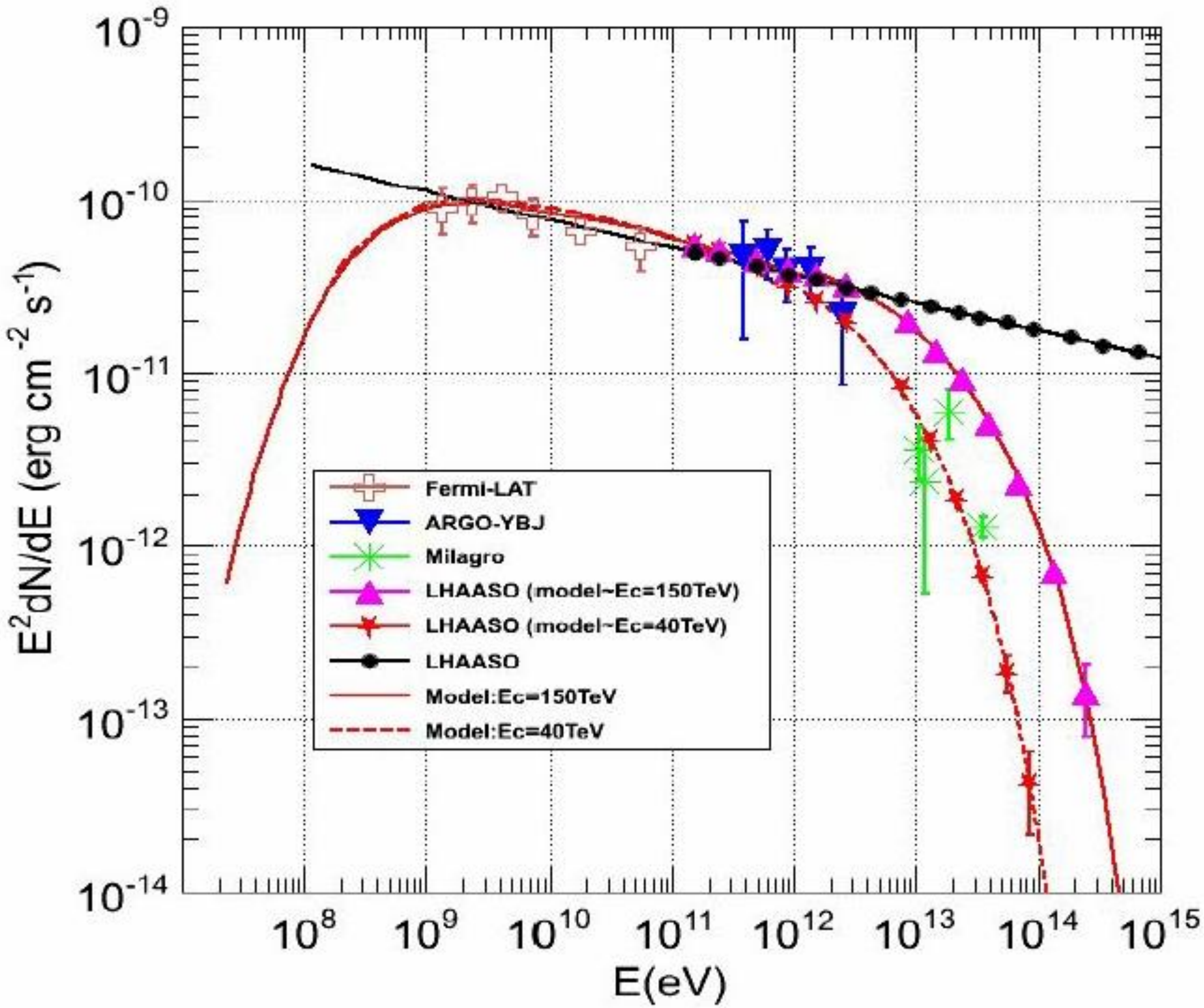
Extrapolated spectra up to 100 TeV



Extrapolation of TeV spectra assuming no cutoff

The real sensitivity depends on spectral slope, culmination angle and angular extension of the source

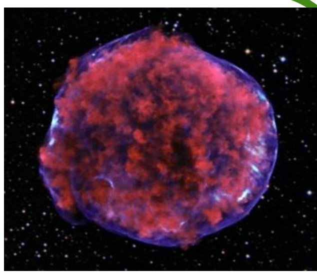
Simulation of the Cygnus Cocoon seen by LHAASO in one year



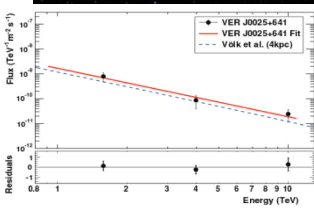
6 Shell SNRs visible by LHAASO

TYCHO SNR

Remnant of a type Ia supernova exploded in 1752



TeV detection by VERITAS

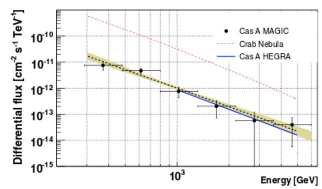


Acciari et al., ApJ 730, L20, 2011

CAS A

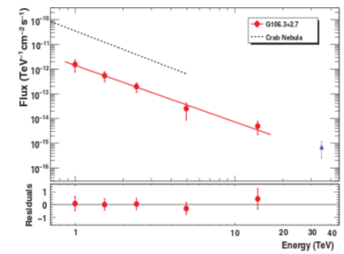
Remnant of a type II supernova exploded ~300 yrs ago

TeV detection: HEGRA MAGIC VERITAS



Albert et al. A&A 474, 937, 2007

SNR G106.3+2.7



Remnant of a SN probably exploded ~10 kyrs ago

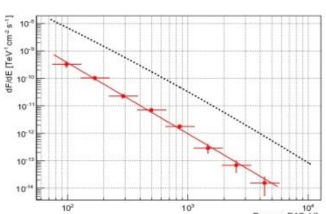
TeV detection: VERITAS MILAGRO

Acciari et al., ApJ 703, L6, 2009

W51

Complex region containing the star-forming regions W51A & W51B and the SNR W51C, remnant of a supernova probably exploded ~30 kyrs ago.

TeV detection: HESS MAGIC MILAGRO

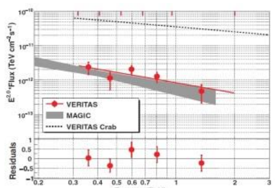


Aleksic et al. A&A 541, A13 (2012)

IC 443

Remnant of a type II SN (?), exploded ~3-30 kyrs ago

Gamma rays associated with a molecular cloud



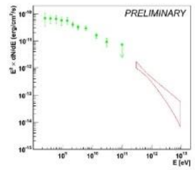
TeV detection: MAGIC VERITAS

Acciari et al., ApJ 698, L133, 2009

W49B

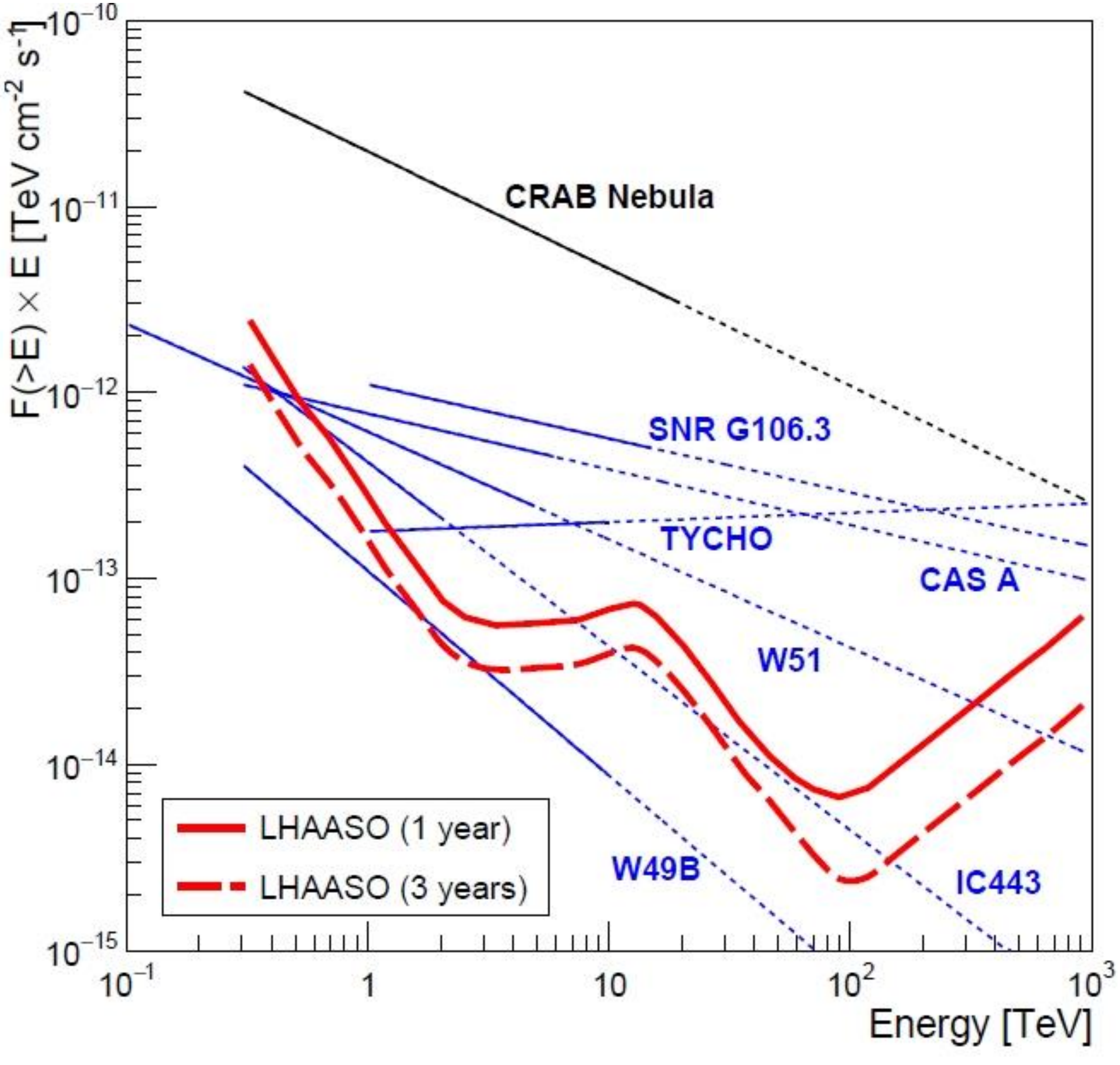
Remnant of a Ib/Ic type SN, probably exploded ~1 kyrs ago, with a possible associated GRB

TeV detection by HESS



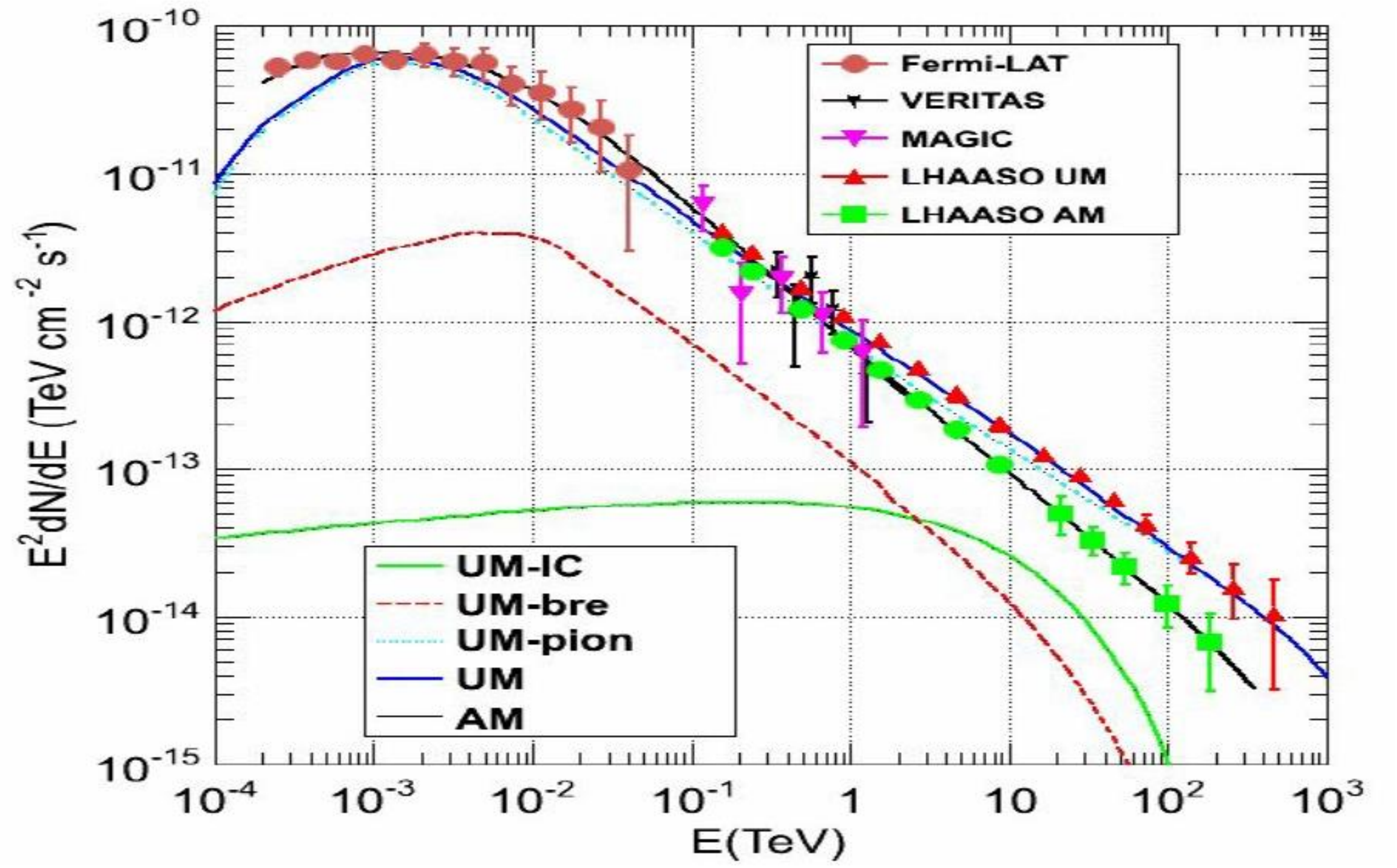
Brun et al., ICRC proc (2011)

SNRs extrapolated spectra

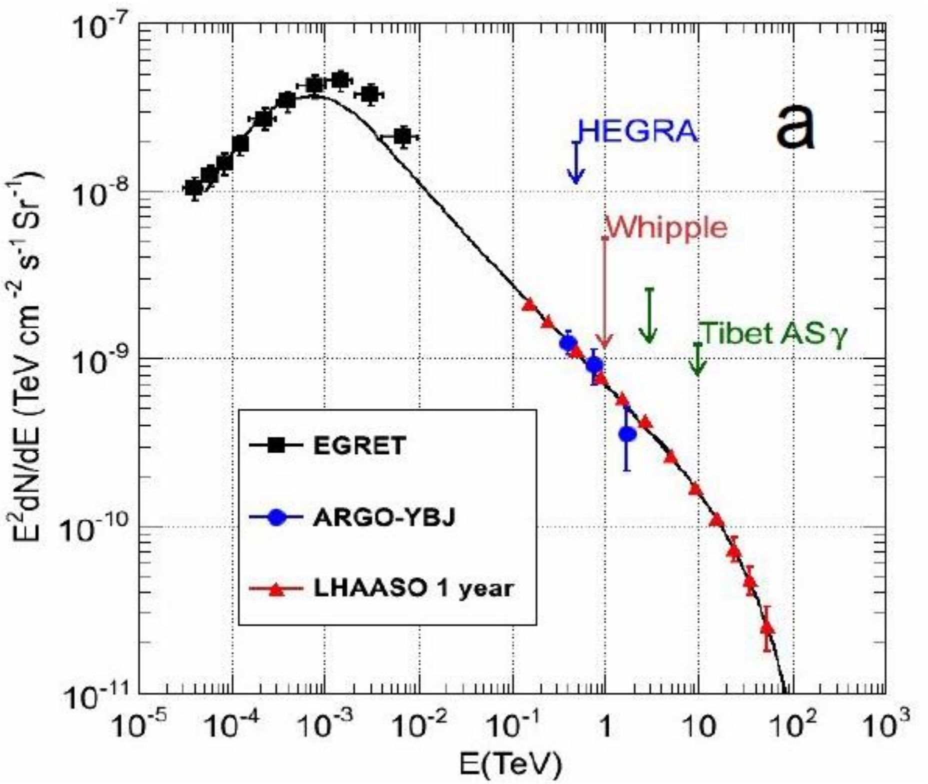


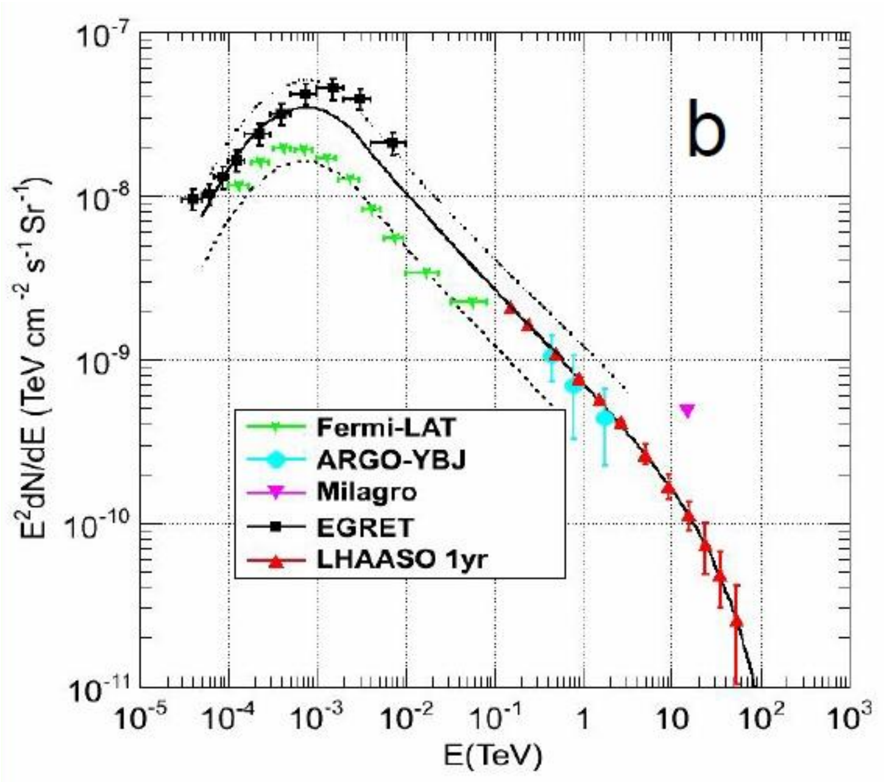
Gamma ray absorption in the Galaxy is not considered

Simulation of IC443 by LHAASO in 5 years



Galactic plane diffuse emission seen by LHAASO in one year

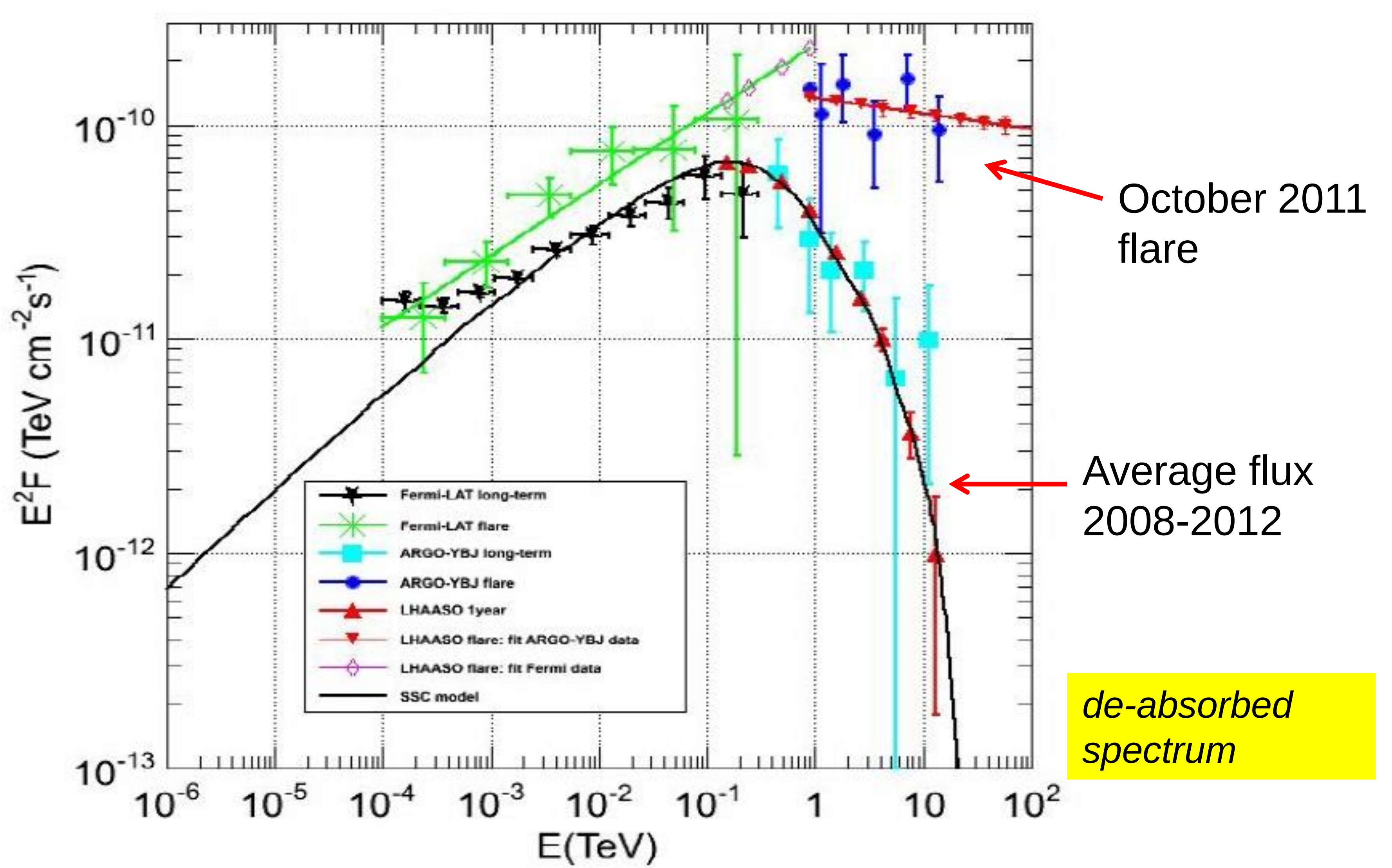




Galactic plane
25° < l < 100°
|b|< 5°

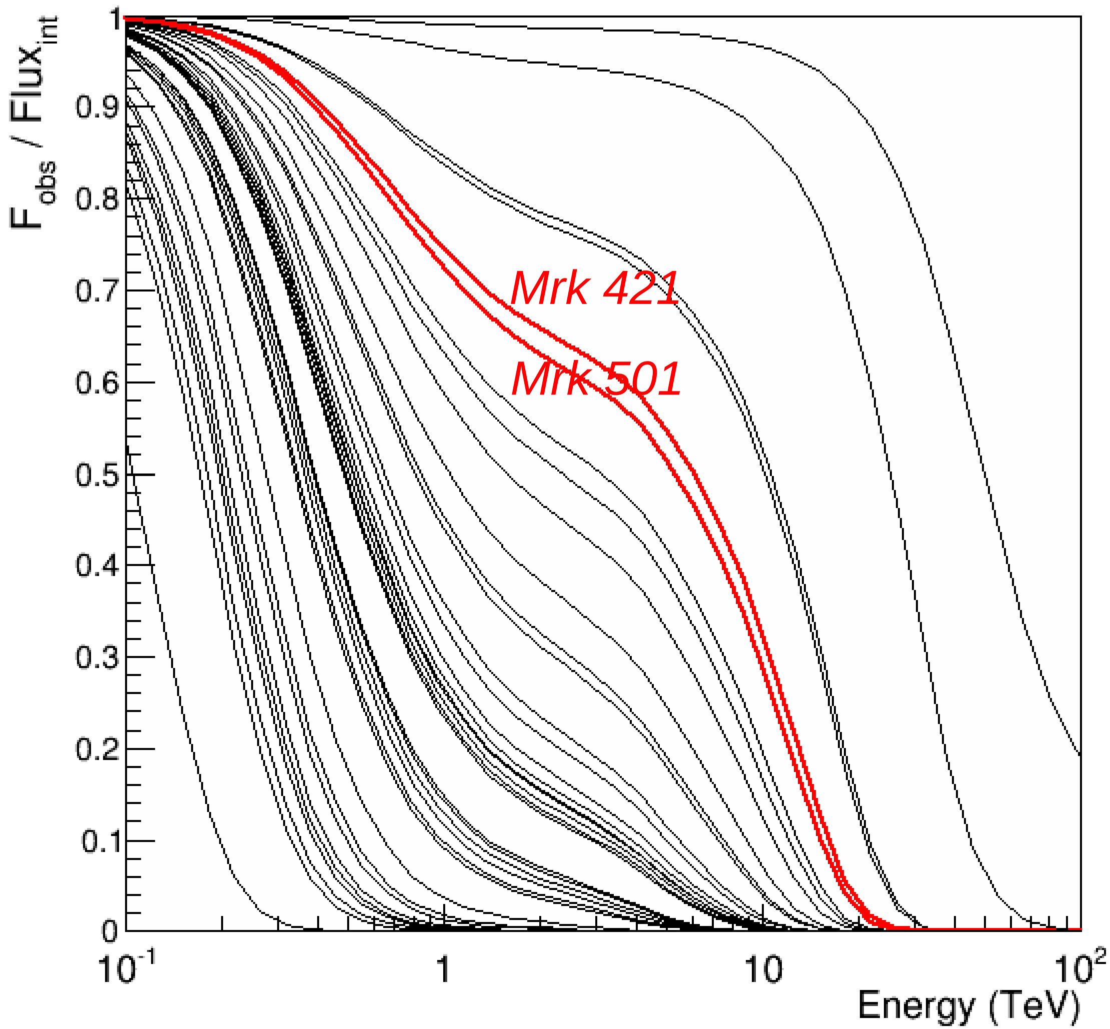
Cygnus region
65° < l < 85°
|b|< 5°

Mrk 501 by LHAASO



de-absorbed spectrum

Extragalactic sources: spectra absorption



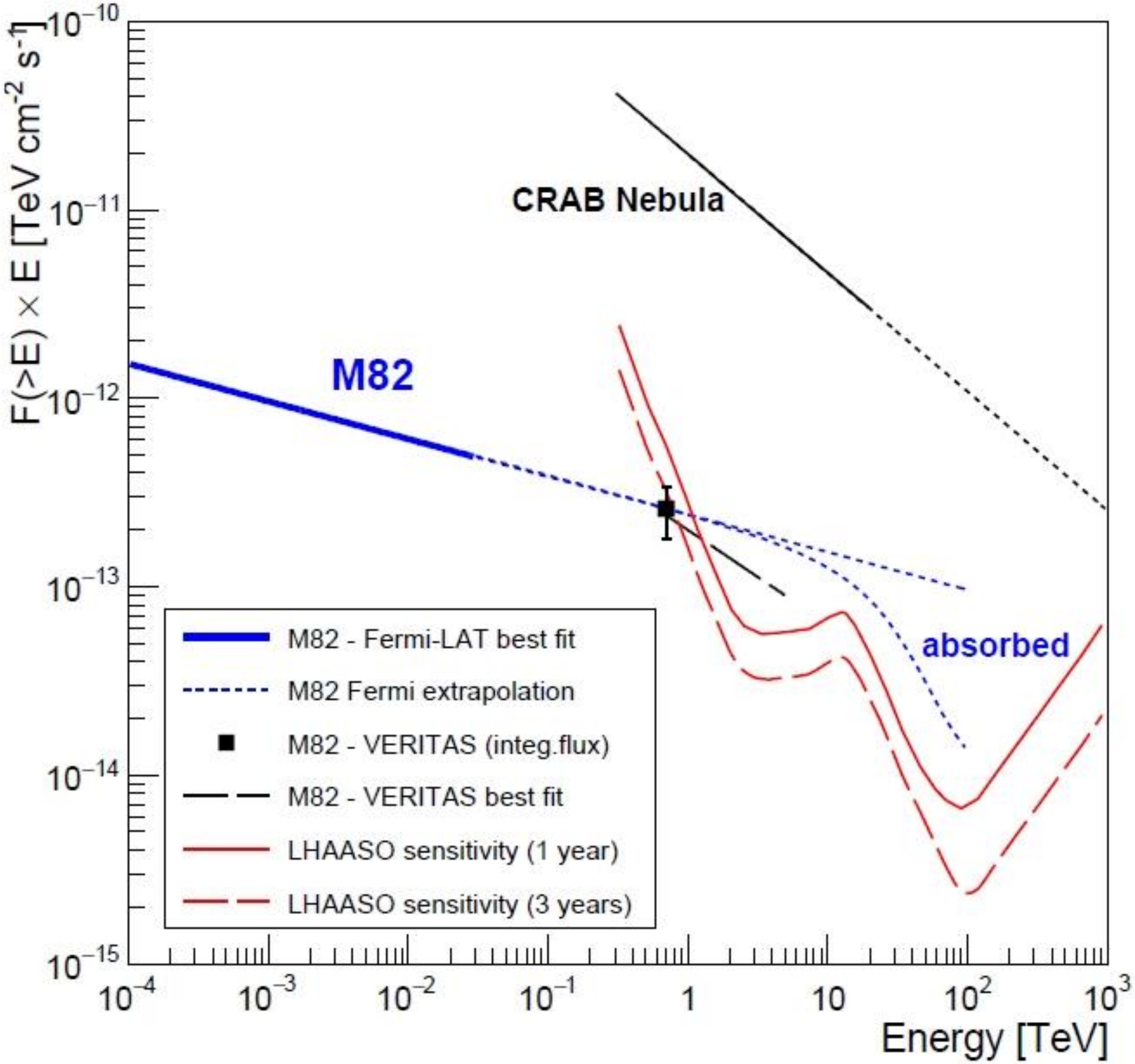
36 TeV sources
In the LHAASO FOV
with known redshift

Franceschini model

The 4 closest extragalactic sources

Source	Zenith angle culm.	type	Distance (z)	Flux (c.u.)	Spectral index
M82	39°	Starburst	0.00073	0.009	2.5
M87	18°	Radio Galaxy	0.0044	Variable Flux up to 10% Crab	2.2
NGC1275	11°	Radio Galaxy	0.018	Variable at VHE ?	4.1
IC310	11°	HBL ?	0.019	Variable Flux up to 15% Crab	2.0

M82 expected flux at 10-100 TeV



Power law spectrum

Fermi index $\alpha = -2.2$

LHAASO time schedule

- LHAASO detector prototypes (~1%) are tested in Yangbajing (4300 m)
- September 2015: start construction of infrastructures
- Spring 2016: start construction of the first quarter of WCDA and KM2A
- Spring 2017: installation of PMTs in the first pond
- Spring 2018: start scientific operation of the first quarter of LHAASO
- 2021: conclusion of installation of main components

Conclusions

- In one year LHAASO can survey the Northen sky at 1 TeV and 100 TeV at a level of % Crab.
- Gamma ray astronomy at 50-100 TeV is a field of research completely new. Even a non-detection would be a discovery.
- The LHAASO sensitivity allow to measure the flux of almost all known TeV sources extrapolated to 100 TeV and study in detail possible cutoffs
- Very promising perspectives for the discovery of Pevatrons.
- Challenging observation of extragalactic sources: a few very close radio galaxy or starburst galaxy could be detected above 30 TeV.

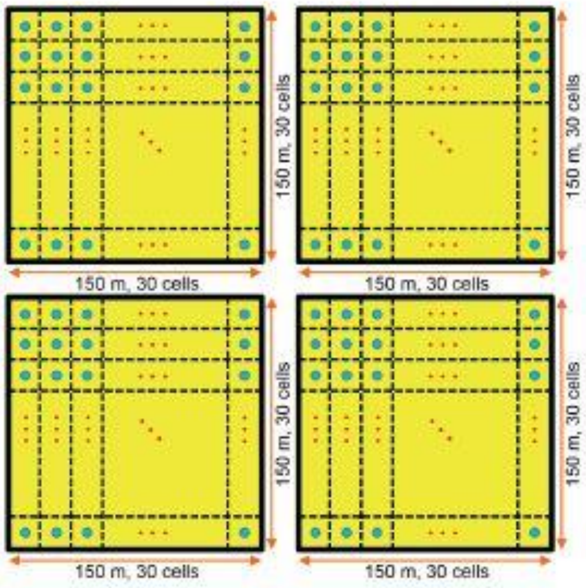
Backup slides

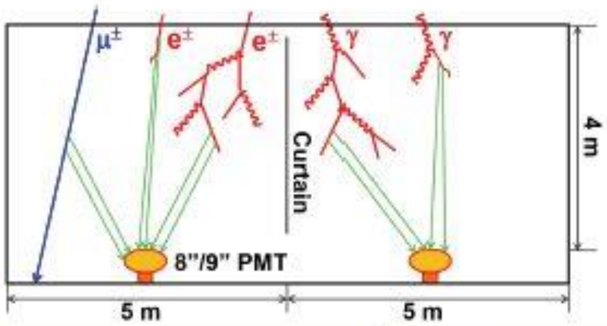
The LHAASO site

The experiment will be located at 4300 m asl (606 g/cm^2) in the Daocheng site, Sichuan province, China.

Coordinates: 29º 21' 31'', 100º 08' 15''

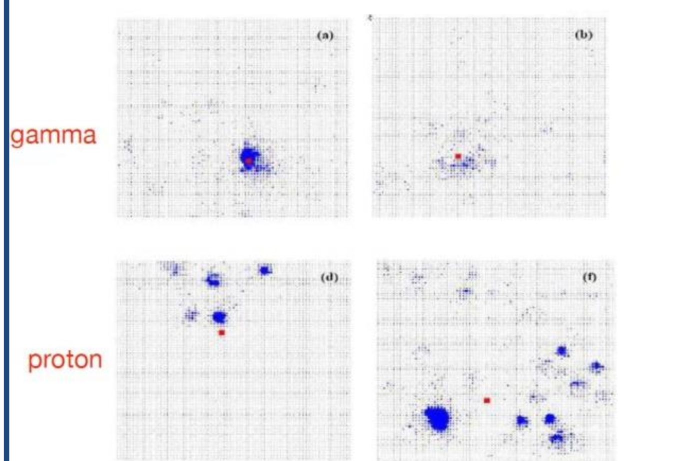
Water Cherenkov Detector Array



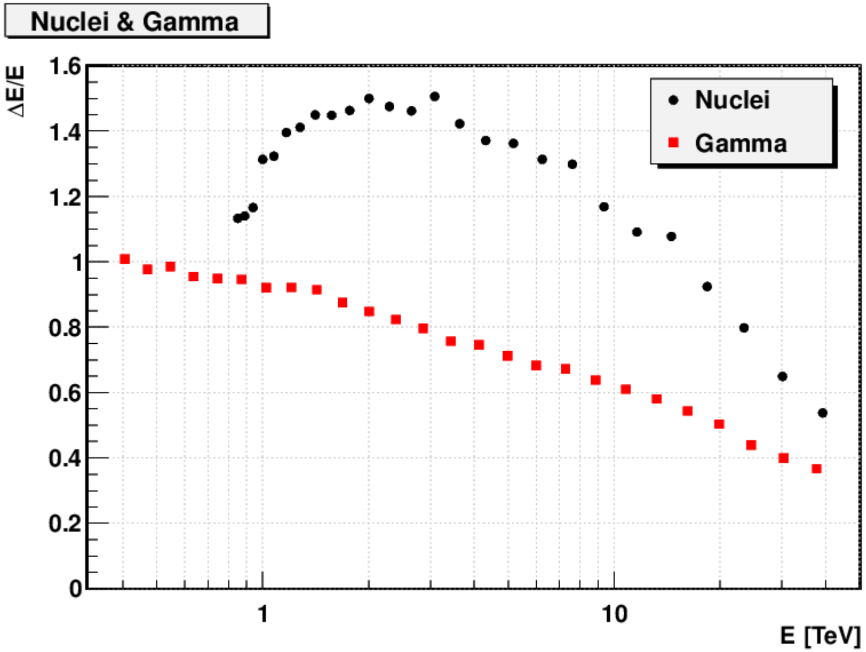


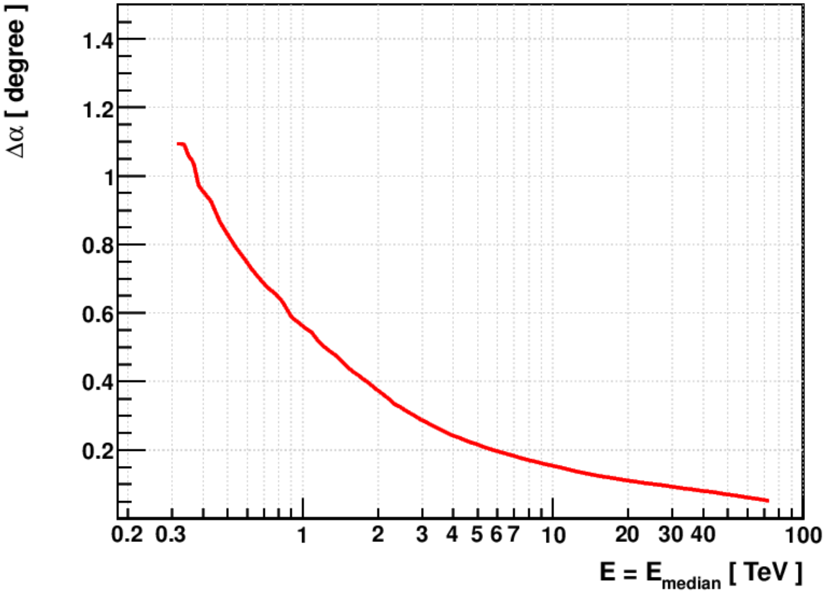
Item	Value
Cell area	25 m²
Effective water depth	4 m
Water transparency	> 15 m (400 nm)
Precision of time measurement	0.5 ns
Dynamic range	1-4000 PEs
Time resolution	<2 ns
Charge resolution	40% @ 1 PE 5% @ 4000 PEs
Accuracy of charge calibration	<2%
Accuracy of time calibration	<0.2 ns
Total area	90,000 m²
Total cells	3600

Hadron discrimination

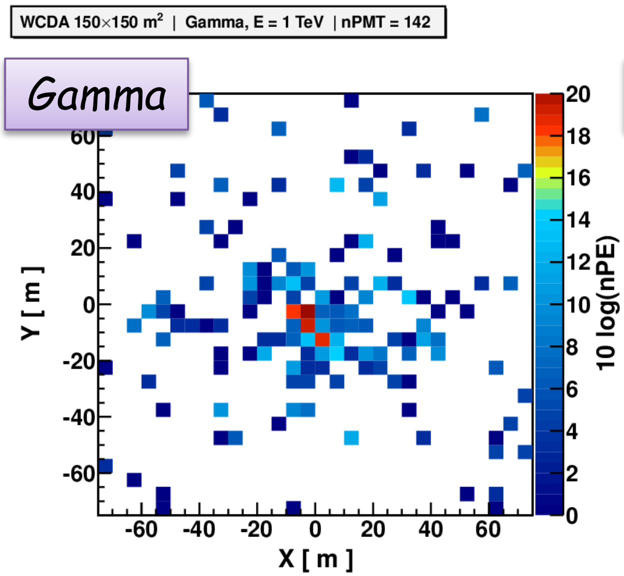


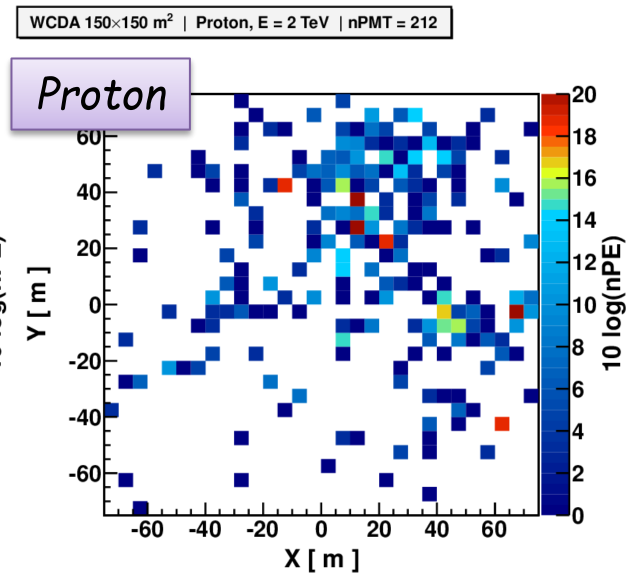
WCDA: Energy resolution & Angular Resolution

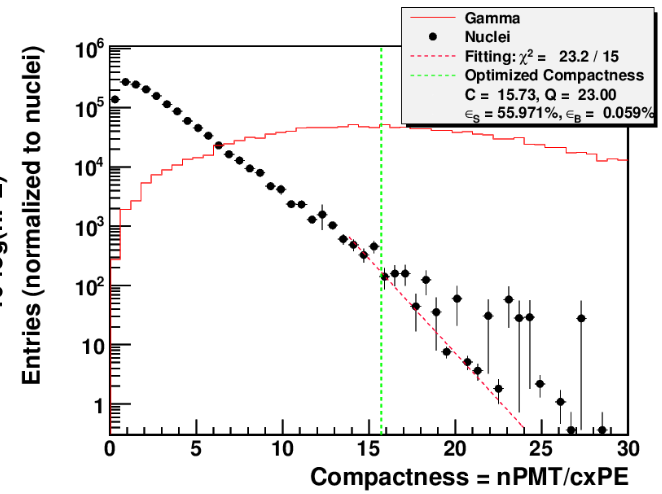


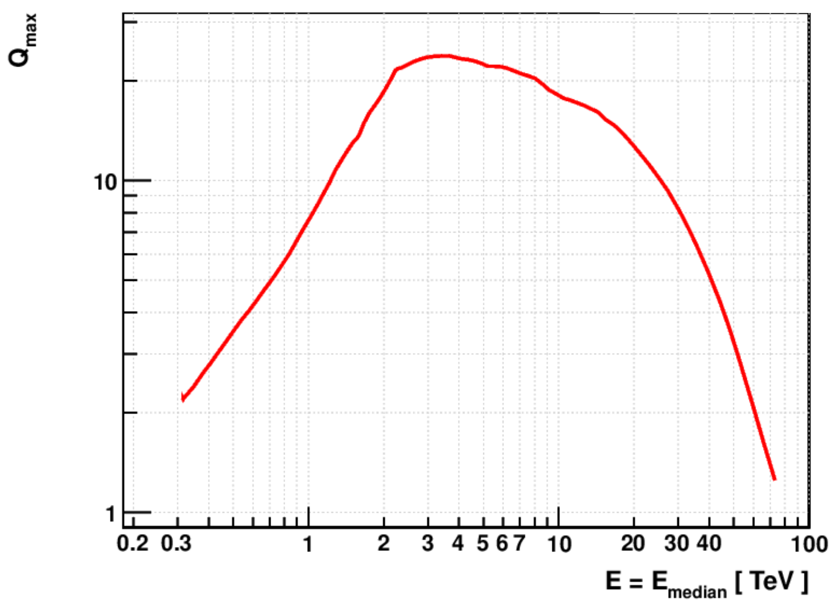


WCDA Gamma/proton Discrimination



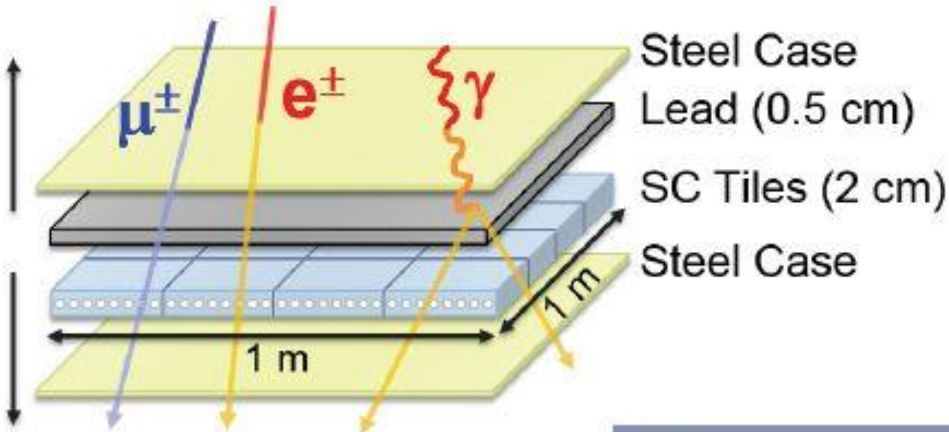






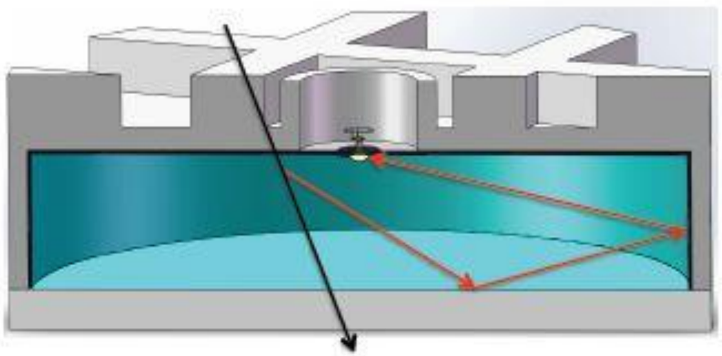
- Brightest "sub-core":
  - Signal of the brightest PMT outside the shower core region (e.g., 45 m);
- "Compactness" is employed to reject cosmic ray background
- Q-factor: 7 @ 1 TeV; 22 @ 5 TeV.

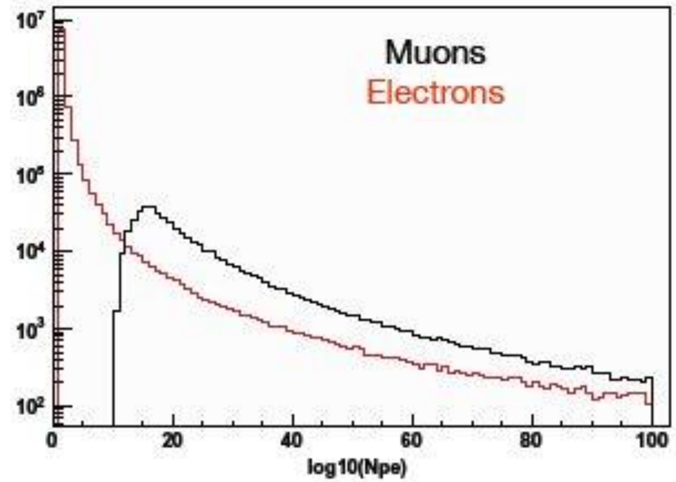
Electromagnetic particle Detector



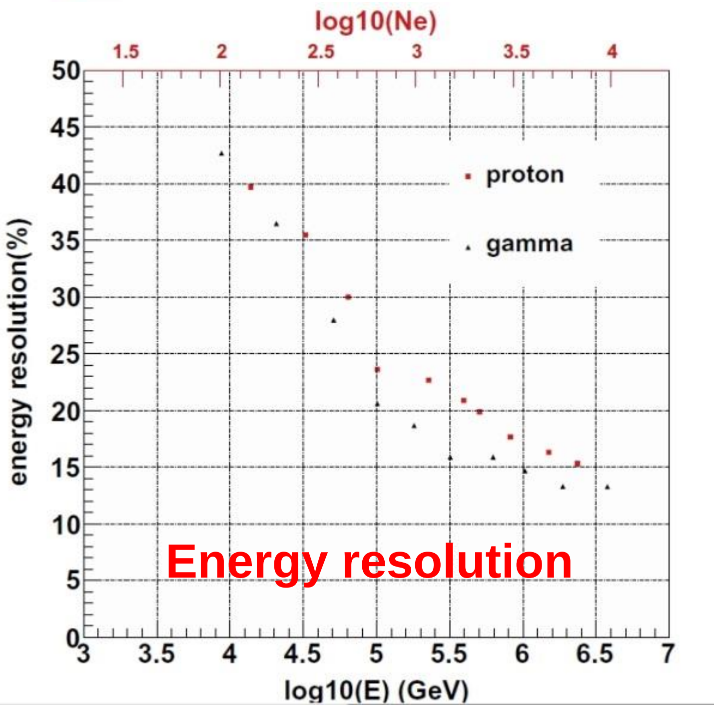
Item	Value
Effective area	1 m^2
Thickness of tiles	2 cm
Number of WLS fibers	8/tilex16 tile
Detection efficiency (> 5 MeV)	>95%
Dynamic range	1-10,000 particles
Time resolution	<2 ns
Particle counting resolution	25% @ 1 particle 5% @ 10,000 particles
Aging	>10 years
Spacing	15 m
Total number of detectors	5635

Muon Detector





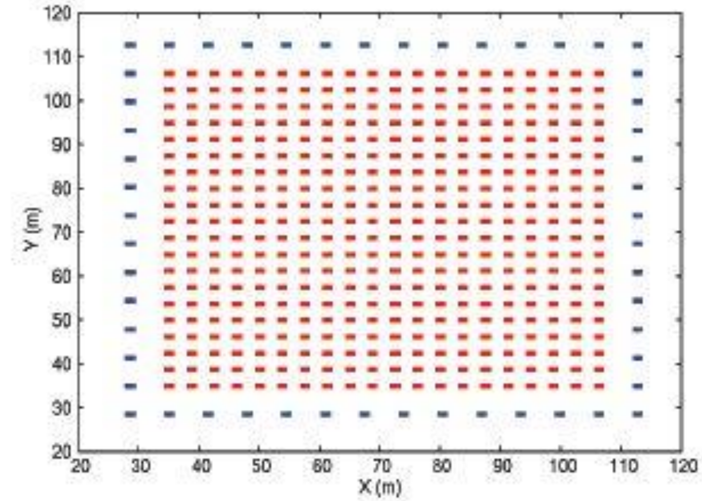
Photoelectrons distribution at R > 100 m from the shower core position



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

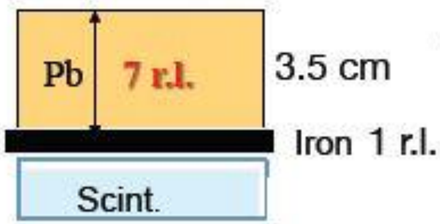
Shower Core Detector Array

- 425 close-packed burst detectors, located near the centre of the array, for the detection of high energy secondary particles in the shower core region.



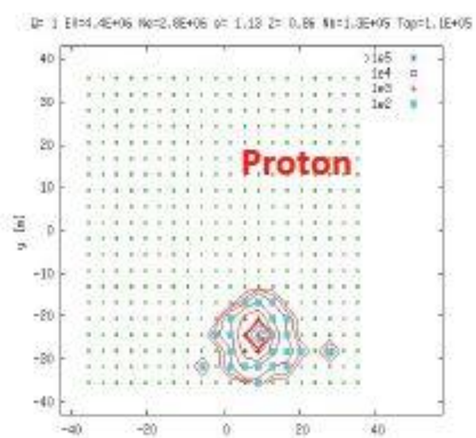
- Number of SCD: 0.5 m² x 452
- Cover Area: 5170 m²
- Energy region: 30 TeV - 10 PeV
- Core position resolution: 1.5 m @50 TeV

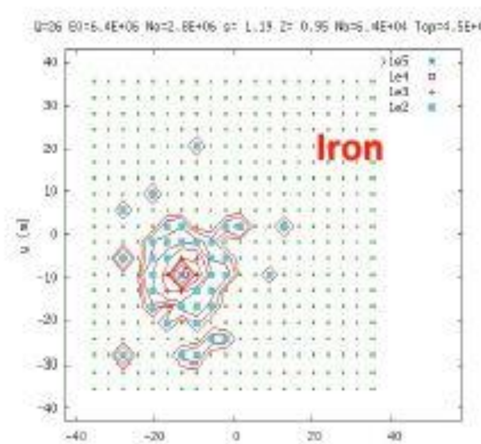
Burst Detector



The burst detectors observe the electron size (burst size) under the lead plate induced by high energy e.m. particle in the shower core region

Each burst detector is constituted by 20 optically separated scintillator strips of 1.5 cm × 4 cm × 50 cm read out by two PMTs operated with different gains to achieve a wide dynamic range (1- 10^6 MIPs).



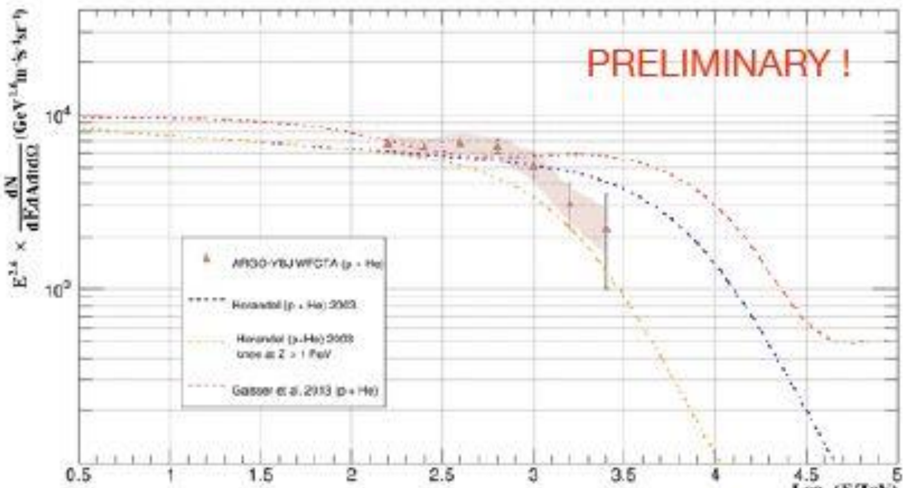


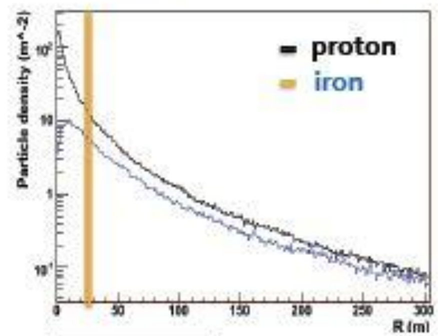
Wide field of view Cherenkov Telescope Array

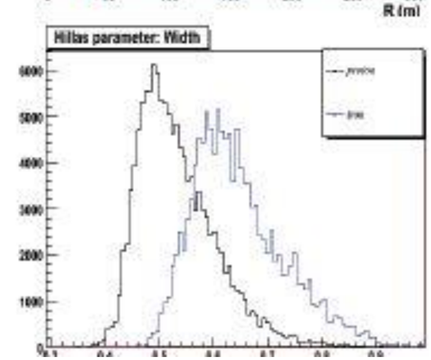
24 telescopes (Cherenkov/Fluorescence)

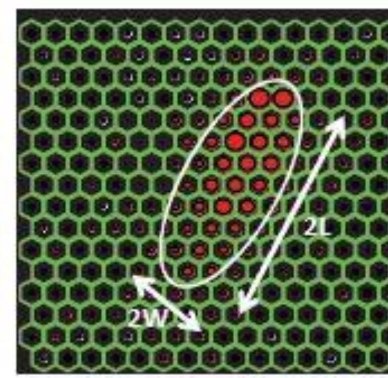
- 5 m² spherical mirror
- 16 x 16 PMT array
- pixel size 1º
- FOV: 14º x 14º
- Elevation angle: 60º

ARGO-YBJ / WFCTA



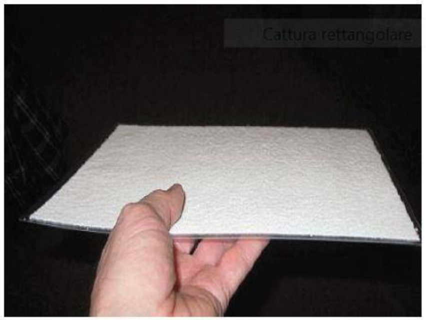


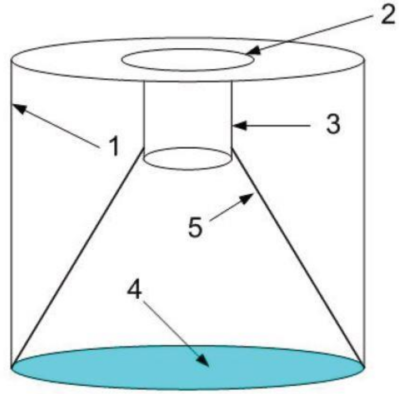




PRISMA - EN detectors

INP, RAS
Russia





Grid of EN-detectors
5 m spacing
Total area 100 x 100 m^2

Figure 1: Left: Photo of the scintillator. Right: Scheme of the en-detector. 1) PE water tank, 72 cm diameter, 57 cm height. 2) 30 cm lid diameter. 3) 6" PMT. 4) scintillator, area $0.36m^2$. 5) reflecting cone.