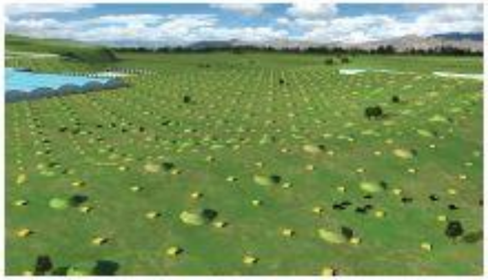
Gamma ray astronomy above 30 TeV with LHAASO

Silvia Vernetto
INAF – INFN Torino

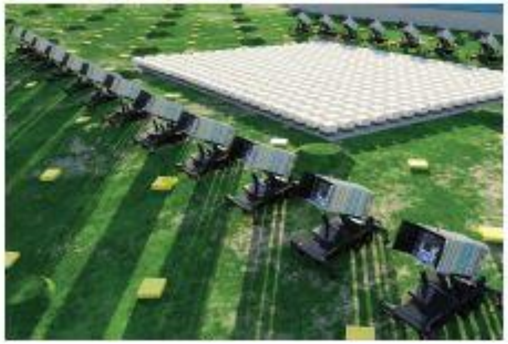
What Next – Padova – 3 Dicembre 2014

LHAASO – A multi component experiment



KM2A
1 km^2 array
5635 scintillator detectors
+ 1221 muon detectors

WCDA
Water Cherenkov Detector
90000 m^2



WFCTA
24 wide field of view
Cherenkov telescopes

SCDA
Shower Core Detector
452 scintillator detectors
with Pb+Fe

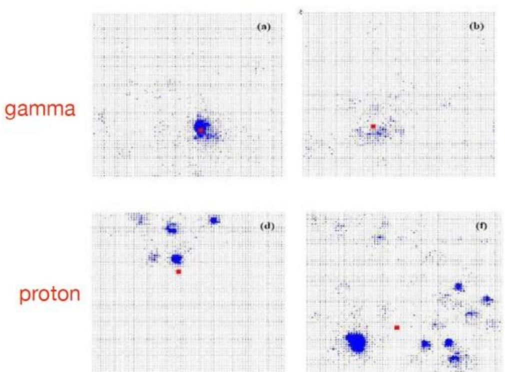
Site: Daocheng
Sichuan Province, China
4300 m a.s.l.

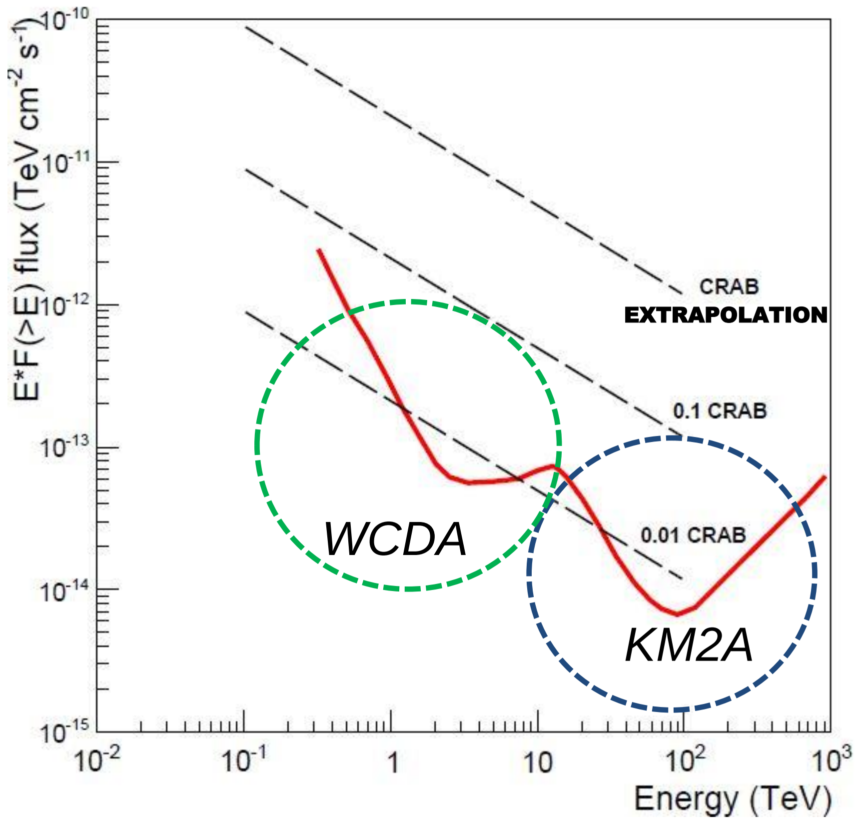
LHAASO integral sensitivity for a Crab-like gamma ray source

T = 1 year

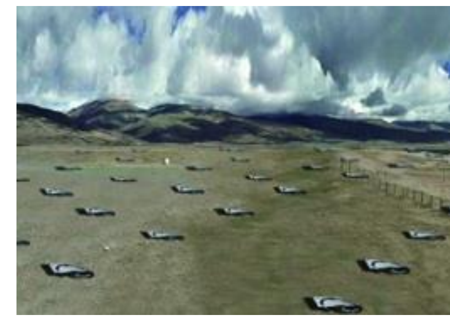
WCDA

Hadron discrimination

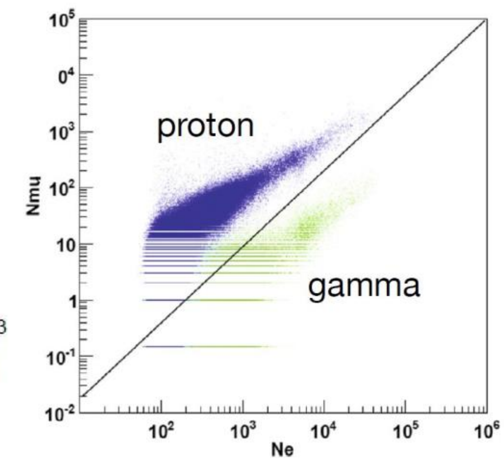




KM2A



Hadron discrimination



LHAASO field of view

Istantaneous FOV: zenith angle < 40°

Ω = 2.2 sr ~18% of the whole sky

LHAASO latitude: 29° North

24 h FOV: -11° < δ < 69°

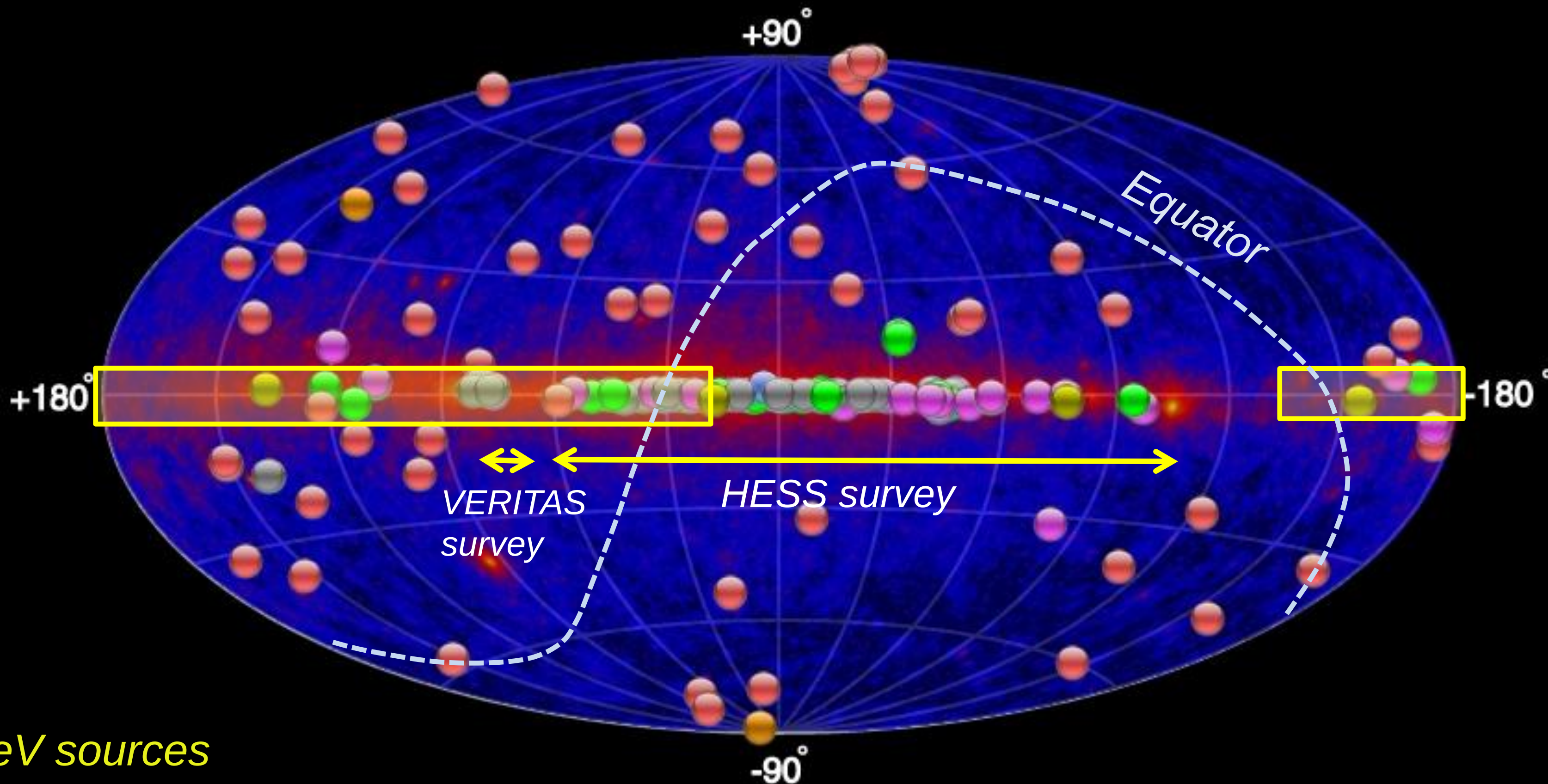
Ω = 7.0 sr ~ 56% of the whole sky

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

Galactic plane in the LHAASO FOV

Zenith angle < 40°

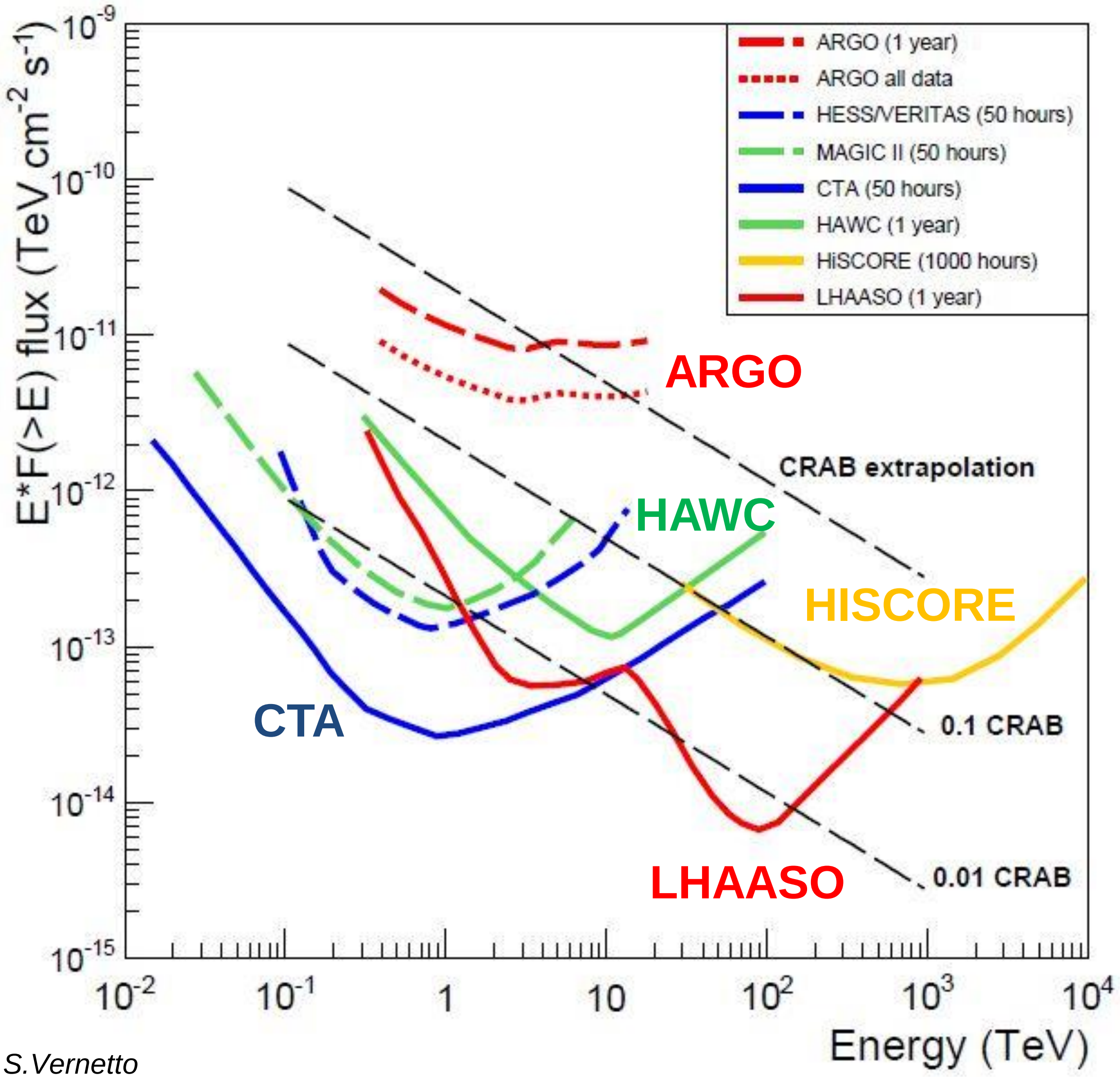
Visible Galactic Plane: l = 20° – 225°



TeV sources from TeVCat

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

Integral sensitivity for a Crab like source

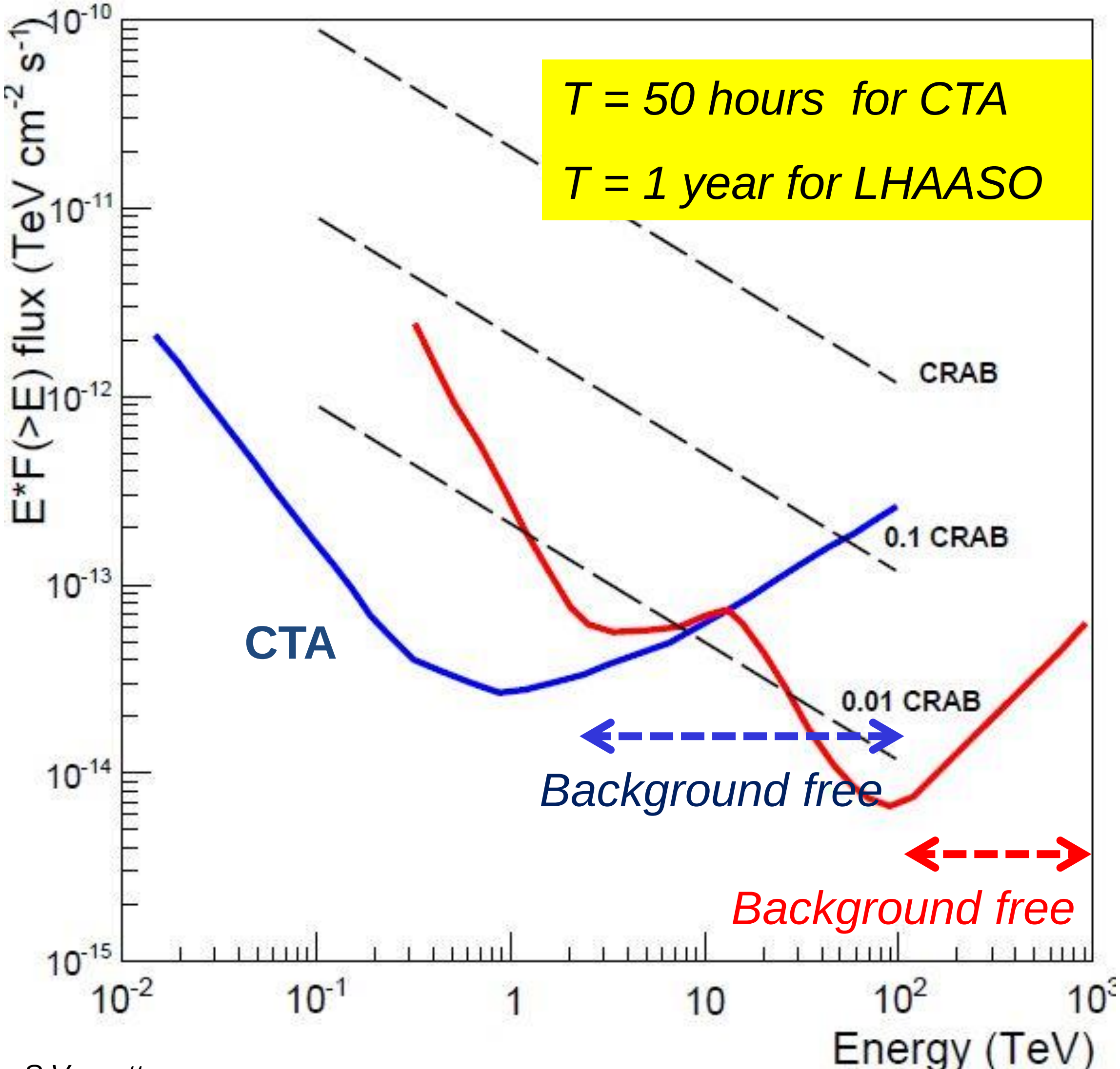


T = 50 hours for IACTs

T = 1 year for EAS arrays

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)

LHAASO and CTA integral sensitivity



5 σ detection

$N_\gamma / N_p^{1/2} > 5$

The sensitivity increases with T $^{1/2}$

Background free
$N_p = 0$

Detection requirement:
$N_\gamma \geq 10$

The sensitivity increases with T

LHAASO sensitivity /CTA sensitivity

Energy	LHAASO/ CTA sensitivity
> 1 TeV	~0.1
> 10 TeV	~1
> 30 TeV	~5
> 80 TeV	~30

T = 50 hours for CTA

T = 1 year for LHAASO

The real comparison depends on what is observed:

- Short flare or long time monitoring
- Point or extended source
- Diffuse emission
- Sky survey

Sky survey with a Cherenkov Telescope

Area of the sky to be scanned: A_{sky}

Very rough estimation!!

$A_{cell} = 4° \times 4°$ area of one cell

$N_{cell} \approx A_{sky} / A_{cell}$ number of cells

In one year every cell is observed for a time:

$T_{cell} \approx 24h \times 365 \text{ days} \times f_{dc} / N_{cells}$ ($f_{dc} \approx 0.15$ duty cycle)

Example 1 : Galactic plane ($-4° < b < 4°$, $\Delta l = 200°$) $T_{cell} = 13$ h

Example 2 : Sky survey ($-10° < \text{decl} < 70°$) ($\Omega_{tot} \approx 7$ sr) $T_{cell} = 0.9$ h

LHAASO sensitivity /CTA sensitivity

Energy	Galactic Plane Survey	Sky survey
> 1 TeV	0.2	0.8
> 10 TeV	4	60
> 30 TeV	20	300
> 80 TeV	100	1600

Very rough estimation!!

Gamma ray astronomy above 30 TeV

State of the art

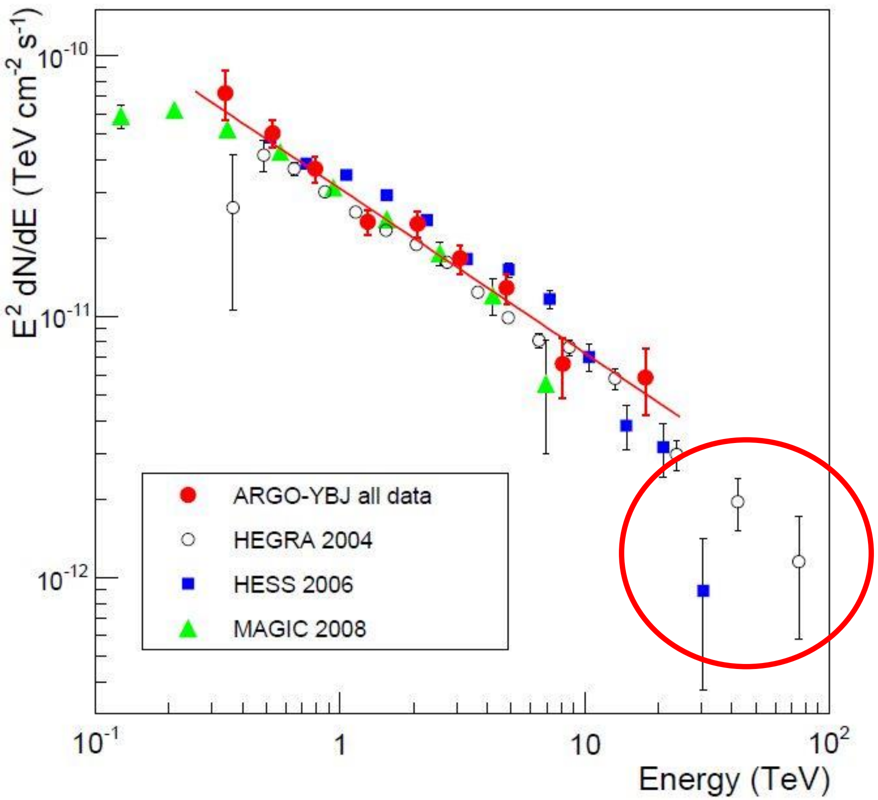
Gamma ray astronomy above 30 TeV

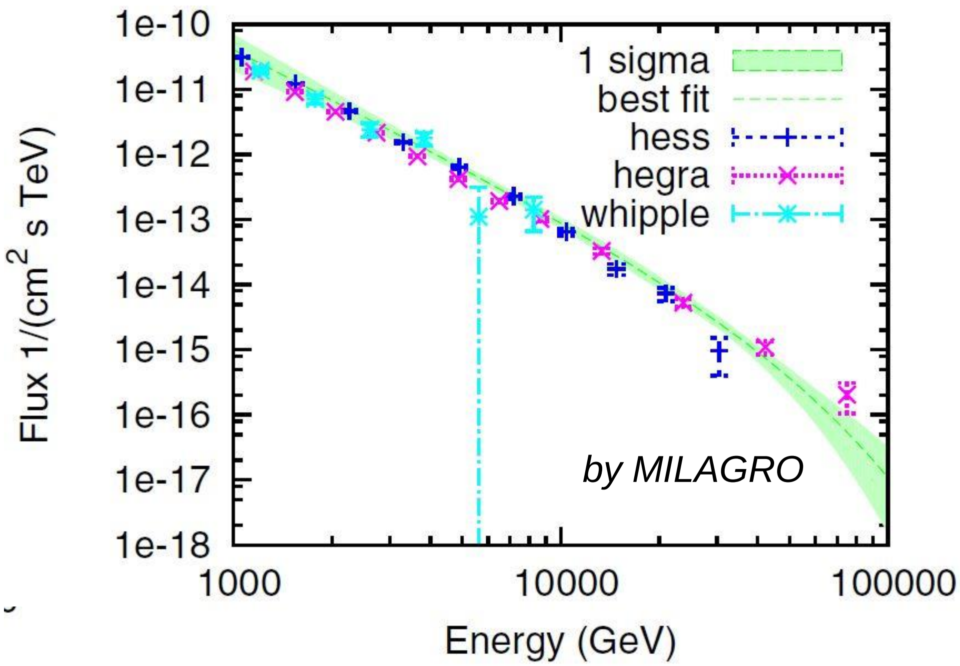
150 TeV sources observed

Sources with data above 30 TeV:

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

TeV Crab Nebula data



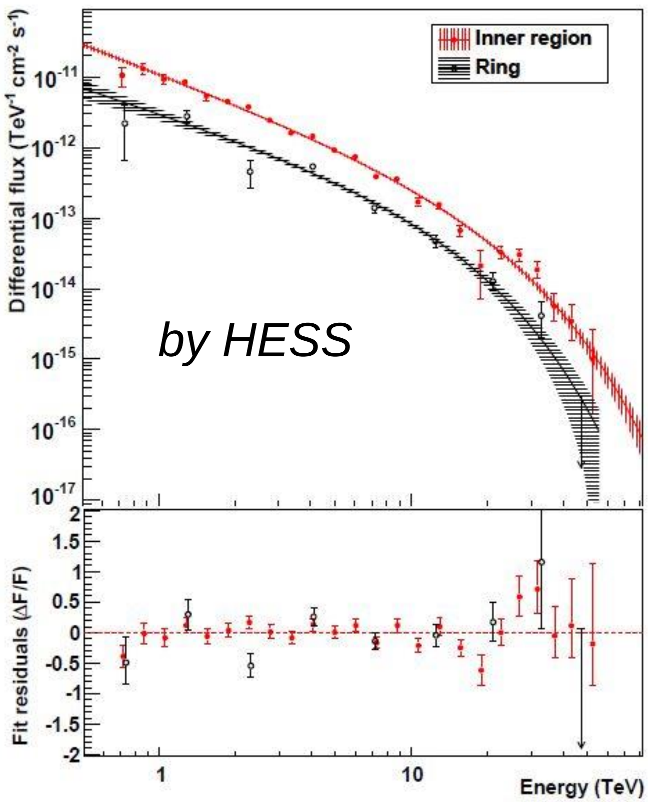


Above 30 TeV: few data and large error bars

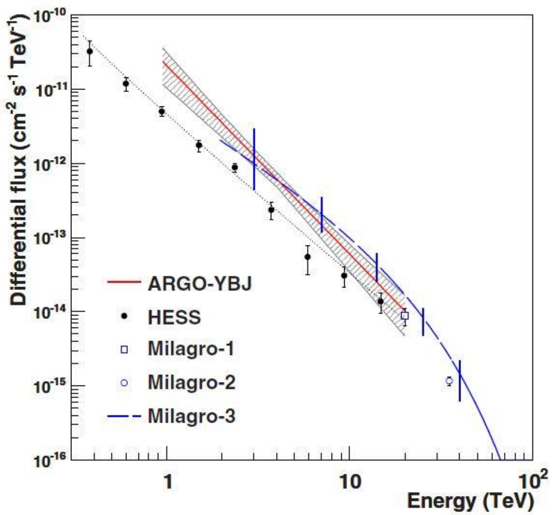
GeV Flares observed → IC component above 10 TeV ?

Other Pulsar Wind Nebulae...

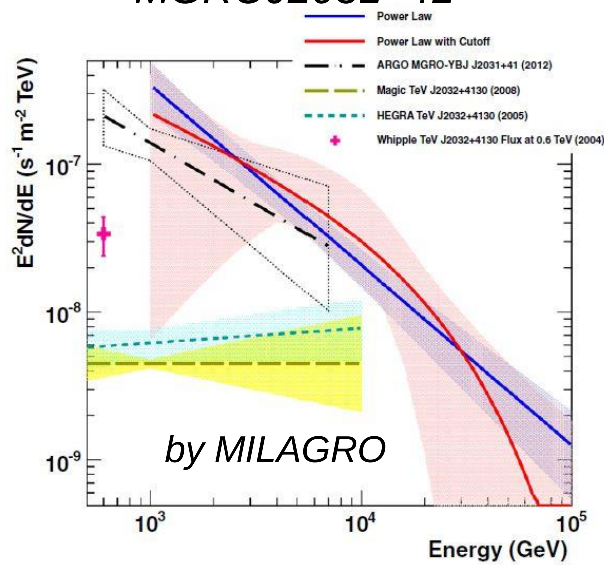
VELA -X

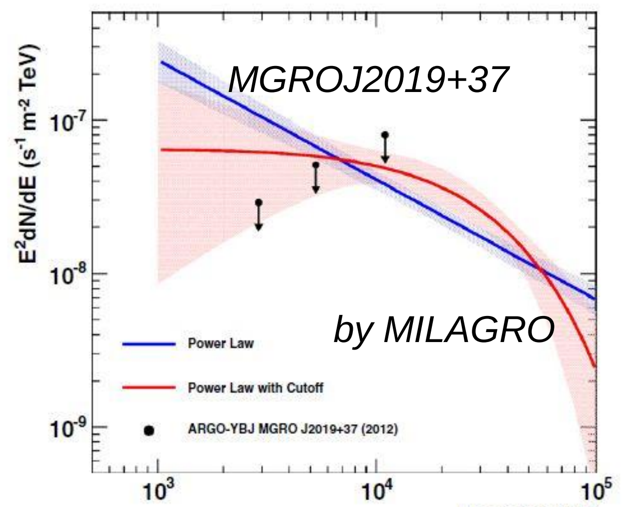


MGROJ1908+06



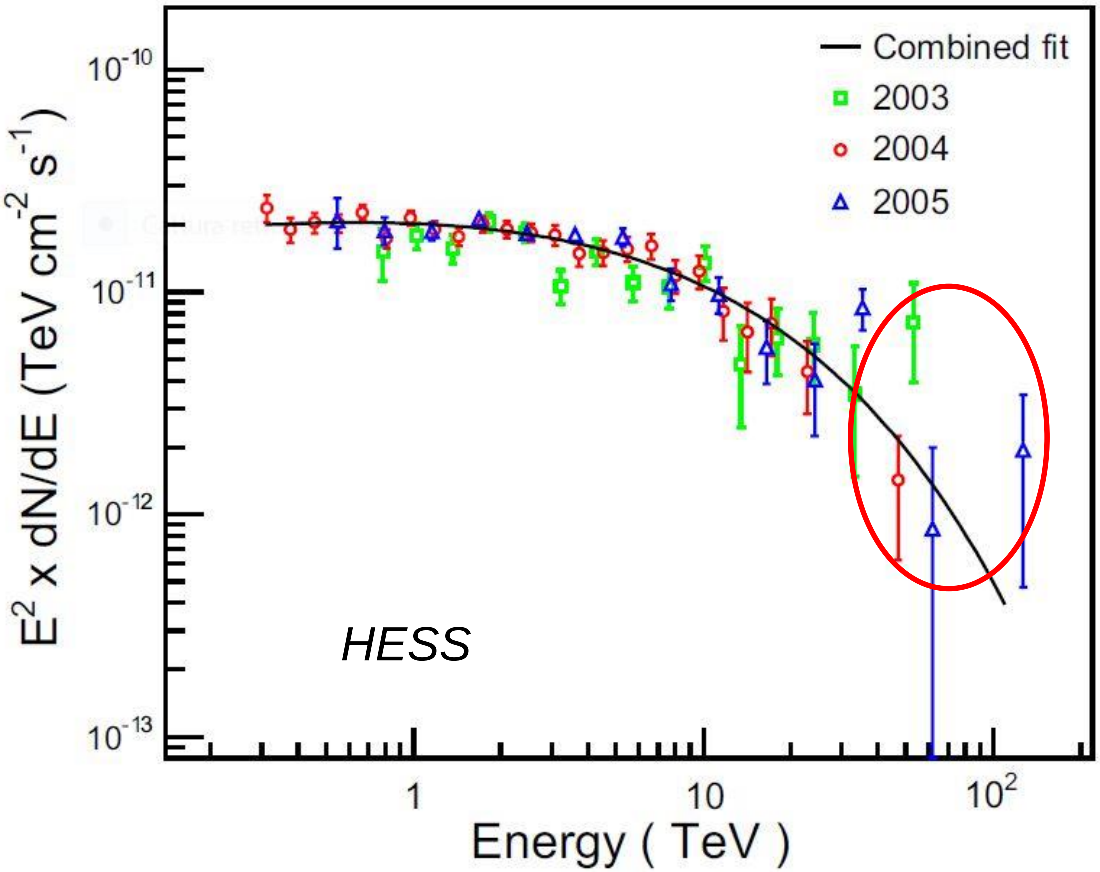
MGROJ2031+41





Data above 30 TeV are very scarce

An other example: SNR RX J1713.7-3946

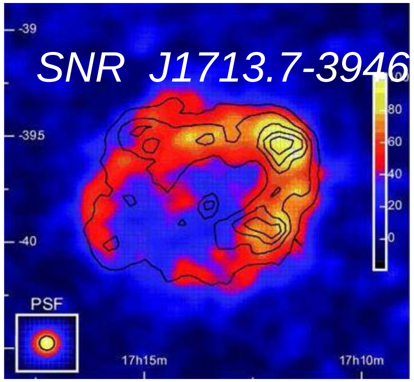


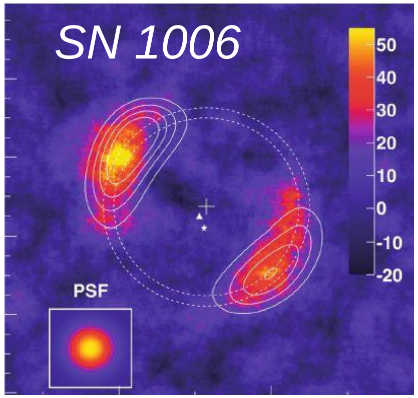
The only SNR data above 30 TeV

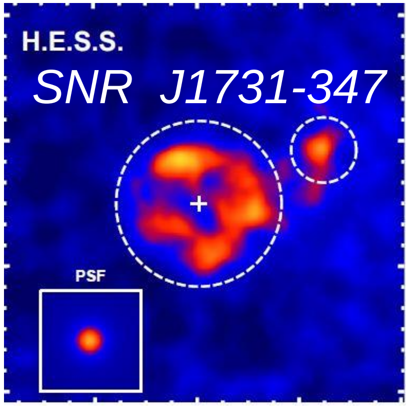
Why data above 30 TeV are important

Searching for cosmic ray sources

- Supernova Remnants are the favorite sites for the acceleration of Galactic cosmic rays
- 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 SNR shocks, but the relative contribution of protons and electrons to the observed flux is still unclear







TeV gamma ray emission from SNR

The relative contribution of protons and electrons to the SNR observed flux is still unclear:

Leptonic emission

- Inverse Compton (IC) scattering of electrons on low energy photons:
    - Cosmic Microwave Background (CMB)
    - Infrared, optical photons
    - Synchrotron photons
    - .....
- Bremsstrahlung

Hadronic emission

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

Inverse Compton scattering

1) *Thomson regime*

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

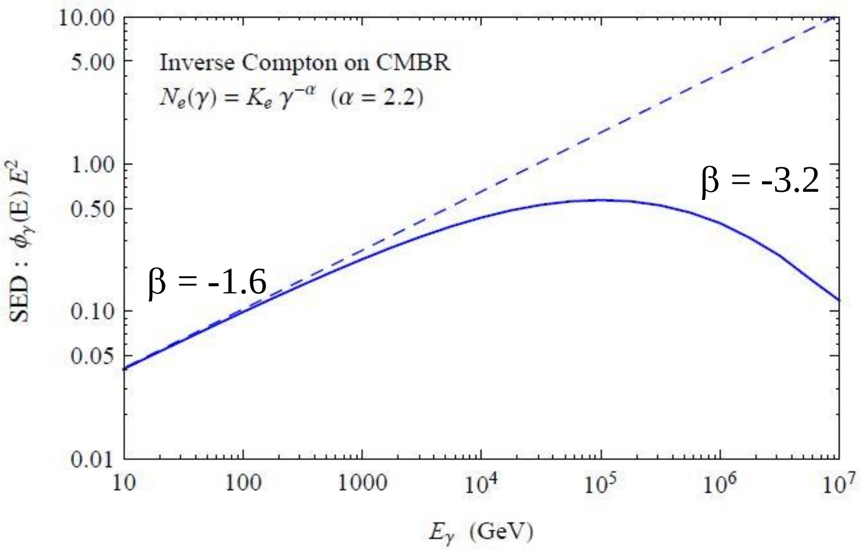
Costant cross section: Thomson cross section

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

2) *Klein-Nishina regime*

The cross section decreases

Photon index $\beta = \alpha+1$



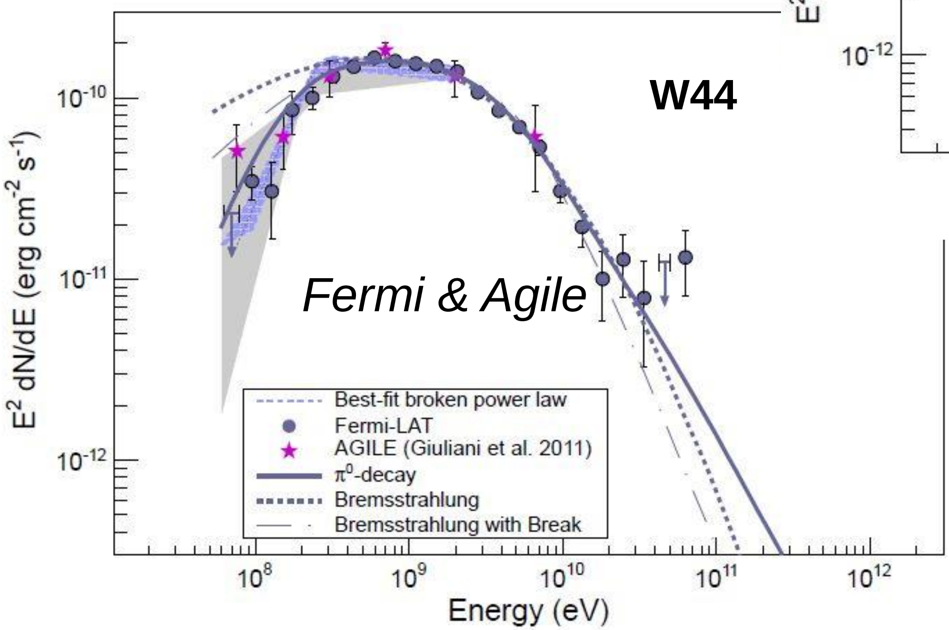
In case of CMB seed photons, the KN regime starts below 100 TeV

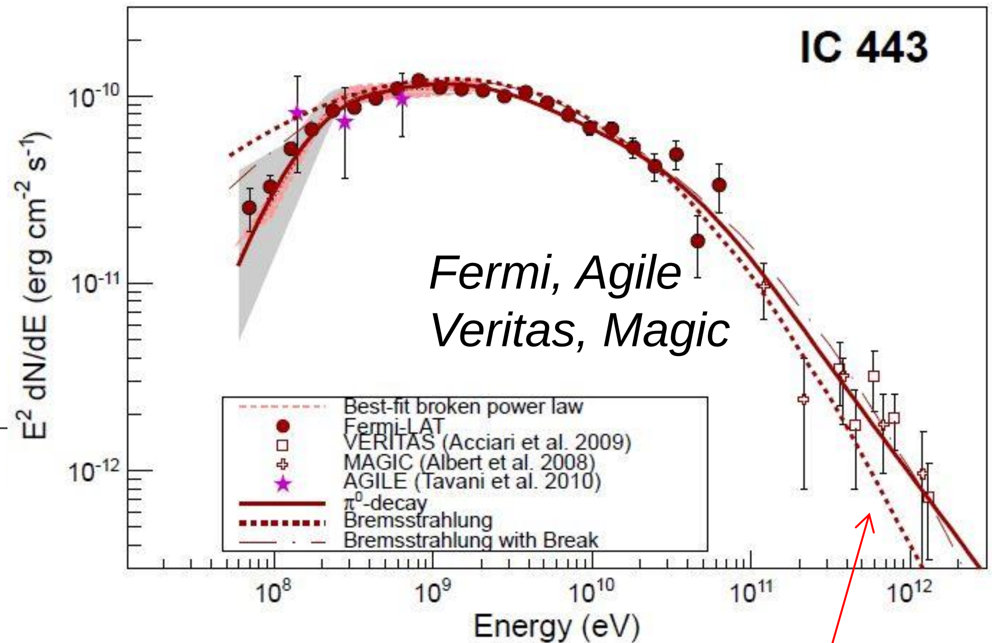
Hadronic interactions

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

- 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*

Two observations of π^0 bumps





Hadrons are accelerated up to a few tens of TeV

Spectra are very soft !

Things are not simple...

Each SNR is individual and has a unique behaviour
In general one expects a combination of leptonic and hadronic emission

The relative contributions depend on:

- Ratio of the injected electrons and protons
- Electrons and protons spectra (Power law? Breaks ? Cutoff ?)
- Particle confinement, escape time
- Density of target material for proton interactions
- Density of low energy seed photons for electron IC
- Magnetic field strength (synchrotron emission)
- SN type
- SNR age and morphology
- Presence of Molecular Clouds
- Absorption of gamma rays
- *......*

Multi-wavelength studies can help

Gamma ray astronomy above 30 TeV

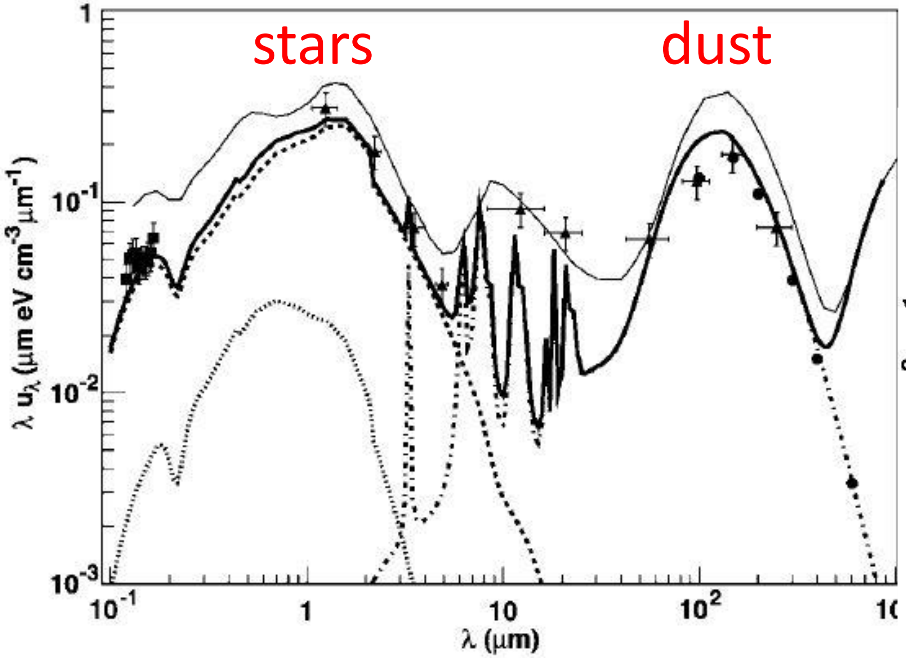
In this complex scenario, one thing is clear:

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

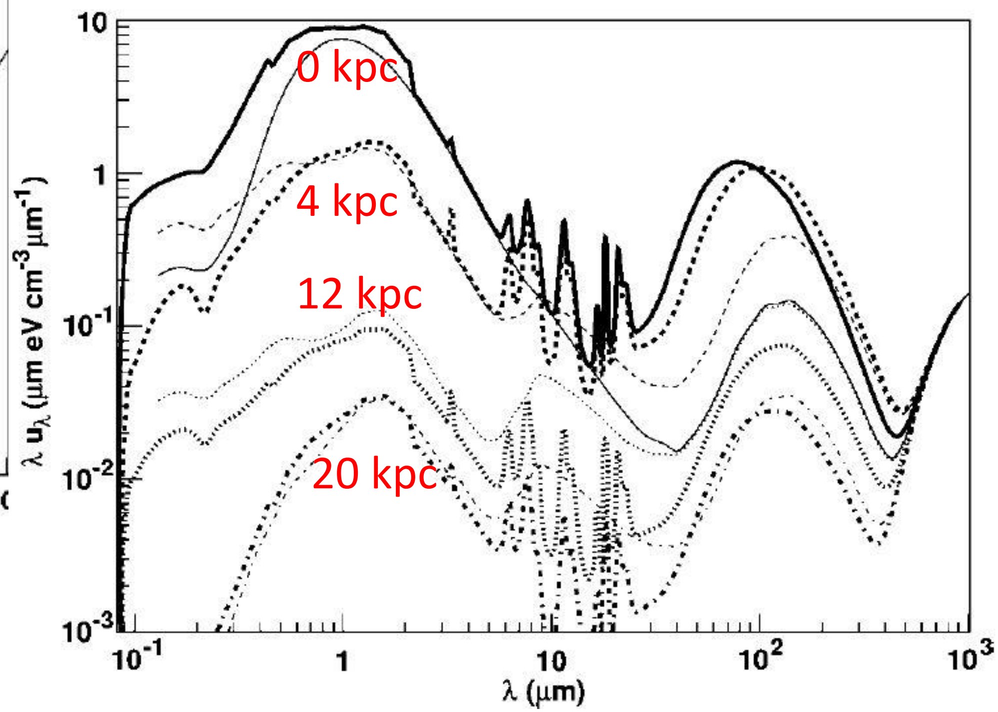
Gamma ray astronomy above 30 TeV could give the definitive answer of the question whether the SNRs are the long sought Pevatrons

Gamma ray absorption in the Galaxy

Local radiation field



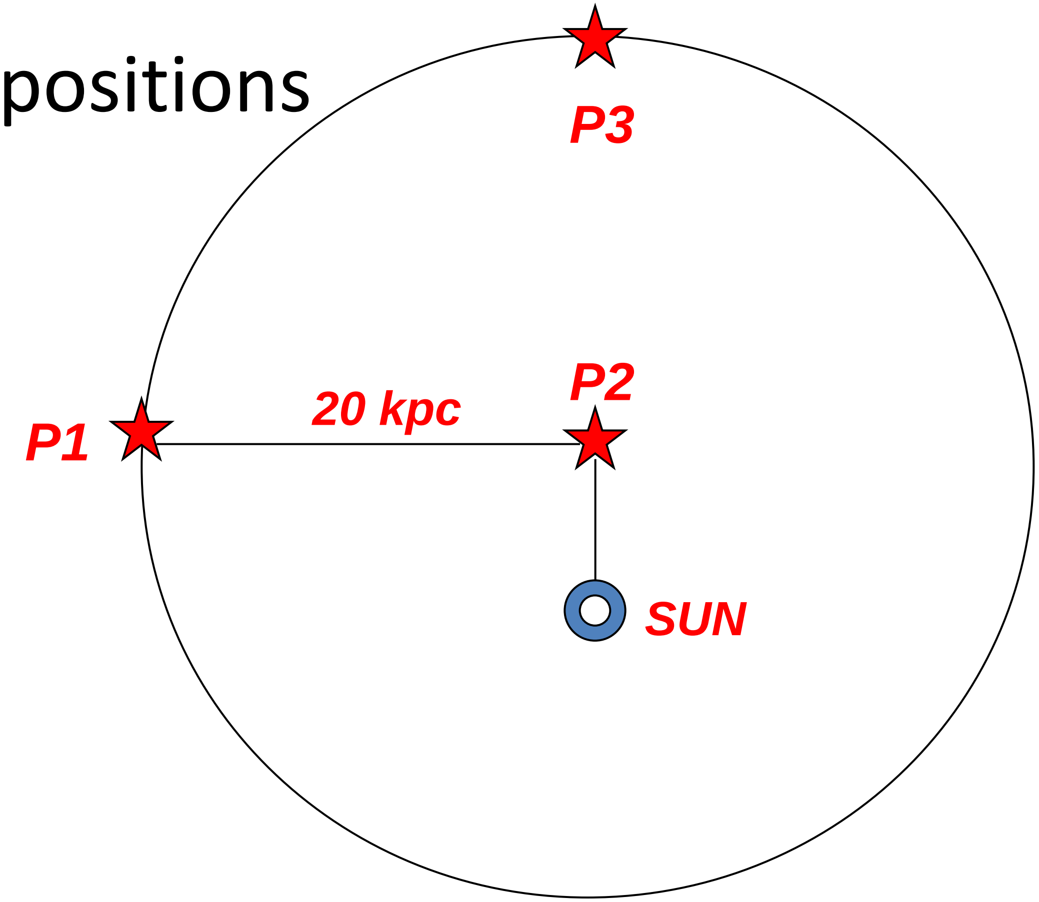
Radiation field for different distances from the galactic center



Moskalenko et al, 2006 ApJL 640, 155

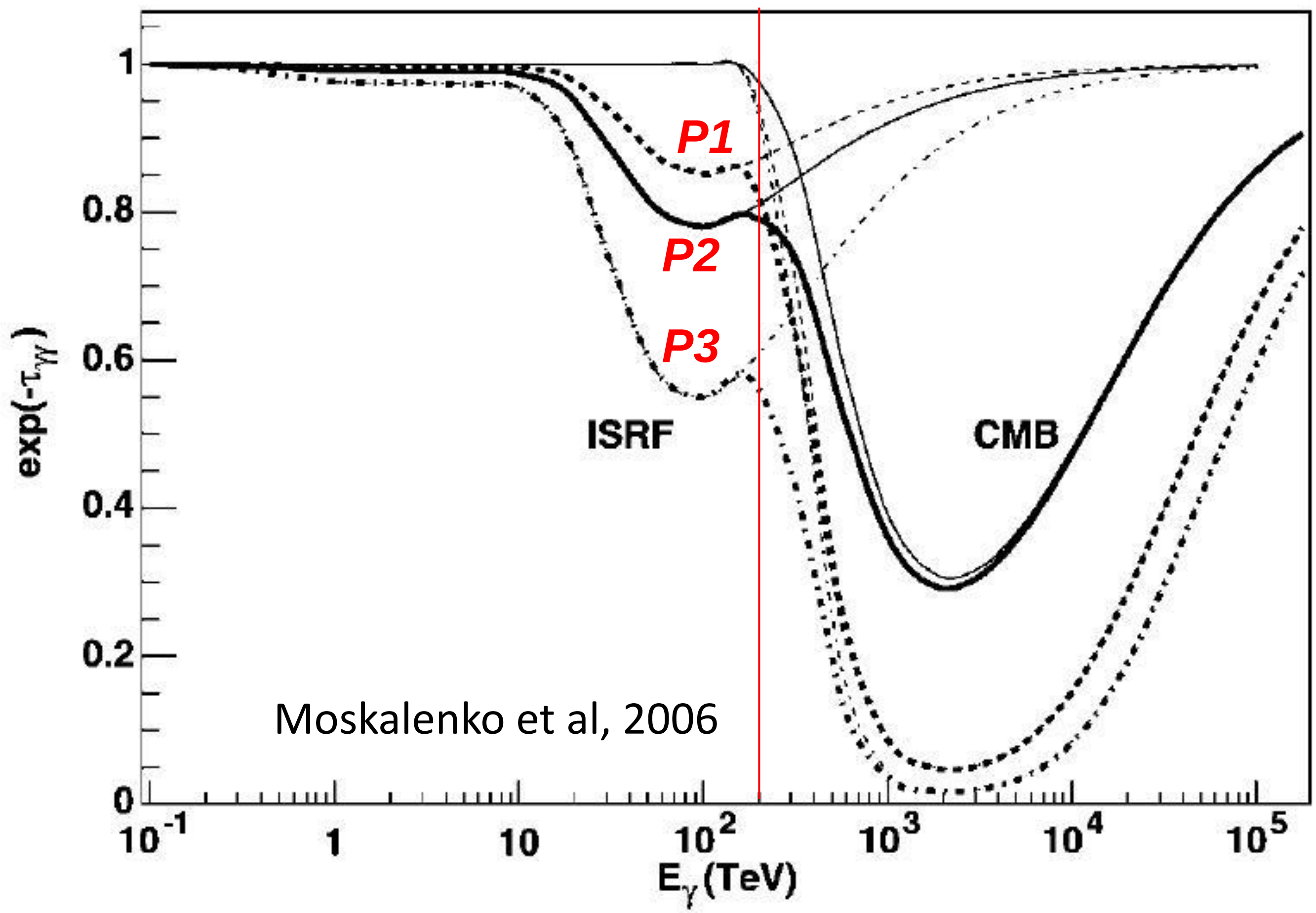
Gamma ray absorption in the Galaxy

3 source positions



Distance Sun – Galactic centre   8.5 kpc

Gamma ray absorption in the Galaxy



Low attenuation up to ~200 TeV for P1 and P2

What LHAASO can see

TeV sources in the LHAASO FOV

From TeVCat :

71 sources culminating at zenith angle < 40°

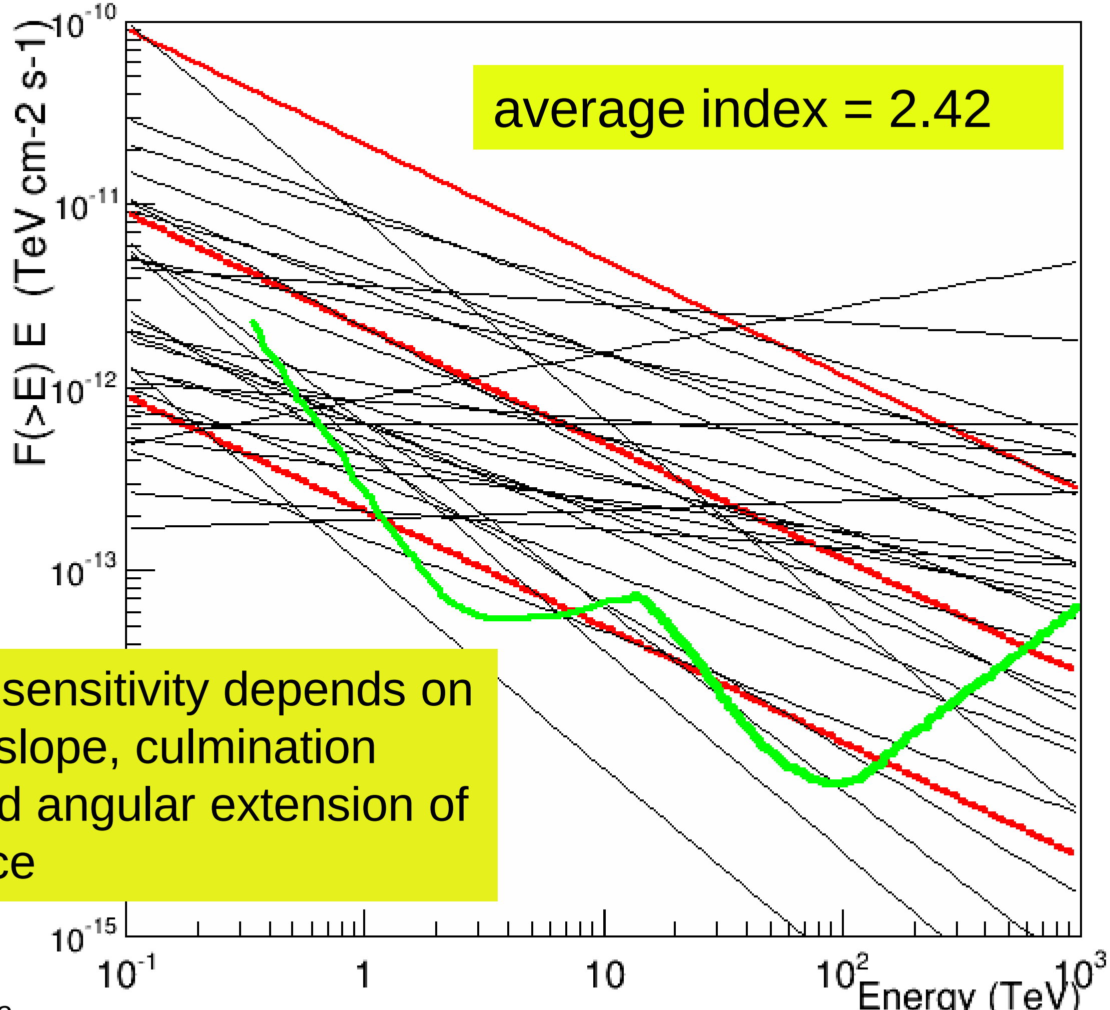
- 31 galactic →

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

- 40 extragalactic

70% of Galactic sources are extended

Extrapolated spectra up to 100 TeV



average index = 2.42

Extrapolation of TeV spectra assuming no cutoff

CRAB

CRAB x 0.1

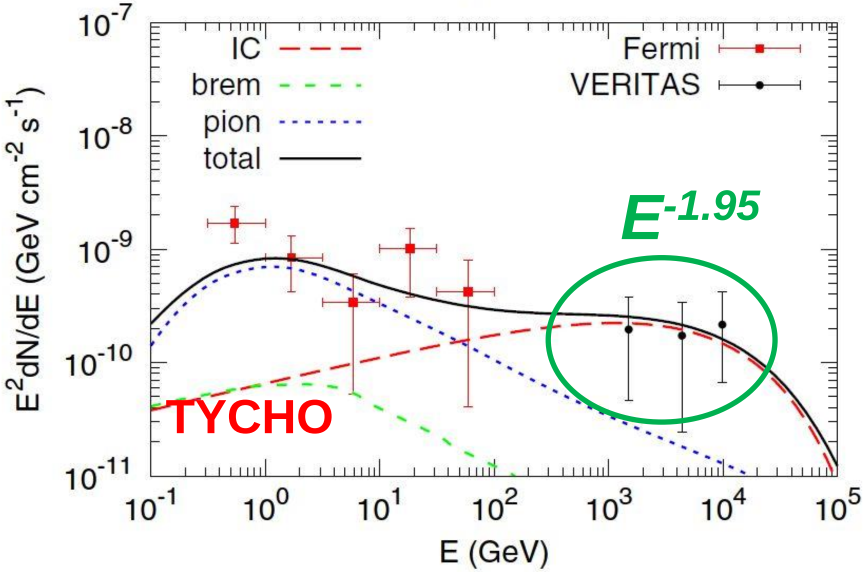
CRAB x 0.01

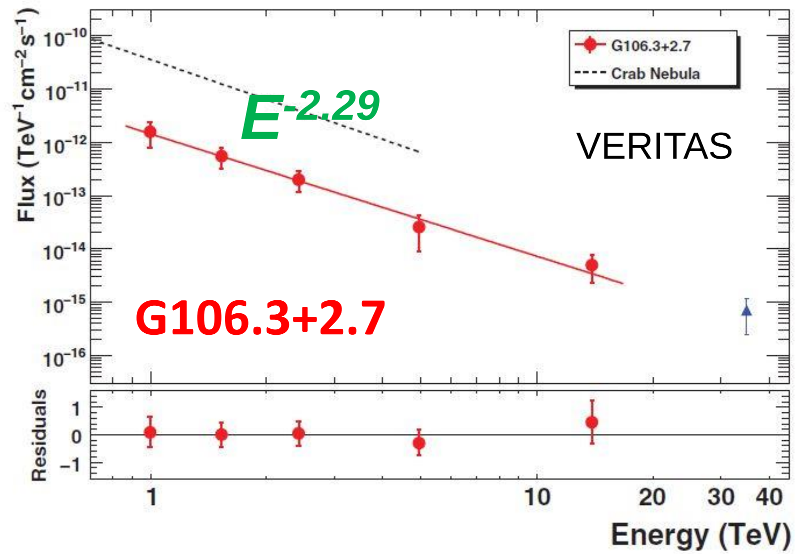
The real sensitivity depends on spectral slope, culmination angle and angular extension of the source

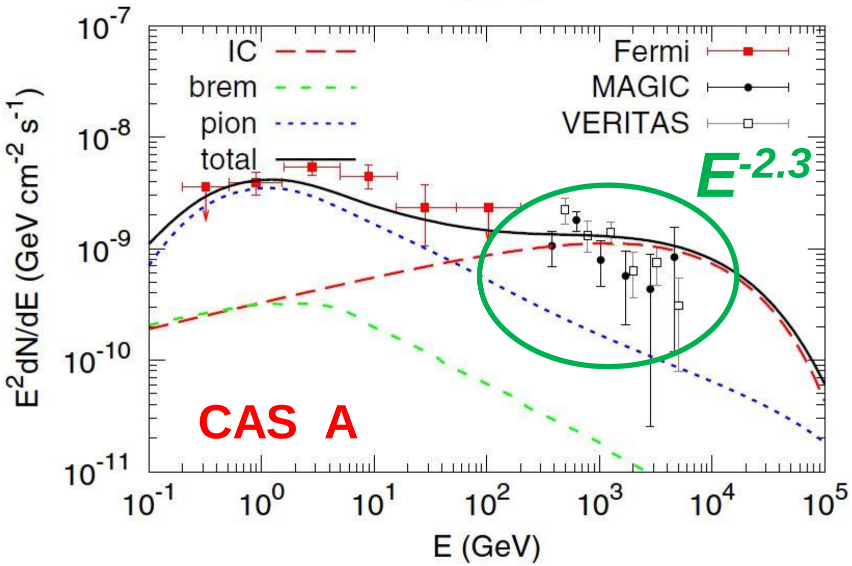
6 Shell SNRs

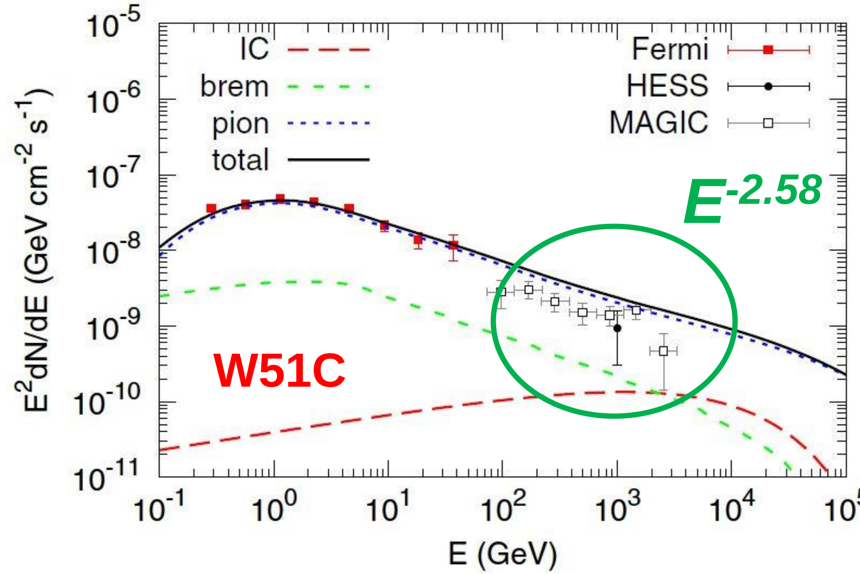
Source	Zenith angle culm.	F > 1 TeV (c.u.)	Energy range	Spectral index	Angular size (σ)
Thyco	34°	0.009	1-10	1.95	
G106.3+2.7	31°	0.03	1-20	2.29	0.3° x 0.2°
Cas A	29°	0.05	0.5-10	2.3	
W51	16°	0.03	0.1-5	2.58	0.12°
IC443	7.5°	0.03	0.1-2	3.0	0.16°
W49B	21°	0.005	0.3-10	3.1	

SNR GeV-TeV spectra

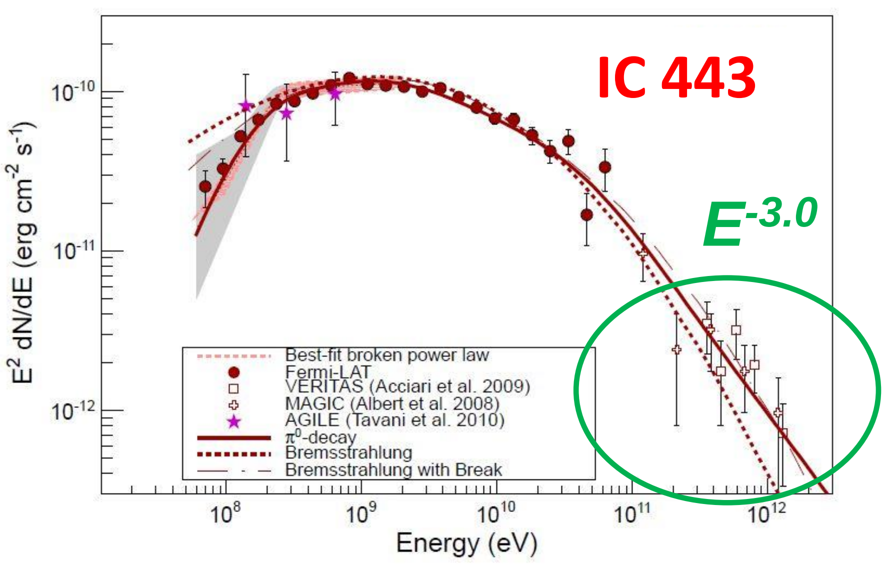


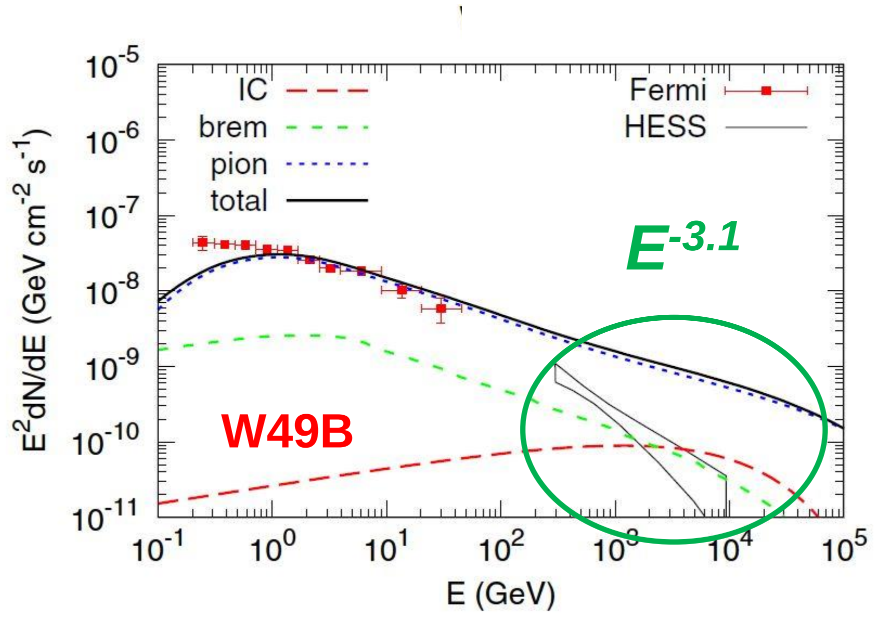






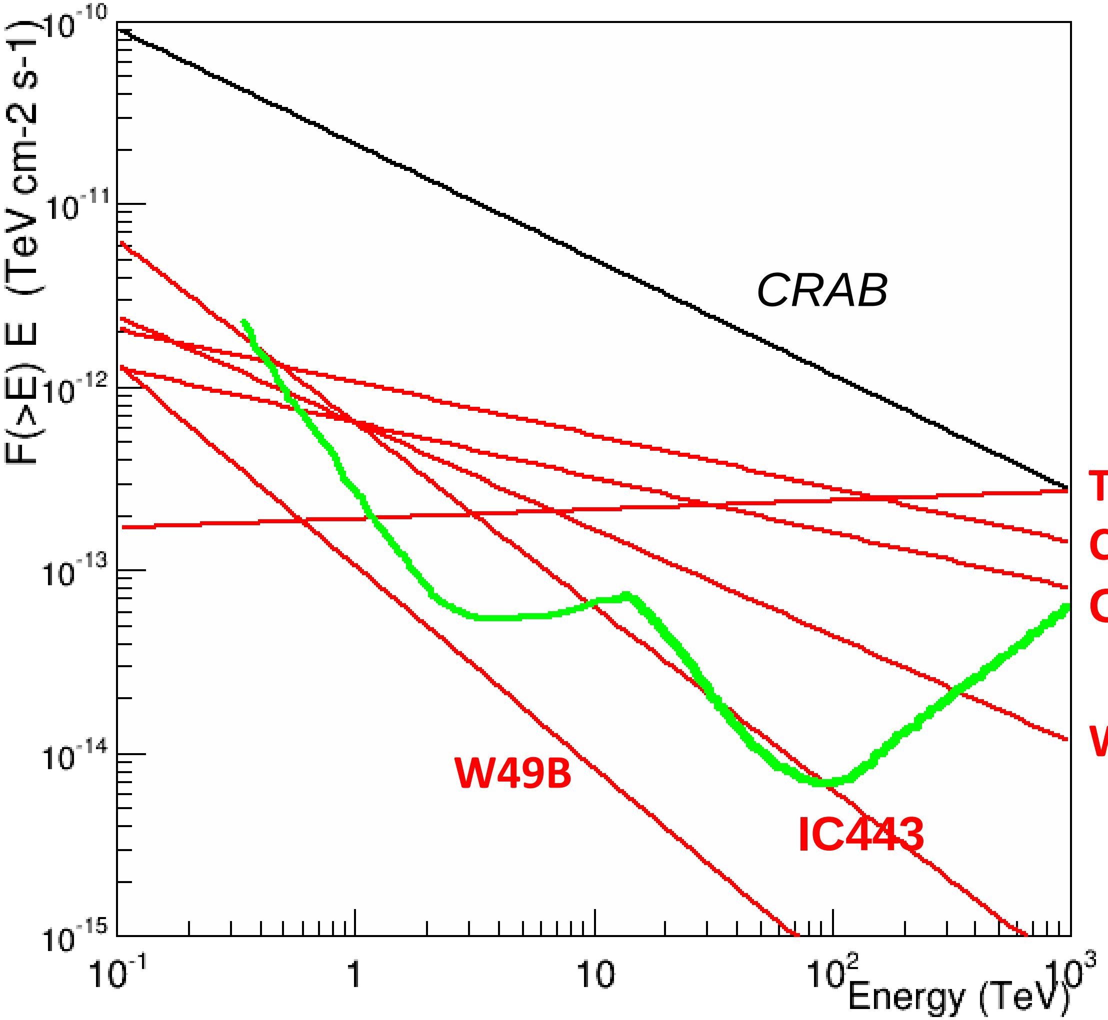
SNR GeV-TeV spectra





No cutoff observed in the 6 TeV spectra

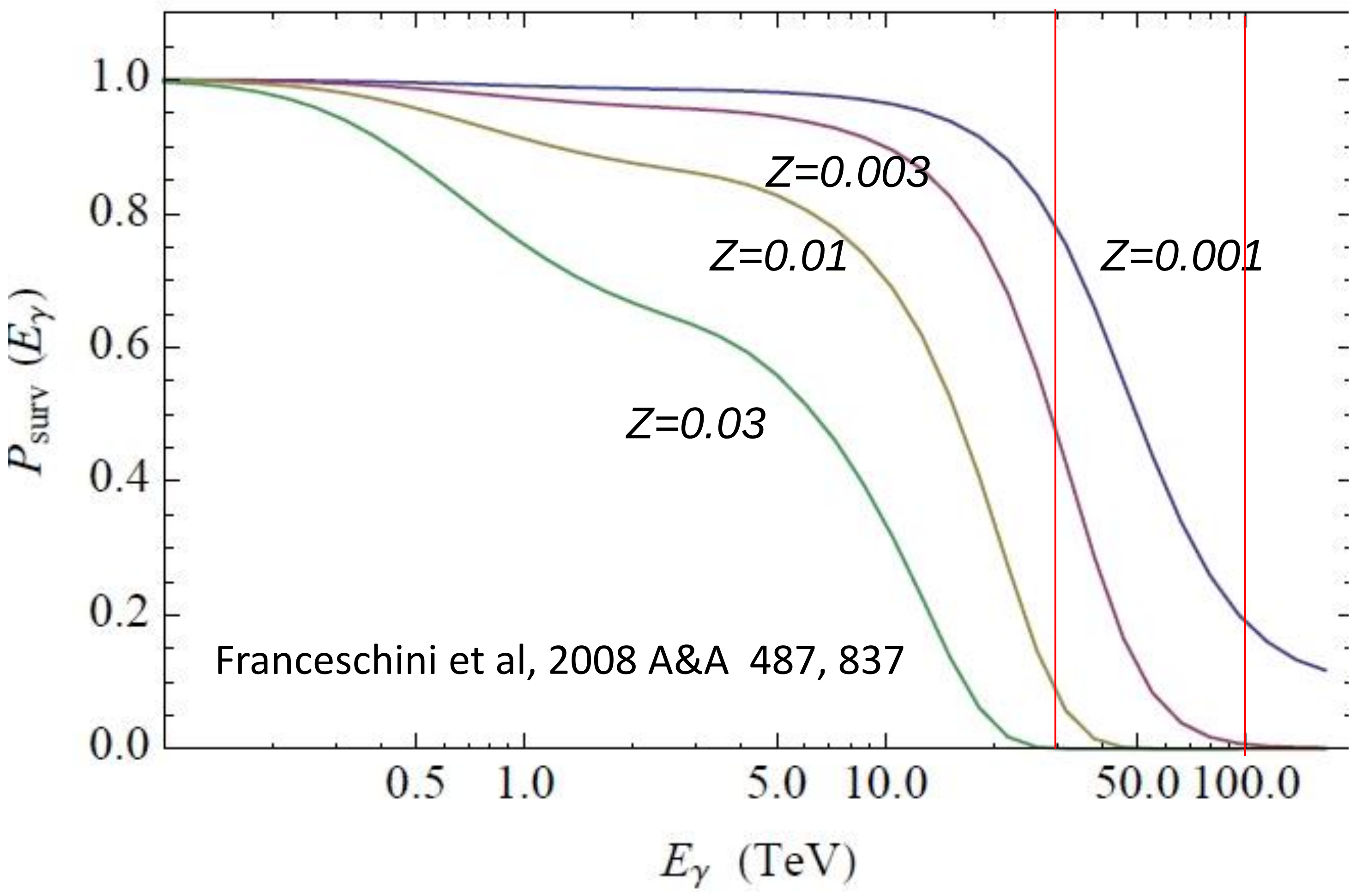
SNRs extrapolated spectra



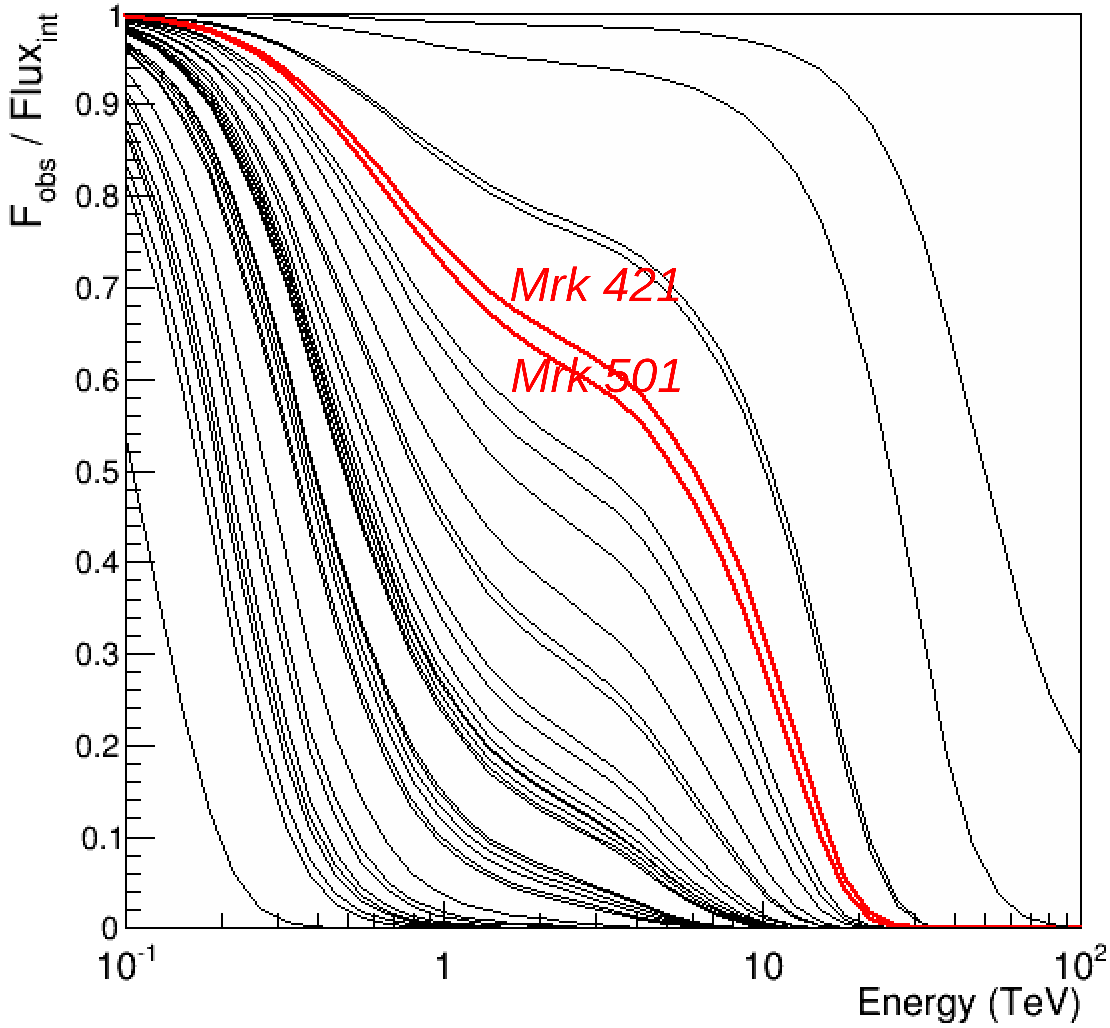
Gamma ray absorption in the Galaxy is not considered

Extragalactic astronomy above 30 TeV ?

Gamma ray attenuation for extragalactic sources



Spectra absorption



36 TeV sources
In the LHAASO FOV
with known redshift

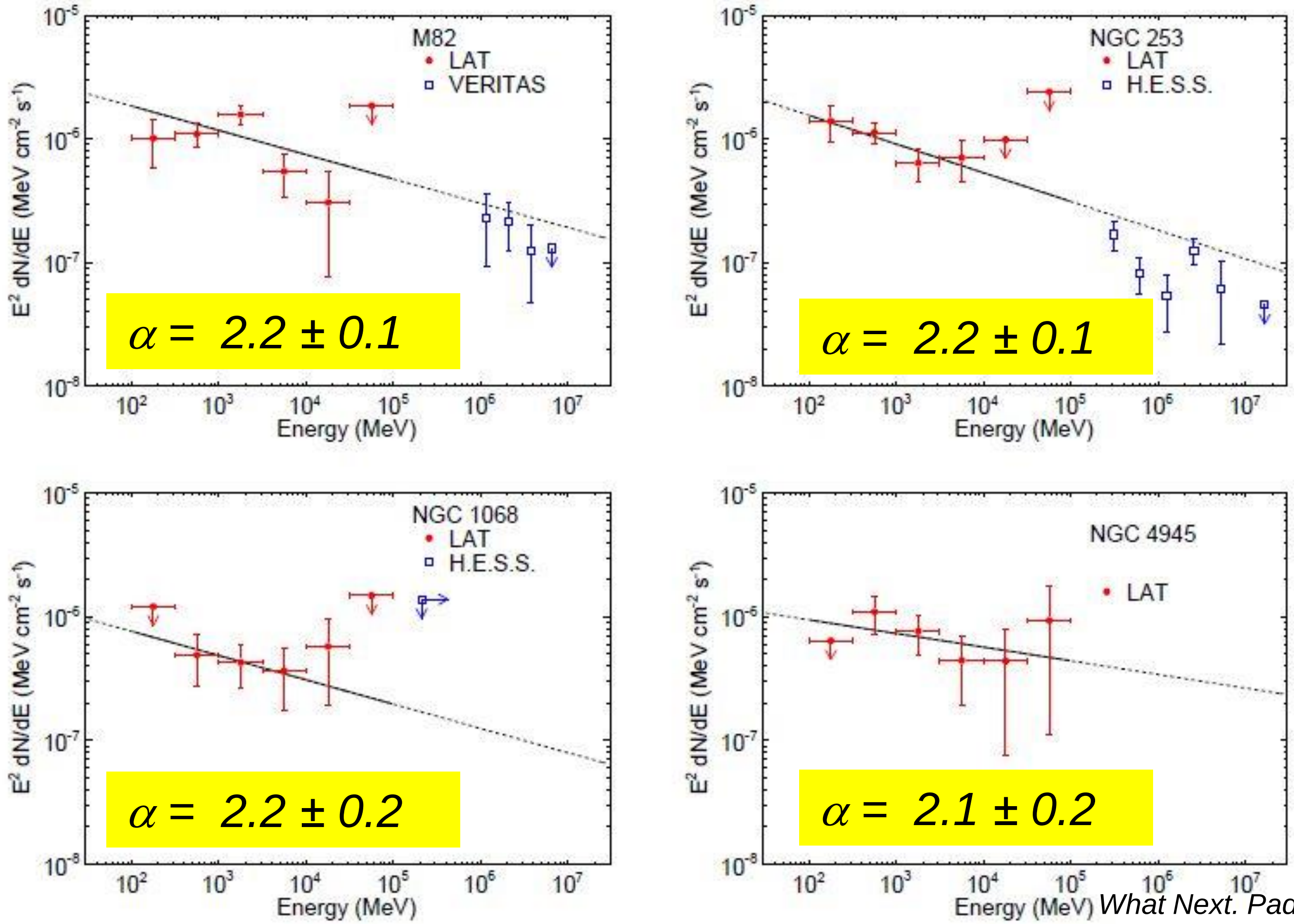
Franceschini model

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

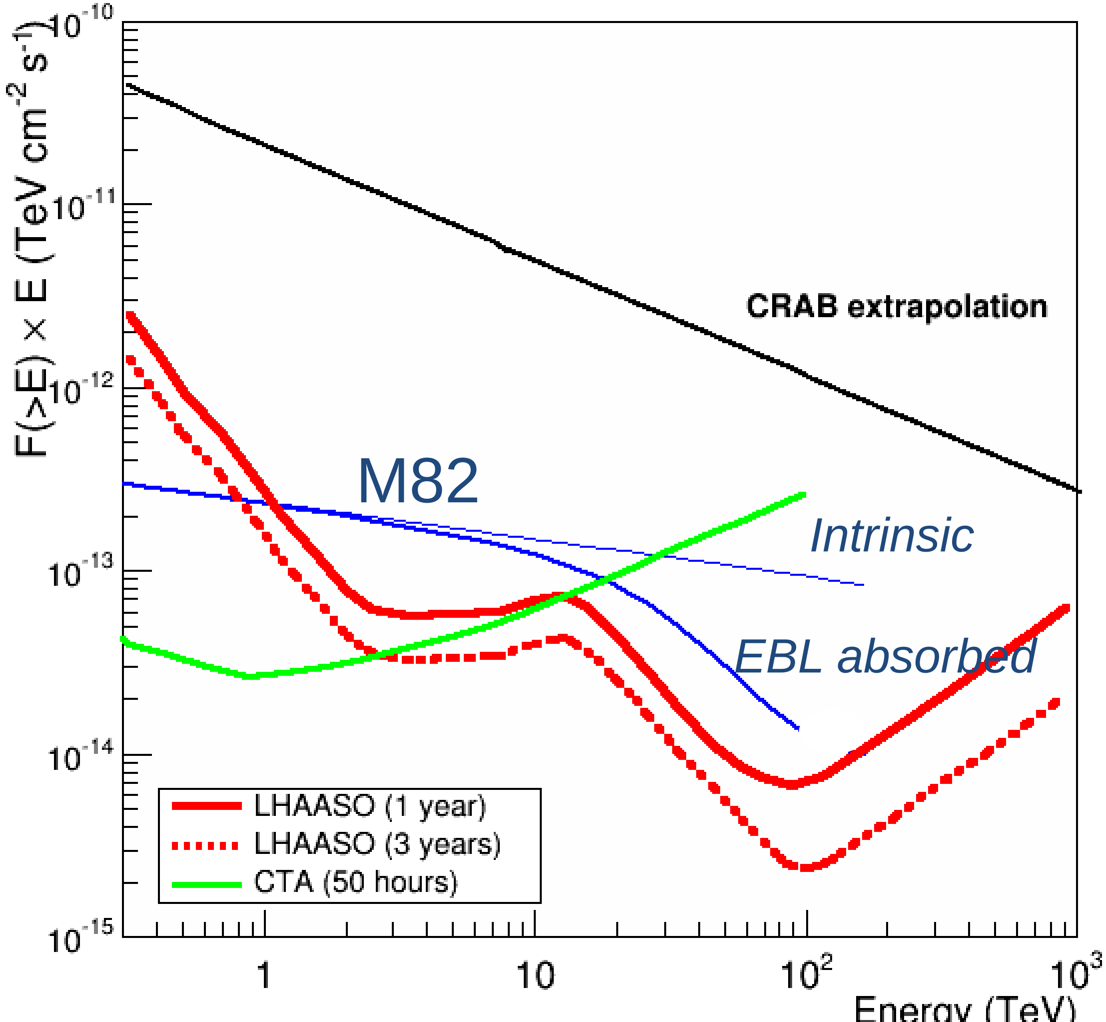
Fermi & Starburst galaxies

Fermi observed 69 Starburst galaxies
Four have been seen
Two of them have also been seen at VHE



Ackermann et al., 2012

M82 expected flux at 10-100 TeV



Power law spectrum

Fermi index $\alpha = -2.2$

Conclusions

- Gamma ray astronomy >30 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 galactic sources. SNRs are Pevatrons?
- Challenging observation of extragalactic sources: a few very close radio galaxy or starburst galaxy could be detected.
- Sky survey: in one year LHAASO can survey the Northen sky at 100 TeV at a level of % Crab.
- What about a LHAASO-like experiment in the Southern hemisphere ?

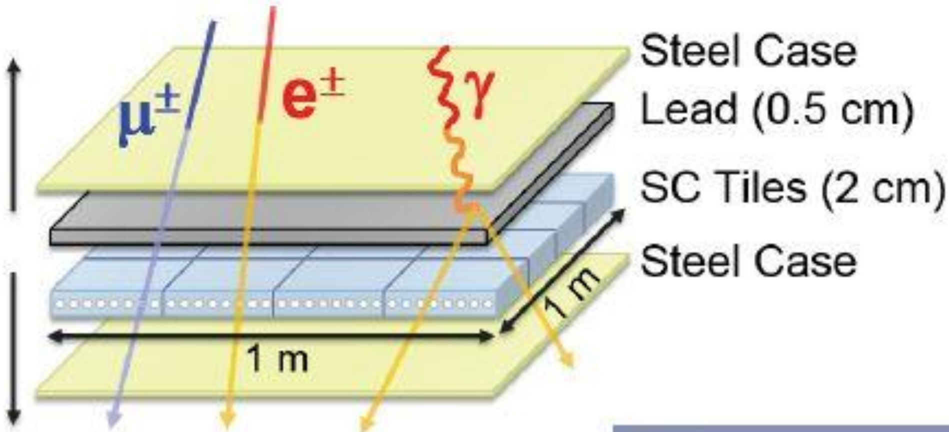
Backup slides

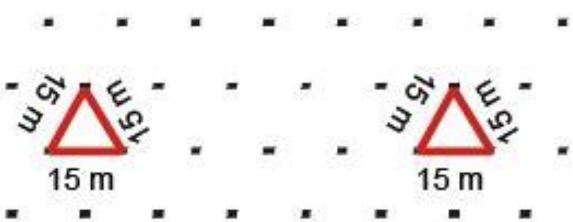
The LHAASO site

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''

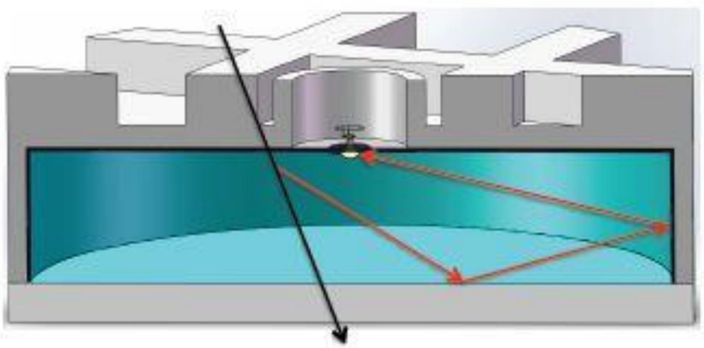
Electromagnetic particle Detector

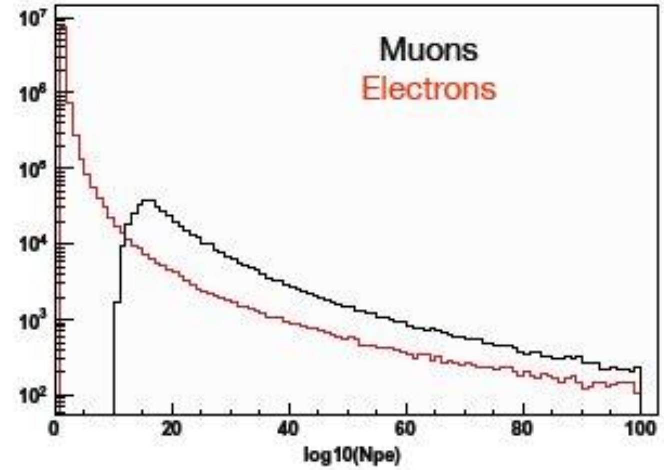




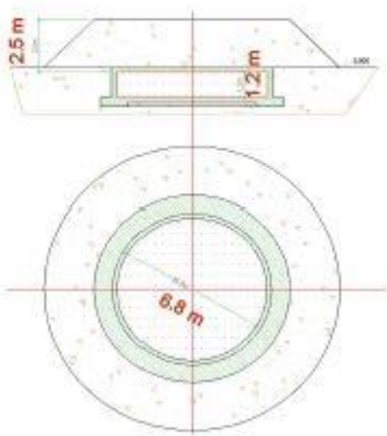
Item	Value
Effective area	1 m^2
Thickness of tiles	2 cm
Number of WLS fibers	8/tilex16 tile
Detection efficiency (> 5 MeV)	>95%
Dynamic range	1-10,000 particles
Time resolution	<2 ns
Particle counting resolution	25% @ 1 particle 5% @ 10,000 particles
Aging	>10 years
Spacing	15 m
Total number of detectors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

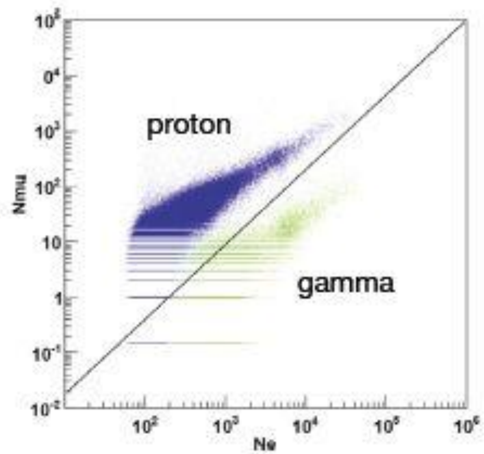
Muon Detector





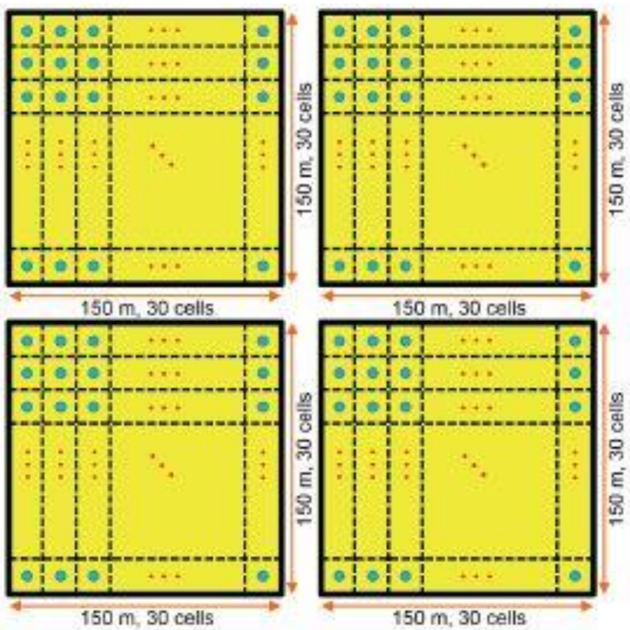
Photoelectrons distribution at R > 100 m from the shower core position

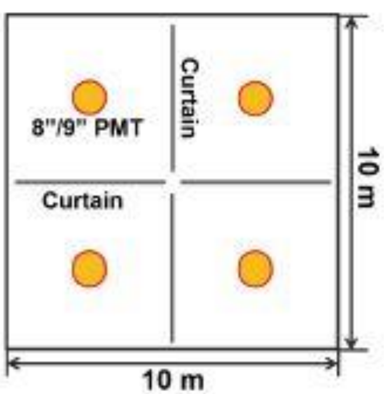


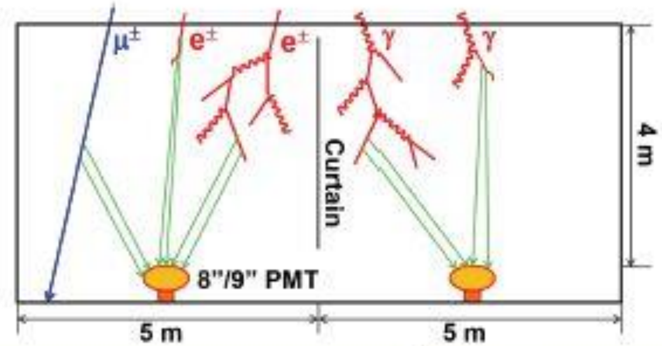


Item	Value
Area	36 m^2
Depth	1.2 m
Molasses overburden	2.5 m
Water transparency (att. len.)	> 30 m (400 nm)
Reflection coefficient	>95%
Time resolution	<10 ns
Particle counting resolution	25% @ 1 particle 5% @ 10,000 particles
Aging	>10 years
Spacing	30 m
Total number of detectors	1221

Water Cherenkov Detector Array





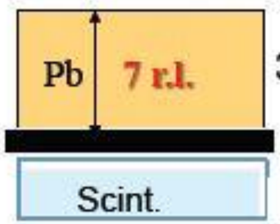


Item	Value
Cell area	25 m²
Effective water depth	4 m
Water transparency	> 15 m (400 nm)
Precision of time measurement	0.5 ns
Dynamic range	1-4000 PEs
Time resolution	<2 ns
Charge resolution	40% @ 1 PE 5% @ 4000 PEs
Accuracy of charge calibration	<2%
Accuracy of time calibration	<0.2 ns
Total area	90,000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

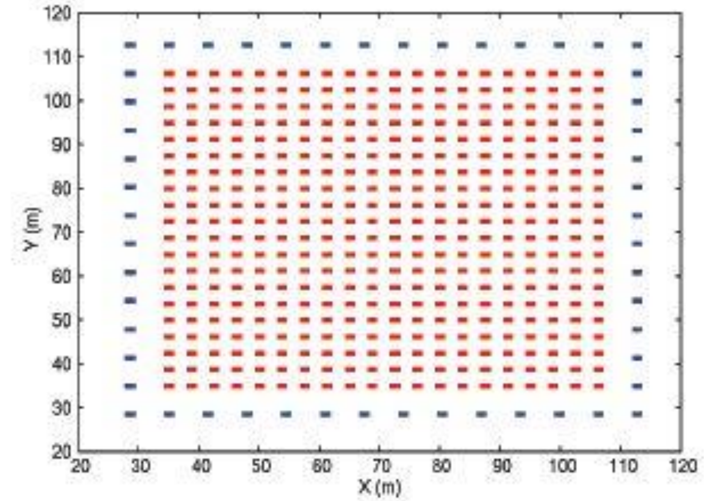
Shower Core Detector Array

- 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.

Burst Detector



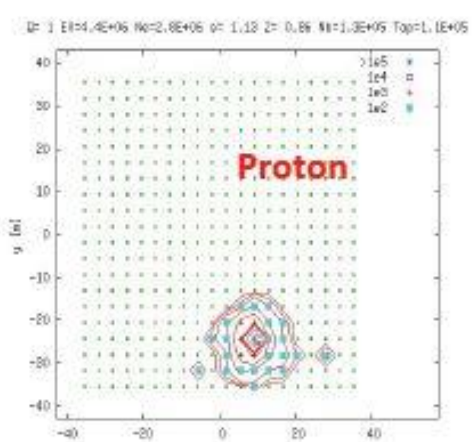
The burst detectors observe the electron size (burst size) under the lead plate induced by high energy e.m. particle in the shower core region

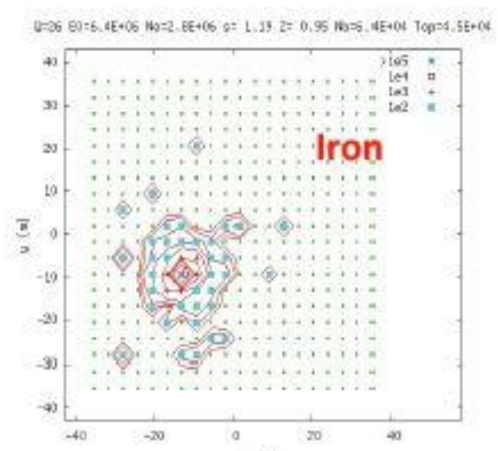


- Number of SCD: 0.5 m² x 452
- Cover Area: 5170 m²
- Energy region: 30 TeV - 10 PeV
- Core position resolution: 1.5 m @50 TeV

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).

- Lead plate (80 cm X 50 cm X 7 rl)
- Iron plate (1 m X 1 m X 1 rl)

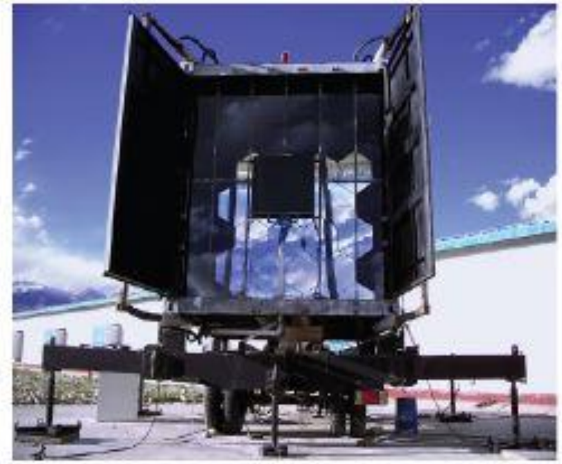




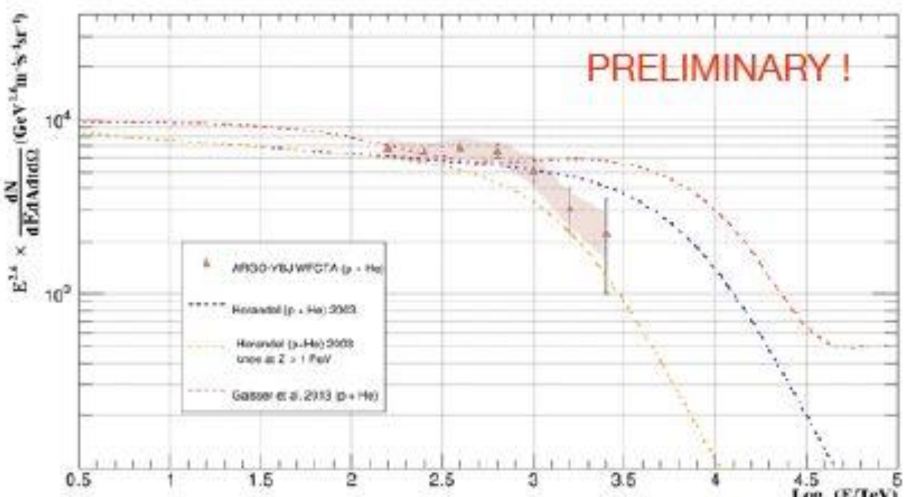
Wide field of view Cherenkov Telescope Array

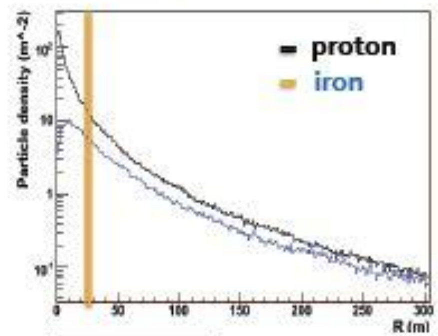
24 telescopes (Cherenkov/Fluorescence)

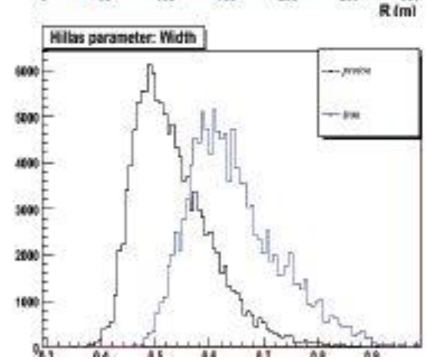
- $5\ m^2$ spherical mirror
- 16 x 16 PMT array
- pixel size 1º
- FOV: 14º x 14º
- Elevation angle: 60º

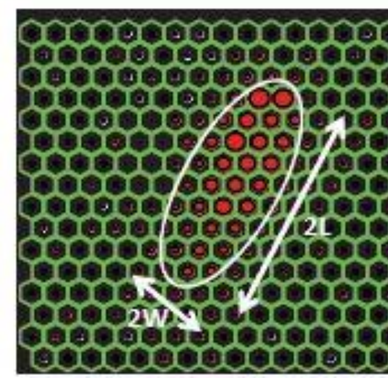


ARGO-YBJ / WFCTA



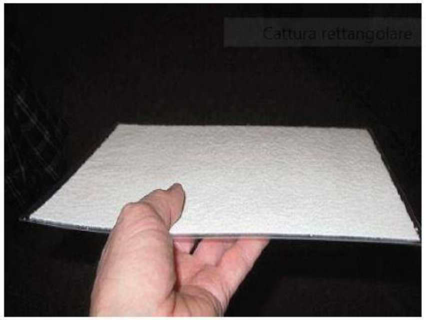


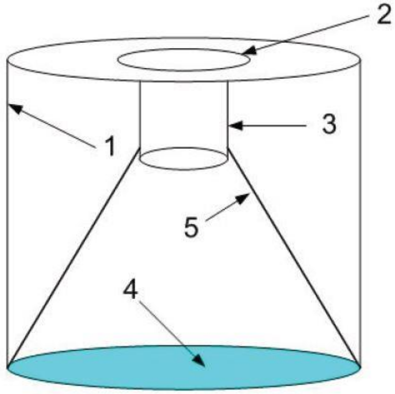




PRISMA - EN detectors

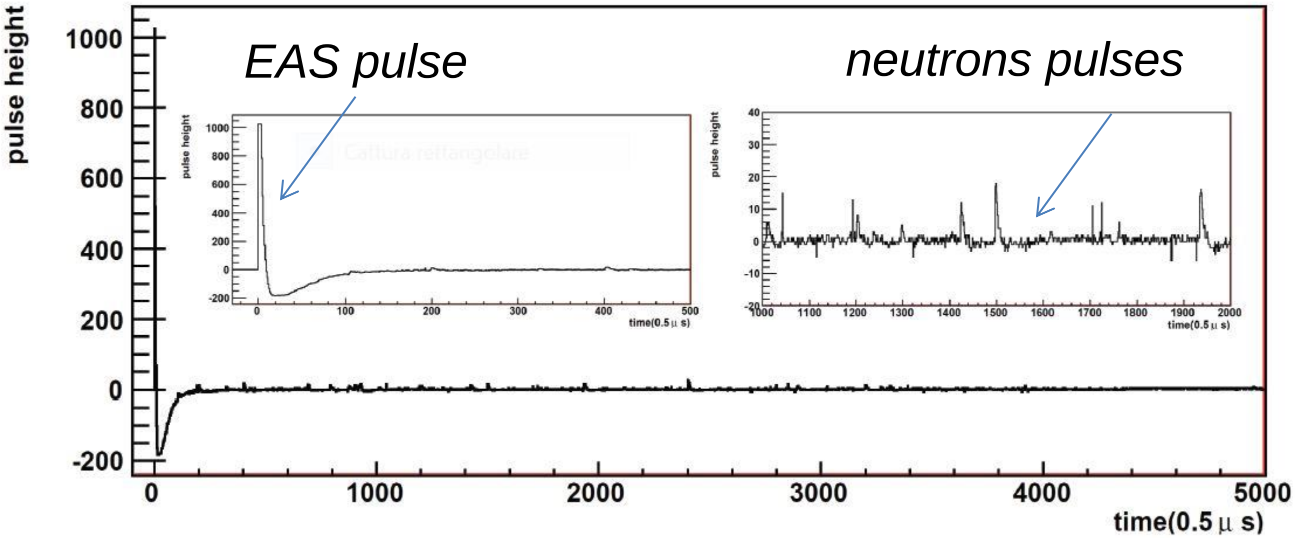
INP, RAS Russia



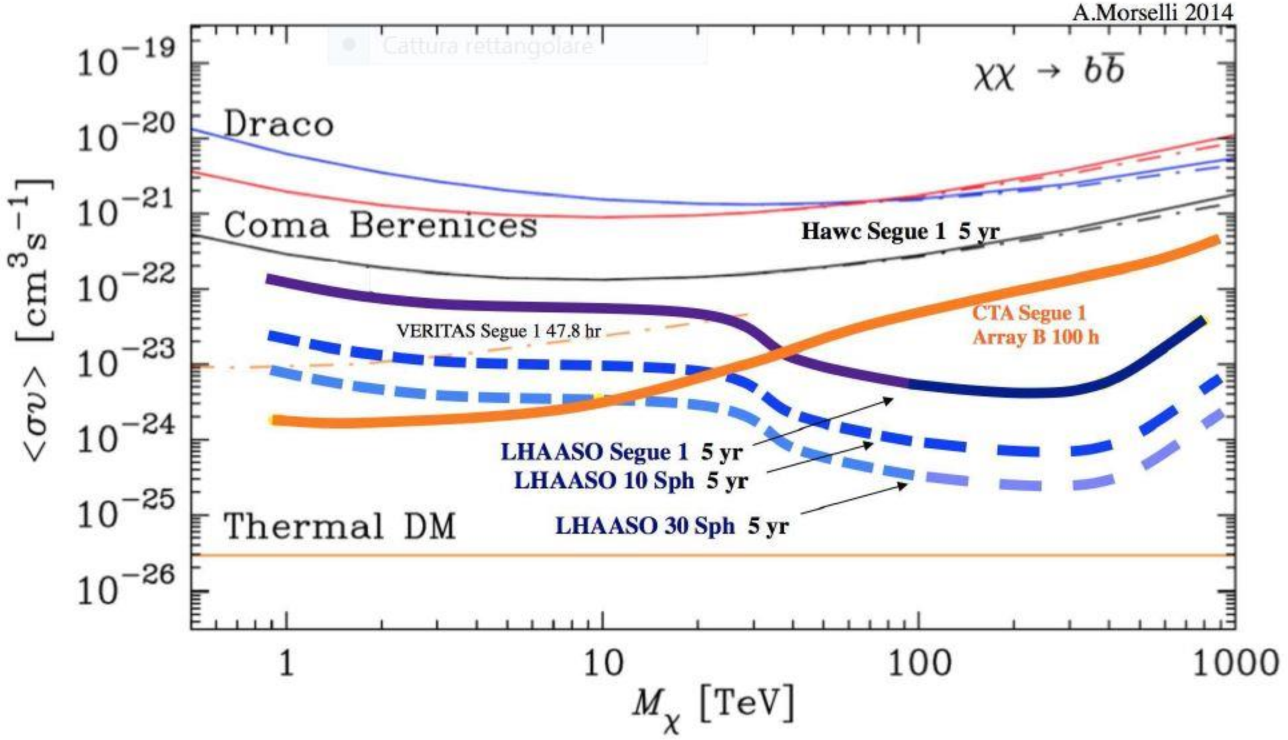


Grid of EN-detectors
5 m spacing
Total area 100 x 100 m^2

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.



LHAASO - dark matter search



Predicted constraints on the dark matter annihilation cross section at 95% C.L for LHAASO compared with CTA and HAWC in the hypothesis of 5 years of data; 10 and 30 dSphs (supposing that the new optical surveys will find new dSph)