Istituto Nazionale di Fisica Nucleare

Wide Field of View Experiments:
from Gamma-Ray Astronomy to Cosmic Ray Physics

G. Di Sciascio
INFN - Sezione Roma Tor Vergata
disciascio@roma2.infn.it

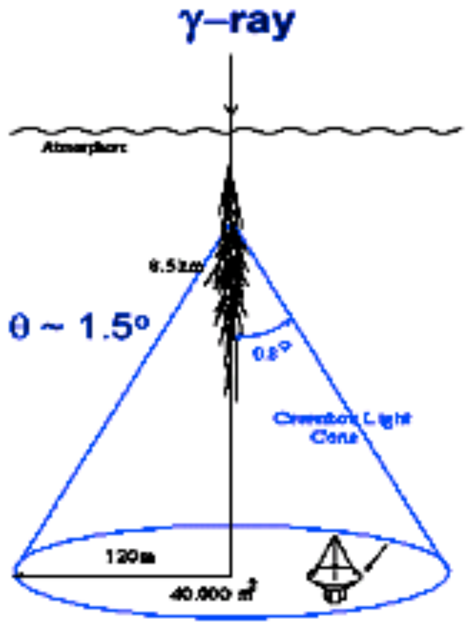
14th AGILE Science Workshop
June 20 and 21, 2016 - ASI Headquarters, Rome

Ground-based Gamma-Ray Astronomy

Detecting Extensive Air Showers

Air Cherenkov Telescopes

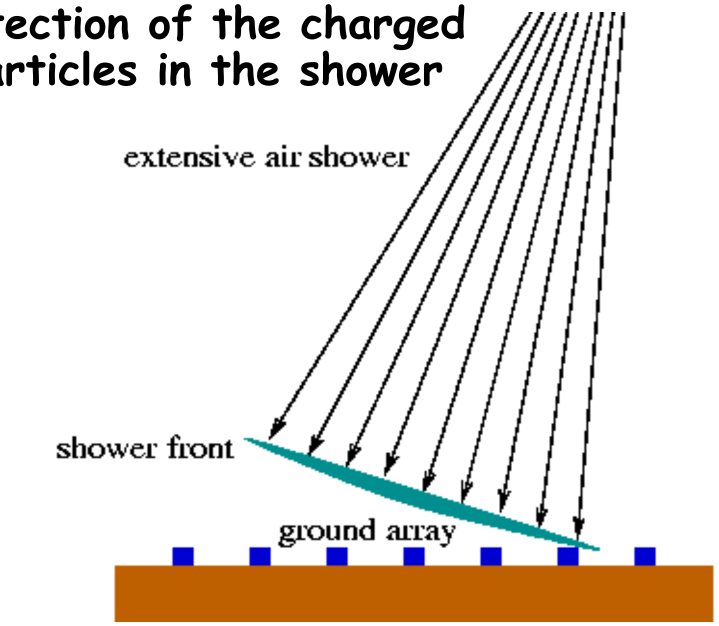
detection of the Cherenkov light
from charged particles in the EAS



Very low energy threshold: (≈ tens GeV)
Excellent bkg rejection (> 99%)
Excellent angular resolution (< 0.05 deg)
Very good energy resolution (≈ 10% - 20%)
High sensitivity (<0.01 Crab)
Low duty cycle (≈10%)
Small field of view (≈ 5 - 8 deg)
Limited energy range: 20 GeV → tens TeV

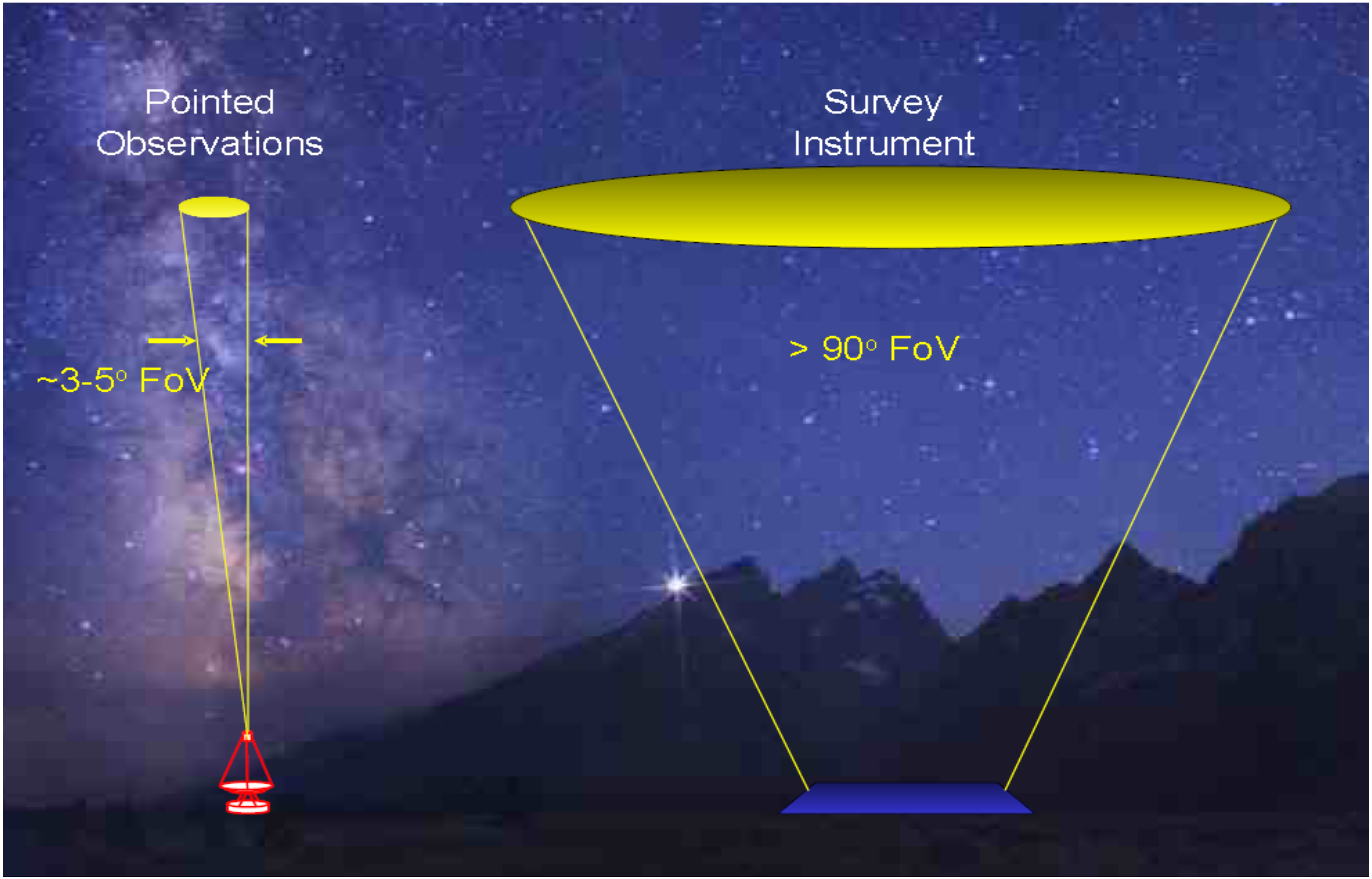
EAS arrays

detection of the charged
particles in the shower

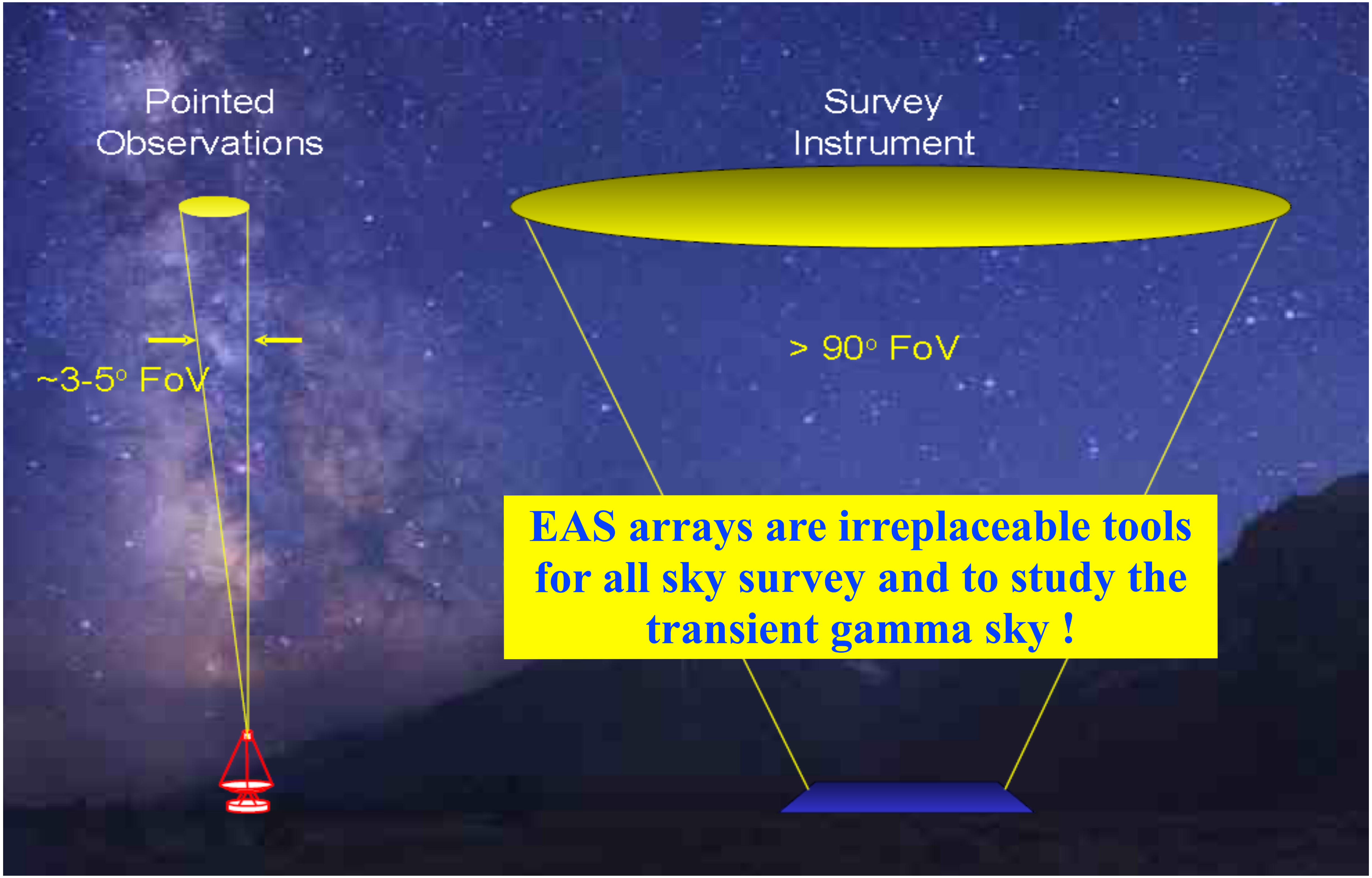


Higher energy threshold: ≈ 300 GeV
Moderate bkg rejection (≈50 → 99 %)
Modest angular resolution (≈0.8 → 0.1 deg)
Modest energy resolution (≈80% → 40%)
Good sensitivity (≈0.1 - 0.2 Crab/year)
High duty-cycle (> 90%)
Large field of view (≈2 sr)
Wide energy range: 100 GeV → PeV

Pointed and Survey Instruments



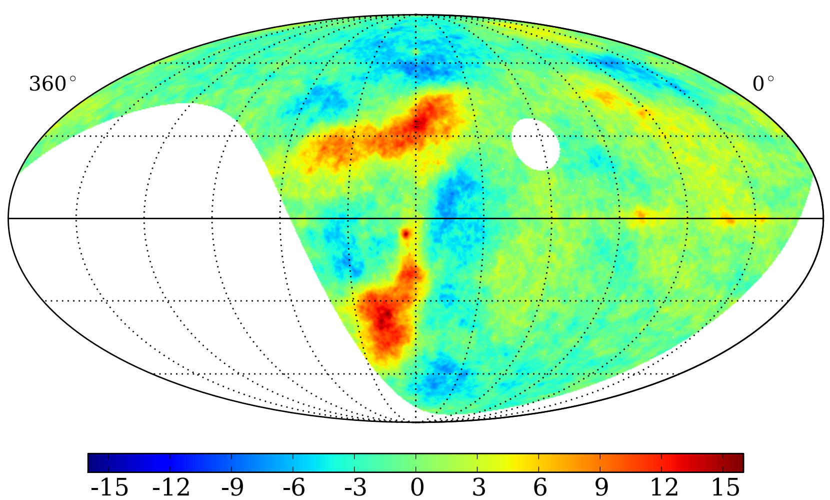
Pointed and Survey Instruments

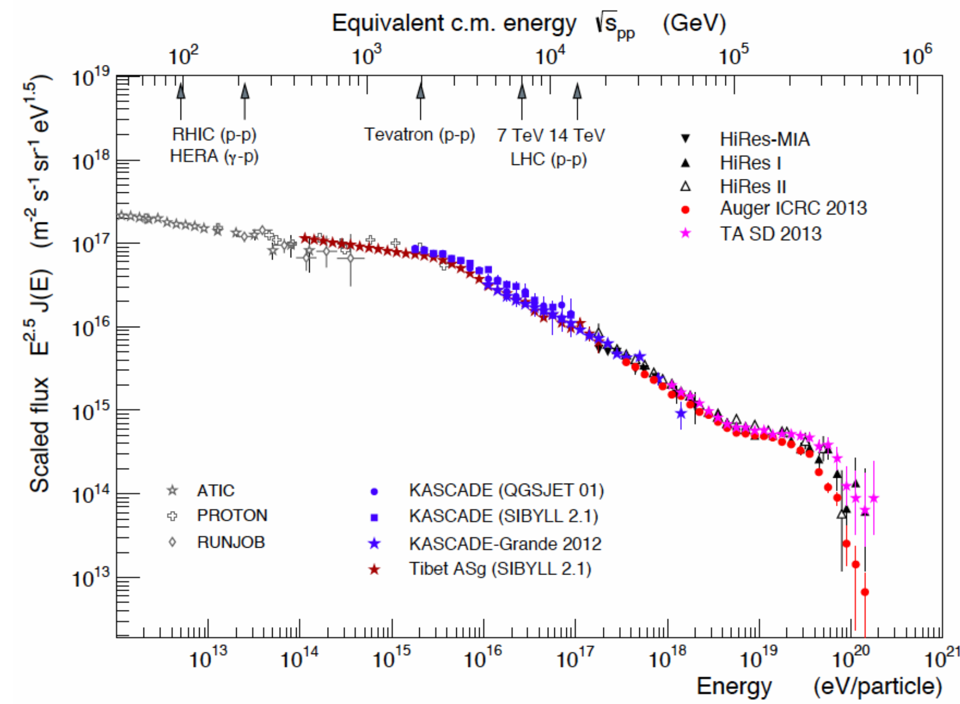


Wide FOV Detectors = Cosmic Ray Experiments

"Classical" Cosmic Ray Physics can be studied only with wide FOV experiments

- CR energy spectrum
- Elemental composition
- Anisotropy





3 fragments of a *"Rosetta stone"* crucial for understanding origin, acceleration and propagation of the radiation

Gamma-Ray Astronomy & Cosmic Ray Physics complementary to investigate the open problems in CR physics

The '*Cosmic Ray connection*'

★ Hadronic emission (CR sources): $p + p/\gamma \Rightarrow n \ (\pi^+ + \pi^- + \pi^0) + h$

$\pi^0 \rightarrow \gamma$ **Gamma-Ray Astronomy**

$\pi^+, \pi^- \rightarrow \nu$ **Neutrino Astronomy**

CRs, photons and neutrinos strongly correlated: the '*cosmic ray connection*'

ONLY charged CRs observed at E > 10^{14} eV so far !

Recent observations of PeV neutrinos by Icecube

★ Leptonic emission (Inverse Compton): $e + \gamma \Rightarrow e' + \gamma'$

scattering of electrons on low energy photons:

- ✓ Cosmic Microwave Background (CMB)
- ✓ Infrared, optical photons
- ✓ Synchrotron photons

SSC model: photons radiated by high energy (10^{15} eV) electrons boosted by the same electrons

Gammas (and neutrinos) point back to their sources (SNR, PWN, BS, AGN ..)

Galactic CRs: main open problems

✦ Cosmic Ray Sources: *"PeVatrons"*

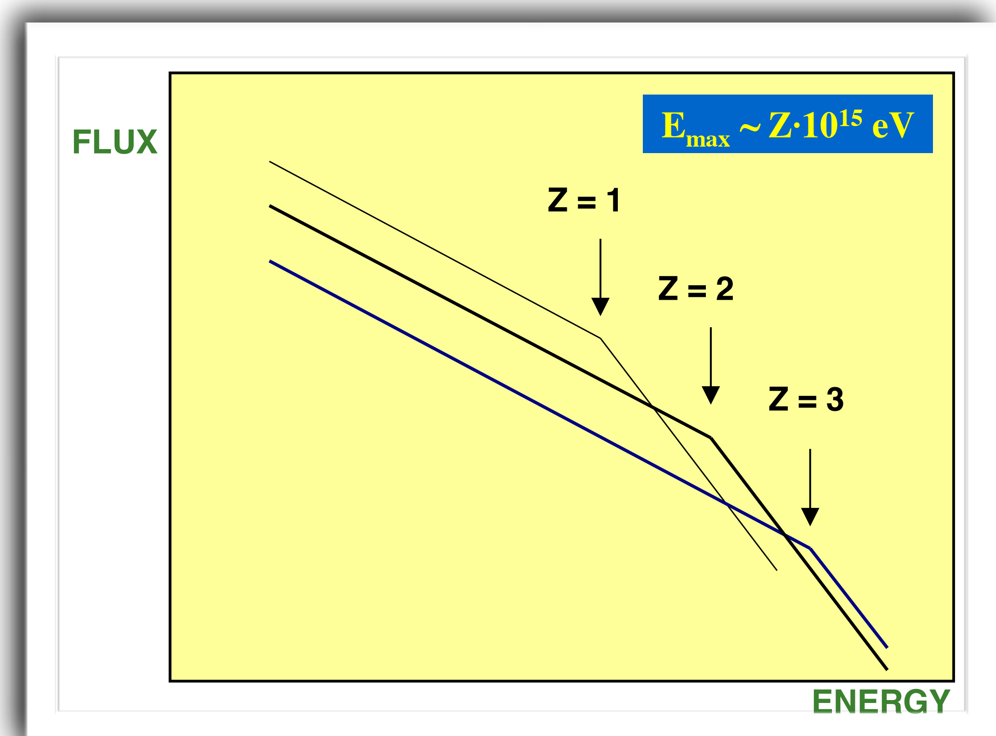
accelerators ?

"astronomy" (gamma, neutrino) but also *anisotropy* !

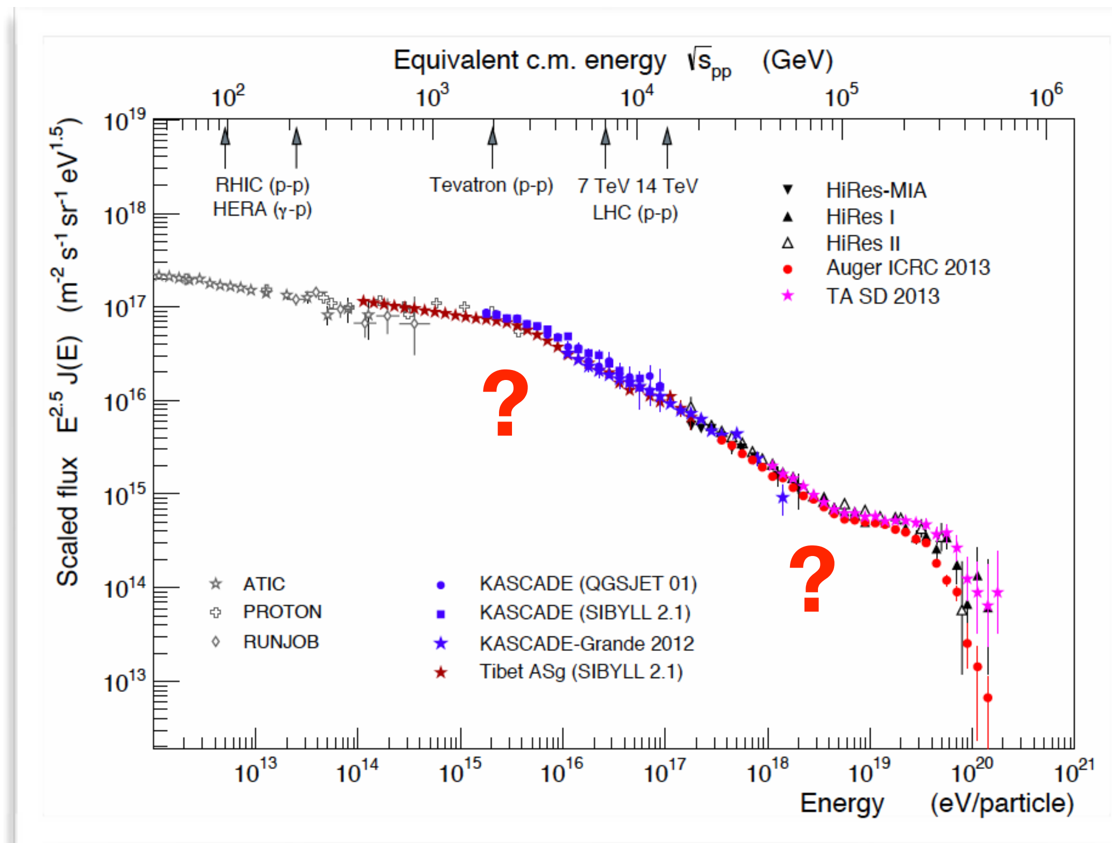
old nearby sources: no more photons but CRs → anisotropy !

✦ Acceleration limit in Cosmic Ray sources: *"proton knee"*

acceleration mechanisms, different source populations ?



E_{max}(iron) = 26 · E_{max}(proton)

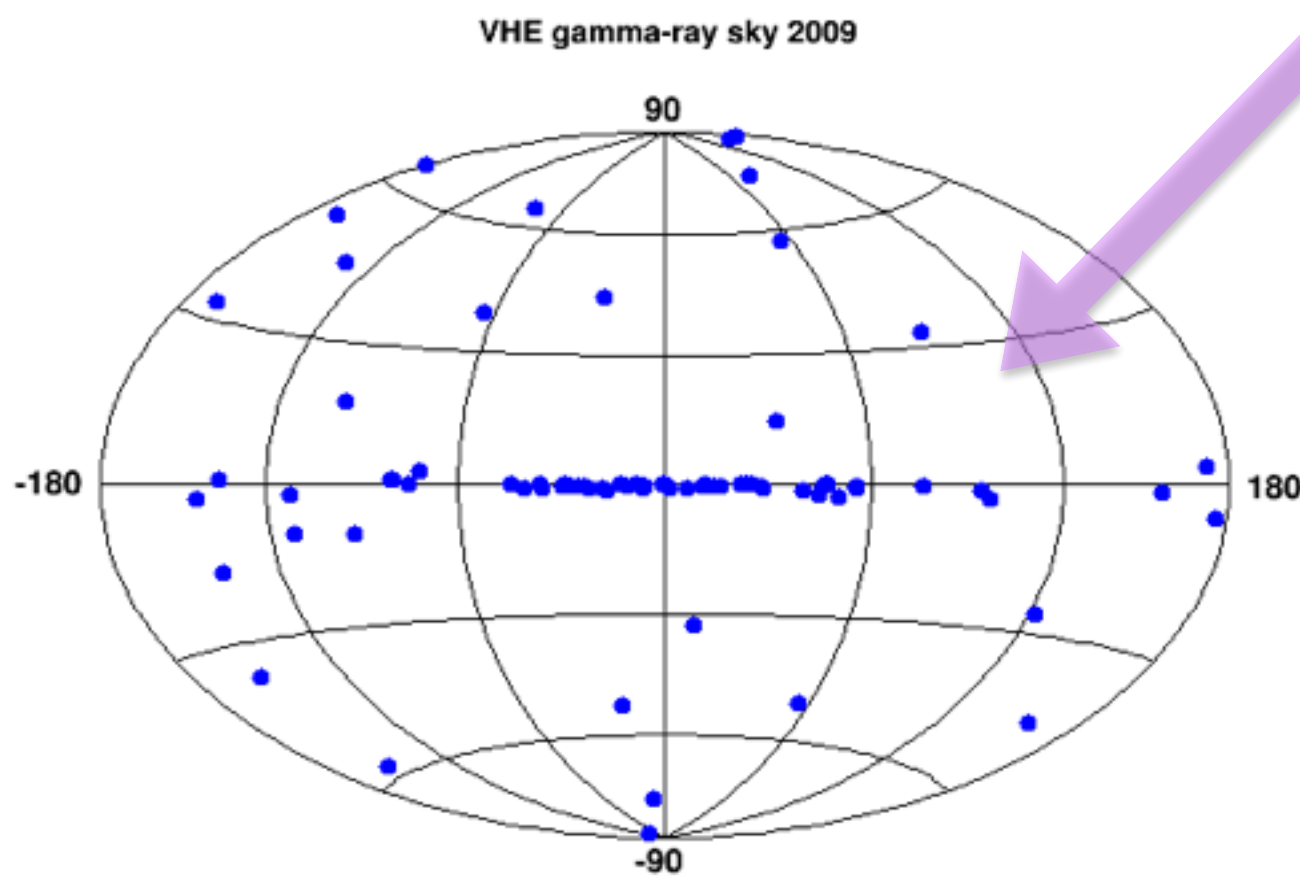


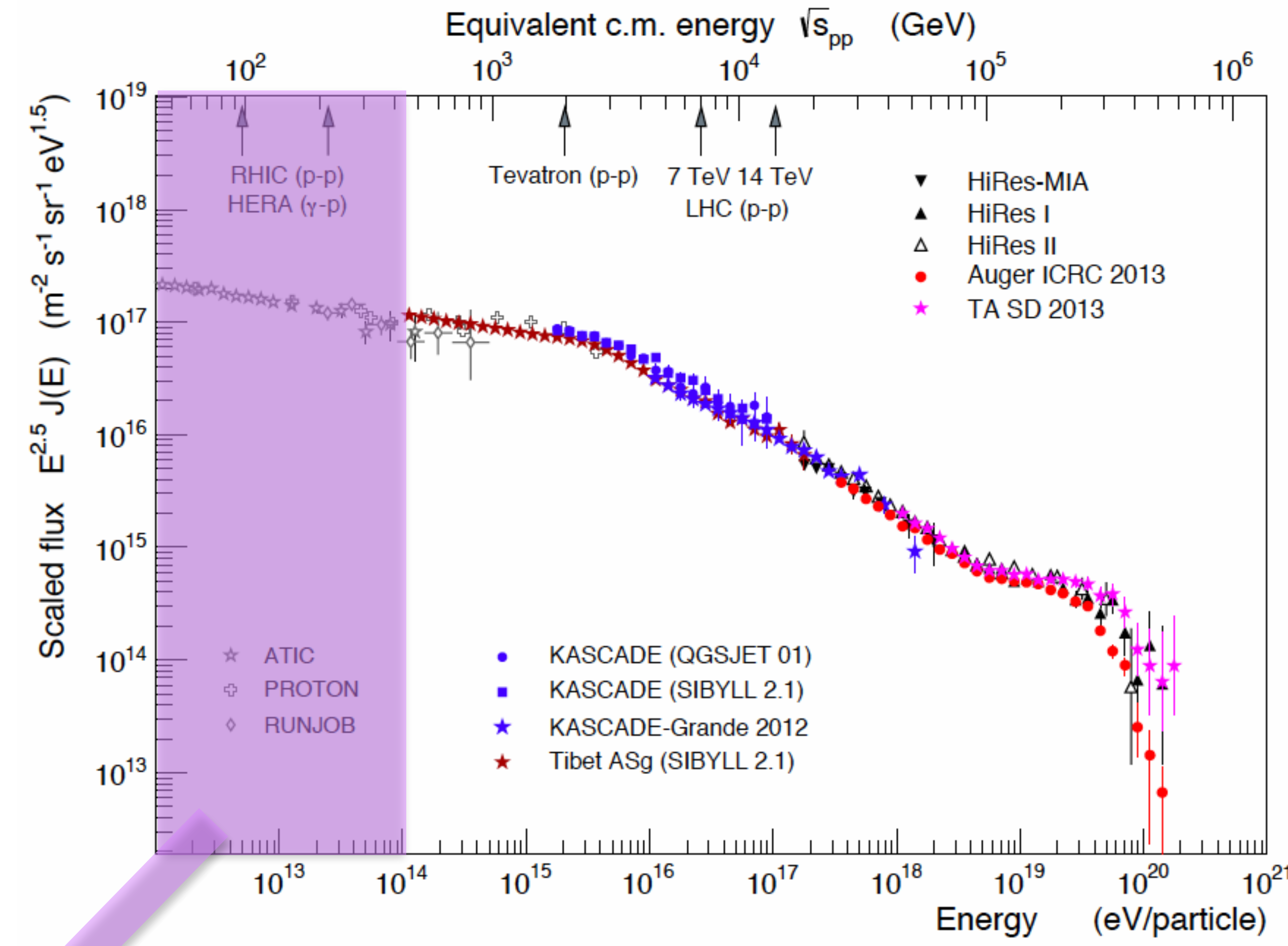
TeVatron Sky

$$p\ (p,\ \gamma) \longrightarrow \pi^0 + rest \\ \hookrightarrow \gamma\gamma$$

Gammas from Galactic Cosmic Rays: $E_\gamma \sim E_{CR}/10$

TeV Cosmic Rays
Photons > 100 GeV !



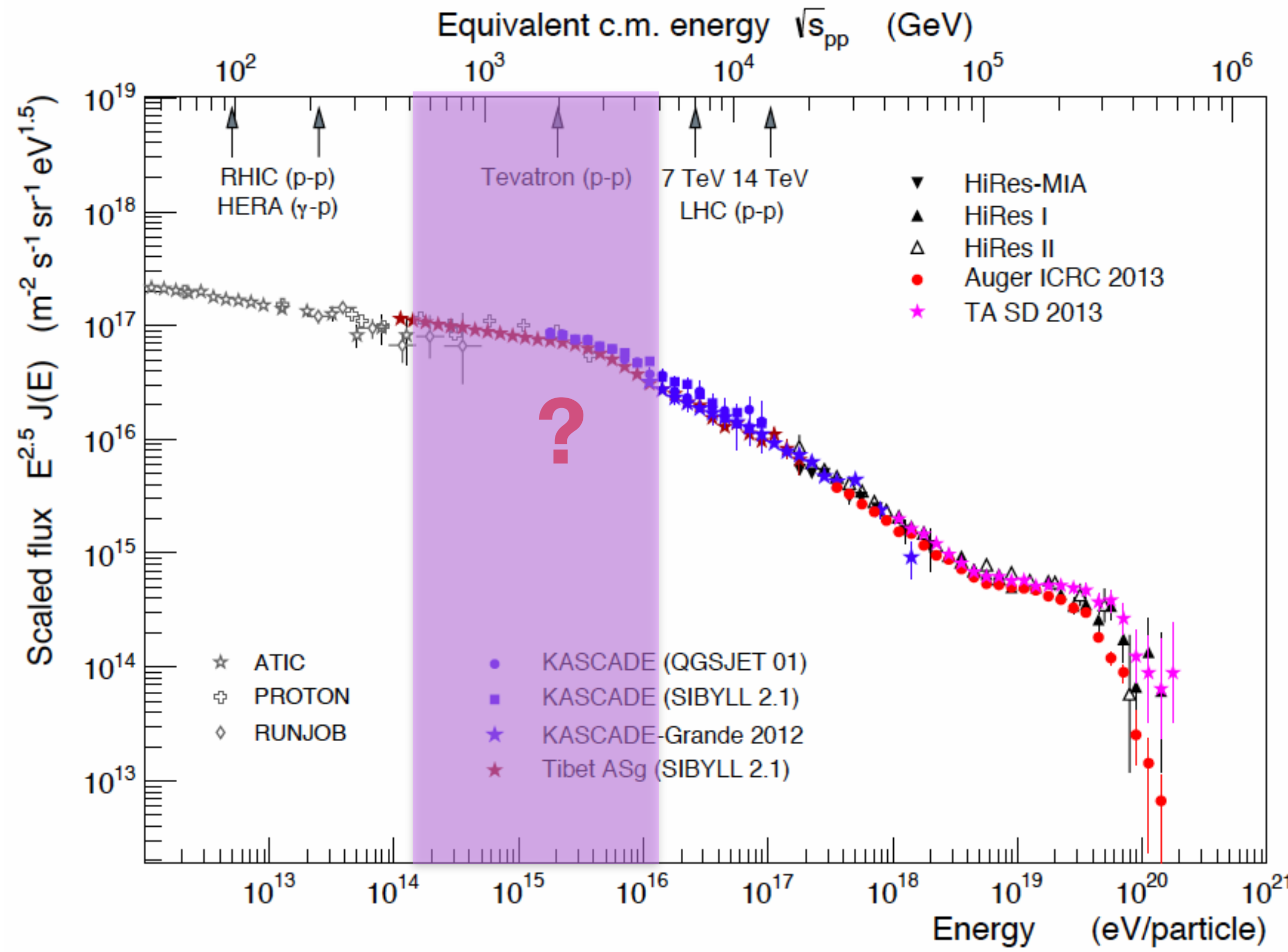


But smoking gun still missing…
leptonic ?
hadronic ?

Complex scenario: each source is individual and has a unique behaviour. In general one expects a combination of leptonic and hadronic emission !

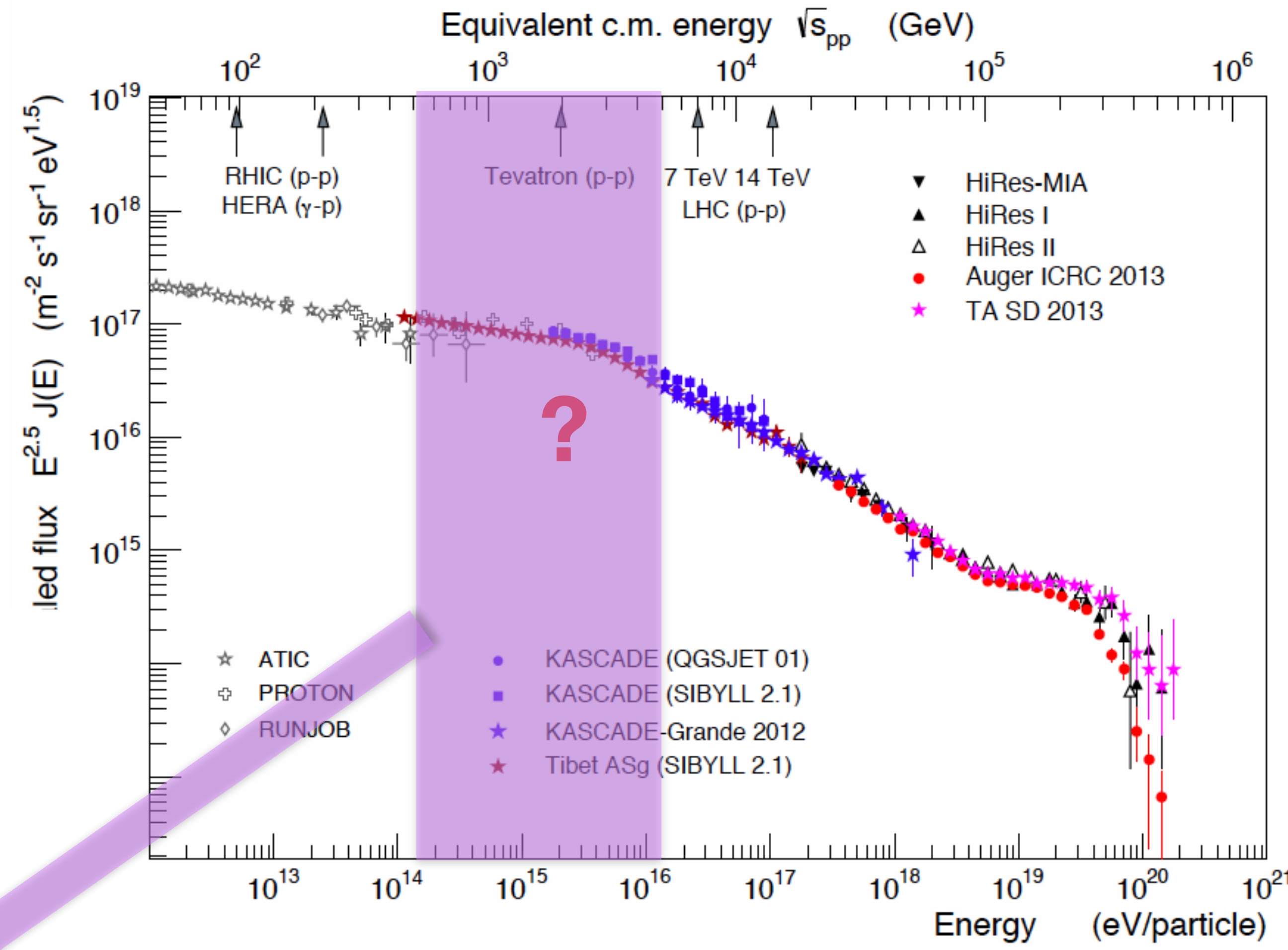
PeVatron Sky

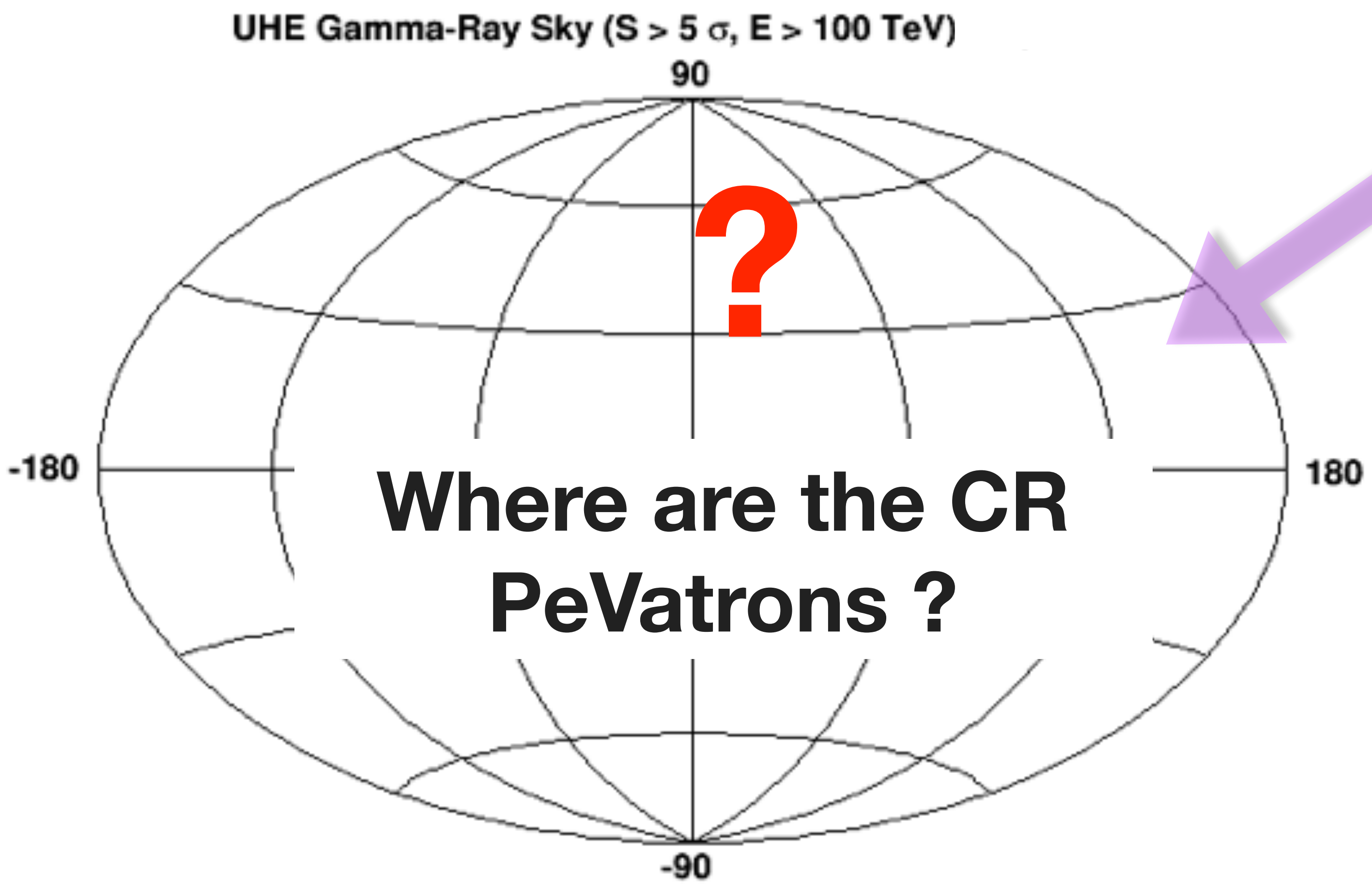
PeV Cosmic Rays
Photons > 100 TeV !



PeVatron Sky

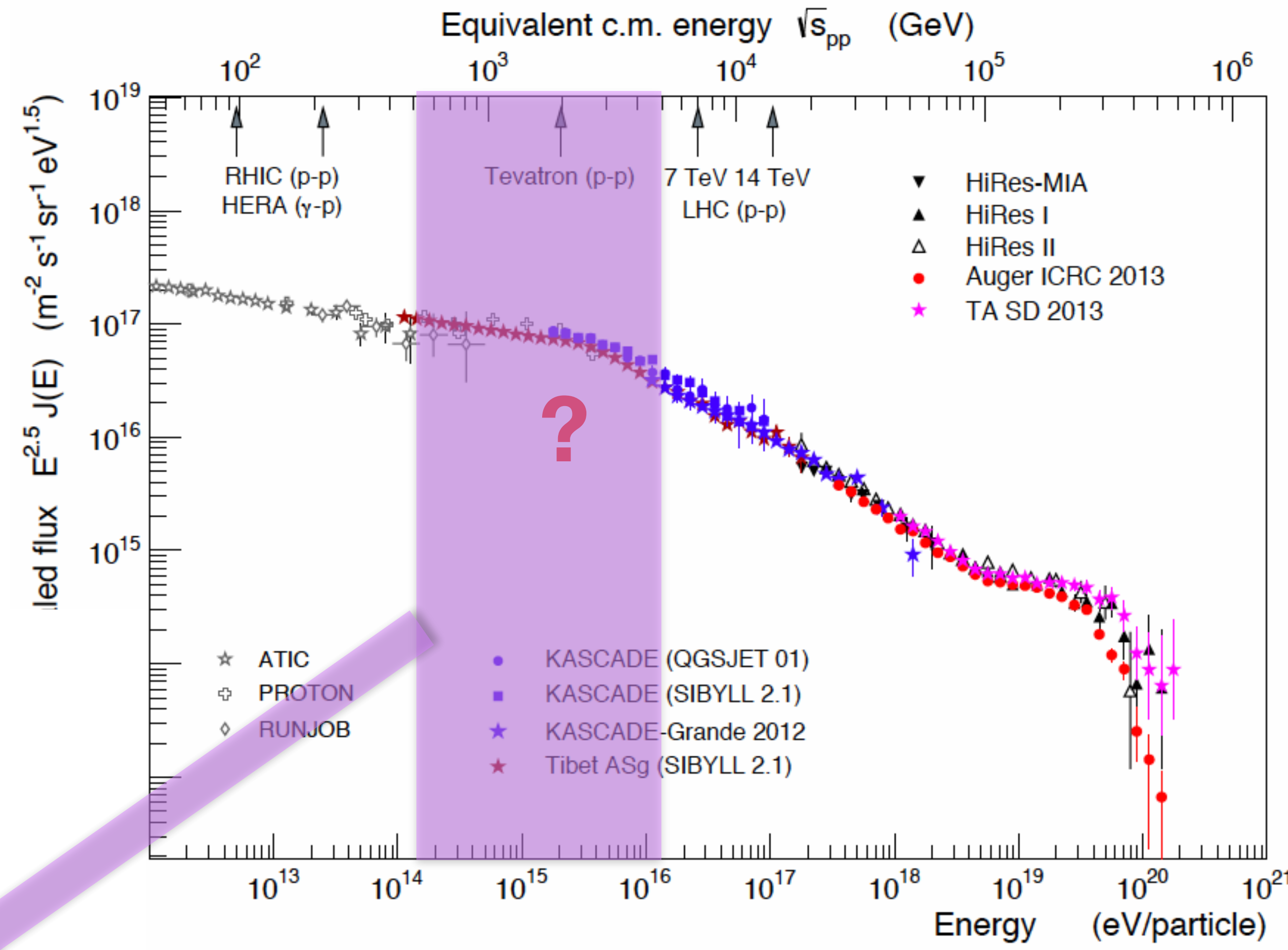
PeV Cosmic Rays
Photons > 100 TeV !

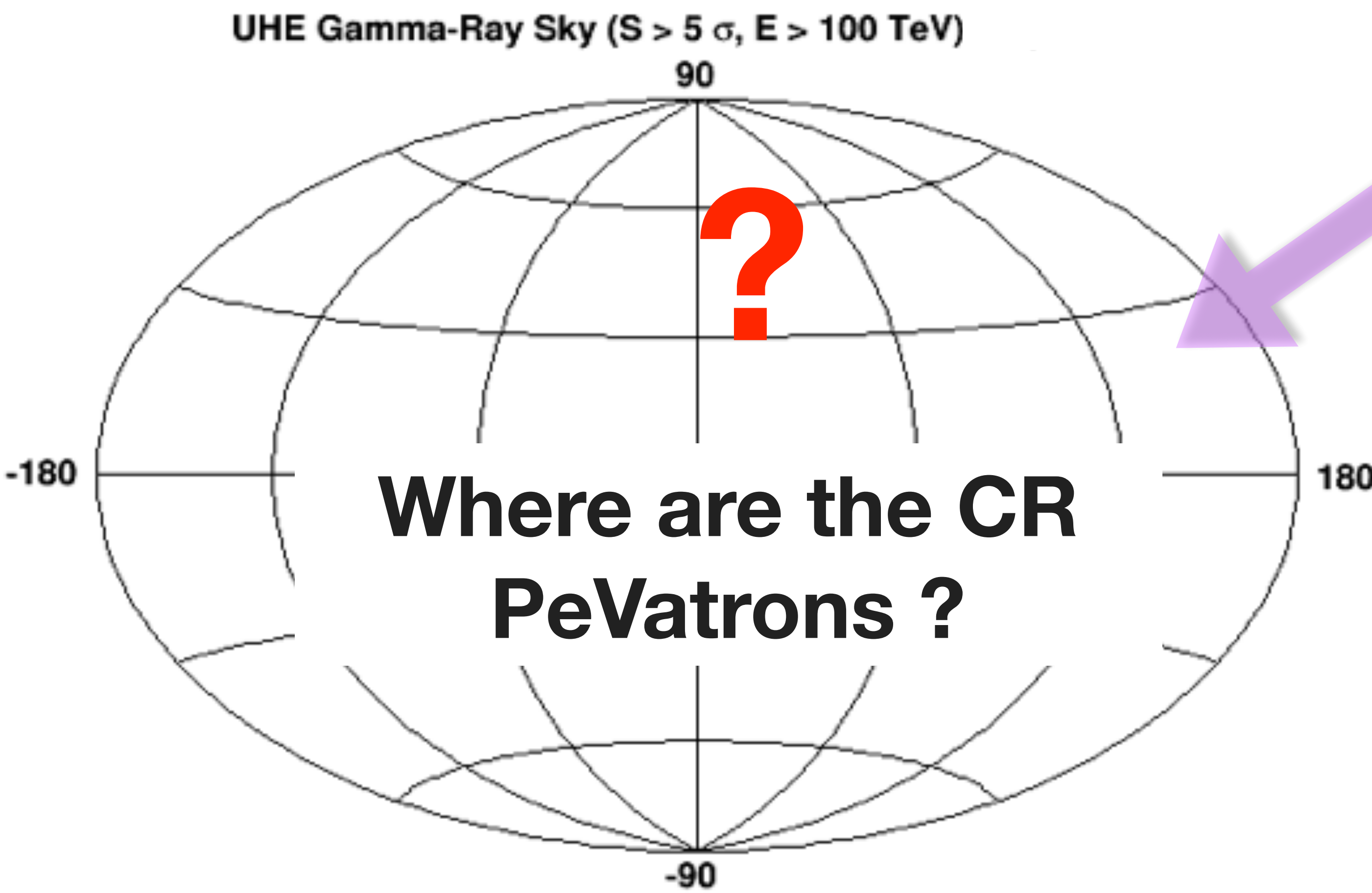




PeVatron Sky

PeV Cosmic Rays
Photons > 100 TeV !





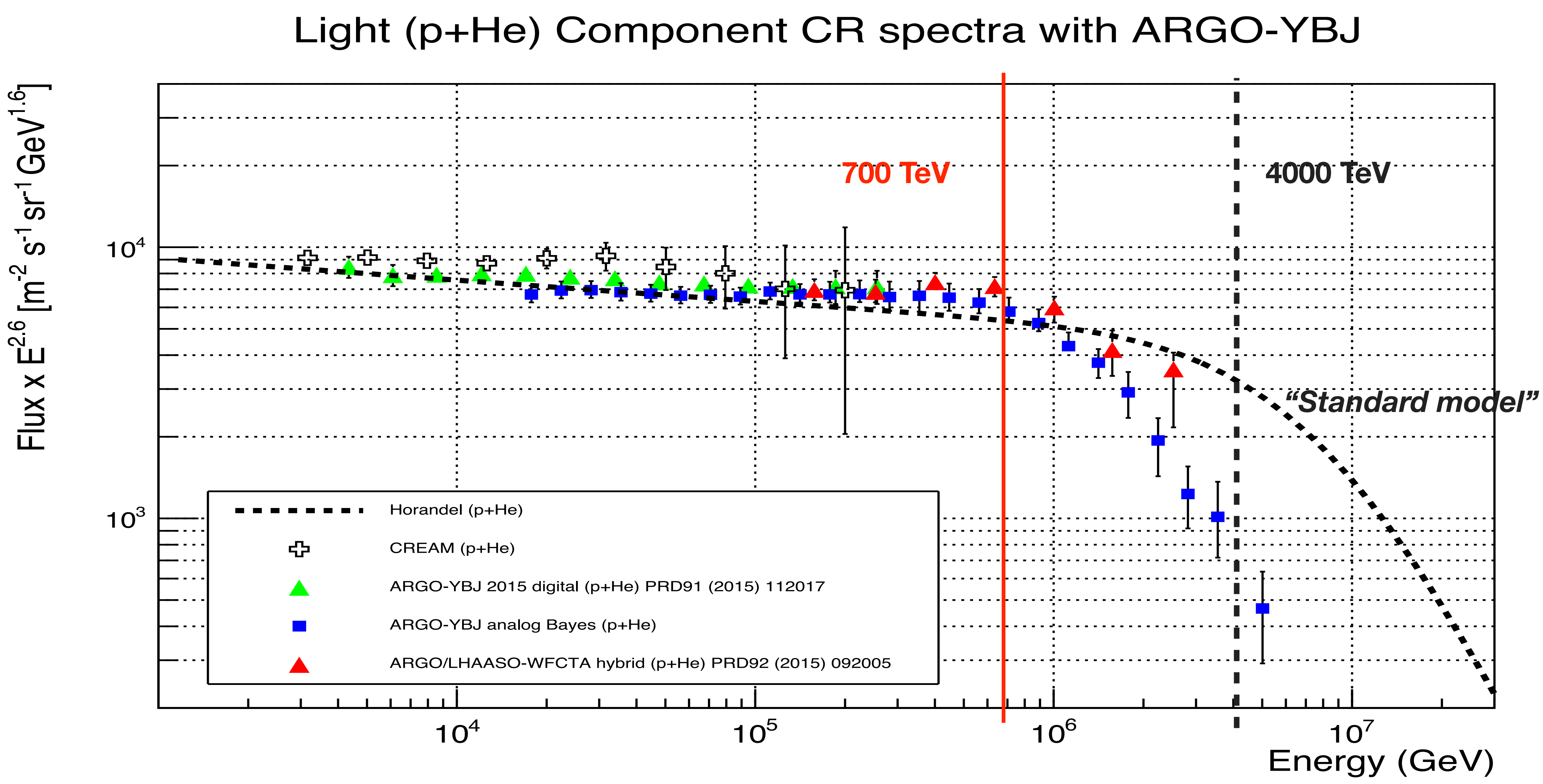
Where are the CR PeVatrons ?

Bonus @ 100 TeV:

Hadronic spectra: *hard*
Leptonic spectra: *soft*
No hard IC gamma rays >100 TeV
IC in deep Klein-Nishina

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

The *'proton knee'*



The origin of the *knee* in the all-particle spectrum of CRs is *inextricably connected* with the issue of the end of the Galactic CR spectrum and the transition to extragalactic CRs.

Status of wide FOV experiments

Northern Hemisphere

Tibet ASγ: 4300 m asl in Tibet (China + Japan) - multicomponent

HAWC: 4100 m asl in Mexico (USA + Mexico) - water Cherenkov

LHAASO: 4400 m asl under installation in China (China) - multicomponent

HiSCORE: project with prototype at Tunka (Russia) - Cherenkov wide FOV

Southern Hemisphere ?

different ideas:

HAWC-South
LATTES: RPCs + water Cherenkov
STACEX: layers of RPCs
ALPACA: Tibet ASγ - like + water pond

Tibet ASγ experiment

The Tibet ASγ experiment started in 1990 at Yangbajing in Tibet at an altitude of 4300 m asl

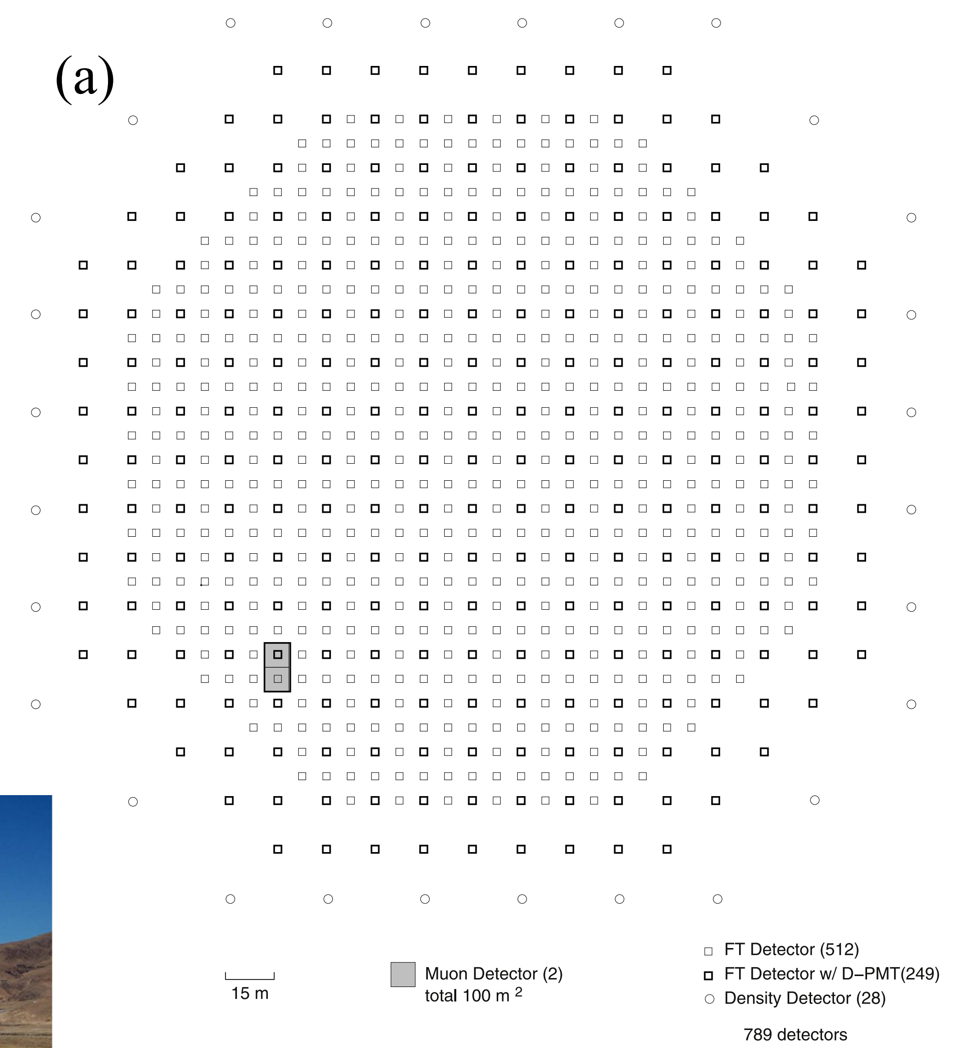
After several upgrades, the Tibet ASγ array now consists of

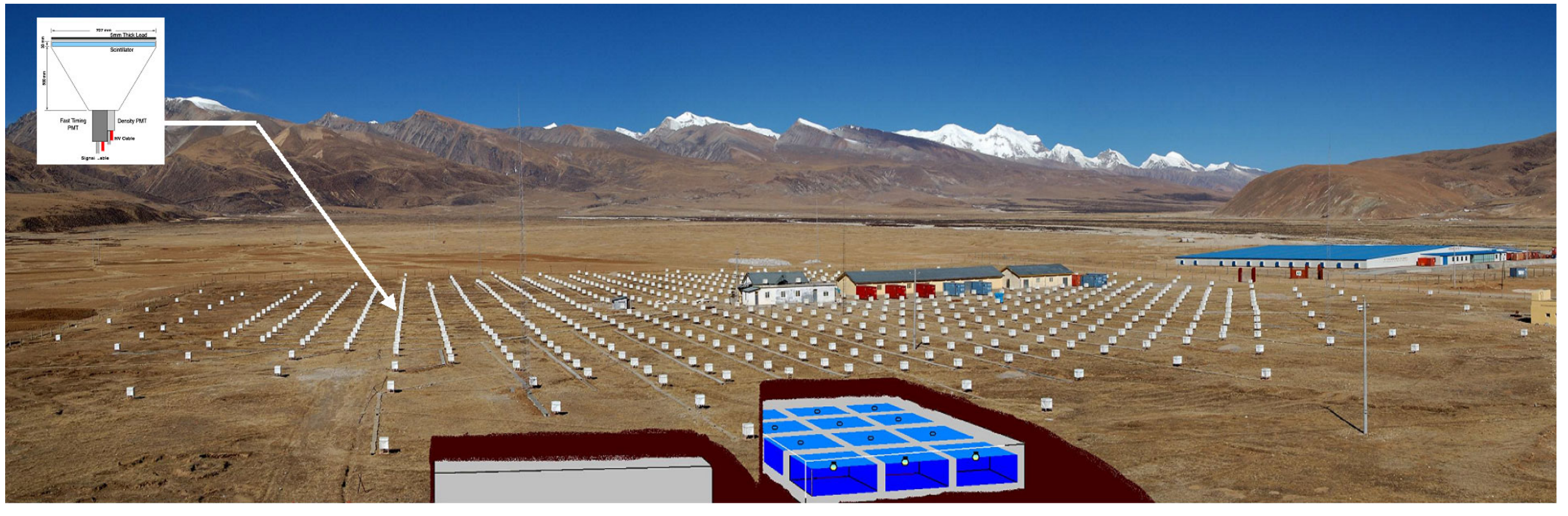
- 761 fast-timing (FT) scintillation counters and
- 28 density (D) counters

covering an effective area of 36,900 m^2.

All of the FT counters are equipped with an 2” PMTs

249 FT counters and all of the D counters are equipped with a wide dynamic range 1.5” PMT.



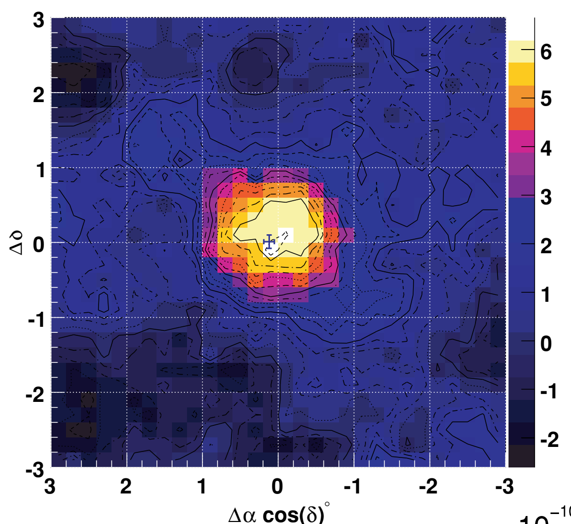


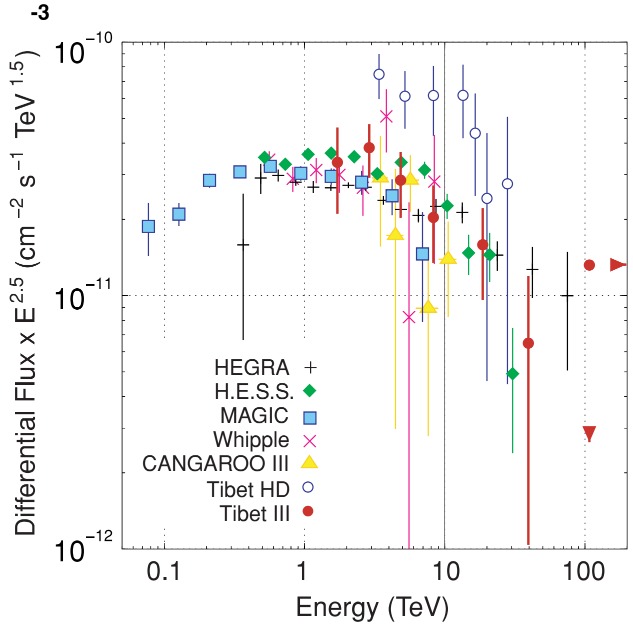
Gamma-Ray Astronomy with Tibet ASγ

Mainly devoted to Cosmic Ray Physics: energy spectrum, composition, anisotropy up to 10^{16} eV

Low sensitivity in gamma-ray astronomy, energy threshold: few TeV

Crab Nebula
6.9 s.d. in 1915 days





ApJ 692 (2009) 61
ApJL 709 (2010) L6

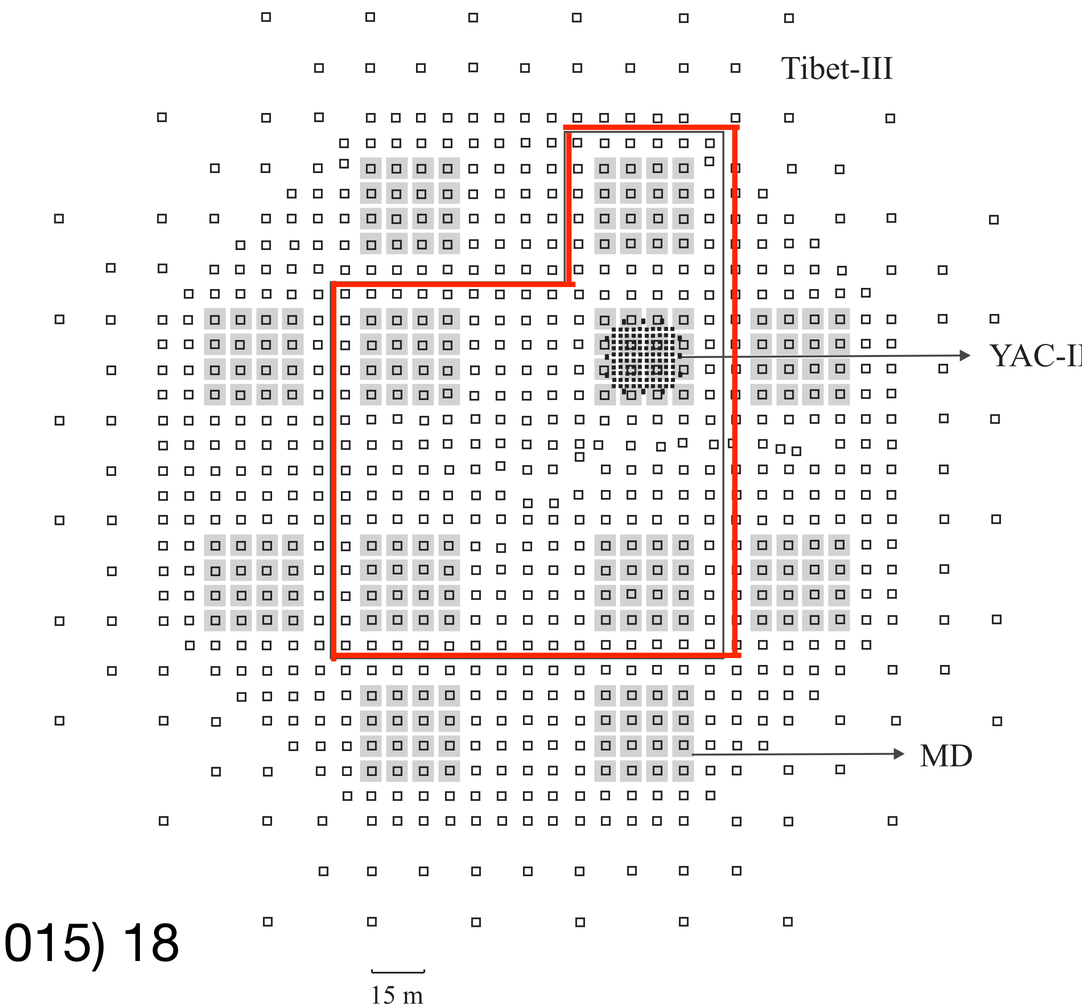
Table 1
Summary of the Tibet-III Array Observations of the *Fermi* Sources

Fermi LAT Source (0FGL)	Class	R.A. (deg)	Decl. (deg)	Tibet-III Signi. (σ)	Milagro[a] Signi. (σ)	Source Associations
J0030.3+0450	PSR	7.600	4.848	1.7	−1.7	
J0357.5+3205	PSR[b]	59.388	32.084	−1.7	−0.1	
J0534.6+2201	PSR	83.653	22.022	6.9	17.2	Crab
J0617.4+2234	SNR	94.356	22.568	0.2	3.0	IC 443
J0631.8+1034	PSR	97.955	10.570	0.3	3.7	
J0633.5+0634	PSR[b]	98.387	6.578	2.4	1.4	
J0634.0+1745	PSR	98.503	17.760	2.2	3.5	Geminga
J0643.2+0858		100.823	8.983	−1.2	0.3	
J1830.3+0617		277.583	6.287	−0.2	0.2	
J1836.2+5924	PSR[b]	279.056	59.406	−0.3	−0.9	
J1855.9+0126	SNR	283.985	1.435	0.7	2.2	W44
J1900.0+0356		285.009	3.946	1.0	3.6	
J1907.5+0602	PSR[b]	286.894	6.034	2.4	7.4	MGRO J1908+06 HESS J1908+063
J1911.0+0905	SNR	287.761	9.087	1.7	1.5	G43.3 − 0.2
J1923.0+1411	SNR	290.768	14.191	−0.3	3.4	W51 HESS J1923+141
J1953.2+3249	PSR	298.325	32.818	−0.0	0.0	
J1954.4+2838	SNR	298.614	28.649	0.6	4.3	G65.1+0.6
J1958.1+2848	PSR[b]	299.531	28.803	0.1	4.0	
J2001.0+4352		300.272	43.871	−0.5	−0.9	
J2020.8+3649	PSR	305.223	36.830	2.2	12.4	MGRO J2019+37
J2021.5+4026	PSR[b]	305.398	40.439	2.2	4.2	
J2027.5+3334		306.882	33.574	−0.3	−0.2	
J2032.2+4122	PSR[b]	308.058	41.376	2.4	7.6	TeV J2032+4130 MGRO J2031+41
J2055.5+2540		313.895	25.673	−0.0	−0.0	
J2110.8+4608		317.702	46.137	0.3	1.1	
J2214.8+3002		333.705	30.049	−1.0	0.6	
J2302.9+4443		345.746	44.723	−0.0	−0.6	
LAT PSR J2238+59[c]	PSR[b]	339.561	59.080	2.5	4.7	

Tibet ASγ upgrades

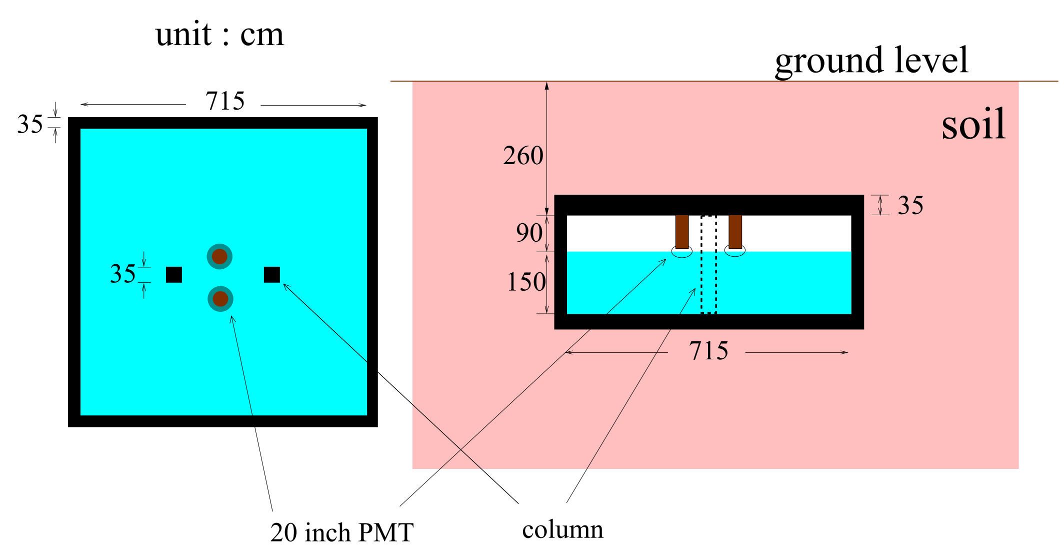
Goal: energy spectrum & composition in the knee energy region through the mesurement of the high energy air shower cores.

50 TeV – 10^{16} eV

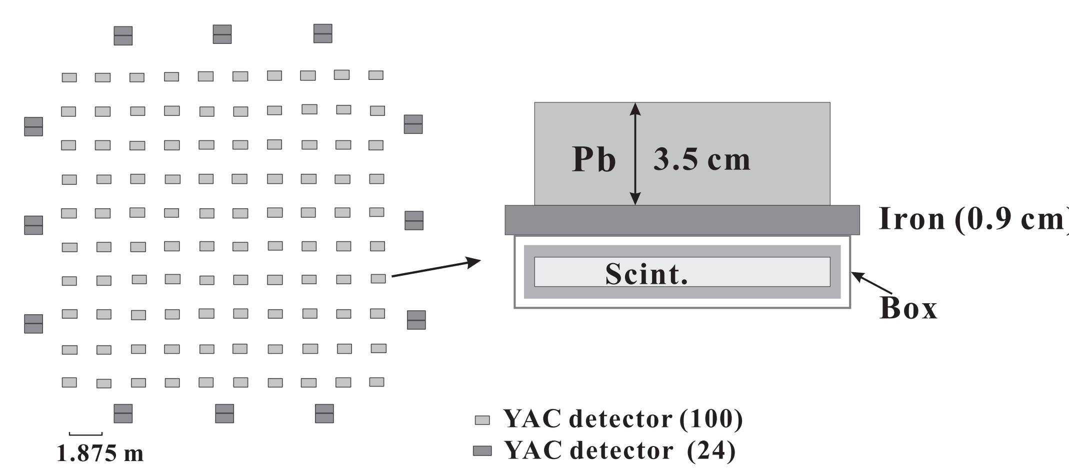


The currently planned full-scale MD array is made up of 12 pools, set up under a 2.6 m thick layer of soil for a total effective area of approximately 10,000 m^2

APP 66 (2015) 18



Yangbajing Air shower Core array



Each pool consists of 16 MDs.

Each MD is a waterproof concrete cell, 7.15 m wide × 7.15 m long × 1.5 m deep in size, equipped with 2 downward-facing 20'' PMTs (HAMAMATSU R3600. Energy threshold ≈1 GeV.

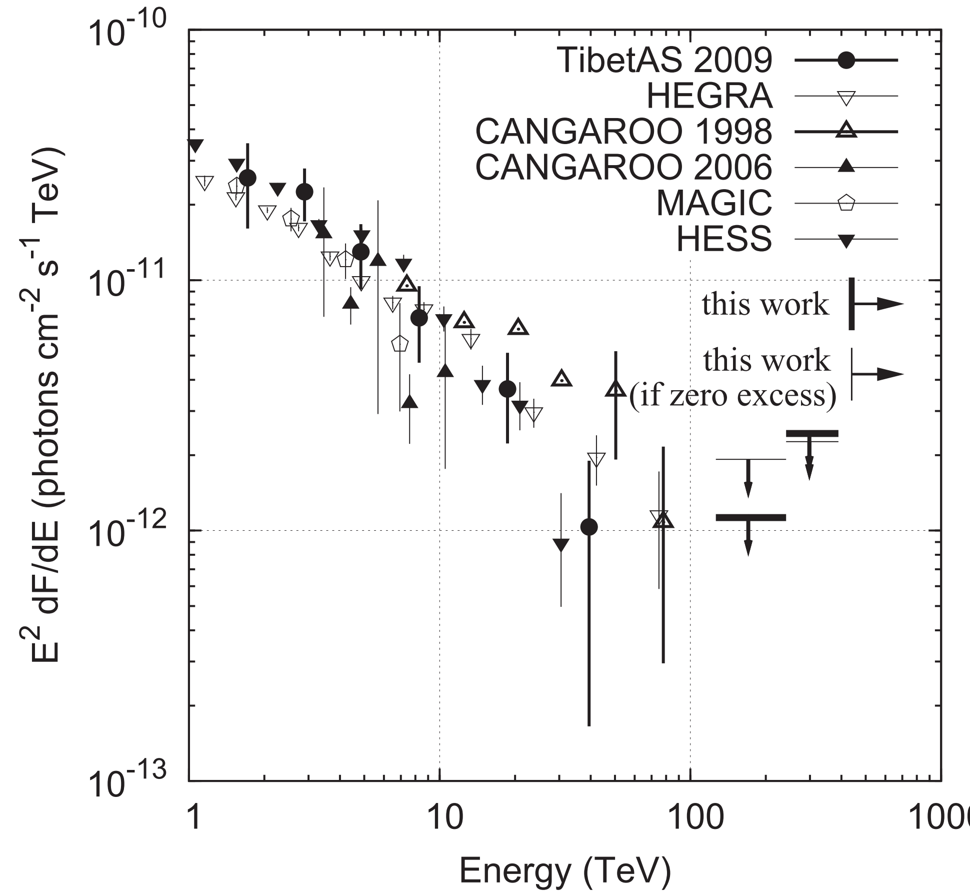
Observation of shower electron size under lead plate (burst size N_b) induced by high energy e.m. particles in shower core region.

Results from a 100 m^2 prototype

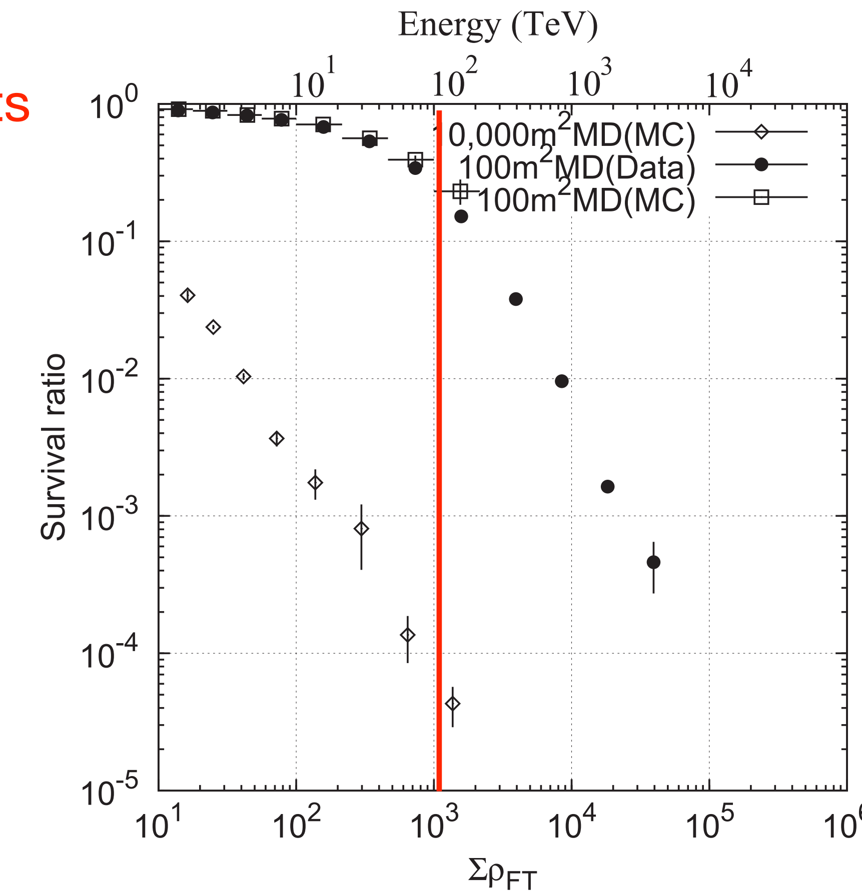
4500 m^2 muon detector funded and installed.

A 100 m^2 muon detector prototype has been operated in Tibet.
First results in ApJ 813 (2015) 98:

"Search for gamma rays above 100 TeV from the Crab Nebula with the Tibet air shower array and the 100 m^2 Muon Detector".



Fraction of surviving events



Discrimination at level of 10^{-4} at 100 TeV background-free above

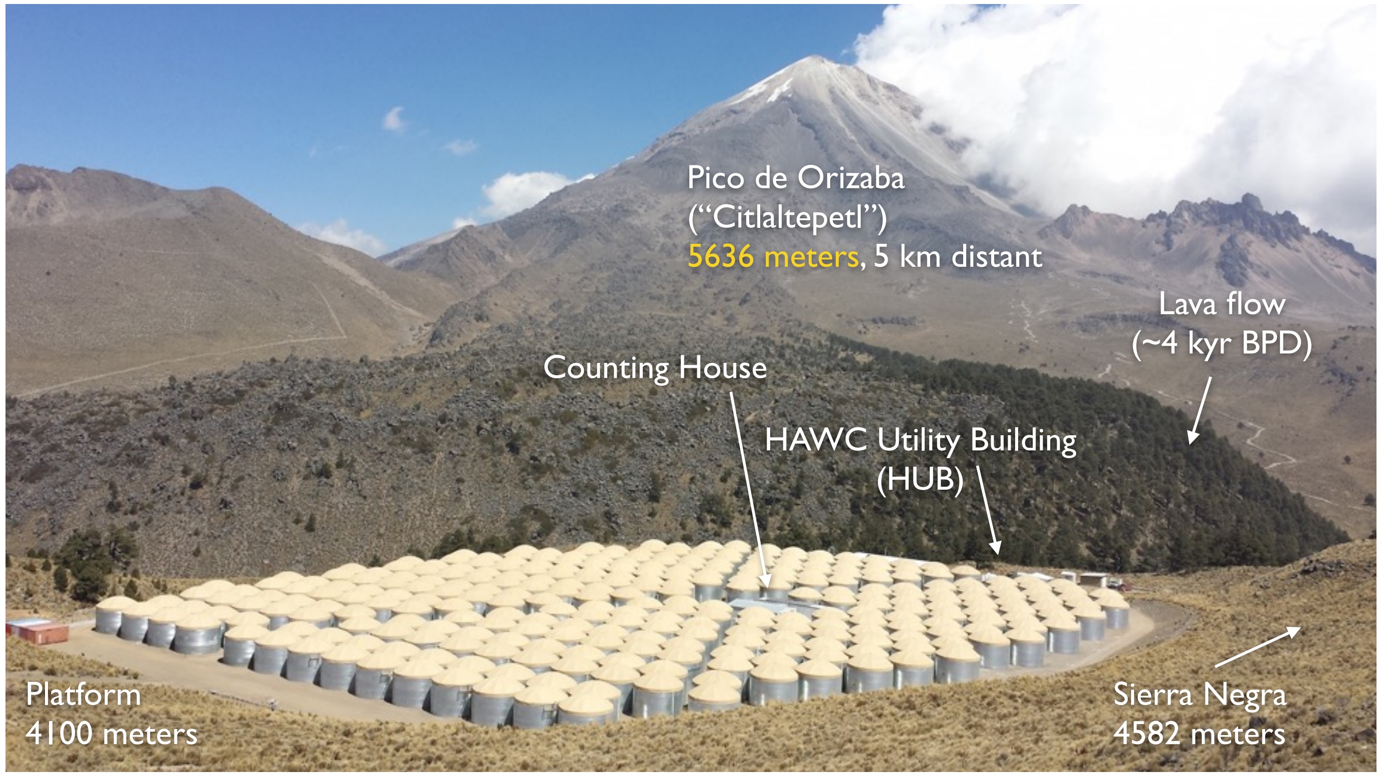
HAWC

The **H**igh **A**ltitude **W**ater **C**herenkov Gamma-ray Observatory (HAWC) is up and running

Goals: observe gamma rays and cosmic rays from half the sky each day between 100 GeV and 100 TeV

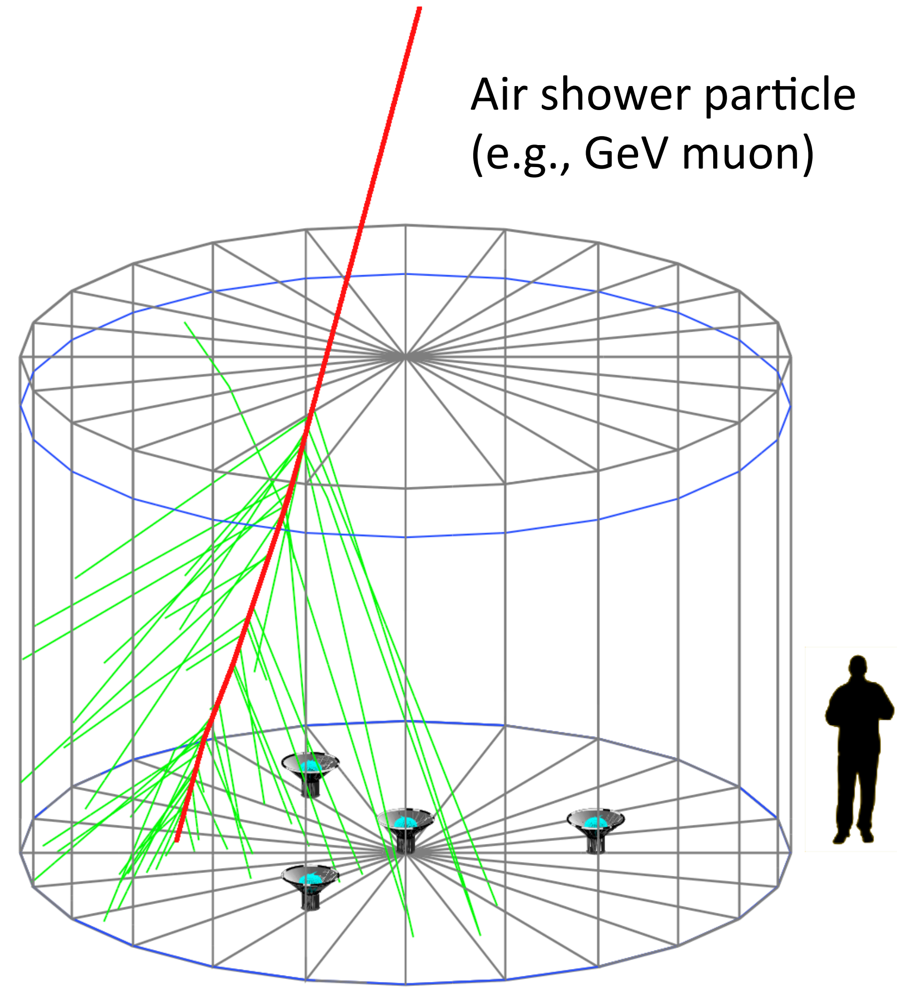
- 4100 meters above sea level
- 19°N latitude (Galactic Center at 48° zenith)
- 300 water tanks, 1200 large photocathode area PMTs 1/6th of sky in instantaneous field of view

- Instrumented Area: 22,000 m^2 $\approx$140 X 140 m^2
- Coverage factor: $\approx$60 %
- 10 kHz event rate



Water Cherenkov Method

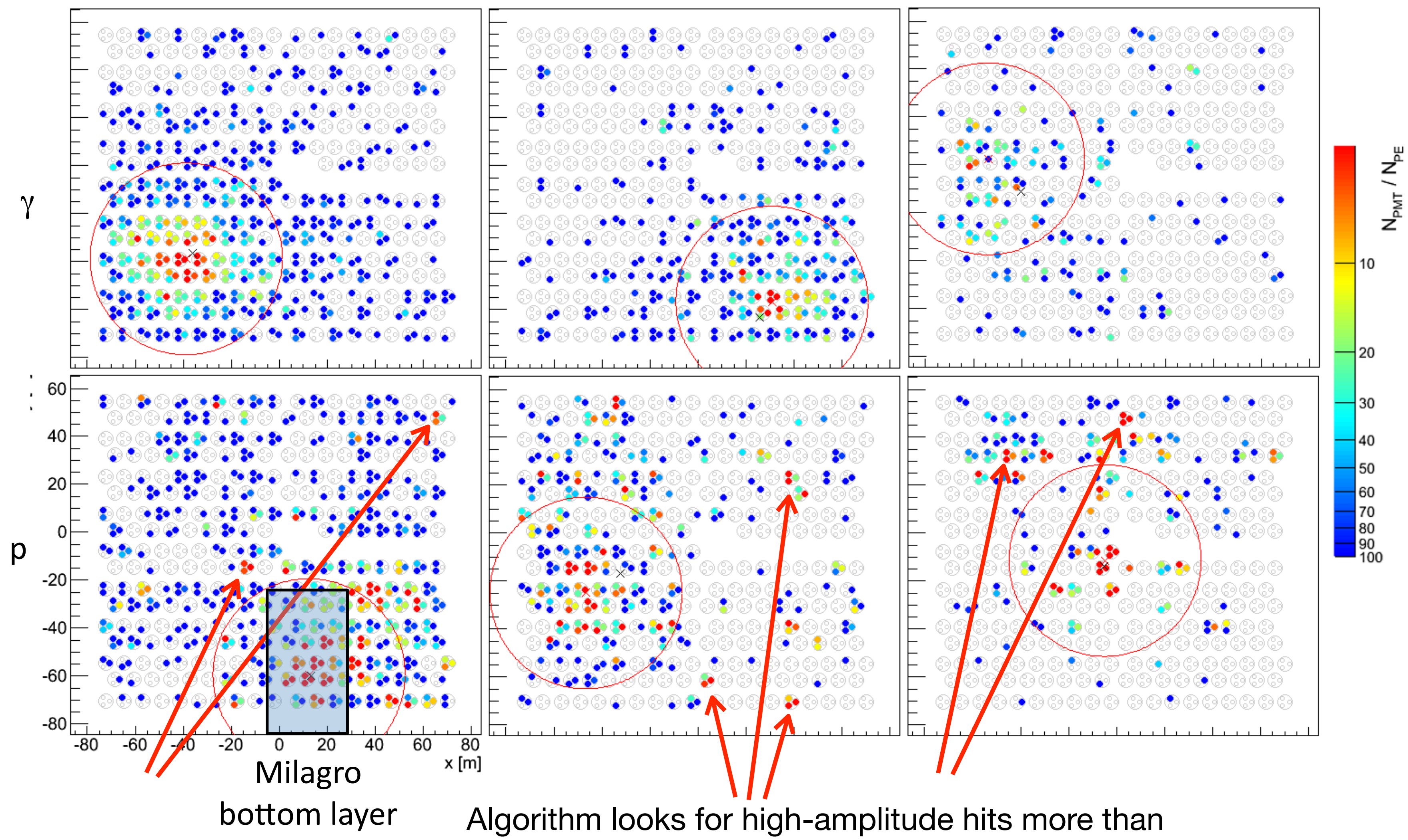
- Robust and cost-effective surface detection technique
- Water tanks: 7.3 m radius, 5 m height, 185 kL purified water
- Tanks contain three 8” R5912 PMTs and one 10” R7081-HQE PMT looking up to capture Cherenkov light from shower front



Final tank deployed: December 15, 2014

Background rejection

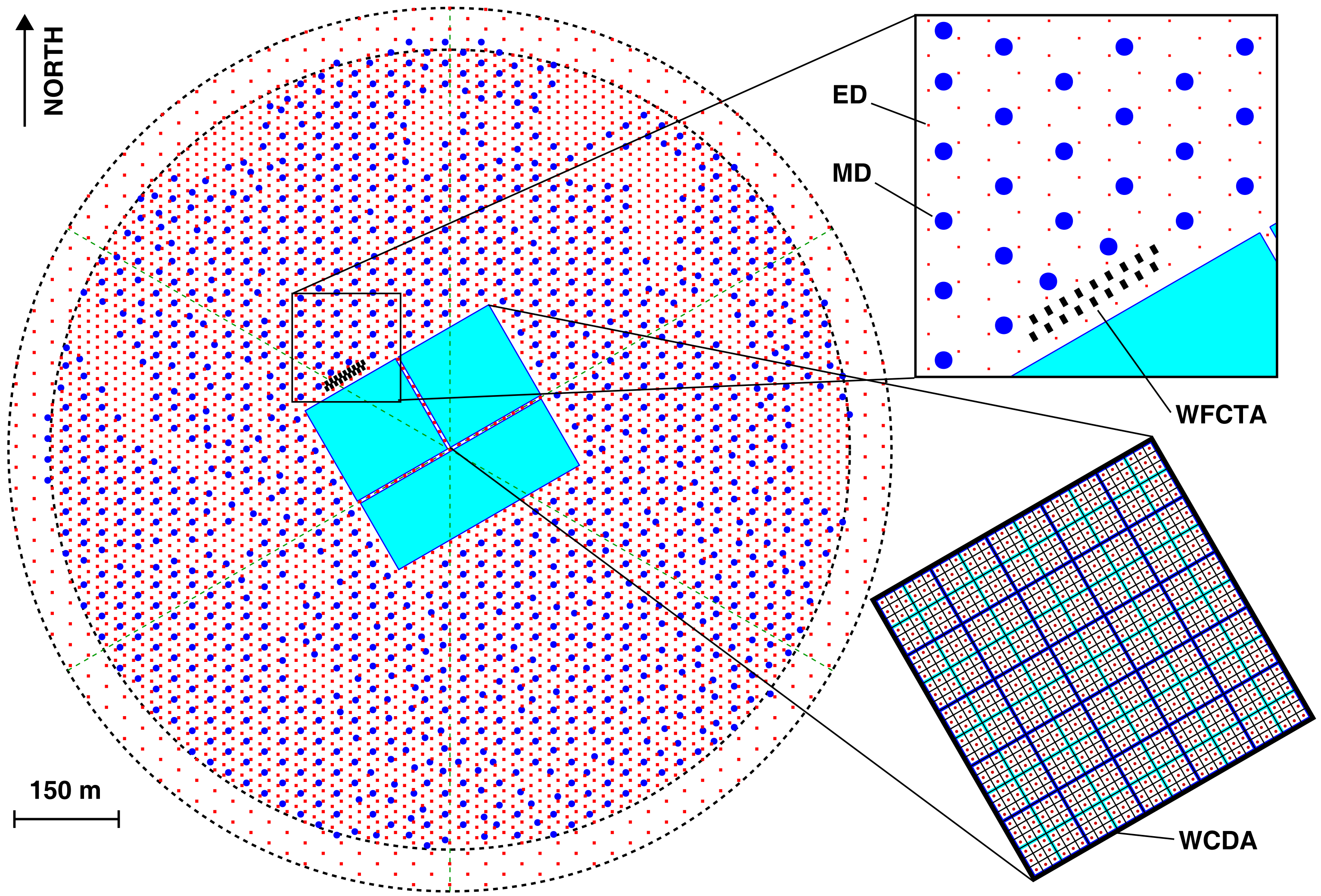
Hadronic showers typically deposit large amounts of energy in distinct clumps far from the shower core (>40 m) ➜ CR rejection using topological cut in hit pattern (the pattern of energy deposition in the detector)



Requires sufficient number of triggered channels (>70) to work well.
Q-value max ($\varepsilon_\gamma/\sqrt{\varepsilon_{CR}}$) is estimated ~5 for point sources.

The LHAASO experiment

- 1 km^2 array, including 4941 scintillator detectors 1 m^2 each, with 15 m spacing.
- An overlapping 1 km^2 array of 1146, underground water Cherenkov tanks 36 m^2 each, with 30 m spacing, for muon detection (total sensitive area ≈ 42,000 m^2).



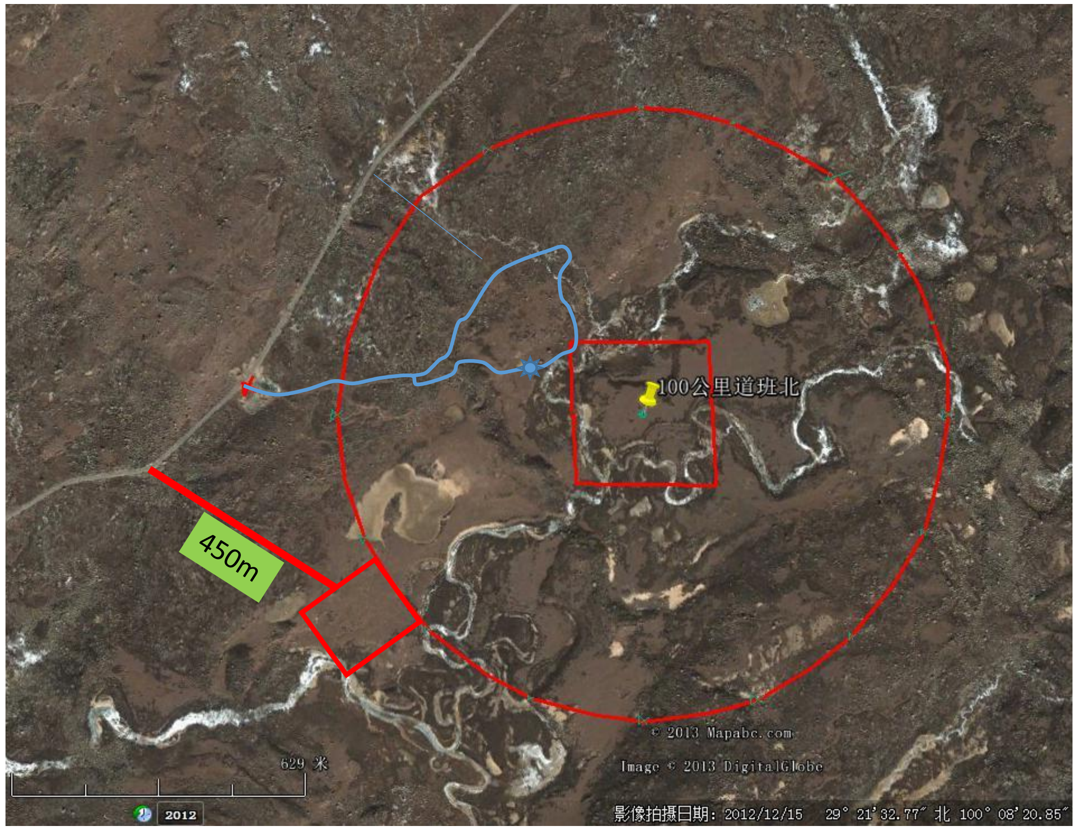
- A close-packed, surface water Cherenkov detector facility with a total area of 80,000 m^2.
- 18 wide field-of-view air Cherenkov (and fluorescence) telescopes.

The LHAASO site

Under installation at 4400 m asl (600 g/cm^2) in the Haizishan (Lakes' Mountain) site, Sichuan province

Coordinates: 29° 21' 31'' N, 100° 08' 15'' E

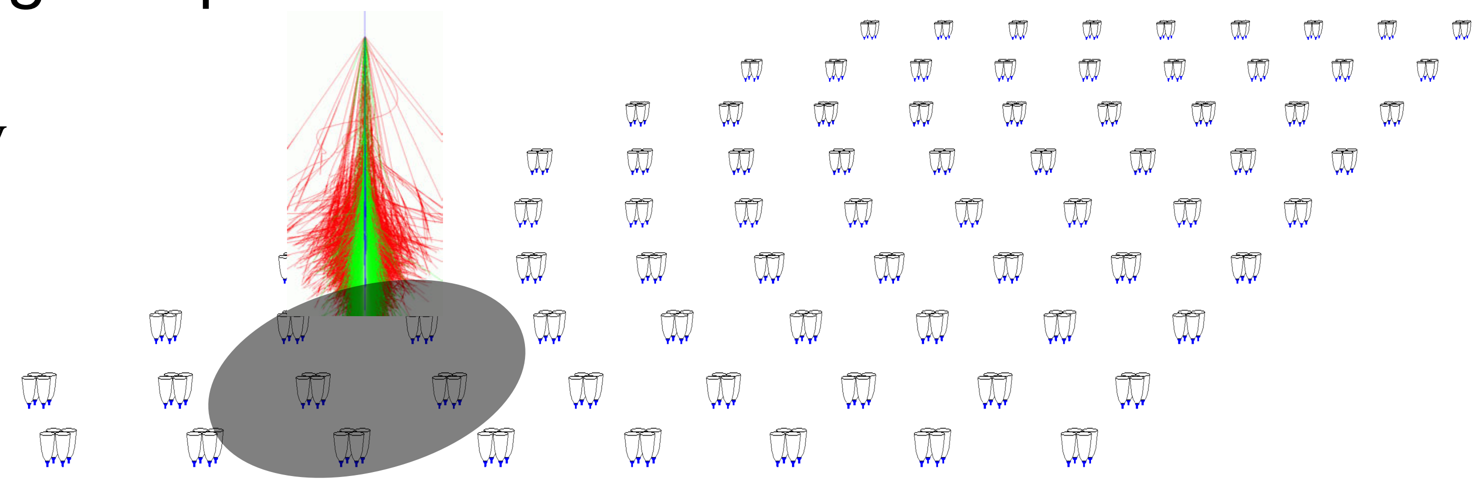
700 km to Chengdu
50 km to Daocheng City (3700 m asl, guest house)
10 km to the highest airport in the world



LHAASO installation

HiSCORE project: opening the PeVatron range

Hundred*i Square-km Cosmic ORigin Explorer



Concept: non-imaging air Cherenkov array

Large area: array up to few 100 km^2
Large Field of view: ~ 0.6 sr

Astroparticle Physics 56 (2014) 42

The HiSCORE concept for gamma-ray and cosmic-ray astrophysics beyond 10 TeV

Martin Tluczykont [a,*], Daniel Hampf [a], Dieter Horns [a], Dominik Spitschan [a], Leonid Kuzmichev [b], Vasily Prosin [b], Christian Spiering [c], Ralf Wischnewski [c]

Energy threshold: ≈50 TeV

Prototype-array at **Tunka-133**:

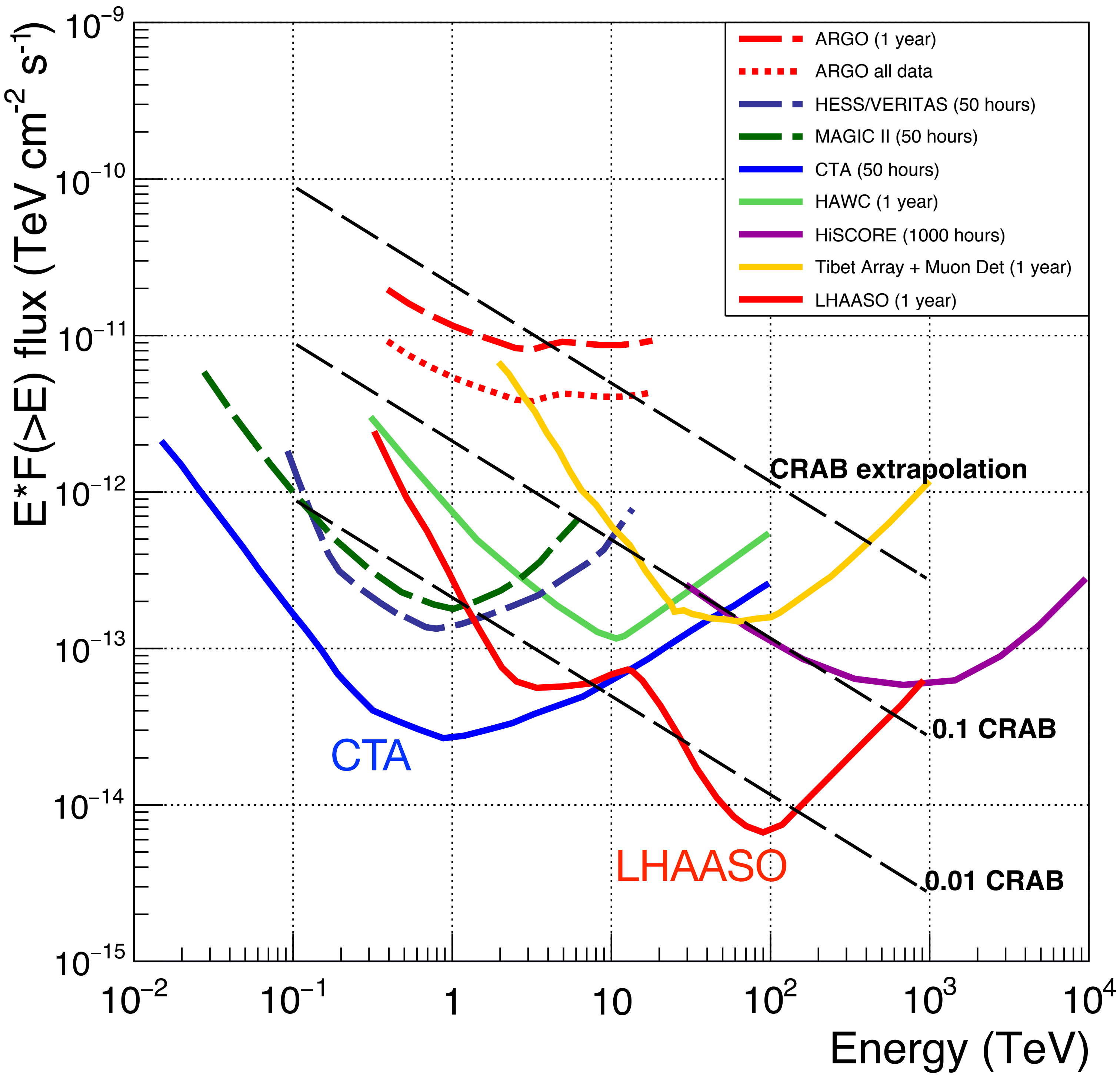
- 9 stations, 300 m × 300 m since October 2013
- 150 m inter-station distance

Table 1
Basic design characteristics of the HiSCORE (highlighted in bold face) detector in comparison with other experiments. The total instrumented area *A*, the light collection area *a* of an individual station, the field of view *FoV*, the inter-station distance *d* and the number of detector stations *N* are listed.

Parameter:	*A*	*a*	*FoV*	*d*	*N*
Unit	[km^2]	[m^2]	[sr]	[m]	
HiSCORE	**100**	**0.5**	**0.60–0.85**	**150**[a]	**4489**
Tunka-133	1[b]	0.031	1.8	85	133
Blanca	0.2	0.1	0.12	35	144
AIROBICC	0.04	0.13	1	15–30	49
Themistocle	0.08	0.5	0.008	50–100	18

[a] Inter-station spacing used for the simulation results presented in the present paper are not optimized yet.
[b] In 2011, the effective area for high energy events was increased to 3 km^2 by extending the array with additional 42 optical detectors, placed at a distance of 1 km from the array center [6].

Sensitivity to gamma point sources



EAS-array: 5 s.d. in 1 year

Cherenkov: 5 s.d. in 50 h *on source*

★ 1 year for EAS arrays means:

(5 h × 365 d) ~1500 - 2200 of observation hours for each source (about 4-6 hours per day).

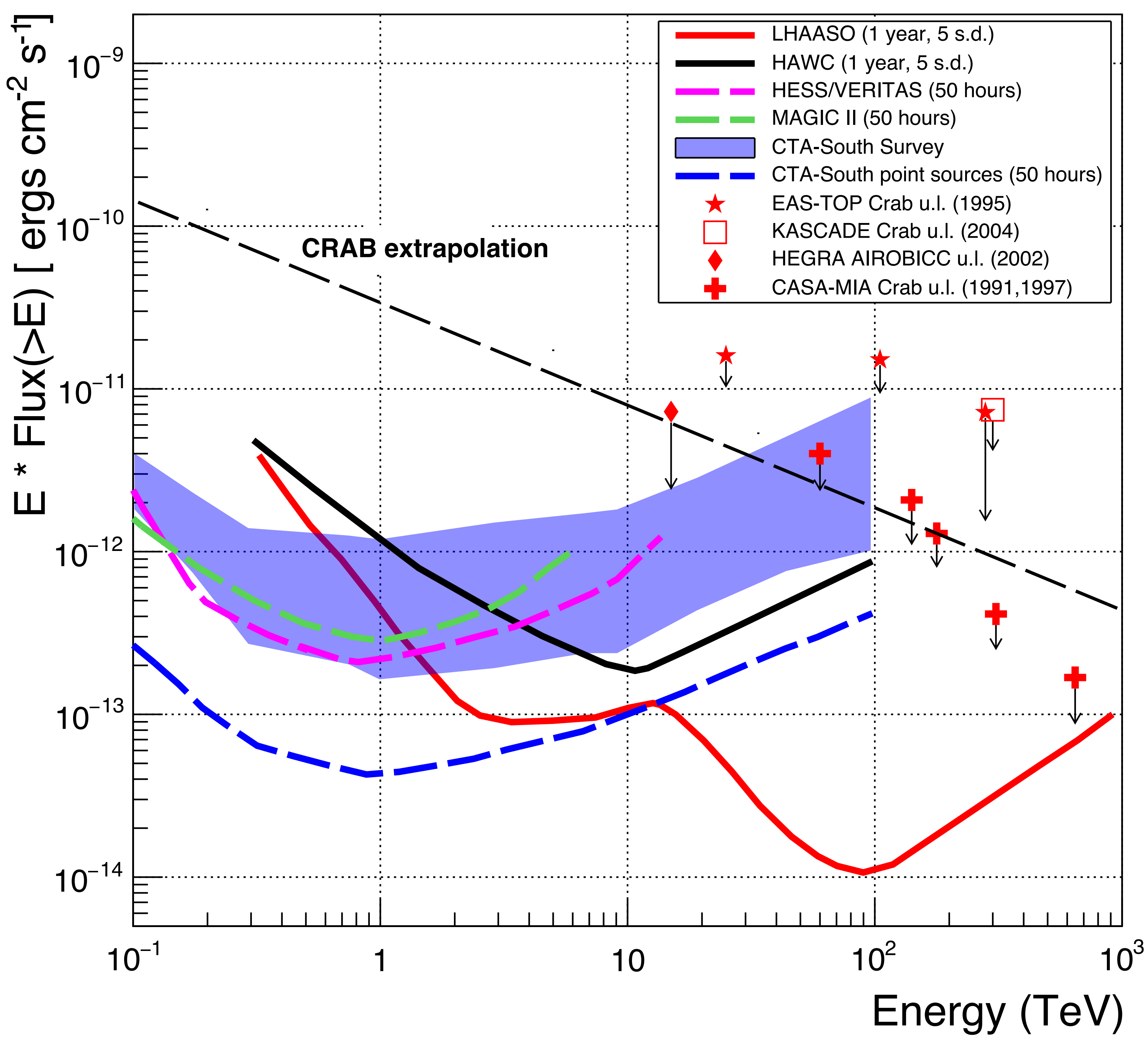
★ For Cherenkov:

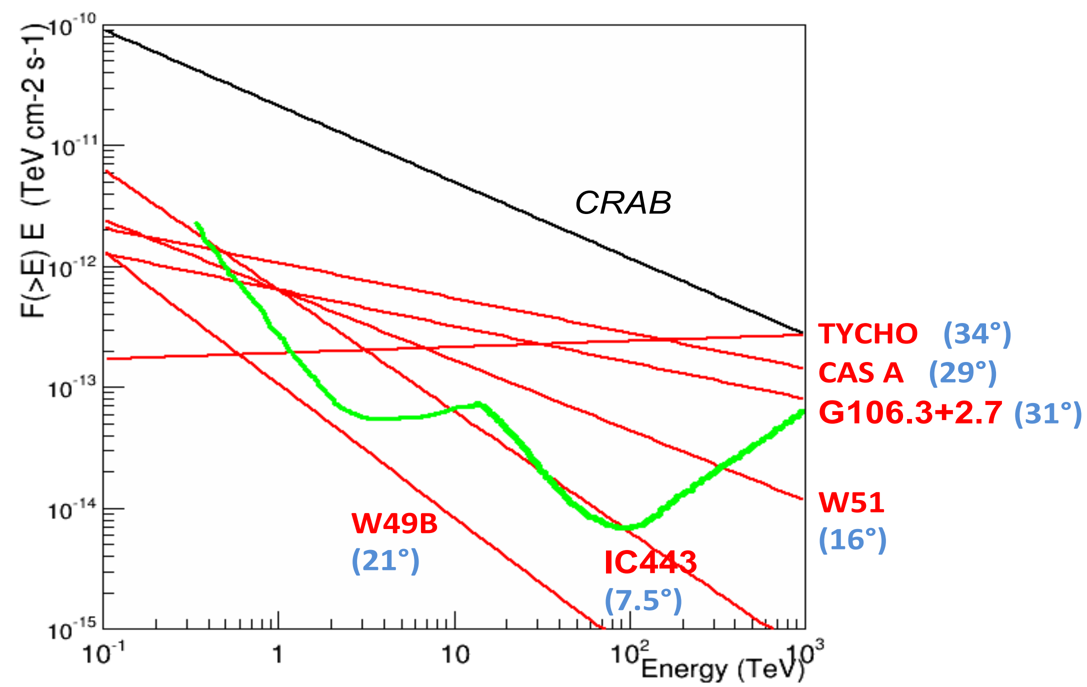
(5 h × 365 d) × d.c. (≈ 15%) ≈ 270 h / y for each source.

The big advantage of wide FOV exps

- High Energy (>10 TeV)
- Sky Survey

Sensitivity to gamma point sources



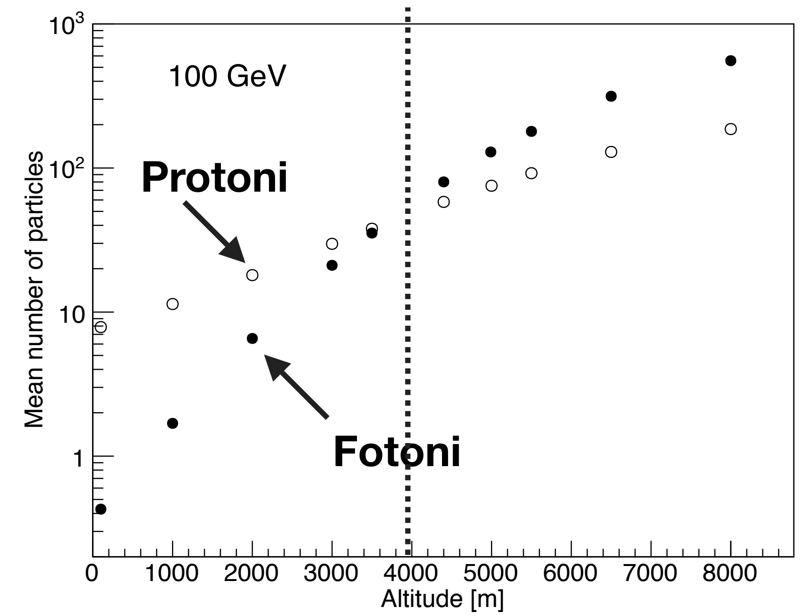


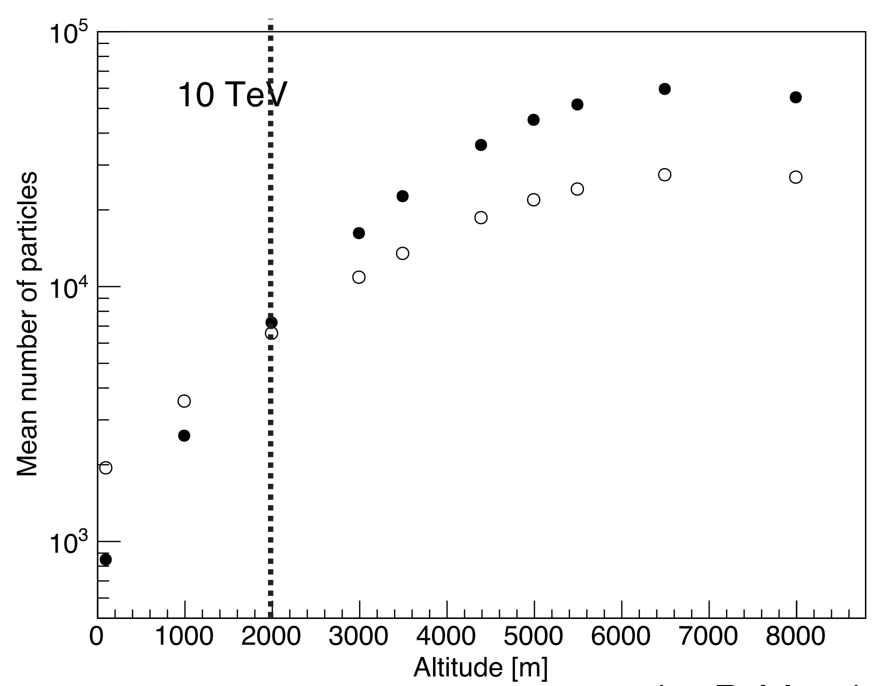
Southern Hemisphere ?

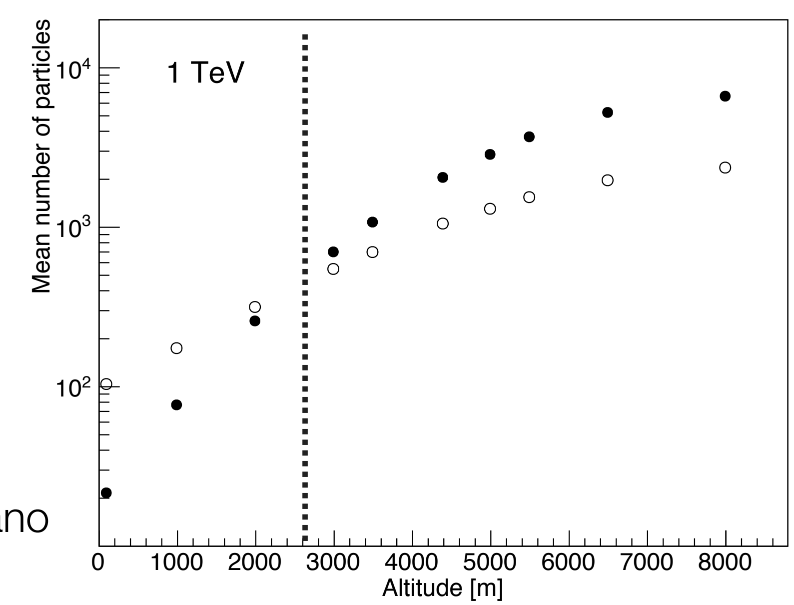
- Galactic Center
- Survery of the Inner Galaxy
- TeV Source finder for CTA south

Started discussions about different ideas for new experiment at higher altitude.
The goal is to lower the energy threshold in the 100 GeV range:

HAWC-South
LATTES: RPCs + water Cherenkov
STACEX: layers of RPCs
ALPACA: scintilator array + water pond

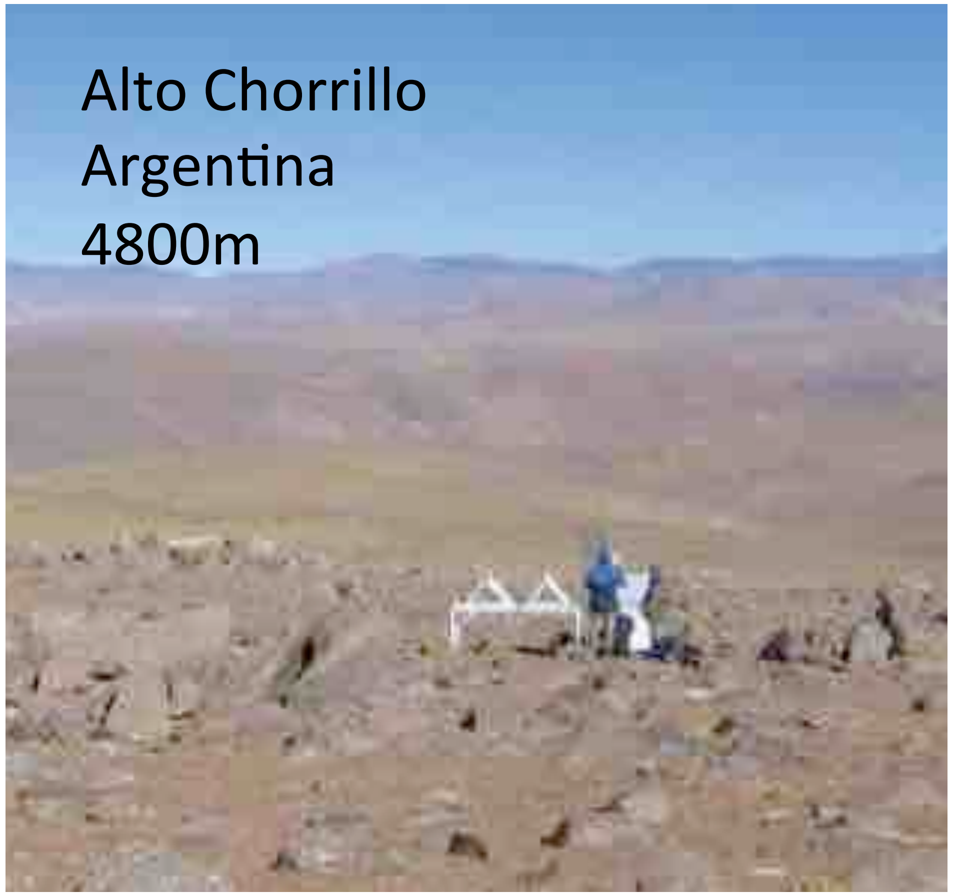






by P. Montini & G. Piano

Southern sites



Chacaltaya 5200 m asl, with long cosmic ray history

South: LATTES

P. Assis, U. Barres de Almeida, A. Blanco, R. Conceicao, A. De Angelis,
P. Fonte, L. Lopes, G. Matthiae, M. Pimenta, R. Shellard, B. Tome

An array of hybrid detectors constituted by

1. one Water Cherenkov Detector (WCD) with a rectangular horizontal surface of 3 m × 1.5 m and a depth of 0.5 m, with signals read by PMTs at both ends of the smallest vertical face of the block.

2. On top of the WCD there are two MARTA RPCs, each with a surface of (1.5 × 1.5) m^2 and with 16 charge collecting pads. Each RPC is covered with a thin (5.6 mm) layer of lead.

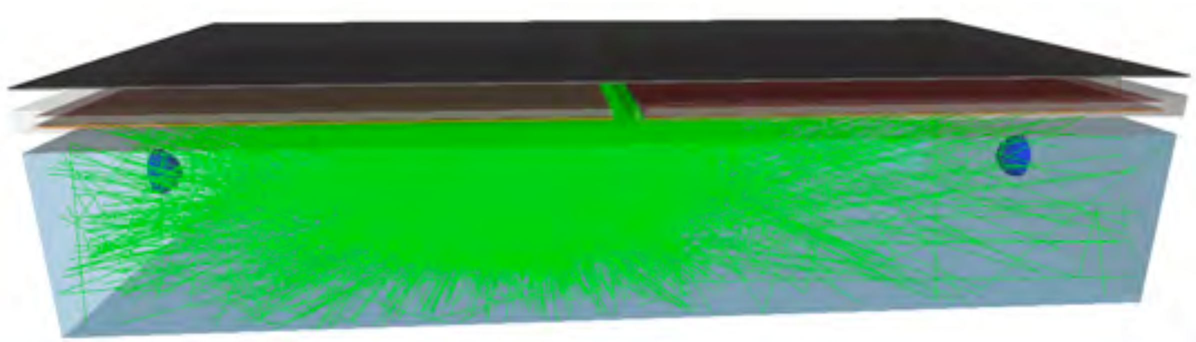
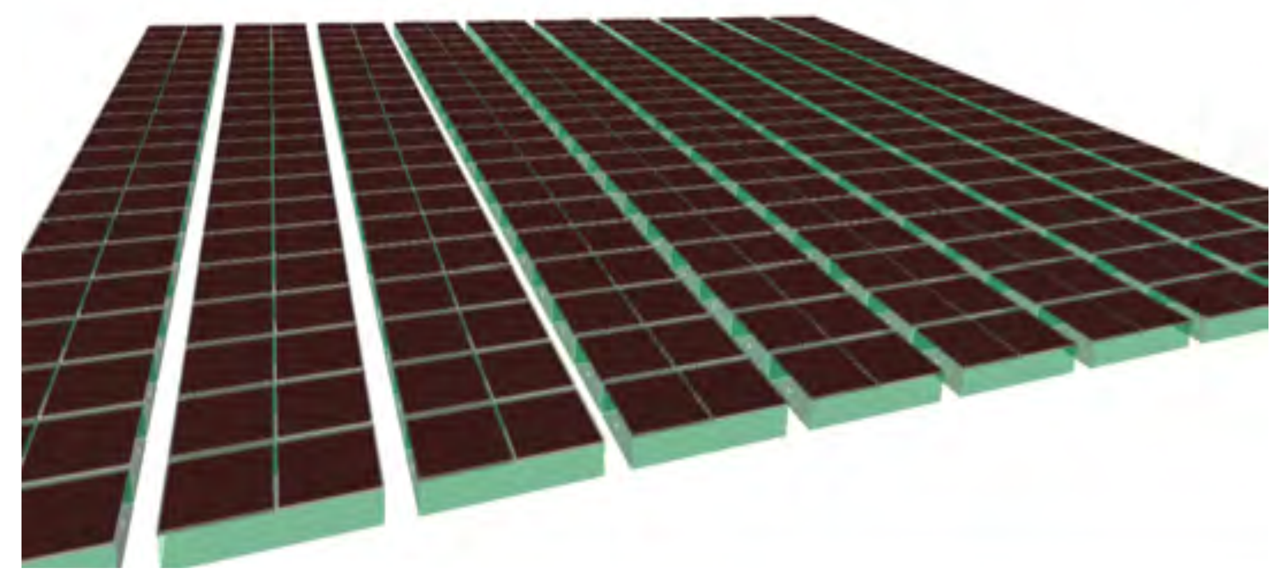


Figure 2: Basic detector station, with one WCD covered with RPCs and a thin slab of lead. The green lines show the tracks of the Cherenkov photons produced by the electron and positron from the conversion of a photon in the lead slab.



LATTES performance

Preliminary calculations

Baseline configuration with 60 rows and 30 lines, covering an effective area of about 10 000 m^2.

Simulated Site at 5200 m asl

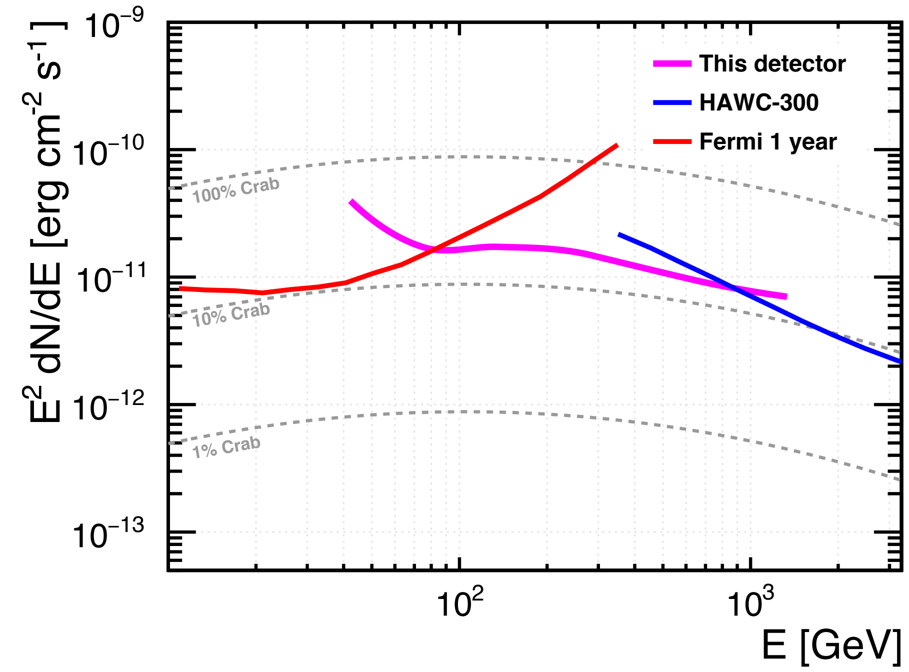
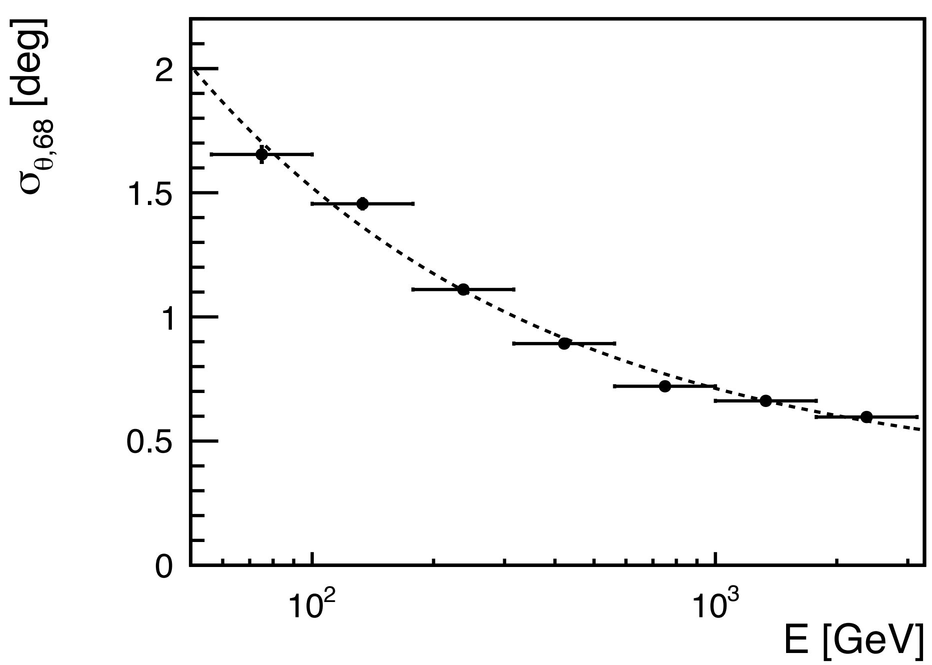
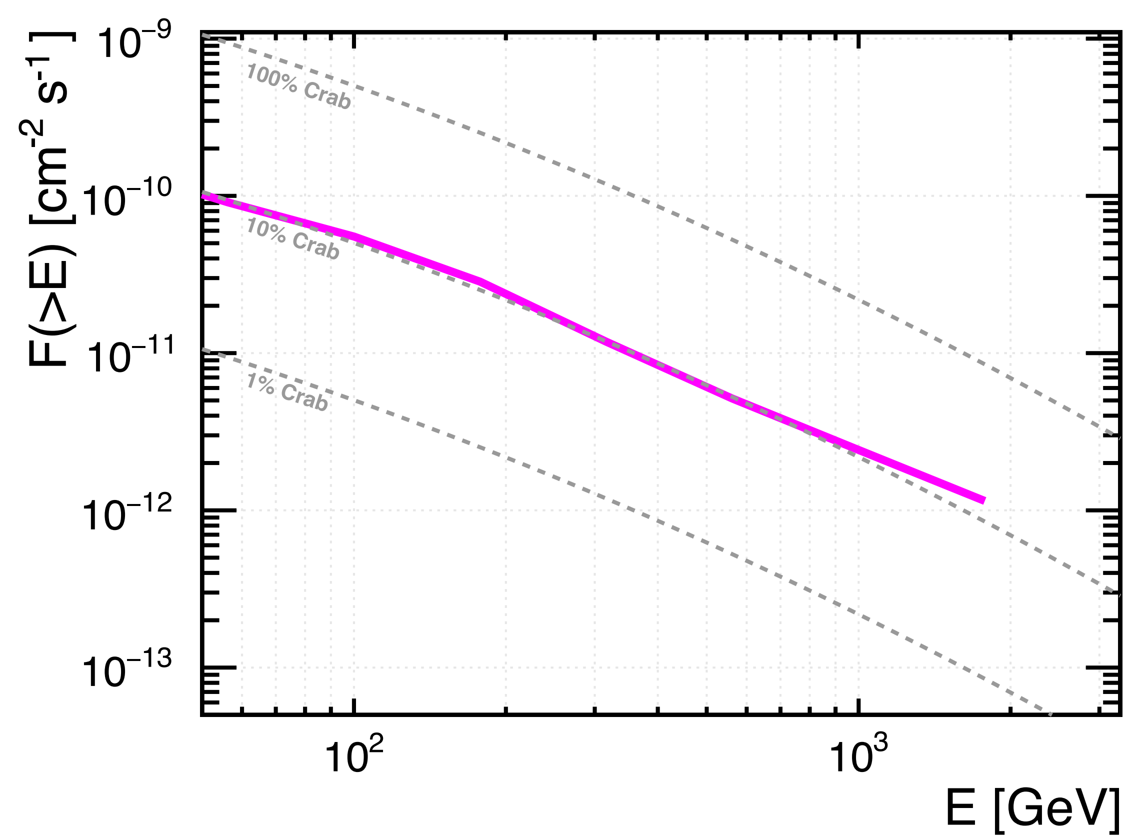


Figure 9: Differential sensitivity. We compute the flux of the source in a given energy range for which $N_{\mathrm{excess}}/\sqrt{N_{\mathrm{bkg}}} = 5$, $N_{\mathrm{excess}} > 10$, after 1 year of time (a 25% duty cycle has been assumed). 4 bins per decade in estimated energy are used. For comparison, fractions of the Crab Nebula spectrum are plotted with the thin dashed gray lines.



A. De Angelis: Private Communication



Chacaltaya, South hemisphere site ?

Japan will finance the construction of a $5 million laboratory in Bolivia for the study of cosmic rays, Japanese Nobel laureate Takaaki Kajita said here Monday.

The new lab is to be built at an altitude of more than 4,750 meters (15,573 feet) on Mount Chacaltaya, a peak near La Paz where the Bolivian university already has a scientific facility.

Construction is expected to be completed in three years.

A score of Japanese and Bolivia researchers will work at the lab under the supervision of Masato Takita, an associate professor at Tokyo University's Institute for Cosmic Ray Research.

La Paz, Press Release May 2, 2016

In the coming 3 years the commissioning of the first 25% of LHAASO is expected.
Therefore, the Chinese group is expected to stop activity in Tibet AS experiment to join LHAASO.

Japan will start activity for ALPACA soon: : scintillator array + high coverage core (water pond ?)
→ LHAASO - like ?

Conclusions

Open problems in cosmic ray physics push the construction of new generation EAS arrays in the 10^{11} - 10^{18} eV energy range.

In the next decade CTA-North and LHAASO are expected to be the most sensitive instruments to study Gamma-Ray Astronomy in the Northern hemisphere from 20 GeV up to PeV.

To maximize the scientific return for Galactic sources, a future instrument should be located at sufficiently Southern latitude to continuously monitor the Galactic Center and the Inner Galaxy.

To maximize the sensitivity at hundreds GeV such an instrument would require very high altitude location (≈ 5000 m asl !), a full coverage approach and an effective area $\gtrsim 10^5$ m^2.

The study of high energy tail of PeVatron emission require very large effective areas (≈1 km^2) at a moderate altitude (≈ 3500 m asl).

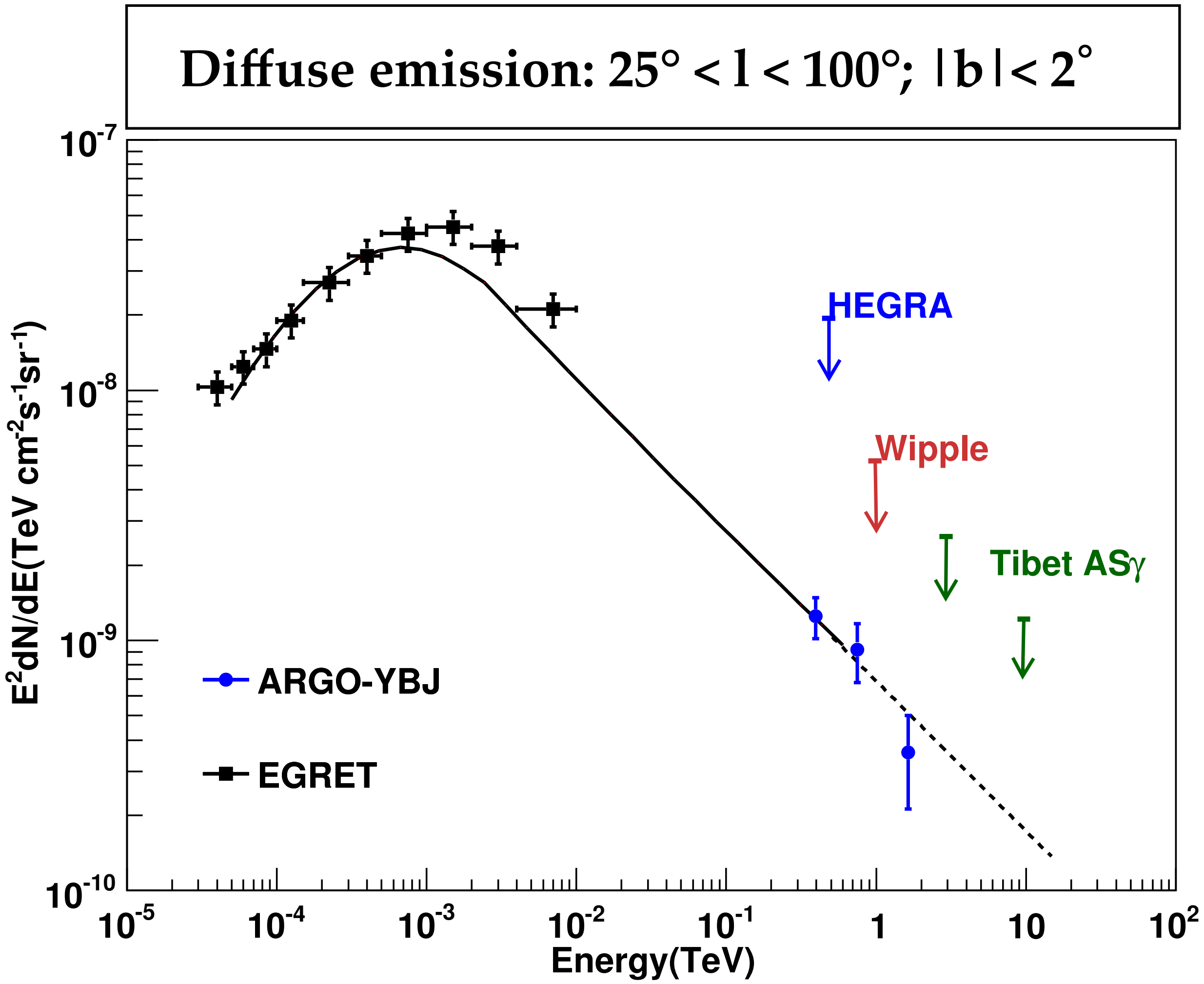
The LHAASO sensitivity should be a reference for new wide FoV experiments

Different ideas to lower the energy threshold at 100 GeV level.

The strong case for all sky survey instruments

The all-sky survey provides un *unbiased map of the sky* useful to

- enable the detection of unexpected sources
- provides testing ground for new theoretical ideas
- provides targets for in-depth observations



- study of flaring phenomena (GRBs, solar flares, AGNs)
- probe of diffuse emission on scales of several degrees
- study of localized CR anisotropies
- search for small and nearby high latitude molecular clouds
- constraints on Dark Matter at multi-TeV scale by *'stacked analysis'*
- blind search for annihilation in Dark Matter subhalos of the Galaxy, without any *a priori* association with an astrophysical object (dwarf galaxy, Galactic Center, etc)
- search for new, unexpected classes of VHE sources ('*dark accelerator*') useful to constrain the density in the Galactic halo of *cloudlets:* cold and dense clumps of material that may constitute a sizeble fraction of *baryonic matter* mostly invisible but not for their gamma-ray emission for CR interaction

Sensitivity

$$n_\sigma = \frac{\text{Signal}}{\sqrt{\text{Backgr}}} = \frac{\Phi_\gamma(>E)\cdot A^\gamma_{eff}(>E)\cdot T_{eff}\cdot\epsilon(\Delta\Omega)}{\sqrt{\Phi_B(>E)\cdot A^B_{eff}(>E)\cdot T_{eff}\cdot\Delta\Omega}}$$

$$= \frac{\Phi_\gamma}{\sqrt{\Phi_B}}\cdot\sqrt{A^\gamma_{eff}}\cdot\sqrt{\frac{T\cdot f}{\pi}}\cdot\sqrt{(d.c.)}\cdot\frac{\epsilon(\Delta\theta)}{\Delta\theta}\cdot R\cdot Q_f$$

$$\frac{\Phi_\gamma}{\sqrt{\Phi_p}} \sim E_{th}^{-(a-b/2)}$$

$$R = \sqrt{\frac{A^\gamma_{eff}(>E)}{A^B_{eff}(>E)}}$$

$$T_{eff} = (d.c.)\cdot T\cdot f$$

$$\Delta\Omega = 2\pi(1-cos\Delta\theta) \simeq \pi(\Delta\theta)^2$$

$$Q_f = \frac{\text{fraction of surviving photons}}{\sqrt{\text{fraction of surviving hadrons}}}$$

$$\Delta\theta = 1.58\ \sigma_\theta \qquad \frac{\epsilon(\Delta\Omega)}{\Delta\Omega} \simeq \frac{0.72}{1.6\sigma_\theta} = \frac{0.45}{\sigma_\theta}$$

Minimum Detectable Flux

$$\Phi_\gamma^{MDF} = n_\sigma \cdot \sqrt{\Phi_B} \cdot \frac{1}{R \cdot \sqrt{A_{eff}^\gamma}} \cdot \sqrt{\frac{\pi}{T \cdot f}} \cdot \frac{1}{\sqrt{(d.c.)}} \cdot \frac{\psi_{70}}{\epsilon(\Delta\theta)} \cdot \frac{1}{Q_f}$$

$$= \quad 5 \cdot \sqrt{\Phi_B} \cdot \frac{1}{R \cdot \sqrt{A_{eff}^\gamma}} \cdot \sqrt{\frac{\pi}{3.15 \cdot 10^7 \cdot 0.25}} \cdot \frac{1}{\sqrt{0.9}} \cdot \frac{\psi_{70}}{0.72} \cdot \frac{1}{Q_f}$$

$$= \quad 4.6 \cdot 10^{-3} \cdot \sqrt{\Phi_B} \cdot \frac{1}{R \cdot \sqrt{A_{eff}^\gamma}} \cdot \psi_{70} \cdot \frac{1}{Q_f}$$

Φ_B (>E) = 1.30 • $(E_{GeV})^{-1.66}$ particles cm^{-2} s^{-1} sr^{-1} (Horandel)

Φ_B (>100 GeV) = 6.2 • 10^{-4} part. cm^{-2} s^{-1} sr^{-1}
Φ_B (>500 GeV) = 4.3 • 10^{-5} part. cm^{-2} s^{-1} sr^{-1}
Φ_B (>1000 GeV) = 1.3 • 10^{-5} part, cm^{-2} s^{-1} sr^{-1}

Φ_γ^{CRAB} (>100 GeV) = 6.5 • 10^{-10} ph. cm^{-2} s^{-1}
Φ_γ^{CRAB} (>500 GeV) = 6.0 • 10^{-11} ph. cm^{-2} s^{-1}
Φ_γ^{CRAB} (>1000 GeV) = 2 • 10^{-11} ph. cm^{-2} s^{-1}

Minimum Detectable Flux

$$\Phi_\gamma^{MDF} = n_\sigma \cdot \sqrt{\Phi_B} \cdot \frac{1}{R \cdot \sqrt{A^\gamma_{eff}}} \cdot \sqrt{\frac{\pi}{T \cdot f}} \cdot \frac{1}{\sqrt{(d.c.)}} \cdot \frac{\psi_{70}}{\epsilon(\Delta\theta)} \cdot \frac{1}{Q_f}$$

$$= \quad 5 \cdot \sqrt{\Phi_B} \cdot \frac{1}{R \cdot \sqrt{A^\gamma_{eff}}} \cdot \sqrt{\frac{\pi}{3.15 \cdot 10^7 \cdot 0.25}} \cdot \frac{1}{\sqrt{0.9}} \cdot \frac{\psi_{70}}{0.72} \cdot \frac{1}{Q_f}$$

$$= \quad 4.6 \cdot 10^{-3} \cdot \sqrt{\Phi_B} \cdot \frac{1}{R \cdot \sqrt{A^\gamma_{eff}}} \cdot \psi_{70} \cdot \frac{1}{Q_f}$$

Φ_B (>E) = 1.30 • $(E_{GeV})^{-1.66}$ particles cm^{-2} s^{-1} sr^{-1} (Horandel)

Φ_B (>100 GeV) = 6.2 • 10^{-4} part. cm^{-2} s^{-1} sr^{-1}

Φ_B (>500 GeV) = 4.3 • 10^{-5} part. cm^{-2} s^{-1} sr^{-1}

Φ_B (>1000 GeV) = 1.3 • 10^{-5} part, cm^{-2} s^{-1} sr^{-1}

Φ_γ^{CRAB} (>100 GeV) = 6.5 • 10^{-10} ph. cm^{-2} s^{-1}

Φ_γ^{CRAB} (>500 GeV) = 6.0 • 10^{-11} ph. cm^{-2} s^{-1}

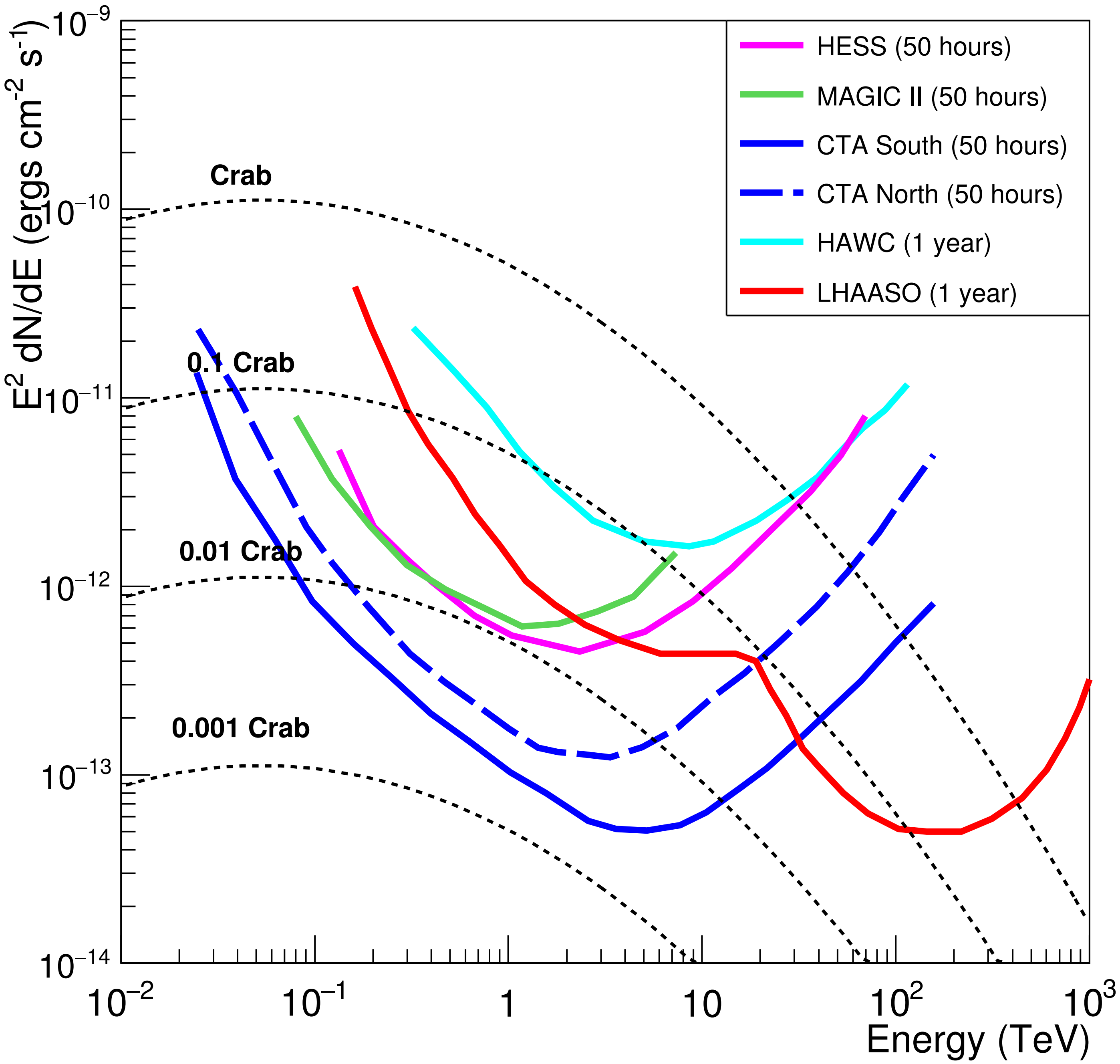
Φ_γ^{CRAB} (>1000 GeV) = 2 • 10^{-11} ph. cm^{-2} s^{-1}

Characteristics of different EAS-arrays

Experiment	Altitude (m)	e.m. Sensitive Area (m^2)	Instrumented Area (m^2)	Coverage
LHAASO	4410	5.2×10^3	1.3×10^6	4×10^{-3}
TIBET ASγ	4300	380	3.7×10^4	10^{-2}
IceTop	2835	4.2×10^2	10^6	4×10^{-4}
ARGO-YBJ	4300	6700	11,000	0.93 (central carpet)
KASCADE	110	5×10^2	4×10^4	1.2×10^{-2}
KASCADE-Grande	110	370	5×10^5	7×10^{-4}
CASA-MIA	1450	1.6×10^3	2.3×10^5	7×10^{-3}

		μ Sensitive Area (m^2)	Instrumented Area (m^2)	Coverage
LHAASO	4410	4.2×10^4	10^6	4.4×10^{-2}
TIBET ASγ	4300	4.5×10^3	3.7×10^4	1.2×10^{-1}
KASCADE	110	6×10^2	4×10^4	1.5×10^{-2}
CASA-MIA	1450	2.5×10^3	2.3×10^5	1.1×10^{-2}

LHAASO sensitivity to gamma point sources



Extrapolation of TeV spectra assuming no cutoff