Institute of High Energy Physics
Chinese Academy of Sciences

The LHAASO project: a new generation Cosmic Ray Experiment

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ARGO-YBJ

Si stanno concludendo le analisi. Nessuna richiesta per il 2016

Attività 2015:

- conclusione analisi emissione diffusa: ApJ 806 (2015) 20.
- conclusione analisi spettro p+He 'digitale': PRD 91 (2015) 112017.
- conclusione analisi 5 anni dati Crab Nebula: ApJ 798 (2015) 119.
- conclusione analisi anisotropia larga scala: ApJ submitted.
- conclusione analisi ibrida spettro p+He fino a 10 PeV: PRD submitted.
- pubblicazione lavori uso digitale RPC: Astrop. Phys. 67 (2015) 47, NIM A783 (2015) 68.

Analisi in corso e da concludere nel 2016:

- conclusione analisi spettro all-particle e (p+He) fino a 10 PeV con ARGO.
- analisi anisotropia per (p+He).
- analisi effetti solari su flusso dei RC ('Sun Shadow').

Outline

- What is LHAASO ?
- Why LHAASO ? ➡ Open problems in Cosmic Ray Physics
- The LHAASO Experiment
- Collaboration Opportunities

What is LHAASO ?

The Large High Altitude Air Shower Observatory (LHAASO) project is a new generation all-sky instrument to investigate the '*cosmic ray connection*' through a combined study of cosmic rays and gamma-rays in the wide energy range 10^{11} -- 10^{17} eV.

The first phase of LHAASO will consist of the following major components:

- 1 km^2 array (LHAASO-KM2A), including 5635 scintillator detectors, with 15 m spacing, for electromagnetic particle detection.
- An overlapping 1 km^2 array of 1221, 36 m^2 underground water Cherenkov tanks, with 30 m spacing, for muon detection (total sensitive area 40,000 m^2).
- A close-packed, surface water Cherenkov detector facility with a total area of 90,000 m^2 (LHAASO-WCDA), four times that of HAWC.
- 24 wide field-of-view air Cherenkov (and fluorescence) telescopes (LHAASO-WFCTA).
- 452 close-packed burst detectors, located near the centre of the array, for detection of high energy secondary particles in the shower core region (LHAASO-SCDA).

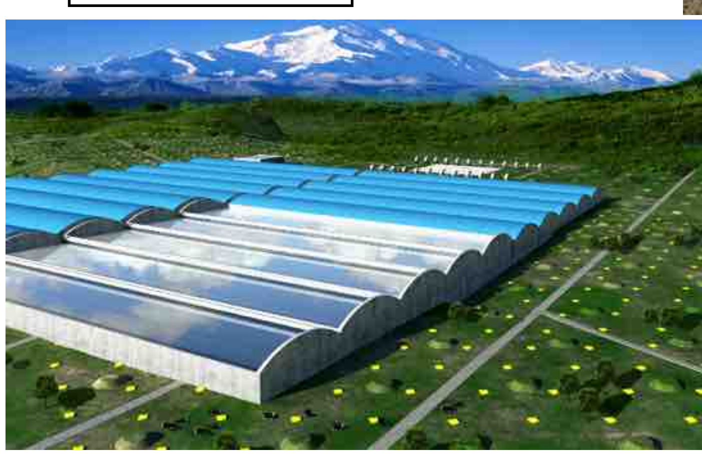
LHAASO main components

1 KM2A:
5635 EDs
1221 MDs

WFCTA:
24 telescopes
1024 pixels each

Coverage area: 1.3 km^2

WCDA:
3600 cells
90,000 m^2



SCDA:
452 detectors

The LHAASO site

The experiment will be located at 4400 m asl (600 g/cm^2) in the Haizishan (Lakes' Mountain) site, Sichuan province

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

700 km to Chengdu
50 km to Daocheng City (3700 m asl, guest house !)
8 km to airport

Status of LHAASO

- LHAASO is one of the '*Five top priorities*' projects of the Strategic Plan of IHEP approved by the Chinese Academy of Sciences (CAS).

- The National Reform and Development Commission (NRDC) and the Finance Ministry (FM) allocated for LHAASO 1 Billion CNY (about 160 M US$) ➜ *“Flagship Project”*.

- The government of Sichuan province will cover the total cost of the infrastructure construction: 300 M CNY.

Tentative Schedule (May 2015)

★ Sept. 2015: start of construction of infrastructures.
★ Spring 2016: start of construction of first quarter of WCDA and KM2A.
★ Spring 2017: installation of PMTs in the first pond.

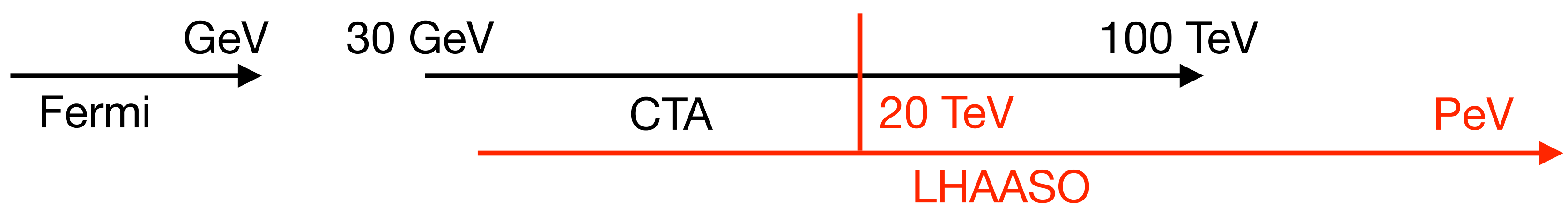
★ Spring 2018: start scientific operation of the first quarter of LHAASO.

★ 2021: conclusion of installation of main components.

Why LHAASO ?

The LHAASO experiment will be the next generation ground-based experiment, capable of acting simultaneously as a Gamma Ray Telescope and a Cosmic Ray Detector.

- Gamma-Ray Astronomy ($10^2 \rightarrow 10^6$ GeV): full sky continuous monitoring
  - *Below 20 TeV*: continuous monitoring of the Northern sky at < 0.01 of the Crab flux → Sky survey: complementarity with CTA (Cherenkov Telescope Array)
  - *Above 20 TeV*: continuous monitoring of the Northern sky up to PeV with a sensitivity 2000x CTA for sky survey > 70 TeV→ search for PeV cosmic ray sources (*Pevatrons)*



- Cosmic Ray Physics ($10^{12} \rightarrow 10^{17}$ eV): precluded to Cherenkov Telescopes
  - CR energy spectrum
  - Elemental composition
  - Anisotropy

Galactic CRs: main open problems

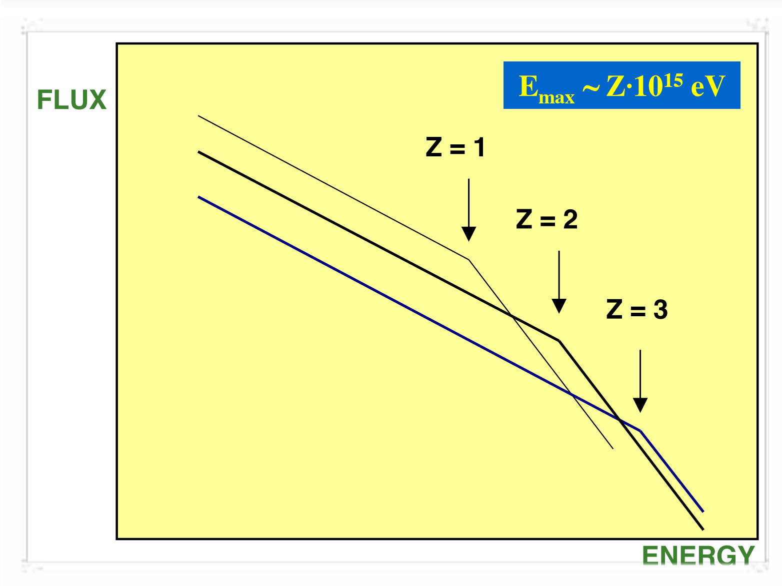
✦ Cosmic Ray Sources: *"PeVatrons"* *"astronomy"* (gamma, neutrino) but also *anisotropy* !

accelerators

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

✦ Proton energy spectrum: *"proton knee"*

acceleration mechanisms, propagation, neutrinos, background



Multi-parameter, Multi-wavelenght, Multi-messanger

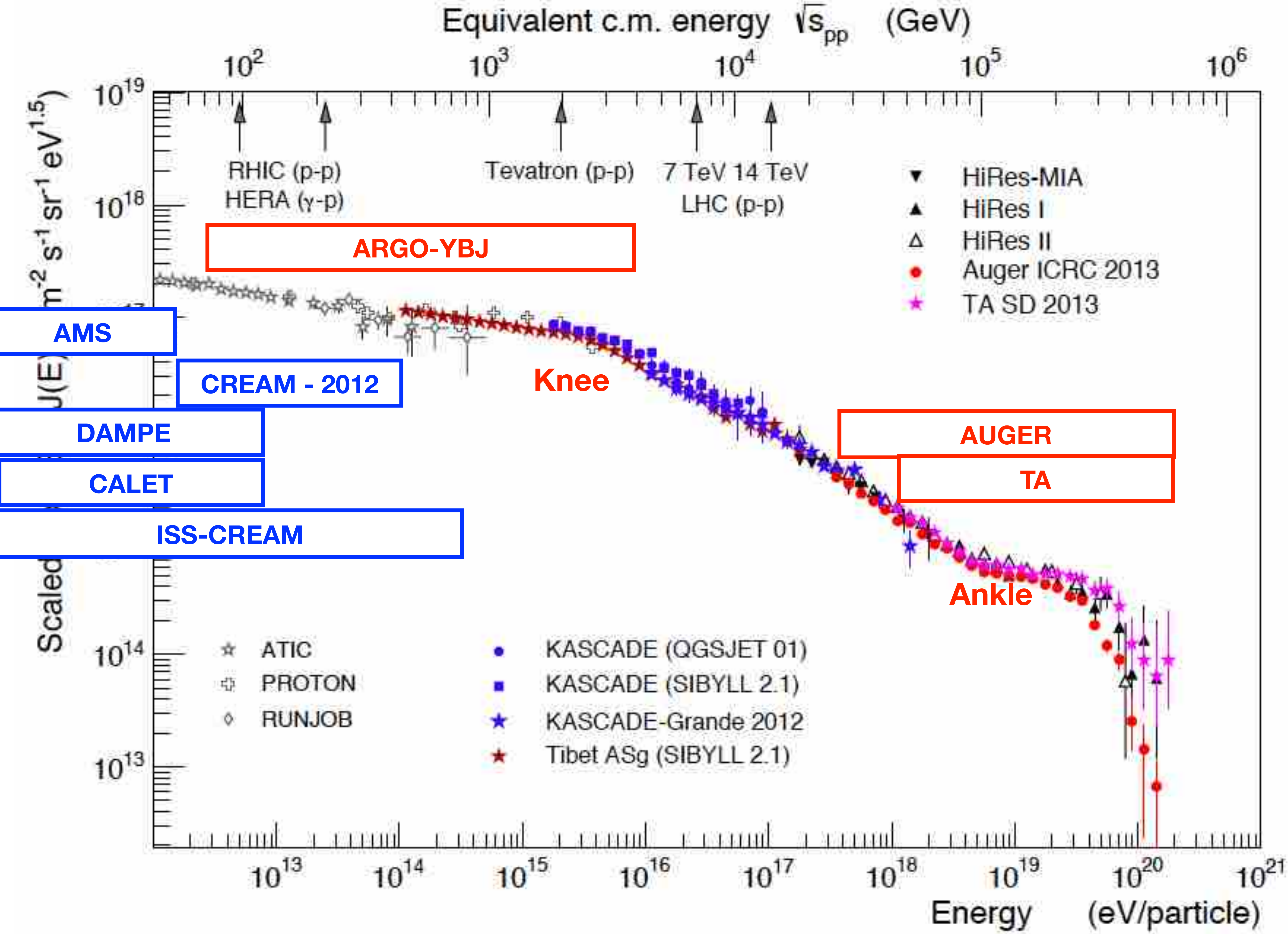
electrons
muons
hadrons
cherenkov
…

X → PeV

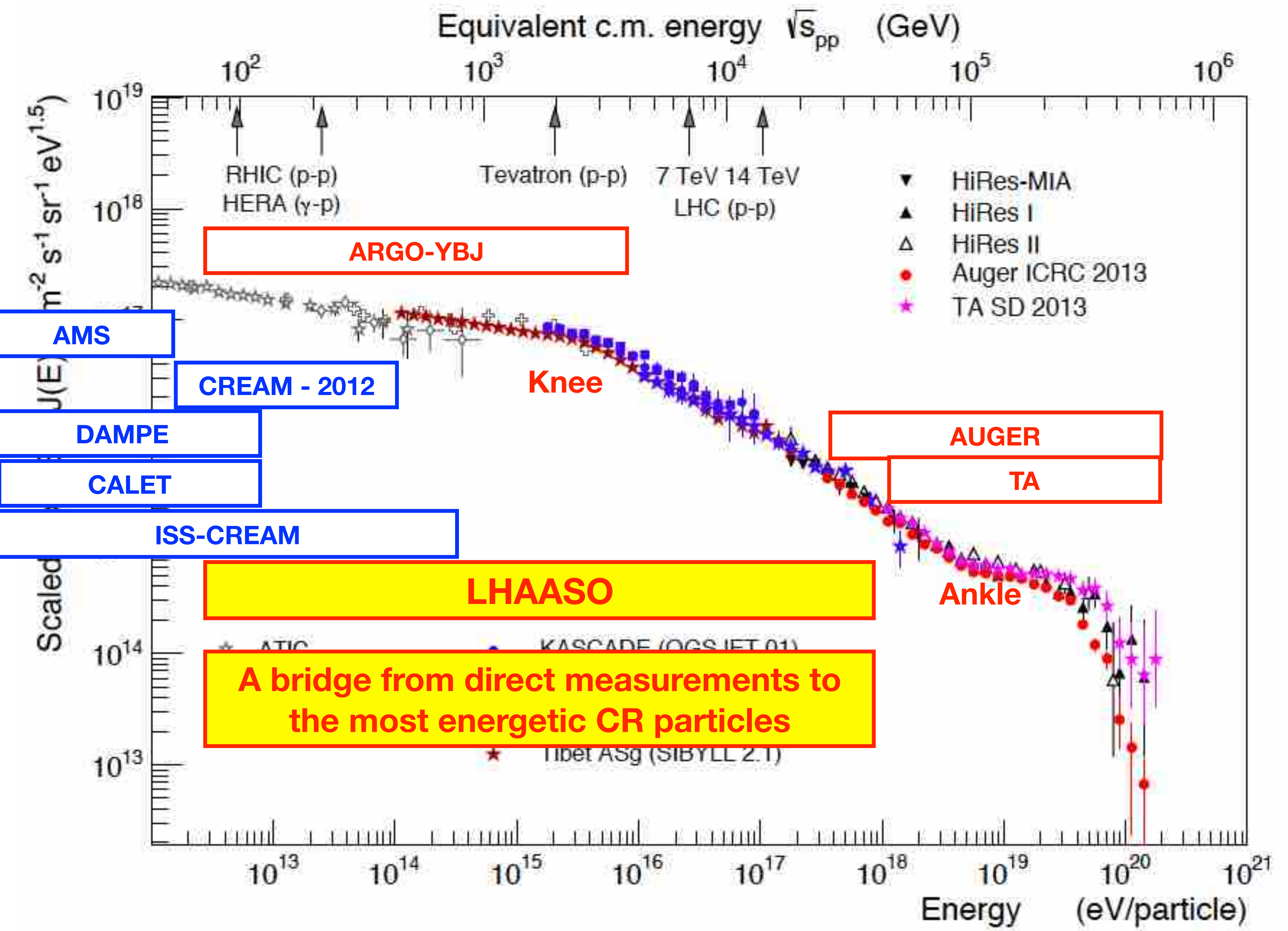
photons
charged
neutrinos

Fermi, Agile, Pamela, AMS, MAGIC, CTA, ARGO-YBJ, Km3Net, …

same scientific program/goals: different/complementary approaches !



Equivalent c.m. energy $\sqrt{s_{pp}}$ (GeV)
10^2
10^3
10^4
10^5
10^6
RHIC (p-p)
HERA (γ-p)
Tevatron (p-p)
7 TeV 14 TeV
LHC (p-p)
HiRes-MIA
HiRes I
HiRes II
Auger ICRC 2013
TA SD 2013
ARGO-YBJ
AMS
CREAM - 2012
DAMPE
CALET
ISS-CREAM
Knee
AUGER
TA
Ankle
10^{19}
10^{18}
10^{14}
10^{13}
ATIC
PROTON
RUNJOB
KASCADE (QGSJET 01)
KASCADE (SIBYLL 2.1)
KASCADE-Grande 2012
Tibet ASg (SIBYLL 2.1)
10^{13}
10^{14}
10^{15}
10^{16}
10^{17}
10^{18}
10^{19}
10^{20}
10^{21}
Energy (eV/particle)



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LHAASO
A bridge from direct measurements to the most energetic CR particles
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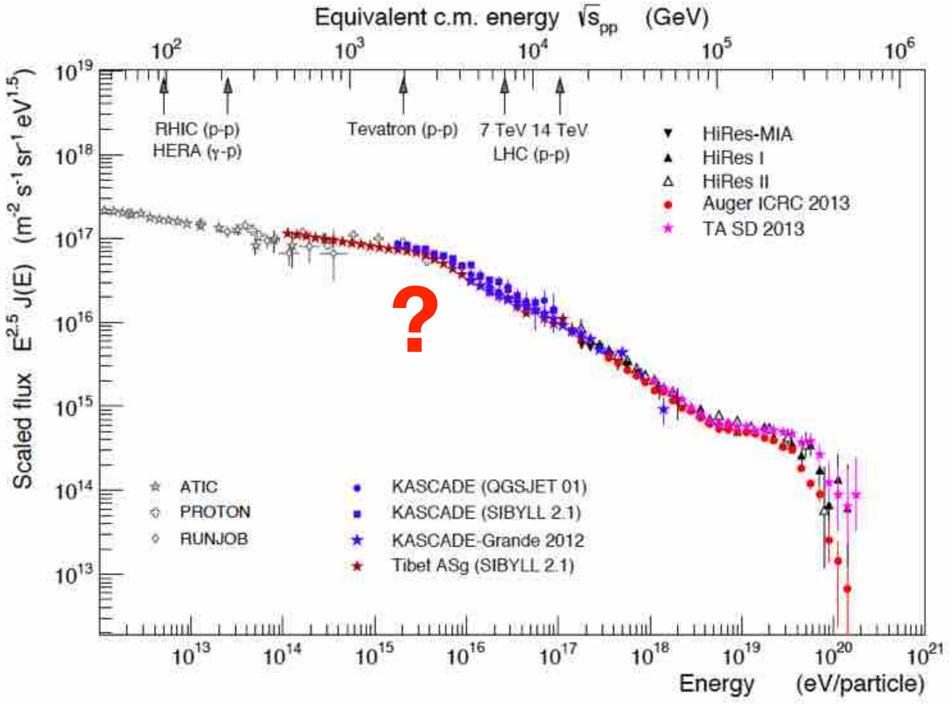
10^{20}
10^{21}
Energy (eV/particle)

Approaching the knee

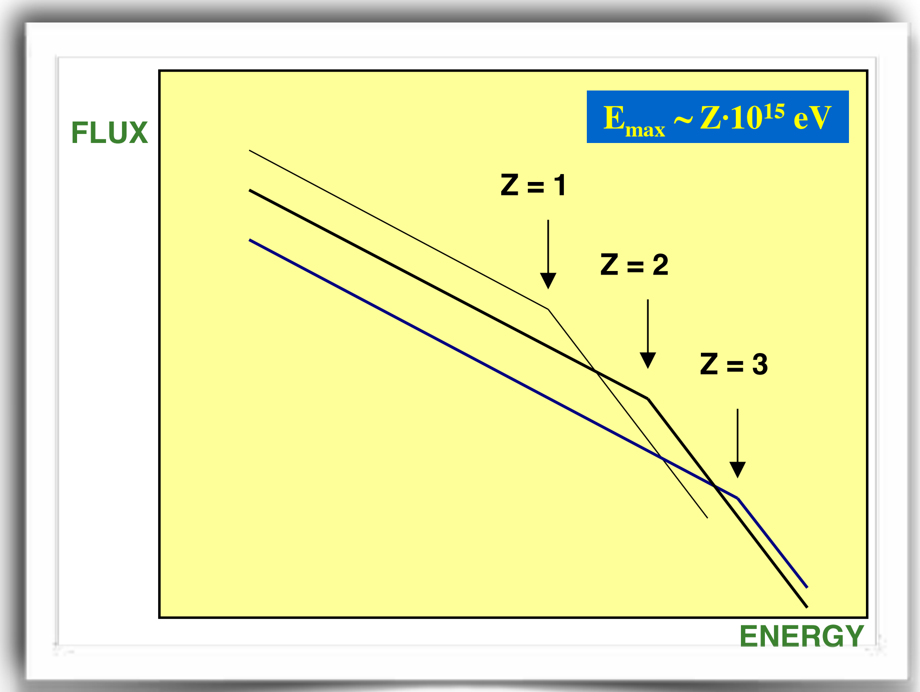
Energy spectrum, elemental composition, anisotropy:

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



The standard model:

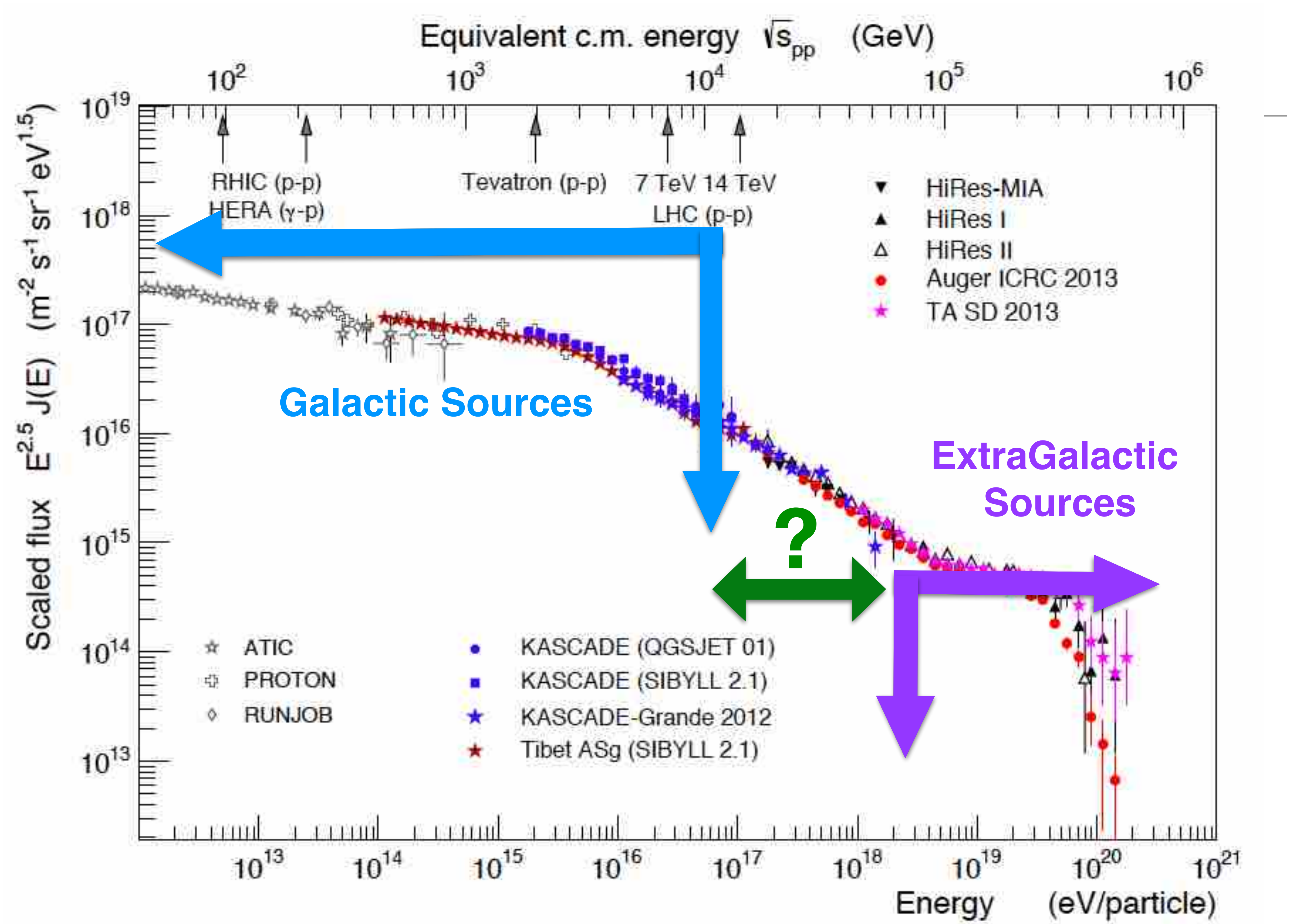
- Knee attributed to light (proton, helium) component
- Rigidity-dependent structure (Peters cycle): cut-offs at energies proportional to the nuclear charge $E_Z = Z \times 4.5$ PeV
- The sum of the flux of all elements with their individual cut-offs makes up the all-particle spectrum.
- Not only does the spectrum become steeper due to such a cutoff but also heavier.



E_{max}(iron) = 26 · E_{max}(proton)

But

The latest results by ARGO-YBJ are deeply challenging the standard model of galactic CRs !



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Scaled flux $E^{2.5}$ J(E) ($m^{-2} s^{-1} sr^{-1} eV^{1.5}$)
Galactic Sources
ExtraGalactic Sources
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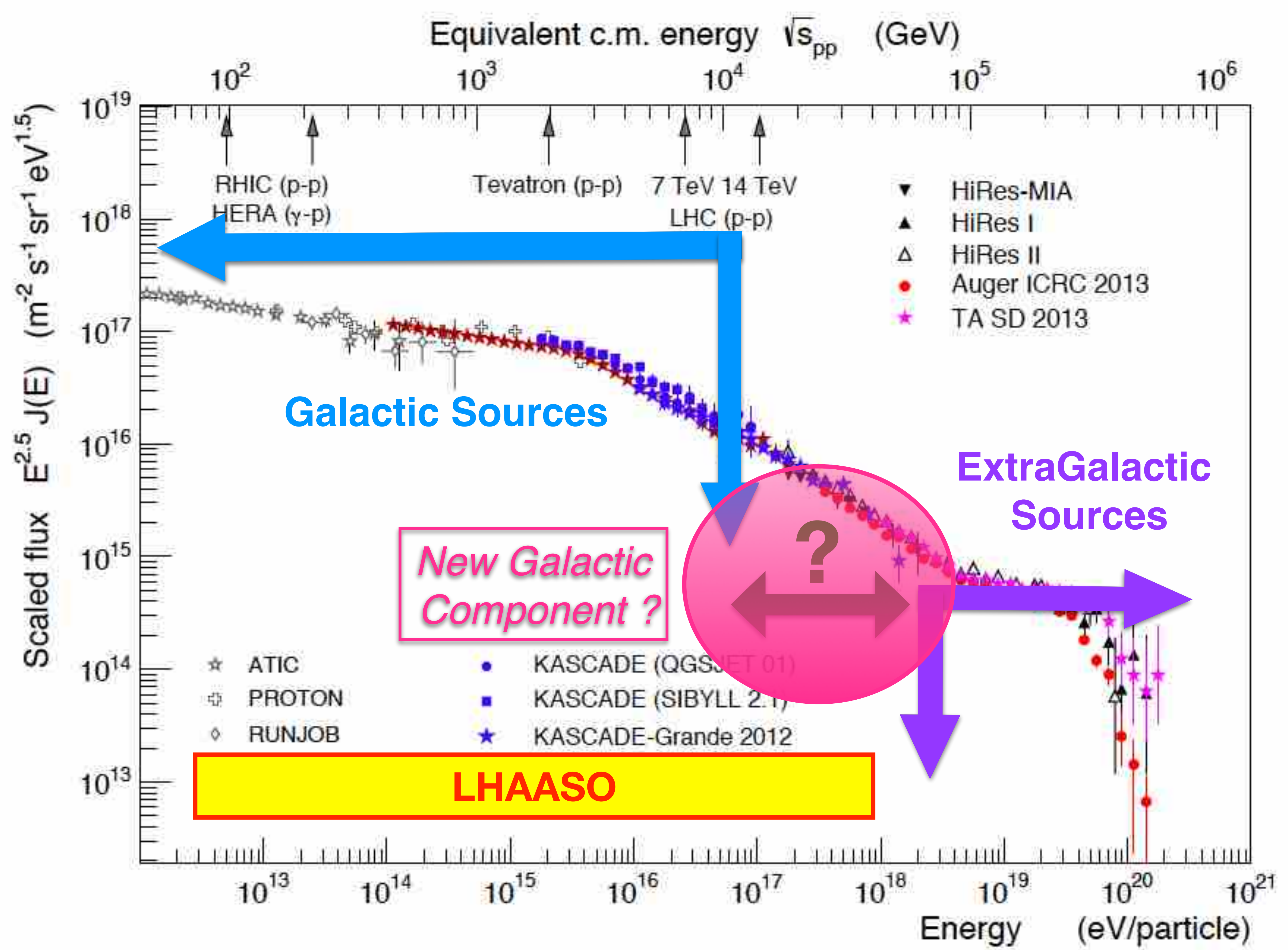
Energy (eV/particle)



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Scaled flux $E^{2.5}$ J(E) ($m^{-2} s^{-1} sr^{-1} eV^{1.5}$)
Galactic Sources
ExtraGalactic Sources
New Galactic Component ?
?
ATIC
PROTON
RUNJOB
KASCADE (QGSJET 01)
KASCADE (SIBYLL 2.1)
KASCADE-Grande 2012
LHAASO
Energy (eV/particle)

The ‘*Cosmic Ray connection*'

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

$\pi^{0} \rightarrow$ γ **Gamma-Ray Astronomy**

$\pi^{+}, \pi^{-} \rightarrow$ ν **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

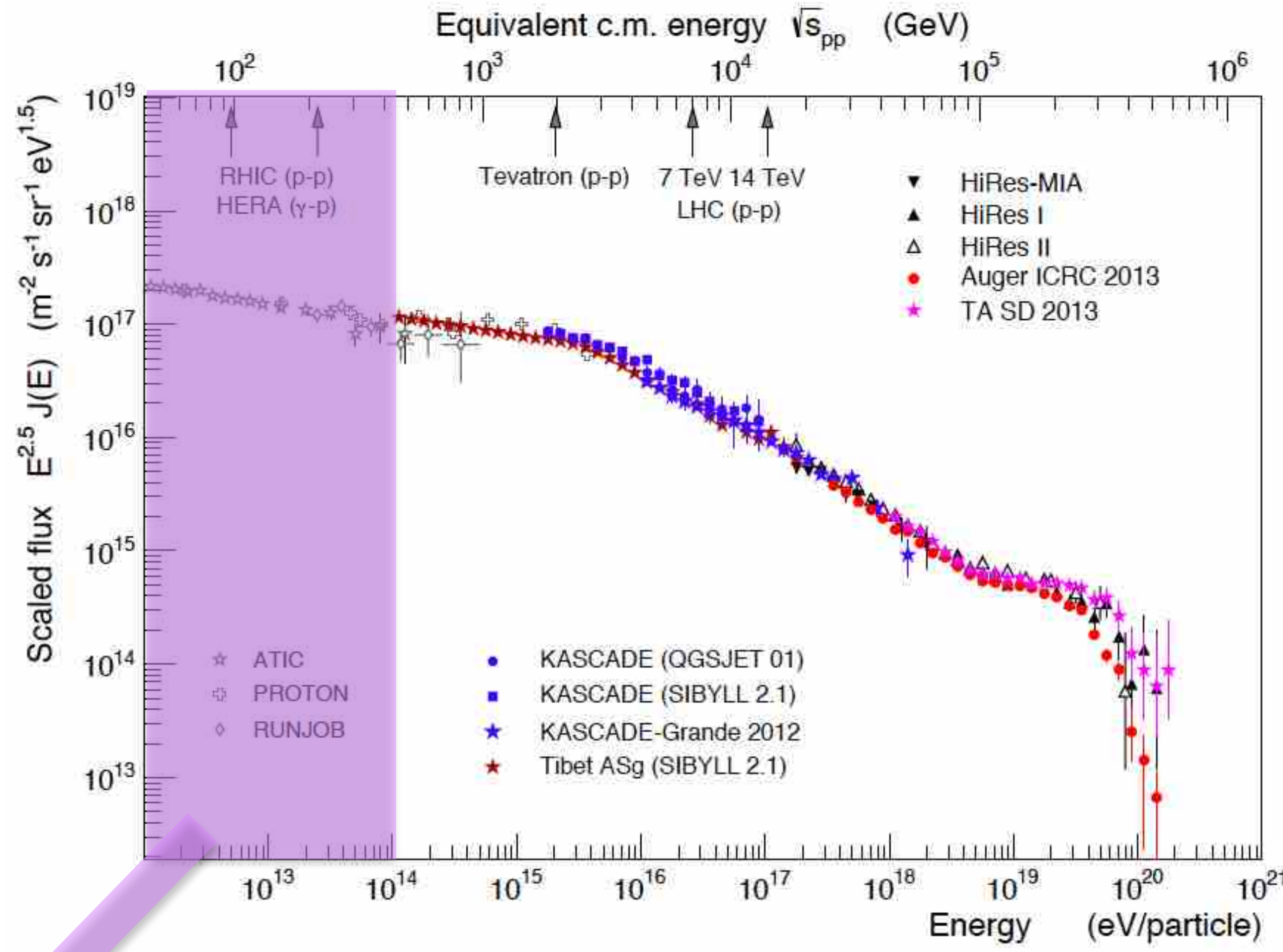
Gammas (and neutrinos) point back to their sources (SNR, PWN, BS, AGN ..)

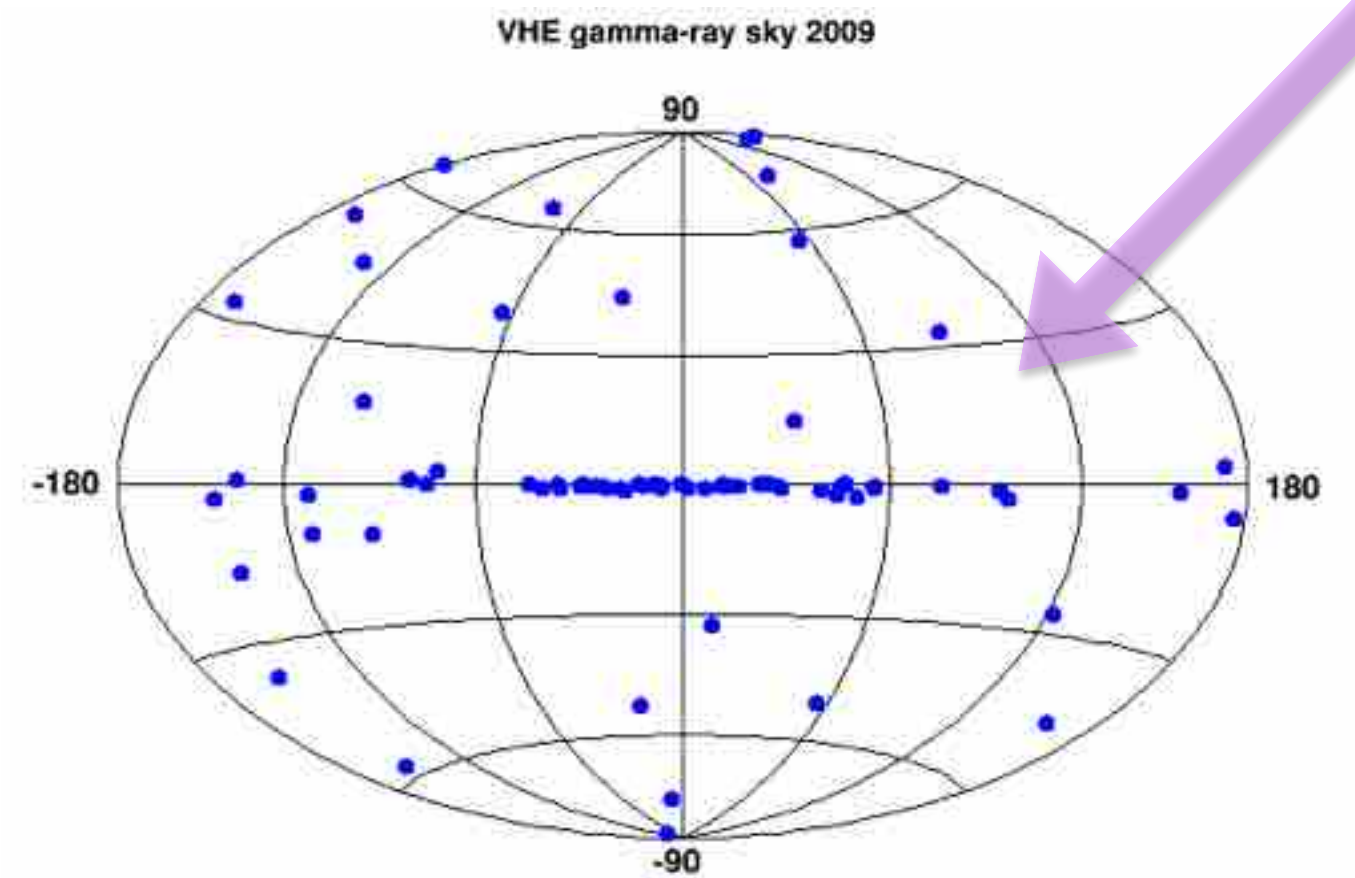
TeVatron Sky

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

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

TeV Cosmic Rays
Photons > 100 GeV !



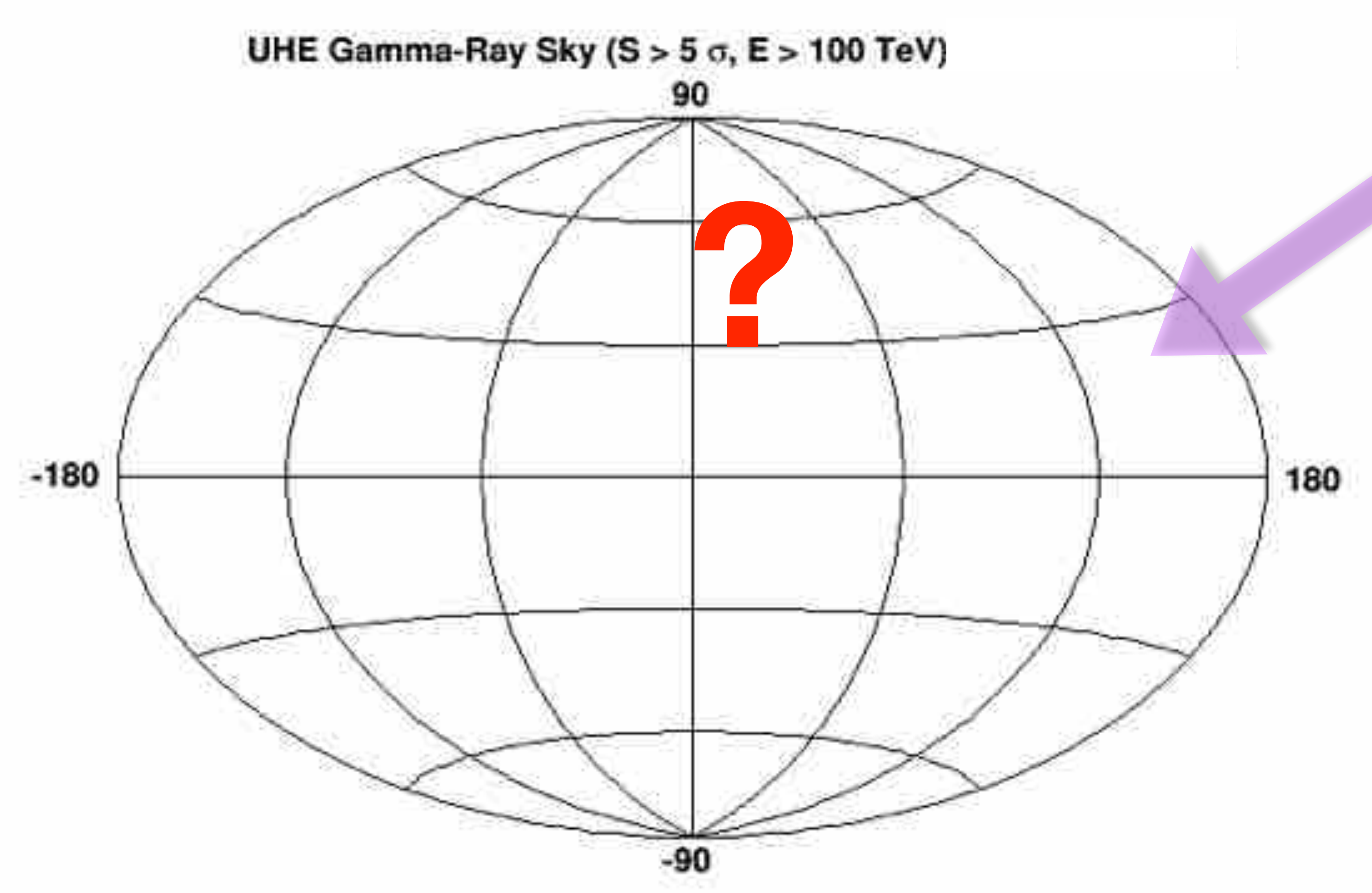


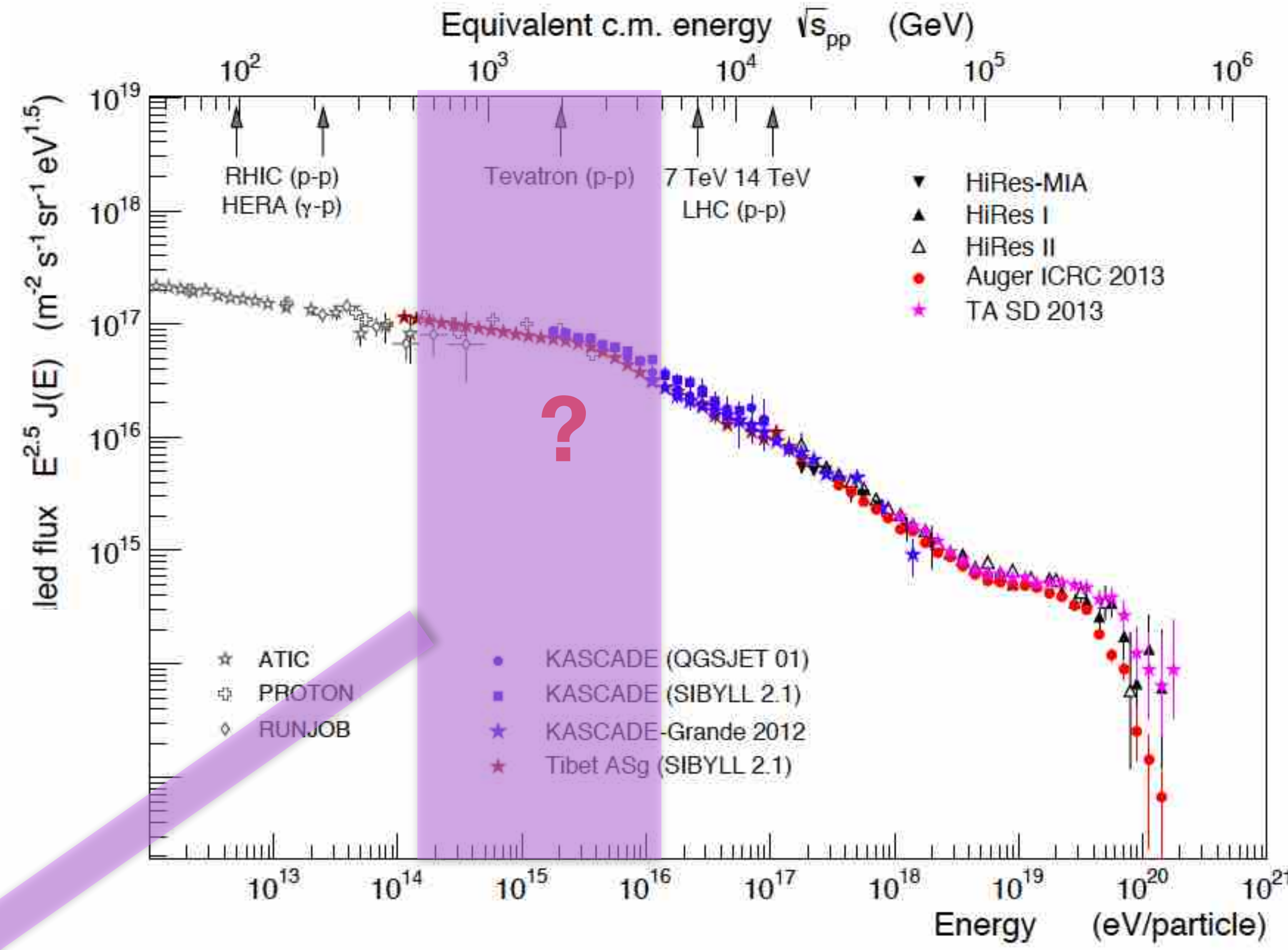
But smoking gun still missing…
leptonic ?
hadronic ?

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
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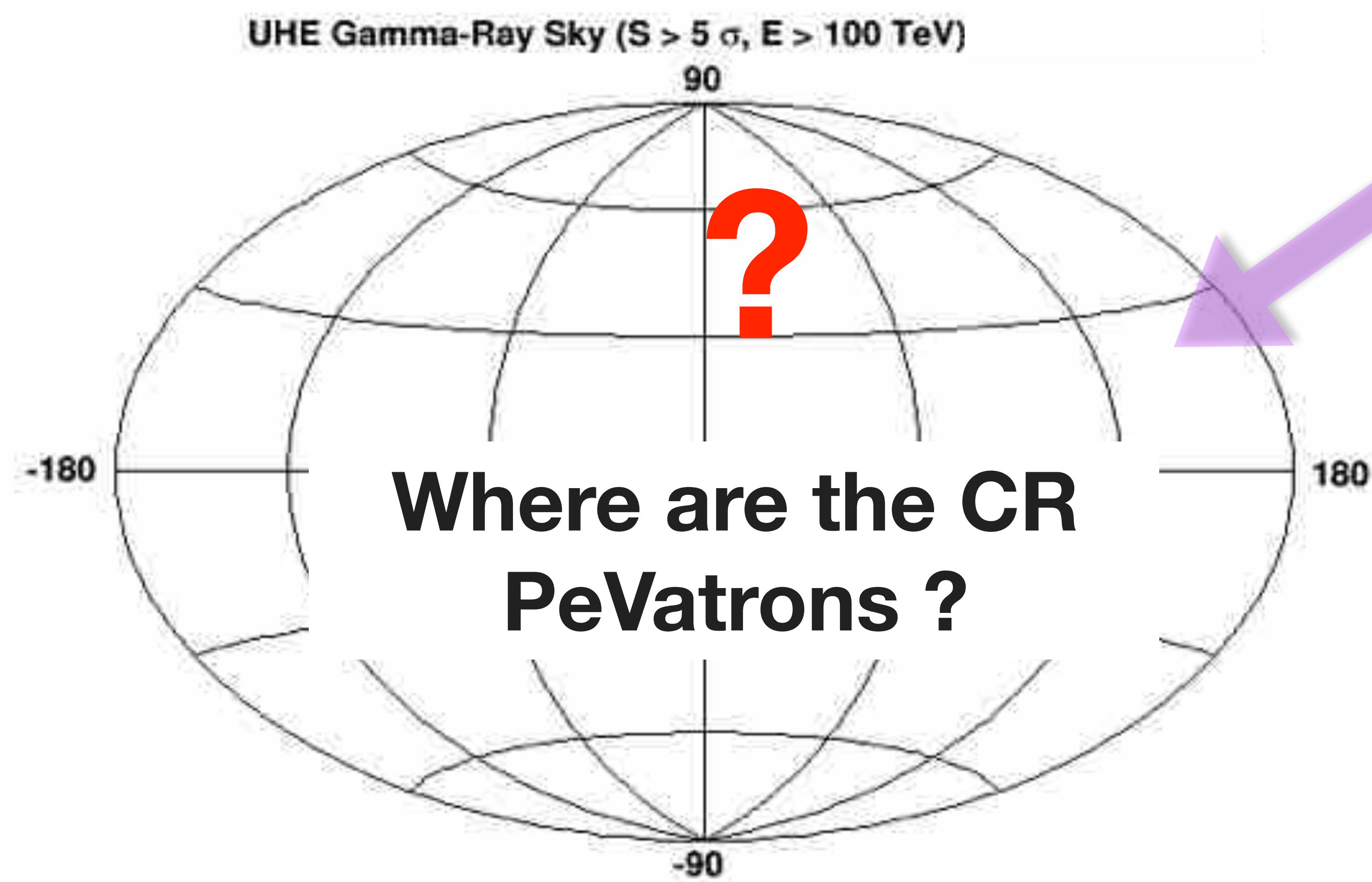
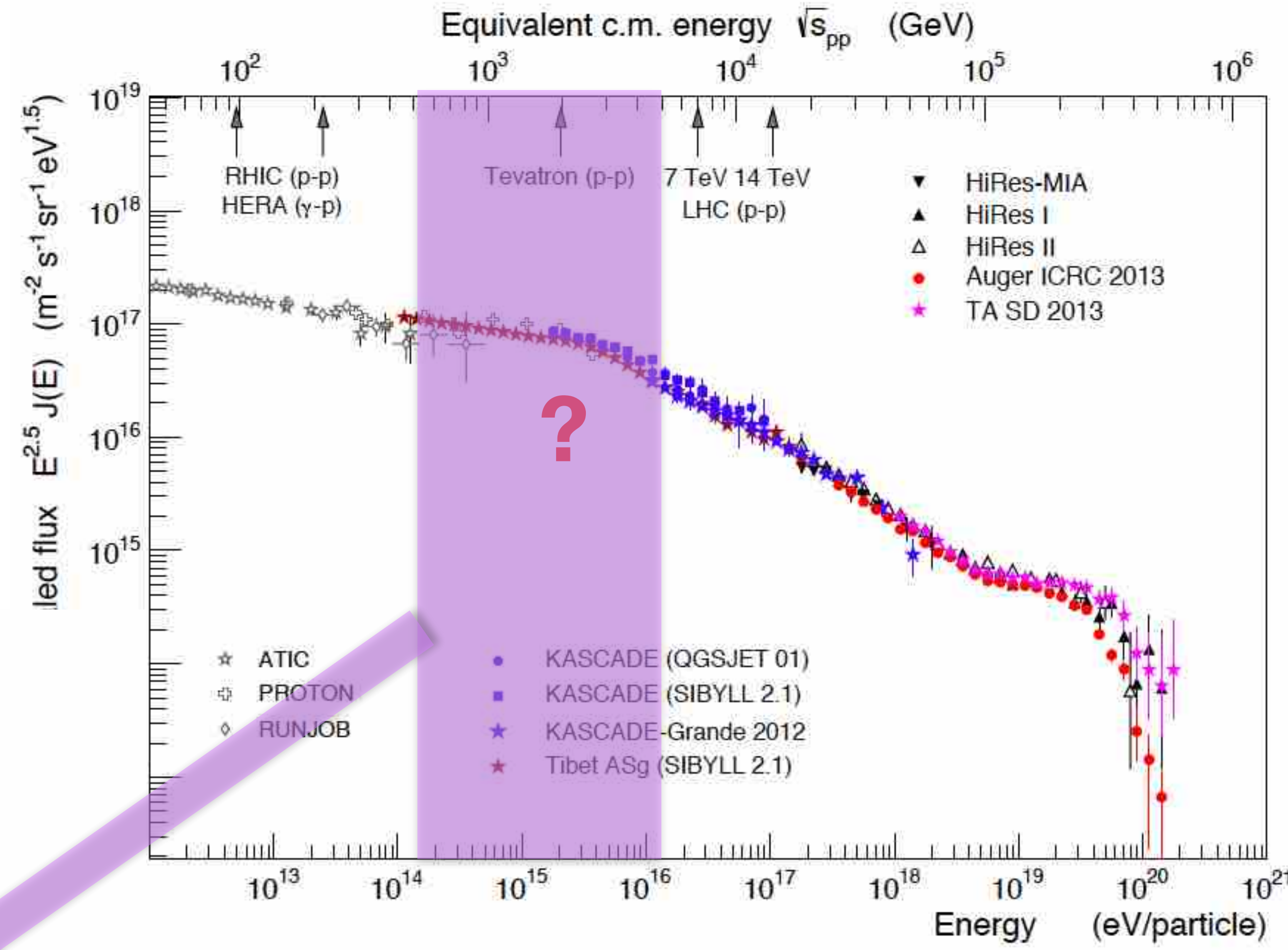


Where are the CR PeVatrons ?



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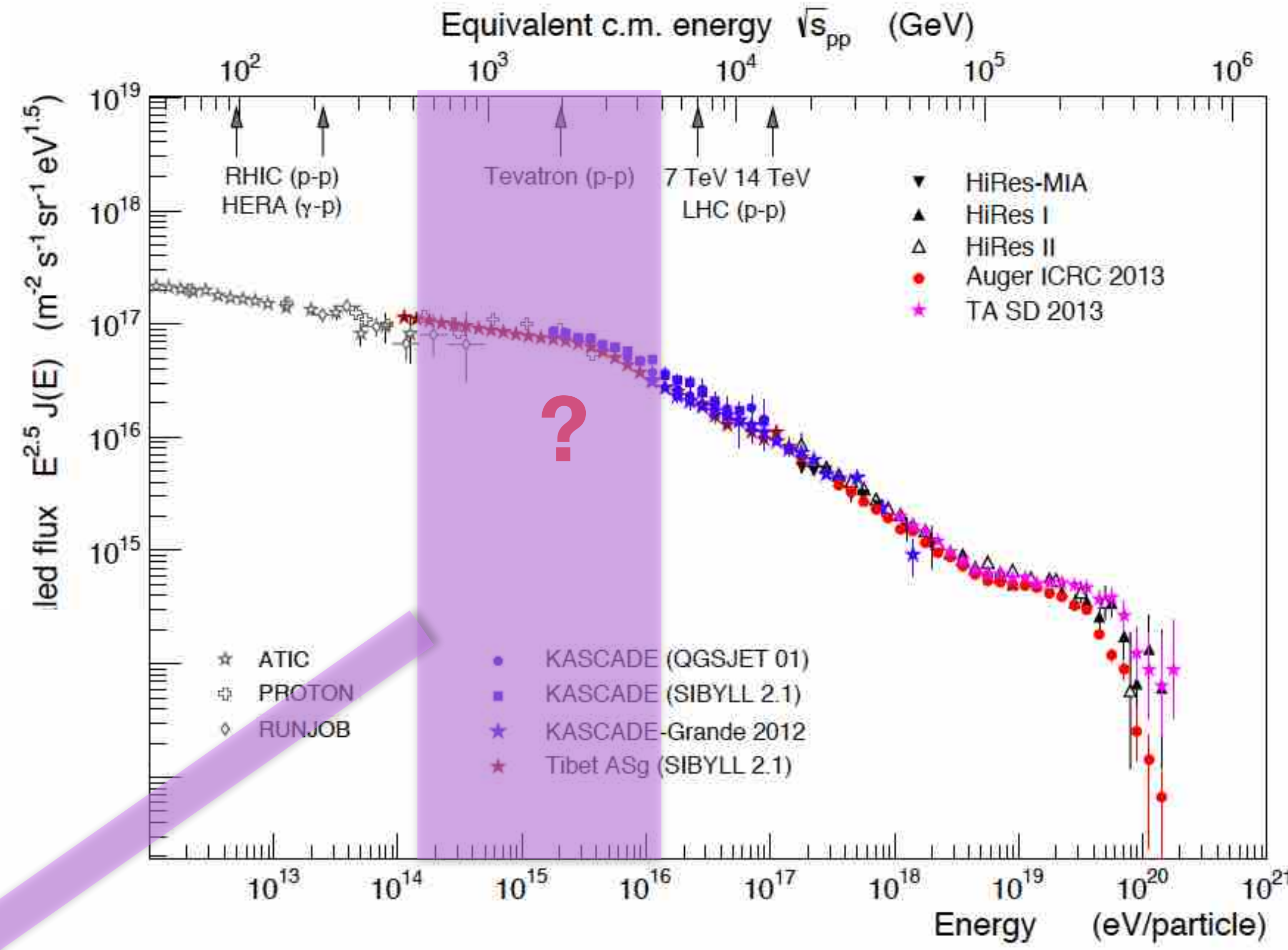
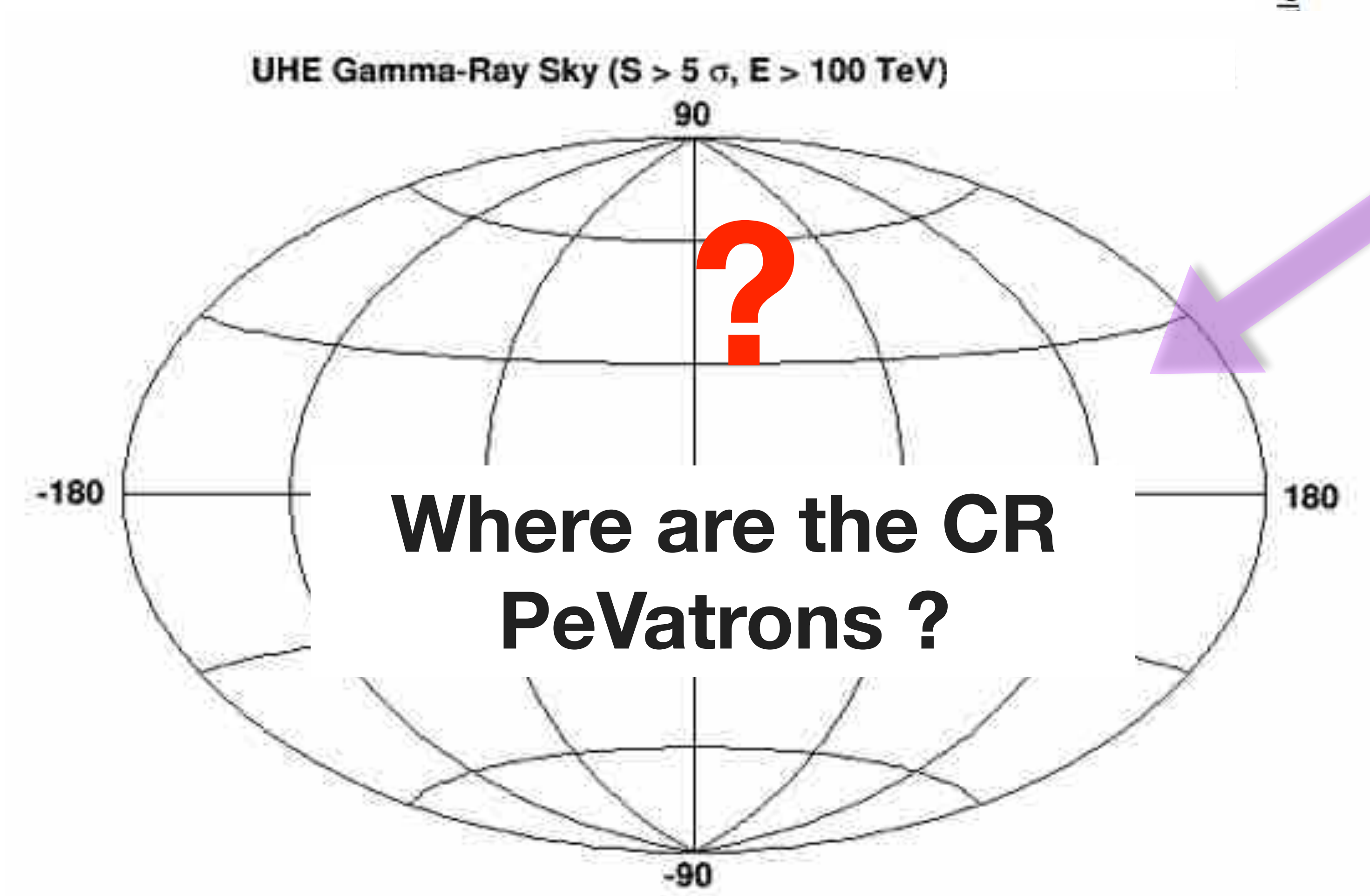




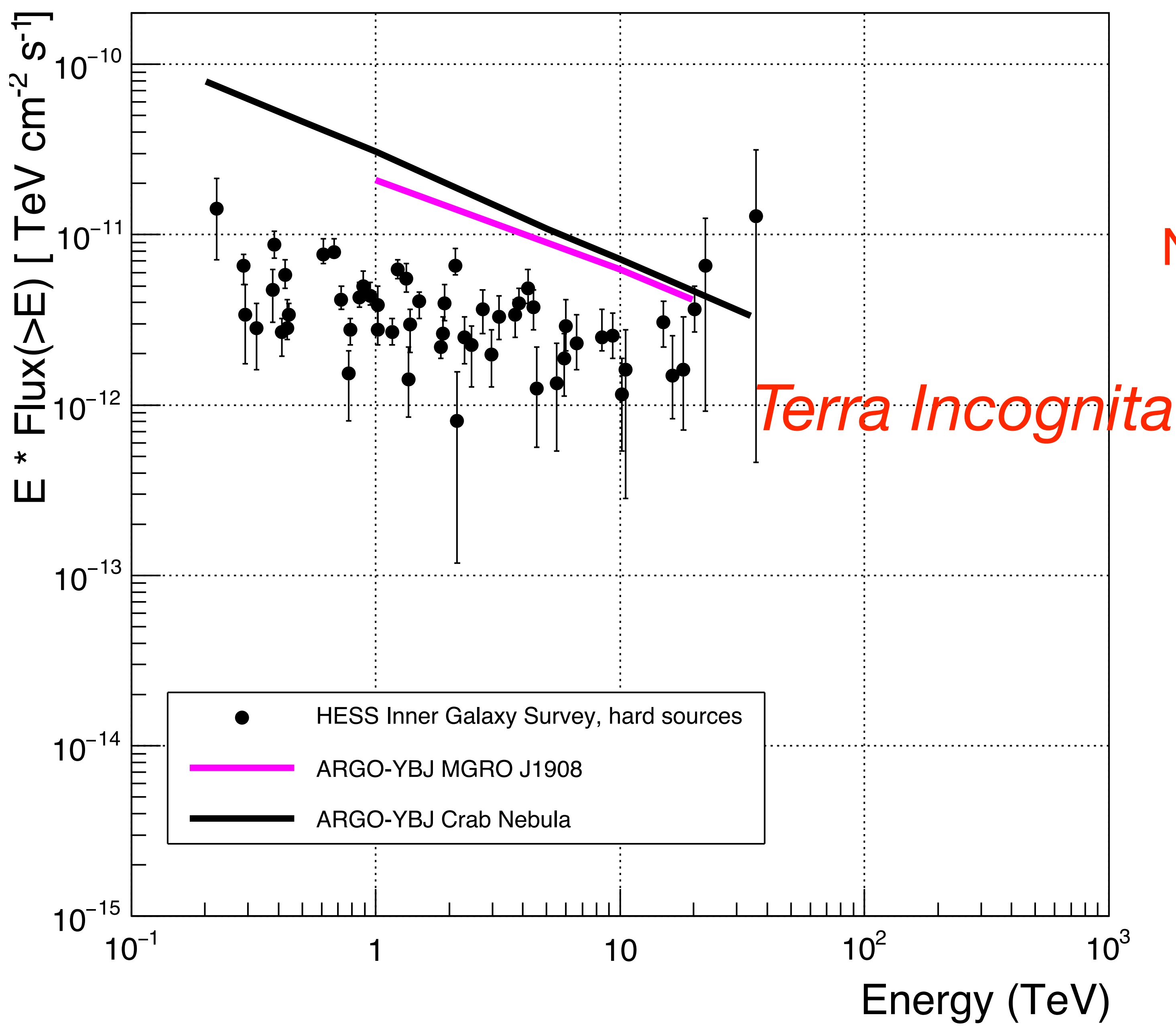
Where are the CR PeVatrons ?

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

Opening the PeVatron range



Data above 20 TeV are very scarce

No photons detected above 100 TeV !

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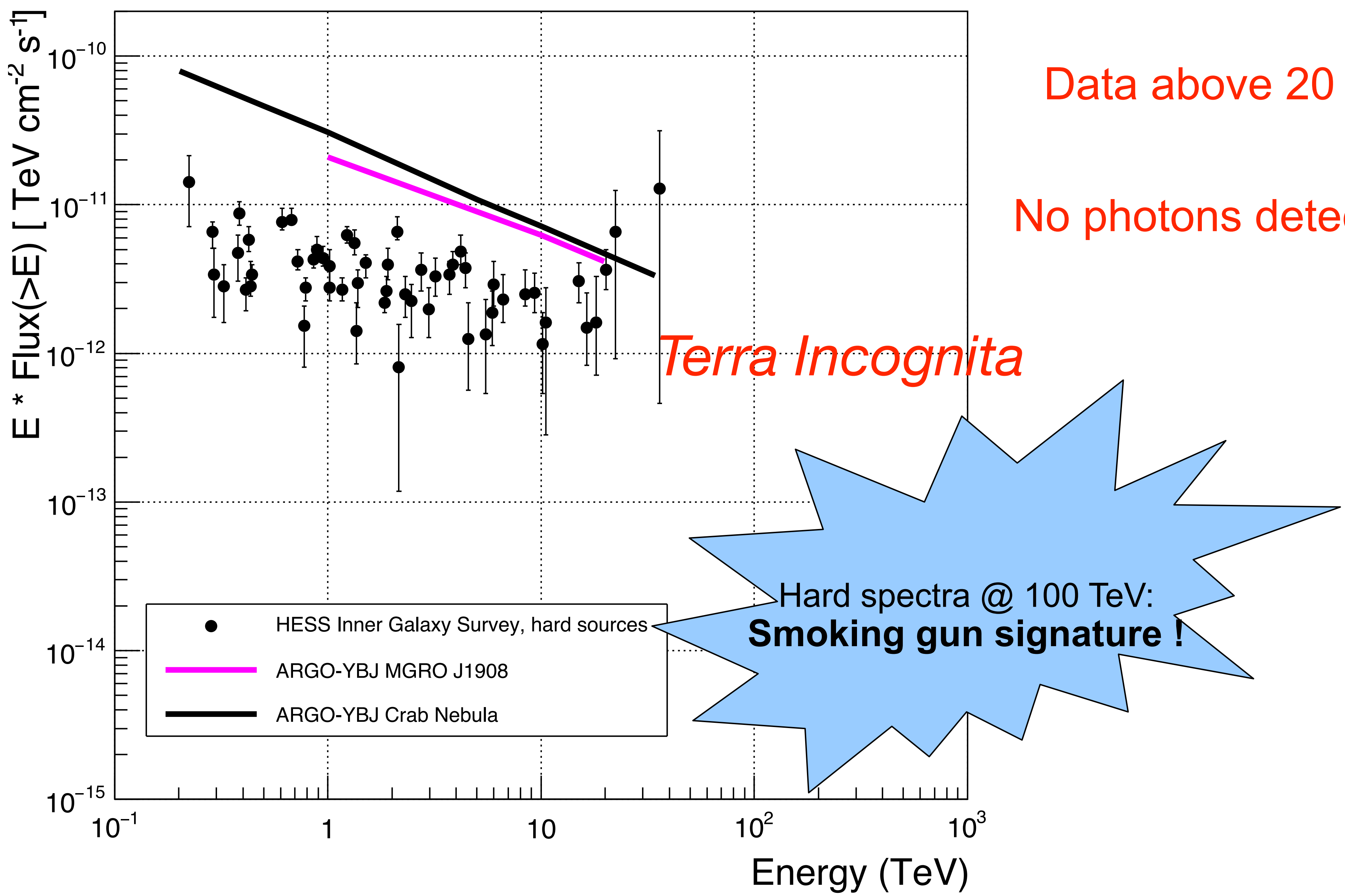

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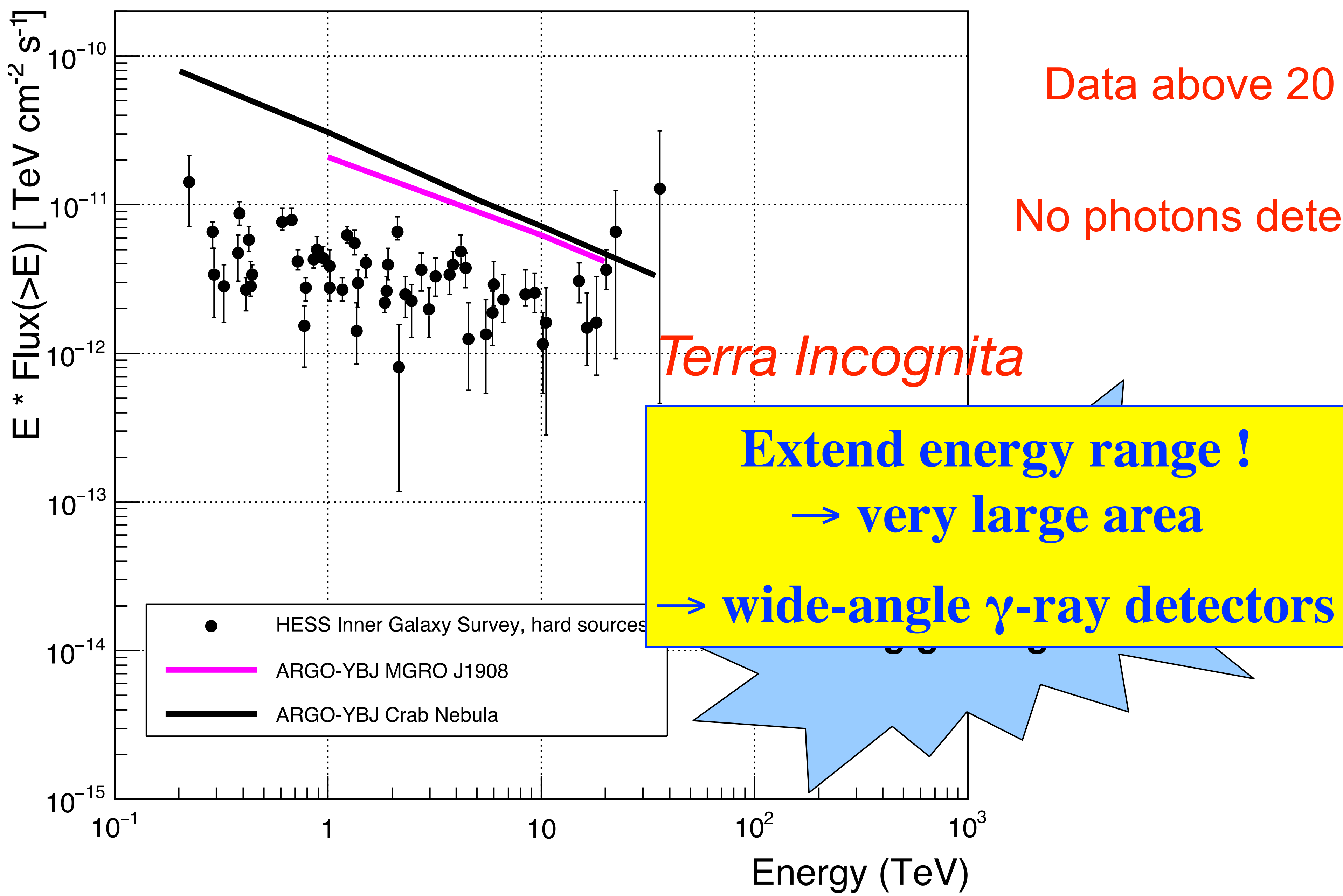

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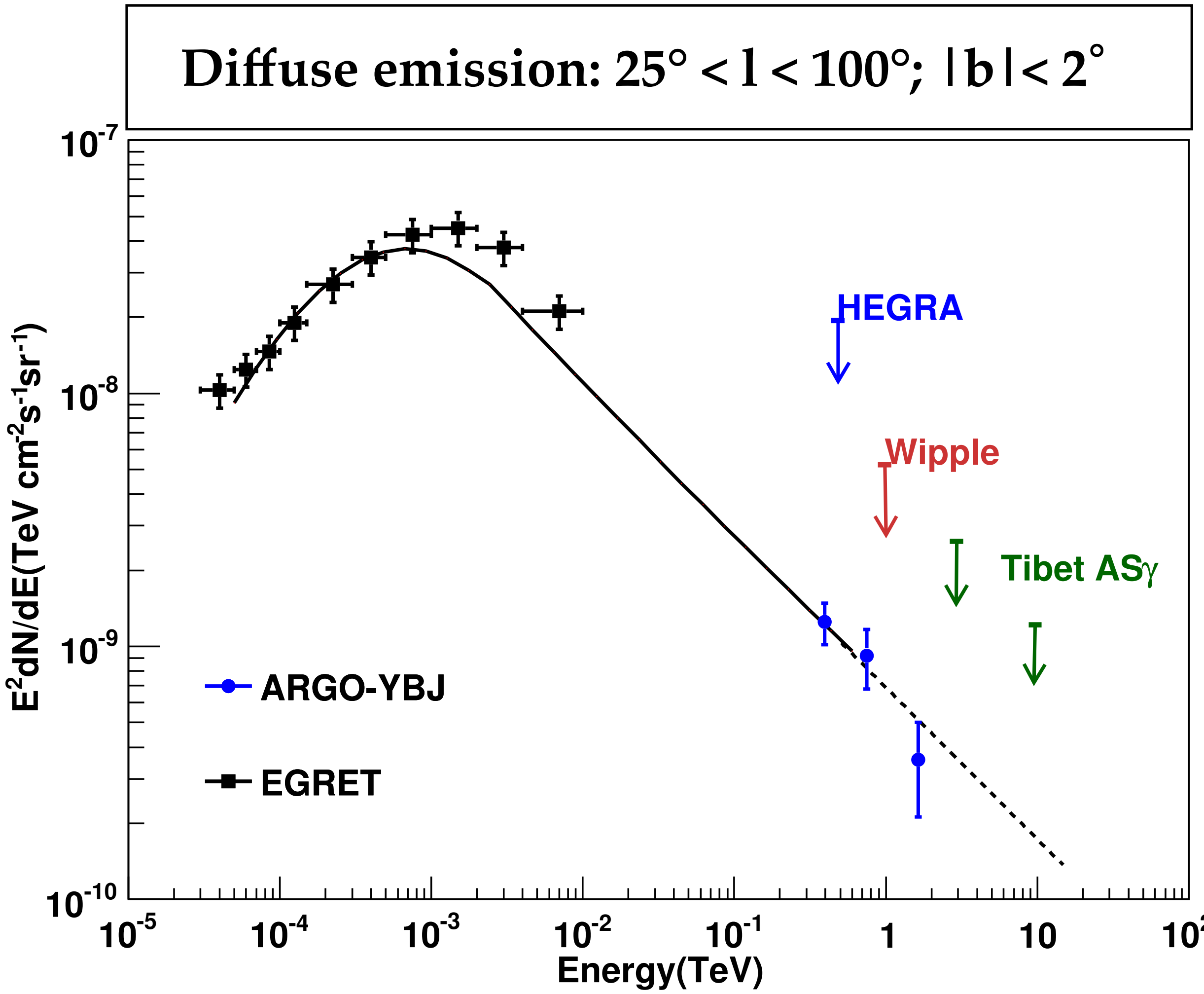
The strong case for all sky survey instruments

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



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- 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

The LHAASO experiment

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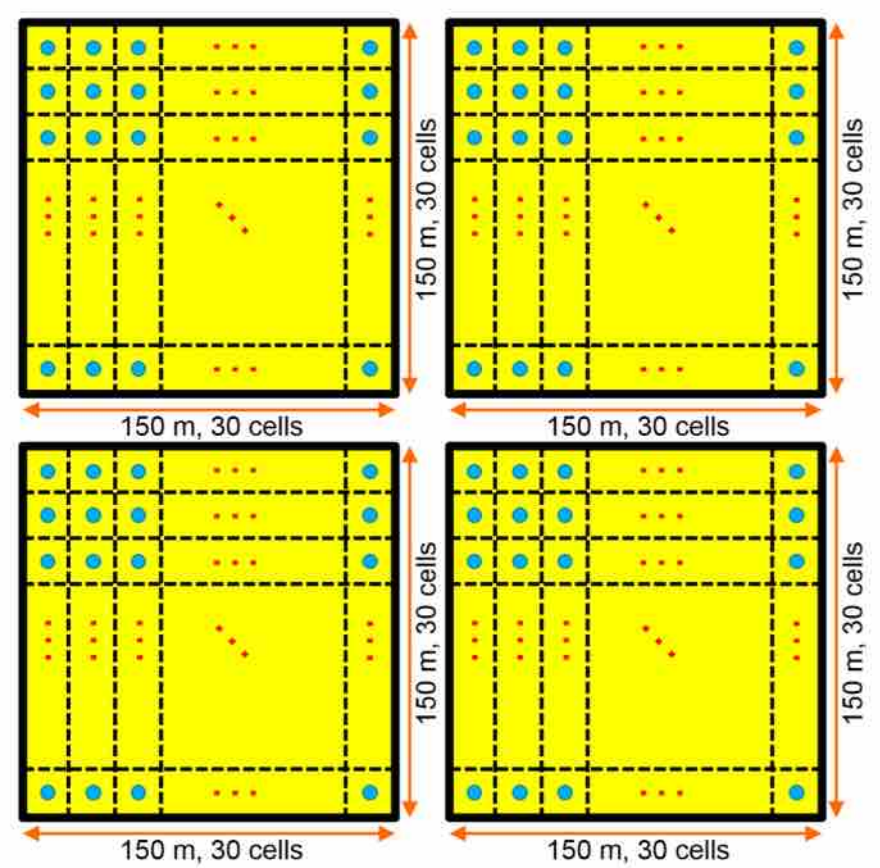
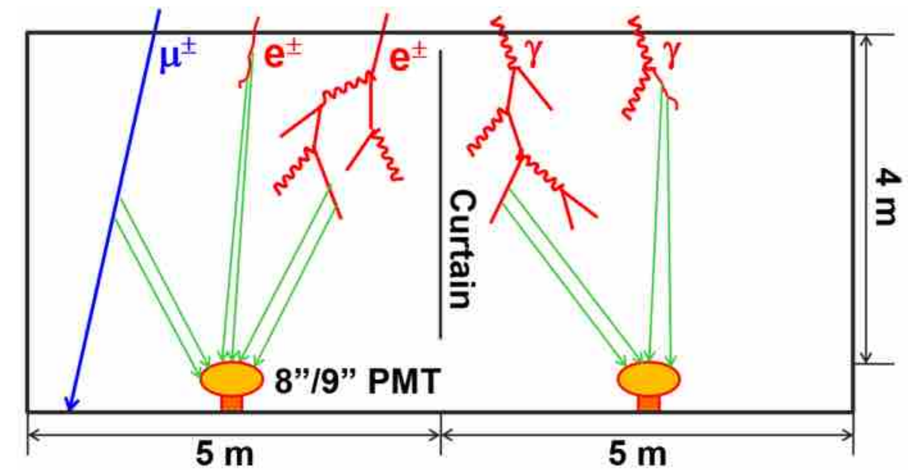
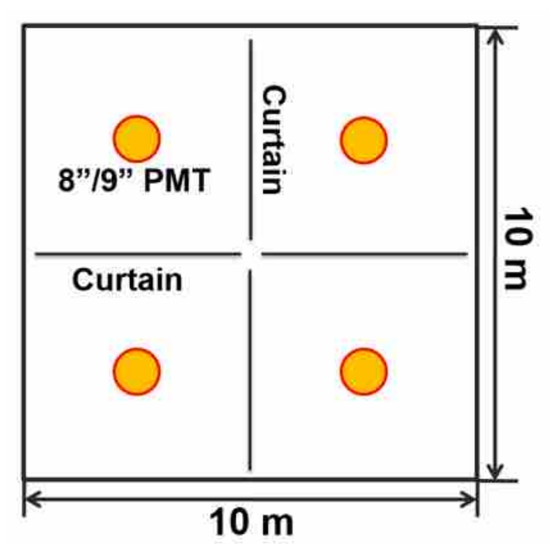
Water Cherenkov Detector Array

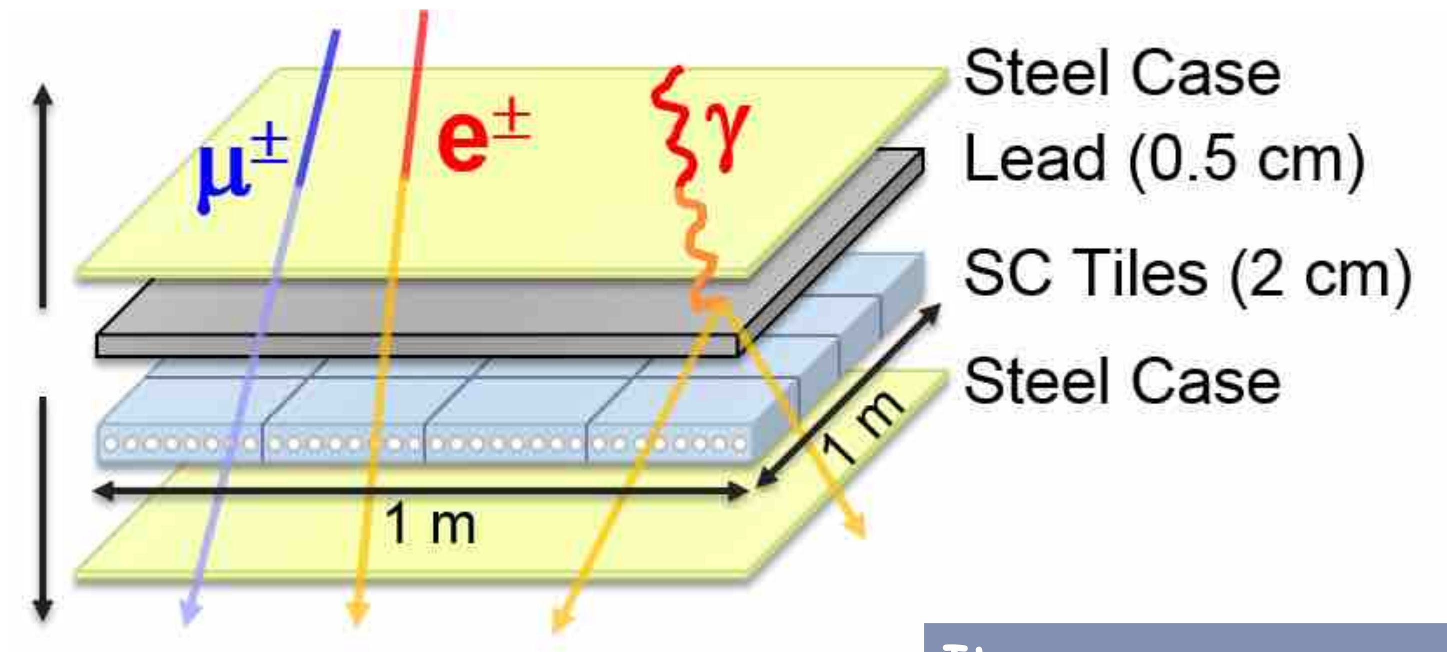


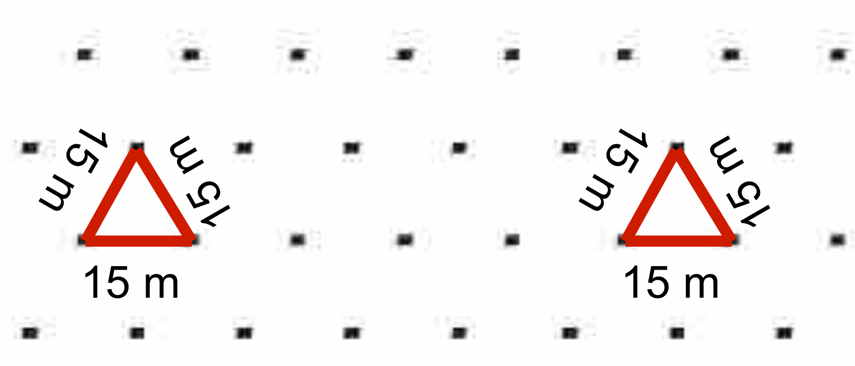




Item	Value
Cell area	25 m^2
Effective water depth	4 m
Water transparency	> 15 m (400 nm)
Precision of time measurement	0.5 ns
Dynamic range	1-4000 PEs
Time resolution	<2 ns
Charge resolution	40% @ 1 PE 5% @ 4000 PEs
Accuracy of charge calibration	<2%
Accuracy of time calibration	<0.2 ns
Total area	90,000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

Electromagnetic particle Detector

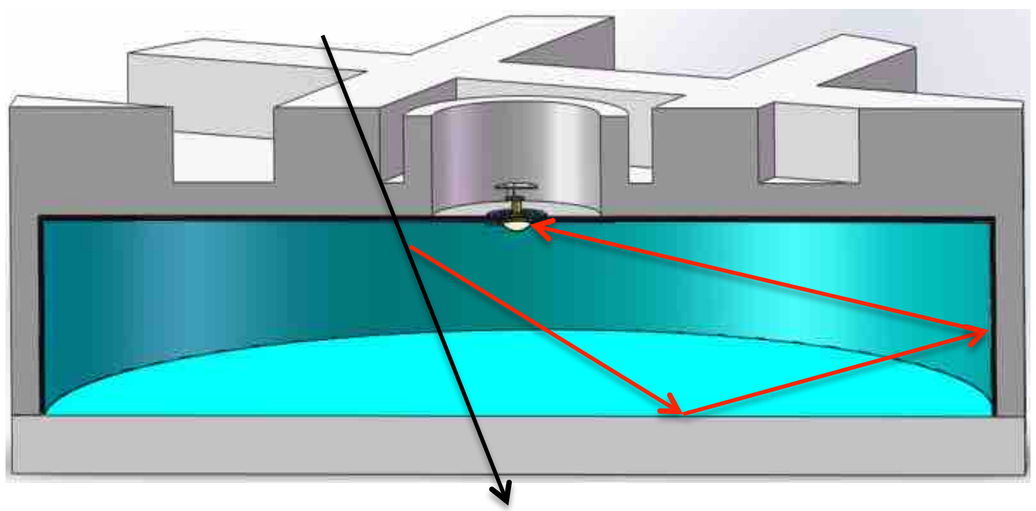


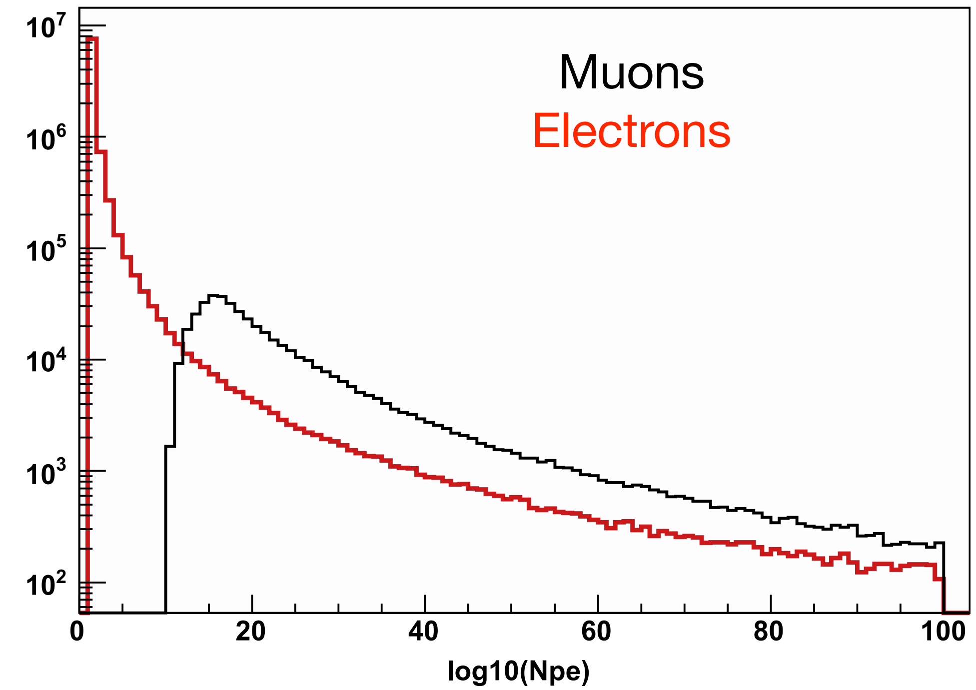


Item	Value
Effective area	1 m^2
Thickness of tiles	2 cm
Number of WLS fibers	8/tile×16 tile
Detection efficiency (> 5 MeV)	>95%
Dynamic range	1-10,000 particles
Time resolution	<2 ns
Particle counting resolution	25% @ 1 particle 5% @ 10,000 particles
Aging	>10 years
Spacing	15 m
Total number of detectors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

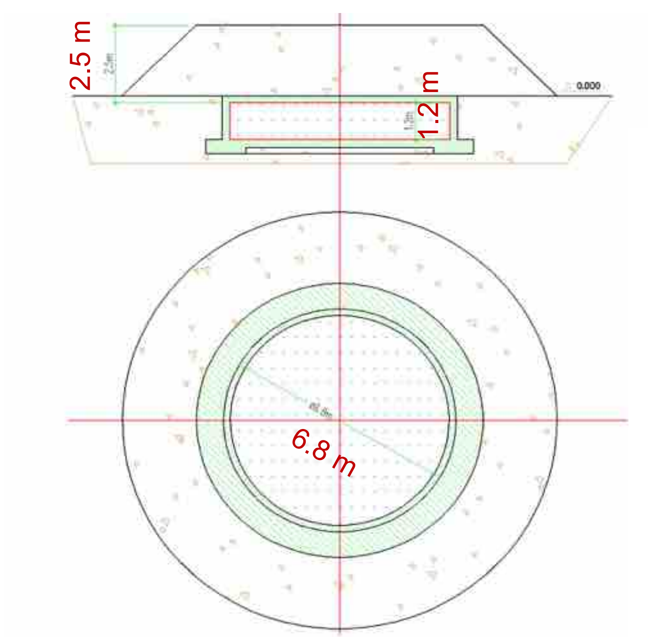
Muon Detector

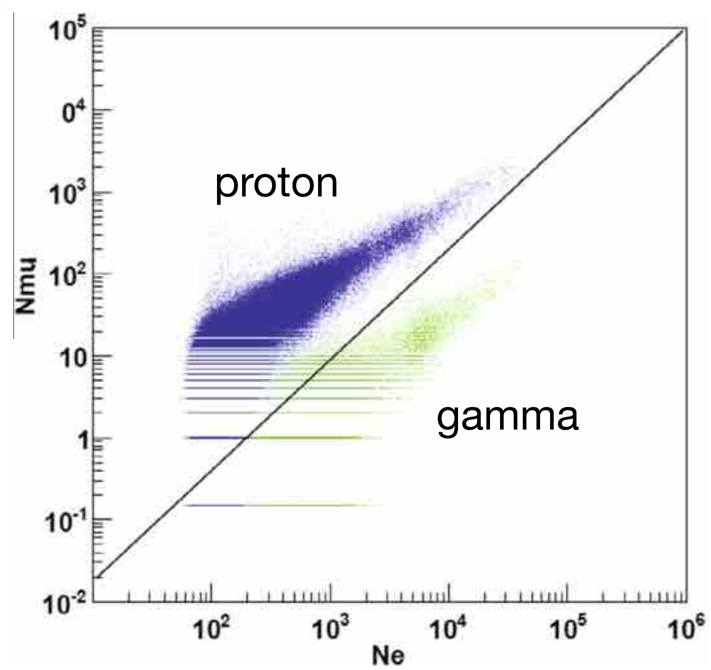
PMT: 8” or 9”





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





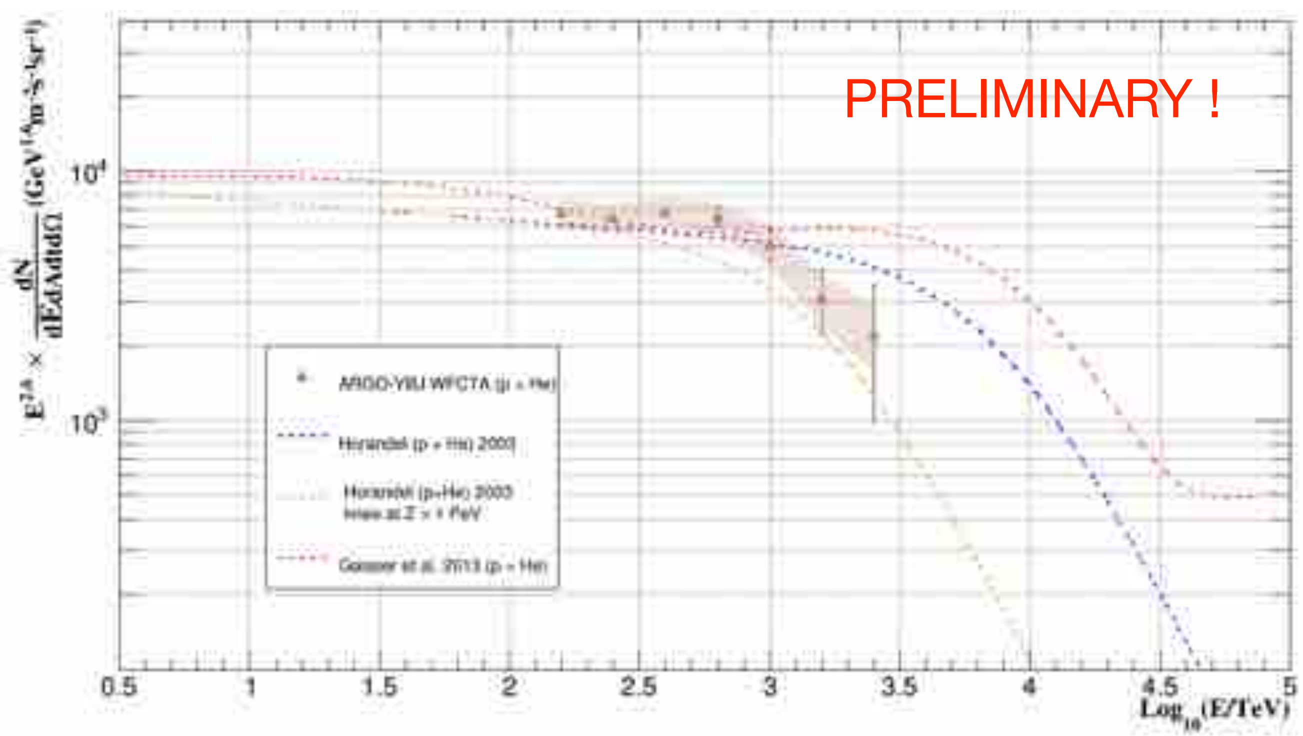
Item	Value
Area	36 m^2
Depth	1.2 m
Molasses overburden	2.5 m
Water transparency (att. len.)	> 30 m (400 nm)
Reflection coefficient	>95%
Time resolution	<10 ns
Particle counting resolution	25% @ 1 particle 5% @ 10,000 particles
Aging	>10 years
Spacing	30 m
Total number of detectors	1221

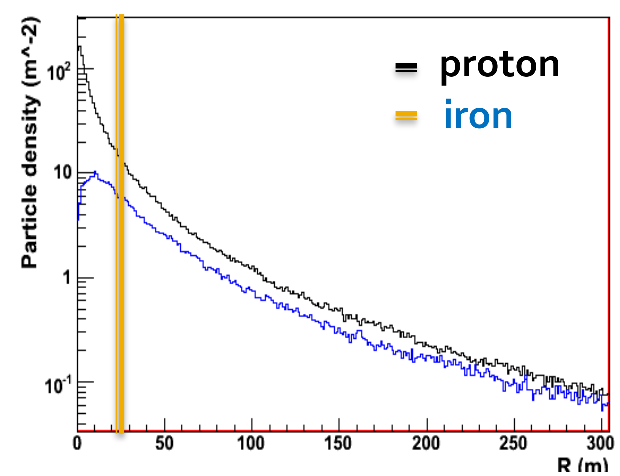
Wide field of view Cherenkov Telescope Array

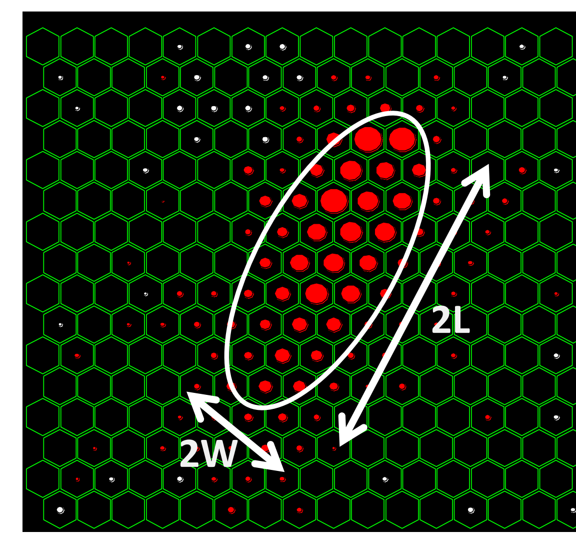
24 telescopes (Cherenkov/Fluorescence)

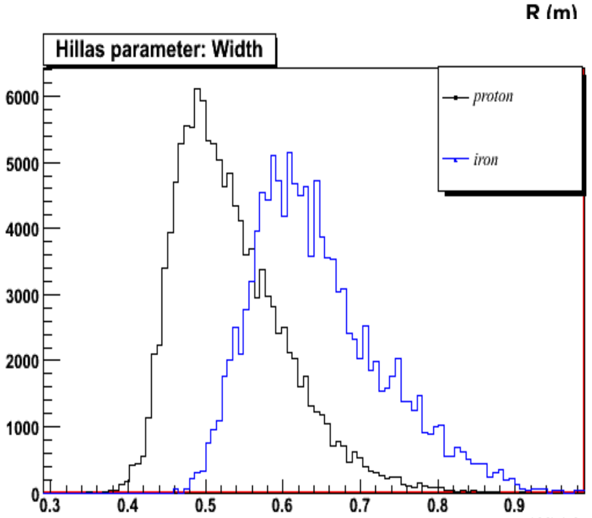
- 5 m^2 spherical mirror
- 16 × 16 PMT array
- pixel size 1°
- FOV: 14° × 14°
- Elevation angle: 60°

ARGO-YBJ / WFCTA





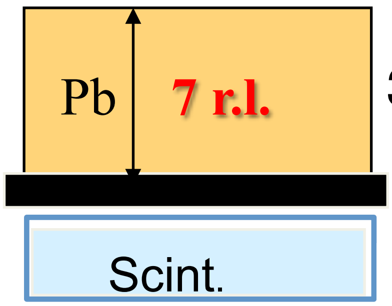




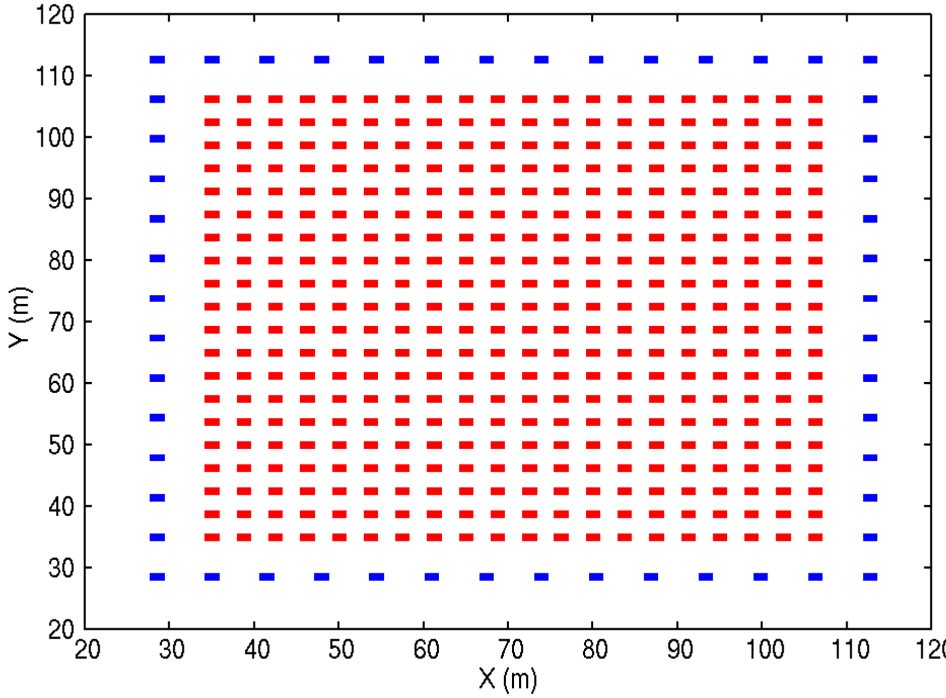
Shower Core Detector Array

- 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



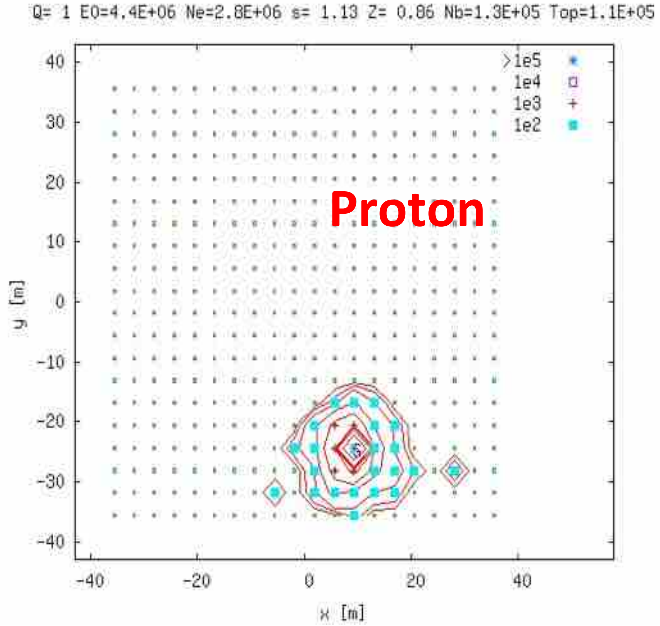
The burst detectors observe the electron size (burst size) under the lead plate induced by high energy e.m. particle in the shower core region

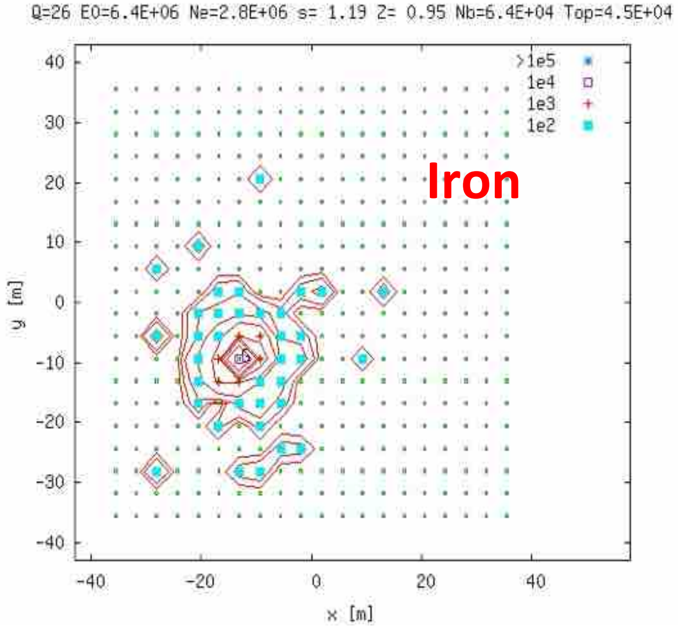


- Number of SCD: 0.5 m^2 x 452
- Cover Area: 5170 m^2
- Energy region: 30 TeV - 10 PeV
- Core position resolution: 1.5 m @50 TeV

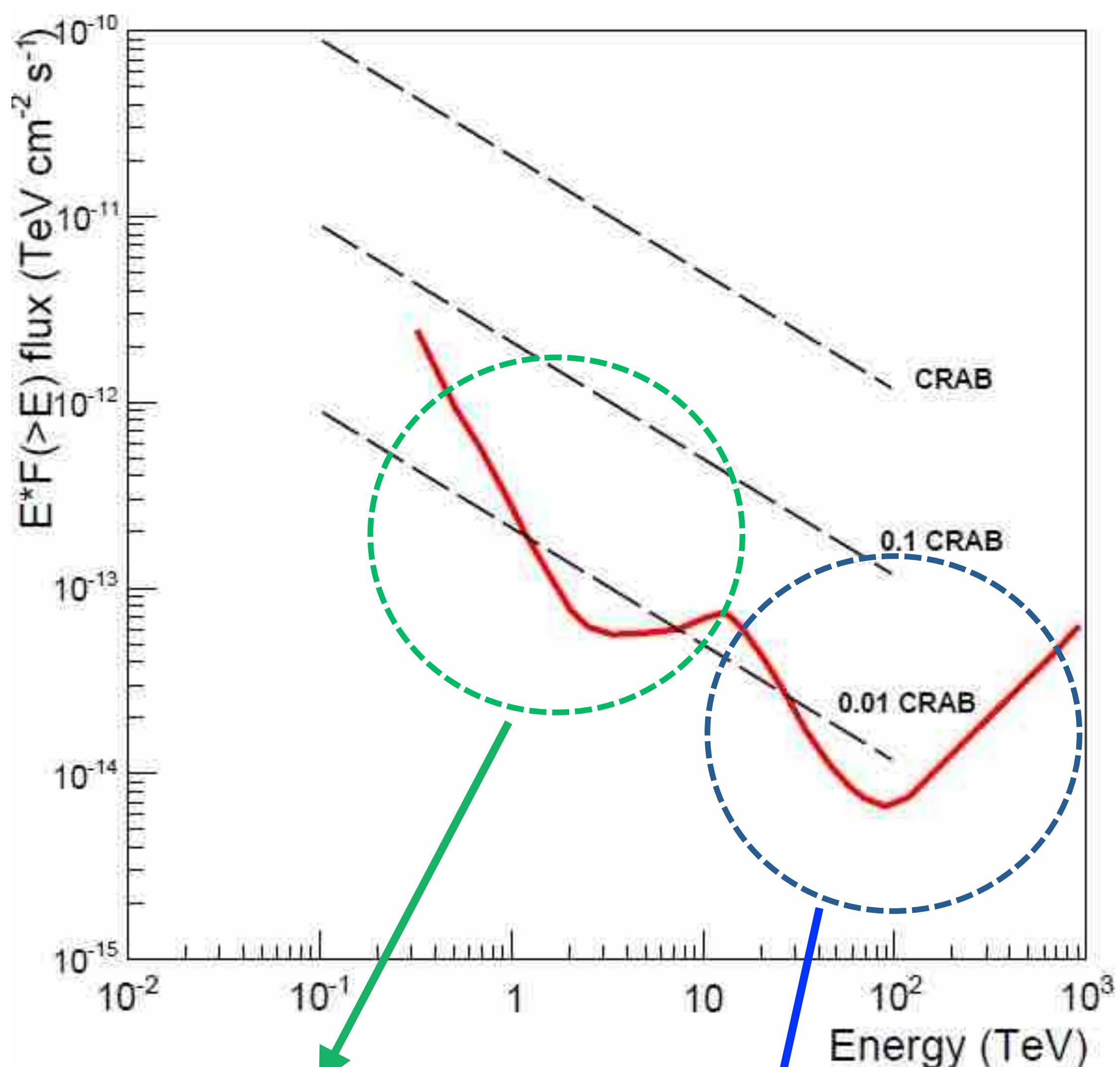
Each burst detector is constituted by 20 optically separated scintillator strips of 1.5 cm × 4 cm × 50 cm read out by two PMTs operated with different gains to achieve a wide dynamic range (1- 10^6 MIPs).

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





LHAASO integral sensitivity for Crab-like sources



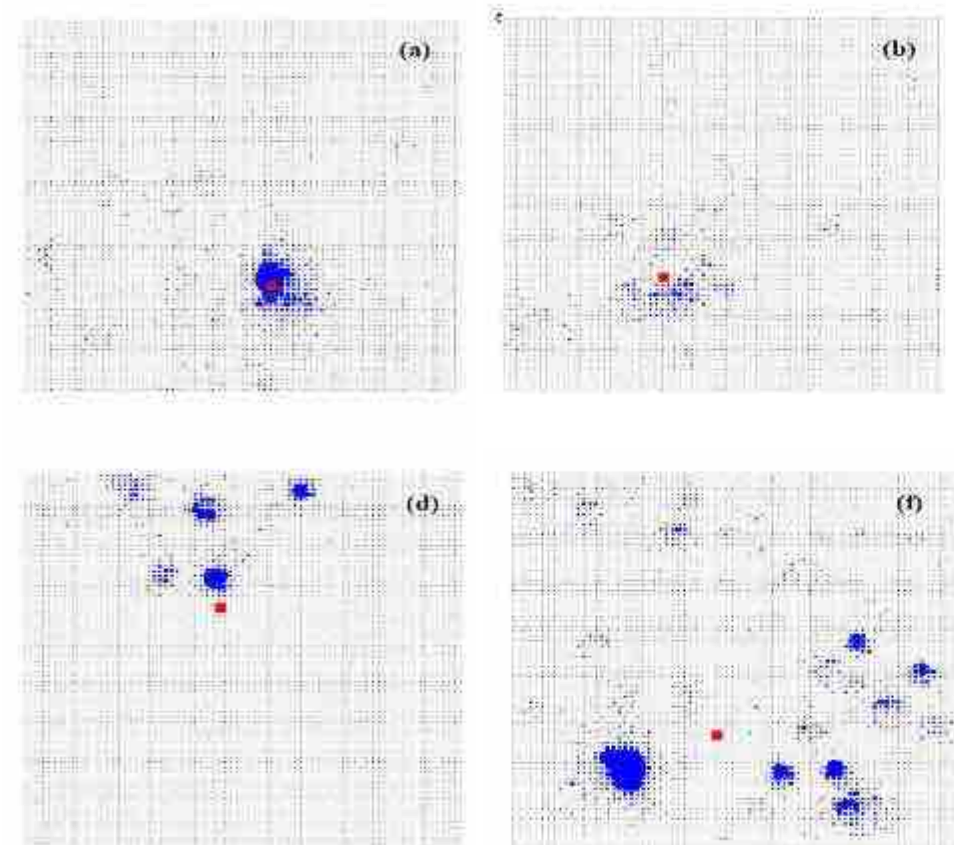
WCDA

1 KM2A (EDs + MDs)

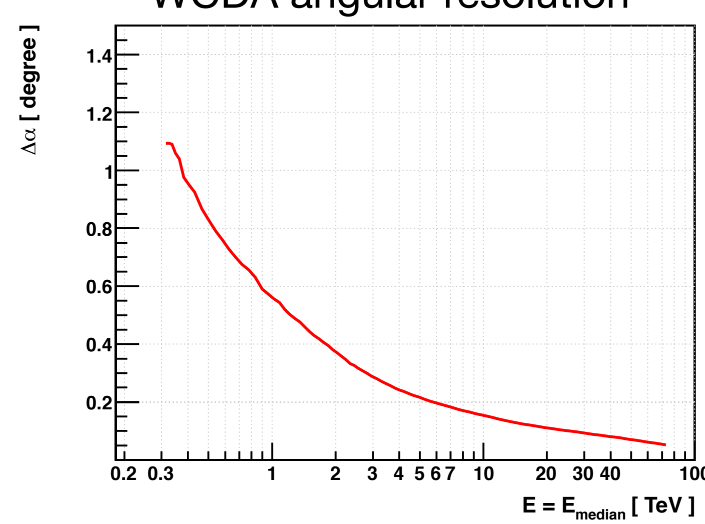
WCDA discrimination

gamma

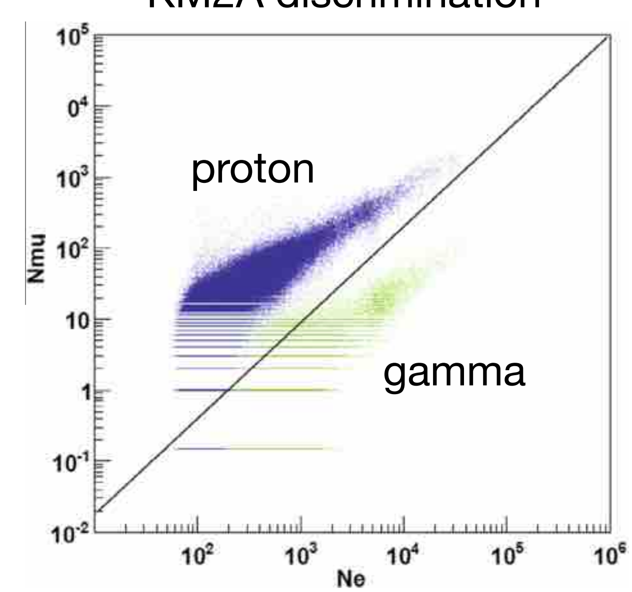
proton



WCDA angular resolution



KM2A discrimination



LHAASO Physics Potential

From TeVCat:

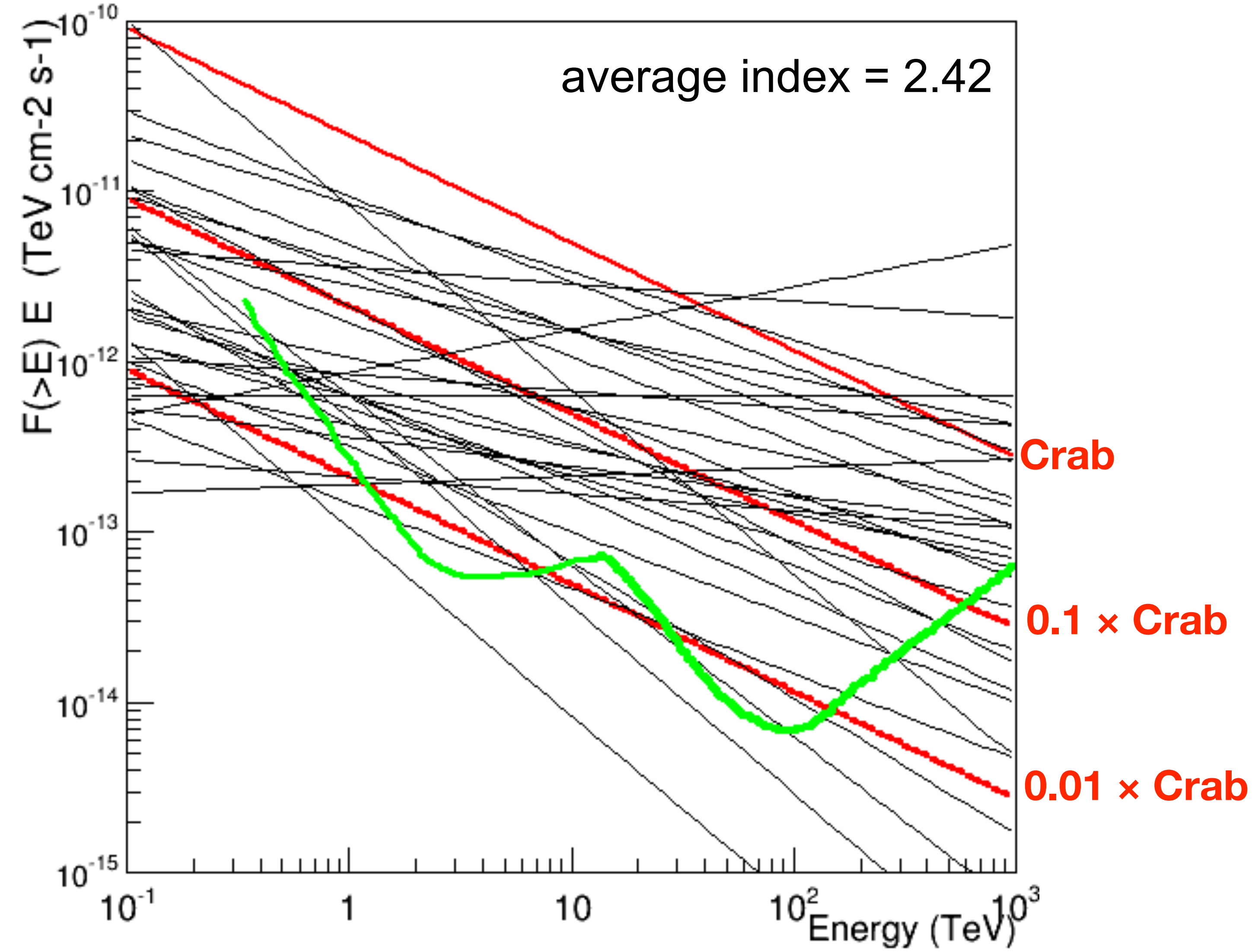
71 sources culminating at zenith angle < 40°

LHAASO latitude = *30° N*
-10° < decl < 70°

- 40 extragalactic
- 31 galactic

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

Extrapolation of TeV spectra assuming no cutoff



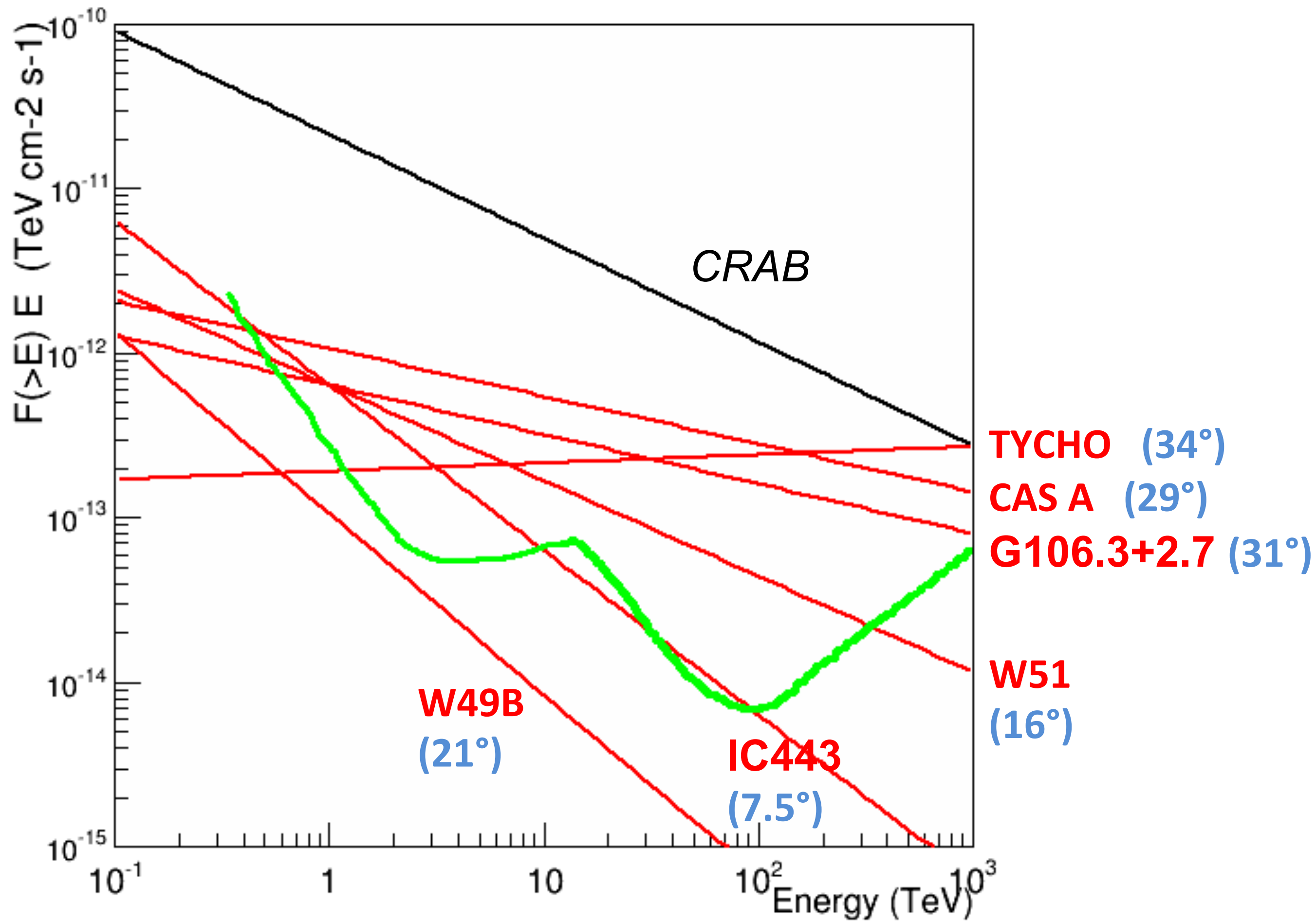
70% of Galactic sources are extended

Probably the fluxes are higher then what measured by IACT

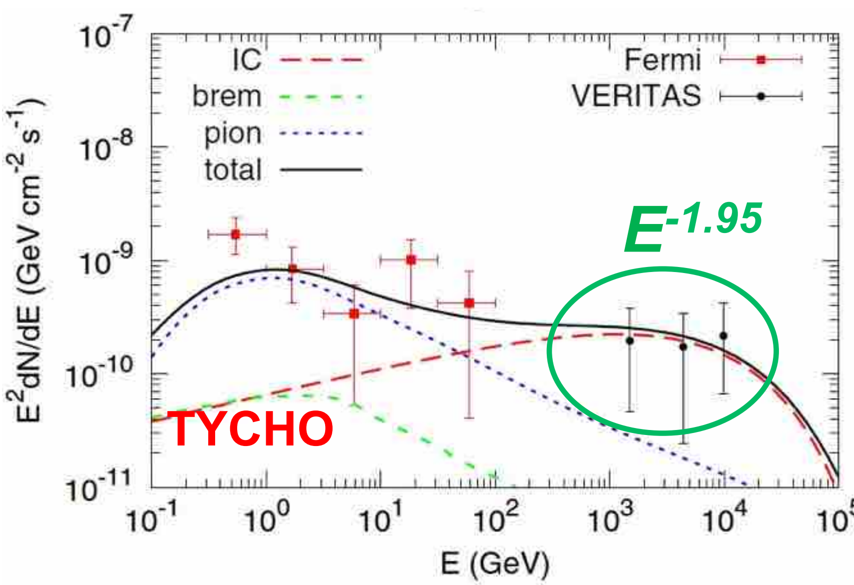
The real sensitivity depends on spectral slope, culmination angle and angular extension of the source

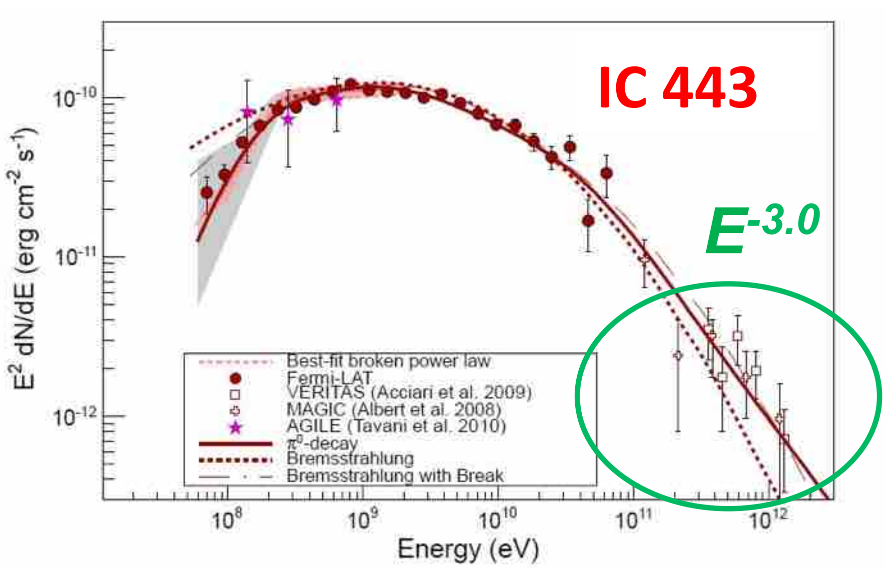
6 Shell SuperNova Remnants

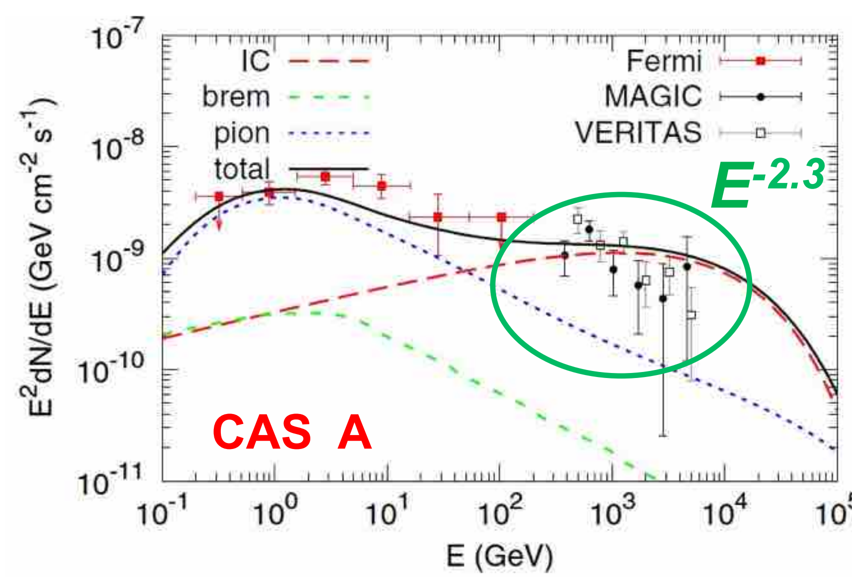
Source	Zenith angle culm.	F > 1 TeV (c.u.)	Energy range	Spectral index	Angular Extension (σ)
Thyco	34°	0.009	1-10	1.95	
G106.3+2.7	31°	0.03	1-20	2.29	0.3° x 0.2°
Cas A	29°	0.05	0.5-10	2.3	
W51	16°	0.03	0.1-5	2.58	0.12°
IC443	7.5°	0.03	0.1-2	3.0	0.16°
W49B	21°	0.005	0.3-10	3.1	



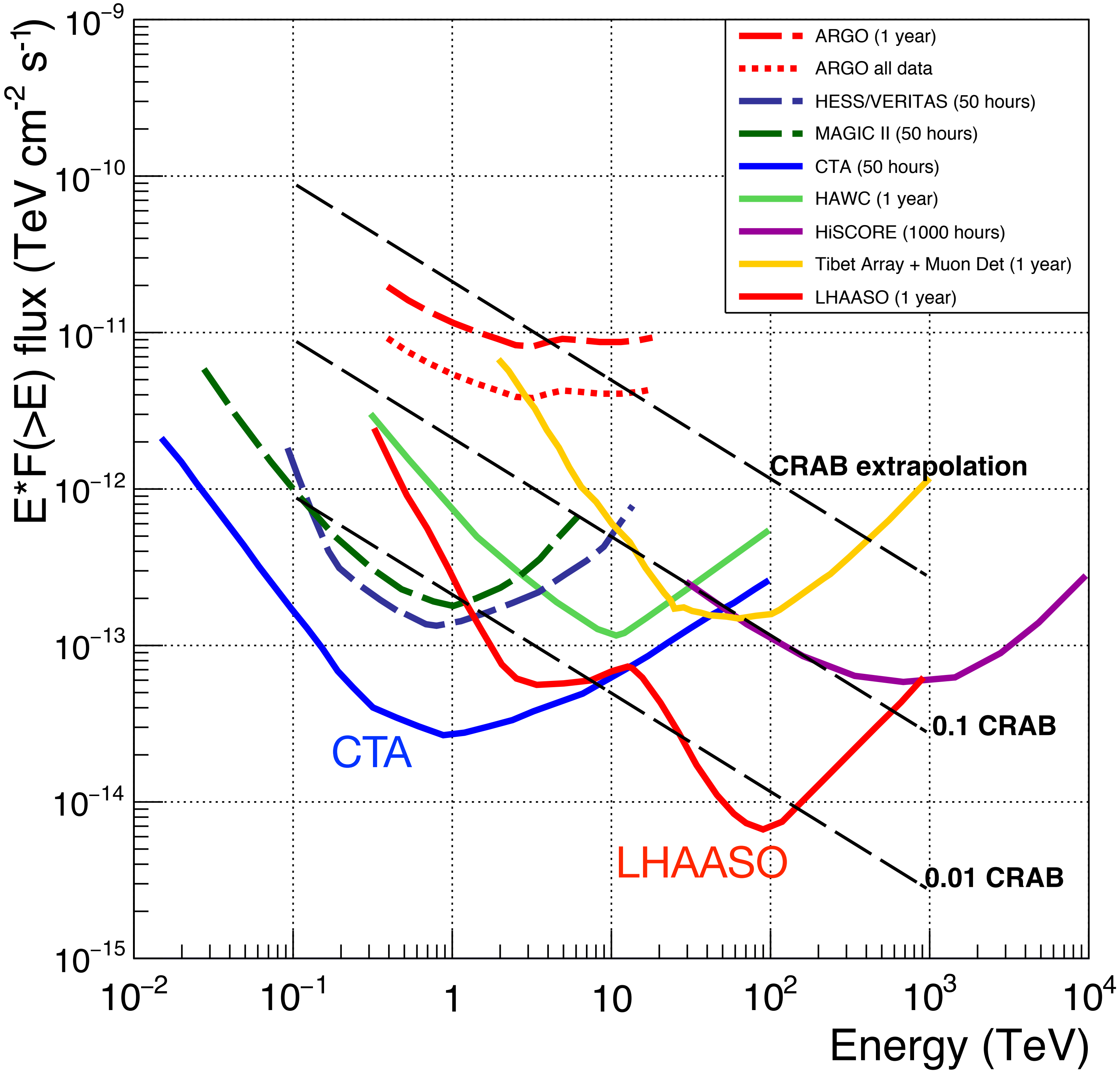
No cutoff observed in the 6 TeV spectra







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:

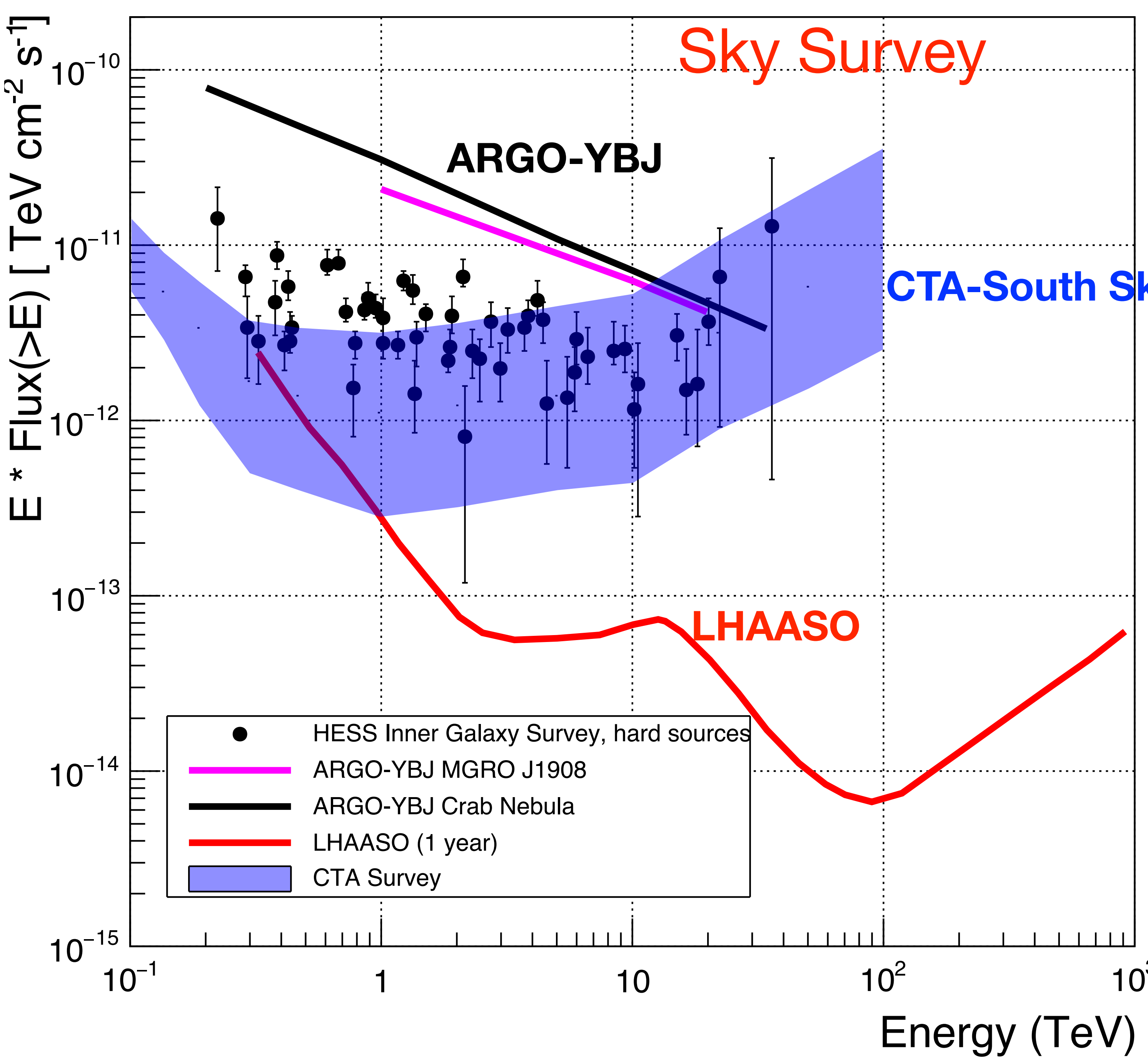
(5 h × 365 d) × d.c. (≈ 15%) ≈ 270 h / y for each source.

The big advantage of LHAASO

- High Energy (>10 TeV)
- Sky Survey

Opening the PeVatron range

Lhaaso has no competitors for sky survey: in one year it can survey the Northen sky at 100 TeV at a level < 0.01 Crab !



Tluczykont et al., APh 56, 42 (2014)
Dubus et al., APh 43, 317 (2013)

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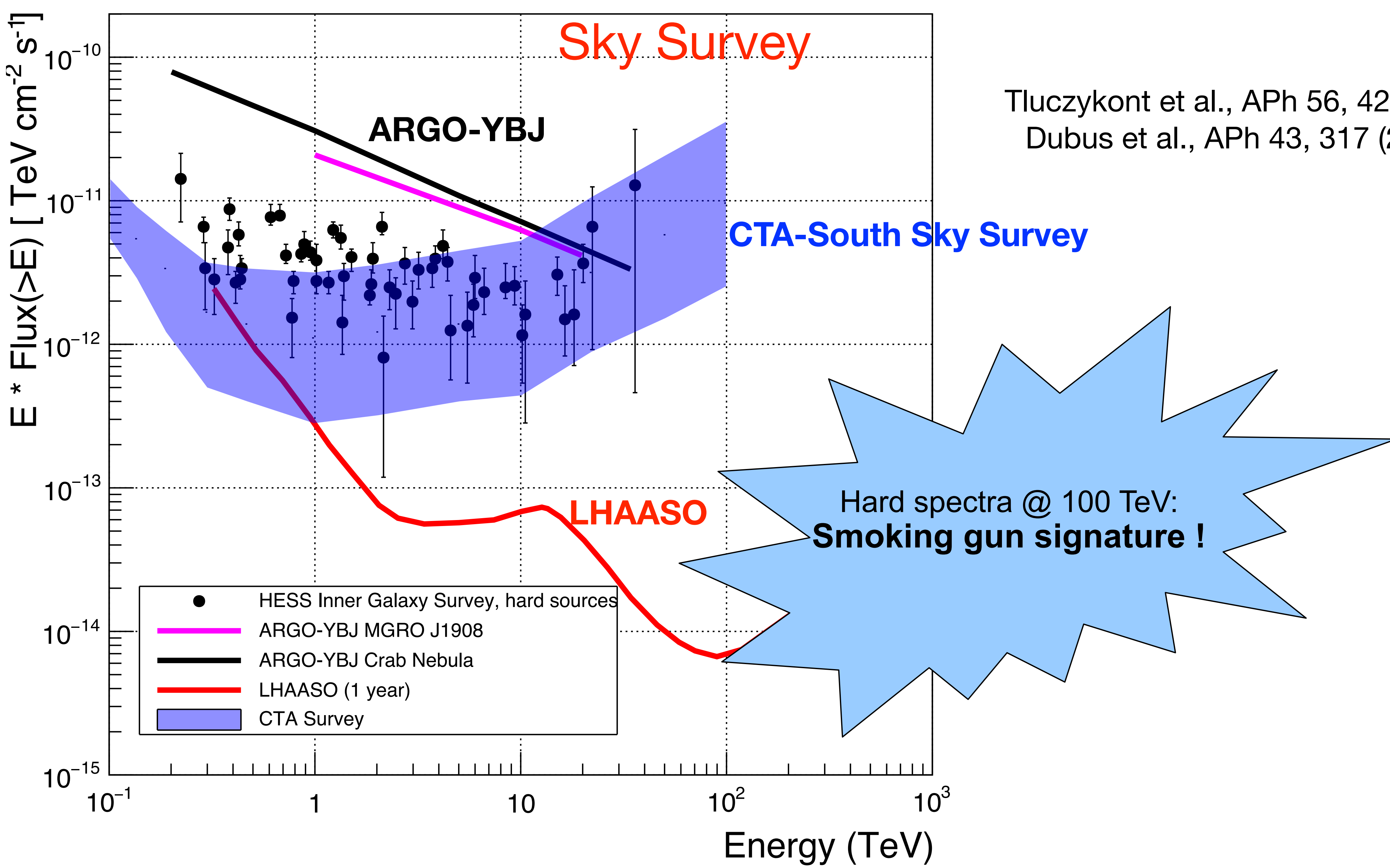


Tluczykont et al., APh 56, 42 (2014)
Dubus et al., APh 43, 317 (2013)

Discussion steps

- Sept. 2013: meeting on Cosmic Rays at LNGS
- March 2014: document posted to the CR WG of “INFN - What Next ?”
- May 2014: meeting INFN-IHEP, Rome
- July 2014: Letter of Intent to INFN Astroparticle Committee and talk to introduce LHAASO.

50 pages discussing scientific opportunities.

- Sept. 2014: talk at the INFN Astroparticle Committee to propose collaboration.

LHAASO is not approved but INFN funded the collaboration for 2015 to have meetings and with some computing resources at CNAF to start studies.

- Dec. 2014: 2 different talks about LHAASO by A. Chiavassa and S. Vernetto at the *“INFN What Next ?”* meeting in Padua.

The LHAASO project: approaching the Cosmic Ray Physics with unprecedented sensitivity

Letter of Intent for a new generation experiment for gamma-ray and cosmic-ray astrophysics

F. Ameli[a], A. Argan[b,c], G. Badino[d,e], A. Capone[a,f], A. Chiavassa[d,e], B. D’Ettorre Piazzoli[g], T. Di Girolamo[g], G. Di Sciascio[c], R. Iuppa[c], P. Lipari[a], S. Mari[h], P. Montini[h], A. Morselli[c], G. Piano[b,c], R. Santonico[i,c], M. Tavani[b,c], P. Vallania[e,j], S. Vernetto[e,j], C. Vigorito[d,e]

Collaboration opportunities

3 LHAASO meetings in the last months to strenghten the collaboration:

- Oct. 2014 - 1 week meeting in Chendgu
- Mar. 2015 - 1 week meeting in Beijing
- May 2015 - 2 days meeting in Beijing

We discussed, and agreed with the Chinese side, the general features of our possible involvement in LHAASO by identifying the major items of interest:

- PMTs and HV
- Trigger and DAQ
- Improvement of the sensitivity
- Simulation of different LHAASO components
- Development/improvement of reconstruction and analysis tools
- Definition of scientific targets

May 2015: INFN - IHEP Bilateral Meeting

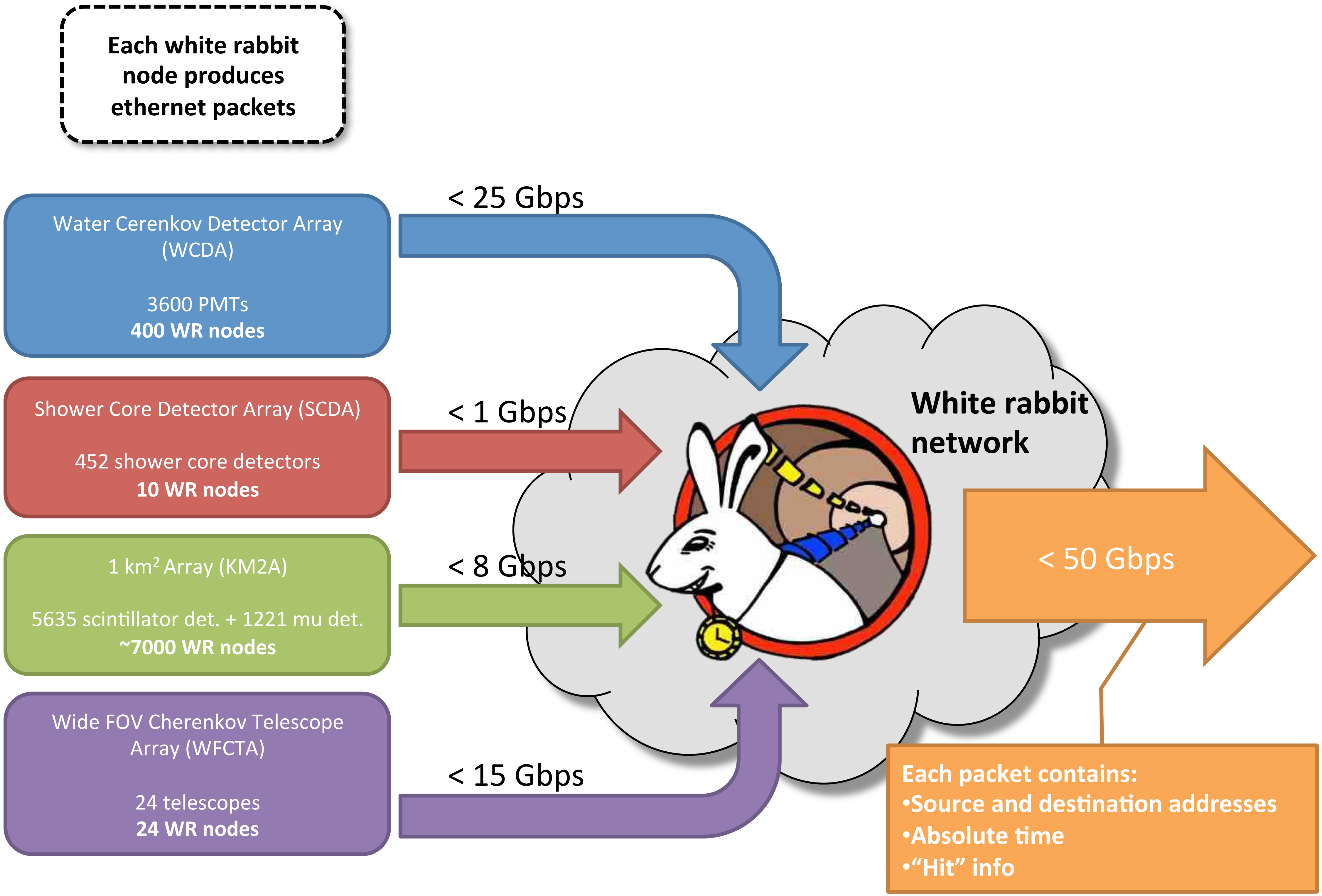
FERRONI:

- It is important that a group with a strong experience in ARGO like yours will get the chance to bring its experience to LHAASO
- Identify a relevant contribution that INFN can bring to this project. A contribution that is backed-up by an adequate man-power.
- You have to select few people that can give an important contribution and focus on few important items.

WANG:

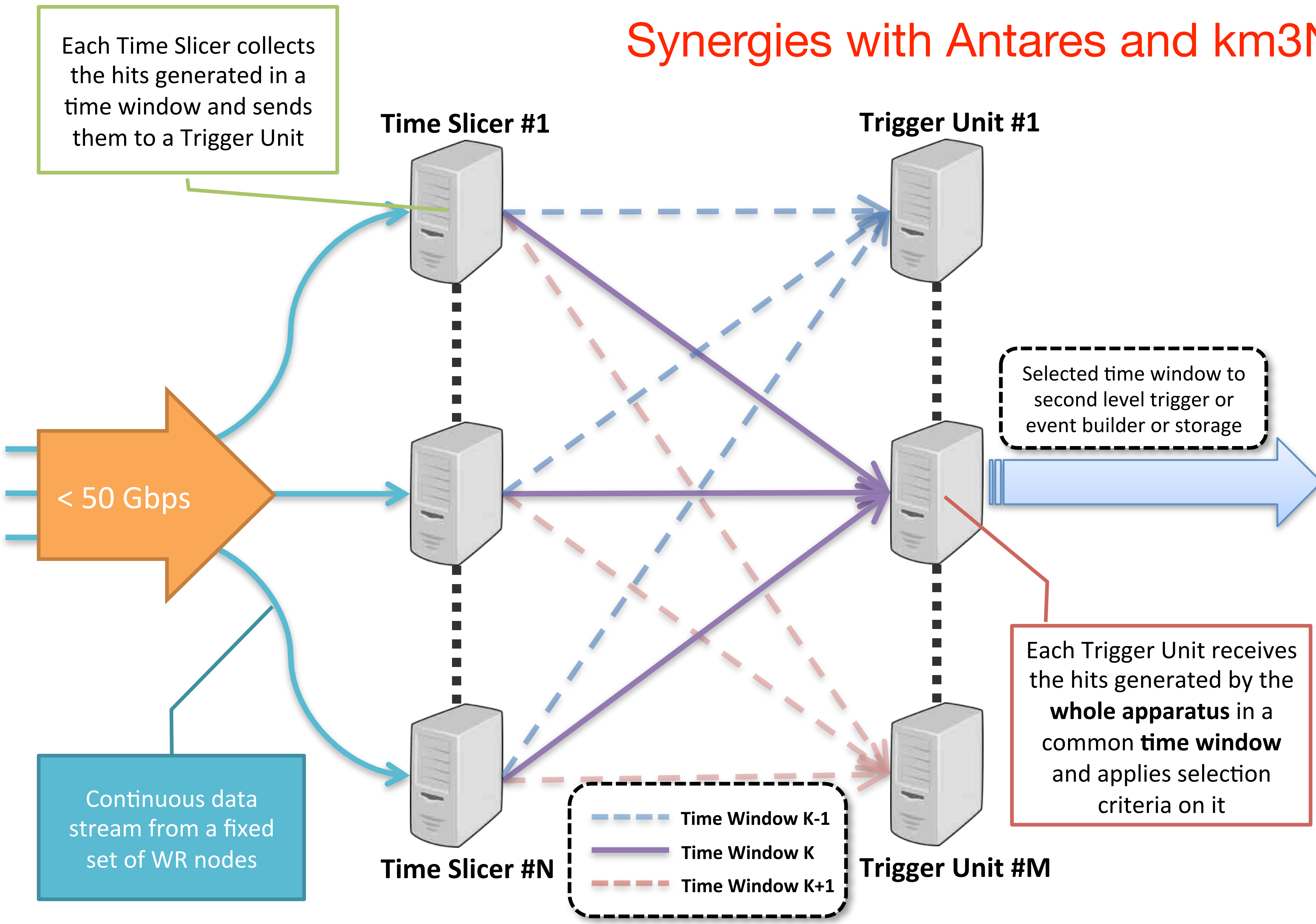
- The time window to join LHAASO is very small because construction is about to start. Commitment has to be shown by the end of this year.

LHAASO: reference numbers



Time slicing mechanism

Synergies with Antares and km3Net



Agreement with the Chinese side of LHAASO

After discussions among senior LHAASO members and with IHEP director Dr. Yifang Wang:

- We welcome our Italian collaborators to take over the DAQ system of the LHAASO experiment
- We hope the Italian group can immediately start the DAQ system design and development
- after we reach an agreement, we will immediately reduce the activity of the existing Chinese DAQ group to a reasonable level that effectively supports the involvement from our Italian colleagues in the project and help guarantee a smooth on-site implementation of the DAQ system and operation in the future
- we hope the new DAQ group can soon work on three tasks as follows.

  (1) Take care of the engineering array currently operating at YBJ, and use the engineering array as a test bench for newly developed/modified DAQ and data pre-processing algorithms.

  (2) Quickly organize to prepare necessary documentations for the Technical Design Report (TDR) that is expected to be finally approved by the end of this year.

  (3) Prepare to join the TDR review and make corresponding efforts to pass the review.

- Once a final agreement is reached and approved by both sides, we will provide all necessary supports and convenience for the new DAQ group to start playing this very important role in the LHAASO project as soon as possible.

LHAASO - INFN

4 sedi: **Torino**, **Roma La Sapienza**, **Roma Tor Vergata**, **Napoli**
8.3 FTE, 16 persone

Roma Tor Vergata: 3.5 FTE, 7 persone

Argan 30%
Di Sciascio 70%
Iuppa: 20%
Montini: 100%
Minenkov: 50%
Piano: 40%
Tavani: 40%

Richieste: **MI: 30 keuro**: 16 keuro meetings in Cina, 2 keuro meetings in Italia
5 keuro conferenze, 7 keuro turnistica in Tibet.

LHAASO science document and TDR

Attività principale 2016: *studio ottimizzazione sensibilità*, simulazione detector (WCDA e KM2A), studio sensibilità astronomia gamma > 10TeV, studio fisica fondamentale, *studio nuovi rivelatori (adroni, neutroni).*

Conclusions

LHAASO is a solid project, proposed by a scientific community whose expertise in the field of high energy physics is well-established and widely recognized.

This experiment has very interesting prospects, being *able to deal with all the main open problems of cosmic ray physics at the same time.*

It is proposed to study CRs in a *unprecedented wide energy range 10^{11} - 10^{18} eV*, from those observable in space with AMS and approaching those investigated by AUGER, thus including, in addition to the 'knee', the whole region between 'knee' and 'ankle' where the galactic/extra-galactic CR transition is expected.

At the same time it is proposed as a tool of great sensitivity - unprecedented above 30 TeV - to monitor *'all the sky all the time'* a gamma-ray domain extremely rich of sources variable at all wavelengths.

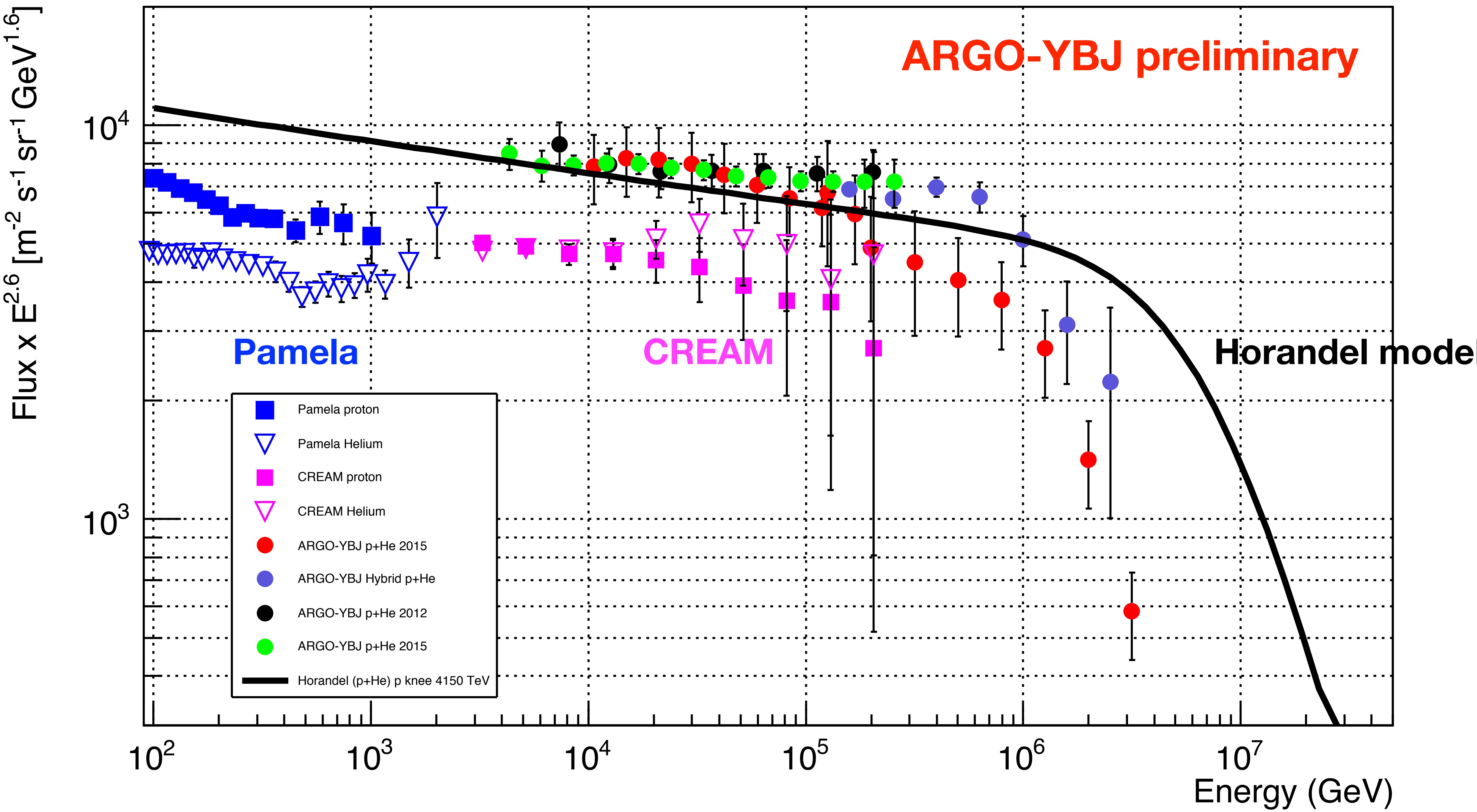
The experimental studies that can be performed with LHAASO are complementary with those of other Astroparticle Physics INFN programs (AMS, AUGER, JEM-EUSO, Fermi, CTA, Neutrino telescope), and will extend, clarify and deepen the Science developed by these programs.

The vast potential physics reach of LHAASO makes this experiment very attractive.

The perspectives for an INFN participation of significant impact are very promising, solidly grounded on previous expertise.

Light component spectrum (3 TeV - 5 PeV) by ARGO-YBJ

ARGO-YBJ reported evidence for a proton knee starting at about 650 TeV and not at 4 PeV (“standard model”)

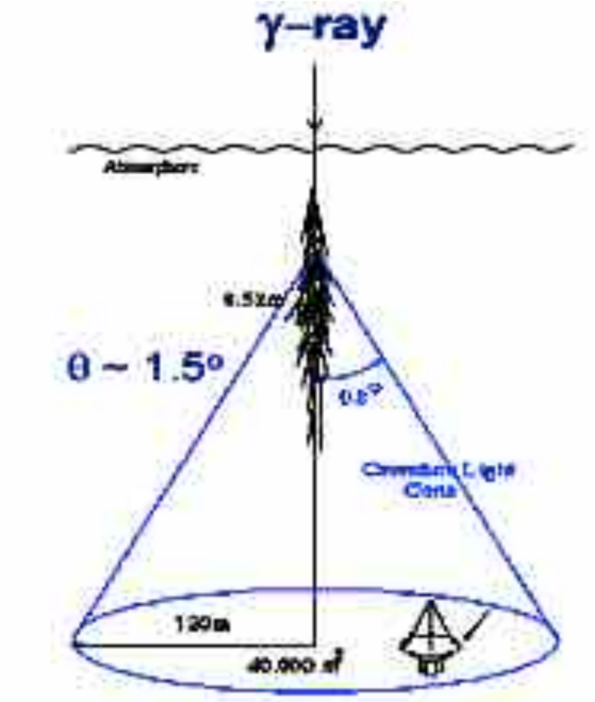


Ground-based Gamma-Ray Astronomy

Detecting Extensive Air Showers

Air Cherenkov Telescopes

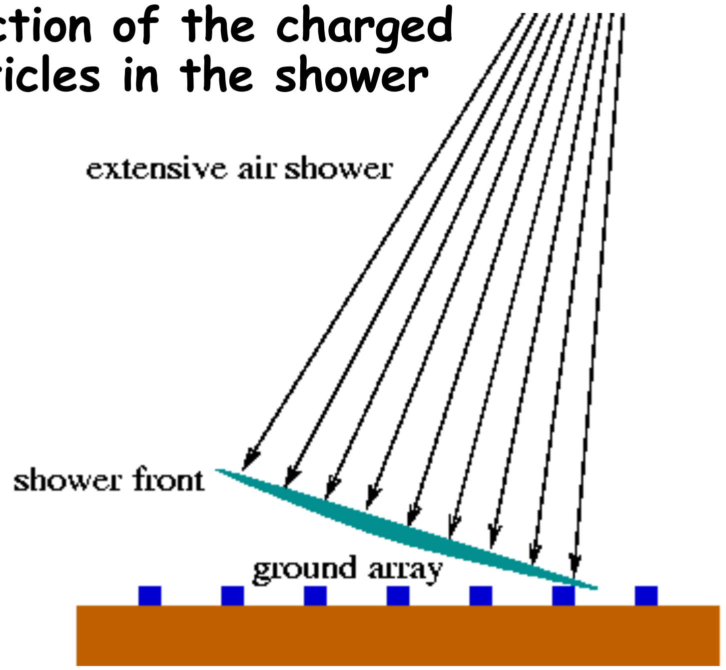
detection of the Cherenkov light
from charged particles in the EAS



Very low energy threshold (≈50 GeV)
Excellent bkg rejection (>99%)
Excellent angular reslution (≈0.05 deg)
Good energy resolution (≈15%)
High Sensitivity (< % Crab flux)
Low duty-cycle (≈10%)
Small field of view (4-5 deg)

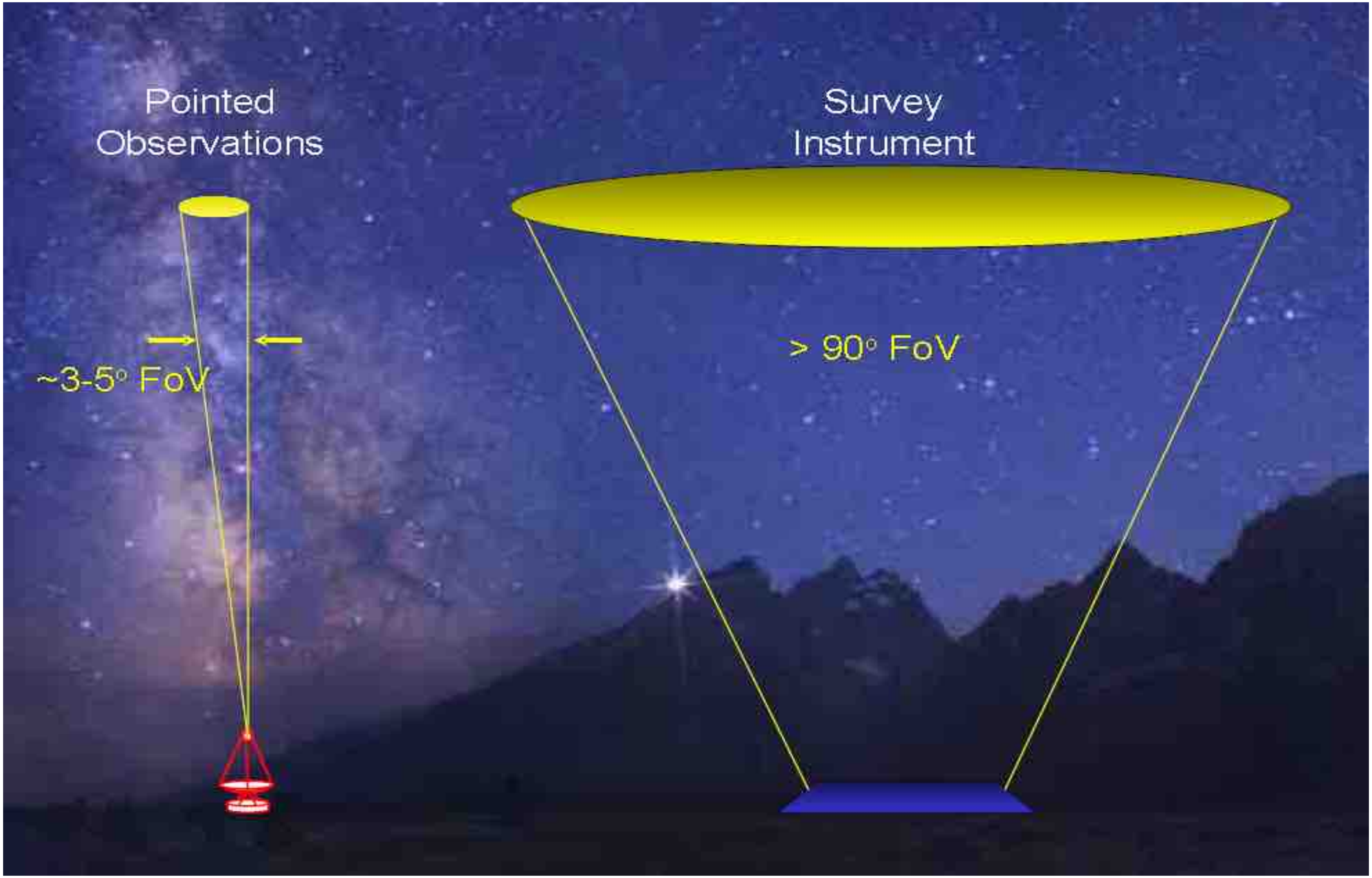
EAS arrays

detection of the charged
particles in the shower

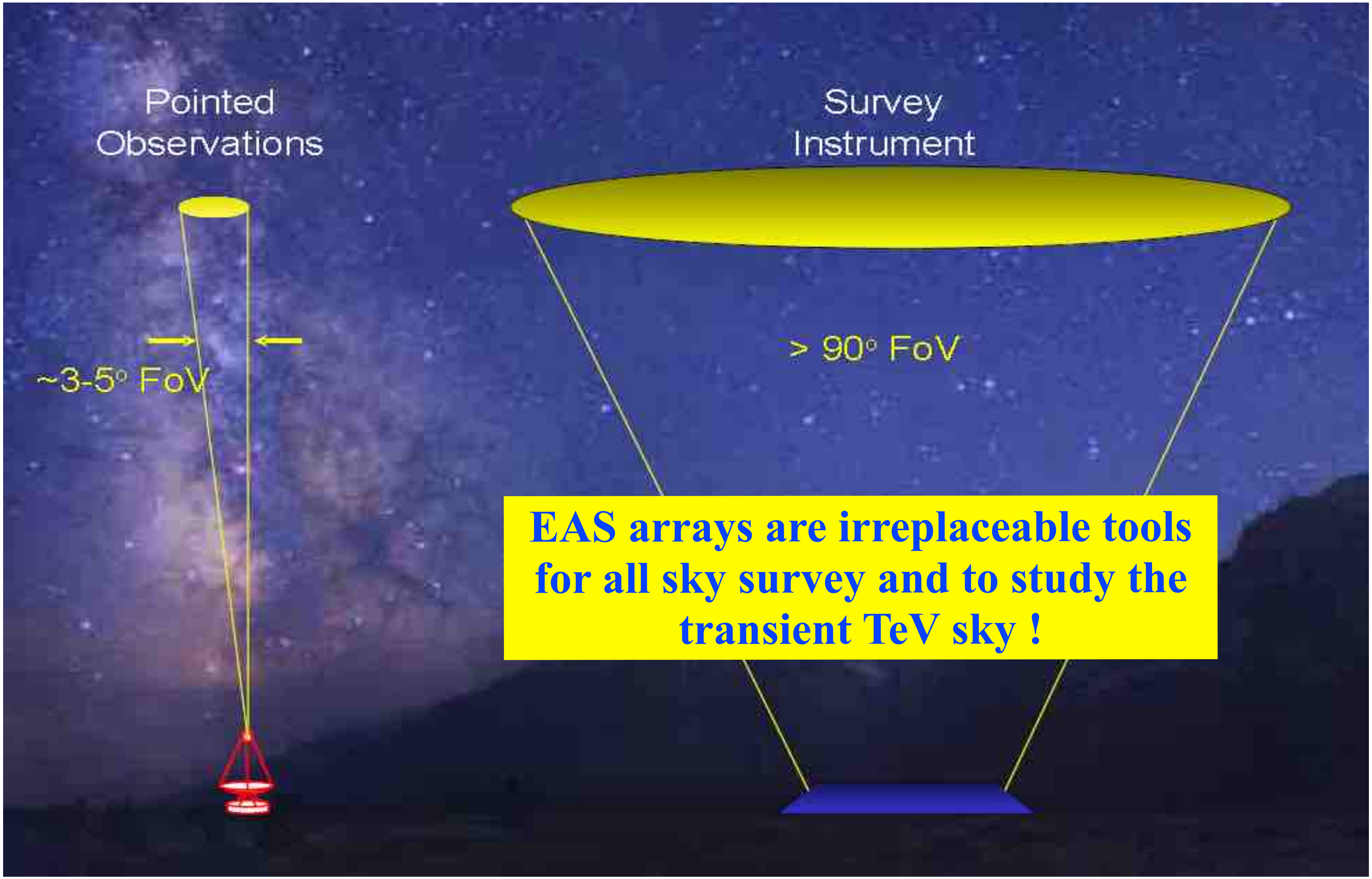


Higher energy threshold (≈300 GeV)
Good bkg rejection (>80%)
Good angular resolution (0.2-0.8 deg)
Modest energy resolution (≈50%)
Good Sensitivity (5-10% Crab flux)
High duty-cycle (≈100%)
Large field of view (≈2 sr)

Pointed and Survey Instruments



Pointed and Survey Instruments



Extended Source Sensitivity

ACT's rely on angular resolution for excellent background rejection.

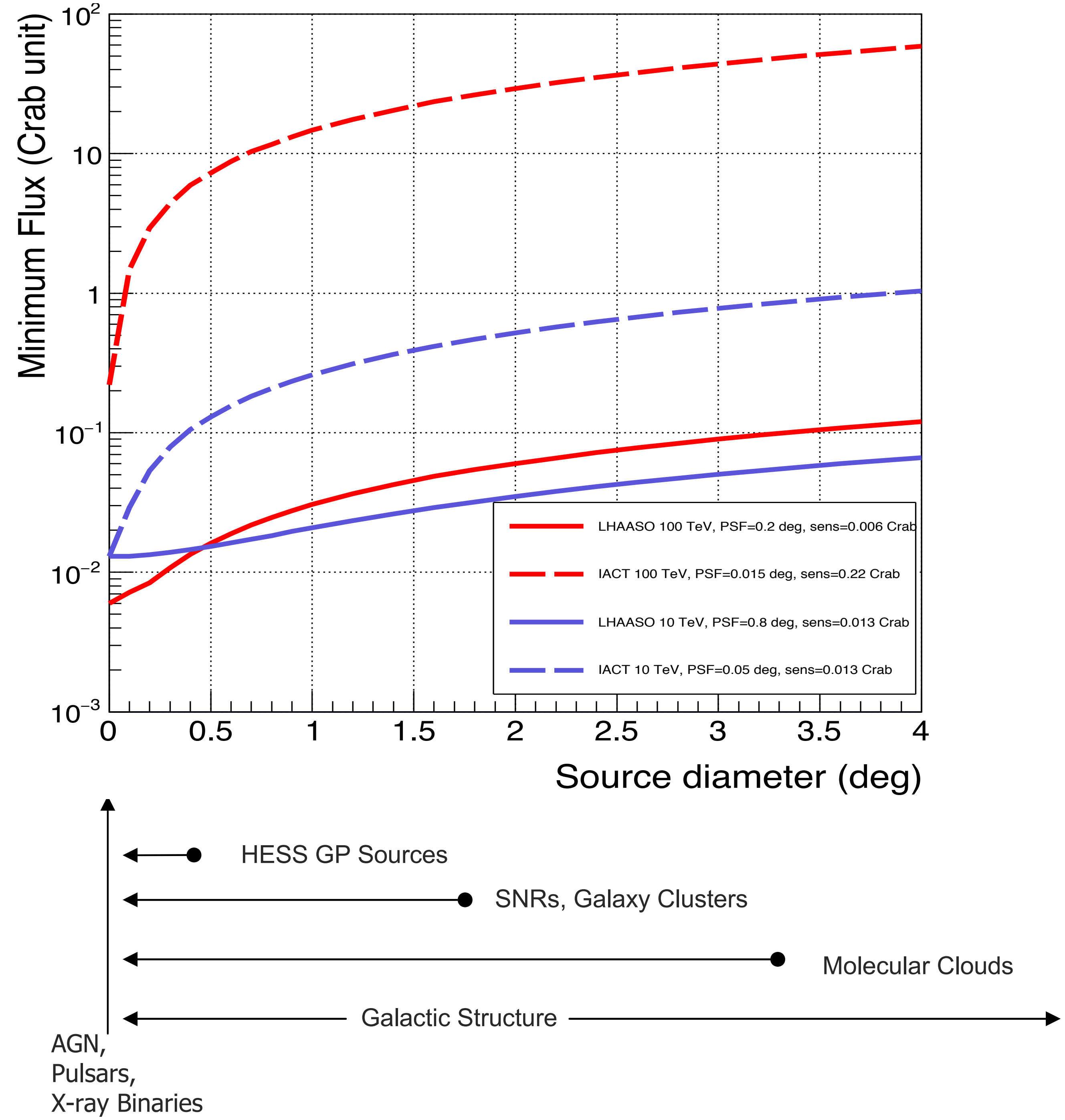
- When the source size is large compared to PSF, sensitivity is reduced by a factor of

$$\sim \sigma_{detector} / \sigma_{source}$$

Source larger than camera (On and Off Observations)

- When the source size is large compared to the FOV, sensitivity is reduced by

$$\sim \sigma_{detector} / \sigma_{source}$$



≈ 80 % of TeV Galactic Sources are extended !