Wide FoV detectors operated at Extreme Altitude

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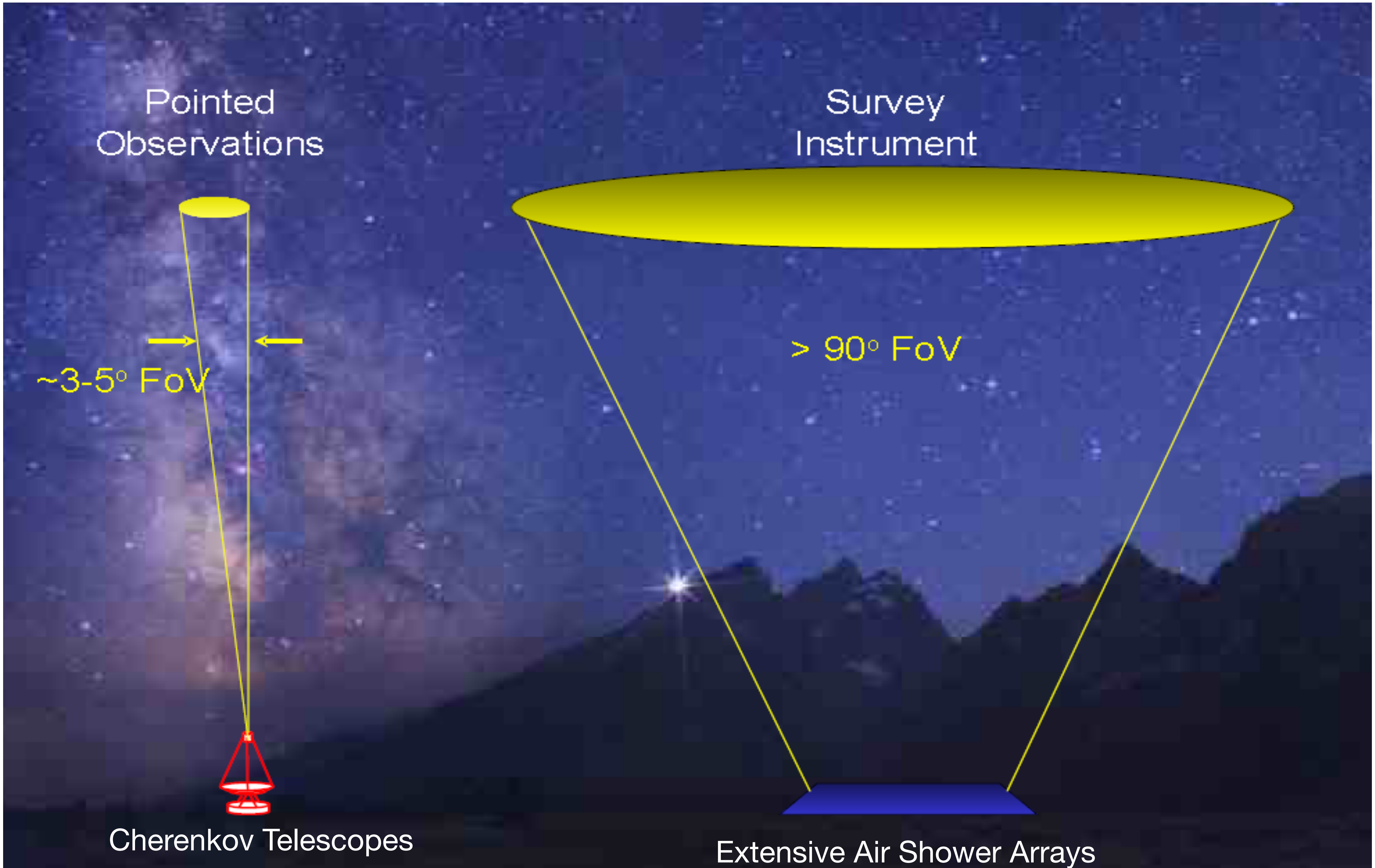
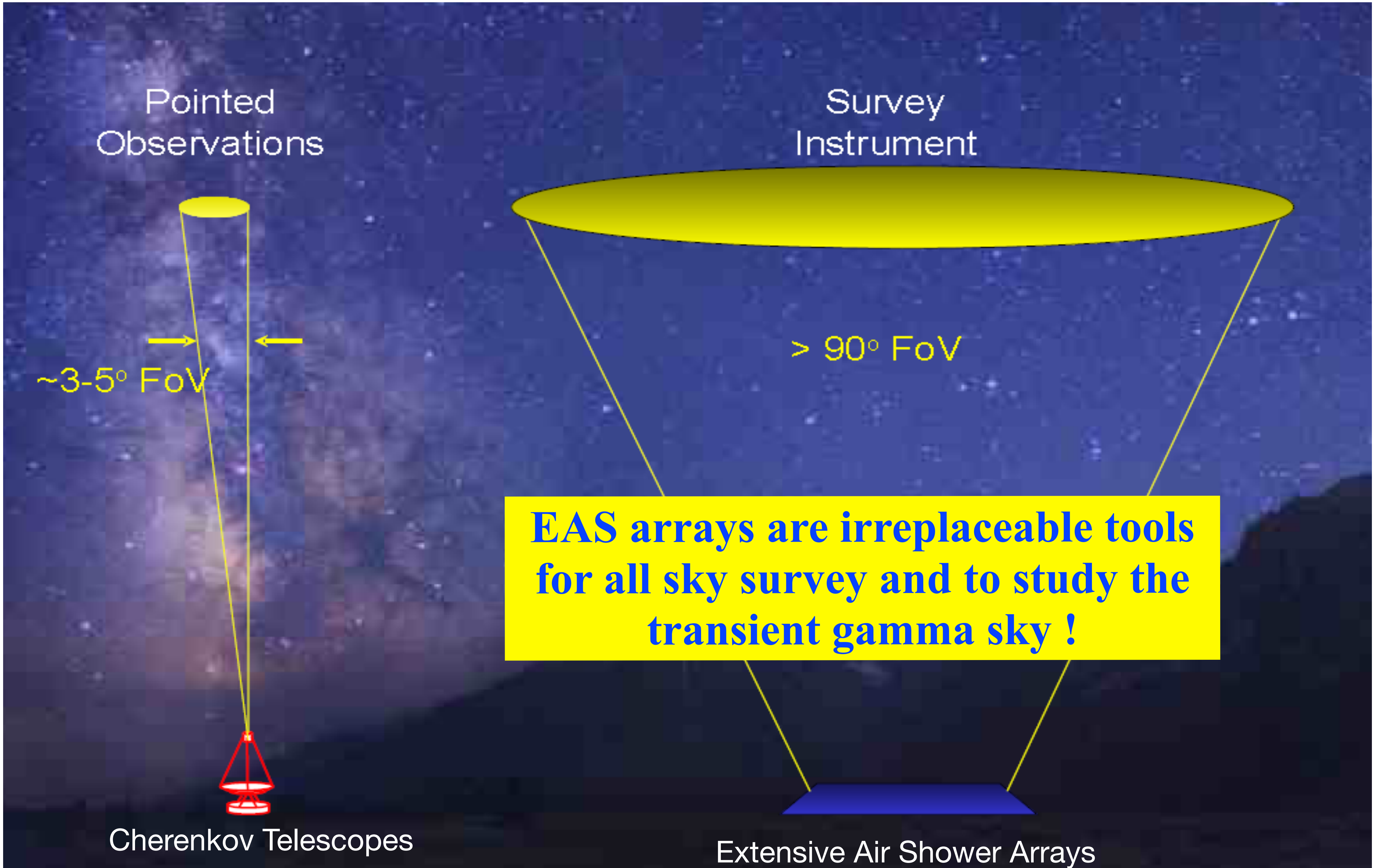
Pointed and Survey Instruments



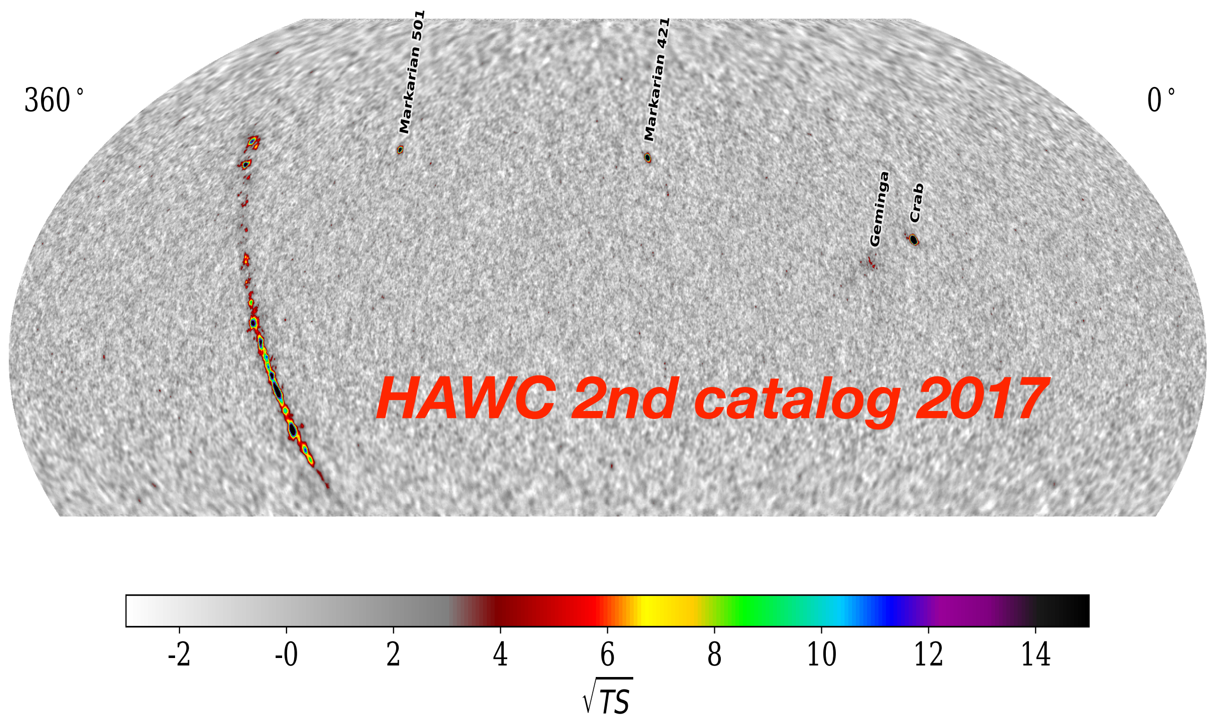
Pointed and Survey Instruments



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)

A full exploration of the Galactic Plane requires both Northern and Southern detectors !

- 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

We need to know

★ Which are the sources of CRs ?

- which acceleration mechanism? ➜ injection spectrum
- total energy in CRs
- maximum energy of accelerated particles

★ How do CRs propagate ?

- magnetic field in the Galaxy
- spatial distribution of sources
- spatial distribution of CRs
- injected ➜ observed spectrum

★ Which is the chemical composition of CRs ?

Why are Wide FoV instruments so cool ?

★ Which are the sources of CRs ? ➜ *Gamma-Ray Astronomy*

- which acceleration mechanism? ➜ injection spectrum
- total energy in CRs
- maximum energy of accelerated particles ➜ *proton PeVatrons*

★ How do CRs propagate ?

- magnetic field in the Galaxy
- spatial distribution of sources
- spatial distribution of CRs ➜ *Anisotropy*
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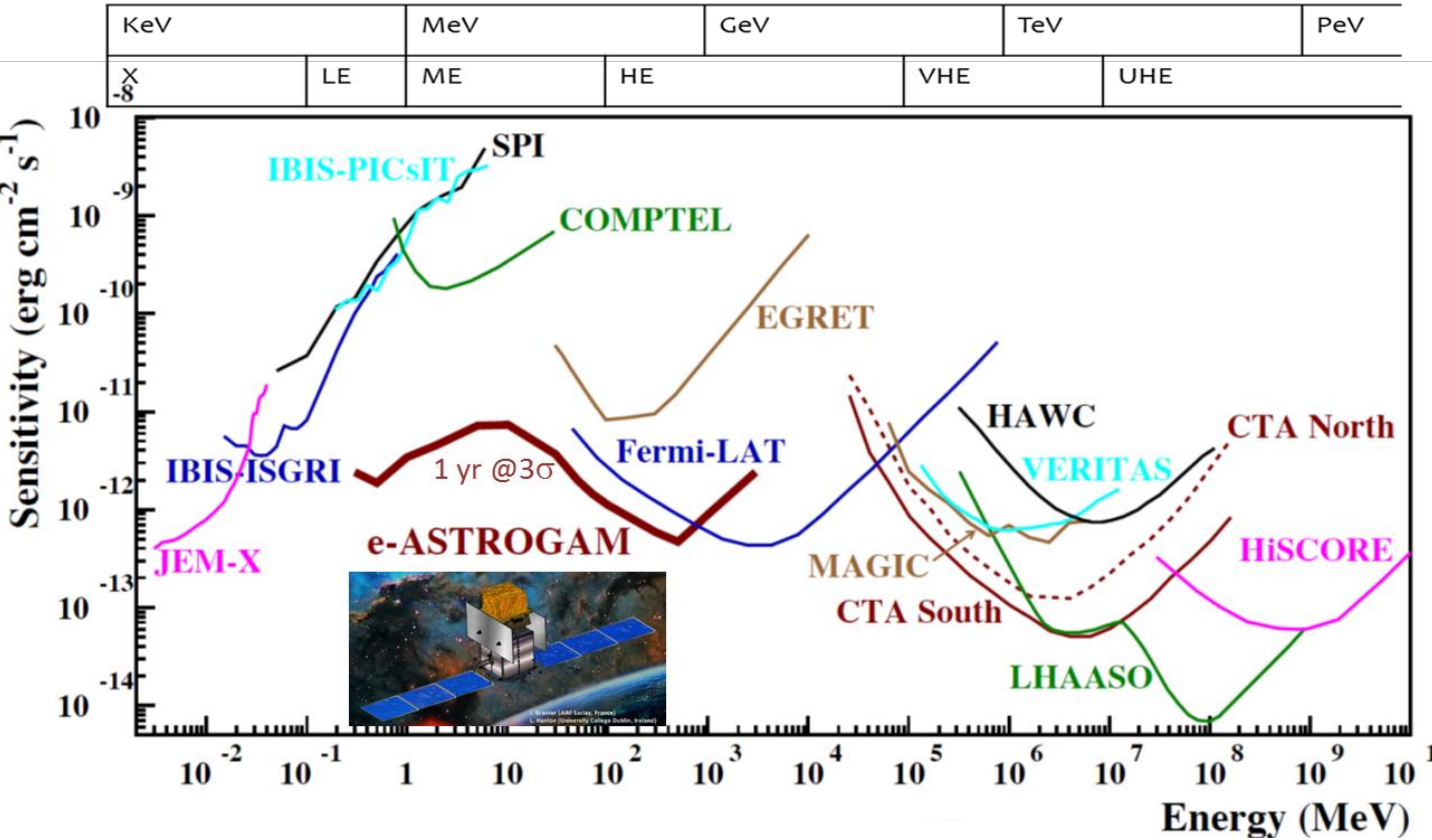
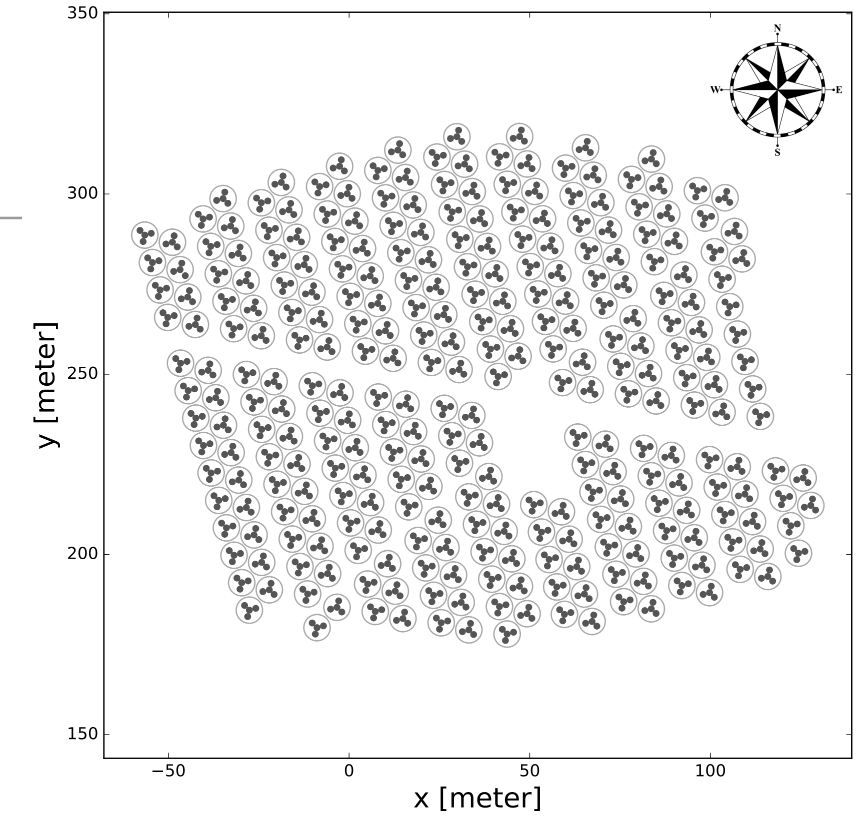
Wide FoV detectors = Multi-Messenger Instrument (by definition)

Gamma-ray experiments



(De Angelis et al, arXiv:1611.02232)

Northern Hemisphere: HAWC

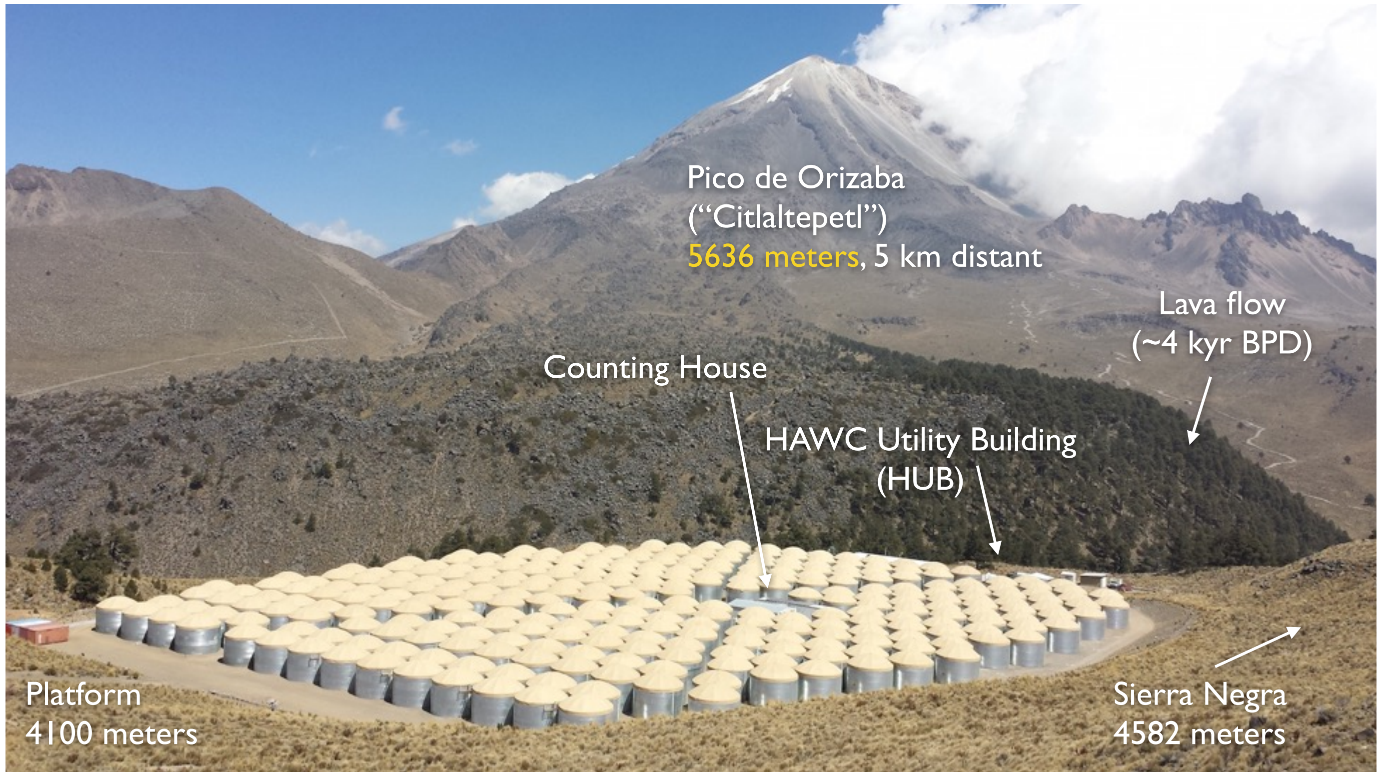


The **H**igh **A**ltitude **W**ater **C**herenkov Gamma-ray Observatory (HAWC) is up and running

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

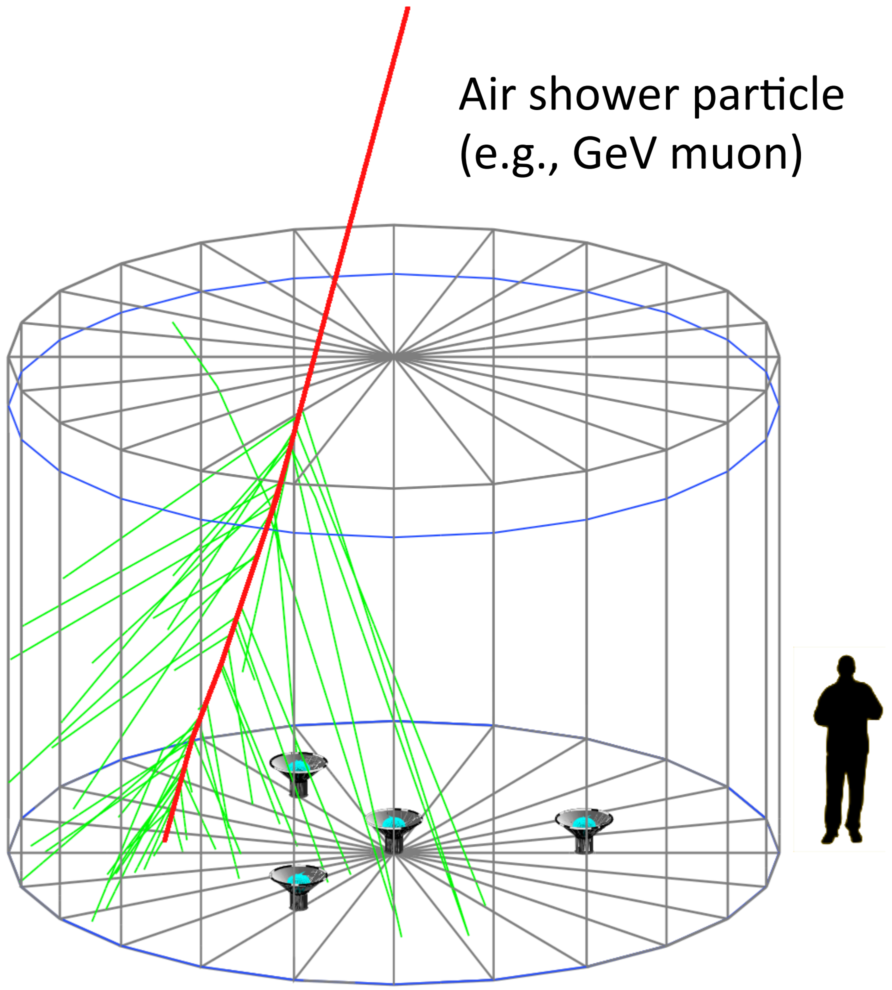
- 4100 meters above sea level
- 19°N latitude (Galactic Center at 48° zenith)
- 300 water tanks, 1200 large photocathode area PMTs 1/6th of sky in instantaneous field of view

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



Water Cherenkov Method

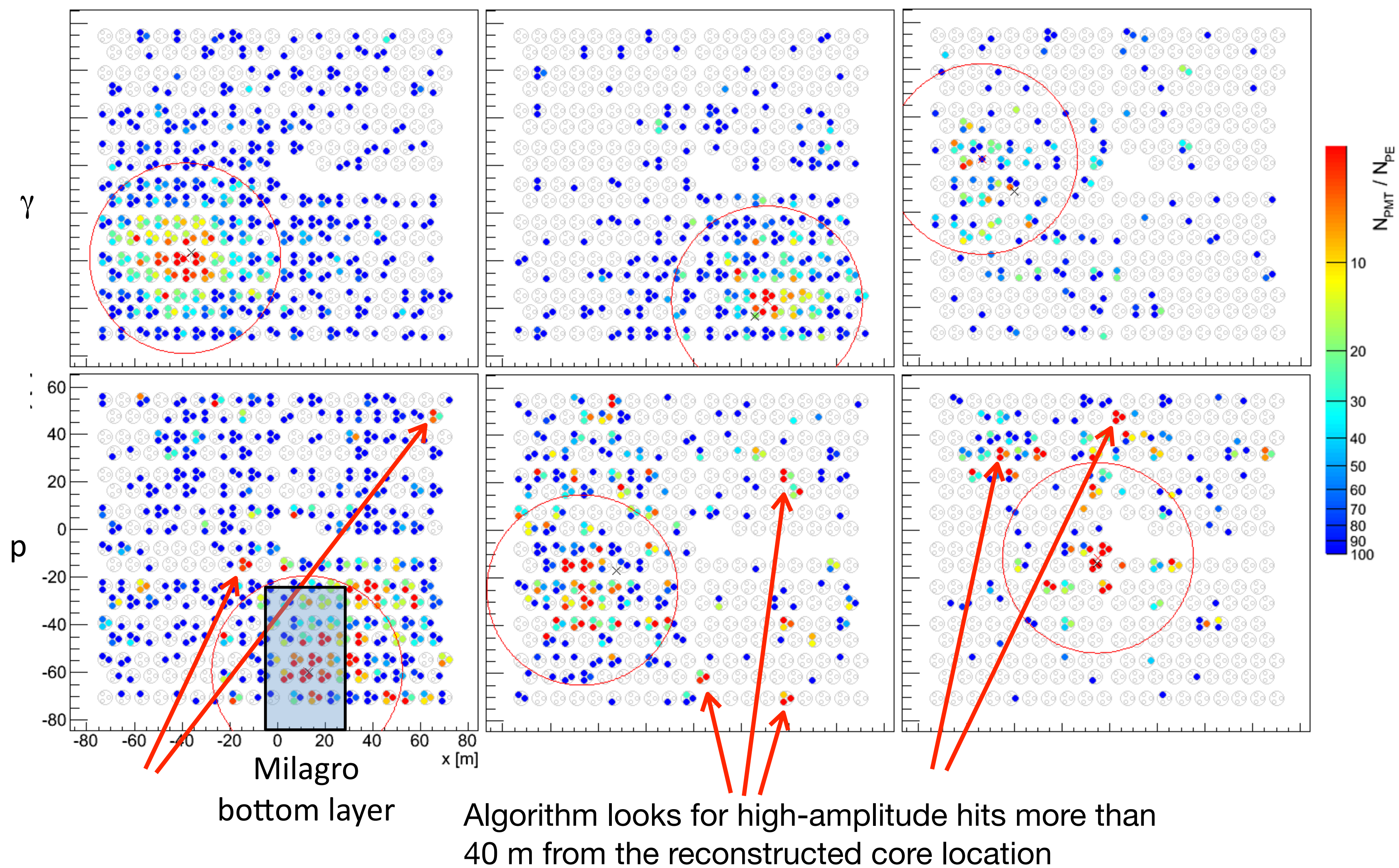
- Robust and cost-effective surface detection technique
- Water tanks: 7.3 m radius, 5 m height, 185 kL purified water
- Tanks contain three 8” R5912 PMTs and one 10” R7081-HQE PMT looking up to capture Cherenkov light from shower front



Final tank deployed: December 15, 2014

Background rejection

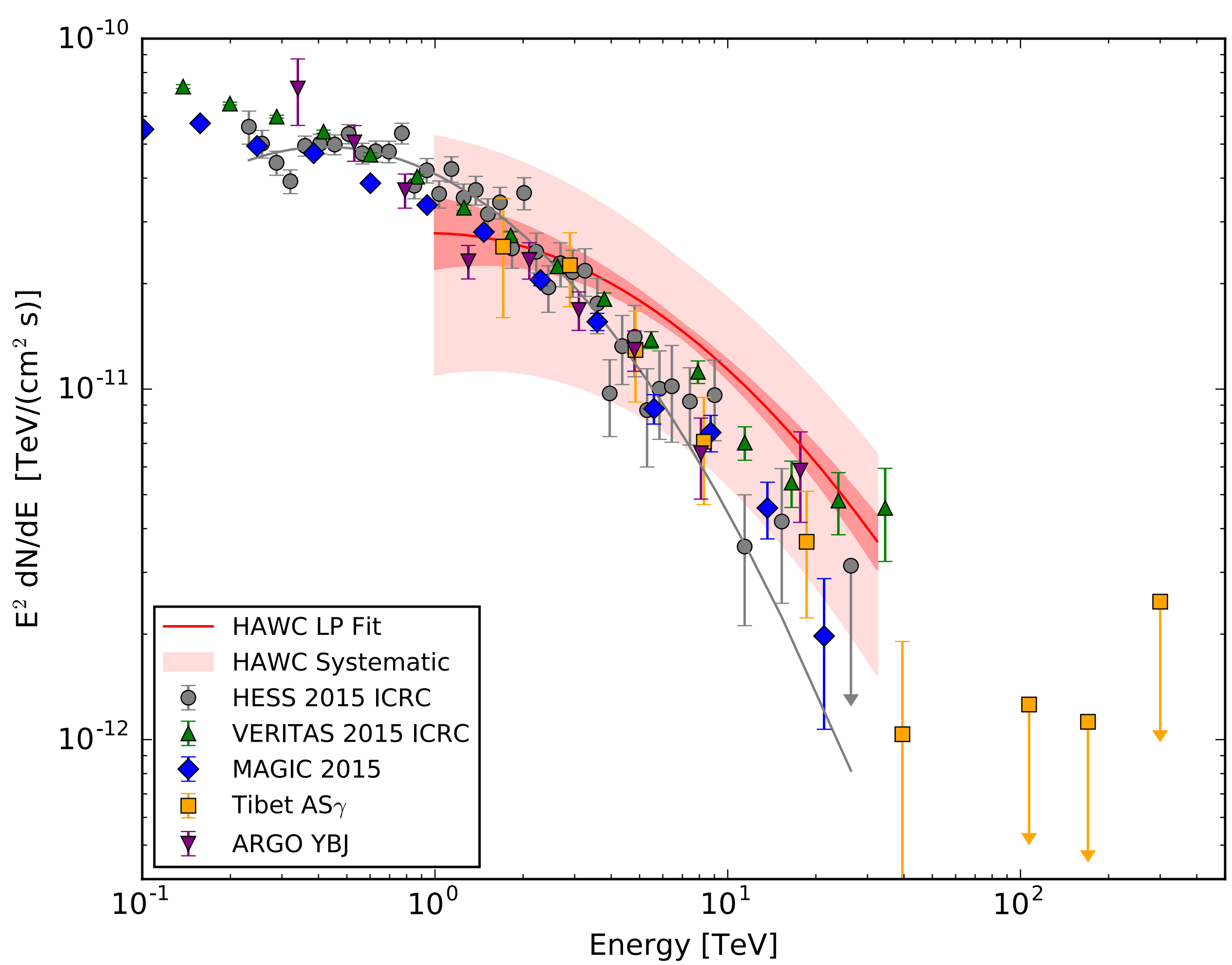
Hadronic showers typically deposit large amounts of energy in distinct clumps far from the shower core (>40 m) ➜ CR rejection using topological cut in hit pattern (the pattern of energy deposition in the detector)



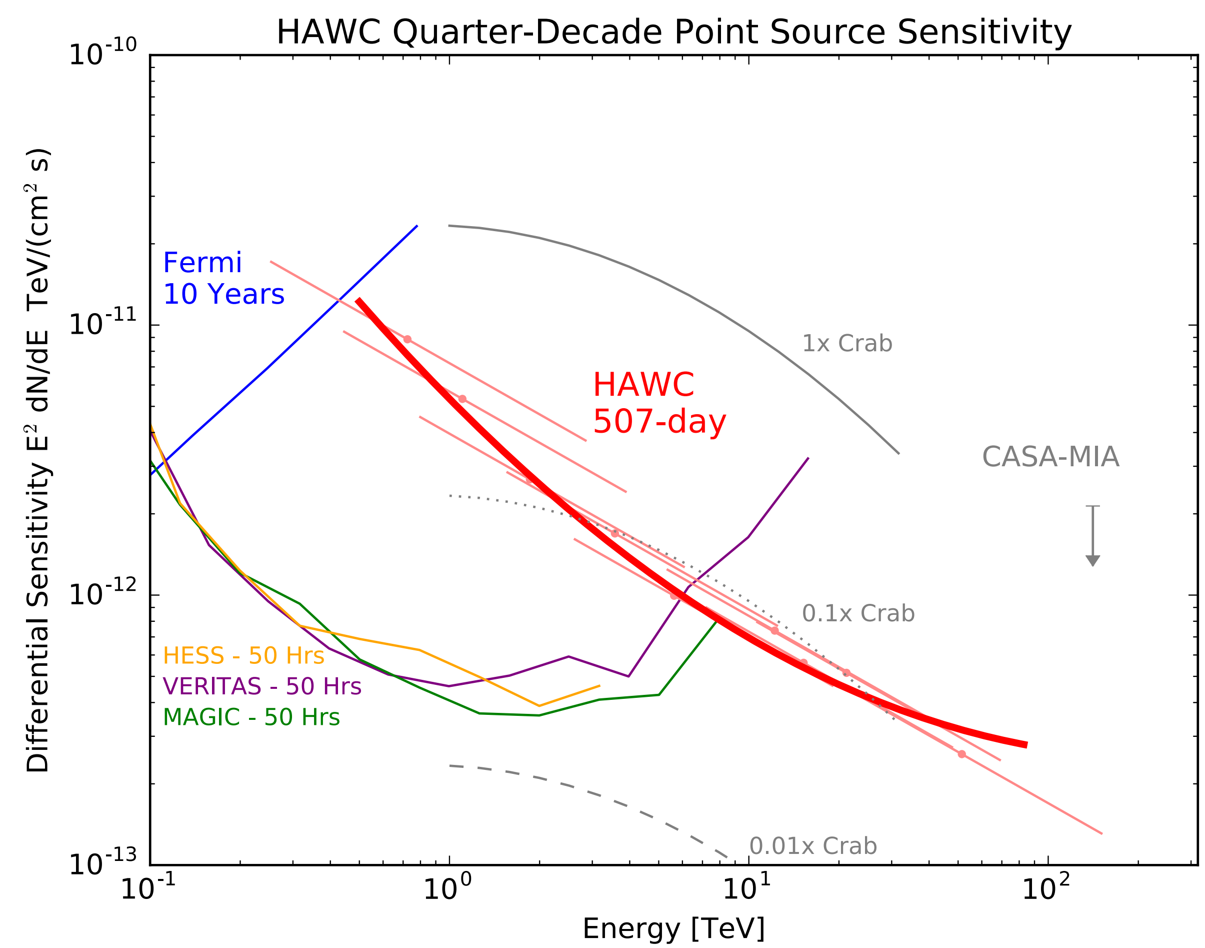
Requires sufficient number of triggered channels (>70) to work well.
Q-value max ($\varepsilon_\gamma/\sqrt{\varepsilon_{CR}}$) is estimated ~5 for point sources.

Crab Nebula with HAWC

The Crab spectrum measured with HAWC
between 1 and 37 TeV with 507 days of data



arXiv:1701.01778



The threshold for this analysis is established by including only events where more than 70 PMTs detect light.

Events with 20-30 PMTs could be reconstructed if the noise could be confidently identified.

2nd HAWC Catalog

arXiv:1702.02992

Table 1. Properties of the nine analysis bins: bin number $\mathcal{B}$, event size $f_{\rm hit}$, 68% PSF containment ψ_{68}, cut selection efficiency for gammas $\epsilon_\gamma^{\rm MC}$ and cosmic rays $\epsilon_{\rm CR}^{\rm data}$, and median energy for a reference source of spectral index −2.63 at a declination of 20° $\tilde{E}_\gamma^{\rm MC}$.

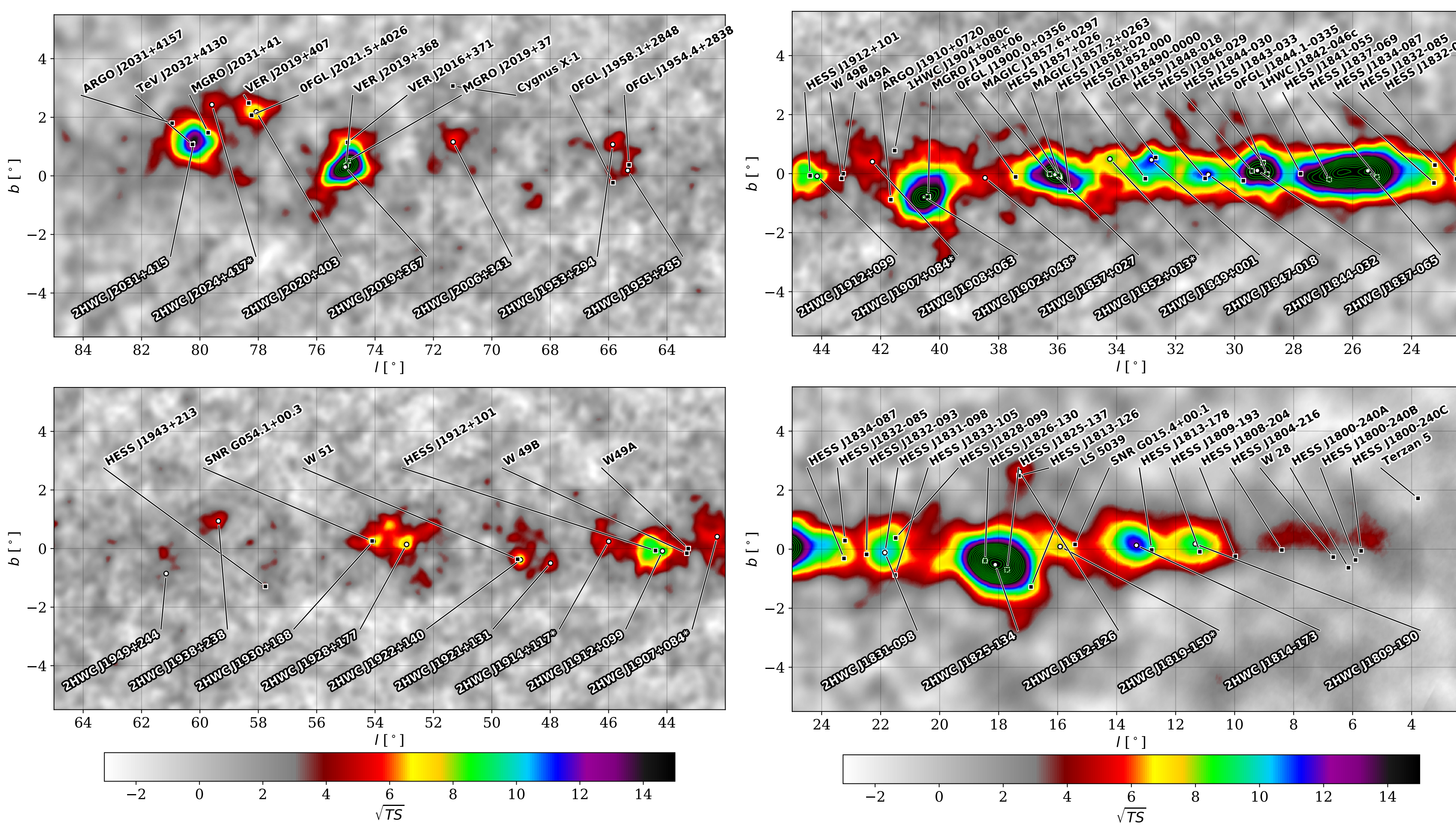
$\mathcal{B}$	$f_{\rm hit}$ (%)	ψ_{68} (°)	$\epsilon_\gamma^{\rm MC}$ (%)	$\epsilon_{\rm CR}^{\rm data}$ (%)	$\tilde{E}_\gamma^{\rm MC}$ (TeV)
1	6.7 – 10.5	1.03	70	15	0.7
2	10.5 – 16.2	0.69	75	10	1.1
3	16.2 – 24.7	0.50	74	5.3	1.8
4	24.7 – 35.6	0.39	51	1.3	3.5
5	35.6 – 48.5	0.30	50	0.55	5.6
6	48.5 – 61.8	0.28	35	0.21	12
7	61.8 – 74.0	0.22	63	0.24	15
8	74.0 – 84.0	0.20	63	0.13	21
9	84.0 – 100.0	0.17	70	0.20	51

A total of 39 sources were detected with 507 days of data.

Out of these sources, 16 are more than one degree away from any previously reported TeV source

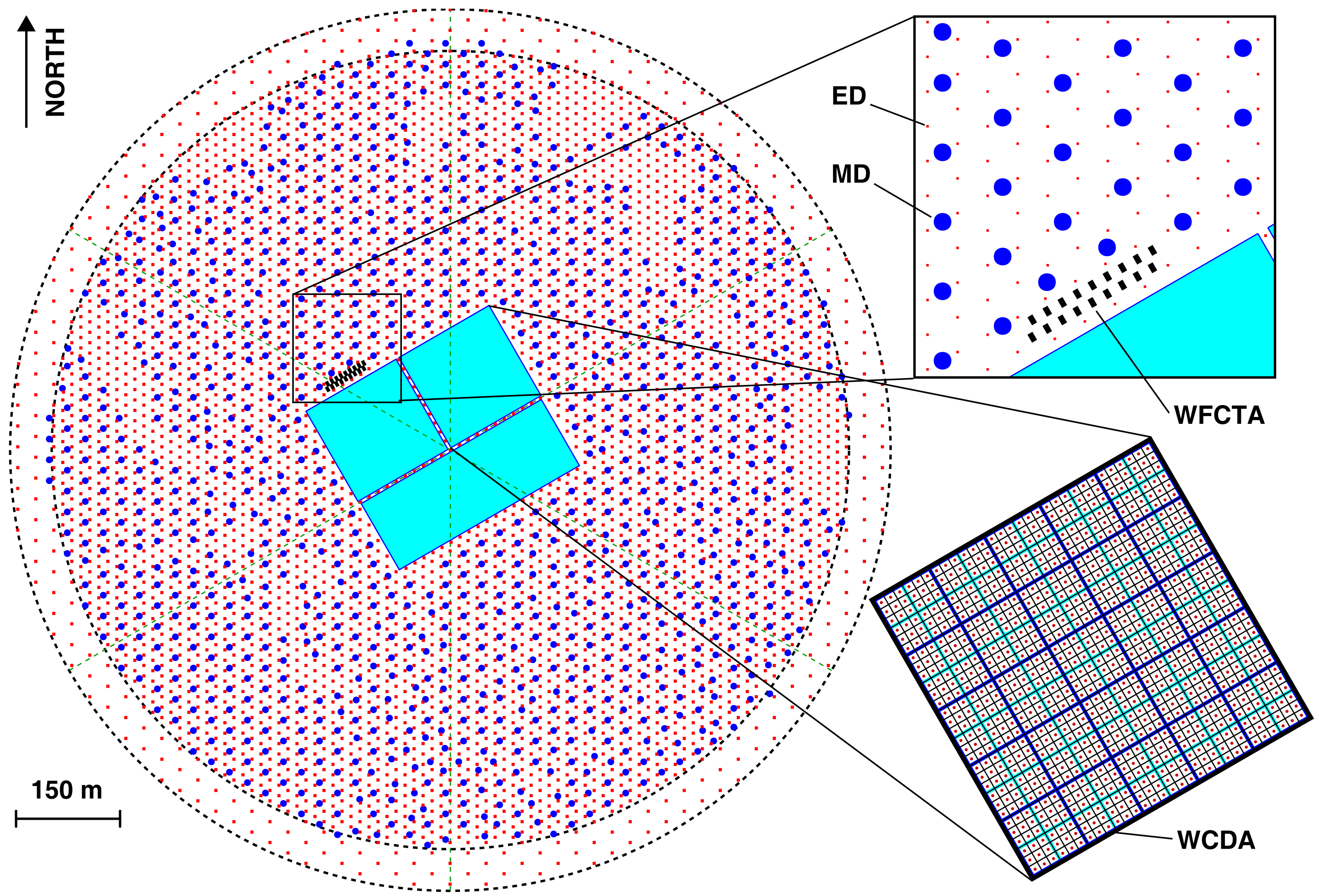
7 of the detected sources may be associated with PWN, 2 with SNRs, 2 with blazars, and the remaining 23 have no firm identification yet.

Energy threshold ≈ 700 GeV



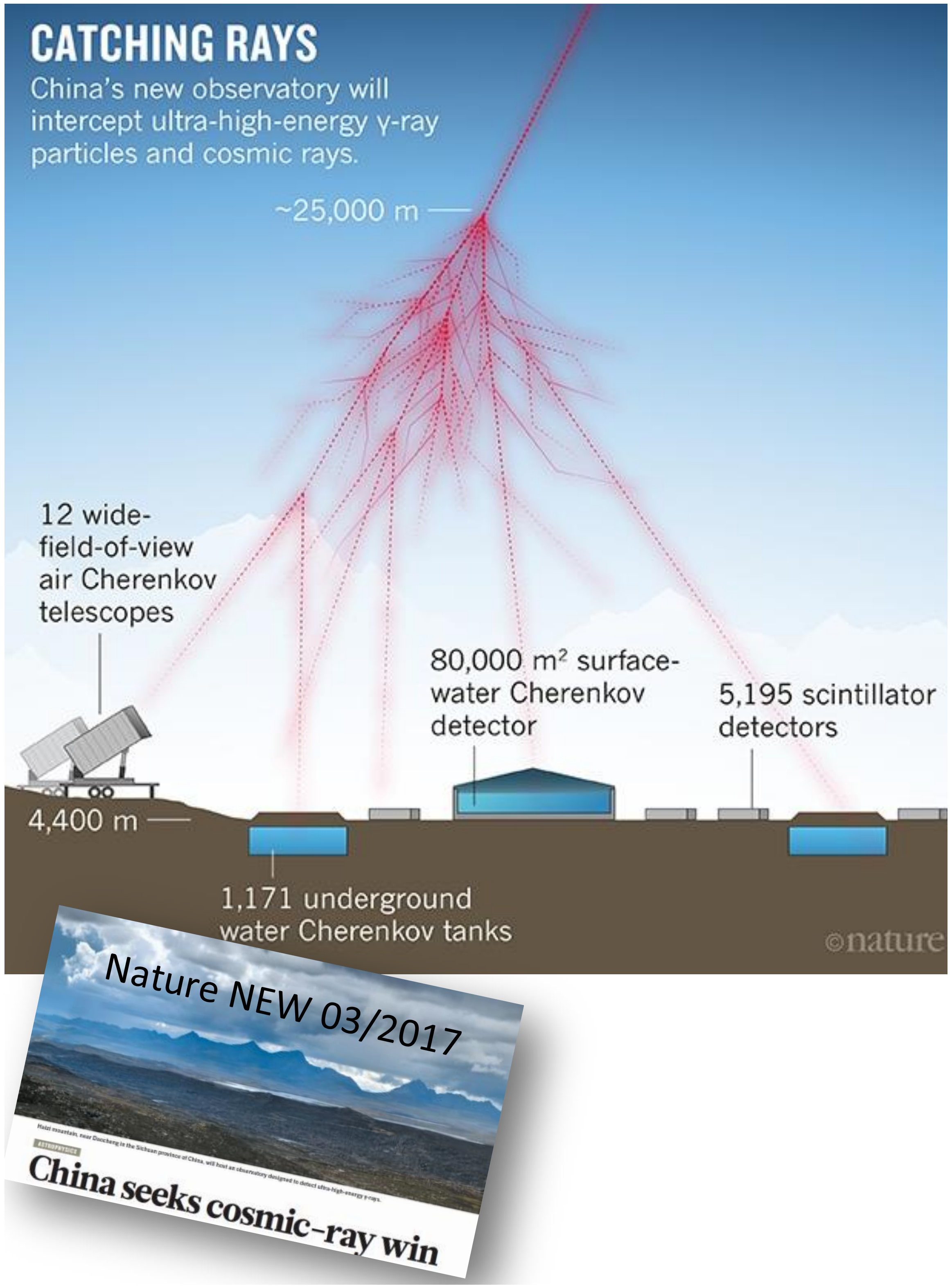
Northern Hemisphere: LHAASO

- 1.3 km^2 array, including 5195 scintillator detectors 1 m^2 each, with 15 m spacing.
- An overlapping 1 km^2 array of 1171, 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.
- Neutron detectors

Status of the experiment



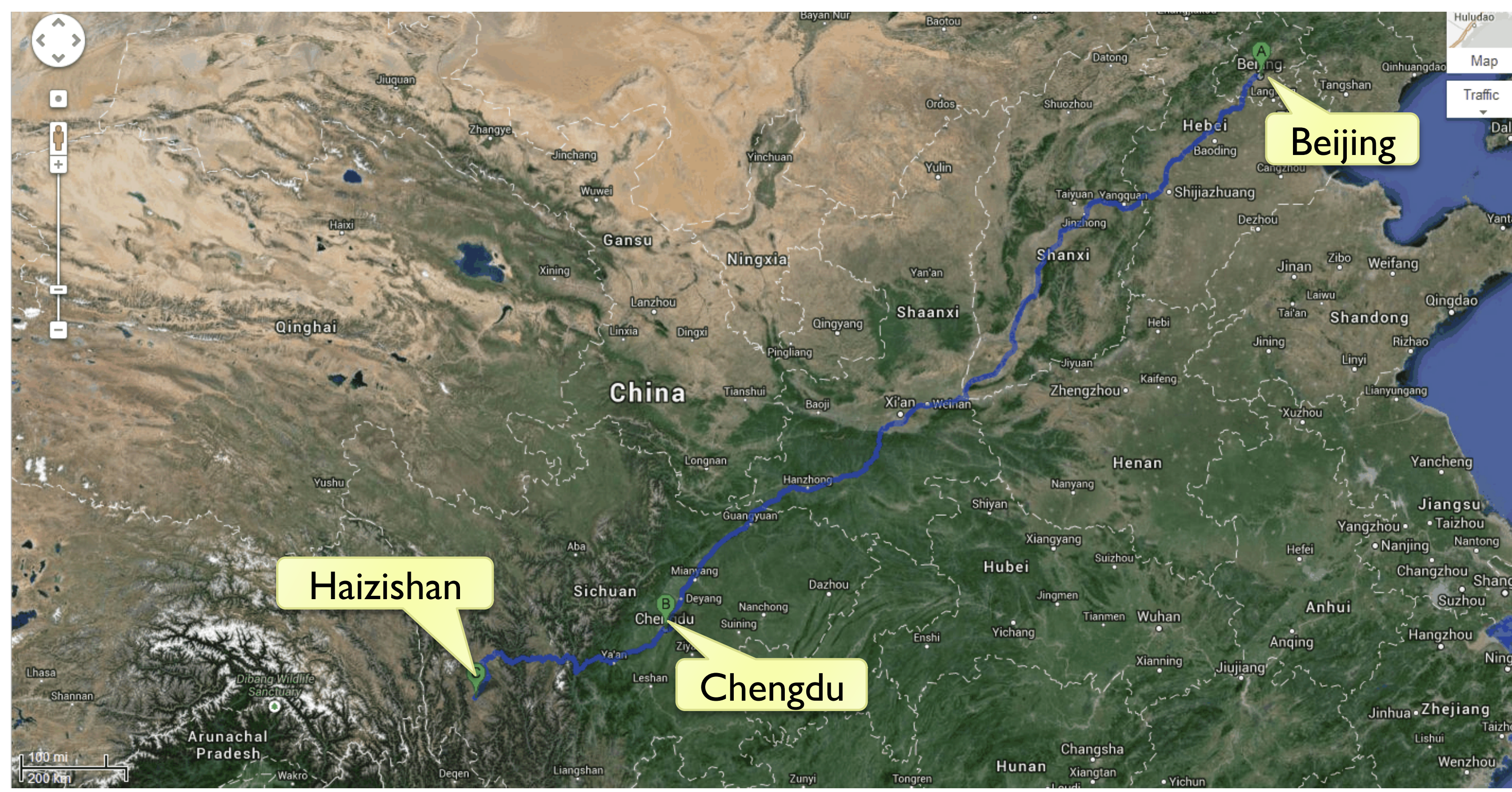
- ★ The first pond (HAWC-like) will be completed by the end of 2017 and instrumented in 2018.
- ★ 1/4 of the experiment in commissioning by the end of 2018 (sensitivity better than HAWC):
  - 6 WFCTA telescopes
  - 22,500 m^2 water Cherenkov detector
  - ≈200 muon detectors covering 250,000 m^2
- ★ Completion of the installation in 2021.

The LHAASO site

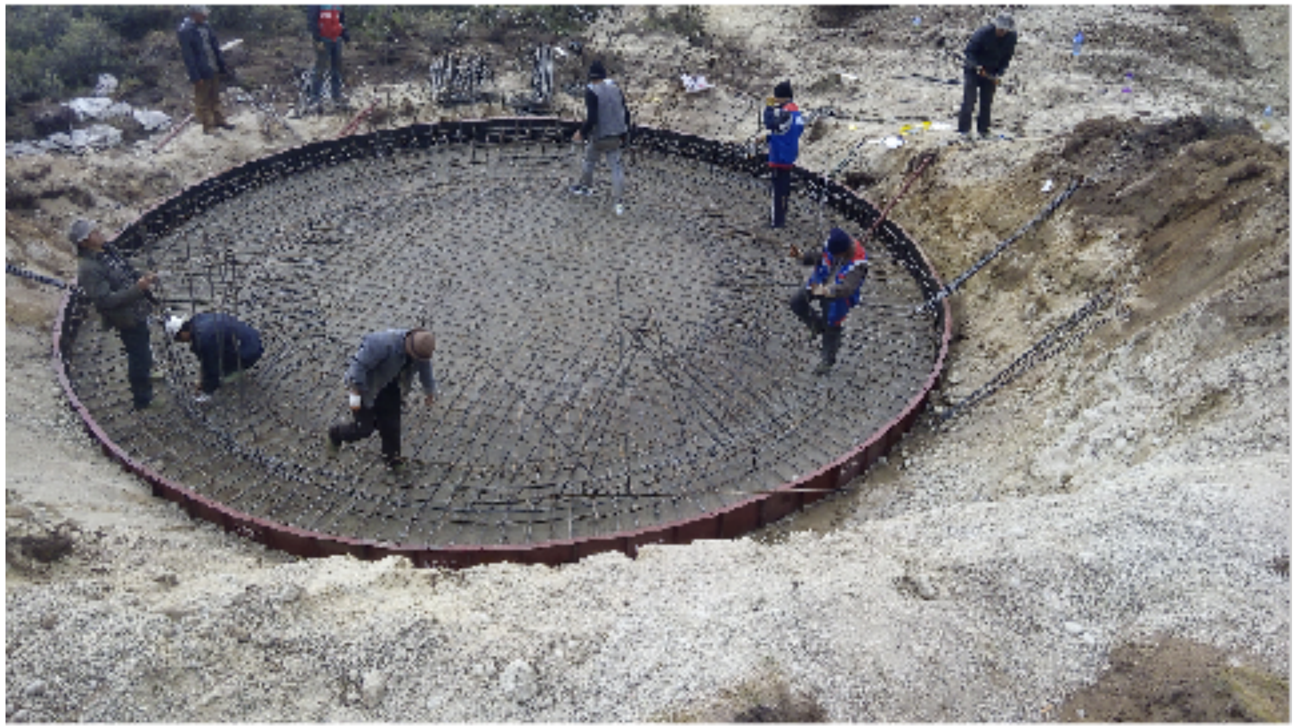
The experiment will be located at 4400 m asl (600 g/cm^2) in the Haizishan (Lakes' Mountain) site, Sichuan province

Coordinates: 29° 21' 31'' 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: muon detectors



Living Base and Data Center at Daocheng

Daocheng town, 50 km from the site at 3750 m asl

Guest House for 50 persons

Assembling House
& Meeting room

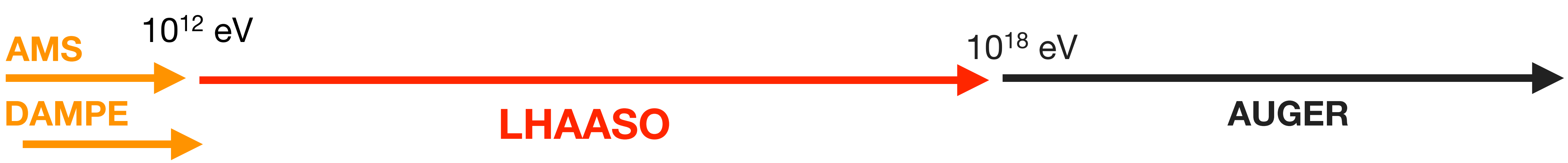
Cafeteria

LHAASO: from γ-Ray Astronomy to Cosmic Rays

LHAASO is an experiment able of acting simultaneously
as a Cosmic Ray Detector and a Gamma Ray Telescope

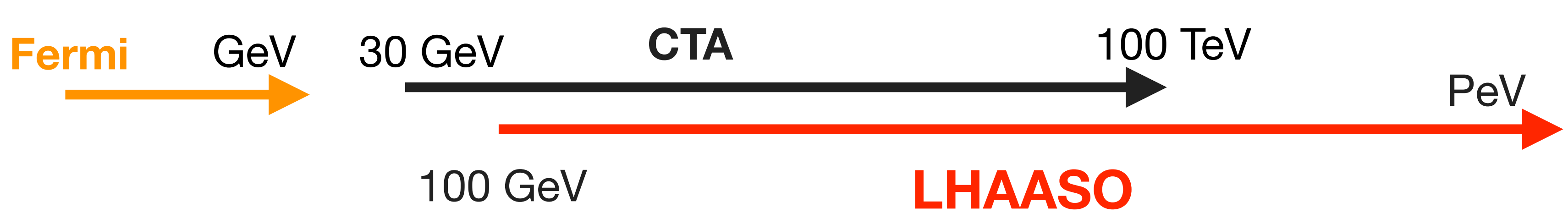
✤ Cosmic Ray Physics ($10^{12} \rightarrow 10^{18}$ eV): precluded to Cherenkov Telescopes

- CR energy spectrum
- Elemental composition
- Anisotropy

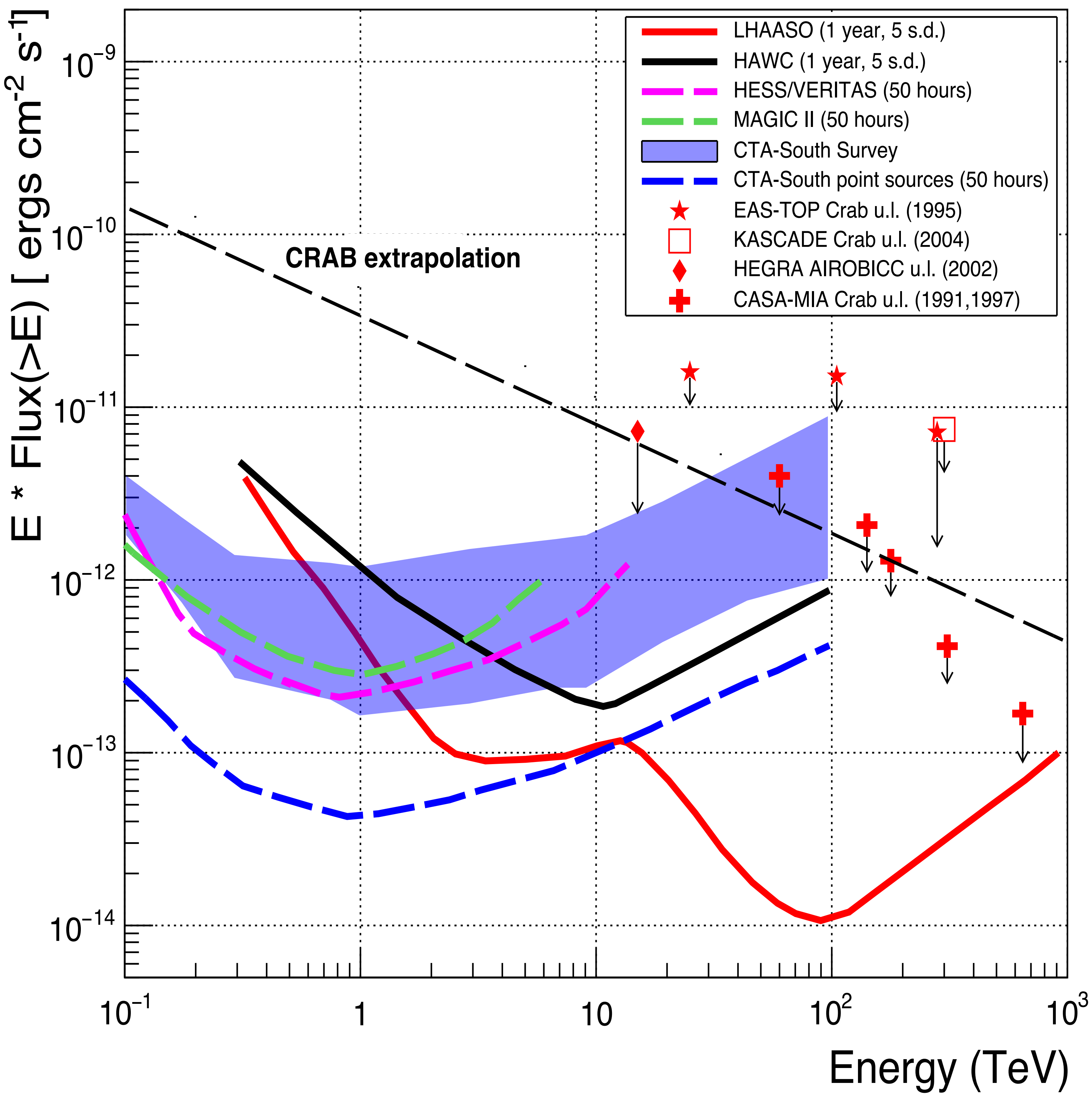


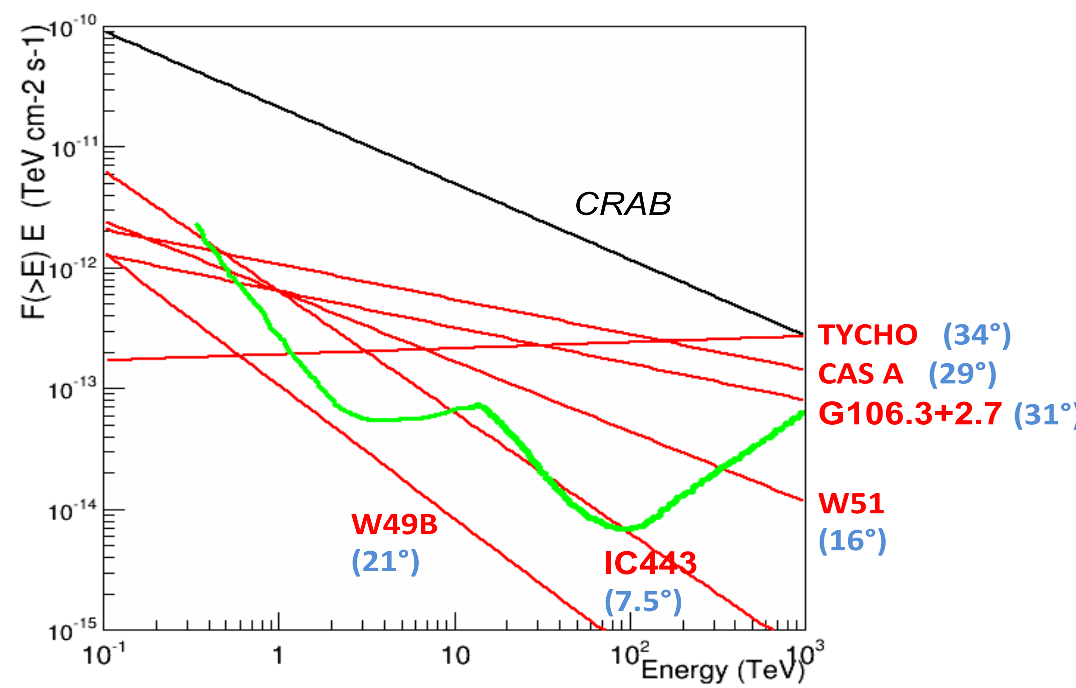
✤ Gamma-Ray Astronomy ($10^{11} \rightarrow 10^{15}$ eV): full sky continuous monitoring

- Complementary with CTA below 20 TeV, with better sensitivity at higher energies and for flaring emission (GRBs), unbiased all-sky survey, extended and diffuse emission.
- Searching for *PeVatrons* (→ neutrino sources)



Gamma-Ray Astronomy with LHAASO





LHAASO will observe at TeVs, with high sensitivity, >40 of the sources catalogued by Fermi-LAT at lower energy, monitoring the variability of >20 AGNs.

Wide Field of View Cherenkov Telescopes

One of the main component of LHAASO is the array of
Wide Field of View Cherenkov Telescopes WFCTA.

The goal: measurement of the CR energy spectrum and composition in the range 10^{13} - 10^{18} eV

Why Cherenkov telescopes at high altitude ?

High altitude:

(1) Measure EASs near maximum development points to reduce fluctuations.

(2) Use an unbiased trigger threshold for heavy components of primaries.

(3) Low energy theshold and wide energy range ($10^{13} \rightarrow 10^{18}$ eV).

Cherenkov signal:

(3) Low energy theshold and wide energy range ($10^{13} \rightarrow 10^{18}$ eV).

(4) Measure the electromagnetic component which is less dependent on hadronic interaction models than the muon component.

(5) Good separation capability between the different masses.

(6) Good energy resolution (<20%).

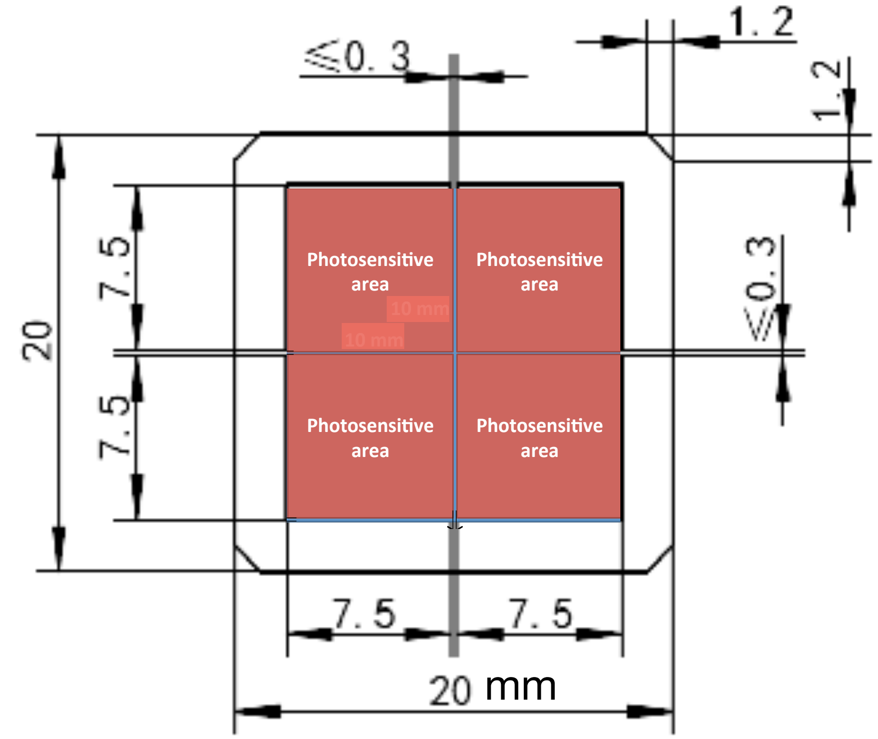
Chin. Phys. C 38, 045001 (2014)
Phys. Rev. D 92, 092005 (2015)

Observation modes: Cherenkov and Fluorescence Light in Phase-II

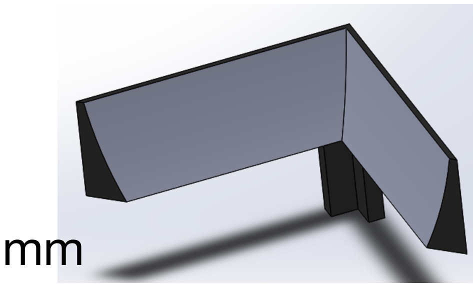
SiPM camera and focal plane

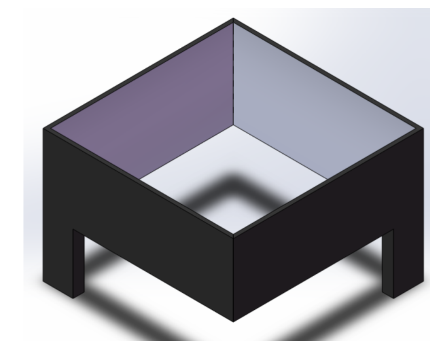
SiPM pixel:
2x2 SiPM 0.75 cm^2 area

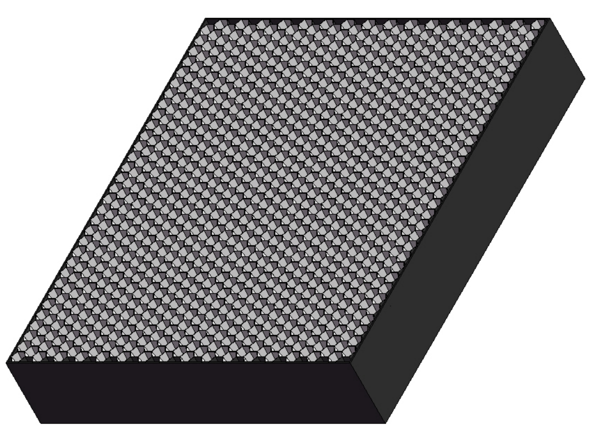
1 HV per pixel
1 temperature sensor per pixel



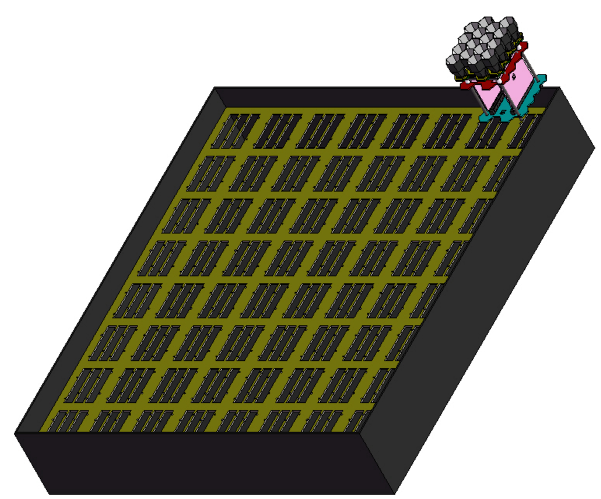
Winston Cone
EXIT： 20 mm × 20 mm
ENTRANCE: 24.4 mm × 24.4 mm
HEIGHT: 9.6 mm





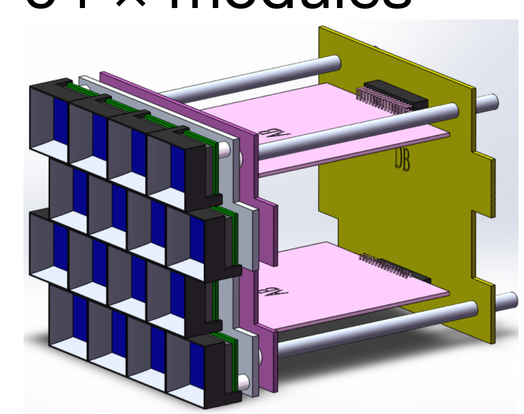


SiPM camera： 32 × 32 SiPM pixels



8 x 8 module camera box

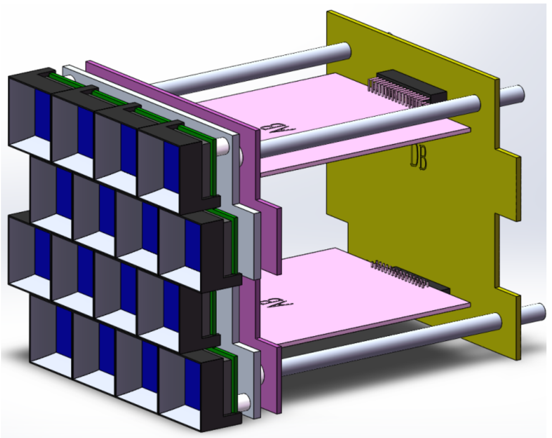
64 × modules

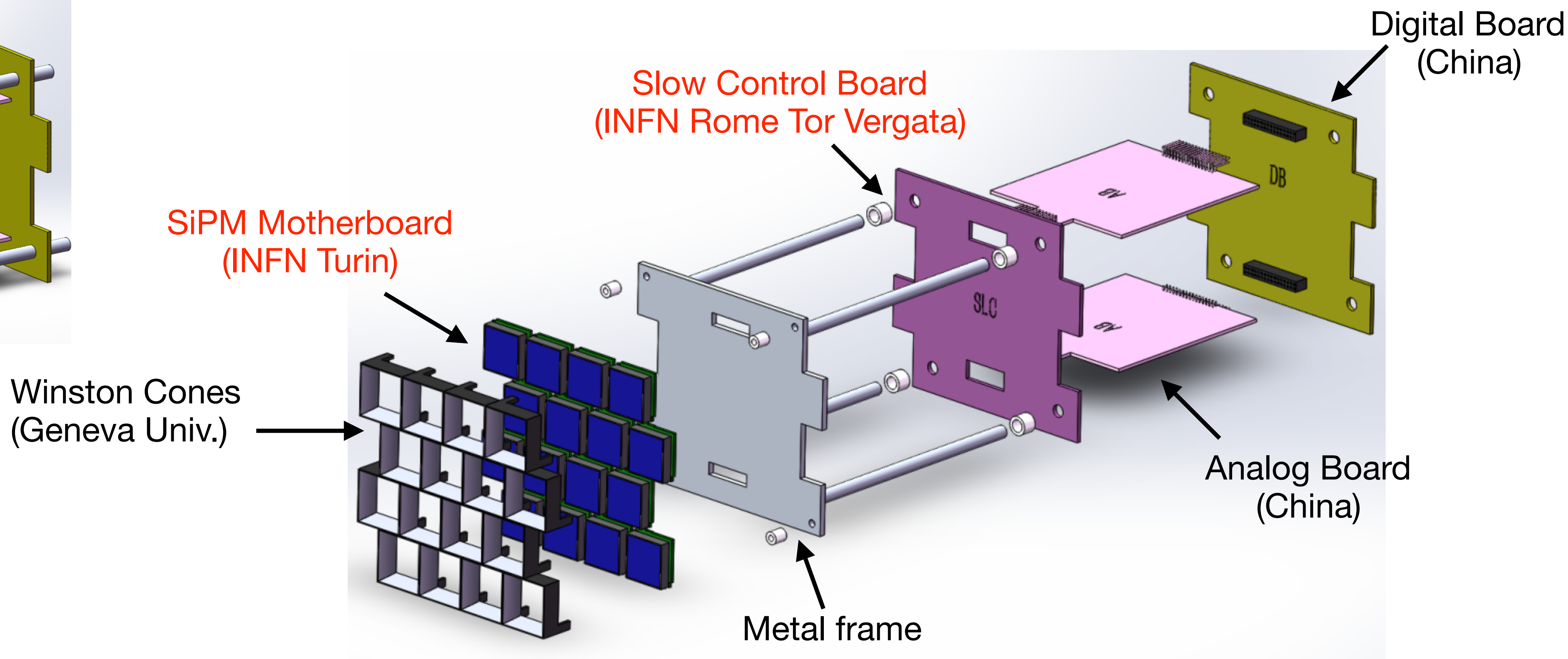


A module has 4×4 pixels

Focal Plane: 2.25 cm^2 x 1024 = 2304 cm^2 / telescope ➜ 4.15 m^2 SiPM total + spare

A SiPM module





A bidding procedure is underway to buy the SiPMs for WFCTA telescopes.

LFoundry company (with INFN for WB packaging) will respond to the bid.

We hope that the SiPMs developed by INFN-FBK for the first time will instrument an operating Cherenkov telescope array.

First telescope in commissioning by the end of 2017 !

Southern Hemisphere: ALPACA

Andes
Large area
PArticle detector for Cosmic ray physics
and Astronomy

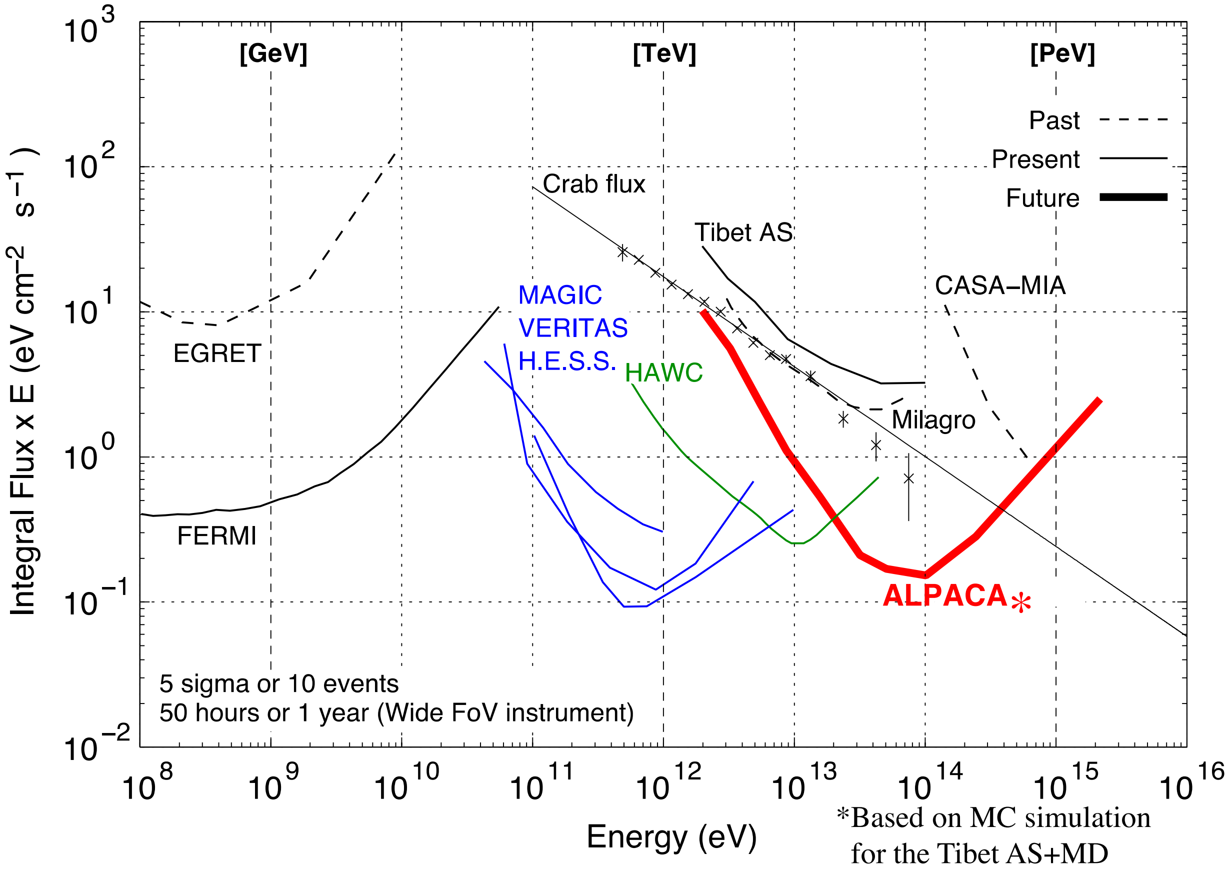
Location: 4,740 m above sea level (16˚23’S, 68˚08’W)

# of scintillation detectors	1 m^2 x 401 detectors
Effective area of	~83,000 m^2
modal energy	~5TeV
angular resolution	~0.2 @100 TeV
energy resolution	~30% @100TeV
field of view	~2 sr

CR rejection power	>99.9%@100 TeV
(γ ray efficiency ~ 90 %)	

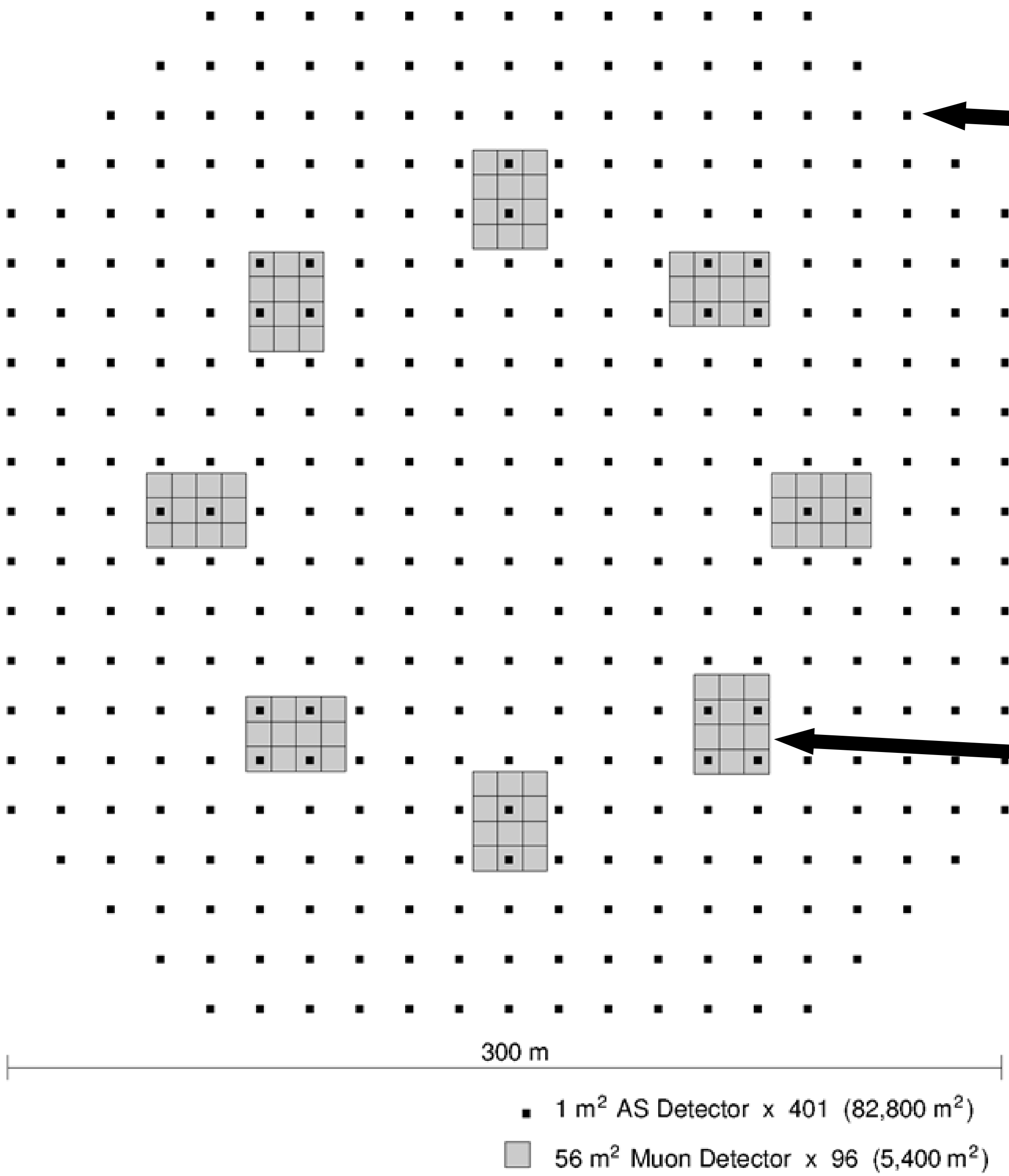
MD Array 56m^2 x 96 detectors

- Effective area for muons ~5400m^2
- CR rejection power >99.9% @100TeV (gamma ray efficiency ~90%)



Tibet ASγ experiment moved from Tibet to Bolivia

ALPACA layout



AS

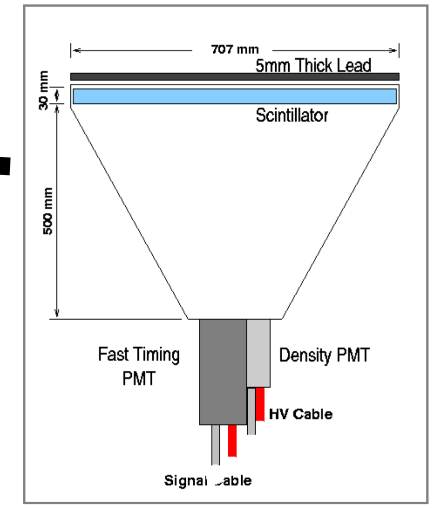


Image of $1m^2$ plastic scintillation detector

MD

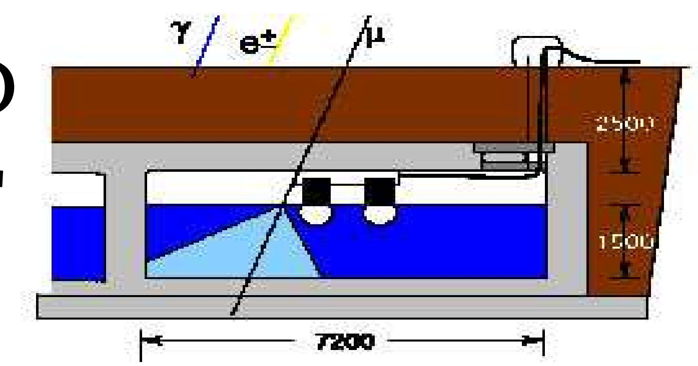


Image of unit ($56m^2$) underground water Cherenkov muon detector

15

ALPAQUITA (1/10 scale ALPACA AS , in 2017)

Southern Hemisphere: LATTES

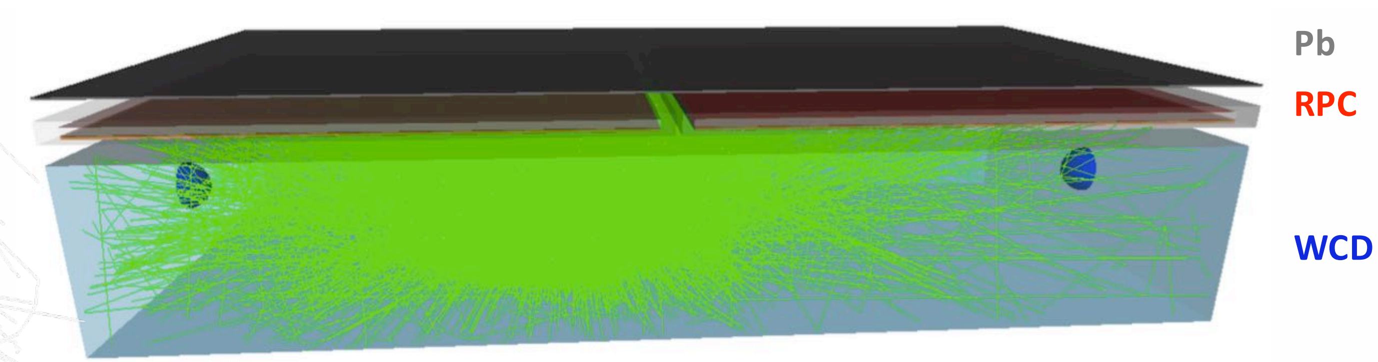
arXiv:1607.03051

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

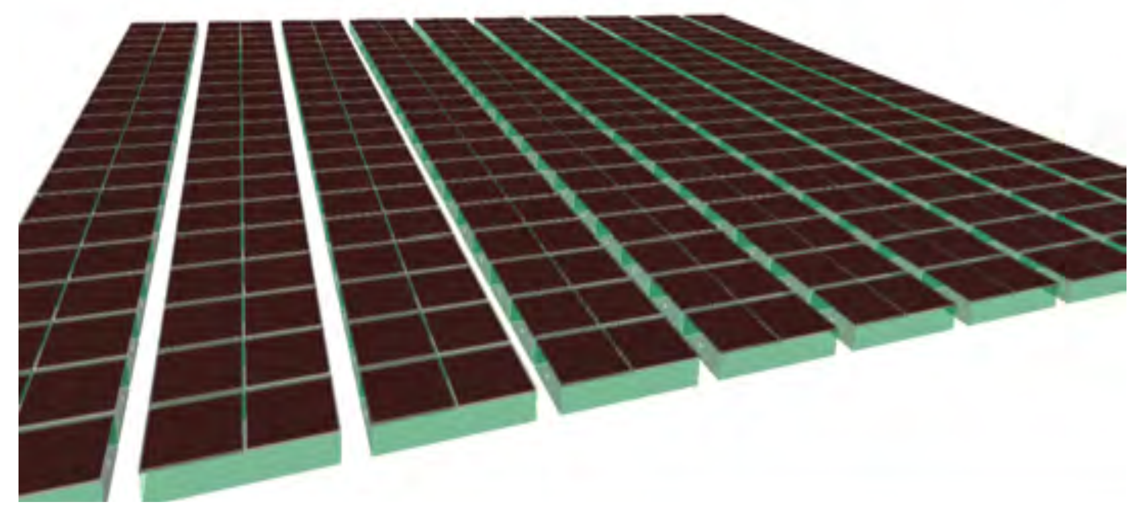
An array of hybrid detectors constituted by

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.



- Thin lead plate (Pb)
  - 5.6 mm (one radiation lenght)
- Resistive Plate Chambers (**RPC**)
  - 2 RPCs per station
  - Each RPC with 4x4 readout pads
- Water Cherenkov Detector (**WCD**)
  - 2 PMTs (diameter: 15 cm)
  - Dimensions: 1.5 m x 3 m x 0.5 m



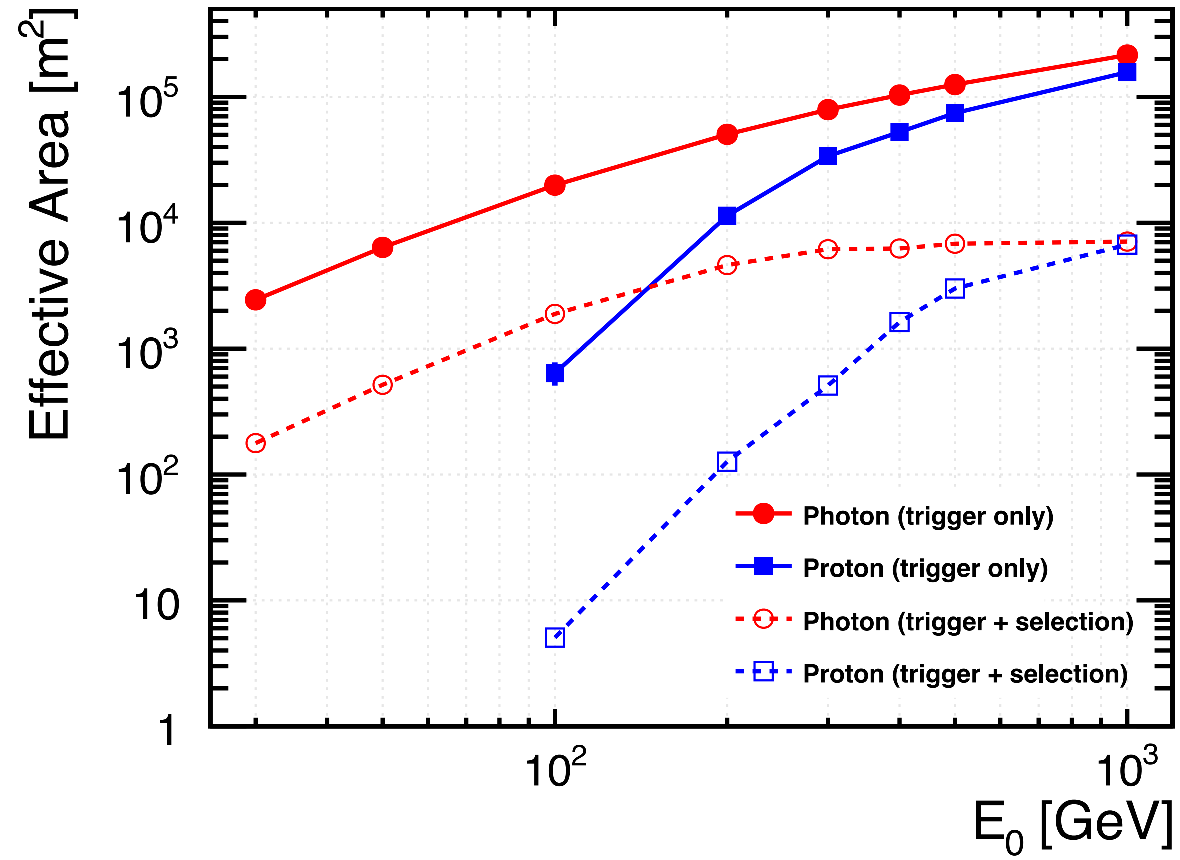
Possible limit: fragility of glass RPCs

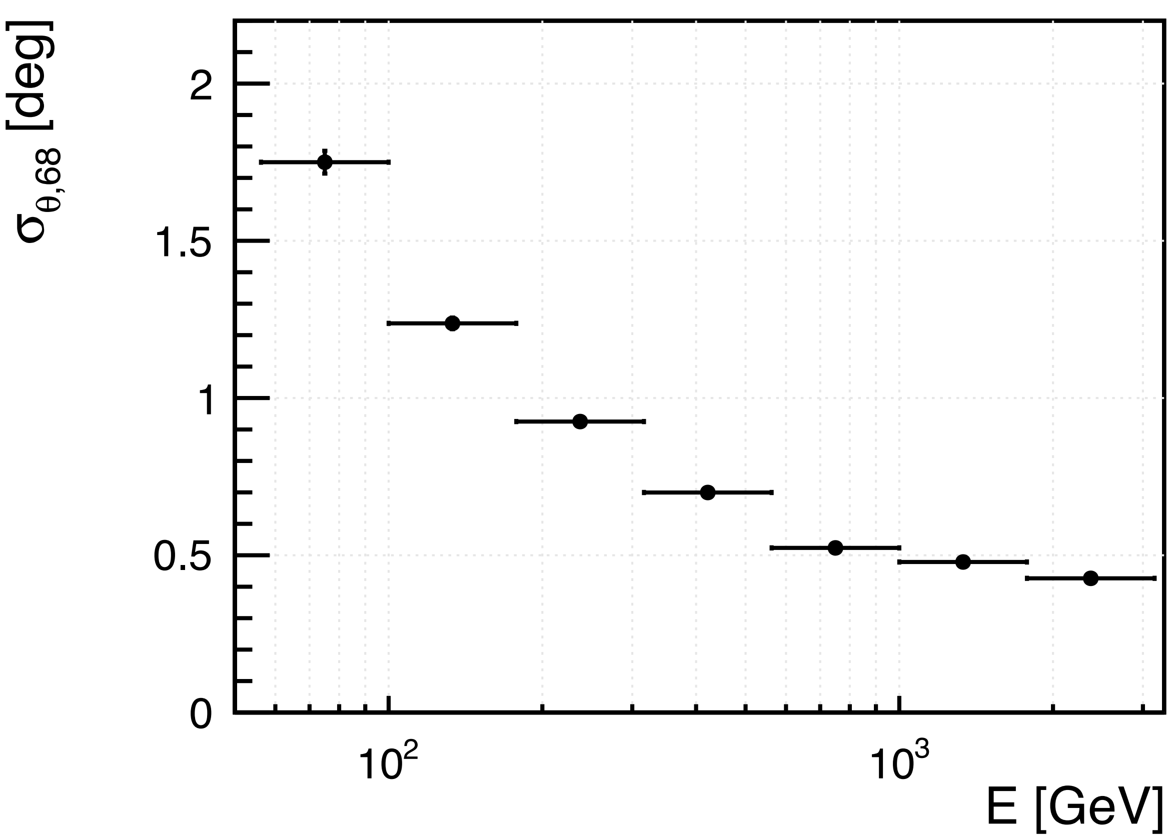
LATTES performance

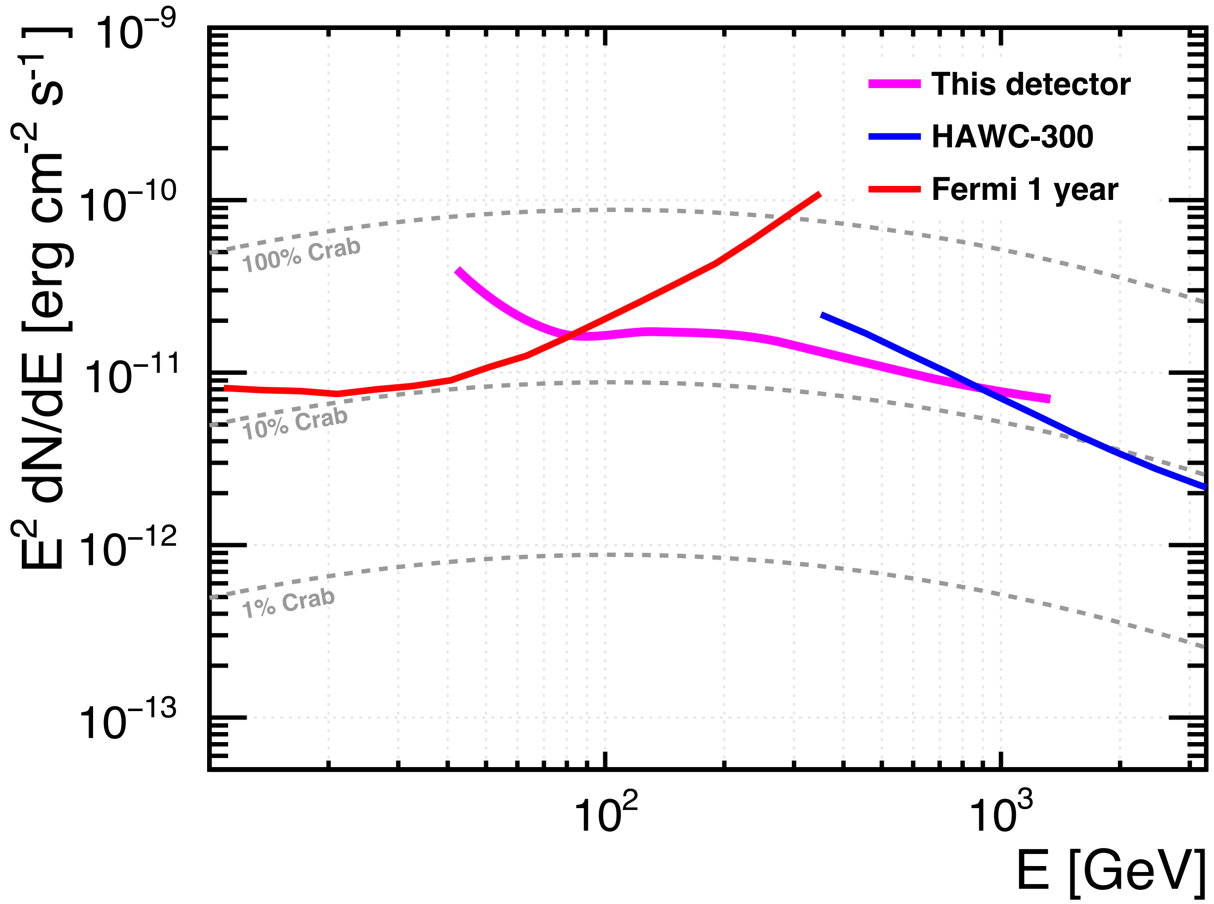
Preliminary calculations

Baseline configuration with 60 rows and 30 lines, instrumented area ≈10,000 m^2.

Simulated site at 5200 m asl

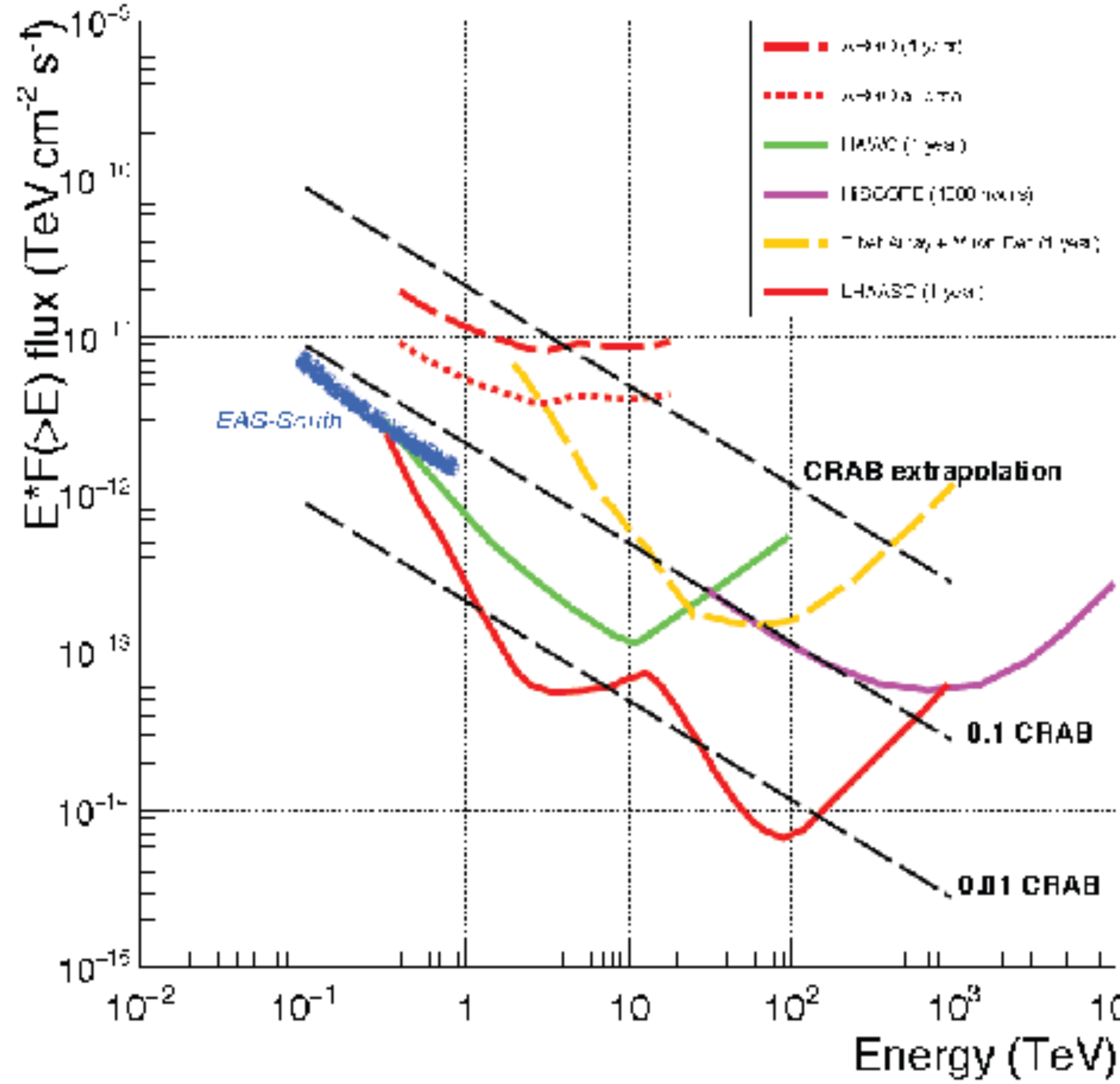






Southern Hemisphere: STACEX

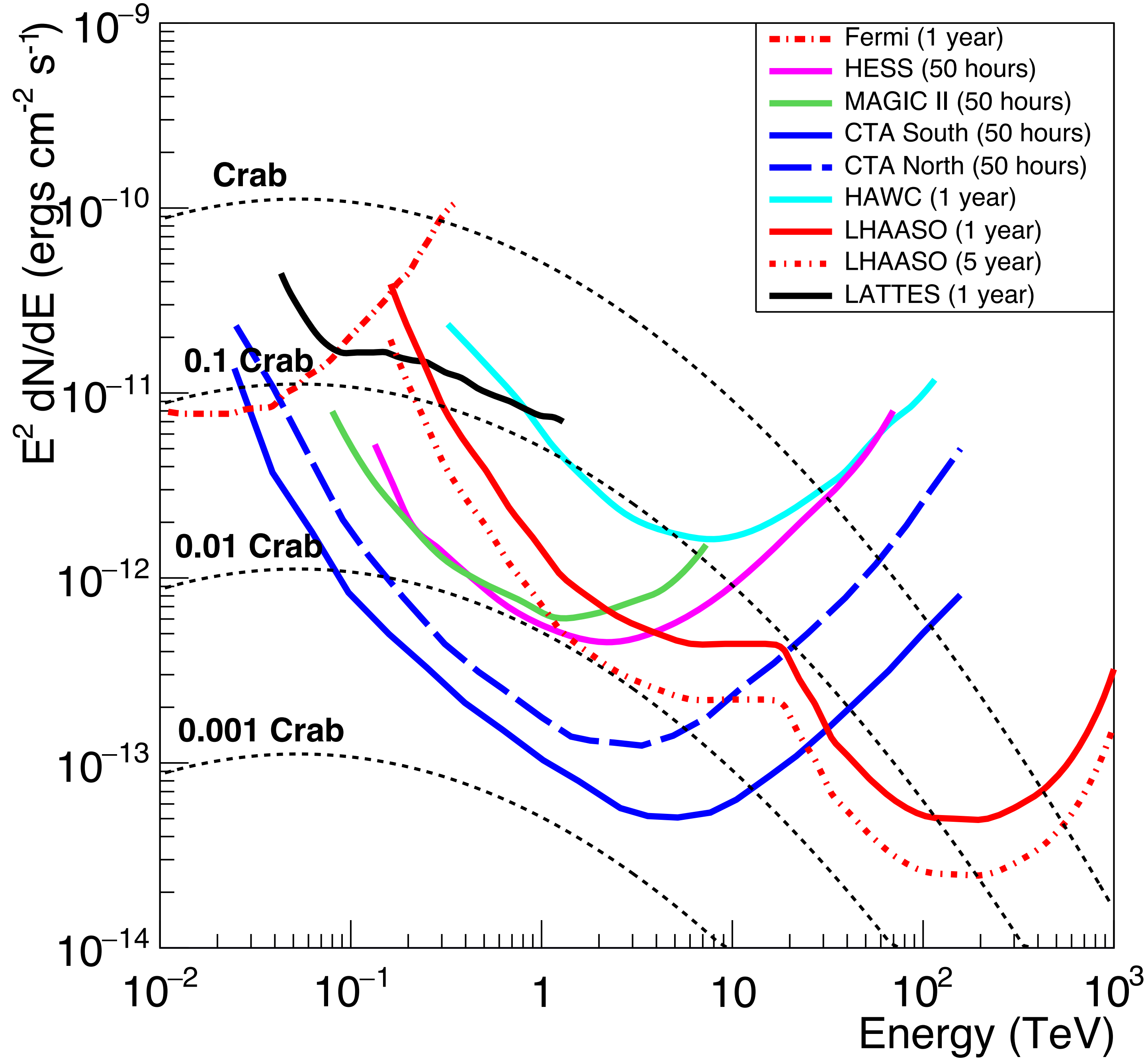
Calorimetric approach with a double layer of RPCs (with lead layer in between) to enhance the conversion of secondary photons.



- A RPC carpet of 100 x 100 m^2 at least
- bakelite RPCs (ARGO-like)
- fully 'analog' read out

A study is underway in Rome to investigate the sensitivity of a RPC carpet operated at extreme altitude.

TeV - PeV γ-ray astronomy



LHAASO sensitivity is well matched to current generation of IACTs (HESS, VERITAS, MAGIC)

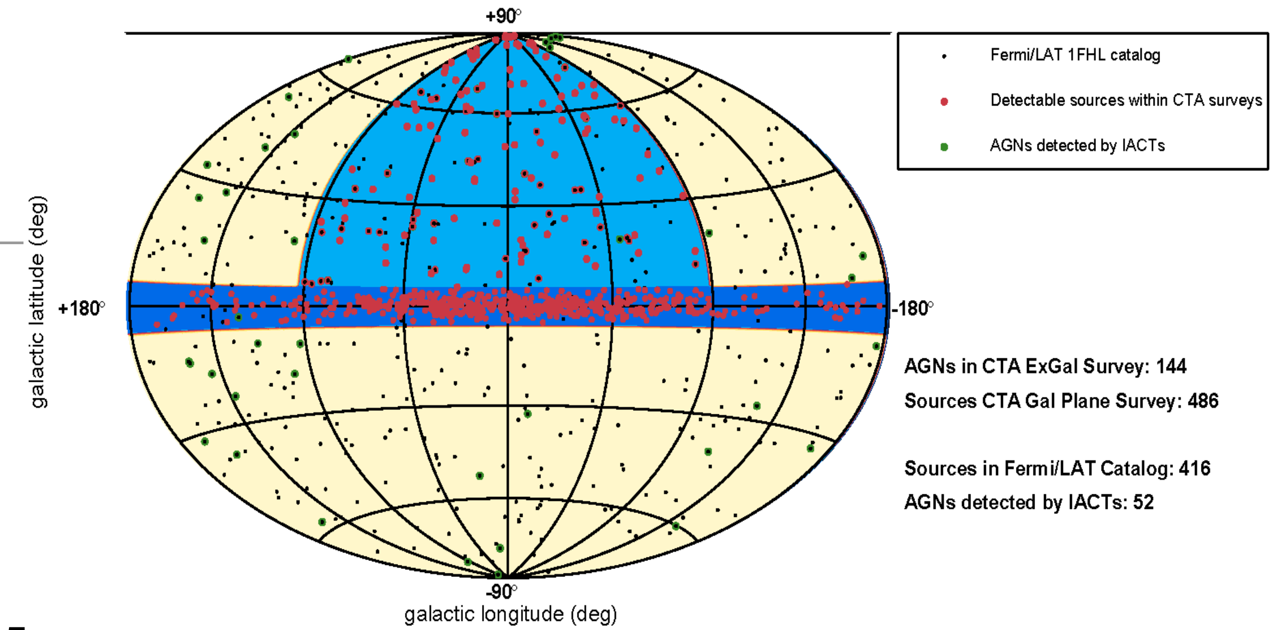
CTA Sky Survey Plans

CTA:

★ Survey of entire Galactic Plane to ≈ 2 - 4 mCrab

★ Unbiased survey of 1/4 sky to ≈ 6 mCrab

from R. Ong, 2015



- Previous Surveys:

Experiment	Hemisphere	Galactic Plane Coverage	Energy (GeV)	Sensitivity (mCrab)
H.E.S.S.-I	S	$-70° < l < 60°$, $\|b\| < 2°$	$>\sim 300$	10 – 30
VERITAS	N	$67° < l < 83°$, $-1° < b < 4°$	$>\sim 300$	20 – 30
ARGO-YBJ	N	Northern Sky	> 300	240 – 1000
HEGRA	N	$-2° < l < 85°$, $\|b\| < 1°$	> 600	150 – 250
Milagro	N	Northern Sky	$> 10,000$	300 – 500

from CTA Science Case, 2015

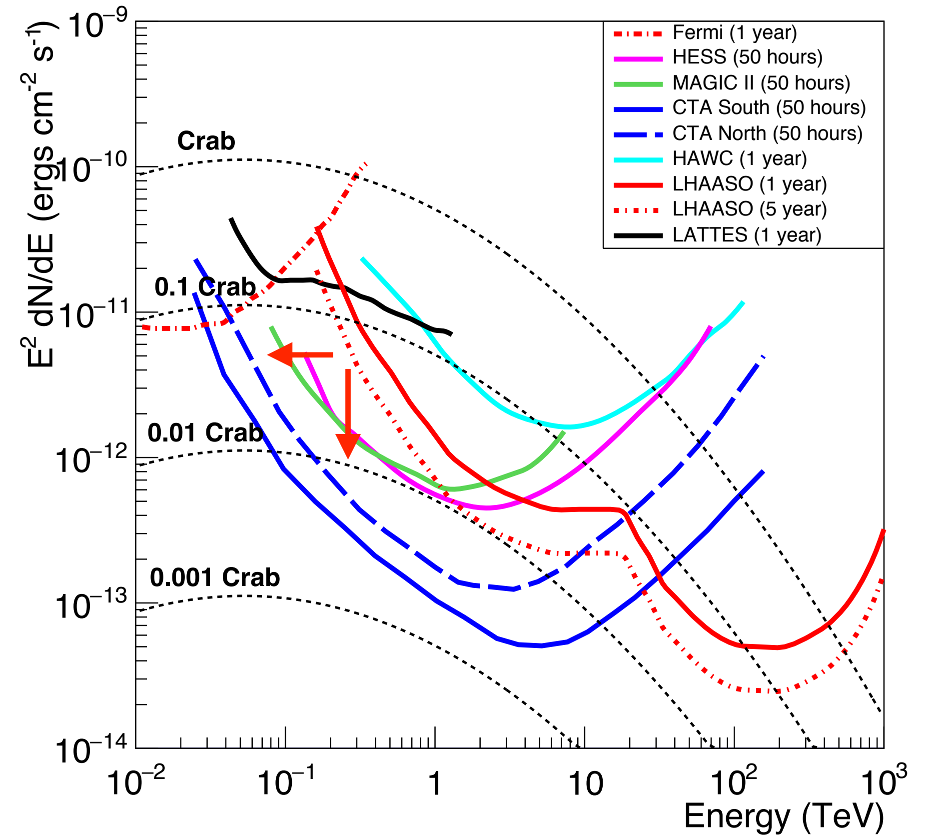
- Present/Future Surveys:

Observatory	Hemisphere	Energy Threshold	Angular Resolution	Pt. Source Sensitivity
CTA	N, S	125 GeV	$\sim 0.07°$ at 1 TeV	2 – 4 mCrab
HAWC	N	2 TeV	$0.30°$	20 mCrab (5 yr)
LHAASO	N	≈ 500 GeV	≈ 0.30° at 1 TeV	10 mCrab (1 yr)

CTA and a new Wide FoV observatory

A future Wide FoV Observatory to be useful to CTA needs:

- ≈ 5x - 10x greater sensitivity below TeV
- Lower energy threshold (≈ 100 - 300 GeV)
- Ability to detect extragalactic transient (AGN, GRBs)
- *Southern hemisphere site*



★ Is this possible ?

Φ_B = background flux

ψ_{70} = opening angle

$A_{eff}^{\gamma,p}(E)$ = effective area

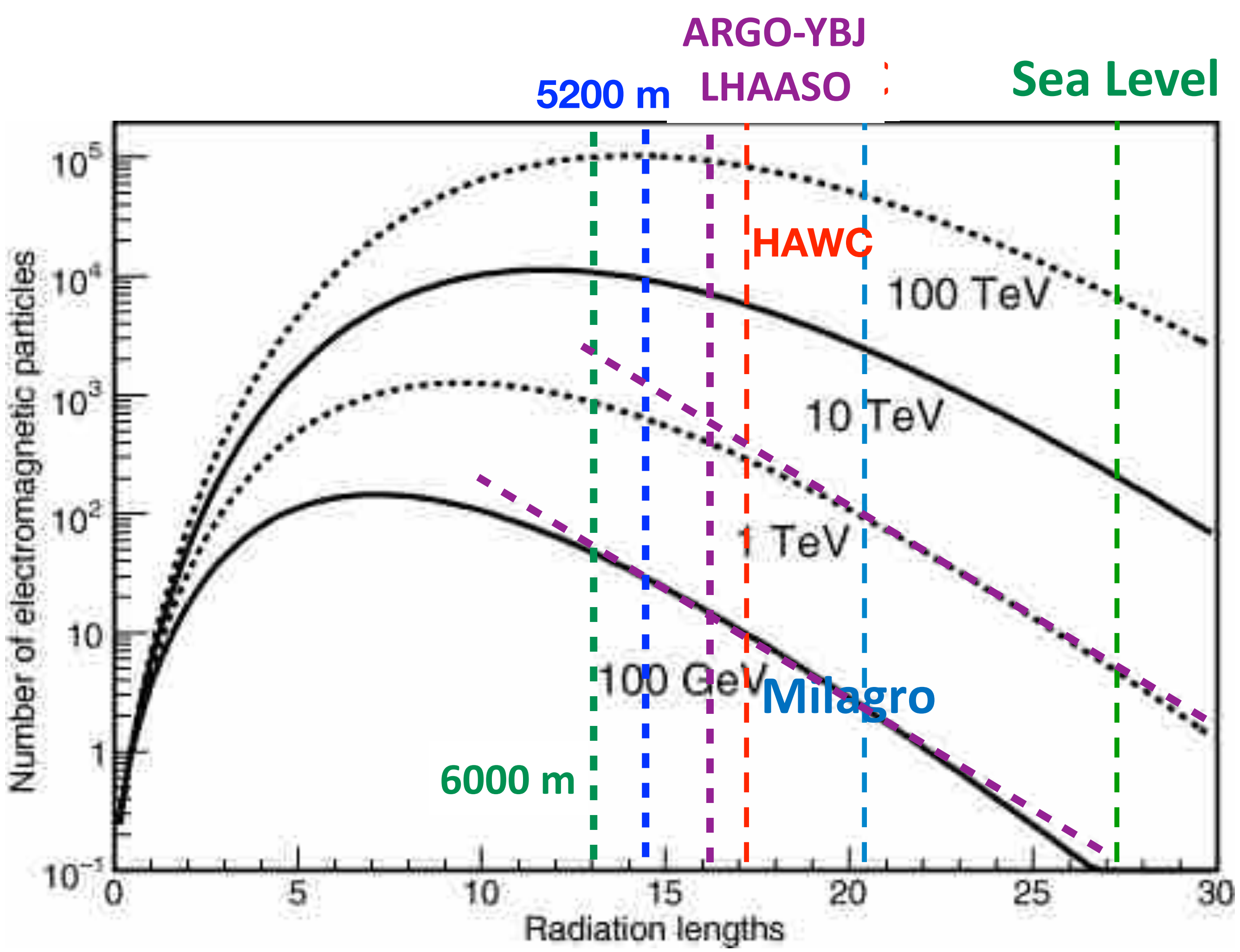
Minimum Detectable Gamma-Ray Flux (1 year):

$$\Phi_\gamma^{MDF} \propto \sqrt{\Phi_B} \cdot \frac{1}{R \cdot \sqrt{A_{eff}^\gamma}} \cdot \psi_{70} \cdot \frac{1}{Q_f}$$

$$R = \sqrt{\frac{A_{eff}^\gamma(E)}{A_{eff}^B(E)}}$$

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

Lowering the energy threshold: extreme altitude



Showers of all energies have the same slope after shower maximum: ≈1.65x decrease per r.l. .
So, for all energies, if a detector is located one radiation length higher in atmosphere, the result will be a ≈1.65x decrease in the energy observable.

HAWC (4100 m asl)
ARGO-YBJ/LHAASO (4400 m asl) = 1, 1 energy thr.
Chacaltaya (5200 m asl) ≈2x, ≈3x energy thr.
6000 m asl ≈3x, ≈5x energy thr.

increase in size **decrease in en. thr.**

This imply that the effective areas of EAS detectors increases at low energies.

Lowering the energy threshold:

- Extreme altitude (>4400 m asl)
- Detector and layout
- Coverage
- Detection of secondary photons

Energy threshold

ARGO-YBJ (final)

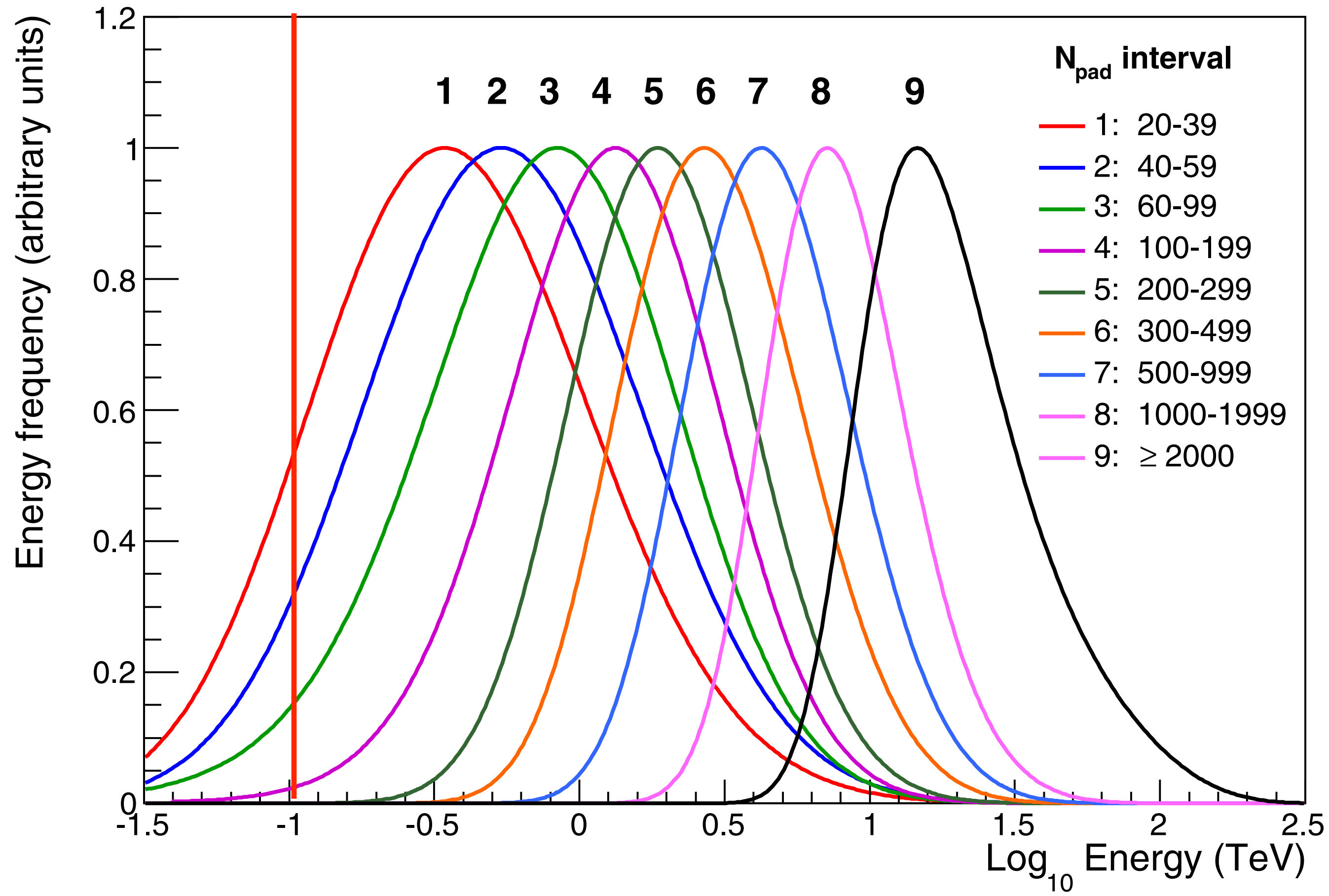


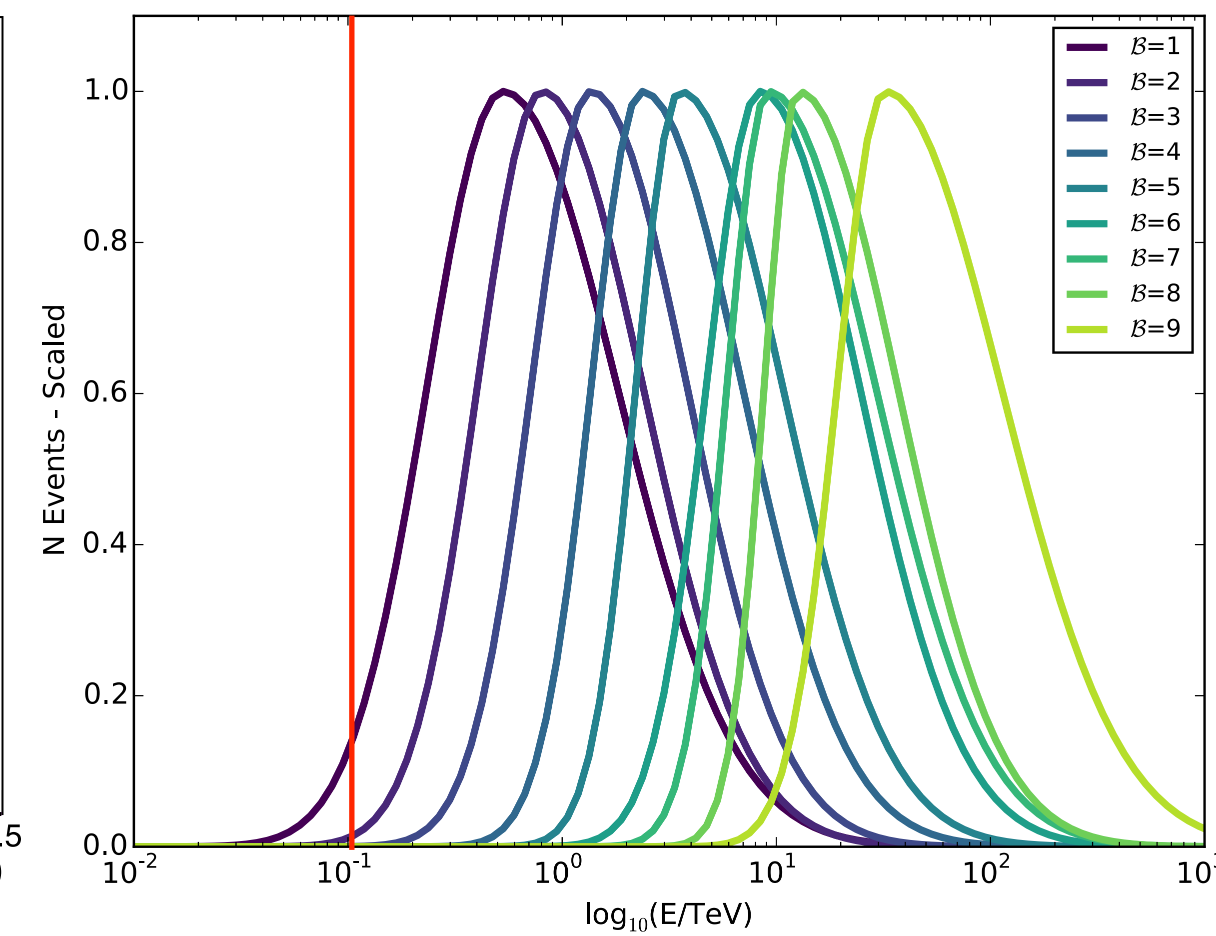
Figure 3. Normalized distribution of the primary gamma-ray energy for different N_{pad} intervals, for a Crab-like source.

full coverage RPC carpet operated at 4300 m asl

coverage ≈ 92%

high granularity

HAWC (2017)

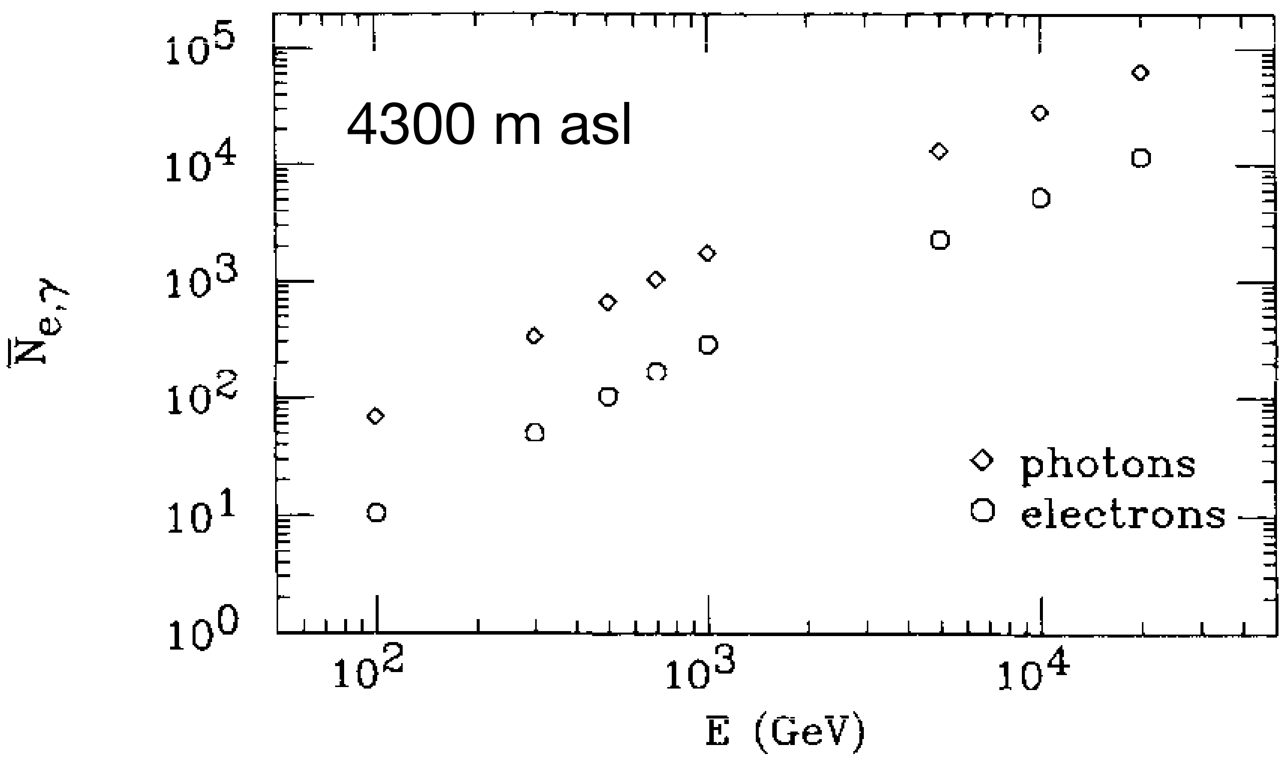


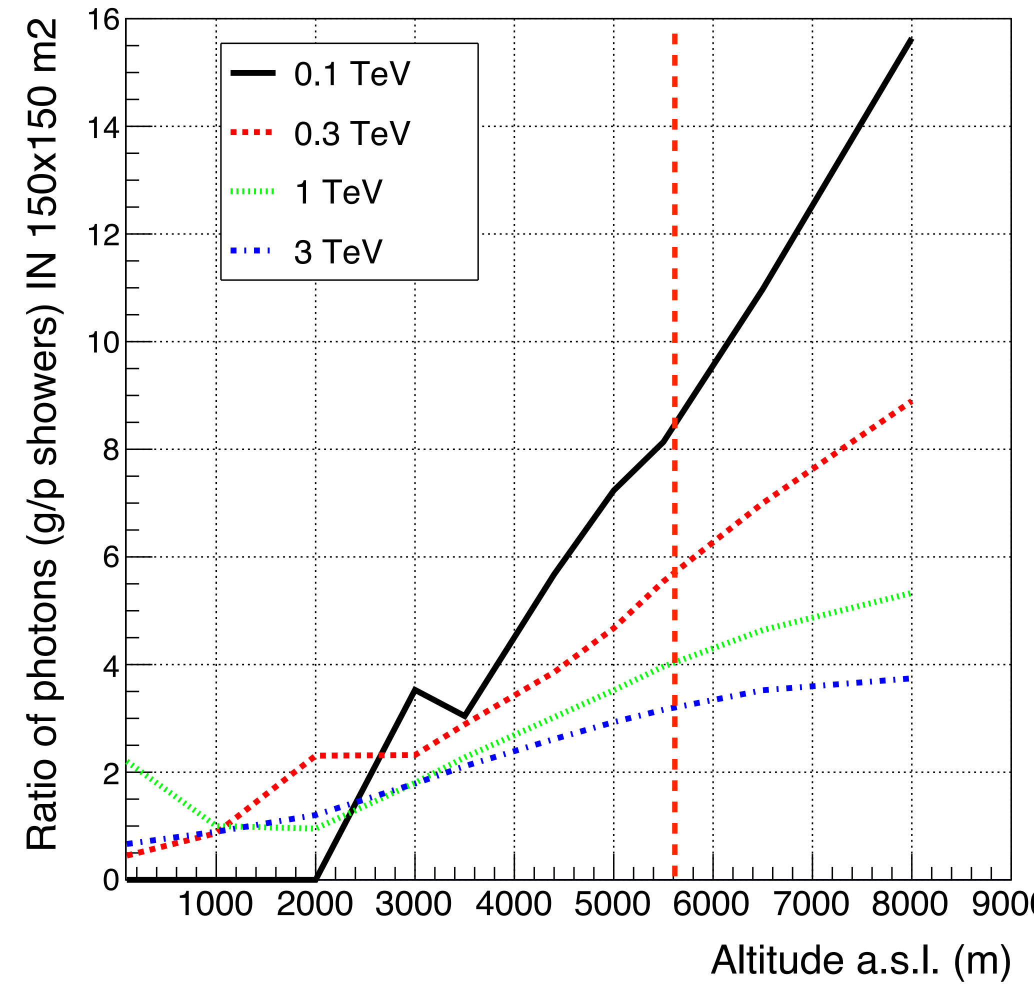
array of water tanks operated at 4100 m asl

coverage ≈ 60%

Secondary photons

gamma rays dominate the particles on ground (≈7:1 for 100 GeV γ-showers at 4300 m asl)





In γ-showers the ratio Nγ/Nch decreases if the comparison is restricted to a small area around the shower core.
For instance, we get Nγ/Nch ≈3.5 at a distance $r < 50$ m from the core for 100 GeV showers.

The number of secondary photons in γ-showers exceeds the number of gammas in p-showers with increasing altitude.

Detection of secondary photons very important to lower the energy threshold and to improve the angular resolution

Effect of a lead converter above a detector

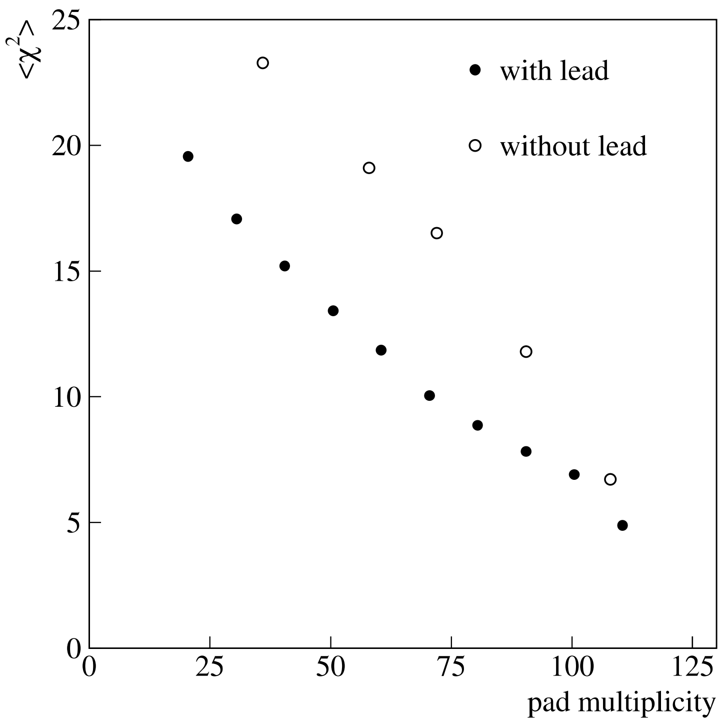
The consequences of placing a thin sheet of dense, high-Z material, above detectors are, qualitatively:

(1) low-energy electrons are absorbed and no longer contribute to the signal (low-energy photons are also absorbed),

(2) high-energy electrons produce an enhanced signal size through multiplication,

(3) high-energy photons materialise, producing additional signal contributions similar in size to those produced by (2).

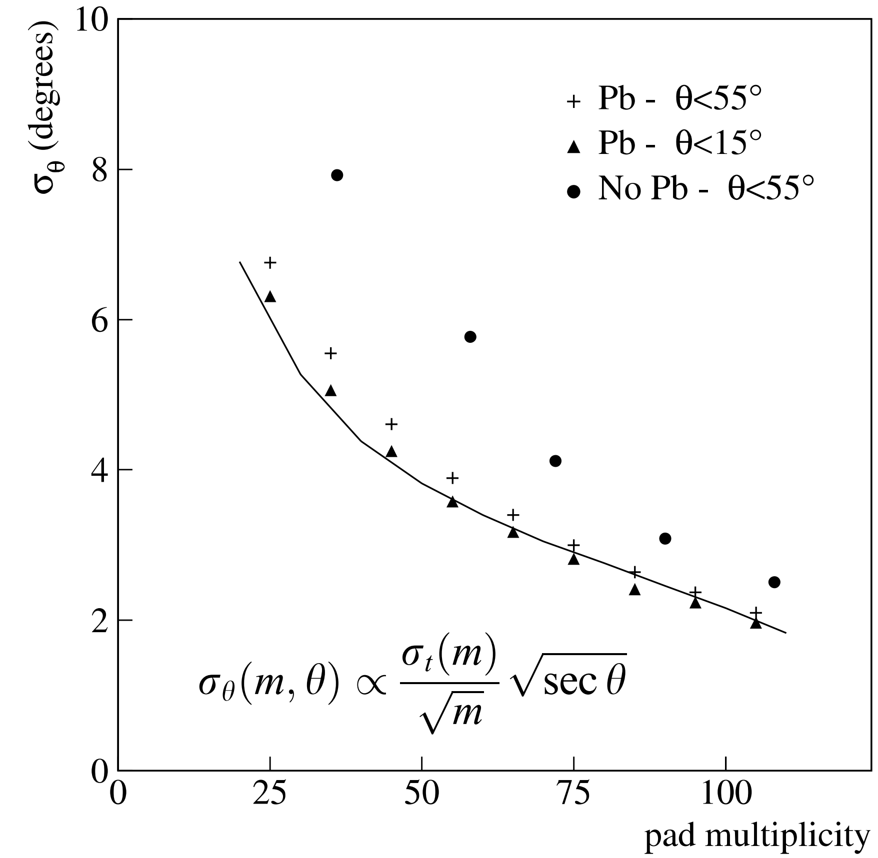
The number of particles gained from processes (2) and (3) exceeds that lost through (1) and hence the *Rossi transition effect* is observed.



$(\chi^2)^{1/2}$ represents (approximately) the average time spread

The enhanced signal alone, arising from this, will reduce the timing fluctuations.

In addition, the contributions gained are concentrated near the ideal time because the higher energy electrons and photons travel near the front of the particle swarm (they suffer from smaller time delays) while those lost tend to lag far behind.



Test with ARGO at YBJ

Angular resolution

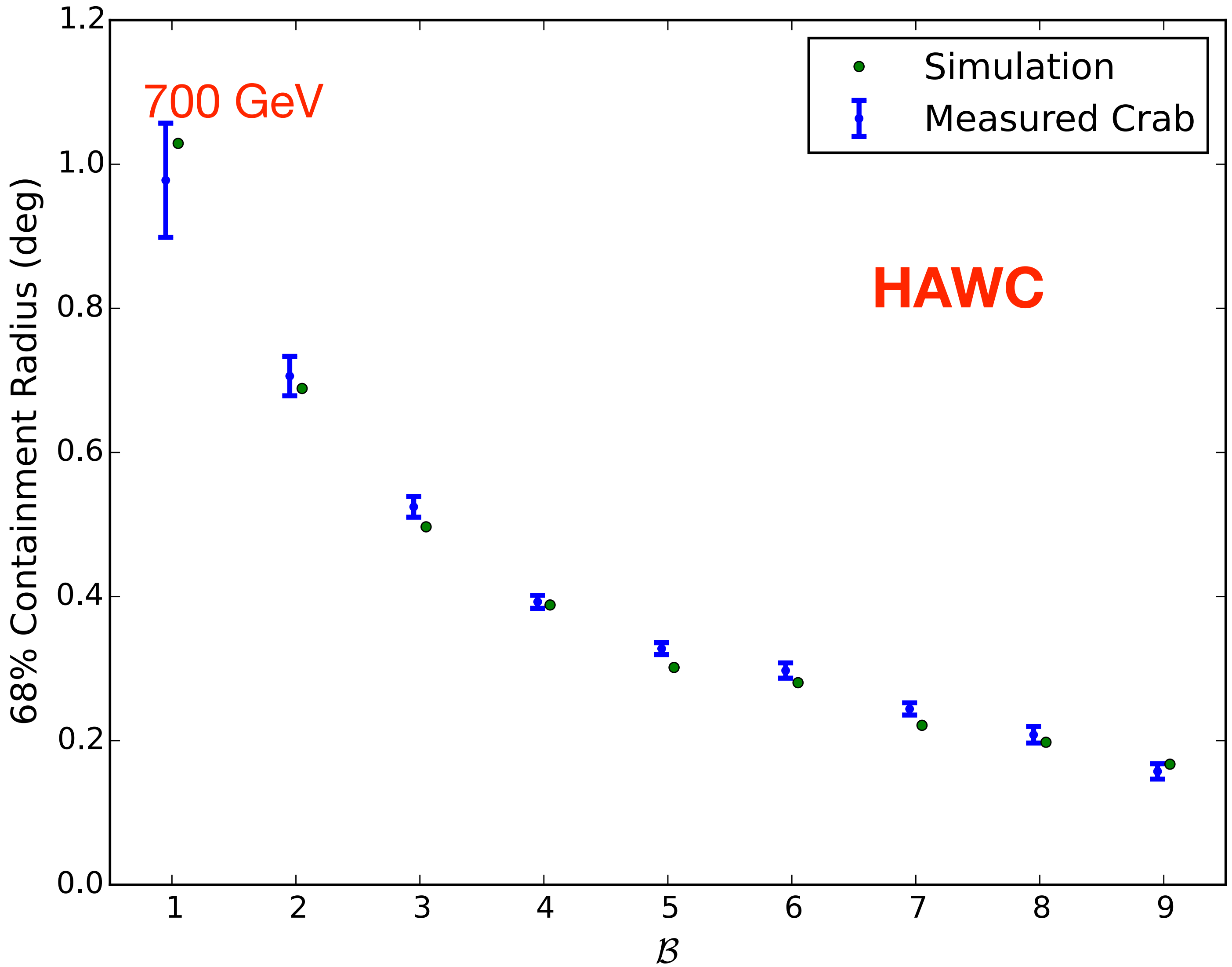
(1) larger carpet: ang. res. improves with the lever arm ➔ from ARGO to 100 x 100 m^2: ≈1.4x
(2) 0.5 mm lead: ≈1.5x at the threshold
(3) 5200 m asl: ≈2x in size ➔ ≈1.4x

bin 20 - 40 pads: photons

$E_{50} \approx 360$ GeV (≈ 1 TeV for protons)
$\sigma_\theta \approx 1.66^o$ (2D Gaussian PSF)
$\varepsilon_\gamma = 73\%$

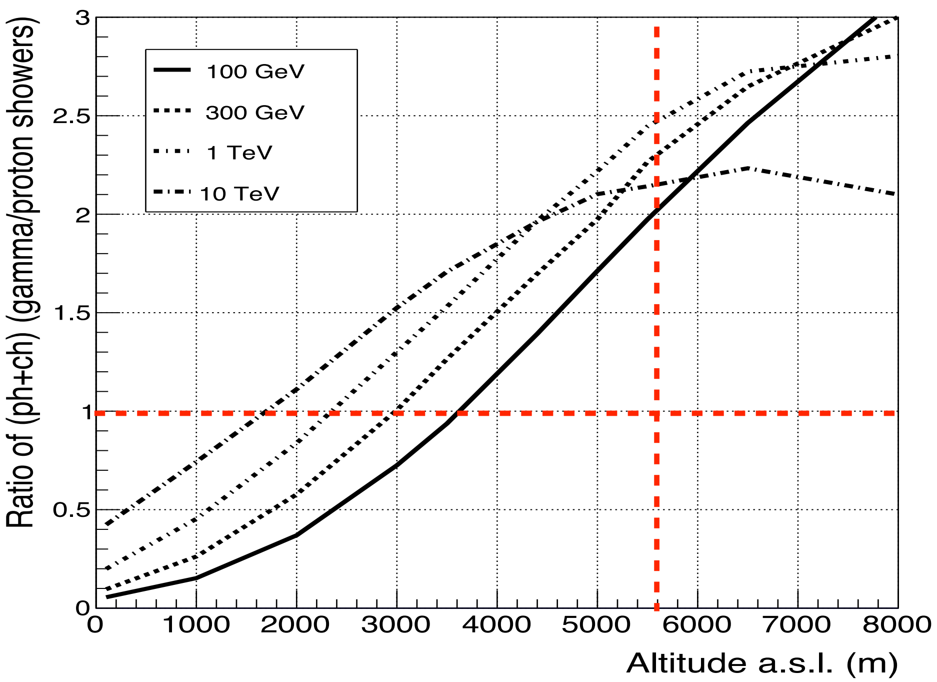
At 5200 m asl we expect ≈ 2.7x
➔ $\sigma_\theta \approx 0.6^o$ at ≈300 GeV

detailed calculations under way !



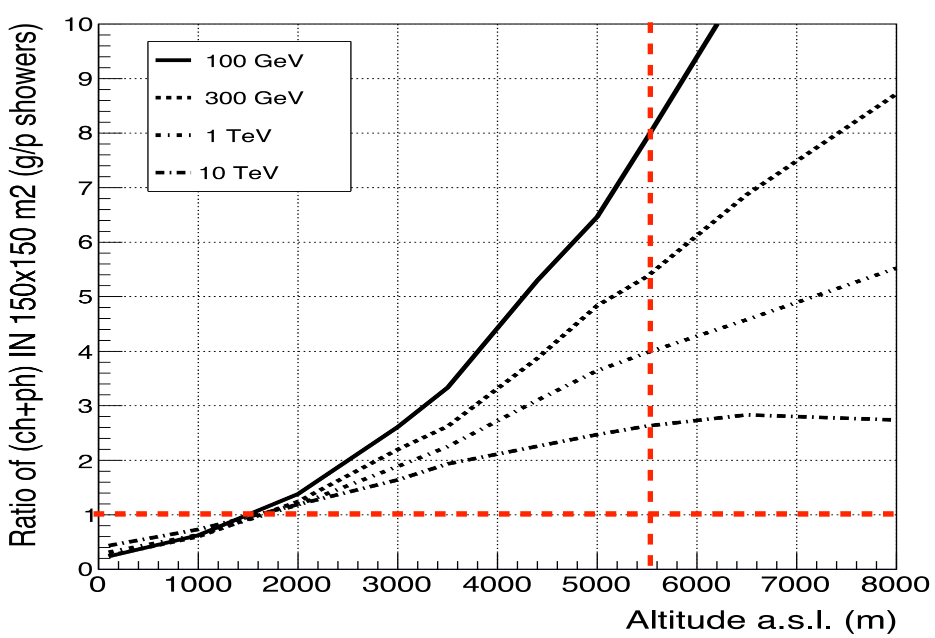
γ/p detection efficiency

High altitude → rejection of the background 'for free' !



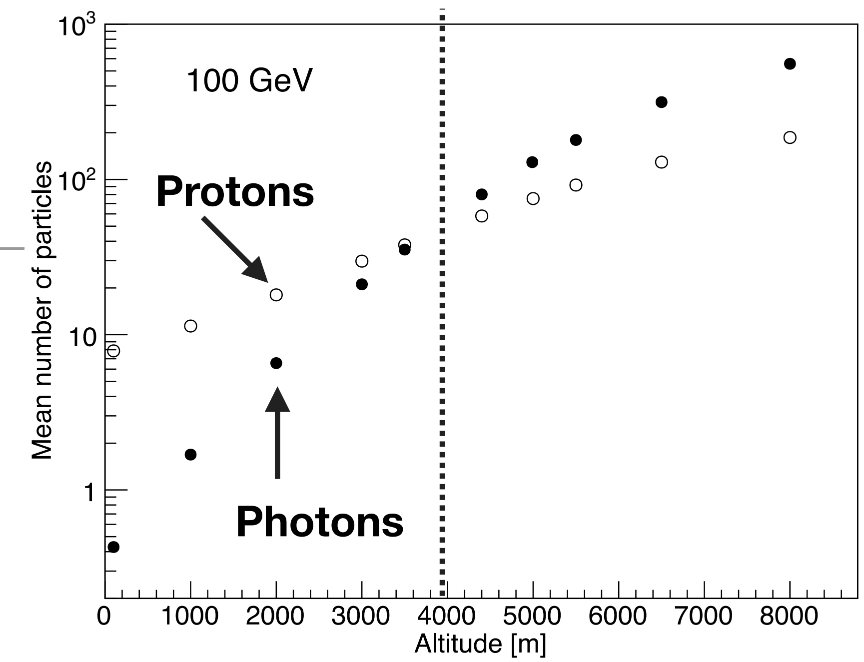
$$R = \sqrt{\frac{A_{eff}^{\gamma}(E)}{A_{eff}^{B}(E)}}$$

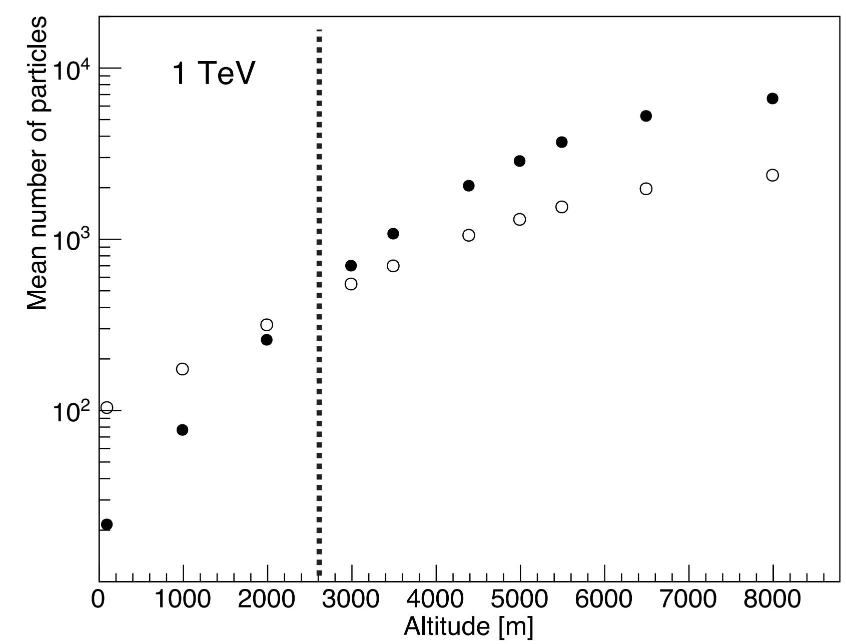
γ/hadron relative trigger efficiency

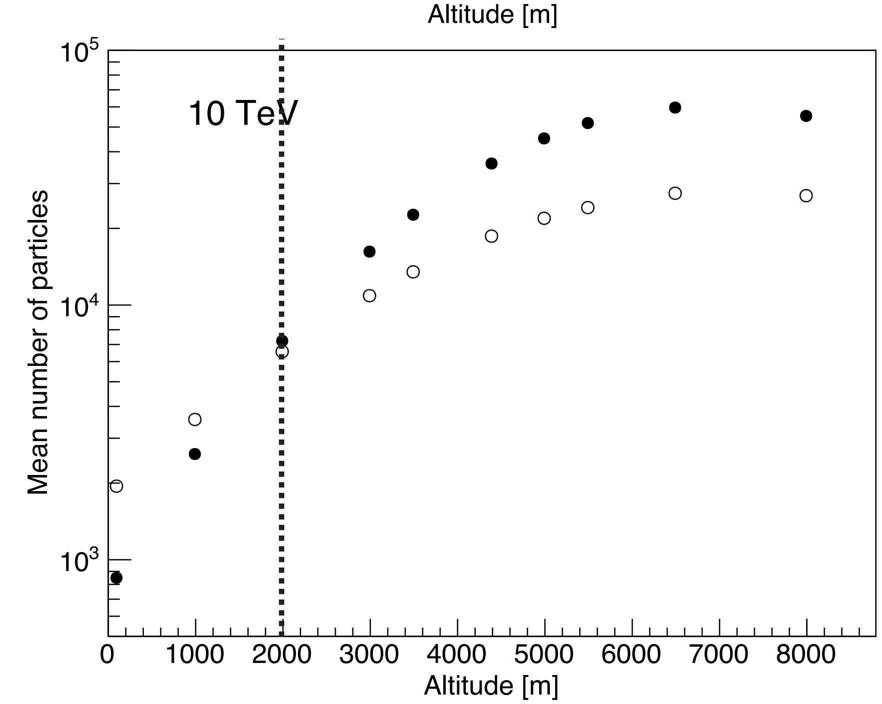


The number of particles in γ-showers exceeds the number of particles in p-showers at extreme altitude.

Trigger probability of a detector larger for γ-showers than for p-showers at extreme altitude.







Effective Area

The Effective Area is function of

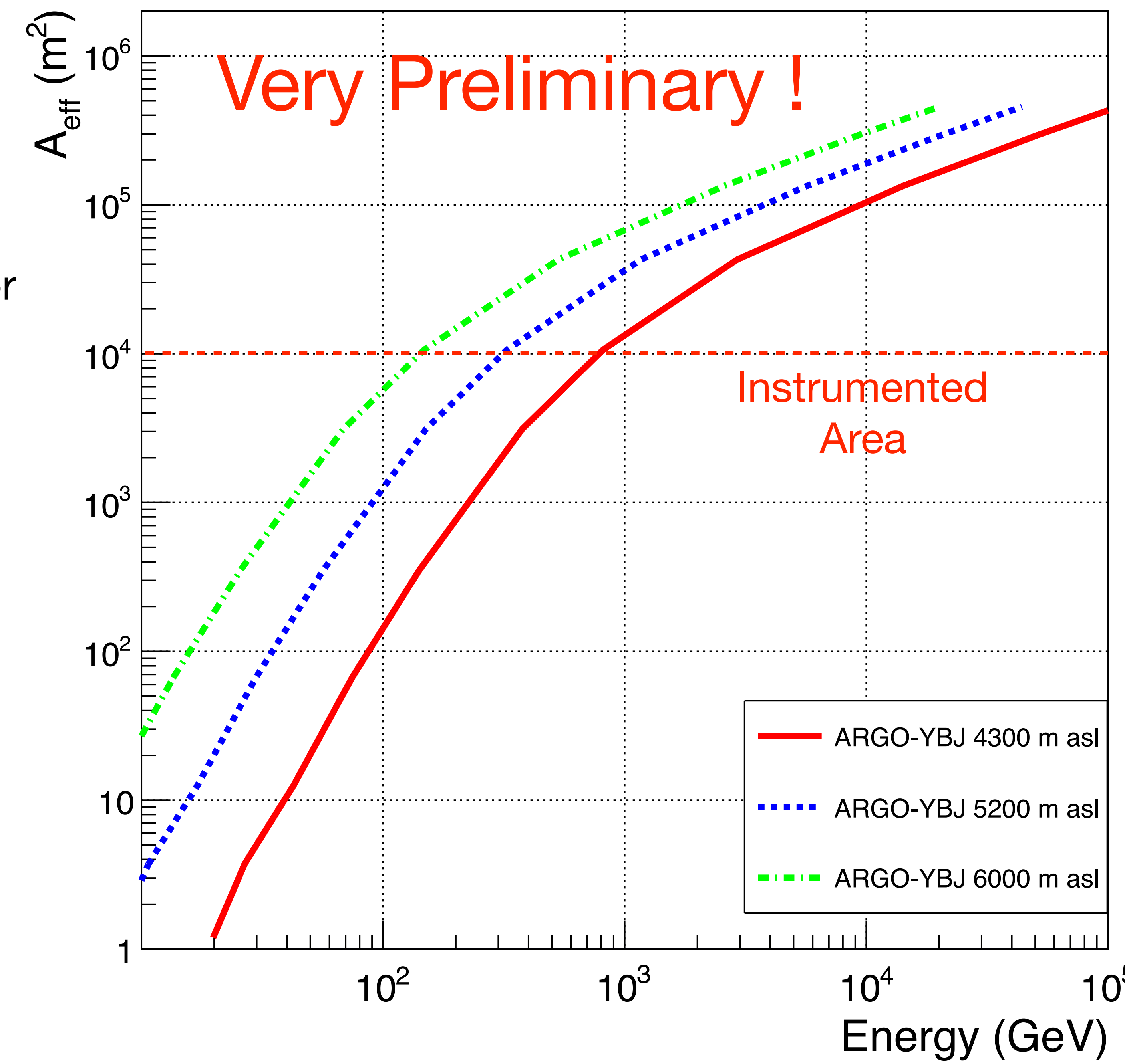
- Number of charged particles
- Dimension and coverage of the detector
- Trigger Logic

Effective Areas at 100 GeV:

≈ 1000 m² at 5200 m asl
≈ 5000 m² at 6000 m asl

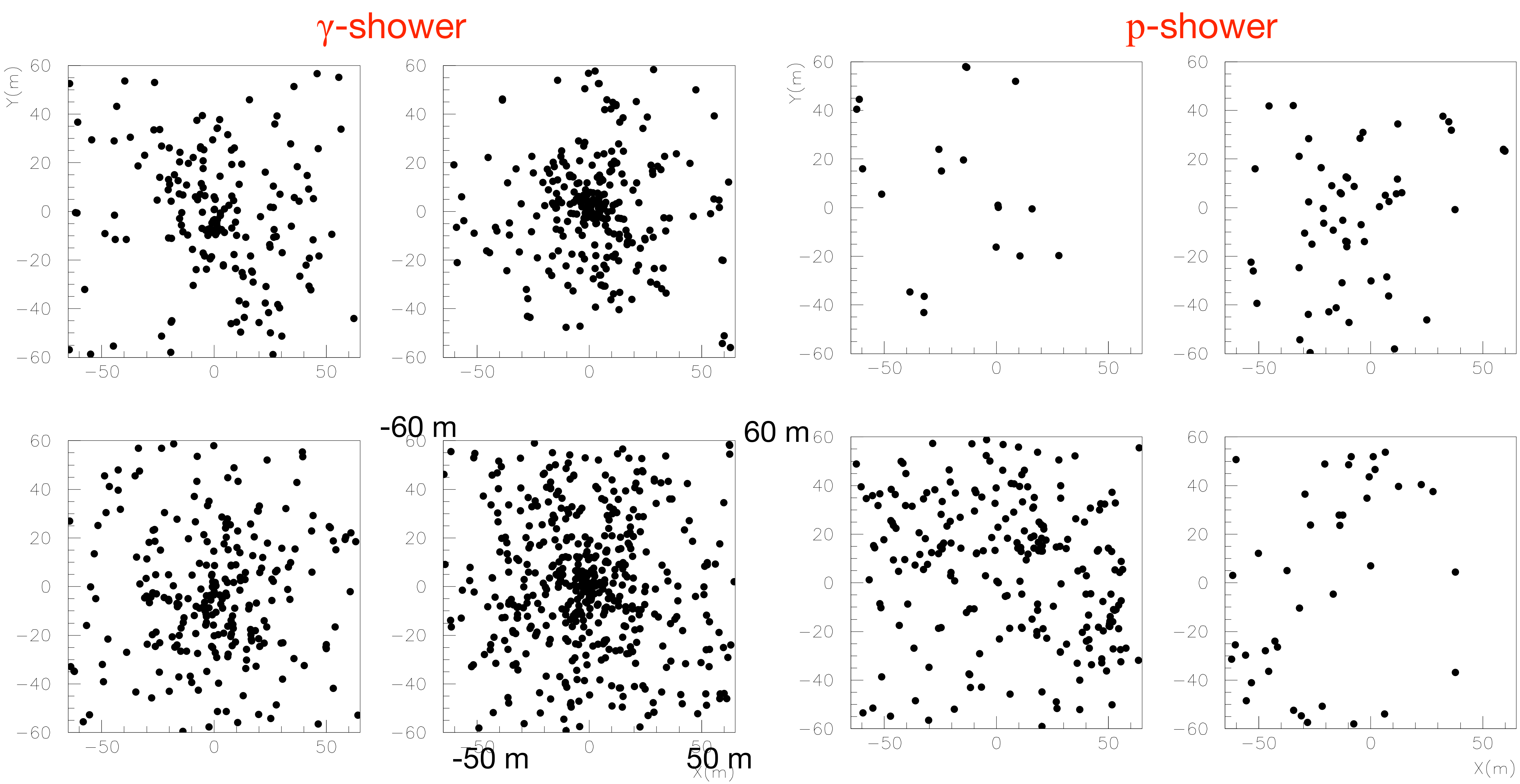
Effective Areas at 300 GeV:

≈ 10,000 m² at 5200 m asl
≈ 20,000 m² at 6000 m asl



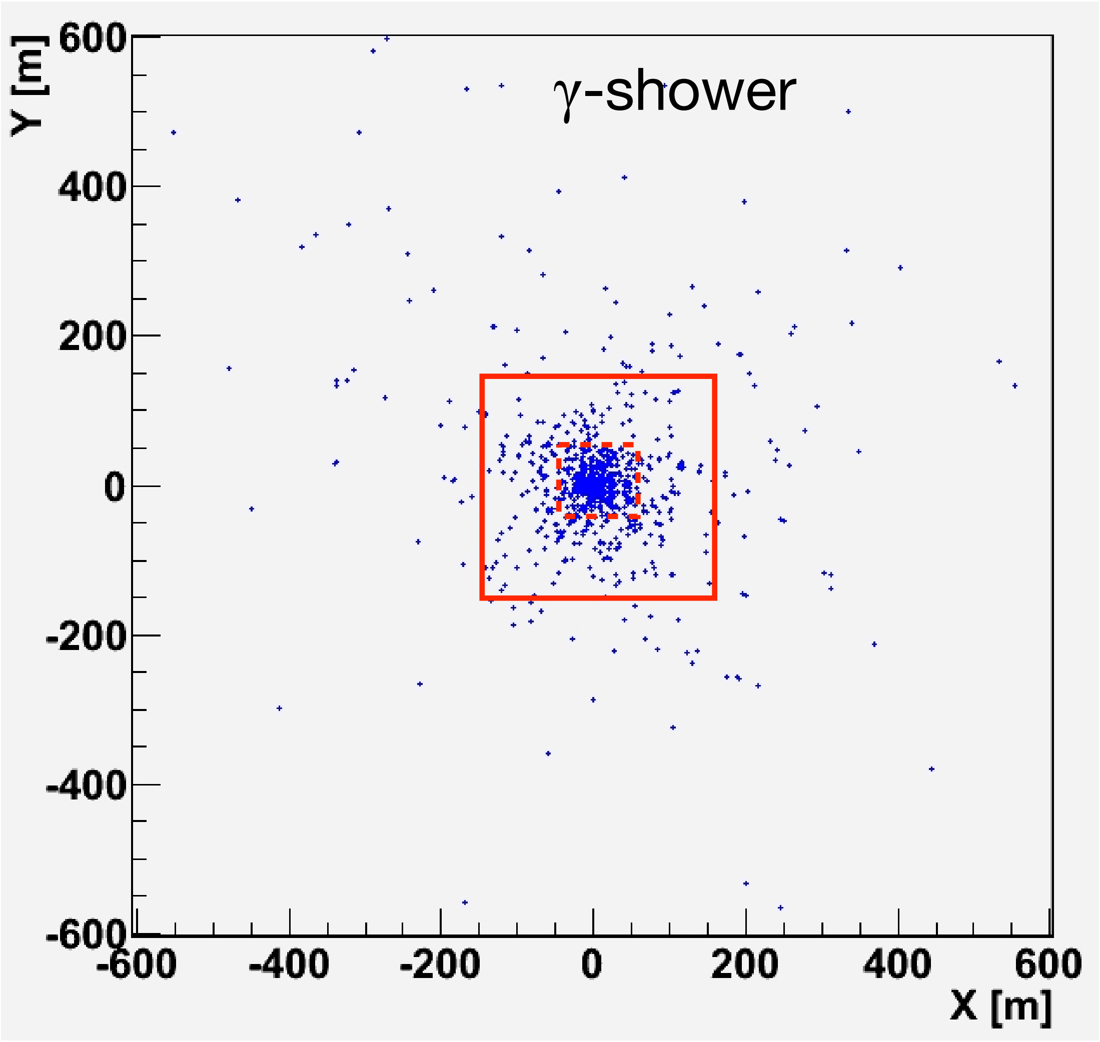
detailed calculations under way !

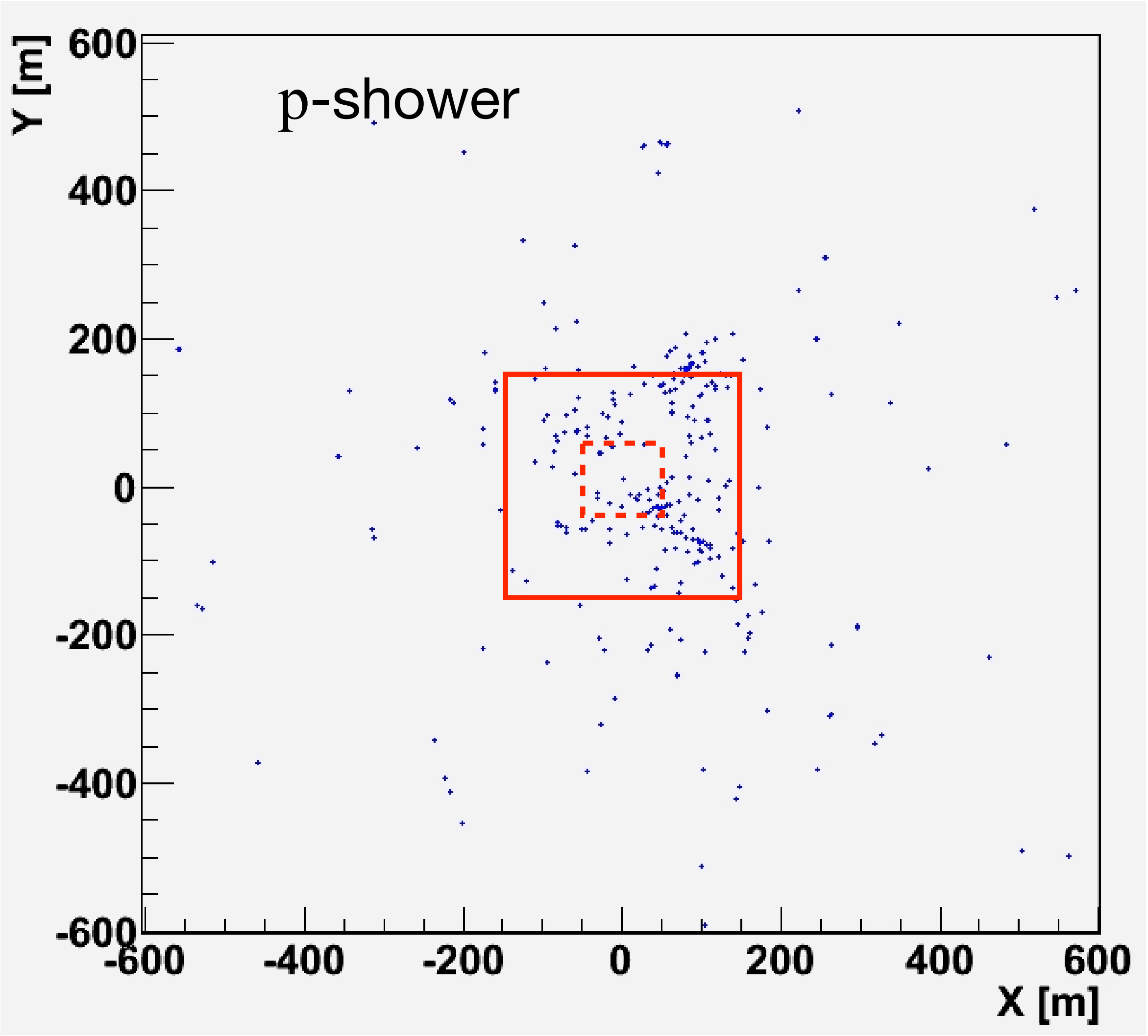
1 TeV showers at 4300 m asl



3 TeV showers at 4300 m asl

Charged particles in a 3 TeV shower





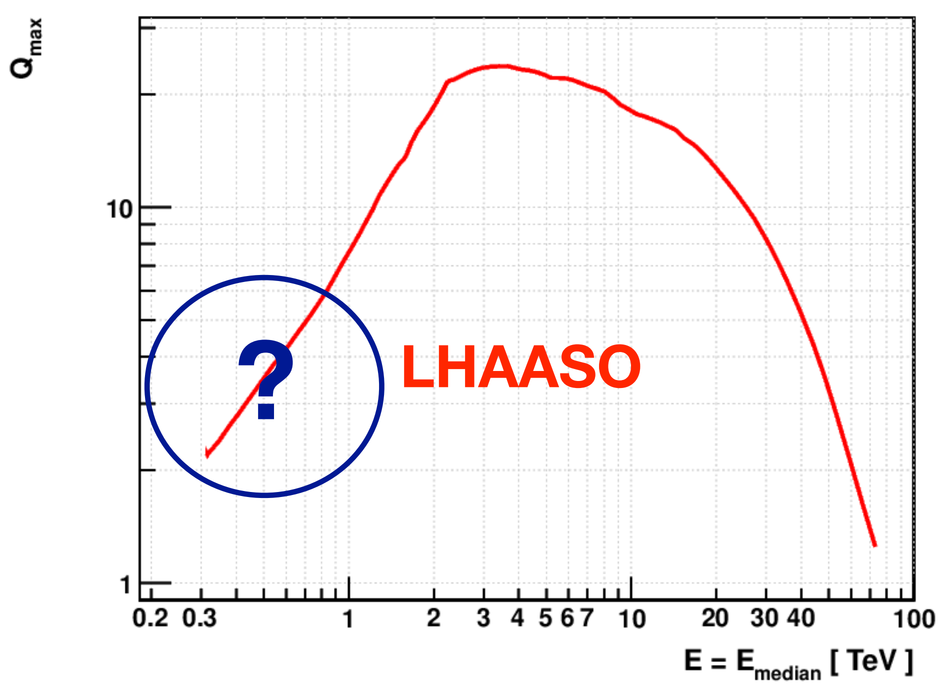
Gamma/Hadron discrimination

Very difficult at low energy (< 1 TeV)

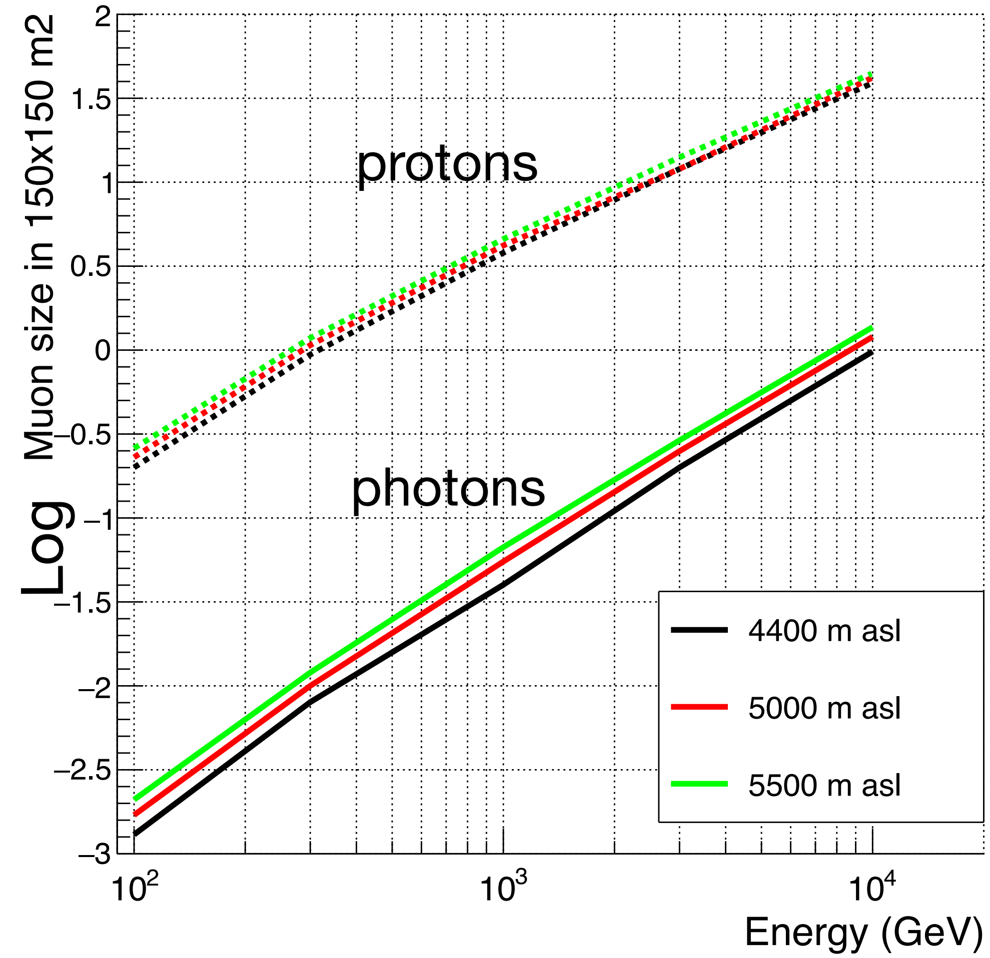
Muon size very small

HAWC/LHAASO approach requires large area: discrimination based on topological cut in the pattern of energy deposition far from the core (>40 m).

Requires sufficient number of triggered channels (>70 - 100)
→ minimum energy required E > 0.5 TeV



LHAASO Q-factor: 3 at 500 GeV, 7 at 1 TeV, 22 at 5 TeV.



Discrimination capability depends on detector area

→ according to HAWC/LHAASO calculations sensitivity $\approx A_{eff}^{0.8}$ and not $A_{eff}^{0.5}$ up to ≈ 300 x 300 m^2 at TeV energies

New ideas ?

Minimum Detectable Flux in 1 year

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

300 GeV:

$\psi_{70} = 1.58 \cdot 0.6^\circ \approx 1^\circ$ R = 4

$\Phi_\gamma^{CRAB}(>300 \text{ GeV}) \approx 1.4 \cdot 10^{-10}\ \text{cm}^{-2}\ \text{s}^{-1}$

$\Phi_B(>E) = 1.30 \cdot (E_{GeV})^{-1.66}$ particles $\text{cm}^{-2}\ \text{s}^{-1}\ \text{sr}^{-1}$ (Horandel)

$$\frac{2 \cdot 10^{-7}}{\sqrt{A_{eff}}} \frac{1}{Q_f}$$

$A_{eff} = 10^8 cm^2$ (100 × 100 m^2) $\frac{2 \cdot 10^{-11}}{Q_f} \approx \frac{0.15}{Q_f}$ *Crab* ≈2x final ARGO (0.25)

$A_{eff} = 10^9 cm^2$ (300 × 300 m^2) $\frac{6 \cdot 10^{-12}}{Q_f} \approx \frac{0.05}{Q_f}$ *Crab* OK but too big !

Open problems

- Conversion of secondary photons
- Angular resolution
- γ/h discrimination < TeV

Conclusions

Open problems in cosmic ray physics push the construction of new generation Wide FOV experiments.

With ARGO-YBJ we demonstrated that RPCs can be safely operated at extreme altitude for many years.

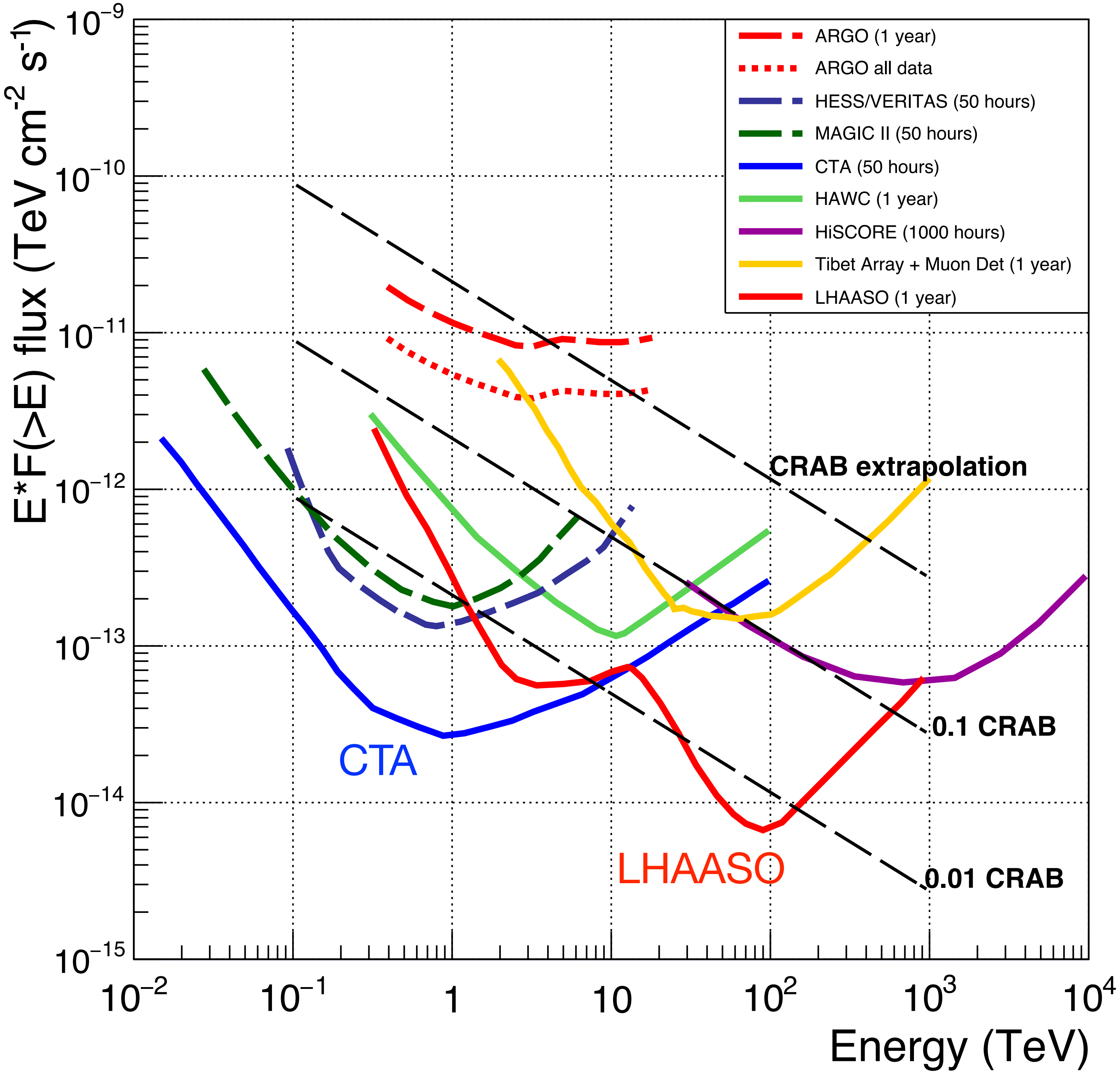
Benefits of RPCs in ARGO-YBJ:

- dense sampling → low energy threshold (≈ 300 GeV)
- wide energy range (with charge read-out): ≈300 GeV → 10 PeV
- high granularity of the read-out → good angular resolution and unprecedented details in the core region

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

- With CTA coming a future all-sky array should have ~5x increase in sensitivity over LHAASO at least.
- Extragalactic transient detection requires low threshold, ≈100 GeV.
- Extreme altitude (≈5500 m asl) and high coverage are key.
- New ideas for background rejection below TeV for a few % Crab sensitivity !
- High energy (>10 TeV) covered by ALPACA ?

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 EAS arrays

- High Energy (>10 TeV)
- Sky Survey

LHAASO vs other EAS arrays

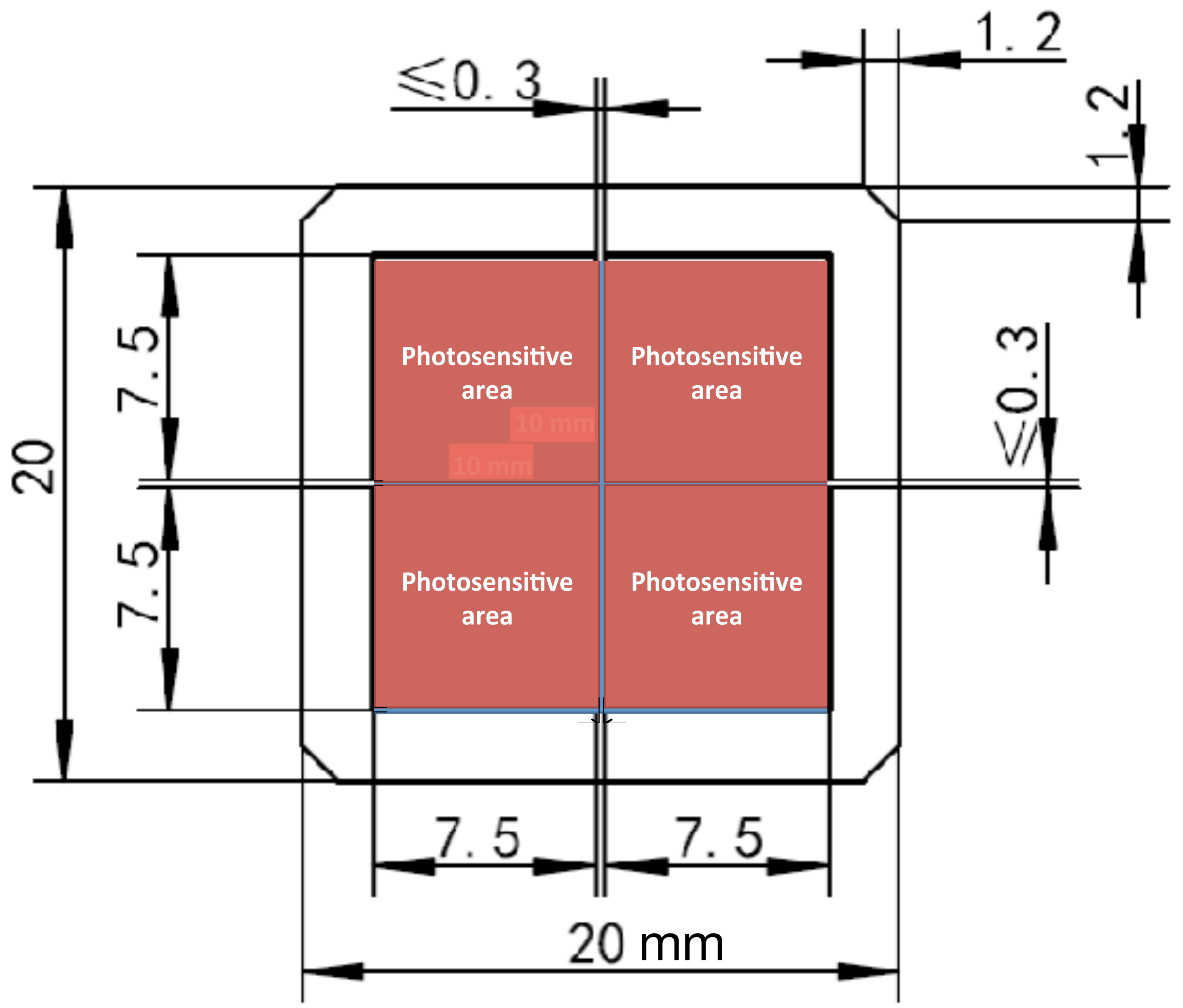
Experiment	Altitude (m)	e.m. Sensitive Area (m^2)	Instrumented Area (m^2)	Coverage
LHAASO	4410	5.2×10^3	1.3×10^6	4×10^{-3}
TIBET ASγ	4300	380	3.7×10^4	10^{-2}
IceTop	2835	4.2×10^2	10^6	4×10^{-4}
ARGO-YBJ	4300	6700	11,000	0.93 (central carpet)
KASCADE	110	5×10^2	4×10^4	1.2×10^{-2}
KASCADE-Grande	110	370	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 will operate with a coverage similar to KASCADE (about %) over a much larger effective area.
- ✓ The detection area of muon detectors is about 70 times larger than KASCADE (coverage 5%) !
- ✓ Redundancy: different detectors to study hadronic models dependence

(✦) Muon detector area: 4.2×10^4 m^2 + 8×10^4 m^2 (WCDA)

SiPM matrix



≤0. 3
1. 2
1. 2
20
7. 5
7. 5
Photosensitive area
Photosensitive area
Photosensitive area
Photosensitive area
10 mm
10 mm
≤0. 3
7. 5
7. 5
20 mm

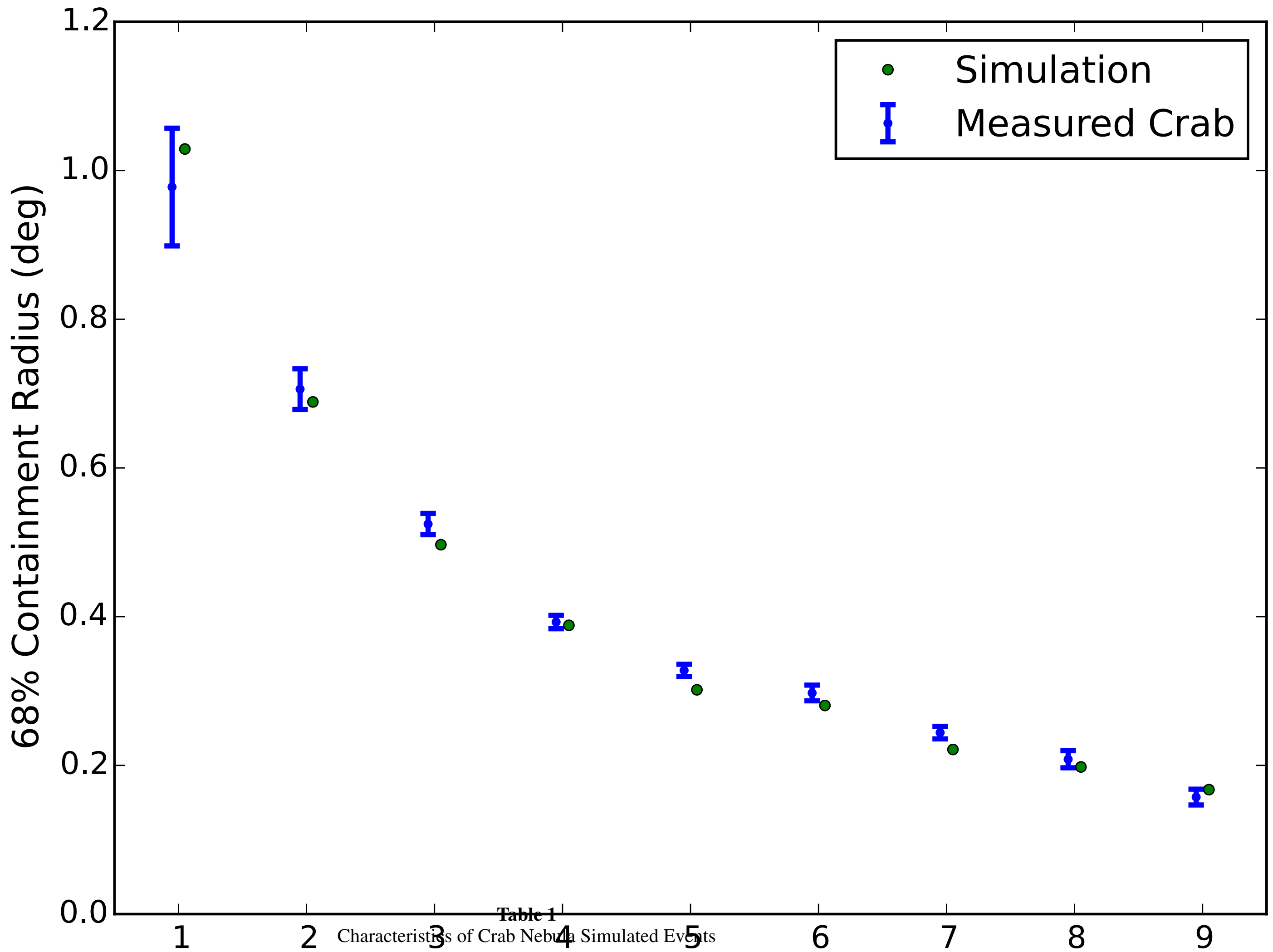


Table 1
Characteristics of Crab Nebula Simulated Events

N_{pad}	D_{cut}[a] (m)	Core Position Error[b] (m)	R_{39}[c] (deg)	Median Energy (TeV)
20–39	No limits	37	1.88	0.34
40–59	No limits	28	1.50	0.53
60–99	90	12	1.04	0.79
100–199	70	6.8	0.70	1.3
200–299	60	4.2	0.50	2.1
300–499	60	3.3	0.41	3.1
500–999	40	2.3	0.32	4.8
1000–1999	30	1.6	0.24	8.1
⩾2000	30	1.0	0.19	17.7

Notes.
[a] Maximum distance of the shower core from the detector center, beyond which the events are rejected.
[b] Distance between the true and reconstructed cores containing 68% of the events.
[c] Angular resolution, defined as the 39% containment radius.

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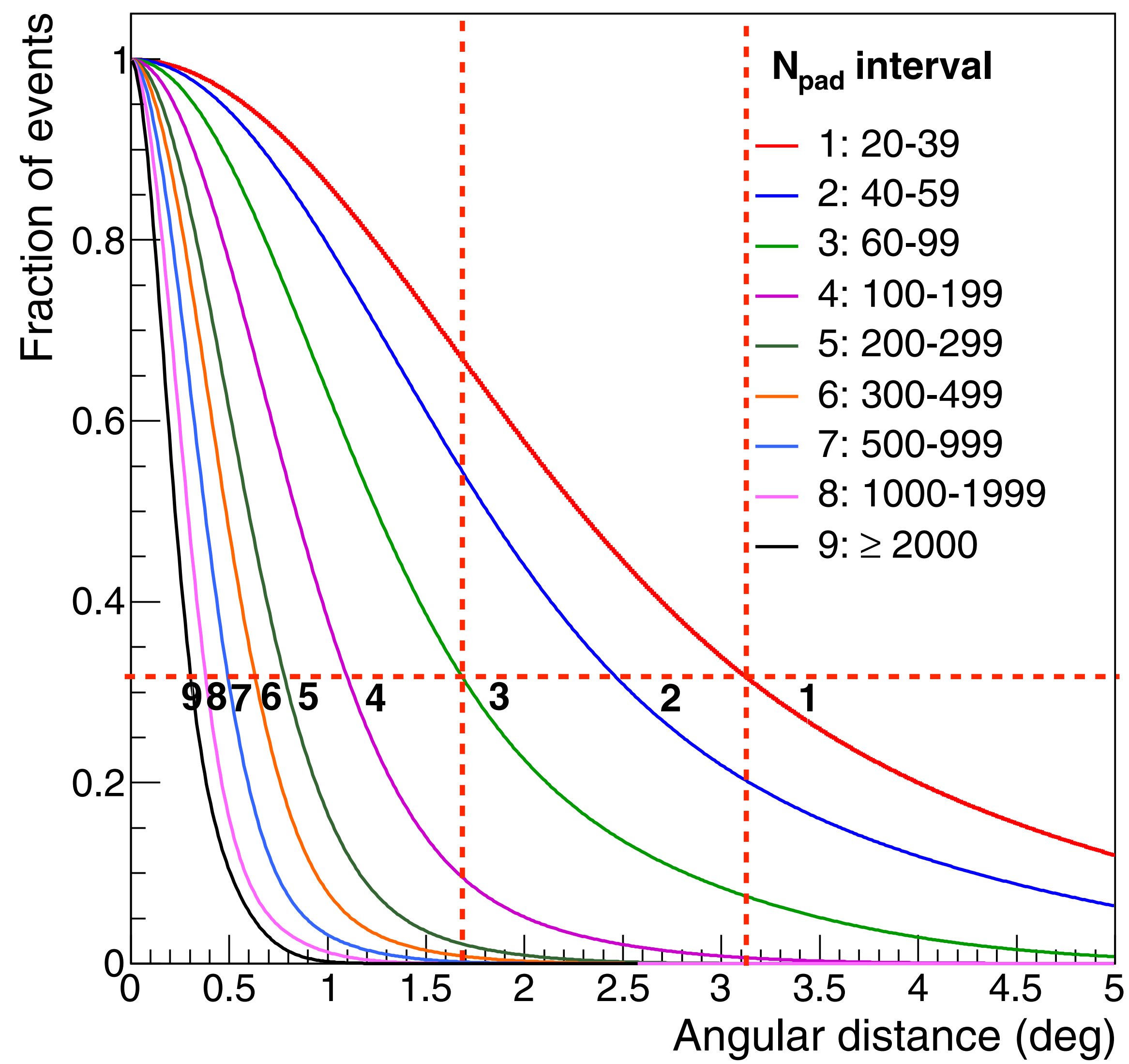

Figure 2. Angular resolution for different N_{pad} intervals, according to simulations. The curves represent the fraction of events beyond the angular distance d from the source, as a function of d.