Half ALPACA and its sensitivity to sub-PeV gamma rays from the Galacitic Center

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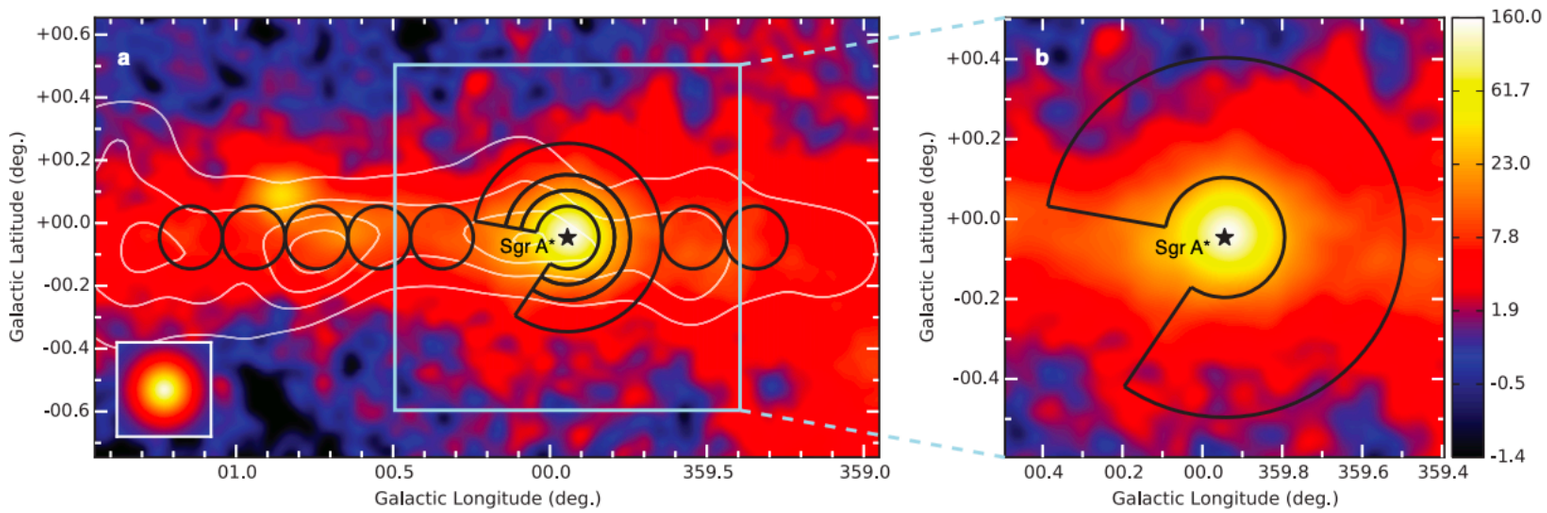
Author List

Introduction



In 2016, few tens TeV diffuse γ-ray around the Galactic center was detected by H.E.S.S. . → PeVatron in the Galactic center ?

↓

We need sub-PeV observation around it.

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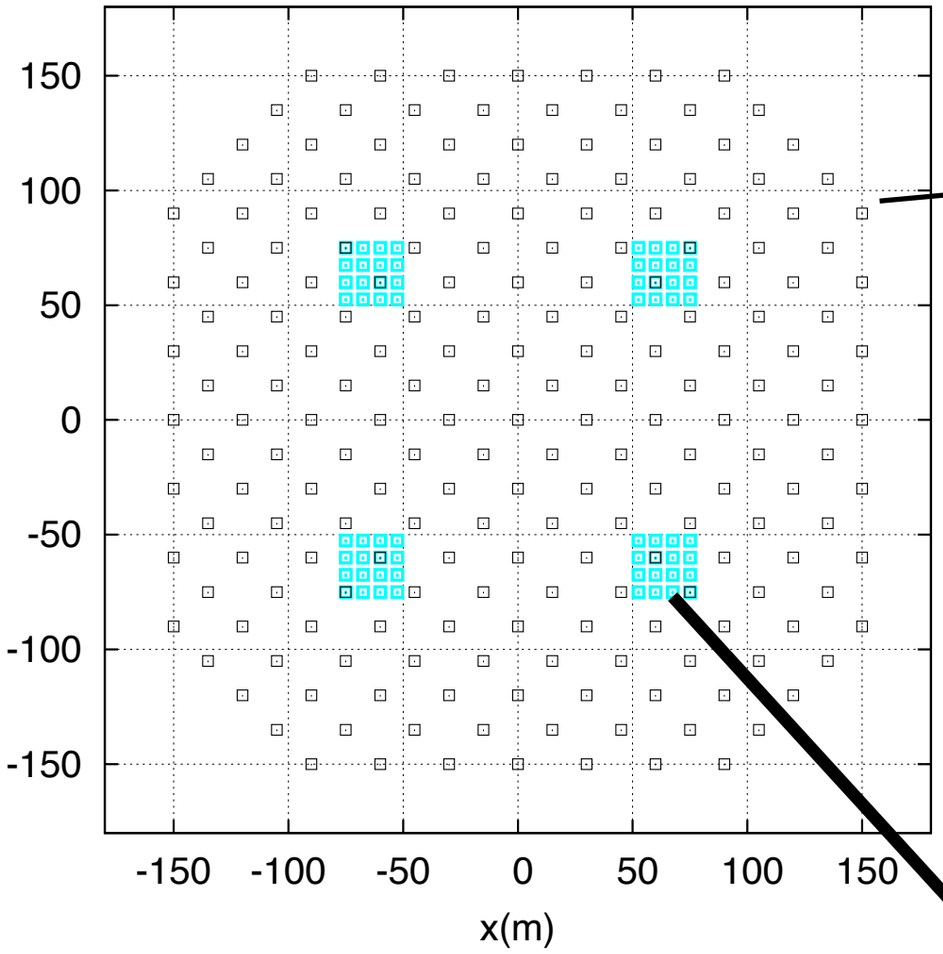
In this presentation, we report on the performance of half ALPACA, especially its sensitivity from the Galactic center, based on our detailed MC simulation.

Abramowski et al., Nature, 531, 476, (2016)

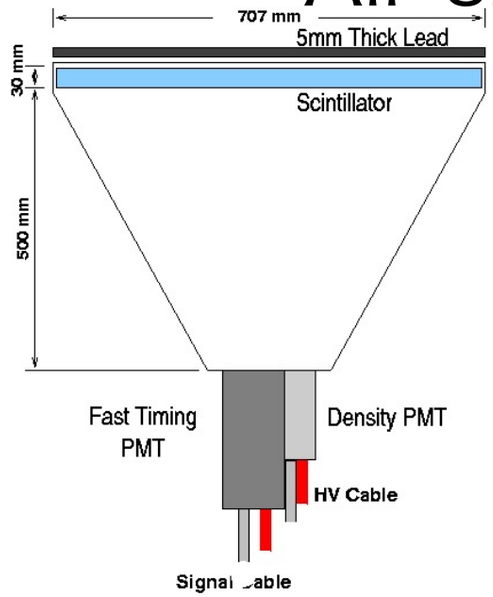
Half ALPACA Experiment

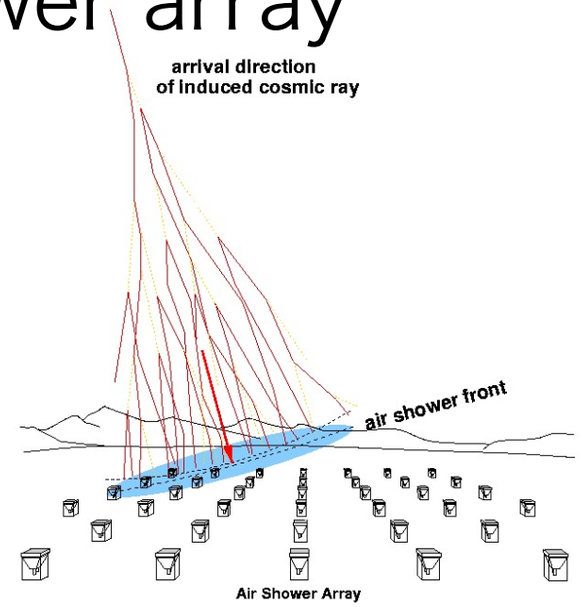
AS+MD array location



- The half size of ALPACA.
- Chacaltaya plateau (16°23'S, 68°08'W, Bolivia)
- Elevation(4,740m(572.4 g/cm^2))
- Air shower array (83000 m^2)
- Muon detector array (3600 m^2)

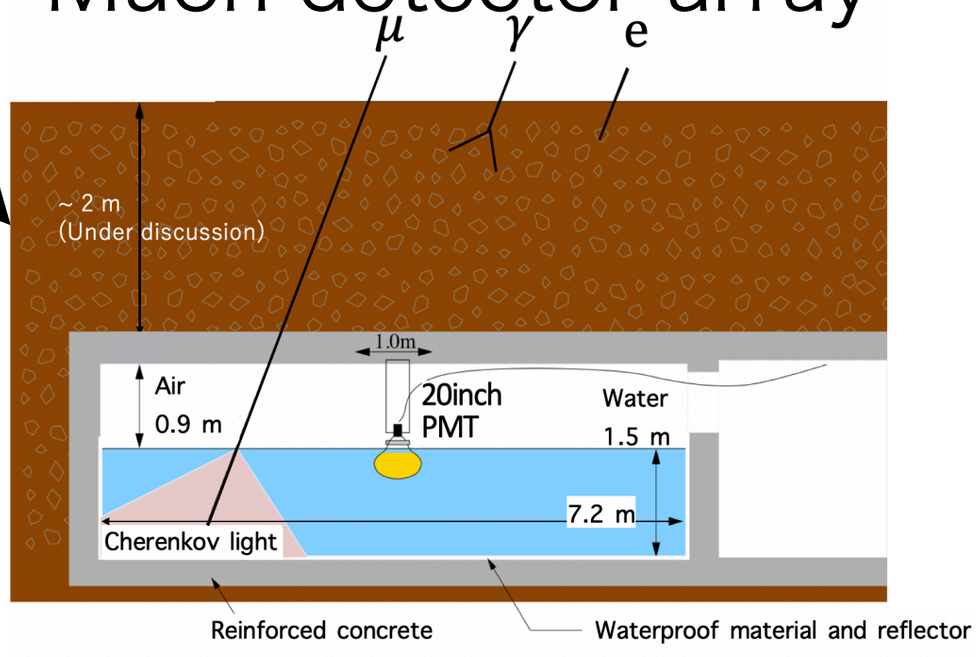
Air shower array





Number of particles detected & detection timing are recorded.
→ Primary Energy & Incoming derection

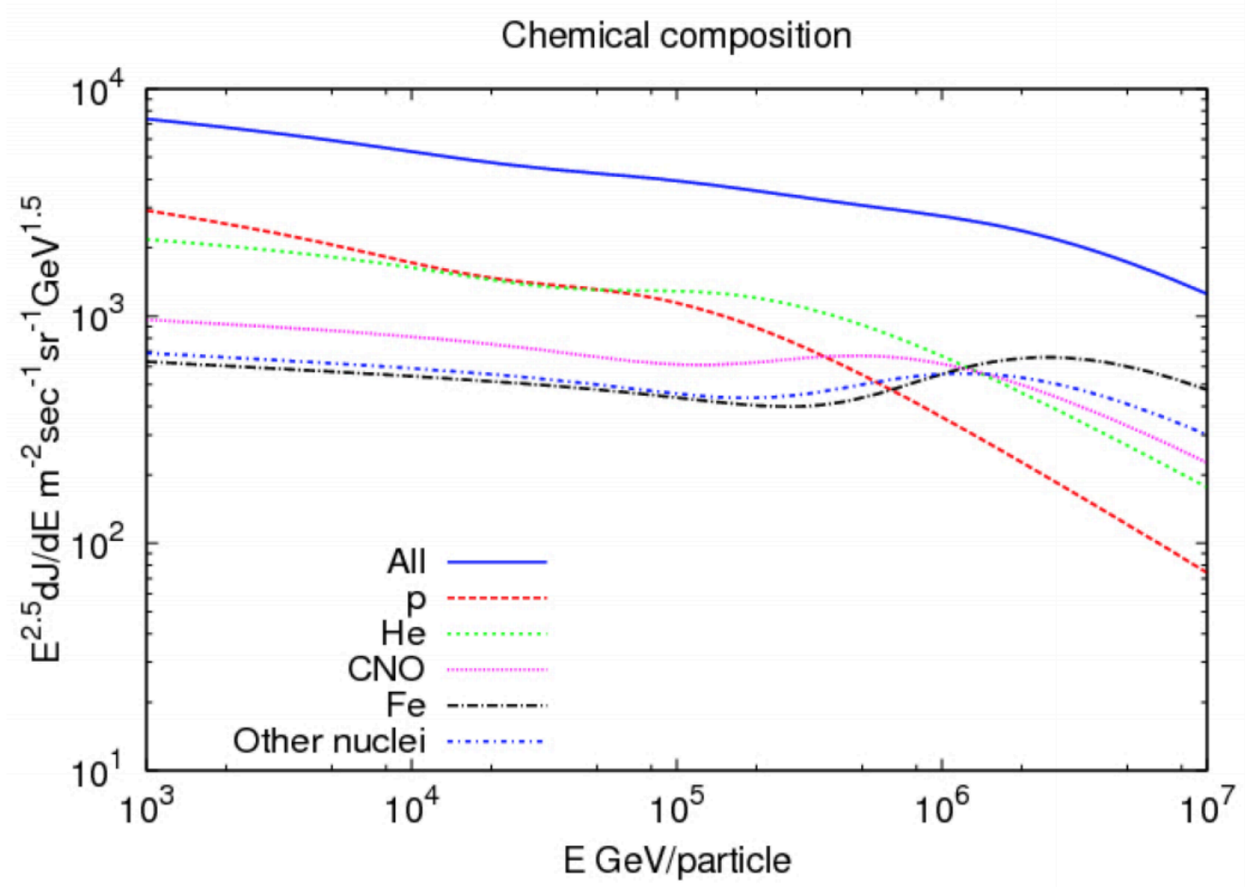
Muon detector array

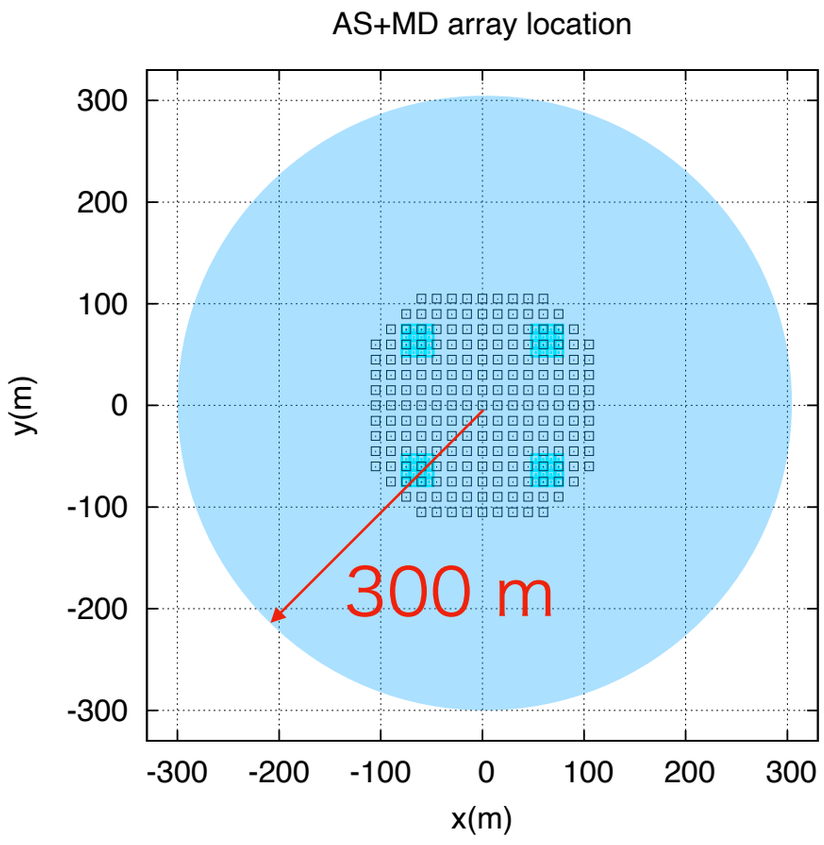


Number of muons are detected.
→Discriminating γ-rays from CRs

Air Shower Generation (CORSIKA 7.7100)

Simulation condition	γ-ray	Back ground CR
Energy range	300 GeV $\leq$ E $<$ 10 PeV	300 GeV $\leq$ E $<$ 10 PeV
Total number of events	1.1×10^8	4.3×10^9
Spectrum	$\propto E^{-2}$	Lower-left figure
Area	Lower-right figure	Lower-right figure





Source Assumption

Orbint & Flux → Galactic center

★ Flux :

$$\frac{dN}{dE} = F_0\left(\frac{E}{1\ \mathrm{TeV}}\right)^{-\Gamma}\ (\mathrm{TeV}^{-1}\mathrm{cm}^{-2}\mathrm{s}^{-1})$$

$$F_0 = 1.92\times10^{-12}\ \left(\mathrm{TeV}^{-1}\mathrm{cm}^{-2}\mathrm{s}^{-1}\right)\ ,\ \Gamma = 2.32\ (\mathrm{Crab})$$

★ Source position :

R.A. : 17h45m39.6s

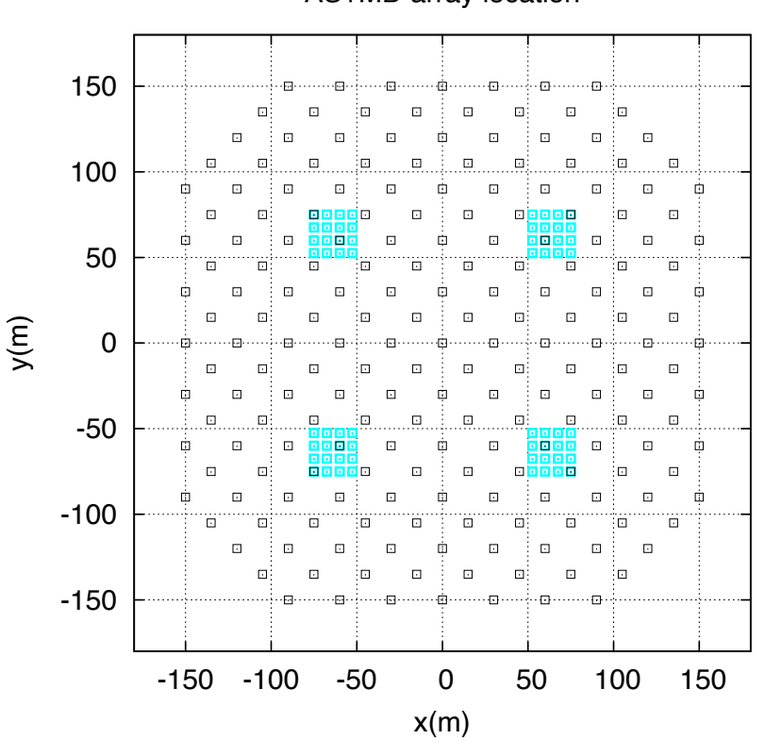
Dec. : -29.06° → Minimum zenith angle = 12.68°

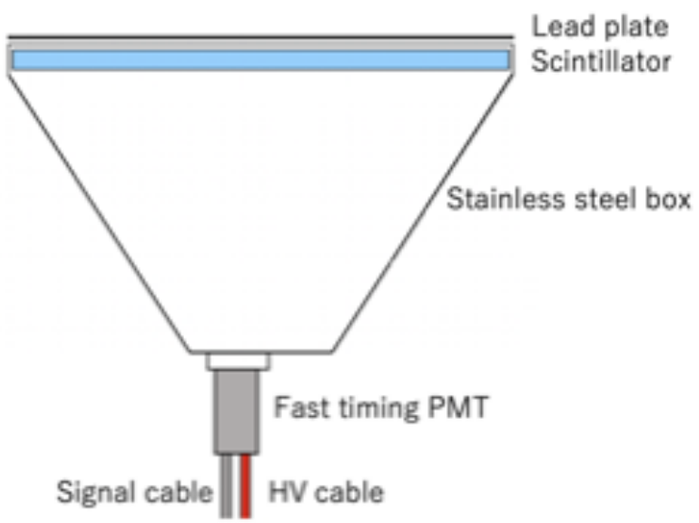
★ Point source

Detector Responses of Airshower Array (Geant4.10.06)

AS array design

half-ALPACA(version 1)

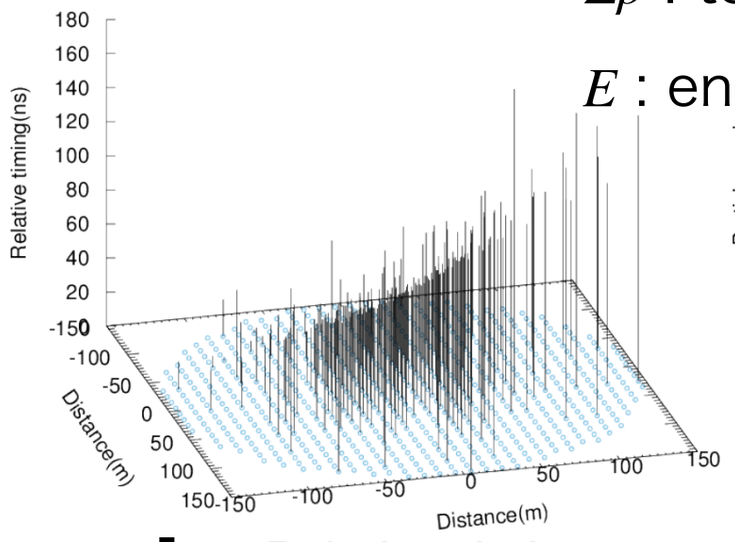




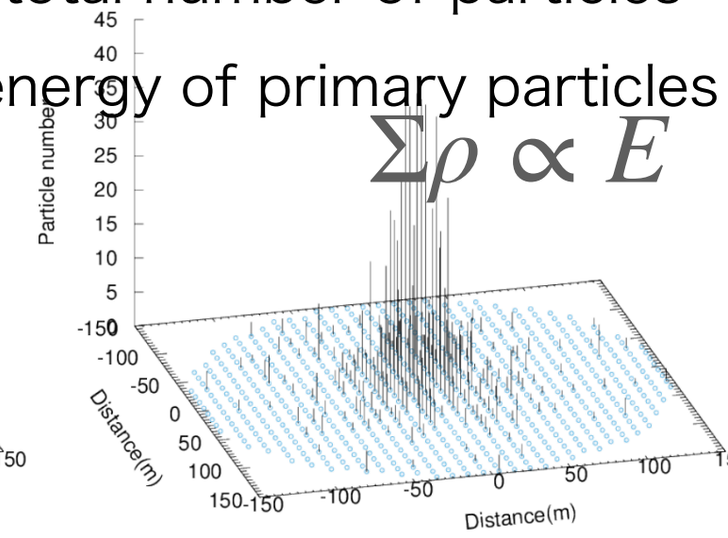
$\Sigma\rho$: total number of particles

E : energy of primary particles

$$\Sigma\rho \propto E$$

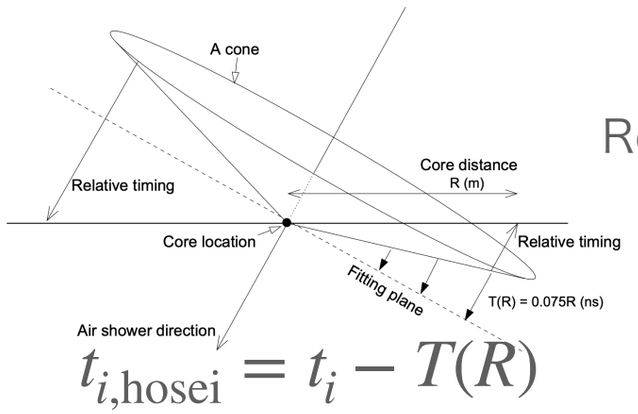


Relative timing



Total number of particles ($\Sigma\rho$)

100 TeV γ-ray



$$t_{i,\mathrm{hosei}} = t_i - T(R)$$

Residual error : $\chi^2 = \Sigma_i w_i \left(\mathbf{x_i}\cdot\mathbf{l} + c(t_{i,\mathrm{hosei}} - t_0)\right)^2$

$$w_i = \frac{\rho_i}{\Sigma_i \rho_i}$$

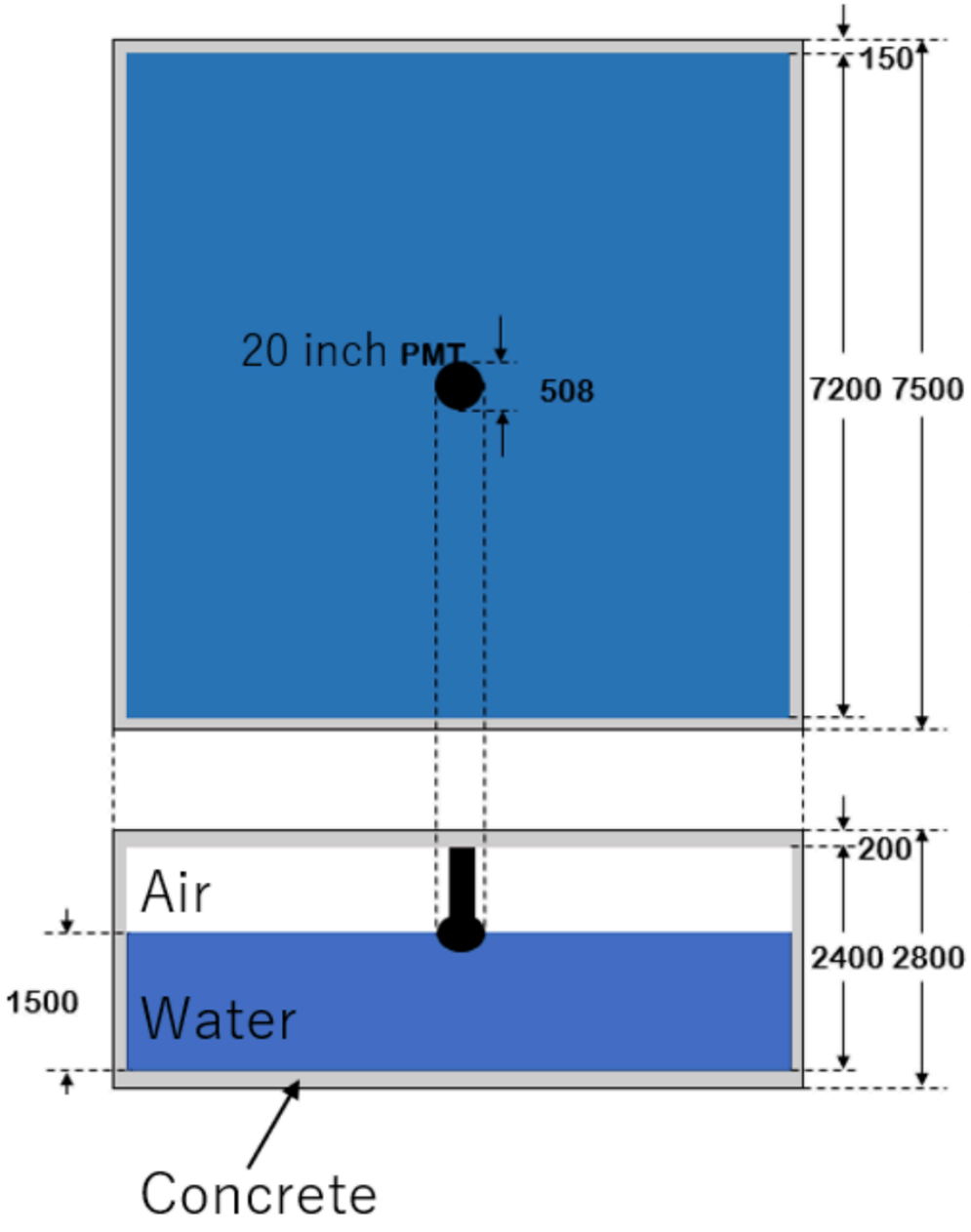
ρ_i : # of pariticles /m^2 in each scintillator

- Total area : version 1 → 83000 m^2
- Trigger condition : 0.5 particle any 4

Part	Density ($\mathrm{g/cm^3}$)	Size
Scintillator	1.032	100×100×5
Steel Box	7.820	103.3×103.3×0.1
Lead plate	11.34	100×100×0.5

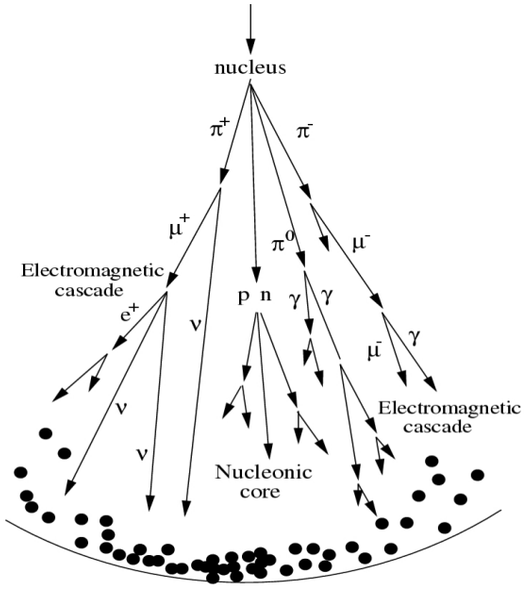
Detector Responses of Muondetector Array (Geant4.10.06)

MD cell design

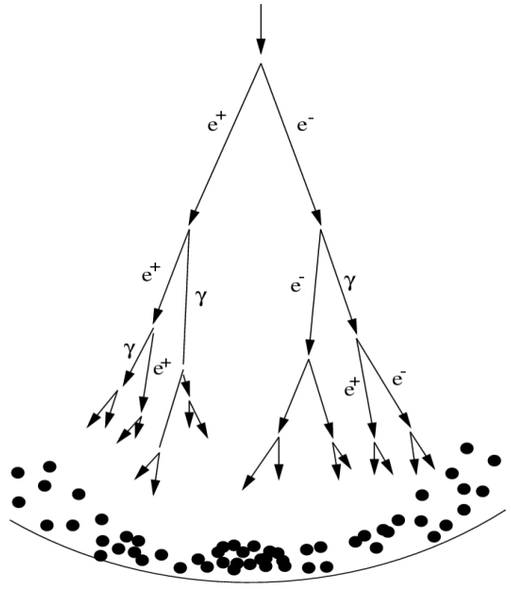


CR/γ dicrimination by counting total number of muons (ΣN_μ)

proton



γ-ray



$\Sigma N_\mu \sim 50$ @ 100 TeV proton $\Sigma N_\mu \sim 1$ @ 100 TeV γ-ray

- Detction area : $50\ \mathrm{m}^2$
- Locate at 2.0 m underground
- Density : soil : $2.1\ \mathrm{g/cm}^3 \times 2\ \mathrm{m}$

  concrete : $2.3\ \mathrm{g/cm}^3 \times 20\ \mathrm{cm}$

$\rightarrow 470\ \mathrm{g/cm}^2$ equiv. to 16 radiation length ($e^{-16} \sim 10^{-7}$)

- Reflectivity at the floor : 80% (diffuse reflection)

Analysis Conditions

① 0.8 particle any 4

② “IN” event : 3 out of 4 hottest detectors locate in an inner area

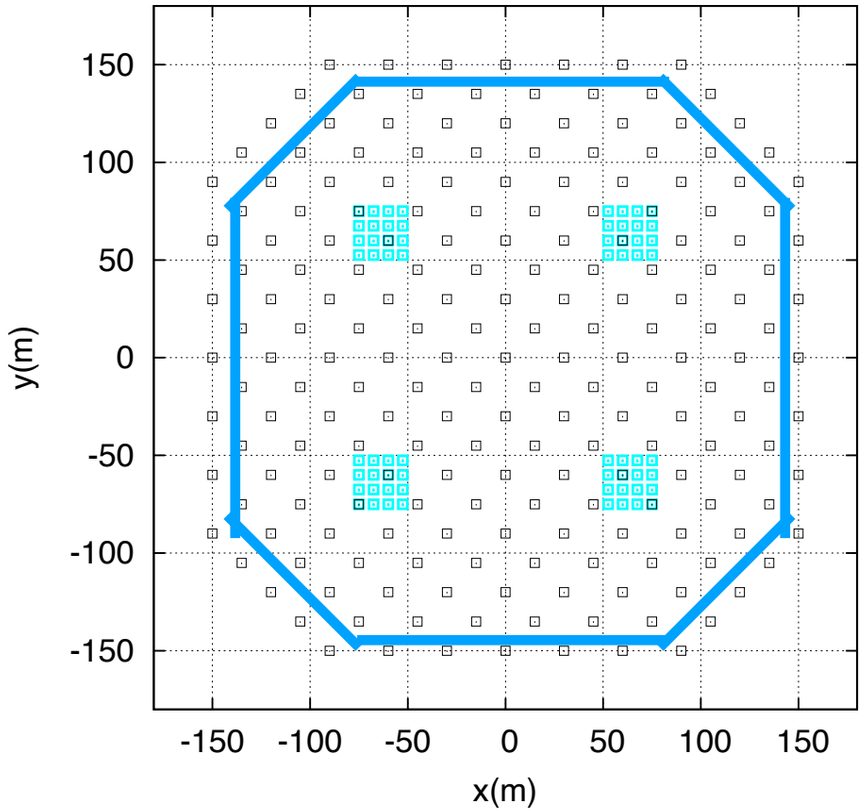
③ Residual error $\chi^2 < 1.0\ \mathrm{m}^2$ (accuracy of determination on incoming direction)

④ Zenith angle $0^\circ \leq \theta \leq 40^\circ$

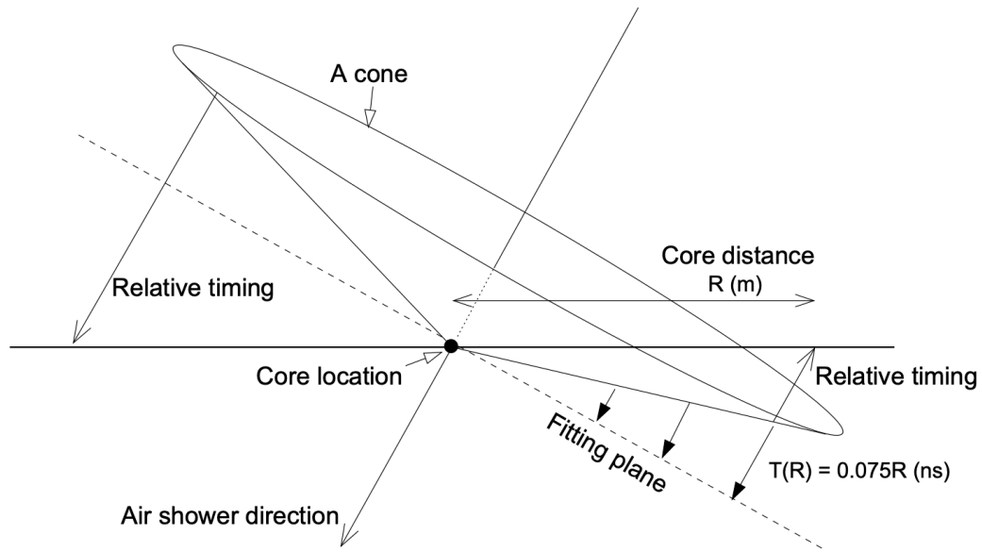
⑤Being Inside the window of radius $r = \dfrac{5.8^\circ}{\sqrt{\Sigma\rho}}$ (※ if $r < 0.5^\circ$, $r = 0.5^\circ$ & if $r > 1.5^\circ$, $r = 1.5^\circ$)

② : Inner area **half-ALPACA(version 1)**

AS+MD array location



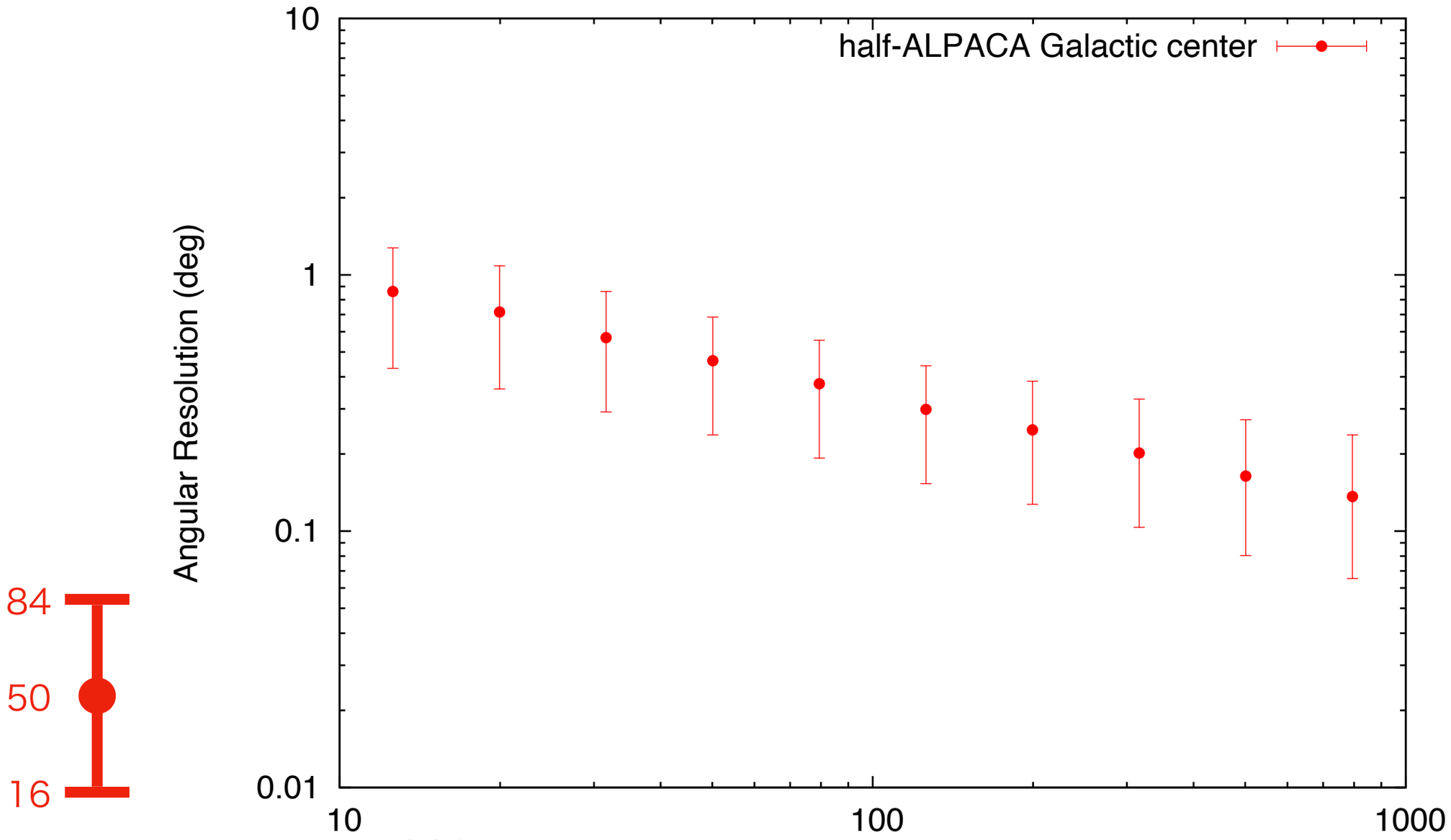
③Residual error : $\chi^2 = \Sigma_i w_i \left(\mathbf{x_i} \cdot \mathbf{l} + c(t_{i,\mathrm{hosei}} - t_0)\right)^2$



$$t_{i,\mathrm{hosei}} = t_i - T(R)$$

$$w_i = \frac{\rho_i}{\Sigma_i \rho_i}$$

Angular Resolution



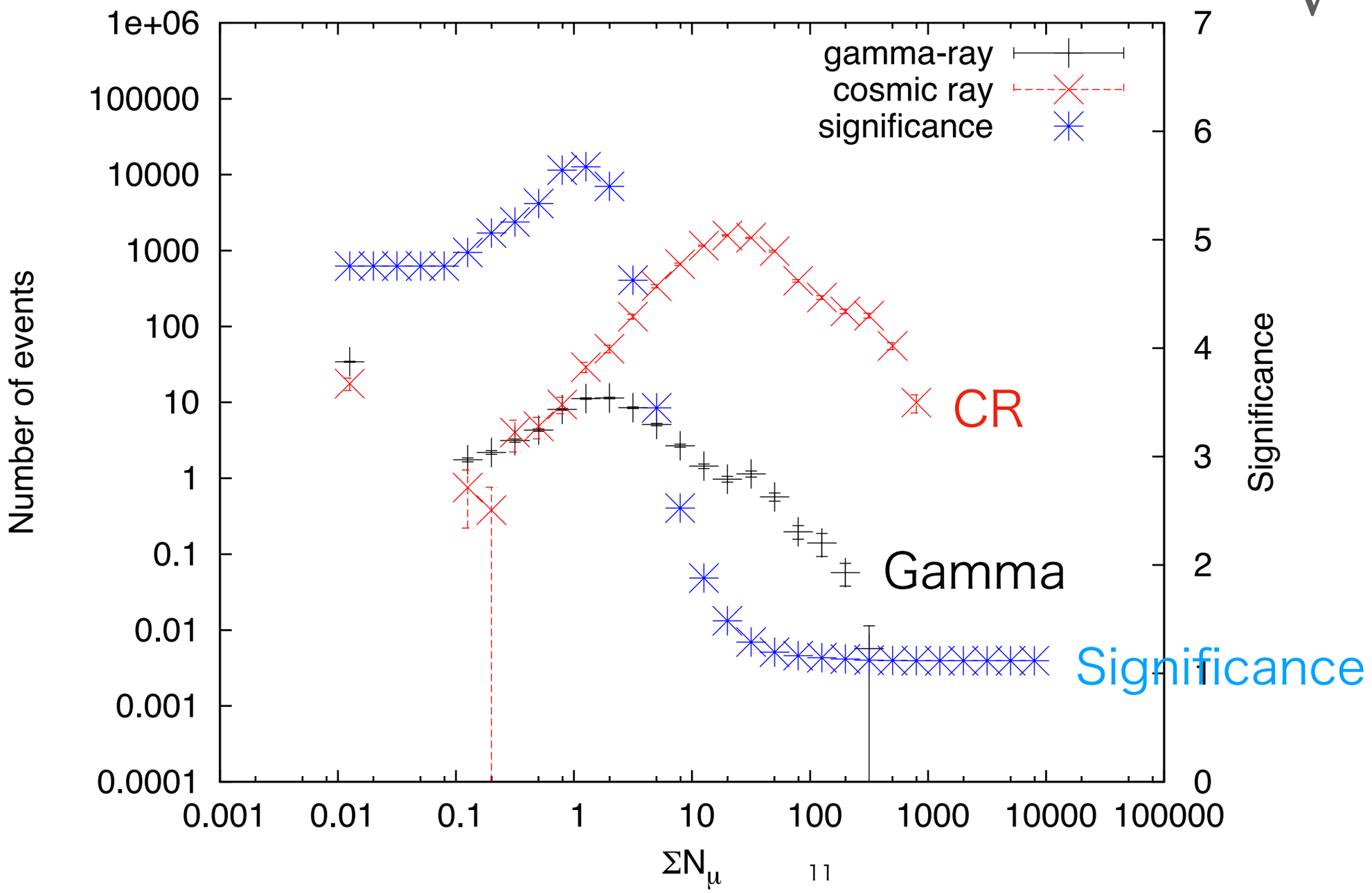
Value containing 50% of total events $\Sigma\rho$

Energy(TeV)	10	30	100
Angular Resolution	0.72	0.38	0.20

Muon Distribution (example)

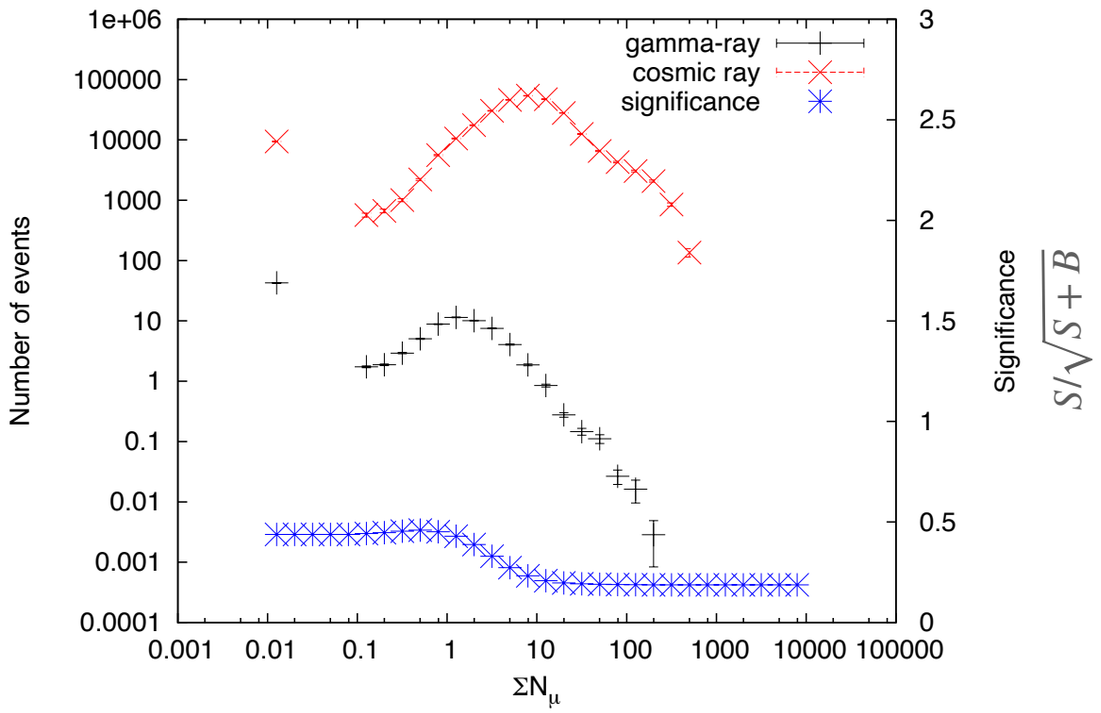
S : sum of the γ − ray events above a ΣN_μ bin
B : sum of the CR events above a ΣN_μ bin

$$\text{Significance} = \frac{S}{\sqrt{S+B}}$$

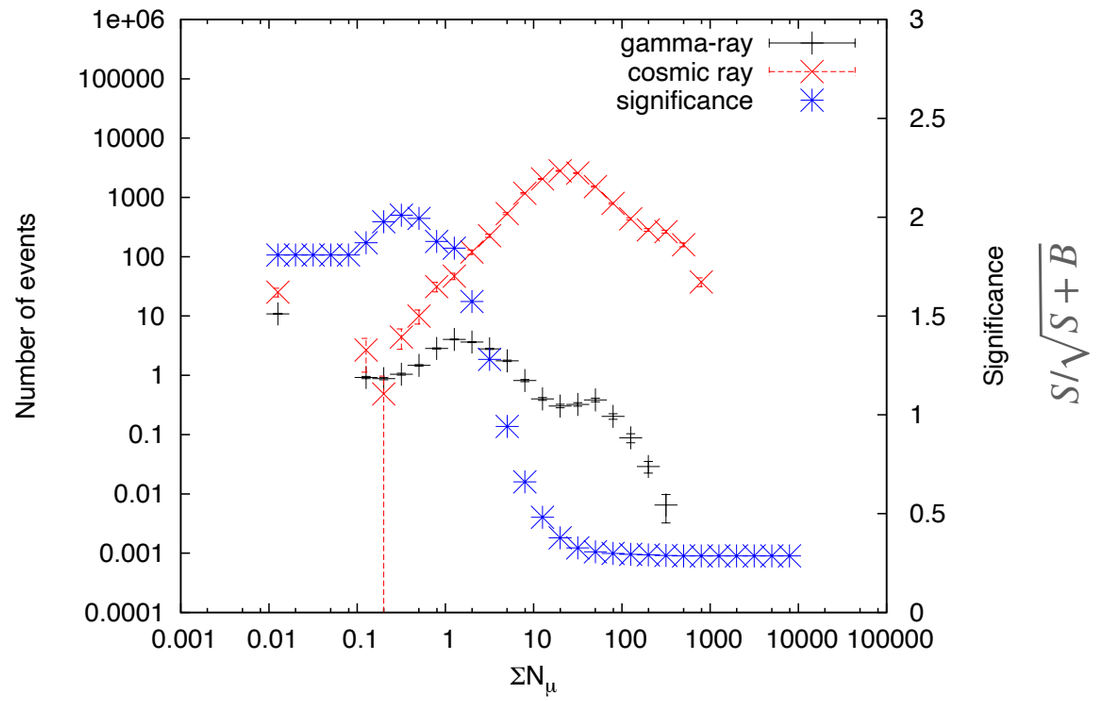


Muon Distribution

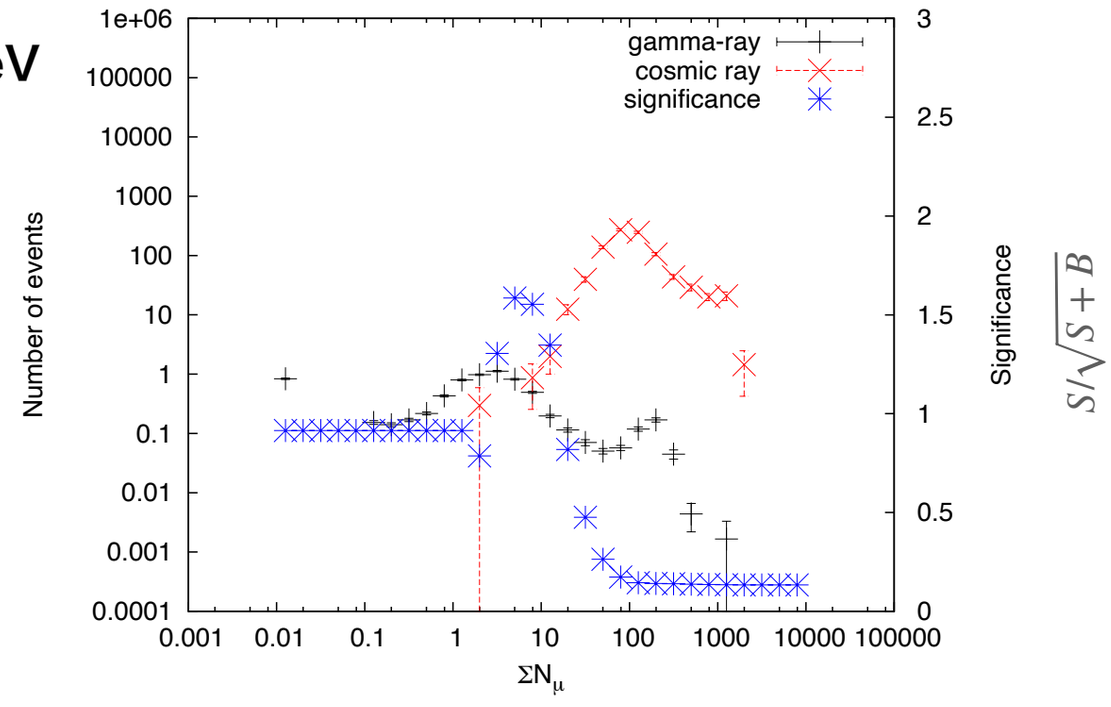
11 TeV



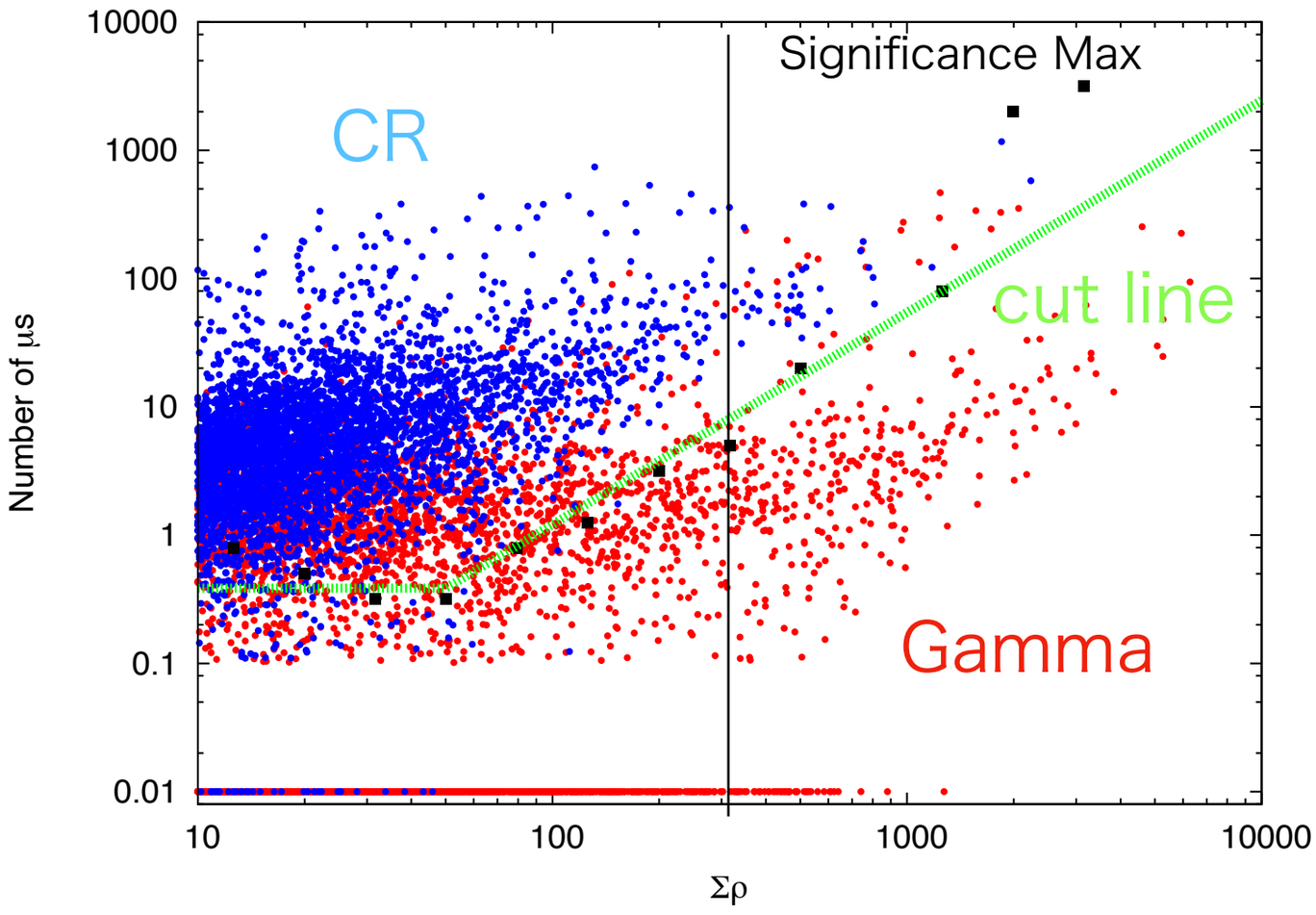
32 TeV



162 TeV

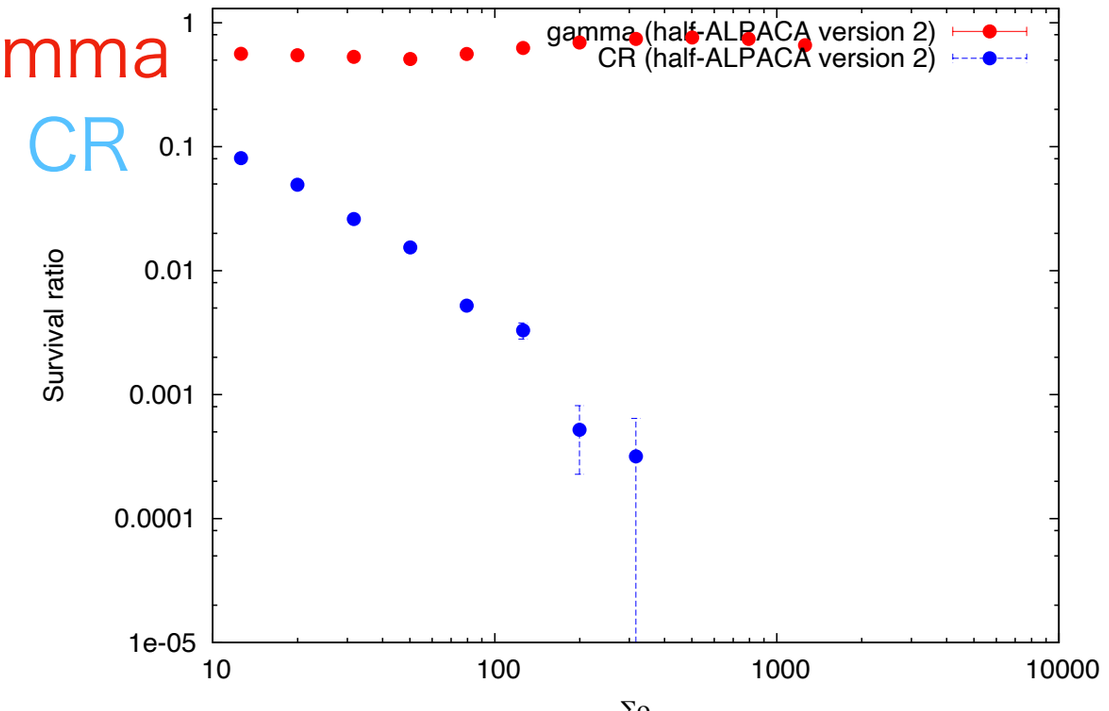


Scatter Plot

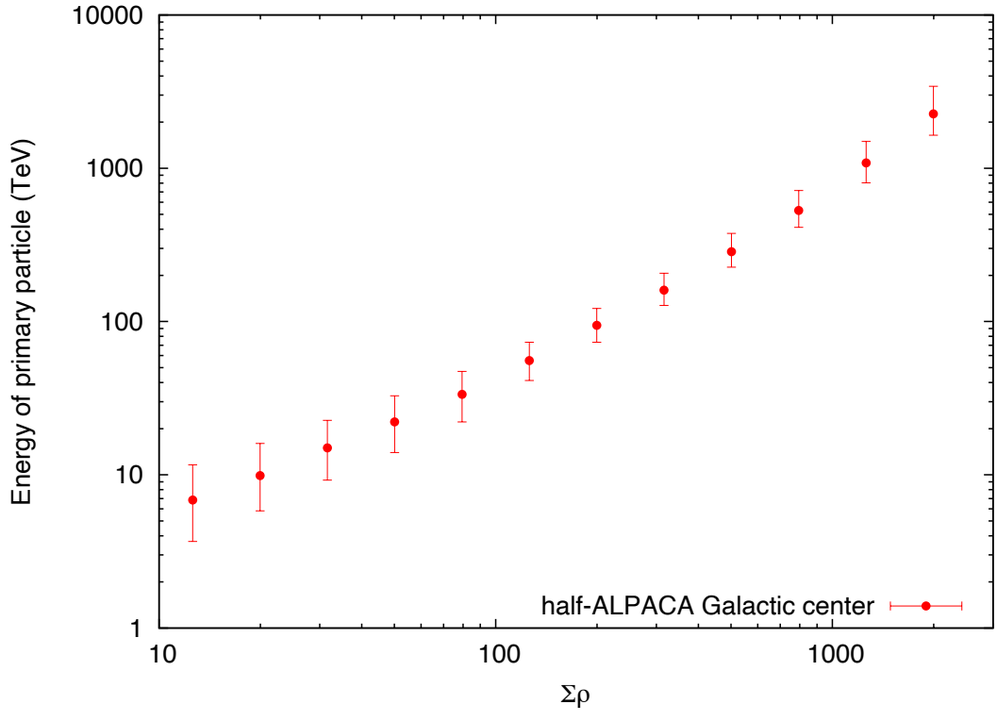


Gamma

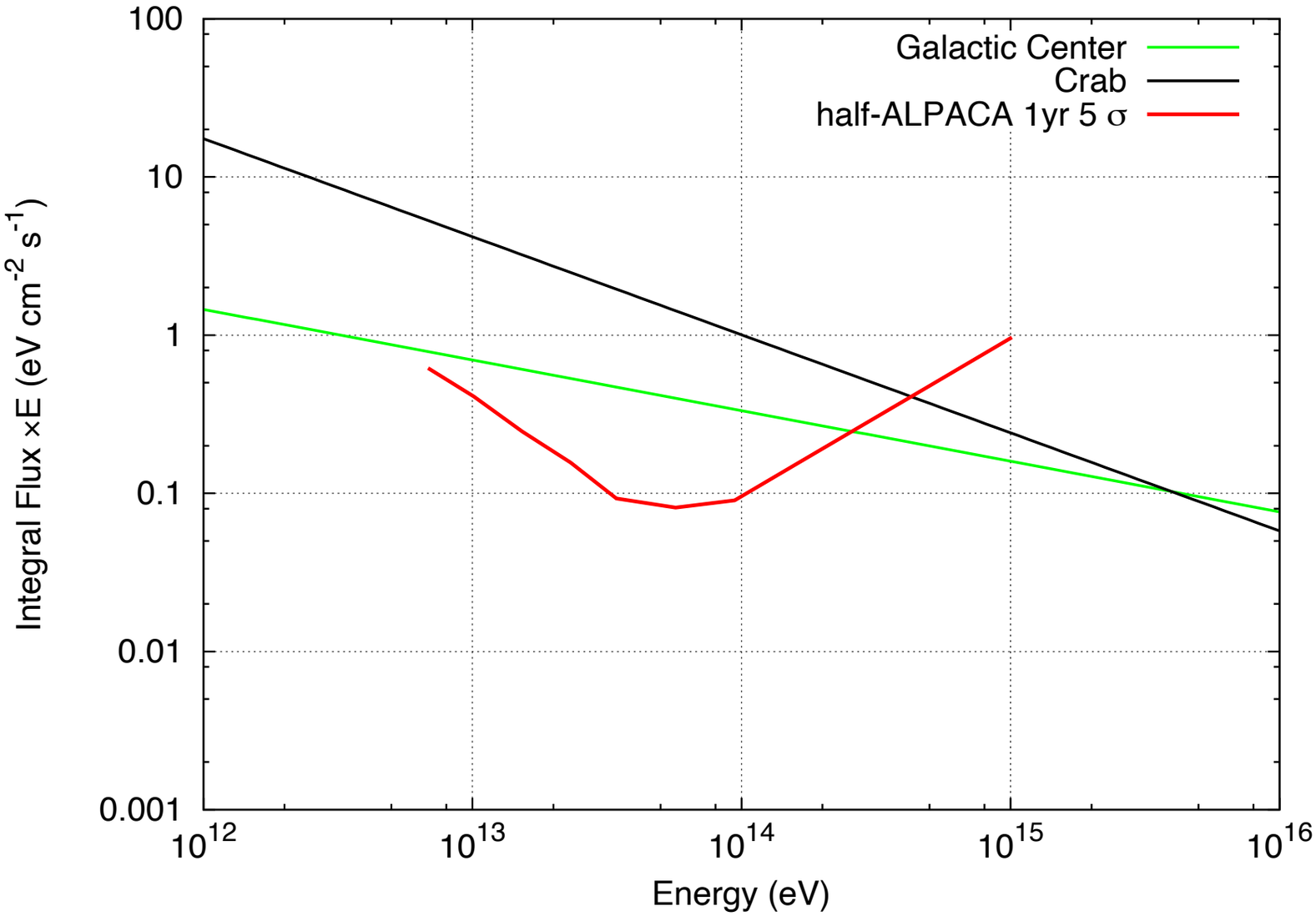
CR



- Survival Ratio of γ-rays :70% (@100TeV)
- CR rejection power ： 99.95% (@100TeV)



Sensitivity Curve



・1year observation;

Diffuse γ-ray around the Galactic center(around 40 TeV ～ 200 TeV)

Crab flux (around 10 TeV ～ 400 TeV)

Summary

★ We report on the performance half ALPACA based on our detailed MC simulations.

★ The performance of half ALPACA

Coverage area; $83000\ \mathrm{m}^2$ (AS array) and $3600\ \mathrm{m}^2$ (MD array)

Basic property; Angular resolution 0.2°(@100 TeV)

Error of Core Location 2.7m(@100 TeV)

Sensitivity; Half ALPACA can detect diffuse γ-ray around the Galactic Center (around 40 TeV ～ 200 TeV) about 1year observation.

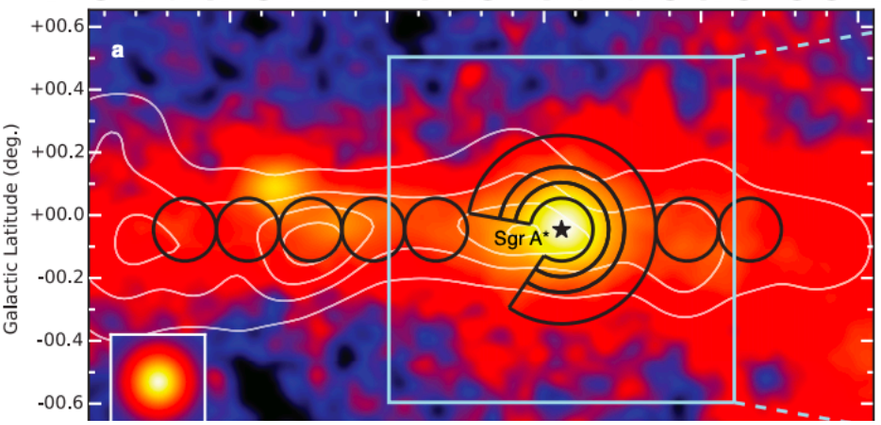
Prospects

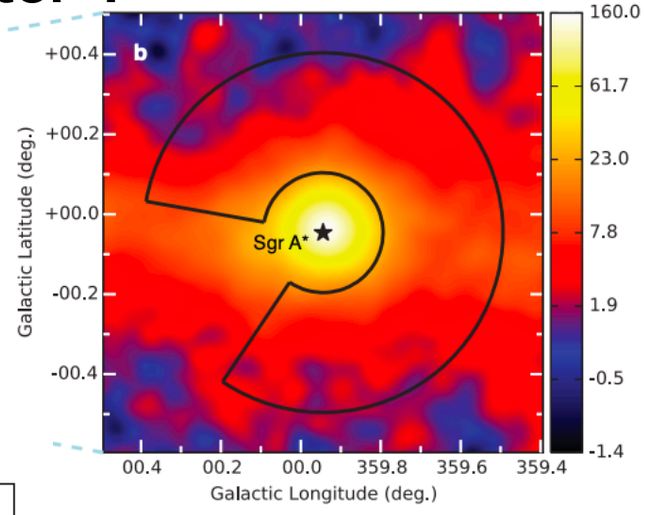
★ In this MC simulation, we assume the point source. However, Galactic Center is an extent object. So, we should consider the effect of extension of the source.

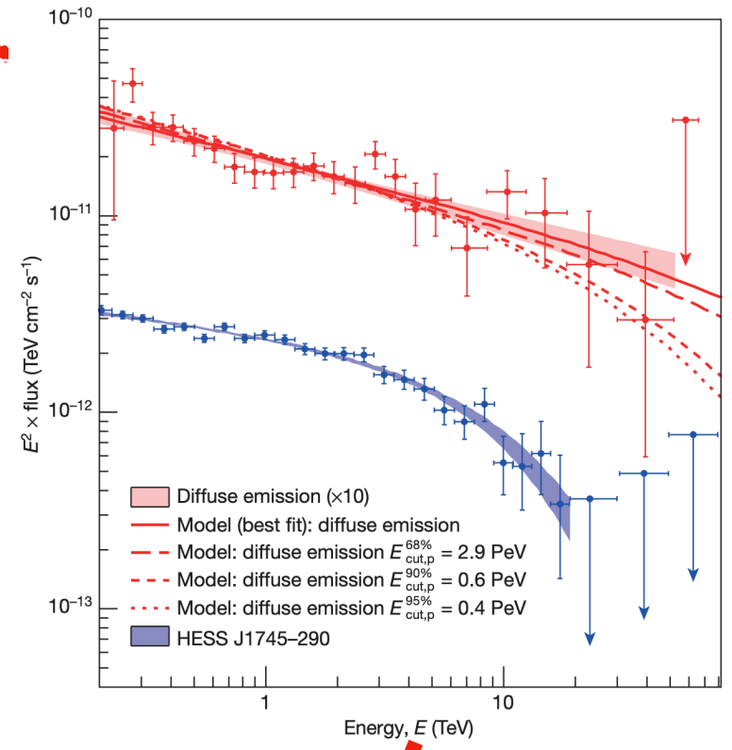
END

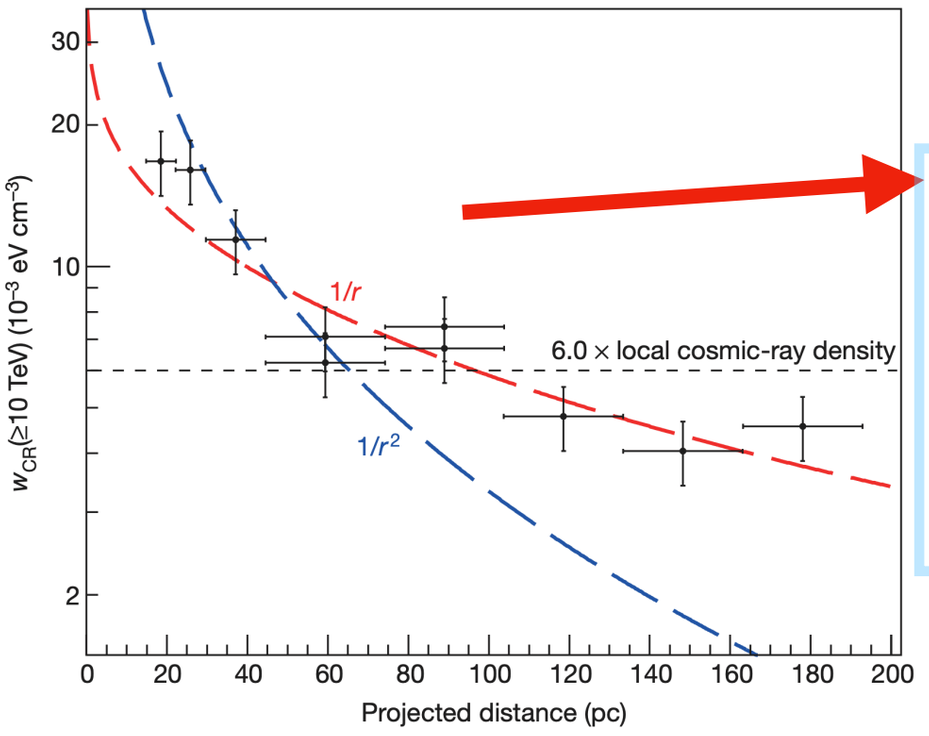
Observation of The Southern Sky

PeVatron in the Galactic center ?









Not electron like .

↓

Proton flows into the centeral molecular zone from the central accelerator.

+

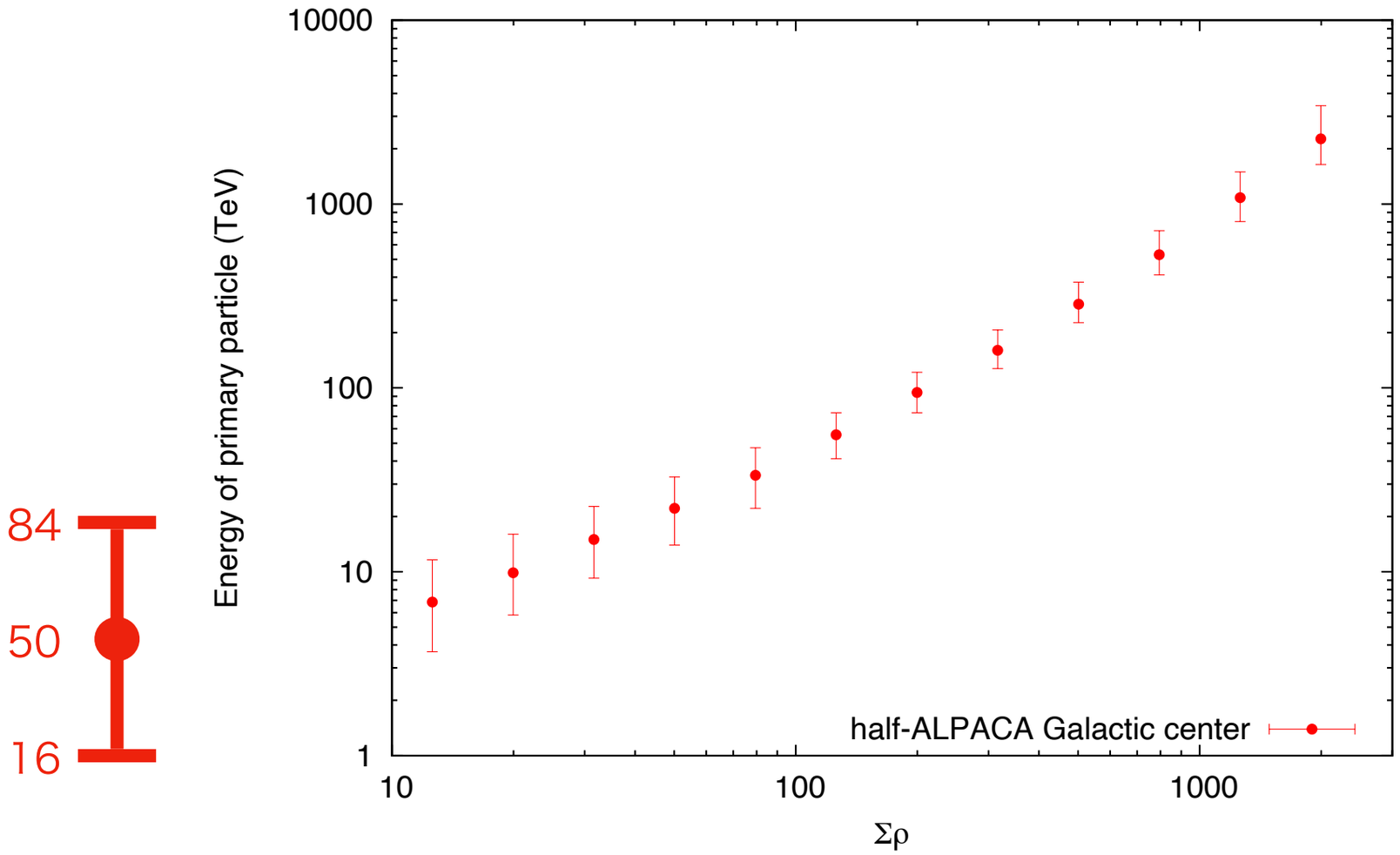
No cutoff ?

↓

(If extends up to 100 TeV region) PeVatron ???

Abramowski et al., Nature, 531, 476, (2016)

Energy - Σ ρ relationship

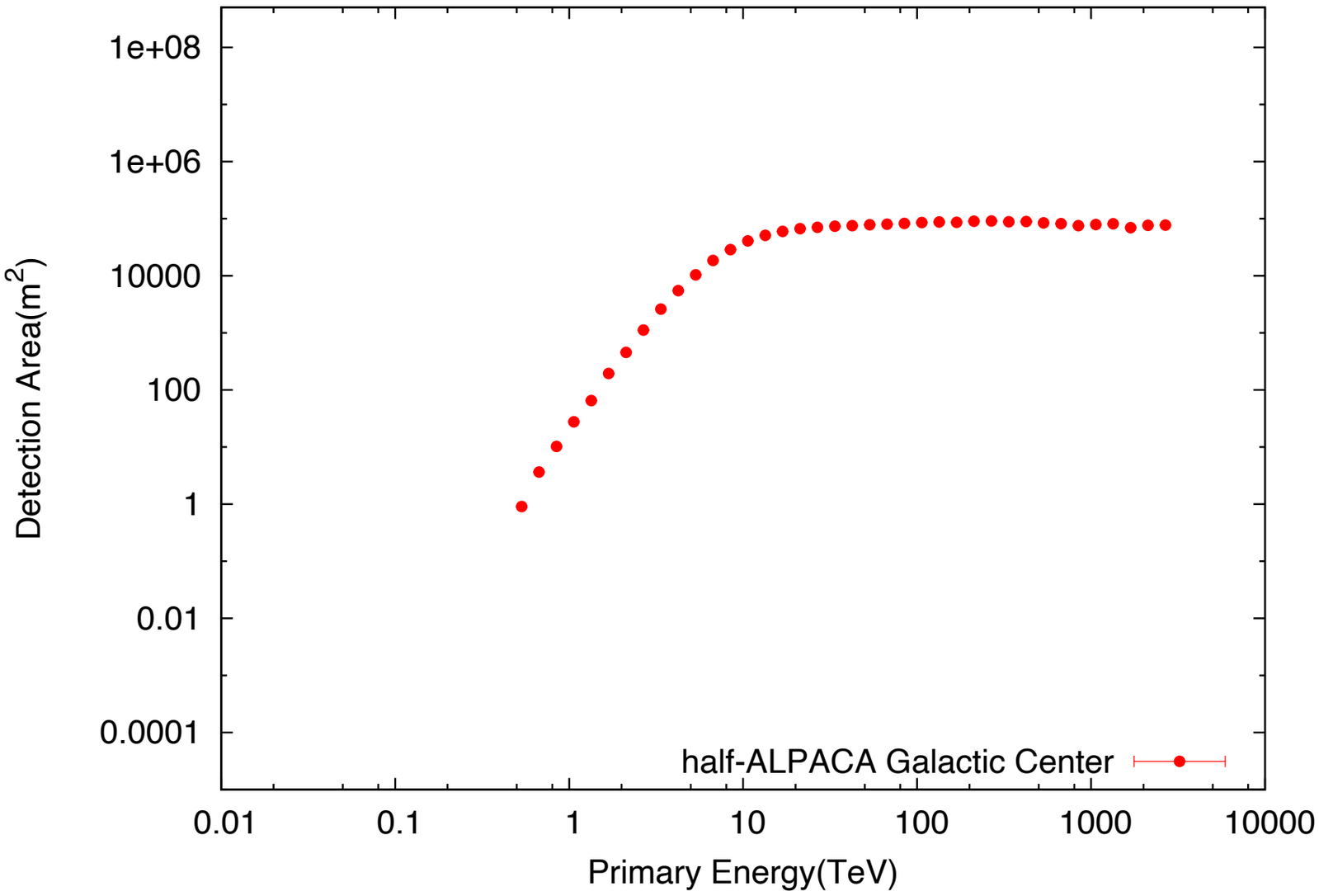


Value containing 50% of total events

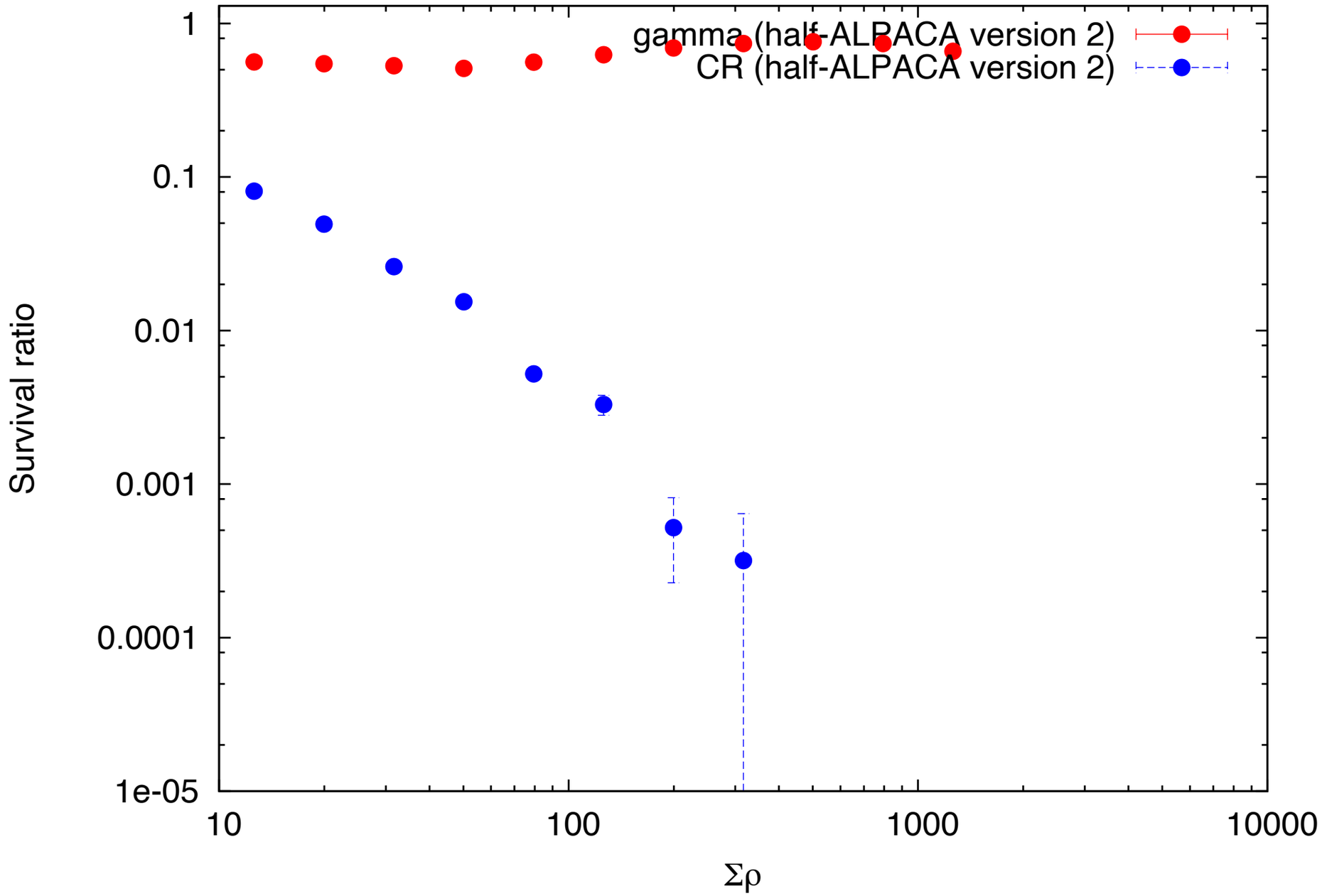
Energy(TeV)	10	30	100
Σ ρ bin	$15.8 \leq \Sigma\rho < 25.1$	$63.1 \leq \Sigma\rho < 100$	$251 \leq \Sigma\rho < 398$

Detection Area

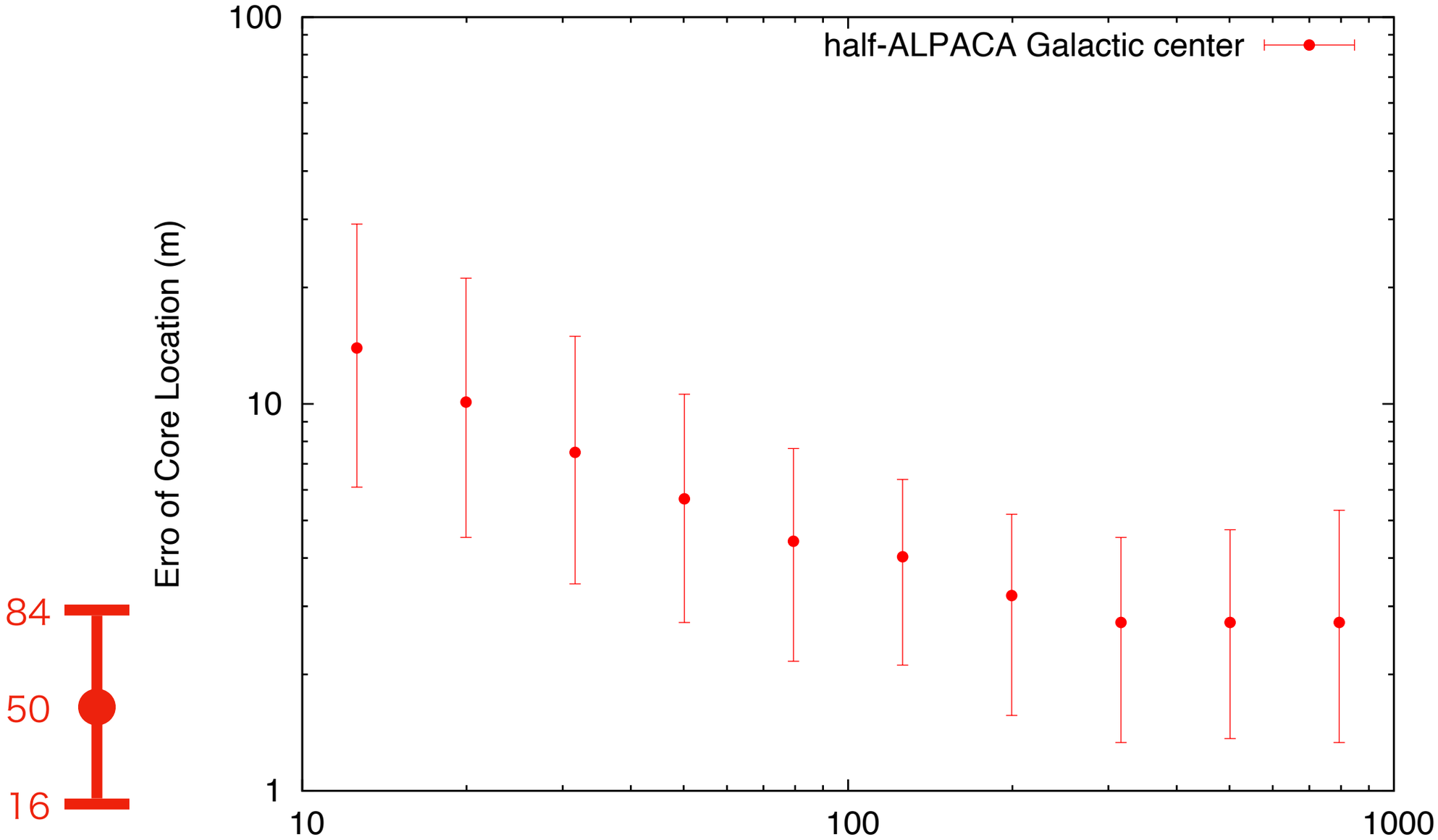
① 0.8 particle any 4
② “IN” event : 3 out of 4 hottest detectors locate in an inner area
③ Residual error $\chi^2 < 1.0\ \mathrm{m}^2$
(accuracy of determination on incoming direction)
④ Zenith angle $0^\circ \leq \theta \leq 40^\circ$



Survival Ratio



Error of Core Location



Value containing 50% of total events $\Sigma\rho$

Energy(TeV)	10	30	100
Error of Core Location	10.1	4.4	2.7