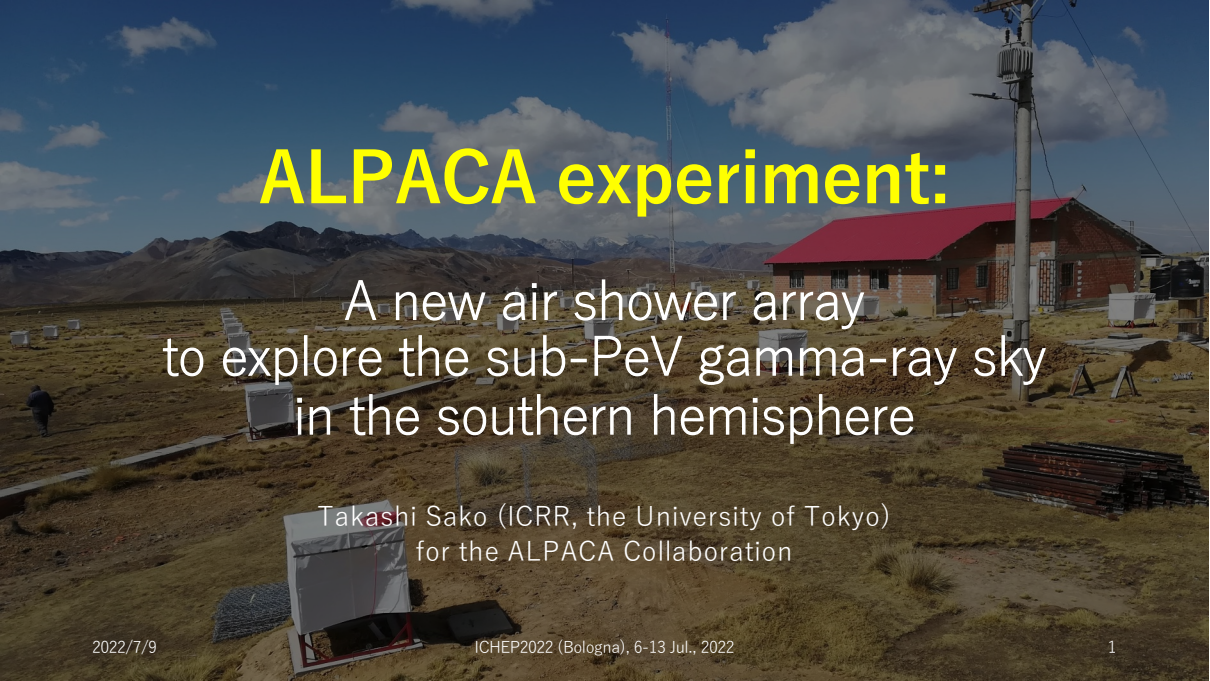
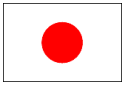


ALPACA experiment:

A new air shower array to explore the sub-PeV gamma-ray sky in the southern hemisphere

Takashi Sako (ICRR, the University of Tokyo)
for the ALPACA Collaboration

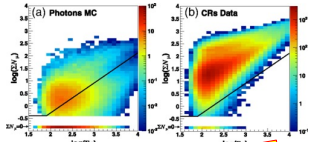
The ALPACA Collaboration



T. Sako [A], M. Anzorena [A], C. A. H. Condori [C], E. de la Fuente [D], A. Gomi [E], Y. Hayashi [B], K. Hibino [F], N. Hotta [G], A. Jimenez-Meza [D], Y. Katayose [E], C. Kato [B], S. Kato [A], I. Kawahara [E], T. Kawashima [A], K. Kawata [A], T. Koi [H], H. Kojima [I], D. Kurashige [E], R. Mayta [J,K], P. Miranda [C], K. Munakata [B], K. Nagaya [E], Y. Nakamura [A], C. Nina [C], M. Nishizawa [M], R. Noguchi [E], S. Ogio [A], M. Ohnishi [A], S. Okukawa [E], A. Oshima [H], M. Raljevich [C], H. Rivera [C], T. Saito [N], Y. Sakakibara [E], T. K. Sako [A], T. Sasaki [F], S. Shibata [I], A. Shiomi [L], M. Subieta [C], N. Tajima [O], W. Takano [F], M. Takita [A], Y. Tameda [P], K. Tanaka [Q], R. Ticona [C], I. Toledano-Juarez [D], H. Tsuchiya [R], Y. Tsunesada [J,K], S. Udo [F], K. Yamazaki [H], Y. Yokoe [A] et al. (The ALPACA Collaboration)

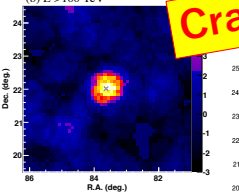
ICRR, Univ. of Tokyo [A], Dept. of Phys., Shinshu Univ.[B], IIF, UMSA [C], Univ. de Guadalajara [D], Fac. of Engn., Yokohama Natl. Univ.[E], Fac. of Engn., Kanagawa Univ.[F], Utsunomiya Univ.[G], Coll. of Engn., Chubu Univ.[H], Astro. Obs., Chubu Univ.[I], Grad. Sch. of Sci., Osaka Metro. Univ.[J], NITEP, Osaka Metro. Univ.[K], Coll. of Ind. Tech., Nihon Univ.[L], NII [M], Tokyo Metro. Coll. of Ind. Tech.[N], RIKEN [O], Fac. of Engn., Osaka Electro-Comm. Univ.[P], Fac. of Info. Sci., Hiroshima City Univ.[Q], JAEA [R]

Dawn of sub-PeV gamma-ray astronomy

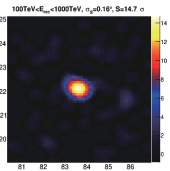


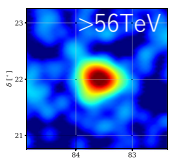
(b) $E>100$ TeV

Crab



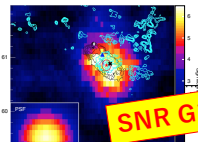
Tibet AS γ Collaboration, PRL 123, 051101 (2019)





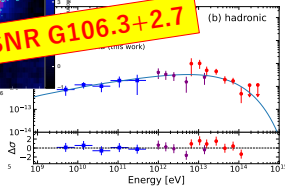
LHAASO Collaboration, Chin. Phys. C45, 023002 (2021)

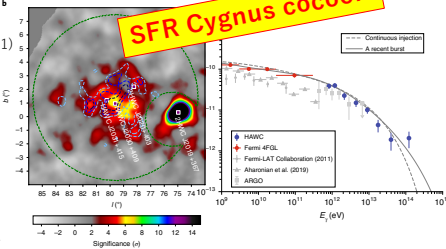
HAWC Collaboration, ApJ 881:134 (2019)



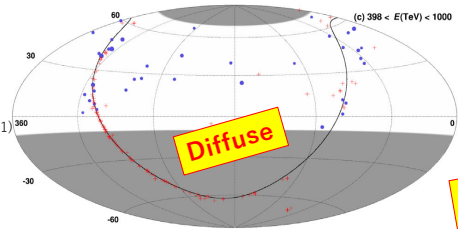
Tibet AS γ Collaboration, Nature Astron., 5, 460-464 (2021)

SNR G106.3+2.7

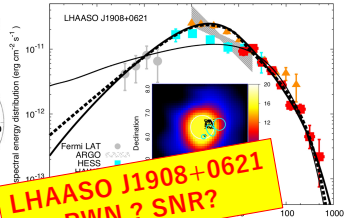




HAWC Collaboration, Nature Astron., 5, 465-471 (2021)



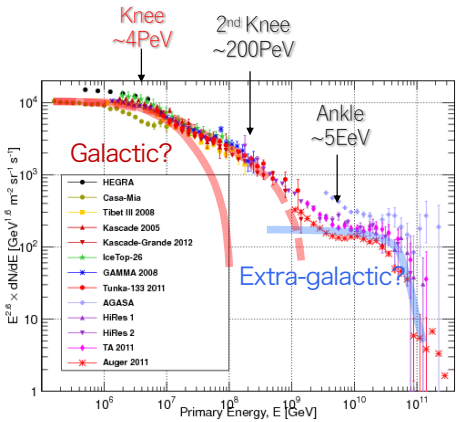
Tibet AS γ Collaboration, PRL 126, 141101 (2021)



LHAASO J1908+0621 PWN,? SNR?

LHAASO Collaboration, Nature, 594, 33-36 (2021)

Why sub-PeV gamma rays?



Gaisser et al. Front.Phys.(Beijing) 8 (2013) 748

- Galactic protons are thought to be accelerated up to PeV (~knee)
  - Where are their origins?
  - Are CRs up to 100PeV (~2nd knee) heavy nuclei?
- Sub-PeV gamma rays point to the sources of PeV CRs

$$p(E) + ISM \rightarrow X + \pi^0 \rightarrow X + 2\gamma(\sim 0.1E)$$

- Diffuse gamma rays tell us the CR distribution in the galaxy.
- Highest energy gamma rays tell us the acceleration limit in energy/nucleon.

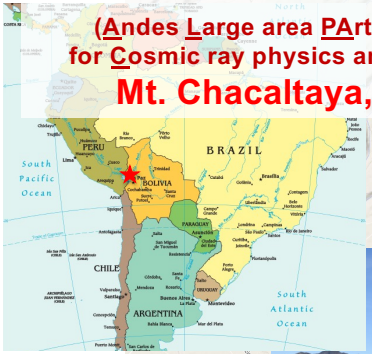
Especially in the **southern hemisphere**, near the Galactic center!!

Where are the CR sources?
What is the maximum acceleration energy (/nucleon)?
How do they propagate in the galaxy?

ALPACA

(Andes Large area PArticle detector for Cosmic ray physics and Astronomy)

Mt. Chacaltaya, Bolivia



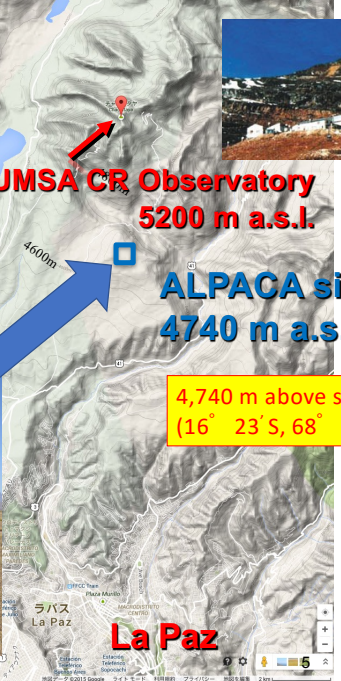
UMSA CR Observatory
5200 m a.s.l.

4600m

4400m

ALPACA site
4740 m a.s.l.

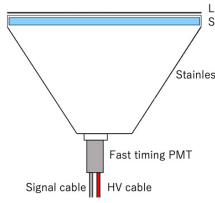
4,740 m above sea level
(16° 23′S, 68° 08′W)

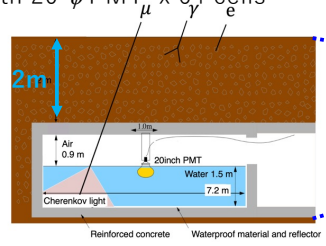


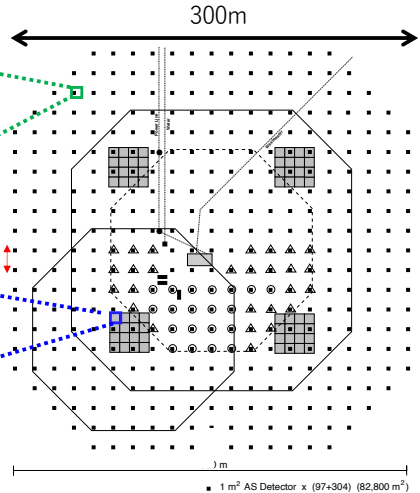
ALPACA Array

1. **Array coverage 82,800m²**
   = 401 x 1m² plastic scintillators

2. **Underground water Cherenkov muon detector (MD) 3700m²**
   Soil over 2m (~16X_0)
   = 58m² with 20"ϕPMT x 64 cells



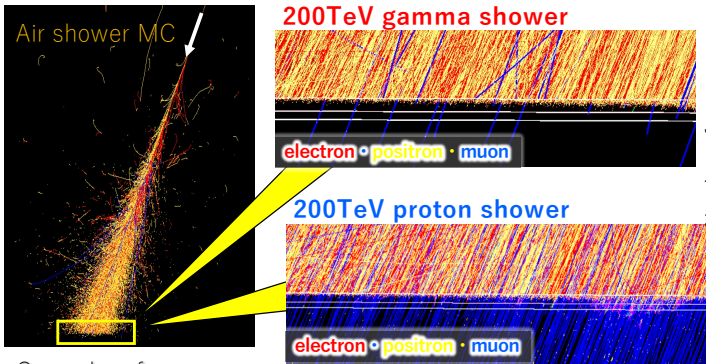




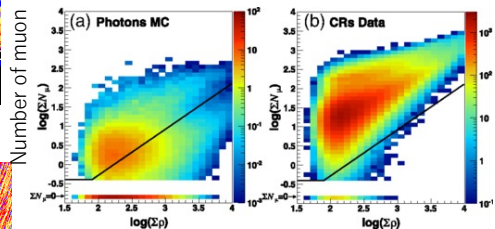
- ✓ Cosmic-ray BG rejection power >99.9% @100TeV.
- ✓ Angular resolution ~0.2° @100TeV, Energy resolution ~20%@100TeV
- ✓ 100% duty cycle, FOV θ_{zen}<40° (well studied), θ_{zen}<60° (in study)

Particle ID

- BG is enormous hadronic CR showers
- Number of penetrating muons 2m underground is used for hadronic/EM shower separation
- Technic is established by the Tibet ASγ Collaboration

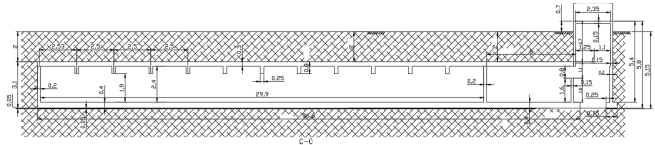


Crab analysis by Tibet AS γ Collaboration
PRL 123, 051101 (2019)



Underground Muon Detector (MD)

Site photo + CG image of MD by design company



- Total 4 units, each composes of 16 cells of 7.5mx7.5m.
- 2m soil overburden allows >1GeV muon penetration.
- Design finalizing with Bolivian construction design company.
- Construction of first MD in this fiscal year.

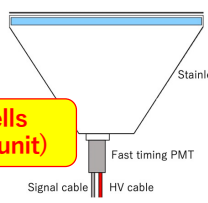
ALPA**QUITA** Array

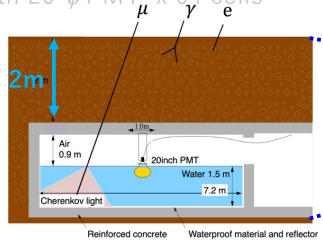
97 detectors

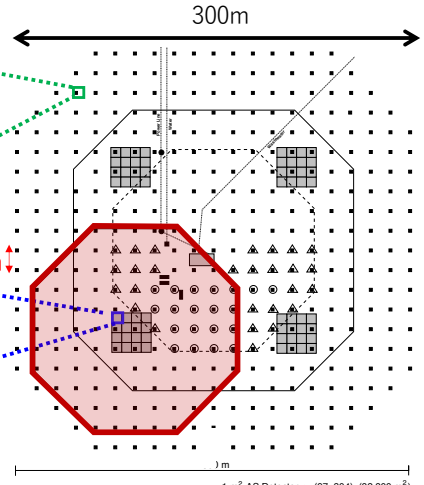
1. **Array coverage 82,800m²**
   = 401 x 1m² plastic scintillators

2. **Underground water Che… muon detector (MD) 37…**
   Soil over 2m (~16X_0)
   = 58m² with 20"ϕPMT x 64 cells

16 cells (1 MD unit)







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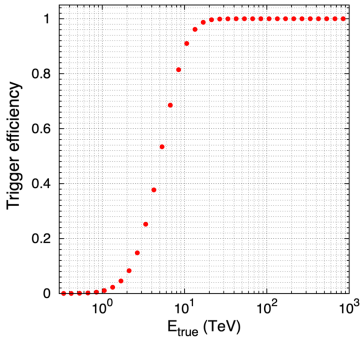
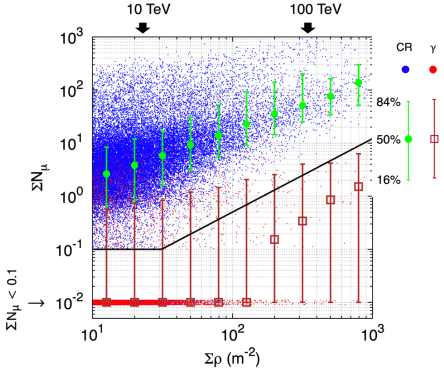
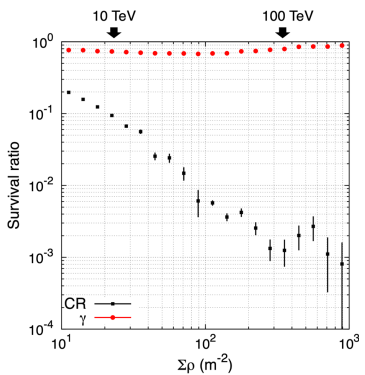
ALPAQUITA Performance



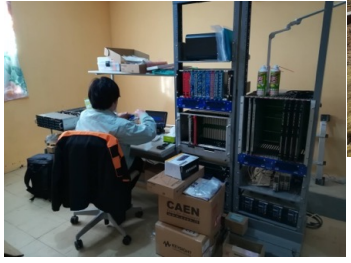




S.Kato et al., Experimental Astronomy (2021) 52:85-107

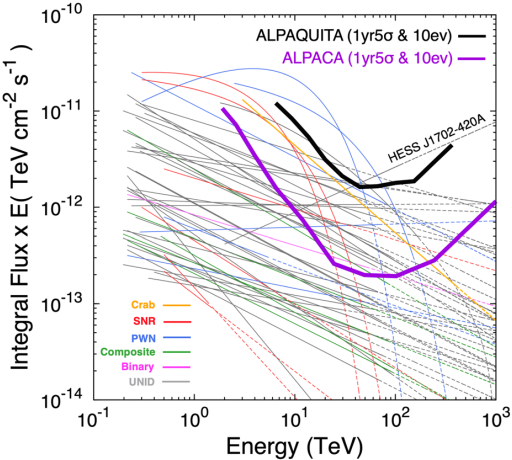
- CORSIKA (FLUKA + EPOS-LHC)+ GEANT4 simulation
- Trajectory of RXJ1713.7-3946 (23.4 deg zenith angle at culmination)
- Full efficiency > 20TeV
- 99.9% BG rejection while keeping 80% of photons @ 100TeV

ALPAQUITA construction in June 2022



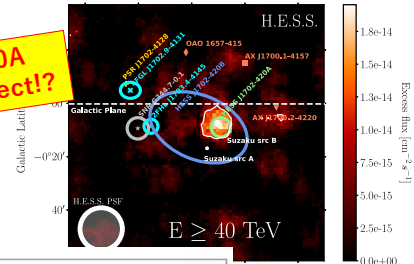
- Construction resumed in June 2022.
- Installation of 97 ground detectors completed.
- HV ON/calibration/DAQ start in Aug.-Sep., 2022.

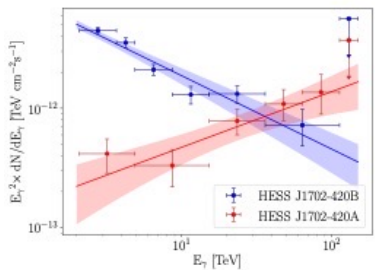
ALPAQUITA sensitivity



S.Kato et al., Experimental Astronomy (2021) 52:85-107

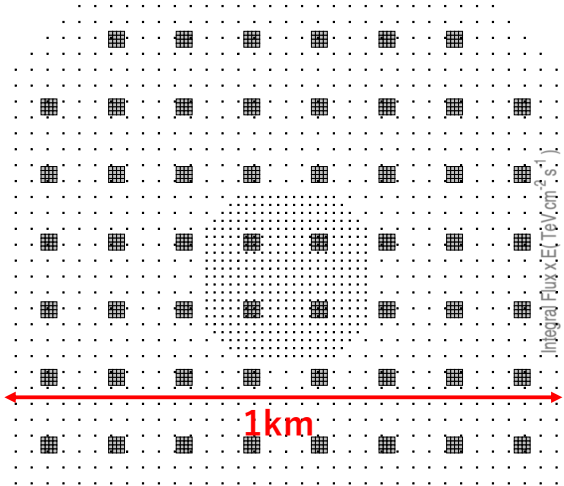
HESS J1702-420A
Mysterious object!?

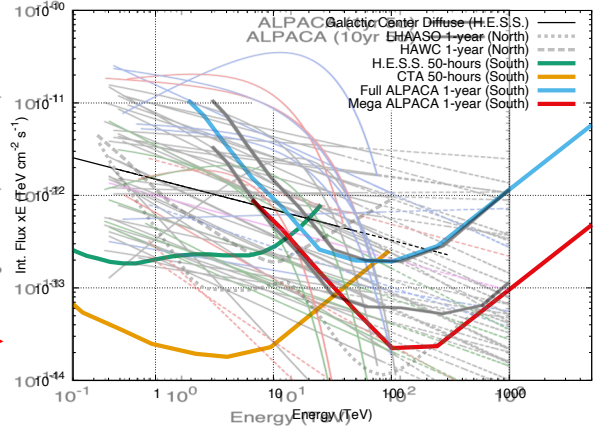




HESS Collaboration, A&A 653, A152 (2021)

Beyond PeV – Mega (m^2) ALPACA





Where is the highest energy accelerator in our Galaxy?

Summary

- **Sub-PeV gamma-ray astronomy opened a new window to reveal the highest energy CR accelerators in the Galaxy**
  - Successful experiments in the northern hemisphere
  - Southern sky is yet unexplored
- **ALPACA is a new air shower array constructed in Bolivia**
  - First sub-PeV observation in the southern hemisphere
  - Underground MD technic established by the Tibet AS γ collaboration
- **Observation will start soon**
  - Observation with 97 ground detectors, **ALPAQUITA**, will start soon
  - Construction of first MD will start in this fiscal year
  - Extension to 401 ground detectors + 4 MDs (full **ALPACA**) follows in 2023-2024
  - Idea of **Mega ALPACA** to reach PeV is proposed

Summary

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Stay tuned for ICRC2023 in Japan!!

ICRC2023

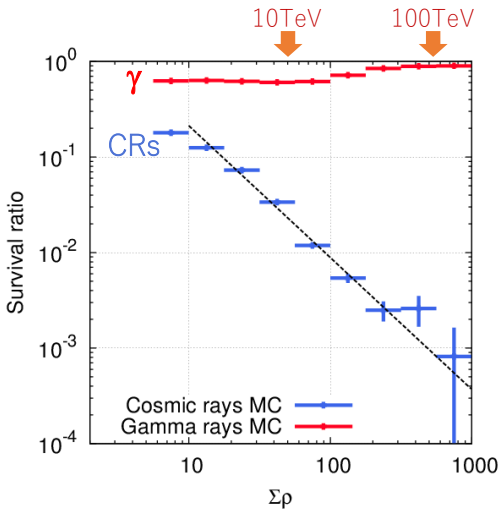
The Astroparticle Physics Conference

Nagoya, Japan, Jul 26–Aug 3, 2023

icrc2023.org

Backup

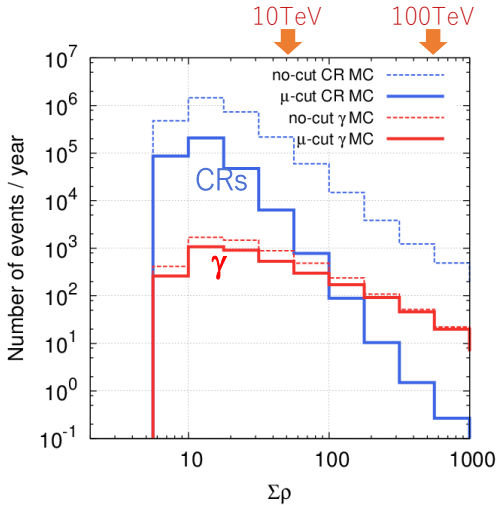
Survival Ratio After Muon Cut



ALPACA full MC simulation
(AS 83000m^2 + MD 5400m^2)
Muon cut is optimized
assuming Crab-like source

- ✓ Cosmic rays will be rejected by ~99.9% @100TeV
- ✓ Gamma rays will be retained over 90% @100TeV

of Events Before/After Muon Cut



ALPACA full MC simulation
(AS 83000m^2 + MD 5400m^2)
Muon cut is optimized
assuming Crab-like source

- ✓ # of cosmic rays ~1 /year >100TeV
- ✓ # of gamma rays ~50 /year >100TeV