ALPACA :
A new air shower array experiment to explore 100TeV gamma-ray sky in Bolivia

Takashi Sako (University of Tokyo) for the ALPACA Collaboration
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Search for ReVPArticle accelerators

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Figure S3 shows the relative muon number ($N_{\text{muon}}$) vs. $N_{\text{shower particle}}$.

For the cosmic-ray background events, the muon cut ($N_{\mu} < 1$) is consistent with that estimated by the photon MC simulation. This is unequivocal evidence for photon-induced air showers from cosmic-ray induced air showers. As shown in Figure 2 in the paper, the muon cut ($N_{\mu} > 1$) distribution above $100 \text{ TeV}$ for the Crab nebula events is more than 100, while the muon cut ($N_{\mu} = 1$) distribution is roughly proportional to energy, and the muon cut line in Figure 2 at the observed $E_{\gamma}$ region, and the relative muon distribution after the muon cut ($N_{\mu} < 1$) is used as the parameter to discriminate. In this paper, the total number of particles detected in the MDs ($N_{\mu} > 100 \text{ TeV}$, where the muon cut ($N_{\mu} = 1000$) roughly corresponds to $\sim 10 \text{ ns}$, but examining the raw PE distributions in data shows the shift due to systematics in the lowest energies by scaling the PSF up by this amount and re-fitting the Crab using the calibration system.

The charge uncertainty encapsulates how much a PMT efficiency from the calibration system can be seen in Figure 13. The maximum significance map above $56 \text{ TeV}$ in reconstructed energy for the GP simulation can be seen in Figure 13, and arose from a mismodeling of the light in the air shower. This is thought to stem from a late light in the air shower. This effect is almost completely negligible. The charge uncertainty is not yet having an energy dependence. The charge uncertainty encapsulates how much a PMT efficiency from the calibration system can be seen in Figure 13. The maximum significance map above $56 \text{ TeV}$ in reconstructed energy for the GP simulation can be seen in Figure 13, and arose from a mismodeling of the light in the air shower. This is thought to stem from a late light in the air shower. This effect is almost completely negligible. The charge uncertainty is not yet having an energy dependence.

### 100 TeV $\gamma$ Fever in 2019

Tibet AS$\gamma$ Collaboration, PRL 123, 051101 (2019)

HAWC in Sierra Negra

ALPACA
(Andes Large area PArticle detector for Cosmic ray physics and Astronomy)
Mt. Chacaltaya, Bolivia

JMSA CR Observatory
5200 m a.s.l.

ALPACA site
4740 m a.s.l.

4,740 m above sea level
(16° 23’S, 68° 08’W)
ALPACA exposure (hours/year)

- Observation time (hour/year) with zenith angle $\theta<45^\circ$
- >2000 hours/year observations for major objects including Galactic center
Array layout of ALPACA

- 400 x 1m² plastic scintillators
- (7mx8m unit) x 12 x 8 (TBD) underground water Cherenkov muon detectors (5400m²)
- 2.2m underground (1GeV muon threshold)

Angular resolution: 0.2° @ 100TeV
Energy resolution: 20% @ 100TeV
ALPACA sensitivity to the H.E.S.S. sources

- Solid lines: observed results by H.E.S.S.
- Dashed lines: extrapolation from the H.E.S.S. results
- Many 10TeV objects with hard spectra → Possible PeVatrons
- Variety of categories, not only SNRs
- Even no-detection determines the maximum energy
current status

- ALPAQUITA -

(little ALPACA, ALPACA-chan)

• Prototype array of ALPACA
  • 20% area of full ALPACA with 97 surface detectors
  • 1 underground muon detector (700-1000m$^2$) to be constructed in 2020 (position TBD)

• Purpose
  • Detection of bright gamma-ray sources
  • Cosmic-ray anisotropy in the Southern hemisphere, space weather study

Detector material arrived at Bolivia early 2019
Sensitivity to Vela X \((\alpha, \delta) = (08^h35^m00^s, -45^\circ36'00'')\) 

Differential flux from inner region + ring: 

\[
d\!N/dE = N_0 E^{-\Gamma} \exp(-E/E_{\text{cut}}) \text{ (TeV}^{-1}\text{cm}^{-2}\text{s}^{-1})
\]

\[
N_0 = 2.1 \times 10^{-11} \text{ (TeV}^{-1}\text{cm}^{-2}\text{s}^{-1}), \ E_{\text{cut}} = 14.0\text{TeV}, \ \Gamma = 1.32
\]
Effective area for Vela X trajectory

Inner area (12,600m²)

$\theta < 40^\circ$

$40 < \theta < 60^\circ$
Optimization of MD location (study on going)

- case1: optimized for full ALPACA array
- case2: optimized for ALPAQUITA only

\[ \Sigma N_\mu: \text{Total number of detected muons in one shower event} \]
\[ \Sigma \rho: \text{Total number of particles [In 39.8 \leq \Sigma \rho < 63.1 (~12 \text{ TeV})]} \]
Bin–by–bin yearly detection significances (Vela X)

<table>
<thead>
<tr>
<th></th>
<th>Case 1: Using lower-left MD</th>
<th>Case 2: Using center MD</th>
</tr>
</thead>
<tbody>
<tr>
<td>~ 8 TeV (25.1 ≤ Σρ &lt; 39.8)</td>
<td>2.52 ± 0.05</td>
<td>3.30 ± 0.08</td>
</tr>
<tr>
<td>~ 12 TeV (39.8 ≤ Σρ &lt; 63.1)</td>
<td>3.03 ± 0.08</td>
<td>3.98 ± 0.14</td>
</tr>
<tr>
<td>~ 18 TeV (63.1 ≤ Σρ &lt; 100)</td>
<td>3.83 ± 0.18</td>
<td>4.73 ± 0.28</td>
</tr>
<tr>
<td>~ 30 TeV (100 ≤ Σρ &lt; 158)</td>
<td>2.81 ± 0.06</td>
<td>3.80 ± 0.09</td>
</tr>
</tbody>
</table>
ALPAQUITA in October 2019
ALPAQUITA in October 2019

- All 97 basements placed
- Assembly of 20 detectors completed
- Cable channels finalized soon
- Assembly of all detectors, cabling, first data taking as soon as possible in 2020
- First muon detector in design, to be constructed in 2020
Summary

• ALPACA is a new air shower array project to explore 100TeV sky in the Southern hemisphere

• Many H.E.S.S. sources can be studied at >10TeV
  • Systematic search of 100TeV emission and cutoff below 100TeV

• Prototype array ALPAQUITA under construction
  • surface array construction to be completed and operation starts early 2020
  • first muon detector construction in 2020
Backup
Power and water

- アレイ周りの柵の設置
- エレキ・作業用ハットの建設
- GPS測量による設置位置の最終確認
- 電力線の移動（これまでのチャカルタヤ観測所までのラインを移動）
- 取水用ポンプ、排水設備の設置
ALPACA exposure (hours/year)

- Galactic Center, RX J1713: >2,000 hours/year ($\theta<45^\circ$)
- >1,000 hours/year for Crab
- $\theta<60^\circ$ allows 3000 hours/year
  - Effects on threshold energy, resolution must be studied

<table>
<thead>
<tr>
<th>Object name</th>
<th>Declination (degree)</th>
<th>Exposure (hours/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crab</td>
<td>22.0</td>
<td>1171</td>
</tr>
<tr>
<td>W51</td>
<td>14.2</td>
<td>1634</td>
</tr>
<tr>
<td>W28</td>
<td>-23.3</td>
<td>2331</td>
</tr>
<tr>
<td>Galactic Center</td>
<td>-29.0</td>
<td>2322</td>
</tr>
<tr>
<td>RX J1713.7-3946</td>
<td>-39.8</td>
<td>2176</td>
</tr>
<tr>
<td>Vela</td>
<td>-45.6</td>
<td>2016</td>
</tr>
<tr>
<td>RX J0852.0-4622</td>
<td>-46.4</td>
<td>1989</td>
</tr>
<tr>
<td>RCW86</td>
<td>-62.4</td>
<td>0</td>
</tr>
<tr>
<td>LMC</td>
<td>-67.6</td>
<td>0</td>
</tr>
</tbody>
</table>

$\text{Table 3: default}$

- Zenith angle limit, $\theta<45^\circ$ and the reduction of geometrical area by $\cos(\theta)$ are taken into account.
ミューオン検出器

- 2020年度に建設予定
- 土盛り＋コンクリート天井 2.5m ($E_\mu > 1$GeV)
- 7.5m × 7.5m のユニットを16基
- 1ユニットあたりPMT 1本
- 内壁をタイベックシートで覆い集光
- 25 p.e./1 MIP (Tibet実績)
- Full ALPACAを考えた建設位置の検討 => 加藤
H.E.S.S. TeV Galactic Plane Survey

• Many gamma-ray sources along the Galactic plane
• Any source beyond $10^{14}$eV?
### Air shower simulation

*Corriska7.6400 is used in a MC simulation*

<table>
<thead>
<tr>
<th>Simulation condition</th>
<th>( \gamma )-ray</th>
<th>Background CR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total # of events</td>
<td>(5.0 \times 10^7) (27 yr for Vela X)</td>
<td>① (300\text{GeV} &lt; E &lt; 10\text{PeV} : 1.1 \times 10^9) (0.6 yr for Vela X)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>② (10\text{TeV} &lt; E &lt; 10\text{PeV} : 1.0 \times 10^8) (18 yr for Vela X)</td>
</tr>
<tr>
<td>Energy range</td>
<td>(300\text{GeV} &lt; E &lt; 10\text{PeV})</td>
<td>(300\text{GeV} &lt; E &lt; 10\text{PeV})</td>
</tr>
<tr>
<td>Spectrum</td>
<td>(\propto E^{-2.0})</td>
<td>See the figure below</td>
</tr>
<tr>
<td>Injected range (from the center of the array)</td>
<td>300m radius</td>
<td>300m radius</td>
</tr>
</tbody>
</table>

**Cosmic-ray spectrum**
