Dark matter search at LHAASO

Xiao-Jun Bi
Institute of High Energy Physics, Chinese Academy of Science, Beijing

The 36th International Cosmic Ray Conference,
Madison, Wisconsin, USA
2019/7/24-8/1

He, Bi, Lin, et al,
arXiv: 1903.11910
LHAASO
Large High Altitude Air Shower Observatory
Measurement of EASs at High Altitude

- Mt. Haizi (4410 m a.s.l., 29°21’ 27.6” N, 100°08’19.6” E), Sichuan, China
- 1/4 array will be completed soon; the project will be finished by 2021.
### Sky Survey, Extended, Transient

<table>
<thead>
<tr>
<th></th>
<th>ARGO</th>
<th>AS+MD</th>
<th>HAWC</th>
<th>LHAASO</th>
<th>CTA</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Area</strong></td>
<td>6,500 m²</td>
<td>50,000 m²</td>
<td>22,500 m²</td>
<td>1 km²</td>
<td>10 km²</td>
</tr>
<tr>
<td><strong>σ_θ (deg)</strong></td>
<td>0.2-0.5</td>
<td>0.2-0.5</td>
<td>0.1-0.5</td>
<td>0.1-0.5</td>
<td>0.05</td>
</tr>
<tr>
<td><strong>BG rejection power</strong></td>
<td>10⁴</td>
<td>100</td>
<td>100/10⁴</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td><strong>Duty Cycle</strong></td>
<td>&gt;90%</td>
<td>&gt;90%</td>
<td>&gt;90%</td>
<td>&gt;90%</td>
<td>10%</td>
</tr>
<tr>
<td><strong>FOV (sr)</strong></td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>0.015</td>
</tr>
<tr>
<td><strong>Sensitivity (c.u.)</strong> @ TeV</td>
<td>0.55</td>
<td>0.06</td>
<td>0.01</td>
<td>0.001</td>
<td></td>
</tr>
<tr>
<td><strong>Energy resolution</strong></td>
<td>30%</td>
<td>30%</td>
<td>&gt;50%</td>
<td>30%</td>
<td>15%</td>
</tr>
</tbody>
</table>

**SED, morphology**
Major Scientific Goals

• Origin of GCRs
  – Searching for GCR sources by measuring SED with an unprecedented sensitivity of 1% $I_{Crab}$ at 50 TeV
  – Energy spectra for individual compositions with energy from 10 TeV to 1 EeV, where the spectrum knees are located

• Gamma ray astronomy
  – Searching for TeV $\gamma$ sources, especially extended and transient ones, with an unprecedented survey sensitivity of 1% $I_{Crab}$ at 3 TeV.

• New physics frontier
  – dark matter, Lorentz invariance, new physics beyond LHC energy, etc

Details about LHAASO see,
Huihai He, GAI1a: Status and First Results of the LHAASO Experiment
Dark matter indirect detection looks for the DM annihilation products

\[ \chi^0 \chi^0 \rightarrow l\bar{l}, q\bar{q}, 2W^\pm, 2Z^0, 2H^0, Z^0H^0, W^+H^-, gg \]
Indirect detection of dark matter -- signals

- Monoenergetic spectrum

\[ \gamma \& \nu \'s \]

LHAASO does not have charge discrimination, it is better to search gamma ray signals from dark matter!
Different targets

- Galactic center (high signal, high background)
- Dwarf galaxies (DM dominates, no astrophysical background)
- Subhalos (blind search, difficult to identify)
- Halo – diffuse gamma (low signal, low background)
- Extragalactic (large uncertainty in signal and background)
Known satellites on the sky

All the dwarf galaxies are possible gamma ray sources by DM annihilation.
Dwarf galaxies in the FOV of LHAASO

<table>
<thead>
<tr>
<th>Source</th>
<th>RA</th>
<th>DEC</th>
<th>$\theta_{\text{max}}$</th>
<th>$\log_{10} J_{\text{obs}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boötes I</td>
<td>210.02</td>
<td>14.50</td>
<td>0.47</td>
<td>18.2 ± 0.4</td>
</tr>
<tr>
<td>Canes Venatici I</td>
<td>202.02</td>
<td>33.56</td>
<td>0.53</td>
<td>17.4 ± 0.3</td>
</tr>
<tr>
<td>Canes Venatici II</td>
<td>194.29</td>
<td>34.32</td>
<td>0.13</td>
<td>17.6 ± 0.4</td>
</tr>
<tr>
<td>Coma Berenices</td>
<td>186.74</td>
<td>23.90</td>
<td>0.31</td>
<td>19.0 ± 0.4</td>
</tr>
<tr>
<td>Draco</td>
<td>260.05</td>
<td>57.92</td>
<td>1.30</td>
<td>18.8 ± 0.1</td>
</tr>
<tr>
<td>Draco II*</td>
<td>238.20</td>
<td>64.56</td>
<td>–</td>
<td>18.1 ± 2.8</td>
</tr>
<tr>
<td>Hercules</td>
<td>247.76</td>
<td>12.79</td>
<td>0.28</td>
<td>16.9 ± 0.7</td>
</tr>
<tr>
<td>Leo I</td>
<td>152.12</td>
<td>12.30</td>
<td>0.45</td>
<td>17.8 ± 0.2</td>
</tr>
<tr>
<td>Leo II</td>
<td>168.37</td>
<td>22.15</td>
<td>0.23</td>
<td>18.0 ± 0.2</td>
</tr>
<tr>
<td>Leo IV</td>
<td>173.23</td>
<td>−0.54</td>
<td>0.16</td>
<td>16.3 ± 1.4</td>
</tr>
<tr>
<td>Leo V</td>
<td>172.79</td>
<td>2.22</td>
<td>0.07</td>
<td>16.4 ± 0.9</td>
</tr>
<tr>
<td>Pisces II*</td>
<td>344.63</td>
<td>5.95</td>
<td>–</td>
<td>16.9 ± 1.6</td>
</tr>
<tr>
<td>Segue 1</td>
<td>151.77</td>
<td>16.08</td>
<td>0.35</td>
<td>19.4 ± 0.3</td>
</tr>
<tr>
<td>Sextans</td>
<td>153.26</td>
<td>−1.61</td>
<td>1.70</td>
<td>17.5 ± 0.2</td>
</tr>
<tr>
<td>Triangulum II*</td>
<td>33.32</td>
<td>36.18</td>
<td>–</td>
<td>20.9 ± 1.3</td>
</tr>
<tr>
<td>Ursa Major I</td>
<td>158.71</td>
<td>51.92</td>
<td>0.43</td>
<td>17.9 ± 0.5</td>
</tr>
<tr>
<td>Ursa Major II</td>
<td>132.87</td>
<td>63.13</td>
<td>0.53</td>
<td>19.4 ± 0.4</td>
</tr>
<tr>
<td>Ursa Minor</td>
<td>227.28</td>
<td>67.23</td>
<td>1.37</td>
<td>18.9 ± 0.2</td>
</tr>
<tr>
<td>Willman 1*</td>
<td>162.34</td>
<td>51.05</td>
<td>–</td>
<td>19.5 ± 0.9</td>
</tr>
</tbody>
</table>

He, Bi, Lin, et al, arXiv: 1903.11910
Signals and background

- DM signals

\[
\phi_s(\Delta \Omega) = \frac{1}{4\pi 2m^2_{\text{DM}}} \langle \sigma v \rangle \int_{E_{\text{min}}}^{E_{\text{max}}} \frac{dN_{\gamma}}{dE_{\gamma}} dE_{\gamma} \cdot \int_{\Delta \Omega} \left\{ \int \rho^2(r) dl \right\} d\Omega'.
\]

\[
S = \epsilon_{\Delta \Omega} \int_{E_{\text{min}}}^{E_{\text{max}}} \Phi_{\gamma}(E) \cdot A_{\text{eff}}^\gamma(E) \cdot \varepsilon_{\gamma}(E) dE \times T
\]

\[
B = \int_{E_{\text{min}}}^{E_{\text{max}}} \int_{\Delta \Omega} \zeta_{cr} \cdot \Phi_p(E) \cdot A_{\text{eff}}^p(E) \cdot \varepsilon_p(E) d\Omega dE \times T
\]
Performance of LHAASO

• $\gamma/p$ separation and angular resolution

Above \(\sim 500\text{GeV}\), we adopt $\varepsilon_p=0.28\%$ (99.72% rejected) for $\varepsilon_\gamma \sim 40\%$

1905.02773, LHAASO science white book
Performance of LHAASO

- Effective areas for different zenith angles for the gamma ray and protons

1905.02773, LHAASO science white book
Method to set bound

• Define likelihood of a signal as

\[ \mathcal{L}(S|B, N) = \prod_i \frac{(B_i + S_i)^{N_i} \exp\left[-(B_i + S_i)\right]}{N_i!} \]

• \( B_i \) is expected background events, \( S_i \) is the expected signal events, \( N_i \) is the observed events

• uncertainty of dark matter density profile of dwarf galaxies are taken into account

\[ \mathcal{L}_j = \prod_i \mathcal{L}_{ij}(S_{ij}|B_{ij}, N_{ij}) \times \mathcal{J}(J_j|J_{\text{obs},j}, \sigma_j) \]

• Combine 19 dwarfs,

\[ \mathcal{L}^\text{tot} = \prod_j \mathcal{L}_j \]

\[ 2\left( \ln \mathcal{L}_{\text{max}} - \ln \mathcal{L}_{95}\right) = 2.71 \]
Sensitivity of dark matter signal

- We consider $b\bar{b}$, $t\bar{t}$, $w\bar{w}$, $\mu\mu\tau\tau$ final states
Sensitivity of dark matter

- Compare with other exps, LHAASO is more sensitivity for DM mass above ~TeV
Summary

• Dark matter search is one most important scientific goal of LHAASO. We give sensitivity calculation of LHAASO based on simulation results.

• Gamma rays from dwarf galaxies are the most promised signal which may be detected at LHAASO. LHAASO has large F.O.V and can probe many dwarf galaxies at the same time.

• LHAASO is more sensitive than other detectors if DM mass is above 1~5TeV depending on final states.