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Search for dark matter with LHAASO

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Detection of gamma rays from the annihilation or decay of dark matter particles is a promising method for identifying dark matter, understanding its intrinsic properties, and mapping its distribution in the universe. The searches feature many different target types, including dwarf spheroidal galaxies, galaxy clusters, the Milky Way halo and inner Galaxy and unassociated Fermi-LAT sources. The LHAASO experiment is a new generation Extensive Air Shower array devoted to detect photon-induced showers in the wide energy range from few hundreds GeV up to PeV and to study cosmic ray physics up to 10^{18} eV. Due to its all-sky field of view and high duty-cycle (about 100%), the dwarf spheroidal galaxies are the most promising target for LHAASO, due the possibility to monitor in the same time different objects. LHAASO will also allow to look for dark matter signatures from unknown locations of the Northern sky with unprecedented sensitivity above tens TeV. In this contribution we present a preliminary calculation of the LHAASO sensitivity to the gamma-ray signatures of high-mass (multi-TeV) dark matter annihilation.

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1. Introduction

One of the major open issues in our understanding of the Universe is the existence of an extremely-weakly interacting form of matter, the Dark Matter (DM), supported by a wide range of observations including large scale structures, the cosmic microwave background and the isotopic abundances resulting from the primordial nucleosynthesis. Detection of gamma rays and cosmic rays from the annihilation or decay of DM particles is a promising method for identifying DM, understanding its intrinsic properties, and mapping its distribution in the universe (for a review see for example [1]).

Dwarf satellites of the Milky Way are among the cleanest targets for indirect DM searches in gamma-rays. They are systems with a very large mass/luminosity ratio (i.e. systems which are largely DM dominated).

The *Fermi*-LAT detected no significant emission from any of such systems and the upper limits on the γ-ray flux allowed us to put very stringent constraints on the parameter space of well motivated WIMP models[2, 3, 4]. Individual and combined upper limits on the annihilation cross section for the $b\bar{b}$ final state are shown in Fig. 1 [3] for 10 Dwarf Spheroidal Galaxies (dSph). As it can be seen from the figure, averaged over the WIMP masses, the combined limits are more than twice as constraining on the DM signal than their strongest individual dwarf galaxy [3].

With the present data we are able to rule out large parts of the parameter space where the thermal relic density is below the observed cosmological dark matter density and WIMPs are dominantly produced non-thermally, e.g. in models where supersymmetry breaking occurs via anomaly mediation. These γ-ray limits also constrain some WIMP models proposed to explain the *Fermi*-LAT and PAMELA e^+e^- data, including low-mass wino-like neutralinos and models with TeV masses pair-annihilating into muon-antimuon pairs.

Note that these searches are really complementary and at the same quantitative level of the searches that can be performed at LHC. See for example Fig. 2 from [5] that show the inferred ATLAS 95% CL limits on WIMP annihilation rates versus mass. The thick solid lines are the observed limits excluding theoretical uncertainties. The ATLAS limits are for the four light quark flavours assuming equal coupling strengths for all quark flavours to the WIMPs. For comparison, high-energy gamma-ray limits from observations of Galactic satellite galaxies with the Fermi-LAT experiment for Majorana WIMPs are shown. The Fermi-LAT limits are scaled up by a factor of two to make them comparable to the ATLAS Dirac WIMP limits. All limits shown here assume 100 % branching fractions of WIMPs annihilating to quarks. The horizontal dashed line indicates the value required for WIMPs to make up the relic abundance set by the WMAP measurement.

In this paper a preliminary calculation of the expected sensitivity of the LHAASO experiment to signatures of DM annihilation is given. The survey capability of a wide field of view detector such as LHAASO is very important in DM signal search. In fact, annihilating DM is expected from different classes of sources and a survey of several source populations is crucial. In addition, multiple sources can be combined to give stronger evidence of a possible DM signal.

2. The LHAASO experiment

LHAASO (Large High Altitude Air Shower Observatory) is a new generation instrument

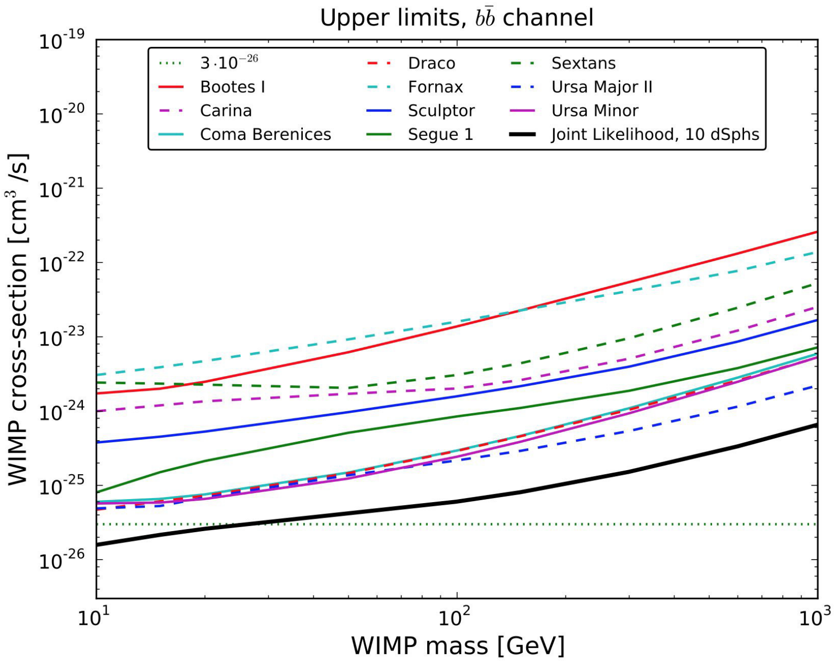

Figure 1: Derived 95% c.l. upper limits on a WIMP annihilation cross section for 10 dSphs and for the joint likelihood analysis for annihilation into the $b\bar{b}$ final state, obtained by Fermi [3]. The most generic cross section ($\sim 3 \cdot 10^{-26}\,\mathrm{cm}^3\mathrm{s}^{-1}$ for a purely s-wave cross section) is plotted as a reference.

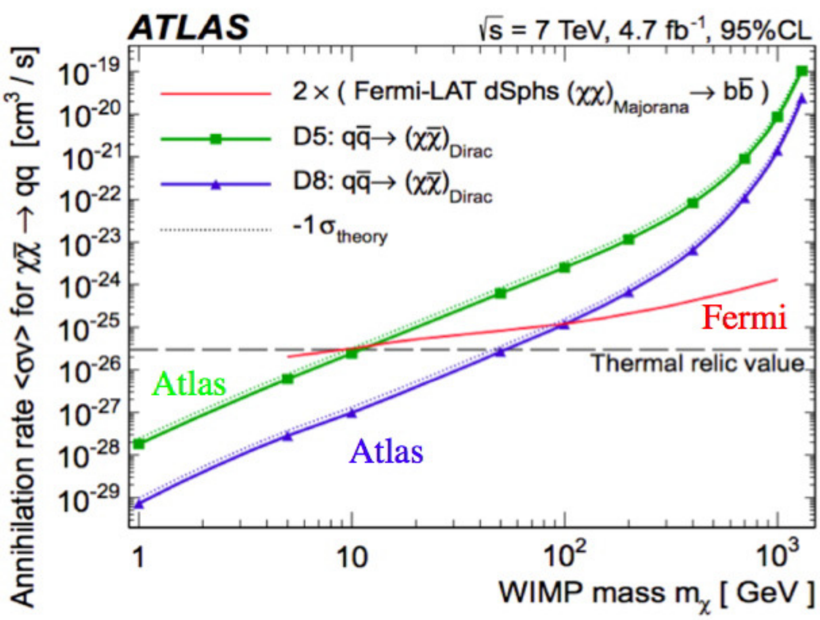

Figure 2: Inferred ATLAS 95% c.l. limits on WIMP annihilation rates versus mass. For comparison, high-energy gamma-ray limits from observations of Galactic satellite galaxies with the Fermi-LAT experiment for Majorana WIMPs are shown.

strategically built to act simultaneously as a wide aperture (∼sr), continuosly-operated gamma ray telescope in the energy range between 10^{11} and 10^{15} eV and as a high resolution cosmic ray (CR) detector in the broad energy range from 10^{13} to 10^{18} eV.

To achieve its scientific goals, the first phase of LHAASO will consist of the following major components [7]:

- 1 km^2 array (LHAASO-KM2A), including 5635 scintillator detectors, with 15 m spacing, for electromagnetic particle detection.
- An overlapping 1 km^2 array of 1221, 36 m^2 underground water Cherenkov tanks, with 30 m spacing, for muon detection (total sensitive area 40,000 m^2).
- A close-packed, surface water Cherenkov detector facility with a total area of 90,000 m^2 (LHAASO-WCDA), four times that of HAWC.
- 24 wide field-of-view air Cherenkov (and fluorescence) telescopes (LHAASO-WFCTA).
- 452 close-packed burst detectors, located near the centre of the array, for detection of high energy secondary particles in the shower core region (LHAASO-SCDA).

LHAASO will be located at high altitude (4400 m asl, 600 g/cm^2, 29° 21' 31" N, 100° 08'15" E) in the Daochen site, Sichuan province, P.R. China. The start of data taking is expected 2 – 3 years after the start of installation planned at the beginning of 2016. The completion of installation in 6 years.

The sensitivity of LHAASO to point–like gamma ray sources is shown in Fig. 3 where is compared to other experiments. The sensitivity curve has been calculated for a Crab Nebula like energy spectrum (power law with exponent -2.63) extending to PeVs without any cutoff [8]. LHAASO is capable of observing sources with a brightness below ∼1 % of the Crab flux in the energy ranges ∼1–10 TeV and ∼30–150 TeV. The LHAASO sensitivity curve shows a structure with two minima, reflecting the fact that the observation and identification of photon showers in different energy ranges is controlled by different components of the detector: water Cherenkov detector (WCDA) in the range ∼0.3–10 TeV and KM2A array above 10 TeV.

One of the most interesting aspects of LHAASO is its sensitivity to gamma rays above 30 TeV. Inspecting Fig. 3 one can see that in this energy region LHAASO, thanks to the KM2A array, will be the most sensitive gamma–ray telescope.

For comparison of sensitivities, it is important to note that the LHAASO sensitivity shown is the point-source survey sensitivity for ∼ 2 sr of the sky. The effective FoV is usually limited to a zenith angle of 50° due to the increasing energy threshold for events coming from larger zenith angles.

While the sensitivities for EAS-arrays (ARGO-YBJ, HAWC, LHAASO, HiSCORE and Tibet ASγ) are also valid for surveys, the sensitivities for Cerenkov telescopes (CTA, HESS, MAGIC and VERITAS) are given for pointed observations of 50 h 'on source' in a small FoV of the order of $\pi/100$ sr. The choice of different conventions is inevitable because of the different operation modes of the two detection techniques. Cherenkov telescopes work only during clear moonless nights, with a total observation time of about 1000–1500 hours per year (depending on the location), and

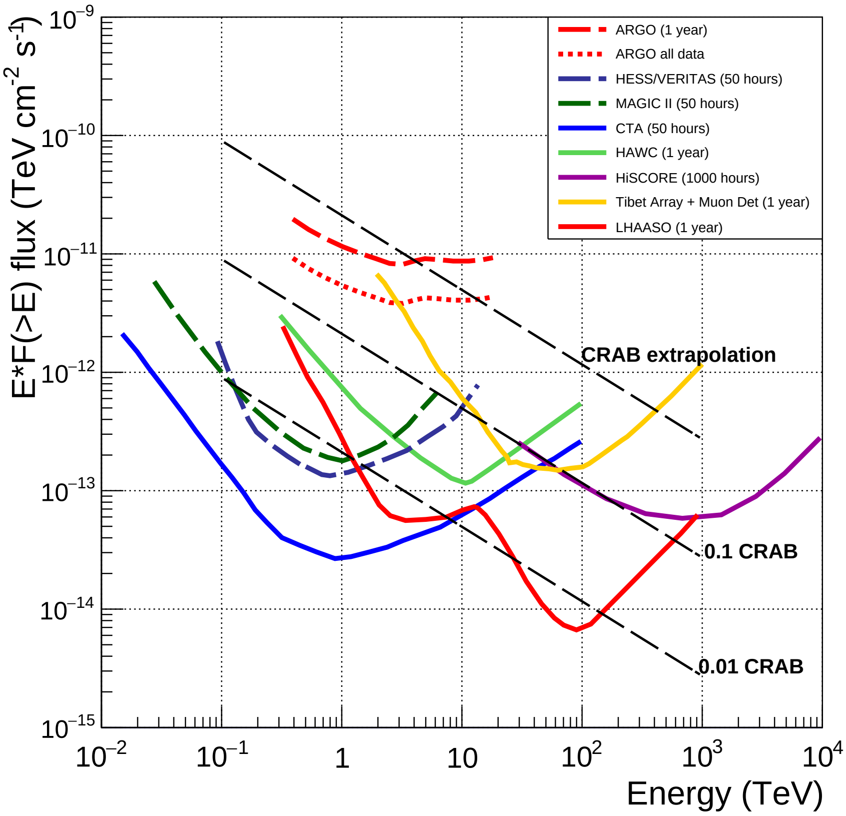

Figure 3: Sensitivity of LHAASO to a Crab-like point source compared to other γ-ray detectors or projects.

have a FoV of a few degrees of radius. This implies that they can observe only one (or very few) sources at the same time, and only in the season of the year when the source culminates during night time. Fifty hours is a typical time that a Cherenkov telescopes will dedicate to a selected source in one year.

In contrast, the sky region observed by an EAS detector is completely determined by its geographical location. The detector observes nearly continuously a large fraction of the celestial sphere (spanning 360 degrees in right ascension and about 90 degrees in declination). Sources located in this portion of the sky are in the FoV of the detector, either always, or for several hours per day, depending on their celestial declination. This situation is ideal to perform sky surveys, discover transients or explosive events (such as GRBs), and monitor variable or flaring sources such as AGNs.

A wide field of view detector such as LHAASO is particularly sensitive to extended sources (molecular clouds, galaxies, dwarf galaxies and galay clusters), being an ideal detector for extended sources of DM. Ground based gamma-ray detectors, both air shower arrays and Cherenkov telescopes, lose sensitivity observing extended sources. When the source size is large compared to PSF (or FoV) the sensitivity for point sources is reduced by a factor $\sigma_{det}/\sigma_{source}$, where σ_{det} is the detector PSF and σ_{source} the source diameter. Air shower arrays, however, due to larger PSF and FoV, are less affected than Cherenkov instruments. In the Fig. 4 the LHAASO minimum detectable flux (in Crab units) is shown as a function of the source diameter for two different photon energies.

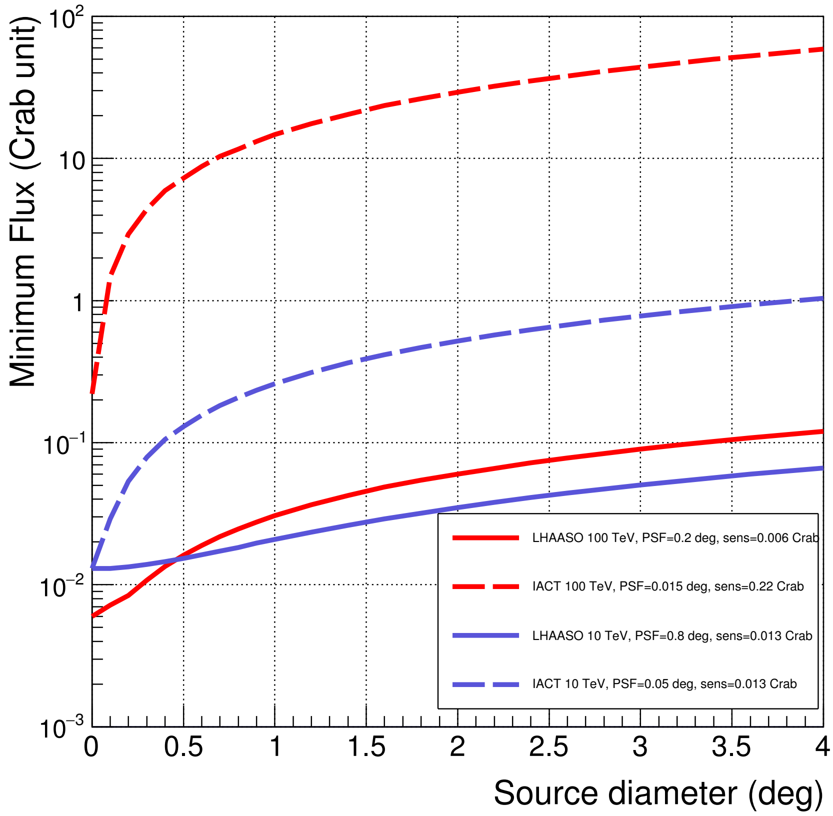

Figure 4: The minimum detectable flux (in Crab units) for LHAASO as a function of the source diameter for two different photon energies. For comparison the minimum flux expected by a Cherenkov telecope is shown. The point source values (diameter less than 0.1°) refer to typical values for 10 and 100 TeV photon energies.

For comparison the minimum flux expected by a typical Cherenkov telecope is shown. The point source values (diameter less than 0.1°) refer to typical values for 10 and 100 TeV photon energies. As it can be seen, an air shower array with the LHAASO characteristics is well suitable for high sensitivity study of extended sources, in particular for energies above tens of TeV.

As will be discussed in the next section, the large LHAASO FoV and the good sensitivity to extended sources is crucial to look for emission from dwarf spheroidals which are currently unknown.

3. Dark Matter limits from LHAASO

By means of a detailed MonteCarlo simulation of the LHAASO main components (WCDA and KM2A) [8] we calculated the point source sensitivity plotted in the Fig. 3 and the significance to a DM flux following the HAWC approach [6].

In Fig. 5, the curves are the preliminary projected 95% CL limits from Draco and Segue 1 dwarf galaxies. These plots show the LHAASO sensitivity to DM annihilation in single dwarf spheroidal galaxies. The exclusion curves are calculated assuming 5 years observation time for

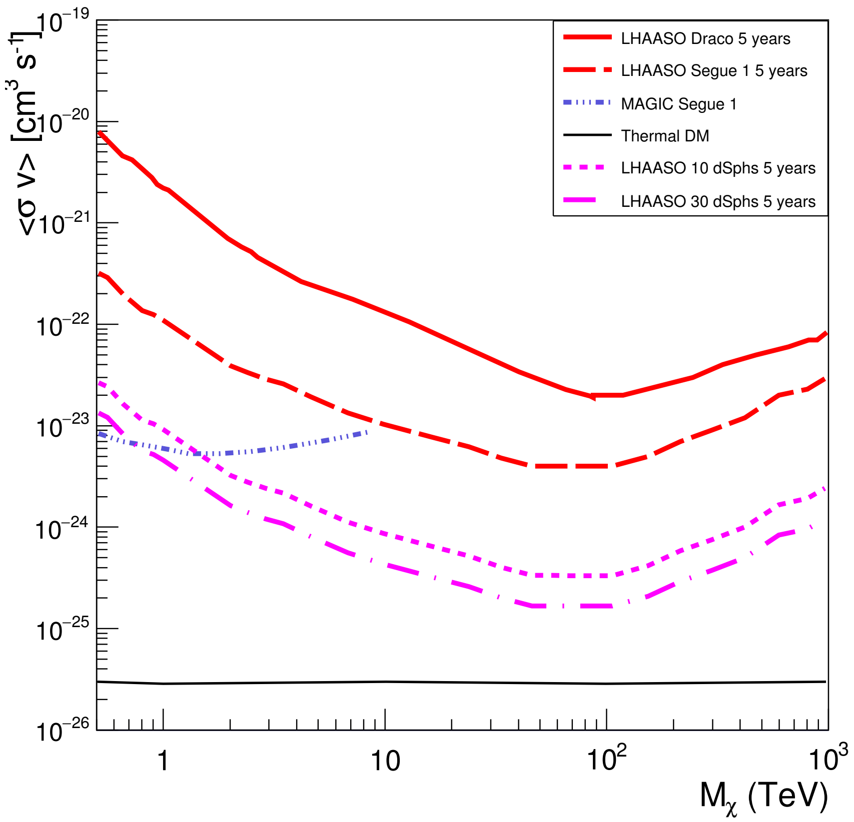

Figure 5: Predicted constraints on the dark matter annihilation $\chi\chi \to b\bar{b}$ cross section at 95% C.L. for LHAASO in the hypothesis of 5 years of data. The MAGIC DM exclusion limits from Segue 1 is shown for comparison [9]. Extrapolations for a joint likelihood analysis of 10 and 30 dSphs (supposing that the new optical surveys will find new dSph) are also shown.

LHAASO and WIMPs which annihilate with a 100% branching ratio into $b\bar{b}$ annihilation channel. In Fig. 5 the limit obtained by MAGIC after 157.9 hours observation of Segue 1 is also shown [9].

The dwarf galaxies, due to the very large mass/luminosity ratio, are extremely faint, and the best candidate galaxies are those with the lowest luminosities. Therefore, it is possible that the best candidate dwarf galaxy for DM analysis has not yet been discovered. The wide aperture of LHAASO will allow, in principle, the search for faint gamma-ray signals with hard in locations with no known counterparts, which would be the expected DM annihilation signal from an unknown dwarf galaxy.

As mentioned in the Introduction, the Fermi-LAT collaboration showed that the combined limits from 10 dwarf galaxies the upper limits increase by a factor up to 12 for the Dwarf Galaxy Segue 1 [3].

In Fig. 5 the predicted constraints on the DM annihilation cross section at 95% c.l. for LHAASO in the hypothesis of a stacked analysis with 10 and 30 dSphs (supposing that the new optical surveys will find new dSphs) is also shown.

At high energies (above 10 – 20 TeV) the LHAASO expected sensitivity is unprecedented providing an important discovery potential.

4. Conclusions

LHAASO is a well suited experiment for searching for annihilating high-mass DM. The wide FoV and the continuous observation time will allow the observation of many expected DM sources and the search of new possible DM annihilation sites. This experiment will complement other leading projects (HAWC and CTA) with unprecedented sensitivity above 10 TeV.

5. Acknowledgement

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