Feasibility Study of Dark Matter Detection using MACE telescope

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Introduction

There is strong evidence for the existence of a new type of non-luminous, non-baryonic matter, which contributes about six times more to universes total energy budget than baryonic matter. This so called Dark Matter (DM) is proposed to be made up of as yet undetected relic particles from the big bang. A prime candidate for DM is the Weakly Interacting Massive Particles (WIMPs) arising from extensions of Standard Model (SM) of particle physics.

Indirect Detection of DM, searches for stable SM particles produced by annihilation or decay of these WIMPs. Very High Energy (VHE) γ-rays are the most commonly searched for annihilation/decay products owing to their ability to point back towards their origin. Ground based Imaging Atmospheric Cherenkov Telescopes (IACTs) used for detecting such γ-rays are appropriate for probing WIMPs in mass range of few 100 GeV up to 100 TeV. The Major Atmospheric Cherenkov Telescope (MACE) recently commissioned by BARC at Hanle, Ladhak, with its 21m diameter dish (largest in northern hemisphere) and at 4270m altitude (highest IACT), provides an opportunity to search for WIMPs with even lower masses due to its lower energy threshold of 30 GeV.

In this study, we investigate the sensitivity of MACE telescope to γ-ray signals from DM annihilation for dwarf Spheroidal galaxies (dSph) visible from the northern hemisphere. We also compare the simulated sensitivities of MACE with that of other IACTs like MAGIC and CTA.

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γ-ray Flux Estimation

The primary γ-ray flux from a majorana type DM annihilation is given by:

$$\frac{d\Phi_\gamma(E)}{dE} = \underbrace{\frac{1}{8\pi M_\chi^2}\sum_f b_f \langle\sigma_f v\rangle \frac{dN_\gamma^f(E)}{dE}}_{\text{particle physics part}} \times J \tag{1}$$

where we have considered the annihilation of DM particles with mass 'M_χ' into f-channel SM particle with a thermal velocity-averaged cross section $\langle\sigma_f v\rangle$. The resulting γ ray spectra from this annihilation is $dN_\gamma^f(E)/dE$. 'J' (J-factor) encapsulates the DM density profile and angular size of the source being studied.

For the present study, we consider primary γ-rays from generic-WIMP DM annihilation into $b\bar{b}$, $\tau^-\tau^+$, W^+W^- channels with 100% branching ratios. These channels are reported to provide the strongest constraints on $\langle\sigma v\rangle$. Also, choosing generic-WIMP DM for our simulation sets the theoretical value of $\langle\sigma v\rangle = 3\times10^{-26}$.

TABLE I: Sources considered in this study, their zenith angle at Hanle (θ_z), distance from earth (D) and Jfactor

Source	$\theta_z(deg)$	D (kpc)	J (GeV^2 cm^{-5})
Segue 1	16	23	1.7×10^{19}
Willman 1	19	38	8.7×10^{18}
Draco	2	87	3.8×10^{18}

Simulation Details

We consider dSph sources visible from northern hemisphere for our study. Those are chosen due to their low luminosity, absence of any high energy process which can contribute VHE γ-rays, and high DM content. We use the commonly used NFW profile to model the DM density in the selected sources. The J-factors are calculated using a code written in

ROOT and has been validated by comparing with reported values for other sources. The sources chosen for this study are tabulated in Table I.

The γ-ray spectra after DM annihilation $(dN_\gamma^f(E)/dE)$ was simulated for DM mass M_χ ranging from 100 GeV to 5 TeV using PYTHIA (8.245), and compared with that given in [1], which is widely used as database. Some difference observed in our result with that of Ref. [1] due to updated hadronization parameters used in the latest version of PYTHIA used by us. The primary γ-ray flux is then calculated from Eqn. (1). Observed γ-ray flux by MACE telescope is obtained by convoluting the flux with the instrument response functions (IRF) of MACE telescope [2]. The irreducible background is due to cosmic ray electrons (CRE) [3], which is estimated by convolution of the CRE with the IRF of MACE. Statistical analysis is performed to estimate the 95% Confidence Level (C.L.). The upper limit on $\langle\sigma v\rangle$ that can be set by MACE in case of non-detection of any significant signal in 200 hours of observation is estimated for different DM mass.

Results and Conclusion

We report the sensitivity of MACE telescope for WIMP annihilation in some important channels. The 95% C.L. upper limits on $\langle\sigma v\rangle$ for DM annihilation in different sources and channels for 200 hours of observation is shown in Figure 1, with the comparison of sensitivities between MACE, MAGIC [4] and CTA Array-I [3] in Figure 2. It is observed that MACE can set stronger upper limits on $\langle\sigma v\rangle$ than MAGIC for $M_\chi < 1$TeV due to its larger size. The stronger limits compared to CTA Array-I are due to Array-I having poorer sensitivity in the lower energy range.

The study shows the capability of MACE in setting stronger constraints on velocity averaged annihilation cross-sections of low mass WIMPs than the currently operating IACTs in the northern hemisphere. Further study to take account for the effects of different particle event generators and DM models on sensitivity is under progress and will be presented.

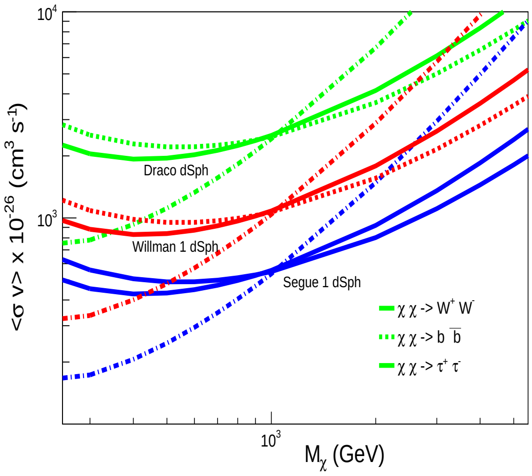

FIG. 1: Simulated 95% C.L. upper limits on $\langle\sigma v\rangle$ for MACE telescope in different dSph sources and DM annihilation channels.

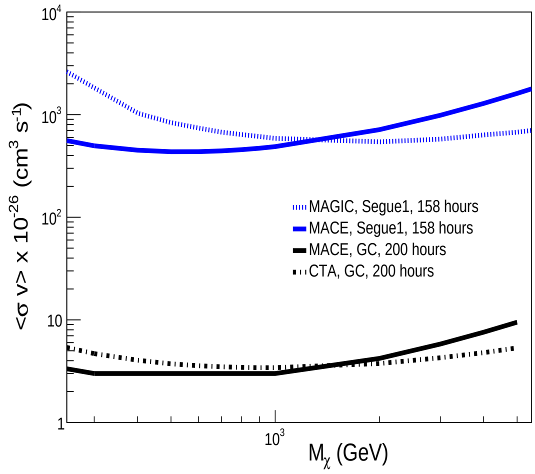

FIG. 2: Comparison of MACE sensitivity with MAGIC and CTA for $b\bar{b}$ channel.

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References

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