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Searches for Dark Matter and BSM physics with the IceCube neutrino telescope

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The IceCube detector is a multipurpose neutrino observatory located at the South Pole. With an instrumented volume of a cubic kilometer, IceCube can detect neutrino fluxes from all flavors in the GeV - PeV energy range. In the recent years IceCube has heralded the birth of neutrino astronomy with the discovery of an astrophysical neutrino flux. Besides its astrophysical program IceCube is also at the forefront of indirect searches for dark matter and physics beyond the standard model. In this contribution I will review the latest results of IceCube as a particle physics detector

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1. Introduction

On December 2010 the last string of the IceCube detector was deployed inside the Antarctic ice completing the full detector geometry. Now, almost 10 years after its realization, IceCube has succeeded in opening a new window to observed the Universe. In 2013, IceCube detected the most sought-after astrophysical neutrinos heralding the birth of neutrino astronomy. IceCube is one of the key players in the multi-messenger framework, as shown in the detection of a flaring Blazar after the very high energy neutrino alert sent by IceCube. In addition, IceCube is an excellent particle physics detector and has provided relevant results regarding the search for dark matter and the evidence for physics Beyond the Standard Model (BSM).

2. The IceCube Experiment

The IceCube Neutrino Observatory is a neutrino telescope deployed at the South Pole underneath the Antarctic ice sheet [1]. It consists of 86 vertical strings with 60 photomultiplier tubes (PMTs) housed inside a pressure resistant vessel conforming the Digital Optical Module (DOMs). There are in total 5,160 DOMs distributed over a volume of roughly 1 km. The inner part of the detector is equipped with high-quantum efficiency PMTs arranged in a much denser 8-string array. This is the *DeepCore* part of the IceCube detector and can reduce the neutrino detection threshold down to 10 GeV. Icecube detection principle is based on the Cherenkov radiation emitted when charge particles cross the detector moving faster than the corresponding speed of light in ice. When a neutrino interacts in the vicinity of the detector it can generate charge leptons that will induce this Cherenkov emission. The background of this detection principle comes from cosmic rays interacting in the upper shells of the Earth's atmosphere and producing atmospheric muons and neutrinos that will reach the detector generating a signal. Muons can be shielded by selecting events coming through the Earth as the muon range is not long enough to cross the Earth's diameter. Atmospheric neutrinos, on the other hand, constitute an almost irreducible background. Different techniques such as self-veto, time and spatial clustering, or the selection of high energy events beyond the atmospheric neutrino spectrum, are used by the collaboration to overcome this background.

3. IceCube as a Beyond Standard Model explorer

The wide energy range at which IceCube is efficient makes it an ideal detector to explore different signal regions for physics beyond the standard model. At the highest energies, IceCube can look for very bright events such as those induced by relativistic monopoles, while at lower energies IceCube is capable of testing dark matter signatures beyond the Weakly Interacting Massive Particle (WIMP) paradigm. In the following sections, the highlight results of a selection of these analyses are given.

3.1 Indirect Searches of Dark Matter

IceCube can search for dark matter by looking at the decay or annihilation products of dark matter [2, 3]. Dark matter self-annihilating (or decaying) into standard model particles can generate a flux of neutrinos that is detectable with the IceCube telescope [4, 5]. This flux is expected to

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increase towards regions with over densities of dark matter. The Galactic Center is therefore one of the best candidate places to search for the annihilation products of dark matter as halo models predict an increase of the dark matter density at the center of the Galaxy. The direction of the Galactic Center lies above the horizon with respect to IceCube's local coordinates which makes it a region of the sky dominated by the large contribution of atmospheric muons. A neutrino telescope located in the northern hemisphere, like the ANTARES neutrino telescope, benefit for a better view of the Galactic Center as Earth will shield the atmospheric muons [6]. The ANTARES telescope is however a smaller detector and sensitive mostly to higher dark matter masses, while IceCube, using muon neutrinos events starting in the DeepCore, can access the low mass range. Recently a combined analysis was performed by these two collaborations in order to exploit this complementarity. The result of this analysis is shown in Fig. 1, where the upper limit on the thermally averaged dark matter self-annihilation cross-section, $\langle \sigma_A v \rangle$ is shown as a function of the dark matter mass for given annihilation channel and assuming a given dark matter halo profile distribution [7].

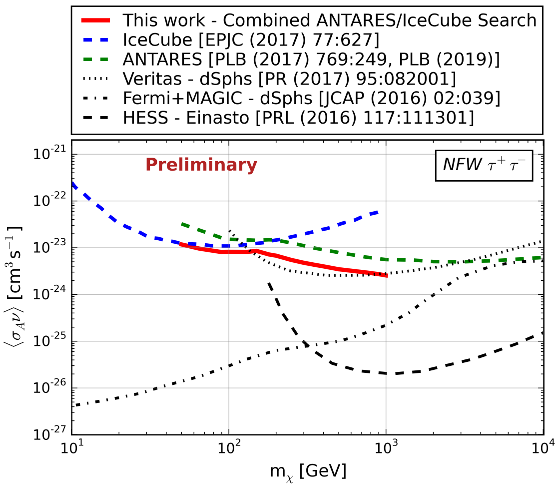

Figure 1: Upper limits on the $\langle \sigma_A v \rangle$ as function of the dark matter mass for the annihilation channel $\chi\chi \to \tau^+\tau^-$ assuming the Navarro-Frank-White halo profile for IceCube (dotted-blue line), ANTARES (dotted-green line) and the combined analysis (solid-red line). ANTARES upper limits have been conservatively placed at the level of their sensitivity. More information in [8].

In addition to the Galactic Center, dark matter can also accumulate at the center of massive bodies such as the Sun or the Earth. This process occurs after dark matter particles lose energy following a scattering with the atoms of the celestial body becoming gravitationally trapped. In this case, only the neutrinos will emerge to the surface as both the Sun and the Earth are very dense to allow other particles escape. The capturing rate, and therefore, the annihilation rate will depend on the mass of the body, its abundance, and the scattering cross-section of dark matter with standard model particles. Capturing is also sensitive to the initial velocity distribution of dark matter, in particular capturing is more effective for low-velocity dark matter particles. This is opposite to direct detection experiments that try to measure the recoil energy which is larger for high-velocity dark matter particles. In order to produce velocity independent limits, IceCube together with a direct detection experiment, PICO [9], have produce a combined limit on the spin-dependent cross-section, σ_{SD} which is independent of the velocity distribution of the dark matter halo. These bounds, by construction, represent the most conservative scenario and therefore are weaker than those assuming a given velocity distribution. Figure 2 shows these limits as a function of the dark matter particle.

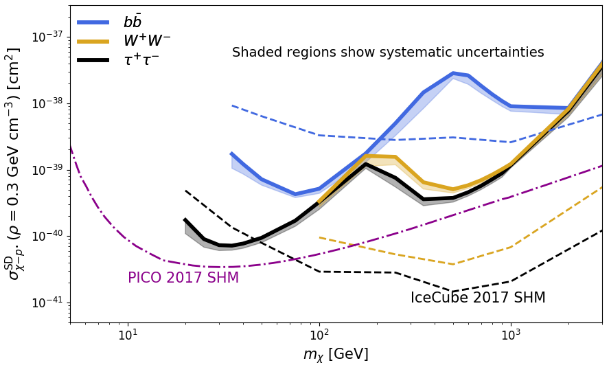

Figure 2: Dark matter velocity independent limits on the spin-dependent scattering cross-section as function of the dark matter mass. Shaded regions indicate systematic uncertainties. More information in [10].

3.2 Searching for exotic signals

IceCube can also search for particles other than neutrinos that will also produce a signature in the detector. One example of these particles are magnetic monopoles. Magnetic monopoles were first considered by Paul Dirac as a way to explain the quantification of the electric charge [11]. Dirac argument also gave a value to the minimal monopole charge to be $g_D = e/2\alpha \simeq 68.5e$, leading to a distinct signature as monopole passes through the IceCube detector. In the context of grand unification theories (GUT) monopoles also arise in history of the Universe before inflation when the temperature exceeded $T \sim \Lambda_{GUT}$ and, while diluted, they are expected to be present today. Since monopoles have a magnetic charge, they can easily be accelerated in Galactic and inter-Galactic magnetic fields. The expected velocity distribution is however unknown and very slow-moving monopoles as well as relativistic ones can be expected. In IceCube a wide variate of searches try to identify the monopole signature for a wide range in velocity β. Monopoles light production mechanism is quite different depending on their speed as well as the detection methods in IceCube. Relativistic monopoles ($\beta > 0.76$) can induce direct Cherenkov light like muons but with a several thousand larger light yield given their magnetic charge. Indirect Cherenkov emission from knock-off electrons occurs at mildly relativistic velocities. At low speeds ($0.1 \leq \beta \leq 0.5$) monopoles can excite the medium and produce luminescence light emission. Finally, very slow-moving monopoles can catalyze the proton decay producing an electro-magnetic shower that will also generate Cherenkov light. Figure 3 shows the limits on the monopole fluxes for the whole range of velocities illustrating all different analyses carried out in IceCube.

4. Conclusions

IceCube is a multipurpose experiment that not only started a new era in astroparticle physics but also offered new means to search for hints of physics beyond the standard model. IceCube is

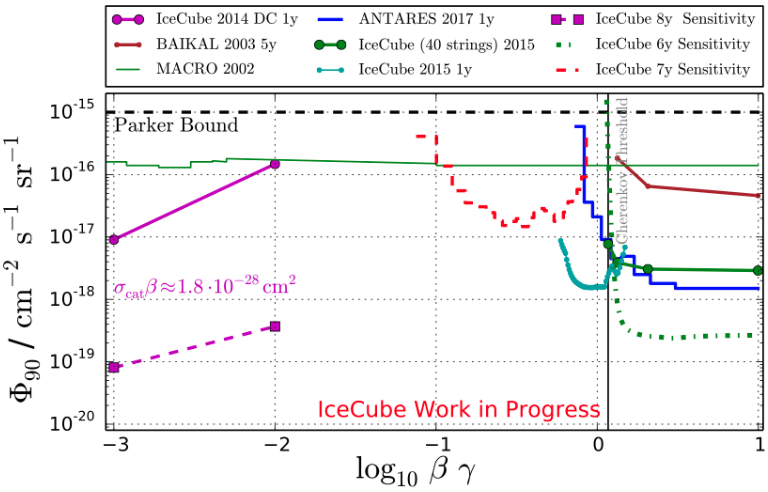

Figure 3: Current best exclusions limits and expected sensitivities on the monopole flux as function of the monopole speed. The *Parker bound* is also shown [14].

at the head of the race in the search for evidence of dark matter providing a complementary view to other indirect detection experiments, such as gamma-rays telescopes, but also to direct detection methods which are sensitive to different regions in the dark matter velocity distribution. As IceCube continues to accumulate more data the understanding of the detector continues to improve which allows for more precise measurements. This consequently makes it possible to search for exotic signatures in the detector like those produced by monopoles and Q-balls.

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