Search for neutrinos from diffuse dark matter annihilation in Super-Kamiokande

Piotr Mijakowski* **for Super Kamiokande-Collaboration**

The Andrzej Sołtan Institute for Nuclear Studies, Otwock-Świerk, Poland

***Abstract*. This work presents a search for a signal from diffuse dark matter annihilation by studying neutrino interactions observed in Super-Kamiokande detector. The methodology of a search is shown together with examples of expected signal from dark matter.**

***Keywords*: dark matter, neutrinos, Super-Kamiokande**

I. INTRODUCTION

We follow the approach described in [1] and consider the model independent scenario with dark matter (DM) particles annihilating directly and only to neutrinos, equally to all flavors: $\chi + \chi \to \bar{\nu} + \nu$. In such a case, resulting neutrino energy would be the same as the mass of annihilating relic particles. Thus, annihilation induced neutrinos would introduce a characteristic modification to the observed atmospheric neutrino energy spectrum (Fig. 1). Moreover, one could also expect that neutrinos from a diffuse dark matter annihilation would have an isotropic zenith angle distribution. The Super-Kamiokande data set of 1489.2 days of exposure (SK-I) is being investigated for the presence of such a signature.

Neutrinos, as the least detectable Standard Model particles, can define an upper limit on the total dark matter self-annihilation cross section $\langle \sigma V \rangle$. The limit on $\langle \sigma V \rangle$, derived with the assumption that dark matter annihilates purely to neutrinos, would give the most conservative bound which cannot be overreached with searches for other annihilation products like γ, $e^{+/-}$, $\bar{p}$...[1]. Limits based on a lack of signal in other searches would be always more stringent than the one obtained with assumption on 100% annihilation to $\nu\bar{\nu}$. The existing limit on $\langle \sigma V \rangle$ related to the search for diffuse neutrino signal from the Milky Way and cosmic space is shown on Fig. 2 and taken from [1].

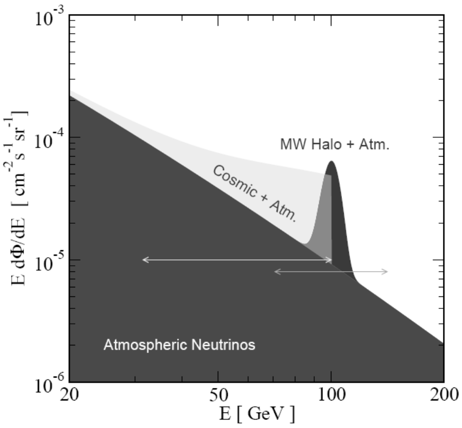

Fig. 1. Illustration of a diffuse $\nu\bar{\nu}$ annihilation signal of a 100 GeV DM particle, added to the atmospheric neutrino spectrum. Here, contributions of DM from Milky Way halo and large distance cosmic sources are taken into account. The halo signal is sharply peaked, the cosmic signal is smeared due to the various redshift distribution of the source. Figure taken from ref. [1].

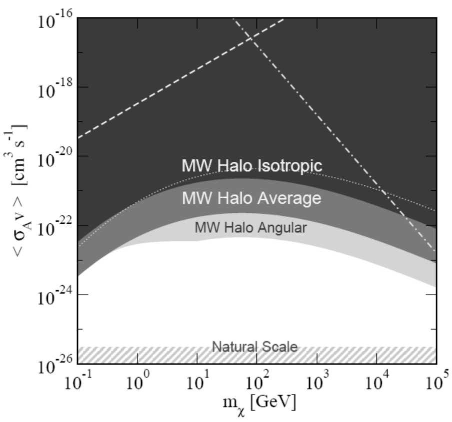

Fig. 2. Limit on the DM total self-annihilation cross section from various components of the Milky Way halo (shaded regions excluded) and on the cosmic signal (region above the dotted line excluded). See [1] for details.

II. METHODOLOGY

Super-Kamiokande is a water Cerenkov neutrino detector located in Kamioka, Japan. Data set consists of four main categories of events: fully-contained (FC), partially-contained (PC), upward-through going and upward-stopping muons (UPMU) [2]. This classification is based on the topology of neutrino induced signal and depends on the parent neutrino energy which in case of atmospheric production spans many orders of magnitude (Fig. 3).

For FC sample we can reconstruct the energy of interacting neutrino. For the PC and UPMU events only some part of the ν energy is deposited in the detector. As the DM particle mass is not constrained the search should cover the widest possible range of neutrino ener-

[1]with only Standard Model particles produced in dark matter annihilation

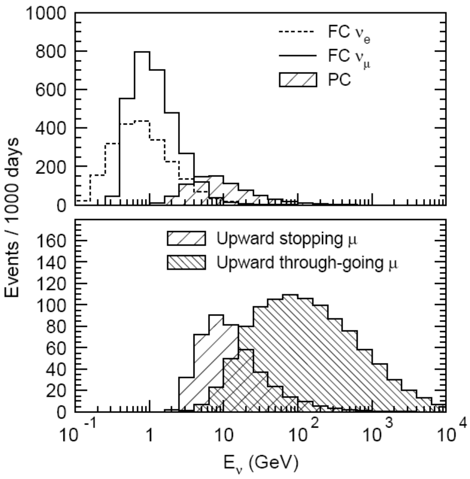

Fig. 3. The parent neutrino energy distributions for the fully-contained, partially-contained, upward stopping-muon and upward through-going muons samples. Rates for the fully-contained and partially-contained samples are for interactions in the 22.5 kiloton fiducial volume. Ref. [2]

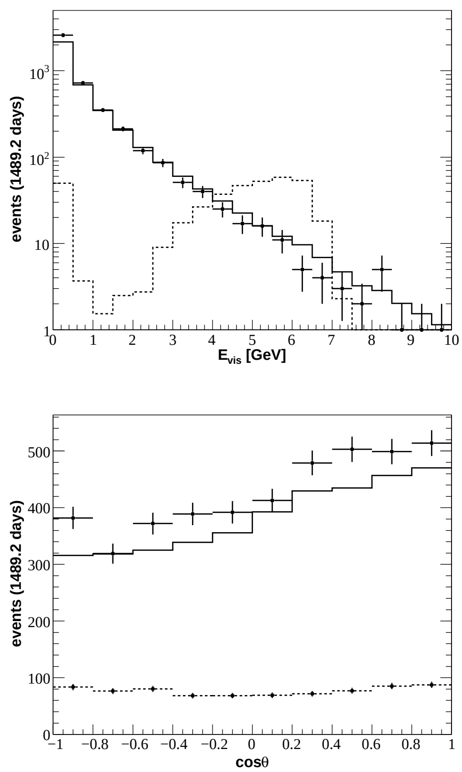

Fig. 4. Zenith angle and visible energy distribution of FC $(\nu_\mu + \bar{\nu}_\mu)$ atmospheric data events (points), atmospheric oscillated MC (solid line) and expected contribution from $\nu\bar{\nu}$ annihilation of 5.5 GeV DM particle (dotted line). DM induced signal is normalized arbitrary for the illustration purpose. Number of events in SK-I data sample is shown for data and atmospheric MC.

gies. That determines the usage of FC, PC and UPMU samples in diffuse DM annihilation search. For the mass of DM particles $\sim <30$GeV we can effectively use FC and PC visible energy distributions (along with zenith angle distributions) in the search for the potential DM annihilation signal contribution. For the higher energies, where PC and UPMU samples contribute, it is only valuable to investigate zenith angle distributions and test them against expected isotropic admixture signature. Monte Carlo simulation of the detector respond exists for atmospheric neutrino interactions. For the neutrinos from DM annihilation the signal was simulated assuming a several neutrino energies corresponding to different DM particle masses.

In order to test the hypothesis of a dark matter annihilation signal contribution in the atmospheric neutrino data we used the method of minimum χ^2:

$$\chi^2 = \sum_{i=0}^{nbins} \frac{(N_i^{data} - (\alpha \cdot N_i^{atmMC} - \beta \cdot N_i^{DM}))^2}{\sigma_i^2} \tag{1}$$

We investigated the visible energy and $cos\theta$ distributions, trying to find the combination of atmospheric neutrino MC and DM signal simulation which would match best the data.

The illustration of the DM signal in FC $\nu_\mu\bar{\nu}_\mu$ sample for the mass of DM particles $= 5.5$ GeV is shown on the Fig. 4. The result of the fit for $M_\chi = 5.5$ GeV gives the following values of the atmospheric (α) and DM signal (β) normalization parameters: $\alpha = 1.112 \pm 0.014$, $\beta = -0.01 \pm 0.002$ (both values correspond to 3838 events). In this case an upper 90% C.L. limit on allowed number of dark matter induced neutrinos is 3.2 events. We estimated also the corresponding upper 90% C.L. limit on total DM self-annihilation cross section $\langle\sigma V\rangle$ following the approach described in [1] assuming only a signal from a Milky Way and *Halo Isotropic* scenario. We obtained here the $\sim$50 times better constrain as compared to the limit shown on Fig. 2 for the same M_χ and signal origin. The reason for such a improvement is due to the dedicated event by event analysis of Super-Kamiokande data instead of a global distribution comparison used in [1]

For the other DM particle masses we initially checked that with Super-Kamiokande dataset we can improve the existing neutrino limit for the total dark matter self-annihilation cross section by a factor of $10 - 100$, comparing to results obtained in [1]. The biggest improvement corresponds to the mass range where energy of the neutrino is known and can be used in the fitting. Smaller improvements are possible where only angular information is available.

III. Acknowledgements

Author is supported by the State Committee for Scientific Research in Poland, grant 1757/B/H03/2008/35.

References

[1] H. Yuksel, S. Horiuchi, J.F. Beacom, S. Ando, Phys. Rev. D 76, 123506, 2007, http://arxiv.org/abs/0707.0196v3
[2] Y. Ashie *et al.* [Super-Kamiokande Collaboration], Phys. Rev. D 71, 112005, 2005, http://arxiv.org/abs/hep-ex/0501064