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Status of GADZOOKS!: Neutron Tagging in Super-Kamiokande

P. Fernández for the Super-Kamiokande collaboration

Department of Theoretical Physics, University Autonoma Madrid, 28049 Madrid, Spain

Abstract

The GADZOOKS! project pursues the upgrade of the Super-Kamiokande detector as a way to efficiently detect thermal neutrons. Inverse beta decay reactions, as well as charged current quasi-elastic (CCQE) scattering of low energy anti-neutrinos (up to a few hundreds of MeV) in SK, produce one positron and one neutron in the final state. Being able to observe the final state neutron in coincidence with the prompt positron would mean that SK could identify these reactions as genuine with very high confidence.

GADZOOKS! will open to Super-Kamiokande - and water Cherenkov detectors in general - a wealth of physics currently inaccessible due to background limitations. The most important is observing for the first time the diffuse supernova neutrino background: Super-Kamiokande enriched with gadolinium will discover it after few years of running.

The main R&D program towards GADZOOKS! is EGADS: a 200 ton fully instrumented tank built in a new cavern in the Kamioka mine. EGADS incorporates all the necessary subsystems to make GADZOOKS! a reality. In this contribution we will describe EGADS, we will present its current status and discuss the main results and conclusions arrived at so far. In addition, we will analyze other issues specific to the running of GADZOOKS!.

Keywords: astrophysics, neutrino, neutron tagging, water Cherenkov detector

1. Introduction

Super Kamiokande (SK) is a 50,000 ton water Cherenkov detector located in the Kamioka mine under 1000 m of rock, which began the data taking in 1996. The detector is divided into inner and outer detector, the former is used for physics measurements and instrumented with 11146 PMTs of 20 inches, while the latter is used as a veto to reduce background and is instrumented with 1885 PMTs of 8 inches. The typical volume used for physics measurements is 22,500 tons, 2 m away from the inner detector wall.

The major achievements of SK are the discovery of the massive character of neutrinos through atmospheric neutrino oscillations [1], explanation of the solar neutrino problem [2] [3], the first indication of terrestrial matter effects through the day/night asymmetry in the solar neutrino flux [4]. As long baseline far detector it has confirmed the atmospheric neutrino results (KEK) [5] [6] and first detected the ν_e appearance (T2K) [7]. It also puts the best proton decay bounds [8] and the most stringent limits on Diffuse Supernova Neutrino Background (DSNB) [9] [10].

2. GADZOOKS!

The scientific capabilities of SK would improve dramatically if it is able to identify anti-neutrino interactions.

GADZOOKS! (Gadolinium Antineutrino Detector Zealously Outperform Old Kamiokande Super!) [11] is the project for upgrading the SK detector by dissolving gadolinium (Gd) in its water. Gd has the largest thermal neutron cross-section of all stable nuclei, of about 49000 barn, so Gd will capture the majority of final state

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neutrons produced in the interactions after they have thermalised. In addition, after the neutron has been captured, the Gd de-excites emitting a γ ray cascade with a total energy of 8MeV. As a result, by adding 0.2 % by mass of Gd as $Gd_2(SO_4)_3$, SK could achieve a very high efficiency for detecting the neutrons produced by the interacting neutrino.

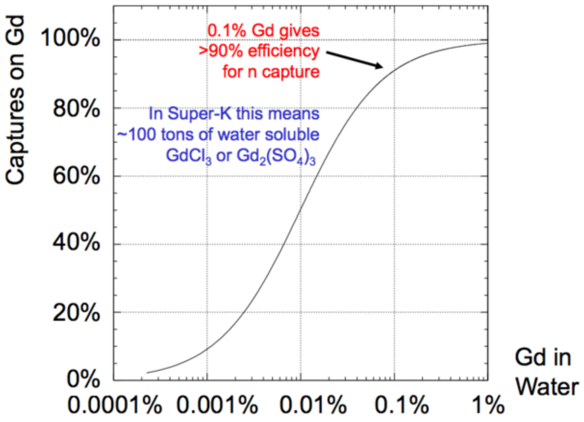

Figure 1: Neutron captures on Gd as a function of the concentration of gadolinium dissolved in water.

With this concentration, the time elapsed after the prompt signal (neutrino corresponding charged lepton) is about 35 μs ($\sim$ 10 μs for neutron thermalisation and $\sim$ 20 μs for the neutron to be absorbed by Gd).
The main interaction of neutrinos in SK especially at low energies (up to hundreds of MeV) are:

$$\nu_\alpha + n \to l_\alpha + p \quad , \quad \bar{\nu}_\alpha + p \to \bar{l}_\alpha + n \qquad (1)$$

Meaning that in this energy range, an efficient neutron tagging technique, such as Gd neutron capture, is able to distinguish between neutrinos and antineutrinos.

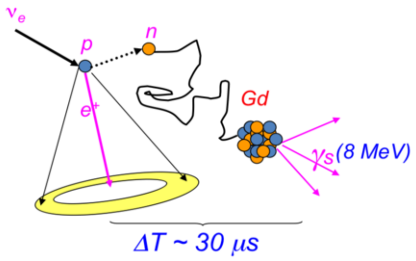

Figure 2: Inverse beta decay in GADZOOKS!

This neutron tagging method is around 5 times more efficient than the current technique, which tags some of the final state neutrons by detecting the 2.2 MeV photon emitted by the deuteron produced when a neutron is captured by the hydrogen present in the water. The weakness of the emitted photon and the larger elapsed time after the prompt signal ($\sim$ 200 μs) makes this method much less efficient.

2.1. Main physics outcomes

Next we go through some of the new physics research paradigms and the improvement of current measurements that GADZOOKS! will be able to do.

- Diffuse Supernova Neutrino Background (DSNB): One of our main goals for this upgrade is to be able to first detect DSNB. This is the neutrino background from all the supernovae that have occurred during along the history of the universe. This measurement will provide very important information, like the mean energy spectrum core collapse supernovae and the star formation rate of the universe. At present, this measurement is largely affected by backgrounds, spallation and solar neutrinos as shown in Fig. 3, that can be excluded effectively with neutron tagging.

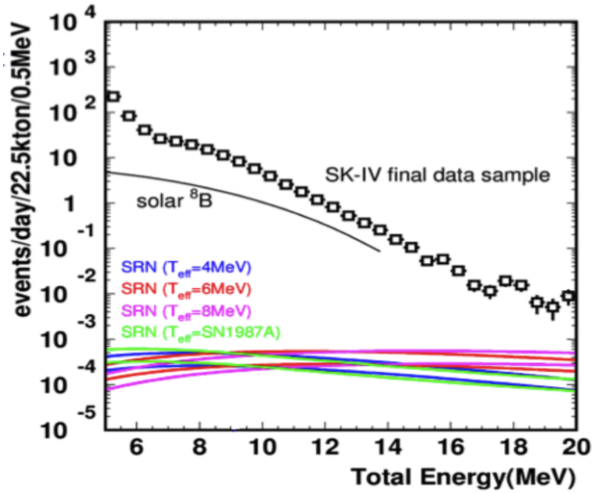

Figure 3: Different theoretical model predictions compared with current SK neutrino final sample, whose main source is the spallation events which still remain after the current spallation cut.

For the time being, SK can only put upper limits which are 2 to 4 times larger than the theoretical predictions [9], as shown in Fig. 4.