Form 8

Research Result Report
ICRR Inter-University Research Program 2022

Research Subject: Data Taking, Calibrations, Measurements & Analysis with Super-Kamiokande I-VII
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Summary of Research Result

The items in the title are fundamental for the collaborative work to get out the most of the Super-Kamiokande experiment, SuperK-Gd and the preparation for the next generation Hyper-Kamiokande. The period spanned by JPF2022 is characterized by:

- It starts with a ~0.02% $Gd_2(SO_4)_3$ concentration (nominal is 0.2%) dissolved in the water since ~22 months of running with no major change being carried out in SK's water system.
- A second $Gd_2(SO_4)_3$ loading was carried out in June 2022 (T1.5); it was 26 tons approximately. Since then, SK is running with a ~0.06% $Gd_2(SO_4)_3$ concentration.

Calibrations and related

We have evaluated with autoXenon and Nickel data the evolution with time of Super-Kamiokande detector's performance, mainly from the point of view of light transmission and detection. Main conclusions and results are:

- Already since the end of 2020, the SK water system is keeping the Top-Bottom-Asymmetry (TBA) in light transmission at 2%, within ± 1% at any time (including Gd loading). During stable running (i.e., no in-purpose extra action to the water system for any reason), it keeps TBA almost constant (± 0.2%)
- The changes with time of TBA is compared with different relevant variables: ID water temperatures, transparency, changes in the Dark Noise; Only clear correlation with ID temperature is observed.
- The variation with time of the gains of the PMTs, grouped by age (so called SKII and SKIII) and by their position in the detector (at top, bottom, or barrel), have been estimated from the corresponding evolution of the 1 photo-electron peak measured with Nickel data. Since the start of SK-V, their effect on relevant variables is already significant (f.i. it reduces the TB-Asymmetry measured with

autoXenon by ~2%). In addition, gain corrected Ni and gain corrected auto-Xenon TBAs match better than uncorrected ones, and also gain corrected autoXenon TBA matches now reasonably well the autoXenon TBA using only pre-calibrated PMTs

SuperK-Gd:

The $Gd_2(SO_4)_3$ concentration after the second load in June corresponds to a ~70% neutron tagging efficiency. The 26 tons of salt dissolved were produced in batches of 1 ton. Of course, all batches were carefully screened before deciding to use them.

- An intensive campaign of measurement and cross checks of samples from all ~26 T1.5 Gd production lots has been performed at three Laboratories: Boulby, Canfranc and Kamioka. In the Canfranc Underground Laboratory, we have screened with high purity Germanium Detectors 12 T1.5 samples.
- No Radioactive Isotope other than small amounts of ^{176}Lu were seen (no harm for physics from this isotope is known).
- The SK detector with ~0.06% $Gd_2(SO_4)_3$ is performing well, no deterioration has been observed after the dissolving of the Gd. The signals from the neutron capture by the Gd are very well identified in all the analysis strategies.
- Among the several publications by the Collaboration or by some of its members, I would like to highlight "Development of ultra-pure gadolinium sulfate for the Super-Kamiokande gadolinium project"; K. Hosokawa, et al. PTEP 2023 (2023) no.1, 013H01.

Physics Analyses

We are getting more and more involved in the main physics goal of SuperK-Gd: the search for the Diffuse Supernova Neutrino Background (DSNB).

- The first paper on DSNB search with Gd neutron tagging has been submitted (May 9th) to *Astrophysical Journal Letters* with title "Search for astrophysical electron antineutrinos in Super-Kamiokande with 0.01wt% gadolinium loaded water."

We are continuing the R&D towards reliable quantitative estimates of the uncertainties in the selection or identification procedures based on Neural Network or, in general, AI algorithms. I.e. to obtain uncertainties estimates that have a mathematically correct statistical meaning. These, and other works by our group, are intended to significantly improve the precision of the systematic error estimates of our measurements, particularly in the "extreme" cases (from the point of view of number of variables involved) of neutron tagging and global neutrino oscillation analysis.