GADZOOKS! (SuperK-Gd): *status and physics potential*

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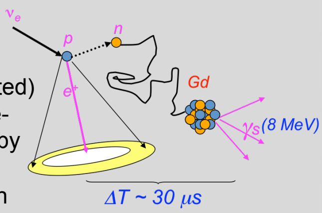
The GADZOOKS! project was the proposed upgrade of the Super-Kamiokande (SK) detector in order to enable it to efficiently detect thermalised neutrons by dissolving gadolinium (Gd) to the SK water, which will enhance antineutrino detectability
The project was approved by the Super-Kamiokande Collaboration 27th June 2015 and renamed SuperK-Gd

Introduction

- **Super-Kamiokande** (**SK**) is a 50,000 ton water Cherenkov detector located in the Kamioka mine under 1000 m of rock
- SK began data taking in 1996
- Currently, SK cannot efficiently distinguish between neutrinos and antineutrinos
- By adding a 0.2 % by mass of a Gd compound ($Gd_2(SO_4)_3$) into the SK water, the majority (90% captured × 90% reconstructed) of final state neutrons produced in the interactions will thermalised and be captured by Gd after ~30 μs and detected through the 8 MeV γ ray cascade from its de-excitation

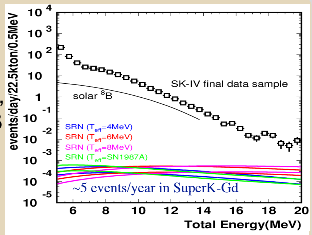


- The efficient neutron tagging Gd-capture provides, gives us a very trustable way to distinguish low energy antineutrinos from neutrinos by identifying its inverse β-decay interaction process

Physics impact

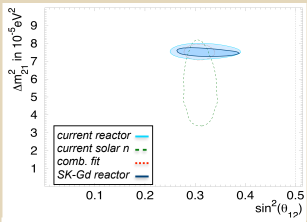
Low energy

- **Diffuse Supernova Neutrino Background** (**DSNB**), currently limited by spallation and solar neutrino backgrounds, highly reduced by identifying the inverse-β interaction of DSNB antineutrinos



Points show current background rate due to spallation and ^{8}B flux, and color lines show different DSNB predictions

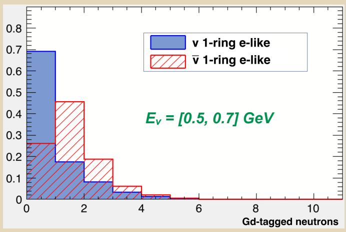
- **Supernova burst** ocurring close enough (our galaxy): measure sprectum and time profile of neutrinos and antineutrinos separetely
- Detectability of **Si-burning stage** (<1 kpc) through the monotonically increasing rate of low energy antineutrinos
- **Reactor antineutrinos** below 10 MeV: SK-Gd will be able to get rid off most of the backgrounds, opening the possibility of a high statistics, independent measurement of the neutrino oscillation parameters of the solar sector



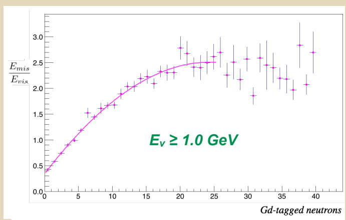
Comparison of sensitivity to solar parameters with five years of SK-Gd data at 95% C.L.

High energy

- **Neutrino - Antineutrino separation** from 0.1 GeV to 10 GeV: antineutrino interactions tend to have larger neutron multiplicities in their final state. This can be used to increase the separation power very significantly, thus improving the sensitivity for the CP violating phase and mass hierarchy in both long baseline and atmospheric neutrino measurements



- **Neutrino energy reconstruction**: the fraction of un-detectedd energy, mostly from hadron production, is strongly correlated to the number of neutrons in the final state. By using these neutrons, one can improve the reconstruction of the neutrino energy up to 40%, depending on the energy



- **Proton decay** searches: these processes hardly ever (7%) produce any neutron. By requiring the number of neutrons in the final state to be zero one can remove 83% of its background from atmospheric neutrinos

ICRC
The Astroparticle Physics Conference
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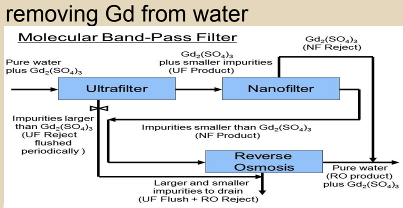
Results from R&D program

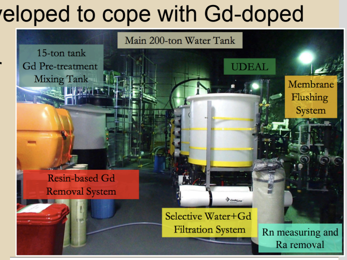
EAGDS *(Evaluating Gadolinium's Action on Detector Systems)*

It was a R&D project for testing the feasibility of adding Gd in water Cherenkov detectors

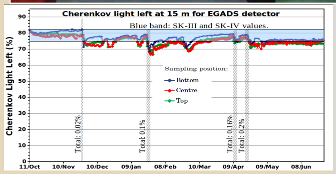
- 200 ton tank instrumented with 227 20" SK-like + 13 HK R&D PMTs
- a selective filtration system specially developed to cope with Gd-doped water, a pretreatment system for dissolving $Gd_2(SO_4)_3$ and another one for removing Gd from water



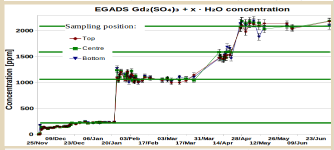
Scheme of the water filtration system, which purifies water keeping the Gd



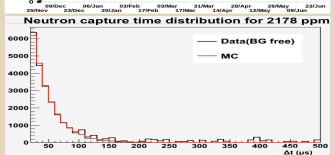
- the UDEAL monitoring system shows a very mild effect of the $Gd_2(SO_4)_3$ in the water transparency, which lies within the SK range pure water quality



- AAS measurements of Gd concentration show good agreement with the expected value, as well as homogeneity and stability along the whole detector's volume

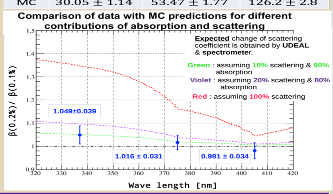


- For checking the Gd-neutron tagging efficiency and its time distribution, an Am-Be source (emitting γ + n) is used Results from data agree very well with expectations for all the concentrations considered



	2178±76ppm	1055±37ppm	225±8ppm
Data	29.89 ± 0.33	51.48 ± 0.52	130.1 ± 1.7
MC	30.05 ± 1.14	53.47 ± 1.77	126.2 ± 2.8

- By using a Rayleigh scattering measuring device we estimate that only 10% of the light loss is due to scattering. This is crucial for studying the impact of the water transparency loss on the physics analysis. In particular, the neutron detection efficiency, which becomes 92%



EGADS is now the world's most advanced water-based supernova ν detector

Radioactivity from $Gd_2(SO_4)_3$

- The Gd compound will be dissolved uniformly along the whole active volume of SK, therefore particular care has to be put to its radioactive contamination
- Measurements in mBq/kg at Canfranc Underground Lab. (LSC, Spain) show that this contamination is not negligible; keeping it under control is needed

Chain	Main sub-chain isot.	Gd-0904	Gd-1008	Gd-1208	Gd-1302	Gd-1303	Gd-1308	Gd-1307a	Gd-1307b	Gd-1412
^{238}U	^{238}U	51± 21	< 33	292±67	74±28	242±60	71±20	47±26	73±27	<76
	^{226}Ra	8±1	2.8±0.6	74±2	13±1	13±2	8±1	5±1	6±1	<1.4
^{232}Th	^{228}Ra	11±2	270±16	1099±12	205±6	21±3	6±1	14±2	3±1	2±1
	^{228}Th	28±3	86±5	504±6	127±3	374±6	159±3	13±1	411±5	29±2
^{235}U	^{235}U	< 32	< 32	< 112	< 25	< 25	< 32	<12	<30	<1.8
	^{227}Ac/ ^{227}Th	214±10	1700 ±20	2956 ±30	1423 ±21	175±42	295±10	<6	<18	190±6
Other	^{40}K	29±5	12±3	101±10	60±7	18±8	3±2	3±2	8±4	<5
	^{138}La	8±1	<	683±15	3±1	42±3	5±1	<1	<2	23±1
	^{176}Lu	80±8	21±2	566±6	12±1	8±2	30±1	1.6±0.3	<2	2.5±0.6

- This radioactive contamination basically affects two measurements:
  - > DSNB, whose main background, ^{238}U SF, is already well below the expected signal
  - > Solar analysis (low energy end): we need to reduce the amount of Ra and Th. For it, an additional R&D program is ongoing

Summary

- Super-Kamiokande will be upgraded to enable an efficient neutron tagging
- Gd-neutron tagging will improve dramatically the sensitivity of SK measurements at both, low and high energy
- The excellent results of the exhaustive R&D programm carried out during years, specially the EGADS demonstrator, guarantee the success and great physics results of SuperK-Gd
- The actual schedule of the project including refurbishment of the tank and Gd-loading time will be determined soon taking into account the T2K schedule