Benefits of Gd for High Energy Neutrinos in SuperK-Gd

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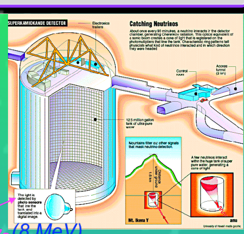
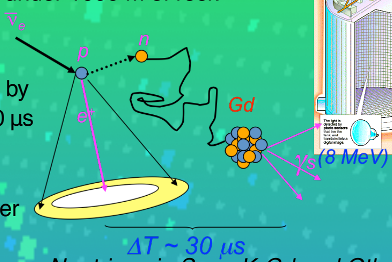
The SuperK-Gd project is the approved upgrade of the Super-Kamiokande (SK) detector in order to enable it to efficiently (> 80%) detect thermal neutrons by dissolving 0.2% of gadolinium sulphate ($Gd_2(SO_4)_3$) into its water. This ability has also significant advantages in the analysis of high energy (> 10^2 MeV) neutrinos in SK, namely atmospheric and long baseline neutrinos.

Here we present the improvements due to the use of the tagged final state neutrons in the separation of the interacting neutrinos and antineutrinos, the distinction between Neutral Current and Charged Current neutrino interactions, and the neutrino energy reconstruction. We study the impact of those features on both, atmospheric and long baseline neutrino oscillation analyses.

The SuperK-Gd Project

- **Super-Kamiokande** (**SK**) is a 50,000 ton water Cherenkov detector located in the Kamioka mine under 1000 m of rock
- SK celebrates this year its 20th anniversary since the start of its measurements in 1996
- **SuperK-Gd** will consist in the addition of 100 tons of $Gd_2(SO_4)_3$, dissolved into the SK water
- By adding this 0.2% by mass of the Gd salt, 90% of the produced neutrons in the detector will be captured by Gd after they thermalise (~10 µs), emitting the latter, a 8 MeV γ ray cascade from its de-excitation after ~20 µs
- **SuperK-Gd** will be able to detect ~80% of all the neutrons produced in the detector, providing a much more complete information of the final state of the interaction
- The **EGADS** R&D program has already show the feasibility and performance of adding Gd to water Cherenkov detectors
- For the complete details toward SuperK-Gd you may refer to Sekiya-san's presentaion, *Supernova Neutrinos in SuperK-Gd and Other Experiments*



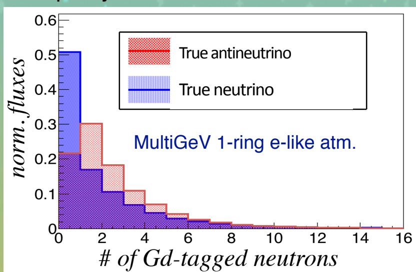


Gd-neutron Tagging in *High Energy Neutrino Physics*

- In addition to the dramatic impact to SK physics at low energy, paradigmatically for measuring the Diffuse Supernova Neutrino Background (DSNB), the efficient neutron tagging of SuperK-Gd has significant advantages for $\mathcal{O}$(GeV) neutrinos

ν — ν̄ separation

Main interactions in the 0.1-10 GeV energy region are **CC**, being more likely for an ν̄ to have larger neutron multiplicity in the final state



Neutron multiplicity is the most relevant variable in the likelihood computation (neural net) for ν-ν̄ separation

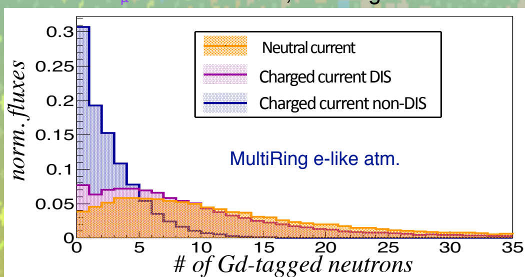
~70% of true ν and ν̄ are correctly classified (depending on the sample)

NC — DIS — CC separation

MultiRing e-like sample (atmospheric) contains ν_e in the most sensitive energy region to the MH. But it is largely contaminated with NC and ν_μ events, which demean its potential MH sensitivity

➡NC events deposit a large fraction of ν energy in the nucleus, implying a large neutron production

➡Most of ν_μ come from DIS, showing similar effect



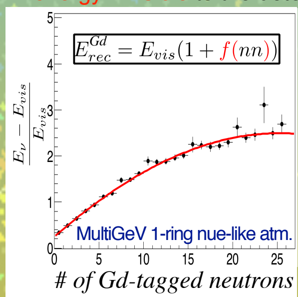
Netron multiplicity is crucial role in the likelihood computation

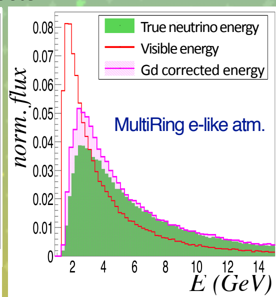
80% of true NC and DIS are correctly classified

ν energy reconstruction

The more energetic is the incoming neutrino the more energy fraction is spent on neutral hadron production (π, η, κ…). These usually interact inside the nuclear media producing a significant amount of neutrons in the final state of the neutrino interaction

➡This suggests that the neutron multiplicity brings along information about the fraction of the neutrino energy invisible to the detector

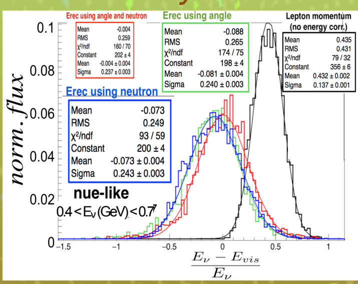




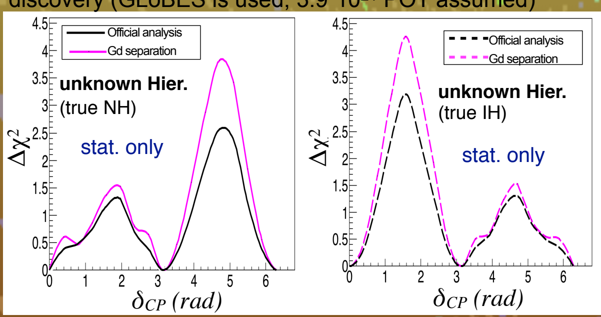
T2K Oscillation analysis

☑Neutron energy correction improves the energy reconstruction similarly to the usage of the precise knowledge of T2K ν incoming direction

☑Main impact of Gd-tagging on T2K osc. analysis comes from ν-ν̄ separation (78% efficiency)



This significantly improves the sensitivity to **CP violation** discovery (GLoBES is used, $3.9\cdot10^{21}$ POT assumed)

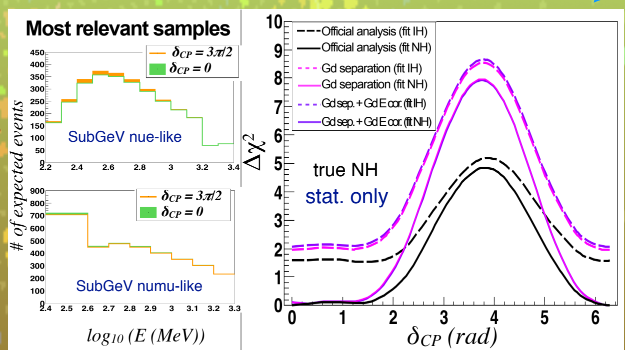


Atmospheric Neutrino Oscillation analysis

☑The sensitivty to the **CP violating phase is** improved due to the better clasification of SubGeV neutrinos and antineutrinos

Right most plot shows the sensitivty for rejecting δCP =0 (exposure: SK-IV livetime, 2339 days)

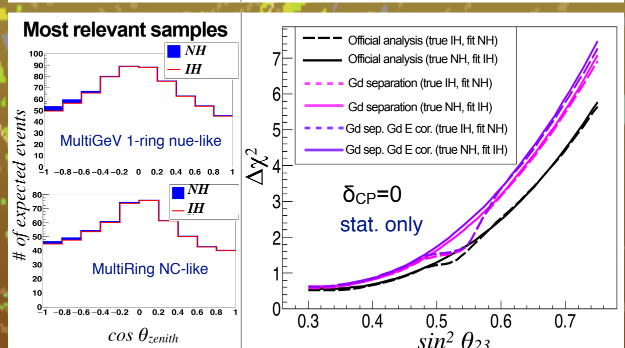
Adjacent plots show the spectra of the most sensitive event samples



☑Right most plot shows the sensitivty to the wrong **mass hierarchy** rejection depending on θ23

It is seen that, in addition, to the better MultiGeV event selection the neutron energy corrections also improves MH sensitivty

Adjacent plots show the zenith angle distribution of the most sensitive samples



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