Overview of the model-dependent approach for the Diffuse Supernova Neutrino Background search with the SK-Gd experiment

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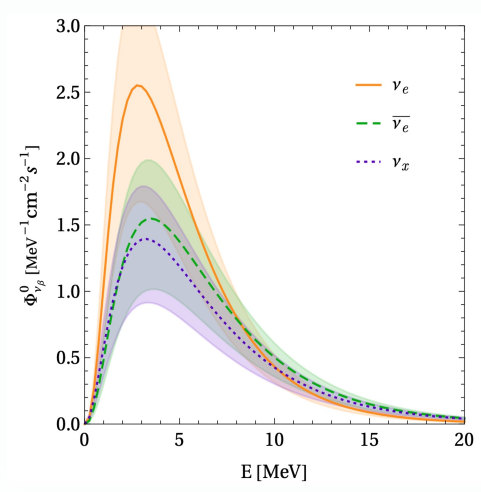
The Diffuse Supernova Neutrino Background (DSNB)

- The DSNB is the flux of neutrinos of all flavors, with **energy $\sim \mathcal{O}(10\ MeV)$**, emitted by all core-collapse supernovae (CCSN) in the observable universe.
- It can be expressed as:

$$\Phi_{DSNB}(E_\nu) = \int_z R_{CCSN}(z) \cdot \frac{dN(E_\nu \cdot (1+z))}{dE_\nu} \cdot \frac{cdz}{H(z)}$$



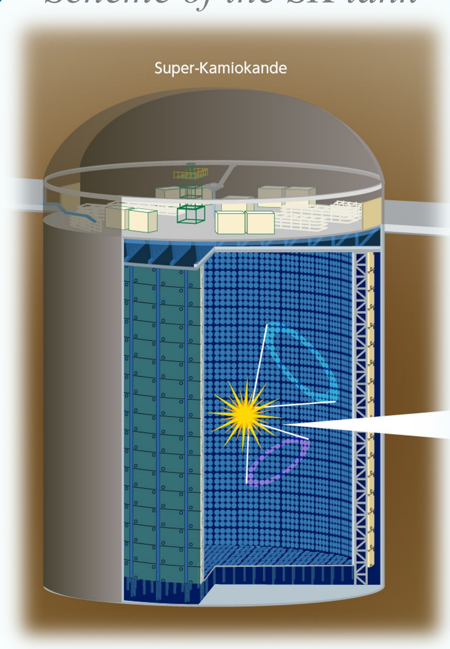
Unoscillated DSNB flux[1]

- … and directly probes e.g.:
  - the *star formation rate*, owing to the lower limit that can be derived with the **supernova rate R_{CCSN}**.
  - the *CCSN explosion mechanism*, through the **supernova neutrino emission spectrum $\frac{dN}{dE_\nu}$**, as ~99% of the explosion released energy is carried by neutrinos.
  - the *history of the universe expansion*, with the **Hubble function H**.

Please see A. Beauchêne's poster (#218) for more !

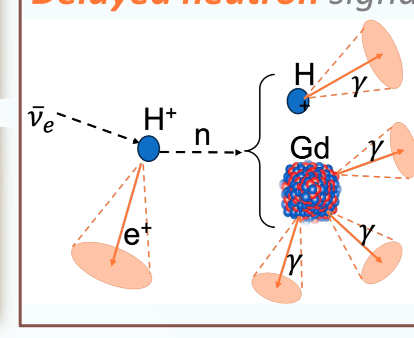
The Gd-loaded Super-Kamiokande (SK-Gd) experiment

Scheme of the SK tank



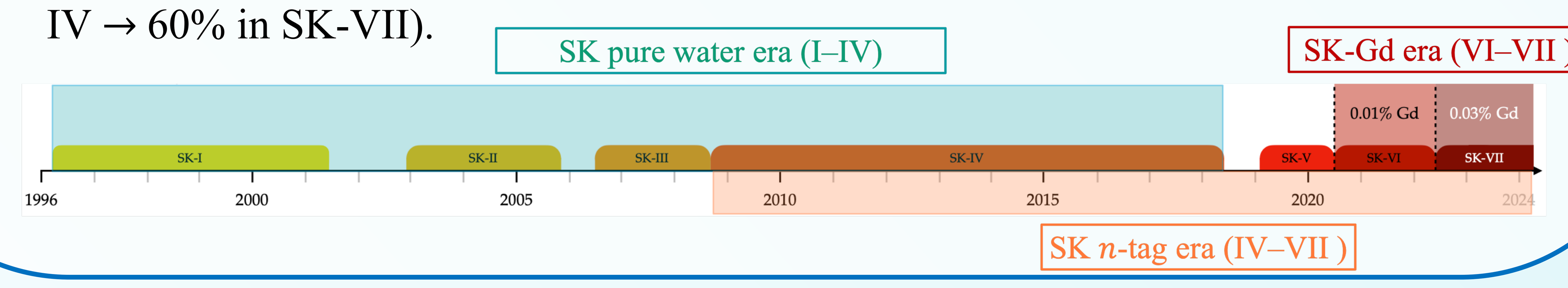
- The SK experiment consists of a 50-kton **water Cherenkov detector**, operated by ~11k Photo-Multiplier Tubes (PMTs).
- It is *only sensitive to the (anti-)electronic component* of the total DSNB flux, via the **inverse beta-decay** (IBD) reaction: $\bar{\nu}_e + p \rightarrow e^+ + n$

***Delayed neutron** signal after **prompt positron** signal, stemming either from:*



1. *Capture on hygrogen (H) nucleus → **2.2 MeV** de-excitation γ signal.*
2. *Capture on gadolinium (Gd) nucleus → **brighter ~8 MeV** de-excitation γ signal.*

- The experiment went through several data-taking periods, punctuated by several refurbishments and improvements of the overall detector apparatus, with in particular:
  - ❖ **SK n-tag era (SK-IV – today)**
    → capability to tag the neutron capture signal, thus giving sensitivity to the DSNB signal.
  - ❖ **SK-Gd era (SK-VI – today)**
    → increasing Gd-loading of SK tank, enhancing the neutron tagging efficiency (25% in SK-IV → 60% in SK-VII).



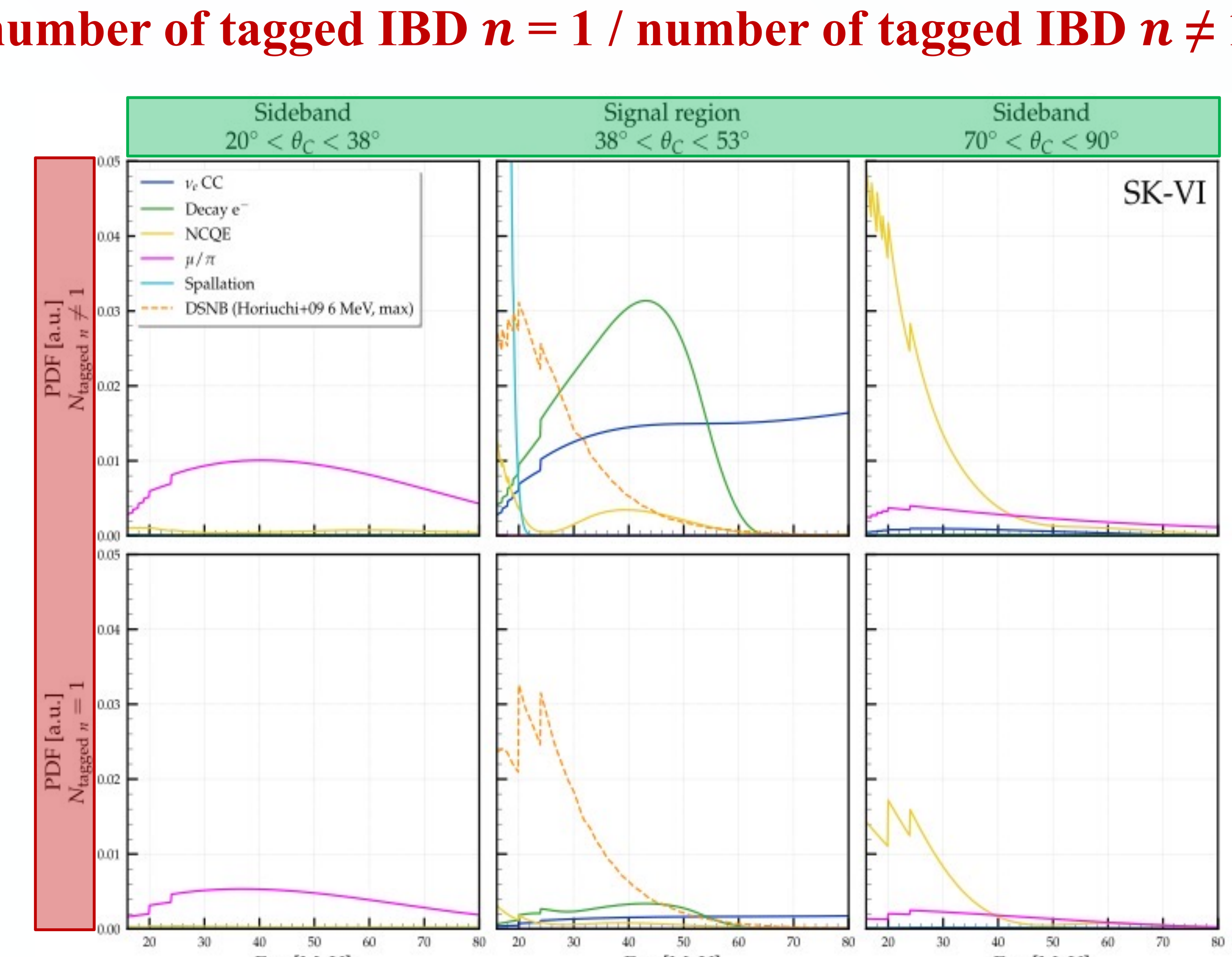
Background categorization in the DSNB analysis at SK

- Dominant background contributions: atmospheric neutrino interactions & cosmic ray induced spallation background.
  → Efficient data reduction is crucial.

Please see A. Santos', M. Harada's, Y. Kanemura's poster (#637) for more on data reduction !

- After reduction steps, the remaining backgrounds are classified in a 6-region parameter space:

(low / med. / high reconstructed Cherenkov angle θ_c of IBD e^+)
$\otimes$
(number of tagged IBD $n = 1$ / number of tagged IBD $n \neq 1$)

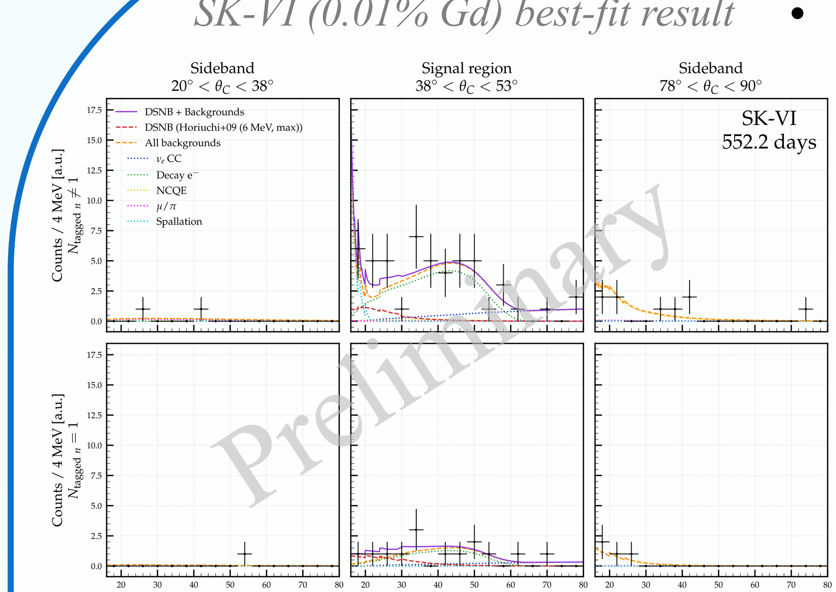


Normalized signal and background spectra, after cuts

- The increasing Gd-loading brings a fair amount of DSNB signal into the region **(med. θ_c)** $\otimes$ **(n-tagged= 1)** where the S/B ratio is higher, leading to ***enhanced sensitivity to DSNB signal.***

DSNB spectral analysis framework, results & prospects

SK-VI (0.01% Gd) best-fit result



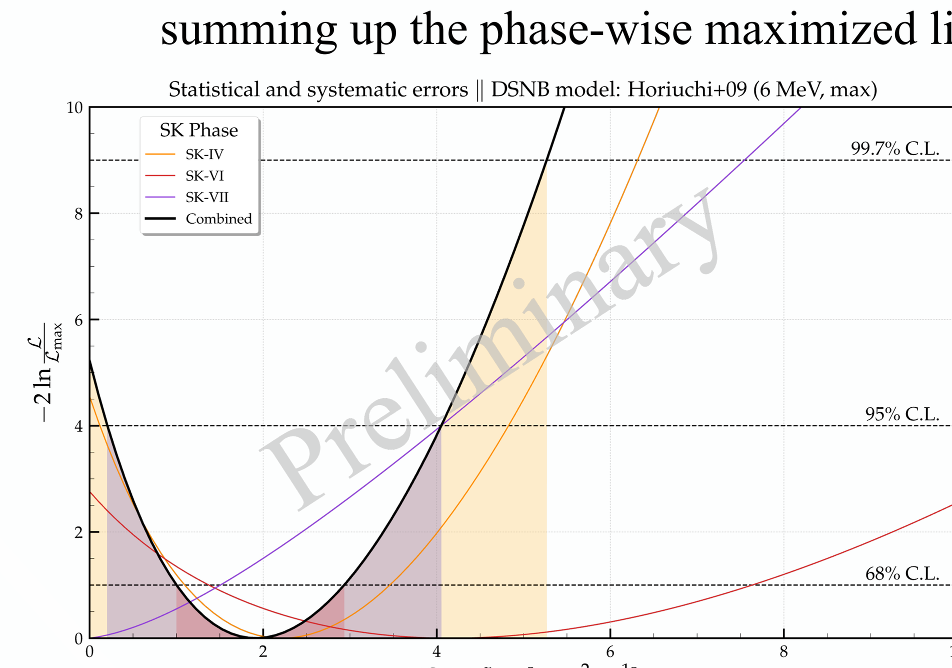
- The DSNB spectral analysis is an ***unbinned*** and ***shape-driven analysis***, consisting in the simultaneous fit of the background contents $\vec{N_b}$ & the DSNB signal content N_s, through an *extended likelihood maximization:*

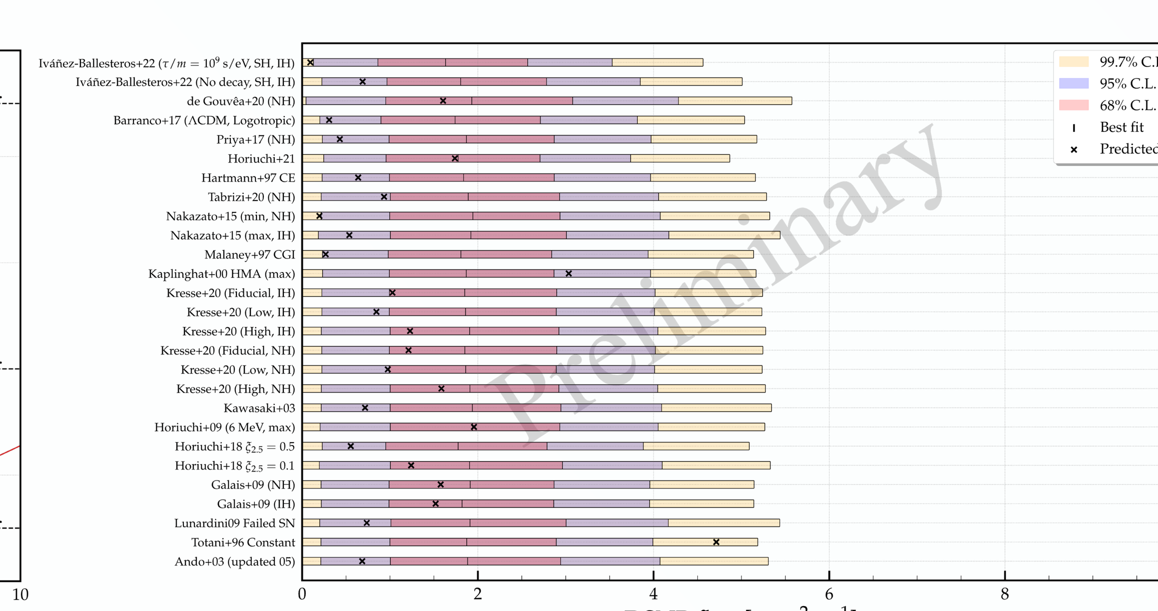
$$\mathcal{L}(Data \mid N_s, \vec{N_b}, \vec{\varepsilon}) =$$

$$\mathcal{L}(\vec{\varepsilon_0} \mid \vec{\varepsilon}) \cdot e^{-\sum_{j\in\{s,\vec{b}\}} N_j} \prod_{i=1}^{N_{data}} \sum_{j\in\{s,\vec{b}\}} N_j \cdot PDF_j(E^i, \theta_C^i, N^i_{tagged\ n} \mid \vec{\varepsilon})$$

Shape-only nuisance parameters in the 6-region parameter space

- **Profile likelihood approach** for statistical inference, and SK-phases combination carried out by summing up the phase-wise maximized likelihoods.





- **2.3σ overall excess across all SK n-tag era.**
- DSNB flux best-fit point mostly independent from the DSNB shape model (statistically limited analysis). In particular, **high consistency with Horiuchi+09 (6MeV, max)**[2] **model.**

- With the (current) predicted SK-VII background rates, preliminary sensitivity studies, carried out with the Horiuchi+09 (6MeV, max) DSNB predicted flux, suggest that we should exclude the background-only hypothesis at **about the 3σ level by the end of the SK-Gd era**.

- <u>*Analysis prospects*</u>:
  - **Lower the analysis threshold** in the **(med. θ_c)** $\otimes$ **(n-tagged= 1)** region, owing to the enhanced neutron tagging performance from Gd-loading → mitigate the neutron mistag rate for the low-energy overwhelming neutronless spallation background.
  - **Rethink the phase combination into a joint fit approach**. Preliminary sensitivity studies suggest a boost of a few tenths of σ in sensitivity.

References

[1]*De Gouvea et al., Phys. Rev. D 106, 103026*
[2]*Horiuchi et al., Phys. Rev. D 79, 083013*