# kamLAND potentiality in the post SNO-NC era

Paola Aliani [1, 2], Vito Antonelli [1, 2], Ruggero Ferrari [1, 2], Marco Picariello [1, 2], Emilio Torrente-Lujan [3, 4]
[1] *Università degli Studi di Milano*, [2] I.N.F.N Milano
[3] *Universidad Autonoma de Madrid*, [4] *CERN-TH division*

## Introduction

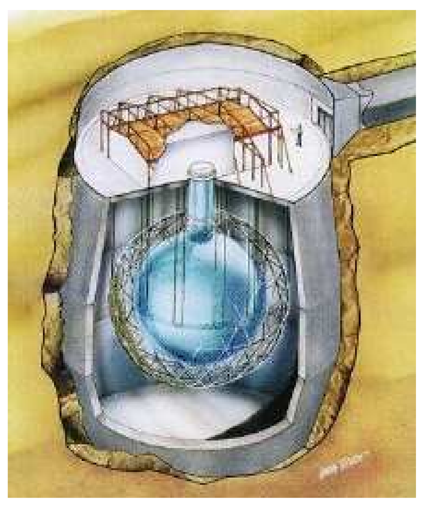


**Fig. 1.—:** A view of the SNO detector

With this poster, we have tried to answer the following question: "Could it be that in just a few years we will have the solution to the long-standing solar neutrino problem?" Although SNO has recently published extremely important data on Charged Current (CC), Neutral Current (NC) [**1**] and day-night asymmetries [**2**], phenomenological analysis in the full solar-neutrino parameter space [**3**] reveals that we have not yet homed in on a definite solution. It has been known for some time that the favored solution lies in the Large Mixing Angle (LMA) region and new SNO data strongly confirms this.

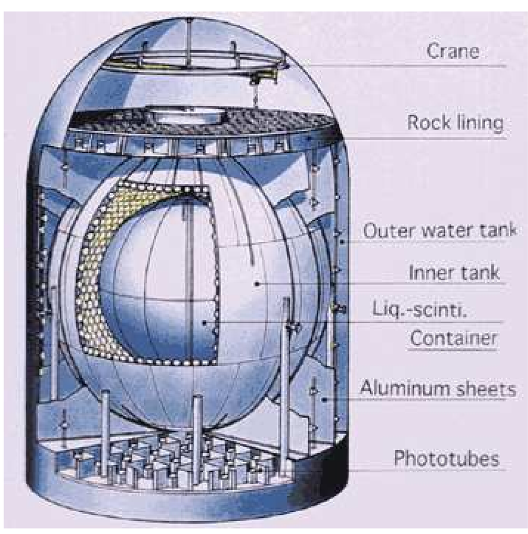



**Fig. 2.—:** A drawing of the kamLAND detector

This turns out to be rather fortunate for the kamLAND collaboration, since the reactor-based experiment is particularly sensitive to this region [**4**], and in particular to the $\Delta m^2_{12}$ parameter, due to the energy-range of the reactor $\overline{\nu}_e$ and the distance they travel from these reactors to the Kamioka site. In what follows, we have tried to determine what extra information will be gained from different hypothetical kamLAND results. Using *global* signals $S_{\rm exp}/S_{\rm th}$ ranging from 0.2 to 0.9, we calculate the best-fit points using all available solar-neutrino data. To determine these points we use a $\chi^2$ method described further on (see also [**5**]).

## Implementation of SNO detector

### Neutrino physics at SNO

The SNO detector is sentitive to all three neutrino flavors via the following interaction on heavy water:

- $\underline{\nu_x + d \to \nu_x + p + n}$ : **N**eutral **C**urrent reaction. Same weight for all neutrino flavors.
- $\underline{\nu_e + d \to p + p + e^-}$ : **C**harged **C**urrent. Sensitive only to electron neutrinos.
- $\underline{\nu_x + e^- \to \nu_x + e^-}$ : **E**lastic **S**cattering. Sensitive to all flavors with different weights.

### Detector simulation

- We produce parameter-dependent signals for the different reactions CC, ES, NC and take the weighed sum of the different signals. We confront this total signal with the experimental data provided by SNO for day and night bins.
- We make NO assumptions regarding spectrum distortion. This allows us to sample in the full oscillation-parameter plane $(\Delta m^2_{12}, \tan^2\theta_{12})$.
- To determine the $\chi^2$, we introduce the following quantities:
$$v_i^{\exp_k} = \left(d_i^{\exp_k}, n_i^{\exp_k}\right),\; v_i^{\mathrm{th}_k} = \left(d_i^{\mathrm{th}_k}, n_i^{\mathrm{th}_k}\right)$$
where $d_i$ and $n_i$ represent the day and night quantities for the i$^{\rm th}$ bin normalized to the standard solar model (SSM) expectation, exp$_k$=SK, SNO and $i = 1 \ldots 19, 17$ for SK and SNO respectively.
- The total $\chi^2$ is then
$$\chi^2_{\rm global+Sp} = \left(R^{\exp_i} - \alpha R^{\mathrm{th}_i}\right)\left(\sigma^{-1}\right)_{ij}\left(R^{\exp_j} - \alpha R^{\mathrm{th}_j}\right) + \\ + \frac{(\alpha-\alpha_0)^2}{\sigma_\alpha^2} + \frac{(\beta-\beta_0)^2}{\sigma_\beta^2}$$
where exp$_i$=CL, GA, SK$_i$ and SNO$_i$, $R^{\rm exp,th}$ are the different signals (including $v_i$ quantities) normalized to the SSM expectation, and $\alpha$ is the flux-normalization constant determined by the minimization of the total $\chi^2$. The last term in the $\chi^2$ comes from the SK bin-correlation.

## Post SNO, pre kamLAND results

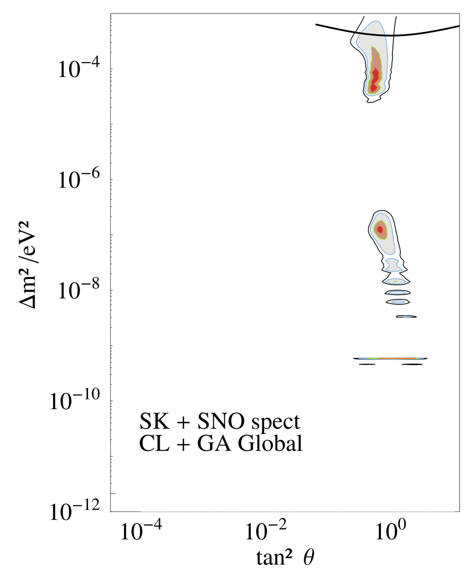



Figure 3. Exclusion plot obtained from the analysis of Homestake, GallEX/GNO, SAGE global rates and SK and SNO day-night spectra. Contour lines correspond to 90%, 95%, 99% and 99.73%. Like [**6**], we have *not* taken the zenith-angle bins into account in our analysis, although we *have* taken spectrum distortion into account. It has been pointed out [**3**] that the inclusion of the zenith day-night bins further decreases the g.o.f. of the LOW solution.

## Implementation of kamLAND detector

- $\underline{\overline{\nu_e} + p \to e^+ + n}$: clear coincidence signal.
- Cross section taken at zero$^{\rm th}$ in the limit of infinite nucleon mass. Angular dependence is trivial and therefore integrated.
- We assume 0.5 MeV positron-energy bins in the range $(2, 8)$ MeV and a resolution of $\sigma(E) = 0.1\sqrt{E}$ (where $E$ is the total detected positron energy) [**8**]. By also analyzing 1 MeV bins, we conclude that the prediction-power of kamLAND does not decrease significantly.
- We consider a fuel composition, averaged over the 7-month fuel cycle in each of the 16 reactors.

## kamLAND spectrum analysis

- We calculate the moment of kamLAND's signal as a function of the solar neutrino oscillation parameters:
$$\left\langle E\left(\tan^2\theta_{12}, \Delta m^2_{12}\right)\right\rangle := \frac{\sum_{\rm bins}\overline{E_i}S_i}{\sum_i S_i}$$
where $\overline{E_i}$ is the average bin-energy.
- We find significant spectrum distortion in the LMA region, whereas the SMA and the LOW are undistorted.
- $<E_{\rm no\ osc}>$=3.4255 MeV, whereas the distortion in the LMA region depends strongly on the mixing parameter $\Delta m^2_{12}$ and to a less extent on $\tan^2\theta_{12}$.
- $<E_{\max}>$=3.7602 MeV & $<E_{\min}>$=3.0037 MeV

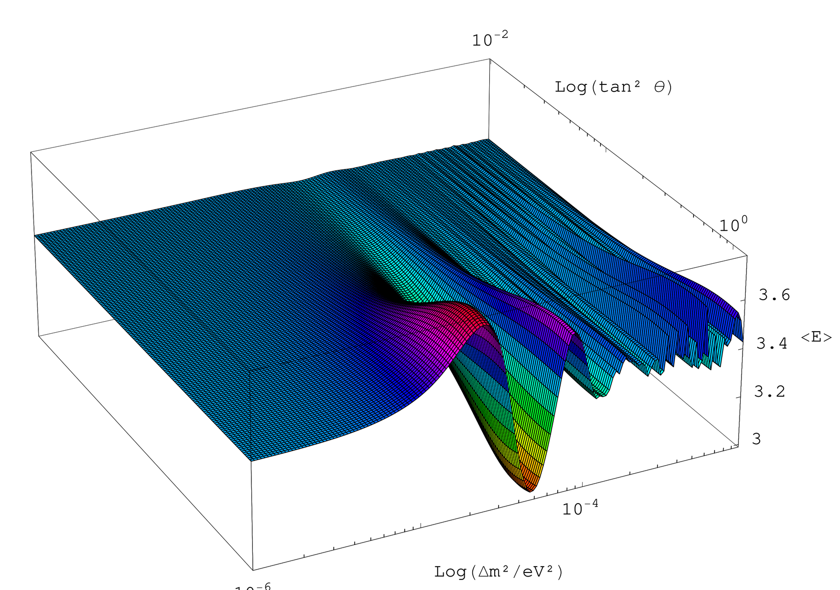



Figure 4. 3D plot of the moment of the kamLAND spectrum as a function of the oscillation parameters. For small $\Delta m^2_{12}$ there is no distortion, and $< E > = < E_{\rm no\ osc} >$. The angular dependence is also quite feeble, even in the LMA region.

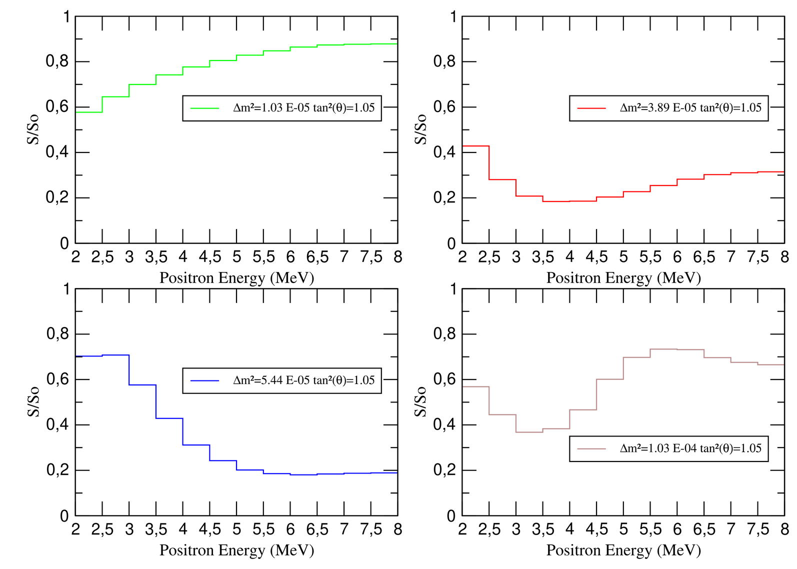
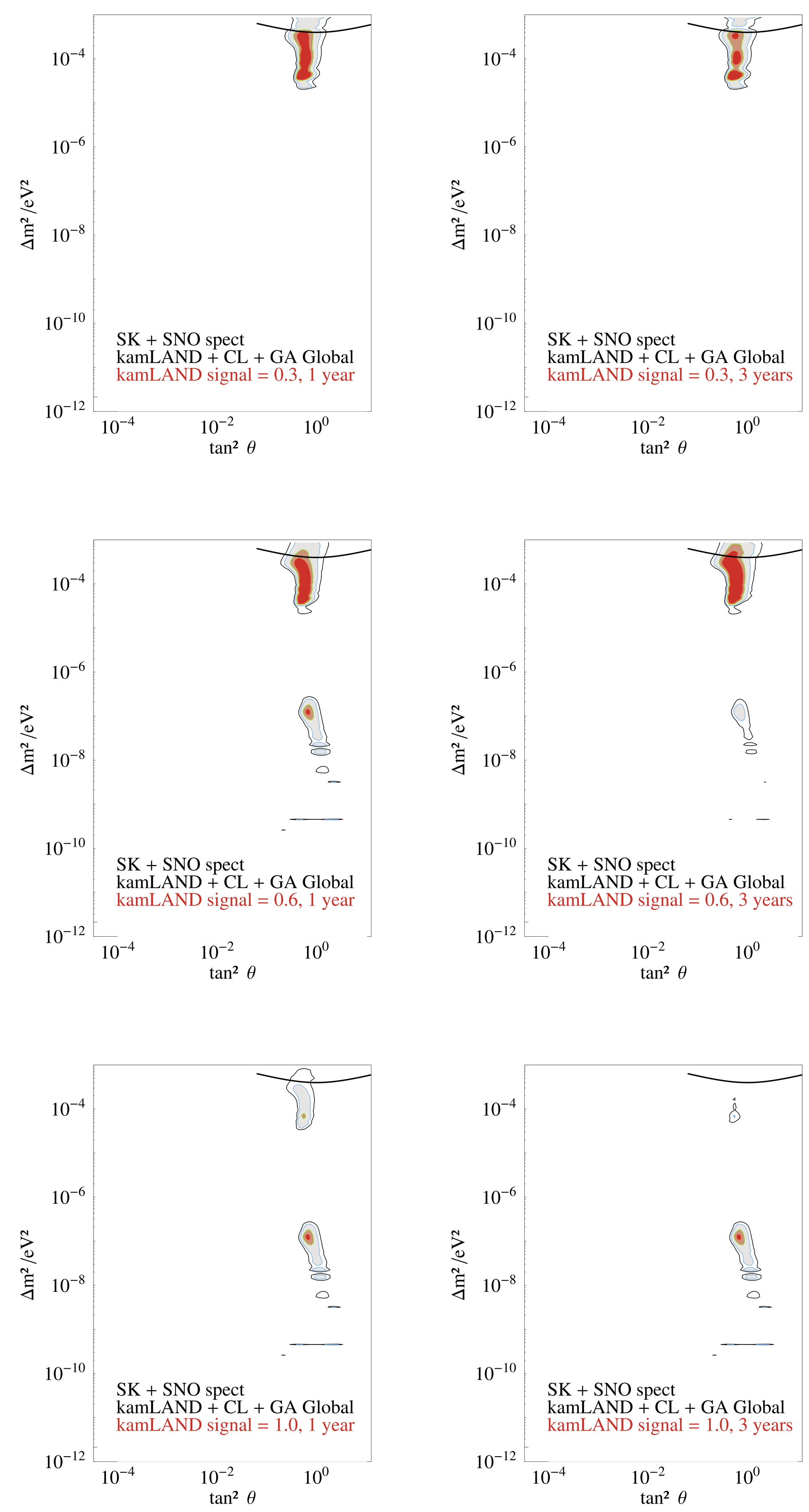



Figure . kamLAND spectra for different points in the **LMA** region. There is a strong dependence on $\Delta m^2_{12}$. An identical analysis based on 1 MeV bins gave substantially the same result. The combined analysis of kamLAND spectrum and global rates will help determine with accuracy the correct value of $\Delta m^2_{12}$.

## Hypothetical post SNO and kamLAND results

Post-kamLAND exclusion plots. From top: $S/S_0$=0.3 for (left) **one** and (right) **three** years of data taking. Middle panel, $S/S_0$=0.6 and bottom panel $S/S_0$=1.0. We estimate an initial 10% error in the first year and a statistically-dominated error in the third year.




## References

**1** Q. R. Ahmad *et al.* [SNO Collaboration], arXiv:nucl-ex/0204009.

**2** Q. R. Ahmad *et al.* [SNO Collaboration], arXiv:nucl-ex/0204008.

**3** J. N. Bahcall, M. C. Gonzalez-Garcia and C. Pena-Garay, arXiv:hep-ph/0204314.

**4** P. Alivisatos *et al.*, STANFORD-HEP-98-03.
A. Piepke [KamLAND Collaboration], Nucl. Phys. Proc. Suppl. **91** (2001) 99.

**5** P. Aliani, V. Antonelli, R. Ferrari, M. Picariello and E. Torrente-Lujan, arXiv:hep-ph/0205053.
P. Aliani, V. Antonelli, M. Picariello and E. Torrente-Lujan, Nucl. Phys. B. 634 (2002) *in press*.

**6** V. Barger, D. Marfatia, K. Whisnant and B. P. Wood, arXiv:hep-ph/0204253.

**7** H. Murayama and A. Pierce, Phys. Rev. D **65** (2002) 013012 [arXiv:hep-ph/0012075].

Table 1:

Fig. 3.—

Fig. 4.—

Fig. 5.—