

Tutorial 1: Sterile neutrino at reactor experiments – assignments

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The purpose of this first tutorial is to understand the phenomenology of sterile neutrinos at reactor experiments. In order to do this, we will use `GLOBESfit` as an instrument to compute the χ^2 as a function of the squared-mass splitting Δm_{41}^2 and of the mixing angle $\sin^2 \theta_{14}$, which are responsible for electron antineutrino disappearance at the baselines considered in the relevant experiments.

After having installed the `GLOBESfit`, it is easy to run its two versions, which allow to compute the χ^2 using rate or spectrum measurements. From the `GLOBESfit` directory, one can run, respectively, `source/glf_rate` or `source/glf_spectrum` to obtain the sum of the χ^2 from all the rate or spectrum experiments. For each category, a number of different experiments is available, the complete list is available in the `GLOBESfit` article <https://arxiv.org/abs/2005.01756>. In both cases, the output can be stored in a file using the option `-o`, for example:

```
source/glf_rate -o output/rate_all.dat
```

The run will need few minutes, at the end you will see that the output file contains three columns: they report the values of $\log_{10} \sin^2 \theta_{14}$, $\log_{10} \Delta m_{41}^2$ [eV²] and the χ^2 .

1 Compare spectrum and rate constraints

Using these simple commands, the first exercise consists in producing the χ^2 files with the default configuration of the rate and spectrum analyses. Once you have the files, you should read them with the program of your choice and try to produce a plot like the one in figure 1. Remember that in order to produce 1, 2, 3 σ contours you have to consider differences $\Delta\chi^2 = 2.30, 6.18, 11.83$ with respect to the best fit, respectively, because we consider two degrees of freedom.

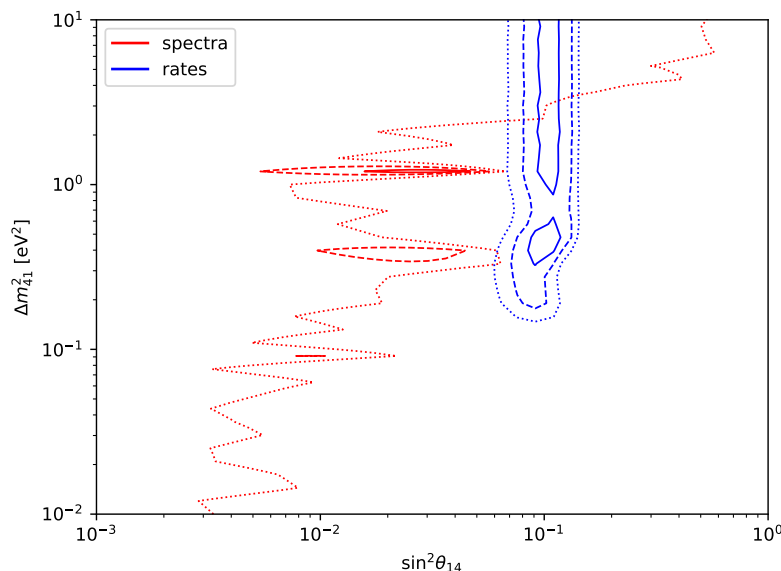


Figure 1: Comparison of 1, 2, 3 σ constraints from rate and spectrum analyses of reactor antineutrino data.

2 Compare single rate or spectrum experiments

GLoBESfit also allows to compute constraints from a subset of experiments. In particular, one can exclude blocks of experiments using the `-b` option. Experiments are organized in blocks because of their correlations, so you may be unable to obtain constraints from a single experiment, especially in the rate analysis. In general, however, you can repeat the `-b` option several times to reduce the number of blocks included in the calculation. Check the appendix B.4 of <https://arxiv.org/abs/2005.01756> for a full list of blocks, and remember that the block index starts from 0. For example, if one wants to perform the spectrum analysis for the DANSS experiment alone, the command to use is:

```
source/glf_spectrum -b1 -b2 -b3 -b4 -b5 -o output/danss.dat
```

In this way, we exclude all the blocks from 1 to 5, which correspond to the other available experiments.

Using this information, you should now try to compare the bounds from the different experiments and see what is their impact on the combined constraint. In the case of rate analyses, you may obtain something like figure 2. This figure shows that some experiments provide upper limits on the mixing angle, while others give a preferred range around $\sin^2 \theta_{14} \sim 0.1$. The combination of the shown experiments with all the other ones gives the black region.

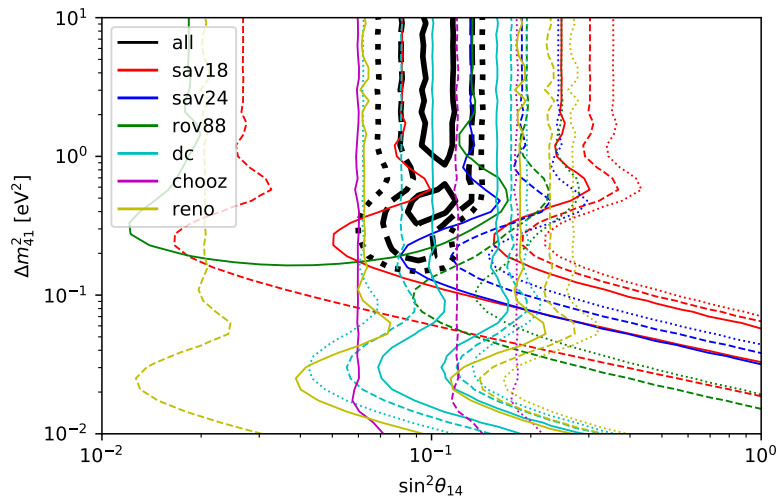


Figure 2: Comparison of the constraints from few different rate analyses.

In a similar way, the spectrum experiments can be divided in two groups: DANSS and NEOS, which have a preferred region for the mixing parameters, and the rest of them, from which we only obtain upper limits (DayaBay, DoubleChooz, Bugey, Reno). A comparison of the two categories around the most interesting region is shown in figure 3. Notice that it is interesting to look at the constraints also outside the plotted region. For example, can you tell which experiment gives the strongest constraints on $\sin^2 \theta_{14}$ at small values of the mass splitting ($0.01 < \Delta m_{41}^2 / \text{eV}^2 < 0.1$) and why? and why the limit on the mixing angle is independent on the mass splittings when this is higher than approximately 5 eV^2 ?

3 Reactor flux models

One final exercise is connected to uncertainties in the theoretical calculation of the reactor antineutrino flux, which is needed to compare predictions with observations in the rate analyses only. The default calculation by GLoBESfit considers a fixed prediction for the reactor spectrum without systematic uncertainties, called the Huber-Müller (HM) model. Three additional options allow the user to turn on systematics for the HM flux (`-S`), or consider two different models instead: the “ab initio” or “summation method” (SM, `-M`) or the Hayen-Kostensalo-Severijns-Suhonen model (HKSS, `-H`). Can you compare the different methods in a rate analysis?

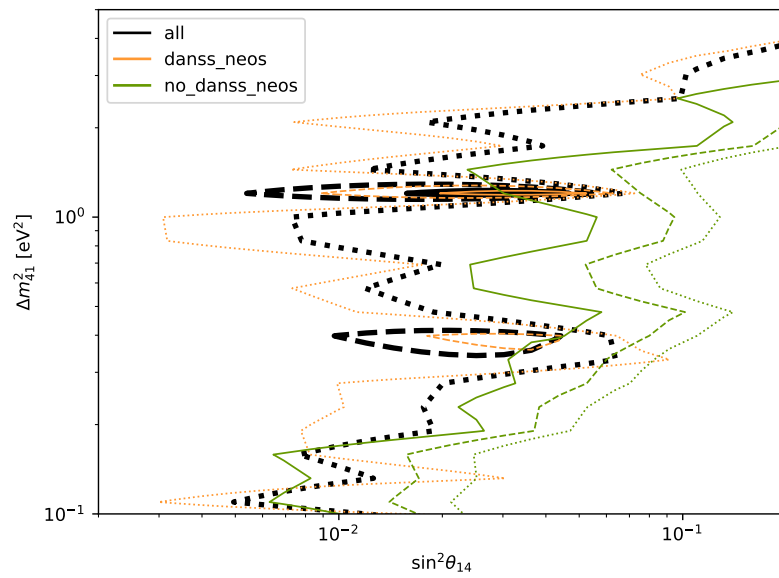


Figure 3: Comparison of the constraints from few different spectrum analyses.