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# Reactor neutrinos, double beta and beta decays experimental review

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This experimental review presents the status of the reactor neutrino oscillation experiments to measure the $\theta_{13}$ parameter, the double beta decay experiments to look for the nature (Majorana or Dirac particle) and the effective mass of the neutrino and the beta decay experiments to measure directly the absolute mass of the neutrino.
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## 1. Introduction

The observations of neutrino oscillations from atmospheric, solar, reactor and accelerator neutrino oscillation experiments have shown that neutrinos are massive particles and the three neutrino mass eigenstates are related to the three neutrino mass flavor eigenstates through the PMNS mixing matrix. This matrix is parameterized by 3 angles: $\theta_{23}$ measured from both atmospheric and accelerator neutrino experiments ($tan^2\theta_{23} = 1 \pm 0.3$); $\theta_{12}$ measured by solar and reactor neutrino experiments ($tan^2\theta_{12} = 0.47 \pm 0.5$); $\theta_{13}$ not yet measured, accessible through reactor and accelerator neutrino experiments : $sin^2\theta_{13} < 0.16$. The PMNS matrix includes also CP violation phases (Dirac and Majorana phases).

Although the oscillation probability depends on the difference of the square mass eigenstates, the absolute mass of the neutrino is still unknown. The neutrino oscillations are sensitive to the differences of the square neutrino mass eigenstate $\Delta m^2_{ij} = |m^2(\nu_i) - m^2(\nu_j)|$. From the solar experiments,we now that $\Delta m^2_{12} = (7.58 \pm 0.21)10^{-5}$ eV$^2$ and from atmospheric and accelerator neutrino measurements $\Delta m^2_{12} = (2.2 \pm 0.2)10^{-3}$ eV$^2$. So, the existence of neutrino oscillations proves that neutrino are massive particles but oscillations don't provide information on the value of the absolute mass $m(\nu_i)$.

The absolute mass can be measured through cosmological observations (CO), neutrinoless double beta decay (DBD) and single beta decay (SDB). The measurement of the neutrino mass with SDB is model independent unlike the CO and DBD methods. The present limits are the following: from beta decay $m_\nu = \sqrt{\Sigma|U_{ei}|^2 m_i^2} < 2.3$ eV, from double beta decay $| < m_\nu > | = |\Sigma U^2_{ei} m_i| < 0.2 - 0.8$ eV (depending of nuclear matrix element calculations) and from cosmology $\Sigma m_i = m_1 + m_2 + m_3 < 1$ eV

Moreover, the sign of the neutrino mass square difference dominant in the atmospheric neutrino oscillations is not yet measured. Then three hierarchy mass schemes are possible [1] :

- Quasidegenerate case $m_1 \simeq m_2 \simeq m_3 \simeq m_0$ ; $m_0 > 0.1$ eV
- Inverted Hierarchy $m_3 << m_1 < m_2$; $m_{1,2} \simeq |\Delta m^2_{31}|^2$
- Normal Hierarchy $m_1 << m_2 < m_3$; $m_2 \simeq |\Delta m^2_{21}|^2$ and $m_3 \simeq |\Delta m^2_{31}|^2$.

## 2. Reactor neutrinos

The existence of the neutrino has been demonstrated by Reines and Cowan with the Poltergeist experiment installed near the Savannah River nuclear reactor in 1956. During the last 40 years, the reactor anti-neutrinos are still studied to look for the neutrino oscillations. Indeed, the survival probability of the electronic anti-neutrino can be written as:

$P(\bar{\nu}_e \rightarrow \bar{\nu}_e) \simeq 1 - sin^2\theta_{13} sin^2(\frac{1.27 L \Delta m^2_{13}}{E}) - cos^4\theta_{13} sin^2 2\theta_{12} sin^2(\frac{1.27 L \Delta m^2_{31}}{E})$

L: distance source- detector (m); E: neutrino energy (MeV)

The first term will dominate for a distance of few kilometers and it is mainly sensitive to $\theta_{13}$. Up to now the best limit $sin2\theta_{13}$ < 0.16 (90 % CL) has been obtained by the CHOOZ experiment. The second term is effective for a distance of 100 - 200 km and depends mainly on $\theta_{12}$.The KamLAND experiment has observed for the first time the oscillations from reactor anti-neutrinos and its results combined with the results of the solar neutrino experiments have allowed to measure $\Delta m^2_{21} = 7.59^{+0.21}_{0.21} \times 10{-}5$ eV$^2$ and $tan^2\theta_{12} = 0.47^{+0.06}_{-0.05}$.

| | Location | Thermal power (GW) | Distance (m) Near/far | Depth (m) Near/far | Target Mass (t) | running | $\sigma_{stat}$ (%) | $\sigma_{syst}$ (%) | $sin2\theta_{13}$ (90 % CL) |
|---|---|---|---|---|---|---|---|---|---|
| Double Chooz | France | 8.5 | 410/1050 | 120/300 | 8.6/8.6 | 2010 (far)<br>2012 (near) | 0.5 | 0.6 | < 0.03 |
| RENO | South Korea | 17.3 | 290/1380 | 120/450 | 16/16 | 2010 | 0.3 | 0.5 | < 0.02 |
| Daya Bay | China | 17.4 | 360/1985<br>500/1613 | 260/910 | 20x2/40 | DB 2011<br>Full 2012 | 0.2 | 0.4 | <0.01 |

**Table 1:** Main parameters of the Double Chooz, RENO and Daya Bay experiments

The sensitivity of CHOOZ experiment was limited by the statistical (2.8 %) and systematical (2.7 %) errors. To improve the sensitivity to $\theta_{13}$, the basic concept of the Double Chooz [2], RENO [3] and Daya Bay [4] experiments is to use at least one near and one far detector in order to cancel some of the systematics (cross section, reactor flux, cut efficiency) and to increase statistics (more powerful reactors, longer time of running and larger mass of target). The objective is to reach a sensitivity $sin2\theta_{13} < 0.01$ - 0.03 (90 %CL) depending on the project. Anti-neutrinos are detected through the reaction $\bar{\nu} + p \rightarrow e^+ + n$ (threshold = 1.8 MeV) followed by the gamma-rays coming from the neutron capture. The designs of these experiments are very similar with a target volume of Gd loaded liquid scintillator surrounded by active and passive vetos. The neutron captures in Gadolinium lead to the emission of gamma rays with an energy sum around 6 MeV. The detectors are installed in shallow site to protect them against neutron background coming from muons spallations.

The double Chooz experiment is located in the French Ardennes at the Chooz nuclear power plant (2 reactors, 8.5 GW$_{th}$) and consists in a near detector at 410 m from the reactors and a far detector installed in the previous Chooz underground site at 1 050 m. The RENO experiment is located at the Yonggwang reactor complex (6 reactors, 17.3 GW GW$_{th}$) in South Korea with one near detector (290 m) and one far detector (1380 m) . The Daya Bay experiment is located in China close to the Daya bay reactor complex (6 reactors, 17.4 GW$_{th}$) and consists in 2X2 near detectors (360 m and 500m) and four far detectors (1613 m and 1985 m). The distance of Daya Bay far detectors is the closest to the oscillation maximum.

The Table 1 presents a comparison of the different experiments, their expected sensitivities (5 years of data) and schedule.

## 3. Beta decay

The beta decay is a well know process corresponding to the emission of an electron and an anti-neutrino: $^3H \longrightarrow e^- + \bar{\nu}_e$

The transition energy is distributed between the electron and the anti-neutrino. If the neutrino is massive,the shape of the beta spectrum energy will be modified near the end-point.

The rate of this decay $\frac{dN}{dE}$ is proportionnal to $[(E_0 - E_e)^2 - {m_{\nu_e}}^2]^{\frac{1}{2}}$ where $E_0$ is the transition energy, $E_e$ energy of the electron and $m_{\nu_e} = \sum |U_{ei}|^2 {m_i}^2$ with $U_{ei}$ mixing matrix and $m_i$ mass eigenstate of neutrino.

The fraction of decay in the interval $[E_0 - m_\nu, E_0]$ is proportionnal to $\Delta E/{E_0}^3$ and implies to select an isotope with the lowest transition energy. The experimenal setup must be able to accomodate high counting rate. It requires also an energy resolution on the order of $m_\nu$. In practice, two isotopes are studied: tritium ($Q_\beta = 18.6$ keV) and $^{187}$Re ($Q_\beta = 2.47$ keV).

Presently, the most sensitive technique uses the principle of magnetic adiabatic collimation (Mac-E filter) with tritium source. The spectrometer acts as a high energy pass filter and the electrons are counted in the detector at the end of the spectrometer. The energy resolution of the spectrometer is given by $\frac{\Delta E}{E} = \frac{B_{min}}{B_{max}}$.

This technique allows a large solid angle (2 $\pi$), a high luminosity and a low background. The background is mainly due to secondary electrons created by natural radioactivity or cosmics rays inside the spectrometer. A limitation of the technique comes from the systematics due to the source itself (inelastic scattering, self charging of $T_2$ film, radiative corrections, ....)

The best results have been obtained by the Mainz and Troisk experiments using the Mac-E filter technique but different source configurations : $T_2$ thin film quenched on cold graphite substrate for Mainz and windoless gazeous $T_2$ for Troisk leading to different systematics. The energy resolution was 4.5 eV (3.5 eV) for Mainz (Troisk). The Mainz limit is ${m_{\nu_e}}^2 = -0.6 \pm 2.2 \pm 2.1$ eV$^2$ corresponding to $m_\nu < 2.3(95\%CL)$. The Troisk experiment published similar limit ${m_{\nu_e}}^2 = -2.3 \pm 2.5 \pm 2.0$ eV$^2$ corresponding to $m_\nu < 2.05(95\%CL)$ but some systematics from end-point fluctations are not included (i.e. corresponds to a periodical small excess of events near the end-point in the Troisk experiment).

The KATRIN (KArlsruhe TRItium Neutrino) [5] is a join effort from Mainz and Troisk collaborations to design and built a spectrometer sensitive to a neutrino mass down to 0.2 eV. It will be based on the use of MAC-E-Filter spectrometer and a very active Windowless Gaseous Tritium Source (WGTS). The MAC-E-Filte is 10 m in diameter and 23 m long with a resolution of $\Delta E = 0.93$ eV and with a luminosity 4-5 times higher than Mainz and Troisk experiments. A WGTS will allow to reduce the systematics compared to a solid source. It consists in a 10 m long tube of 90 mm diameter filled with molecular tritium gas (isotopic enrichment $> 95\%$) in a magnetic field of 3.6 T. The tritium is injected at the middle of the pipe and pumped out by differential pump stations to reach a density of $5.10^{17}$ molecules/cm$^2$ leading to a counting rate 100 times higher than previous experiments. The electrons are guided to the spectrometer through a system of superconducting solenoid guide. They are detected by an array of 400 PIN photodiodes. An active shield allows to reject external background.

The expected sensitivity after 3 years of data taking is $m_{\nu_e} < 0.2$ eV/c$^2$ at 90 % (C.L.). A signal can be observed at $5(3)\sigma$ for a neutrino mass of $m_{\nu_e}0.35(0.30)$ eV/c$^2$. The test of the main spectrometer is scheduled for 2011 and the complete system integration for 2012.

Another technique uses low temperature bolometers of $AgReO_4$. The natural Re contains 62.8 % of $^{187}$Re beta emitter, $E_0 = 2.47eV$, with a period of $(4.35 \pm 0.13)10^{10}y$ (the activity is 1 Bq/mg in natural Re). The avantages of using bolometers are to suppress systematics from the source and the possibility of using large amount of bolometers. Currently, the bolometer technique is limited by the background from the pile-up due to the time response of the thermal sensors.

The MARE I experiment starting in 2010 [6] uses 300 $AgReO_4$ bolometers (energy resolution (FWHM) 10 - 20 eV). The objective is to reach the sensitivity of Mainz and Troisk experiments on the neutrino mass ($\simeq$ 2.3 eV) for 5 years of data taking.

A second phase,MARE II (5000 micro-bolometers) scheduled for 2018, requires the development of a new technology to improve of the energy resolution and to reduce pulse risetime down to 1 - 5 $\mu s$ (100 times less than the present detectors) in order to decrease the background from the pile-up. For 10 years of data, a sensitivity of 0.2 eV could be reached.

## 4. Double beta decay

The neutrinoless double beta decay consists to the decay of two neutrons in two protons with emission of two electrons: (A,Z) $\rightarrow$ (A,Z+2) + $e^-$ + $e^-$

This process is forbidden in the Standard Model of the electroweak interaction because of the non-conservation of the leptonic number. The electron sum energy of the $\beta\beta(0\nu)$ decay would be simply a peak at the value of the transition energy. Due to the energy resolution the ultimate background is the allowed double beta decay ($\beta\beta(2\nu)$):(A,Z) $\rightarrow$ (A,Z+2) + $e_1^-$ + $e_2^-$ + $\bar{\nu}_1$ + $\bar{\nu}_2$

In the case of light neutrino exchange, the expression of the half-life depends on the effective neutrino mass: $[T^{0\nu}_{\frac{1}{2}}(0^+ \rightarrow 0^+)]^{-1} = G^{0\nu}.|M^{0\nu}|^2.\langle m_\nu \rangle^2$

Where $G^{0\nu}$ is the calculable phase space factor, $M^{0\nu}$ is the nuclear matrix element (NME) of the process. The calculation of the NME is a difficult subject, several models (QRPA methods, Shell Model) are used. There are recent progresses on these calculations and the discrepencies between models tend to be reduced.

$\langle m_\nu \rangle = ||U_{e1}|^2 m_1 + |U_{e2}|^2 m_2 \exp i\phi_1 ||U_{e3}|^2 m_3 expi\phi_2$ is the effective Majorana neutrino mass

$m_1, m_2, m_3$ are the neutrino mass eigenstates, $U_{e1}, U_{e2}, U_{e3}$ are the coeficients of the neutrino mixing matrix and $\phi_1, \phi_2$ are the Majorana CP phases ($\pm 1$ if CP is conserved). In this review, the range for the limit on the effective neutrino mass is calculated taking into account NME calculations from [9], [10], [11]

The effective neutrino mass can be rewritten as a function of the oscillation parameters and the CP phase violation. The measurement of the effective neutrino mass could allow to determine the neutrino mass hierachy: a mass $\langle m_\nu \rangle > 0.05$ eV would correspond to the quasi-degenerate hierarchy, if $0.01 < \langle m_{nu} \rangle < 0.05$ eV than it would correspond to the inverted hierarchy and if $\langle m_\nu \rangle < 0.005$ eV then the mass hierarchy is normal. Detailed discussion can be found in [1].

Today, the experiments uses about 10 kg of enriched isotopes and have a sensitivity to explore the QD region. The next generation of double beta decay experiments will have at least 100 kg of enriched isotopes starting to explore the IH region. To fully explore the IH scheme, it will be necessary to be able to built detector with a mass of 1 ton of isotope. This review will present the last results and the phase at 100 kg for each experiment.

Several techniques can can be used for the $\beta\beta(0\nu)$ decay search [7] [8]:

- Pure calorimeter like semi-conductor detectors or bolometers where the efficiency, mass and good energy resolution are optimized
- Tracko-calo detectors to suppress the background by identification of the electrons and to allow choice of the isotope.
- TPC (Xe) for optimization of the efficiency and mass and also background if the daughter nucleus can be identified.
- Inorganic scintillators or loaded organic scintillator to optimize efficiency and to use large mass

of isotopes

The main backgrounds come from the natural radioactivity (in particular $^{208}$Tl and $^{214}$Bi), the neutrons (mainly through (n,$\gamma$) reactions), the radon and the cosmics rays (through cosmogenic production and neutron spallation production).All the detectors are installed deep underground and shielded againt external neutrons and gamma-rays.

The best results for the limit on the effective neutrino mass has been obtained with Ge diodes enriched at 86 % in $^{76}$Ge by the Heidelberg-Moscow (11 kg) and IGEX experiments (8.4 kg) $\langle m_\nu \rangle < 0.35 - 1.05$ eV . There is a very contreversial 4 $\sigma$ claim about observation of signal from the Heidelberg-Moscow experiment. Recently, two other experiments have reached similar limits Cuoricino (bolometric experiment) and NEMO3 (tracko-calo experiment).

Cuoricino is based on the technique of cryogenic detectors. The Cuoricino detector is a tower made of modules of crystals of $TeO_2$ (40 kg) operating at 8 mK. The main avantage of using natural Tellurium is the high isotopic abundance of $^{130}Te$ (34%), there is no need to have isotopic enrichment. The energy resolution at 2530 keV is between 7 and 9 keV (FWHM) depending of the crystal size. Cuoricino stopped data taking in 2009 after 6 year of running in the Laboratori Nazionali del Gran Sasso (LGNS, Italy). For 19.75 kg.y of $^{130}$Te, a limit for the $\beta\beta(0\nu)$ decay is set to $T_{1/2} > 3.0\ 10^{24}$ y (90% C.L.) corresponding to a range for the effective neutrino mass limit : $\langle m_\nu \rangle <$ 0.19 - 0.68 eV depending of the nuclear matrix element calculations.

The NEMO3 detector is based on a tracking device associated to a calorimeter to detect the electron. It allows to reduce drastically the background. The measurement of the angular distribution and the individual energy of the electron could allow in case of signal to distinguish the process leading to the $\beta\beta(0\nu)$ decay. The detector is running since 2003 in the Laboratoire Souterrain de Modane (France) and will stop end 2010. It consists of a thin central source foil (40-60 mg/cm$^2$) sandwiched by 2 volumes of drift cells operating in Geiger mode to reconstruct three-dimensionnal tracks and surrounded by a calorimeter made of plastic scintillators coupled to low radioactive photomultipliers. The energy resolution (FWHM) at 1 MeV ranges from (14% to 16%) depending of scintillator size. A solenoid intalled around the detector produce a 25 gauss magnetic field in order to distinguish electrons and positrons. The detector contains mainly $^{100}$Mo (6914 g) and after 4.5 years of data taking, the limits obtained are $T_{1/2} > 1.0\ 10^{24} y$ (90% C.L.) and $\langle m_\nu \rangle <$ 0.47 - 0.96 eV.

The next generation of double beta decay experiment will be able to measure at least 100 kilograms of enriched isotopes. There are two strategies. A step by step approach (GERDA, CUORE, SuperNEMO,...) based on a progressive increasing of the mass of the isotopes up to at least 100 kg to check the control of background. A more aggressive strategy (EXO,SNO+, KamLAND-ZEN,...), in this case several hundred kg on enriched isotopes are directly introduced inside the detector under the assumption that background is already under control.

The next Ge diode experiments are GERDA and Majorana. The basic concept of the GERDA experiment is to operate Ge diodes in liquid nitrogen or argon in order to remove materials to reduce the background. The first phase, starting in 2010 in the Laboratori Nazionali del Gran Sasso, will consist in 17.9 kg of enriched Ge (86% in 76Ge) coming from Heidelberg-Moscow and IGEX experiments. The aim is to decrease the background by a factor 10 ($10^{-2}$ counts/keV/kg/y) compared to HM and IGEX experiment to reach a sensitivity of $T_{1/2} > 3.\ 10^{25}$ y and $\langle m_\nu \rangle$ < 0.25 eV to check the claim by Prof. Dr. H. V. Klapdor-Kleingrothaus. The second phase will correspond to 40 kg of enriched $^{76}$Ge diodes with a part of Ge segmented diodes (20 kg). The expectation for the sensitivity with a background of $10^{-3}$ counts/keV/kg/y and 3 years of data taking is $T_{1/2} > 2.\ 10^{26}$ y and $\langle m_\nu \rangle < 0.11$ eV. This phase in planned for 2012.

The Majorana collaboration proposes to operate 500 kg of 86% enriched Ge detectors divided in modules of 60 kg. The objectives are to use very pure materials, to improve the pulse shape discrimination and to use segmented cristals to reject multi-site events corresponding to background events. Presently, segmented Ge crystals are under study to check the impact of the segmentation on signal and background. The R&D phase will start with 30-60 kg of enriched Ge crystals (with some of them segmented). The objective is to decrease the background at a level inferior at 1 counts/t/y in the region of interest around 2033 keV. The ultimate goal is to reach a sensitivity on the half-life $T_{1/2} > 4.10^{27}$ y with a background less than 1 count/ton/keV/y.

The CUORE detector is the successor of the bolometric Cuoricino experiment. The detector will be composed of 988 5x5x5 cm3 crystal of TeO$_2$ operated at 8 mK. The total mass will be 741 kg of TeO$_2$ and consequently 203 kg of $^{130}Te$. The present background of Cuoricino in the energy region of the $\beta\beta(0\nu)$ decay is 0.18 ± 0.02 count/keV/kg/y. This background is mostly coming from the surface contamination of the crystals and the copper frame. A strategy to reduce these surface events is under study. The expected background with suppression of surface event is 0.01 count/keV/kg/y corresponding to a sensitivity of $T_{1/2} > 2.110^{26} y$ and $\langle m_\nu \rangle < 0.03$ - 0.07 eV for 5 years of data. The data taking is foreseen in 2012.

The SuperNEMO experiment is an extrapolation by a factor ten of the NEMO3 experiment. The detector will be modular and consists in 20 modules with 5 kg each of enriched source. The total mass of isotope will be 100 kg. The calorimeter will have an energy resolution of 4% (FWHM) at 3 MeV and the background will be reduced by factor 10 compared to NEMO3 to reach activities less than 20 $\mu$Bq/kg in $^{214}$Bi and 2 $\mu$Bq/kg $^{208}$Tl. The gas of the tracking detector must be radon free at the level of 100 $\mu$Bq/m$^3$ which imposes severe constraint on the activities of the materials used to built the detector. With this technique several isotopes can be studied like $^{82}$Se, $^{150}$Nd, $^{116}$Cd, $^{100}$Mo and $^{48}$Ca. The baseline is to use 100 kg of $^{82}$Se, the expected sensitivity for 5 years of data taking is $T_{1/2} > 1.10^{26} y$ and $\langle m_\nu \rangle < 0.07$ - 0.12 eV. The schedule is to start to run the first module in 2013.

The EXO experiment is looking for $\beta\beta(0\nu)$ decay of $^{136}$Xe to $^{136}$Ba with a Time Projection Chamber (TPC). The main avantages of $^{136}$Xe are the ease to enrich it compare to the other $\beta\beta$ candidates and also the long period of the $\beta\beta(2\nu)$ process. The challenge is to attempt to tag the $^{136}$Ba$^{++}$ ion after its partial neutralization to Ba$^{+}$. The identification of the final state of the decay would drastically reduce the background and could be potentially lead to a zero background experiment. EXO will start by using 200 kg of enriched $^{136}$Xe in liquid phase by detecting the scintillation light without Ba ion tagging. The prototype EXO-200 is in commissioning in the WIPP laboratory. The expected sensitivity after 2 years of data taking is $T_{1/2} > 6.4\ 10^{25}$ y and $\langle m_\nu \rangle < 0.27$ - 0.38 eV.

The SNO+ experiment proposes to dissolve Nd salt inside the liquid scintillator of the SNO detector. The avantage is the use of an existing low background detector. Due to the large volume of liquid scintillator, it is possible to dissolve a large mass of natural Nd or enriched $^{150}$Nd. Such detector allows high mass and has high efficiency. The external background will be measured during the phase without Nd. It will require to purify the Nd salt in order to remove any U and Th contamination. The expected sensitivity on the neutrino mass with 150 kg of $^{150}Nd$ is $\simeq$ 80 meV.

The KamLAND-ZEN experiment consists in using the well-known KamLAND detector by installing at the center of the liquid scintillator volume a balloon containing enriched $^{136}$Xe dissolved inside liquid scintillator. The external background is already measured by the present experiment. The sources of background will come from the radiopurity of Xe and spallation of muons inside the detector. The first phase will start in 2011 with 400 kg of $^{136}$Xe with an expected sensitivity on the effective neutrino mass 50 meV.

There are various other projects for double beta decay searches. A non-exhautive list is:CANDLES experiment will use $CaF_2$ scintillating crystals to look for $\beta\beta(0\nu)$ decay of $^{48}Ca$.DCBA is a project of gazeous TPC to study $\beta\beta(0\nu)$ decay of $^{150}$Nd. The energy will be measured by the curvature of the tracks. COBRA would use semi-conductor crystal of ZnCdTe ($^{116}$Cd) with a possible tracking capability. NEXT would be a Xenon TPC with tracking capability to reduce background.

## 5. Conclusion

Some fundamental parameters or properties of the neutrino like nature, absolute mass or $\theta_{13}$ mixing angle are still unkown. During the next decade, we can expect to have important progress and maybe discoveries. Around 2015, the three reactor neutrino experiments will reach a sensitivity of $sin2\theta_{13} < 0.1$ - 0.03 . The KATRIN experiment will obtain in 2017 a sensitivity on the absolute mass $m_{\nu_e} < 0.2$ eV. The various double beta decay experiments will reach a sensitivity on the effective neutrino mass around 50 meV for the same period.

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