

Convocatorias 2014

Proyectos de I+D “Excelencia” y Proyectos de I+D+I “Retos Investigación”
Dirección General de Investigación Científica y Técnica
Subdirección General de Proyectos de Investigación

a. RESUMEN DE LA PROPUESTA/SUMMARY OF THE PROPOSAL**a.1. DATOS DEL PROYECTO COORDINADO**

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TÍTULO GENERAL DEL PROYECTO COORDINADO: Construcción puesta a punto y operación del experimento NEXT en el Laboratorio Subterráneo de Canfranc.

ACRÓNIMO DEL PROYECTO COORDINADO: NEXT.

RESUMEN DEL PROYECTO COORDINADO:

NEXT (Neutrino Experiment with a Xenon TPC) es un experimento para buscar desintegraciones doble beta sin neutrinos ($\beta\beta 0\nu$), cuya detección demostraría unívocamente que el neutrino es una partícula de Majorana (es decir su propia antipartícula) y supondría un descubrimiento con profundas consecuencias en física de partículas y cosmología.

El isótopo escogido por NEXT es el ^{136}Xe . El experimento dispone de cien kilos de gas xenón enriquecido al 90 % en ^{136}Xe . La tecnología se basa en el uso de cámaras de proyección temporal operando a una presión típica de 15 atmósferas (HPXE). Las características principales de esta técnica experimental son: a) excelente resolución en la medida de la energía; b) capacidad de reconstruir la trayectoria de los electrones emitidos en la desintegración, lo que refuerza la capacidad del experimento para reducir el ruido de fondo; c) escalabilidad a grandes masa y d) la posibilidad de reducir el ruido de fondo hasta niveles despreciables mediante la técnica conocida como BATA (de las siglas en inglés, *Barium Tagging*).

El experimento NEXT contempla cuatro fases: i) Demostración de la tecnología HPXE con prototipos que usan ~ 1 kg de xenón natural; ii) Medida de los ruidos de fondo y de la señal del proceso permitido ($\beta\beta 2\nu$) con un detector NEW) basado en 12 kilos de xenón enriquecido y operando en el Laboratorio Subterráneo de Canfranc (LSC); iii) Búsqueda de desintegraciones $\beta\beta 0\nu$ con el detector NEXT-100, una réplica a escala 2:1 (en tamaño) y 8:1 (en masa) de NEW, que usará por tanto 100 kilos de gas enriquecido; iv) Búsqueda de desintegraciones $\beta\beta 0\nu$ con el detector BEXT (Barium-tagging Experiment with a Xenon TPC), con una masa de alrededor de una tonelada de ^{136}Xe , que introducirá la técnica de BATA para reducir el ruido de fondo hasta niveles despreciables.

La primera fase de NEXT ha sido completada con éxito durante el periodo 2009-2013. Durante esta etapa se han construido los prototipos NEXT-DEMO (IFIC) y NEXT-DBDM (Berkeley) que han demostrado las características principales de la tecnología. El experimento se encuentra en estos momentos en su segunda fase. El detector NEW está siendo construido por la colaboración y operará en el LSC durante el año 2015. La financiación del detector NEW proviene de un Advanced Grant (AdG/ERC) concedido en 2013 al IP de este proyecto (operativo desde Febrero de 2014 a Febrero de 2018). El detector NEXT-100 supone la tercera fase del proyecto. Se construirá y pondrá a punto durante 2016 y 2017 e iniciará su toma de datos en 2018. La cuarta fase depende de los resultados de la fase tres, en la que se podría realizar ya un descubrimiento. Previsiblemente, BEXT podría funcionar en el LSC a partir del 2020.

NEXT es una colaboración internacional, liderada por grupos españoles y con una fuerte contribución de grupos norteamericanos. El desarrollo de la tecnología laser necesaria para el BaTa se realiza en colaboración con el Centro de Láseres Pulsados de Salamanca (CLPU).

Este proyecto de investigación requiere *cofinanciación* para desarrollar la fase tres del experimento. Concretamente, se requiere: a) fondos para adquirir una parte de los equipos y material fungible necesarios para la construcción del detector NEXT-100 (cofinanciado por el AdG y los fondos provenientes de la colaboración); b) fondos para una parte del personal científico y técnico; y c) fondos para cofinanciar el R&D dedicado al BATA.

PALABRAS CLAVE DEL PROYECTO COORDINADO: neutrinos, TPC, HPXe, xenón, desintegración doble beta, Canfranc, alta presión, electroluminescencia.

TITLE OF THE COORDINATED PROJECT: Construction commissioning and operation of the NEXT experiment at the LSC underground laboratory.

ACRONYM OF THE COORDINATED PROJECT: NEXT.

SUMMARY OF THE COORDINATED PROJECT:

NEXT (Neutrino Experiment with a Xenon TPC) is an experiment to search neutrino less double beta decay processes ($\beta\beta 0\nu$). The detection of such processes would demonstrate that neutrinos are Majorana particles (that is their own antiparticles) and would have deep consequences in physics and cosmology.

The isotope chosen by NEXT is ^{136}Xe . The collaboration has access to hundred kilograms of xenon enriched at 90 % in ^{136}Xe , owned by the Underground Laboratory of Canfranc (LSC). The NEXT technology is based in the use of time projection chambers operating at a typical pressure of 15 bar and using electroluminescence to amplify the signal (HPXe). The main advantages of the experimental technique are: a) excellent energy resolution; b) the ability to reconstruct the trajectory of the two electrons emitted in the decays, a unique feature of the HPXe which further contributes to the suppression of backgrounds; c) scalability to large masses; and d) the possibility to reduce the background to negligible levels thanks to the barium tagging technology (BATA).

The NEXT roadmap was designed in four stages: i) Demonstration of the HPXe technology with prototypes deploying a mass of natural xenon in the range of 1 kg; ii) Characterisation of the backgrounds to the $\beta\beta 0\nu$ signal and measurement of the $\beta\beta 2\nu$ signal with the NEW detector, deploying 12 kg of enriched xenon and operating at the LSC; iii) Search for $\beta\beta 0\nu$ decays with the NEXT-100 detector, which scales up the NEW detector by a factor 2:1 in size (8:1 in mass) and deploys, thus, 100 kg of enriched xenon. iv) Search for $\beta\beta 0\nu$ decays with the BEXT detector (Barium-tagging Experiment with a Xenon TPC), which will deploy a mass in the ton scale and will introduce the technology of BATA in order to reduce backgrounds to negligible levels.

The first stage of NEXT has been successfully completed during the period 2009-2013. The prototypes NEXT-DEMO (IFIC) and NEXT-DBDM (Berkeley) were built and operated for more than two years. These apparatus have demonstrated the main features of the technology. The experiment is currently developing its second phase. The NEW detector is being constructed during 2014 and will operate in the LSC during 2015. The funding for the construction and operation of NEW comes from an Advanced Grant (AdG/ERC) granted to the PI of this project in 2013. The NEXT-100 detector will be built and commissioned during 2016 and 2017 and will start data taking in 2018. NEXT-100 could discover $\beta\beta 0\nu$ processes if the period of the decay is equal or less than 6×10^{25} year. The fourth phase of the experiment (BEXT) could start in 2020.

NEXT is an international collaboration, lead by spanish groups (the PI of this proposal is the spokesperson of the collaboration) and with a very significant contribution of US groups. The laser technology needed for the BEXT phase is being developed in collaboration with the Spanish Center for Pulsed Lasers (CLPU).

This proposal requires *co-funding* to complete the phase three of the experiment. Specifically we request: a) funds to co-finance the construction of the NEXT-100 detector (which is being partially paid by the AdG as well as by the international collaboration, primarily US groups); b) funds to co-finance personnel; and c) a modest contribution of the R&D to develop the BATA technology.

KEYWORDS OF THE COORDINATED PROJECT: neutrinos, TPC, HPXe, xenon, double beta decay, Canfranc, high pressure electroluminescence.

b. INFORMACIÓN ESPECÍFICA DEL EQUIPO

c. DOCUMENTO CIENTÍFICO/SCIENTIFIC DOCUMENT

c.1. JUSTIFICACIÓN DE LA COORDINACIÓN/JUSTIFICATION OF THE COORDINATION

NEXT is organised as an international collaboration, which includes groups from Spain, Portugal, Russia, US, and Colombia. The spanish groups participating in NEXT are: Instituto de Física Corpuscular (IFIC), a joined center of the University of Valencia (UV) and the Spanish Council for Research (CSIC). The Polytechnic University of Valencia (UPV). University of Santiago de Compostela (US). Autonomic University of Madrid (UAM); and University of Zaragoza (UZ).

The leading groups participating in this coordinated project form the core of the collaboration. The spokesperson (and PI of this coordinated project), the technical coordinator, the software coordinator and the leaders of several working packages are members of IFIC. The coordinators of the electronics, DAQ, and risk management are members of the UPV. The coordinator of calibration and reconstruction is a member of US. The groups participating in this coordinated project invest 100 % of their research time and resources in the NEXT project. The other national groups participating in NEXT (UZ and UAM) share their dedication between NEXT and other projects, and have/will present independent grant proposals.

The IFIC, UPV, UV and US groups work in a fully co-ordinated way. The NEXT collaboration is organised in terms of Working Packages (WP) which include members of the different groups. In addition of the WP structure, a general “hardware coordination meeting” and a “software coordination meeting” which involves members of all the groups is organised on a weekly-basis. Last, but not least, the coordination of the groups is essential to construct, commission and operate the NEW and NEXT-100 detectors at the LSC. The management of the laboratory and its Scientific Committee (SC), require a formal Project Management Plan (PMP) from the NEXT collaboration, and reviews its progress every six months. The PMP integrates the activities of all the collaboration groups and in particular of the groups participating in this project.

Furthermore, a strong collaboration is currently being formed between IFIC and the Center for Pulsed Lasers, to develop the laser technology which could be used to tag the barium ion emitted in the $\beta\beta$ decays, resulting (when combined with the excellent energy resolution of NEXT and its topological signature) in a virtually background-free experiment. We are in the process of preparing a “white paper” detailing the theoretical grounds and the experimental procedures to address a successful BATA program.

c.2. PROPUESTA CIENTÍFICA/SCIENTIFIC PROPOSAL

Introduction

Neutrinos, unlike the other fermions of the Standard Model of particle physics, could be Majorana particles, that is, indistinguishable from their antiparticles. The existence of Majorana neutrinos would have profound implications in particle physics and cosmology.

If neutrinos are Majorana particles, there must exist a new scale of physics (at a level inversely proportional to the neutrino masses) that characterises underlying dynamics beyond the Standard Model. The existence of such a new scale provides the simplest explanation of why neutrino masses are so much lighter than the charged fermions. Indeed, understanding the new physics that underlies neutrino masses is one of the most important open questions in particle physics, and it could have profound implications in our comprehension of the mechanism of symmetry breaking, the origin of mass and the flavor problem.

The existence of Majorana neutrinos would imply that lepton number is not conserved, which could be the origin of the matter-antimatter asymmetry observed in the Universe. The new physics related to neutrino masses could provide a new mechanism to generate the asymmetry called leptogenesis. Although the predictions are model dependent, two essential ingredients must be confirmed experimentally: 1) the violation of lepton number and 2) CP violation in the lepton sector.

The only practical way to establish experimentally that neutrinos are their own antiparticles and that lepton number is not conserved is the detection of neutrinoless double beta decay ($\beta\beta 0\nu$). This is a hypothetical, very slow nuclear transition in which a nucleus with Z protons decays into a nucleus

with $Z + 2$ protons and the same mass number A , emitting two electrons that carry essentially all the energy released ($Q_{\beta\beta}$). The process can occur if and only if neutrinos are Majorana particles.

The experimental landscape

The detectors used in double beta decay searches are designed to measure the energy of the radiation emitted by a $\beta\beta$ source. In the case of $\beta\beta 0\nu$, the sum of the kinetic energies of the two released electrons is fixed by the mass difference between the parent and the daughter nuclei: $Q_{\beta\beta} \equiv M(Z, A) - M(Z+2, A)$. However, due to the finite energy resolution of any detector, $\beta\beta 0\nu$ events are reconstructed within an energy region centered around $Q_{\beta\beta}$, typically following a gaussian distribution (Region of Interest or ROI). Other processes occurring in the detector can fall in the ROI, becoming a background and compromising drastically the expected sensitivity. It follows that $\beta\beta 0\nu$ experiments require **excellent energy resolution**, and indeed the field was traditionally dominated by germanium calorimeters, devices with superb resolution.

All double beta decay experiments have to deal with an intrinsic background, the $\beta\beta 2\nu$, the standard process of a double β -decay with the emission of two neutrinos, that can only be suppressed by means of good energy resolution. Backgrounds of cosmogenic origin force the **underground operation of the detectors**. Natural radioactivity emanating from the detector materials and surroundings can easily overwhelm the signal peak, and hence **careful selection of radiopure materials is also essential**. **Additional experimental signatures** that allow the distinction between signal and background are certainly a bonus, and this has been in the last few years an important line of work to increase the sensitivity of $\beta\beta 0\nu$ detectors. Several other factors such as **detection efficiency** or the **scalability to large masses** must be also taken into account during the design of a double beta decay experiment.

Recent results

The status of the field has been reviewed recently by the PI¹. Three new-generation experiments, with fiducial masses in the range of the 100 kg, have recently published the results of their searches for $\beta\beta 0\nu$ processes. These are: GERDA, a high resolution calorimeter based in Ge-76 diodes; KamLAND-Zen, a low resolution, high-mass, self-shielding liquid scintillator calorimeter, with xenon dissolved in the scintillator; and EXO-200, a liquid xenon (LXe) TPC. All the experiments published negative results and therefore a limit in the period of $\beta\beta 0\nu$ processes, $T_{1/2}^{0\nu}$. This limit can be translated into a limit in the *effective Majorana mass* of the electron neutrino defined as:

$$m_{\beta\beta} = \left| \sum_i U_{ei}^2 m_i \right|, \quad (1)$$

where m_i are the neutrino mass eigenstates and U_{ei} are elements of the neutrino mixing matrix. $m_{\beta\beta}$ is related to the period through the equation:

$$(T_{1/2}^{0\nu})^{-1} = G^{0\nu} |M^{0\nu}|^2 m_{\beta\beta}^2. \quad (2)$$

Here, $G^{0\nu}$ is an exactly-calculable phase-space integral for the emission of two electrons and $M^{0\nu}$ is the nuclear matrix element (NME) of the transition, which has to be evaluated theoretically. The uncertainty in the NME affects the value of $m_{\beta\beta}$ which can be obtained from $T_{1/2}^{0\nu}$.

GERDA has a resolution of $\sim 0.2\%$ FWHM around the $Q_{\beta\beta}$ of ^{76}Ge . The specific background rate in the ROI is 10^{-2} counts/(keV · kg · y) and the total exposure deployed $21.6 \text{ kg} \times \text{yr}$. The experiment sets a limit $T_{1/2}^{0\nu} > 2 \times 10^{25} \text{ yr}$, which translates in a range for $m_{\beta\beta}$ of [258 – 649] mili electron volts (meV). The lowest value of $m_{\beta\beta}$ corresponds to the IBM2 NME set, while the highest value corresponds to the ISM set.

EXO achieves an energy resolution of 3.6% FWHM at $Q_{\beta\beta}$, and a background rate of 4.0×10^{-3} counts/(keV · kg · y). The total exposure used for the published result is $100 \text{ kg} \cdot \text{yr}$. They have published a limit on the half-life of $\beta\beta 0\nu$ in ^{136}Xe of $T_{1/2}^{0\nu}(^{136}\text{Xe}) > 2 \times 10^{25} \text{ yr}$ (assuming background only). The limit translates into a range for $m_{\beta\beta}$ of [125 – 352] meV.

KamLAND-Zen compensates a worse energy resolution of 10% FWHM at $Q_{\beta\beta}$ with a very small background rate of $\sim 4 \times 10^{-4}$ counts/(keV · kg · y). After an exposure of $108.8 \text{ kg} \cdot \text{yr}$, they obtain a limit $T_{1/2}^{0\nu}(^{136}\text{Xe}) > 2.6 \times 10^{25} \text{ yr}$, which translates into a range for $m_{\beta\beta}$ of [110 – 309] meV.

¹St. Andrews lectures

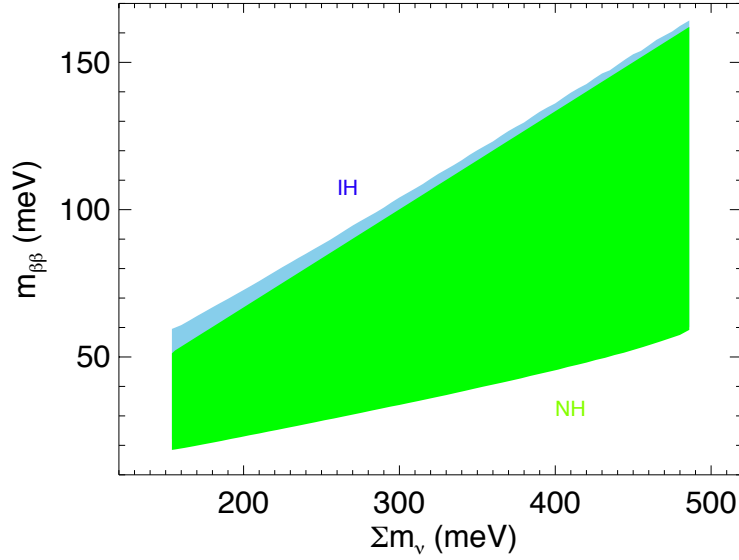


Figura 1: The allowed $m_{\beta\beta}$ region, as a function of the sum of the neutrino masses, assuming that $\sum m_i = 0,32$ eV.

Potencial for discovery

Several analysis from recent cosmological results suggest that the sum of the masses of the three neutrinos could be ~ 0.3 eV². The PI and collaborators have demonstrated that, in this case, if the neutrino is a Majorana particle, then, $m_{\beta\beta} \sim [20 - 150]$ meV³, as shown in Figure ?? . In this scenario, the sensitivity of GERDA is outside the region “cosmologically relevant region” (CRR), while both EXO-200 and KamLAND-Zen would have already explored a significant fraction of CRR *for the most optimistic NME set* (while they would be outside CRR for the most pessimistic).

Clearly, the experimental effort to determine if the neutrino is a Majorana particle, far from being completed is, rather, in its infancy. To establish unambiguously that the neutrino is (or not) a Majorana particle, even in this favourable scenario in which the sum of the neutrino masses is relatively high, experiments must be sensitive to $m_{\beta\beta} \sim 20$ meV, *even for the most pessimistic NME set*. On the other hand, a xenon experiment probing a $T_{1/2}^{0\nu} > 2,6 \times 10^{25}$ yr, has chances of making a discovery.

The NEXT experiment and its innovative concepts

The *Neutrino Experiment with a Xenon TPC* (NEXT)⁴ will search for $\beta\beta 0\nu$ in ¹³⁶Xe using high-pressure xenon gas time projection chambers (HPXe). The advantages of the technology are: a) **excellent energy resolution**, with an intrinsic limit of about 0.3 % FWHM at $Q_{\beta\beta}$, close to that of ⁷⁶Ge detectors; b) **tracking capabilities** that provide a powerful topological signature to discriminate between signal (two electron tracks with a common vertex) and background (mostly, single electrons); c) **a fully active and homogeneous detector**, with no dead regions; d) **scalability** of the technique to larger masses; e) the possibility of exciting the barium ion produced in the xenon decay from the fundamental state $^2S_{1/2}$ to the state $^2P_{1/2}$, using a “blue” laser (493.54 nm), and observing the “red light” emitted in the transition from $^2P_{1/2}$ to $^2D_{3/2}$, thus “tagging” the presence of a barium atom in the xenon gas, which cannot be produced by any known background.

The design of the NEXT chambers is optimised for energy resolution by using proportional electroluminescent (EL) amplification of the ionisation signal. The detection process involves using the prompt scintillation light from the gas as start-of-event time, drifting the ionisation charge to the anode by means of an electric field ($\sim 0,3$ kV/cm at 15 bar) where secondary EL scintillation will be produced in the region defined by two highly transparent meshes, between which there is a field of ~ 20 kV/cm at 15 bar. The detection of EL light provides an energy measurement (in the energy plane,

²Phys. Rev. Lett. 112, 051303 (2014)

³JCAP 1303 (2013) 043

⁴<http://next.ific.uv.es/>

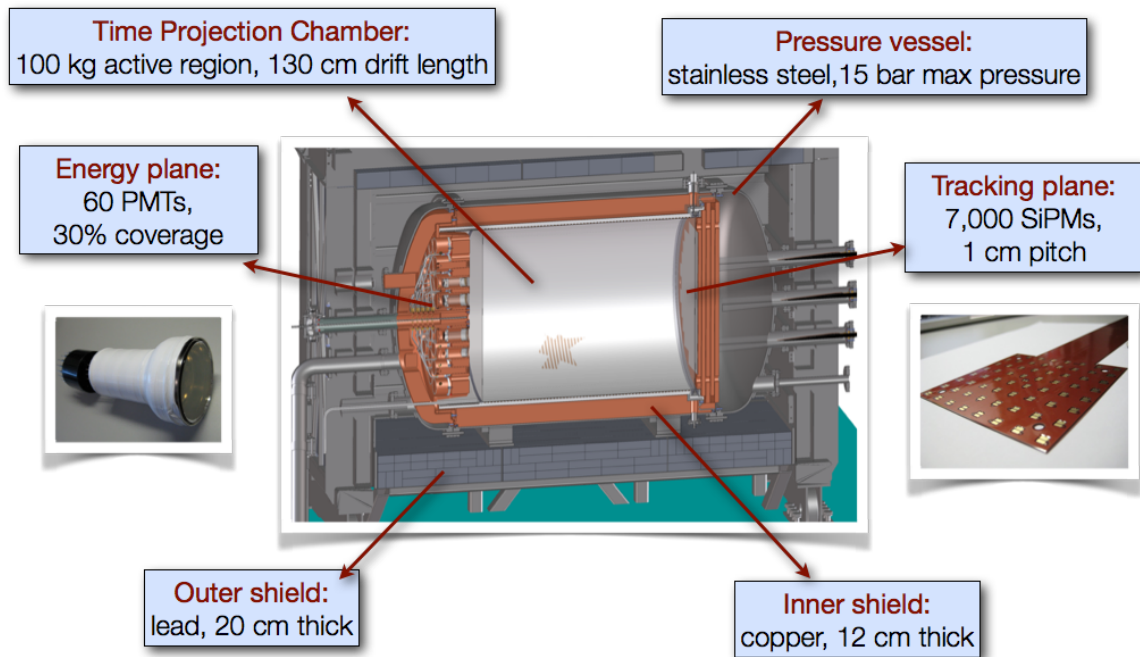


Figura 2: A drawing of the NEXT-100 detector showing its main parts.

made of PMTs, located behind the cathode) as well as providing tracking through its detection a few mm away from production at the anode plane, via a dense array (1 cm pitch) of 1-mm² SiPMs (the *tracking plane*).

The design of the NEXT-100 detector (Figure ??) has been described in a *Technical Design Report*.⁵ NEXT-100 has the structure of a Matryoshka (a russian nesting doll). The outermost layer is a shield made of lead, which attenuates the background from the LSC rock by 6 orders of magnitude (e.g., the ²⁰⁸Tl photons are attenuated from $\sim 10^{12}$ per year to $\sim 10^6$ per year). The pressure vessel, built out of steel, can hold 150 kg of xenon at 15 bar. Finally, an inner copper shield, 12 cm thick, constitutes the innermost and more radio-clean layer of the Matryoshka. In addition, all NEXT components have been selected and screened for low background. Of particular importance are the PMTs, whose activity is only 0.4 mBq of ²¹⁴Bi and 0.3 mBq of ²⁰⁸Tl per unit. Our TDR included a detailed background model. A recent paper has validated these results from measurements in a extensive screening campaign carried out in the past year.⁶ Currently, most of the major components entering the NEXT detector have been measured, and those numbers are incorporated in our background model.

NEXT prototypes

From 2009 to 2013 the NEXT Collaboration has carried out an intense R&D program that has culminated in the construction, commissioning and operation of the NEXT-DEMO prototype located at IFIC, and the NEXT-DBDM prototype operating at LBNL. The description of these prototypes and the initial results obtained with them have recently been published⁷.

NEXT-DEMO, shown in figure ??, is as a large-scale prototype of NEXT-100. The pressure vessel has a length of 60 cm and a diameter of 30 cm. The vessel can withstand a pressure of up to 15 bar. The maximum capacity of the detector is 10 kg but in its current configuration (the fiducial volume is an hexagon of 16 cm diameter and 30 cm length) it holds 4 kg at 15 bar. NEXT-DEMO is equipped with an energy plane made of 19 Hamamatsu R7378A PMTs and a tracking plane made of 300 Hamamatsu MPPCs.

The detector has been operating successfully for more than one year and has demonstrated: (a) very good operational stability, with no leaks and very few sparks; (b) good energy resolution ; (c) track reconstruction with PMTs and with SiPMs coated with TPB; (d) excellent electron drift lifetime, of the order of 20 ms. In summary, the operation of NEXT-DEMO has been instrumental in the development

⁵ Alvarez:2012haa.

⁶ Alvarez:2012as.

⁷ Alvarez:2012hh; Alvarez:2012nd; Alvarez:2012hu.

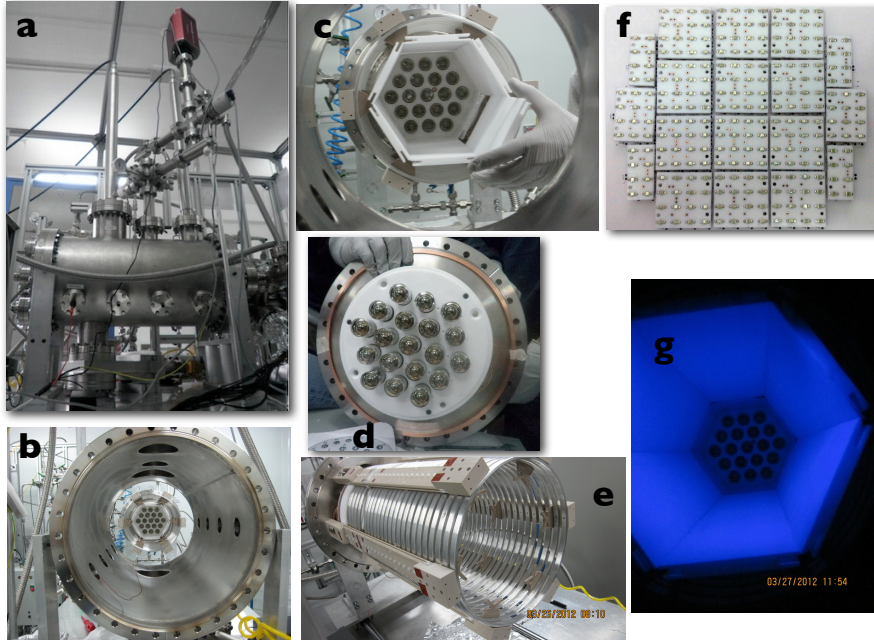


Figura 3: The NEXT-DEMO prototype. (a) The pressure vessel, showing the HVFT and the mass spectrometer; (b) an expanded view of the detector; (c) Teflon light tube; (d) energy plane, made of pressure resistant Hamamatsu R7378A PMTs; (e) field cage; (f) tracking plane equipped with 300 Hamamatsu MPPCs; (g) Light tube coated with TPB, reflecting UV light in blue.

of the required knowledge to design and build the NEXT detector.

The NEXT-DBDM prototype is a smaller chamber, with only 8 cm drift, but an aspect ratio (ratio diameter to length) similar to the NEXT detector. The device has been used to perform detailed energy resolution studies. NEXT-DBDM achieves a resolution of 1 % FWHM at 660 keV and 15 bar, which extrapolates to 0.5 % at $Q_{\beta\beta}$.

Topological signature

Double beta decay events leave a distinctive topological signature in HPXe: a continuous track with larger energy depositions (*blobs*) at both ends due to the Bragg-like peaks in the dE/dx of the stopping electrons (figure ??, topleft). In contrast, background electrons are produced by Compton or photoelectric interactions, and are characterised by a single blob and, often, by a satellite cluster corresponding to the emission of ~ 30 -keV fluorescence x-rays by xenon (figure ??, bottonleft). Reconstruction of this topology using the tracking plane provides a powerful means of background rejection, as can be observed in the figure. In our TDR we chose a conservative cut to separate double-blob from single-blob events which provided a suppression factor of 20 for the background while keeping 80 % of the signal.

Energy resolution

Figure ?? shows the resolution obtained with the NEXT-DBDM apparatus. A resolution of 1 % FWHM with 662 keV photons, has been measured, which extrapolates to 0.5 % FWHM at $Q_{\beta\beta}$. This result is not far from the expected limit obtained adding in quadrature the different factors that contribute to the resolution (Fano factor, photoelectron statistics and electronic noise). The resolution measured in NEXT-DEMO extrapolates to 0.7 % FWHM. The difference between both prototypes is due to better photoelectron statistics and aspect ratio in DBDM. The results, are, in any case, better than the target of 1 % FWHM described in the TDR.

The status of the NEXT experiment and the results achieved by the prototypes have been described in a recent paper ⁸

⁸Present status and future perspectives of the NEXT experiment, NEXT Collaboration (J.J. Gomez-Cadenas et al.), DOI: 10.1155/2014/907067. arXiv:1307.3914

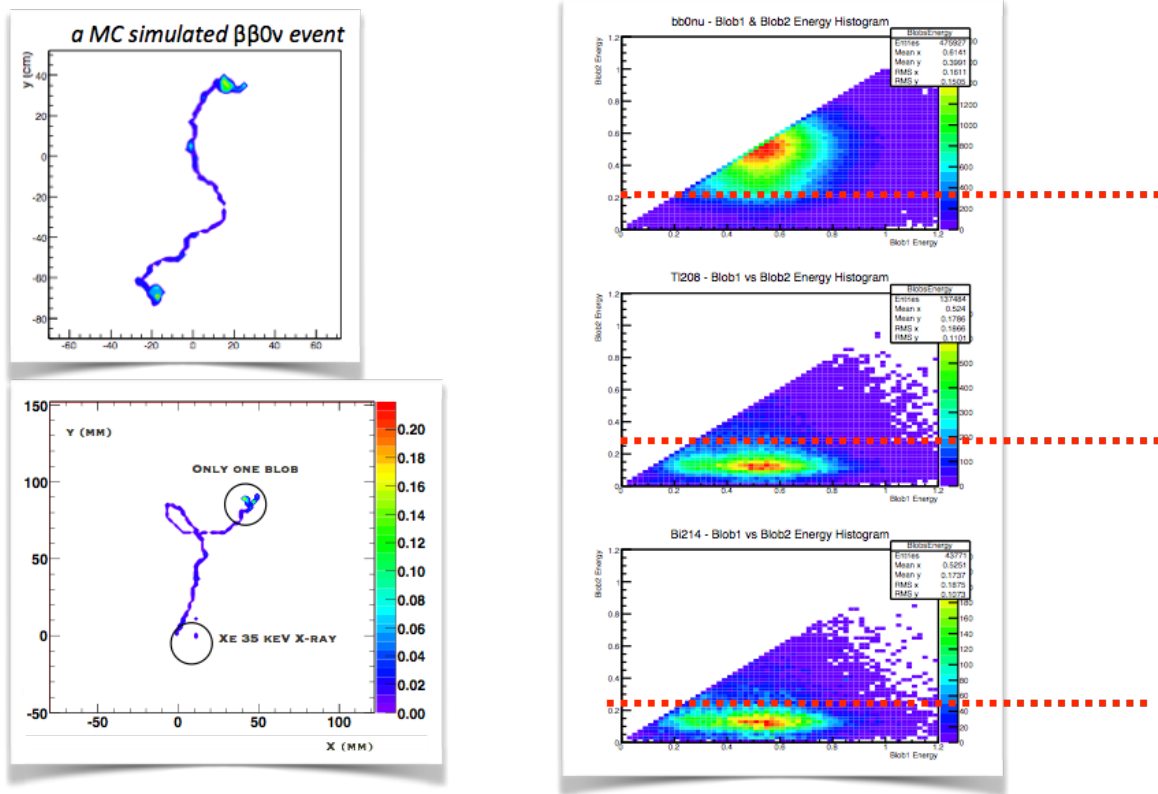


Figura 4: NEXT has a topological signature, not available in most $\beta\beta\nu$ detectors. The panel shows the reconstruction of a Monte Carlo signal (left) and background (right) event. The signal has two electrons (two blobs). The background has only one electron (one blob) and the associated emission of a 35 keV X-ray. The color codes energy deposition in the TPC. An scatter plot of the energy of the two blobs shows a clear separation between signal and background regions.

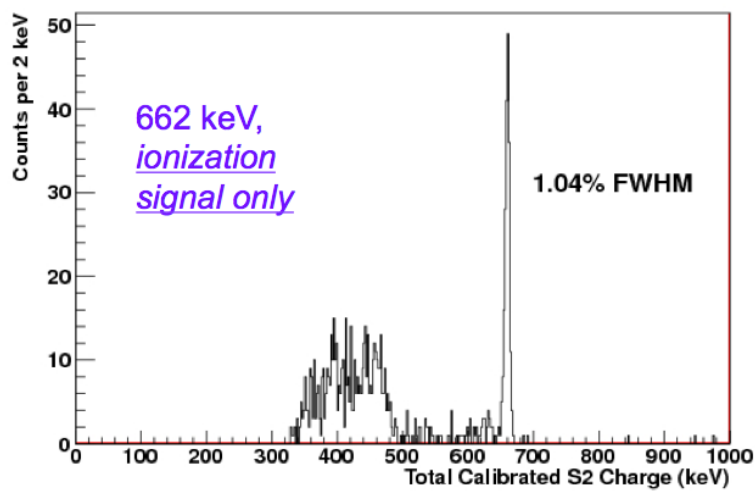


Figura 5: The resolution of the photo peak for 662 keV electrons in NEXT-DBDM, at 15 bar is 1 % FWHM (0.5 % FWHM at $Q_{\beta\beta}$).

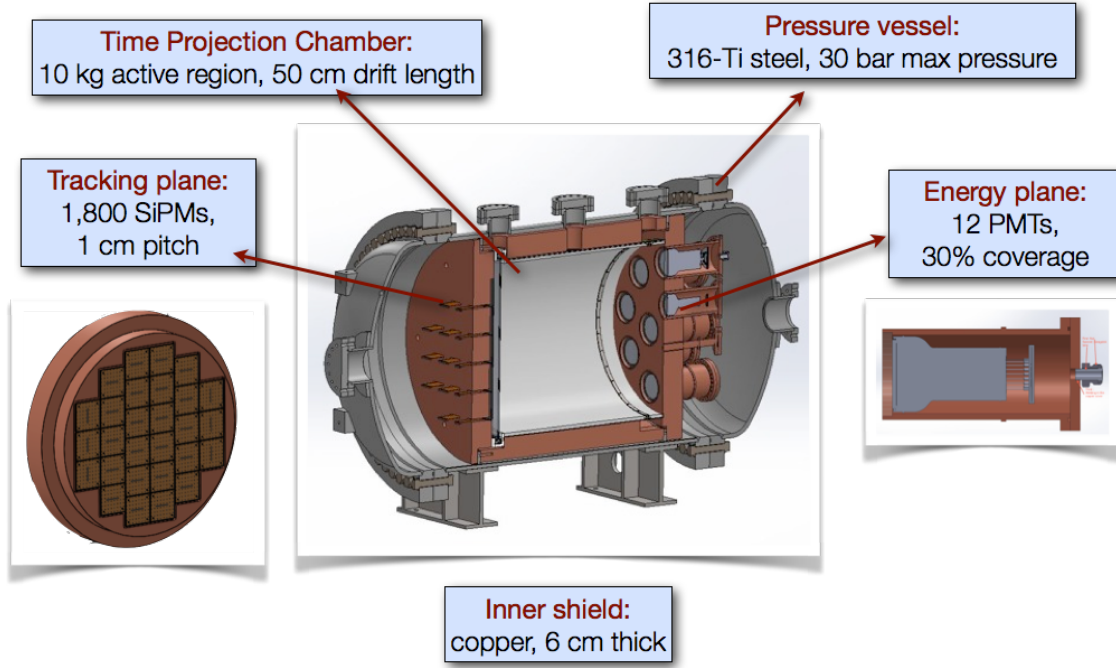


Figura 6: The NEW apparatus.

The NEW detector

The NEW (NEXT-WHITE) apparatus⁹, shown in Figure ?? is the first NEXT detector to operate underground. NEW has a triple goal:

1. **Technology:** it will validate the technological solutions adopted by NEXT-100.
2. **Radiopurity:** it will allow the NEXT collaboration an extra step in the implementation of a radiopure detector.
3. **Physics:** it will demonstrate with measurements of the ^{214}Bi and ^{208}Tl lines, as well as with the measurement of the $\beta\beta 2\nu$ spectrum, the physics capabilities of NEXT-100.

NEW is a scale 1:2 in size (1:8 in mass) of NEXT-100. The energy plane contains 12 radio pure PMTs of 3 inches diameter, isolated from the gas inside vacuum-tight copper enclosures (we refer to these as PMT cans). The tracking plane technology consists of 30 Kapton Dice Boards (KDB) deploying 1800 SiPMs. The field cage has a diameter of 50 cm and a length of 60 cm.

The NEXT background model is currently based on a sophisticated Monte Carlo simulation of all expected background sources in each part of the detector. NEW will allow the validation of the background model with the data themselves. Furthermore, it will allow us to identify and correct any possible hot spots, which can only be identified with operating experience.

Furthermore, the calibration of NEW with sources of higher energy, will allow a precise study of the evolution of the resolution with the energy. In particular it will be plausible to measure the resolution near $Q_{\beta\beta}$ using a Thorium source, which provides 2.6 MeV gammas. Last, but not least, we intend to reconstruct the spectrum of $\beta\beta 2\nu$. Those events are topologically identical to signal events ($\beta\beta 0\nu$) and can be used to demonstrate with data the power of the topological signature.

Discovery potential of NEXT-100

The excellent resolution of NEXT (0.5-0.7 % FWHM) and the combination of low radioactive budget and topological signature (which yields an expected background rate of $5 \times 10^{-4} \text{ counts}/(\text{keV} \cdot \text{kg} \cdot \text{y})$), will allow the NEXT-100 detector to reach a sensitivity on the $\beta\beta 0\nu$ period of $T_{1/2}^{0\nu} > 7 \times 10^{25} \text{ yr}$ for a exposition of $300 \text{ kg} \times \text{yr}$. This translates in a range for $m_{\beta\beta}$ of $[67 - 187] \text{ meV}$. Therefore NEXT-100 will have a substantial chance of making a discovery if the NME is sufficiently high.

⁹The name honours the memory of Professor James White, recently deceased and one of the key scientists of the NEXT Collaboration.

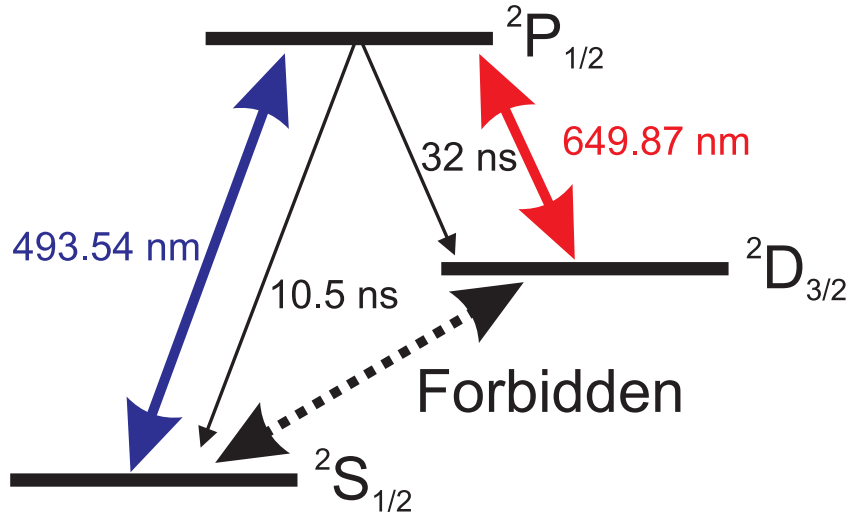


Figura 7: The BATA concept.

Towards a ton-scale high-pressure xenon TPC. BEXT

If no discovery is made by the current generation of experiments, the full exploration of the CRR region (corresponding to the inverse hierarchy of neutrino masses) requires detectors of larger mass (at least 1 ton), good resolution and extremely low specific background. The HPXE technology has the potential to provide the most sensitive detector in the ton scale, by scaling the detector to a mass in the range of the ton and adding additional handles to further suppress the background.

One of the most promising possibilities is to develop the technology to unambiguously tag the barium ion produced in the xenon decay, $Xe \rightarrow Ba^{++} + 2e$. The conceptual idea to tag Ba^+ is illustrated in Figure ???. A “blue” laser of wavelength 493.54 nm excites (“pumps”) the S state, inducing $S \rightarrow P$ transitions, with a lifetime of ~ 10 ns. About 30 % of the times the $^2P_{1/2}$ states decay to the state $^2D_{3/2}$, emitting “red” (649.86 nm) fluorescence in a characteristic time of 30 ns. The state $^2D_{3/2}$ is metastable, but a second laser of suitable wavelength (2051.66 nm) can be used to induce the transition to the ground state (this is known as “deshelving”). The whole cycle takes less than 50 ns, and therefore several millions of red fluorescence photons can be emitted by a single ion.

Of course, the practical application of this beautiful conceptual idea is by no means easy, and in fact, it has been shown to be extremely difficult in liquid xenon by the work of the EXO collaboration. However, it may be feasible in an HPXE detector, where a number of fortunate conditions may occur. These conditions are: a) charge reduction of the emitted barium ion, from Ba^{++} to Ba^+ , which can be induced by collisions with xenon atoms, or by the addition of a suitable quencher, such as TEA, as demonstrated by Sinclair et al¹⁰, b) “trapping” of the barium ion “in situ” by the surrounding Xe atoms, which result in a very low drift velocity for the ion; c) location of the ion, done by reconstructing the event vertex.

All the above needs to be demonstrated with a systematic R&D program, which must also address many other experimental issues such as pressure broadening of the laser, filtering of Rayleigh scattering, etcétera. Most importantly, such an experimental program must be carried out by an interdisciplinary group, combining the experience in laser spectroscopy and atomic physics, with the experience in HPXE instrumentation.

The on-going collaboration between the IFIC (and other groups of NEXT) and the Center for Pulsed Lasers (CLPU)¹¹, a national facility dedicated to ultra-intense lasers research and development has made possible to create precisely the interdisciplinary team needed for a successful R&D program, which can culminate in a “Barium-tagging Experiment with a Xenon TPC” (BEXT). We are currently preparing a white paper which describes the theoretical grounds and details the experimental program to be developed¹².

A future detector of 1 ton mass, with a resolution of 0.5 % FWHM and a background rate in the range of 10^{-6} counts/(keV · kg · y) (thanks to the implementation of barium-tagging) would be able

¹⁰Sinclair.

¹¹<http://www.clpu.es>

¹²To be found here

to fully cover the CRR (inverted hierarchy) region in less than 5 years run, assuming a favourable scenario for the NME. Even the most pessimist scenario could be fully explored, however, with a longer run, since the sensitivity to period increases in this case (virtually background free experiment) linearly with exposure.

Clearly the construction of a ton-scale HPXe detector implementing a full BATA technology is a very challenging enterprise. On the other hand, we believe that the incremental approach devised by the NEXT collaboration will also work in this case. The construction of the NEW detector is progressing without significant problems thanks to the expertise and know-how gained during DEMO phase, and we expect that NEXT-100 will fully benefit from the experience gained with NEW. Similarly, the BATA technology could be ready in a period of 5-7 years, by approaching the problem step by step.

To conclude, we have shown that the NEXT-100 detector, which we aim to construct, commission and operate during the next few years has a significant potential of making a major discovery. We have also shown that the HPXe technology with BATA included may be the most promising experimental path to find out if the neutrino is its own antiparticle.

ANTECEDENTES/PREVIOUS WORK

This research project is the continuation of the CONSOLIDER-INGENIO project CUP (2010-2014), and the SIEID project FIS-XXX— (2012-2014). During the period 2015-2018 in which this project, if granted, will be active, the AdG/ERC granted to the PI will also be active.

To assess the achievements of the collaboration so far it is useful to review the historical development of the project. The largest HPXe chamber ever operated in the world before NEXT was the so-called St. Gotthard TPC **Luscher:1998sd**. It had a total mass of 5 kg of xenon, and was, therefore, of a similar size as our NEXT-DEMO prototype, although it operated at a considerably lower pressure (5 bar). Furthermore, the St. Gotthard TPC amplified the ionisation charge —needed to measure the event energy— with a plane of wires at high voltage. This classical technology, the only one mature enough in the mid 90's, when the experiment operated, required the addition of a quencher (CH_4) to the xenon, to avoid sparks. Unfortunately, the methane destroyed the scintillation signal in xenon, with two undesirable consequences: a) the possibility to measure the start-of-the-event or t_0 , defined by the prompt scintillation signal was lost; and b) the measurement of the energy resolution degraded. The energy resolution of the St. Gotthard TPC was 7 % at $Q_{\beta\beta}$ and the background was dominated by events coming from the detector walls that could not be vetoed due to the lack of t_0 . The (relatively) poor results obtained with this early experiment, prompted the EXO experiment to choose liquid xenon and abandon the HPXe technology. However, a LXe TPC has mediocre resolution, due to abnormal partition between scintillation and ionisation in the liquid phase (EXO-200 measures 3.6 % FWHM at $Q_{\beta\beta}$) and the topological signature of the event (the track of the two electrons) is also lost due to the high density of the liquid.

The first problem that the NEXT project faced was to develop the technology to build high-pressure, radio-pure xenon chambers. High-pressure implies also moderately high-vacuum, needed for gas purity. The technology did not exist in Spain, and was rather underdeveloped elsewhere. All the HPXe detectors built prior to 2009 (except for the St. Gotthard TPC) were small objects, typically holding a few hundred grams of gas at moderately low pressures. Radiopure copper, as in the St. Gotthard TPC, could not be used to build the pressure vessel, since the NEXT-100 detector was much larger and had to hold much higher pressures. It was necessary, therefore, to find a radiopure solution for the pressure vessel, either in steel or in titanium (an alloy of steel and titanium was chosen at the end). Furthermore, it was necessary to develop a way to read the ionisation signal without killing the scintillating signal (i.e. without using quenchers) and without degrading the excellent intrinsic resolution available in the gas.

The construction of the NEXT-100 detector faced, therefore, a large number of challenges. From the instrumental point of view, it was necessary:

1. *To acquire the technology.* This required equipping state-of-the-art laboratories, hiring specialised personnel and building prototypes.
2. *To study technological solutions, in order to read the ionisation and scintillation signals.* A number of possibilities were, a priori, available. In particular, the ionisation charge could be transformed in secondary VUV light and be read with optical sensors (the EL solution), or amplified with

micro-pattern devices (the micromegas or MM solution). Within the EL solution, there was the choice of using photomultipliers (PMTs) and multi-pixel (SiPMs) devices or avalanche photo diodes (APDs).

Coupled with those instrumental challenges, the collaboration had to attack major mechanical engineering problems:

1. *Design and build a radiopure pressure vessel*, capable of holding at least 100 kg of xenon and capable of withstanding up to 15 bar with negligible losses (less than 1 gram a year).
2. *Design and build a radiopure energy plane*, capable of protecting the PMTs inside the pressure vessel.
3. *Design and build a radiopure tracking plane*, including large custom feedthroughs, needed to extract the signals of ~ 8000 SiPMs from the pressure vessel.
4. *Design and build a state-of-the-art gas system*, capable of guaranteeing gas purity via continuous recirculation in a hermetic loop. The gas system had to guarantee redundancy and safety to minimise to negligible level the chances of losing any substantial amount of enriched xenon gas.
5. *Design and build the shielding of the detector*, choosing between several possible solutions (e.g., a water tank or a lead castle).
6. *Design and build the infrastructures* to hold the apparatus (working platform, seismic pedestal).

Finally, one had to provide solutions for the electronics of the PMTs and the SiPMs, the DAQ and the software.

In the years 2010-2013, the various problems were attacked in a systematic way: a brief summary can be jotted down as follows:

1. *Learning R&D period (2010)*, needed to acquire the very innovative technology the detector is based on, and to equip state-of-the-art laboratories in some of our participating institutions. This phase of the project resulted in the construction of several prototypes, including NEXT-DEMO, capable of holding up to 4 kg of gas (thus, the same mass than the St. Gotthard TPC, and much higher pressure). DEMO has been operating continuously at IFIC for more than two years, demonstrating, in addition to its excellent performance the stability of the technology.
2. *Selection R&D period (2011)*, targeted to choose among the various technological solutions candidate to be implemented in NEXT-100. This period culminated in June of 2011 with the presentation of a Conceptual Design Report (CDR), where the NEXT detector was defined as an electroluminescent HPXe TPC equipped with photomultipliers (PMTs), to read the event energy and multipixel proportional counters (MPPCs also called SiPMs), to reconstruct the event topology.
3. *R&D targeted to produce a Technical Design Report (TDR)*, which defined the actual detector to be built. The TDR was presented in February 2012 and in final version in May 2012. The TDR defined solutions for the instrumentation, mechanical design of detector and infrastructures, electronics, DAQ and software, as well as the detector background model.
4. *Demonstration of performance*: during 2012 and 2013, the results of the prototypes were analysed and published, showing the excellent performance (energy resolution, electron reconstruction) of the apparatus, as well as the robustness of the EL technology ¹³.

The proposal of the PI to the AdG/ERC was granted in 2013, after the successful completion of the R&D phase. The objectives described in the proposal were:

1. Validate the critical subsystems of the NEXT-100 detector both from the point of view of the technology and the radiopurity (NEW detector, to be operated in 2015).

¹³<http://next.ific.uv.es/next/talks.html>

2. Assemble the NEXT-100 detector (2016).
3. Commission the NEXT-100 detector (2017).
4. Search for $\beta\beta 0\nu$ events with the NEXT-100 detector (2018 and beyond).
5. Carry out, in parallel with the physics run of the improved NEXT detector R&D targeted to address the scalability of the detector to one ton (the R&D focuses currently in the BATA program).

The overall goals proposed in this co-ordinated project are the same. Indeed, as noted in the AdG proposal, while the NEW detector construction, commissioning and operation can be fully covered by the AdG grant, NEXT-100 requires additional funding for equipment and personnel (see below for a detailed description).

OBJETIVOS

RETO: INNOVACIÓN EN CIENCIA Y TECNOLOGÍA (RETO 6)

OBJETIVOS SUBPROYECTOS

METODOLOGÍA

INFRAESTRUCTURAS Y EQUIPOS

CRONOGRAMA

PERSONAL

c.3. IMPACTO ESPERADO DE LOS RESULTADOS/EXPECTED IMPACT

c.4. CAPACIDAD FORMATIVA DEL EQUIPO/TRAINING CAPABILITIES OF THE GROUP

c.5. IMPLICACIONES ÉTICAS Y/O DE BIOSEGURIDAD/ETHICS AND SAFETY IMPLICATIONS