3rd Colombian Meeting on High Energy Physics (COMHEP III)
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Status of the NEXT-White neutrinoless double beta decay experiment

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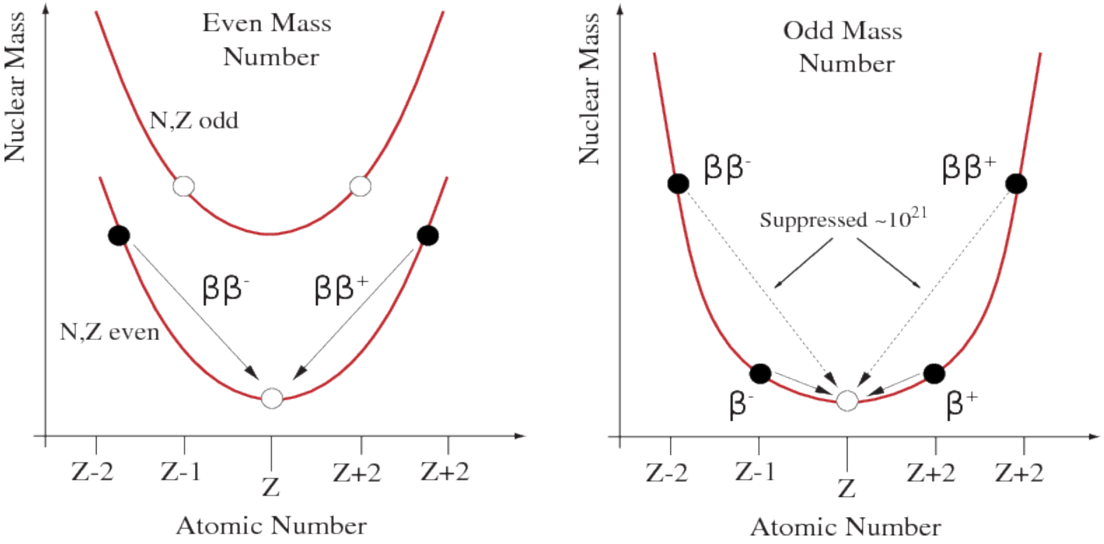
on belhaf of the NEXT collaboration

Outline

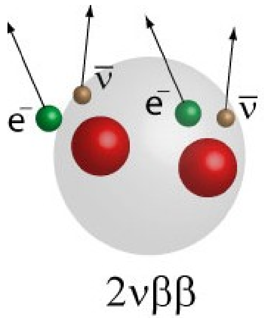
1) Double beta decay and neutrinoless double beta decay
2) … measuring a 0νββ decay
3) NEXT concept
4) Kr calibrations results.

Double beta decay

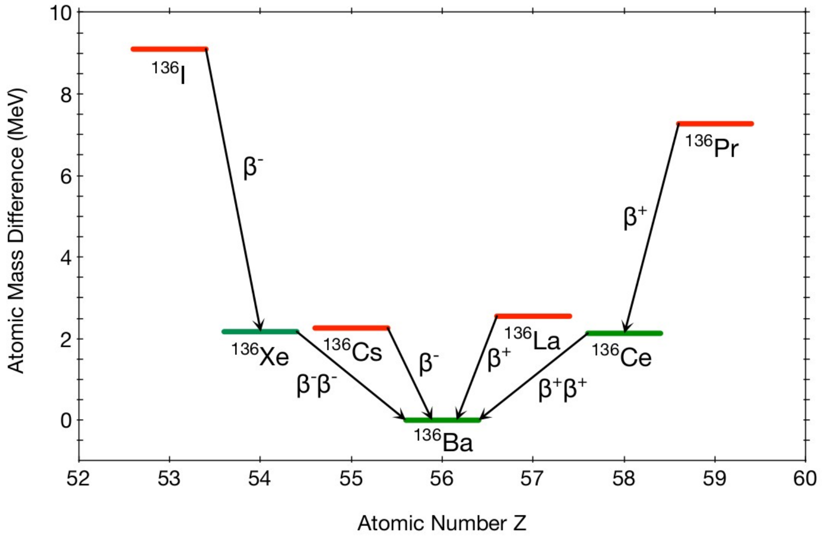


From S. Dell'Oro et al., arXiv:1601.07512

$$(A,Z) \longrightarrow (A,Z+2) + 2e^{-} + 2\nu_e$$

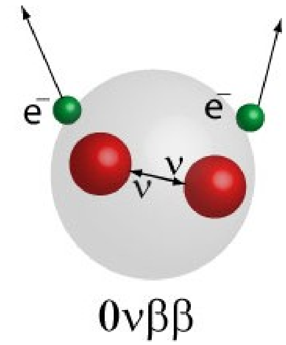


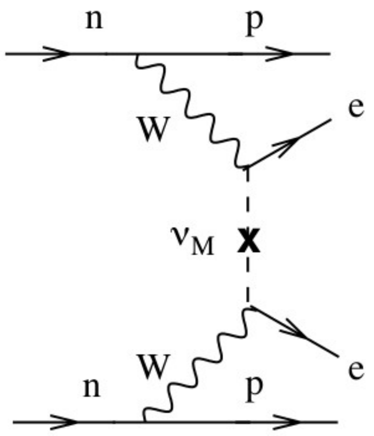
Maria Goeppert-Mayer proposed double beta decay in 1935.



- First direct observation was made using ^{83}Se in 1987.
- Typical lifetimes of the order of 10^{18} – 10^{21} years.
- This decay is only possible if the Z+2 nucleus is stronger bound than Z nucleus.
- β decay to the Z + 1 must be either energetically forbidden or highly suppressed.

Neutrinoless double beta decay





- 0νββ decay: a hypothetical process
- Proposed by W. Furry in 1939
- $m_\nu \neq 0$
- Lepton number violation
- $m_{\beta\beta}$ can be inferred from 0νββ measurements.

In 1937, Ettore Majorana predicted that some class of fermions could be their own antiparticle.

Assuming the exchange of a light Majorana ν :

$$\left(T^{0\nu}_{1/2}\right)^{-1} = G^{0\nu}\,\left|M^{0\nu}\right|^2 \left(\frac{m_{\beta\beta}}{m_e}\right)^2$$

Half-life

Phase space integral

Nuclear matrix element

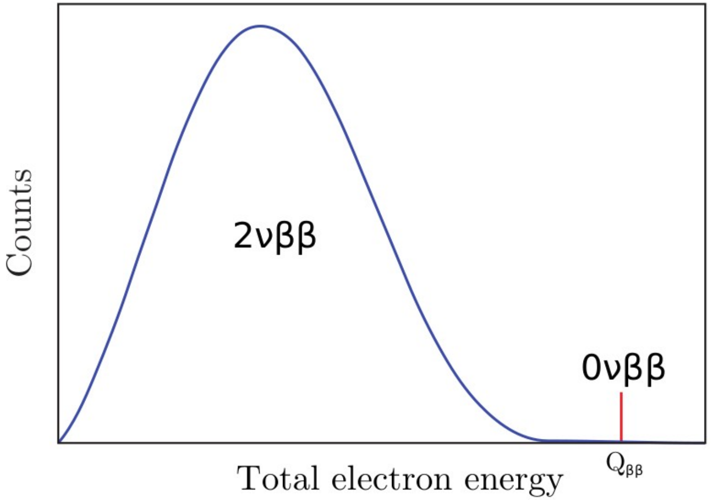
$$m_{\beta\beta} \equiv \left|\sum_i U^2_{ei}\, m_i\right|$$

Effective Majorana mass

Considerations for a 0νββ experiment (1/3)

0νββ signature ...

- Searches for a 0νββ signal rely on the measurement of sum kinetic energy of the two emitted electrons.
- It is expected to observe a mono-energetic peak at the Q-value of the transition between Z and Z+2 nucleus.
- Despite this very clear signature, the detection of the 2e is complicated by the presence of background events in the large mass (enriched material is a necessary condition).
- Topology of decay electrons can be taken as an extra signature (two electrons from a common vertex)



The expected number of detected decays (if there is no background) is :

$$N_{\beta\beta 0\nu} = \log 2 \cdot \frac{M_{\beta\beta} \cdot N_A}{W_{\beta\beta}} \cdot \epsilon \cdot \frac{t}{T^{0\nu}_{1/2}}$$

For the case of a $m_{\beta\beta}$ = 50 meV ($T^0_{1/2} = 10^{26} – 10^{27}$ y.), macroscopic masses of ββ isotope of the order of **100 kg** are needed, for one year of exposure time, **to observe 1 decay !**

Considerations for a 0νββ experiment (2/3)

Sensitivity ...

- All double beta decay experiments have to deal with non-negligible **backgrounds**.
- The background is proportional to the exposure Mt and the energy resolution ΔE of the detector.
- Thus, background limits dramatically the sensitivity of a 2ββ-experiment, improving only as $(Mt)^{1/4}$.
-

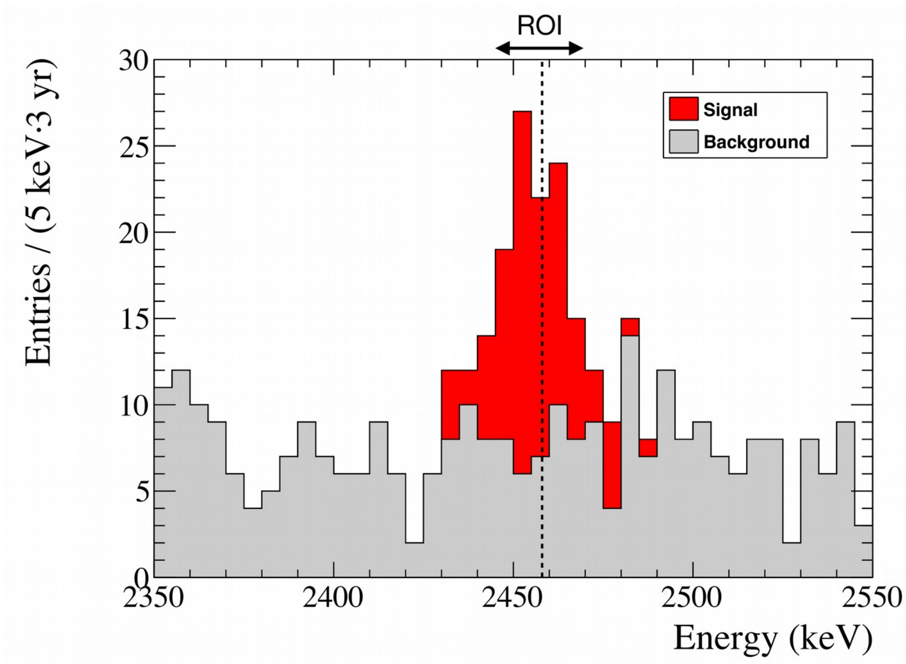
$$\boxed{b = c \cdot M \cdot t \cdot \Delta E}$$

c: background rate (per unit energy, mass and time)

$$\boxed{\mathcal{S}(m_{\beta\beta}) = \mathcal{A}' \sqrt{1/\varepsilon} \left(\frac{c\,\Delta E}{M\,t}\right)^{1/4}}$$

Considerations for a 0νββ experiment (3/3)

Energy resolution ...



- M = 1,000 kg
- t = 3 yr
- $T_{1/2} = 10^{26}$ yr
- ε = 100%
- **ΔE = 1% FWHM**
- $c = 5\cdot10^{-4}$ /(keV·kg*yr)

$$T^{0\nu}_{1/2} \propto \sqrt{\frac{M_{\beta\beta}\, t}{c\, \Delta E}}$$

- Signal is a gaussian defined by detector resolution.
- Detectors with good energy resolution (< ∼ 1 % FWHM) can give an optimal signal/background rate.
- Energy resolution depends on 0νββ background type: contamination of detector components, cosmogenics, intinsic 2νββ decays, etc.

NEXT Experiment

The NEXT Collaboration

IFIC (Valencia), U. Santiago de Compostela, U. Zaragoza, U. Politécnica de Valencia, DIPC (San Sebastian), U. Autónoma de Madrid, U. de Girona, IKERBASQUE.

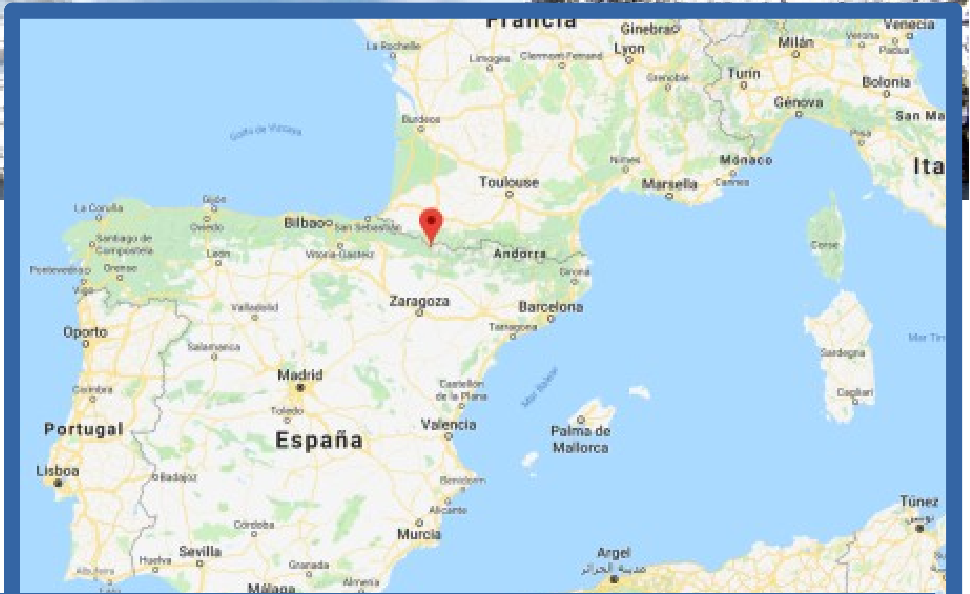
U. de Aveiro, U. de Coimbra.

U. Antonio Nariño.

U. of the Negev.

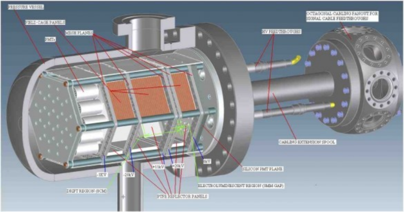
Harvard University, FNAL, LBNL, Argonne National Laboratory, Iowa State University, University of Texas at Arlington, Texas A&M University.

The Canfranc Underground Laboratory



NEXT Phases

DBDM (at LBNL)

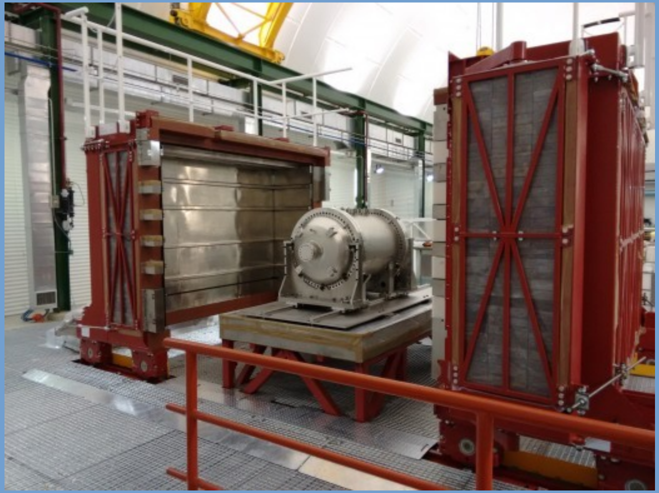


DEMO (at IFIC)

〜 1 kg (2009-2014)

Goals : To demonstrate the robustness of the technology, its excellent resolution and its unique topological signal.

NEXT-White (NEW) (at LSC)



〜 5 kg (2015-2019)

Goals :

- To validate the HPXe-EL technology in a large-scale radiopure detector.
- To compare background model with data.
- To study energy resolutions and the background rejection power of the topological signature.
- To measure 2νββ decay mode.

NEXT-100 (at LSC)

〜 100 kg (2019-2020)

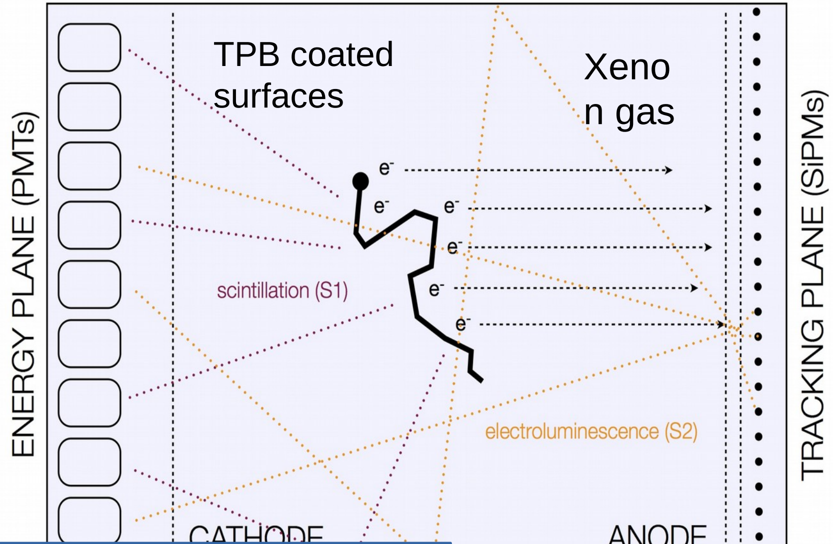
Goal : 0νββ decay search

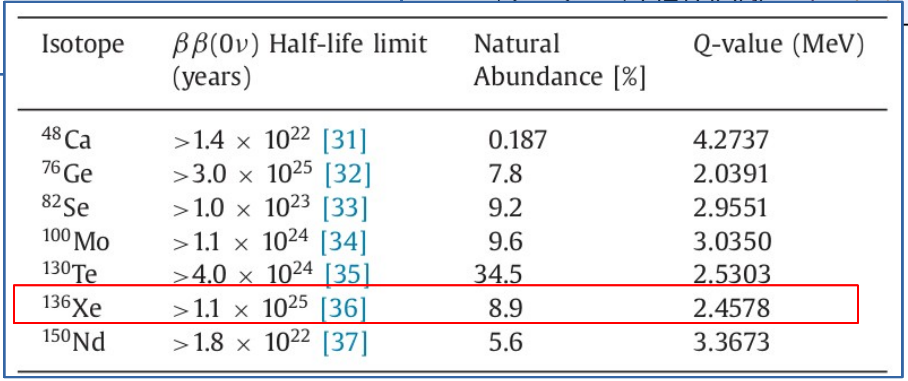
NEXT-tonne (〜 **1000 kg**)
[Future Generation ...]

NEXT concept

High-pressure xenon gas Time Projection Chambers (TPCs) with electroluminescent amplification of signal (**HPXe-EL**)

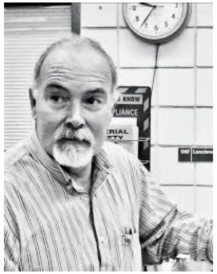
- Isotope: gaseous ^{136}Xe (relatively cheap and easy to enrich and purify).
- High Pressure Xenon TPC (operation 10-20 bar).
- EL amplification allows to achieve excellent energy resolution (< 1 % FWHM @ Q-value).
- Provides a topological signature (track of the two electrons) to improve the background rejection.
- It is built using radio pure materials.



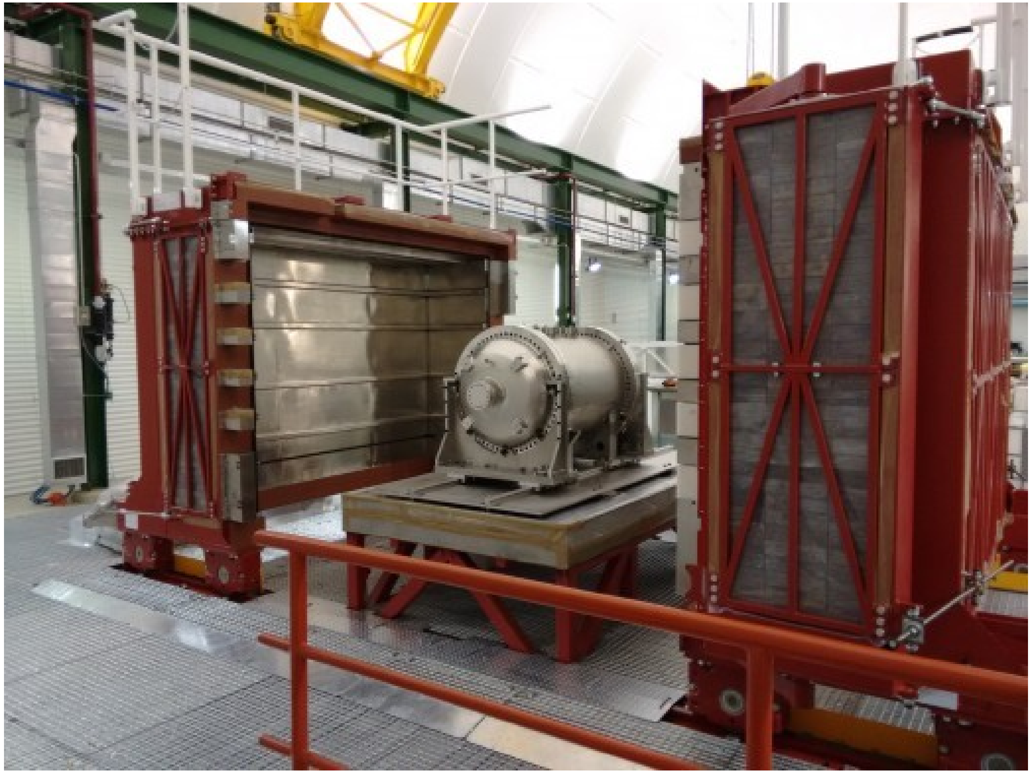


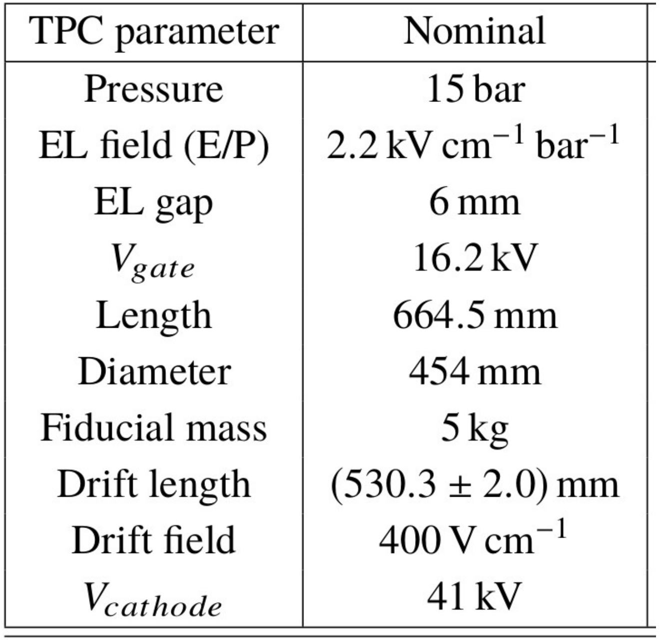
Isotope	$\beta\beta(0\nu)$ Half-life limit (years)	Natural Abundance [%]	Q-value (MeV)
^{48}Ca	$>1.4 \times 10^{22}$ [31]	0.187	4.2737
^{76}Ge	$>3.0 \times 10^{25}$ [32]	7.8	2.0391
^{82}Se	$>1.0 \times 10^{23}$ [33]	9.2	2.9551
^{100}Mo	$>1.1 \times 10^{24}$ [34]	9.6	3.0350
^{130}Te	$>4.0 \times 10^{24}$ [35]	34.5	2.5303
^{136}Xe	$>1.1 \times 10^{25}$ [36]	8.9	2.4578
^{150}Nd	$>1.8 \times 10^{22}$ [37]	5.6	3.3673

NEXT-White (1/2)



In honour of
James White

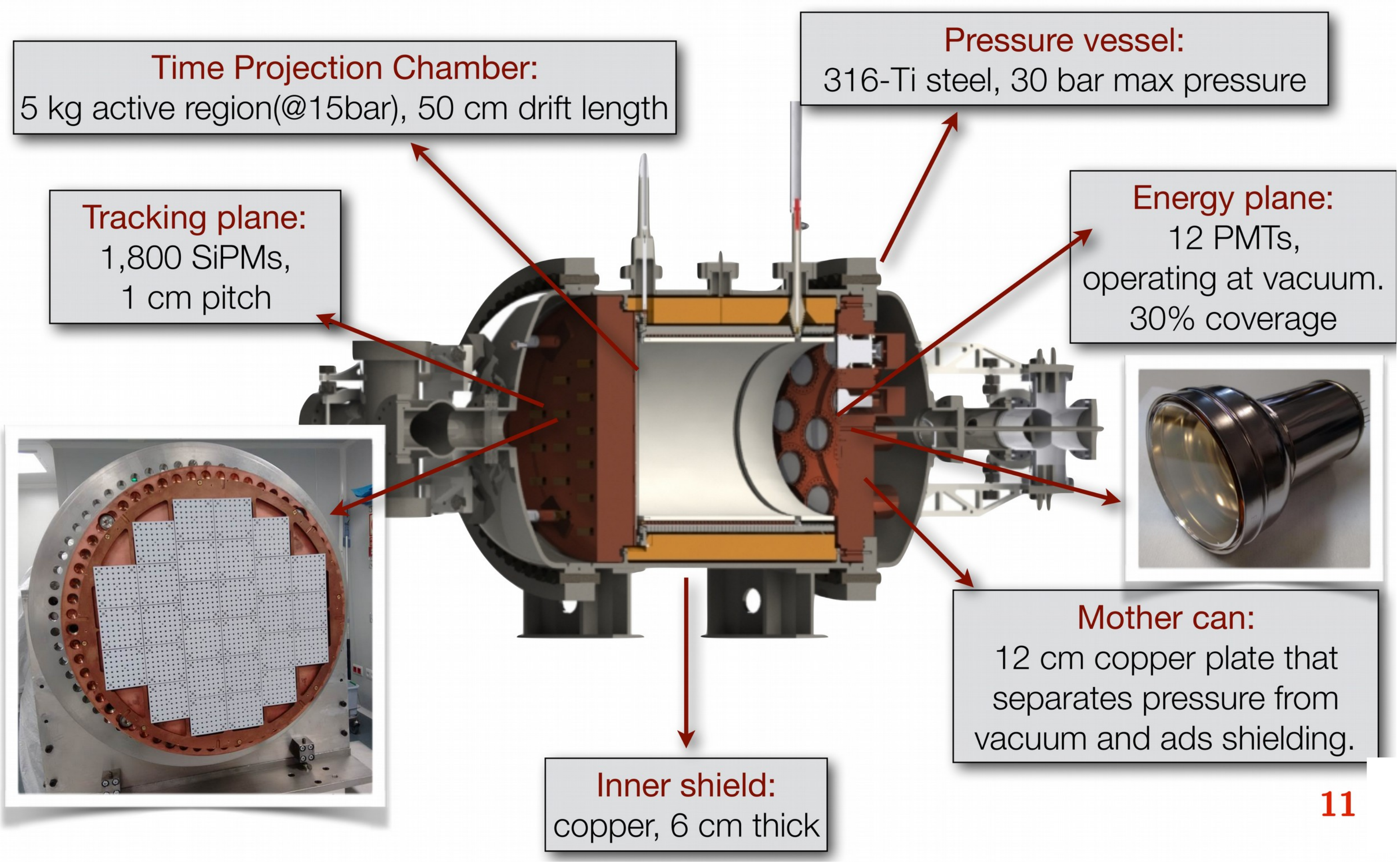




TPC parameter	Nominal
Pressure	15 bar
EL field (E/P)	$2.2\,\mathrm{kV\,cm^{-1}\,bar^{-1}}$
EL gap	6 mm
V_{gate}	16.2 kV
Length	664.5 mm
Diameter	454 mm
Fiducial mass	5 kg
Drift length	(530.3 ± 2.0) mm
Drift field	$400\,\mathrm{V\,cm^{-1}}$
$V_{cathode}$	41 kV

NEXT-White is a 1:2 scale model of the NEXT-100 detector

NEXT-White (2/2)



Time Projection Chamber:
5 kg active region(@15bar), 50 cm drift length

Pressure vessel:
316-Ti steel, 30 bar max pressure

Tracking plane:
1,800 SiPMs,
1 cm pitch

Energy plane:
12 PMTs,
operating at vacuum.
30% coverage

Mother can:
12 cm copper plate that
separates pressure from
vacuum and ads shielding.

Inner shield:
copper, 6 cm thick

Principle of operation (1/2)

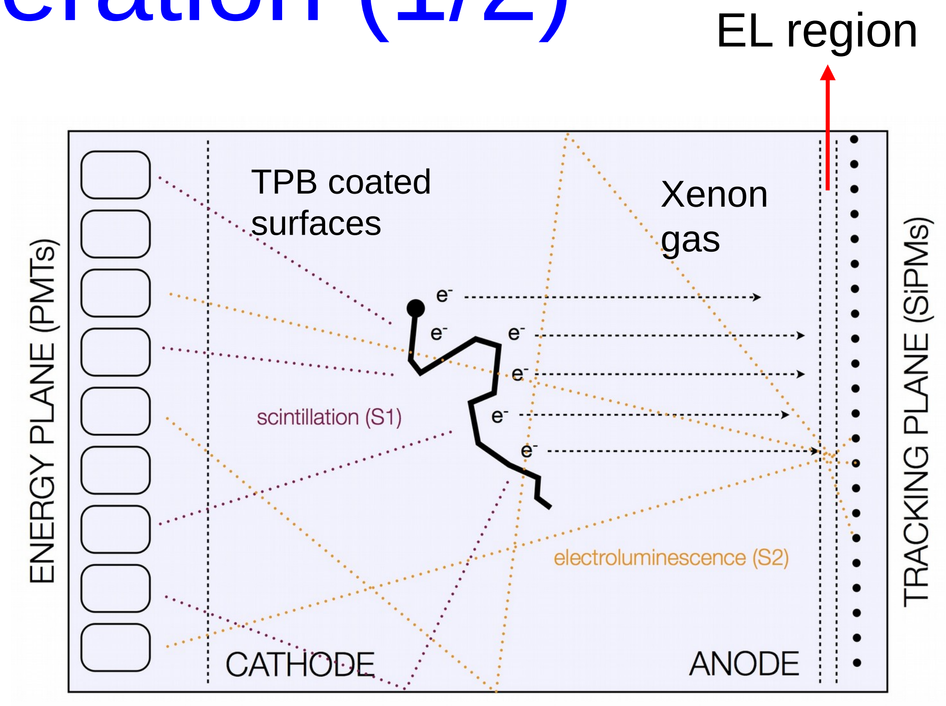
➔A charged particle in the dense gas loses energy by ionizing and exciting atoms of the medium.

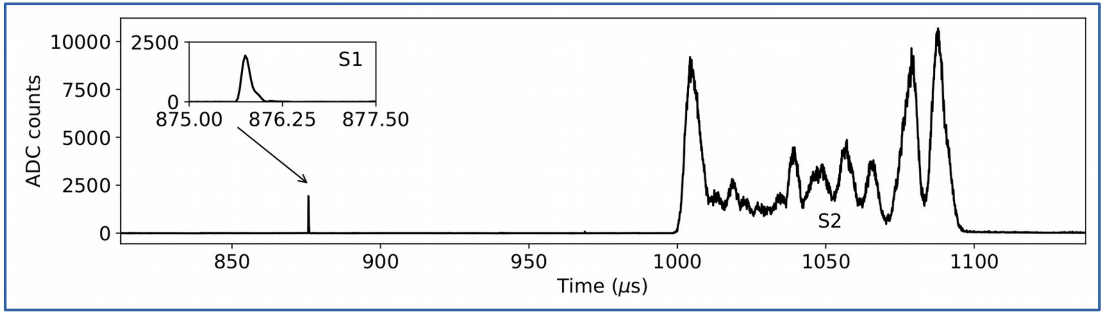
➔The excited atoms return to the ground state by a prompt emission of VUV (172 nm) scintillation light (S1) giving the starting time of the event.

➔Ionization electrons drift toward the TPC anode where they produce an amplified signal (S2) inside EL region.

➔S1 and S2 signasl are recorded by the PMTs.

➔S2 signal is used to trigger the data acquisition and to measure the total energy deposition of the event.



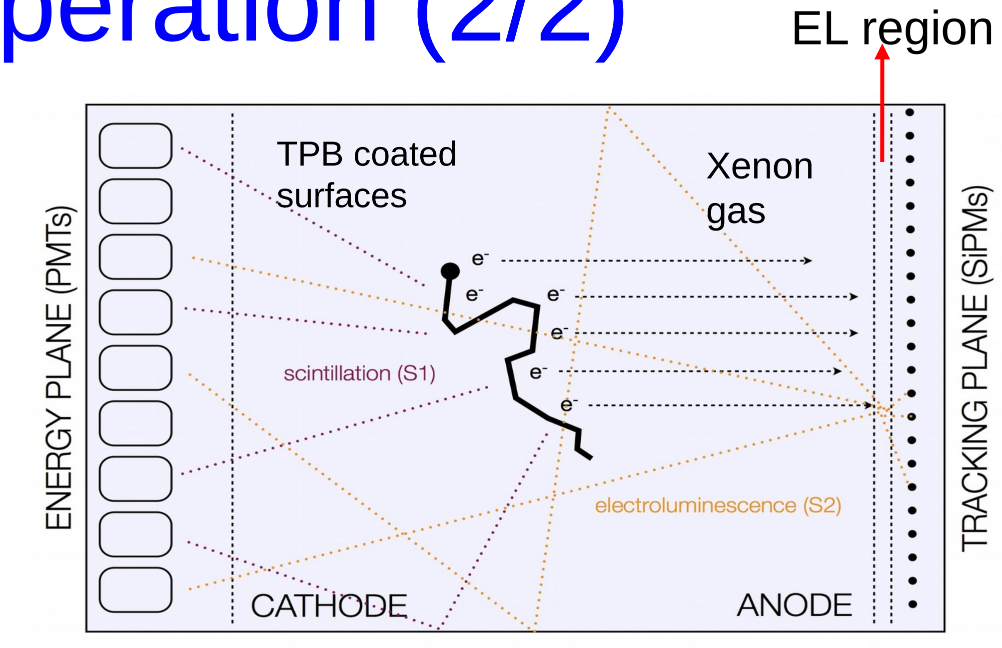


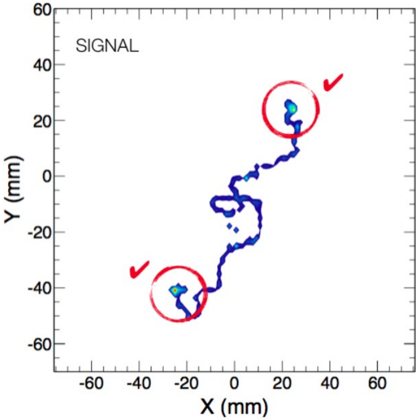
Principle of operation (2/2)

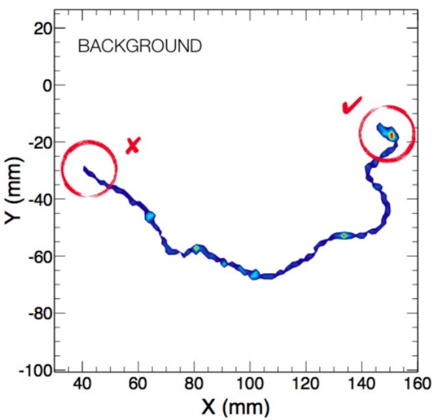
➔The time difference between S1 and S2 signals provides the timing information used to localize the event within the drift volume.

➔The S2 signal is also recorded by the dense grid of SiPMs (tracking plane).

➔This information allows to establish the transverse position of the arriving ionization electrons with a precision of a few millimeters.







Results about calibration using ^{83m}Kr decays

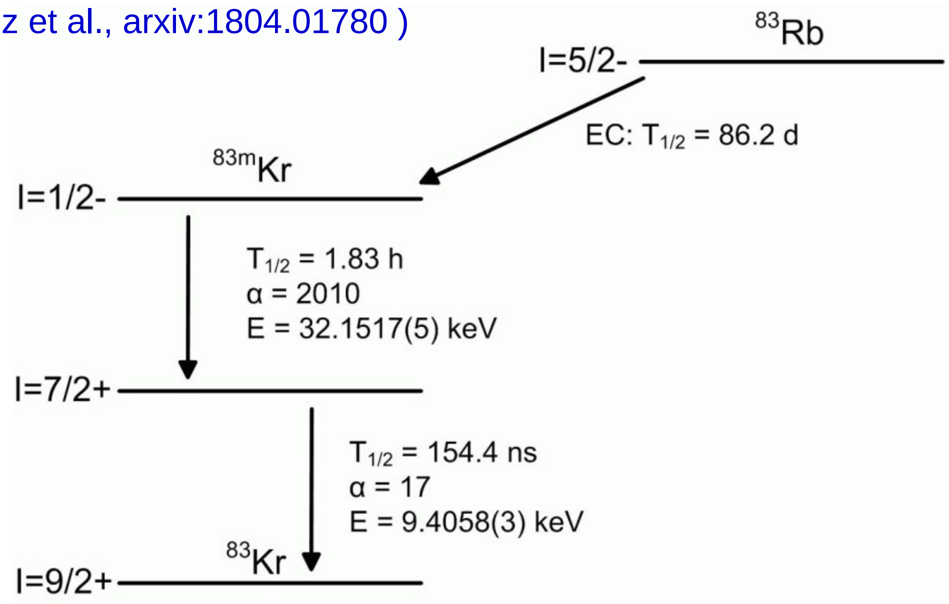
(NEXT Collaboration, G. Martinez et al., arxiv:1804.01780)

To get a correct measure of the energy of an event in NEXT-White it is necessary to correct two instrumental effects:

a) *The finite electron lifetime (attachment of ionizationelectrons)*

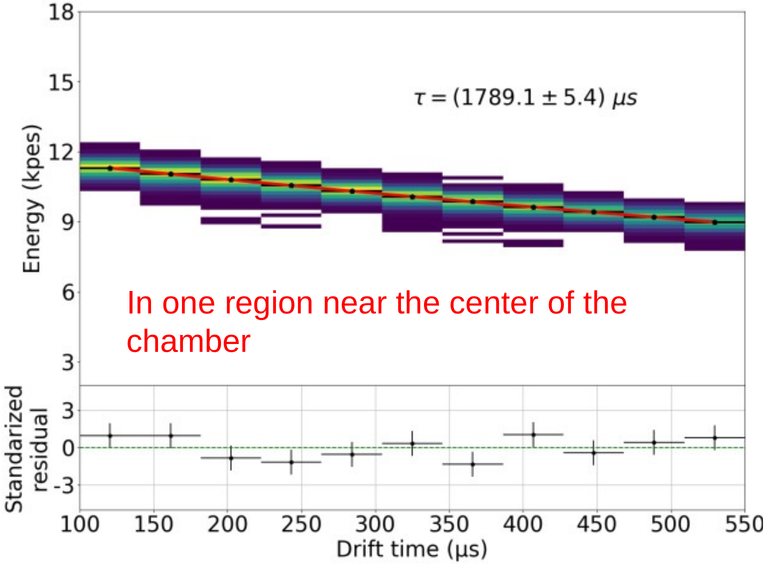
b) *The dependence of the light detected by the energy plane on the (x,y) coordinates.*

Kr calibrations offers a power tool to measure and correct both effects !

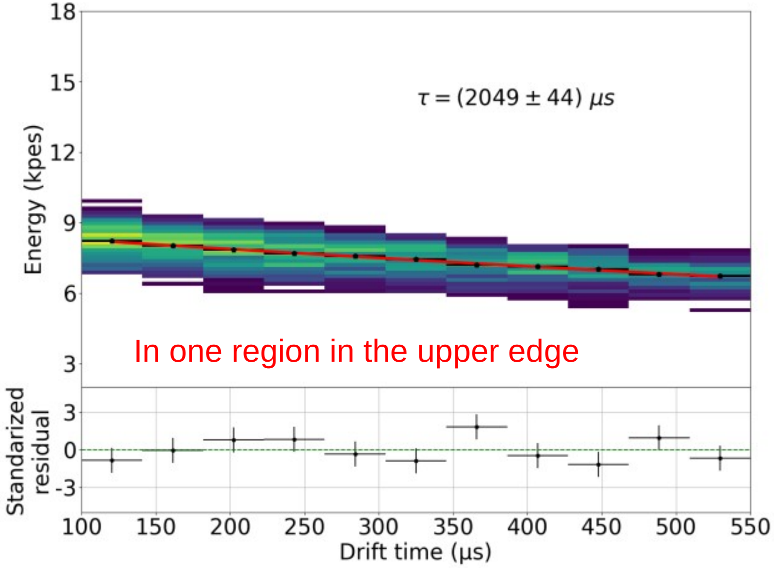


- A rubidium source (small zeolite balls) are stored in a specific section of the gas system.
- The ^{83m}Kr nuclei are produced after decay of ^{83}Rb by EC and flows directly inside the gas chamber.
- The total released energy sums 41.5 keV and the ground state of ^{83}Kr is stable.
- As ^{83m}Kr decay results in a point-like deposition.

Lifetime map and energy map



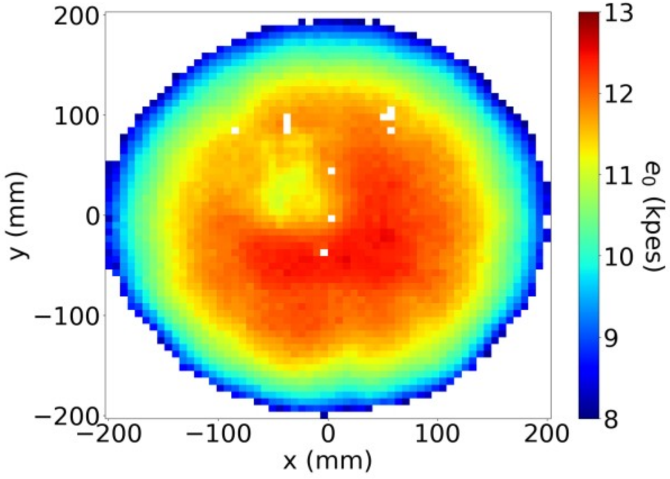
In one region near the center of the chamber



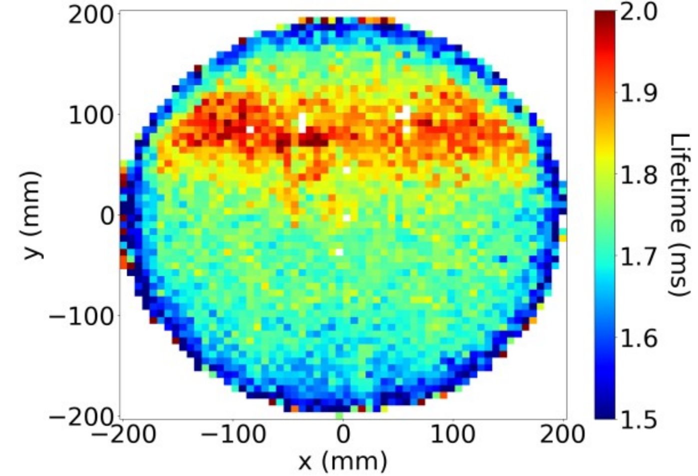
In one region in the upper edge

An exponential fit is performed to the distribution of Kr integrated signal as a function of the drift time (data used for the analysis were collected on October 2017):

$$f(t) = e_0\, e^{-t/\tau}$$

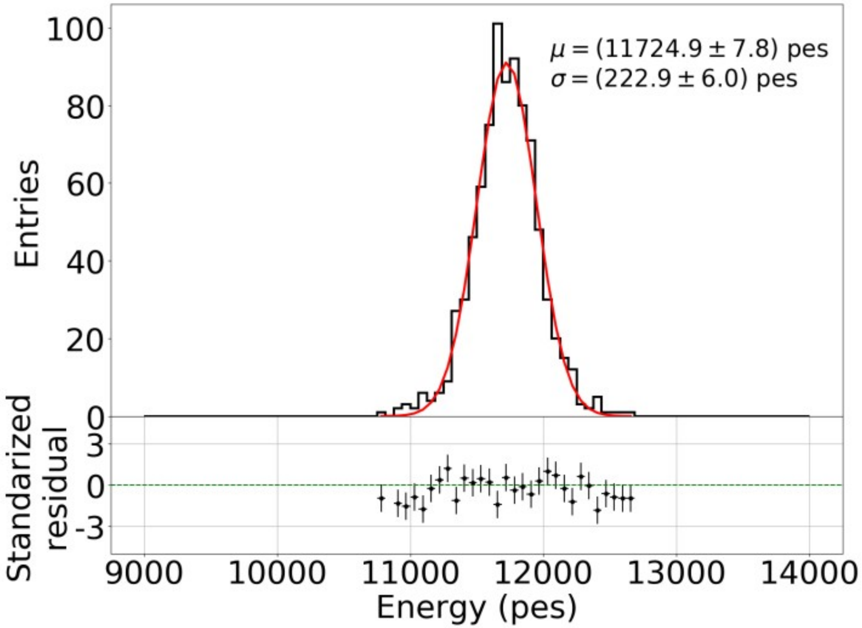


Energy map obtained by factoring the lifetime effect out

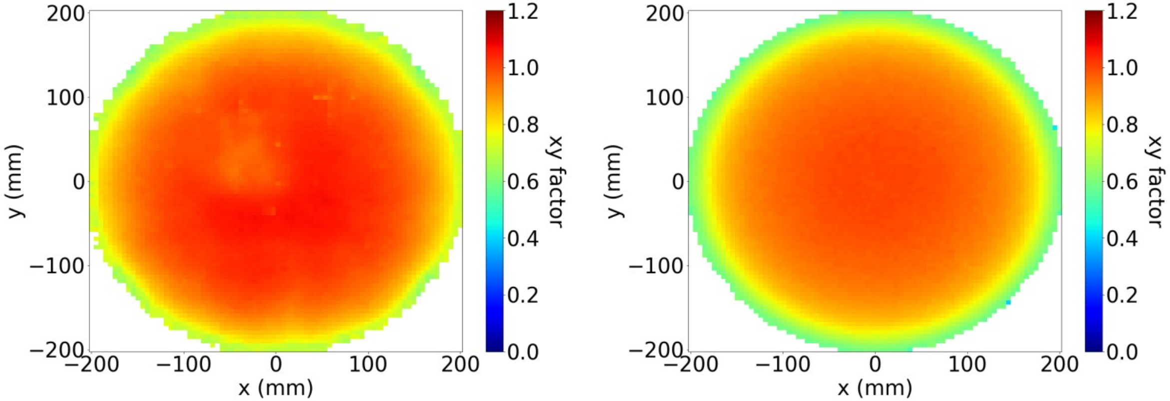


The lifetime map is built by dividing the chamber in 60x60 *(x,y)* bins, and fiiting for the lifetime in each bin.

The fit used to obtain the lifetime maps allows correct the sum of the PMT energies for each bin. (Example for the region x=[0,10] mm, y=[0,10] mm)



The refined and normalized energy map is compared with the energy map using Monte Carlo data.



(a) Data

(b) Monte Carlo

Summary

- 0νββ decay search requires a dedicated experiment that must meet requirements such as the ability to measure the signature, effectively reduce all background and a high resolution.

- NEXT-White detector provides a novel approach to 0νββ-searching detector by combining two different technologies.

- NEXT-White detector has a high resolution and an extra way to identify the signatures through a topolgy track of the electrons.

- Lifetime maps and energy maps can be obtained through Krypton calibration to measure the energy properly of any event in the NEXT-White detector.

Thank you for you attention

Acknowledgements

1) My short research stay at the IFIC and Laboratorio Subterráneo de Canfranc would have been impossible without the financial support of the **European Union's Horizon 2018 research and innovation programme under the Marie Skłodowska-Curie grant agreement (InvisiblesPlus RISE)**.

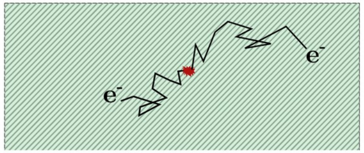
2) I would like to thank the **Vicerrectoria de Ciencia, Tecnología e Innovación of the Universidad Antonio Nariño** for the financial support to attend the COMHEP 2018.

Backup

The Race to 0νββ

- It's impossible to optimize all features simultaneously.
- Many experiments using different techniques and isotopes, which exploit some of them.

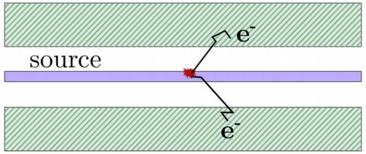
source = detector



S. Dell'Oro et al.,
Advances in High Energy Physics,
(2016) 2162659

- The isotope itself is also the calorimetric medium.
- Good scalability.
- Techniques: diodes, bolometers, TPCs, liquid scintillators loaded with isotope…

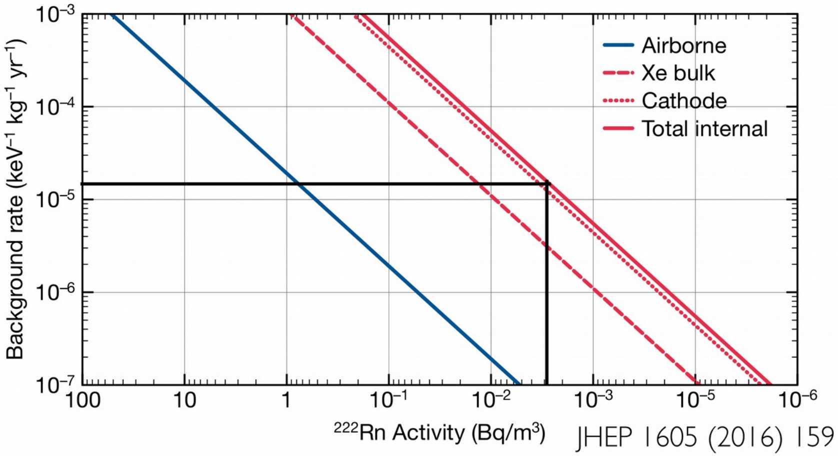
source != detector



- Electrons must leave the source material to be detected.
- Poor energy resolution.
- Bad scalability.

The Radon Problem

- Rn gas produces Bi-214 and Tl-208, very dangerous.
- Airborne Rn in the lab can be reduced by a radon abatement system down to ~ mBq/m^3.



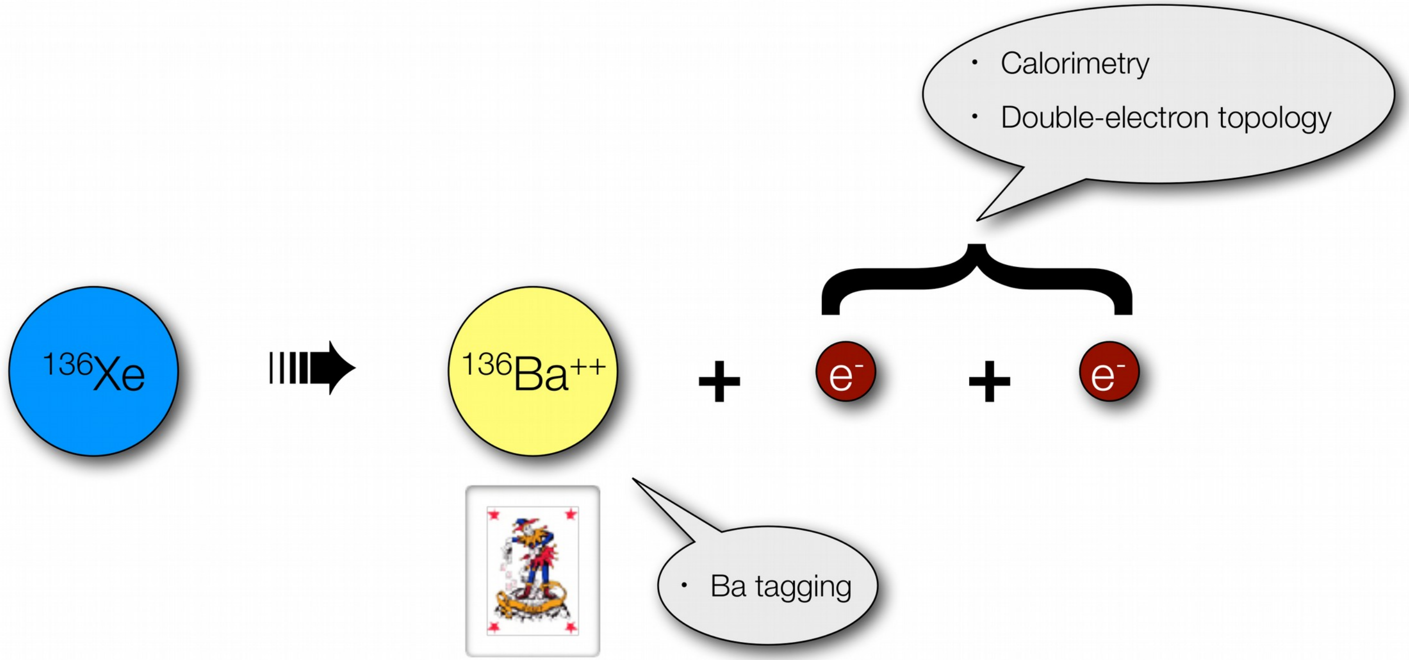
JHEP 1605 (2016) 159

- Radon emanation measurements for all detector materials.
- Alternatives to high sources of Rn such as SAES hot getters are explored (e.g., Ca-based chips).

- Rn emanation from detector components and getters gets into active volume.
- Rn charged daughters stick to internal surfaces.
- A reduction to few mBq/m^3 would lower Rn contribution to the level of the rest of background.

Is daughter ion tagging possible?

- Active R&D in ^{136}Xe experiments (liquid and gas) to detect ^{136}Ba^{++} ion:



- Calorimetry
- Double-electron topology

^{136}Xe $\Rightarrow$ ^{136}Ba^{++} + e^- + e^-

- Ba tagging

- If successful, one would be left with ββ2v background only!