Search for neutrinoless double beta decay with a high pressure Xenon TPC

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On behalf of the NEXT collaboration

Buenos Aires, 29-30 Jun 2017

NEXT

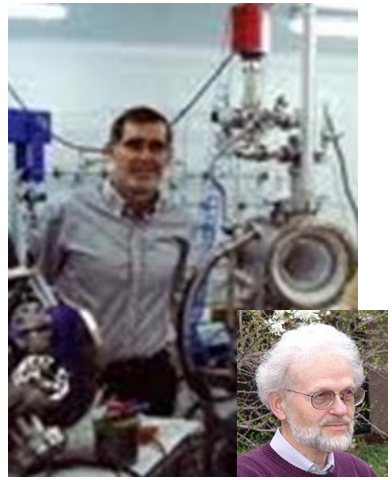
- **What**: time projection chamber with high-pressure (10-15 bar) ^{136}Xe gas
- **Why**: energy resolution and electron tracks reconstruction
- **Where**: Laboratorio Subterráneo de Canfranc, LSC, Spain
- **Who**: 

NEXT Collaboration

- 80 collaborators
- 17 institutions
- 5 countries

NEXT COLLABORATION

Co-Spokespersons:
Juan José Gómez-Cadena
IFIC-Valencia, España
gomez@mail.cern.ch
Dave R. Nygren *
University of Texas
Arlington, USA



NEXT
Neutrino
Experiment with a
Xenon
TPC*

Neutrinoless double beta decay, **ββ0ν**, with EL&TPC, filled with Xe 91% of ^{136}Xe → two features of great value:

- excellent energy resolution: <1% FWHM at 2.5 MeV
- charged-particle tracking for the active suppression of background

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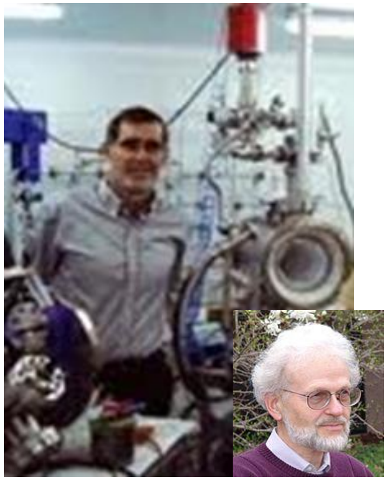

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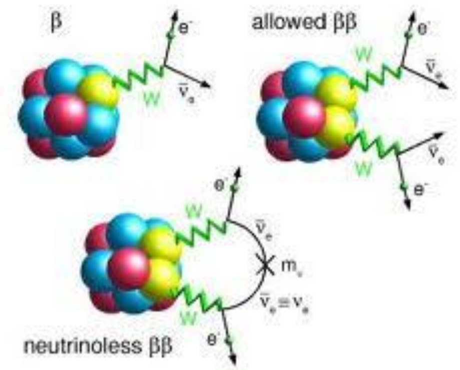
- excellent energy resolution: <1% FWHM at 2.5 MeV
- charged-particle tracking for the active suppression of background

Furthermore: extrapolable to large source masses, important for present and future detectors ……NEXT-1Ton ANDES!!

NEXT MOTIVATION

Discovering Neutrinoless Double-Beta Decay, ββ0ν:
remains a central focus in contemporary particle physics.

ββ0ν is an hypothetical second-order weak process:



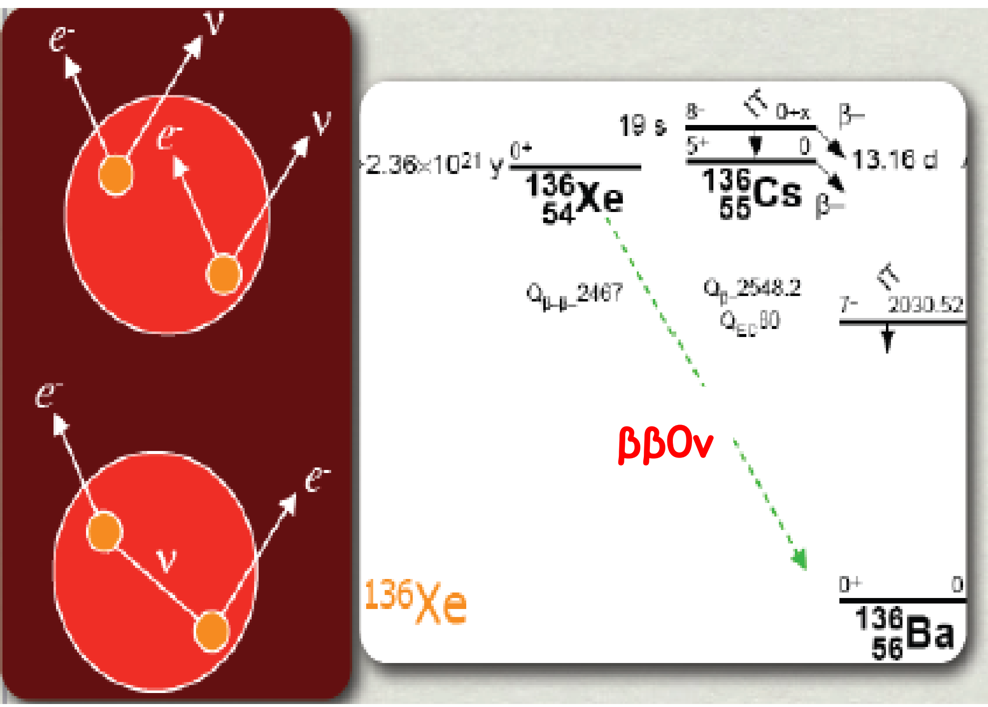
Z → Z + 2 and A → A
$2p \longrightarrow 2n + 2e^-$

Is the neutrino its own anti-particle?

Would have profound implications in our understanding of nature!

NEUTRINOLESS DOUBLE BETA DECAY

ββ: 35 isotopes



- **ββ2ν:**

 2 electrons and 2 ν

10^{18} to 10^{21} years

- **ββ0ν (rare and hypothetical):**

2 electrons and 0 ν

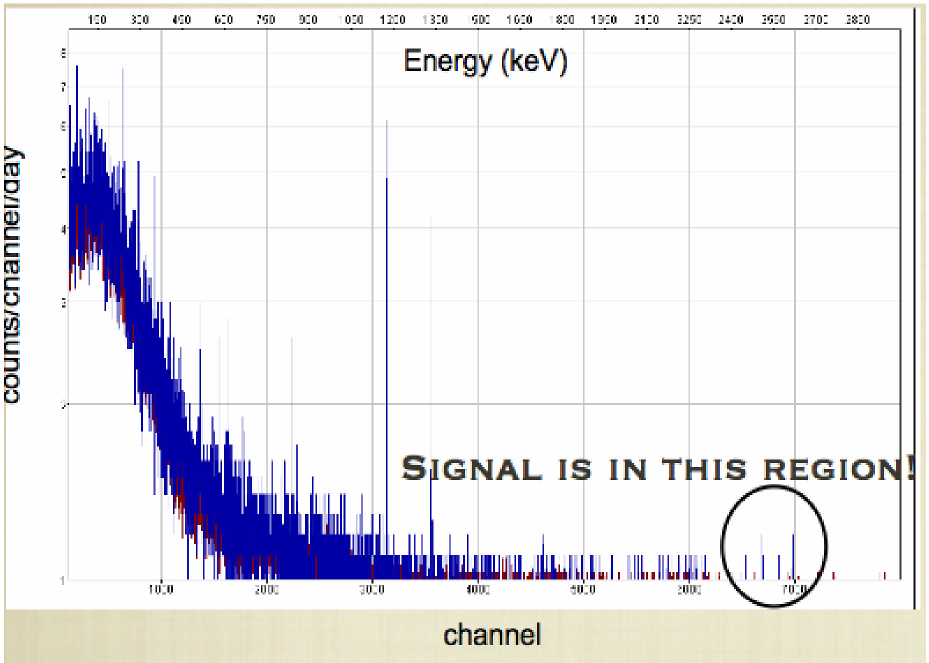
1948, ^{124}Sn: > 3×10^{15} years

2001, ^{76}Ge: > 1.9×10^{25} years

EXPERIMENTAL CHALLENGE of ββ0ν

To eventually detect ββ0ν events:

- **mass ν < 1 eV → high energy resolution**
- **large life time → large isotope masses**
- **weak signals → high sensitivity**
- **abundant noise and background → shielding and noise rejection**

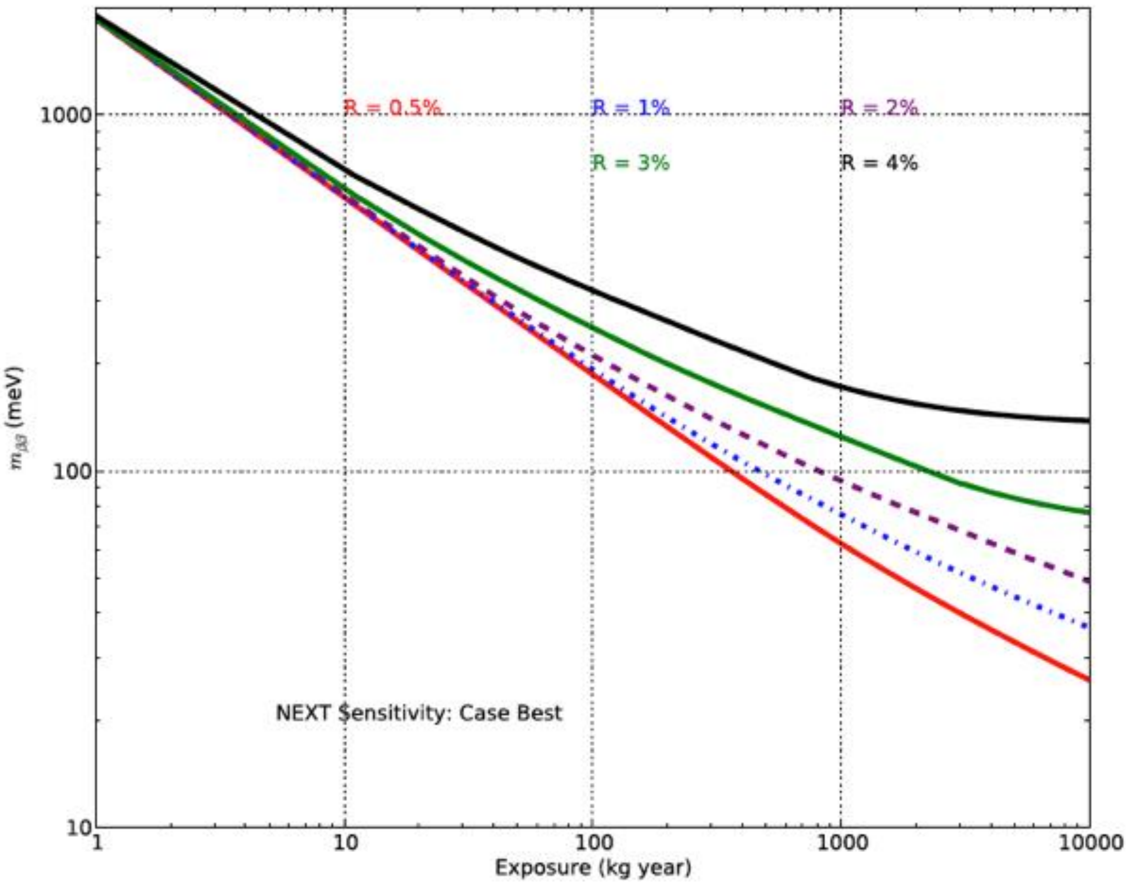


There is not an ideal experiment without conflicting requirements?

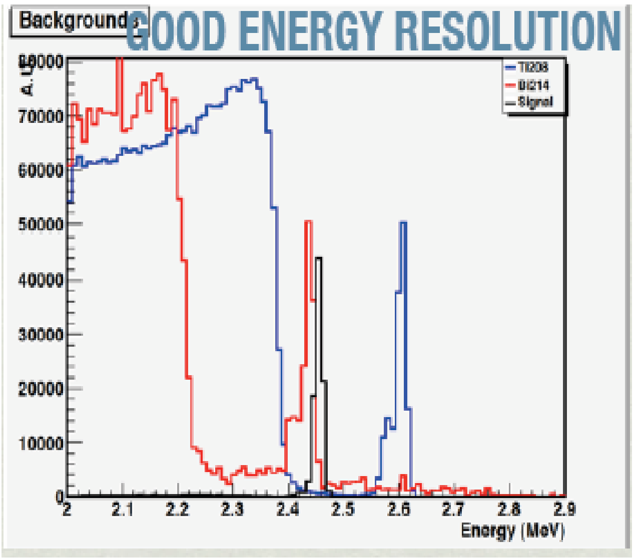
several experiments with different and compromises between these aspects

ENERGY RESOLUTION: INDISPENSABLE BUT NOT SUFFICIENT

EXPERIMENTAL CHALLENGE of ββ0ν



Resolution matters, but isotope mass too!



EXPERIMENTAL CHALLENGE of ββ0ν

Q ≡ mass difference between the initial and final atoms of a radiative process.

Detectors of **ββ**: measure the energy of the radiation emitted by a source.

⟶ **ββ0ν**: kinetic energies of the two released electrons is equal to the Q value: $Q_{\beta\beta}$

The number of signal events N, in particular, can be related to the half-life of the process:

$$T_{1/2}^{0\nu} = \log 2 \, \frac{N_A}{W} \, \frac{\varepsilon \, M \, t}{N},$$

N_A: Avogadro constant,
W: atomic mass of the **ββ0ν** isotope,
ε: signal detection efficiency,
M: source mass,
t: measuring time
N: the number of **ββ0ν** events observed in the experiment.

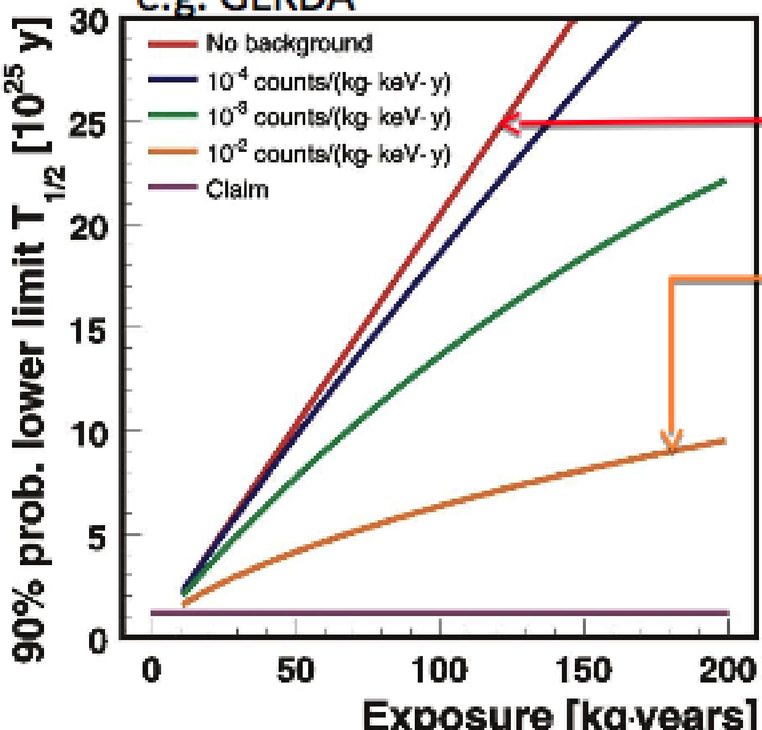
EXPERIMENTAL CHALLENGE of ββ0ν

Half life [yr]	approx. signal rate [cts/(ton yr)]
10^{25}	500
5×10^{26}	10
5×10^{27}	1
$>10^{29}$	<0.05

Present exp. sensitivities →

Goal next generation →

e.g. GERDA

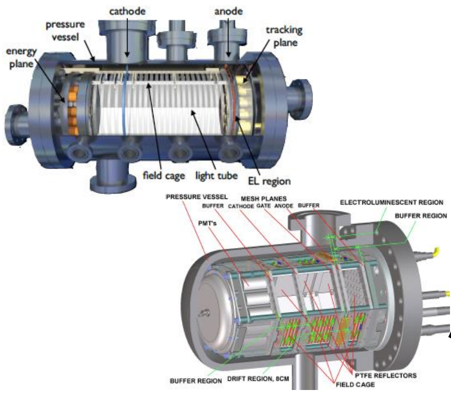


$$(T^{0\nu}_{1/2})^{-1} \propto \varepsilon_{eff}\, f_{enr}\, M\, T$$ <u>Background-free</u>

$$(T^{0\nu}_{1/2})^{-1} \propto \varepsilon_{eff}\, f_{enr}\, \sqrt{\frac{M\, T}{B\, \Delta E}}$$ <u>Background limited</u>

- Large exposure ($\varepsilon_{eff}\, f_{enr}$ MT) of ββ-isotope
- Bgd-free operation in 0νββ peak region
- Best possible energy resolution to discriminate 0νββ from 2νββ
- Several isotopes

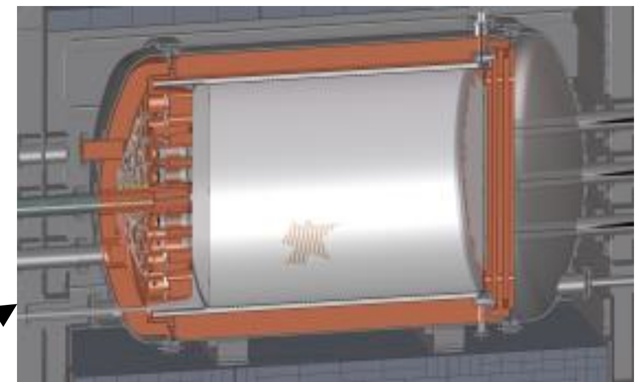
DEVELOPING NEXT-100



NEXT-DEMO
and
NEXT-DBDM

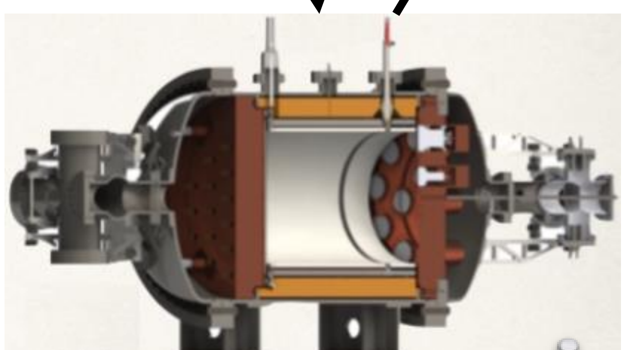
Prototypes (~1 kg)
[2009 - 2014]

Demonstration of detector concept



NEXT-100 (~100 kg)
[2018 - 2020's]

Neutrinoless double beta decay searches



NEXT-NEW (~5 kg)
[2015 - 2018]

Underground and radio-pure operations, background, $\beta\beta2\nu$

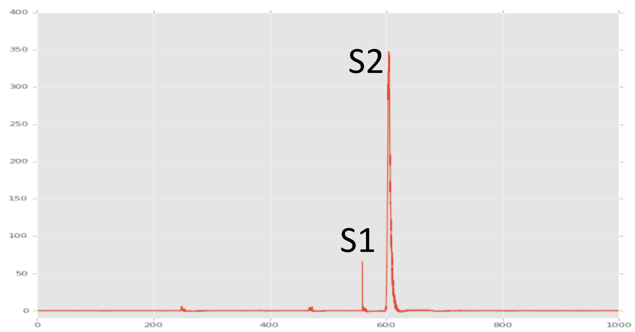
NEXT-1Ton (~1000 kg)
[future generation]
ANDES?

DEVELOPING NEXT

Demonstration prototypes ~1 kg natural Xe at 10-15:

NEXT-DEMO: best energy resolution 1.62% FWHM at 511 keV → extrapolates 0.74% FWHM [13]; track reconstruction possible with EL-based application [14] ; energy-deposition pattern used for the identification of signal-like and background-like event topologies [15]

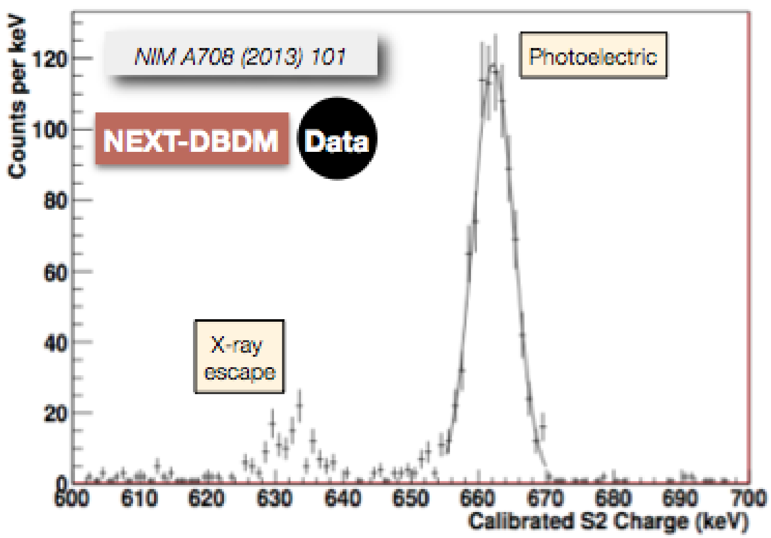
NEXT-DBDM: best energy resolution 1% FWHM at 662 keV, extrapolates to 0.5% FWHM; measurement of Q value of 136Xe [12].

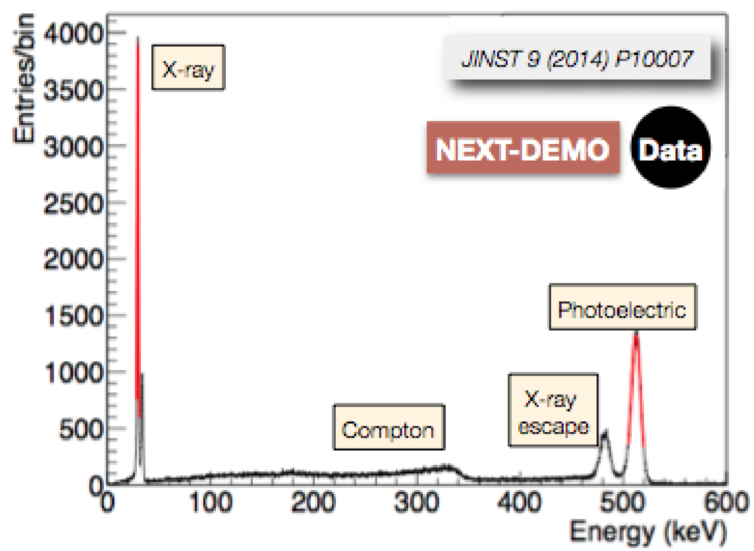


IFIC (SOFT)

LBNL (SOFT)

DEVELOPING NEXT



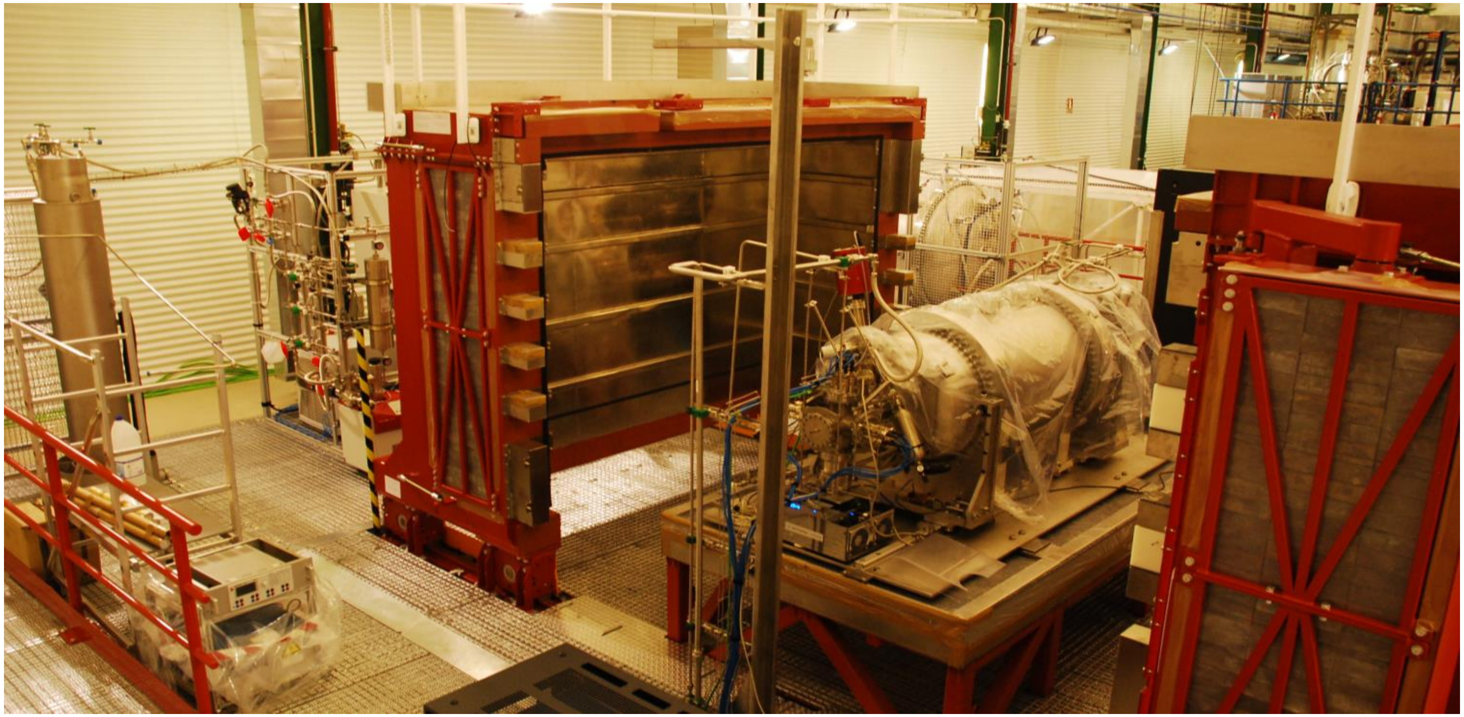


- 1.1% FWHM resolution for 662 keV electrons

- 1.6% FWHM resolution for 511 keV electrons

DEVELOPING NEXT-100

- **NEXT- White* (NEW)**: data for optimization of calibration, reconstruction methods and validation of background model. Currently in commissioning phase: operating with ^{136}Xe-depleted xenon since October 2016



LSC

DEVELOPING NEXT-100

NEXT at Canfranc Underground Laboratory, LSC

Main hall

Building

Main entrance

Under the Pyrenees mountain "El Tobazo"

- **1985 to 2010 increased from A 185m^2 to 1250m^2 and V 10^{4}m^3**
- **850m deep providing 2500 meters water equivalent of shielding from cosmic rays and offers a low background environment**
- **214 scientific users from 15 Countries**

DEVELOPING NEXT-100

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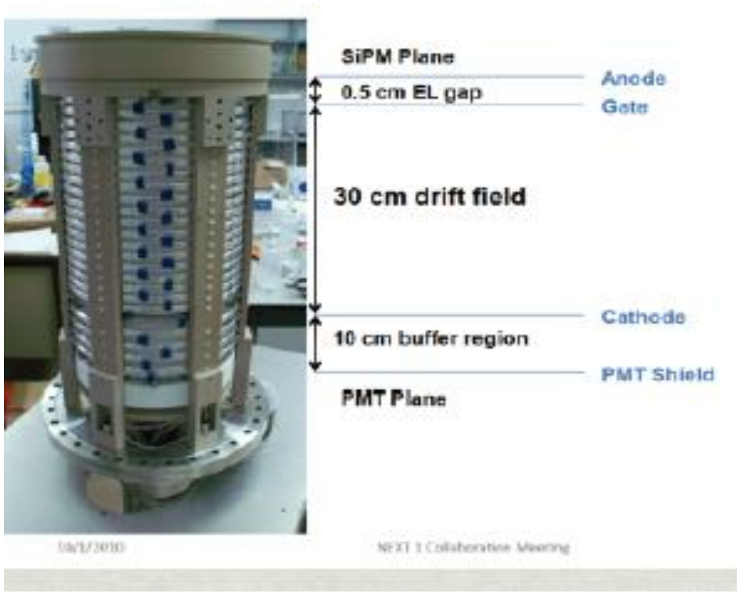
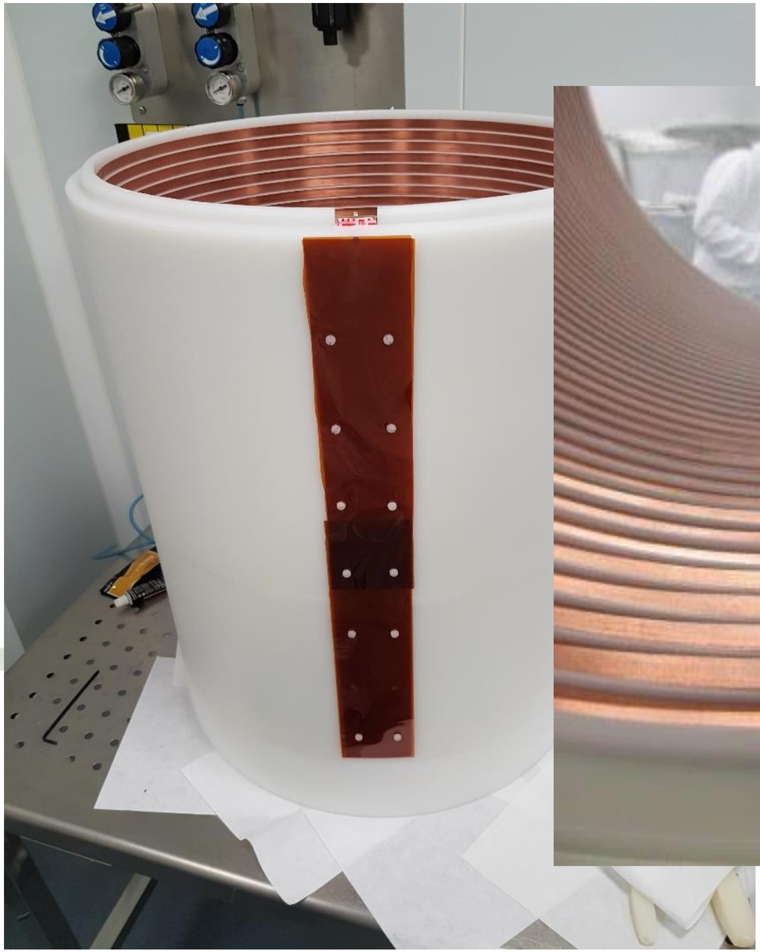
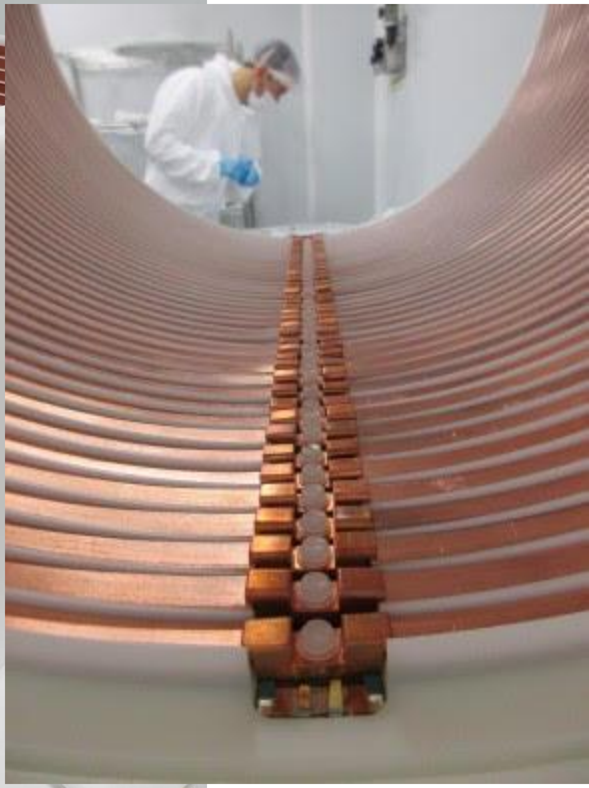
ANDES.... better conditions?

DEVELOPING NEXT-100

NEXT-100: compromise between collecting as much light as possible and minimize sensors to reduce cost, technical complexity and radioactivity





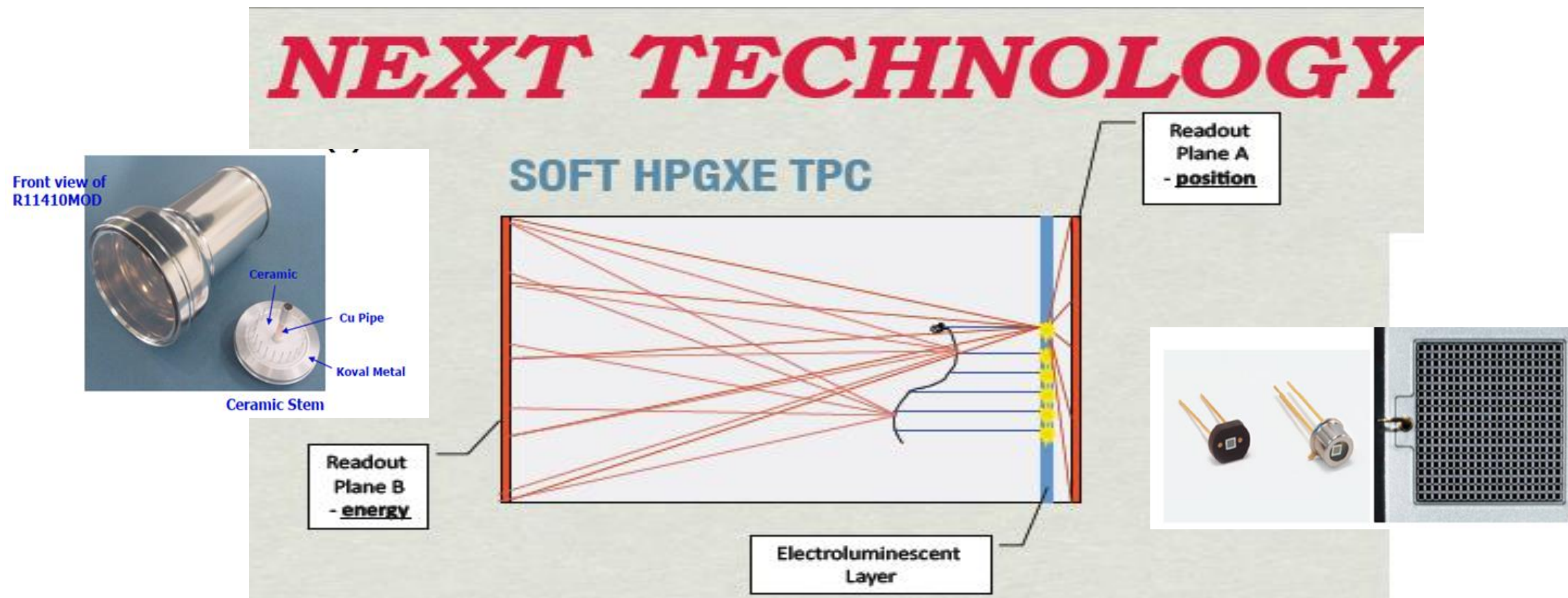


Field Cages

DEVELOPING NEXT-100

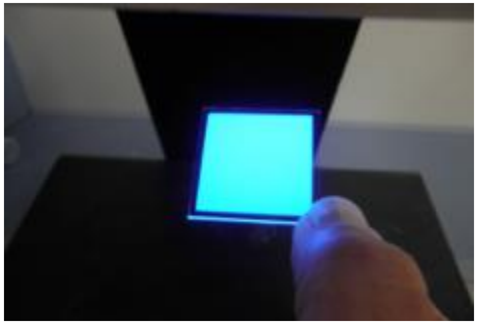
NEXT TECHNOLOGY: efficient and elegant for rare events

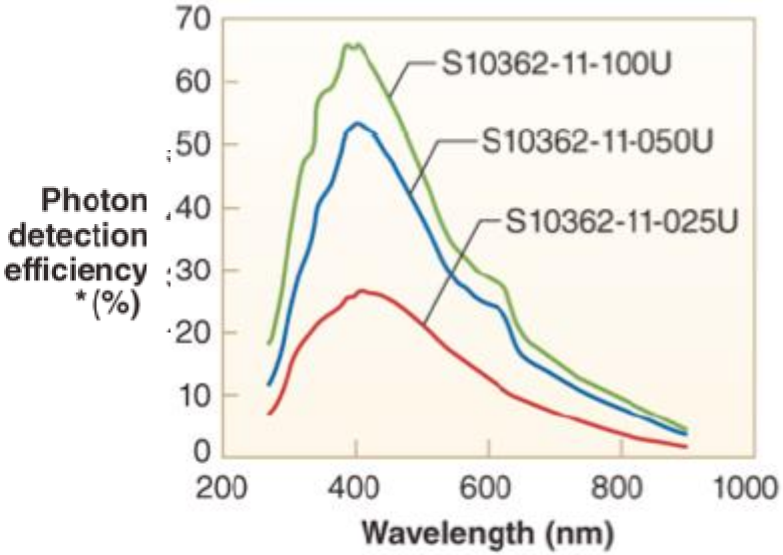
SOFT: Separated Optimization FuncTions
HPGXe: High Pressure Gaseous Xe
TPC: Time Projection Chamber

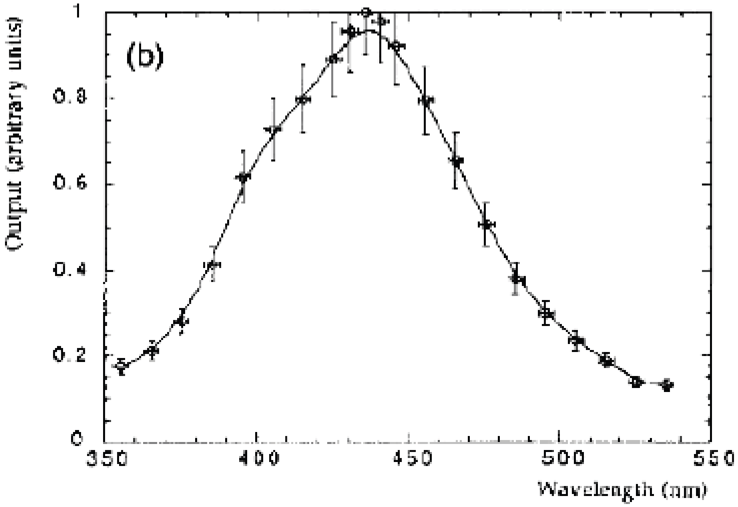


DEVELOPING NEXT-100

SiPMs and/or PMT
are coated with TPB







DEVELOPING NEXT-100

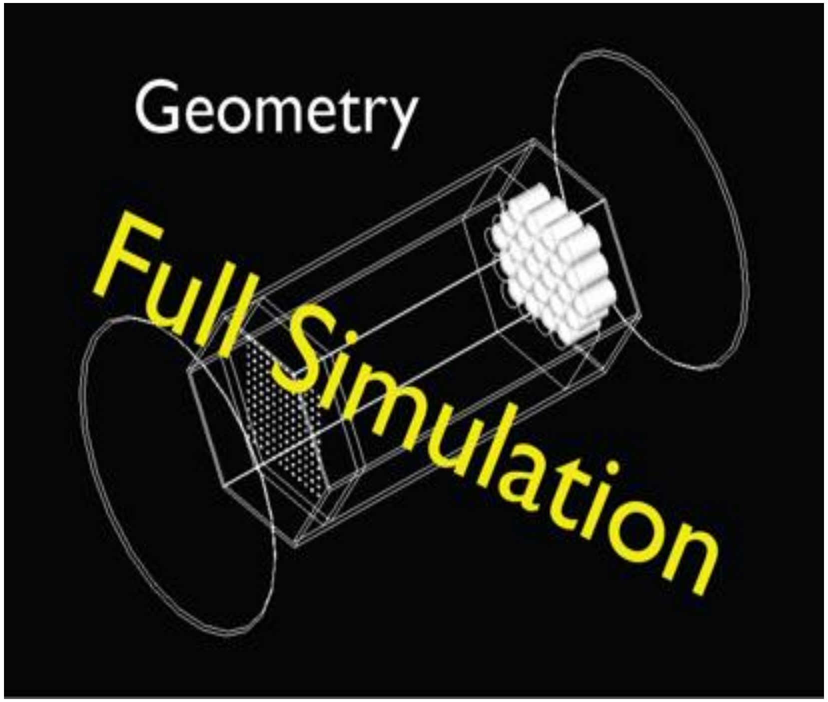
Gas System

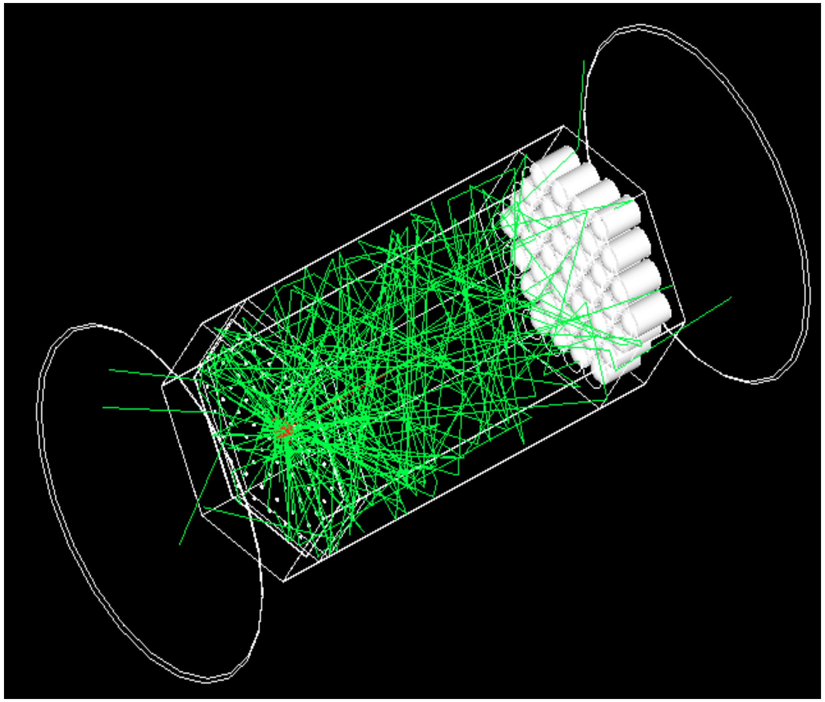
To maintain 100 kg of Xe with 91% of 136Xe at high pressure without leaks, clean and pure:

Valves structure with “buffer”, vacuum pump, recuperation, purification, recirculation pump, purity monitoring, equalization, etc.

DEVELOPING NEXT-100

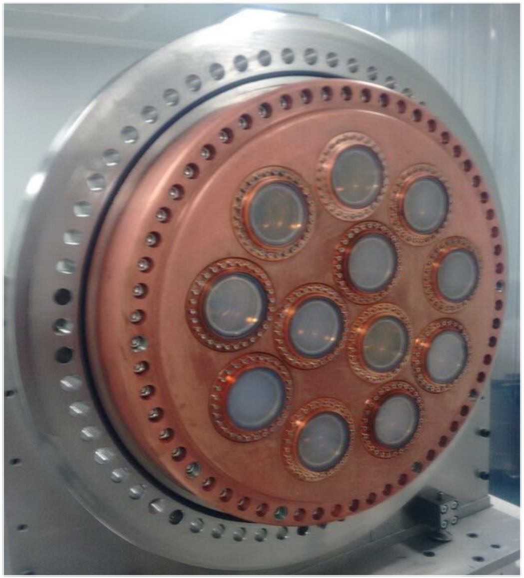
Simulation and Analysis

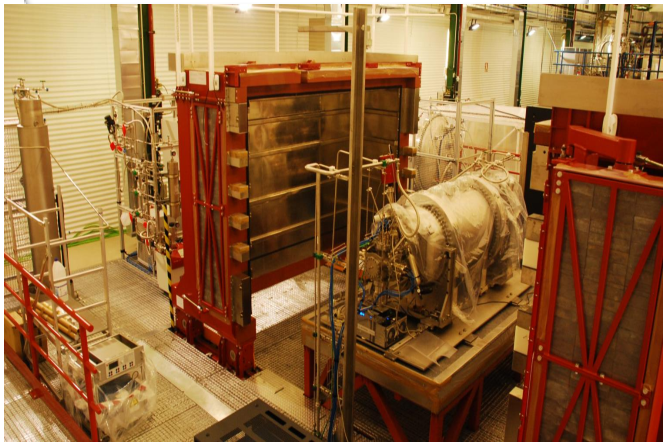


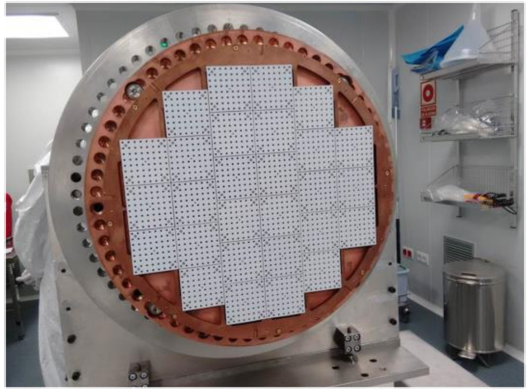


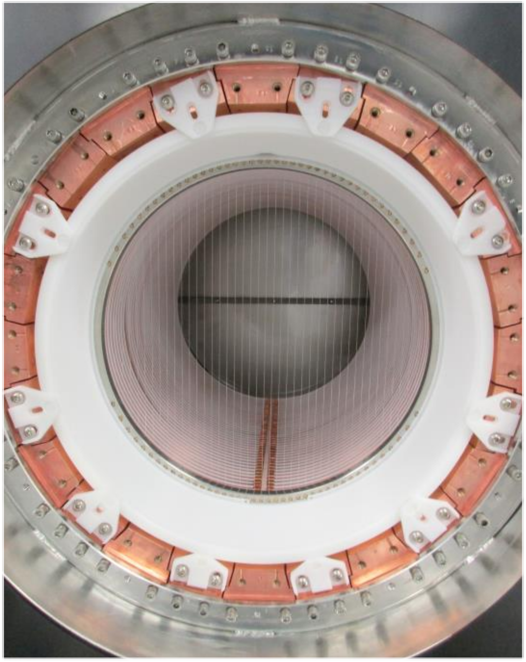
NEXT-NEW AND RESULTS: Construction

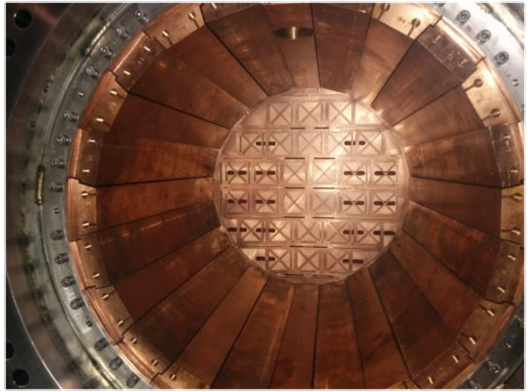
2015-2016

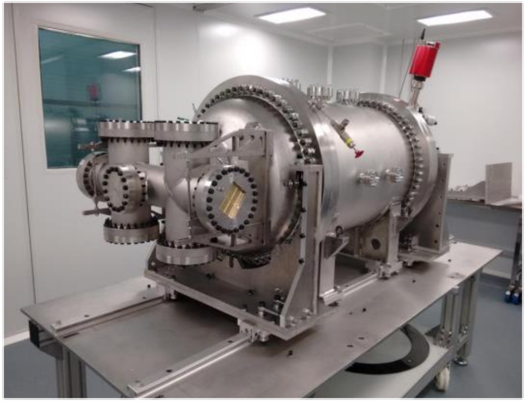






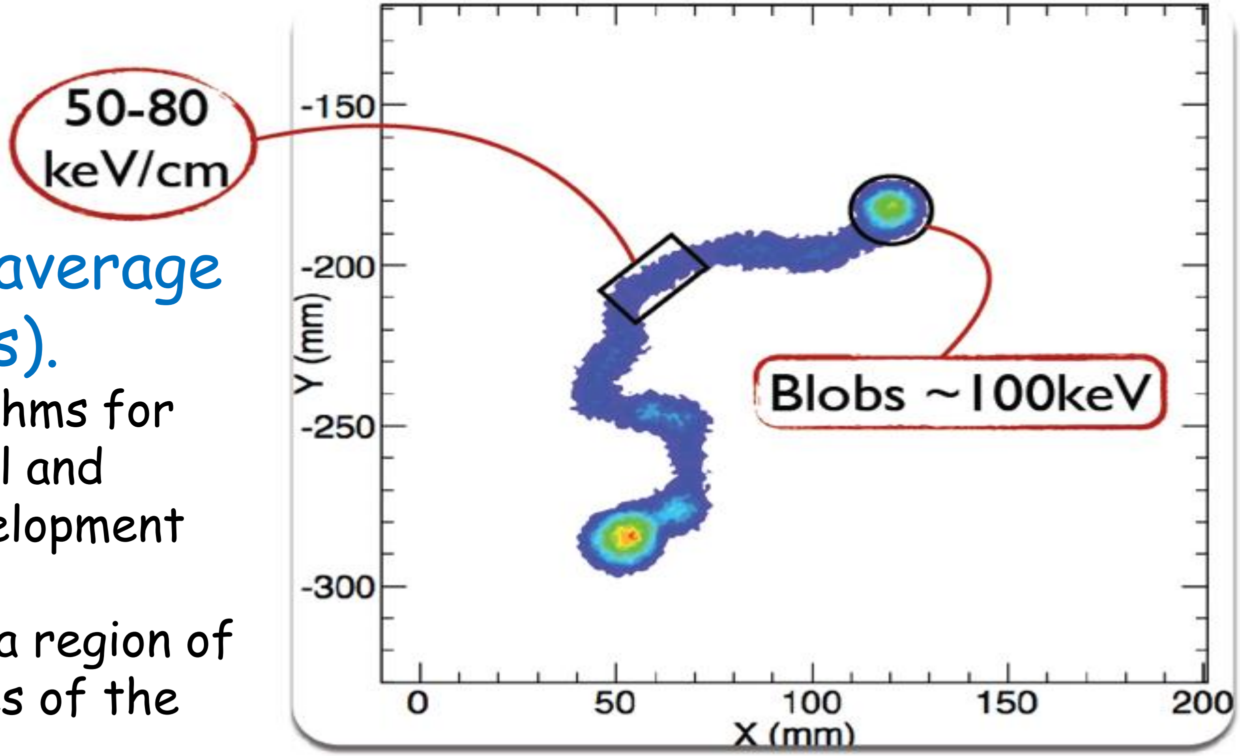






NEXT-NEW AND RESULTS: Simulation

Topology: numerical reconstruction of a $\beta\beta 0\nu$ event trajectory



Electrons travel on average 15 cm each (a few ns).

More sophisticated algorithms for the discrimination of signal and background are under development

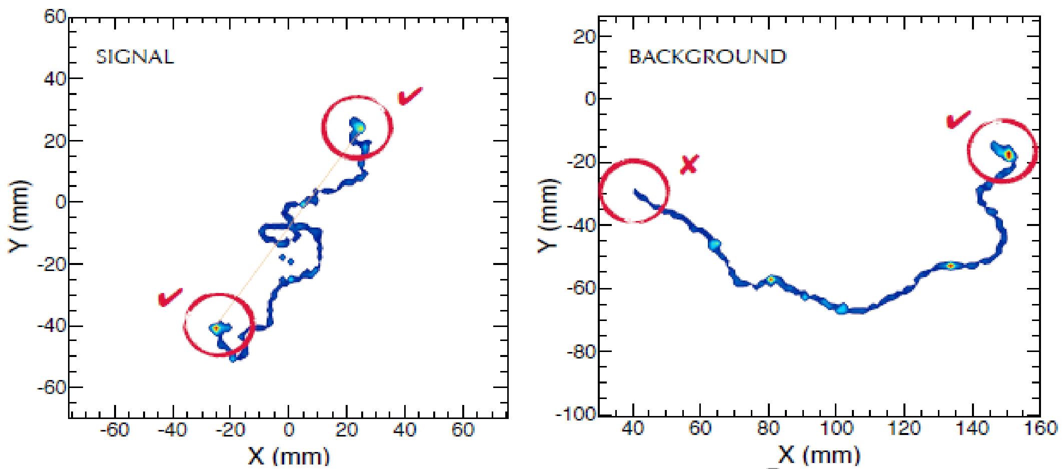
Fiducial volume: excluding a region of 2 cm around the boundaries of the active volume.
Events with energy between 2.4 and 2.5 MeV.

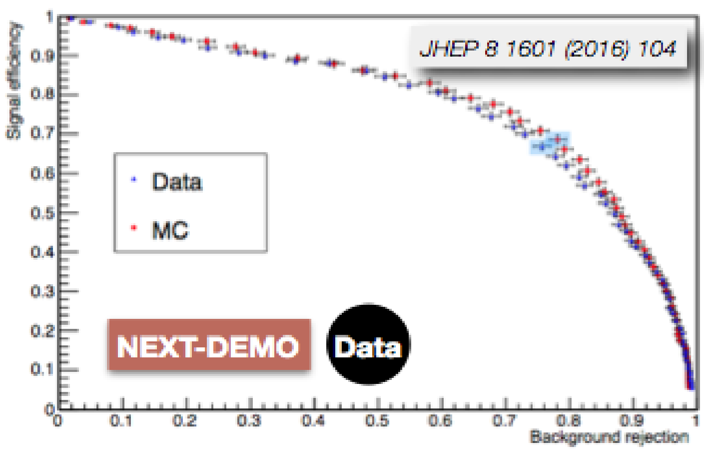
Topology: 30cm continuous trajectory with one blob in each extreme → Qbb≈2.47MeV

NEXT-NEW AND RESULTS: Background

Energy region around Q value of ^{136}Xe:

- charged particles elimination efficiency > 99% by fiducial volume
- neutral particles suppressed by distinctive energy-deposition pattern





Below critical energy ~12 MeV in gaseous Xe, electrons *dE/dx* relatively constant until they become non-relativistic then, mostly due to the occurrence of strong multiple scattering the particles lose the remaining *E* in a blob:

- **ββ0ν** two blobs at both ends
- Background one end-of-track blob.

NEXT-NEW AND RESULTS: Background

Detector subsystem	Material	Quantity	^{208}Tl (mBq)	^{214}Bi (mBq)
Pressure vessel				
Total	Steel 316Ti	1310 kg	< 197	< 603
Energy plane				
PMTs	R11410-10	60 units	11(3)	21(5)
PMT enclosures	Copper CuA1	60×4.3 kg	< 0.36	< 3.1
Enclosure windows	Sapphire	60×0.14 kg	0.34(8)	< 2.6
Tracking plane				
SiPMs	SensL 1 mm^2	107×64 units	< 0.2	< 0.6
Boards	Kapton FPC	107 units	1.11(12)	7.5(5)
Field cage				
Barrel	Polyethylene	128 kg	< 1	< 8
Shaping rings	Copper CuA1	120×3 kg	< 0.5	< 4
Electrode rings	Steel 316Ti	2×5 kg	< 1.5	< 5
Anode plate	Fused silica	9.5 kg	0.32(4)	2.0(5)
Resistor chain	1-GΩ resistors	240 units	< 0.0026	< 0.02
Shielding				
Inner shield	Copper CuA1	9620 kg	< 13	< 120
Outer shield	Lead	60700 kg	2060(430)	21300(4300)

Table 3. Radioactivity budget of the NEXT-100 detector. The figures in parentheses after the measurements give the 1-sigma uncertainties in the last digits. The upper limits in the activity of most subsystems originate in the 95% CL limits set on the specific activity of the corresponding materials quoted on Table 2.

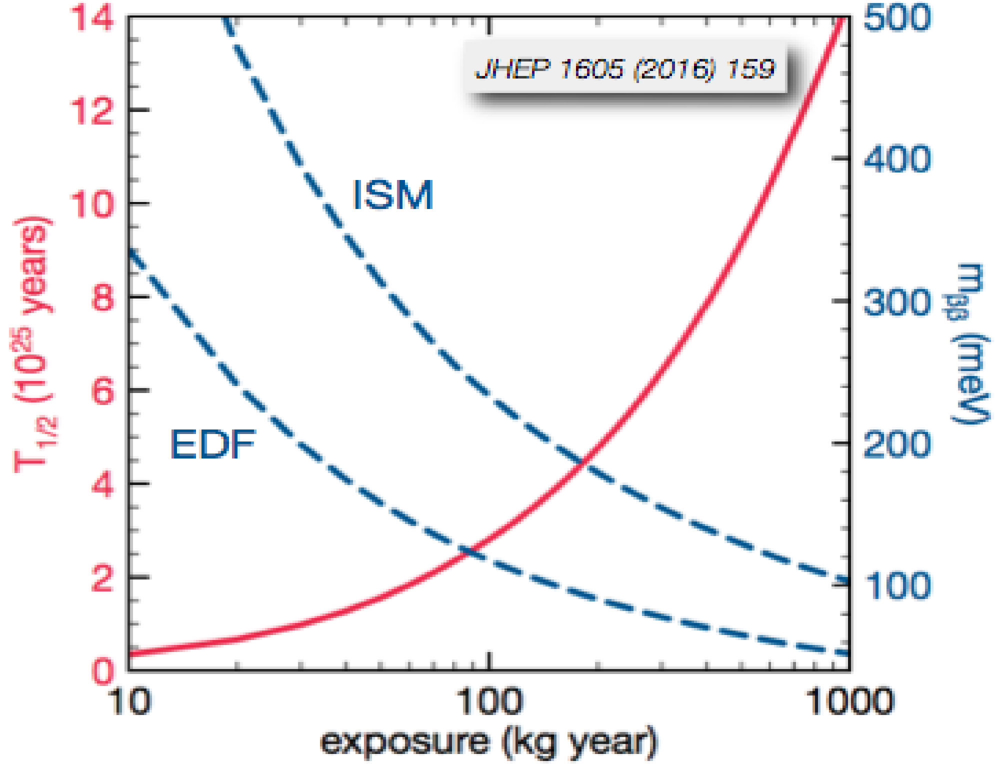
Campaign of material screening and selection: gamma-ray and mass spectroscopy techniques (international assistance).

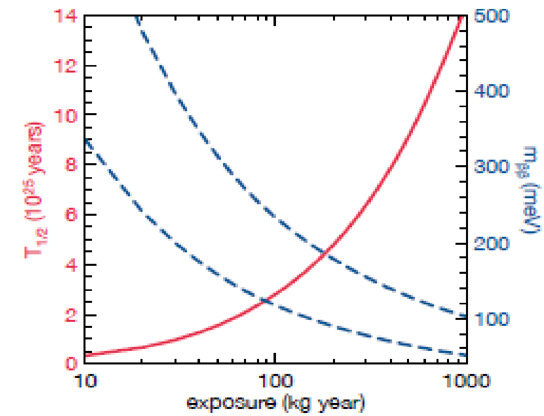
NEXT and all **ββ0ν** experiments, the main source of background: high-energy gammas from decays of ^{214}Bi and ^{208}Tl

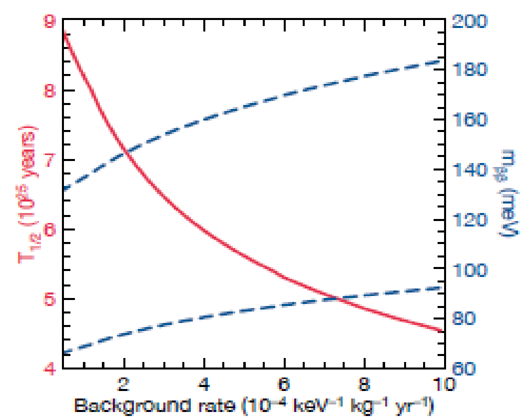
Muons and neutrinos are the only surviving radiation from the atmosphere and outer space at the depths of the underground laboratories.

NEXT-NEW AND RESULTS: Sensitivity

- $T_{1/2} = 6\times10^{25}$ yr sensitivity expected in 3 yr (90% CL)

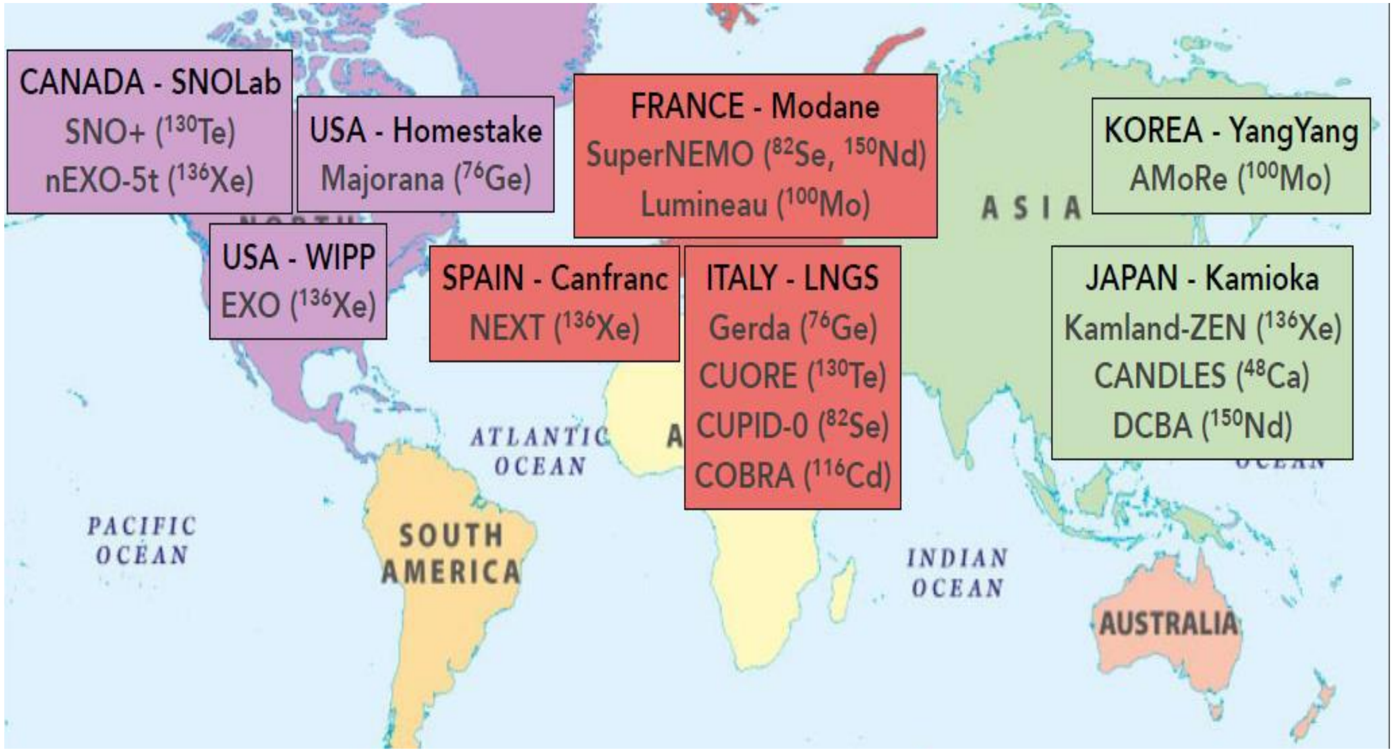




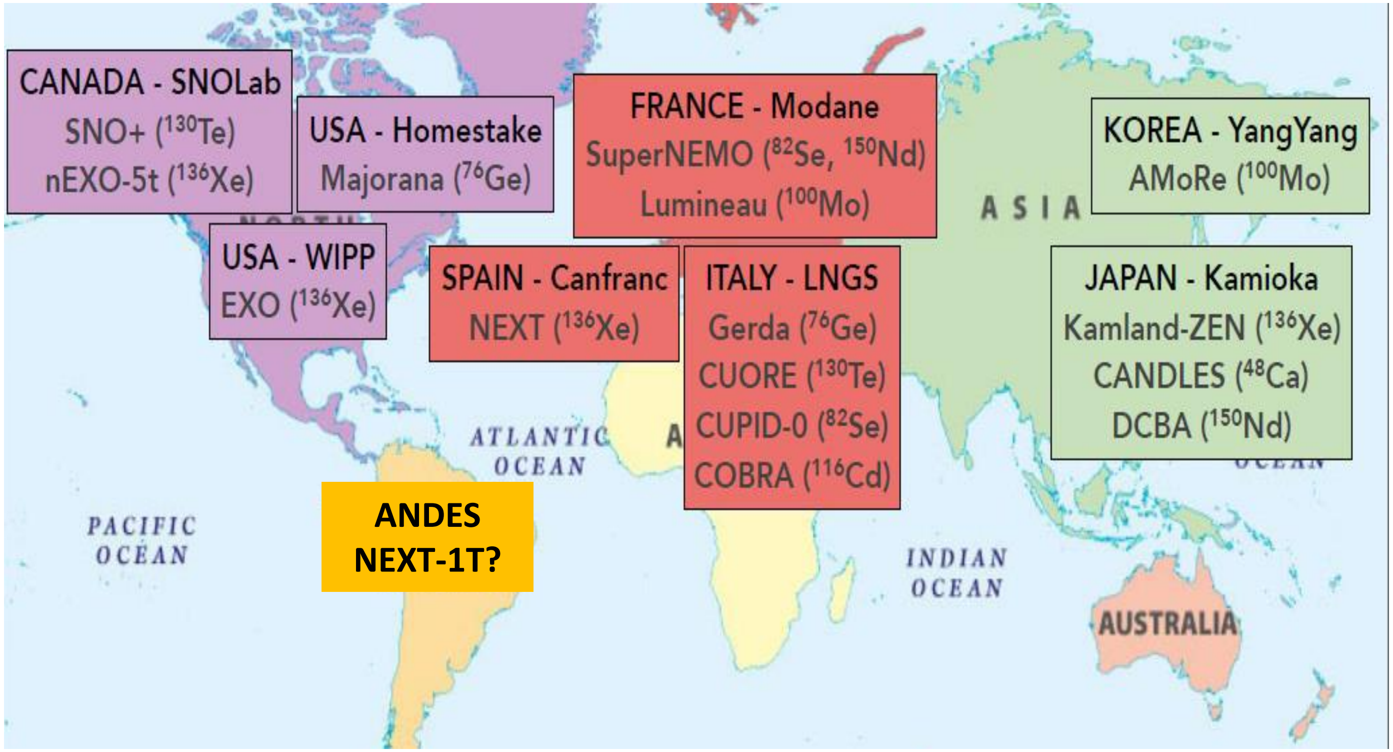


The NEXT-NEW data will provide in the near future a quantitative assessment of this question.

PRESENT GENERATION EXPERIMENTS FOR ββ0ν



PRESENT GENERATION AND FUTURE EXPERIMENTS FOR ββ0ν



COMPARISONS WITH LEADING ββ0ν EXPERIMENTS

NEXT main technique advantages over the competing experiments:

1. Excellent energy resolution:~ 0.3% FWHM (Full Width High Medium) intrinsic, 0.5% extrapolated with prototypes
2. Topological signature: background rejection factor ~100%

$$T^{-1}_{1/2} \propto a \cdot \varepsilon \sqrt{M.t/\Delta E.B}$$

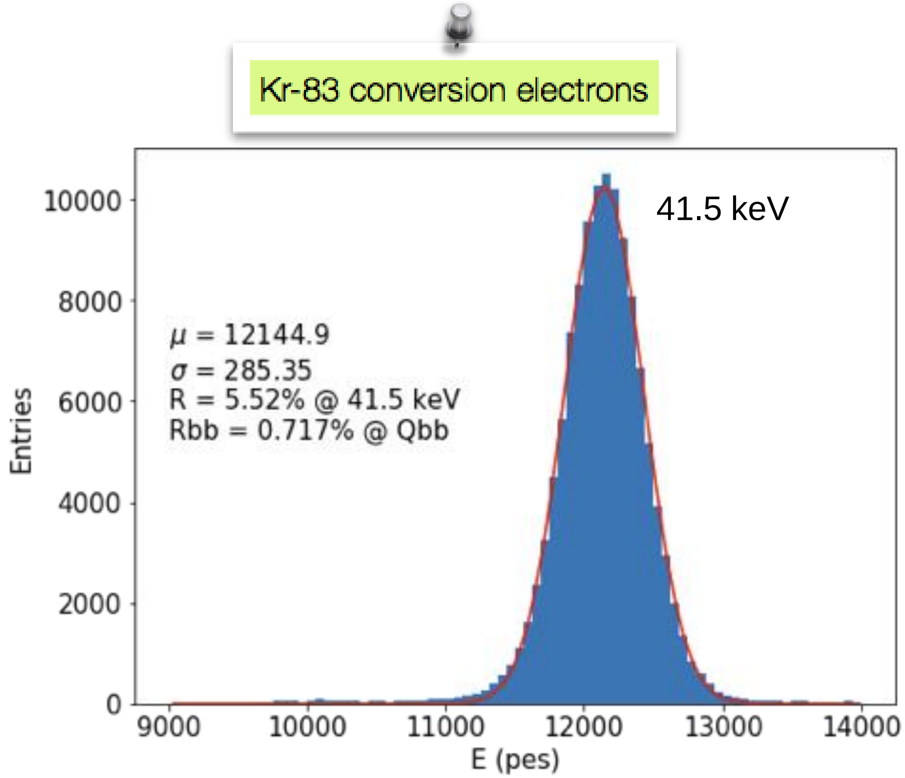
a: isotopic abundance
ε: overall efficiency
ΔE: resolution
B: Background rate
M.t: total exposure

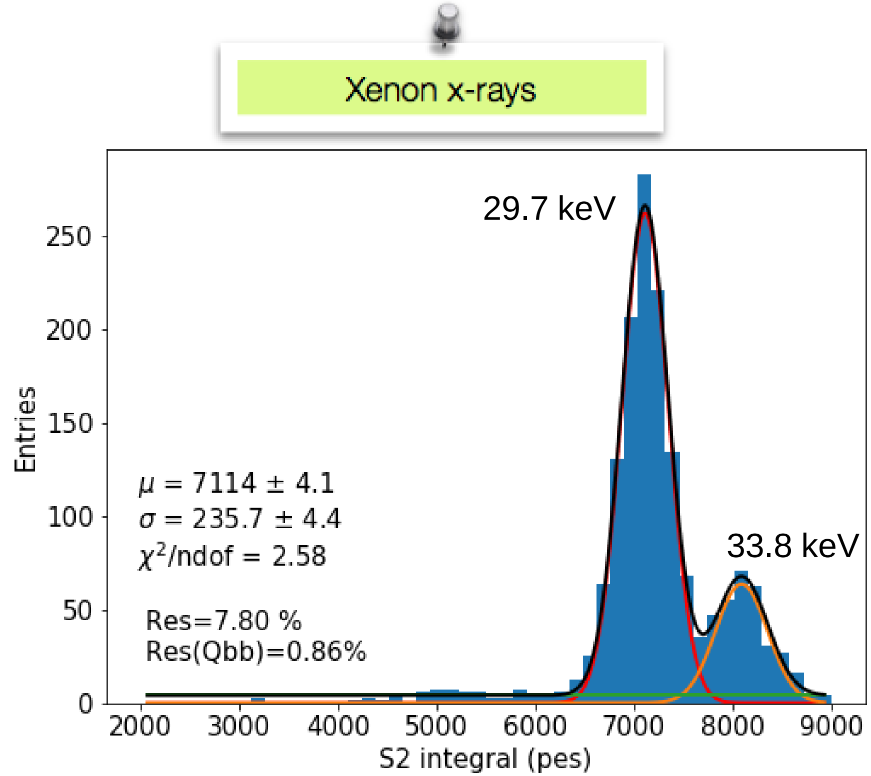
Parameter	EXO	KZEN	NEXT
a	0.8	0.9	0.9
ε	0.34	0.33	0.33
ΔE (FWHM in keV at Qββ)	100	250	18
B (in counts/(keV · kg · y))	8×10^{-4}	2×10^{-4}	2×10^{-4}
M (total, in kg)	200	330	100

LAST RESULTS NEXT-NEW

Energy resolution-low energies:

- 5.5% FWHM energy resolution measured with Kr-83 conversion electrons at 41.5 keV → 1/√E extrapolation yields 0.7% FWHM resolution at $Q_{\beta\beta}$
- Sufficient to separate 29.7 and 33.8 keV Xenon x-rays



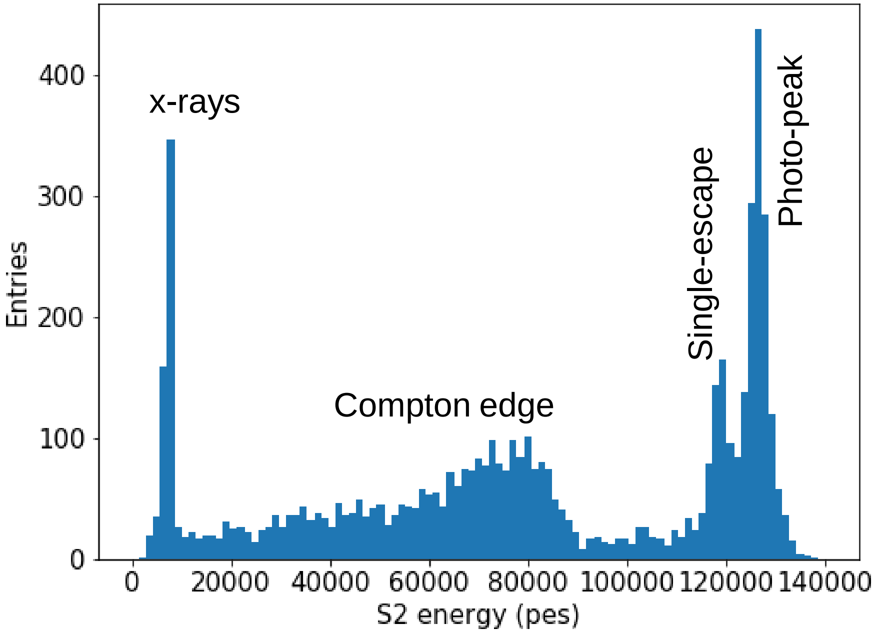


LAST RESULTS NEXT-NEW

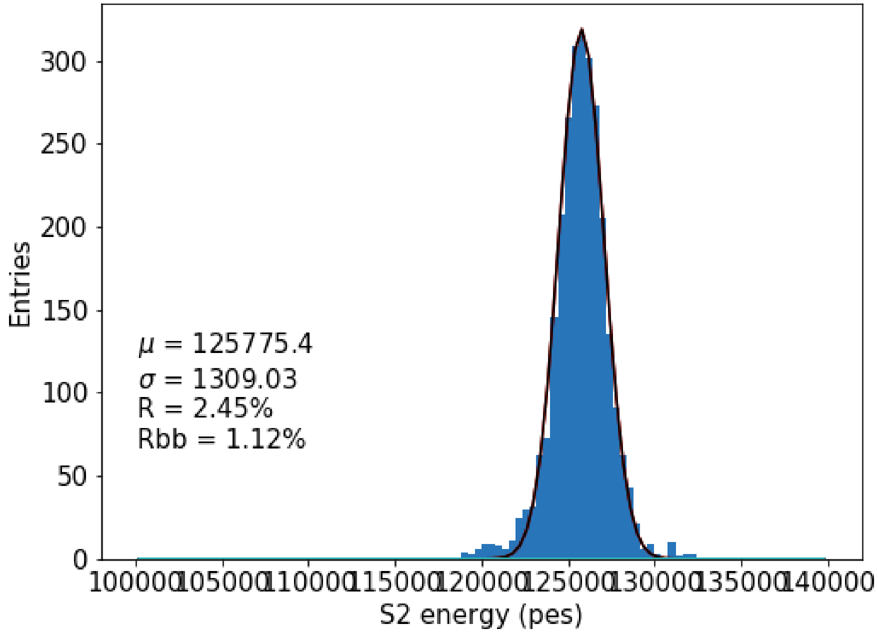
Energy resolution-higher energies

- Good energy resolution maintained at higher energies (511 keV from ^{22}Na)

Full spectrum



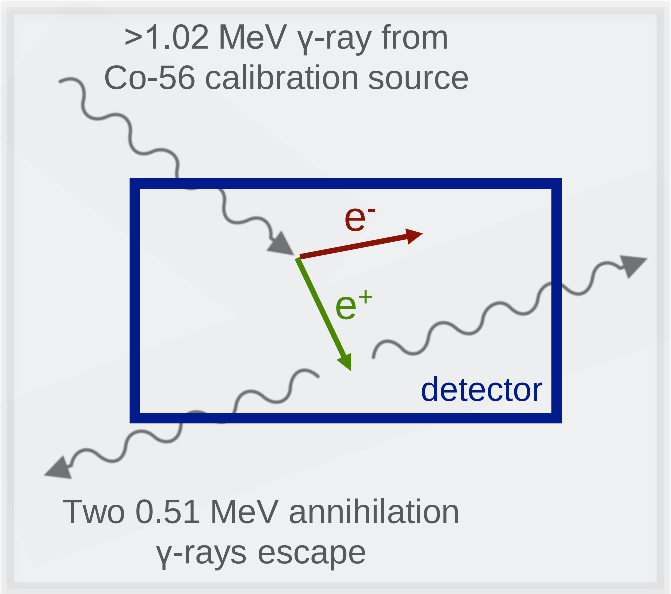
Select ^{22}Na photo-peak events

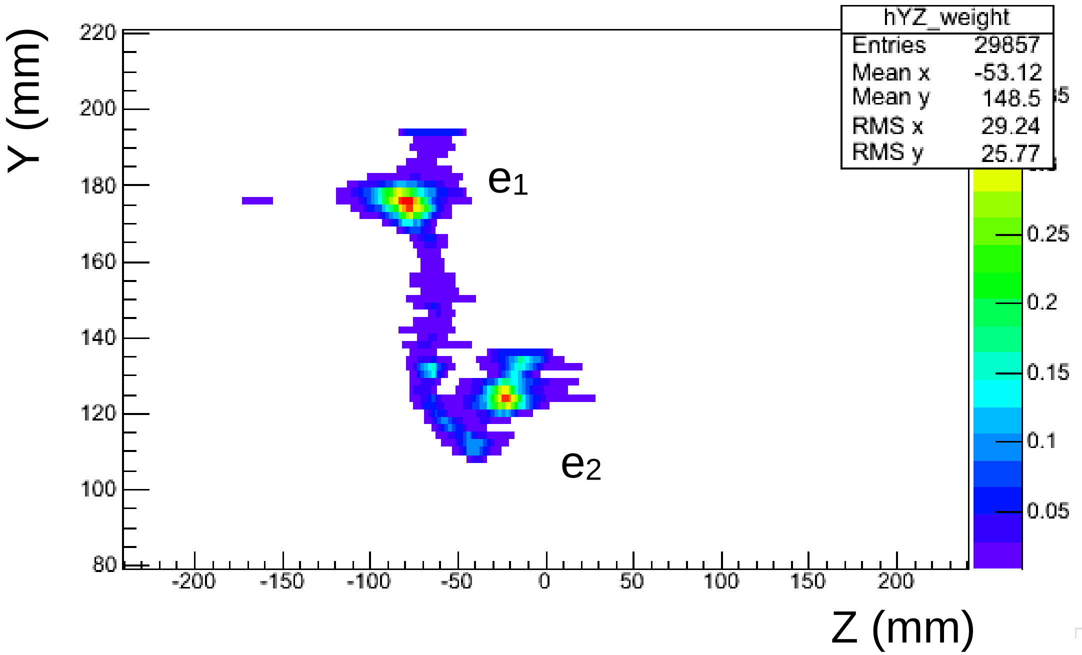


LAST RESULTS NEXT-NEW

Topological reconstruction

- Observe the two stopping electron tracks emitted from common vertex, characteristic of double beta decays
- Powerful handle for single-electron background suppression

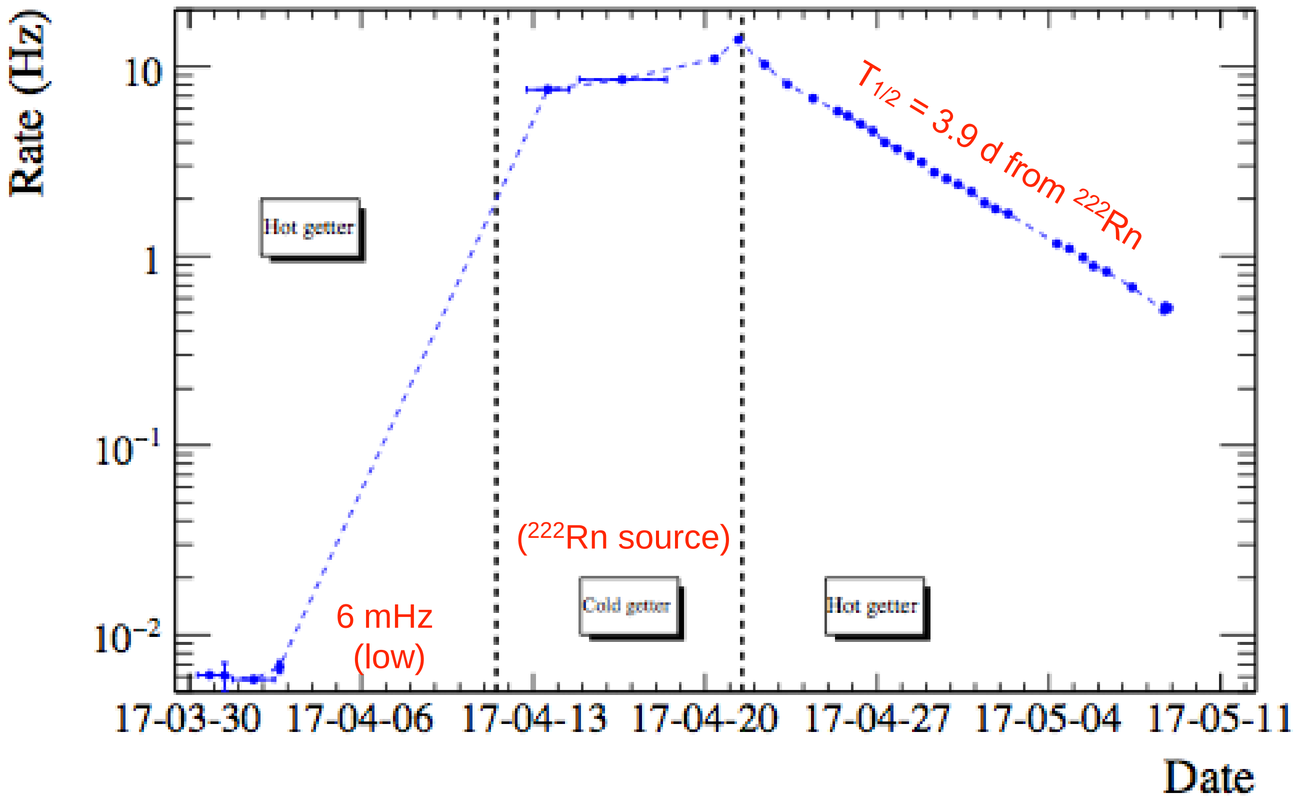




LAST RESULTS NEXT-NEW

Radon-induced backgrounds

- Alpha production rate measured in NEW during normal (hot getter) operations point to very low ^{222}Rn-induced backgrounds for NEXT-100
  - *< 10^{-4} counts / (keV·kg·yr)*



Summary and Conclusions

•NEXT is a new-generation experiment for ββ0ν
•NEXT marries TPC and EL in a novel approach: very good energy resolution and tracking for background rejection with relatively low cost and easily scalable for future ββ0ν generation detection.
•**The next decade will provide further experimental results to pin down neutrino properties and all its consequences for modern physics.**
• **ANDES: right moment for NEXT-1Ton, last generation experiment of ββ0ν towards the complete determination of the ν**

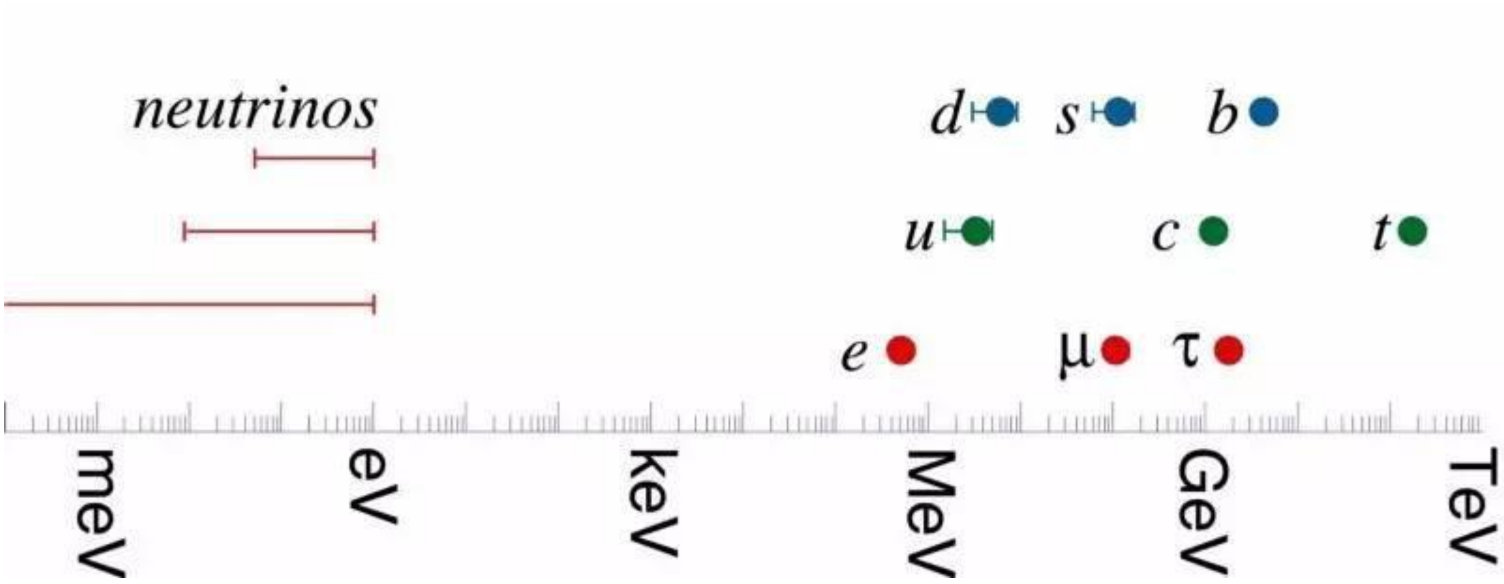
- **fast commissioning**
- **R&D ready and proved**
- **possible outstanding contribution to modern physics in LA at relatively low cost**

Thanks!
Gracias!

Backup slides

STANDARD MODEL

Basic constituents of matter



Murayama

Accounts for three of the four fundamental forces

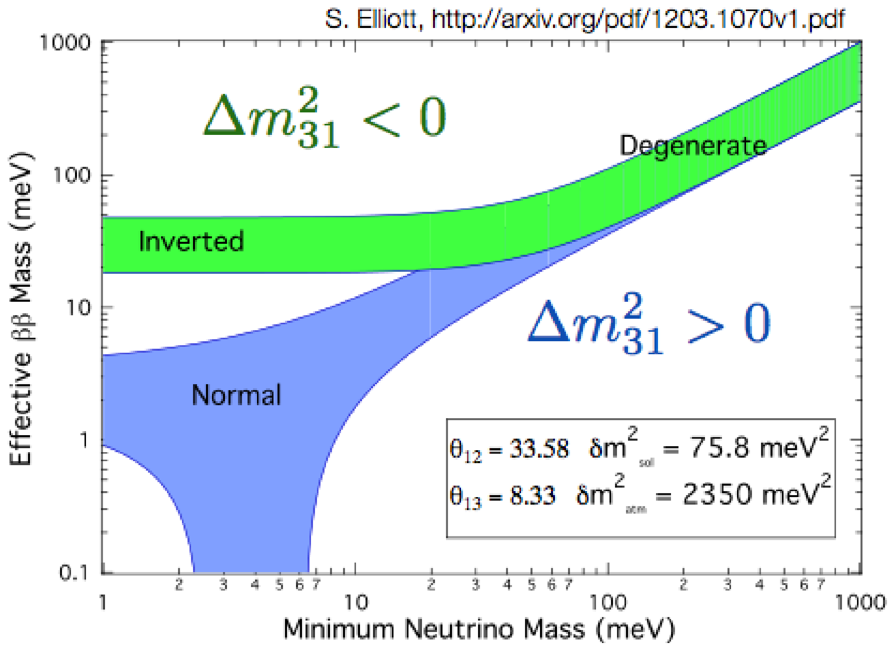
SU(3)xSU(2)xU(1)

Effective Majorana mass

$$\Gamma^{0\nu} = \frac{1}{T^{0\nu}_{1/2}} = G^{0\nu}(Q,Z)|M^{0\nu}|^2 \frac{|m_{\beta\beta}|^2}{m_e^2}$$

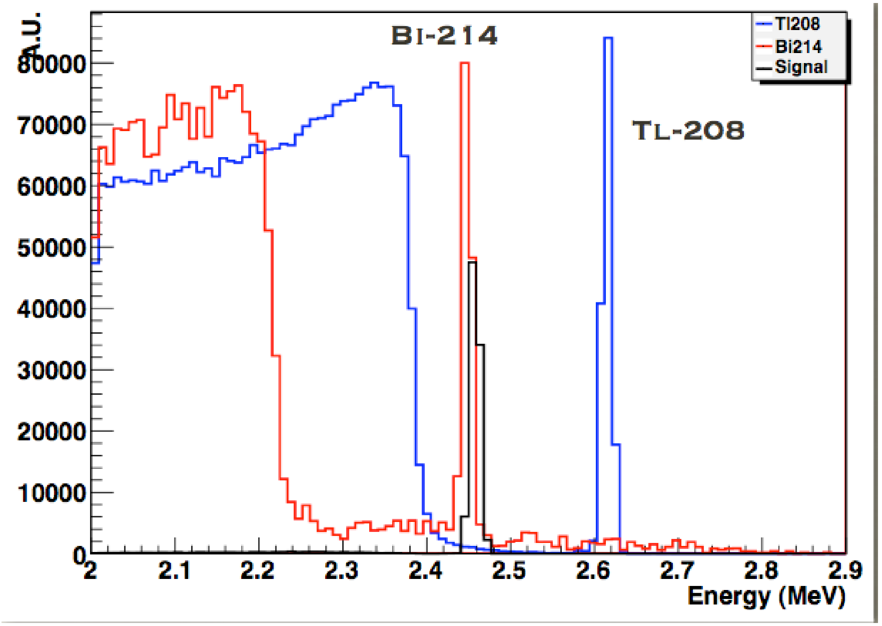
U is the neutrino mixing matrix

$$|m_{\beta\beta}| = |m_1|U_{e1}|^2 + m_2|U_{e2}|^2 e^{i(\alpha_1-\alpha_2)} + m_3|U_{e3}|^2 e^{i(-\alpha_1-2\delta)}|$$



These experiments are sensitive to: the absolute mass scale, the mass hierarchy, and the nature of neutrinos.

Radioactive background in Xe. Signal versus background



Main background are high energy gammas

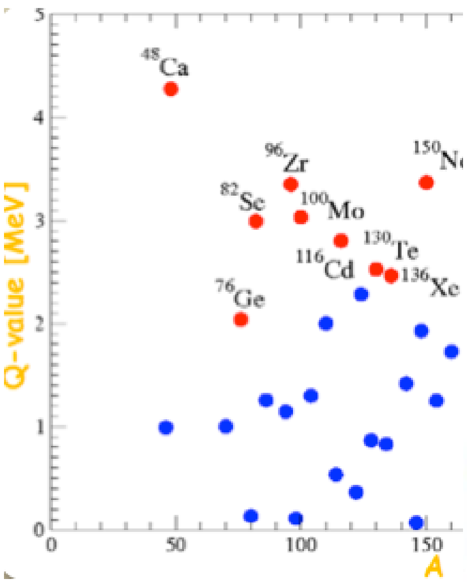
If $T_{1/2} \sim 10^{25}$ y

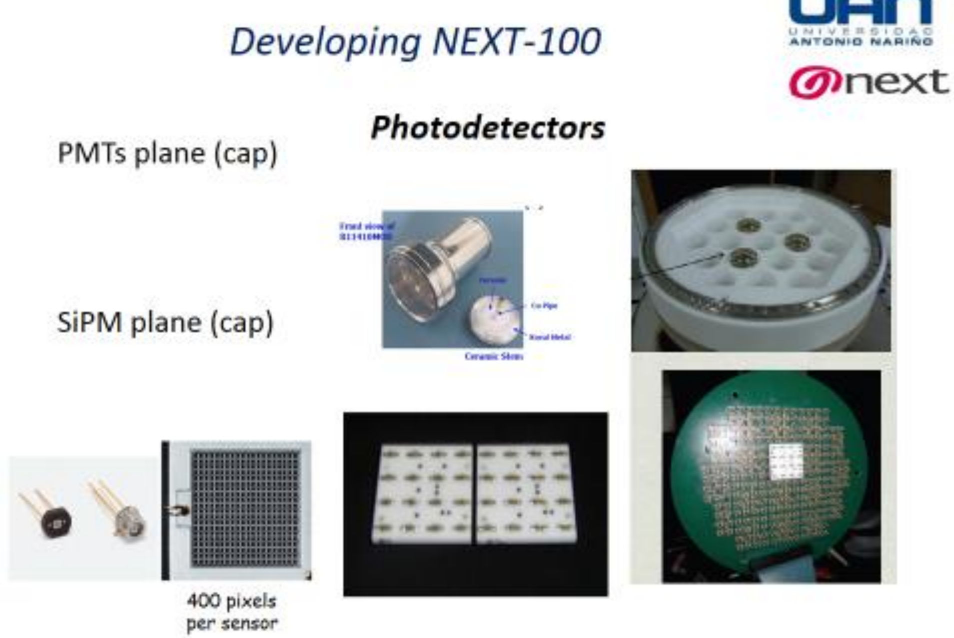
$$N_{\beta\beta}(Xe^{136}) = \log 2 \frac{6 \cdot 10^{23} \cdot 10^{3}(g) \cdot 1(y)}{10^{25} \cdot 136} \sim 0.1$$

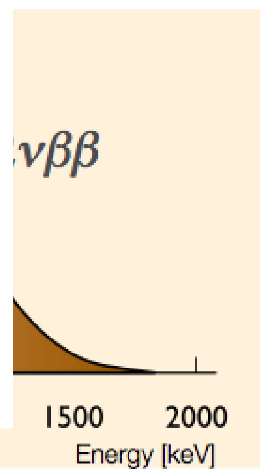
==> Need 100 kg y for signal

B/S ~ 1

NEUTRINOLESS DOUBLE BETA DECAY, ββ0ν







$(Q, Z)|M^{2\nu}|^2$

About 10 isc

A ~ 70-150

Q_{bb} ~ 2-3.5MeV

$T_{1/2}$ ~ 10^{18} - 10^{21} y

$$Q = E_{e1} + E_{e2} + E_{\nu 1} + E_{\nu 2} - 2m_e$$

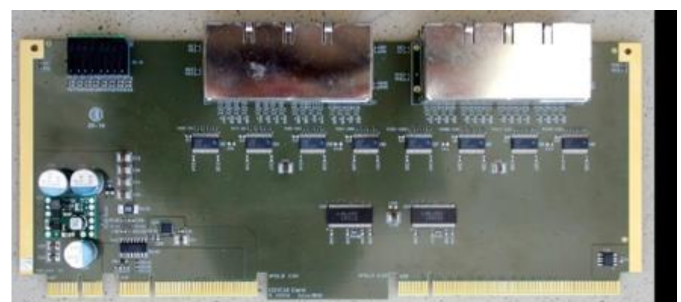
Developing NEXT-100

DAQ & Electronics

Three main components

I - The FEC card

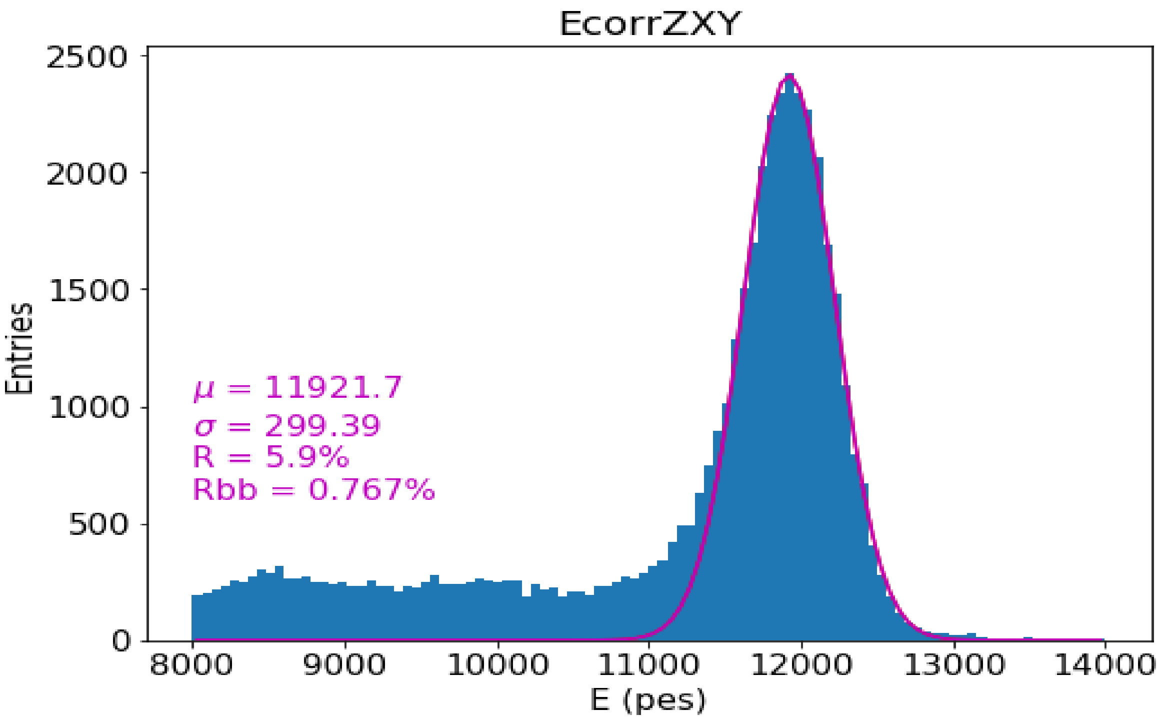
II - The CERN ADC add-in card.
PMT readout



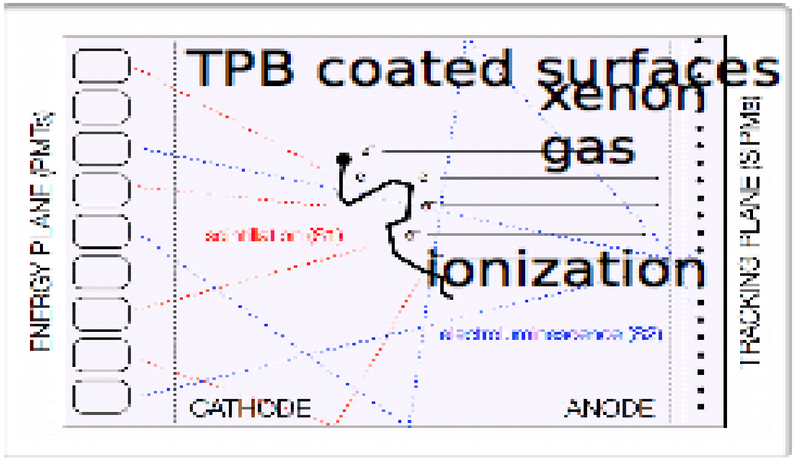
III - CDTC16 - The dual function add-in card.
Tracking and trigger interface

Last Results NEXT-NEW

- Krypton: at 10 Hz, (lifetime in excess of 700μ): resolution 5.9 % extrapolated to 0.767 % at Qbb. improvement with more statistics and better lifetime.
- Krypton lifetime and alphas lifetime are consistent.
- Next steps:
  a) Running with Na-22 in the axial port, triggering in S1 for 511 keV gammas and then in S2 for 1.275 MeV gammas (June-July 2017).
  b) Running with Cs-137 (July 2017).
  c) Co-56 source (starting 1st July 2017).



DETECTING ββ0ν WITH NEXT



- NEXT: High Pressure Xenon (HPXe) TPC operating in electroluminescent (EL) mode.
- NEXT-100: 100 kg of Xenon enriched at 90% in Xe-136 (in stock) at a pressure of 15 bar.
- Excellent energy resolution in gas phase:
- $\delta E/E = 5 \times 10^{-3}$ FWHM possible
- Topology available for background rejection