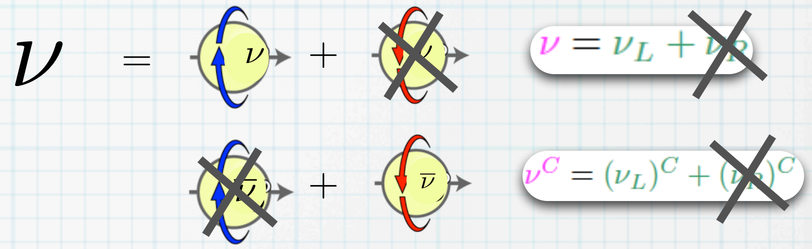
NEXT

Jose A. Hernando
(Universidade de Santiago de Compostela, Spain)
(on behalf of the NEXT collaboration)

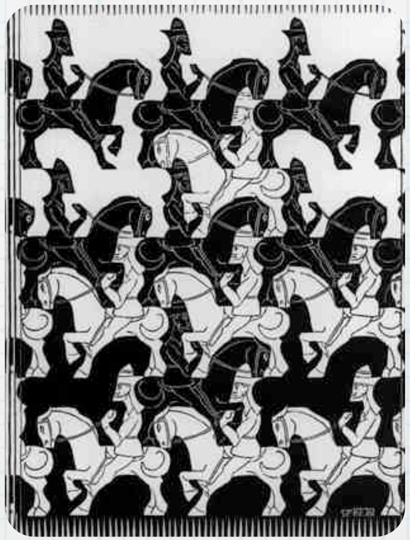
The nature of the neutrino



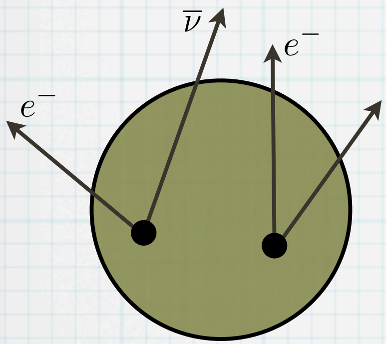
- Neutrinos could open the door to NP beyond the SM
- SM needs to be completed to provide masses to neutrinos
- There are two methods to provide the neutrino mass: Dirac or Majorana

$$\nu = \nu_L + \nu_L^C \qquad \nu^c = \nu \qquad \nu = \bar{\nu}$$

- Majorana neutrinos are 'economic', as there are only two states instead of four
- If they are Majorana, neutrino is its own antiparticle
- The only experiment to determine if neutrinos are Majorana is Neutrino Double Beta Decay (ββ0ν) without emission of neutrinos

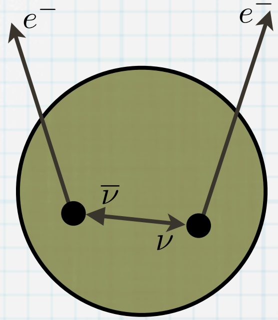


Double Beta Decay



$\beta\beta 2\nu$

- A second order weak process that can occur in some specific nuclei
- ββ2ν measured in some nuclei (with large half-live time)
- If neutrinos are Majorana, ββ0ν (without neutrinos) can occur (with even larger half-live time)



$\beta\beta 0\nu$

$T_{1/2} \sim 10^{18} - 10^{20}$ y

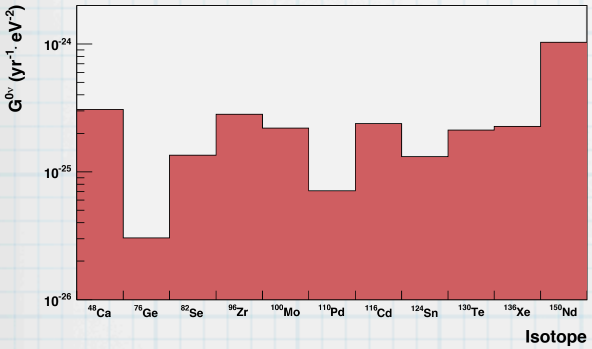
$$(T^{0\nu}_{1/2})^{-1} = G^{0\nu}(Q,Z)\,|M^{0\nu}|^2\, m^2_{\beta\beta}$$

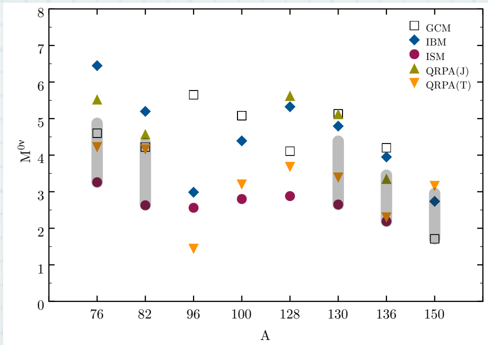
$T_{1/2} > 10^{25}$ y

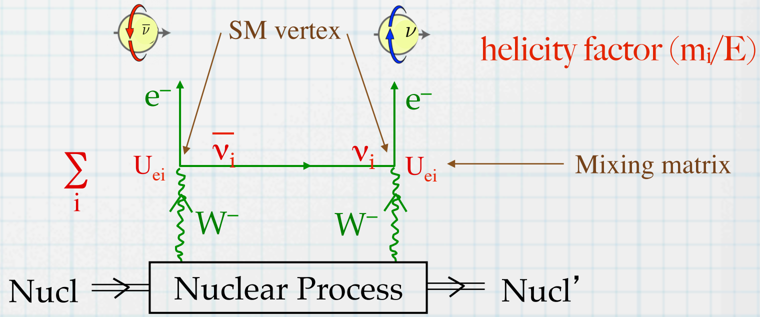
Phase space

NME calculations

$m_{\beta\beta}$ effective ν mass







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

MNPS mixing matrix elements

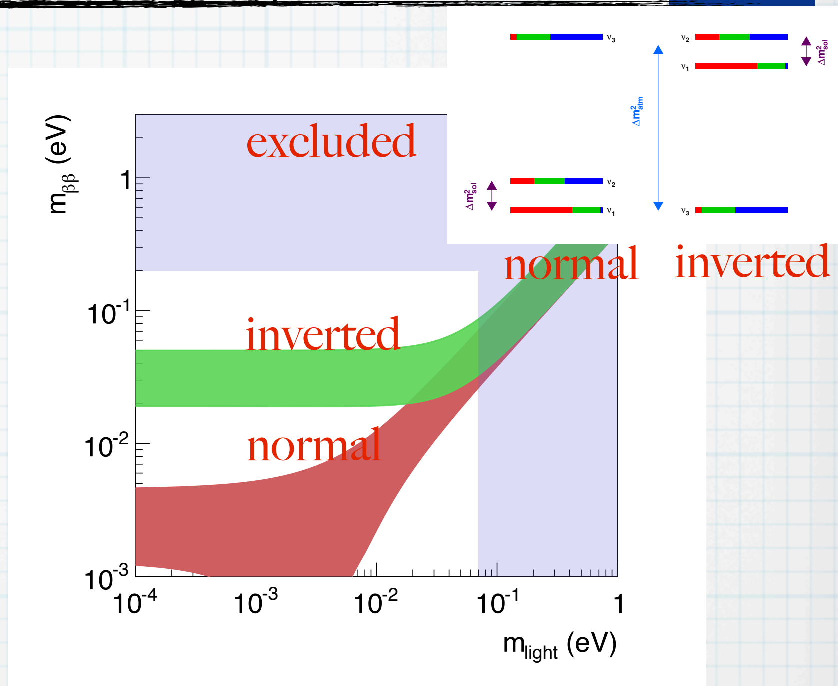
Unknown Majorana phases

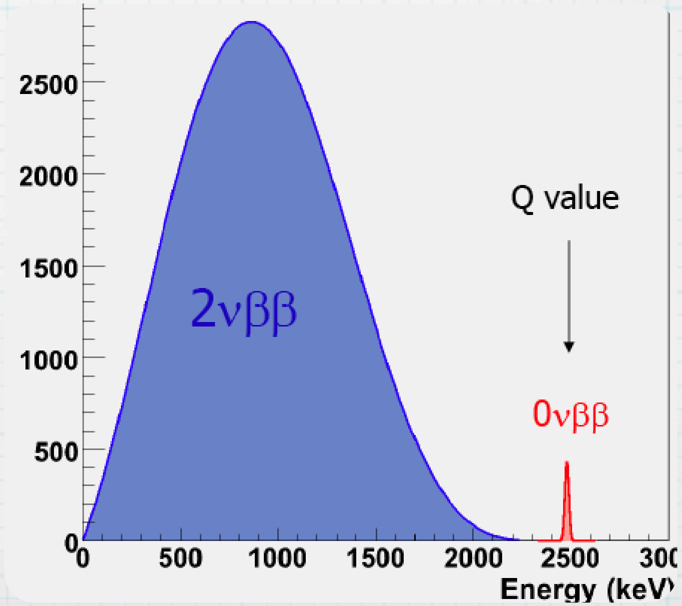
The Majorana Landscape

- A historical search, current limits by EXO, KamLAND-Zen (^{136}Xe), Gerda (^{76}Ge).
- it requires $m_{\beta\beta}$<20 meV! to cover normal neutrino hierarchy. Current experiments get limits around 200 meV
- Normal hierarchy not accessible...

$$T_{1/2}^{-1} \propto a \cdot \epsilon \cdot \sqrt{\frac{Mt}{\Delta E \cdot B}}$$

- Efficiency: detector = target
- Mass (i.e 100 kg Xe, if 10^{-25} y, 3 events ββ0ν /y)
- Energy Resolution
- Background rejection

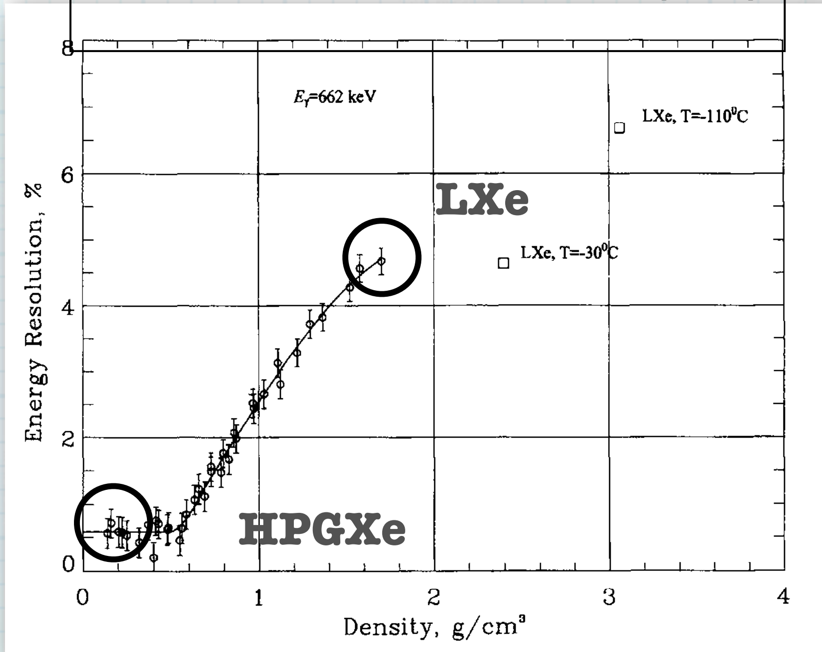


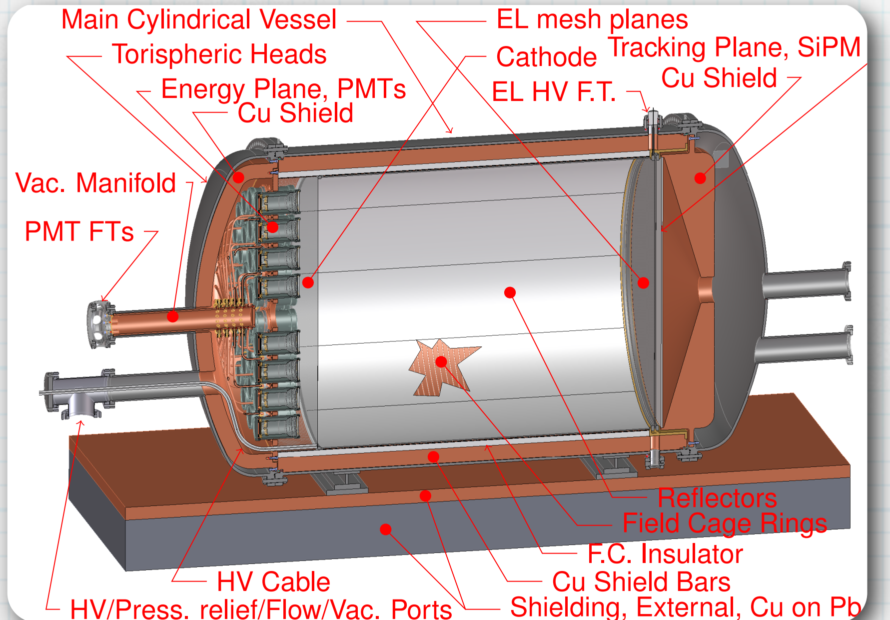


Xenon and NEXT

- 136Xe, cheap, easy to enrich
- $Q_{\beta\beta}$ = 2458 keV, reduce radioactive backgrounds
- Noble gas, fully active mass
- Scalable (for several ton detector)

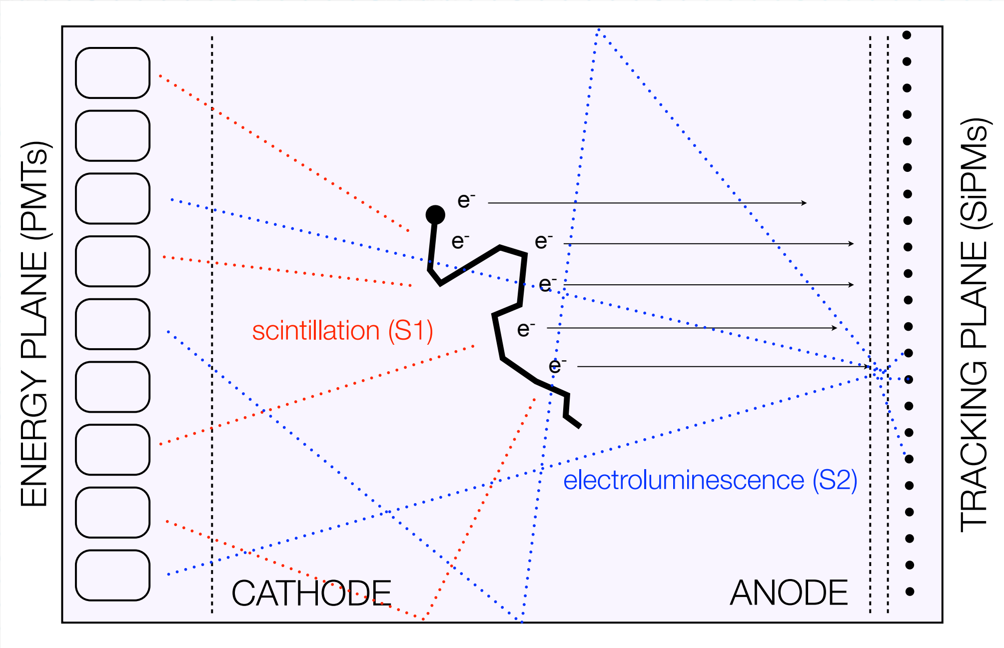
Bolotnikov, Ramsey NIM A 396 (1997)





- High Pressure Gas TPC
- 100 kg 136Xe at 15 bar
- Energy and topological reconstruction of ββ0ν
- Radiopure components

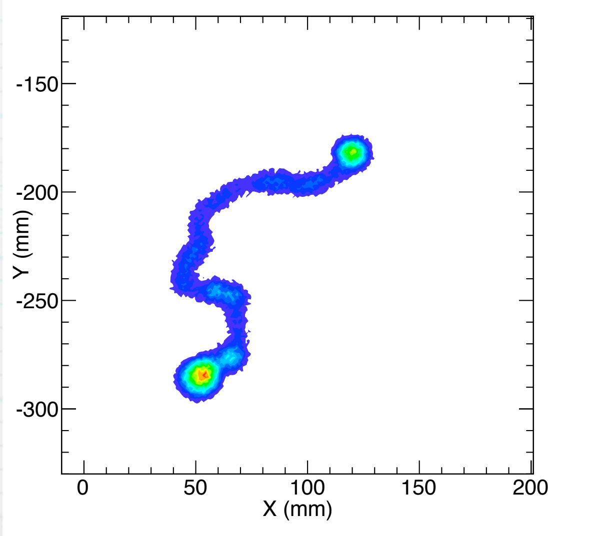
NEXT-Concept



- electron excites and ionizes Xe
- excited Xe emit scintillation light (S1)
- electrons from ionization drift
- electrons in the electroluminiscence (EL) mesh excite Xe and produce photons (S2)

idealization of $\beta\beta0\nu$ event:

2 electrons that form a track with two 'blobs' (large energy deposition) at the end-points



- NEXT objectives:
  - Radiopure $5\ 10^{-4}$ counts /(keV kg y)
  - Energy resolution <1% (FWHM @ $Q_{\beta\beta}$)
  - Topology: identify electron end-point (blob)

NEXT-Collaboration

IFIC (Valencia), U. Zaragoza, U. Santiago, U. Girona, U. Politécnica Valencia, U. A. Madrid

U. Coimbra, U. Aveiro

LBNL, Texas A&M U., Iowa State U.

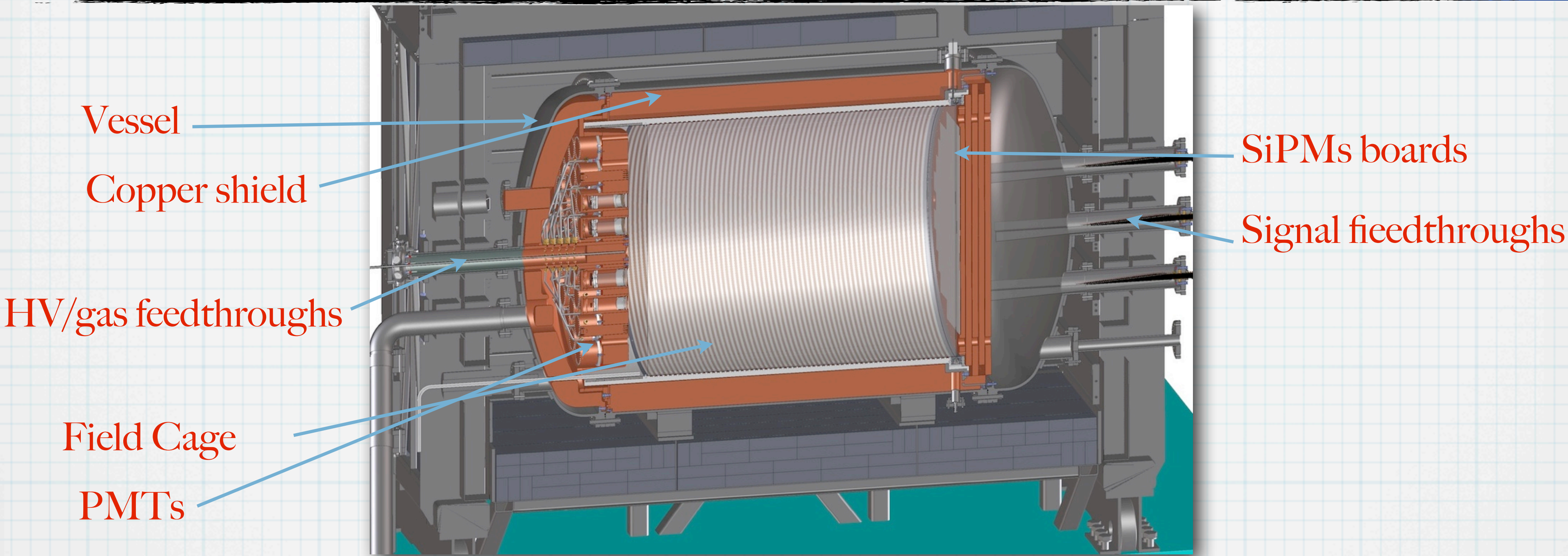
JINR (Dubna)

U. Antonio Nariño (Bogotá)

Collaboration members at Canfranc Underground Laboratory (LSC), 80 people, 5 countries

Grants: Consolider-2010 (Spain), ERC-ADG 2013 (EU)

NEXT-100

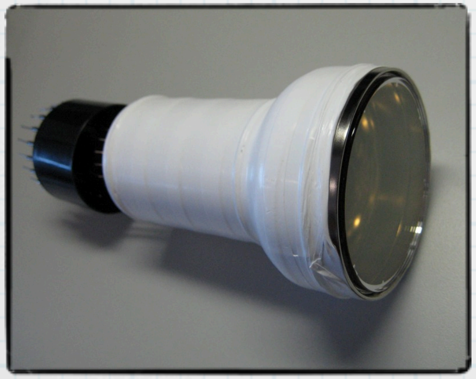


- Vessel: 1,2 tons stainless steel ^{316}Ti alloy, very low activity, with 12 cm inner copper shield (it blocks radiation by a factor 100)
- Field cage: 130 cm long, 105 cm diameter, high density polyethlene cylindrical shell, EL 1cm, 3 wire meshes with 88% transparency
- Energy plane: 60 PMTs, low radioacticity, 30% coverage, but encapsulated in cans with sapphire windows to hold pressure
- Tracking plane: 7 k SiPMs 1 mm^2 active area, located in boards (8x8 each), separated 1 cm, coated to a wavelength shifter (TPB)

NEXT-100

Vessel

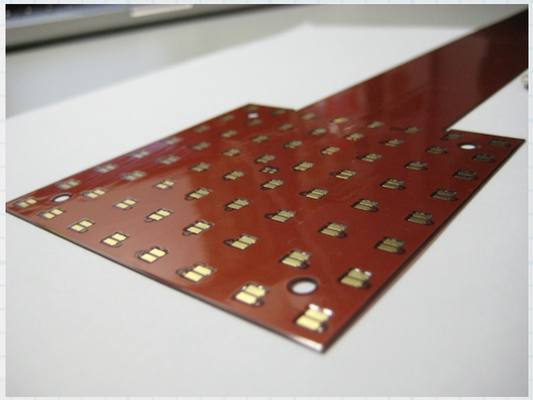
R11410-10
Hamamatsu PMT



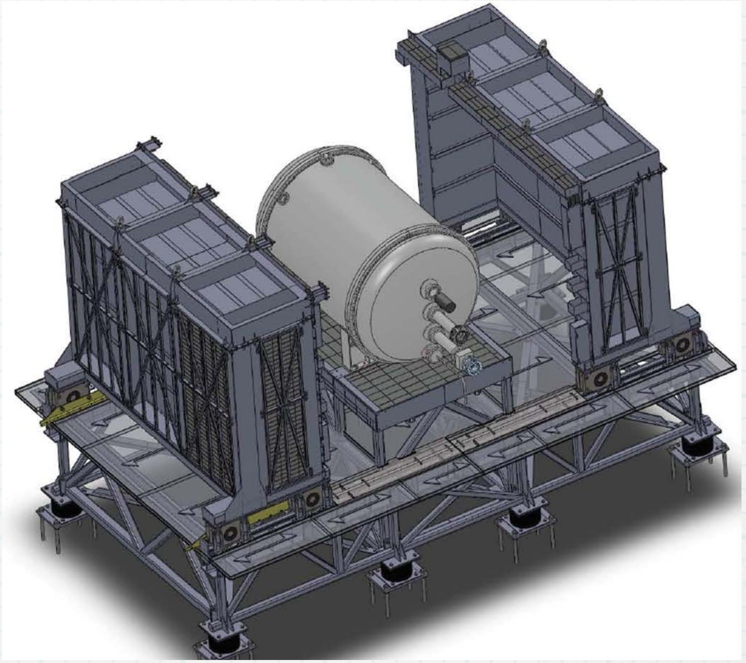
can

S10362-11-050P
SiPM

8x8 SiPM board
and cable



NEXT-100



Xenon

gas system

- Seismic platform and gas system: been installed at LSC.
- Xe procured and at LSC

Radiopurity measurements

- Main contamination (from Th, U chains):
  - ^{208}Tl (γ,2615 keV), ^{214}Bi (γ,2448 kEV)
- Radioactive budget measured at LSC

•[NEXT Collaboration]
``Radiopurity control in the NEXT-100 double beta decay experiment: procedures and initial measurements" JINST 8 T01002 (2013)

#	Material	Supplier	Technique	Unit	^{238}U	^{226}Ra	^{232}Th	^{228}Th	^{235}U	^{40}K	^{60}Co	^{137}Cs
	Shielding											
1	Pb	Cometa	GDMS	mBq/kg	0.37		0.073			<0.31		
2	Pb	Mifer	GDMS	mBq/kg	<1.2		<0.41			0.31		
3	Pb	Mifer	GDMS	mBq/kg	0.33		0.10			1.2		
4	Pb	Tecnibusa	GDMS	mBq/kg	0.73		0.14			0.91		
5	Pb	Tecnibusa	Ge	mBq/kg	<94	<2.0	<3.8	<4.4	<30	<2.8	<0.2	<0.8
6	Pb	Tecnibusa	Ge	mBq/kg	<57	<1.9	<1.7	<2.8	<22	<1.7	<0.1	<0.5
7	Cu (ETP)	Sanmetal	GDMS	mBq/kg	<0.062		<0.020					
8	Cu (C10100)	Luvata (hot rolled)	GDMS	mBq/kg	<0.012		<0.0041			0.061		
9	Cu (C10100)	Luvata (cold rolled)	GDMS	mBq/kg	<0.012		<0.0041			0.091		
10	Cu (C10100)	Luvata (hot+cold rolled)	Ge	mBq/kg		<7.4	<0.8	<4.3		<18	<0.8	<1.2
	Vessel											
11	Ti	SMP	Ge	mBq/kg	<233	<5.7	<8.8	<9.5	3.4±1.0	<22	<3.3	<5.2
12	Ti	SMP	Ge	mBq/kg	<361	<6.6	<11	<10	<8.0	<15	<1.0	<1.8
13	Ti	Ti Metal Supply	Ge	mBq/kg	<14	<0.22	<0.5	3.6±0.2	0.43±0.08	<0.6	<0.07	<0.07
14	304L SS	Pfeiffer	Ge	mBq/kg		14.3±2.8	9.7±2.3	16.2±3.9	3.2±1.1	<17	11.3±2.7	<1.6
15	316Ti SS	Nironit, 10-mm-thick	Ge	mBq/kg	<21	<0.57	<0.59	<0.54	<0.74	<0.96	2.8±0.2	<0.12
16	316Ti SS	Nironit, 15-mm-thick	Ge	mBq/kg	<25	<0.46	<0.69	<0.88	<0.75	<1.0	4.4±0.3	<0.17
17	316Ti SS	Nironit, 50-mm-thick	Ge	mBq/kg	67±22	<1.7	2.1±0.4	2.0±0.7	2.4±0.6	<2.5	4.2±0.3	<0.6
18	Inconel 625	Mecanizados Kanter	Ge	mBq/kg	<120	<1.9	<3.4	<3.2	<4.6	<3.9	<0.4	<0.6
19	Inconel 718	Mecanizados Kanter	Ge	mBq/kg	309±78	<3.4	<5.1	<4.4	15.0±1.9	<13	<1.4	<1.3
	HV, EL components											
20	PEEK	Sanmetal	Ge	mBq/kg		36.3±4.3	14.9±5.3	11.0±2.4	<7.8	8.3±3.0	<3.3	<2.6
21	Polyethylene	IN2 Plastics	Ge	mBq/kg	<140	<1.9	<3.8	<2.7	<1.0	<8.9	<0.5	<0.5
22	Semitron ES225	Quadrant EPP	Ge	mBq/kg	<101	<2.3	<2.0	<1.8	1.8±0.3	513±52	<0.5	<0.6
23	SMD resistor	Farnell	Ge	mBq/pc	2.3±1.0	0.16±0.03	0.30±0.06	0.30±0.05	<0.05	0.19±0.08	<0.02	<0.03
24	SM5D resistor	Finechem	Ge	mBq/pc	0.4±0.2	0.022±0.007	<0.023	<0.016	0.012±0.005	0.17±0.07	<0.005	<0.005
	Energy, tracking planes											
25	Kapton-Cu PCB	LabCircuits	Ge	mBq/cm^2	<0.26	<0.014	<0.012	<0.008	<0.002	<0.040	<0.002	<0.002
26	Cuflon	Polyflon	Ge	mBq/kg	<33	<1.3	<1.1	<1.1	<0.6	4.8±1.1	<0.3	<0.3
27	Bonding films	Polyflon	Ge	mBq/kg	1140±300	487±23	79.8±6.6	66.0±4.8	60.0±5.5	832 ±87	<4.4	<3.8
28	FFC/FCP connector	Hirose	Ge	mBq/pc	<50	4.6±0.7	6.5±1.2	6.4±1.0	<0.75	3.9±1.4	<0.2	<0.5
29	P5K connector	Panasonic	Ge	mBq/pc	<42	6.0±0.9	9.5±1.7	9.4±1.4	<0.95	4.1±1.5	<0.2	<0.8

PMTs radio level measurement at LSC

estimations counts / (keV kg y)

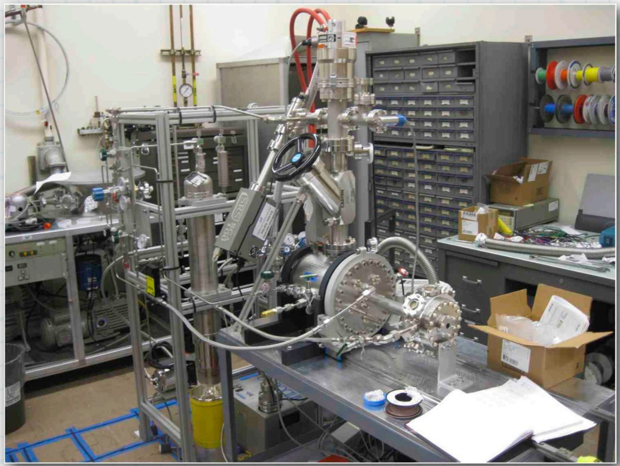
	^{208}Tl	^{214}Bi
energy plane	3×10^{-5}	2×10^{-5}
tracking plane	2×10^{-4}	2×10^{-5}
pressure vessel	3×10^{-5}	2×10^{-6}
field cage	2×10^{-5}	2×10^{-5}

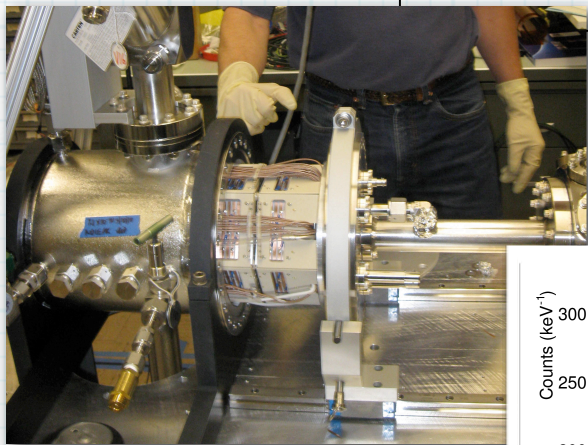
estimate $4 \; 10^{-4}$ counts /(keV kg y)

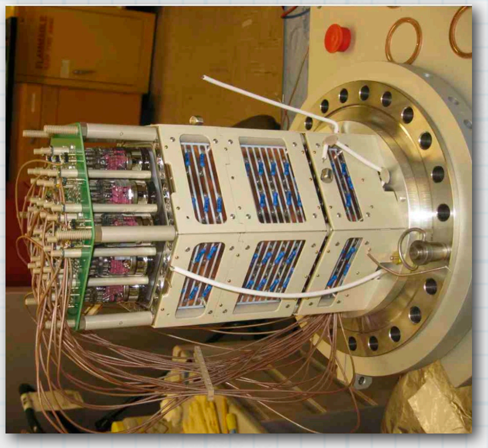
Prototypes NEXT-DBDM

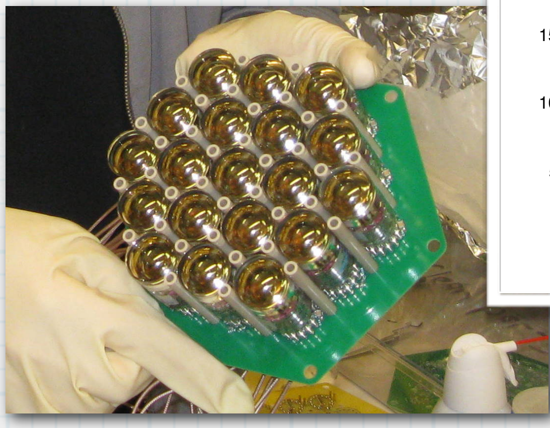
- Berkeley lab (1 kg):
  - demonstrate energy resolution

•**V. Alvarez, *et al.* [NEXT Collaboration],** **"Near-Intrinsic Energy Resolution for 30 to 662 keV Gamma Rays in a High Pressure Xenon Electroluminescent TPC," arXiv:1211.4474 [physics.ins-det].**

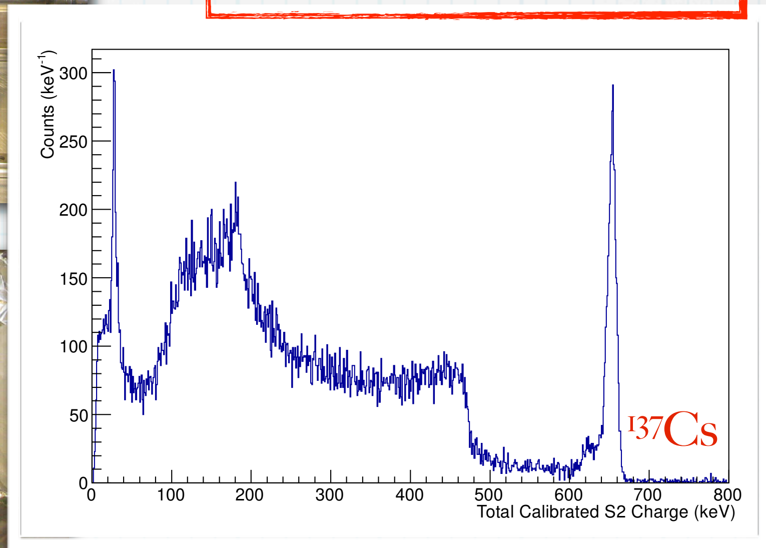








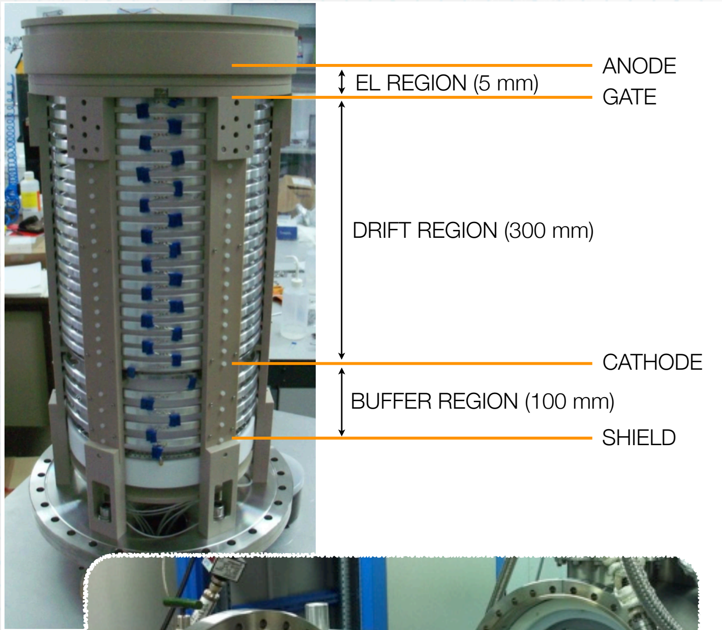
0.5 % FWHM extrapolated @ $Q_{\beta\beta}$

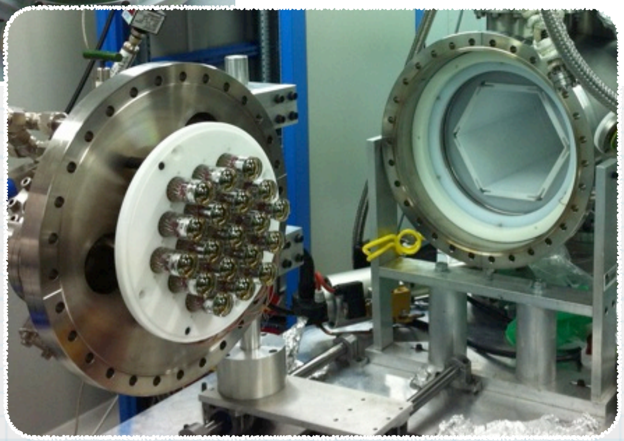


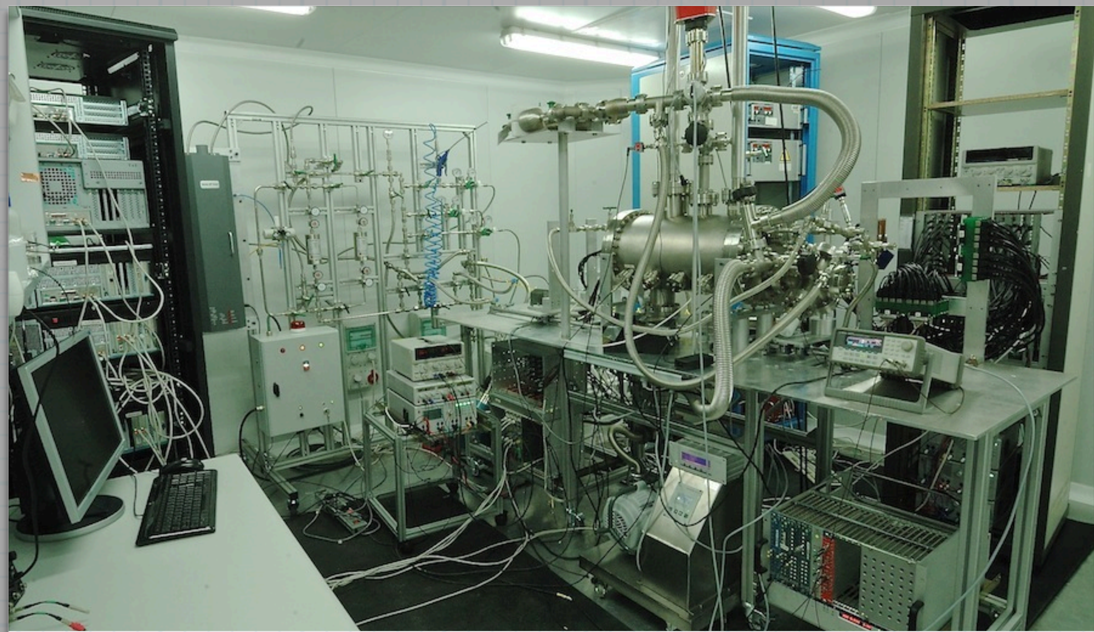
Prototypes NEXT-DEMO

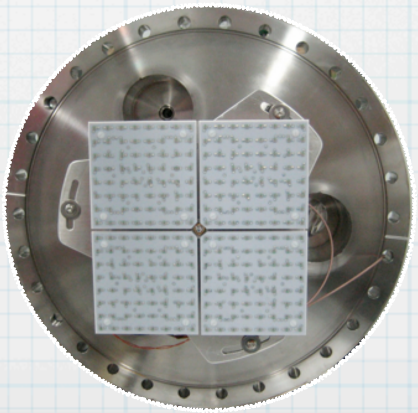
- IFIC-Valencia (2.5 kg) :
  - Technical viability
  - Energy and Topology reconstruction

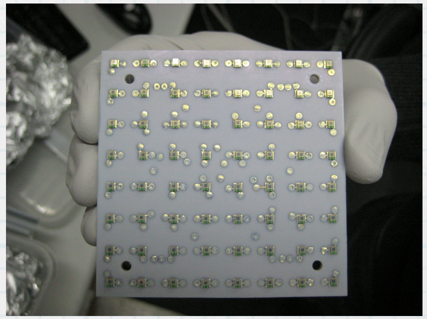
•**[NEXT Collaboration],**
``Initial results of NEXT-DEMO, a large-scale prototype of the NEXT-100 experiment,'' arXiv:1211.4838 [physics.ins-det].







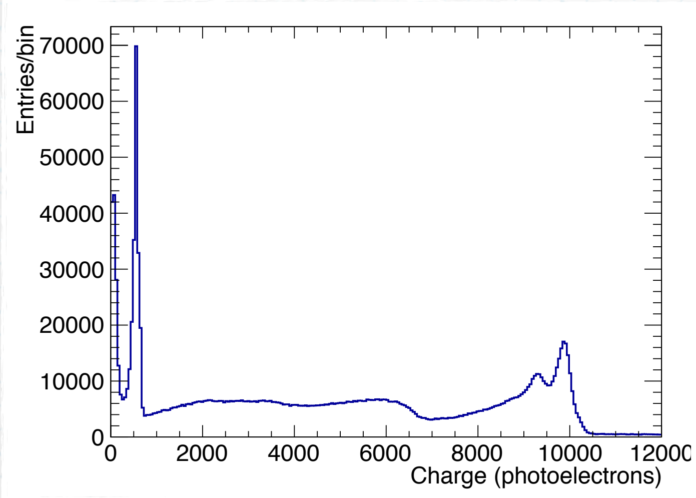




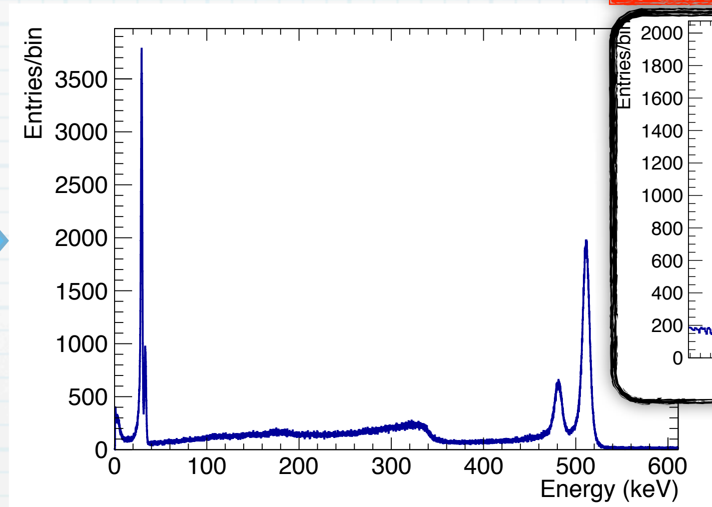
NEXT-DEMO Energy resolution

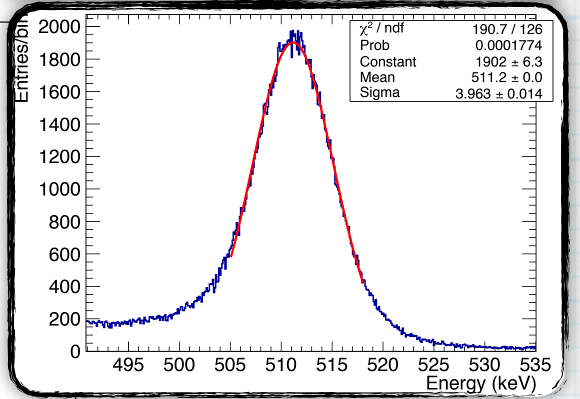
0.8 % FWHM
extrapolated @ $Q_{\beta\beta}$

^{22}Na raw spectrum

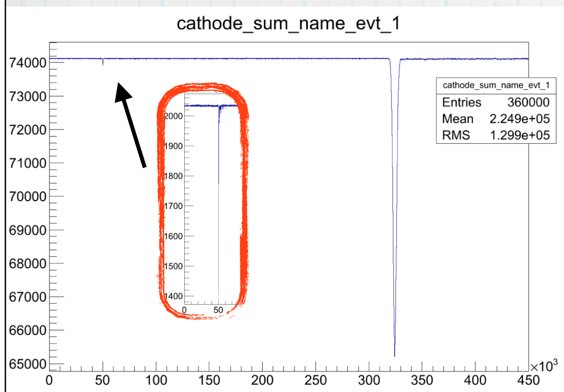


^{22}Na corrected spectrum

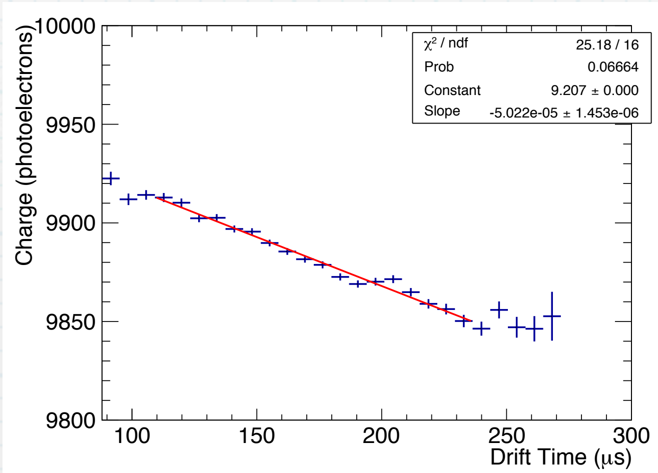




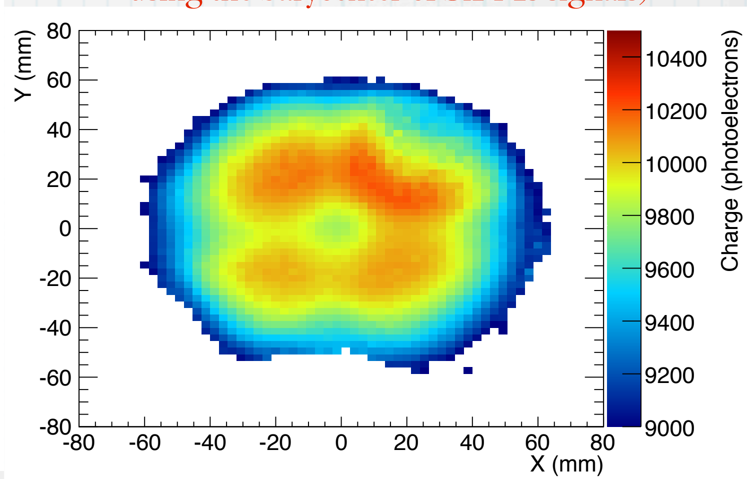
S1 & S2 PMT signal



z-correction
lifetime 20 ms

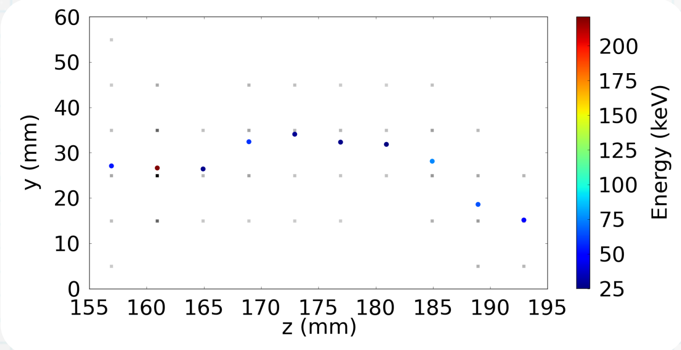


XY correction
(photopeak value vs x,y position computed using the barycenter of SiPMs signals)

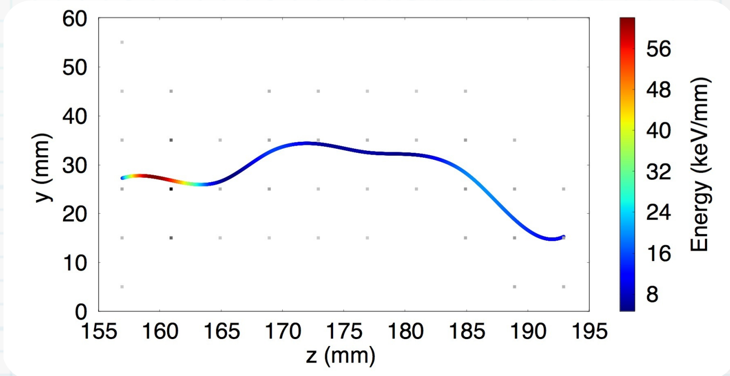


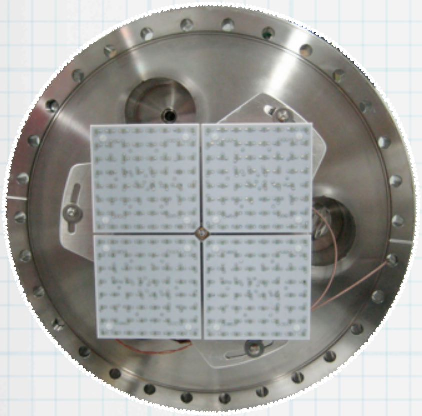
NEXT-DEMO Topology

ZY projection - barycenter

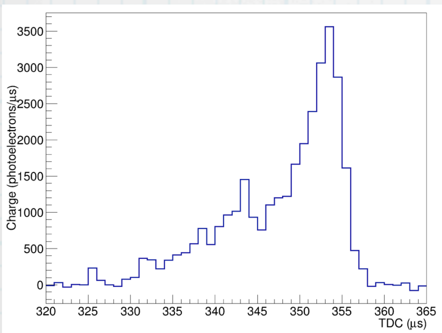


3D splines - ZY projection

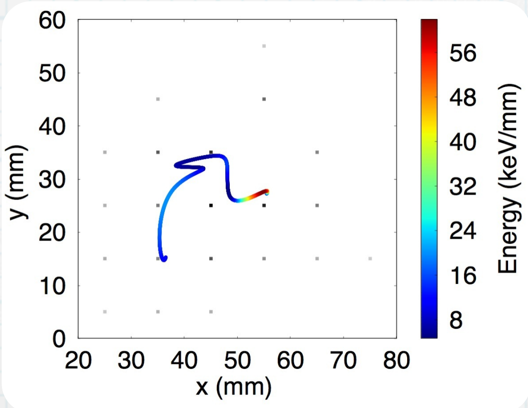




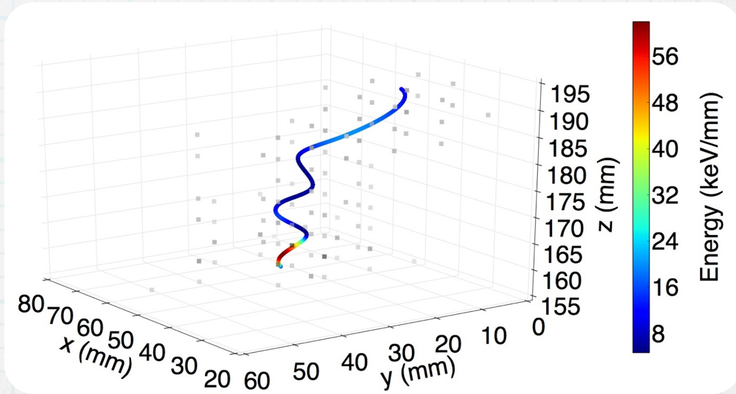
SiPM signal vs time



XY projection



3D splines - 3D view



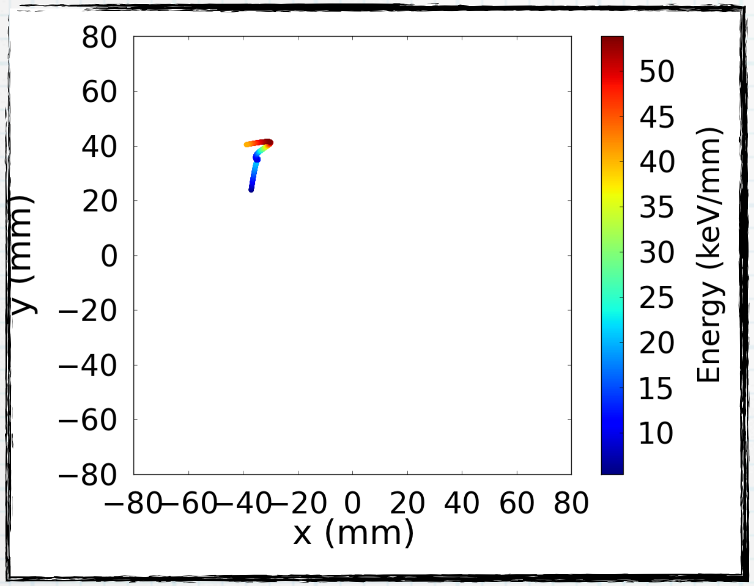
- Topology reconstruction:
  - Barycenter using SiPM signal integrated in 4 μs slices and track reconstrured using 3D splines
  - Energy of each slice given by the Energy plane

'blob' of the electron clearly visible!

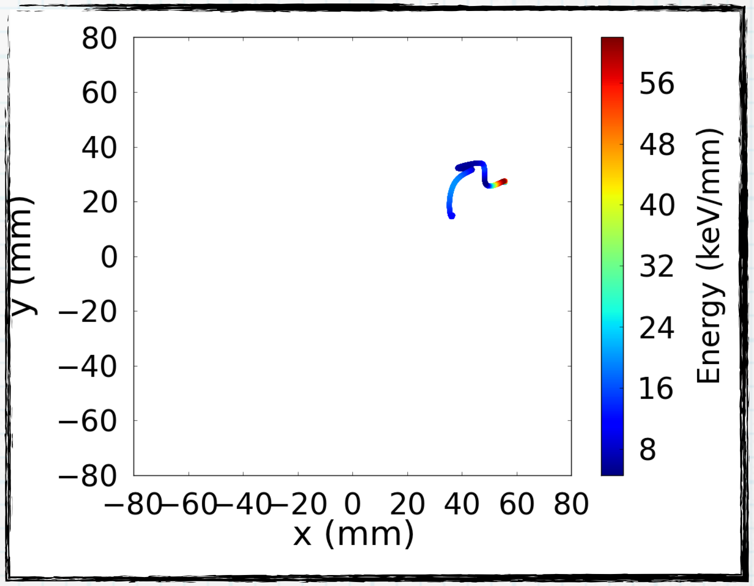
NEXT-DEMO Topology

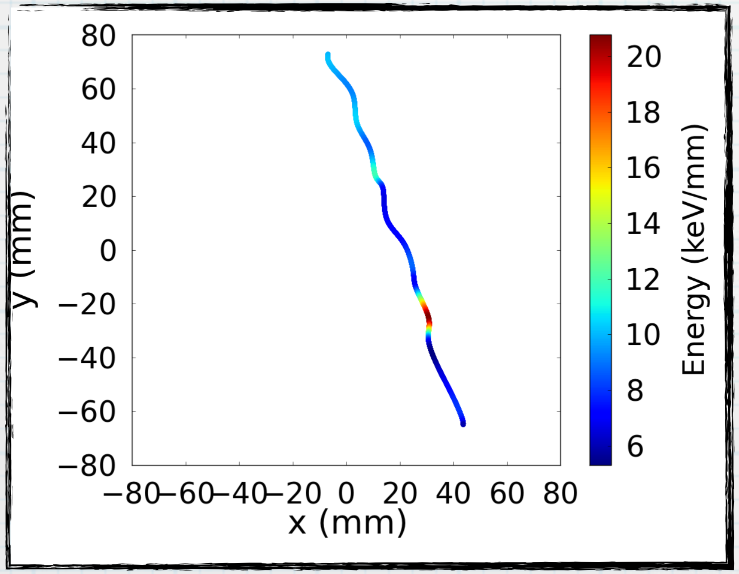
Different track types reconstructed!

^{22}Na (511 keV)

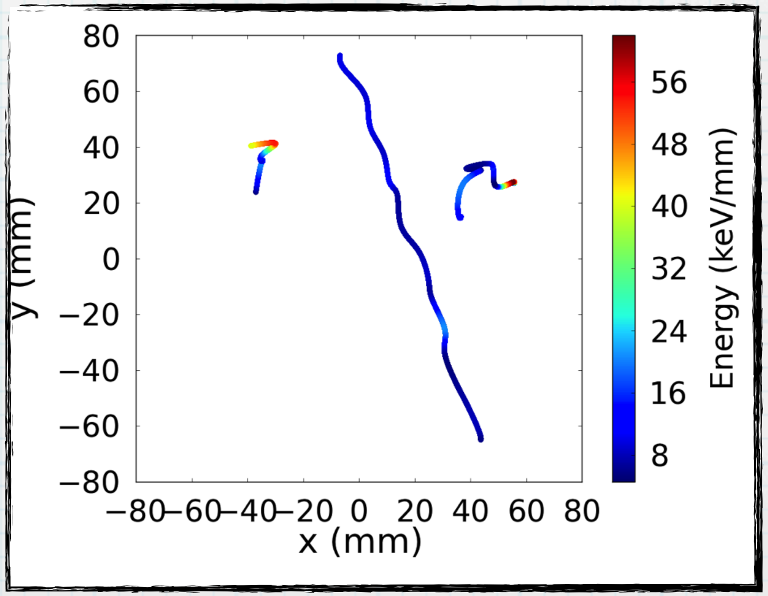


^{137}Cs (662 keV)





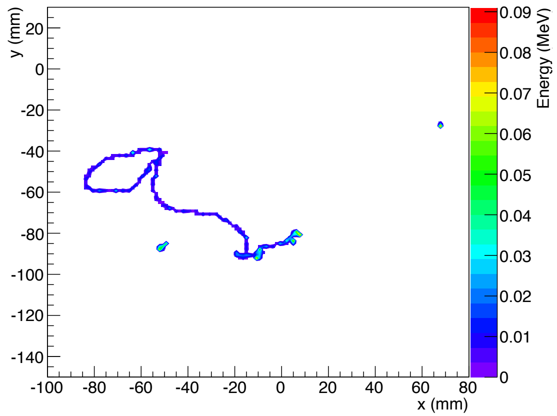
Cosmic μ



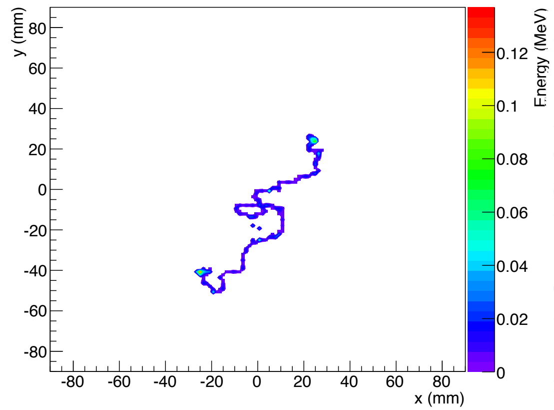
NEXT-100 background MC studies

- Complete Geant-4 MC simulation of detector and physics
- Simple cut analysis:

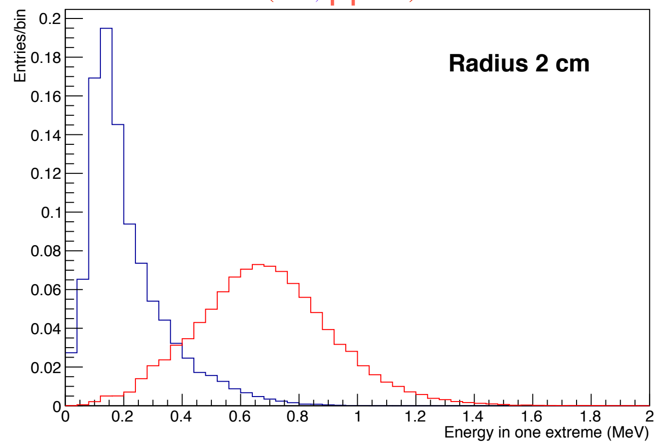
^{214}Bi (1 electron and extra activity)



ββ0ν (2 electrons)



Energy in second blob candidate (Bi, ββ0ν)

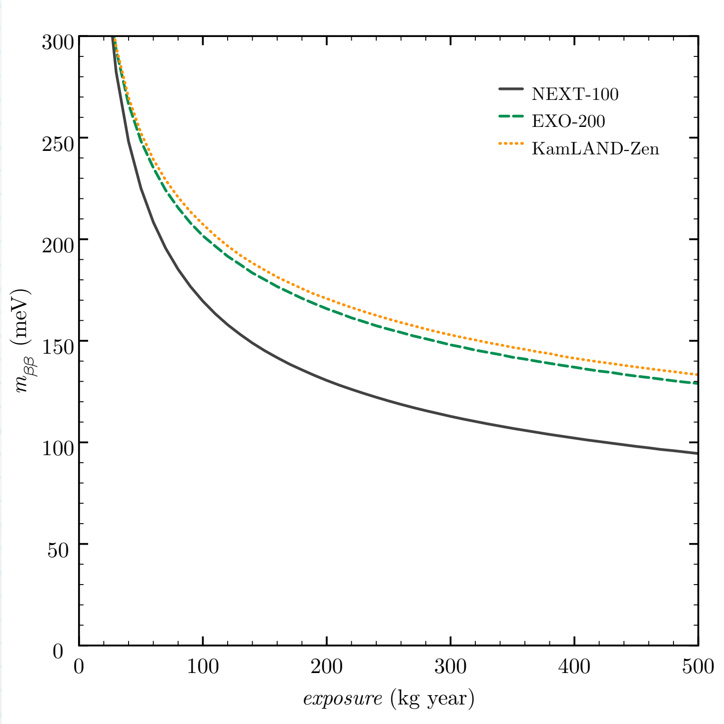


Selection cut	Fraction of events			
	$\beta\beta0\nu$	$\beta\beta2\nu$	^{214}Bi	^{208}Tl
$E \in (2.3, 2.6)$ MeV	0.776	3.31×10^{-6}	1.52×10^{-4}	8.02×10^{-3}
Fiducial	0.678	2.95×10^{-6}	1.13×10^{-4}	4.77×10^{-3}
Single track	0.508	2.27×10^{-6}	1.36×10^{-5}	8.44×10^{-4}
dE/dx	0.381	1.70×10^{-6}	1.36×10^{-6}	8.10×10^{-5}
ROI				
0.5% FWHM	0.311	3.24×10^{-12}	1.23×10^{-7}	3.23×10^{-7}
1.0% FWHM	0.315	3.57×10^{-11}	3.69×10^{-7}	5.40×10^{-7}

reduction factor: 0.45 signal, 3 10^{-3} Bi

Comparing NEXT

- EXO200 and KamLAND-Zen set current best limits on ^{136}Xe $\beta\beta0\nu$
    - Assume same background and energy resolution that currently measured
- NEXT-100 reach on $m_{\beta\beta}$
    - Using estimation of background contamination and measurements of energy resolution with prototypes

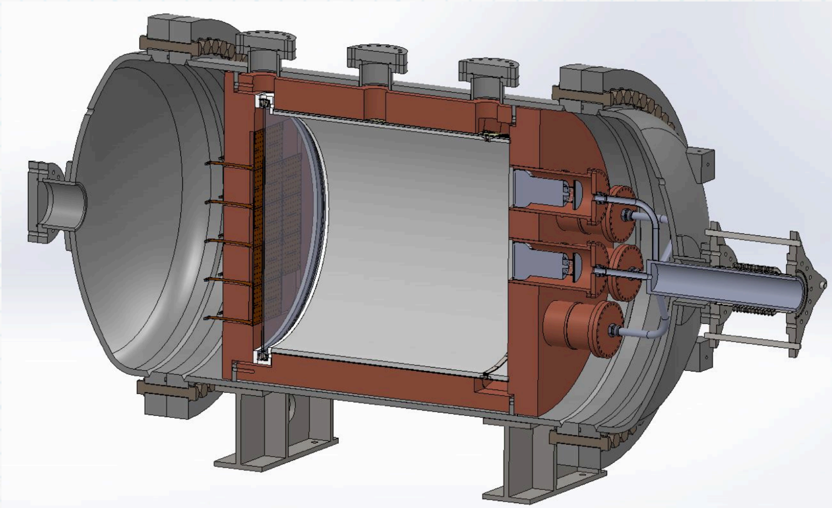


$m_{\beta\beta}$ vs exposure (same mass)

Experiment	M (kg)	enrichment (%)	efficiency (%)	resolution (% FWHM)	b (10^{-3} ckky)
EXO-200	110	81	52	3.9	1.5
KamLAND-Zen	330	91	62	9.9	1.0
NEXT-100	100	91	31	0.5–1.0	0.4–0.9

NEW before NEXT-100

- NEXT White (NEW) prototype
  - 1:2 dimensions (i.e field cage)
  - 10 kg ^{136}Xe
  - 20% of sensors: 12 PMTs, 20 SiPMs boards
- Objective:
  - Test of technical implementations
  - Validation of background model. It is a radiopure detector
  - measurement of a topological signal (2 electrons) from ββ2ν signal
- Commissioning during 2014



In memoriam of James White

Conclusions

- NEXT-100 is a 100 kg ^{136}Xe (90% enriched) High Pressure Gas TPC able to explore ββ0ν to 100 meV effective ν masses
- NEXT has an excellent energy resolution (<1%) FWHM at Qββ, extrapolated from the measurements done with NEXT-DBDM and NEXT-DEMO prototypes
- NEXT-DEMO has demonstrated the tracking capabilities of NEXT (reconstruction of electron and identification of the 'blob') that will largely reduce the background contamination
- The detector is now under construction (Vessel, sensors, electronic, DAQ, gas system,...). Installation and commissioned expected by 2016 at Canfranc Underground Laboratory (Spain)
- As a 1st step we will install a 10 kg prototype (NEW) at LSC by 2014 , able to measure ββ2ν and validate the background model and the topology reconstruction of 2 electrons
- Due to its modularity, NEXT can be a solution for a (several) ton next generation ^{136}Xe ββ decay experiment to explore down to 20 meV in ν effective mass