The next neutrinoless double beta decay experiment

M. Sorel (IFIC - CSIC & U. Valencia)

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Outstanding questions about neutrinos

Identity	Dirac or Majorana fermion?
Mass scale	What is the neutrino mass value?
Mass ordering	Normal or inverted?
Mixing	Is CP symmetry violated in the neutrino sector?
Species	Are there light sterile neutrinos?

Answers to these questions will have far-reaching consequences!

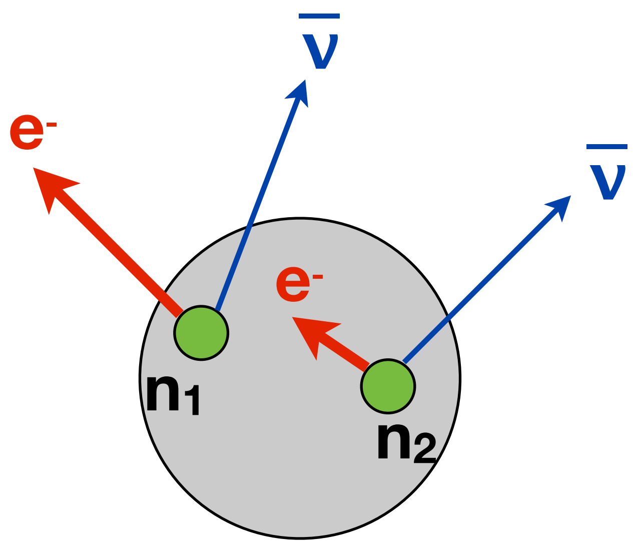
See lectures by M. Maltoni and T. Lasserre

Neutrinoless double beta decay

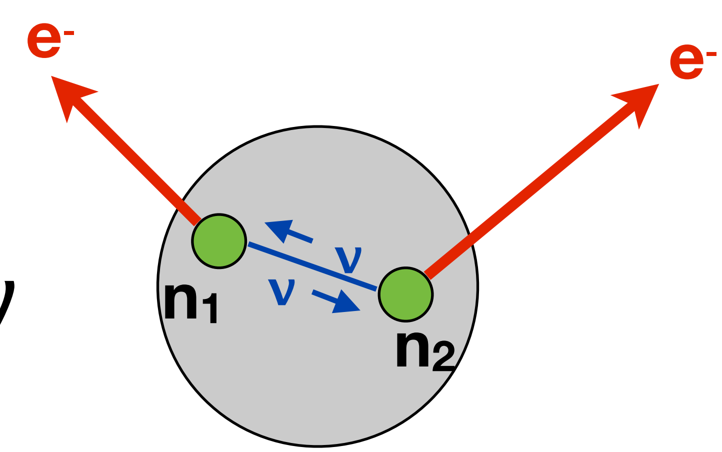
Double beta decay

- Rare (Z,A)→(Z+2,A) nuclear transition, with emission of two electrons
- Two basic decay modes

ββ2ν



ββ0ν



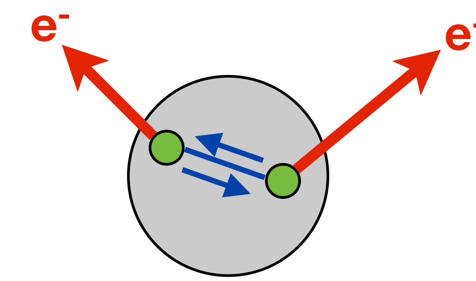
Two neutrino mode

- Observed in several nuclei
- 10^{19}-10^{21} yr half-lives
- Standard Model allowed

Neutrinoless mode

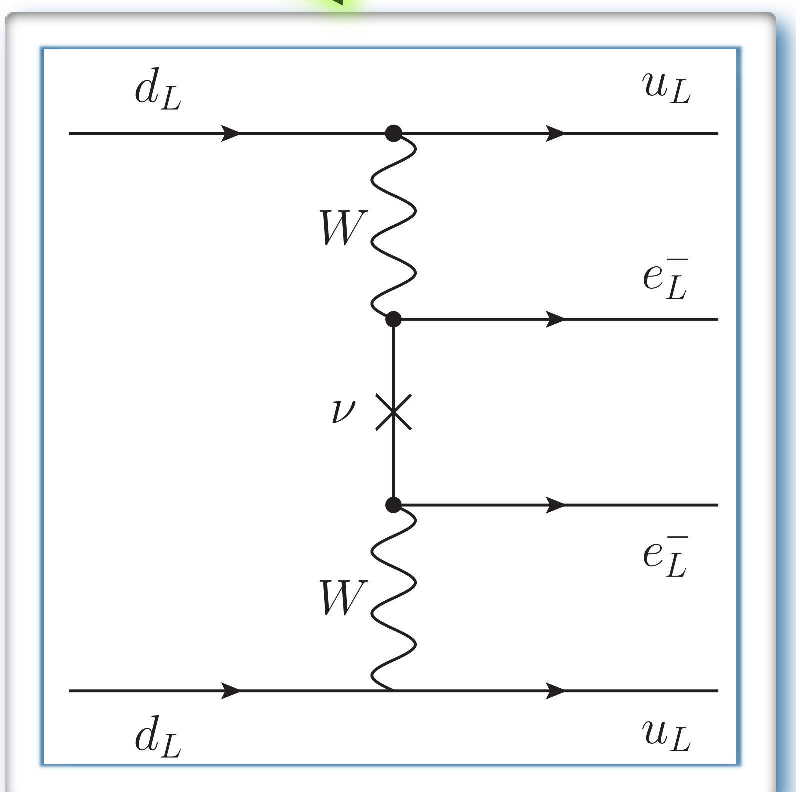
- Not observed yet in Nature
- >10^{25} yr half-lives
- Would signal Beyond-SM physics

Neutrinoless double beta decay and the neutrino questions



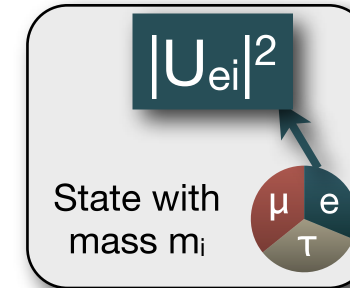
Lepton number violating process implying massive Majorana neutrinos

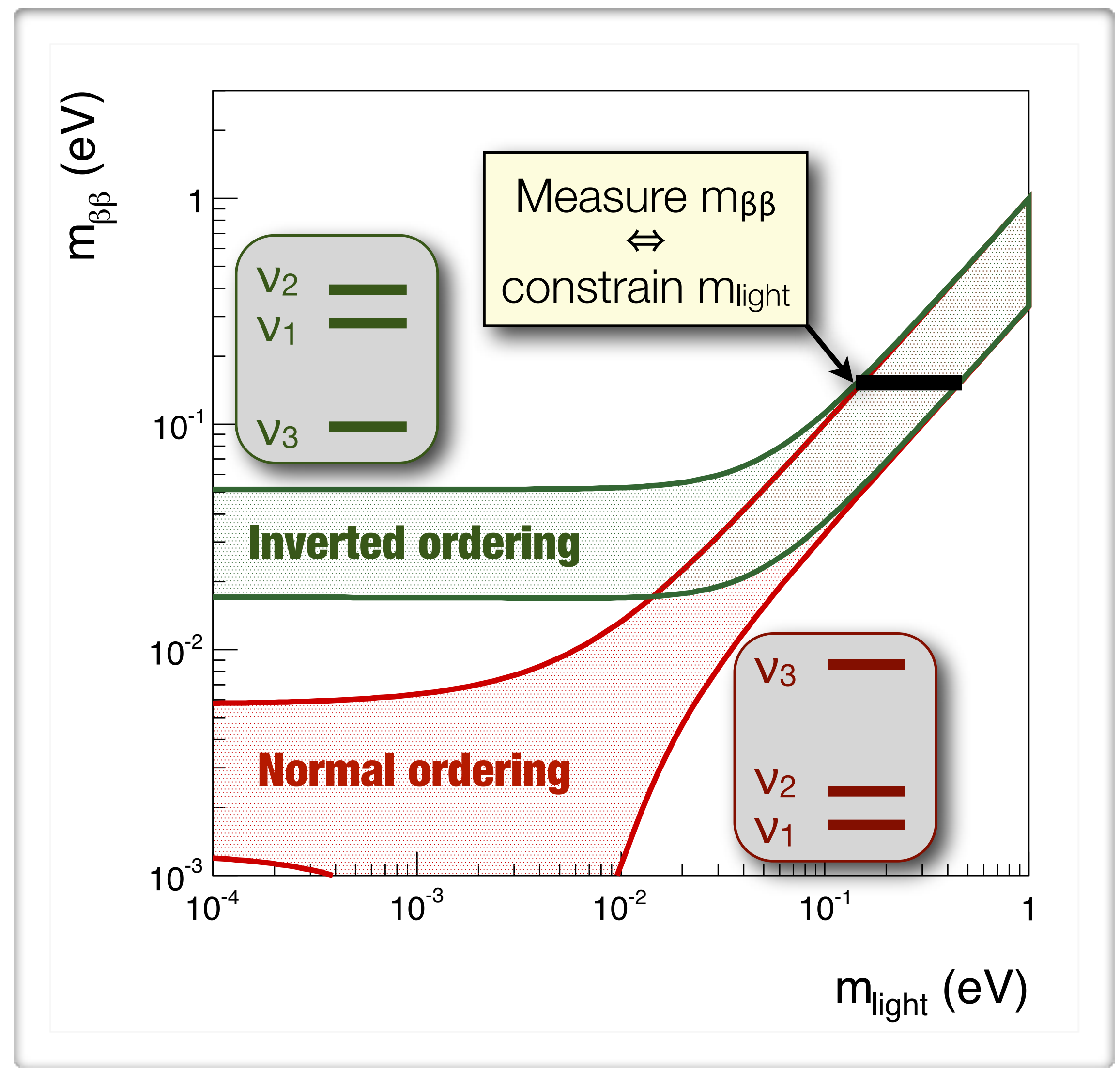
- Identity
- Mass scale
- Mass ordering
- Mixing
- Species



$(\text{Rate})_{\beta\beta 0\nu} \propto m_{\beta\beta}^2$

Majorana ν mass:
$m_{\beta\beta} \equiv \left| \sum_i m_i U_{ei}^2 \right|$





The ββ0ν landscape around 2008

- Field “rejuvenated” by neutrino mass discovery!
- Controversial claim for ββ0ν discovery in ^{76}Ge (Klapdor et al.) sets current-generation goal:

100 meV mass ⇔ 10^{26} yr half-life sensitivity

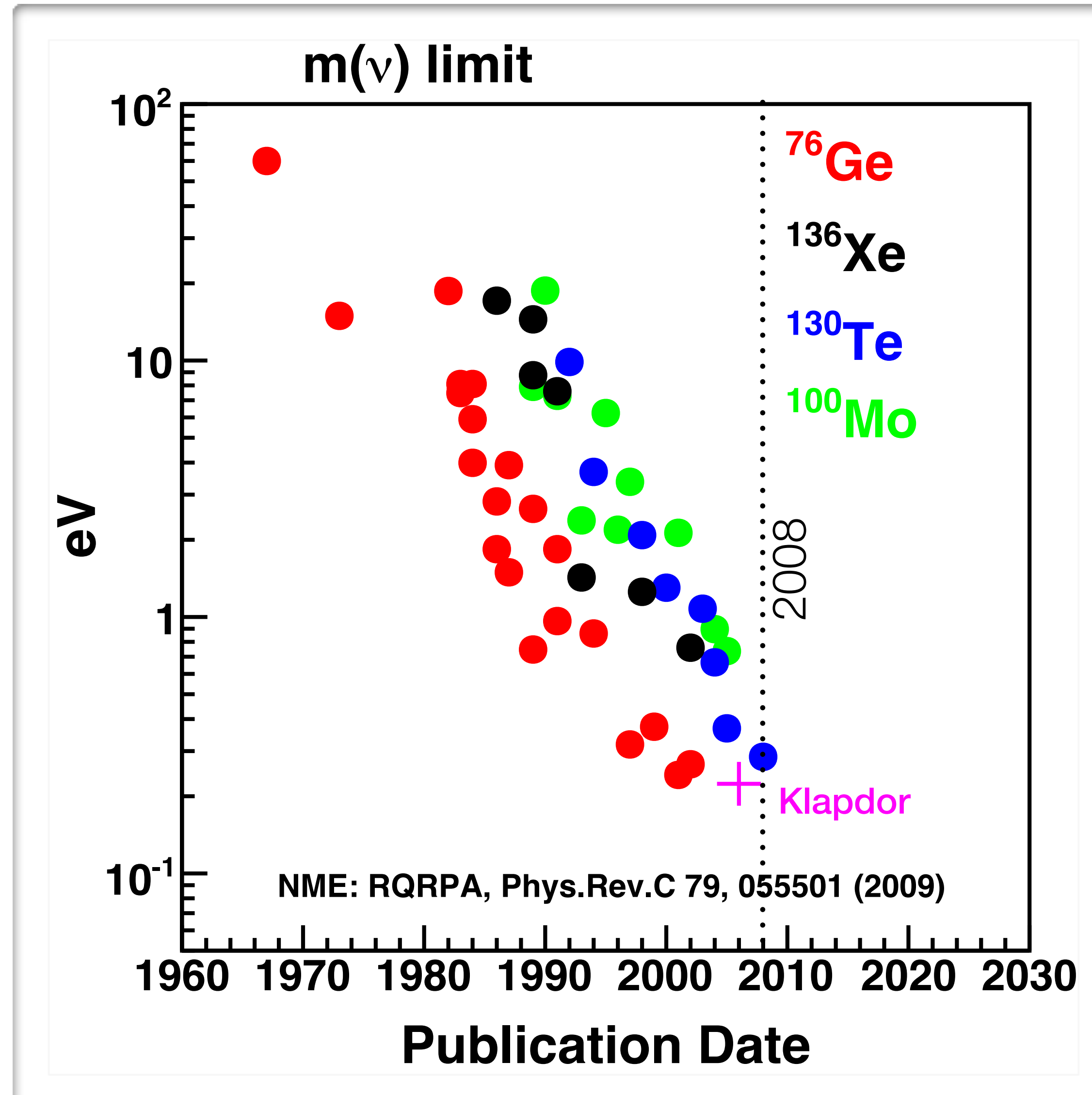
➩ultra-low background, 100 kg-scale experiments

- Realization that ^{136}Xe experiments may be as/more competitive than ^{76}Ge and ^{130}Te ones

$^{76}_{32}$Ge GERDA

$^{130}_{52}$Te CUORE

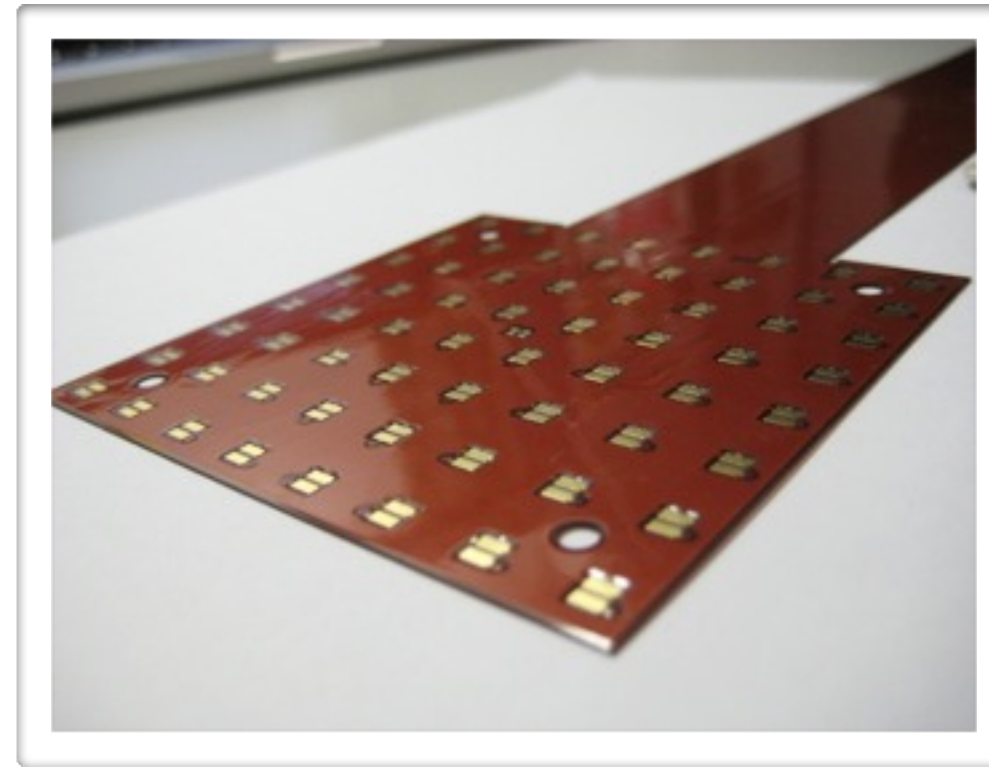
$^{136}_{54}$Xe next



NEXT experiment at the LSC

LSC
Laboratorio Subterráneo de Canfranc

next



- **Goal:** push discovery reach for $\beta\beta0\nu$ down to 100 meV Majorana neutrino masses

- Time Projection Chamber with 100 kg of high-pressure ^{136}Xe gas
- **2008-2013**: R&D phase with 1 kg-scale prototypes at home institutions — **COMPLETED**
- **2014-2016**: 10 kg detector at LSC — **APPROVED AND FULLY FUNDED**
- **2016-2020**: full 100 kg detector at LSC — **APPROVED AND SUBSTANTIALLY FUNDED**

The NEXT Collaboration

IFIC Valencia • Zaragoza • Politécnica Valencia • Santiago de Compostela • Autónoma Madrid • Girona

LBNL • Iowa State • Texas A&M

Coimbra • Aveiro

JINR

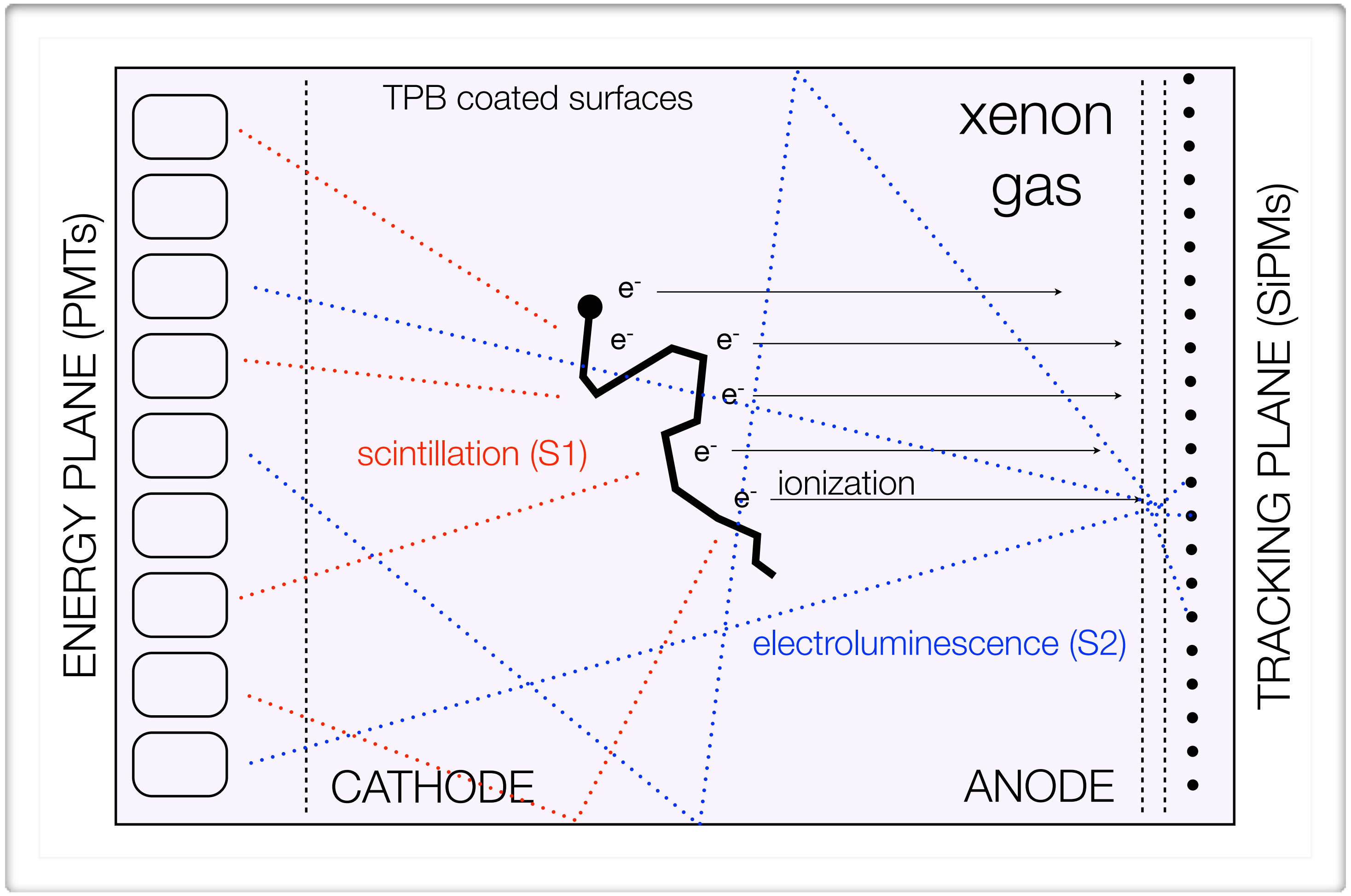
A. Nariño

- **Leadership:** Spain

PROGRAMA ingenio 2010 · Consolider · erc European Research Council Established by the European Commission

NEXT detection concept

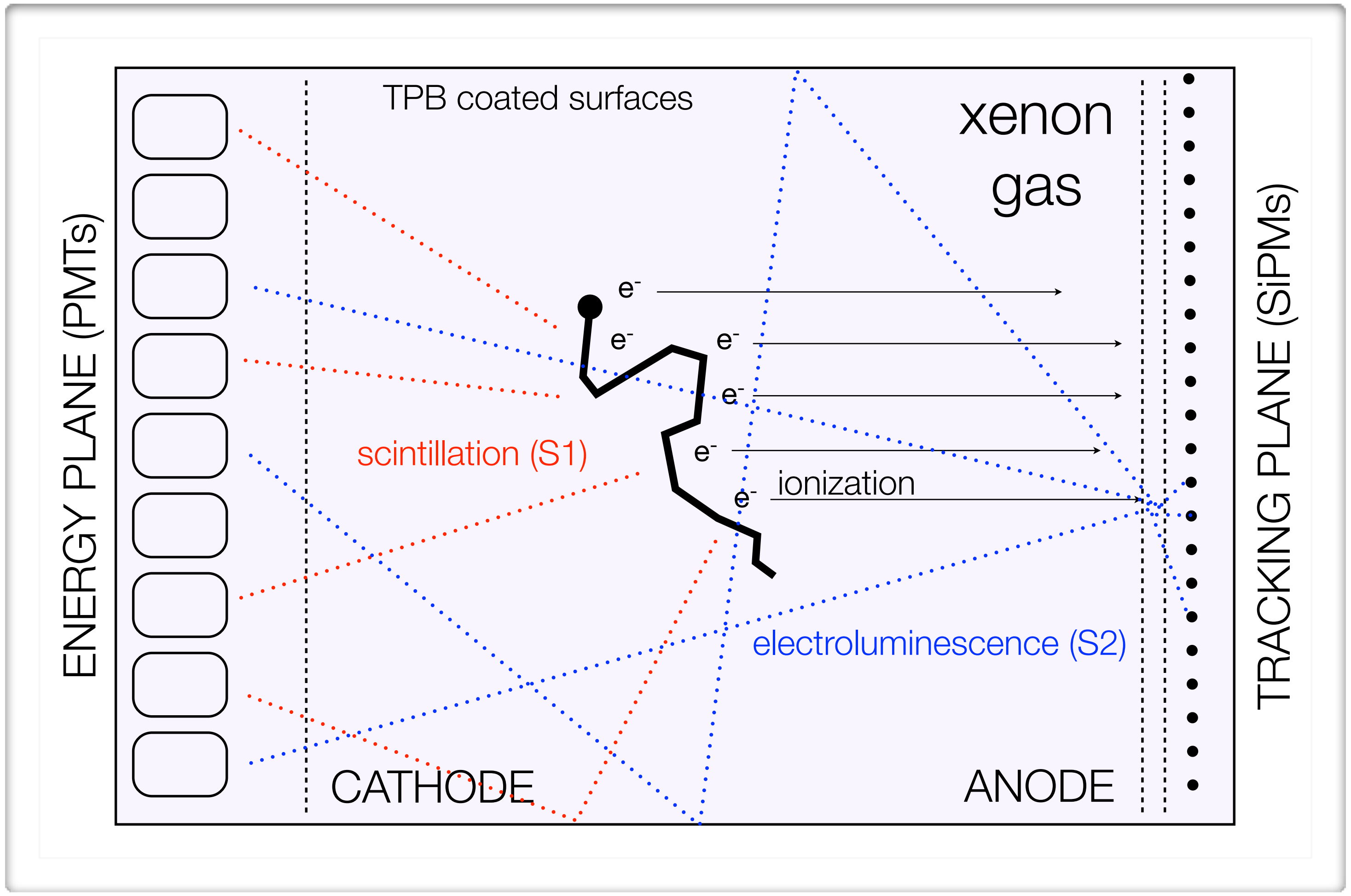
NEXT detection concept



NEXT detection concept

Idea #1:

Use a xenon gas TPC (10-15 bar)



NEXT detection concept

Idea #1:

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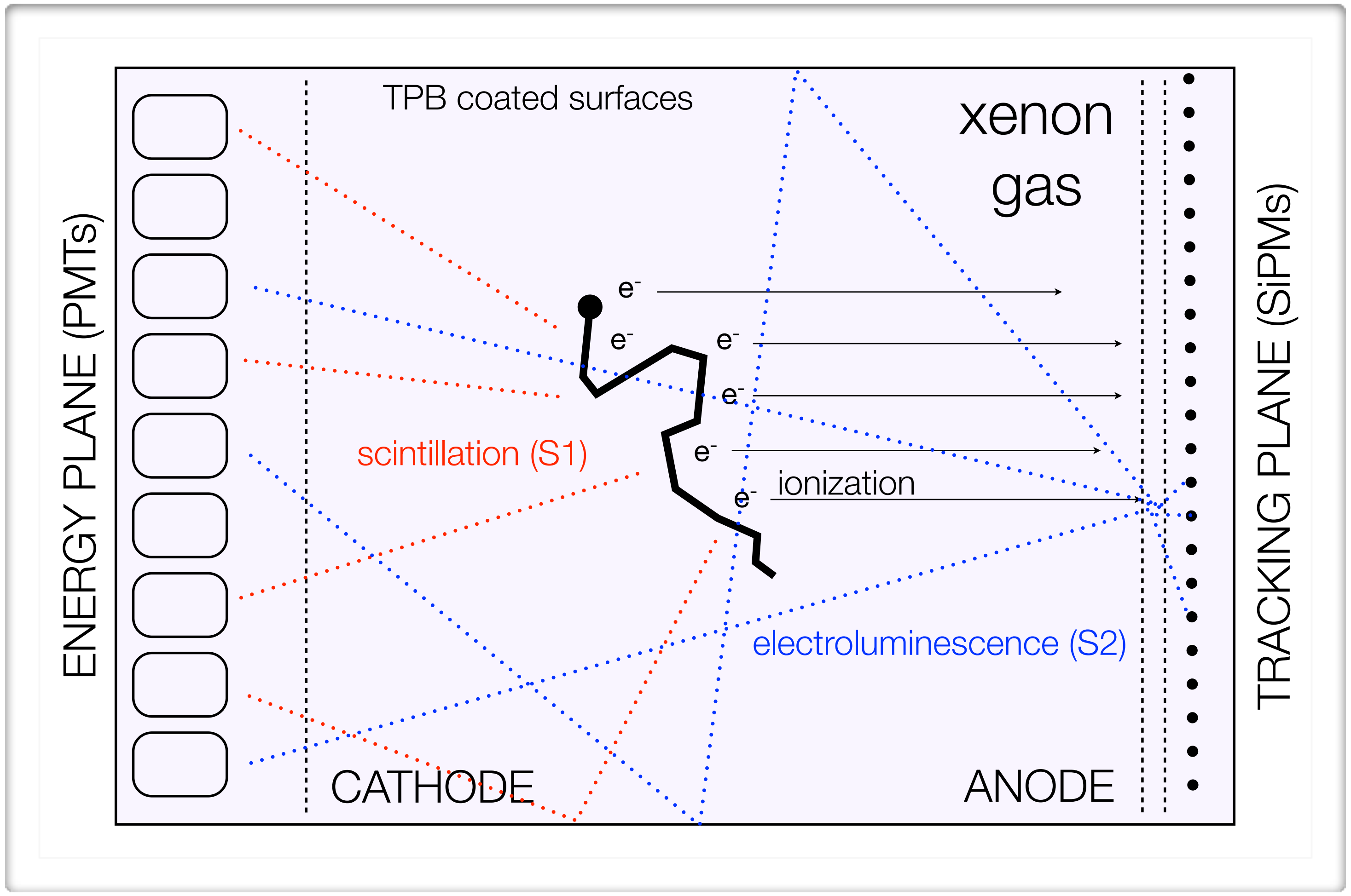
Idea #2:

Use *electroluminescence (EL)* as a linear amplification stage for ionization



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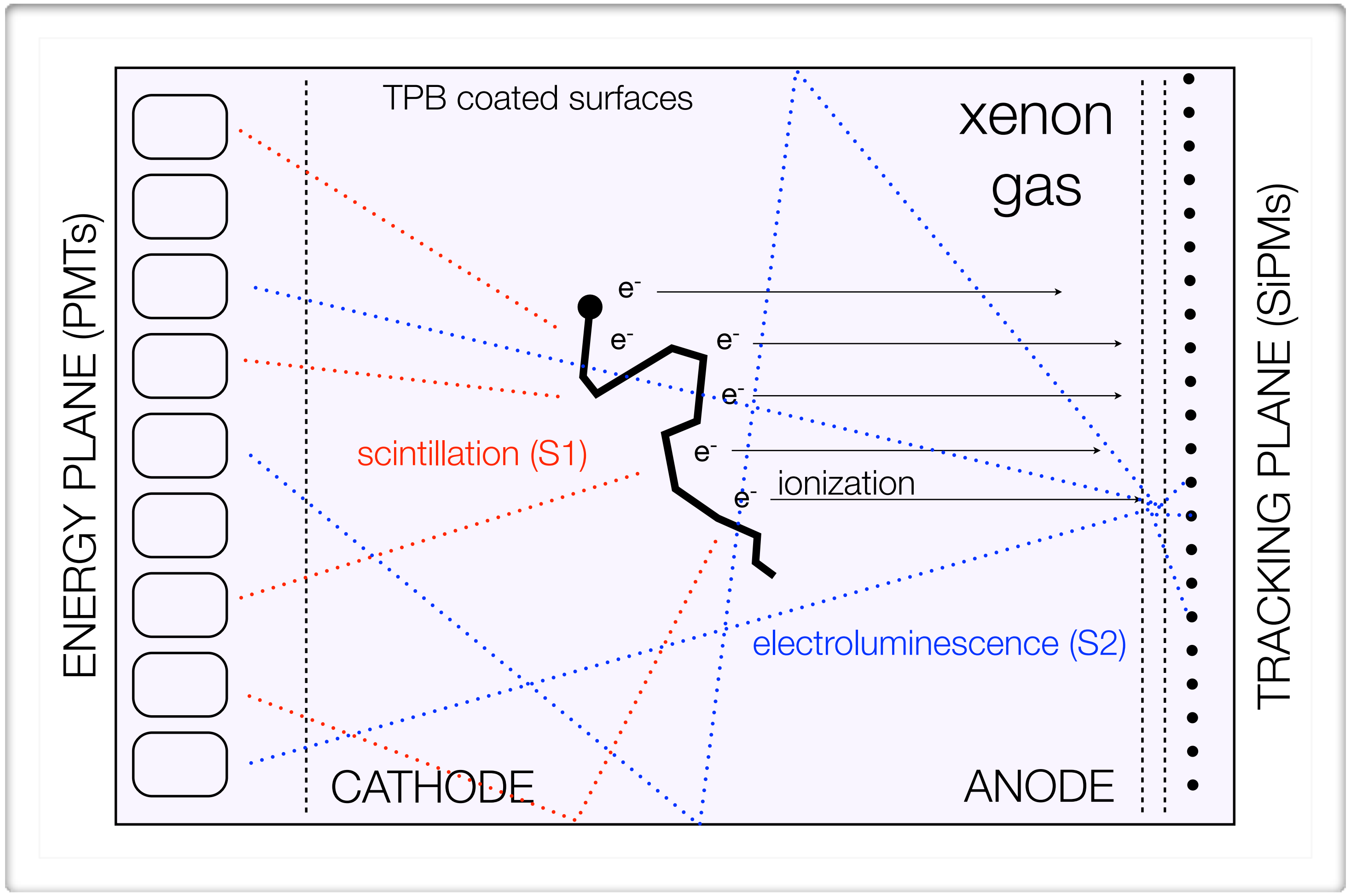
EL used for separated energy and tracking measurements



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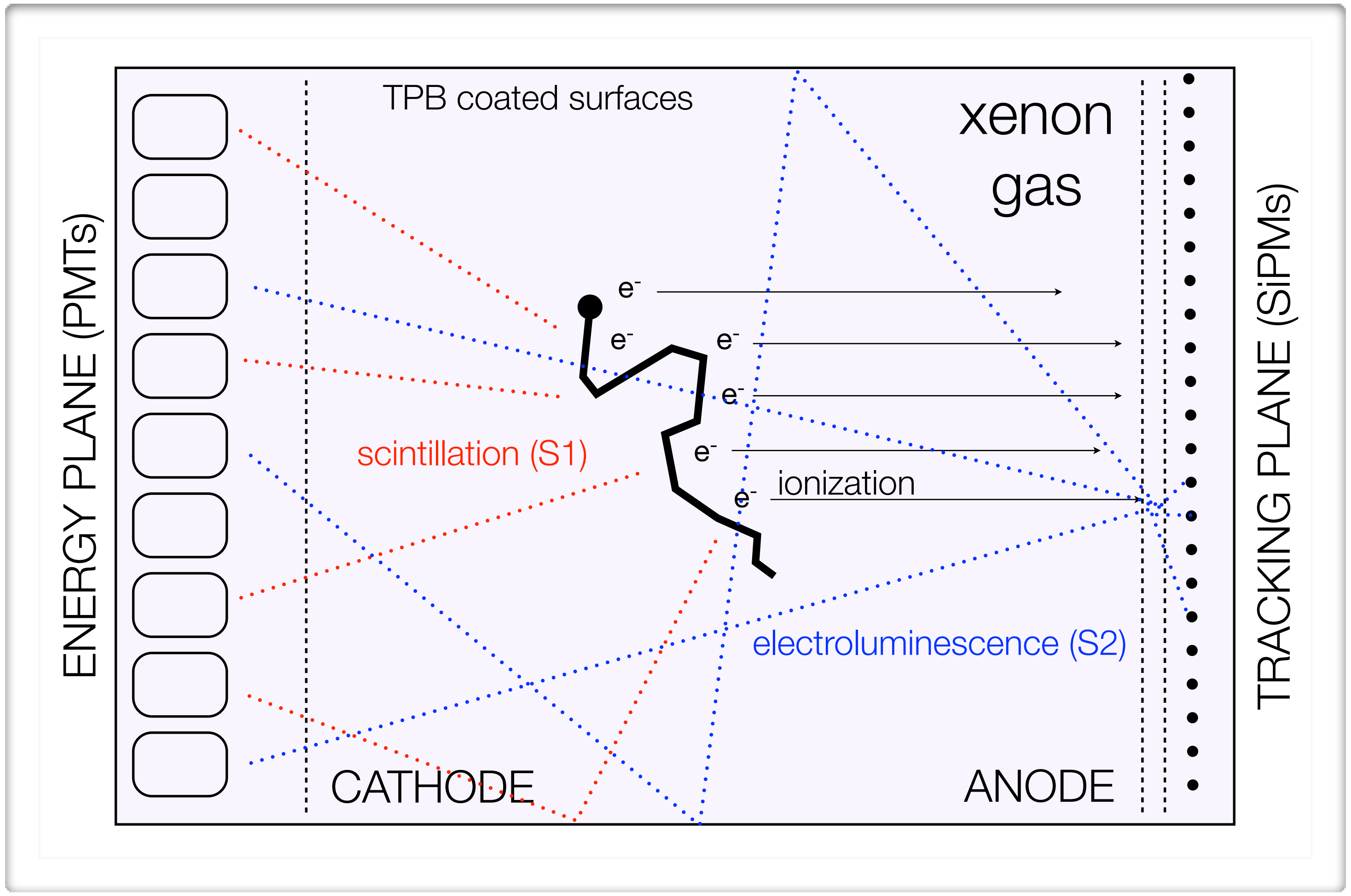
Energy sensors detect also primary scintillation for t_0 determination



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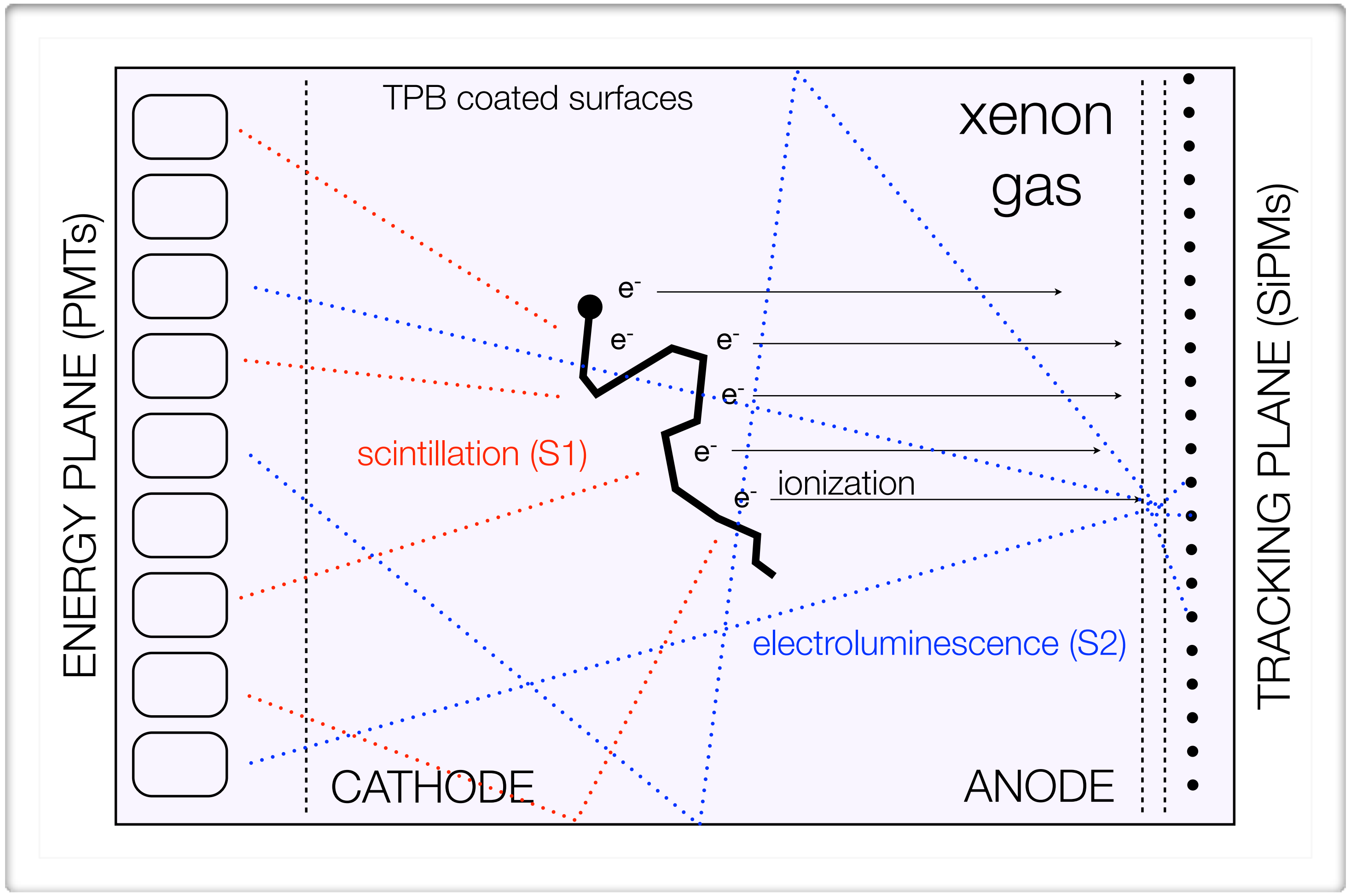
Idea #5:

170 →430 nm light with TPB waveshifter



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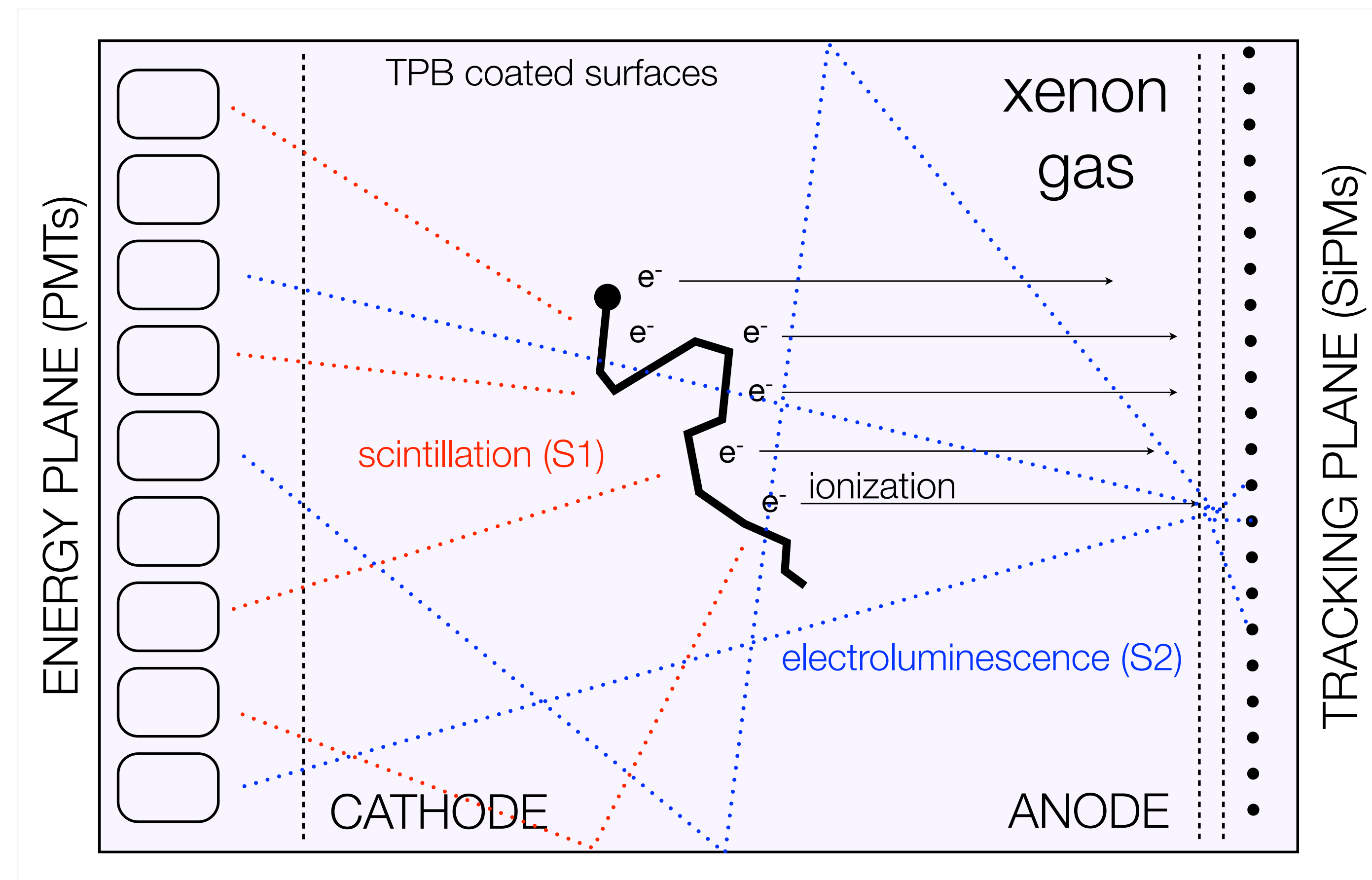


Concept fully validated with prototypes

Strengths:

- Mass scalability
- Excellent energy resolution and tracking

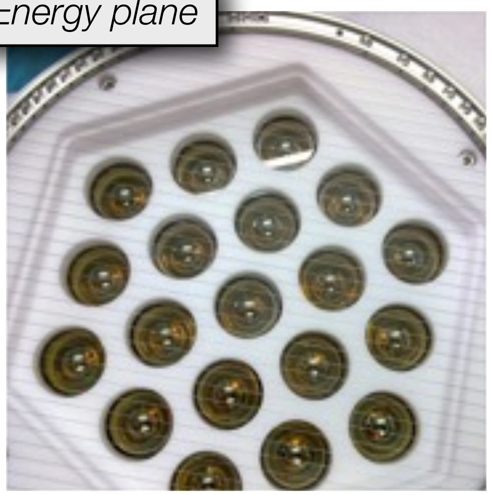
R&D

(2008-2013)

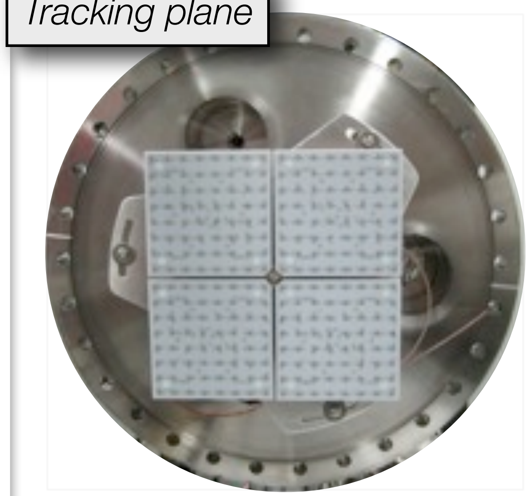
NEXT R&D goals

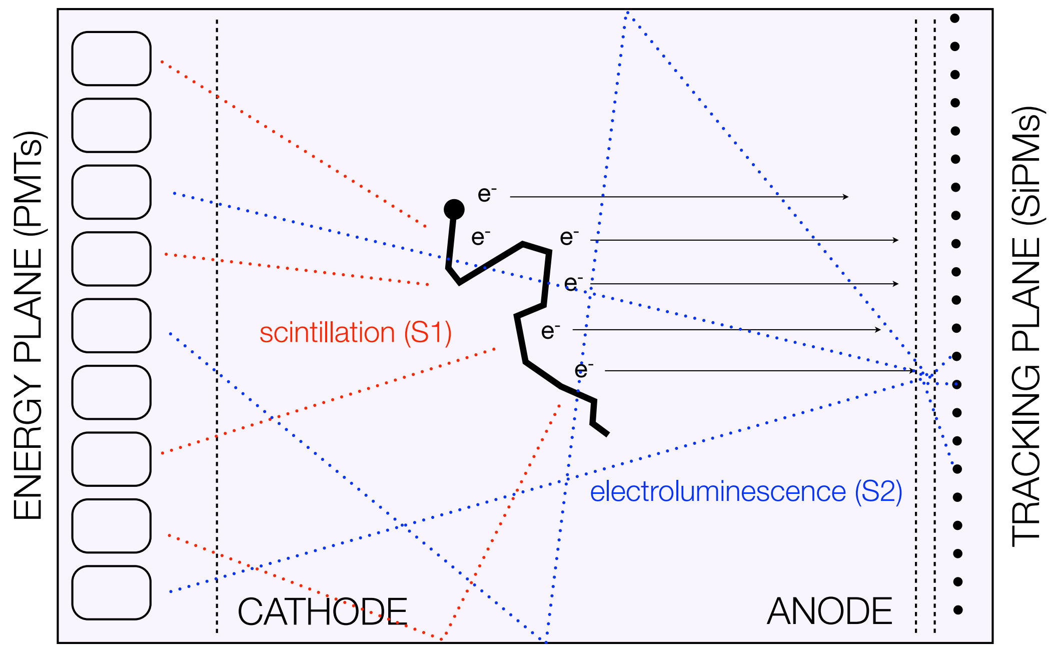
- Realize innovative detector concept at 1 kg-scale
- Choose technological solutions
- Quantify detector performance

Energy plane

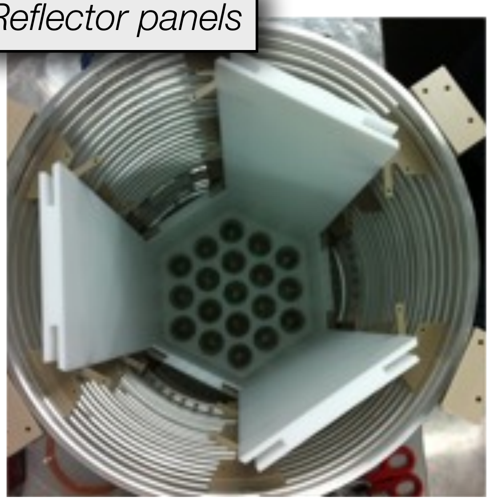


Tracking plane

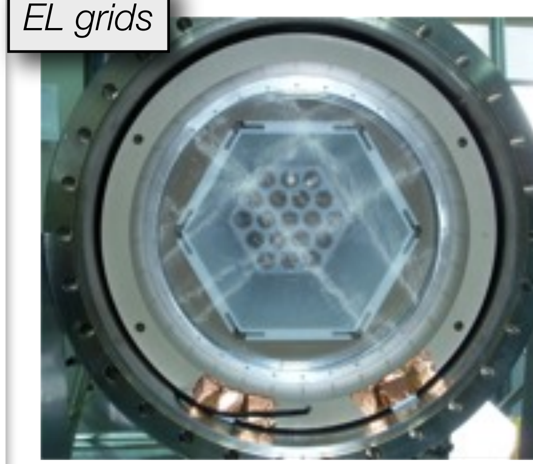




Reflector panels

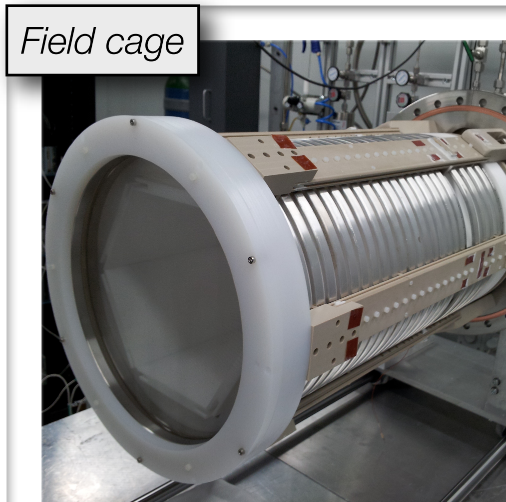


EL grids



Pressure vessel

Field cage

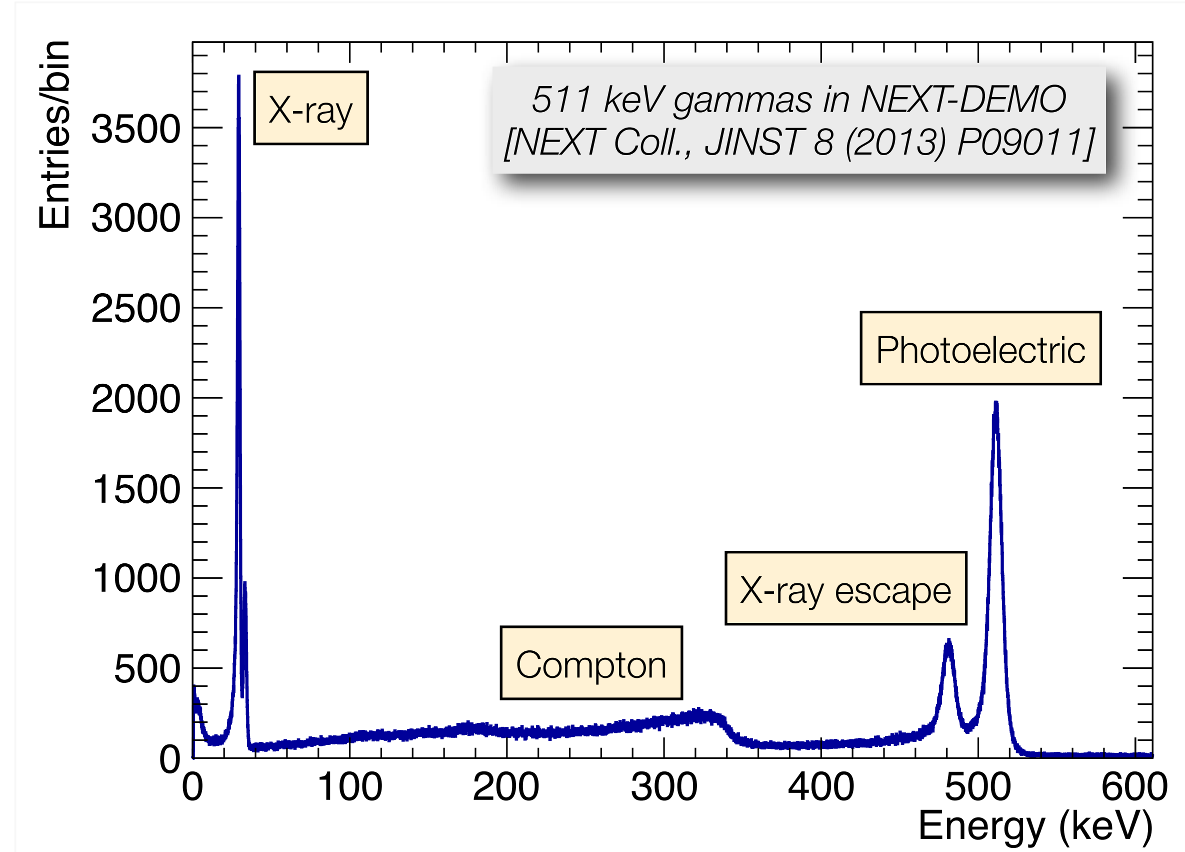


- *Images: NEXT-DEMO at IFIC*
- *Other prototypes at LBNL and Zaragoza*

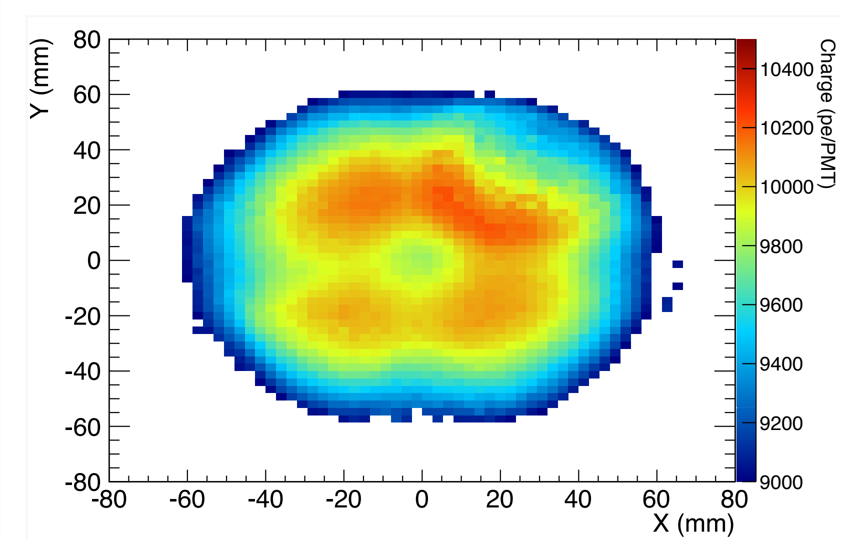
NEXT R&D: detector performance achievements

- **1.8% FWHM** energy resolution for **511 keV** electrons over large fiducial volume

- Extrapolates to **0.8% FWHM** at $\mathbf{Q}_{\beta\beta}$ energy of ^{136}Xe decay

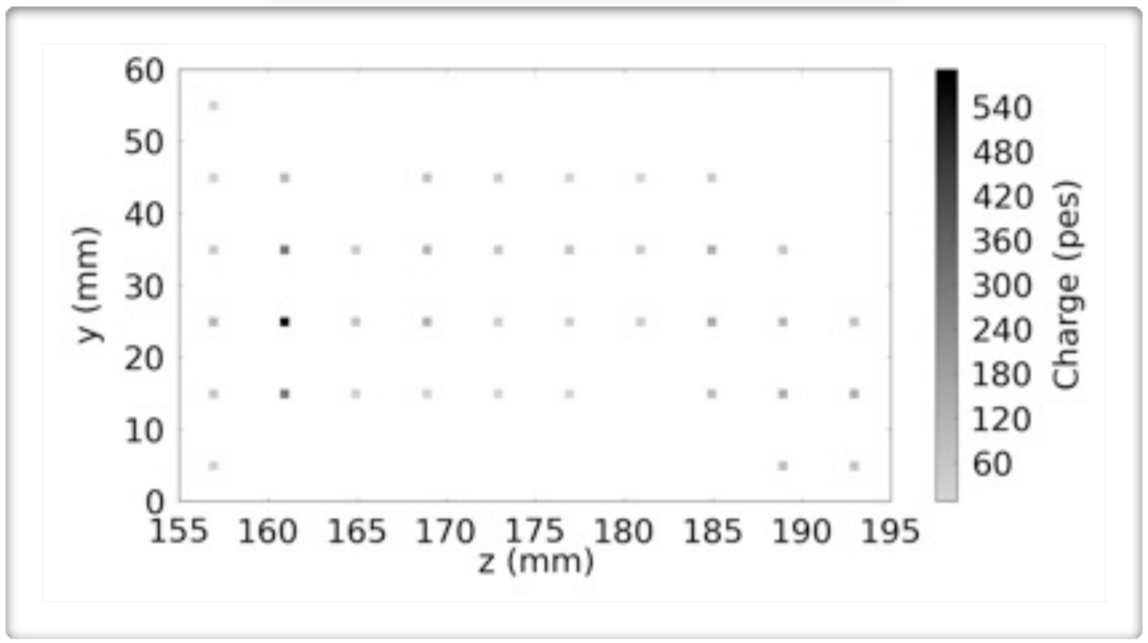


- Requires mapping energy response in plane perpendicular to drift field

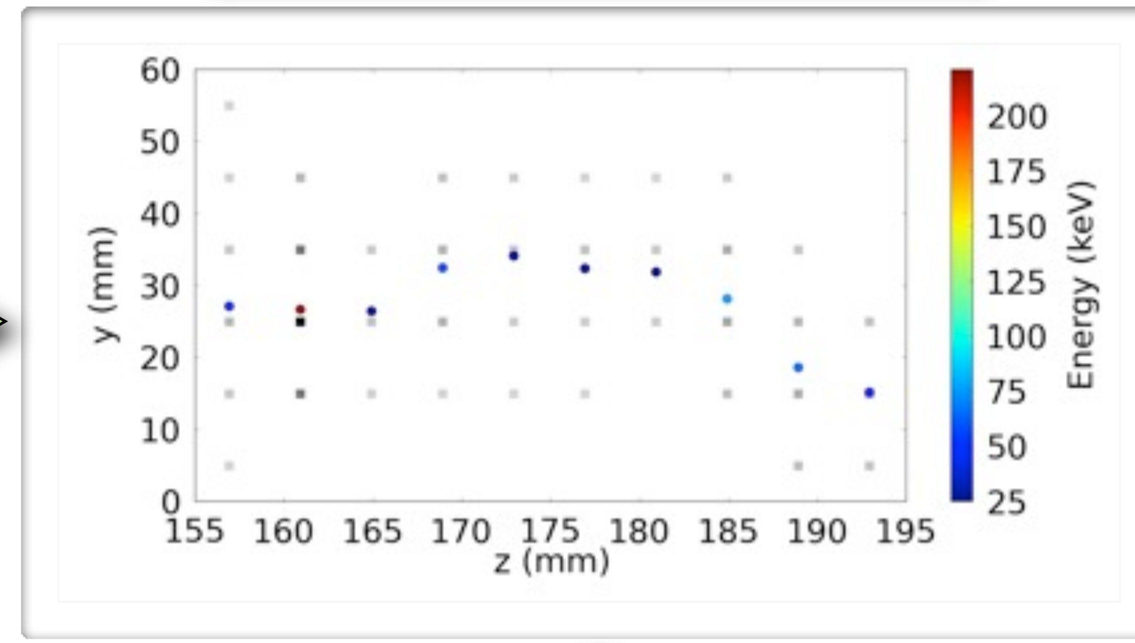


NEXT R&D: detector performance achievements

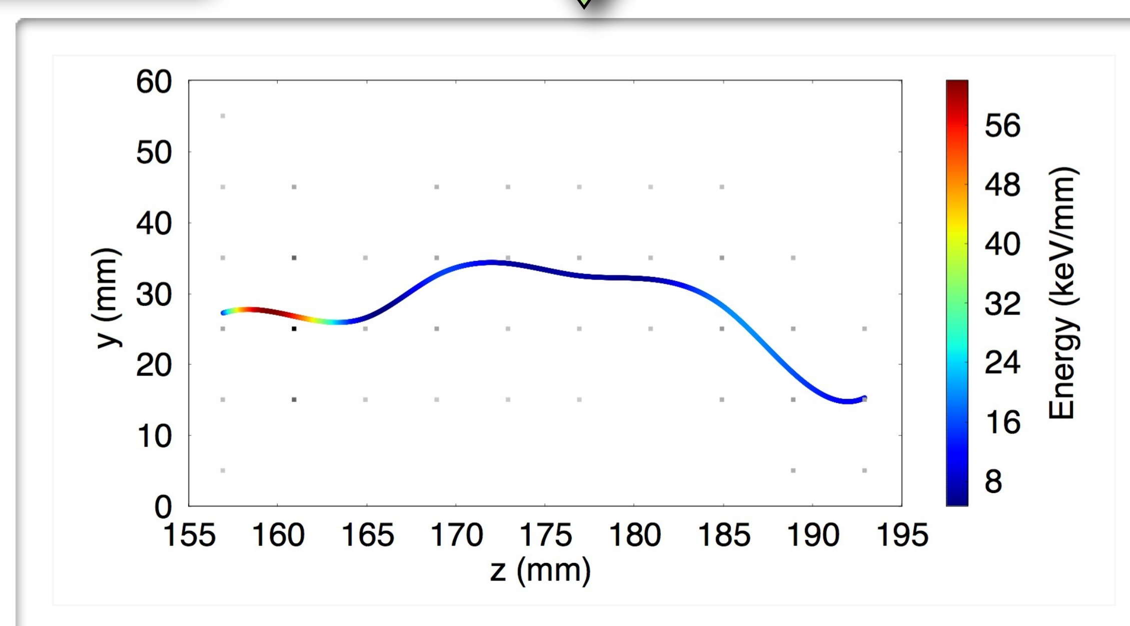
SiPM information only



SiPM plus PMT information



662 keV electron in NEXT-DEMO [NEXT Coll., JINST 8 (2013) P09011]



- Higher energy deposition clearly visible at electron track end-point
- Excellent energy resolution and tracking ➩ low background!

R&D

(2008-2013)

$\beta\beta 2\nu$

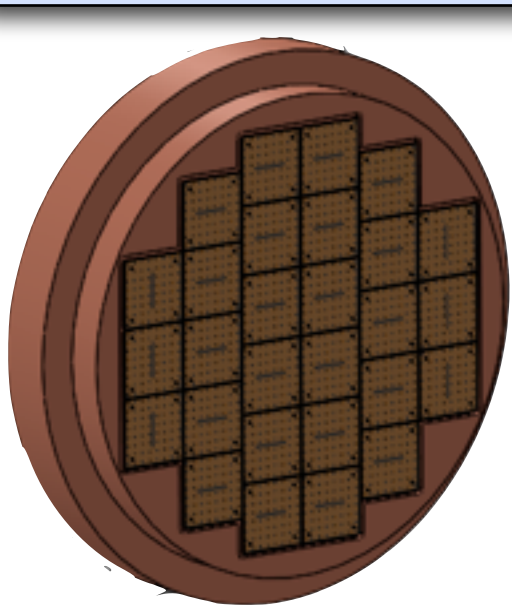
(2014-2016)

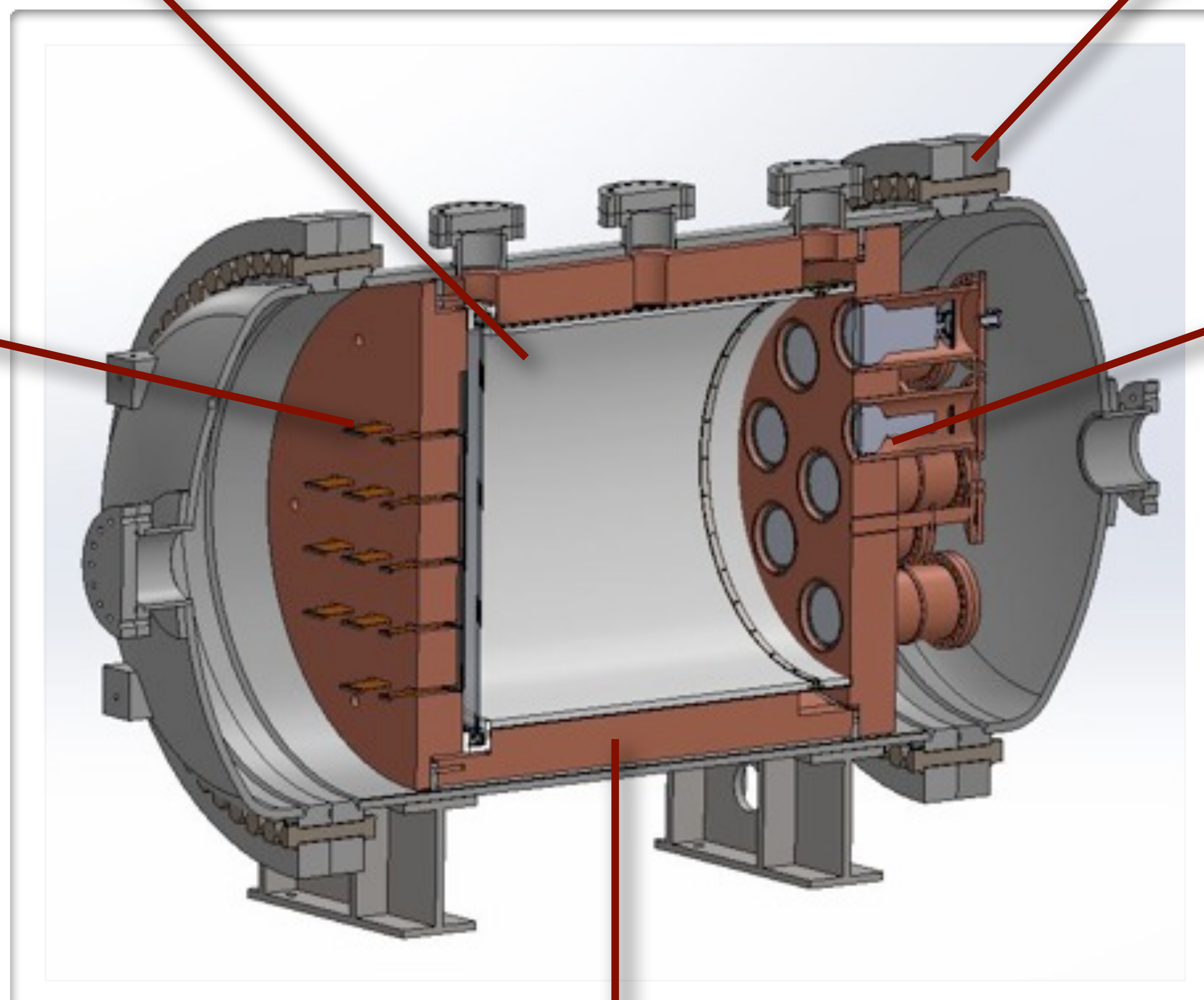
NEXT-NEW 10 kg detector at LSC: main features

Time Projection Chamber:
10 kg active region, 50 cm drift length

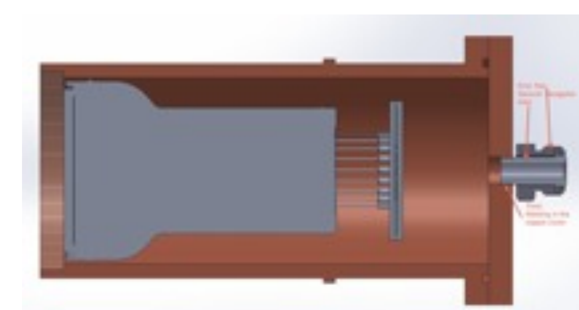
Pressure vessel:
stainless steel, 30 bar max pressure

Tracking plane:
1,800 SiPMs,
1 cm pitch

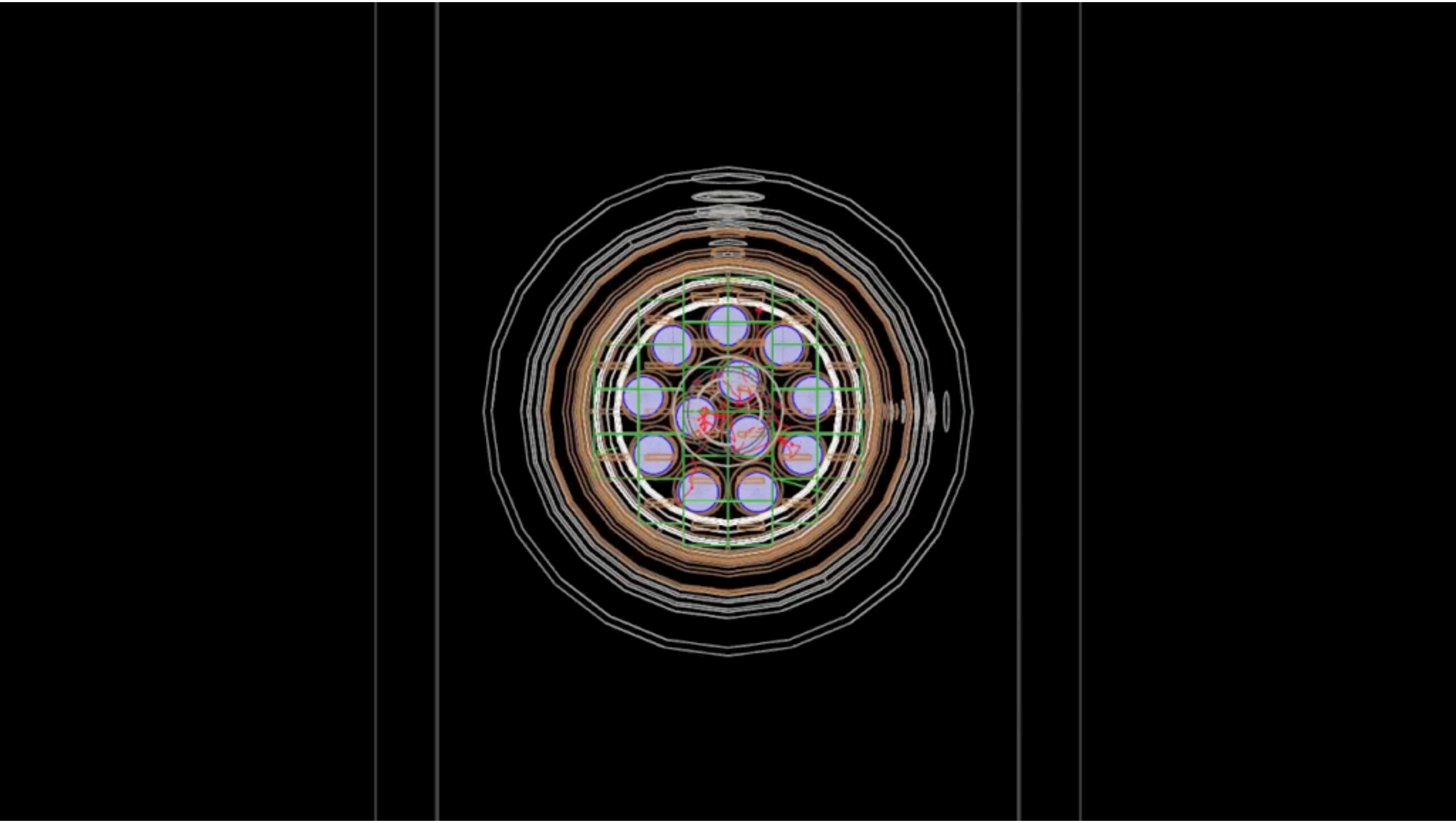




Energy plane:
12 PMTs,
30% coverage



Inner shield:
copper, 6 cm thick



NEXT-NEW 10 kg detector at LSC: goals

First NEXT detector that:

- Is radiopure
- Is operated underground
- Uses enriched xenon (^{136}Xe)
- Comfortably contains O(MeV) electrons

➪ new opportunities!

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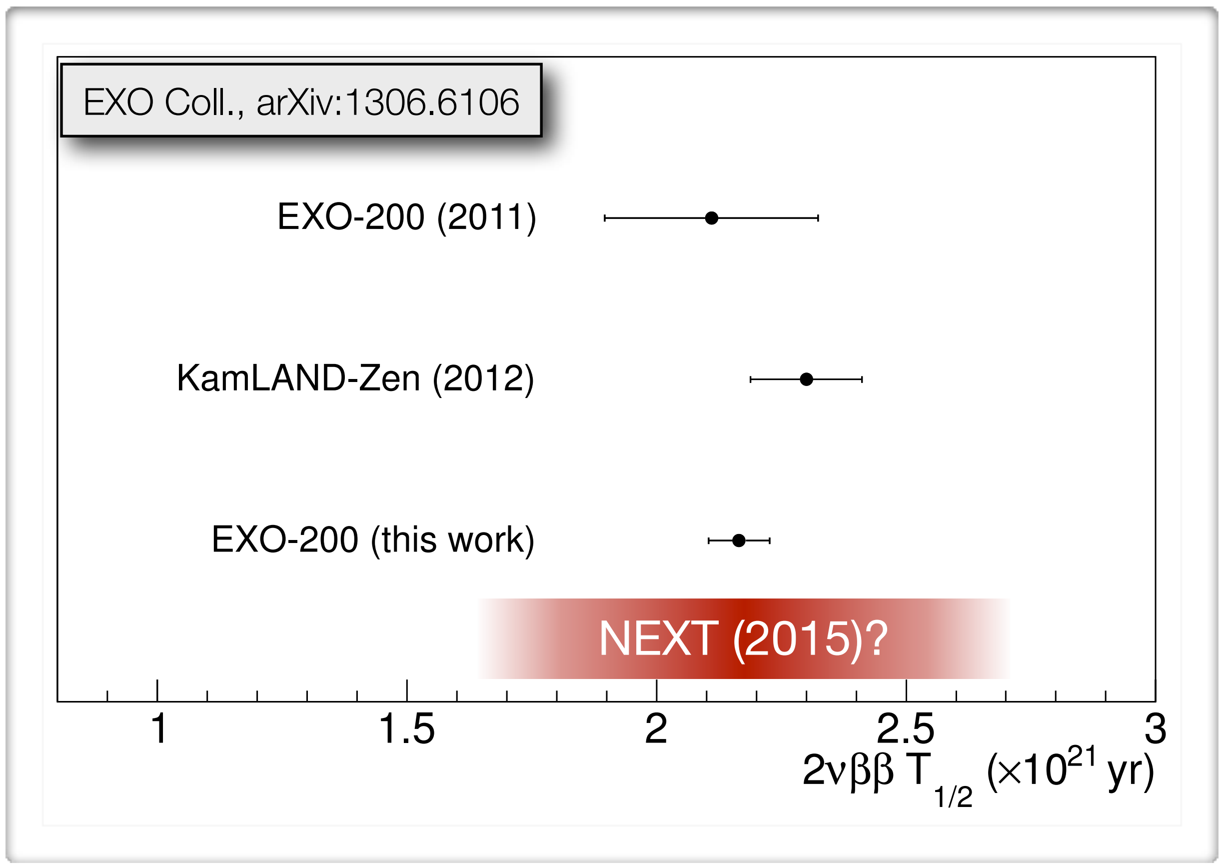
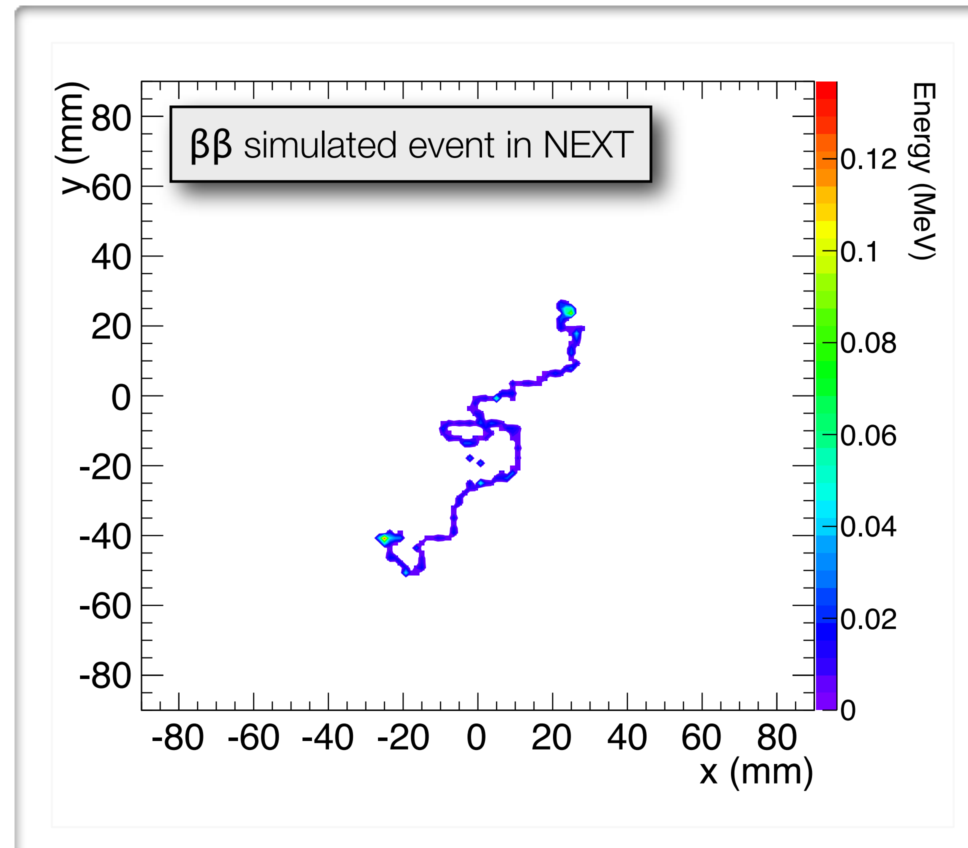


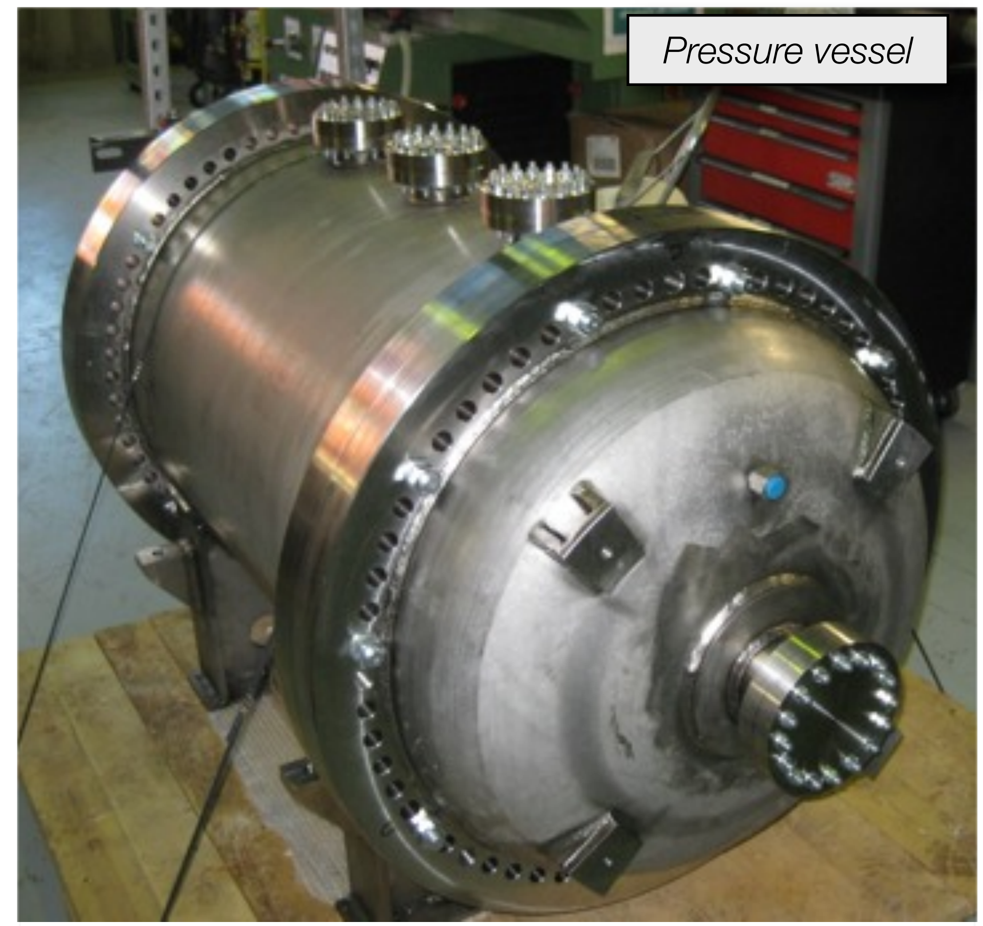


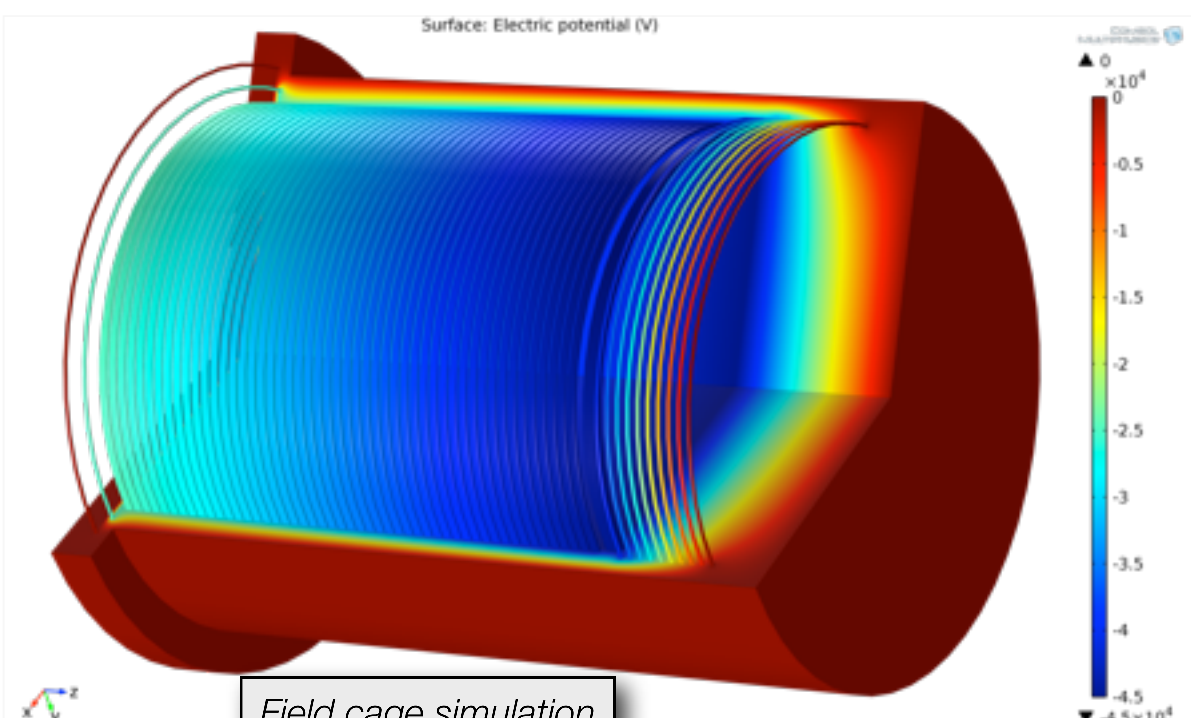
Goals:

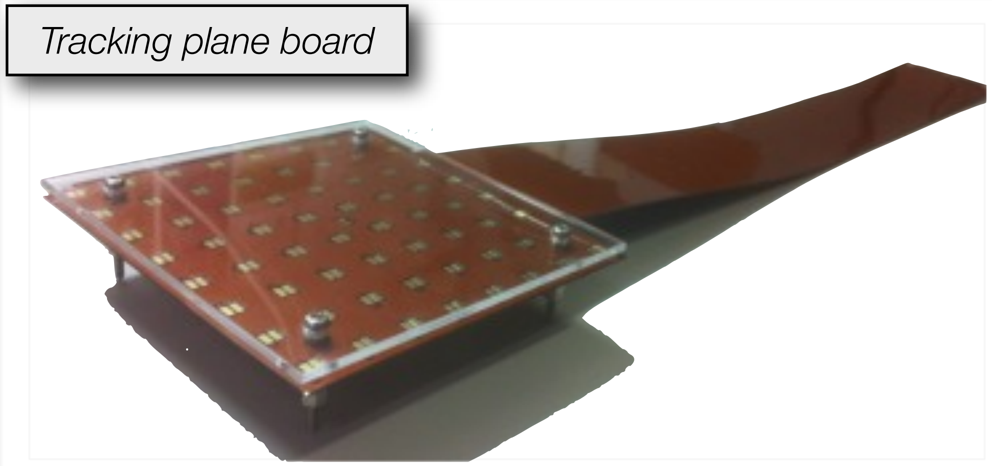
- ββ2ν half-life measurement
- Understand ββ topology
- Understand ββ0ν backgrounds

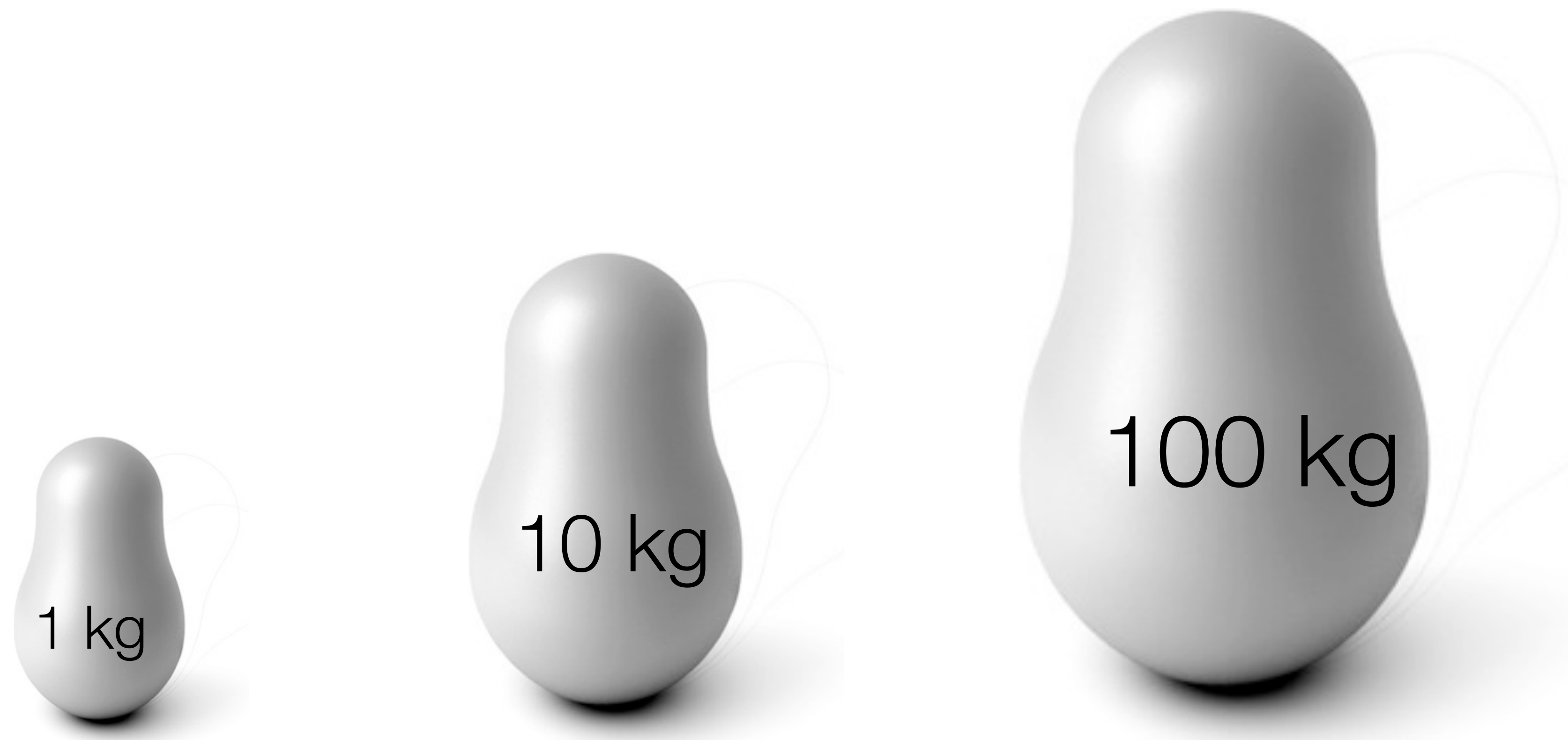
NEXT-NEW status

- All detector components designed
- Some components already delivered and being tested
- Detector integration and commissioning at IFIC during 2014
- Detector operating at LSC starting on Feb, 2015



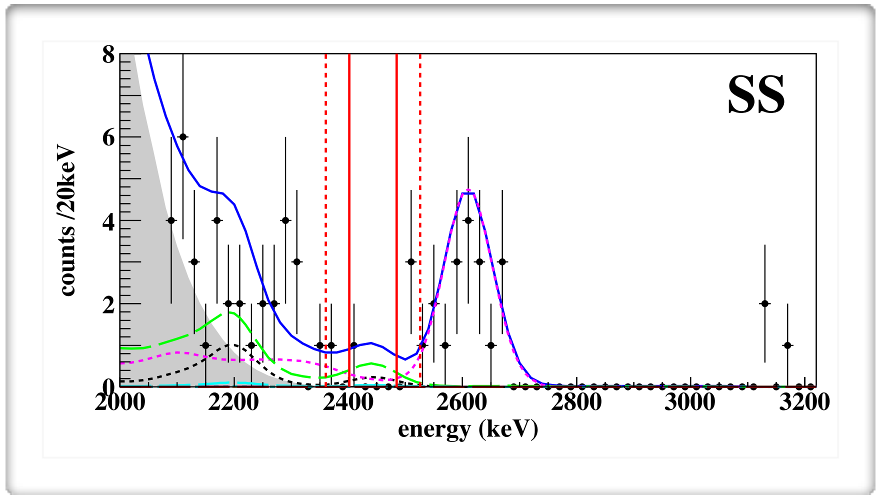


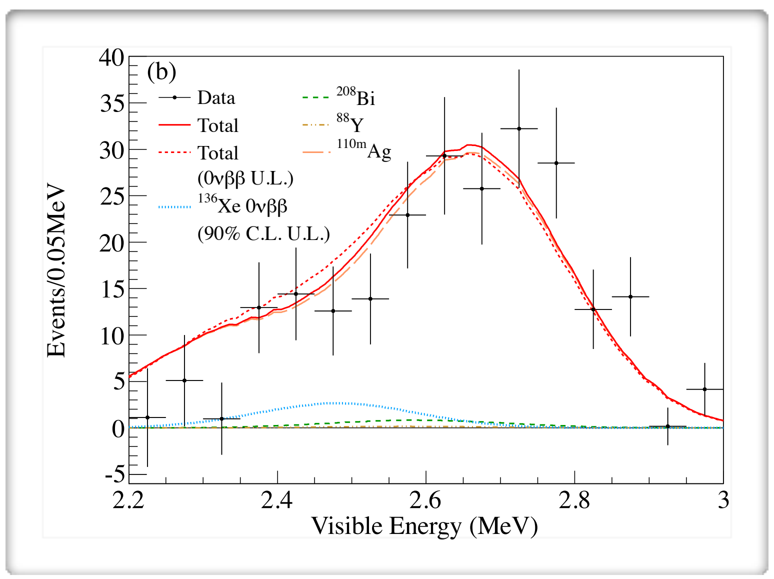


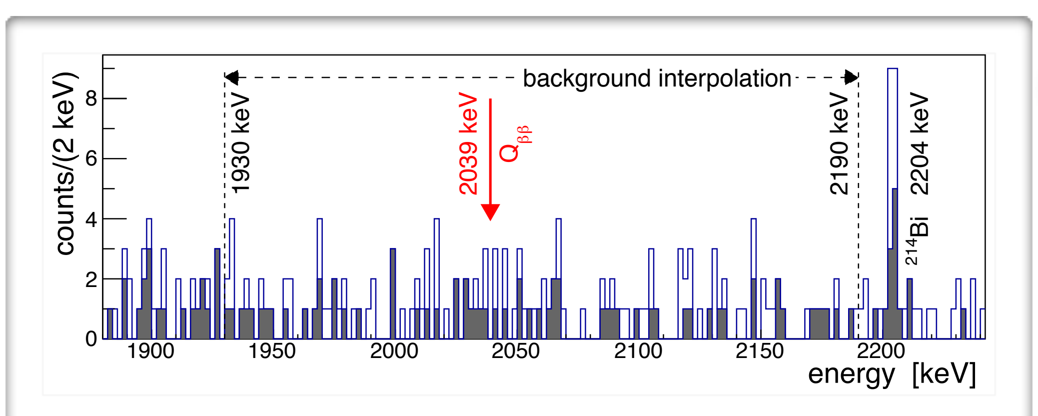


R&D	ββ2ν	ββ0ν (100 meV)
(2008-2013)	(2014-2016)	(2016-2020)

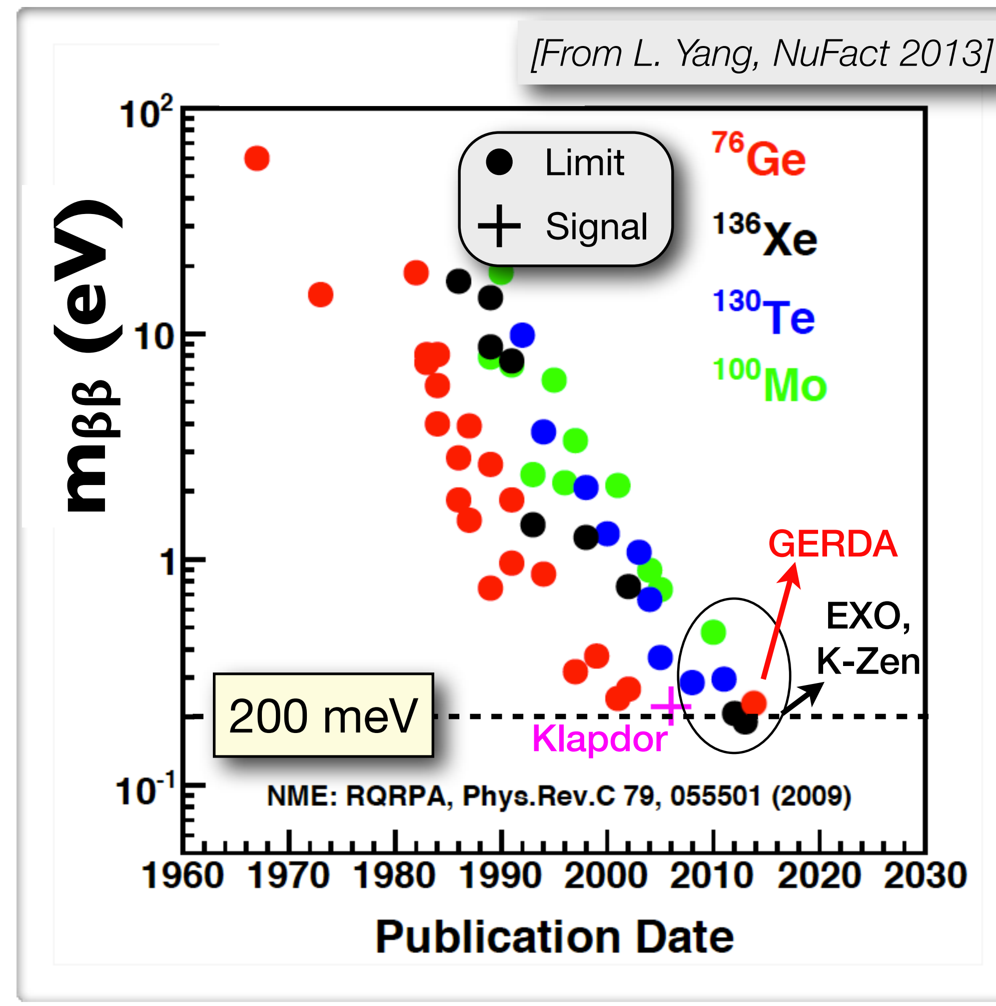
The ββ0ν landscape around 2014







- Claim for ββ0ν strongly disfavored by null results in ^{136}Xe and ^{76}Ge
- $m_{\beta\beta}$ < 200 meV

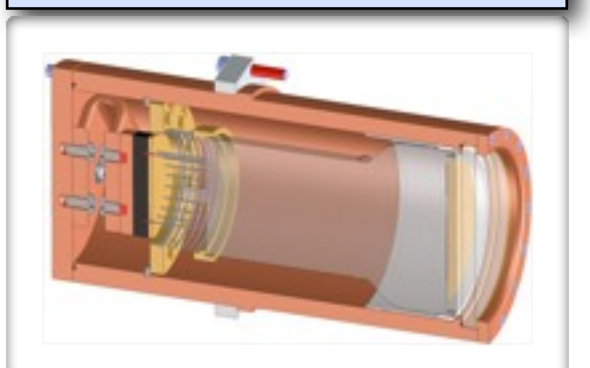


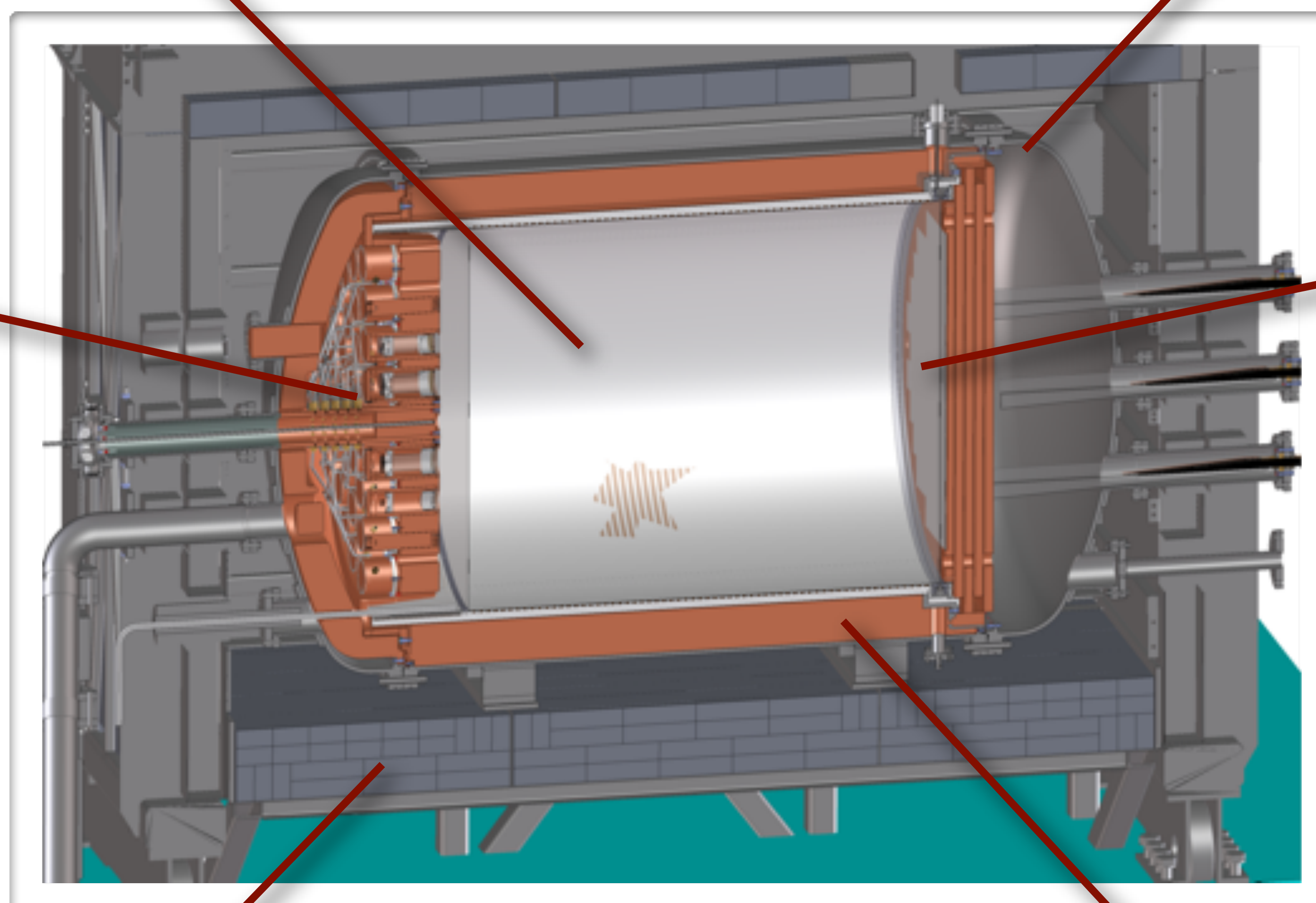
NEXT 100 kg detector at LSC: main features

Time Projection Chamber:
100 kg active region, 130 cm drift length

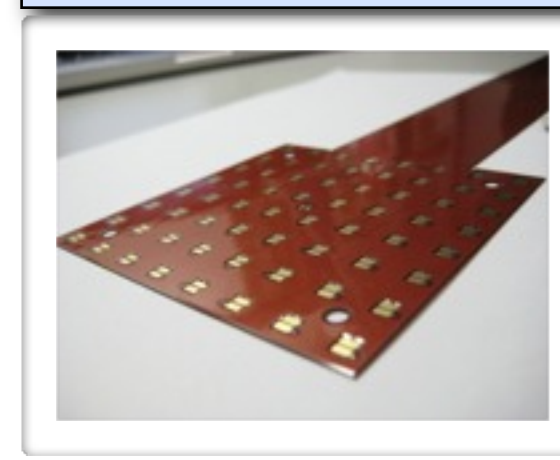
Pressure vessel:
stainless steel,15 bar max pressure

Energy plane:
60 PMTs,
30% coverage





Tracking plane:
7,000 SiPMs,
1 cm pitch



Outer shield:
lead, 20 cm thick

Inner shield:
copper, 12 cm thick

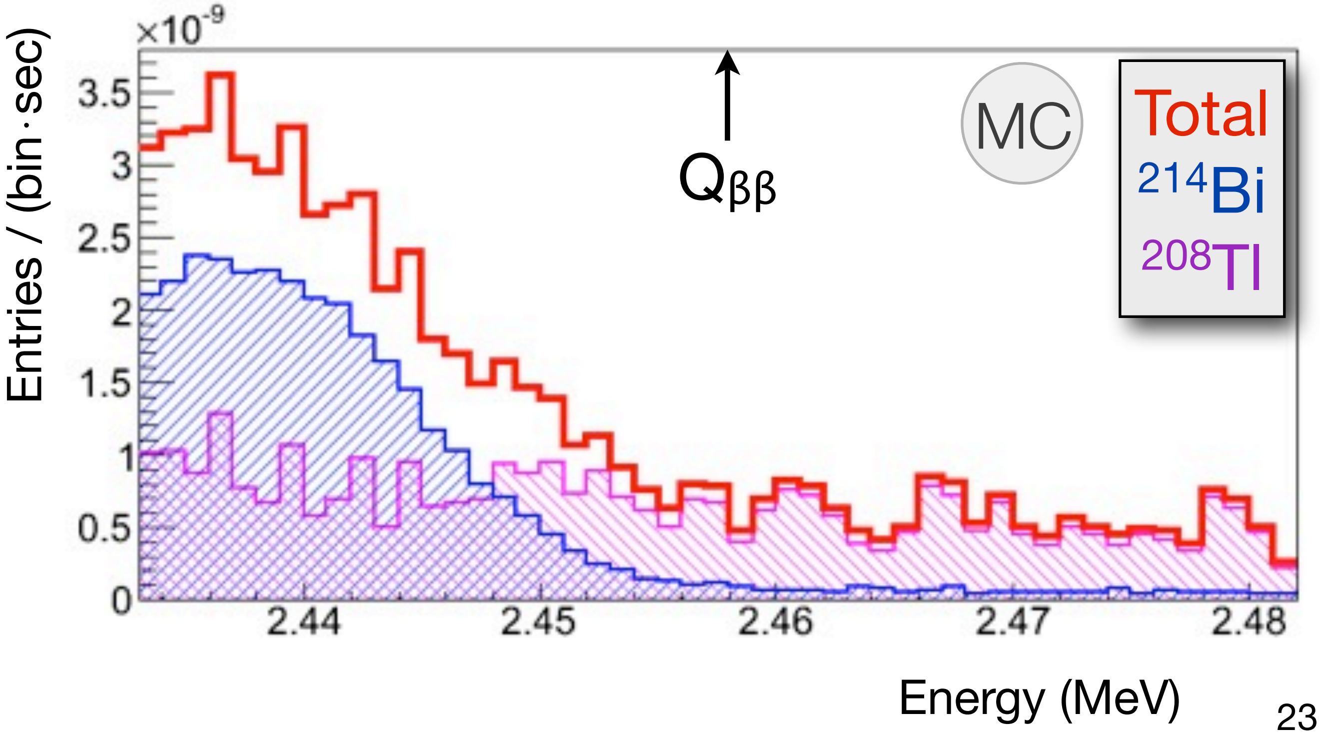
NEXT 100 kg detector at LSC: projected performance

Background model:

- Activities from material screening - joint NEXT+LSC effort
- Signal efficiency and background rejection factors from simulations

Backgrounds at $Q_{\beta\beta}$=2.458 MeV: gammas from ^{208}Tl and ^{214}Bi:

Component	Estimated backgrounds [10^{-4} cts/(kg·keV·yr)]
Pressure vessel	0.2
Field cage	0.4
Energy plane	3.1
Tracking plane	1.2
Total	4.9



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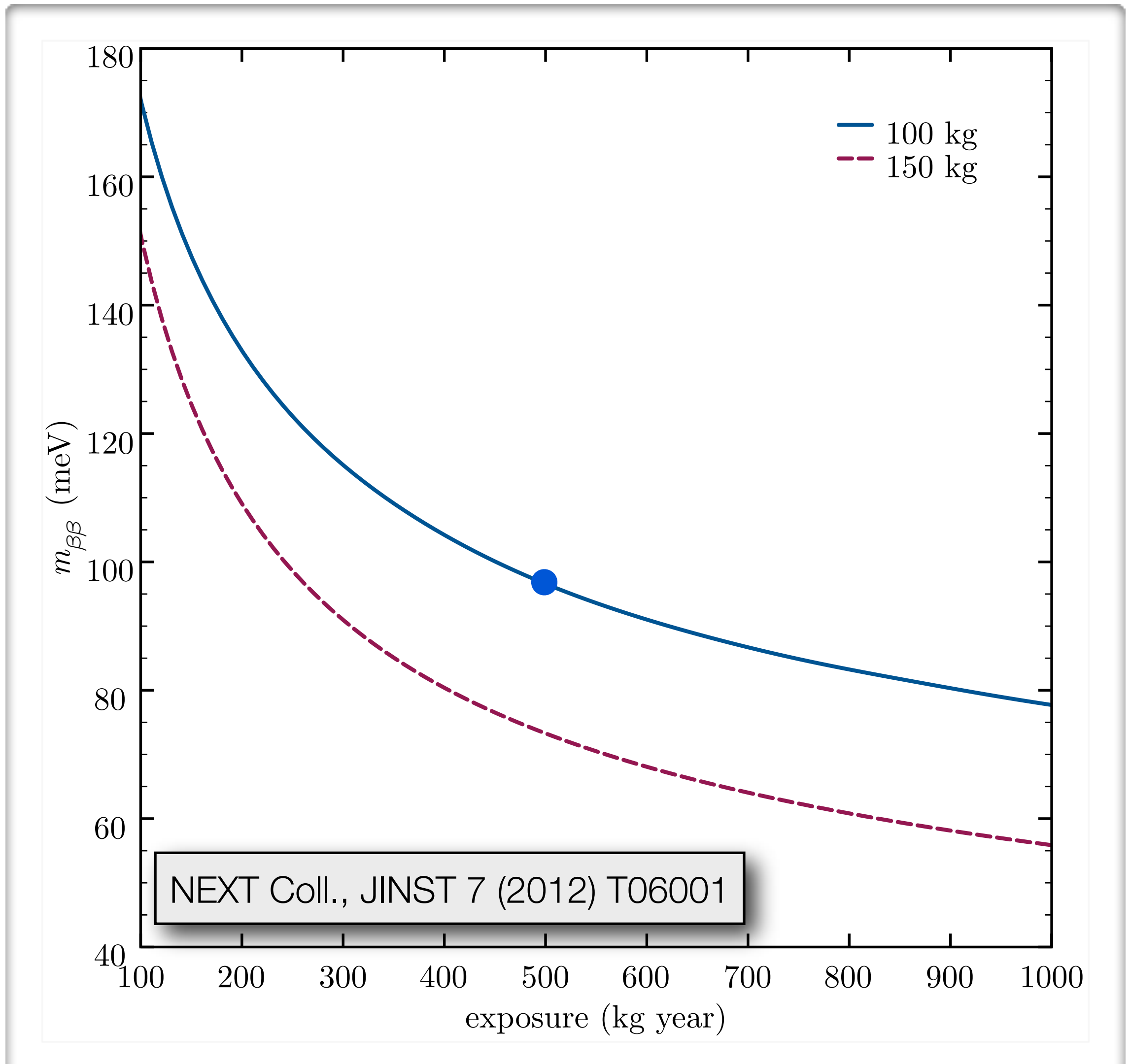
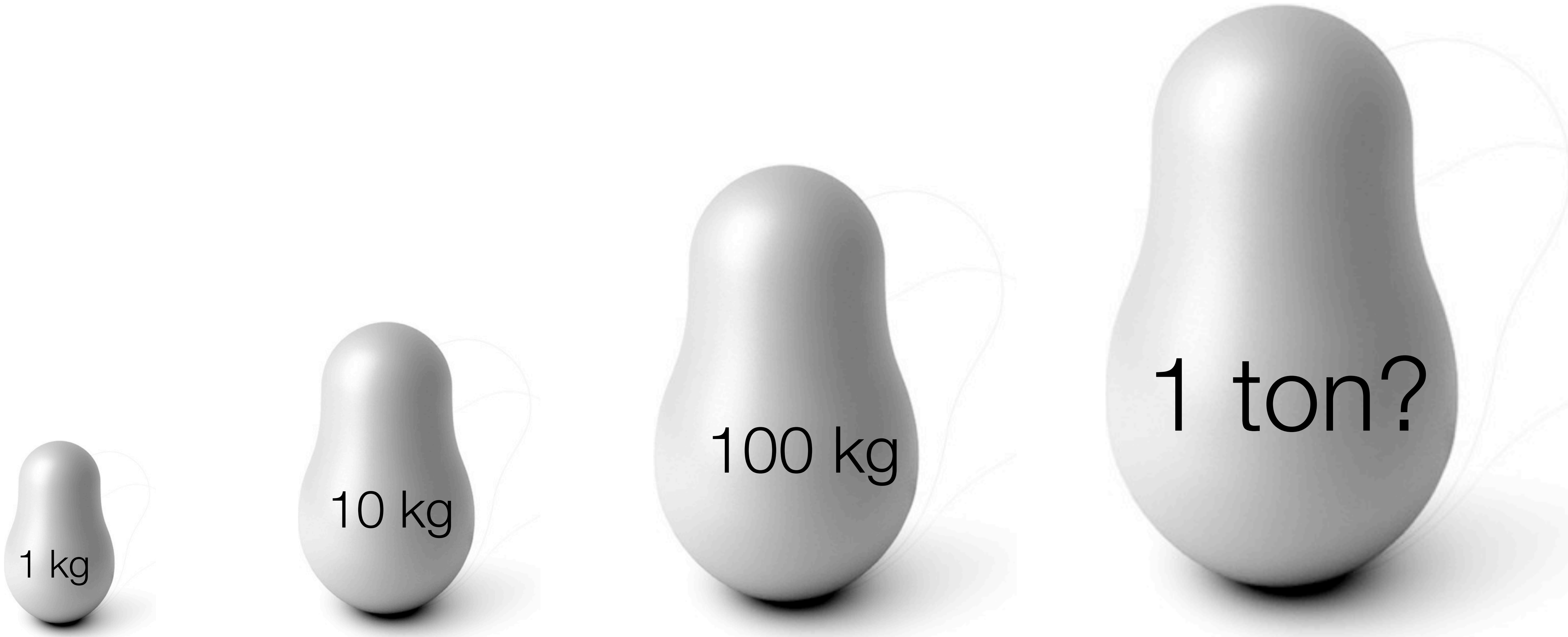
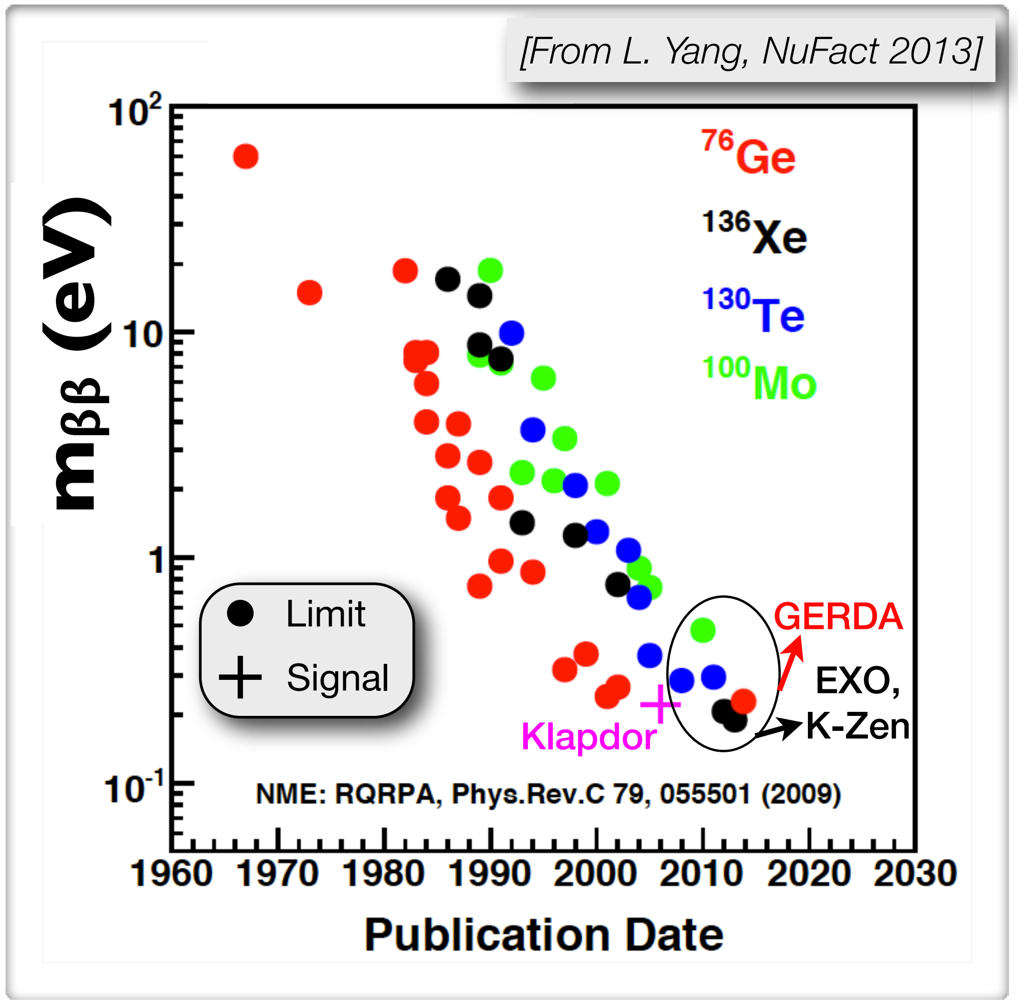


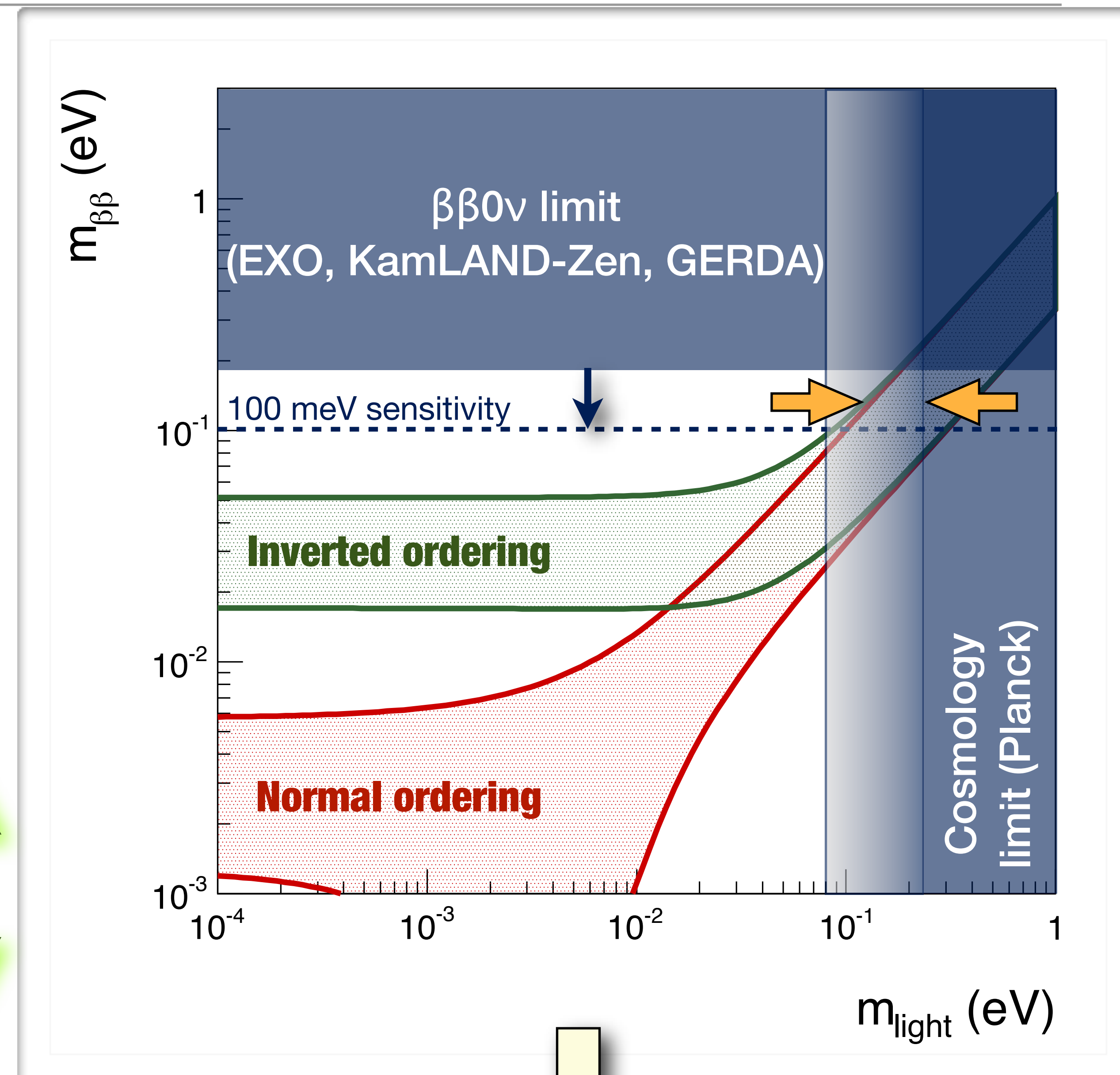
- 100 meV sensitivity after 5 years

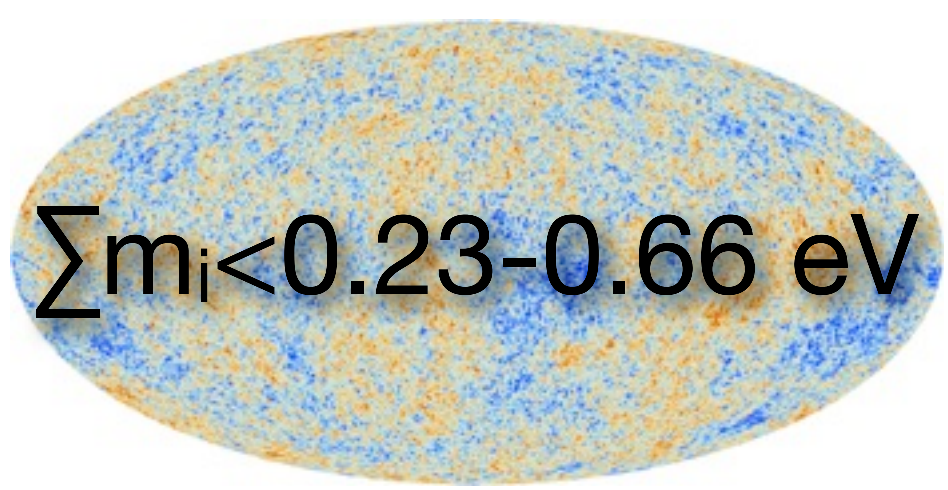


R&D	ββ2ν	ββ0ν (100 meV)	ββ0ν (15 meV)
(2008-2013)	(2014-2016)	(2016-2020)	(2020+)

Short-term prospects to measure neutrinoless double beta decay

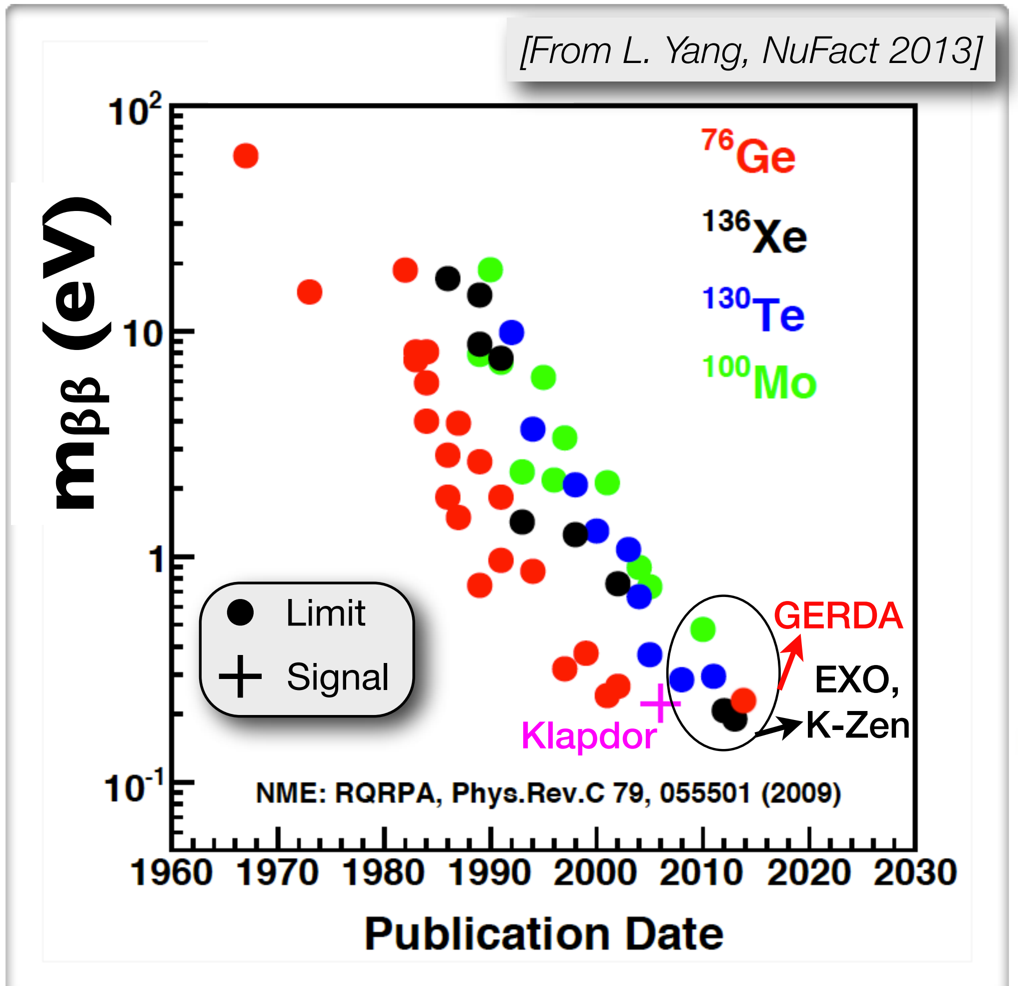


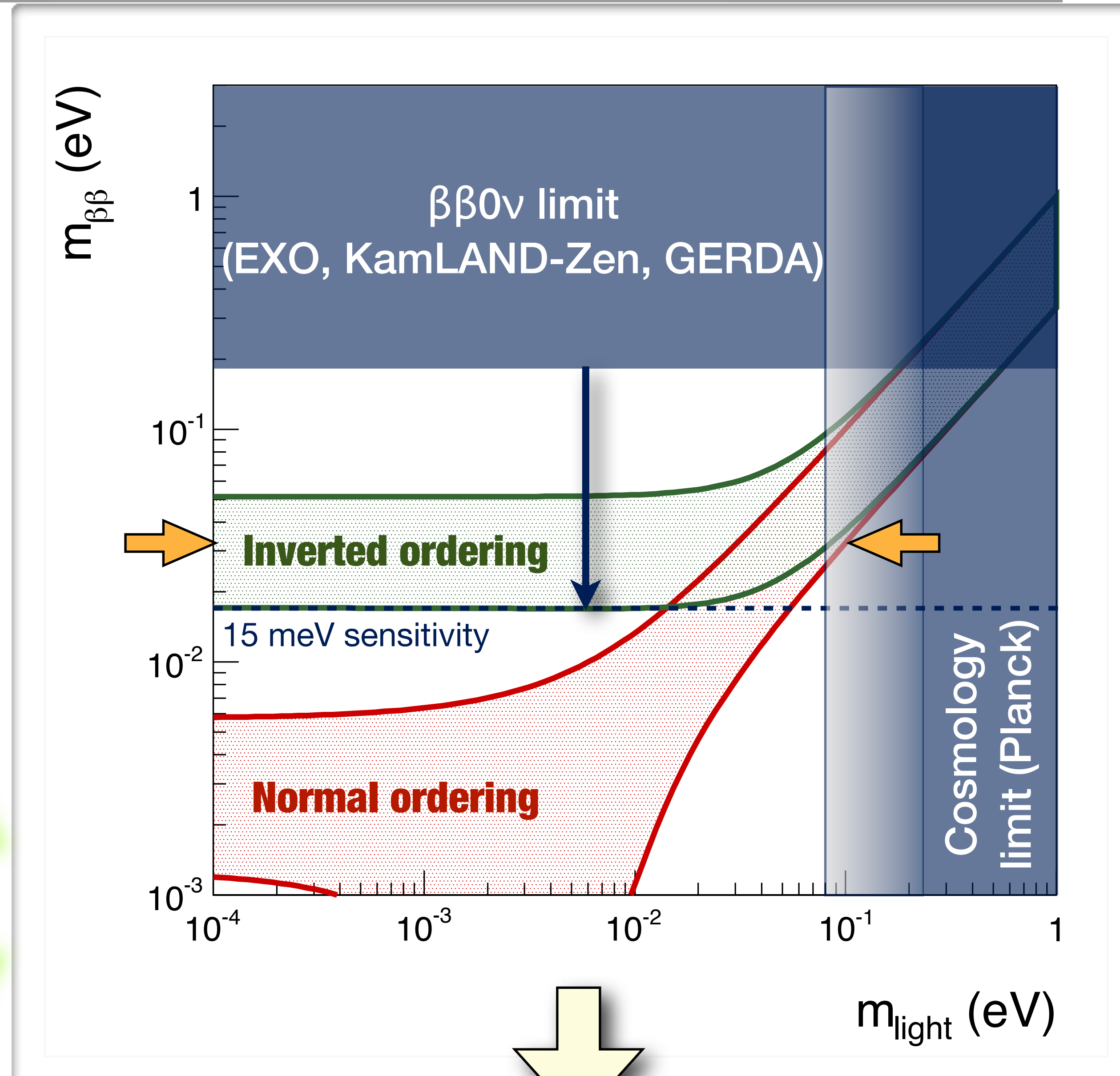


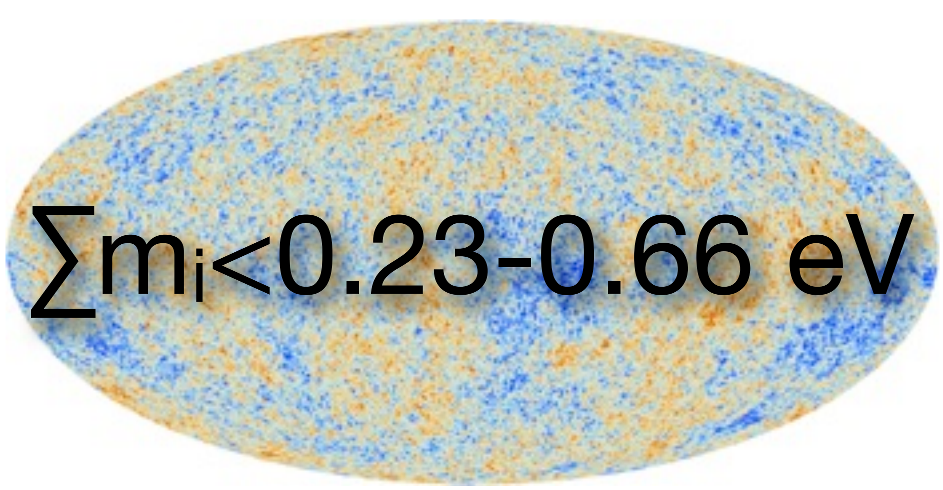


Possible, but unlikely, that current-generation experiments will discover ββ0ν

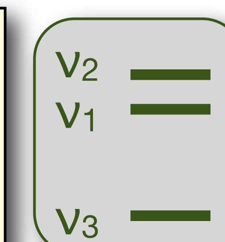
Goal for next-generation (2020+) experiments: 15 meV Majorana neutrino mass sensitivity







Guaranteed ββ0ν discovery if neutrinos are Majorana and have "inverted" mass ordering



Toward a xenon gas time projection chamber at the ton-scale

Two-three ton-scale $\beta\beta0\nu$ experiments very likely to be built (2020+), but... which technology?

atomic, nuclear, particle physics

$$1/T_{1/2}^{0\nu} = G^{0\nu} \cdot |M^{0\nu}|^2 \cdot m_{\beta\beta}^2$$

Isotope	Q-value (MeV)	Phase space $G^{0\nu}$ (yr^{-1} eV^{-2})	Matrix element $\|M^{0\nu}\|$	Isotopic abundance (%)	Indicative cost (normalized to ^{76}Ge)	Current experiments
^{76}Ge	2.04	3.0×10^{-26}	≈4.1	7.8	1	GERDA, Majorana
^{130}Te	2.53	2.1×10^{-25}	≈3.6	33.8	0.2	CUORE, SNO+
^{136}Xe	2.46	2.3×10^{-25}	≈2.8	8.9	0.1	EXO, KamLAND-Zen, NEXT

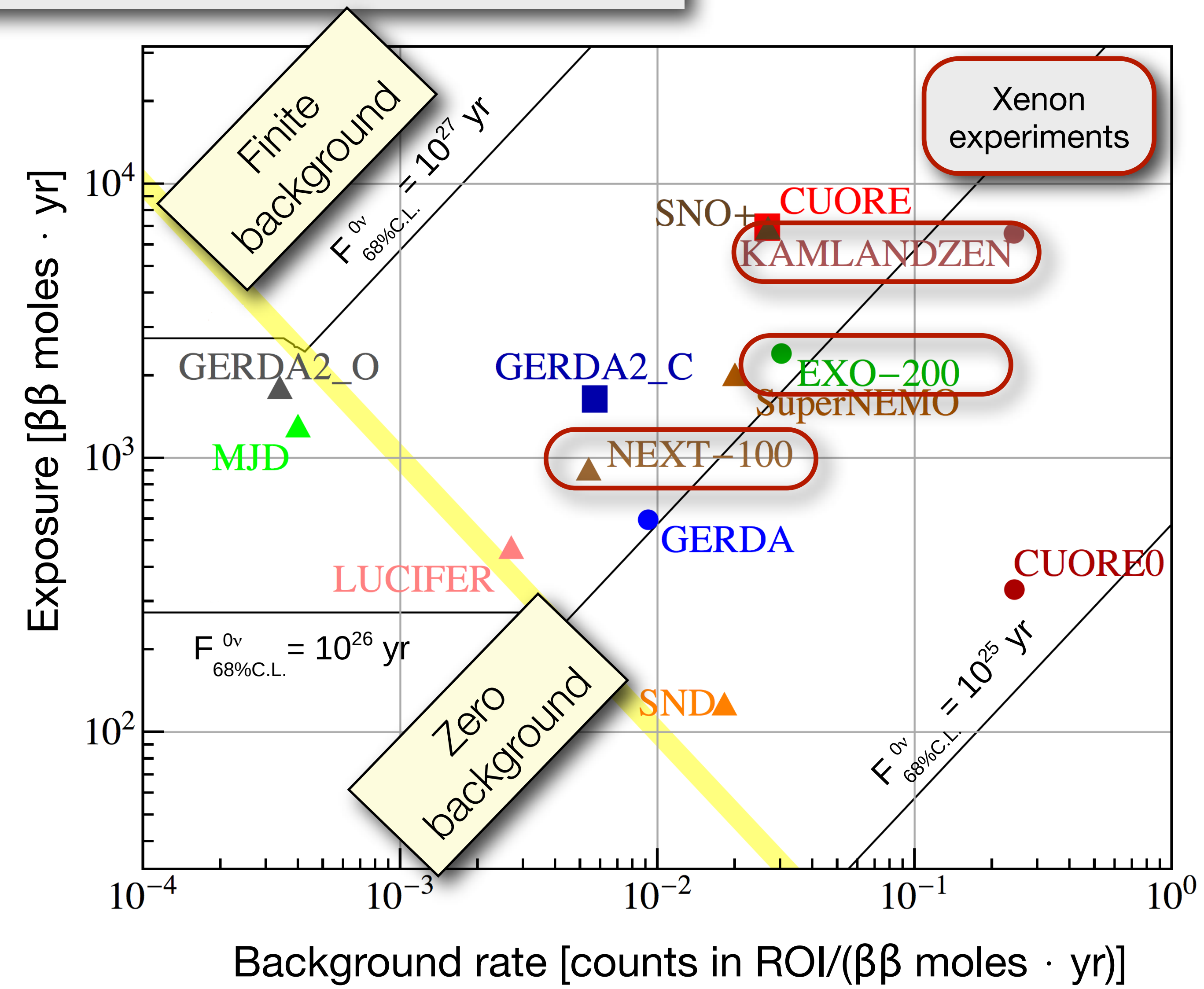
The higher, the better

The lower, the better

Toward a xenon gas time projection chamber at the ton-scale

Two-three ton-scale ββ0ν experiments very likely to be built (2020+), but... which technology?

[From O. Cremonesi, M. Pavan, arXiv:1310.4692]

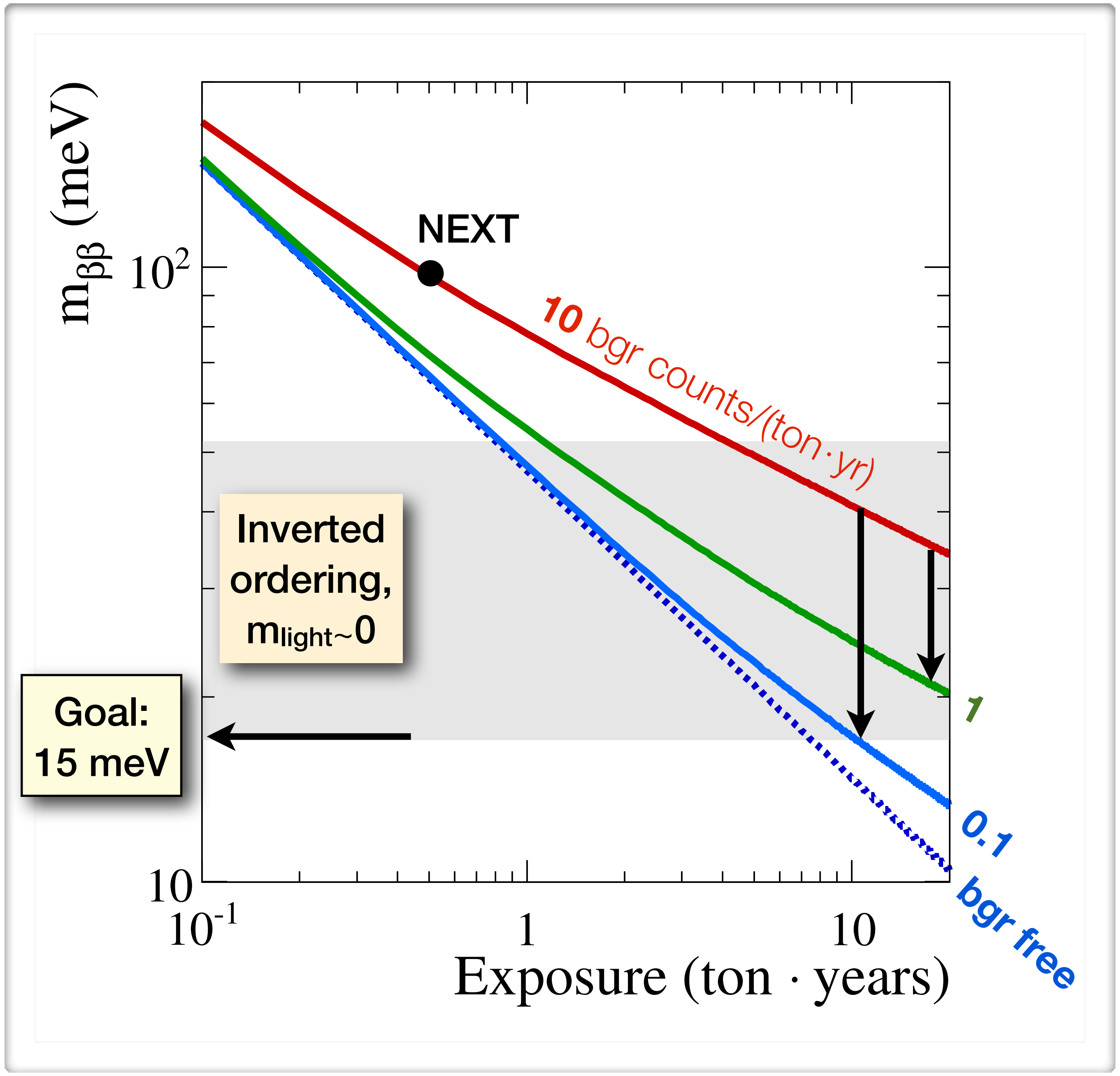


Gas TPC excellent energy resolution and tracking ⇔ low background

Background requirements

$$(\text{Rate})_{\beta\beta0\nu} \propto m_{\beta\beta}^2 \equiv \left| \sum_i m_i U_{ei}^2 \right|^2$$

- Ton-scale detector is necessary but not sufficient requirement to reach 15 meV
- First need to build and operate NEXT to fully understand backgrounds!
- Will likely also need 1-2 orders of magnitude background reduction compared to NEXT!



Summary

- Neutrinoless double beta decay: unique tool to answer fundamental questions

- Xenon-based experiments providing best $\beta\beta0\nu$ constraints to date

- NEXT high-pressure xenon gas TPC concept may outperform EXO and KamLAND-Zen thanks to excellent energy resolution and tracking

- NEXT timeline and goals:

R&D	$\beta\beta2\nu$	$\beta\beta0\nu$ (100 meV)	$\beta\beta0\nu$ (15 meV)
(2008-2013)	(2014-2016)	(2016-2020)	(2020+)