nEXO:
Search for Neutrinoless Double Beta Decay in 5-Tonnes of Enriched Xe

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1st Yemilab Workshop

High-1, Korea

ibs CENTER FOR UNDERGROUND PHYSICS

EXO-200 Liquid-Xenon Time Projection Chamber (TPC) Concept for 0νββ search

- Xe is used both as the source and detection medium.
- Enriched to 80% in ^{136}Xe

$Q_{\beta\beta}$ = **2457.8±0.4 keV**

(M. Redshaw, J.McDaniel, E. Wingfield and E.G. Myers, Phys. Rev. Lett. **98**, 053003)

- Simultaneous collection of both ionization and scintillation (175nm) signals.

  $N_{e-}+N_{ph}$ = E/11.5 ev (ratio depends on field)

G. Anton et al (EXO-200) Phys. Rev. C 101, 065501 (2020)

- Full 3-D reconstruction of all energy depositions in LXe ~ 1cm spatial resolution.
- Single-site Multi-site rejection.
- Decomposition of uniform signal and non-uniform background.

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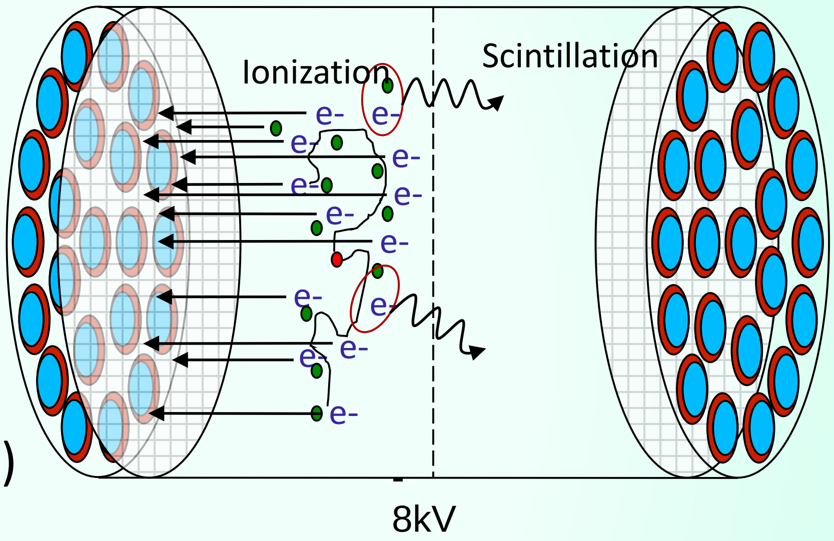
TPC schematic (EXO-200)



Charge collection

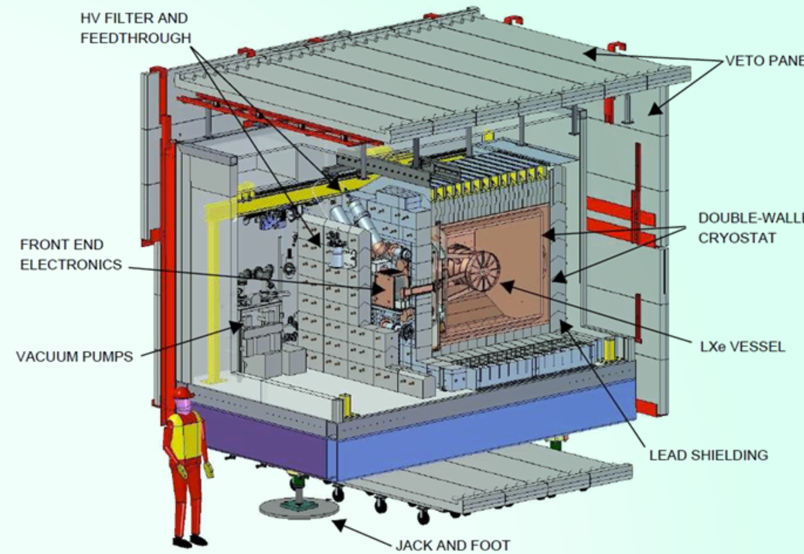
EXO-200 Detector System

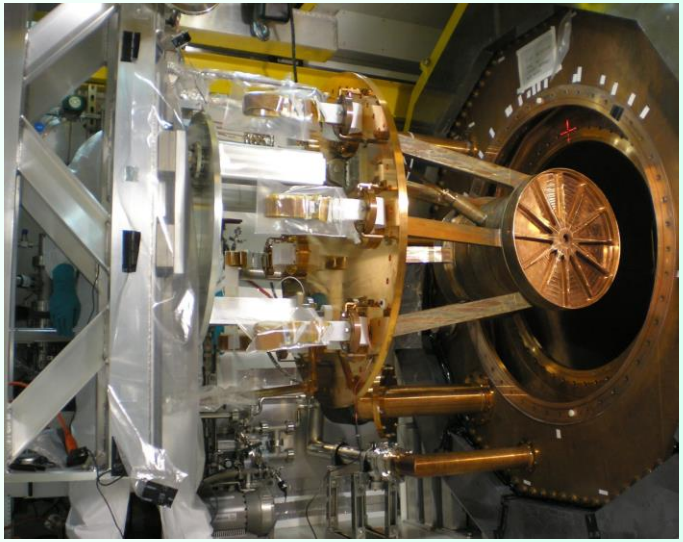
- Aprox 1600 m.w.e under salt at WIPP, Carlsbad N.M. U.S.A..
- ~100 kg fiducial Xe @ 80% ^{136}Xe
- Muon veto: plastic scintillator, ~96% coverage.
- Cu Cryostat contiained in ~ 25cm thick Pb
- Detector: Semi-cryogenic (~165K) time-projection chamber (TPC).
- TPC sitting in HFE thermal bath/shielding.
- Xe recirculation system maintained purity

  (3-5 ms e- lifetime)
- Ran in two phases from 2011 to 2019, with an interruption due to accident at WIPP.

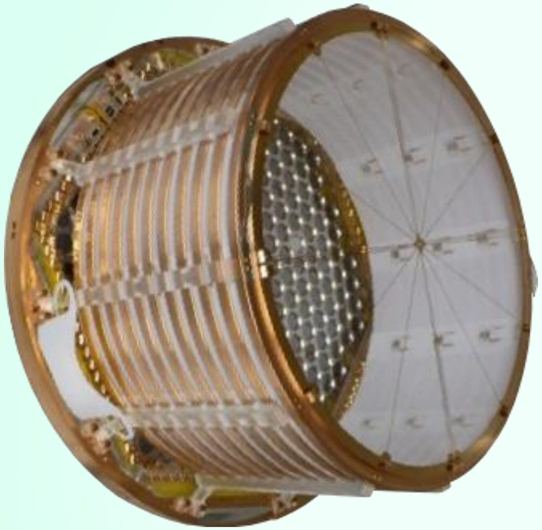
- Total 234.1 kg yr ^{136}Xe exposure

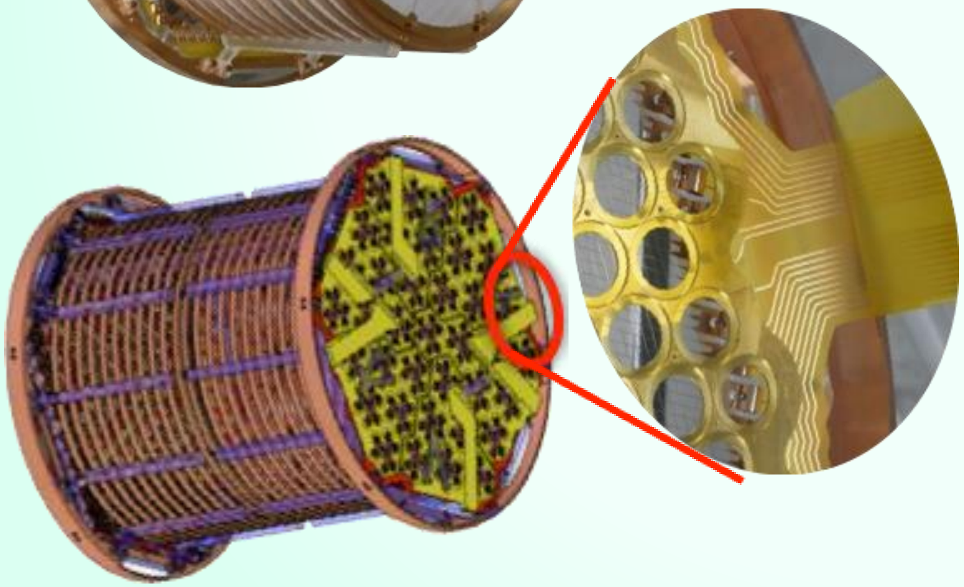
design detailed in JINST **7** (2012) P05010,
JINST **17** (2022) P02015





The EXO-200 TPC





Two almost identical halves reading

ionization and 178 nm **scintillation**, each with:

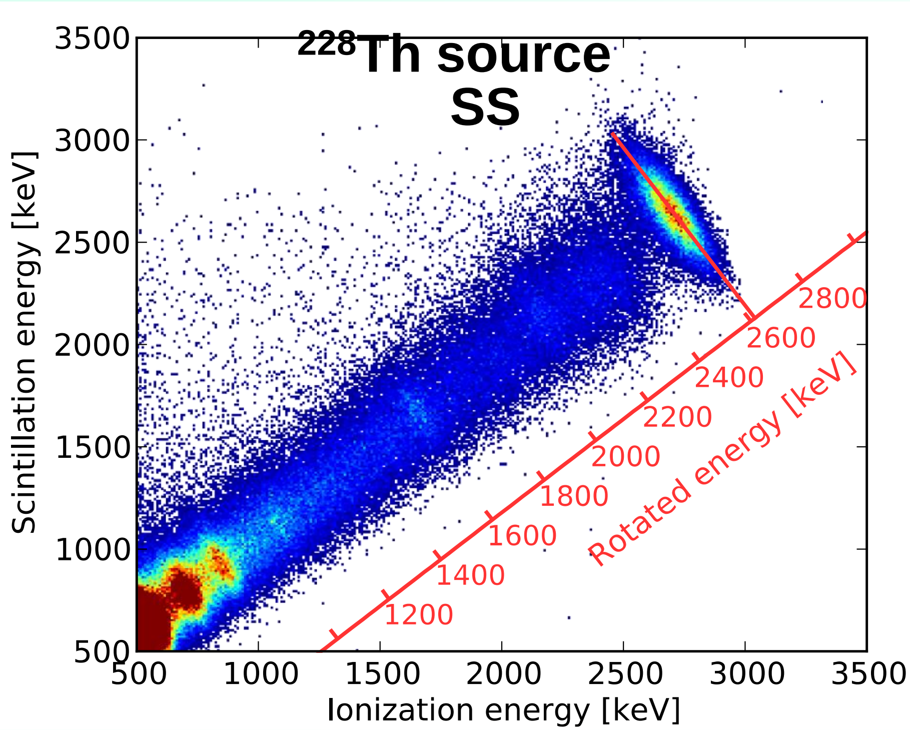
Wire Grid

- 38 U triplet wire channels (charge)
- 38 V triplet wire channels, crossed at 60^o (induction)

Light

- 234 large area avalanche photodiodes (LAAPDs, light in groups of 7)
- All signals digitized at 1 MHz, $\pm$1024 µs around trigger (2 ms total)
- Drift field 376 V/cm
- TPC housed in a copper vessel with 1.37 mm wall thickness

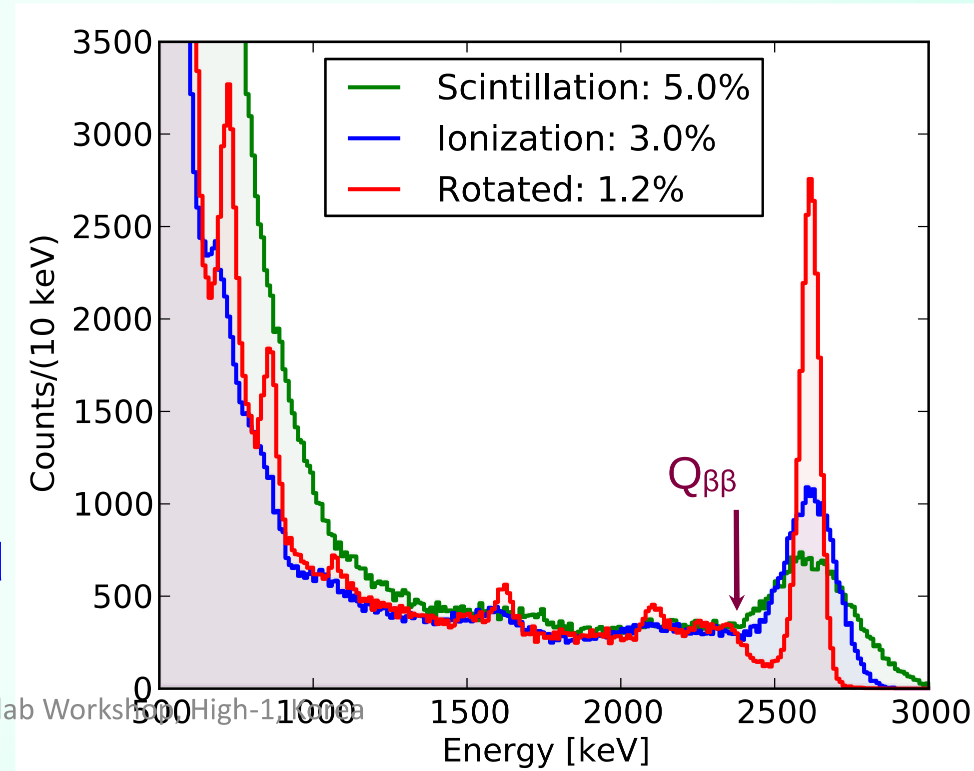
Light, Charge, and Energy Resolution



Combining Ionization and Scintillation energy to enhance energy resolution

Anticorrelation between scintillation and ionization in LXe known since early EXO R&D

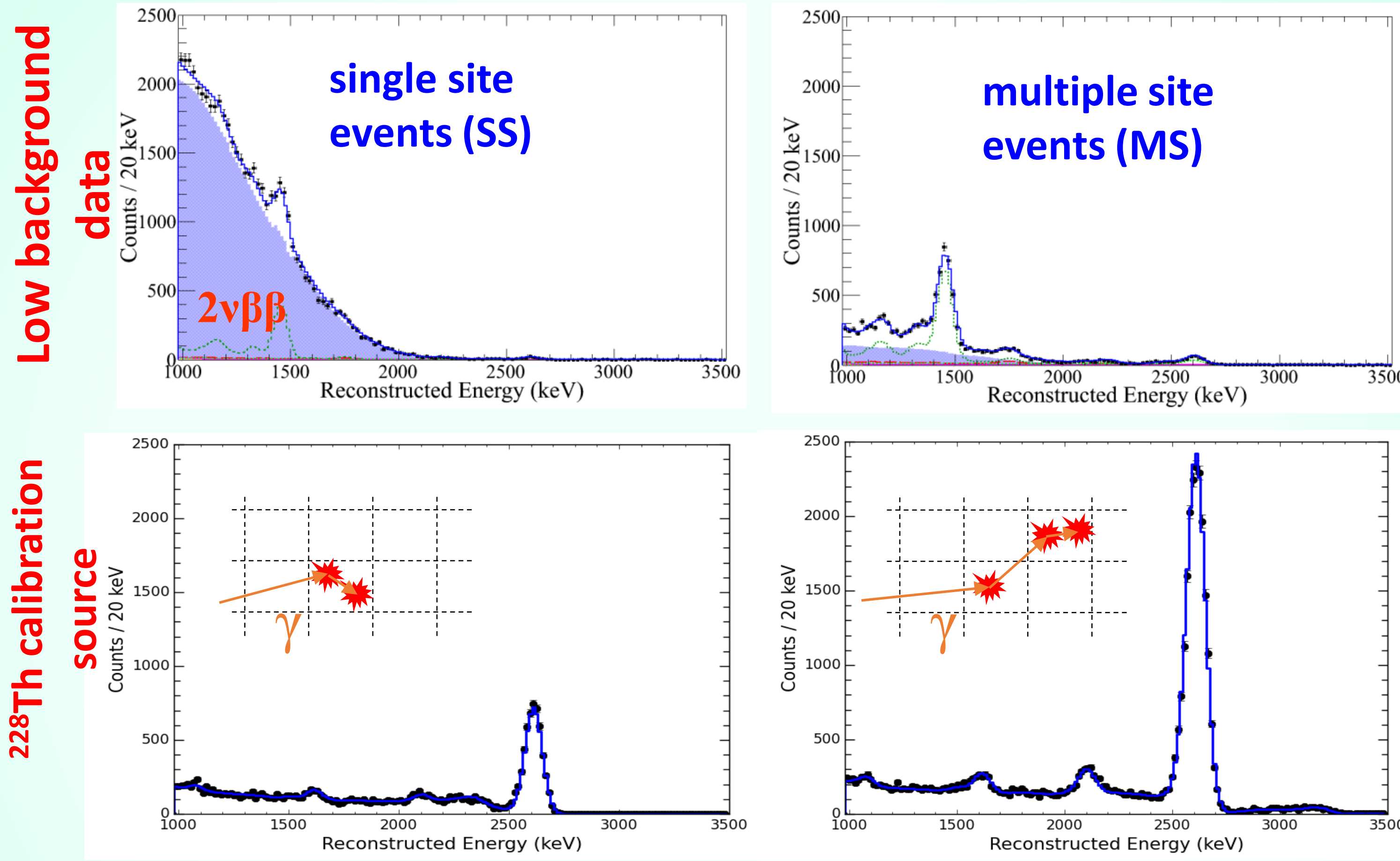
(E.Conti et al. Phys Rev B 68 (2003) 054201)



EXO-200 has achieved ~ 1.15% energy resolution at the Q value.

nEXO will reach resolution < 1 %, sufficient to suppress background from 2νββ.

Topological Event Information



- **TPC allows the rejection of gamma backgrounds because Compton scattering results in multiple energy deposits.**
- **SS/MS discrimination is a powerful tool not only for background rejection, but also for signal discovery.**

EXO-200 Background Control

Techniques:

Gamma Counting: U. of Alabama (UA) above ground, U. of Bern (Vue-des Alpes)

ICP-MS and GDMS: INMS Canada, included resin extraction methods

Neutron Activation Analysis (NAA): UA

Alpha counting (for lead samples)

Radon counting (Laurentian)

Cosmogenic Studies: *J.B. Albert et al.,JCAP 04 (2016) 029.*

Assays: *D.S. Leonard et al., Nucl. Ins. Meth. A 591 (2008) 490*
D.S. Leonard et al., Nucl. Inst. Meth. A871 (2017) 169
M. Auger et al., J. Inst. 7 (2012) P05010.

From EXO-200 Data: *J.B. Albert et al. Phys. Rev. C 92 (2015) 015503.*

Materials Database:

Tracked measurents, sources, conditions (cleaning etc) of all materials.

Over 300 materials entries, even more samples and measurements.

Simulations:

Initial Geant 3 simulations (UA), simplistic for background estimation only.

Derived ”hit efficiencies”

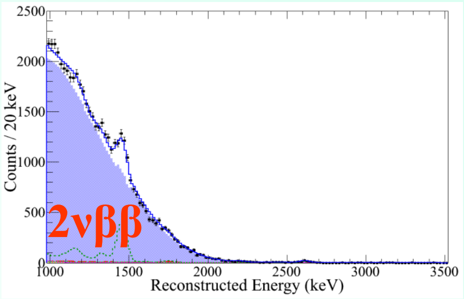
Impact table

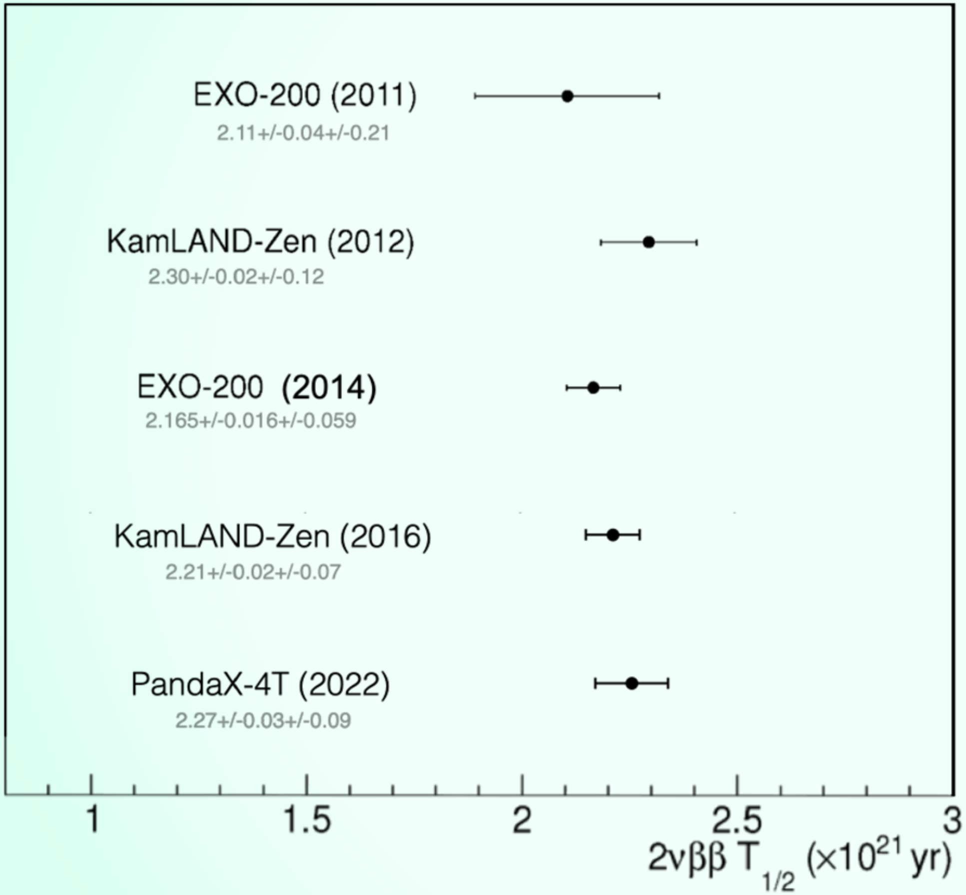
Define part; input mass; select material; select MC => output background

Predicted backgrounds before taking data!!!

Events in $\pm 2\sigma$ around Q	Radioactive bkgd prediction using certification data and G4 Monte Carlo	^{137}Xe bkgd	Background from 0v analysis fit
90%CL Upper	56	18	63.2 ± 4.7 (65 events observed)
90%CL Lower	8.2		

EXO-200 2νββ discovery





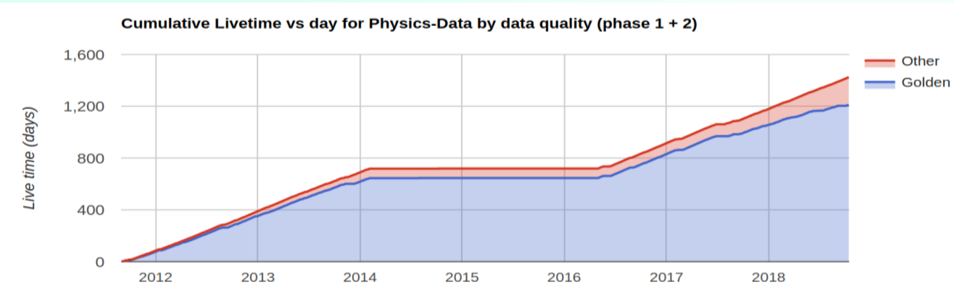
Discovery of 2νββ decay in ^{136}Xe
PRL 107 (2011) 212501

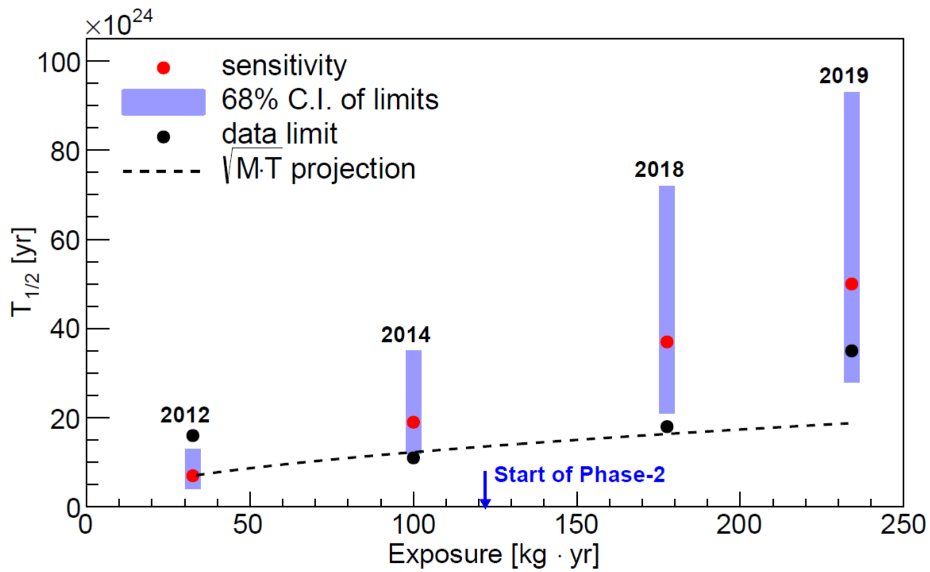
Confirmation by
KamLAND-ZEN
PRC 85 (2012) 045504

Precision measurements (~3%)
PRC 89, 015502 (2014)
PRL 117, 082503 (2016)
arXiv.2205.12809

EXO-200 still has the best measurement, in spite of exposure disadvantage.

EXO-200 Results





Initial analysis was statistically lucky. Sensitivity improved with exposure and systematic/analysis improvements.

2012: Phys.Rev.Lett. 109 (2012) 032505
2014: Nature 510 (2014) 229-234 ***(Phase I)***
2018: Phys. Rev. Lett. 120, 072701 (2018)
2019: Phys. Rev. Lett.123 (2019)161802 ***(Phase II)***

Total exposure: 234.1 kg·yr
Bckground index in ROI:
$(1.7 \pm 0.2) \times 10^{-3}$ /(kg·yr·keV)

$T_{1/2}(0\nu\beta\beta)$:
Sensitvity: $5.0 \cdot 10^{25}$ yr (90% CL)
LIMIT: $> 3.5 \cdot 10^{25}$ yr (90% CL)

$\langle m_{\beta\beta} \rangle <$ 93–286 meV

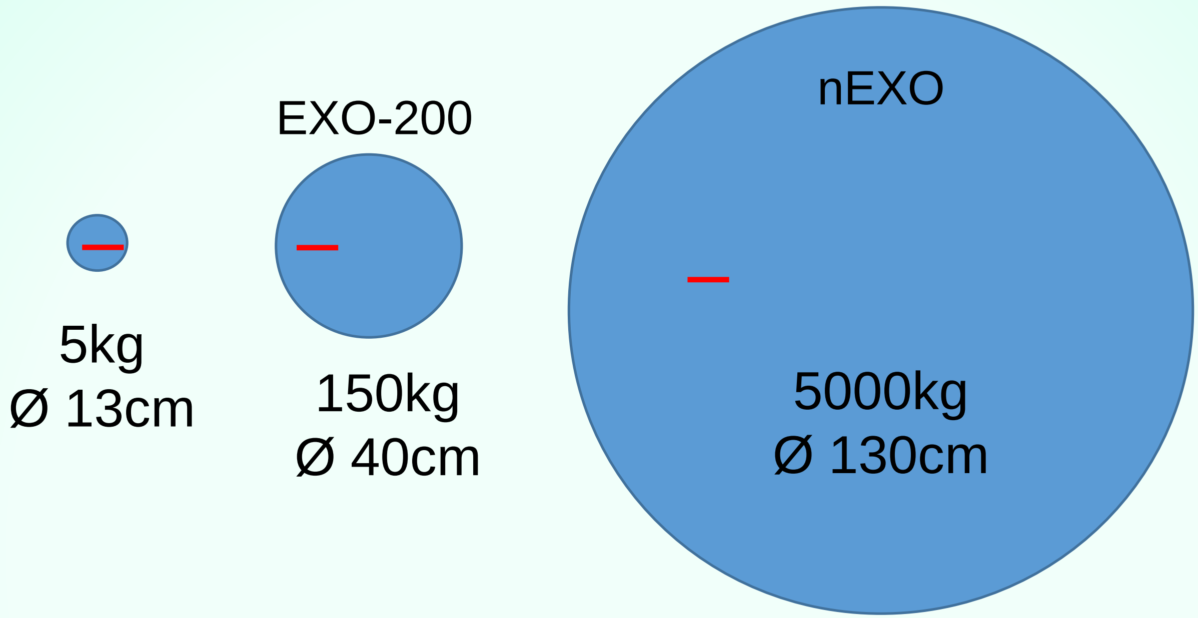
Upgrades:
-Improved electronics
-Deep neural net multi-site analysis and "standoff" distance analysis (see later slides)
-Response uniformity improvements
…

Best Xe limit to date:
KamLAND-Zen 800 limit **$T_{1/2}$ < 2.3 X 10^{26}**
arXiv:2203.02139 (March 2022)

So Why Xenon

- Because it worked!! (This used to be the first slide)
- High Q-value (above 2615 ^{228}Th peak)
- Highly enrich-able
- Easy to re-purify,
- Minimal cosmogenic activation
- Some particle identification (high alpha light yield)
- Re-usable and scalable.
- Possibility to collect and identify Ba daughter ion.
- Self-confirming: Can replace with natural xenon, same detector, mostly same backgrounds.

nEXO: Going Bigger

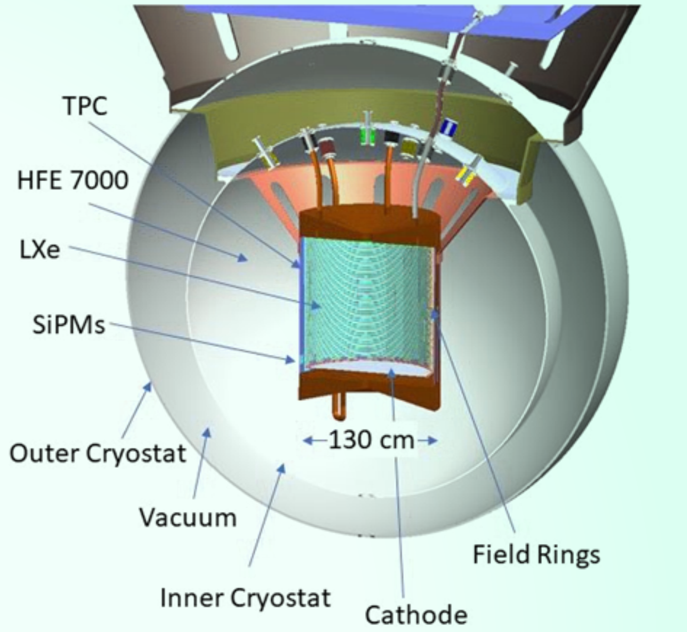


2.5MeV gamma ray attenuation length 8.5 cm = —

- **Higher exposure of course.**
- **Active xenon shielding**
  - **Blocks backgrounds => extremely clean inner volume.**
  - **Rejects inner-region events with outer region Comptons (MS).**
  - **Measures inner backgrounds using higher outer backgrounds statististics.**

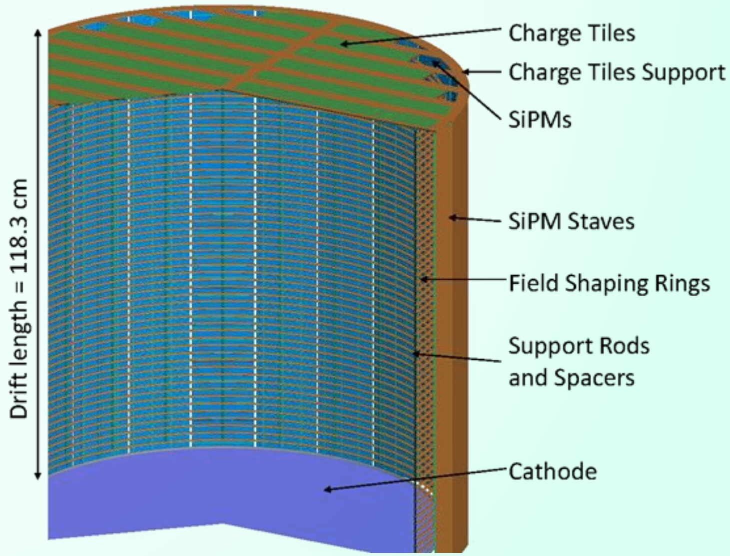
nEXO Design Overview

- 5000 kg LXe (90% ^{136}Xe)
- Sevral facilities available in western Europe and U.S., production capabilities verified.
- Cu TPC vessel in HFE (like EXO-200)
- Carbon-fiber cryostat: strong, light, low activity.
- 5 to 10 ms e- lifetime target/goal.
- Gridless segmented tile anode charge readout.
- SiPM light collection on barrel
- In-LXe ASICs with digital signal output.
- 50kV (25 for EXO-200), single-ended.
- Resolution: 0.8% (goal) to 1.2% (requirement).
- Discovery focused: multiple event signatures + natural xenon verification.
- Pre-Conceptual Design Report : https://arxiv.org/abs/1805.11142



Example Carbon-Fiber Vessel

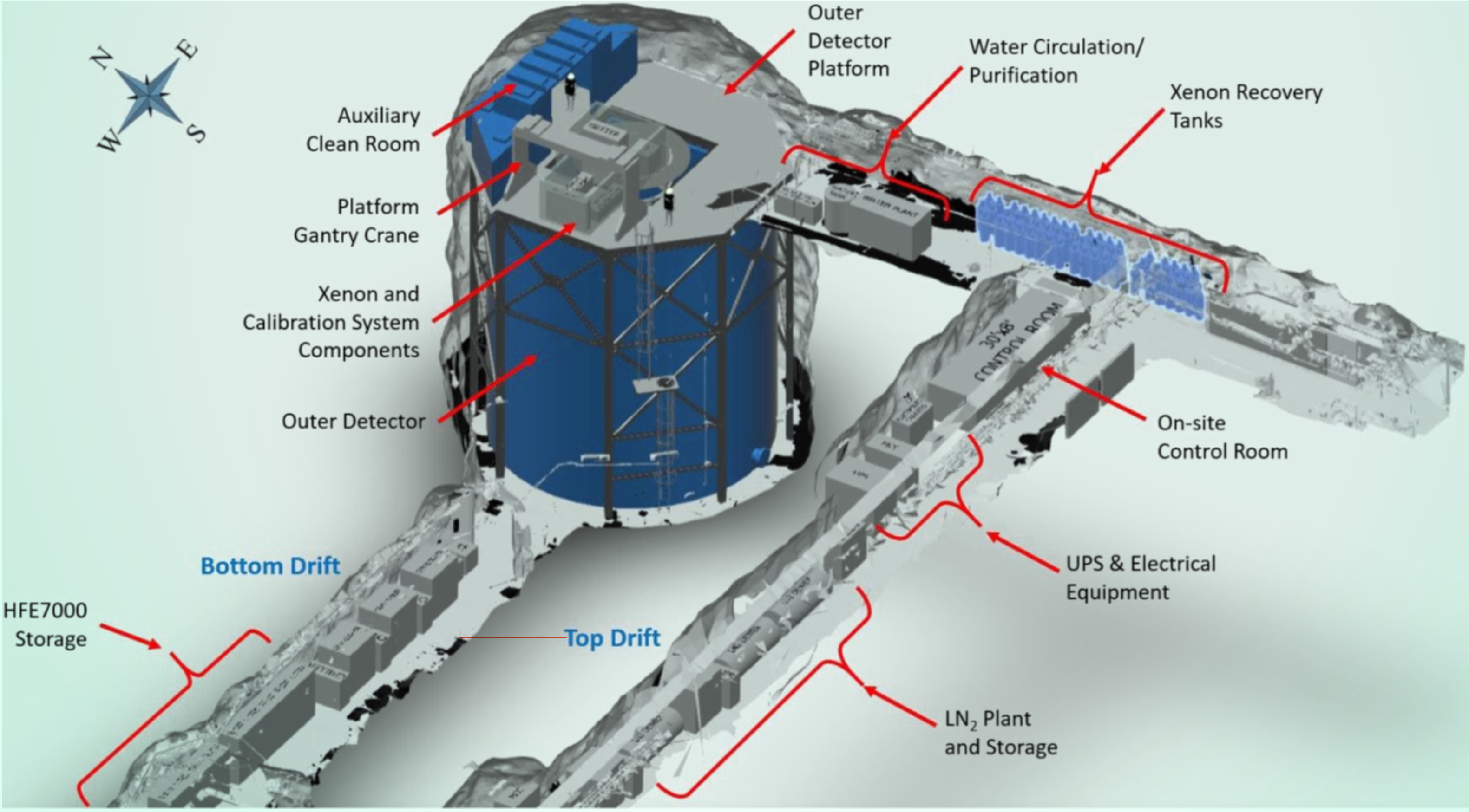
nEXO vessel to be wound on location



nEXO Location:

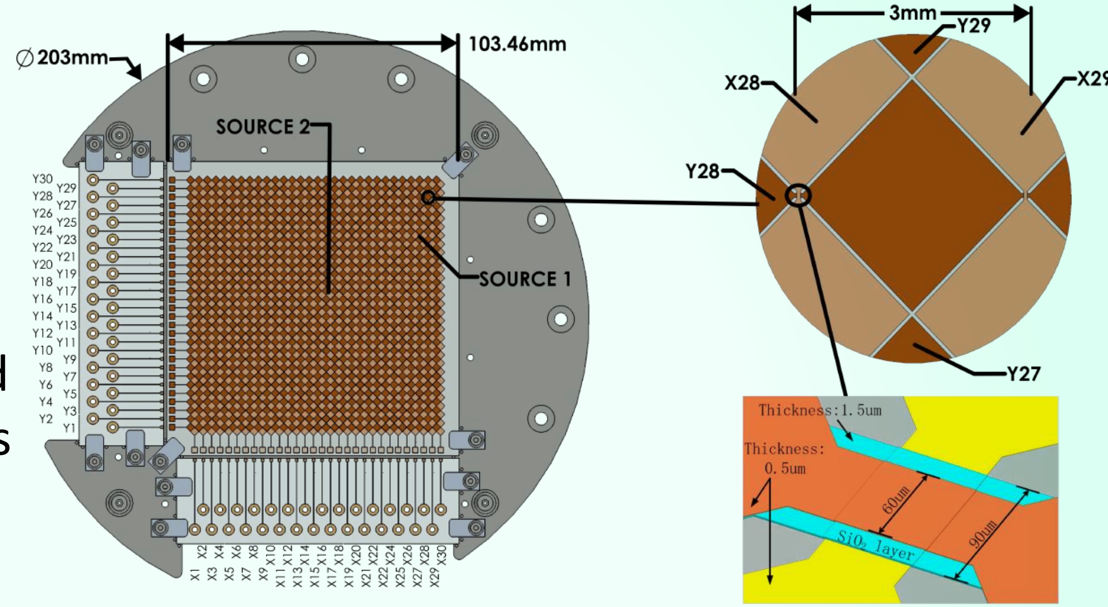
SNOLAB Cryopit is favored

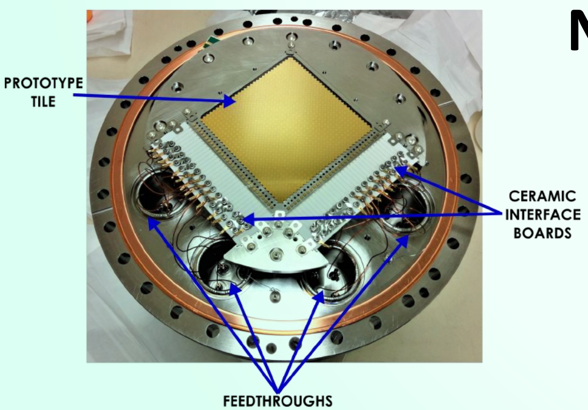
- Site engineering already provided by SNOLAB
- Includes subsystem layout and utilities.



Charge Readout Tiles

- 10cm x 10cm “tiles” segment the collection area.
- X and Y strips cross at 60um bridge, with SiO_2 separation.
- Through-quartz vias (TQV) planned for back-side in-Xe ASIC electronics (low noise).





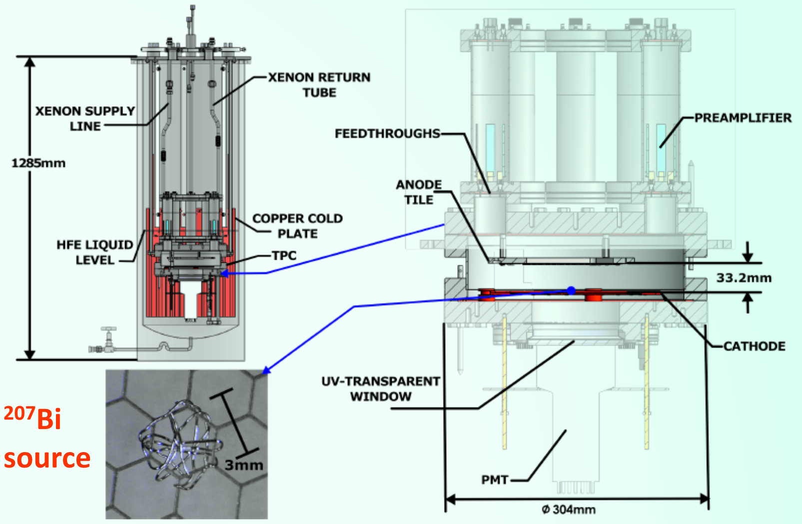
No grid!

- More complex charge collection signal (no shielding).
- No tensioning structure/difficulty
- Less mass.
- Less pick-up noise.
- Segmentation reduces ambiguity in event topology

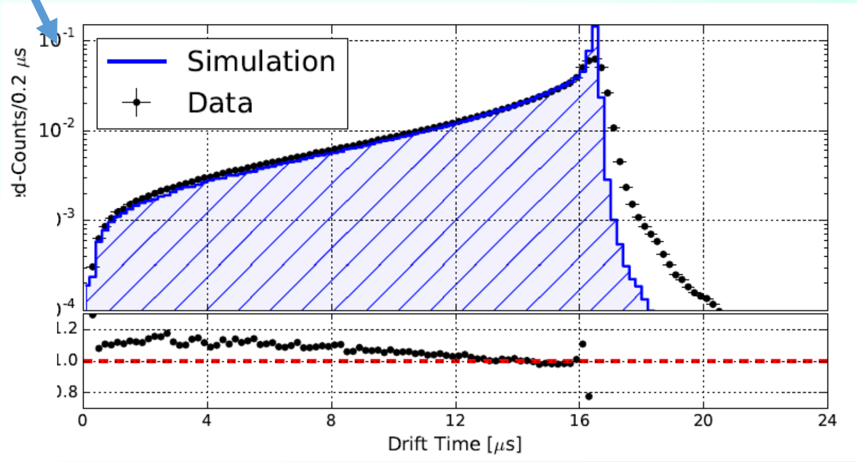
Charge Tile Characterization

- ^{207}Bi source with tile in test TPC.
- 5.5% σ/E at 570 keV, 936V/cm, near intrinsic charge resolution.
- Full GEANT4-based simulation of charge drift, diffusion, induction, electronics.
  => good agreement with data.
- Input to full nEXO tile simulation for boosted decision tree (BDT) deep neural net (DNN) single-site (SS)/multi-site(MS) discrimination
- DNN reduces nEXO background ~60% w.r.t. PCDR @ 5% signal loss.
- Informs optimization of tile pitch.

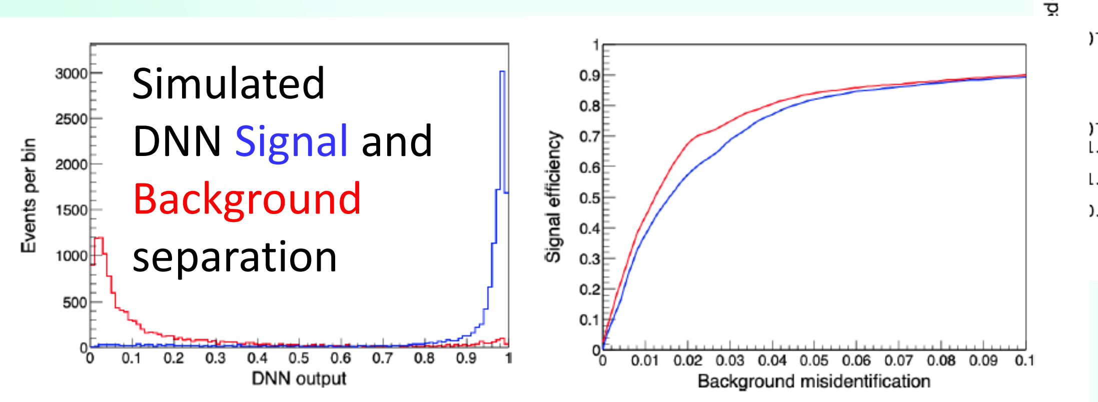
Test TPC with ^{207}Bi source



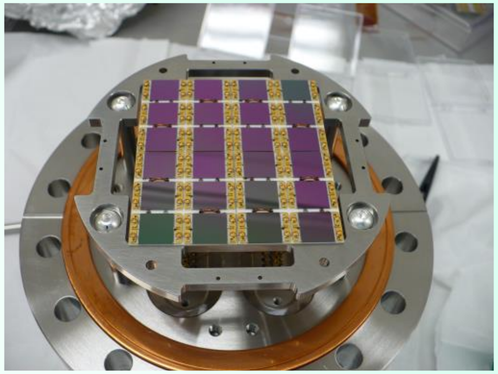
M. Jewell et al, JINST 13 P01006(2018)



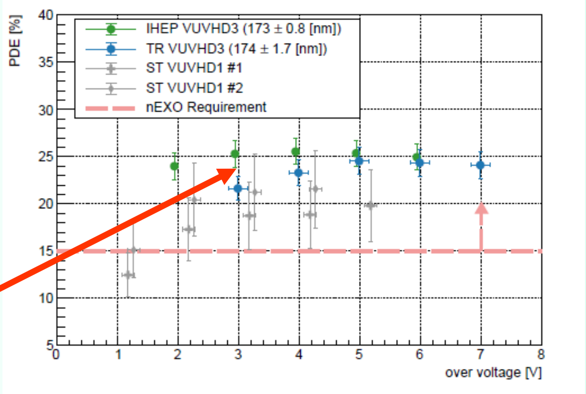
Z. Li et al, JINST 14 P09020

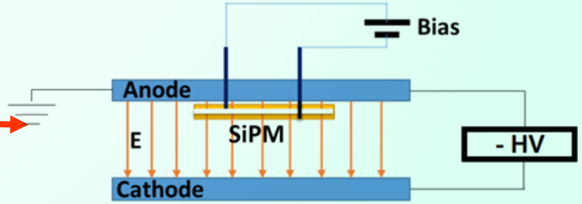


Light Readout: Silicon Photo-Multipliers (SiPMs)



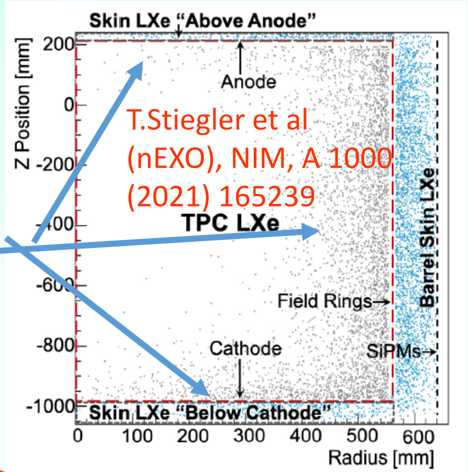
- LAAPD's, high mass, difficult to scale up.
- Cover barrel with SiPM, on electronics "interposer" layer.
- Digitize in xenon: low noise.
- Lower efficiency than LAAPD, but lower mass, higher area.
- Studied Hamamatsu and FBK VUVHD3 made for nEXO SiPMs
  G. Gallina et al, NIM A 940 (2019) 371,
  G. Gallina et al arXiv:2209.07765
- Over 7 nEXO LXe setups involved (just in one study).
- Extensive studies of characteristics :
  - Dark rate
  - Detailed after-pulsing and cross-talk parameters.
  - Detailed modelling and measurement of detection resolution effects.
  - Detection efficiency vs V,λ and T (15% required):
    24.3% at 175nm, 3 V overvoltage, 163K
  - Reflectivity vs. Angle. M. Wagenpfeil et all arXiv:2104.07997
  - Performance in electric fields: X.L. Sun et al 2018 JINST 13 T09006





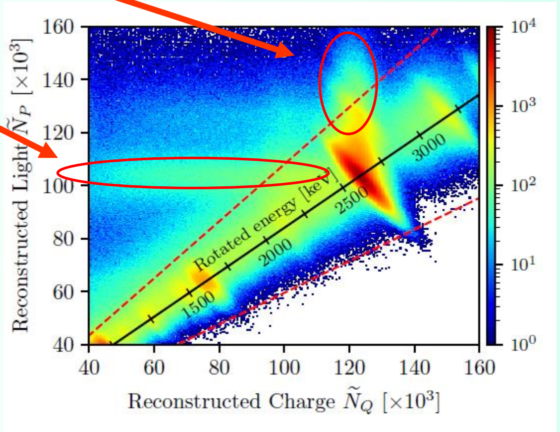
Open Field Cage Design

Barell SiPM's require open field cage for light detection:



- "Skin" region detects light without charge
- MS events can have skin and fiducial contribution.
  - Full energy gamma plus extra light (coinc. gamma)
  - Single gamma, partial charge collection.
- C/L (Charge/Light) ratio cut removes sufficiently.
- Skin helps tag ^{214}Bi-^{214}Po coincidence

  α => high light



G. Gallina et al arXiv:2209.07765

Symbol	Meaning		Value	Ref.
Q [keV]	Q-value		2458.07	[8,9]
W [eV]	Energy for 1 quantum		11.5	[44,46]
$n = Q/\mathrm{W}$ [#]	Number of quanta		213745	-
γ_p [γ/eV]	Light yield		0.037	[44]
$n_p = Q \times \gamma_p$ [#]	Number of photons		90949	-
PTE [#]	Photon Transport Eff.		33.3%	[7]
σ_{lm} [#]	Res. calib. uncertainty		0.5%	[7]
PDE [#]	Photon Detection Eff.		Sec. 3.4	-
R [#]	Reflectivity	FBK	27.7 ± 1.6%	[34]
		HPK	20 ± 1%	
ε_p [#]	Total Photon Det. Eff.		Eq. 16	-
$\langle\Lambda\rangle$ [PE]	Mean of CA		Sec. 3.3.1	-
σ_Λ [PE]	RMS of CA		Sec. 3.3.1	-
$n_q = n - n_p$ [e^-]	Number of electrons		122797	-
$\sigma_{q,noise}$ [e^-]	Noise charge ch.		1132	[7]
l [m]	Drift length		1.187	[7]
v [mm/µs]	Drift velocity		1.73	[7]
τ [ms]	Electron lifetime		10	[7]
$\varepsilon_q = e^{-t/\tau}$ [#]	Charge coll. eff.		96.6%	-

- Detailed sims include all studied light/charge parameters.
- NEST light model updated to match EXO-200 data
- nEXO resolution: ~0.8% with 6mm charge pitch

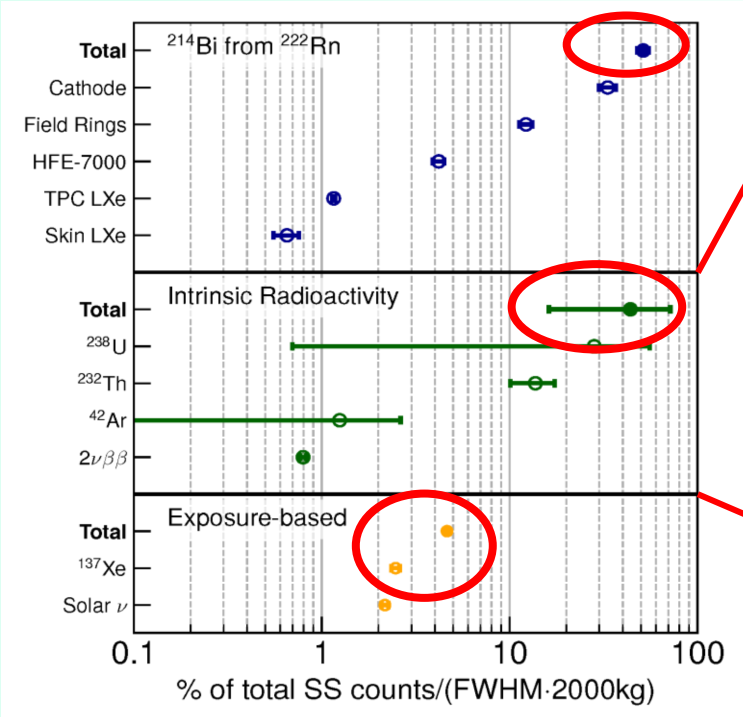
Backgruond Assay program:
builds on experience of EXO-200, adds resources

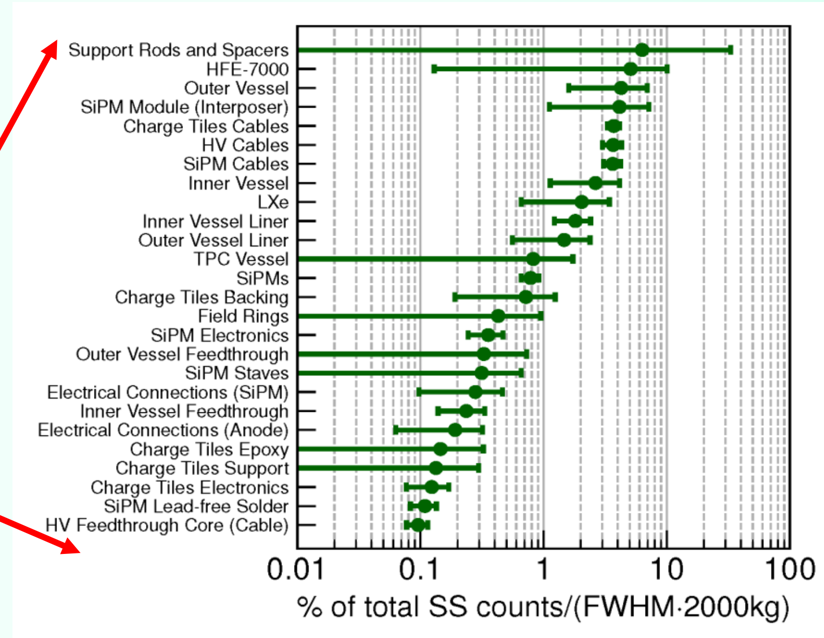
- **Above ground Ge counting** (270 ppt, 120 ppt): 0.4 devices at UA
- **Underground Ge counting** (best 2.3 ppt, 1.2 ppt): 4.8 devices at SURF, SNOLAB Started working with LNGS too.
- **ICP-MS** (best 0.0008 ppt, 0.0026 ppt): 2.2 devices at PNNL, IHEP, CUP
- **NAA** (best 0.015 ppt, 0.015 ppt): 2.6 setups at UA
- **α-counting** (^{210}Po surface, 5 mBq/m^2 Si-det, 0.1 mBq/m^2 XIA): 4 Si-det, 1.5 XIA at UA, PNNL, SLAC
- **Rn counting** (^{222}Rn steady state activity, 0.1 mBq or 8.6 atoms/d): 8.8 Si-diodes with electro-static collection at SNOLAB/Laurentian, SLAC + LS counting at UA
- **AMS** (Th, U and ^{210}Pb): under development at Carleton

The nEXO materials database:
> 300 new sample measurements, 316 EXO-200 materials and 27 radon outgassing measurements.

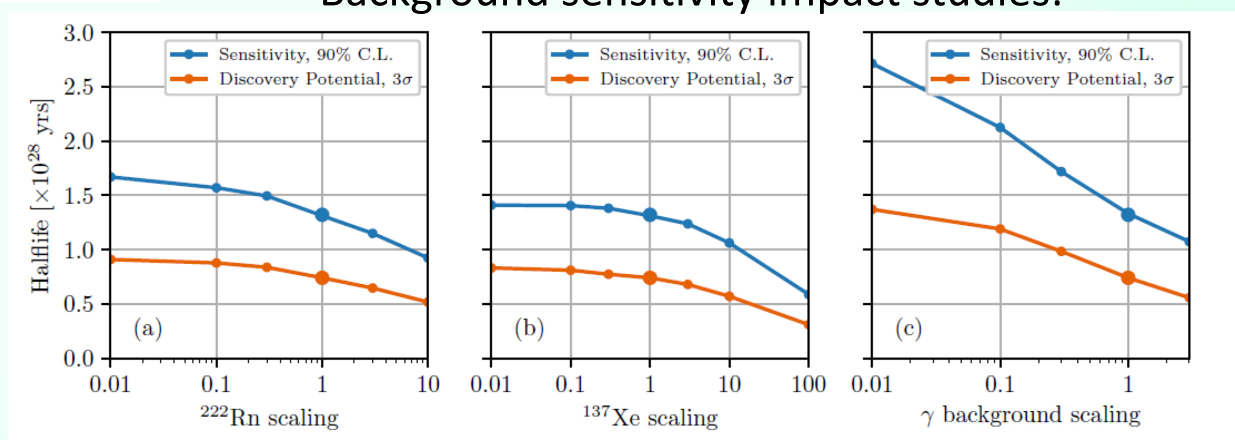
Material	Supplier	Method	^{238}U (ppt)	^{232}Th (ppt)	^{40}K (ppb)	^{60}Co (mBq/kg)
Electroformed Copper†	In-house	ICP-MS	< 0.01	< 0.01	-	-
Copper	Aurubis	ICP-MS/Ge/ GDMS	0.254 ± 0.008	0.13 ± 0.06	< 6.4	< 0.0033
Sapphire	GTAT	NAA	< 8.9	6.0 ± 1.1	9.5 ± 2.0	-
Quartz	Heraeus	NAA	< 1.5	< 0.23	0.55 ± 0.03	-
SiPM	FBK	ICP-MS/NAA	0.86 ± 0.05	0.45 ± 0.12	-	-
Epoxy*†	MasterBond	Ge	< 360	< 540	< 930	-
AuSn solder†	Nippon Micrometal	ICP-MS	90 ± 20	68 ± 14	-	-
Gold wire bonding†	Ametek	ICP-MS	< 230	26 ± 8	-	-
Polyimide†	Taiflex	ICP-MS	0.71 ± 0.04 pg/cm^2	0.71 ± 0.20 pg/cm^2	-	-
HFE-7000*	3M	NAA	< 0.015	< 0.015	-	-
CFC (Resin)†	SCC	Ge	< 7.7	< 19	< 31	< 0.03
CFC (Fiber)†	Grafil	Ge	40 ± 15	74 ± 39	810 ± 100	< 0.11
ASICs (Silicon)†	Global Foundry	ICP-MS	0.35 ± 0.13	1.3 ± 0.7	-	-
Titanium†	LZ TIMET	Ge	< 12	57 ± 5	< 29	< 0.033
Water	SNOLAB		< 1	< 1	< 1000	-
Stainless Steel†	GERDA	Ge	< 48	< 200	< 58	16.8 ± 2.4
HDPE†	Dielectric Sci.	NAA	100 ± 19	63.6 ± 2.7	350 ± 10	-
PTFE*†	DuPont	NAA	< 0.78	< 0.26	1.8 ± 0.2	-
Cond. PE†	Quadrant	ICP-MS	224 ± 32	10.1 ± 1.4	-	-

nEXO Background Simulation





Background sensitivity impact studies:



<u>Background Categories:</u>

- ^{222}Rn
- Intrinsic Radioactivity
- Cosmogencis and ν's.

^{222}Rn

- 600 atoms in Xe based on EXO-200.
- Rn emanation program ongoing.
- Dust: Control with witness plates, tape lifts, ICP-MS
- Bi-Po tagging reduces ~ 50% of Rn events:
  - basically 100% of fiducial volume and barrel skin events.
  - Remaining background is external/non-uniform.
- Purification upgrades and Rn distillation are available backup weapons.
- 1500 atoms in HFE: OK

Cosmogenics

137Xe from n capture

- β endpoint 4173 keV. Potentially uniform distribution in liquid => Potential background.
- Muon production + prompt γ gives tagging: **OK**
- Water shielding sufficient for rock neutrons: **OK**
- (α ,n) reactions from ^{210}Po, etc (See Raymond Tsang's talk LRT 2022)
    - Controllable with Rn exposure/emanation control.
    - Simulations performed for ^{210}Po tolerance on many surfaces.
    - Rn plateout studies/measurements/modelling ongoing.

Above-ground cosmogenics in copper etc..:

- Simulated: **OK**

Discovery Potential

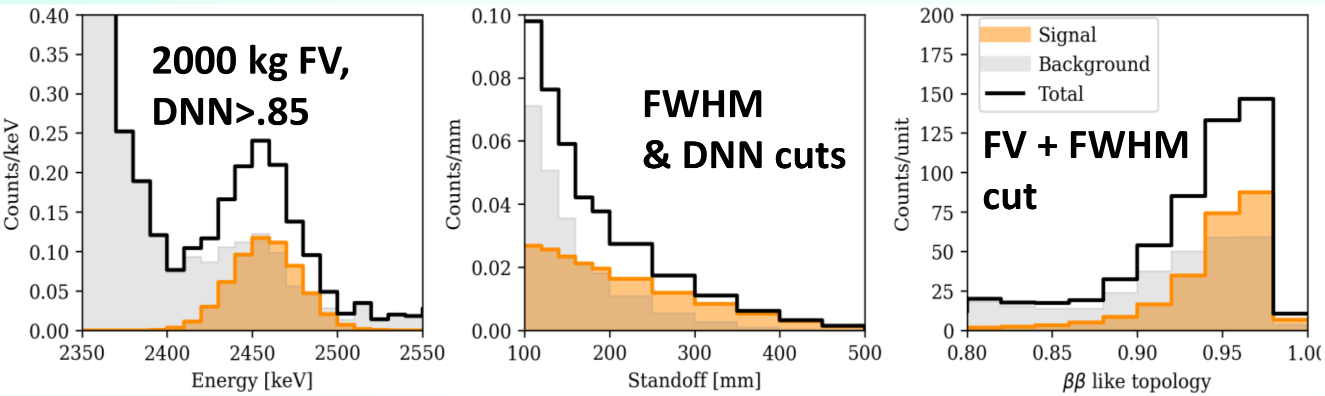
G. Adhikari *et al* 2022 *J. Phys. G: Nucl. Part. Phys.* **49** (2021) 015104

- Detailed charge, light, and digitization modelled in Geant4 sim.
  - Tuned with real data, real detectors, real reflectivity, modified NEST (light propagation), etc…
  - Assumes 6mm charge tile pitch (compromise of resolution and background/cost).
  - 380 V/cm
- 3D fit to: Energy, DNN output, standoff distance.

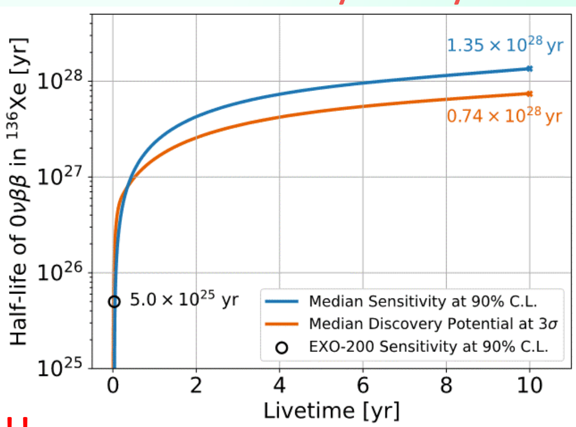
  Cannot be distilled to box cuts: FV-cut, ROI-cut, average background-index, DNN-cut, etc.
- 3D pdfs generated for all background components (combining some).
  - Normalizations fixed in Toy MC data production
  - Floated, along with $0\nu\beta\beta$, in fit to toy MC data.
- Median 10 yr sensitivity: **$T_{1/2}$ = 1.35 X 10^{28} yr 90% CL**
- Median 3σ discovery potential: $T_{1/2}$ = 0.74 X 10^{28}

Compare to Ideal 0-background sensitivity: 3.6 X 10^{28} yr !!

3D projections, 2D cuts, of fit to Toy MC data with 3σ $0\nu\beta\beta$ signal:



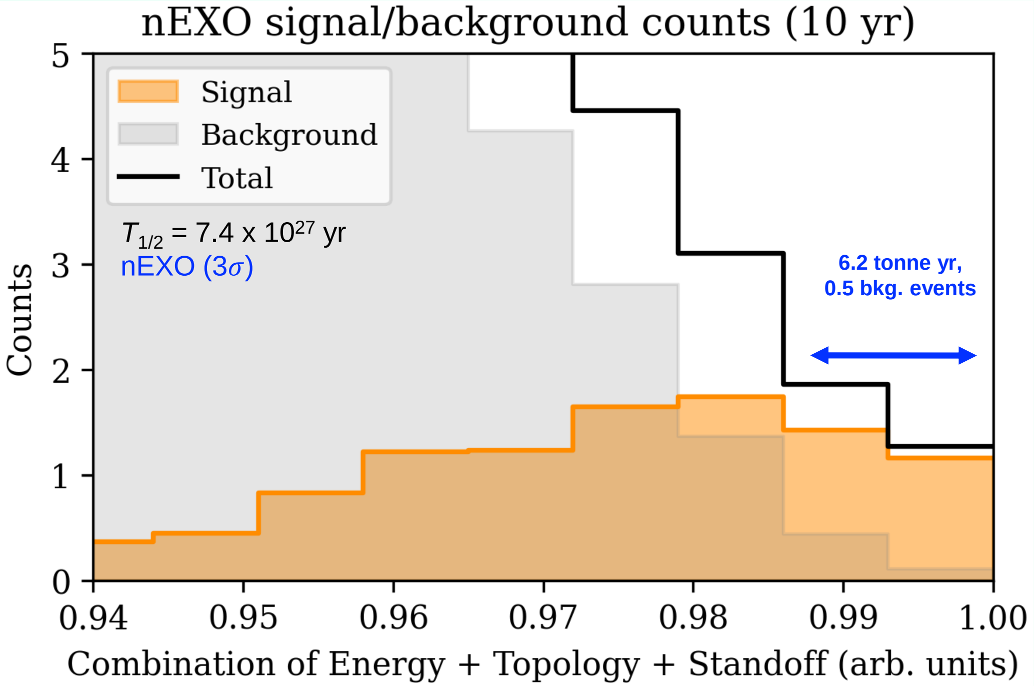
10^{28} Sensitivity in 6 years:



For visualization only. Full analysis does not use projections or cuts!!

Discovery Potential

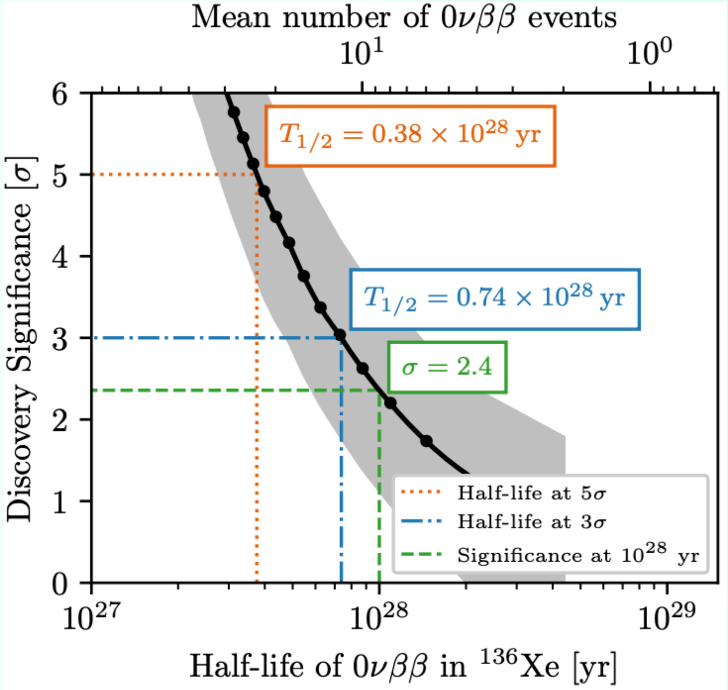
3D bins ordered in 1D from background-like to signal-like:



← Background-like ------------------ Signal-like →

No cuts in this optimal projection!

nEXO Discovery Potential vs. Half-Life:

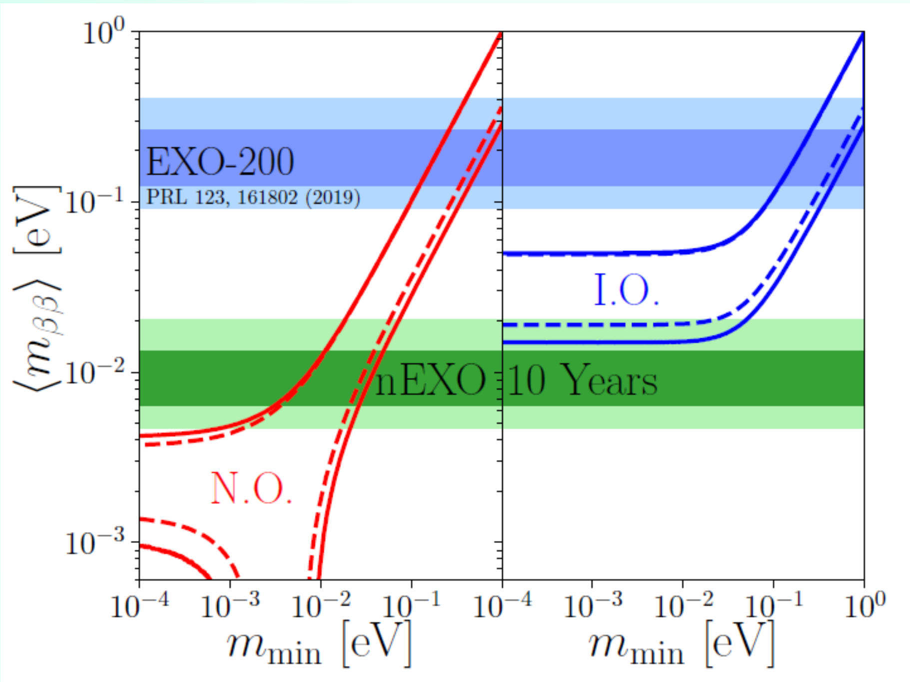


← Existing limits (~10^{26} yr)

3σ discovery at 7.4×10^{27} yr
5σ at 3.8×10^{27} yr

Effective Majorana Mass Sensitivity

Allowed parameter space and nEXO exclusion sensitivity (90% CL):



-Shaded bands: NME distribution.

-Solid vs dashed, mixing parameter errors.

	$m_{\beta\beta}$ [meV], (*median NME*)	
	90% excl. sens.	3σ discov. potential
nEXO	8.2	11.1
LEGEND	10.4	11.5
CUPID	12.9	15.0

$T_{1/2}$ values used [x10^{28} yr]:

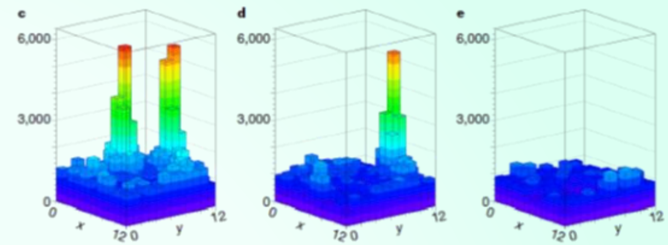
nEXO: 1.35 (90% sens.), 0.74 (3σ discov.)
LEGEND: 1.6 (90% sens.), 1.3 (3σ discov.)
CUPID: 0.15 (90% sens.), 0.11 (3σ discov.)

Median nEXO 3σ discovery sensitivity: 11.1 meV

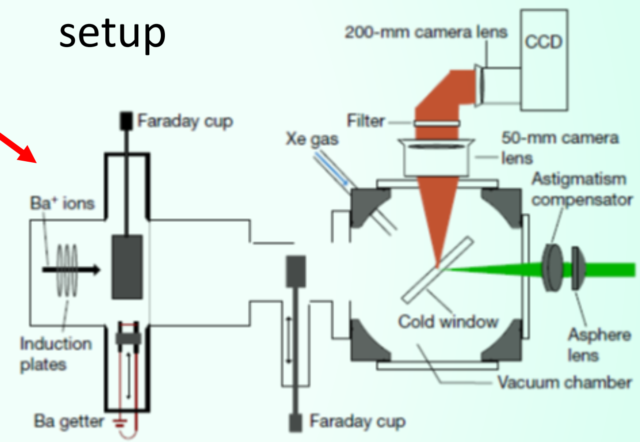
Ba tagging

- Identification of ^{136}Ba would be smoking gun, enable zero-background, larger experiments, push further into NO region.
- Single-atom Ba detection demonstrated:
  Chris Chambers et al *Nature* **569**, (2019) pages 203–207
- Trapping and transport demonstrated:
  T. Brunner et al IJMS 379 (2015) 110–120
  B. Flatt et all (EXO-200) NIM A 578 (2007) 399–408

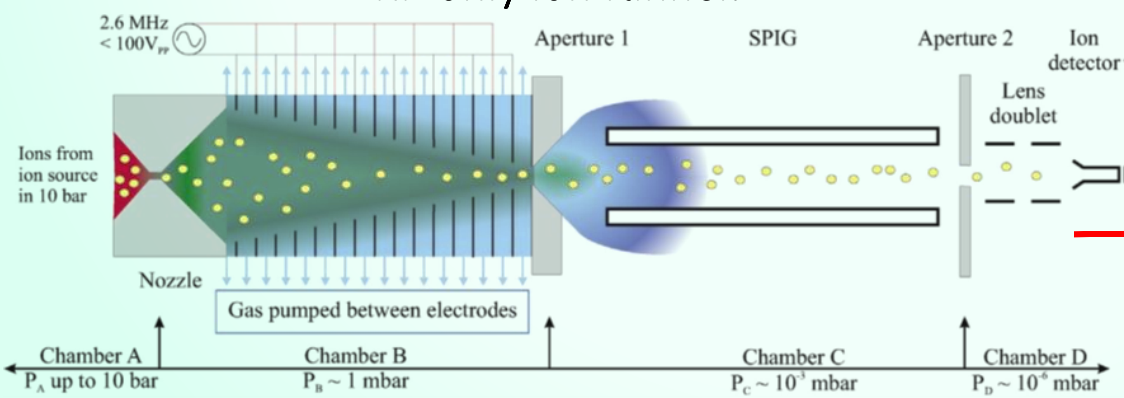
Two, one, zero, atoms:



Ba laser fluorescence setup



RF-only ion funnel:

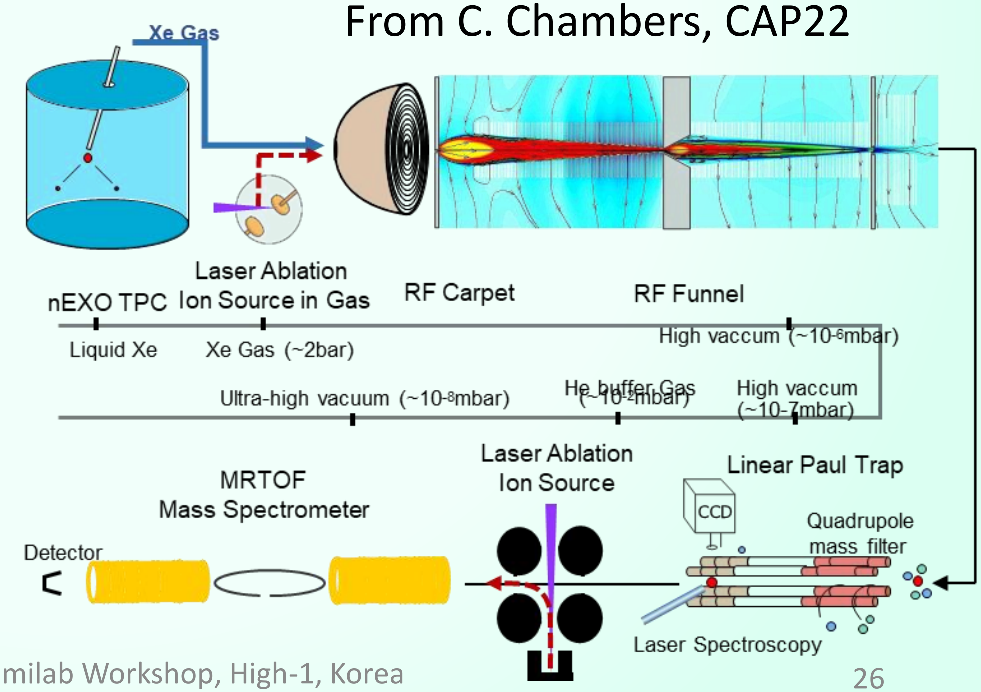


Ba tagging future

- Ice probe + flouresence development continues at CSU
- Full session, at CAP22 on Canadian tagging efforts for nEXO
  - Uses capillary tube extraction from nEXO, plus laser ablation calibration source.
  - RF Carpet -> RF Funnel -> linear trap w/spectroscopy -> Mass spec.
  - Six talks presented on development of all aspects.

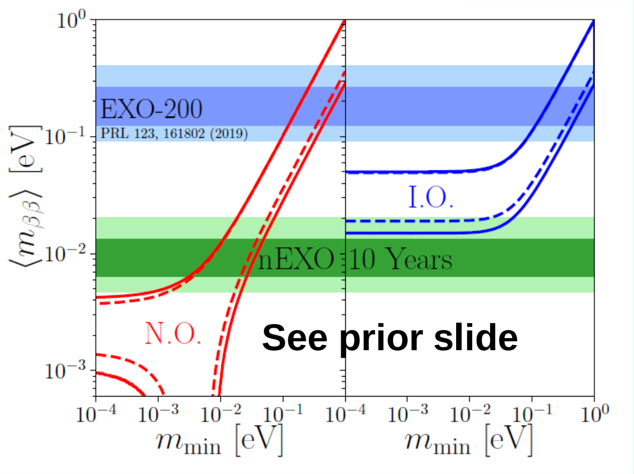
- Ambitions, long term program, but pieces are being proven now.
- Could be future upgrade to nEXO (and/or larger experiment?)

From C. Chambers, CAP22



Conclusions

- **nEXO builds on proven EXO-200 success.**
- **New elements extensively validated.**
- **Robust sensitivity estimate: Sims matched to LXe measurements for all systematic parameters.**
- **nEXO 3σ discovery potential reaches deep into normal ordering region.**
- **Extends $T_{1/2}$ observable-physics reach two-orders of magnitude.**
- **Best Majorana mass reach, barely, with NME uncertainty.**
- Ba tagging leaves room to grow beyond baseline nEXO.
- **Jan 2022: First Project Funding**



The nEXO Collaboration: 35 institutions

The END

Backup Slides

Nuclear Matrix elements:

References for the NMEs used

Method	Year	Citation
IBM	2015	PRC 91 034304 (2015)
NSM	2008	PRL 100, 052503 (2008)
IBM	2020	PRD 102, 095016 (2020)
QRPA	2014	PRC 89, 064308 (2014)
NSM	2016	PRC 93, 024308 (2016)
QRPA	2015	PRC 91, 024613 (2015)
QRPA	2018	PRC 98, 024608 (2018)
NSM	2018	JPS Conf. Proc. 23, 012036 (2018)
QRPA	2013	J. High Energ. Phys. 2013, 25 (2013)
QRPA	2013	PRC 87, 064302 (2013)
QRPA	2013	PRC 87, 045501 (2013)
QRPA	2018	PRC 97, 034315 (2018)
QRPA	2010	Nucl.Phys.A 847 (2010) 207
EDF	2013	PRL 111, 142501 (2013)
EDF	2015	PRC 91, 024316 (2015)
QRPA	2018	PRC 97, 045503 (2018)
EDF	2017	PRC 96, 054310 (2017)
QRPA	2015	PRC 91, 024613 (2015)
EDF	2010	Prog.Part.Nucl.Phys. 66 (2011) 436

Copper (790 kg)

Initially nEXO planned using Aurubis copper for the TPC body and internals, as EXO-200.

ICP-MS showed a distinct advantage of using electroformed copper. The copper background contribution went from $0.074\,\frac{cnt}{FWHM \cdot ton}$ (46% of total background, largest component) to now $0.0044\,\frac{cnt}{FWHM \cdot ton}$ (1.7% of total background).

Material	Analysis	ID	^{232}Th [ppt]	^{238}U [ppt]
Aurubis cathode	Ge (Bern)	R-002.8.1	<2.3	<1.2
Aurubis cathode	ICP-MS (PNNL)	R-002.11.1	0.127±0.06	0.254±0.008
PNNL electroformed	ICP-MS (PNNL)	R-168.1.1	0.006±0.001	<0.0094
PNNL electroformed	ICP-MS (IHEP)	R-168.1.2	0.13±0.04	<0.11

Electroformed copper is now the baseline material.

HFE heat transfer fluid (31800 kg)

The HFE-7000 or HFE-7200 heat transfer fluid also serves as innermost radiation shield. Because of the large amount it needs to be very clean.

Material	Analysis	ID	^{232}Th [ppt]	^{238}U [ppt]
HFE-7000	NAA (UA)	P-139	<0.015	<0.015
HFE-7000	ICP-MS (PNNL)	R-181.1.1	<0.0013	0.0034±0.0005
HFE-7200	ICP-MS (PNNL)	R-182.1.1	<0.0013	<0.0043

Extreme purity found by NAA was confirmed and improved by ICP-MS. A ^{210}Po analysis is under way.

Fractional background contribution went from 9.3% to 6.3%.

SiPM light readout (2.9 kg)

Products by FBK and Hamamatsu were found to meet the nEXO technical specs. Both were assayed for radioactivity.

Material	Analysis	ID	^{232}Th [ppt]	^{238}U [ppt]
FBK early	NAA (UA)	R-003.2.4	<0.37	<11
FBK VUV SF	ICP-MS (PNNL)	R-076.2.1	0.44±0.05	0.99±0.02
FBK VUV SF	ICP-MS (IHEP)	R-076.2.2	0.11±0.03	0.07±0.02
FBK VUV LF	ICP-MS (PNNL)	R-076.1.1	0.45±0.12	0.86±0.05
Hamamatsu VUV3 (no trenches)	ICP-MS (PNNL)	R-096.1.1	<0.63	0.72±0.19
Hamamatsu VUV3 (no trenches)	ICP-MS (IHEP)	R-096.1.2	0.31±0.03	0.21±0.03

Radioactivity wise both FBK and Hamamatsu products were found suitable for nEXO. SiPM background contribution is small, about 0.8%.

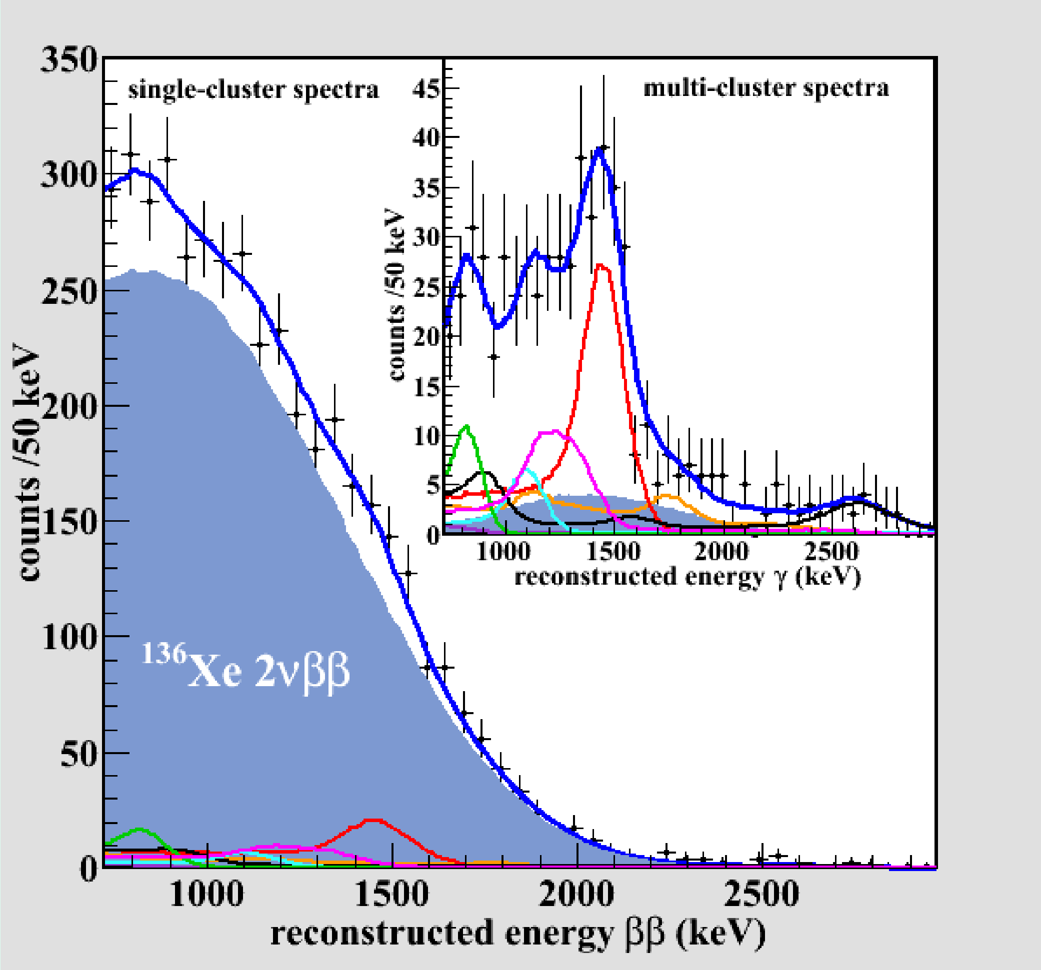
Dielectric TPC internals

Baseline for TPC field cage: sapphire holding rods and spacers. Sapphire (Al_2O_3) is difficult to assay: (a) doesn't dissolve in mineral acids (ICP-MS), (b) when n-activated forms large side activities via ^{27}Al(n, α)^{24}Na, limiting NAA sensitivity to ^{238}U.

1. Assayed structural polymers by NAA to explore design alternatives
2. Developed a γ-γ-coincidence counting approach: boosts sensitivity for ^{238}U 8-fold

Material	Analysis	ID	^{232}Th [ppt]	^{238}U [ppt]	
GTAT (Ligo)	NAA (UA)	R-046.1.1	6±1	<8.9	
Saint Gobain	NAA (UA)	R-048.6.1	<0.49	<10.5	6.3%
Precision Sapphire	NAA (UA)	R-084.1.1	410±41	985±99	
PEI Sabic 1000 Advanced Polymer	NAA (UA)	R-146.1.1	84±10	21±13	
PEI Sabic 1000 Ensinger	NAA (UA)	R-147.1.1	9.5±2.3	<15	
PAI Mitsubishi Duratron	NAA (UA)	R-145.1.1	<28	<579	
PEI Mitsubishi Ultem 1000	NAA (UA)				

First 2-nu Observation in Xe



May 21, 2011 through July 9, 2011

$T_{1/2}$ (ββ2ν) =
2.11 +- 0.04 (stat.)
+- 0.21 (sys.)
x 10^21 yr

From first month of data.

Ackerman, et al. (EXO Collaboration), PRL 107 (2011) 212501