EXO-200 results and cosmogenic backgrounds

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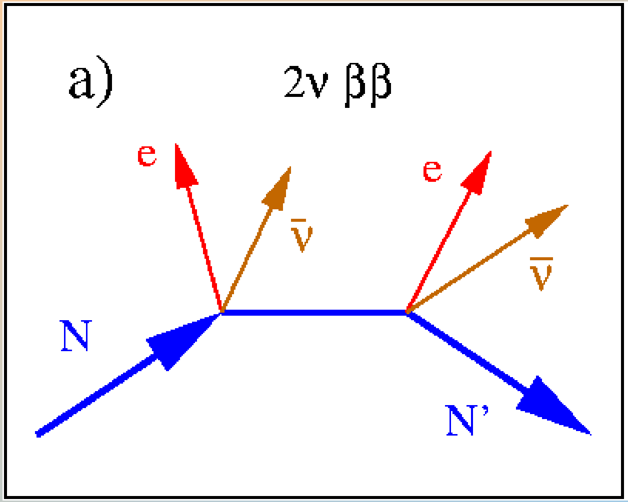
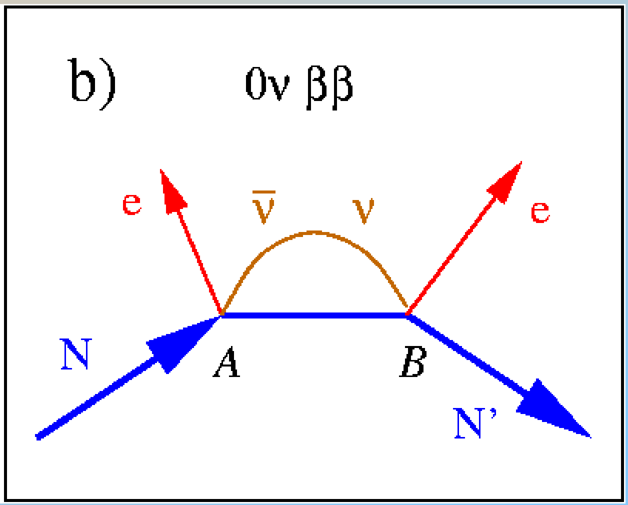
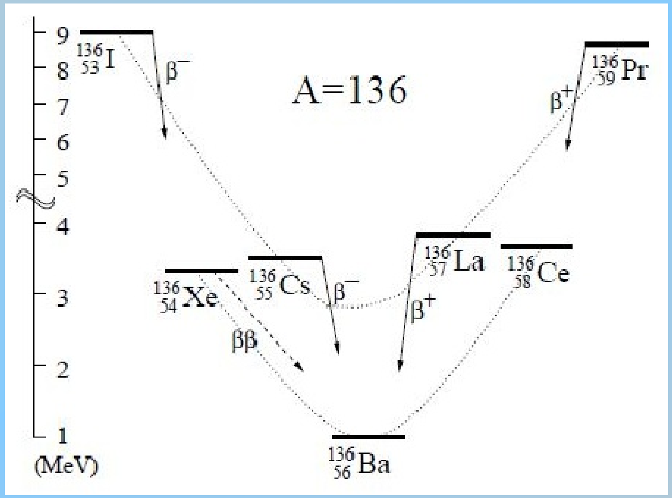
for EXO-200 collaboration

ICPPA-16, Moscow, 12 October 2016

Double beta decay



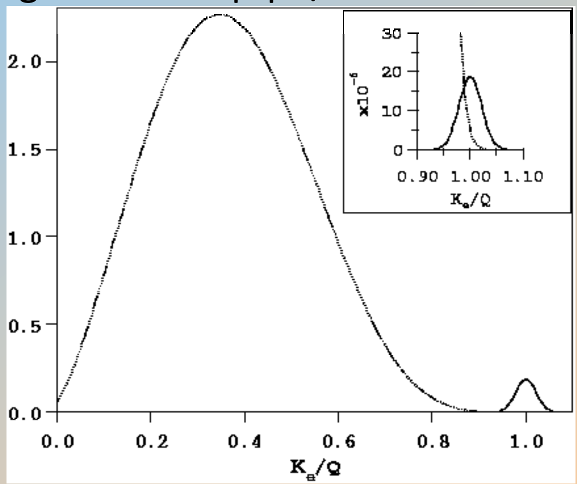




2ν mode:
a conventional
2nd order process
in Standard Model

0ν mode:
a hypothetical process
can happen only if:
$\langle m_\nu \rangle \neq 0$, $\nu = \bar{\nu}$
$|\Delta L|=2$, $|\Delta(B-L)|=2$

Simulated double beta decay spectrum
P.Vogel. arXiv:hep-ph/0611243



To reach high measurement sensitivity for 0ν mode one requires,

- High energy resolution
- Large Isotope mass
- Low background

Why xenon

Energy resolution is poorer than the crystalline devices (~ factor 10), but...

Monolithic detector. Xenon can form detection medium, allow self shielding, surface contamination minimized. Very good for large scale detectors.

Has high Q value. Located in a region relatively free from natural radioactivity.

Isotopic enrichment is easier. Xe is already a gas & ^{136}Xe is the heaviest isotope.

Xenon is "reusable". Can be purified & recycled into new detector (no crystal growth).

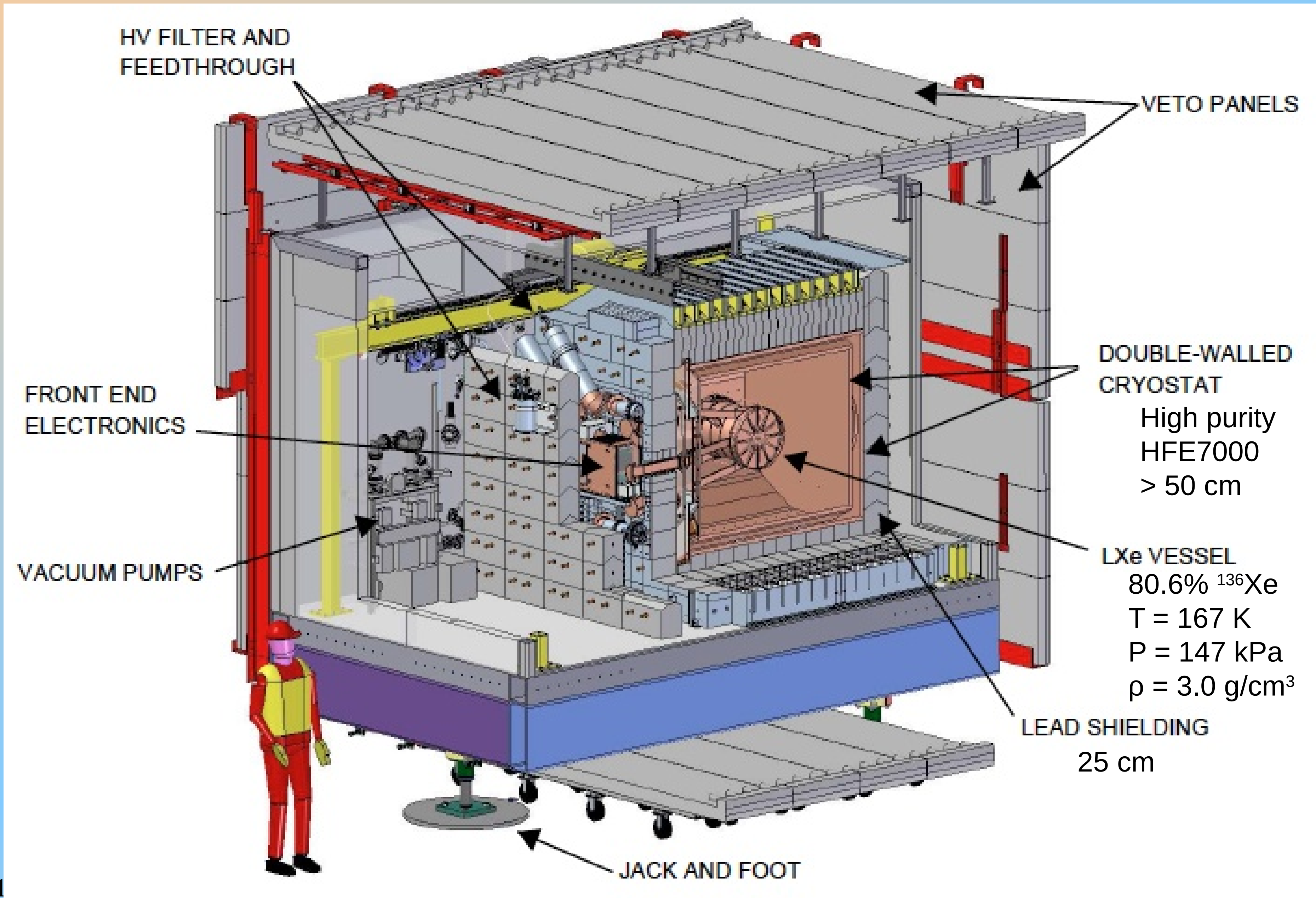
Minimal cosmogenic activation. No long lived radioactive isotopes of Xe.

Energy resolution in LXe can be improved. Scintillation light/ionization correlation.

Particle identification. Slightly limited, but can be used to tag alphas from Rn chain.

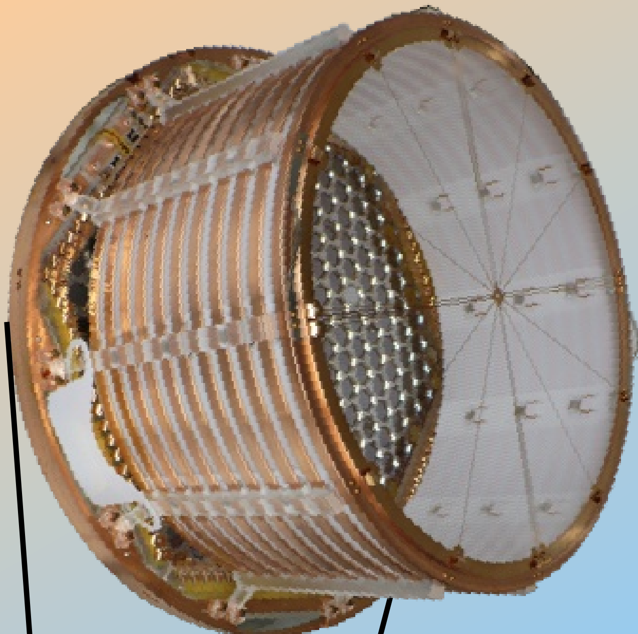
… admits a novel coincidence technique. Background reduction by Ba daughter tagging (M.Moe PRC 44, R931, 1991).

EXO-200 detector

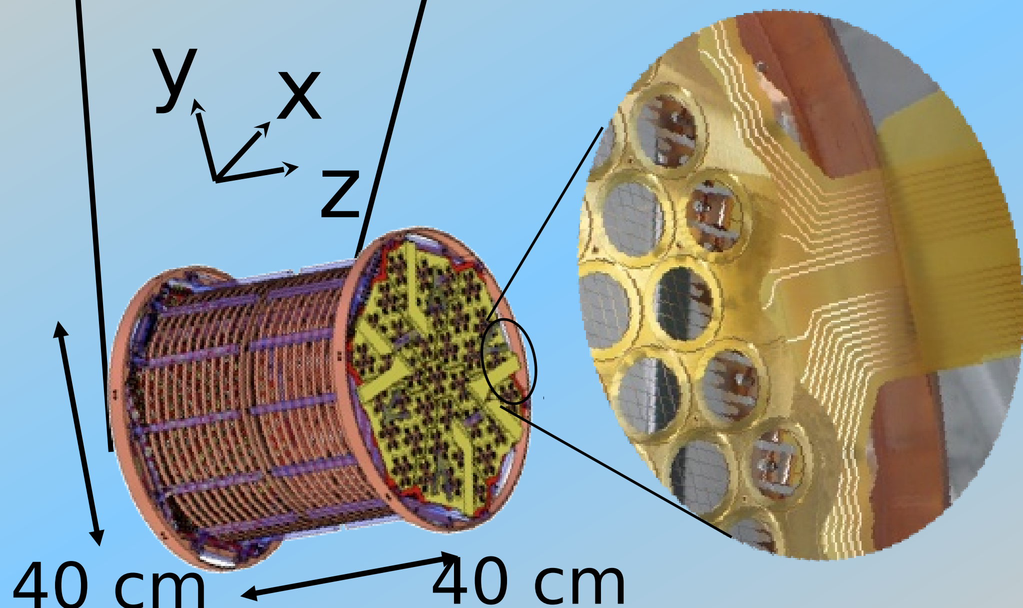


The EXO-200 TPC

Two almost identical halves reading ionization and 178 nm scintillation, each with:

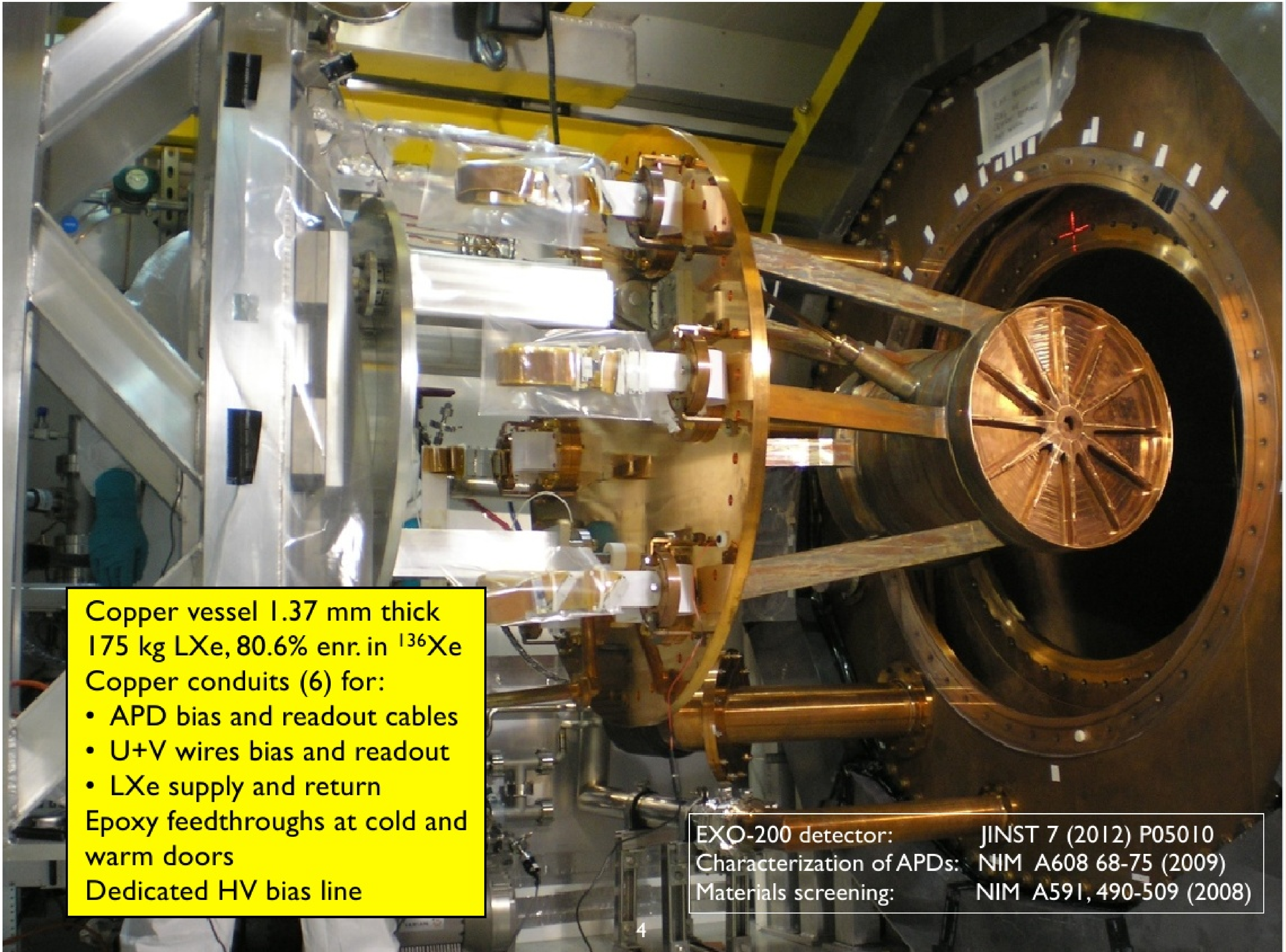


- 38 U triplet wire channels (charge)
- 38 V triplet wire channels, crossed at 60^o (induction)
- 234 large area avalanche photodiodes (APDs, light in groups of 7)
- Wire pitch 3 mm (9 mm per channel)
- Wire planes 6 mm apart and 6 mm from APD plane
- All signals digitized at 1 MS/s, ±1024S around trigger
- Drift field 564 V/cm



- Field shaping rings: copper
- Supports: acrylic
- Light reflectors/diffusers: Teflon
- APD support plane: copper; Au (Al) coated for contact (light reflection)
- Central cathode, U+V wires: photo-etched phosphor bronze
- Flex cables for bias/readout: copper on kapton, no glue

Comprehensive material screening program



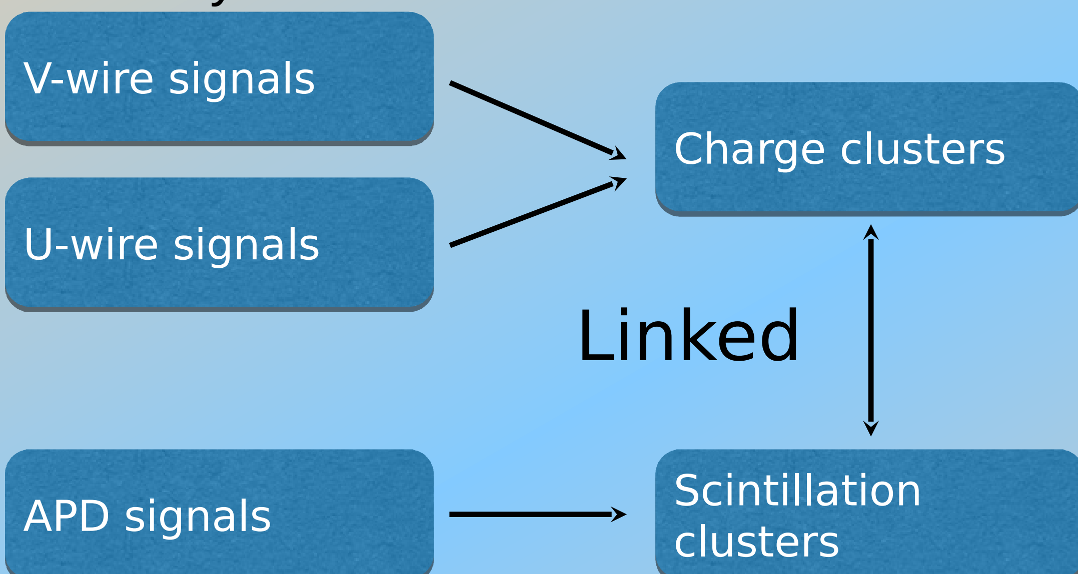
Copper vessel 1.37 mm thick
175 kg LXe, 80.6% enr. in ^{136}Xe
Copper conduits (6) for:
- APD bias and readout cables
- U+V wires bias and readout
- LXe supply and return

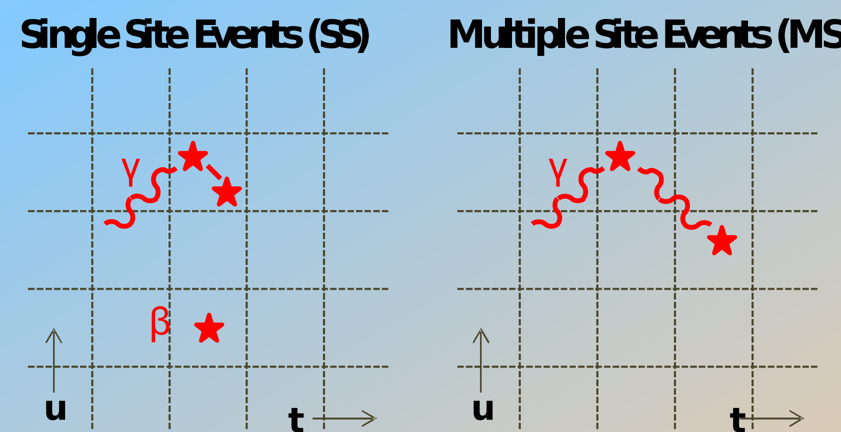
Epoxy feedthroughs at cold and warm doors
Dedicated HV bias line

EXO-200 detector:	JINST 7 (2012) P05010
Characterization of APDs:	NIM A608 68-75 (2009)
Materials screening:	NIM A591, 490-509 (2008)

Event reconstruction

- Signal finding. Digital filters are used on waveforms from U,V wires and APDs
- Parameters of pulses (t, E) are estimated for both charge and light
- Pulses are combined into clusters producing position, multiplicity (SS or MS) and energy.
- Position is used in form of Standof Distance (SD) that is distance from any cluster to the nearest wall



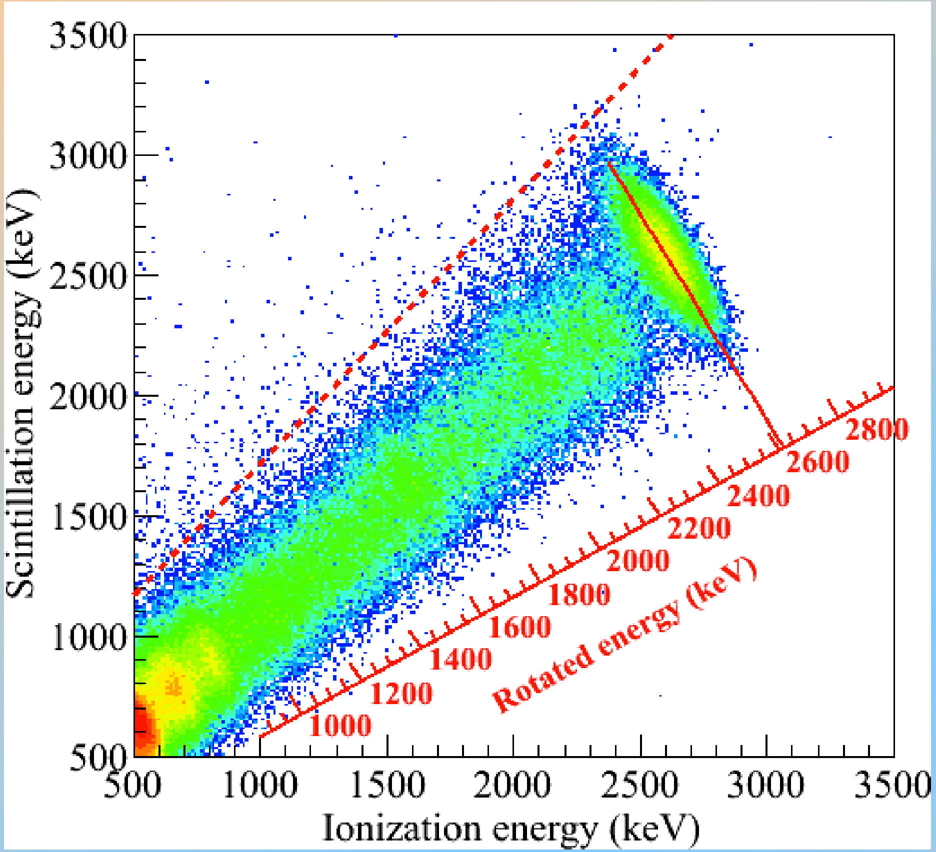


Efficiency to get into SS: 2β0ν ~90%

γ 2.5MeV ~30%

But we don't throw MS events away! We use them in the fit to help predict background

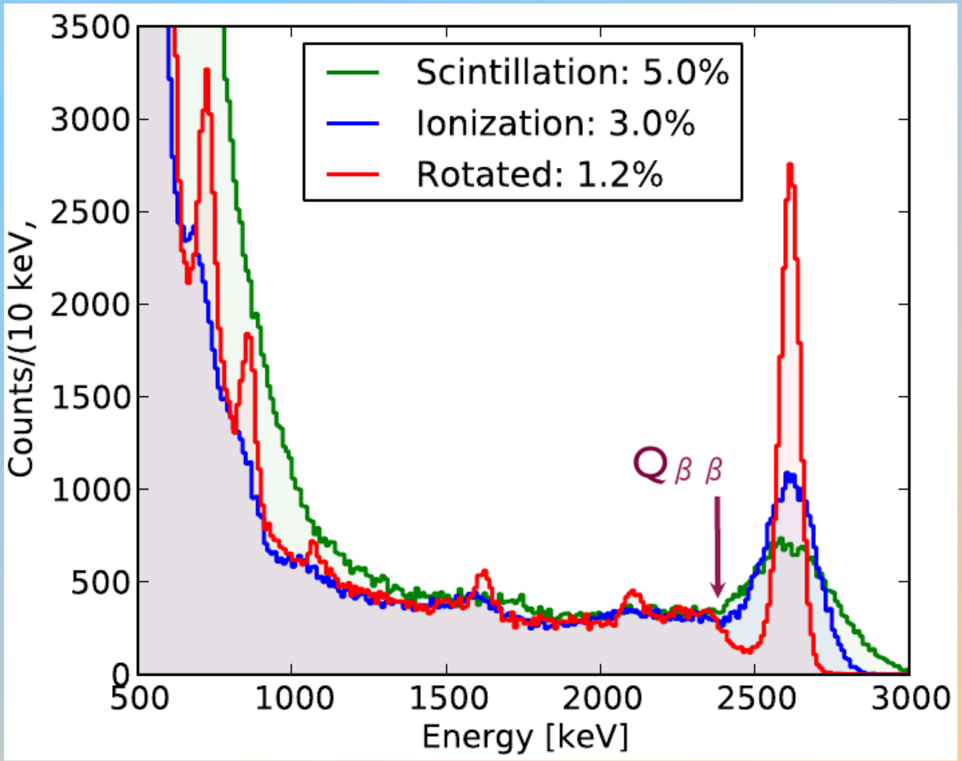
Combining ionization and scintillation



Properties of xenon cause increased scintillation to be associated with decreased ionization (and vice-versa)

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

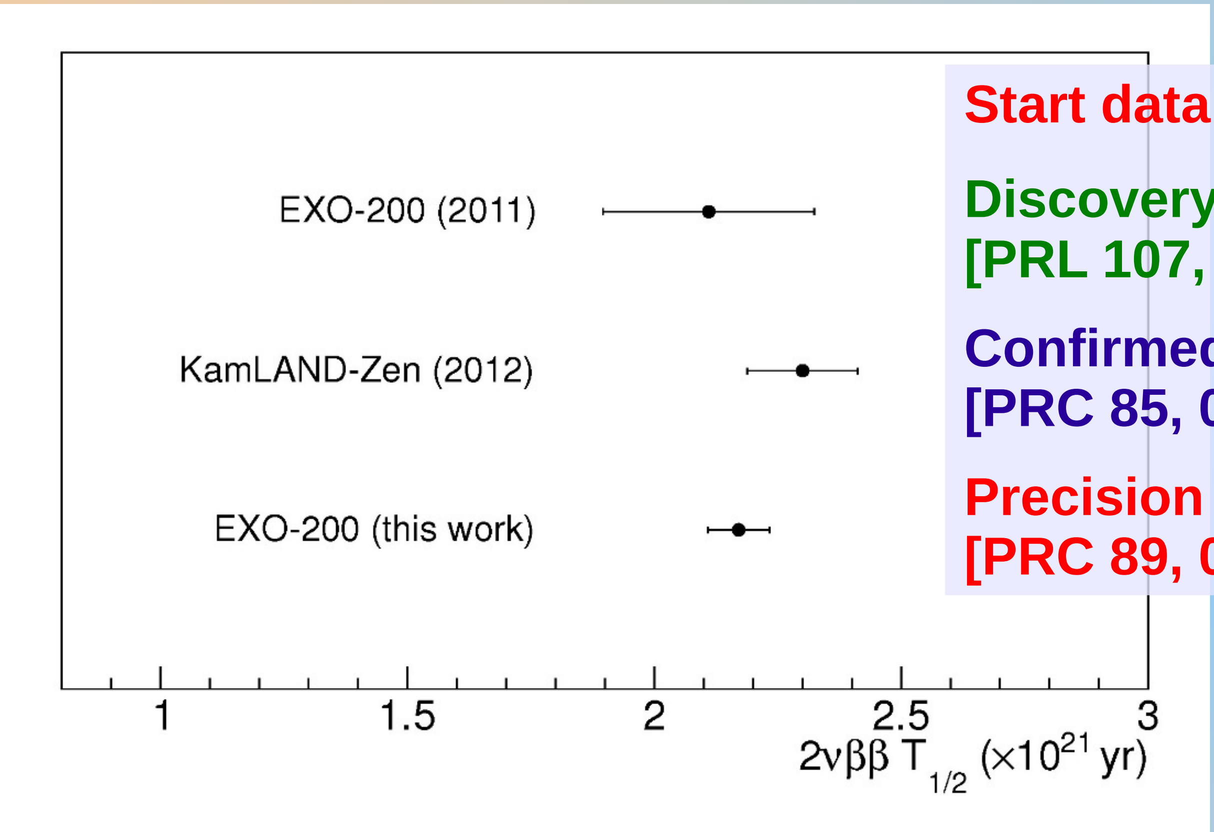
Mixing angle is chosen to optimize energy resolution at 2615 keV line.



EXO-200 has achieved ~ 1.25% energy resolution at the Q value.

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

Phase-1 2β2ν measurement



Start data taking in June 2011

Discovery of 2β2ν decay of ^{136}Xe
[PRL 107, 212501 (2011)]

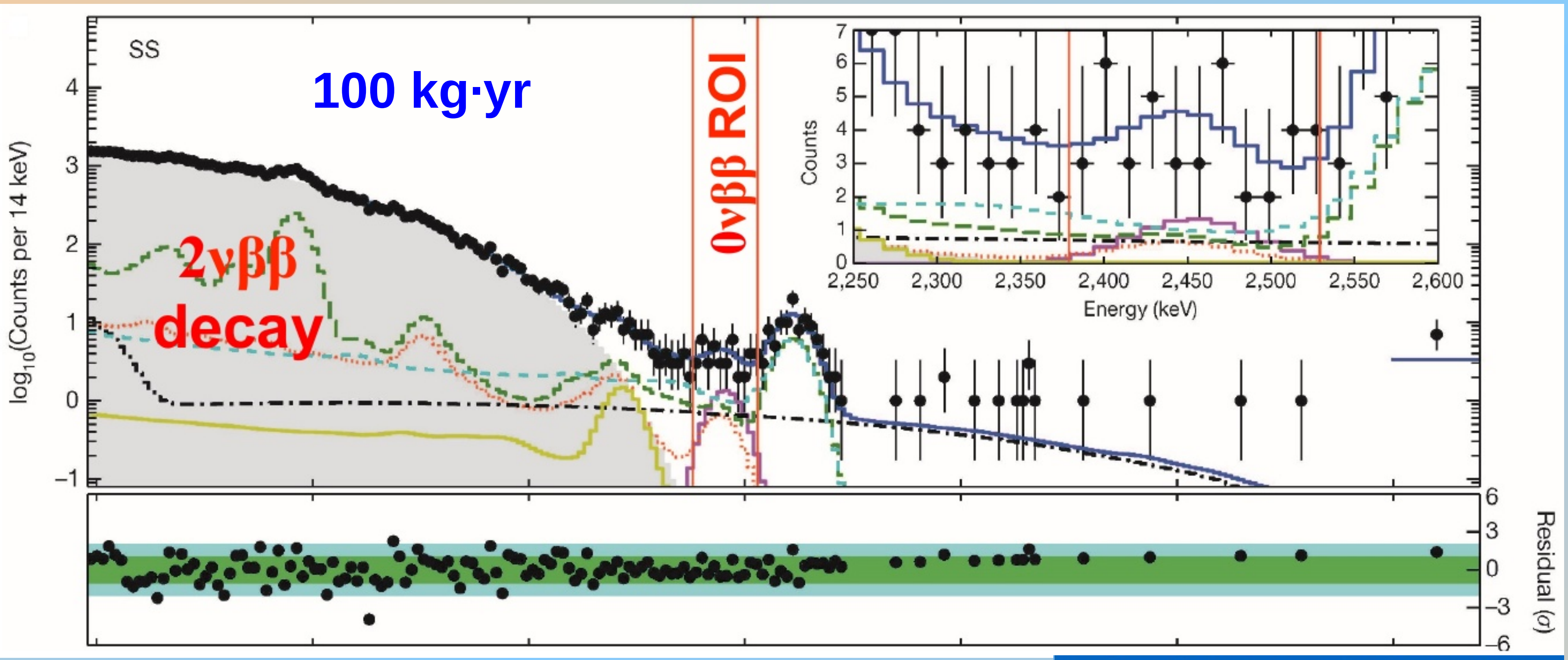
Confirmed by KamLAND-Zen
[PRC 85, 045504 (2012)]

Precision measurement
[PRC 89, 015502 (2014)]

$$T_{1/2}(2\beta) = (2.165 \pm 0.016\ (stat) \pm 0.059\ (syst)) \cdot 10^{21}\ yr$$

The longest yet most precisely measured 2β decay half-life of all 'practical' isotopes

Phase-1 2β0ν measurement



Background in the 0ν ROI: (1.7±0.2)·keV^{-1} ton^{-1} yr^{-1}

From profile likelihood:

$T_{1/2}(0\nu\beta\beta) > 1.1\cdot10^{25}$ yr

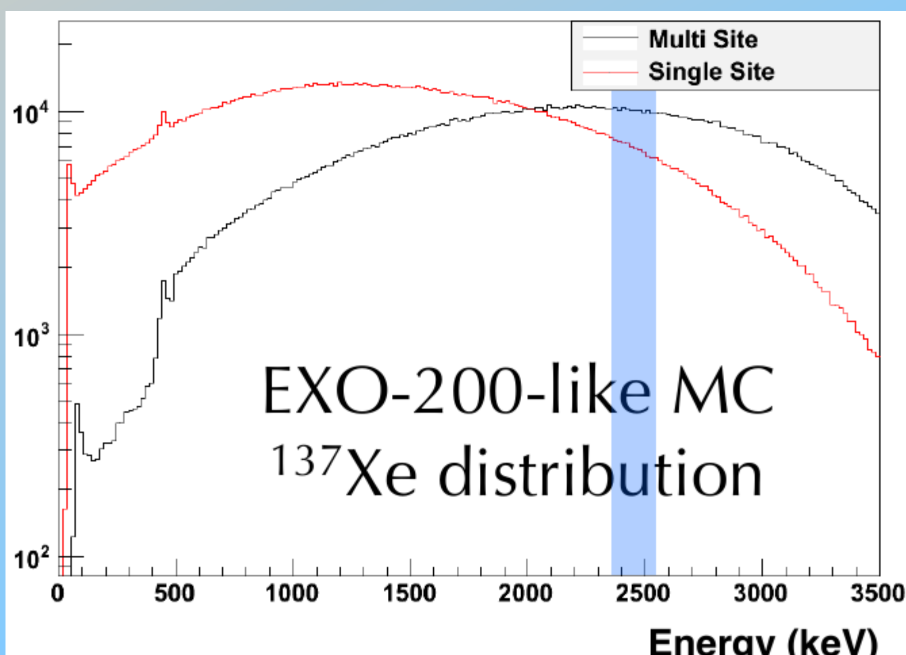
$\langle m_{\beta\beta} \rangle$ < 190 – 450 meV (90% C.L.)

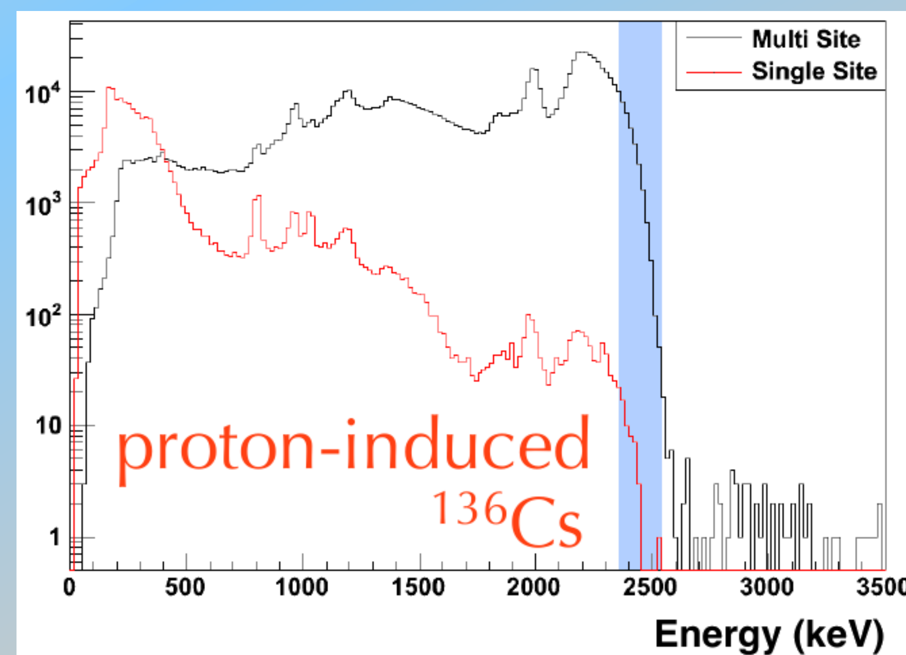
Nature (2014) doi:10.1038/nature13432

Backgrounds in ± 2σ ROI	
Th-228 chain	16.0
U-232 chain	8.1
Xe-137	7.0
Total	**31.1 ± 3.8**

Cosmogenics

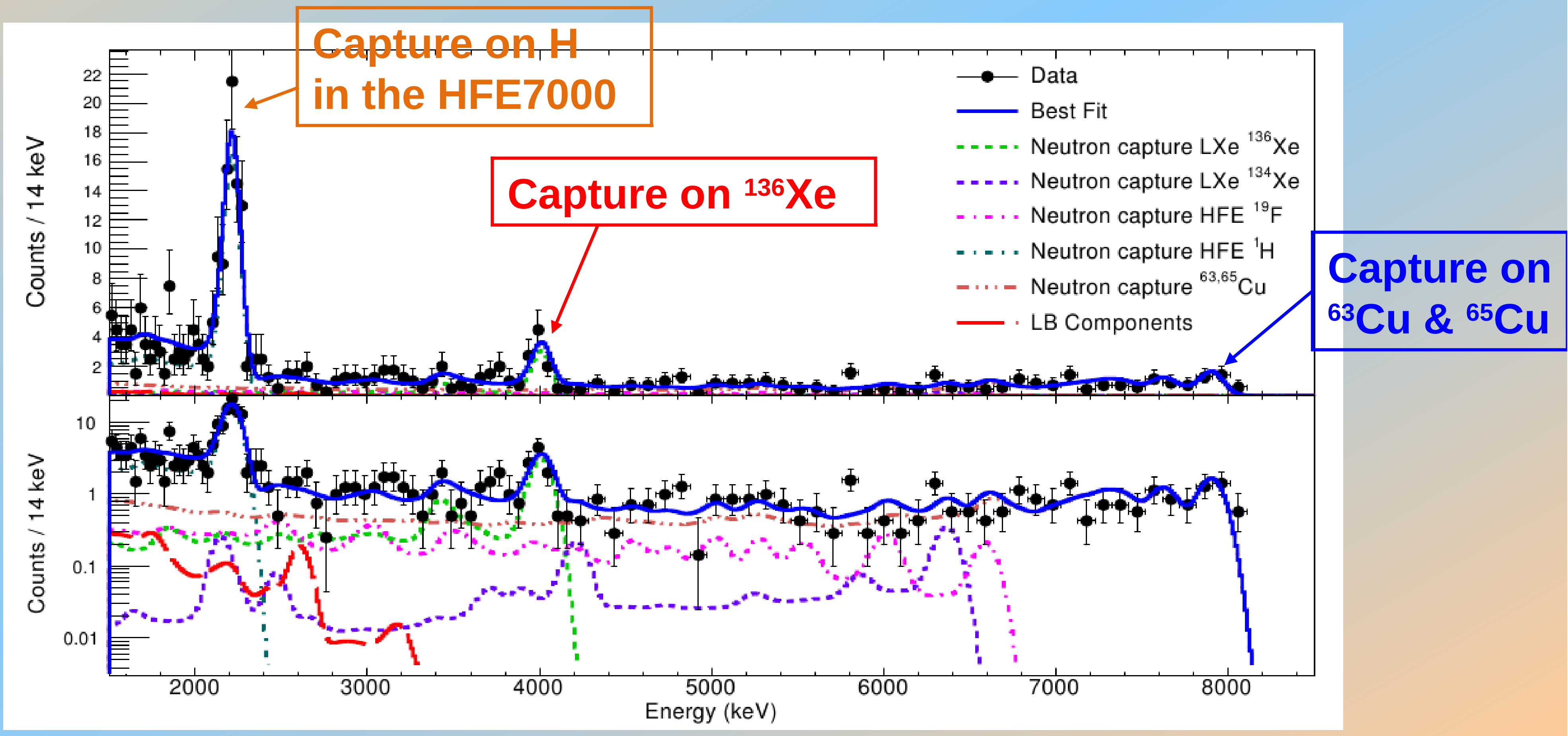
A serious danger for an ultra-sensitive low-background experiment comes from activation of detector materials by cosmic muons.
Some of the isotopes, especially created directly in liquid xenon, can make an irreducible background for 2b0n searches.
So we performed a big simulation of EXO-200 using FLUKA and GEANT4 to study this.





Cosmogenics

We plotted neutron-capture gammas to verify our simulation.
Events are within 10 us – 5 ms time window after active veto signal.
Rates agree with FLUKA and GEANT4 simulation.
[JCAP 1604 (2016) no.04, 029]



EXO-200 results

- Operated a 200 kg scale LXe TPC for 2 years
- Discovered a double beta decay of ^{136}Xe
- Made the **most precise** measurement of its halflife
- Measured **residual backgrounds are very low**
- Reached design (anticorrelated) **energy resolution, σ/E(Q)=1.5%**
- Achieved stable **electron lifetime of ~3 ms** or better
- Utilized **self-shielding in monolithic detector**
- Demonstrated power of **β/γ discrimination** (SS/MS)

- Implemented novel detector solutions and analysis techniques
- 500 LAAPDs for VUV (175 nm) scintillation detection
- Photo-etched, charge collection wires, cathode, and fasteners
- Epoxy-poned, kapton flat cable feedthroughs
- HFE-7000 thermal bath and radiation shield
- Ultra-light design, no solder joints

What else from EXO-200?

Following 2 accidents at the WIPP mine, EXO-200 personnel is now granted regular access to the site and recovery operations are ongoing

- EXO-200 can still contribute to the leading set of experiments
- Funding for EXO-200 is extended for at least 2 years
- Analysis improvements (Xe137 veto, b/g discrimination) ongoing

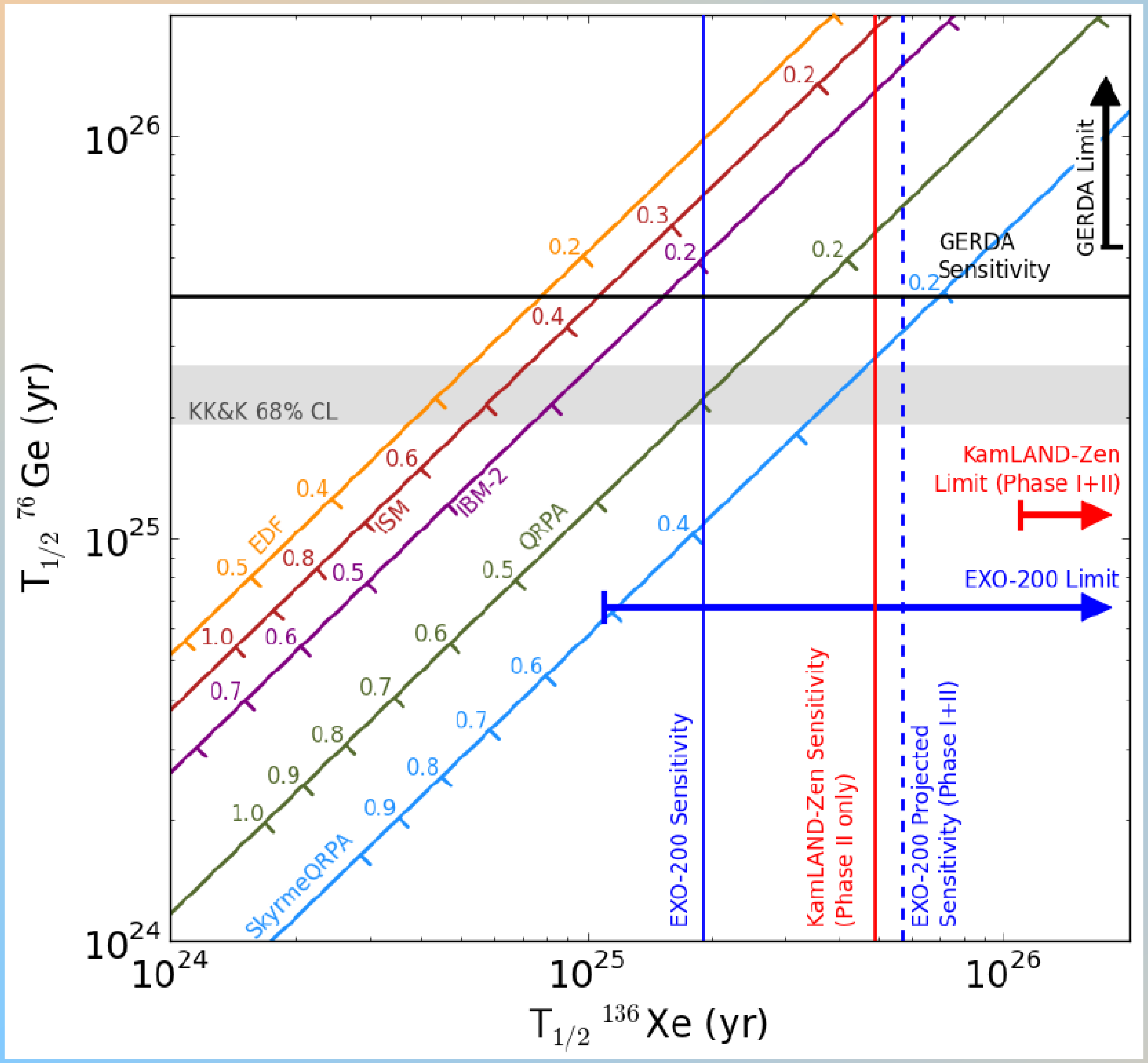
- Upgrades had been installed :
  - Radon suppression system for air around the detector
  - Upgraded electronics (get to 1.2% energy resolution)

Phase-II Restart:

- Oct. 2015 – Jan. 2016, system cooldown, liquid xenon filling
- Feb. – April 2016, detector upgrades
- April 2016, Phase-II Physics data taking begins

Look forward for nEXO

Phase-2 2β0ν sensitivity



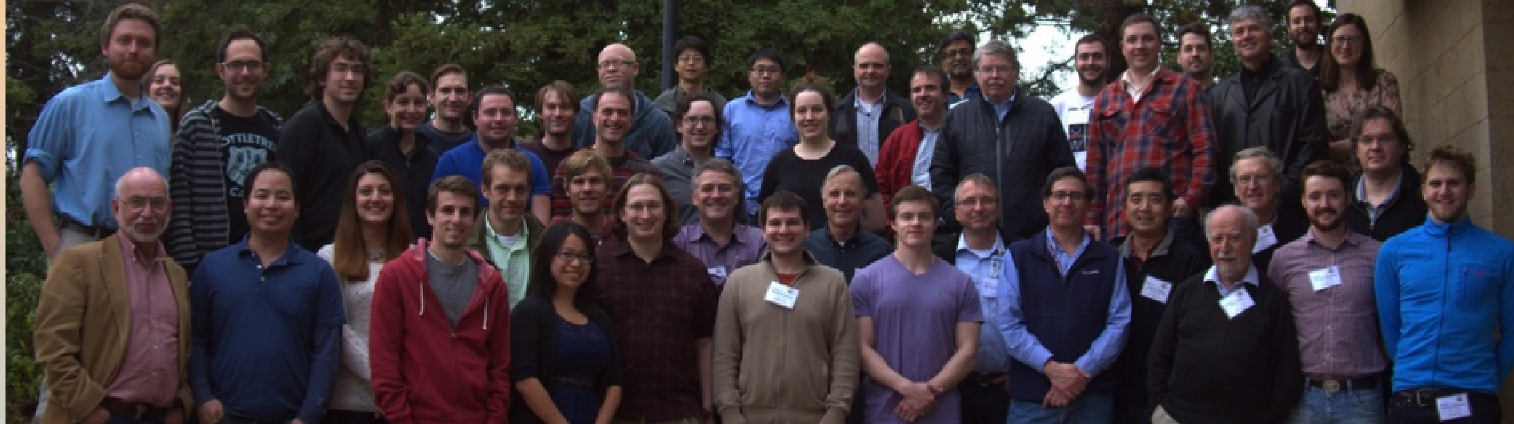
EXO-200 can reach 2b0ν half-life sensitivity of

5.7×10^{25} yr

With lower threshold, EXO-200 can improve measurement of 136Xe 2νββ and searches in other physics channels.

Nature 510, 229 (2014)
PRL 111 (2013) 122503
PRL 110 (2013) 062502
Mod. Phys. Lett., A21 (2006) 1547

Enriched Xenon Observatory
EXO
for double beta decay



The EXO-200 Collaboration

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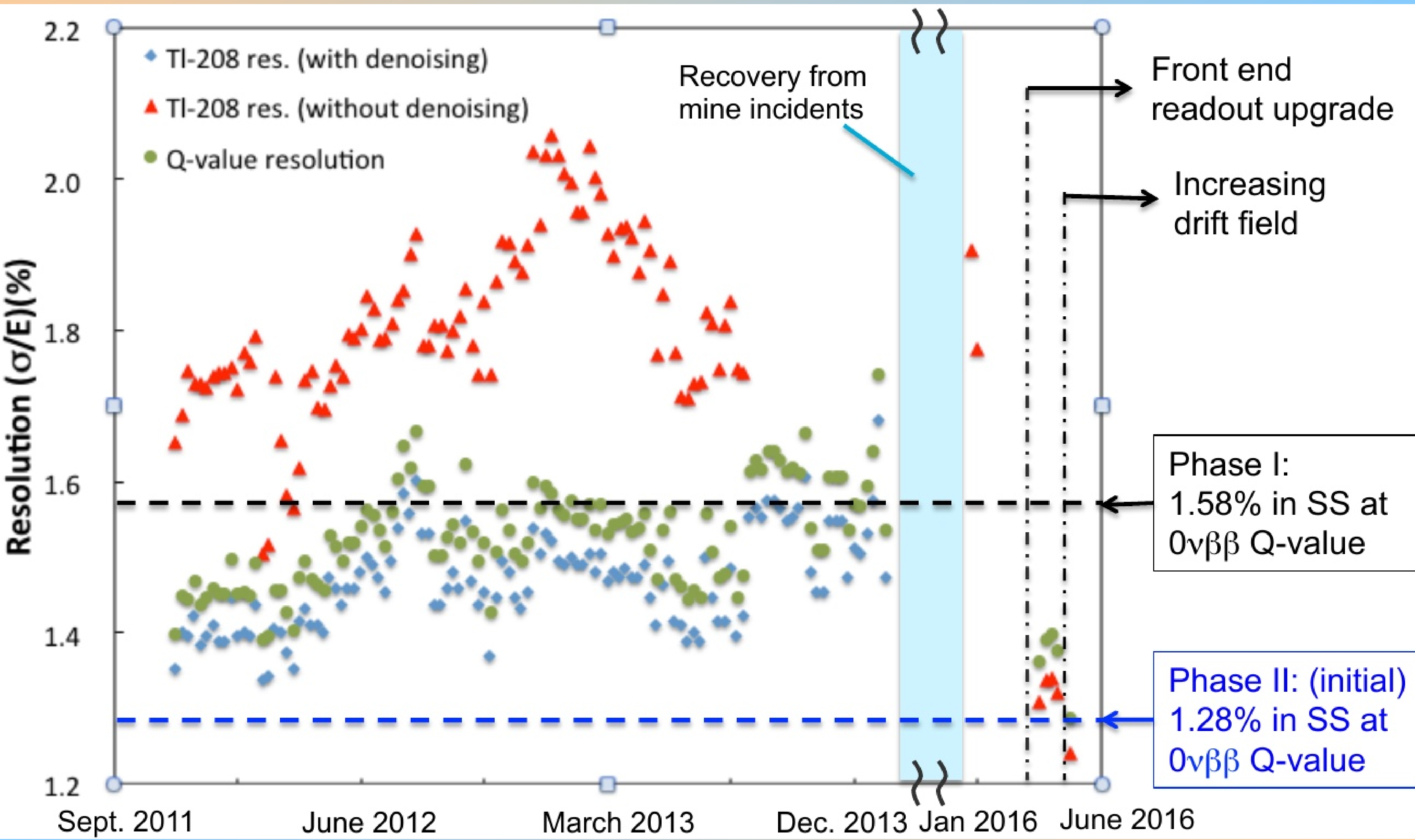
Technical University of Munich, Garching, Germany — W Feldmeier, P Fierlinger, M Marino
TRIUMF, Vancouver BC, Canada — J Dilling, R Krücken, F Retière, V Strickland

Upgrade performance



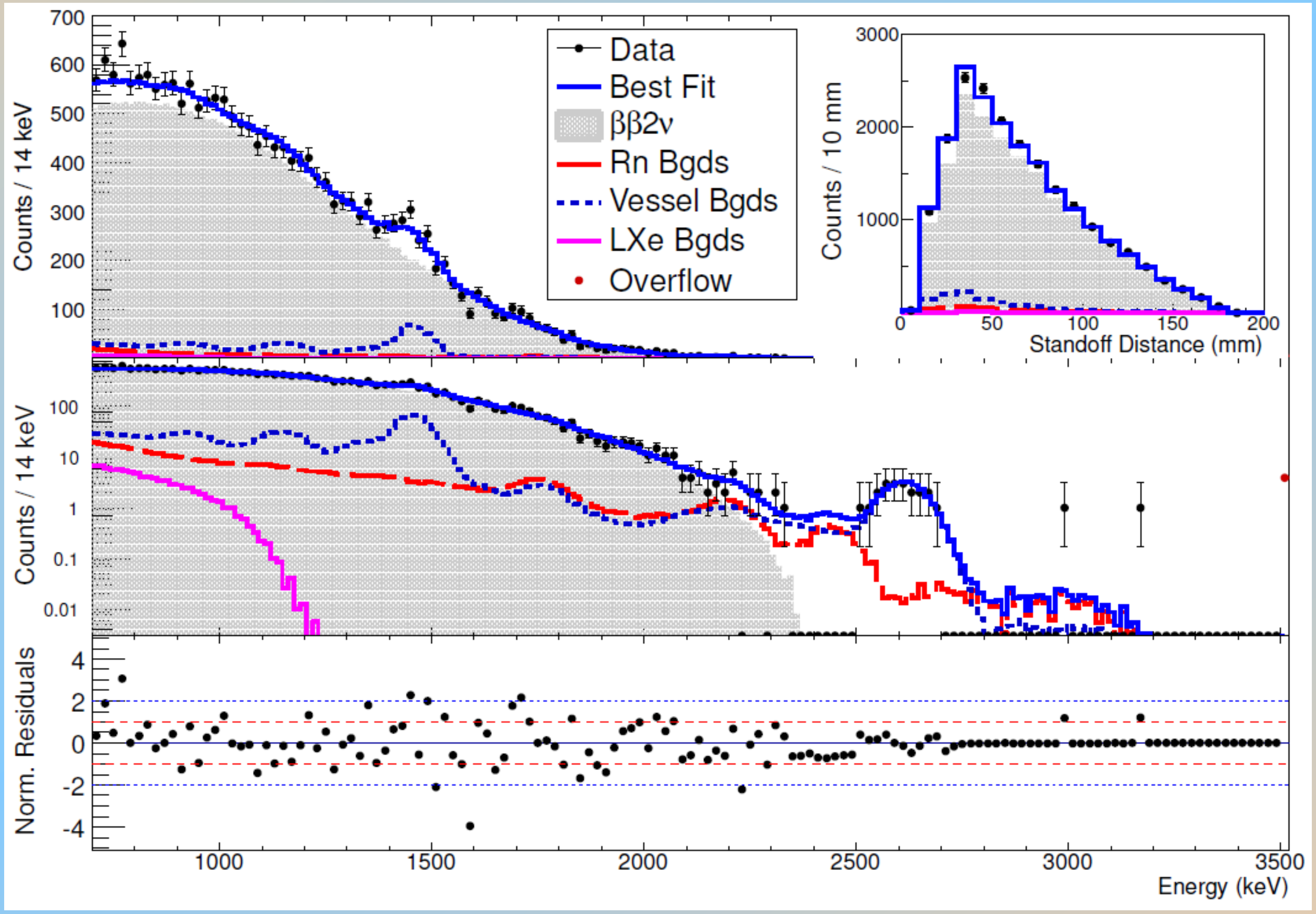
2β2ν measurement

The most precise measurement of halflife of any isotope to date

$T_{1/2}^{2\nu\beta\beta} = 2.165 \pm 0.016(\text{stat}) \pm 0.059(\text{sys}) \times 10^{21}$ yr

[PRC **89**, 015502 (2014)]

total relative uncertainty 2.85%



Efficiency to 2β
58 % (87 %)

Full exposure
127.6 days
23.14 kg y

2β events
18984

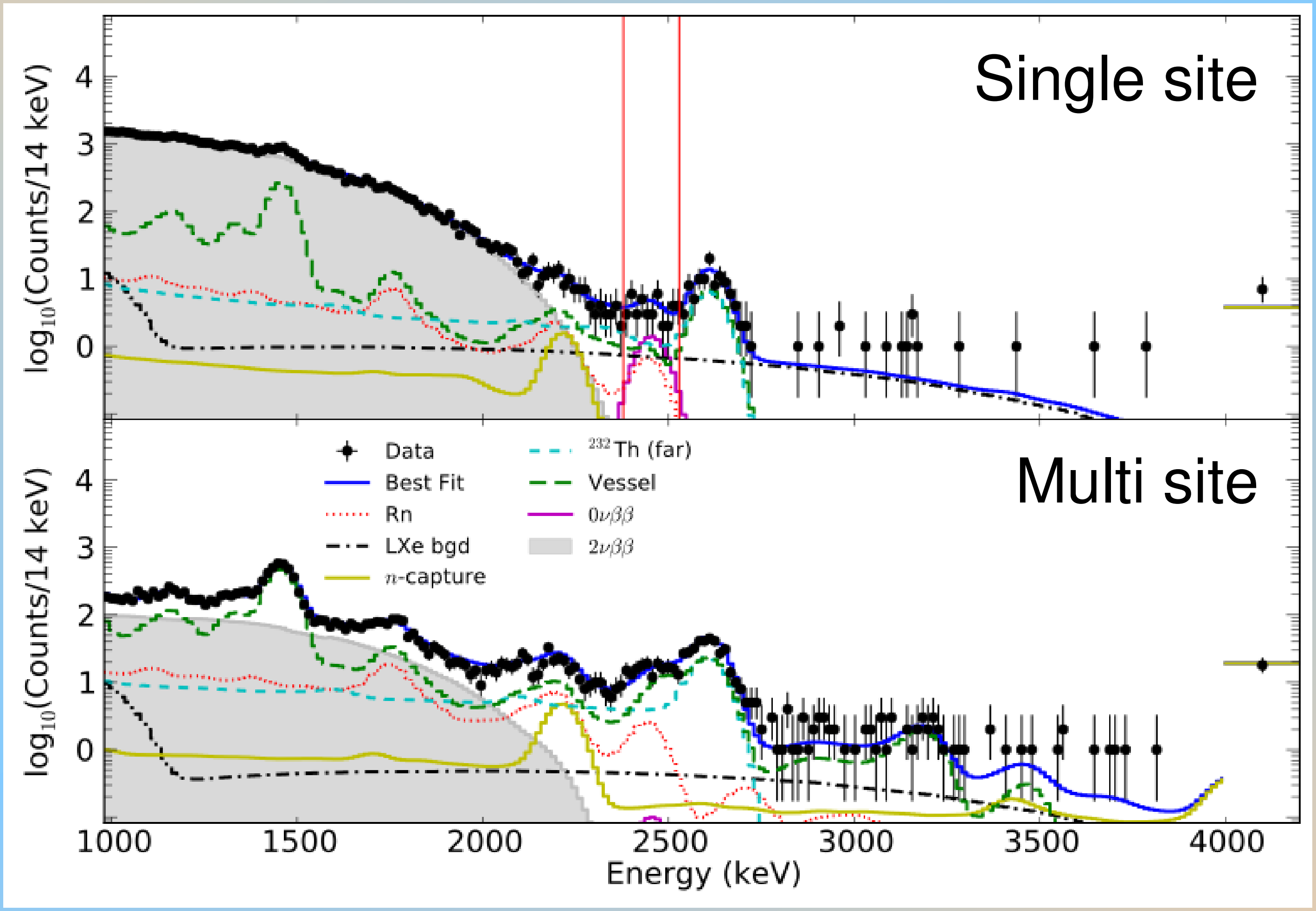
Reanalyzed Run 2a data from (PRL 109, 032505, 2012)

2β0ν measurement

The lowest background index among comparable detectors

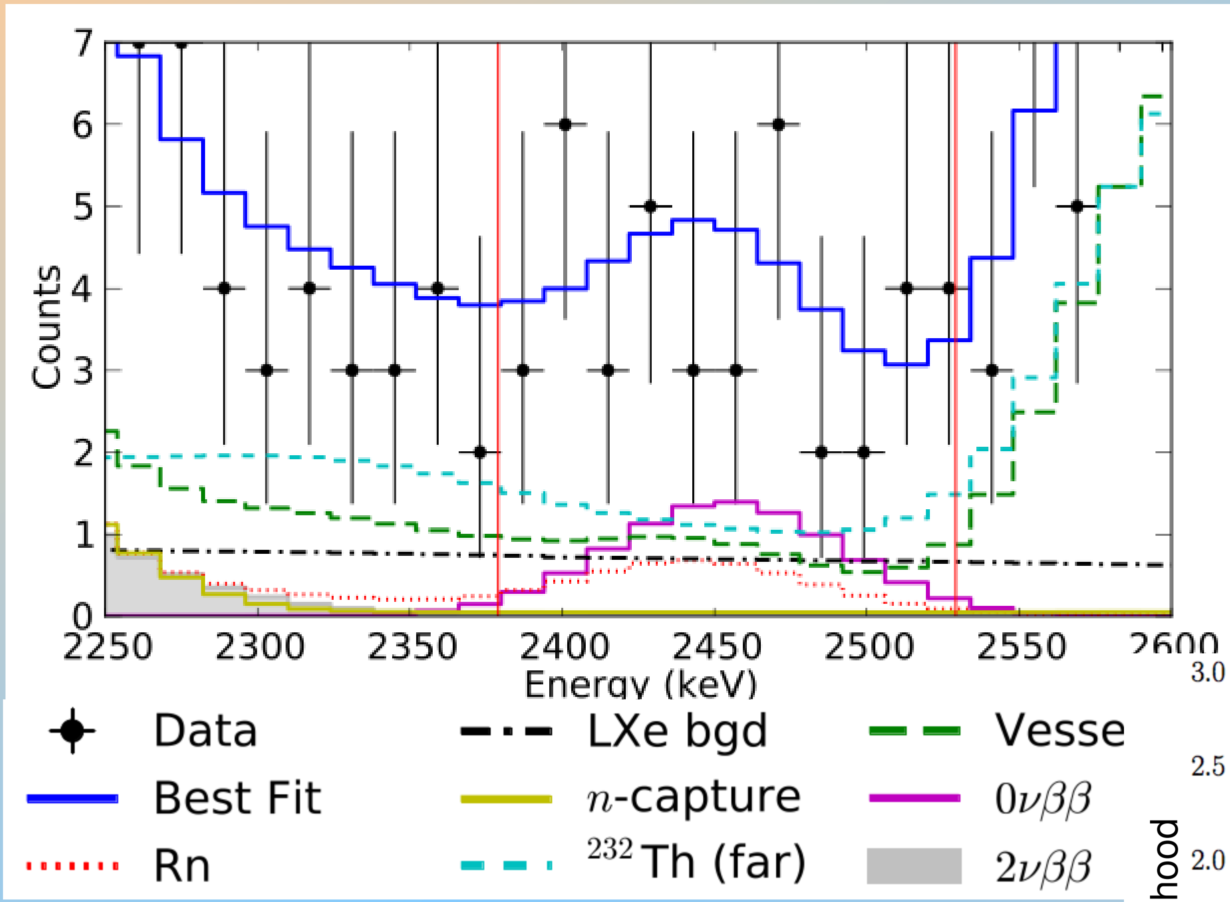
BI = 1.7 ± 0.2 × 10^{-3} keV^{-1} kg^{-1} y^{-1}

[*Nature* **510**, 229 (2014)]



Efficiency to 2β events
85 %
Full livetime
477.6 d
100.0 kg y
2β events
~37000
Energy resolution at Q
1.53% (SS)
1.65% (MS)

2β0ν measurement



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(90% C.L.)

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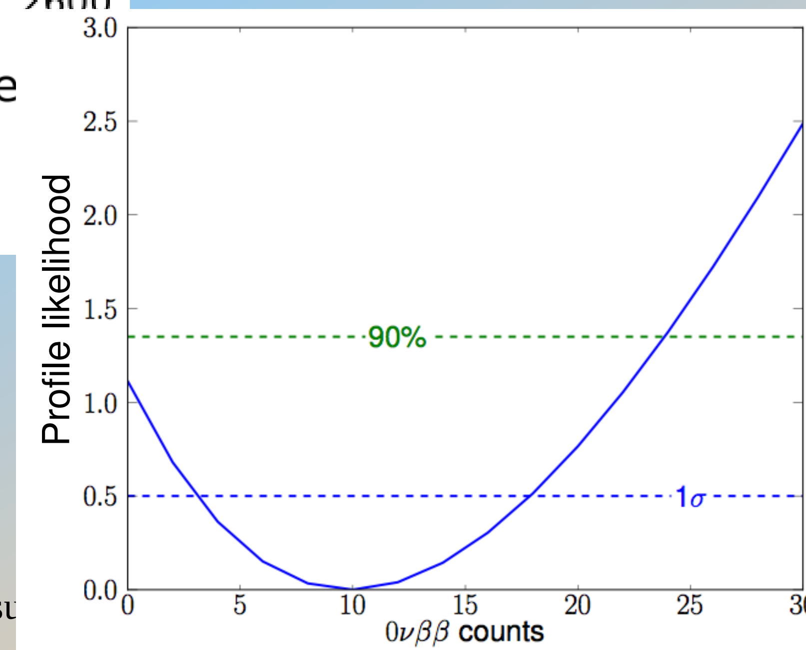
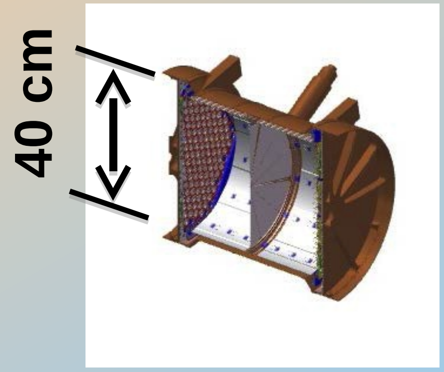
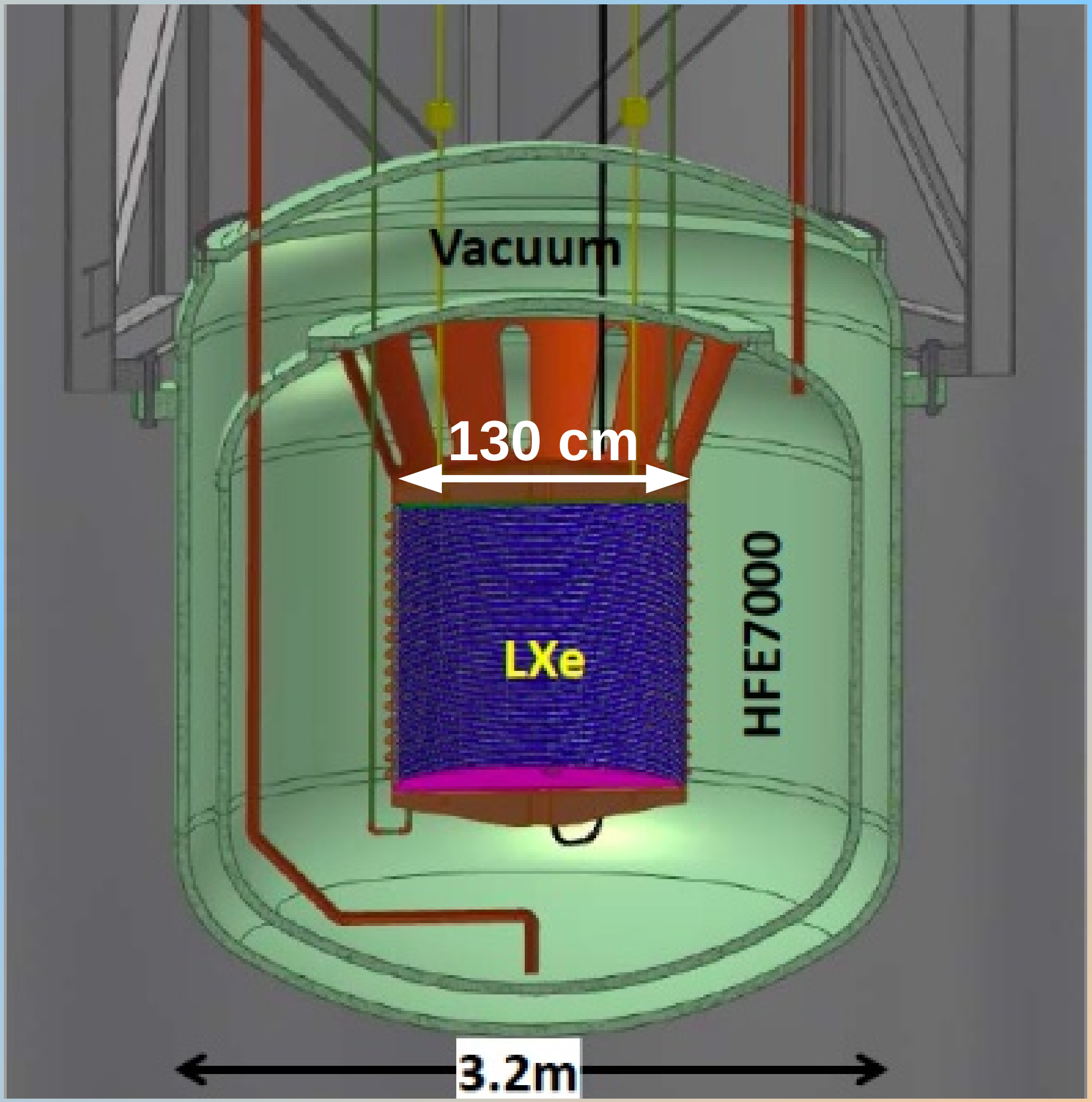


nEXO concept

EXO-200

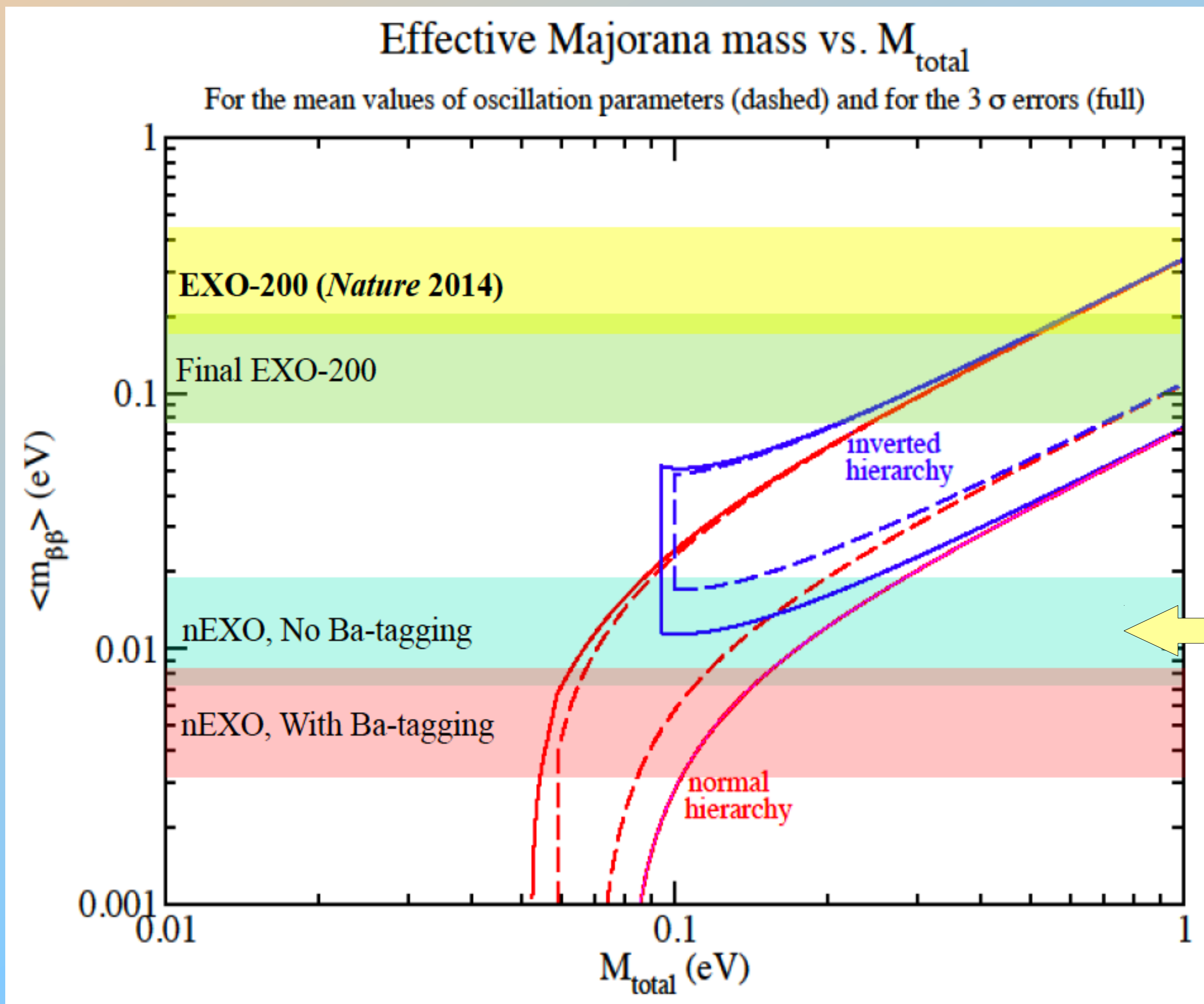


- 5 tonnes of enriched LXe
- Monolithic design dramatically improves performance with size
- Using enhanced self-shielding
- x100 better $T_{1/2}$ sensitivity
- < 1% energy resolution
- no central cathode
- *no* Ba tagging (initially)



nEXO projected sensitivities

nEXO is an active international R&D program for a x100 the sensitivity of EXO-200!



Combining all our experience and the best technologies we plan

$T_{1/2}$ = 6 · 10^27 yr in 5 years of counting

Majorana neutrino mass $\langle m_{\beta\beta}\rangle$ sensitivity of 7-18 meV