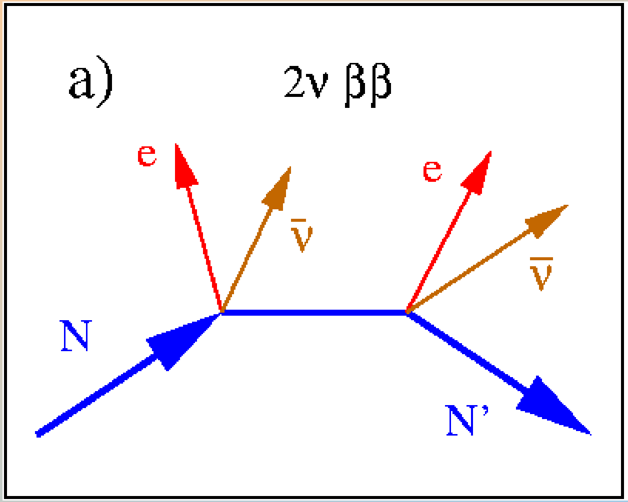
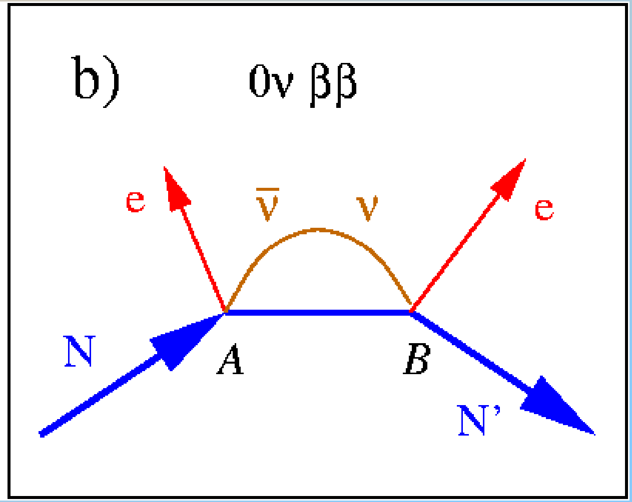
From EXO-200 to nEXO

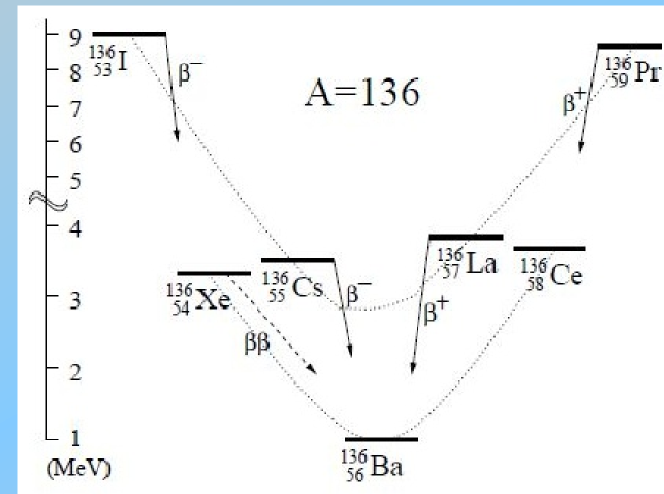
Vladimir Belov, ITEP
for EXO-200 and nEXO
collaborations

BNO-50, Nalchik, 06 June 2017

Double beta decay



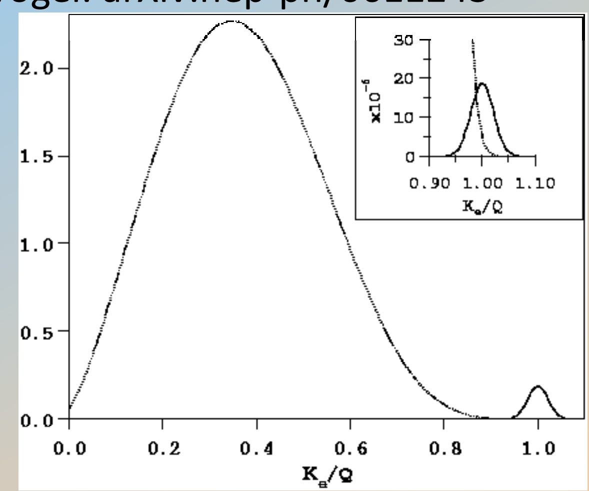




2ν mode:
a conventional
2nd order process
in Standard Model

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

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/ionizatio correlation.

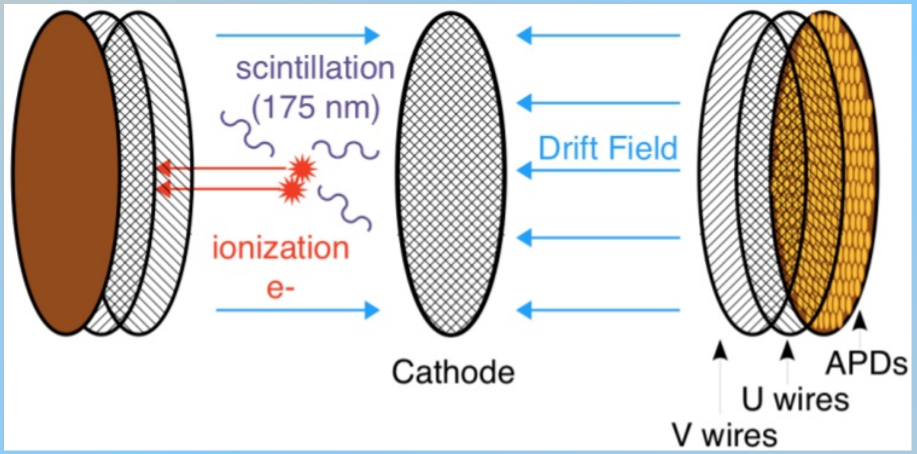
Particle identification. Slightly limited, but can be used to ta from Rn chain.

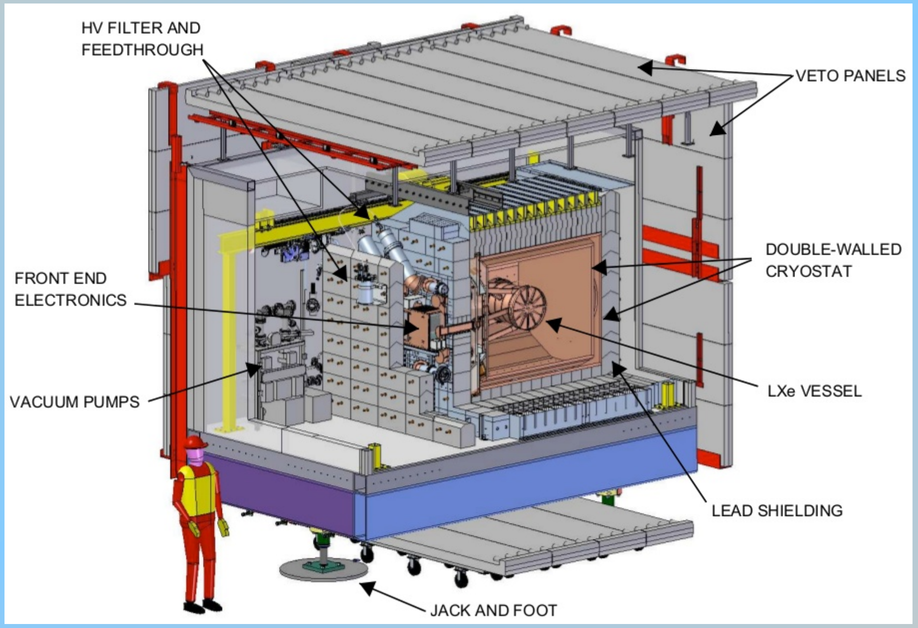
See talk by D.Sinclair

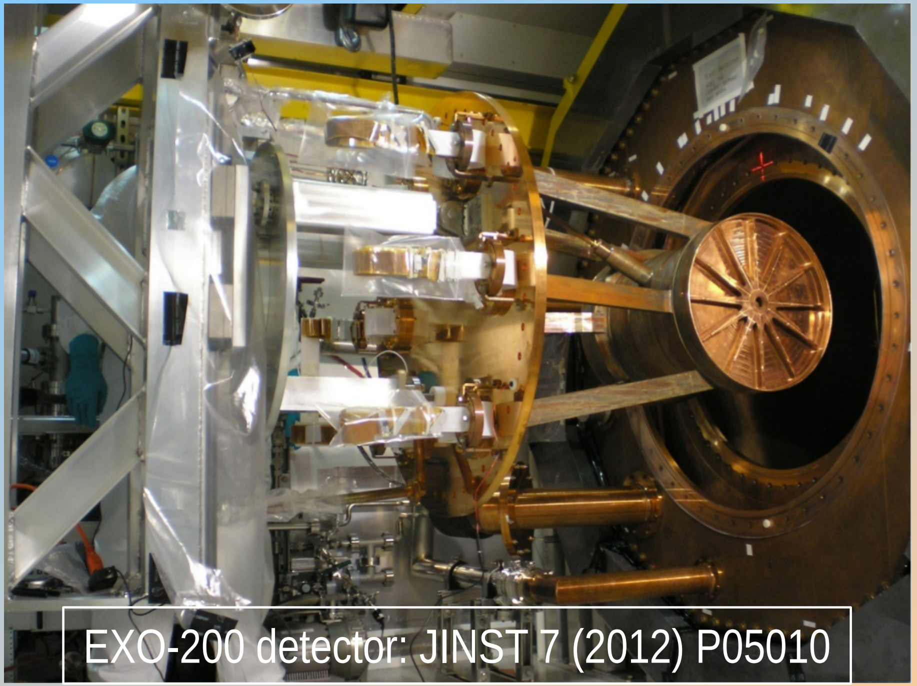
… admits a novel coincidence technique. Background reduction by Ba daughter tagging (M.Moe PRC 44, R931, 1991).

EXO-200 detector

- Double Time Projection Chamber (TPC)
- 110 kg of liquid xenon in active volume enriched to 80.6 in ^{136}Xe
- Reading both ionization and scintillation
- Drift field 564 V/cm
- Comprehensive material screening program
- Massive background shielding (> 50 cm of HFE, 5 cm of copper, 25 cm of lead)
- Located in salt mine at 1600 m.w.e.

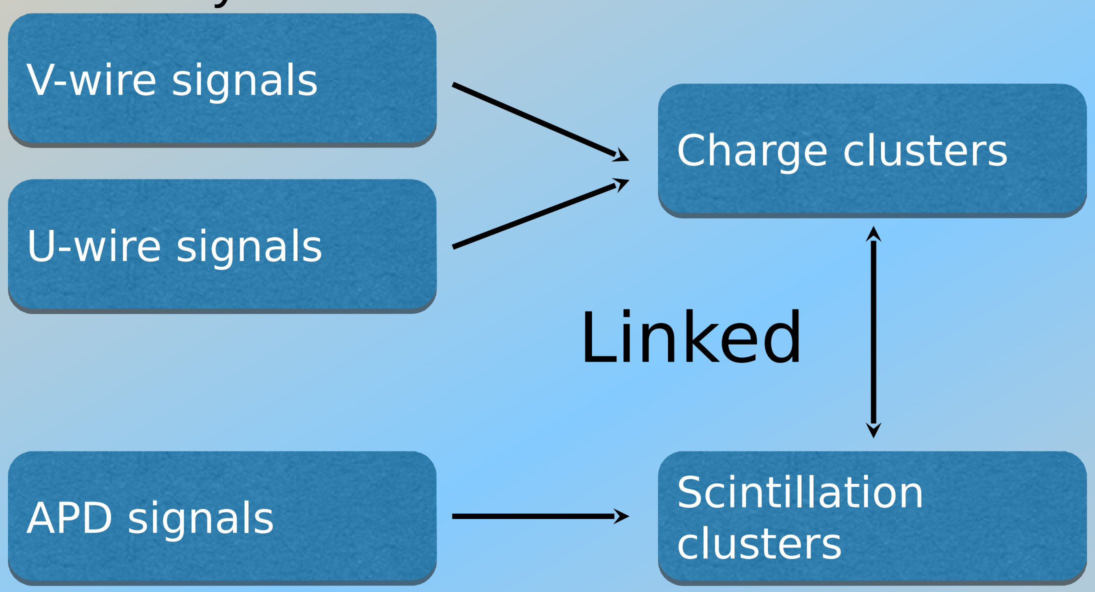


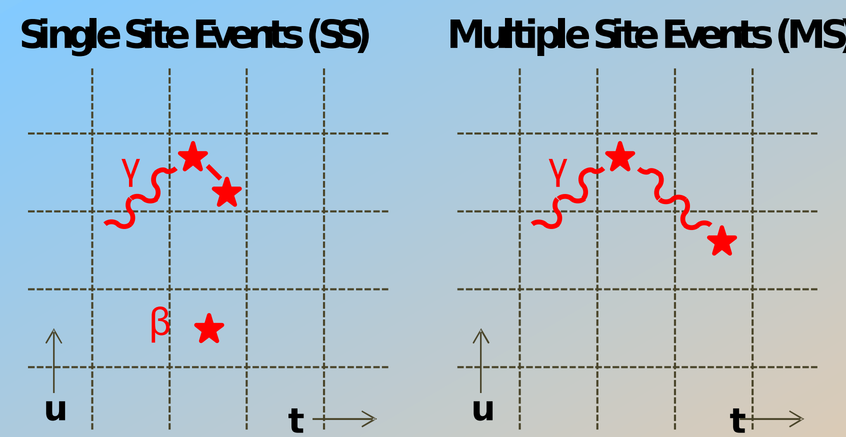




Event reconstruction

- 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



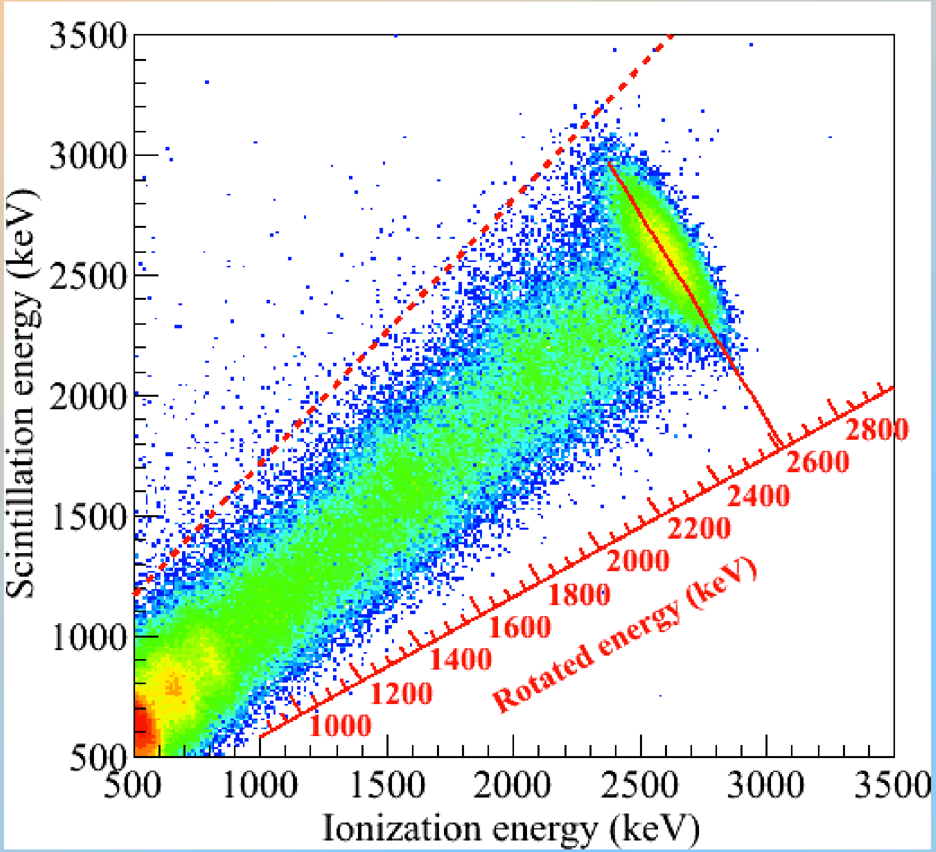


Efficiency to get into SS: $2\beta0\nu$ ~90%

γ 2.5MeV ~30%

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

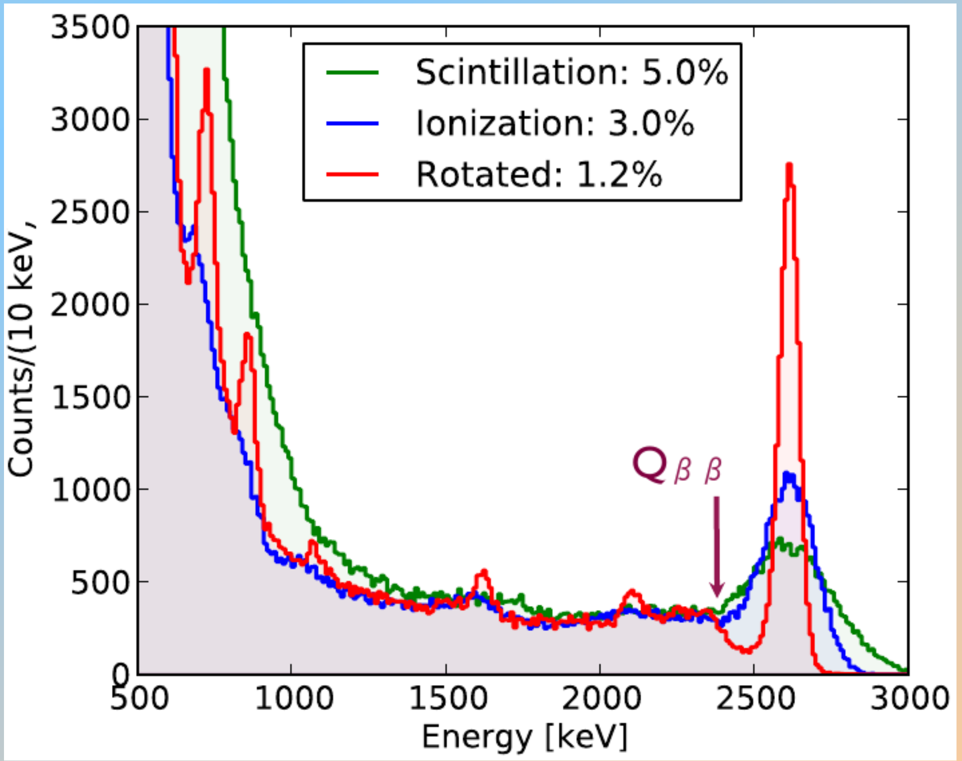
Combining ionization and scintillation



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

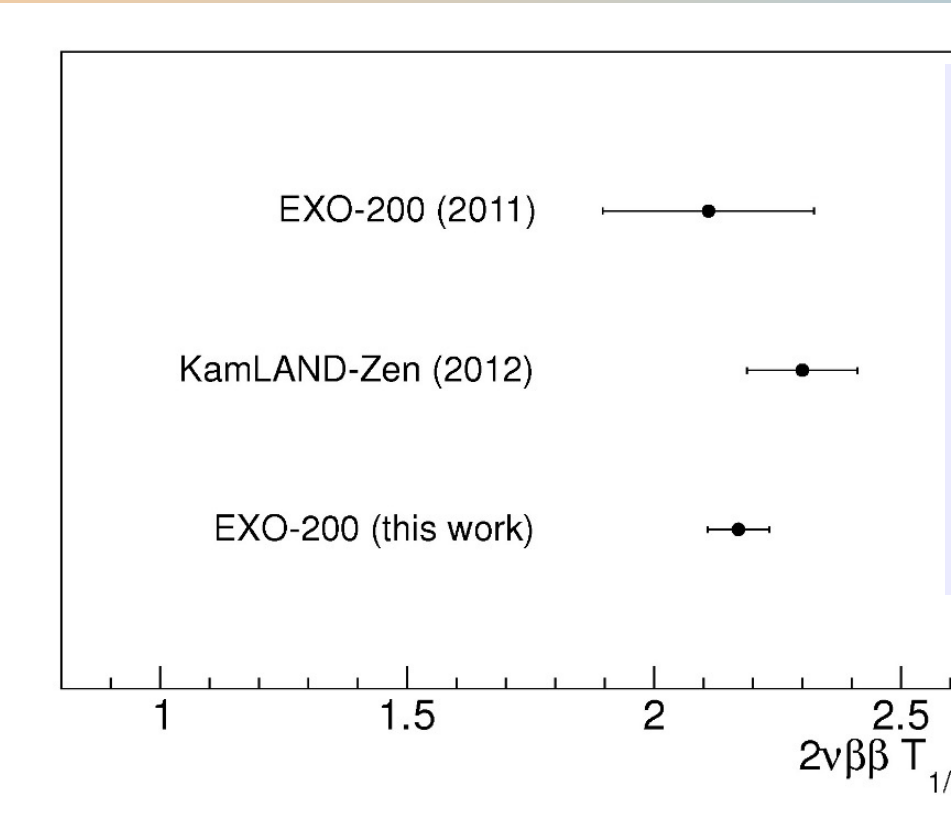
E. Conti et al. Phys. Rev. B 68 (2003) 054201

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



EXO-200 has achieved ~ 1.2% energy resolution at the Q value. nEXO will reach resolution < 1%, sufficient to suppress background from 2νββ.

Phase-1 $2\beta2\nu$ measurement



Start data taking in June 2011

Discovery of $2\beta2\nu$ decay of ^{136}Xe [PRL 107, 212501 (2011)]

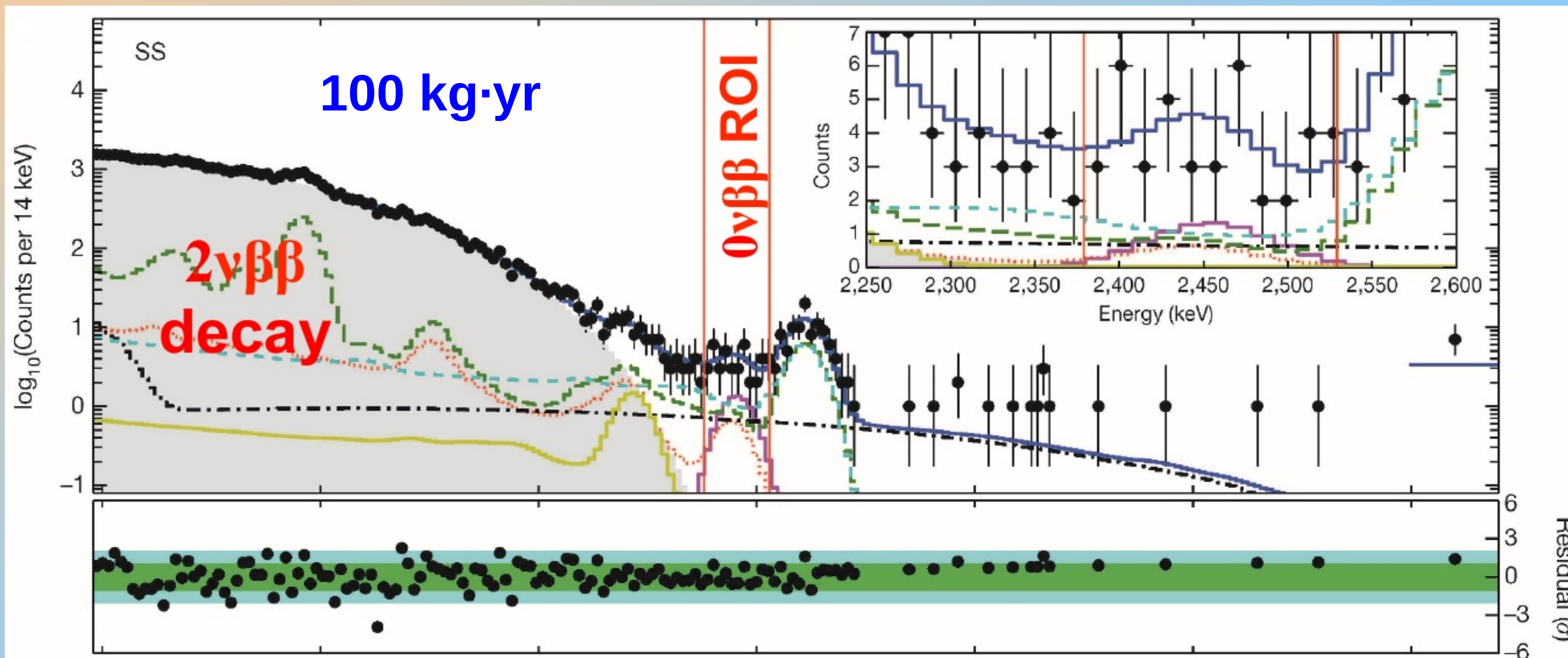
Confirmed by KamLAND-Zen [PRC 85, 045504 (2012)]

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:

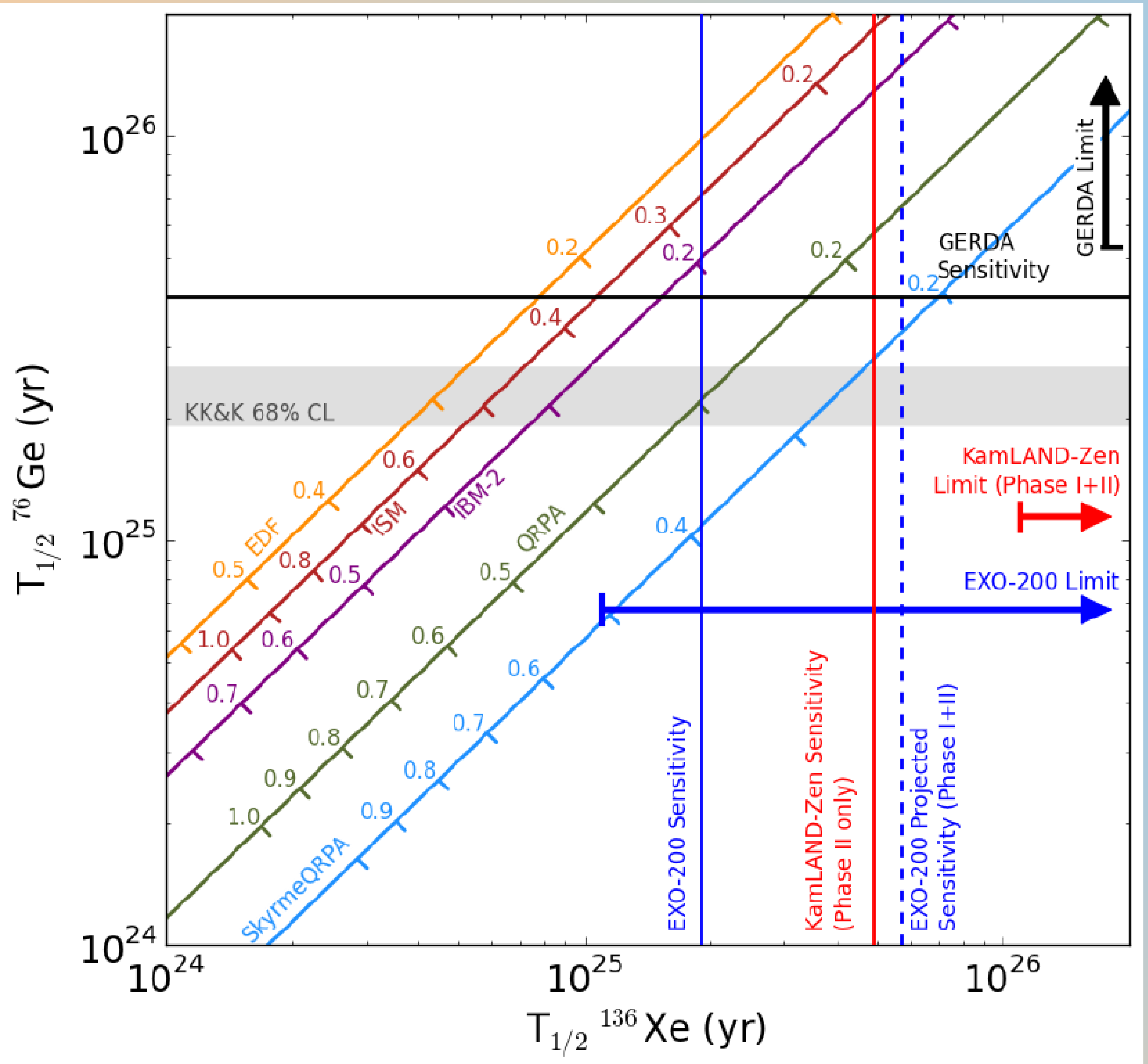
$T_{1/2}(0\nu\beta\beta) > 1.1\cdot10^{25}$ yr

$\langle m_{\beta\beta} \rangle$ < 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**

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 ^{136}Xe 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

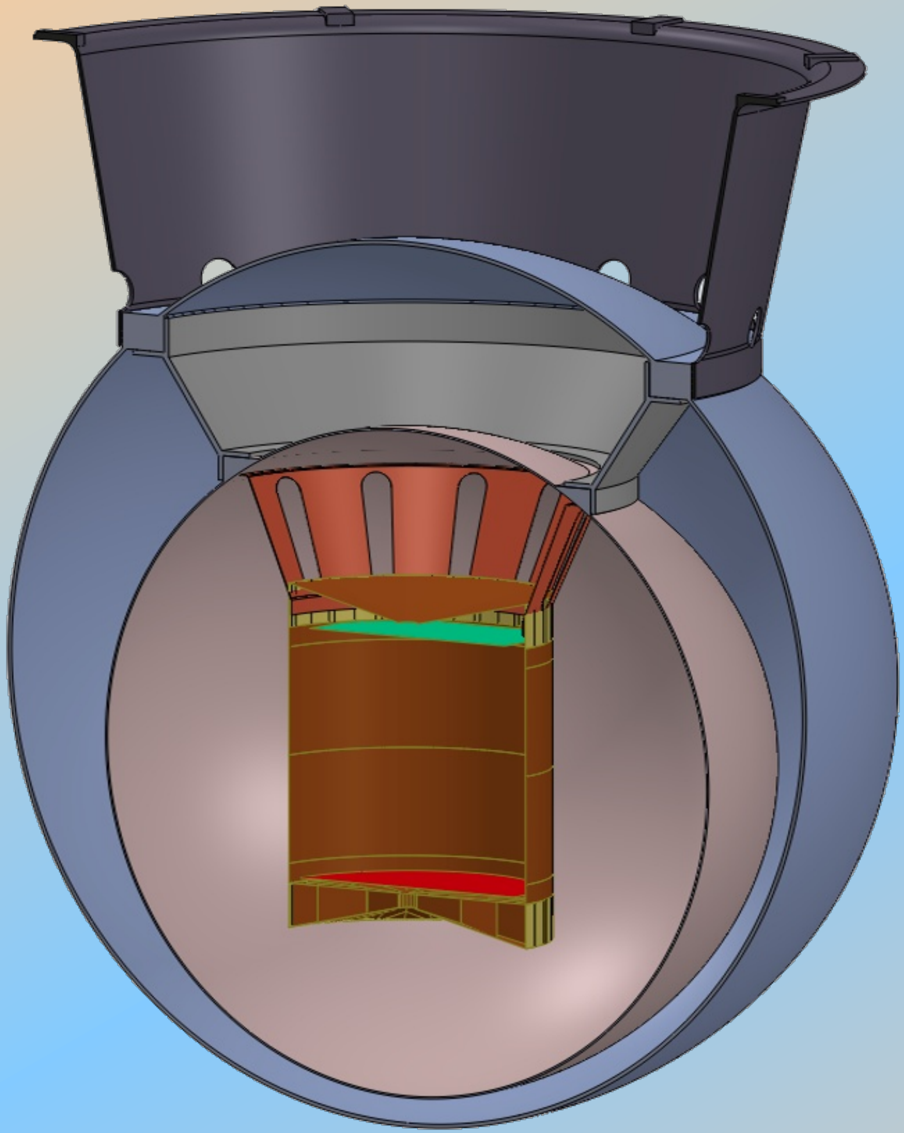
EXO-200 status

- Operated a 200 kg scale LXe TPC for 5 years
- Discovered a double beta decay of ^{136}Xe
- Made the **most precise** measurement of its halflife
- Measured **residual backgrounds are very low**
- Achieved stable **electron lifetime of ~3 ms** or better
- Utilized **self-shielding in monolithic detector**
- Demonstrated power of **β/γ discrimination** (SS/MS)

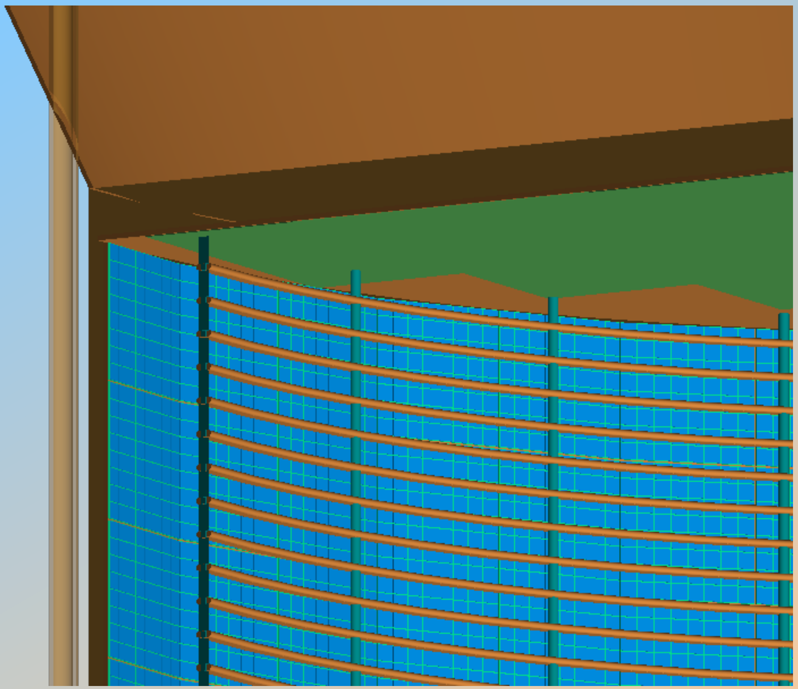
- Last year finished recovery from an accident at WIPP mine
- Increased drift field strength
- Upgraded electronics (get to **1.2% energy resolution !**)
- Installed radon suppression system for air around the detector
- Started new Phase-II measurements in Apr'16
- Developed an improved analysis

Look forward for EXO-200 new papers

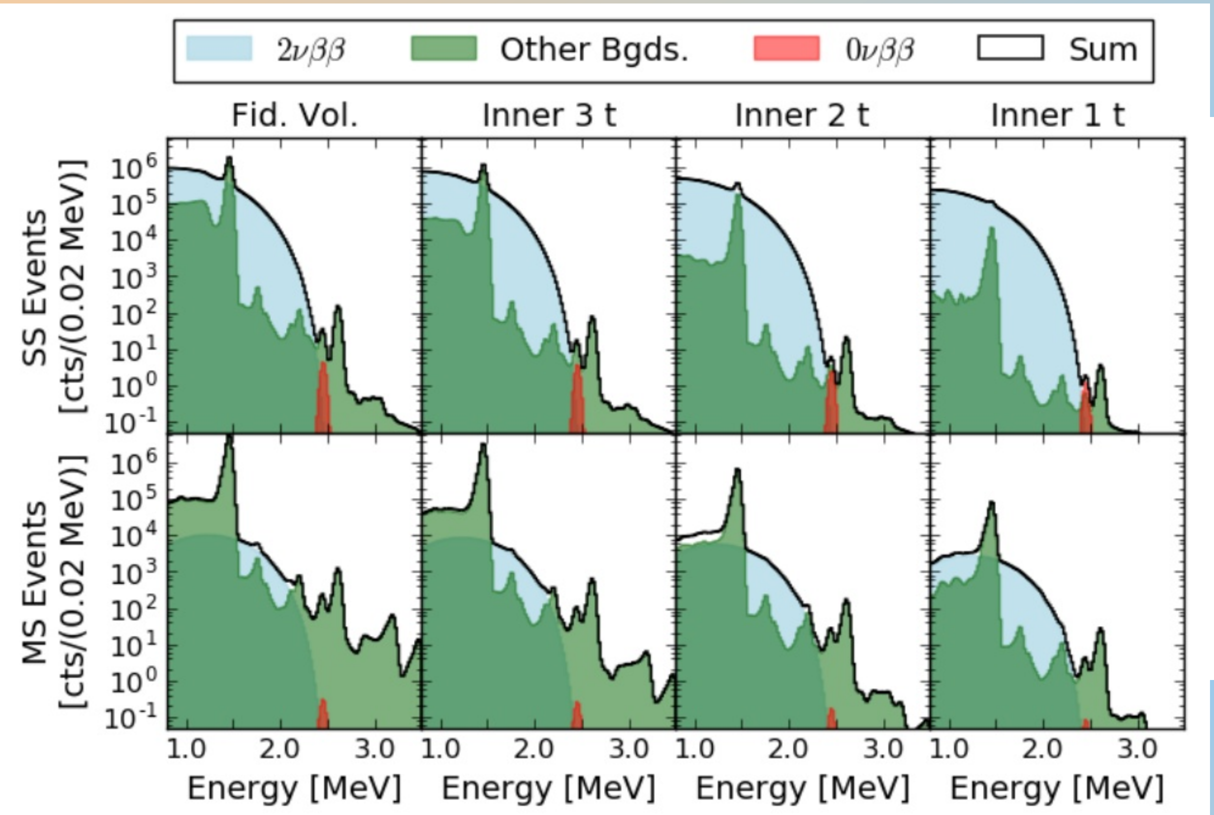
nEXO detector design



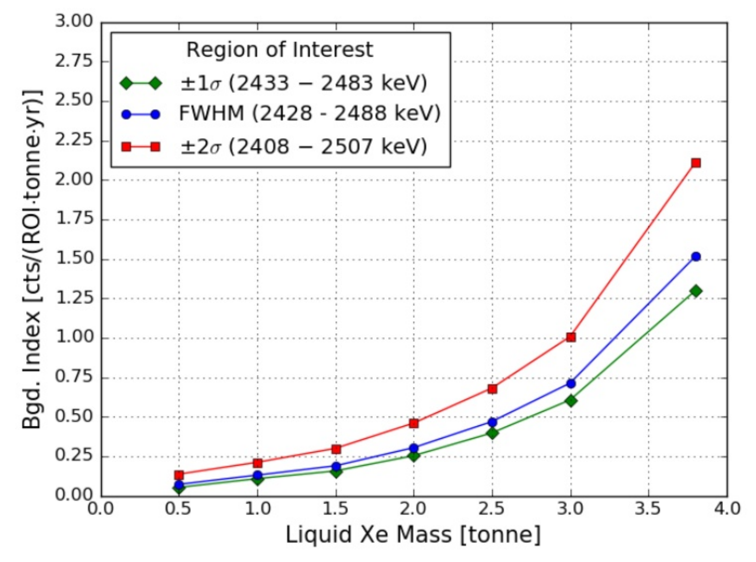
- 1.3 × 1.3 m cylinder TPC
- About 30× active xenon mass
- Single drift zone
- Charge tiles instead of wires
- SiPMs on the barrel
- Cold front-end electronics
- Better than 1% energy resolution
- Deeper location site



Signal and Background



Background index in ROI as a function of fiducial cut

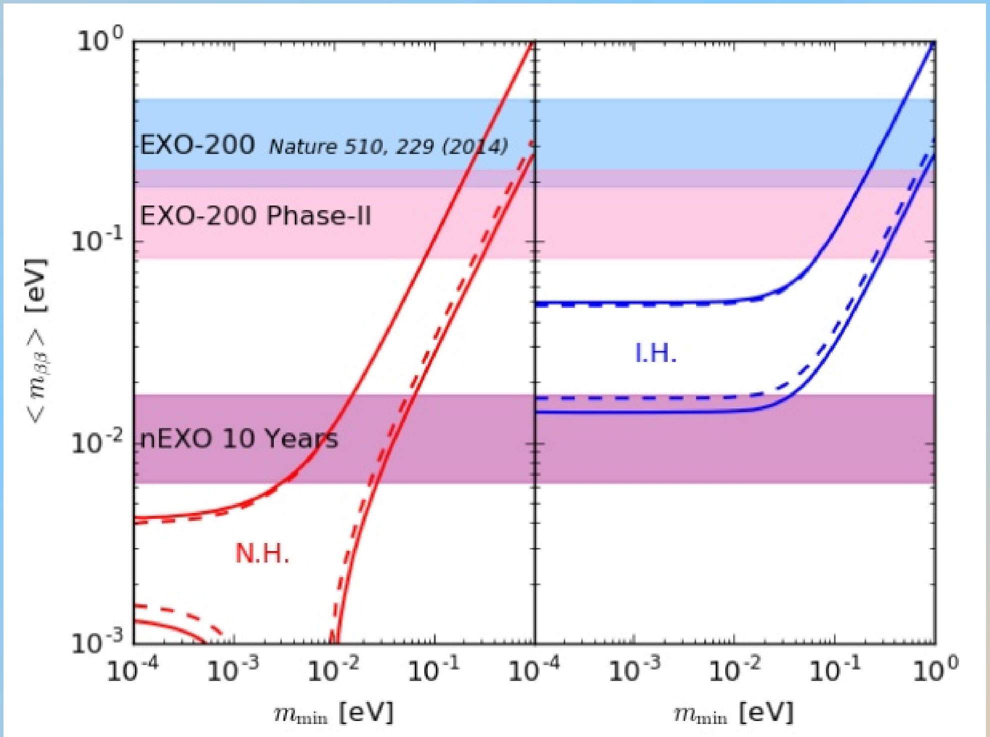


Background contribution	
^{238}U	77,8%
^{232}Th	14,2%
^{222}Rn	5,7%
^{137}Xe	2,0%
2β2v	0,2%

- Current background estimate: ~0.7 counts/ROI/t/yr assuming a 3 tonne fiducial volume.
- 90% C.L. sensitivity with 10-year exposure is 9.5×10^{27} yr

nEXO sensitivity

- nEXO is a next generation 2β0ν experiment with ongoing R&D.
- Will have discovery potential in the IH region.
- Estimated to have a sensitivity of 9.5×10^{27} yr at 90% C.L. to the ^{136}Xe 2β0ν half-life with a 10-year exposure.



Enriched Xenon Observatory
EXO
for double beta decay

The EXO-200 Collaboration

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Drexel University, Philadelphia PA, USA — E Callaghan, MJ Dolinski, YH Lin, E Smith, Y-R Yen
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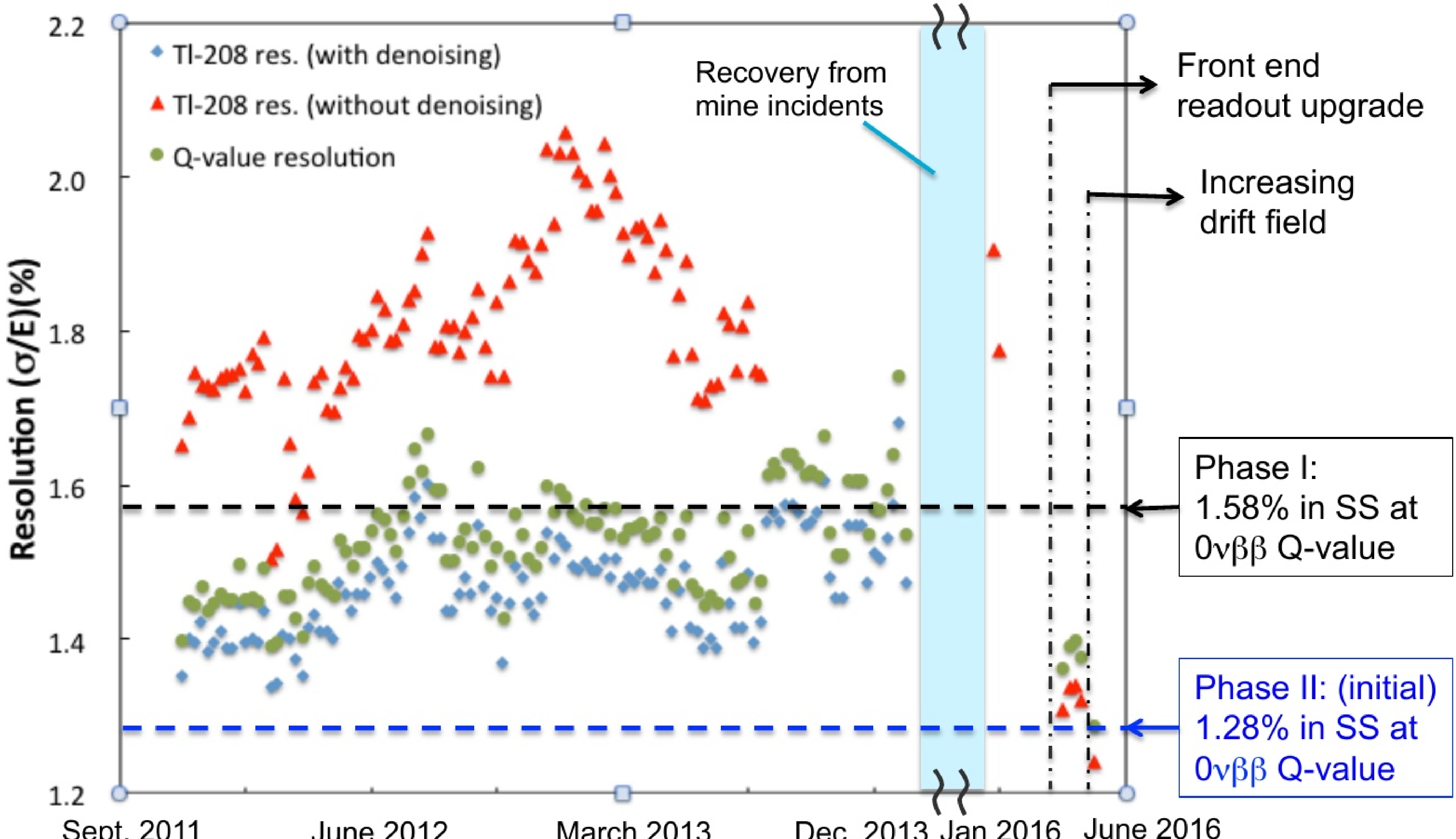
Technical University of Munich, Garching, Germany — W Feldmeier, P Fierlinger, M Marino
TRIUMF, Vancouver BC, Canada — J Dilling, R Krücken, F Retière, V Strickland

Upgrade performance



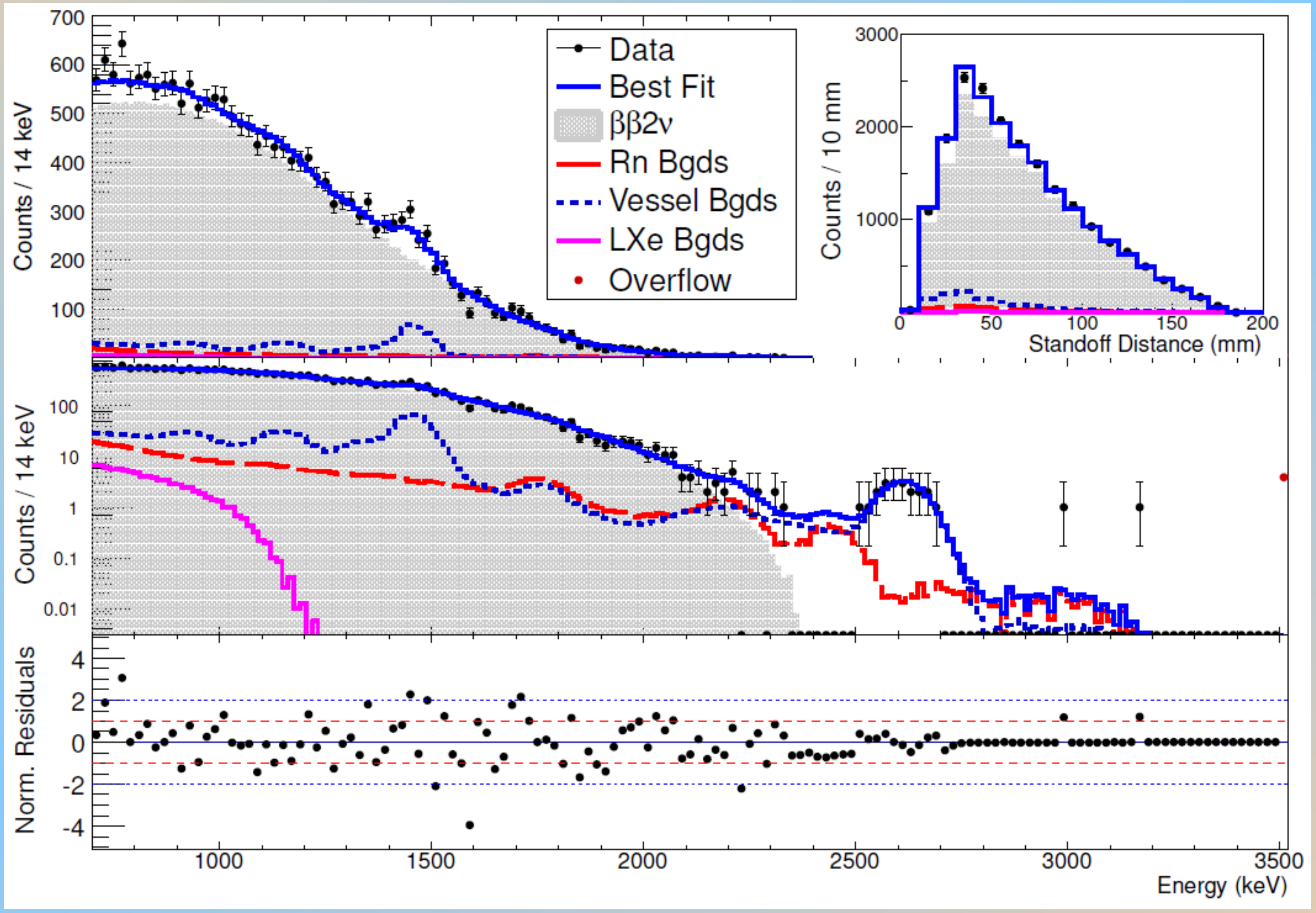
2β2ν measurement

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

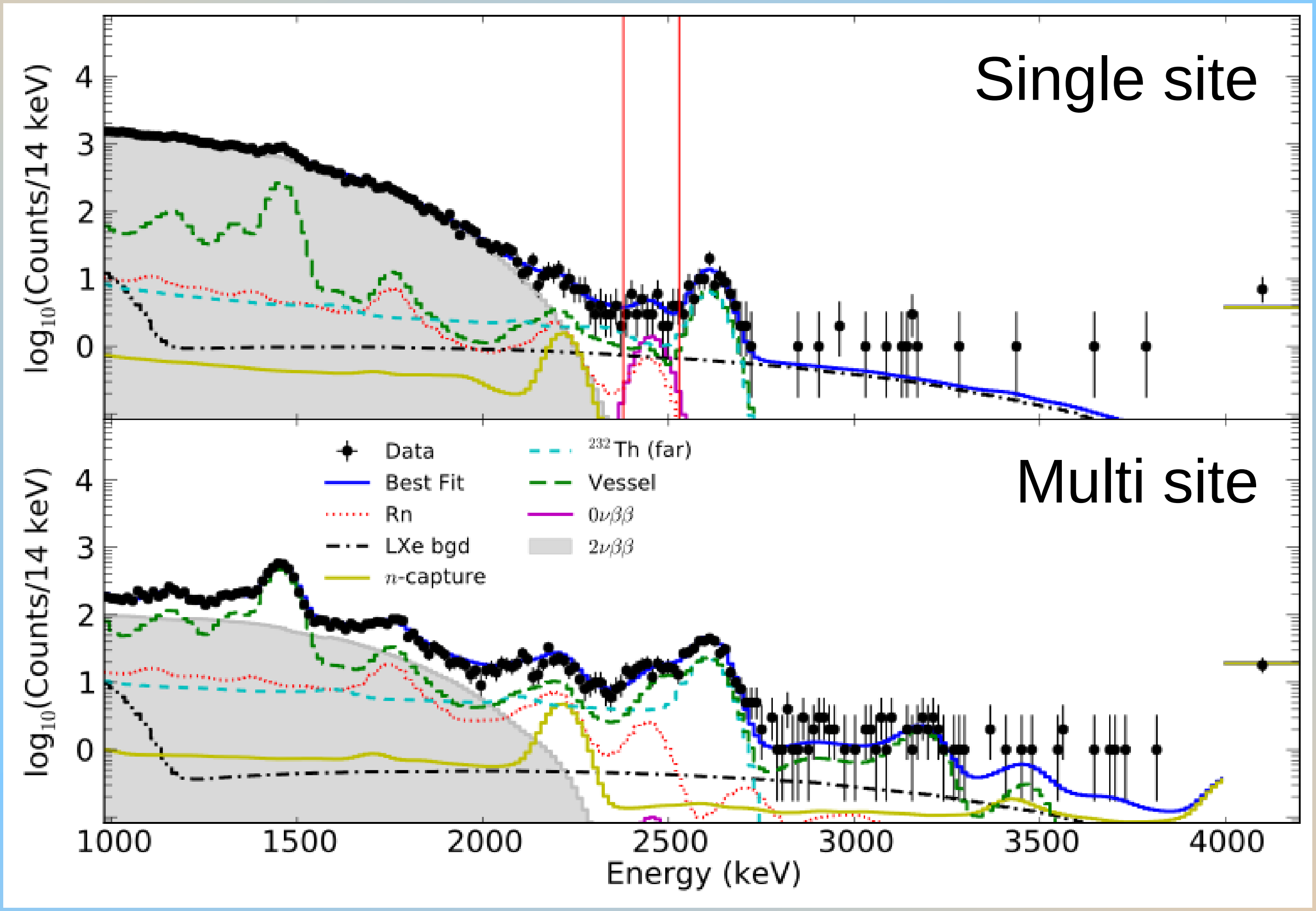
Reanalyzed Run 2a data from (PRL 109, 032505, 2012)

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)]



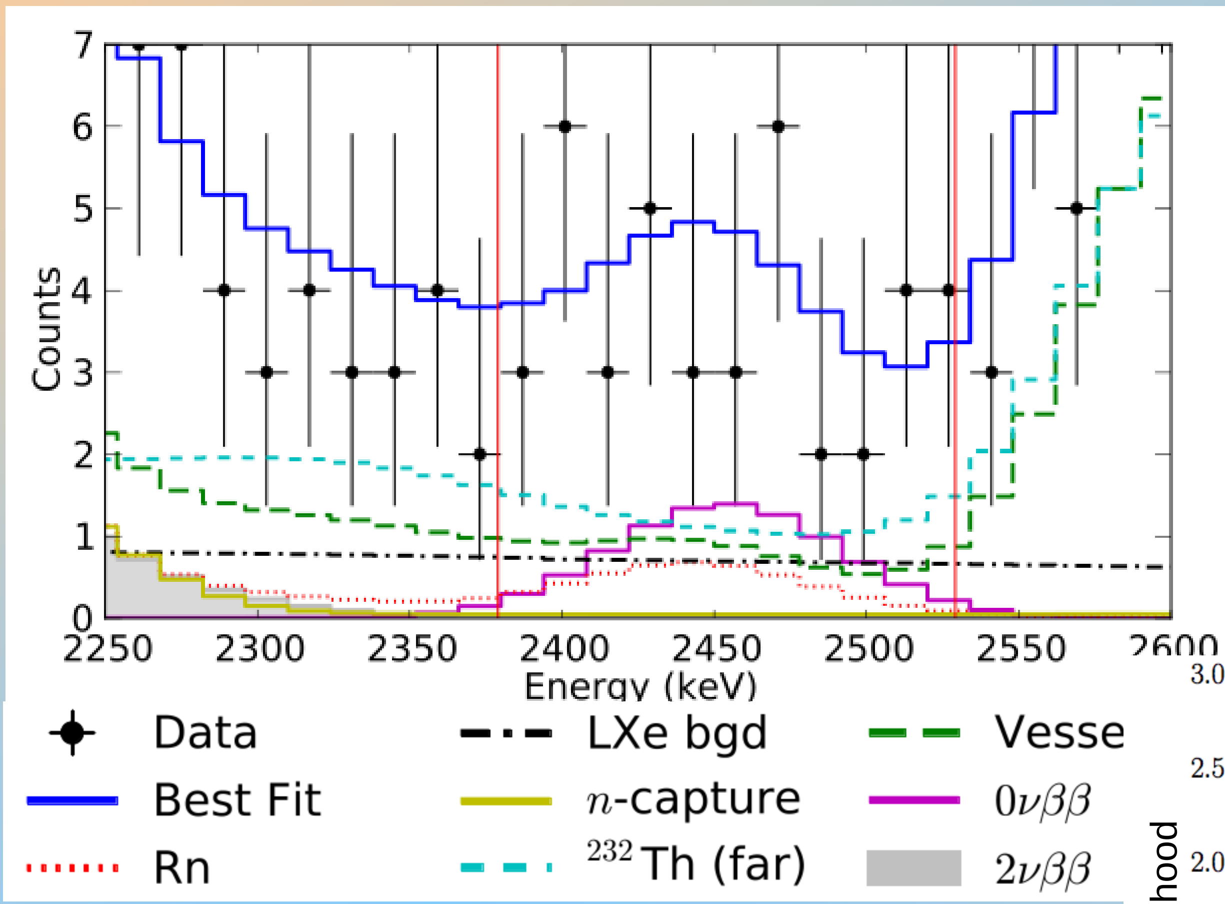
Efficiency to 2β events
- 85 %

Full livetime
- 477.6 d
- 100.0 kg y

2β events
- ~37000

Energy resolution at Q
- 1.53% (SS)
- 1.65% (MS)

2β0ν measurement



Backgrounds in ± 2σ ROI	
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(90% C.L.)

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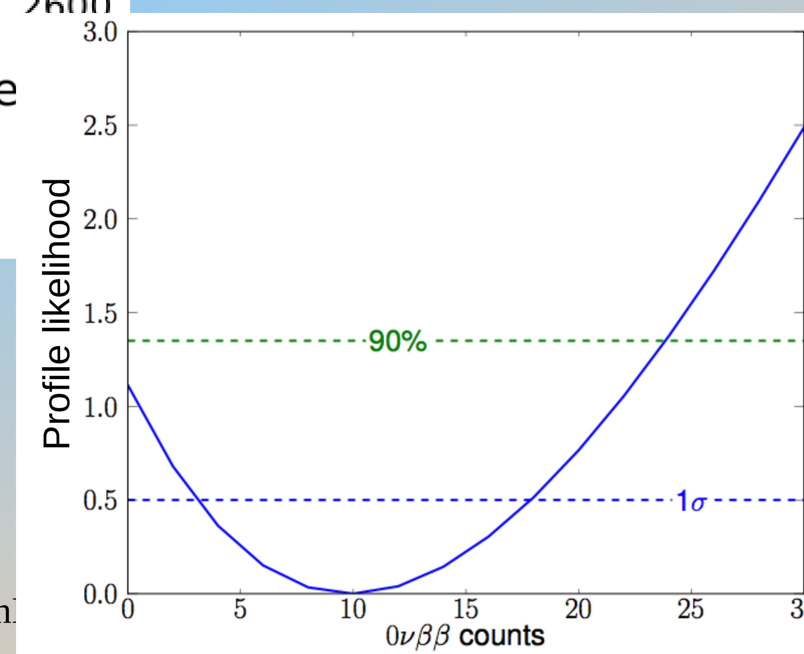
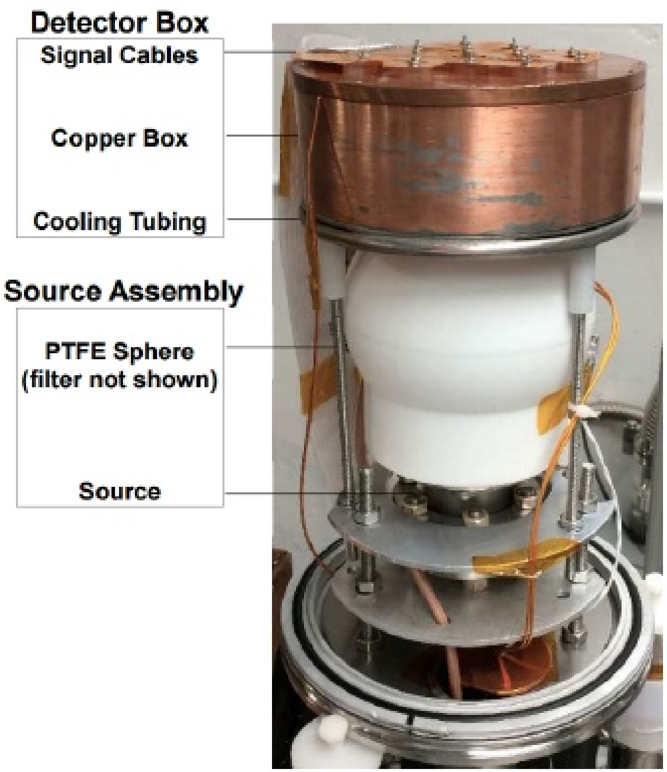


nEXO Photodetectors

- SiPMs of about 1 cm size, mounted on staves that span almost the full length of the TPC.
- The vertical staves line the TPC barrel as a 24-gon.
- Some characterization of the SiPMs has been performed. [2]
- More testing underway:
  - Tests in LXe, in vicinity of HV
  - PDE and reflectivity measurements
  - Large scale integration

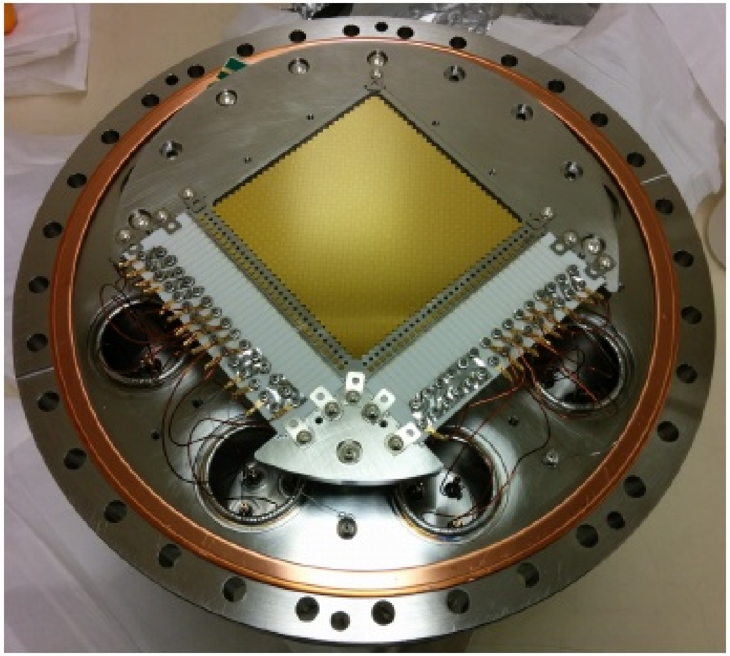
SiPM testing setup

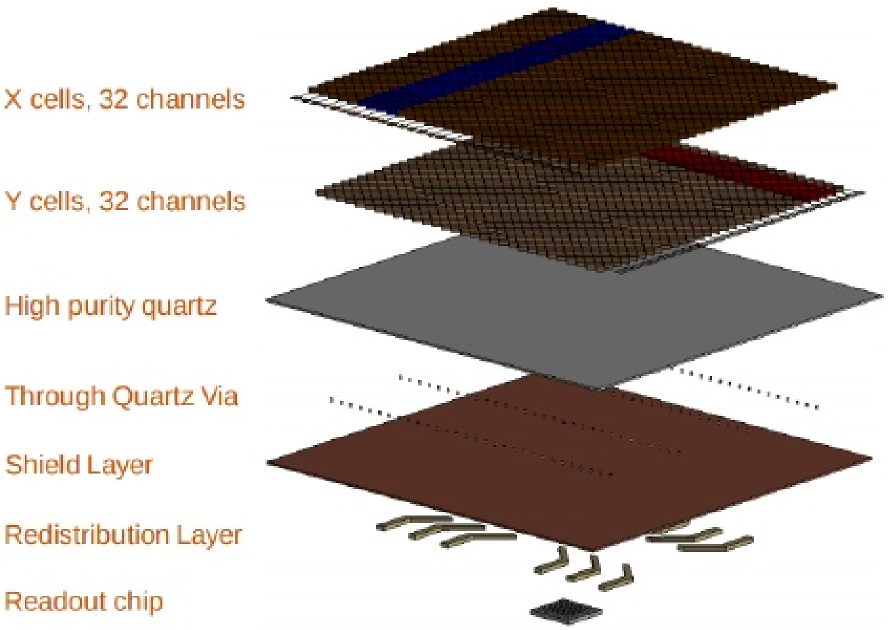


[2] I. Ostrovskiy, IEEE Transactions on Nuclear Science, vol. 62, no. 4, pp. 1825-1836, August 2015

nEXO Charge collection

- Orthogonal, noble-metal strips of 10 cm length on a quartz substrate
- Each strip consists of small metal pads linked diagonally, lying parallel to either the X- or the Y-axis.





In going R&D:

- Improving fabrication process.
- Investigating different readout schemes.
- Integrating with cold electronics.

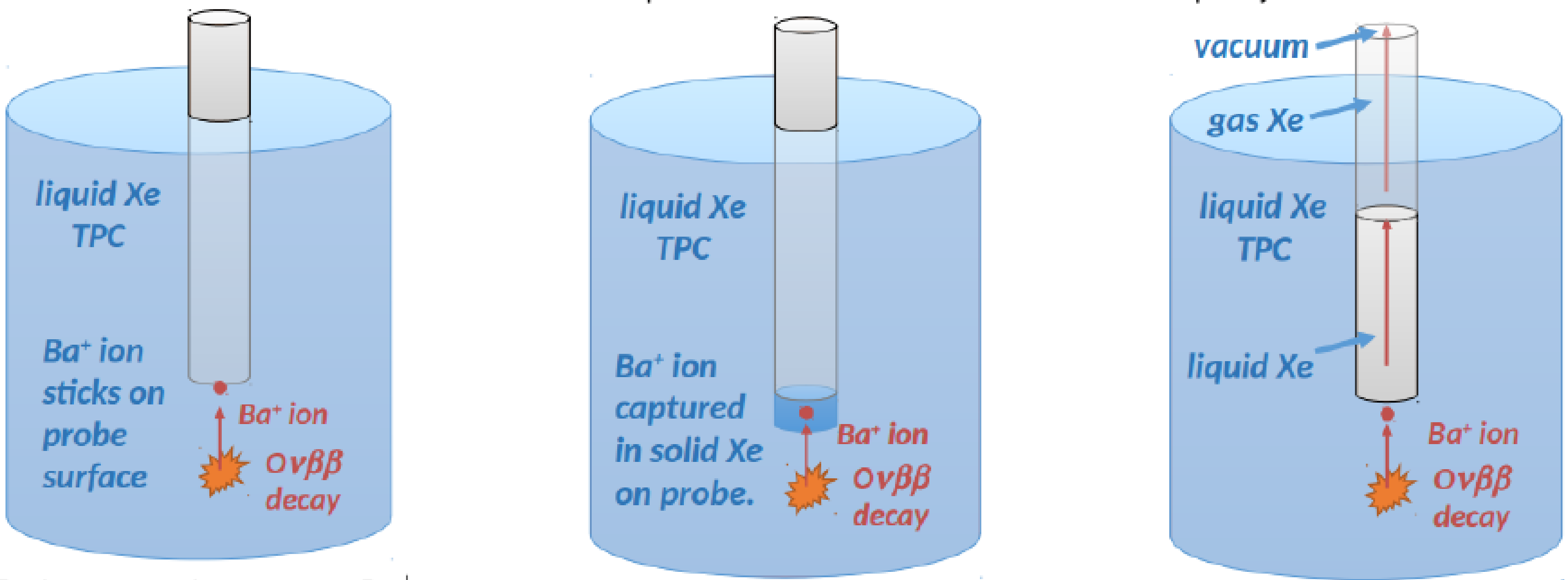
nEXO Barium tagging

Goal of barium tagging:

- Recover and identify xenon decay daughter barium if present
- Suppress background to almost background free

Several concepts are being investigated:

Conducting Probe | Cold probe [3] | Capillary extraction [4]



Probe removed to vacuum; Ba^+ identified by (1) laser ablation/resonance ionization or (2) thermal desorption/ionization

Probe removed to vacuum; Ba/Ba^+ identified laser fluorescence single atom imaging in SXe

Ba^+ "sucked" out of LXe through capillary into ion trap and identified laser fluorescence and MRTOF spectroscopy

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[3] B. Mong et al., "Spectroscopy of Ba and Ba^+ deposits in solid xenon for barium tagging in nEXO", Phys. Rev. A 91, (2015) 022505

[4] T. Brunner et al., "An RF-only ion-funnel for extraction from high-pressure gases", Int J. Mass Spec., 379, 110-120 (2015)