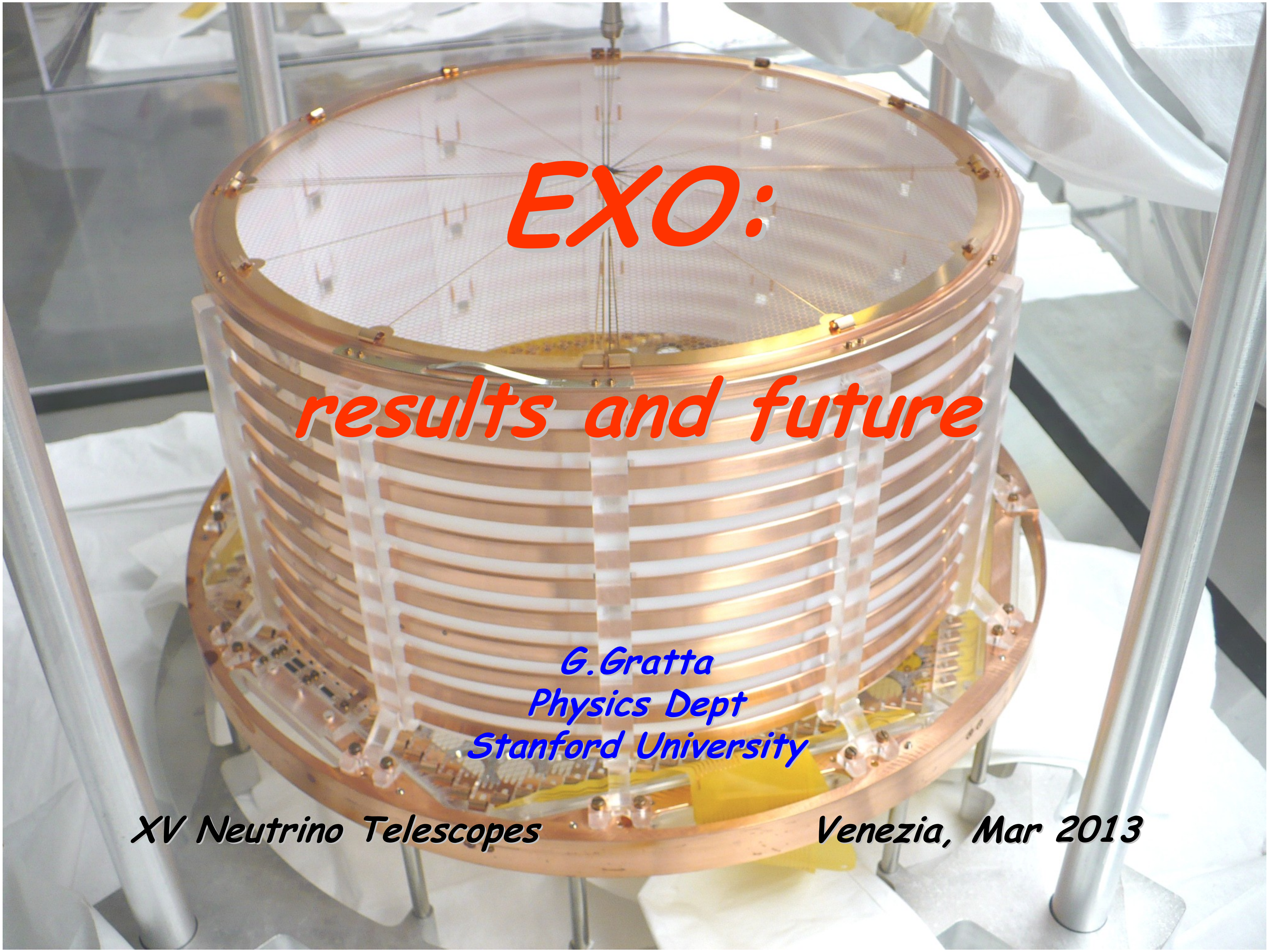


EXO:

results and future

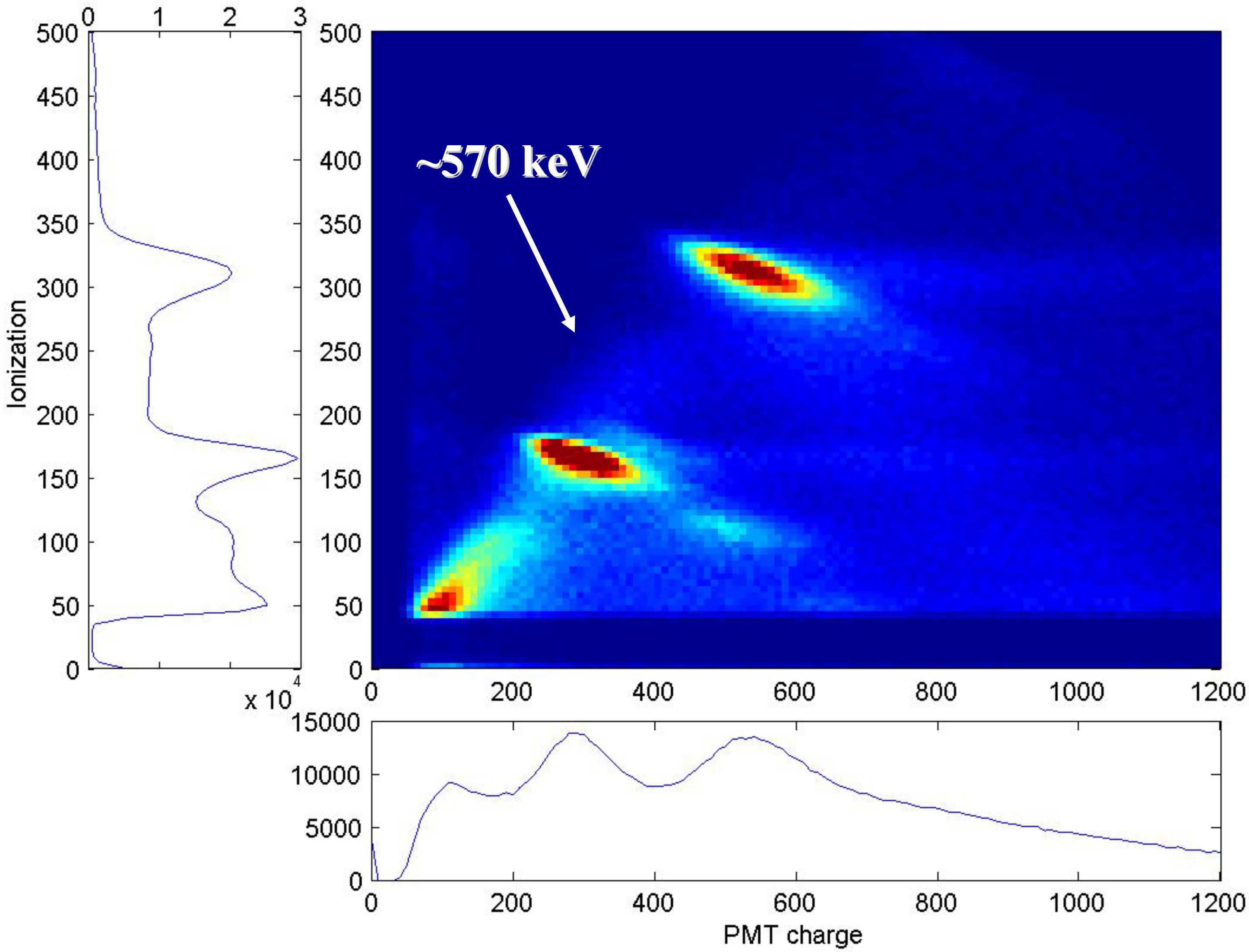
G.Gratta
Physics Dept
Stanford University

XV Neutrino Telescopes Venezia, Mar 2013

Xe is ideal for a large ββ experiment

- No need to grow crystals
- Can be re-purified during the experiment
- No long lived Xe isotopes to activate
- Can be easily transferred from one detector to another if new technologies become available
- Noble gas: easy(er) to purify
- ^{136}Xe enrichment easier and safer:
  - noble gas (no chemistry involved)
  - centrifuge feed rate in gram/s, all mass useful
  - centrifuge efficiency ~ Δm. For Xe 4.7 amu
- Only known case where final state identification appears to be not impossible
  → elominate all non-ββ backgrounds
- ^{129}Xe is a hyperpolarizable nucleus, under study for NMR tomography… a joint enrichment program ?

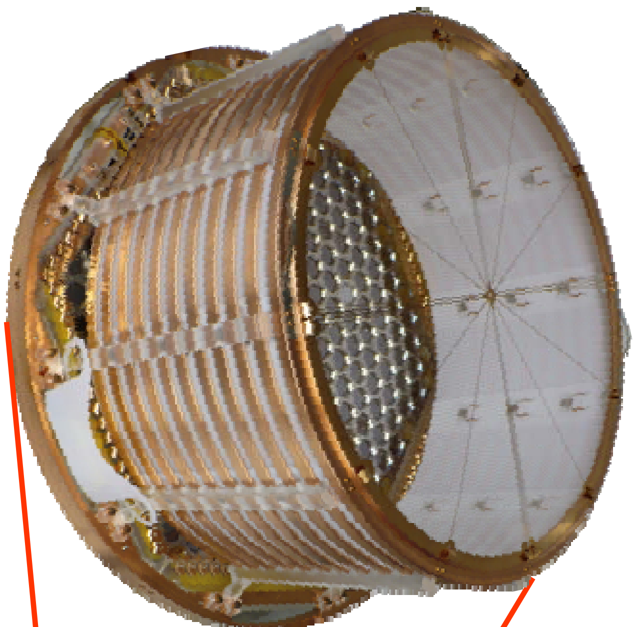
EXO R&D showed the way to improved energy resolution in LXe: *Use (anti)correlations between ionization and scintillation signals*



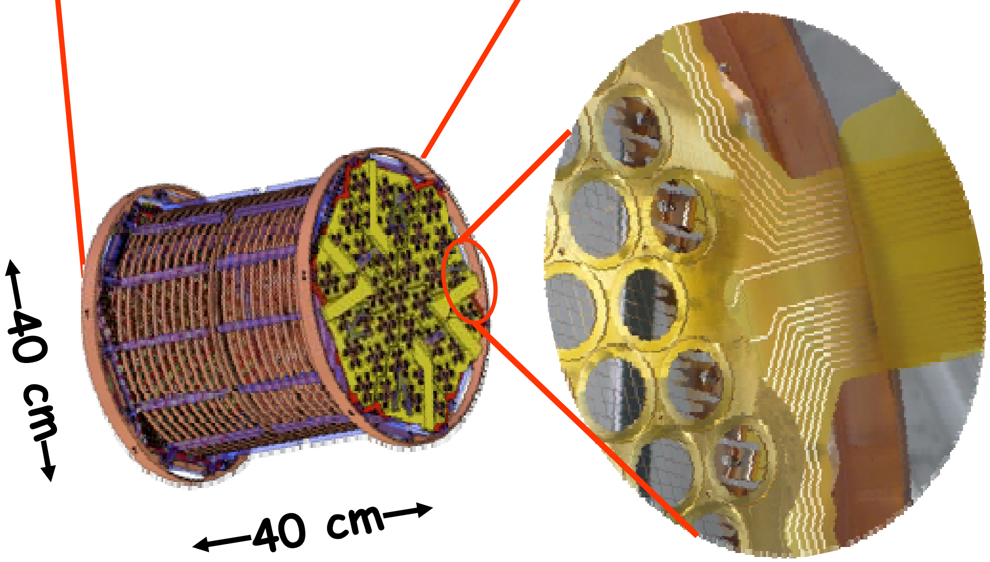
E.Conti et al., Phys Rev B 68 (2003) 054201

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, at 60° (induction)
- 234 large Avalanche PhotoDiodes (in gangs of 7)
- Triplet pitch 9 mm
- Wire planes 6 mm apart and 6 mm from APDs
- Signals digitized at 1 MS/s, ±1024s around trigger
- Drift field 376 V/cm



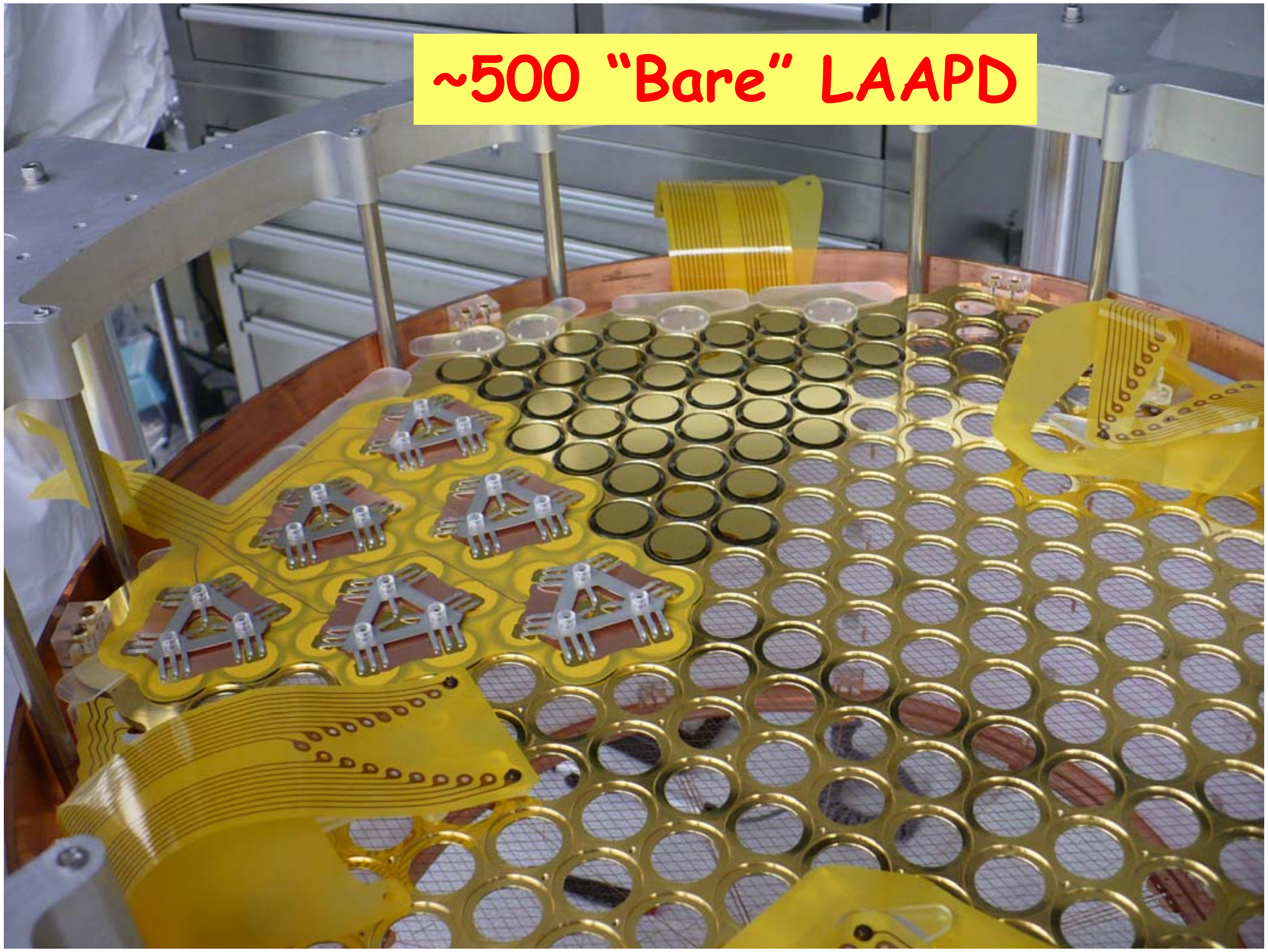
- Field shaping rings: copper
- Supports: acrylic
- Light reflectors/diffusers: Teflon
- APD support plane: copper; Au (Al) coated for contact (light reflection)
- Central cathode, U+V wires: photo-etched phosphor bronze
- Flex cables for bias/readout: copper on kapton, no glue
- Vast material screening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

Ultra-low activity Cu vessel

- Very light (~1.5mm thin, ~15kg) to minimize materials

- Different parts e-beam welded together
- Field TIG weld(s) to seal the vessel after assembly (TIG technology tested for radioactivity)
- All machining done at a shallow underground site

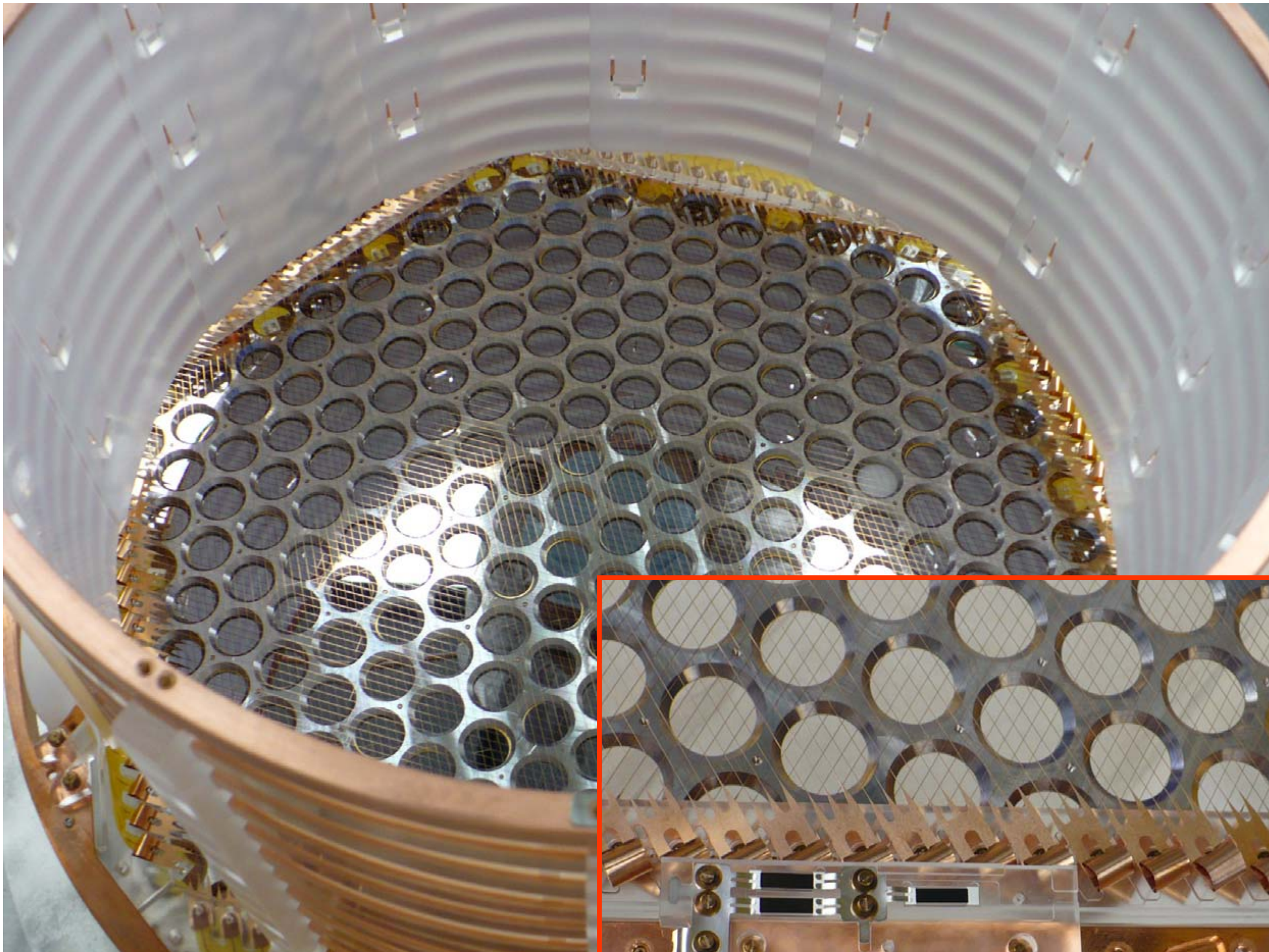
R. Neilson, et al. NIM A 608 (2009) 6875

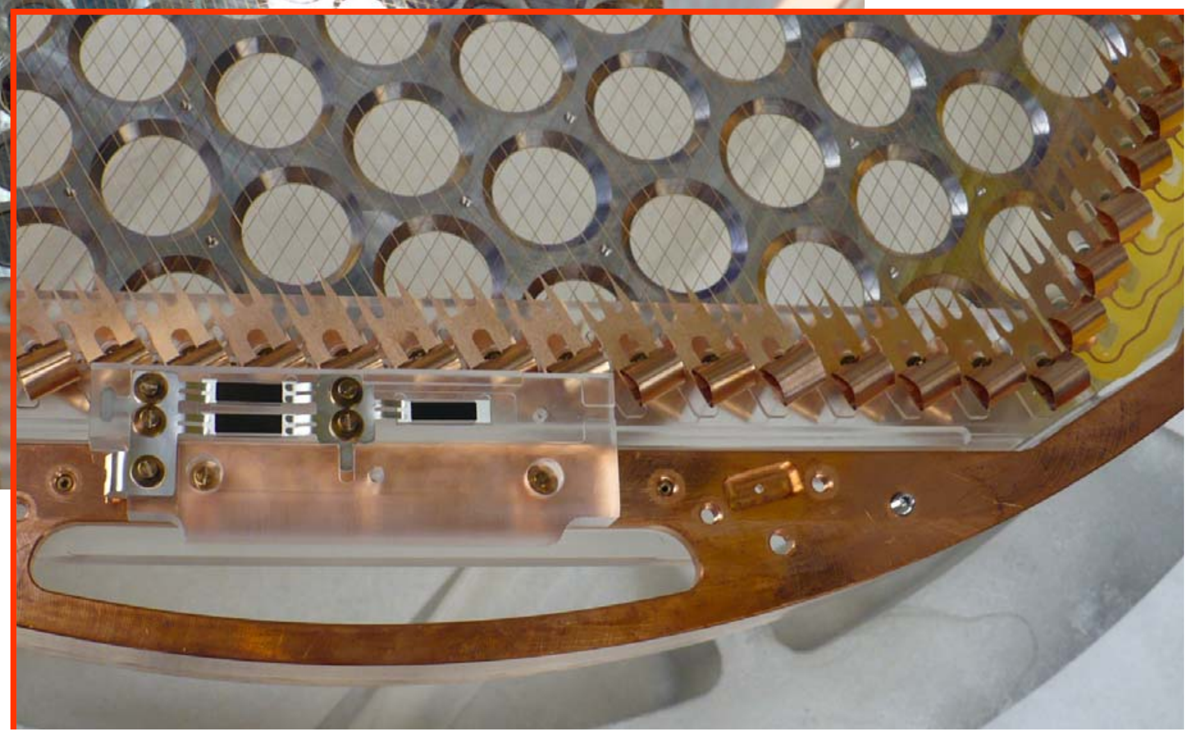


APDs are ideal for our application:
- very clean & light-weight,
- very sensitive to VUV

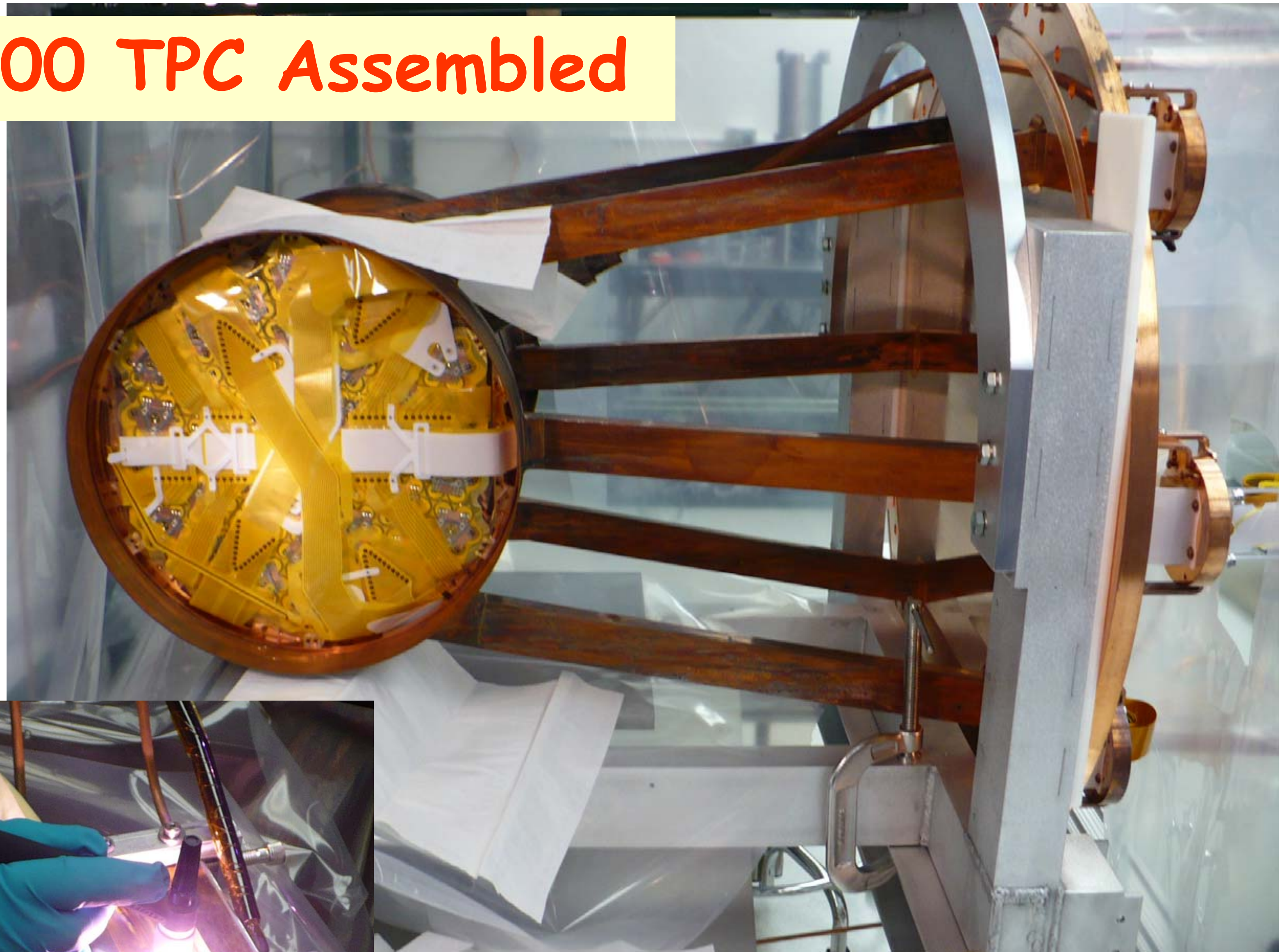
QE > 1 at 175nm

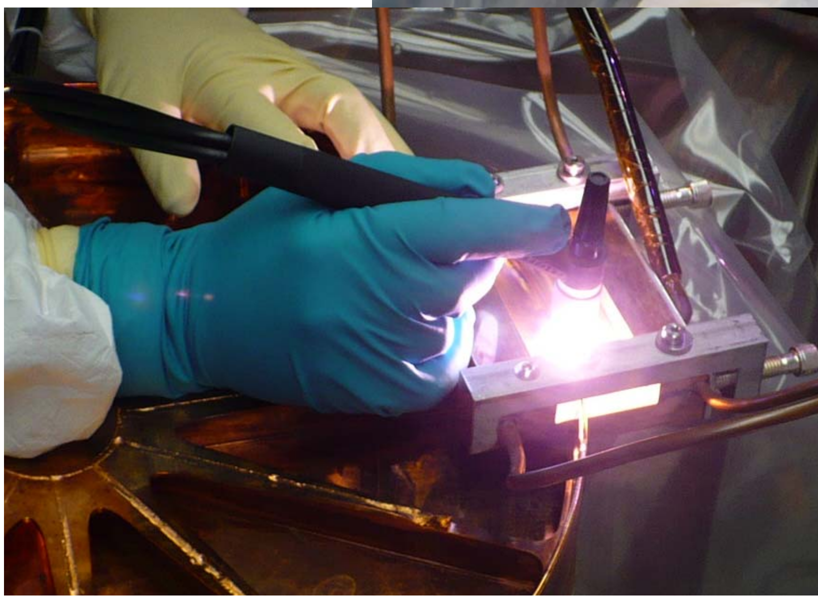
Gain set at ~200
V~1500V
ΔV < ±0.5V
ΔT < ±1K   APD is the driver for temperature stability
Leakage current OK cold



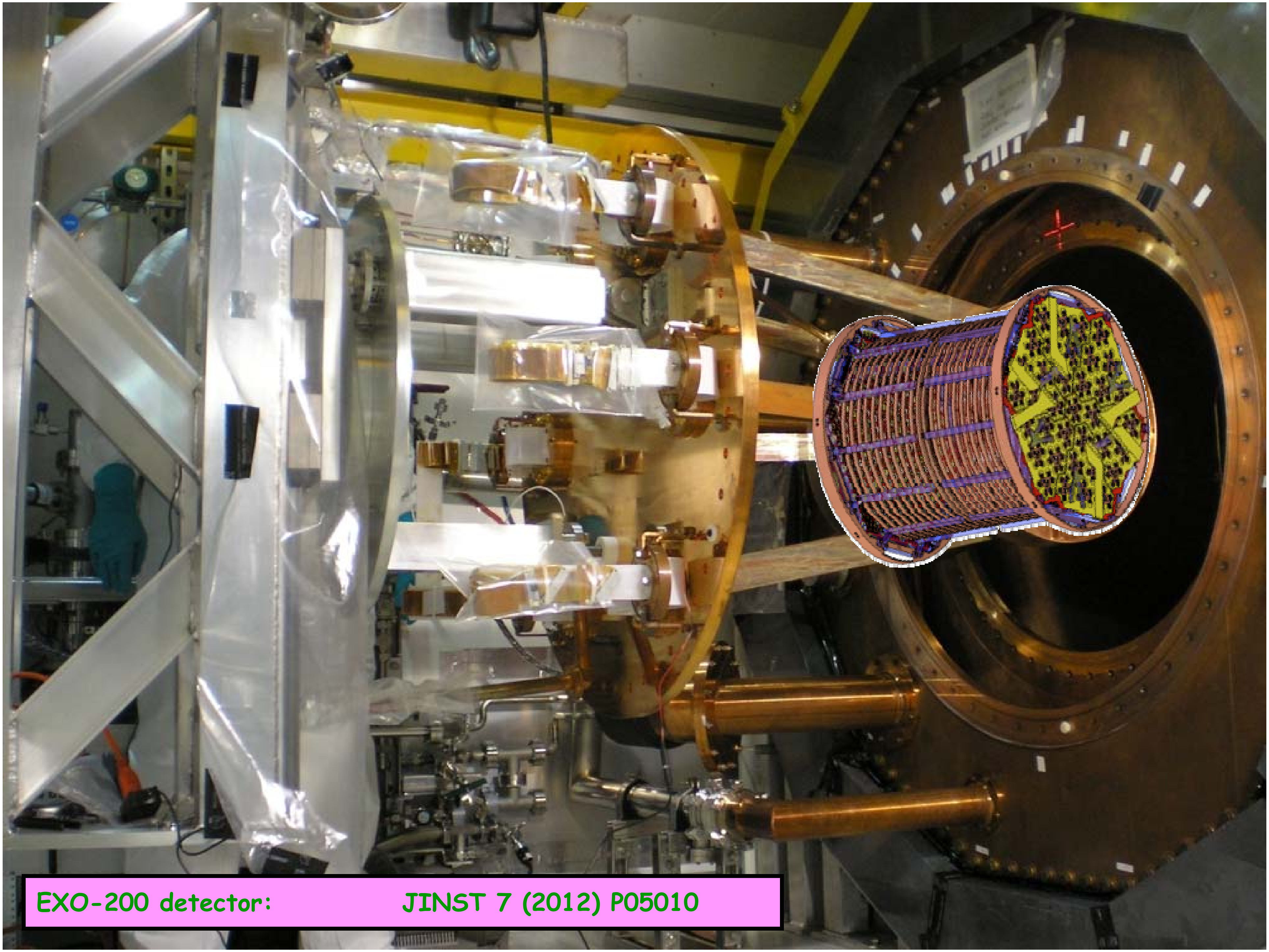


EXO-200 TPC Assembled





...and welded shut



EXO-200 detector: JINST 7 (2012) P05010

Massive effort on material radioactive qualification using:

- NAA
- Low background γ-spectroscopy
- α-counting
- Radon counting
- High performance GD-MS and ICP-MS

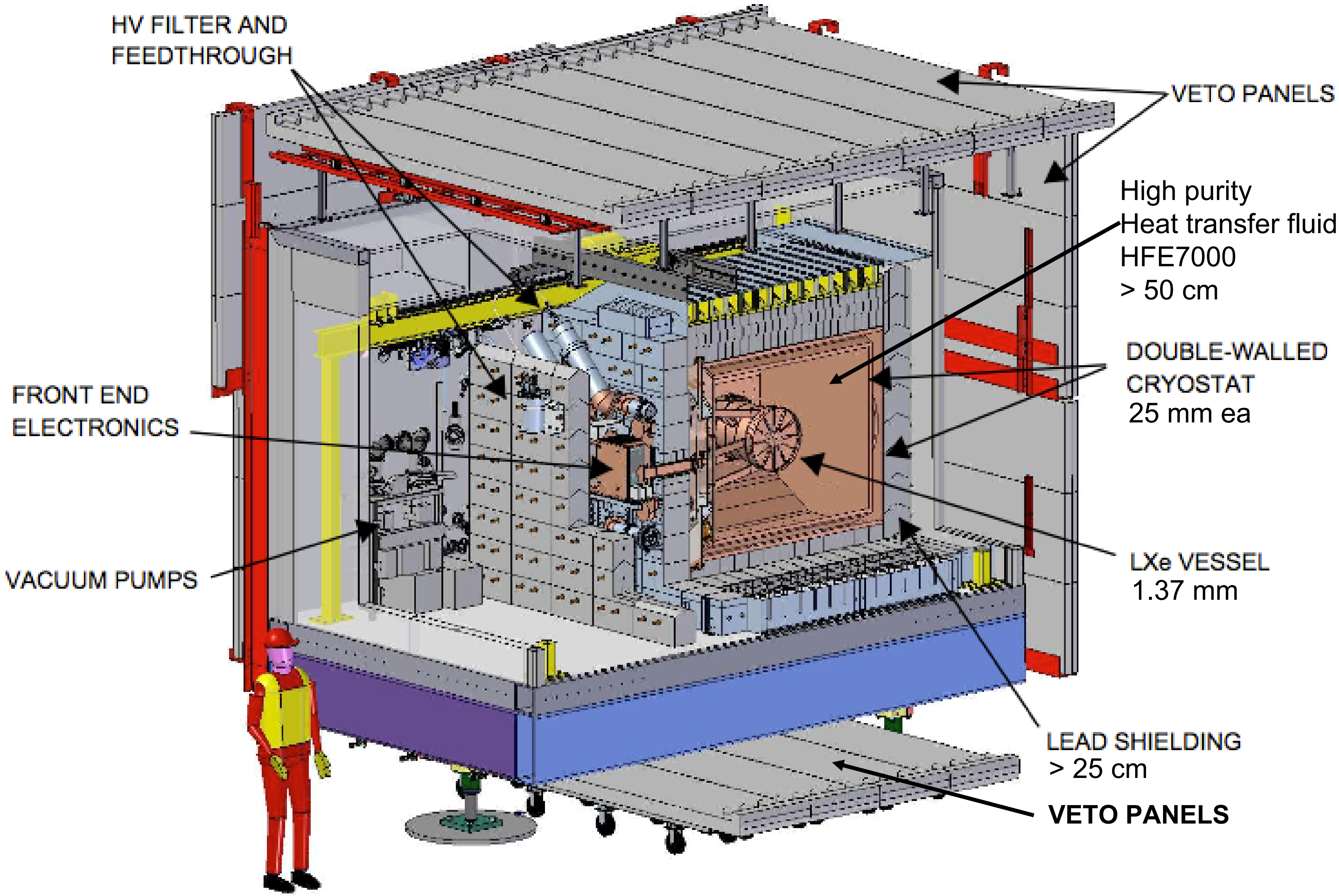
At present the database of characterized materials includes >300 entries

D.S. Leonard et al., Nucl. Ins. Meth. A 591, 490 (2008)

The impact of every screw within the Pb shielding was evaluated before acceptance

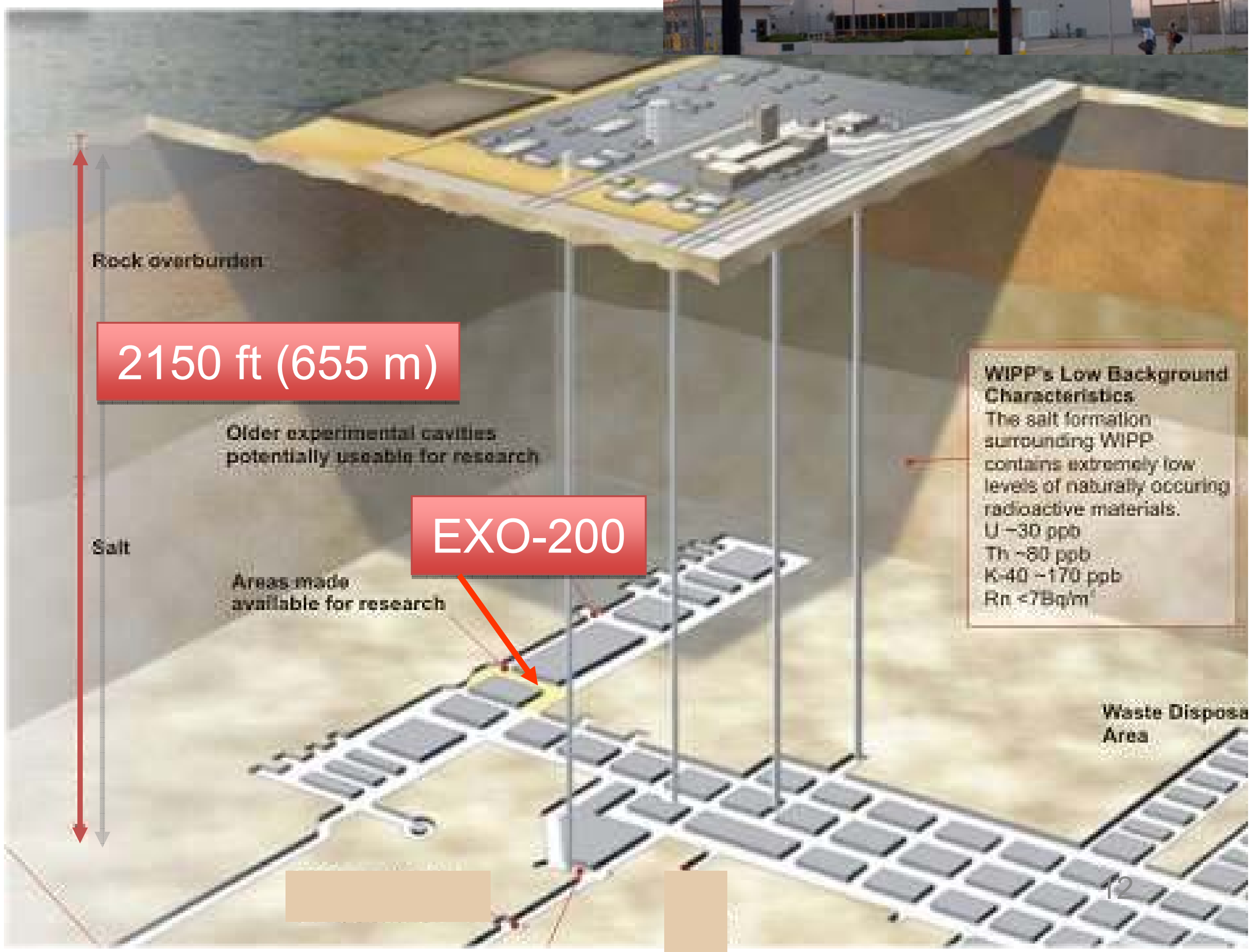
→ Goal: 40 cnts/2yr in the $0\nu\beta\beta$ $\pm 2\sigma$ ROI in 140kg of LXe

The EXO-200 Detector



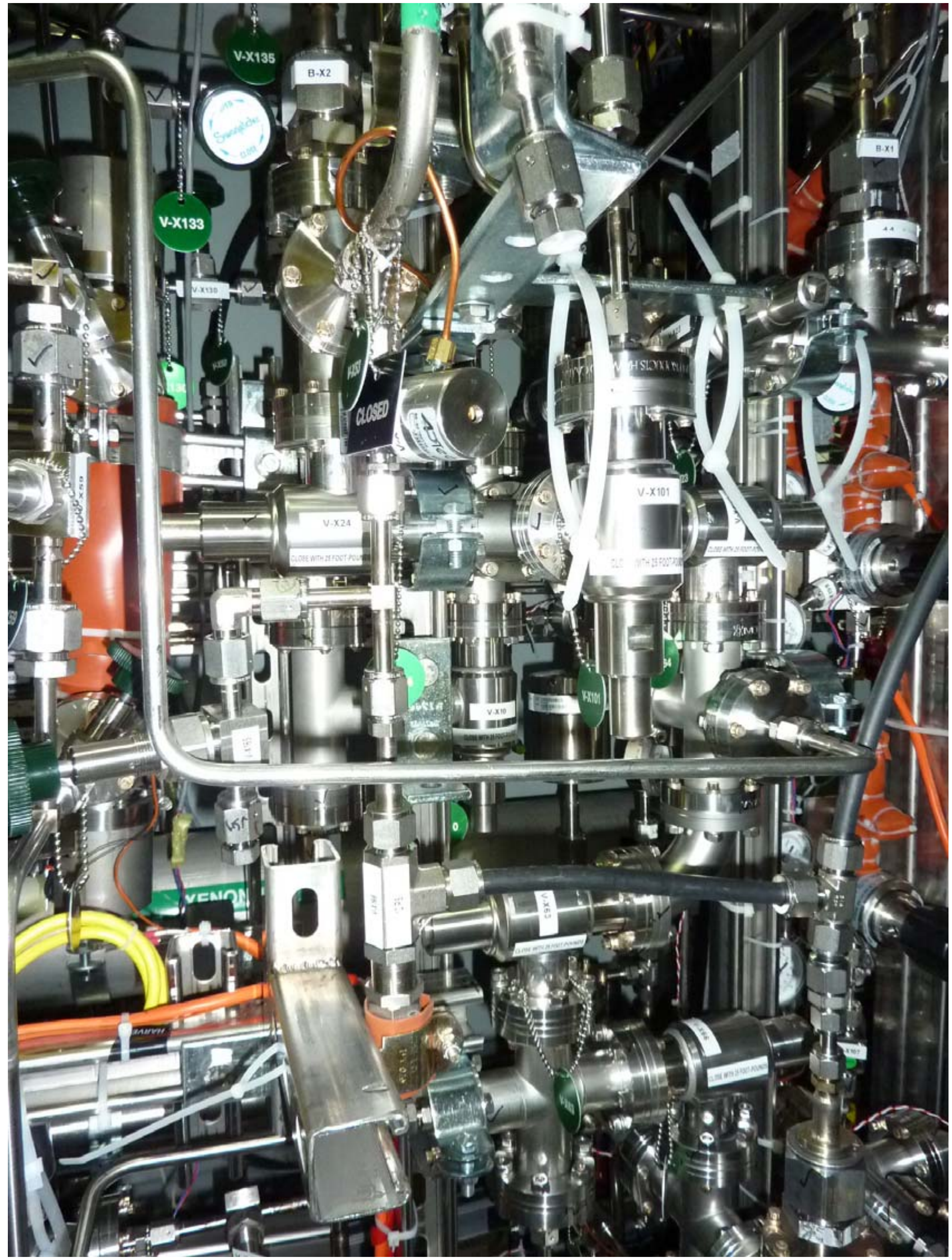
Underground location:
Waste Isolation Pilot Plant (WIPP) Carlsbad, NM

- ~1600 meter water equivalent flat overburden
- Relatively low levels of U and Th (<100 ppb in EXO-200 drift)
- Low levels of Rn (~20 Bq/m^3)
- Rather convenient access with large conveyance



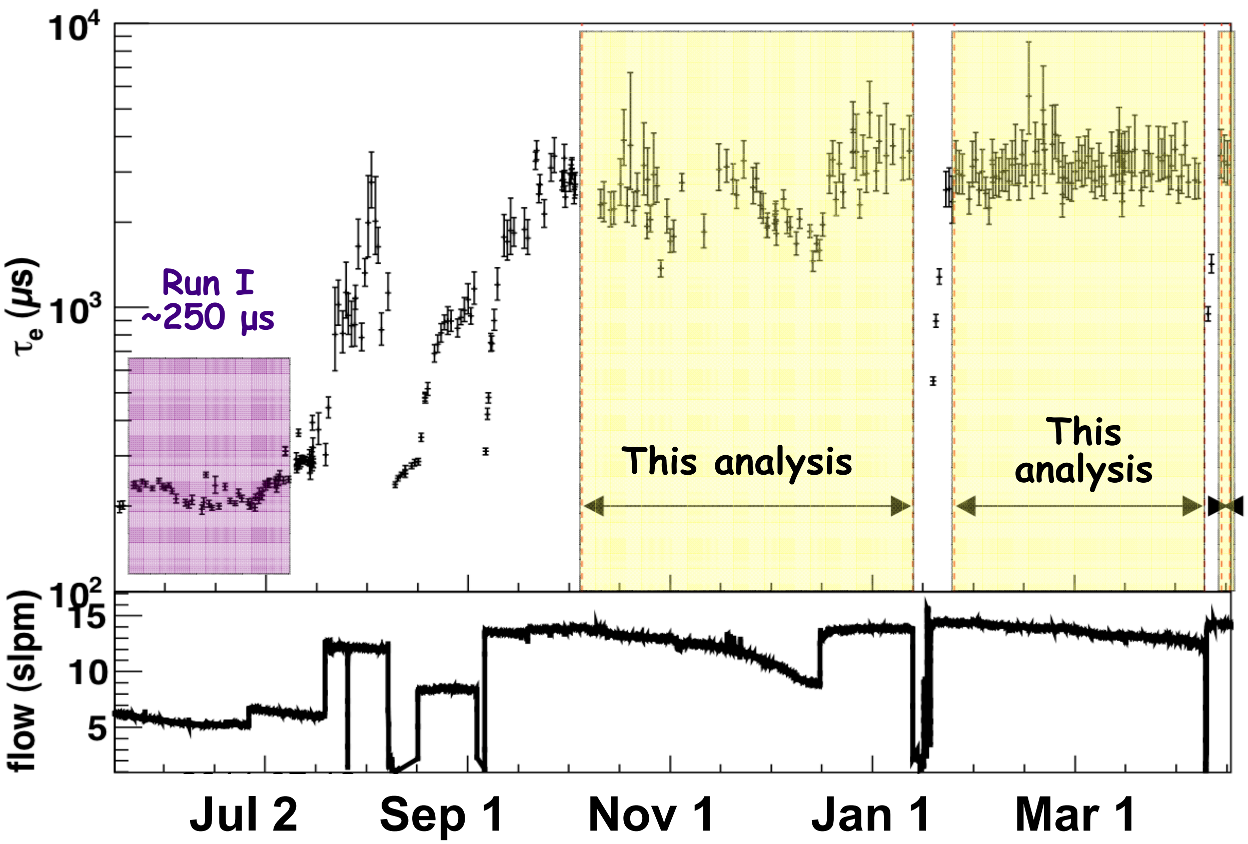
A substantial system is required to

- protect the 1.5mm thin LXe container from pressure
- recirculate Xe in gas phase to purify it
- fill/empty the detector
- manage emergencies



Data taking phases and Xenon Purity

	Run I	Run 2 (this analysis)
Period	May 21, 11 – Jul 9, 11	Sep 22, 11 – Apr 15,12
Live Time	752.7 hr	2,896.6 hr
Exposure	3.2 kg-yr	32.5 kg-yr
Publ.	PRL 107 (2011) 212501	arXiv:1205:5608 (May 2012)



Xenon gas is forced through heated Zr getter by a custom ultraclean pump.

Electron lifetime τ_e:
→ measure ionization signal attenuation as a function of drift time for the full-absorption peak of γ ray sources

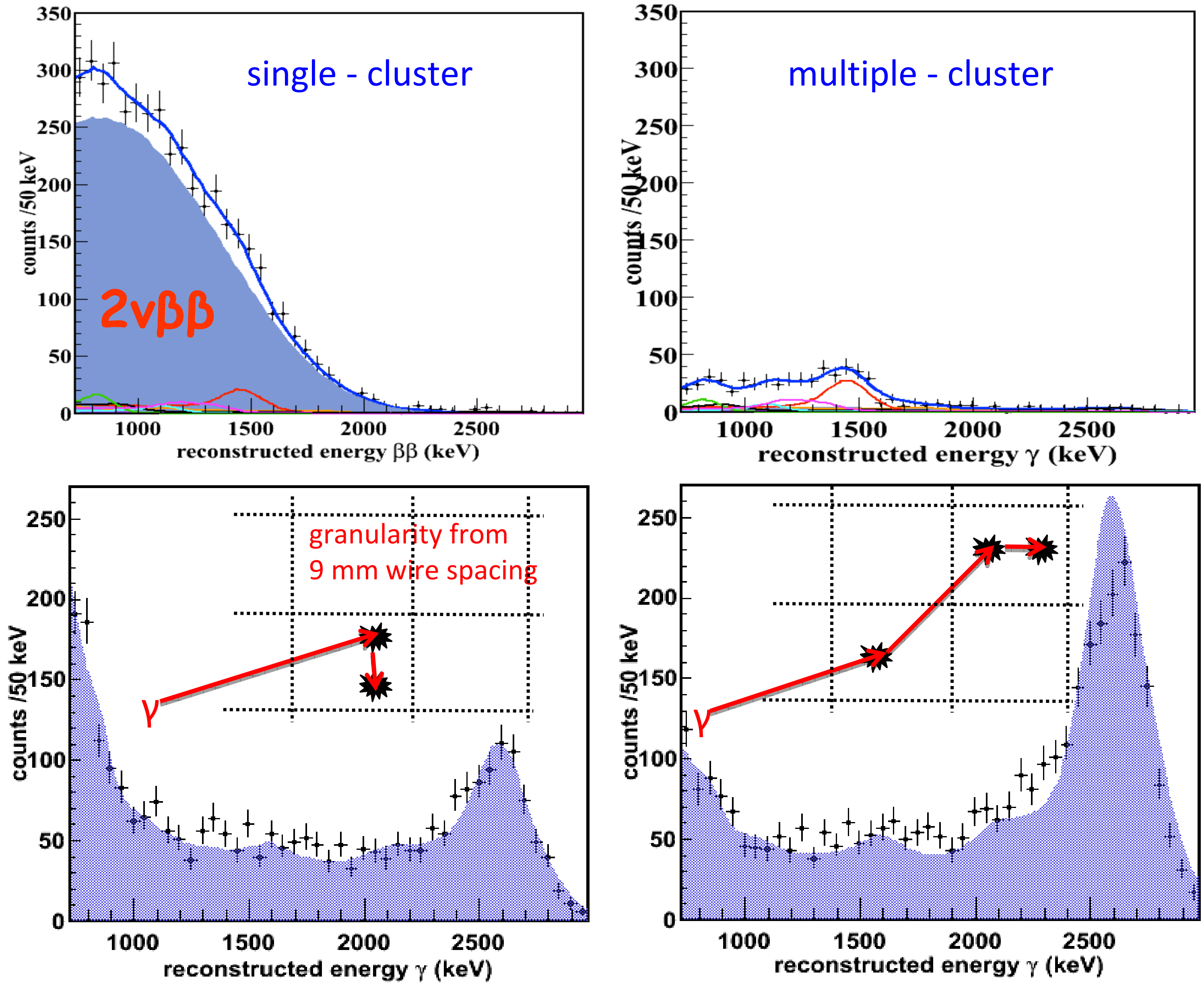
At τ_e = 3 ms:
- drift time <110 μs
- loss of charge: 3.6% at full drift length

Ultraclean pump:
Rev Sci Instr. 82 (10) 105114
Xenon purity with mass spec:
NIM A675 (2012) 40
Gas purity monitors:
NIM A659 (2011) 215

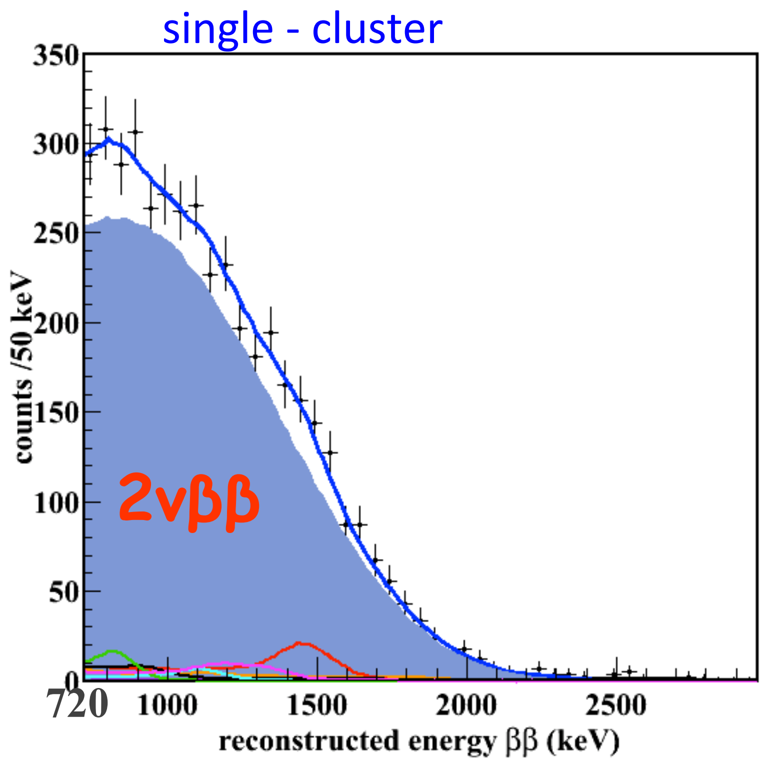
Pattern is a very powerful tool against background

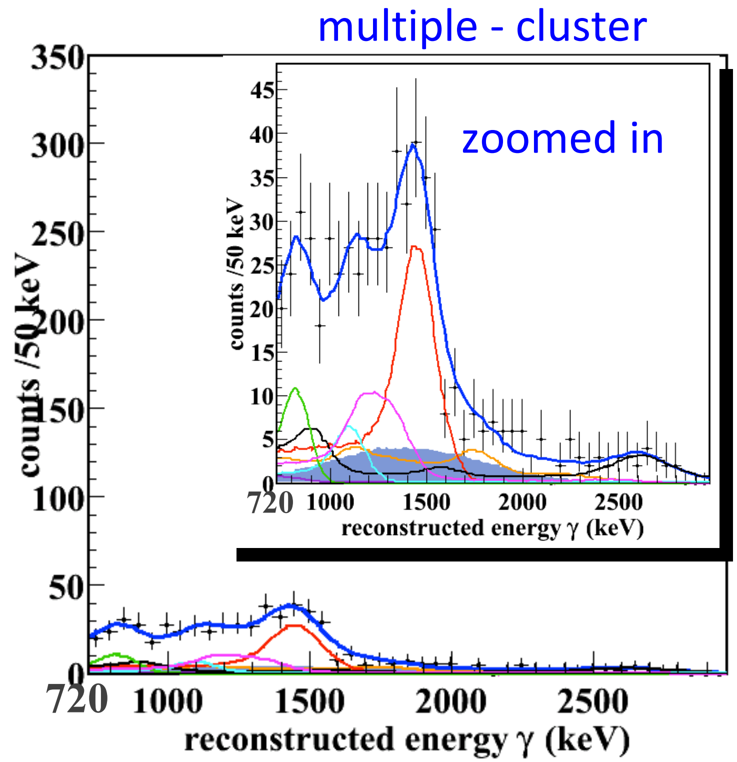
Low background data

^{228}Th calibration source



First observation of the 2νββ decay in ^{136}Xe

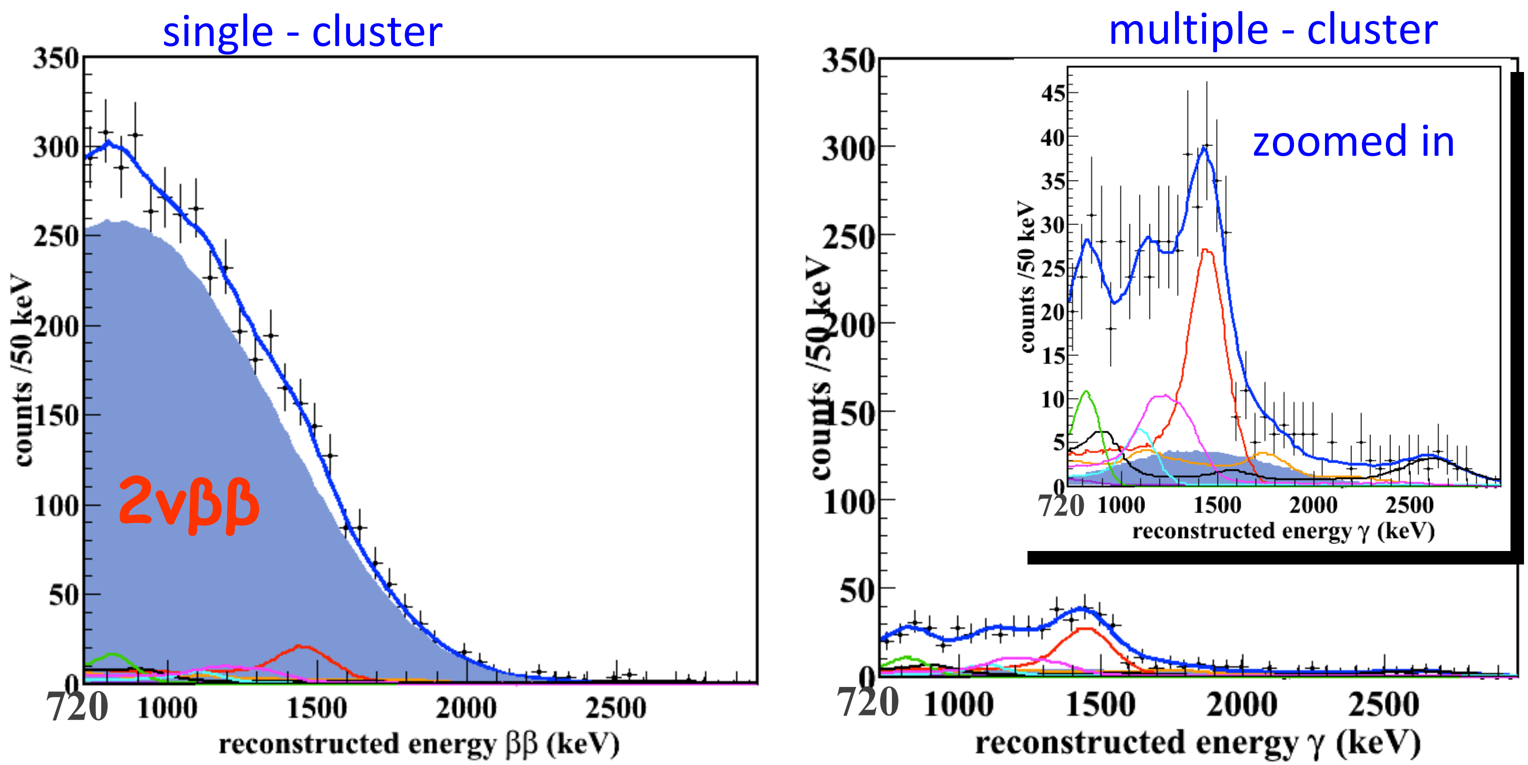




$T_{1/2} = (2.11 \pm 0.04 \text{ stat} \pm 0.21 \text{ sys}) \cdot 10^{21}$ yr

[Ackerman et al Phys Rev Lett 107 (2001) 212501]

First observation of the 2νββ decay in ^{136}Xe



$T_{1/2}$ = (2.11 ± 0.04 stat ± 0.21 sys) · 10^{21} yr

[Ackerman et al Phys Rev Lett 107 (2001) 212501]

In significant disagreement with previous limits:

$T_{1/2}$ > $1.0 \cdot 10^{22}$ yr (90% C.L.) (R. Bernabei *et al.* Phys. Lett. B 546 (2002) 23)

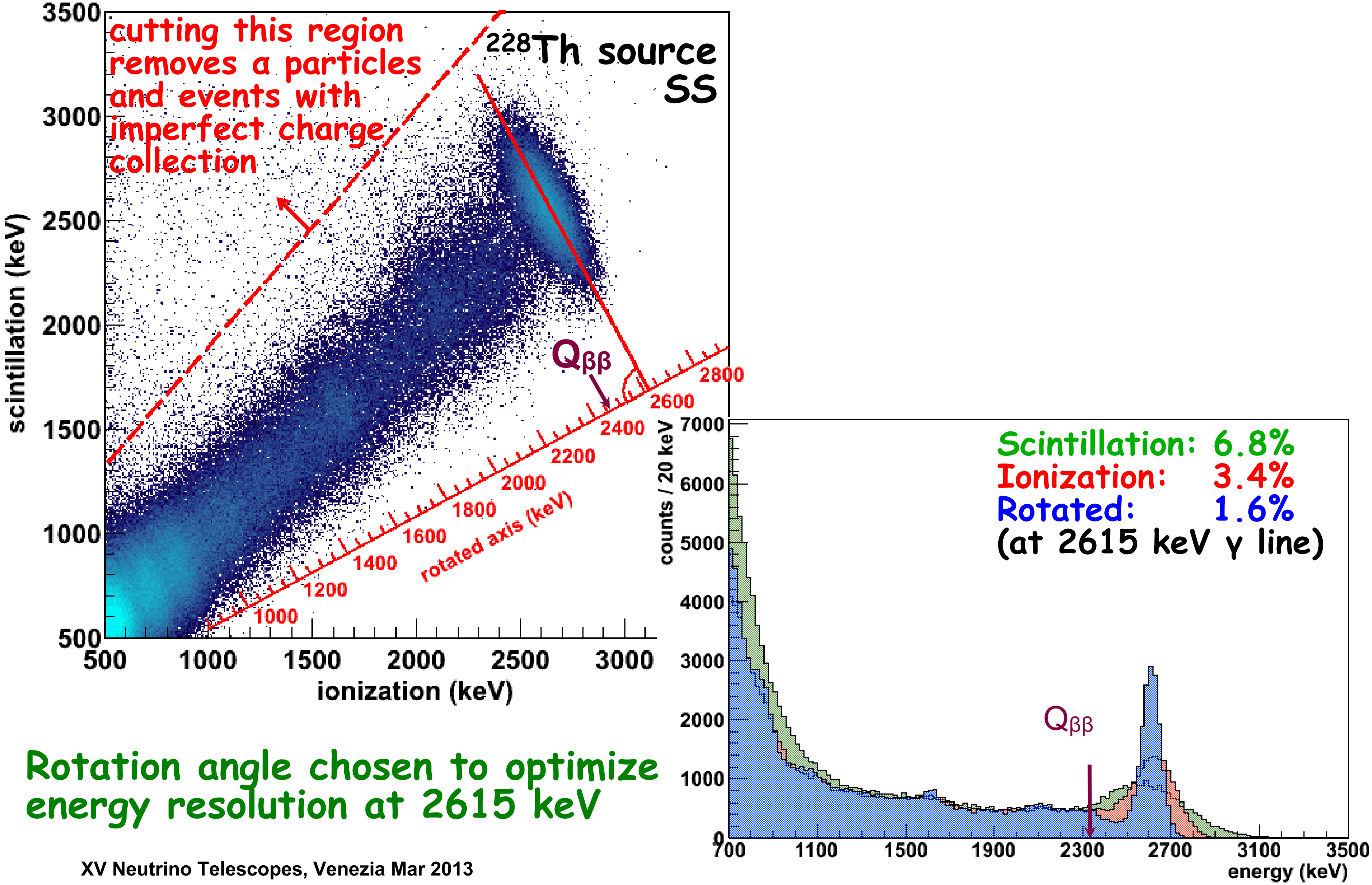
$T_{1/2}$ > $8.5 \cdot 10^{21}$ yr (90% C.L.) (Yu. M. Gavriljuk *et al.*, Phys. Atom. Nucl. 69 (2006) 2129)

Later confirmed by KamLAND-ZEN

$T_{1/2}$=(2.38 ± 0.02stat ± 0.14sys)·10^{21} yr

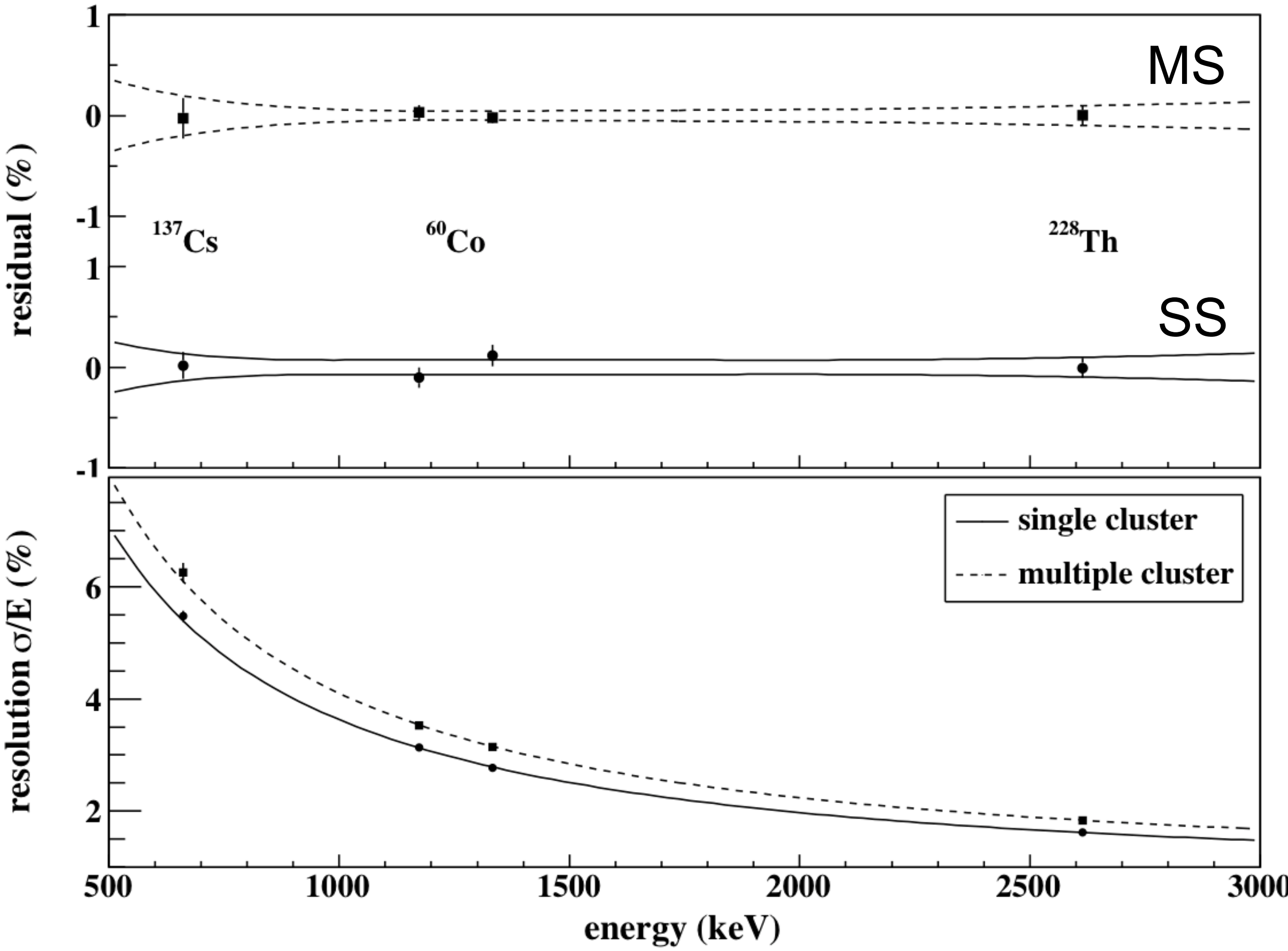
[A.Gando et al. Phys Rev C 85 (2012) 045504]

Combining Ionization and Scintillation



Rotation angle chosen to optimize energy resolution at 2615 keV

Energy Calibration



Energy resolution model:

$$\sigma_{tot}^2 = p_0^2 E + p_1^2 + p_2^2 E^2$$

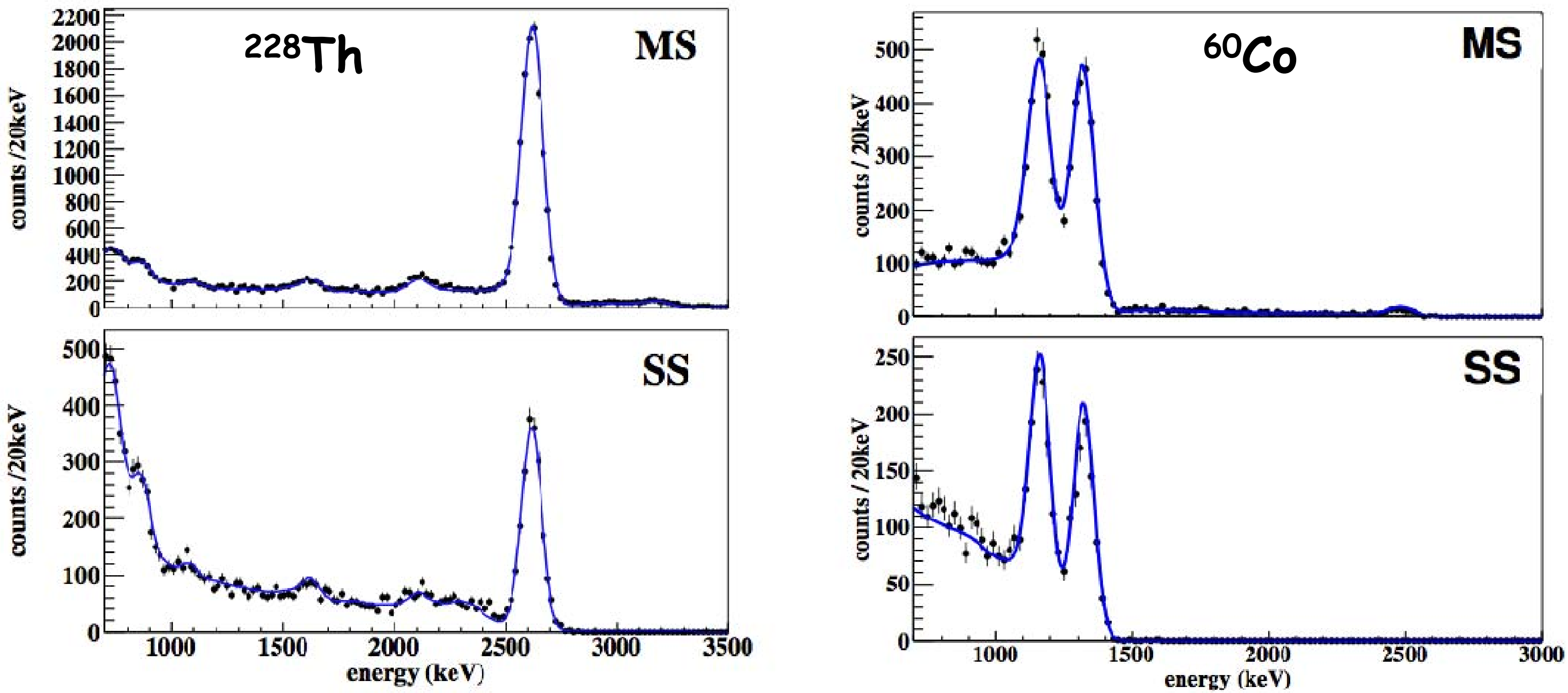
Residuals <0.1%

Resolution dominated by constant (noise) term p_1

At $Q_{\beta\beta}$ (2458 keV):

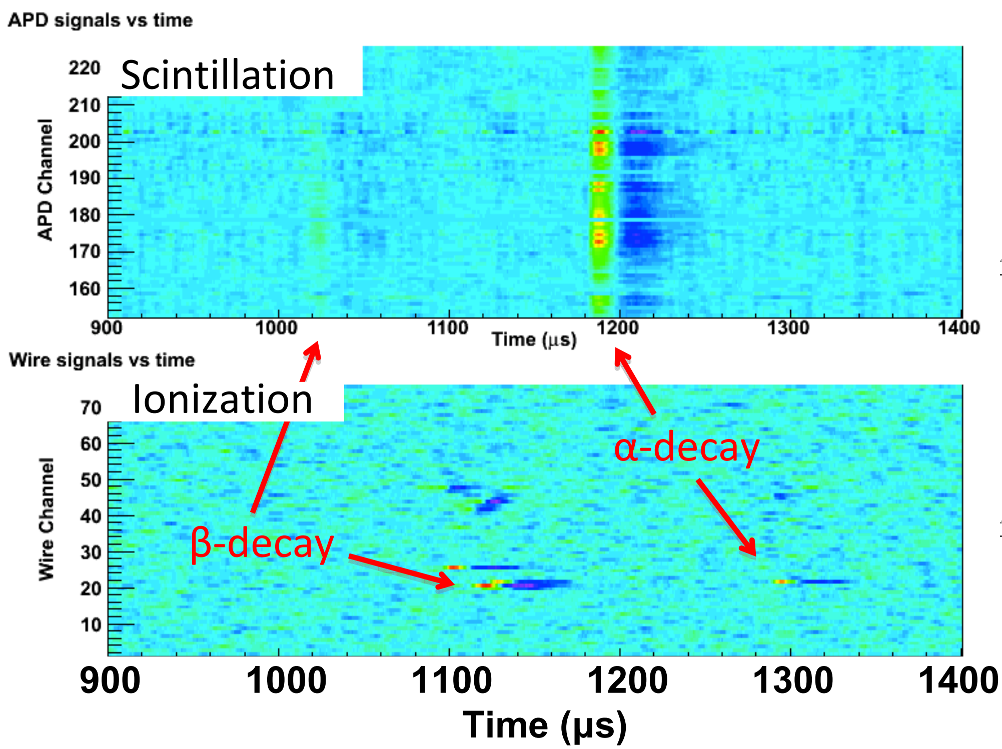
σ/E = 1.67 % (SS)
σ/E = 1.84 % (MS)

Source Data/MC Agreement

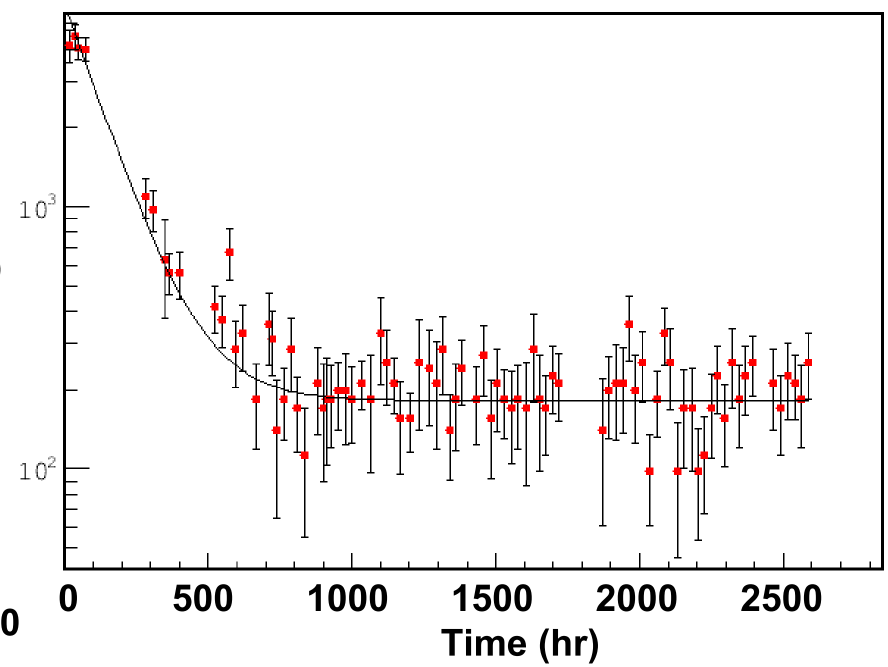


- Single site fraction agrees to within 8.5%
- Source activities measured to within 9.4%

Rn Content in Xenon



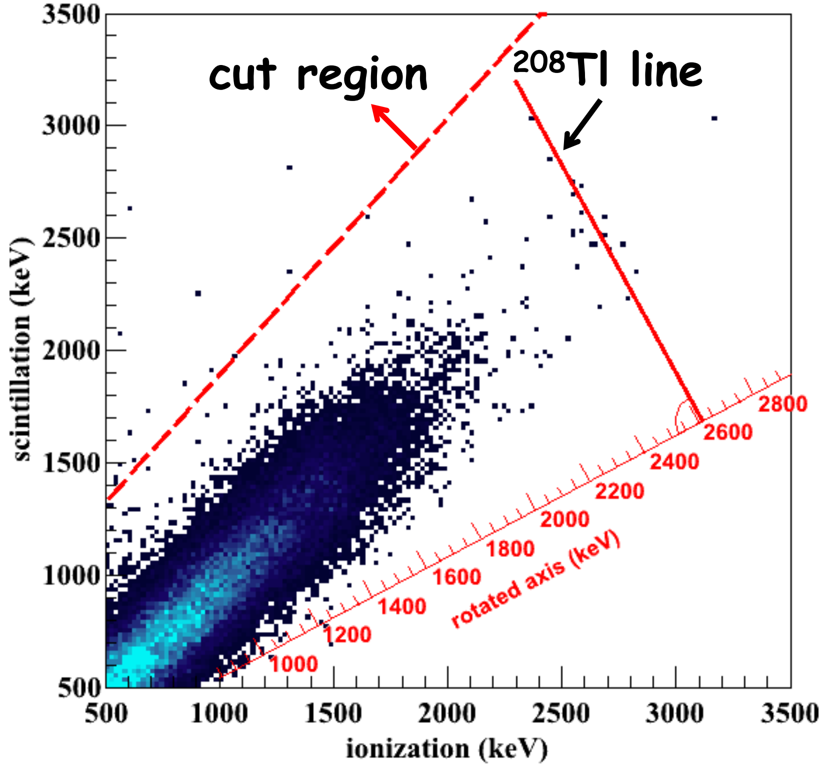
^{214}Bi – ^{214}Po correlations in the EXO-200 detector

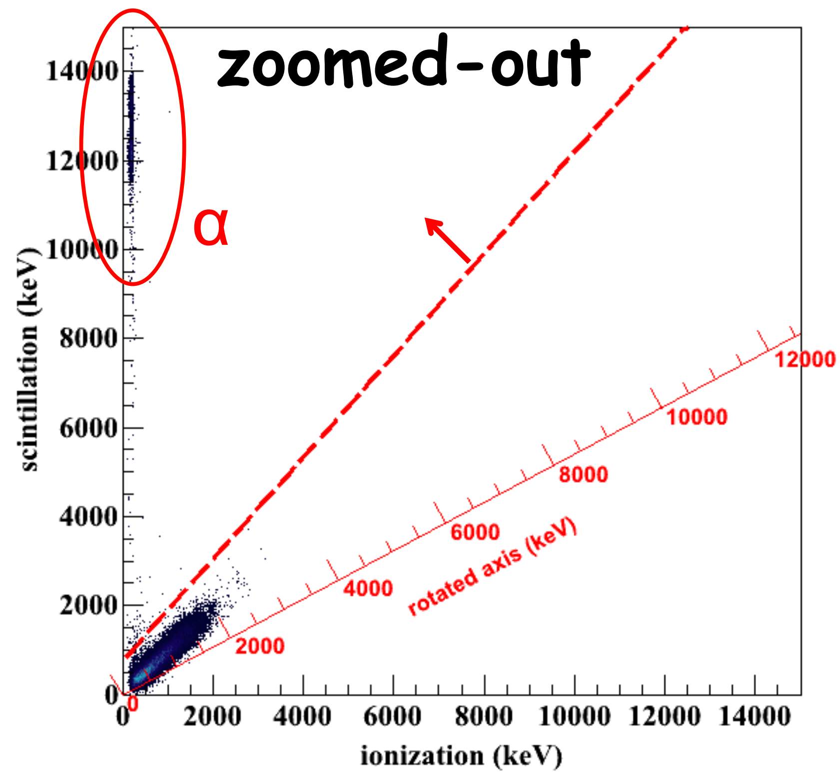


Total ^{222}Rn in LXe after initial fill

Long-term study shows a constant source of ^{222}Rn dissolving in ^{enr}LXe: 360 ± 65 μBq (Fid. vol.)

Low Background 2D SS Spectrum

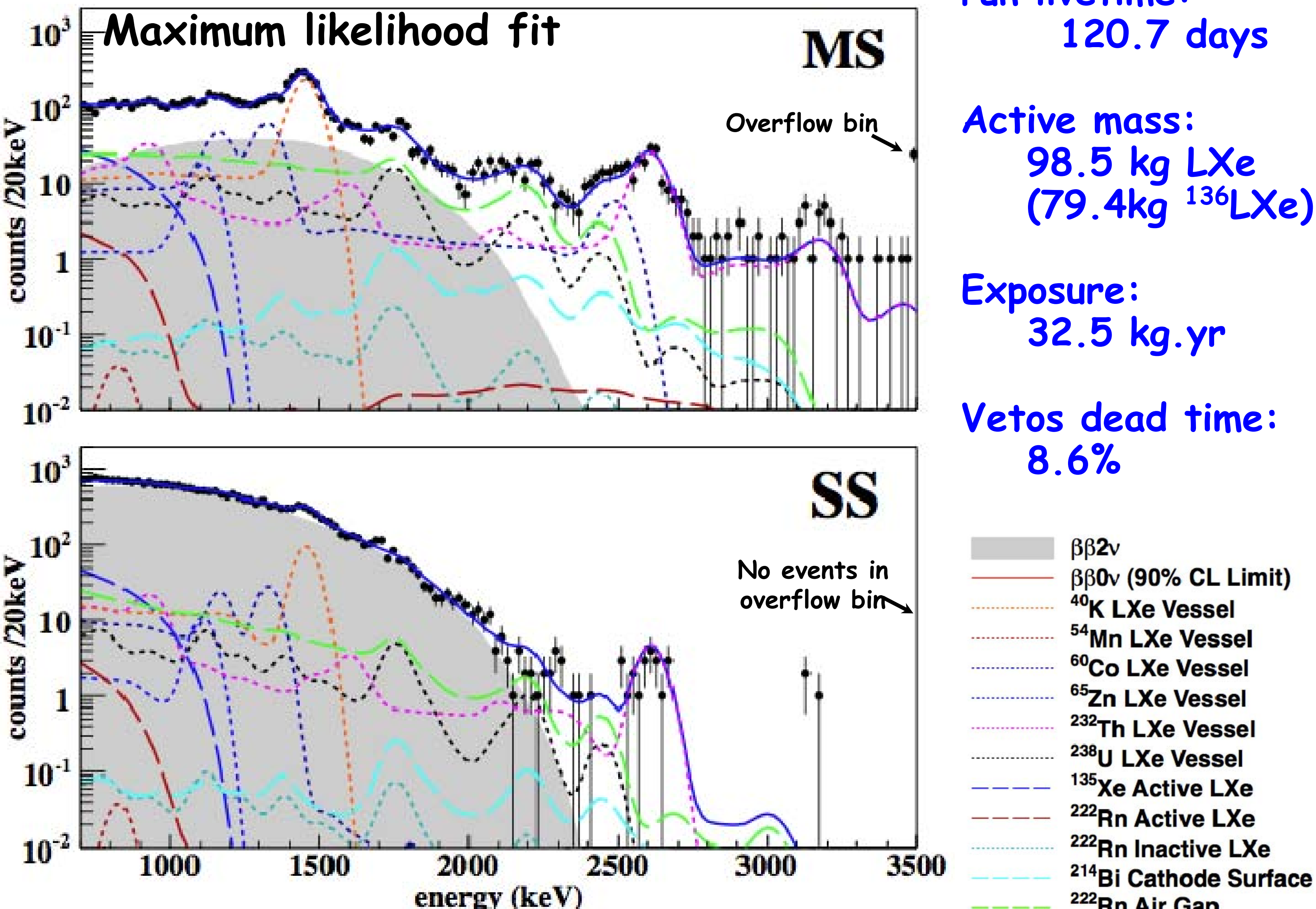




Events removed by diagonal cut:

- α (larger ionization density → more recombination → more scintillation light)
- events near detector edge → not all charge is collected

Run 2 Low Background Spectrum

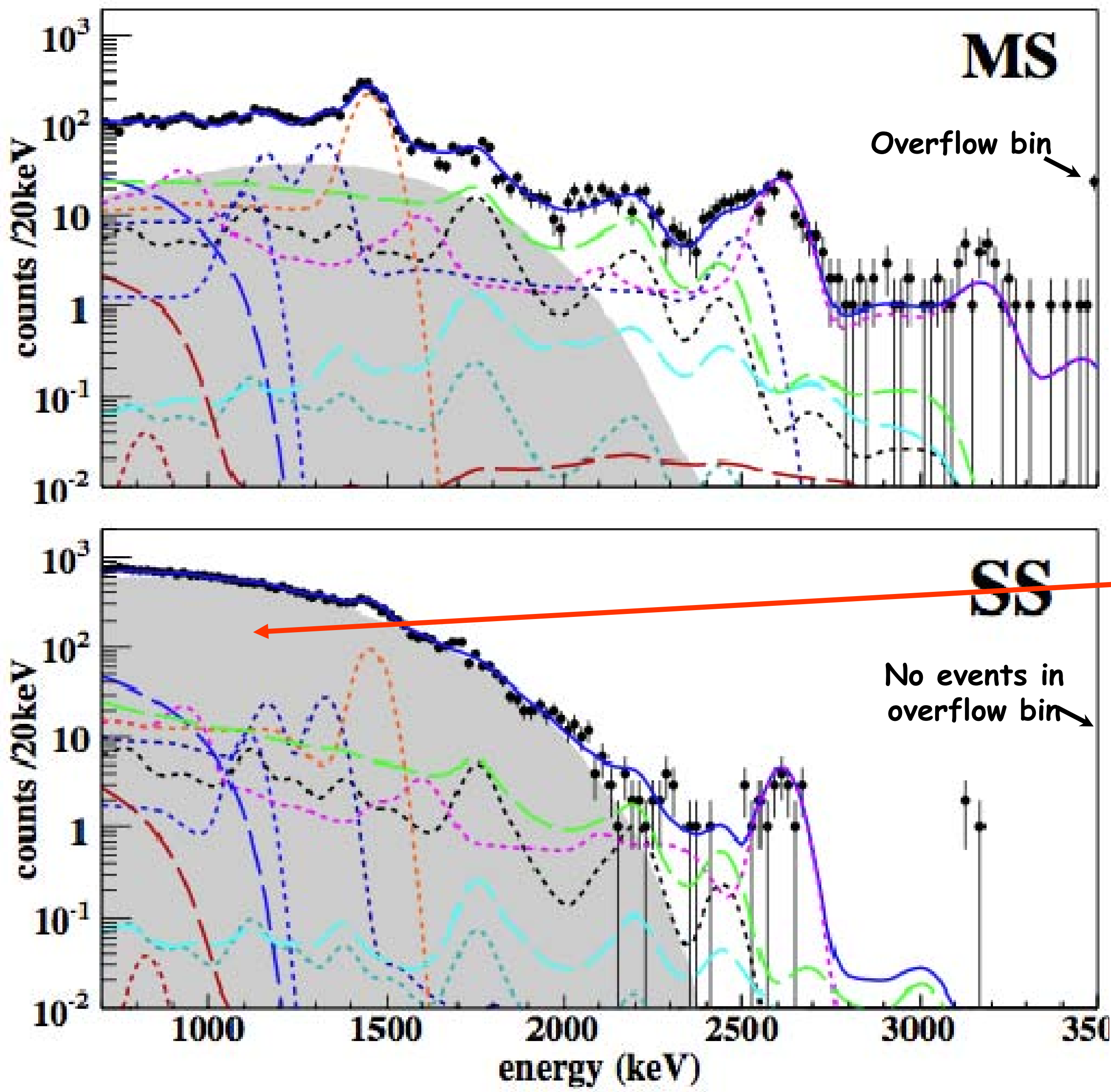


Low background run livetime:
120.7 days

Active mass:
98.5 kg LXe
(79.4kg ^{136}LXe)

Exposure:
32.5 kg.yr

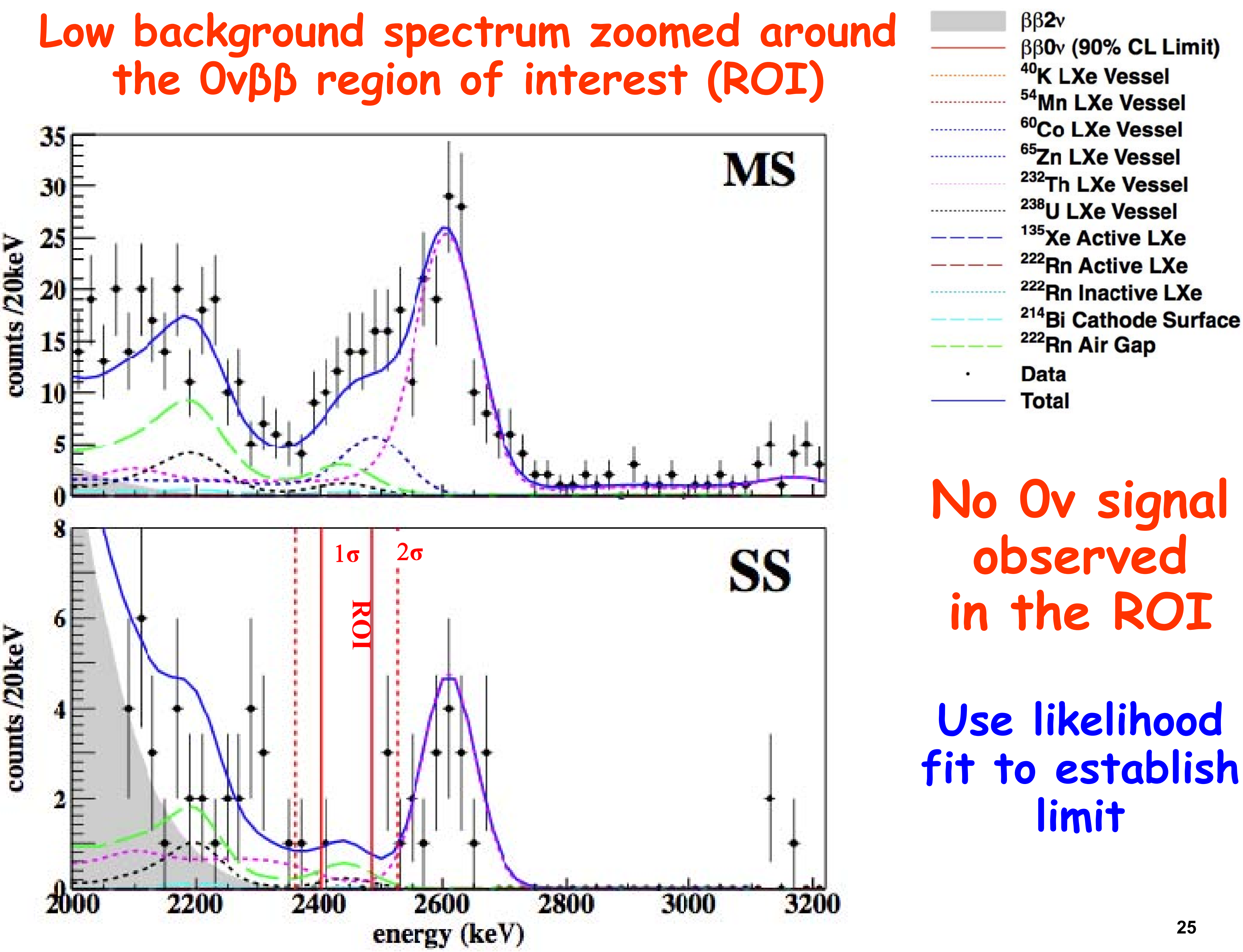
Vetos dead time:
8.6%



~22,000 2νββ events !

This is a mode that until Aug 2011 we did not know existed!

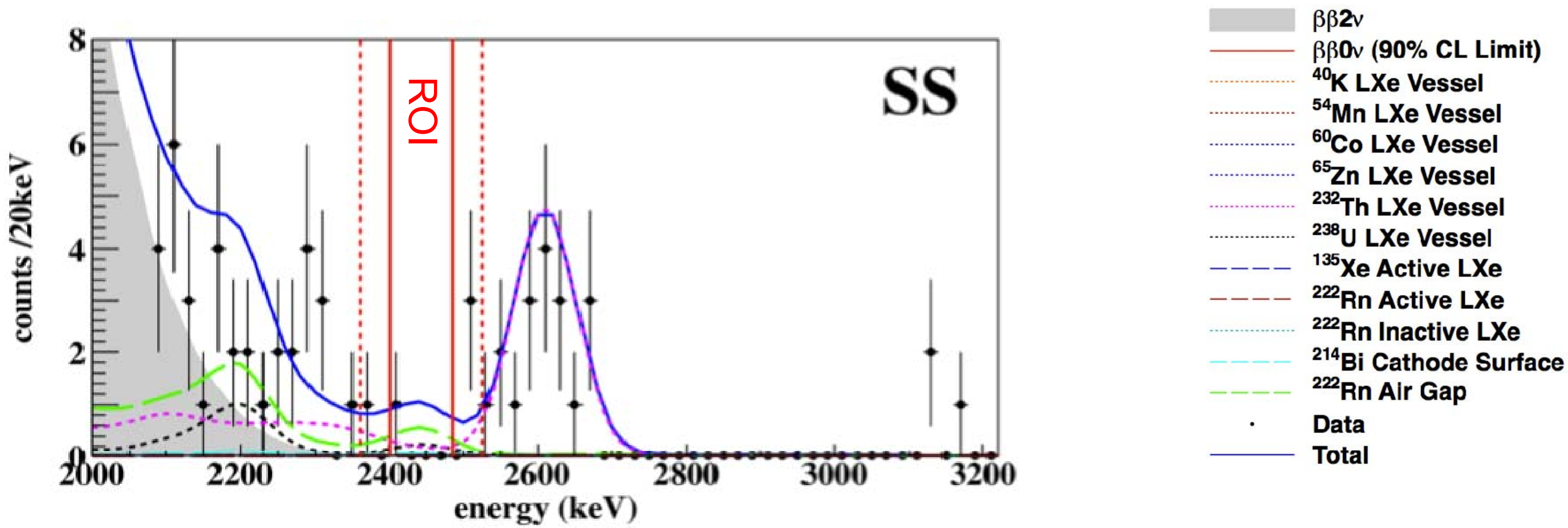
Low background spectrum zoomed around the $0\nu\beta\beta$ region of interest (ROI)



No 0ν signal observed in the ROI

Use likelihood fit to establish limit

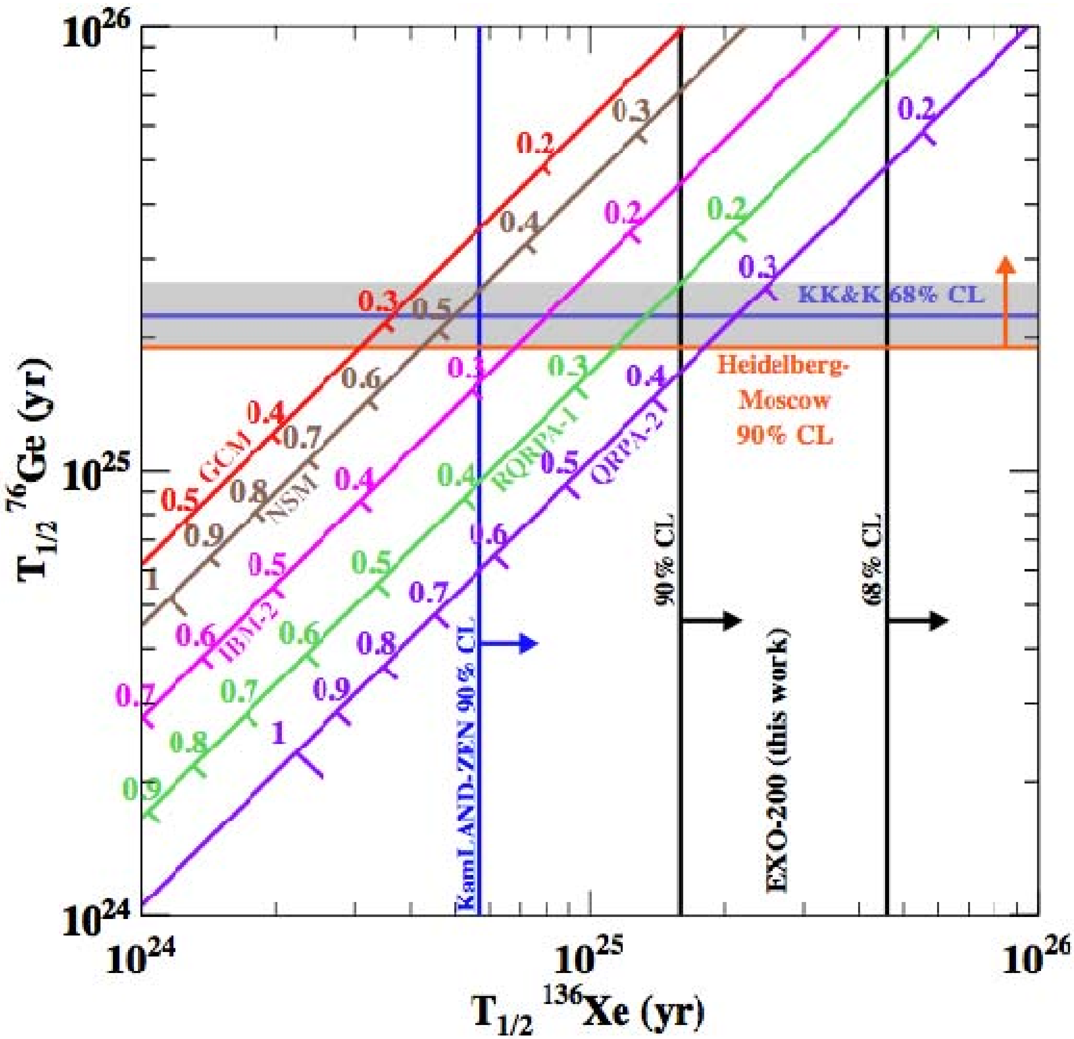
Background counts in ±1,2 σ ROI



	Expected events from fit			
	±1 σ		±2 σ	
^{222}Rn in cryostat air-gap	1.9	±0.2	2.9	±0.3
^{238}U in LXe Vessel	0.9	±0.2	1.3	±0.3
^{232}Th in LXe Vessel	0.9	±0.1	2.9	±0.3
^{214}Bi on Cathode	0.2	±0.01	0.3	±0.02
All Others	~0.2		~0.2	
Total	4.1	±0.3	7.5	±0.5
Observed	1		5	
Background index b ($kg^{-1}yr^{-1}keV^{-1}$)	$1.5 \cdot 10^{-3}$ ± 0.1		$1.4 \cdot 10^{-3}$ ± 0.1	

in the 0νββ ±2σ ROI
in 140kg of LXe
➔ 60 cnts/2yr

Limits on $T_{1/2}^{0\nu\beta\beta}$ and $\langle m_{\beta\beta}\rangle$



From profile likelihood:

$T_{1/2}^{0\nu\beta\beta} > 1.6 \cdot 10^{25}$ yr

$\langle m_{\beta\beta}\rangle < 140–380$ meV

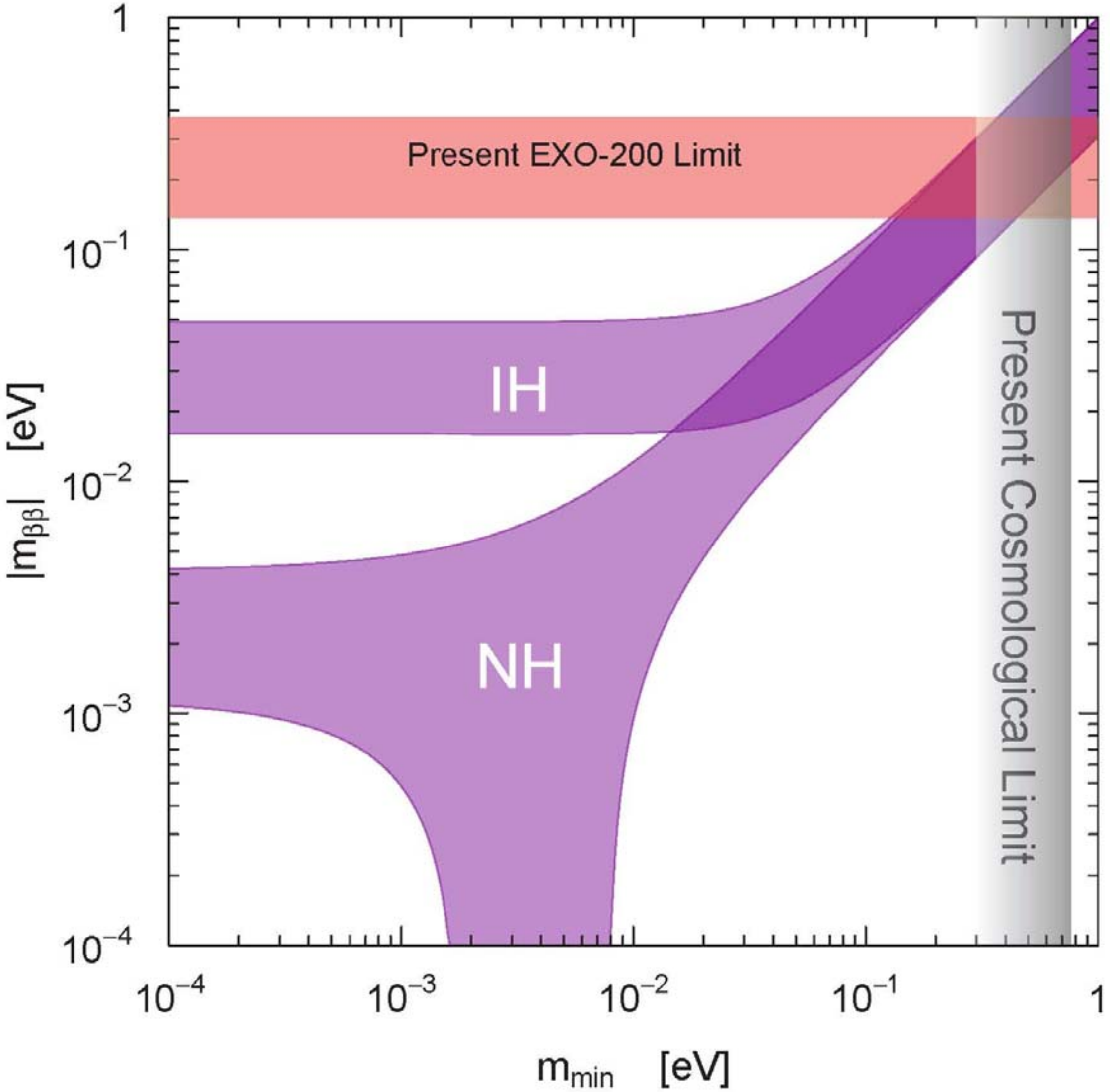
(90% C.L.)

Phys Rev Lett
109 (2012) 032505

The future of EXO-200

- 3x dataset on disk
- Better analysis/reconstruction in progress
- Rn suppression system (in the air outside the cryostat) to be installed in the spring
- Electronics upgrade under discussion
- Approved to run till end of 2014
- Possibly extend for ~2 more years

EXO-200 projected sensitivity

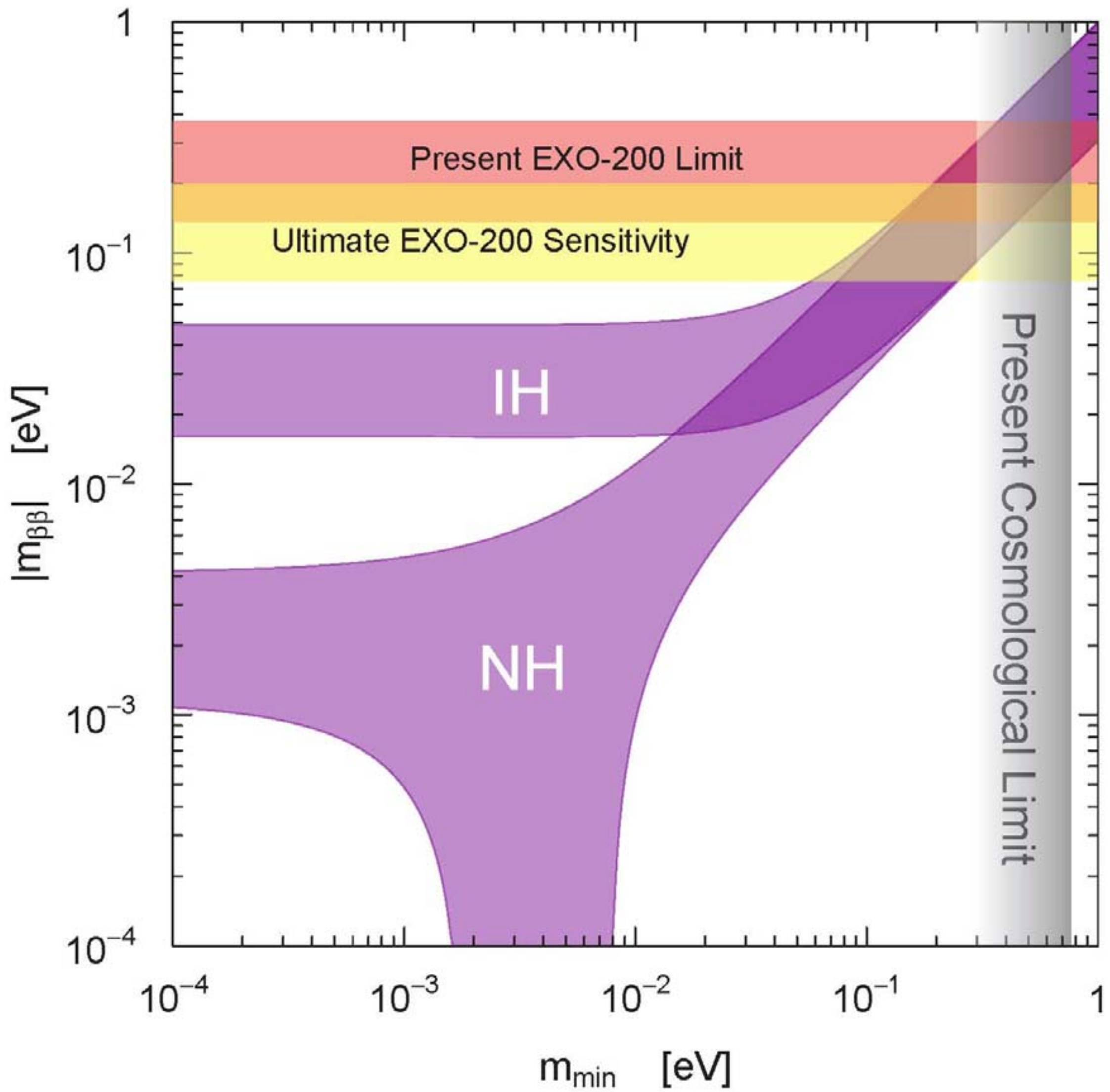


Adapted from Bilenky & Giunti arXiv:1203.5250v2

Blue bands are 68%CL from oscillation experiments for "Inverted" and "Normal" Hierarchy

The EXO-200 "Present limit" is the 90%CL envelope of Limits (for different NMEs) from PRL 109 (2012) 032505

EXO-200 and nEXO projected sensitivities



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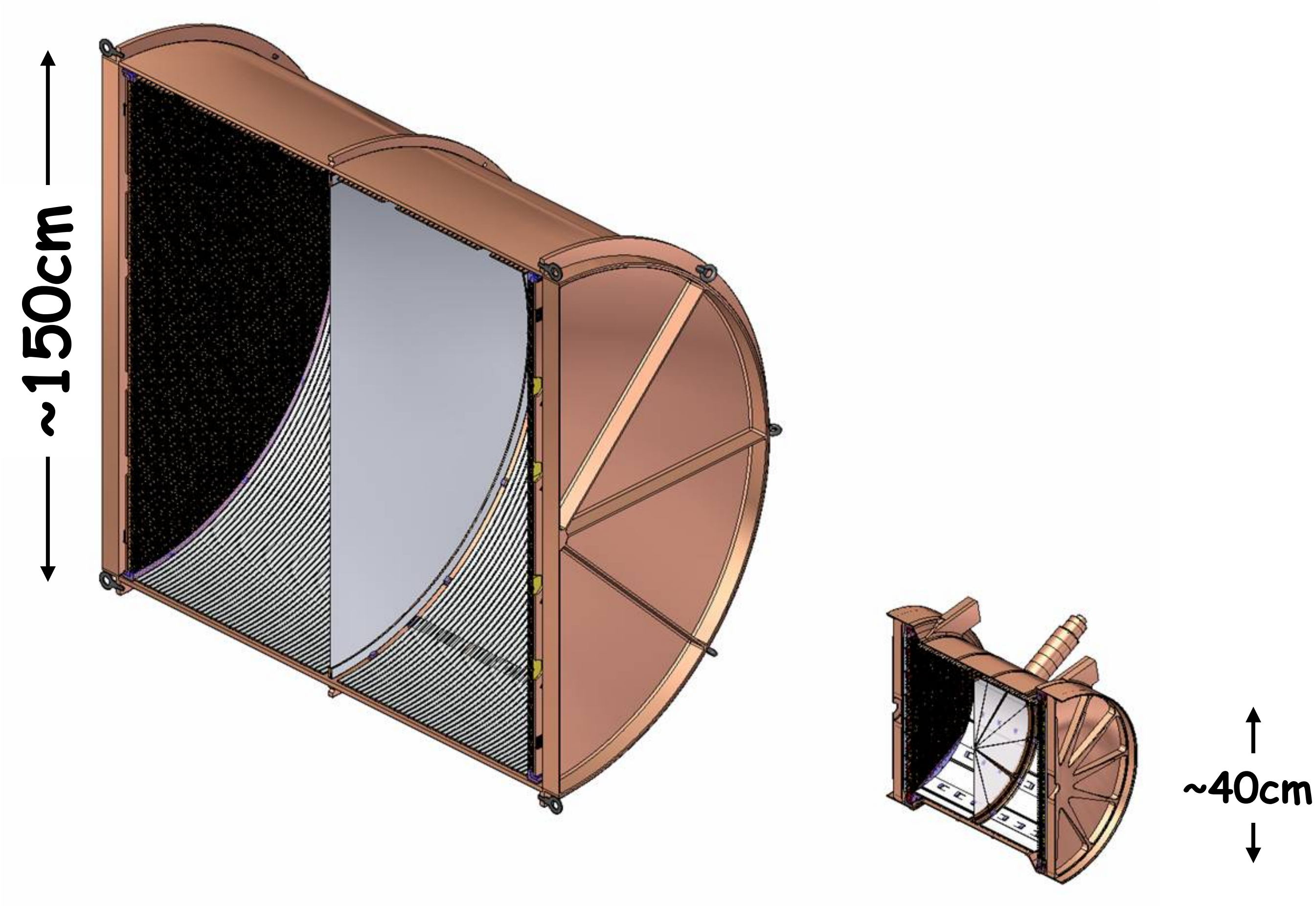
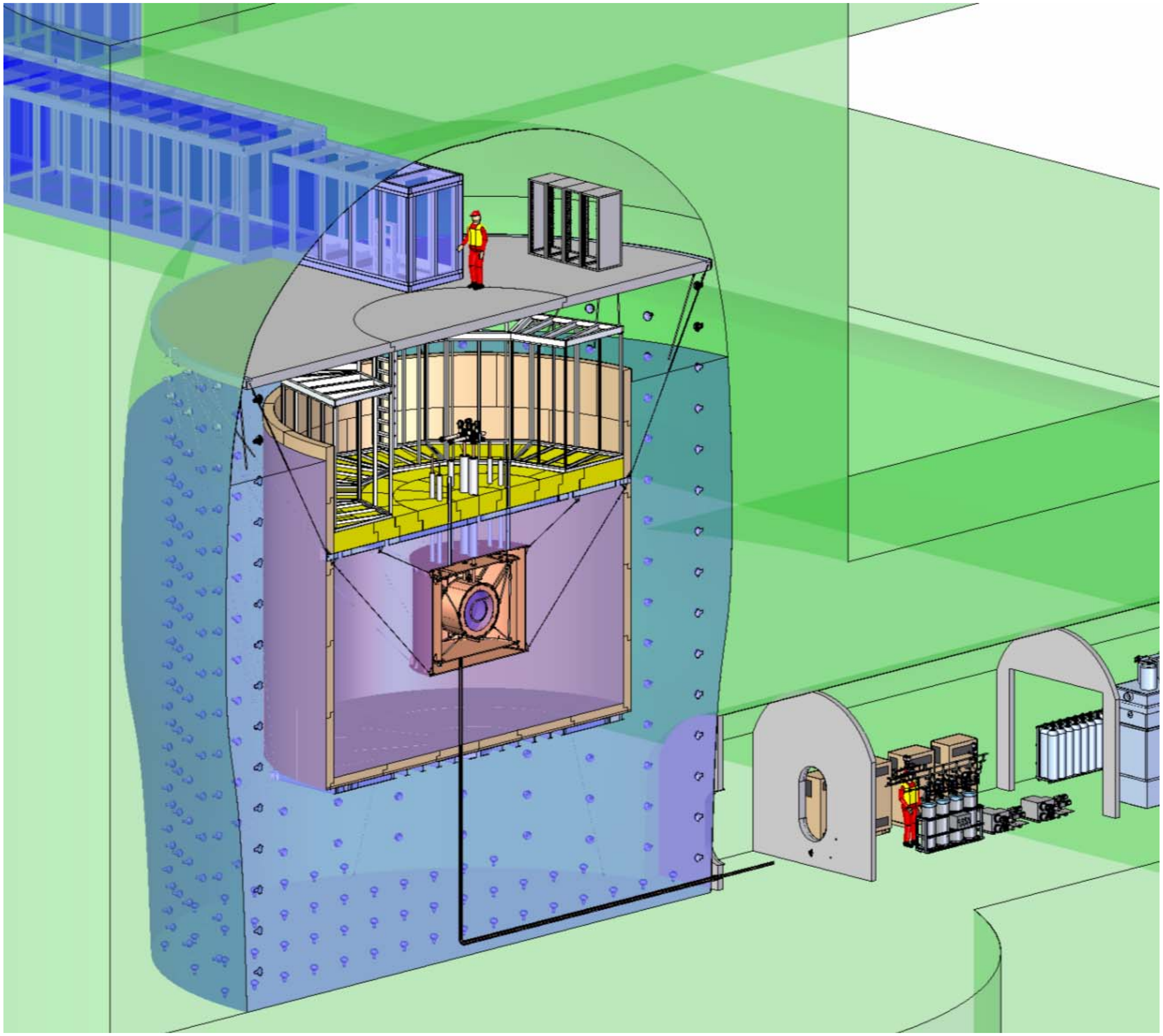
The EXO-200 "Ultimate" sensitivity: 90%CL for no signal in 4 yrs livetime with new analysis & Rn removal

nEXO @SNOlab

- 5 tonne LXe TPC "as similar to EXO-200 as possible"
- Provide access ports for a possible later upgrade to Ba tagging



nEXO in the SNOlab Cryopit



nEXO R&D items

- Understand HV issues
  (all LXe detectors seem to have HV issues…)
- Low background, cryogenics electronics
  (fewer cables, lower noise,more channels)
- SiPM photodetectors
  (no HV, lower mass, larger gain)
- Alternative charge collection scheme
  (no wires to break, better event reconstruction, lower bkgnd)

Historical development of ββ techniques

- Final state ID: 1) "Geochemical": search for an abnormal abundance of (A,Z+2) in a material containing (A,Z)

  2) "Radiochemical": store in a mine some material (A,Z) and after some time try to find (A,Z+2) in it

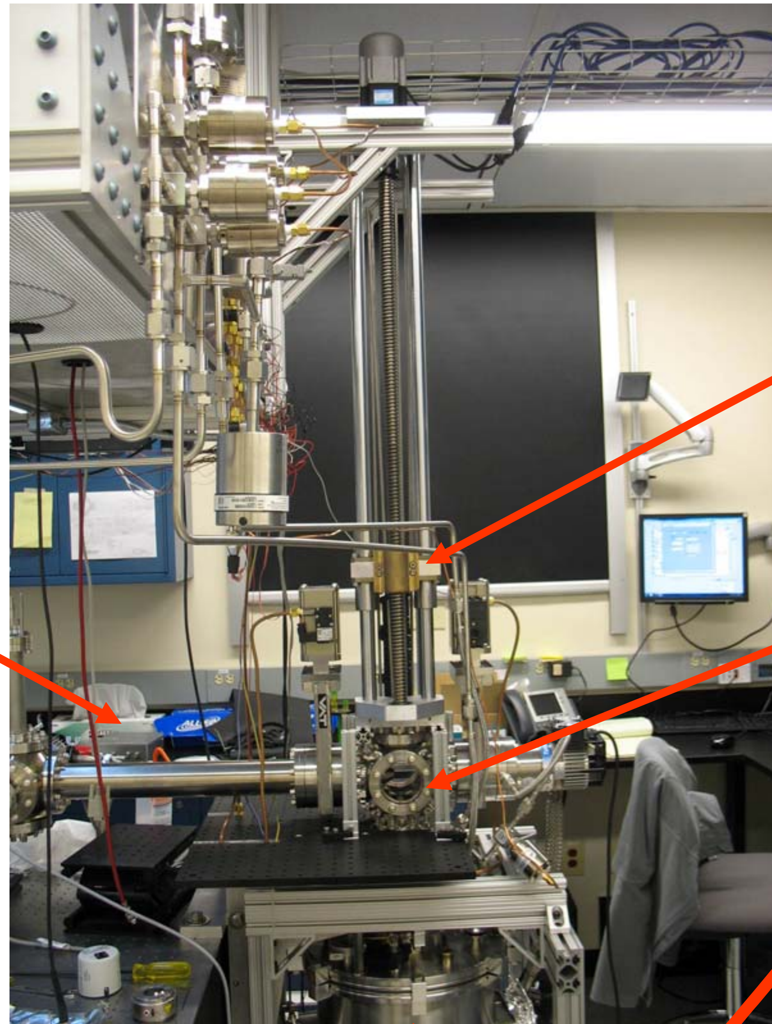
  + Very specific signature
  + Large live times (particularly for 1)
  + Large masses
  - Possible only for a few isotopes (in the case of 1)
  - No distinction between 0ν, 2ν or other modes
- "Real time": ionization or scintillation is detected in the decay

  a) "Homogeneous": source=detector

  b) "Heterogeneous": source≠detector

  + Energy/some tracking available (can distinguish modes)
  + In principle universal (b)
  - Many γ backgrounds can fake signature
  - Exposure is limited by human patience

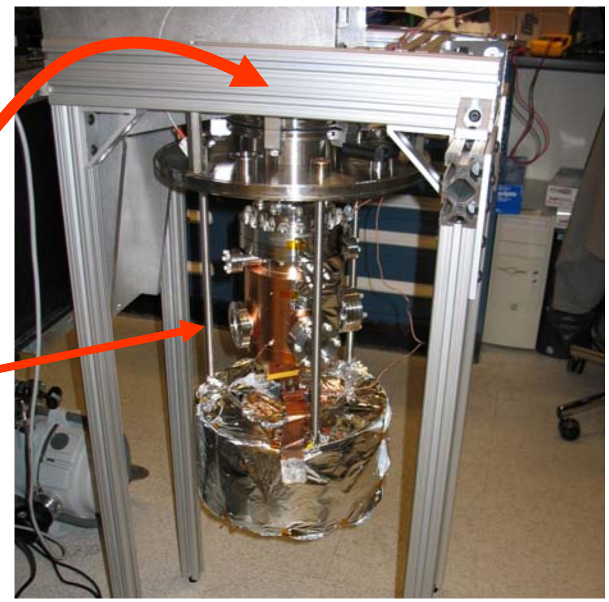
Ba tagging demonstrator



TOF spectrometer

Probe actuator

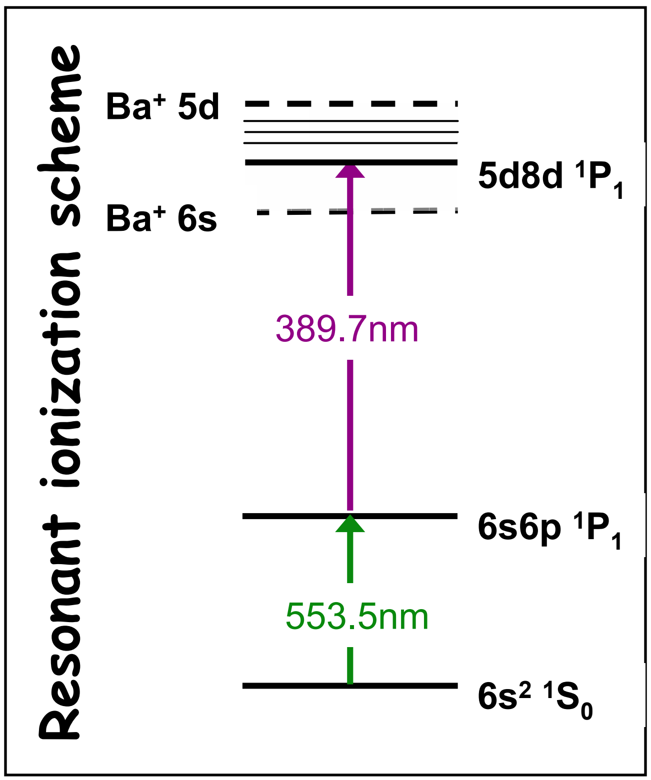
Laser chamber

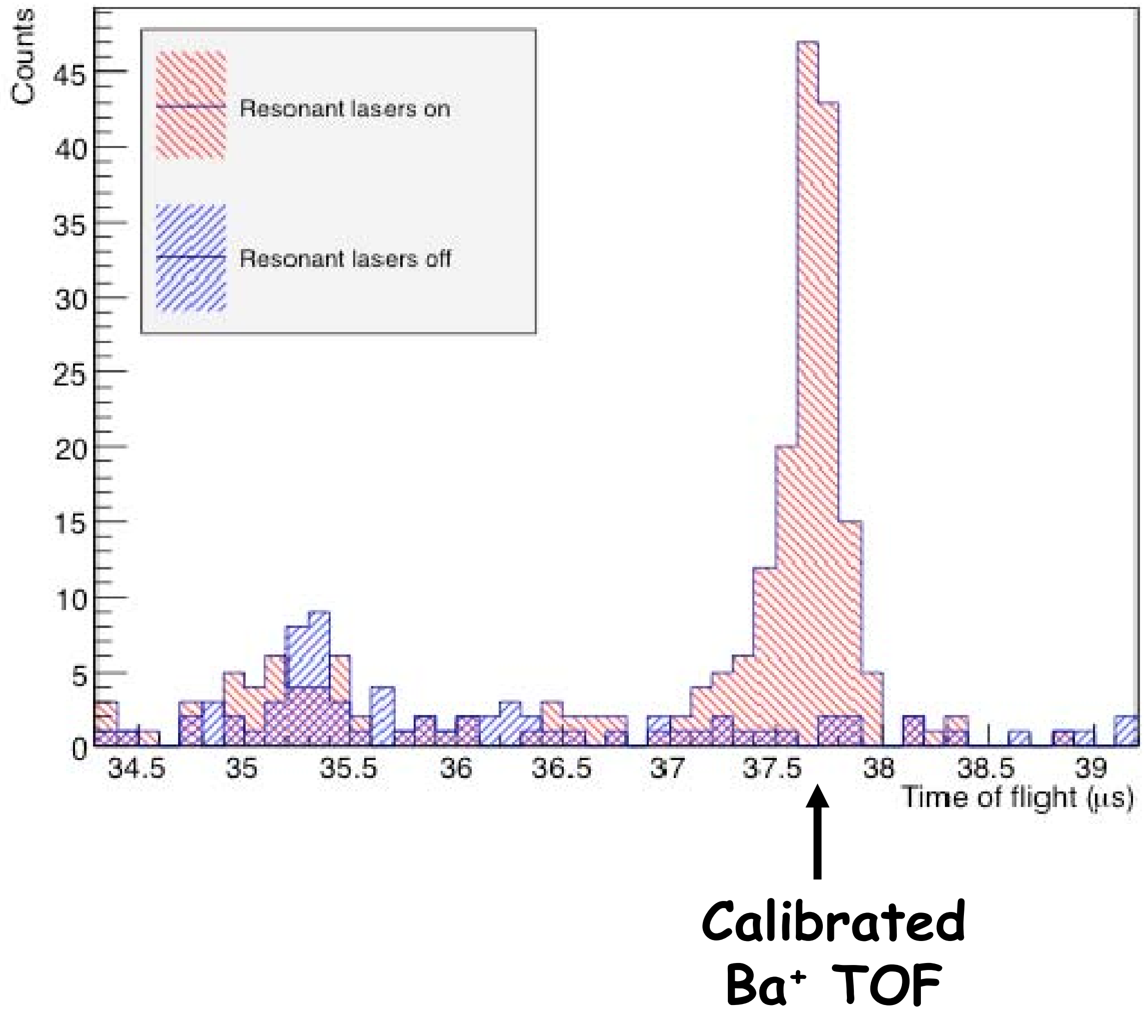


LXe chamber

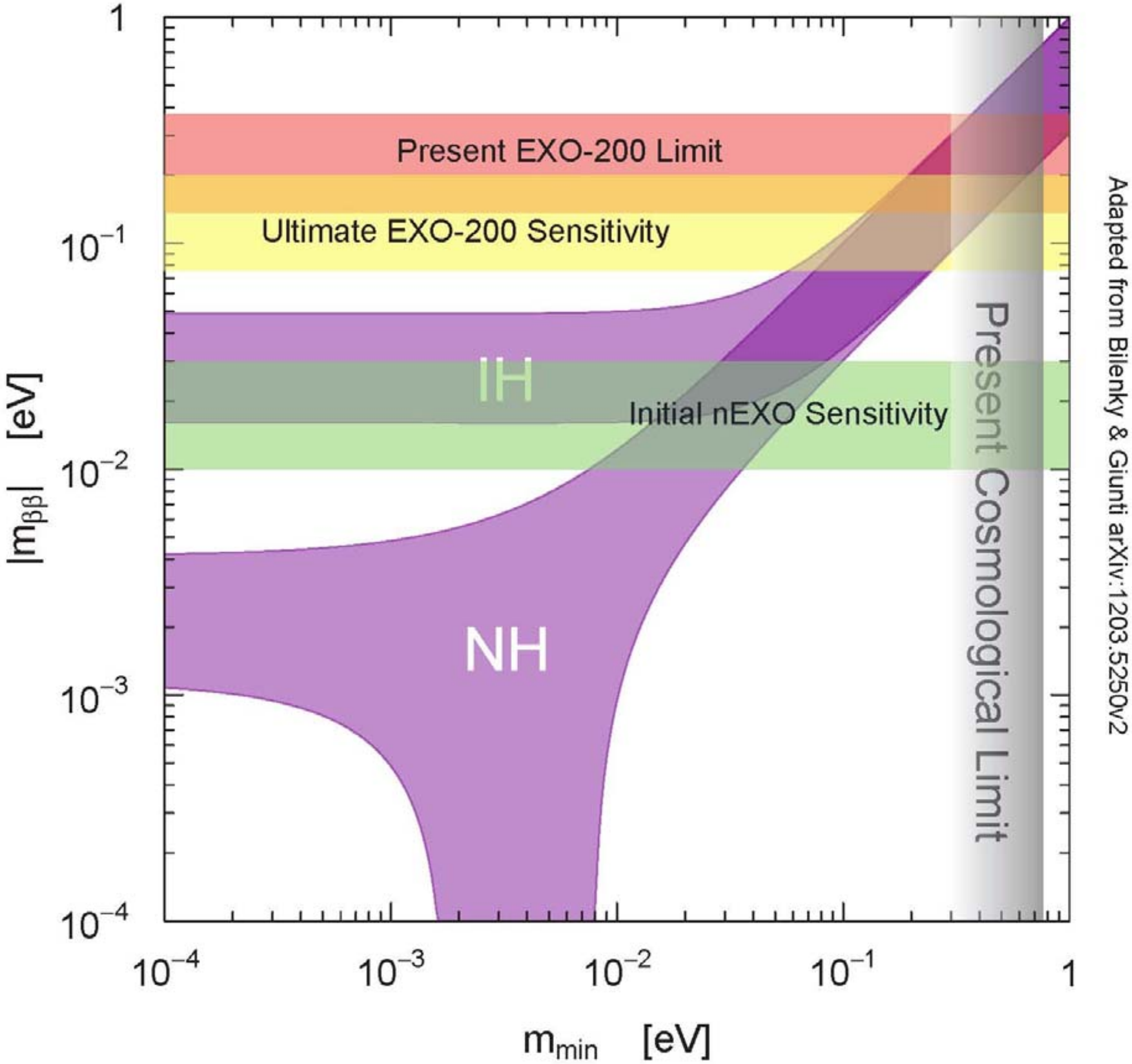
For the time being fish Ba from vacuum (no LXe)

- Background ~0
- Efficiency still small (<1%)





EXO-200 and nEXO projected sensitivities



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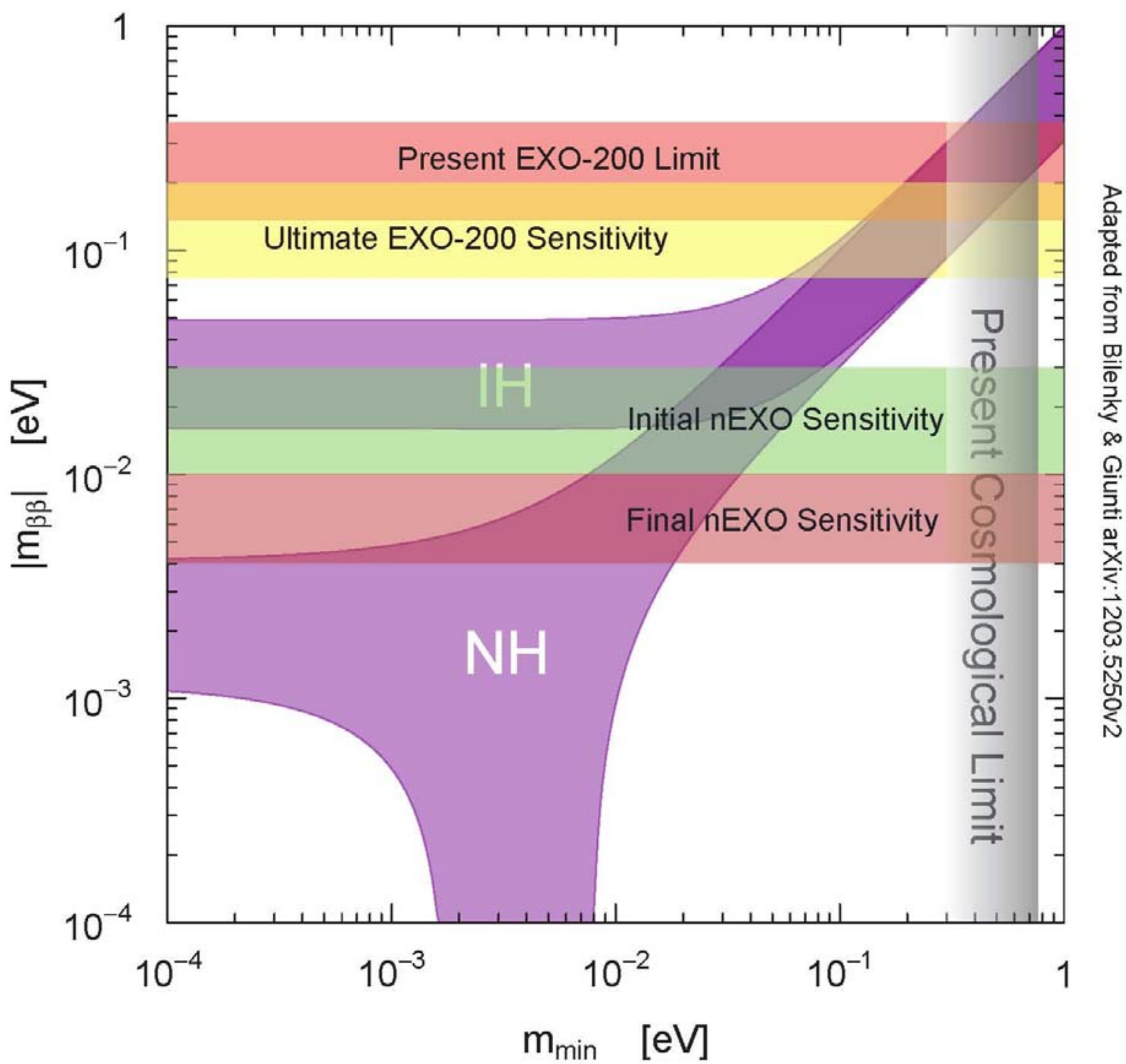
The EXO-200 "Ultimate" sensitivity: 90%CL for no signal in 4 yrs livetime with new analysis & Rn removal

The "Initial nEXO" band refers to a detector directly scaled from EXO-200, including its measured background and 10yr livetime.

EXO-200 and nEXO projected sensitivities



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The EXO-200 "Ultimate" sensitivity: 90%CL for no signal in 4 yrs livetime with new analysis & Rn removal

The "Initial nEXO" band refers to a detector directly scaled from EXO-200, including its measured background and 10yr livetime.

The "Final nEXO" band refers to the same detector and no background other than 2ν

Summary

- EXO-200 taking data since Jun 2011
- Detector already reached nominal performance for resolution and background
- Discovered the 2νββ decay in ^{136}Xe
- Very competitive limit on the 0νββ decay with the first 4 month of data: almost exclude the Klapdor claim
- More data and better performance expected
- nEXO start taking shape
- The next few years expected to be very interesting!

The EXO Collaboration

University of Alabama, Tuscaloosa AL, USA - D. Auty, M. Hughes, A. Piepke, K. Pushkin, M. Volk

University of Bern, Switzerland - M. Auger, S. Delaquis, D. Franco, G. Giroux, R. Gornea, T. Tolba, J-L. Vuilleumier, M. Weber

California Institute of Technology, Pasadena CA, USA - P. Vogel

Carleton University, Ottawa ON, Canada - A. Coppens, M. Dunford, K. Graham, C. Hägemann, C. Hargrove, F. Leonard, C. Oullet, E. Rollin, D. Sinclair, V. Strickland

Colorado State University, Fort Collins CO, USA - S. Alton, C. Benitez-Medina, C. Chambers, A. Craycraft, S. Cook, W. Fairbank, Jr., K. Hall, N. Kaufold, T. Walton

Drexel University, Philadelphia PA, USA - M.J. Dolinski, E. Smith

University of Illinois, Urbana-Champaign IL, USA - D. Beck, J. Walton, M. Tarka, L. Yang

IHEP Beijing, People's Republic of China - G.F. Cao, X.S. Jiang, Y.B. Zhao

Indiana University, Bloomington IN, USA - J. Albert, S. Daugherty, T. Johnson, L.J. Kaufman

University of California, Irvine, Irvine CA, USA - M. Moe

ITEP Moscow, Russia - D. Akimov, I. Alexandrov, V. Belov, A. Burenkov, M. Danilov, A. Dolgolenko, A. Karelin, A. Kovalenko, A. Kuchenkov, V. Stekhanov, O. Zeldovich

Laurentian University, Sudbury ON, Canada - E. Beauchamp, D. Chauhan, B. Cleveland, J. Farine, B. Mong, U. Wichoski

University of Maryland, College Park MD, USA - C. Davis, A. Dobi, C. Hall, S. Slutsky, Y-R. Yen

University of Massachusetts, Amherst MA, USA - T. Daniels, S. Johnston, K. Kumar, M. Lodato, C. Mackeen, K. Malone, A. Pocar, J.D. Wright

University of Seoul, South Korea - D. Leonard

SLAC National Accelerator Laboratory, Menlo Park CA, USA - M. Breidenbach, R. Conley, K. Fouts, R. Herbst, S. Herrin, J. Hodgson, A. Johnson, R. MacLellan, A. Odian, C.Y. Prescott, P.C. Rowson, J.J. Russell, K. Skarpaas, M. Swift, A. Waite, M. Wittgen, J. Wodin

Stanford University, Stanford CA, USA - P.S. Barbeau, J. Bonatt, T. Brunner, J. Chaves, J. Davis, R. DeVoe, D. Fudenberg, G. Gratta, S.Kravitz, M. Montero-Díez, D. Moore, I. Ostrovskiy, K. O'Sullivan, A. Rivas, A. Sabourov, D. Tosi, K. Twelker, L.J. Wen

Technical University of Munich, Garching, Germany - W. Feldmeier, P. Fierlinger, M. Marino