Low Radioactivity Techniques 2015 Workshop
17-20 March 2015, Seattle, WA USA

Liquid Xenon Purification, De-Radonation (and De-Kryptonation)

Group: LRT

2015 3.19

Xe

Xeattle

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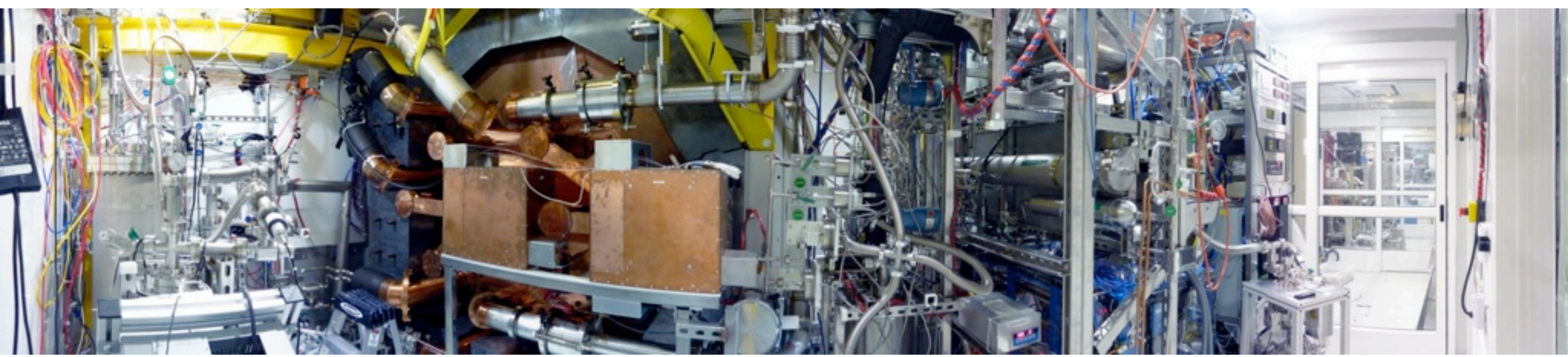
on behalf of the EXO-200 and nEXO collaborations

Outline

- Introductory notes
- Xe purity issues in EXO-200
- Radon-related issues in EXO-200
- Krypton backgrounds
- Outlook: purity and radon in nEXO



The Enriched Xenon Observatory

Search for 0νββ decay of ^{136}Xe (Q=2458 keV) with enriched xenon TPC's (with scintillation readout) of increasing sensitivity and size

Enrichment is relatively simpler and less expensive
- 10% --> 80-90% proven on the 100's kg scale

Continuous re-purification possible
- form electronegative and radioactive contaminants

Xenon is reusable
- could be transferred between experiments

Monolithic detector, remarkable self-shielding

Good (enough) energy resolution
- with combined scintillation + ionization

ββ/γ discrimination
- event topology

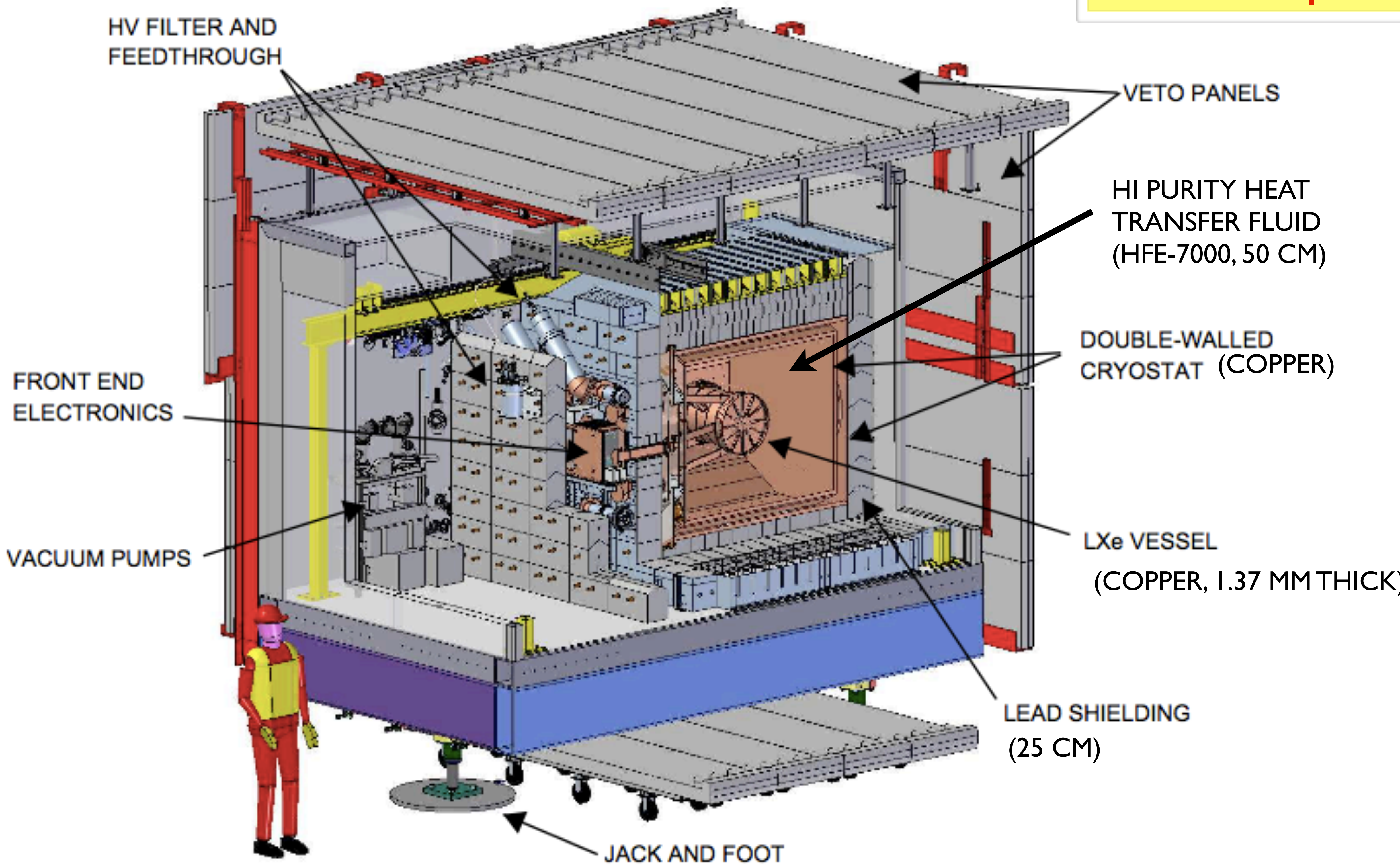
Limited cosmogenic activation
- longest-lived 4 minutes

Xenon admits a novel coincidence technique
- Ba daughter tagging

M. Moe, PRC 44, R931 (1991)

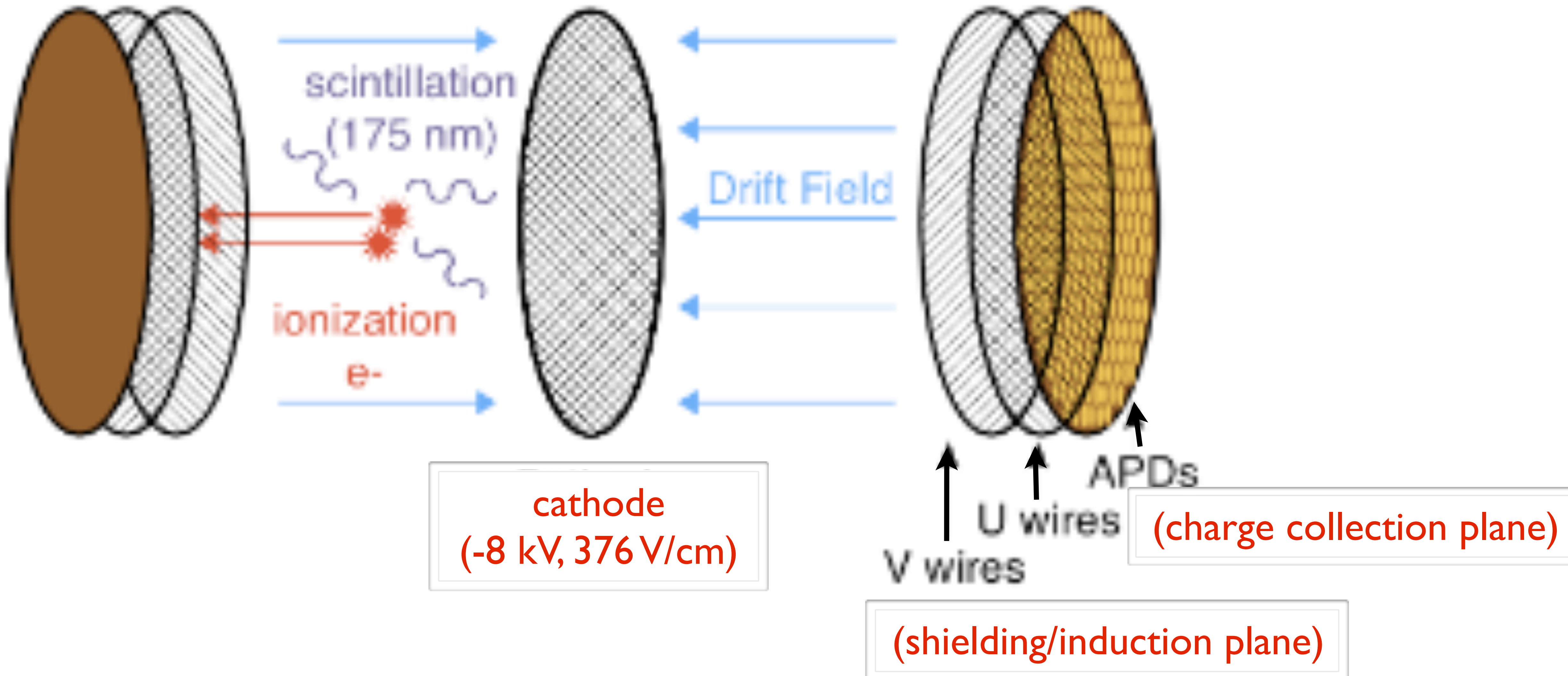
The EXO-200 detector at WIPP (~1,500 m.w.e.)

Rn: ~6 Bq/m^3



JINST 7 (2012) P05010

The EXO-200 Time Projection Chamber (TPC)



- Radio-pure, dual TPC, filled with ~150 kg LXe, 80.6% ^{136}Xe)
- Scintillation detected by APDs at interaction time
- x/y from collection and shielding wire planes
- z from electron drift time

JINST 7 (2012) P05010

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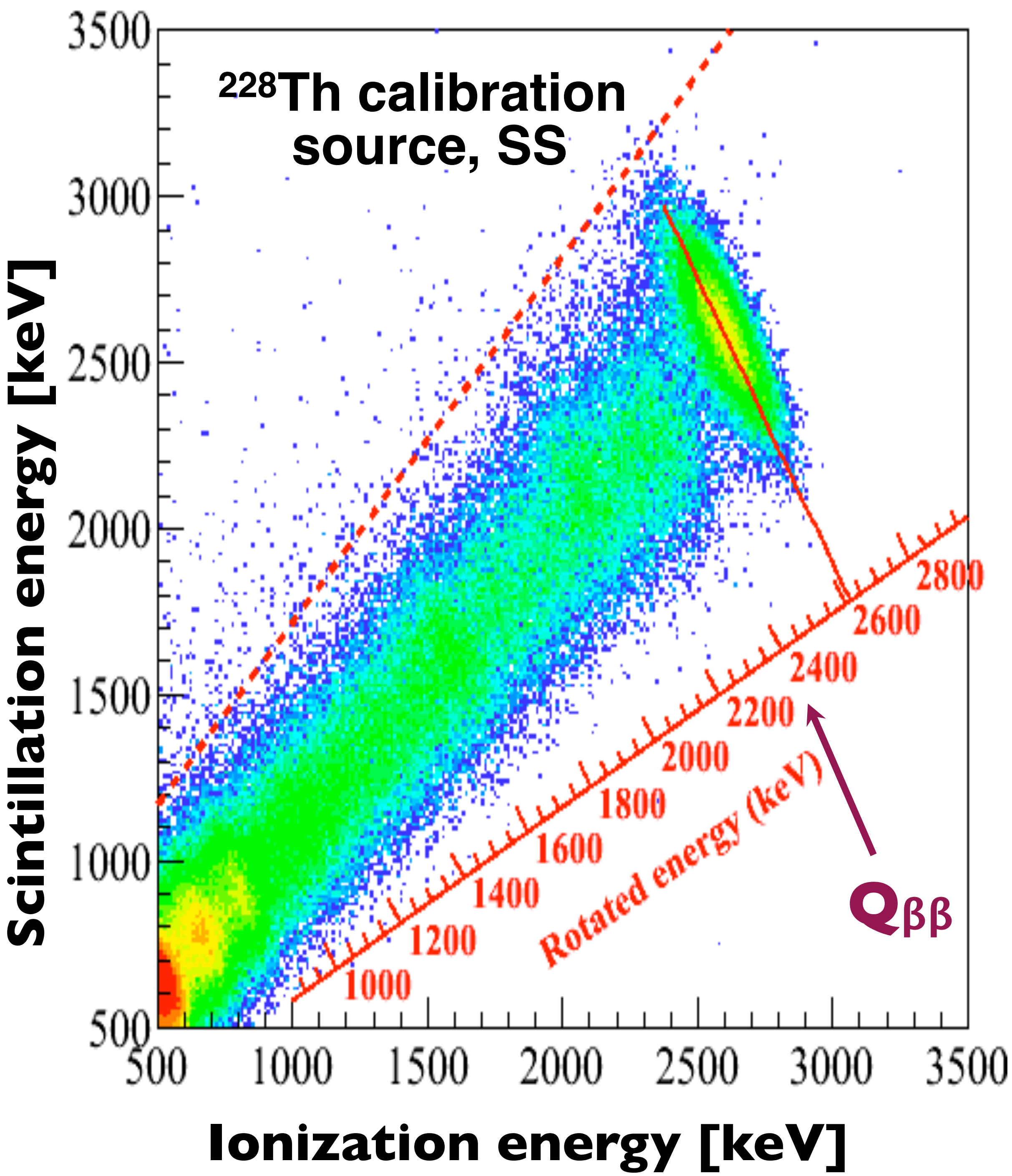
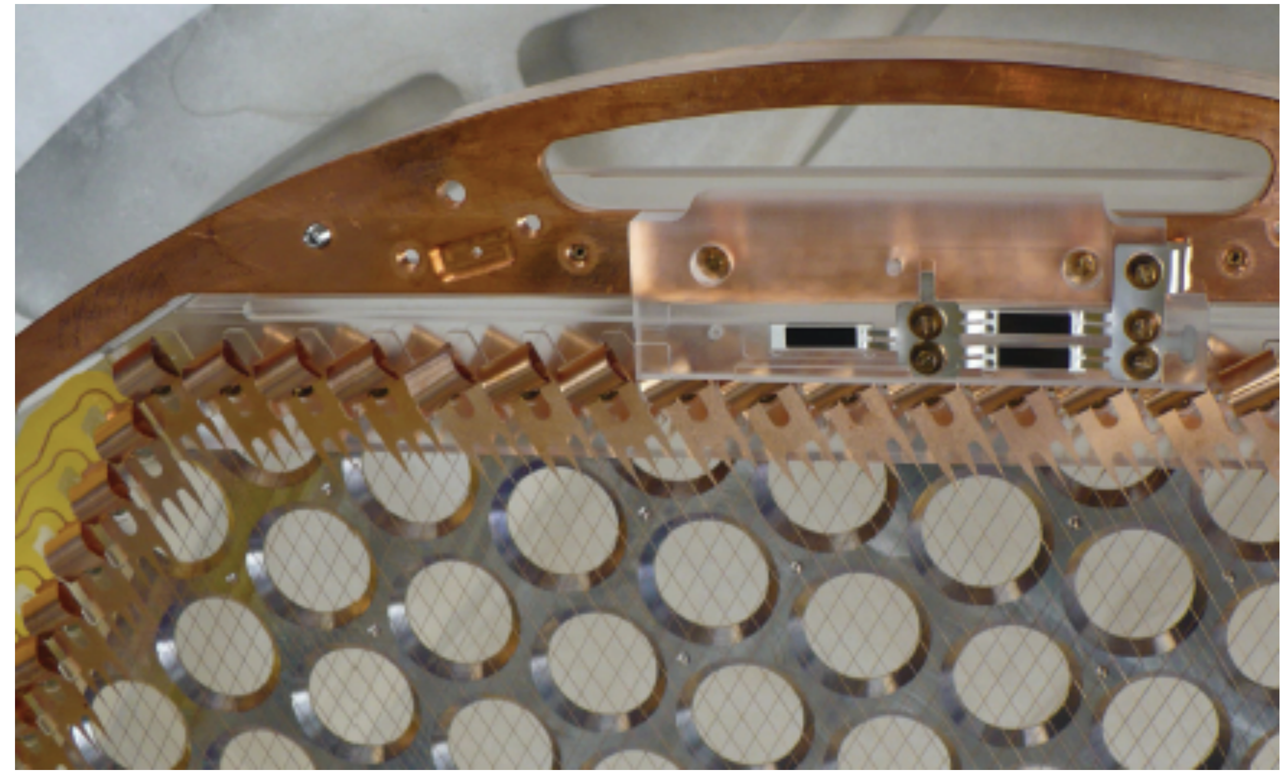
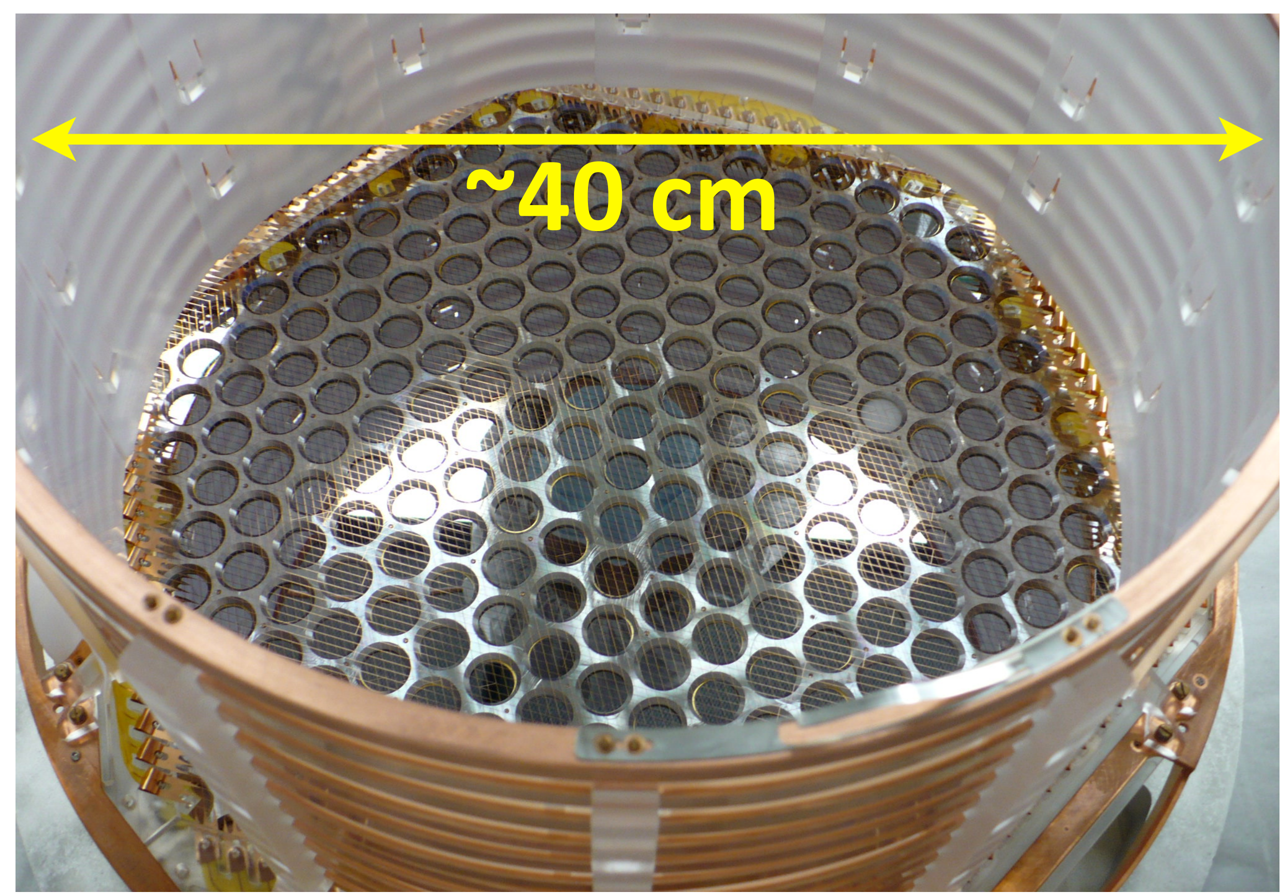
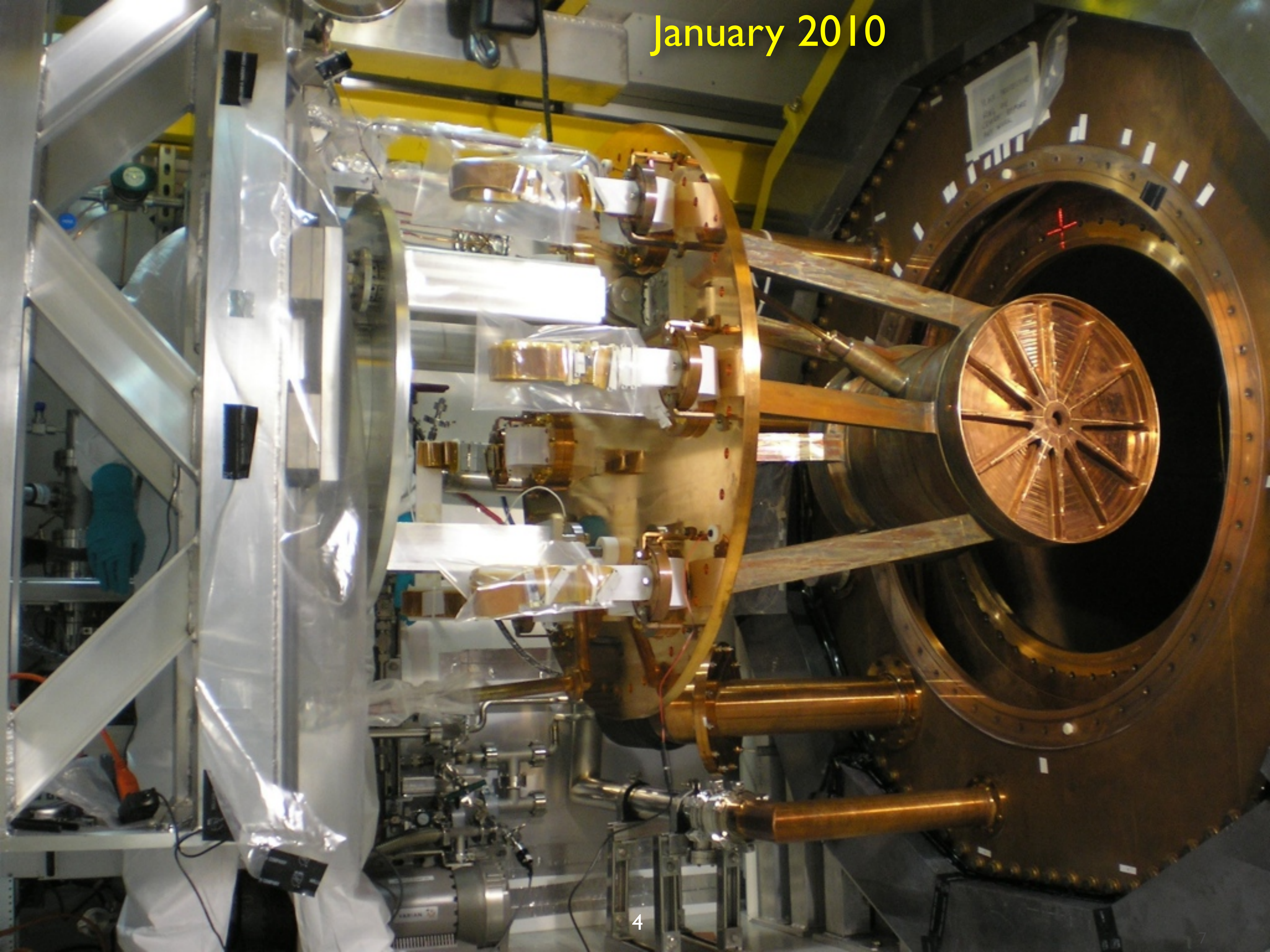


[E. Conti et al. Phys. Rev. B 68 (2003) 054201]





January 2010



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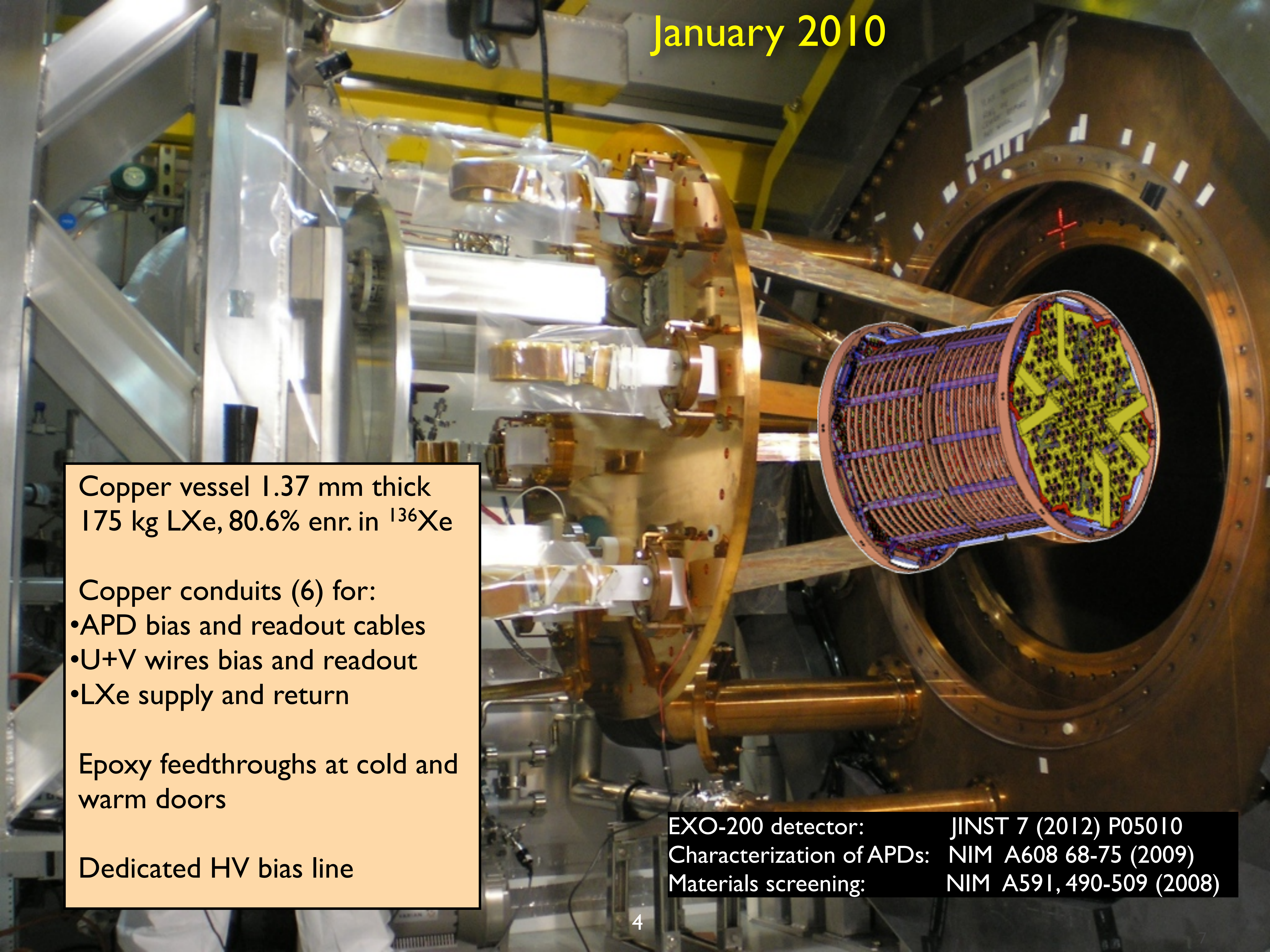


Copper vessel 1.37 mm thick
175 kg LXe, 80.6% enr. in ^{136}Xe

Copper conduits (6) for:

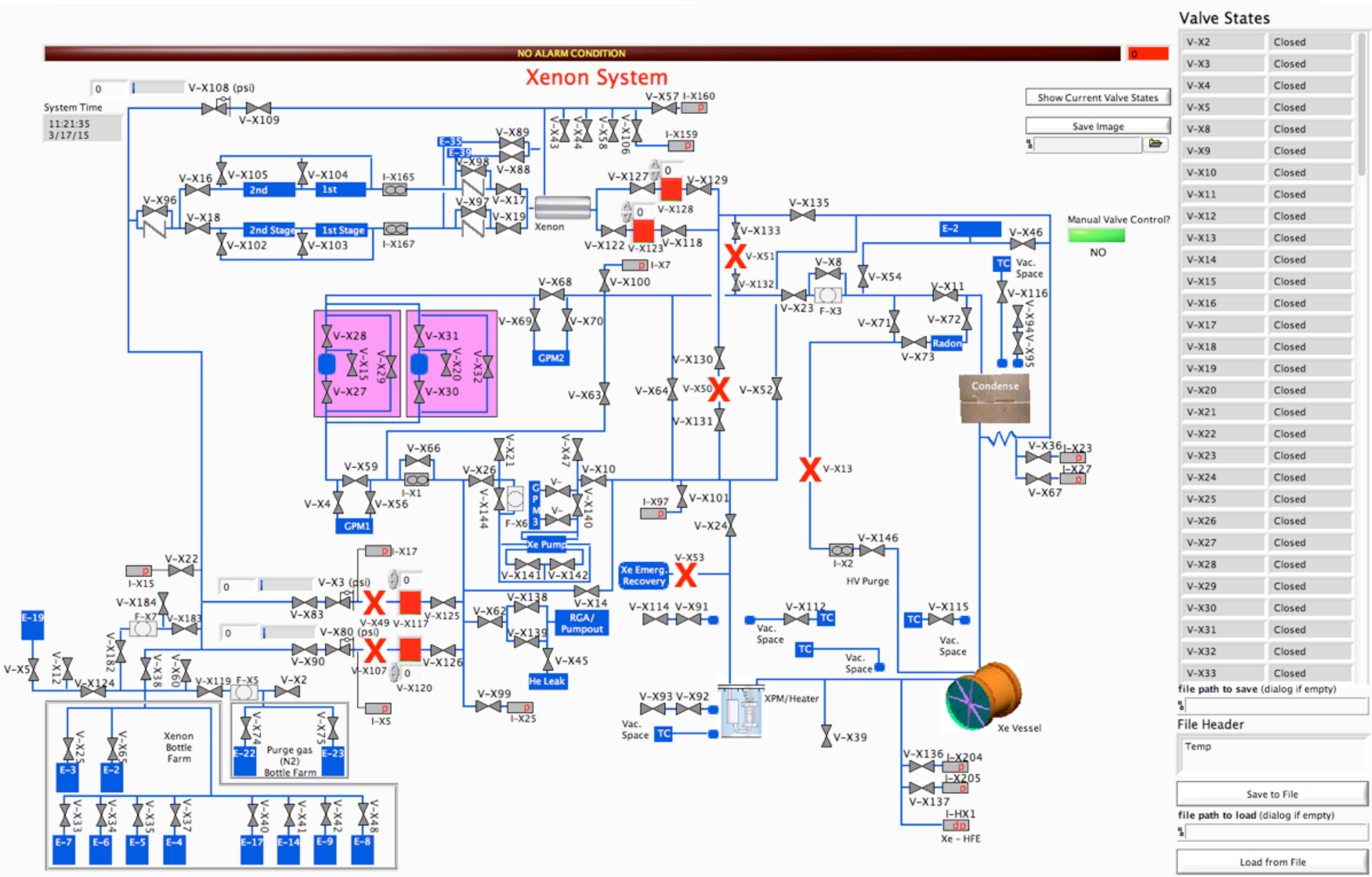
- APD bias and readout cables
- U+V wires bias and readout
- LXe supply and return

Epoxy feedthroughs at cold and warm doors

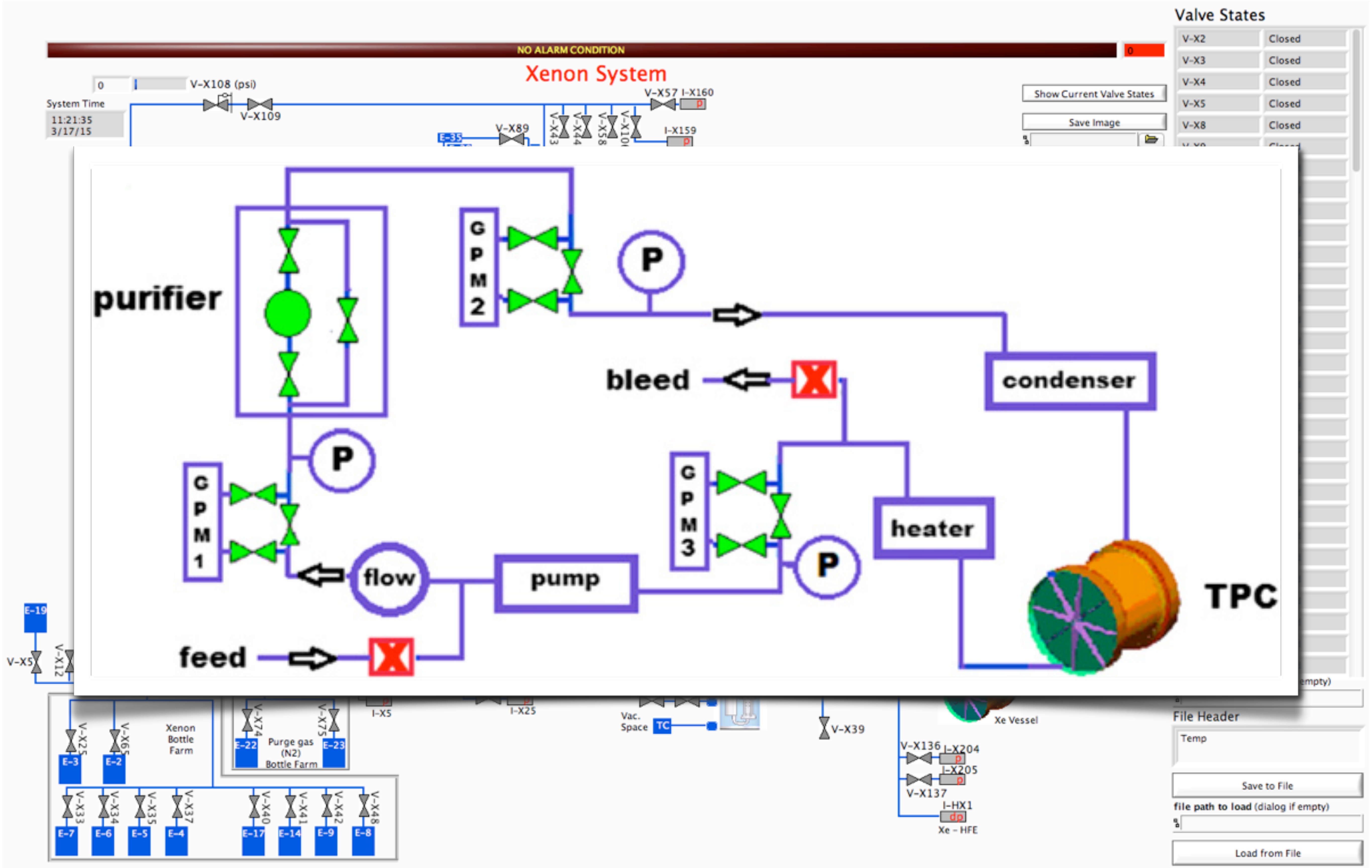
Dedicated HV bias line

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

EXO-200 Liquid Xenon System

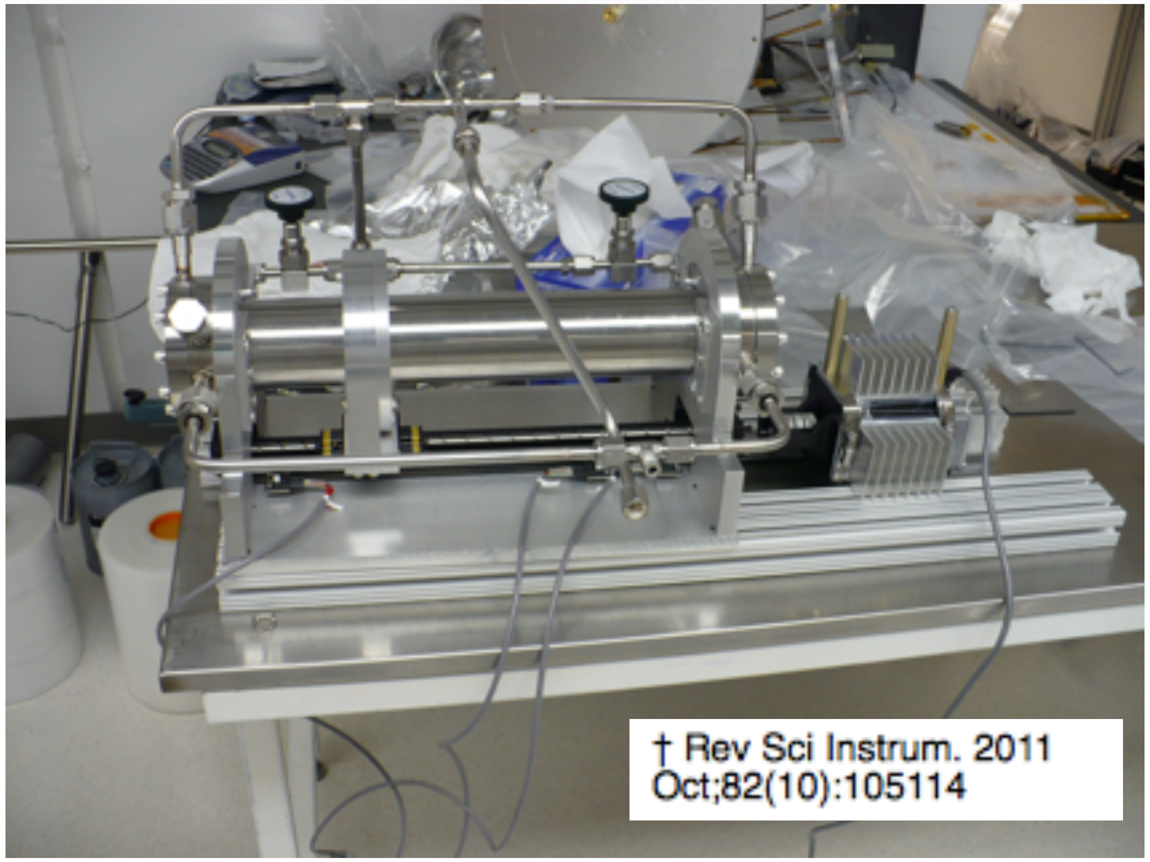


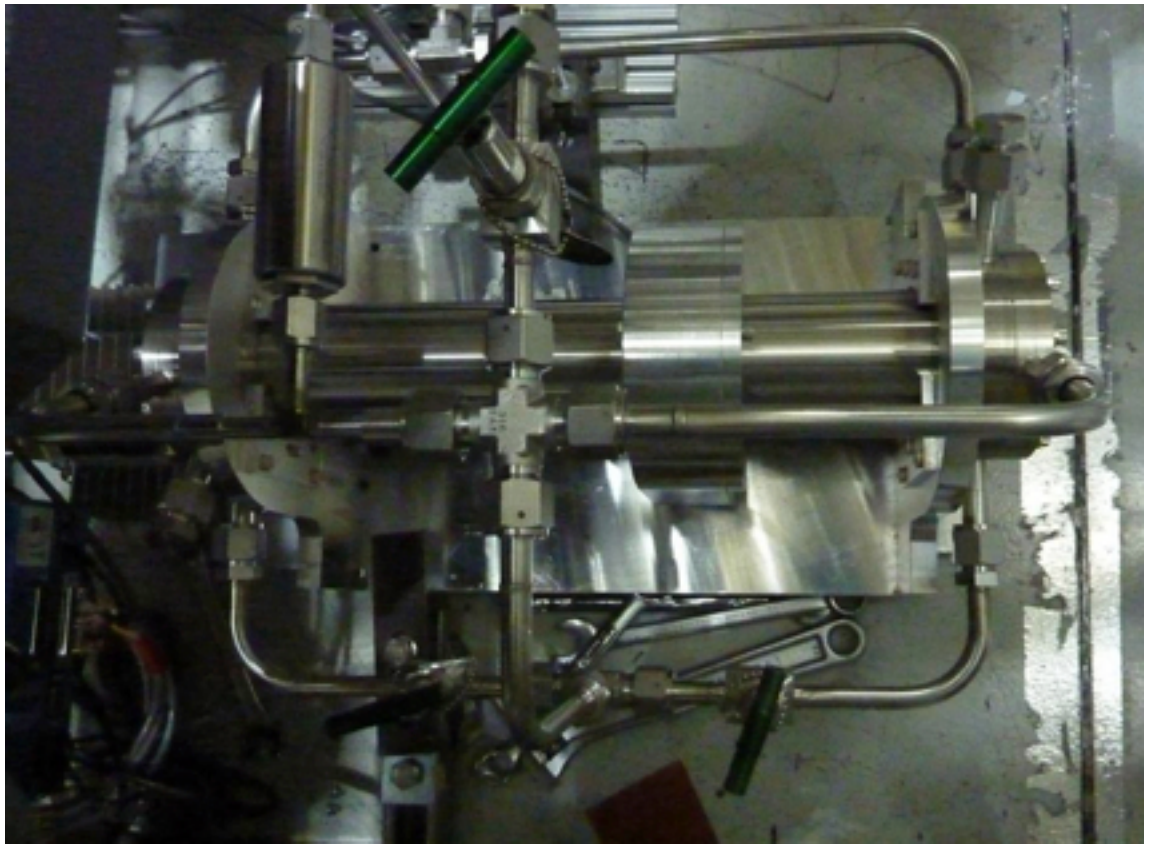
EXO-200 Liquid Xenon System



EXO-200: initial operations with natural Xenon

- TPC was kept under inert nitrogen atmosphere in transit from Stanford to WIPP
- All plastic components had been precision cleaned, baked or annealed and stored in flushed boxes for ~months before installation
- Circulated warm xenon gas through the TPC and two hot Zr getters in parallel (SAES MonoTorr) before cooldown

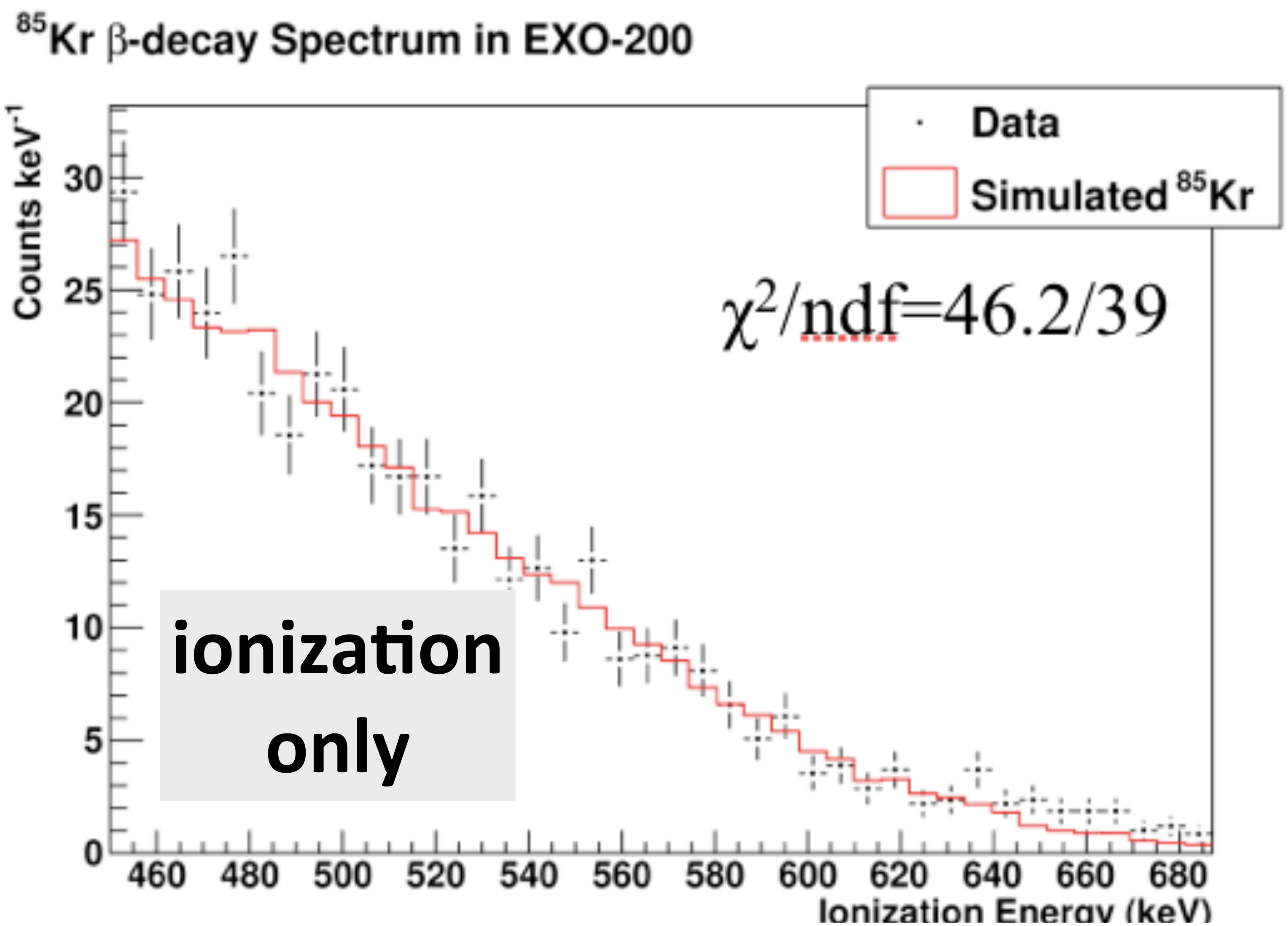




Krypton-85

The total Kr in the ^{nat}LXe used for the EXO-200 engineering run was measured to be, using a special technique involving mass-spec*, $(42.6 \pm 5.7) \cdot 10^{-9}$ g/g

[NIM A675 (2012) 40]

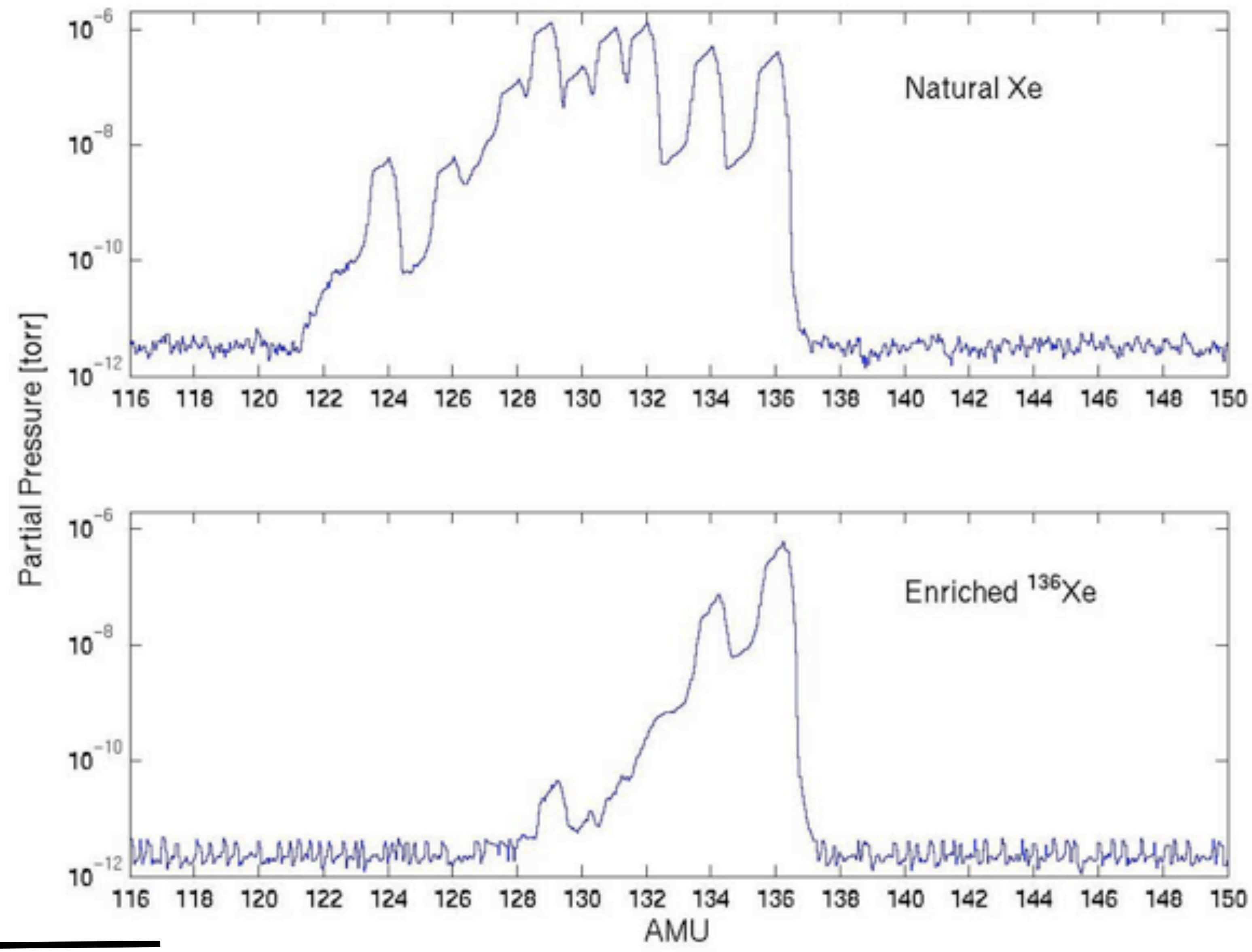


→ Consistent with Mass Spec result assuming standard concentration:

^{85}Kr/Kr ~10^{-11}

Xenon Enrichment (80.6% Xe-136)

- The enr-Xe fill showed an unexpected electronegative impurity level due to some unknown centrifuge lubricant

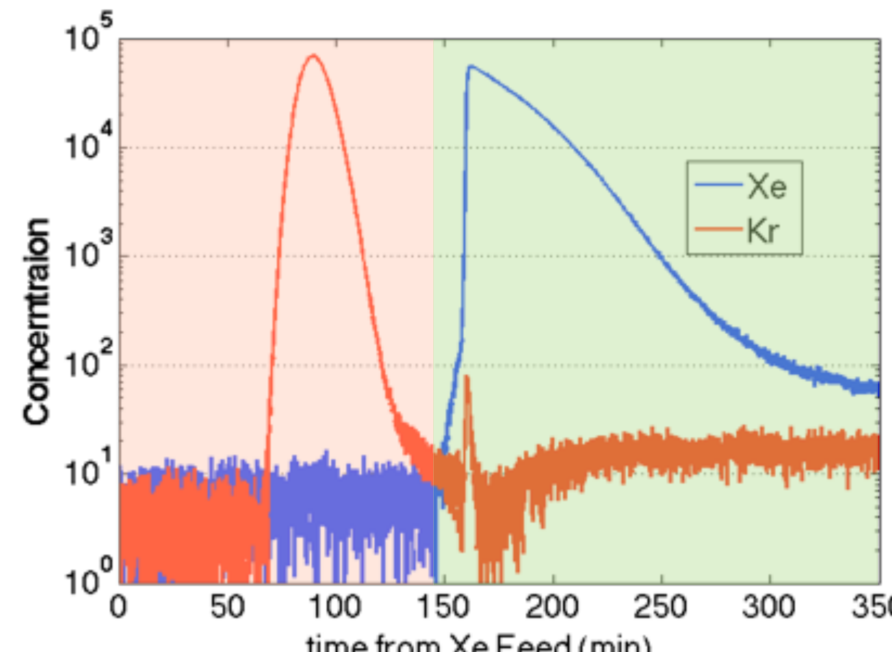


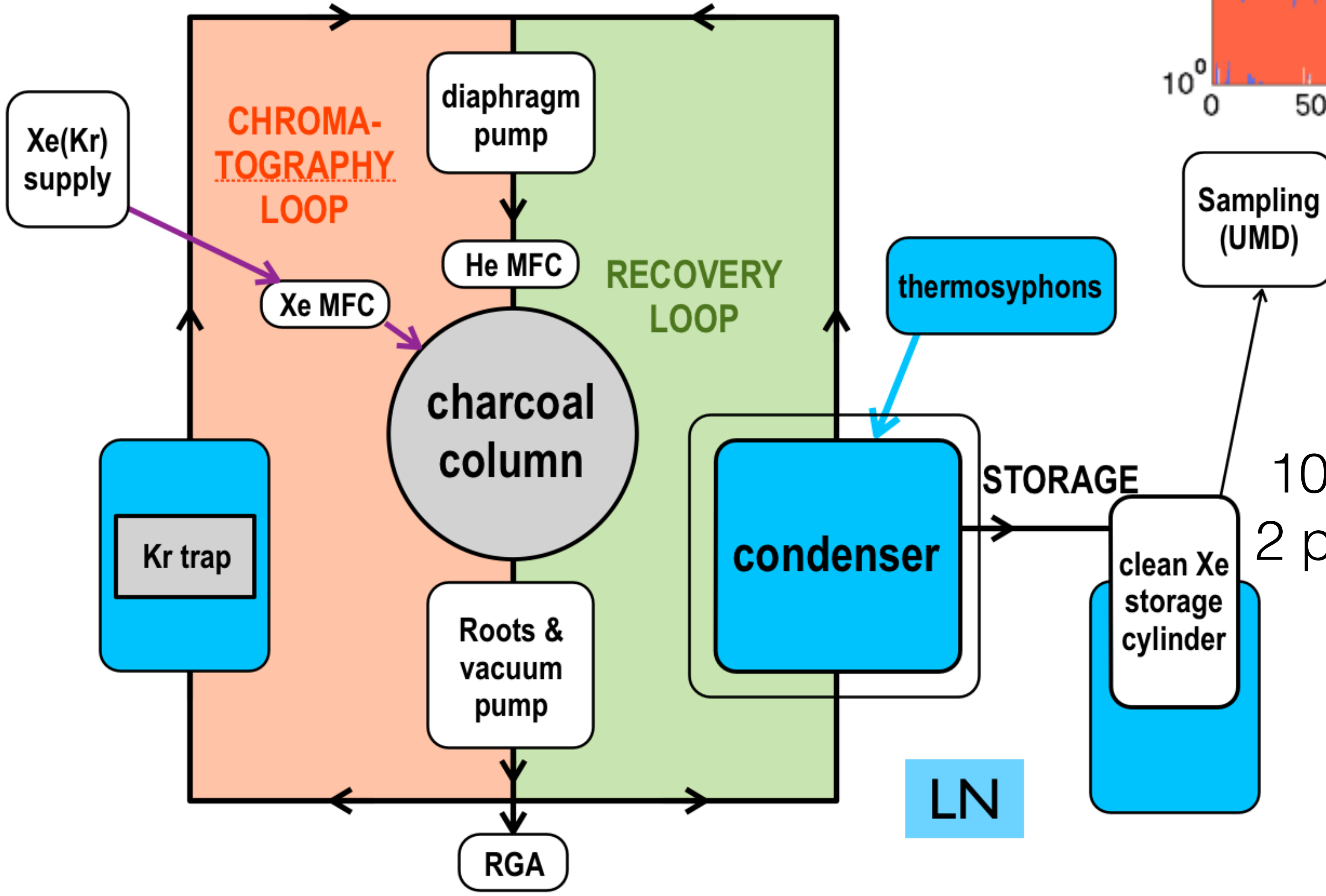
Depletion of light noble elements:
Kr-85 (<0.4 ppb)
Ar-39, Ar-42

De-Kryptonation in LXe - LUX/LZ, chromatography

Gas charcoal chromatography Kr removal system

For LUX: 400 kg processed at Case:
130 ppb reduced to 4 ppt





LZ plan:
10t to be processed at SLAC
2 passes reduce to 0.015 ppt

[Courtesy of the LZ Collaboration]

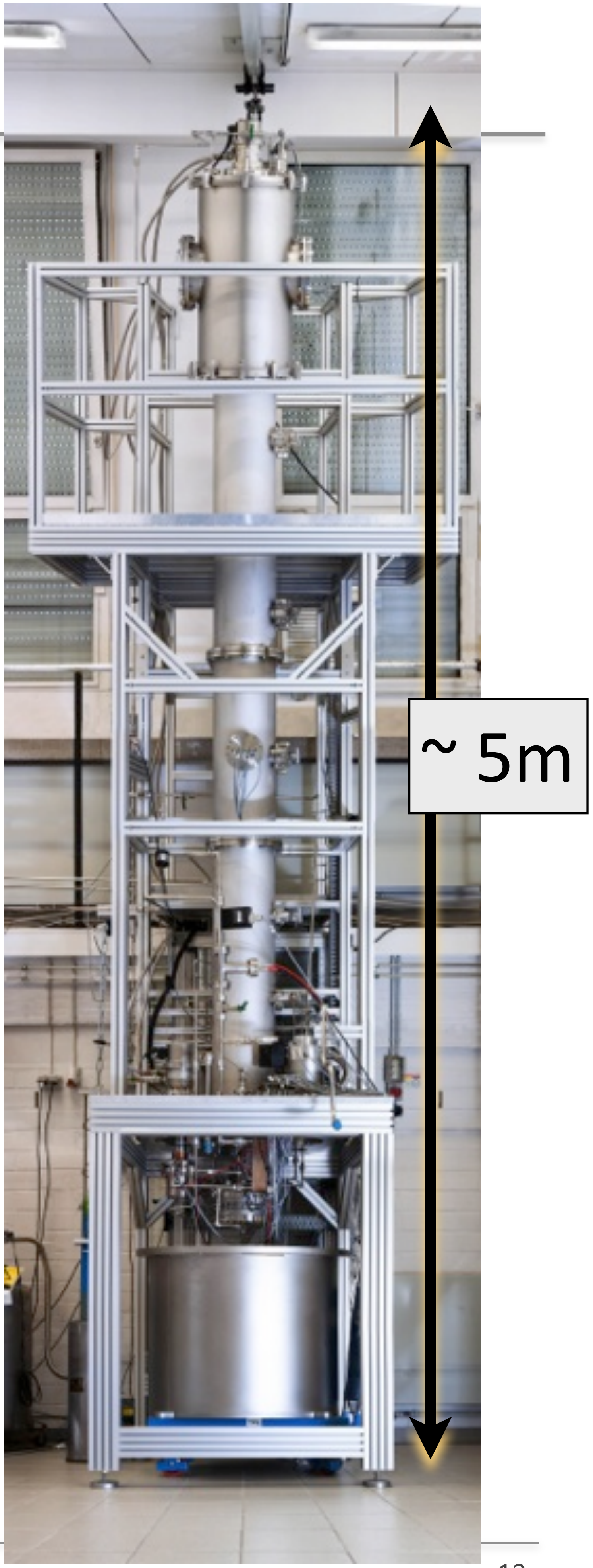
De-Kryptonation in LXe - distillation

[Astropart.Phys. 31 (2009) 290-296]

- XMASS
  - Kr/Xe ~ 3×10^{-12}

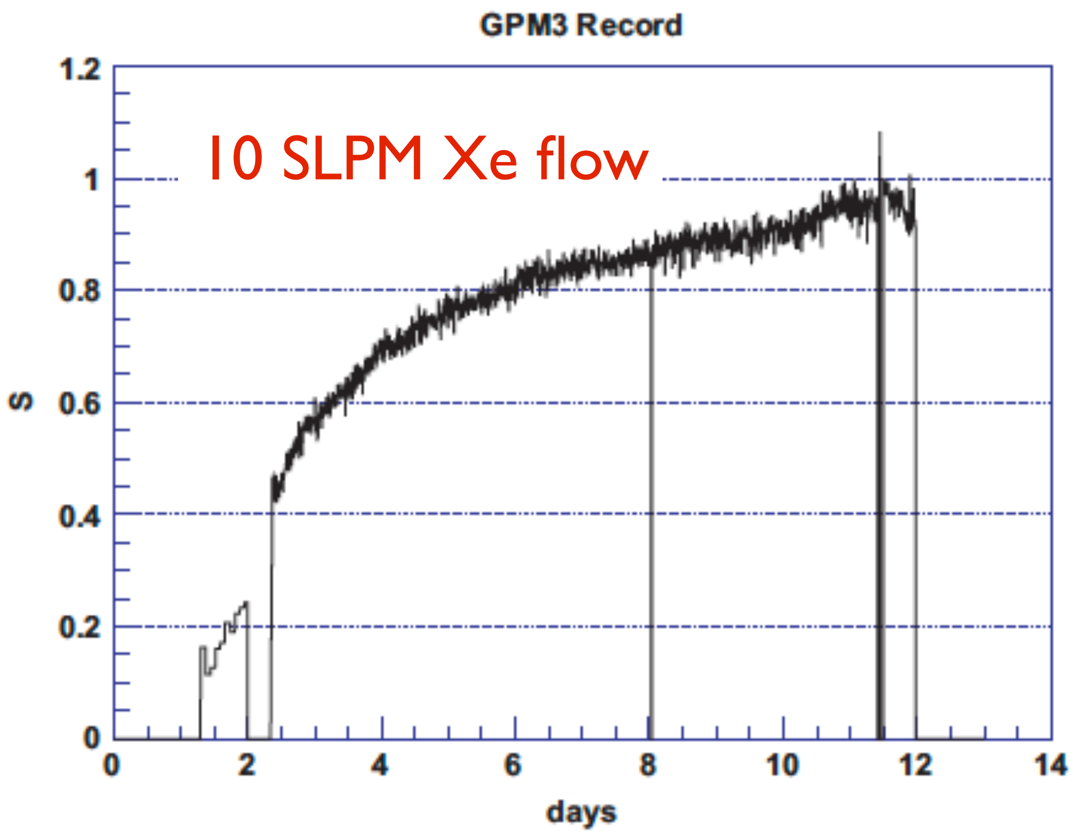
- XENON 1ton
  - Phase 1: Kr/Xe < 26×10^{-15}
  - Phase 2: >120,000× reduction

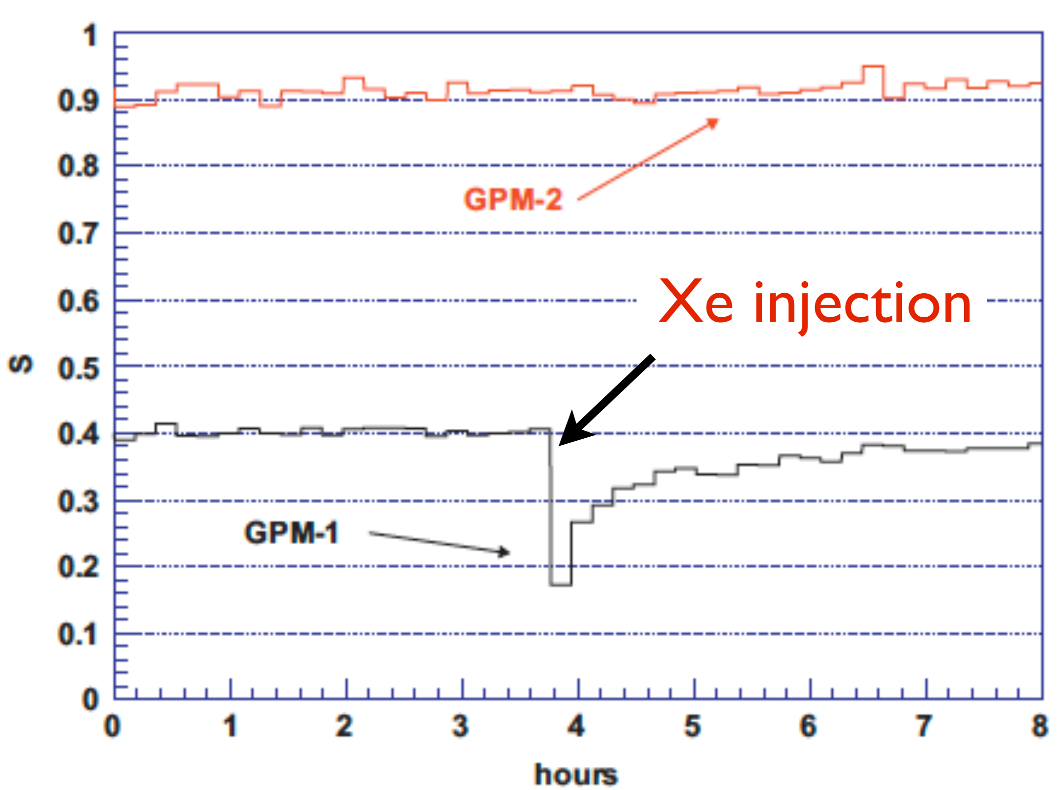
J Phys Conf Ser 564 (2014) 012006
Eur Phys J C 74, 2746 (2014)
JINST 9, P10010 (2014)

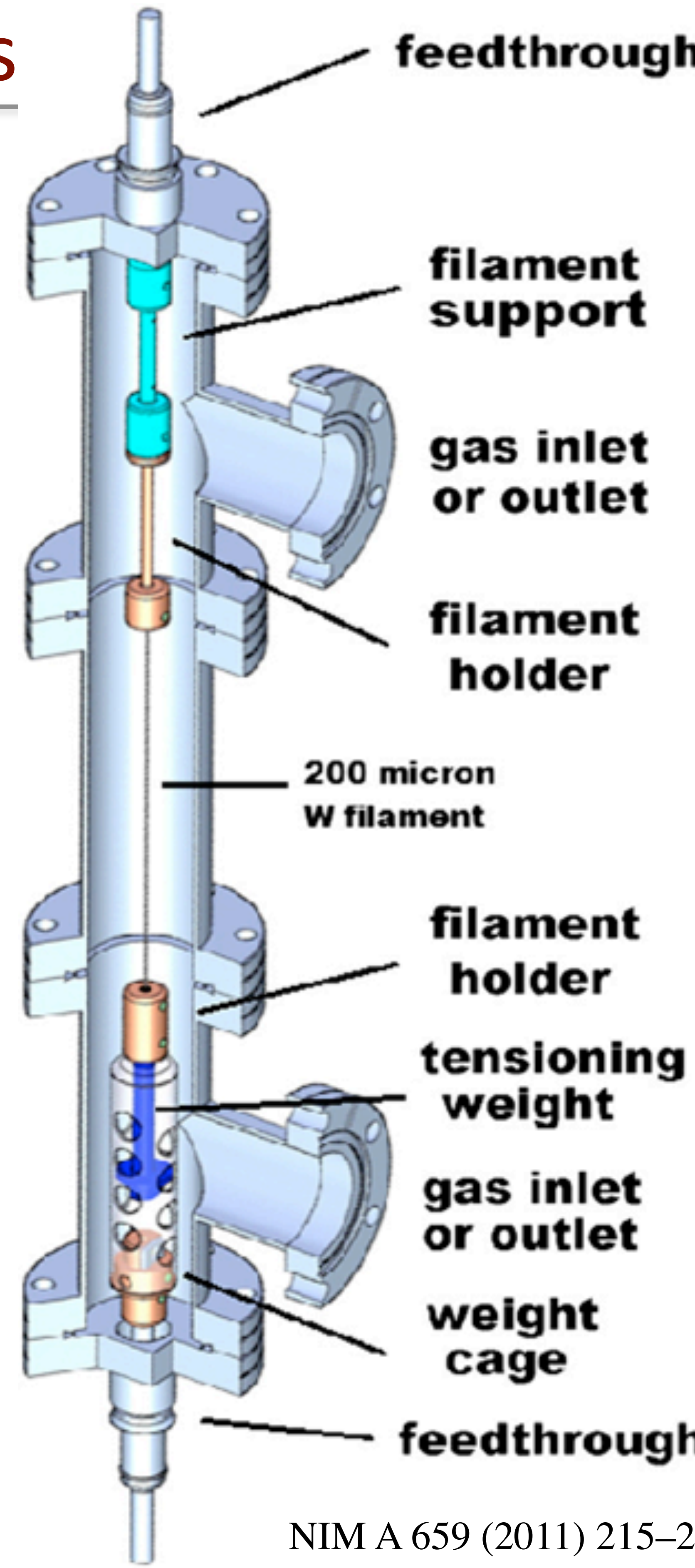


[information courtesy of Y. Suzuki and C. Weinheimer]

EXO-200 Xenon Gas purity monitors







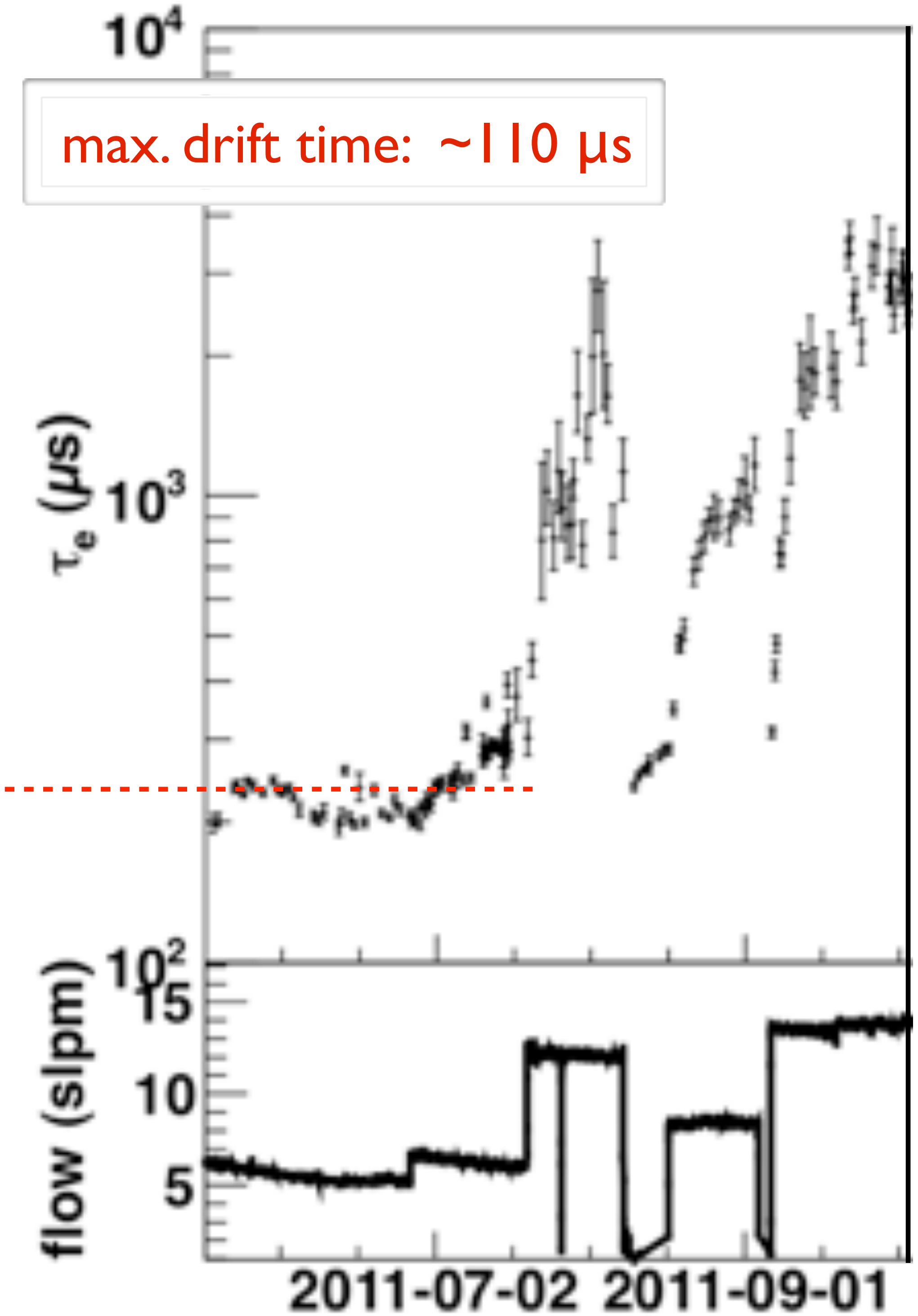
NIM A 659 (2011) 215–228

Xe purity and electron drift

- LXe purity is measured as the attenuation of the ionization signal of the 2.6 MeV full absorption peak of Tl-208 versus drift time

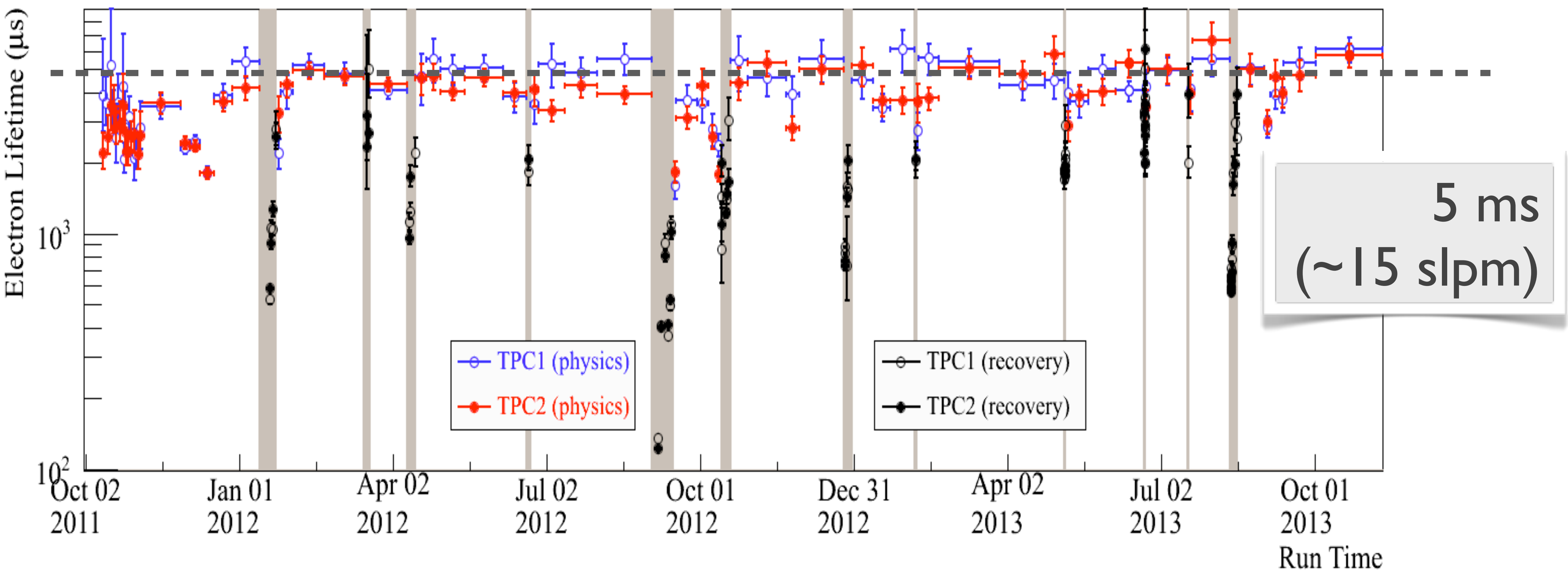
~250 μs

- First observation of 2νββ decay of Xe-136 performed at initial purity



[PRL 107, 212501 (2011)]

Xenon purity from electronegative species - Run 2

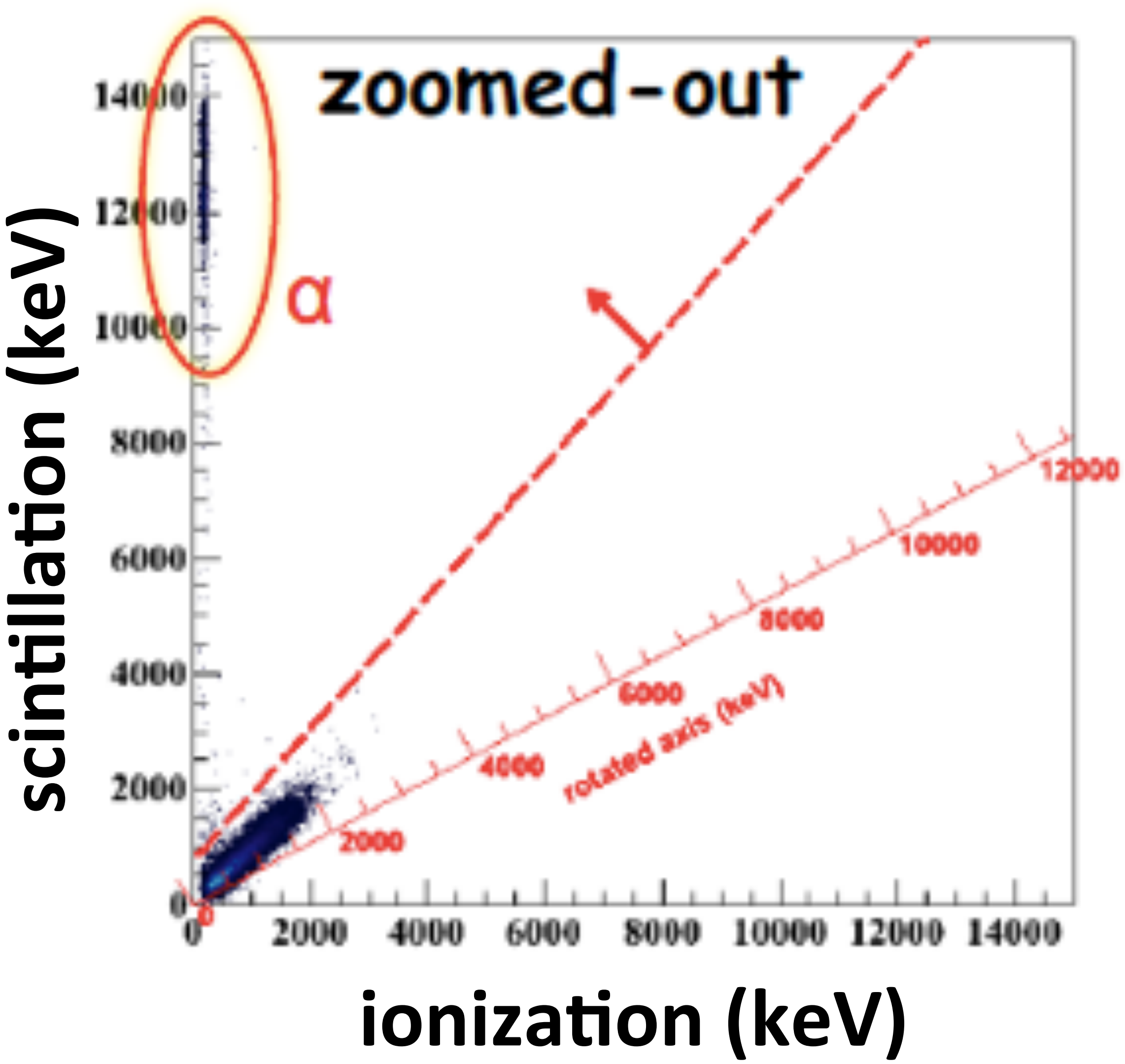


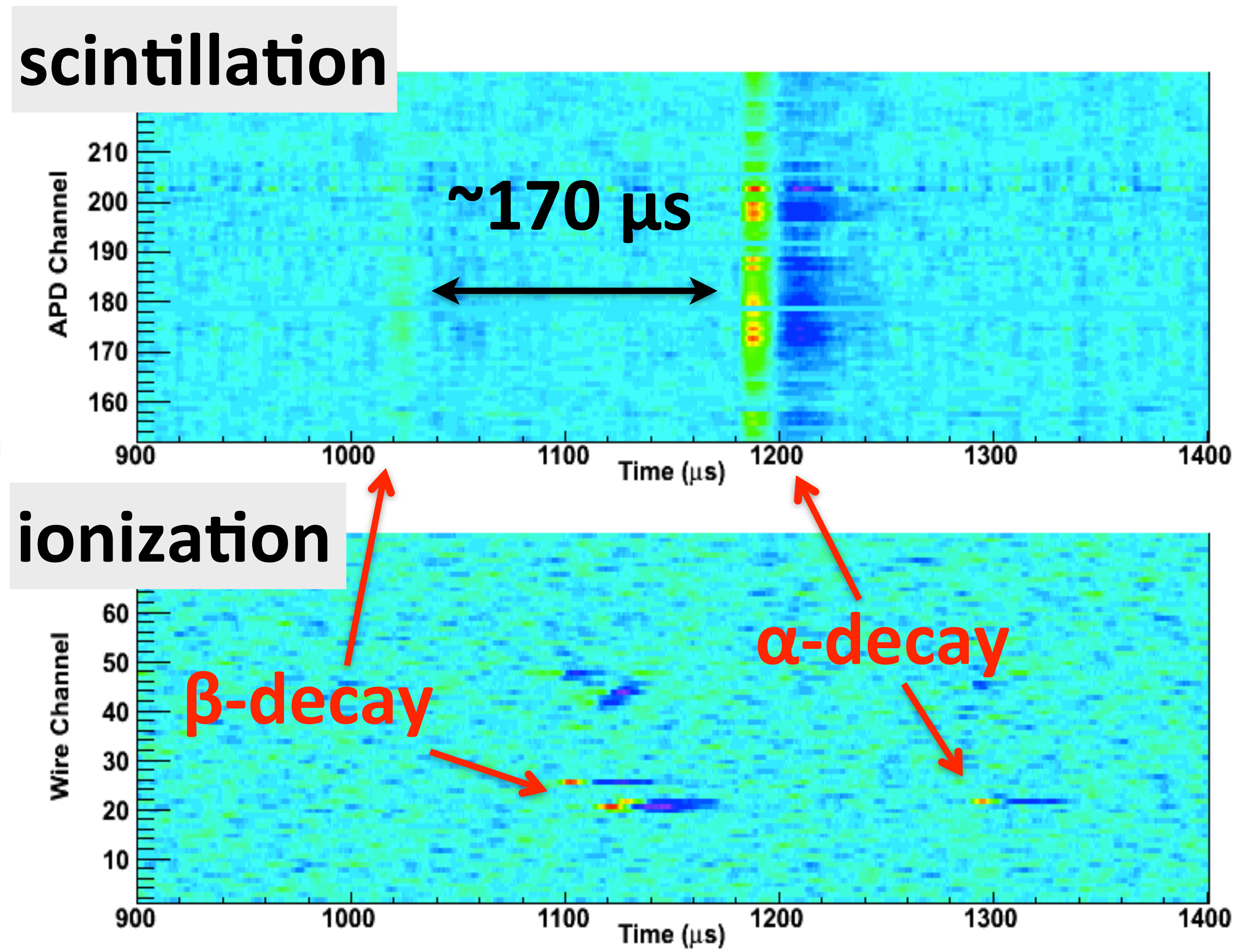
Xenon gas is forced through heated Zr getter by a custom ultraclean pump.

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*

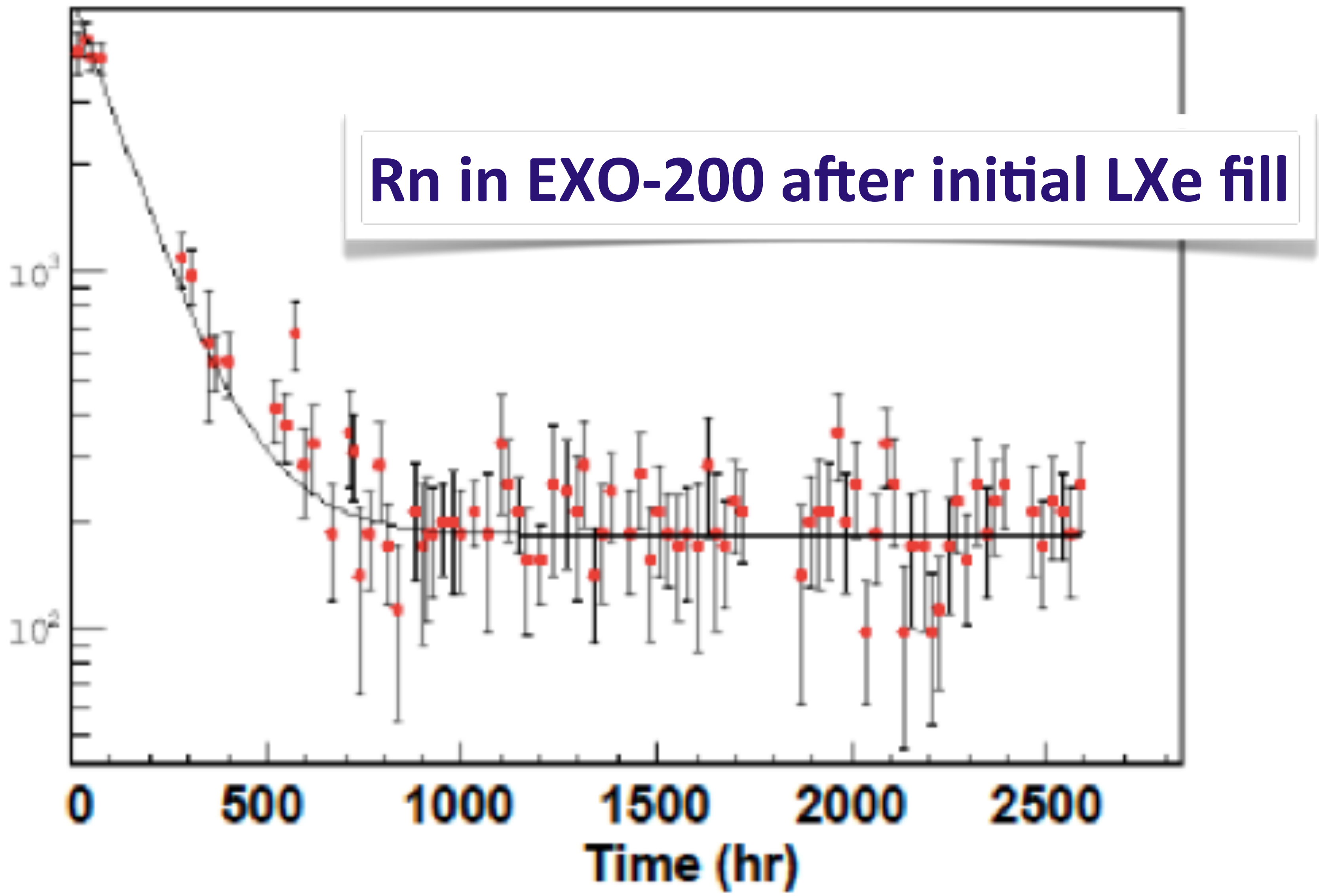
Radon from BiPo-214 events, α tagging





- Diagonal cut (large scintillation, low charge) identifies α decay
- Short time coincidence identifies BiPo-214 event

Radon in the EXO-200 LXe



Long term study shows a steady state activity in the ^{enr}LXe of 360 ± 65 μBq (fiducial volume)

~200 atoms of ^{222}Rn

Phys. Rev. C, 89, 015502 (2014).

The EXO-200 “deradonator”

- Charcoal-based
- Room temperature
- self-regenerating
- 10-30 cfm delivered
- operated at WIPP
- flush detector envelope

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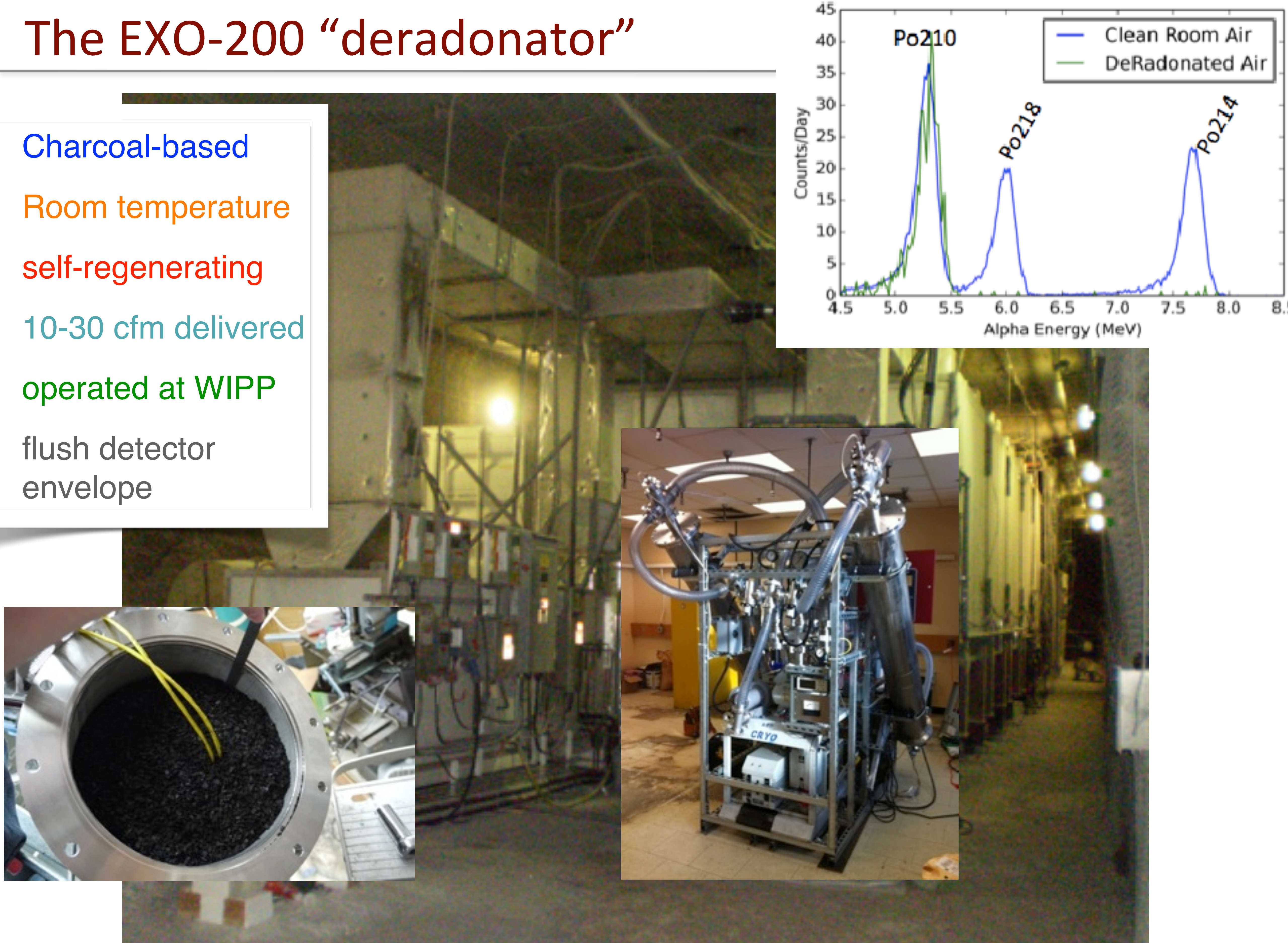
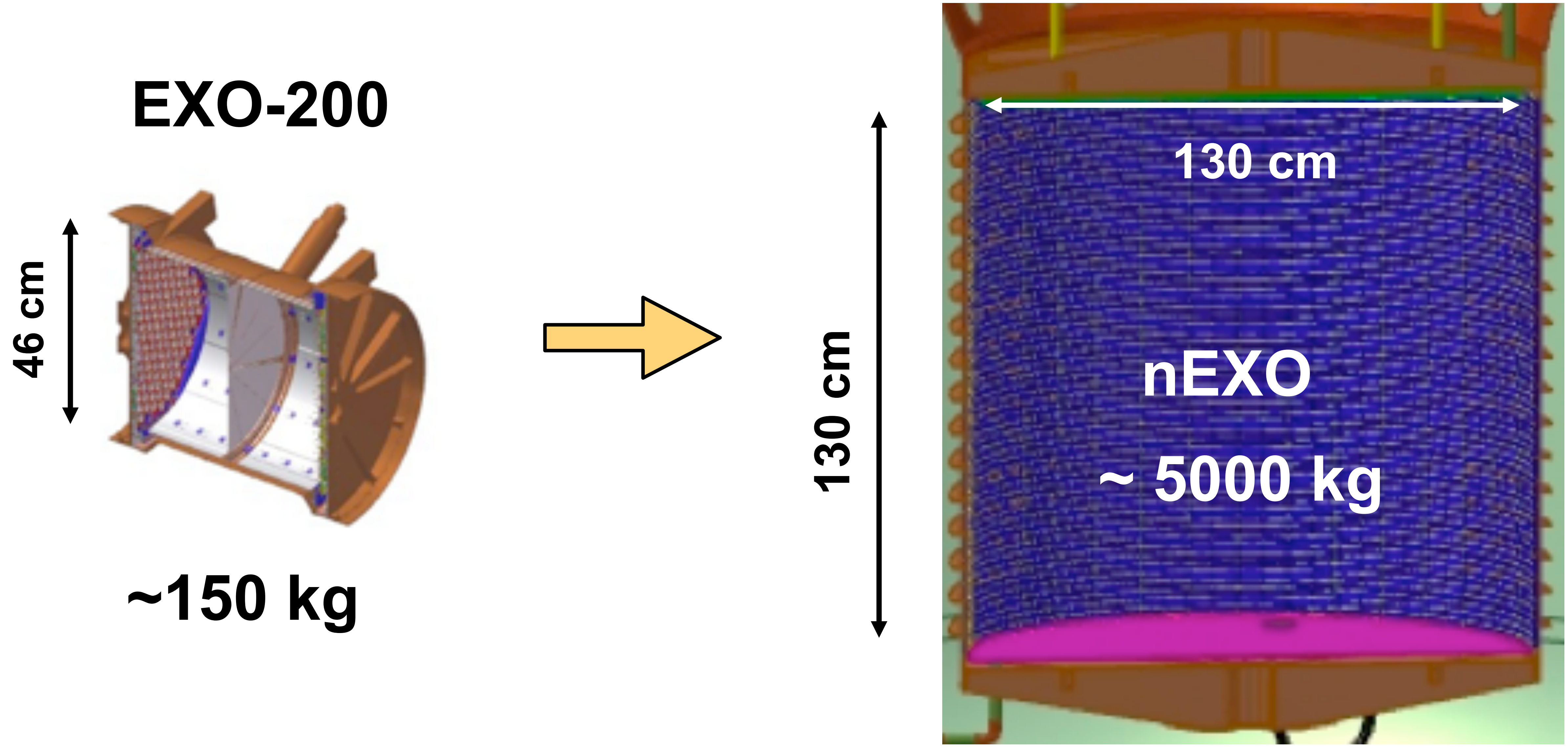


From EXO-200 to nEXO

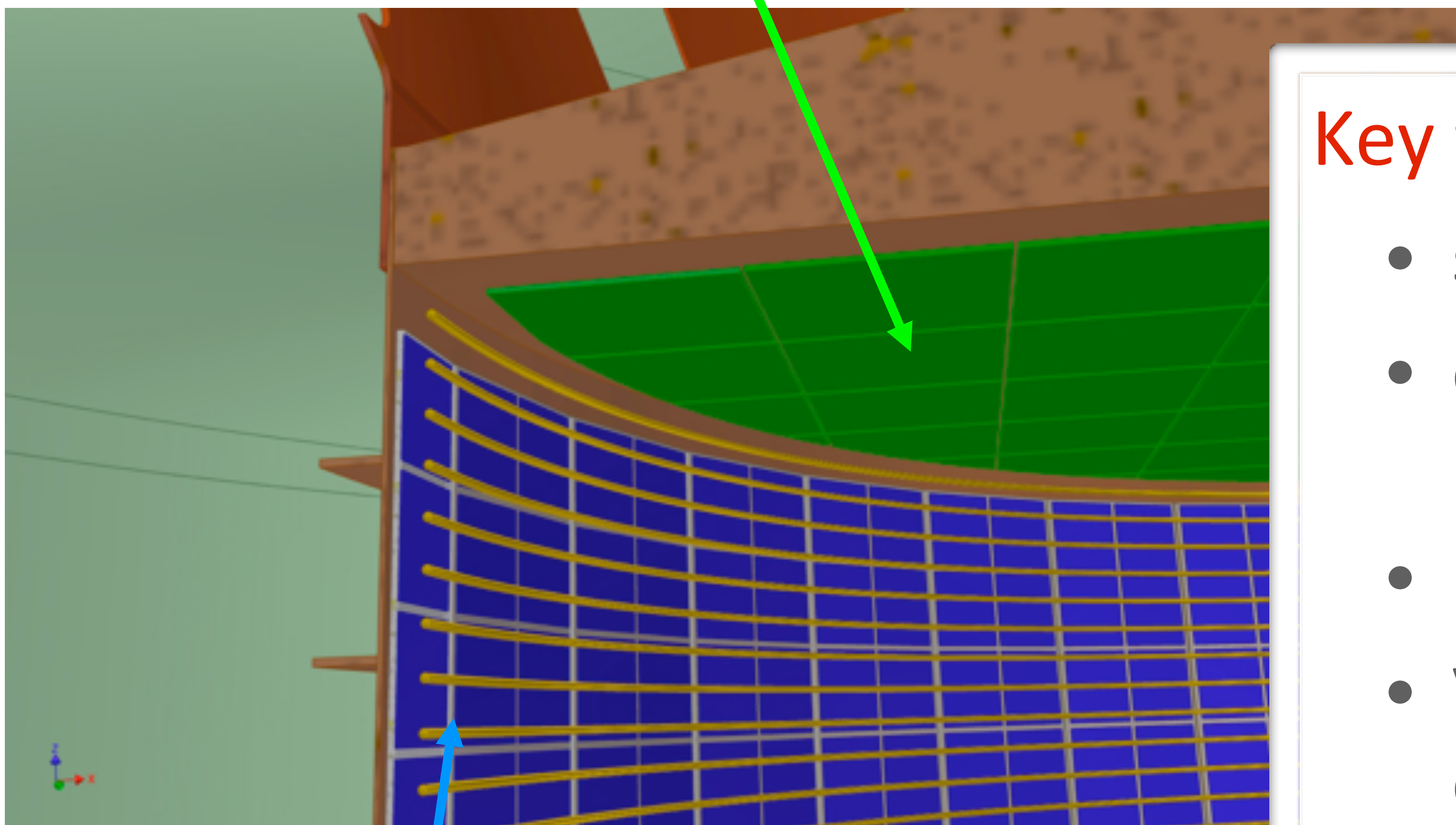
- 5 tonnes of enriched LXe
- enhanced self-shielding
- x100 better $T_{1/2}$ sensitivity

- < 1% energy resolution
- no central cathode
- ≳ 10 ms electron lifetime



nEXO TPC

Charge Readout Tiles



Silicon PhotoMultipliers
(SiPMs)

TPC: ~ 1.3 m x 1.3 m

Key features

- single drift volume
- charge collected on pads
- ‘no’ plastics
- VUV scintillation collected on SIPMs behind the field cage
- thin Cu vessel

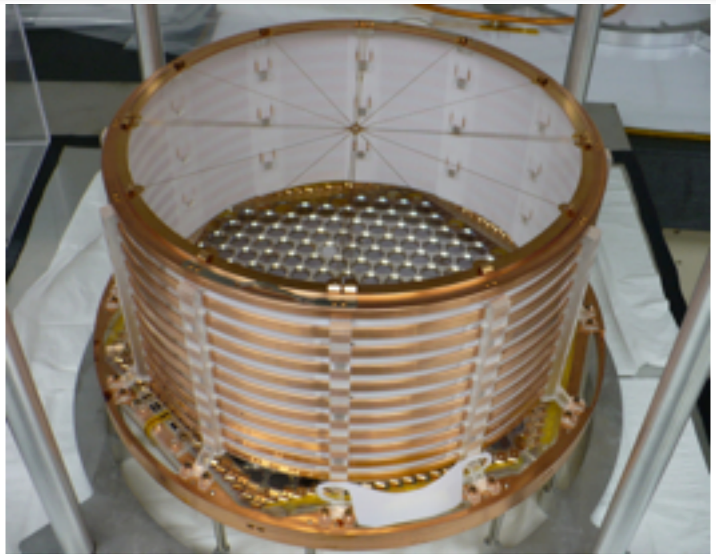
nEXO R&D in full swing

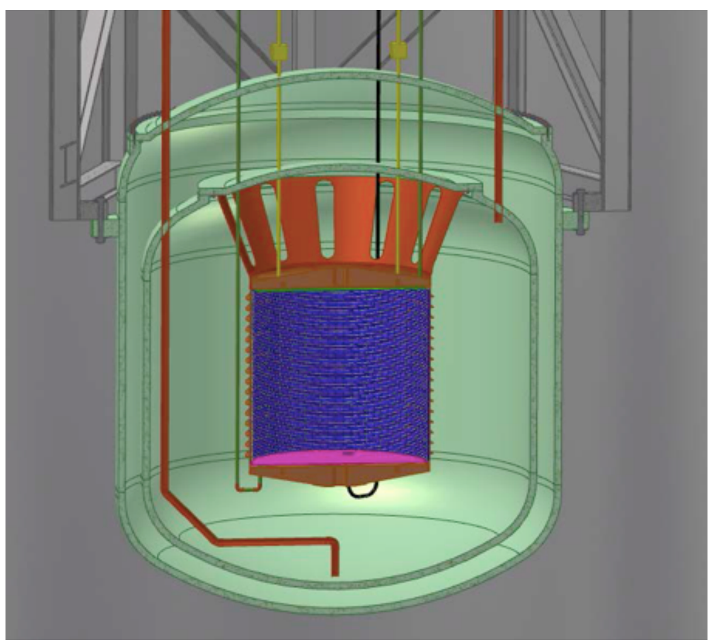
Radon mitigation for nEXO

- Target Rn level set to < 600 atoms in TPC
- EXO-200: steady-state is ~200 Rn atoms
- unknown if sources are in TPC and/or plumbing
- nEXO TPC is much larger
- Two-fold strategy: Screening and In-situ removal (trap)
- 1) enhance screening capacity with a) higher sensitivity counters; b) larger counters; c) in-line, ultralow bgnd counter
- 2) develop a Rn trap: initial work with bare metals (Cu, Ni) unsuccessful; now testing activated charcoal – but sizing might be an issue

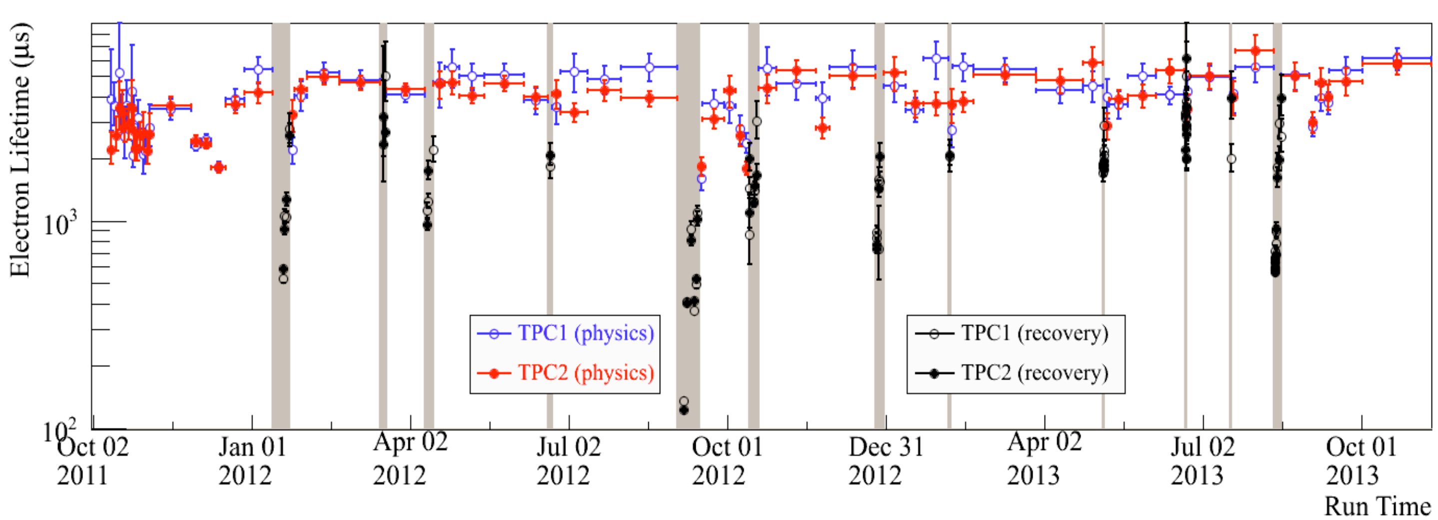
Summary

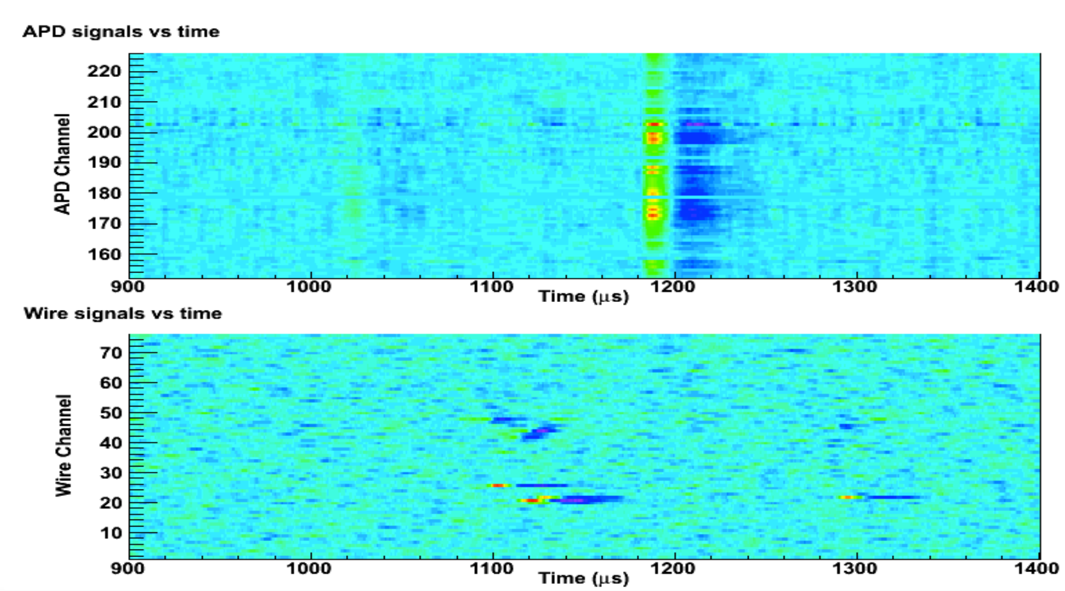
stay hungry, my friend





- EXO-200 has i) demonstrated the LXe TPC technology at the ~100 kg scale; ii) achieved excellent Xe purity and very low Rn contamination iii) indicated a plausible way towards a leading tonne-scale experiment (nEXO)
- nEXO has an active international R&D program for a tonne-scale LXe DBD experiment with x100 the sensitivity of EXO-200
- The nEXO requirements for Xe purity and Rn background are shared by the large LXe community for rare event physics





125 researchers
25 institutions
7 countries

University of Alabama, Tuscaloosa AL, USA - D. Auty, T. Didberidze, M. Hughes, A. Piepke, R. Tsang
University of Bern, Switzerland - S. Delaquis, R. Gornea, T. Tolba, J-L. Vuilleumier
Brookhaven National Laboratory, Upton NY, USA – M. Chiu, G. De Geronimo, S. Li, V. Radeka, T. Rao, G. Smith, T. Tsang, B. Yu
California Institute of Technology, Pasadena CA, USA - P. Vogel
Carleton University, Ottawa ON, Canada - Y. Baribeau, V. Basque, M. Bowcock, M. Dunford, K. Graham, P. Gravelle, R. Killick, T. Koffas, C. Licciardi, E. Mane, K. McFarlane, R. Schnarr, D. Sinclair
Colorado State University, Fort Collins CO, USA - C. Chambers, A. Craycraft, W. Fairbank, Jr., T. Walton
Drexel University, Philadelphia PA, USA - M.J. Dolinski, J.K. Gaison, Y.H. Lin, E. Smith, Y.-R Yen
Duke University, Durham NC, USA - P.S. Barbeau, G. Swift
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IHEP Beijing, People's Republic of China - G. Cao, X. Jiang, H. Li, Z. Ning, X. Sun, N. Wang, W. Wei, L. Wen, W. Wu
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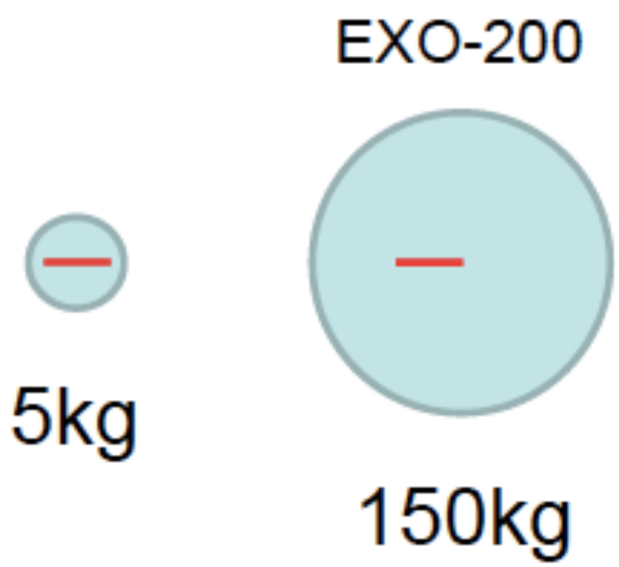
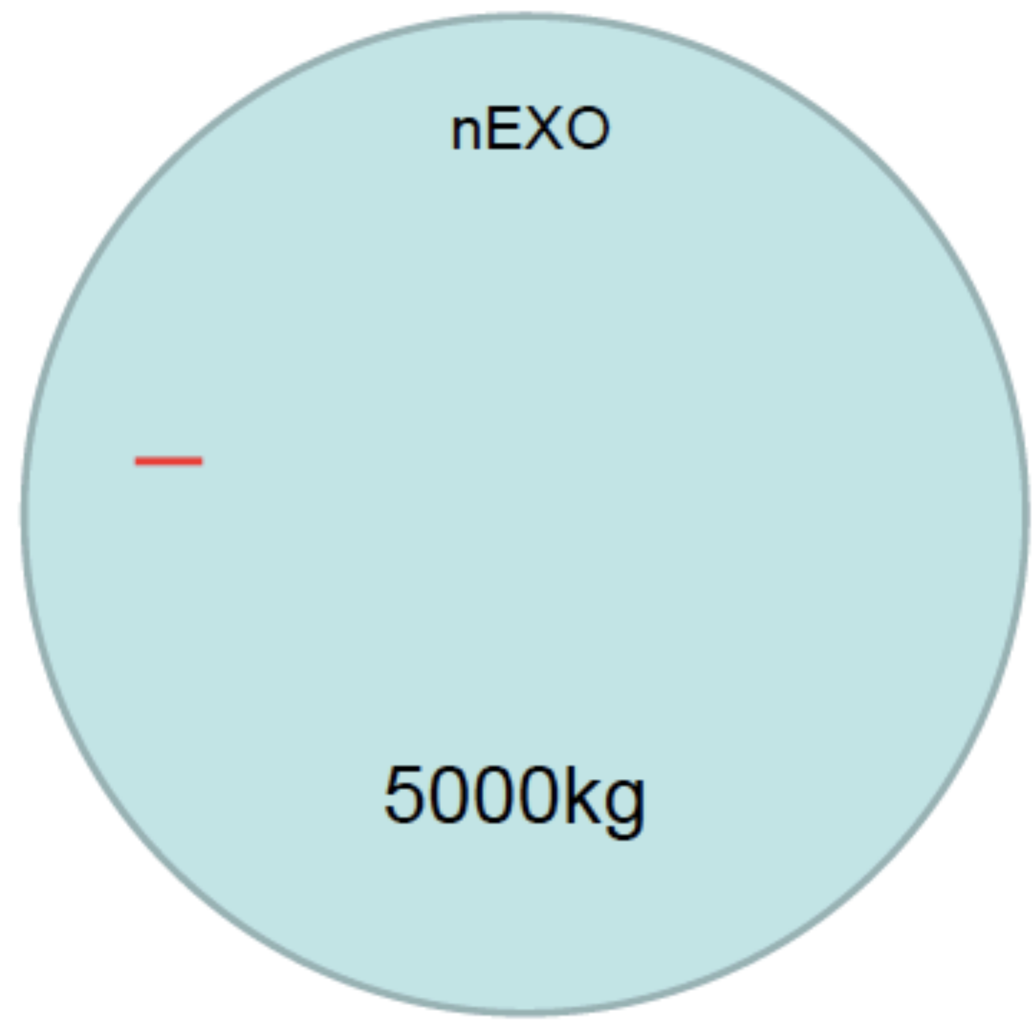
University of Massachusetts, Amherst MA, USA - J. Dalmasson, S. Johnston, A. Pocar
Oak Ridge National Laboratory, Oak Ridge TN, USA – L. Fabris, D. Hornback, R.J. Newby, K. Ziock
IBS Center for Underground Physics, Daejeon, South Korea - D.S. Leonard
SLAC National Accelerator Laboratory, Menlo Park CA, USA - T. Daniels, K. Fouts, G. Haller, R. Herbst, K. Nishimura, A. Odian, P.C. Rowson, K. Skarpaas
University of South Dakota, Vermillion SD, USA – R. MacLellan
Stanford University, Stanford CA, USA - T. Brunner, J. Chaves, R. DeVoe, D. Fudenberg, G. Gratta, M. Jewell, S.Kravitz, D. Moore, I. Ostrovskiy, A. Schubert, K. Twelker, M. Weber
Stony Brook University, SUNY, Stony Brook, NY, USA – K. Kumar, O. Njoya, M. Tarka
Technical University of Munich, Garching, Germany - P. Fierlinger, M. Marino
TRIUMF, Vancouver BC, Canada – J. Dilling, P. Gumplinger, R. Krücken, F. Retière, V. Strickland

From EXO-200 to nEXO



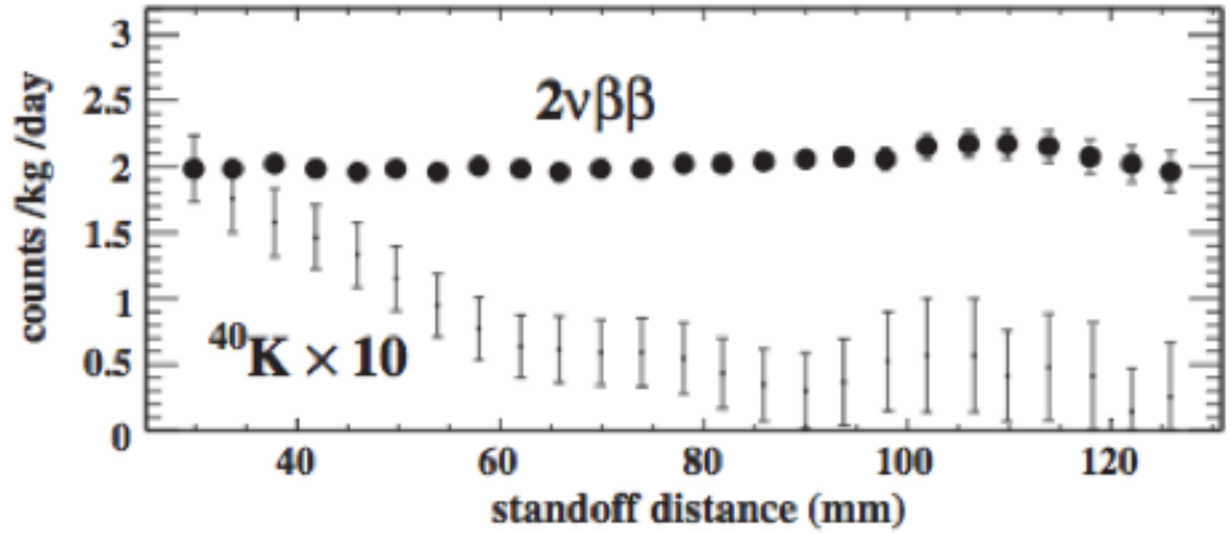


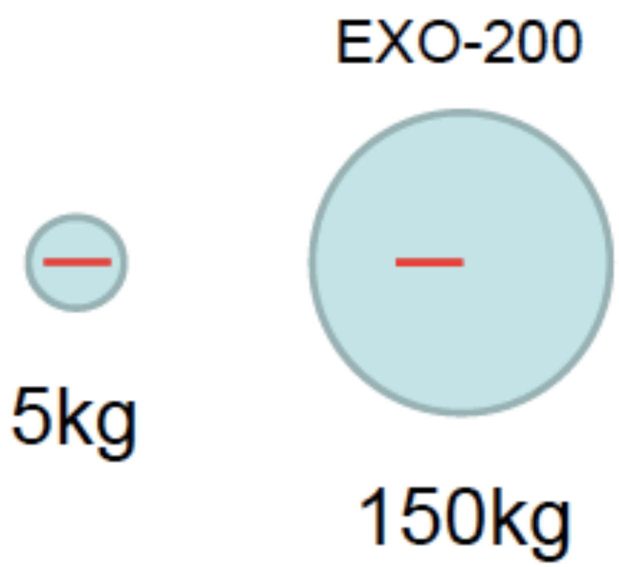
LXe mass (kg)	Diam. or length (cm)
5000	130
150	40
5	13

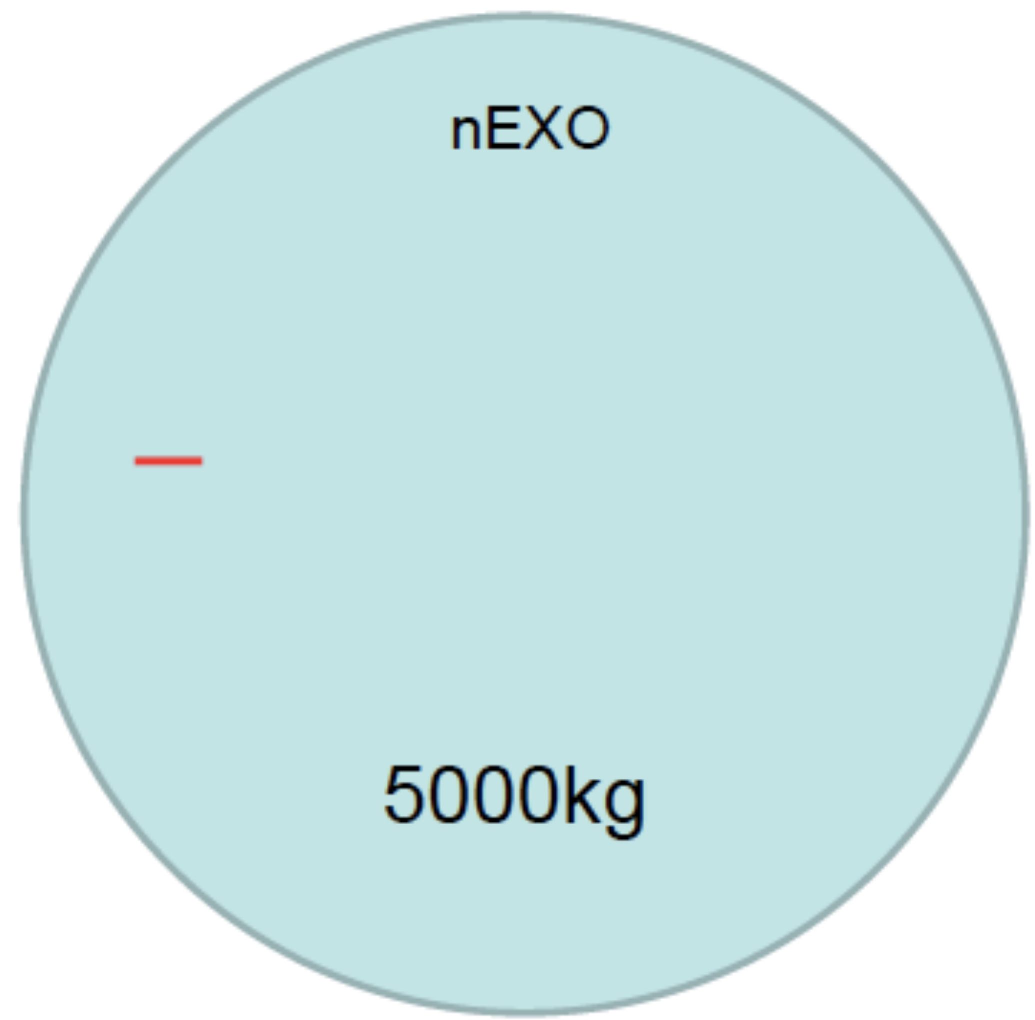
2.5MeV γ ray attenuation length 8.5 cm = —

Monolithic design is dramatically improves performance with size

From EXO-200 to nEXO







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Self shielding (EXO-200)