The Enriched Xenon Observatory

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for the EXO Collaboration

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The Enriched Xenon Observatory (EXO)

The goal of EXO is to search for neutrinoless double beta decay of ^{136}Xe using a large-scale Xe detector with Ba^+ tagging.

Motivation for the EXO detector

Ba^+ tagging

- -Ba^+ trapping
- -Daughter ion extraction

Ton-scale Xe detector technologies

- -Liquid-phase research and development
- -Gas-phase research and development

EXO-200 detector

- -Recent progress
- -Schedule

Sensitivity

$$S_{1/2}^{0\nu} \propto \varepsilon \frac{a}{A}\left[\frac{MT}{B\Gamma}\right]^{1/2}$$

ε is efficiency
a is isotopic abundance
A is atomic mass
M is source mass
T is time
B is background
Γ is resolution

To maximize sensitivity:

- Large mass
- Low background
- High detection efficiency
- Good energy resolution

In addition, identification of the daughter isotope would reject most sources of background and confirm double beta decay.

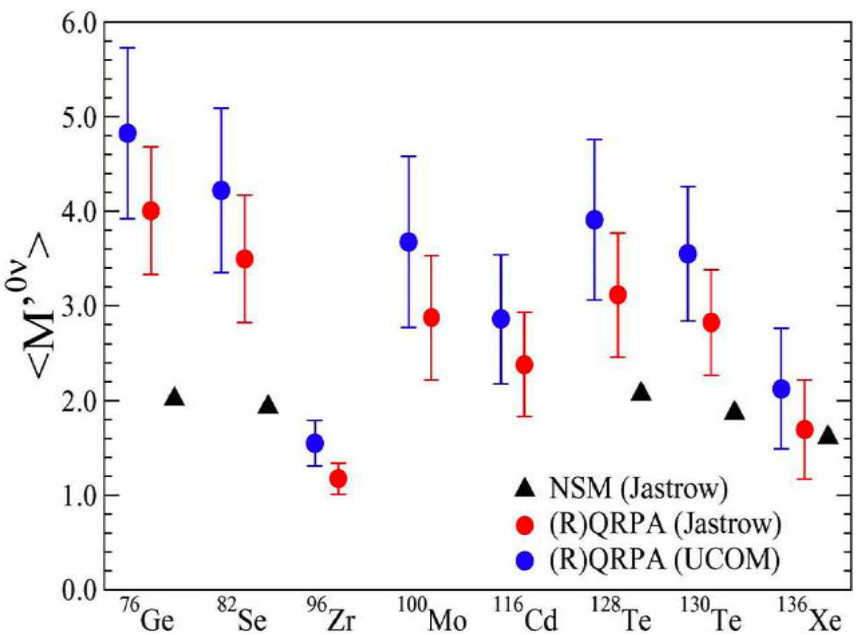
Choice of isotope

EXO will search for the decay:

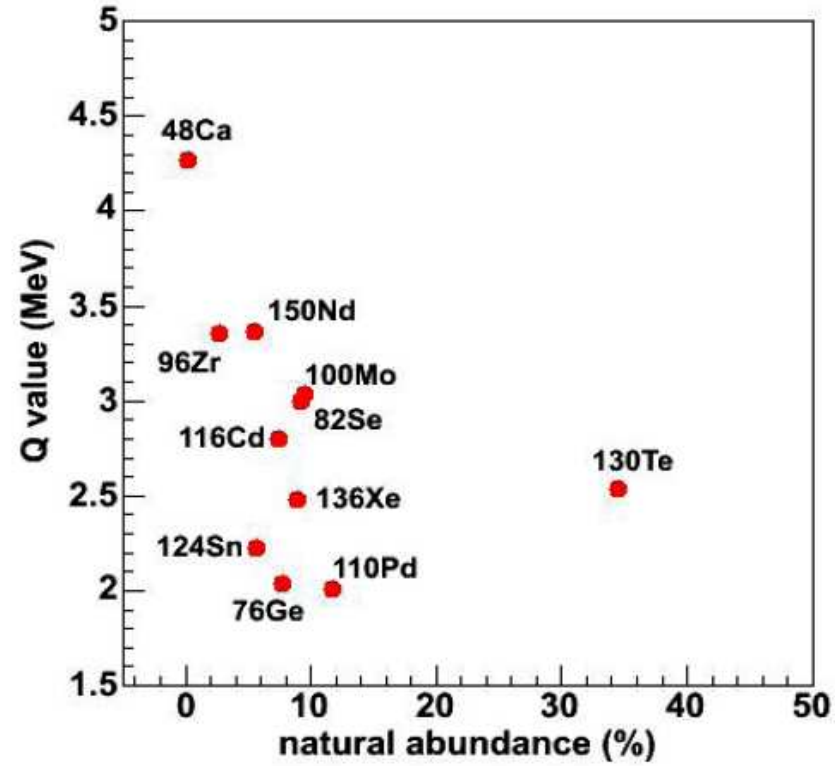
$$^{136}Xe \rightarrow {}^{136}Ba + 2e^-$$

$$T_{1/2}^{0\nu} > 1.2 \times 10^{24}\ y\ (90\%\ C.L.)$$

R.Bernabei et. al., Phys.Lett. 546B, 23 (2002)



F.Simkovic et al., Phys.Rev.C77:045503,2008



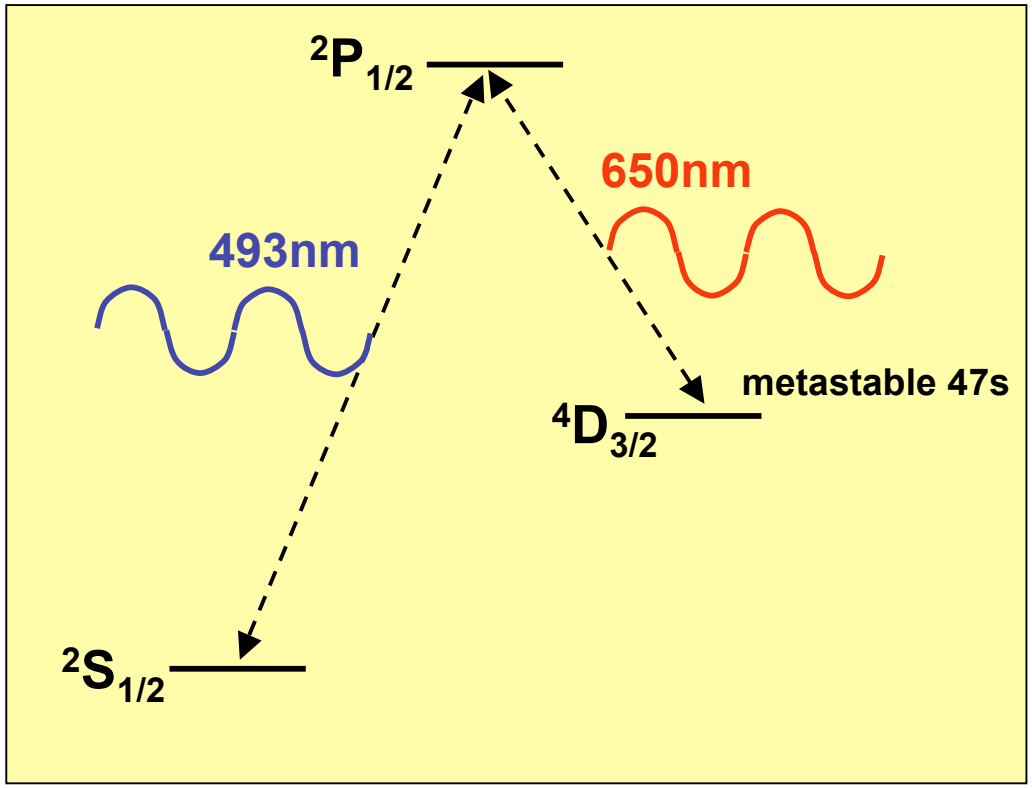
Natural isotopic abundance of 8.9 %
-Inexpensive enrichment

Q-value of 2479 keV
-favorable phase space
-above most naturally occurring γ-rays

Ba^+ tagging

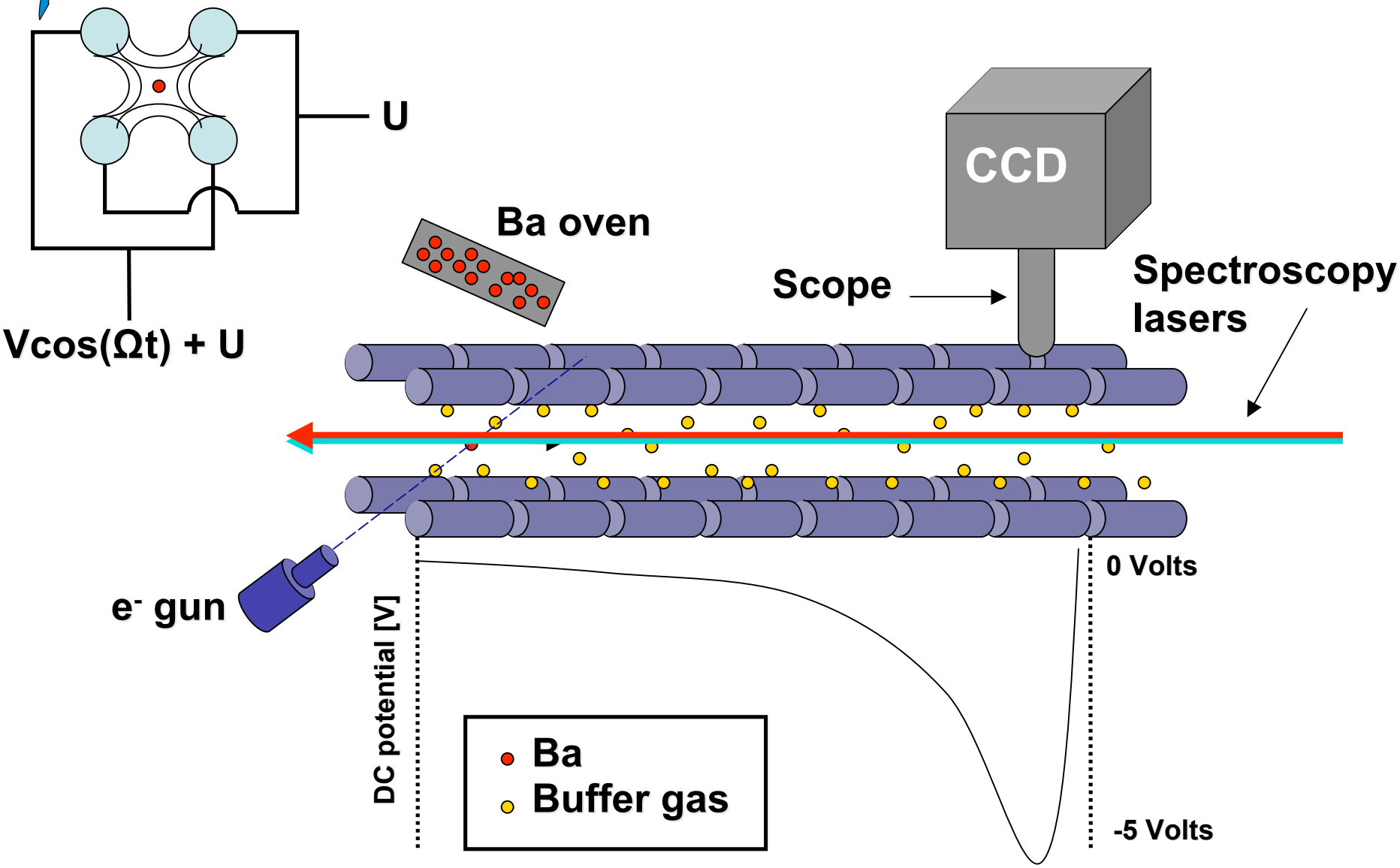
$^{136}Xe \rightarrow {}^{136}Ba^{++} + 2e^-$

- Ba^+ system best studied (Neuhauser, Hohenstatt, Toshek, Dehmelt 1980)
- Very specific signature
- Single ions can be detected from a photon rate of 10^7/s

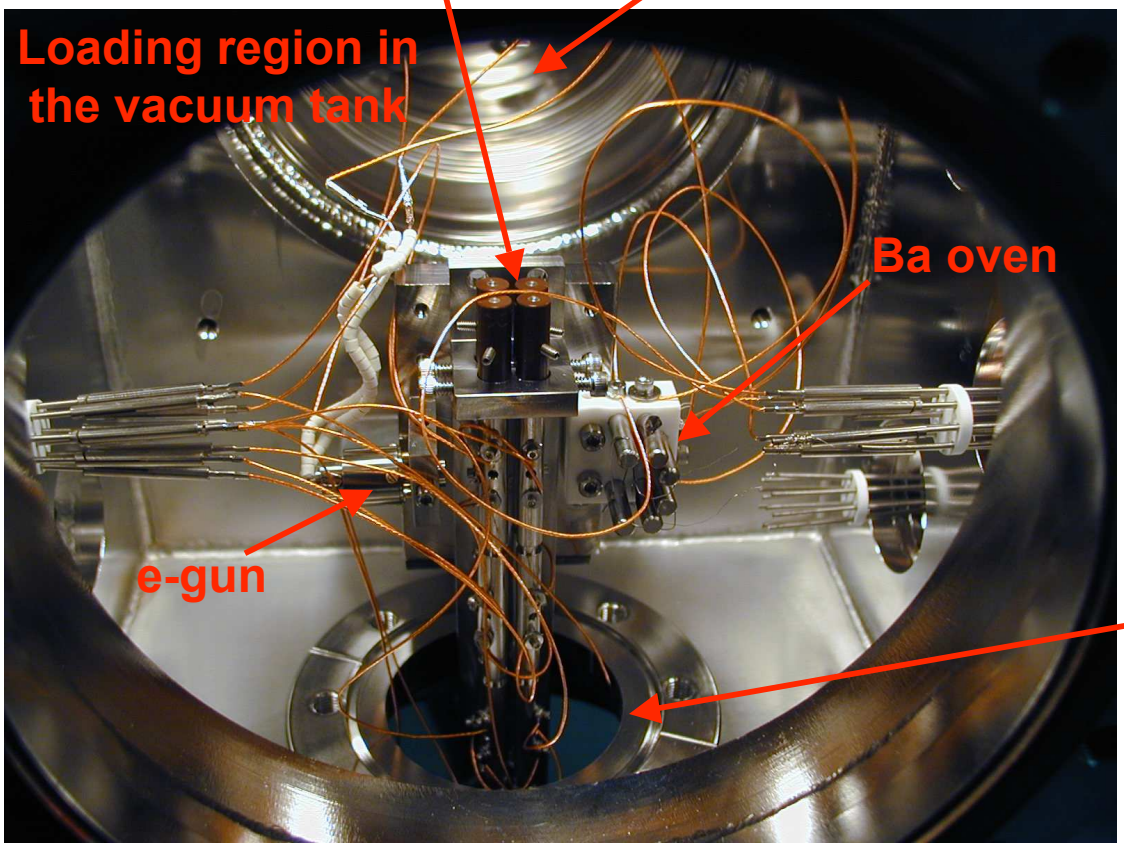


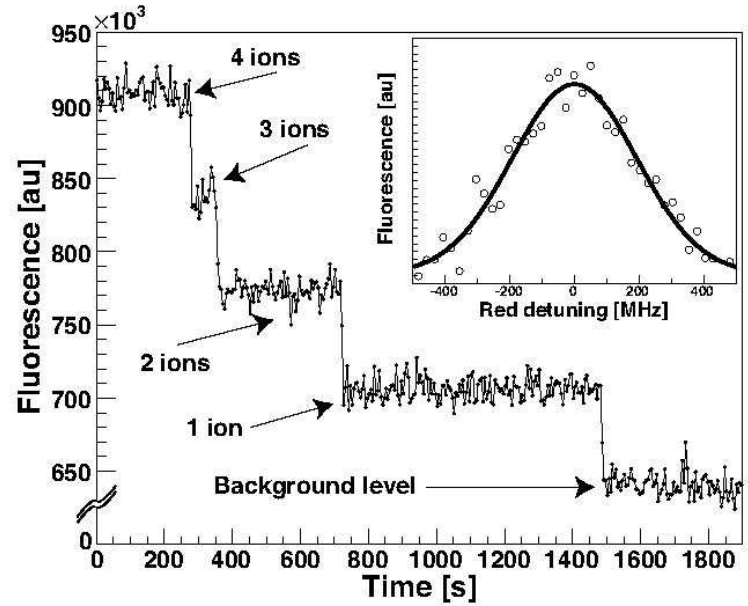
Ba^+ tagging would allow for the elimination of all backgrounds except the background from $2\nu\beta\beta$.

Trapping


U
Vcos(Ωt) + U
Ba oven
CCD
Scope
Spectroscopy lasers
e- gun
DC potential [V]
0 Volts
-5 Volts
Ba
Buffer gas

Trapping





~9σ discrimination in 25s integration

M.Green et al., Phys Rev A 76 (2007) 023404

B.Flatt et al., NIM A 578 (2007) 409

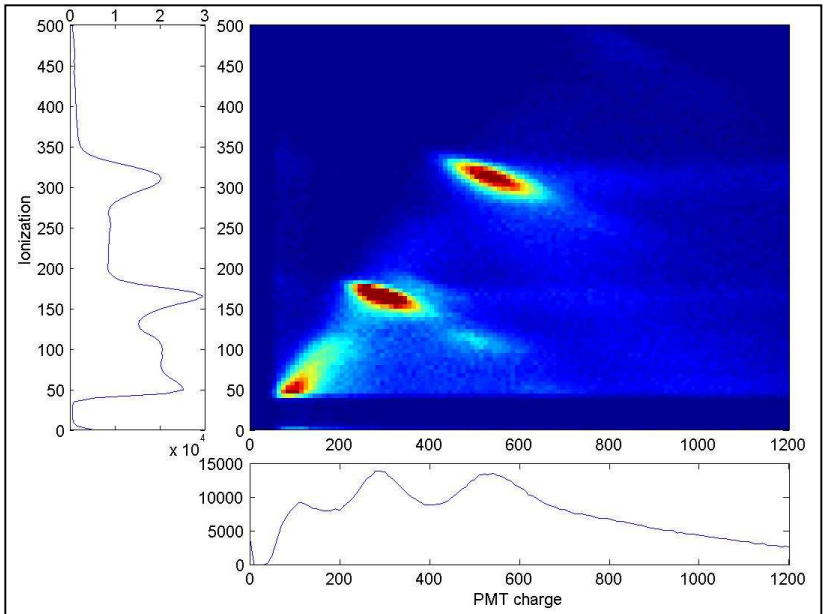
Liquid-phase R&D

Advantages of LXe detector:

- -Compact detector
- -Low background

Development:

- -EXO-200
- -Ba^+ extraction probes

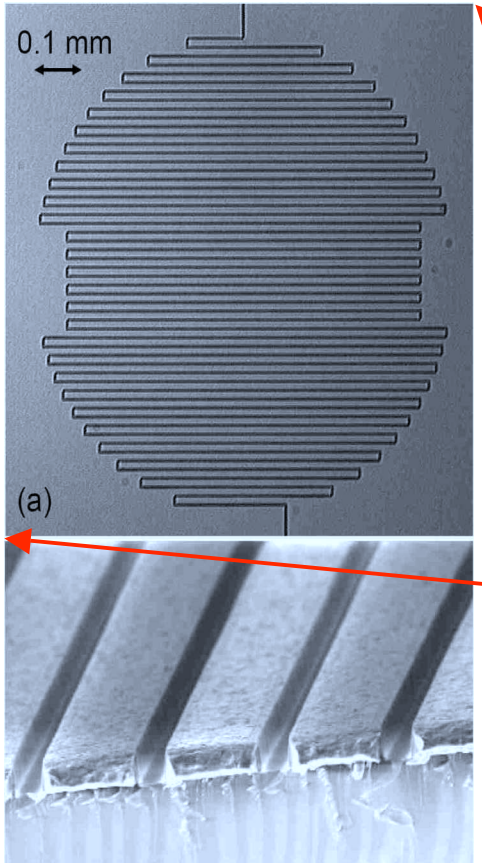


Ionization alone:
σ(E)/E = 3.8% @ 570 keV
or 1.8% @ $Q_{\beta\beta}$

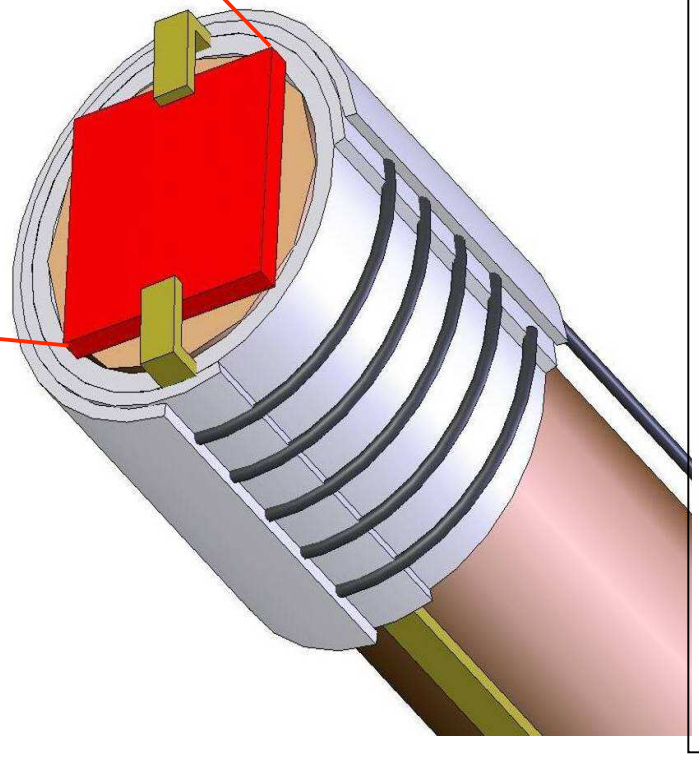
Ionization & Scintillation:
σ(E)/E = 3.0% @ 570 keV
or 1.4% @ $Q_{\beta\beta}$

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

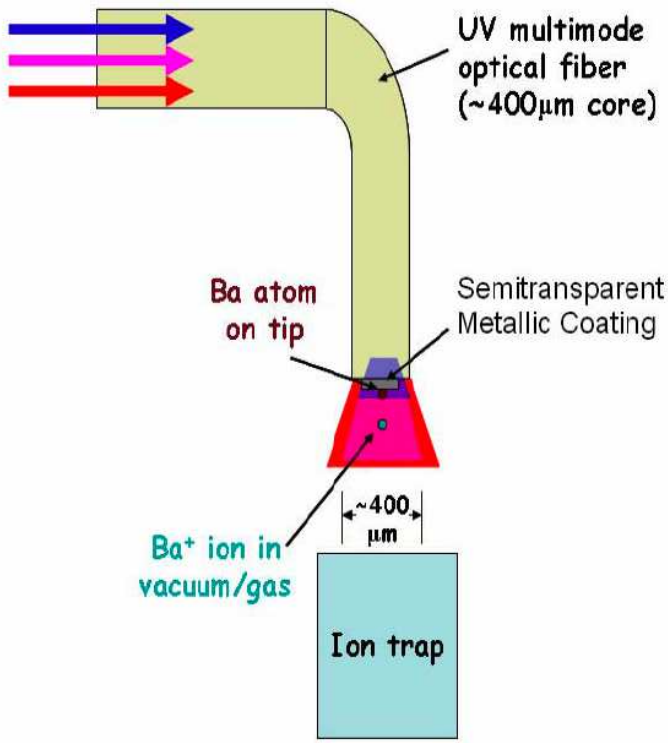
Ba^+ extraction - Liquid phase



Cryogenic probe



Resonance-ionization spectroscopy (RIS)



P.Fierlinger et al, Rev. Sci. Instr. 79, 045101 (2008)

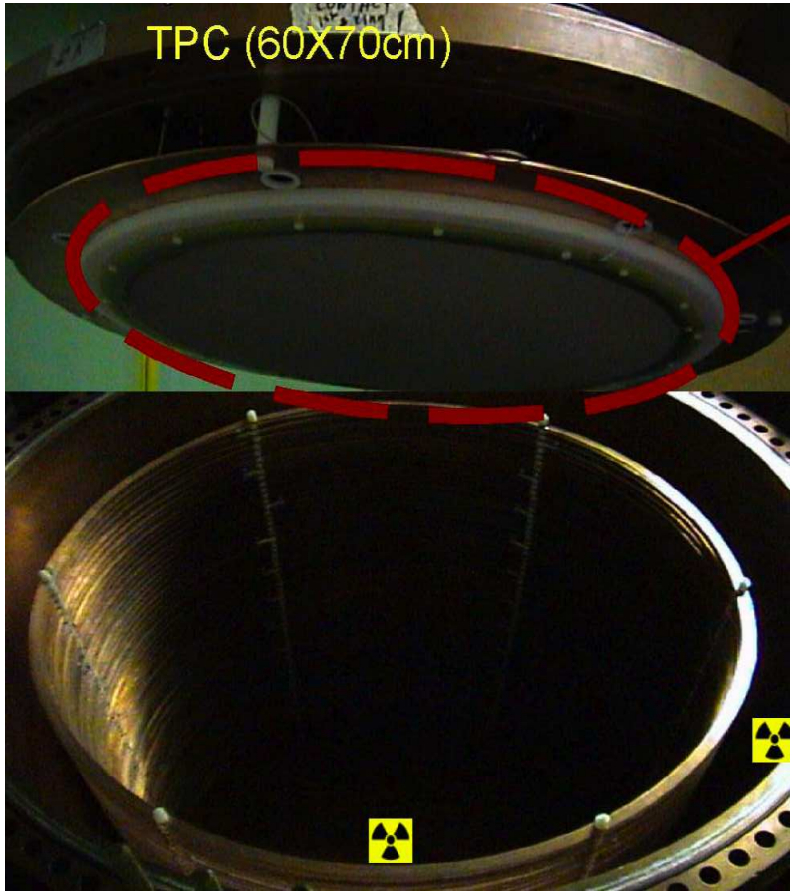
Gas-phase R&D

Advantages of GXe detector:

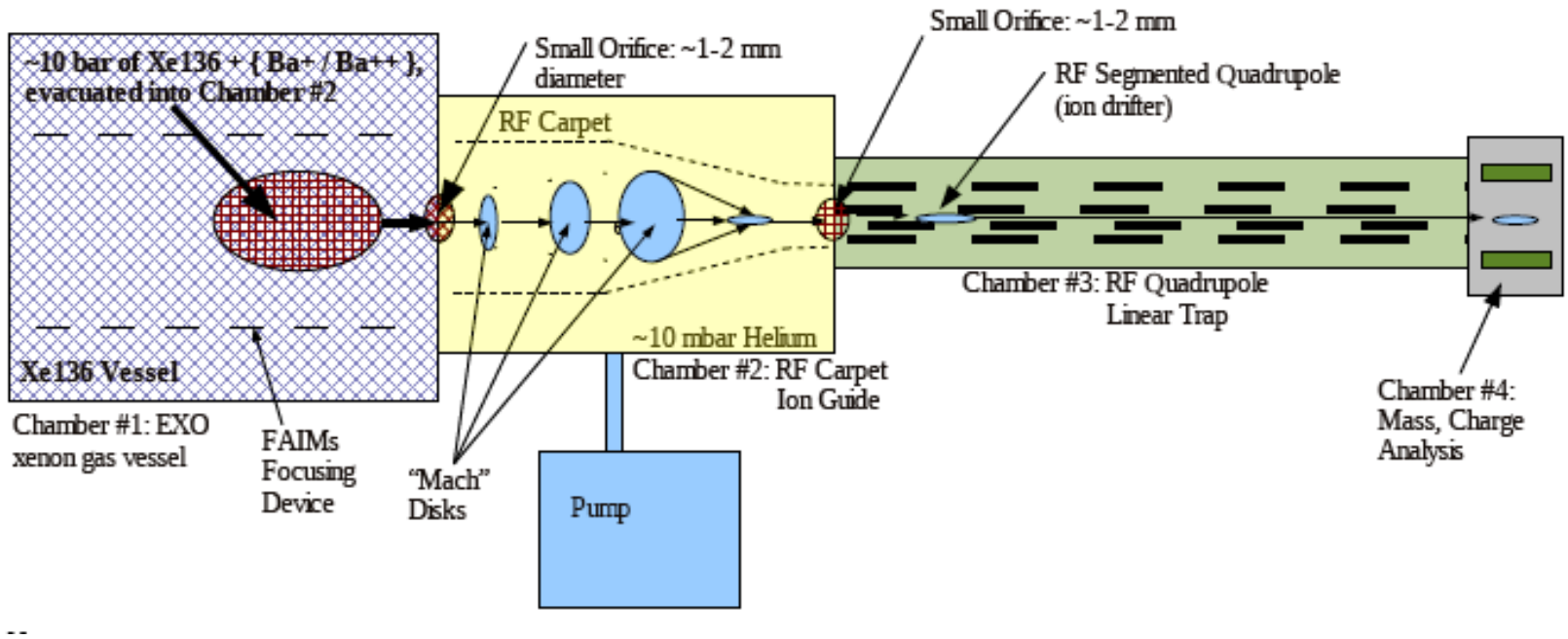
- -Improved resolution
- -Tracking capabilities
- -Possible *in situ* ID of Ba^+ daughter

Development:

- -Gas TPCs at Gotthard and Laurentian University

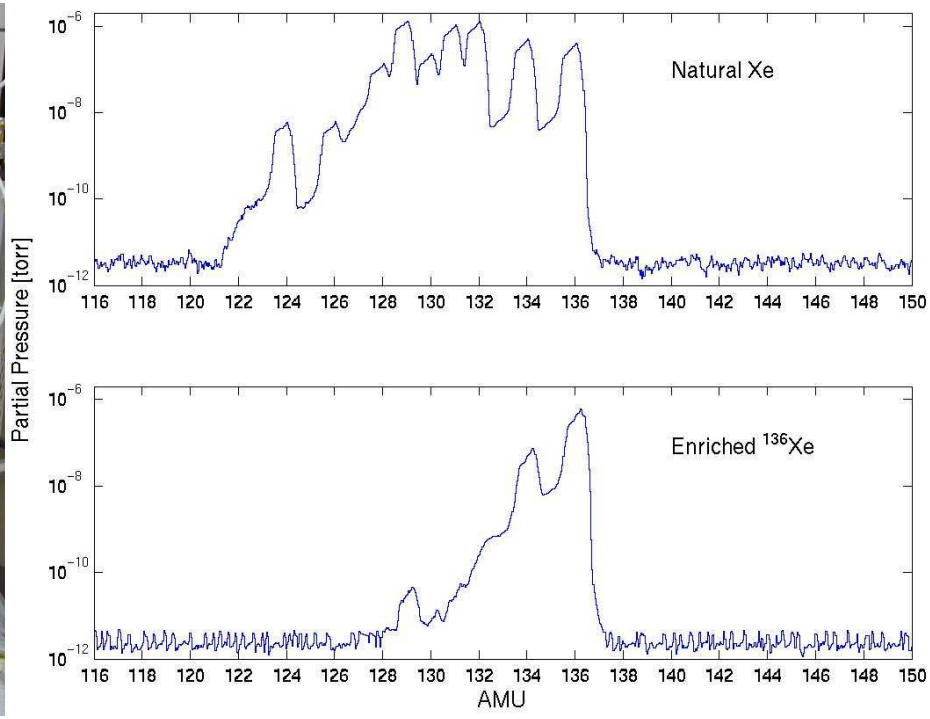


Ba^+ extraction - Gas phase



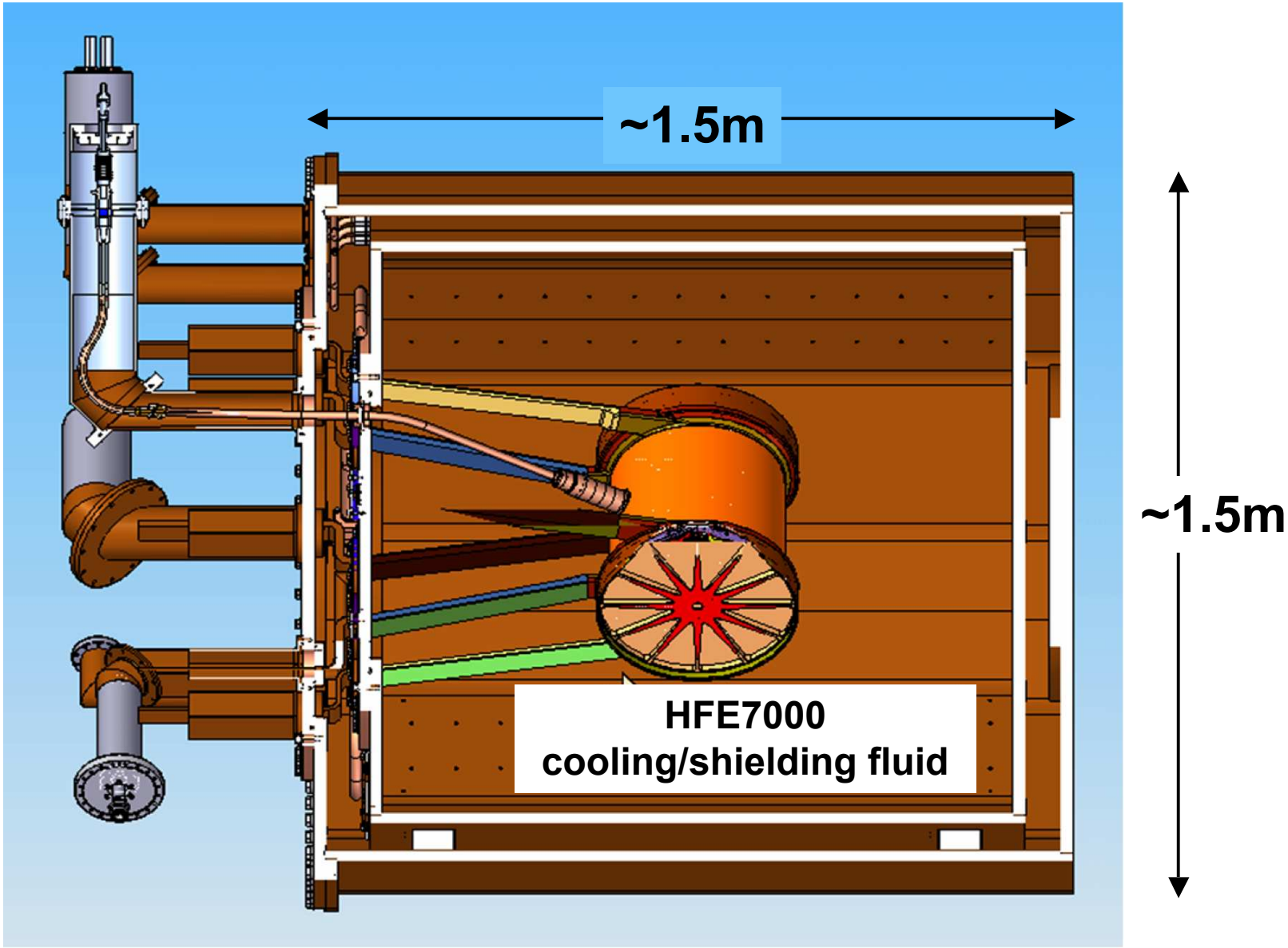
Barium ions are guided towards the exit orifice and focused using a high-field asymmetric waveform technique. The second chamber is maintained at a pressure of ~10-30 mb using a cryopump and is lined with an RF carpet. An RF funnel guides the ions towards the RF quadrupole which is at high vacuum.

EXO-200: Enriched Xe

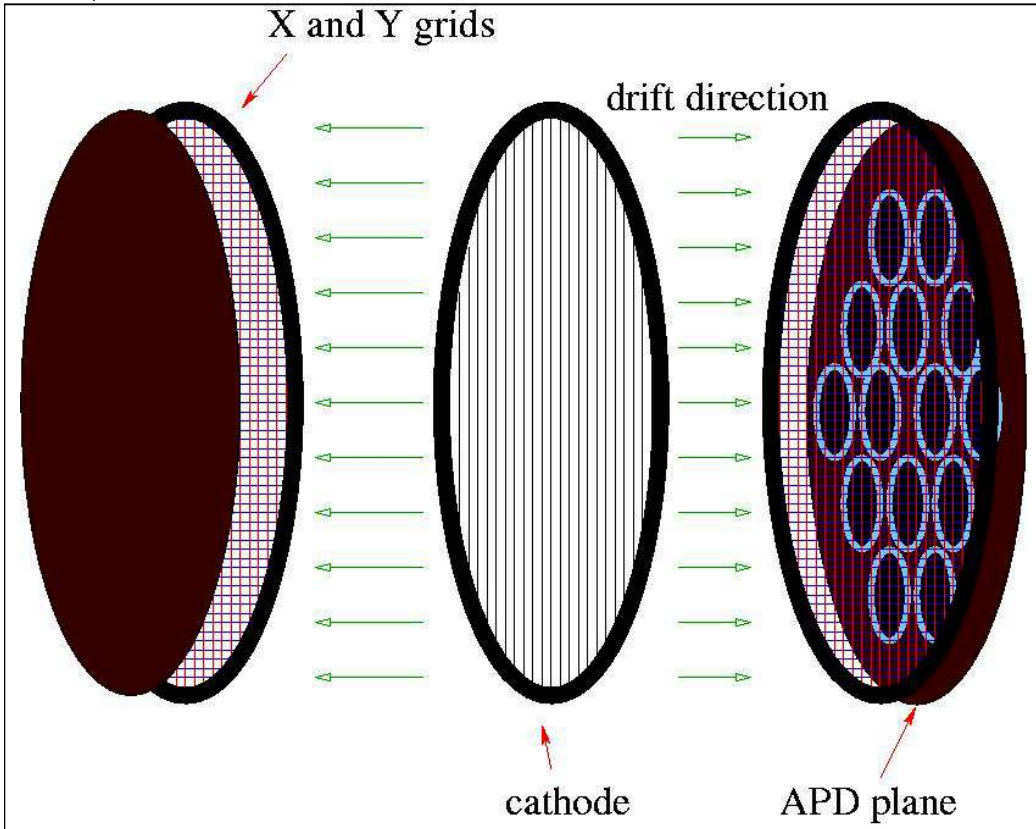


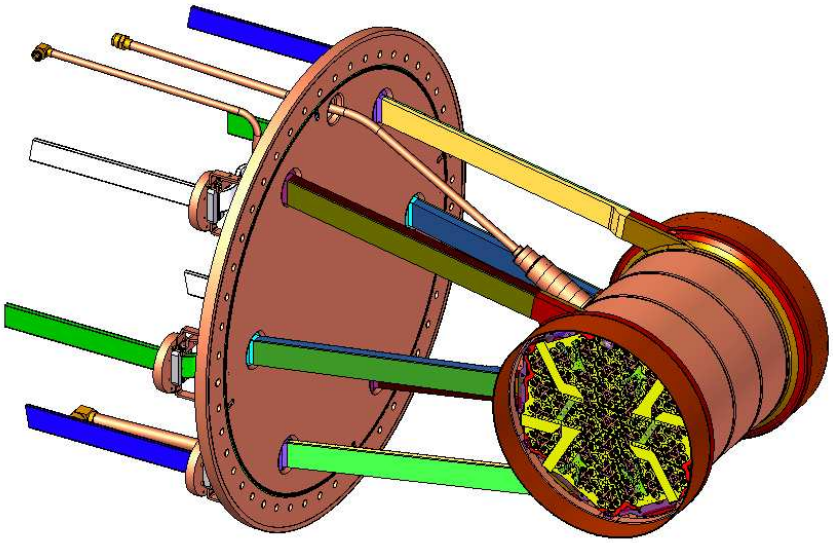
The EXO collaboration has 200 kg of Xe, enriched to 80% in ^{136}Xe.

EXO-200: Detector



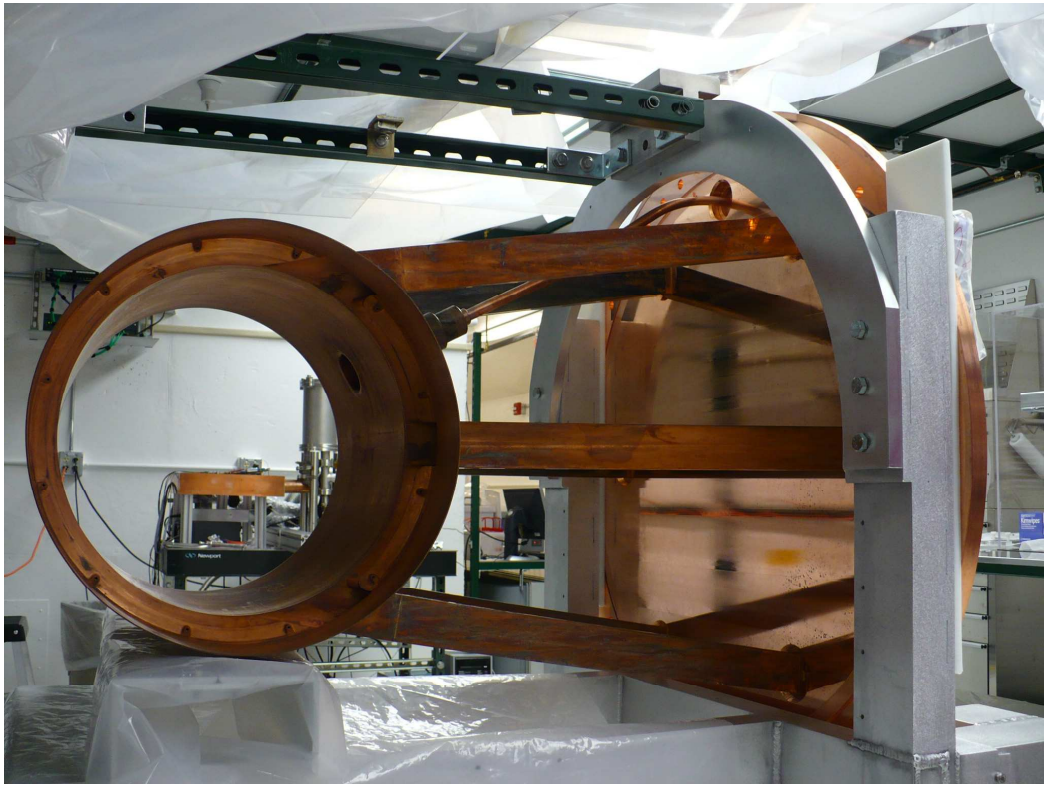
EXO-200 TPC



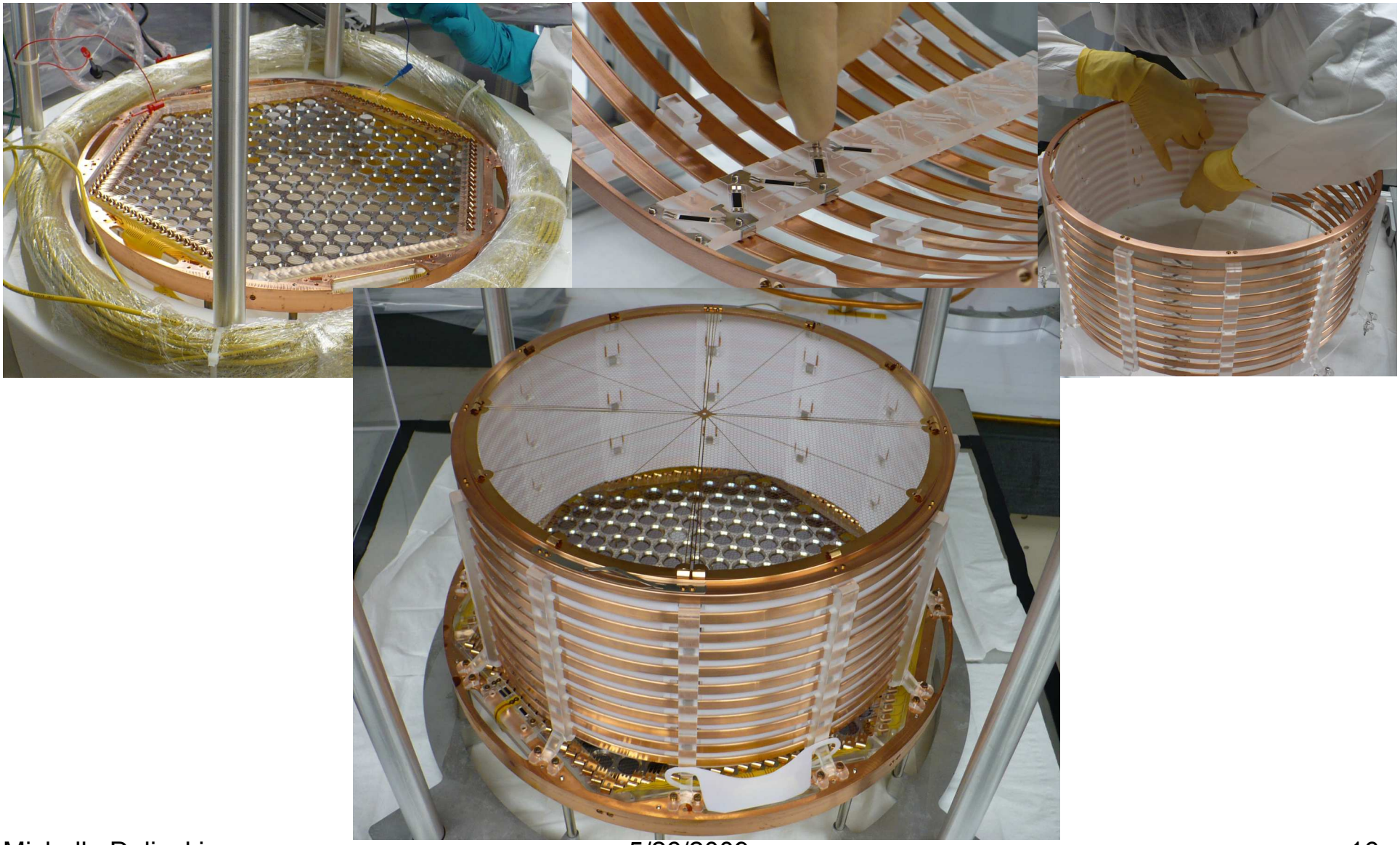


X and Y wire grids provide position-sensitive collection of ionization. LAAPDs collect scintillation signal and give timing information.

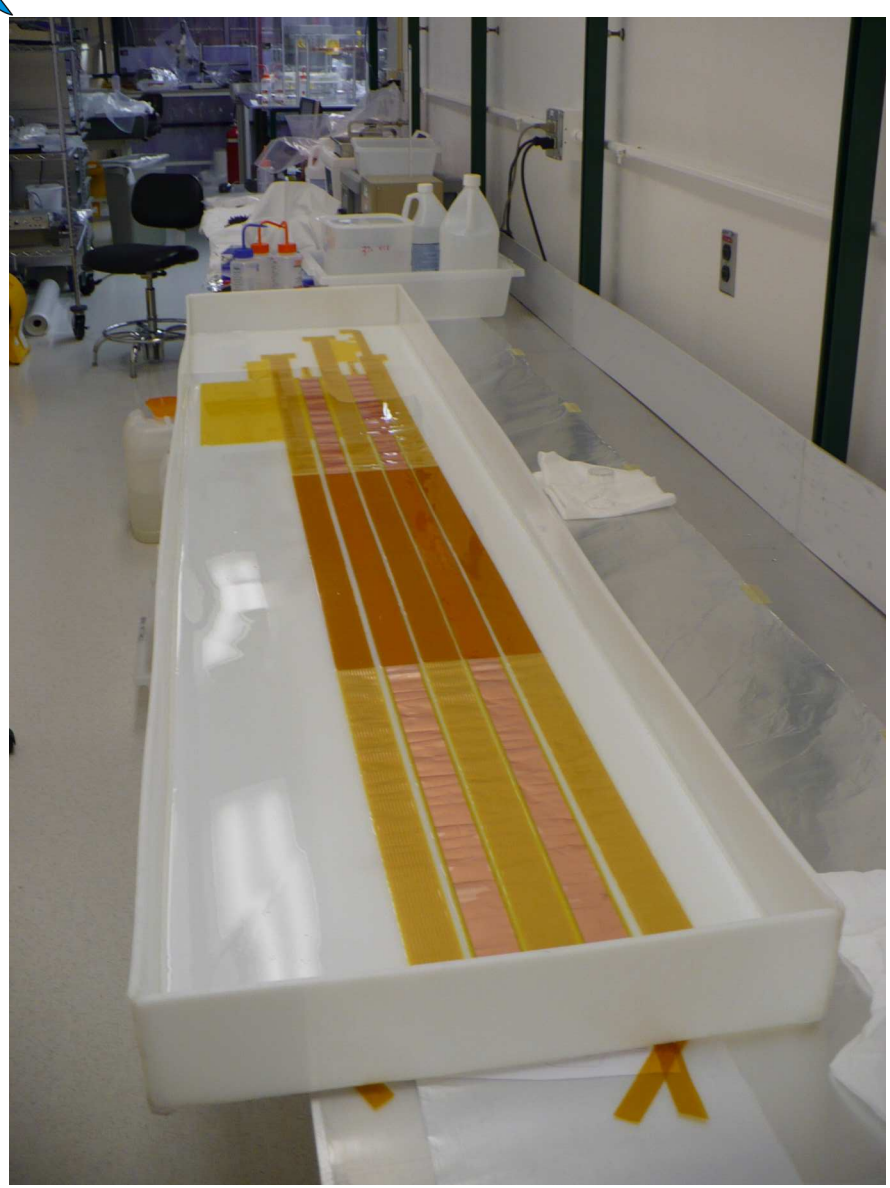
Copper vessel

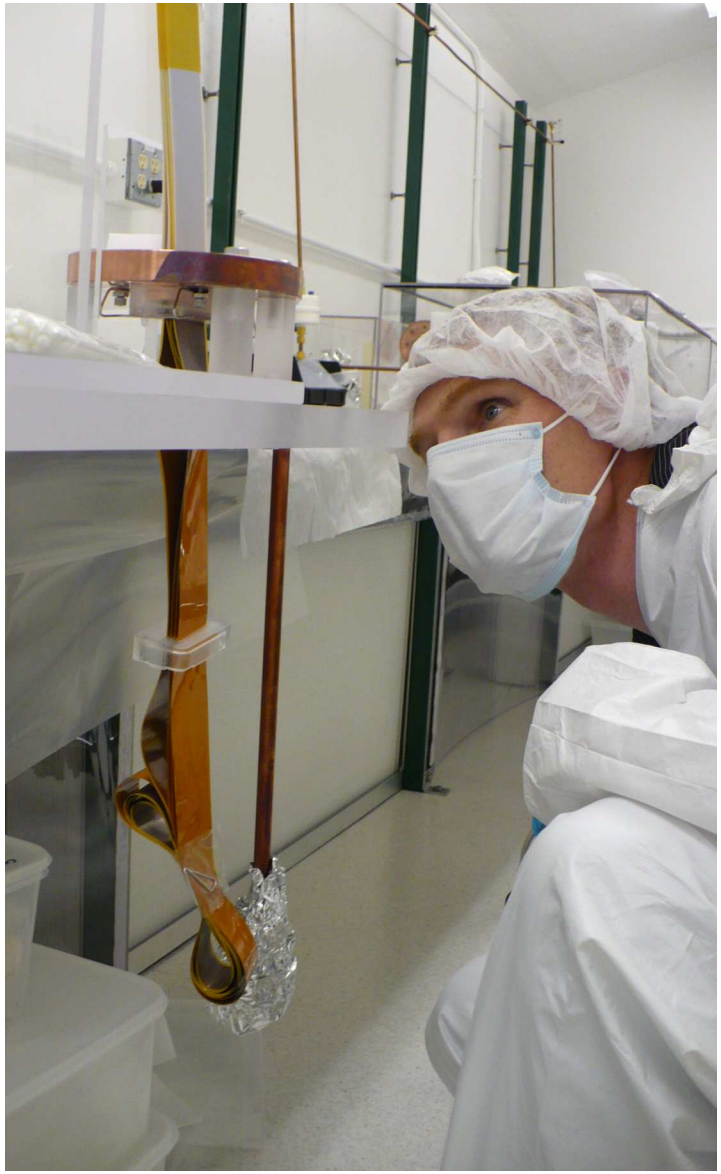


TPC halves

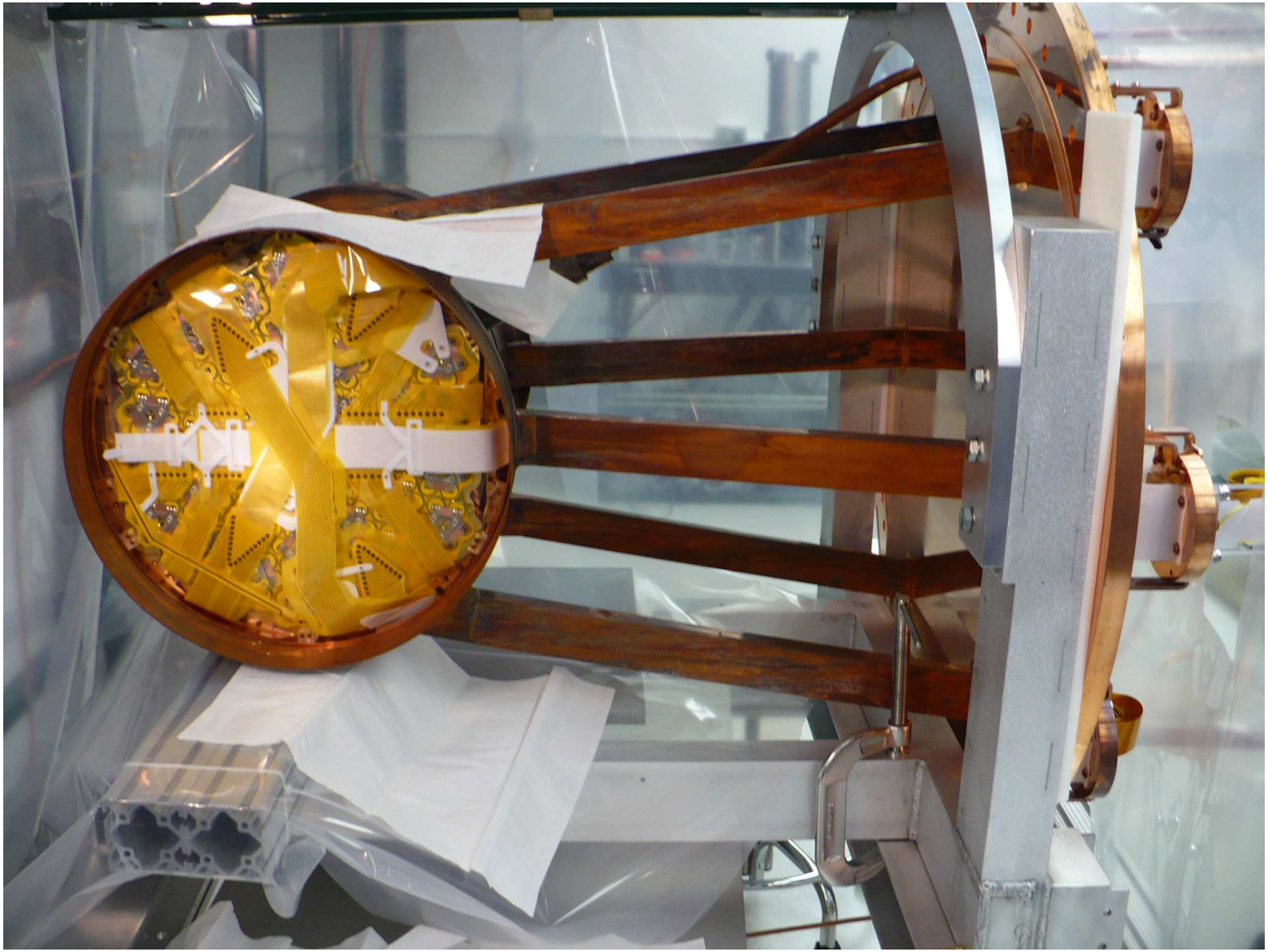


Flex cables



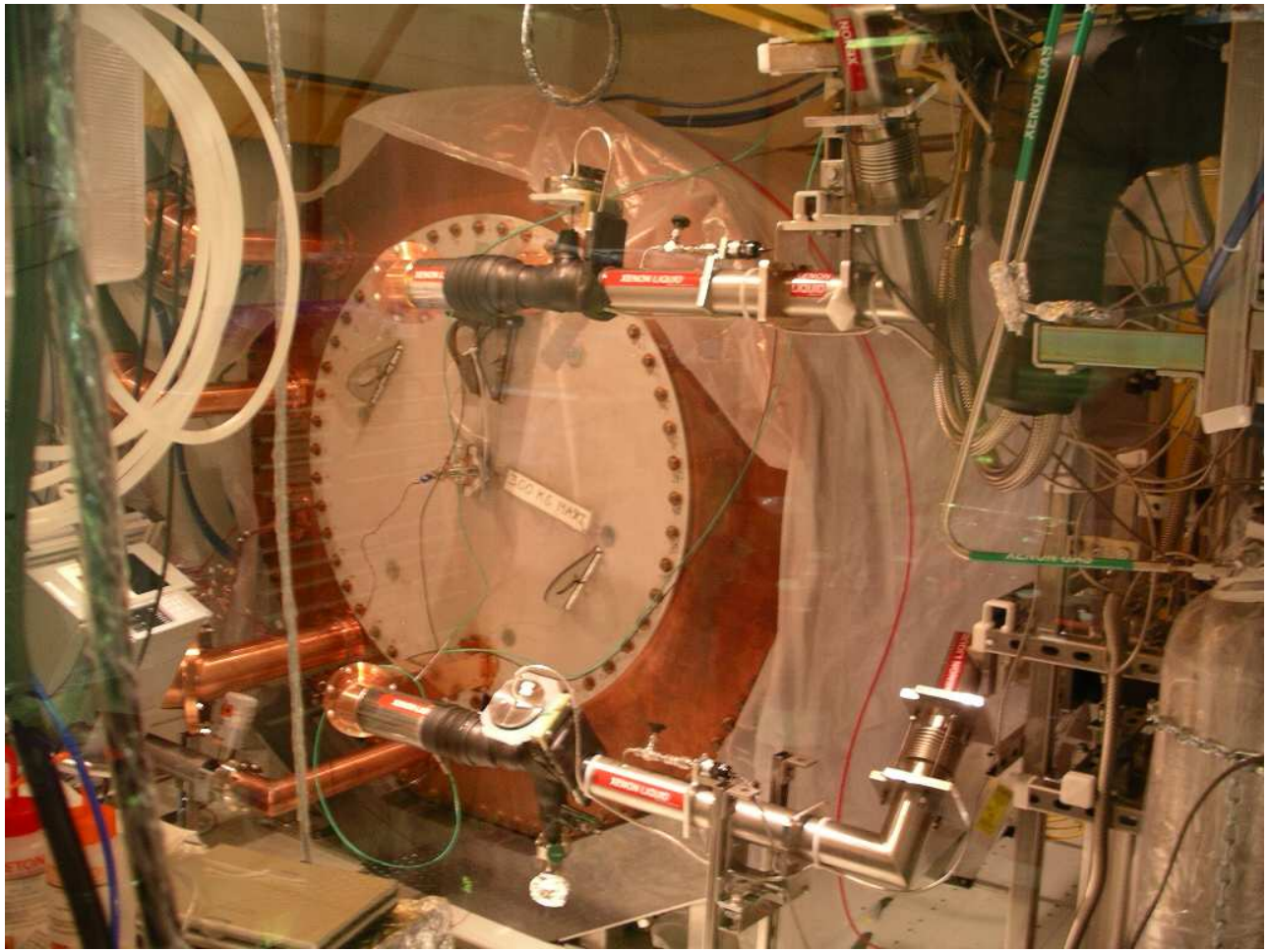


EXO-200 detector



Cryogenics

Commissioning of cryogenics at WIPP is currently underway.



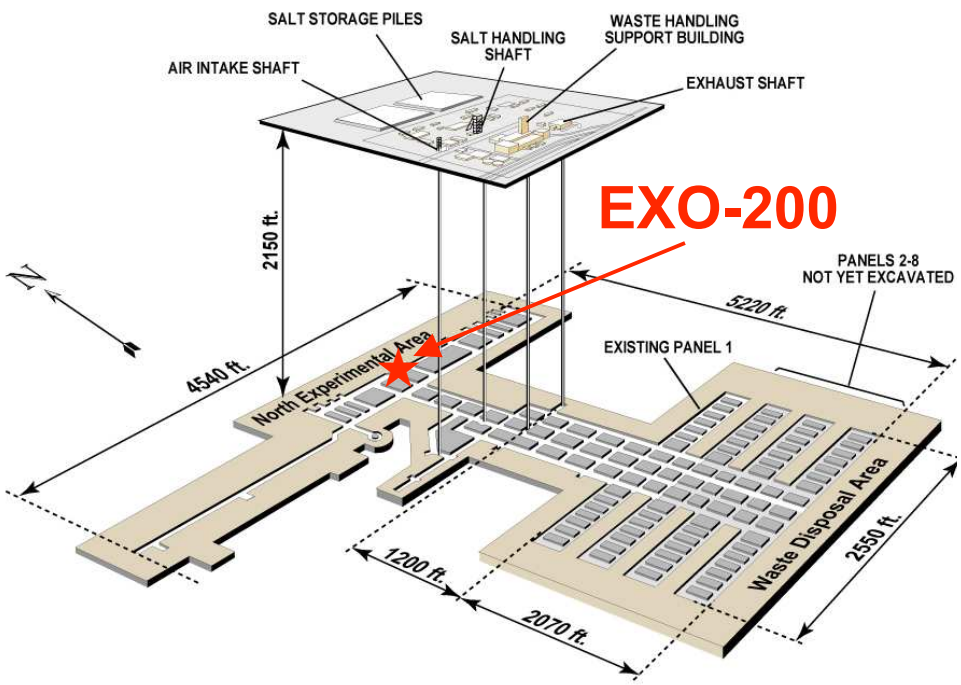
Cryo-commissioning at Stanford, Spring 2007

WIPP

Waste Isolation Pilot Plant in Carlsbad, NM.

Salt mine and low level radioactive waste storage.

~1600 m.w.e. flat overburden.



Background

Massive effort on material radioactive qualification using:

- Neutron activation analysis
- Low background γ-ray spectroscopy
- α-counting
- Radon counting
- High sensitivity GD-MS and ICP-MS

At present the database of characterized materials includes >300 entries.

NIM article published on the subject with entries for 225 materials
[D.Leonard et al., Nucl. Instr. Meth. A 591, 490 (2008)]

Case	Mass (ton)	Eff. (%)	Run Time (yr)	σ_E/E @ 2.5MeV (%)	Radioactive Background (events)	$T_{1/2}^{0\nu}$ (yr, 90%CL)	Majorana mass (eV) QRPA	Majorana mass (eV) NSM
EXO-200	**0.2**	**70**	**2**	**1.6**	**40**	**6.4×10^{25}**	**0.133†**	**0.186***

† Rodin, *et. al.,* Nucl. Phys. A 793 (2007) 213-215
*Caurier, *et. al.*, arXiv:0709.2137v1

Sensitivity to 2ν mode

$2\nu\beta\beta$ of ^{136}Xe has never been observed.

	$T_{1/2}$ (yr)	evts/year in EXO-200 (no efficiency applied)
Experimental limit		
Leuscher et al	$>3.6\cdot10^{20}$	<1.3 M
Gavriljuk et al	$>8.1\cdot10^{20}$	<0.6 M
Bernabei et al	$>1.0\cdot10^{22}$	<48 k
Theoretical prediction [$T_{1/2}^{max}$]		
QRPA (Staudt et al)	$=2.1\cdot10^{22}$	=23 k
QRPA (Vogel et al)	$=8.4\cdot10^{20}$	=0.58 M
NSM (Caurier et al)	($=2.1\cdot10^{21}$)	(=0.23 M)

Excellent prospects for detection of the 2ν decay mode in EXO-200.

Sensitivity of full EXO

Assumptions:

1) 80% enrichment in ^{136}Xe
2) Intrinsic low background + Ba tagging eliminate all radioactive background
3) Energy resolution only used to separate the 0v from 2v modes:
   Select 0v events in a ±2σ interval centered around the 2.481MeV endpoint
4) Use for 2vββ $T_{1/2}>1\cdot10^{22}$yr (Bernabei et al. measurement)

Case	Mass (ton)	Eff. (%)	Run Time (yr)	σ_E/E @ 2.5MeV (%)	2vββ Background (events)	$T_{1/2}^{0v}$ (yr, 90%CL)	Majorana mass (meV) QRPA‡	NSM#
Conservative	1	70	5	1.6	0.5 (use 1)	2×10^{27}	24	33
Aggressive	10	70	10	1	0.7 (use 1)	4.1×10^{28}	5.3	7.3

‡ Rodin, *et. al.,* Nucl. Phys. A 793 (2007) 213-215
# Caurier, *et. al.*, arXiv:0709.2137v1

Schedule

EXO-200 detector assembly complete, installation at WIPP in 2009.

First physics data by the end of the year. The results will determine the future direction of the EXO program.

Continuing development of Ba^+ tagging technologies.

Work is going forward on gas-phase Xe detectors.

Collaboration

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