Status of EXO experiment

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The EXO experiment

The **Enriched Xenon Observatory** aims to detect "neutrino-less double-beta decay" using a TPC with large amounts (1-10 t) of xenon isotropically enriched (80%) in ^{136}**Xe**

$\beta\beta0\nu$ process: $^{136}Xe \rightarrow {}^{136}Ba^{++} + 2e^{-}$

Goals:

- Measure effective Majorana neutrino masses with a sensitivity close to 0.01 eV
- Probe the Majorana nature of neutrinos

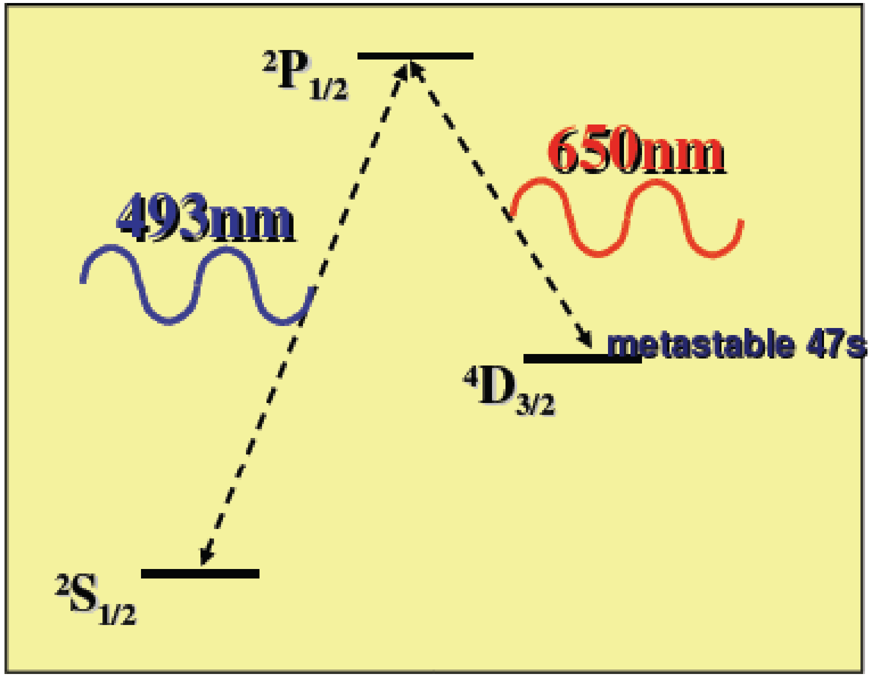
- **In addition of the electrons energy measurement, a background reduction using optical spectrometry to tag the barium final state**

Barium tagging

- **Final state ^{136}Ba tagging with optical spectroscopy**

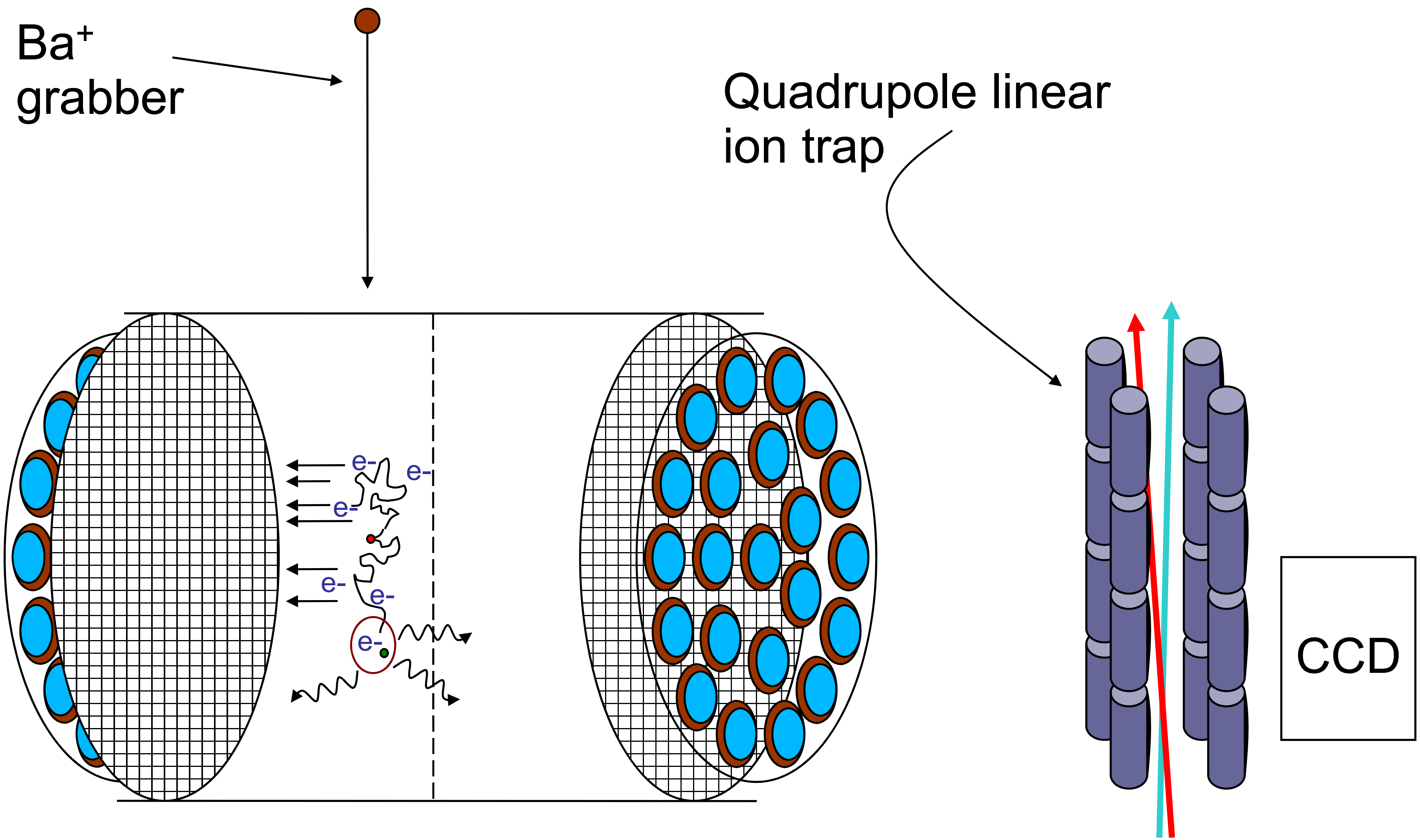
- Ba^+ system well studied (Neuhauser, Hohenstatt, Toshek, Dehmelt 1980)
- Very specific signature

- Important additional constraint
- Drastic background reduction



Energy levels of Ba^+.

Ba⁺ Tagging Schematic for EXO



From Kevin O'Sullivan (Stanford)

The Plan

Build a ~200kg LXe TPC to measure the $2\nu\beta\beta$ decay half-life in ^{136}Xe with competitve sensitivty to $0\nu\beta\beta$ decay

Gain operational experience

EXO-200

Data taking in 2008

Ba Tagging

Build a trap capable of identifying single Ba ions

Develop a method for transfering Ba ions from LXe to the trap

Demonstrate the ability to transfer and detect Barium ions with high efficiency

Build a ton scale experiment with background rejection using Ba-tagging

EXO FULL

In progress

Done

To do

EXO-200

- Exo-200 will not make use of laser tagging but it will:
  - Test all technical aspects of EXO
  - Operate underground at WIPP lab (1700 m.w.e) for 2 years
  - Measure for the first time $\beta\beta 2\nu$ process in ^{136}Xe
  - Have a sensitivity sufficient to explore $\beta\beta 0\nu$ range in $|\langle m_\nu \rangle|$ suggested by the Heidelberg-Moscow experiment

1) 200kg of Xe enriched to 80% in 136
2) $\sigma(E)/E$ = 1.6% obtained in EXO R&D (Conti et al., Phys Rev B 68 (2003) 054201)
3) Low but finite radioactive background: 20 events/year in the $\pm 2\sigma$ interval centered around the 2457.9(0.4) keV endpoint [a]
4) Negligible background from $2\nu\beta\beta$ ($T_{1/2} > 1 \cdot 10^{22}$yr) [b]

Case	Mass (ton)	Eff. (%)	Run Time (yr)	σ_E/E @ 2.5MeV (%)	Radioactive Background (events)	$T_{1/2}^{0\nu\beta\beta}$ (yr, 90%CL)	Majorana mass (eV) QRPA	Majorana mass (eV) NSM
EXO-200	**0.2**	**70**	**2**	**1.6**	**40**	**6.4×10^{25}**	**0.27[†]**	**0.38[♦]**

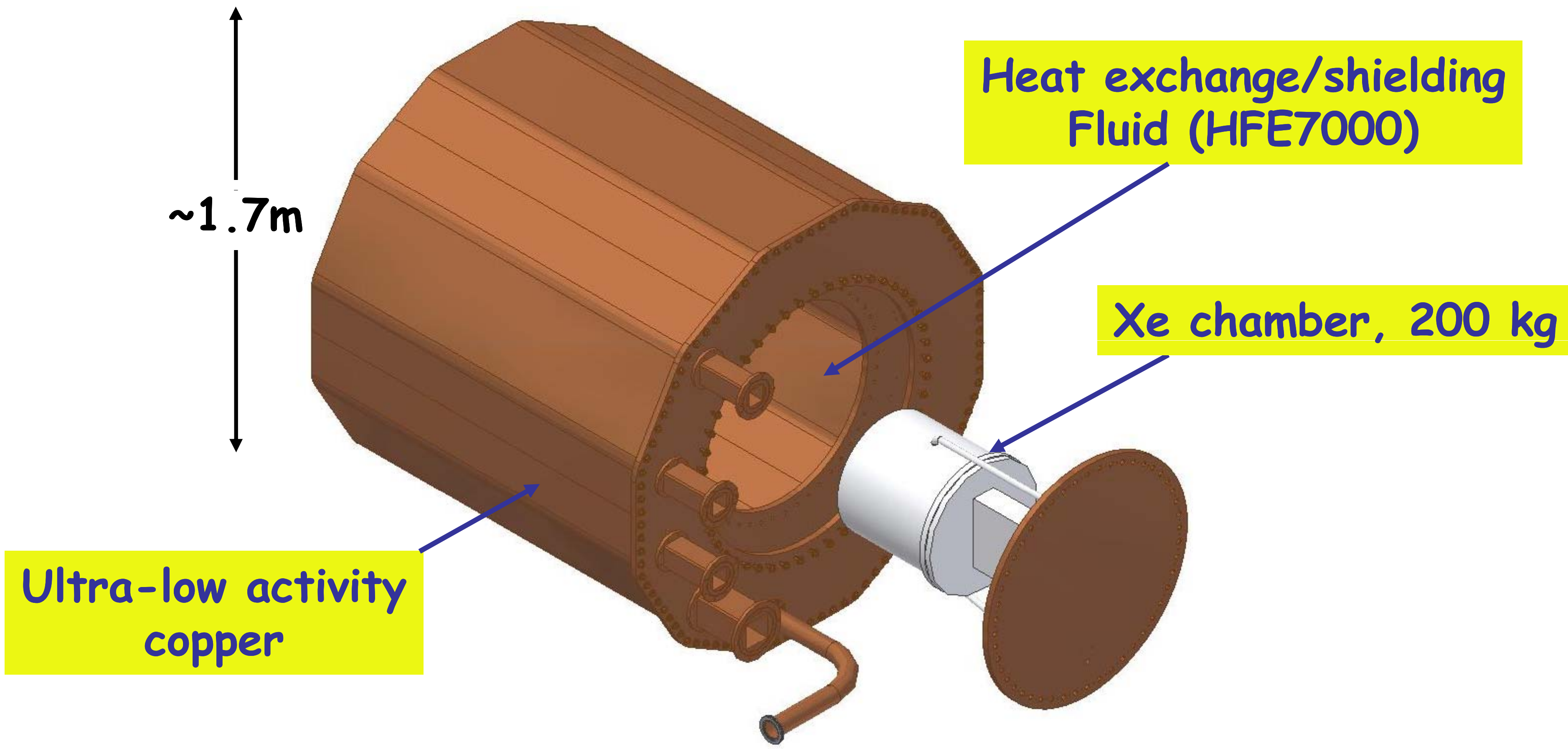
[†] Rodin et al Phys Rev C 68 (2003) 044302

[♦] Courier et al. Nucl Phys A 654 (1999) 973c

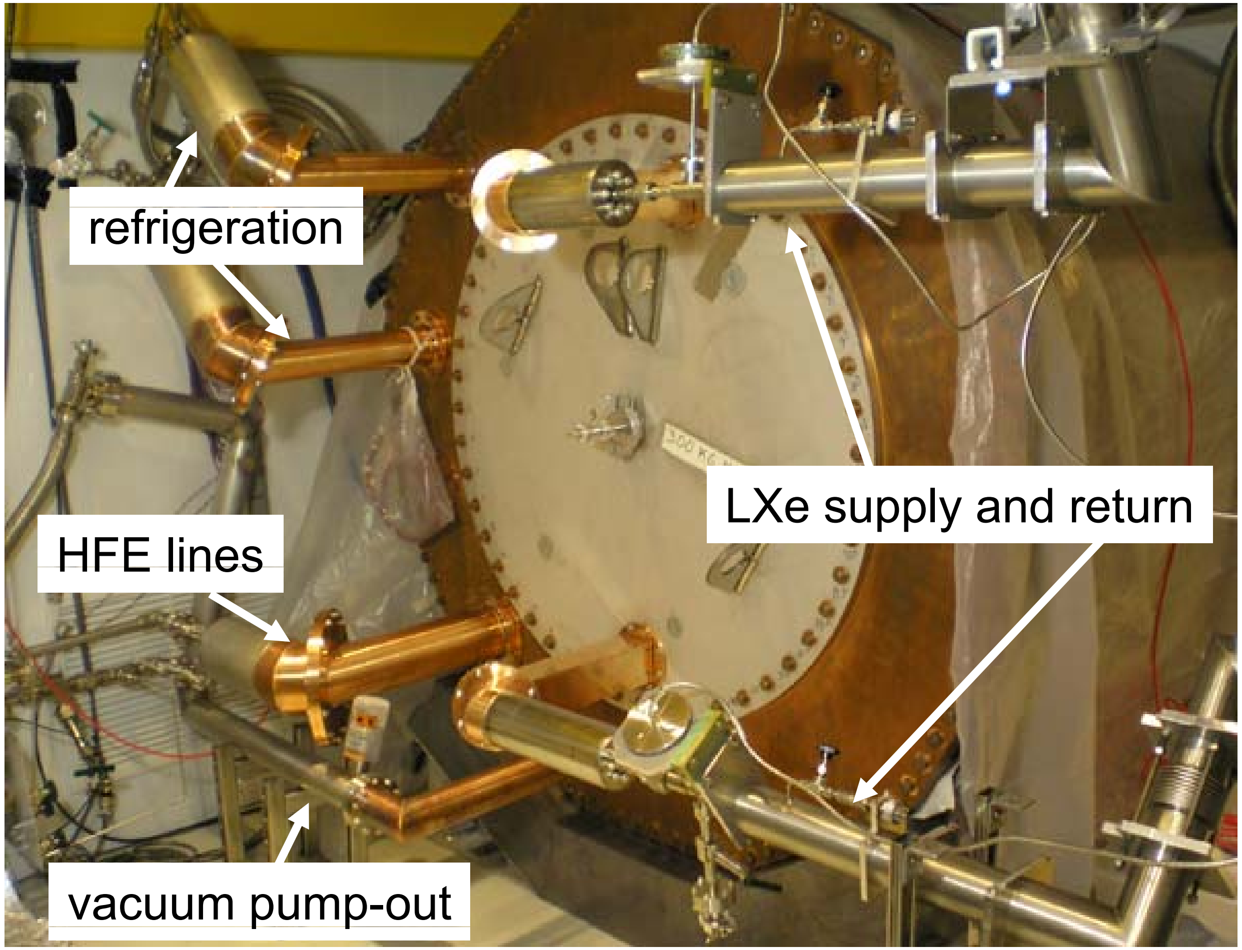
[a] M. Redshaw, J., McDaniel, E. Wingfield and E.G. Myers (Florida State Precision Penning Trap), to be submitted to Phys. Rev C.

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

EXO-200: a 200kg LXe TPC with scintillation readout in a ultra-low background cryostat/shielding

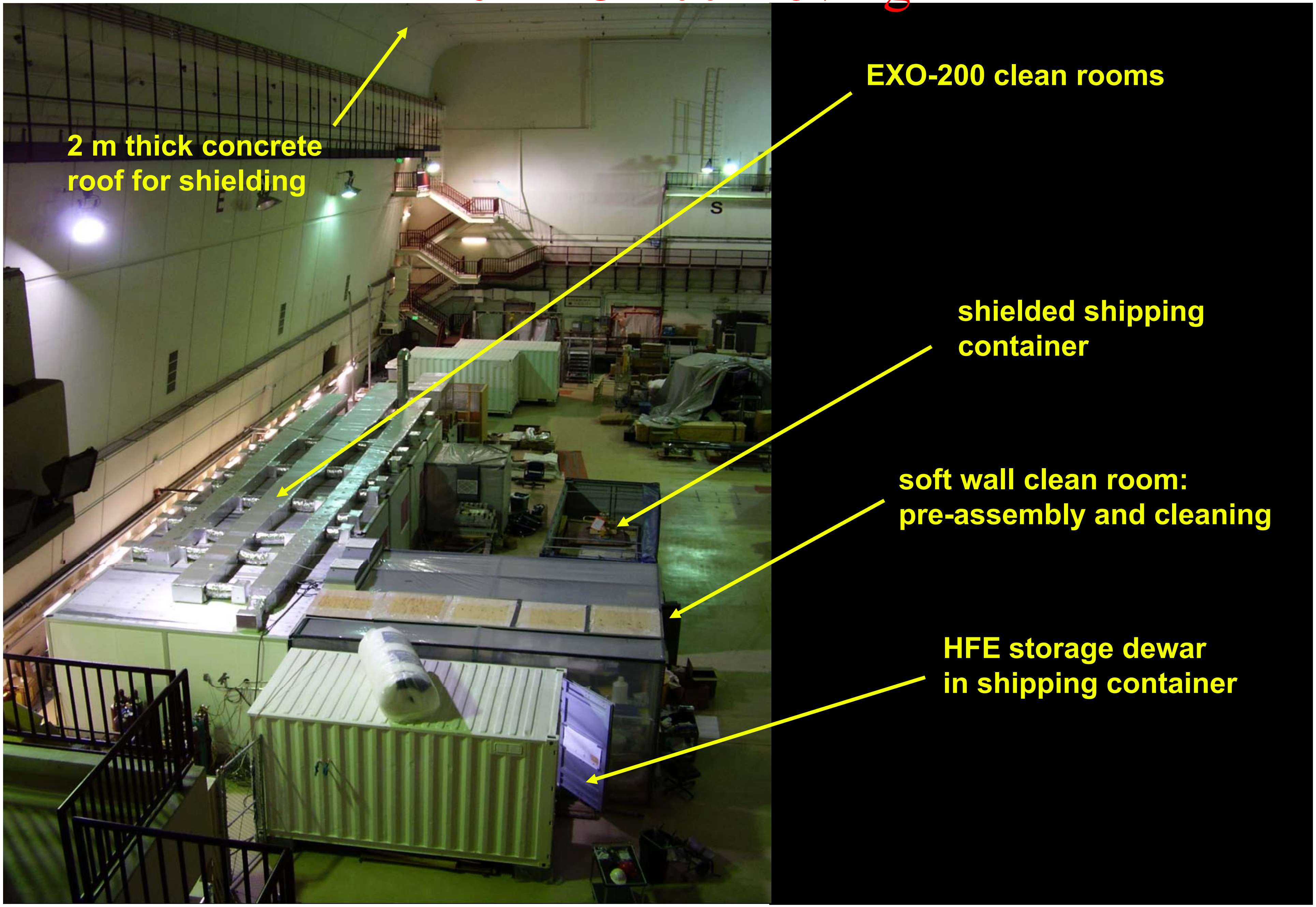


The Cryostat



Xenon handling and cooling system commissioned in April ’07, liquefying 30kg of LXe

The EXO-200 moving

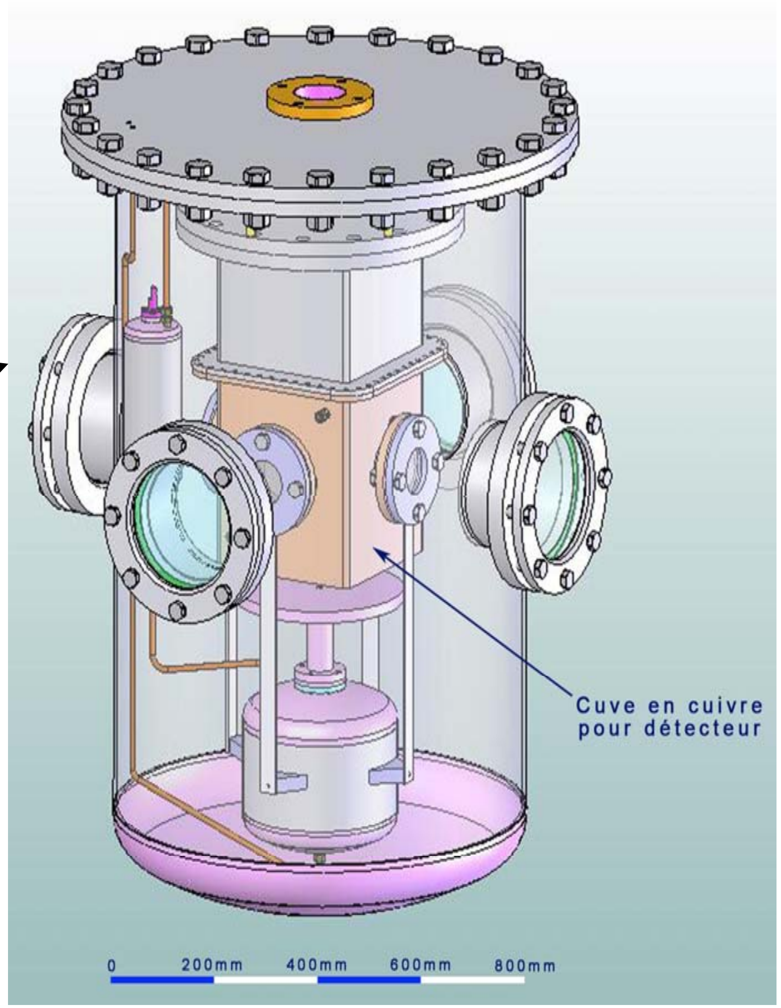


Ba$^+$ Tagging

release from a metallic tip is challenging:

3 techniques under study in parallel:

- Icy probe
- Hot probe
- Field emission probe



Cryostat under construction in Neuchâtel:
- 100 Kg LXe
- Will test the grabbing efficiency with Barium source

EXO-FULL Sensitivity

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 0ν from 2ν modes:

   Select 0ν events in a ±2σ interval centered around the 2.458 MeV endpoint
4) Use for 2νββ $T_{1/2}>1\cdot10^{22}$yr b

Case	Mass (ton)	Eff. (%)	Run Time (y)	σ_E/E 2.5MeV (%)	2νββ Background (events)	$T_{1/2}^{0\nu}$ (y, 90%CL)	Majorana mass (meV) QRPA‡	Majorana mass (meV) NSM#
Conservative	1	70	5	1.6*	0.5 (use 1)	$2*10^{27}$	50	68
Aggressive	10	70	10	1†	0.7 (use 1)	$4.1*10^{28}$	11	15

* σ(E)/E = 1.4% obtained in EXO R&D, Conti et al Phys Rev B 68 (2003) 054201

† σ(E)/E = 1.0% considered as an aggressive but realistic guess with large light collection area

‡ Rodin et al Phys Rev C 68 (2003) 044302

\# Courier et al. Nucl Phys A 654 (1999) 973c

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

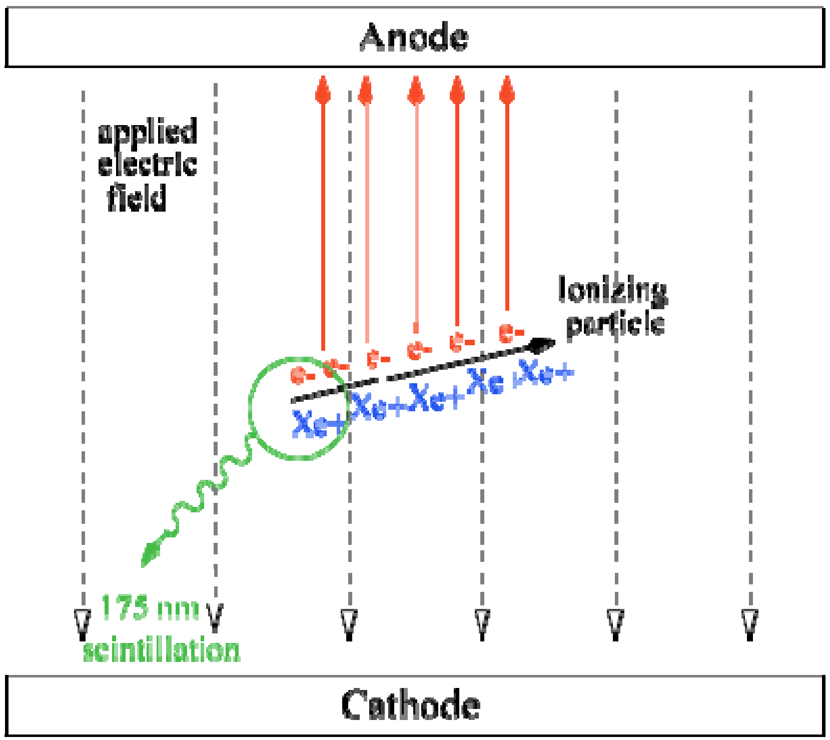
Summary

- **EXO-200**
  - Xenon handling and cryogenic systems built and commissioned
  - The electronics boards are in production
  - About 1/3 of the APDs have been tested
  - The cleanrooms are all at WIPP
  - The TPC is under construction
  - First data in 2008 during 2 years

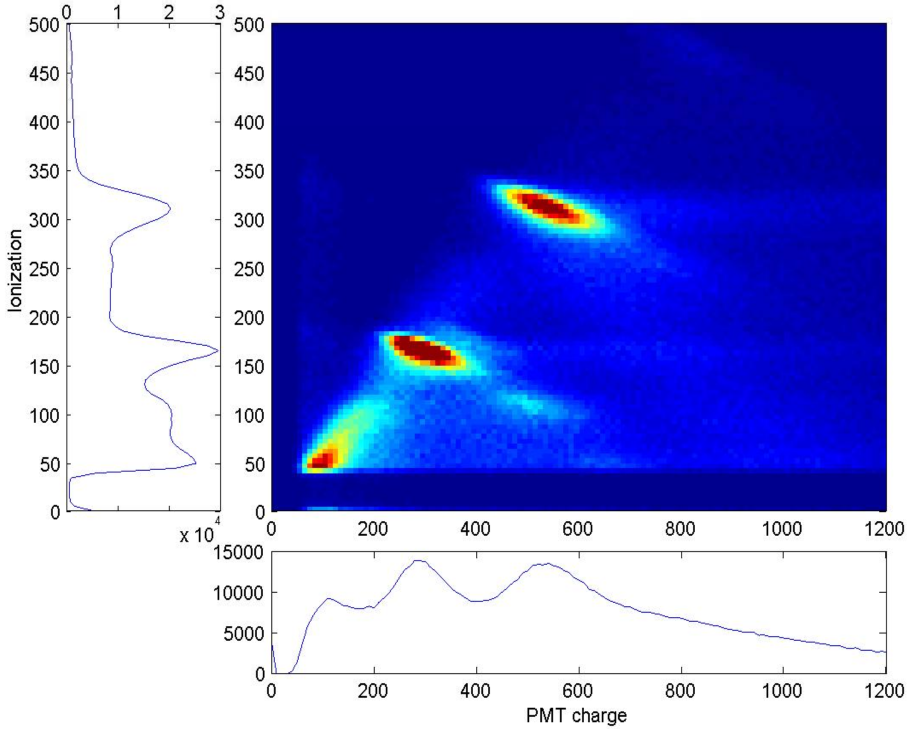
- **Ba tagging**
  - Ion trapping in buffer gas well understood
  - Possible ion transfer methods being developed
  - Apparatus for testing ion transfer from liquid being developed

Back-up

Improving the Energy Resolution



Ionization and Scintillation
results using ^{207}Bi

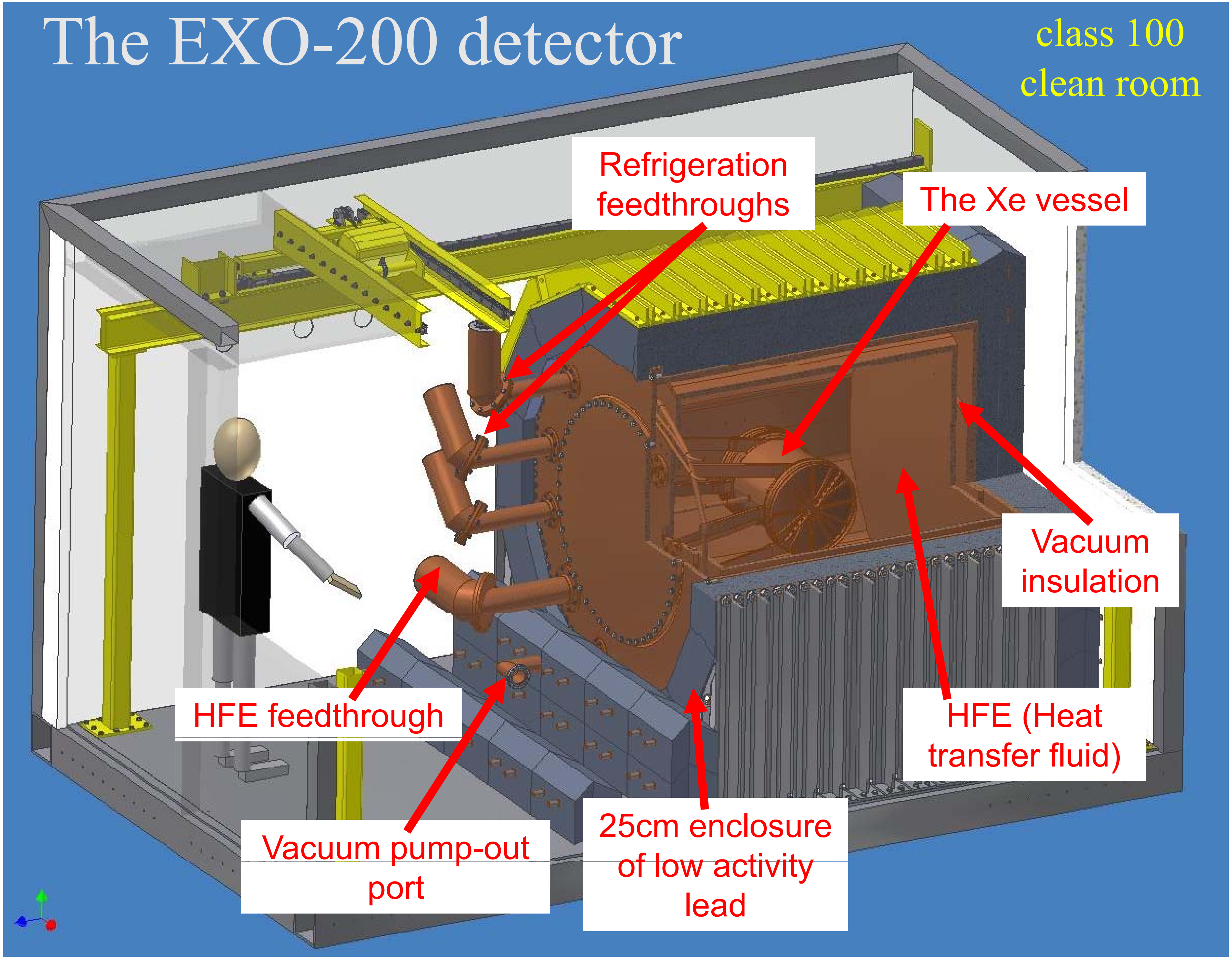


- ☞ Ionisation : 3.8% @ 570 keV -> 1.8% @ $Q_{\beta\beta}$
- ☞ Ionisation+Scintillation : 3.0% @ 570 keV -> 1.4% @ $Q_{\beta\beta}$

Two detector options under consideration

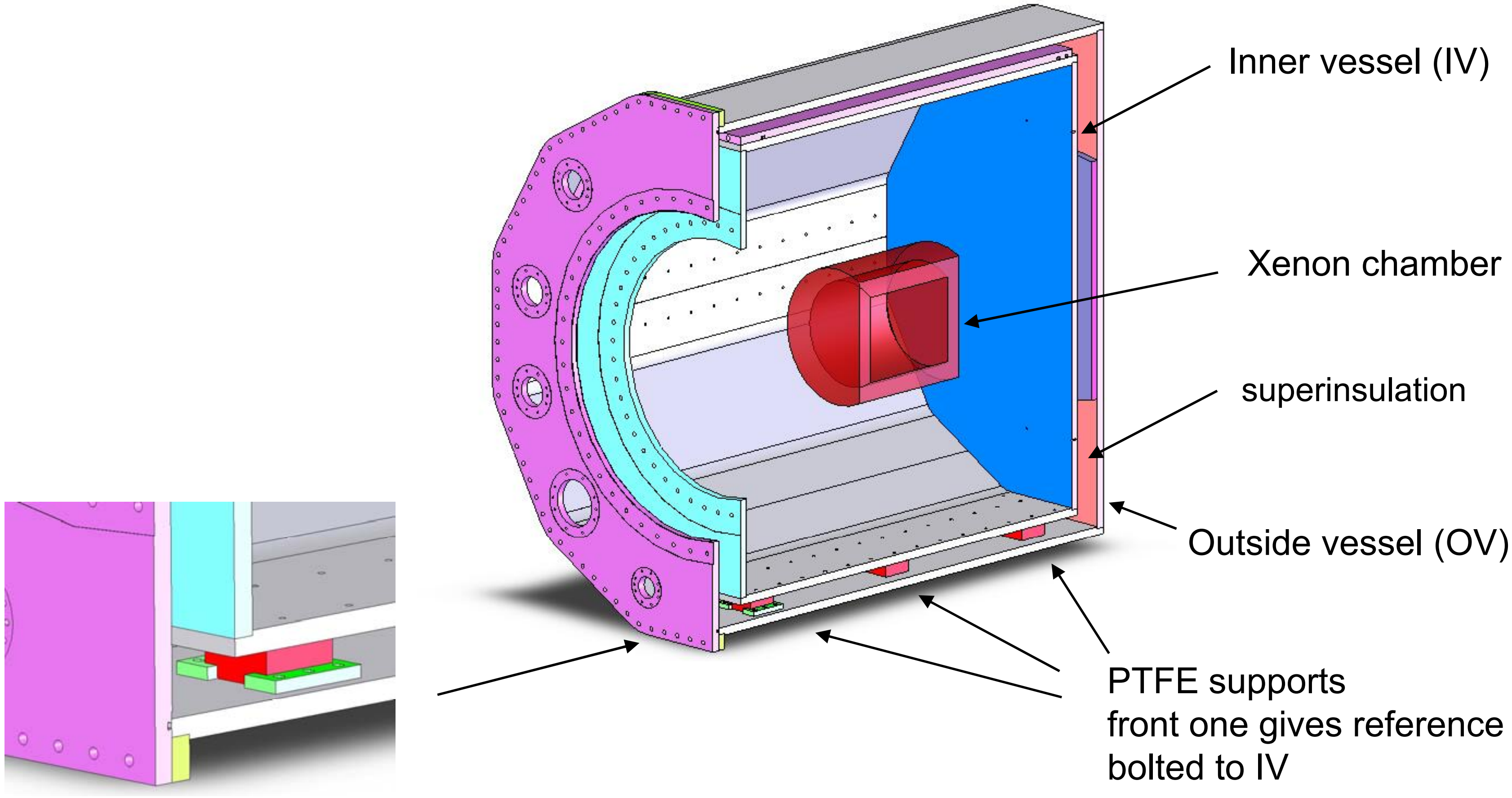
High Pressure gas TPC	Liquid Xe chamber
• 5-10 atm, 50 m^3 modules, 10 modules for 10 t	•Very small detector (3m^3 for 10tons)
•Xe enclosed in a non-structural bag	•Need good E resolution
• β range ~5-10cm: can resolve 2 blobs	•Position info but blobs not resolved
•2.5m e-drift at ~250kV	•Readout Xe scintillation
•Readout Xe scintillation with WLSB (T0)	•Can extract Ba from hi-density Xe
•Additive gas: quenching and $Ba^{++} \rightarrow Ba^{+}$ neutralization	•Spectroscopy at low pressure: ^{136}Ba (7.8% nat'l) different signature from natural Ba (71.7% ^{138}Ba)
•Steer lasers or drift Ba-ion to detection region	•No quencher needed, neutralization done outside the Xe

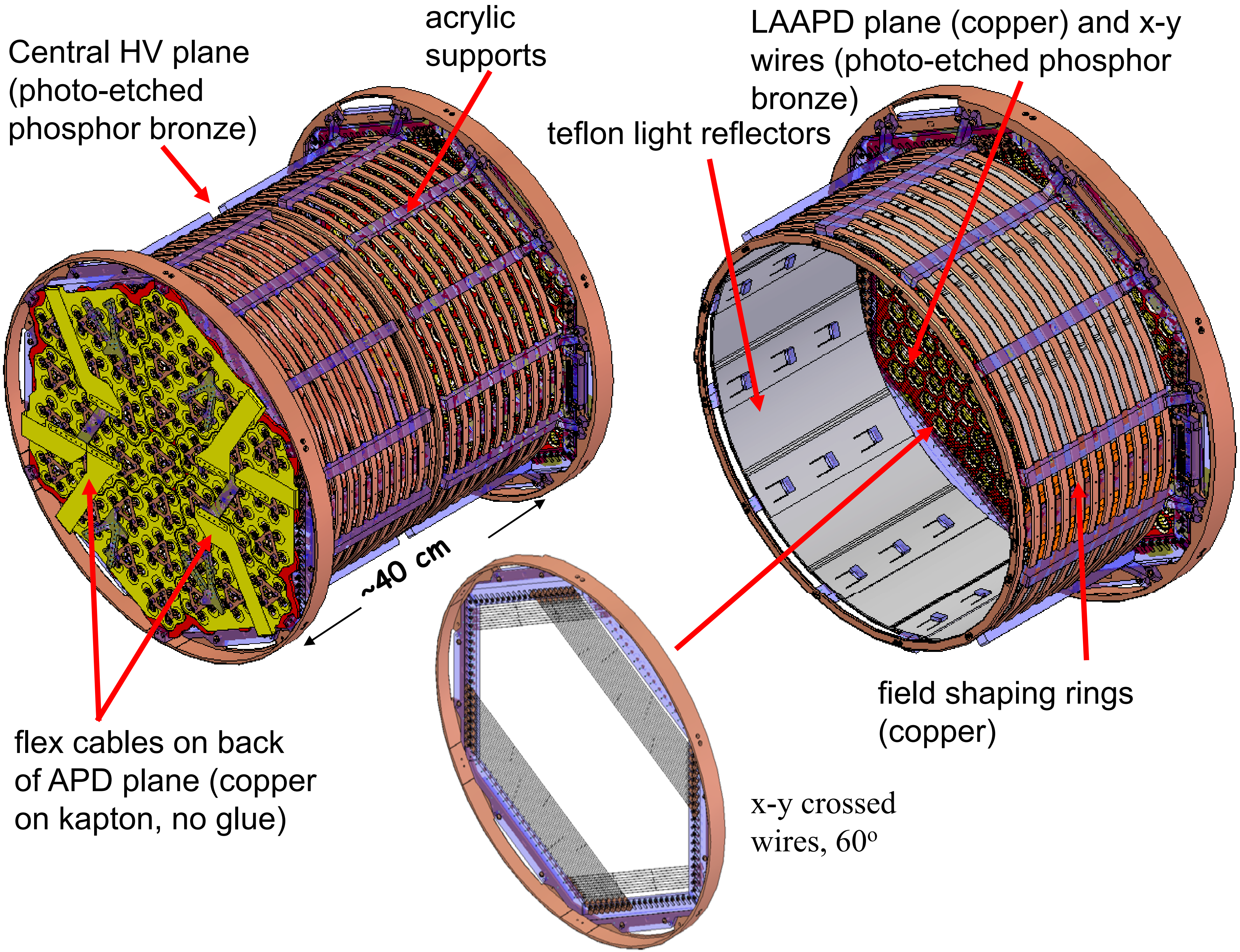
The EXO-200 detector



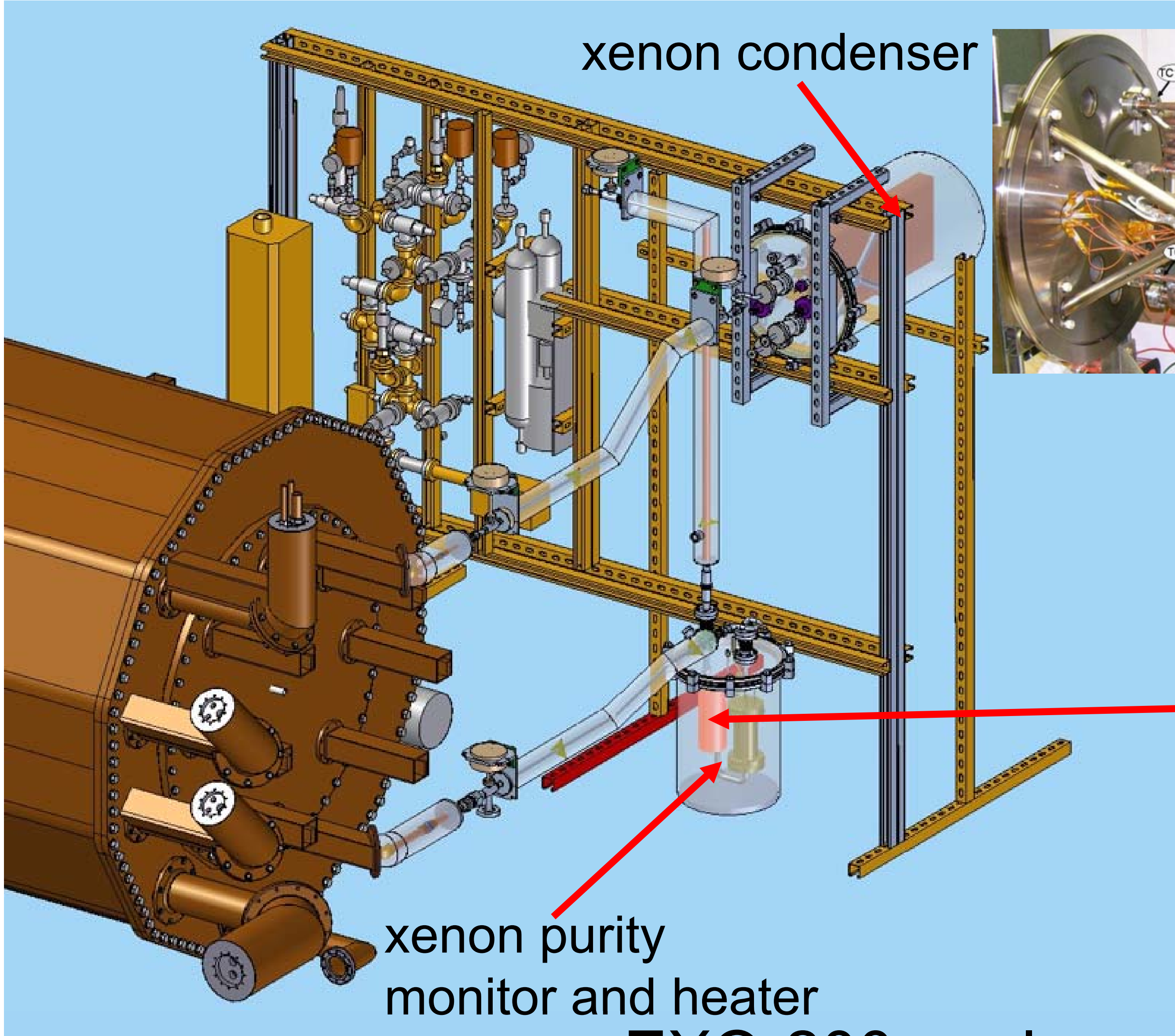
Cryostat concept is frozen (Neuchâtel+Yverdon)

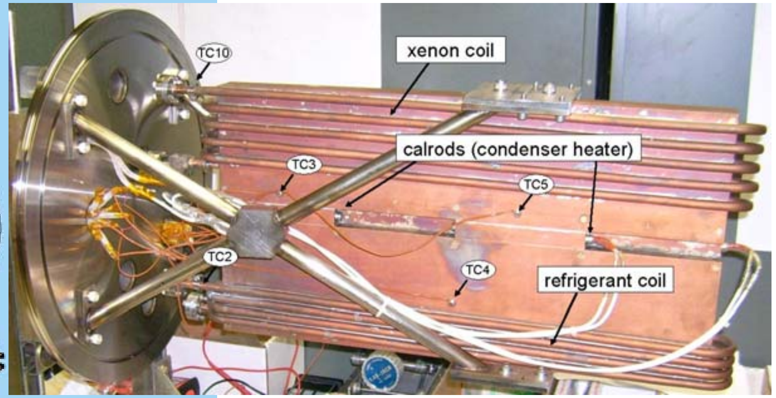
- No lead attached to cryostat
- FEA: Outer vessel can be evacuated (for thermal insulation)
- FEA: Inner vessel can stand 2 bar internal pressure (HFE vapor pressure), with vacuum outside
- IV wrapped with superinsulation, maintained by a net
- Xenon chamber attached to door of IV (or extra supports?)
- All feed-throughs to xenon chamber through IV door




Central HV plane (photo-etched phosphor bronze)
acrylic supports
LAAPD plane (copper) and x-y wires (photo-etched phosphor bronze)
teflon light reflectors
~40 cm
flex cables on back of APD plane (copper on kapton, no glue)
field shaping rings (copper)
x-y crossed wires, 60°

Xenon Handling System





EXO-200 goal: 0.1 ppb O_2 equivalent

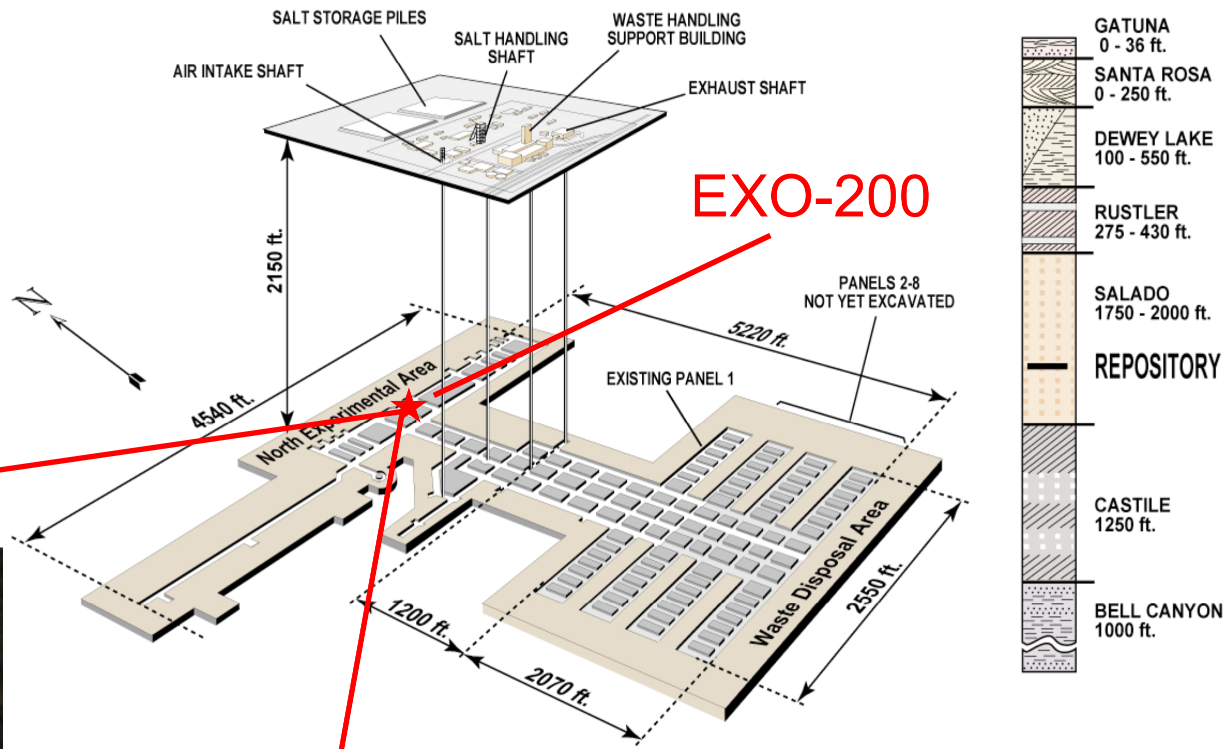
t ~ 4 ms (electrons)

muon flux at WIPP (~ 1700 m.w.e.):

$4.77\times10^{-3}\,m^{-2}s^{-1}$
$(3.10\times10^{-3}\,m^{-2}\,s^{-1}sr^{-1}$, $\sim15\,m^{-2}\,h^{-1})$

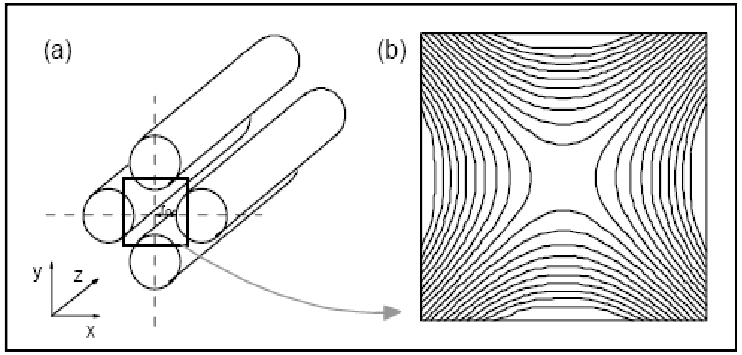
E.-I.Esch et al.,
Nucl. Instr. Meth. A 538(2005)516

WIPP Facility and Stratigraphic Sequence



Single Ba ion trapping

RF quadrupole potential in each segment
Multiply by 16, and add a buffer gas to cool down the ions injected at one end of the trap into a DC minimum

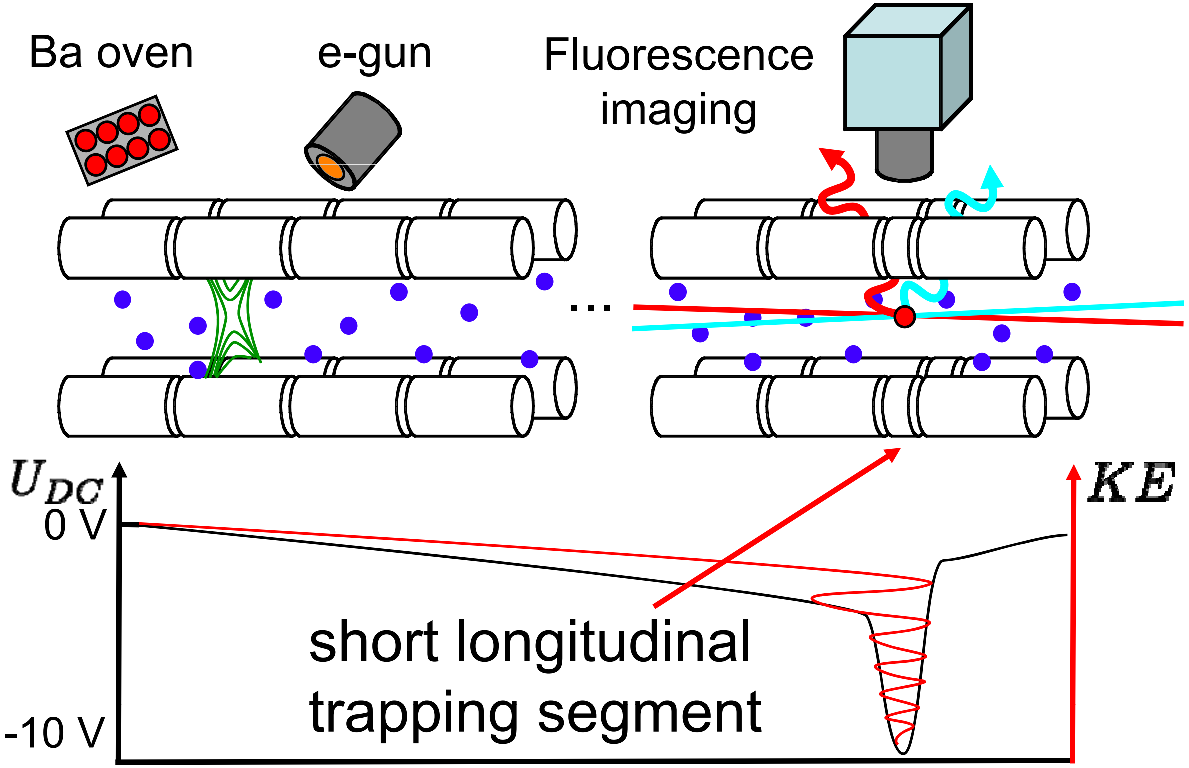


$$\Phi = \frac{\varphi_0}{2}\left(1 + \frac{x^2 - y^2}{r_0^2}\right)$$

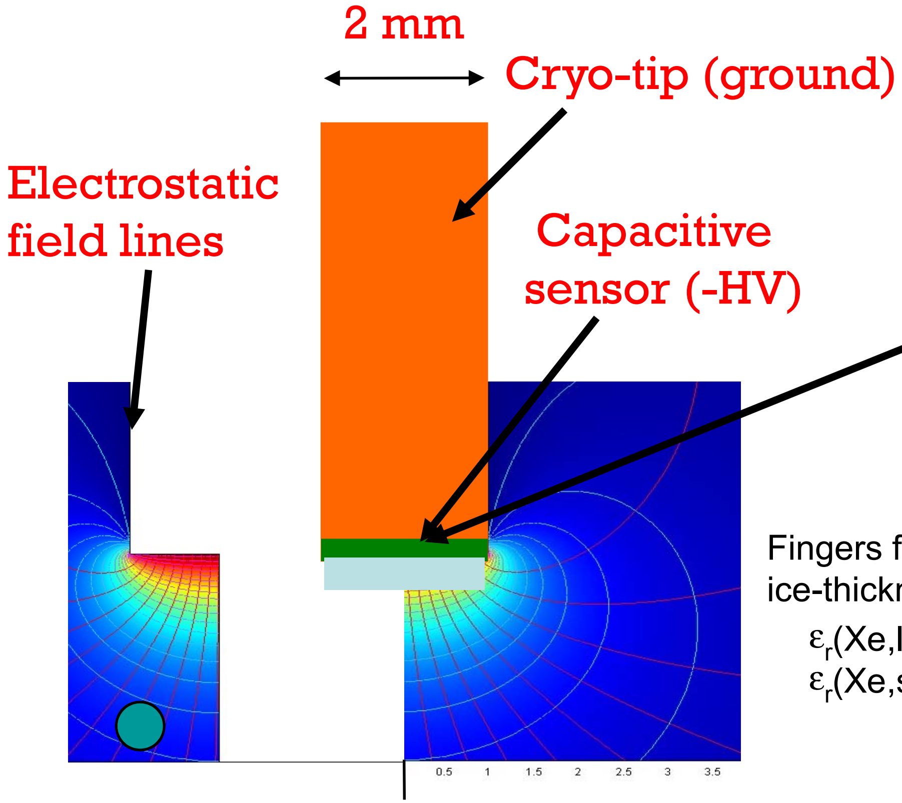
$$\varphi_0 = U_{DC} + V_{RF}\cos\Omega t$$

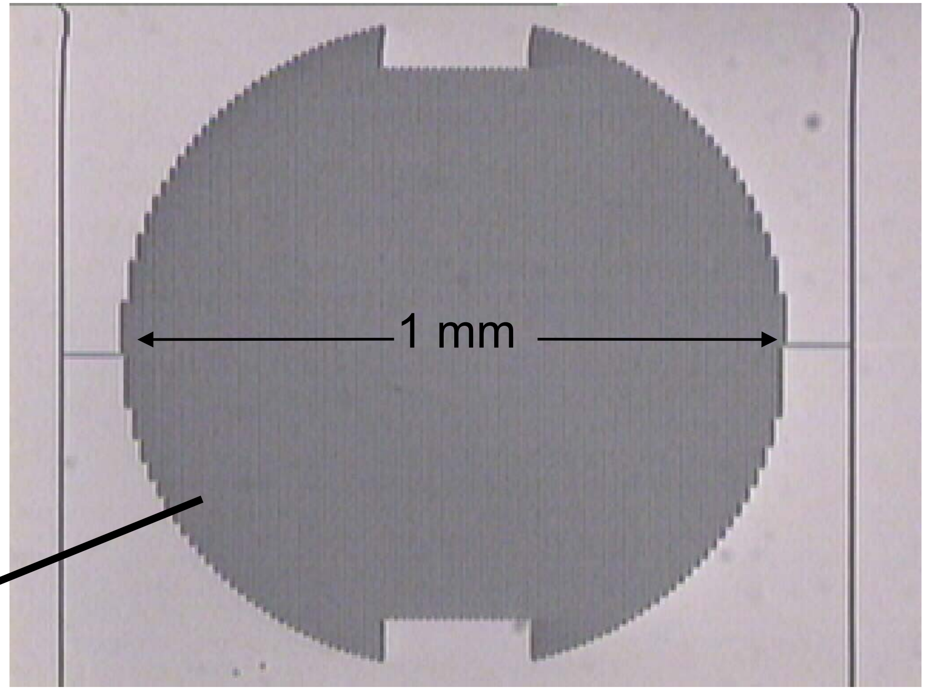
longitudinal trapping

radial trappin
g



Capacitive cryo-tip

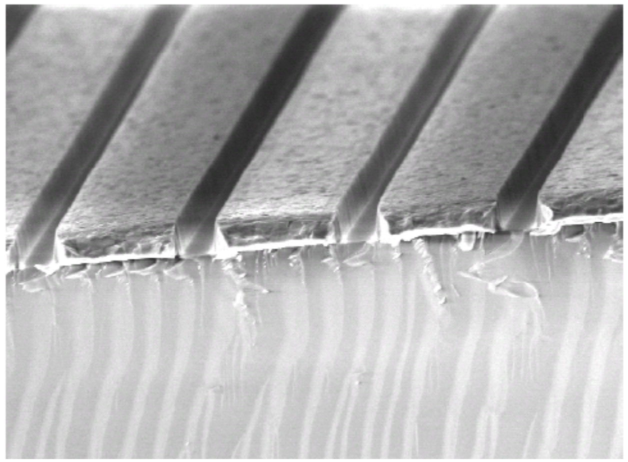




Fingers for dielectric ice-thickness measurement:

ε_r(Xe,liquid) = 1.88

ε_r(Xe,solid) = 2.25



Ion mobility: $\mu \sim 0.3\ cm^2/kVs$

$v = \mu \times 1kV/cm \sim 0.3\ cm/s$

K. Wamba et al., NIM A 555 (2005) 205