Detecting neutrinoless double beta decay with the Enriched Xenon Observatory

C. Hägemann

for the EXO collaboration

Lake Louise Winter Institute

02/18/2010

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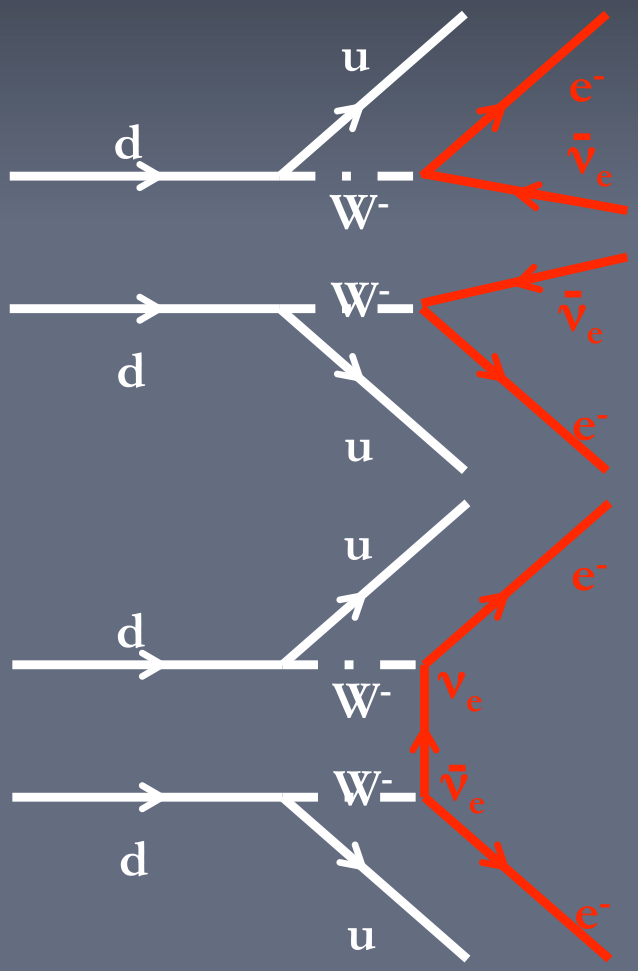
EXO collaboration:

Pursuing the detection of neutrino-less double beta decay in 136-Xe using either a liquid or gaseous detector

double beta decay



$$\left[T_{0\nu}^{1/2}\right]^{-1} = \Gamma_{0\nu} = G_{0\nu}\left|M_{0\nu}\right|^2\left\langle m_{\beta\beta}\right\rangle^2$$

G = phase space factors (easy)
|M| = nuclear matrix elements (hard)
$m_{\beta\beta}$ = effective neutrino mass (want to know)
$\Gamma_{0\nu}$ → half-life/count rate (limit already 10^{25}yrs)

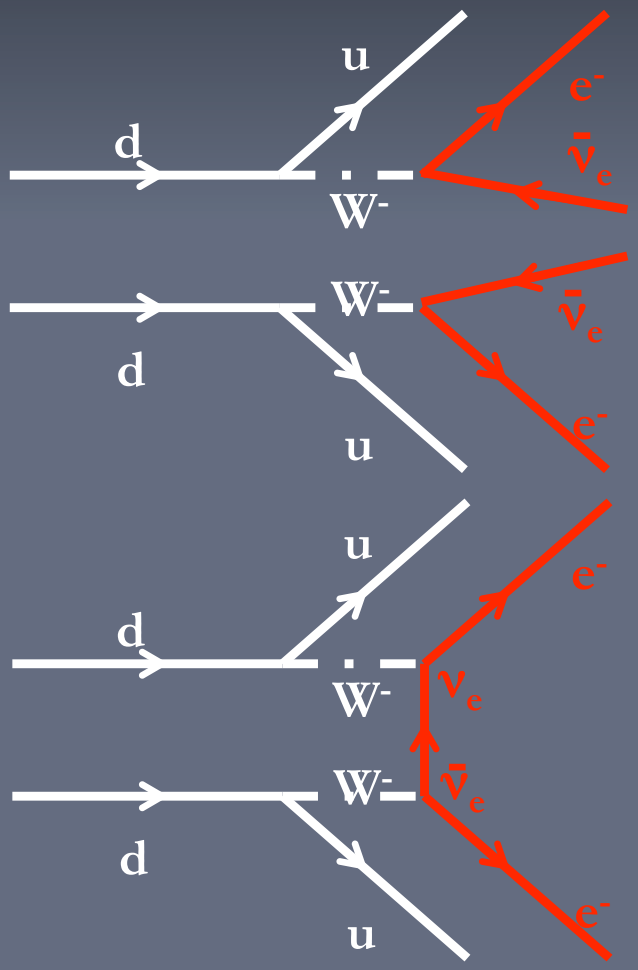
- Are neutrinos Majorana particles ?
- ΔL=2 lepton number violation?
- Neutrino mass scale
- Neutrino mass hierarchy

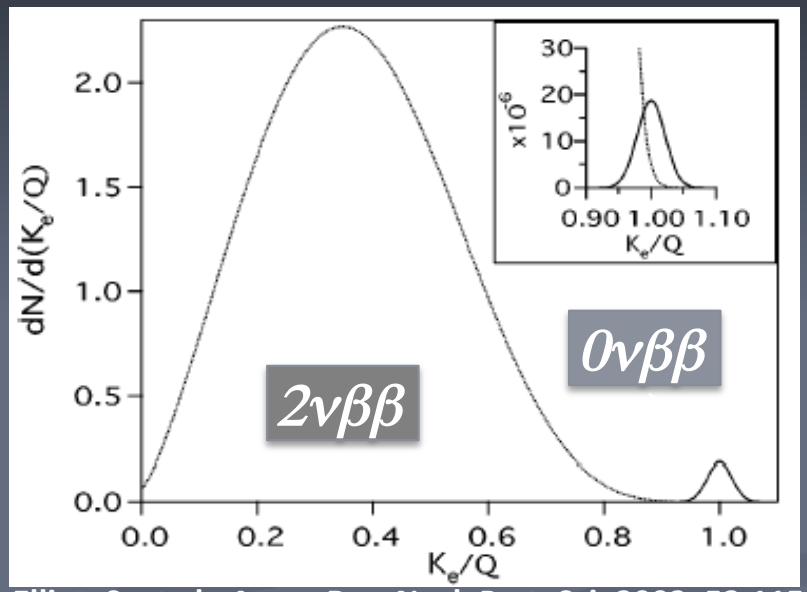
$^{136}Xe \rightarrow Ba^{++} + 2e^- + (2\nu_e)$

EXO collaboration:

Pursuing the detection of neutrino-less double beta decay in 136-Xe using either a liquid or gaseous detector

double beta decay





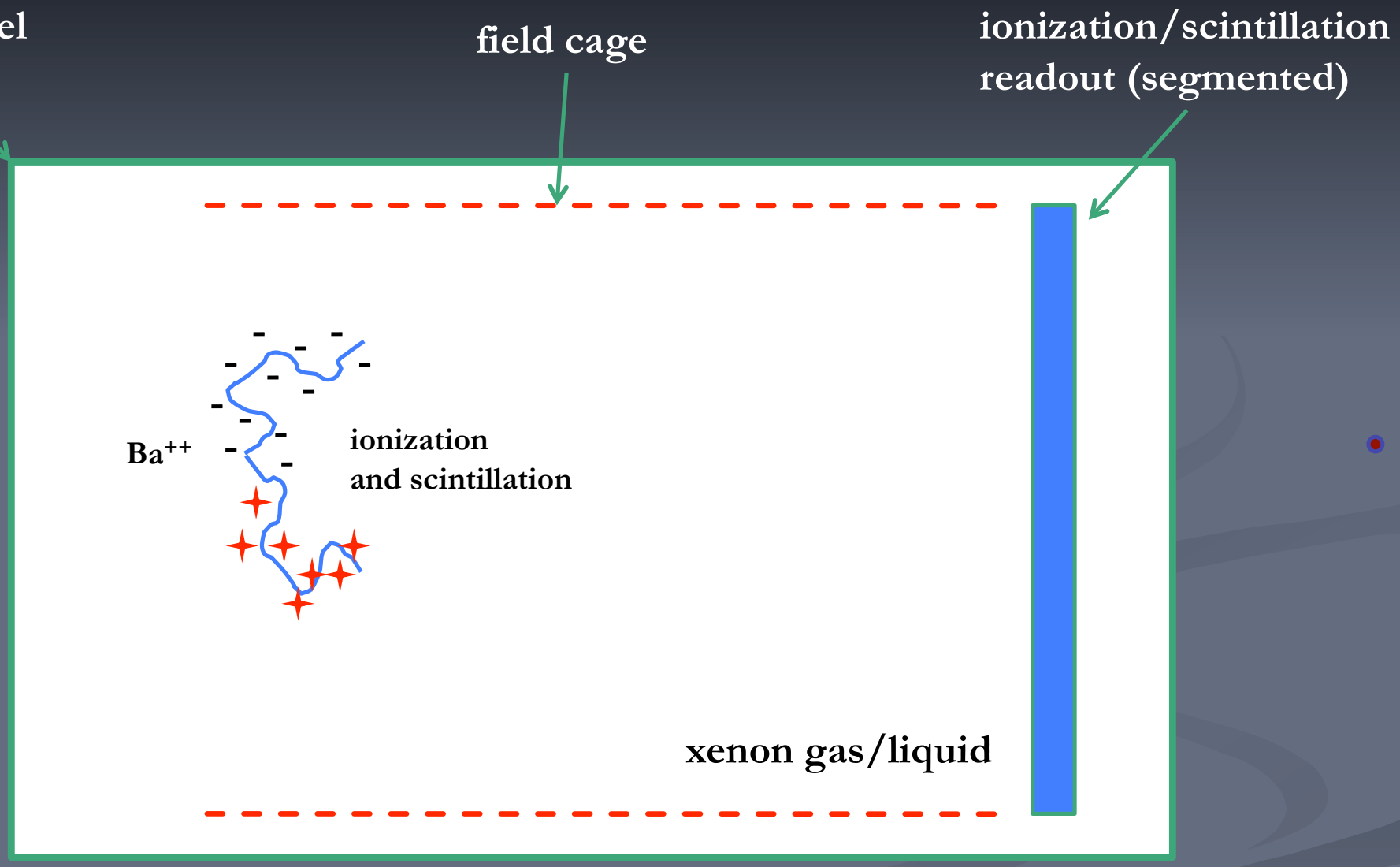
Elliot, S. et al., Annu. Rev. Nucl. Part. Sci. 2002. 52:115–51

detect the two e^-
(ionization +scintillation)

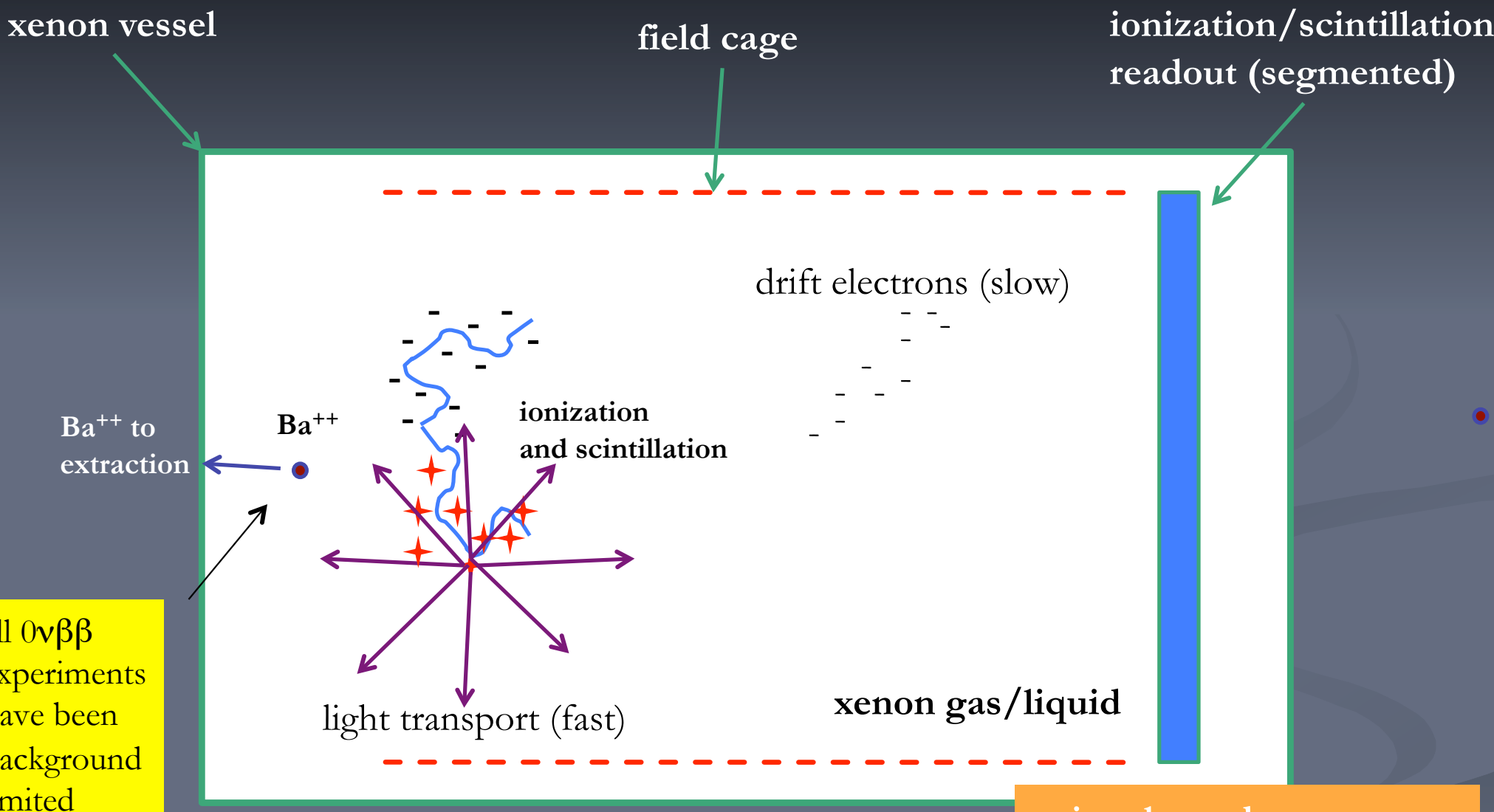
$$^{136}Xe \rightarrow Ba^{++} + 2e^- + (2\nu_e)$$

ID Ba^+ using optical spectroscopy

Detector concept for EXO



Detector concept for EXO



all 0νββ experiments have been background limited

- signals read out
- processed by electronics
- event reconstruction

Full EXO program

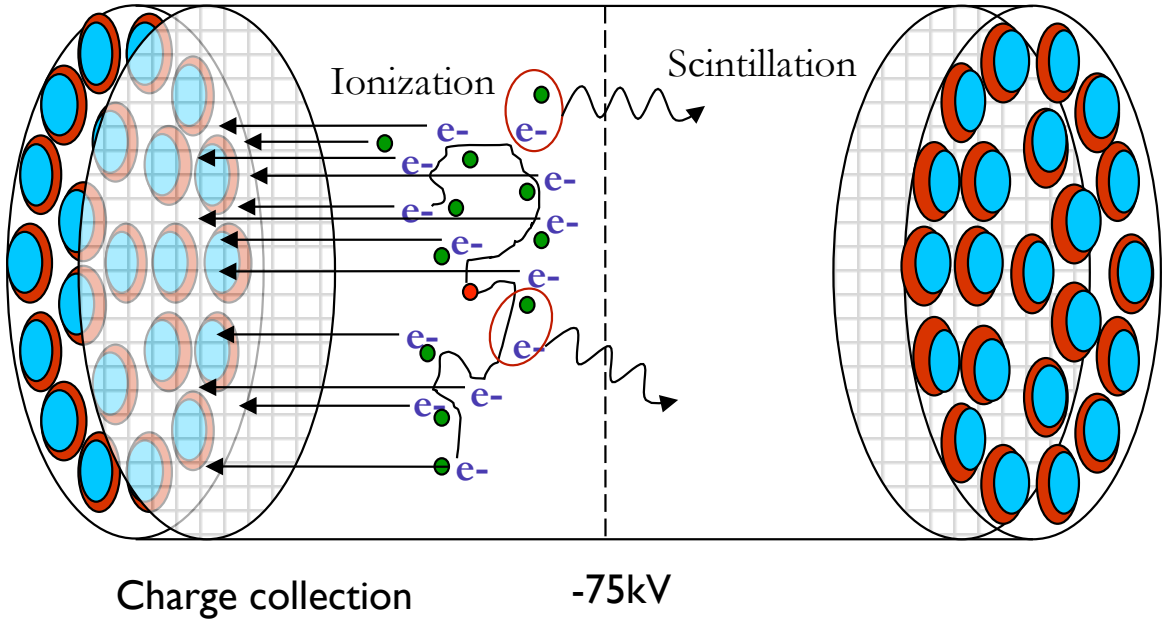
First measurement of ^{136}Xe $2\nu\beta\beta$ and search for $0\nu\beta\beta$

- **EXO 200**
  - liquid xenon time projection chamber (scintillation and ionization)
  - 200 kg of enriched xenon (~80%)
  - demonstrate energy resolution/low bkgs/physics results (!!!)
  - continued barium tag development

- **EXO Gas**
  - prototype gas-phase TPC (scintillation and ionization)
  - event reconstruction (σ_E~1%, tracking, dE/dx)
  - gas-phase barium tag

- **"Full EXO"**
  - multi-ton TPC
  - utilize 'best' technologies developed

EXO-200

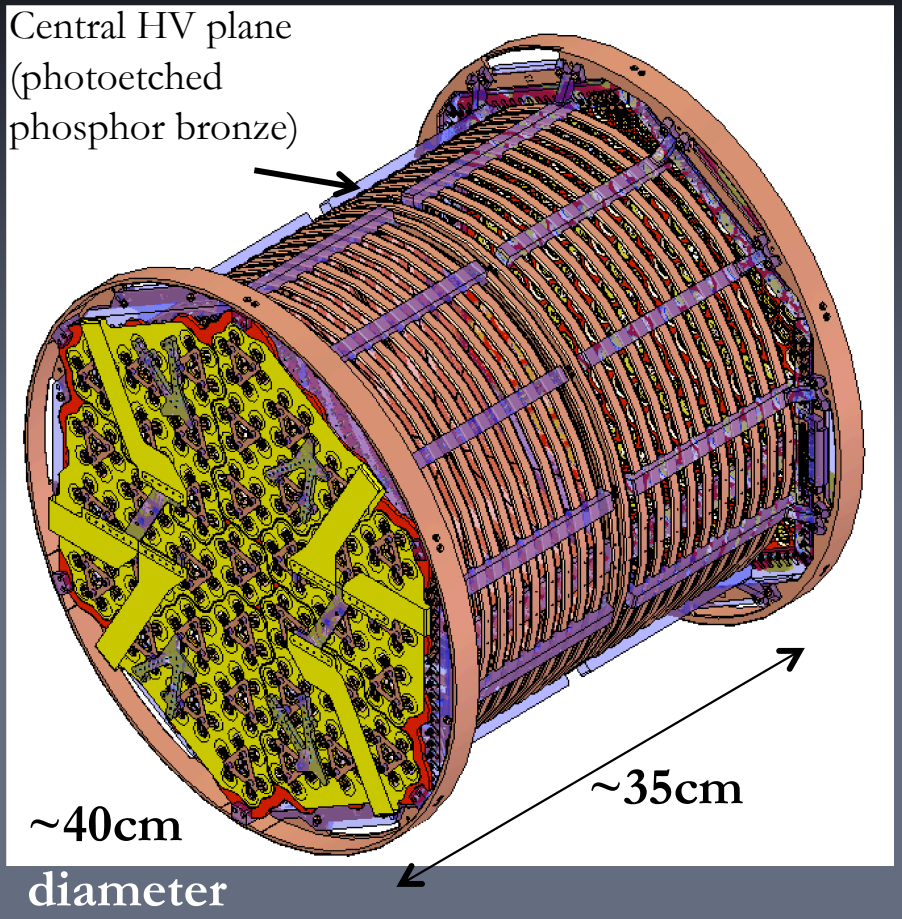


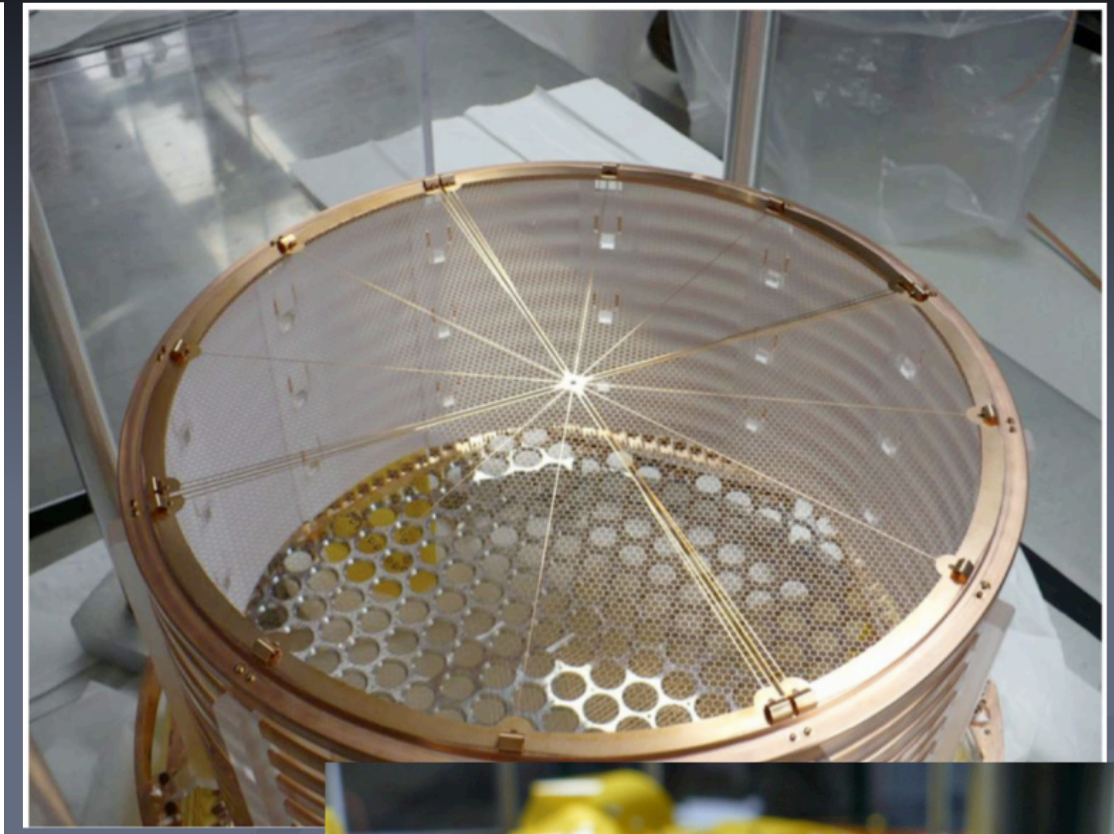
Avalanche photodiodes (scintillation light collection)

- $0\nu\beta\beta$ decay daughter ($^{136}Ba^{++}$)
- Ionized/excited Xe
- e- $0\nu\beta\beta$ ionization trail e-

- Ionization along track is collected on X-Y wires (at 60 degree angle)
- Scintillation light (175nm) is collected on Avalanche Photo Diodes (APDs)
- Energy reconstruction from combined ionization and scintillation signals yielding predicted $\Delta E/E = 1.4\%$ at $Q_{\beta\beta}$
- Position reconstructed from charge distribution and t_{SCINT}-t_{ION} ; needed for Ba extraction in full scale EXO

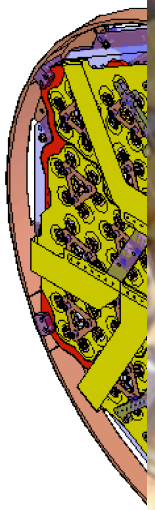
EXO-200


Central HV plane
(photoetched
phosphor bronze)
~40cm
diameter
~35cm



EXO-200

Central HV plane
(photoetc
phosphor



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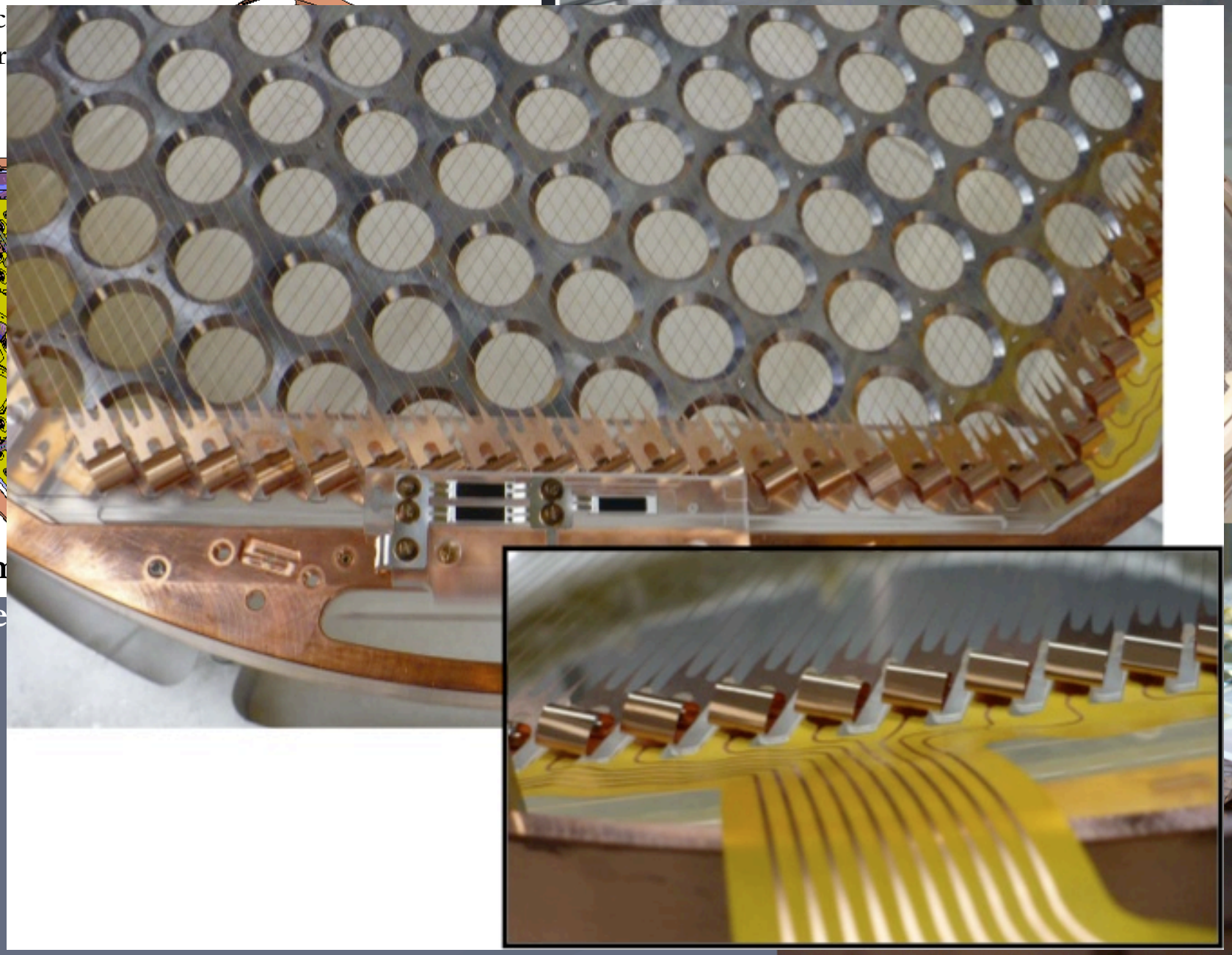
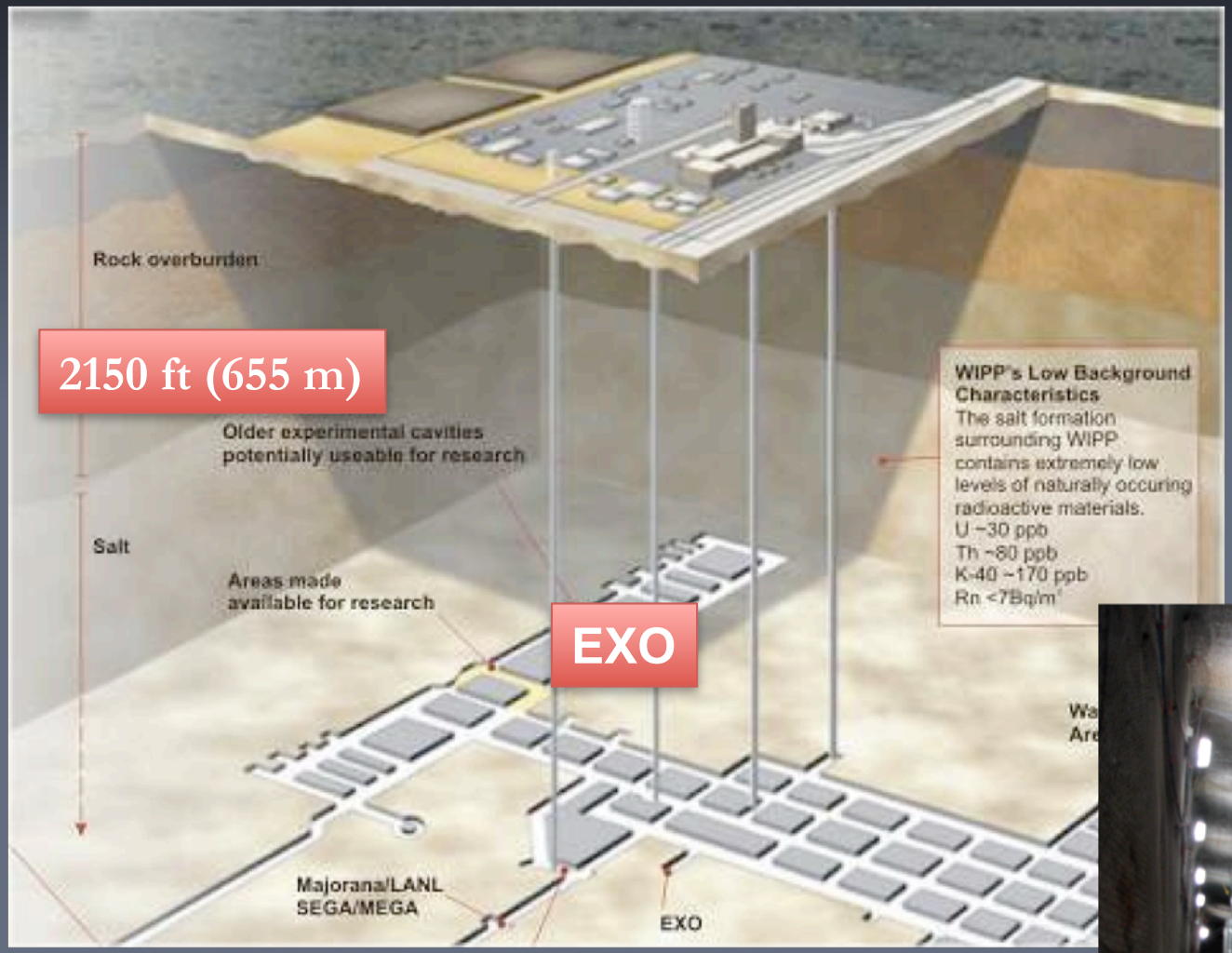


Current status of EXO-200

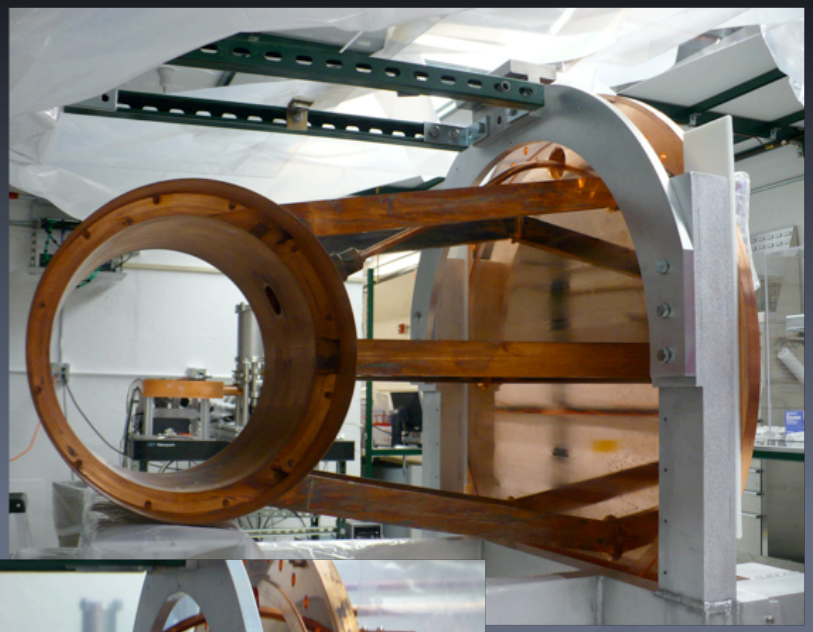
EXO-200 is located in WIPP site in Carlsbad, New Mexico

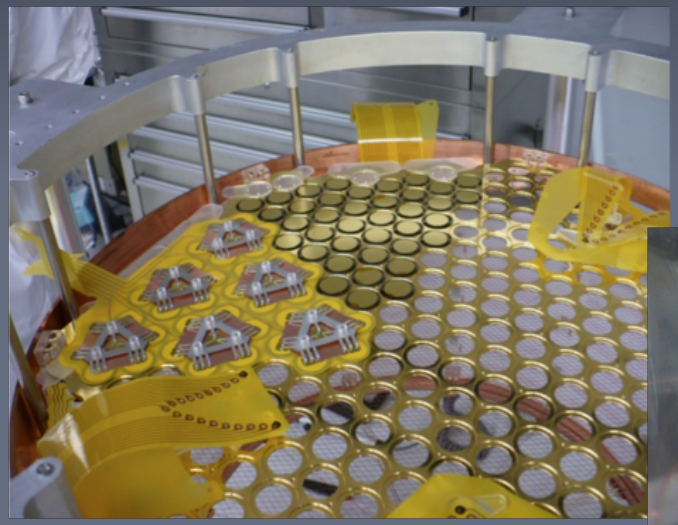


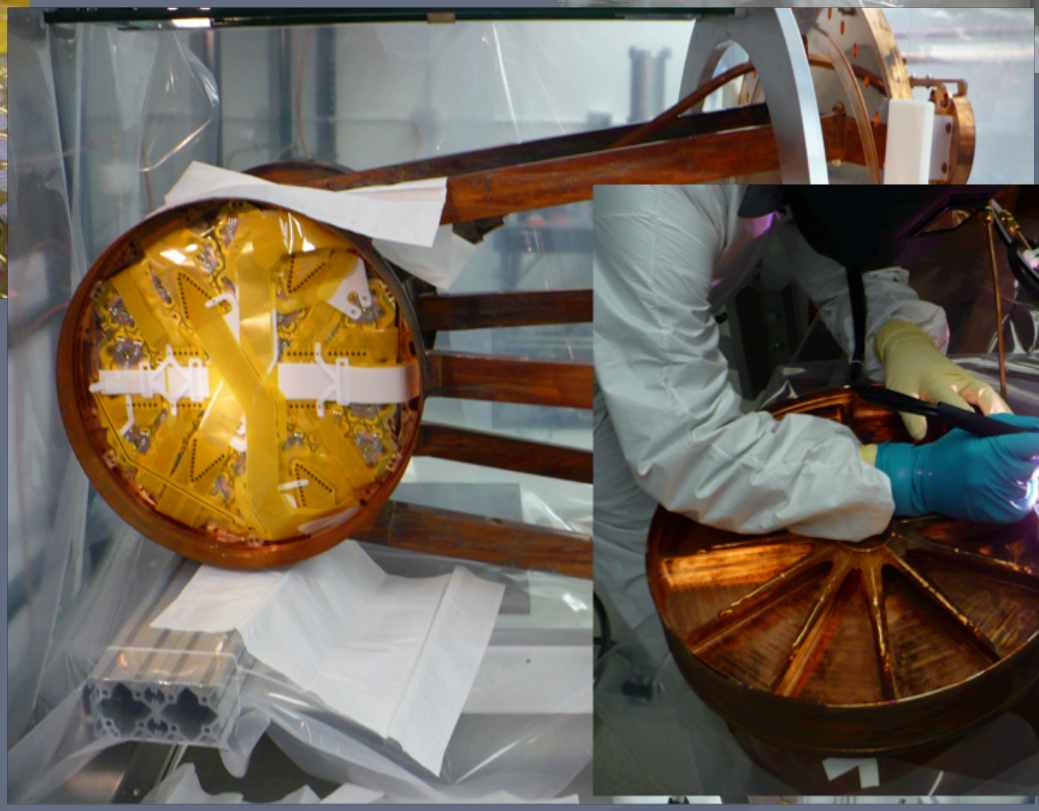
- 1600 mwe flat overburden (2150 feet, 650 m)
- Salt "rock" low activity relative to hard-rock mine

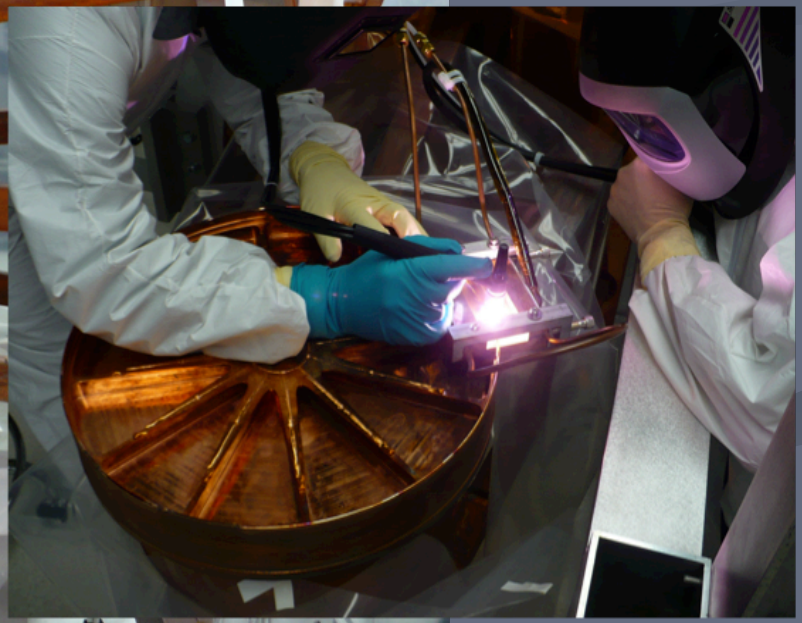
Current status of EXO-200

TPC assembled and welded shut at Stanford in October 2009 and shipped to WIPP In November 2009







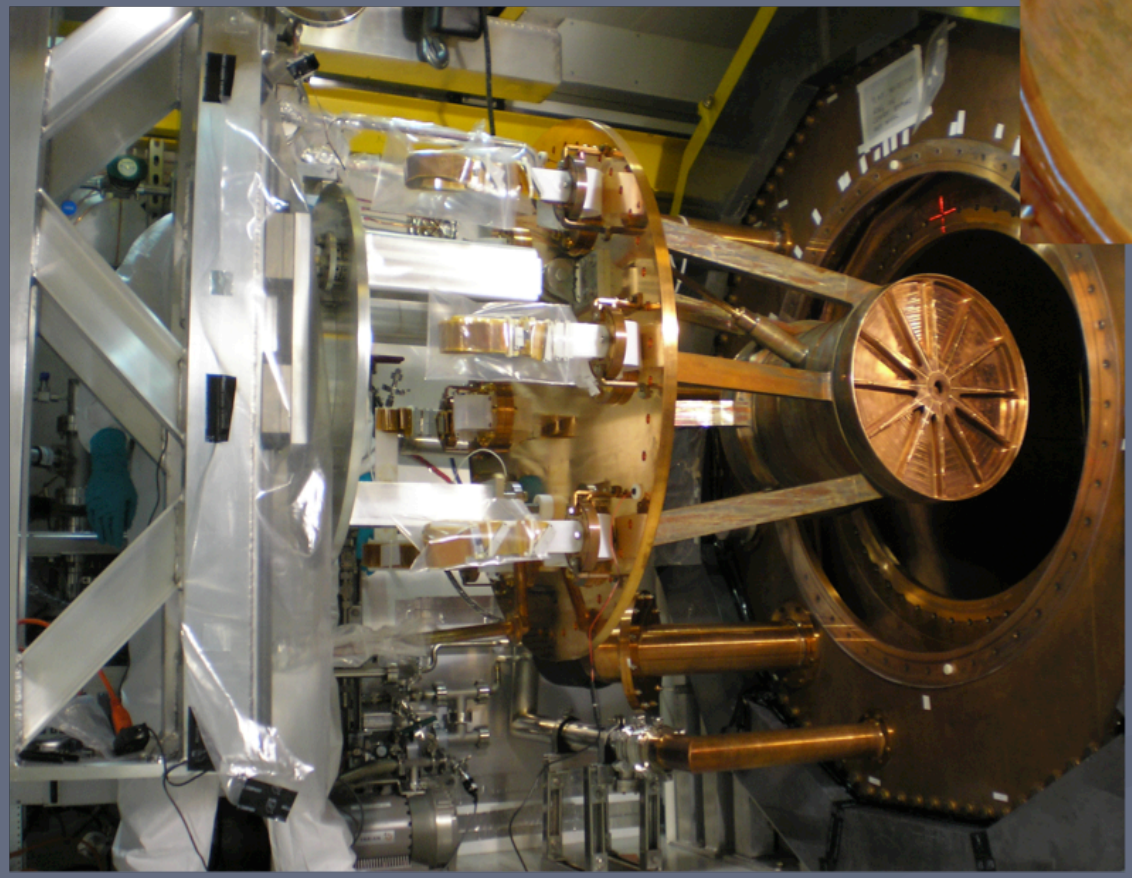


Massive effort on materials qualification – database of ~330 entries

(D. Leonard et al., Nuclear Instruments and Methods in Physics Research A 591 (2008) 490–509)

Current status of EXO-200

- Successful systems commissioning completed in November 2009
- Calibration tubing installed in Jan 2010
- **TPC installed in the cryostat in Jan 2010!**



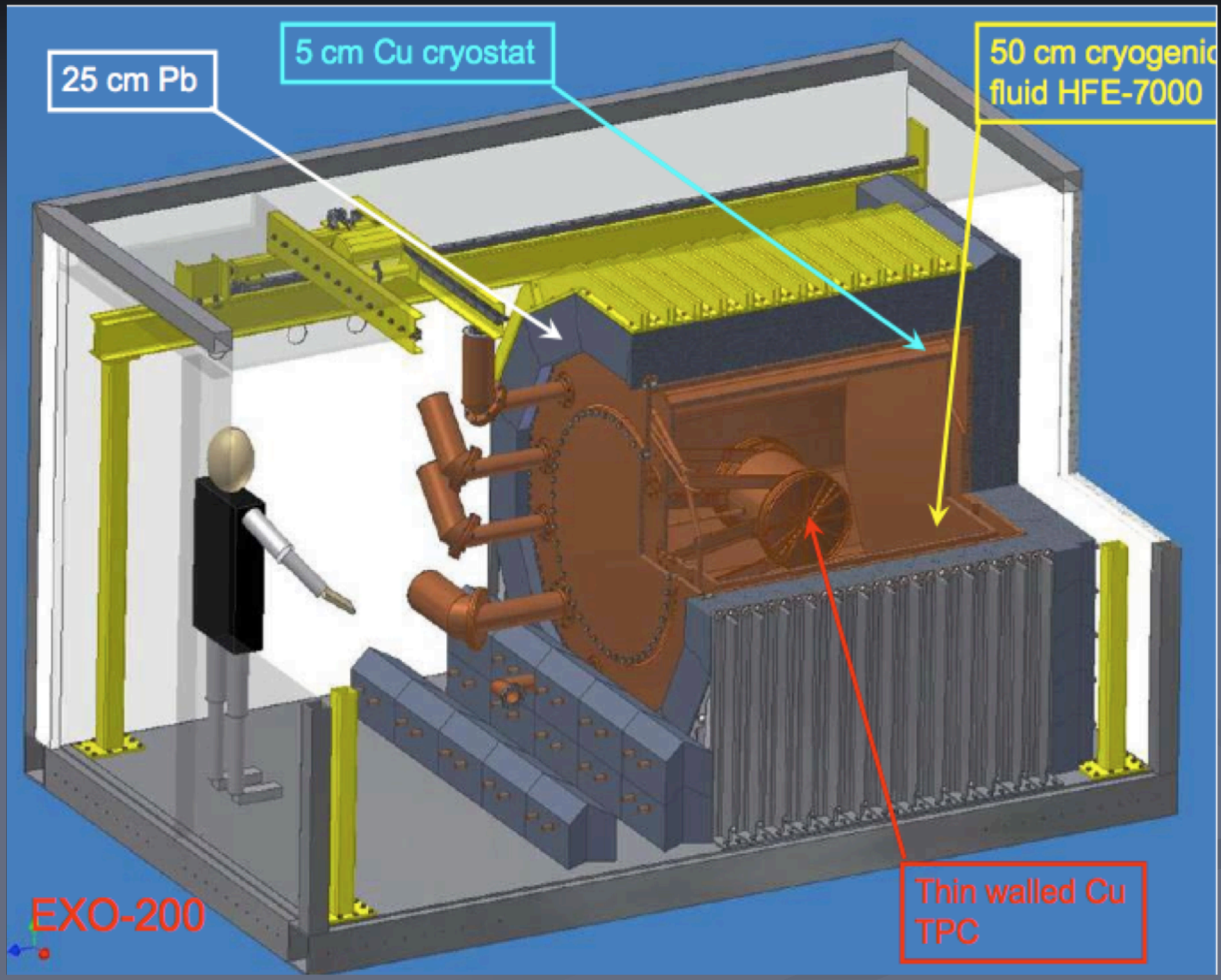
Current status of EXO-200

- Successful systems commissioning completed in November 2009
- Calibration tubing installed in Jan 2010
- **TPC installed in the cryostat in Jan 2010!**
- Muon veto system completely installed in Jan 2010

Next steps:

- Installation and testing of electronics and DAQ
- Commissioning of the muon veto system
- Ready for first running with natural Xenon in mid 2010

Current status of EXO-200



Physics of EXO-200

$2\nu\beta\beta$

	$T_{1/2}$ (yr)	evts/year EXO-200
Bernabei et al	$>1.0\cdot10^{22}$	<48 k
QRPA (Staudt et al) [$T_{1/2}^{max}$]	$=2.1\cdot10^{22}$	=23 k
QRPA (Vogel et al)	$=8.4\cdot10^{20}$	=0.58 M
NSM (Caurier et al)	$(=2.1\cdot10^{21})$	(=0.23 M)

$0\nu\beta\beta$

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 (meV) QRPA[1]	NSM[2]
EXO-200	0.2	70	2	1.6*	40	$6.4*10^{25}$	133	186

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

Gas Phase R&D:

- Build 10bar gaseous Xenon prototype
- Contain 1MeV electrons
- Use a segmented readout for tracking
- Demonstrate 1% or better energy resolution for electrons

Approach:

- Electroluminescence (EL) technique to achieve gain in Xe

$$N_{ph} = 70\ (E/p - 1)\ p\ dx$$

- CsI photocathode to readout UV light created in the EL region as well as the scintillation light along the initial track

Properties of Electroluminescence:

✧ EL is well studied technique in noble gases and noble gas mixtures

✧ At 10bar, 7kV/cm, dx=1cm about 1000 EL photons are produced

✧ Gain process exhibits normal fluctuations with low variances ⇒ **good resolution**

✧ Single photo detection technology can be used to measure both **scintillation** and **ionization** (through EL) signals

✧ CsI photocathode can be used at different gain configurations or at no gain setting

✧ relatively high quantum efficiency at 175nm (ref. achieve between 20 and 35%)

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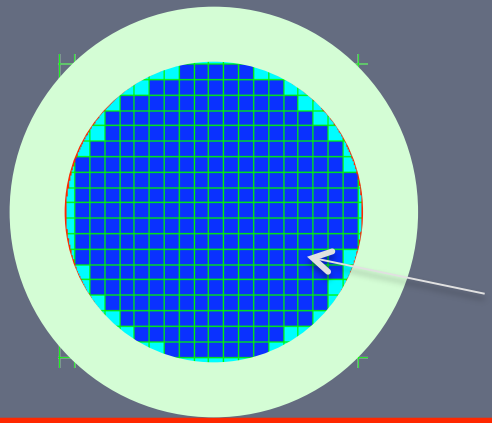
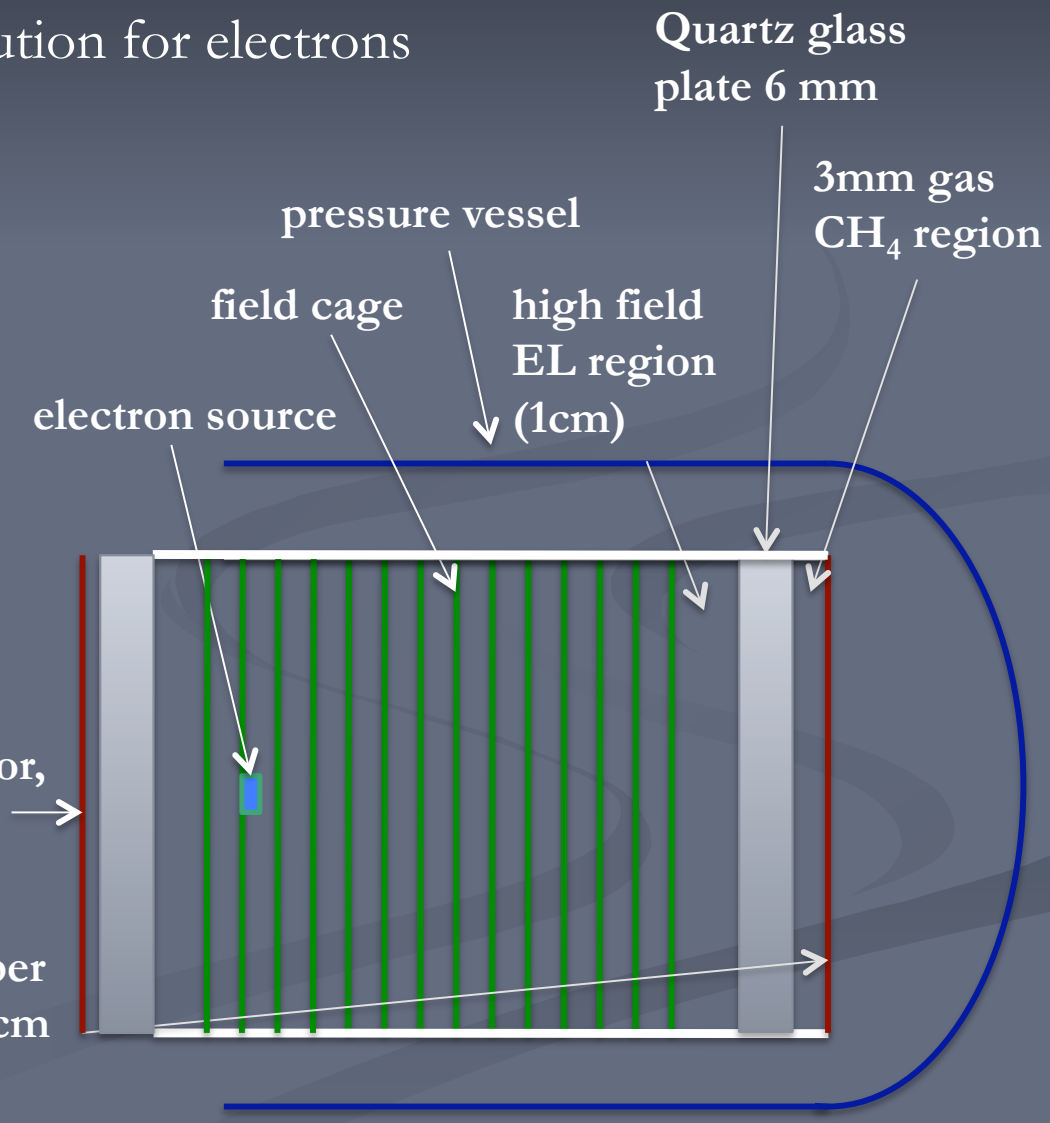
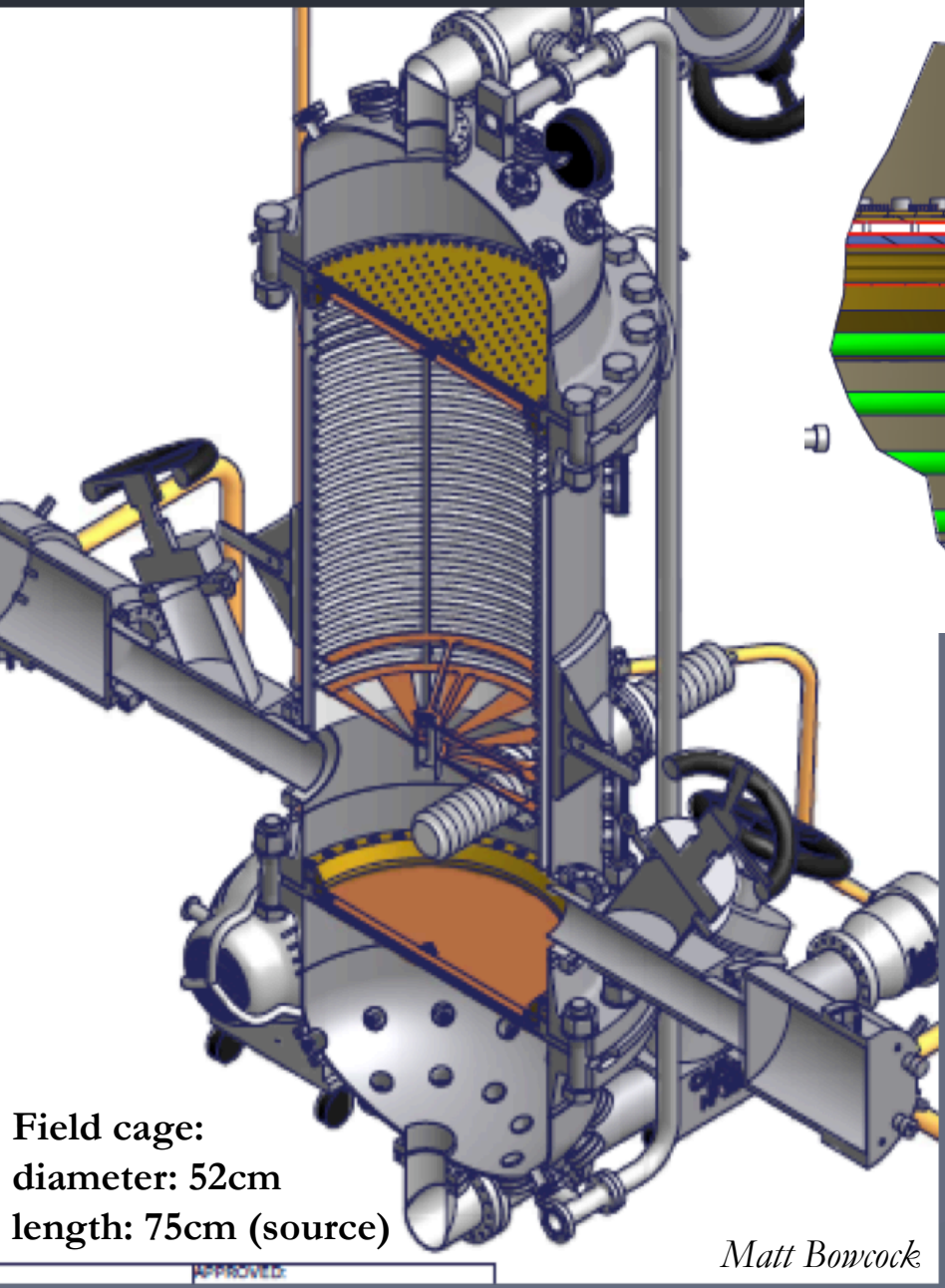




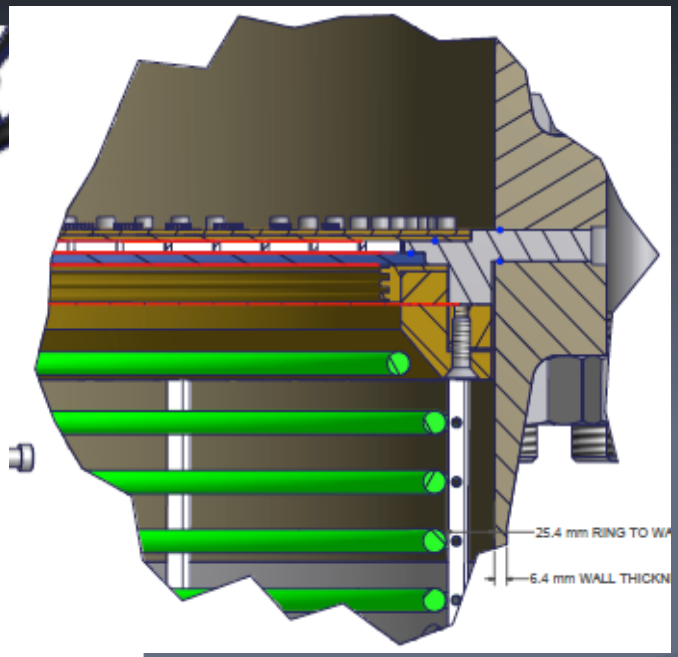
Gas Phase R&D:

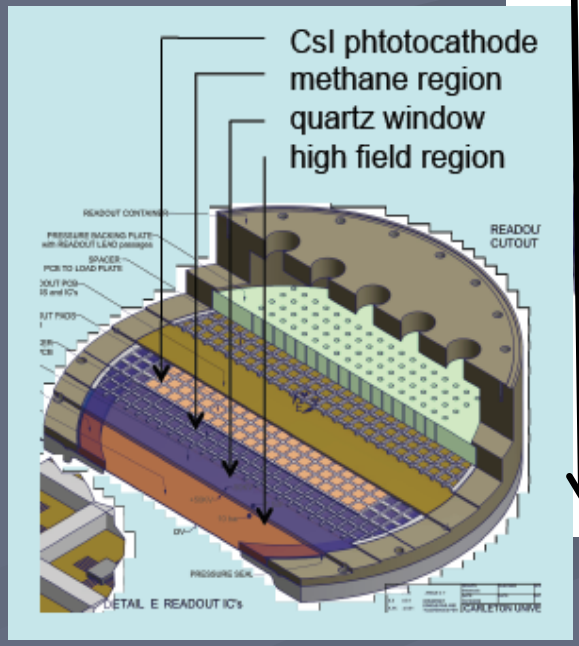
Pressure vessel has been designed and is being built:

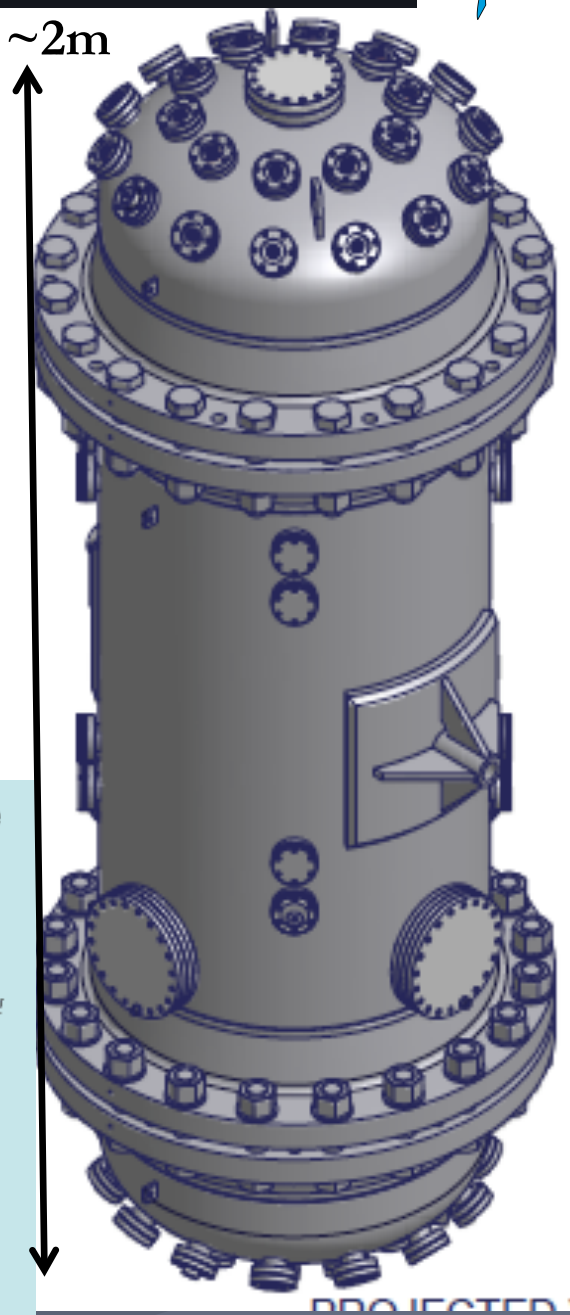


Field cage:
diameter: 52cm
length: 75cm (source)

Matt Bowcock







Milestones & Long Term plans

Task ID	Task Name	By Sept 2010	By Sept 2011	By Sept 2012
-	EXO-200	First Data !!!	^{136}Xe run in progress	Run
			First technical paper	First Physics Paper
1	Ba tag (LXe and GXe)	Tagging workshop	RIS tip decision	Tag from LXe results
		Xe ice tip decision	Tag-from-GXe setup built	Tag-from-GXe results
		Ba ion source operational		
		Tag-from-GXe setup designed		
2	GXe detector	Results from GXe resolution MC	Resolution data from GXe setup	More results GXe setup
		GXe chamber operational !!!	Compare data with MC	
3	LXe – Ba tag integration	Dipper design	Dipper built	Results from dipper
			Monte Carlo simulation of LXe flow	

Currently on schedule to have a decision by 2012 on the best way to proceed to a ton scale Xe-136 neutrino-less double beta decay experiment!