The Enriched Xenon Observatory for Double Beta Decay

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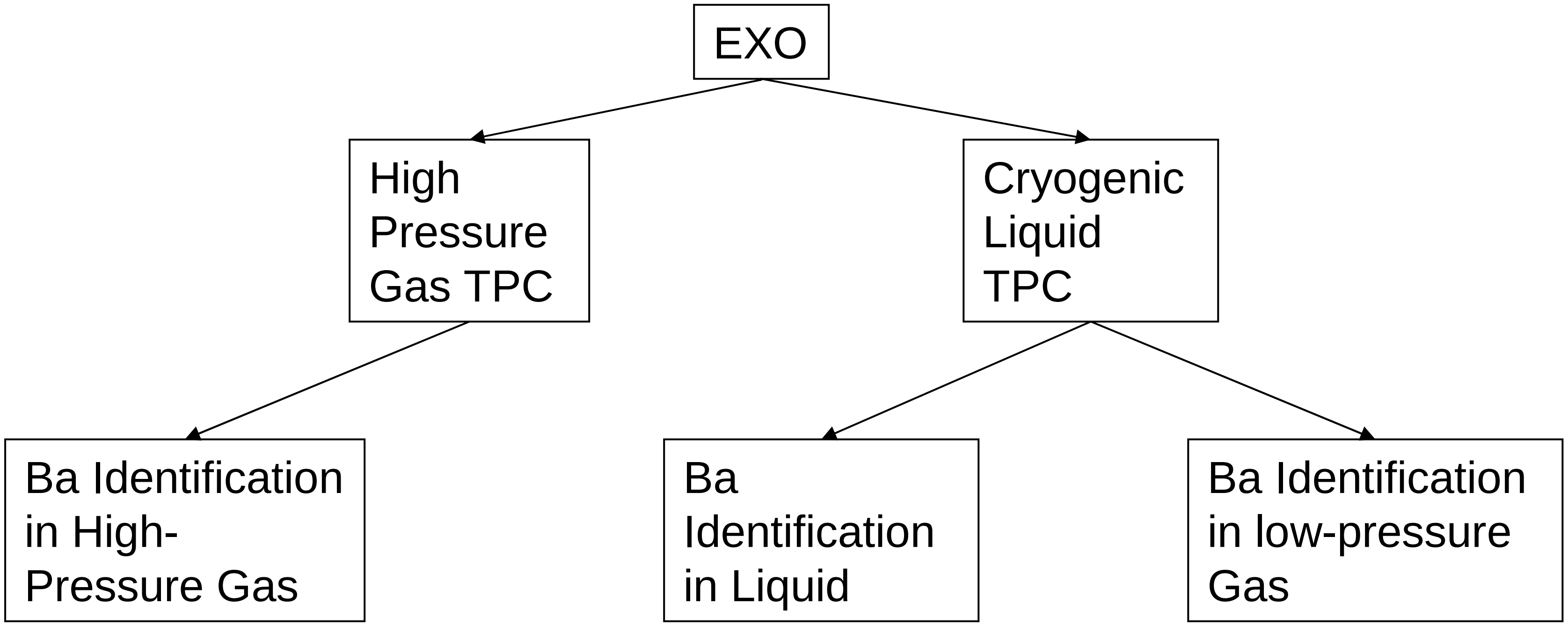
EXO neutrino effective mass sensitivity

Assumptions:
1) 80% enrichment in 136
2) Intrinsic low background + Ba tagging eliminate all radioactive background
3) Energy res 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 (Bernabei et al. measurement)

Case	Mass (ton)	Eff. (%)	Run Time (yr)	σ_E/E @ 2.5MeV (%)	2νββ Background (events)	$T_{1/2}^{0\nu}$ (yr, 90%CL)	Majorana mass (meV) QRPA‡	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

¥ Redshaw et al. Phys Rev Let 90, 053003 (2007)
* 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

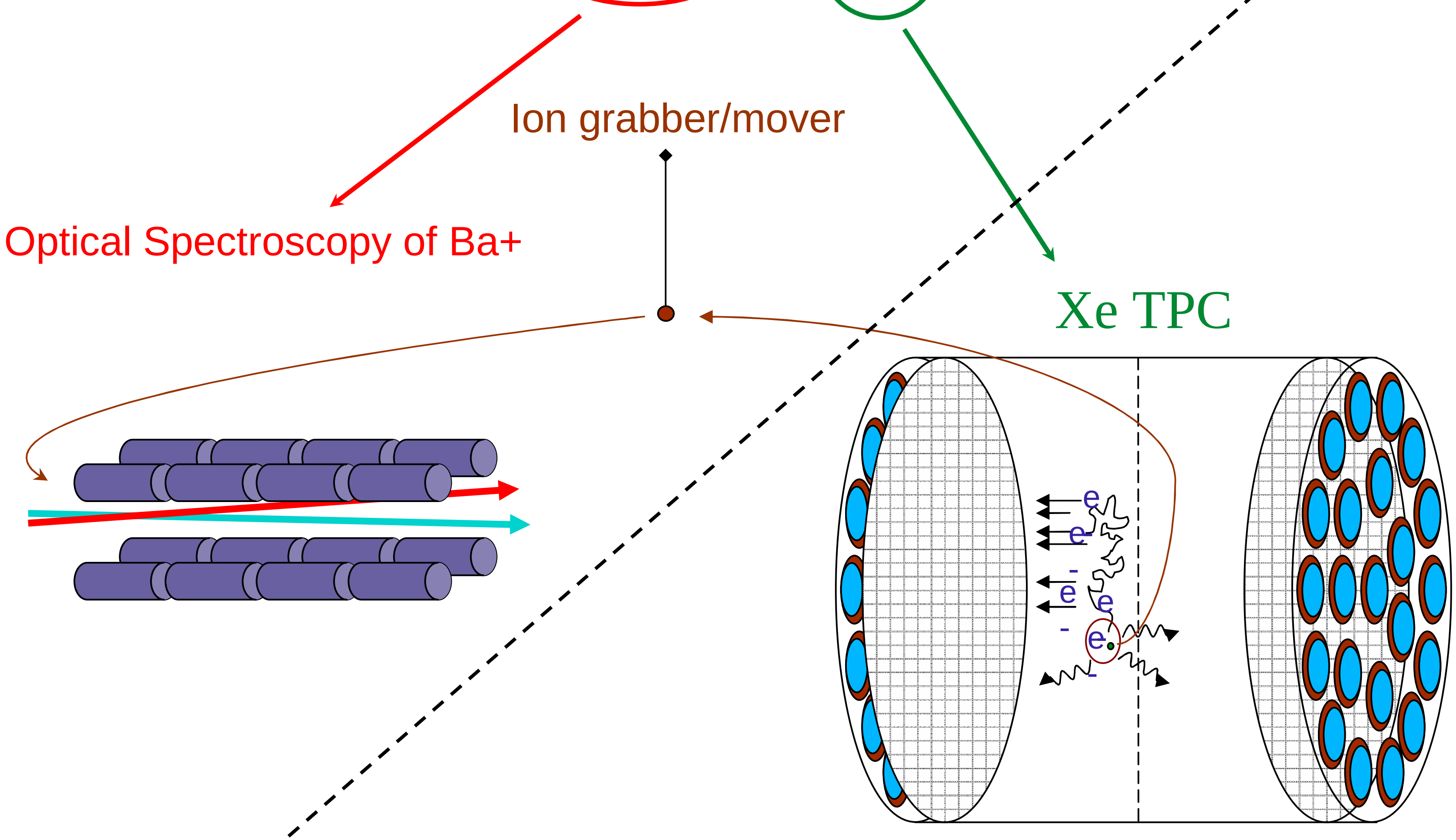
Multiple Paths to a Background Free Detector



Detection Method Overview

[M. Moe, Phys. Rev. C 44 (1991) R931]

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



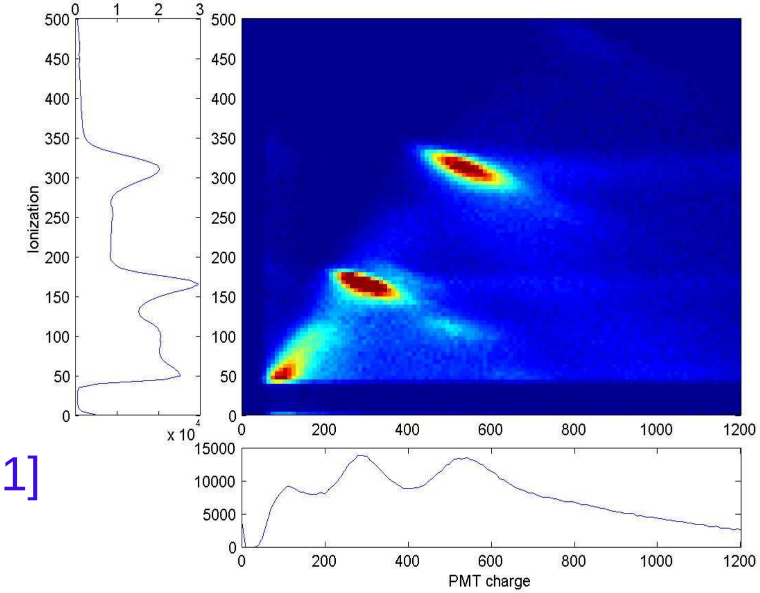
EXO-200 Goals

- Search for 0νββ in ^{136}Xe with competitive sensitivity
- Measure 2νββ half life of ^{136}Xe (best limit currently set by Bernabei et al, $1x10^{22}$y)
- Understand the operation of a large LXe detector
  - Understand backgrounds / characterize detector materials
  - Learn about large scale Xe enrichment
  - Understand Xe handling, purification, resolution

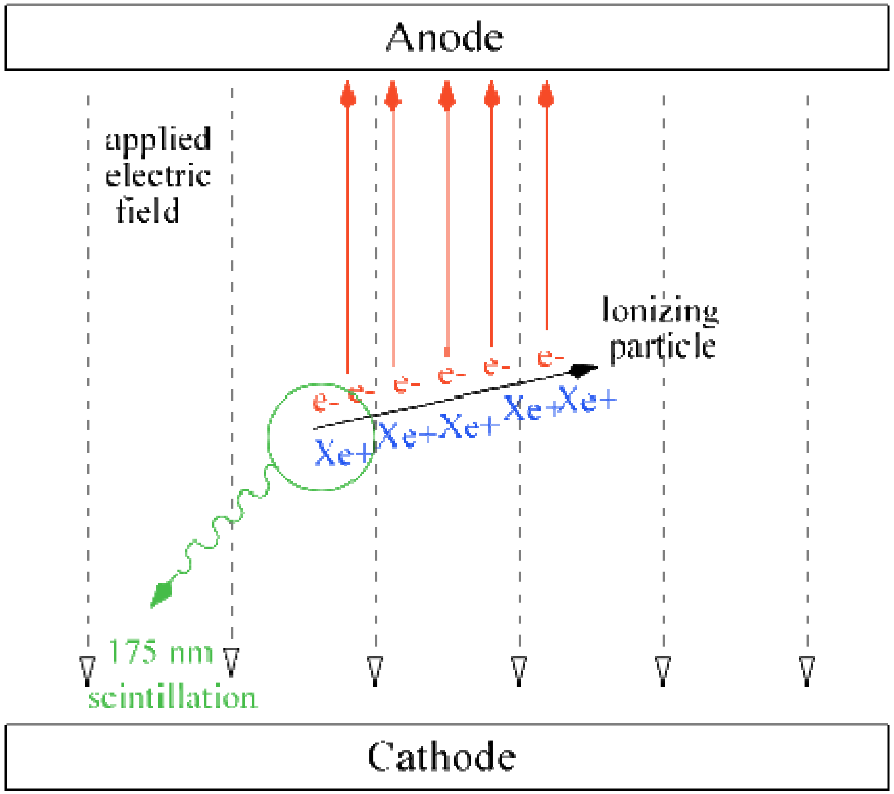
EXO-200 Detector

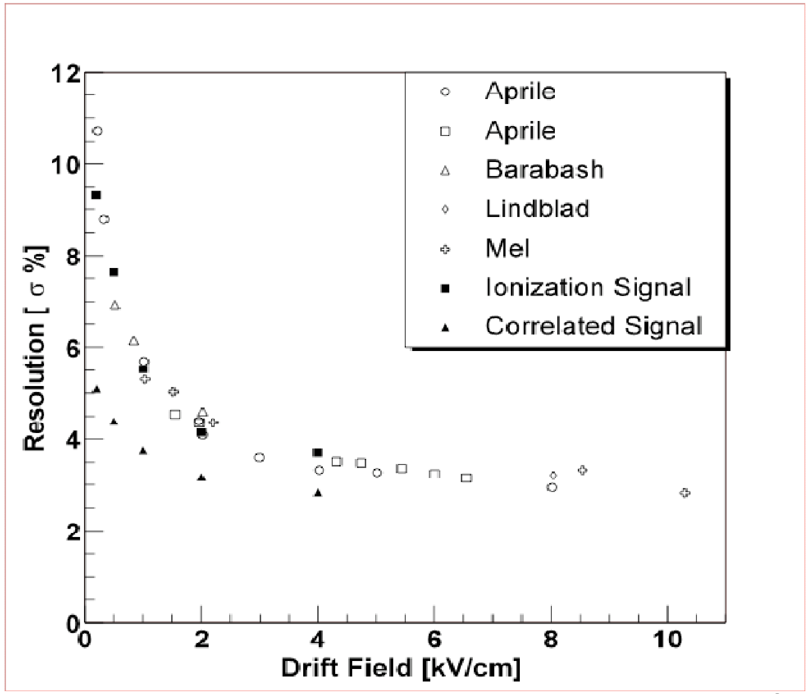
Improve energy resolution via simultaneous collection of ionized electrons and scintillation light (confirmed by others)

E. Conti et al. (EXO Collab), PRB: **68**(2003)054201]



Ionization and Scintillation results using ^{207}Bi



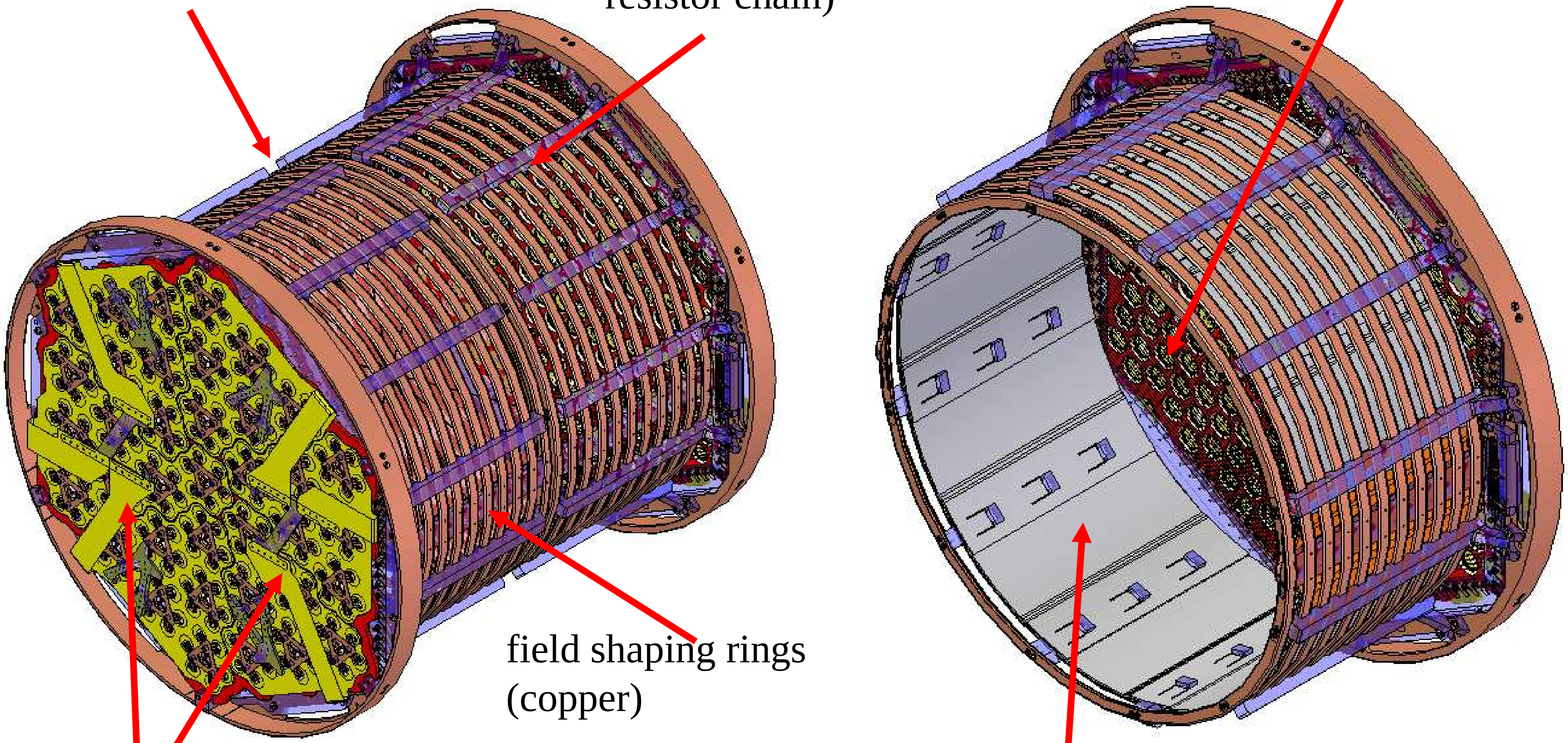


EXO-200 TPC

Central HV plane (photo-etched phosphor bronze)

acrylic supports
(one holds the field divider resistor chain)

APD plane (copper) and grid plane (photo-etched phosphor bronze)

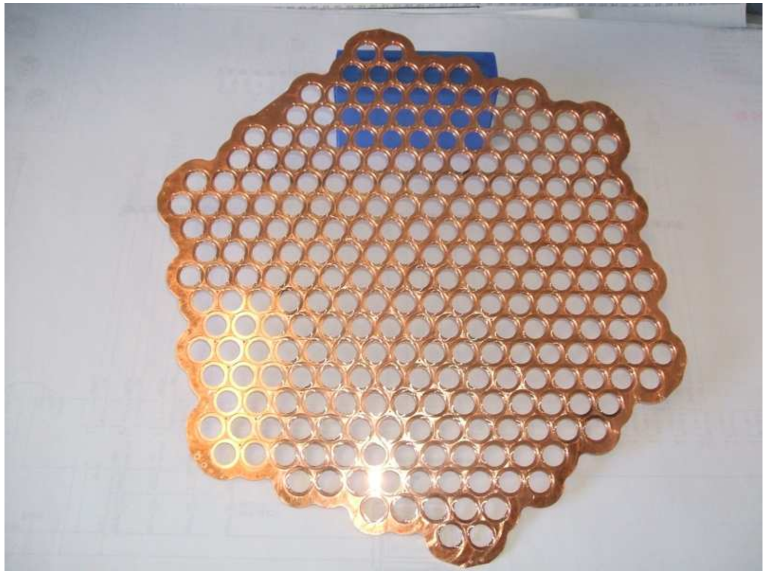


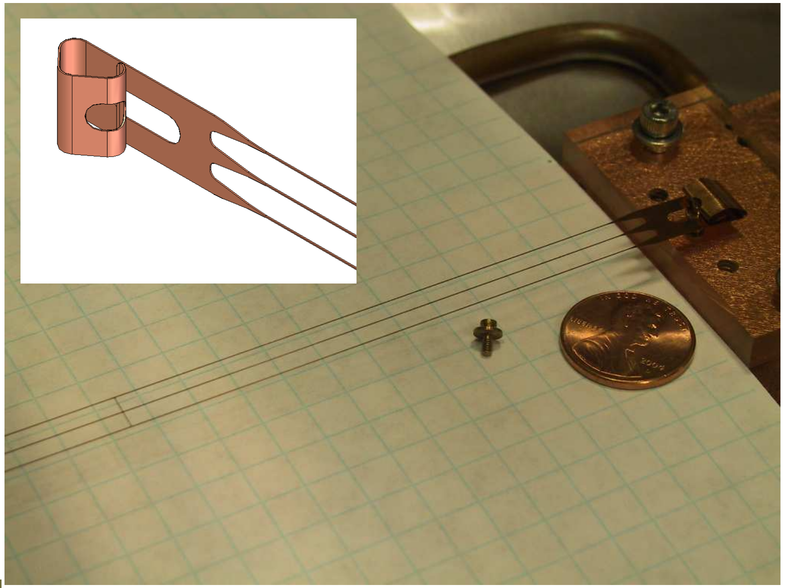
field shaping rings (copper)

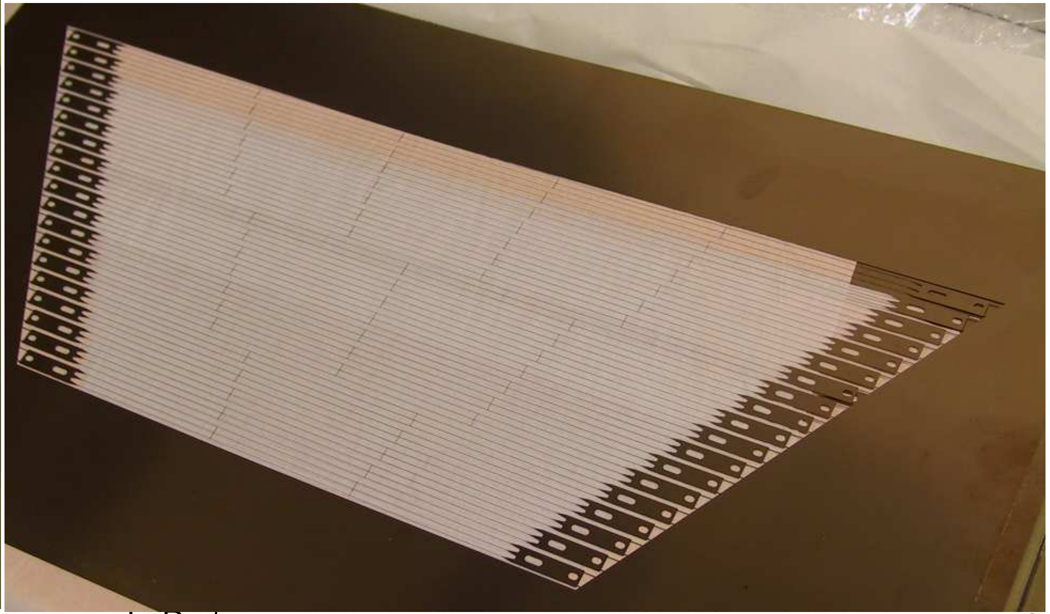
flex cables on back of APD plane (copper on kapton, no glue)

teflon light reflectors/diffusers

Detector Components



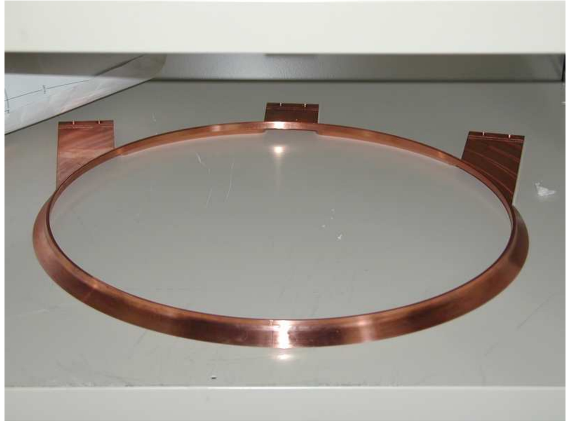


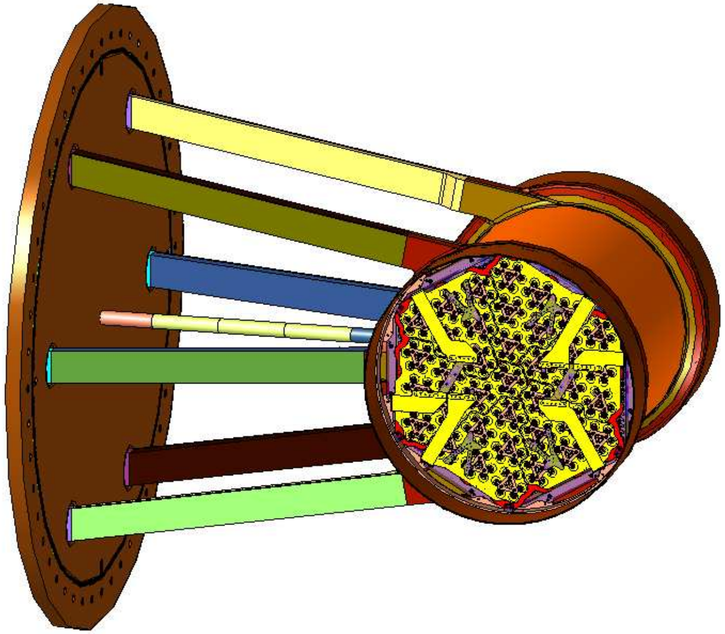


Chamber

Chamber is fully designed and being machined at Stanford University under 7 m.w.e shielding

E-beam welding will be used for all but final weld to minimize introduction of radioactive background

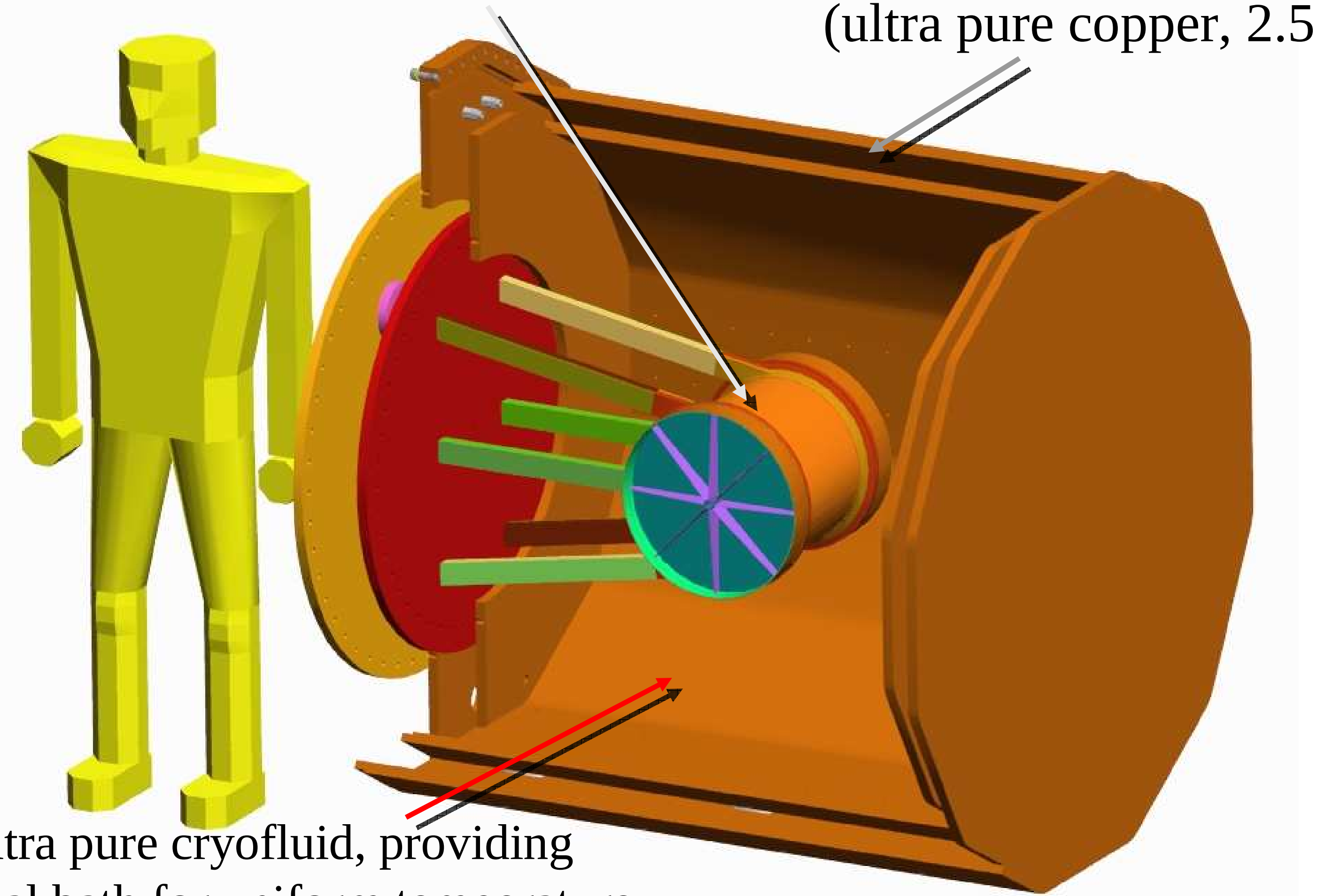




The EXO-200 detector

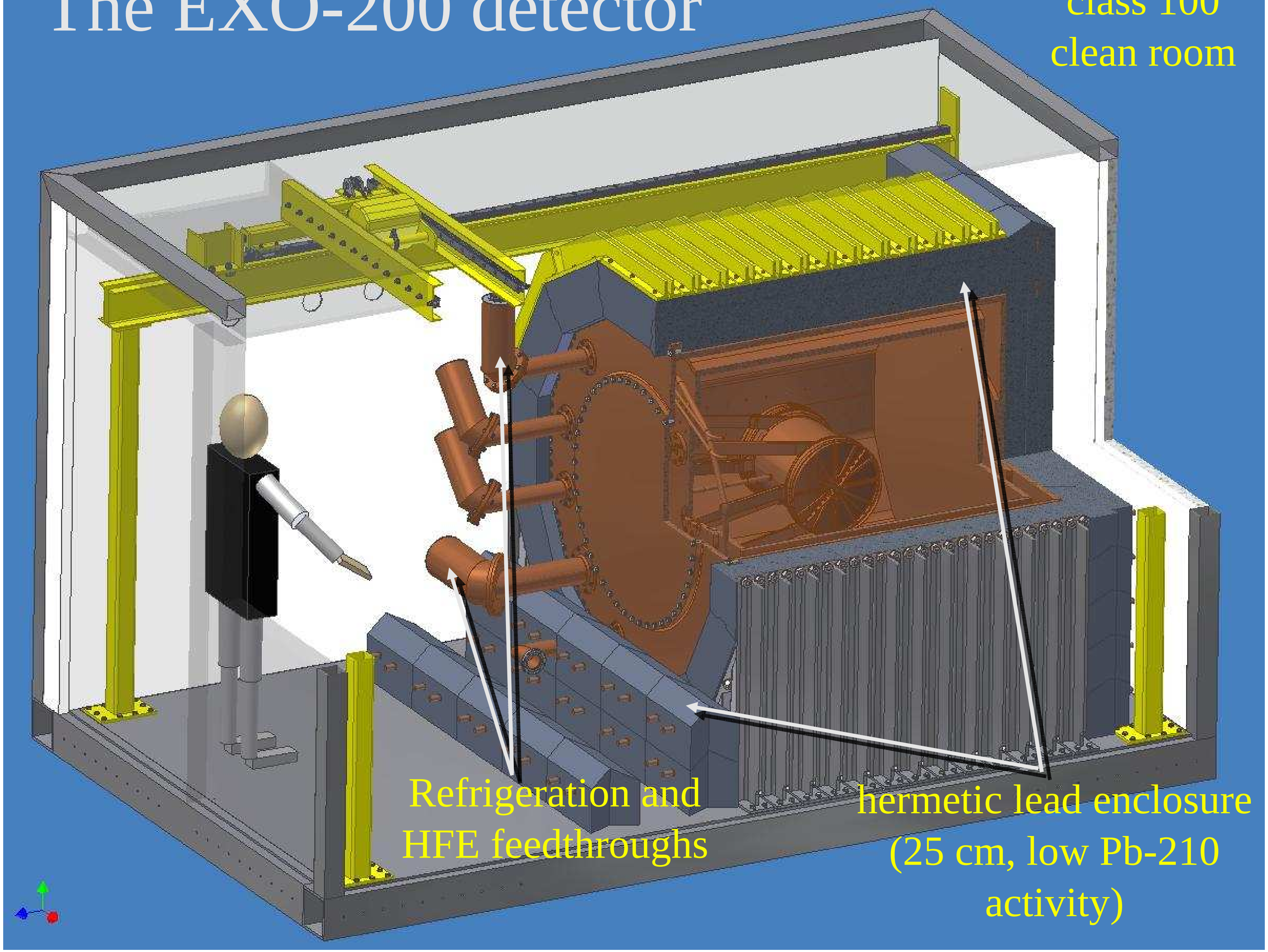
200 kg of LXe in thin vessel
(ultra pure copper, 1.5 mm thick)

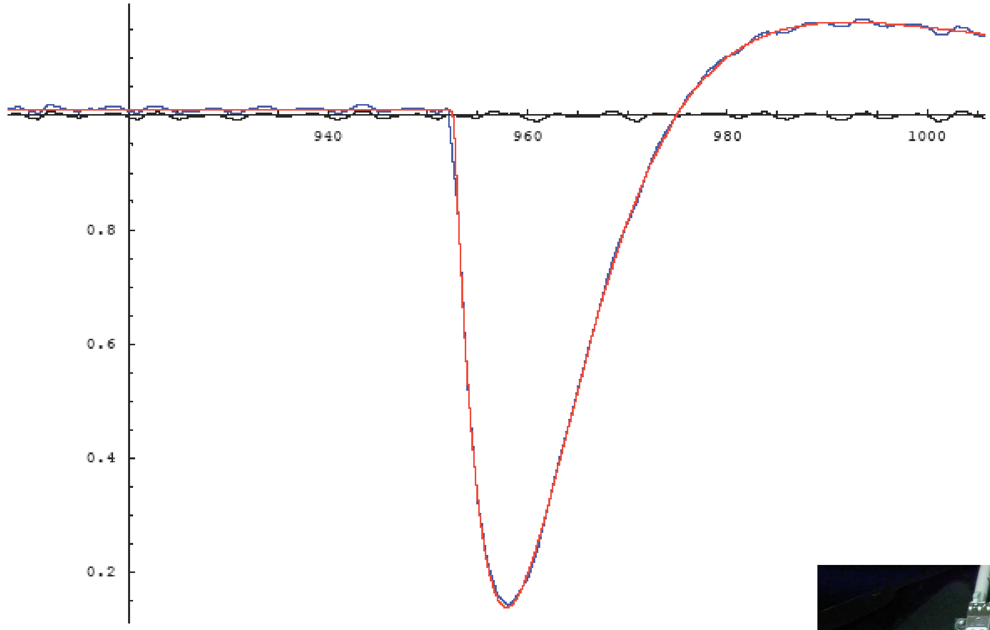
double walled vacuum insulated cryostat
(ultra pure copper, 2.5 cm thick)



50 cm of ultra pure cryofluid, providing large thermal bath for uniform temperature and excellent screening from external γ rays (density = 1.8 at -100 C)
(3M HFE-7000, hydrofluoroether $C_3F_7OCH_3$)

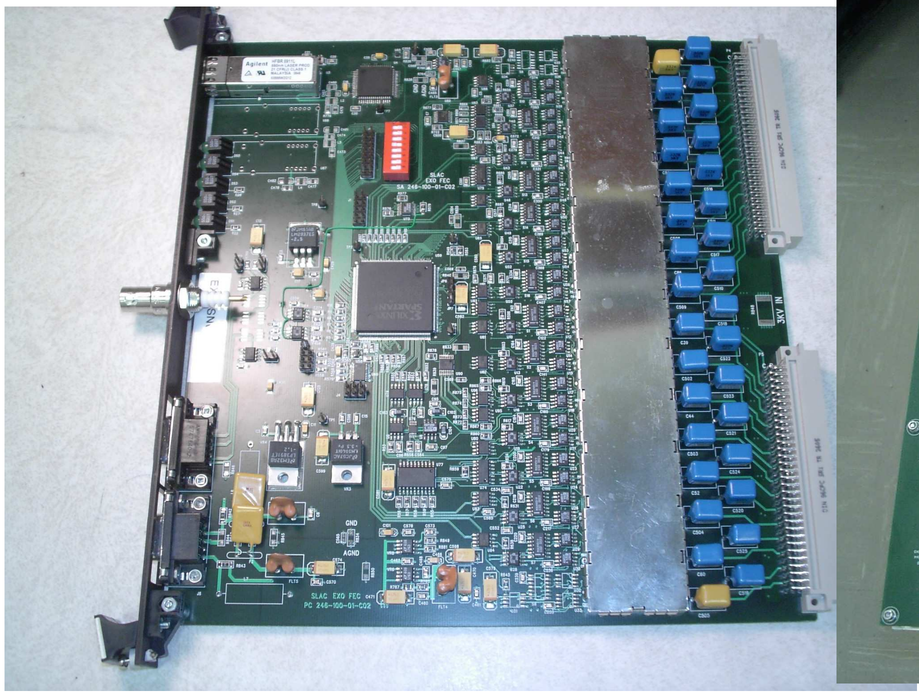
The EXO-200 detector

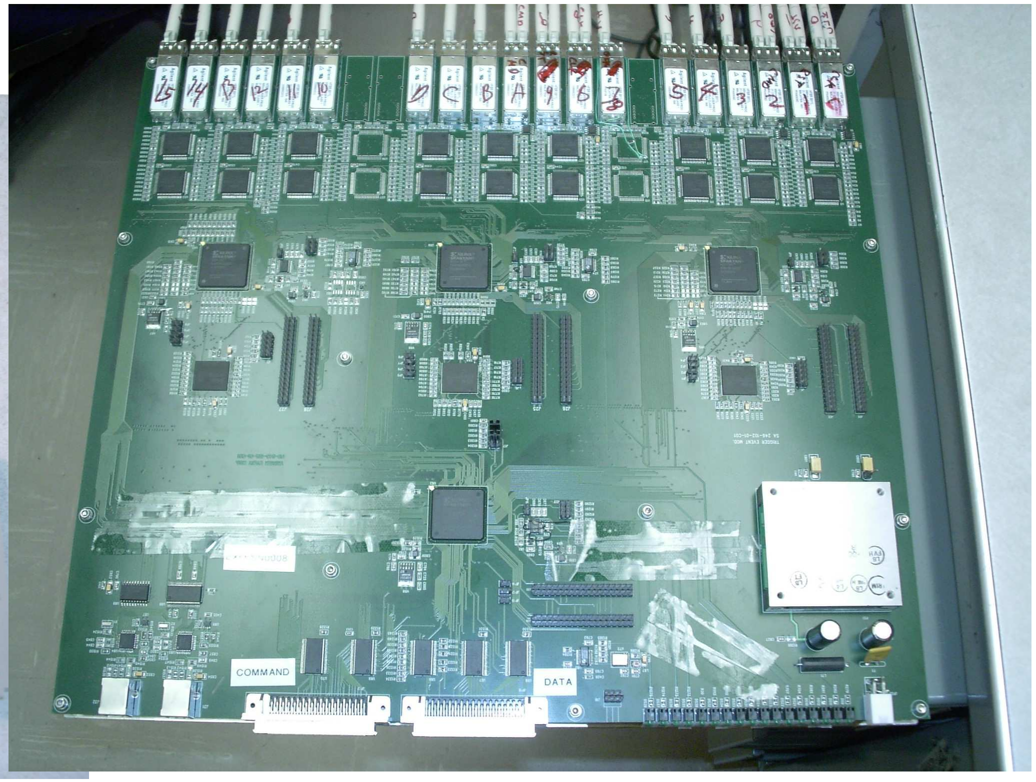




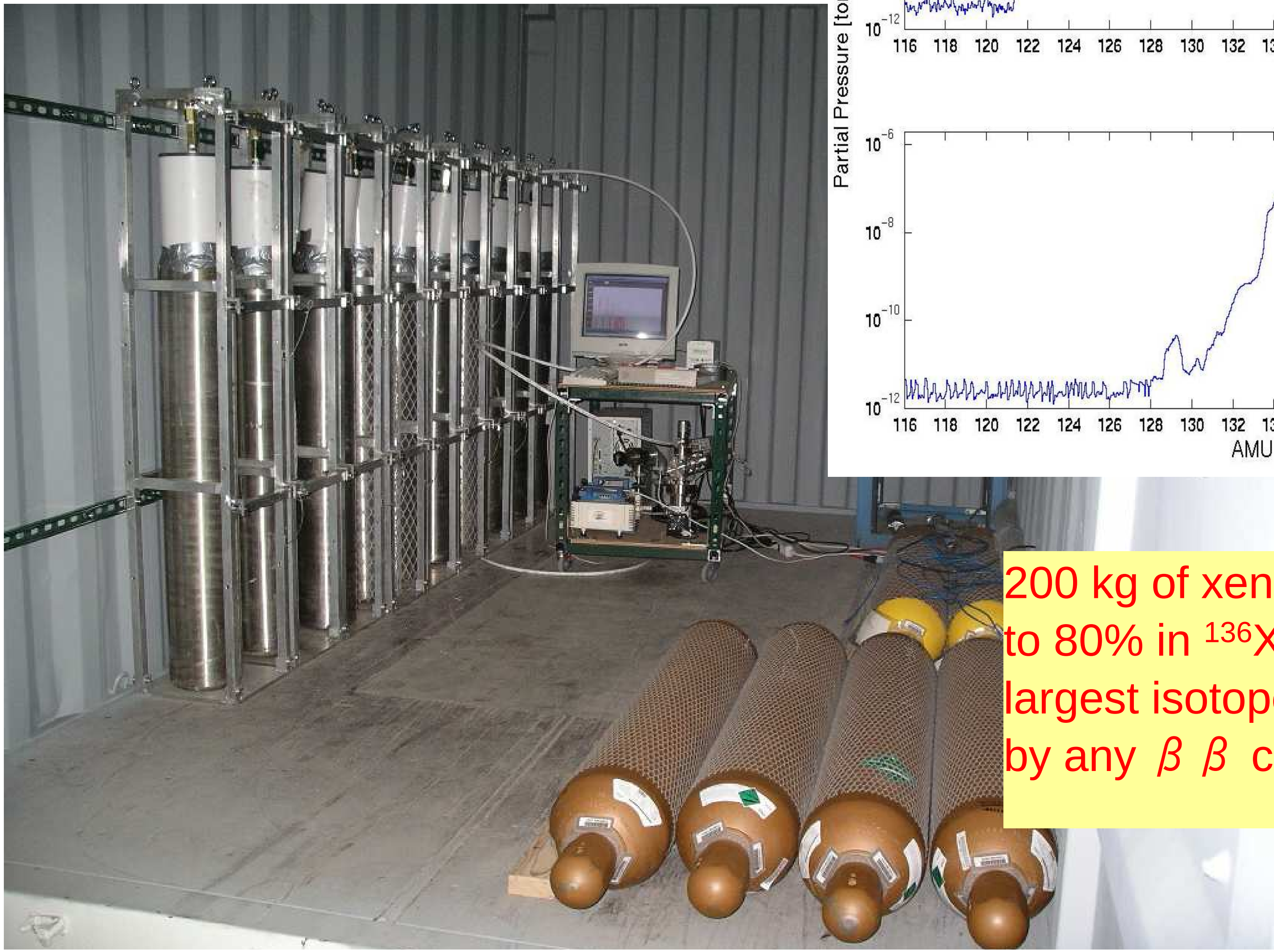
Electronics

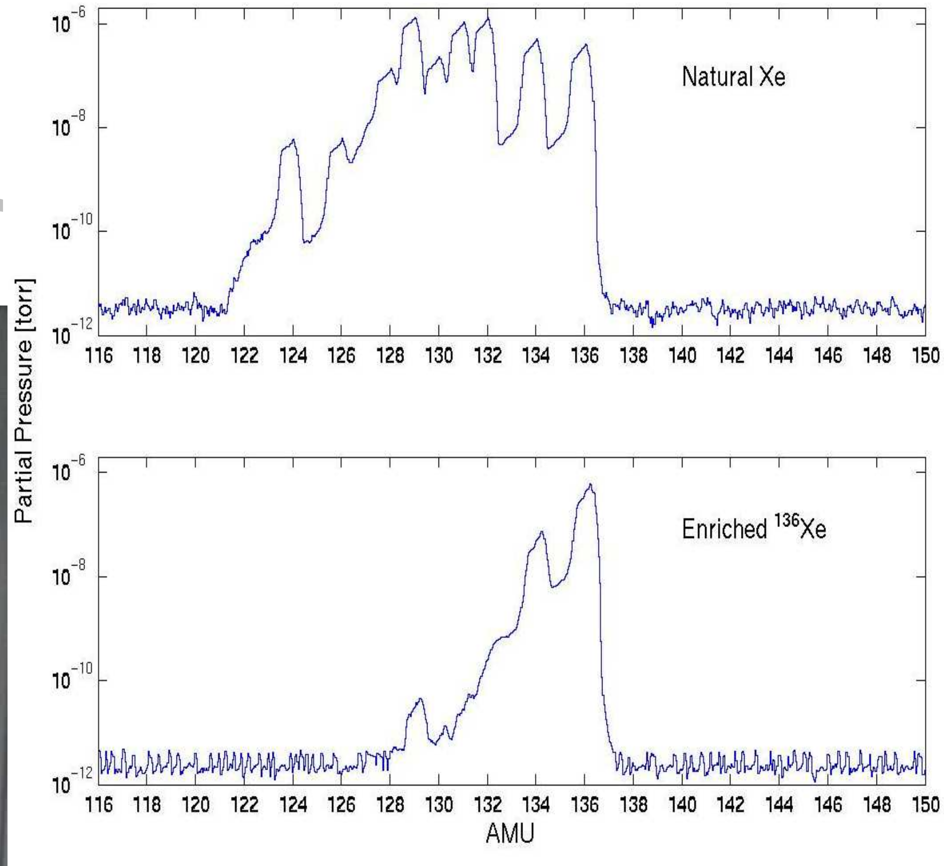
-Fully designed and in production
-DAQ software has been written
-Fine tuning of shaping times and other parameters underway





^{136}Xe stockpile in shipping container

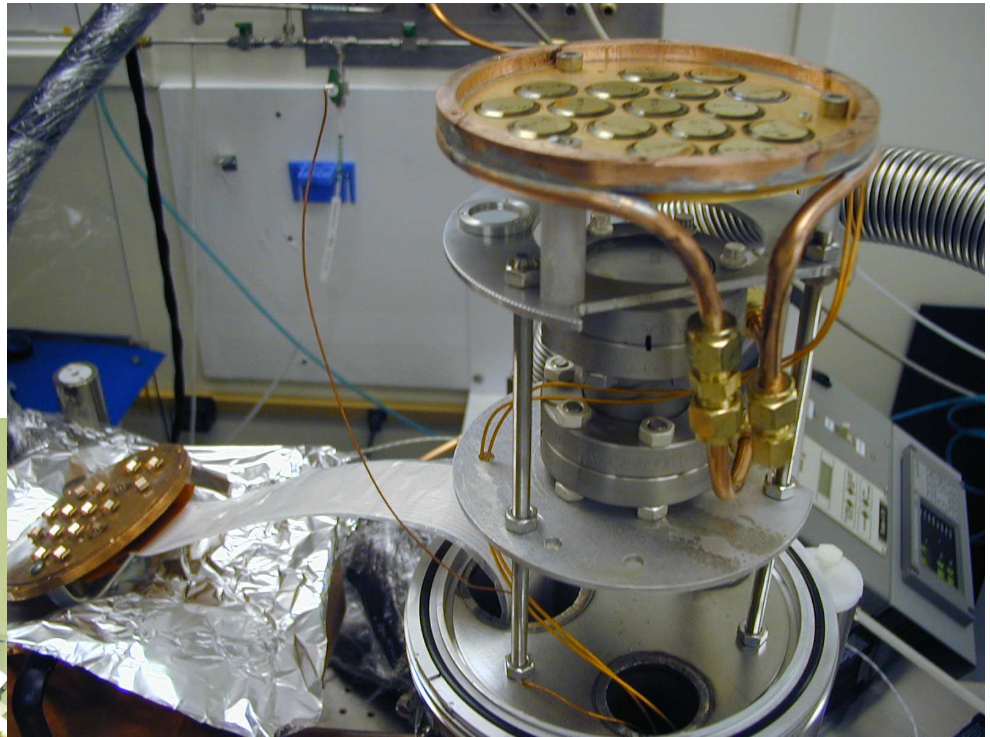


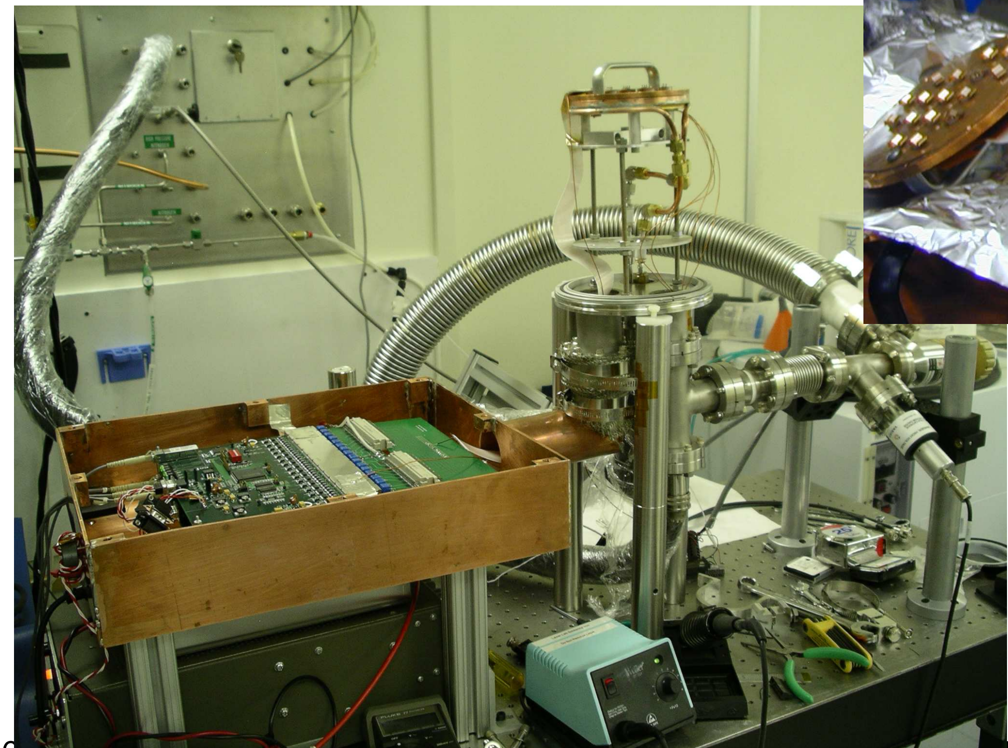


200 kg of xenon enriched to 80% in ^{136}Xe : the largest isotope possession by any $\beta\beta$ collaboration

APD and Electronics commissioning

- Test 16 APDs simultaeously using a Xe scintillation source and an ^{55}Fe source

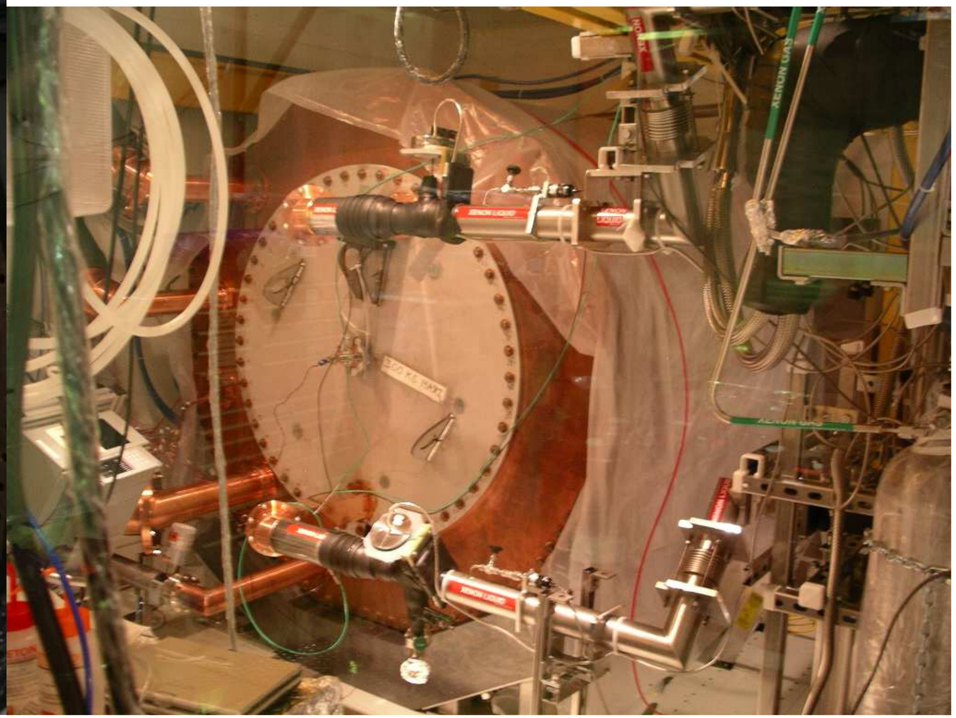




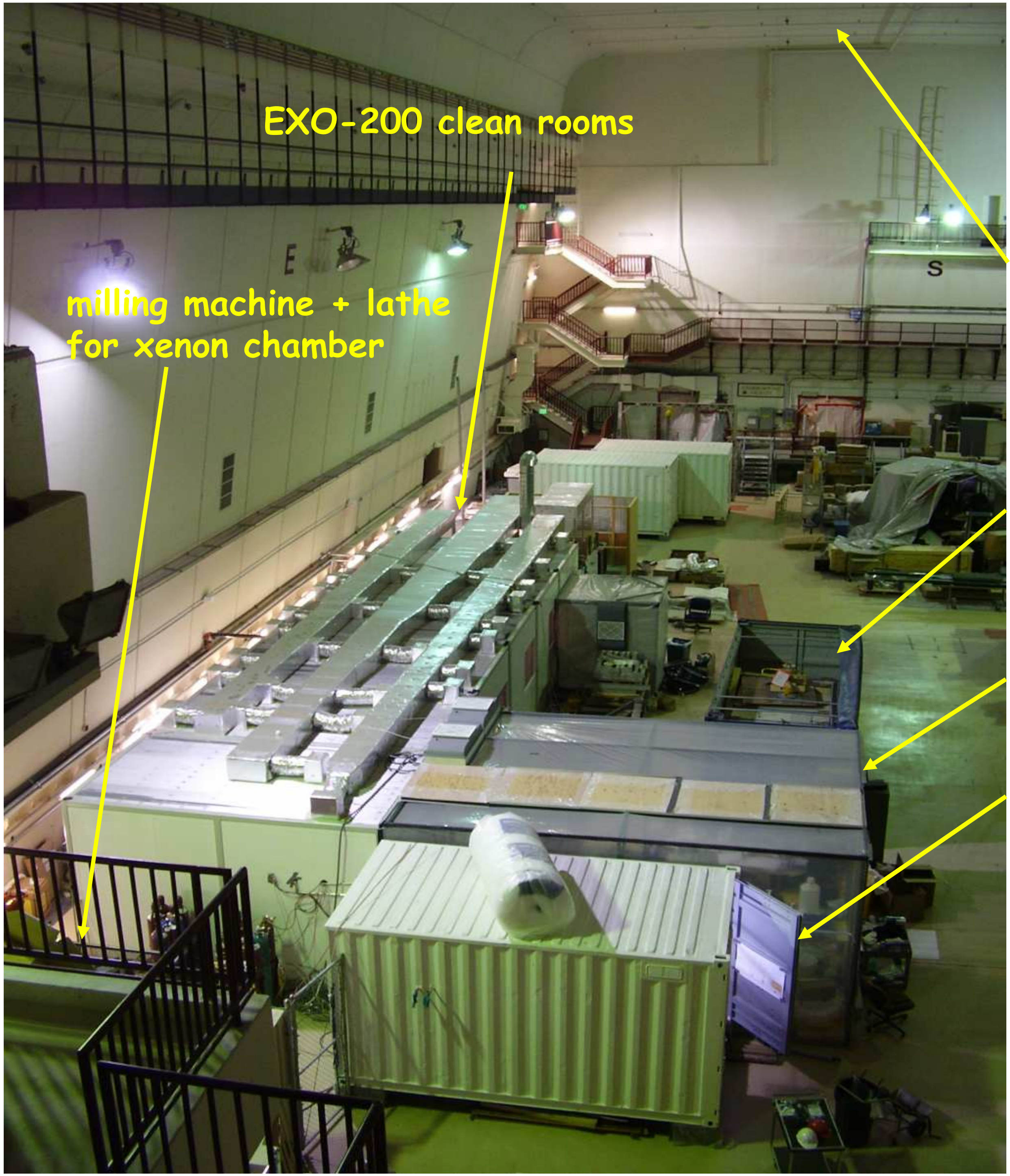
- Full DAQ chain in use (HV board, FEC, TEM, Linux PC with DAQ software)

Commissioning LXe and Refrigeration Systems

In April, successfully liquefied 30 kg of Natural Xe in a “dummy” stainless steel vessel!



The EXO-200 modular clean rooms



2m thick concrete roof

Sheilded shipping container for Cu and Detector

soft wall clean room: pre-assembly and cleaning

HFE storage dewar in shipping container


WERNER

Materials qualification database

- Neutron Activation Analysis (NAA) - Alabama (MIT reactor)
- ICP-MS and GD-MS - INMS (Ottawa)
- Radon emanation - Laurentian (Sudbury)
- Gamma counting - Neuchatel, Alabama
- Alpha counting - Alabama, Carleton, SLAC, Stanford

EXO Materials Testing Summary

(Status 8/31/2006)
287 entries

~ 330 entries

Material	Information Source	MD#	K conc. [10^{-9} g/g]	Th conc. [10^{-12} g/g]	U conc. [10^{-12} g/g]
TPC and Internals					
SNO acrylic, batch 48, panel 09.	UA, NAA 8/26/06	59	<3.1	<16	<22
Dupont Vespel, batch SP-1 PLAQUE PGF 9713. Plaque 1. EXO production 6/22/06. Material reserved at Dupont.	UA, NAA 8/26/06	74.1	282±29	<12	<18
Dupont Vespel, batch SP-1 PLAQUE PGF 9714. Plaque 2. EXO production 6/22/06. Material reserved at Dupont.	UA, NAA 8/26/06	74.2	62±7	<25	<28
Norddeutsche Affinerie OFRP copper. Produced 6/1/2006 for EXO. Batch E263/3E1. Sample DOWN collected at DESY.	INMS (Canada) ICPMS 9/1/06	85	<55	<0.5	<0.3
	INMS				

EXO-200kg Majorana mass sensitivity

Assumptions:

1) 200kg of Xe enriched to 80% in 136
2) $\sigma(E)/E$ = 1.4% 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 2.458MeV endpoint
4) Negligible background from $2\nu\beta\beta$ ($T_{1/2} > 1 \cdot 10^{22}$yr R.Bernabei et al. measurement)

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
Prototype	0.2	70	2	1.6*	40	$6.4 \cdot 10^{25}$	0.27†	0.38♦

What if Klapdor's observation is correct ?

Central value $T_{1/2}$ (Ge) = $1.2^{+3}_{-0.5} \cdot 10^{25}$, ($\pm 3\sigma$)
(Phys. Lett. B 586 (2004) 198-212
consistently use Rodin's matrix elements for both Ge and Xe)

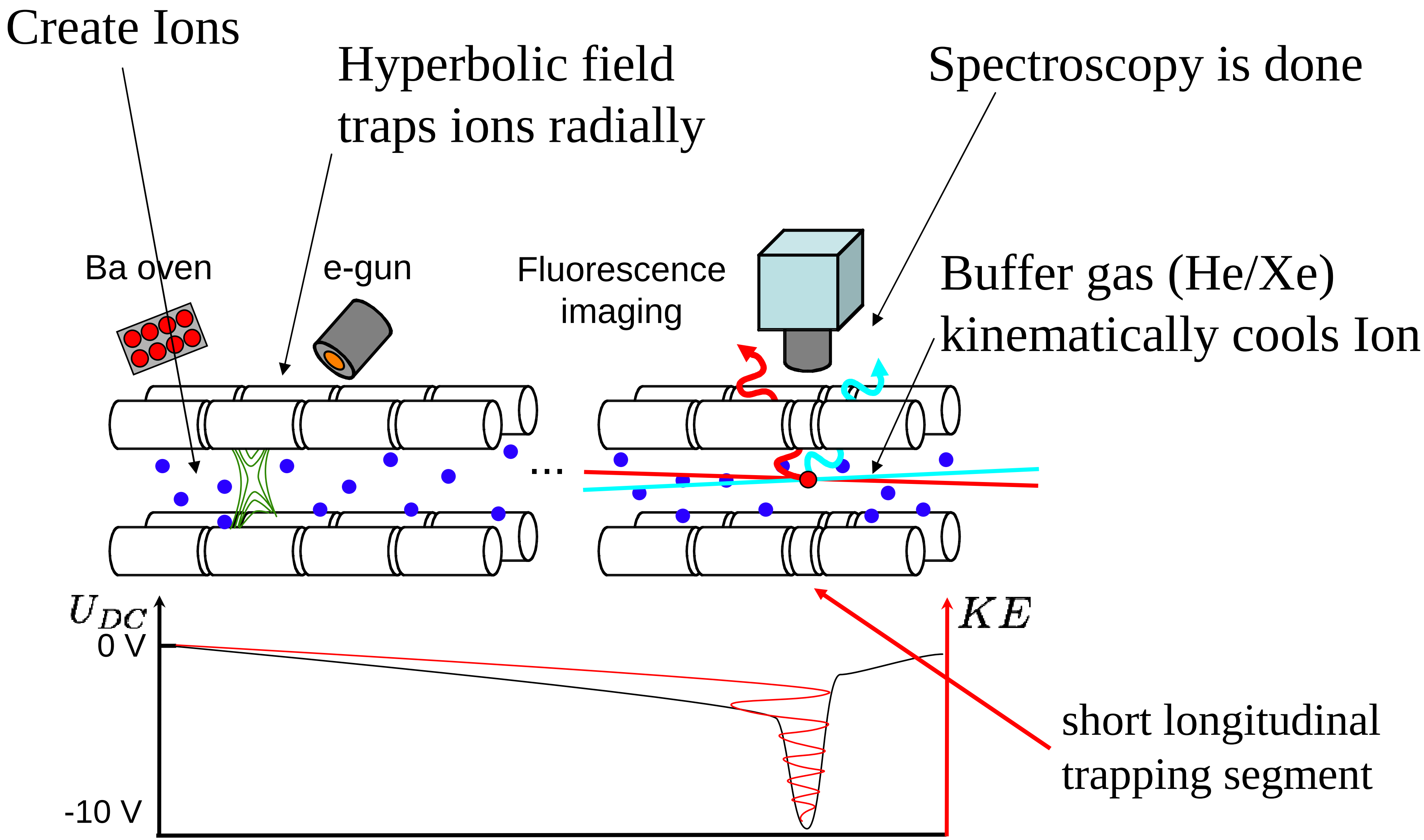
In 200kg EXO, 2yr:

- Worst case (QRPA, upper limit) 15 events on top of 40 events bkgd → 2σ
- Best case (NSM, lower limit) 162 events on top of 40 bkgd → 11σ

Ba Retrieval and Tagging Goals

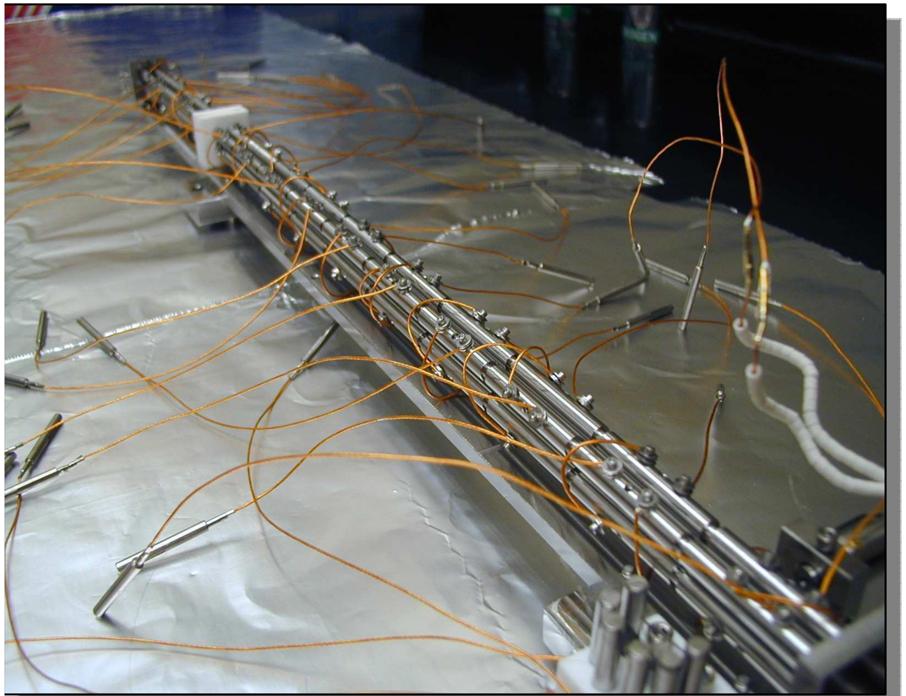
- Identify the Ba daughter of the ββ decay with high efficiency
- One method:
  - Retrieve Ba daughter from LXe
  - Release Ba daughter into a linear RF quadrupole trap
  - Positively identify Ba daughter via laser spectroscopy, possibly in the presence of Xe gas
- Other methods under development:
  - Spectroscopy of Ba directly in LXe
  - Spectroscopy of Ba in high pressure GXe

Single Ba ion trapping

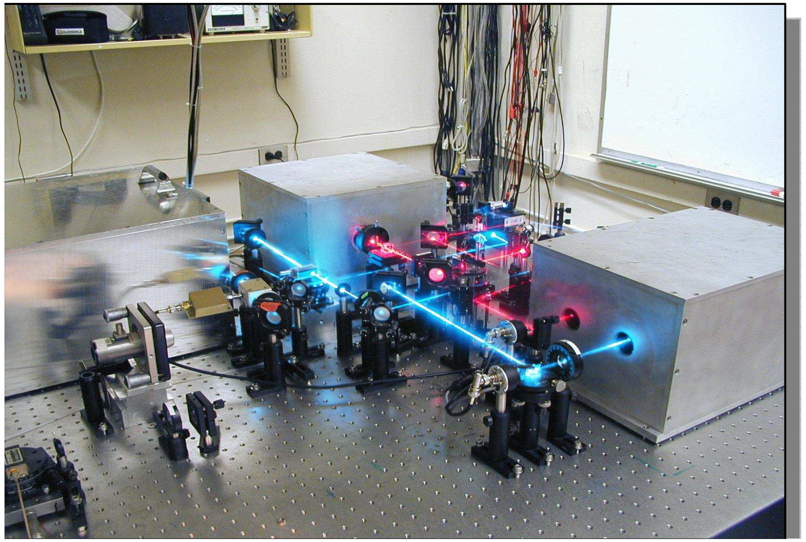


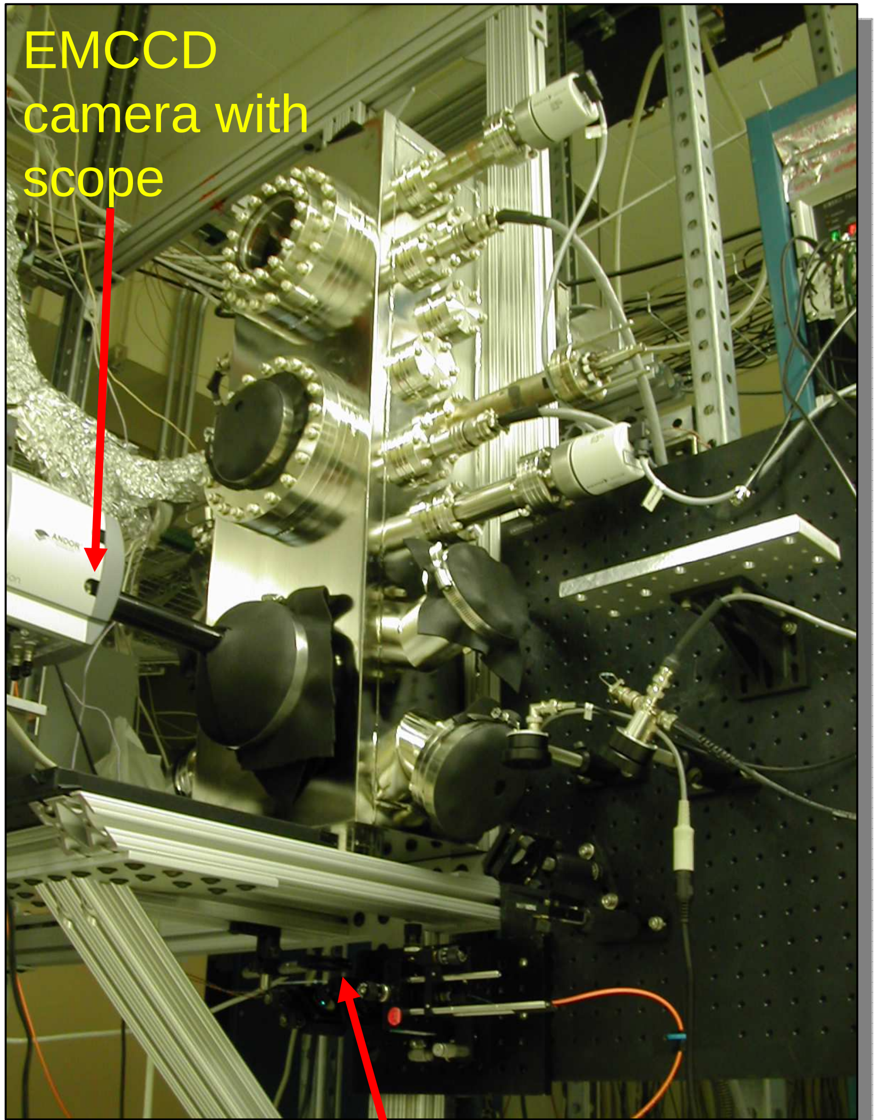
DC field is graded to trap Ions axially

Linear ion trap at Stanford



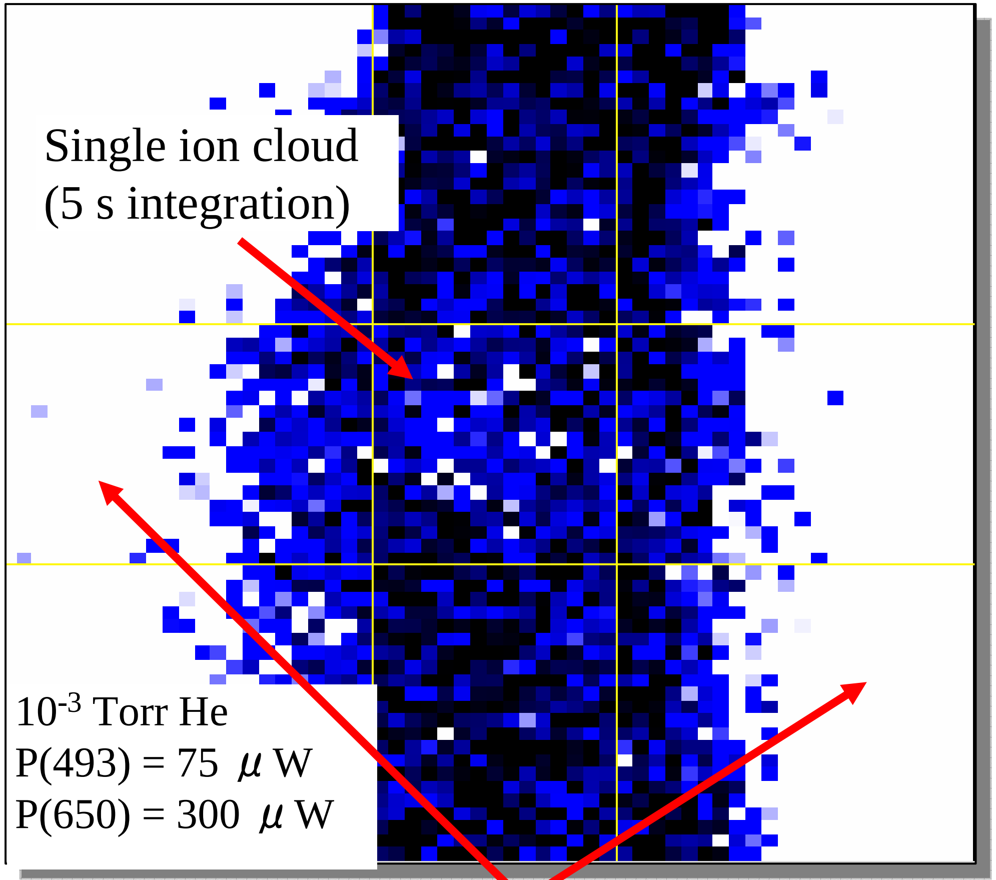
493/650 nm lasers

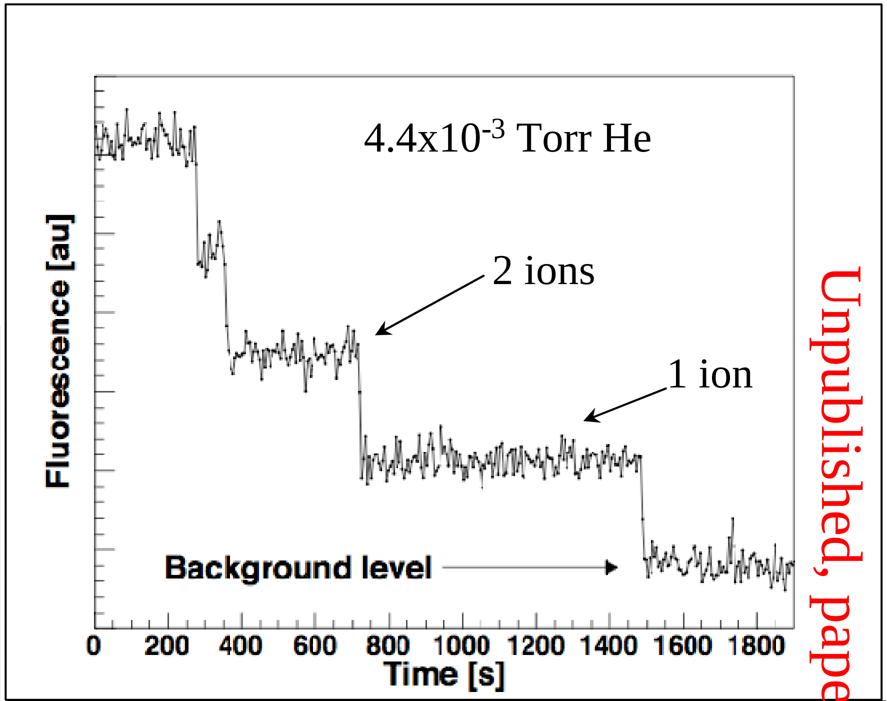


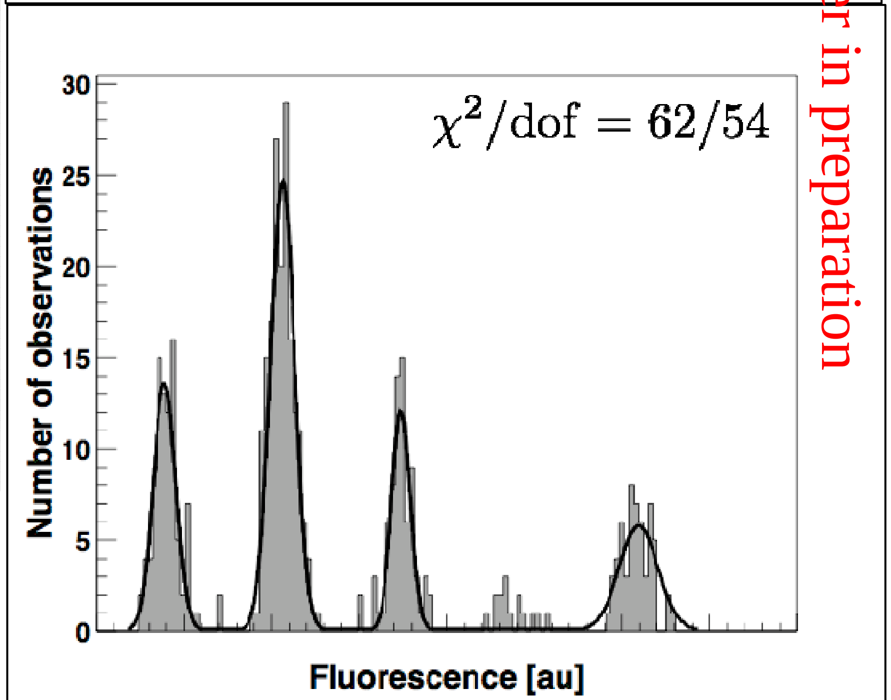


Input optics (493 nm, 650 nm beams on single fiber)

First detection of single ions in buffer gas!

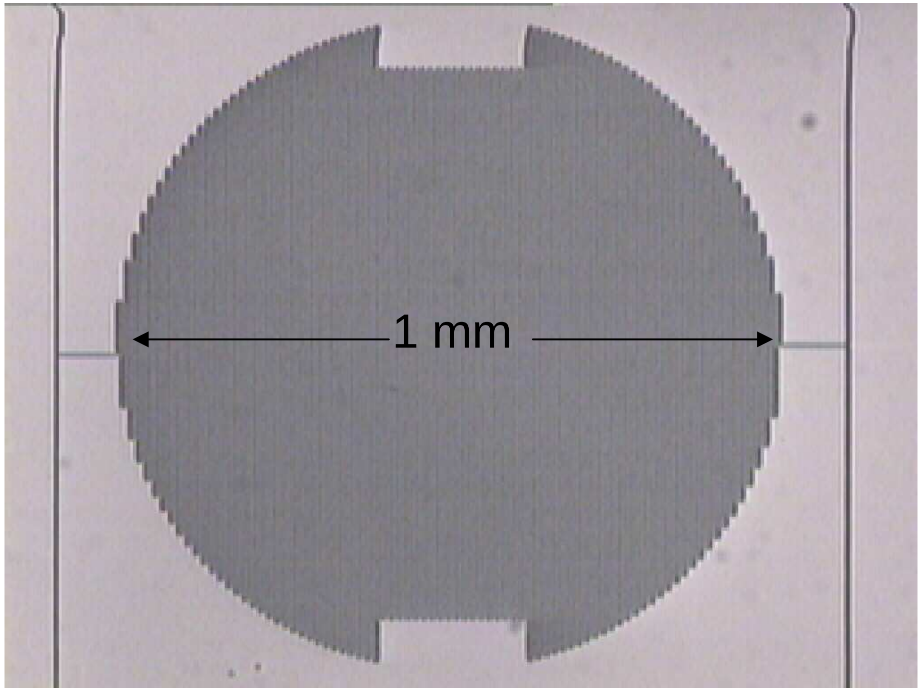


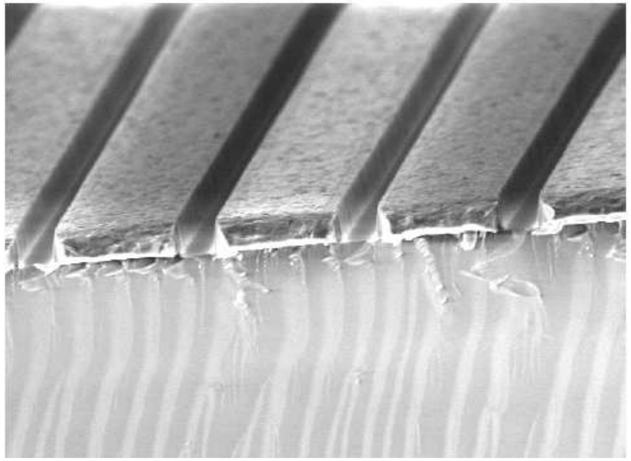




Unpublished, paper in preparation

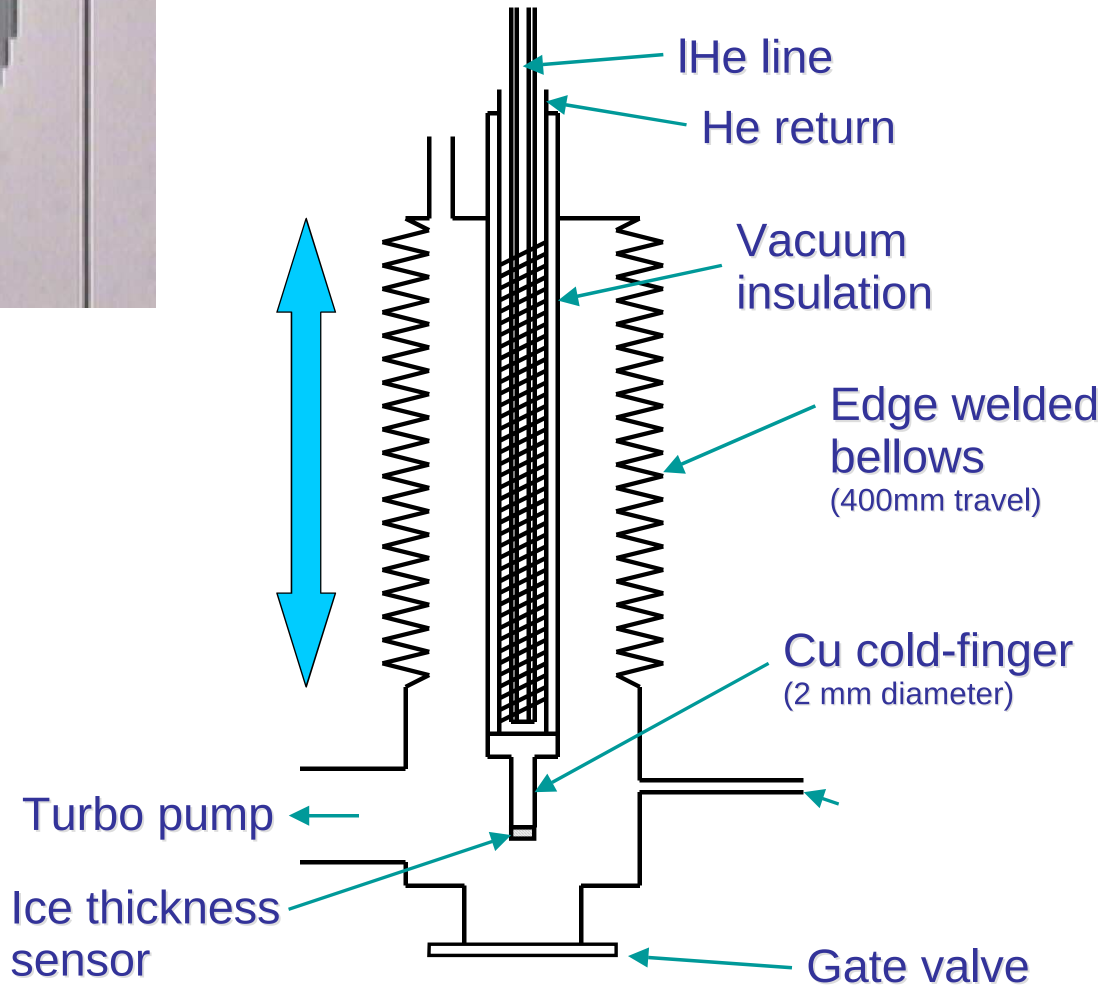
Capacitive cryo-tip



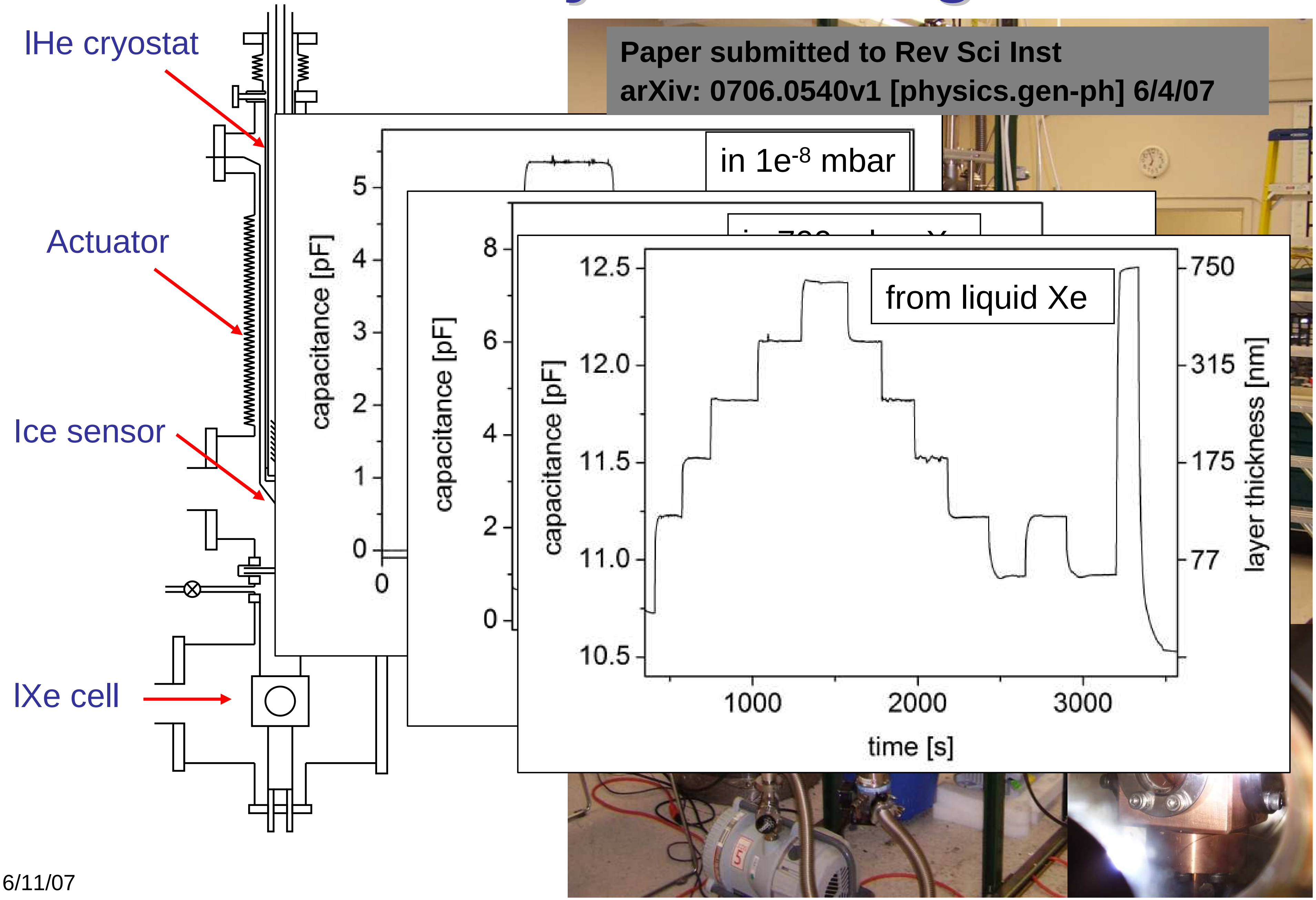


Fingers for dielectric
ice-thickness measurement:

ε_r(Xe,liquid) = 1.88
ε_r(Xe,solid) = 2.25



Thin layer freezing



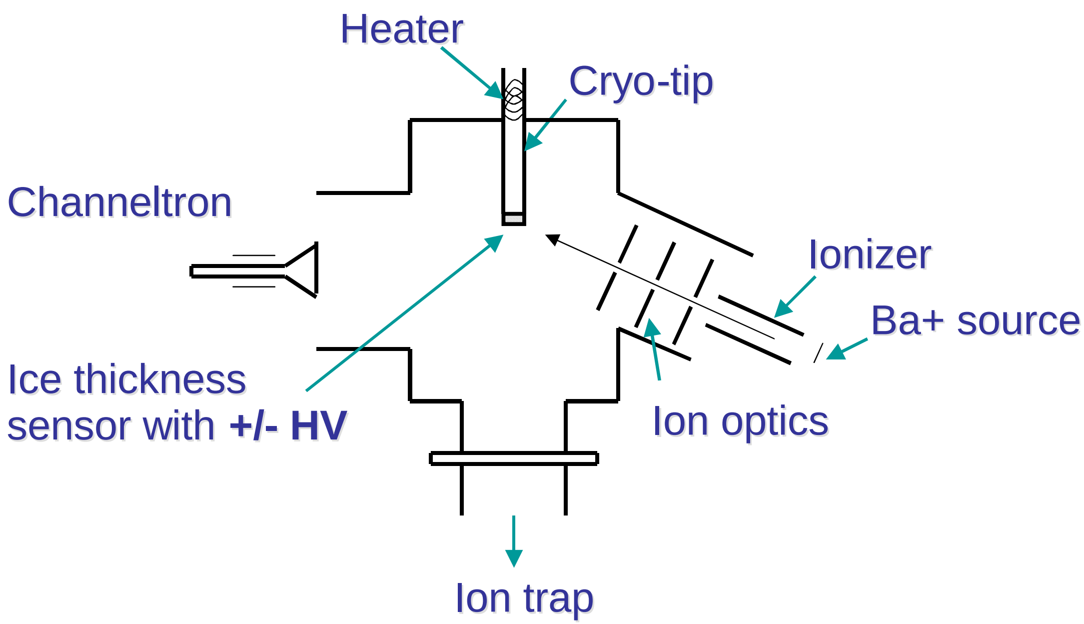
Preliminary Results

-Freeze thin Xe layer on tip

-Load Ba ions onto tip, trapping them in Xe Ice

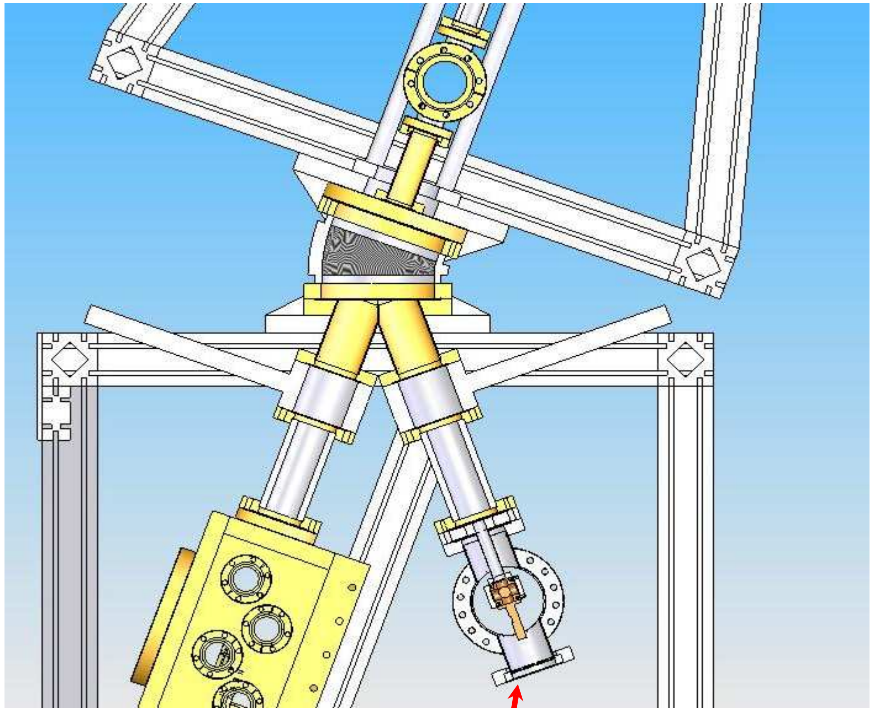
-Vaporize the Xe, view time correlated signal in Channeltron

-Unfortunately, no sensitivity to ion type

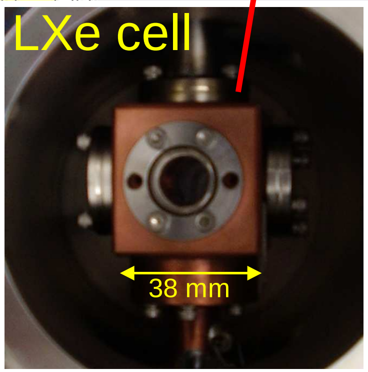


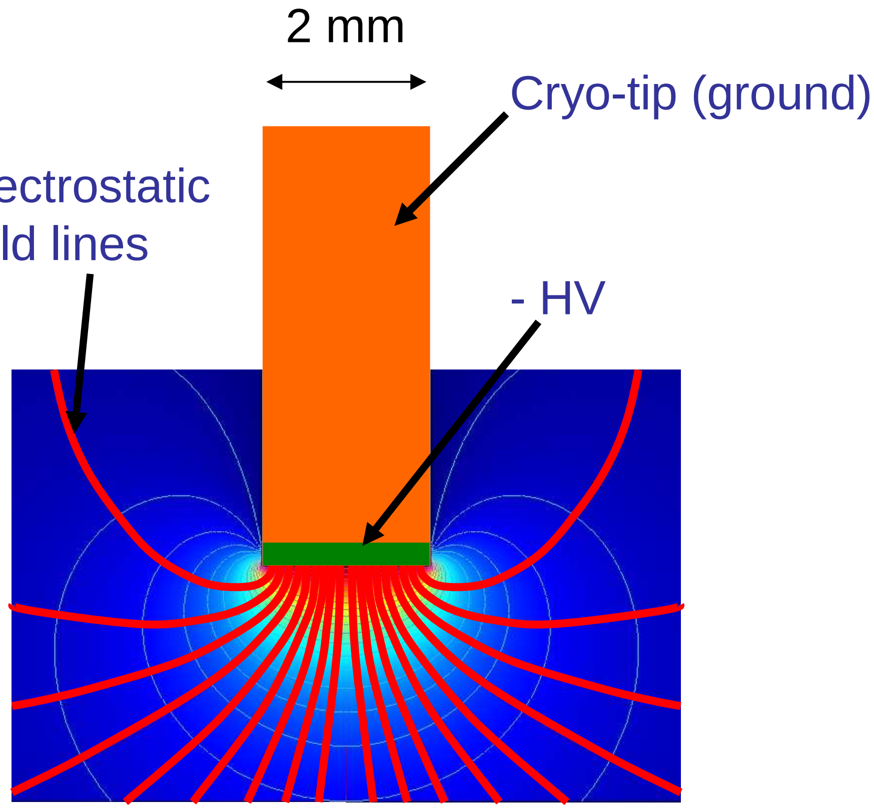
In progress

Tip moving robot



Ion trap





Ion mobility: μ ~ 0.3 cm^2/kVs

v = μ x 1kV/cm ~ 0.3 cm/s

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

Conclusions

- EXO-200 will move to WIPP in July!
  - Commissioning of many major components complete
  - Detector design complete, components are in hand and being assembled
- Ba retrieval and identification along the path to completion
  - Single Ion Ba spectroscopy in buffer gas well understood
  - Retrieval system being pursued with good success
  - Integrated system designed and in early stages of assembly
- Full EXO is on the horizon!

Enriched Xenon Observatory
for double beta decay

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Main γ (external) backgrounds

- γ (2449 keV) from ^{214}Bi decay (from ^{238}U and ^{222}Rn decay chains)
- γ (2615 keV) from ^{208}Tl decay (from ^{232}Th decay chain)
- γ (1.4 MeV) from ^{40}K (a concern for the 2νββ)
- ^{60}Co: 1173 + 1333 keV simultaneous γ's (from $^{63}Cu(\alpha,n)^{60}Co$)
- other γ's in ^{238}U and ^{232}Th chains
- other cosmogenics of Cu (a concern for the 2νββ)

Single Ba ion trapping

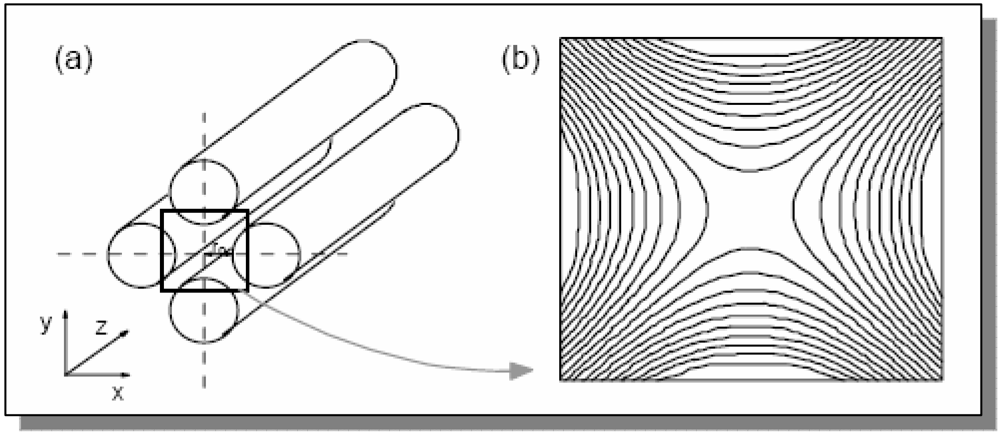
Build an AC quadrupole potential:

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

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

longitudinal trapping

radial trapping



write: $\vec{F} = q\vec{E} = m\vec{a}$

$$m\begin{pmatrix}\ddot{x}\\ \ddot{y}\end{pmatrix} = \begin{pmatrix}-\frac{e\varphi_0}{r_0^2}x\\ +\frac{e\varphi_0}{r_0^2}y\end{pmatrix}$$

trap parameters:

$$V_{RF} = 150V_{pk}, \quad f = 1.1\text{MHz}$$
$$U_{DC} = 10V$$