Enriched Xenon Observatory
EXO
for double beta decay

The EXO-200 detector

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Double beta decay and neutrino masses workshop - HAW05
Maui, Sept. 17-20, 2005

Outline

1) EXO and EXO-200

2) EXO-200 goals

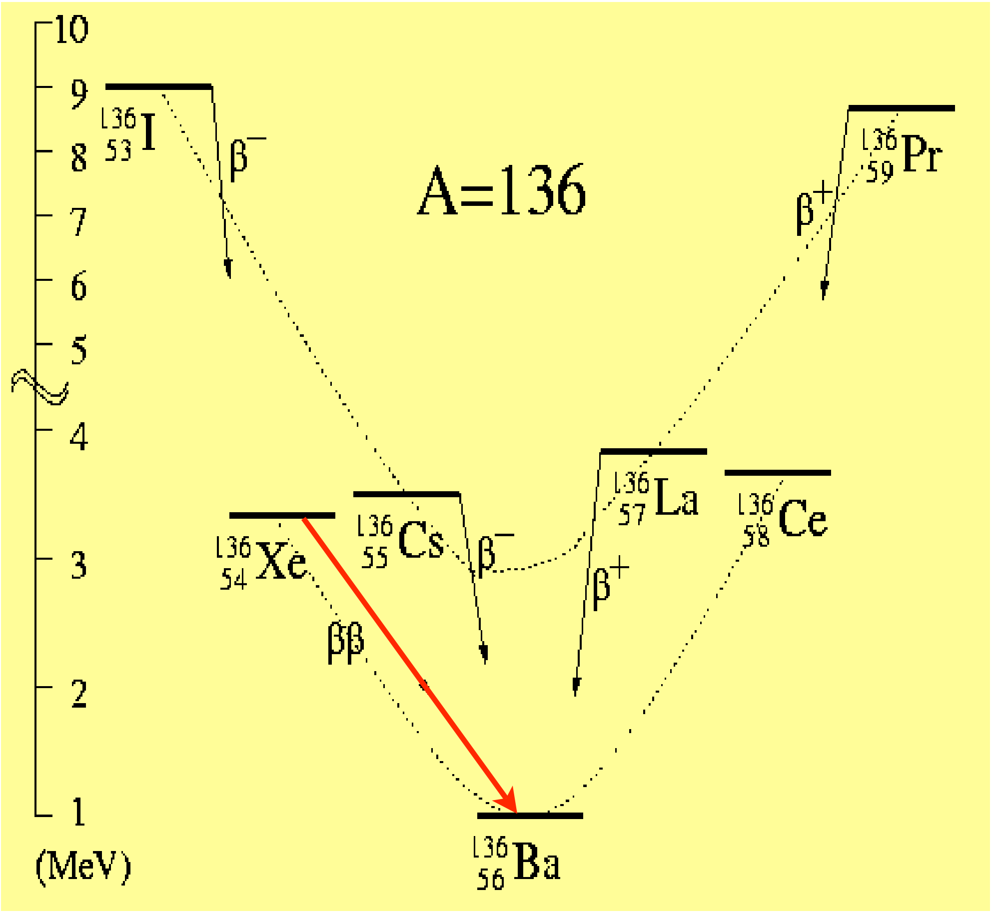
3) detector design

4) status of the detector

The Enriched Xenon Observatory

for double beta decay

Goal: detection of ββ-decay of ^{136}Xe using a combination of techniques, to obtain a virtually "background-free" experiment:



1) real-time event detection in a LXe TPC coupled with scintillation light collection (Xe enriched in the 136 isotope)

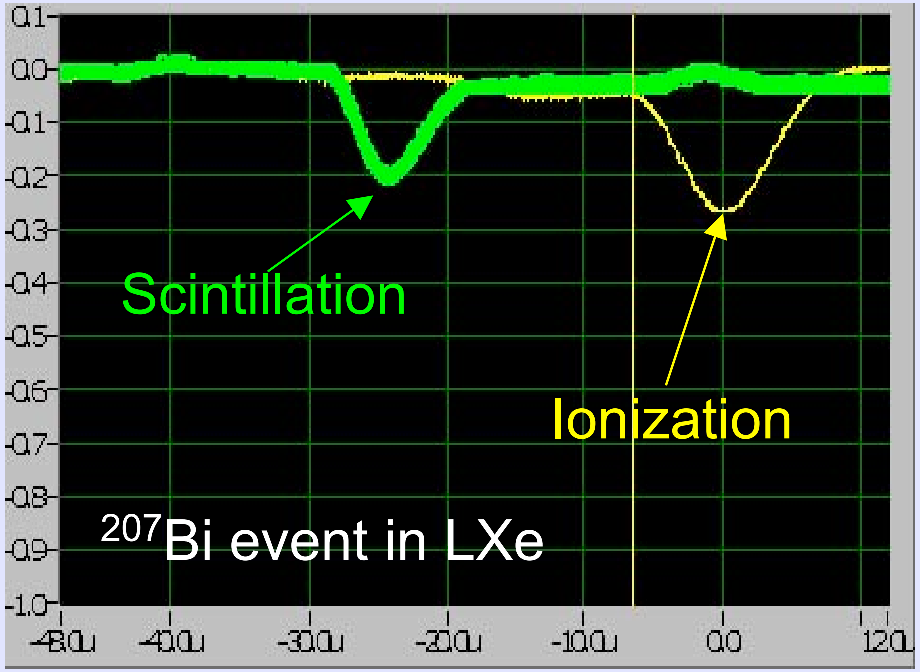
2) identification of the final state by optical spectroscopy of the daughter ion ($^{136}Ba^+$)

[M. Moe, Phys. Rev. C 44 (1991) 931, M. Danilov et al., Phys. Lett. B 480 (2000) 12]

The EXO strategy

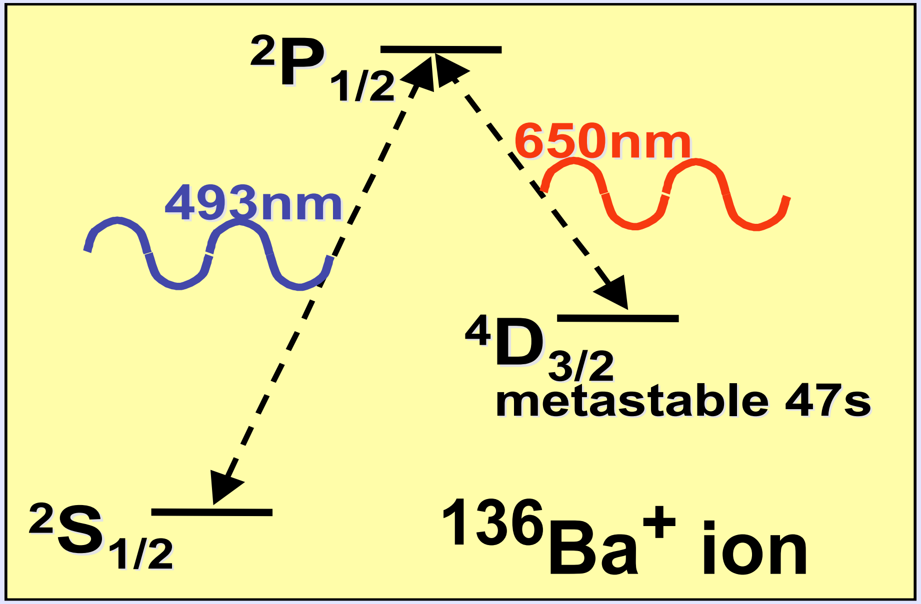
TPC with light collection:

+ real-time energy, position, and tracking information
+ large target mass (self-shielding)
- γ backgrounds
- need isotopic enrichment (~ ton scale target yet compact)



Final state identification:

+ specific signature (”coincidence”) (background reduction)
+ spectroscopy of $^{136}Ba^+$ well known
- γ backgrounds
- no channel specificity



EXO: high risk, high reward

background scaling like Nt: $\langle m_\nu \rangle \propto 1/\sqrt{T_{1/2}^{0\nu\beta\beta}} \propto 1/(Nt)^{1/4}$

no background experiment: $\langle m_\nu \rangle \propto 1/\sqrt{T_{1/2}^{0\nu\beta\beta}} \propto 1/\sqrt{Nt}$

[M. Moe, Phys. Rev. C 44 (1991) 931]

Why xenon?

- no need to grow cystals
- can be re-purified *in situ* during the experiment
- good surface to volume ratio
- ^{136}Xe enrichment safe, efficient, and relatively easy
  (no chemistry, grams/s feed rate, Δm(Xe) ~ 4.7)
- no long-lived isotopes to activate

but: energy resolution modest compared to ^{76}Ge and ^{130}Te

Towards EXO

The EXO collaboration is proceeding with two parallel efforts towards the realization of a 1-10 ton-scale detector

- EXO-200 $\rightarrow$ this talk

- R&D for the $^{136}Ba^{+}$ identification

  $\rightarrow$ Carter Hall's talk in this workshop

EXO-200

EXO-200 is a LXe TPC with scintillation light readout that uses 200 kg of enriched xenon (80% ^{136}Xe)

→ EXO-200 has no $^{136}Ba^{+}$ identification ←

Goals:

- look for $0\nu\beta\beta$ decay of ^{136}Xe with competitive sensitivity ($T_{1/2}^{0\nu} > 6 \times 10^{25}$ y, current limit: $T_{1/2}^{0\nu} > 1.2 \times 10^{24}$ y)
- measure the standard $2\nu\beta\beta$ decay of ^{136}Xe and measure its lifetime (best upper limit to date: $T_{1/2}^{2\nu} > 1 \times 10^{22}$ y)

  [R. Bernabei et al., Phys. Lett. B 546 (2002) 23]
- test TPC components, light readout, and radioactivity of materials

$2\nu\beta\beta$ event rate

$2\nu\beta\beta$ decay has never been observed in ^{136}Xe. Some of the lower limits on its half life are close to (and in one case below) the theoretical expectation. EXO-200 is well positioned to solve this issue

	$T_{1/2}$ (yr)	evts/year in the 200kg prototype (no efficiency applied)
Experimental limit		
Leuscher et al	$>3.6 \cdot 10^{20}$	<1.3 M
Gavriljuk et al	$>8.1 \cdot 10^{20}$	<0.6 M
Bernabei et al	$>1.0 \cdot 10^{22}$	<48 k
Theoretical prediction		
QRPA (Staudt et al) [$T_{1/2}^{max}$]	$=2.1 \cdot 10^{22}$	=23 k
QRPA (Vogel et al)	$=8.4 \cdot 10^{20}$	=0.58 M
NSM (Caurier et al)	$(=2.1 \cdot 10^{21})$	(=0.23 M)

EXO-200 sensitivity

Case	Mass (ton)	Eff. (%)	Run Time (yr)	$\sigma(E)/E$ @ 2.5MeV (%)	Radioactive Background (events)	$T_{1/2}^{0\nu}$ (yr, 90%CL)	Majorana mass (eV) QRPA‡	(NSM#)
EXO-200	0.2	70	2	1.6*	40	6.4×10^{25}	0.18	(0.53)

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

‡ QRPA: A.Staudt et al. Europhys. Lett.13 (1990) 31; Phys. Lett. B268 (1991) 312

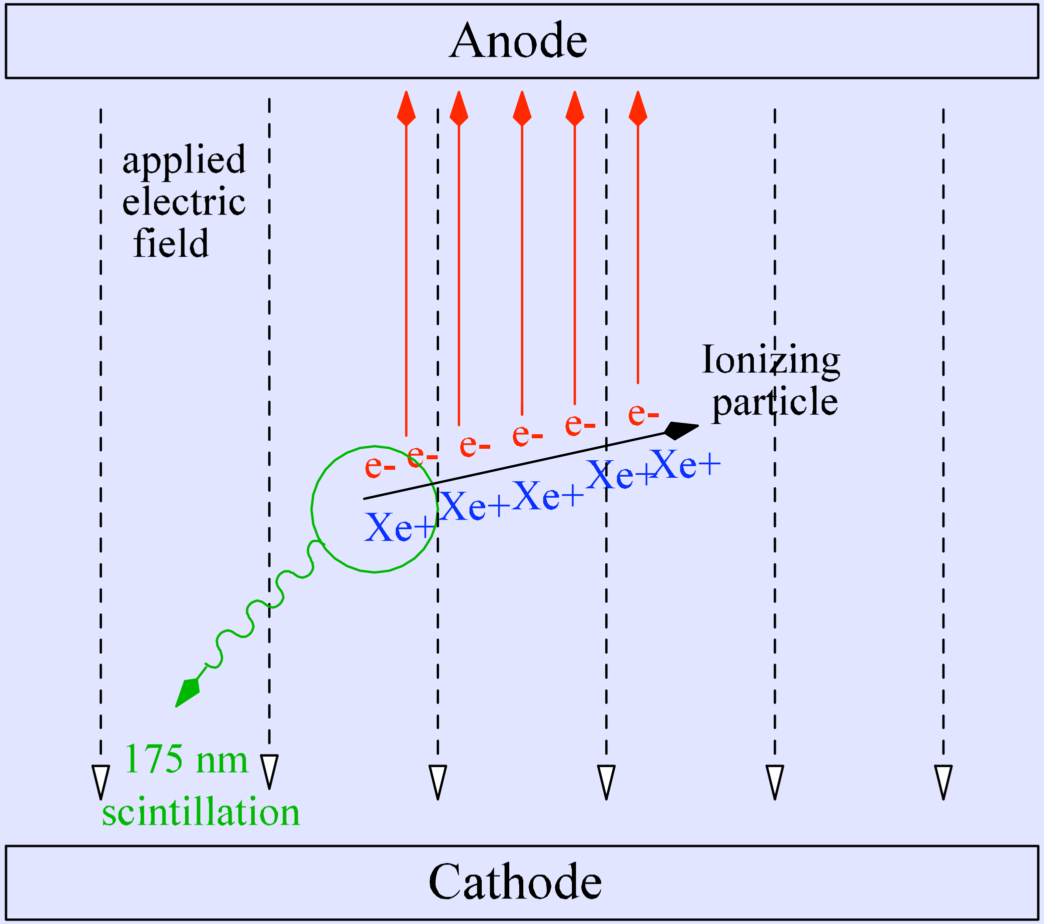
\# NSM: E.Caurier et al. Phys Rev Lett 77 (1996) 1954

Improves current limits on ^{136}Xe by one order-of-magnitude

Discovery claim (Phys. Lett. B 586 (2004) 198):
Central value ‹m›=0.44 eV, ±3σ range (0.24eV – 0.58eV)

In 200kg EXO, 2yr would observe 57 events (QRPA) on top of 40 events bkgd
Using lower bound (0.24 eV) would have 17.3 signal events (and 40 bkgd), a 2.3 σ effect

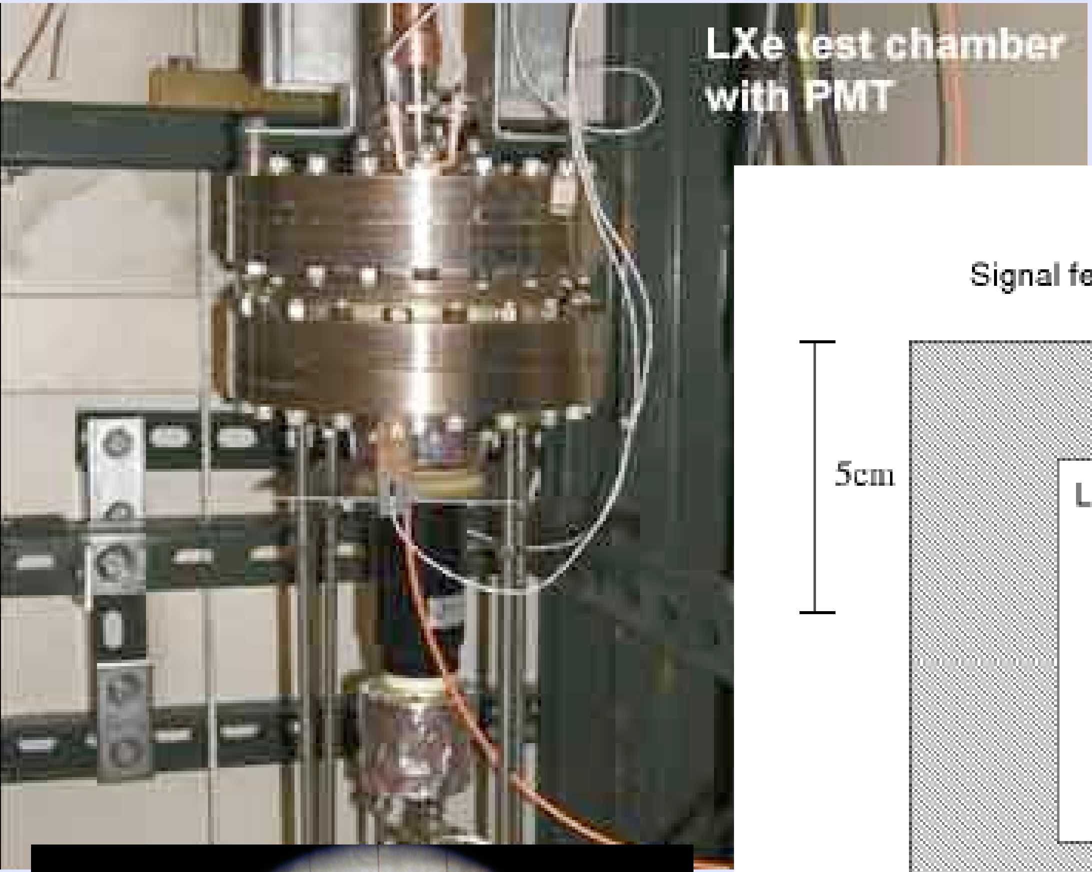
Dual readout: ionization and scintillation

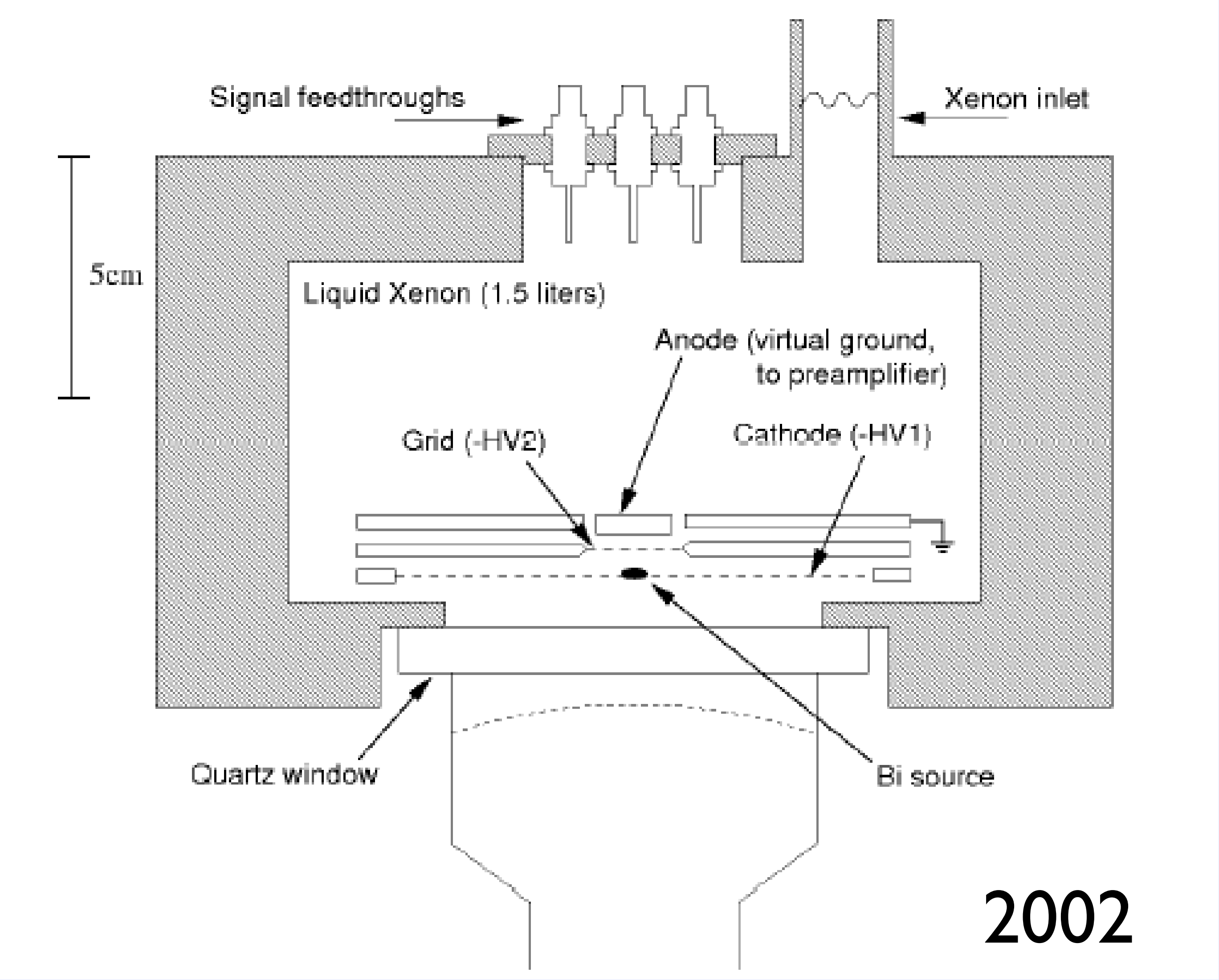


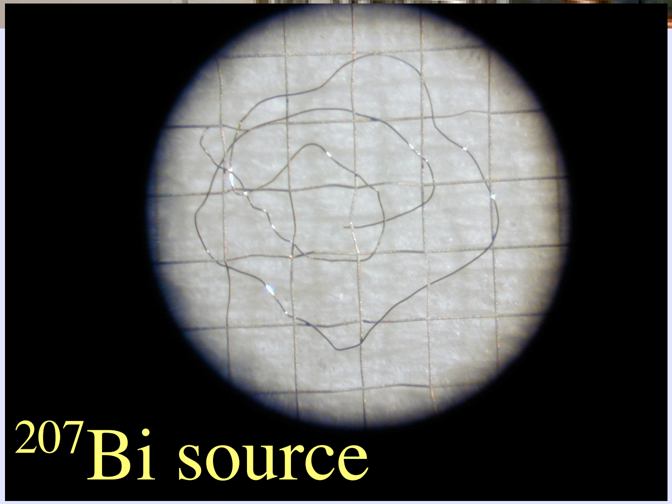
The event energy can be measured by collecting the ionization on the anode and/or observing the scintillation.

"There are indications that correlations between the two variables help improve resolution"
[J. Seguinot et al. NIM A 354 (1995) 280]

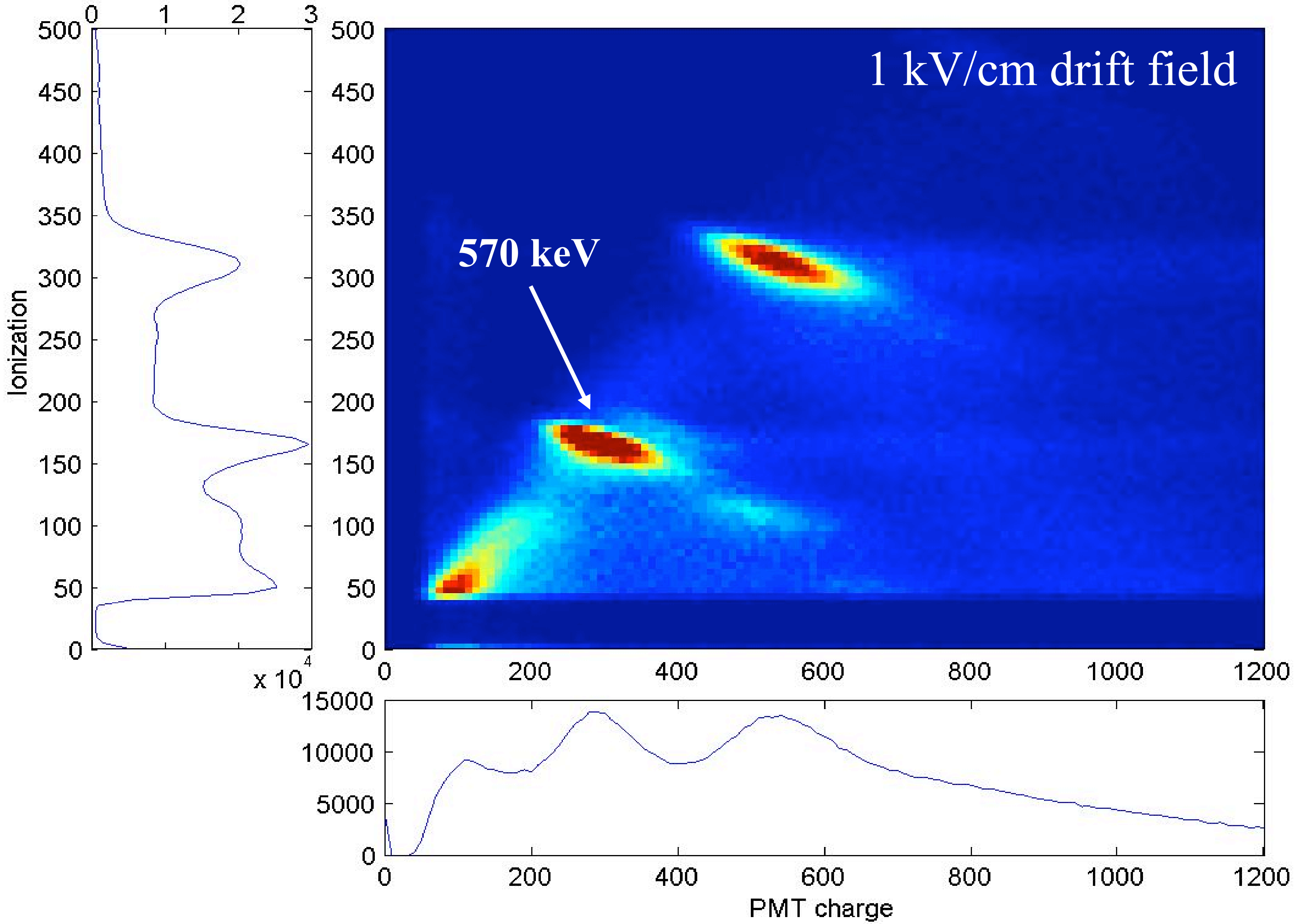
EXO LXe energy resolution experiment



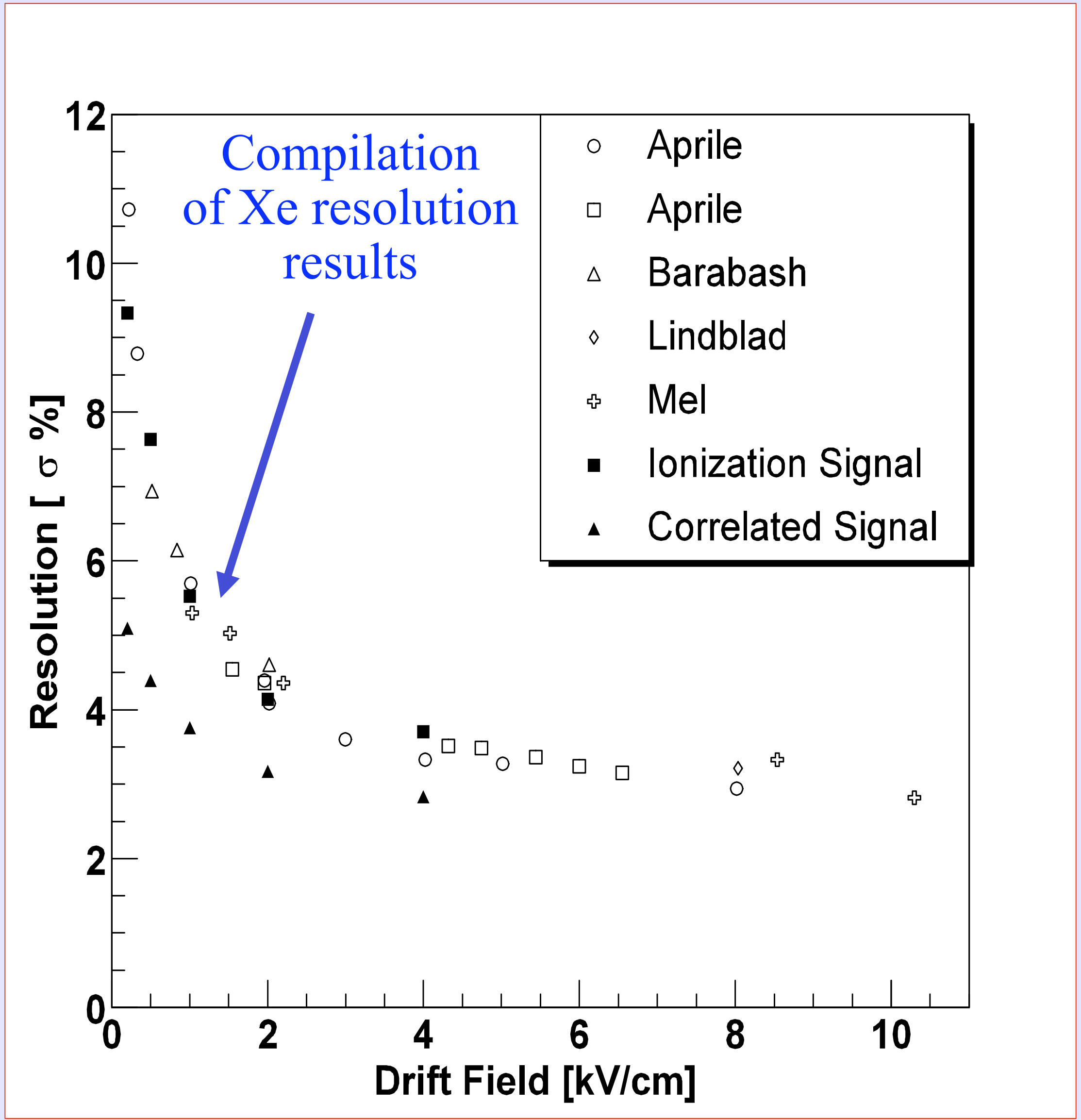




Data show microscopic anticorrelation between inonization and scintillation



Anti-correlated ionization and scintillation improves the energy resolution in LXe



[E. Conti et al., Phys. Rev. B: **68** 054201]

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

Ionization & Scintillation:
$\sigma(E)/E = 3.0\%$ @ 570 keV
or 1.4% @ $Q_{\beta\beta}$
(twice as good as most recent xenon $\beta\beta0\nu$ experiment)

EXO-200 will collect 3-4 times as much scintillation... possibly giving further improvement

Resolution improvement is very important to separate the $0\nu\beta\beta$ and $2\nu\beta\beta$ modes

The EXO-200 detector

• 200 kg of enriched LXe contained in very low background cylindrical (teflon) vessel that houses the TPC and light sensors (LAAPDs) (44 cm inner diameter and 44 cm long), surrounded by

• 50 cm of ultra pure cryofluid, inside a

• double-walled, vacuum-insulated copper cryostat, shielded by

• 25 cm of thick low activity lead

Also:
- refrigerators (cool cryofluid buffer via heat exchangers on inner wall of the cryostat)
- xenon handling system with recirculation pump, inline purifier, and xenon condenser
- compressors for xenon recovery
- electronics

All selected materials screened for radioactivity

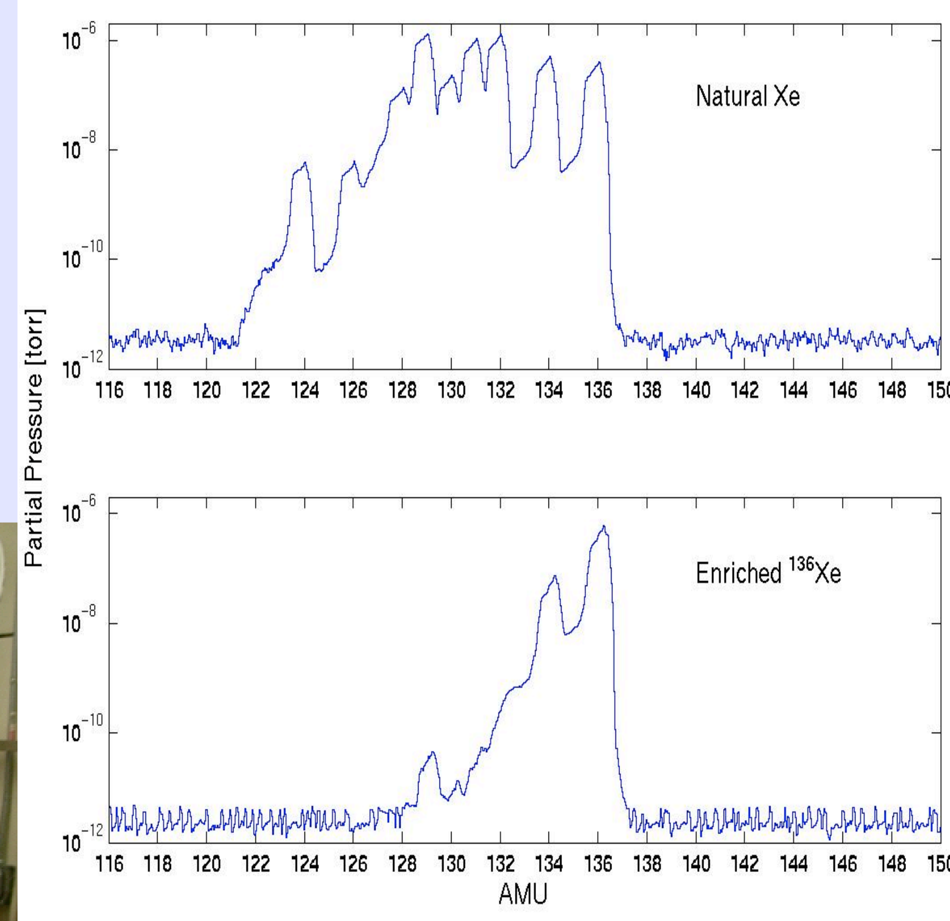
The EXO-200 TPC

- Two symmetric drift regions (22 cm long) along the cylinder axis, defined by a central cathode plane running at negative high voltage
  - max high voltage is 70 kV (3.5 kV/cm drift field); energy resolution improves with drift field, but possibly lower fields will allow for a better separation between 1 and 2 electrons (optimization is part of EXO-200's goals)
  - two sets of crossed anode wires (3 mm pitch, 100μm diameter) at each end of the cylinder, read out in groups of 3 (48 × 48 channels), for a total of 96 channels per ½ detector

- ~ 300 Large Area Avalache Photodiodes (LAAPDs) at each end of the cylinder, behind the anode wires (90% light transmission)
  - ”bare” devices, DUV sensitive (QE ~ 1 @ 175 nm)

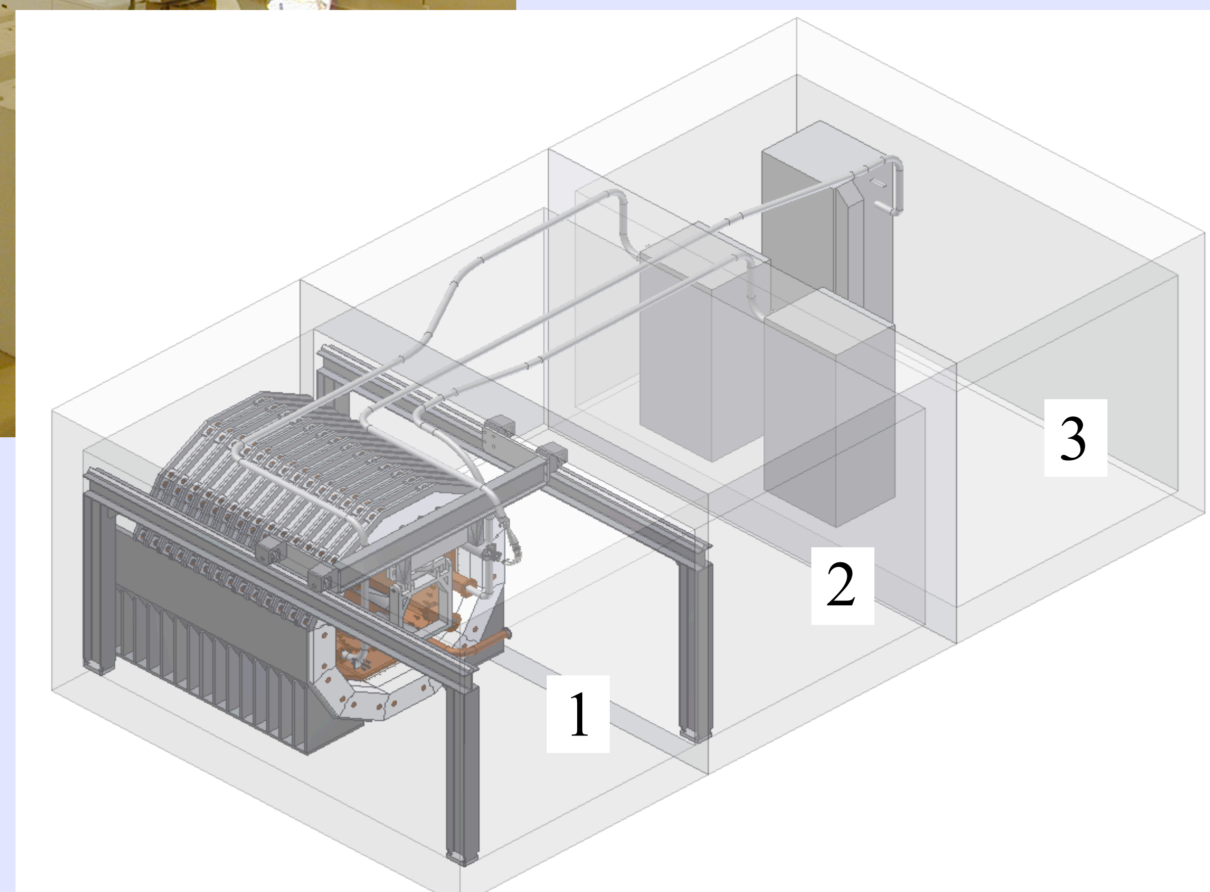
- y-position given by induction signal on shielding grid.
  x-position and energy given by charge collection grid.
  APD array observes prompt scintillation to measure drift time.

^{136}Xe stockpile at Stanford



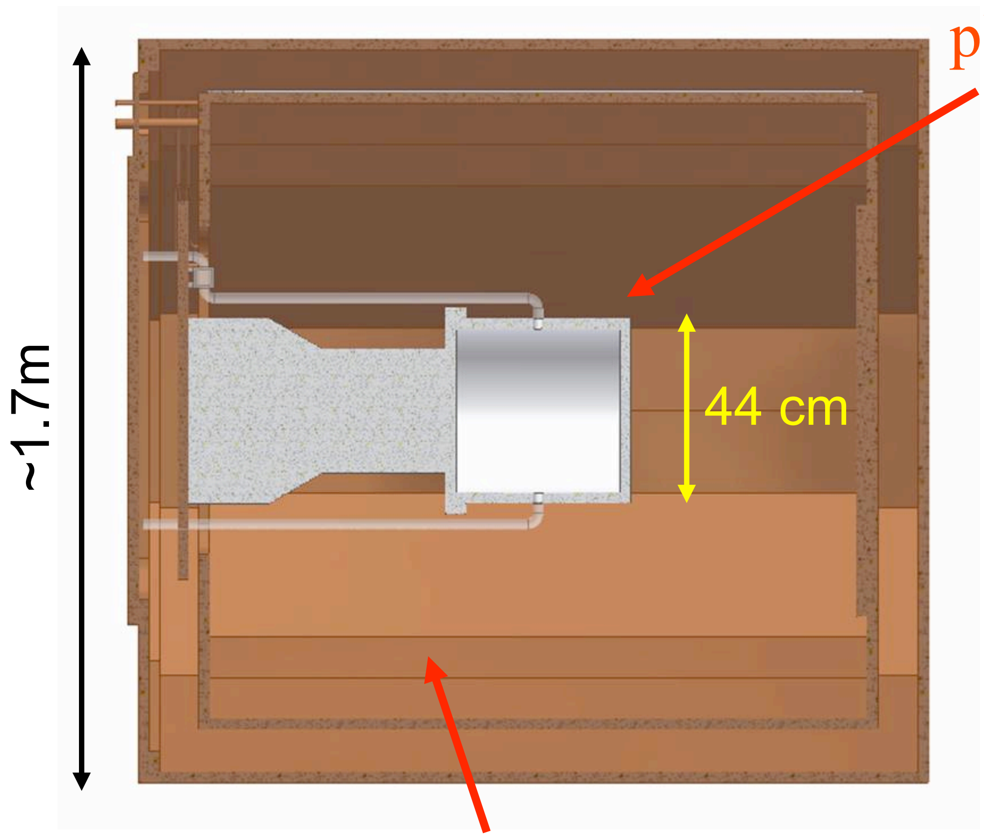
200 kg of xenon enriched to 80% in ^{136}Xe : the most isotope possession by any ββ collaboration

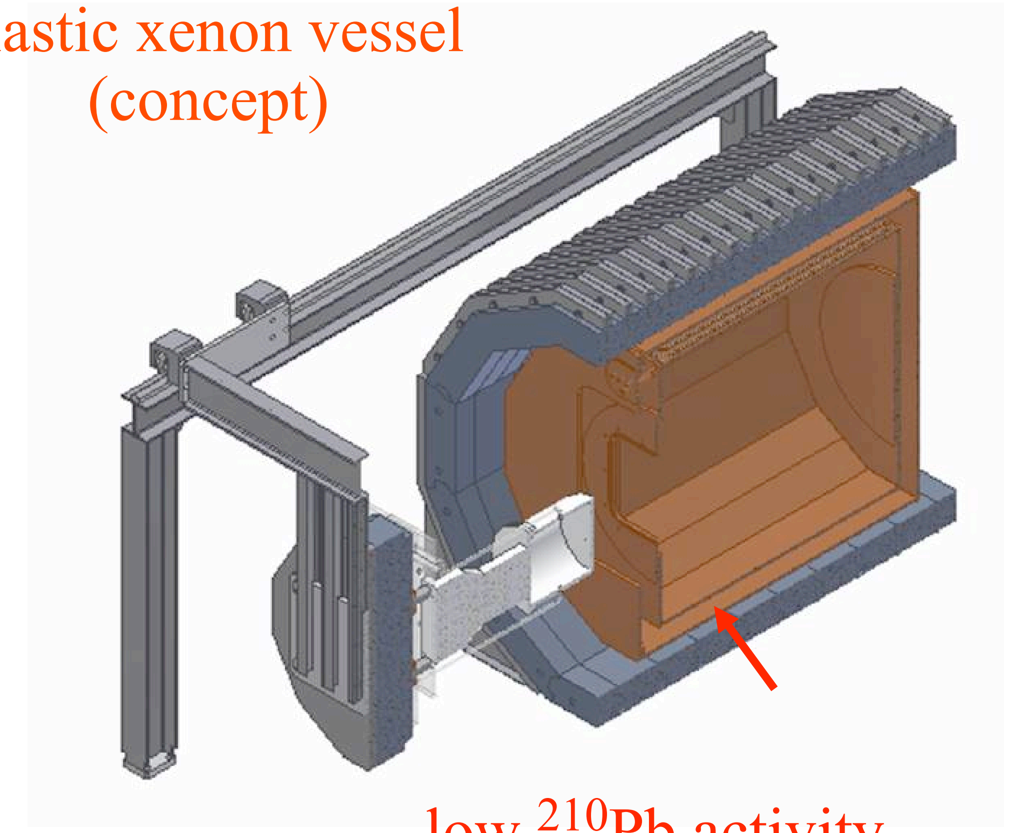
The EXO-200 modular clean rooms



1 - EXO-200 deetctor (class 100)
2 - LXe handling and Xe bottles
3 - refrigeration units
4 - electronics
5 - control room
6 - entrance, air shower

The EXO-200 detector





plastic xenon vessel
(concept)

HFE-7000 cryofluid by 3M
(hydrofluoroether $C_3F_7OCH_3$)

low ^{210}Pb activity
lead shielding

Cryostat fabrication at SDMS (Grenoble)

e-beam welding
vacuum chamber

copper from
Norddeutsche Affinerie

After machining
and welding plates
are returned to
shielded storage

Outer Vessel

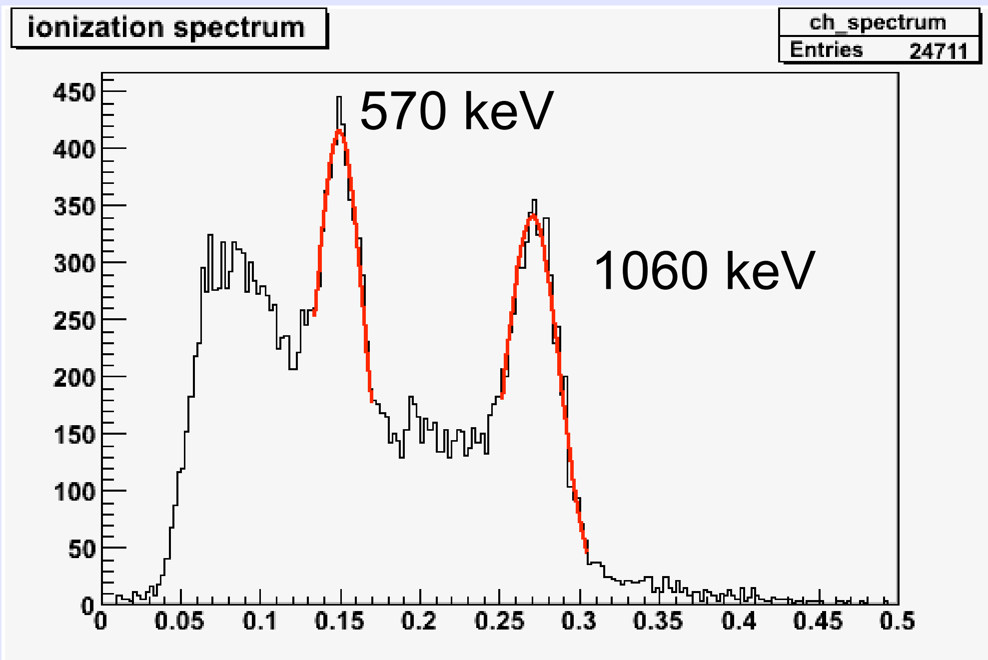
Xenon chamber

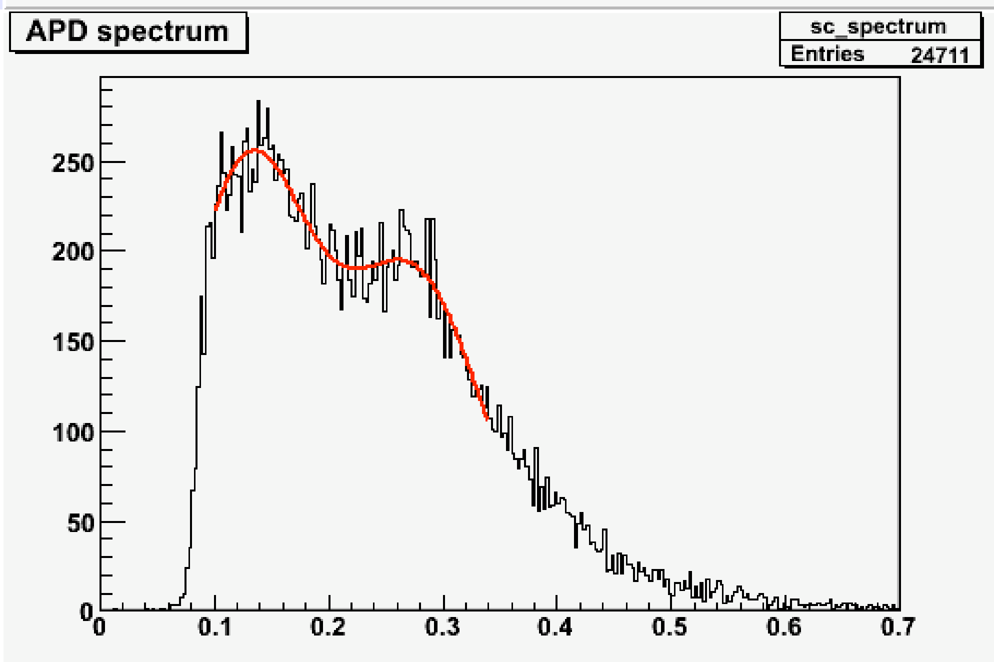
A couple, selected varieties of teflon have turned out extremely pure (and have no cosmogenic activation problems)
→ prime candidate material for TPC

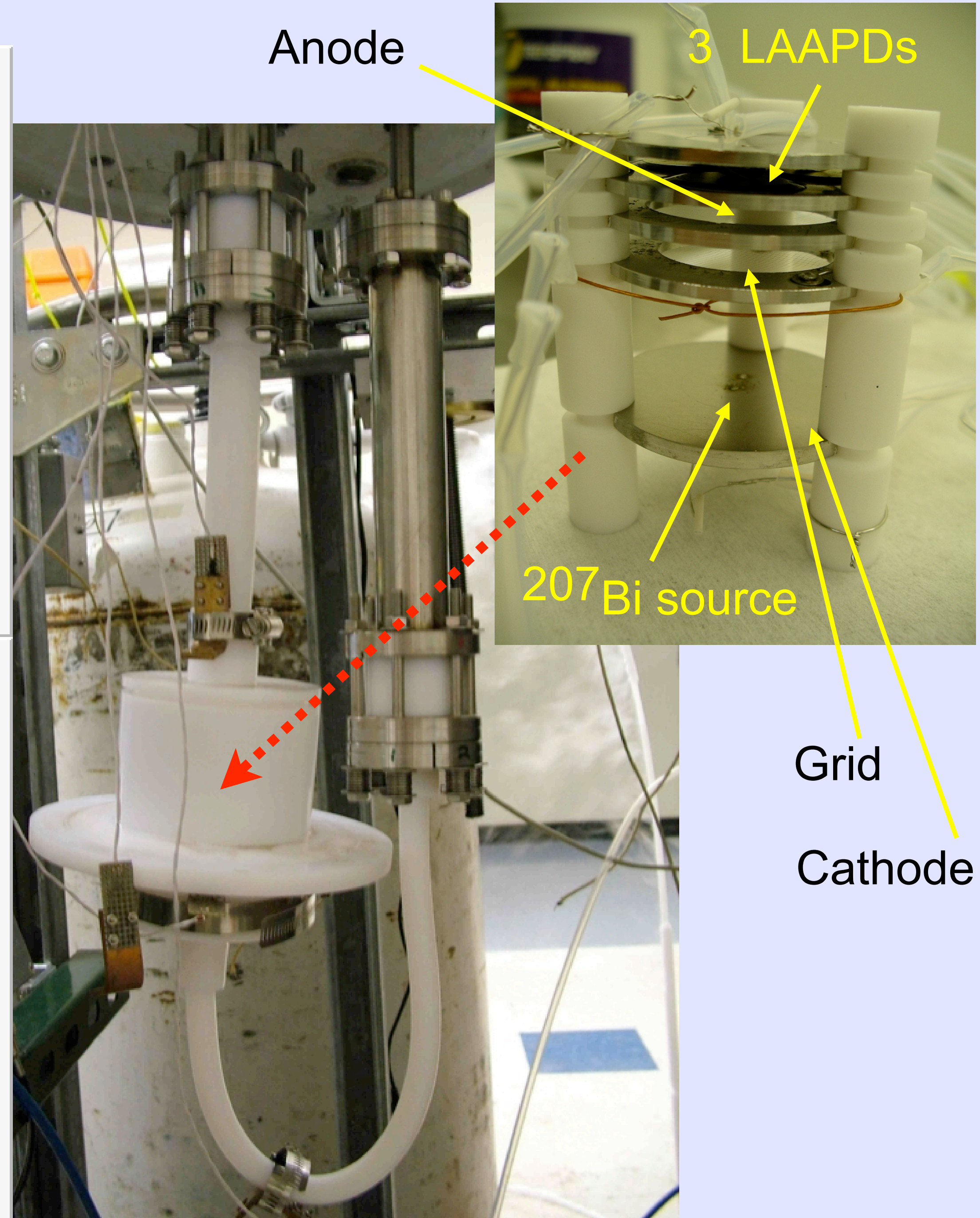
All-teflon, welded chambers (~ 0.5 litres) successfully produced
R&D performed with APT
(Rhode Island, DOE-SBIR grants I and II)

several full-size chamber design under study, which involve (not necessarily all):
1) teflon welds (3 types)
2) teflon to copper cold seals (many sizes)
   (two designs already proven in the lab)

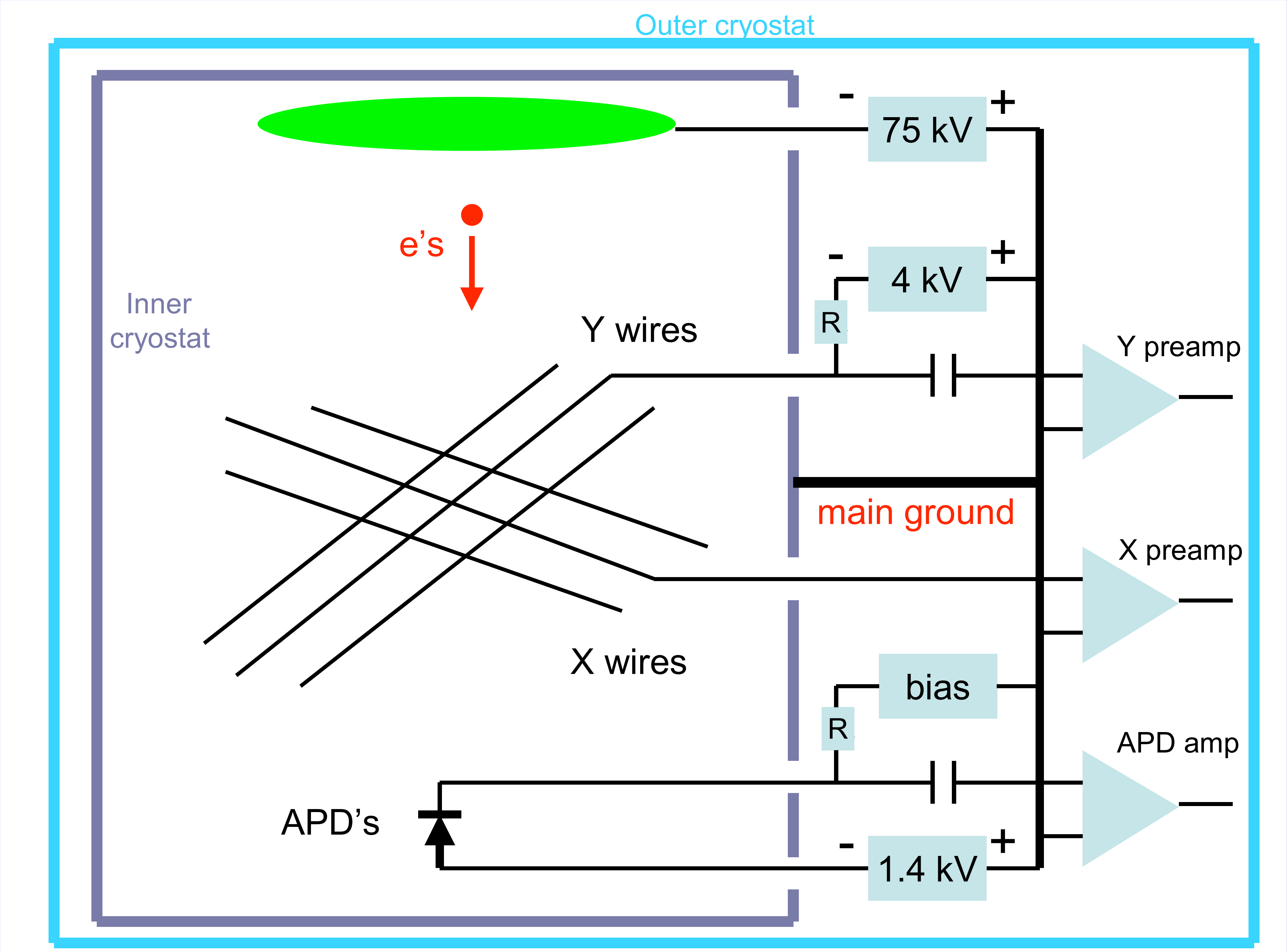
results with prototype teflon chamber

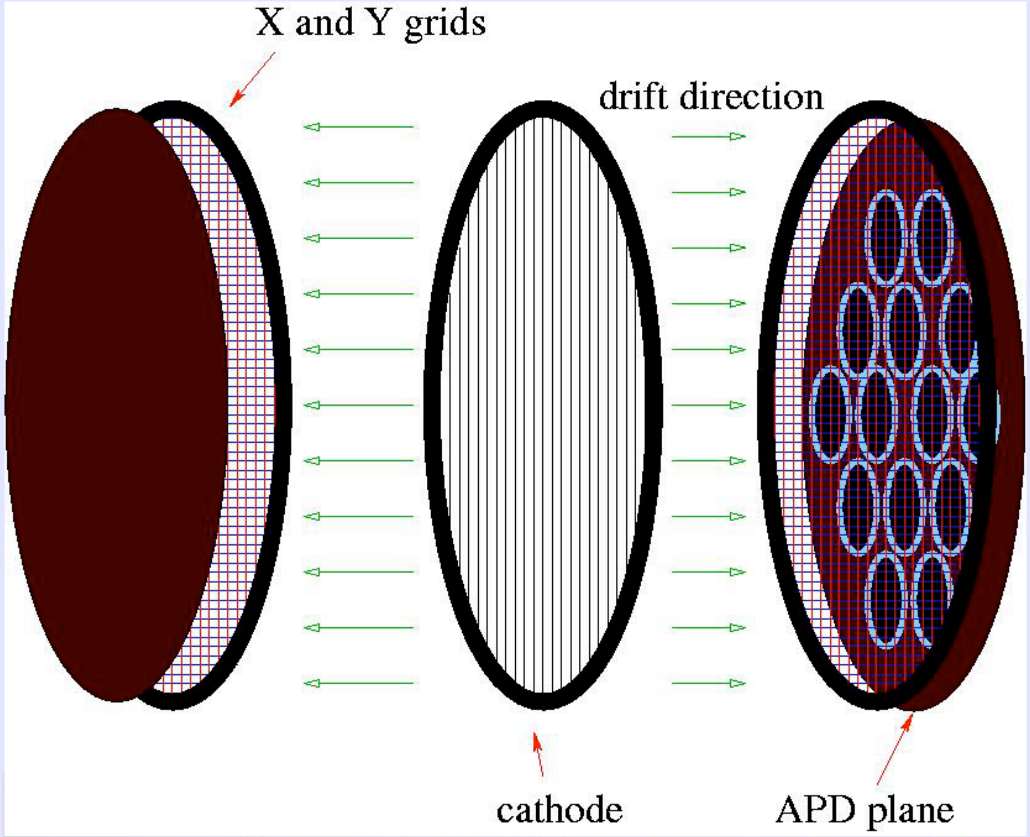




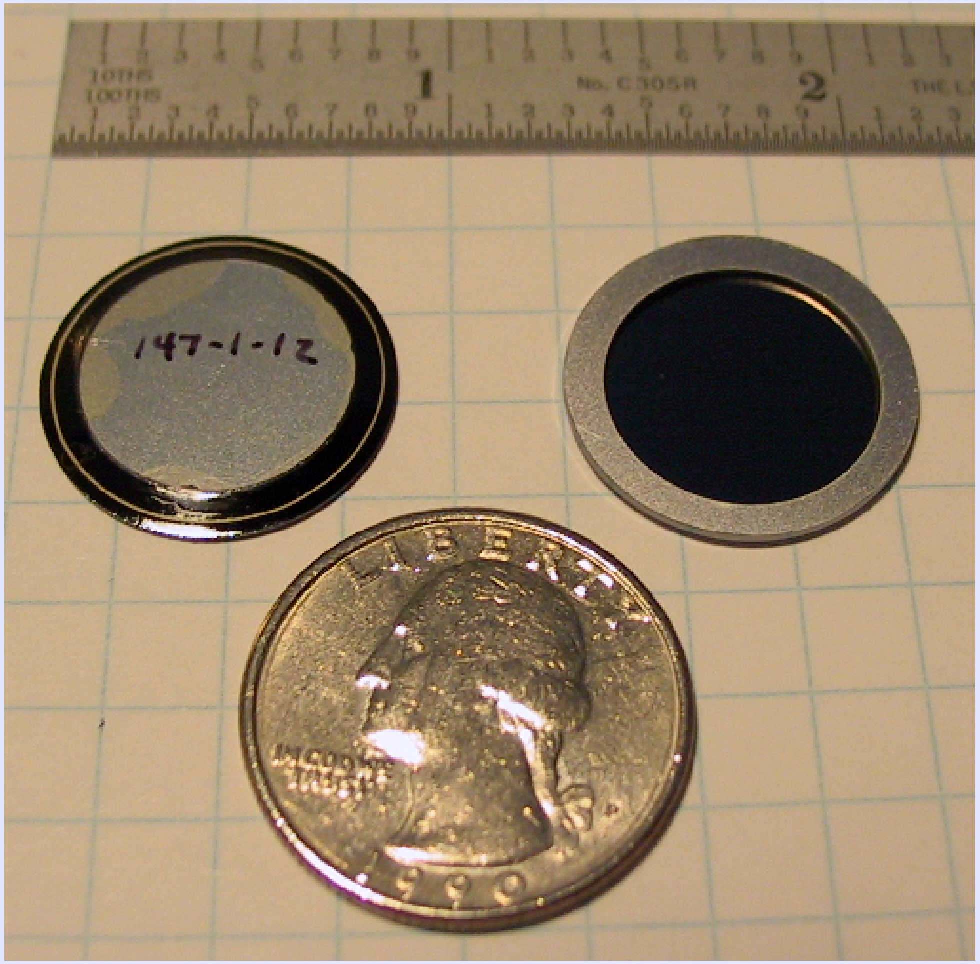


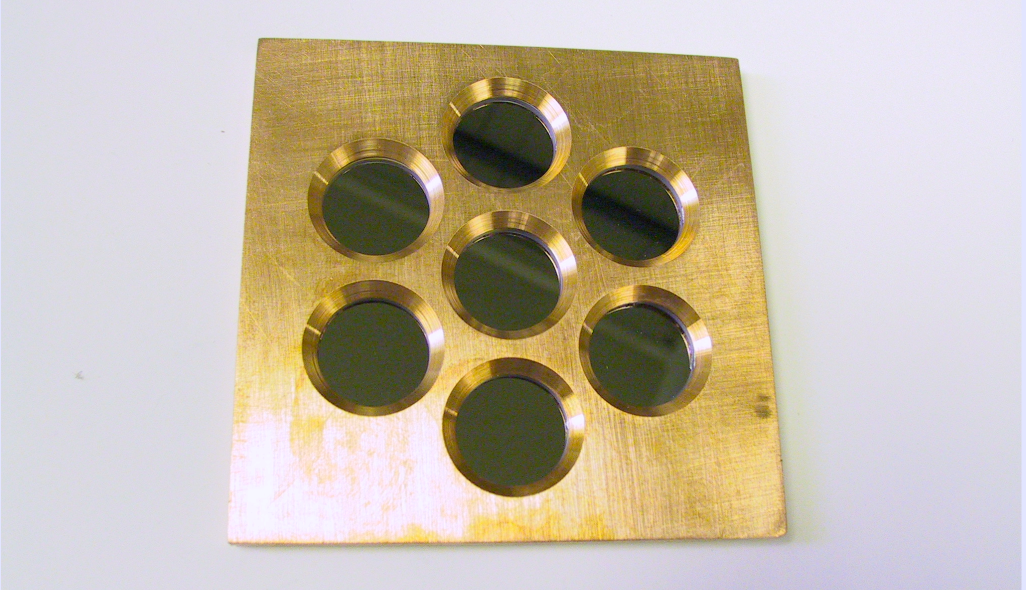
The EXO-200 readout





APDs

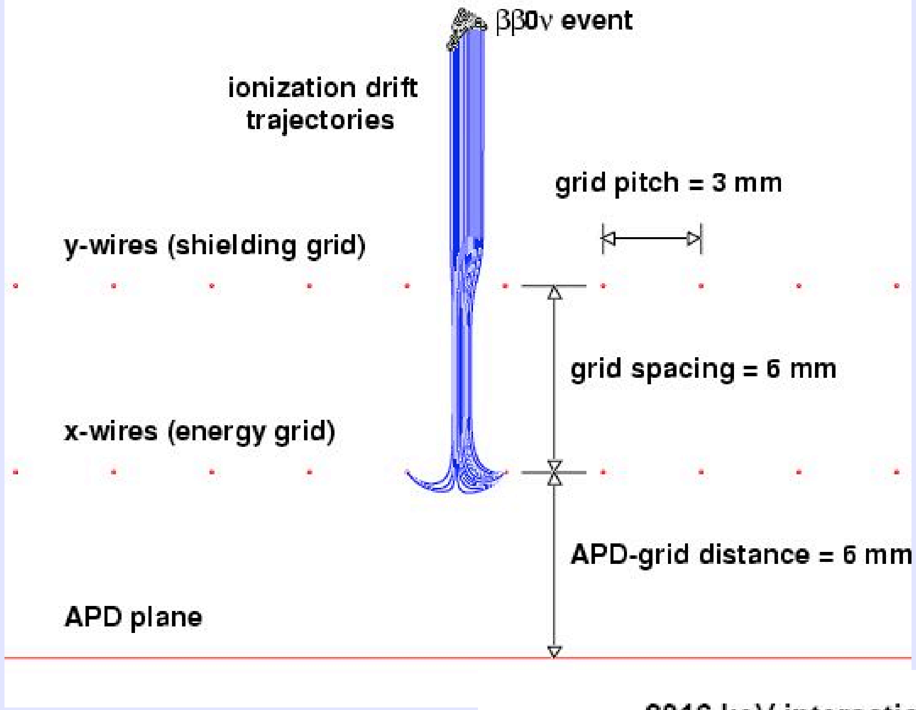




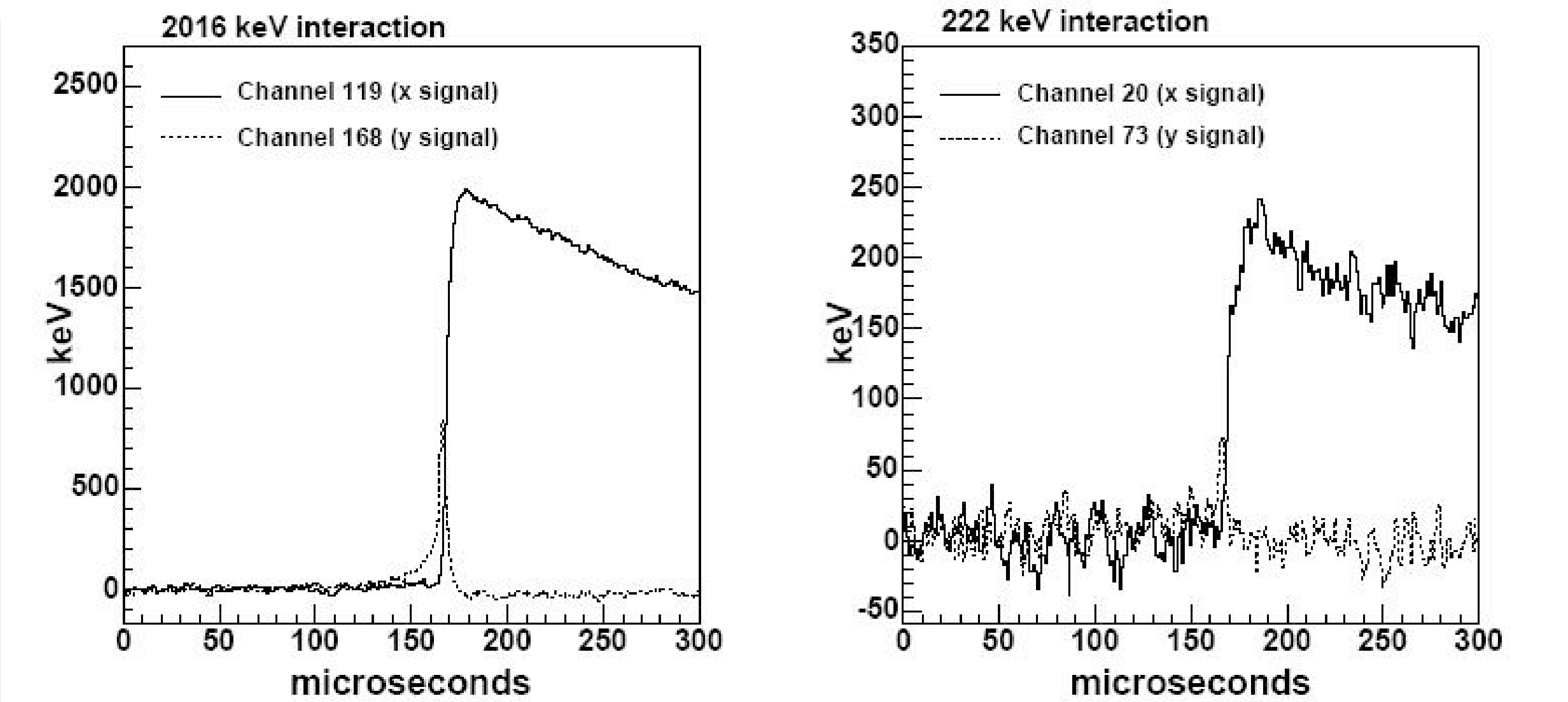
"gang-of-7" test setup

- low mass, low radioactivity
- gold-less (Al-plated for EXO)
- gain = 100-150 (T stable to 1 K)
- bias ~ 1500 Volt
- leakage current ~ 10s nA (-100 °C)

Signal example
(GEANT4 simulation)



X and Y signals for two of the charge clusters (800 electrons of noise added with correct frequency spectrum)



Xe handling system

UHV compliant system

electronics rack

SAES Zr purifier

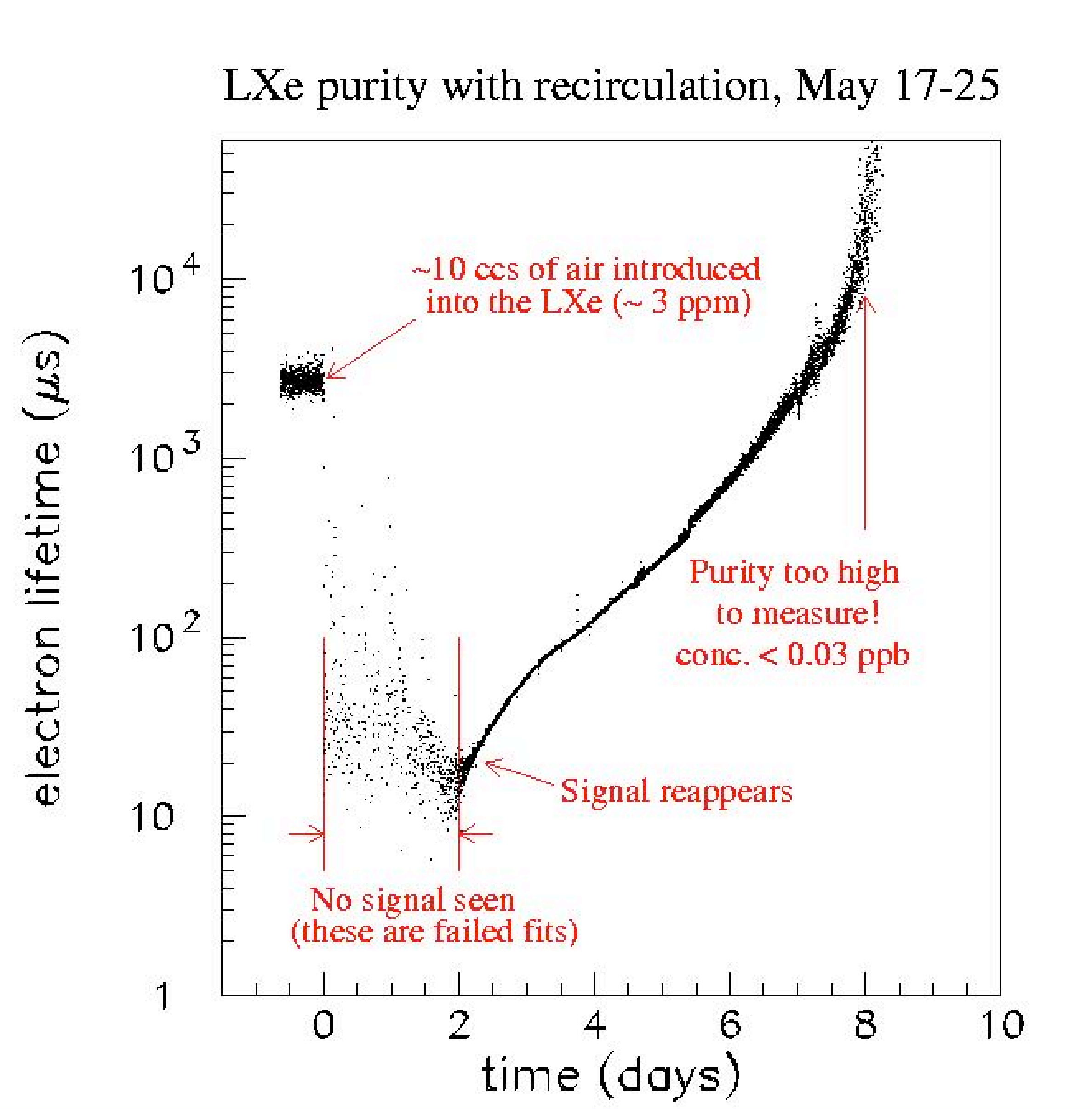
valves and instrumentation manifold

RGA

turbo pump

SAES Zr purifier currently being Rn-emanation tested

Xe inline purification

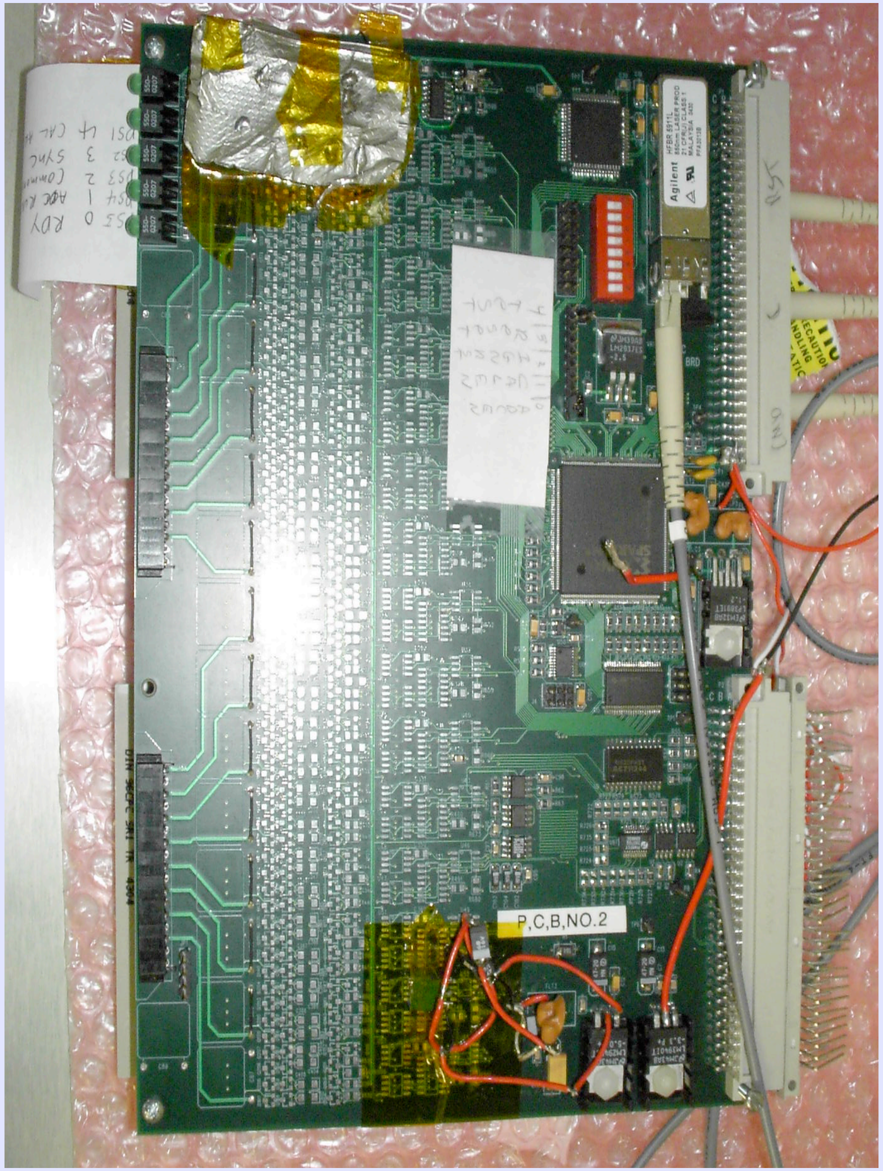


Remove chemical (O_2, CO_2, H_2O) and radioactive impurities

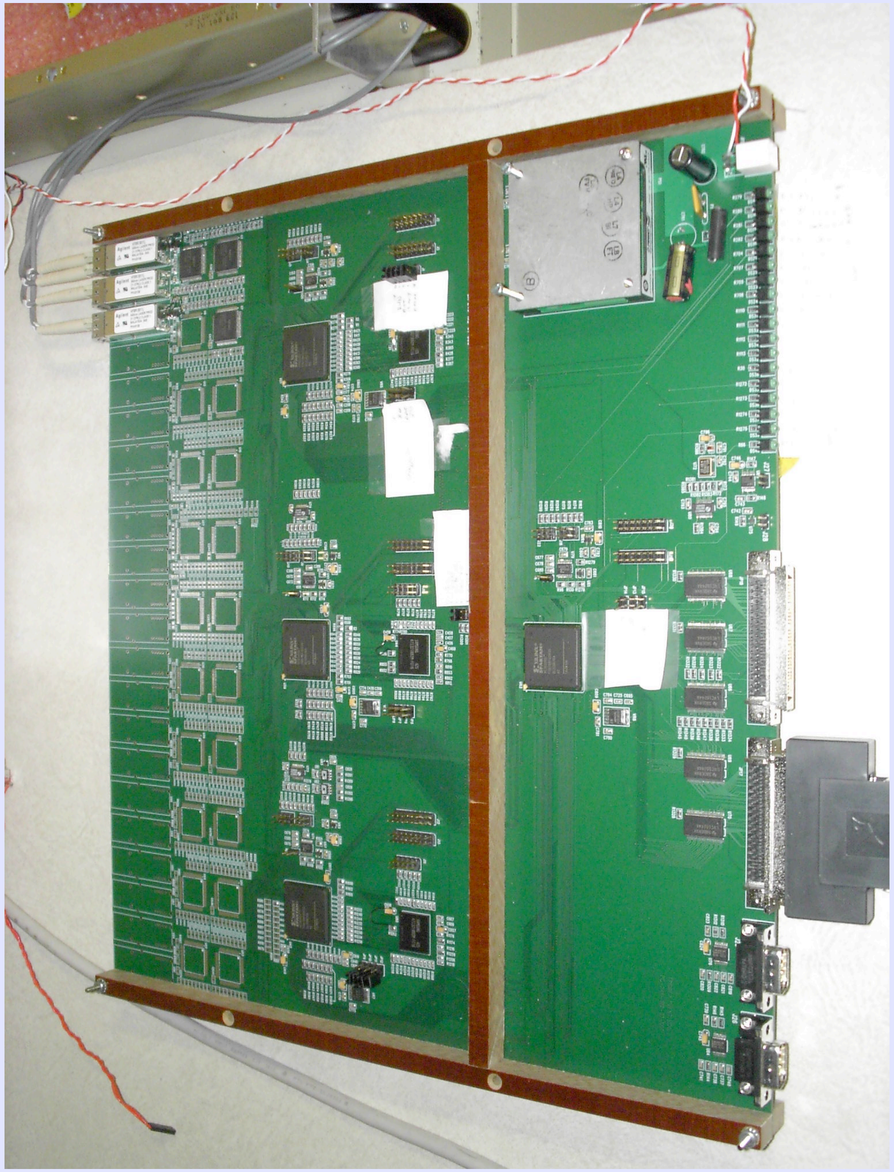
EXO-200 goal:
- 0.1 ppb O_2 equivalent
- t ~ 4 ms (electrons)

Continuous or frequent recirculation of xenon likely with large amounts of teflon

The EXO-200 electronics



Front-end board



Trigger module

Material qualification

- NAA[a]
- Low background g-spectroscopy[b]
- α-counting[c]
- Radon counting[d]
- High performance GD-MS and ICP-MS[e]

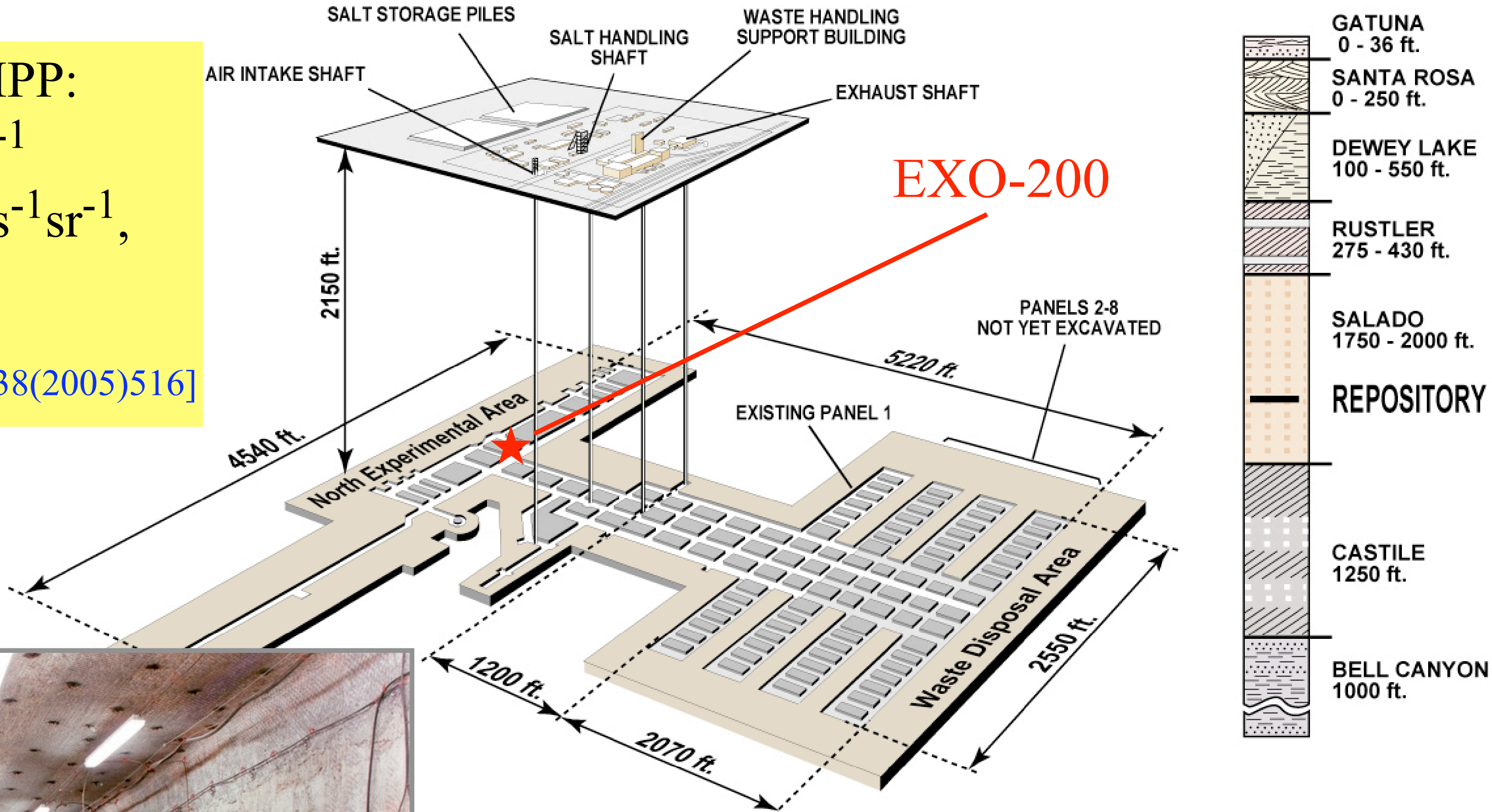
Online database for collaborators at present includes ~80 entries

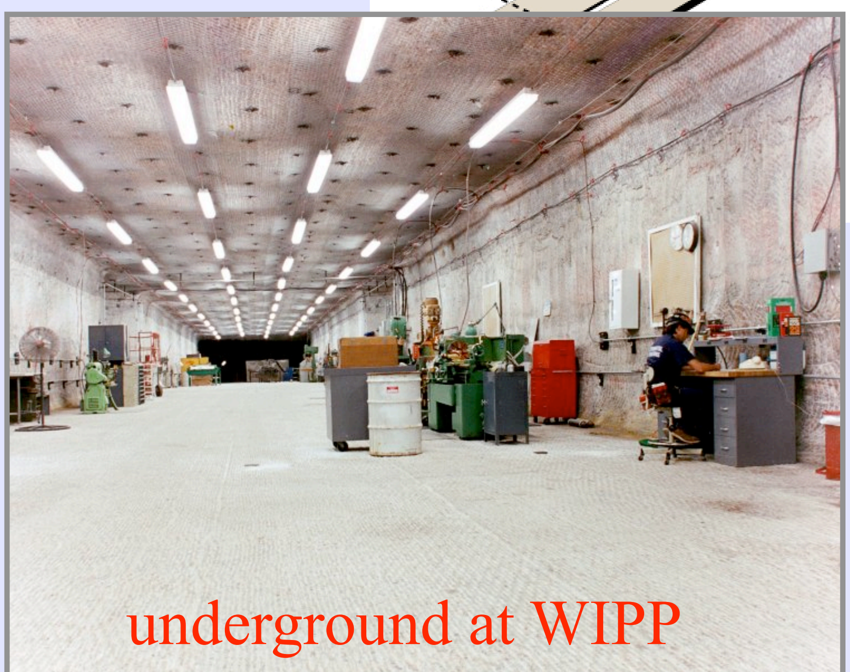
MC simulation of backgrounds

[a] MIT, Alabama
[b] Neuchatel, Alabama
[c] Alabama, Stanford, SLAC, Carleton
[d] Laurentian
[e] Commercial, Canadian Inst. Standards

WIPP Facility and Stratigraphic Sequence

muon flux at WIPP:
$4.77\times10^{-3}\ m^{-2}\ s^{-1}$
$(3.10\times10^{-3}\ m^{-2}\ s^{-1}sr^{-1}$,
$\sim15\ m^{-2}\ h^{-1})$
[E.-I.Esch et al.,
Nucl. Instr. Meth. A 538(2005)516]





EXO 200 kg prototype will be assembled and commissioned at Stanford, then the six clean rooms will be shipped to WIPP
Operations expected in 1-2 years

Summary

EXO-200 is a competitive double beta decay experiment that will be able to probe the degenerate neutrino mass hierarchy ($\langle m_{\beta\beta} \rangle \sim$100s meV) in the near future

Its construction is well under way, and together with the R&D on the Ba tagging will provide an indispensable benchmark for a (multi)ton-scale EXO experiment

EXO Collaboration

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