EXO- An Enriched Xenon Observatory for Double Beta Decay

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Search for Baryon and Lepton Number Violation Workshop

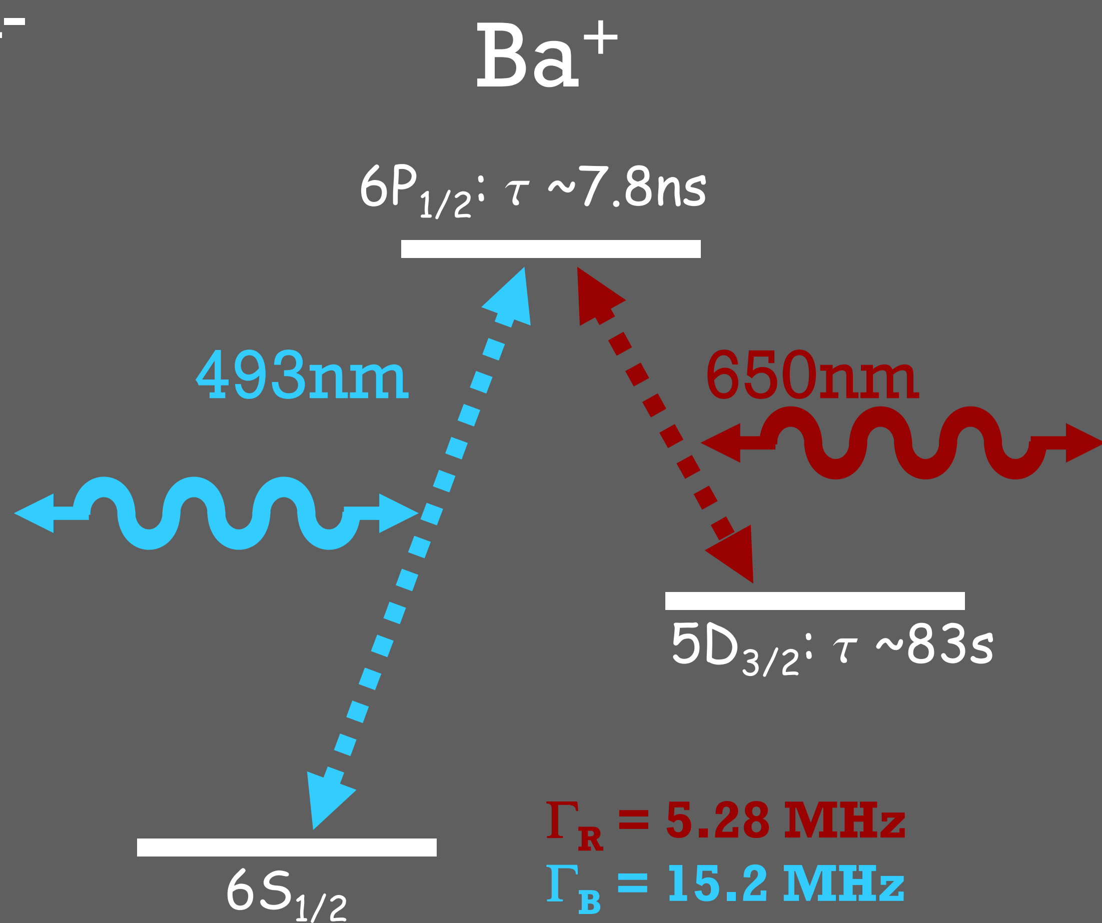
LBNL - September 21, 2007

Why a ^{136}Xe Detector?

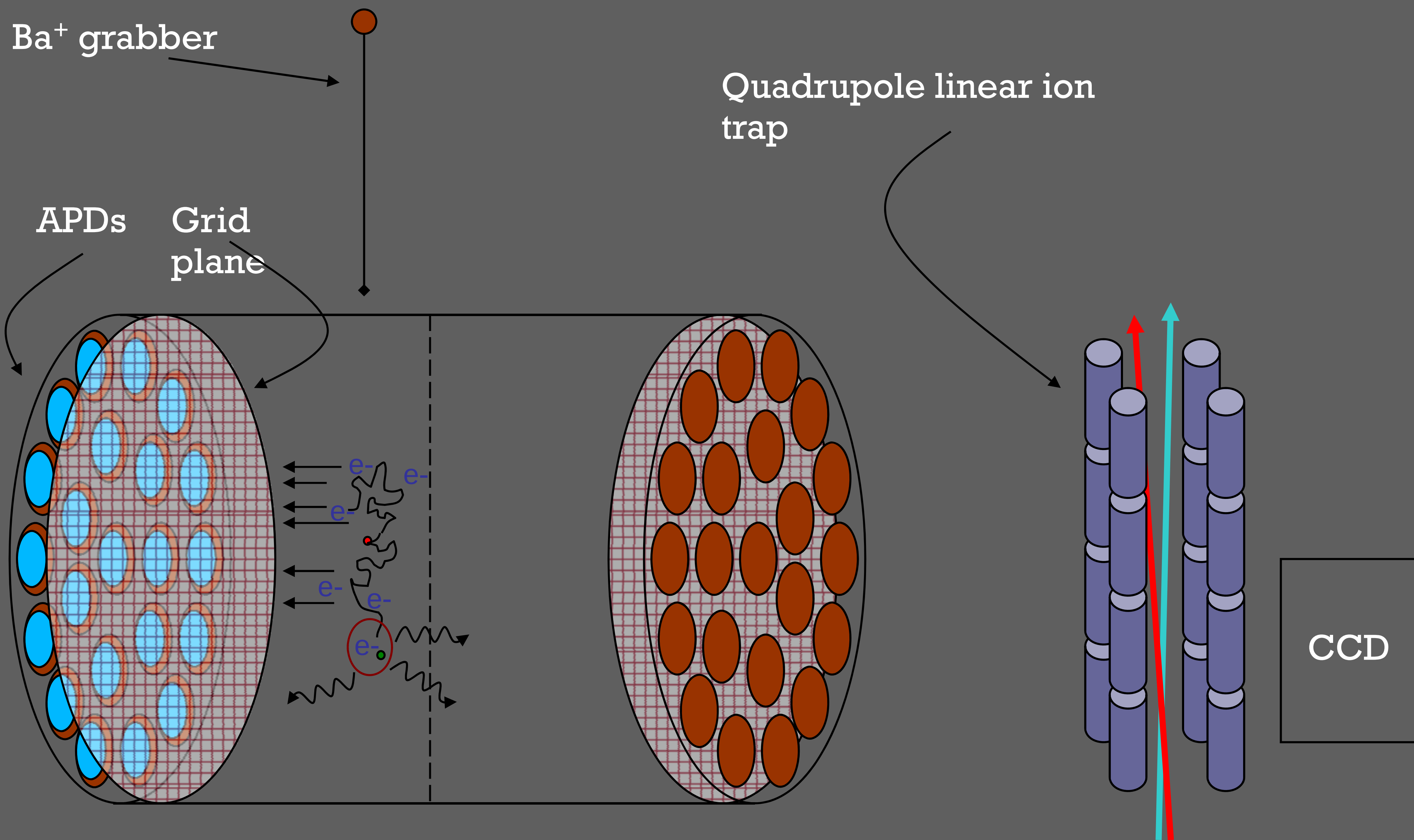
- Xenon is a noble gas
  - No crystals to grow
  - Chemistry is non-toxic
  - Easier to purify
  - Repeated (or continuous) purification possible
- No long lived cosmogenics
- Efficiently enriched by ultracentrifuge
- Scalable to 10 tons or more
- And our Ace in the hole…

Xe offers a qualitatively new tool against background: $^{136}Xe \rightarrow {}^{136}Ba^{++} + 2e^{-}$ final state can be identified using optical spectroscopy. (M.Moe PRC44 (1991) 931)

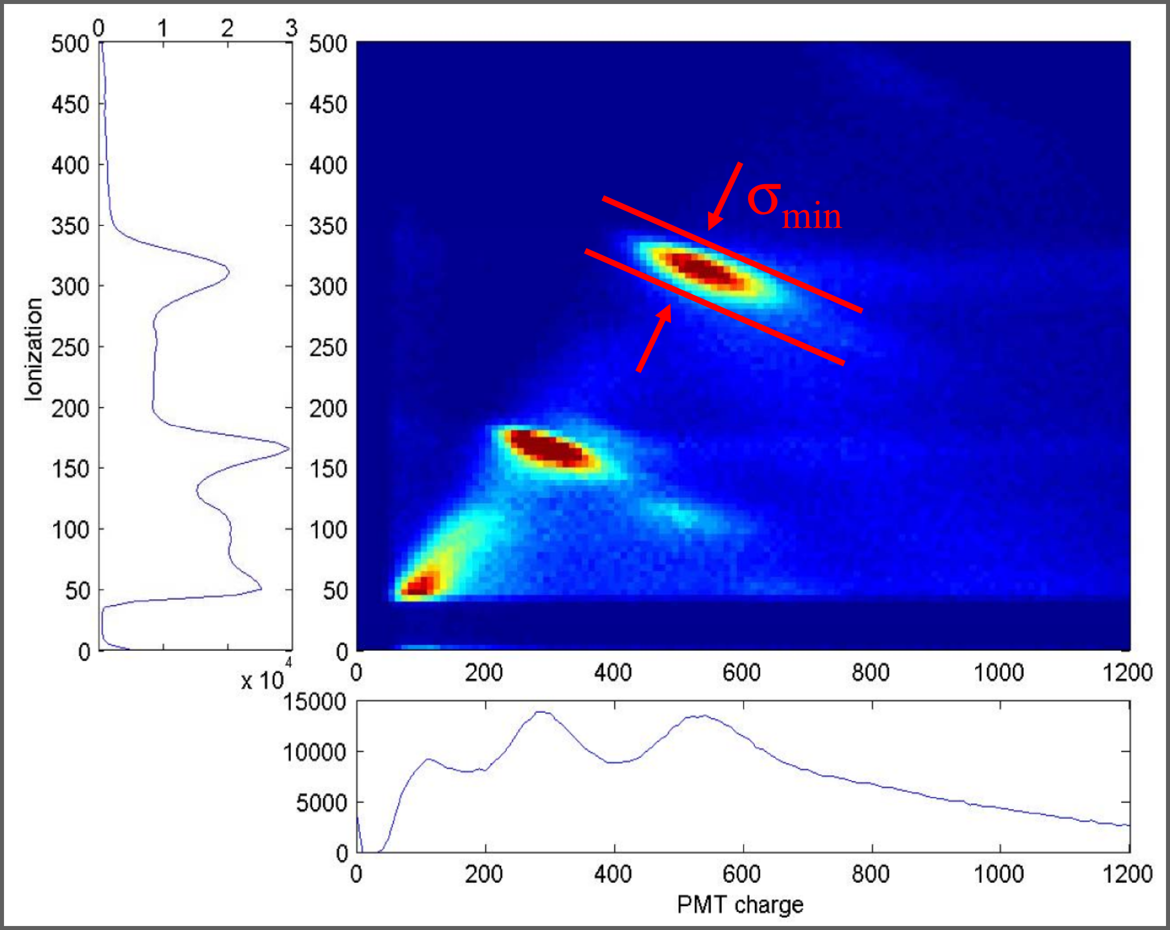
- 3 level "Λ" configuration-
  - 493nm drive
  - 650nm repump
- Highly specific
- 10^7 photon/sec spontaneous emission rate allows detection of single atoms
- Charge state allows confinement using RF traps.

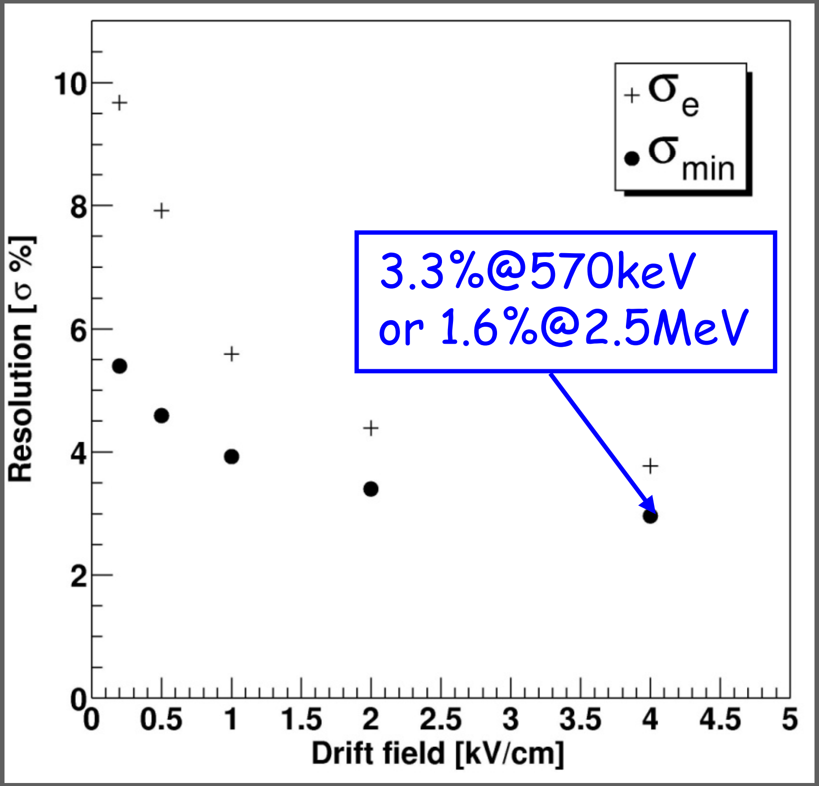


0νββ Detection in EXO



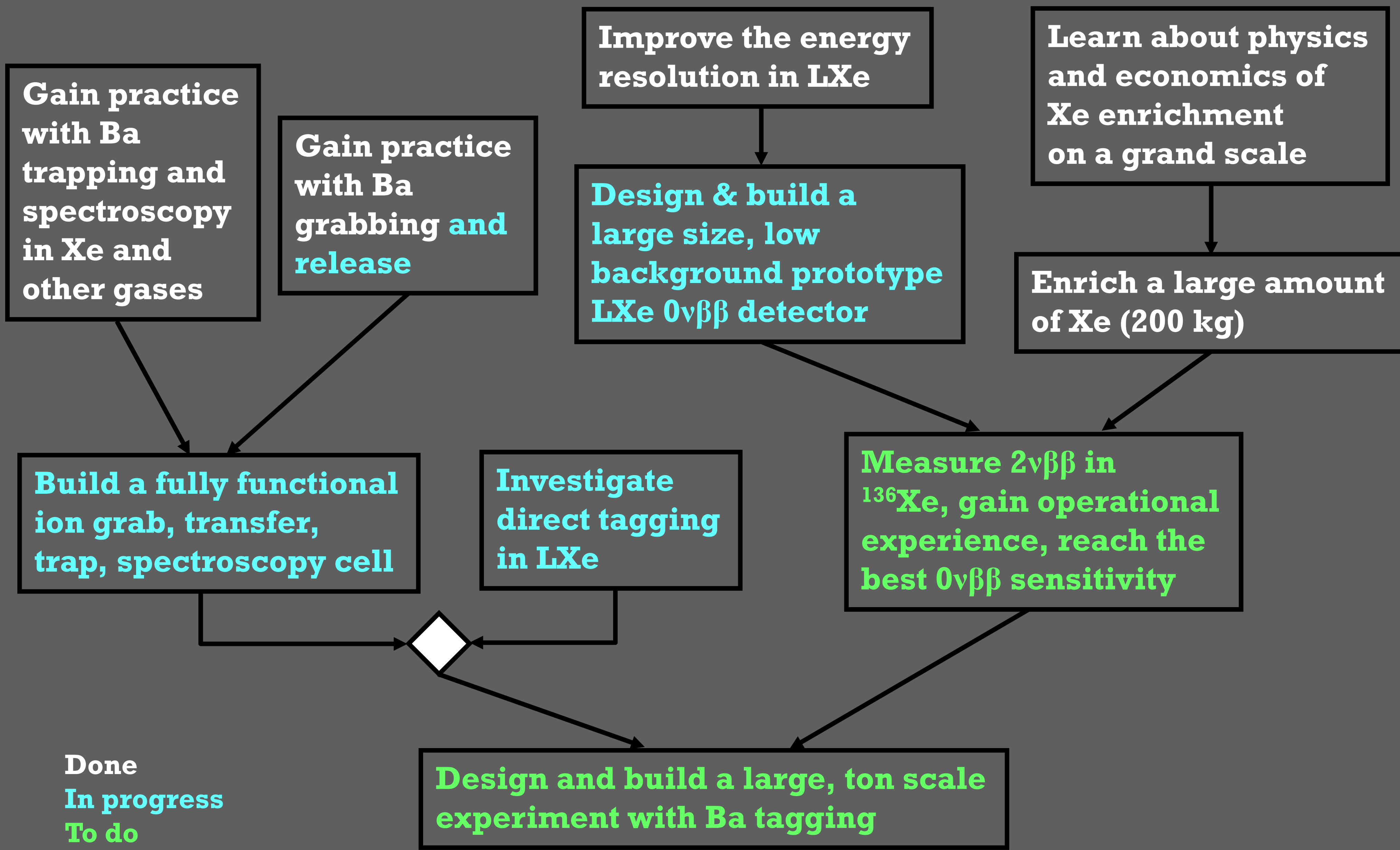
Liquid Xenon Energy Resolution





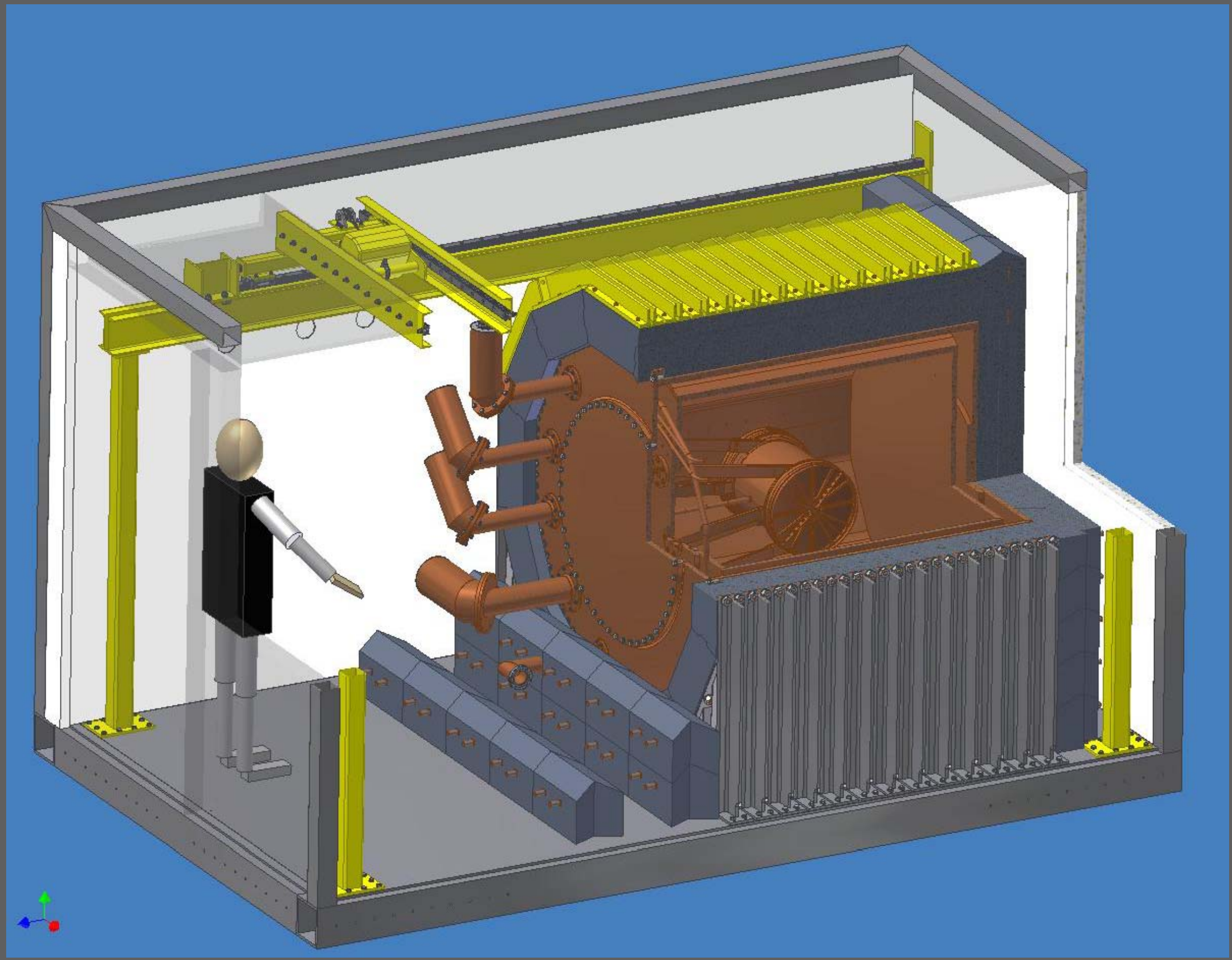
E. Conti et al Phys Rev B 68 (2003) 054201

The roadmap to the background free discovery of Majorana neutrinos and the neutrino mass scale

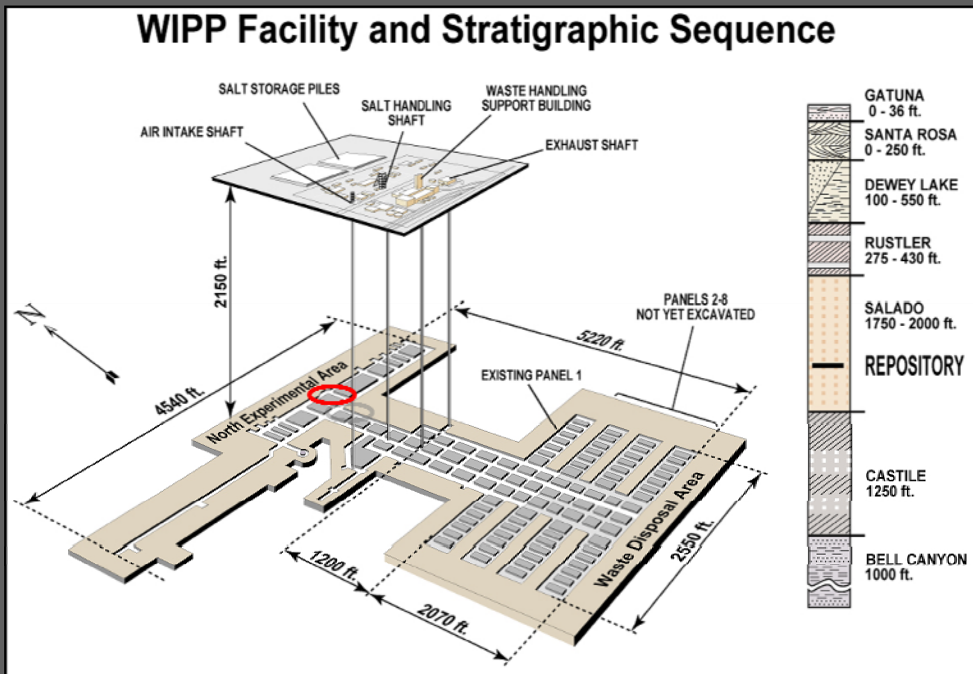


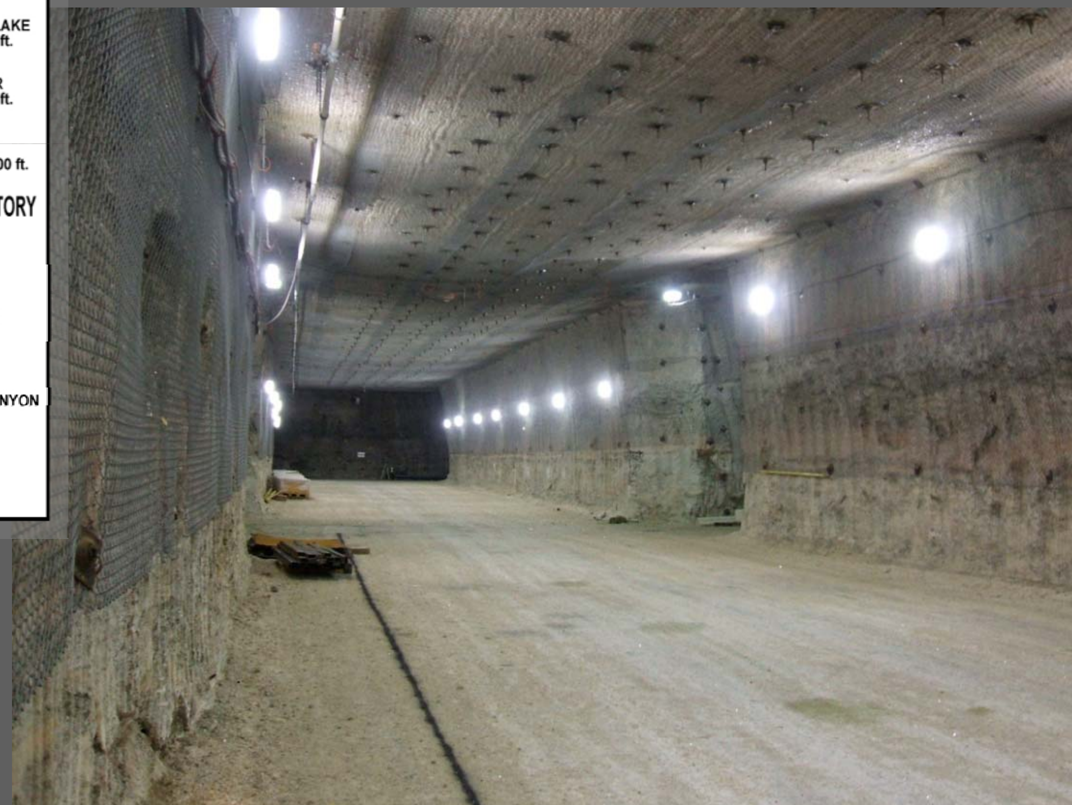
EXO-200

- 200kg LXe Scintillation / Ionization detector
- 75kV drift
- 518 LAAPDS for scintillation readout
- Copper Vessel
- Thermal Bath
- Copper Cryostat
- 25cm lead shielding
- No Ba Tagging



EXO-200 Experimental Site





- 655 m underground (rock + salt), 1585 m.w.e
- vertical muon flux = 3.1×10^{-7} sec^{-1} cm^{-2} sr^{-1}

(NIMA 538 (2005) 516)

Massive effort on material radioactive qualification using:

- NAA (MIT-Alabama)
- Low background γ-spectroscopy (Neuchatel, Alabama)
- α-counting (Alabama, Stanford, SLAC, Carleton)
- Radon counting (Laurentian)
- High performance GD-MS and ICP-MS (Canadian Inst. Standards)

At present the database of characterized materials includes >200 entries

MC simulation of backgrounds at Alabama and Stanford/SLAC

The impact of every screw within the Pb shielding is evaluated before acceptance

Materials Evaluation Paper!

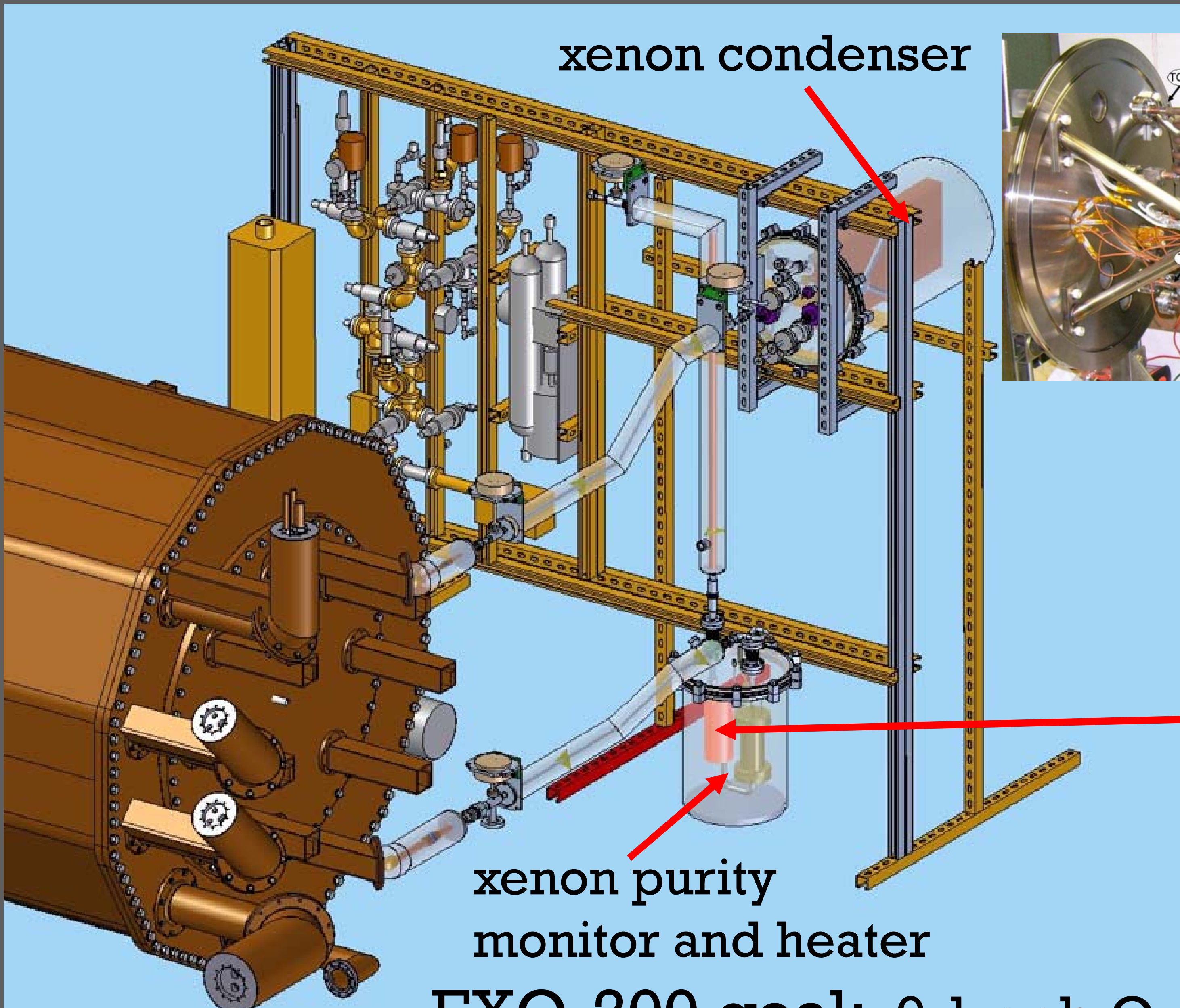
Systematic study of trace radioactive impurities in candidate construction materials for EXO

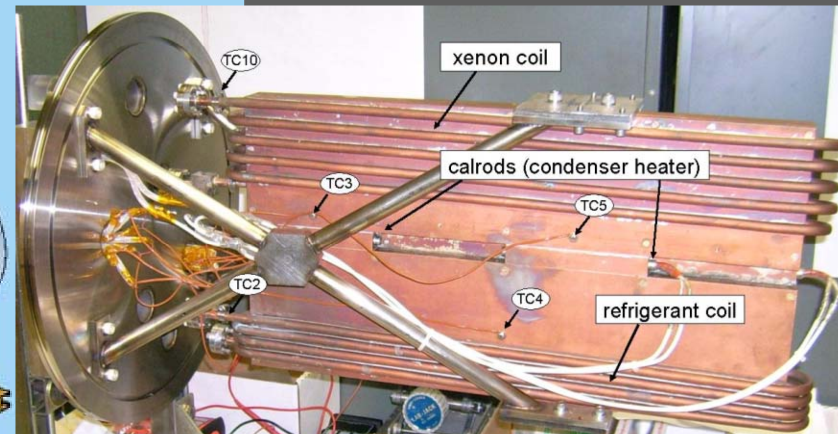
D.S. Leonard[a], P. Grinberg[b], P. Weber[c], E. Baussan[c], Z. Djurcic[a], G. Keefer[a], A. Piepke[a], A. Pocar[e], J.-L. Vuilleumier[c], J.-M. Vuilleumier[c], R. Conley[d], W. Craddock[d], D. Akimov[ℓ], A. Bellerive[h], M. Bowcock[h], M. Breidenbach[d], A. Burenkov[ℓ], M. Danilov[ℓ], R. DeVoe[e], M. Dixit[h], A. Dolgolenko[ℓ], I. Ekchtout[h], W. Fairbank Jr.[f], P. Fierlinger[e], B. Flatt[e], J. Farine[g], G. Gratta[e], M. Green[e], C. Hall[j], K. Hall[f], D. Hallman[g], C. Hargrove[h], R. Herbst[d], J. Hodgson[d], S. Jeng[f], S. Kolkowitz[e], A. Kovalenko[ℓ], D. Kovalenko[ℓ], F. LePort[e], D. Mackay[d], M. Montero Díez[e], M. Moe[i], R. Neilson[e], A. Odian[d], L. Ounalli[c], K. O'Sullivan[e], C.Y. Prescott[d], P.C. Rowson[d], D. Schenker[c], D. Sinclair[h], K. Skarpaas[d], G. Smirnov[ℓ], V. Stekhanov[ℓ], V. Strickland[h], C. Virtue[g], K. Wamba[d], J. Wodin[e,1]

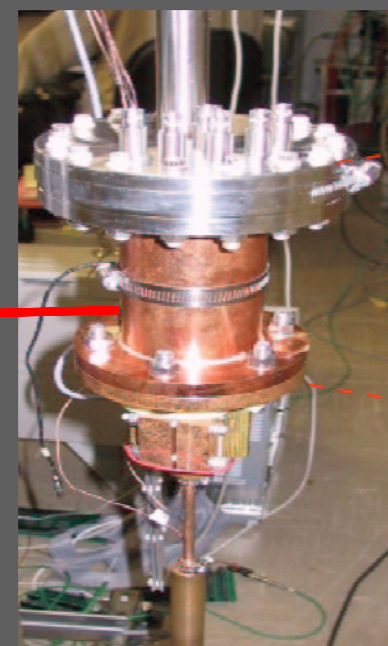
Watch out for D.S. Leonard et al. on arXiv!


E

Xenon Handling System



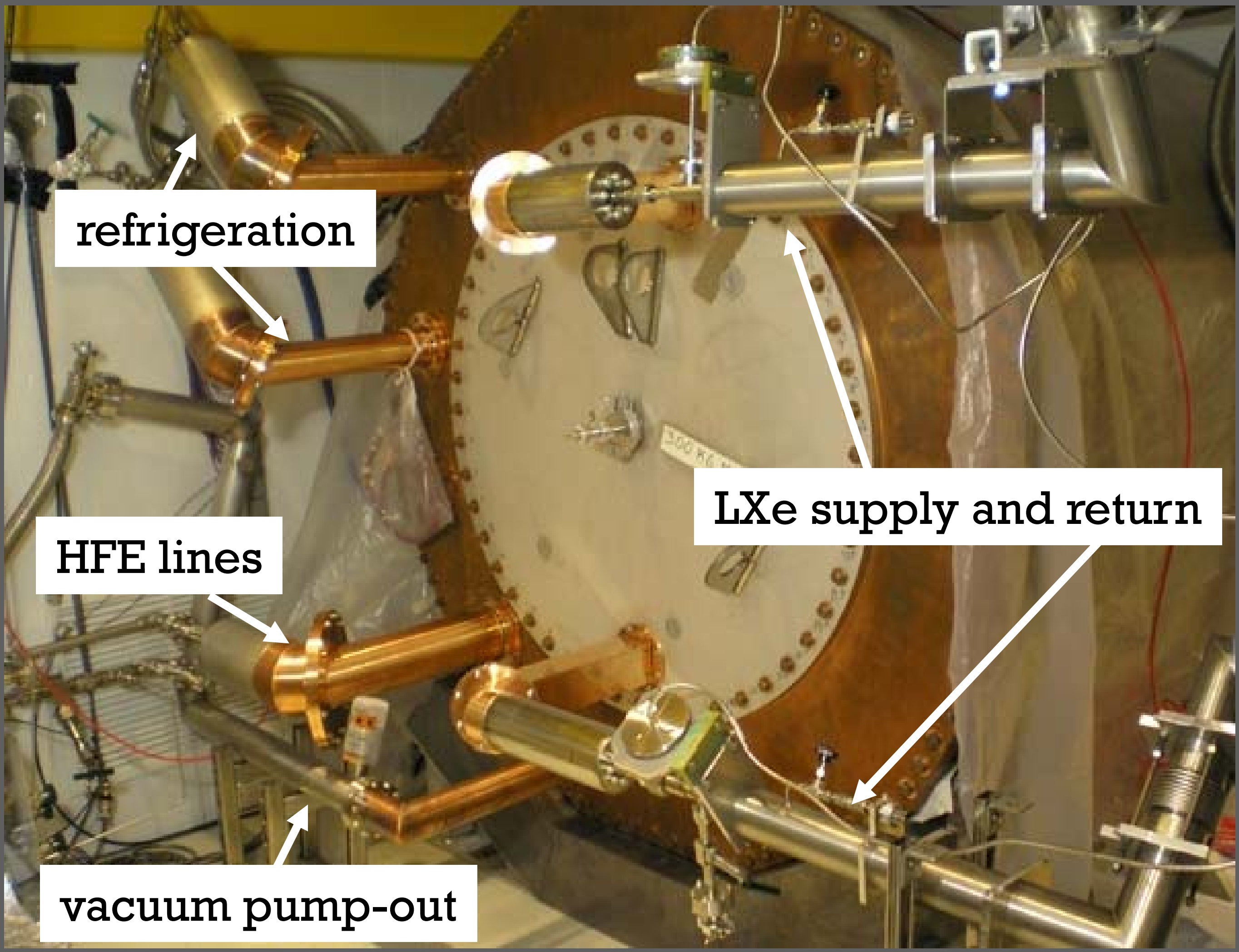


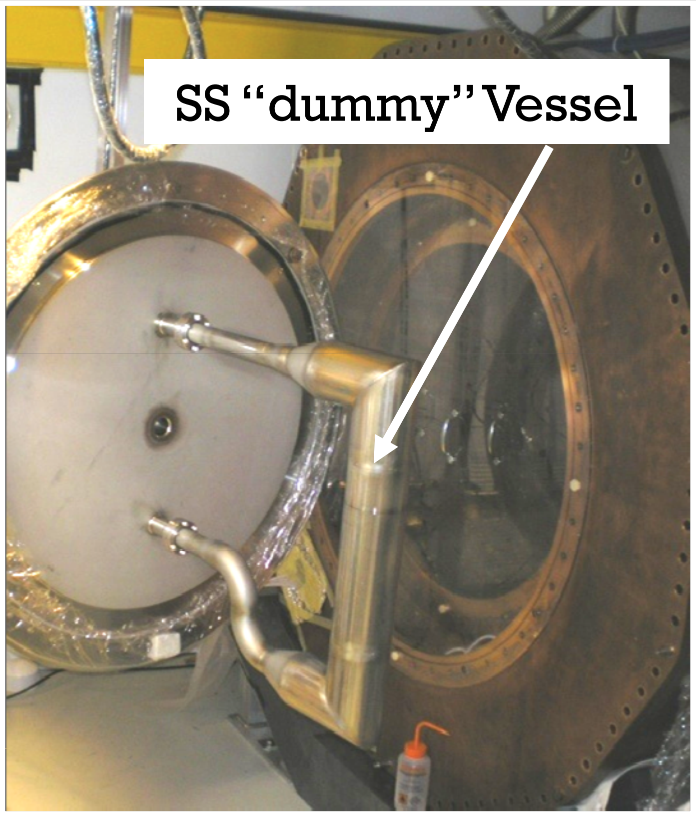


EXO-200 goal: 0.1 ppb O_2 equivalent

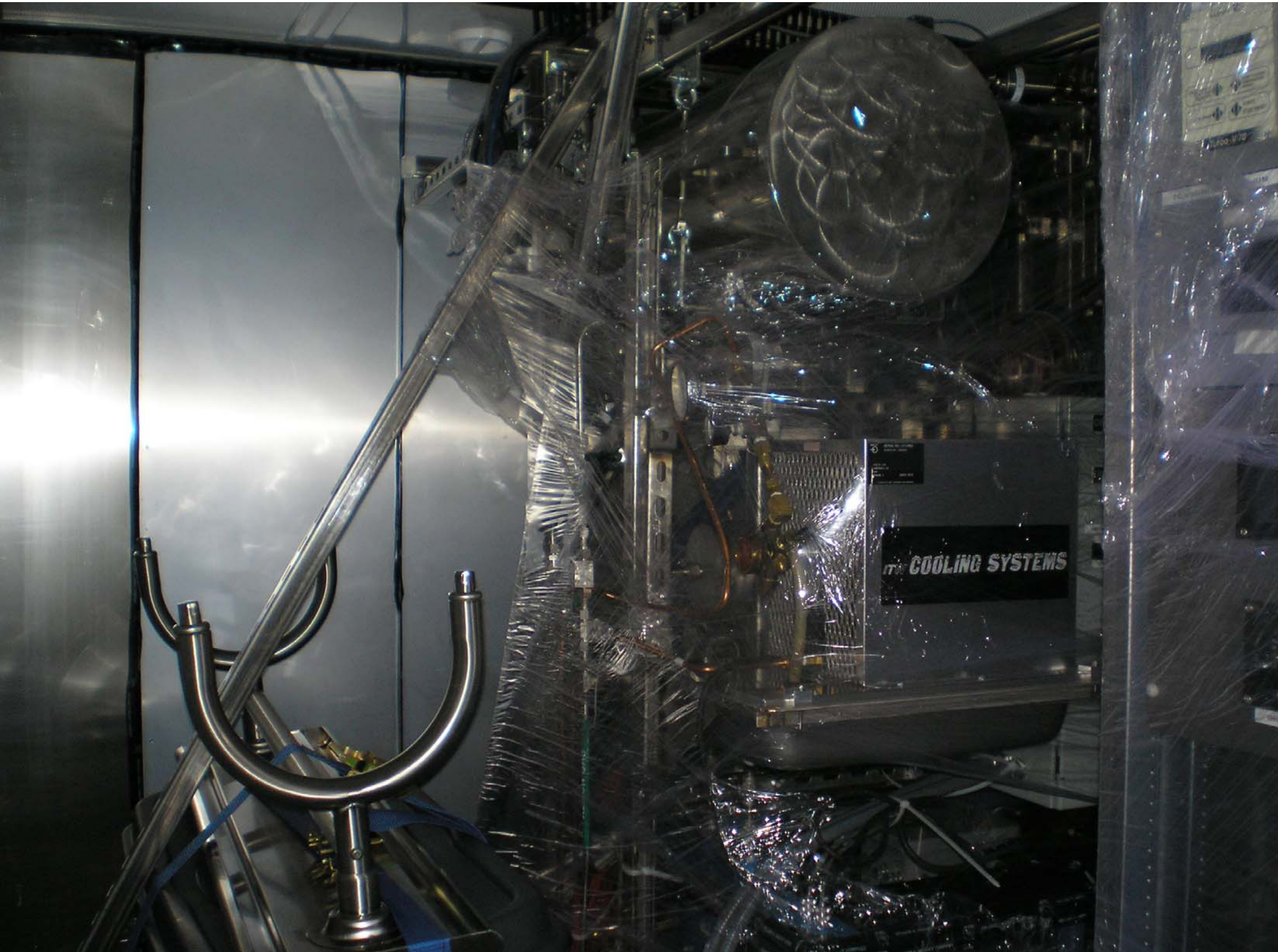
t ~ 4 ms (electrons)

The Cryostat





Xenon handling and cooling system commissioned in April '07, liquefying 30kg of Xe


COOLING SYSTEMS


STOP
NATIONAL
OVERSIZE LOAD
727-5612

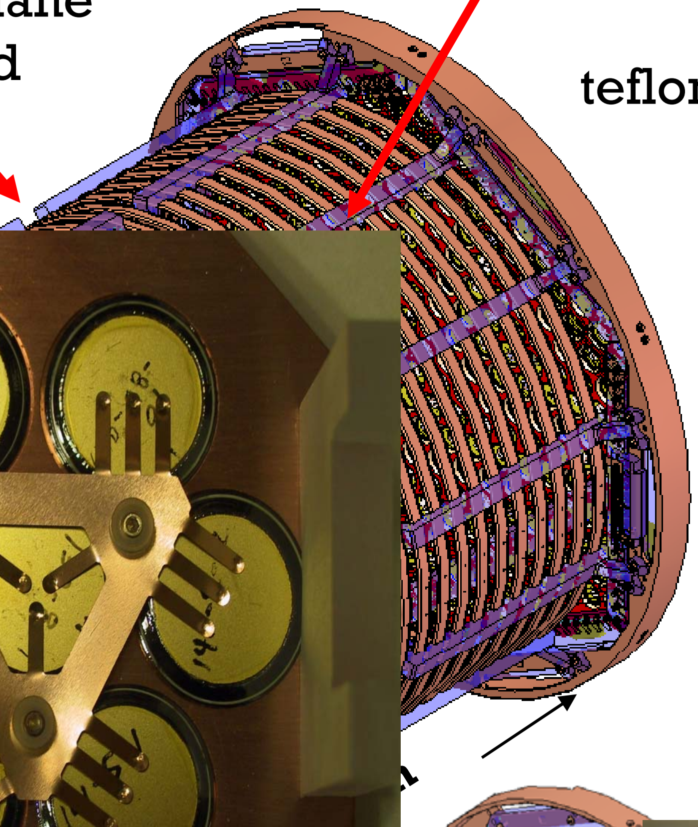

Harness and Line
Required Around
Open Shaft
CAUTION

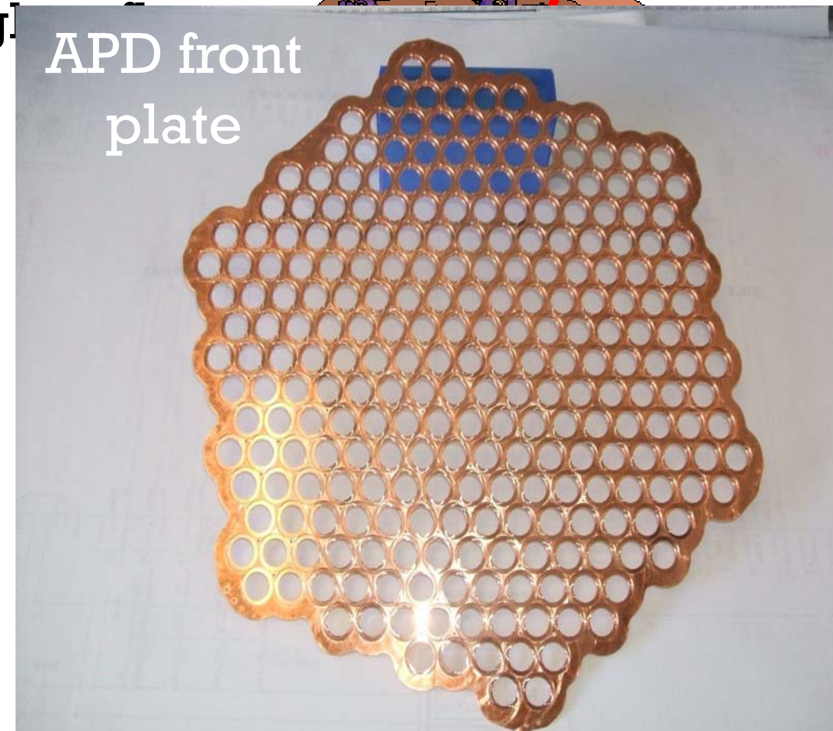
acrylic supports

LAAPD plane (copper) and x-y wires (photo-etched phosphor bronze)

Central HV plane (photo-etched phosphor bronze)

teflon ligh





APD front plate

ngs

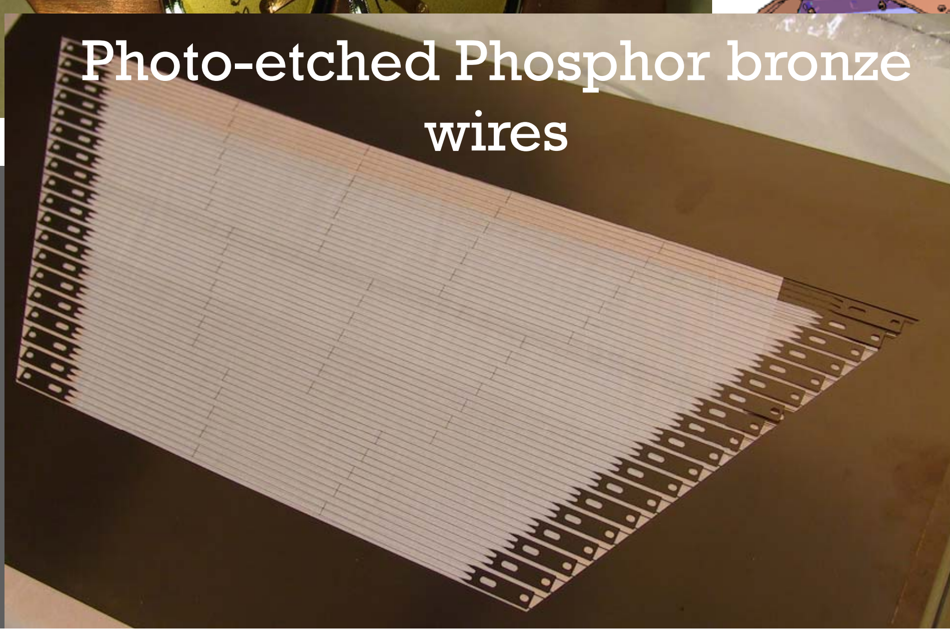
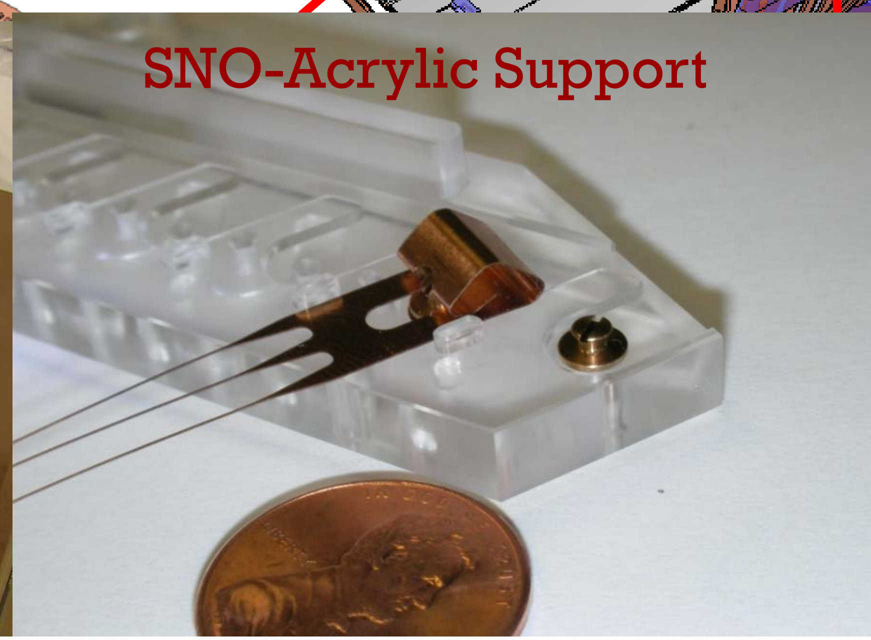


Photo-etched Phosphor bronze wires

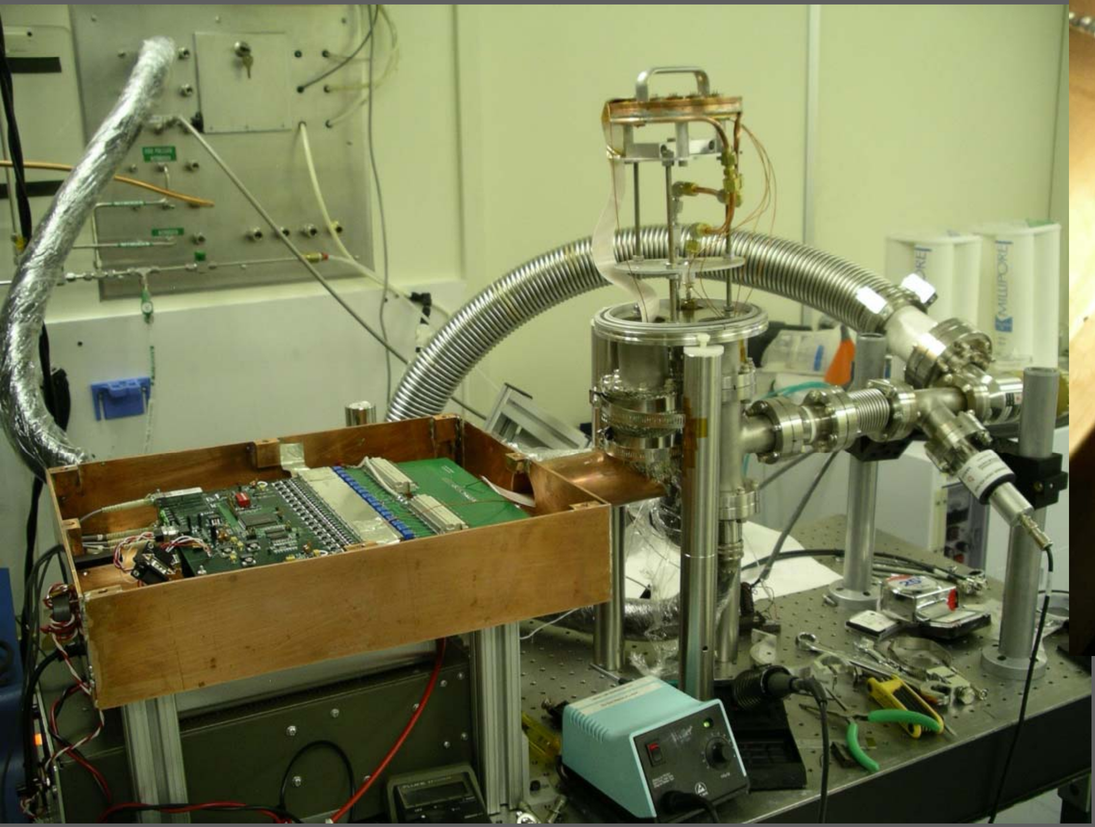


SNO-Acrylic Support

APD testing rig to measure
16 APDs at the time in vacuum
At -100C.

For each APD gain, leakage
current, QE will be measured

Readout using production
EXO-200 electronics (one card)



EXO-200 Progress Report

- We have 200kg of enriched xenon
- Clean rooms, cryostat, shielding, xenon at WIPP
- Cryogenics commissioned
- Electronics designed and fabricated
- Detector vessel mostly designed, to be fabricated soon
- Over 1/3 of needed LAAPDs delevered and evaluated; The rest due to arrive by Dec.
- DAQ software nearly fully implemented, event reconstruction software in development
- Muon veto in development

EXO-200: “Stop calling me prototype!”

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 2.4579MeV 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	NSM
EXO-200	0.2	70	2	1.6	40	$6.4 \cdot 10^{25}$	0.27†	0.38♦

‡ Rodin et al. arxiv:0706.4304v1

0.16? 0.19?

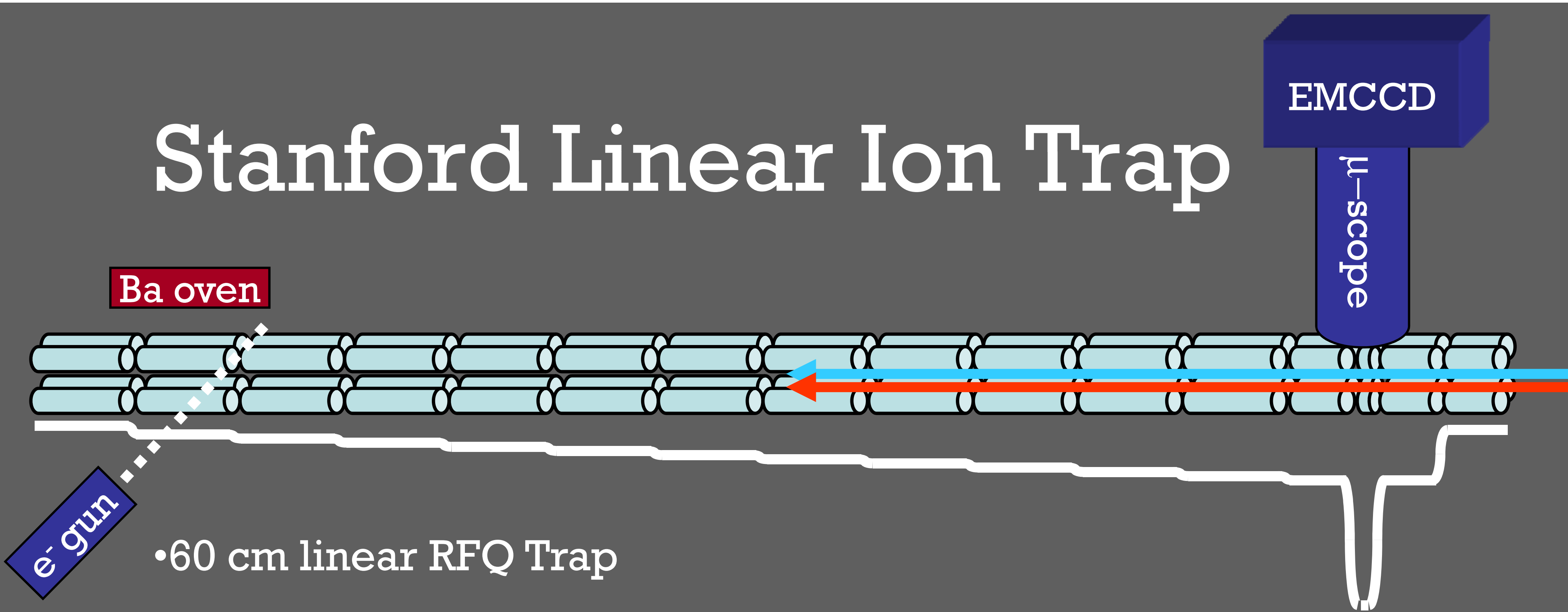
What if Klapdor’s observation is correct ?

Central value $T_{1/2}$ (Ge) = $1.2^{+3}_{-0.5} \cdot 10^{25}$, $\pm 3\sigma$ range (0.24eV – 0.58eV)
(Phys. Lett. B 586 (2004) 198-212)

In 200kg EXO, 2yr:

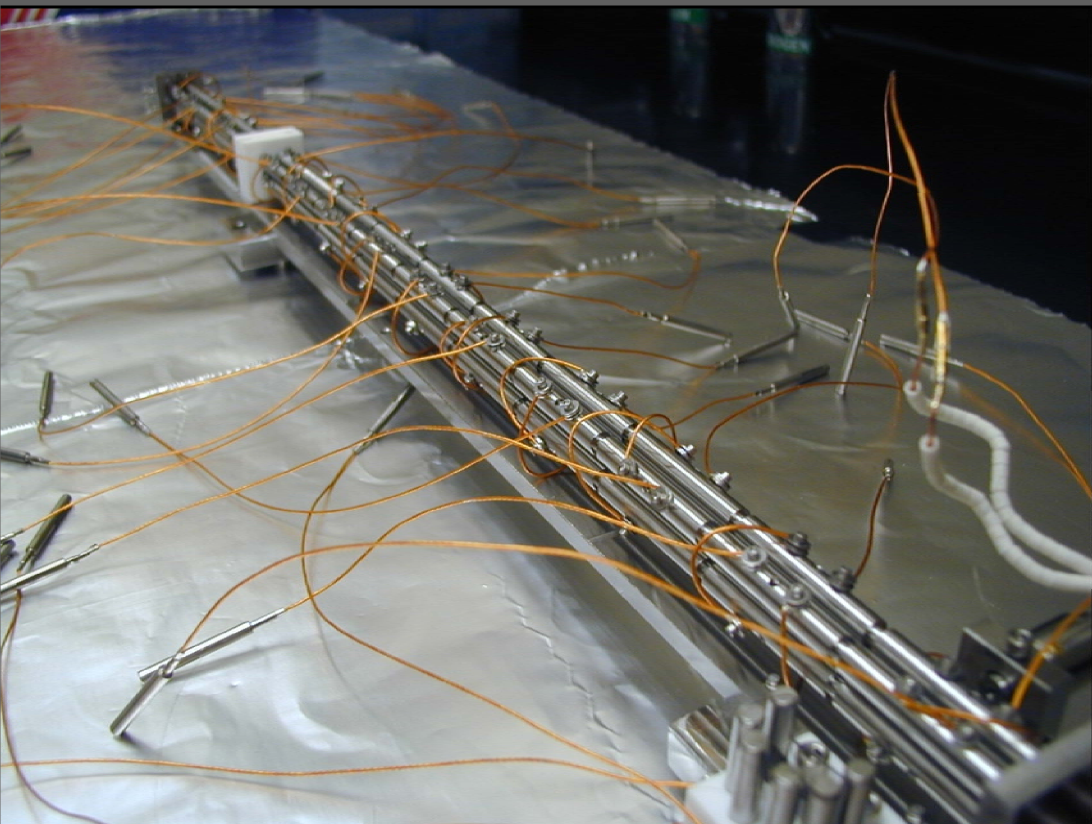
- **Worst case (QRPA, upper limit) 15 events on top of 40 events bkgd → 2σ**
- **Best case (NSM, lower limit) 162 events with 40 bkgd → 8.5σ**

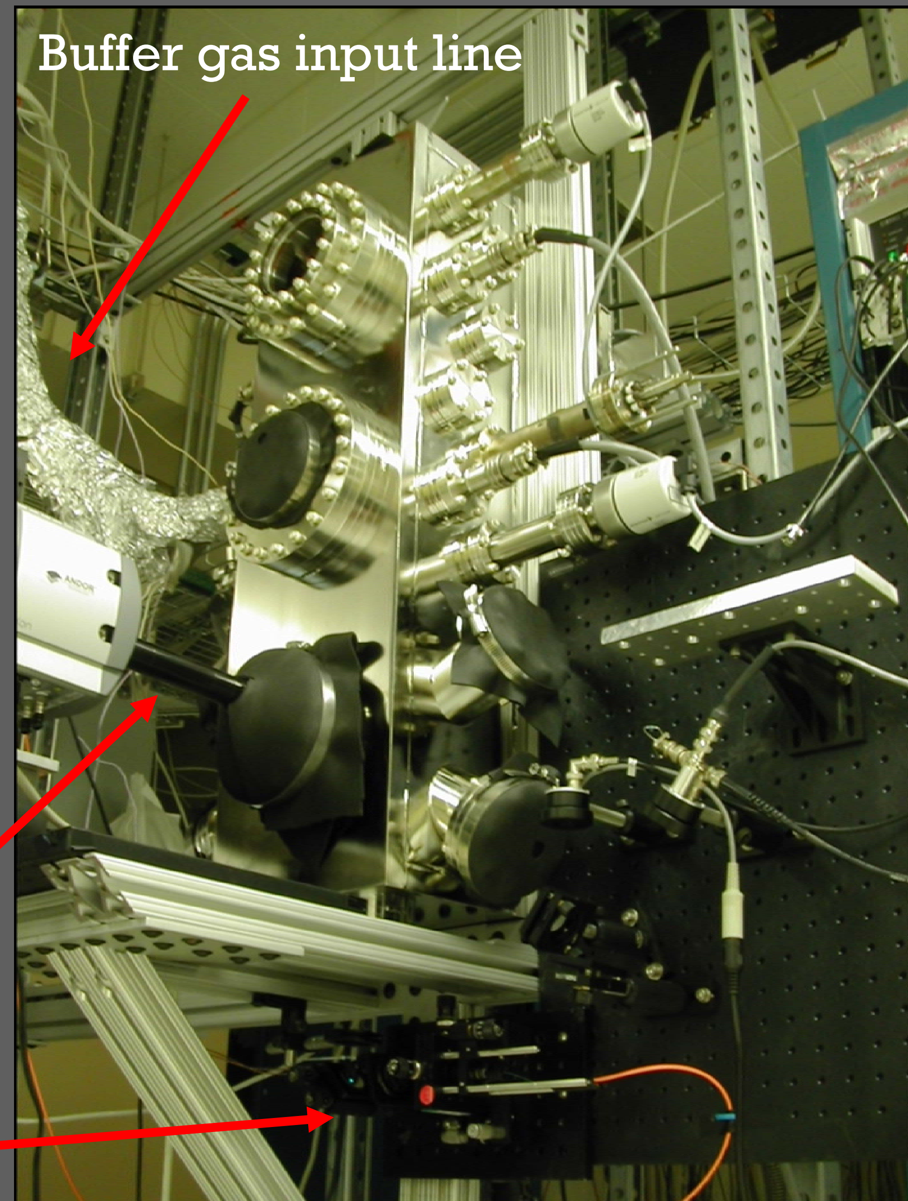
Stanford Linear Ion Trap



- 60 cm linear RFQ Trap
- 6mm dia. rods, divided into 16 segments
- Ions loaded by Ba oven and electron gun in segment 2
- Buffer gas cooling of energetic ions along length of trap
- Potential minimum in segment 14 – detection region
- Lasers introduced axially
- Fluorescence detected perpendicular to laser propagation

The 60cm Linear RFQ Trap



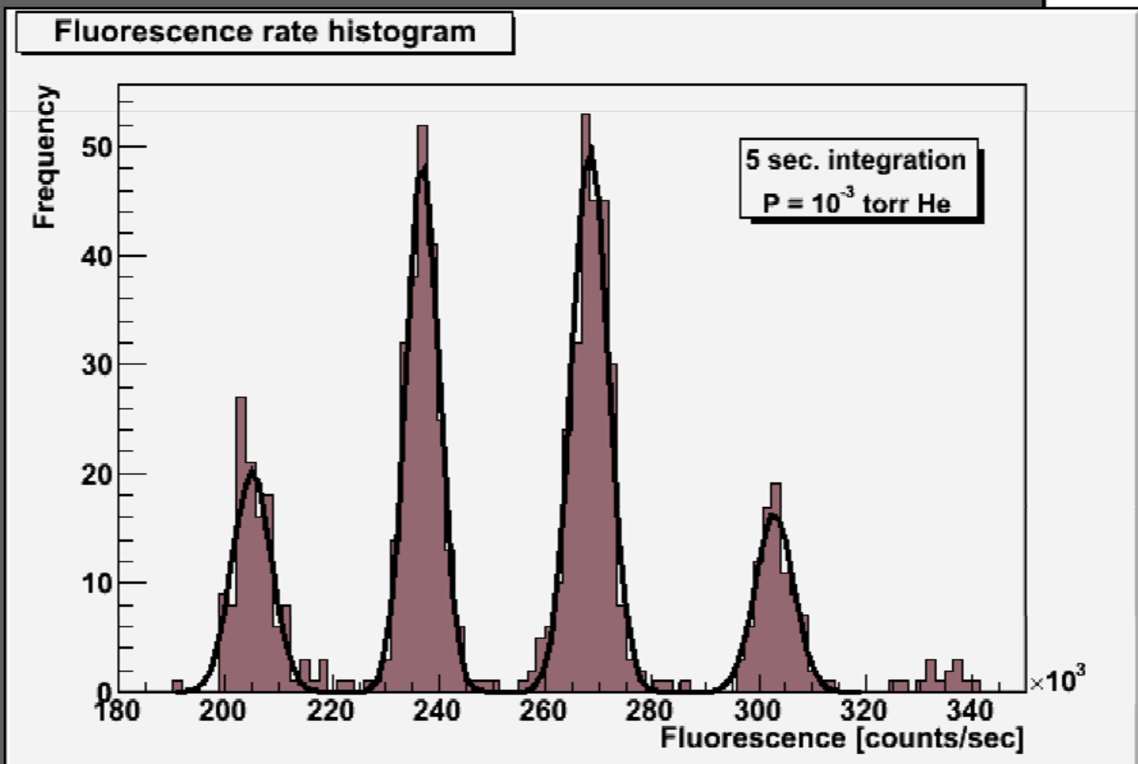


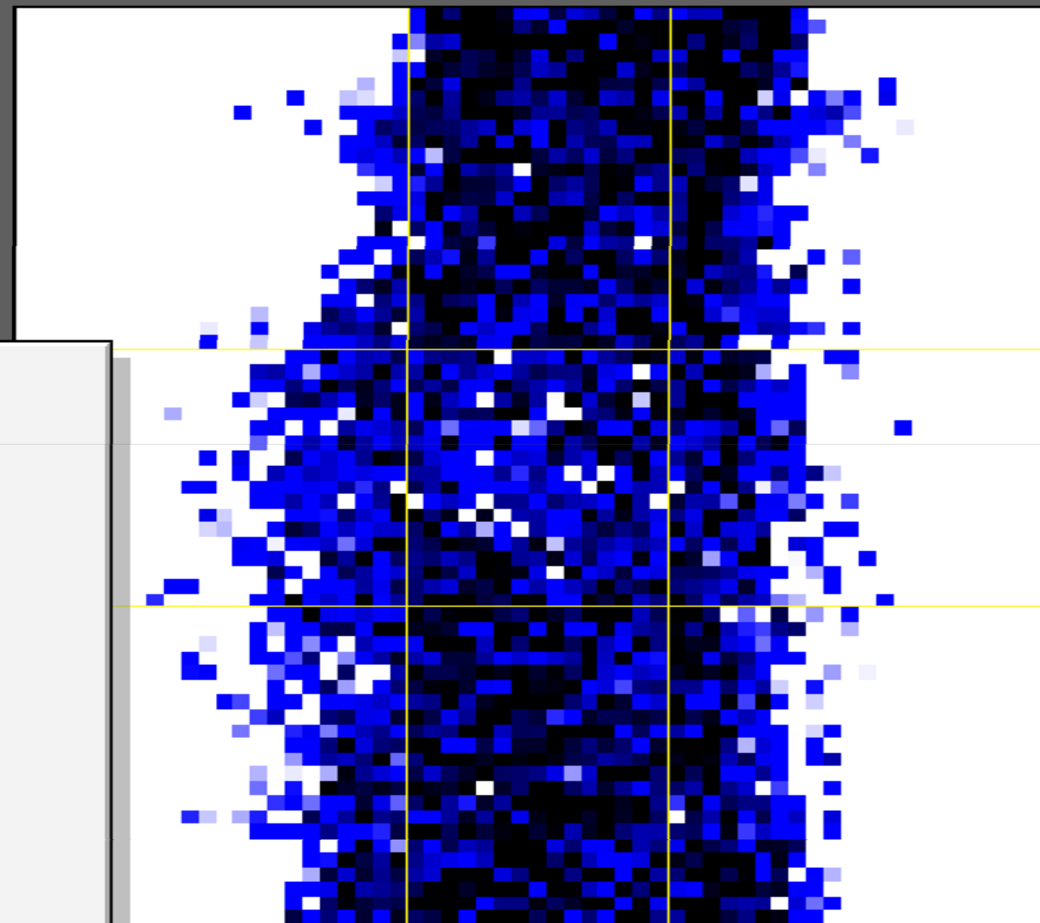
EMCCD camera with scope

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

Individual trapped Ba^+ in Helium

- P_{buffer} ~ 10^{-3} Torr Helium
- 5 sec integration per point
- Peak separation ~ 8.7σ





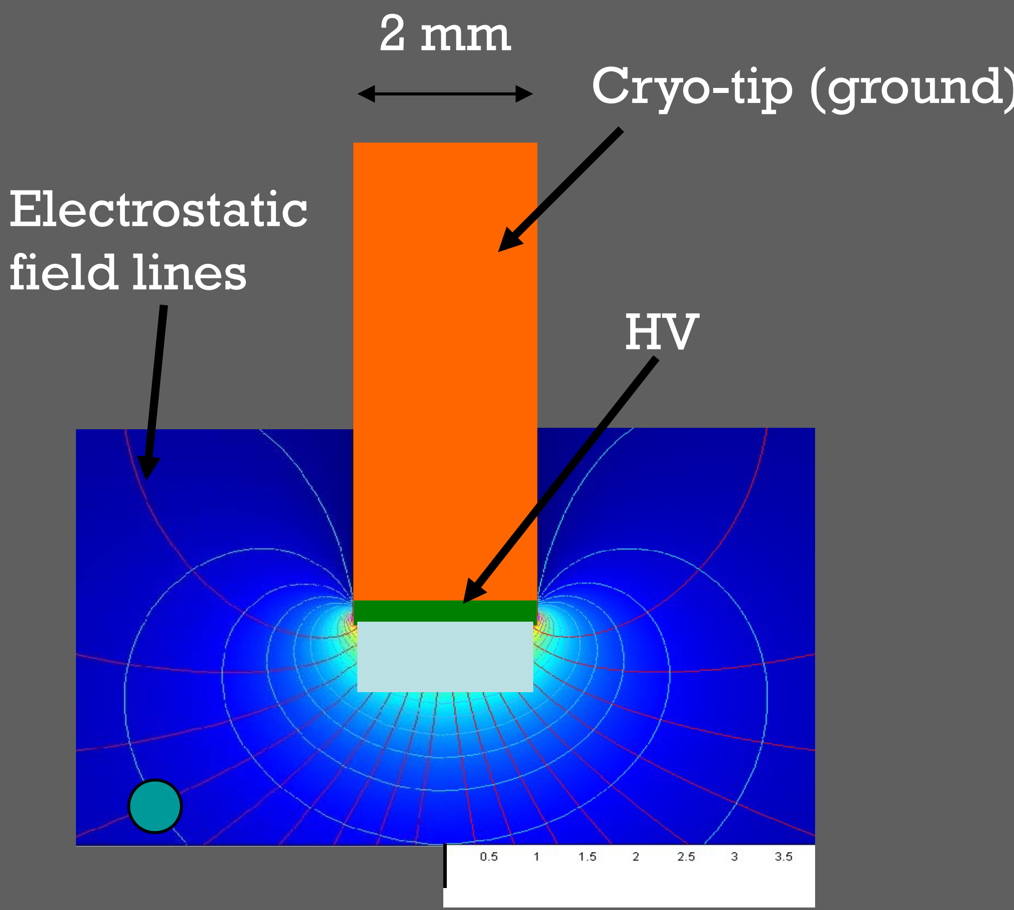
Details in-

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

B. Flatt et al., NIMA 578, (2007) 399

Grabbing Ions in LXe – A Cryogenic Tip

- A 2mm cold finger is inserted in the LXe volume.
- A thin layer of Xe ice is frozen on the tip.
- -HV is applied beneath the ice to attract the Ba^+ ion.
- Another thin layer is frozen over the ion.
- The probe is extracted from the liquid, HV is reversed, and the ice is sublimated to release the ion



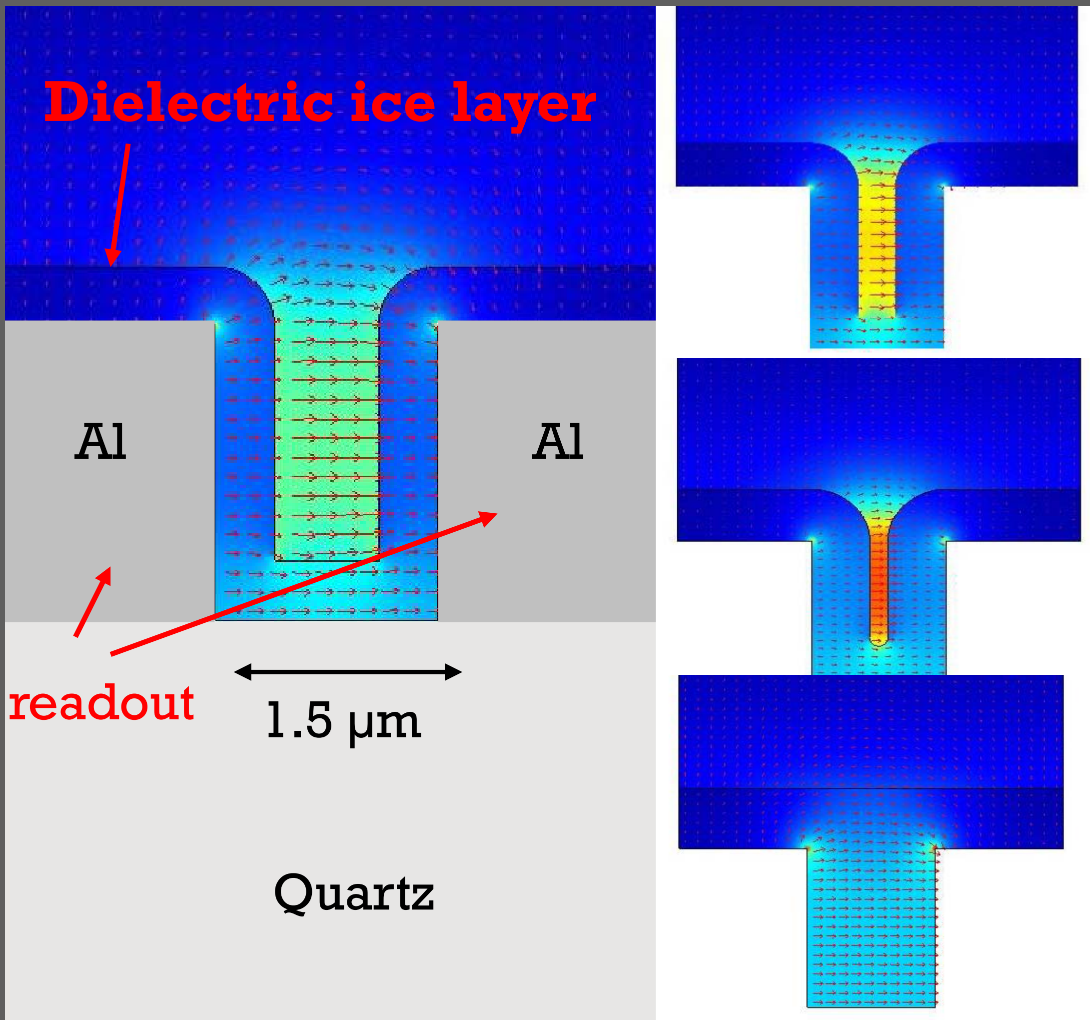
Ion mobility: $\mu \sim 0.3\ cm^2/kVs$

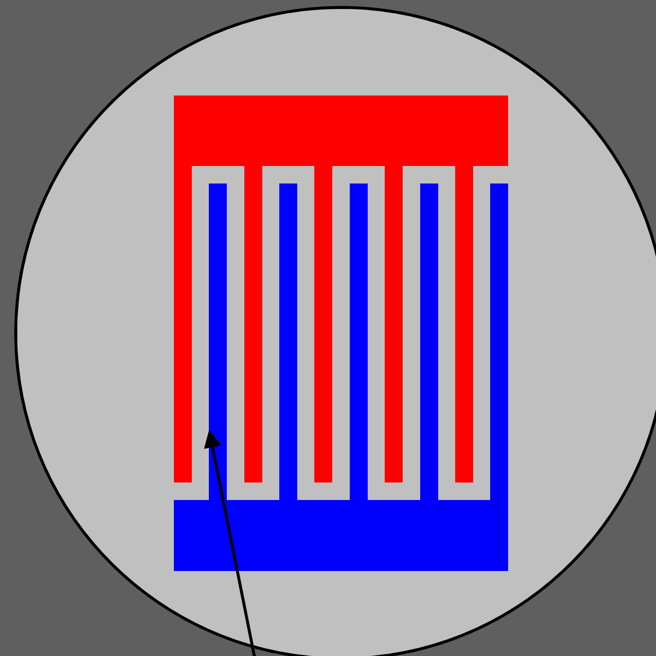
$v = \mu \times 1 kV/cm \sim 0.3\ cm/s$

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

Dielectric Ice Thickness Sensor

Micro-fabricated Al layer on quartz





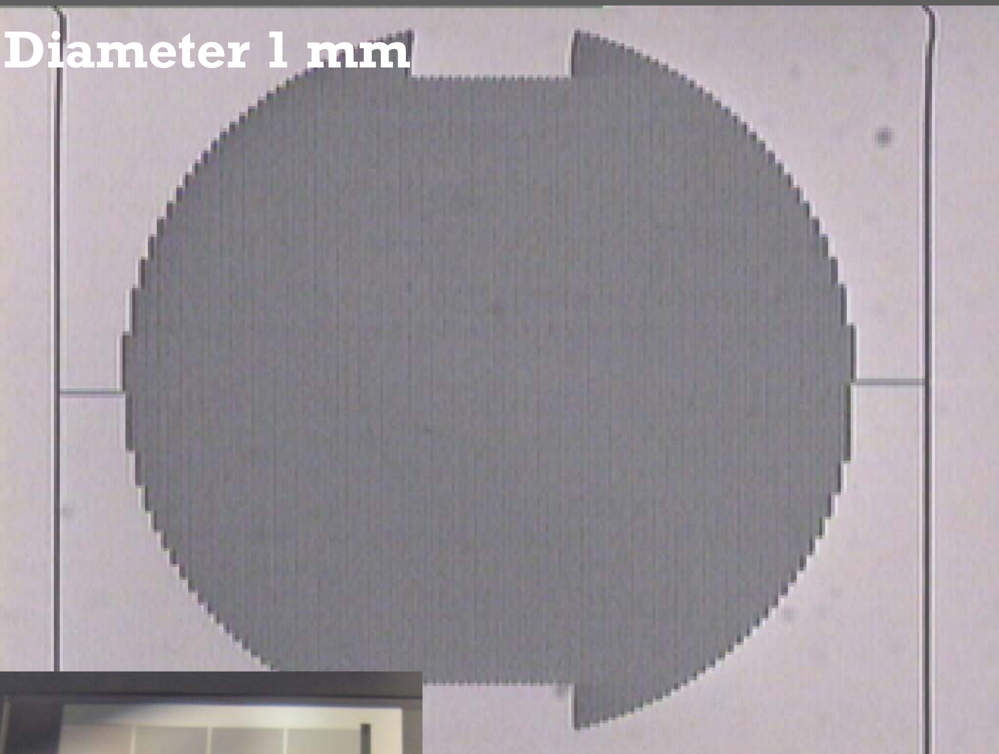
'fingers' for dielectric ice-thickness measurement:

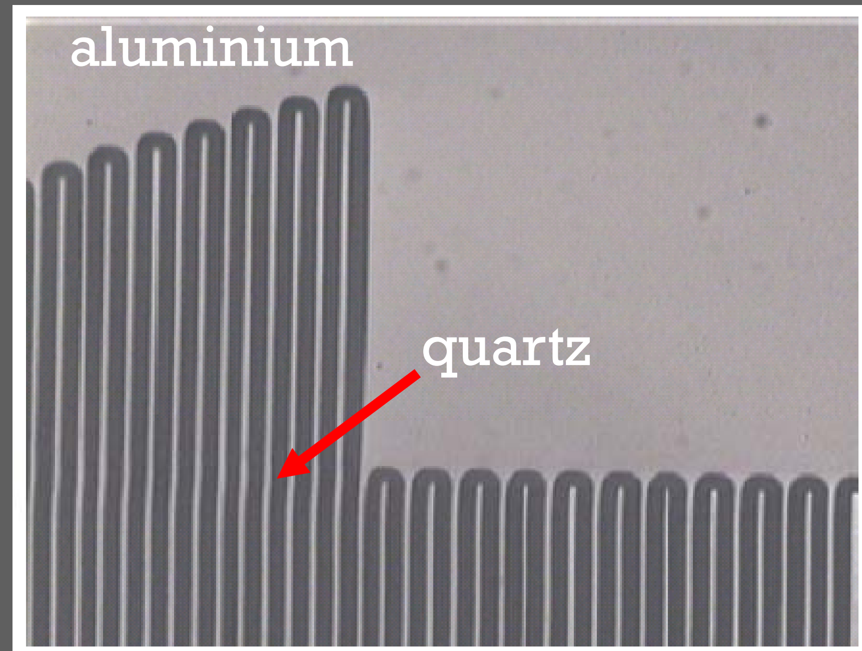
ε_r(Xe,liquid) = 1.88
ε_r(Xe,solid) = 2.25

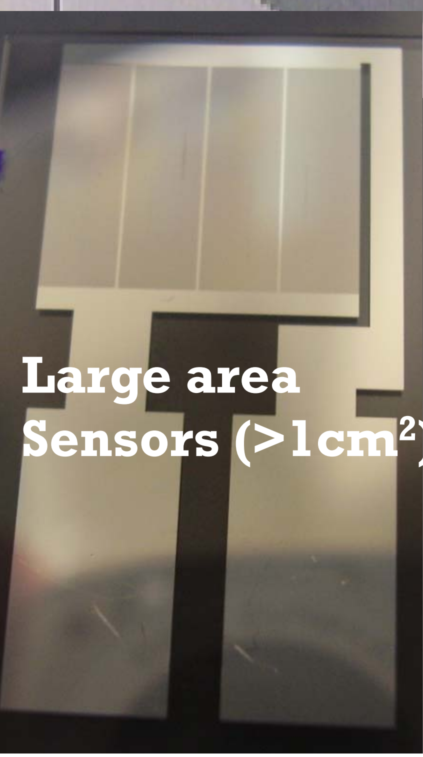
0-750 nm ice thickness

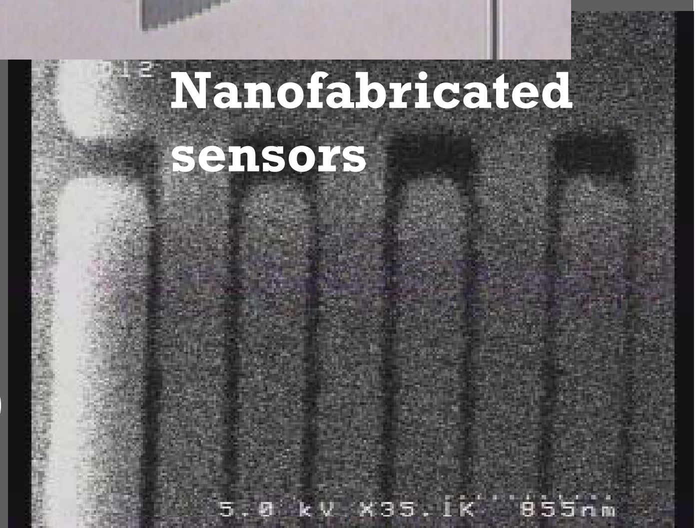
resolution ~ 1 fF/monolayer

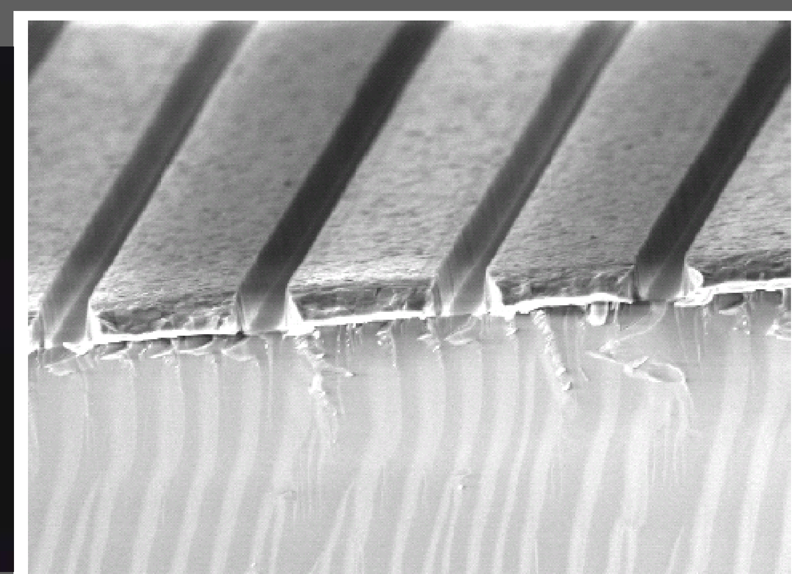
Dielectric Ice Thickness Sensor





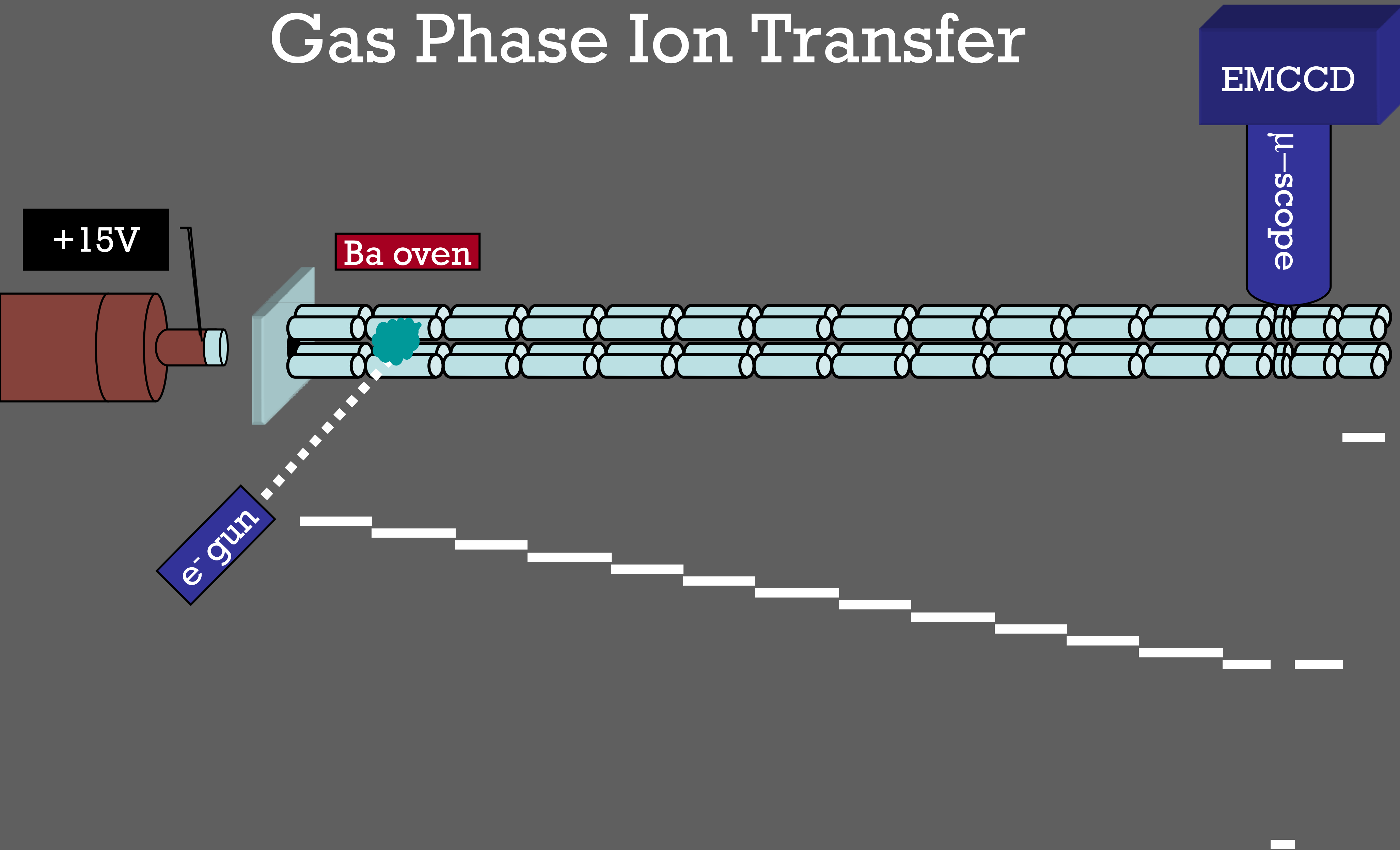






Details in P. Fierlinger et al., submitted to RSI, Aug '07.

Gas Phase Ion Transfer



EXO effective mass 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 0n events in a $\pm 2\sigma$ interval centered around the 2.4579 MeV endpoint
4) **Use for $2\nu\beta\beta$ $T_{1/2} > 1\cdot 10^{22}$ yr (Bernabei et al. measurement)**

Case	Mass (ton)	Eff. (%)	Run Time (yr)	σ_E/E @ 2.5MeV (%)	$2\nu\beta\beta$ 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**

28?	**33?**
6?	**7?**

*** $\sigma(E)/E$ = 1.4% obtained in EXO R&D, Conti et al Phys Rev B 68 (200**
† $\sigma(E)/E$ = 1.0% considered as an aggressive but realistic guess with
collection area

‡ Rodin et al. nucl-th\0706.4304
 # Caurier et al. nucl-th\0709.2137

Enriched Xenon Observatory

for double beta decay

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