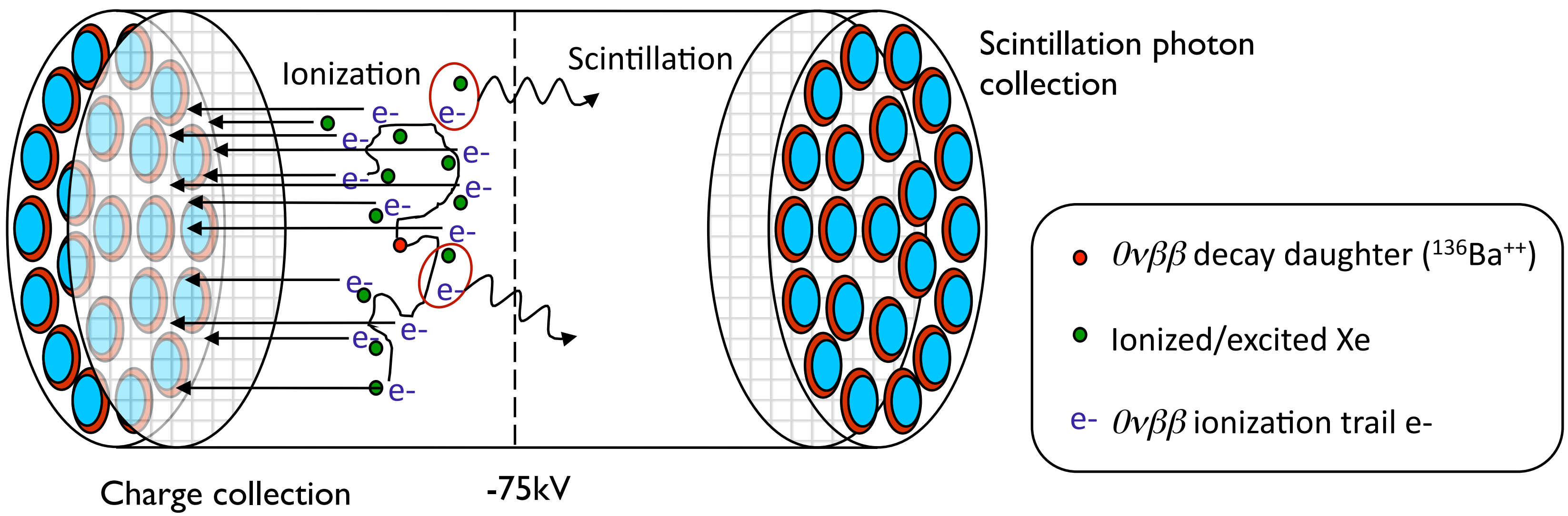
EXO status and prospects

Jesse Wodin for the EXO collaboration

SLAC

Measuring $0\nu\beta\beta$ with EXO-200



- 200kg ^{136}Xe (80% enrichment) liquid phase (170 K), both source and detector of $0\nu\beta\beta$
- $Q_{\beta\beta}^{Xe-136}$ = 2.458 MeV $\beta\beta$ endpoint energy
- TPC signals ~ 5x10^4 e$^-$/MeV, ~ 10^4 γ/MeV ➔ $\Delta E/E = 1.4\%$ at $Q_{\beta\beta}$[(1)]
- Event topology from charge distribution and t_{SCINT}-t_{ION} (useful for background rejection and possibly Ba tagging on full EXO)

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

EXO-200 details

- Measure both ionization electrons and scintillation photons for best energy resolution
  - Ion. & scint. anti-correlated -> improved energy resolution (~ 1.4% at $Q_{\beta\beta}$)
  - Event topology important for background rejection

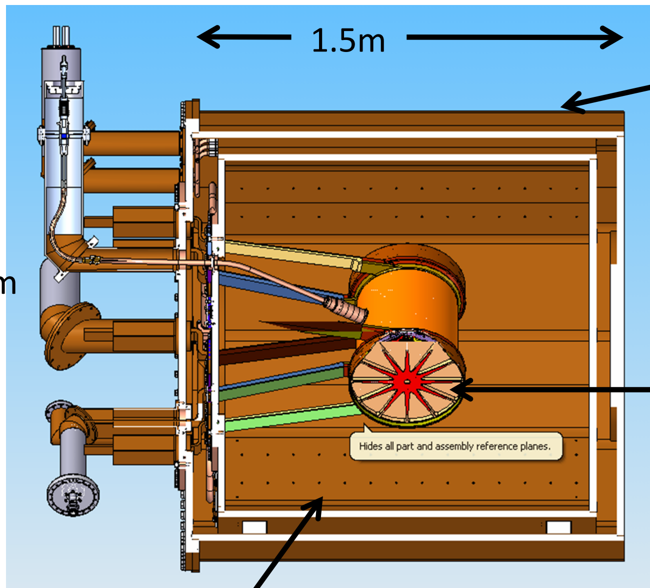
- Detector geometry cylindrical ~ 40cm ID x 40 cm length
  - TPC ~ 1.4 mm thick walls, minimized for background reduction
  - Cylinder split by -70 kV cathode plane at center, creating two symmetrical drift regions (3.5 kV/cm drift field)

- Ionization read out by photoetched wires
  - No crimps at feed-throughs (common failure point) – in fact, no feedthroughs!
  - 100 μm width, 3 mm pitch, ganged in groups of 3 (48 ch x, 48 ch y, total 96 ch per 1/2 detector)

- Scintillation photons read out by Large Area APDs
  - 516 ϕ16 mm (active area) APDs
  - TPC lined with teflon (175 nm scintillation photon reflector)
  - 15% - 20% light detection efficiency (spread mostly due to event position along long axis of TPC)

- Low background construction, shielding
  - All components screened for low-activity via ICPMS, NAA, gamma counting, GD-MS
  - 50 cm cold LIQUID SHIELDING around TPC provides FULL coverage around TPC
  - 10 cm Pb shielding, screened for low ^{210}Pb content

EXO-200 TPC and cryostat

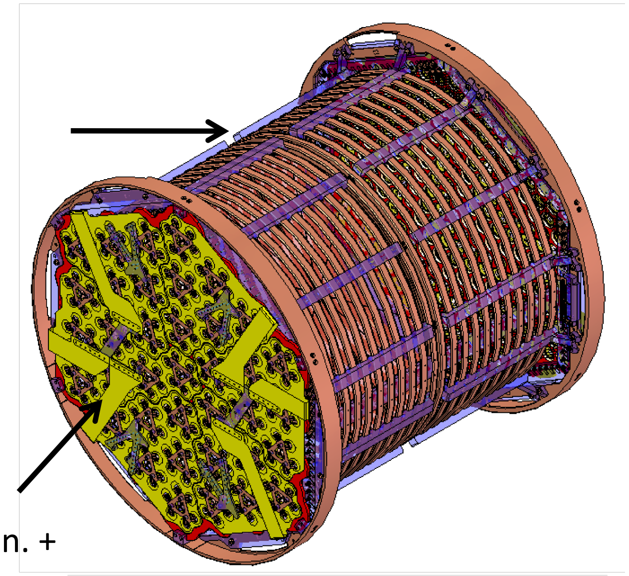


1.5m

Outer cryostat

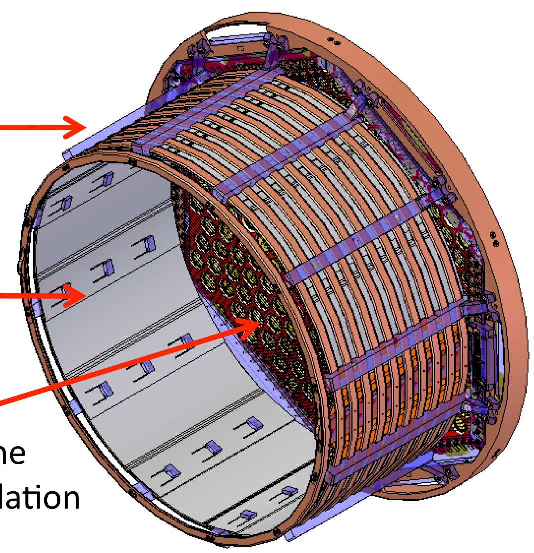
TPC

Inner cryostat filled with 50 cm HFE7000 cooling/shielding fluid (~ 1.8 g/cm^3 at 170 K)



Central HV plane (photoetched phosphor bronze)

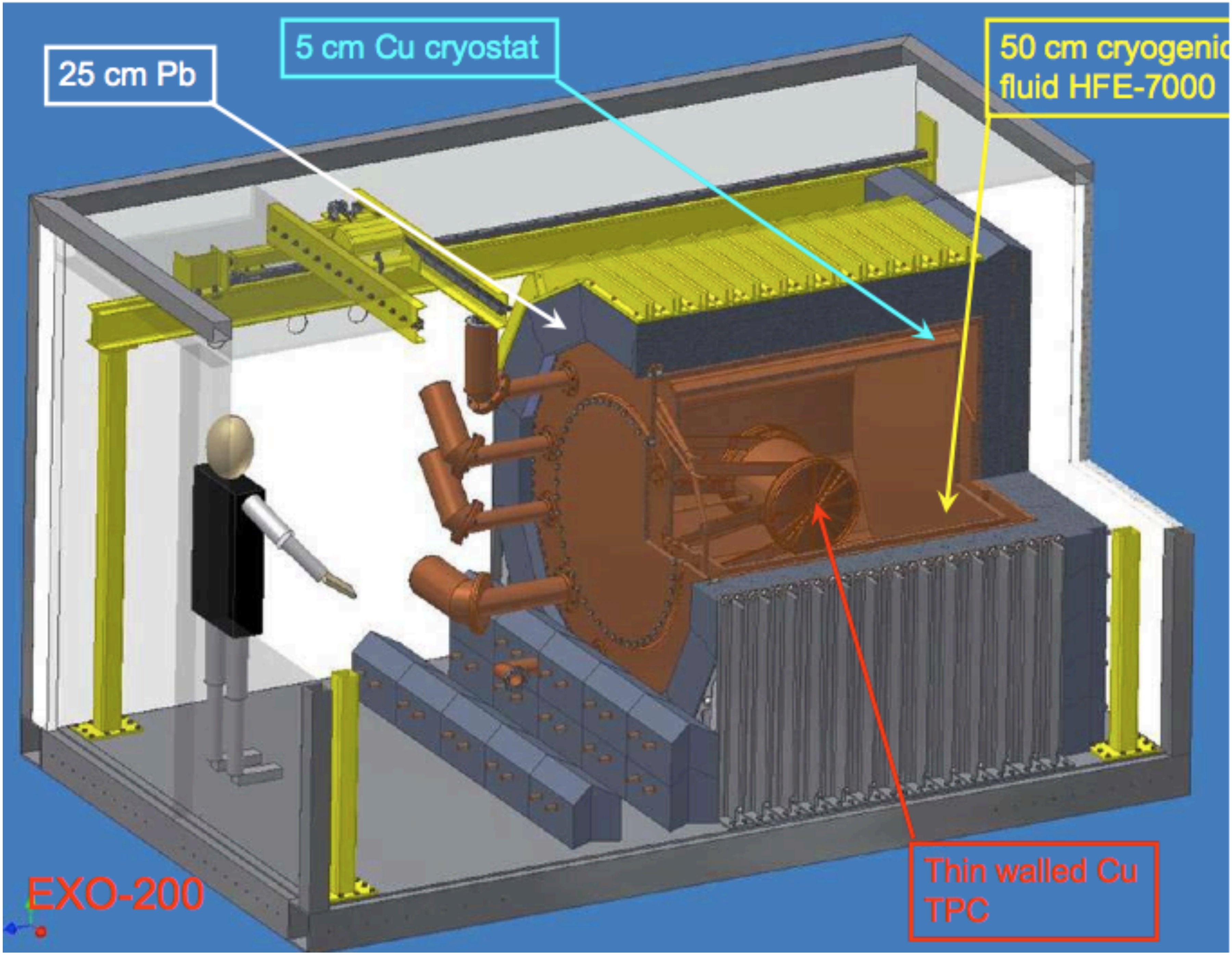
Custom kapton signal cables (ion. + scint. readout)



Acrylic supports and field shaping rings

Teflon light reflector

APD plane (avalanche photodiodes, scintillation detection)

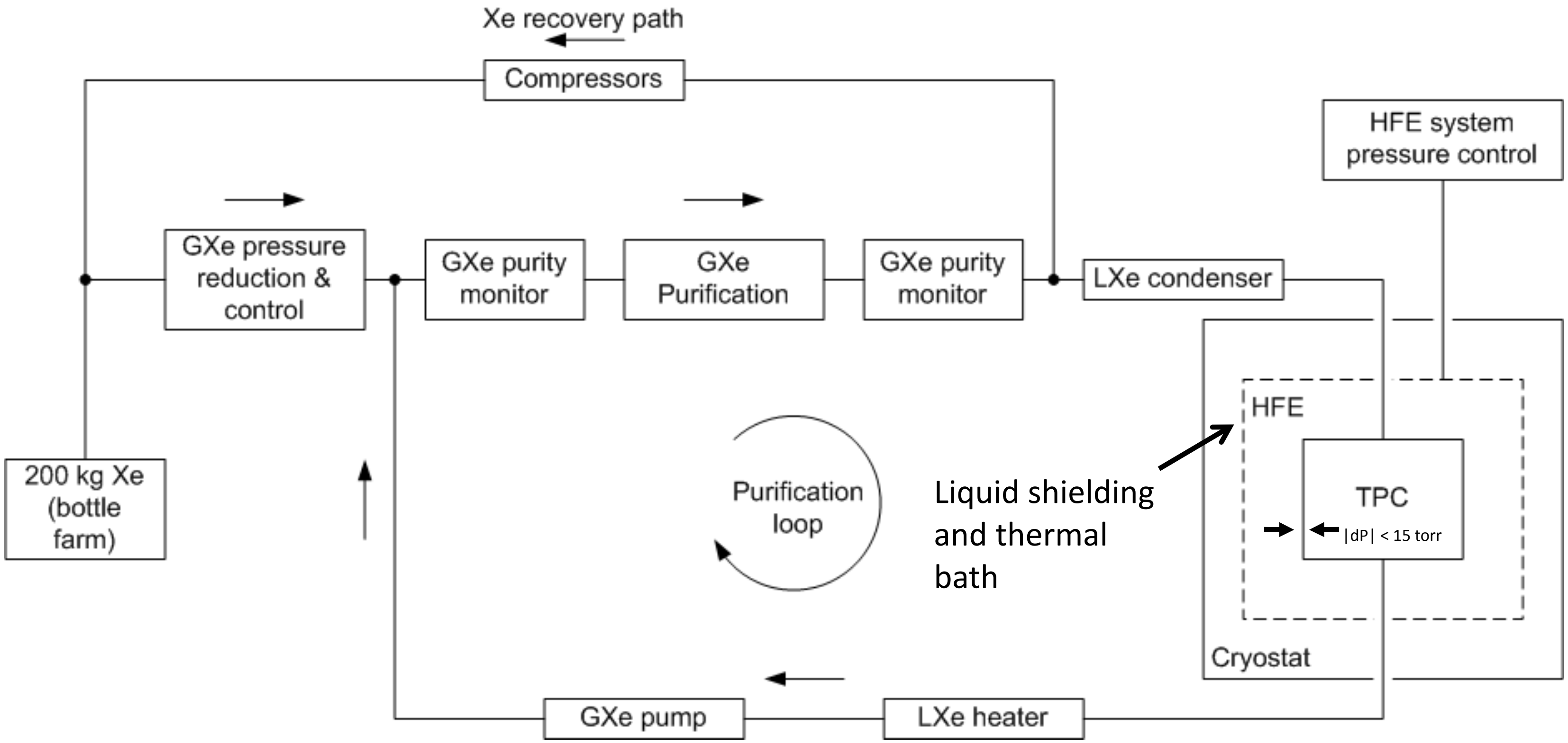

25 cm Pb
5 cm Cu cryostat
50 cm cryogenic
fluid HFE-7000
Thin walled Cu
TPC
EXO-200

EXO-200 material screening

- Stringent requirements on K/Th/U concentrations on materials inside cryostat
- Large-scale materials testing, published in *Nucl. Instr. and Meth. A 591 (2008) 490–509*
- In particular:

Component	K 10^{-9} g/g	Th 10^{-12} g/g	U 10^{-12} g/g	^{210}Po Bq/kg
3M Novec HFE-7000, 1-methoxyheptafluoropropane	<1.08	<7.3	<6.2	
Lead shielding	<7	<1	<1	17-20
Copper	<55	<2.4	<2.9	
Acrylic	<2.3	<14	<24	
TPC grid wires	<90	47 +/- 2	320 +/- 2	

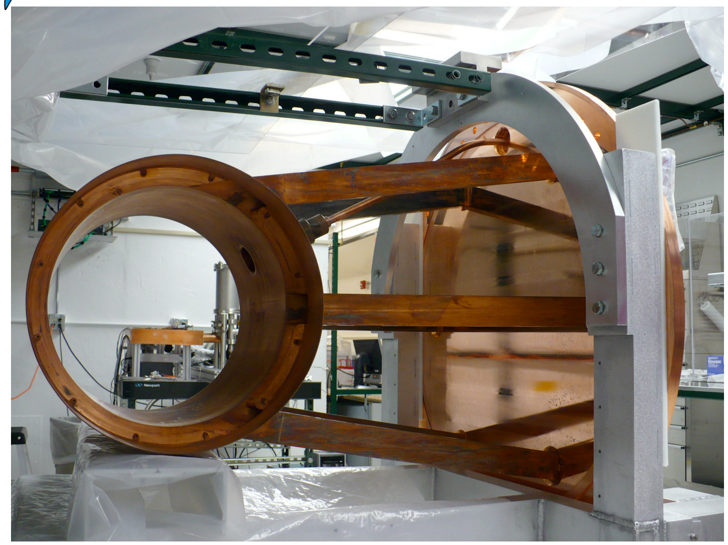
EXO-200 Xe handling system: designed around 1.4mm thin-walled TPC, constant purification

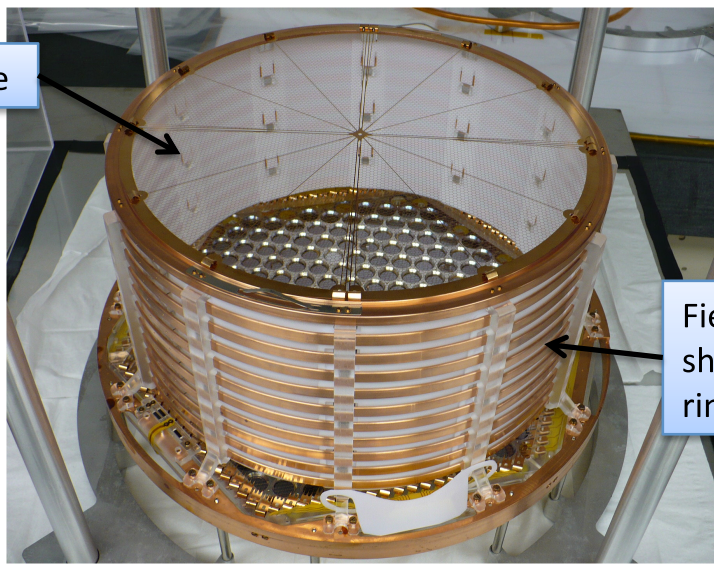


Design goals:

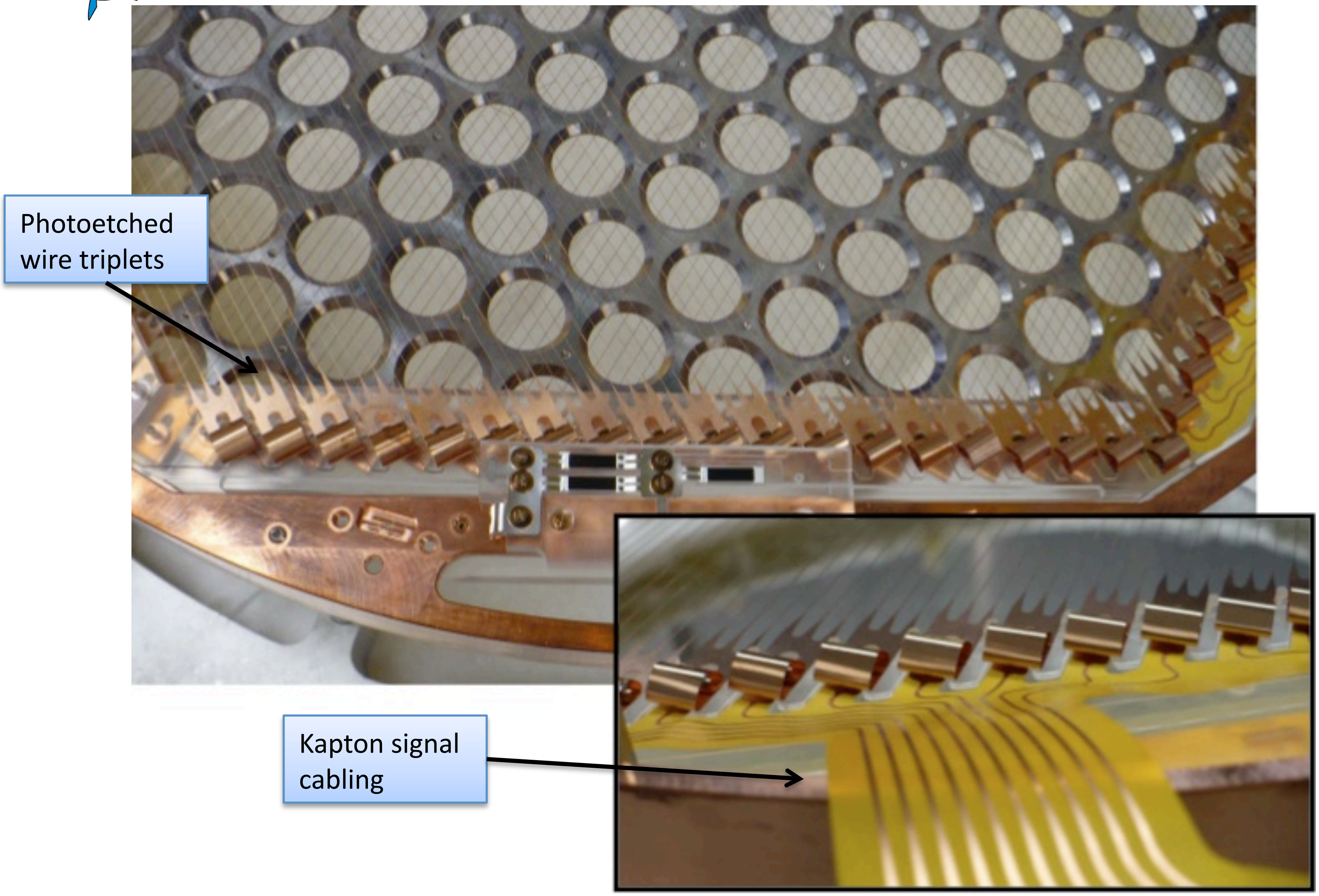
1. 20 SLPM circulation rate for continuous purification (uses heater, pump, condenser) while TPC full
2. Continuous purification with commercial (SAES) getters
3. Continuous purity monitoring of circulating gas (GPMs – see A. Odian's talk on Wed.)
4. Differential pressure across TPC walls $|dP| = |P_{Xe}-P_{HFE}| < 15$ torr at all times, due to thin-walled (~ 1.5mm) TPC construction (driven by radiopurity requirements)
5. Xe recovery to bottle farm with compressors
6. Triply redundant cryocooling system (3x Polycold refrigerators)

EXO-200 detector construction

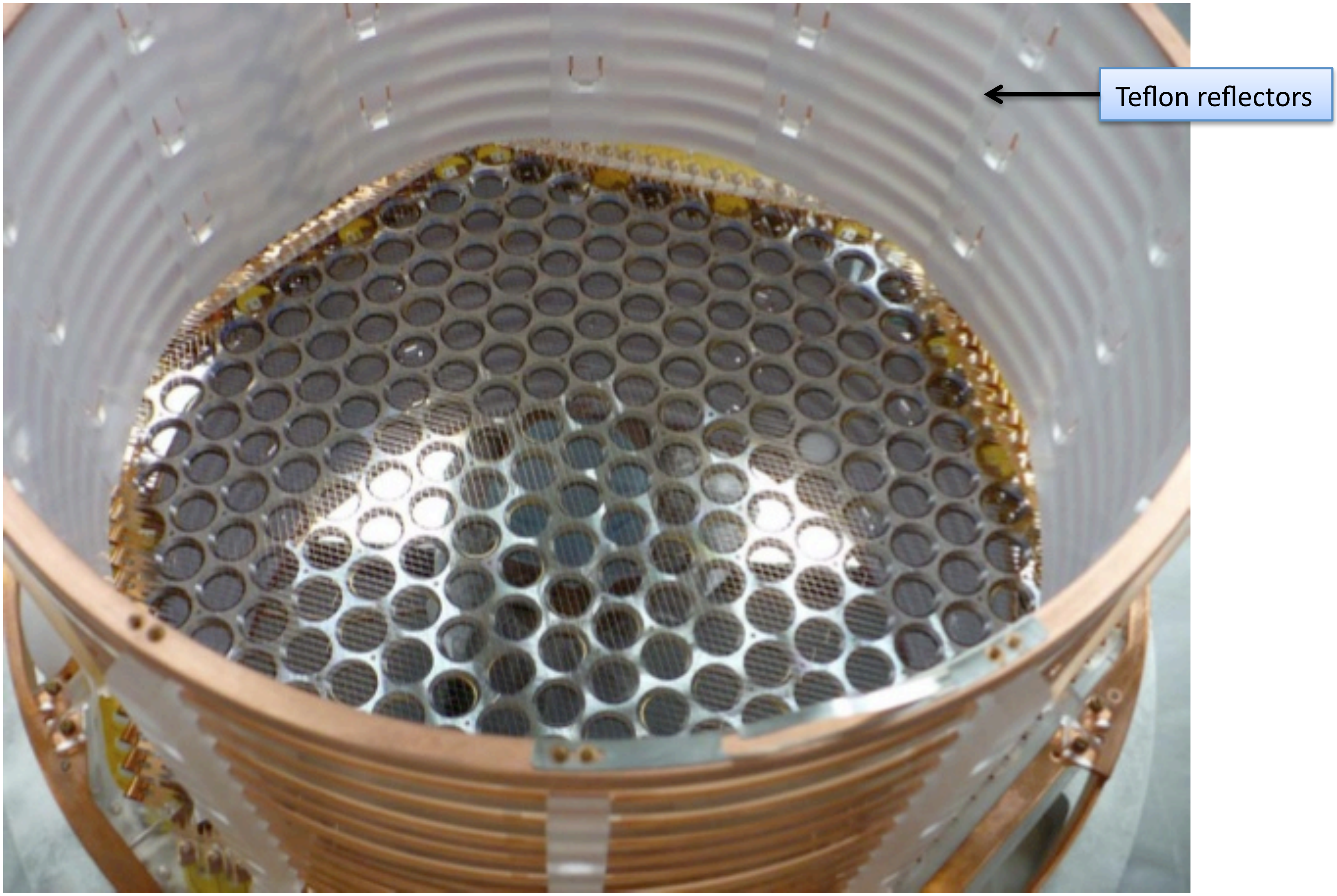




EXO-200 crossed ionization collection wires

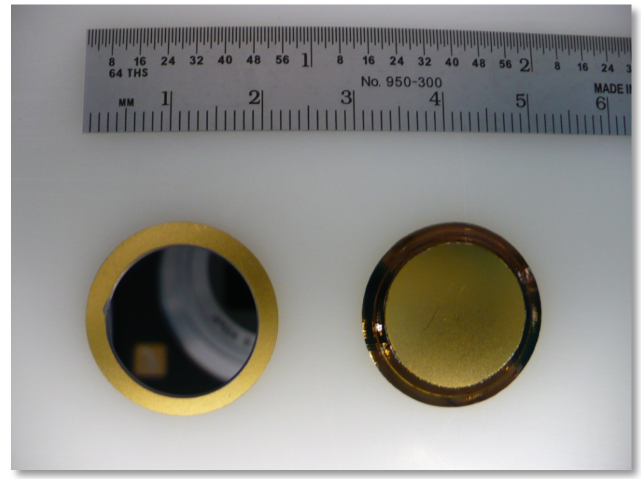


Looking into EXO-200 detector without APDs



EXO-200 LAAPD specs

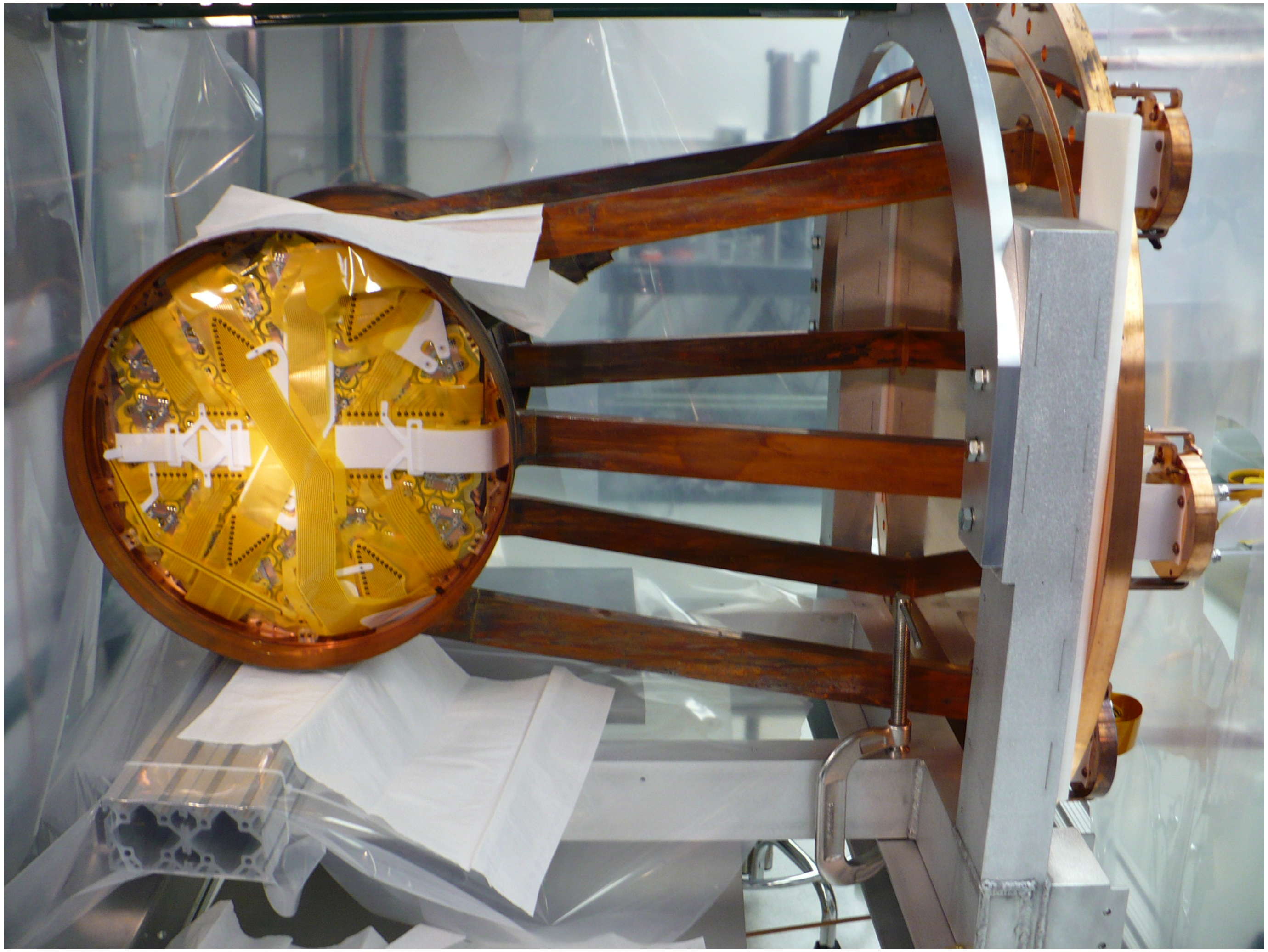
- Mass ~ 0.5 g/LAAPD
- Low radioactivity construction (used bare, no window, no ceramic, EXO-supplied chemicals & metals)[a]
- QE > 1 at 175 nm (NIST)
- Gain set at 100-150
- V ~ 1500V
- ΔV < ±0.5V
- ΔT < ±1K   APD is the driver for temperature stability
- Leakage current cold < 1μA
- Capacitance ~ 200 pF at 1400 V
- ϕ16 mm active area per LAAPD



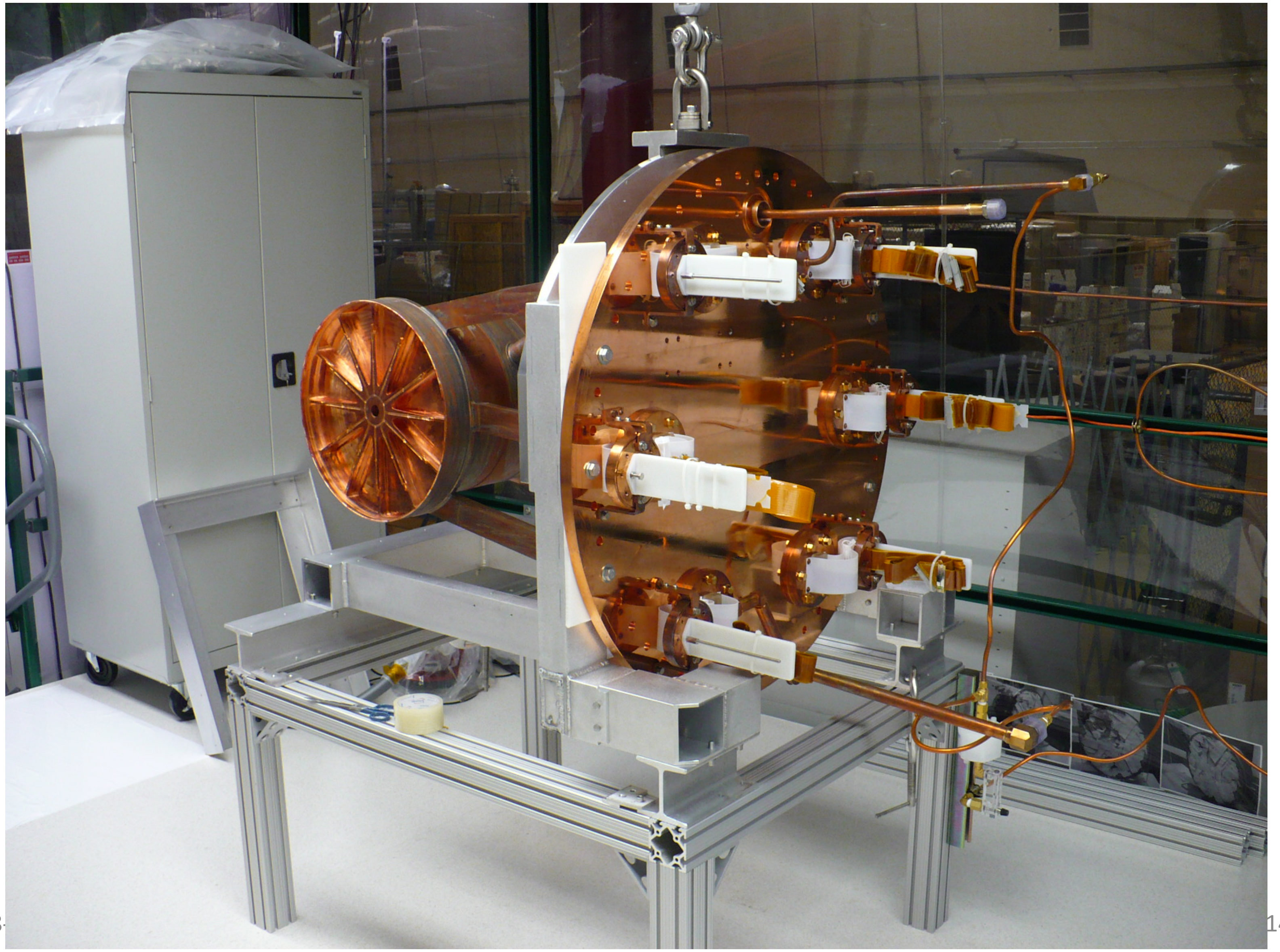
[a] D. S. Leonard, et al., Nucl. Instr. and Meth. A 591 (2008) 490-509

EXO-200 APD installation

EXO-200 TPC after cable and APD installation, before final endcap welding

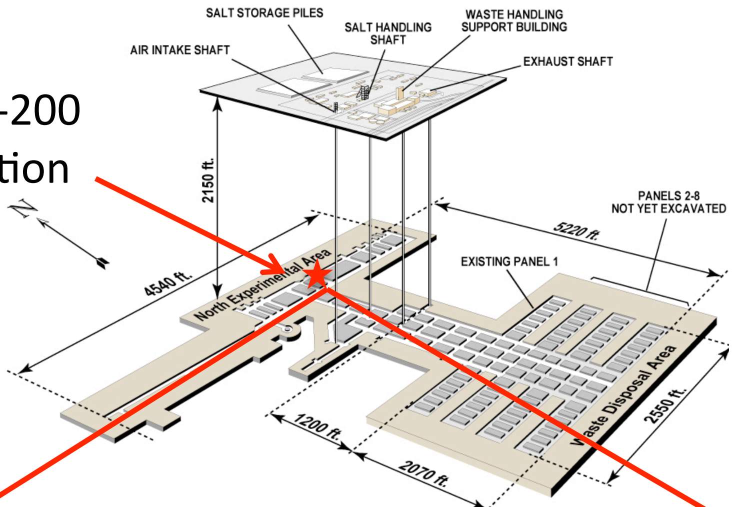


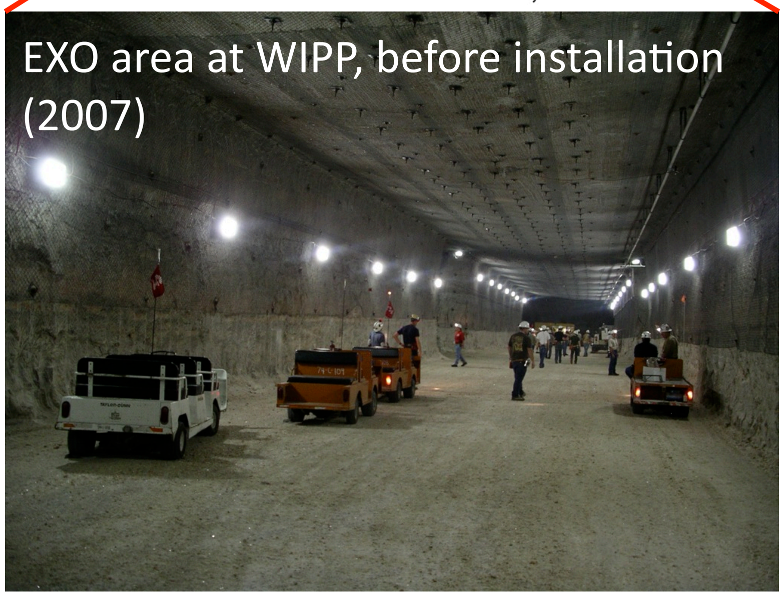
EXO-200 TPC ready for packaging at Stanford



EXO-200 installation site: WIPP

EXO-200 location




EXO area at WIPP, before installation (2007)

- EXO-200 installed at WIPP (Waste Isolation Pilot Plant), in Carlsbad, NM
- 1600 mwe flat overburden (2150 feet, 650 m)
- Salt mine for low-level radioactive waste storage
- Salt "rock" low activity relative to hard-rock mine

$$\Phi_\mu \sim 1.5 \times 10^5 yr^{-1} m^{-2} sr^{-1}$$

$$U \sim 0.048\, ppm$$

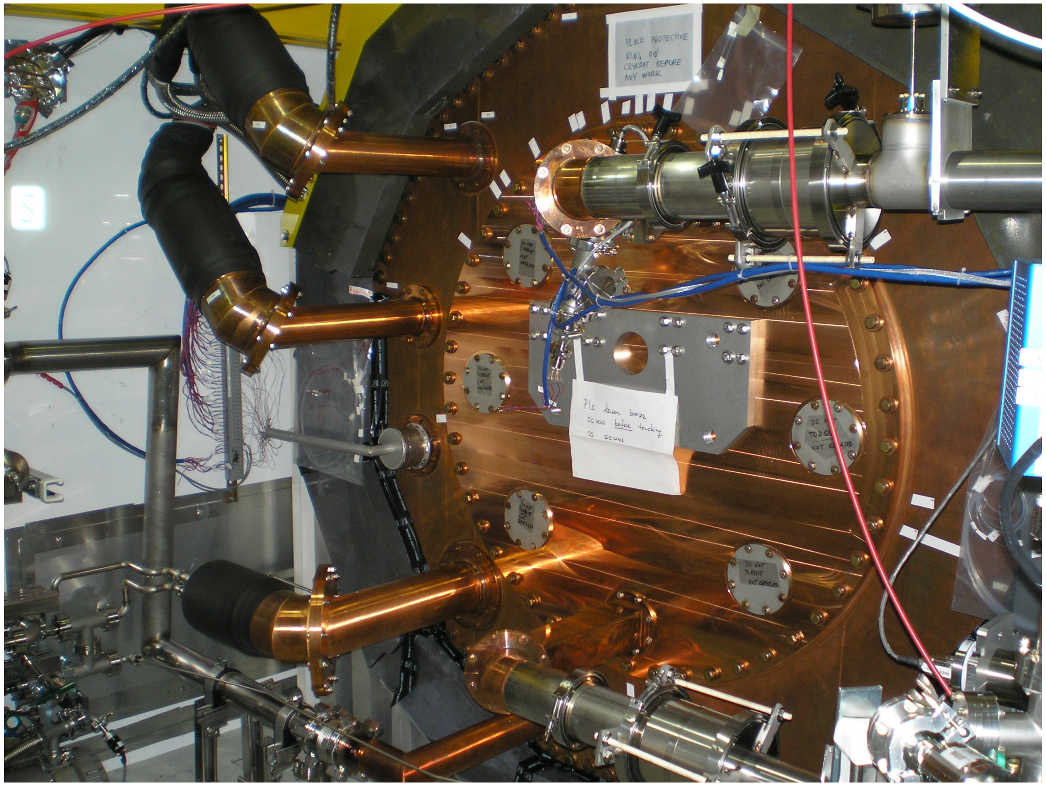
$$Th \sim 0.25\, ppm$$

$$K \sim 480\, ppm$$

Esch et al., arxiv:astro-ph/0408486 (2004)

Enriched Xenon Observatory
EXO
for double beta decay

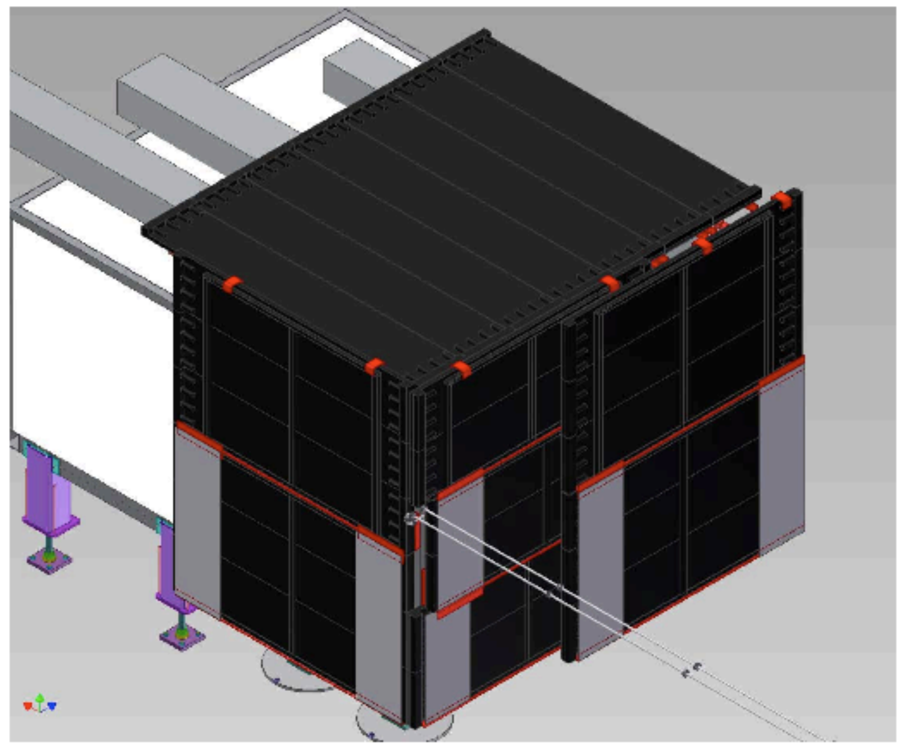
EXO-200 facility at WIPP



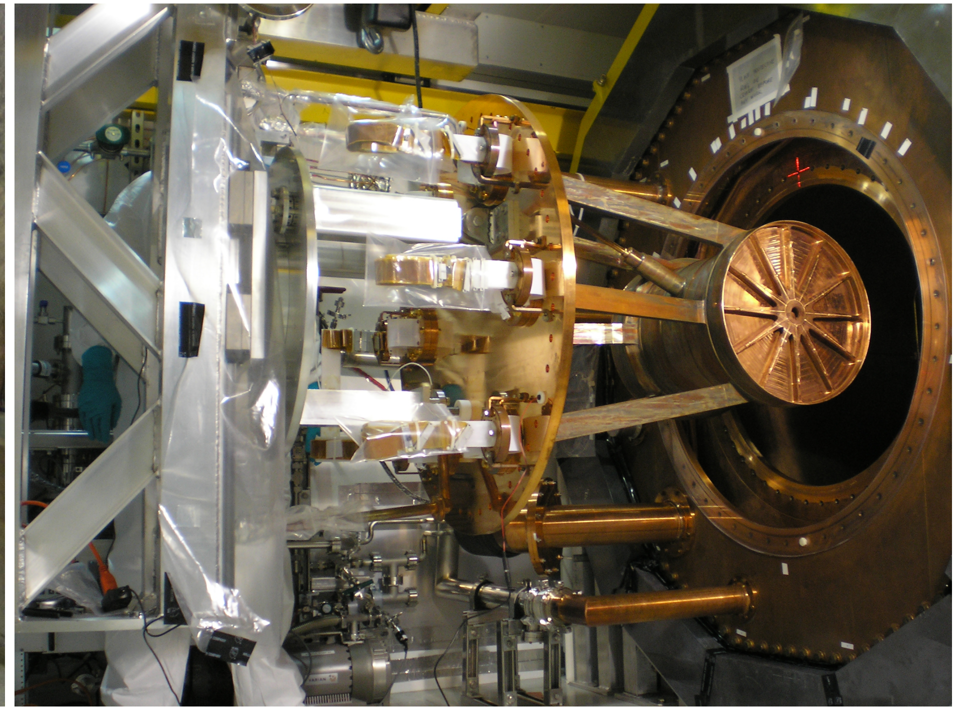
- Systems (xenon, refrigeration, liquid shielding, purification, purity monitoring, slow control, etc.) commissioning completed 9/2009 - 12/2009

Active muon veto

- Active muon veto system installed 2009
- Testing and integration into DAQ underway



TPC arrival & installation at WIPP

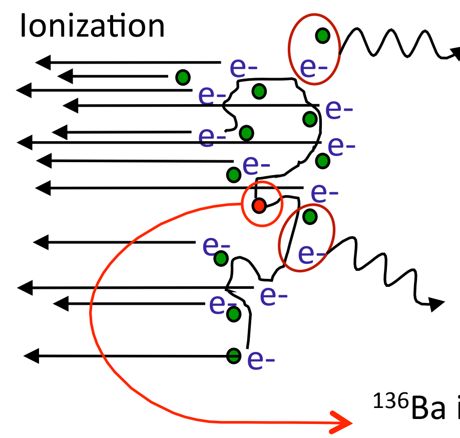


- TPC shipped from Stanford to WIPP 11/2009 in shielded container
- TPC installed in cryostat 12/2009
- LXe line re-hookup, followed by DAQ testing at WIPP
- Natural Xe run scheduled to begin mid-2010

Full EXO R&D

- Full EXO ~ ton scale gas or liquid TPC
- "Tagging" of $0\nu\beta\beta$ daughter nucleus ^{136}Ba ion for background rejection – R&D underway
  - Ion extraction from a TPC
  - Ion trapping
  - Ion identification with
    - Laser Induced Fluorescence (LIF)
    - Resonant ionization spectroscopy (RIS)
  - Single ion RIS
  - Others…
- GXe TPC R&D underway
  - 10 bar GXe TPC under construction
  - Test tracking, ionization+scintillation readout, $\Delta E/E$, Ba tagging interface, etc.

Full EXO $0\nu\beta\beta$ detection



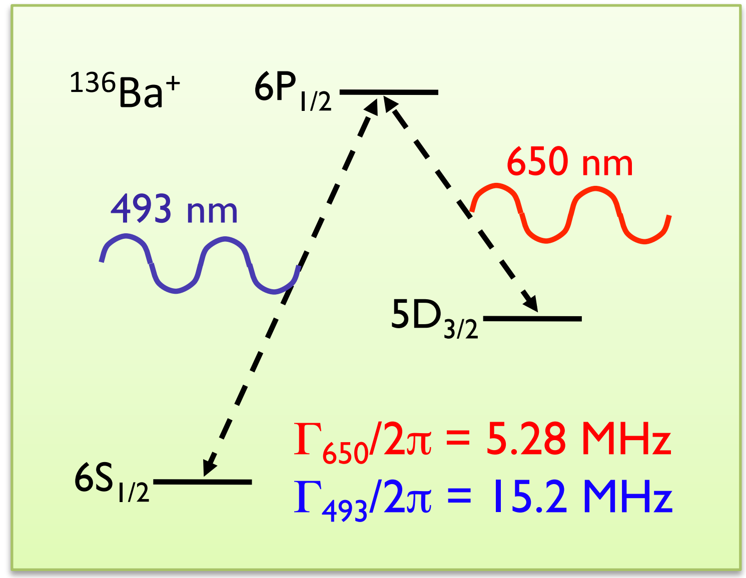
"Tagging" ^{136}Ba ion in real time may allow for rejection of all backgrounds except $2\nu\beta\beta$.

Single Ba+ identification with Laser Induced Fluorescence

Goal: extract and ID single ^{136}Ba ions in real time from liquid or gas TPC for background rejection

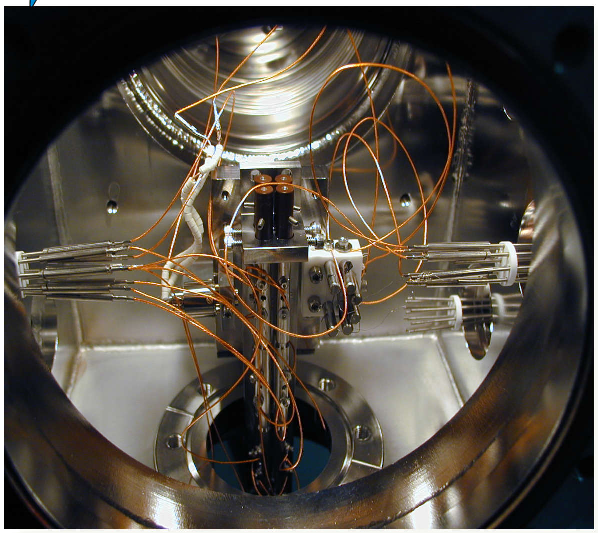
- $^{136}Xe \rightarrow {}^{136}Ba^{++} + 2e^-$
- $^{136}Ba^{++} \rightarrow {}^{136}Ba^{+}$ in LXe
- Isolate single ion in an ion trap
- Identification and dynamics of single Ba^+ in ion traps well studied (1)
- 493 nm, 650 nm lasers cycle trapped ion electronic states
- LIF ~10^7 photons/sec/ion into 4π

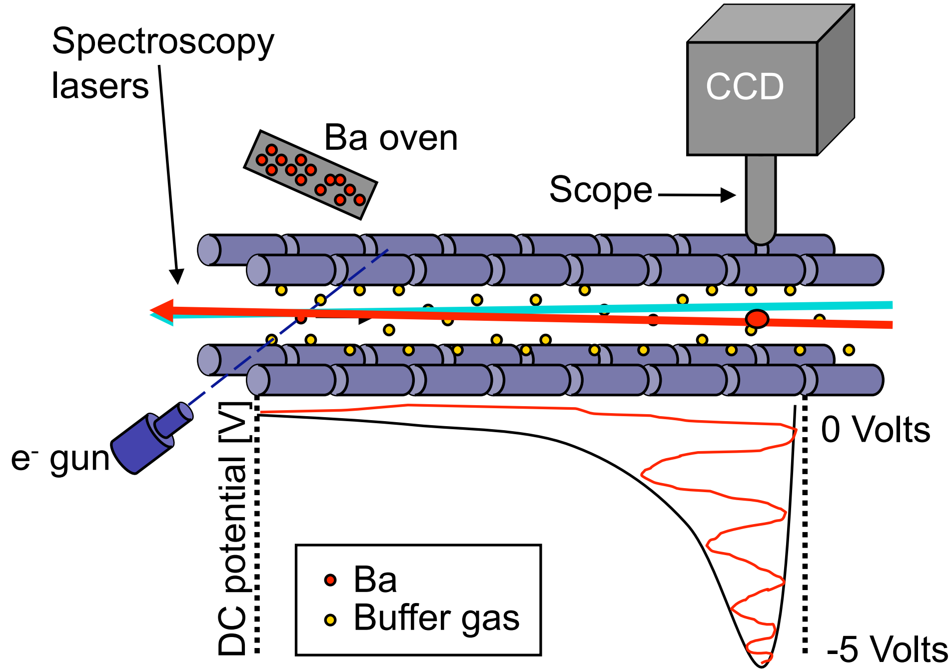
$^{136}Ba^+$ level structure

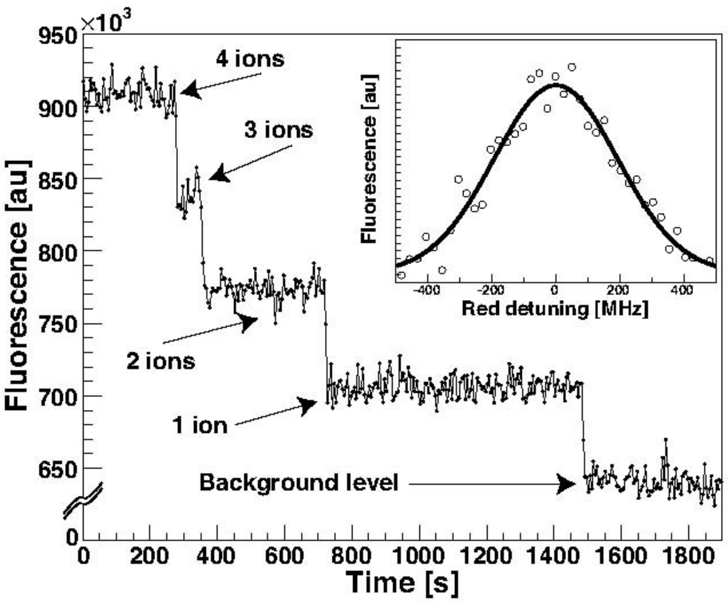


(1) H. Dehmelt et al. Phys. Rev. A 22, 1137 - 1140 (1980)

Single Ba^+ in a gas-filled quadrupole ion trap





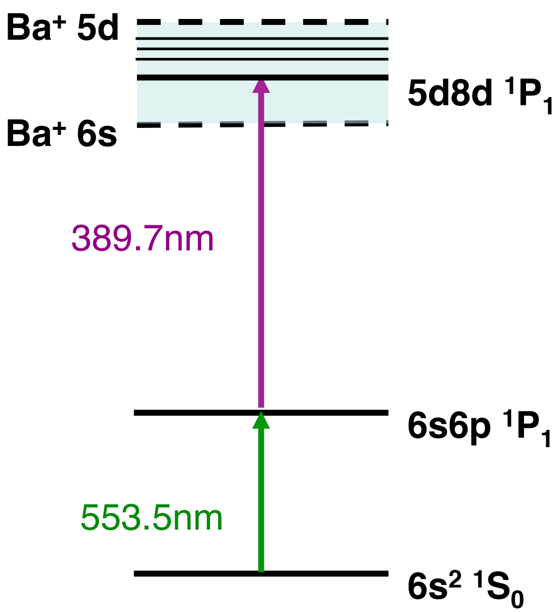


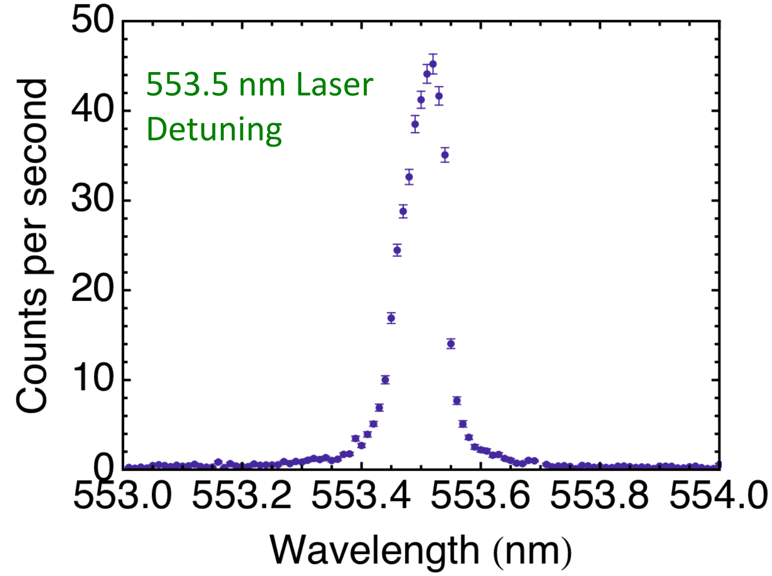
- Observed LIF of a single Ba^+ in a buffer gas filled ion trap (~ 10^{-3} torr He, some Xe)
- ~ 9σ observation at 25s storage time

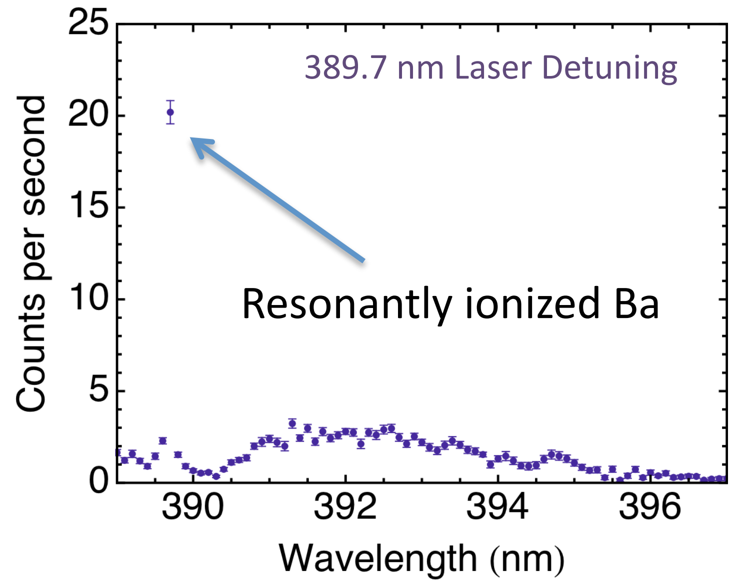
M.Green et al., Phys Rev A 76 (2007) 023404
B.Flatt et al., NIM A 578 (2007) 409

Resonant Ionization Spectroscopy (RIS)

- RIS uses lasers tuned to atomic resonances to first *excite* and then *ionize* neutral Ba.
- Pulsed dye lasers at 553.5 nm and 389.7 nm
- Ions counted in a channeltron
- Plan: couple RIS system to quadrupole ion trap

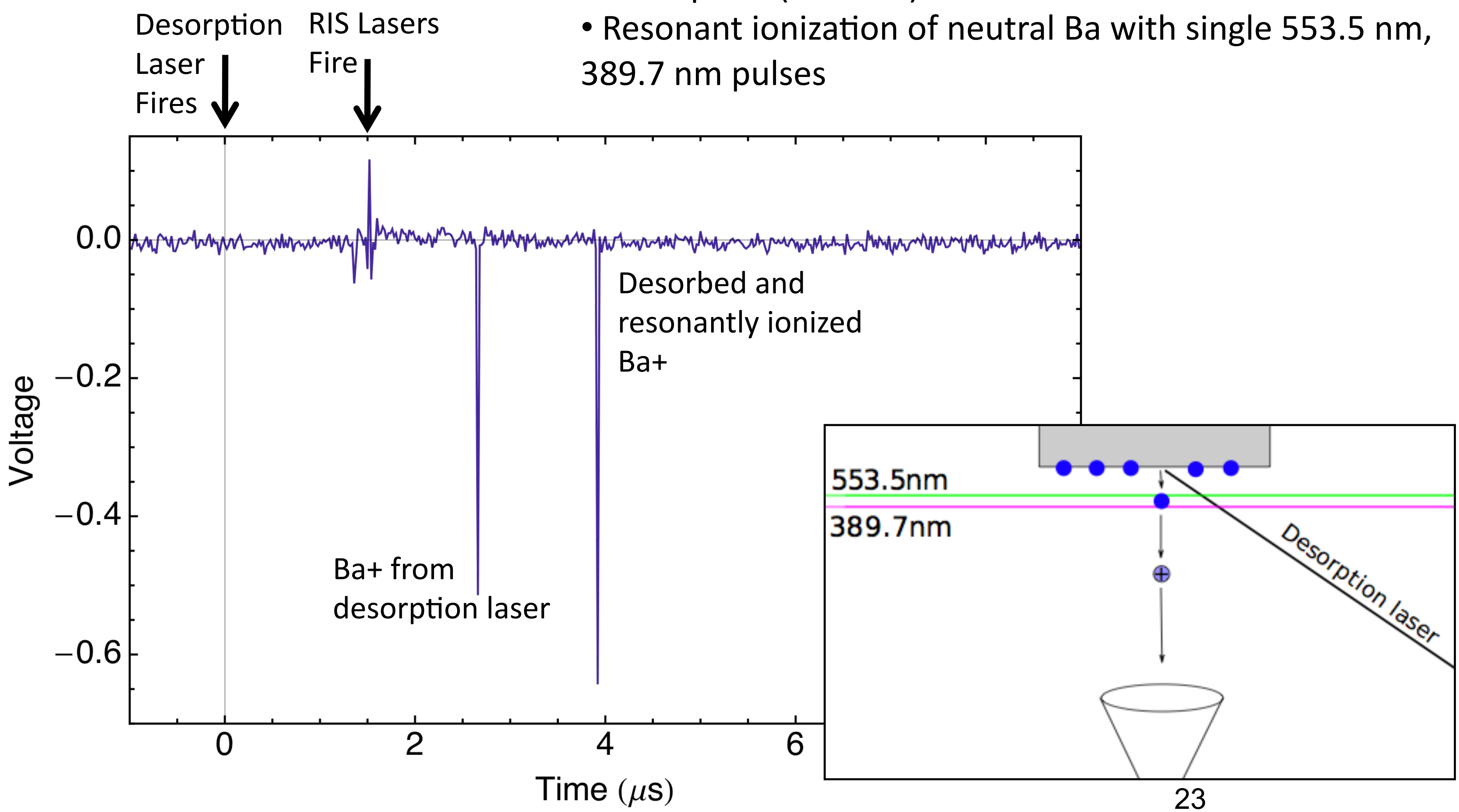






DRIS: Desorption Resonant Ionization Spectroscopy

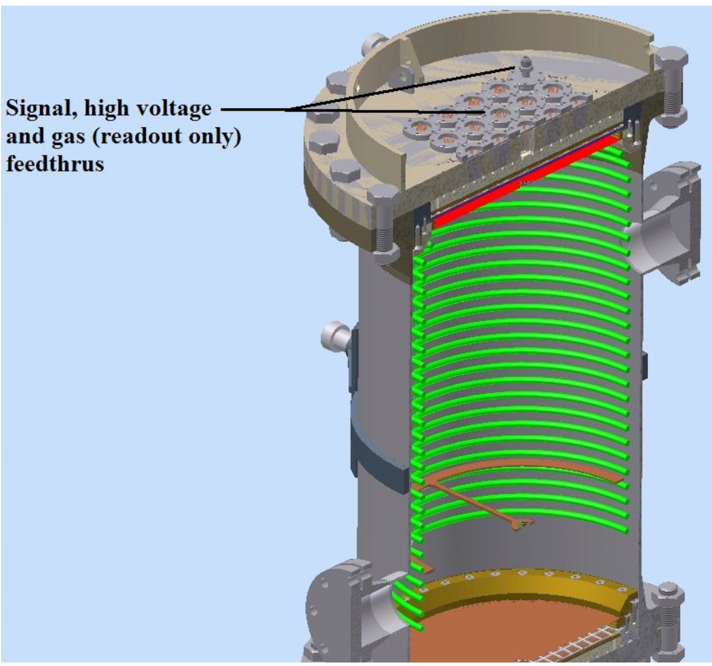
- Neutral Ba on "probe" surface
- Desorption (thermal) of neutral Ba with YAG
- Resonant ionization of neutral Ba with single 553.5 nm, 389.7 nm pulses

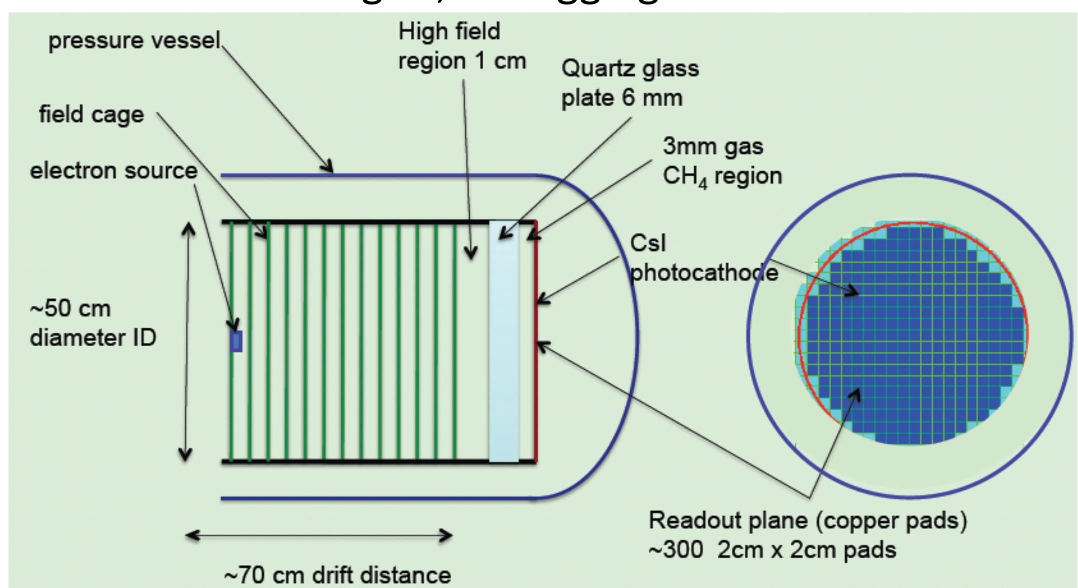


Full EXO GXe TPC R&D in progress

Goal: Test tracking, ΔE/E, electronics,ionization + scintillation readout, Ba tagging interface in 1-10 bar GXe

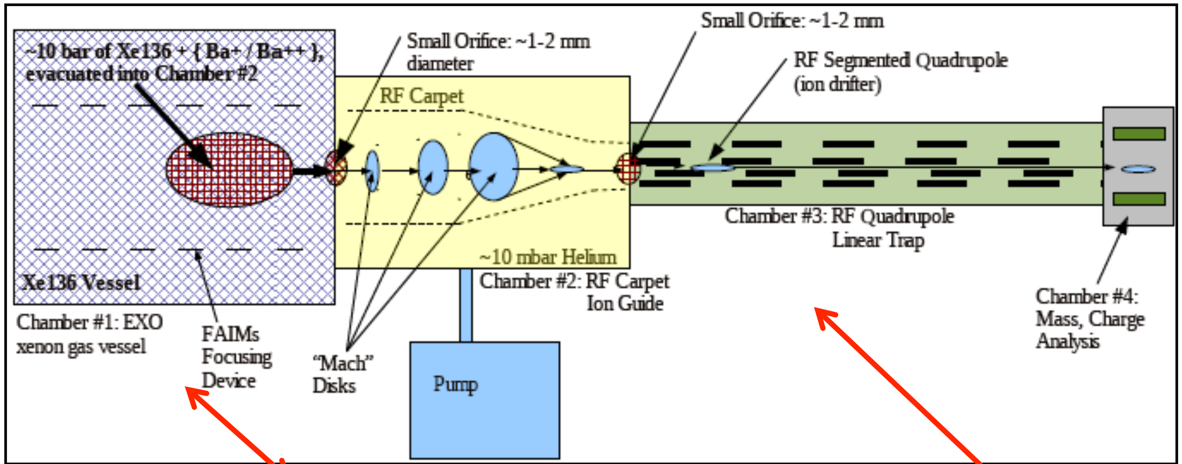
- 10 bar GXe cylindrical TPC
- 1 MeV e^- source
- Segmented readout (tracking) on both ends
- Electroluminescent gap + CsI photocathode for both charge and scintillation readout
- Replaceable endcaps for alternate charge/light readout technologies, Ba tagging interface



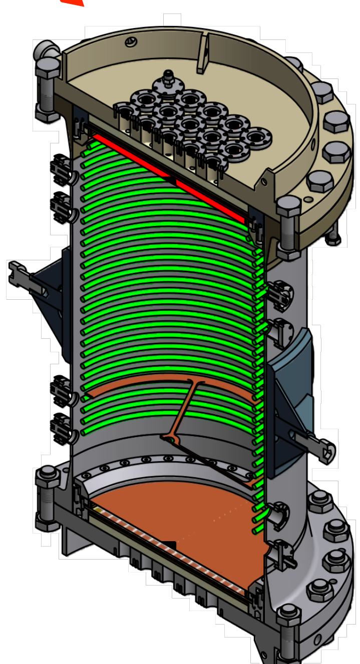


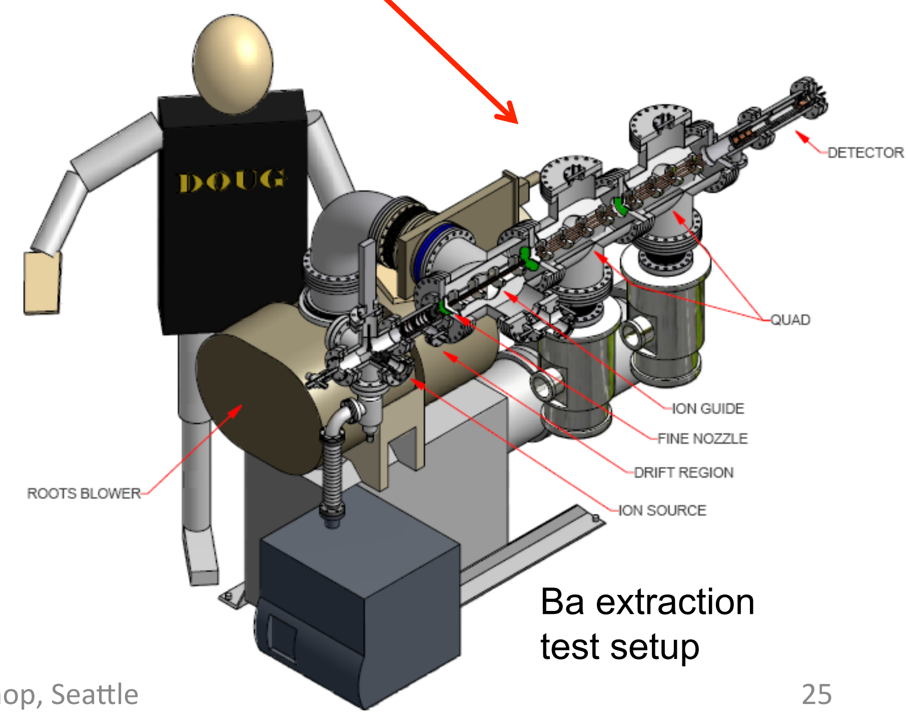
- Field cage length: 780 mm
- Field cage diameter: 535 mm

Coupling a quadrupole trap to a TPC



- Ion transport, stopping, through quadrupoles well known to heavy-ion nucl. phys.
- Eventual goal is to test full pipeline efficiency for single ion extraction, ID





Ba extraction test setup

EXO-200 Majorana mass $<m_{\beta\beta}>$ sensitivity

Assumptions

1. 200 kg of ^{136}Xe, 80% enrichment
2. Low but finite radioactive background: 20 events/yr in $\pm 2\sigma$ interval around Q=2.481 MeV
3. Negligible background from $2\nu\beta\beta$ ($T_{1/2}$ > $1x10^{22}$ yr, Bernabei et al.)

Case	Mass [ton]	Efficiency [%]	Run time [yr]	σ_E/E @ 2.5 MeV [%]	Radioactive background [events]	$T_{1/2}^{0\nu\beta\beta}$ [yr, 90% CL]	Neutrino majorana mass [eV]	
							QRPA	NSM
EXO-200	0.2	70	2	1.6	40	$6.4x10^{25}$	0.13 (1)	0.19 (2)

If Klapdor's observations are correct, EXO-200, 2-yr runtime:

1. 46 events on top of 40 (QRPA) → 5σ measurement
2. 170 events on top of 40 (NSM) → 11.7σ measurement

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

EXO Majorana mass $\langle m_{\beta\beta} \rangle$ sensitivity

Assumptions

1. ^{136}Xe, 80% enrichment
2. Intrinsic low backgrounds & Ba tagging eliminate all radioactive backgrounds
3. Energy resolution used to separate $0\nu\beta\beta$ from $2\nu\beta\beta$ modes (select 0ν events in +/- 2σ interval around 2.458 MeV endpoint)
4. *$2\nu\beta\beta$* ($T_{1/2} > 1\text{x}10^{22}$ yr, Bernabei et al.)

Case	Mass [ton]	Efficiency [%]	Run time [yr]	σ_E/E @ 2.5 MeV [%]	$2\nu\beta\beta$ background [events]	$T_{1/2}^{0\nu\beta\beta}$ [yr, 90% CL]	Neutrino majorana mass [meV]	
							QRPA	NSM
Conservative	1	70	5	1.6 [3]	0.5 (~1)	$2.0\text{x}10^{27}$	24 [1]	33 [2]
Aggressive	10	70	10	1.0 [4]	0.7 (~1)	$4.1\text{x}10^{28}$	5.3 [1]	7.3 [2]

(1) Rodin et al., Nucl. Phys. A 793 (2007) 213-215
(2) Caurier et al., arXiv:0709.2137v1
(3) σ_E/E = 1.6% obtained in EXO R&D, Conti et al., Phys. Rev. B 68 (2003) 054201
(4) σ_E/E = 1.0% considered aggressive but realistic guess with large light collection

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