The Enriched Xenon Observatory: EXO-200 and Ba^+ tagging

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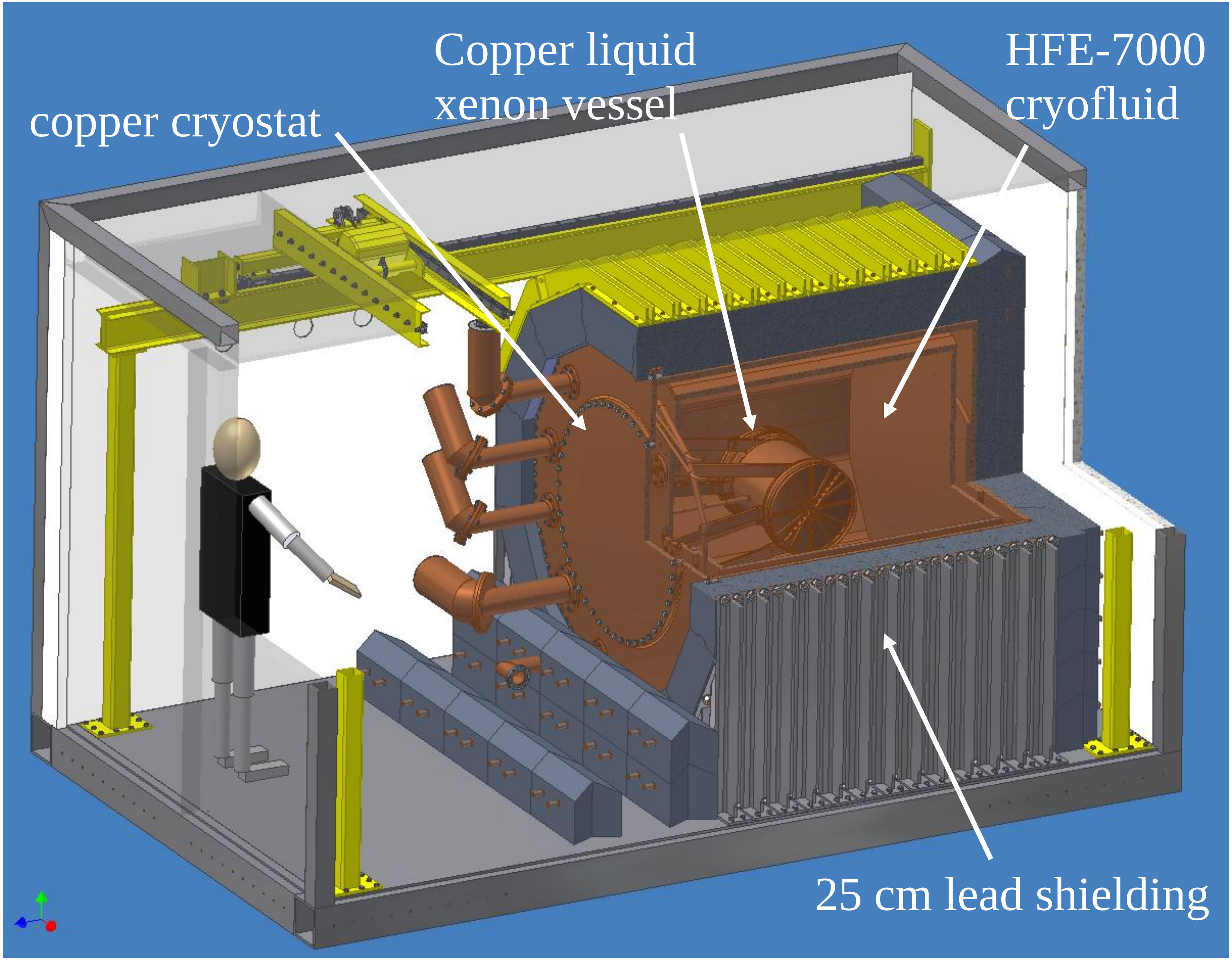
for the EXO Collaboration

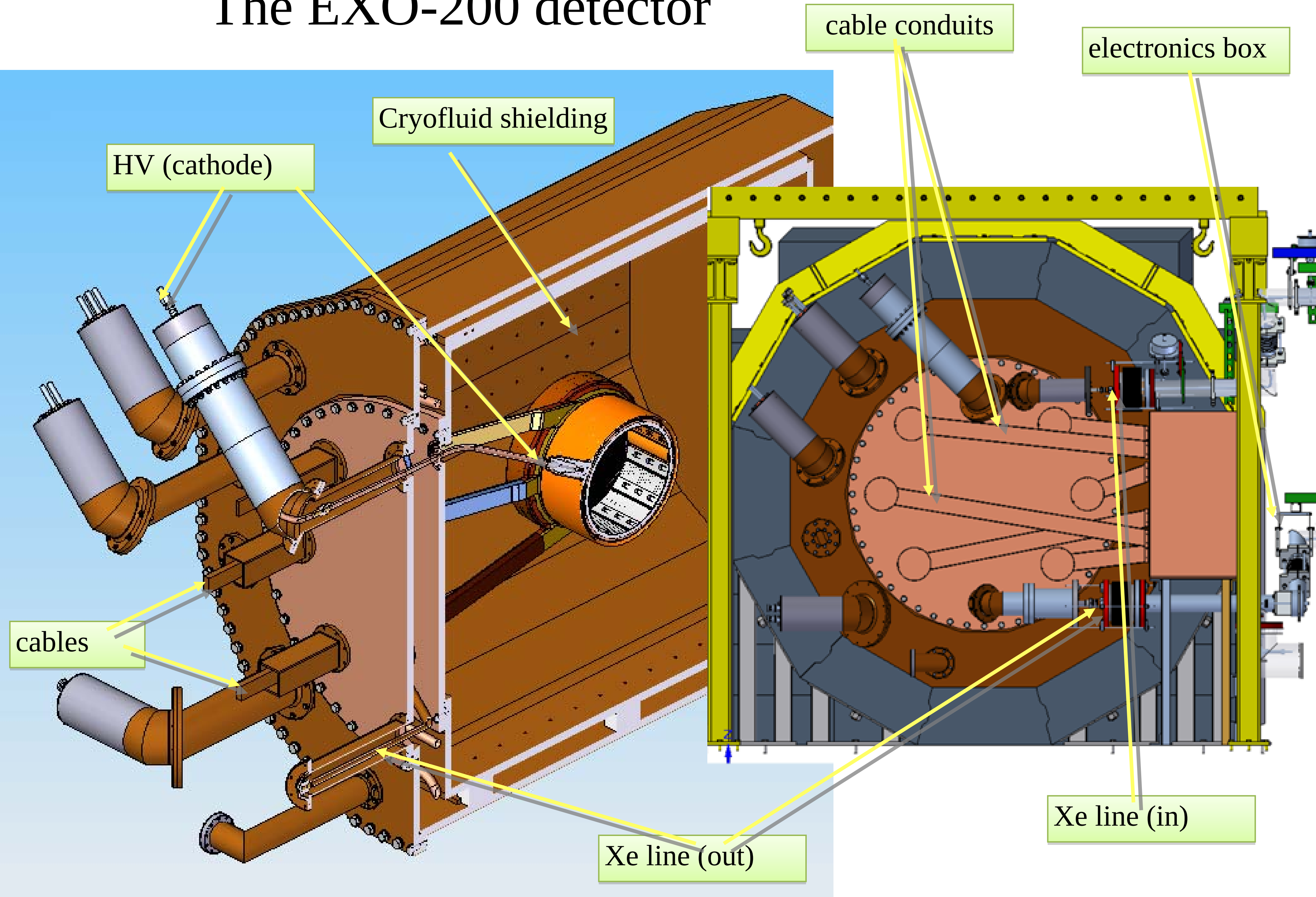
EXO-200: the first 200 kg double beta decay experiment

200 kg of xenon enriched to 80% = 160 kg of ^{136}Xe:
The most isotope in possession by any ββ0ν collaboration

EXO-200: the first 200 kg ββ0ν experiment



The EXO-200 detector

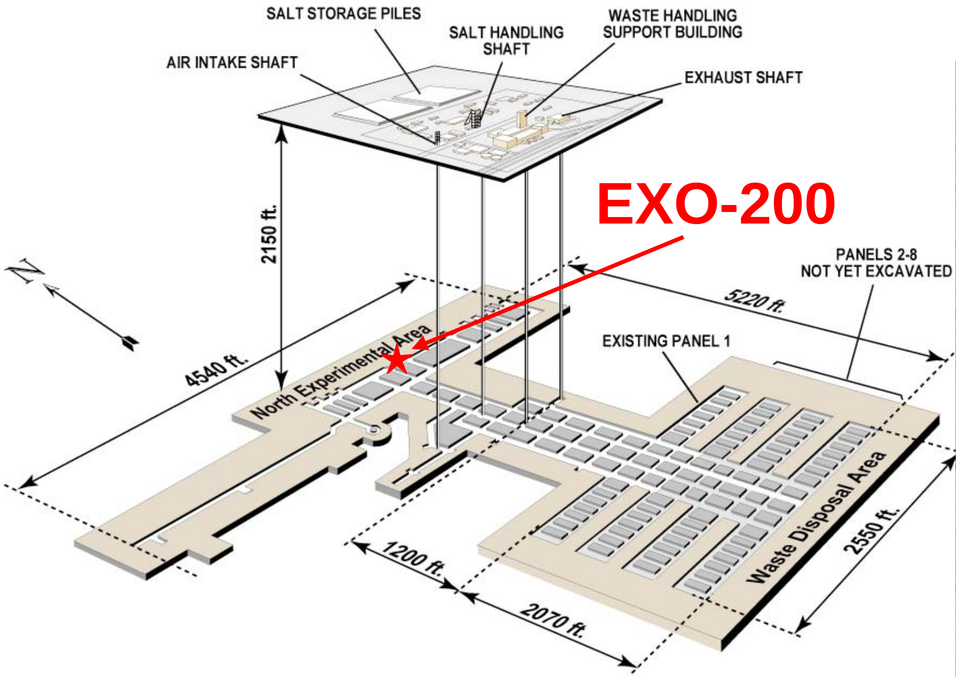


EXO-200: Underground @ WIPP

Qu Time™ and a
compressor
ar to see this picture.

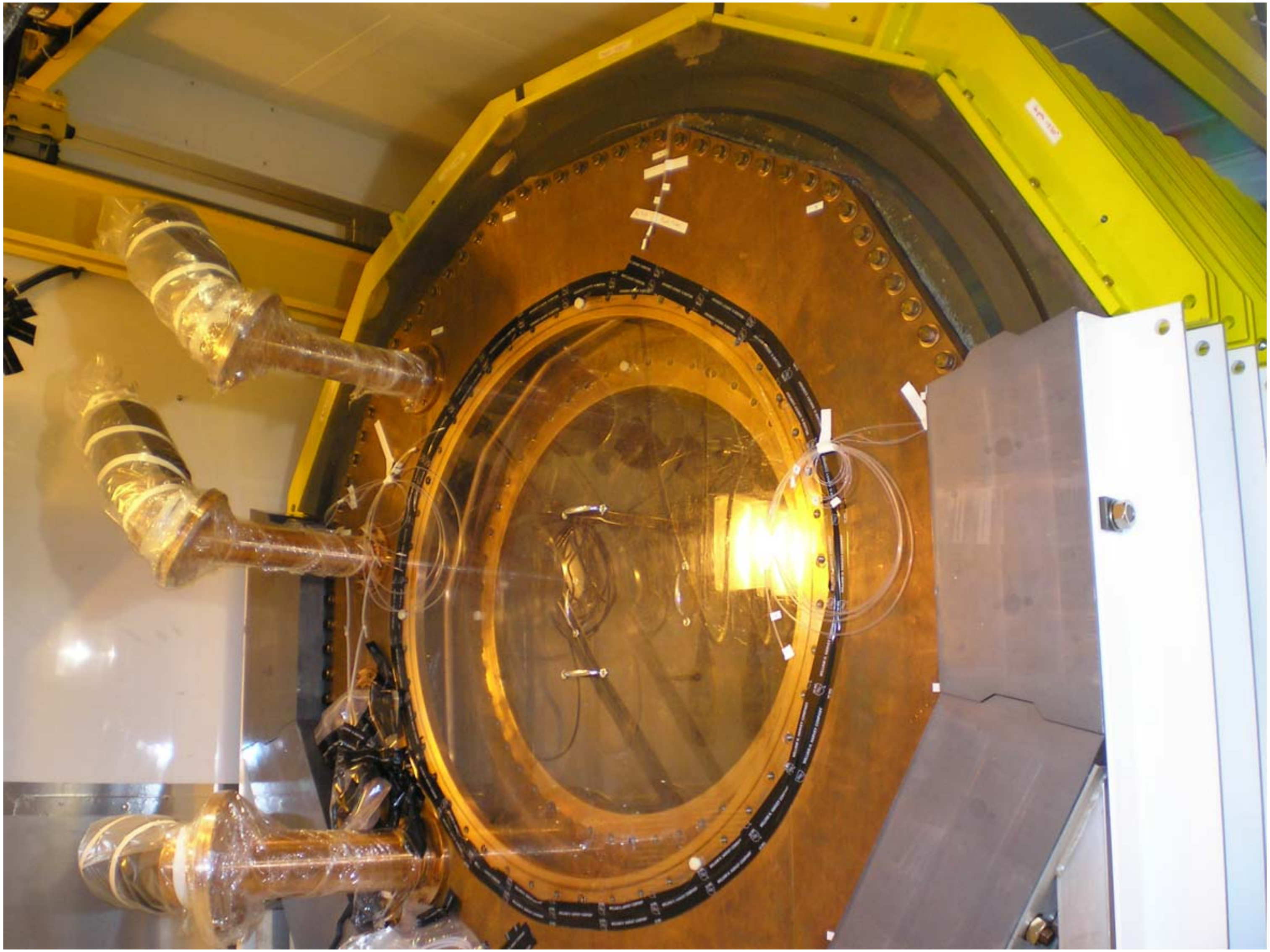
EXO-200 is sited at the Waste Isolation Pilot Plant in Carlsbad, NM, a radioactive waste disposal facility located 2150 ft underground in a salt deposit.

- ~1600 m water equivalent flat overburden [Esch et. al., *NIM* A**538**, 516(2005)]
- Relatively low levels of U and Th (measurements < 100 ppb in EXO-200 drift), Rn (~20 Bq/m^3)

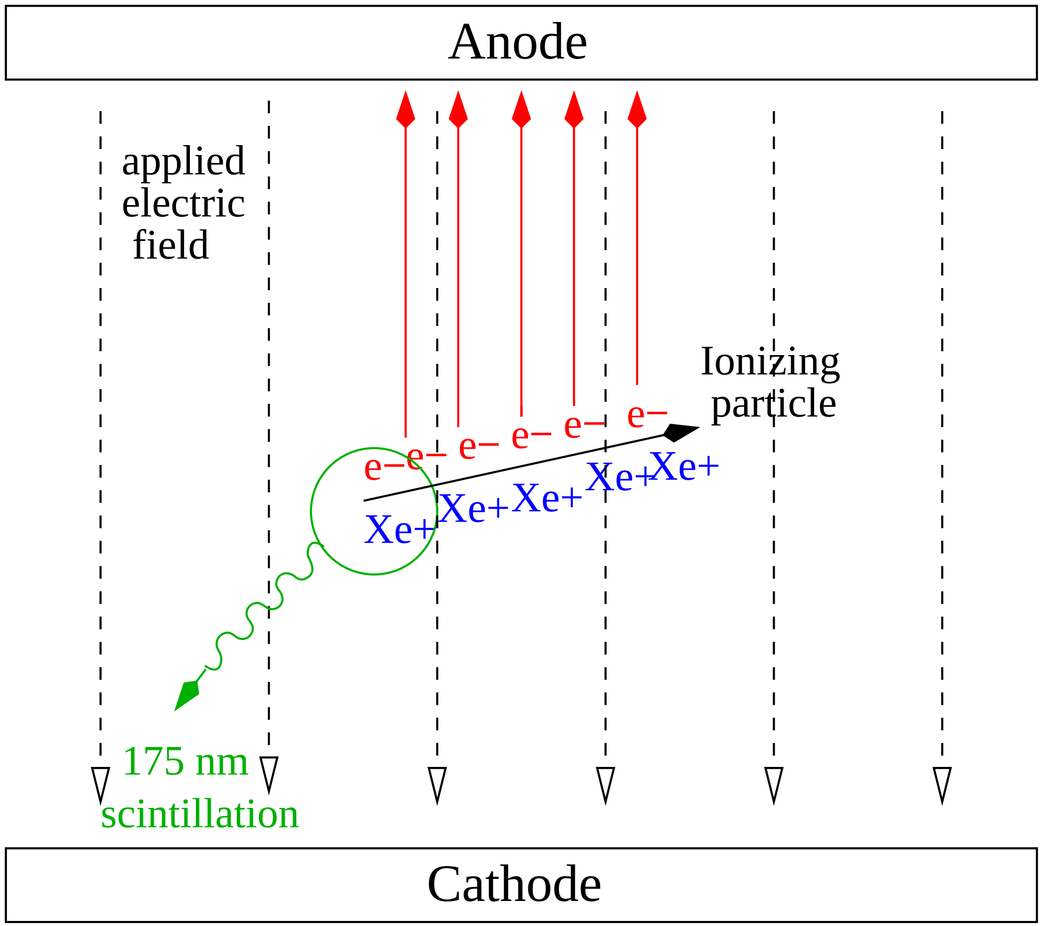


EXO-200 Cryostat & Lead

Installed underground in Spring 2008

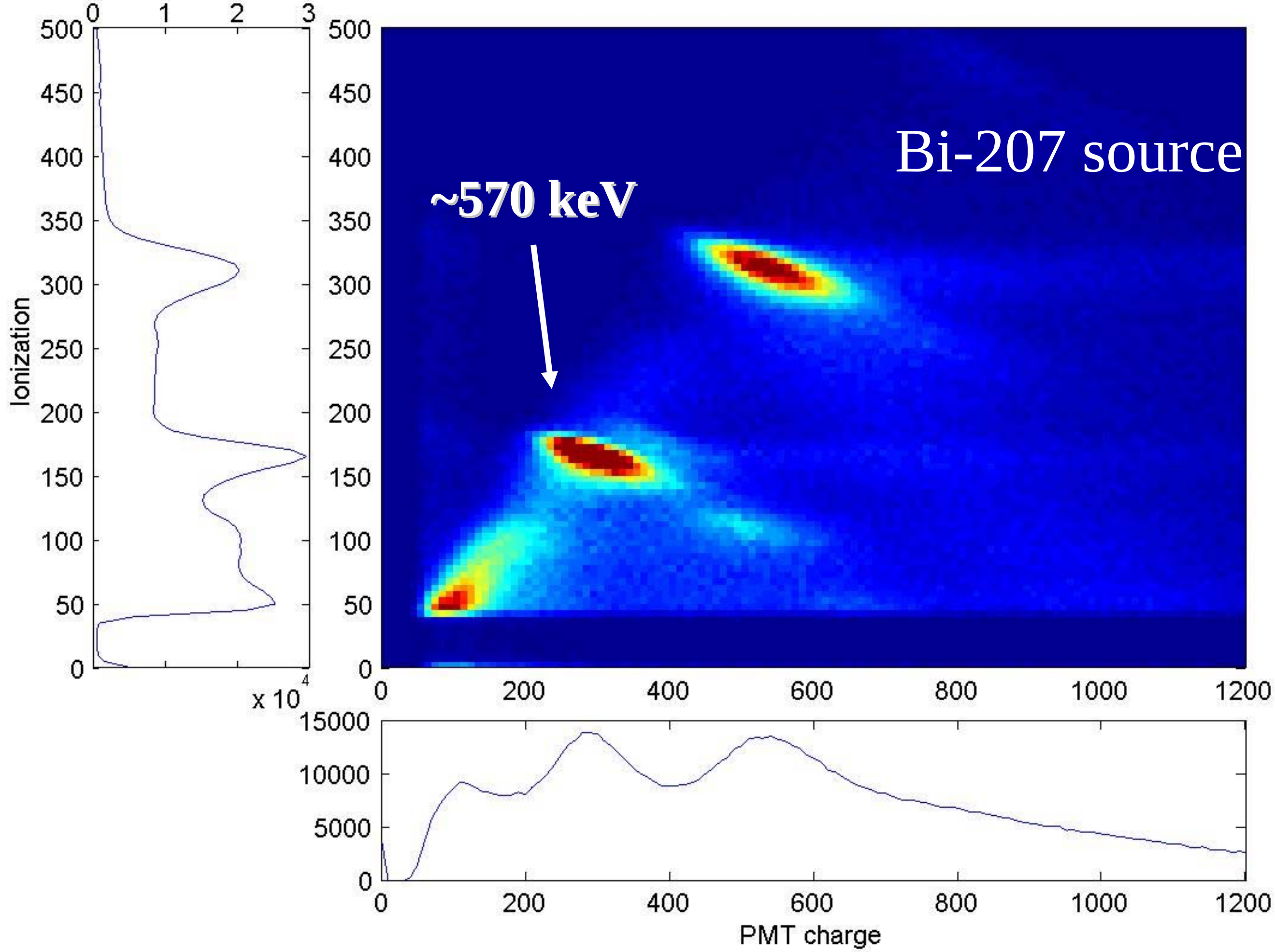


Liquid xenon calorimetry



Measure the event energy by collecting the ionization on the anode and/or observing the scintillation.

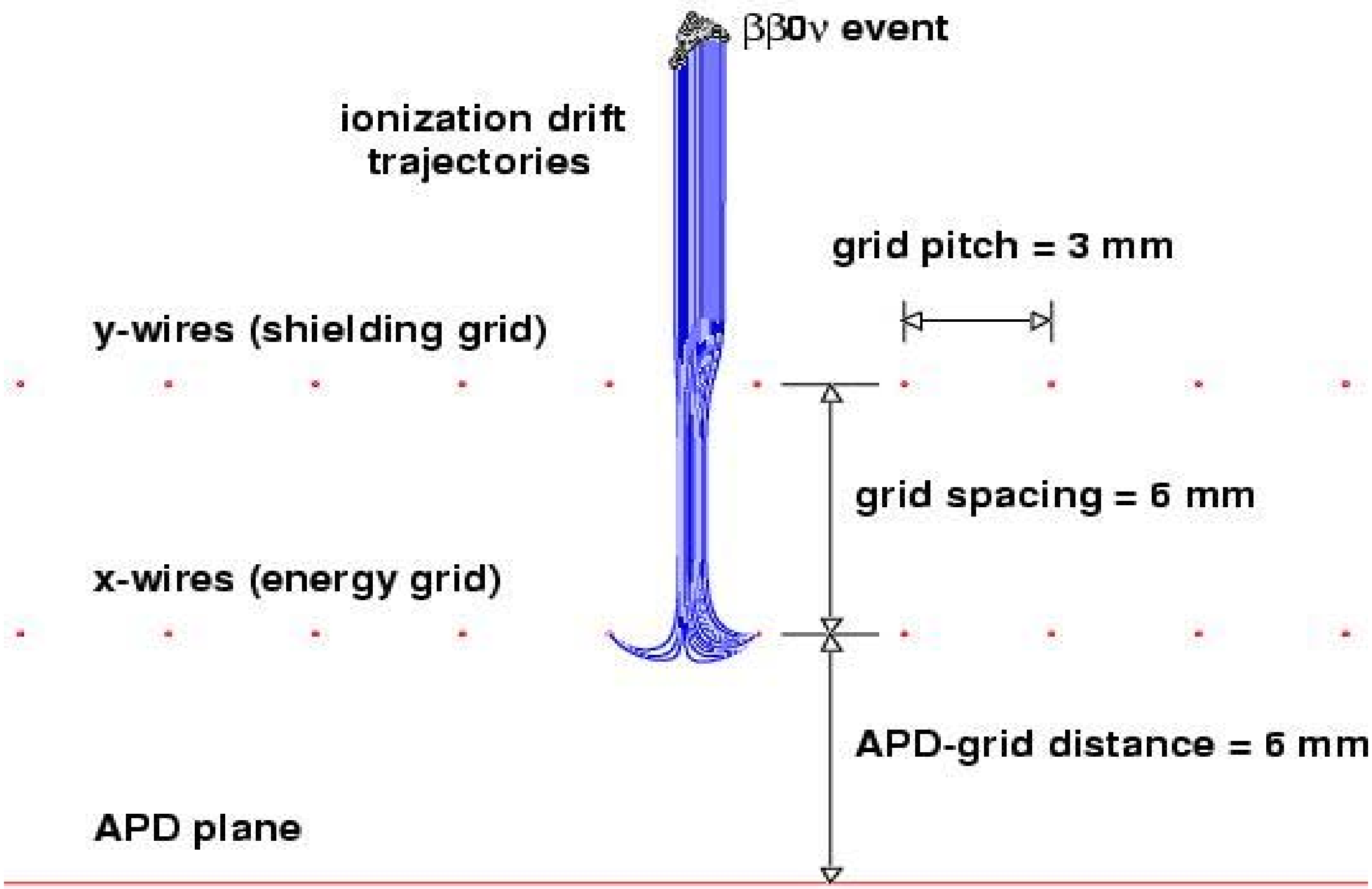
Liquid xenon data show an anti-correlation between ionization and scintillation



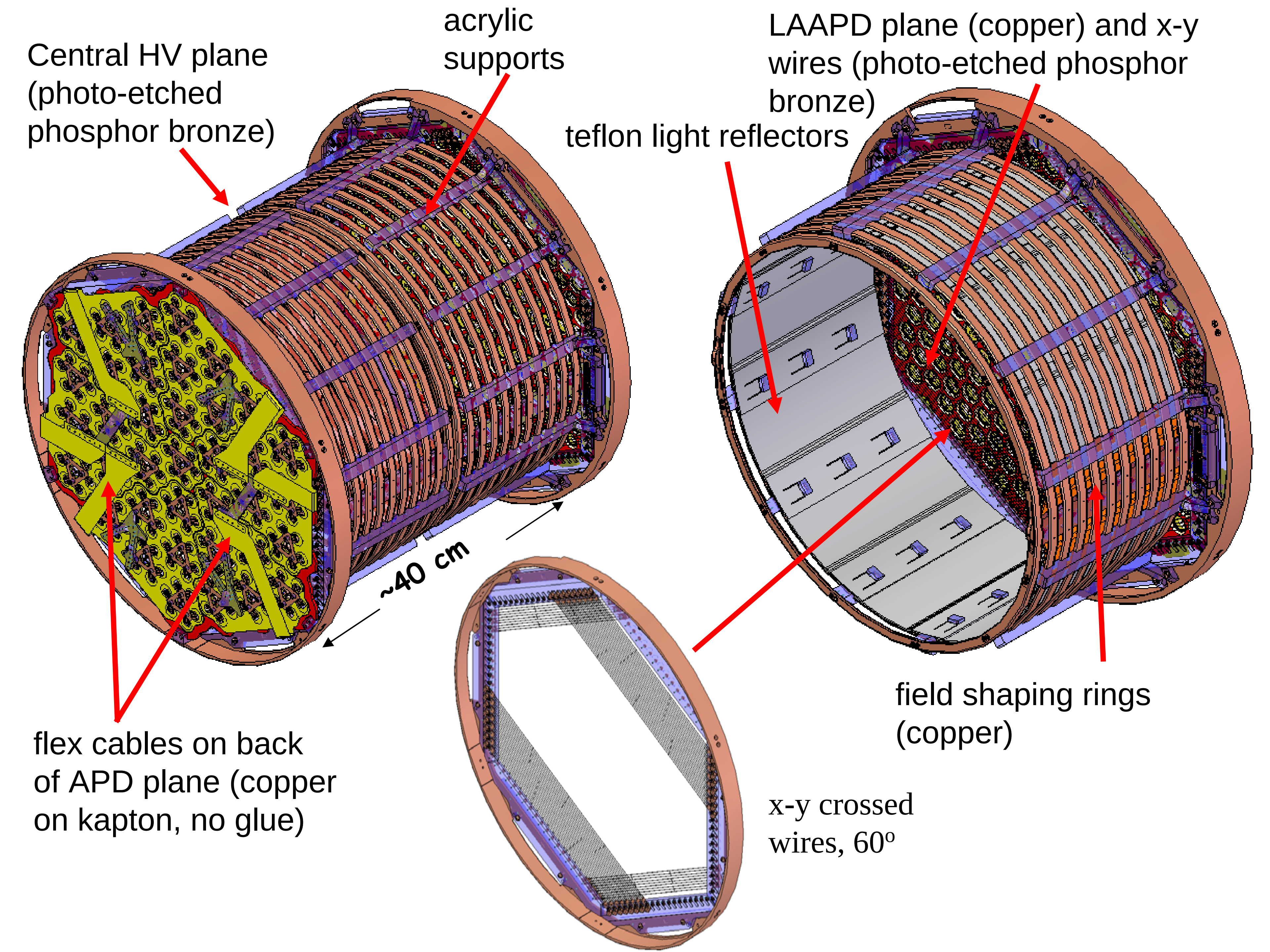
Energy resolution: 3.0% @ 570 keV or 1.4 % @ Q(ββ)

Factor of two better than most recent Xe experiment

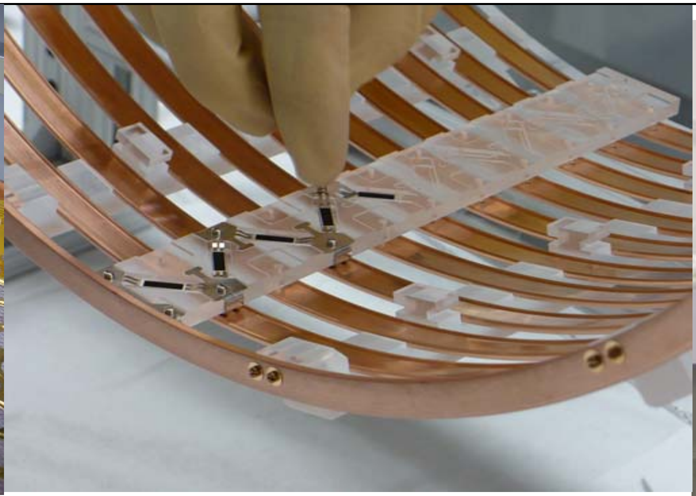
Crossed wire planes and APD array measure event energy and position

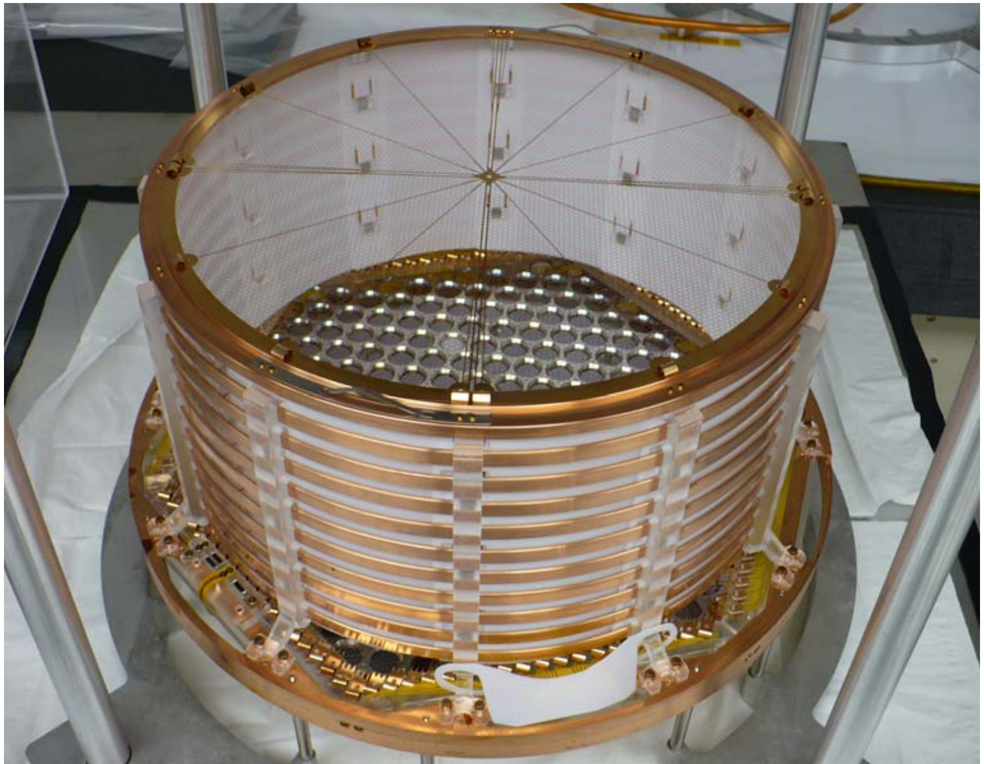


y-position given by induction signal on shielding grid.
x-position and energy given by charge collection grid.
APD array observes prompt scintillation to measure drift time.


Central HV plane
(photo-etched
phosphor bronze)
acrylic
supports
LAAPD plane (copper) and x-y
wires (photo-etched phosphor
bronze)
teflon light reflectors
~40 cm
flex cables on back
of APD plane (copper
on kapton, no glue)
field shaping rings
(copper)
x-y crossed
wires, 60°

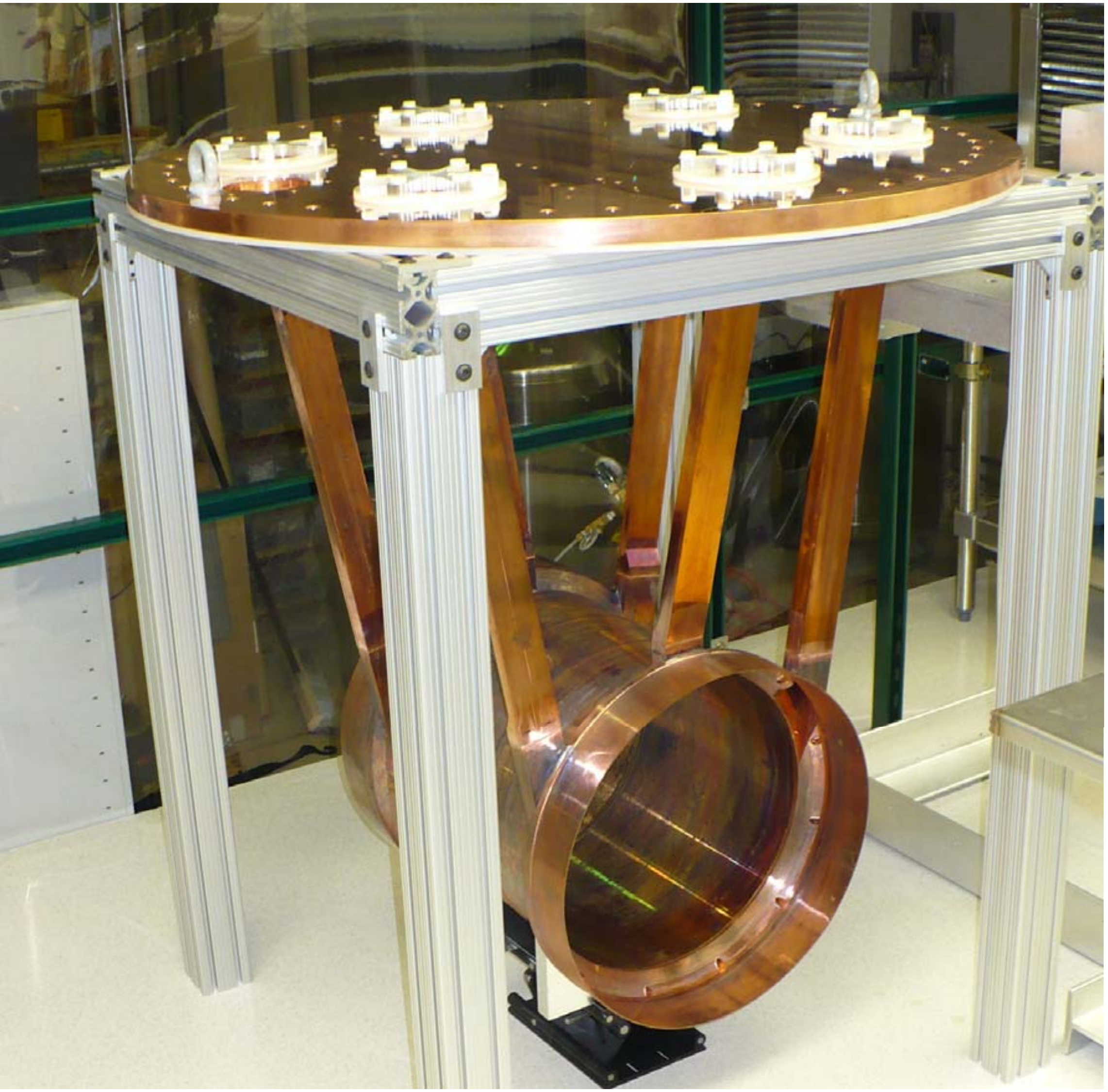
EXO-200: TPC Construction in 2009





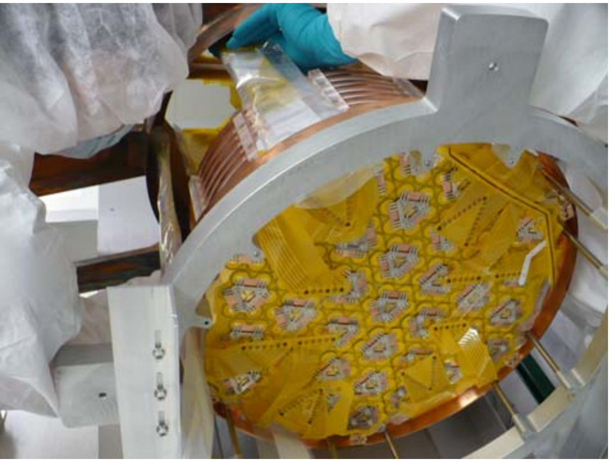
Left: Building one half of the inner detector.
Above: Potting kapton flex cables.

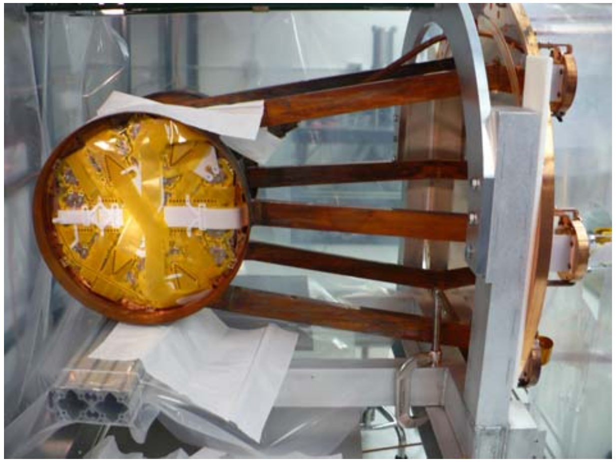
A thin copper liquid xenon vessel

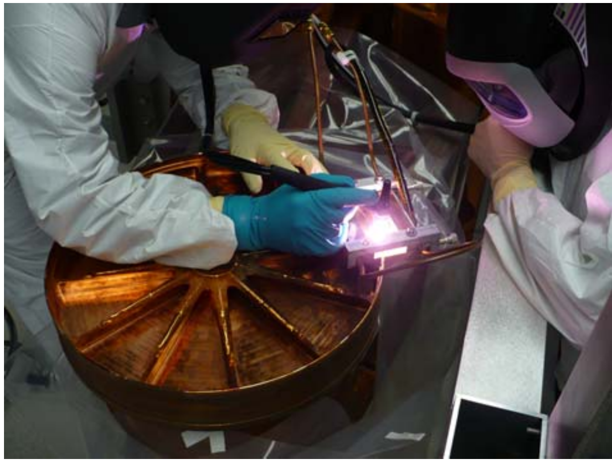


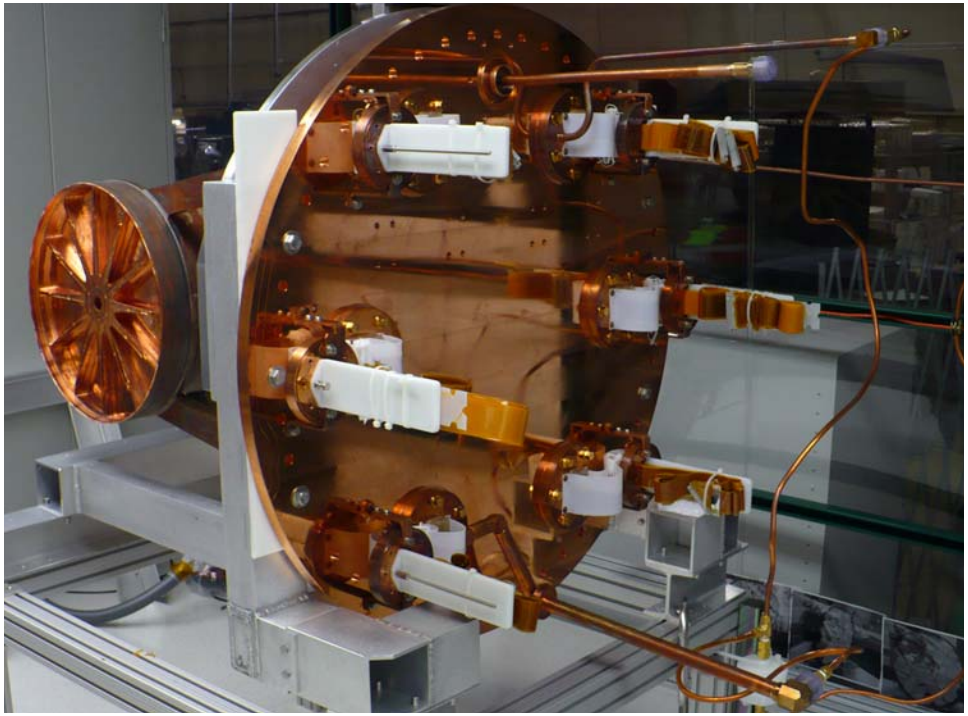
- Very light (wall thickness 1.5 mm, total weight 15 kg), to minimize material.
- All parts machined under 7 ft of concrete shielding to reduce activation by cosmic rays.
- Different parts are e-beam welded together at Applied Fusion. Construction of the vessel with 55 welds has been completed.
- End caps will be TIG welded.

EXO-200: TPC constuction in 2009



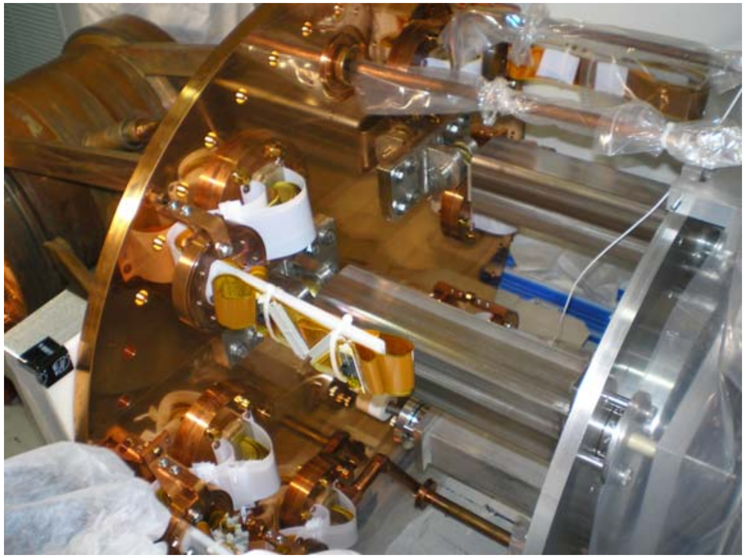


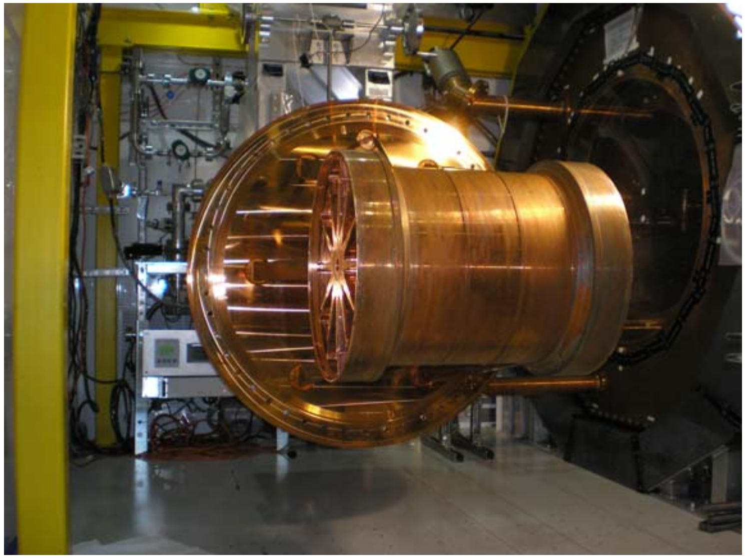


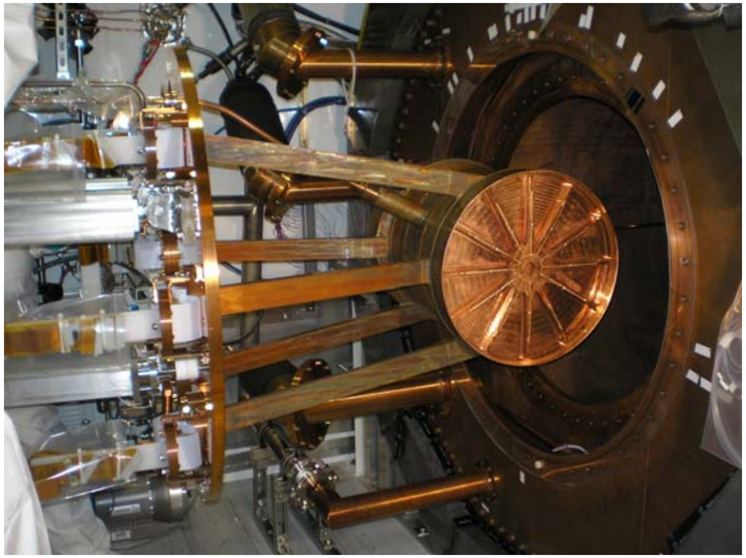


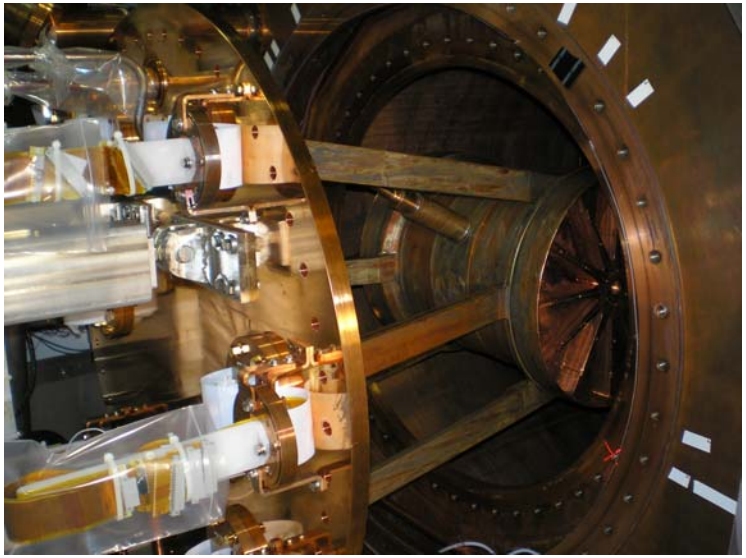
EXO-200: Final TPC Installation in January 2010

QuickTime™ and a
decompressor
are needed to see this picture.



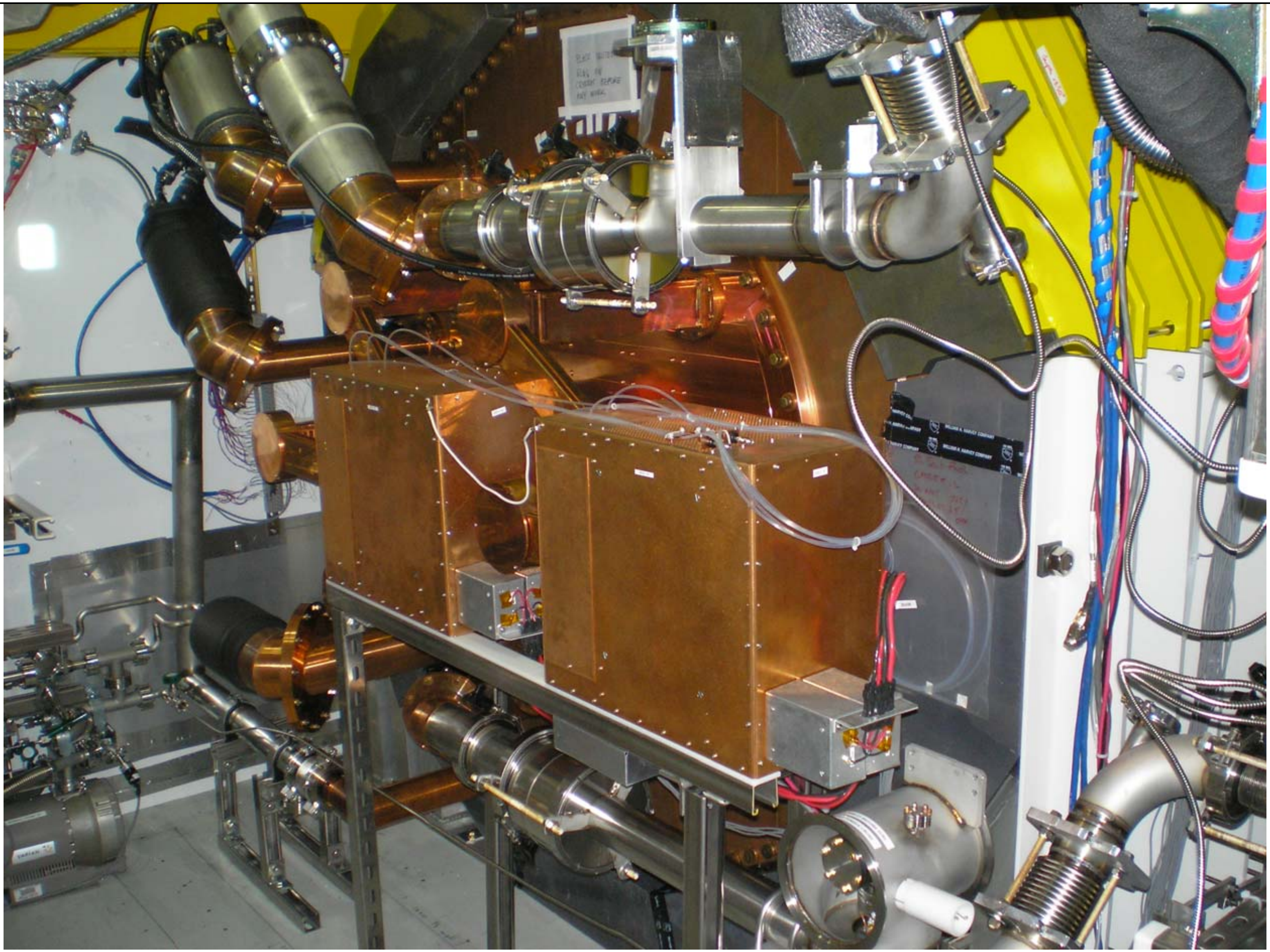






EXO-200: First data expected this summer

QuickTime™ and a decompressor are needed to see this picture.



Sensitivity of EXO-200

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]	Majorana mass (meV) NSM[2]
EXO-200	0.2	70	2	1.6*	40	$6.4*10^{25}$	109	135

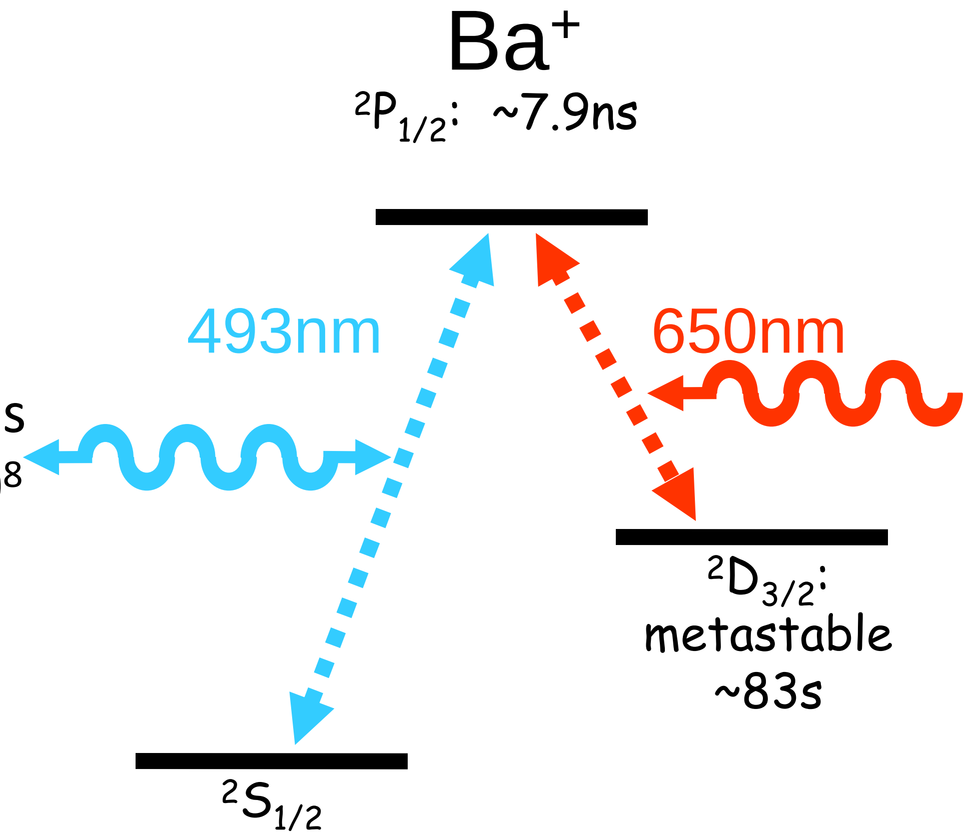
1) Simkovic et al. Phys. Rev. C**79**, 055501(2009) (use RQRPA and g_A= 1.25)
2) Menendez et al., Nucl. Phys. A**818**, 139(2009), (use UCOM results)

Get smarter: Single Ba^+ ion detection

$^{136}Xe \rightarrow ^{136}Ba^{++}\ e^- e^-$

Daughter identified by optical spectroscopy of Ba^+, well studied in ion traps for more than 25 years

[Neuhauser, Hohenstatt, Toshek, Dehmelt, Phys. Rev. A 22 (1980) 1137]



- very specific signature ("Λ" shelving)

- cycling 493/650 nm transitions gives a fluorescence rate of ~10^8 Hz (in vacuum)

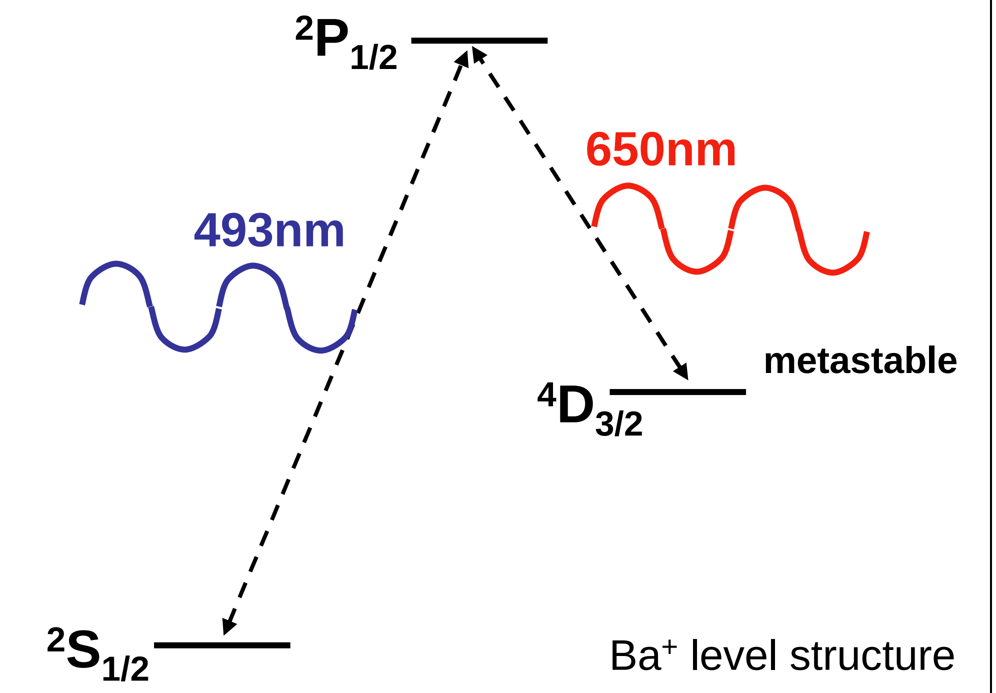
plenty of light!

Ba^+ Spectroscopy

QuickTime™ and a decompressor are needed to see this picture.

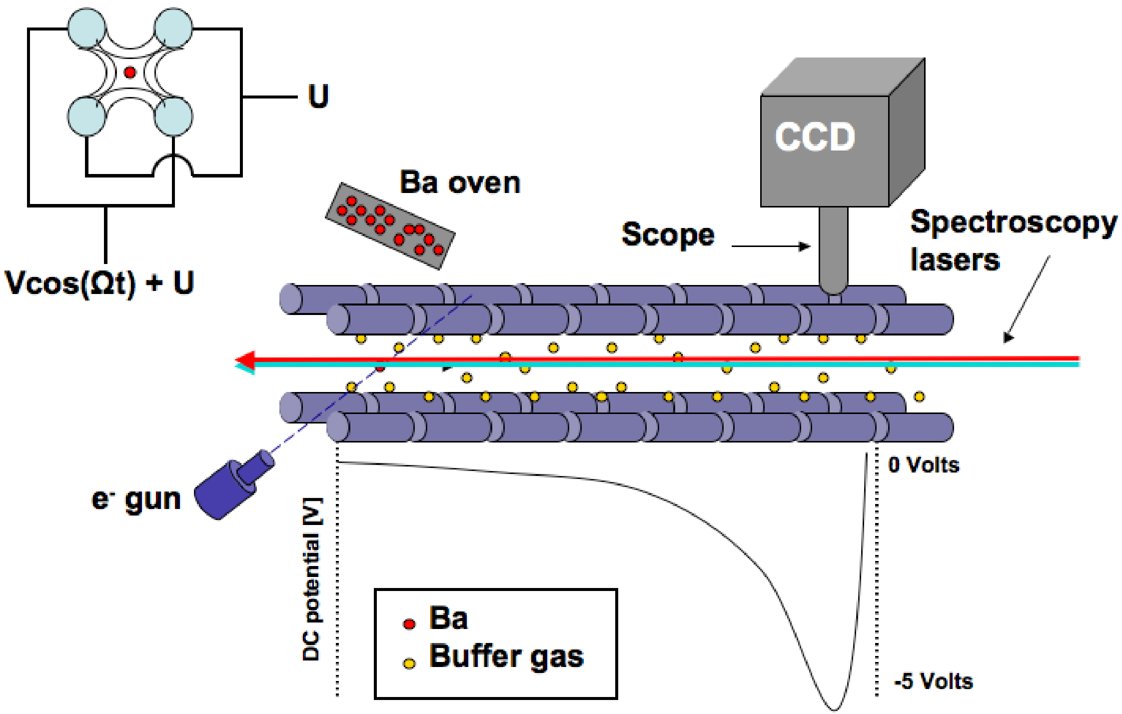
$^{136}Xe \rightarrow {}^{136}Ba^{++} + 2e^-$

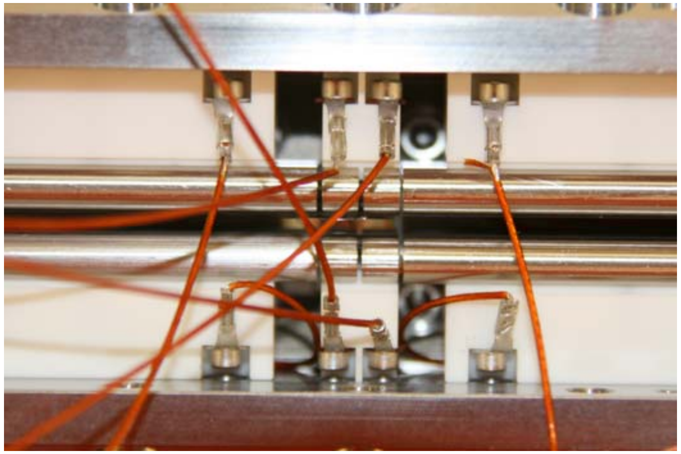
- Ba^+ system is well studied. See H. Dehmelt et al. *Phys. Rev*. A**22**, 1137 (1980).
- Very specific signature with laser induced fluorescence.
- Single ions can be detected from a photon rate of 10^7/s

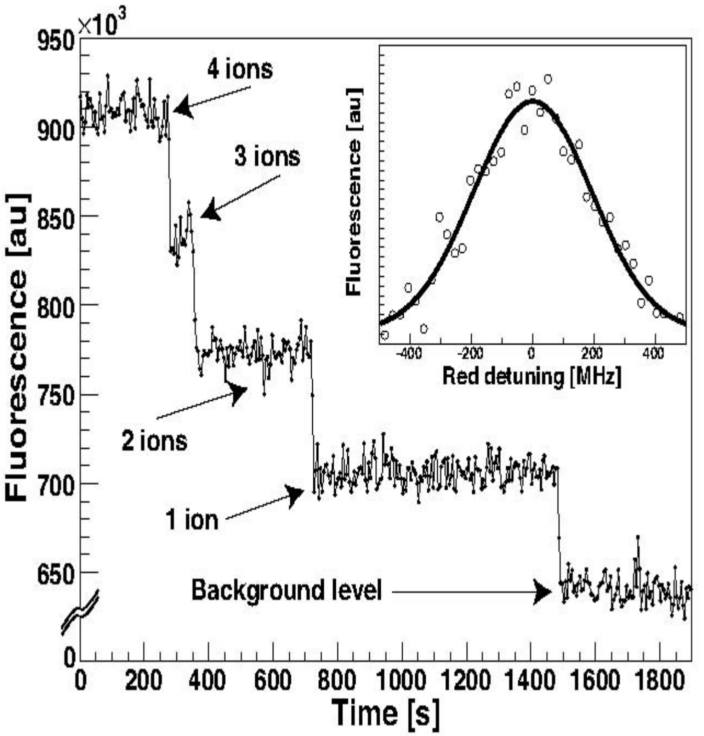


Ba⁺ level structure

Ba$^+$ Tagging: Ion Trap + fluorescence





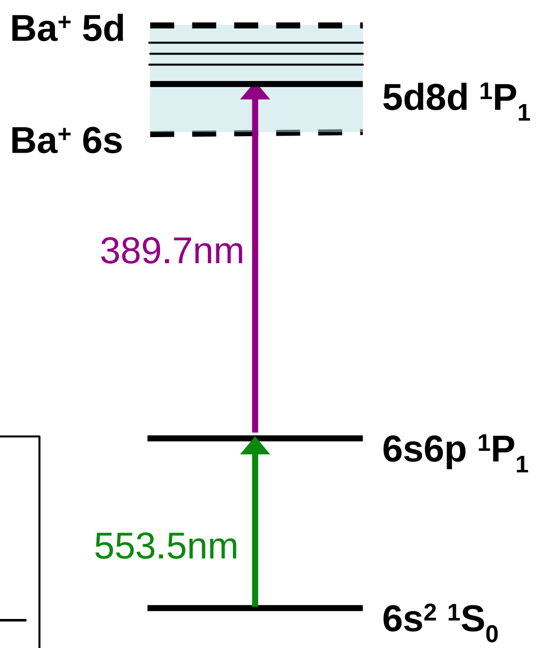


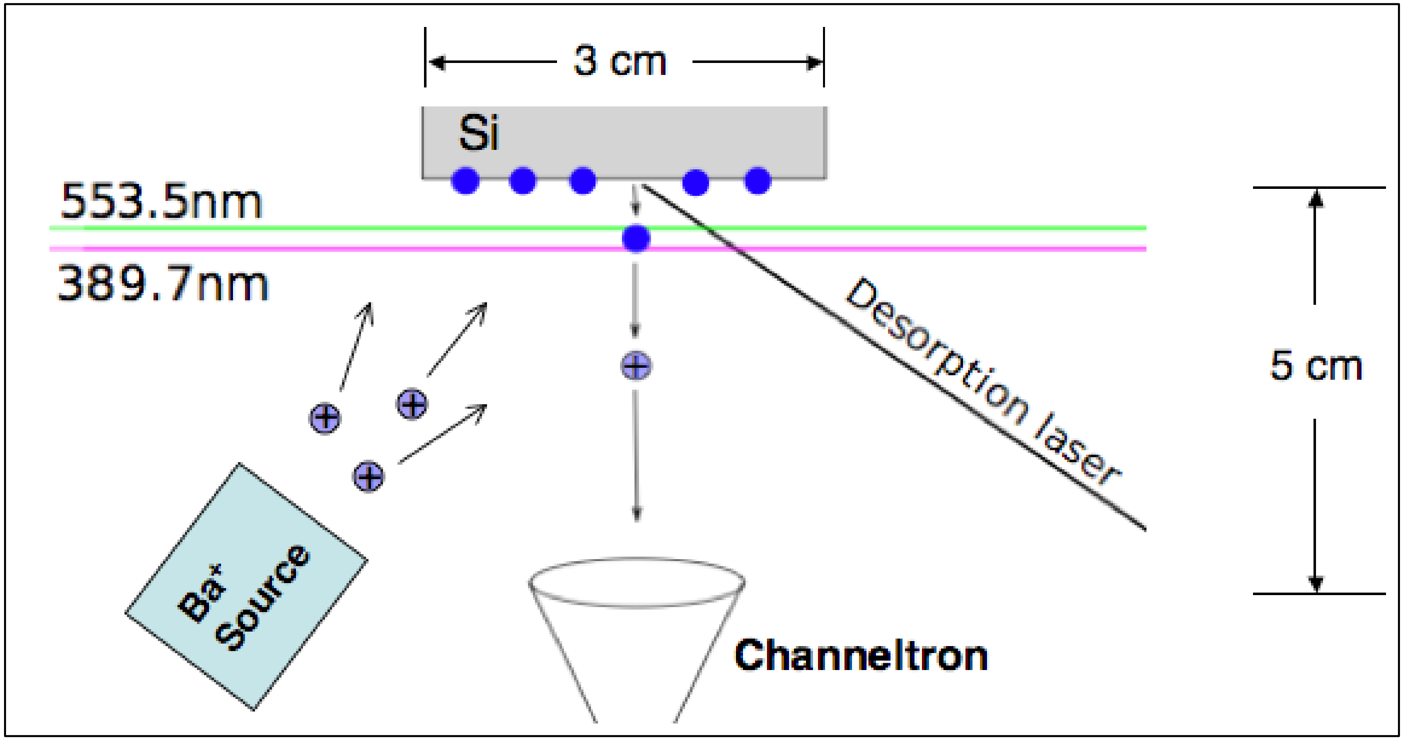
~9σ discrimination in 5s integration

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

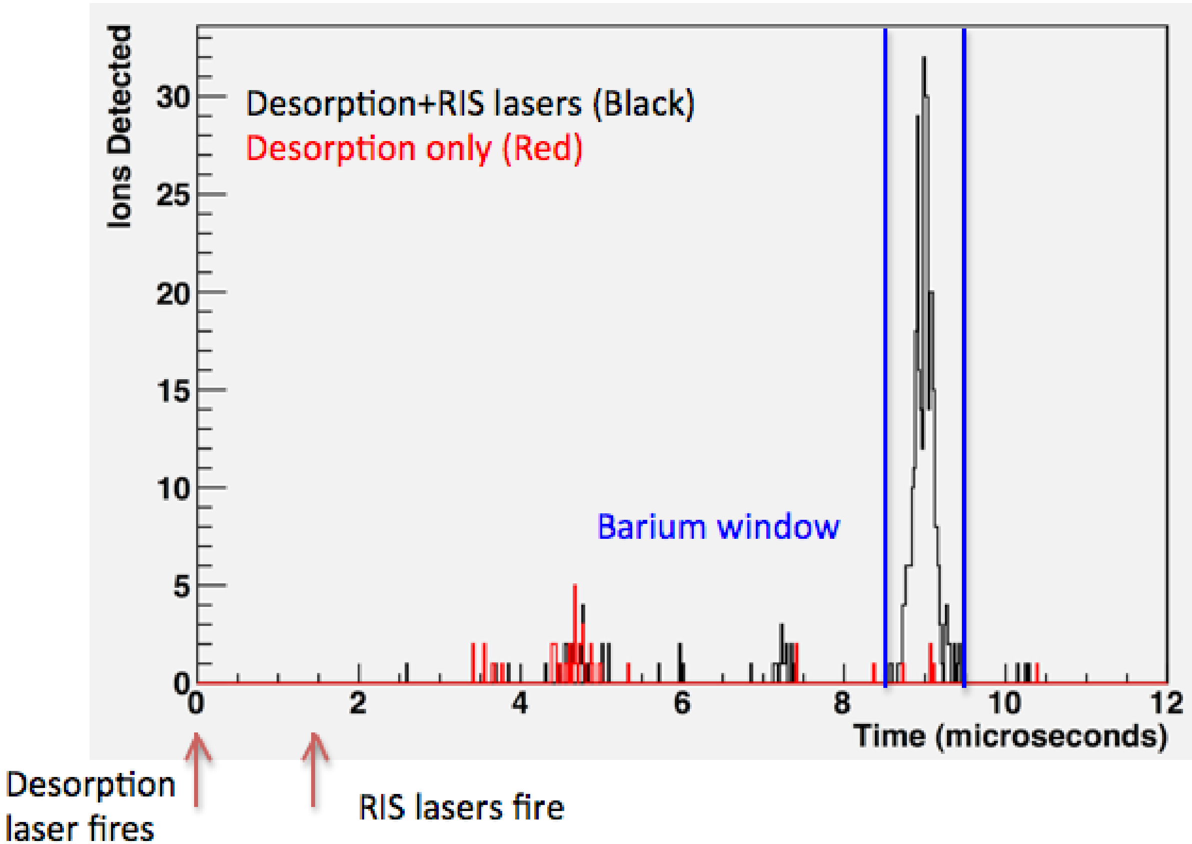
Ba^+ Tagging: RIS

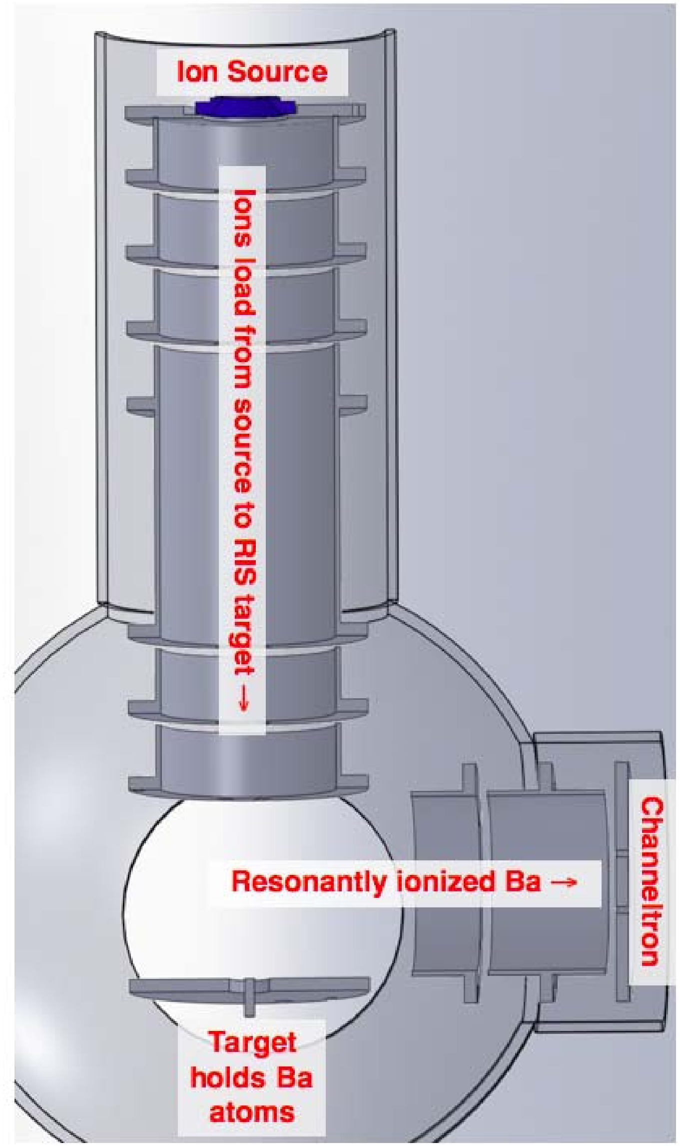
- Resonant Ionization Spectroscopy uses lasers tuned to atomic resonances to first *excite* and then *ionize* specific atoms.
- We use pulsed dye lasers at 553.5 nm and 389.7 nm.
- Autoionization: The 5d8d $^1P_1$ state decays to a lower energy ionized state, allowing use of the high cross section of the resonance to achieve ionization.





Ba⁺ Tagging: RIS





Efficiency of ~10^{-3} in “bulk mode” setup. New “single ion mode” setup about to start taking data.

Ba+ Tagging: Solid Xe

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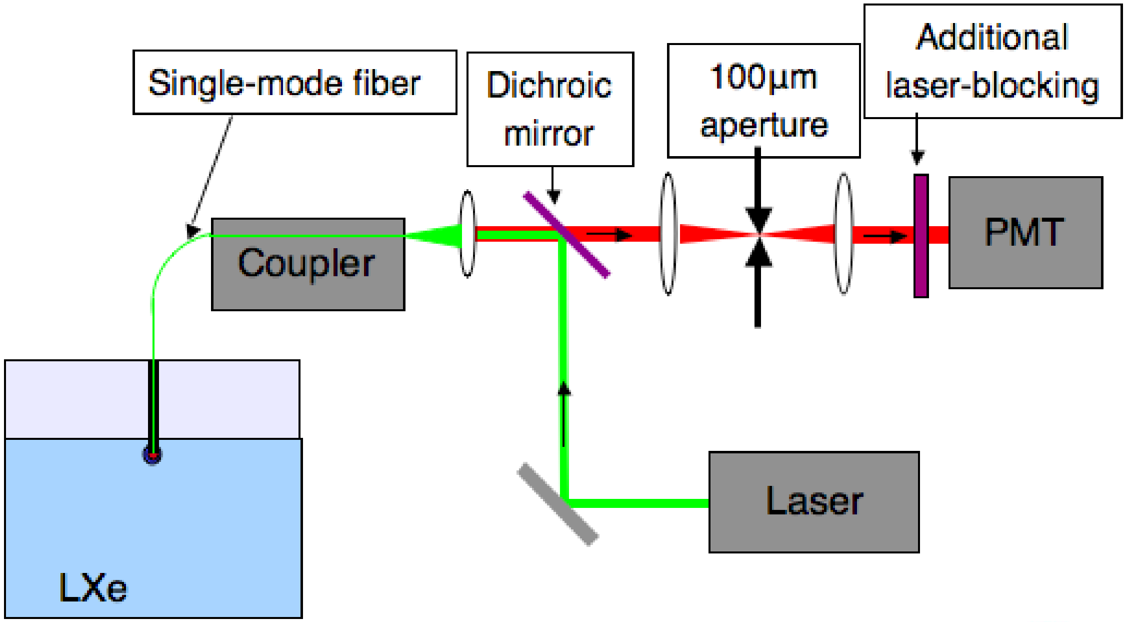
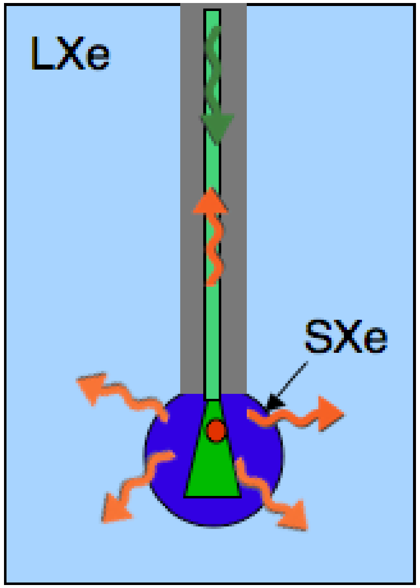
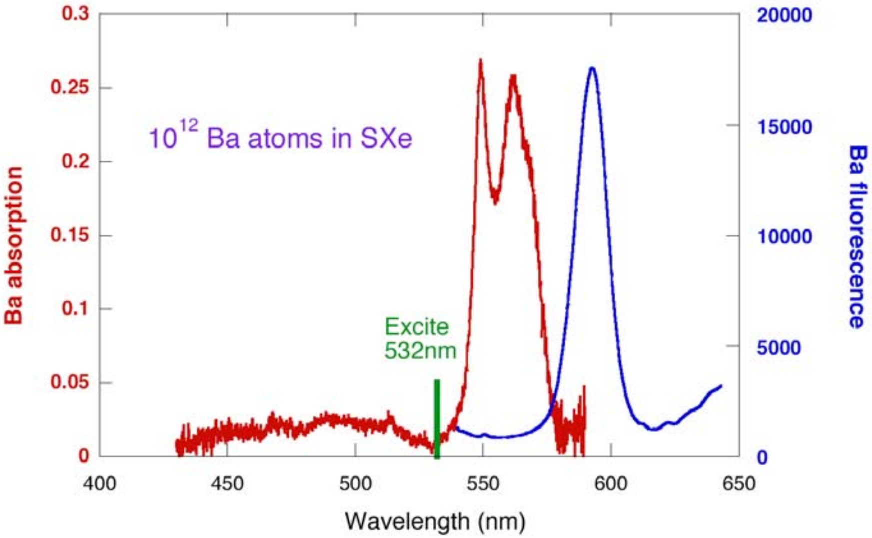




Laser light delivered by fiber to single Ba atom or ion in solid xenon. Fluorescence collected back up the fiber and detected by photomultiplier or APD.



Current detection limit: 10^4-10^5 Ba atoms. Improvement 10^4 in collection efficiency and 10^2 in laser intensity => *single Ba detection possible.*

Sensitivity of ton-scale EXO with barium tagging

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[1]	NSM[2]
Conservative	1	70	5	1.6*	0.5 (use 1)	$2*10^{27}$	19	24
Aggressive	10	70	10	1†	0.7 (use 1)	$4.1*10^{28}$	4.3	5.3

1) Simkovic et al. Phys. Rev. C**79**, 055501(2009)
2) Menendez et al., Nucl. Phys. A**818**, 139(2009)

EXO Collaboration

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