EXO

an Overview

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DBD09, Waikoloa Hilton, Oct 12, 2009

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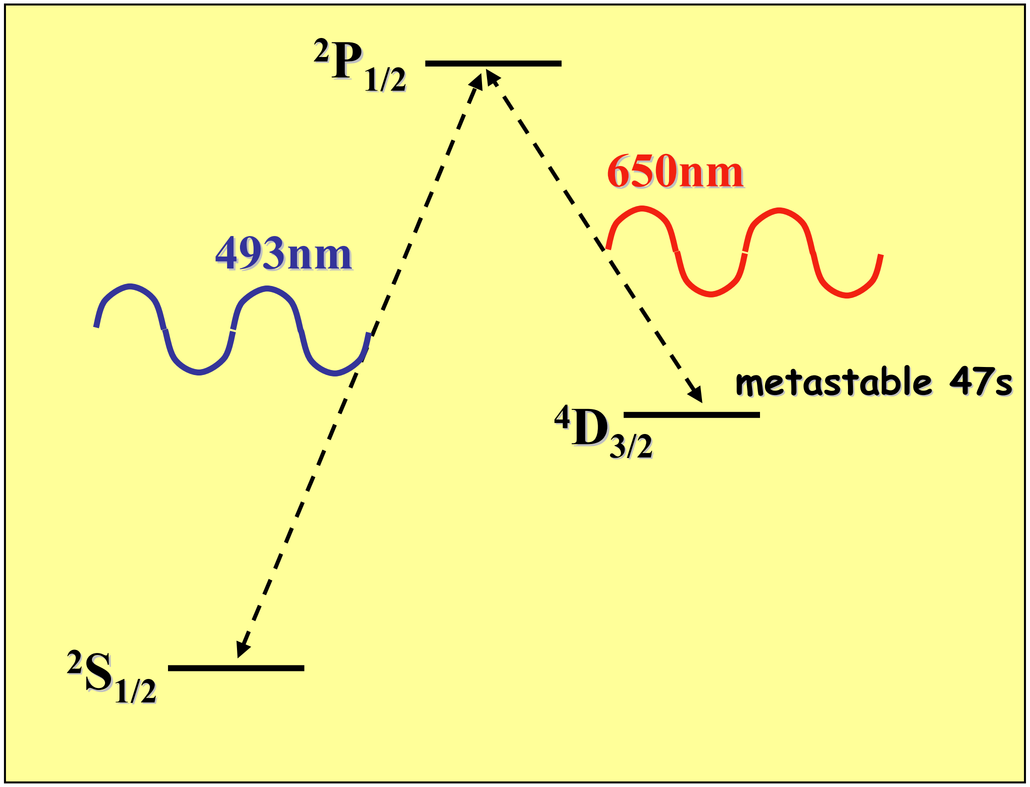
Xe is ideal for a large experiment

- No need to grow crystals
- Can be re-purified during the experiment
- No long lived Xe isotopes to activate
- Can be easily transferred in different detectors if alternate technologies become available
- Noble gas: easy(er) to purify
- ^{136}Xe enrichment easier and safer:
  - noble gas (no chemistry involved)
  - centrifuge feed rate in gram/s, all mass useful
  - centrifuge efficiency ~ Δm. For Xe 4.7 amu
- ^{129}Xe is a hyperpolarizable nucleus, under study for NMR tomography… a joint enrichment program ?

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

Ba^+ system best studied (Neuhauser, Hohenstatt, Toshek, Dehmelt 1980)
Very specific signature "shelving"
Single ions can be detected from a photon rate of 10^7/s

- Important additional constraint
- Drastic background reduction



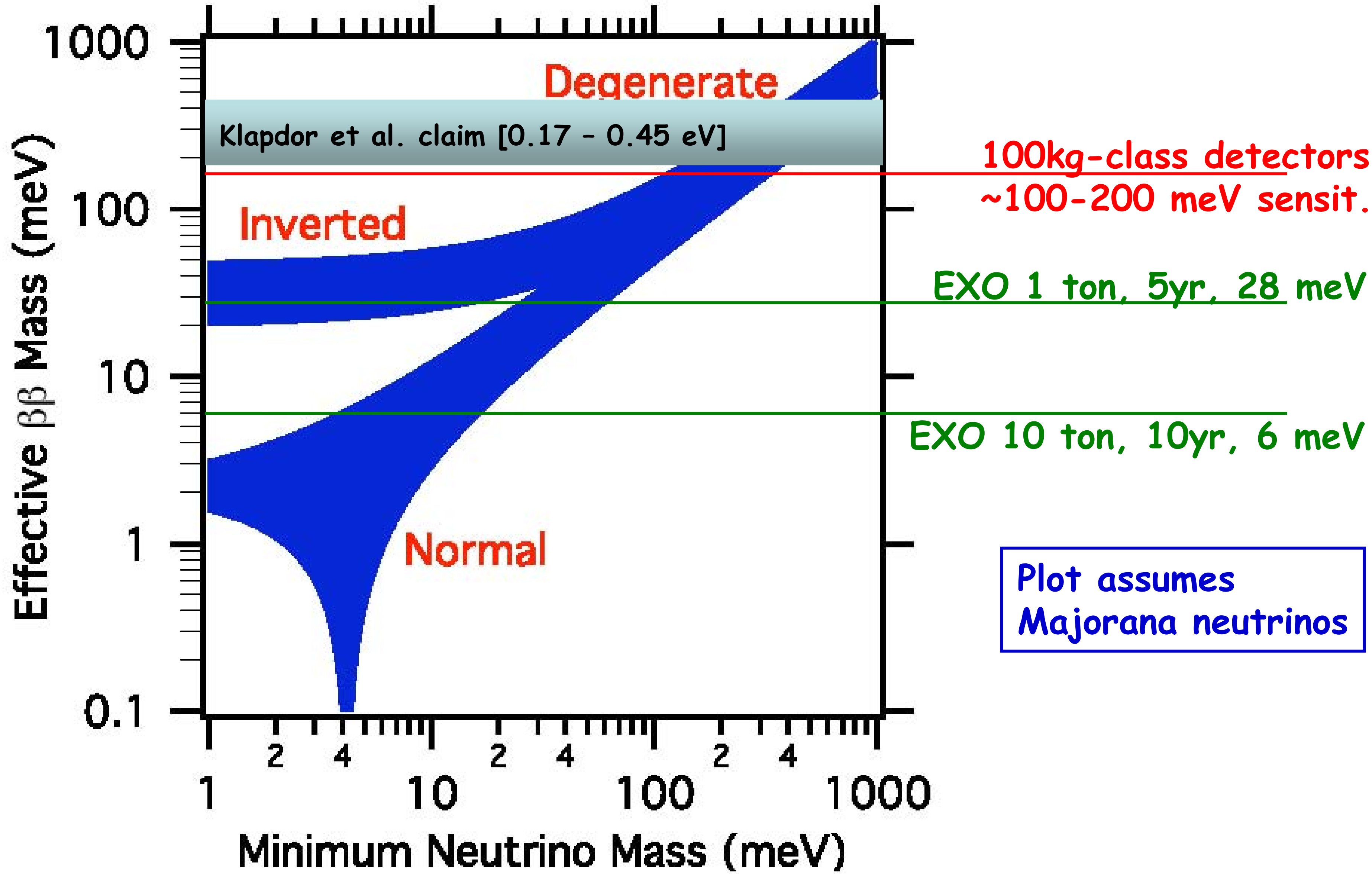
- This may be the only viable technique if <m> happens to be very small
- Xe (in gas phase) *is* the best way to try using decay kinematics to study the decay after it has been observed

Assume an "asymptotic" fiducial mass of 10 tons of ^{136}Xe at 80%

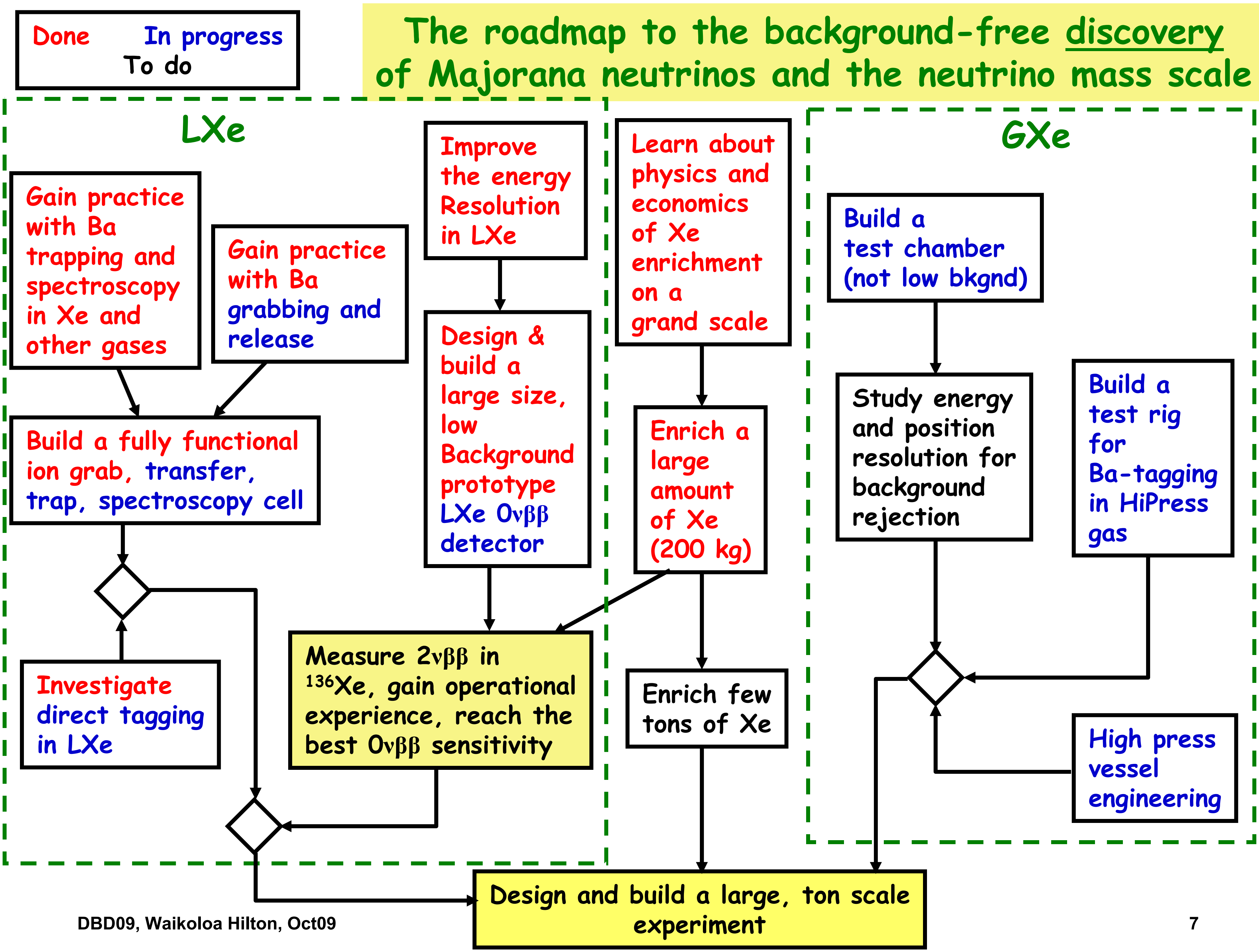
Mainly going in light bulbs, plasma displays and satellite propulsion

A somewhat natural scale:

- World production of Xe is ~40 ton/yr
- Detector size
- $2 \cdot 10^3$ size increase: good match to the 10^{-2} eV mass region



Plot from Avignone, Elliott, Engel arXiv:0708.1033 (2007)


Done
In progress
To do
The roadmap to the background-free discovery of Majorana neutrinos and the neutrino mass scale
LXe
Gain practice with Ba trapping and spectroscopy in Xe and other gases
Gain practice with Ba grabbing and release
Improve the energy Resolution in LXe
Design & build a large size, low Background prototype LXe 0νββ detector
Build a fully functional ion grab, transfer, trap, spectroscopy cell
Investigate direct tagging in LXe
Measure 2νββ in 136Xe, gain operational experience, reach the best 0νββ sensitivity
Learn about physics and economics of Xe enrichment on a grand scale
Enrich a large amount of Xe (200 kg)
Enrich few tons of Xe
GXe
Build a test chamber (not low bkgnd)
Study energy and position resolution for background rejection
Build a test rig for Ba-tagging in HiPress gas
High press vessel engineering
Design and build a large, ton scale experiment

EXO-200

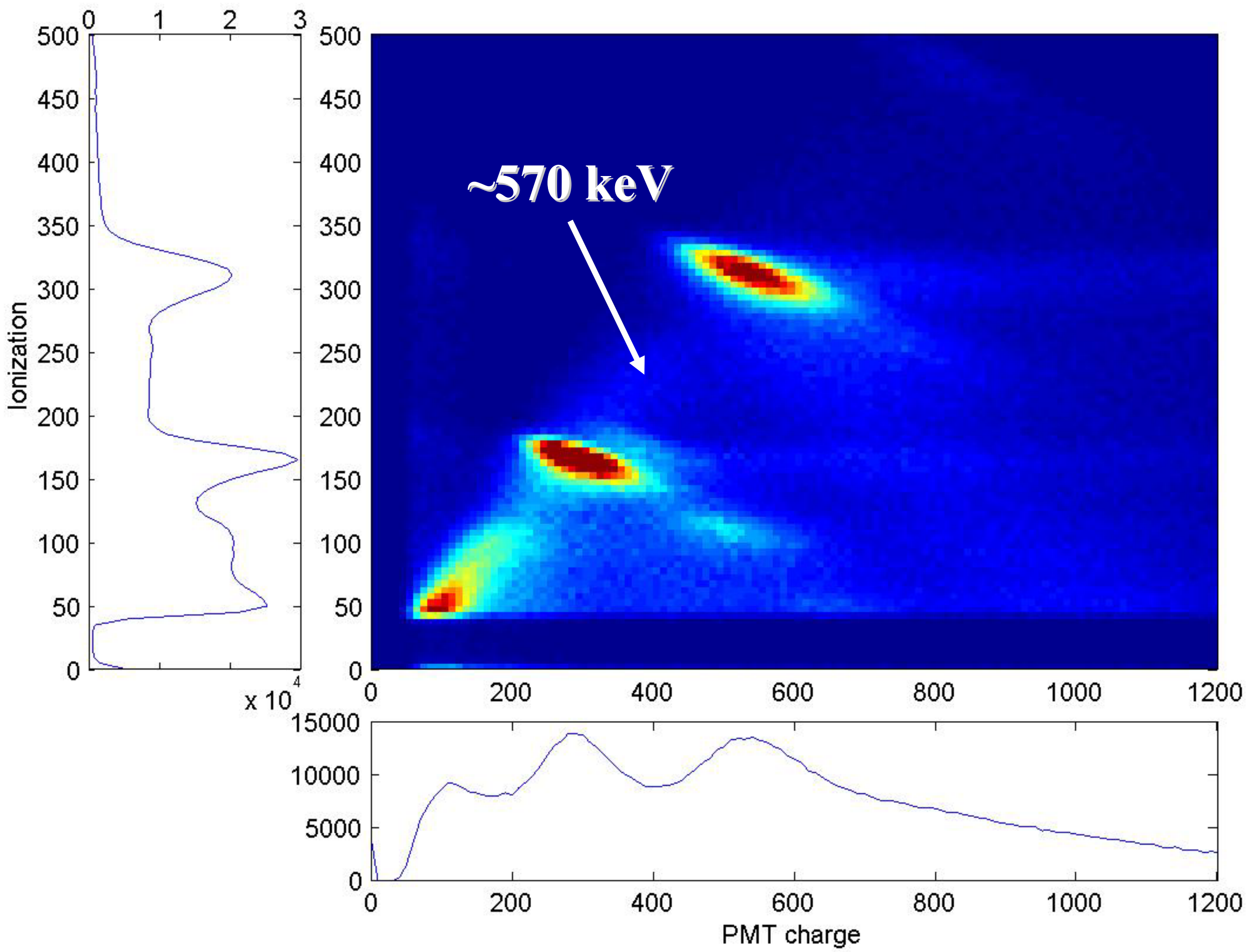
See also:

L.Yang, "Status of the EXO-200 experiment"
DJ2, Thursday 19:15

R.Neilson, "Large Area APDs in the EXO-200 experiment"
DJ3, Thursday 19:30

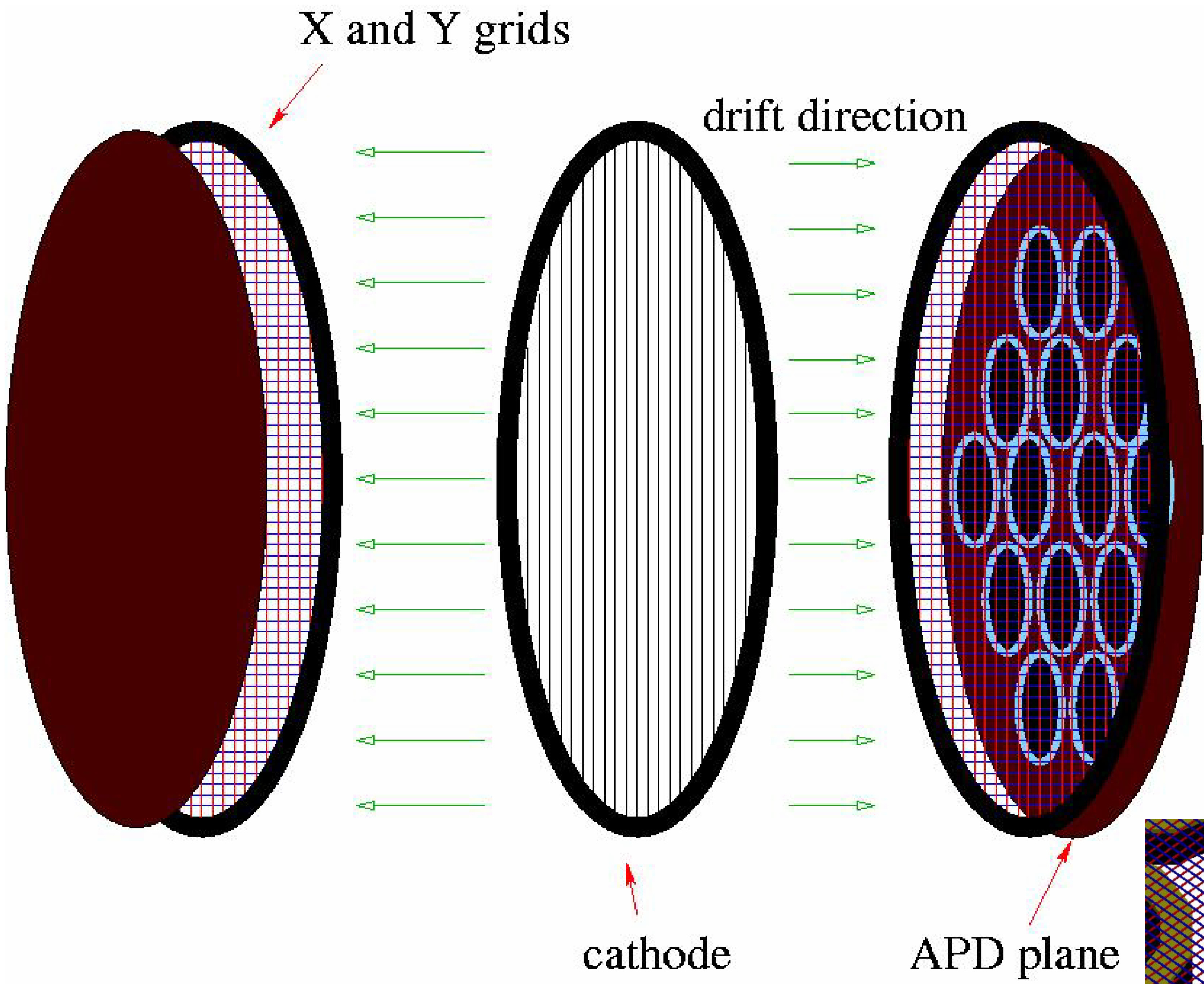
Both ionization and scintillation readout to optimize E resolution → see Steve Elliott's talk

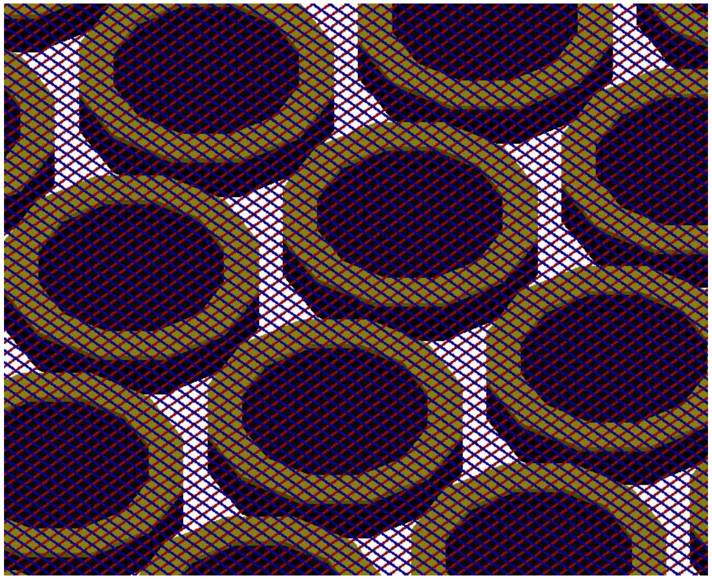
Expect σ_E<1.4% at 2.5MeV

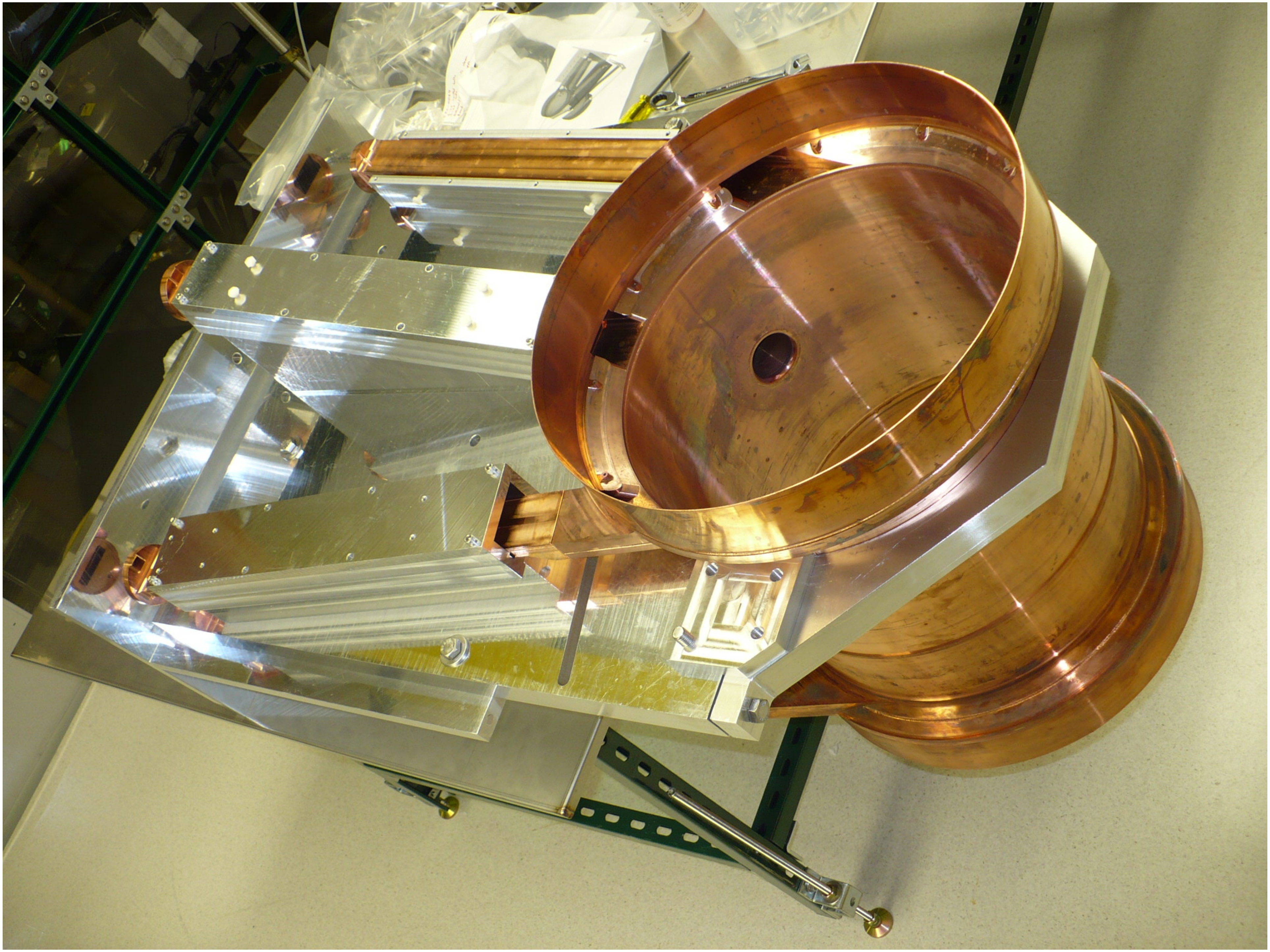


E.Conti *et al.*, Phys Rev B 68 (2003) 054201

EXO-200 TPC basics

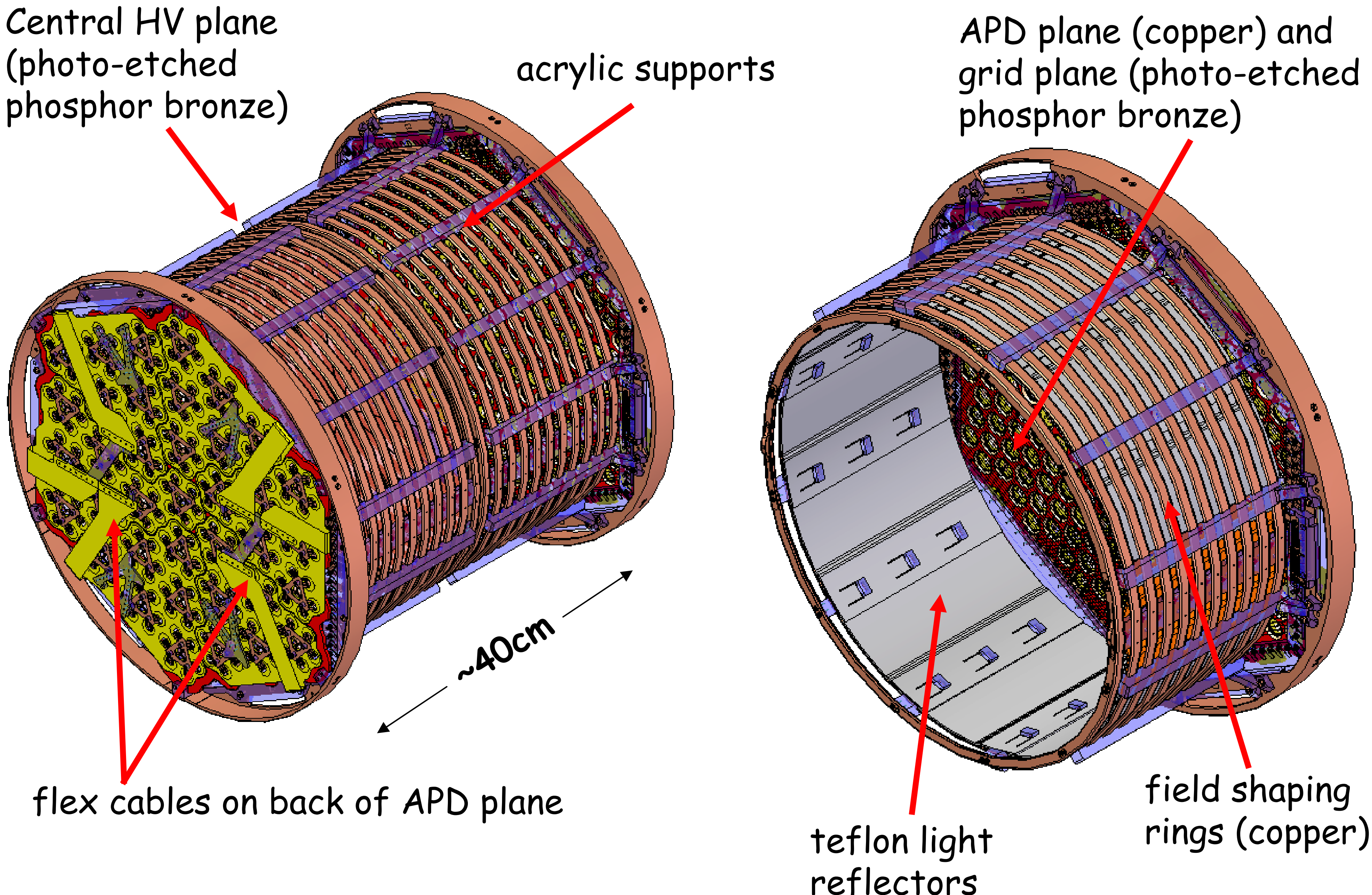


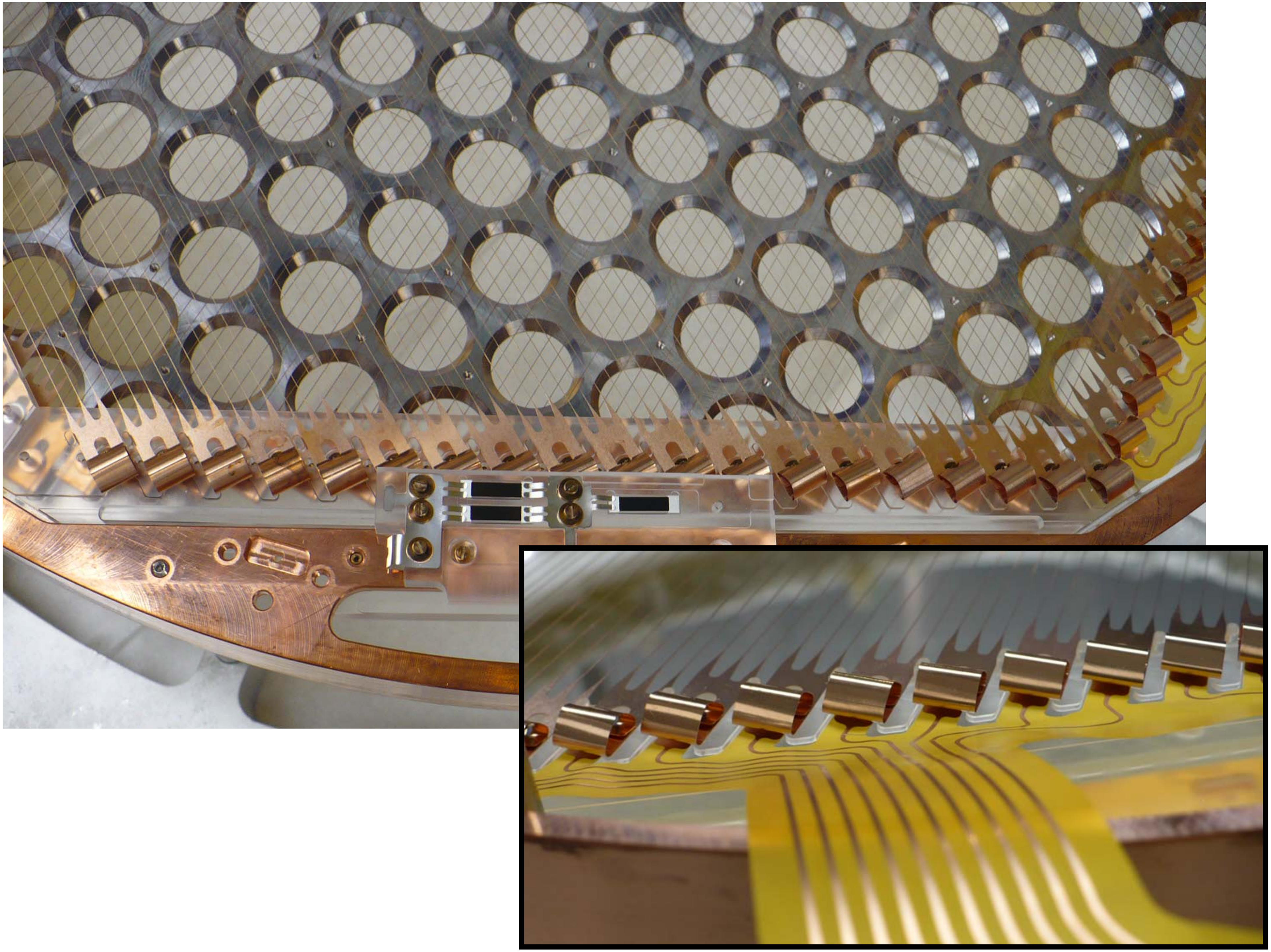


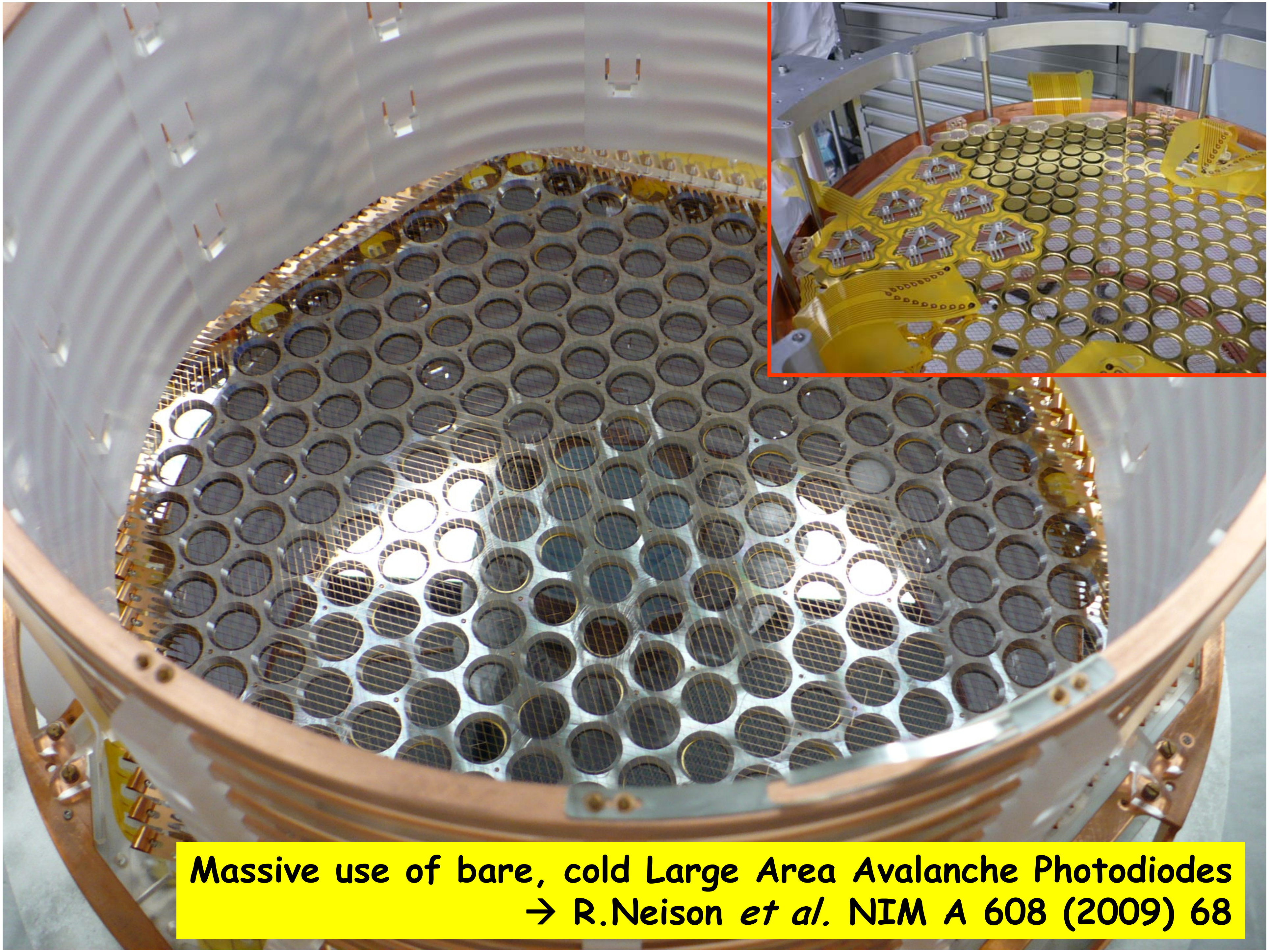


Massive program of materials screening for radioactive contamination:
D.S.Leonard *et al.*, NIM A 591 (2008) 490
(to be updated soon)

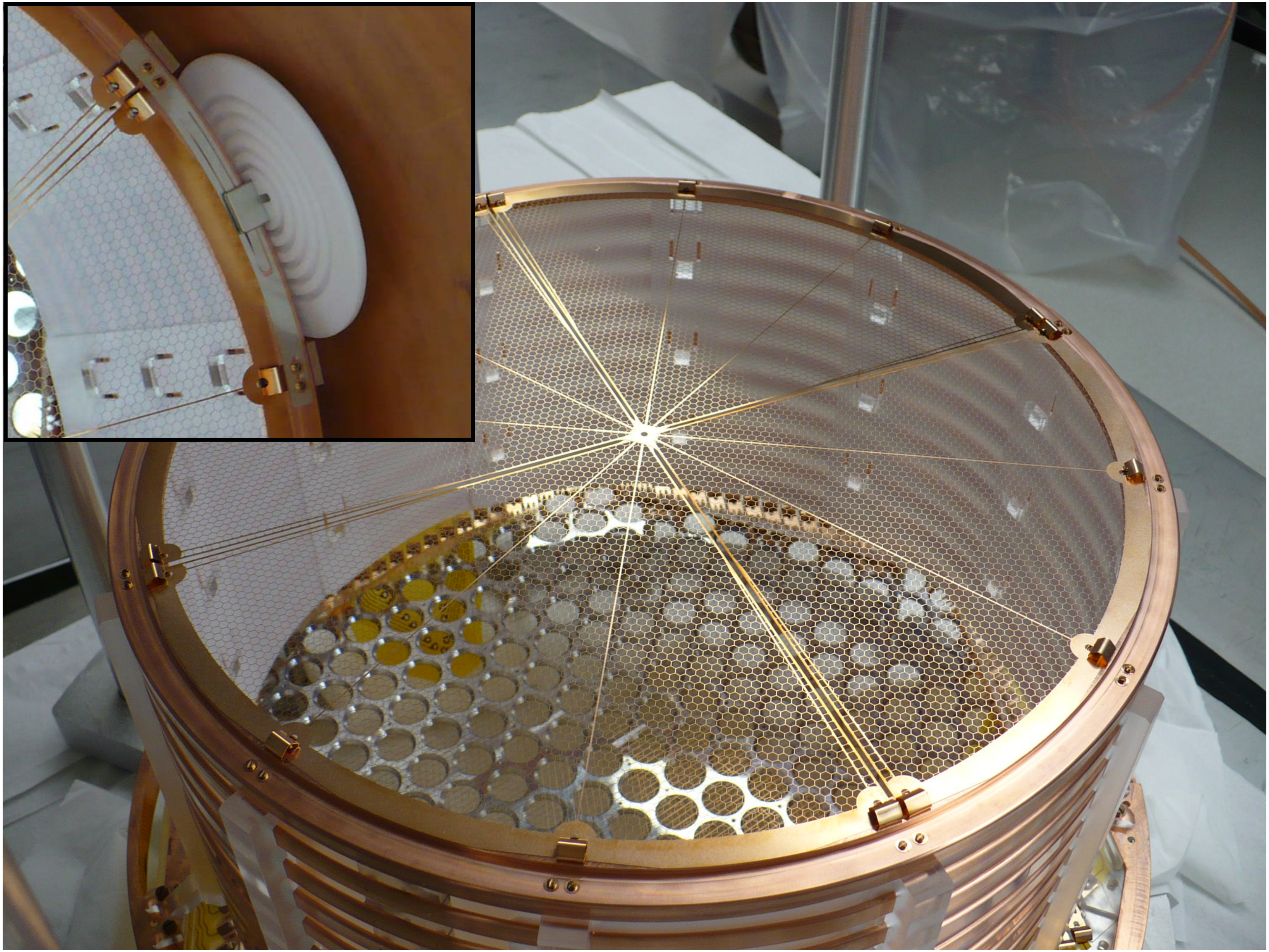
EXO-200 LXe TPC field cage & readout planes

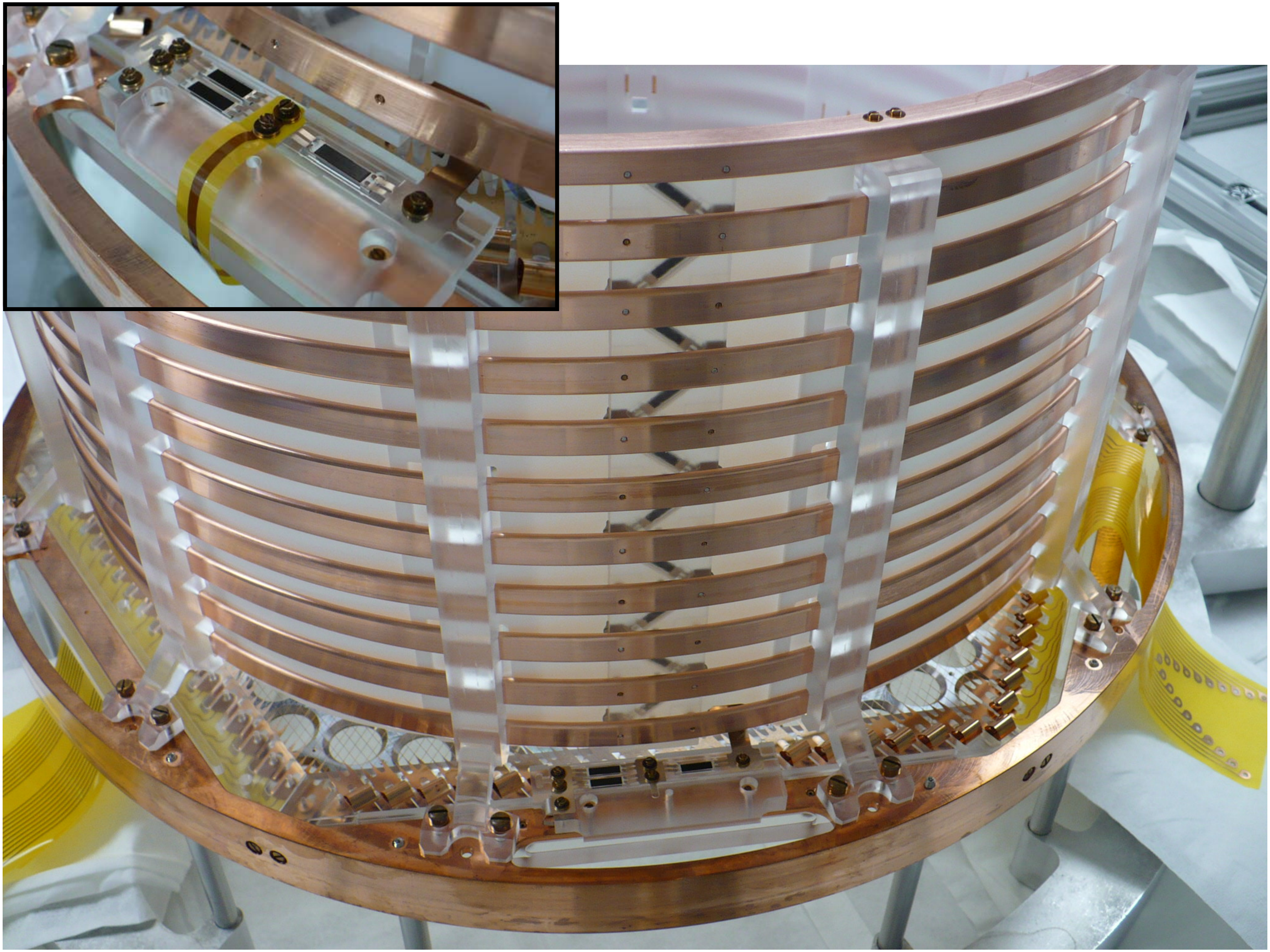


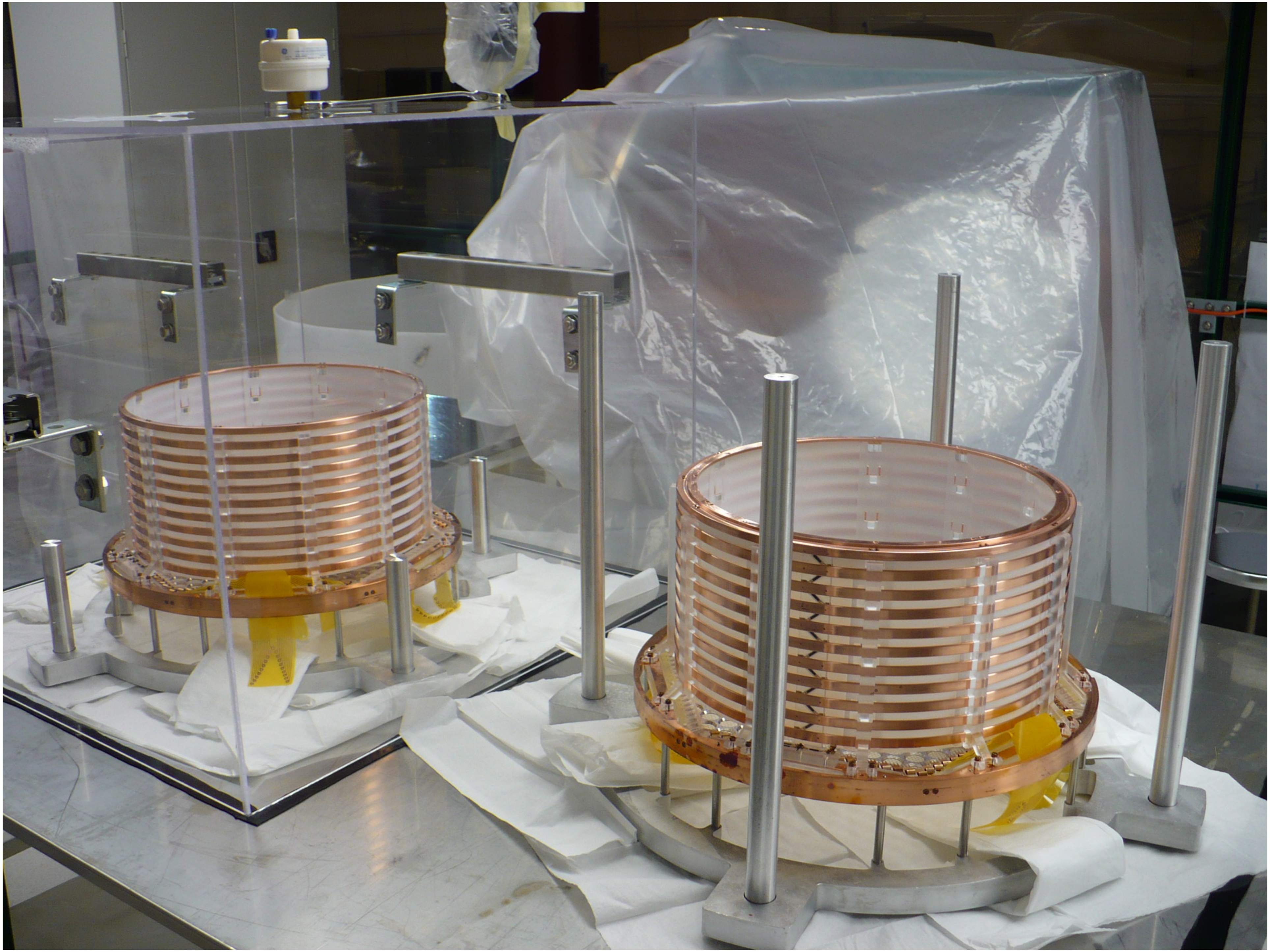


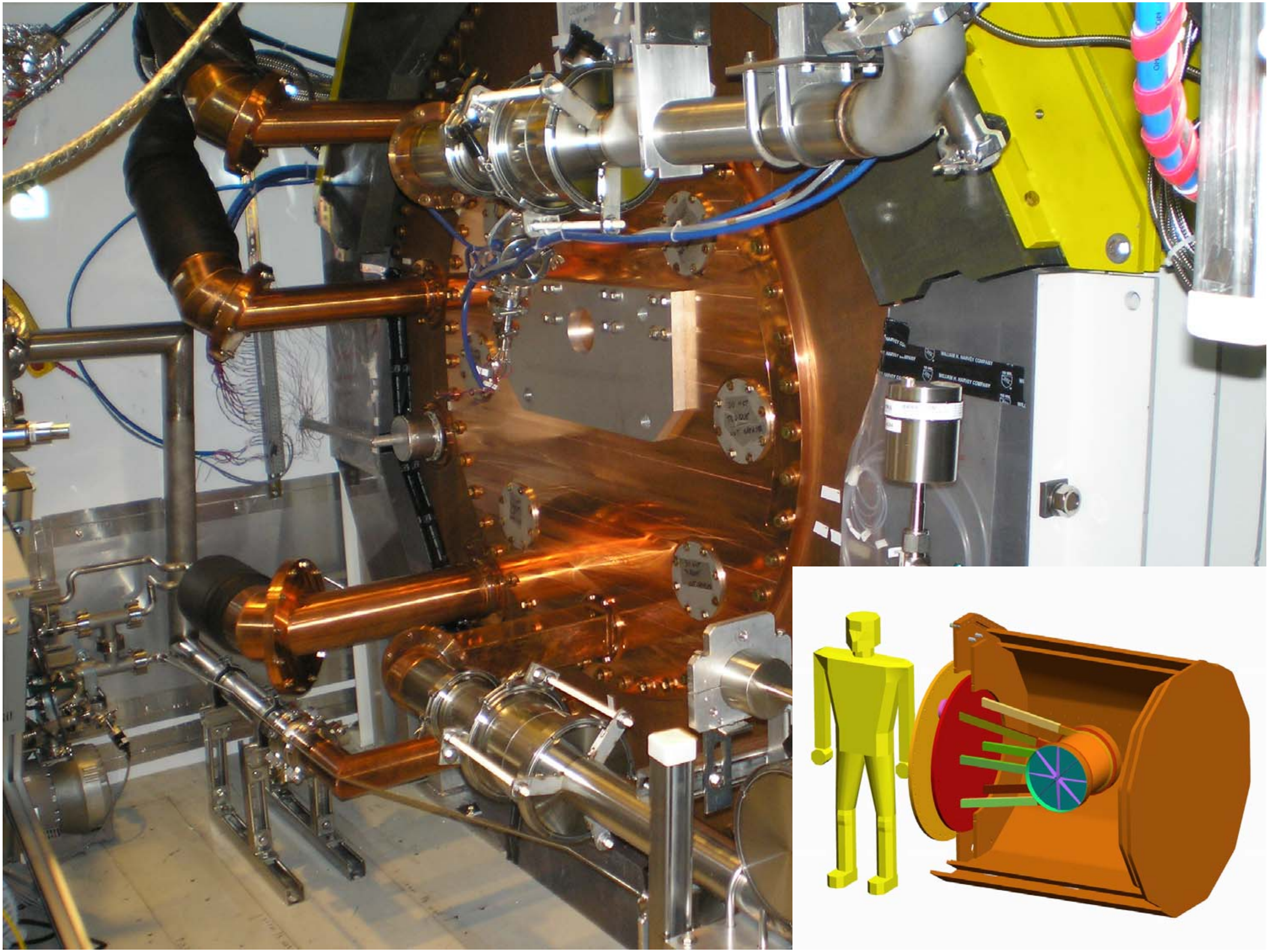


Massive use of bare, cold Large Area Avalanche Photodiodes
→ R.Neison *et al.* NIM A 608 (2009) 68

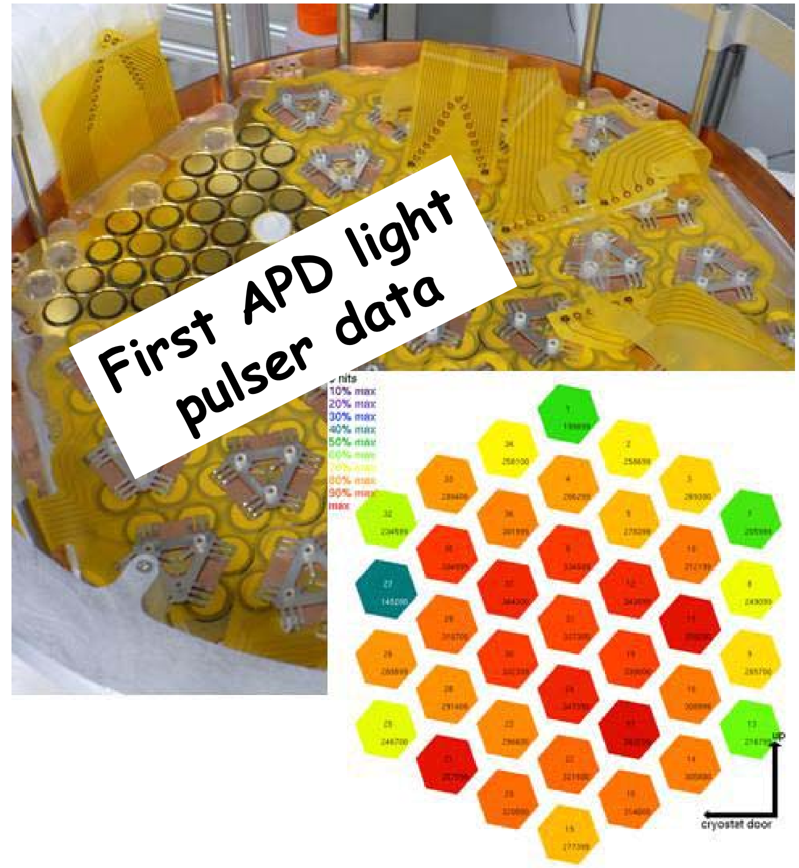








EXO-200 Summary



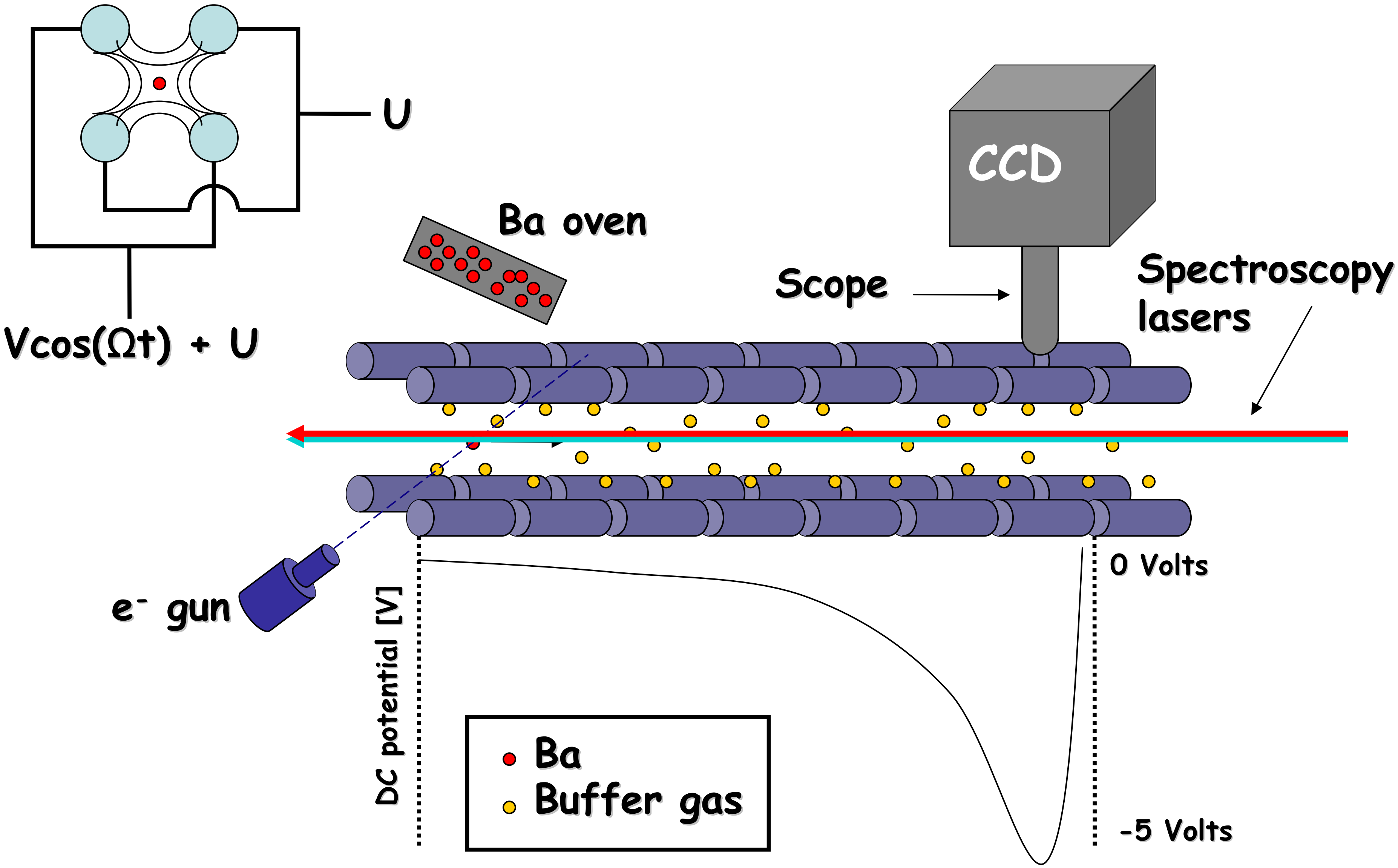
- TPC was tested with full electronics in the Summer 09 and passed all tests (but of course w/o LXe).
- TPC being packed, to arrive WIPP on Oct 31, 09
- Commissioning test run of all cryogenics at WIPP ongoing
- Expect to install TPC in the cryostat starting in ~ late Nov 09
- Expect to start running sometimes in early 2010

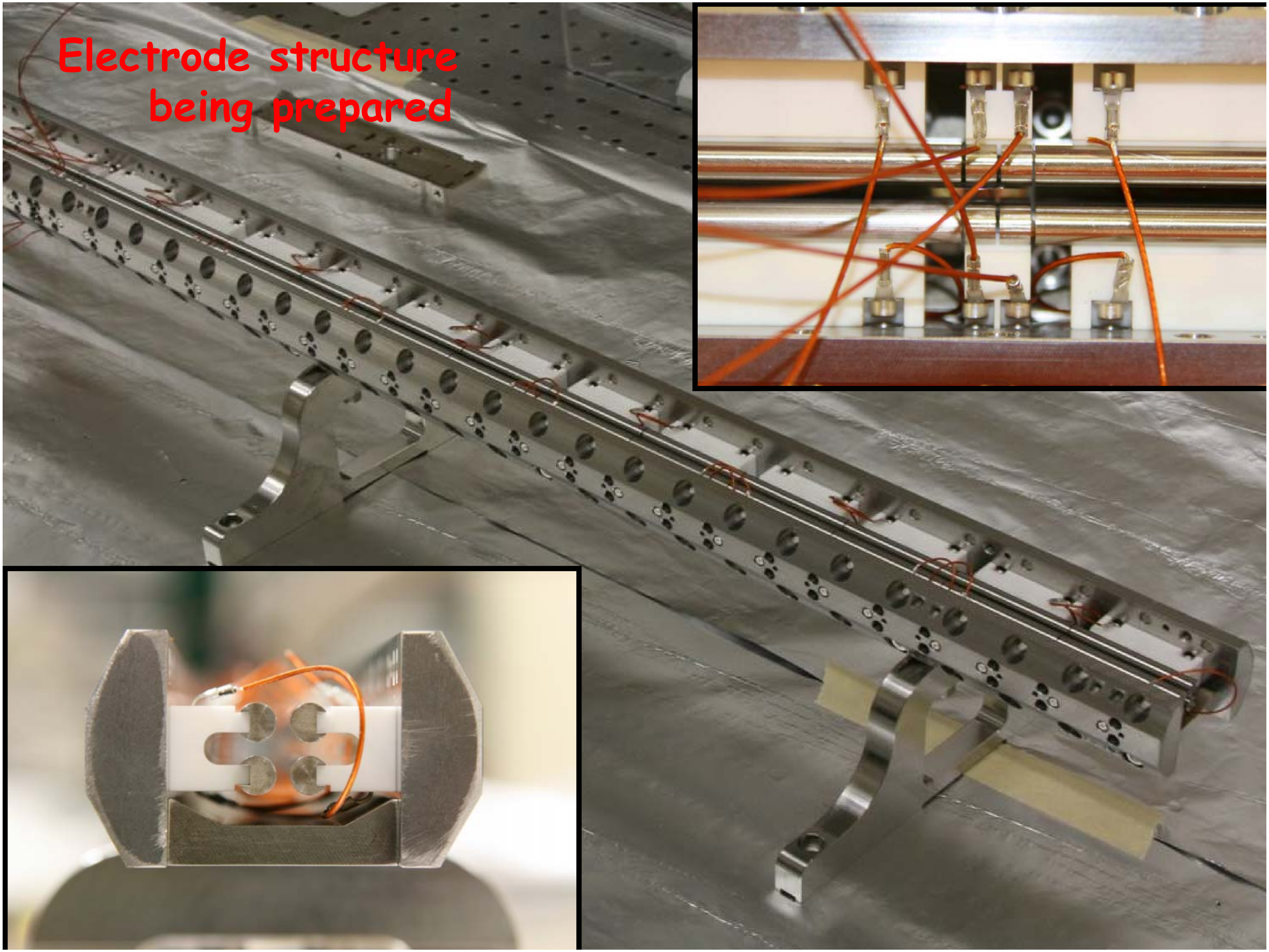
Ba tagging R&D

See also:

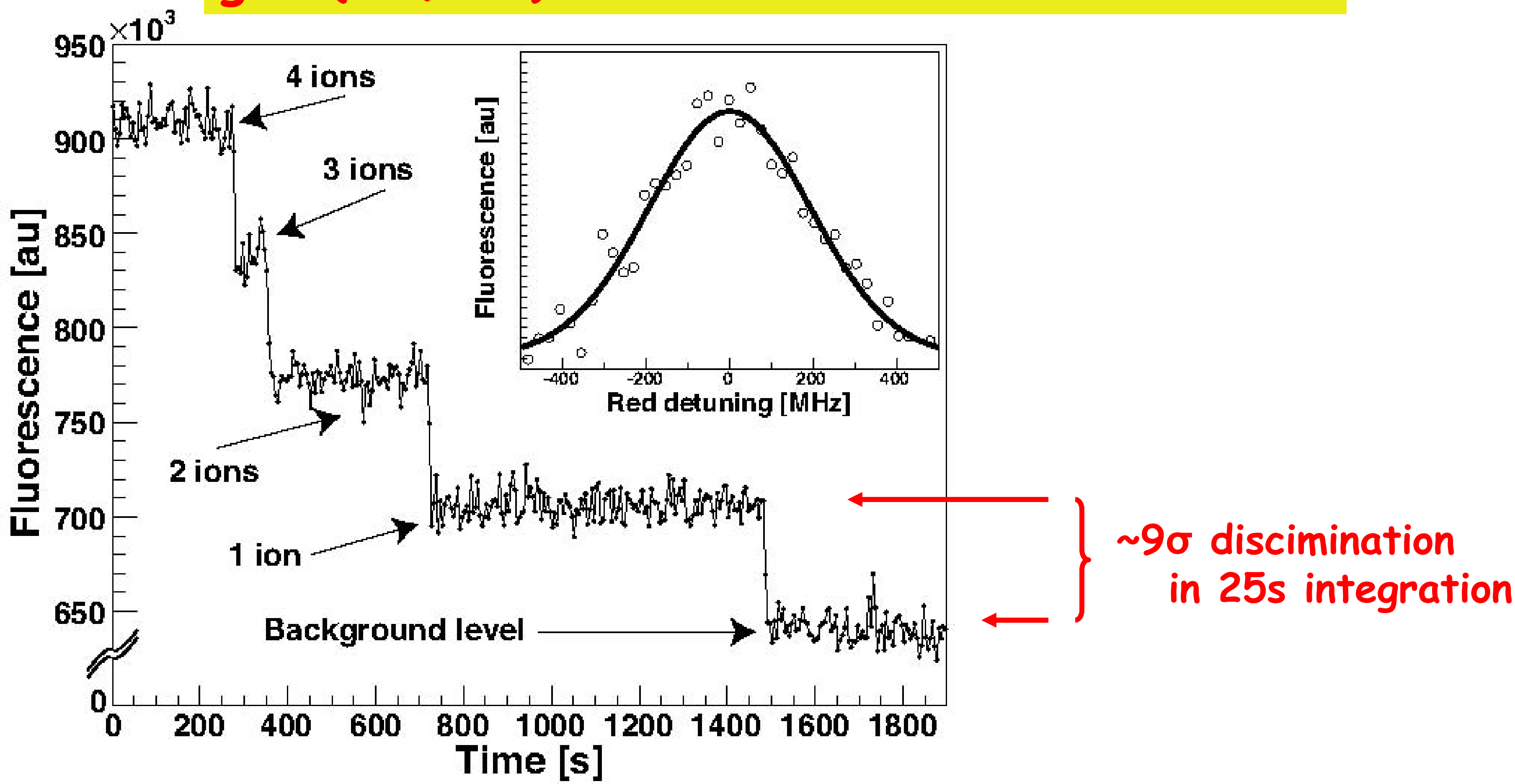
A.Reimer-Mueller, "The Barium Tagging system for EXO"
DJ4, Thursday 19:45

Ba^+ identification in a Linear Ion Trap



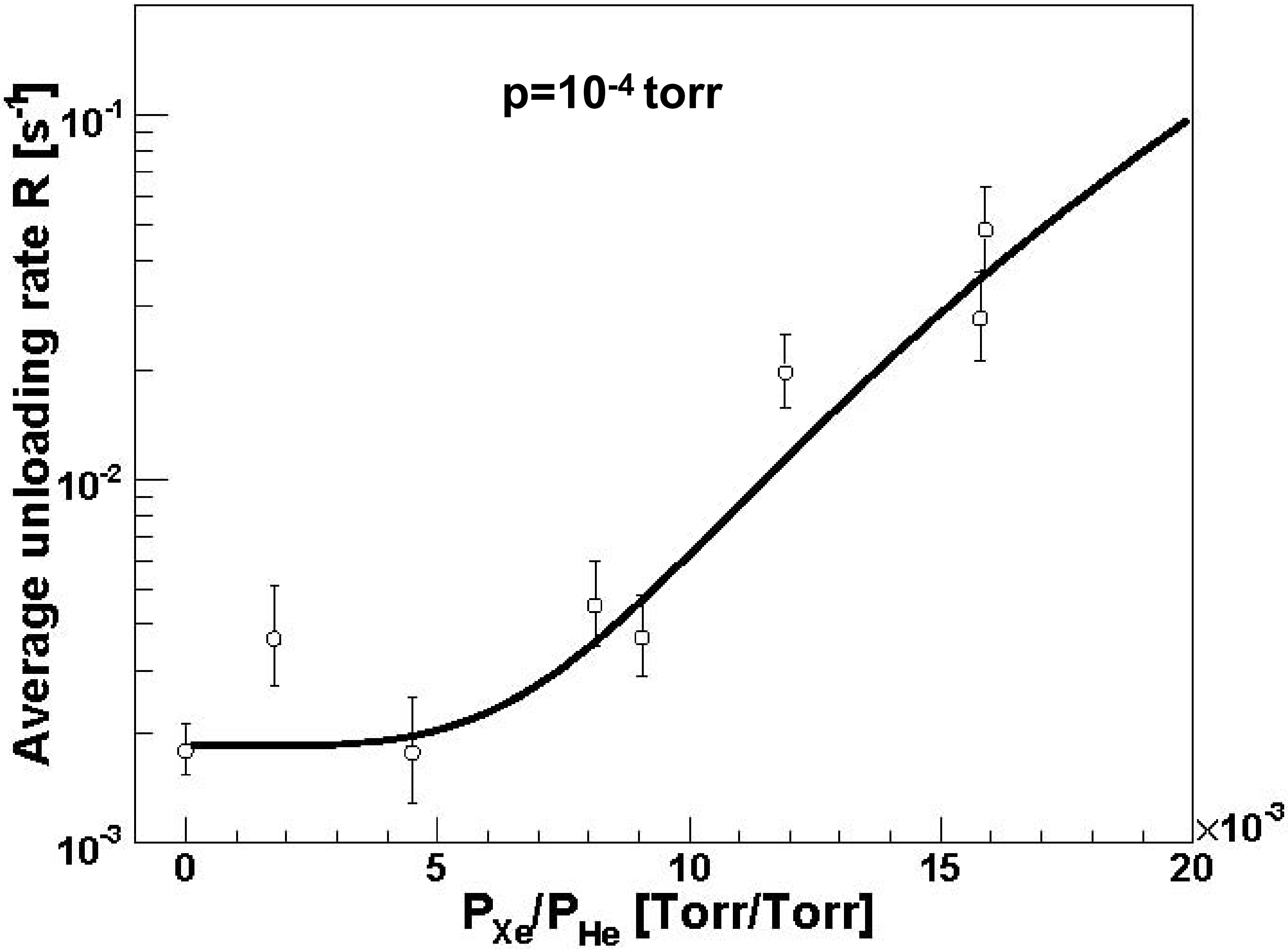

Electrode structure
being prepared

First single ion detection in high pressure gas (He, Ar)

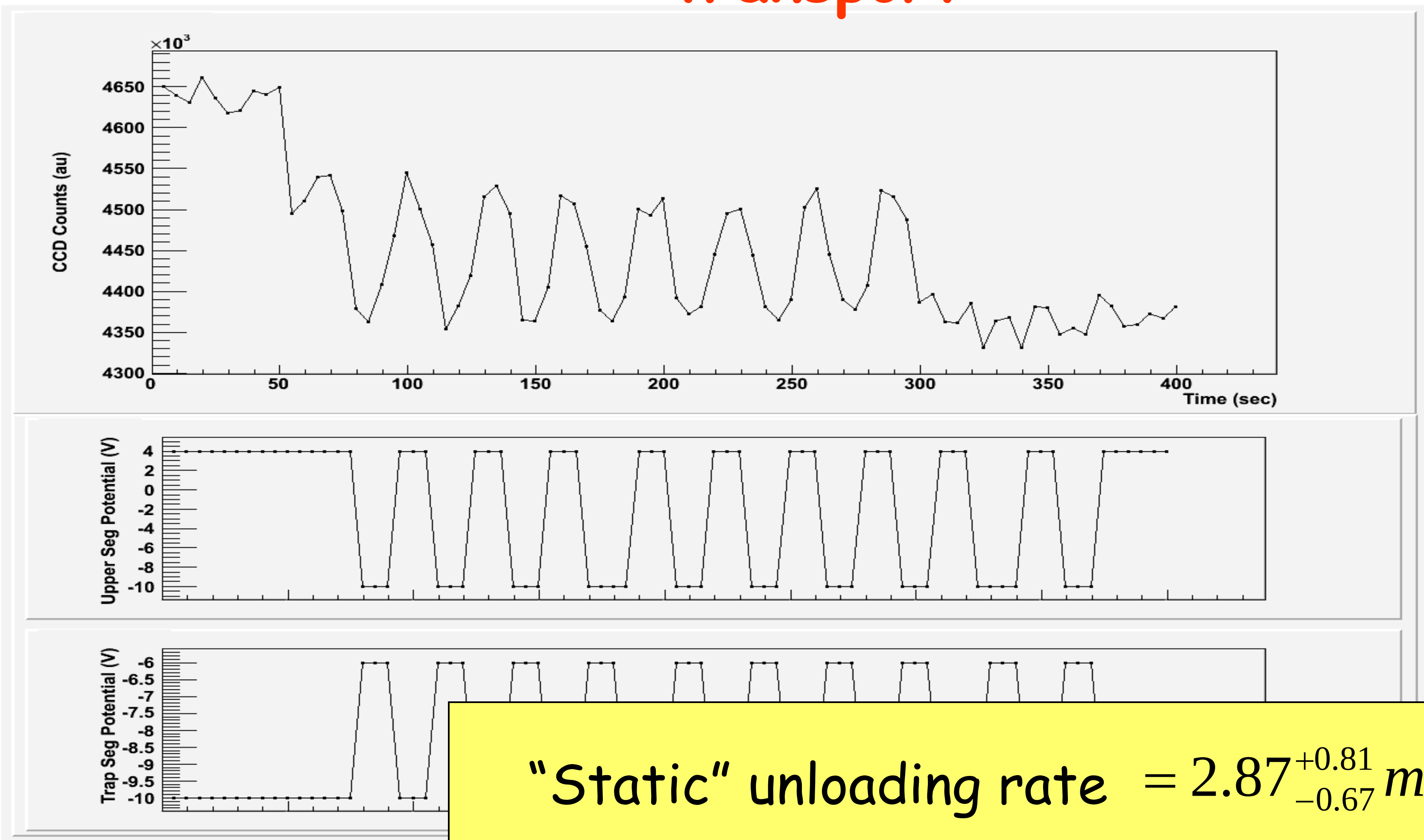


M.Green et al. arXiv:0702122, Phys Rev A 76 (2007) 023404
B.Flatt et al. arXiv:0704.1646, NIM A 578 (2007) 409

Single ion spectroscopy & identification possible in some Xe atmosphere provided He is added to the trap



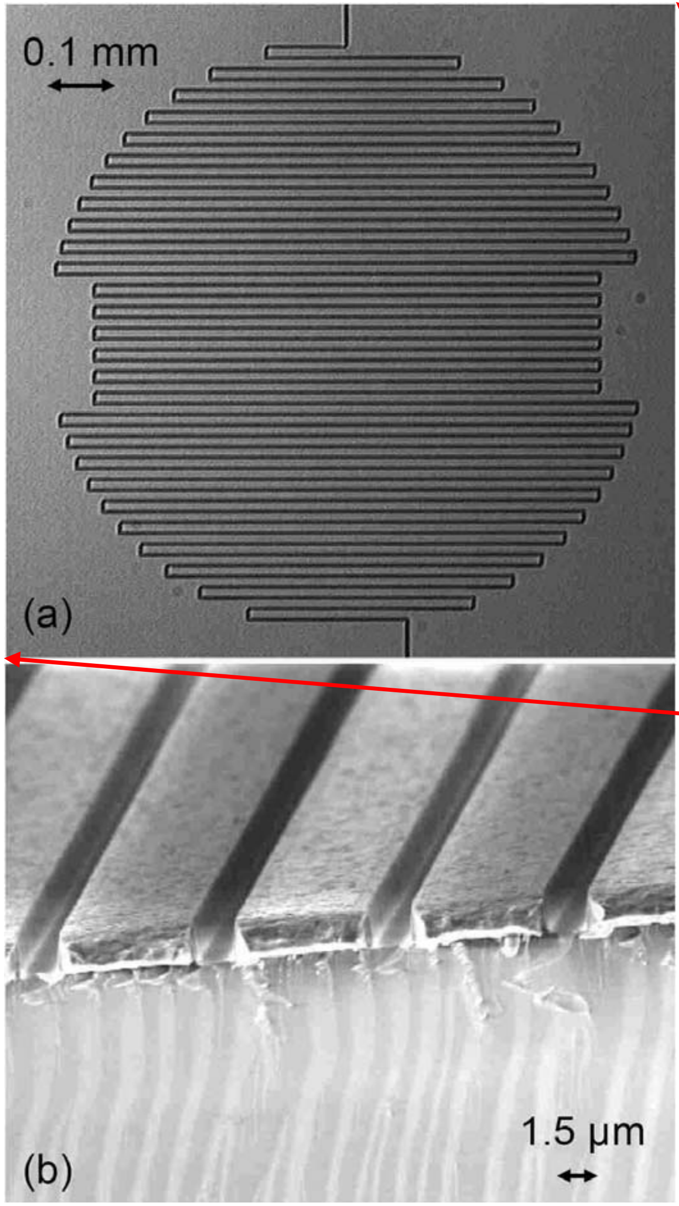
Trap also allows for very "clean" ion transport



"Static" unloading rate $= 2.87^{+0.81}_{-0.67}\, mHz$

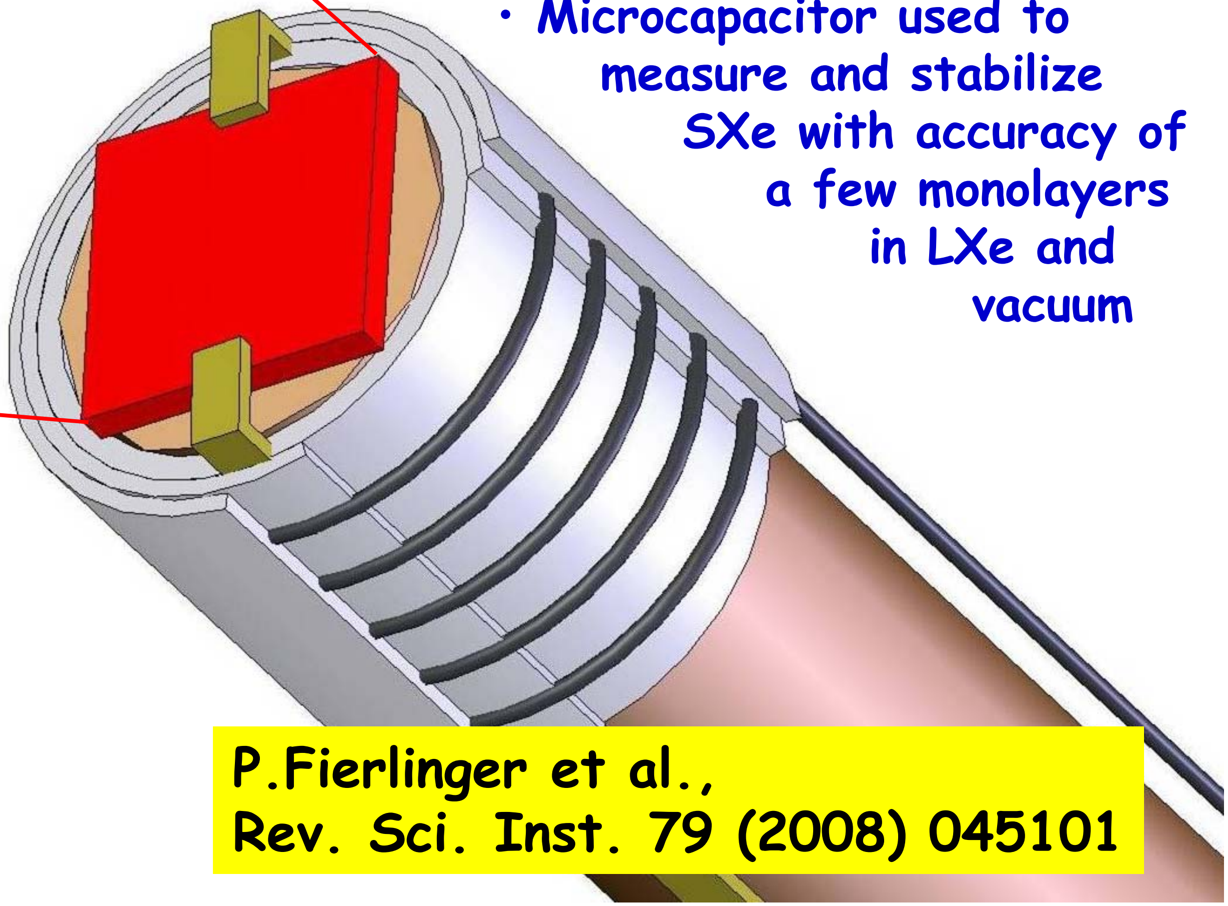
"Cycling" unloading rate $= 7.80^{+1.56}_{-2.34}\, mHz$

Remaining challenge is the efficient transfer of single Ba ions from LXe to the ion trap



Cryogenic dipstick

- Capture ion on SXe coating
- LHe cooling (~20K) to maintain stable SXe coating in 10^{-8} torr vacuum
- Microcapacitor used to measure and stabilize SXe with accuracy of a few monolayers in LXe and vacuum



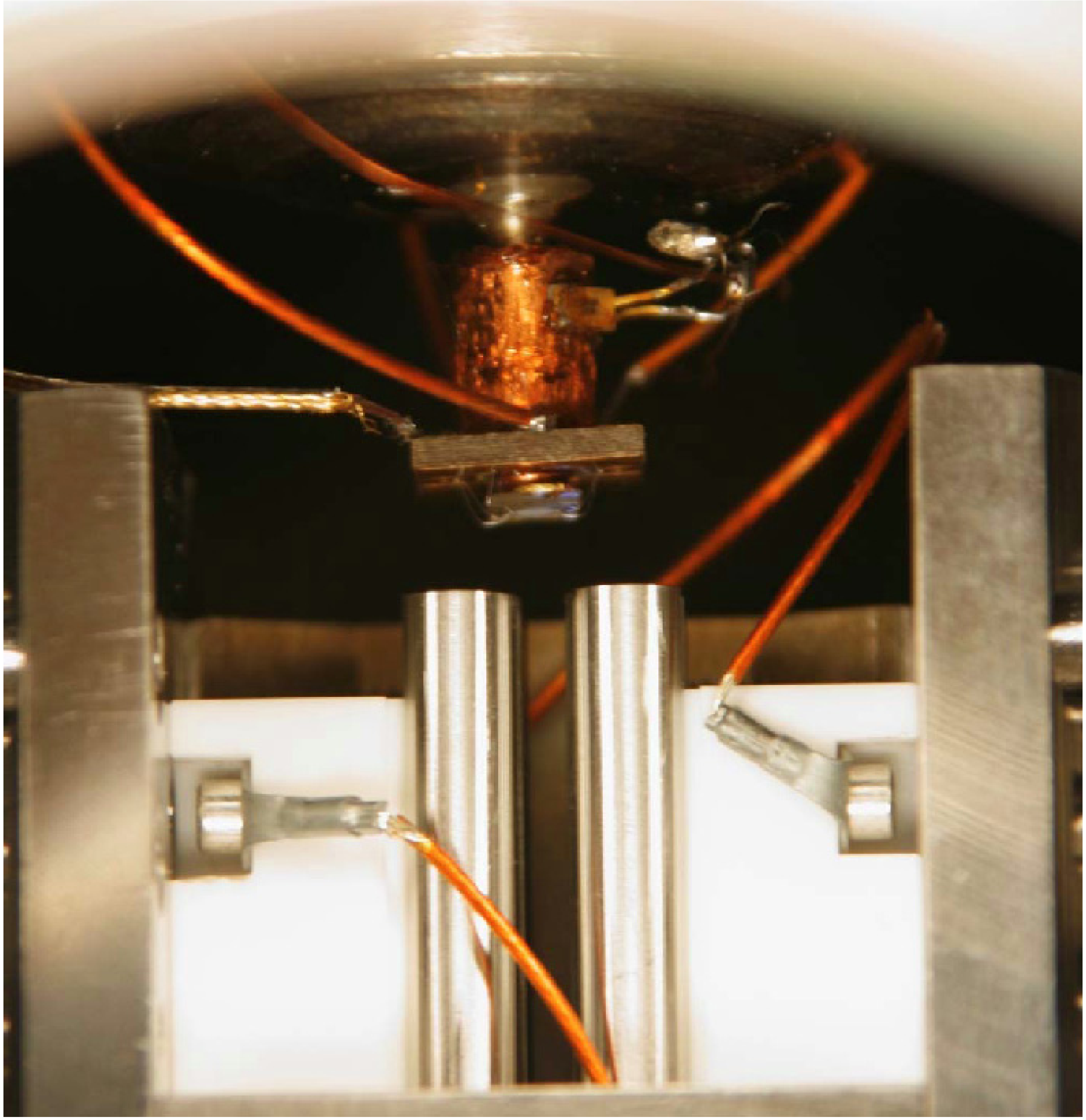
P.Fierlinger et al.,
Rev. Sci. Inst. 79 (2008) 045101

In progress...

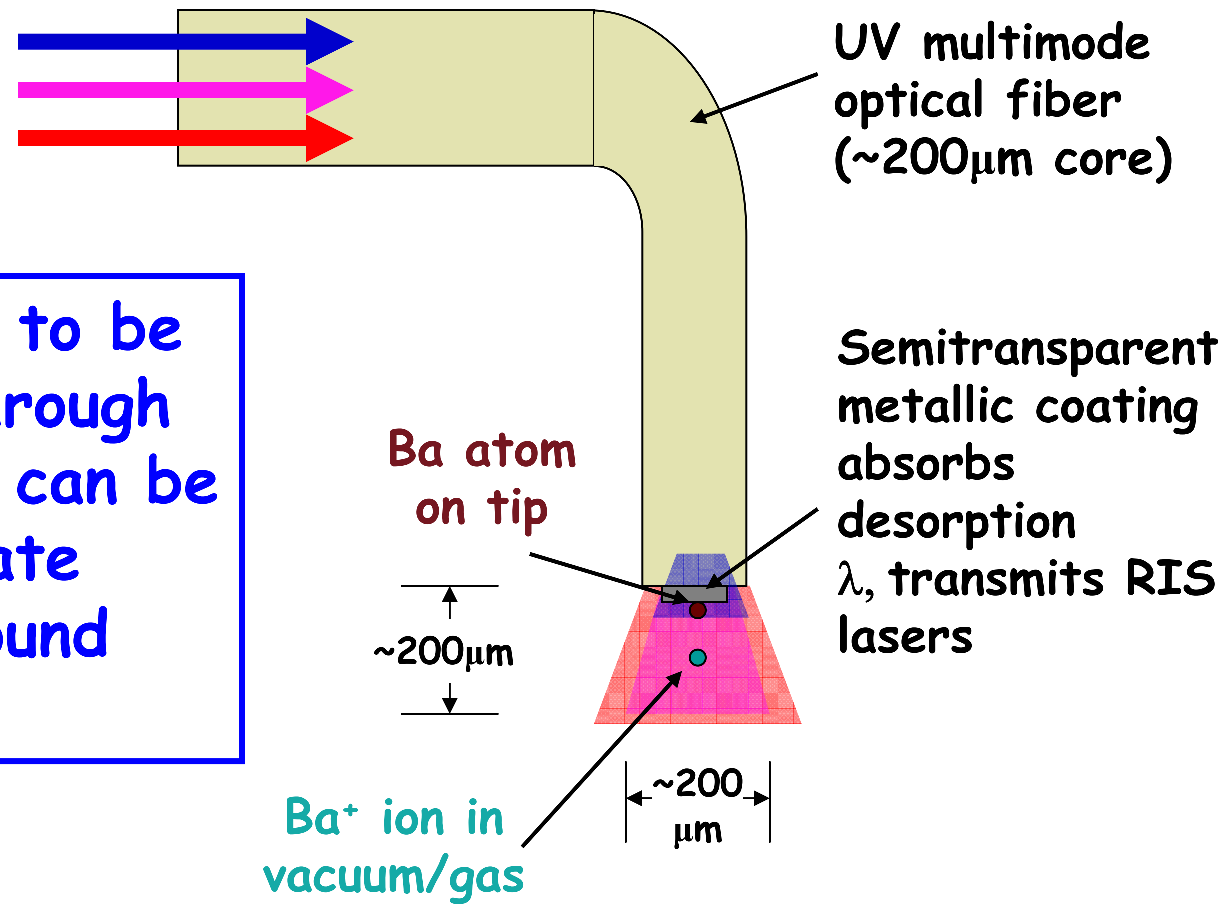
Shoot ions from the trap onto the cryotip and back into the ion trap

Measure the product of efficiencies

This does not work yet:
- *Does the Ba^+ neutralize in SXe?*
- *Does the Ba^+ get emitted coated with Xe?*



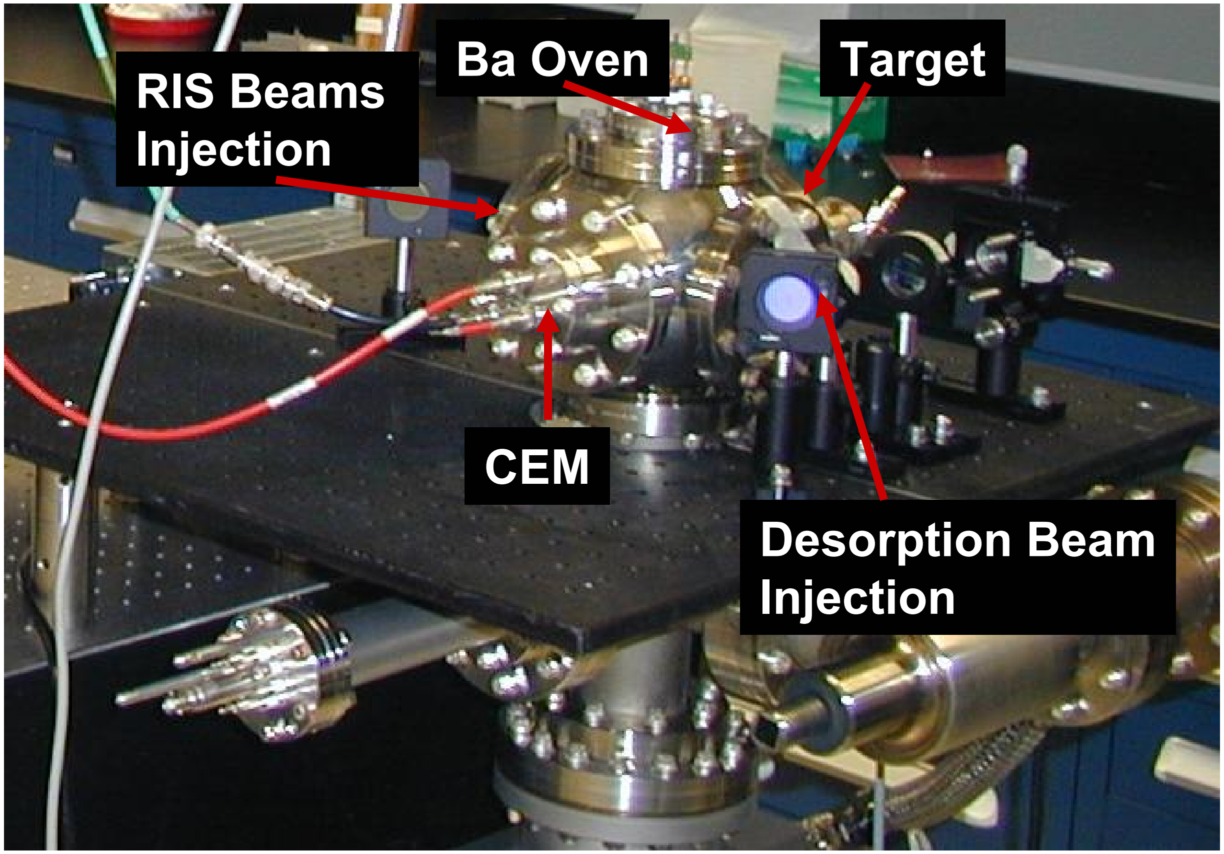
An alternative way to transport the Ba ion:

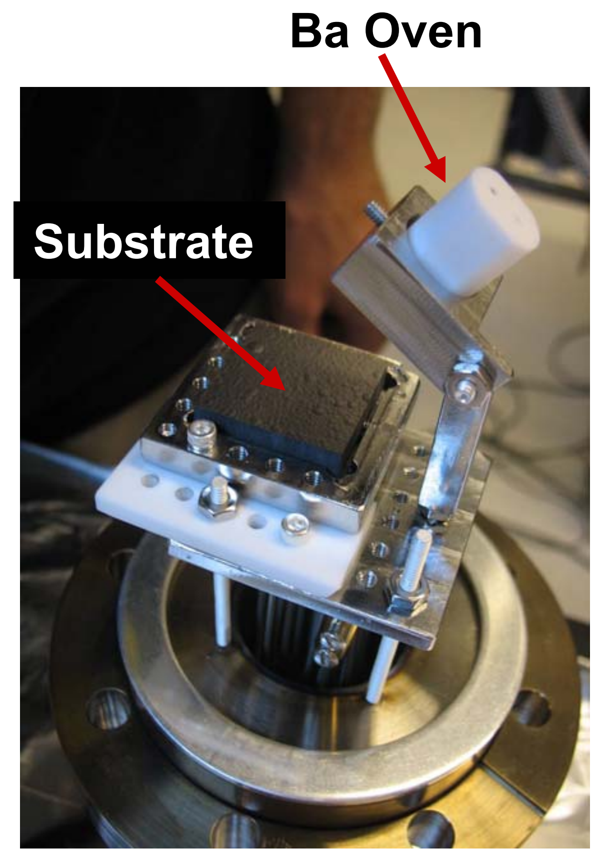


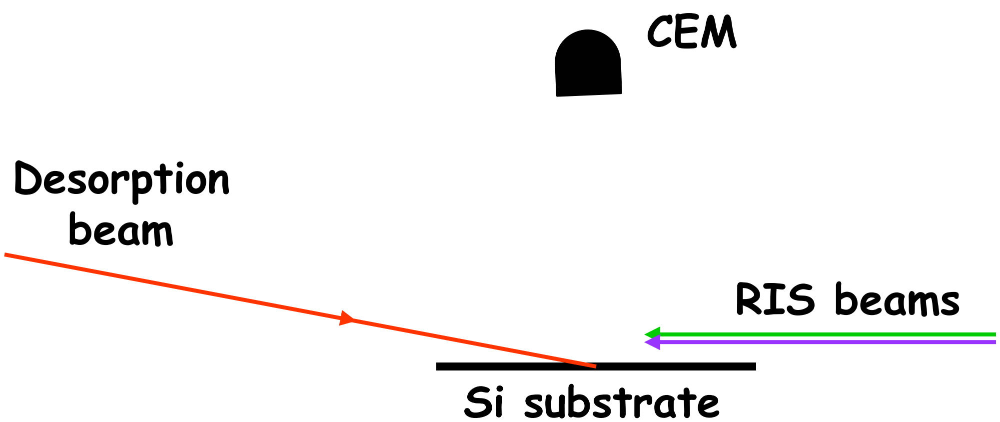
This does not have to be necessarily done through a fiber, the lasers can be shot at the substrate where the ion is bound from the "outside"

In this case *each step* can be documented to work with high efficiency in the literature !

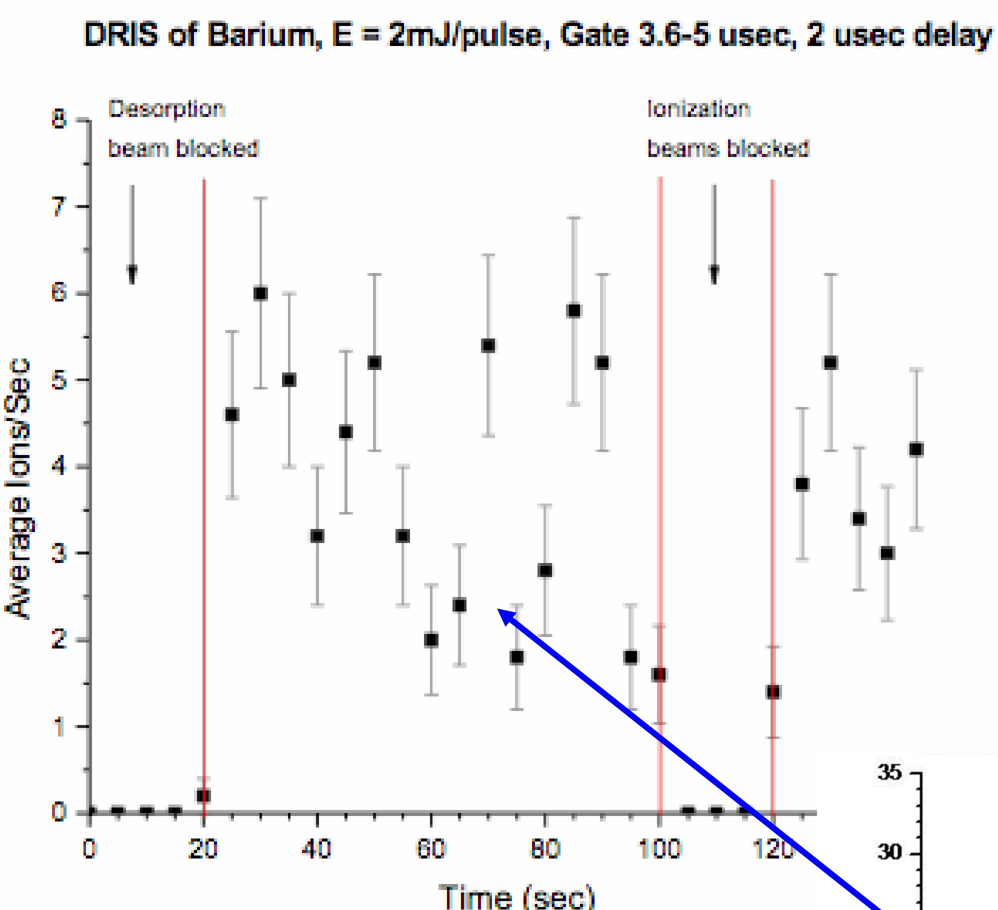
…and cell


RIS Beams Injection
Ba Oven
Target
CEM
Desorption Beam Injection

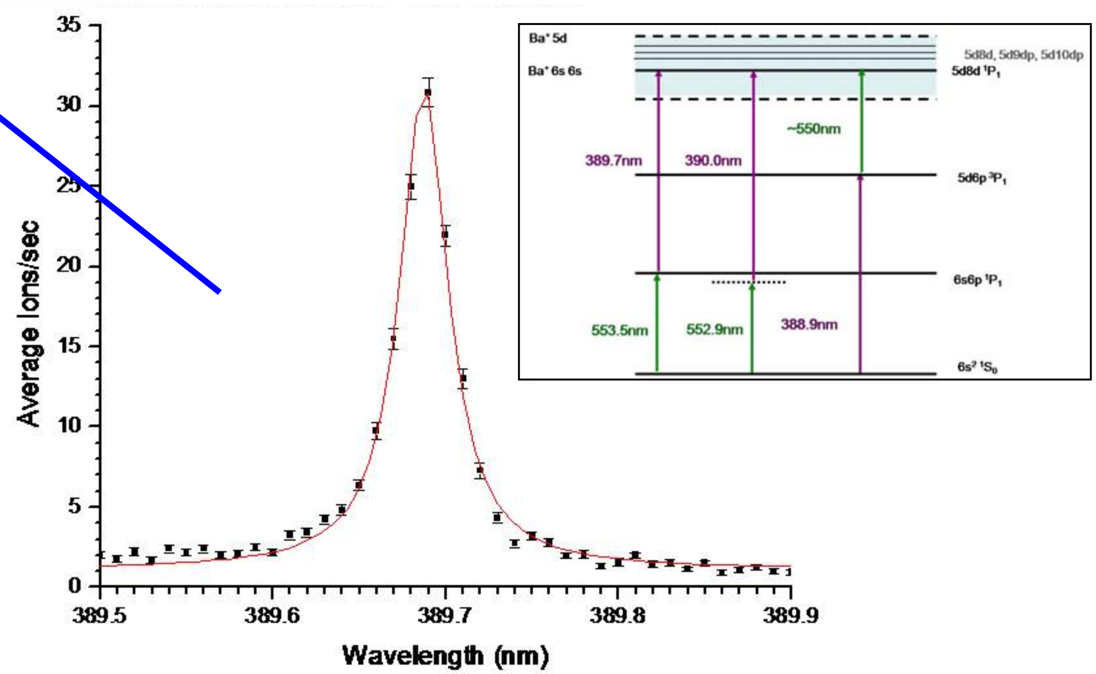

Ba Oven
Substrate


CEM
Desorption beam
RIS beams
Si substrate

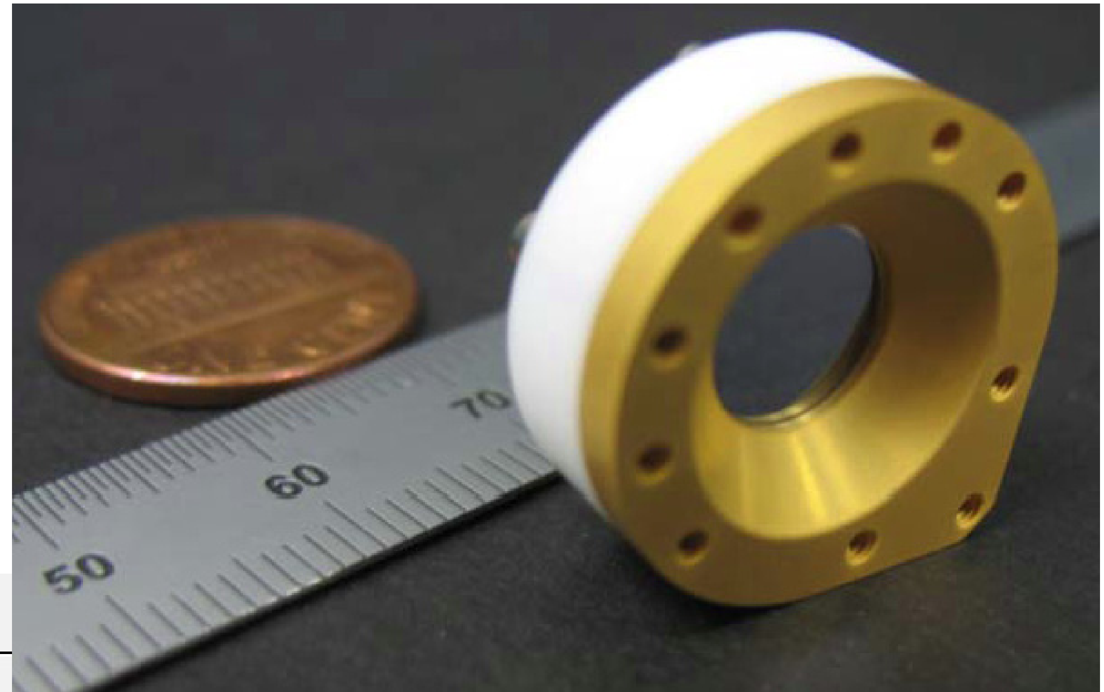
RIS of Ba from a Si surface

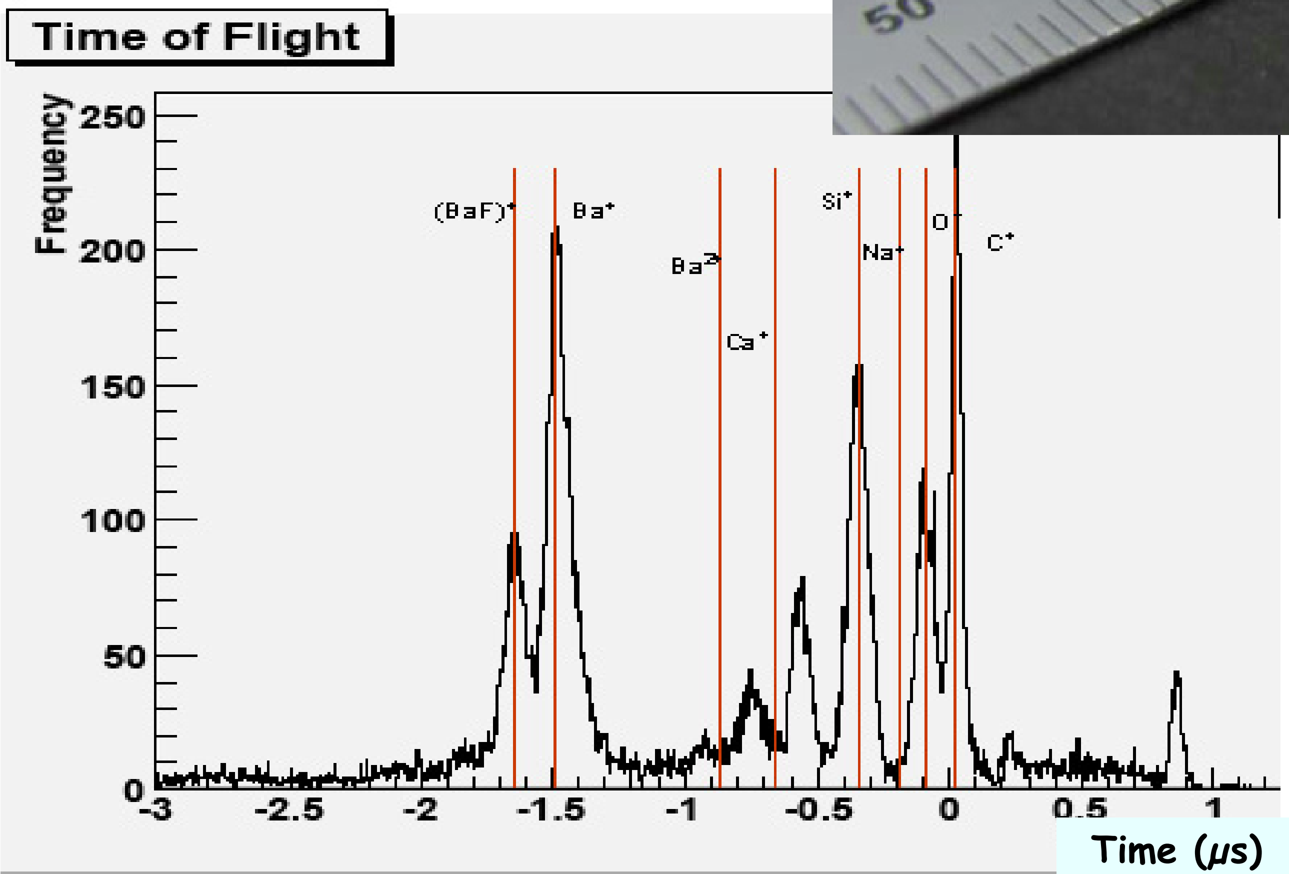


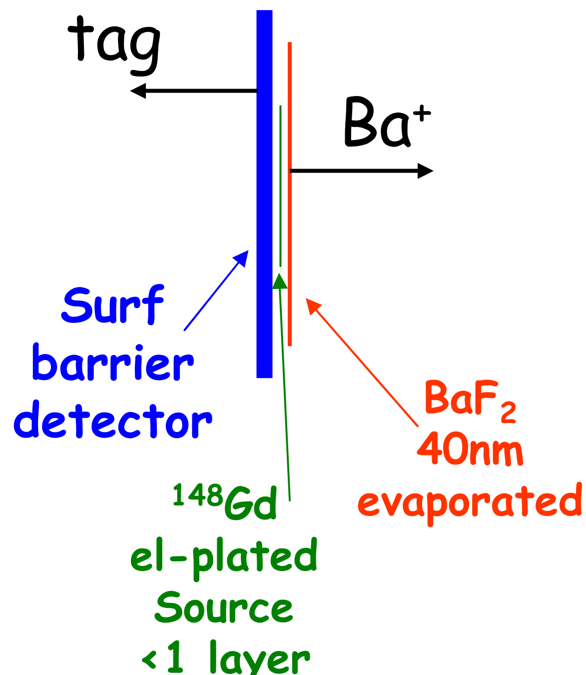
Needs a tagged single Ba^{+} source to measure efficiency



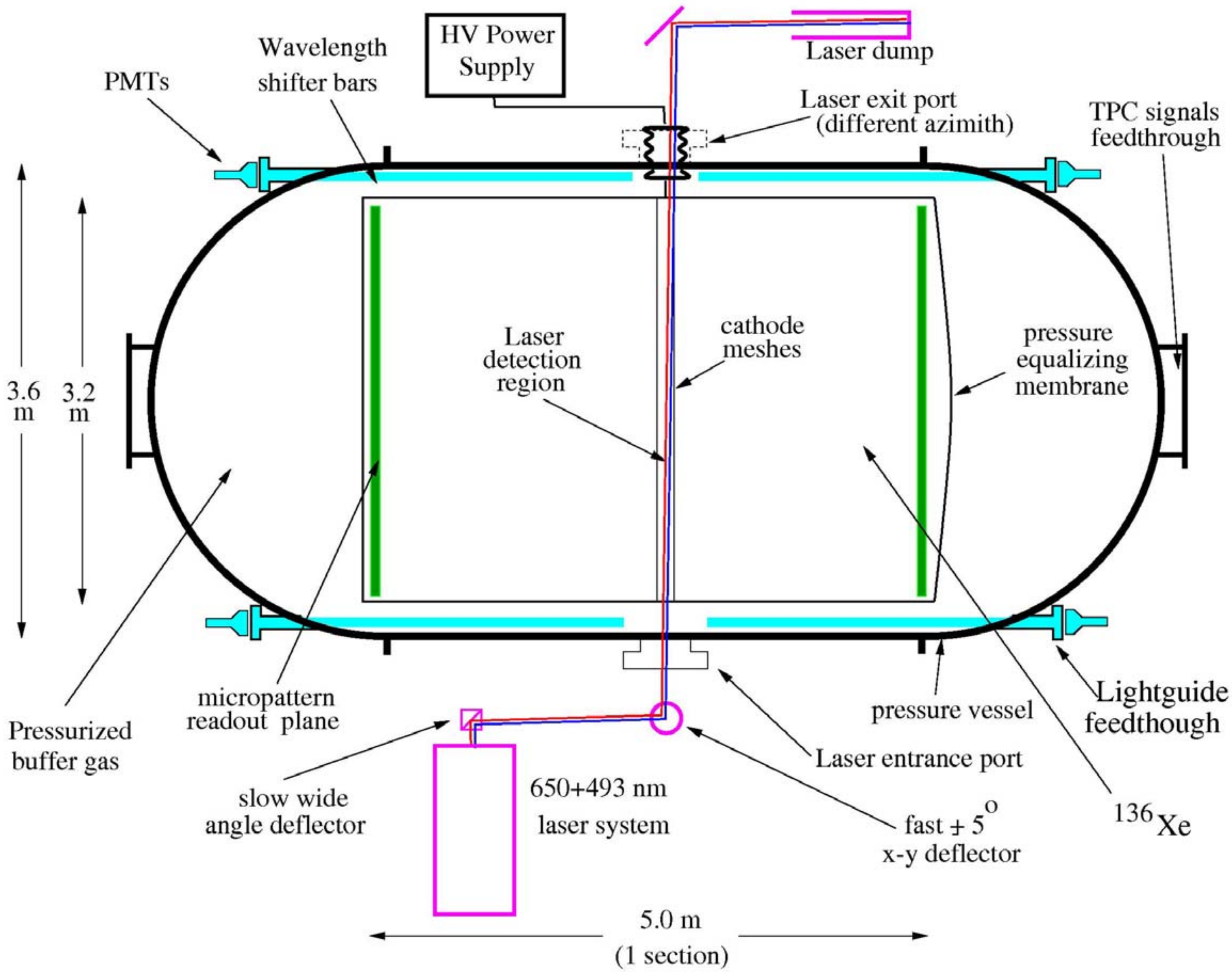
Simple tagged Ba^+ capable of operation in different media







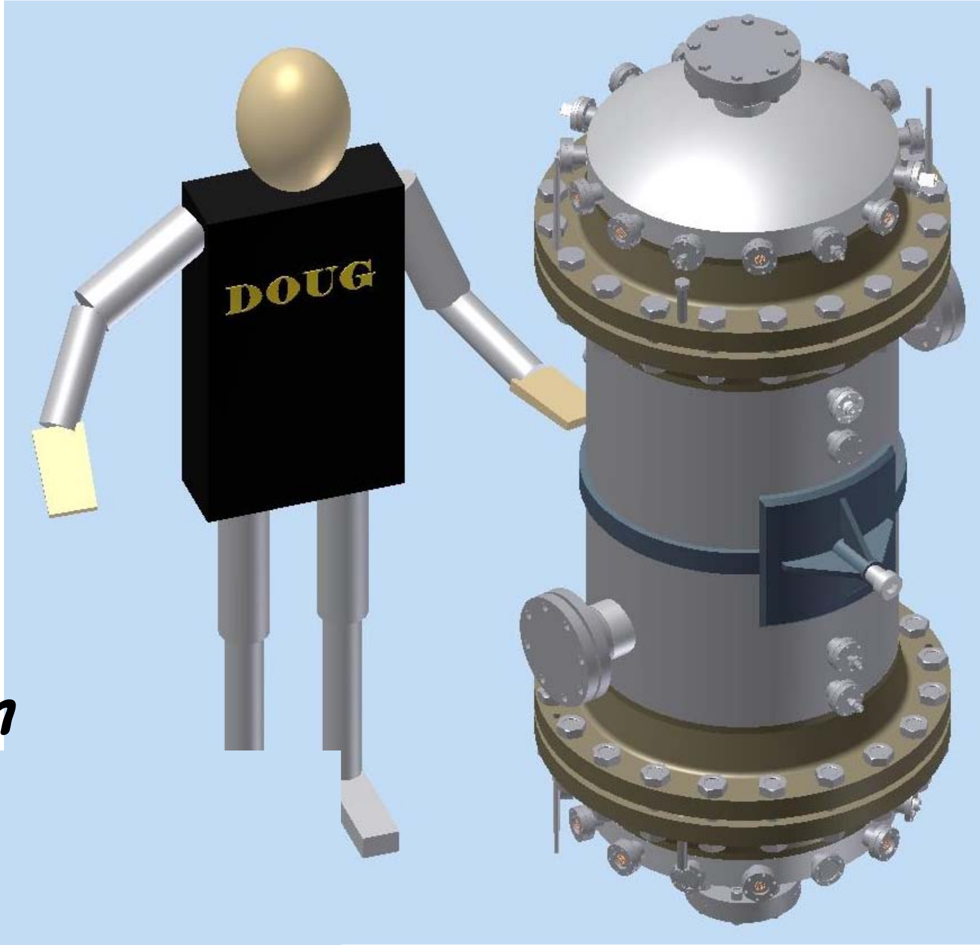
Conceptual scheme of a GXe detector with Ba tagging

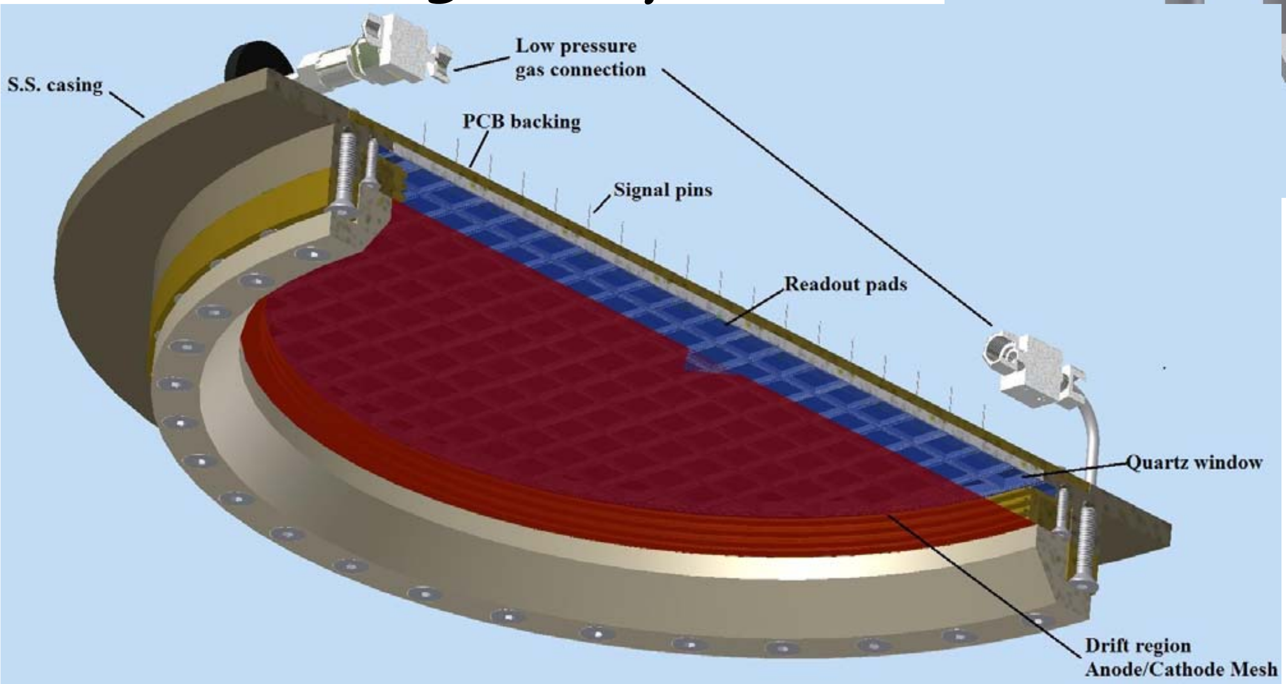


~M.Danilov et al. (EXO Collab.), Phys. Lett. B 480 (2000) 12

Mature design of a non-low-background high-pressure GXe test-bed detector

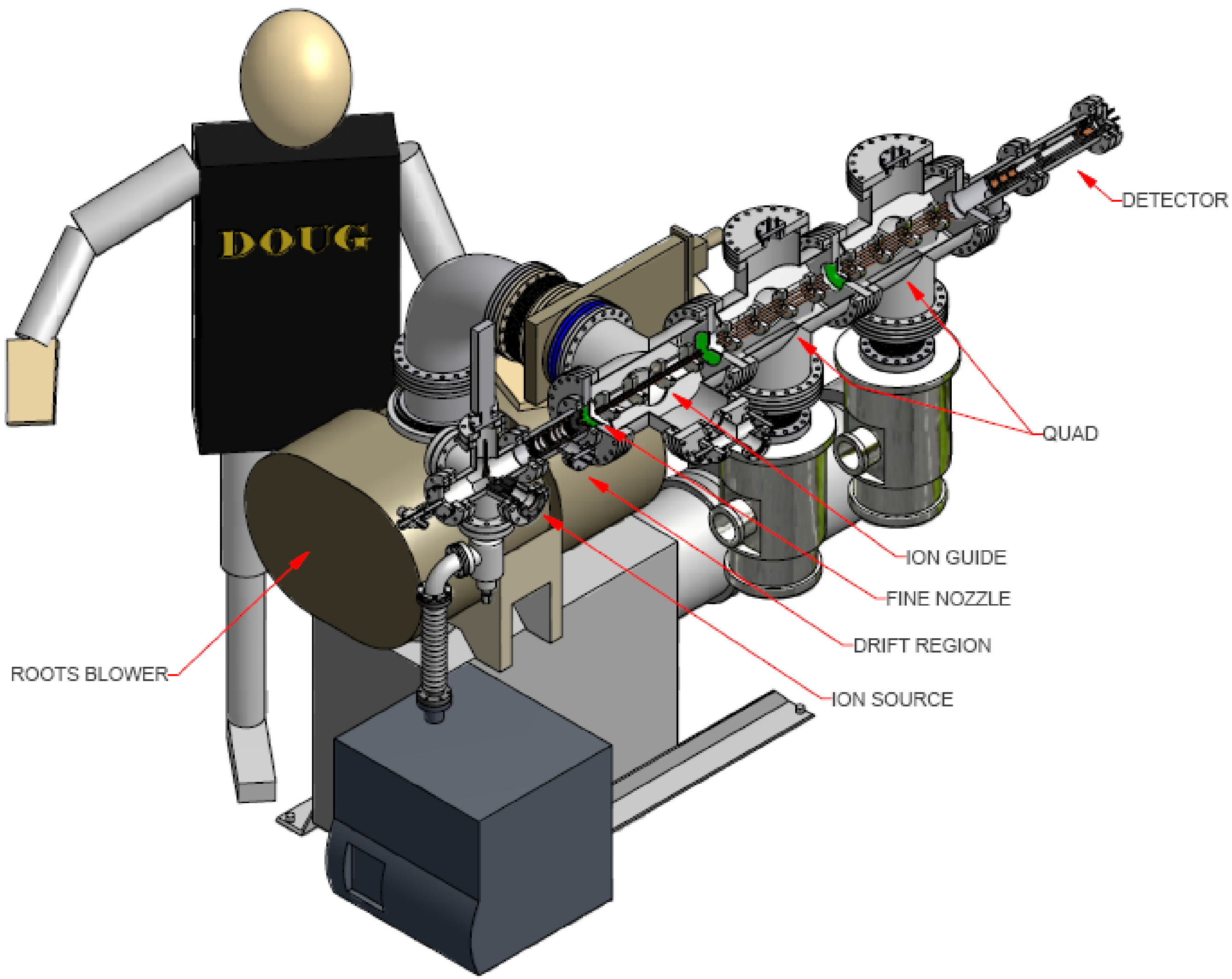
Choice of electroluminescence light readout with photocathodes and electron gas amplification





Conceptual design of the setup for extrating and tagging Ba ions from 10 bar GXe chamber

This activity is ramping up really fast and is receiving lots of input from the online isotope production/ separation community




Enriched Xenon Observatory
EXO
for double beta decay

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 2.481MeV 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
EXO-200	0.2	70	2	1.6*	40	$6.4 \cdot 10^{25}$	0.133†	0.186*

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

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 $\pm 2\sigma$ interval centered around the 2.481MeV endpoint
4) Use for 2νββ $T_{1/2} > 1 \cdot 10^{22}$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}	24	33
Aggressive	10	70	10	1†	0.7 (use 1)	4.1×10^{28}	5.3	7.3

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

† $\sigma(E)/E$ = 1.0% considered as an aggressive but realistic guess with large light collection area

‡ Rodin, *et. al.*, Nucl. Phys. A 793 (2007) 213-215

\# Caurier, *et. al.*, arXiv:0709.2137v1

Status of 2ν mode in ^{136}Xe

2νββ 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.

	$T_{1/2}$ (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 should definitely resolve this issue