Ba Tagging activities in EXO

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EXO neutrino mass sensitivity

Assumptions:

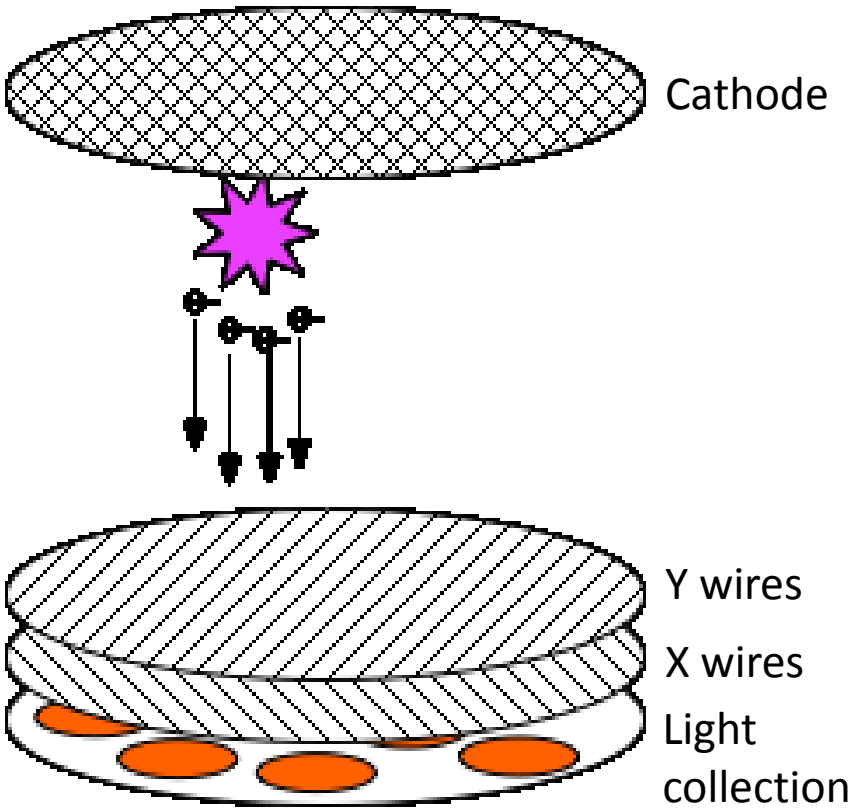
1) 80% enrichment in 136
2) Intrinsic low background + Ba tagging eliminate all radioactive background
3) Energy res only used to separate the 0ν from 2ν modes:
   Select 0ν events in a ±2σ interval centered around the 2.481MeV endpoint
4) Use for $2\nu\beta\beta$ $T_{1/2}>1\cdot10^{22}$yr (Bernabei 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‡	Majorana mass (meV) NSM#
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

* σ(E)/E = 1.4% obtained in EXO R&D, Conti et al Phys Rev B 68 (2003) 054201
† σ(E)/E = 1.0% considered as an aggressive but realistic guess with large light collection area
‡ F.Simkovic et al., *Phys. Rev.* C79, 055501 (2009)
# Menendez et al., *Nucl. Phys.* A818, 139 (2009)

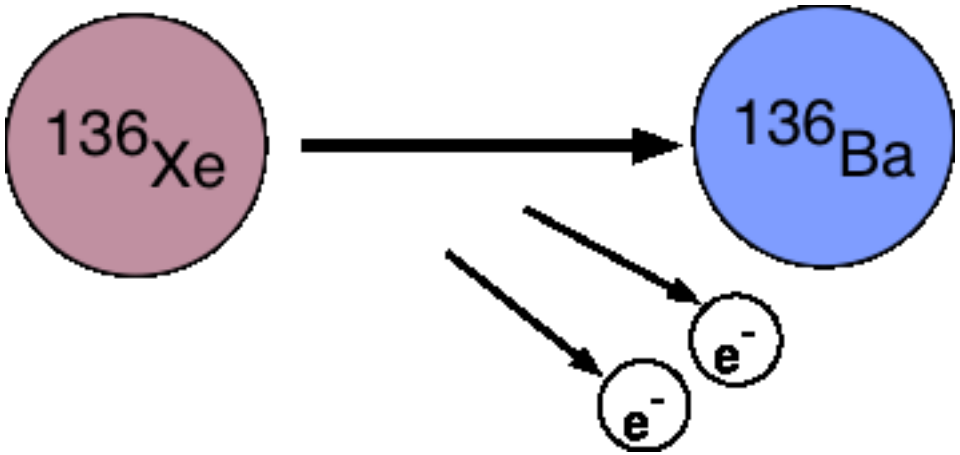
TPC locates decay

- Either a gas or liquid TPC will allow precise location of the decay and the daughter nucleus.



Background control

Backgrounds must be controlled at an extreme level.



← We're going to tag the daughter nucleus.

Lots of tagging operations

	Sub task	Where	Status (Jul 2010)
1	Ion trap with Laser tagging	Stanford	Done
2	Cold probe	TUM	Being assembled
3	RIS probe	Stanford	Sensitivity >10^{-3}, installing new setup
4	Hot probe	SLAC/ Stanford	Work in progress
5	Low E Ba^{+},Ba^{++} implant in SXe	CSU	Pulsed Ba^{+}, Ba^{++} beam almost ready
6	Direct detect. in LXe	CSU	Conflicting evidence for Ba+ vs. BaO
7	Detection on fiber tip	CSU	Sensitivity ~10^{4} Ba atoms with window. 1 dye molecule with fiber
8	LXe dipper	Stanford	Hardware in hand
9	Cs-137 source	UMD	Working in vacuum
10	Gd-BaF_2source	Stanford	Working, in use
11	Triggered source in vac.	Stanford	Under development
12	GXe to vac pumping demo	Stanford	All major components in hand. Assembly started.
13	Nozzles	Carleton/ Stanford	Nozzle test chamber being assembled

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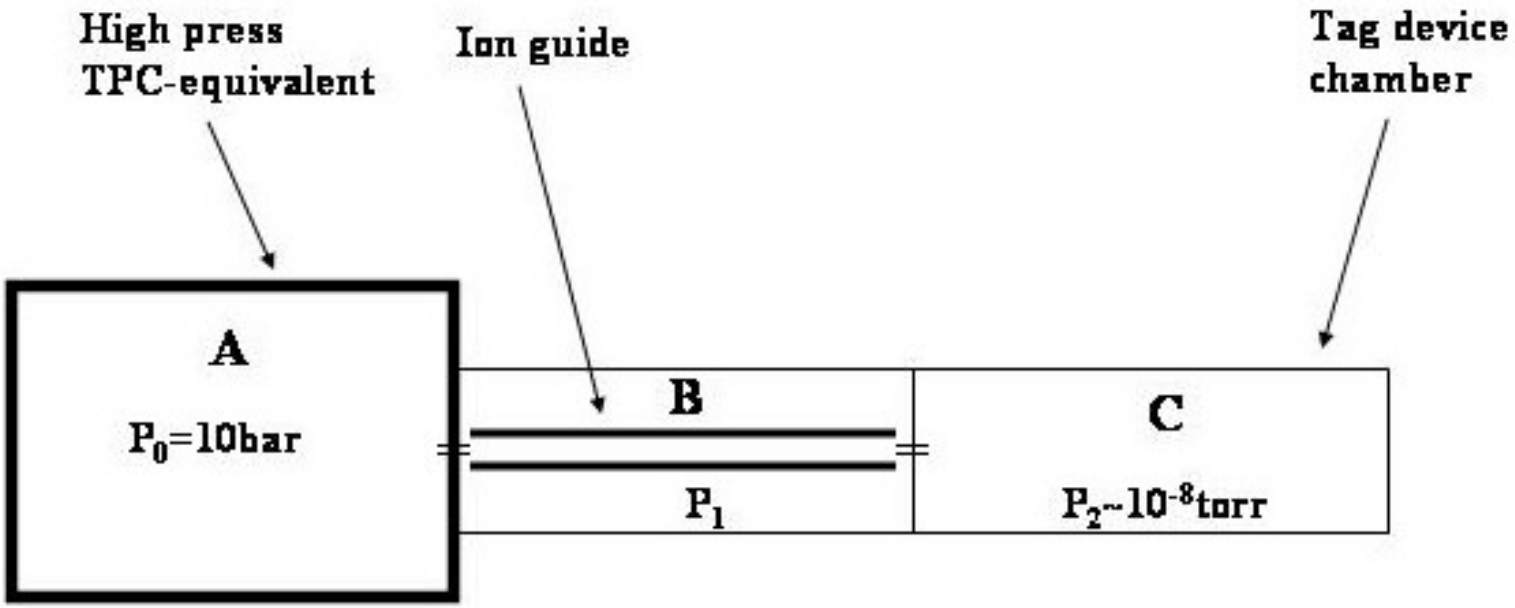
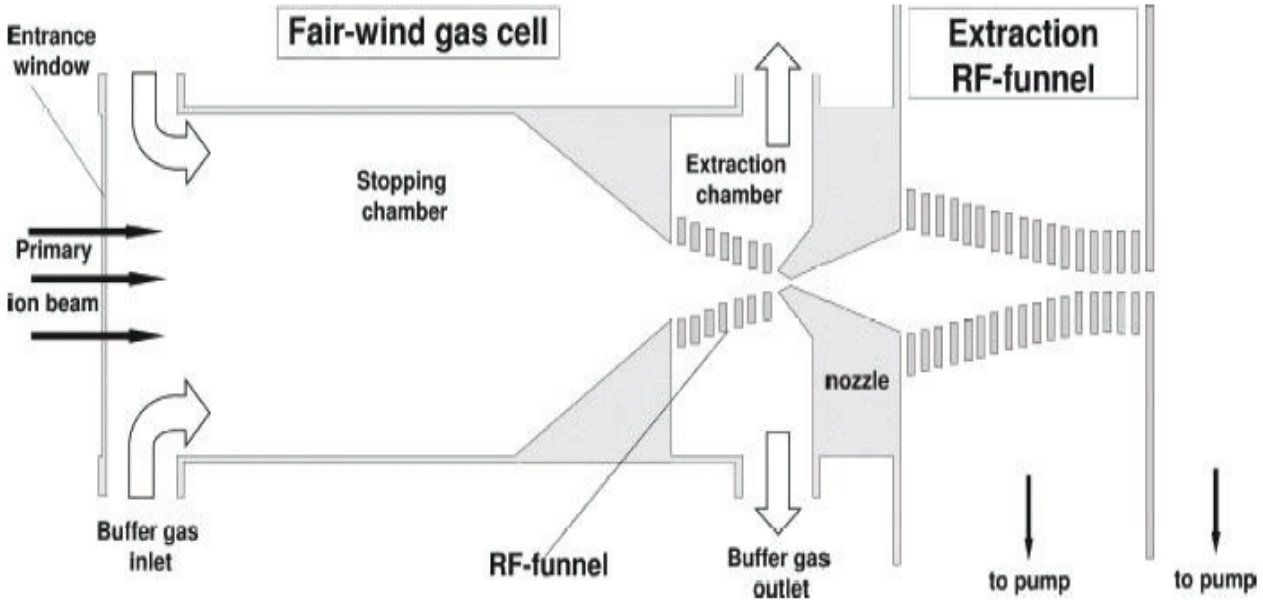
Gas tagging test system

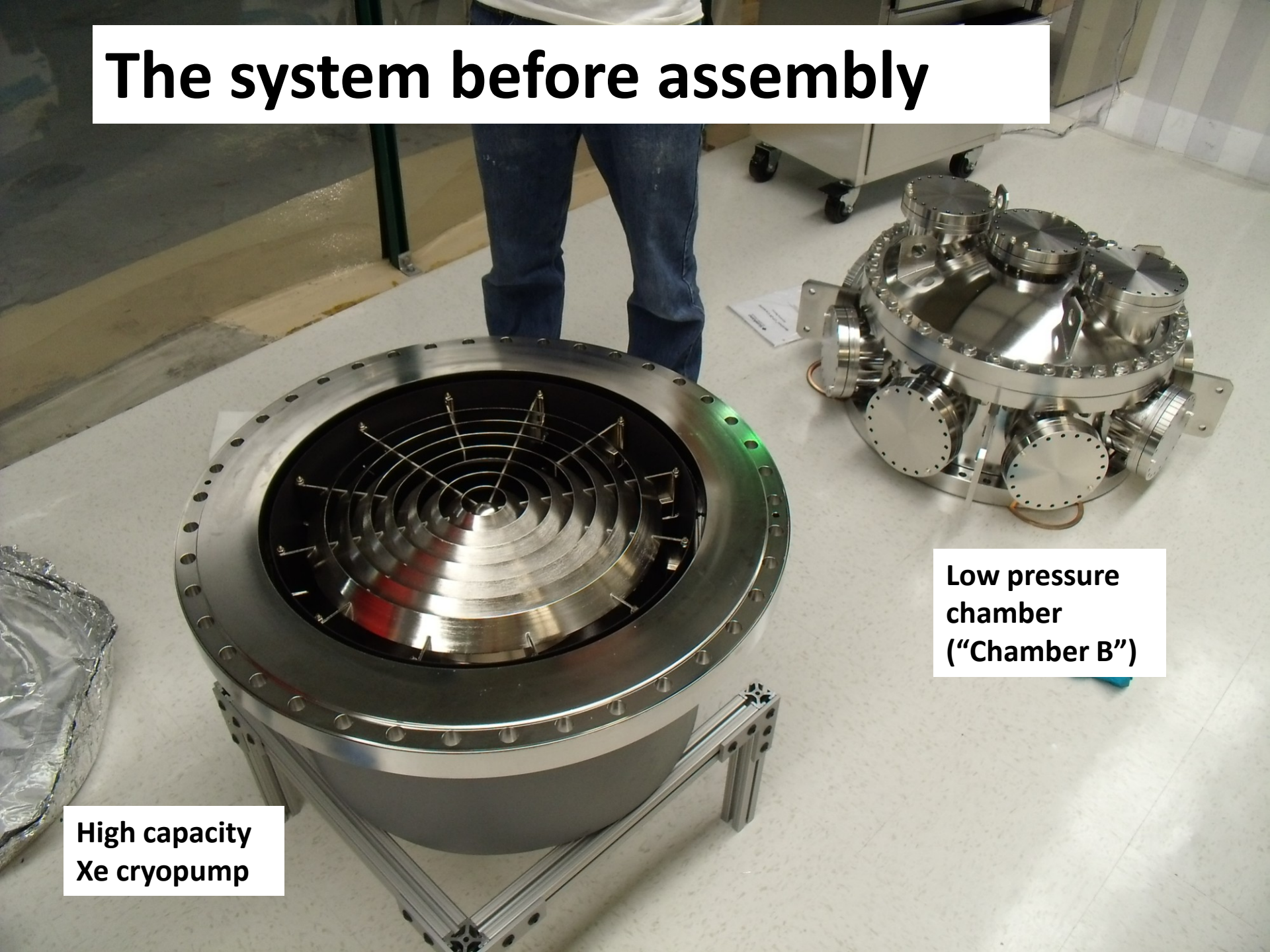


To test Ba^+ extraction from high pressure Xe

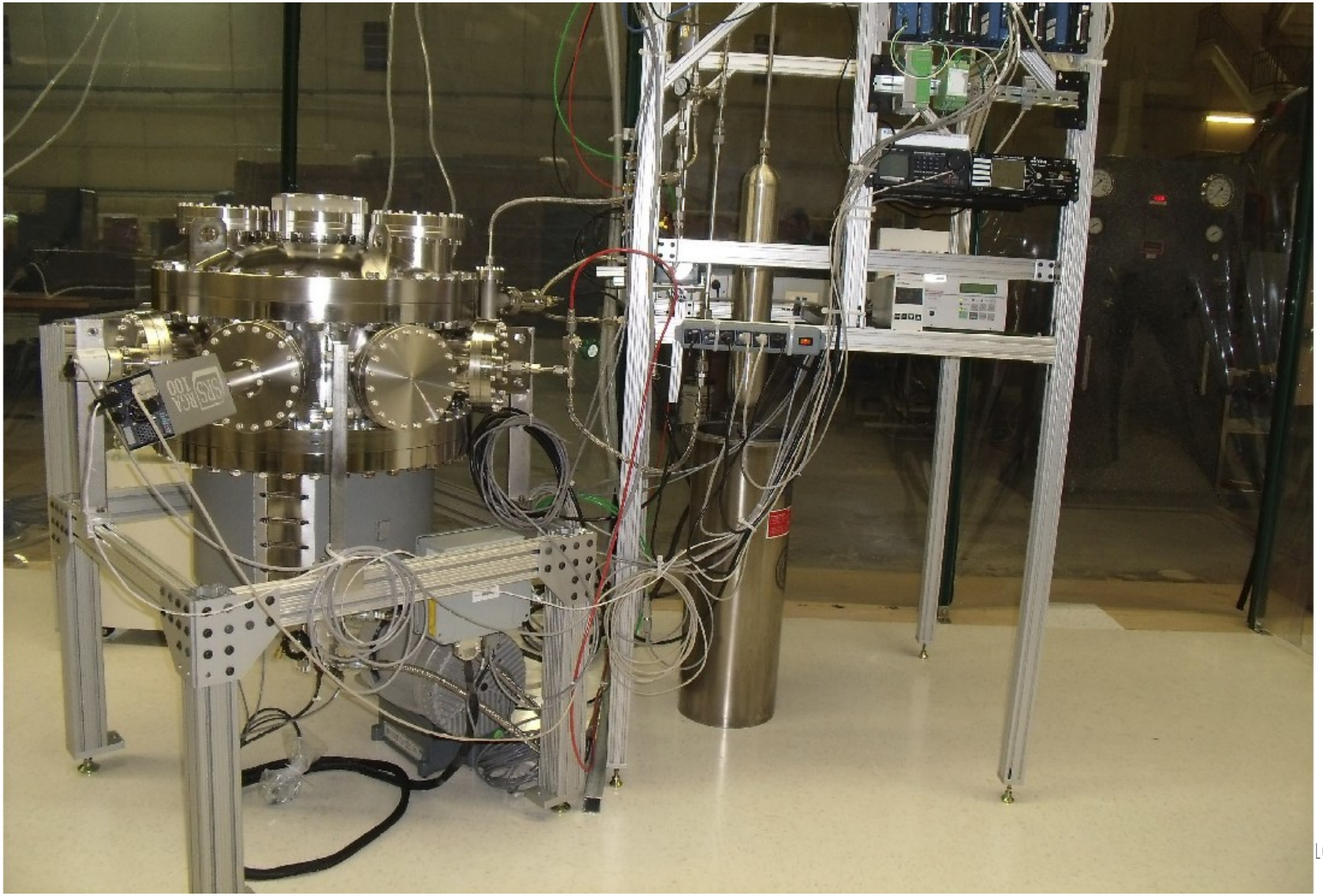
The same idea used in exotic nuclei production



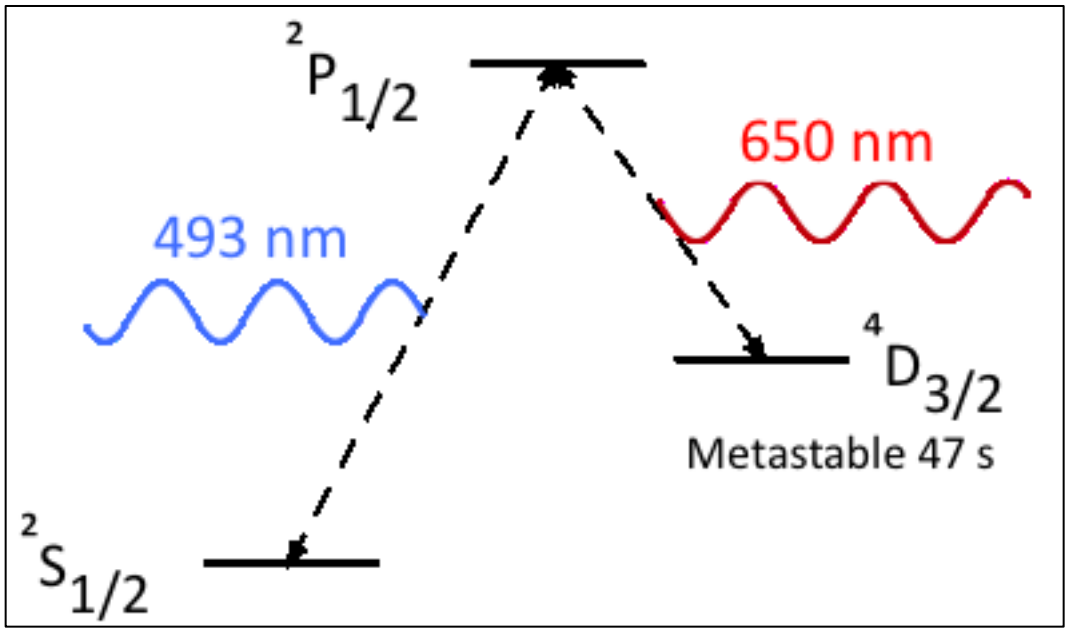
The system before assembly



Gas tagging transport test

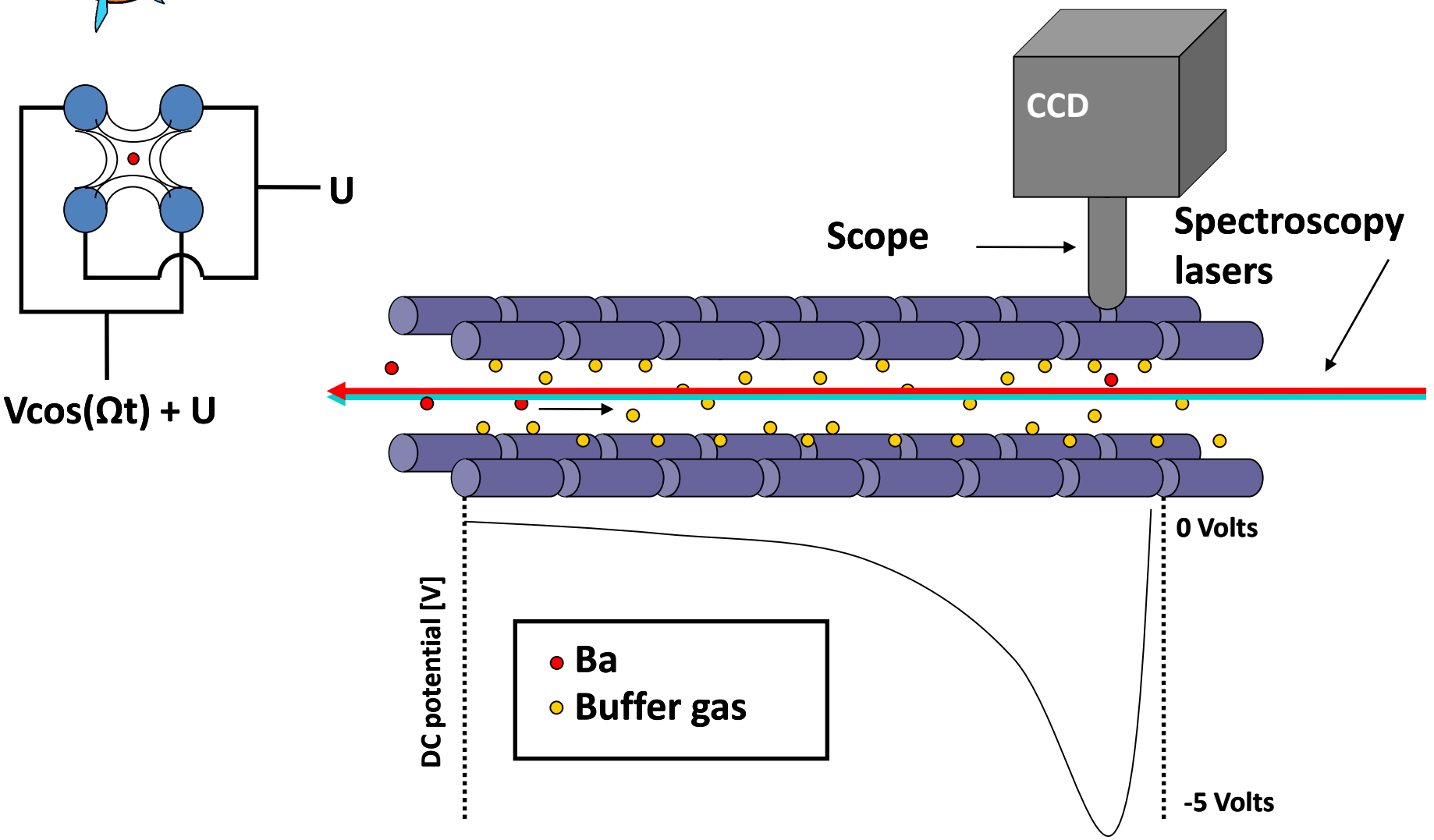


Possible barium identification

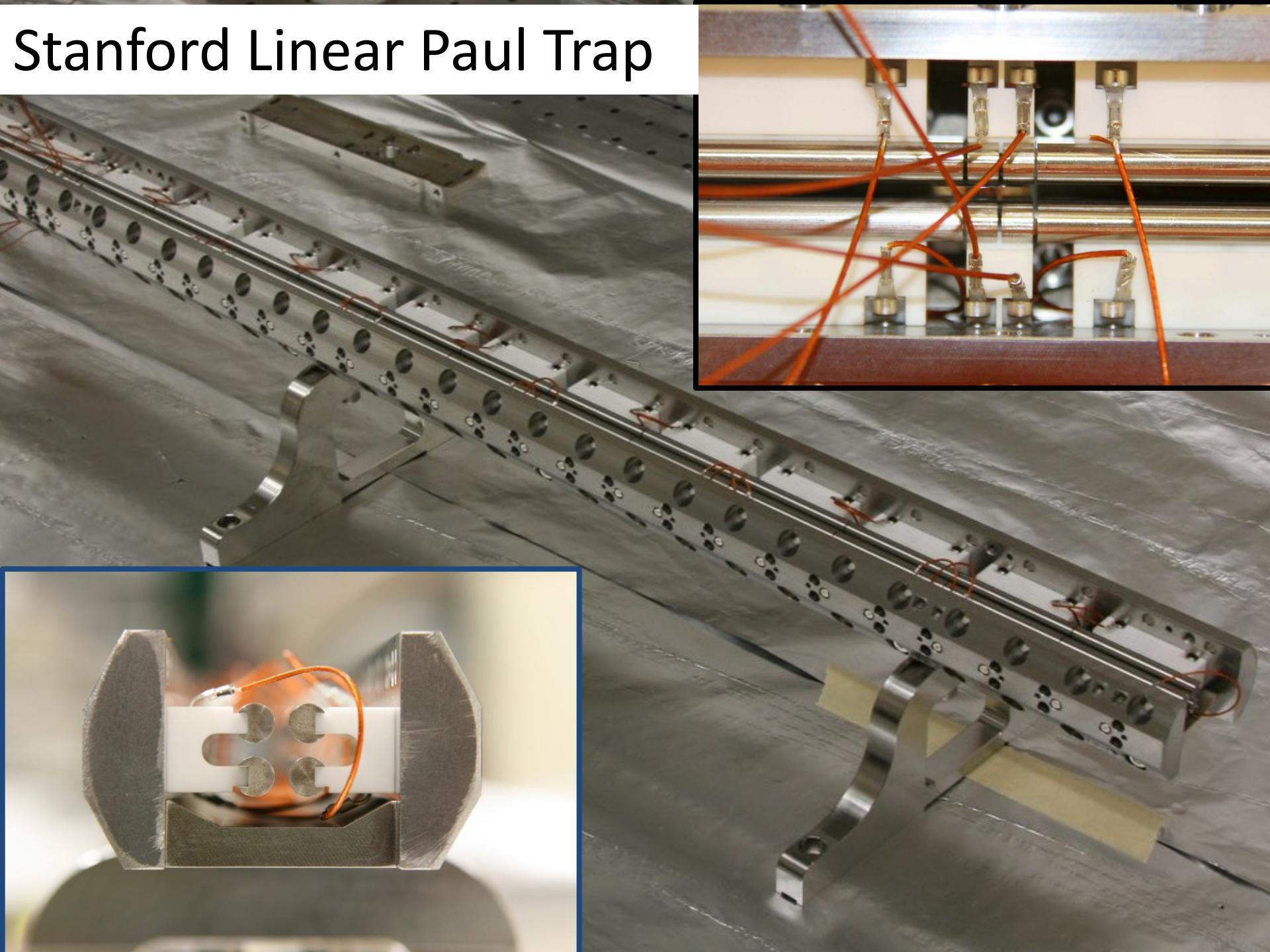


Single Ba^+ ions can be detected from a photon rate of 10^7/s (Neuhauser, Hohenstatt, Toshek, Dehmelt 1980)

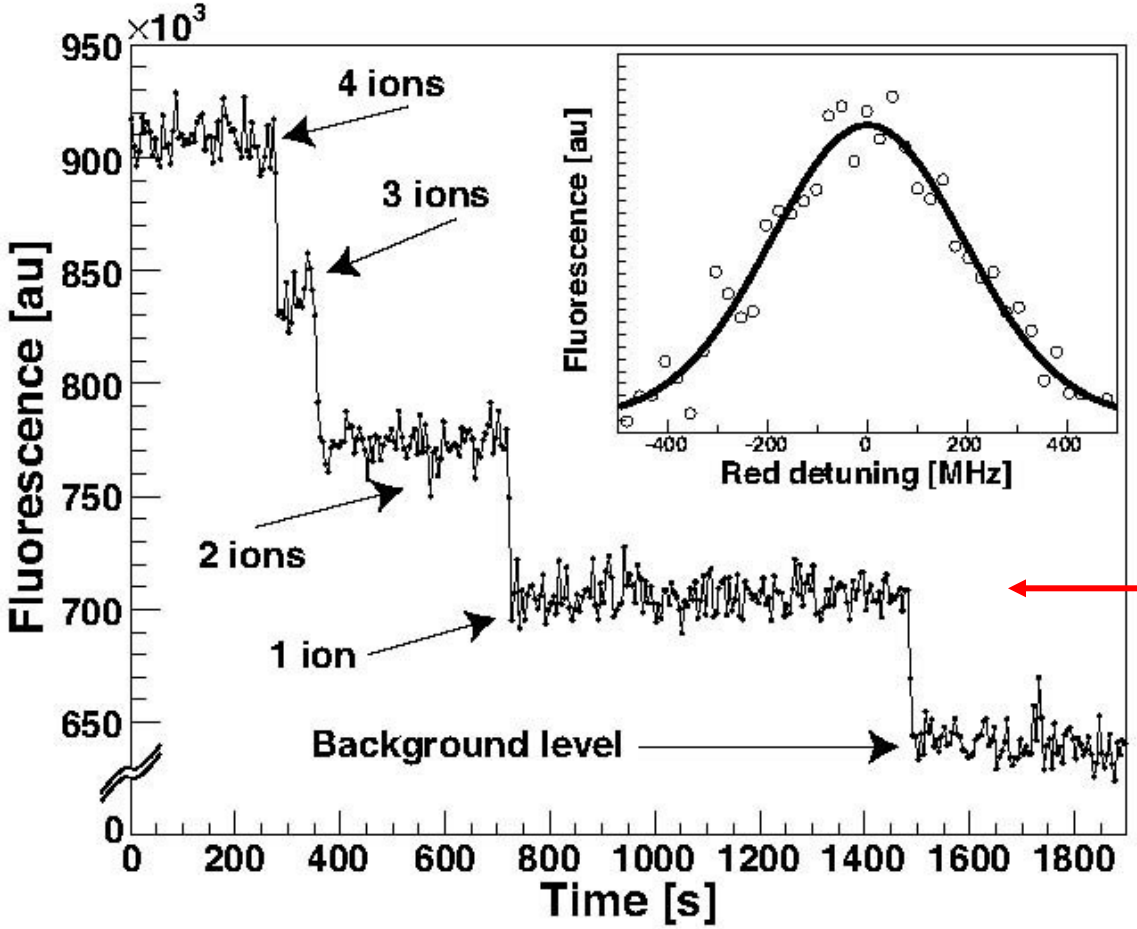
Our RF Paul Trap



Stanford Linear Paul Trap



Single ion detection



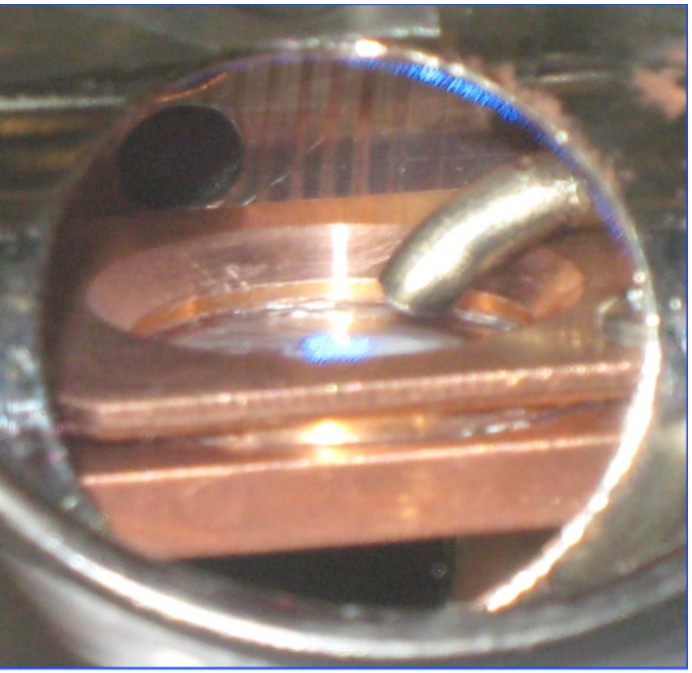
Trap can detect single ions in high pressure gas (He, Ar)

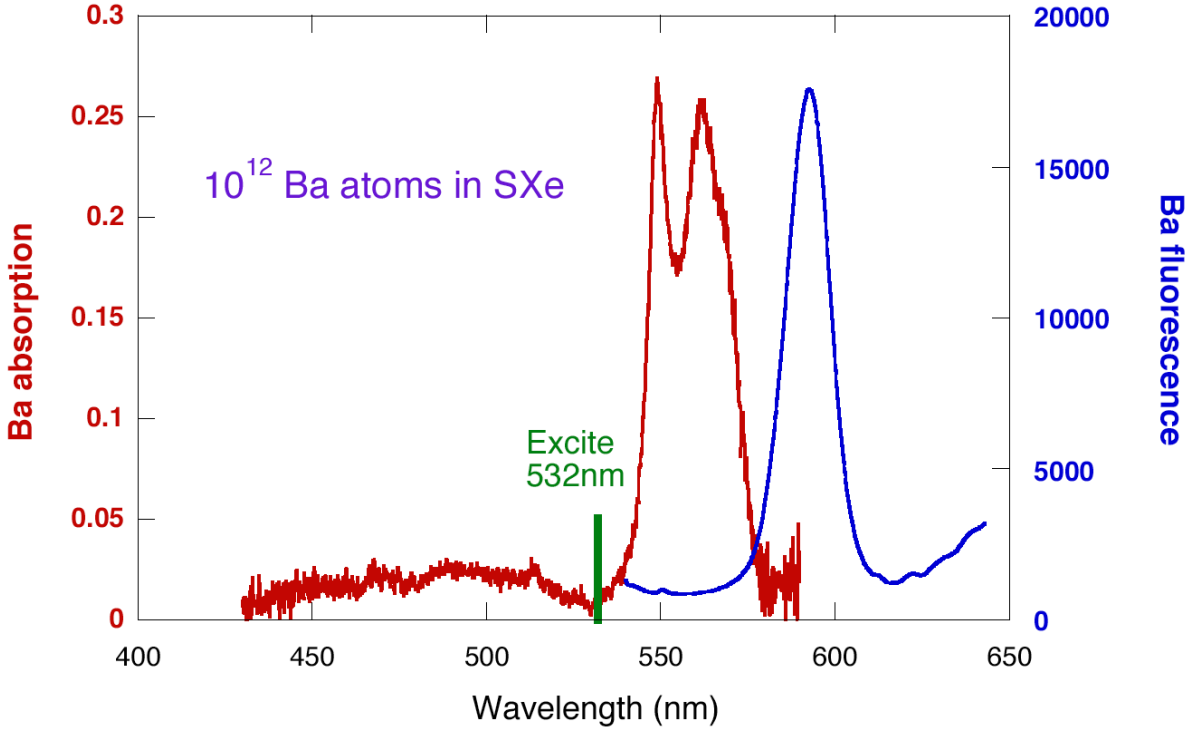
~9σ discrimination in 25s integration

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

B.Flatt et al. NIM A 578 (2007) 409

Initial tests on a window



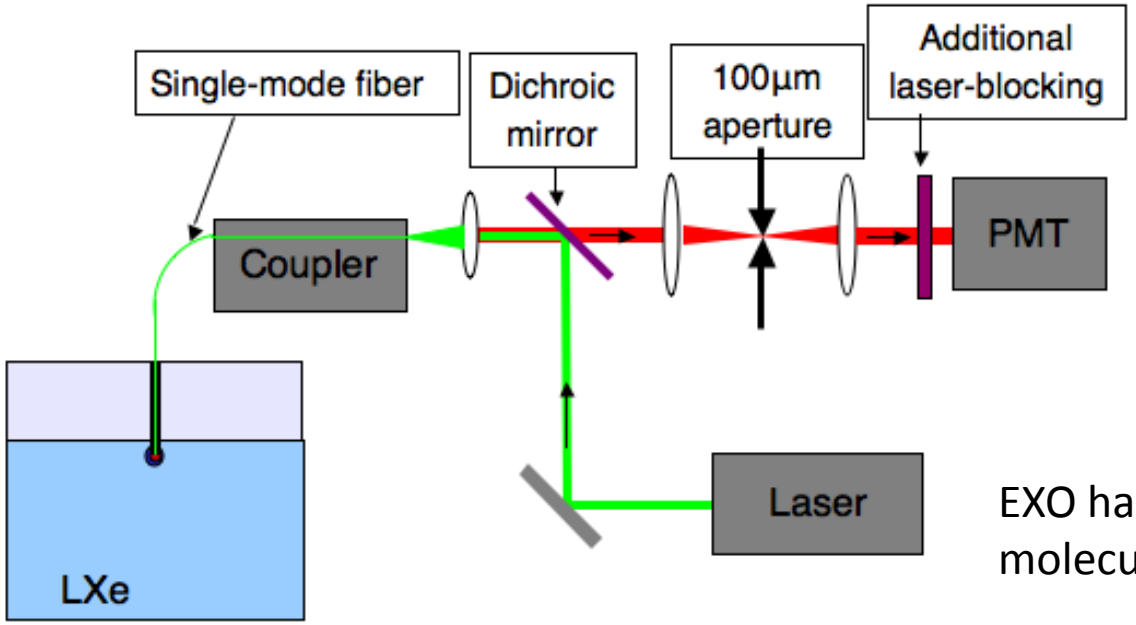


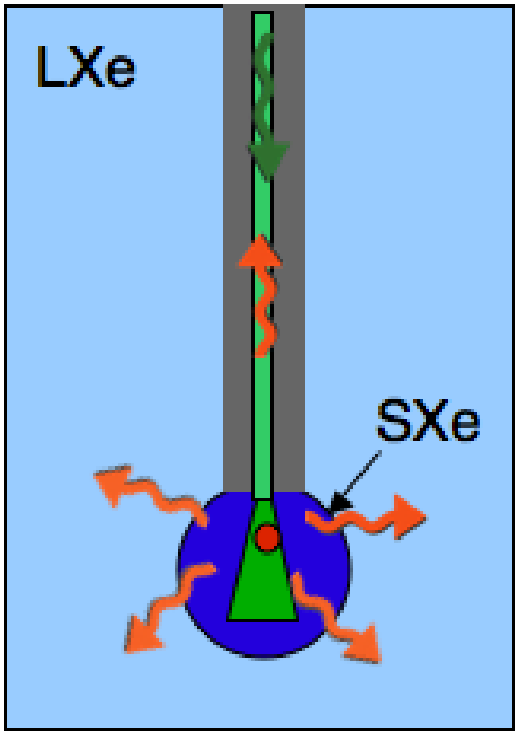
The detection limit is as low as 10^4 ions deposited, but many fewer are in the laser spot.

Detecting Ba while still in LXe

Ions could be trapped in solid xenon frozen on the end of an optical fiber.

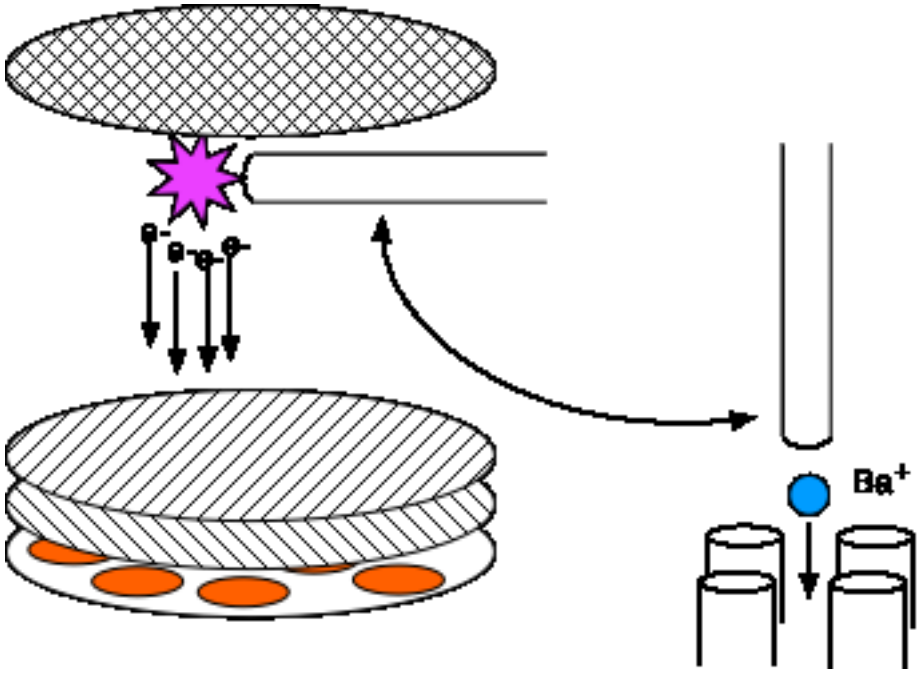
The fiber could be used to both illuminate the ion and capture fluorescence from the ion.

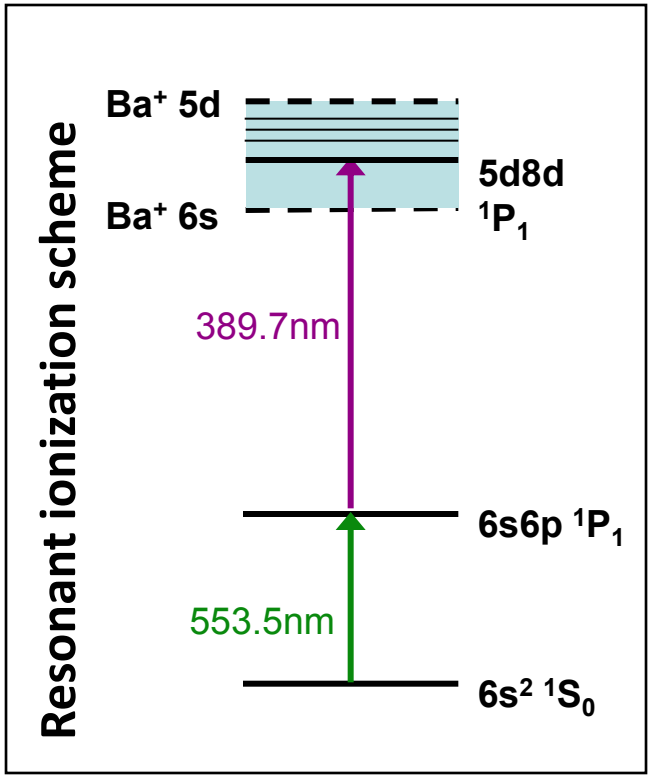




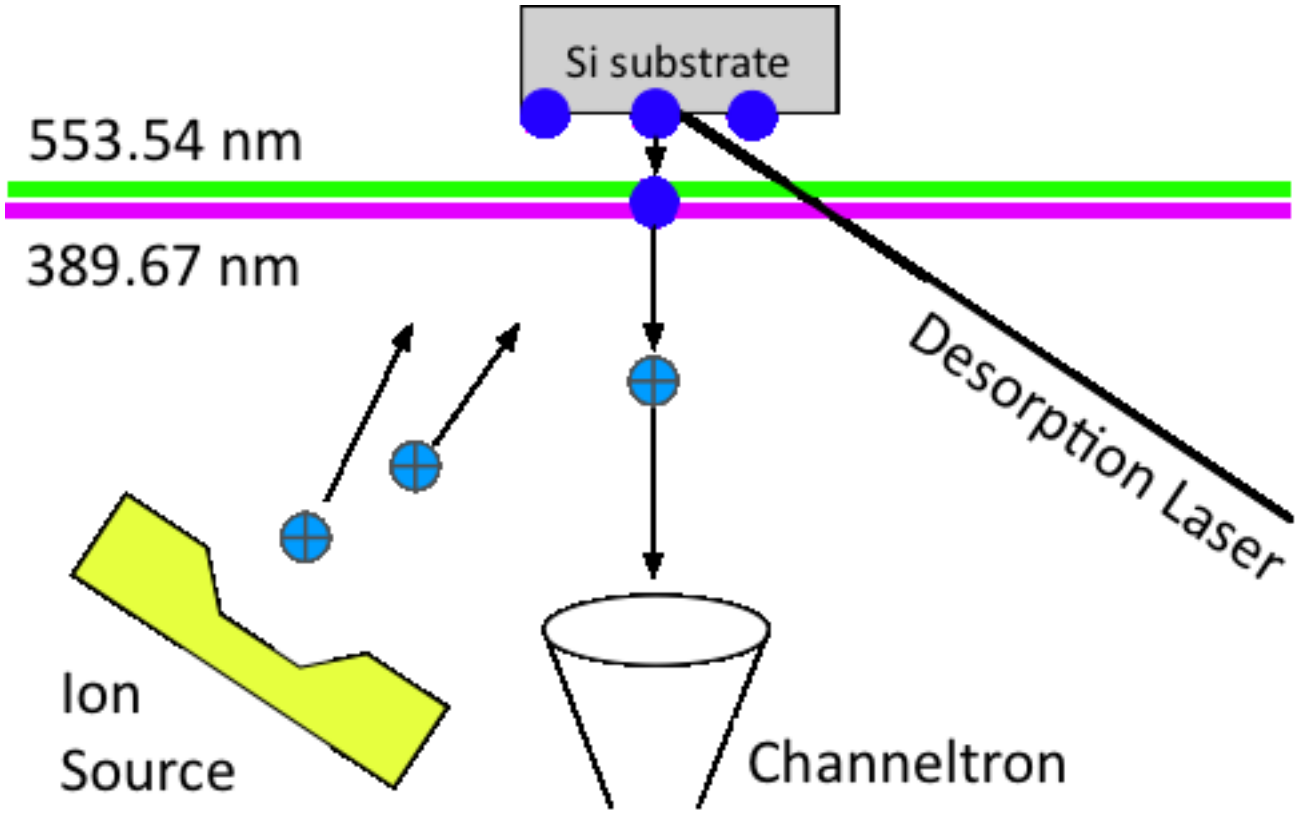
EXO has already achieved single dye molecule detection with fiber

Resonance Ionization Spectroscopy as a release technique





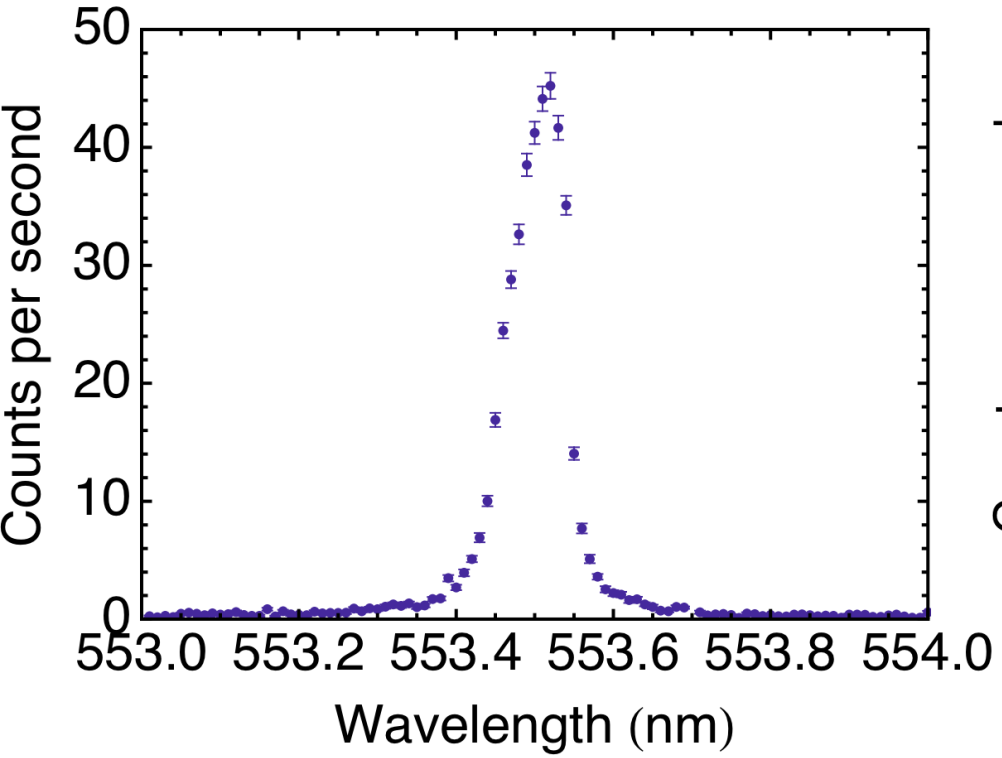
Schematic of the test system

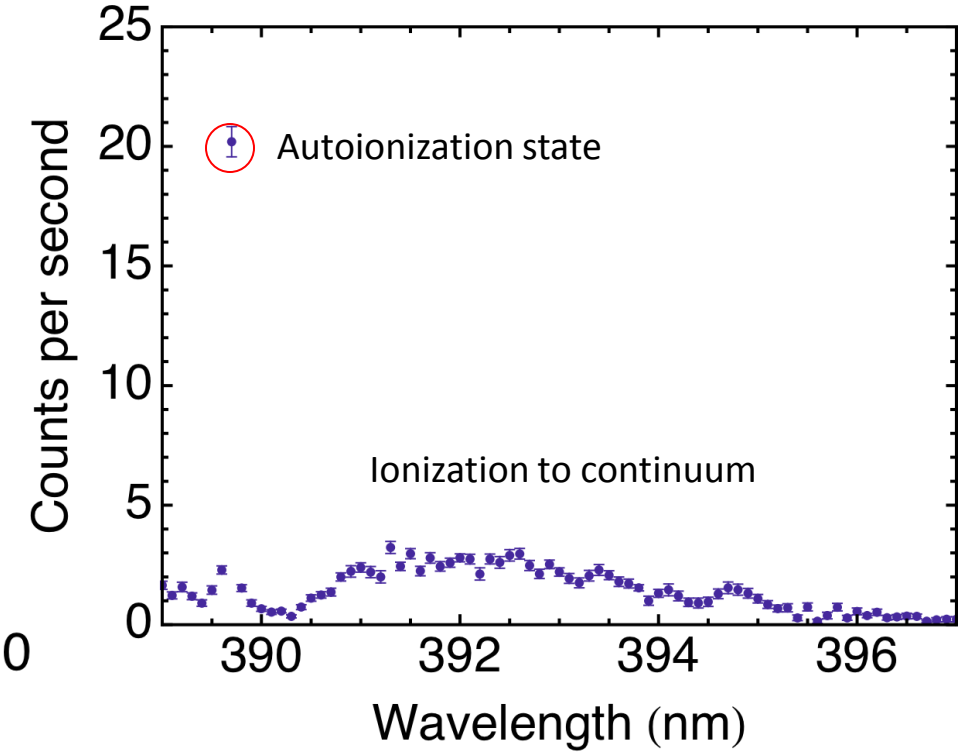


Optical Spectroscopy Identification: Detuning the lasers

553.5 nm Laser Detuning

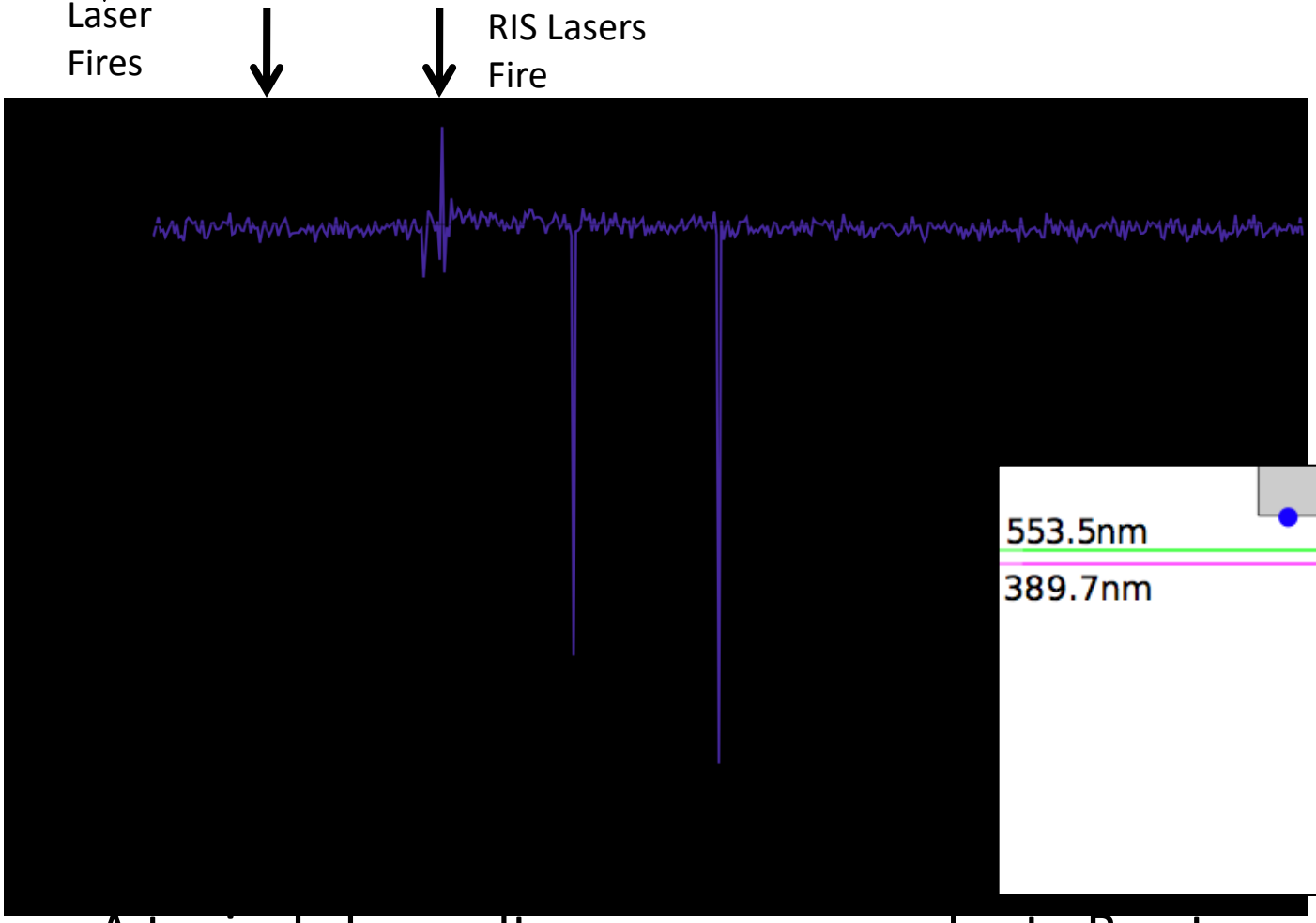
389.7 nm Laser Detuning

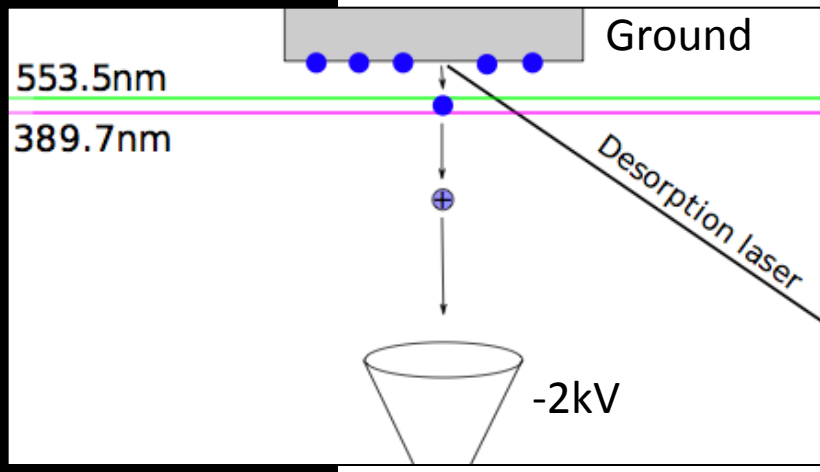




RIS from gas phase

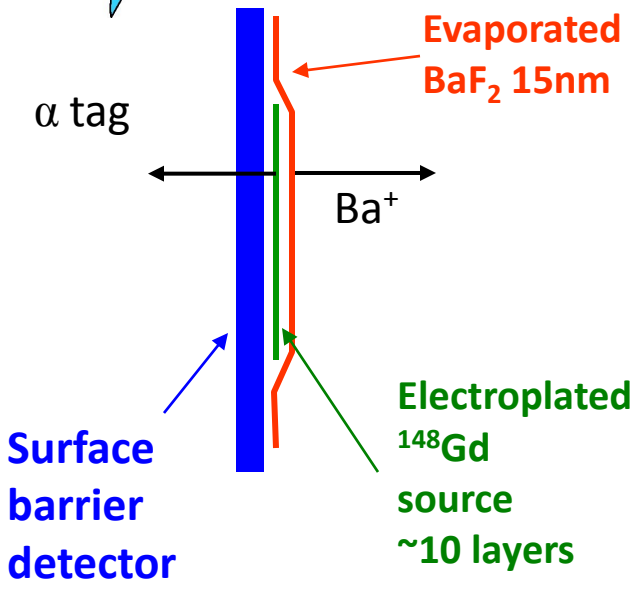
Mass Spectroscopy Identification: time of flight





A typical channeltron pre-amp readout. Ba atoms are desorbed at t=0.

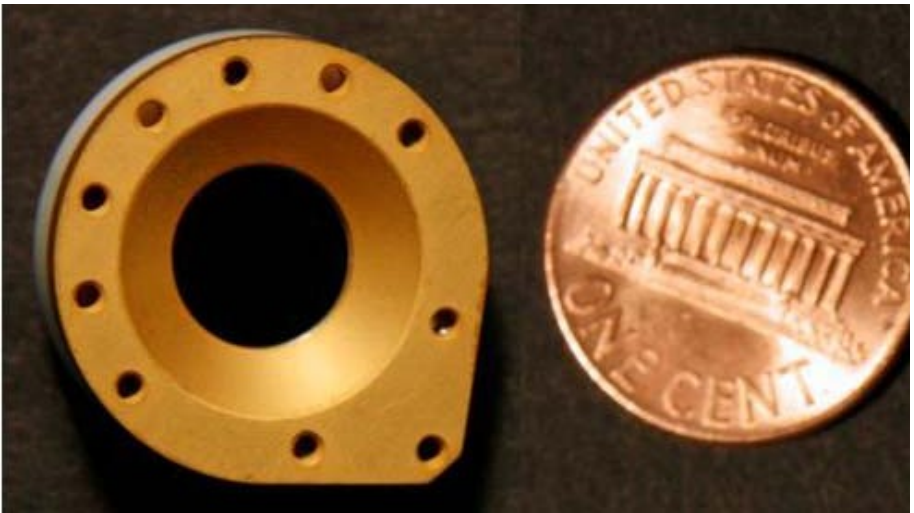
Single Ion Source

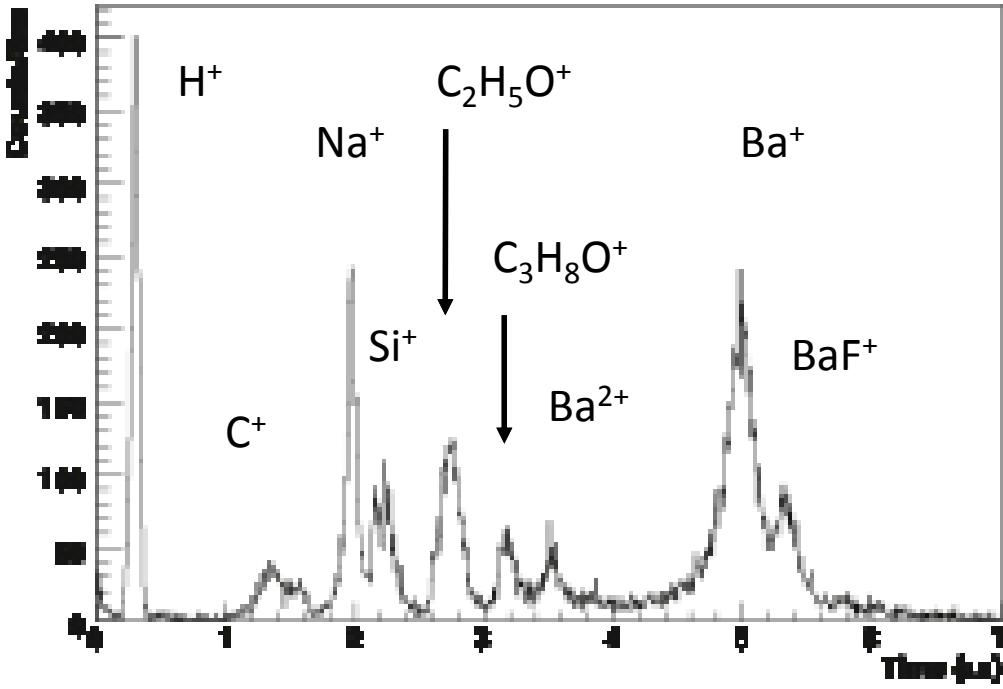


Use recoils from a very thin α emitter to dislodge Ba atoms from a carefully designed layer of BaF_2

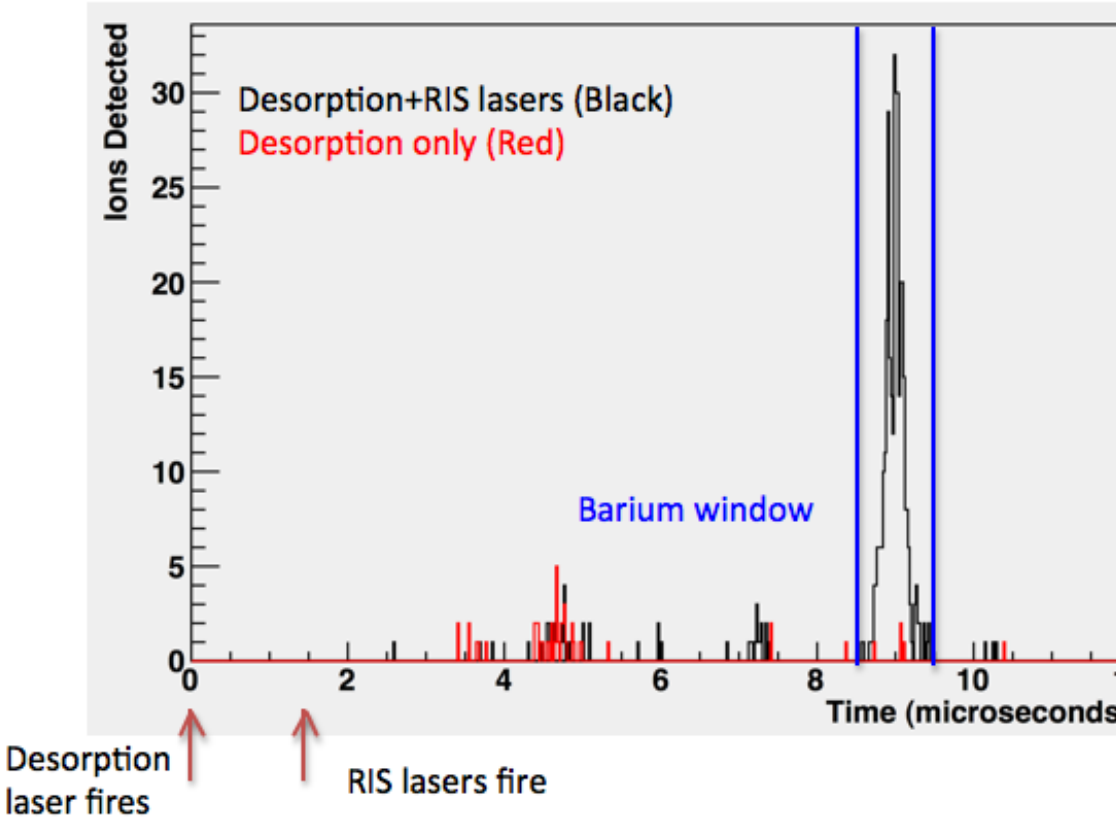
A fraction of the Ba emitted is Ba^+

Rev. Sci. Inst. 81, 113301 (2010)

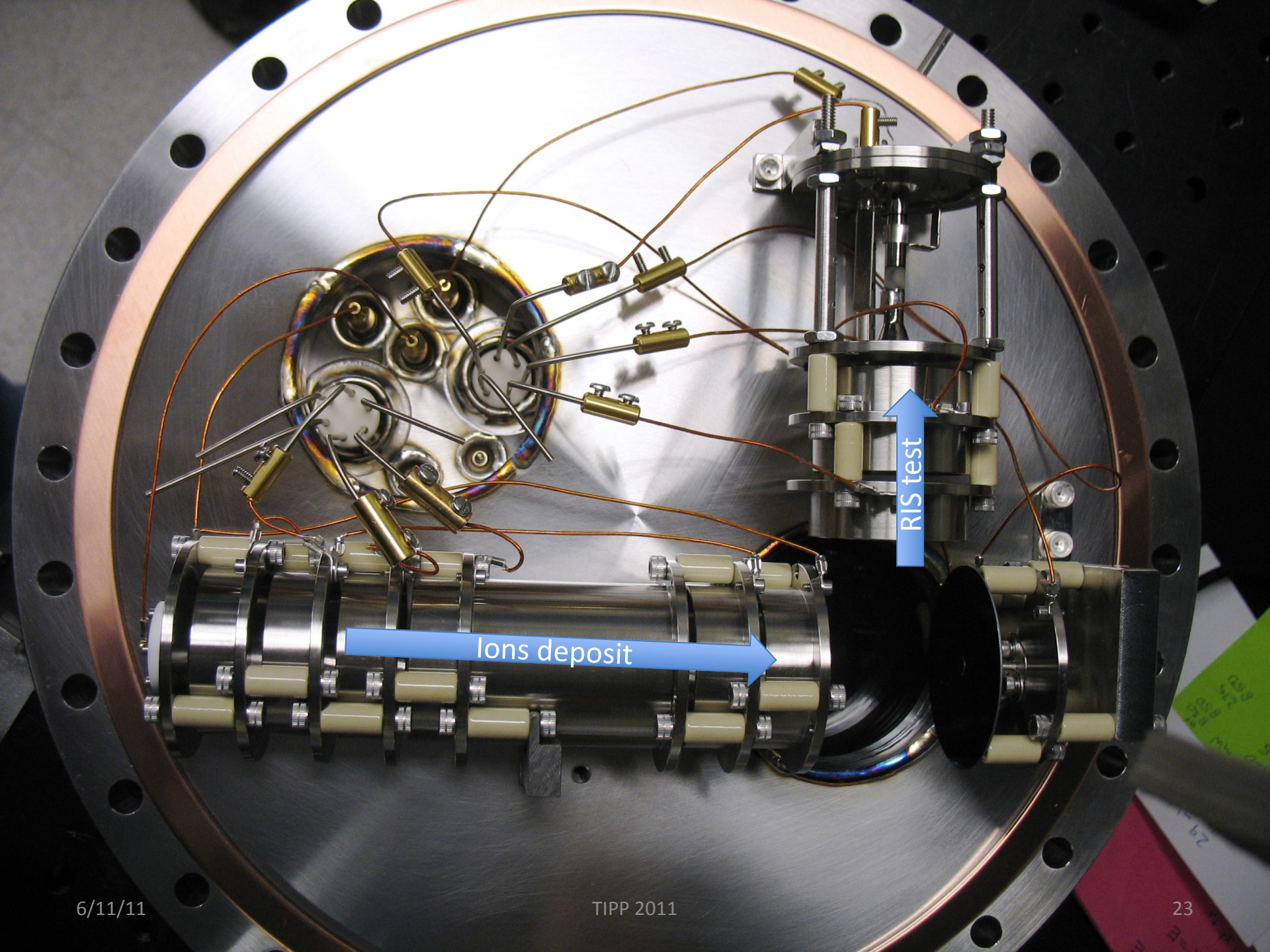




Gaining efficiency



Efficiency >10^{-3} (deposit 10^5, wait hours, get >100 out)


RIS test
Ions deposit

Something to build on…

- Gas tagging R&D is progressing, transport test ready soon.
- Barium ion spectroscopy in solid xenon is approaching single-ion level.
- Resonance Ionization Spectroscopy efficiencies are > 10^{-3} and growing, the new system will allow for single ion operation.

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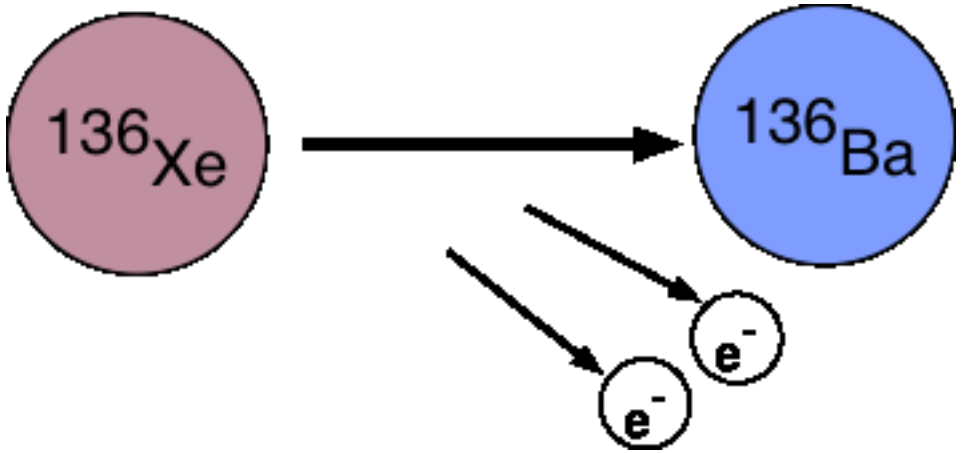
Backup Slides

Background and neutrino mass sensitivity

Backgrounds must be controlled at an extreme level.

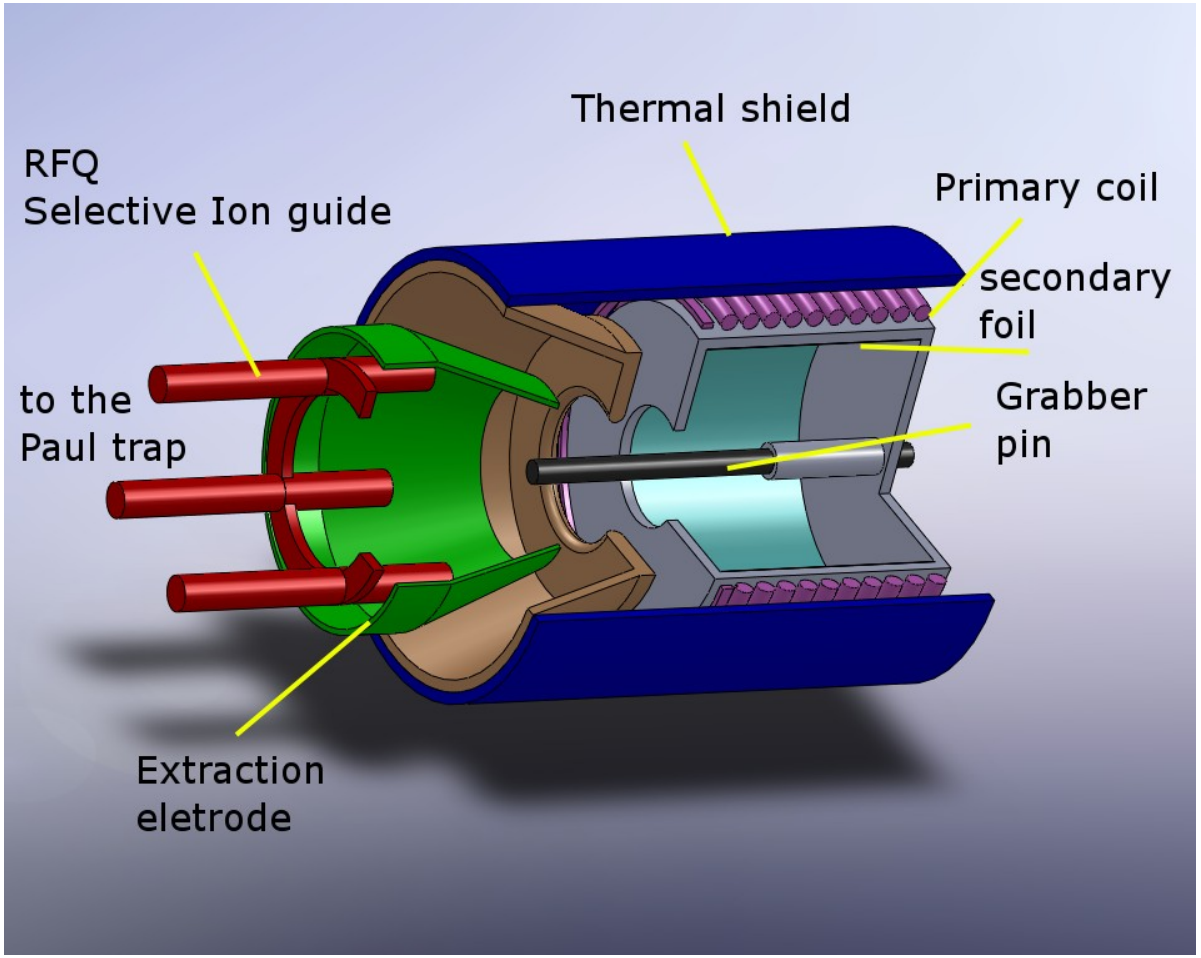
Without background: $\langle m_\nu \rangle \propto 1/\sqrt{T_{1/2}^{0\nu\beta\beta}} \propto 1/\sqrt{Nt}$

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

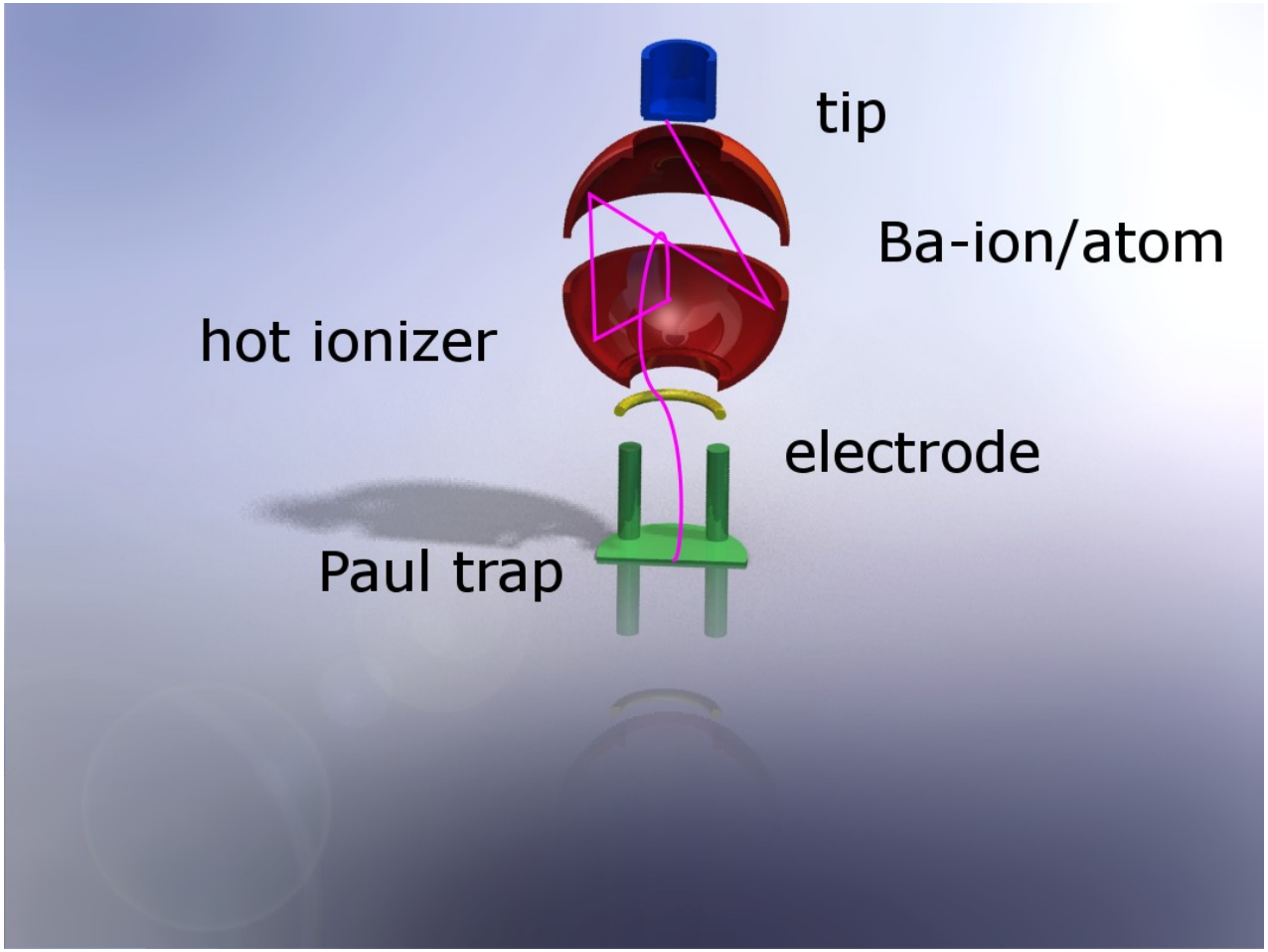


← Can be Identified with optical spectroscopy

Hot ionizer design



Hot ionizer scheme



The RIS test apparatus