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New Opportunities in On-line Laser Spectroscopy: Neutral Atom Traps and an Intense Cf-252 Source

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Office of Science
U.S. DEPARTMENT OF ENERGY

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Outline

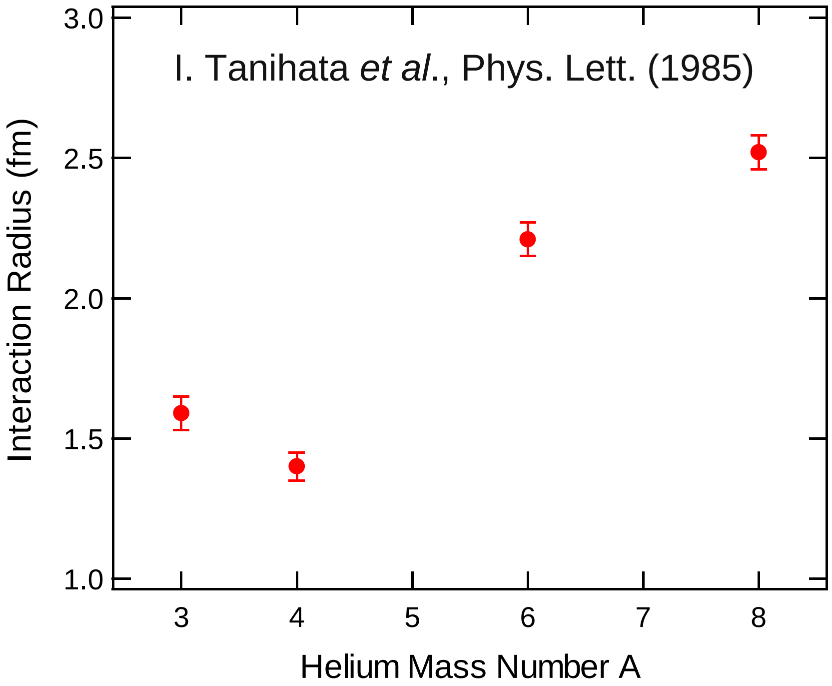
- Neutral Atom Trap
  - Charge Radii of ^{6}He and ^{8}He
  - What Atom Traps Can (Cannot) Do

- CARIBU: An Intense Source for Ca-252 Fission Isotopes
  - Facility Layout
  - Opportunities for Laser Spectroscopy

Neutron Halo Nuclei ^{6}He and ^{8}He

Isotope	Half-life	Spin	Isospin	Core + Valence
He-6	807 ms	0^+	1	α + 2n
He-8	119 ms	0^+	2	α + 4n

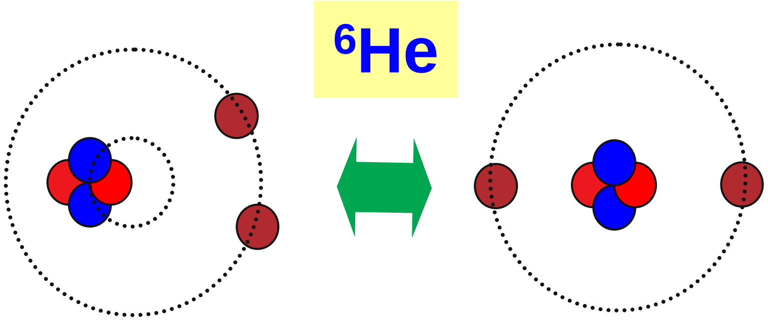
Borromean



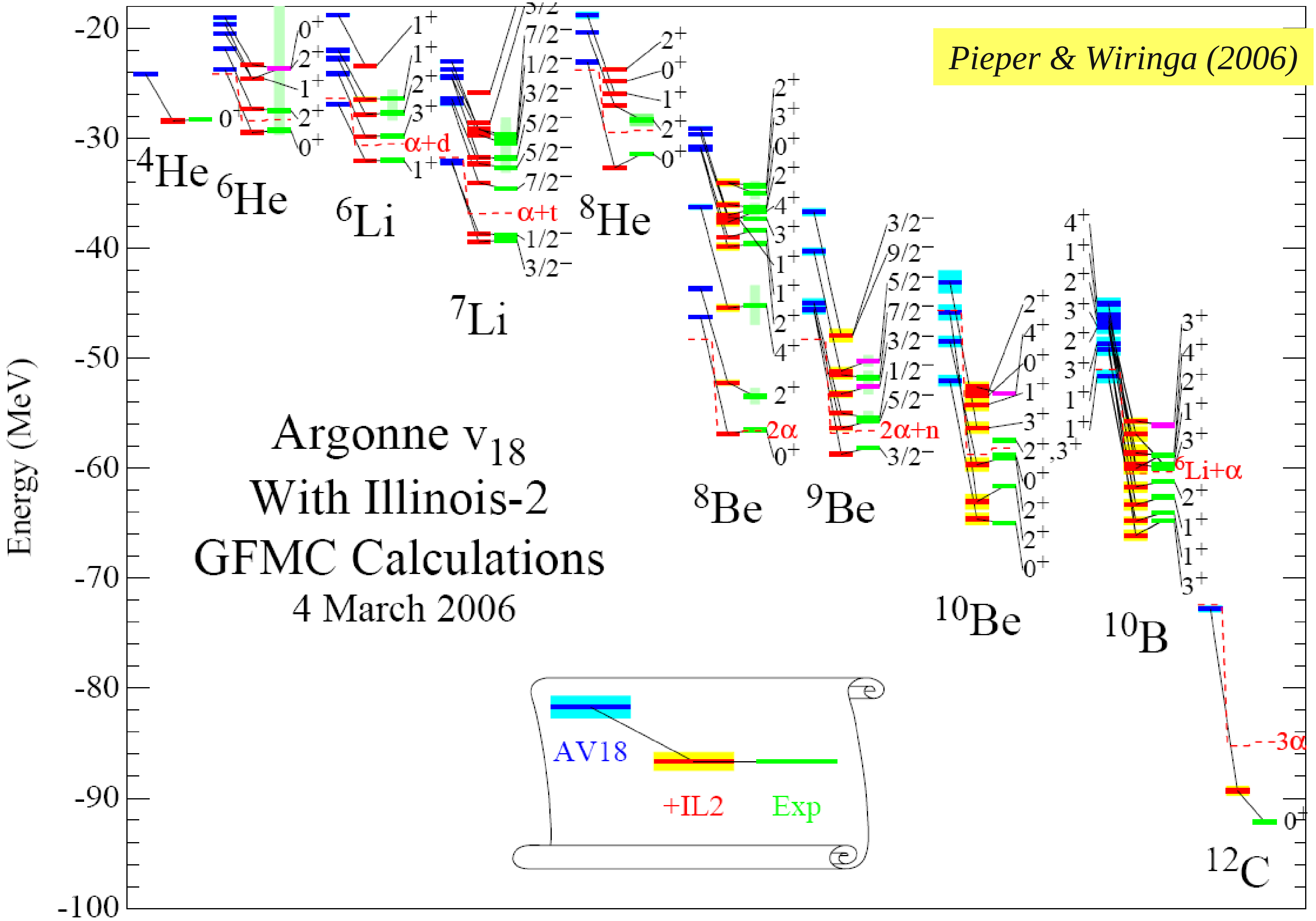
Core-Halo Structure

$$\sigma_I(^6He) - \sigma_I(^4He) = \sigma_{-2n}(^6He)$$

I. Tanihata *et al*., Phys. Lett. (1992)



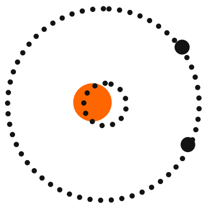
“Ab-Initio” Calculations of Light Nuclei



Isotope Shifts and Charge Radii

Mass shift:

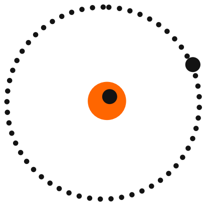
due to change in CM



$$\delta\nu_{MS} = C_{MS}\,\frac{A - A'}{AA'}$$

Field shift:

due to change in charge distribution



$$\delta\nu_{FS} = C_{FS}\,\delta\langle r^2\rangle$$

He-6/8

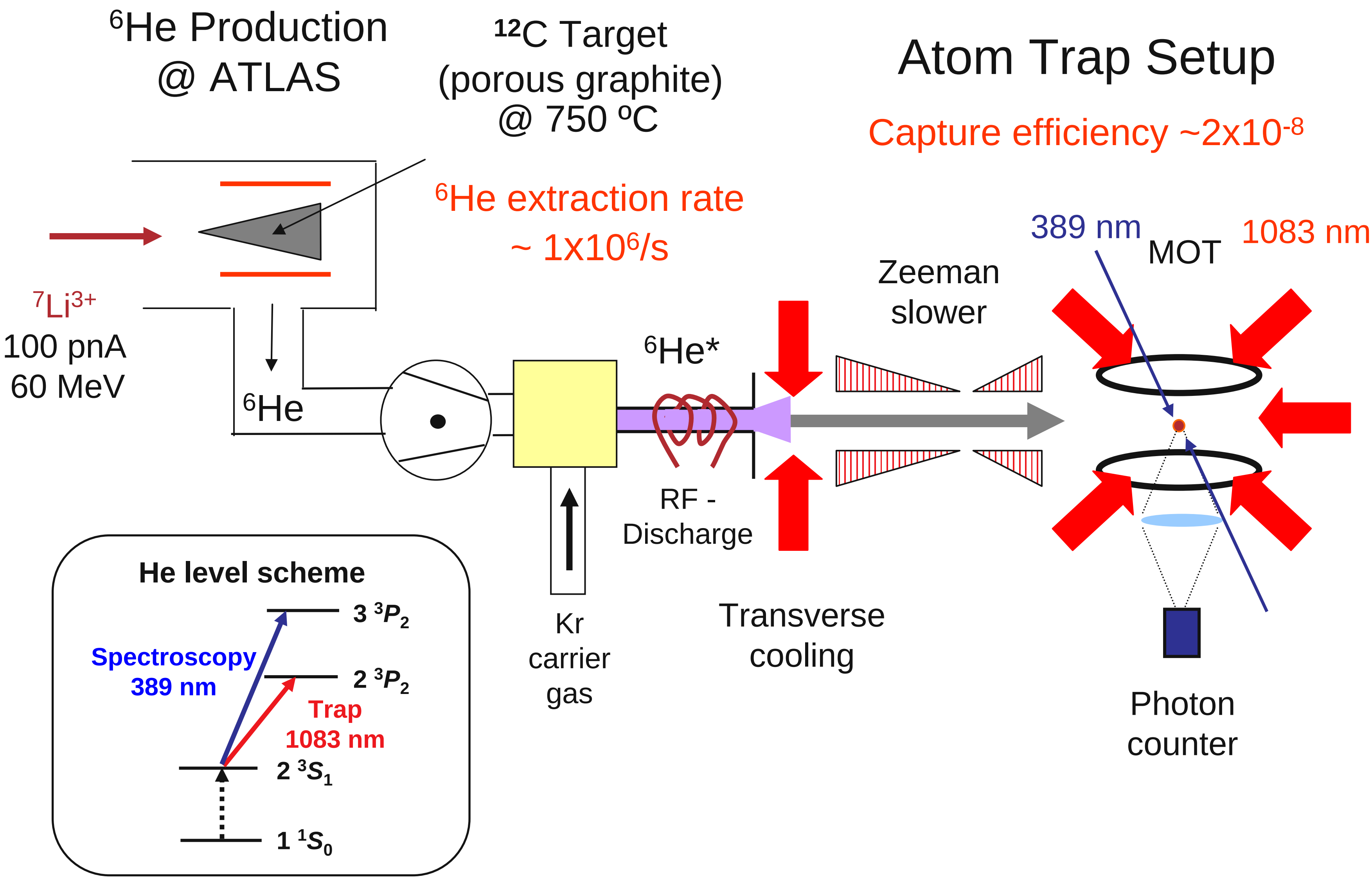
^{6}He - ^{4}He IS for $2^3S_1 - 2^3P_2$ transition

$$\delta\nu = 43196.202(16)\ \text{MHz} + 1.008\ (\langle r^2\rangle_{He4} - \langle r^2\rangle_{He6})\ \text{MHz/fm}^2$$

G.W.F. Drake, Univ. of Windsor, *Nucl. Phys. A737c, 25 (2004)*

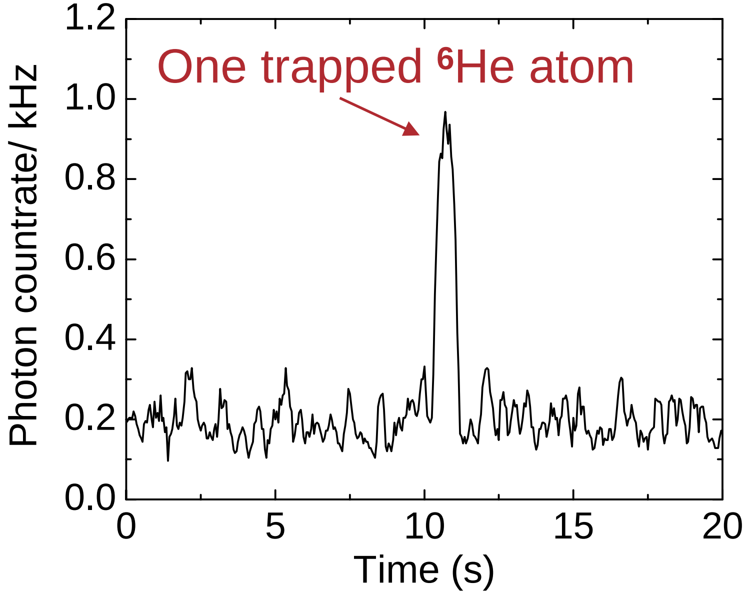
100 kHz error in frequency ←→ ~ 1% error in radius

Atom Trapping of ^{6}He

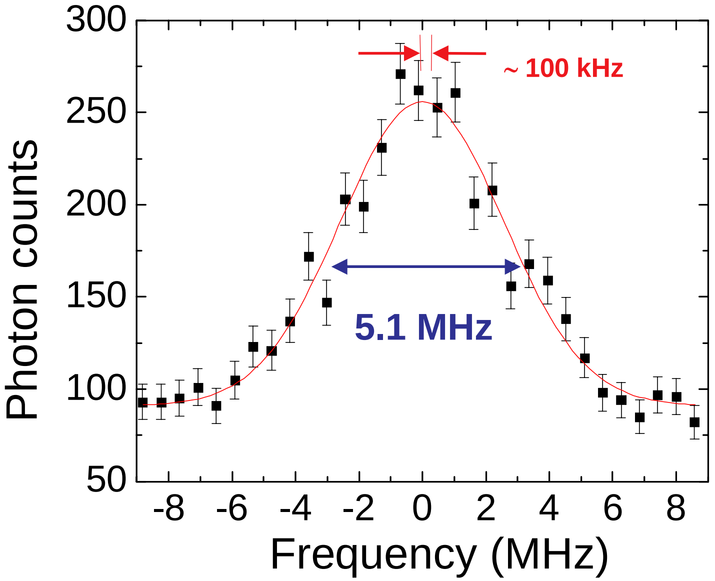


Precision Spectroscopy of ^{6}He

Single atom signal



^{6}He spectroscopy



- Single-atom signal ~ 1.0 kHz
- Single-atom S/N ~ 10 in 100 ms

- Spectroscopy with ~150 ^{6}He in one hour

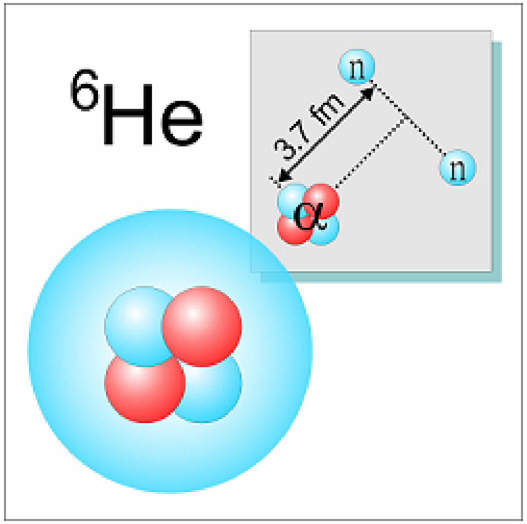
^{6}He Nuclear Charge Radius

Isotope shift
(2^3S_1 - 3^3P_2, ^{6}He – ^{4}He)

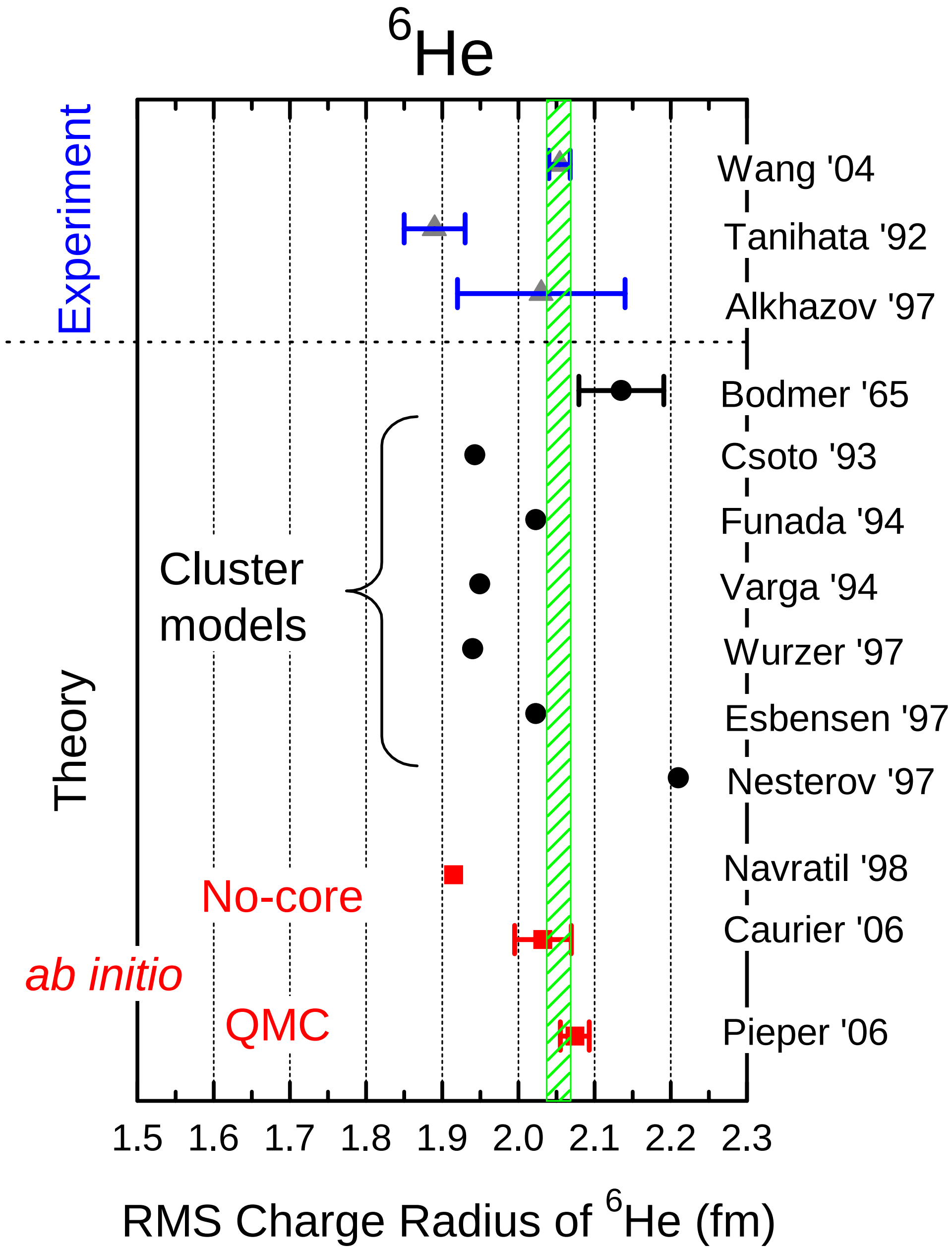
43 194.772(56) MHz

^{6}He rms charge radius

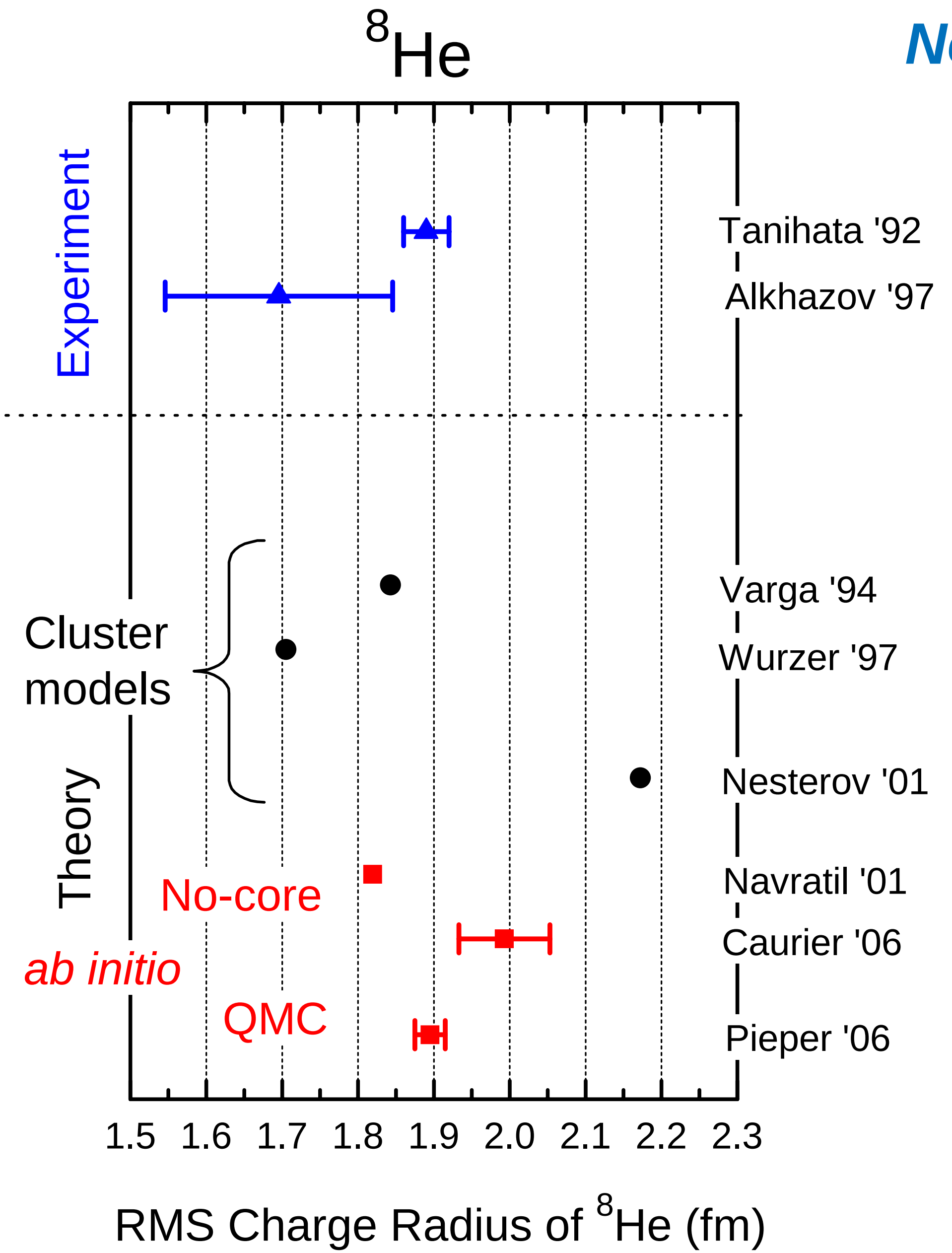
2.054(14) fm (0.7%)



L.-B. Wang *et al.*,
PRL **93**, 142501 (2004)



Next Goal - ^{8}He ($t_{1/2}$ = 120 ms)



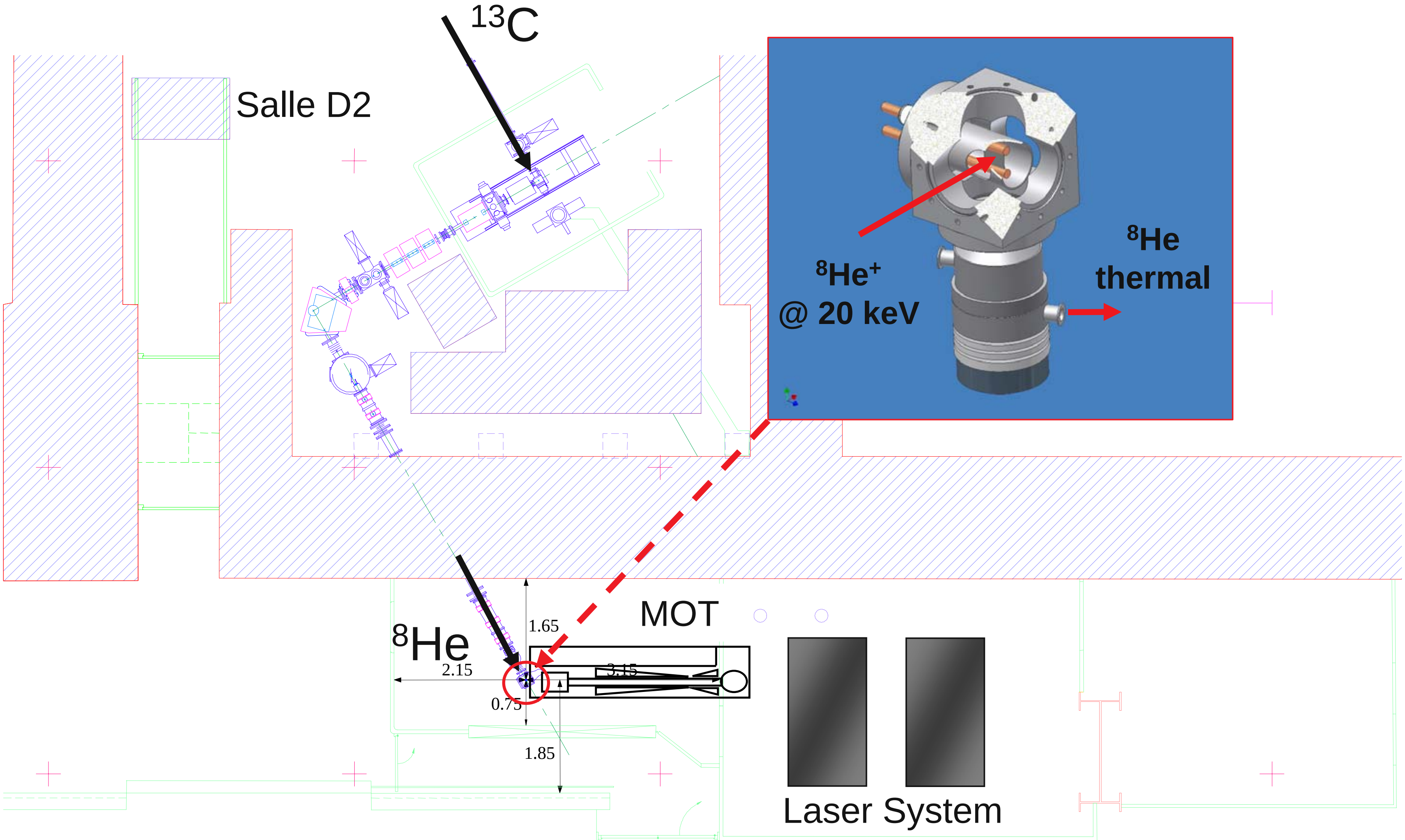
^{8}He Yield

- ATLAS, Argonne < 1 x 10^{4} s^{-1}
- GANIL, France ~ 2 x 10^{5} s^{-1}

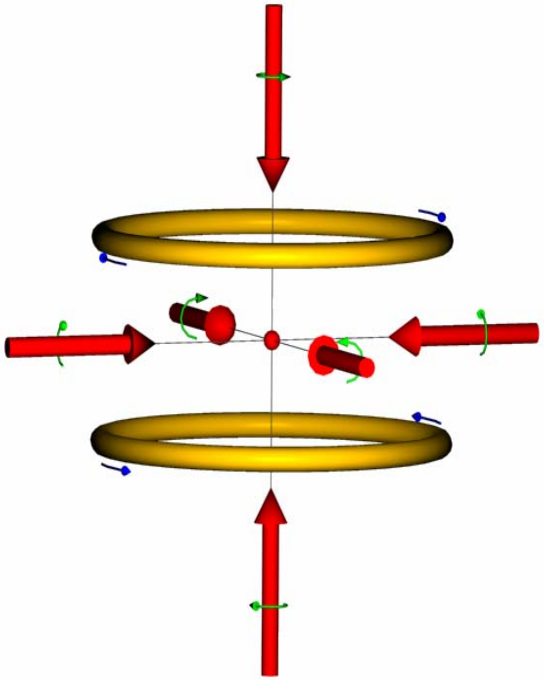
Current Status

- Efficiency increased by x20
  - more laser power
  - improve transverse cooling
  - discharge
- Laser safety documents approved;
- Site preparation and move underway;
- On-line in spring 2007.

Atom Trapping of ^{8}He @ GANIL



What Atom Traps Can Do



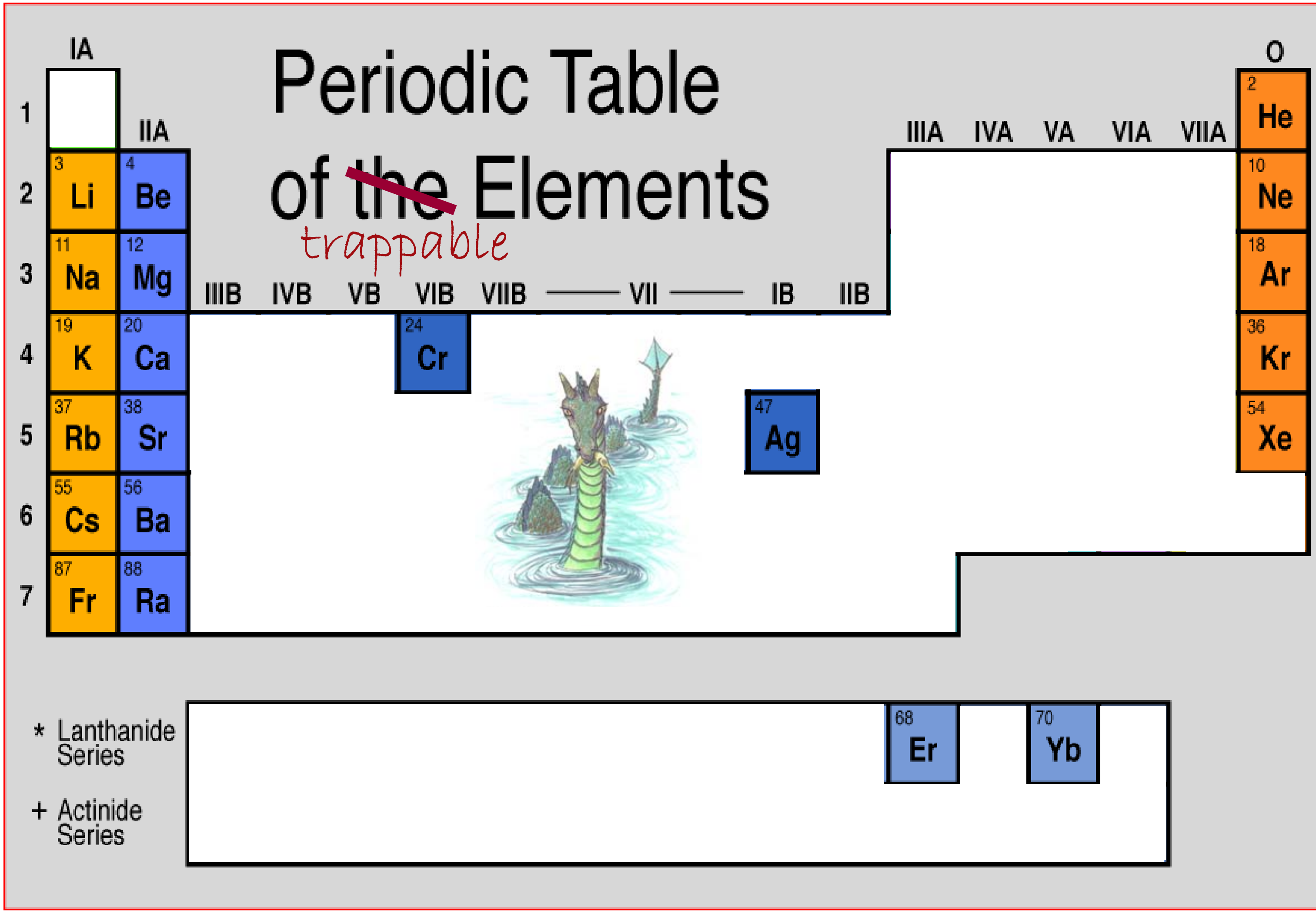
MOT Advantages

- Selectivity – no isotopic interference
- Sensitivity – single atom
- Cold sample in free space – T << 1 K
- Spatial confinement – << 1 mm
- Long storage time – up to many seconds

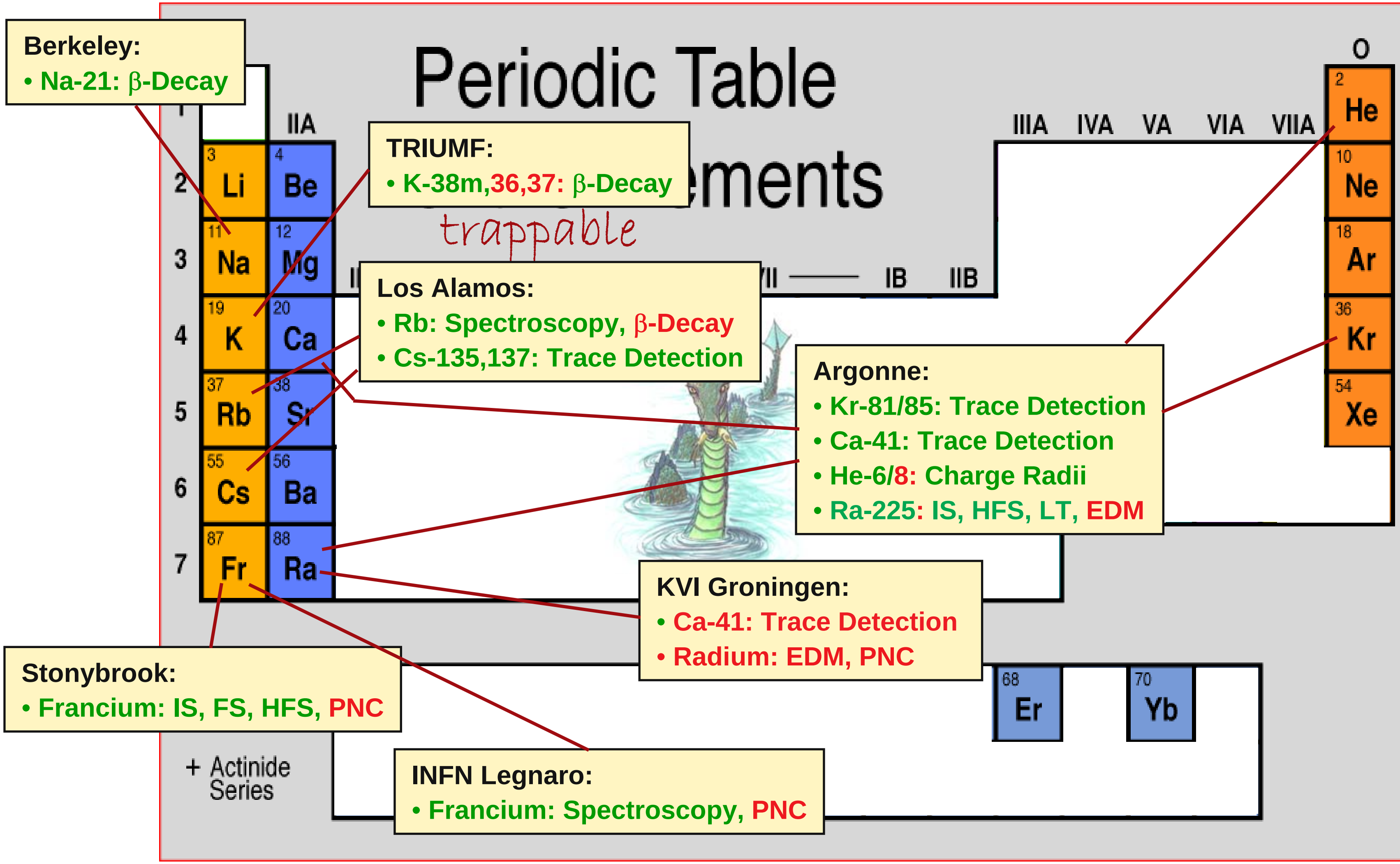
But …

need cycling transition …

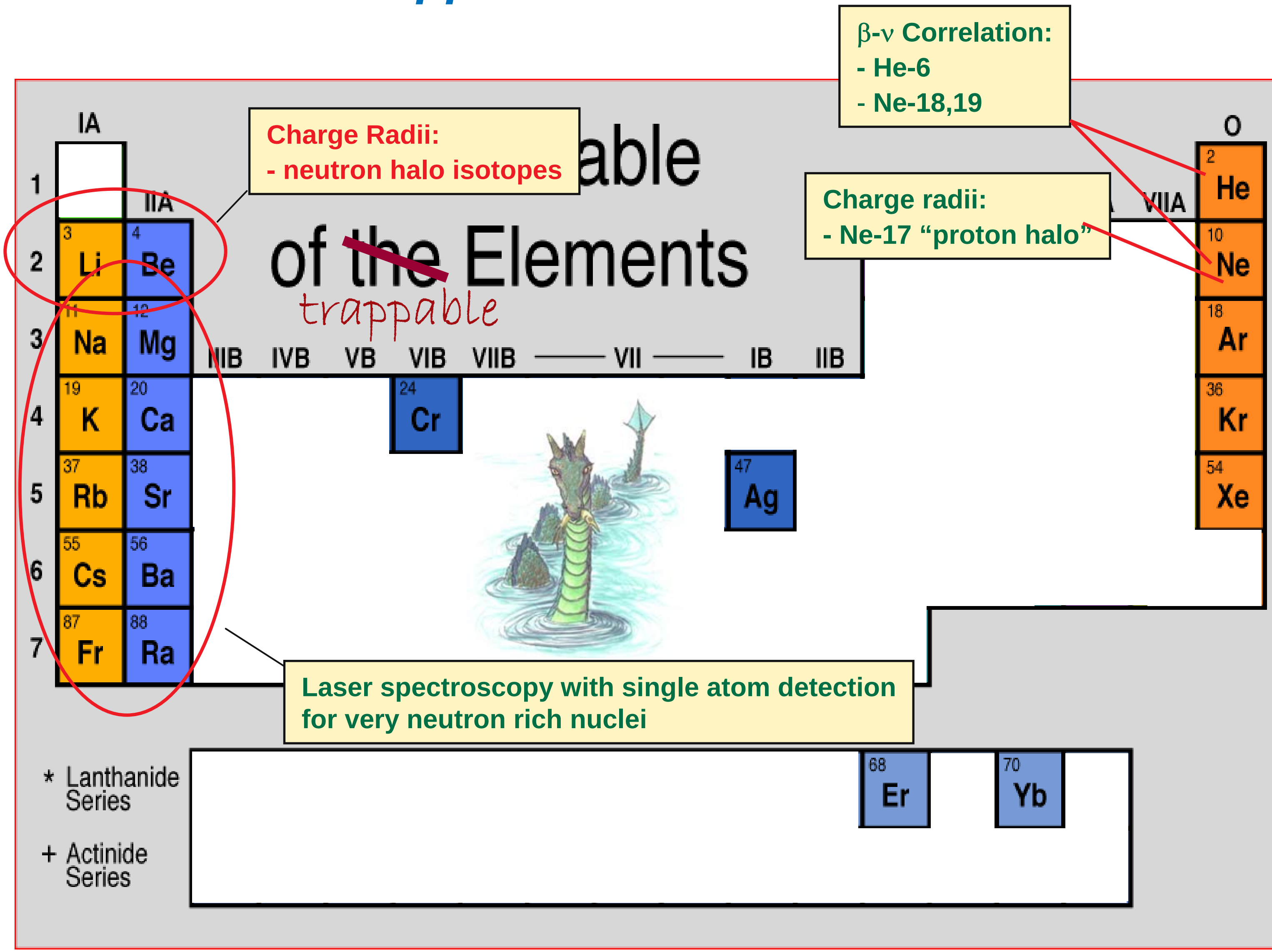
Periodic Table for Atom Trappers



Atom Traps of Rare Isotopes

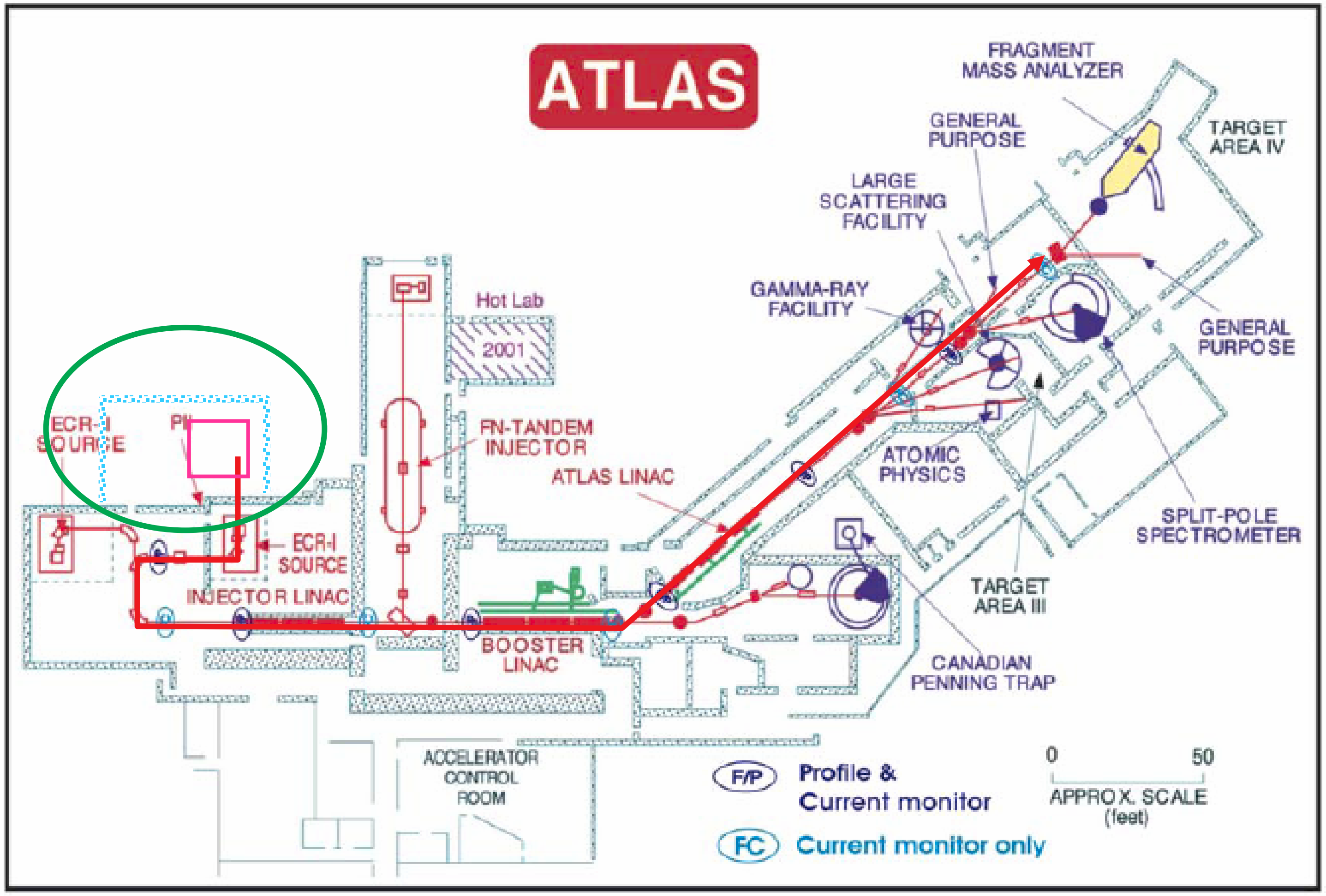


More Possibilities & Opportunities



CARIBU: Californium Rare Isotope Breeder Upgrade

Contact: Guy Savard, Richard Pardo, Physics Division, Argonne

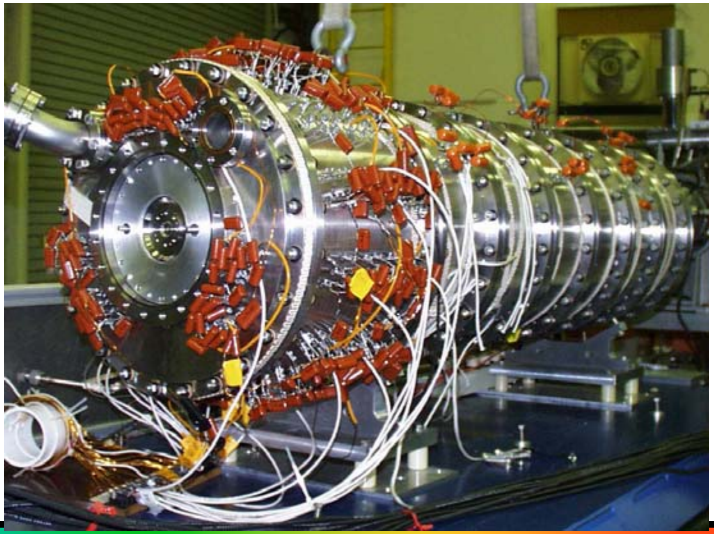


http://www.phy.anl.gov/atlas/caribu.html

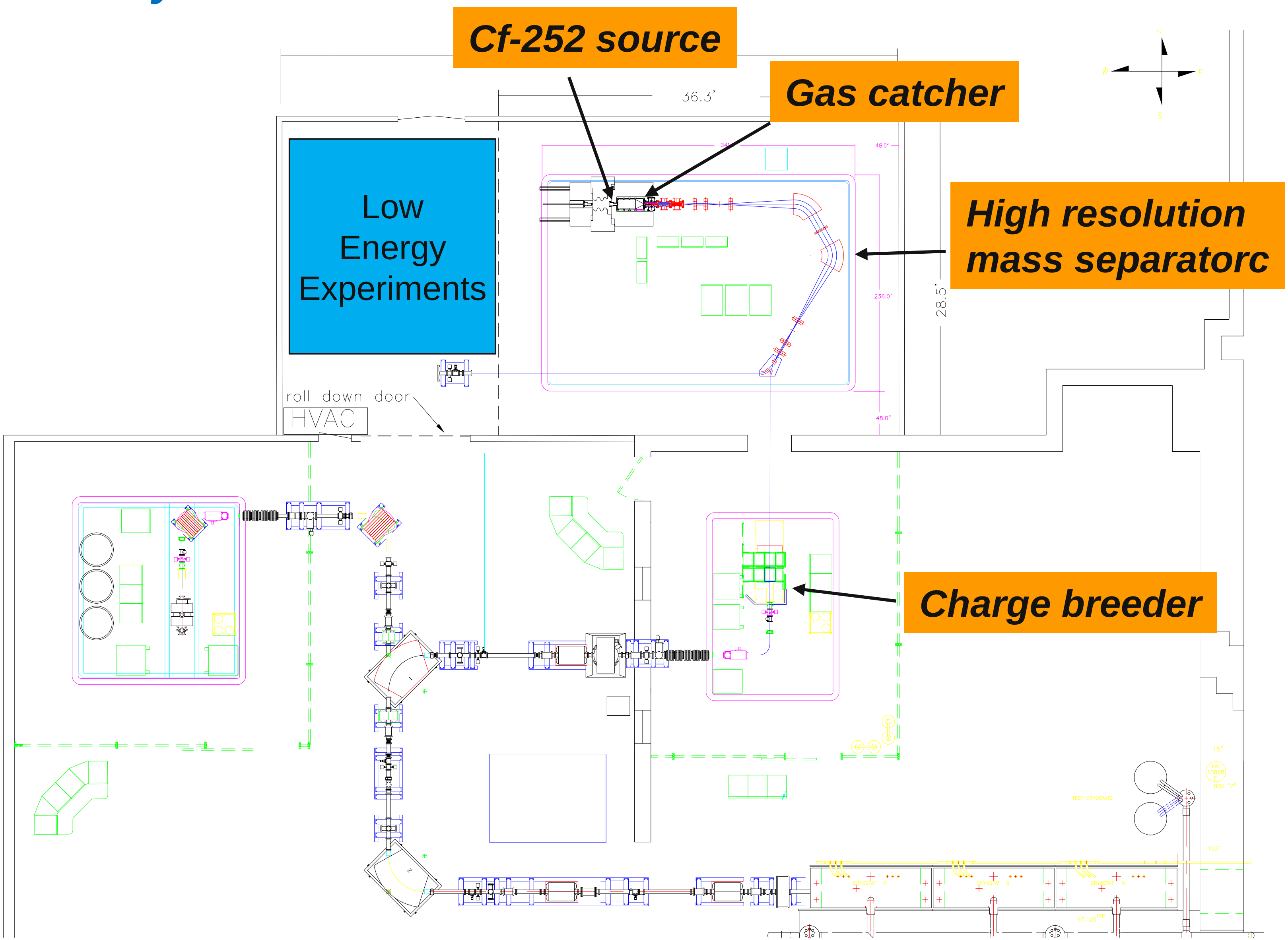
^{252}Cf source + large gas catcher as neutron-rich isotope source

- **Shortened version of RIA gas catcher can efficiently stop fission products from a fission source**
  - **~ 50% stopped in gas for backed source**
- **About 45% of those can be extracted as charged ions**
- **Very efficient and fast source, provides cooled bunched beams for post-acceleration**
- **Production peaks in new regions and extraction is element independent … new isotopes available**

Gas catcher technology developed, tested and now routinely used at ATLAS for CPT and RIA programs

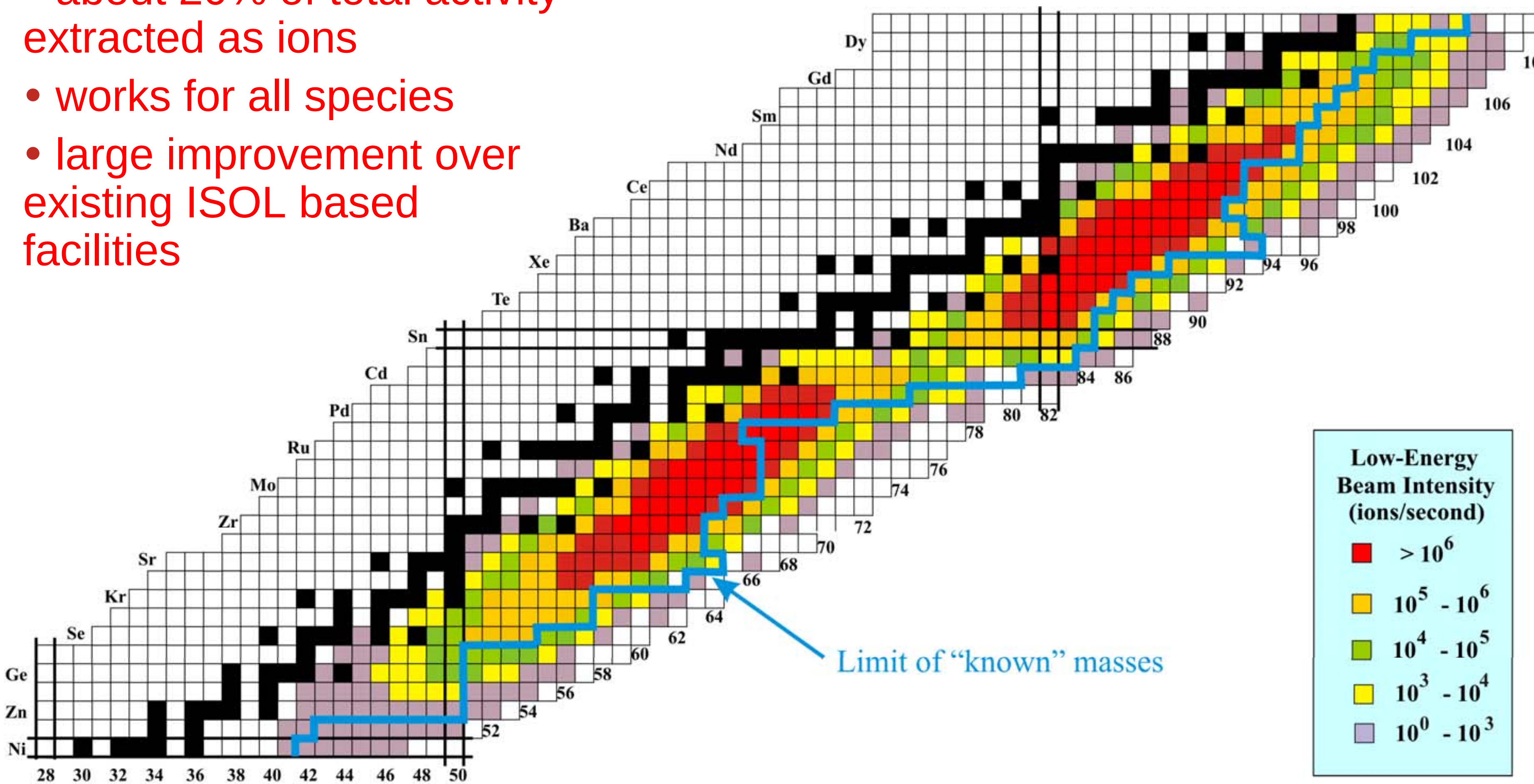


CARIBU Layout



Extracted isotope yield at low energy

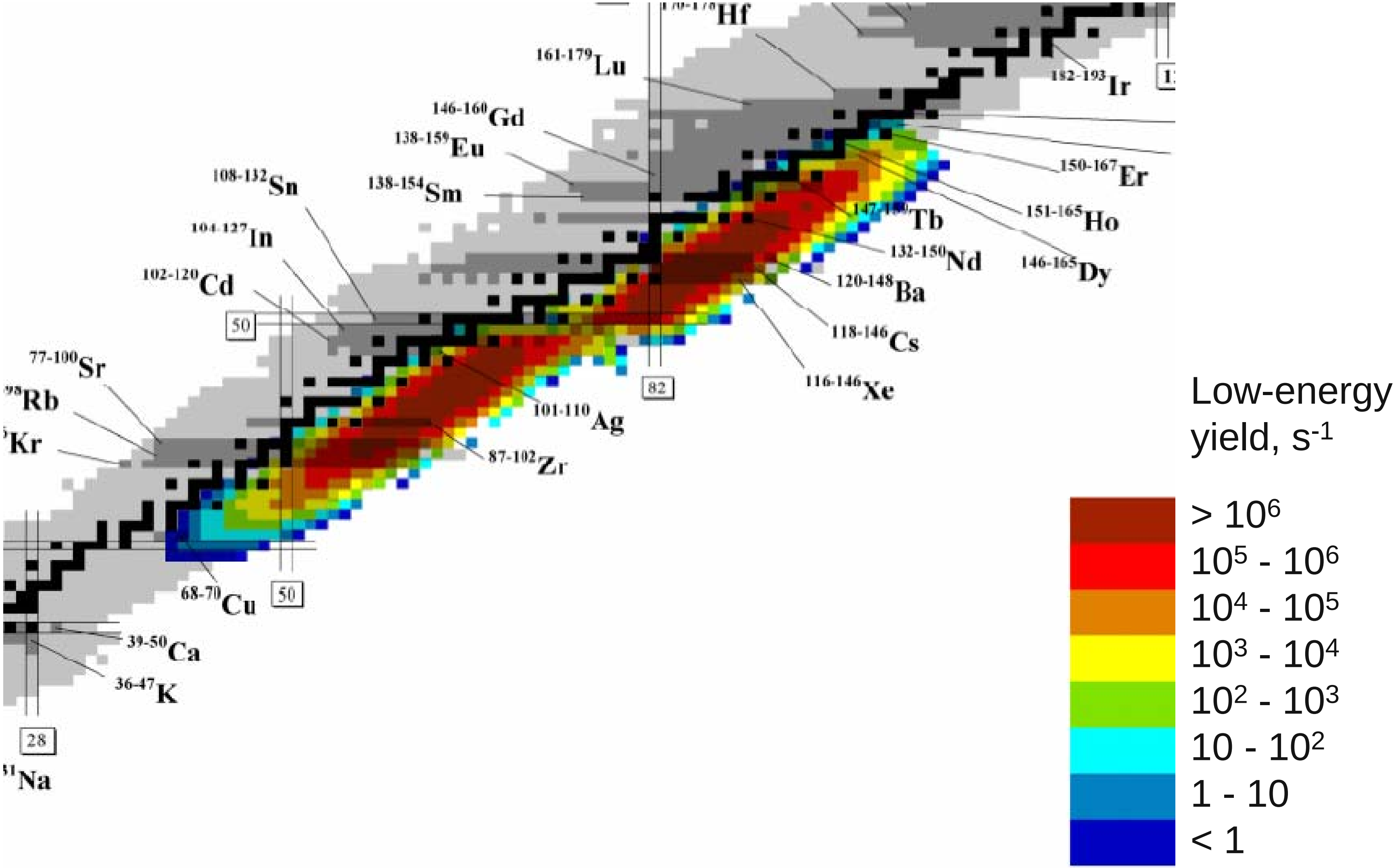
- 1 Ci ^{252}Cf source
- about 20% of total activity extracted as ions
- works for all species
- large improvement over existing ISOL based facilities



Important physics questions

- **modification of nuclear structure in neutron-rich systems**
  - ***shell-structure quenching***
  - ***single particle structure near neutron-rich magic nuclei***
  - ***pairing interaction in weakly-bound systems***
- **collective behavior in neutron-rich systems**
- **r-process path**
  - ***ground-state information***
    - ***mass***
    - ***lifetime***
    - ***beta-delayed neutron branching ratio***
  - ***neutron capture rate***
  - ***fissionability of very heavy neutron-rich isotopes***

Isotopic Menu



Isotopic Menu – "Low Mass"

		Wavelengths, nm		Laser Spectroscopy		CARIBU	
		I	II	LS	Method	Range > 100/s	
30	Zn	589.4				75	79
31	Ga	417.2				76	83
32	Ge	*265.16				77	86
33	As	197.2				79	89
34	Se	207.48				80	92
35	Br	*827.47				83	94
36	Kr	*811.52		72 .. 96	CS	85	97
37	Rb	780.0		76 - 96	CS	87	97
38	Sr	460.86	421.7	77 - 100	CS	89	102
39	Y	414.4		JYFL .. 102	CS	91	104
40	Zr	388.65		87 … 102	CS	94	106
41	Nb	492.45				97	109
42	Mo	390.41				100	112
43	Tc	429.82				101	113
44	Ru	392.7				103	115
45	Rh	369.34				105	118
46	Pd	276.39				109	124
47	Ag	328.16		101 … 110	CS	111	125
48	Cd	326.1	214.5	102 … 120	CS	112	126
49	In	451.3	236.5	104 - 127	CS	115	133
50	Sn	452.5		108 - 132	CS, RIMS	124	136

MOT

Collinear

N = 50 (Zn–Br)

Refractory elements (Y–Pd)

N = 82 (In–Sn)

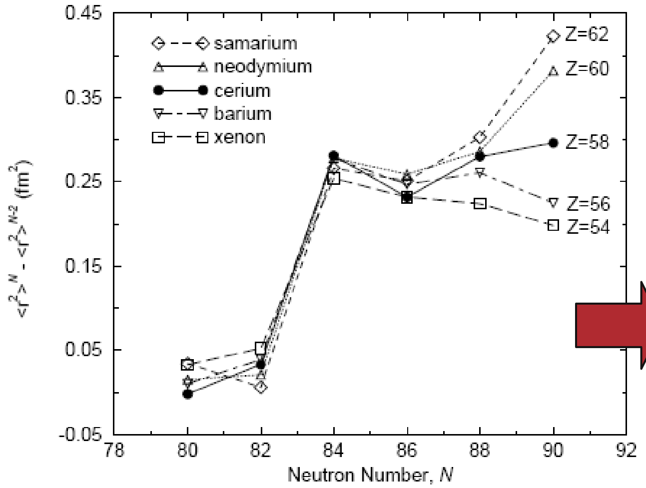
Menu of Isotopes – "High Mass"

		Wavelengths, nm		Laser Spectroscopy		CARIBU	
		I	II	LS	Method	Range > 100/s	
51	Sb	231.22				124	138
52	Te	214.35				129	140
53	I	183.04				131	142
54	Xe	*882.18		116 … 146	CS	133	146
55	Cs	455.65		118 - 146	CS	135	148
56	Ba	553.7	455.4	120 - 146	CS	137	150
57	La	418.84		… @ TRIUMF	CS	139	152
58	Ce	450.64	331	… @ JYFL	CS	141	155
59	Pr	495.14	590			144	157
60	Nd	468.34	590	132 … 150	RIS	146	159
61	Pm	?				149	161
62	Sm	471.71		138 - 154	RIS	151	164
63	Eu	459.4	604.9	138 - 159	RIS	154	166
64	Gd	432.71		146 - 160	RIS	156	168
65	Tb	432.64		147 ... 159	RIS	159	169
66	Dy	404.71		146 … 165	RIS	162	171
67	Ho	410.38		151 … 165	RIS	166	171
68	Er	415.23		150 … 167	RIS	169	172

MOT

Collinear

N = 82



New CARIBU building addition under construction

CARIBU Schedule

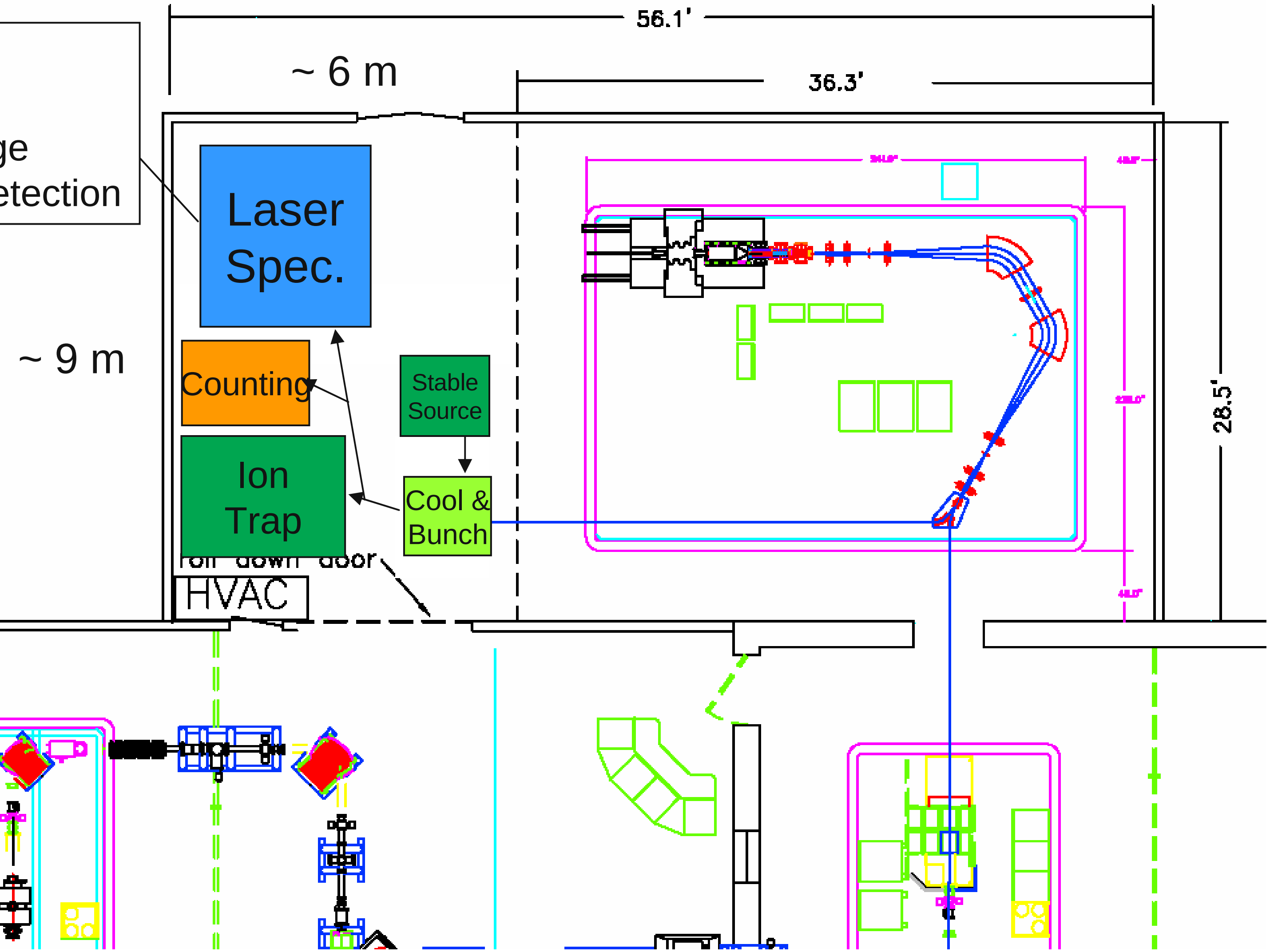
	CY2006				CY2007				CY2008			
Component	FQ1	FQ2	FQ3	FQ4	FQ1	FQ2	FQ3	FQ4	FQ1	FQ2	FQ3	FQ4
ATLAS Facility Space	Construct/ Enhance											
ECR Charge Breeder	Design	Fabricate/Procure			Install	Commission				Pre-Operations		
HV Platform	Design		Fab./Procure		Install	Comm.						
HV Transformer									Procure		Comm.	
Gas Catcher/Gas Cooler	Design		Fabrication/Procurement				Install			Commission		PreOp
Isobar Separator	Design		Fabrication/Procurement					Install		Comm.		PreOp
Source, Cask, & Transport	Design				Fabrication/Procurement				Install		Comm.	PreOp
Phase I (1 mCi Source)									Proc/Ins			
PhaseII (30 mCi Source)										Proc	Ins	
PhaseIII (1Ci activity)											Ins	
ATLAS Diagnostics			Design						Fabric.	Install	Comm.	PreOp
Low-Energy Beamline					Design				Fabric.	Install	Comm.	

low-E beams

Reaccelerated beams

CARIBU Low Energy Beam Experiments

- Collinear LS
- Bunched beam
- Charge exchange
- Fluorescence detection



Thank You!

^{6}He Collaboration

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Argonne Atom Trappers

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