Laser spectroscopy and isomeric beam production at DESIR

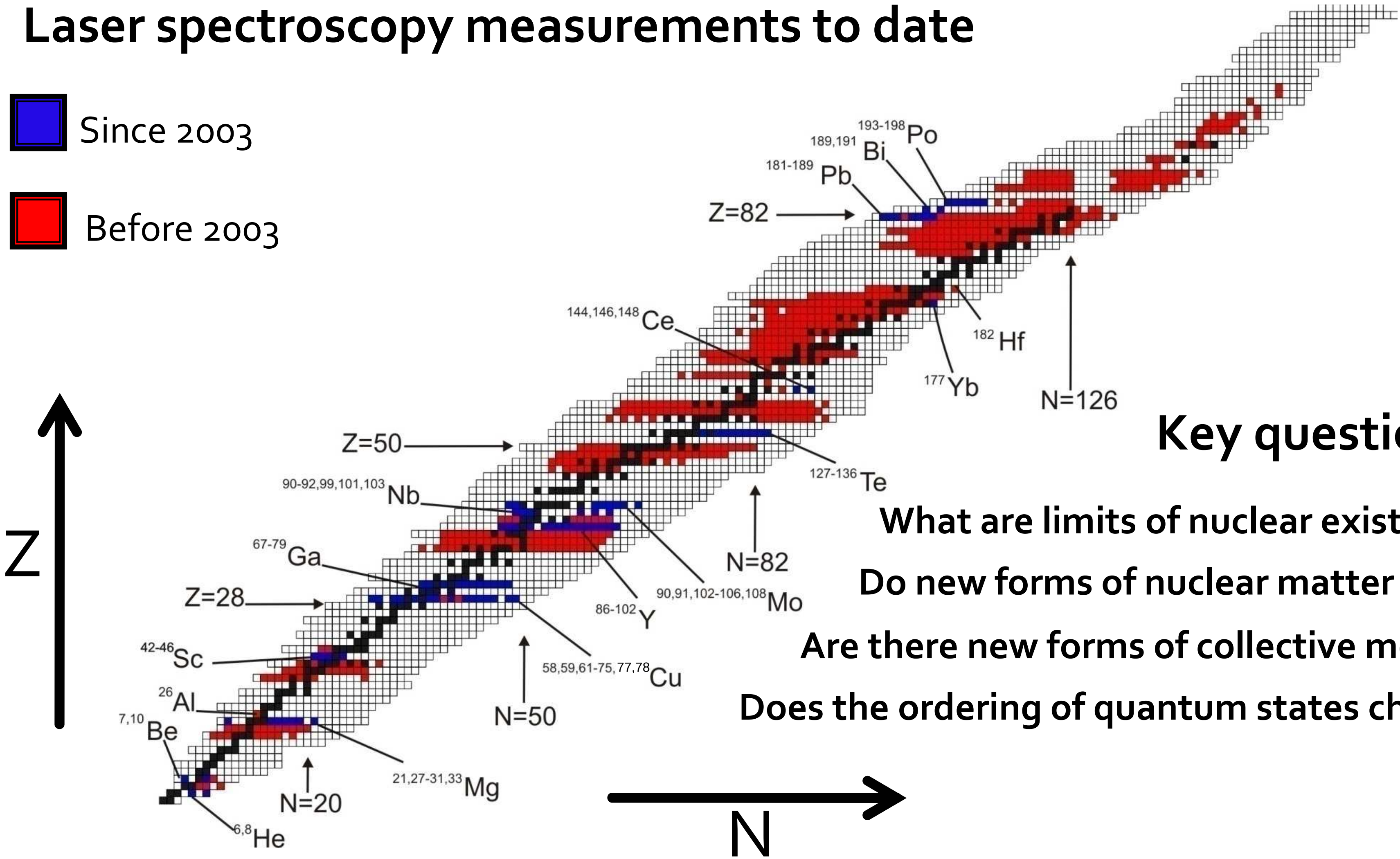
Kieran Flanagan
University of Manchester

DESIR: A unique facility for laser spectroscopy

Laser spectroscopy measurements to date

Since 2003

Before 2003



Key questions

What are limits of nuclear existence?

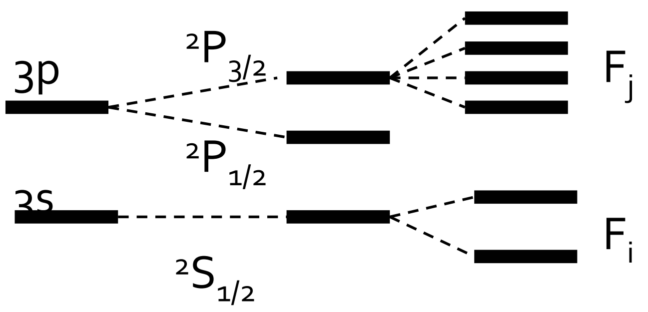
Do new forms of nuclear matter exist?

Are there new forms of collective motion?

Does the ordering of quantum states change?

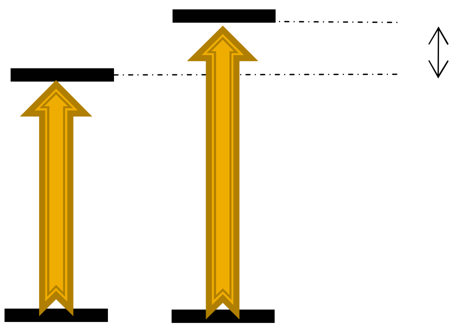
Nuclear moment and radii measurements with laser spectroscopy

Hyperfine Structure



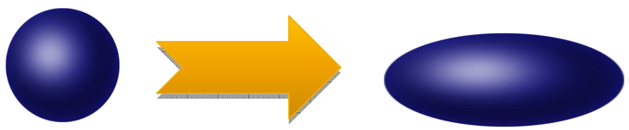
Spin, magnetic and electric moments , all nuclear observables are extracted without model dependence.

Isotope Shift

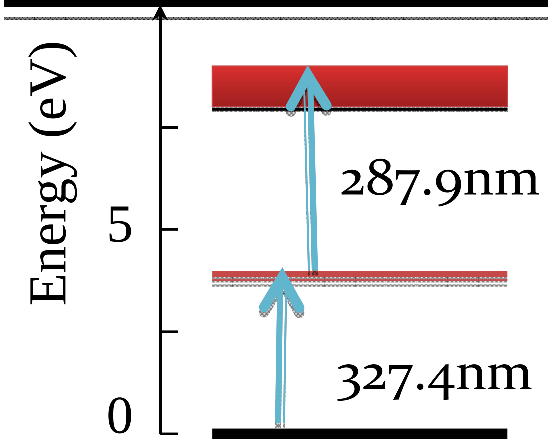


$$\Delta\nu_{IS} = \Delta\nu_{MS} + \Delta\nu_{FS}$$

Changes in nuclear charge radii and sensitive to changes in dynamic nature and deformation as well as volume.

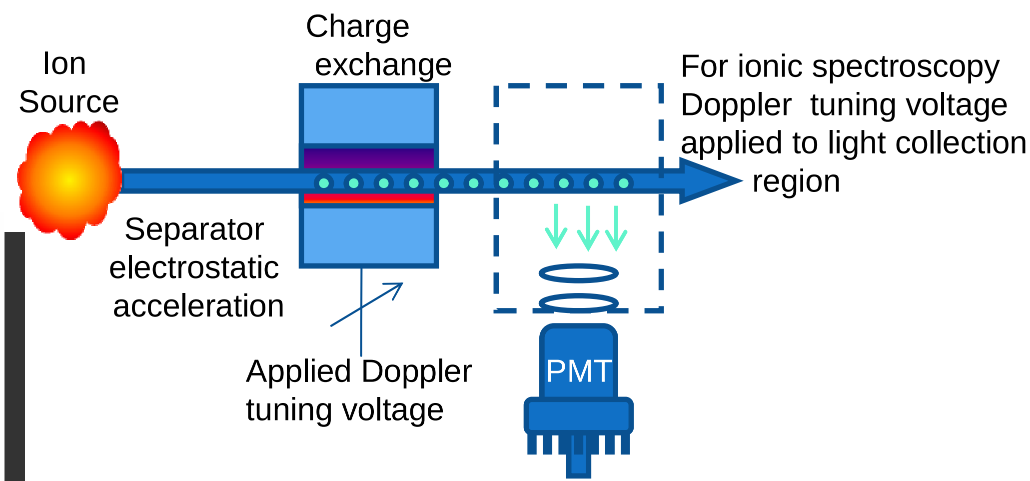


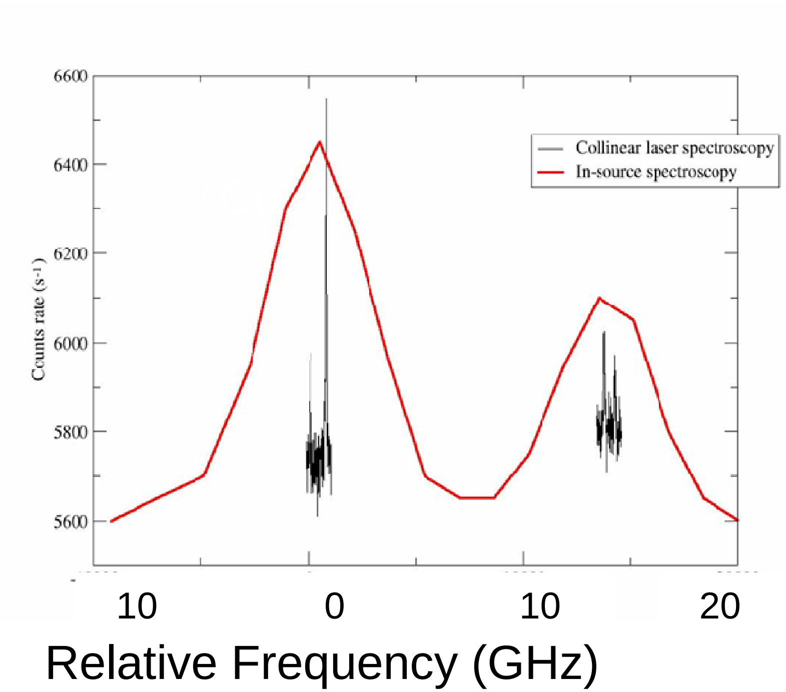
High resolution vs high sensitivity



Collinear Concept

$$\Delta E = const = \delta(^1/_2 mv^2) \approx mv\delta v$$

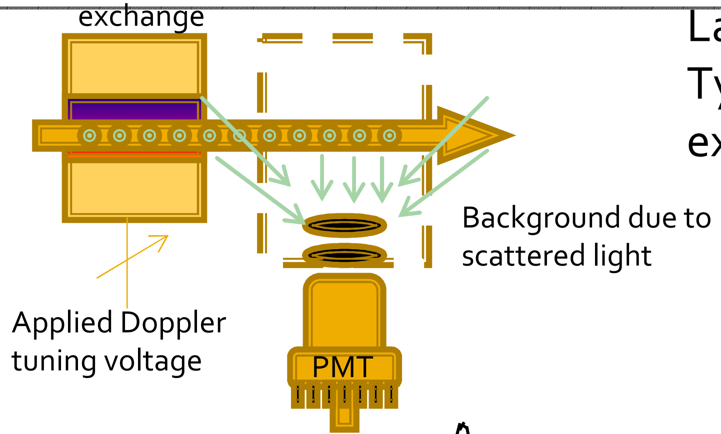




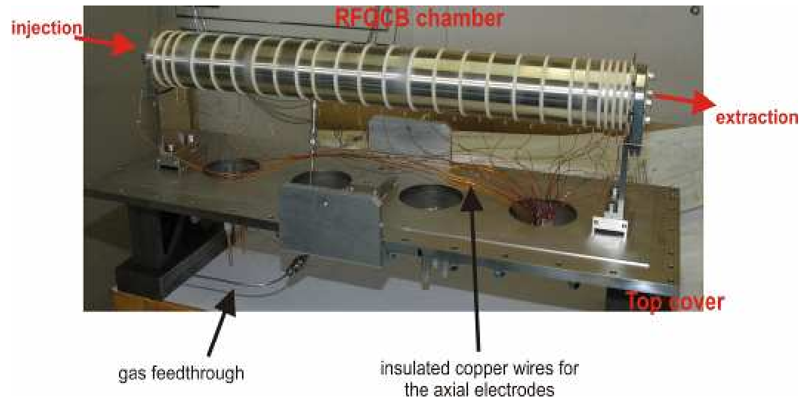
In-source + collinear will dramatically reduce the scanning region
and therefore the required time to locate resonances.

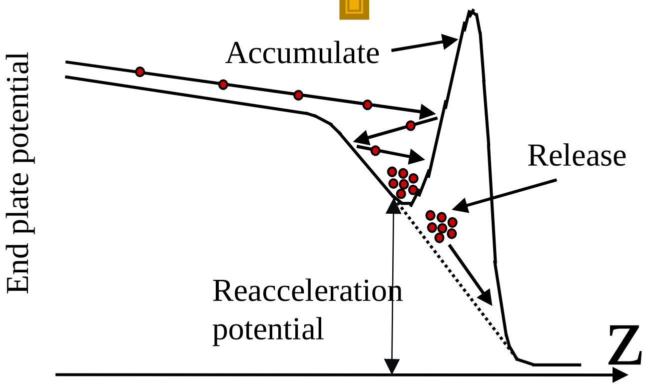
Innovations in fluorescence detection

Large background due to scattered light 1000-5000/s
Typical lower limit on yield is 10^6/s (with a couple of exceptions)

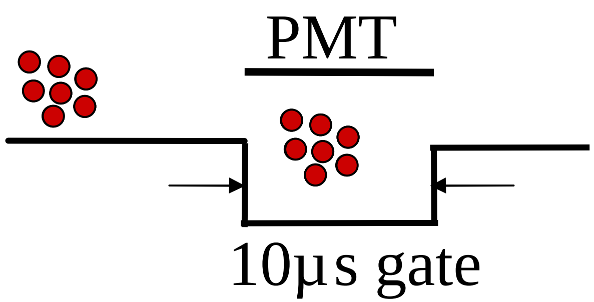


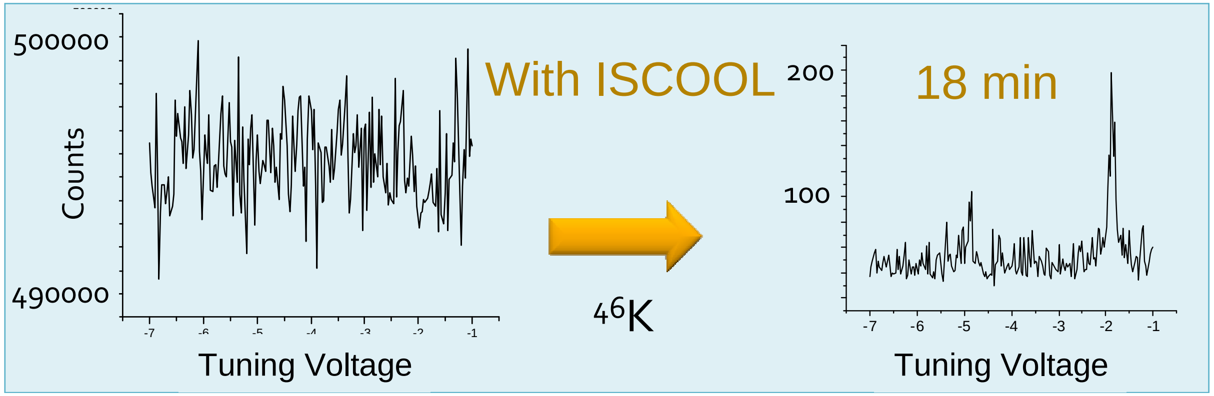
ISCOOL



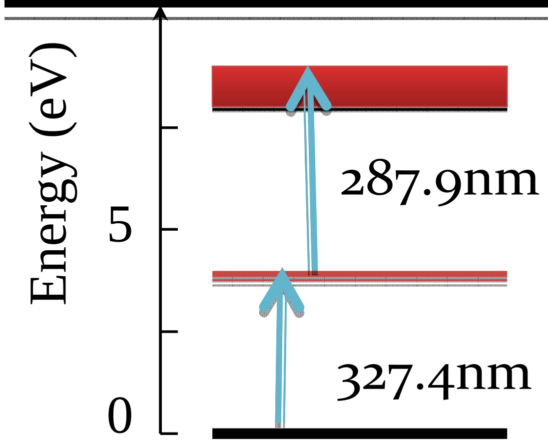


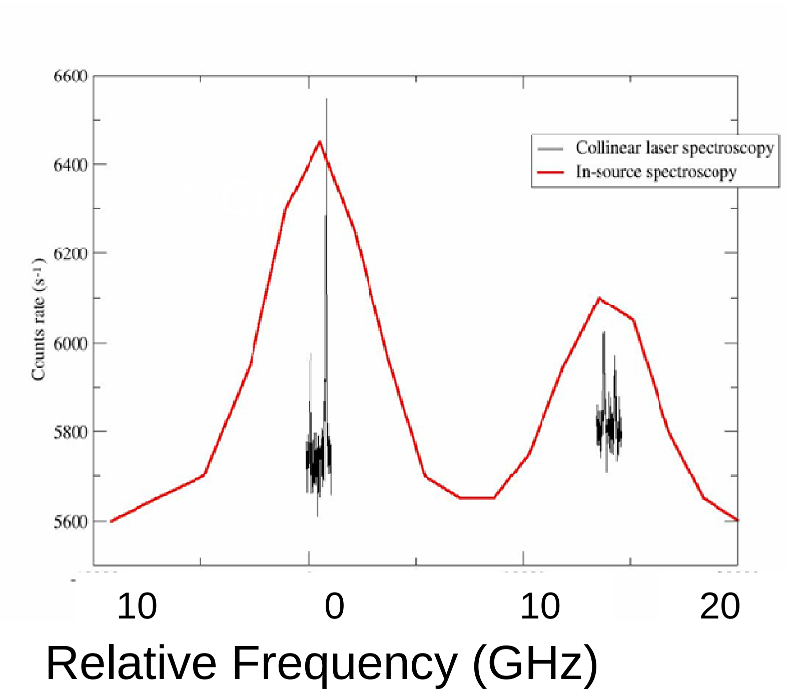
$$\text{Background suppression} = \frac{\text{eg. 200ms accumulation}}{10\mu s \text{ gate width}} \sim 10^4$$





High resolution vs high sensitivity





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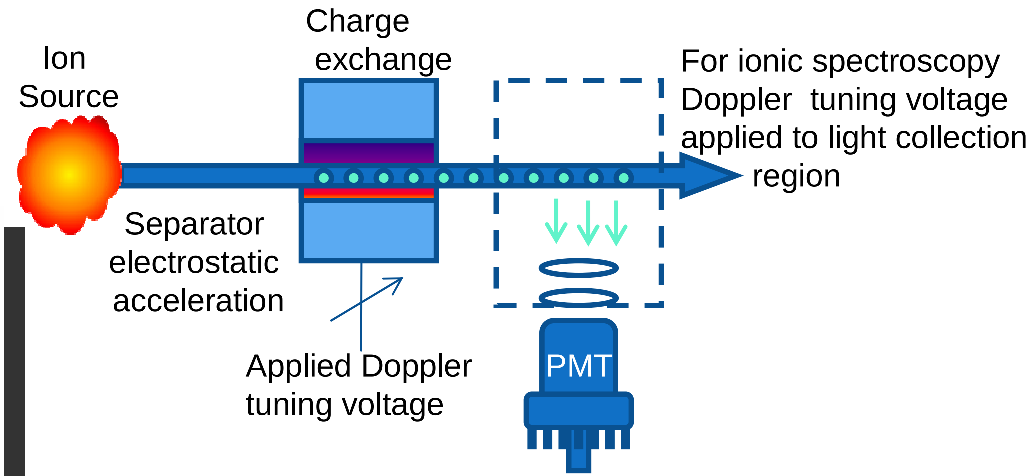
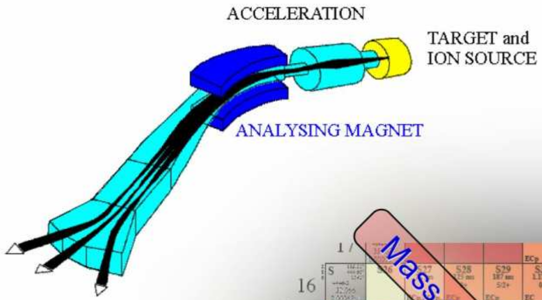
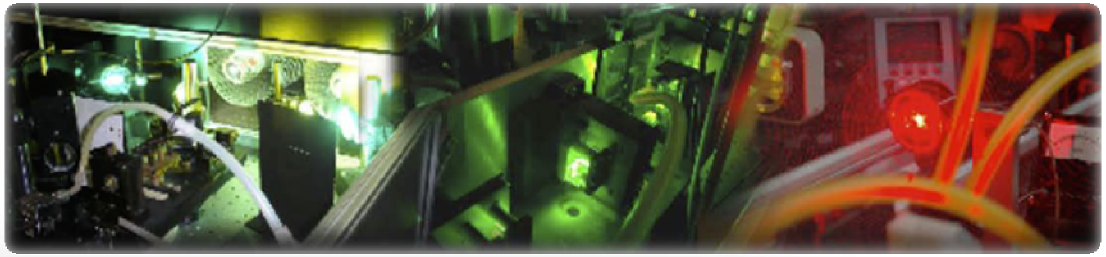
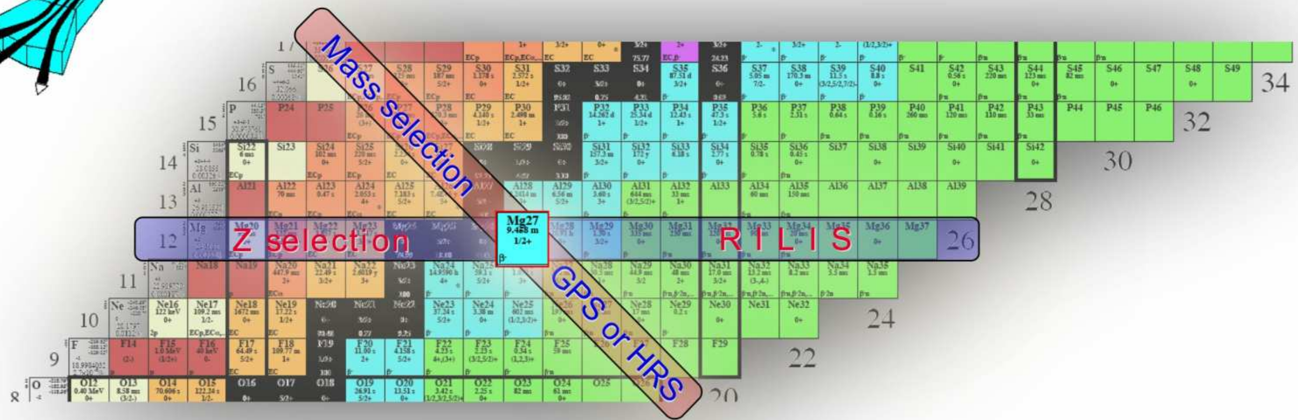


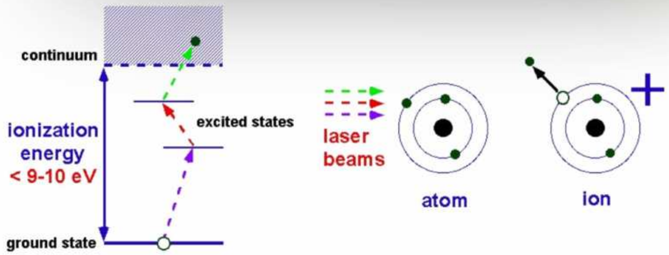
In-source + collinear will dramatically reduce the scanning region
and therefore the required time to locate resonances.

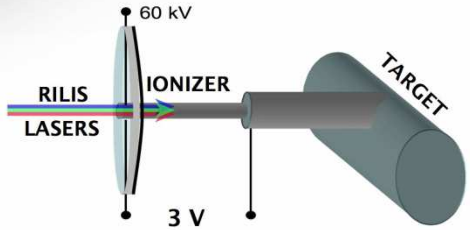
RILIS: The ISOLDE laser ion source







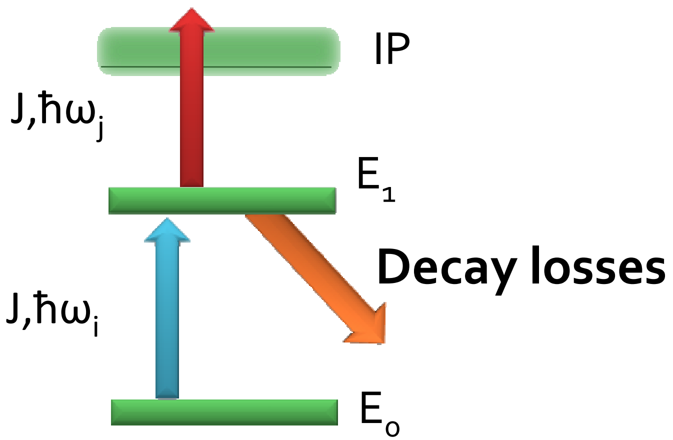


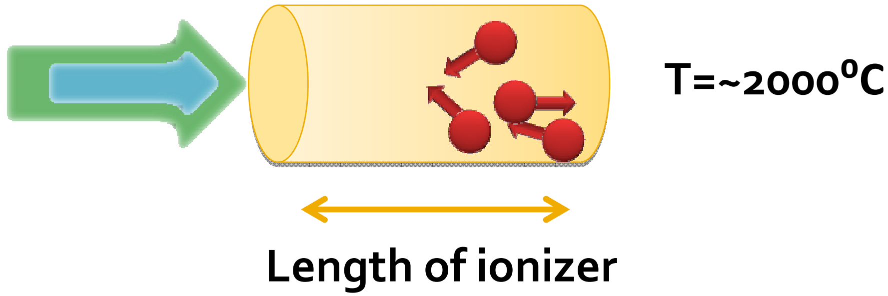


Laser ionization in a hot cavity

B.A. Marsh (RILIS website)

Considerations for in-source laser spectroscopy





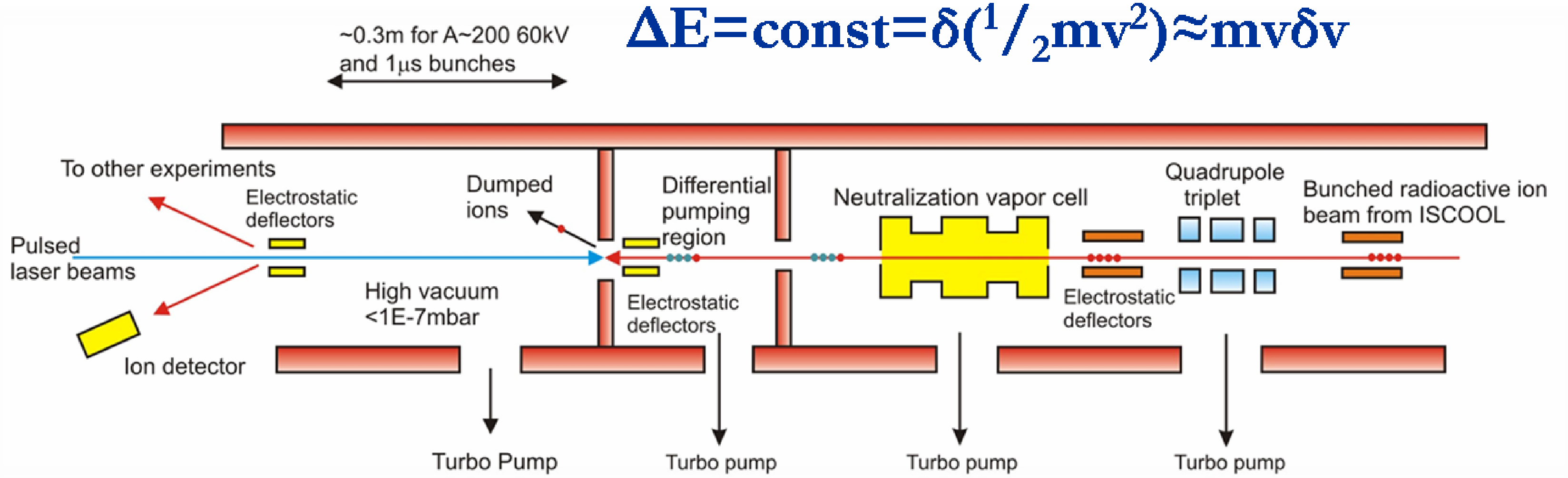
Evacuation time ~100μs
Therefore a repetition rate of 10kHz is required for maximum efficiency.

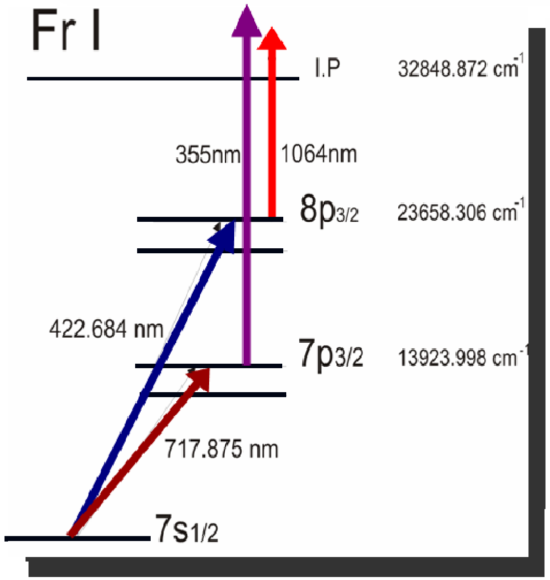
- Need to satisfy the Flux and Fluence conditions in order to saturate transitions and maximise efficiency.
- Short duration pulsed lasers (10-20ns) with ~1-10mJ per pulse.
- CW Laser> 500W (and tight focus) just to saturate the first step!

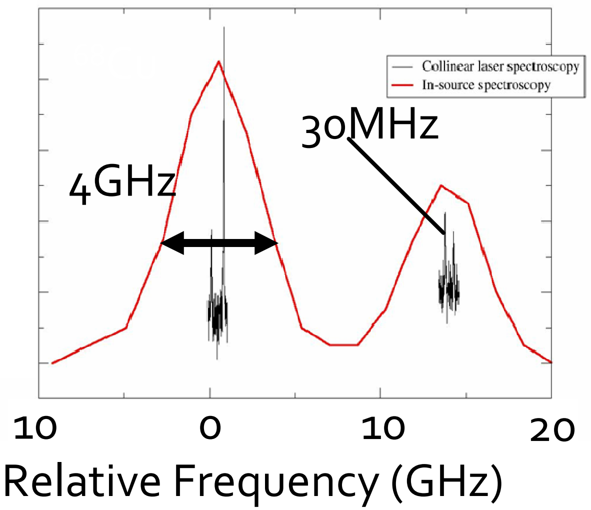
~100mW at 10kHz for resonant steps
~1-5W at 10kHz for quasi resonant steps
~10-20W at 10kHz for non-resonant steps

Collinear Resonant Ionization Spectroscopy (CRIS) @ ISOLDE

$$\Delta E = const = \delta(^1/_2 mv^2) \approx mv\delta v$$







Combining high resolution nature of collinear beams method with high sensitivity of in-source spectroscopy. Allowing extraction of B factors and quadrupole moments.

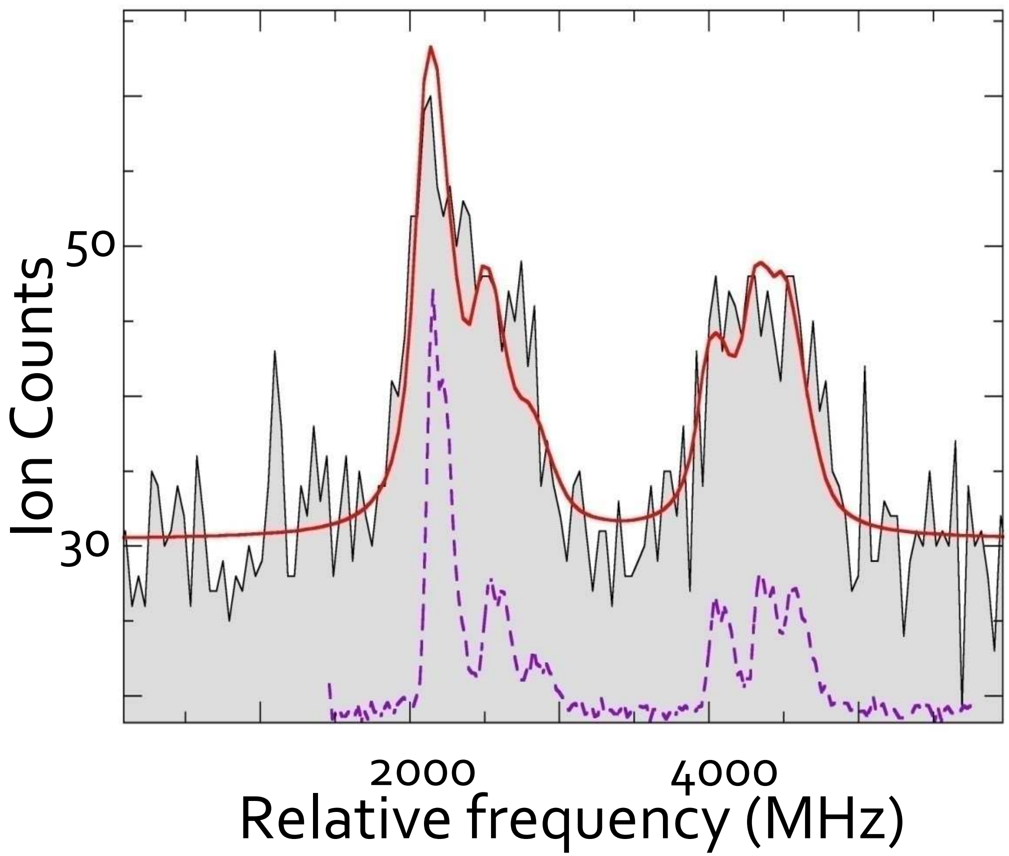
Yu. A. Kudriavtsev and V. S. Letokhov, *Appl. Phys.* **B29** 219 (1982)

Collinear resonant ionization laser spectroscopy (CRIS)

- RIS performed on a fast atomic bunched beam.
- Pulsed Amplified CW laser has a resolution which is Fourier limited.
- Background events are due to non-resonant collisonal ionization, which is directly related to the vacuum
- Very high total experimental efficiency
  - Neutralization (element dependent)
  - Ionization efficiency 50-100% (no HFS)
  - Detection efficiency almost 100%
  - Transport through ISCOOL 70%
  - Transport to experiment 80-90%

1:30 From Jyvaskyla
off-line tests
(K. Flanagan, PhD)

Off-line CRIS test at the IGISOL



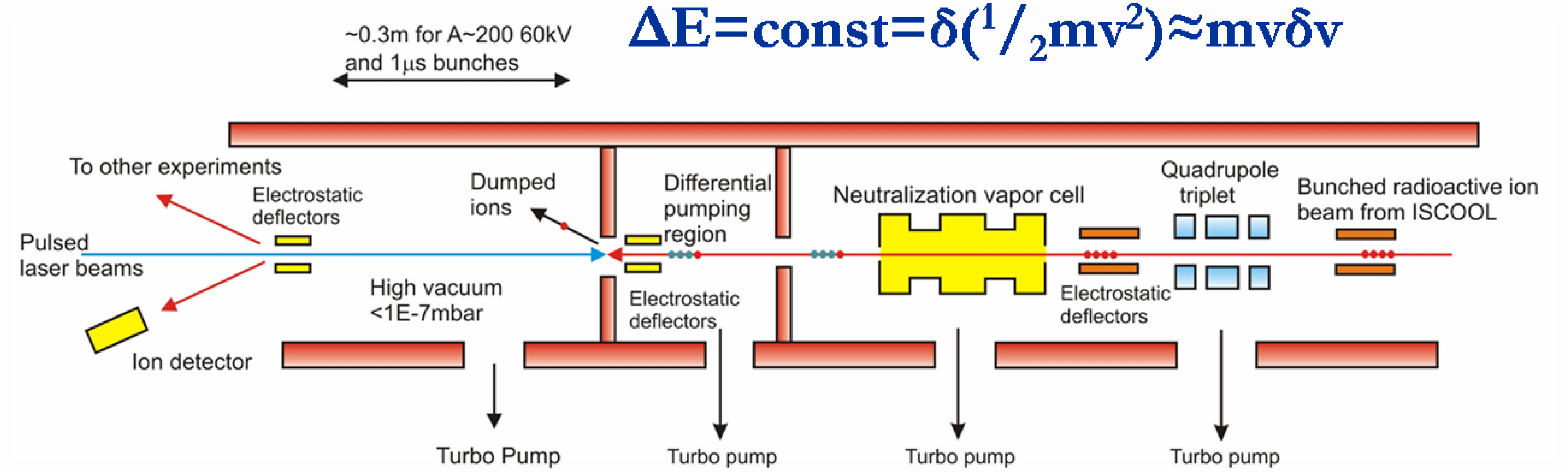
- 200 ions per bunch
- 6 scans
- 1:30 efficiency
- Factor of 1000 increase in detection efficiency.

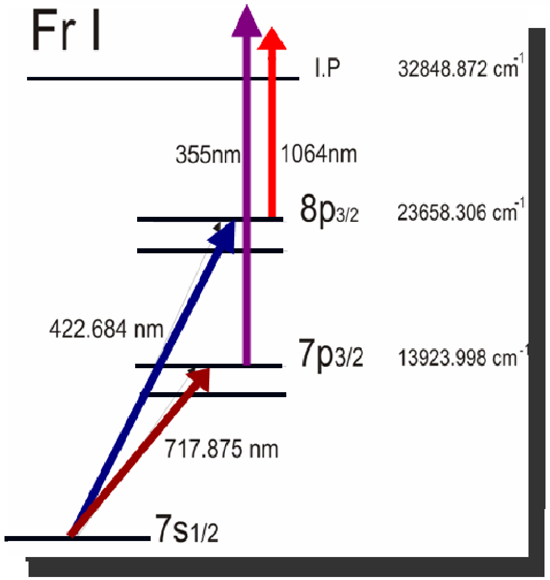
Background due to non-resonant collisional ionization in poor vacuum (10^{-5} mbar)

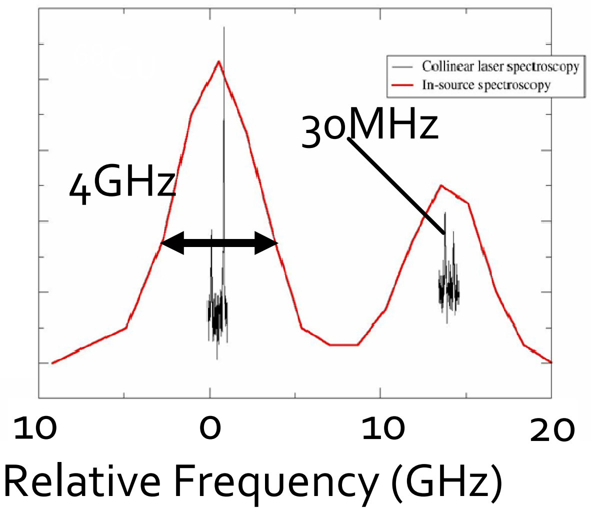
~5 non-resonant ions per bunch

Collinear Resonant Ionization Spectroscopy (CRIS)

$$\Delta E = const = \delta(^1/_2 mv^2) \approx mv\delta v$$







Combining high resolution nature of collinear beams method with high sensitivity of in-source spectroscopy. Allowing extraction of B factors and quadrupole moments.

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Limiting factors:Efficiency and isobaric contamination

- **From the ISCOOL tests a limit of 10^7 per bunch were trapped and measured on an MCP.**
- Conservative efficiency of 1:30 (number from Jyvaskyla work) and a pressure of 10^{-9} mbar and a high isobaric contamination of 10^7 (expect much lower).

Background suppression:
Pressure 10^{-9} mbar = 1:200 000
Detection of secondary electrons by MCP

→ Limited to > 100pps

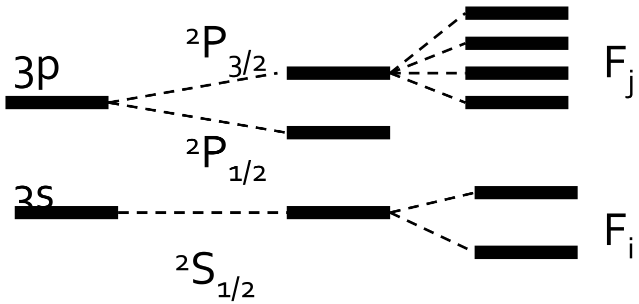
Alpha decay detection allows discrimination of isobaric contamination (50-100cts/s)

→ Limited >5pps

With 50% efficiency and signal limited noise regime = 0.3pps

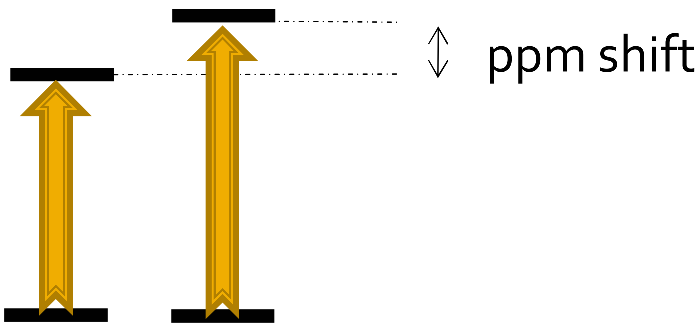
Isomer Selection

Hyperfine Structure



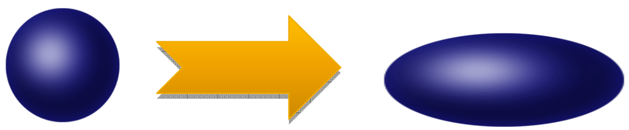
Spin, magnetic and electric moments can dramatically change for the isomeric state.

Isotope Shift

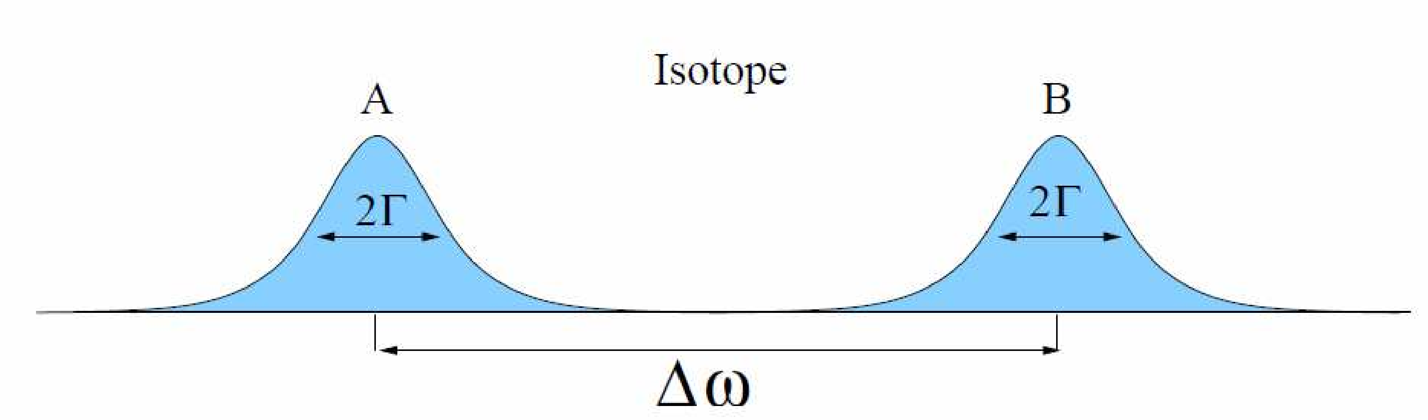


large shift in the transition frequency for the isomeric state compared to the ground state

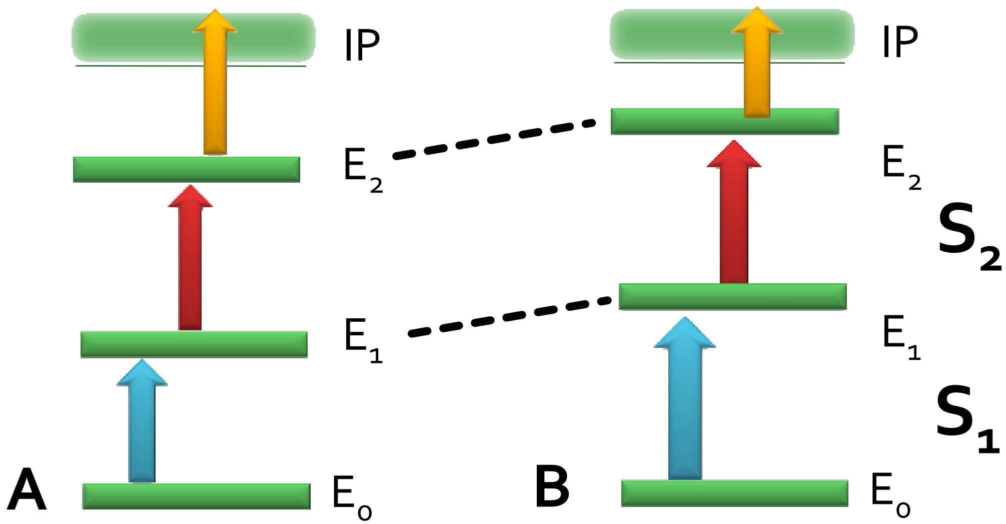
$$\Delta\nu_{IS} = \Delta\nu_{MS} + \Delta\nu_{FS}$$



Selectivity



$$S = (\Delta\omega_{AB}/\Gamma)^2$$

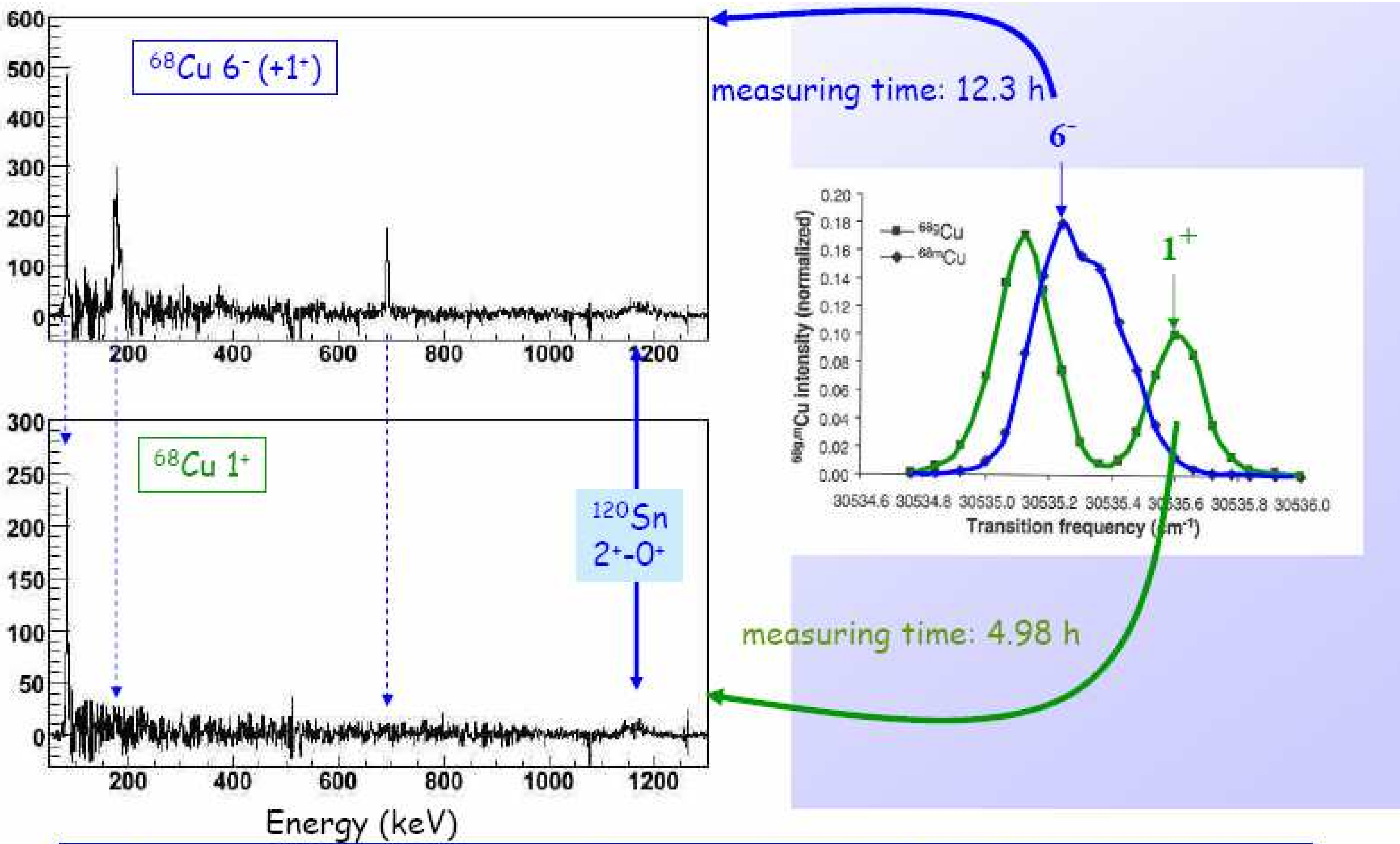


$S = \Pi S_i = S_1 * S_2$

S_i of 10^4 is possible

With more than three steps S can reach 10^{14}

Post accelerated Isomeric Beams at ISOLDE: ^{68}Cu



➤ $^{68m,g}Cu$ (2.83 MeV/u, 3 10^5 pps, 74% pure) @ ^{120}Sn (2.3 mg/cm^2)

Isomeric beams ($^{68,70}Cu$) from REX-Isolde

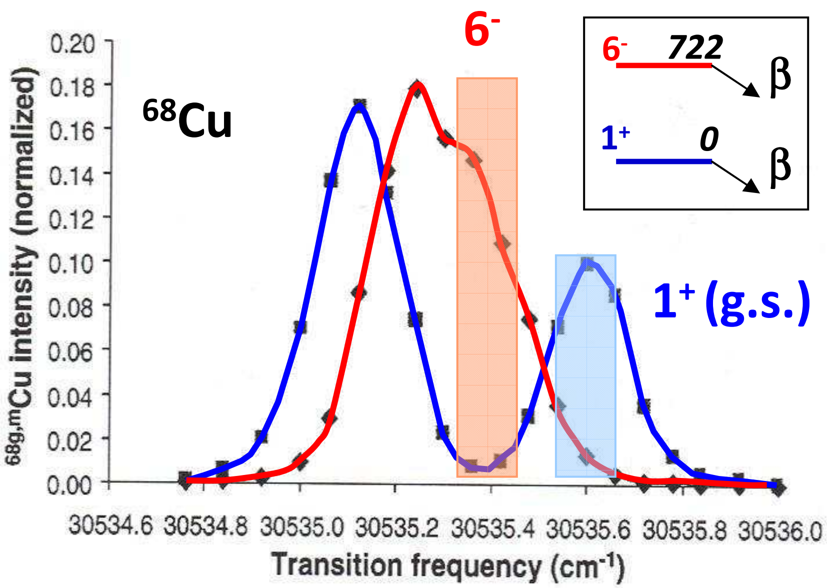
$^{70}Cu/^{70}Ga$ = **50%/50%** → lasers ON vs. lasers OFF

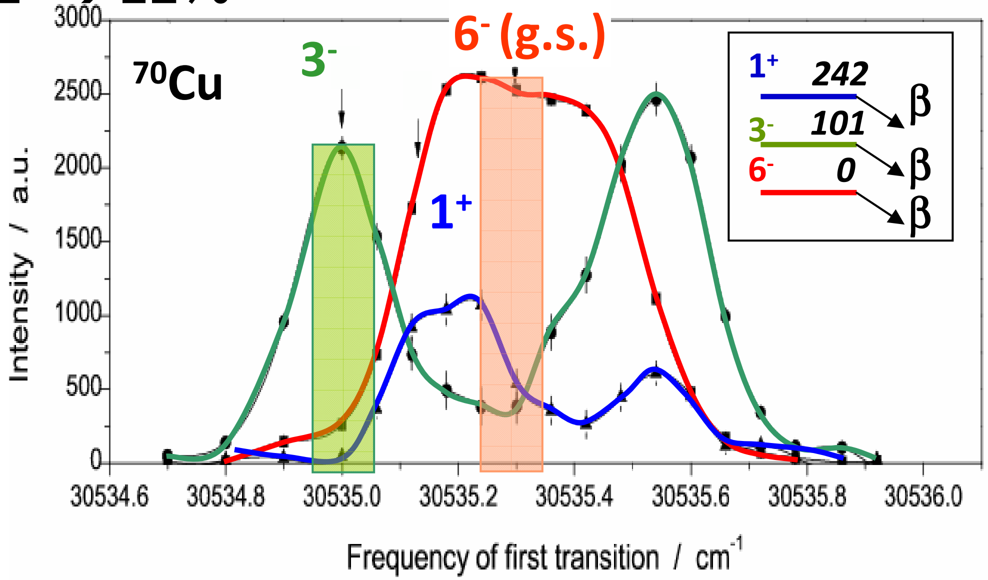
^{70}Cu:

6^- → 65%

3^- → 23% →~12% of the total beam

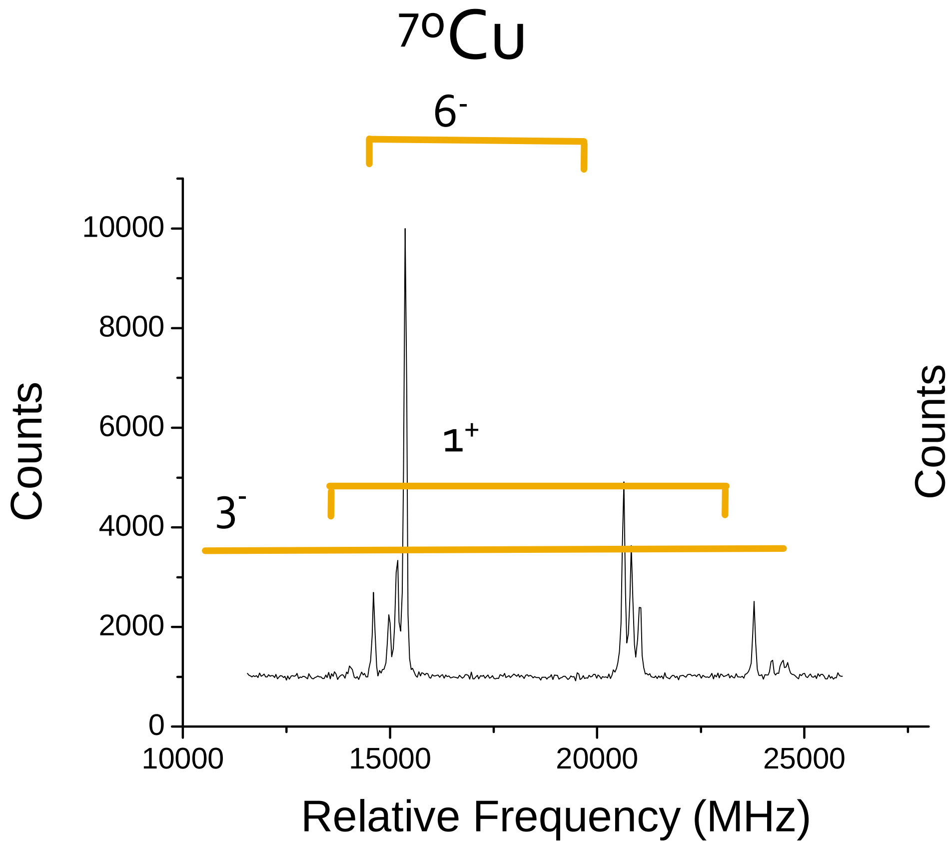
1^+ →12%

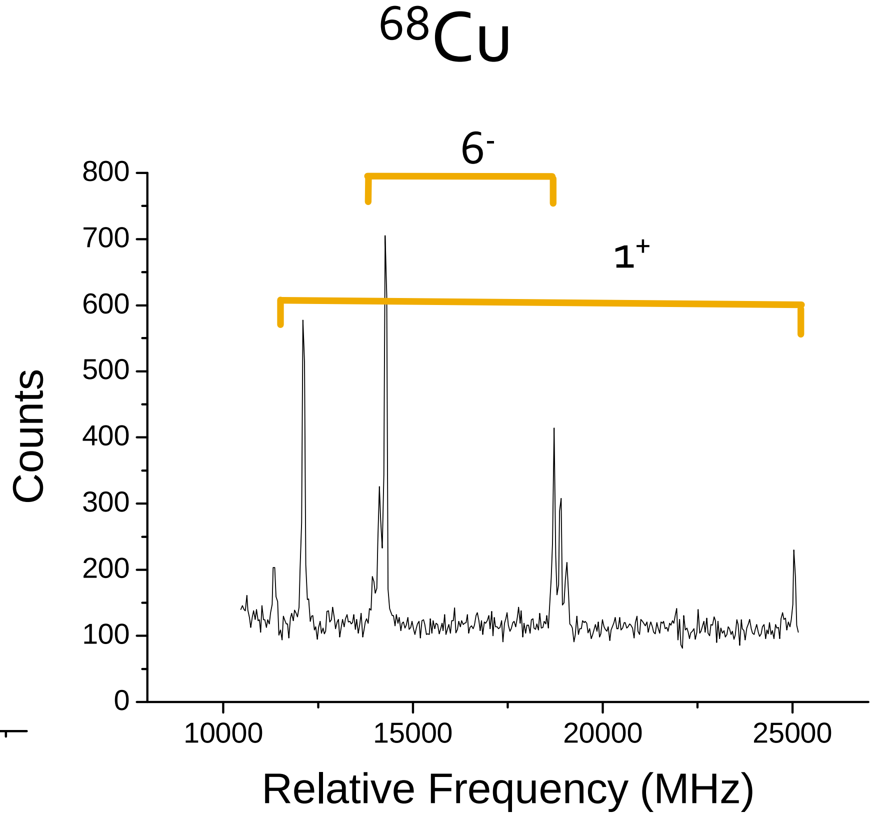




(Ü. Köster et al., NIM B, 160, 528(2000); L. Weissman et al., PRC65, 024315(2000)), I. Stefanescu PRL 98, 122701 (2007))

Collinear ^{68}Cu and ^{70}Cu (2008 data)





Limiting factors:yield and isobaric contamination

- From the ISCOOL tests limit of 10^7 per bunch were trapped and measured on an MCP.
- Conservative efficiency of 1:30 (number from Jyvaskyla work) and a pressure of 10^{-9} mbar and a high isobaric contamination of **10^7** (expect much lower).

Isobar suppression:
Pressure 10^{-9} mbar = 1:200 000

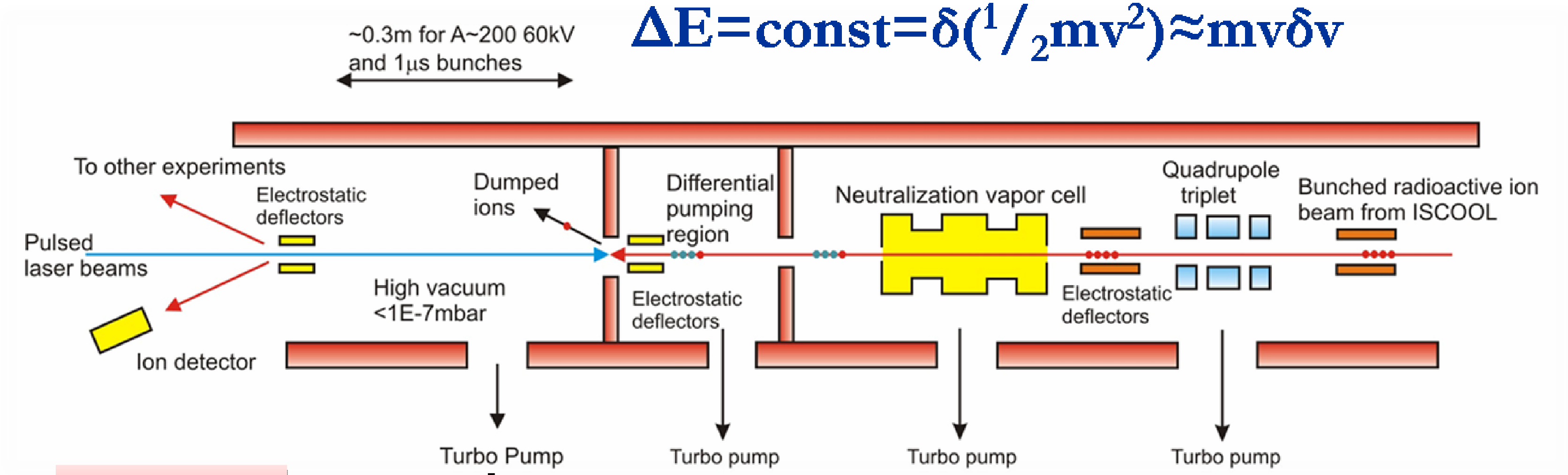
→ **10^7 ppb reduces to less than 100ppb**

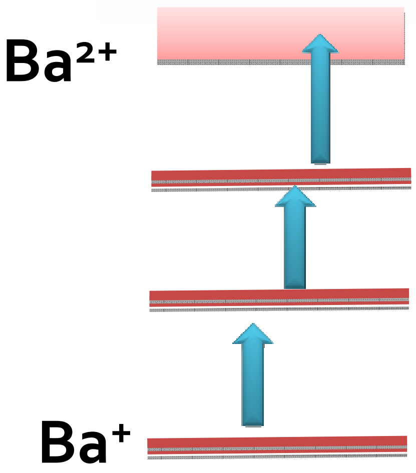
Isomer selection per transition:
$S_i = 10^3 - 10^4$

→ **For two resonant steps $S_i \sim 10^7$**

Collinear Ion Resonant Ionization Spectroscopy

$$\Delta E = const = \delta(^1/_2 mv^2) \approx mv\delta v$$

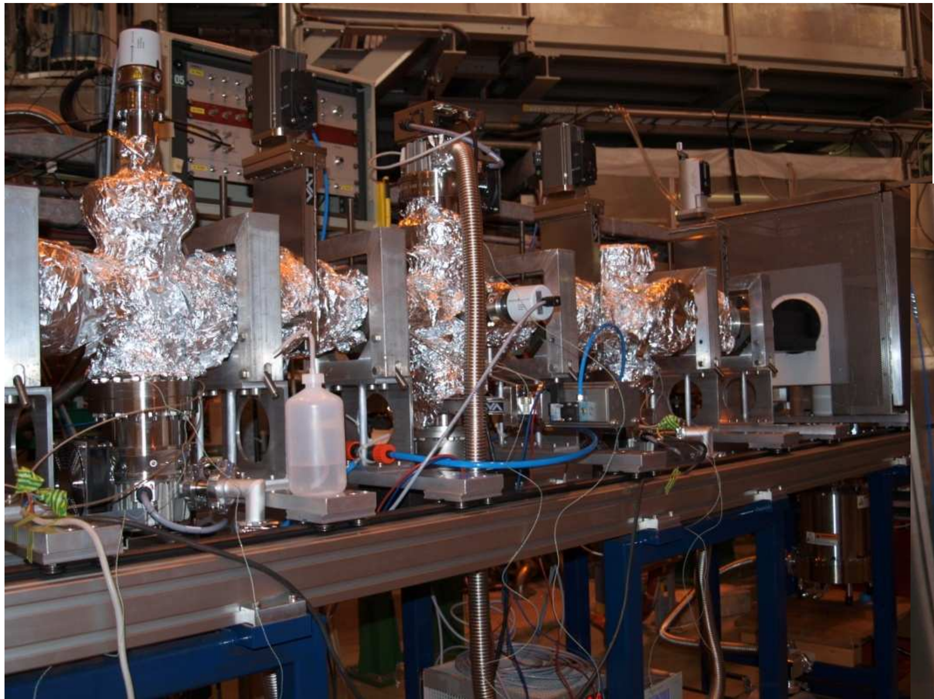


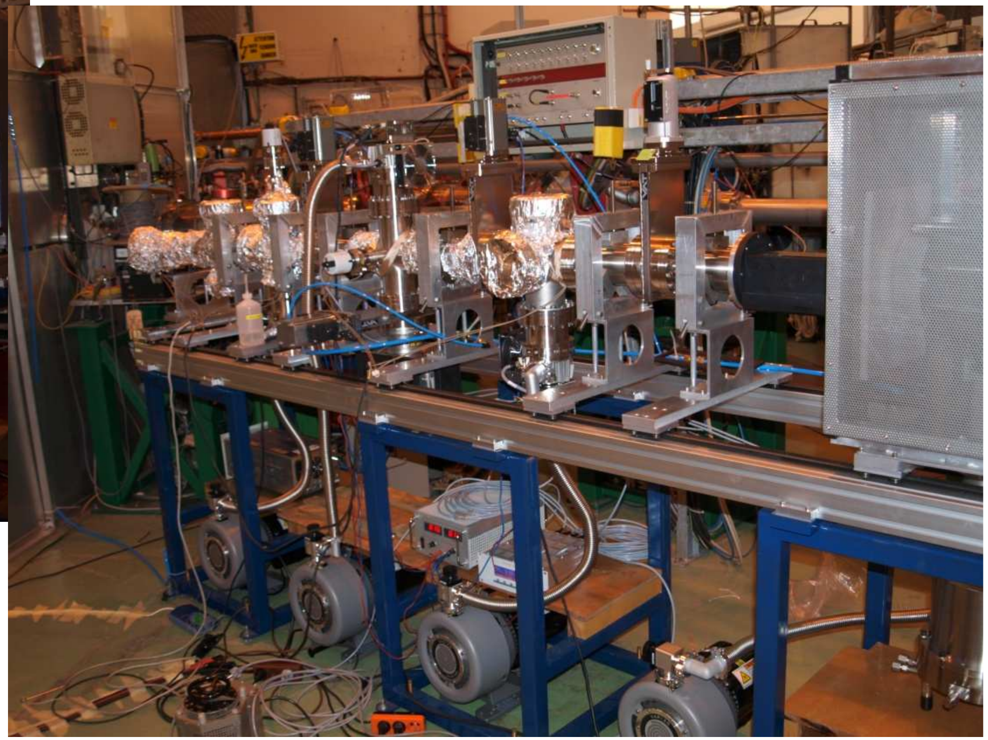


No need to neutralise and therefore more efficient.
Non-resonant 2+ production rate is very low (will need to measure this)
Many step schemes possible (2 scheme shown here would have $S_i \sim 10^7$

B. Cheal

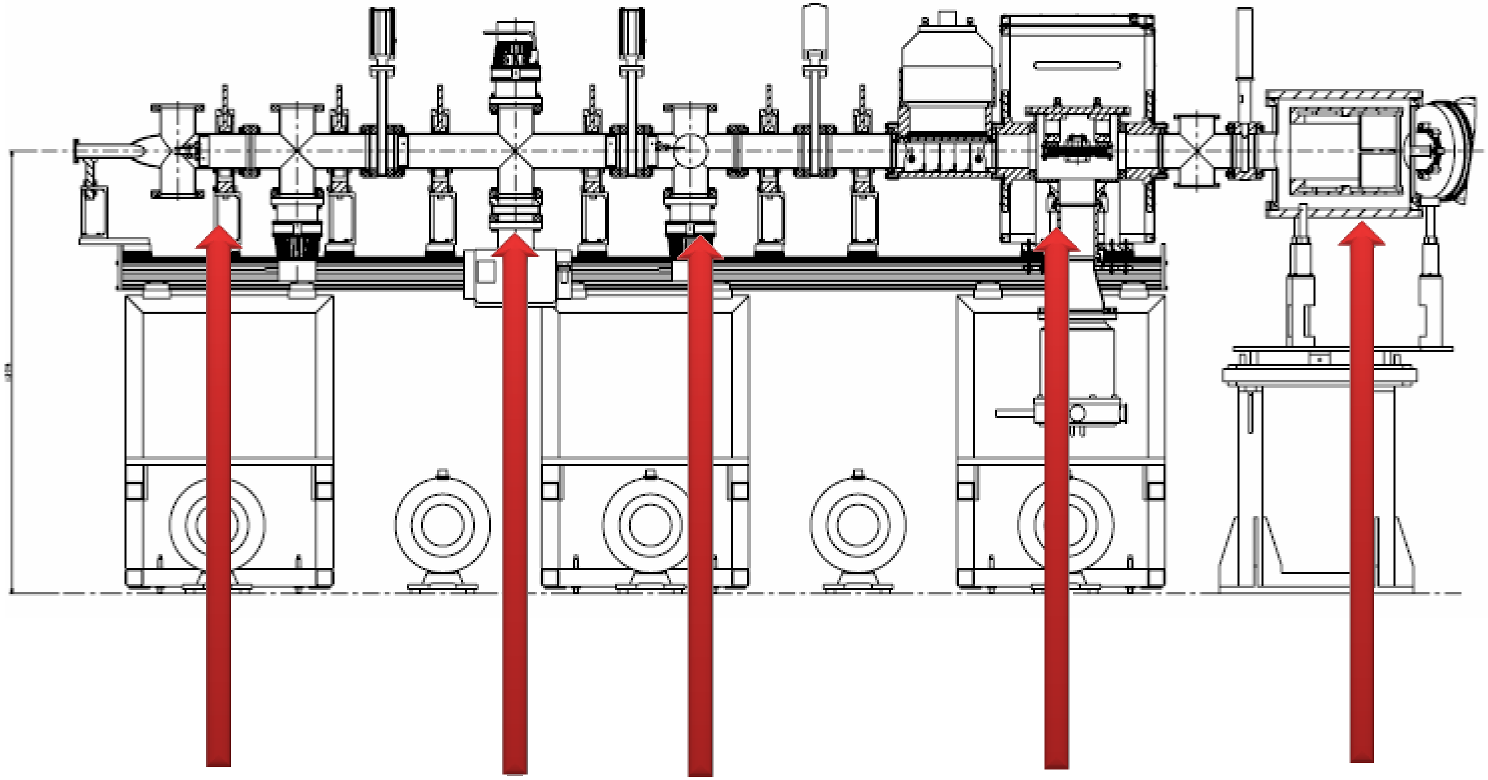
July 2009





Vacuum testing, initial bake-out of UHV section reached <5e-9mbar (limit of the gauge) in the interaction region.

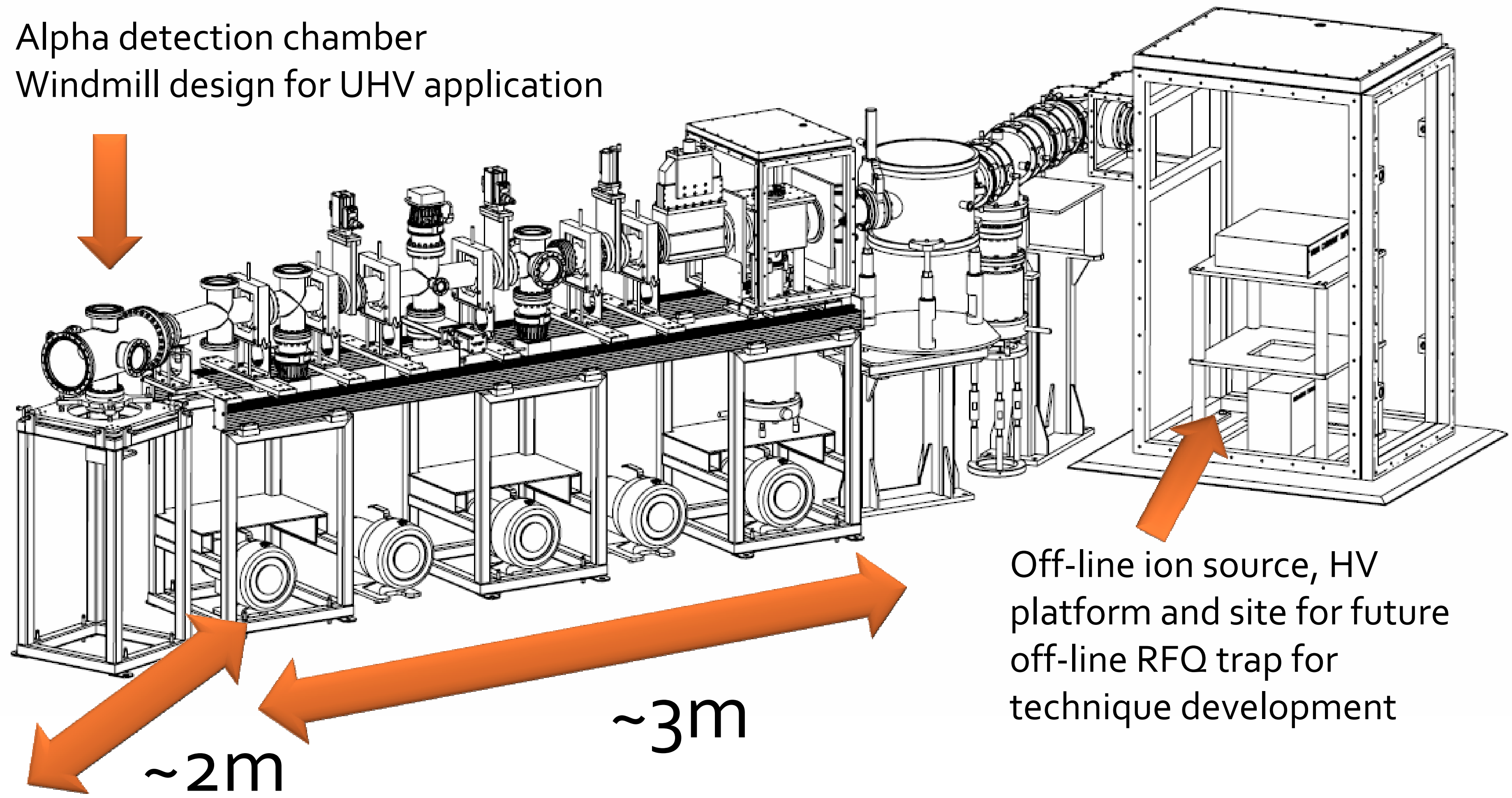
Collinear Resonant Ionization Spectroscopy (CRIS)



9.11e-9 mbar | <5e-9 mbar | 7.24e-8mbar | 9.64e-7mbar | 7.5e-7mbar

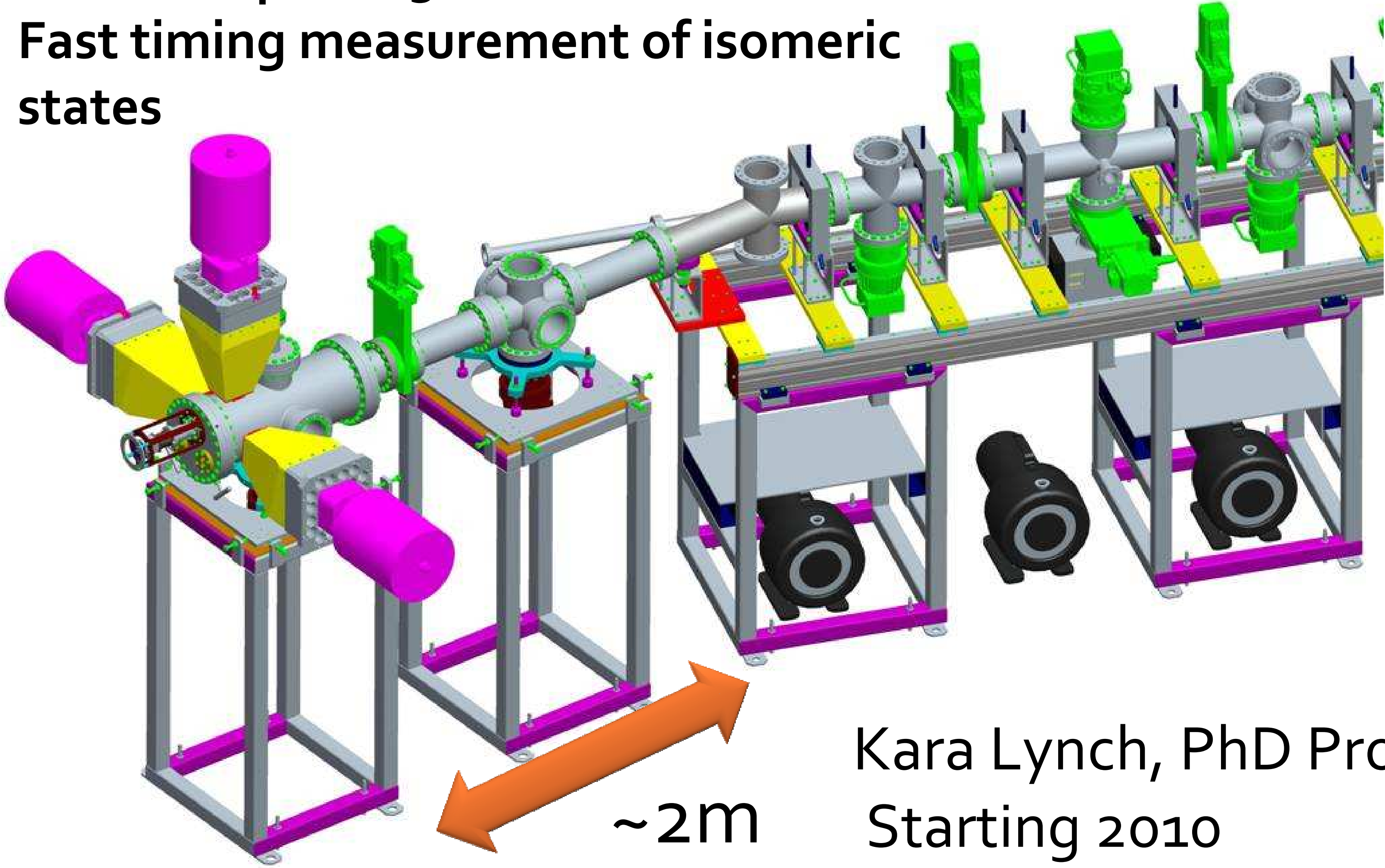
Results from ISOLDE

Future: 2010-2011



Laser Assisted Decay Spectroscopy:LADS

Possible option: 3 EUROGAM / EUROBALL detectors
Fast timing measurement of isomeric states



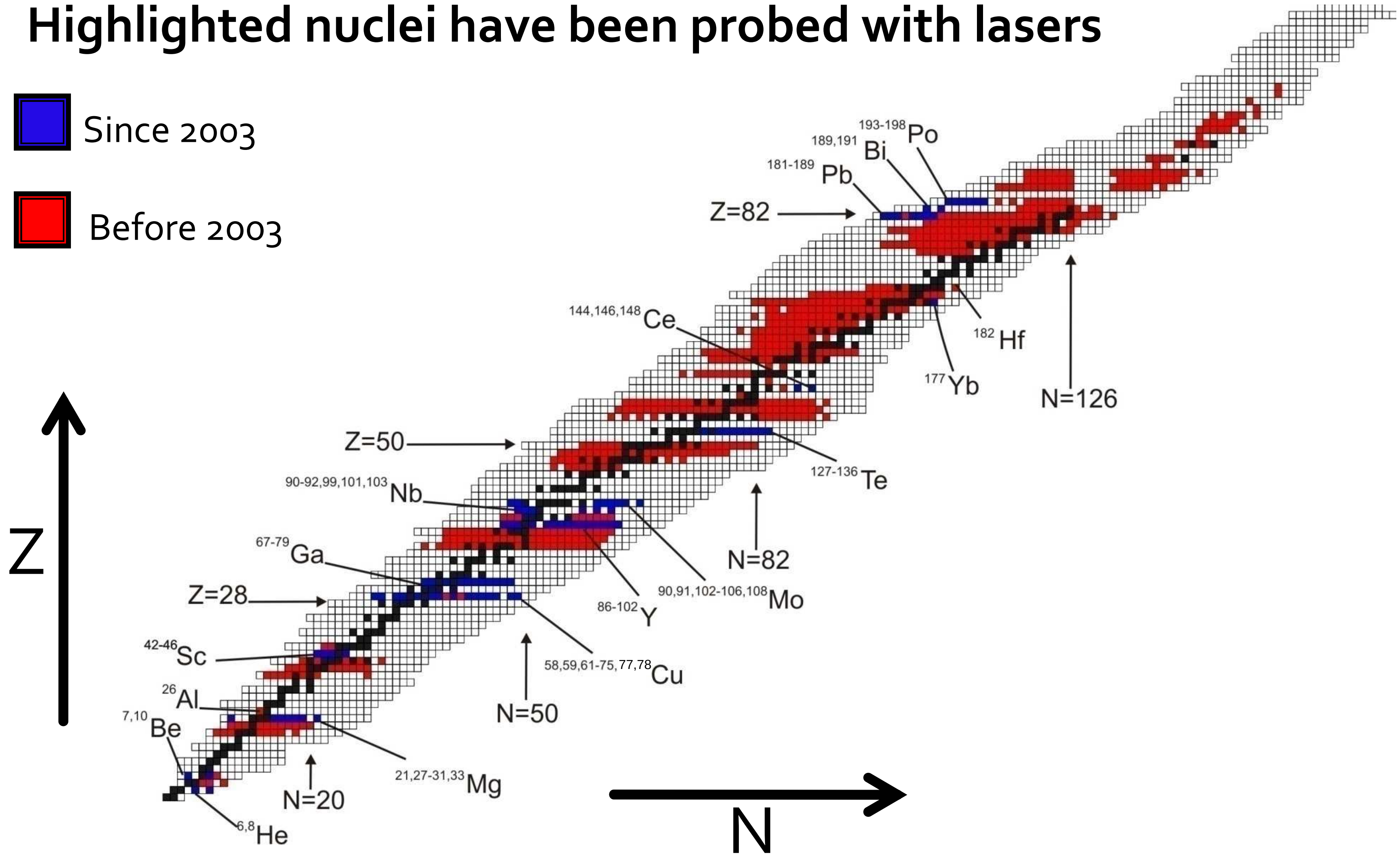
Kara Lynch, PhD Project
Starting 2010

LADS: Possible cases

Highlighted nuclei have been probed with lasers

Since 2003

Before 2003



Thank you for your attention

Collaboration

J. Billowes, M. Bissell, F. Le Blanc, B. Cheal, K.T. Flanagan, D.H. Forest, R. Hayano, M. Hori, T. Kobayashi, G. Neyens, T. Procter, M. Rajabali, H.H Stroke, G. Tungate, W. Vanderheijden, P. Vingerhoets, K. Wendt.

MAX-PLANCK-INSTITUTE OF QUANTUM OPTICS GARCHING

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