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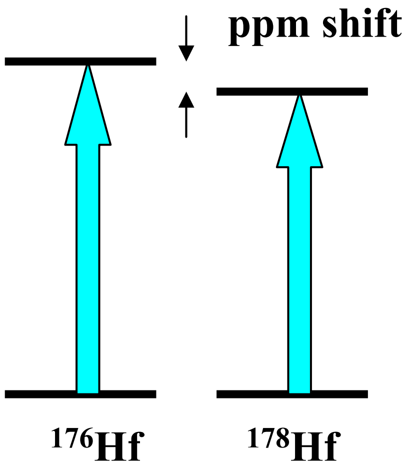
Structures and shapes from ground state properties

Jon Billowes

1. **Nuclear properties from laser spectroscopy**
2. **Status of laser measurements of moments and radii**
3. **New opportunities using the ISCOOL ion cooler**

1. Nuclear properties from laser spectroscopy

Isotope shift of atomic transition



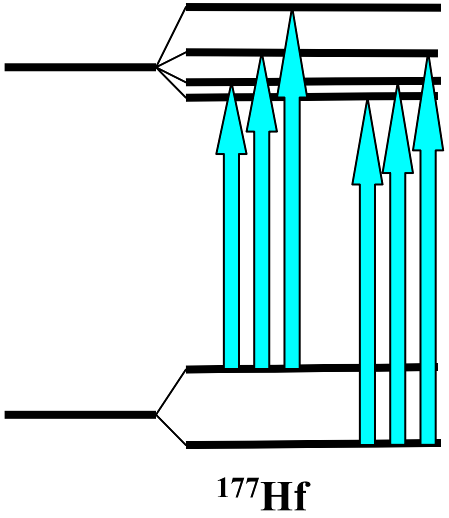
Analysis yields the change in nuclear mean square charge radius $\delta\langle r^2\rangle^{A'A}$

↓

Nuclear size, static and dynamic deformations

Hyperfine structure of atomic transition

(Isotope shift found using centroids of hyperfine multiplet)

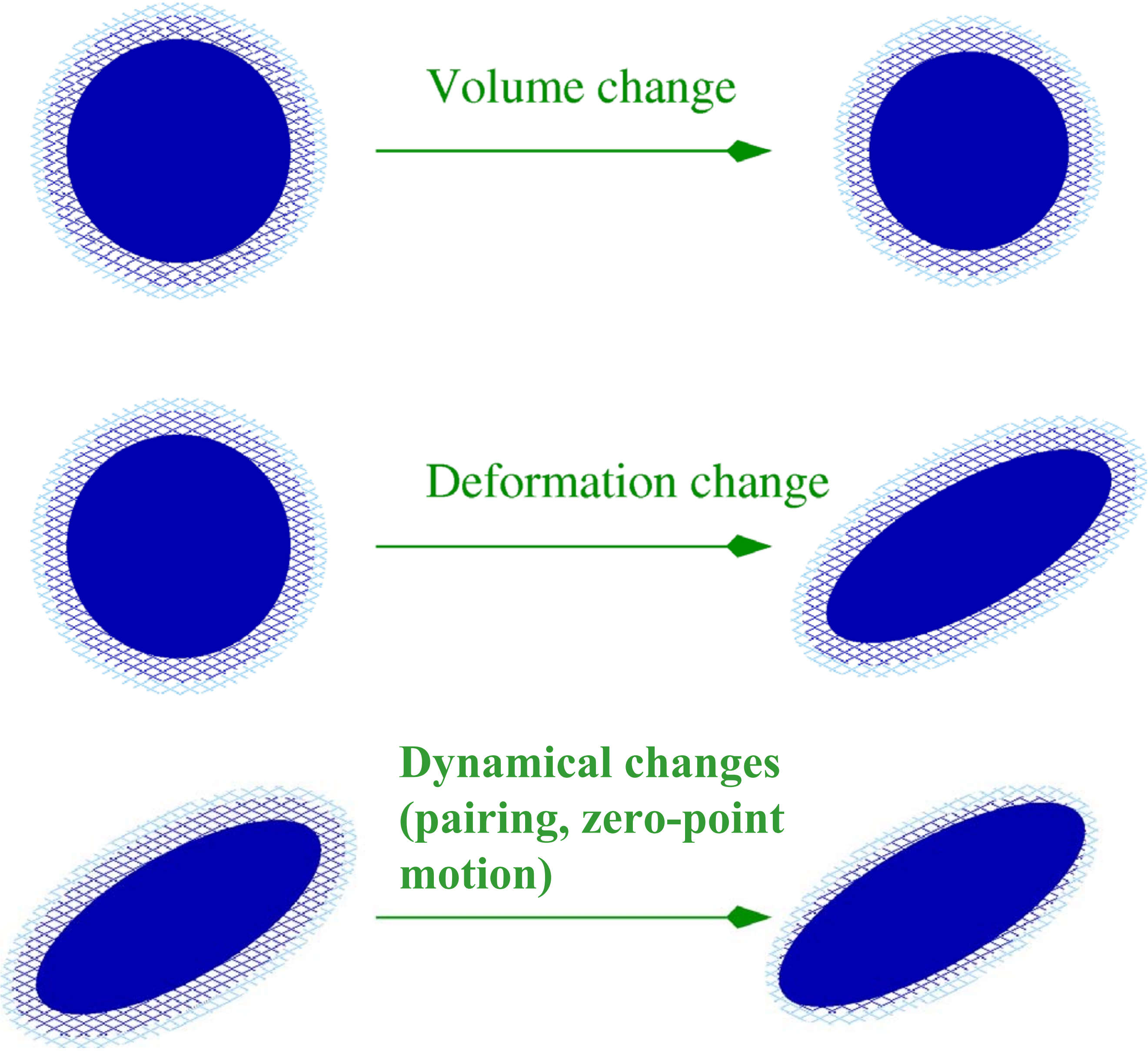


Nuclear spin I

Magnetic moment μ

Quadrupole moment Q_s

Factors controlling $\delta < r^2 >$



Volume change

Deformation change

Dynamical changes (pairing, zero-point motion)

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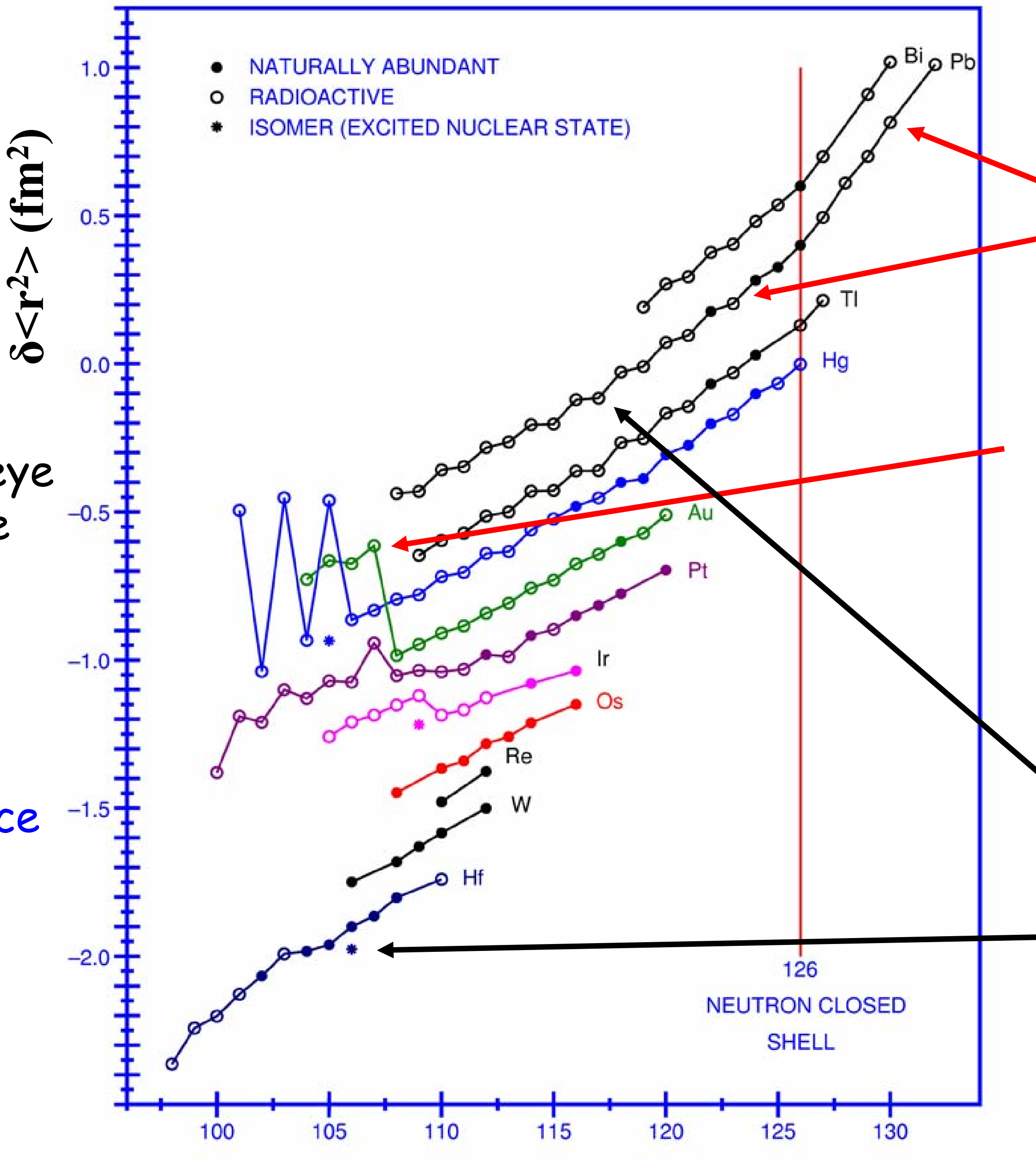
Mean square charge radii



Obvious-to-the-eye nuclear structure features:

Neutron skins

Deformations

Shape-coexistence

Shell closures

Volume

Deformation

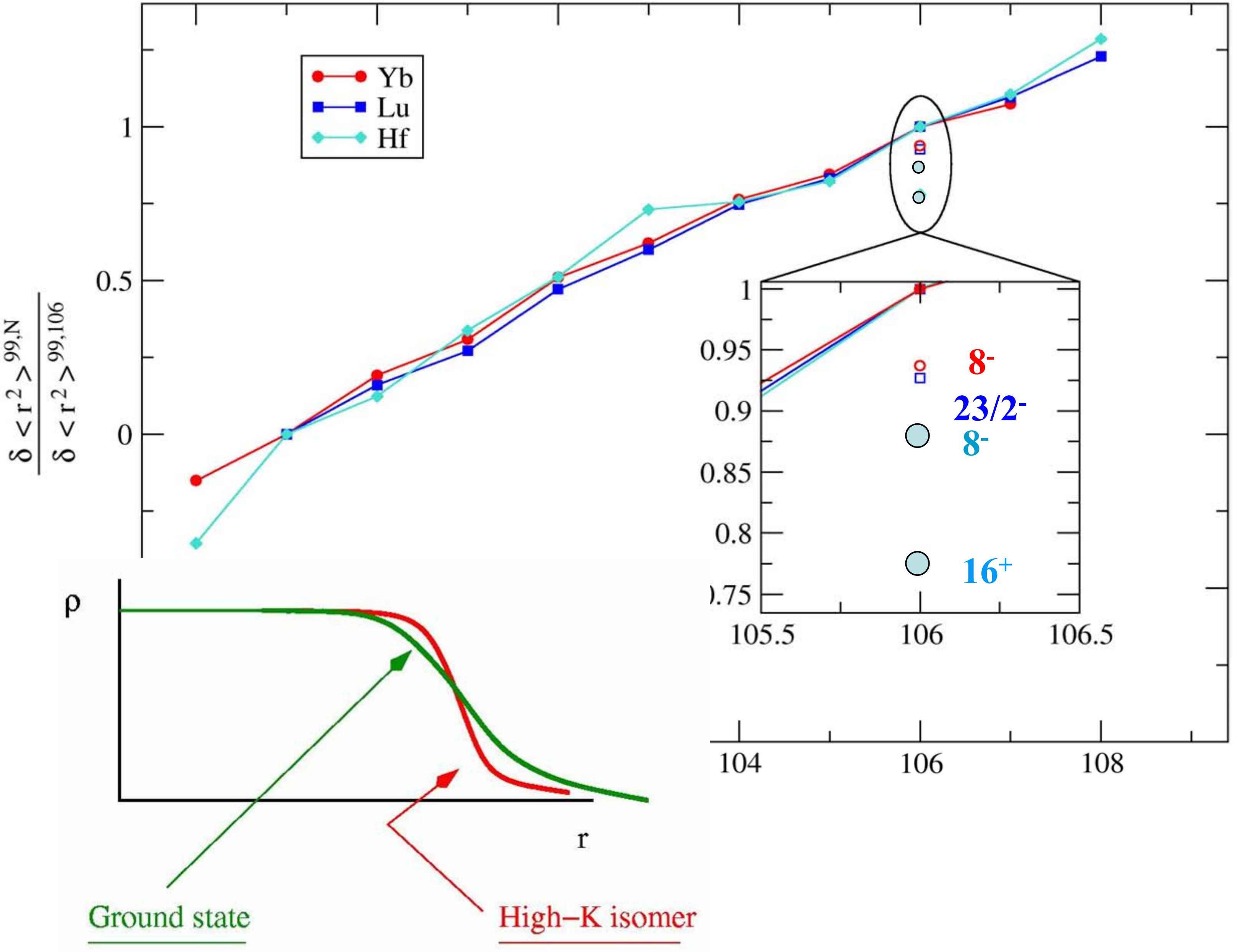
Dynamical effects

Odd-even staggering

Isomer shifts

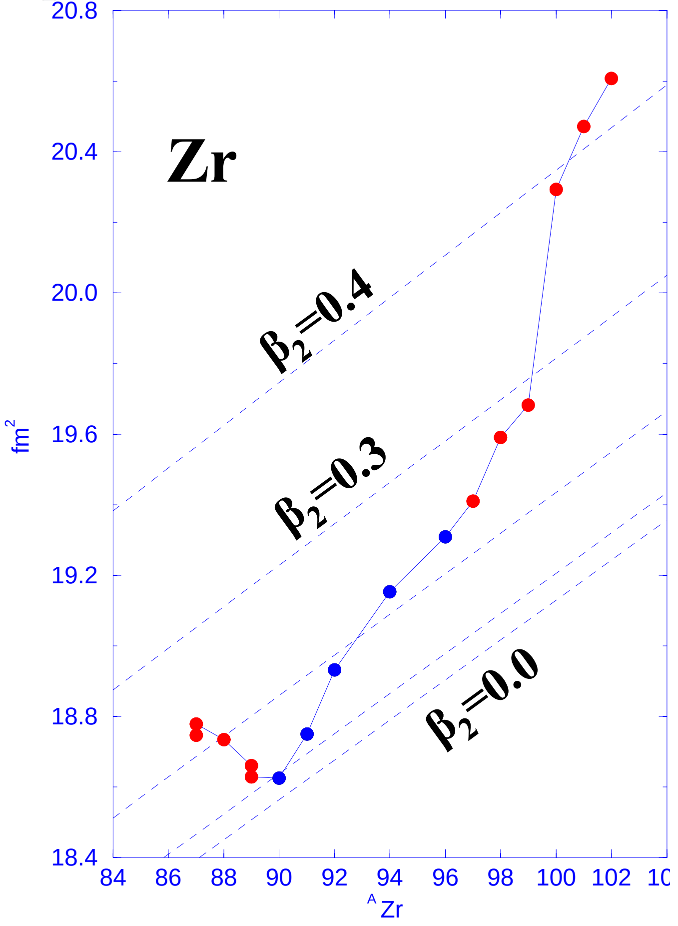
Weakly-deformed nuclei (Zr, Y examples)

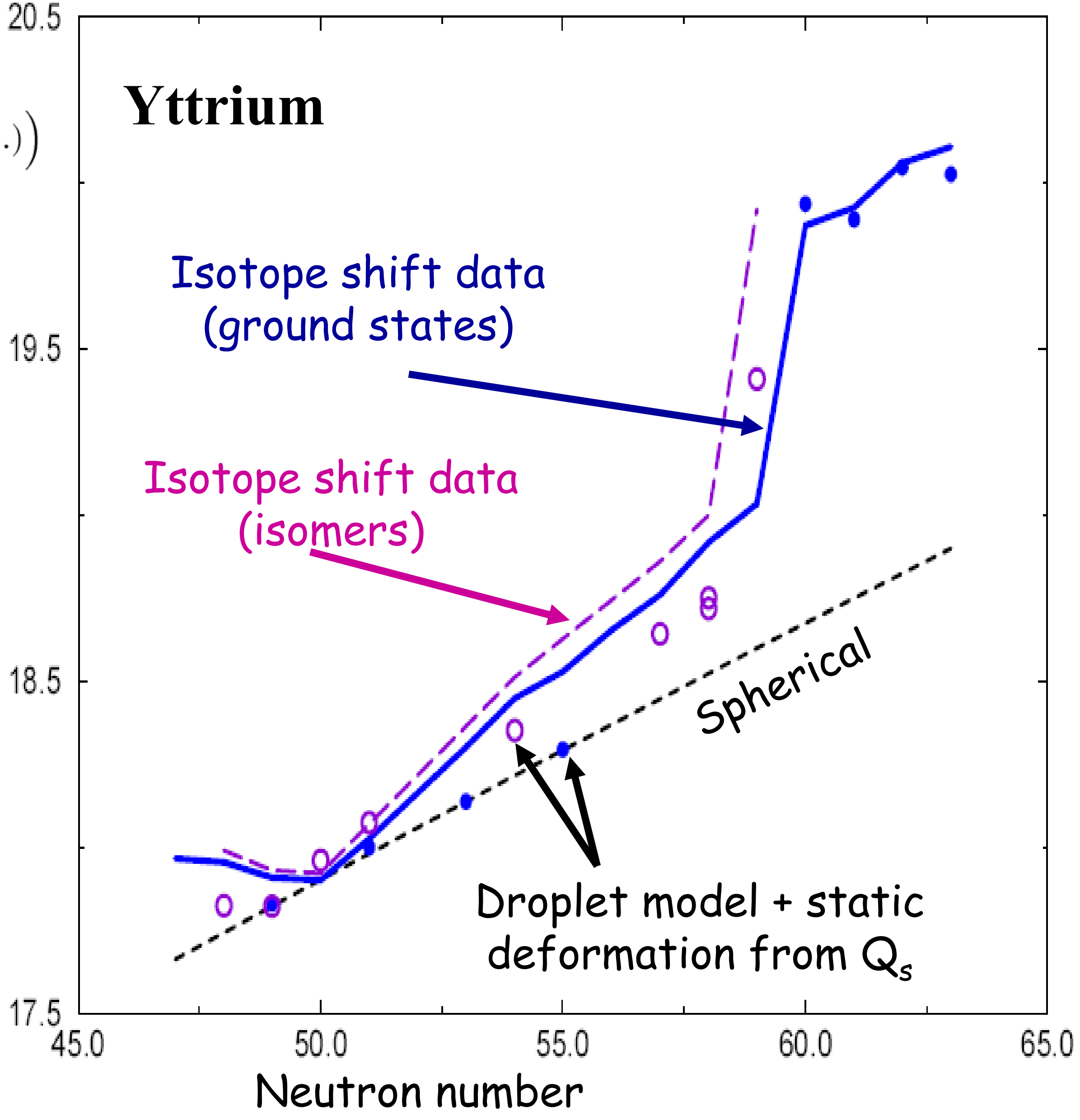
Negative isomer shifts in multi-quasiparticle isomers



Dynamic effects in charge radii

$$\langle r^2\rangle = \langle r^2\rangle_0\left(1+\frac{5}{4\pi}\left(\langle\beta_2^2\rangle+\langle\beta_3^2\rangle+...\right)\right)$$

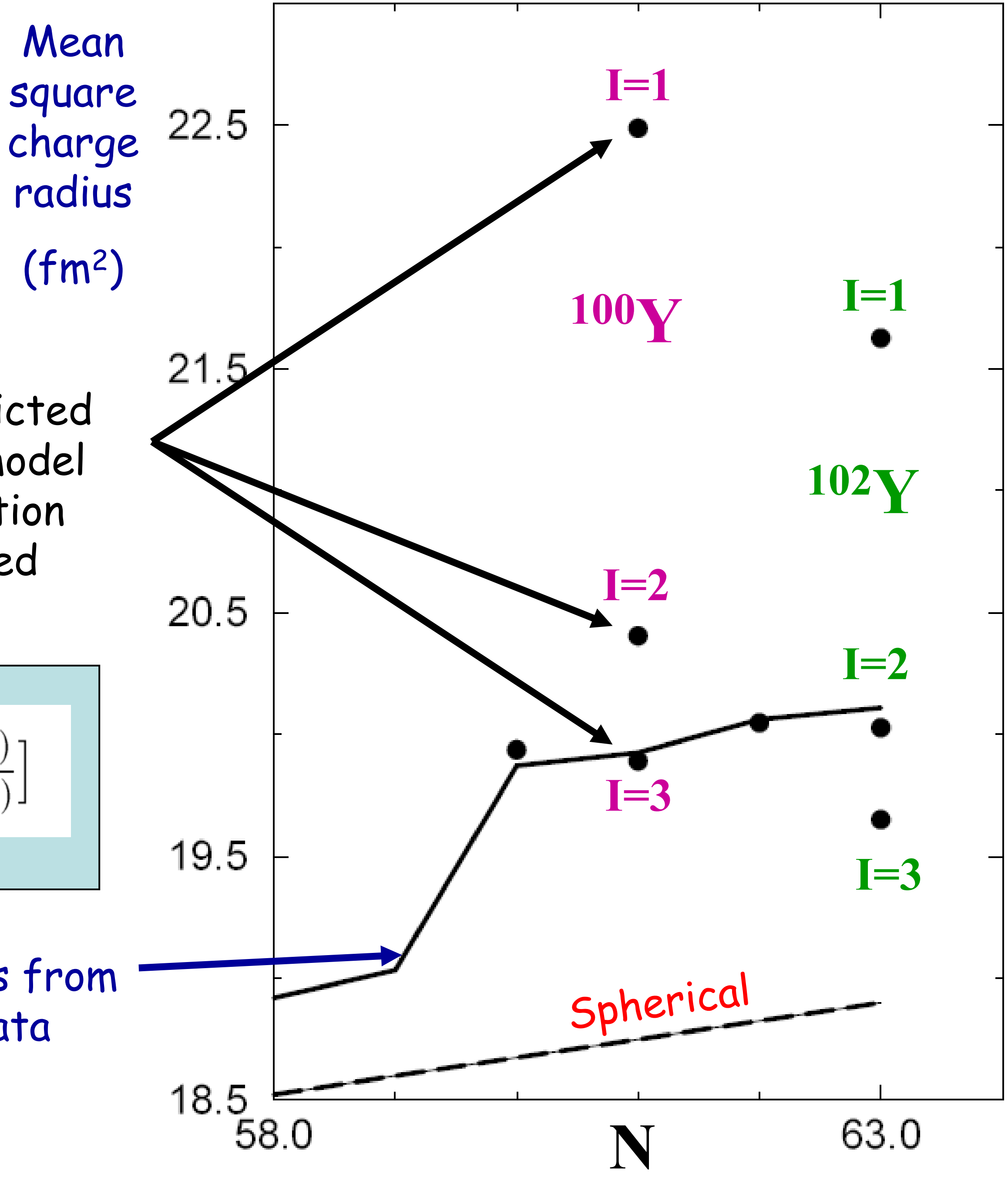




Isotope shift data
(ground states)

Isotope shift data
(isomers)

Droplet model + static deformation from Q_s



Mean square radius predicted from spherical droplet model corrected for deformation deduced from measured quadrupole moment

$$Q_s = Q_0\left[\frac{3\Omega^2 - I(I+1)}{(I+1)(2I+3)}\right]$$

Mean square radius from isotope shift data

Summary of nuclear properties

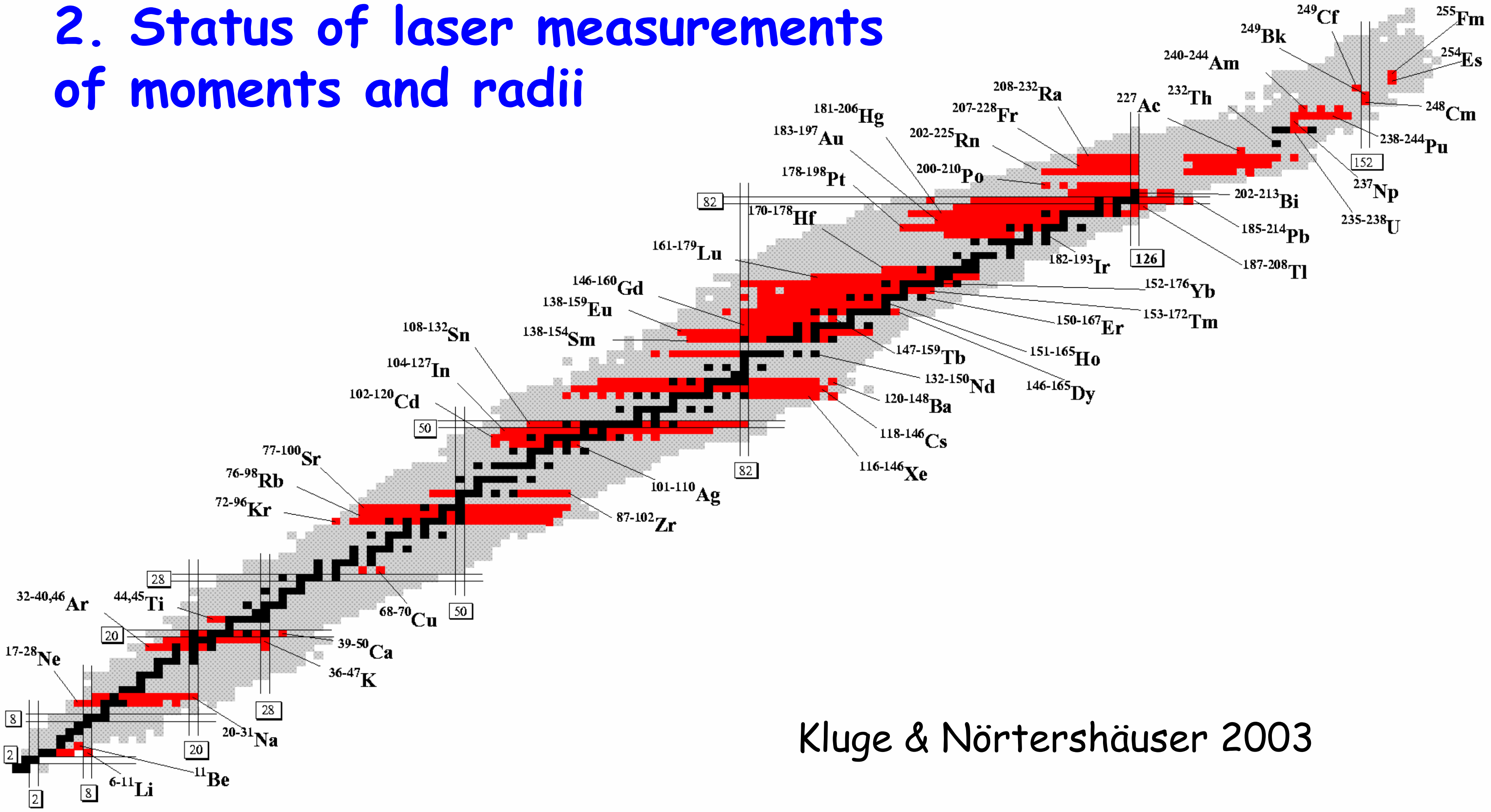
1. **Laser resonance can confirm existence of new isotope**
2. **Nuclear moments (μ_I, Q_s)**
3. **Nuclear spin**
4. **Precise comparison of mean square charge radii**

A problem and opportunity:

Most isotope shifts and isomer shifts are measured with considerable precision and detect even small changes in the mean square charge radius. The charge radius is influenced by a number of factors, such as nuclear volume, nuclear deformation (β_2, γ, β_3, β_4) and dynamical effects, which are only partially understood.

An improved theoretical understanding of these factors would allow more structural information to be deduced both from the existing body of data and new data on nuclei far from stability.

2. Status of laser measurements of moments and radii



Kluge & Nörtershäuser 2003

General techniques for measuring isotope shifts far from stability

Need: - Sub-Doppler resolution for light and medium-mass nuclei
- High sensitivity
- Ability to work from stability to sub-second half-lives

In-Source laser spectroscopy (Doppler broadened)

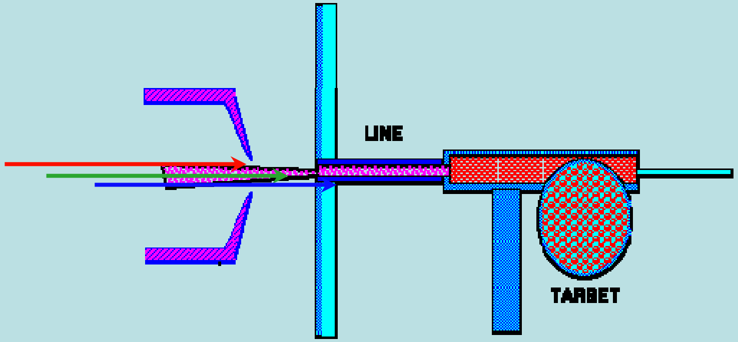
RILIS + ISOLDE - 1 atom/sec signal, heavy elements only

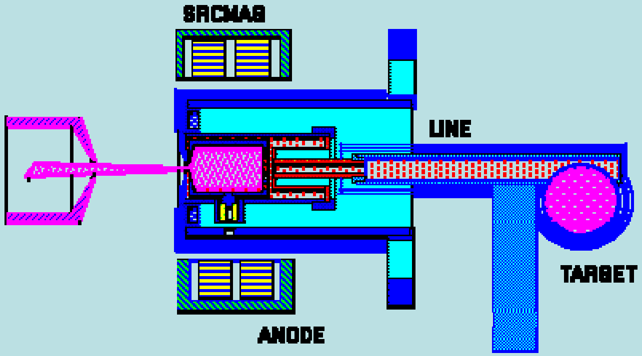
Collinear beams laser spectroscopy (fluorescence detection)

ISOLDE (COLLAPS) - 10^6 ions/sec (reviewed by Gerda Neyens)

JYFL (with cooler/buncher) - 10^3 ions/sec

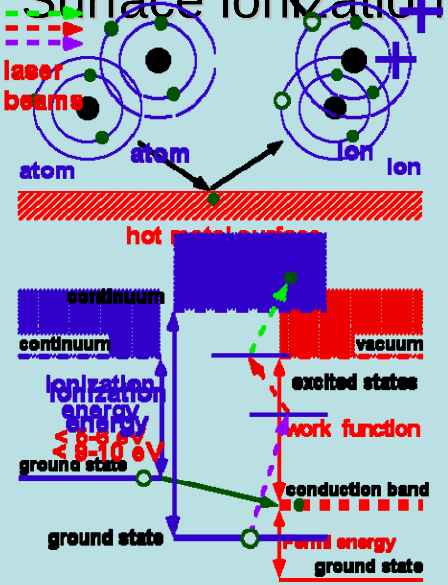
RILIS – resonance ionization laser ion source



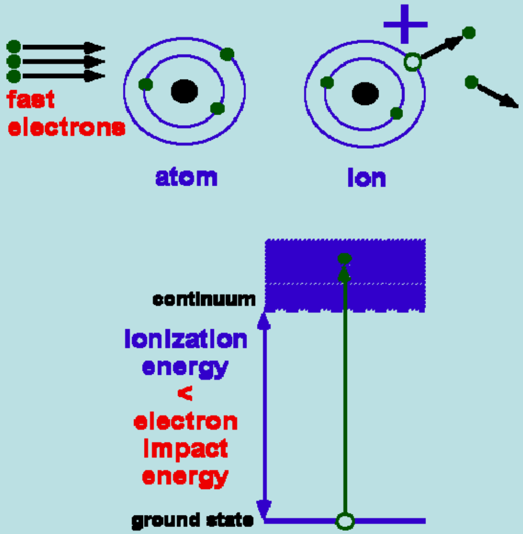


Resonance Laser ionization

Surface ionization



Electron impact ionization

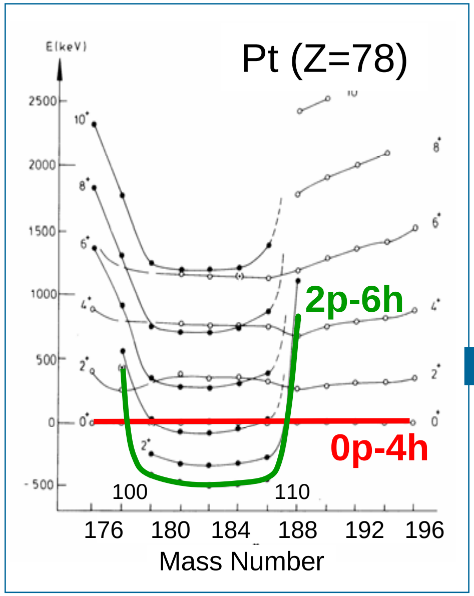


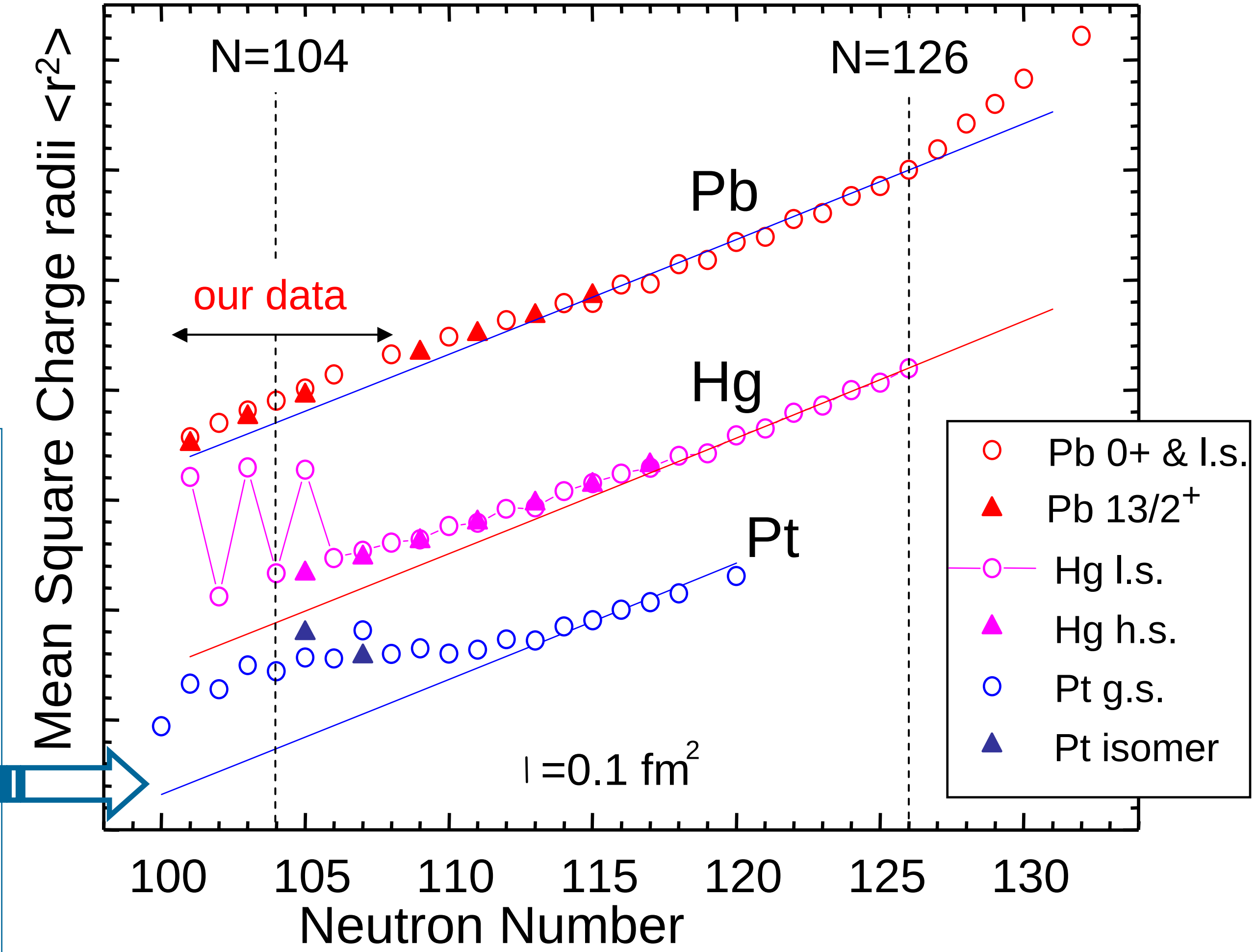
RILIS+ISOLDE: Pb CHARGE RADII MEASUREMENTS ('02 & '03)

^{182}Pb

$T_{1/2}$ = 55ms

(under analysis)



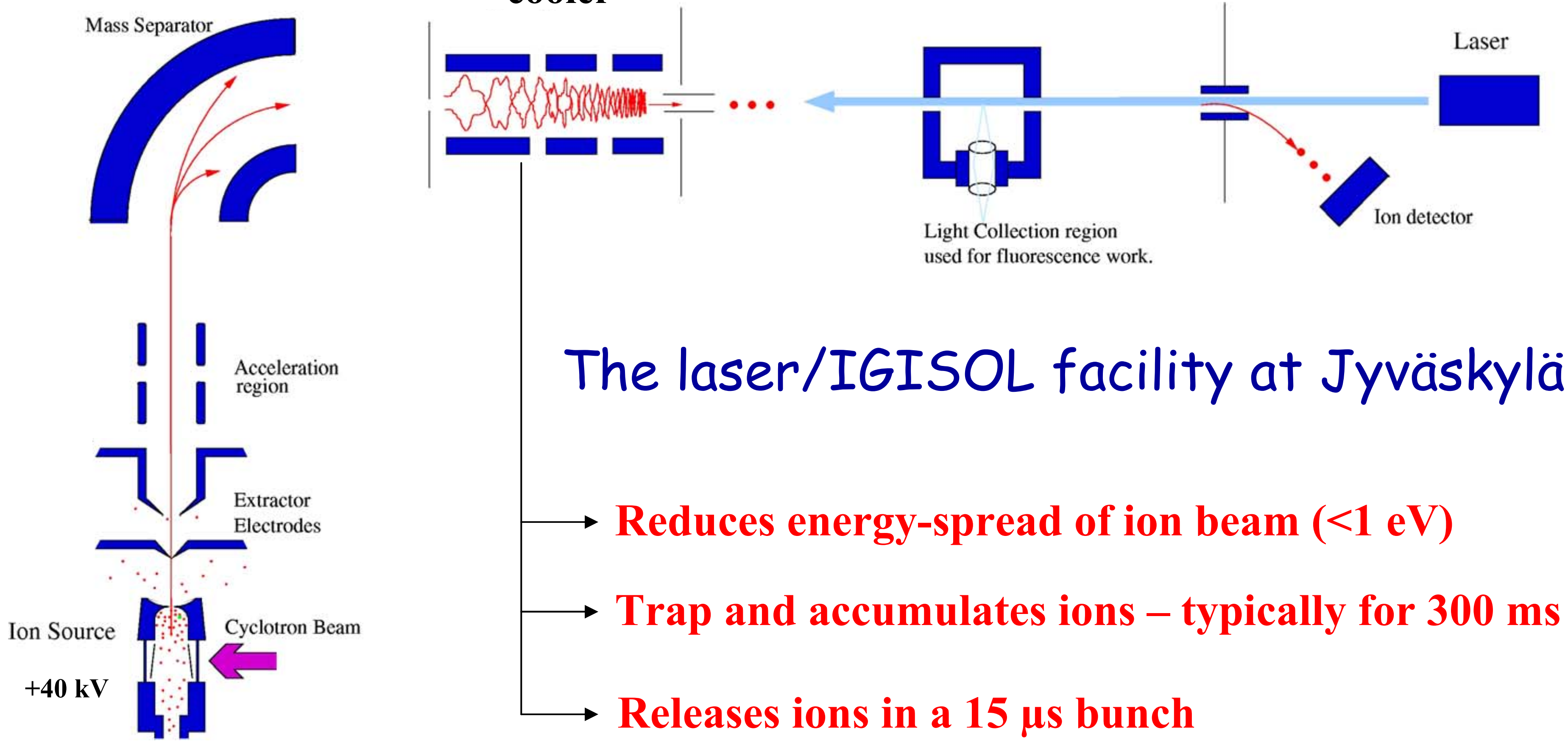


Limited mixing between intruder and g.s. configurations in Pb isotopes

A. Andreyev et al. EPJA14, 63 (2002) and H. De Witte, under analysis

H. De Witte, PhD thesis 2004 (IKS, KU Leuven)

Laser spectroscopy with and ion cooler-buncher



Ion beam cooler

Light collection region

(Laser resonance fluorescence)

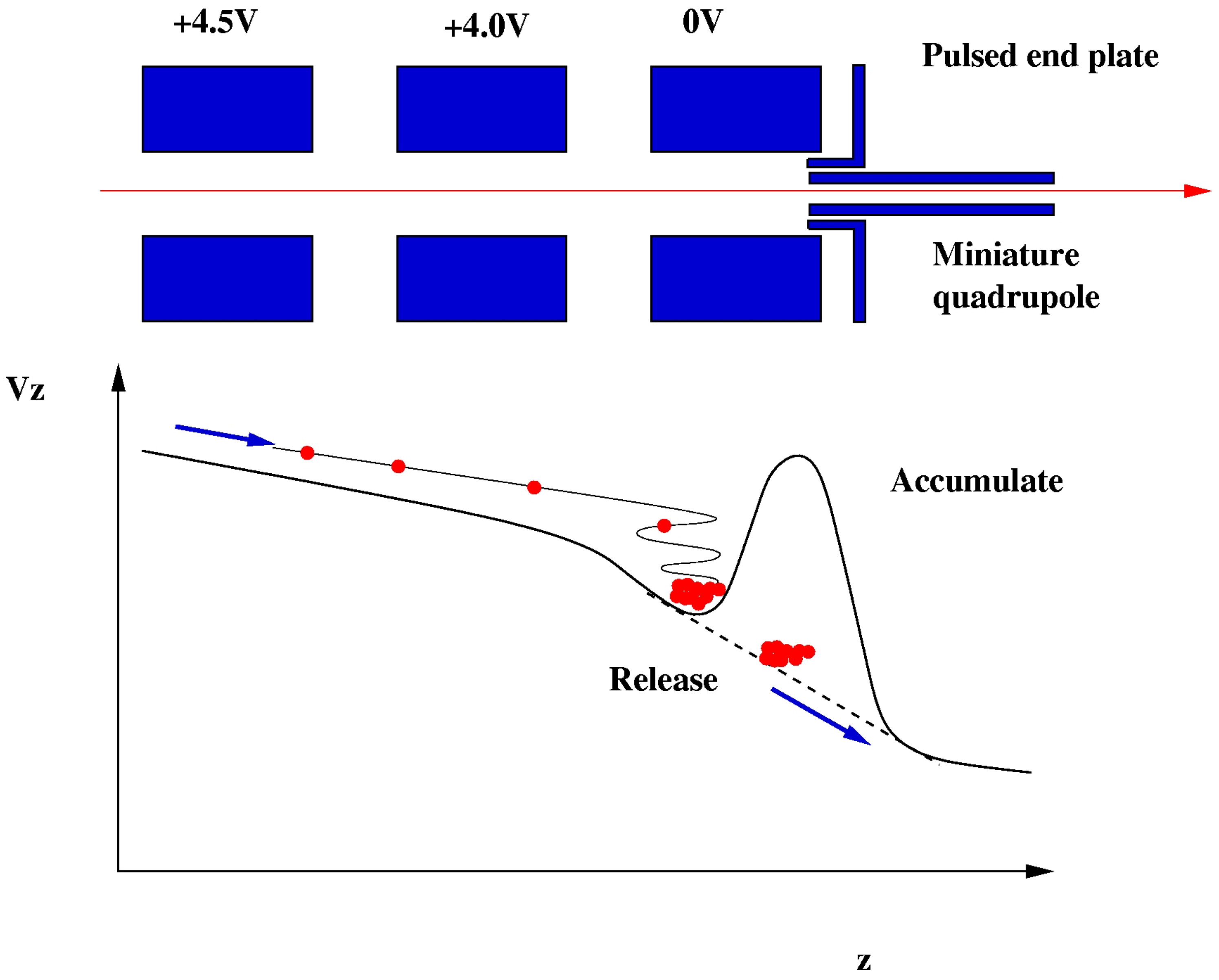
The laser/IGISOL facility at Jyväskylä

Reduces energy-spread of ion beam (<1 eV)

Trap and accumulates ions – typically for 300 ms

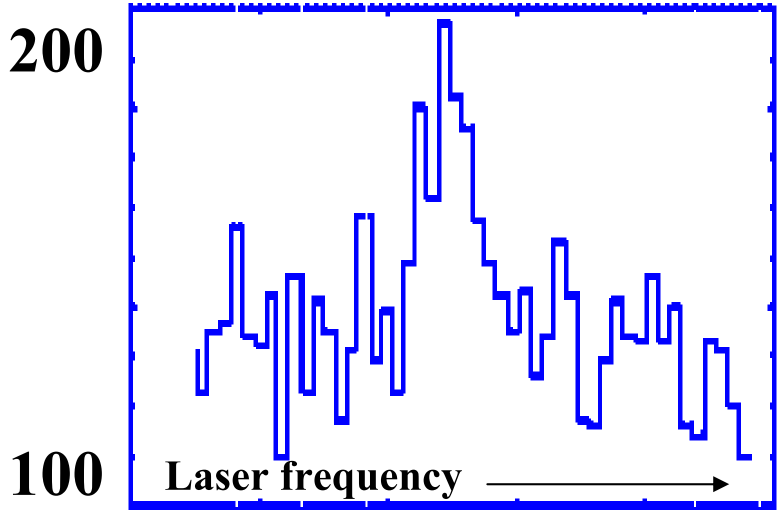
Releases ions in a 15 µs bunch

Bunching ions in the RFQ cooler



Sensitivity gains using the RFQ ion-cooler

BEFORE



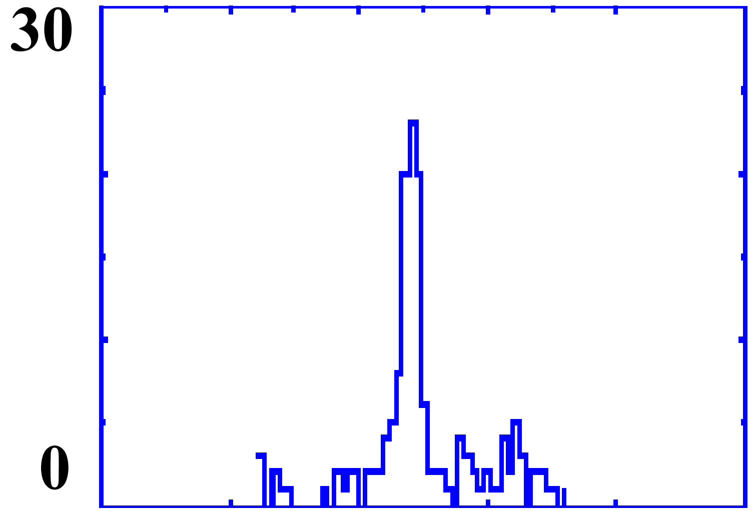
8000 ions/sec

5.3 hours

(Photon-ion coincidence method)

Photons from laser-excitation of radioactive ^{88}Zr

AFTER



2000 ions/sec

48 minutes

3. New opportunities using the ISCOOL ion cooler-buncher at ISOLDE (from 2006)

Conventional fluorescence-detection methods could:

- be applied to new isotopes chains
- extend known chains further from stability

New techniques

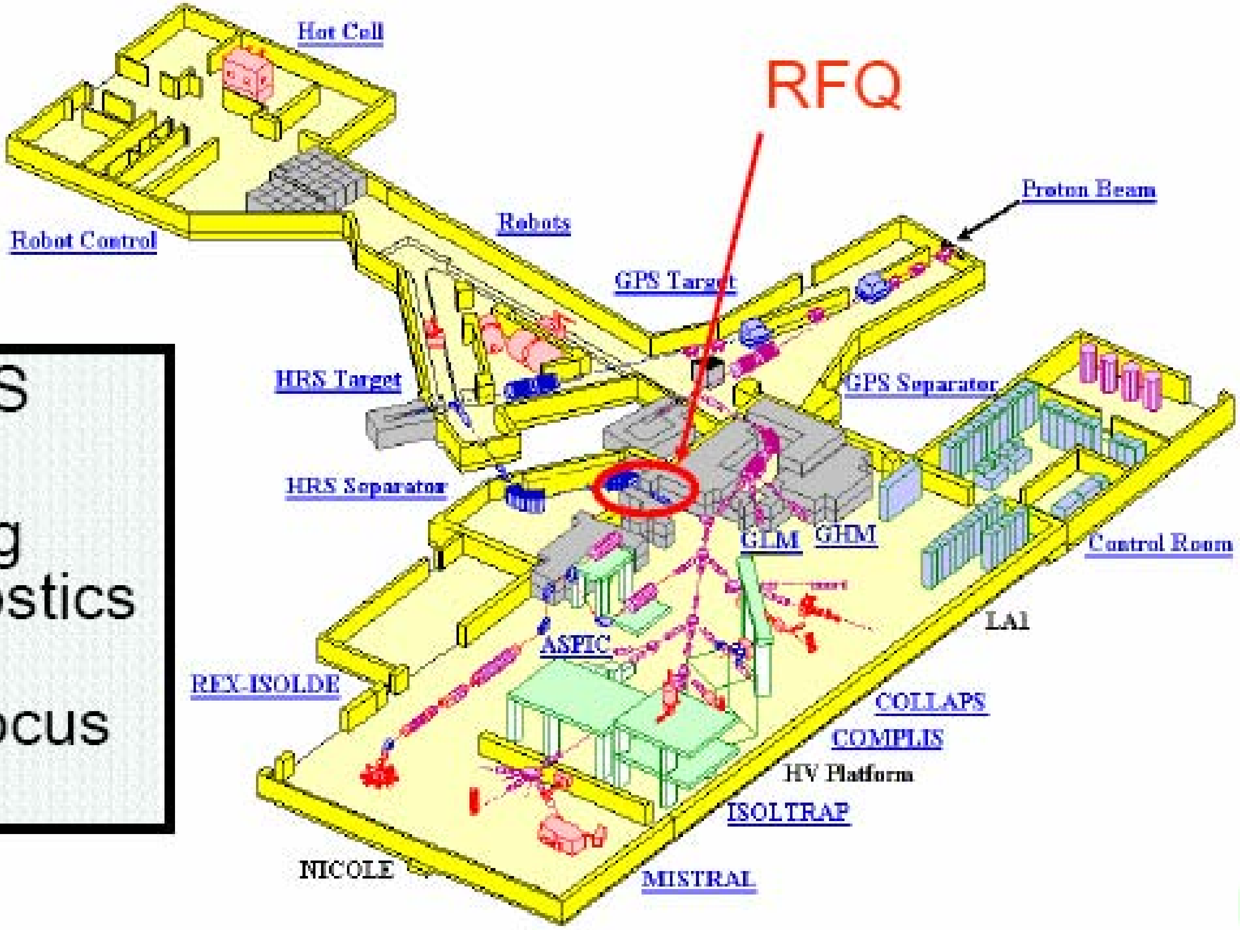
- Collinear Resonance Ionization Spectroscopy (CRIS)

  Sub-Doppler precision; single atom sensitivity
- Optical pumping of ions; preparing ions in metastable state;

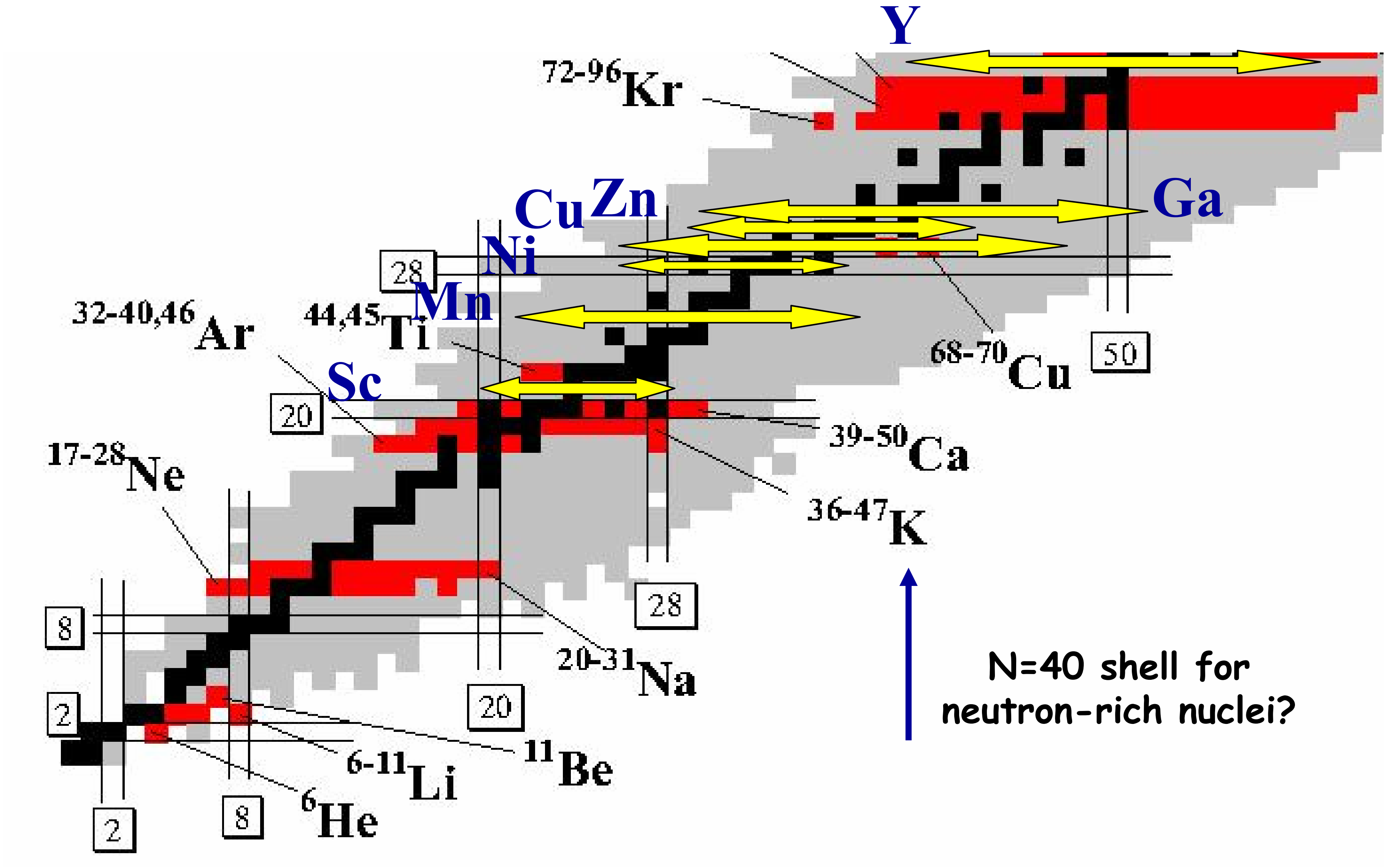
  polarised or aligned nuclear beams.

Location beam section at ISOLDE layout

- After the HRS final focus
- Up to existing beam diagnostics box after the beam gate focus



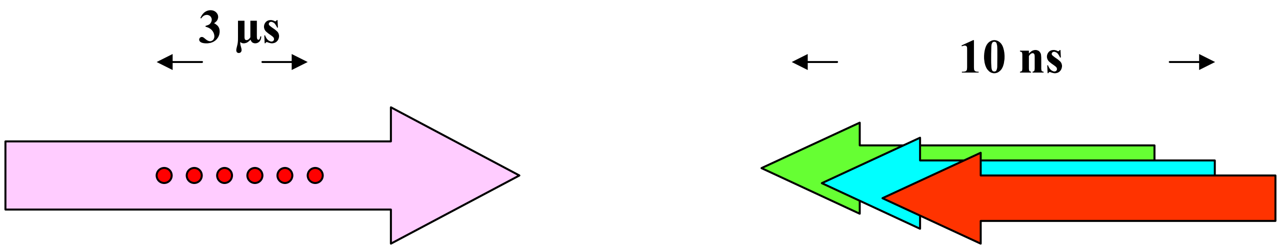
Scope for new laser measurements



N=40 shell for neutron-rich nuclei?

Collinear Resonance Ionization Spectroscopy

(K.T.Flanagan, PhD Thesis)



3 µs

10 ns

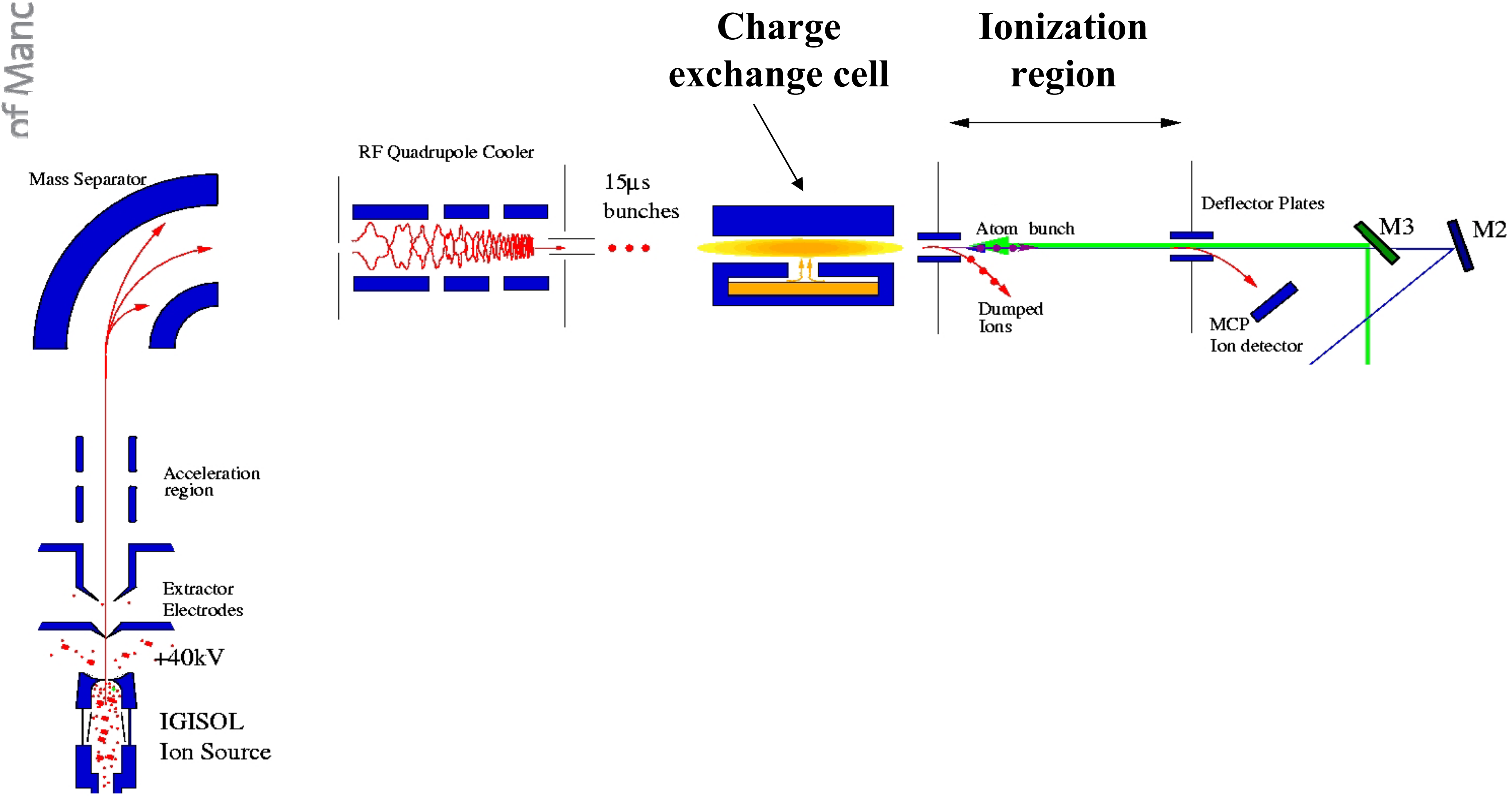
50 Hz
repetition
rate lasers

Atom bunch

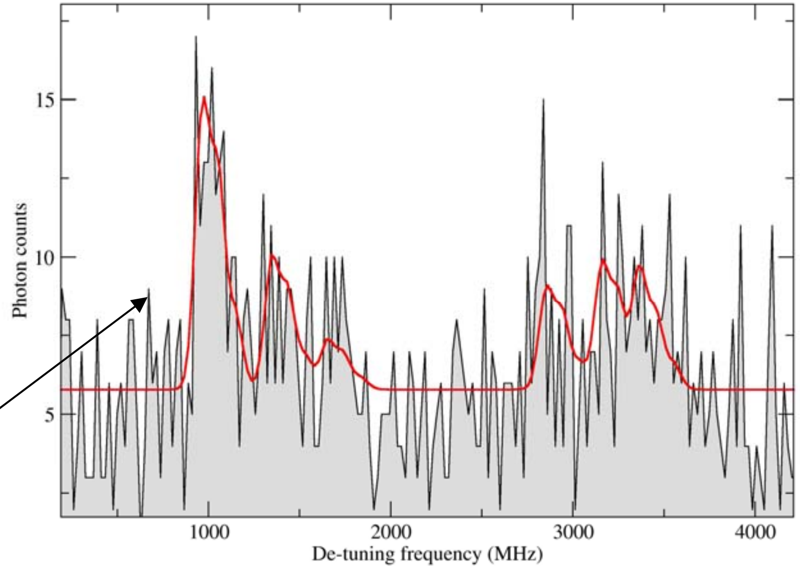
50 Hz delivery rate,
synchronized with
laser pulse

- All atoms from the ion source have a chance to be ionized
- Resonance located by ion counting (not photon counting)
- Doppler-broadening free

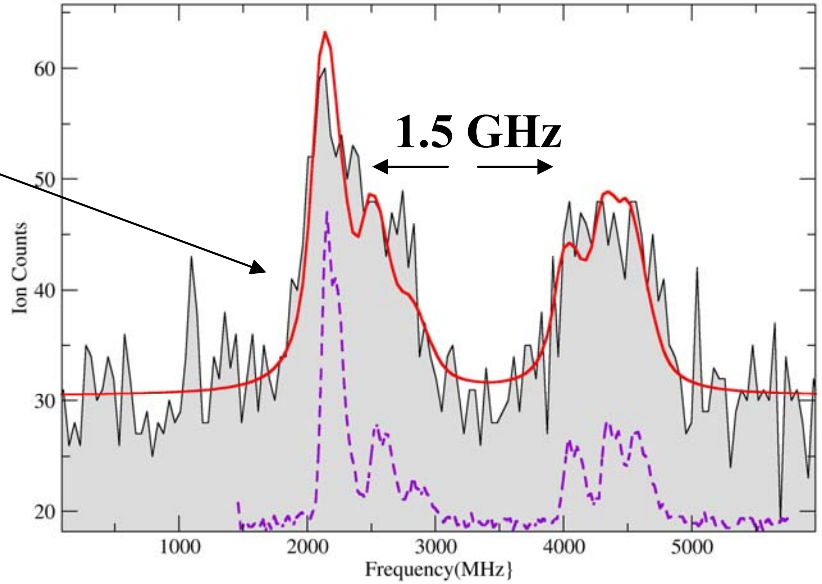
Collinear resonance ionization spectroscopy



Comparison with low-flux bunched beams



Photon counting (12 minutes)



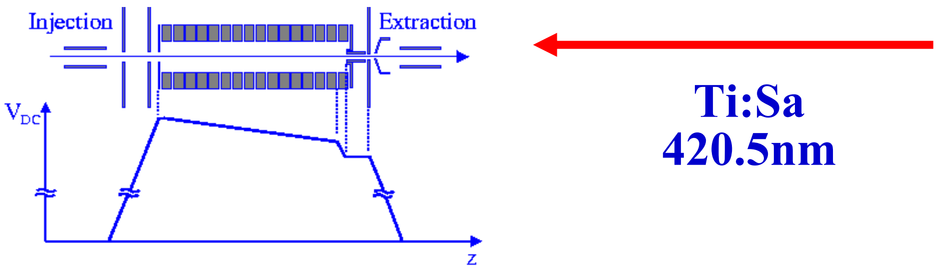
Ion counting (4 minutes)

Sensitivity:

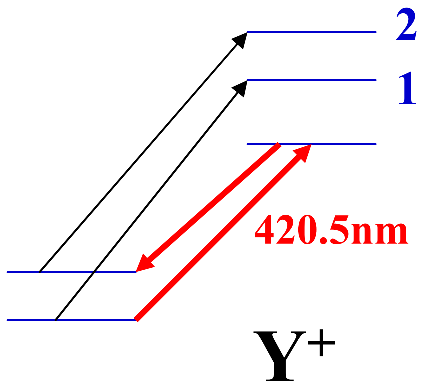
1 resonance ion per 30 atoms within 1 µs time window

(compared with 1 photon per 50,000 atoms)

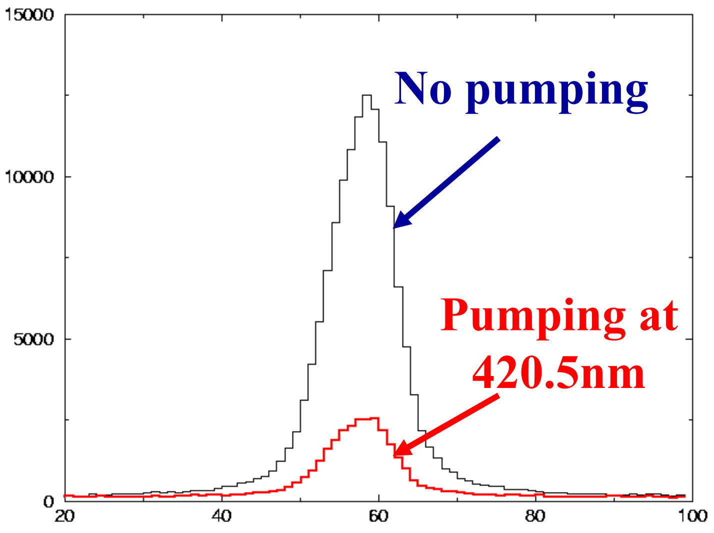
Optical pumping in the cooler before the laser spectroscopy

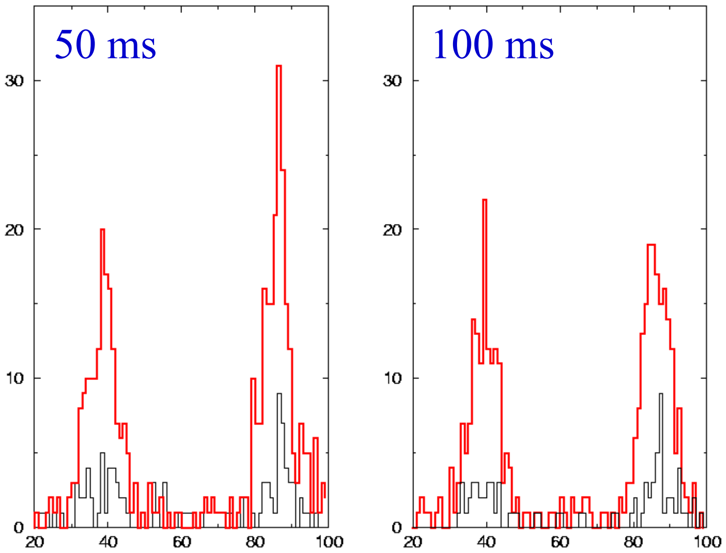


**Ti:Sa
420.5nm**



Ground state signal (1) **(Ti:Sa on)** **Metastable state signal (2)**





Desirable developments at ISOLDE

- Improvements in isobaric purity (avoid space charge limit of cooler-buncher)
    - LIST development
    - HRS performance
- Range of elements (new RIS schemes and lasers)
- Faster extraction times for short-lived isotopes
- Stable beams for off-line development and setting-up