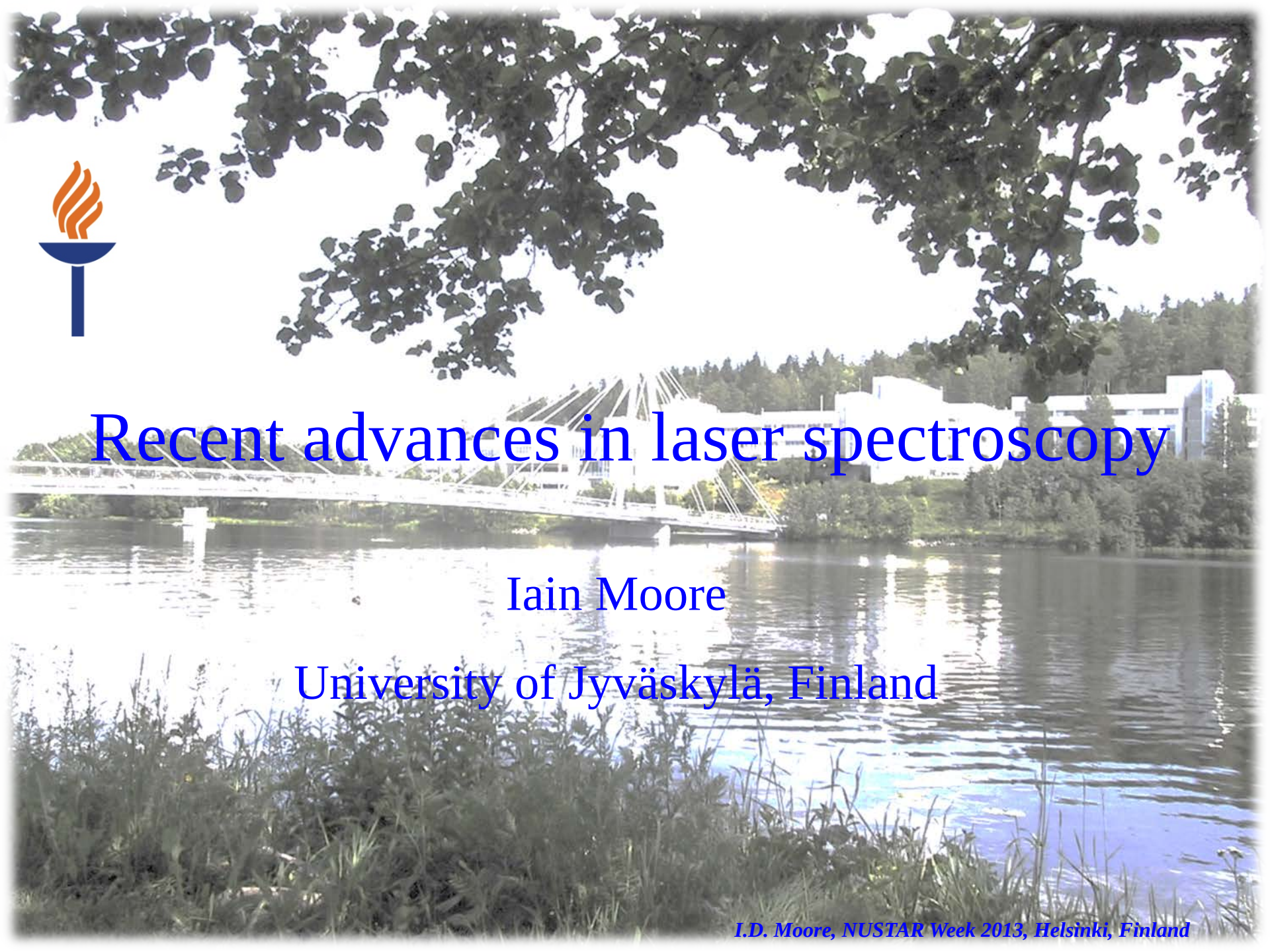
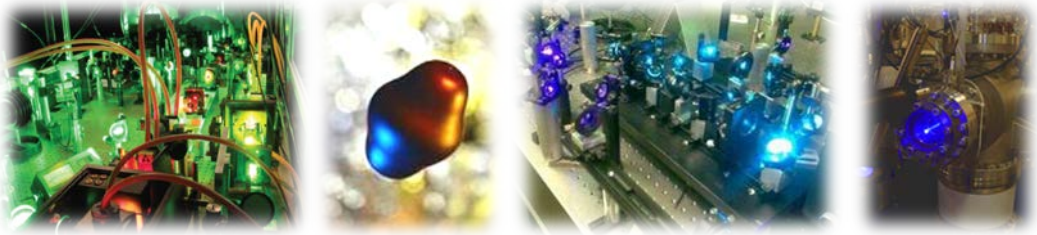


Recent advances in laser spectroscopy

Iain Moore

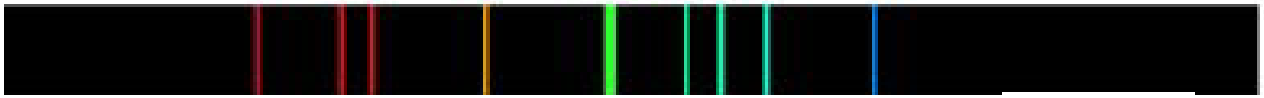
University of Jyväskylä, Finland

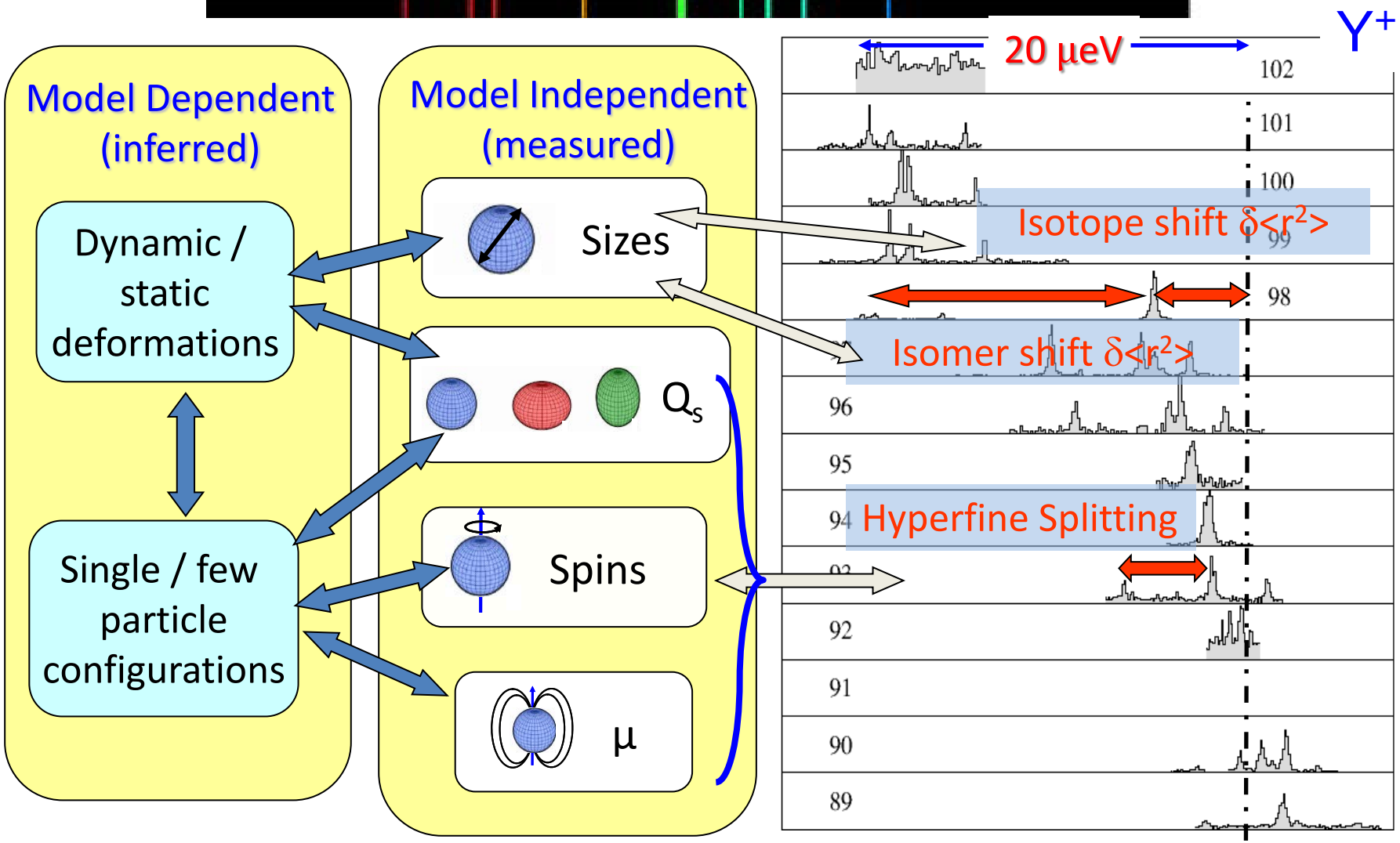
Outline of talk



- A nuclear fingerprint in the atomic spectrum
- Collinear laser spectroscopy & extensions
- Commissioning of the new IGISOL-4 facility
- In-source and in-jet resonance ionization
- Laser developments and a look to the future

A nuclear fingerprint in the atomic spectrum



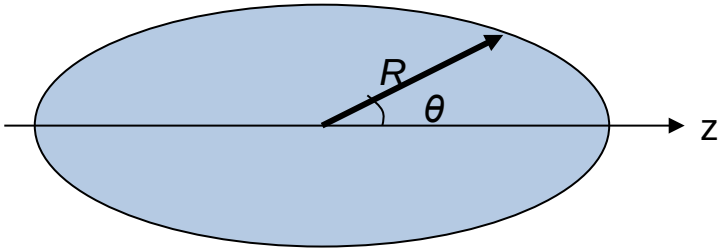


Probing the deformation of nuclei

Quadrupole deformation parameter

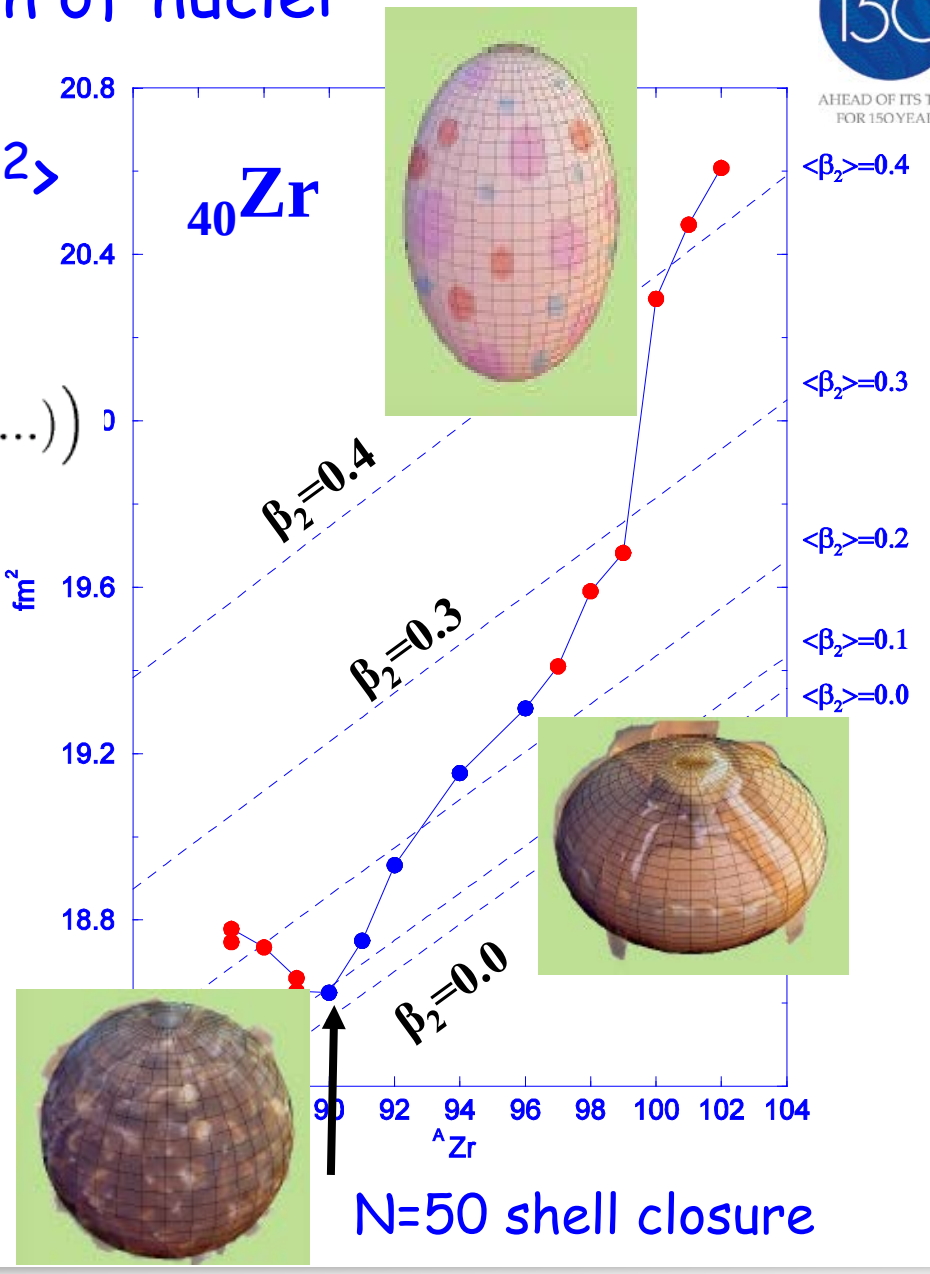
$$\langle r^2 \rangle = \langle r^2 \rangle_0 \left(1 + \frac{5}{4\pi}(\langle \beta_s^2 \rangle + \langle \beta_3^2 \rangle + \ldots)\right)$$

Radius of spherical nucleus of same volume



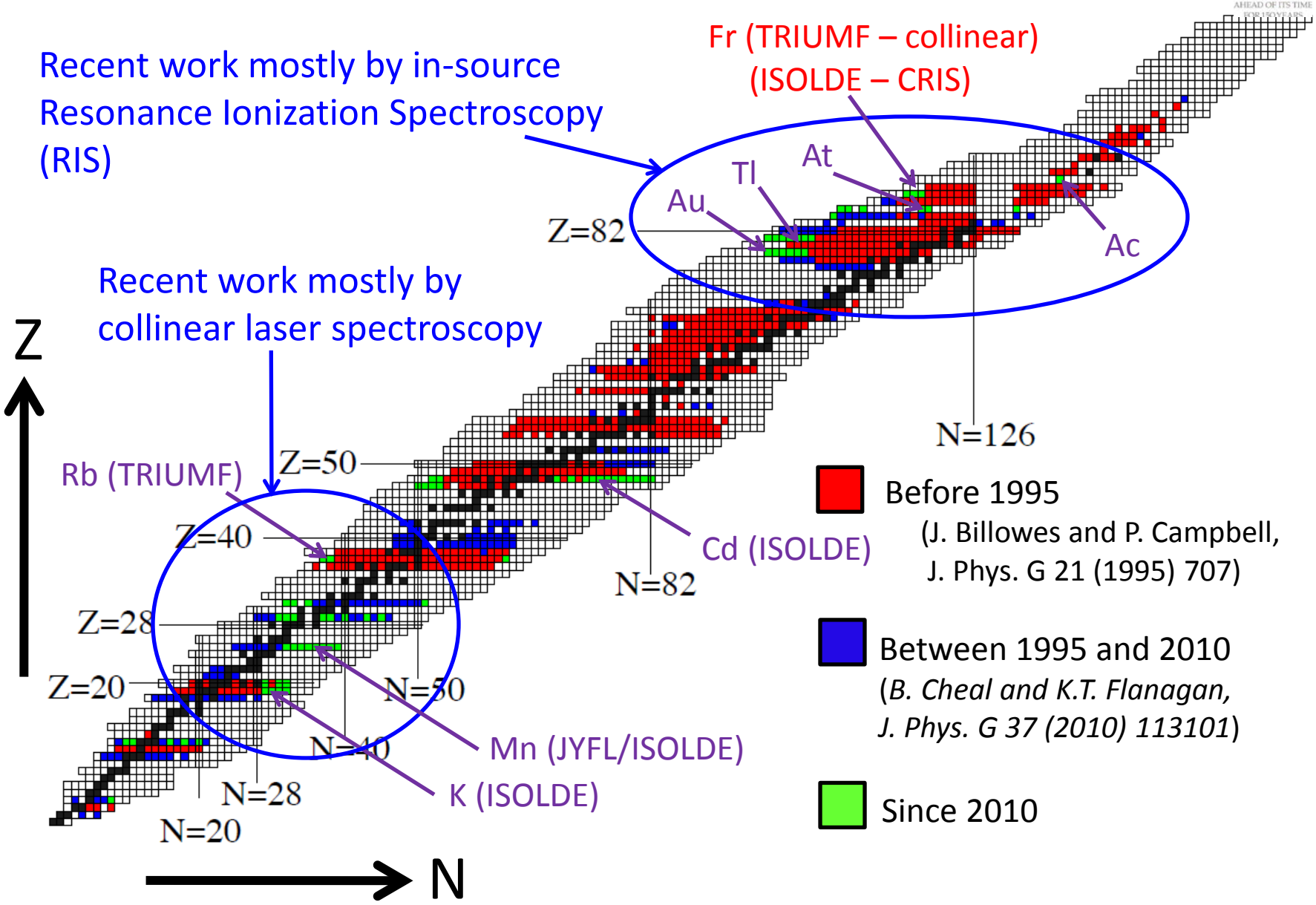
$R = R_0 \, (1 + \beta_2 \, Y_{2,0} \, (\theta,\varphi))$

$\delta\langle r^2 \rangle$

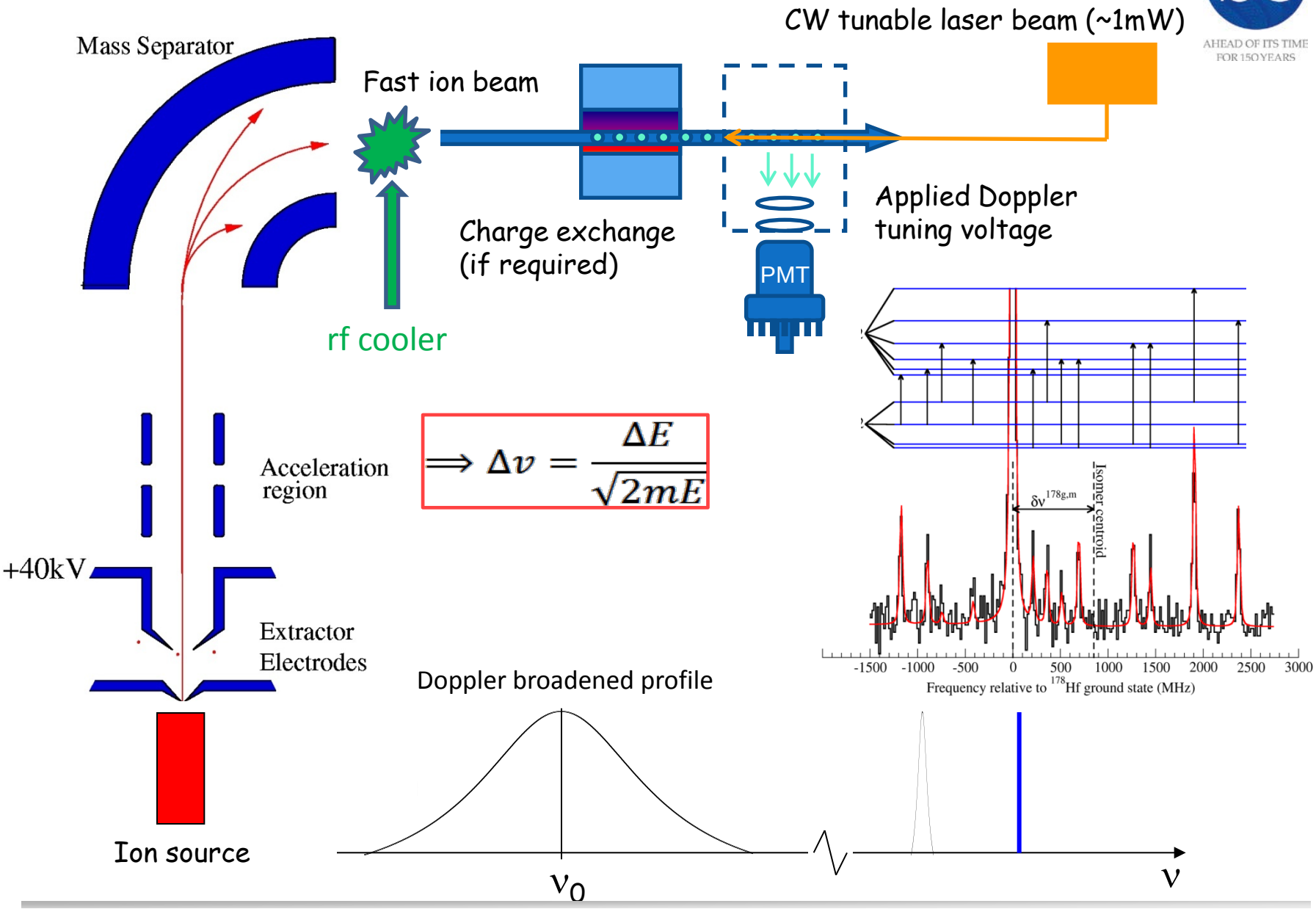


N=50 shell closure

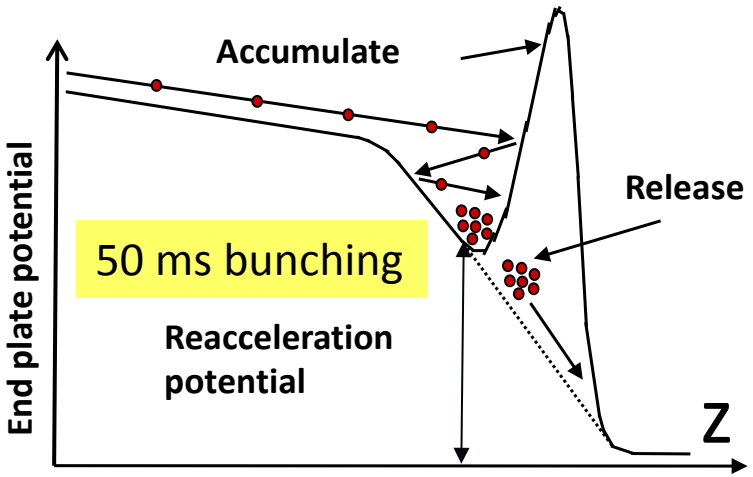
Laser spectroscopy of radioisotopes - status

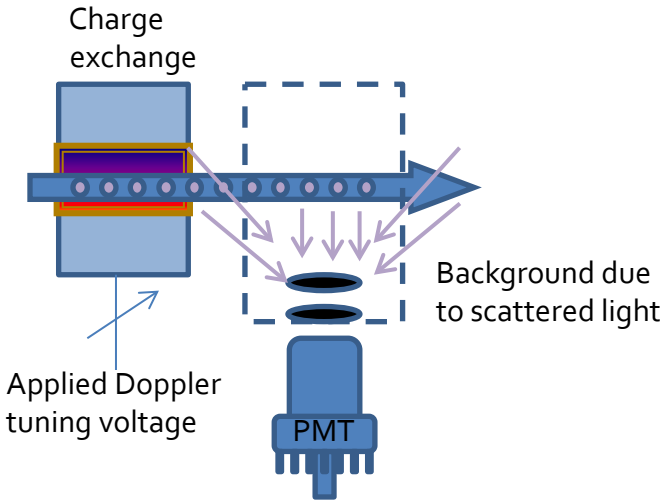


Workhorse: Collinear Laser Spectroscopy (CLS)



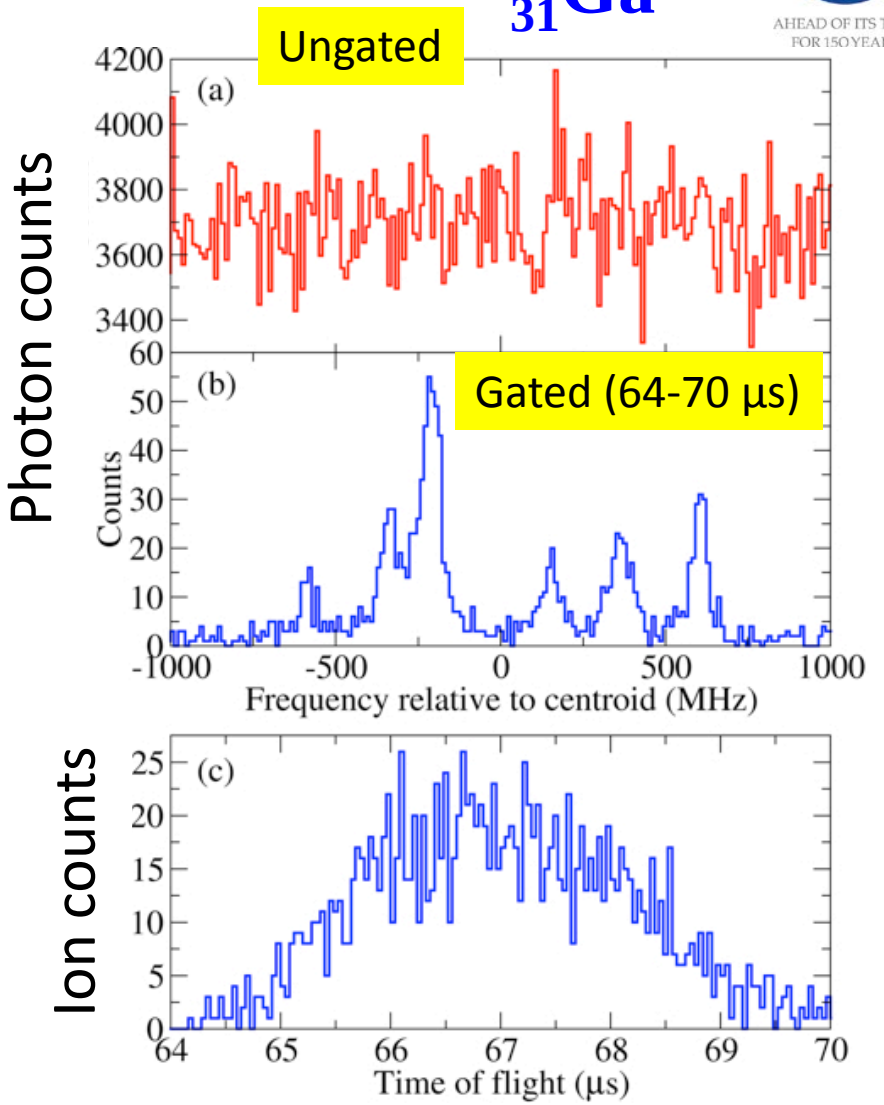
CLS on cooled and bunched beams





Background suppression

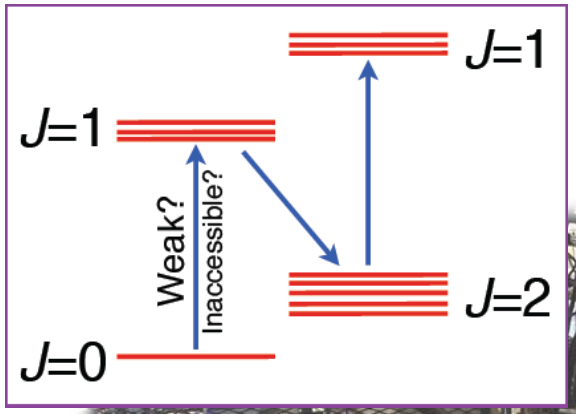
50 ms/6 μs = ×10^4

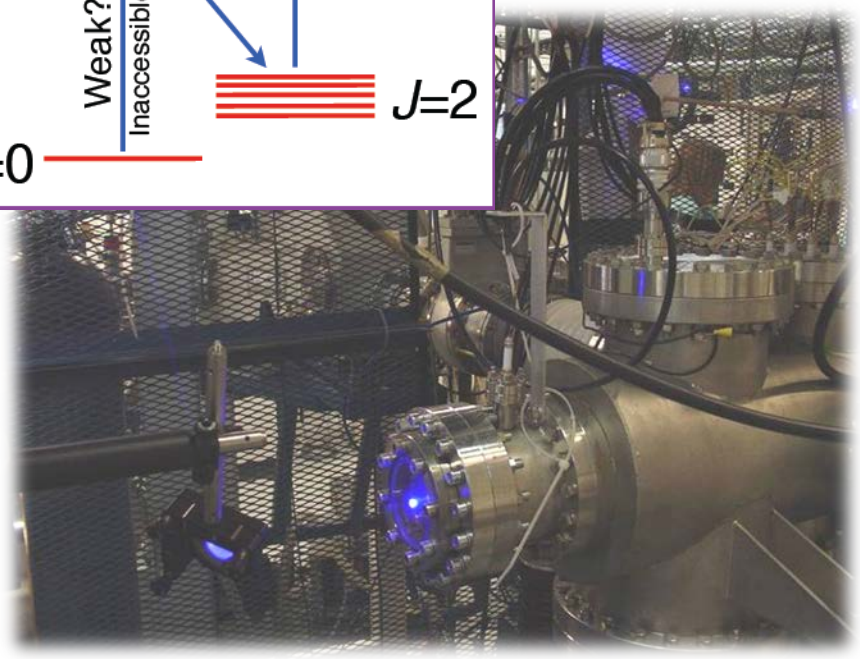


E. Mané et al., PRC 84 (2011) 024303

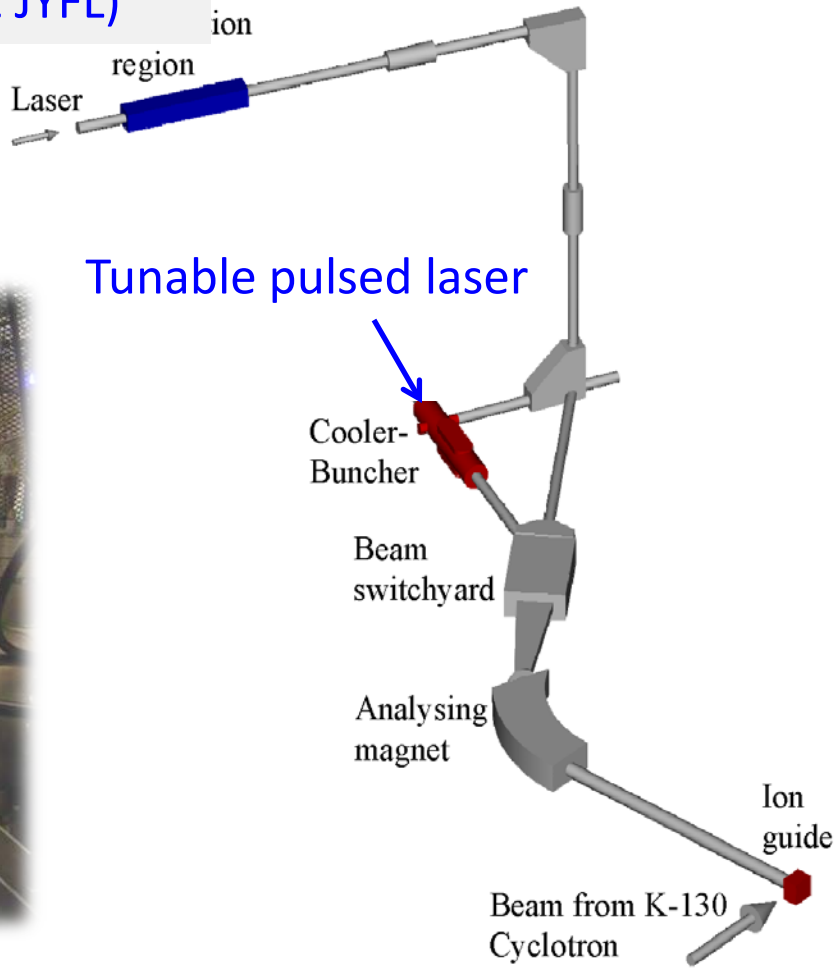
Optical manipulation in the RFQ

- J=0→J=1 gives μ, Q, $\delta\langle r^2\rangle$ but not I
- Access to more accessible/efficient transitions
- New elements to study (eg. Nb, Mn at JYFL)





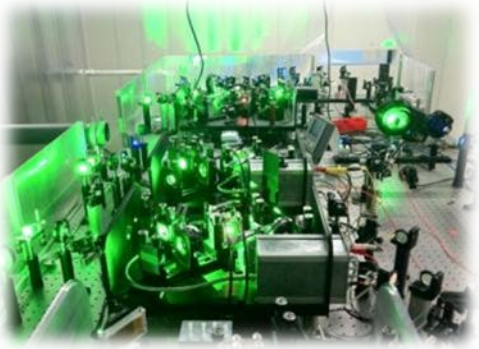
IGISOL-3 layout



B. Cheal et al., Phys. Rev. Lett. 102 (2009) 222501

Ultra-pure beams: Ion Resonance Ionization

Multiple pulsed lasers
(resonantly ionize $1^+ \rightarrow 2^+$)

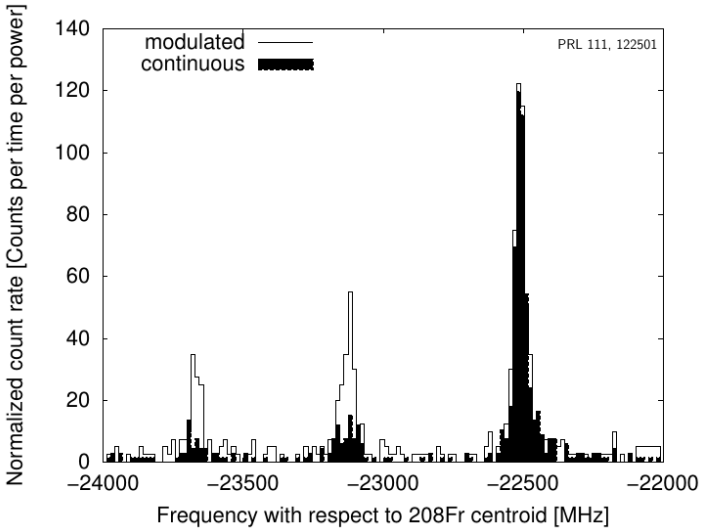


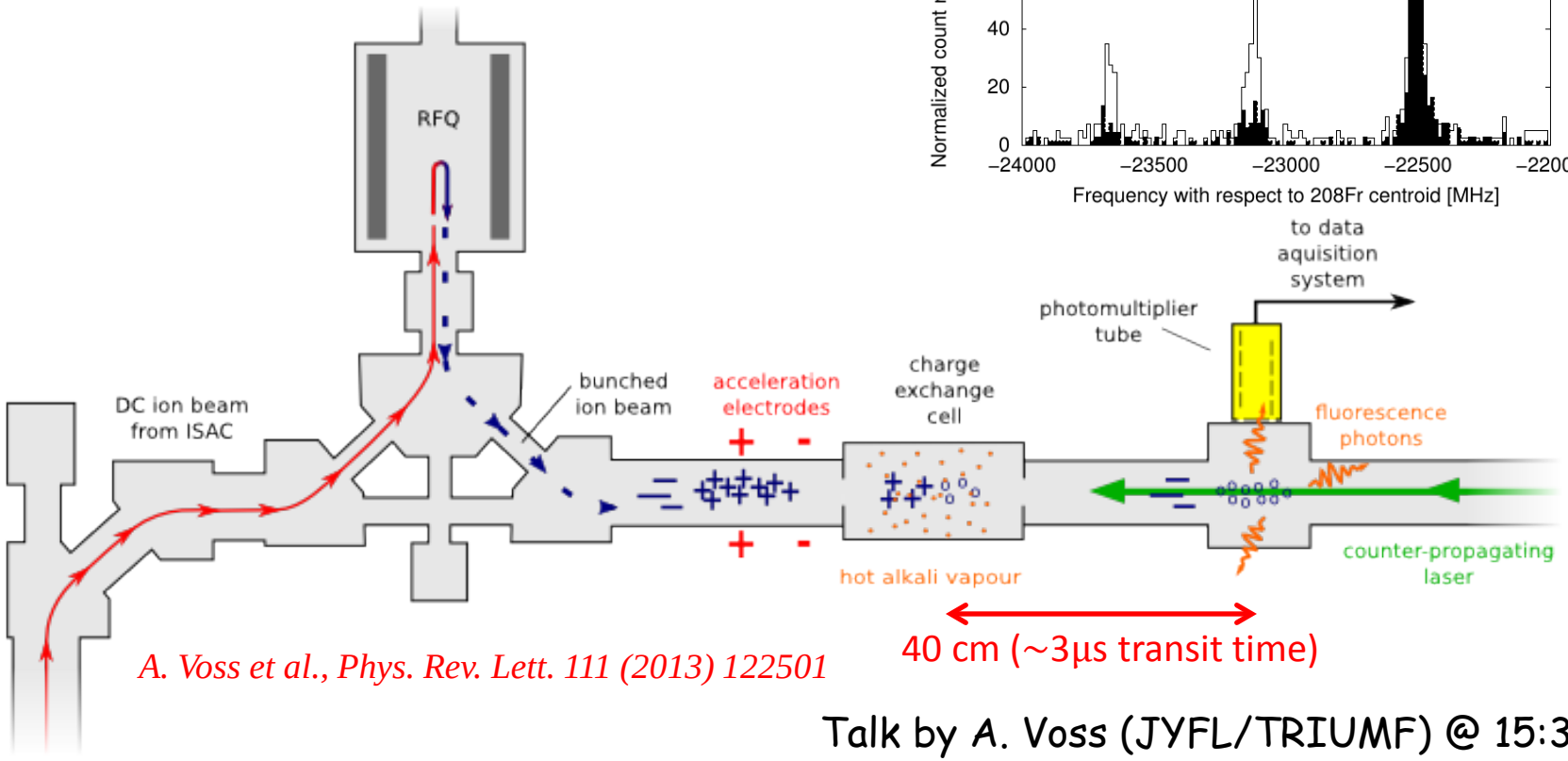
Currently planned for 2014 at JYFL: Proposal B. Cheal

- Ultra pure beam of single *A* **and** *Z*
- No contaminant will have *m*/*q* selected by magnet **and** *m*/(2*q*) selected by TOF (or other device)

High frequency intensity modulation on bunched atom beams

- Intensity modulation of the laser light suppresses hyperfine pumping in CLS of atoms
- Demonstrated at TRIUMF on neutron deficient $^{206,205,204}Fr$
- Immediately transferable to facilities, eg LaSpec





A. Voss et al., Phys. Rev. Lett. 111 (2013) 122501

Talk by A. Voss (JYFL/TRIUMF) @ 15:30

The new IGISOL-4 facility

https://www.jyu.fi/fysiikka/en/research/accelerator/igisol

from K=130 MeV cyclotron

K=30 MeV cyclotron

Off-line ion sources:
(discharge, carbon cluster…)

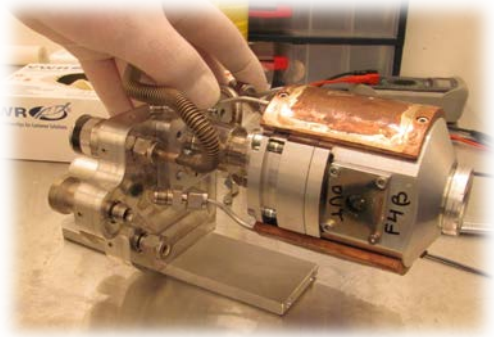
Laser transport for optical manipulation/ IRIS

Laser ionization in-source/in-jet

Collinear laser spectroscopy

Decay spectroscopy

Mass spectrometry & post-trap spectroscopy



- Fast extraction (~1 ms)
- Chemically non-selective

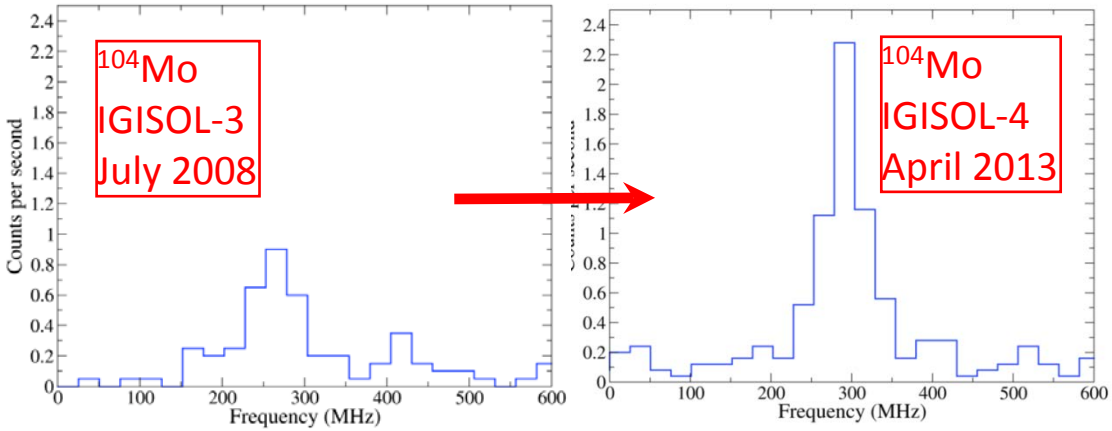
Commissioning of the collinear beam line (2013)

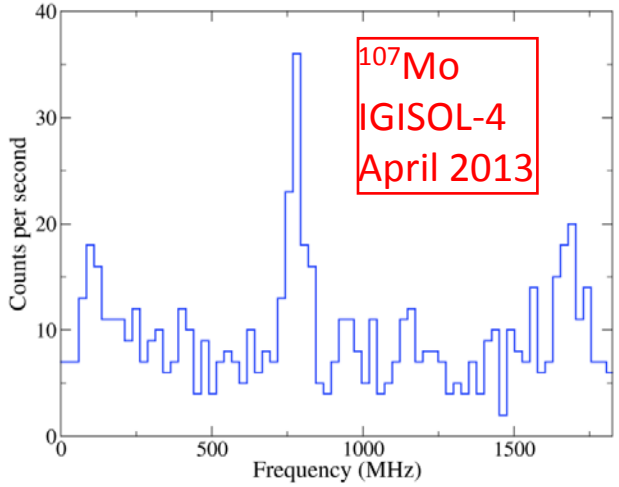
AHEAD OF ITS TIME FOR 150 YEARS

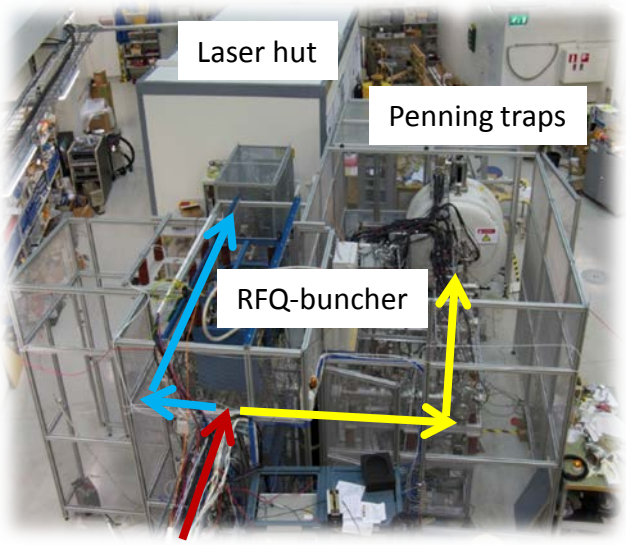
Laser spectroscopy of neutron rich Mo fission fragments

($^{102\text{-}106,108}$Mo) *F.C. Charlwood et al., Phys. Lett. B 674 (2009) 23*

$4d^4 5s^6 D_{1/2}$ (11783 cm^{-1}) → $4d^4 5p^6 F_{1/2}$ (45853 cm^{-1})

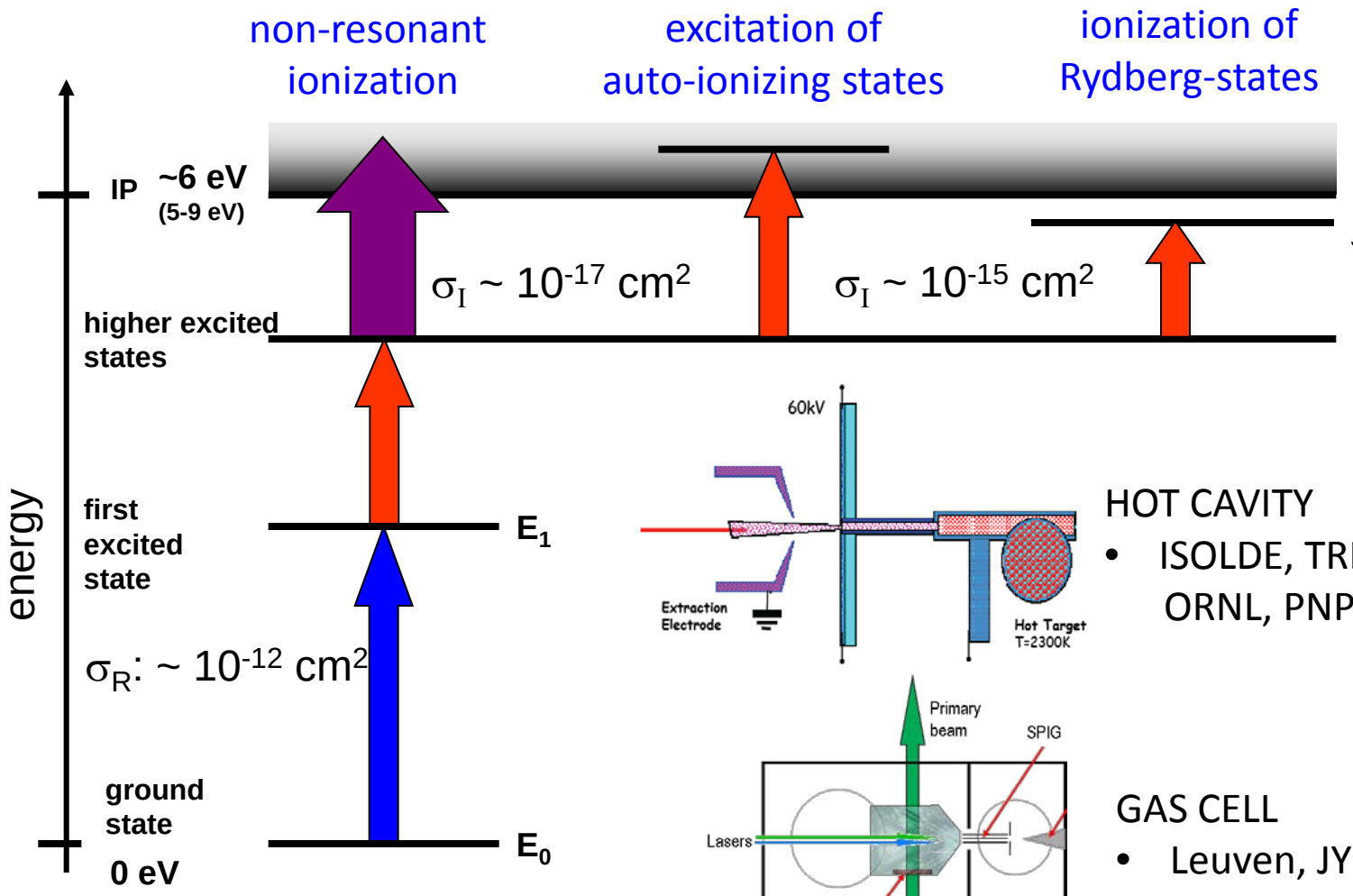






- First "commissioning run"
- Fission yields 2-3× higher than IG-3
- ^{107}Mo measured for the first time
- Further optimisation planned

Resonant laser ionization (spectroscopy)



HOT CAVITY

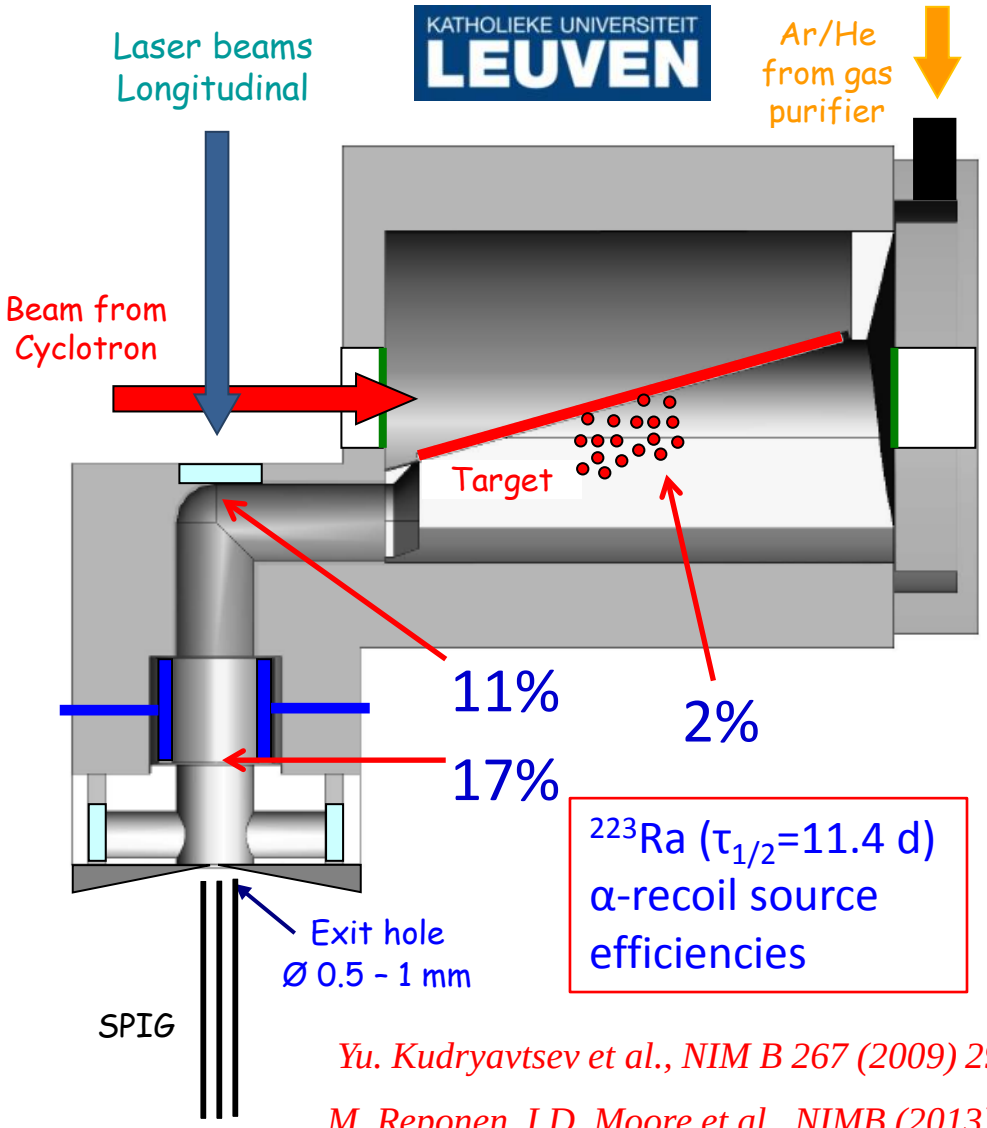
- ISOLDE, TRIUMF, GANIL, ORNL, PNPI, ALTO, (SPES)

GAS CELL

- Leuven, JYFL, (PALIS)

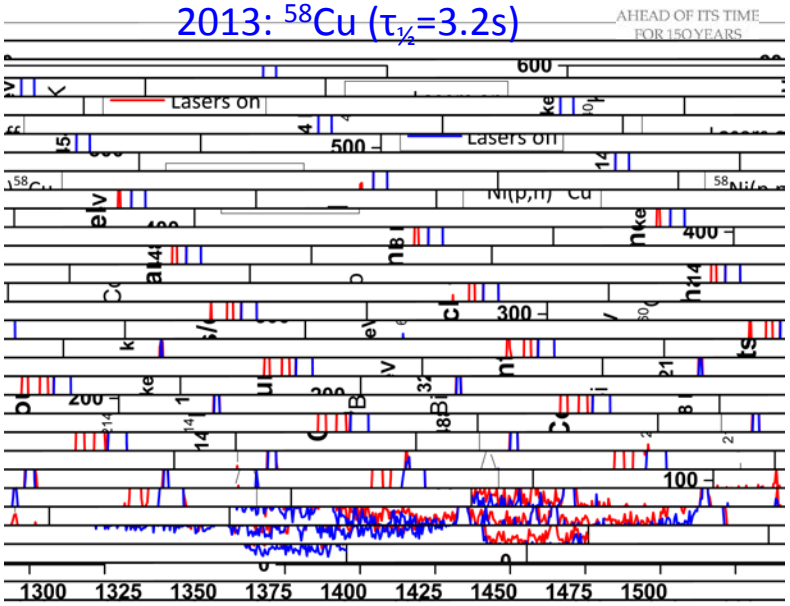
SELECTIVITY & EFFICIENCY

Dual-chamber gas cell (Leuven/JYFL)



^{223}Ra ($\tau_{1/2}$=11.4 d)
α-recoil source
efficiencies

2013: ^{58}Cu ($\tau_{½}$=3.2s)



Separation of stopping and laser ionization volume improves:

- Laser ionization efficiency at high cyclotron beam current
- Increasing selectivity (collection of non-neutral ions)

Yu. Kudryavtsev et al., NIM B 267 (2009) 2908

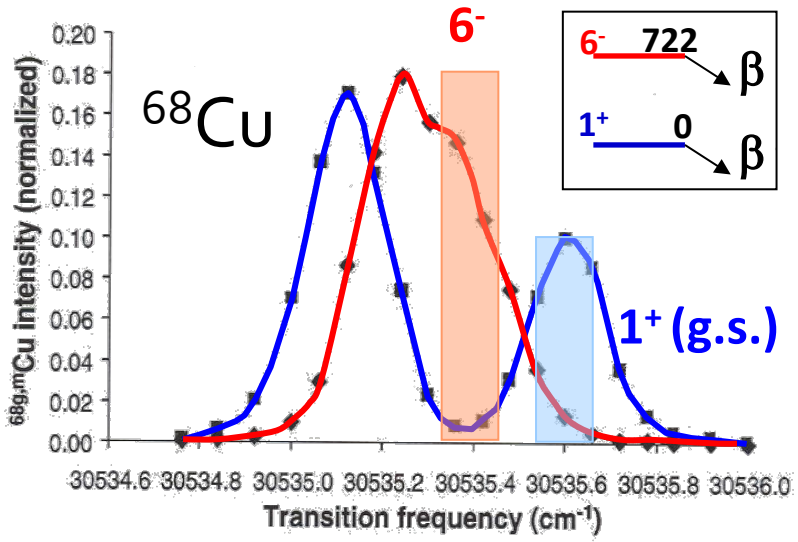
M. Reponen, I.D. Moore et al., NIMB (2013), doi:10.1016/j.nimb.2013.05.061

RIS in-source vs. collinear laser spectroscopy

AHEAD OF ITS TIME FOR 150 YEARS

IN-SOURCE (RIS)

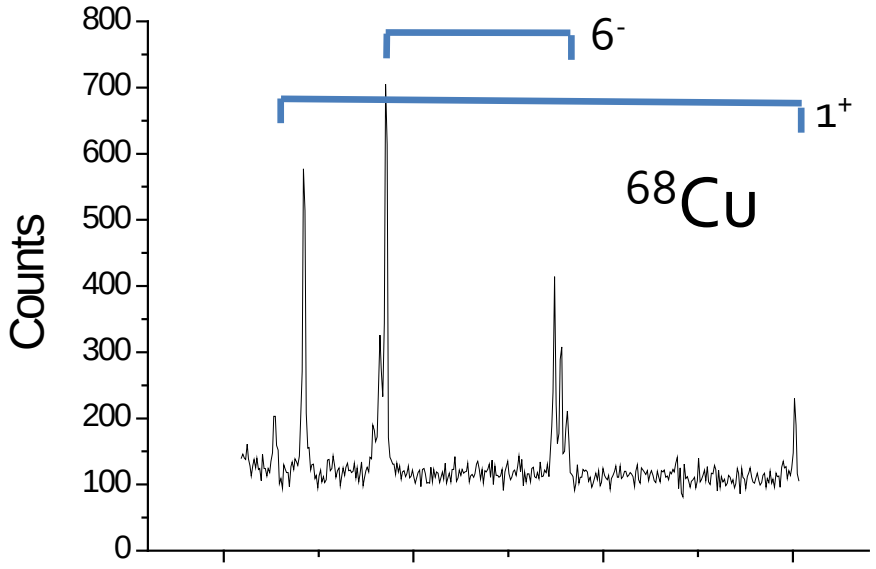
Selective process
Low lifetimes, low yields (<1 ion/s)
High detection efficiency
Poor resolution (100-1000× < CLS)



I. Stefanescu et al., PRL 98 (2007) 122701

COLLINEAR (FAST BEAMS)

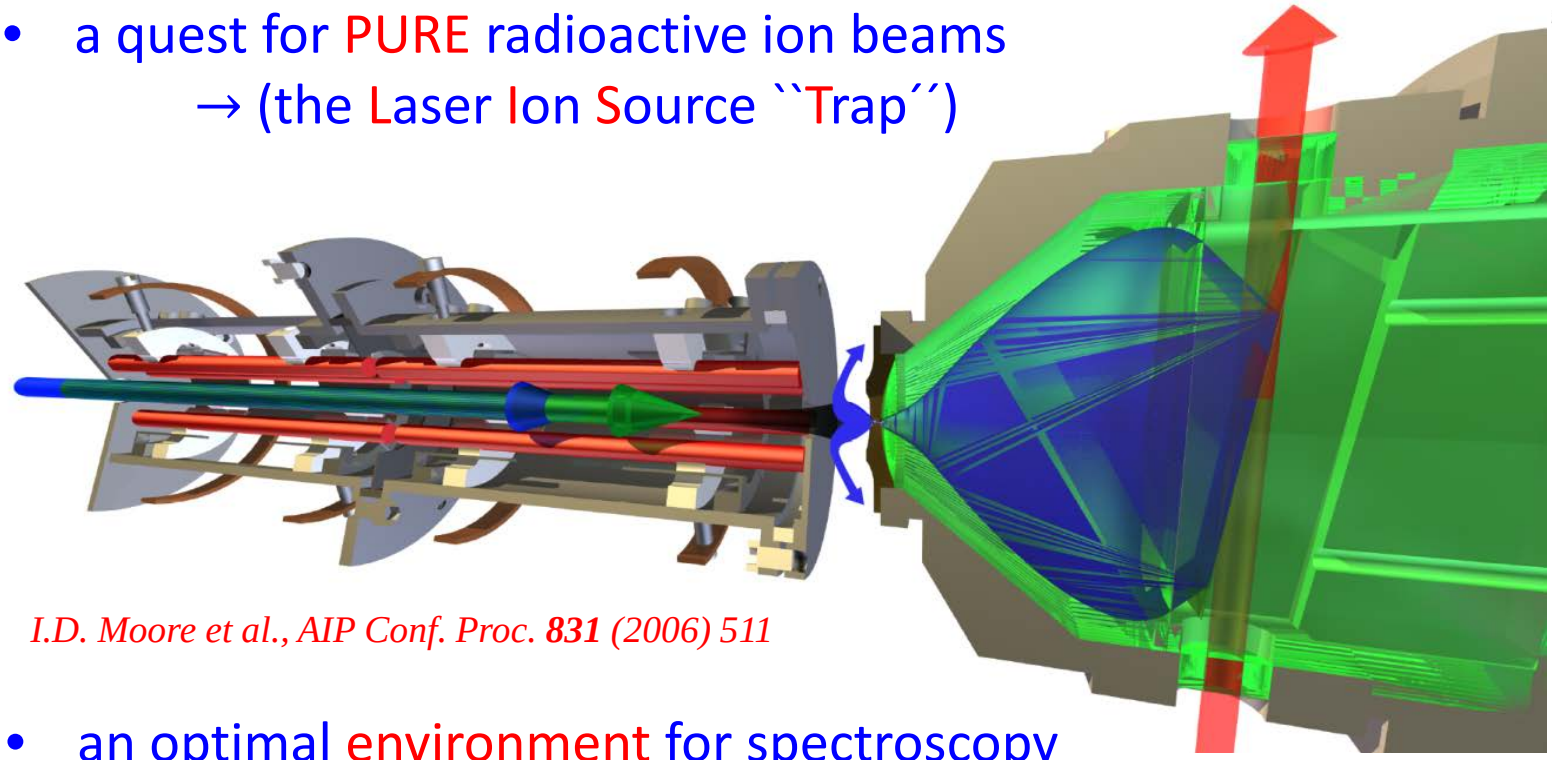
High resolution
Scanning voltage, not frequency
Limited by detection method
Beams of some 10^3 ions/s



P. Vingerhoets et al., PRC 82 (2010) 064311

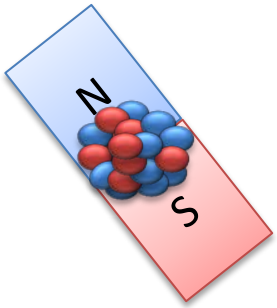
Gas jet laser ionization – a tool for the future

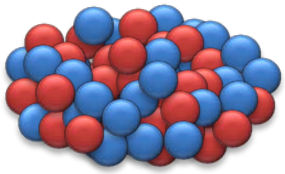
- a quest for PURE radioactive ion beams
  → (the Laser Ion Source ``Trap´´)

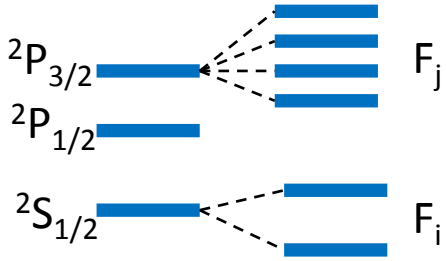


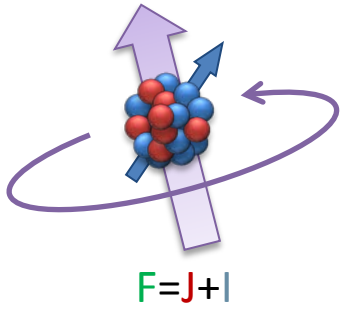
I.D. Moore et al., AIP Conf. Proc. ***831*** *(2006) 511*

- an optimal environment for spectroscopy (reduced temperature and pressure)

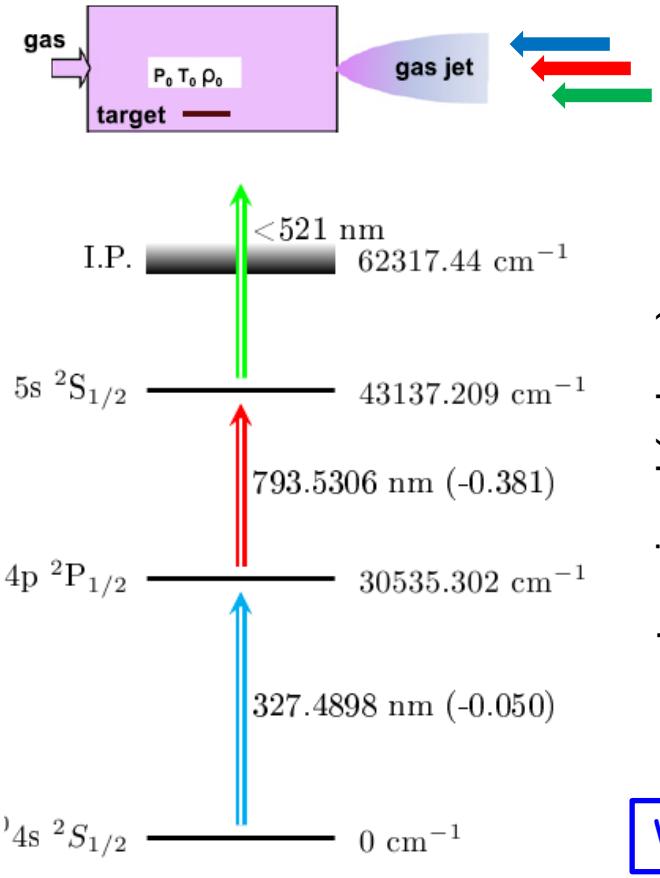




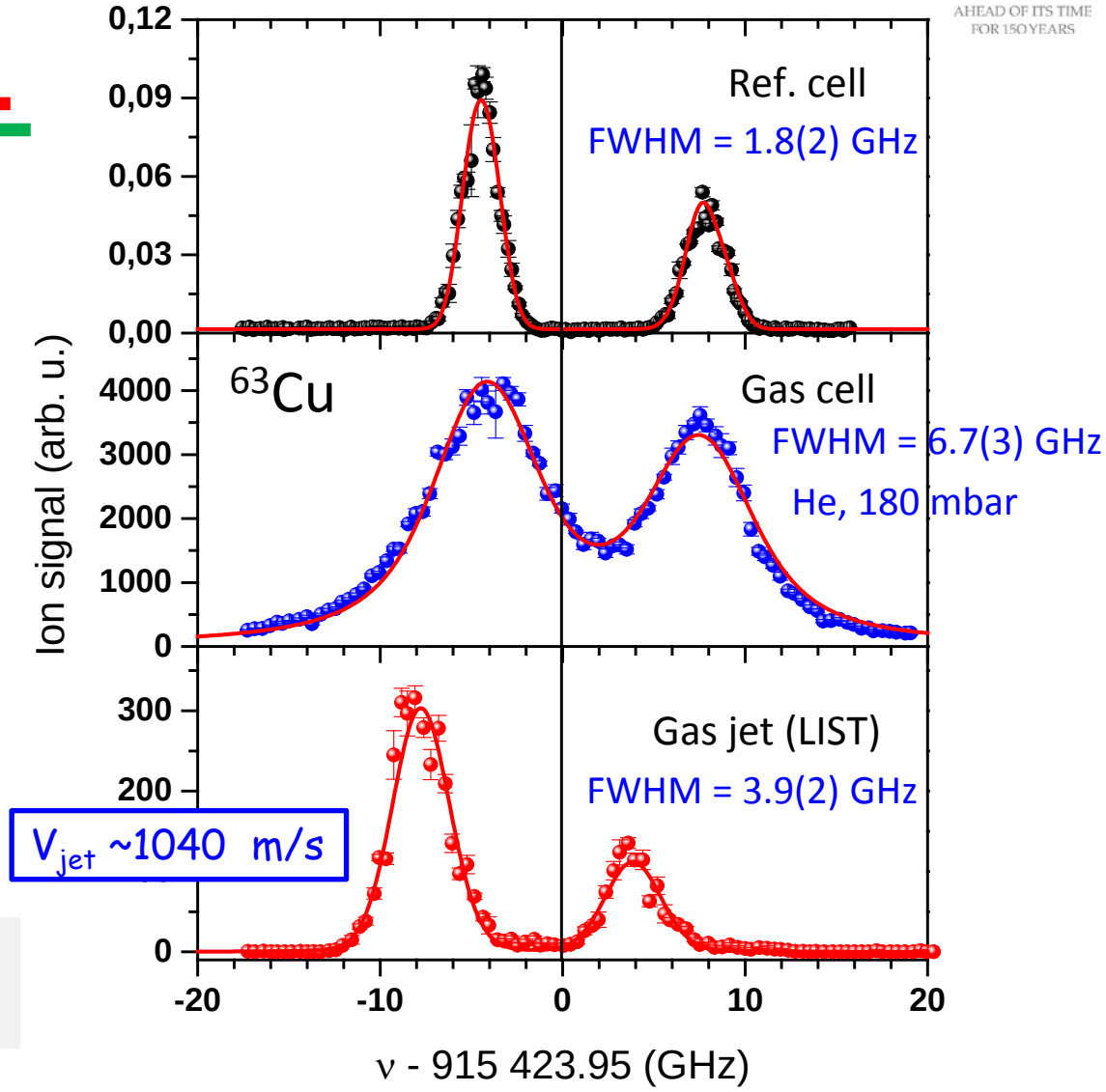




First free jet ions in LIST geometry at JYFL

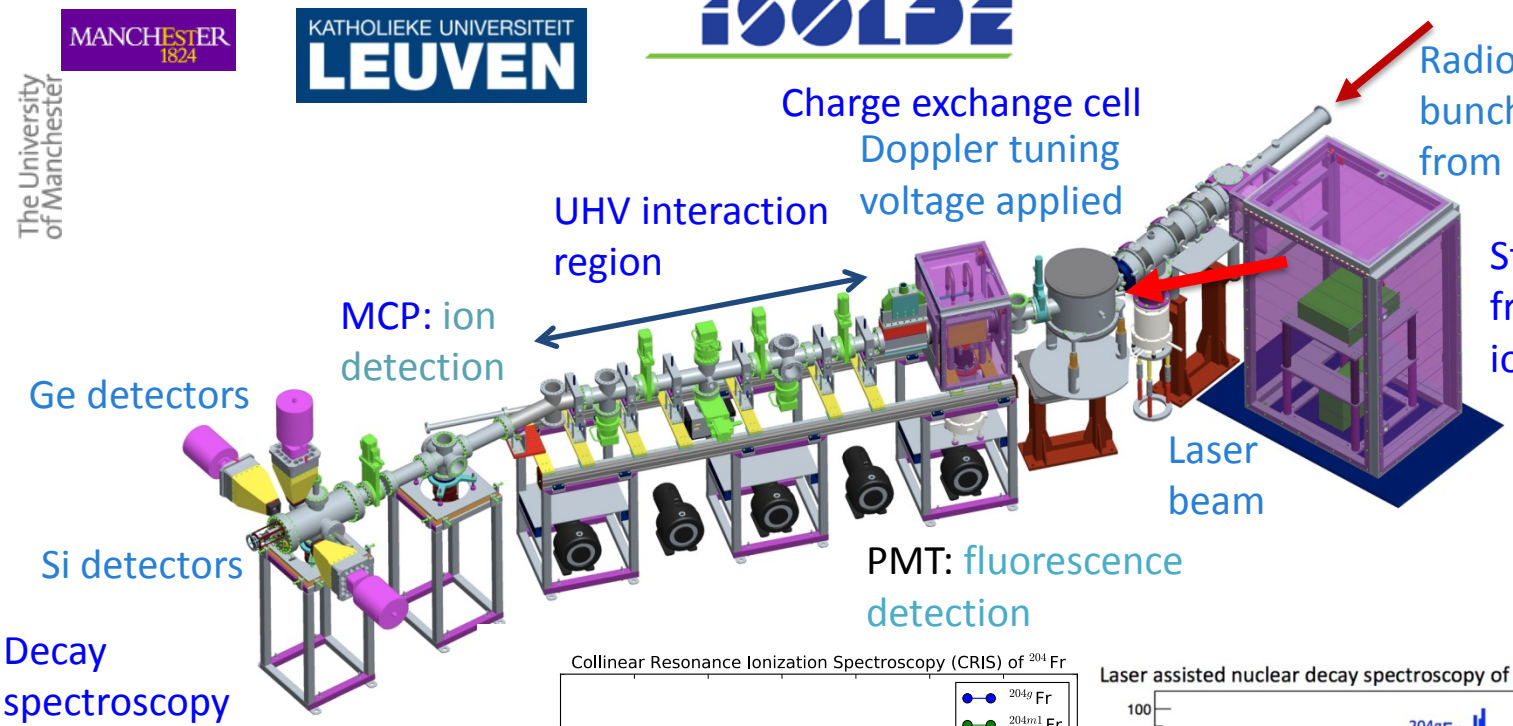


- Employ special nozzles
- Laser linewidth dominated



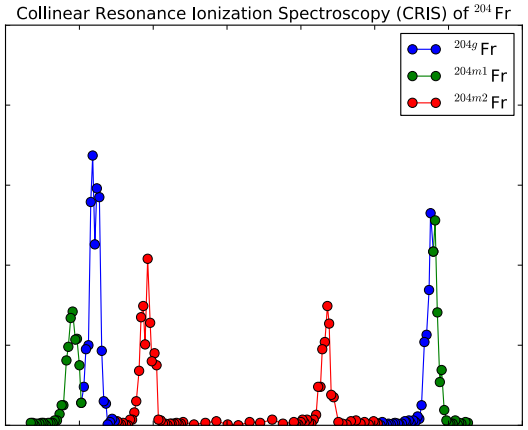
I.D. Moore et al., NIMB (2013), doi:10.1016/j.nimb.2013.06.036

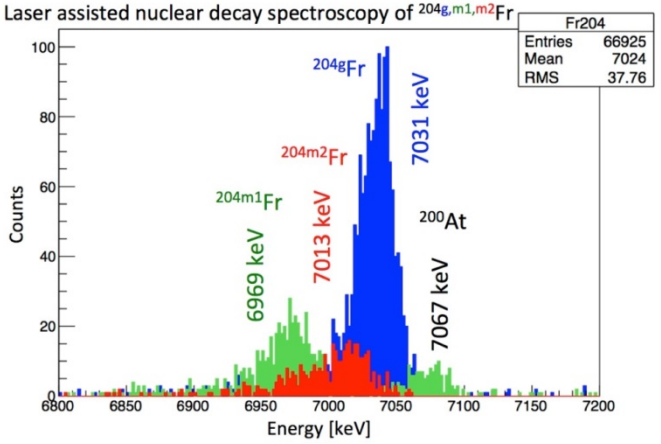
Collinear resonance ionization spectroscopy



^{202,203,204,205,207,211}Fr

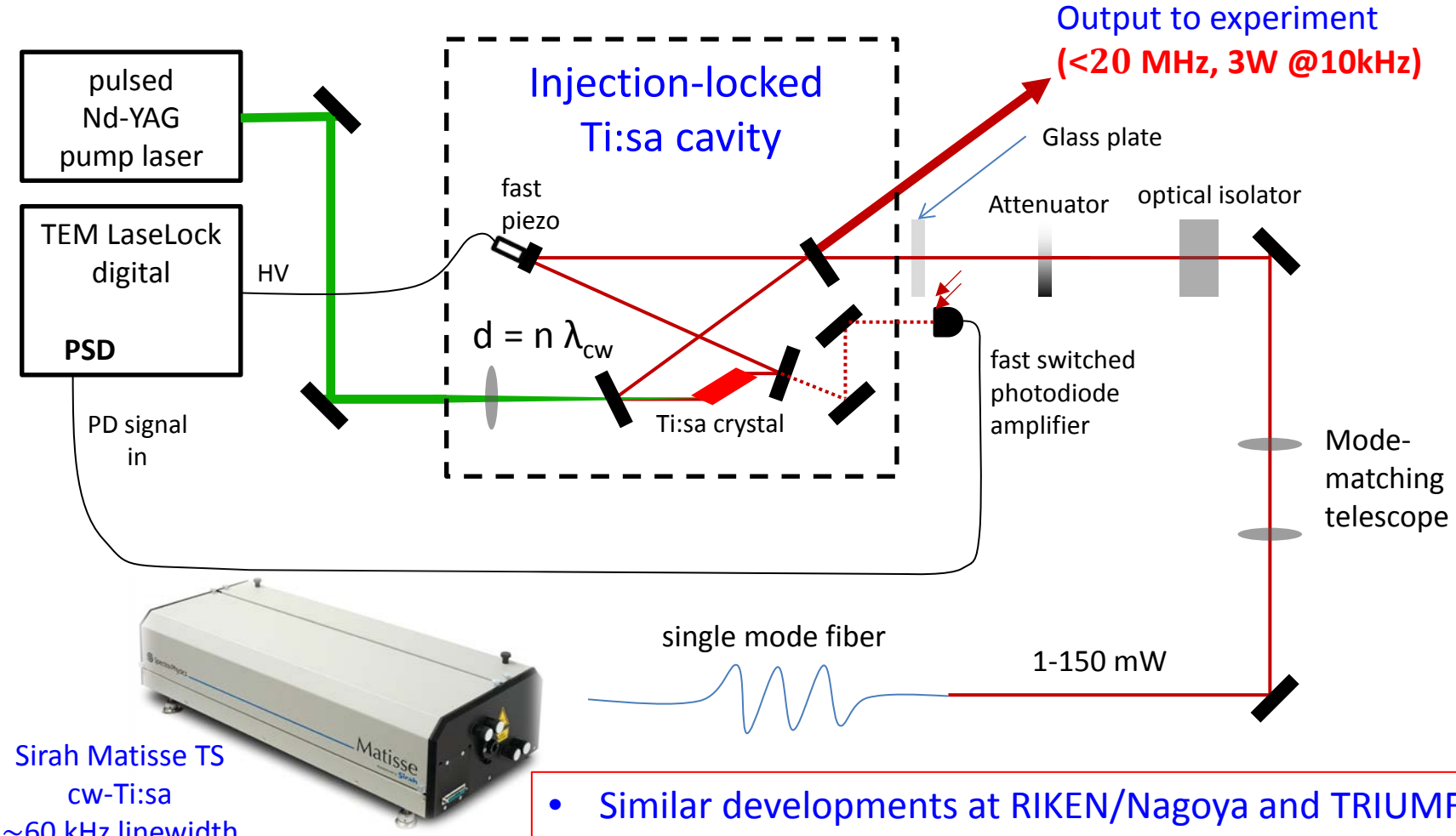
^{218,219,220,221,229,231}Fr





Talk by K. Flanagan (Manchester) @ 16:25

Development of narrow-band pulsed Ti:sapphire lasers

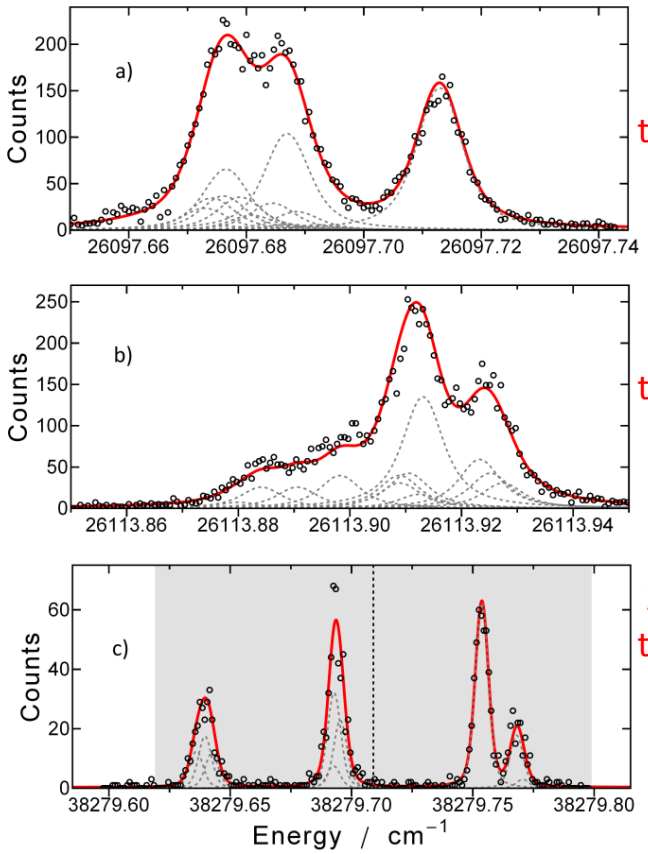


Sirah Matisse TS
cw-Ti:sa
~60 kHz linewidth

- Similar developments at RIKEN/Nagoya and TRIUMF
- RESIST Joint Research Activity for ENSAR 2

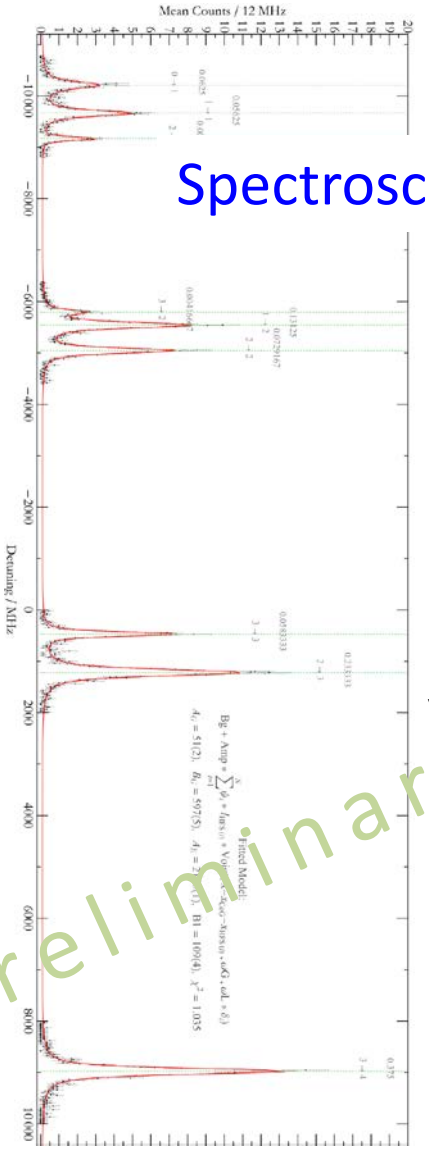
Applications: high resolution spectroscopy

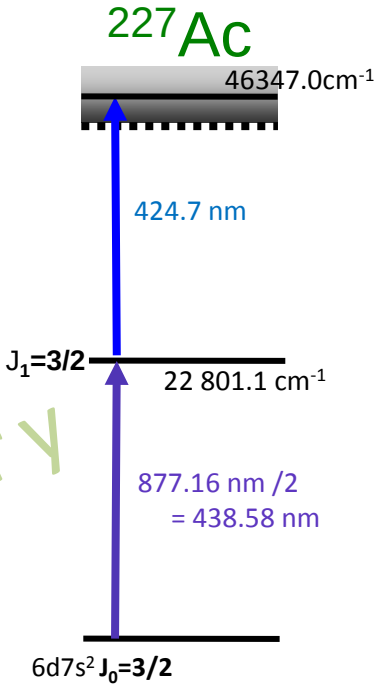
Spectroscopy of ^{229}Th



V. Sonnenschein et al., J. Phys. B 45 (2012) 165005

Spectroscopy of ^{227}Ac

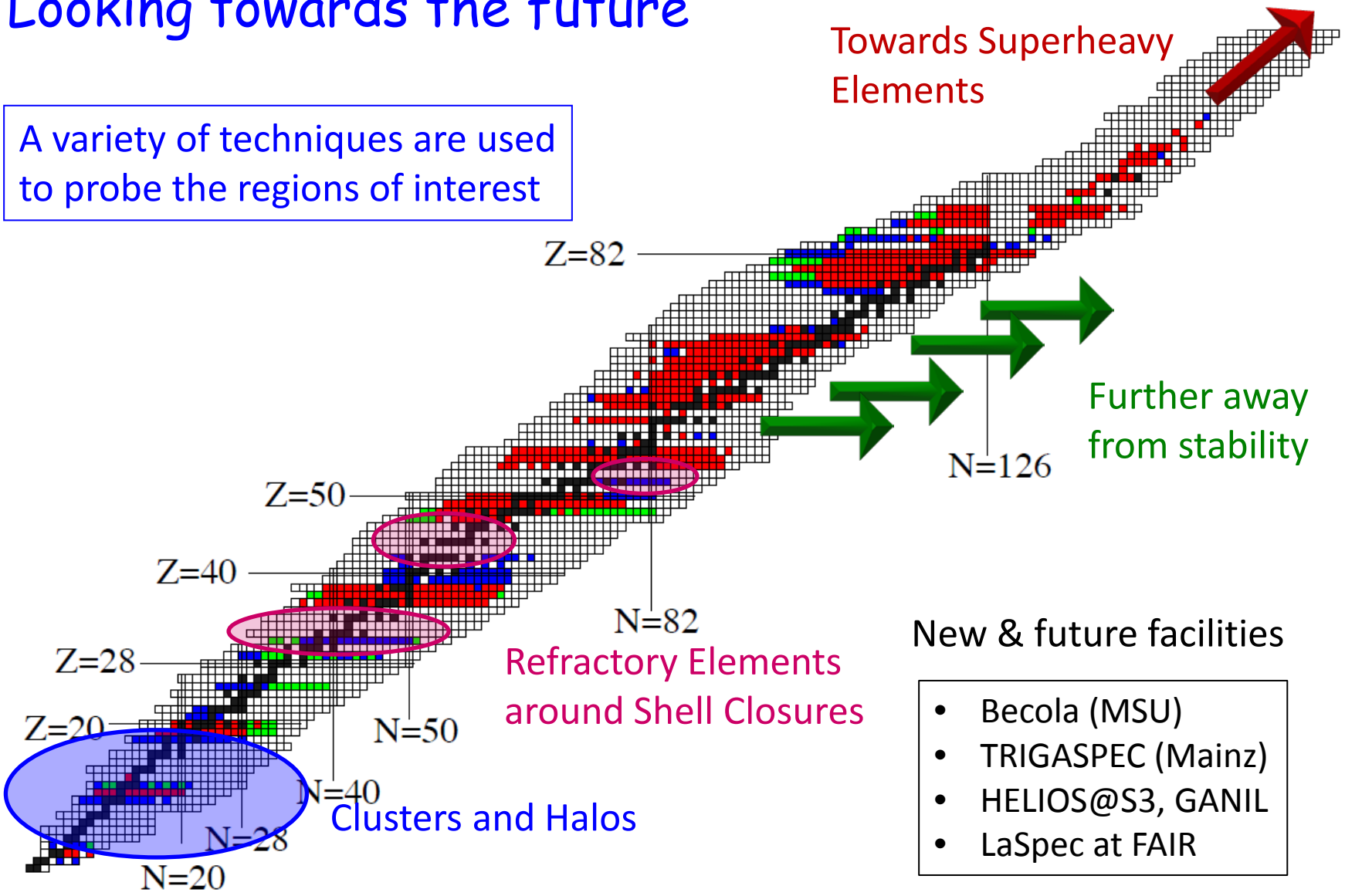




Preliminary

Looking towards the future

A variety of techniques are used to probe the regions of interest



New & future facilities

- Becola (MSU)
- TRIGASPEC (Mainz)
- HELIOS@S3, GANIL
- LaSpec at FAIR


Thank you