Opportunities with collinear laser spectroscopy at DESIR:

the LUMIERE facility

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GOALS of LUMIERE experiments:

(1) measure ground state properties of exotic isotopes: (see Campbell, Cheal, Flanagan, Charlwood, Furukawa, Cocolios)

- * nuclear spin
- * magnetic moment + sign → deduce parity of the g.s.
- * quadrupole moment + sign → deduce deformation / core polarization
- * charge radius

→ get information on single particle and collective behavior and their interplay

(2) measure β-asymmetry of a specific β-decay branch: (see T. Shimoda talk)

→ determine spins of levels in daughter isotope

Opportunities with collinear laser spectroscopy at DESIR:

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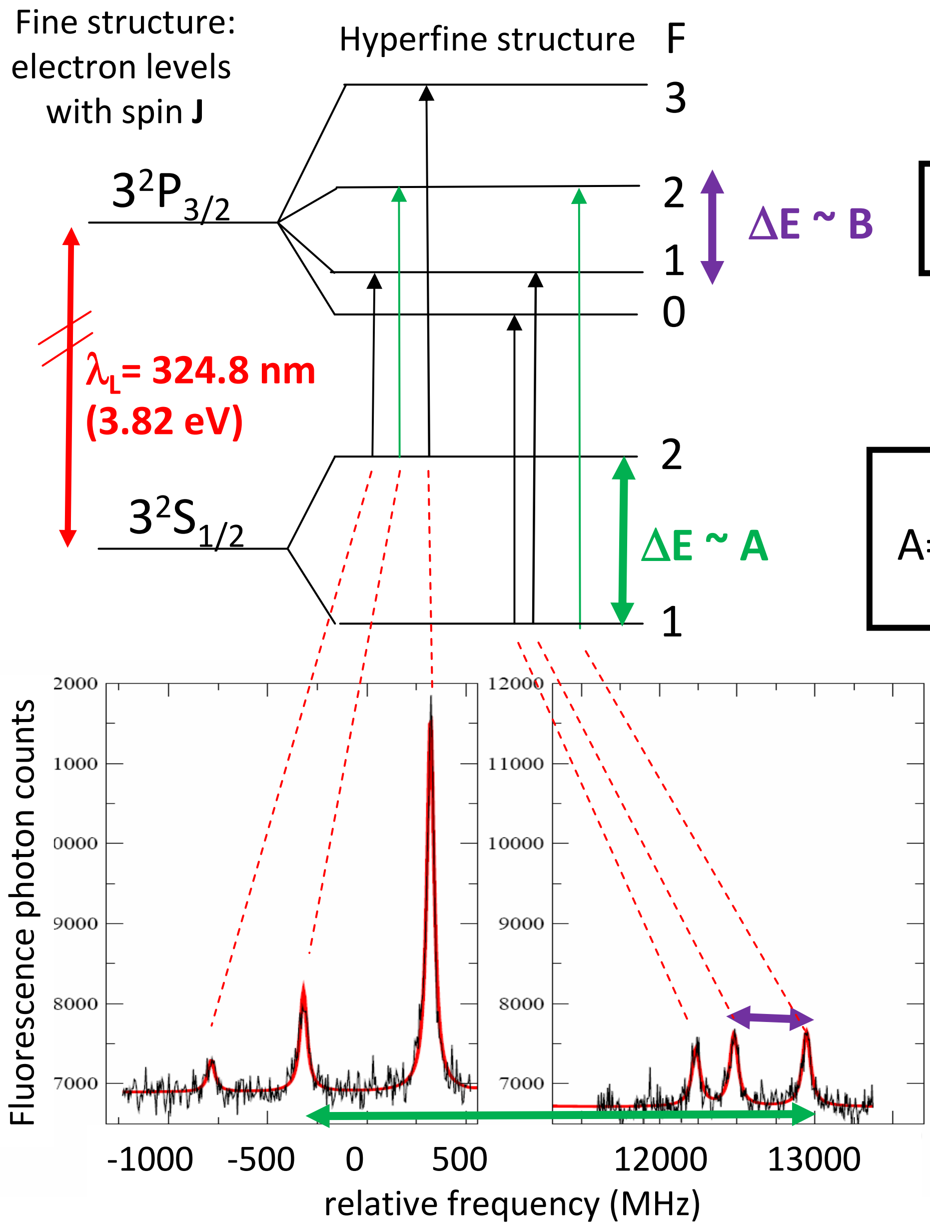
LUMIERE:
Laser Utilization for Measurement and Ionization of Exotic Radioactive Elements

Methods based on ion (or atom) – laser interactions:

- **Colinear laser spectroscopy**
- **β-NMR spectroscopy on laser-polarized beams**
- **β-decay spectroscopy on laser-polarized beams**

• Colinear laser spectroscopy:
measure the hyperfine structure (HFS) in a free atom/ion

Example: atomic levels and HFS of ^{67}Cu
(nuclear g.s. spin I=3/2)
$|I-J| < F < |I+J|$



$$\boxed{B = e\,Q\,V_{zz}}$$

measure Q

$$\boxed{A = \frac{\mu B_J}{IJ} = g\,B_J/J}$$

measure g

Relative distances: spin dependent

→ Need to resolve all HFS levels to be measure the spin

- ➔ High resolution needed
- ➔ ion velocity should be very well defined to reduce Doppler broadening of the resonances (< 0.01% error on beam velocity)
- ➔ use an **accelerated ion beam**

= **COLINEAR** LASER SPECTROSCOPY

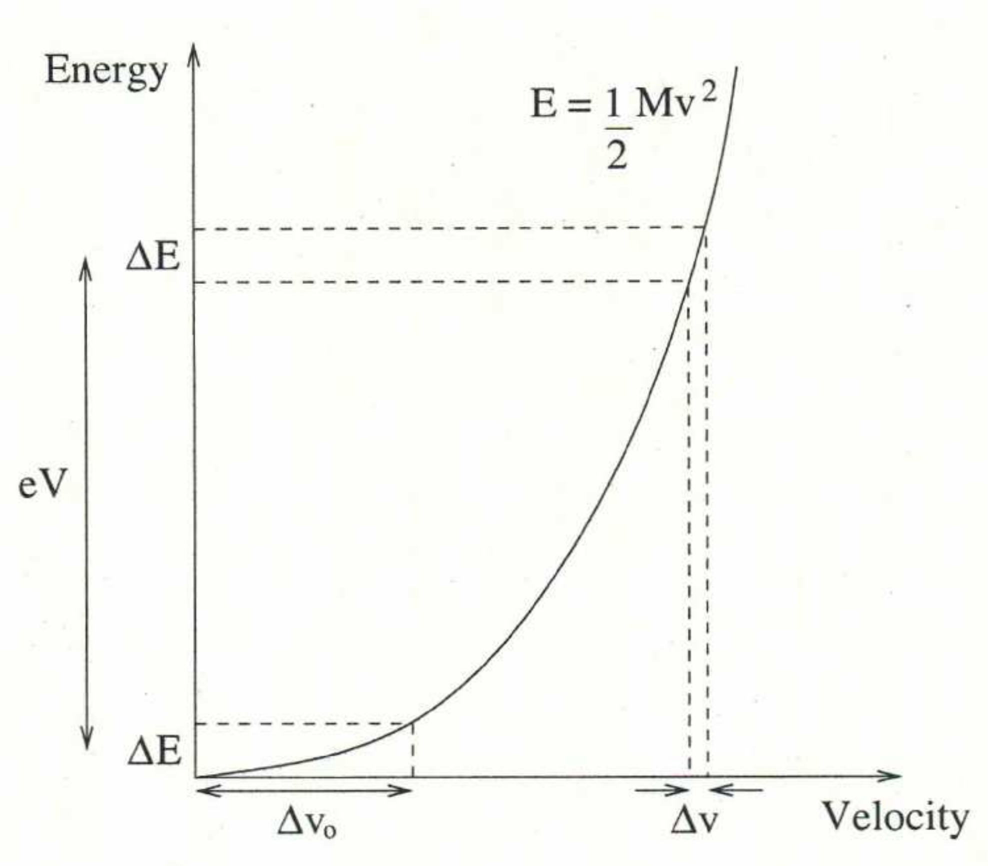
Colinear Laser Spectroscopy:
resonant interaction between **accelerated ion beam** and a **parallel laser beam**

ion beam from ISOL-target/gas cell :   energy uncertainty ~ few/several eV

→ **error on energy remains constant during acceleration**

→ **error on beam velocity decreases** with increasing beam velocity:

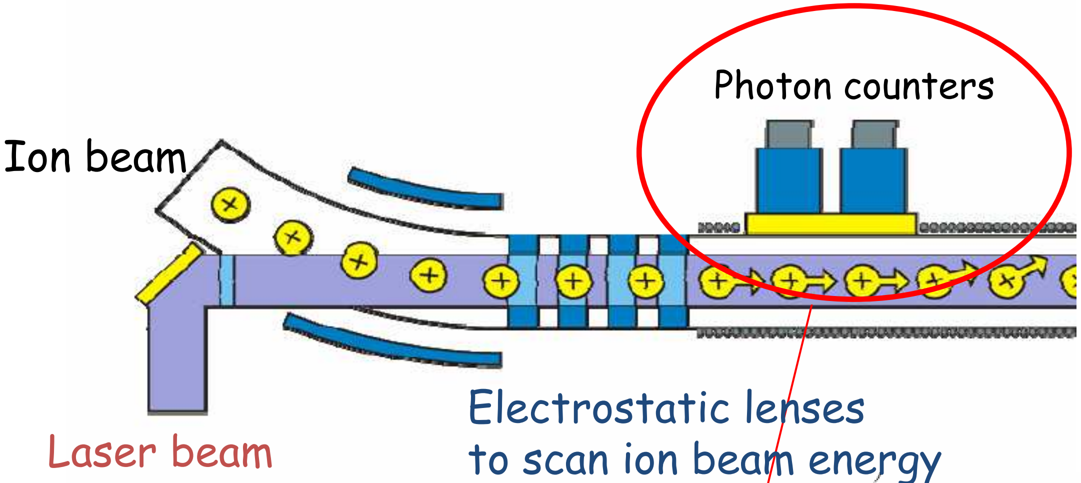
$$\Delta E = \text{const} = \delta(^1/_2 mv^2) \approx mv\delta v$$



→ Narrow Doppler line width
~ 50 MHz can be achieved
with beam of 60 keV

Collinear Laser Spectroscopy with **optical detection** of the fluorescent decay on continuous ion beam

➔ Need 10^6 ions/s



→ Large photon background
from laser beam !

Electrostatic lenses
to scan ion beam energy
from +10 keV to -10 keV

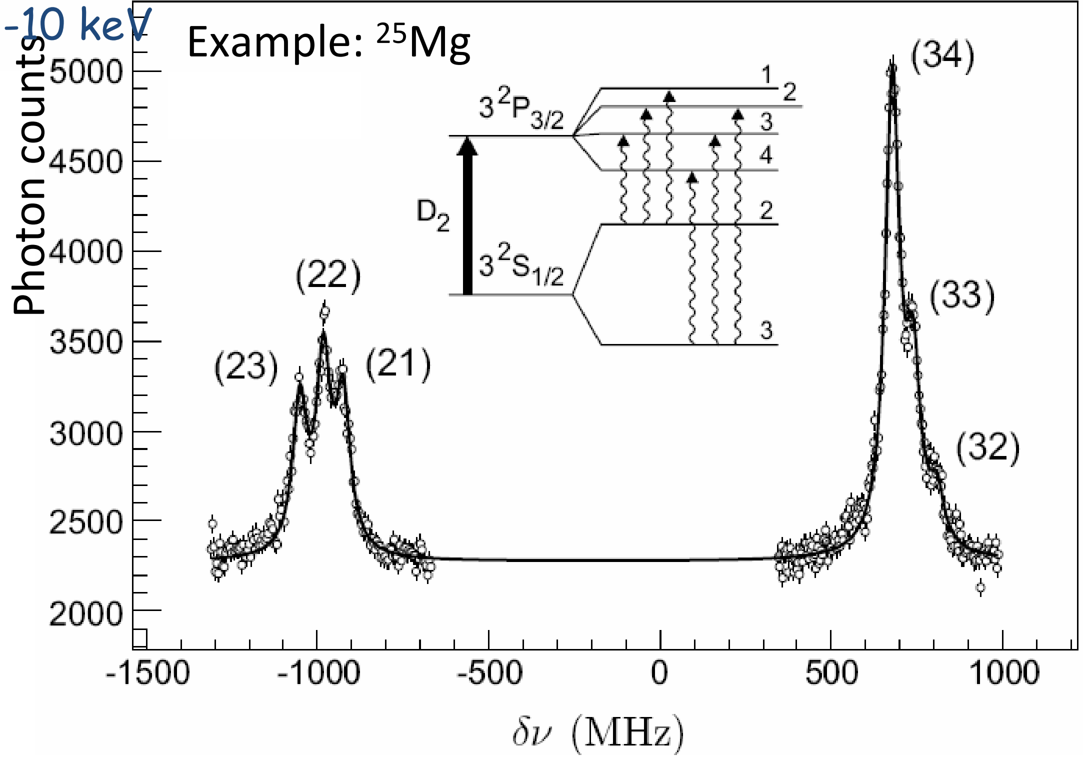
Change velocity of ion beam
= Doppler tuning of ion beam

to scan hyperfine structure levels:

$$\nu_{scan} = \nu_{laser}\gamma(1+\beta)$$
$$\beta \sim U^{1/2}$$

measure fluorescent photon decay

Example: ^{25}Mg

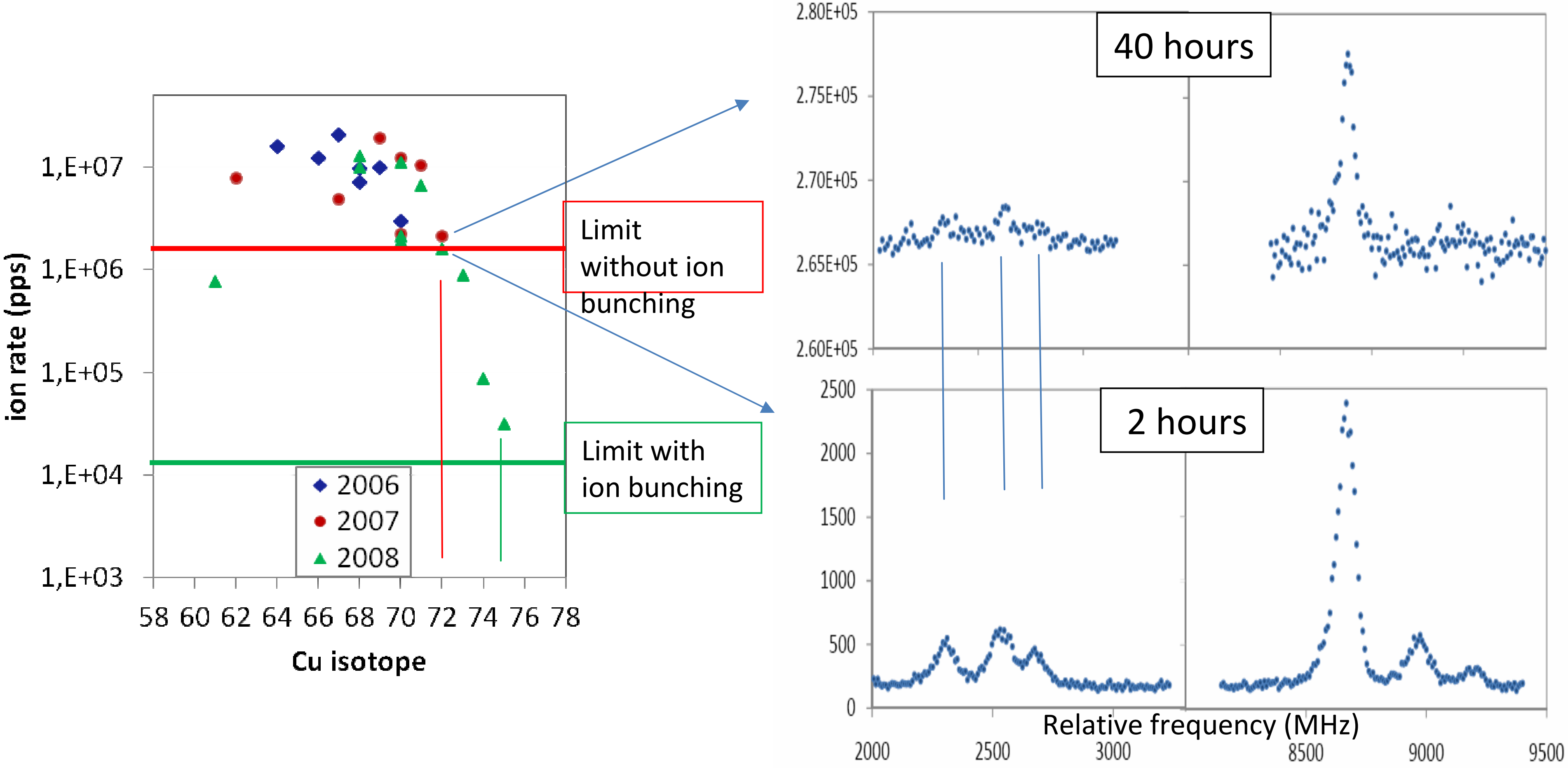


Collinear Laser Spectroscopy
with **optical detection** of the fluorescent decay on bunched beam

IMPROVE DETECTION SENSITIVITY by 2 orders of magnitude
by using a BUNCHED ion beam
➔reduces photon background by factor 4000 = T/ΔT
ΔT = 25 μs pulse length
T = 100 ms repetition rate

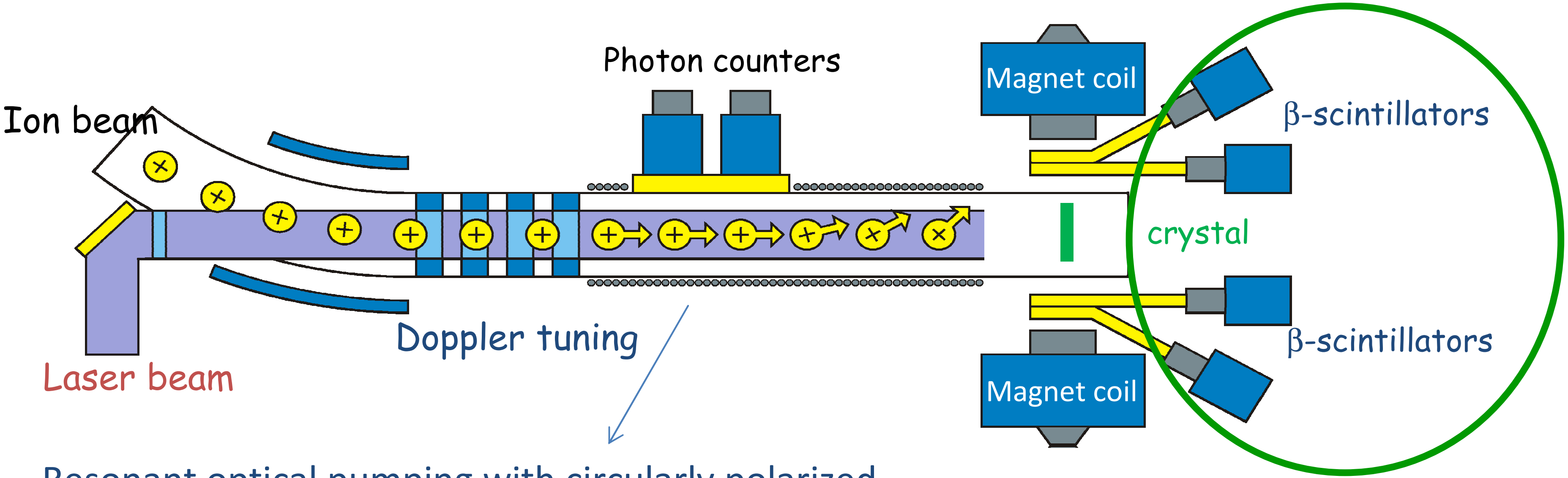
➔ Need 10^4 ions/s

Example: ^{72}Cu



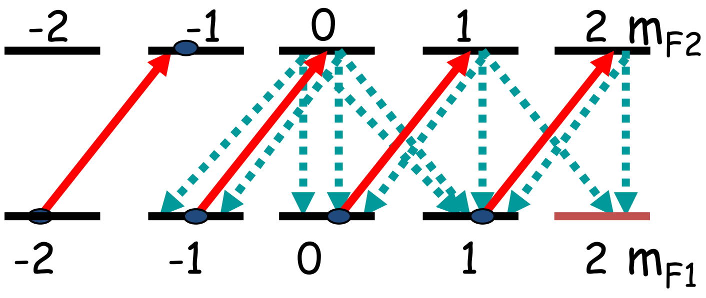
Collinear Laser Spectroscopy with **β-asymmetry detection** on polarized nuclei

→ Need 10^3 ions/s

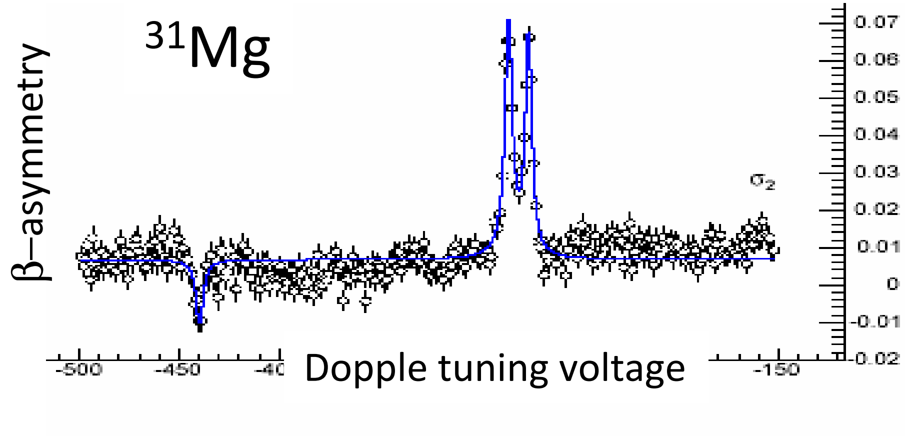


Resonant optical pumping with circularly polarized laser light to polarize the atoms and nuclei

Detection of HFS via asymmetric nuclear β-decay after implantation in crystal



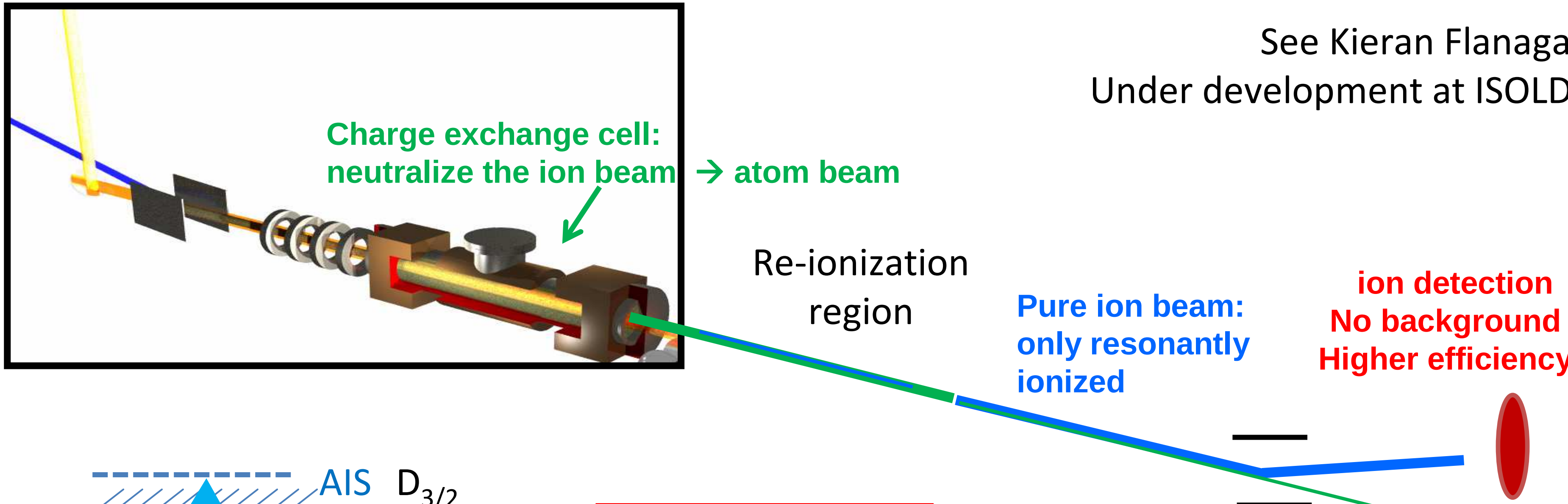
Total atomic spin F gets polarized through pumping
→ Nuclear spins are polarized !



Collinear Laser Spectroscopy with **ion detection or β/α-decay detection** after resonant re-ionization (CRIS)

→Need 1-100 ion/s

See Kieran Flanagan
Under development at ISOLDE



Charge exchange cell: neutralize the ion beam → atom beam

Re-ionization region

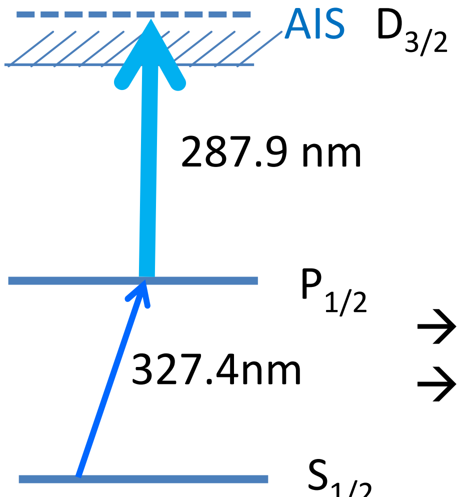
Pure ion beam: only resonantly ionized

ion detection
No background !
Higher efficiency !

Deflection of ions towards ion detector

Neutral background

CONDITION:
Ulta High Vacuum



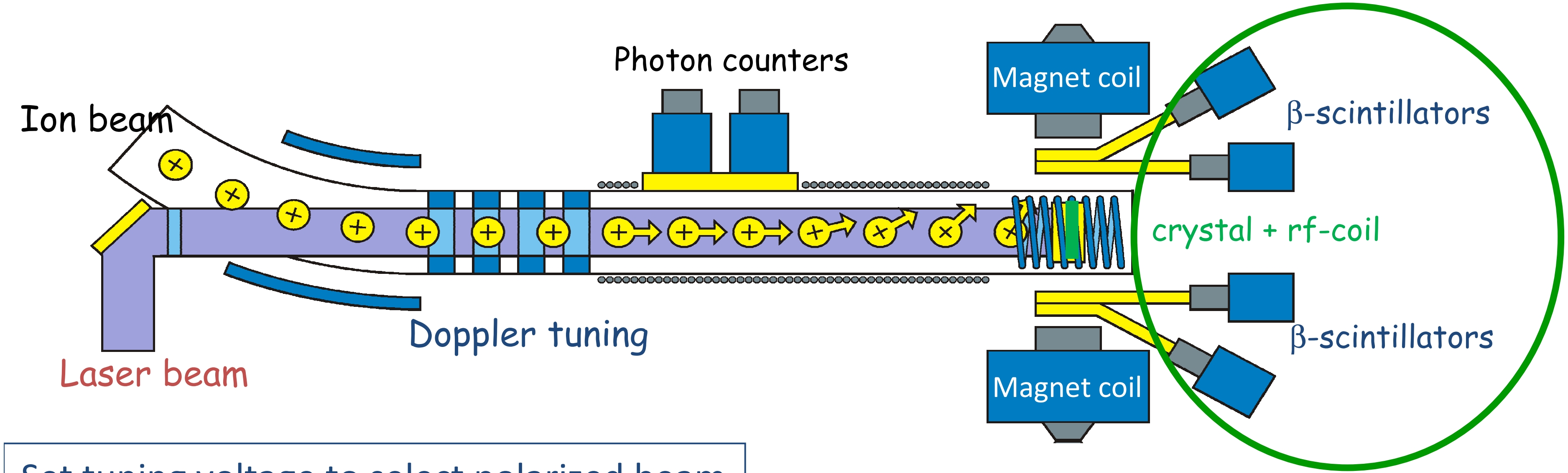
Cu atomic levels

→ resonant re-ionisation of atom beam:

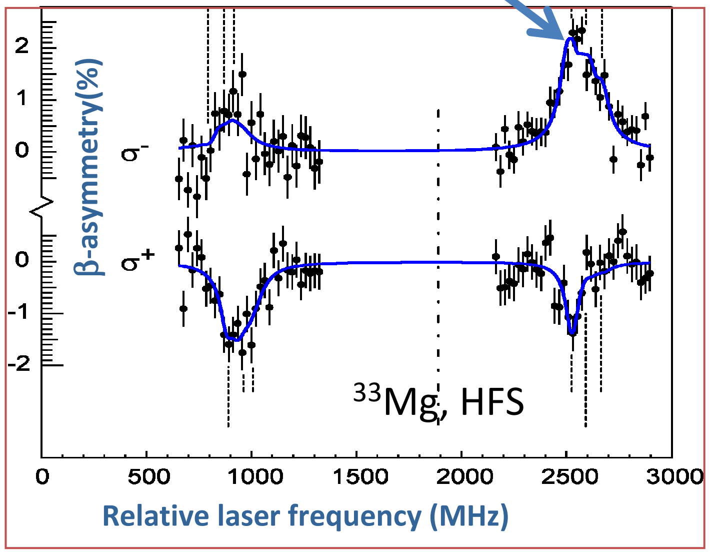
→ apply two lasers at same time:
- step one: resonant excitation (narrow band laser)
  (to scan hyperfine structure)
- step two: ionization (broad band)

- **β-NMR spectroscopy on laser-polarized beams:**
  → High precision measurements of g-factor, Q-moment

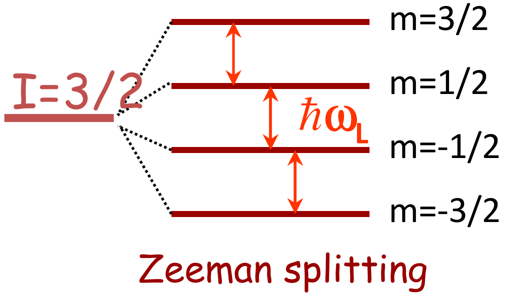
→ Need 10^3 ions/s

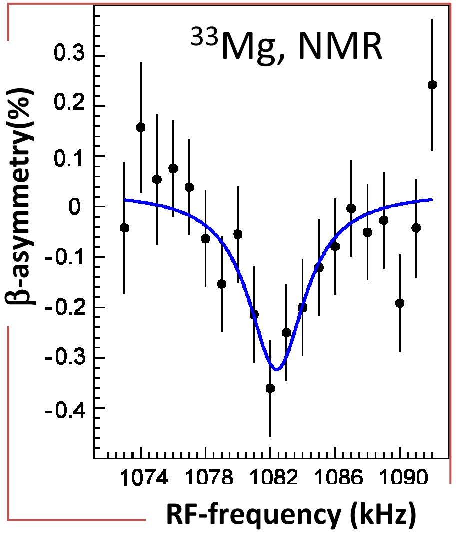


Set tuning voltage to select polarized beam



Scan the rf-frequency ω_{rf} → g-factor

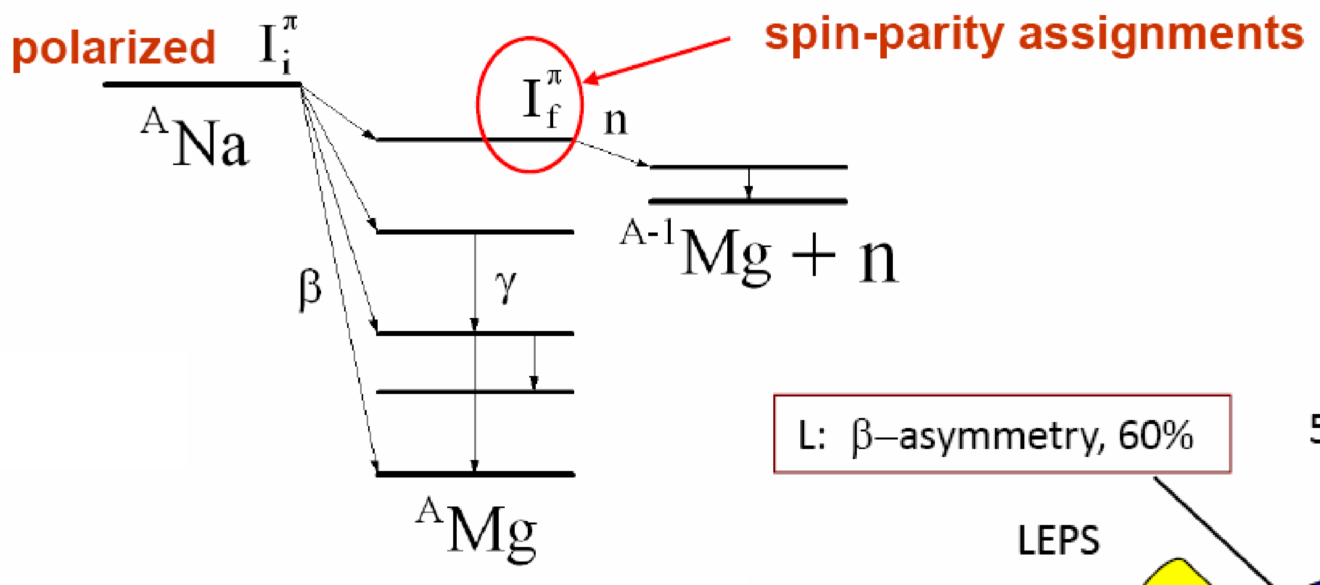




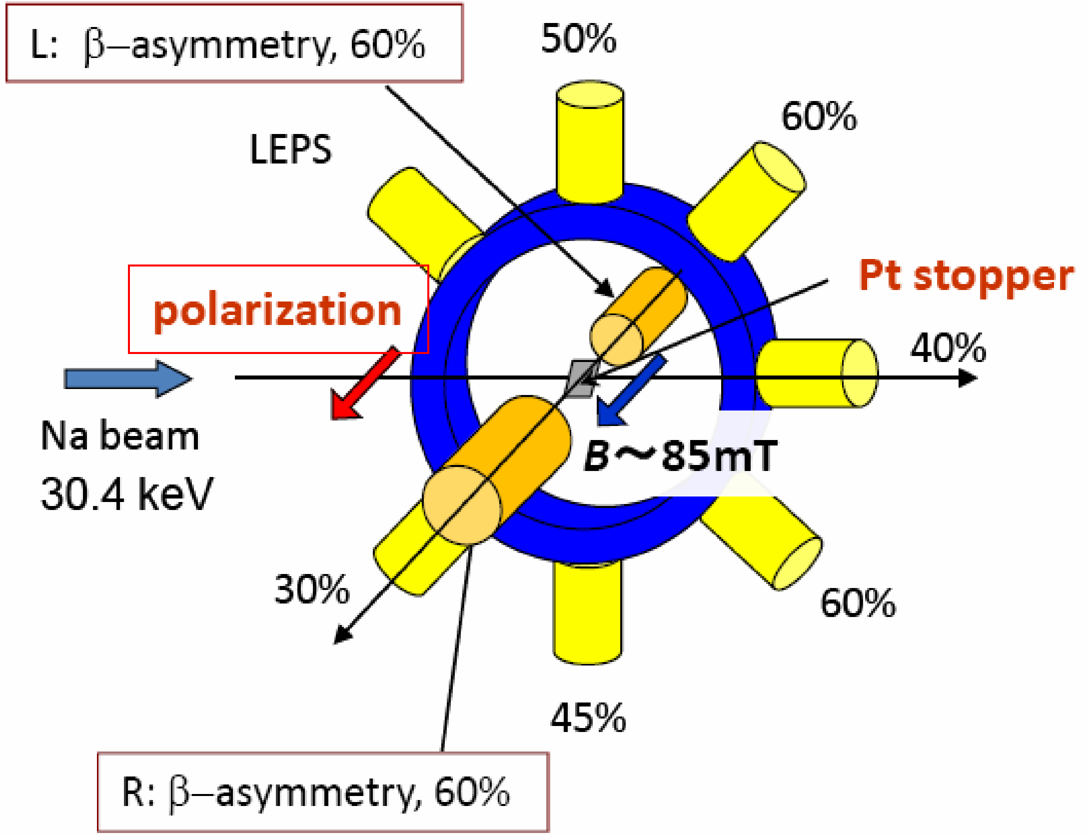
- **β-decay on laser-polarized beams:**
  → measure β-decay asymmetry parameter in β–γ and β–γ–γ coincidence

➔ Need 100 ions/s

See T. Shimoda
Developed at Triumf

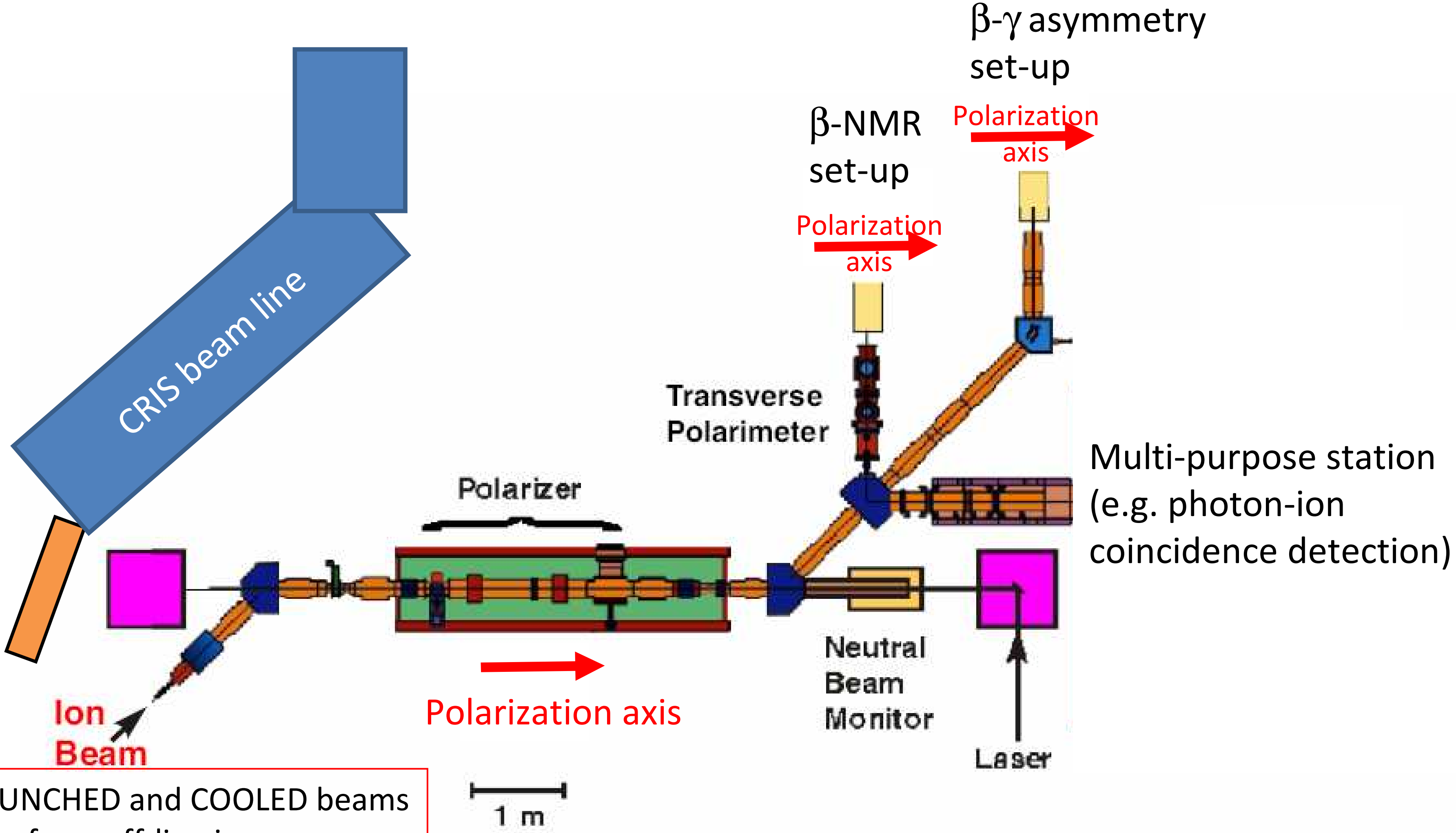


Asymmetry parameter in allowed β-decay depends on the initial and final spin.



Possible layout for collinear spectroscopy at DESIR:

- ➔ a normal-vacuum line with 2 (or 3) end stations for optical detection, polarized beam experiments, …
- ➔ a UHV beam with differential pumping for CRIS



BUNCHED and COOLED beams
from off-line ion source
S2 or S3 beams

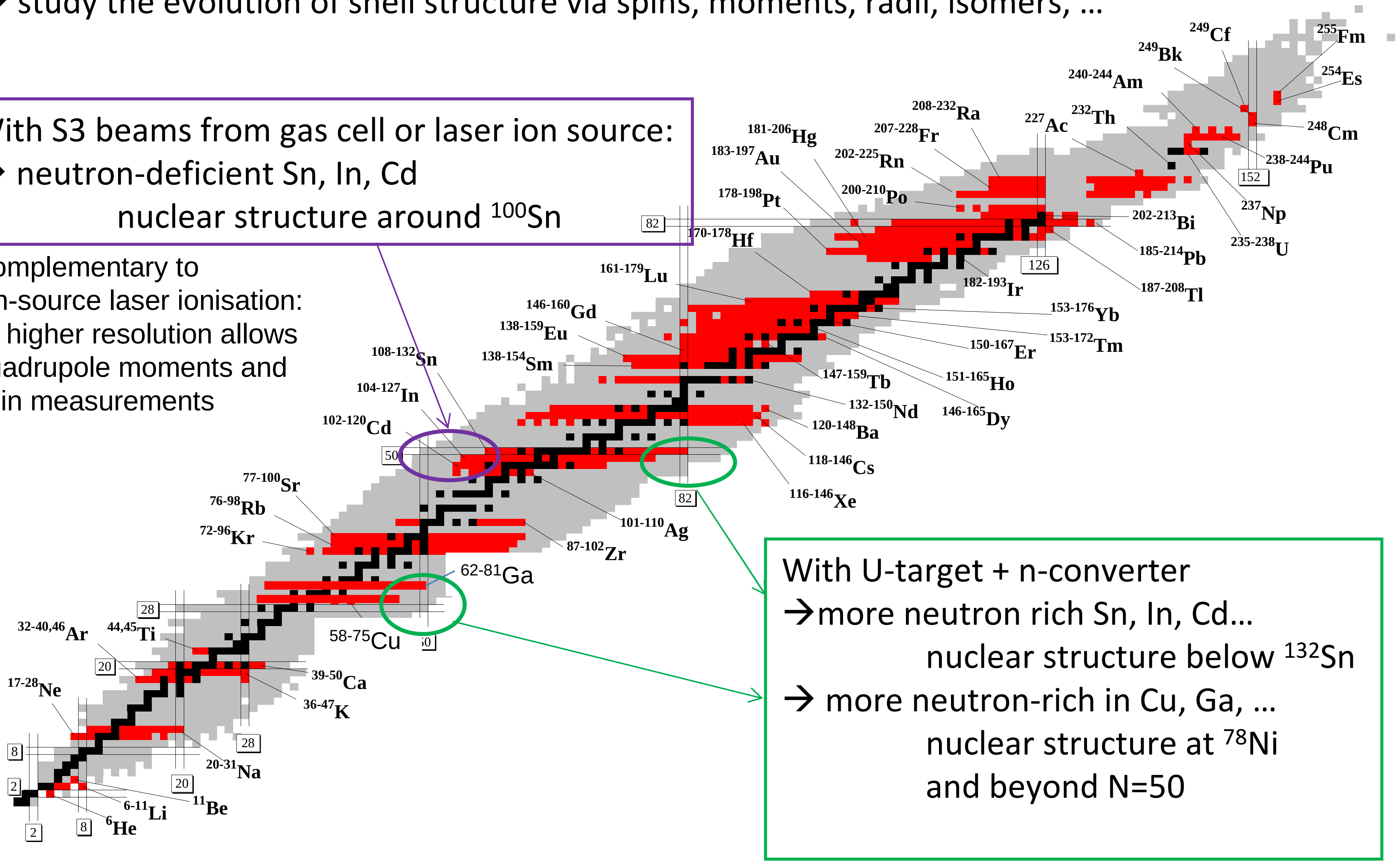
based on collinear laser beam line at TRIUMF
C.D.P. Levy et al. / Nuclear Physics A 746 (2004) 206c–209c

Day-1 experiments: shell structure far from stability (^{78}Ni, ^{132}Sn, ^{100}Sn)

Extend existing laser spectroscopy studies beyond doubly-magic nuclei far from stability
➔ study the evolution of shell structure via spins, moments, radii, isomers, …

With S3 beams from gas cell or laser ion source:
→ neutron-deficient Sn, In, Cd
nuclear structure around ^{100}Sn

Complementary to
ion-source laser ionisation:
→ higher resolution allows
quadrupole moments and
spin measurements



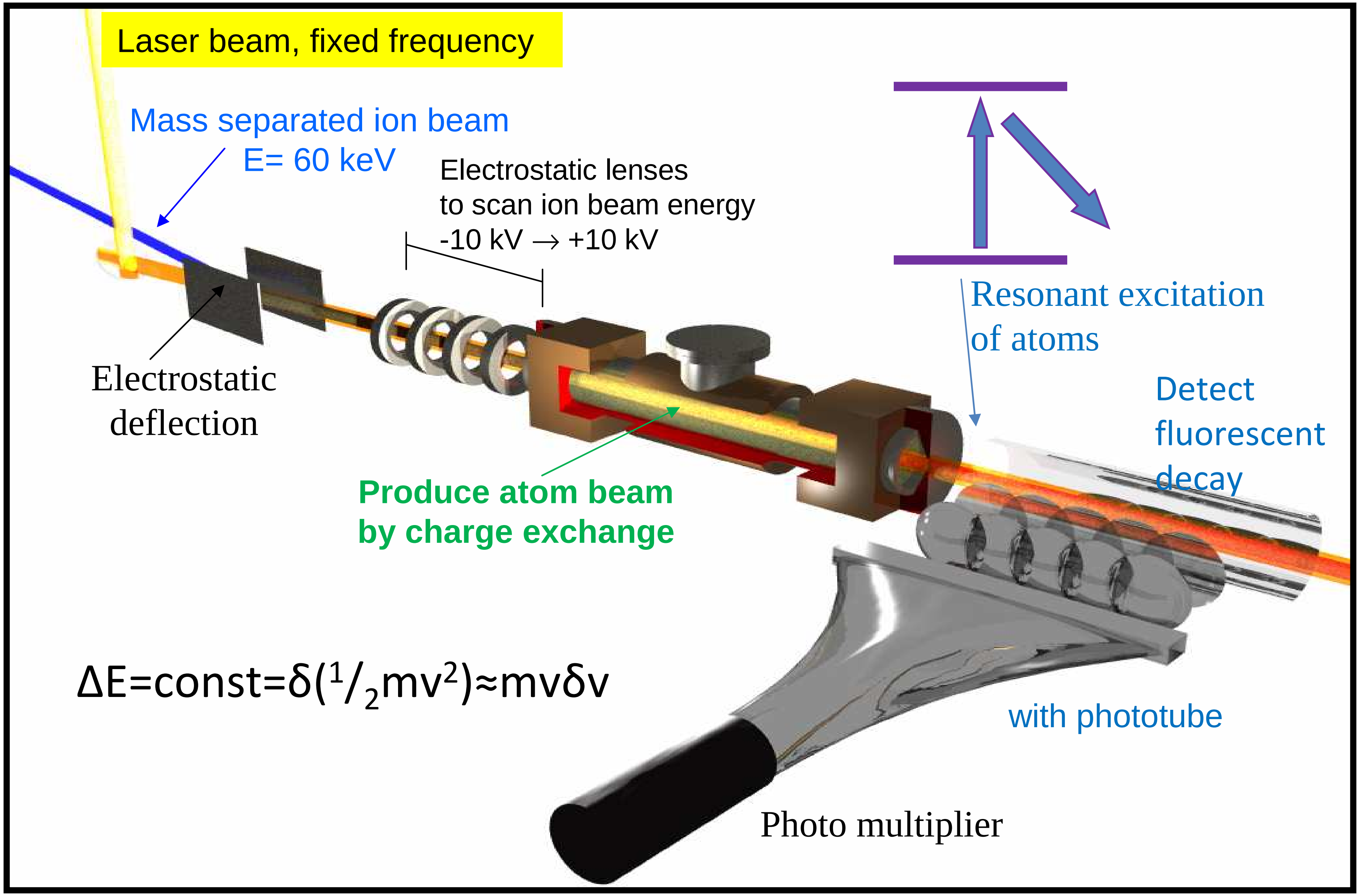
With U-target + n-converter
→more neutron rich Sn, In, Cd…
nuclear structure below ^{132}Sn
→ more neutron-rich in Cu, Ga, …
nuclear structure at ^{78}Ni
and beyond N=50

Currently following groups showed interest:

P. Campbell, K. Flanagan, J. Billowes, University of Manchester
G.N., M. Bissell, K.U. Leuven
F. Leblanc, IPN Orsay
J.C. Thomas, GANIL
D. Yordanov, ISOLDE-CERN
G. Georgiev, CSNSM Orsay
D.L. Balabanski, INRE, Sophia

Please contact me if you are interested to help building (or financing) this set-up

Collinear Laser Spectroscopy
with **optical detection** of the fluorescent decay



Laser beam, fixed frequency

Mass separated ion beam
E= 60 keV

Electrostatic lenses
to scan ion beam energy
-10 kV → +10 kV

Electrostatic
deflection

Resonant excitation
of atoms

Detect
fluorescent
decay

Produce atom beam
by charge exchange

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

with phototube

Photo multiplier