Selective laser ionization of odd-mass number isotopes (odd-mass selection) for the partitioning of palladium and zirconium

RIKEN Center for Advanced Photonics

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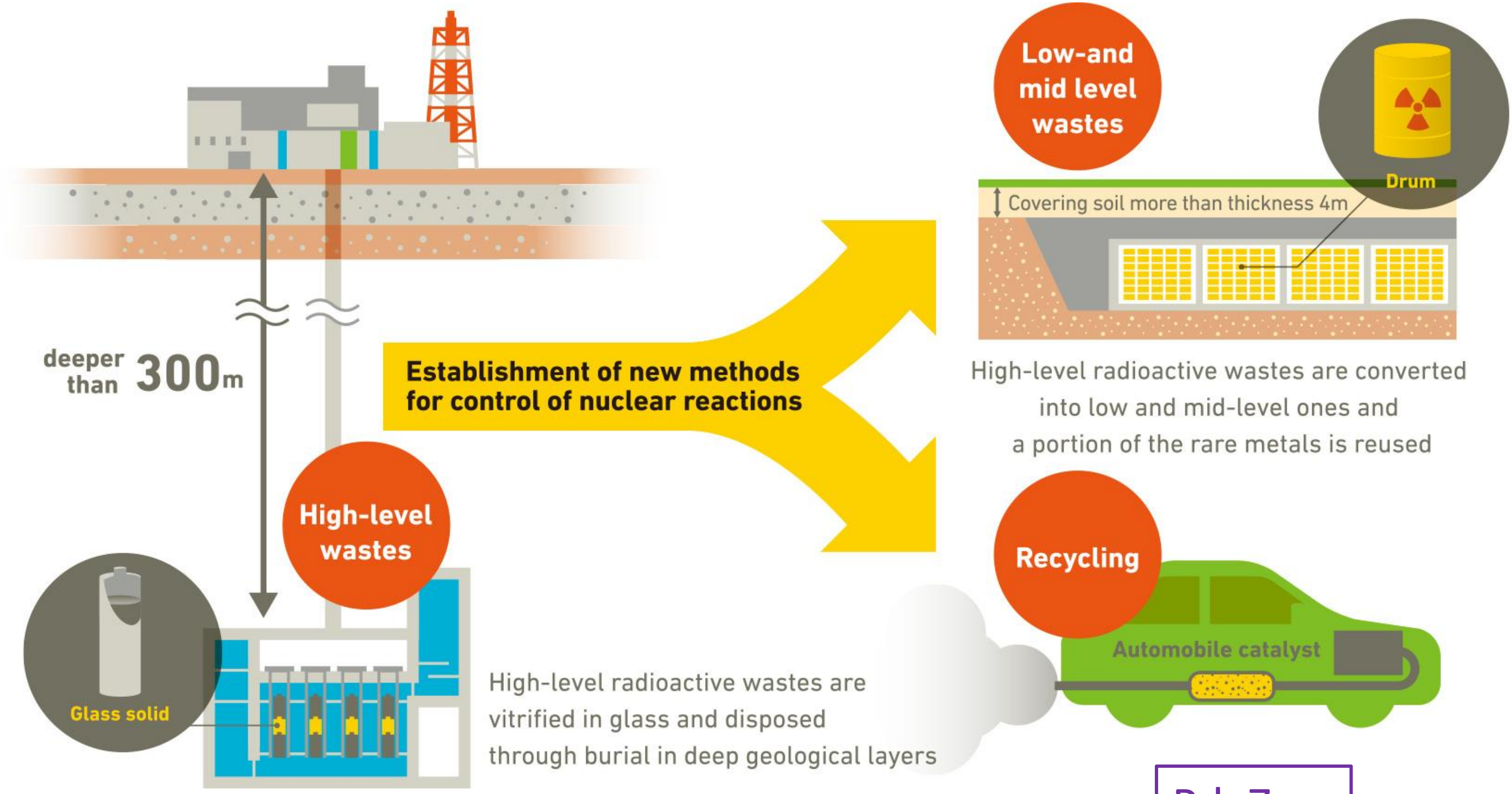
Reduction and resource recycling of high-level radioactive wastes through nuclear transmutation

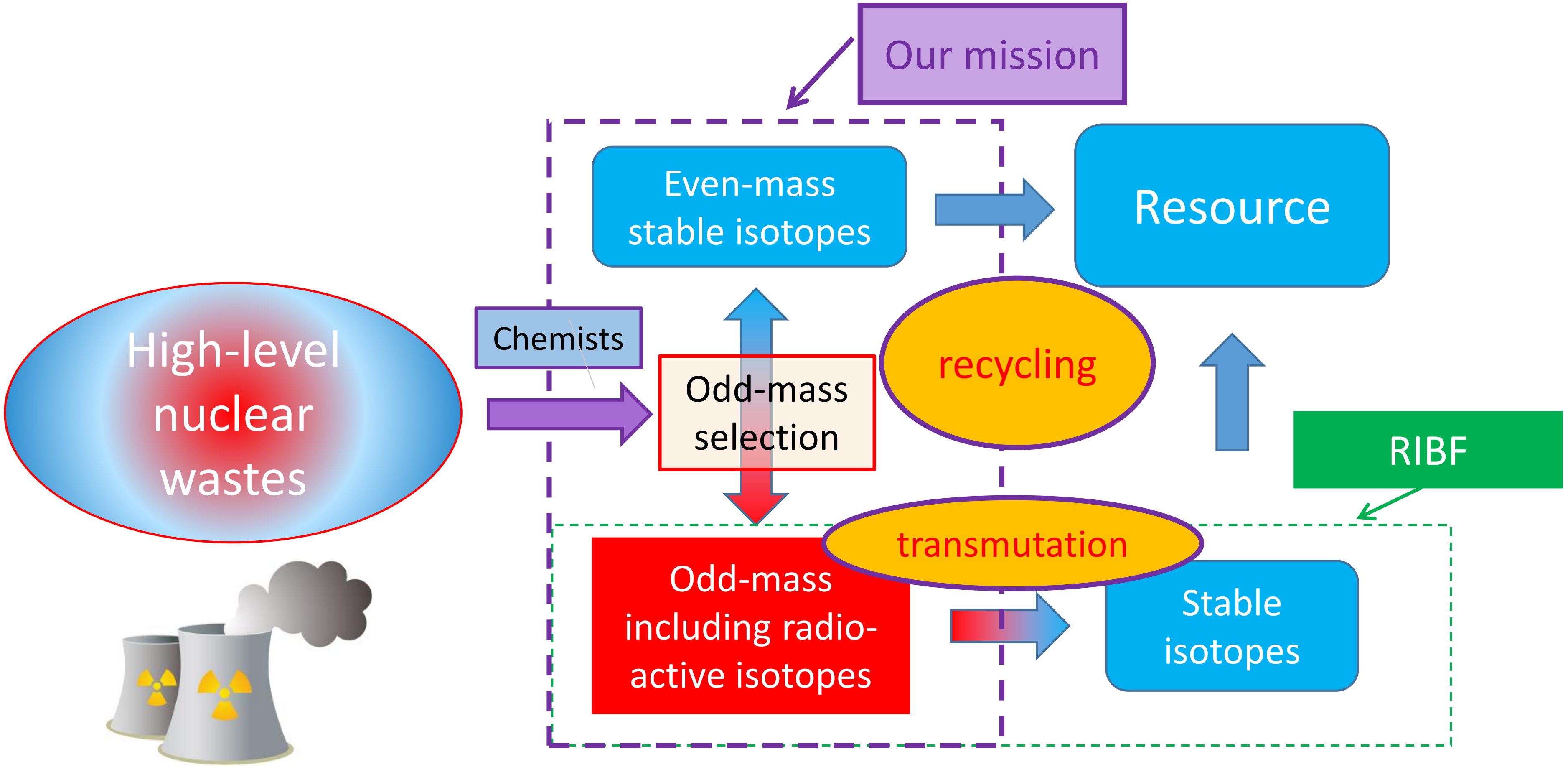


Pd, Zr, ..

http://www.jst.go.jp/impact/en/program/08.html

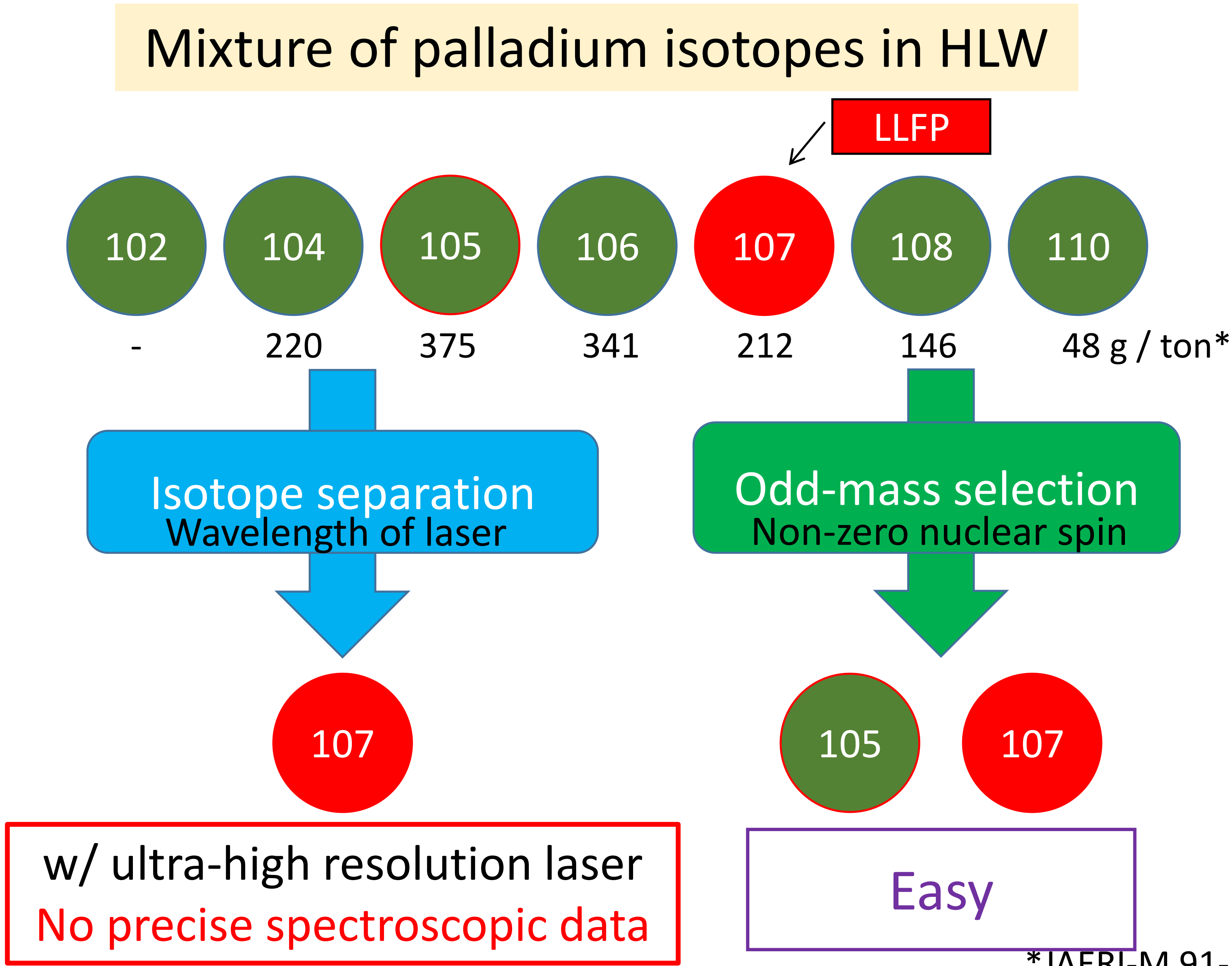
Our mission in ImPACT program

Develop efficient extraction technique of LLFP isotopes ($^{93}Zr^{*}$, $^{107}Pd^{*}$) aiming at both the nuclear transmutation and recycling.



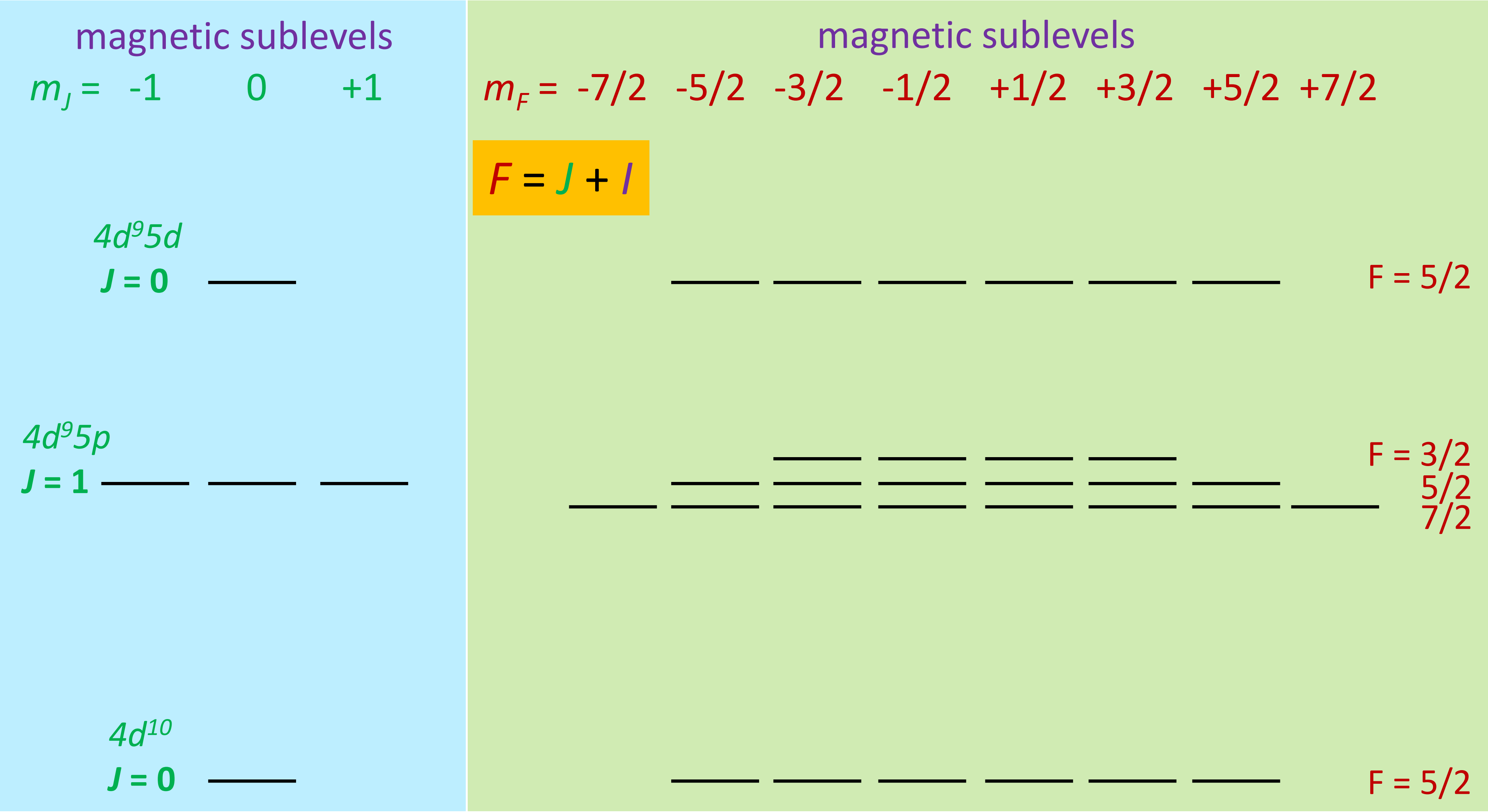
Isotope separation vs. odd-mass selection

In the case of palladium (Pd)



*JAERI-M 91-147

Difference in the electronic state structure of palladium between even-mass (I=0) and odd-mass (I≠0) isotopes



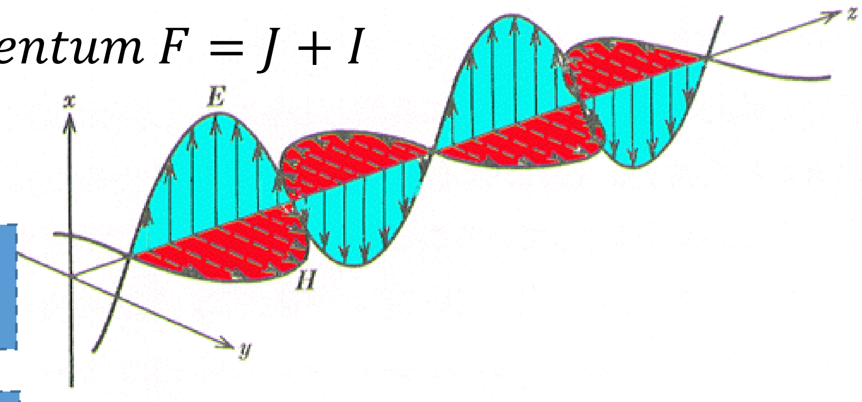
Even-mass number isotopes (***I* = 0**) **Odd**-mass number isotopes $^{105,\,107}$Pd (***I* = 5/2**)

Selection rules for electronic transition

absorption of photons

$\Delta J = 0, \pm 1$

Total angular *momentum* $F = J + I$



電磁波の電界ベクトル（E）と磁界ベクトル（H）

☆Linear polarization

Rule

$\Delta m_J = 0$ — Nuclear spin $I = 0$

$\Delta m_F = 0$ — Nuclear spin $I \neq 0$

Easy to maintain

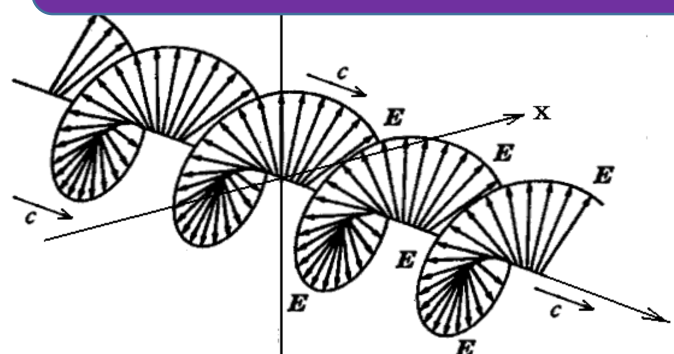
☆Circular polarization

Rule

$\Delta m_J = \pm 1$ — Nuclear spin $I = 0$

$\Delta m_F = \pm 1$ — Nuclear spin $I \neq 0$

+1 for LHC and -1 for RHC.



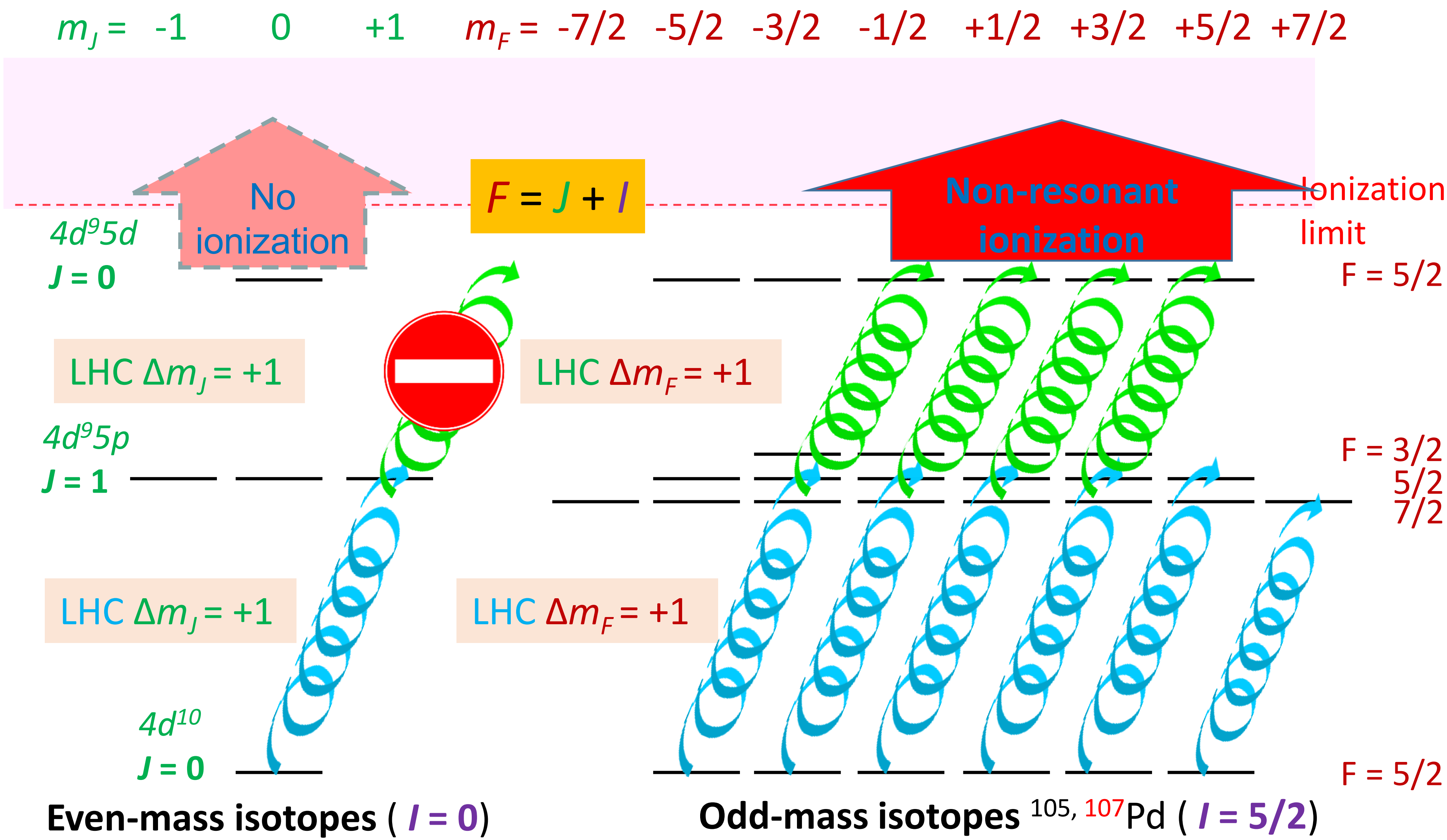
Not easy to maintain

We need to choose proper combination of electronic states of particular *J* to realize selective excitation and ionization.

Original scheme proposed by Hao-Lin Chen (1980)

2-LHC lasers + ionization laser: 3 lasers

Only odd-mass isotopes absorb the 2nd laser photon



Drawbacks of the original scheme

For selective excitation

- Using two circularly polarized lasers

  Not easy to maintain polarization

  Not suitable for multi-pass optics

For ionization

- Non-resonant ionization Low efficiency

As for the Cost

- Totally 3 lasers for selective ionization

  High initial and maintenance costs

We have developed 2-laser scheme.

For selective excitation

- Using two //-linearly polarized lasers

  Easy to maintain polarization

  Suitable for multi-pass optics

For ionization

- Resonant ionization = High efficiency

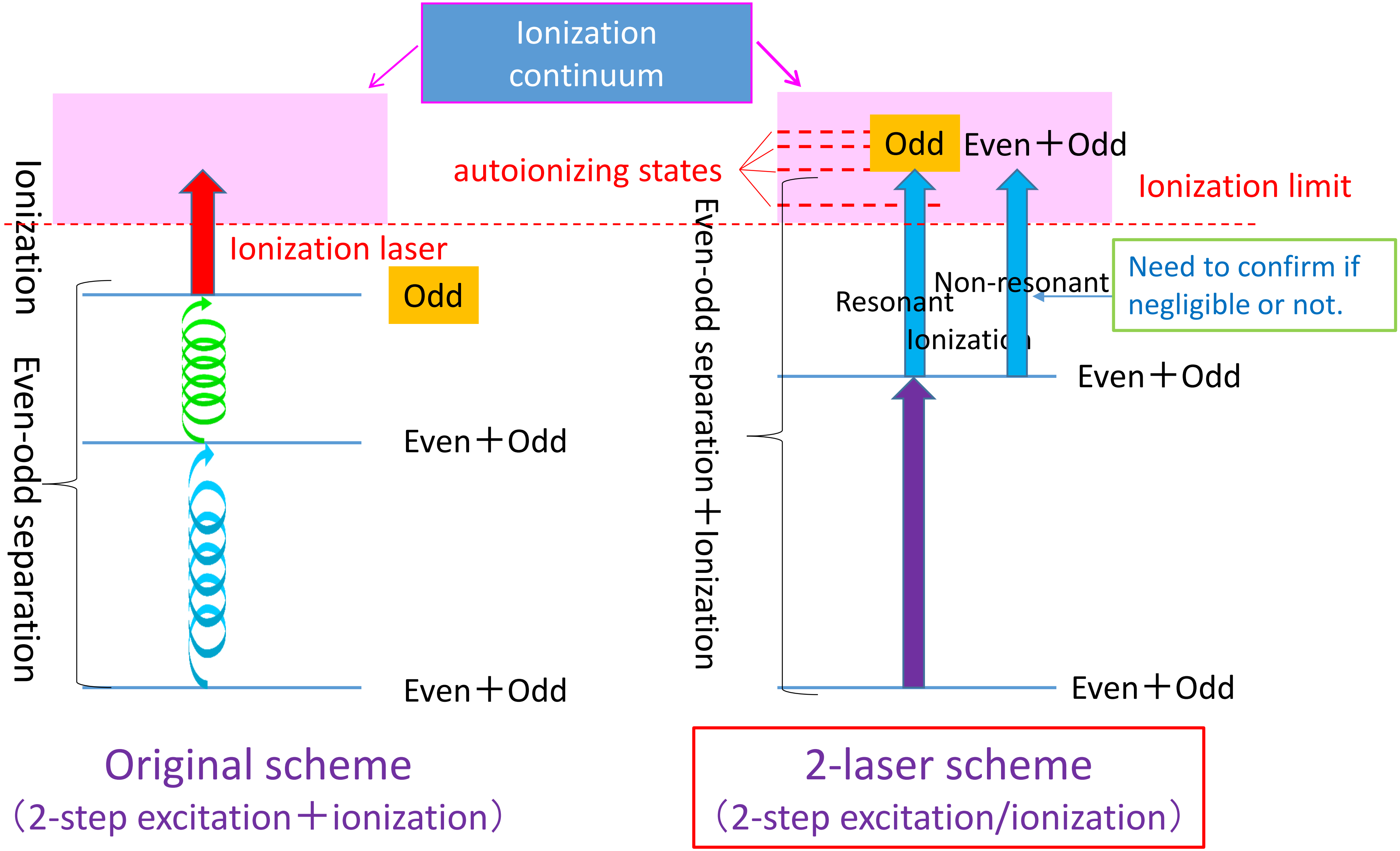
As for the Cost

- Reduced number of lasers to 2

  Less initial and maintenance costs

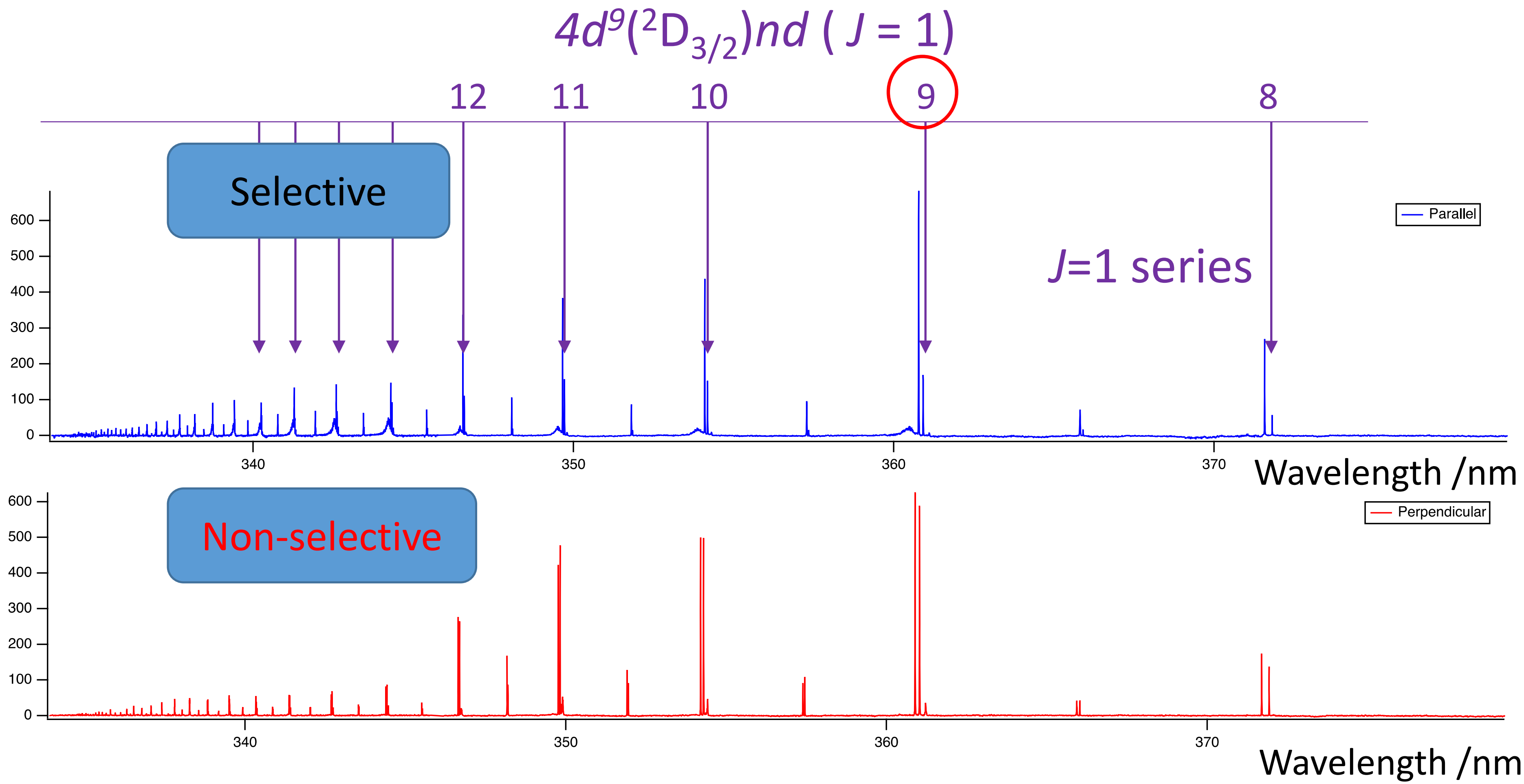
2−laser scheme

Appl. Phys. B**123**, 240 (2017).



Spectroscopic investigation of autoionizing states

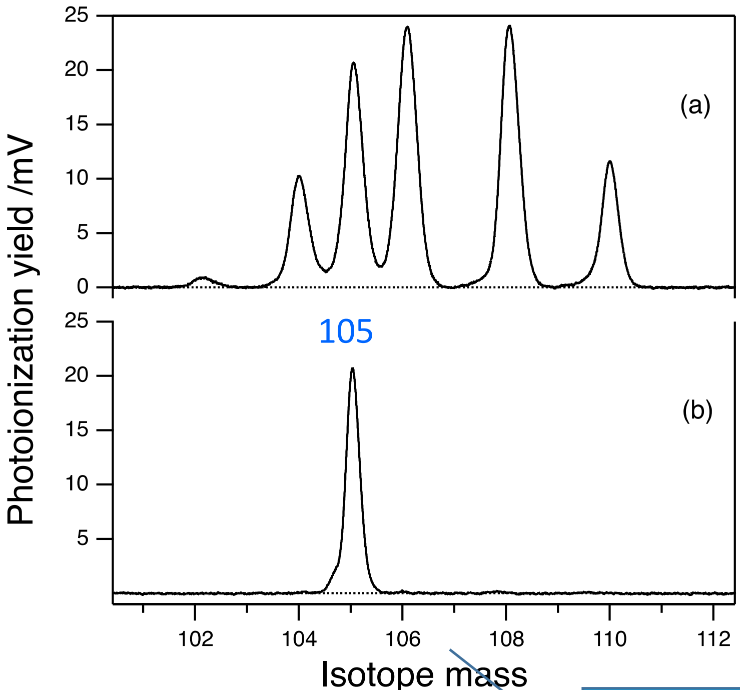
Selective (//) and non-selective (⊥) excitations

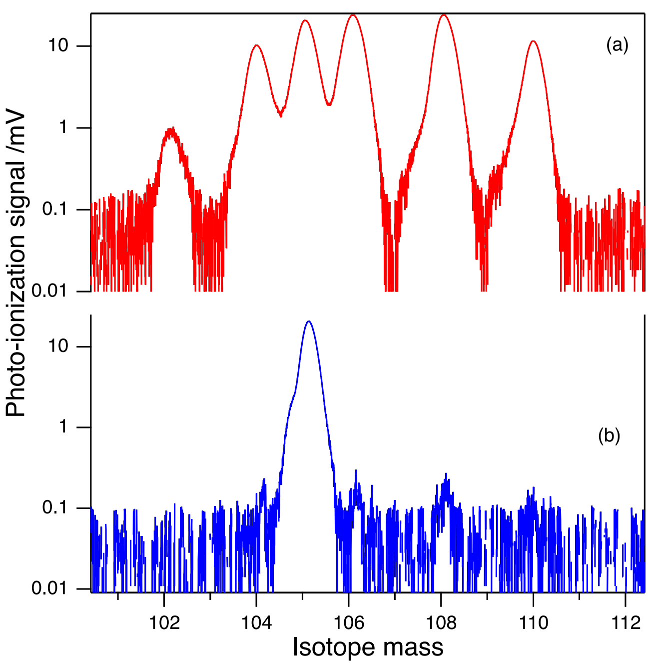


Selectivity check

Appl. Phys. B**123**, 240 (2017).

Non-selective





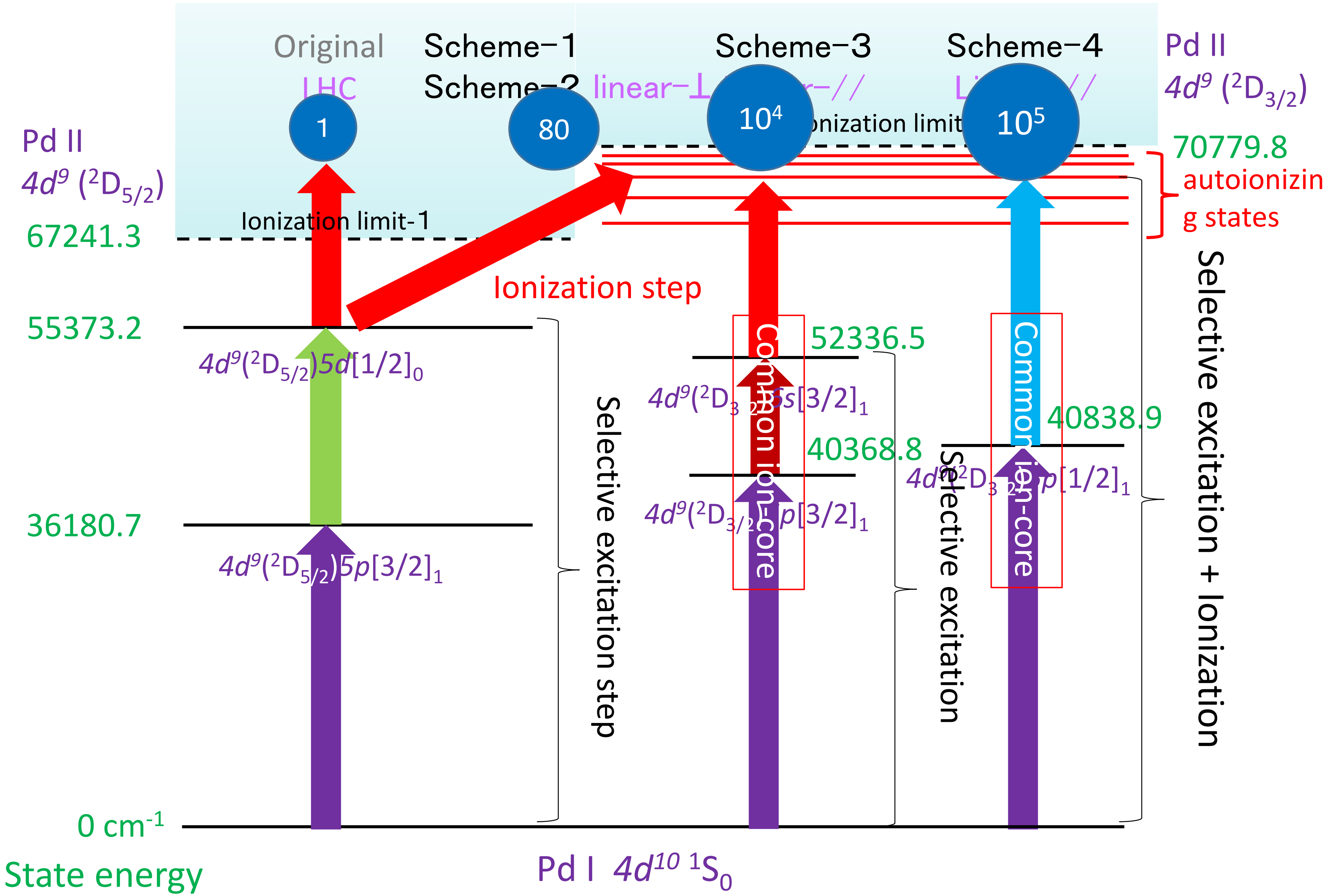
Selective

$^{105}Pd^{+}$ > 99.7 %

β>1000 confirmed!

The result suggests transition to ionization continuum is negligible.

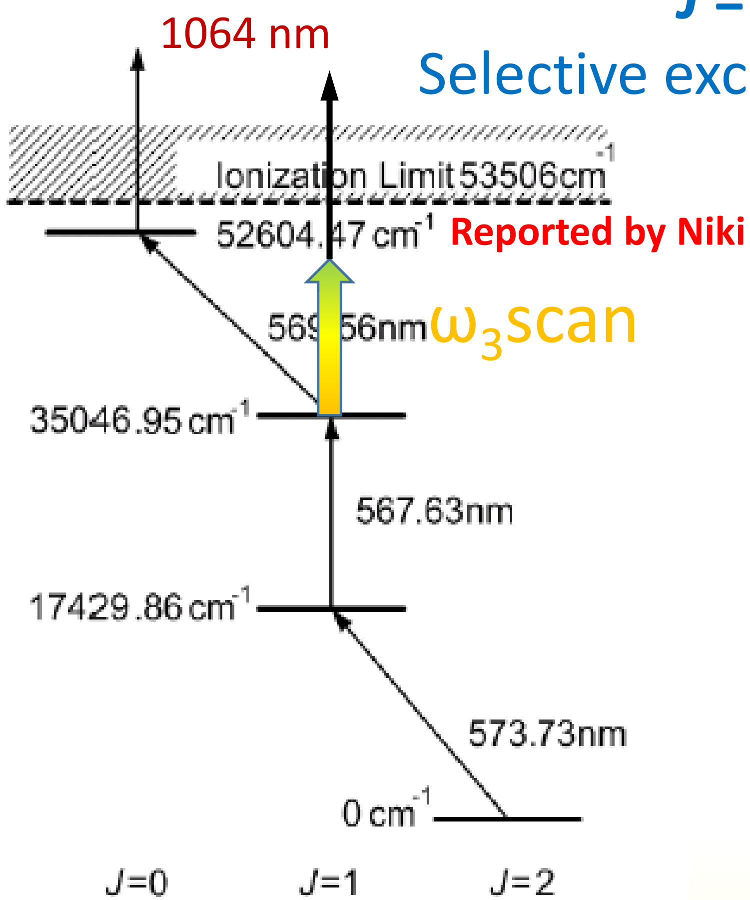
Comparison in ion yield

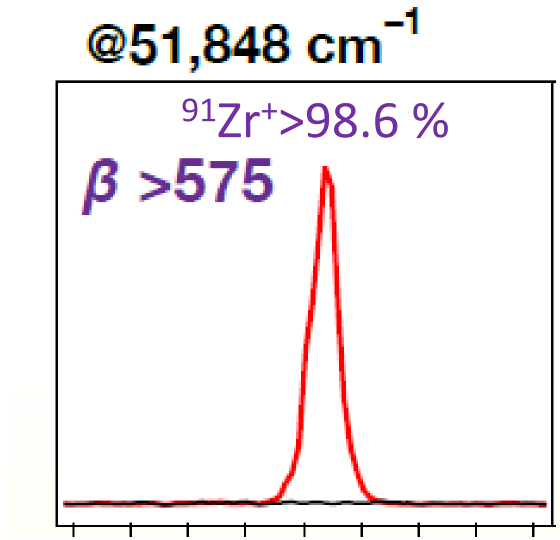


Zirconium: Tuning ω_3 in search of *J*=0 state

***J* = 2 ⇒ 1 ⇒ 1 ⇒ 0 ⇒ ionization**

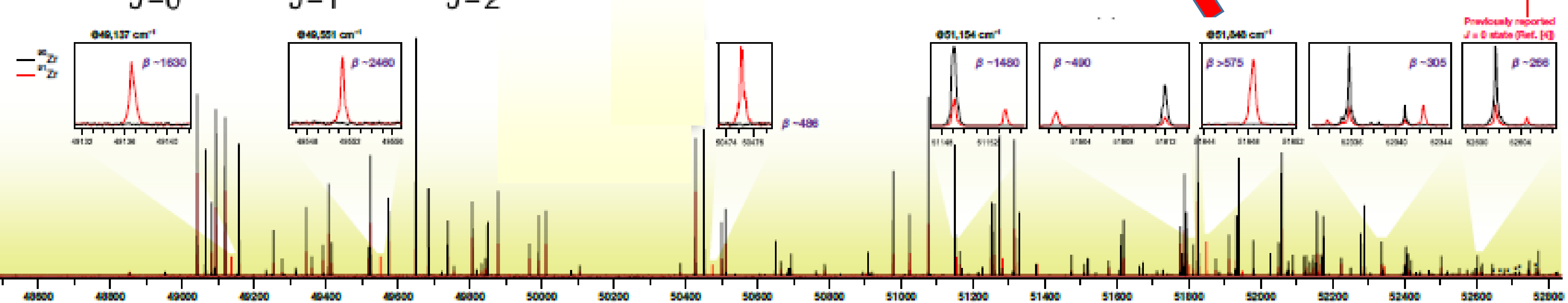
Selective excitation with 3-// linearly polarized lasers





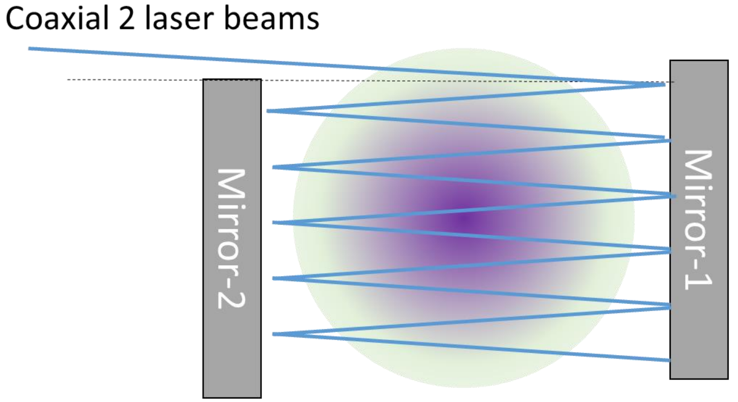
30 times larger intensity than the previous report.

Dr. Niki's line



Effort to increase ion yield (Pd)

Simple multi-pass optics

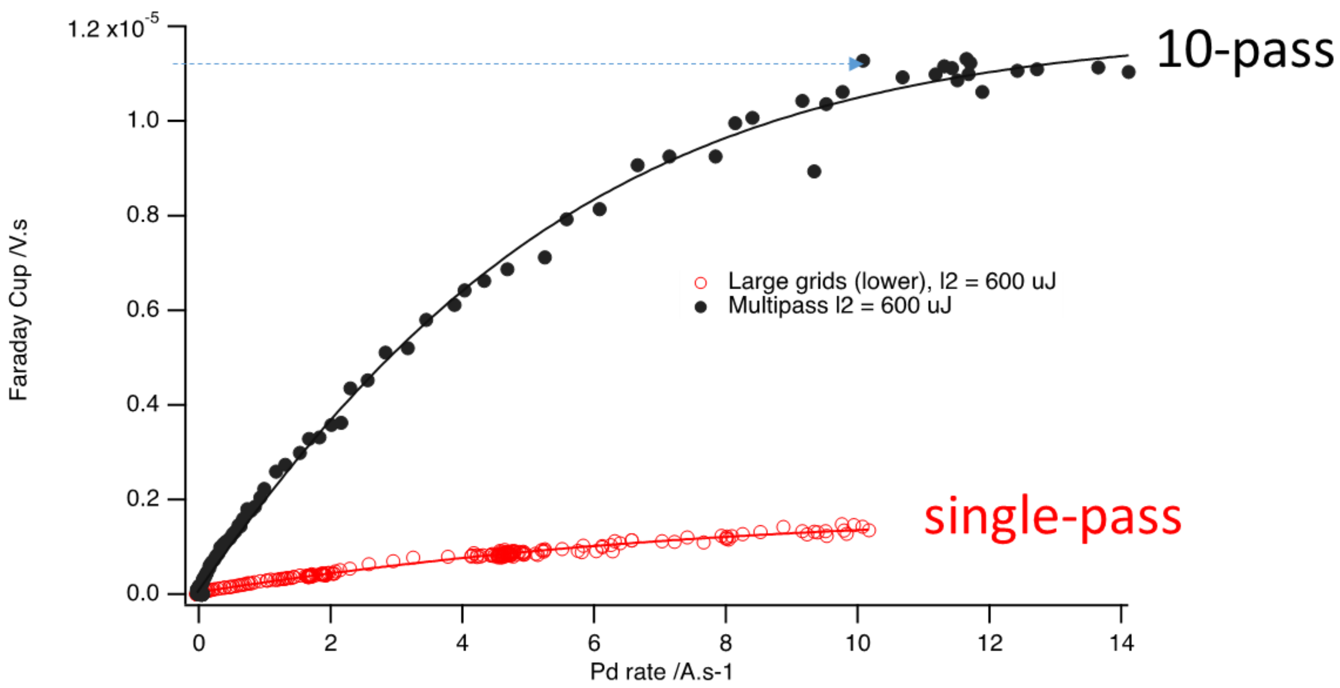


Vapor of Pd

77 g/year @10 kHz

0.21 g/day @10 kHz

$1.1 \times 10^{-5} Vs$ @ 12.0 Ås-1 $= 1.4 \times 10^{12}$ ions/pulse



Pd vapor flux

Road to practical realization

Nuclear power plant
1.0 GW

High-level nuclear waste (HLW) 20 ton/year

Pd 27 kg/year

$\times 350$

Our value 77 g/year

- High power lasers
- Large volume multi-pass optics

The difference will be overcome in the near future.

Acknowledgements

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