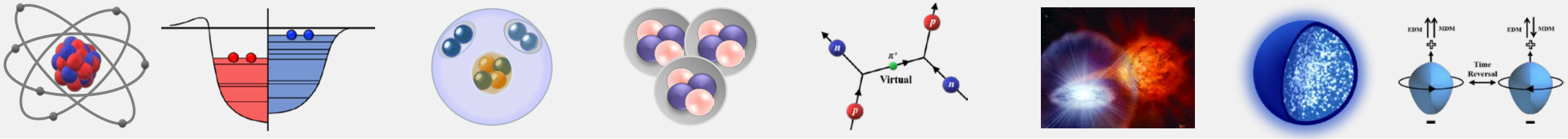


High-resolution laser spectroscopy on the cooled and bunched radioactive ion beams

Xiaofei Yang

State Key Laboratory of Nuclear Physics and Technology
School of Physics, Peking University

International Symposium on Stored Ions for Precision Measurements, 22-24 Nov. Shanghai China

Outline

◆**Introduction to laser spectroscopy (for exotic nuclei)**

-General overview of laser spectroscopy

-Why cooled and bunched ion beams?

◆**Recent study of exotic nuclei using laser spectroscopy**

-Radii of $^{46\text{-}49}$Sc up to $N = 28$

-Moments and Radii of ^{81,82}Zn above $N = 50$

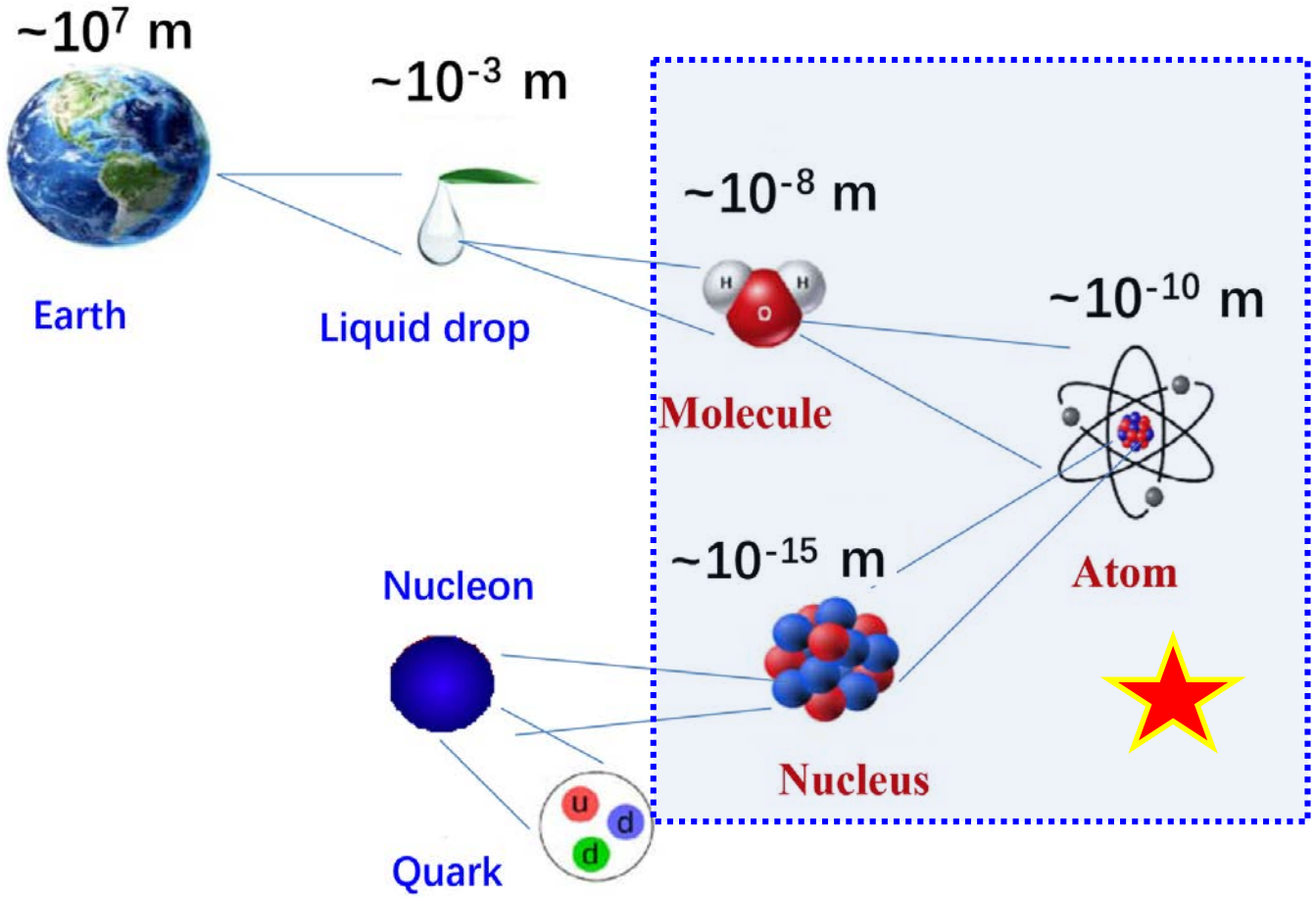
◆**Progress of CLS development in China**

- CLS and CRIS setups

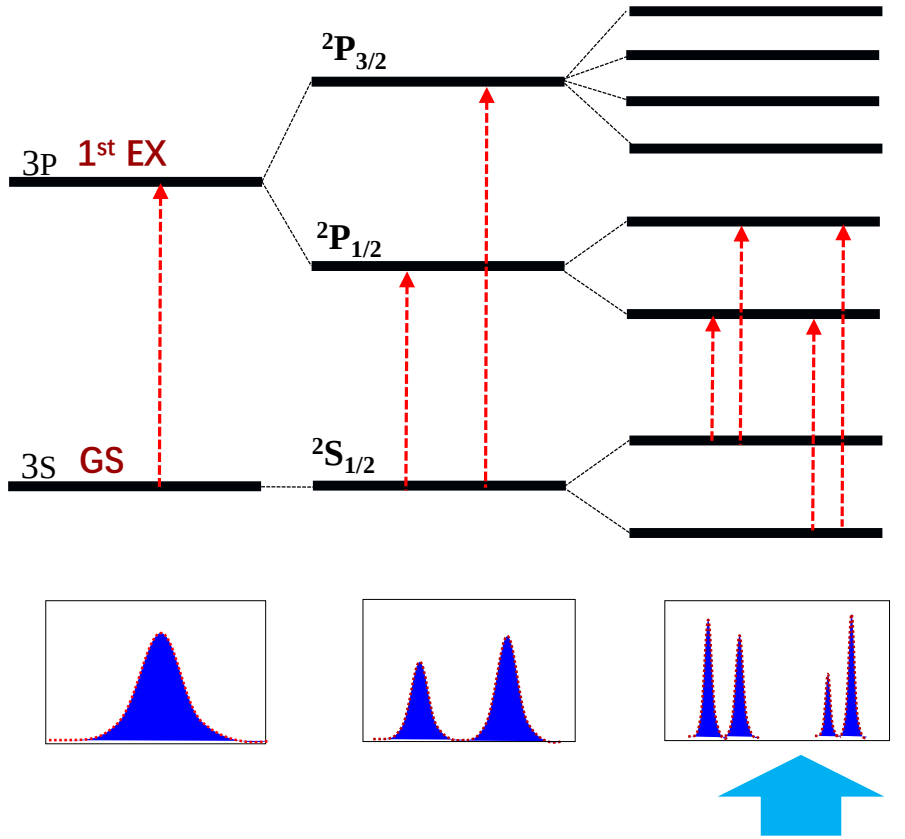
- First online-commissioning experiment at BRIF

◆**Future plans**

Hyperfine interaction: EM interaction between atomic nucleus and the surrounding electrons

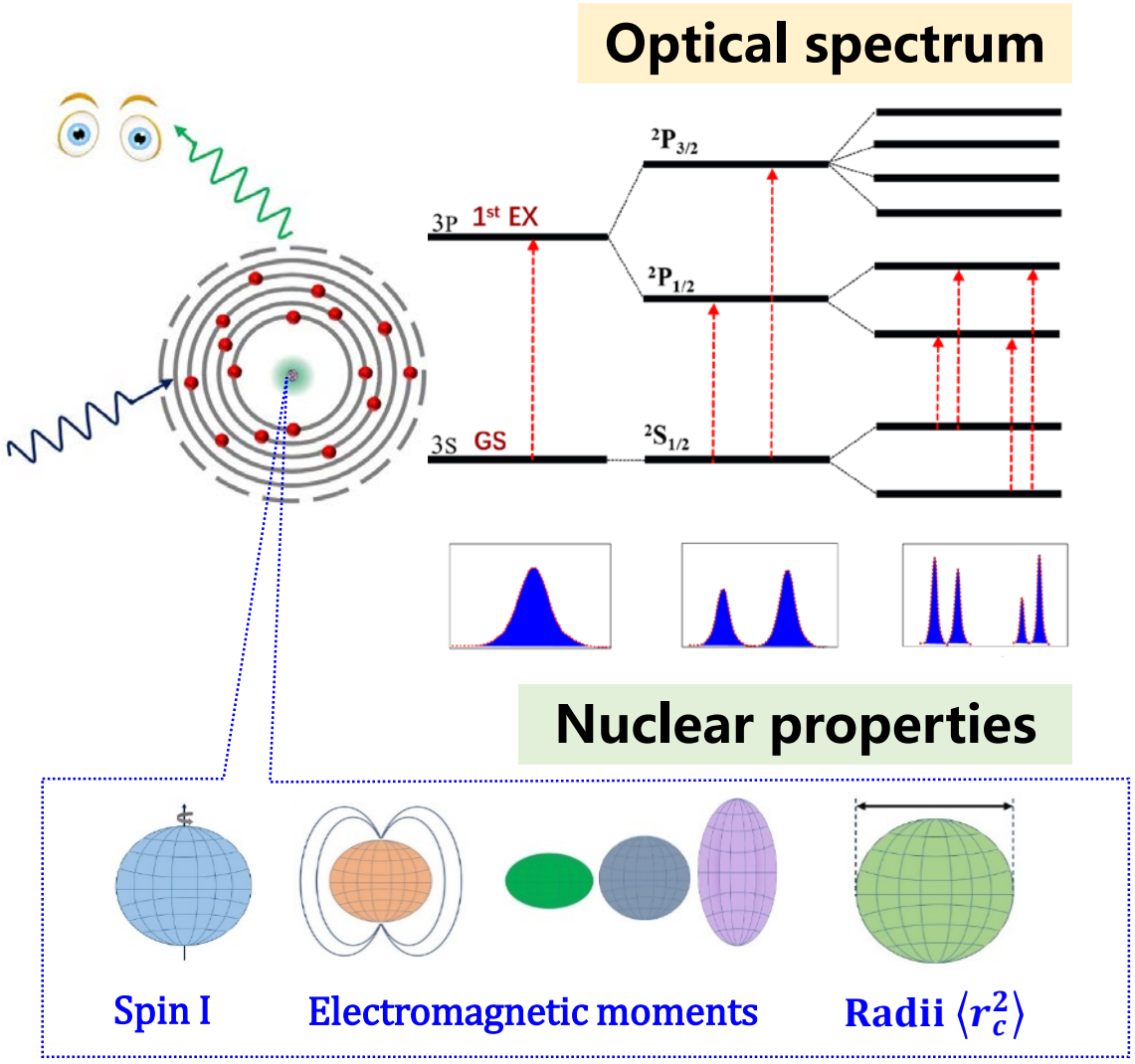


Hyperfine structure/Isotope shift

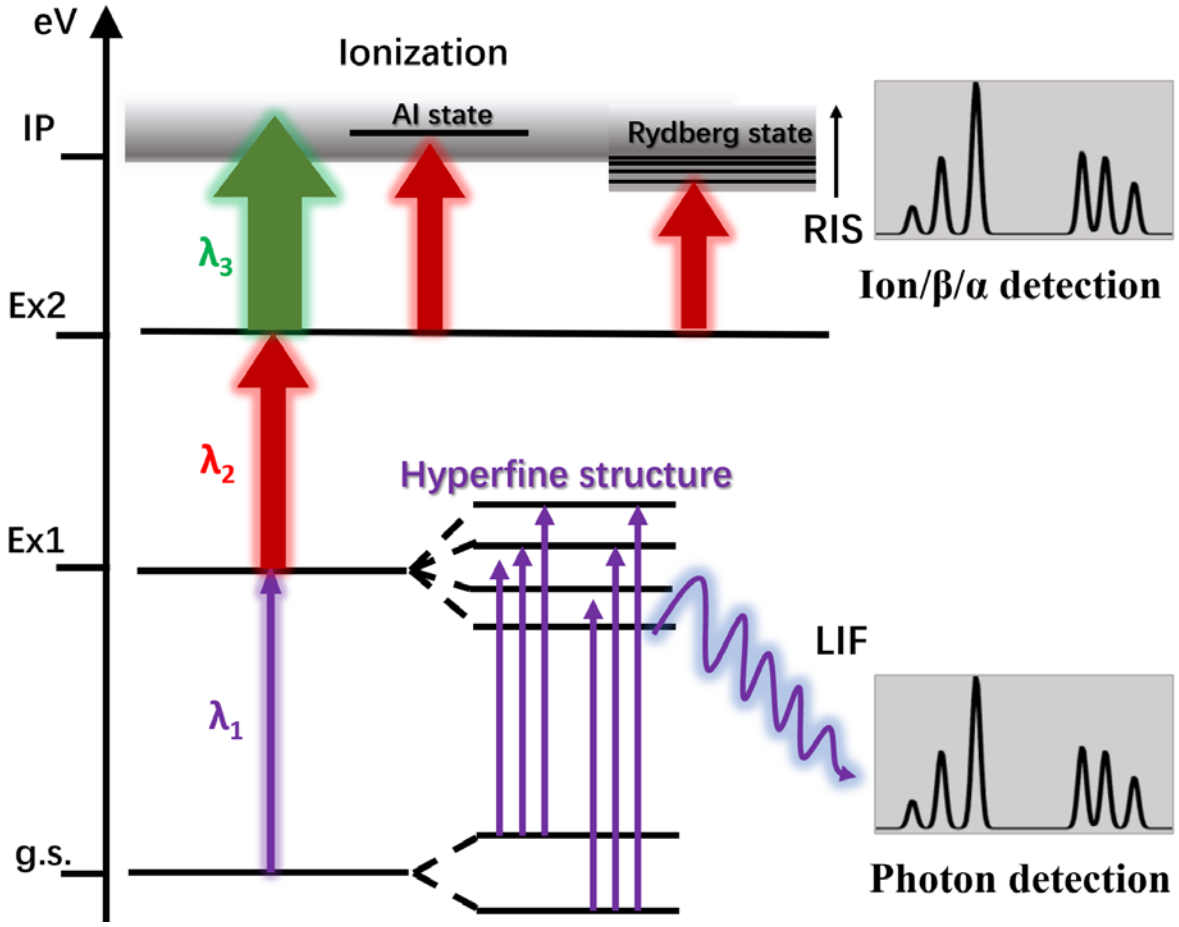


Hyperfine structure spectrum

Introduction to laser spectroscopy

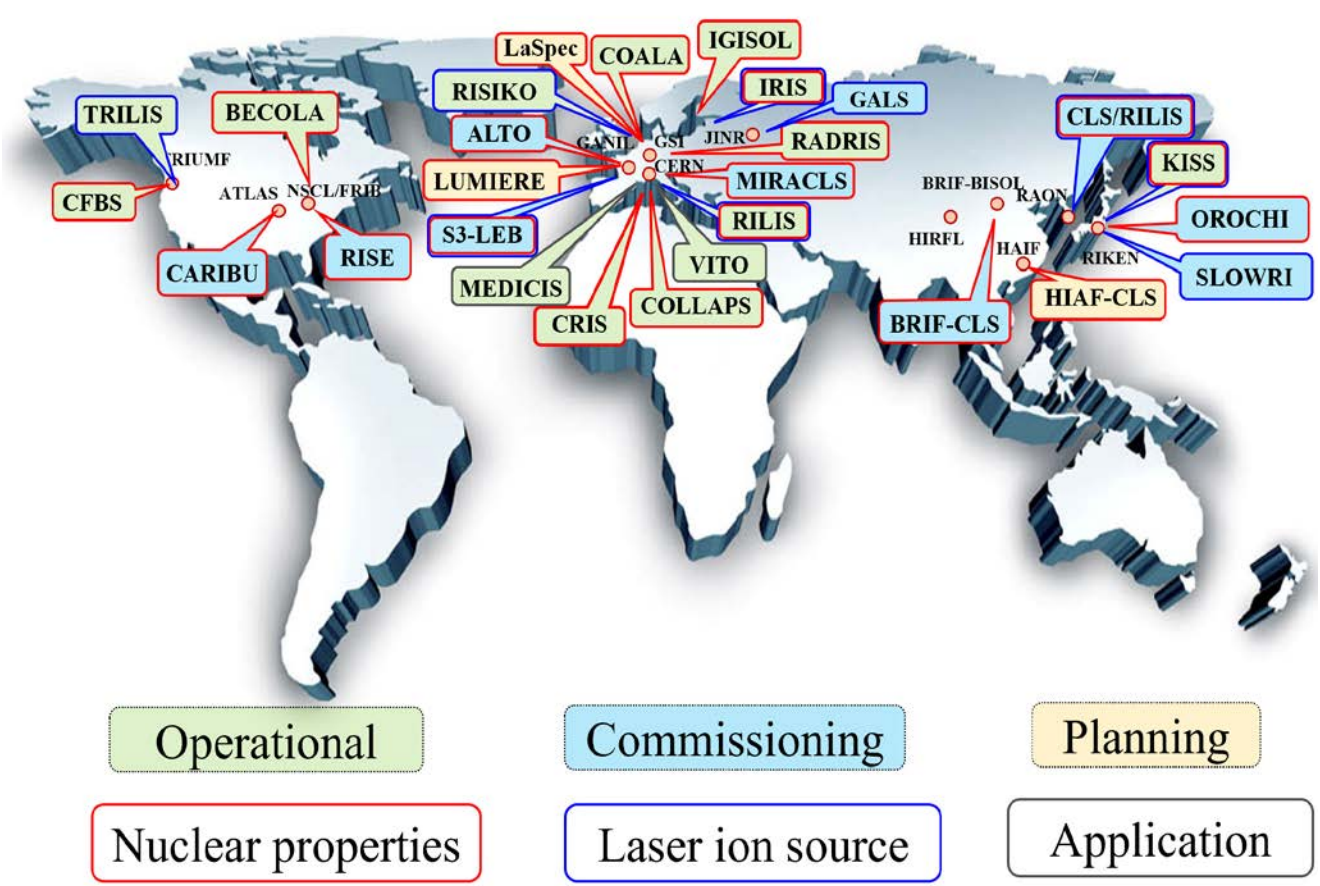


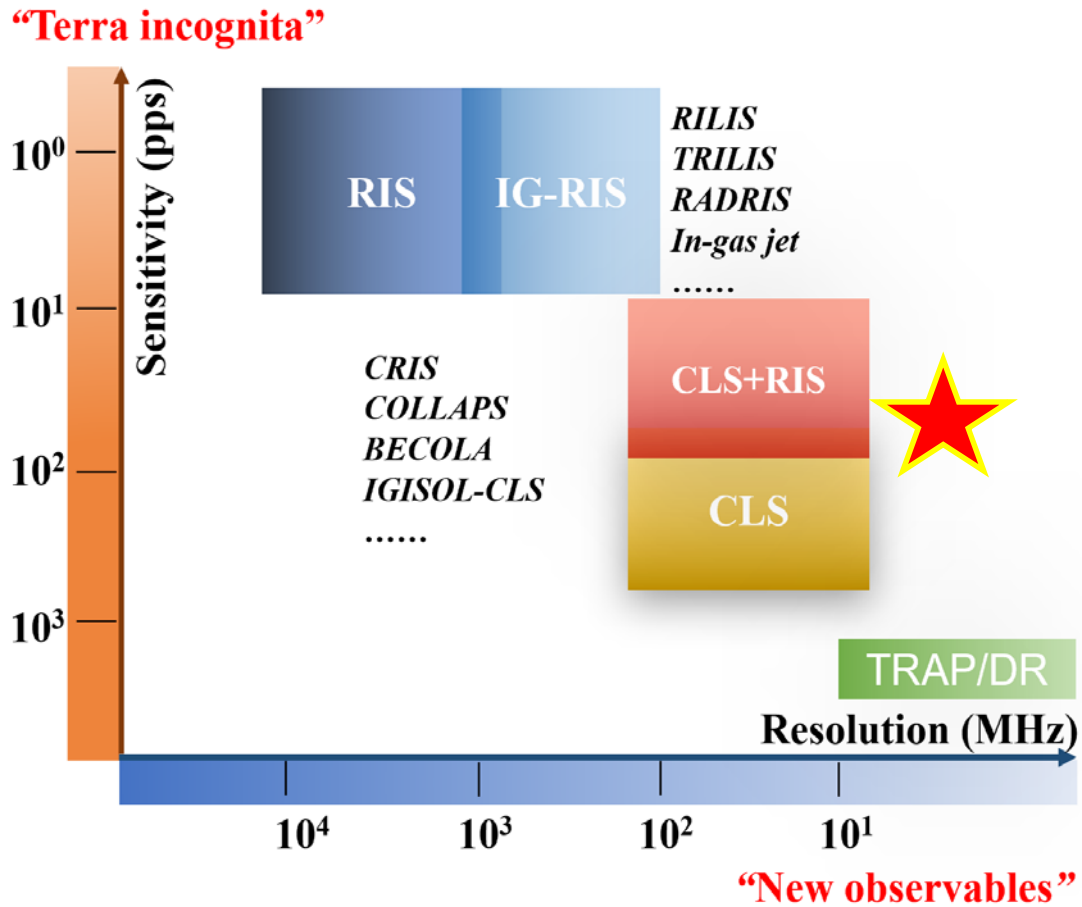
In a nuclear-model independent manner



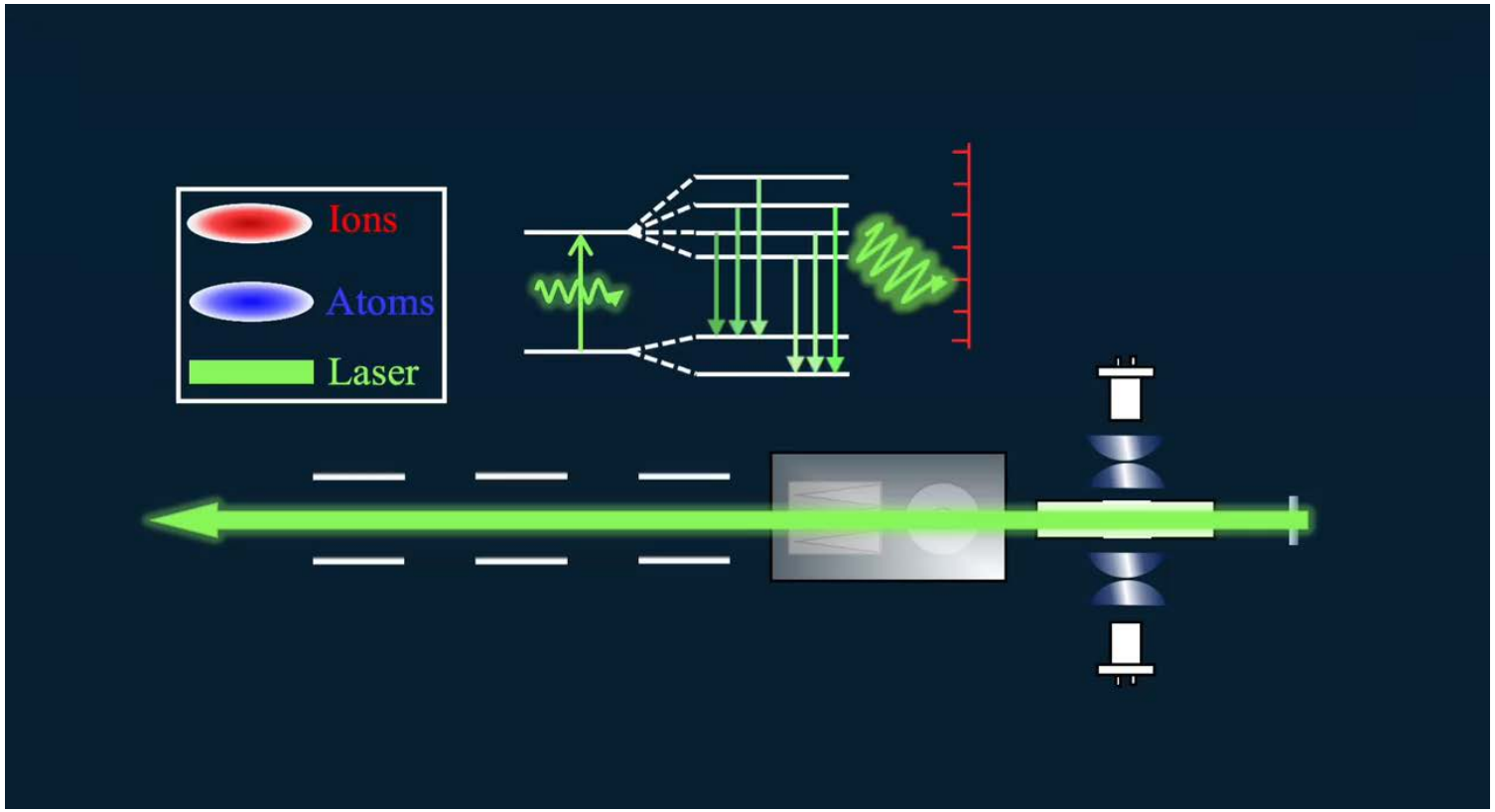
- LIF: Laser Induce Fluorescence
- RIS: Resonance ionization spectroscopy

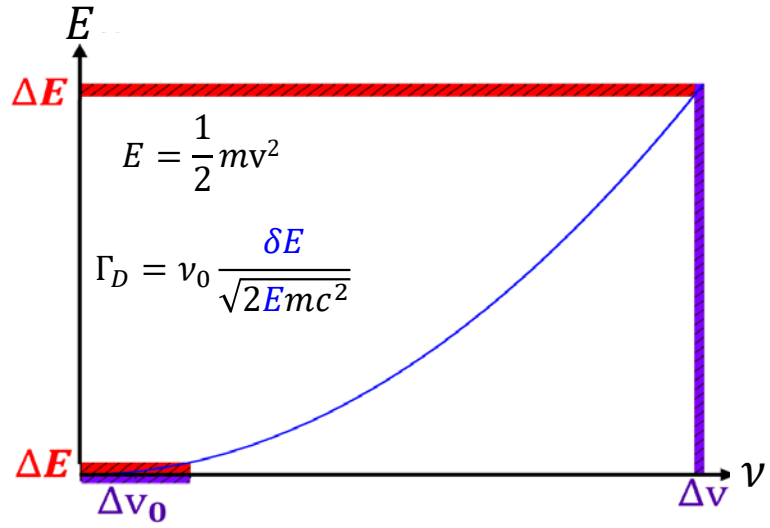
Introduction to laser spectroscopy

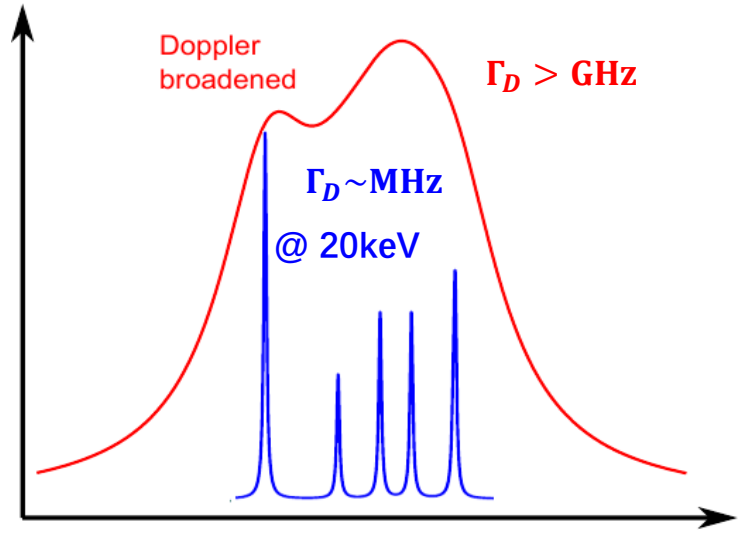




Introduction to laser spectroscopy

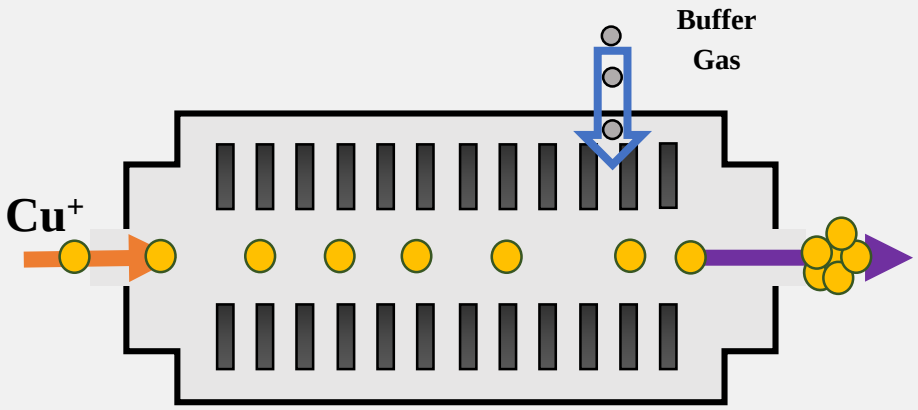


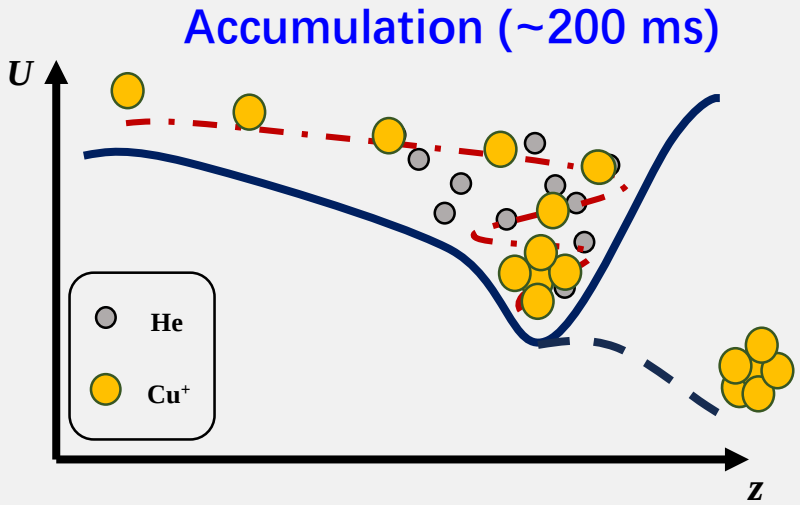


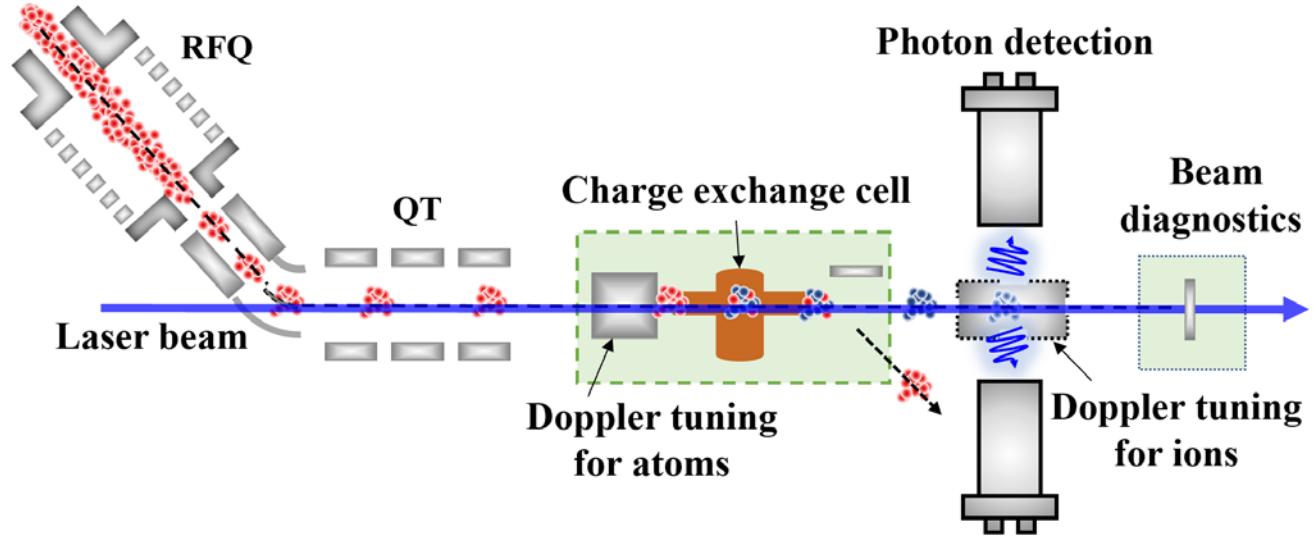


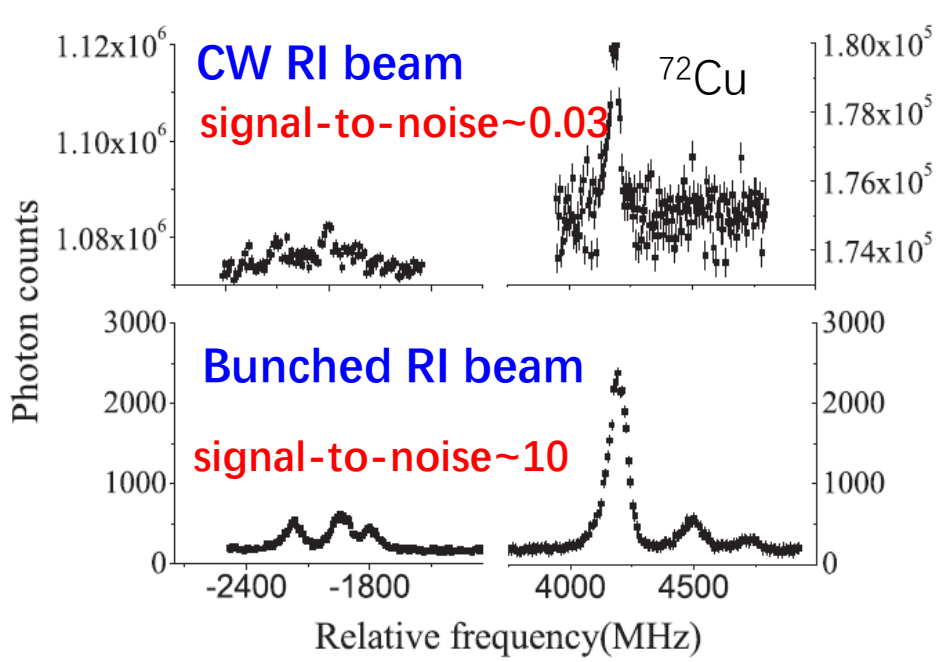
RI beam is overlapped with laser in a collinear/ant-collinear geometry

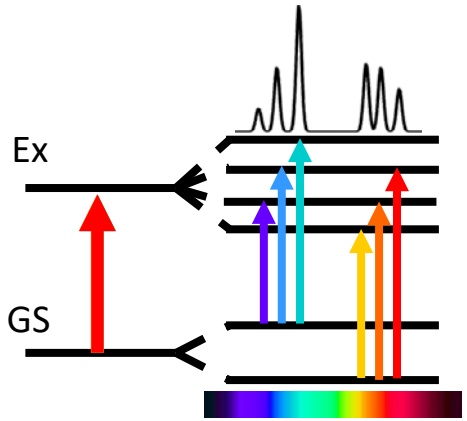
Introduction to laser spectroscopy Collinear laser spectroscopy (COLLAPS-ISOLDE)



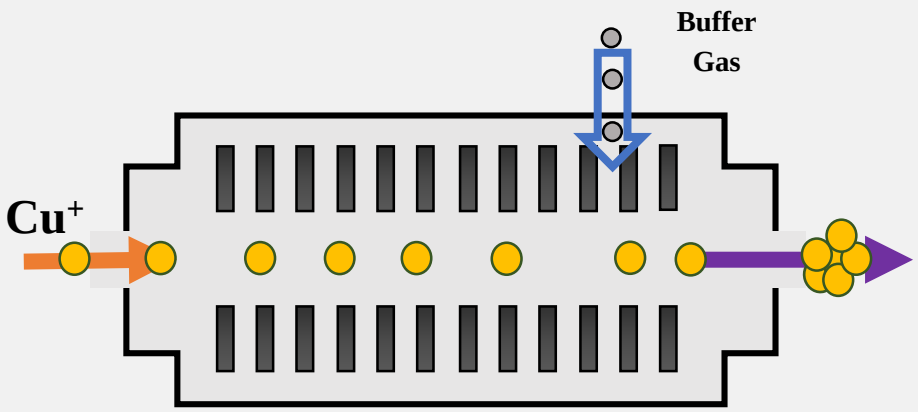


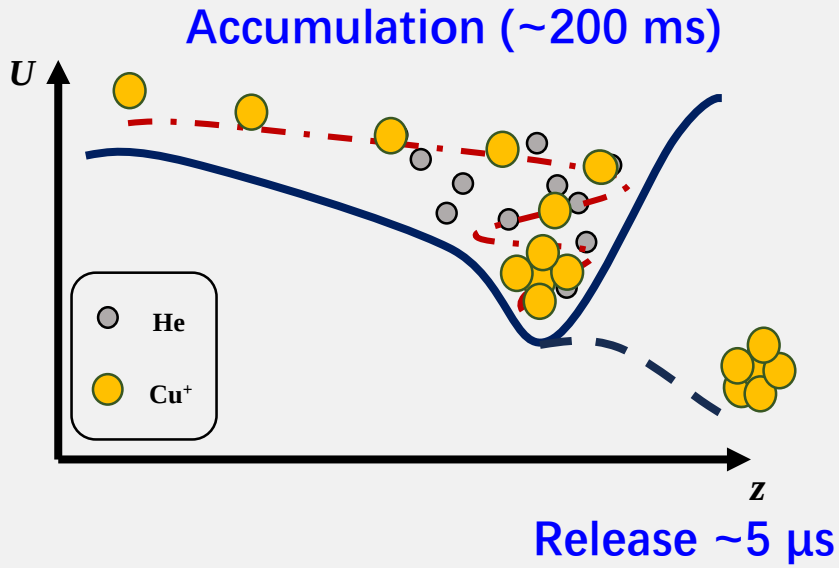


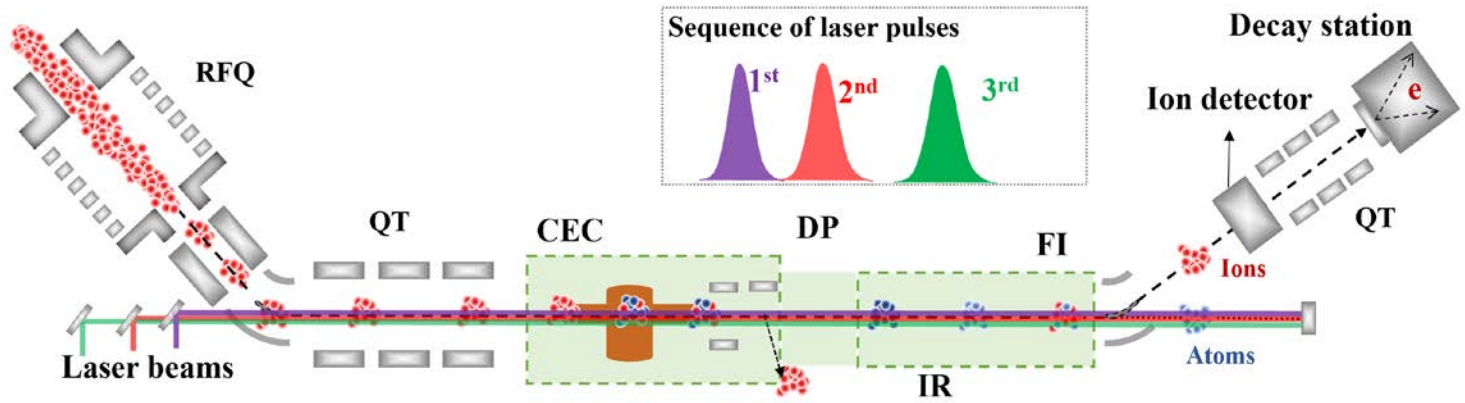




Introduction to laser spectroscopy Collinear resonance ionization spectroscopy (CRIS-ISOLDE)







- **CRIS with CW RI beam:**

(J. Phys. B 24, 1991) ε = 0.001 %

Duty cycle loss with CW beam

- **CRIS with bunched RI beam:**

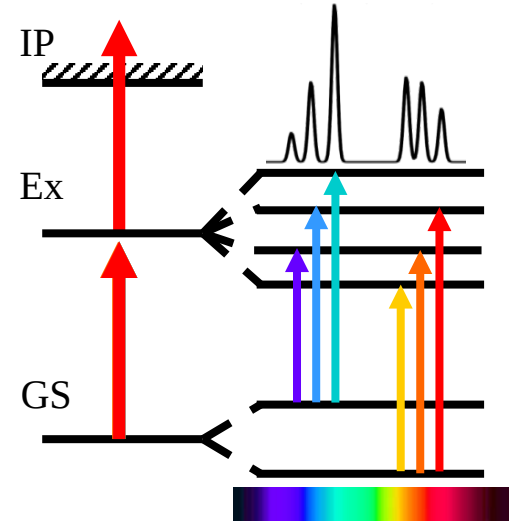
(PRL 111, 212501, 2013) ε = ~1 %

resolution ~ 1 GHz !

- **CRIS with bunched RI beam:**

(Recent Zn experiment (2023) ε = ~0.2-0.3 %

resolution < 100 MHz!



Ion detection

Outline

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-Moments and Radii of ^{81,82}Zn above $N = 50$

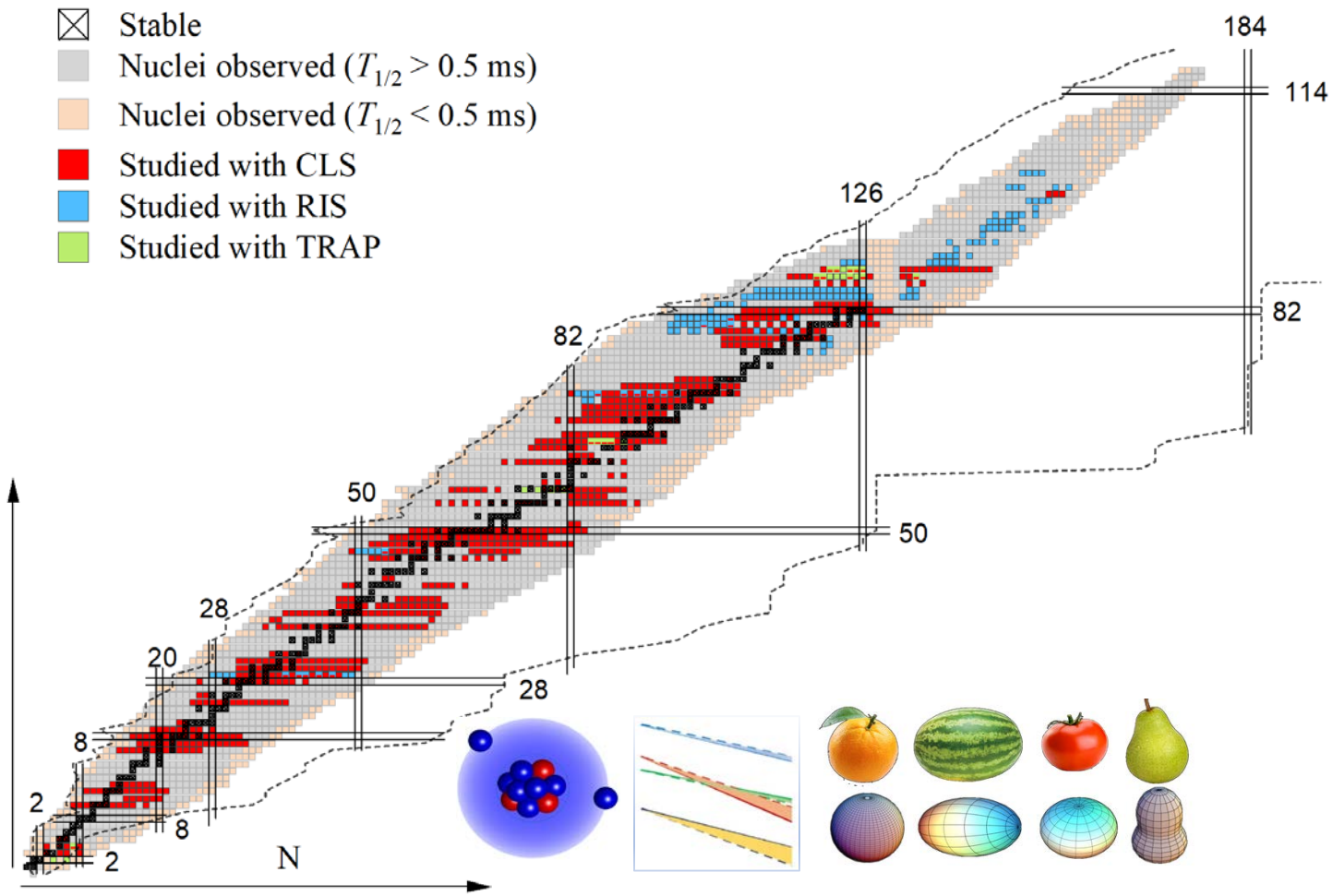
◆**Progress of CLS development in China**

- CLS and CRIS setups

- First online-commissioning experiment at BRIF

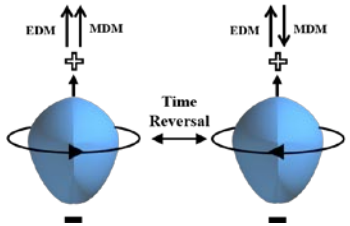
◆**Future plans**

Exotic nuclei studied by laser spectroscopy



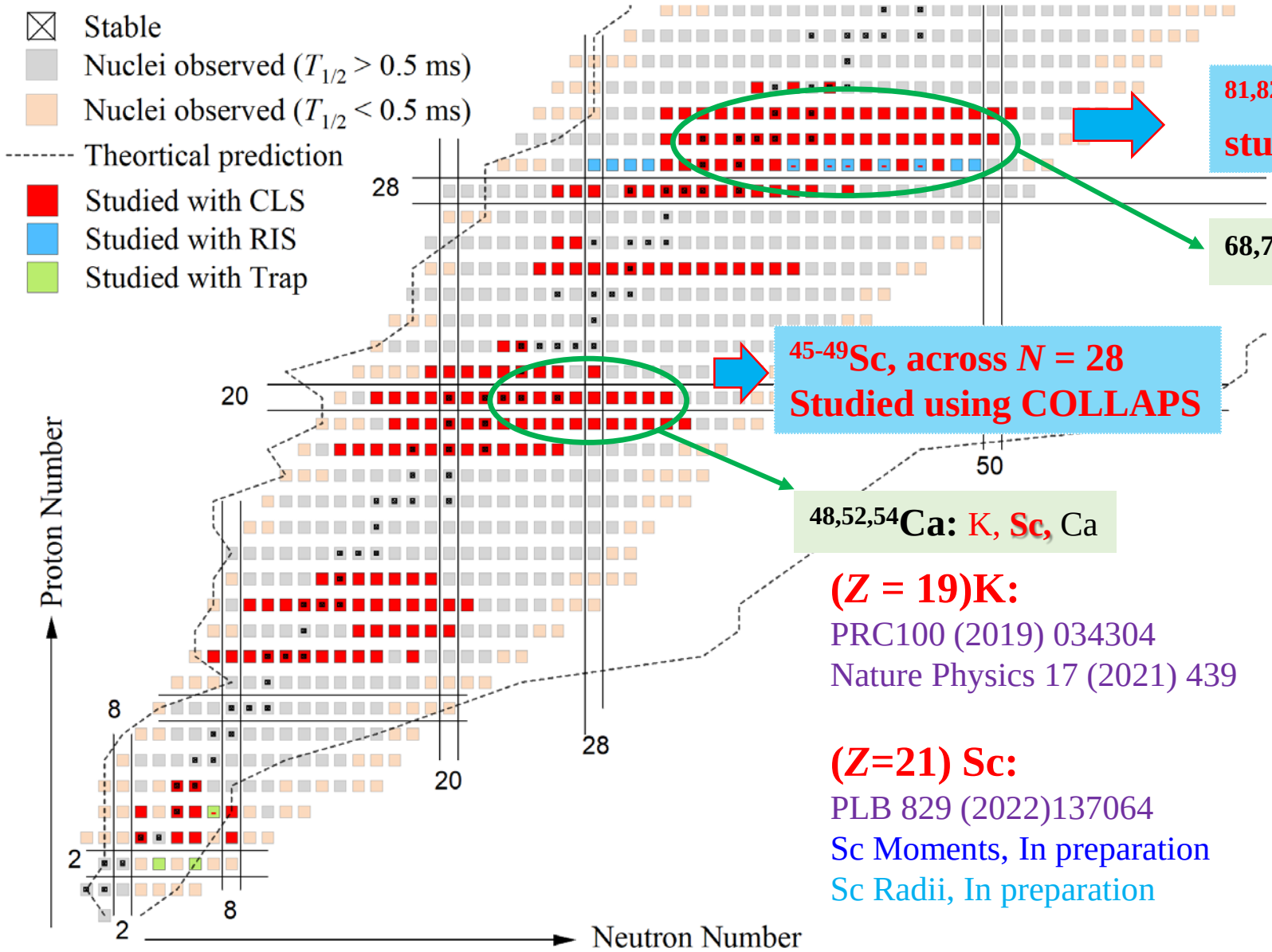
X.F. Yang et al., Prog. Part. Nucl. Phys. 129 104005 (2023)

- **about 1000 nuclei was investigated so far**
  - **-contribute significantly to the study of nuclear structure and NN interactions**
- **First laser spectroscopy of RaF (radioactive molecule)**
  - **-offer new opportunity for the study of fundamental symmetry**



- *Nature 581, 396 (2020);*
- *Physical Review Letters 127, 033001 (2021)*
- *Nat. Phys. In press (2023)*

Exotic nuclei studied by laser spectroscopy COLLAPS and CRIS @CERN-ISOLDE



^{81,82}Zn, above N = 50 studied using CRIS

^{68,78}Ni : Ni, Cu, **Zn,** Ga, Ge

$^{45-49}$Sc, across N = 28 Studied using COLLAPS

^{48,52,54}Ca: K, **Sc,** Ca

$^{62-82}$Zn(Z=30):

PRL116 (2016) 182502
PLB 771(2017)385
PRC. 97 (2018) 044324
PLB 797(2019)124805
Moments of ^{81}Zn, In preparation
Radii of ^{81,82}Zn, In preparation

(Z = 19)K:

PRC100 (2019) 034304
Nature Physics 17 (2021) 439

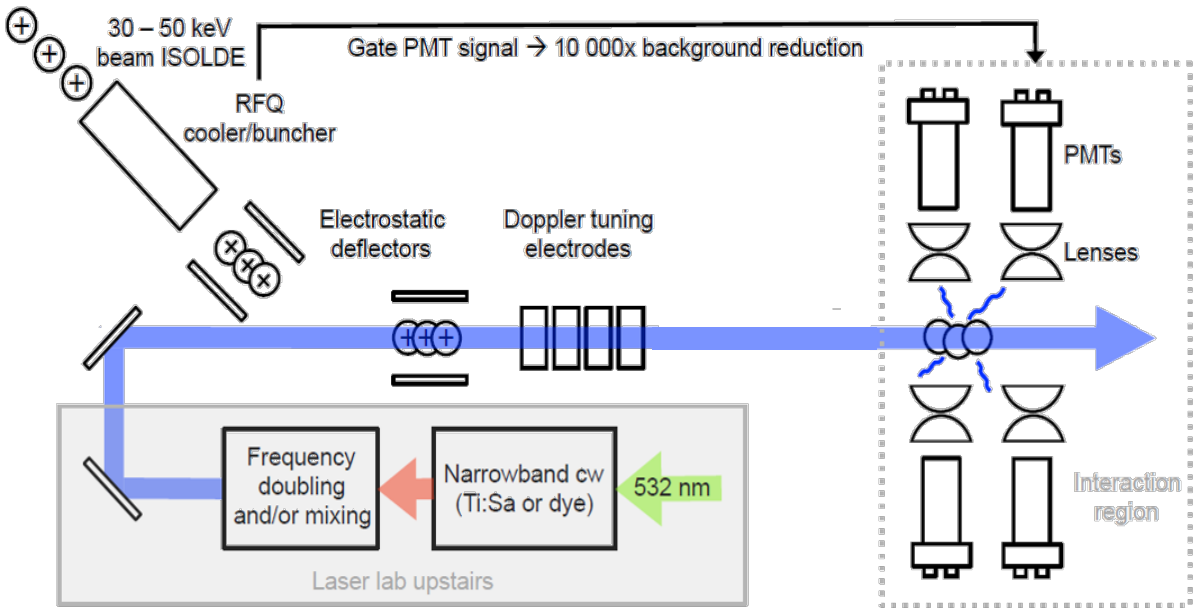
Ge (Z=32) :

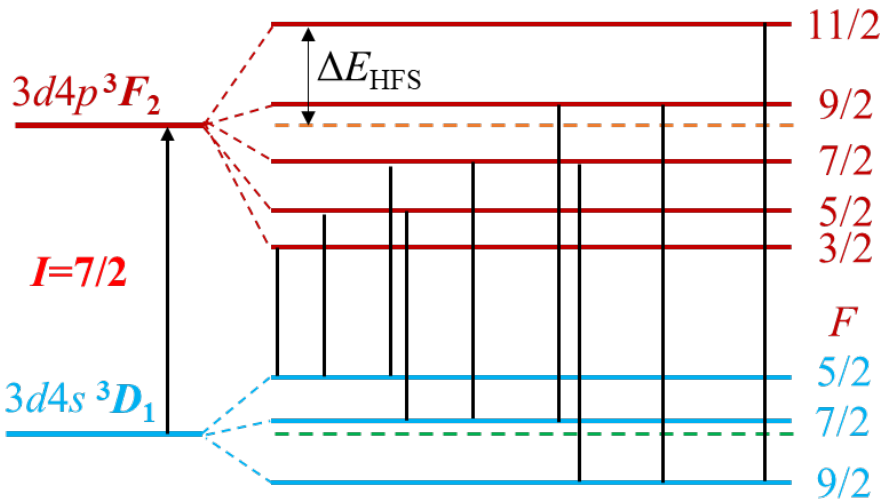
PRC102(2020)054331
Ge Radii, to be submitted (2023)

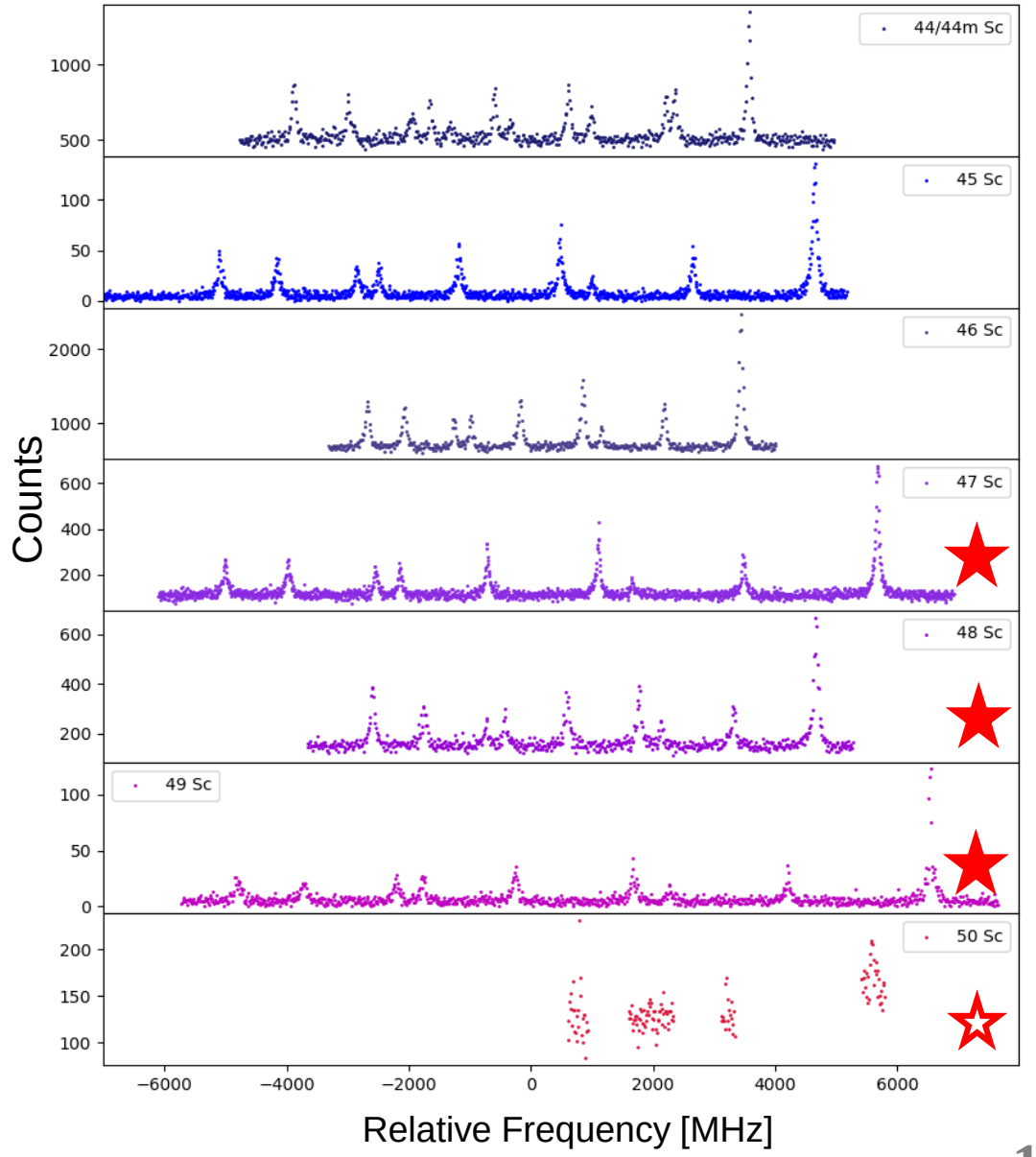
(Z=21) Sc:

PLB 829 (2022)137064
Sc Moments, In preparation
Sc Radii, In preparation

Exotic nuclei studied by laser spectroscopy Neutron-rich Sc isotopes @COLLAPS

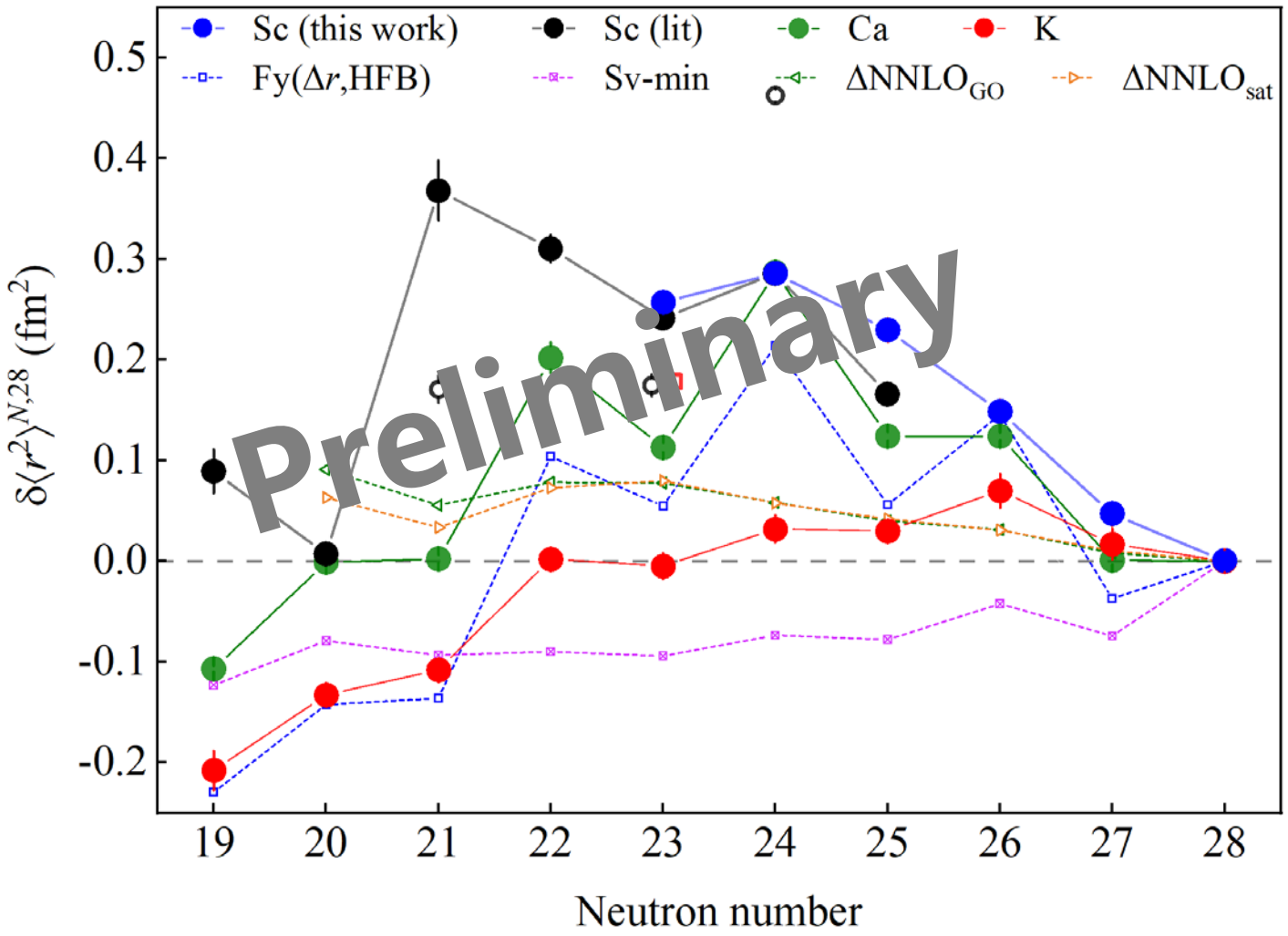






Charge radii of Sc isotopes up to $N = 28$

$$\delta\nu^{AA'} = M\frac{A'-A}{AA'} + F\,\delta\langle r^2\rangle^{AA'}$$



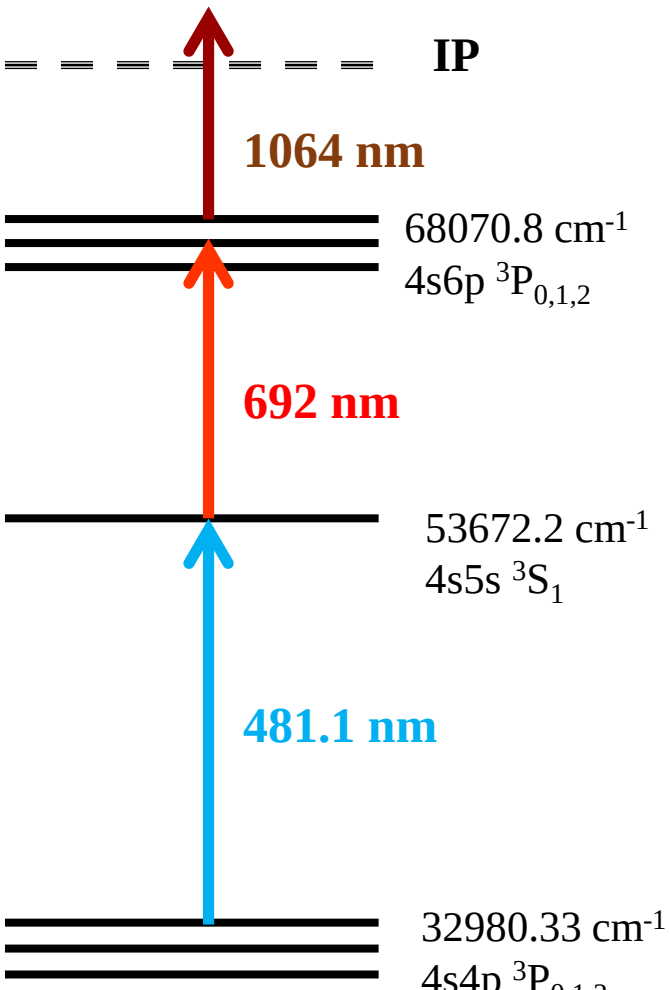
★ $N = 20$ kink is back for Sc

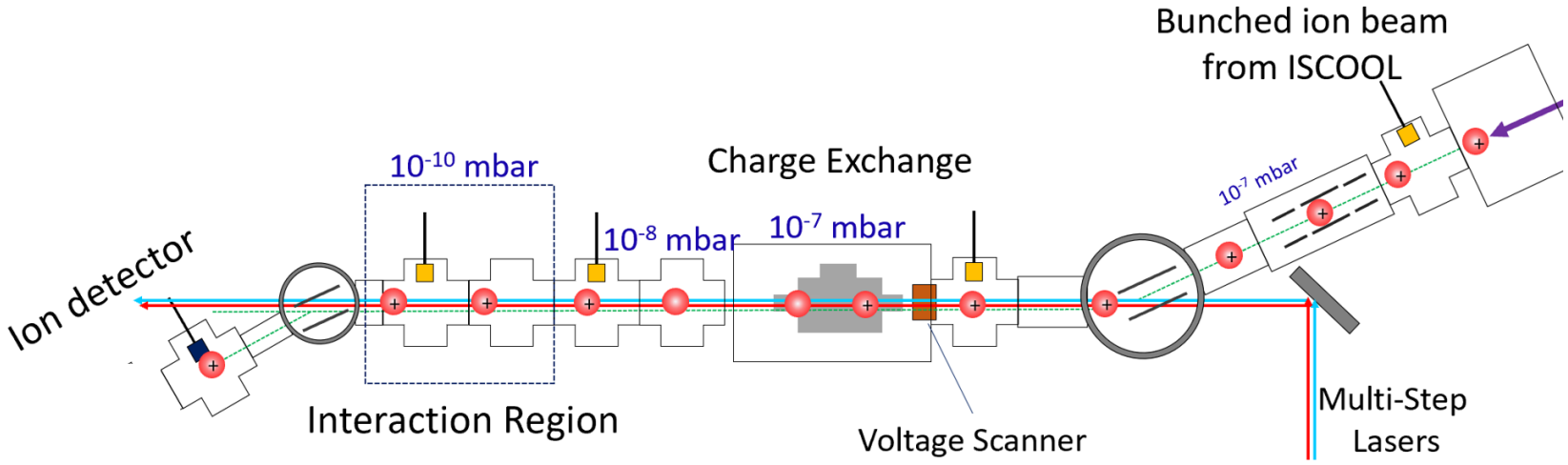
Kristian König et al., Phys. Rev. Lett. 131, 102501 (2023) @ MSU

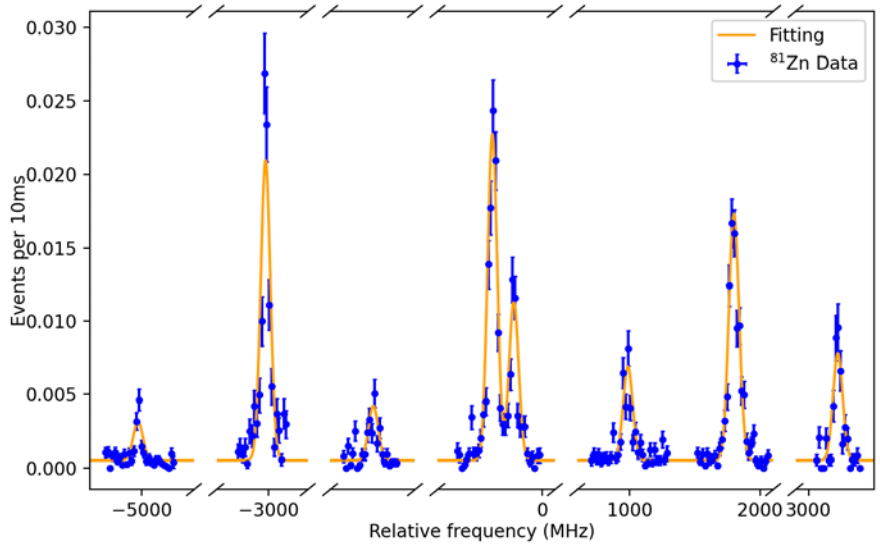
★ Parabola trend between $N = 20$ and 28 is back for Sc

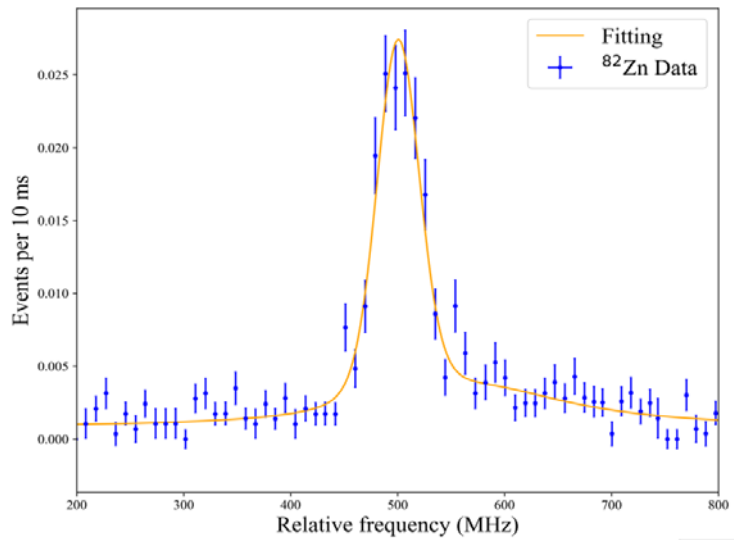
S.W. Bai, X.F. Yang et al., In preparation (2023)

Exotic nuclei studied by laser spectroscopy ^{81,82}Zn isotopes above $N = 50$ @CRIS





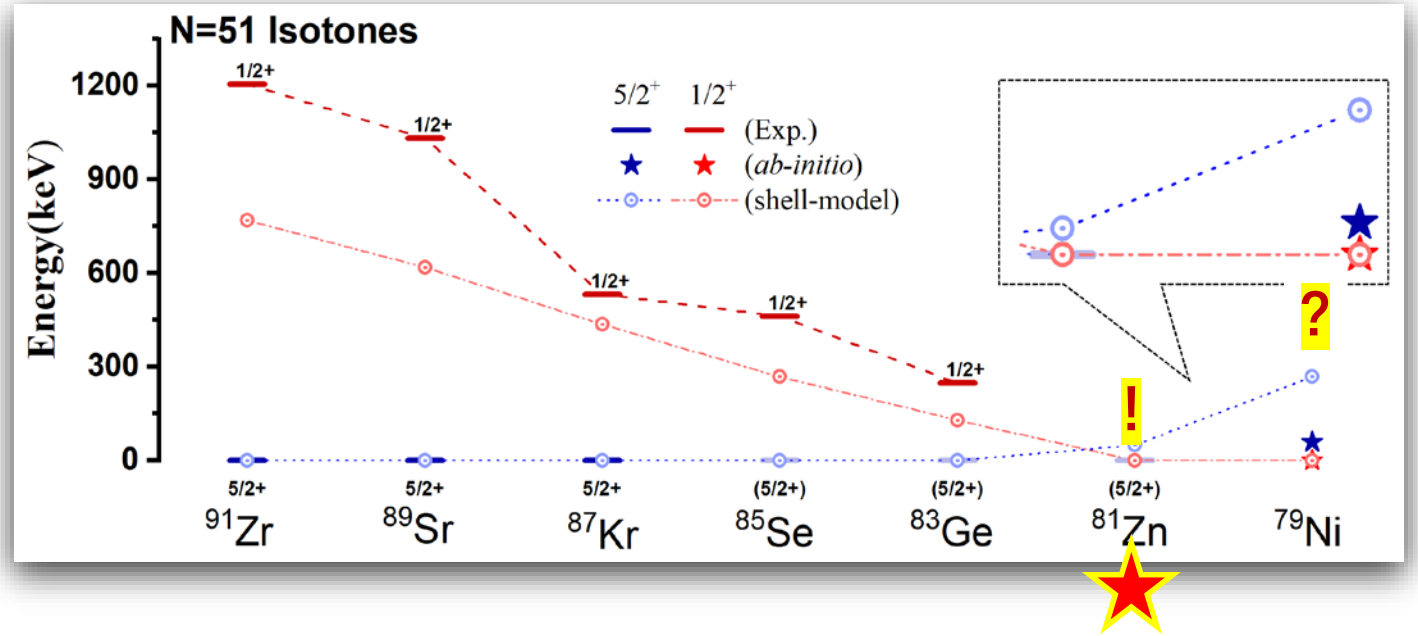


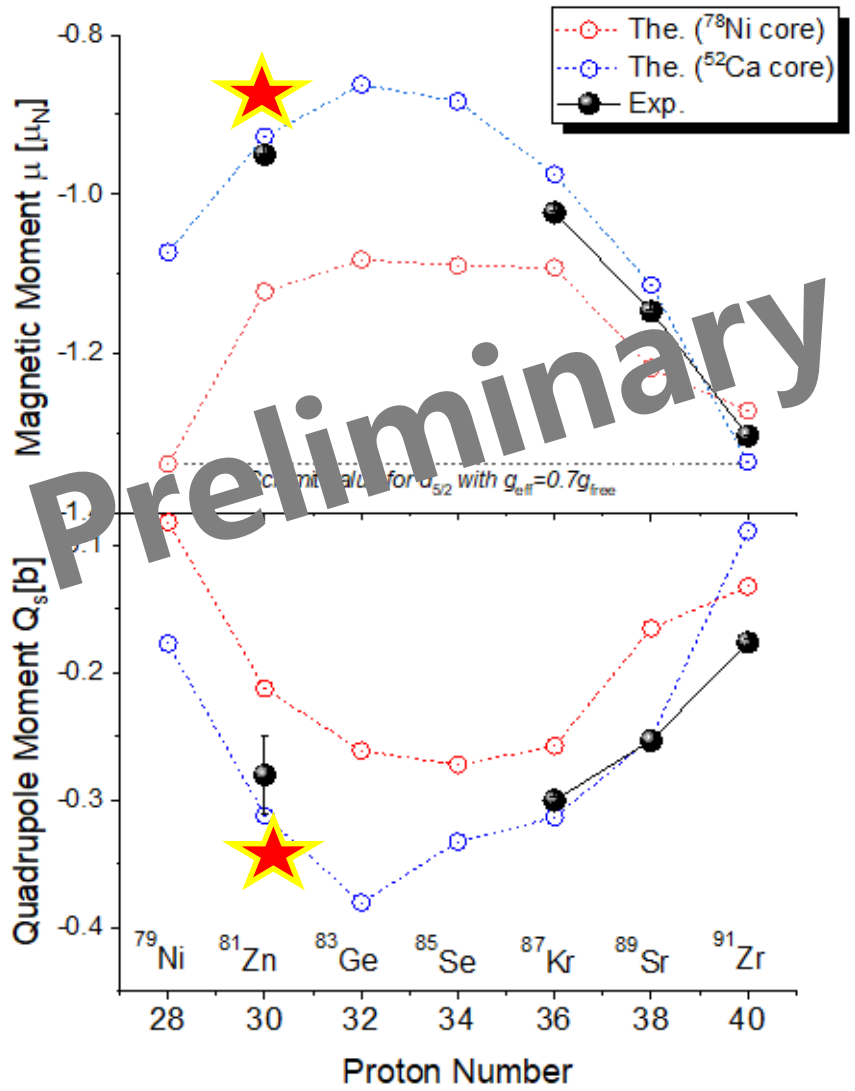


Exotic nuclei studied by laser spectroscopy: ^{81,82}Zn isotopes above $N = 50$ @CRIS

Spin, magnetic and quadrupole moment of ^{81}Zn

Y.C. Liu, X.F. Yang et al., In preparation (2023)



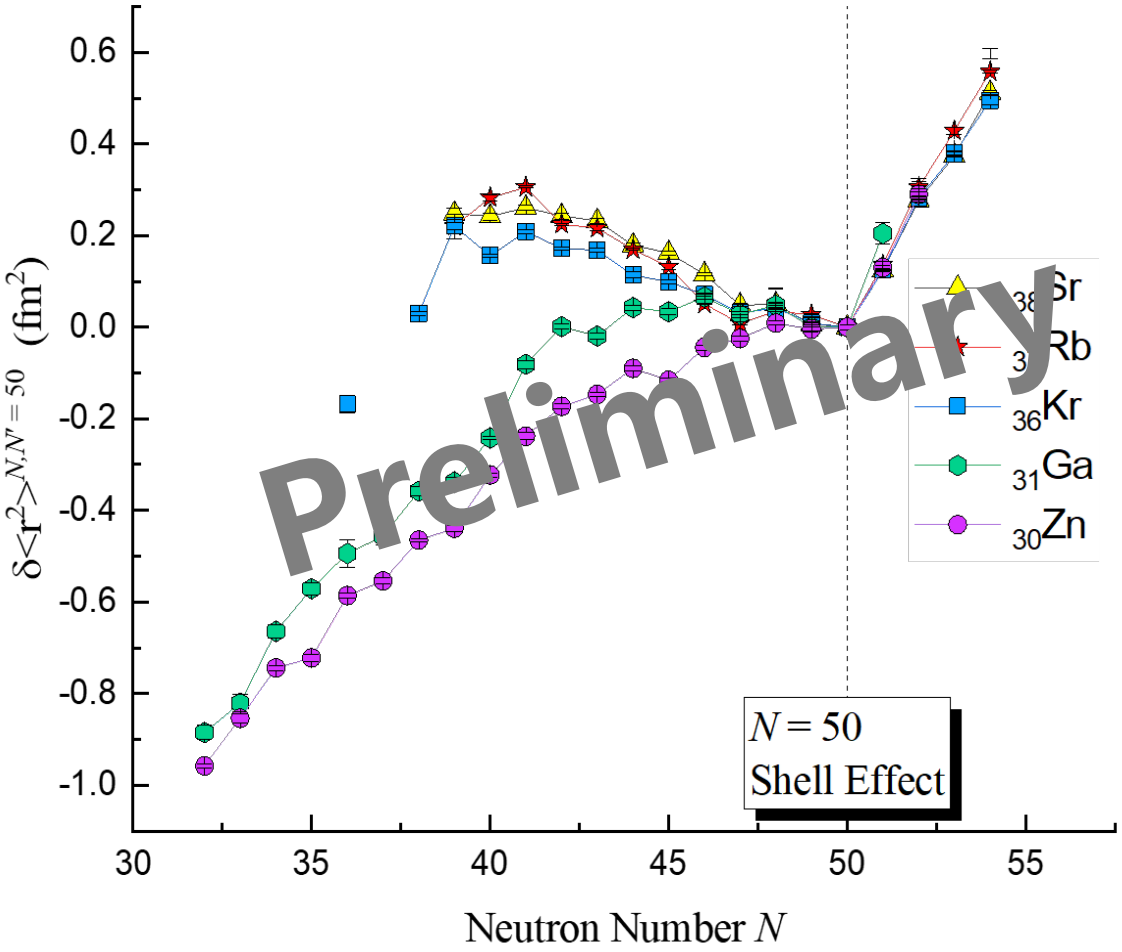


- G.S. spin of ^{81}Zn is now firmly assigned to be $5/2^+$

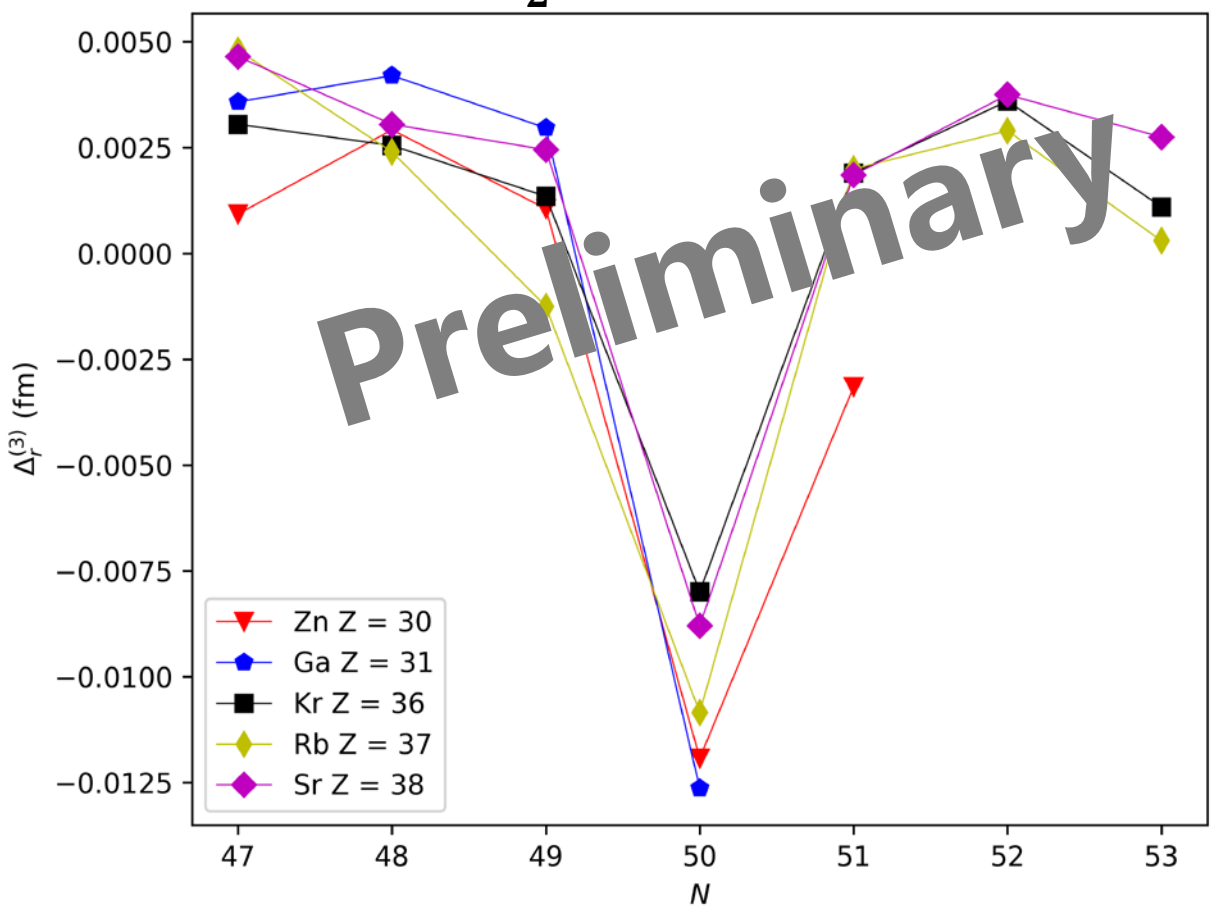
- SM calculation shows core excitations of ^{78}Ni is needed to reproduce the moments of ^{81}Zn

Exotic nuclei studied by laser spectroscopy: ^{81,82}Zn isotopes above N = 50 @CRIS

Charge radii of ^{81,82}Zn



$$\triangle_{1n}^{(3)} r = \frac{1}{2}(-1)^{N+1}[r_{N+1} - 2r_N + r_{N-1}]$$



Y.C. Liu, X.F. Yang et al., In preparation (2023)

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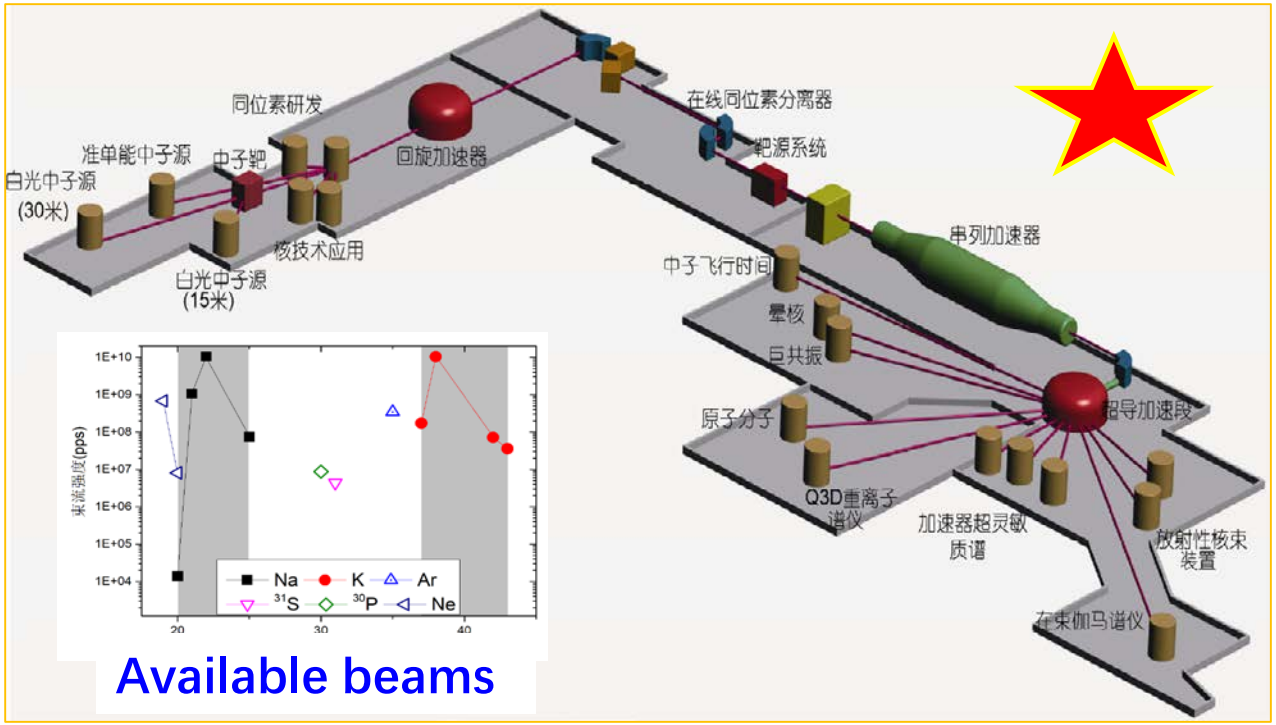
Progress of CLS development in China (PKU, CIAE, IMP, LZU)

Current and future RIB facilities in China

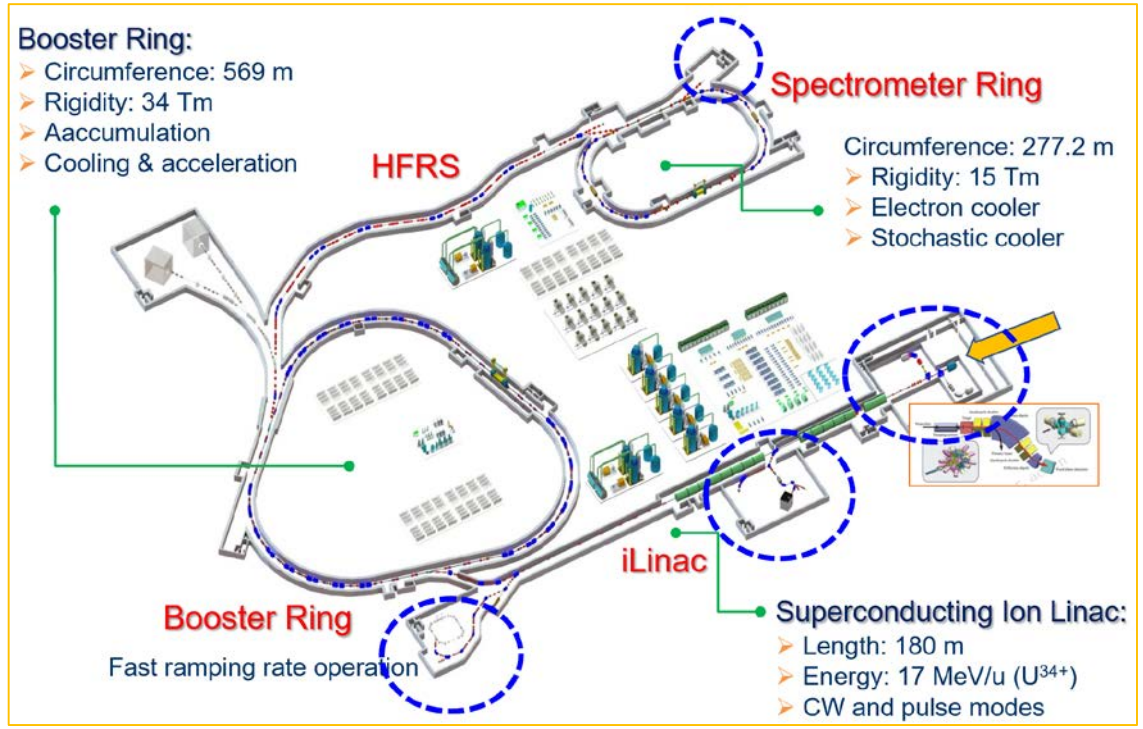
BRIF@CIAE, Beijing



- 100 MeV proton beam (200uA) +Target
- kW ISOL Target +online separator

Beijing Radioactive Ion Beam Facility (BRIF)

HIAF@IMP, Huizhou, Guangdong

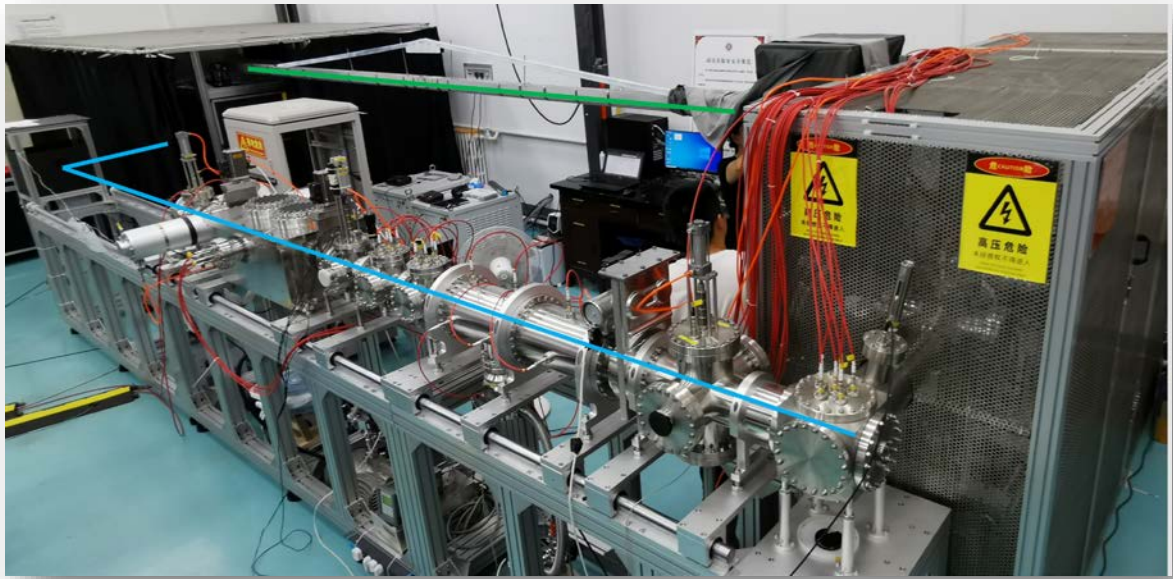


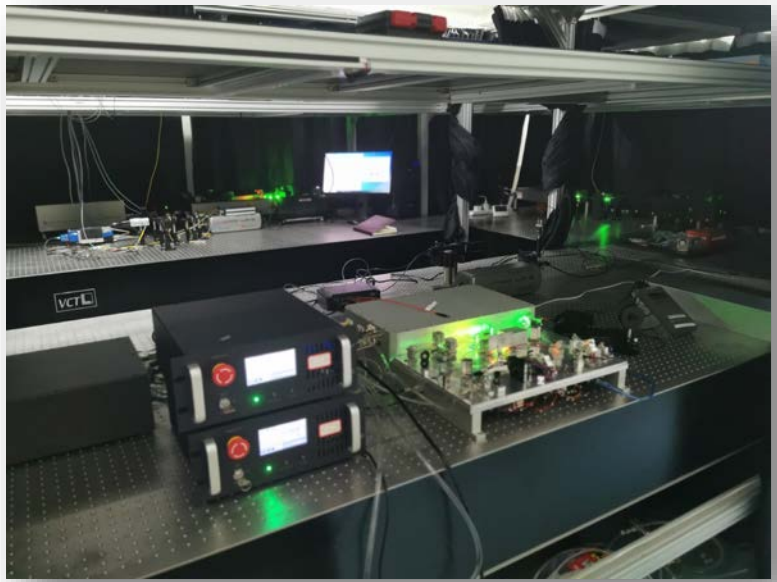
- **Under construction**

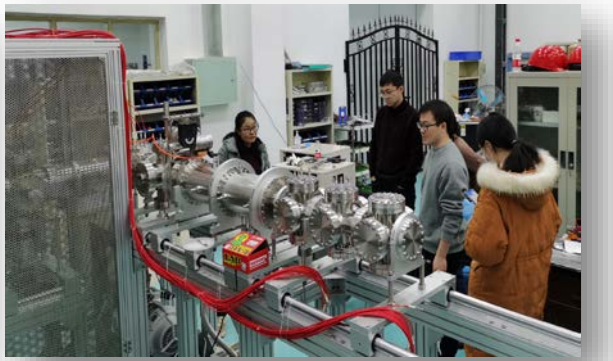
High-Intensity Heavy Ion Accelerator Facility (HIAF)

Progress of CLS development in China (PKU, CIAE, IMP, LZU) Offline CLS lab.

We have established an OFFLINE LAB at PKU for CLS/CRIS setup @2021

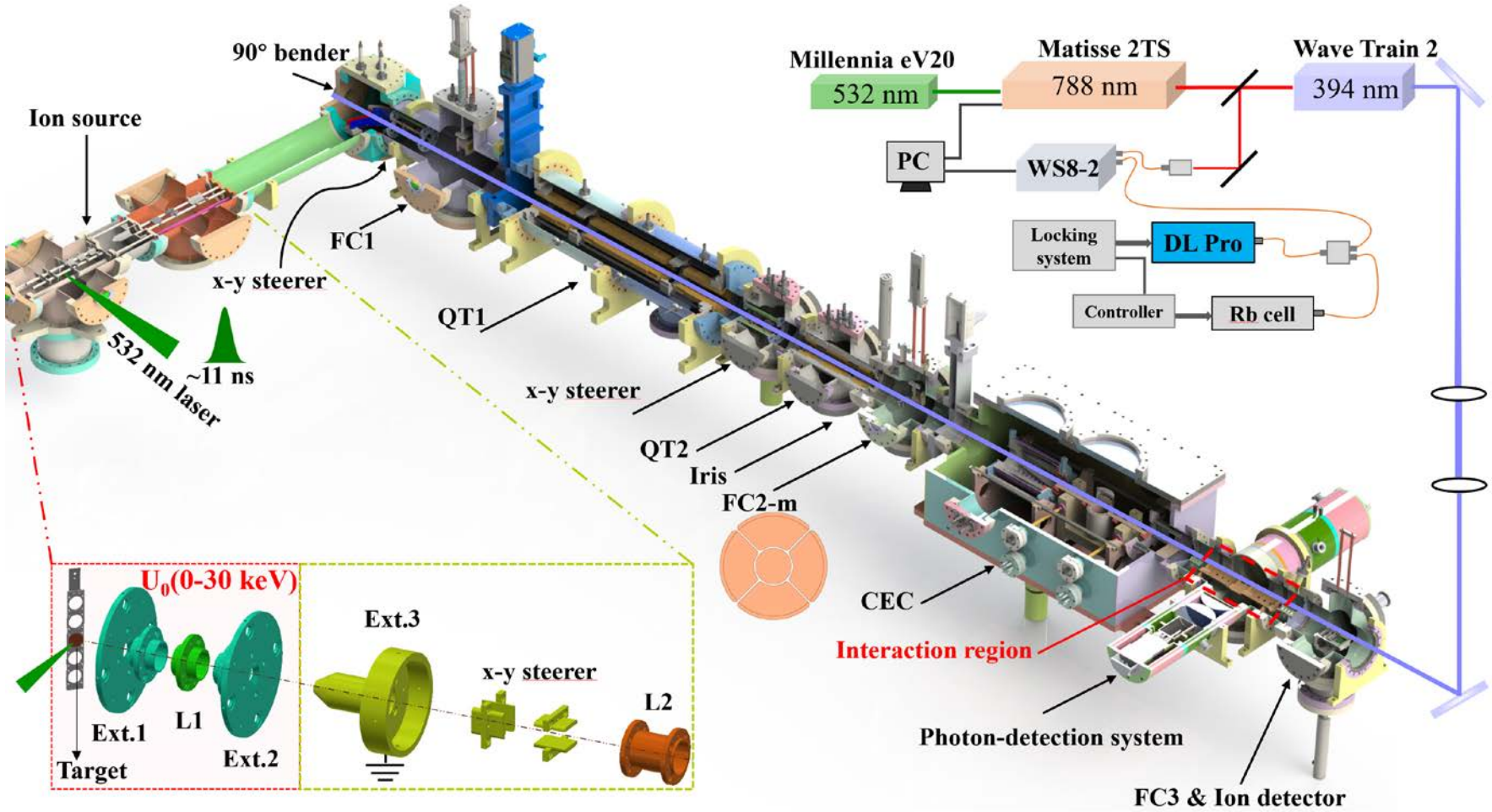


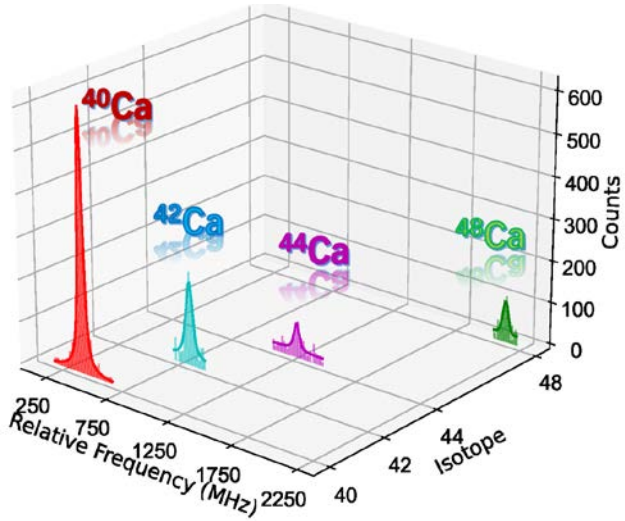


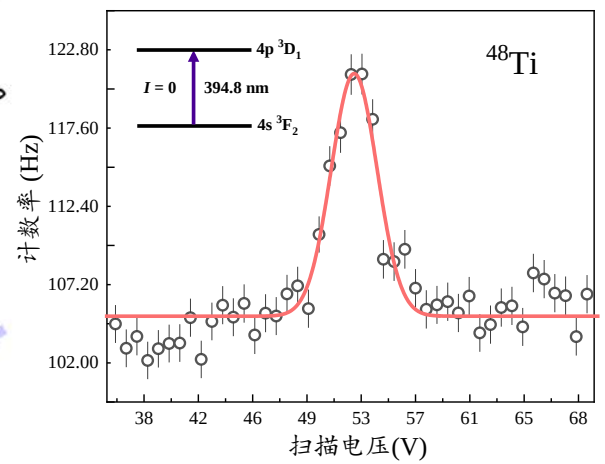


Progress of CLS development in China (PKU, CIAE, IMP, LZU) CLS offline test

The offline CLS has been tested with stable Ca/Ti beam @2021





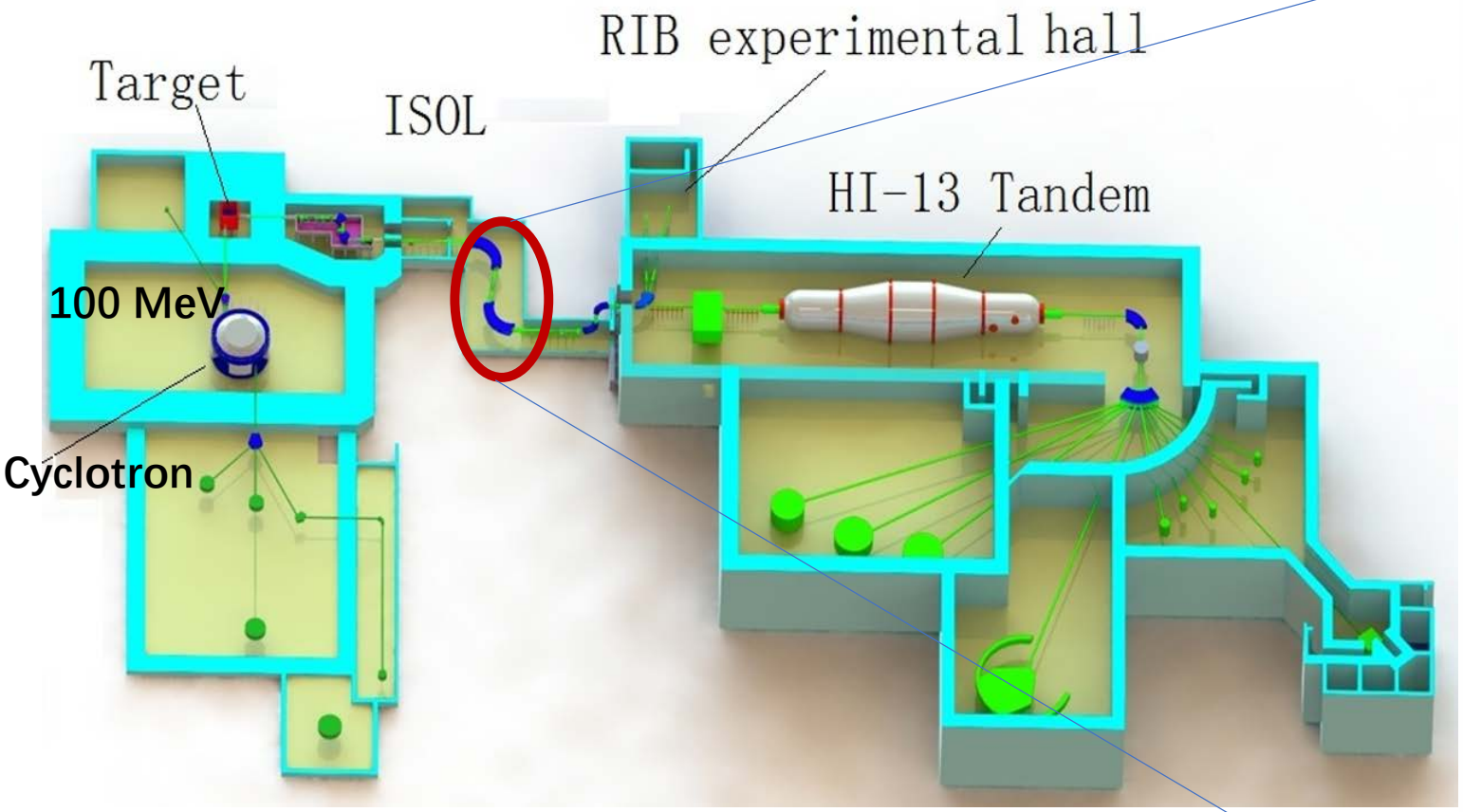


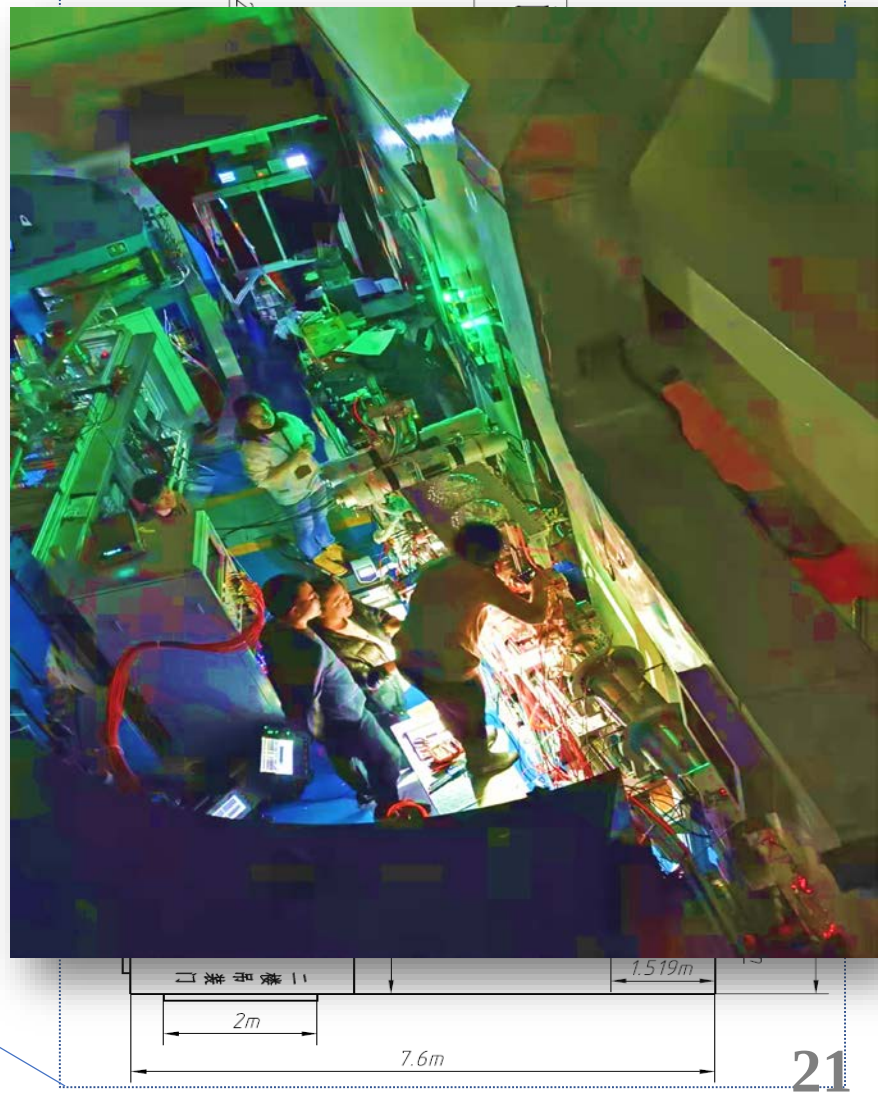
S.W. Bai, X.F. Yang et al., NST. 33, 9 (2022)* *Y.C. Bai, X.F. Yang* et al., NST. 34, 38 (2023)*

Progress of CLS development in China (PKU, CIAE, IMP, LZU)

Online commissioning

The CLS part has been commissioned at BRIF RIB facility@2021

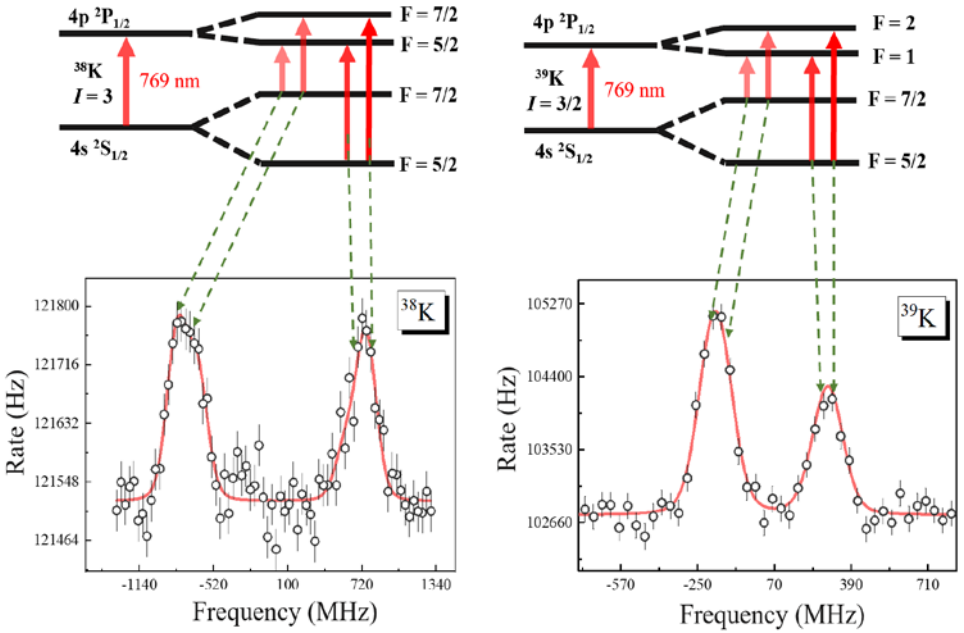




B. Tang et al., NIMB https://doi.org/10.1016/j.nimb.2019.06.003
China Institute of Atomic Energy (CIAE)

Progress of CLS development in China (PKU, CIAE, IMP, LZU)

Online commissioning



QT: Quadrupole Triplet

CEC: Charge Exchange Cell

FC: Faraday Cup

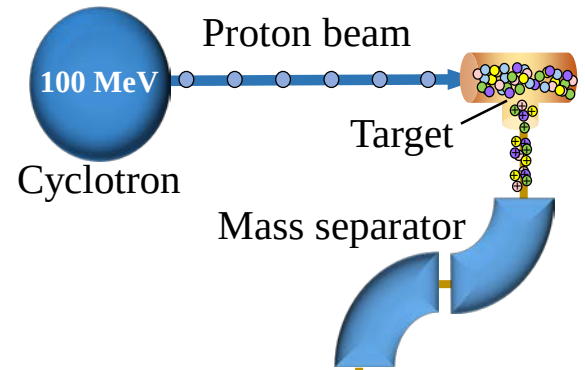
APA: Aperture array

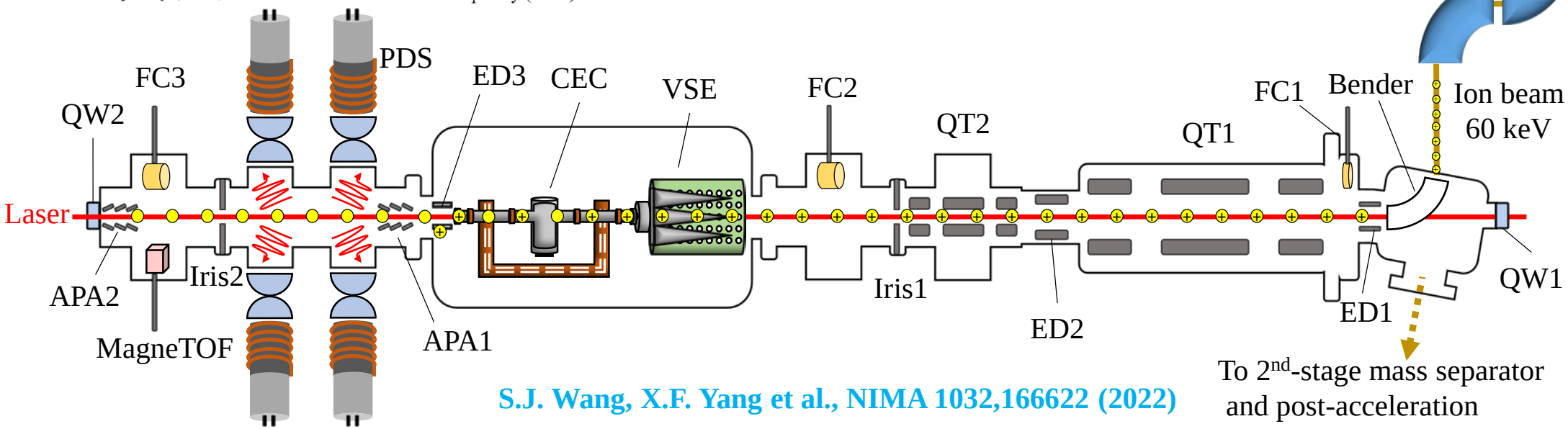
ED: Electrostatic Deflector

VSE: Voltage-scanning electrode

PDS: Photo-detection system

- **Target:** CaO
- **Ion Beam:** ^{38,39}K
- **Energy:** 60 keV
- **Continuous beam**
- **CEC: K vapor 50%**



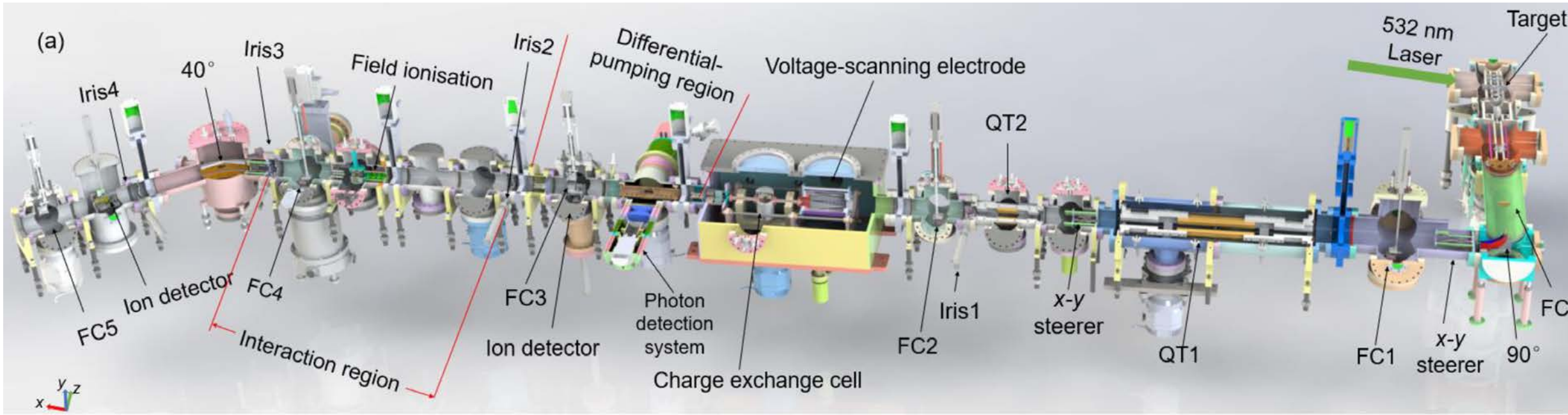


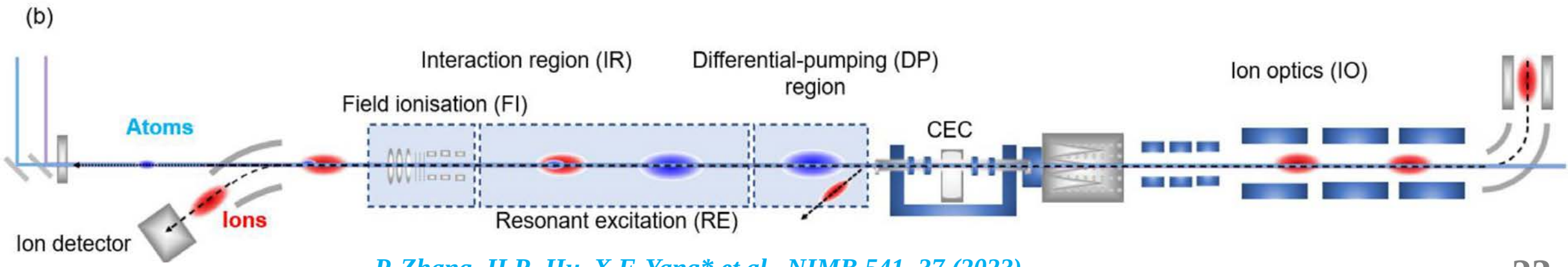
S.J. Wang, X.F. Yang et al., NIMA 1032,166622 (2022)

Progress of CLS development in China (PKU, CIAE, IMP, LZU)

CRIS setup

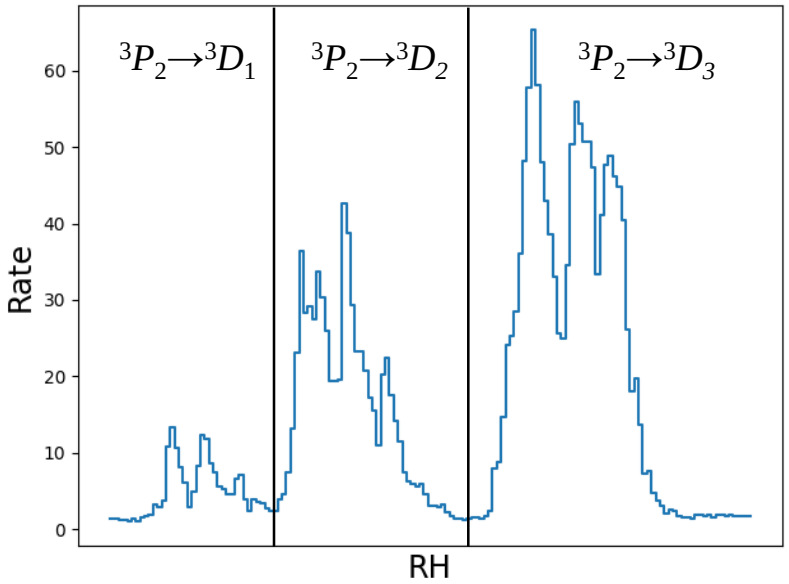
The offline CLS has been further developed into CRIS system@ 2022-2023

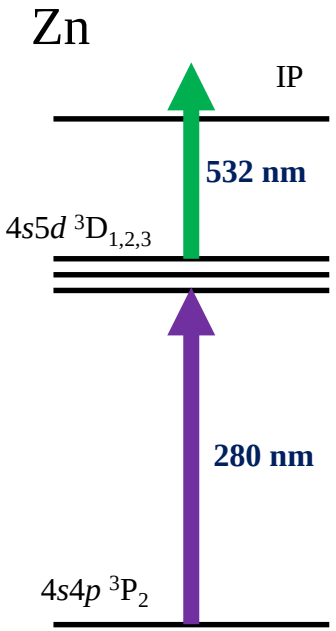


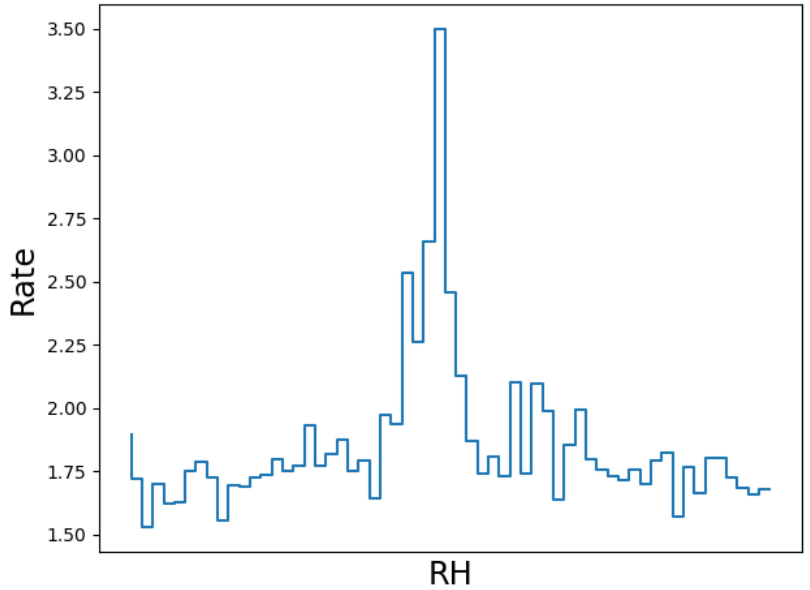


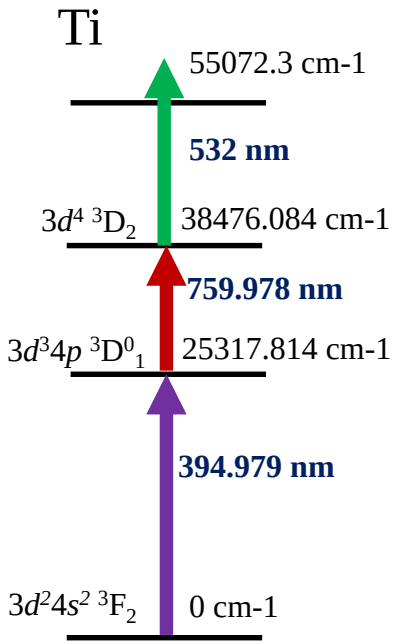
P. Zhang, H.R. Hu, X.F. Yang et al., NIMB 541, 37 (2023)*

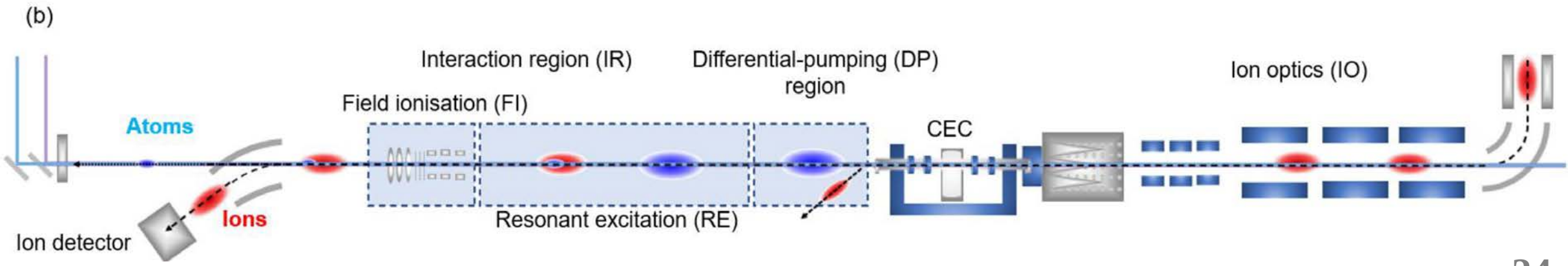
The offline CLS has been further developed into CRIS system@ 2022-2023









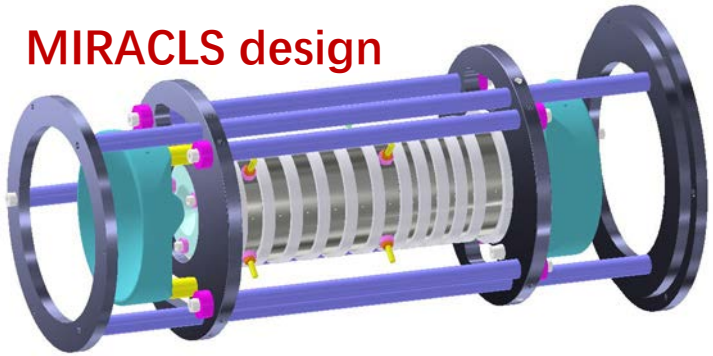


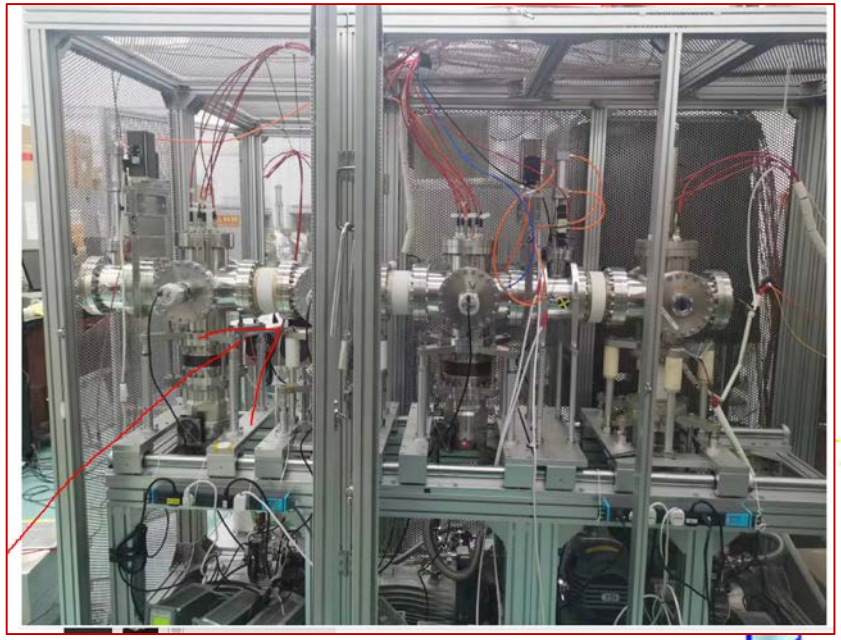
Progress of CLS development in China (PKU, CIAE, IMP, LZU)

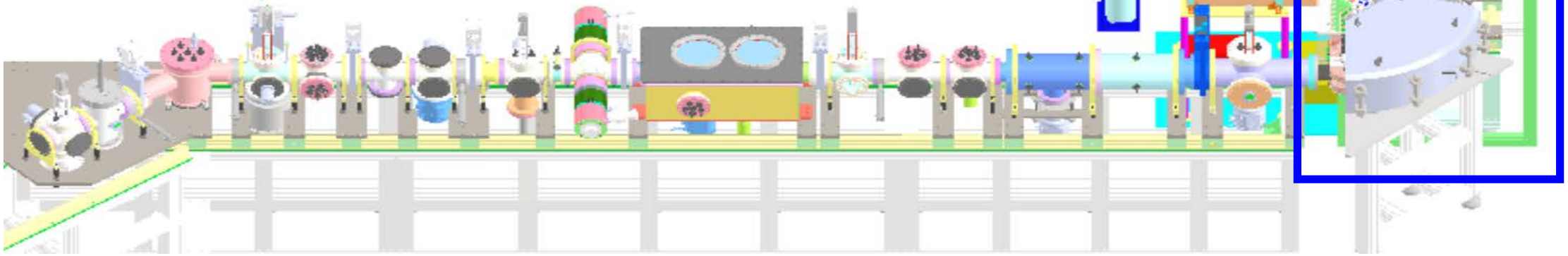
RFQ test

A RFQ and surface ion source is installed @09. 2023; RFQ test is on going

MIRACLS design







Outline

◆**Introduction to laser spectroscopy (for exotic nuclei)**

-General overview of laser spectroscopy

-Why cooled and bunched ion beams?

◆**Recent study of exotic nuclei using laser spectroscopy**

-Radii of $^{46\text{-}49}$Sc up to $N = 28$

-Moments and Radii of ^{81,82}Zn above $N = 50$

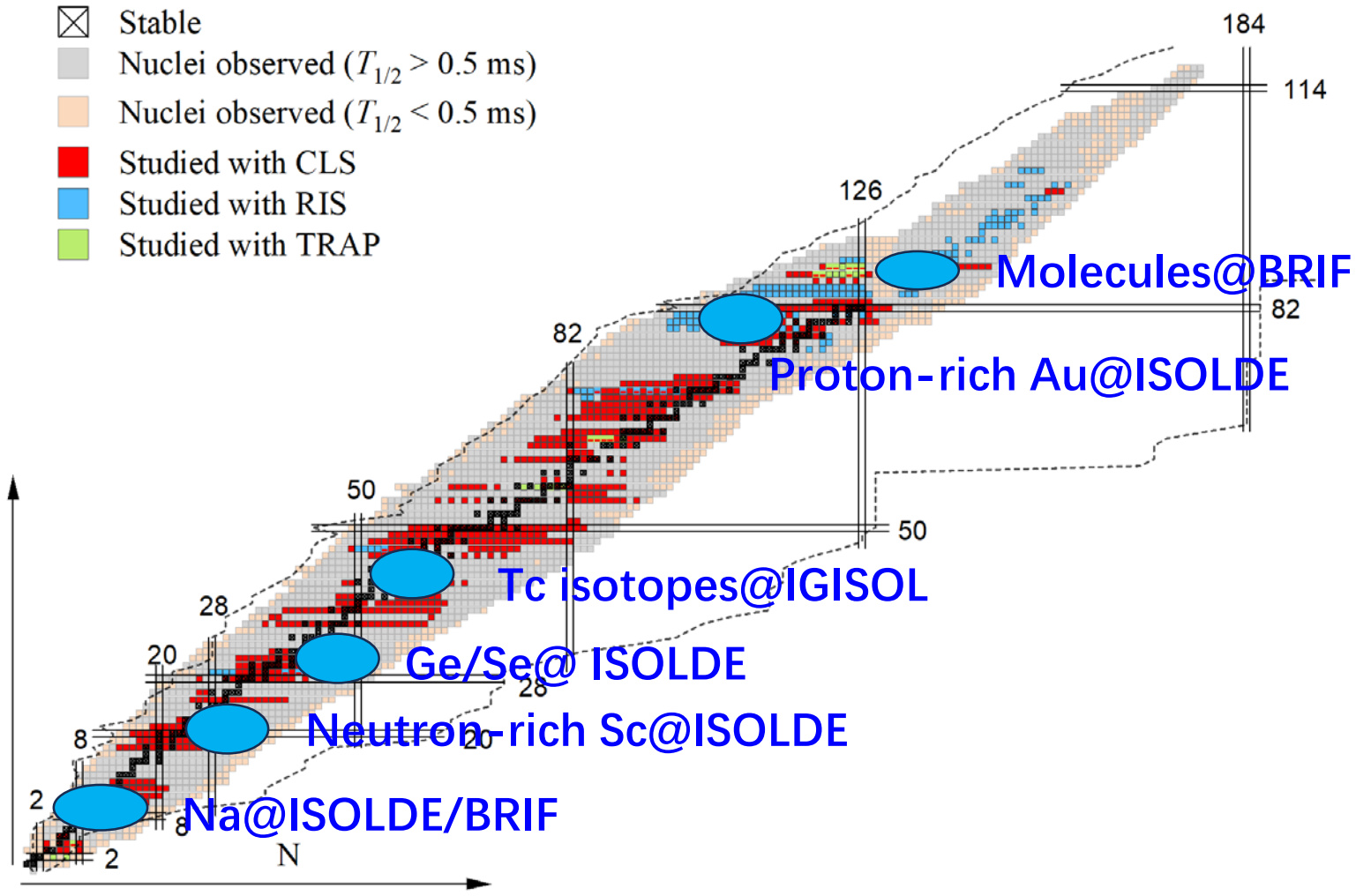
◆**Progress of CLS development in China**

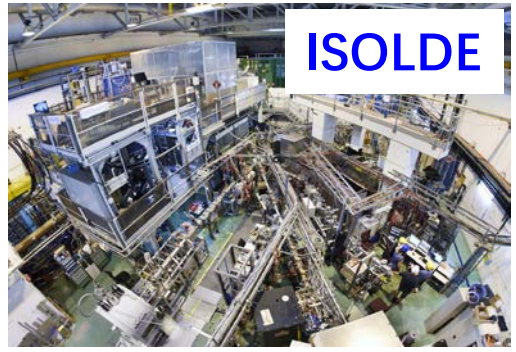
- CLS and CRIS setups

- First online-commissioning experiment at BRIF

◆**Future plans**

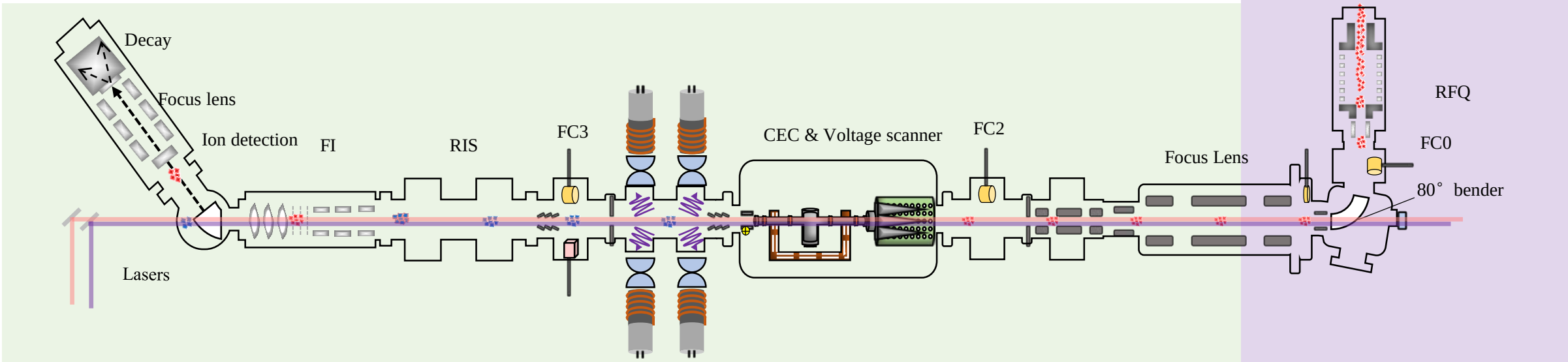
Future plans



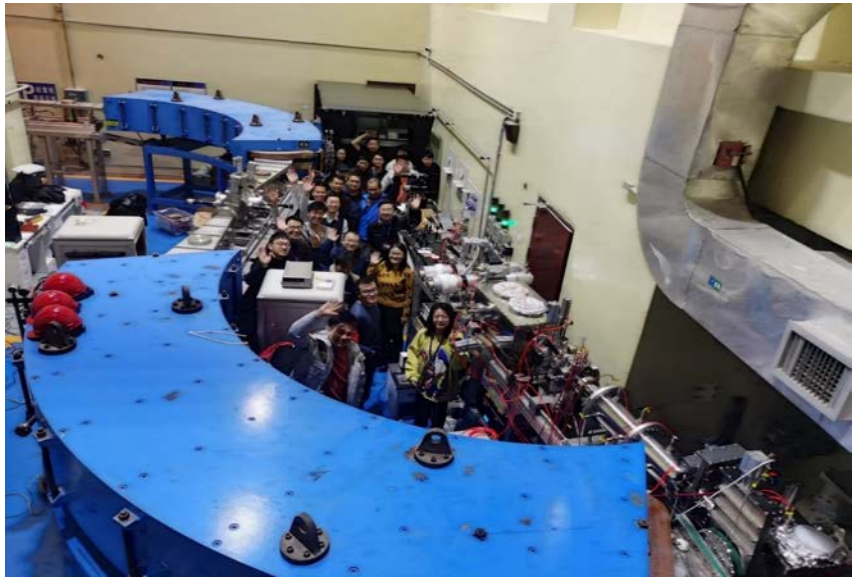


Future plans

- Online commissioning of CRIS setup and the first physics experiment at BRIF is planned for next year
- Neutron-rich Rb isotopes produced from UCx target will be measured to study the nuclear shape transition in this region
- Applying CRIS setup to the future HIAF is also considered

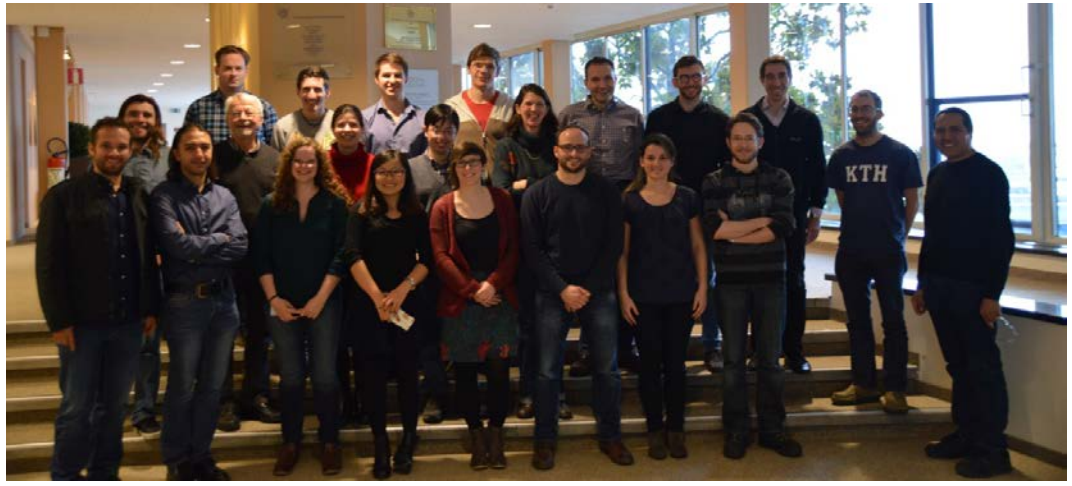


Collaboration with CIAE team



Collaboration with IMP and LZU teams

COLLAPS: *https://collaps.web.cern.ch/*



CRIS： *https://isolde-cris.web.cern.ch/*

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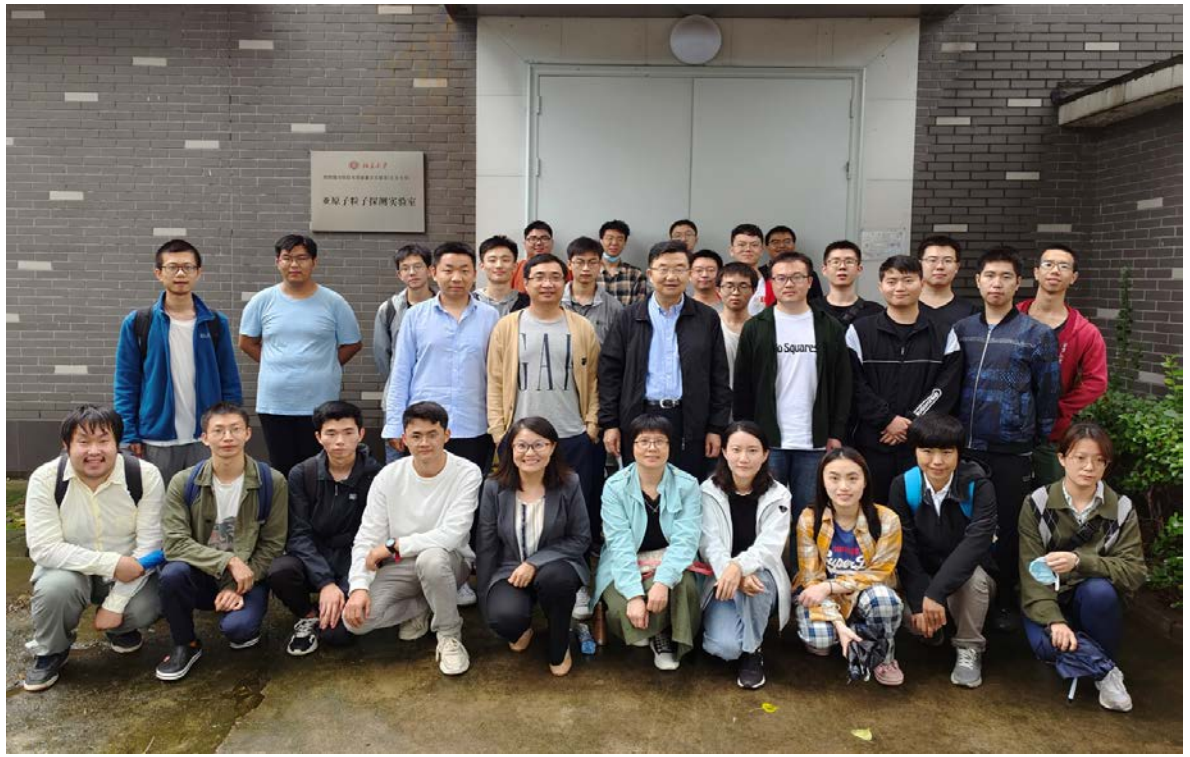
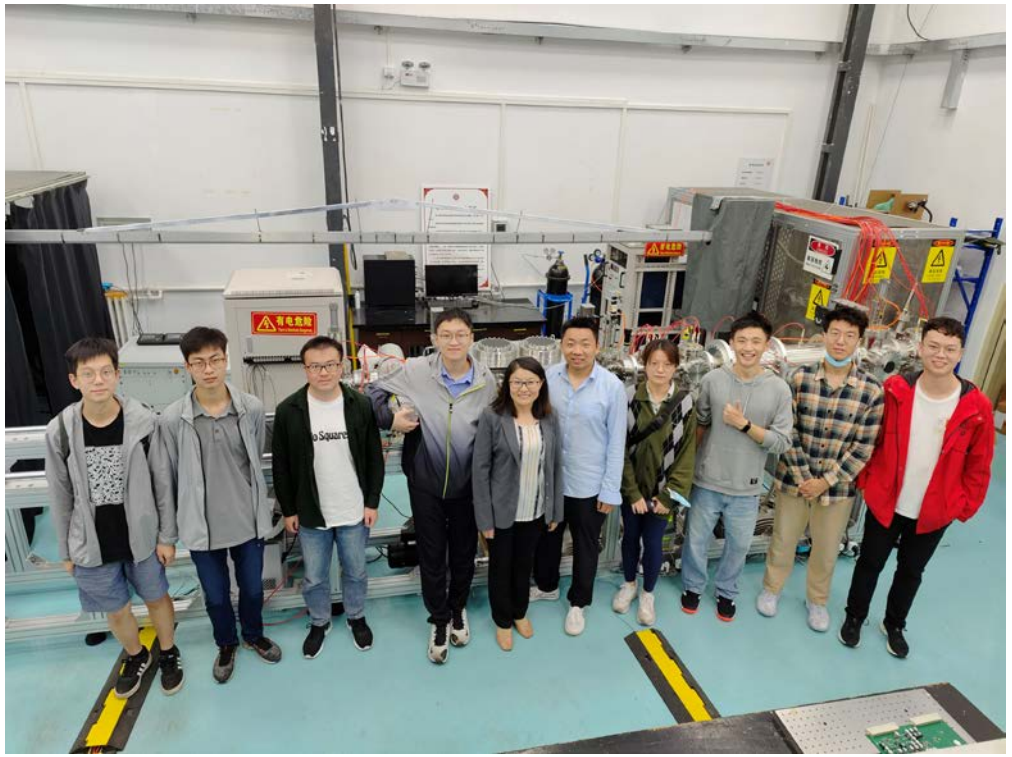
Thanks for your attention!





https://faculty.pku.edu.cn/yangxiaofei/zh_CN/index.htm