Nuclear properties and exotic structure of $^{81,82}Zn$ isotopes beyond $N = 50$ (IS682)

Speaker: Yongchao Liu on behalf of CRIS Collaboration

Peking University

ISOLDE Workshop and Users Meeting 2023

Acknowledgment

Co-authors: Xiaofei Yang [2]; Bram van den Borne [3]; Thomas E Cocolios [3]; Michail Athanasakis-Kaklamanakis [3]; Mia Au [4]; Shiwei Bai [2]; Silvia Bara [3]; Ruben P de Groote [3]; Kieran T Flanagan [5]; Ronald F Garcia Ruiz [6]; Yangfan Guo [2]; Dag Hanstorp [7]; Michael Heines [3]; Hanrui Hu [2]; Ágota Koszorús [3]; Louis A Lalanne [4]; Pierre Lassegues [3]; Razvan Lica [8]; Yinshen Liu [2]; Kara M Lynch [5]; Abi McGone [5]; Catalin Neascu [8]; Gerda Neyens [3]; Jordan R Reilly [5]; Christine Steenkamp [9]; Simon Stegemann [4]; Julius Wessolek [4]

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Outline

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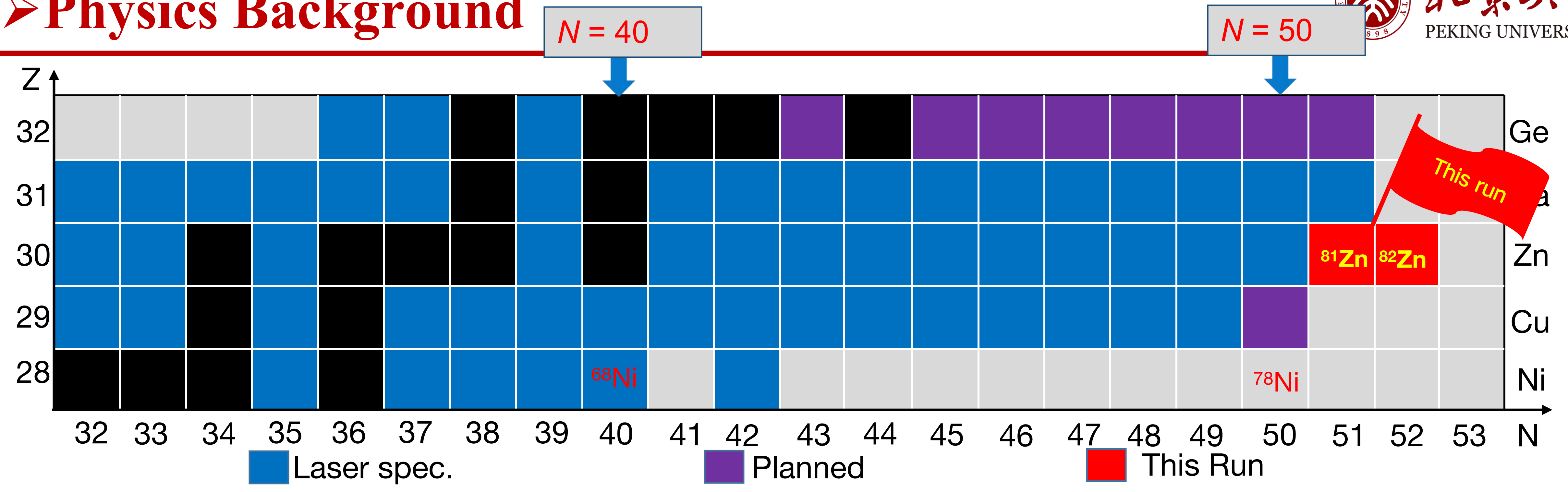
- **Physics motivation**
- **Experimental method**
  - Production of Zn isotopes
  - CRIS method
  - New decay station system
- **Results**
  - HFS spectrum for $^{81,82}Zn$
  - Ground state properties of $^{81,82}Zn$
  - Half-life measurement of $^{75g,m}Zn$

➢Physics Background



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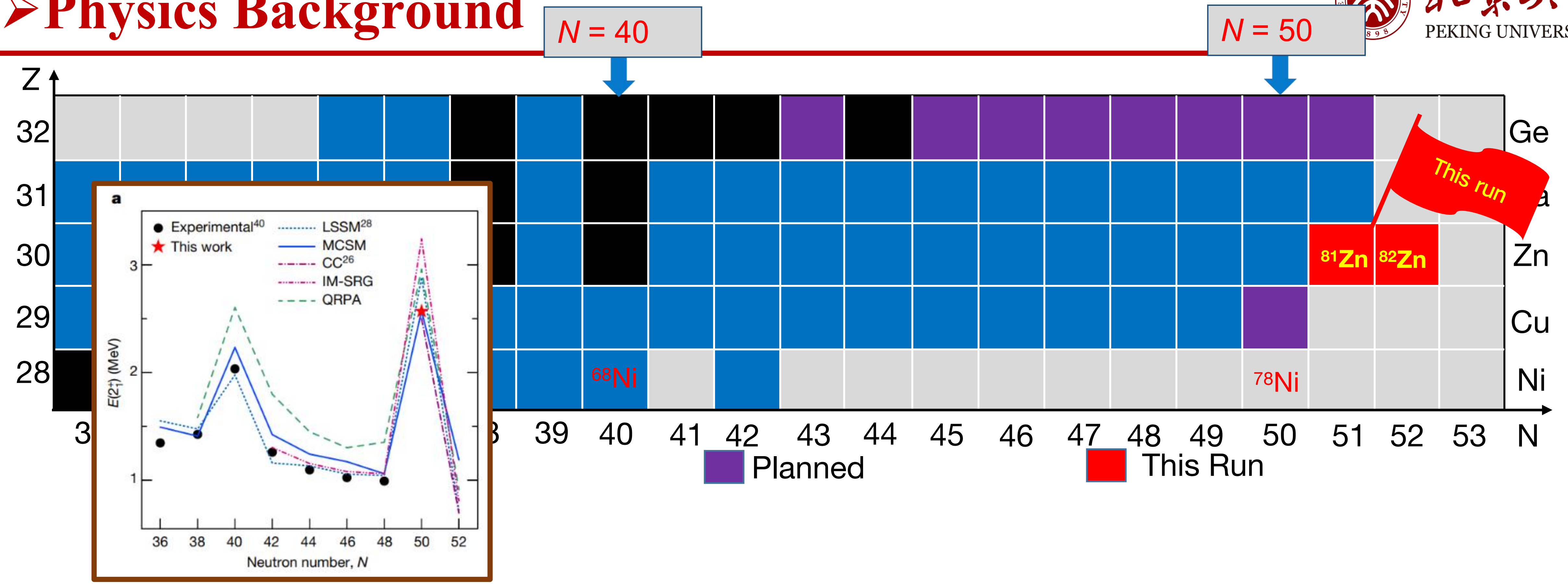

Double Magic properties and shape coexistance at ^{78}Ni[1]
Shell evolution(Cu)[2]and shape coexistence(Zn)[3]
Subshell effect at $N = 40$ on ^{68}Ni[4]
Theoretical developments (SM, DFT, ab-initio)

[1]R. Taniuchi, et al. Nature, 569, (2019) 53;
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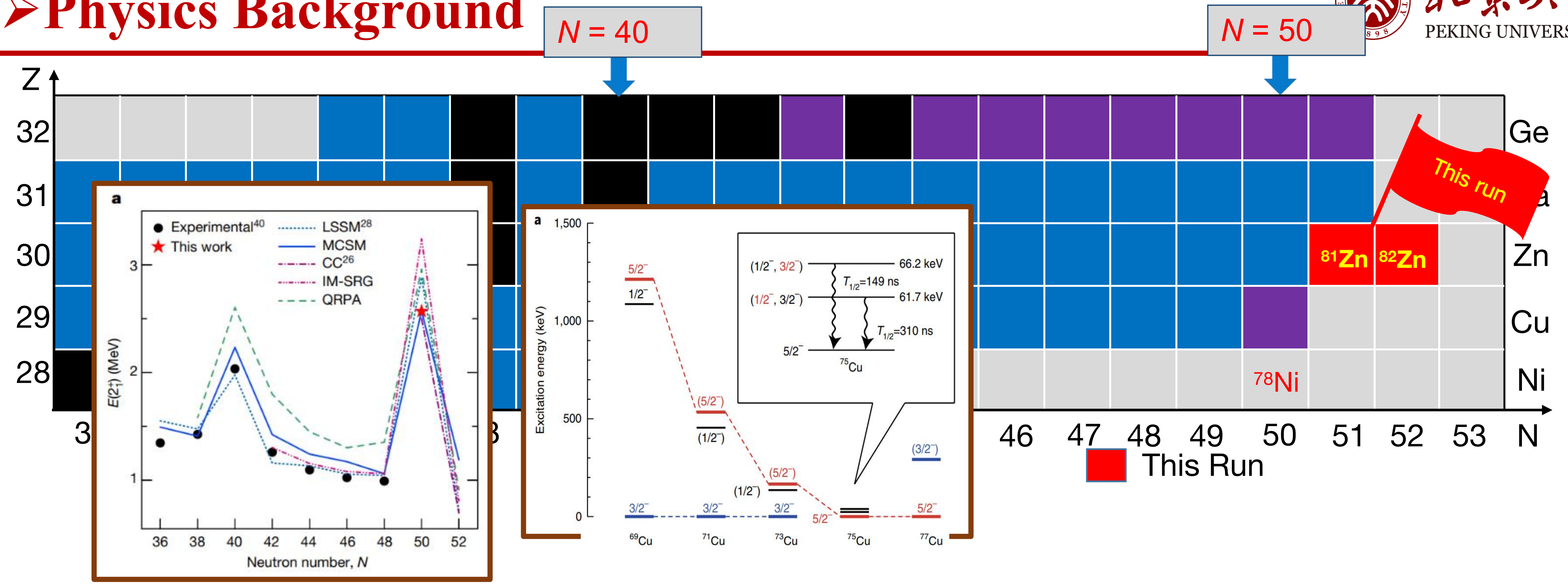

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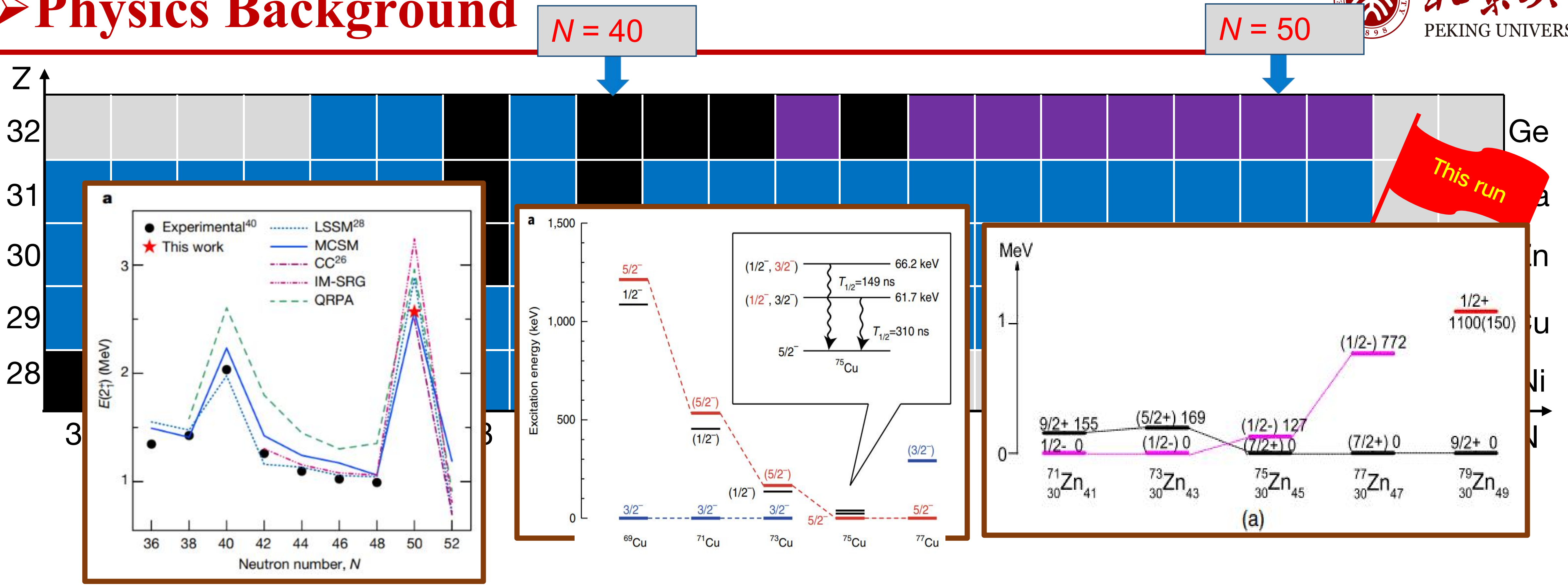

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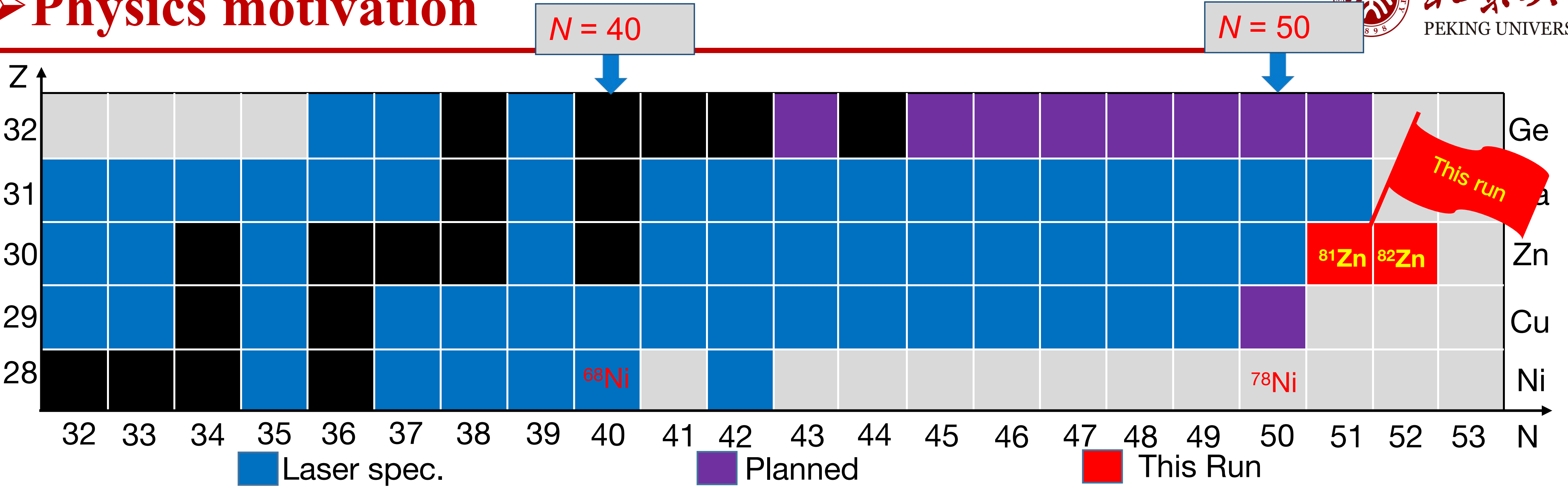
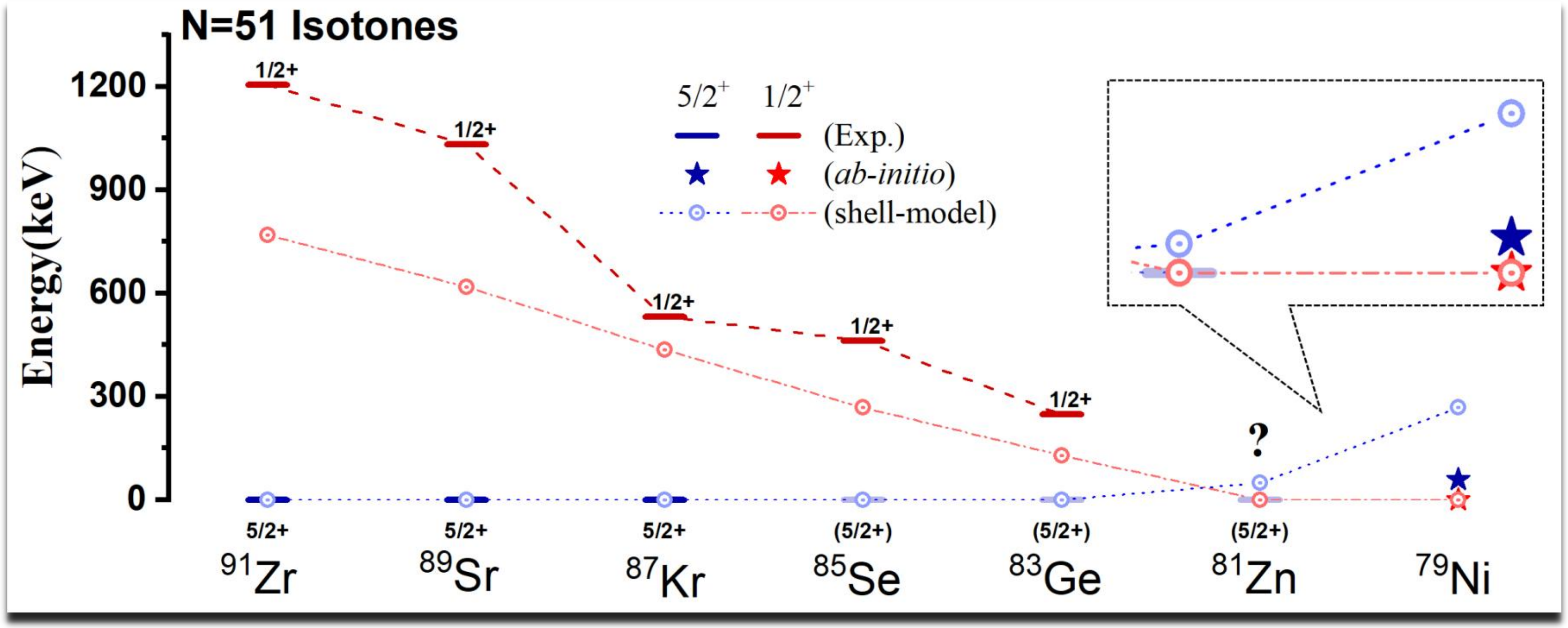
➢Physics motivation

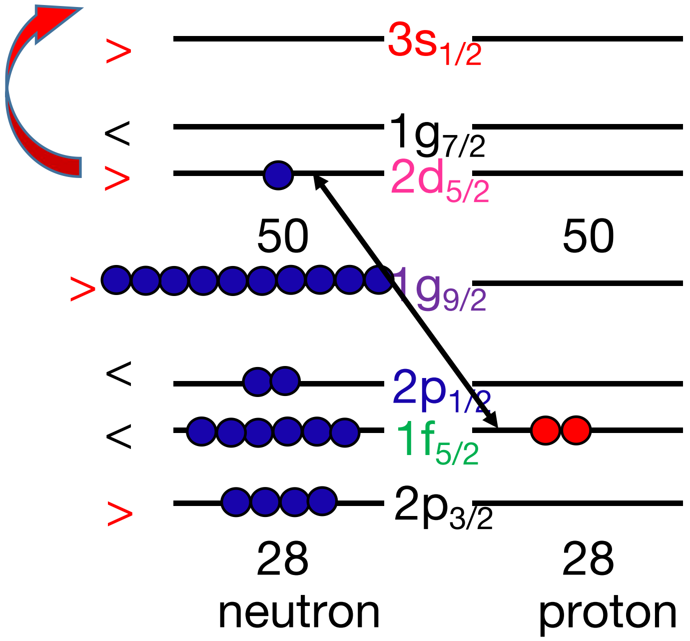


- **Investigating the ground state configuration and structure, and searching for a possible isomer state of ^{81}Zn.**
- **Studying the shell evolution and the predicted inversion of neutron single-particle orbits in the *N* = 51 isotones when approaching ^{78}Ni [1,2].**
- **Probing the magicity of *N* = 50 when approaching *Z* = 28, by measuring the charge radii up to ^{82}Zn [3].**

[1] R. Taniuchi, C. Santamaria, P. Doornenbal, et al. *Nature* **569** (2019), 53. [2] G. Hagen, G. R. Jansen, and T. Papenbrock, *Physical Review Letters* **117**, (2016), 172501. [3] X. Yang, T. Cocolios, S. Geldhof, et al. CERN-INTC CERN-INTC-2020-064 (2020) INTC–P–579.

➤Physics motivation: shell evolution on $N = 51$





- ***N* = 51 isotones: energy drop of the ½+ state**
- **SM calculation (jj45pna) : ½+ become g.s. in ^{81}Zn**

- ***Ab-initio* calculation: ½+ become g.s. in ^{79}Ni**

Tensor force effect

Otsuka, et al. Rev Mod Phys, 92 (2020)

Continuous effect

G. Hagen, et al. PRL 117 (2016)172501

➢Physics motivation: spin and nuclear moments of ^{81}Zn

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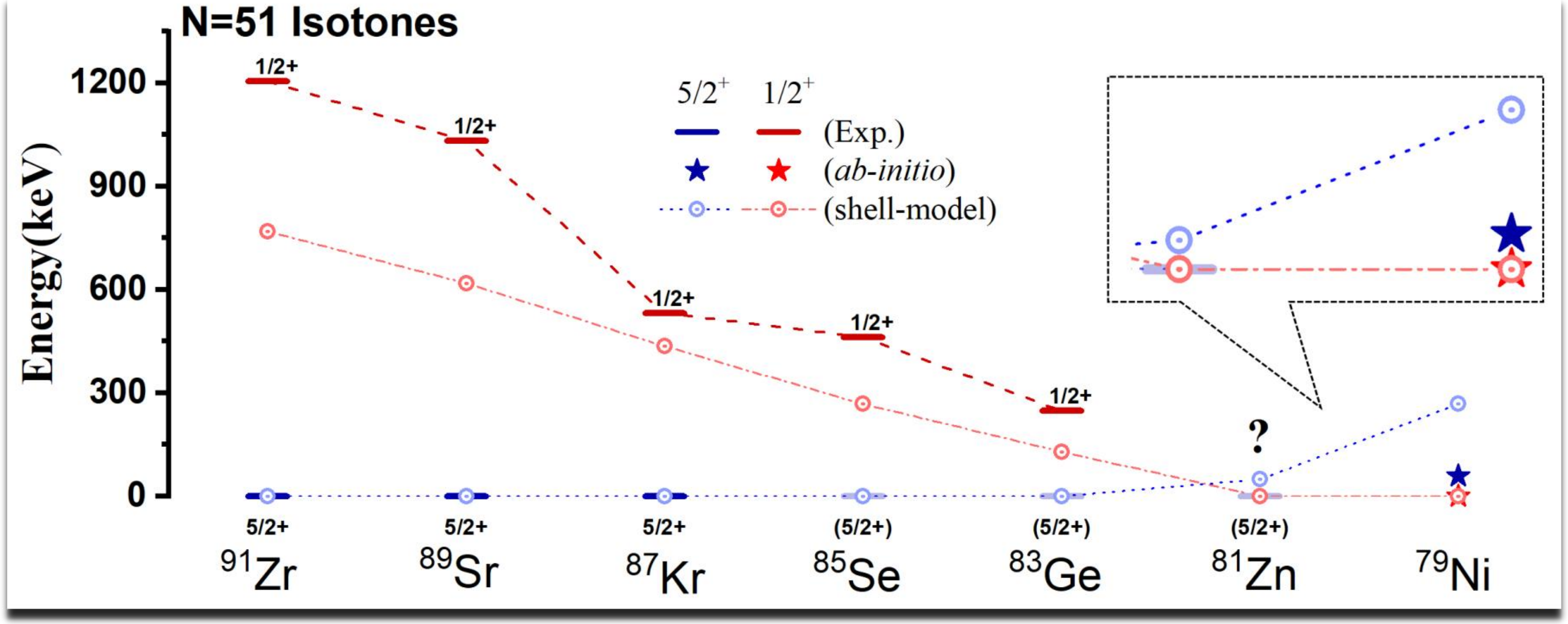

Spin:

PRC76(2007) 054312

($1/2^+$) g.s.

PRC82(2010)064314

($5/2^+$) g.s.

PRC102(2020)014329

($5/2^+$ or $1/2^+$) g.s.

Nuclear Moments:

- **Single-particle state or configuration mixing?**
- **Spherical or deformed?**

$[s^1_{1/2}]\,1/2^+$ or $[2^+ \otimes d^1_{5/2}]\,1/2^+$??

- **Require the magnetic and quadrupole moments measurement of ^{81}Zn**
  =>providing stringent test for the nuclear theoretical models

➢Physics motivation: nuclear charge radii of ^{81,82}Zn

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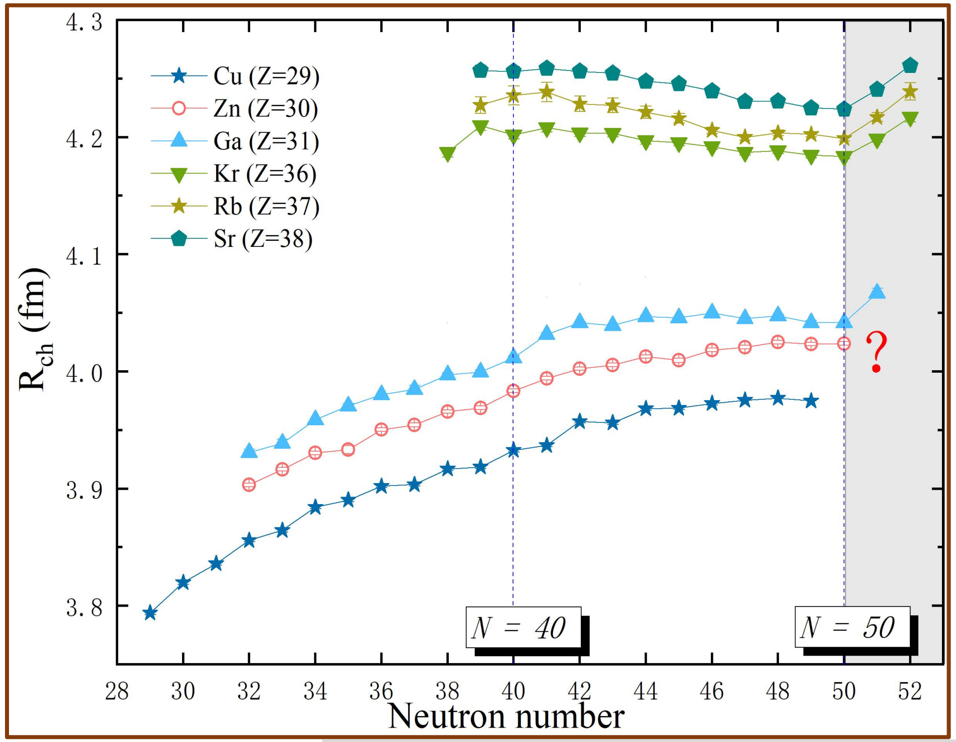
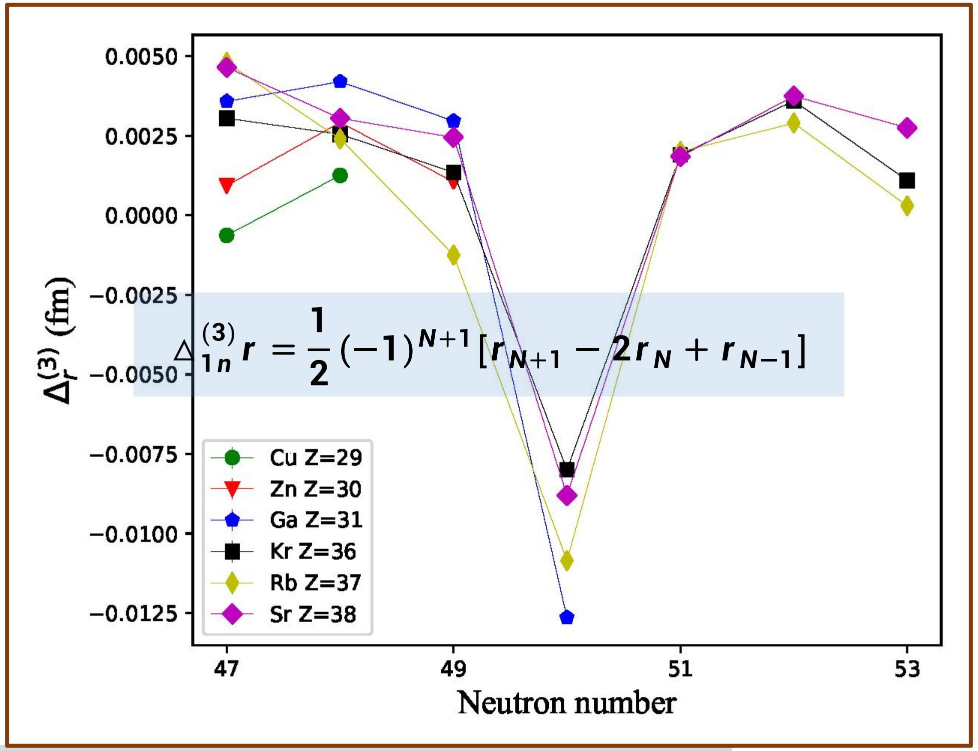
- Approaching $Z = 28$, charge radii data above $N = 50$ are limited!
- $N = 50$ magic effect in the charge radii of isotopes closed to ^{78}Ni?
- Magic effect can be better observed as a local inversion of the OES!





- **Require the charge radii measurement of ^{81,82}Zn.**

  =>providing test for the state-of-the-art nuclear theories

[Zn-Radii]L. Xie et al., PLB797(2019)134805; [Cu-Radii]R. P. de Groote et al., Nat.Phys16(2020)620

➢Experimental method: CRIS beamline

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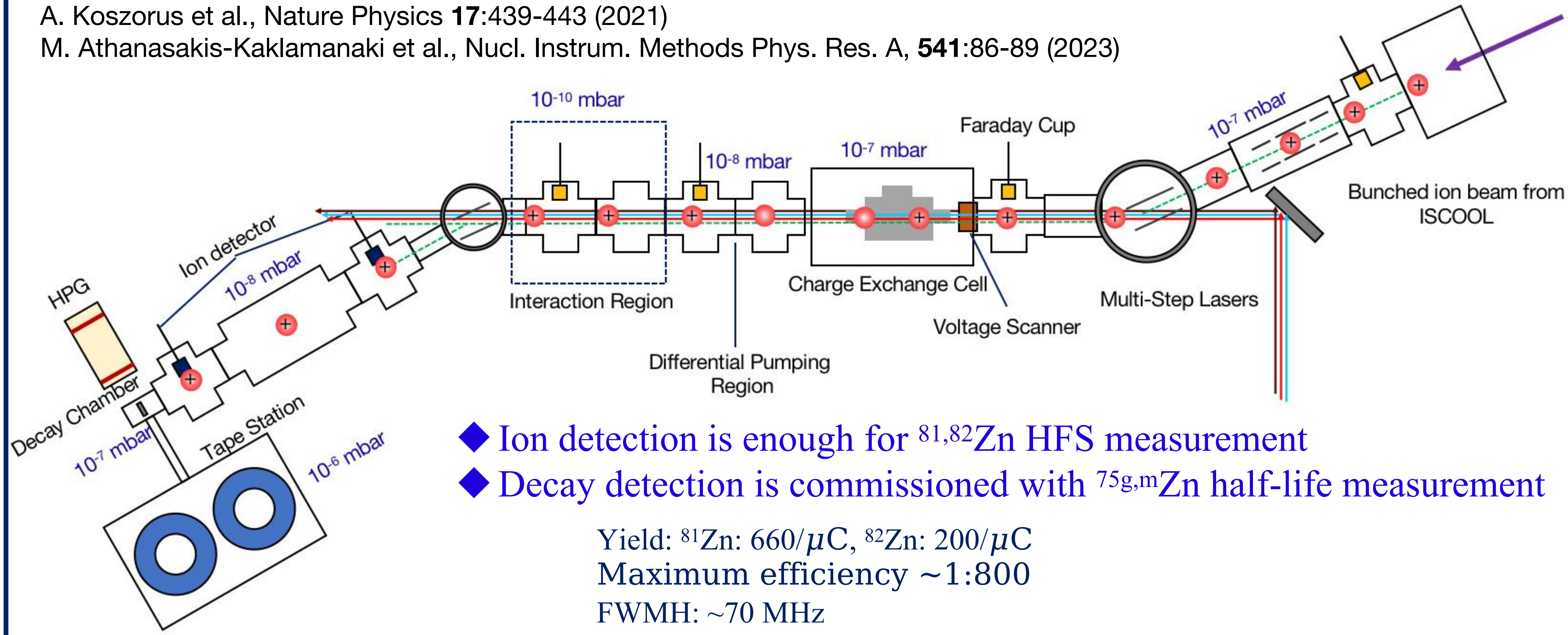
A. Koszorus et al., Nature Physics **17**:439-443 (2021)
M. Athanasakis-Kaklamanaki et al., Nucl. Instrum. Methods Phys. Res. A, **541**:86-89 (2023)



- ◆ Ion detection is enough for ^{81,82}Zn HFS measurement
- ◆ Decay detection is commissioned with ^{75g,m}Zn half-life measurement

Yield: ^{81}Zn: 660/μC, ^{82}Zn: 200/μC
Maximum efficiency ~1:800
FWMH: ~70 MHz

Low background, high resolution, high efficiency!!!

➢Experimental method: main difficulties

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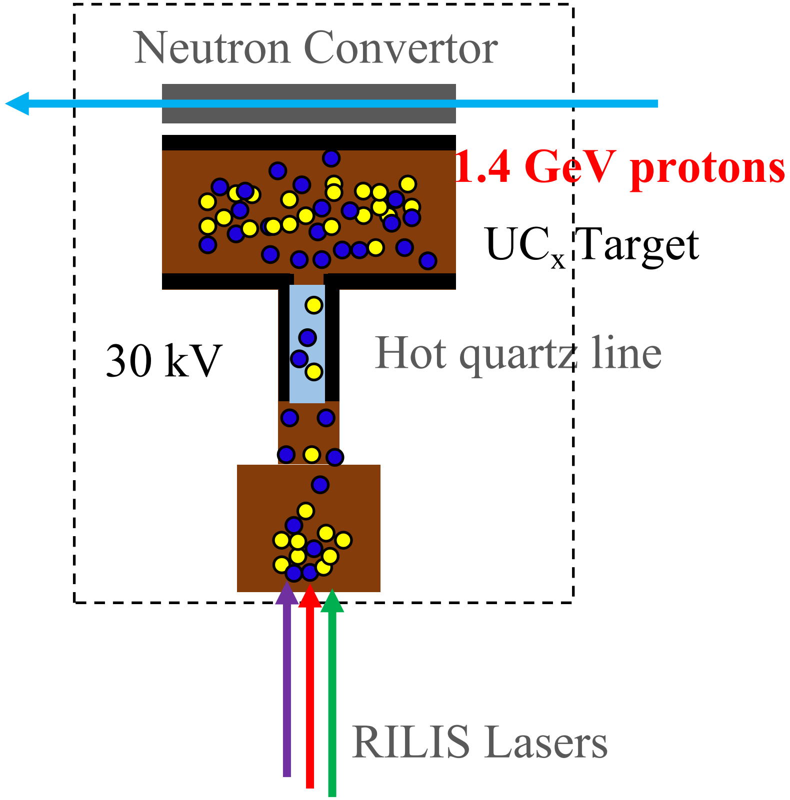
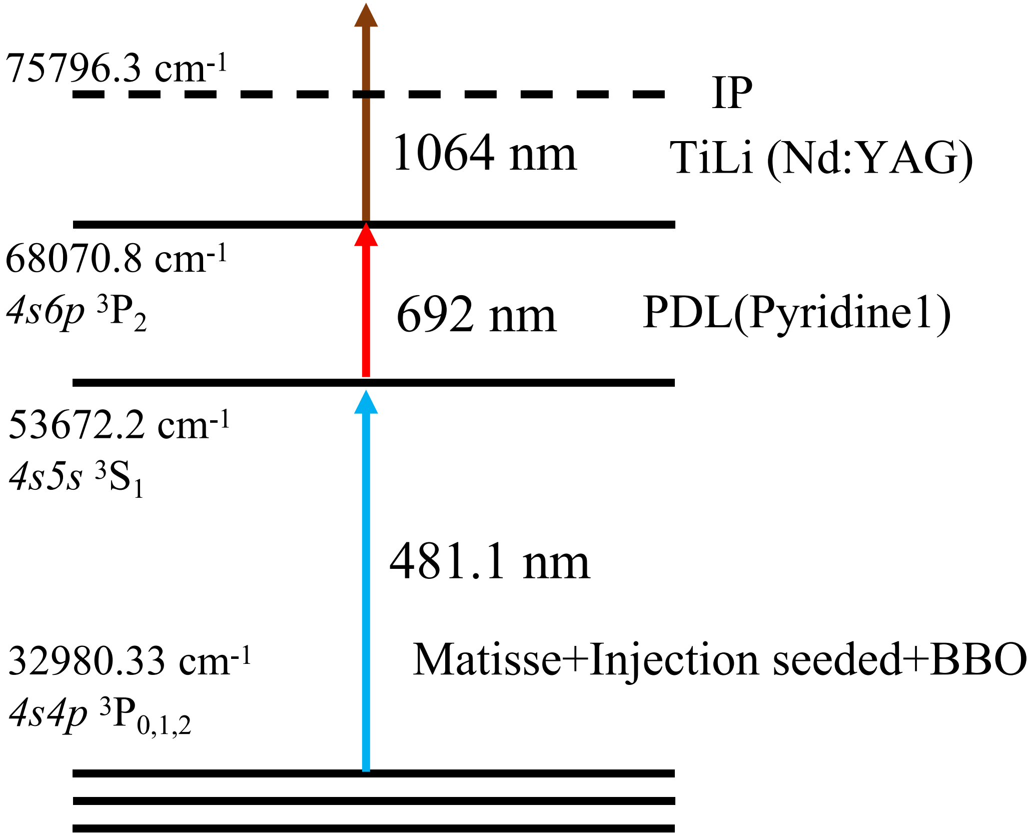
Suppress Rb contamination



In Zn run, the ISOLDE target group combined the **neutron convertor**[1] and **hot quartz line**[2] to suppress the Rb background

[1]https://doi.org/10.1016/j.nimb.2014.04.026
[2]https://doi.org/10.1016/j.nimb.2008.05.060

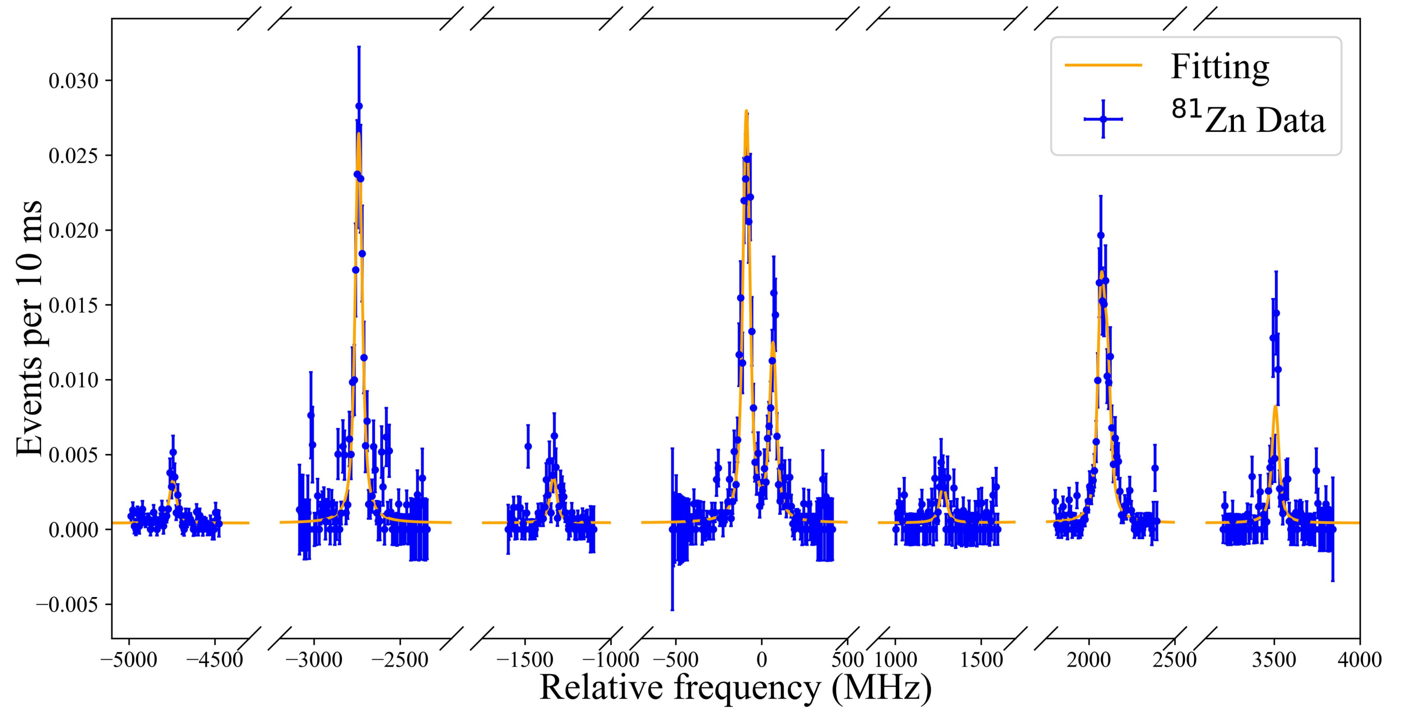
Ionization scheme for Online Experiment

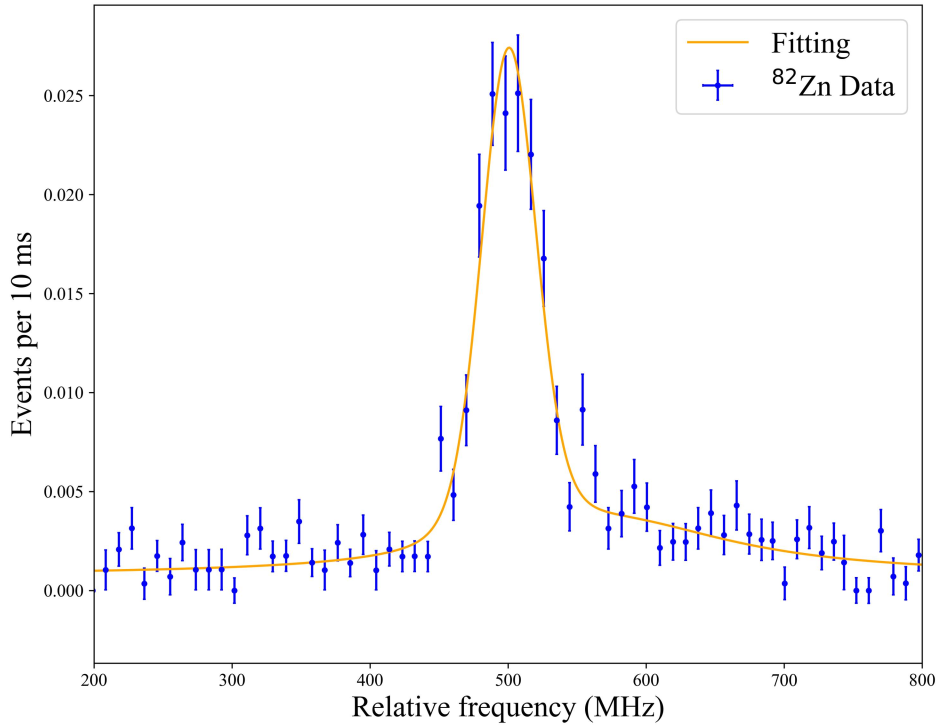


The first transtiion has been studied at COLLAPS [PRL116(2016)182502]

➢Results: HFS spectrum of ground state ^{81,82}Zn

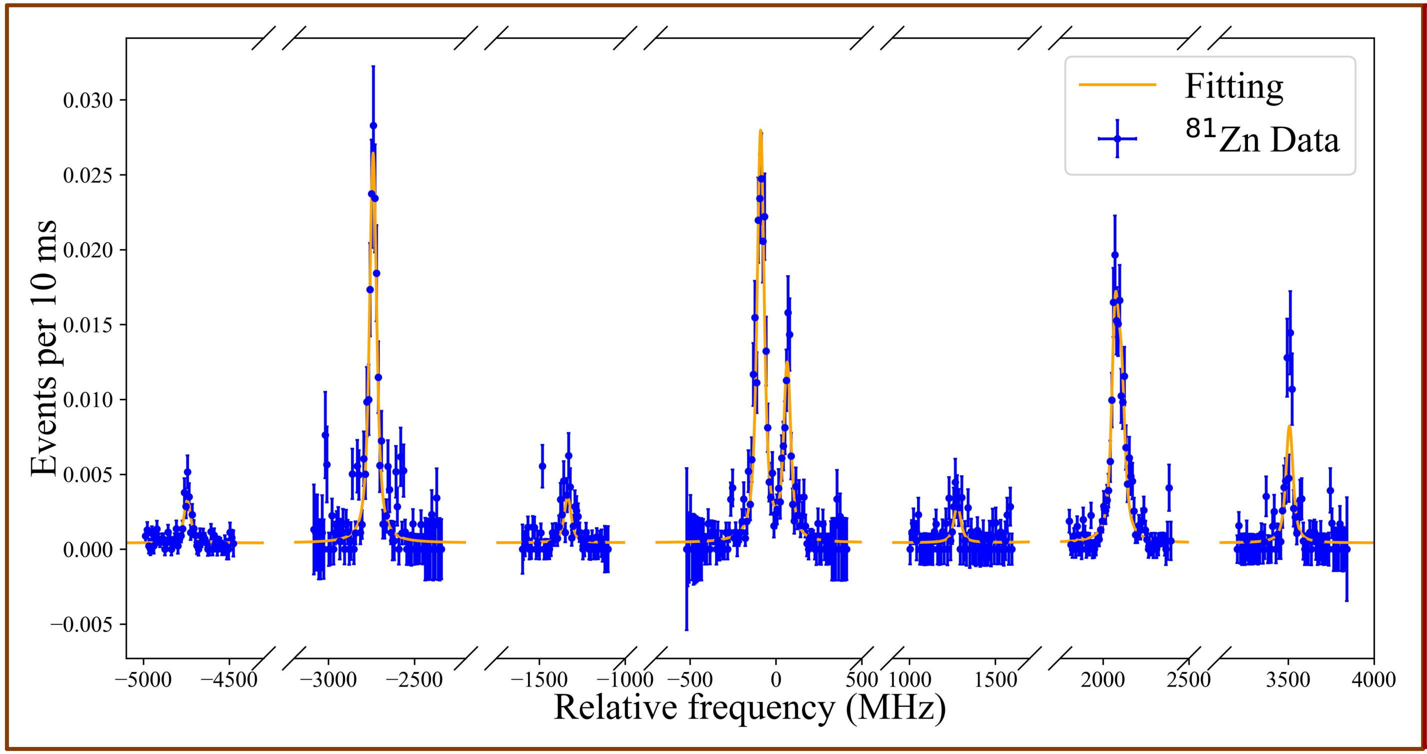
Laser Spectroscopy of ^{81,82}Zn isotopes for *4s4p* $^3P_2$ ⟶ *4s5s* $^3S_1$

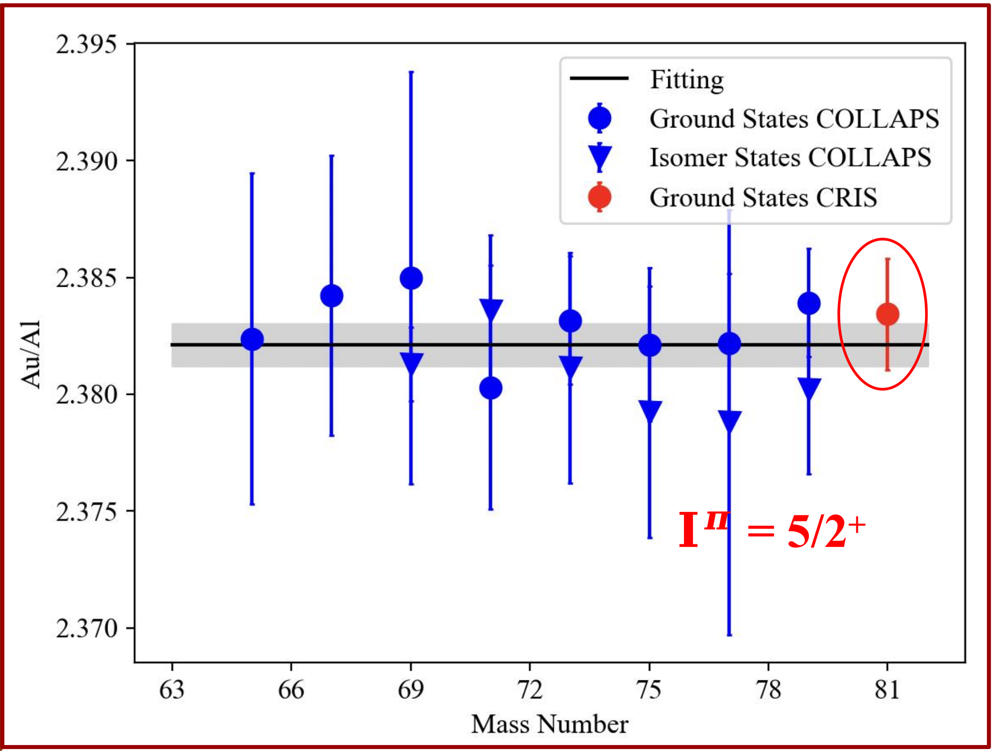




➢Results: HFS spectrum of ground state $^{81,82}Zn$

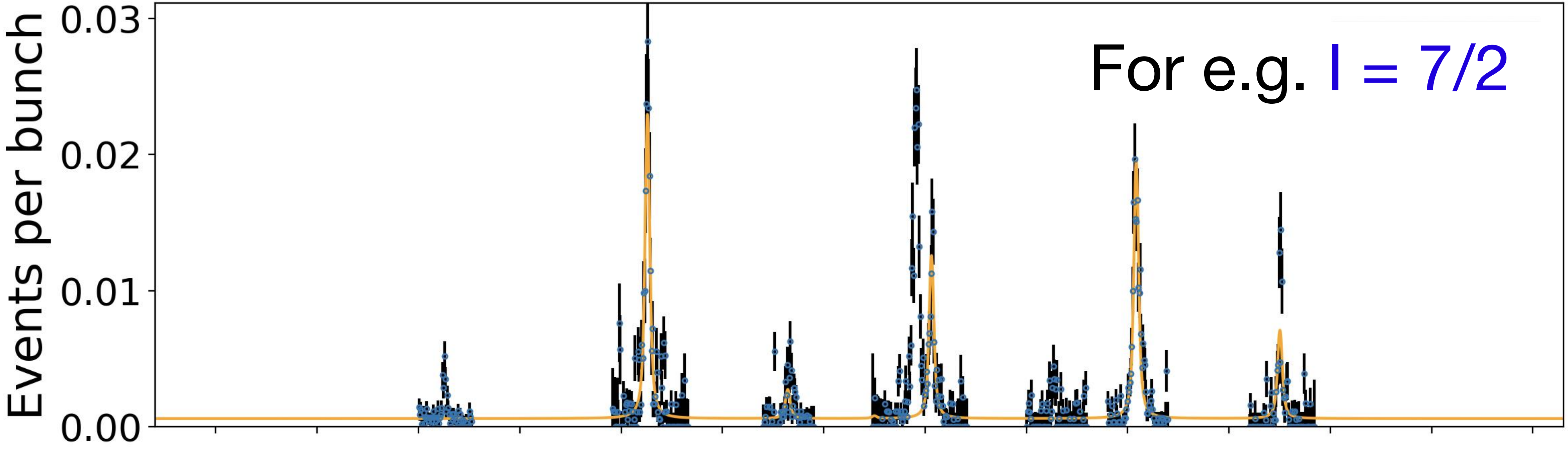
I^{π} = 5/2⁺ ground state is confirmed!!





For spin = 3/2 or 7/2, the HFS peaks cannot fit with the data

➢Results: HFS spectrum of ground state $^{81,82}Zn$



For spin = 3/2 or 7/2, the HFS peaks cannot fit with the data

➢Results: Spin electromagnetic moments of ^{81,82}Zn

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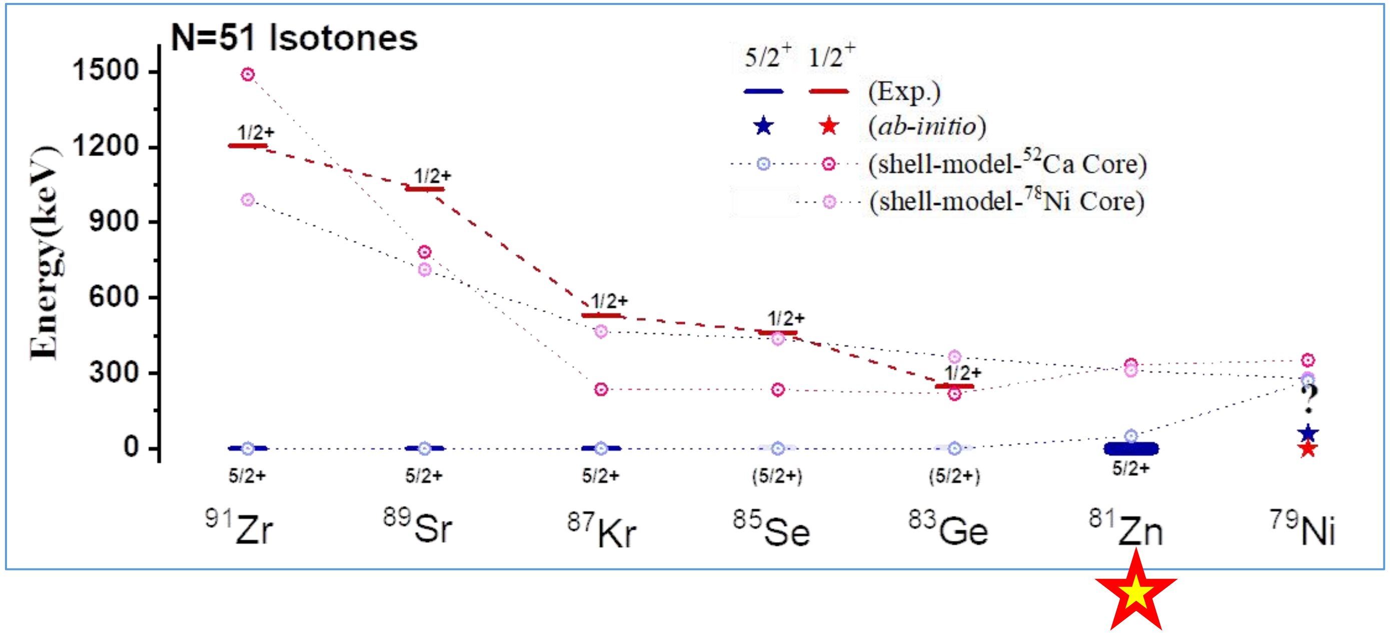

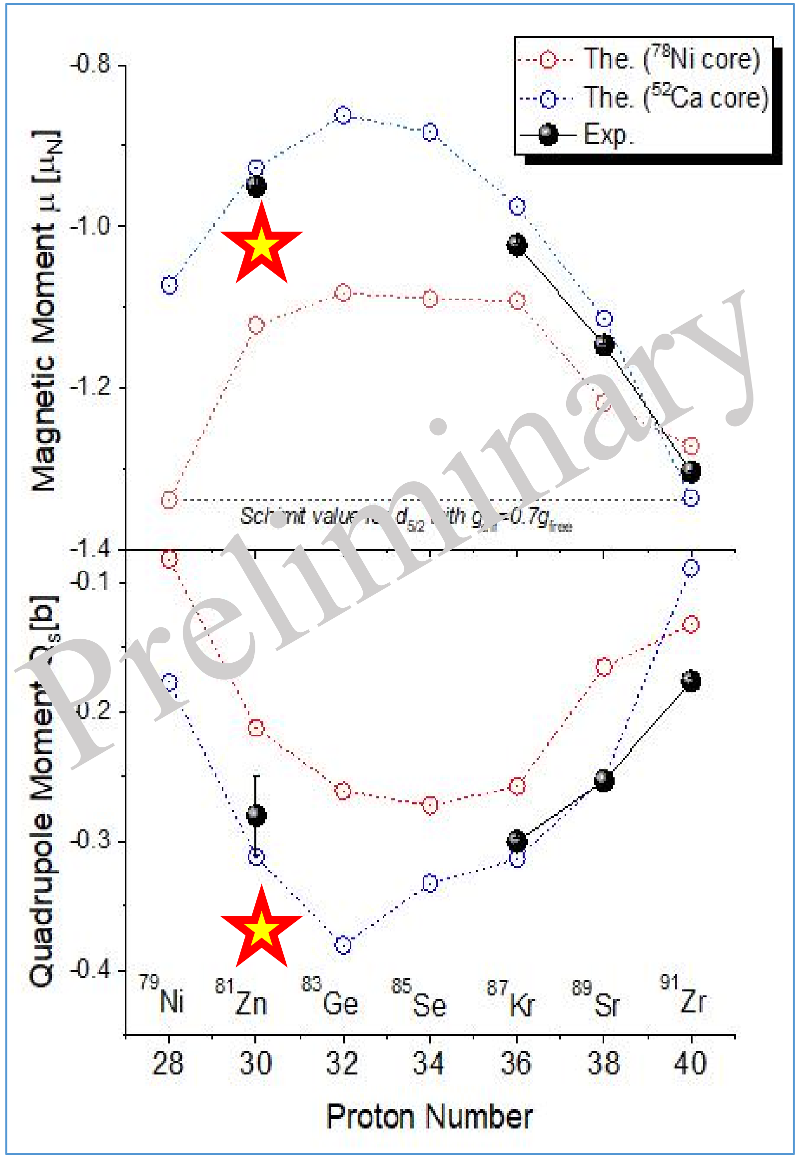

- G.S. Spin of ^{81}Zn is now firmly assigned to be $5/2^+$
- SM calculation shows core excitations of ^{78}Ni is needed to reproduce the moments of ^{81}Zn

➤Results: charge radii of $^{81,82}Zn$

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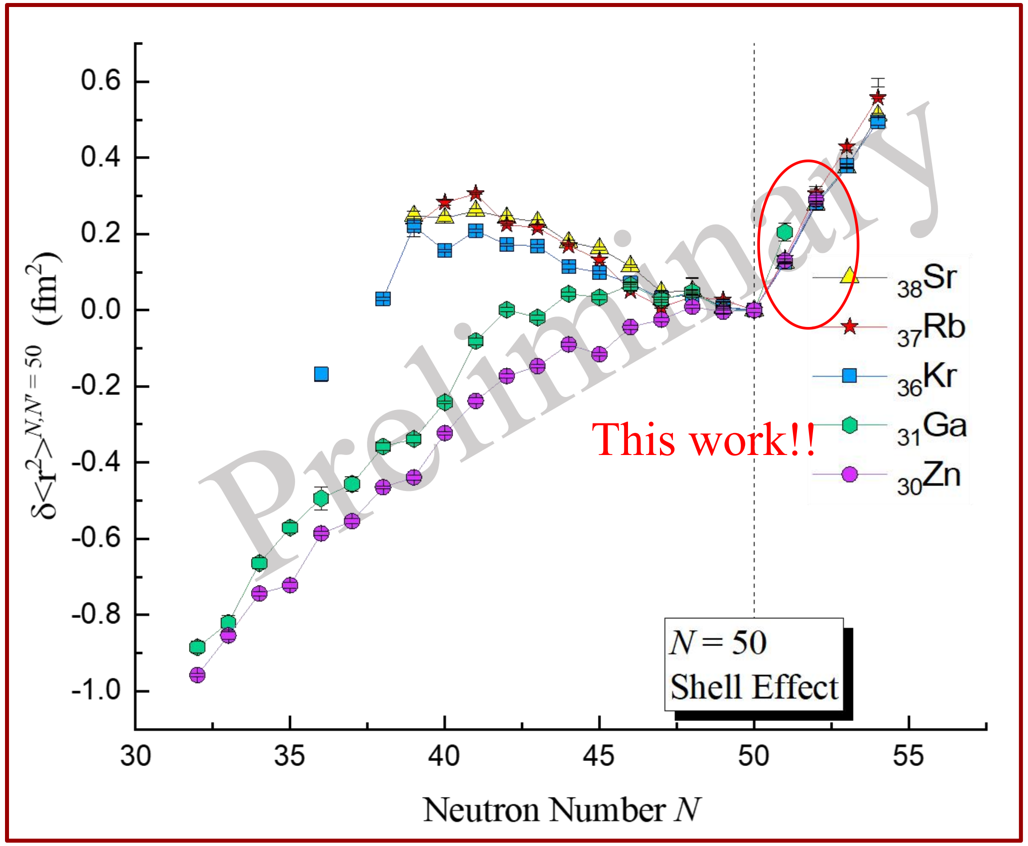
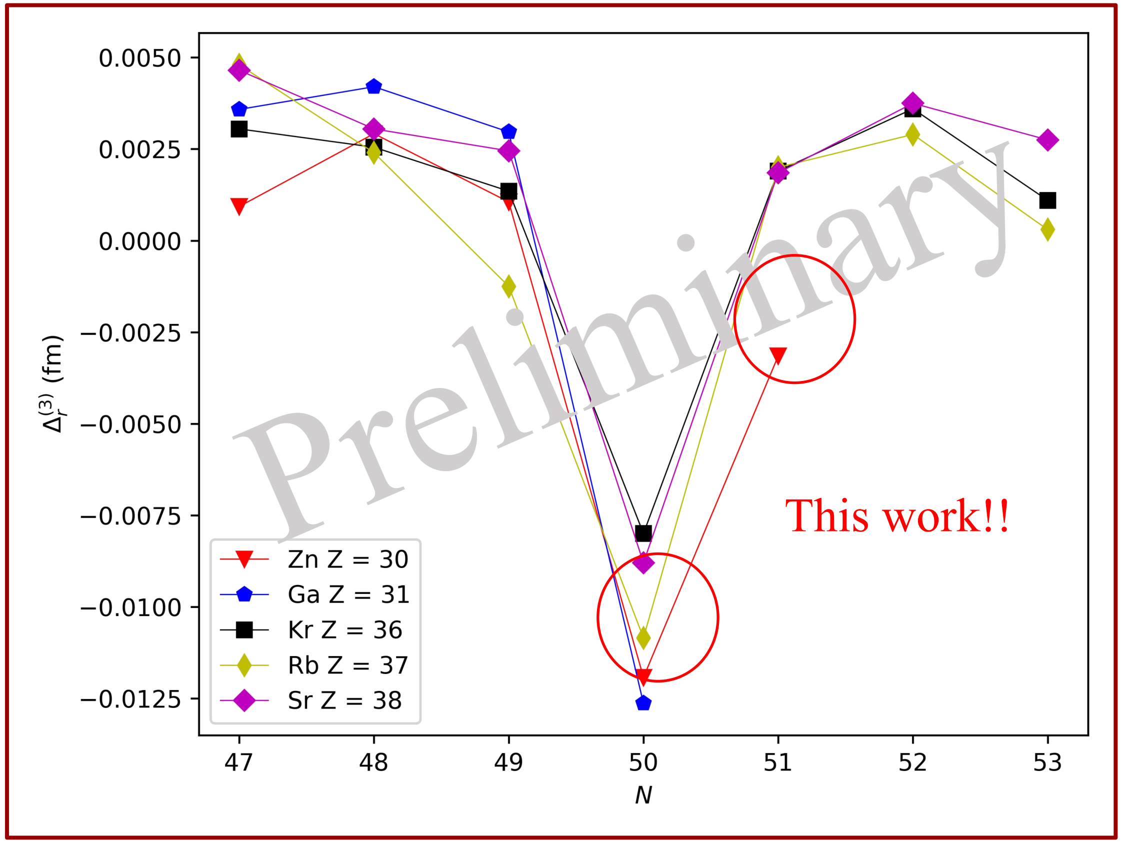
$$\Delta_{1n}^{(3)} r = \frac{1}{2}(-1)^{N+1}[r_{N+1} - 2r_N + r_{N-1}]$$





A large kink is also observed on $N = 50$ along Zn isotope chain

➤Experimental method: new decay station

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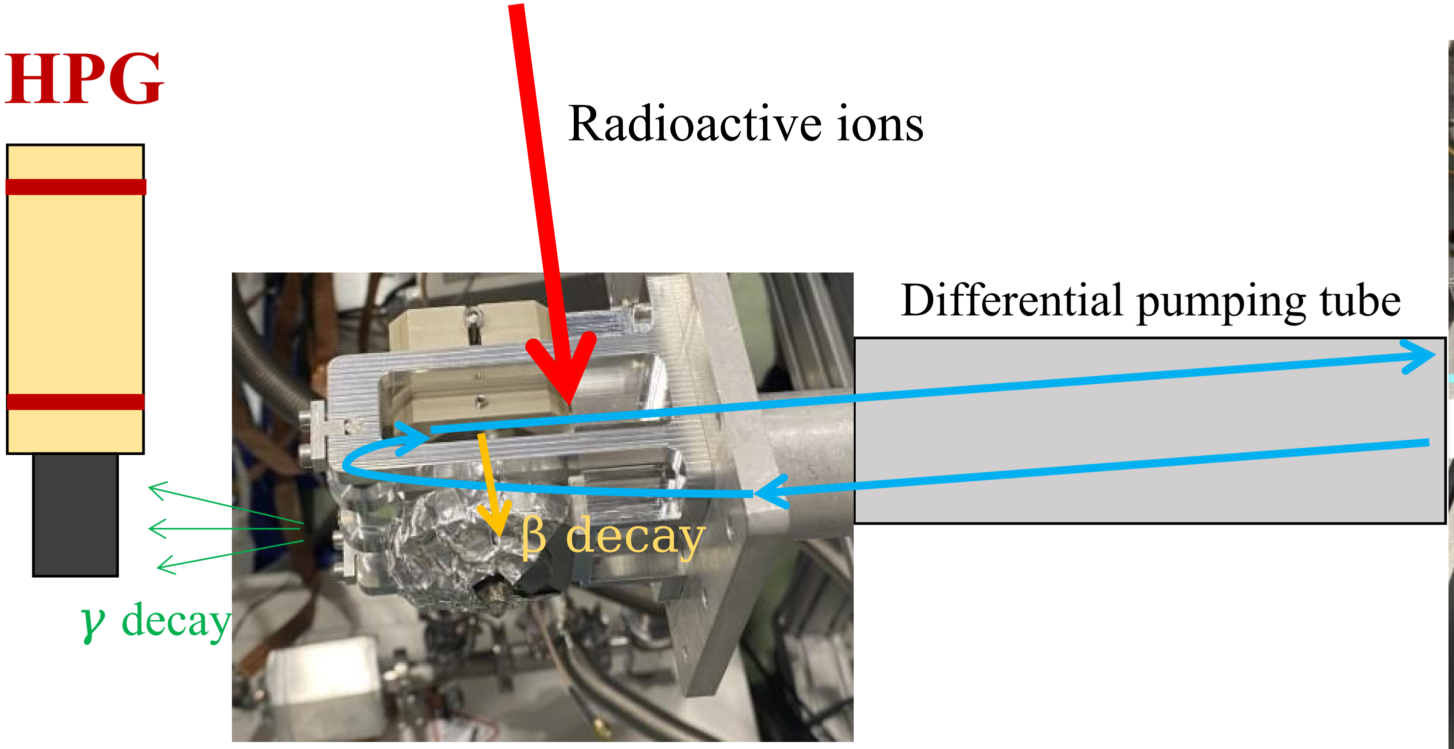
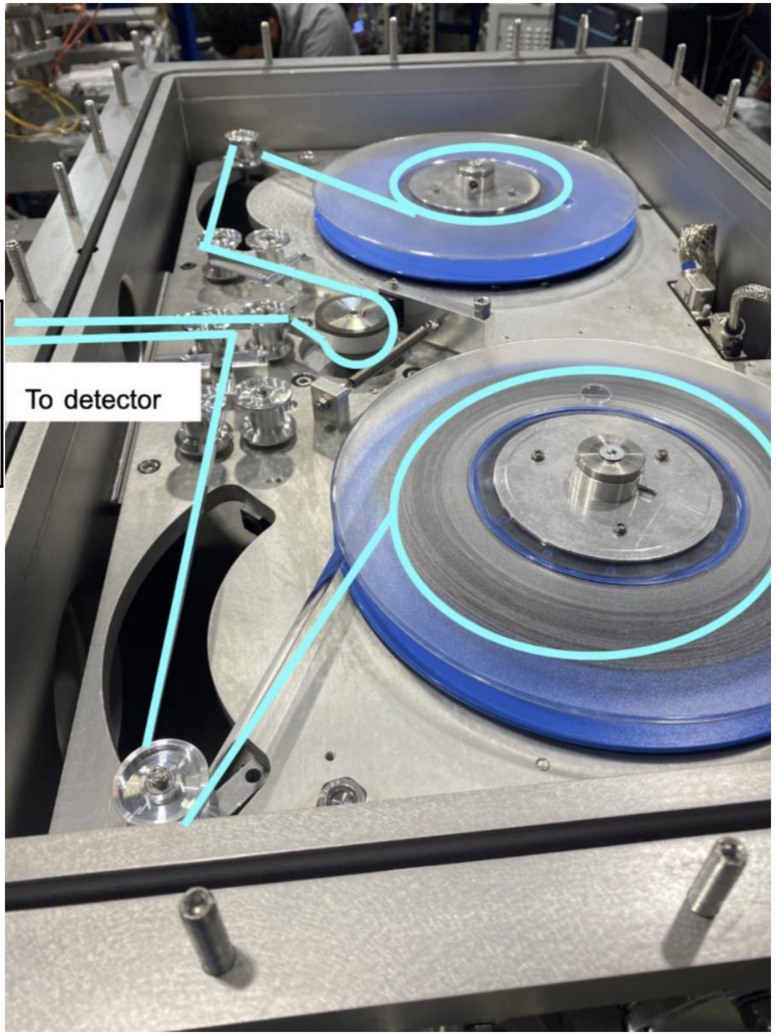


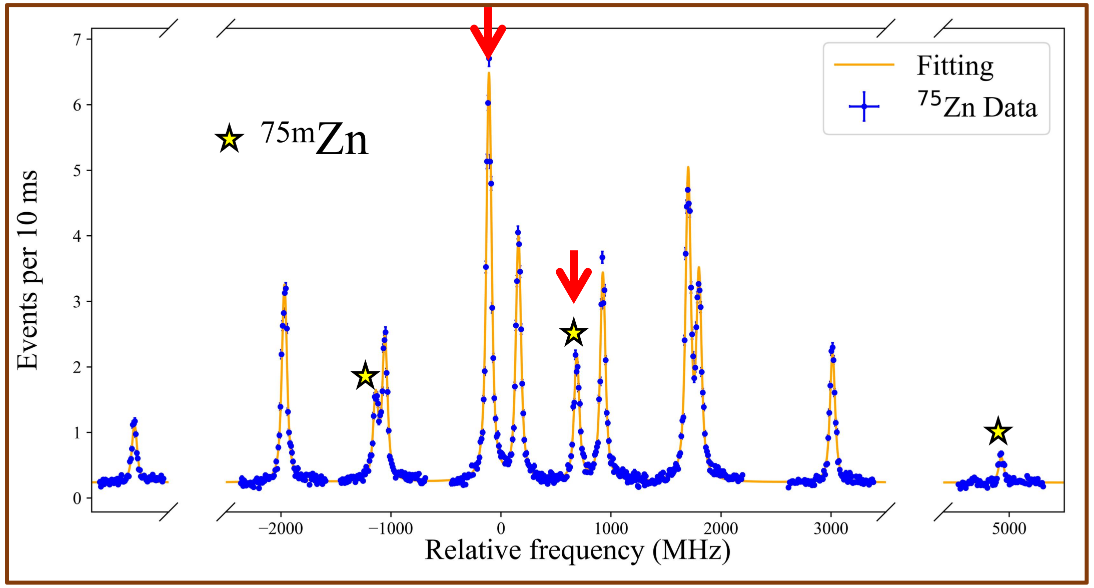


Silicon Detector (PIPS)

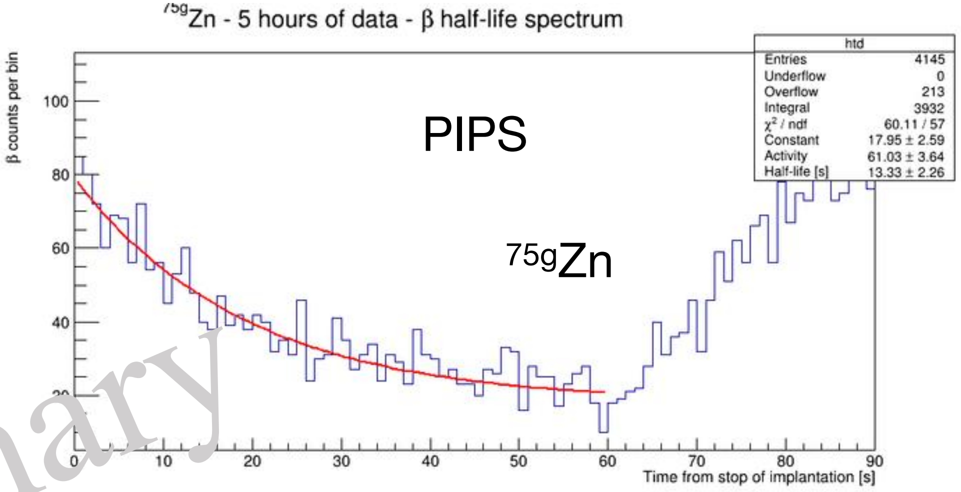
Tape Station

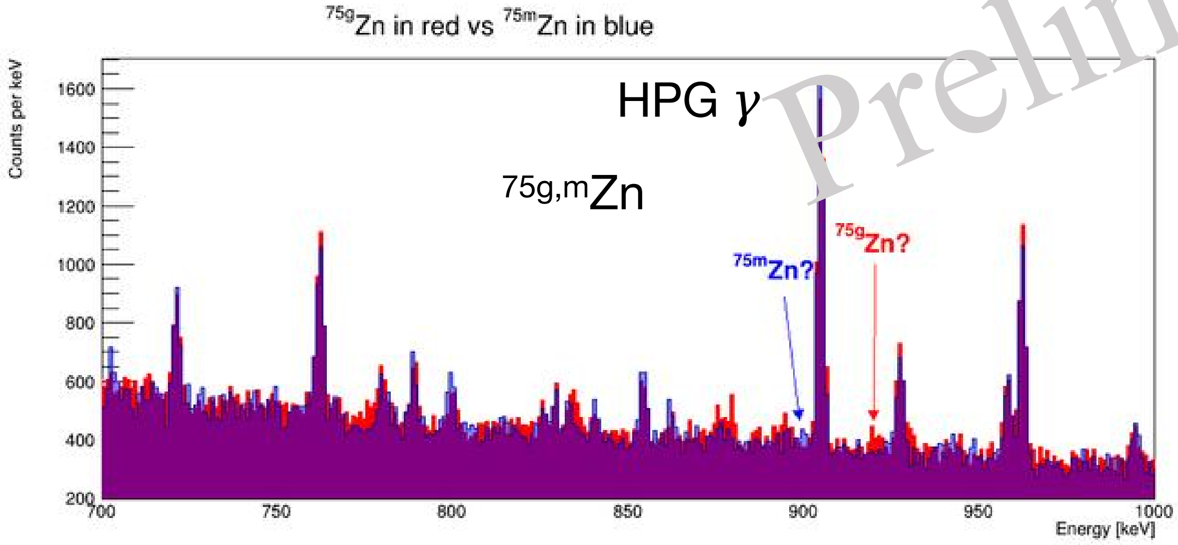
1. **Designed for high contamination Laser spectroscopy measurement**
2. **Half-life measurement for isomer state combined with laser method**

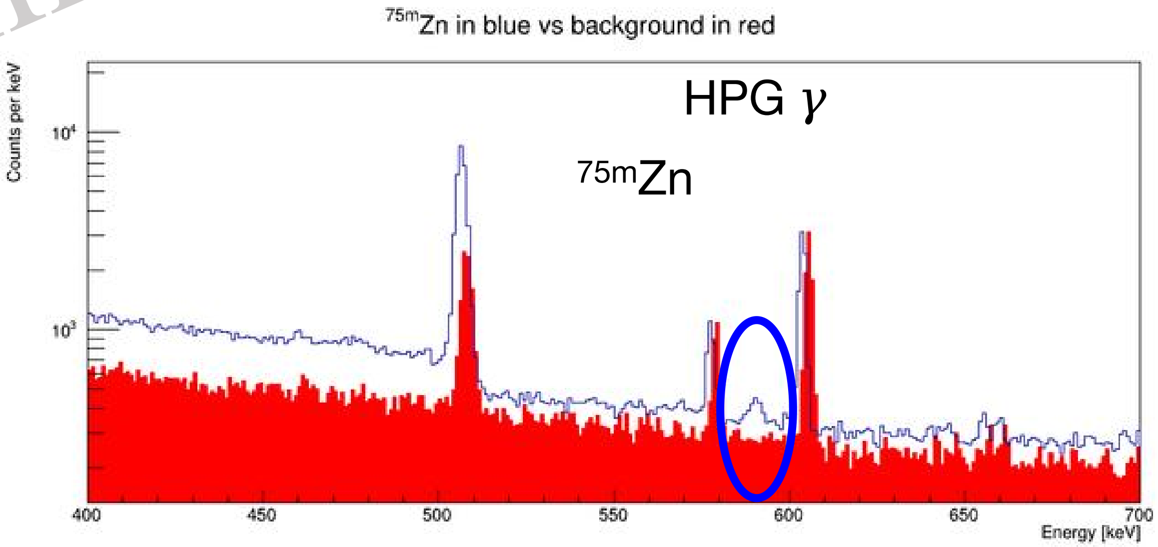
➢Results: half life measurement of ^{75g,m}Zn with new DSS



Laser Assisted Decay Spectroscopy(LADS)







Preliminary

Summary

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- With the UCx target and the assist of **neutron convertor& quartz line**, the **$^{81,82}Zn$ HFS** are successfully measured.
- The ground state spin of ^{81}Zn is assigned to be **5/2+**, no shell inversion at ^{81}Zn.
- The cross shell excitation of ^{78}Ni core is required to reproduce the moments of ^{81}Zn in shell model.
- A **large charge radii kink** is observed at $N = 50$ in Zn isotope chain.
- The new DSS setup is successfully commissioned on ^{75}Zn half-life measurement.

Thanks for your attention!

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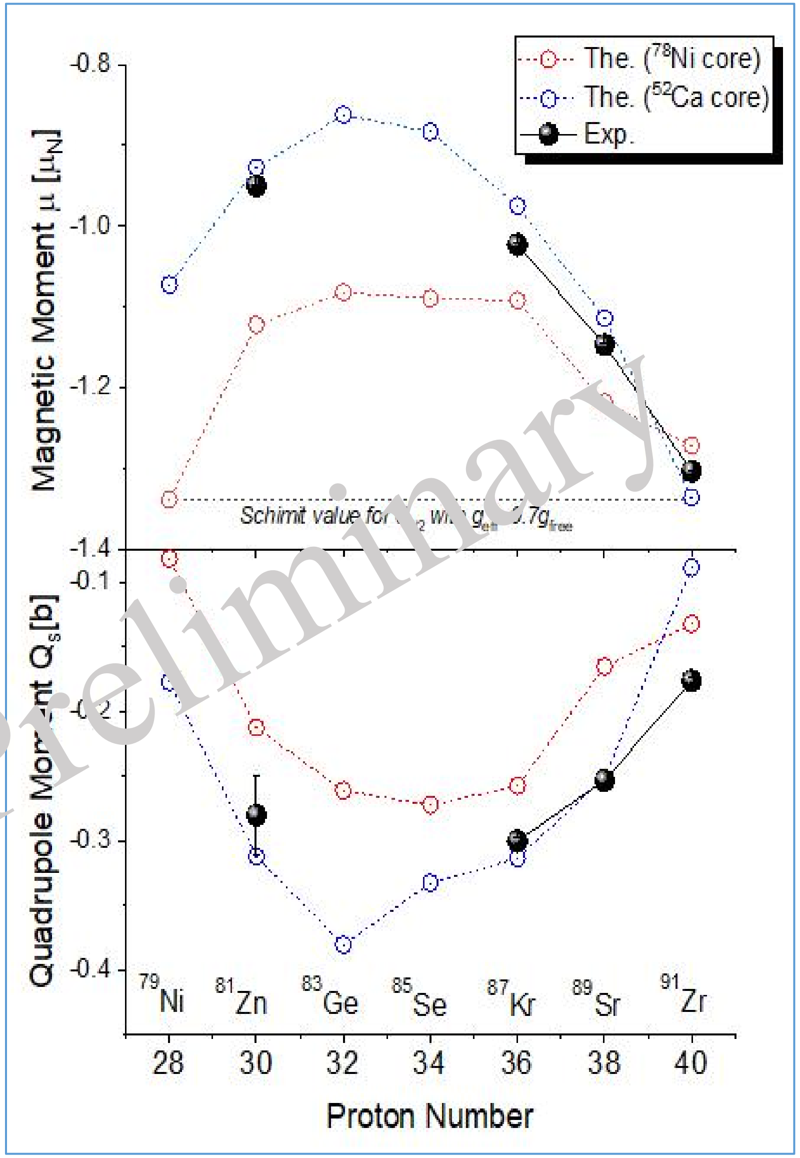
➢Results: electromagnetic moments of ^{81}Zn



Model Space:

^{78}Ni core
proton: 1p3/2 0f5/2 1p1/2 0g9/2
neutron: 1d5/2 2s1/2 1d3/2 0g7/2 0h11/2

^{52}Ca core
proton: pf-shell
neutron: 0f5/2 1p1/2 0g9/2 1d5/2 1d3/2 2s1/2

➢Results: charge radii of ^{81,82}Zn

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