Probing the magicity and shell evolution in the vicinity of *N* = 50 with high-resolution laser spectroscopy of ^{81,82}Zn isotopes

Spokespersons: **Xiaofei Yang**
Thomas E. Cocolios
Local contact: **Sarina Geldhof**

Outline

◆**Physics motivation**

-General physics motivation in Ni region

-Physics cases for neutron rich $^{81\text{-}82}$Zn

◆**Experimental method**

-CRIS method

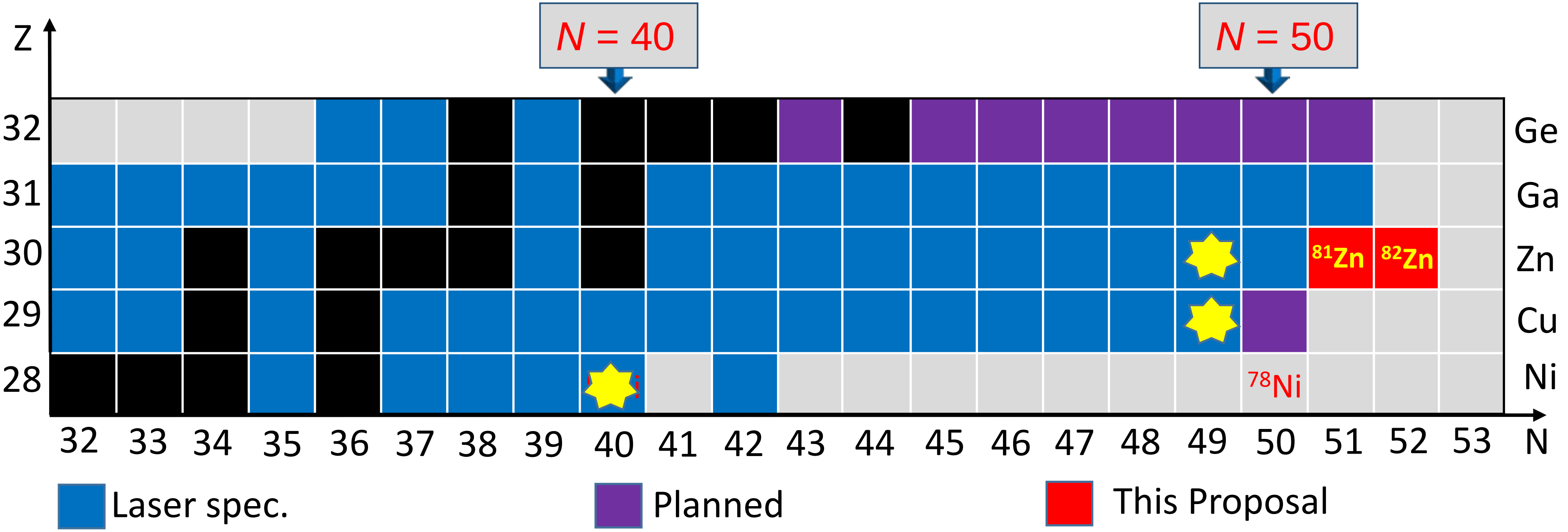
-Ionization schemes for Zn

◆**Beamtime request**

- Beam production

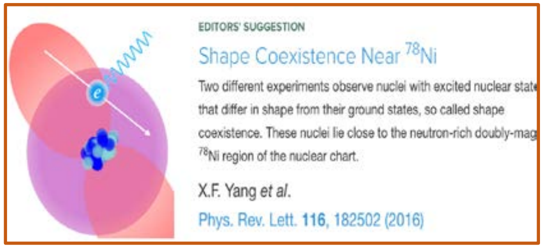
- Beam time request

◆Physics motivation: Ni region in general



Z	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	
32	⬜	⬜	⬜	⬜	🟦	🟦	⬛	🟦	⬛	⬛	⬛	🟪	⬛	🟪	🟪	🟪	🟪	🟪	🟪	🟪	⬜	⬜	Ge
31	🟦	🟦	🟦	🟦	🟦	🟦	⬛	🟦	⬛	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	⬜	⬜	Ga
30	🟦	🟦	⬛	🟦	⬛	⬛	⬛	🟦	⬛	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦 ✶	🟦	🟥 ^{81}Zn	🟥 ^{82}Zn	⬜	Zn
29	🟦	🟦	⬛	🟦	⬛	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦 ✶	🟪	⬜	⬜	⬜	Cu
28	⬛	⬛	⬛	🟦	⬛	🟦	🟦	🟦	🟦 ✶	⬜	🟦	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜ ^{78}Ni	⬜	⬜	⬜	Ni

🟦 Laser spec.
🟪 Planned
🟥 This Proposal



EDITORS' SUGGESTION

Shape Coexistence Near ^{78}Ni

Two different experiments observe nuclei with excited nuclear state that differ in shape from their ground states, so called shape coexistence. These nuclei lie close to the neutron-rich doubly-mag ^{78}Ni region of the nuclear chart.

X.F. Yang *et al.*

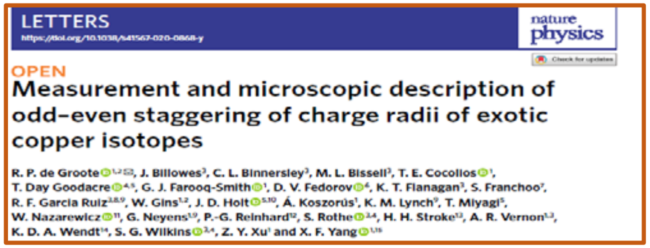
Phys. Rev. Lett. **116**, 182502 (2016)

PHYSICAL REVIEW LETTERS **124,** 132502 (2020)

Charge Radius of the Short-Lived ^{68}Ni and Correlation with the Dipole Polarizability

S. Kaufmann,[1] J. Simonis,[2] S. Bacca,[2,3] J. Billowes,[4] M. L. Bissell,[4] K. Blaum,[5] B. Cheal,[6] R. F. Garcia Ruiz,[4,7,‡] W. Gins,[8] C. Gorges,[1] G. Hagen,[9] H. Heylen,[5,7] A. Kanellakopoulos,[8] S. Malbrunot-Ettenauer,[7] M. Miorelli,[10] R. Neugart,[5,11] G. Neyens,[7,8] W. Nörtershäuser,[1,*] R. Sánchez,[12] S. Sailer,[13] A. Schwenk,[1,5,14] T. Ratajczyk,[1] L. V. Rodríguez,[15,‡] L. Wehner,[16] C. Wraith,[6] L. Xie,[4] Z. Y. Xu,[8] X. F. Yang,[8,17] and D. T. Yordanov[15]

[1]Institut für Kernphysik, Technische Universität Darmstadt, D-64289 Darmstadt, Germany
[2]Institut für Kernphysik and PRISMA$^+$ Cluster of Excellence, Johannes Gutenberg-Universität Mainz, D-55128 Mainz, Germany
[3]Helmholtz Institute Mainz, GSI Helmholtzzentrum für Schwerionenforschung GmbH, D-64291 Darmstadt, Germany
[4]School of Physics and Astronomy, The University of Manchester, Manchester, M13 9PL, United Kingdom
[5]Max-Planck-Institut für Kernphysik, D-69117 Heidelberg, Germany
[6]Oliver Lodge Laboratory, Oxford Street, University of Liverpool, Liverpool L69 7ZE, United Kingdom
[7]Experimental Physics Department, CERN, CH-1211 Geneva 23, Switzerland



LETTERS
https://doi.org/10.1038/s41567-020-0868-y

nature physics

OPEN

Measurement and microscopic description of odd–even staggering of charge radii of exotic copper isotopes

R. P. de Groote[1,2], J. Billowes[3], C. L. Binnersley[3], M. L. Bissell[3], T. E. Cocolios[1], T. Day Goodacre[4,5], G. J. Farooq-Smith[1], D. V. Fedorov[6], K. T. Flanagan[3], S. Franchoo[7], R. F. Garcia Ruiz[3,8,9], W. Gins[1,2], J. D. Holt[5,10], Á. Koszorús[1], K. M. Lynch[9], T. Miyagi[5], W. Nazarewicz[11], G. Neyens[1,9], P.-G. Reinhard[12], S. Rothe[3,4], H. H. Stroke[13], A. R. Vernon[1,3], K. D. A. Wendt[14], S. G. Wilkins[3,4], Z. Y. Xu[1] and X. F. Yang[1,15]

Physics

- *N*=40 subshell? *N*=50 magicity?
- Shell evolution, shape coexistence
- Theoretical developments (SM, DFT, *ab-initio*)

Achievements

(Zn) PRL 116(2016)182502; PLB 771(2017) 385-391; PRC 97(2018)044324; PLB 797(2019)134805; **(Ga)**PRC 96(2017)044324; **(Ni)**PRL 124(2020)132502; **(Cu)**PRC 93 (2016)064318; PRC 96(2017) 041302(R); Nat.phys 16(2020)620; **(Ge)** PRC(2020) accepted;

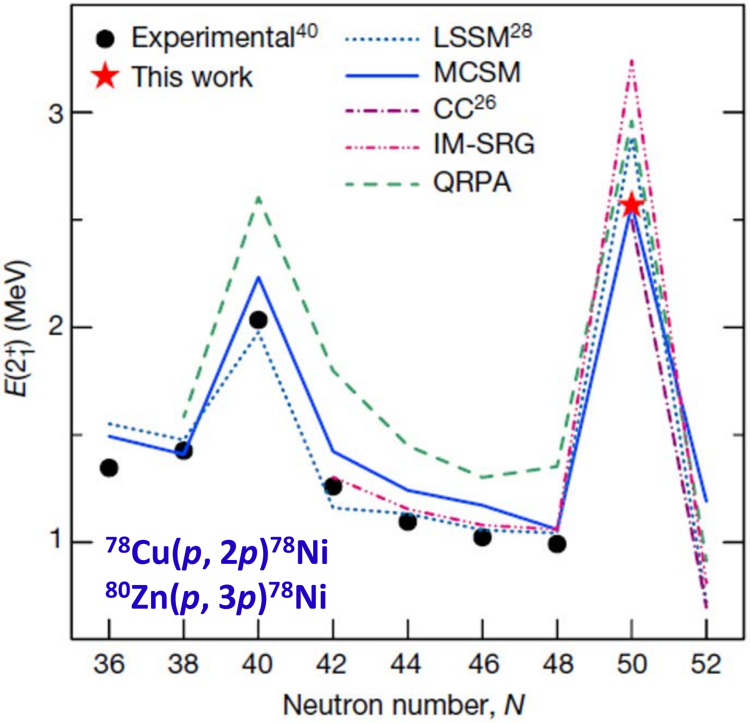
◆Physics motivation: ^{78}Ni?

Continuously theoretical investigation is progressing

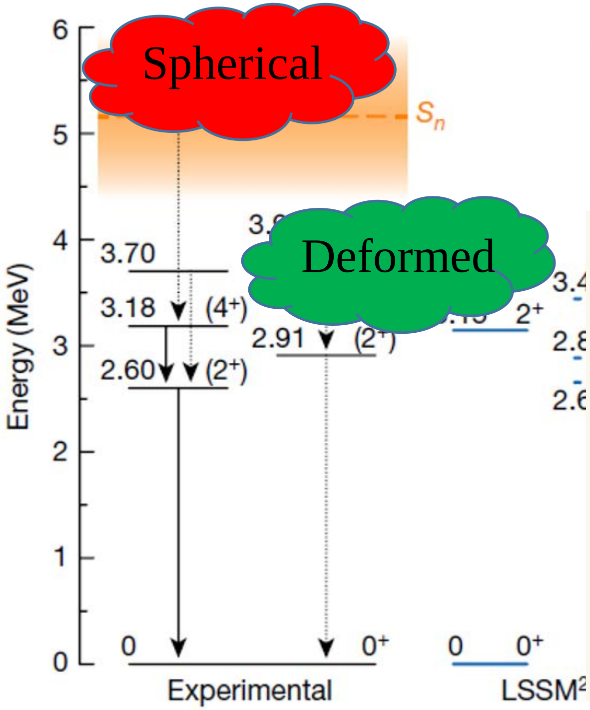
F. Nowacki et al., PRL 117(2016) 272501:
SM: shape coexistence in ^{78}Ni

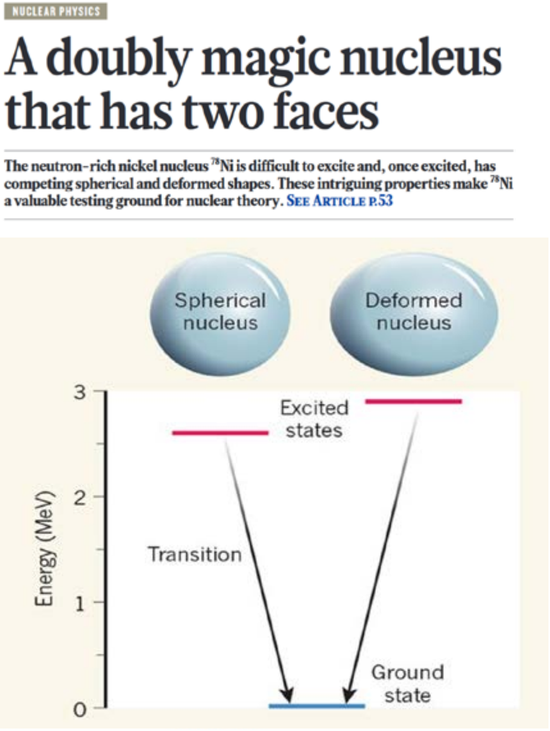
G.Hagen et al., PRL 117(2016) 172501
CC: Doubly magic of ^{78}Ni

R. Taniuchi, et al. Nat. 569(2019) 53



^{78}Cu(*p*, 2*p*)^{78}Ni
^{80}Zn(*p*, 3*p*)^{78}Ni




NUCLEAR PHYSICS

A doubly magic nucleus that has two faces

The neutron-rich nickel nucleus ^{78}Ni is difficult to excite and, once excited, has competing spherical and deformed shapes. These intriguing properties make ^{78}Ni a valuable testing ground for nuclear theory. SEE ARTICLE P.53

- **Doubly magic nucleus have spherical and deformed faces!**
- **Deformed g.s. for more exotic nickel isotopes are suggested!**

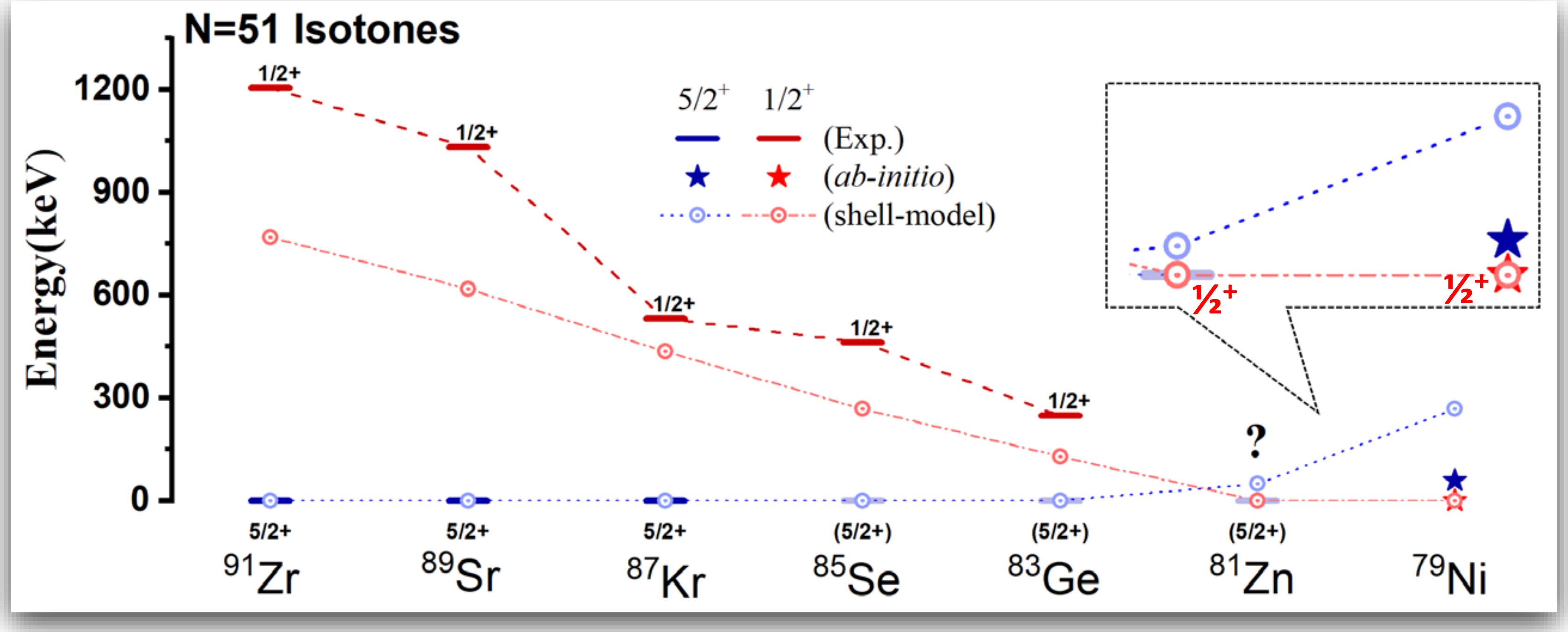
◆Physics motivation: neutron-rich ^{81,82}Zn

- 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 effect of the monopole interaction

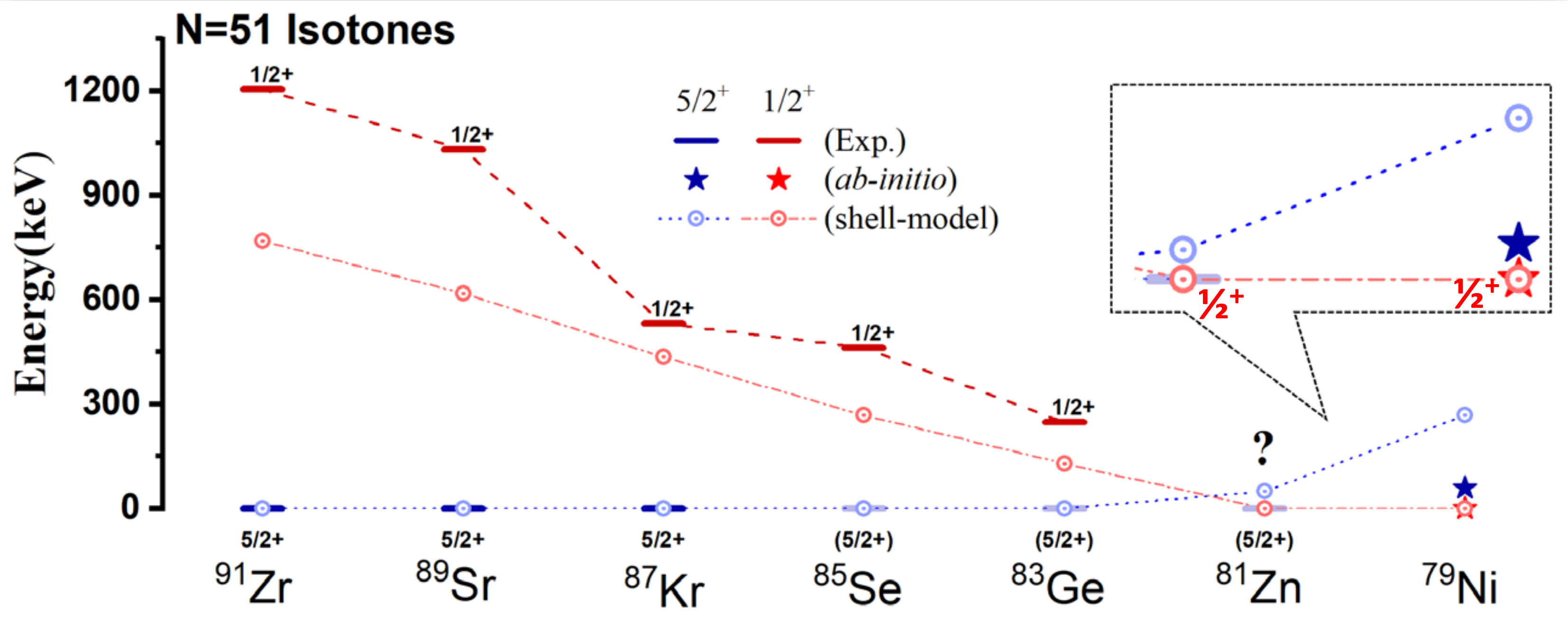
Continuum effect
PRL 117 (2016) 172501



◆Physics motivation: neutron-rich ^{81,82}Zn

- **Experimentally, β-decay of ^{81}Zn have been performed several times**

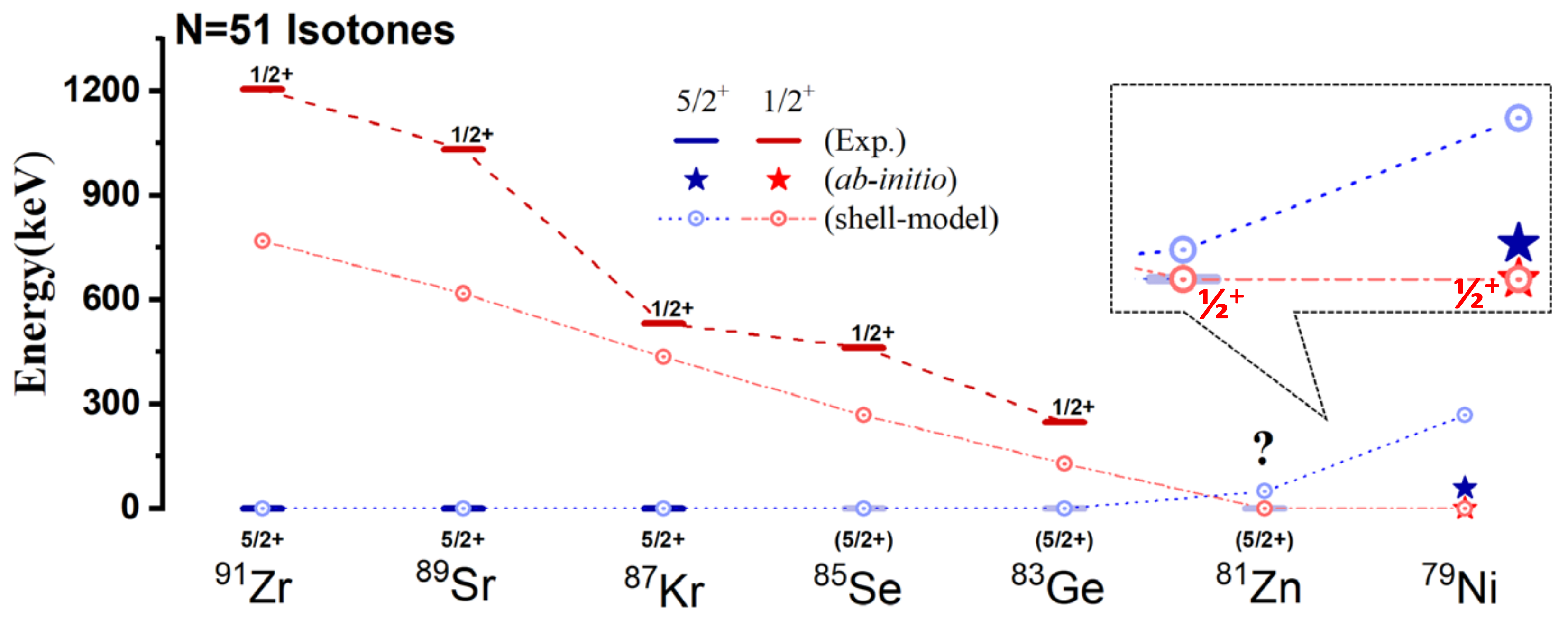
PRC**76(2007)** 054312	PRC**82(2010)**064314	PRC**102(2020)**014329
(1/2^{+}) g.s.	**(5/2^{+}) g.s.**	**(5/2^{+} or 1/2^{+}) g.s.**



- **g.s. spin assignment of ^{81}Zn is highly motivated**
- **Laser spectroscopy can provide a firm spin assignment**
- **^{81}Zn is currently accessible with laser spectroscopy at ISOLDE**

◆Physics motivation: neutron-rich ^{81,82}Zn

- Configuration of g.s wavefunction : $[s^{1}_{1/2}]\,1/2^{+}$ or $\left[2^{+}\otimes d^{1}_{5/2}\right]1/2^{+}$??
- **Single-particle state or configuration mixing?**
- **Spherical or deformed?**



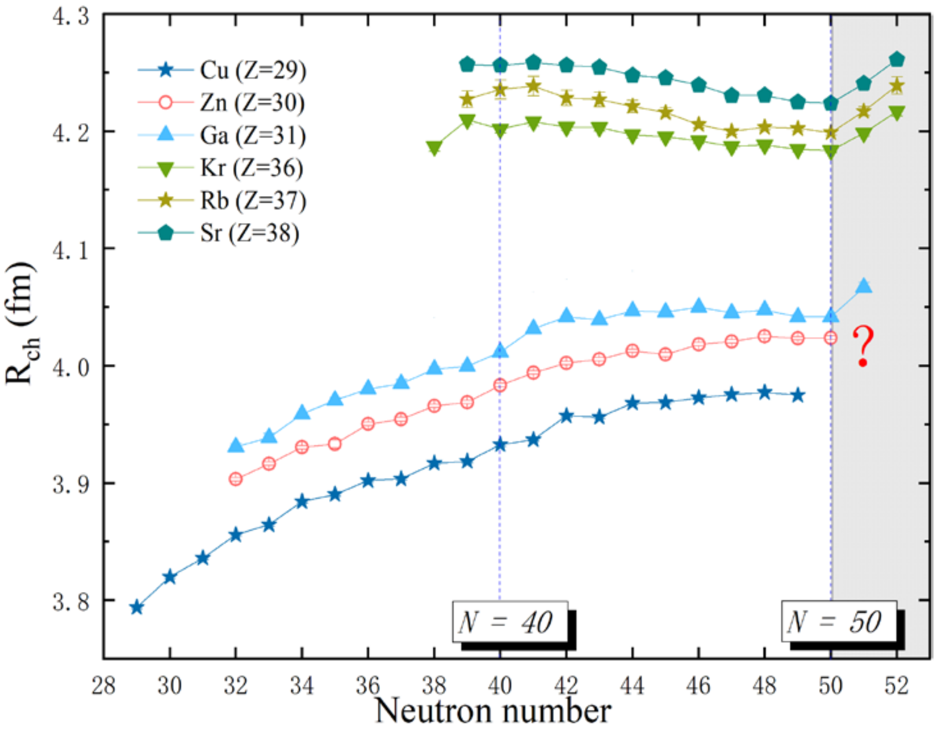
- **Require the magnetic and quadrupole moments measurement of ^{81}Zn =>providing stringent test for the nuclear theoretical models**

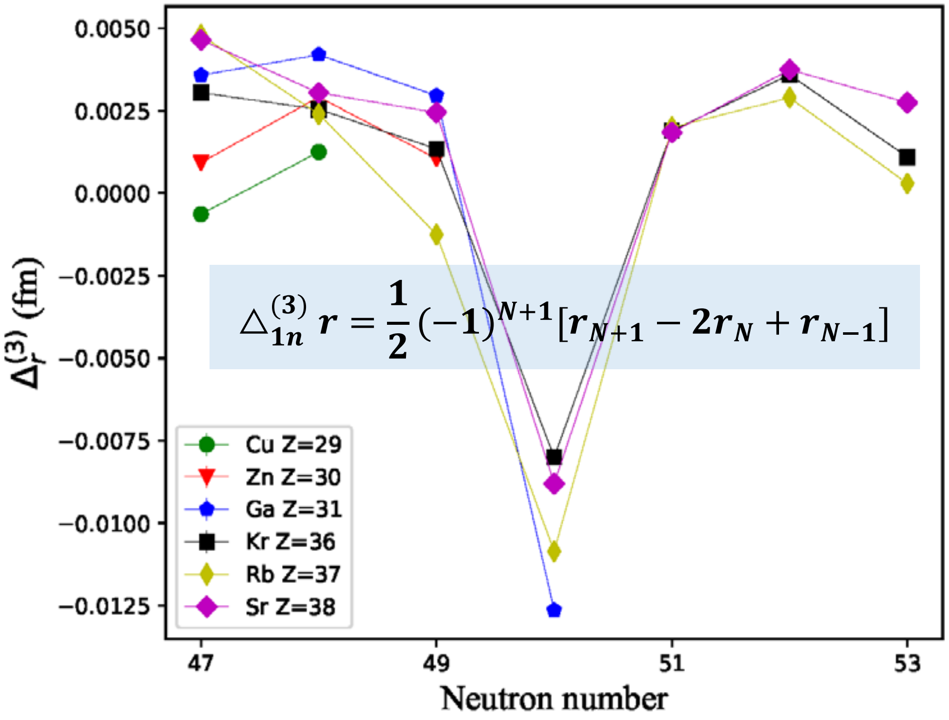
[Zn-Moments]C. Wraith et al.,PLB771(2017)385; **[Cu-Moments]**R. P. De Groote et al., PRC96(2017)041302(R)

◆Physics motivation: neutron-rich ^{81,82}Zn

北京大学
PEKING UNIVERSITY

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





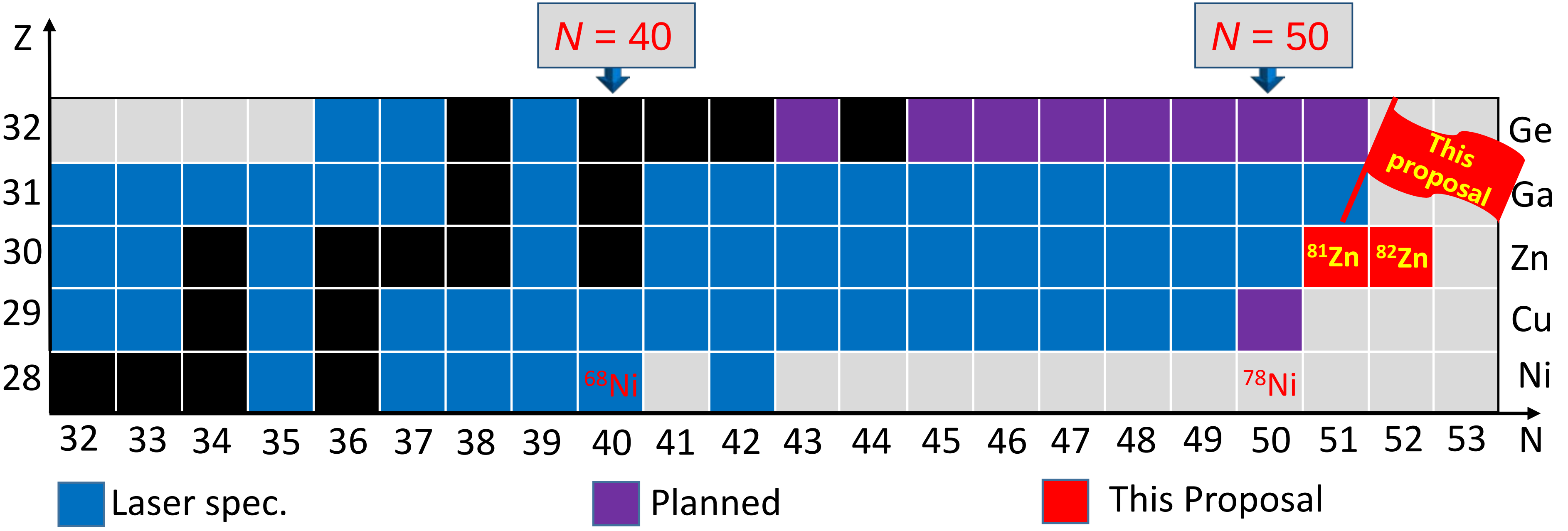
$$\triangle_{1n}^{(3)} r = \frac{1}{2}(-1)^{N+1}[r_{N+1} - 2r_N + r_{N-1}]$$

- **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

◆Physics motivation:



We propose to perform laser spectroscopy measurements of $^{81\text{-}82}$Zn isotopes, aiming to address the following questions:

1. **What is the g.s. spin in ^{81}Zn (evolution of $1/2^+$ level in $N = 51$ isotones)?**
2. **Is the g.s.of ^{81}Zn a single-particle state?**
3. **How does the charge radii trend and the local OES behave above $N = 50$?**

✚ **Provide a compelling test for theory models (SM, DFT, *ab-initio*)**

Outline

◆**Physics motivation**

-General physics in Ni region

-Physics for study of $^{81\text{-}82}$Zn

◆**Experimental method**

-CRIS method

-Ionization schemes for Zn

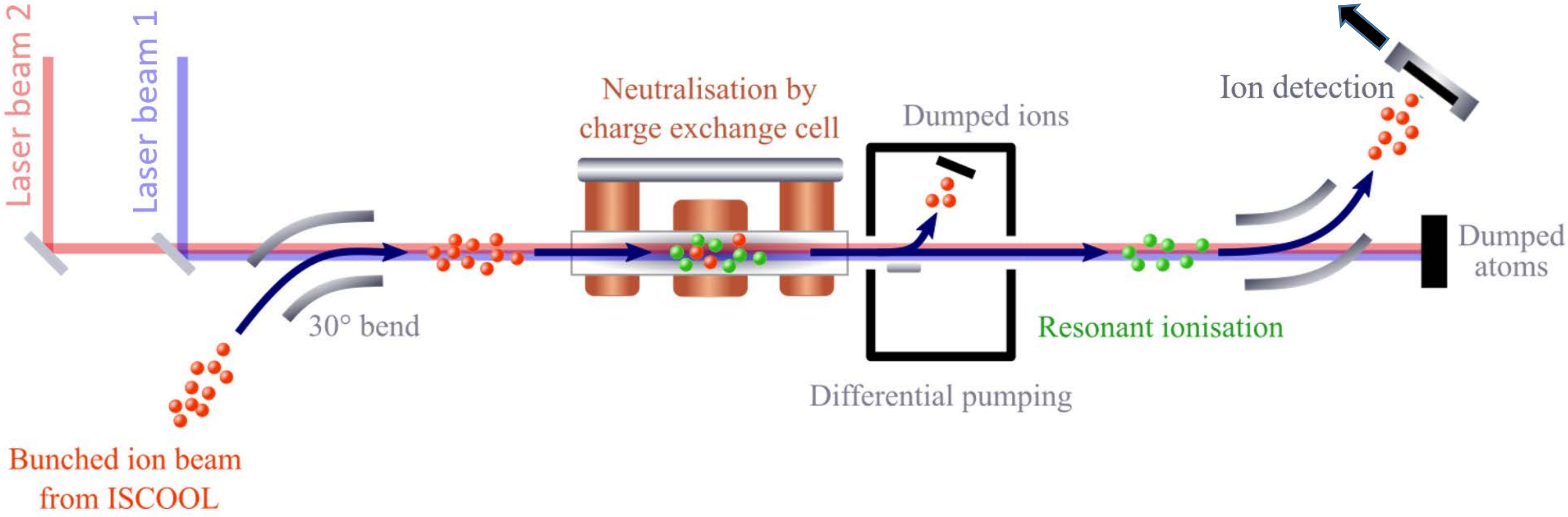
◆**Beamtime request**

- Beam production
- Beam time request

◆Experimental method

- **Collinear resonance ionization laser spectroscopy**

Removable



- Using current standard CRIS setup
- High resolution (Fr, In, Sn, Cu, K….)
- High sensitivity (demonstrated for ^{78}Cu)

Fr: K.M.Lynch et al., PRX 4(2014)011055.
In: R.F.Garcia Ruiz et al., PRX 8(2018)041005 2018.
Cu: R.P.de Groote et al., Nat.Phys 16(2020)620.
Sn: F.P.Gustafsson et al., Accepted to PRA(2020)
K: Á.Koszorús et al., PRC 100(2019) 034304

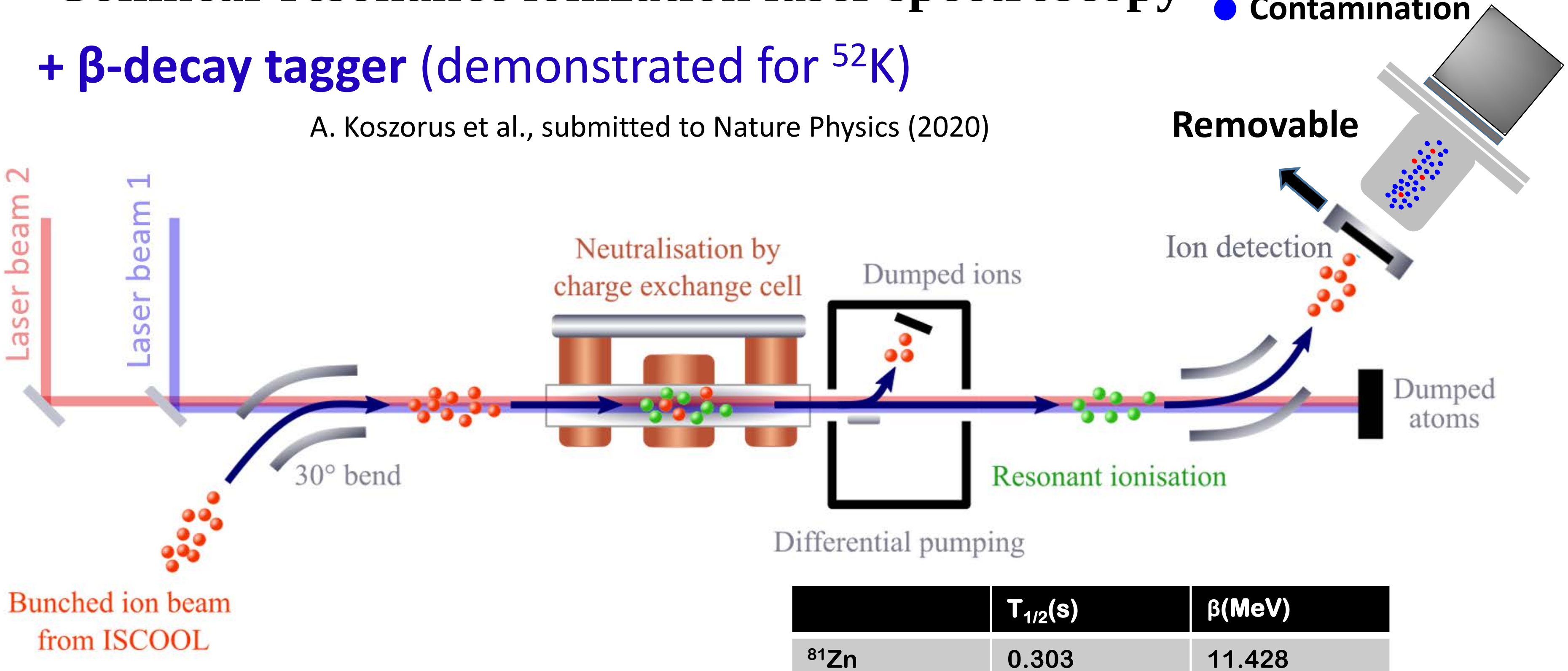
◆Experimental method

- **Collinear resonance ionization laser spectroscopy**

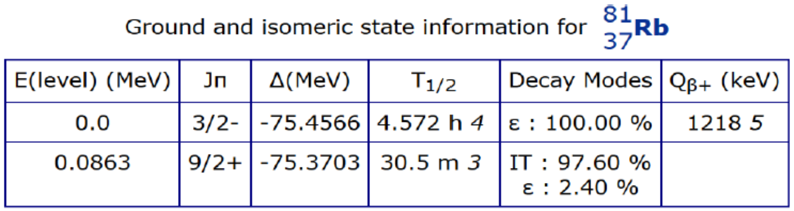
+ β-decay tagger (demonstrated for ^{52}K)

A. Koszorus et al., submitted to Nature Physics (2020)

● Zn isotopes
● Contamination

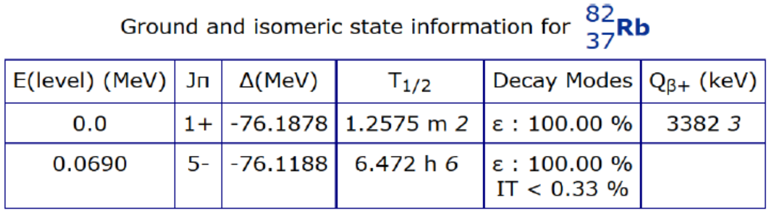


	$T_{1/2}$(s)	β(MeV)
^{81}Zn	0.303	11.428
^{82}Zn	0.228	10.617



Ground and isomeric state information for $^{81}_{37}$Rb

E(level) (MeV)	Jπ	Δ(MeV)	$T_{1/2}$	Decay Modes	$Q_{\beta+}$ (keV)
0.0	3/2-	-75.4566	4.572 h *4*	ε : 100.00 %	1218 *5*
0.0863	9/2+	-75.3703	30.5 m *3*	IT : 97.60 % ε : 2.40 %	

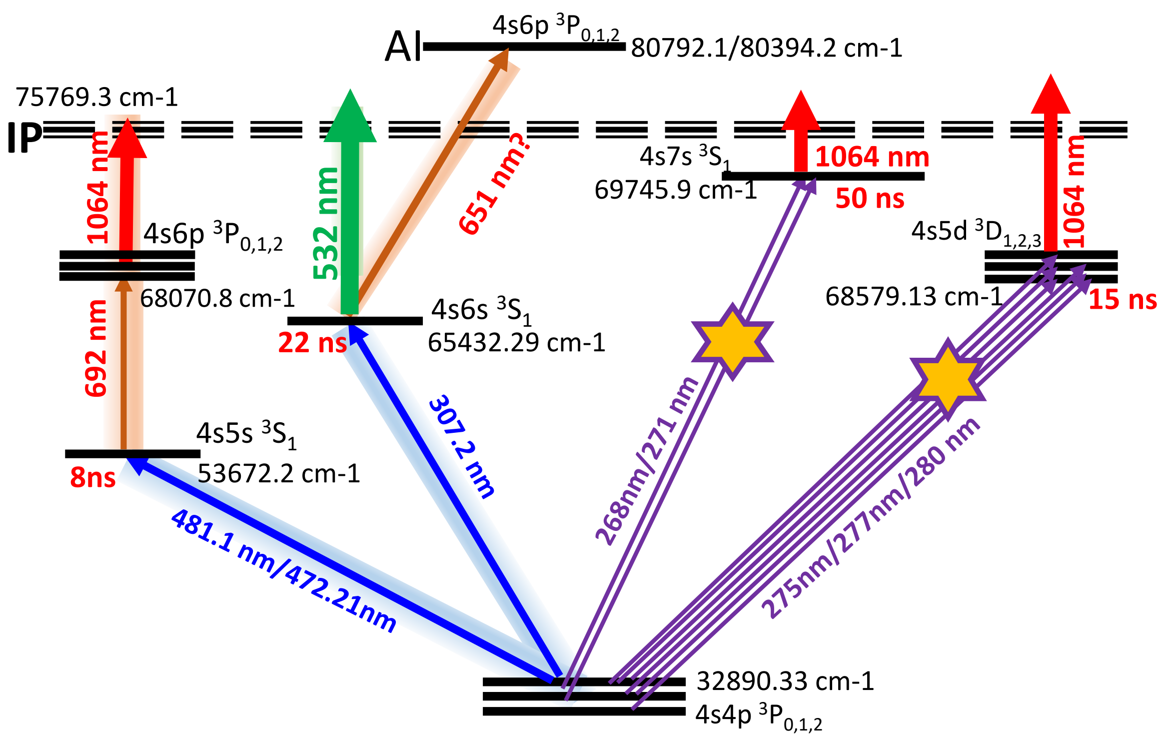


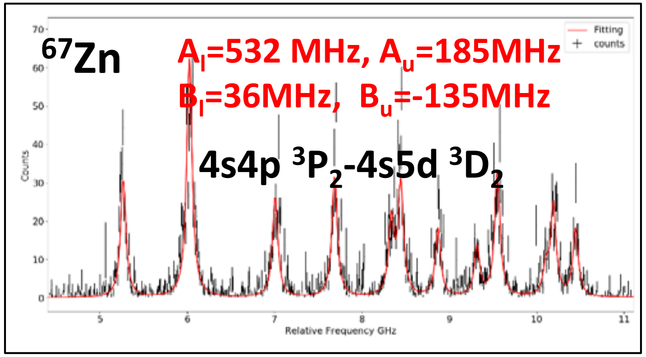
Ground and isomeric state information for $^{82}_{37}$Rb

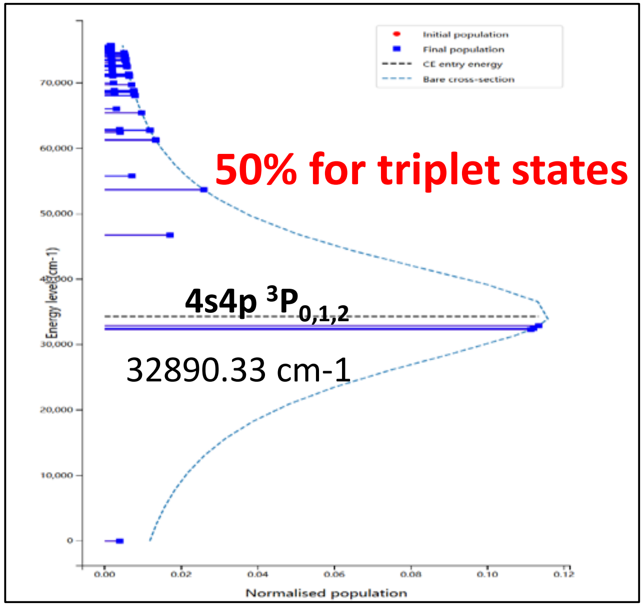
E(level) (MeV)	Jπ	Δ(MeV)	$T_{1/2}$	Decay Modes	$Q_{\beta+}$ (keV)
0.0	1+	-76.1878	1.2575 m *2*	ε : 100.00 %	3382 *3*
0.0690	5-	-76.1188	6.472 h *6*	ε : 100.00 % IT < 0.33 %	

◆Experimental method

Ionization scheme & Experimental feasibility







- **8 transitions have been easily tested with CRIS.**
- **Other transitions will be tested before the experiment.**
  -- some has been studied at COLLAPS [PRL116(2016)182502] and Manchester[J.Phys.B 30(1997)2351]
- **Higher sensitivity field ionization [Sci. Rep. 10(2020)12306] has been tested preliminary for Zn**
  --further test with high resolution is planned.

Outline

◆**Physics motivation**

-General physics in Ni region

-Physics for study of $^{81\text{-}82}$Zn

◆**Experimental method**

-CRIS method

-Ionization schemes for Zn

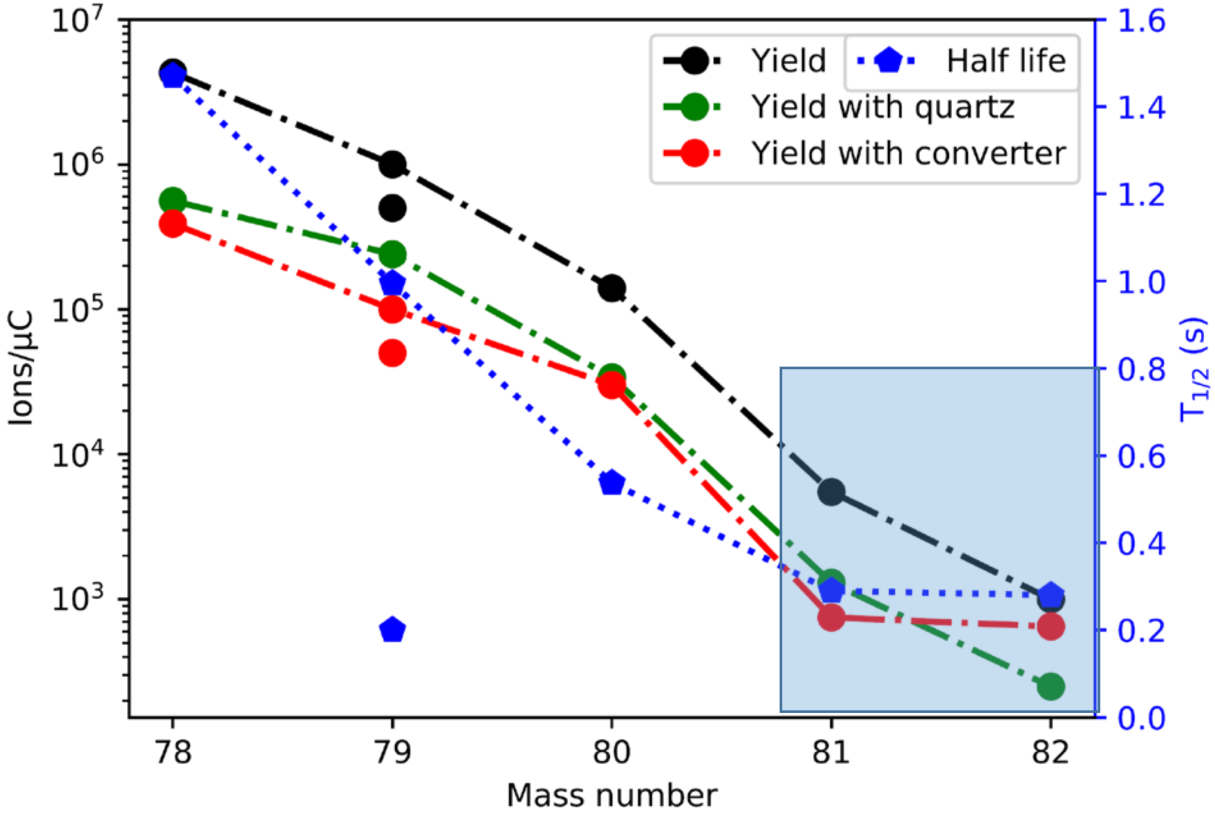
◆**Beamtime request**

- Beam production
- Beam time request

◆Beamtime request

- **Production yields and beam time request**

AIP Conf. Proc. 798(2005)315; Eur. Phys. J. Special Topics 150(2007)277

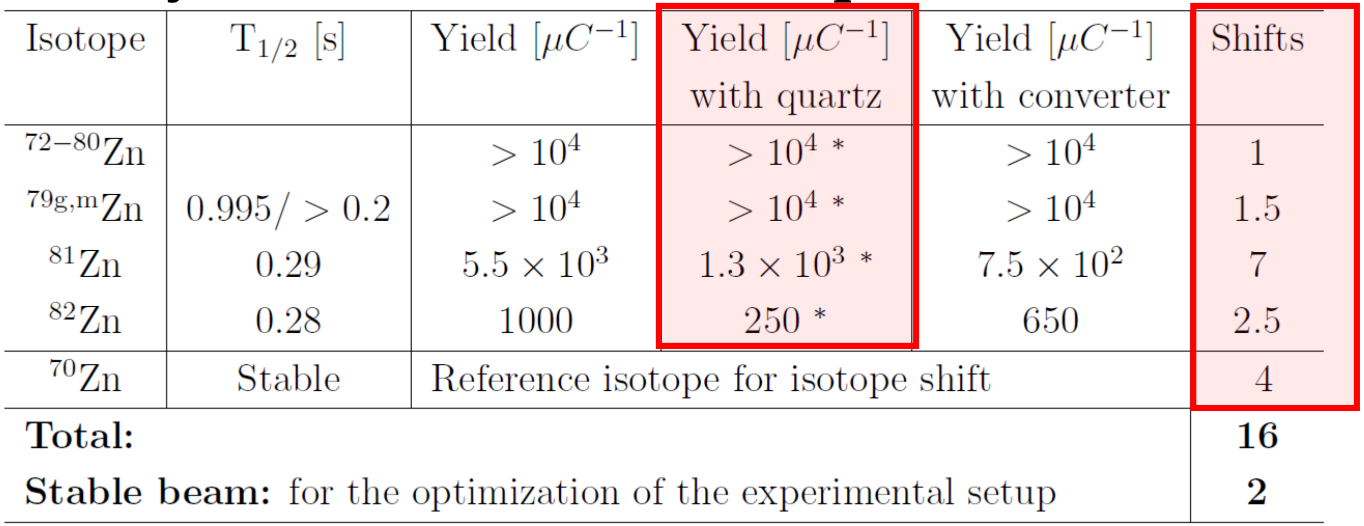


- $^{81\text{-}82}$Zn are produced at ISOLDE **with >100 pps yield**
- We suggest to use the **quartz transfer line only**

=> giving the best compromise of contamination and the production

◆Beamtime request

- **Production yields and beam time request**



Isotope	$T_{1/2}$ [s]	Yield [μC^{-1}]	Yield [μC^{-1}] with quartz	Yield [μC^{-1}] with converter	Shifts
$^{72-80}$Zn		$> 10^4$	$> 10^4$ *	$> 10^4$	1
^{79g,m}Zn	$0.995/ > 0.2$	$> 10^4$	$> 10^4$ *	$> 10^4$	1.5
^{81}Zn	0.29	5.5×10^3	1.3×10^3 *	7.5×10^2	7
^{82}Zn	0.28	1000	250 *	650	2.5
^{70}Zn	Stable	Reference isotope for isotope shift			4
Total:					**16**
Stable beam: for the optimization of the experimental setup					**2**

Number of shifts are estimated by considering:

- **Beam production yield**
- **Estimated efficiency for Zn measurement at CRIS**

  -transmission and detection (40%), neutralization and population(5%), ionization(5%)
- **HFS frequency scan range**

  -spin, isomeric state, hyperfine structure A,B values (~10/0.5 GHz for ^{81}Zn/^{82}Zn)

Total: ***16 shifts of radioactive beam***

2 shifts of stable beams for setup optimization

Thanks for your attention!!

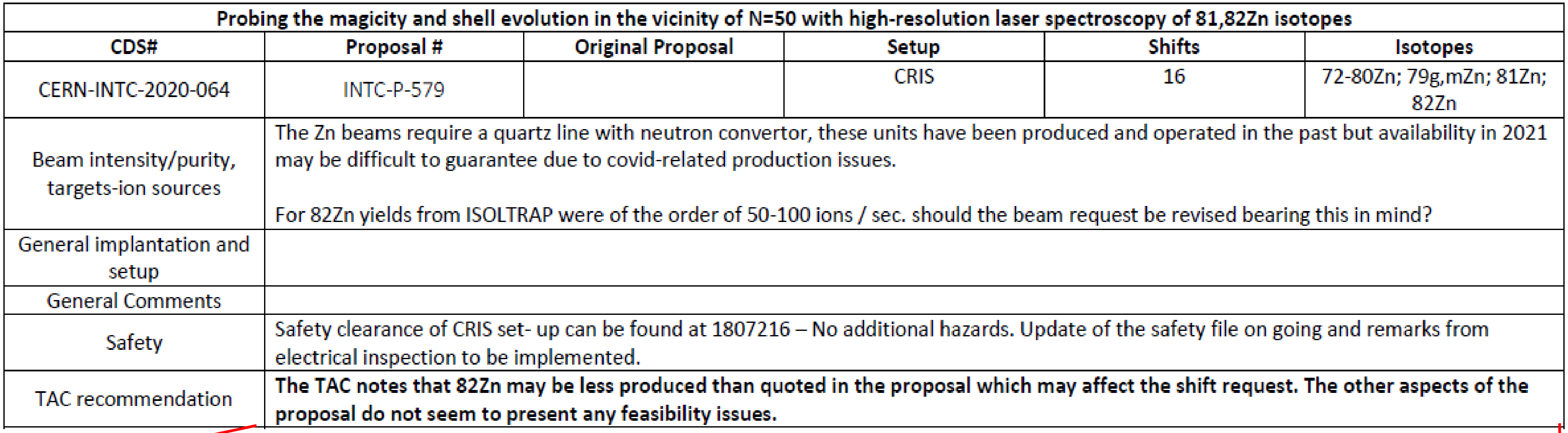
CRIS Collaboration:

M. Athanasakis,[1,2] S. W. Bai,[3] S. Bester,[4] M. L. Bissell,[5,6] T. E. Cocolios,[1] A. de Bruyn,[4] R. P. de Groote,[7] C. Duchemin,[1,6] K. T. Flanagan,[5,8] S. Franchoo,[9] R. F. Garcia Ruiz,[10] S. Geldhof,[1] R. Heinke,[1] J. Johnson,[1] Á. Koszorús,[11] Y. C. Liu,[3] G. Neyens,[1,2] F. P. Gustafsson,[1] C. M. Ricketts,[5] S. Rothe,[6] C. M. Steenkamp,[4] D. Verney,[9] A. R. Vernon,[10] S. J. Wang,[3] F. J. Waso,[4] S. G. Wilkins,[10] W. Wojtaczka,[1] X. F. Yang[3]

[1] *KU Leuven, Instituut voor Kern- en Stralingsfysica, B-3001 Leuven, Belgium*
[2] *Experimental Physics Department, CERN, CH-1211 Geneva 23, Switzerland*
[3] *School of Physics and State Key Laboratory of Nuclear Physics and Technology, Peking University, Beijing 100871, China*
[4] *Laser Research Institute, Stellenbosch University, 7600, Stellenbosch, South Africa*
[5] *School of Physics and Astronomy, The University of Manchester, Manchester M13 9PL, United Kingdom*
[6] *Engineering Department, CERN, CH-1211 Geneva 23, Switzerland*
[7] *Department of Physics, University of Jyväskylä, PB 35(YFL) FIN-40351 Jyväskylä, Finland*
[8] *Photon Science Institute Alan Turing Building, University of Manchester, Manchester M13 9PY, United Kingdom*
[9] *Institut de Physique Nucléaire Orsay, IN2P3/CNRS, 91405 Orsay Cedex, France*
[10] *Massachusetts Institute of Technology, Cambridge, MA 02139, USA*
[11] *Department of Physics, University of Liverpool, Liverpool L69 7ZE, United Kingdom*

◆Beamtime request

- **TAC Comments**



<table>
<tr><th colspan="6">Probing the magicity and shell evolution in the vicinity of N=50 with high-resolution laser spectroscopy of 81,82Zn isotopes</th></tr>
<tr><th>CDS#</th><th>Proposal #</th><th>Original Proposal</th><th>Setup</th><th>Shifts</th><th>Isotopes</th></tr>
<tr><td>CERN-INTC-2020-064</td><td>INTC-P-579</td><td></td><td>CRIS</td><td>16</td><td>72-80Zn; 79g,mZn; 81Zn; 82Zn</td></tr>
<tr><td>Beam intensity/purity, targets-ion sources</td><td colspan="5">The Zn beams require a quartz line with neutron convertor, these units have been produced and operated in the past but availability in 2021 may be difficult to guarantee due to covid-related production issues.
For 82Zn yields from ISOLTRAP were of the order of 50-100 ions / sec. should the beam request be revised bearing this in mind?</td></tr>
<tr><td>General implantation and setup</td><td colspan="5"></td></tr>
<tr><td>General Comments</td><td colspan="5"></td></tr>
<tr><td>Safety</td><td colspan="5">Safety clearance of CRIS set- up can be found at 1807216 – No additional hazards. Update of the safety file on going and remarks from electrical inspection to be implemented.</td></tr>
<tr><td>TAC recommendation</td><td colspan="5">**The TAC notes that 82Zn may be less produced than quoted in the proposal which may affect the shift request. The other aspects of the proposal do not seem to present any feasibility issues.**</td></tr>
</table>

The TAC notes that ^{82}Zn may be less produced than quoted in the proposal which may affect the shift request. The other aspects of the proposal do not seem to present any feasibility issues.

Response:

The yield quoted in the TAC comments is from the quartz line with neutron convertor. We requested to use quartz line only, which results in a higher production for ^{82}Zn than that using quartz line with neutron-convertor.