International Symposium on Nuclear Science (ISNS-24) September 11, 2024
Sofia, Bulgaria

Isomer nuclear-moment measurement of neutron-rich nuclei ^{75}Cu and ^{99}Zr using highly spin-aligned beams

Yuichi Ichikawa
Kyushu University

First collaboration in 2008

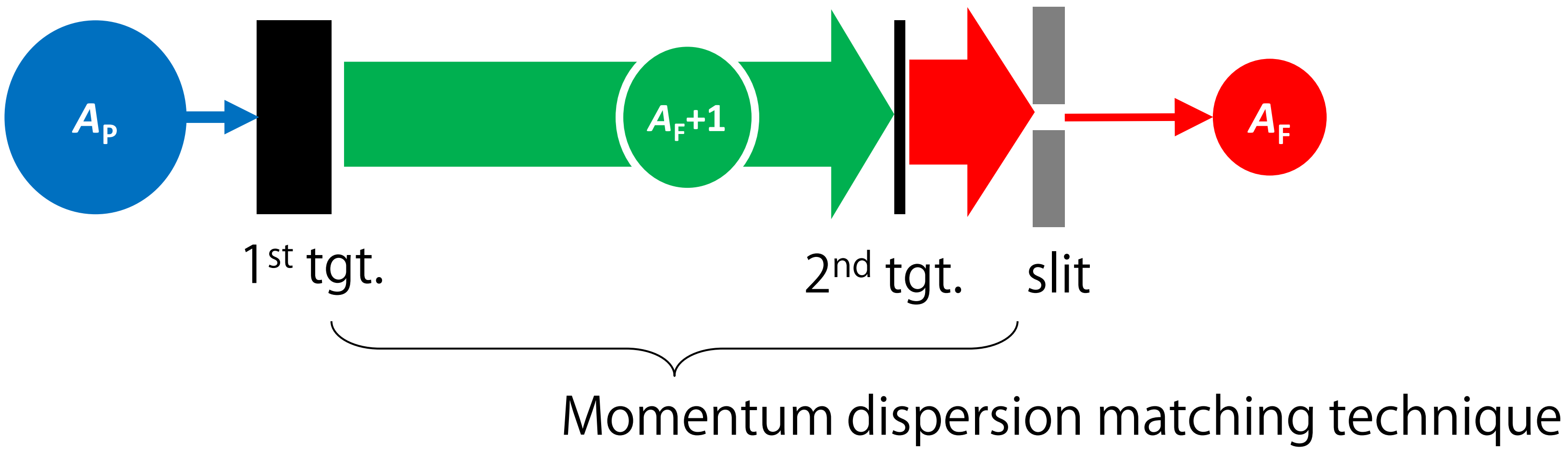
Collaboration in 2010

Cheers!

Highly spin-aligned RI beam

Two-step fragmentation scheme

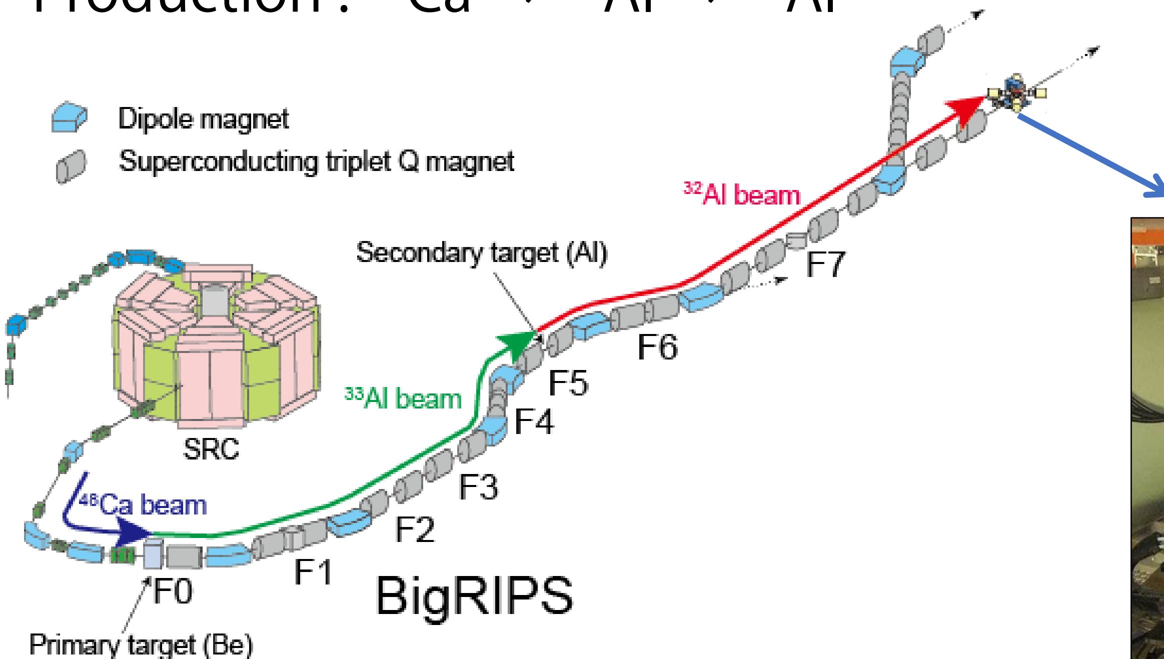
(Figure of Merit) ∝ (Spin alignment)^2 × (Statistical yields)



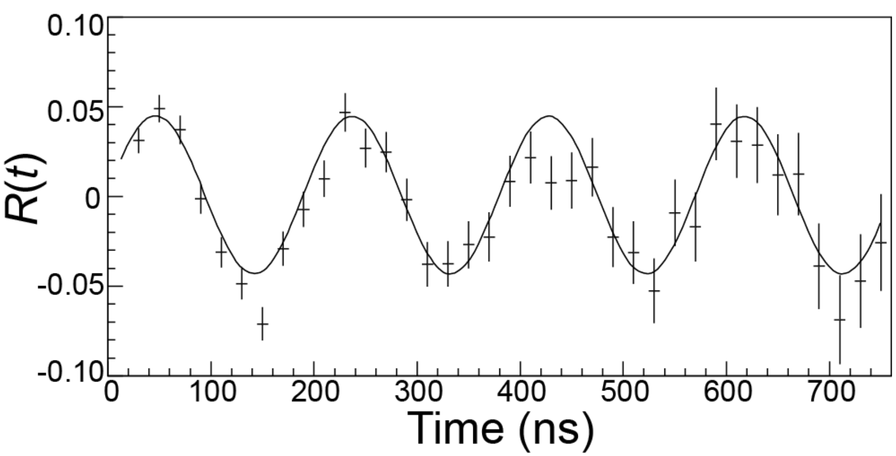
- Maximize spin alignment by simplest reaction
- Enhance yields by momentum dispersion matching

Experimental demonstration in 2010

Production : ^{48}Ca → ^{33}Al → ^{32}Al

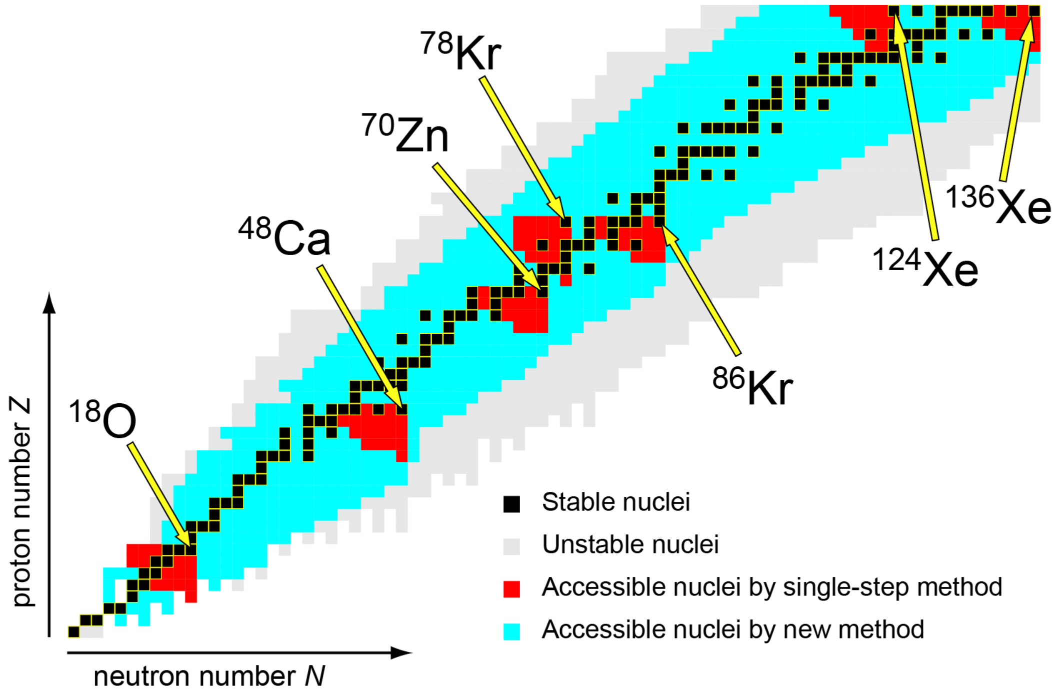


TDPAD apparatus



- 8(1)% spin alignment for ^{32}Al
- First measurement of $g(^{32}\mathrm{Al})=1.32(1)$
- FOM improvement >50

Broadening of accessible RI



Universal way to provide spin alignment

ARTICLES
PUBLISHED ONLINE: 21 OCTOBER 2012 | DOI: 10.1038/NPHYS2457
nature physics

Production of spin-controlled rare isotope beams

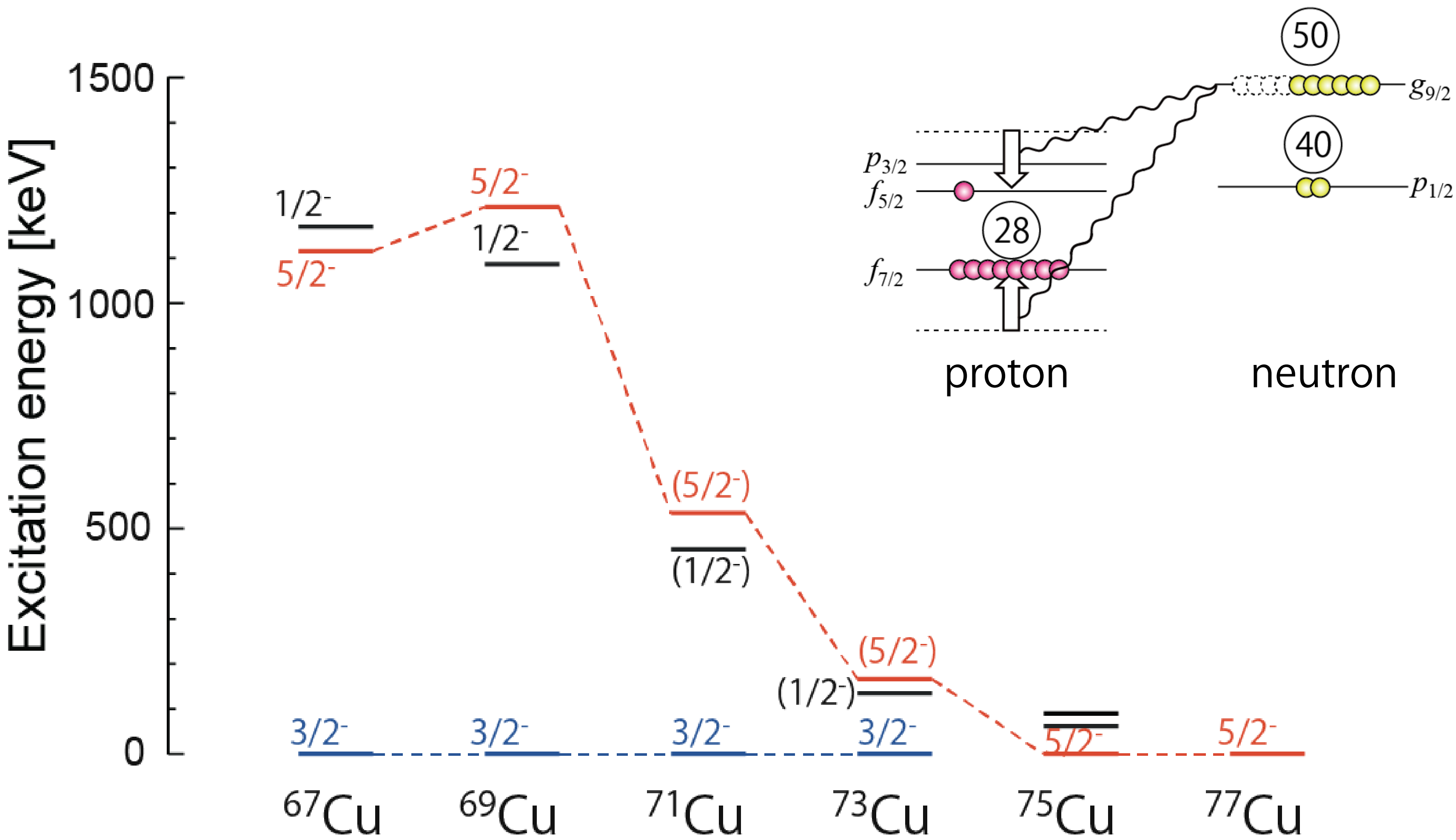
Yuichi Ichikawa[1*†], Hideki Ueno[1], Yuji Ishii[2], Takeshi Furukawa[3], Akihiro Yoshimi[4], Daisuke Kameda[1], Hiroshi Watanabe[1], Nori Aoi[1], Koichiro Asahi[2], Dimiter L. Balabanski[5], Raphaël Chevrier[6], Jean-Michel Daugas[6], Naoki Fukuda[1], Georgi Georgiev[7], Hironori Hayashi[2], Hiroaki Iijima[2], Naoto Inabe[1], Takeshi Inoue[2], Masayasu Ishihara[1], Toshiyuki Kubo[1], Tsubasa Nanao[2], Tetsuya Ohnishi[1], Kunifumi Suzuki[2], Masato Tsuchiya[2], Hiroyuki Takeda[1] and Mustafa M. Rajabali[8]

The degree of freedom of spin in quantum systems serves as an unparalleled laboratory where intriguing quantum physical properties can be observed, and the ability to control spin is a powerful tool in physics research. We propose a method for controlling spin in a system of rare isotopes which takes advantage of the mechanism of the projectile fragmentation reaction combined with the momentum-dispersion matching technique. The present method was verified in an experiment at the RIKEN RI Beam Factory, in which a degree of alignment of 8% was achieved for the spin of a rare isotope ^{32}Al. The figure of merit for the present method was found to be greater than that of the conventional method by a factor of more than 50.

Y. Ichikawa *et al.*, Nature Phys. 8 (2012) 918-922.

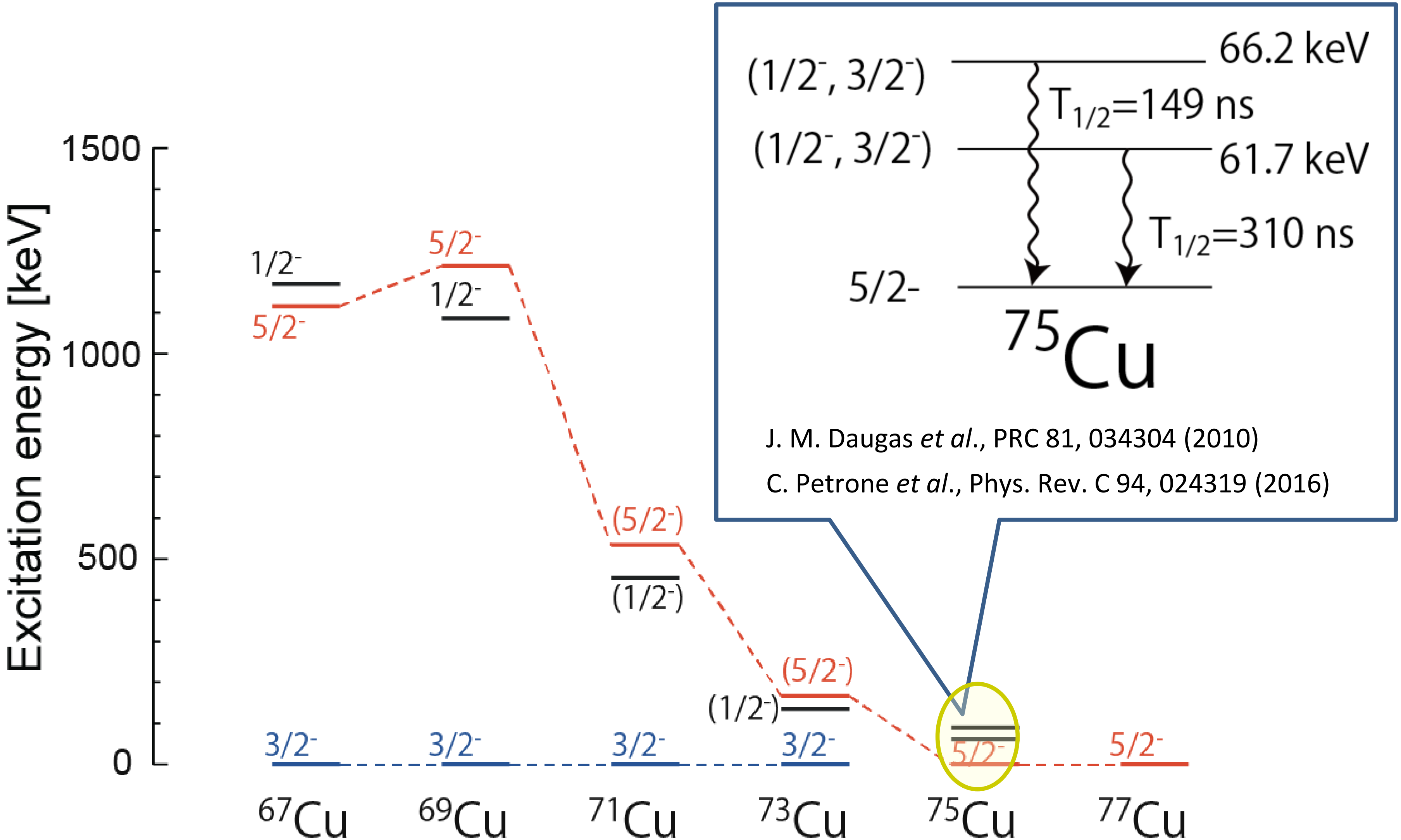
Recent experiments
-^{75}Cu-

Shell evolution in Cu isotopes



S. Franchoo *et al.*, PRL 81, 3100 (1998)
K. T. Flanagan *et al.*, PRL 103, 142501 (2009)

Shell evolution in Cu isotopes



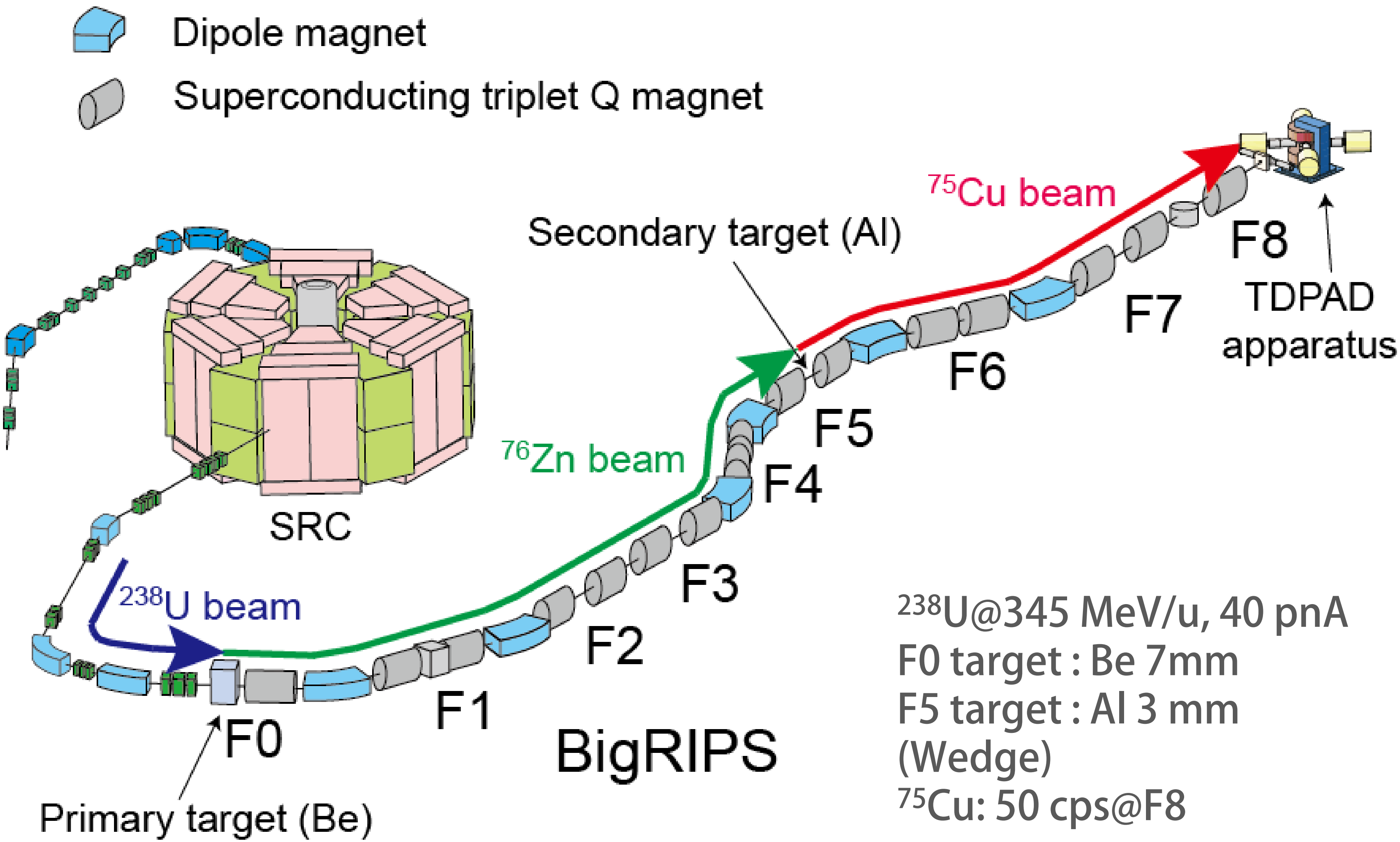
J. M. Daugas *et al.*, PRC 81, 034304 (2010)

C. Petrone *et al.*, Phys. Rev. C 94, 024319 (2016)

S. Franchoo *et al.*, PRL 81, 3100 (1998)

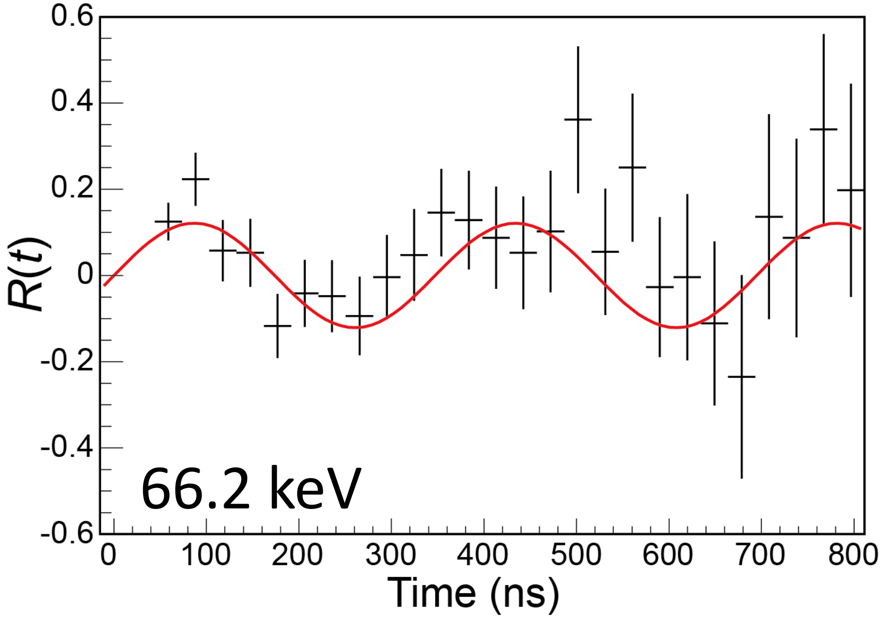
K. T. Flanagan *et al.*, PRL 103, 142501 (2009)

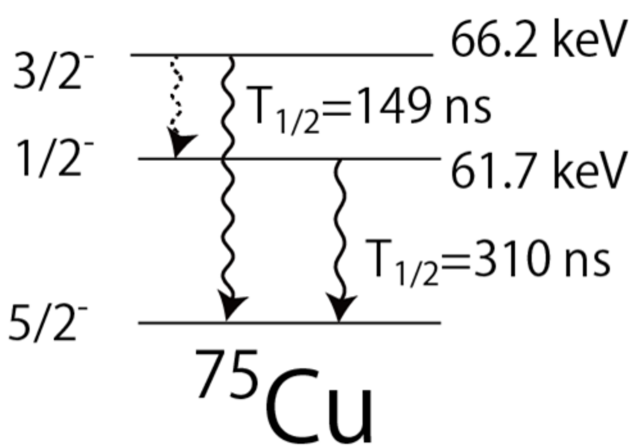
^{75}Cu production at BigRIPS



^{238}U@345 MeV/u, 40 pnA
F0 target : Be 7mm
F5 target : Al 3 mm (Wedge)
^{75}Cu: 50 cps@F8

Results





① Spin-parity assignment

66.2 keV level : $I^{\pi} = 3/2^{-}$

② Spin alignment

$$\rho_2 F_2 = A B_2 F_2 = -0.17(3)$$

$B_2 F_2 = -0.602$: E2 + M1 (δ=0.47)

for $3/2^{-} \rightarrow 5/2^{-}$ transition

$$A = 30(5)\ \%$$

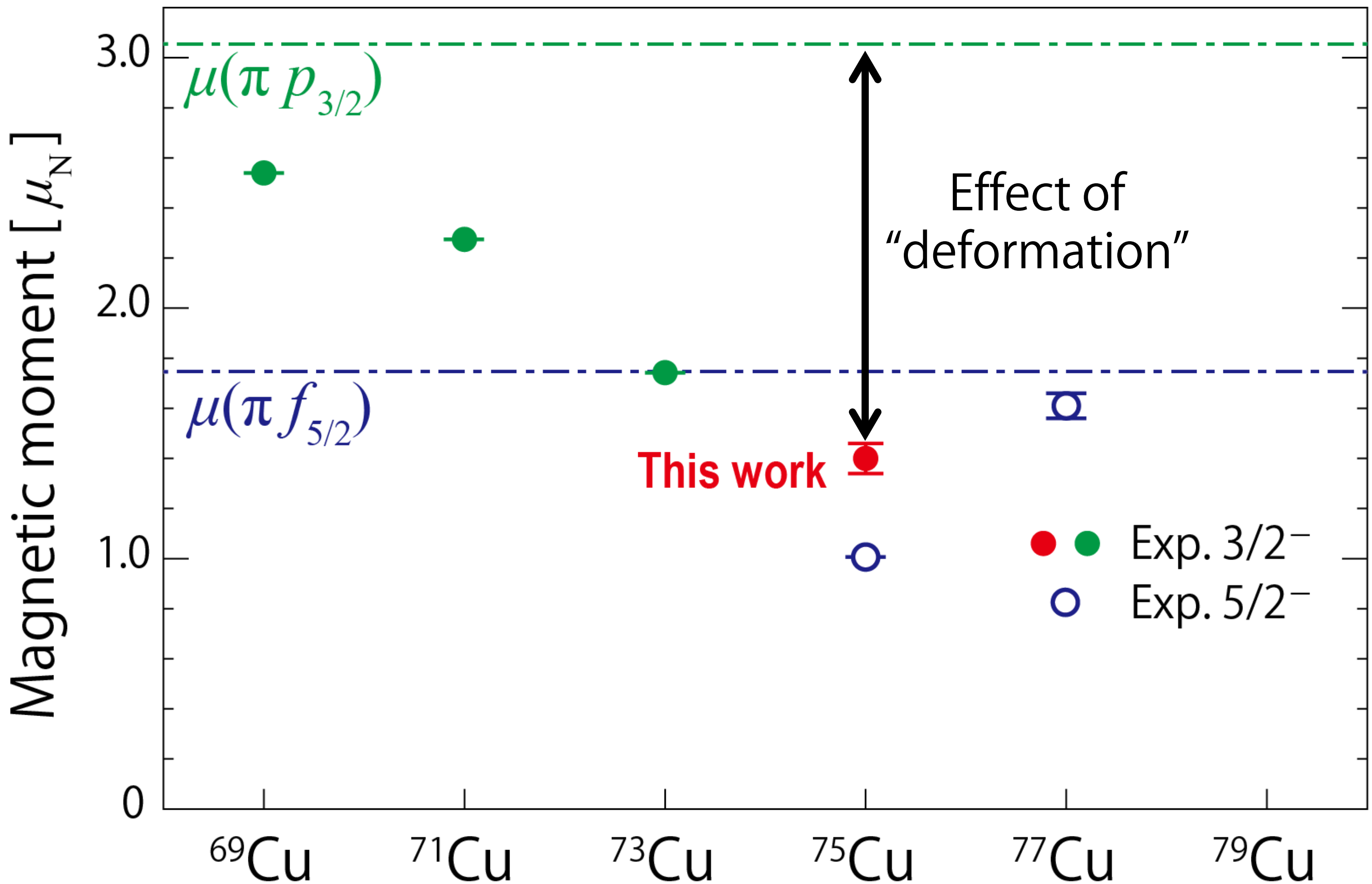
③ Magnetic moment

$$\omega_{\mathrm{L}} = -\frac{g \mu_{\mathrm{N}} B_0}{\hbar}$$

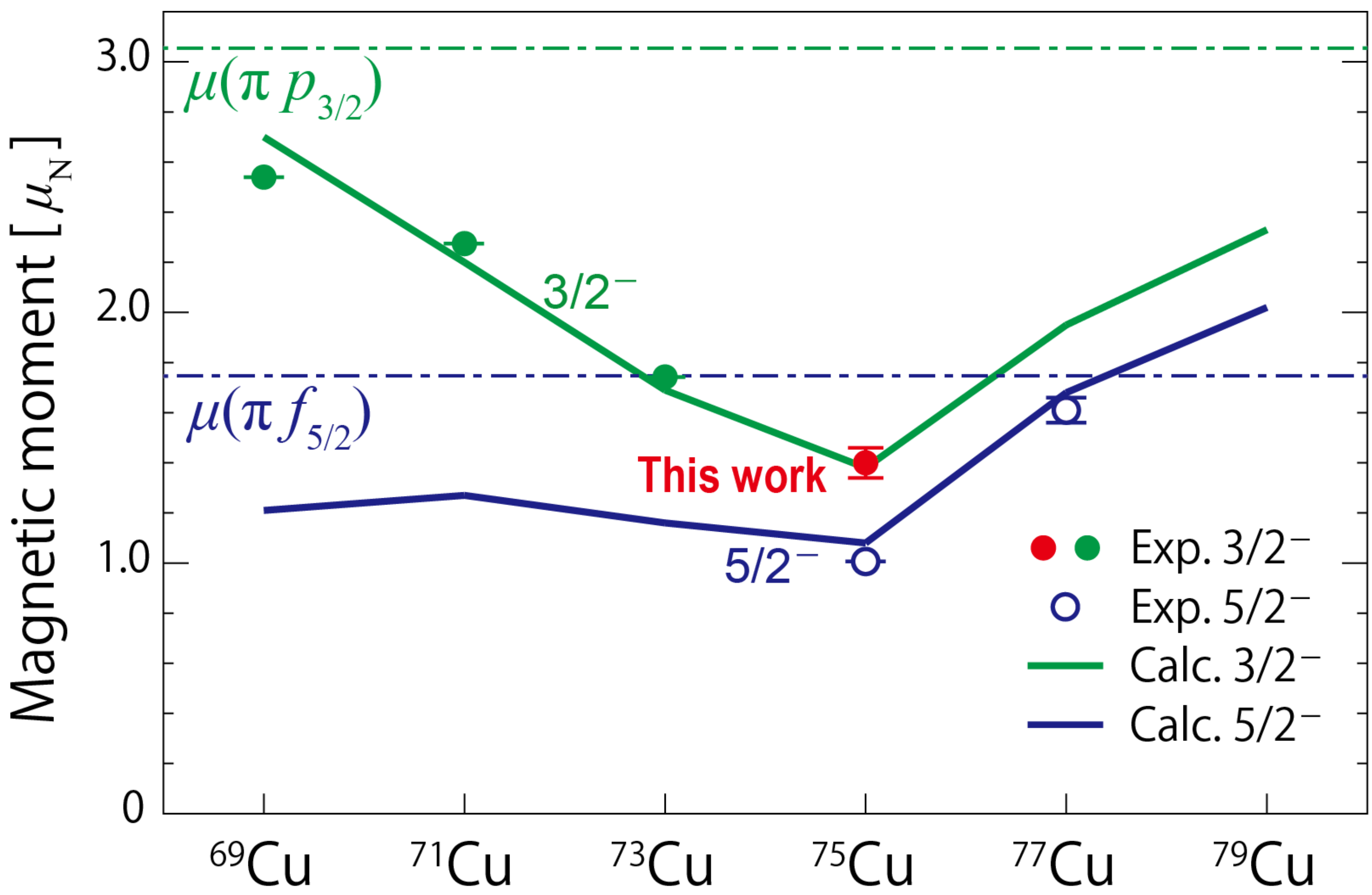
$$g = 0.93(4)$$

$$\mu = 1.40(6) \mu_{\mathrm{N}}$$

Magnetic moment systematics

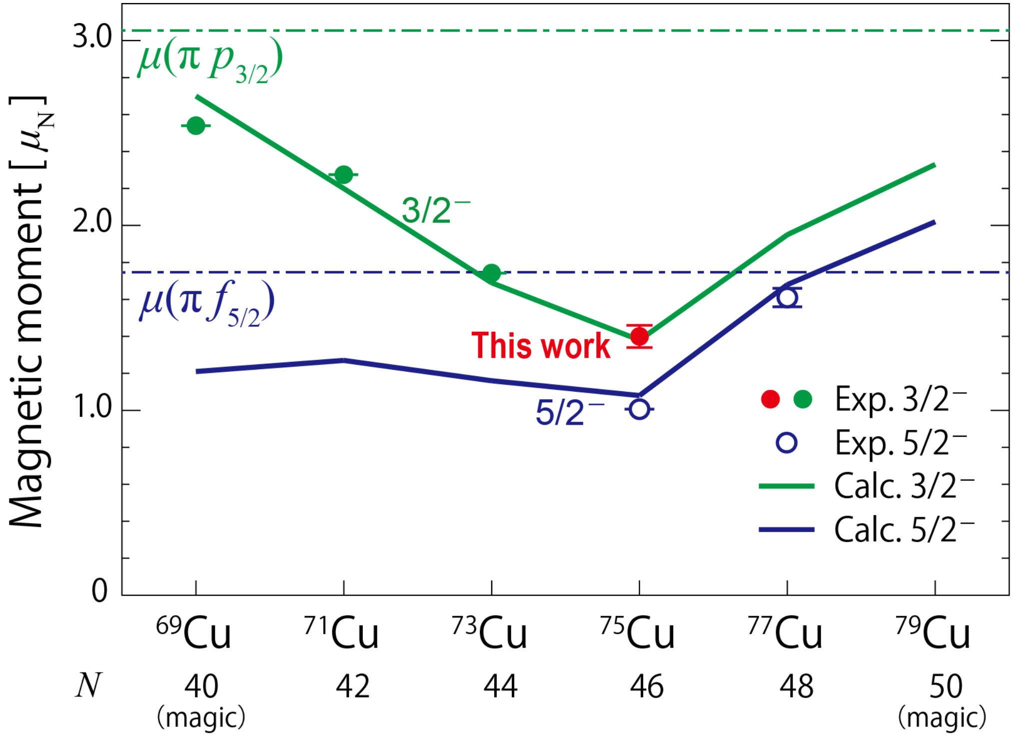


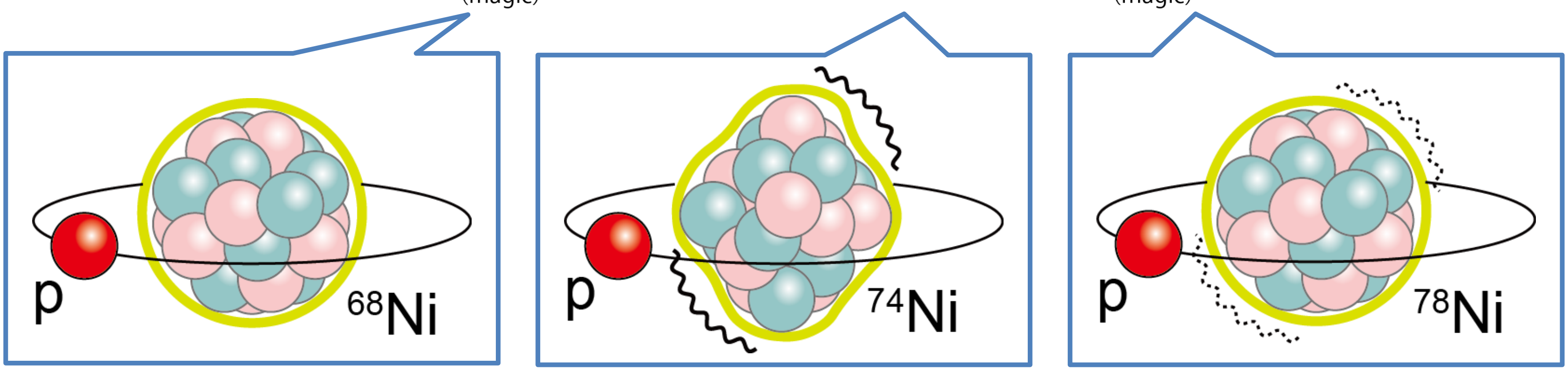
Magnetic moment systematics



MCSM calculation by T. Otsuka and Y. Tsunoda

Shell evolution on deformation

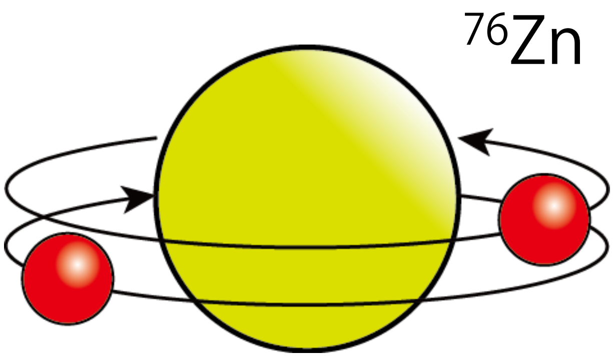


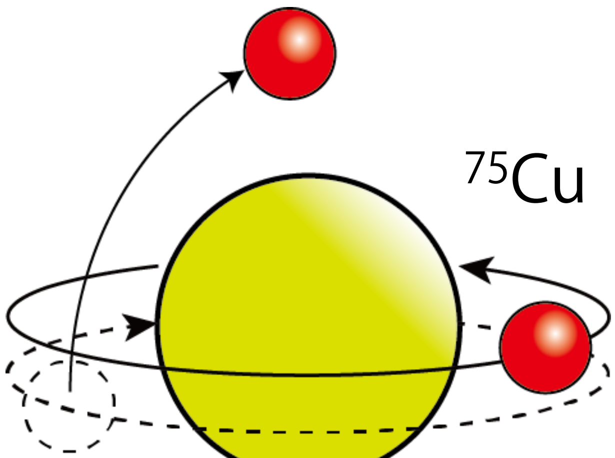


Y. Ichikawa *et al.*, Nature Phys. 15, 321-325 (2019)

What is key?

“Spin” correspondence



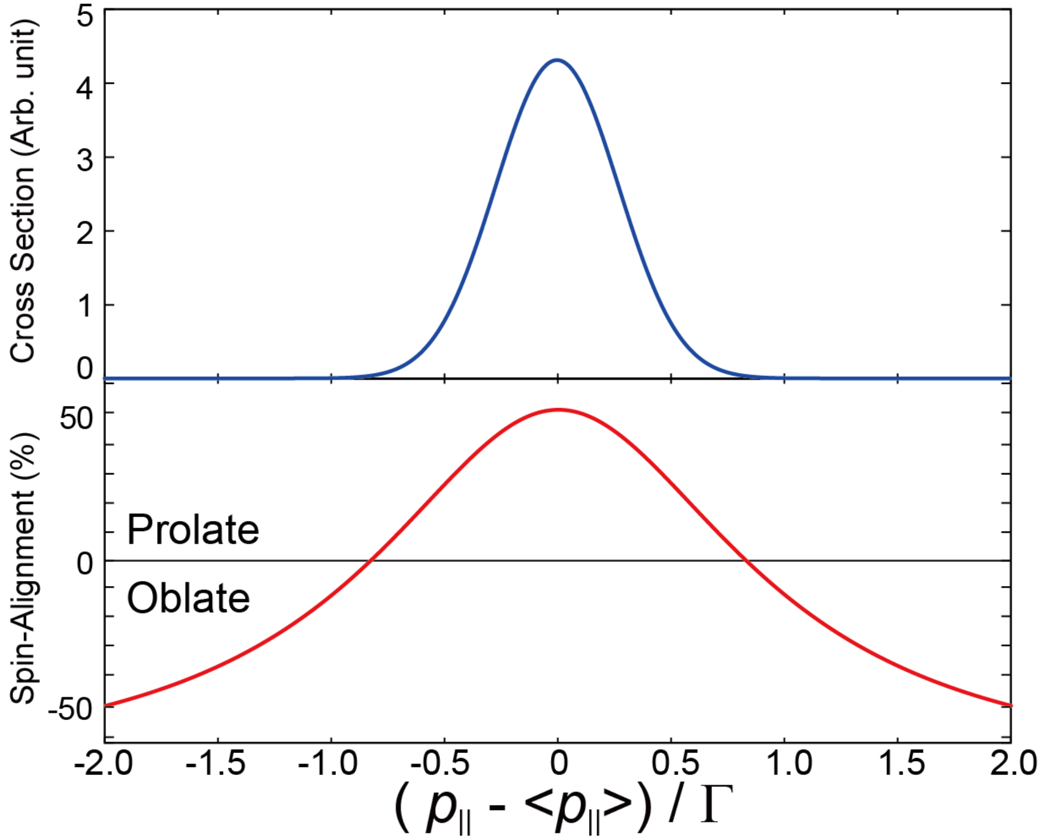


^{76}Zn(0^+)

p($\pi p_{3/2}$) + ^{75}Cu($3/2^-$)

- Good correspondence between ini. & fin. states
- Extremely simple (one-shot) reaction

Reaching maximum

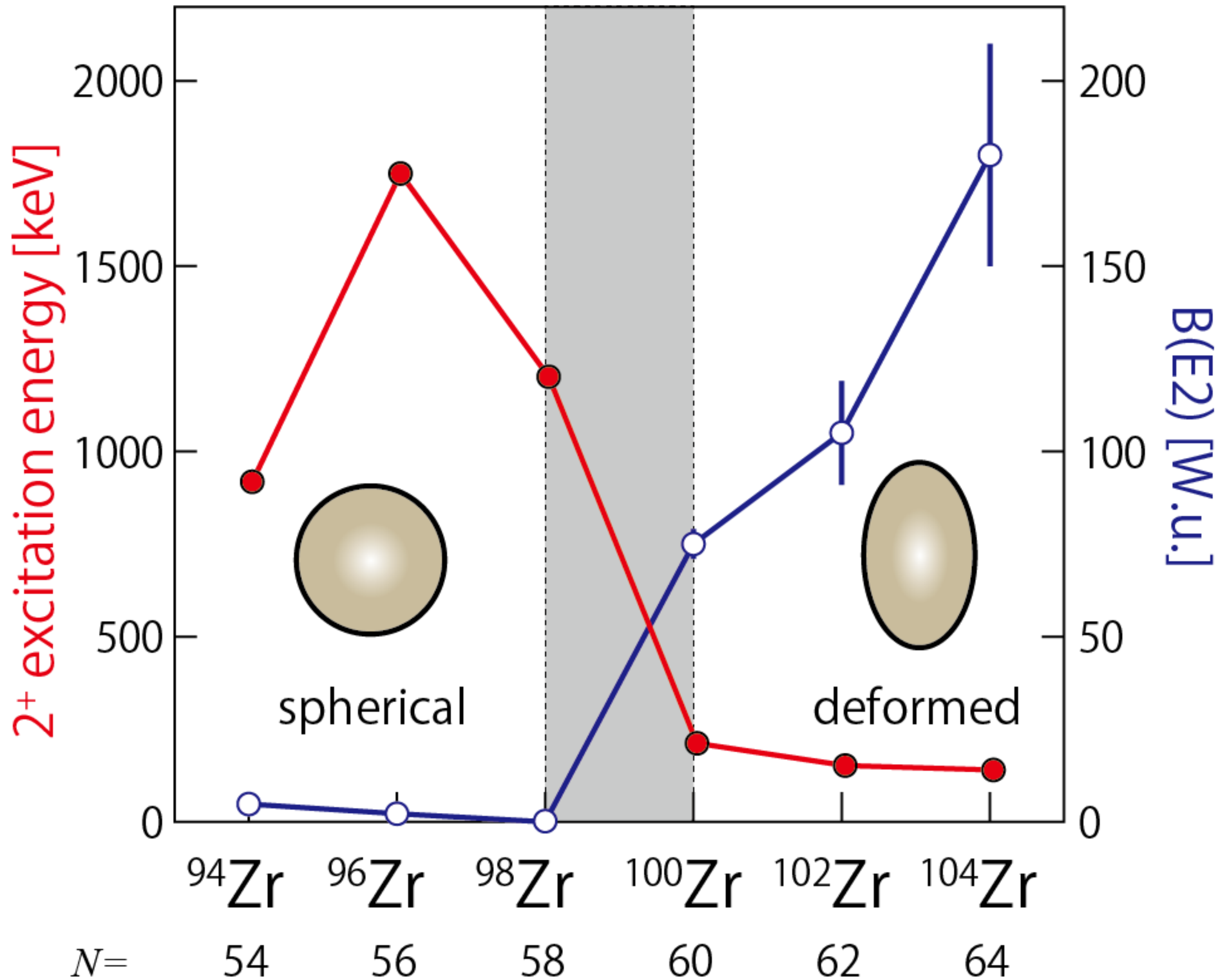


Realized 30(5)% for Maximum 41%

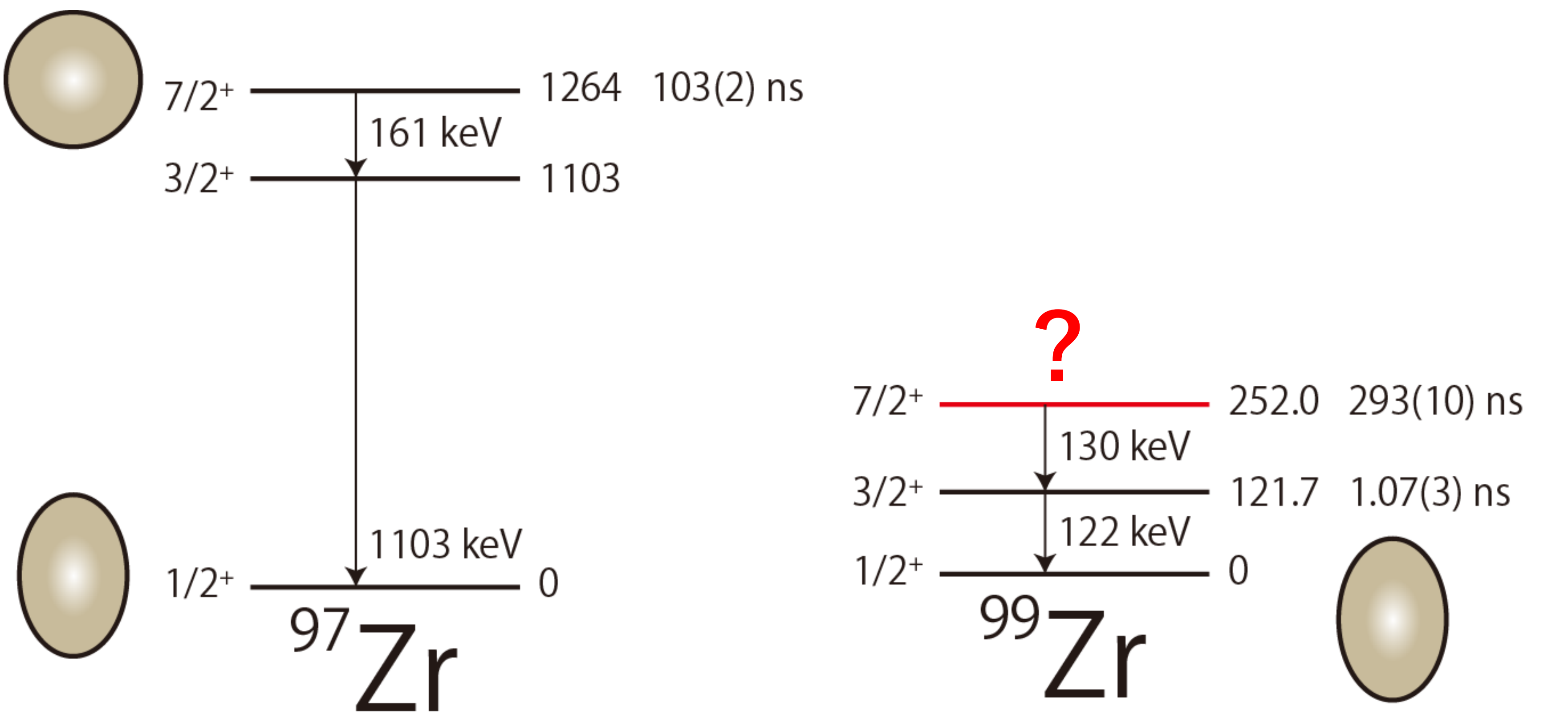
Trend : “clean experiment” with high spin alignment

Recent experiments
-^{99}Zr-

Sudden shape change



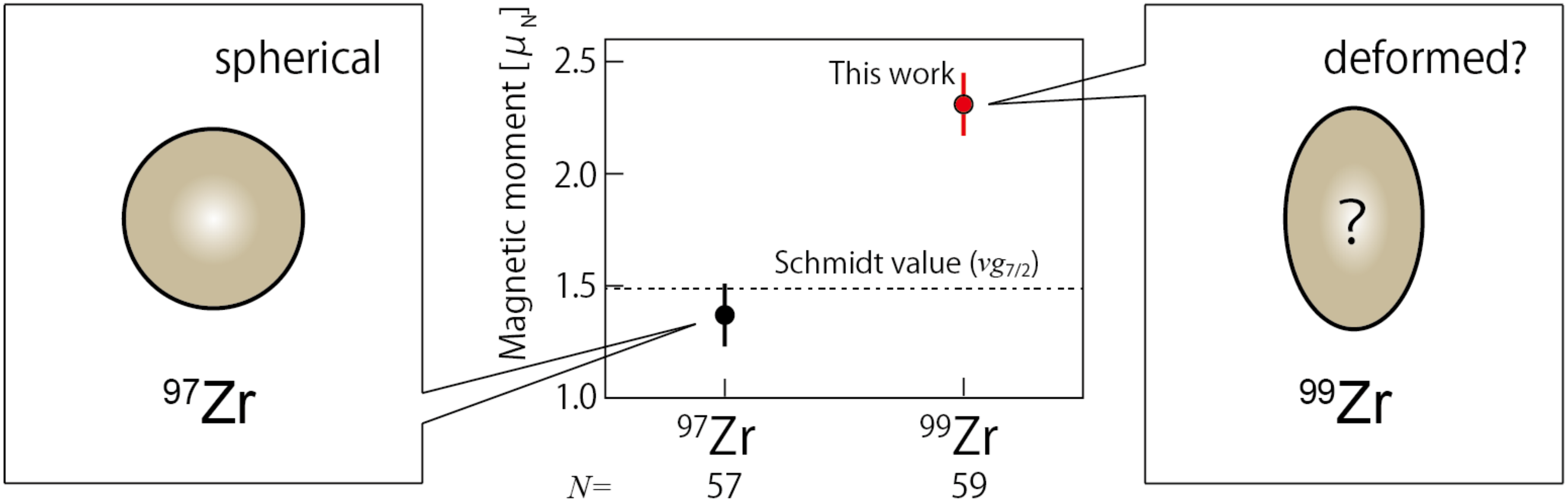
Border N=59



$N = 57$

$N = 59$

How is its shape?

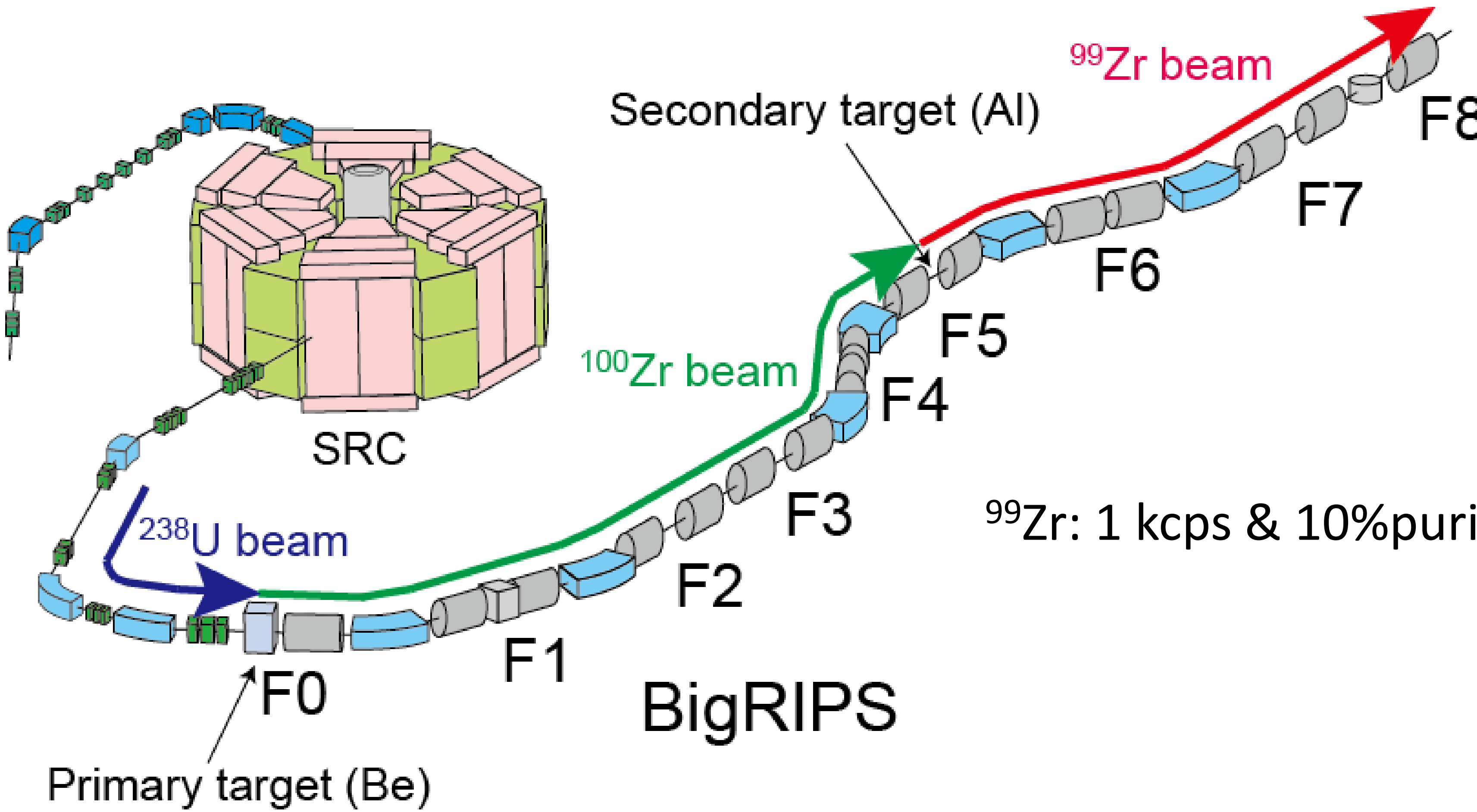


F. Boulay *et al.*, Phys. Rev. Lett. 124, 112501 (2020)

- Not spherical also for excited state
- Q moment measurement with higher spin aligned beam

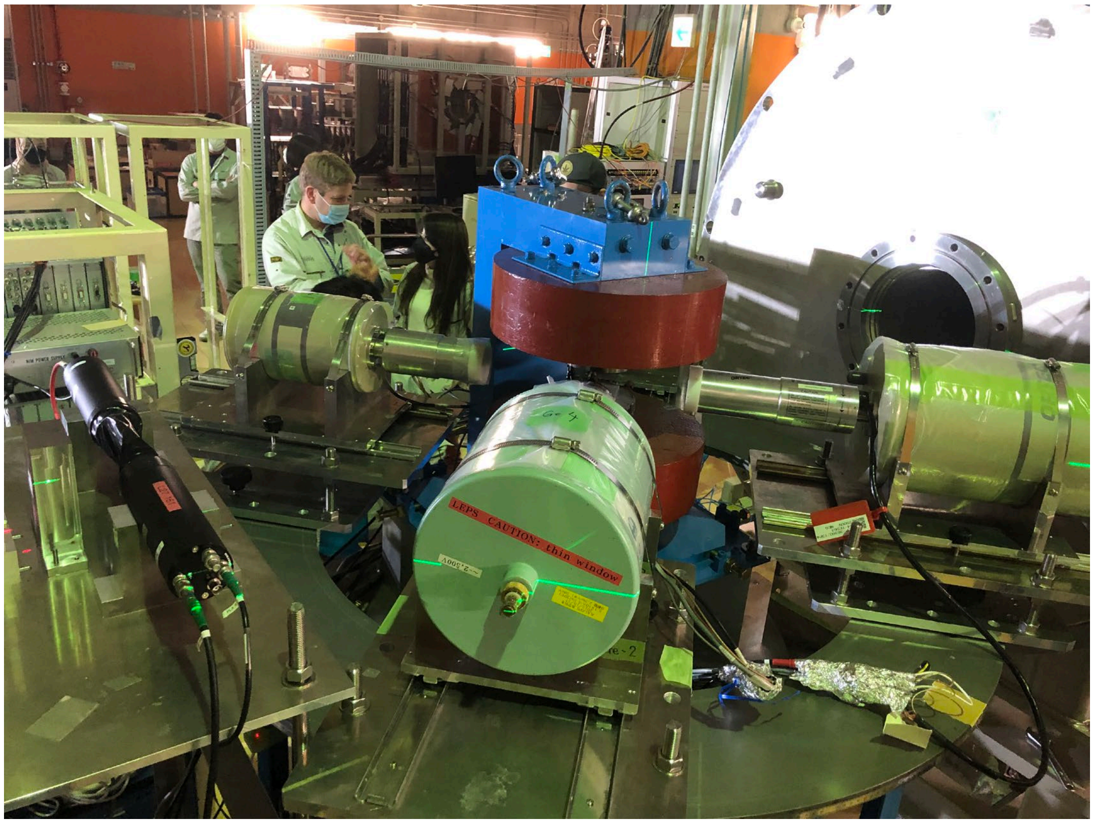
Q moment measurement of ^{99}Zr

NP1912-RIBF175 (done in April, 2022)



^{99}Zr: 1 kcps & 10%purity

Setup for μ moment



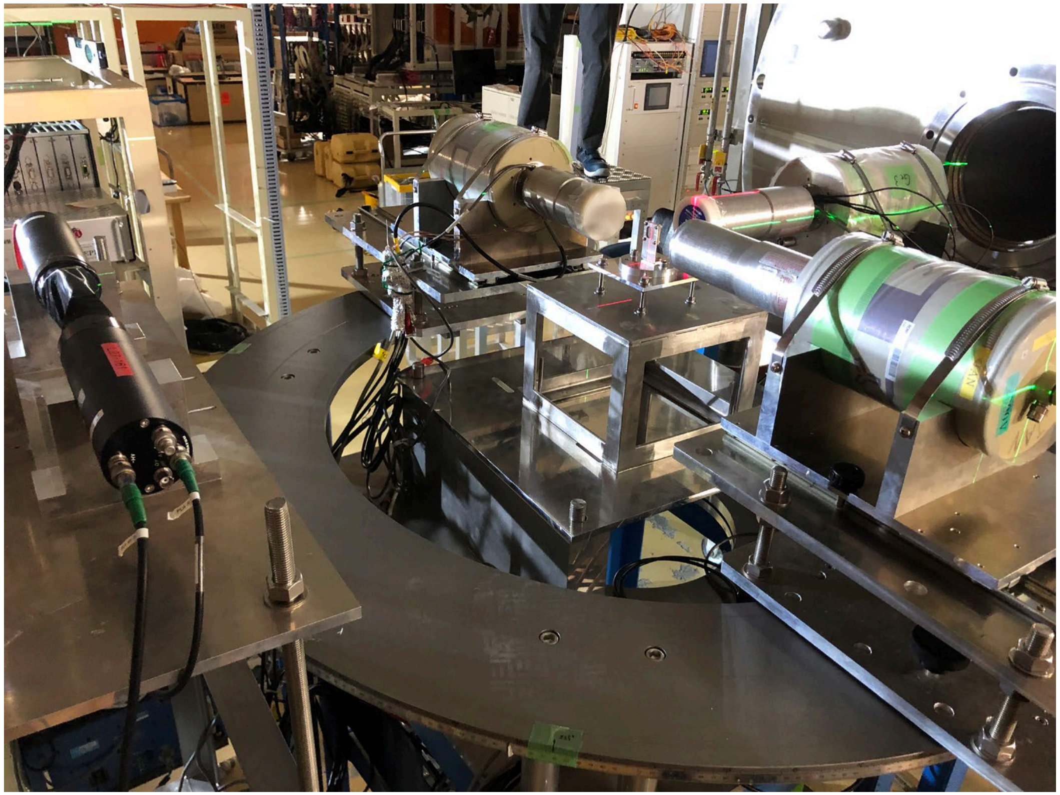
Beam stopper
- Cu （annealed）
- 3 mm^{t}

Dipole magnet
- $B_0 = 0.200$ T
- Instability in time <0.1%
- Inhomogeneity <0.1%

Ge detectors
- LEPS×2, Co-axial×2
- 7 cm from stopper center

Plastic scintillator
- 0.1 mm^{t}
- Time zero definition

Setup for Q moment



Beam stopper

- Zr single crystal
  (grain cluster)
- c-axis alignment > 1/(3~4)
- 15 mm×15 mm×3 mm^t

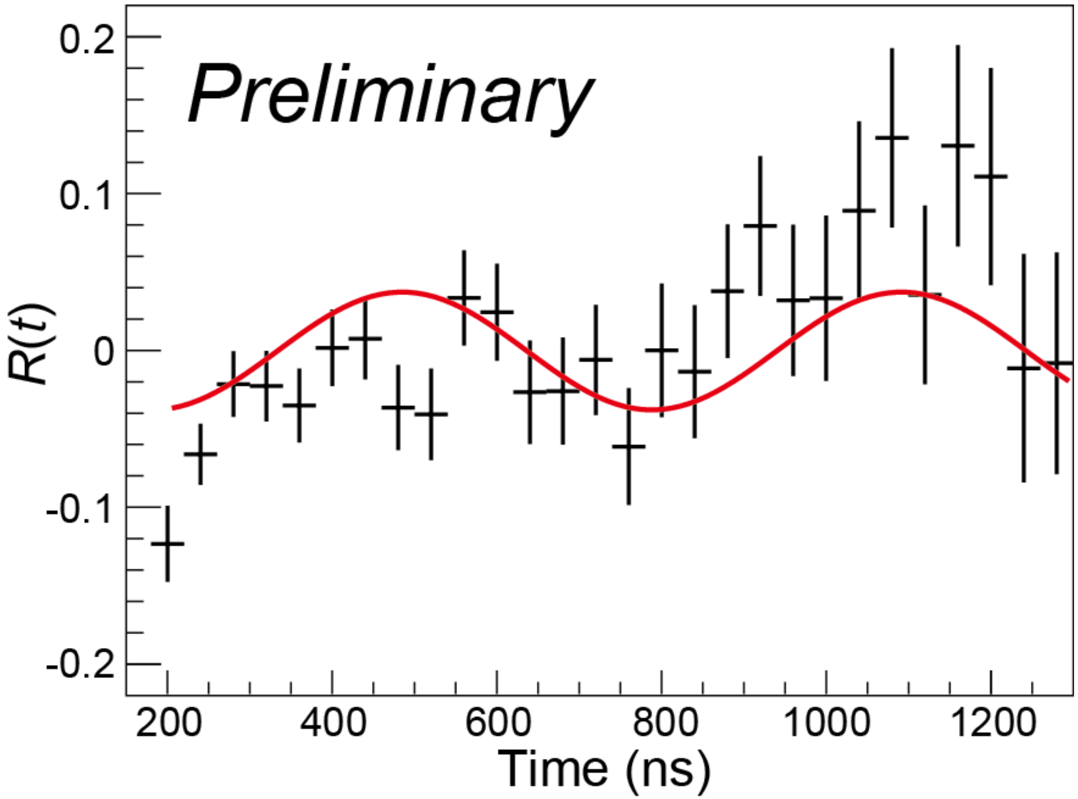
Ge detectors

- LEPS & Co-axial
  (not very good condition…)
- 7~10 cm from stopper center

Plastic scintillator

- 0.1 mm^t
- Time zero definition

Preliminary R(t) signal



- 30,000 events of 130-keV γ ray for μ measurement
- Preliminarily, ～10% alignment in ^{99}Zr
- Analysis on Q moment is on-going

Summary

- **Spin aligned RI beams**
  - ✓ Two-step scheme
  - ✓ Highly spin aligned RI beams
  - ✓ Isomer moment measurements

- **Recent experiments**
  - ✓ μ measurement of ^{75}Cu
  - ✓ 30% alignment for ^{75}Cu
  - ✓ μ & Q measurement of ^{99m}Zr