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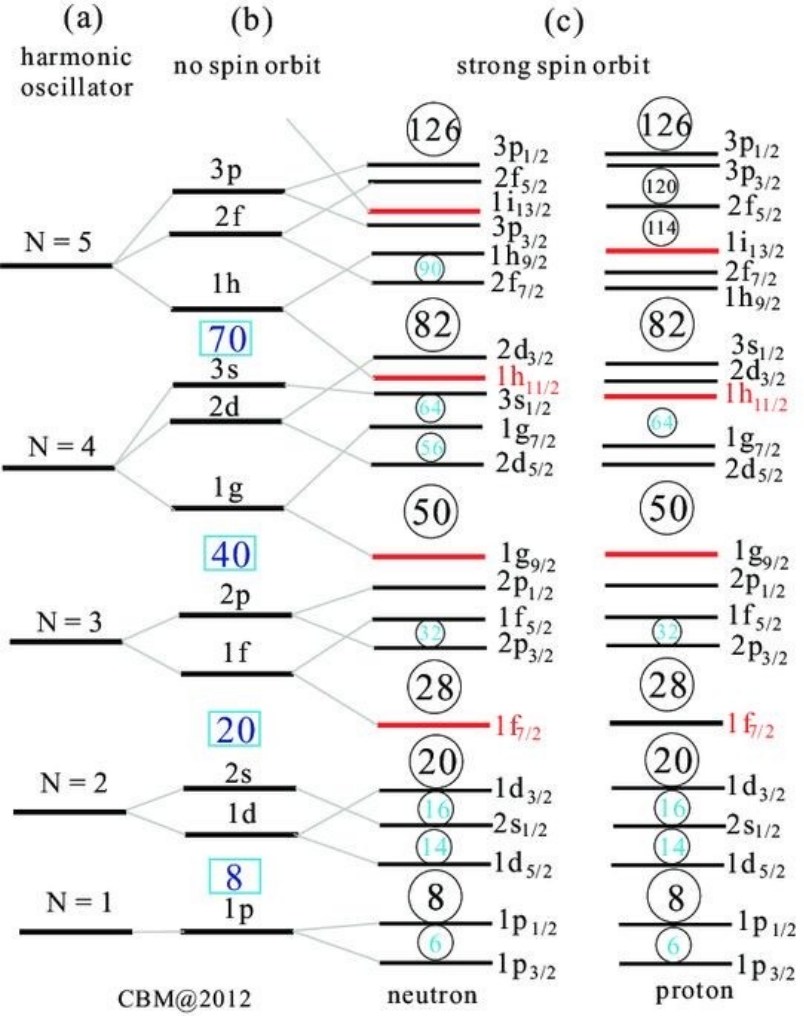
Status of In-beam γ-ray spectroscopy of neutron-rich scandium isotopes with N=34 and 36

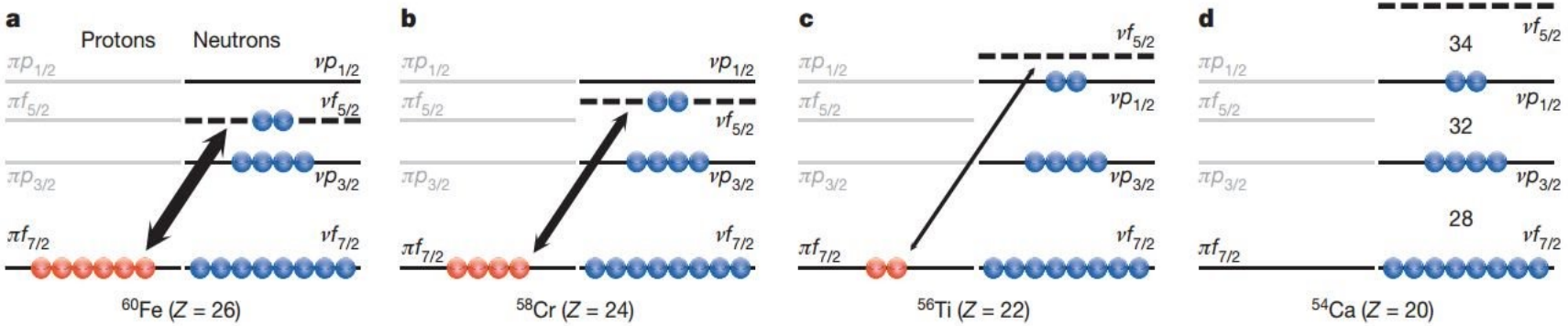
Jiseok Kim[1)*]; Kathrin Wimmer[2)]; Takuma Koiwai[3,4)] and HiCARI collaboration

Department of Physics, Korea University, Seoul 02841, Republic of Korea[1)]
GSI Helmoltzzentrum für Schwerionenforschung GmbH, Planckstr. 1, 64291 Darmstadt, Germany[2)]
Department of Physics, University of Tokyo, 7-3-1 Hongo, Bunkyo, Tokyo 113-0033, Japan[3)]
RIKEN Nishina Center, 2-1 Hirosawa, Wako, Saitama 351-0198, Japan[4)]

Motivation

Nuclear Shell model



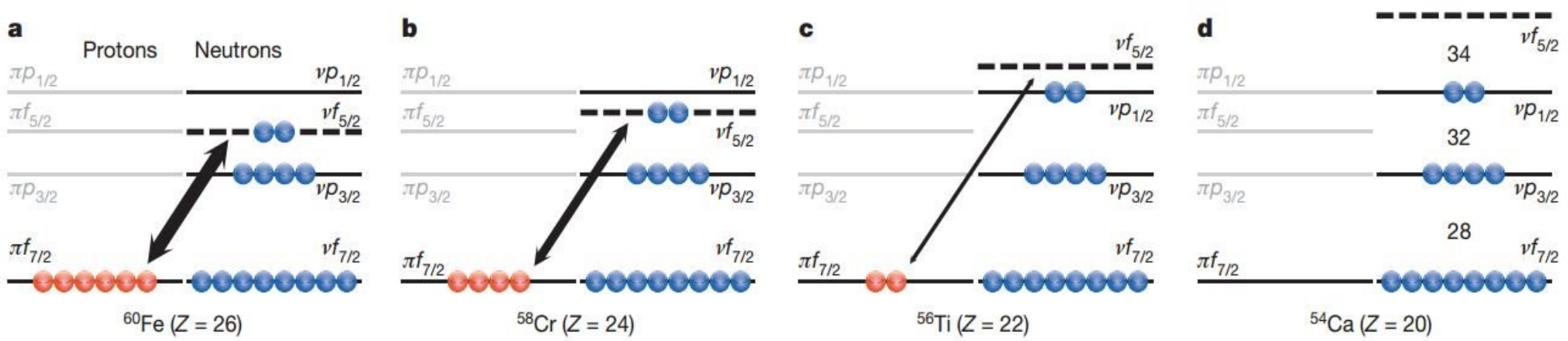


D.Steppenbeck et al., Nature **502**, 207-210 (2013)

- Interaction between $\pi f_{7/2}$ and $\nu f_{5/2}$ becomes weaker as the proton number decreases. (Inversion of $\nu f_{5/2}$ and $\nu p_{1/2}$)

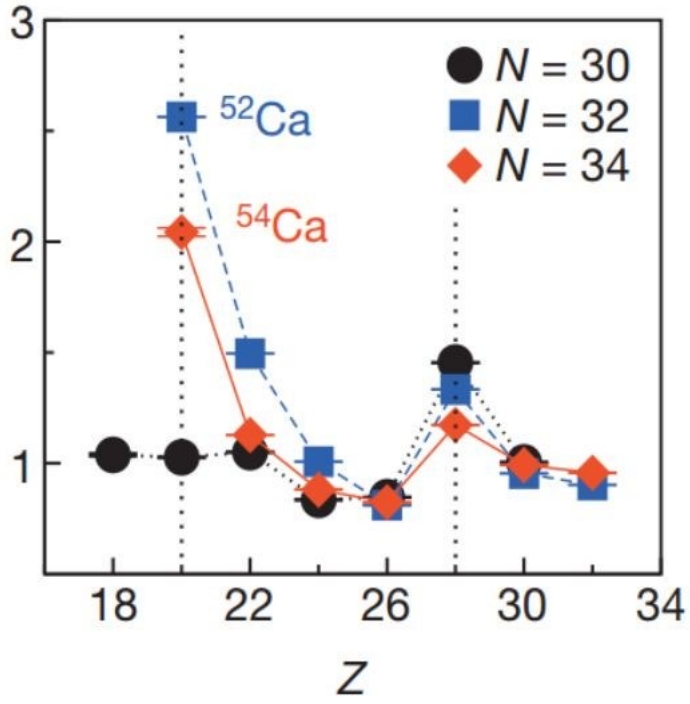
- New neutron magic number 32 and 34 in Ca isotopes (Subshell closure)

Motivation



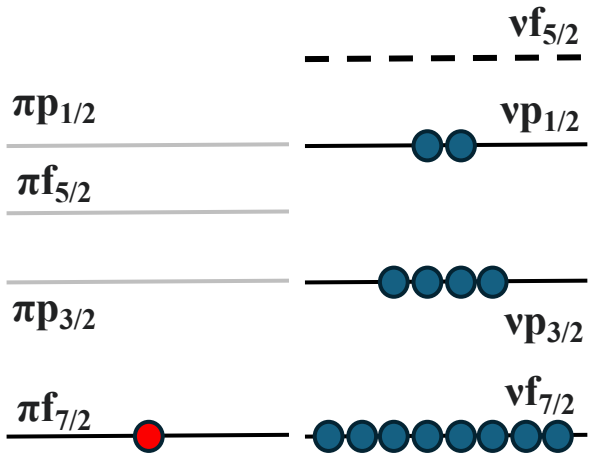
- Breakdown of the neutron magic number 32 already in Ti isotopes.
- Addition of two protons dramatically changes neutron occupation.

→ Study Sc with Z = 21

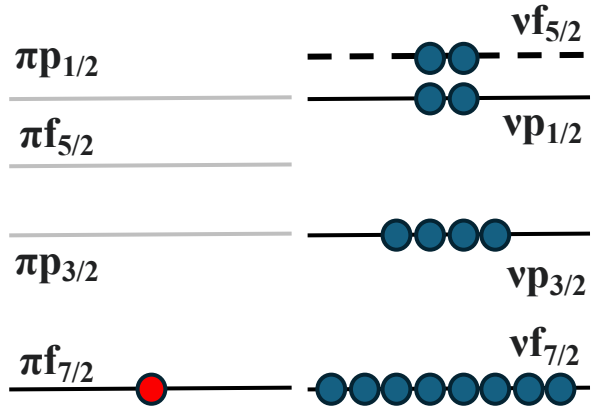


D.Steppenbeck et al., Nature **502**, 207-210 (2013)

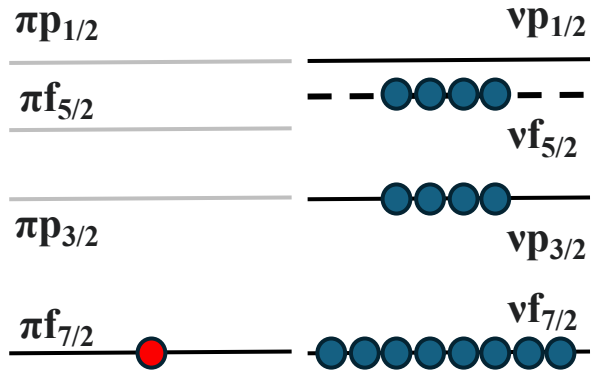
Motivation



^{55}Sc (N = 32)



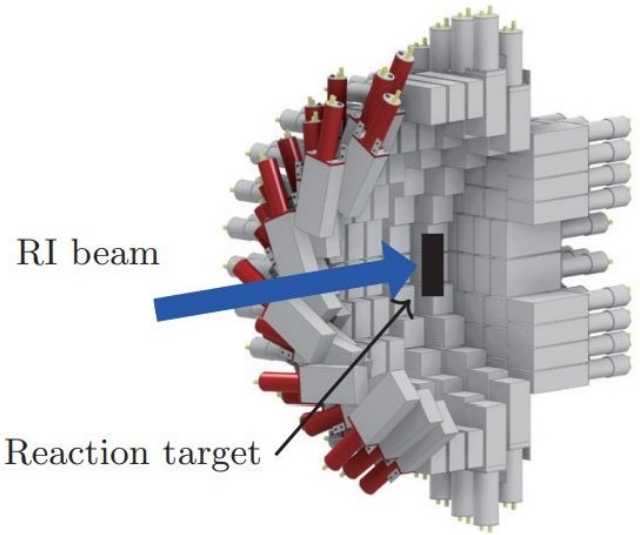
^{57}Sc (N = 34) - Case 1



^{57}Sc (N = 34) - Case 2

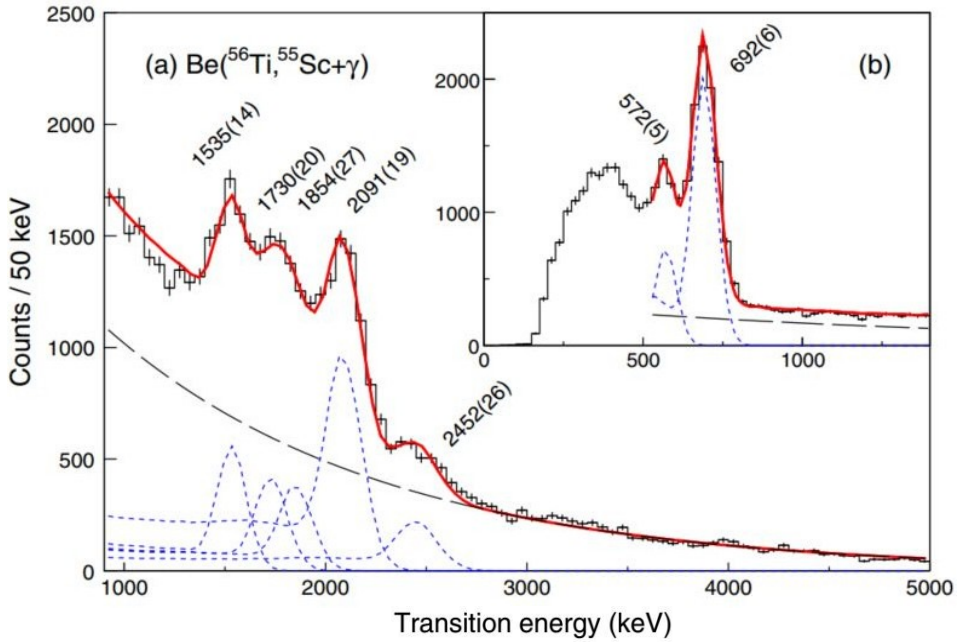
Motivation

DALI2+ (NaI crystal)

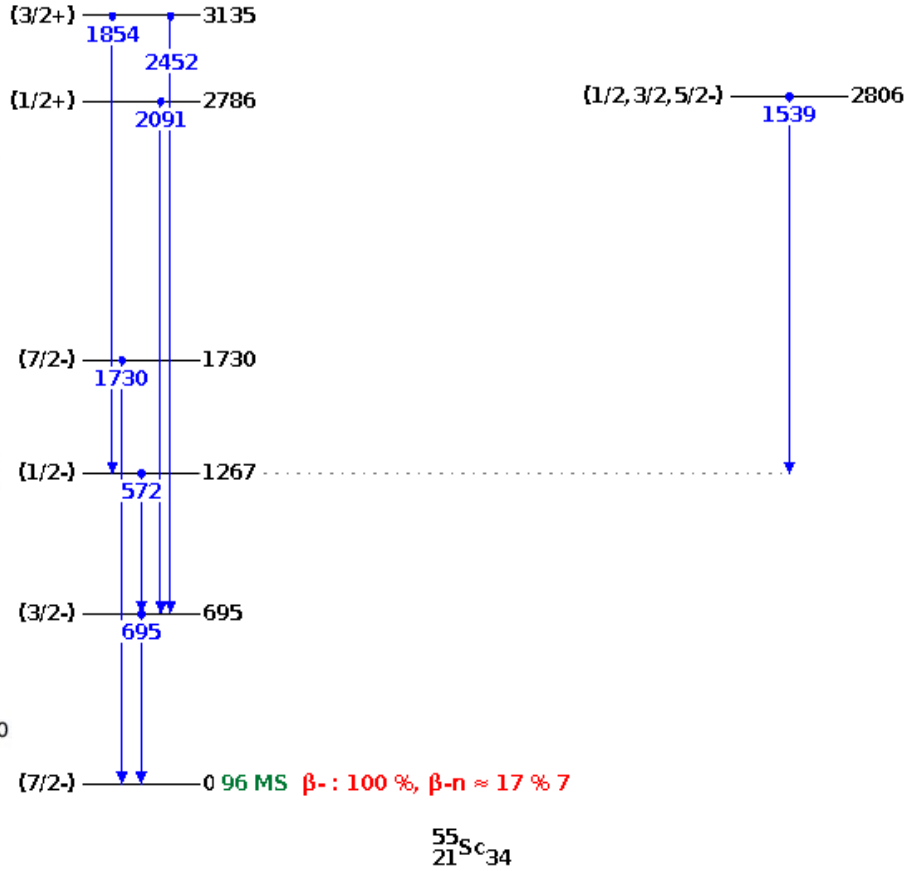


I.Murray et al., RIKEN Accel. Prog. Rep. 51 (2018)

Previous results of ^{55}Sc from DALI2+



D.Steppenbeck et al., PRC **96**, 064310 (2017)

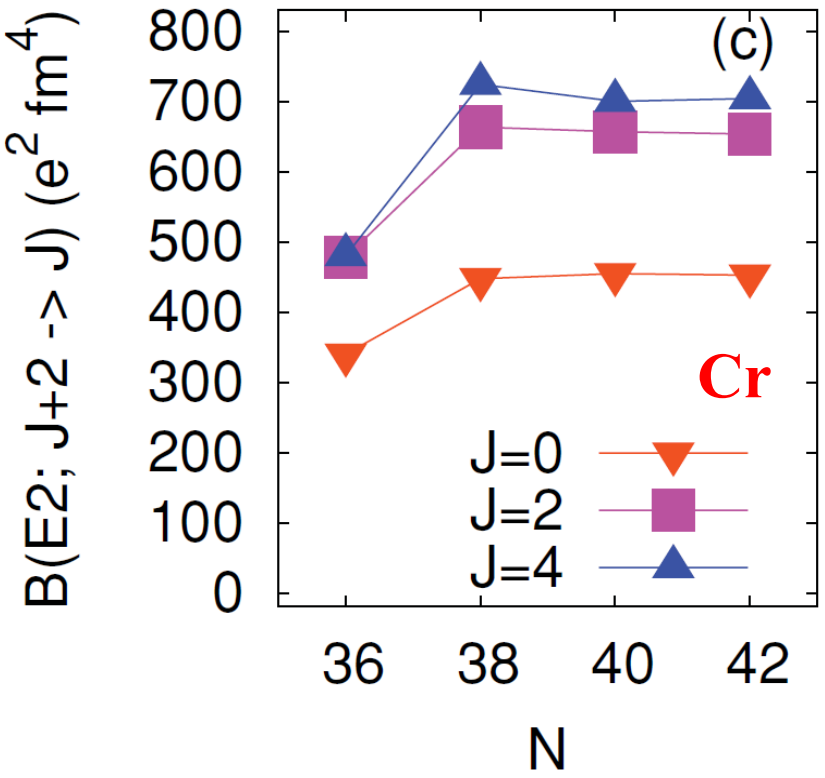


NuDat[Website]. (2023, April 17). https://www.nndc.bnl.gov/nudat3/

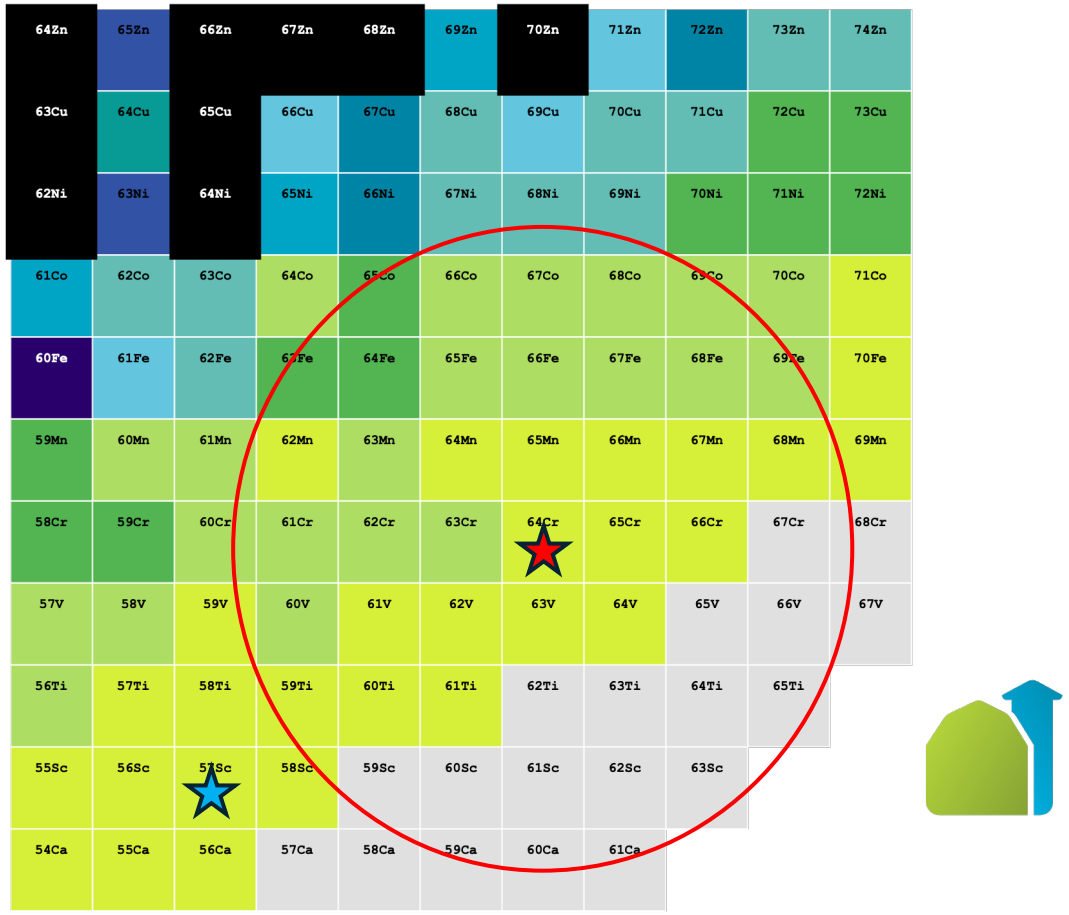
- The level structure of ^{55}Sc was already established by previous experiment but need more detailed spectroscopy and new observables.

  → High–resolution spectroscopy and lifetime measurements

Motivation



S. M. Lenzi et al., PhysRevC.**82**.054301 (2010)



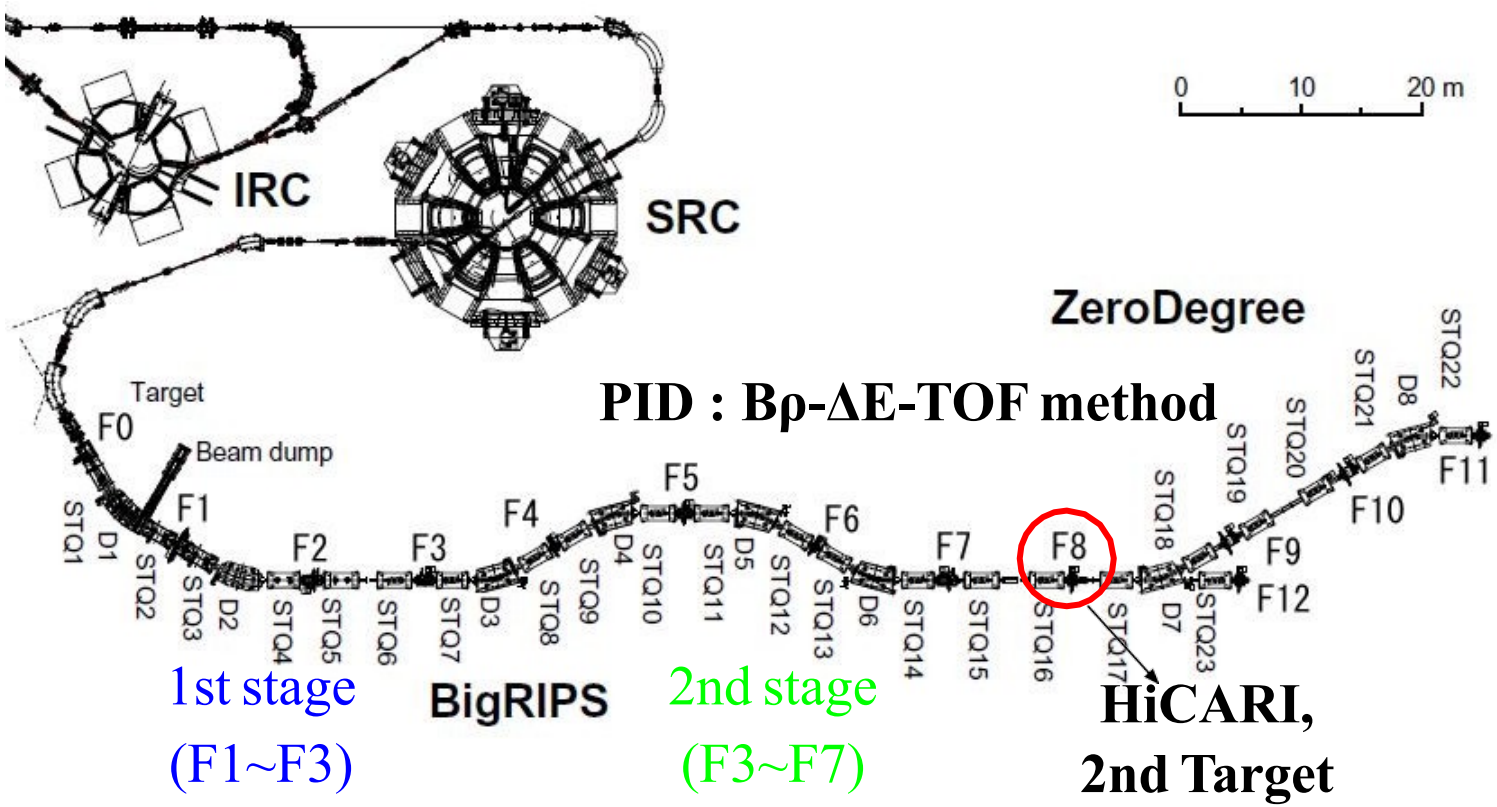
NuDat[Website]. (2024, December 12). https://www.nndc.bnl.gov/nudat3/

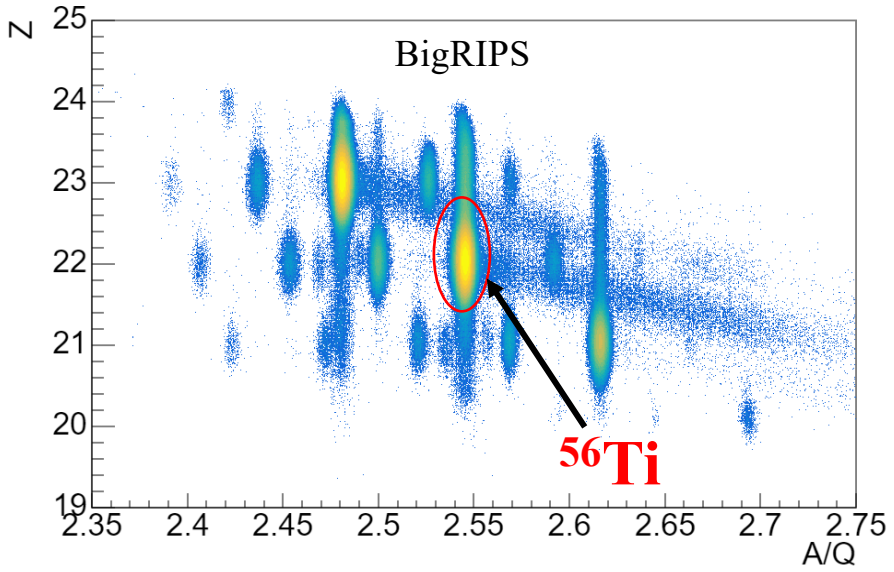
- Study on the boundary of the island of inversion.

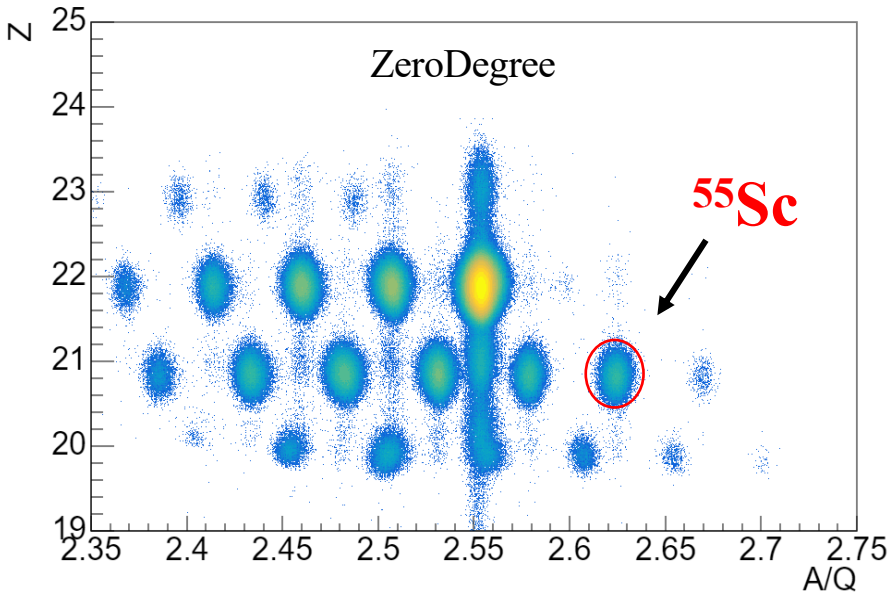
→ Energy and lifetime measurements in ^{55,57}Sc with proton knockout reaction from ^{56,58}Ti & Studies on single particle states of proton

NP1912-RIBF142

- Primary Beam : ^{70}Zn @345 AMeV
- Secondary Beams : ^{56,58}Ti @180-190 AMeV
- Secondary Targets : Be 3mm
- ^{56}Ti(^{9}Be,^{55}Sc)X : 12 hours
- ^{58}Ti(^{9}Be,^{57}Sc)X : 28 hours

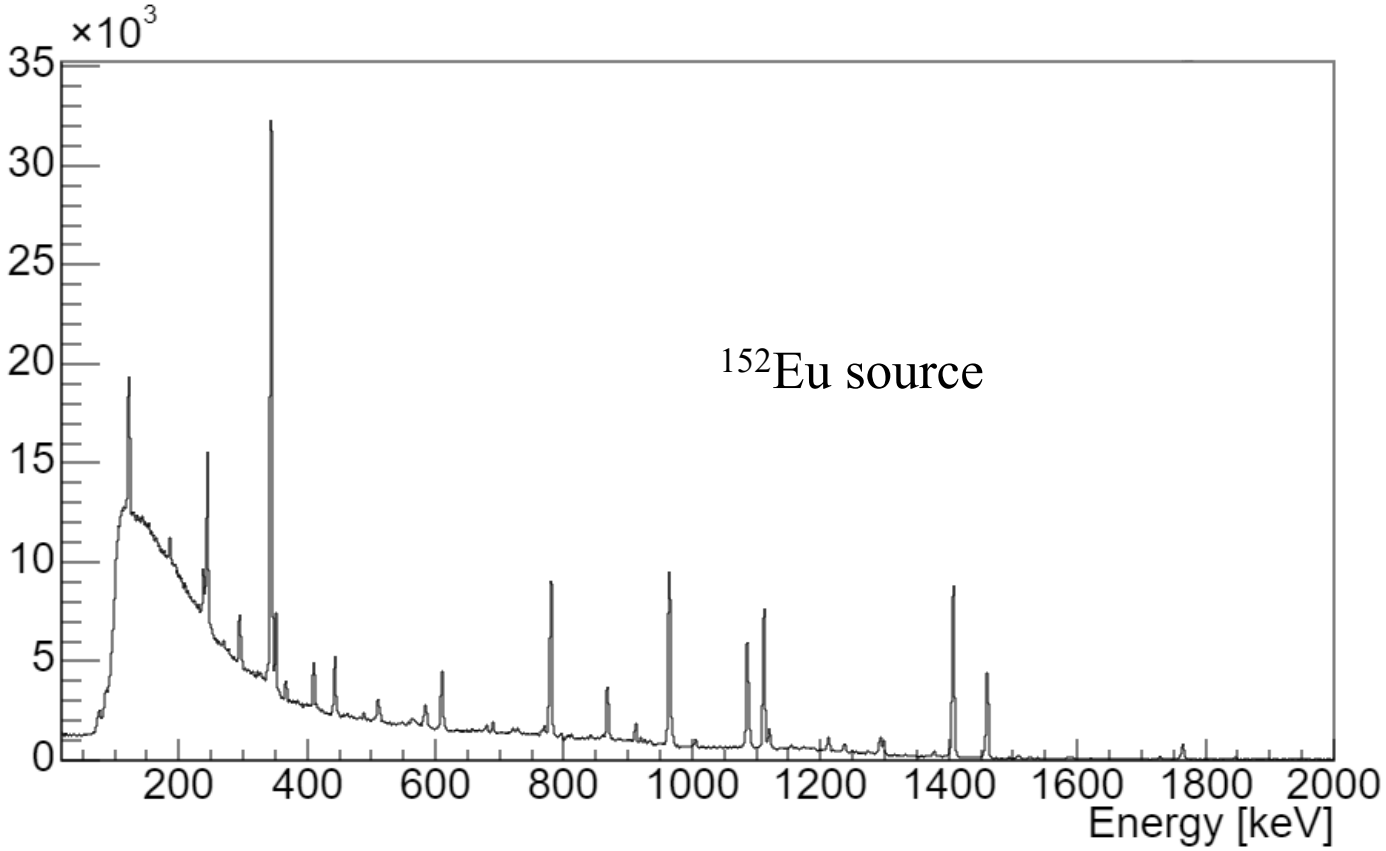


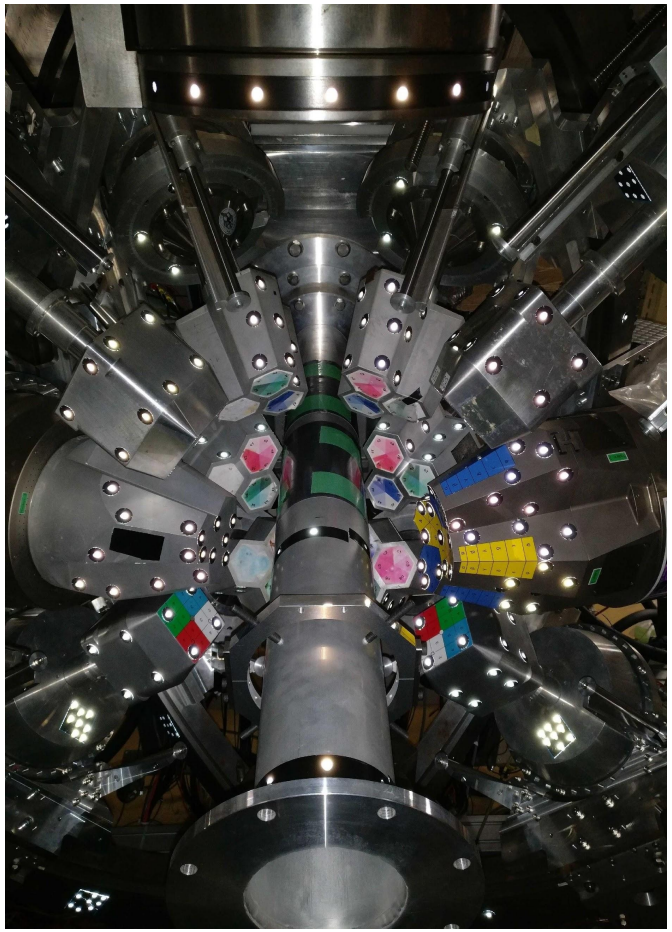




HiCARI campaign

- High-resolution Cluster Array at RIBF (HiCARI) in 2020 and 2021
- A germanium-based gamma-ray spectrometer composed of MINIBALL (Europe), Clover detectors (IMP), and Ge tracking detectors (LBNL & RCNP)



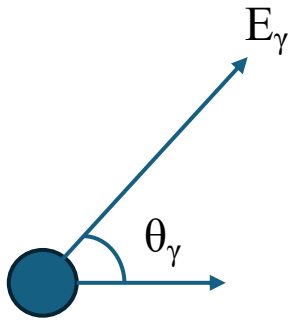


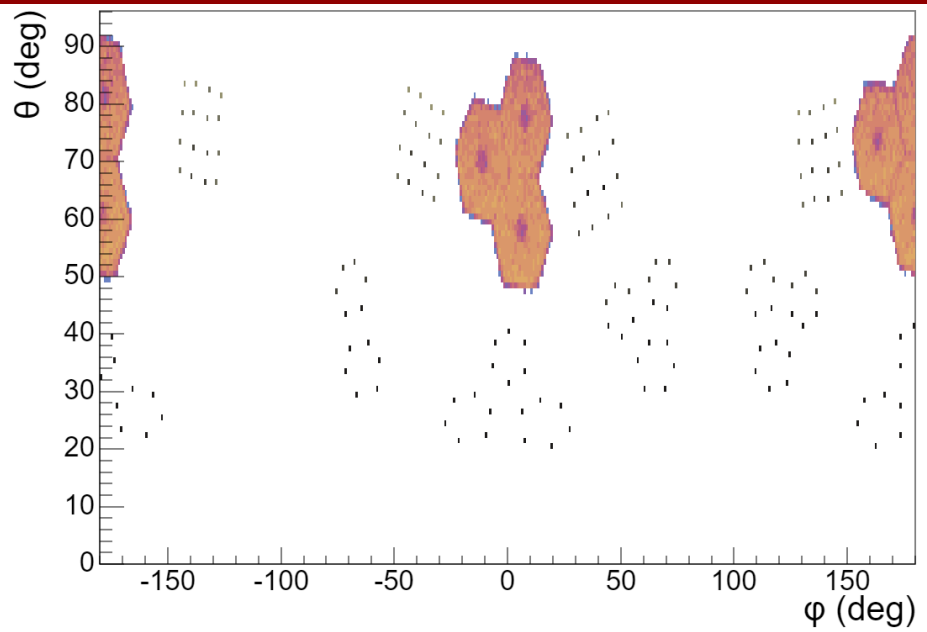
HiCARI assembly

In-Beam γ spectroscopy

Doppler effect

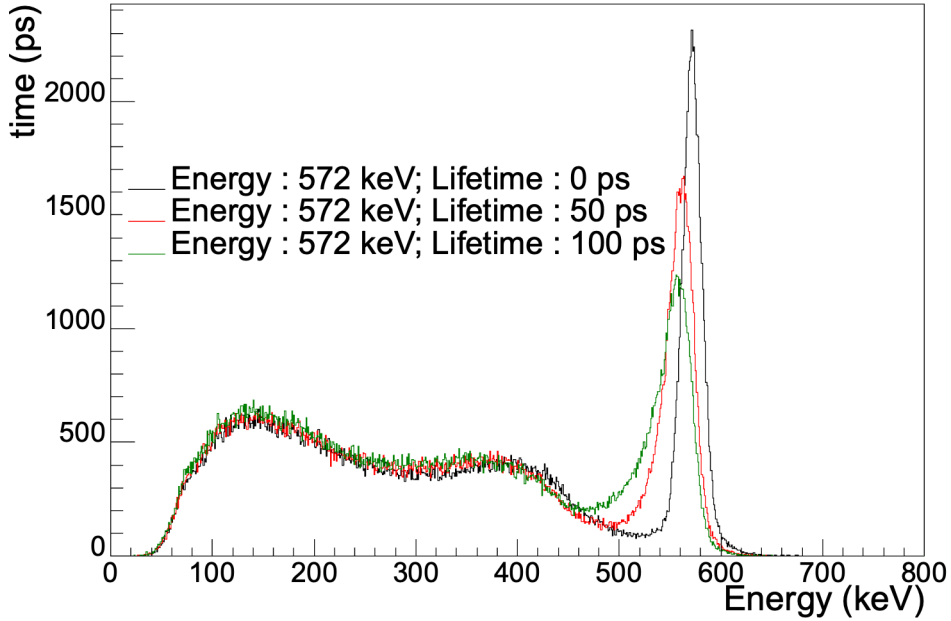
$$\frac{E_\gamma}{E_{\gamma 0}} = \frac{\sqrt{1-\beta^2}}{1-\beta cos\theta_\gamma}$$





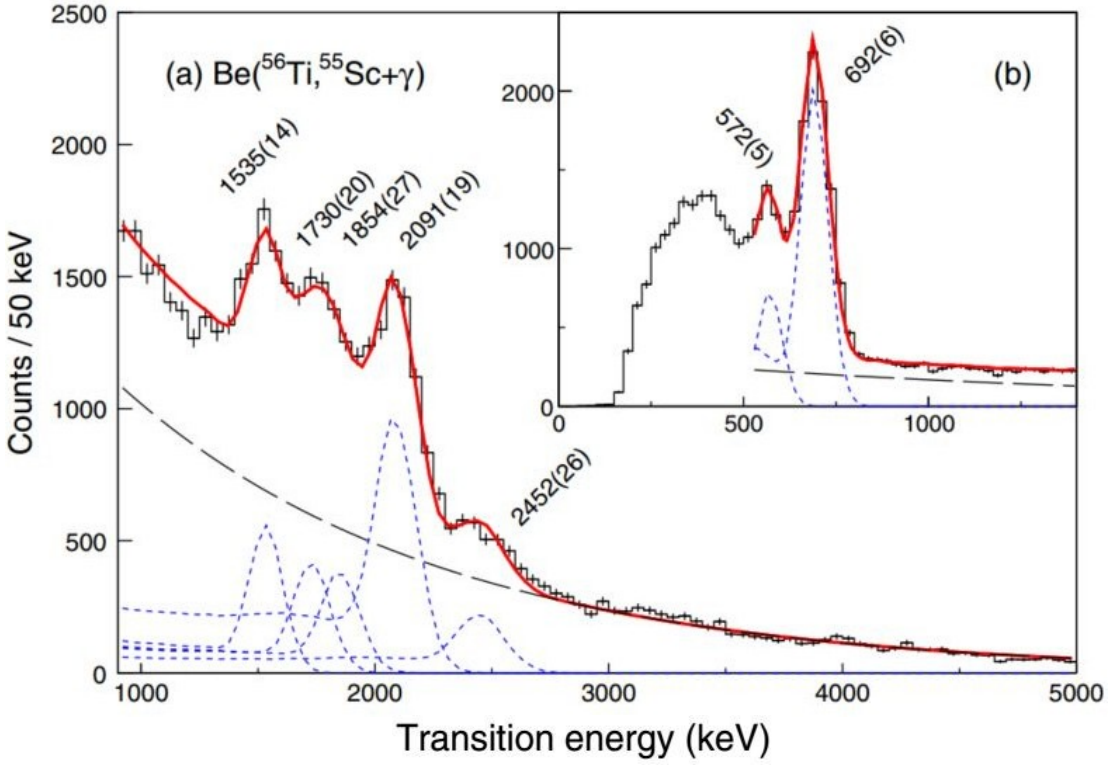
- The Doppler effect causes an energy shift depending on the γ-ray emission angle and beam velocity.

- Since the emission angle changes according to the lifetime, the γ-ray response function obtained through simulation can be used to determine energy and lifetime in the spectra.



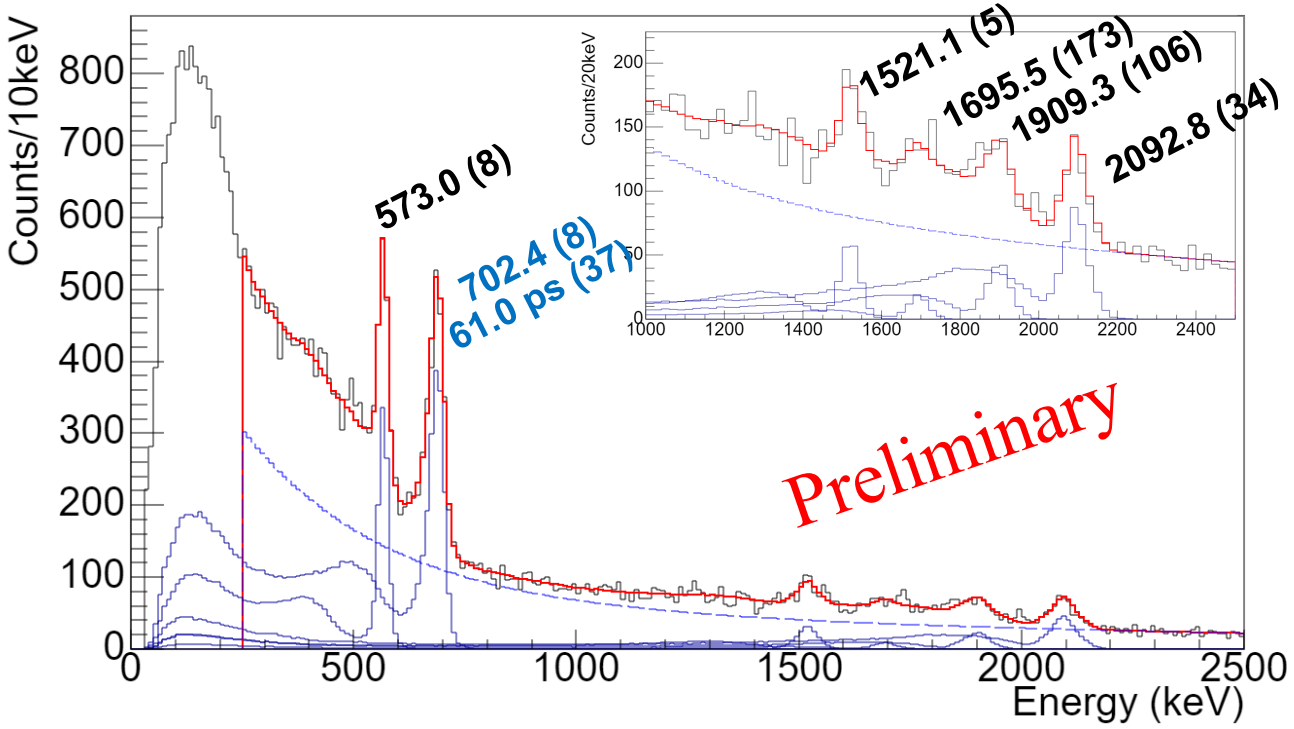
Results - ^{55}Sc

Previous results from DALI2+



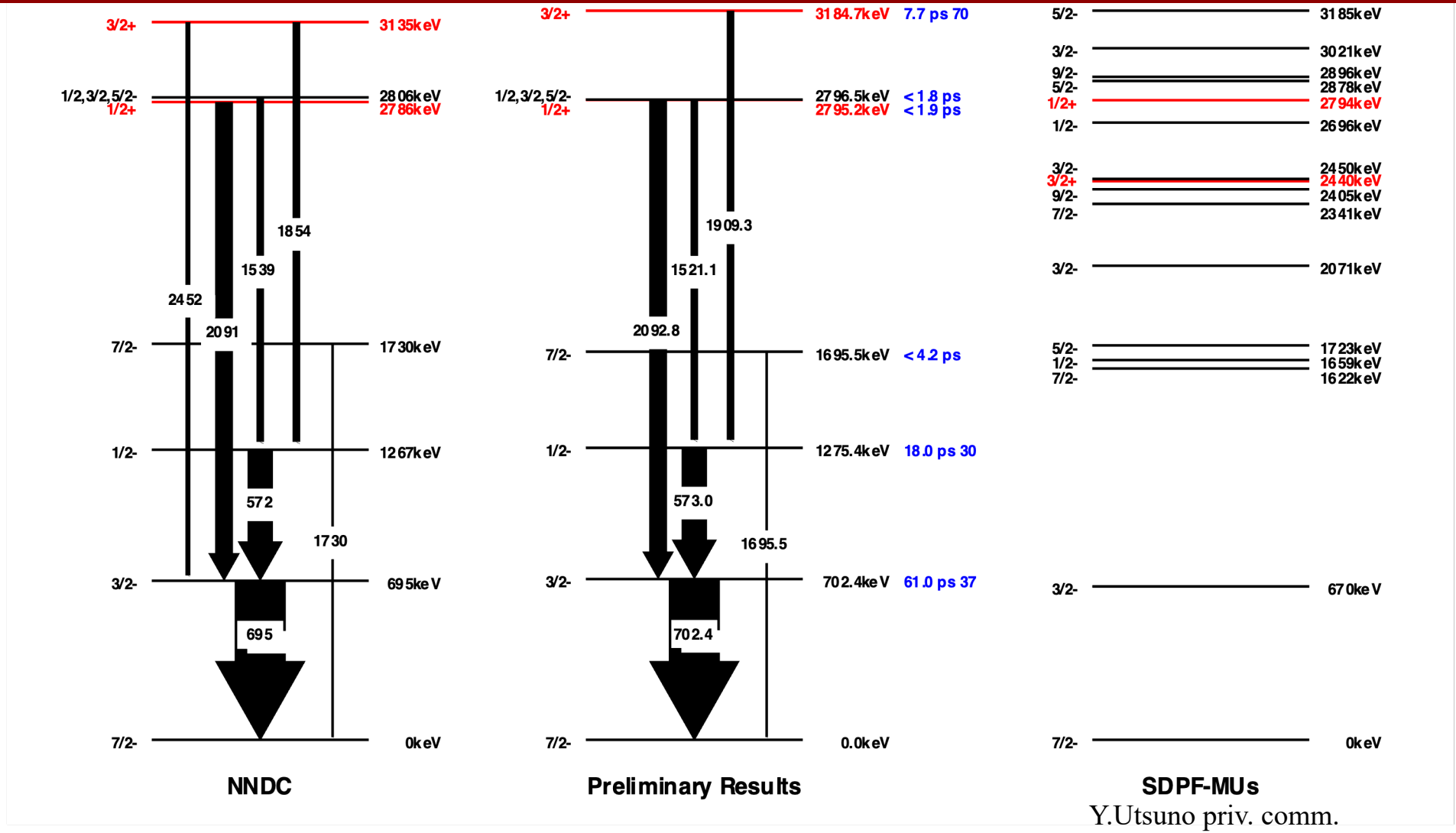
D.Steppenbeck et al., PRC **96**, 064310 (2017)

Preliminary results from HiCARI



Doppler corrected spectrum
γ response function obtained by the GEANT4 simulation
Fit function
Two exponentials for background

Results - ^{55}Sc

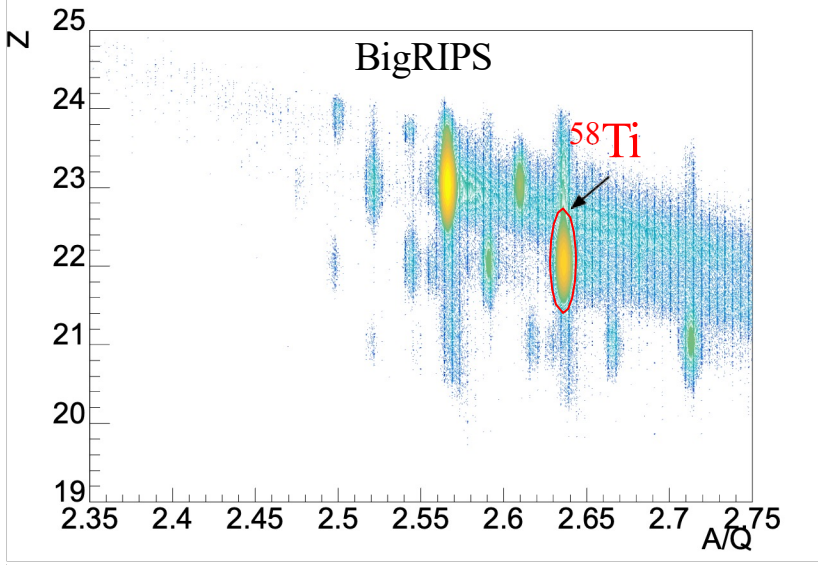


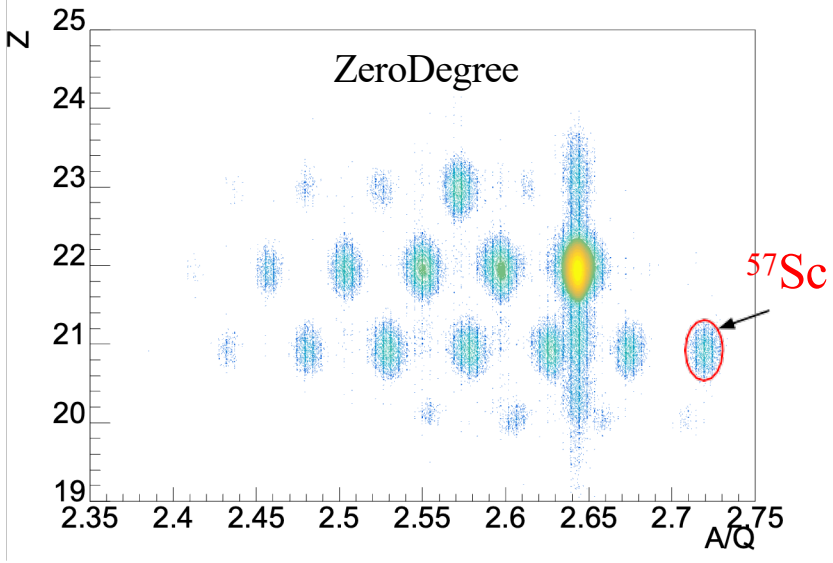
Y.Utsuno priv. comm.

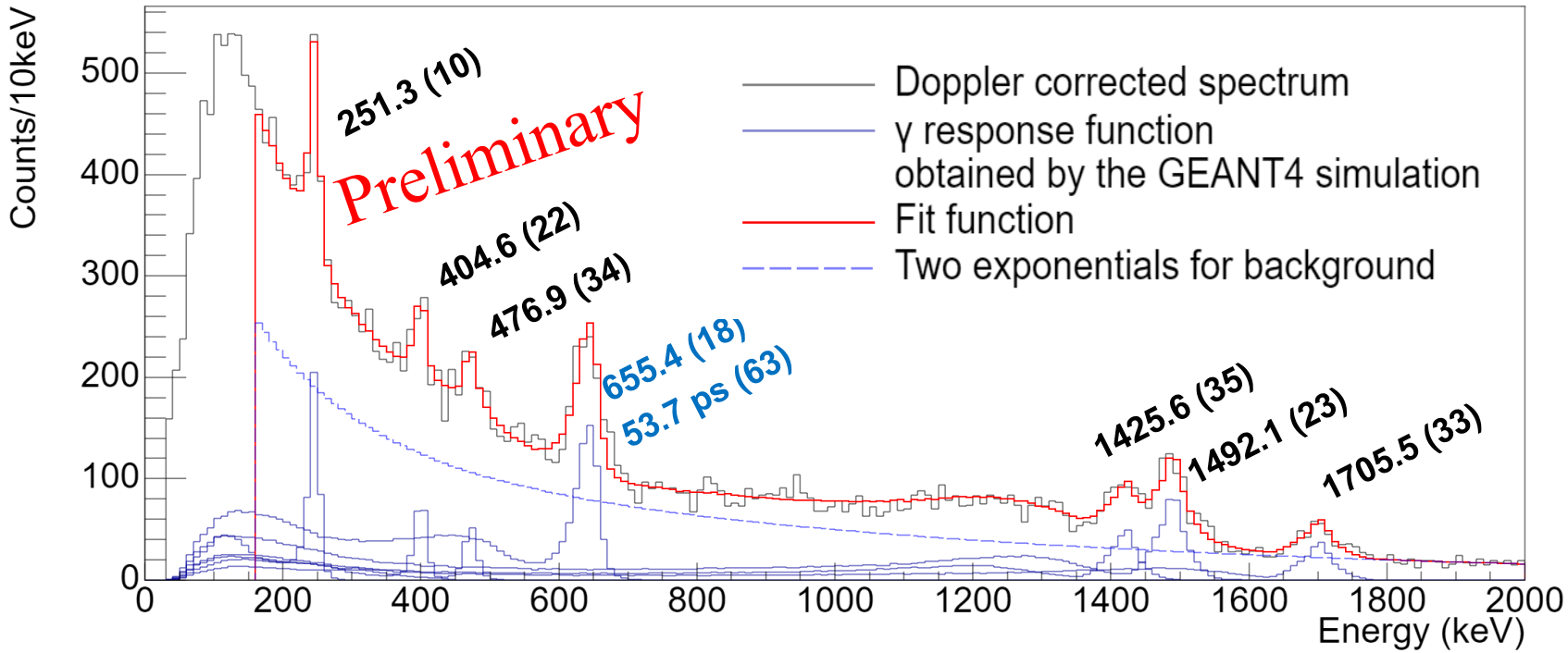
- Spin assignments based on previous results

  → Cross sections and spectroscopic factors will be analyzed.

Results - ^{57}Sc

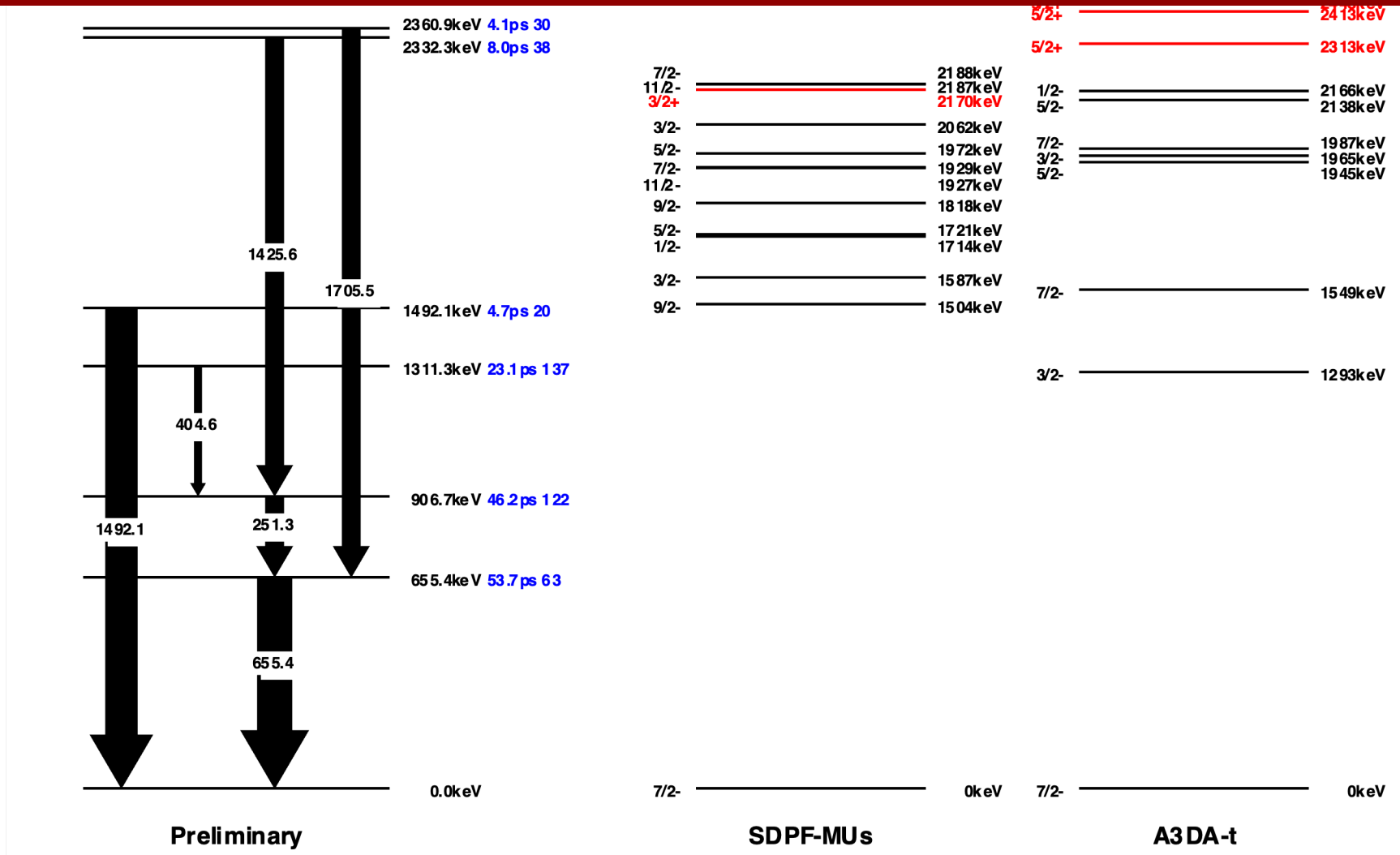






- First spectroscopy of ^{57}Sc

Results - ^{57}Sc



Y.Utsuno Priv. comm.

- Theory underestimates low lying levels.

  → sign of deformation : ^{57}Sc (N=36) inside island of inversion

Summary

- The HiCARI campaign were held in 2020 and 2021 to achieve higher resolution results for in-beam γ-ray spectroscopy.
- Recent research showed 54Ca is a double magic nuclei and ^{56}Ti is a nuclei with moderate collectivity.
- The process of shell evolution can also be seen through the evolution of the $\pi f_{7/2}$ - $\nu f_{5/2}$ orbital interaction of scandium isotopes.
- It is the first lifetime measurement of ^{55}Sc and also the first spectroscopic studies of ^{57}Sc.
- ^{57}Sc is well deformed, so it is expected inside island of inversion.
- Cross sections and Spectroscopic factors will be analyzed.

Thank you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NISHINA
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SUNFLOWER COLLABORATION
GSI
LIBERTAS JUSTITIA VERITAS
KOREA UNIVERSITY
CENuM
CENS
CENTER FOR EXOTIC
NUCLEAR STUDIES