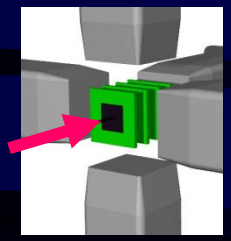
# Decay Spectroscopy Project at the RIBF

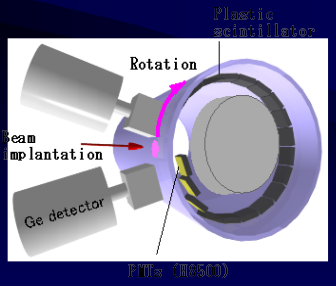
**Shunji Nishimura**
**RIKEN Nishina Center**

2009 2010 2011 2012 2013

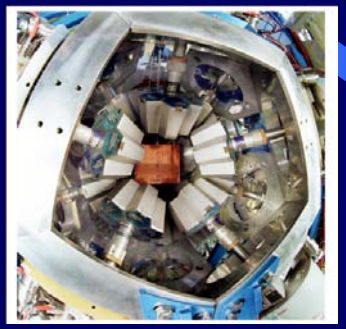


1st Decay Exp. (Si)
$^{110}$Zr region
(2.5-days)

*PLB 696, 186 (2011)
*PRL. 106, 052502 (2011)
*PRL. 106, 202501 (2011)
*PLB 704, 270 (2011)




Test Exp. (CAITEN)
A = 30 ~ 40



EURICA Project
(40 % of RIBF beam time)

# Decay Spectroscopy

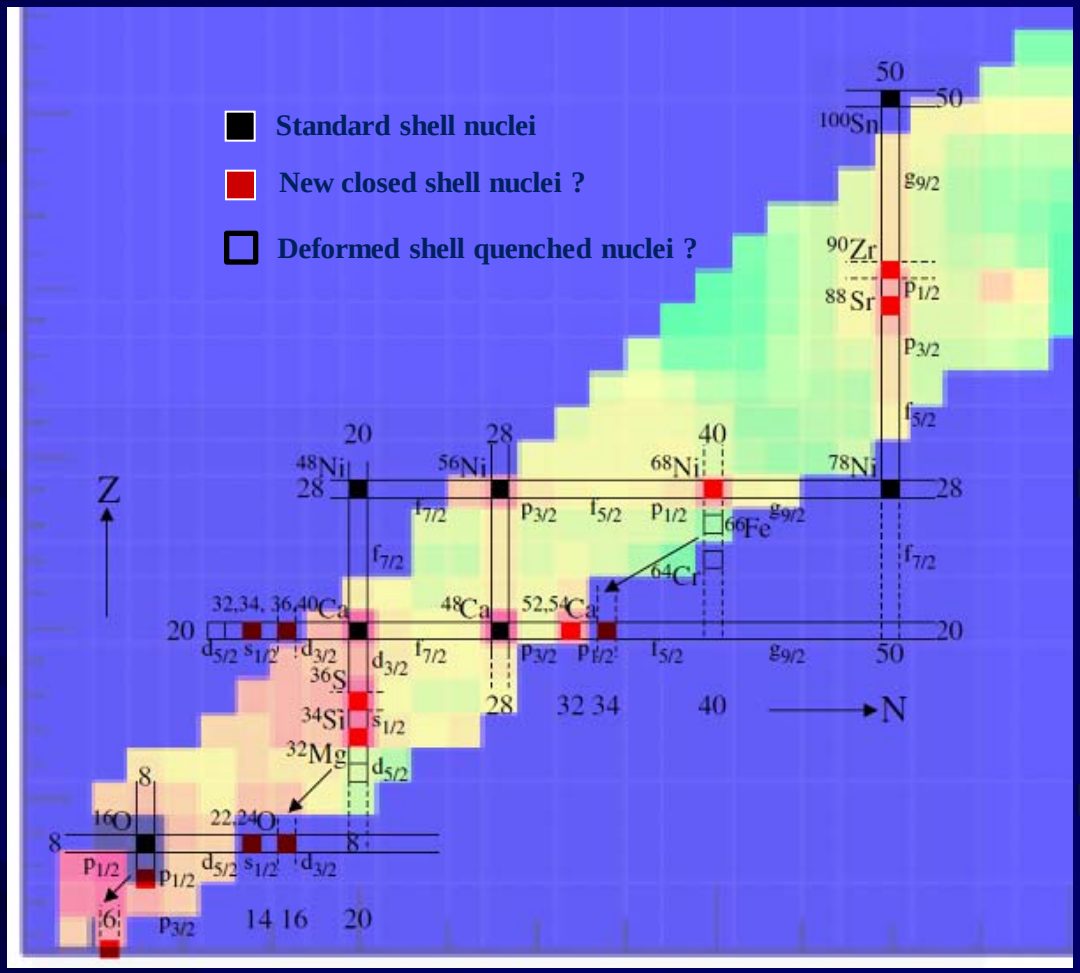
H.Grawe, et al. Eur. Phys. J A 25 (2005) 357
+ E(2+) map

**Measurements by decay exp.**

- **Decay curve : $T_{1/2}$**
- **Excited states : $E(2^+)$, ..**
- **Isomeric states**
- **$Q_\beta$**
- **Neutron emission ($P_n$)**

***Systematic Study***

- Nuclear Structure
  - **New magic number ?**
  - **Disappearance?**
  - **Shell quenching?**
  - **Deformation?**

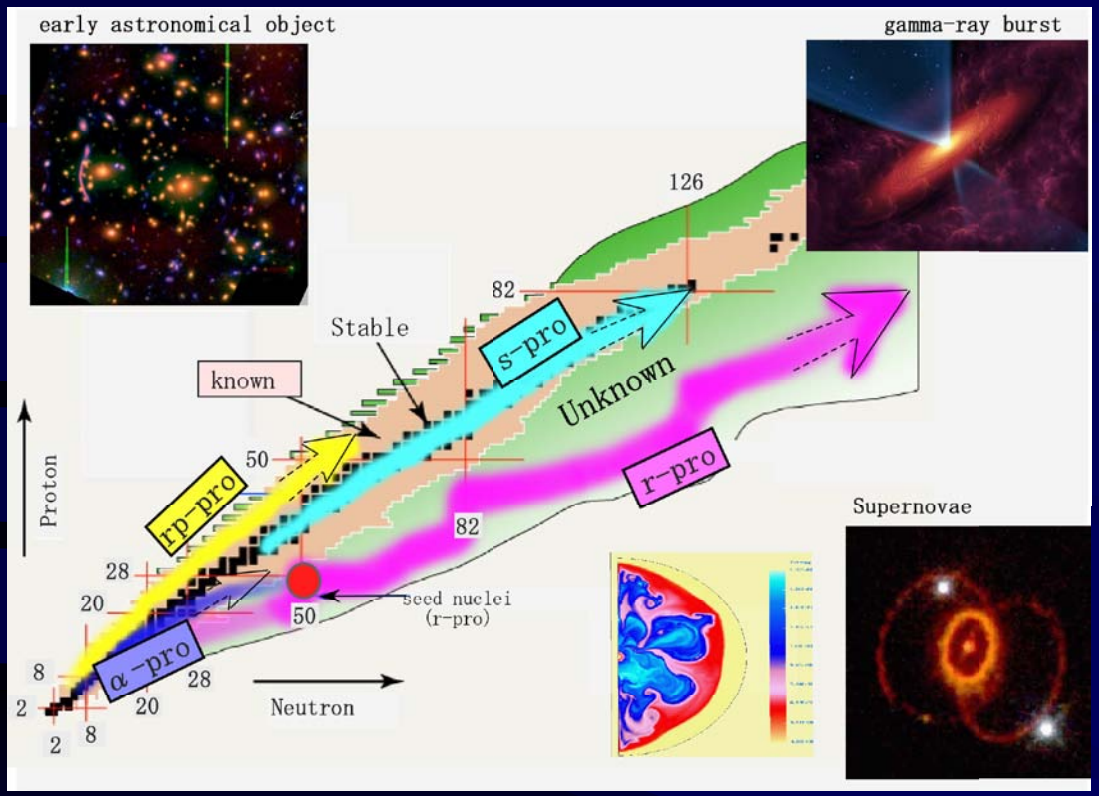



***Inputs***

**Feedback to Nuclear Theory**

# Decay Spectroscopy

(Astrophysics Nucleosynthesis)




B.Meyer's talk

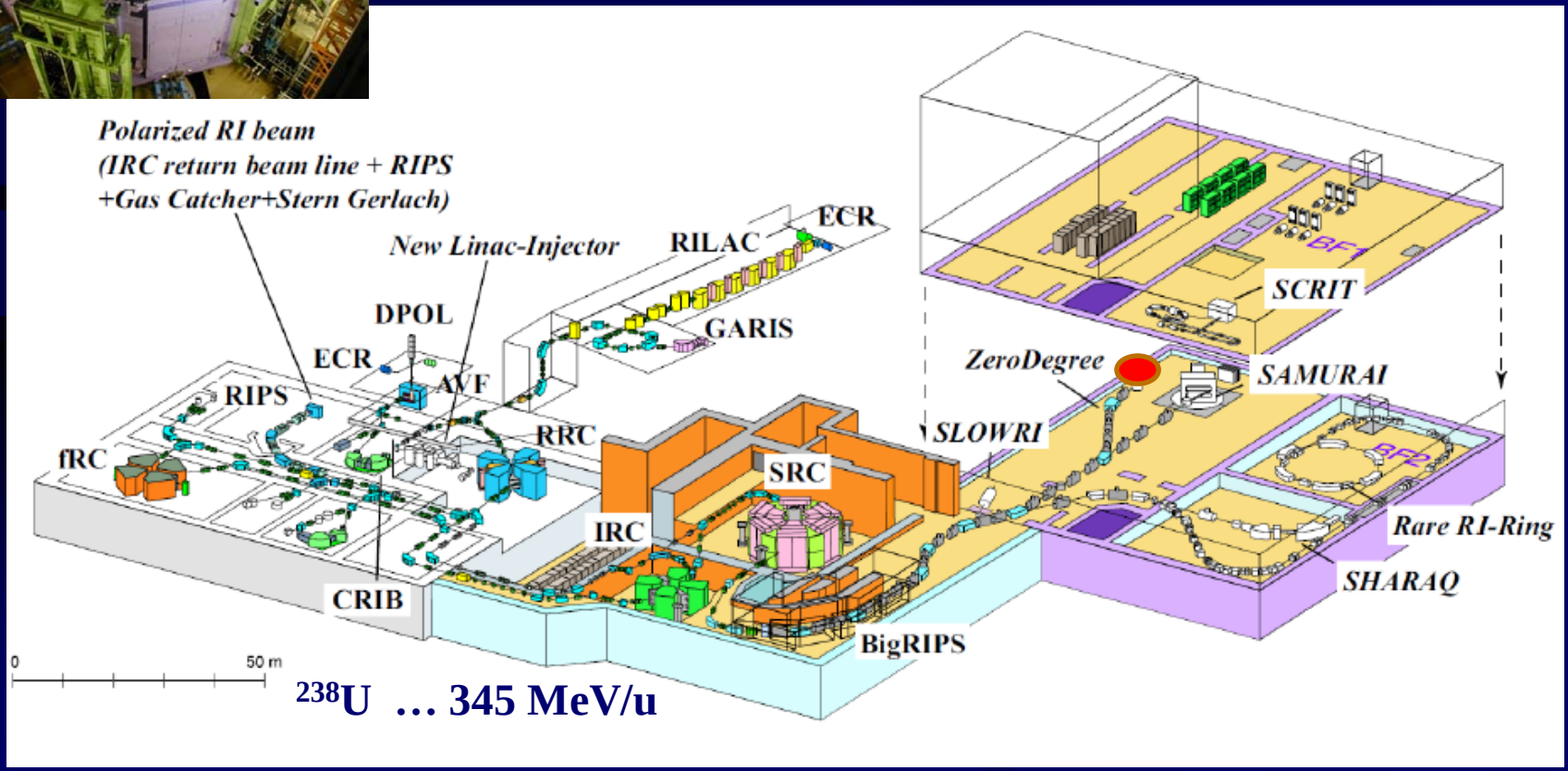
☆ Half-lives （$T_{1/2}$）
→ abundance
→ process speed

☆ Masses (A, $Q_\beta$, $S_n$)
→ location of the path

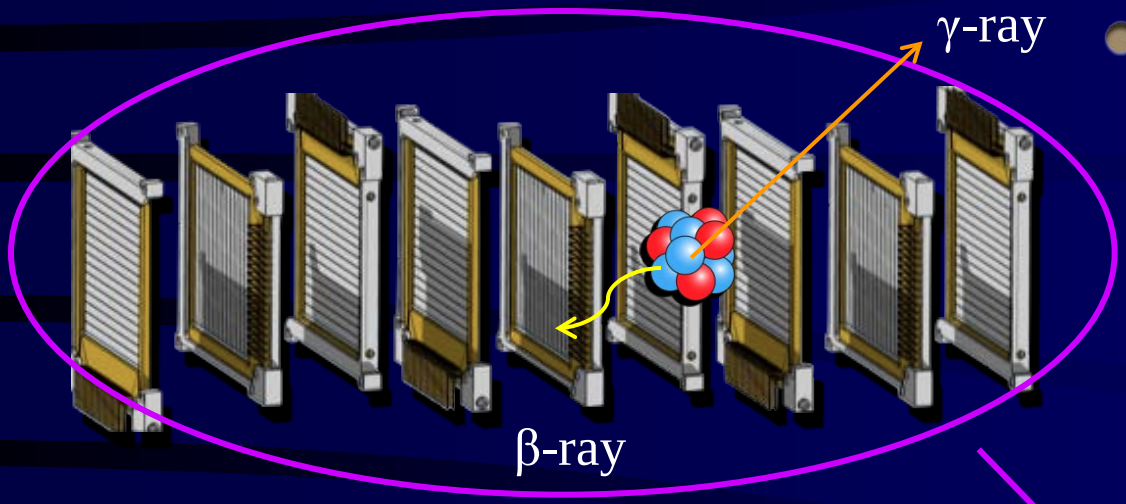
☆ β-delayed neutron （$P_n$）
→ final abundances

Half-lives ($T_{1/2}$) : strongly depends on nuclear structure.
- determined by $Q_\beta$-value from the mass difference of nuclide and its daughter.
- Sensitive to deformation.

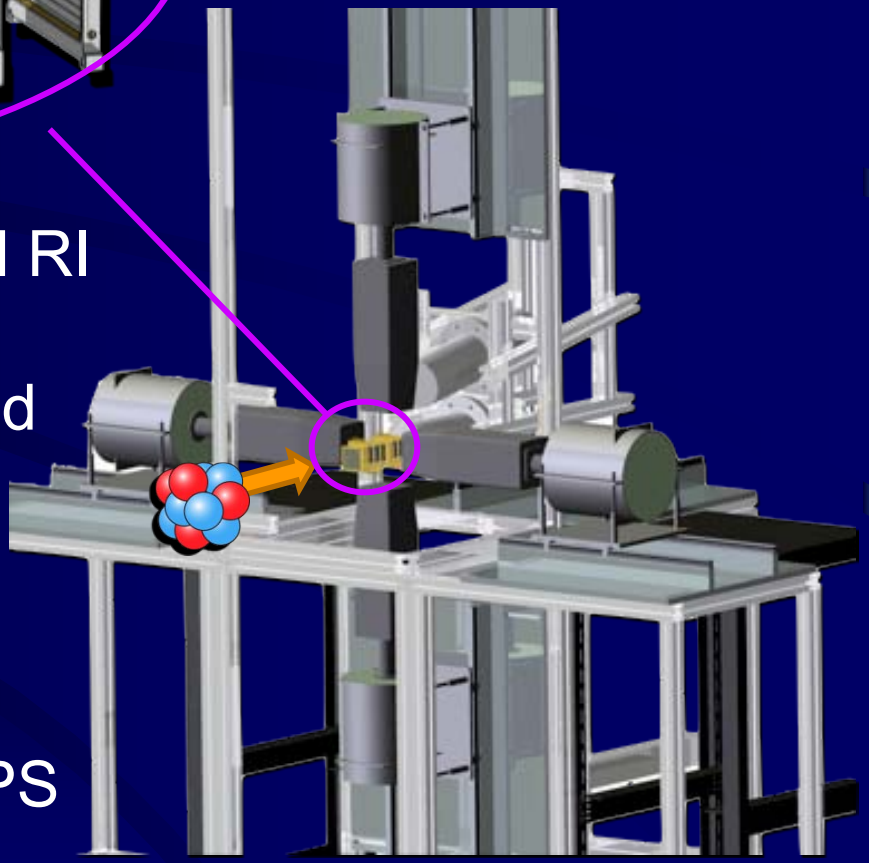
# RIBF at RIKEN



# Experimental Setup in 2009




- **RI & β-ray detection**
  - **9 DSSDs (50 x 50 x 1 mm$^3$)**
  - **16 x 16 strips**
  - **~ 2000 pixels in total**

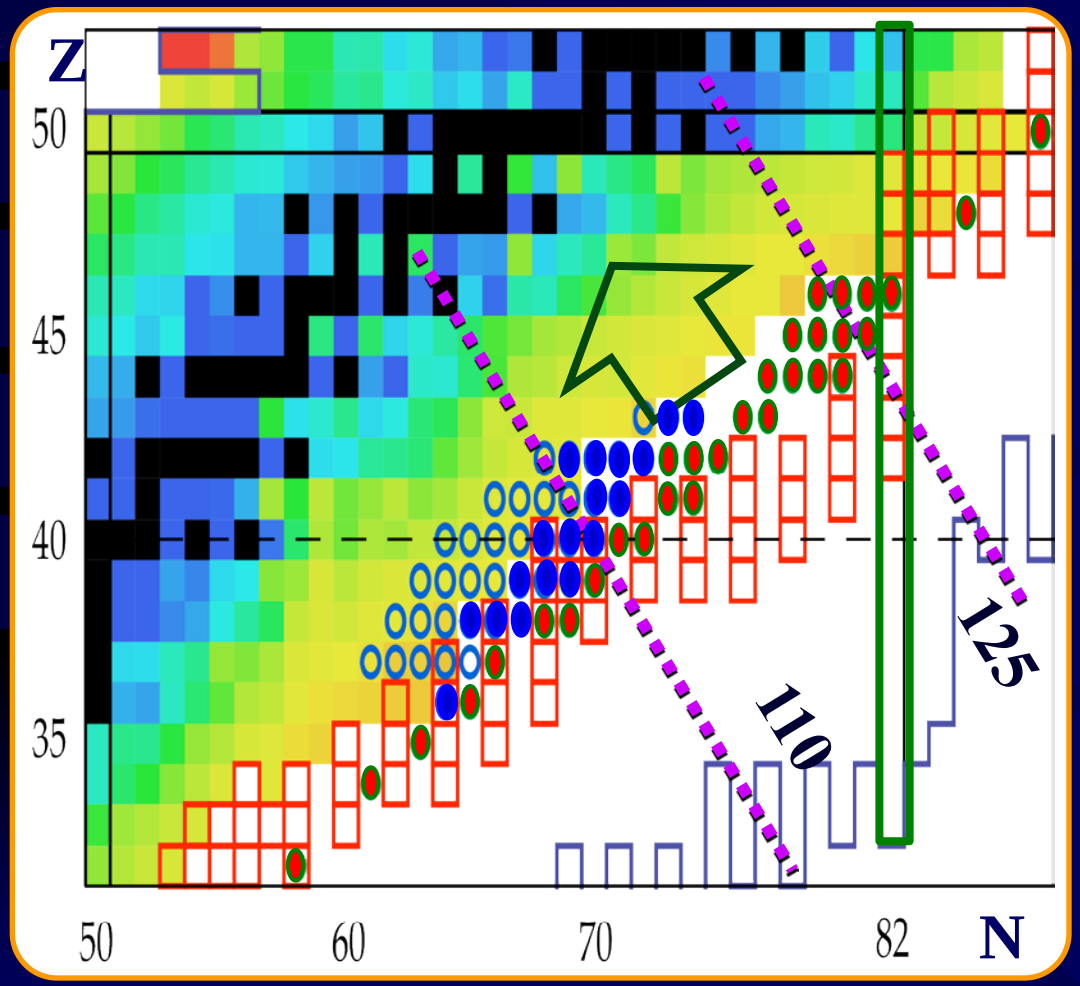


- The implantation of an identified RI is associated with the following β-decay events that are detected in the same DSSD pixel

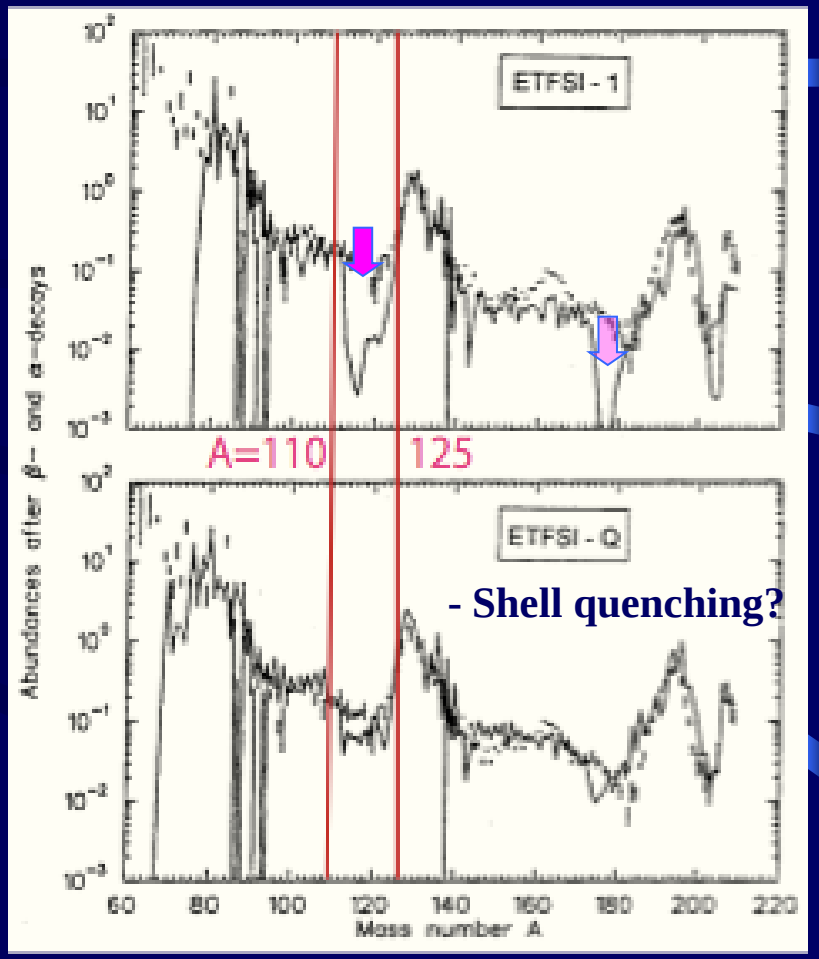
- ΔE-TOF-Bρ method using the focal plane detectors in BigRIPS

# R-process Abundance around 2nd peak

T.Ohnishi, JPSJ 79 (2010).. 45 new isotopes



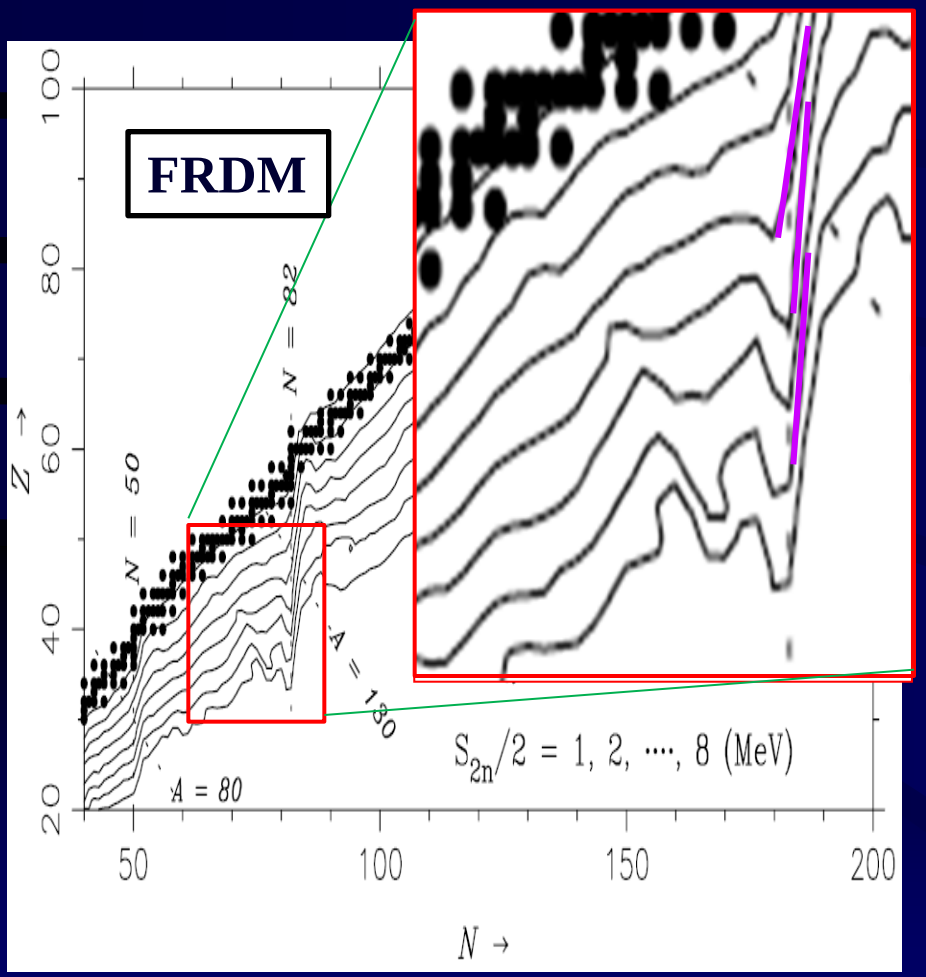

B.Pfeiffer et al. Z. Phys. A357 (1997)

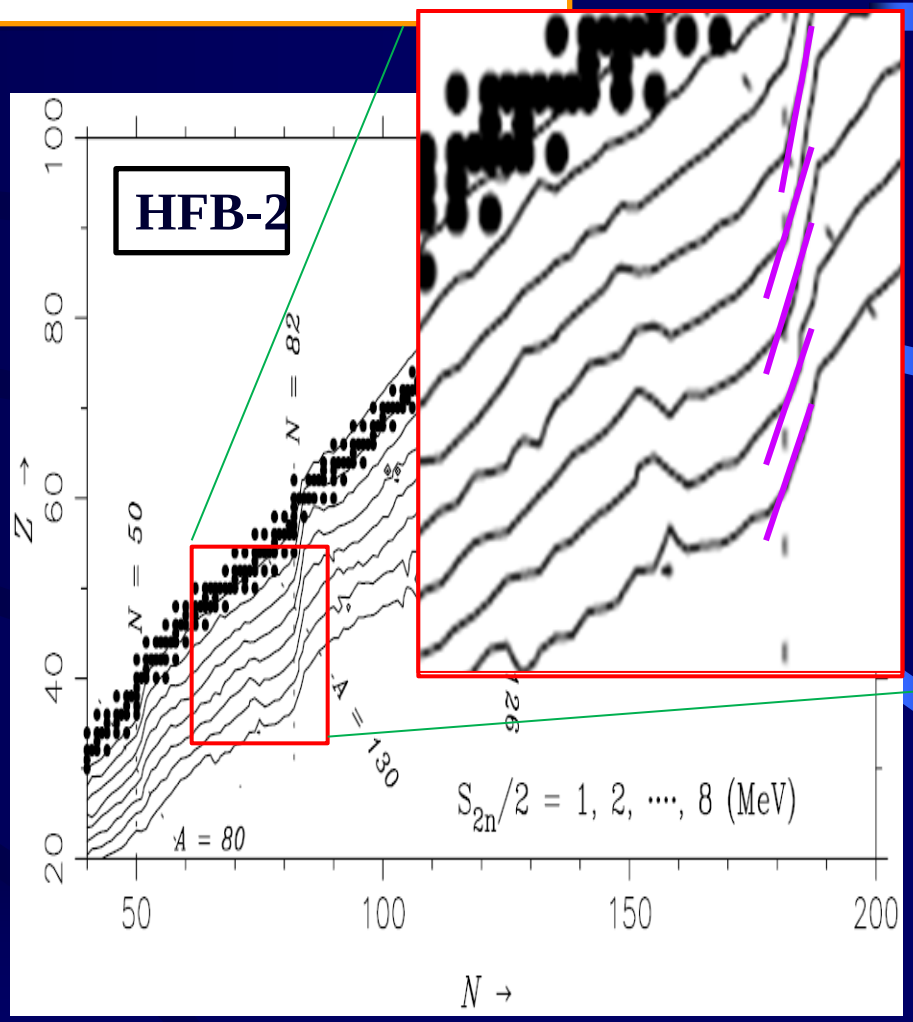



**Significant improvement of $T_{1/2}$ information ! & 18 new half-lives**

# Neutron Separation Energies

**Location of r-process path depends on $S_n$ (2 – 3 MeV)**
**(n,γ)-(γ,n) competition**

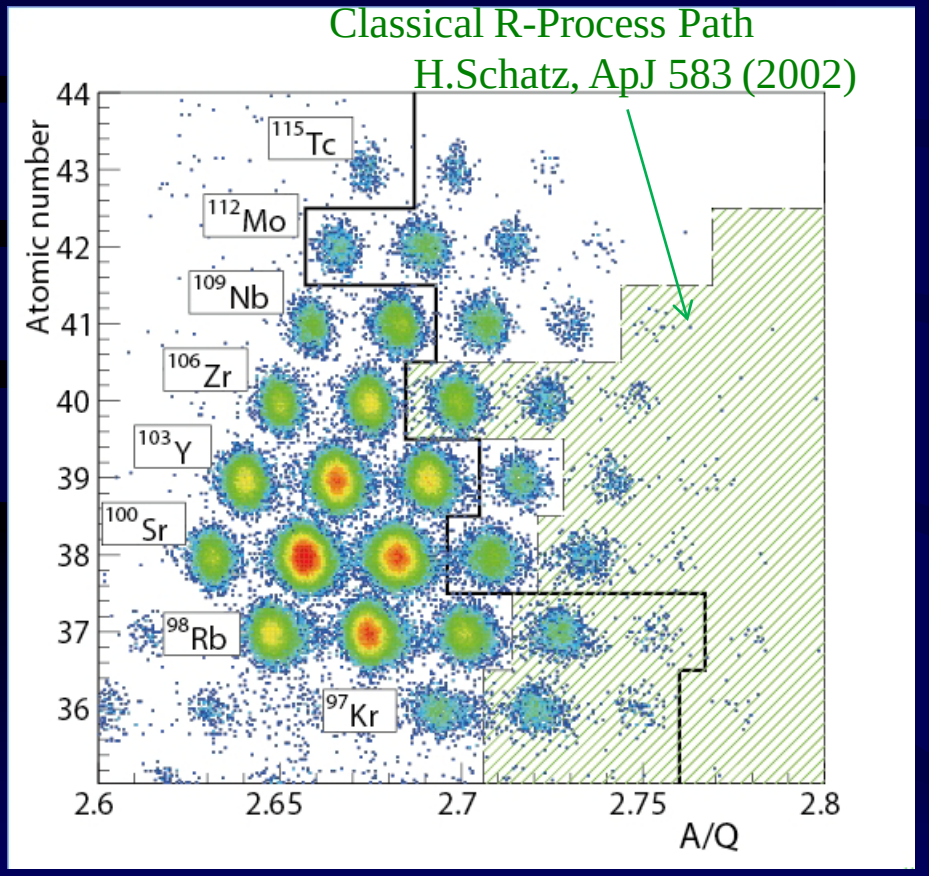


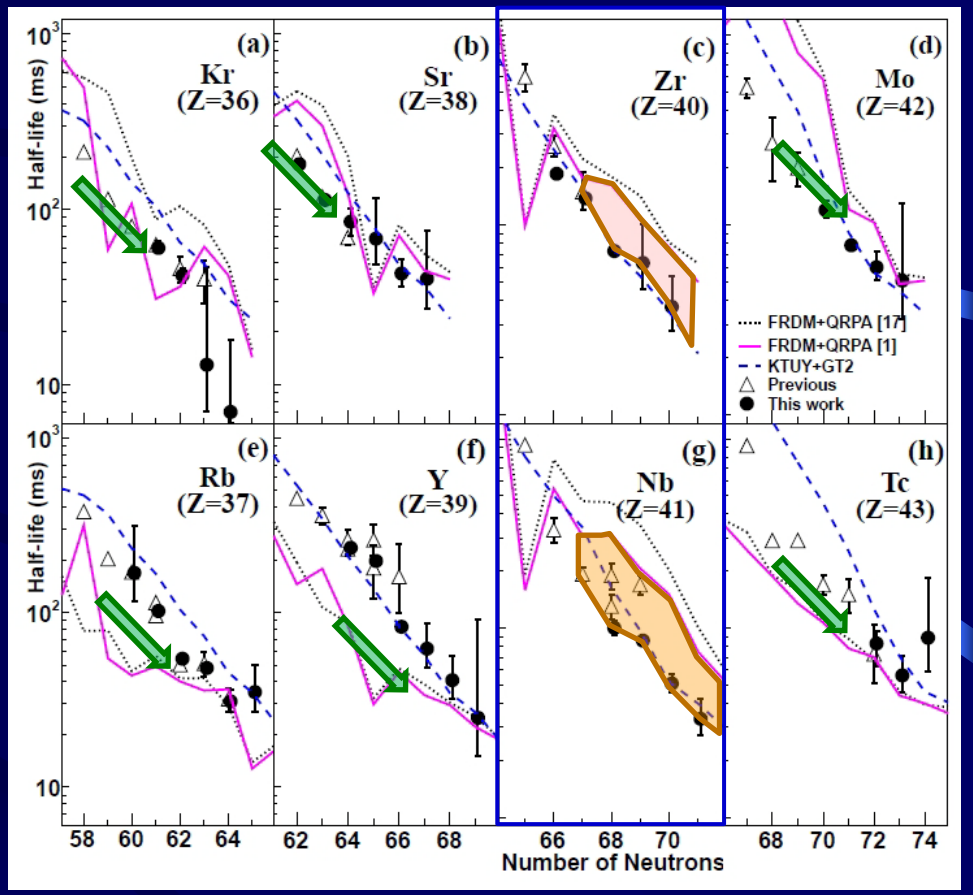




S.Wanajo, S.Goriely, M.Samyn, N.Itoh, Astro.J 606 (2004).

# Beta-decay Half-life $T_{1/2}$ for Kr-Tc

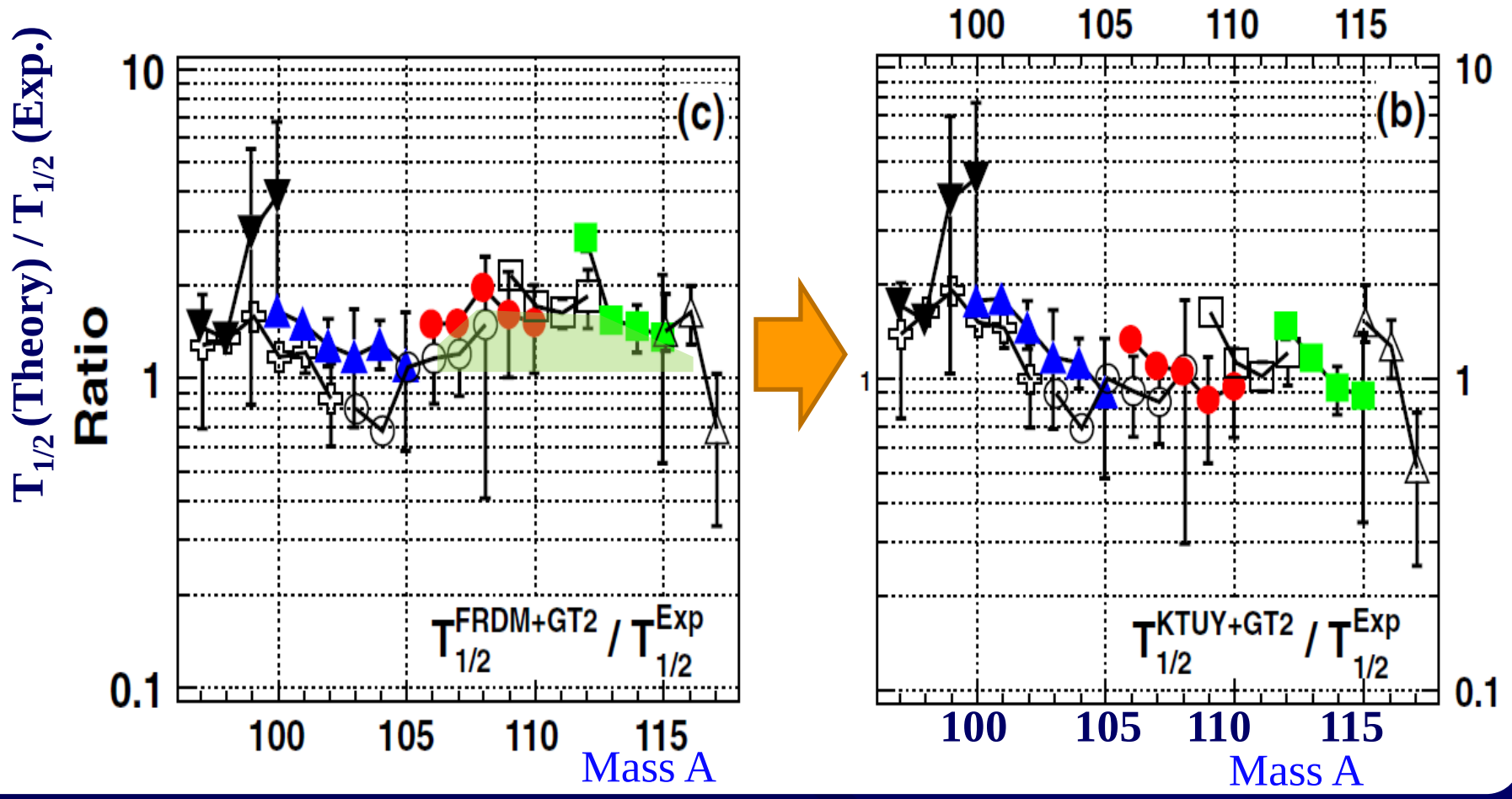
Part of data set (8 hours)
Low rate implantation ~ 8 cps




Zr and Nb decay faster than expected by FRDM+QRPA ( $T_{1/2}$ : 1/2 ~ 1/3 ~ )

# (FRDM → KTUY) +GT2

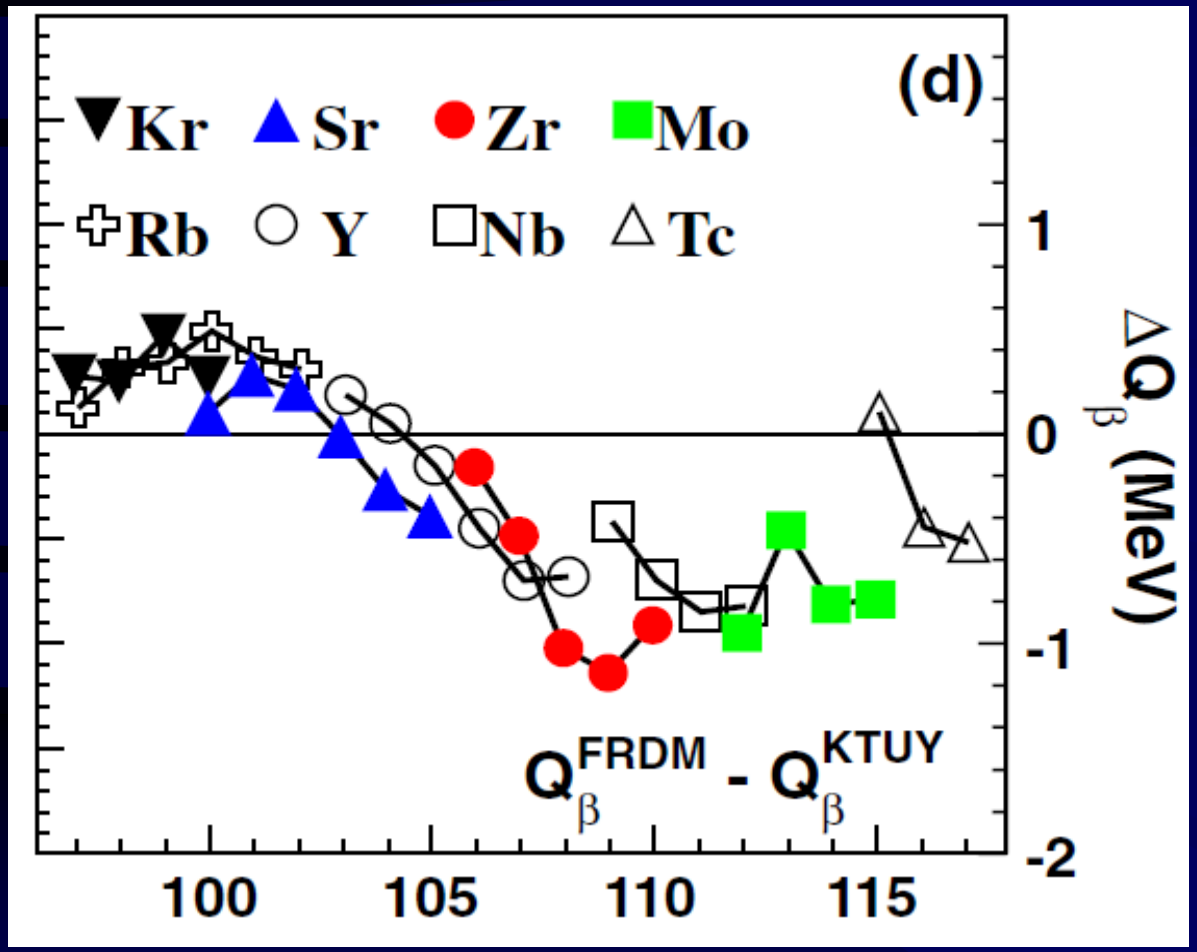



Overestimation of T1/2 by factor of ~ 2

Better agreement for KTUY !

→ WHY ?!

# Better prediction with KTUY (H.Koura) ?



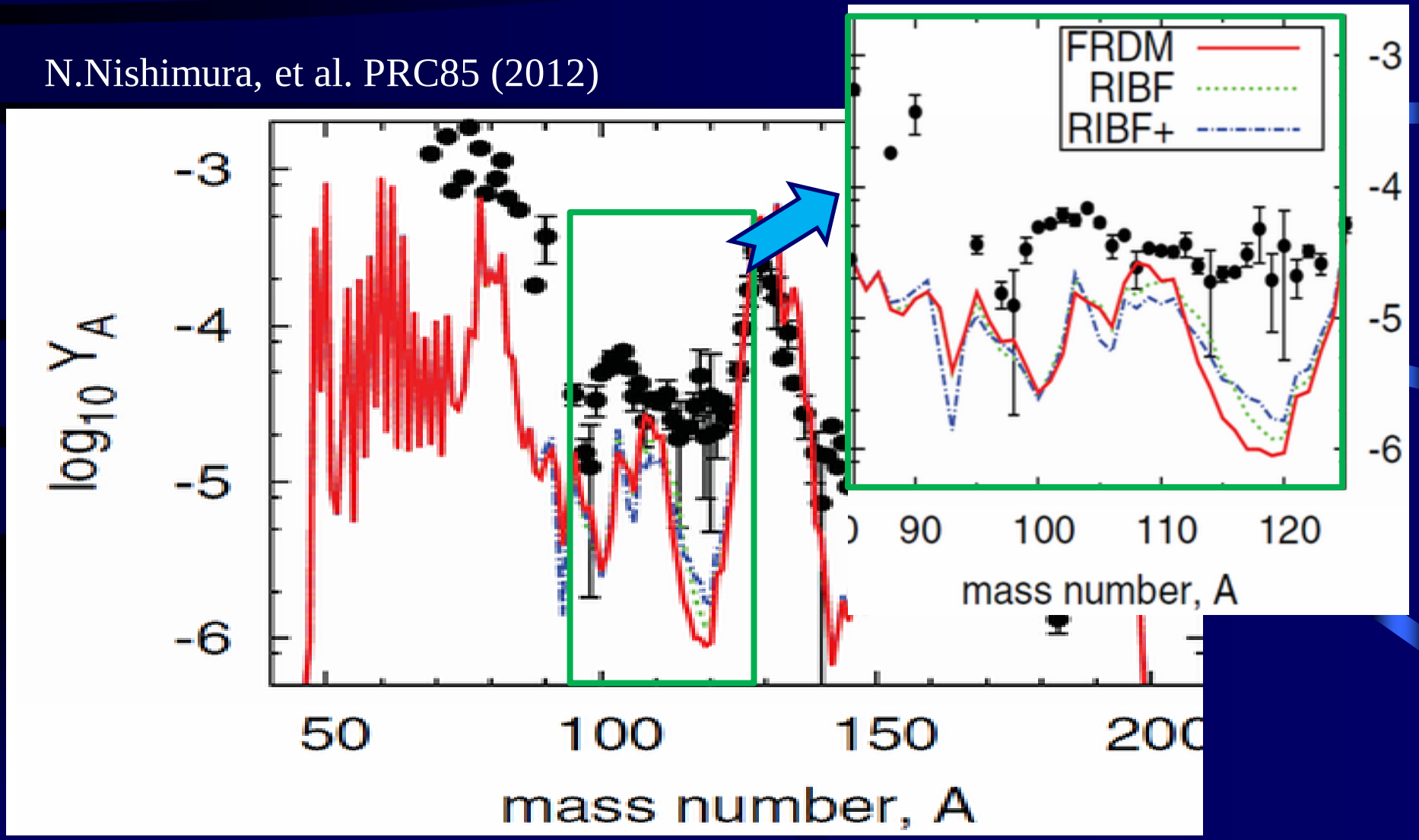

$$1/T_{1/2} = \sum_{E_i \geq 0}^{E_i \leq Q_\beta} S_\beta(E_i) \times f(Z, Q_\beta - E_i);$$

$$f \sim (Q_\beta - E_i)^5$$

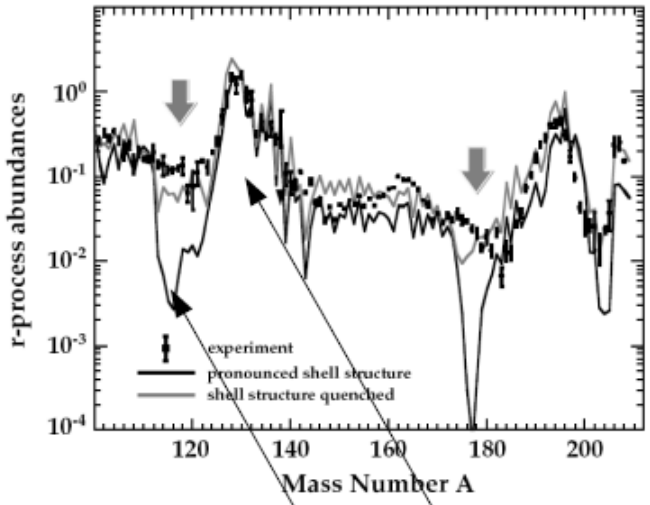
**FRDM may underestimate the Q value : dQ ~ 1 MeV @ A ~ 110.**

# RIBF new data → Network calculation

N.Nishimura, et al. PRC85 (2012)



# Evolution of shell structure N = 70-82

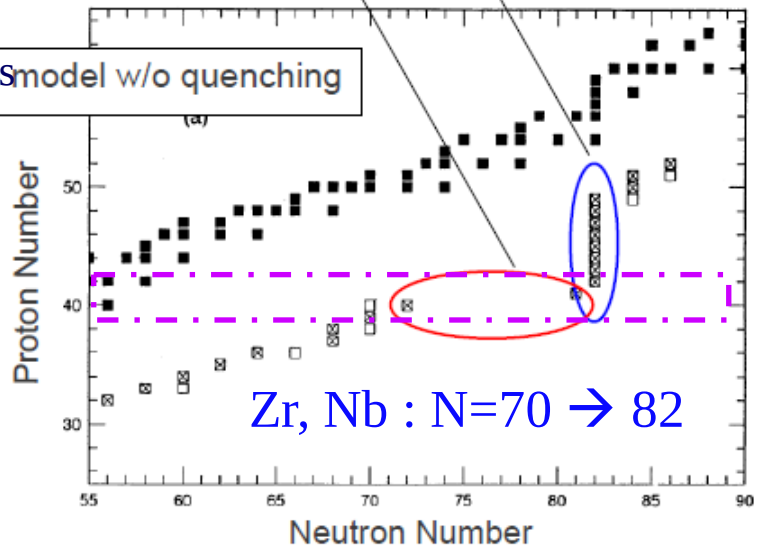



Profound astrophysical impact of:

- Quenching of the N=82 shell gap (need to study region around $^{128}Pd_{82}$)
- appearance of the a N=70 sub-shell closure (need to study region around $^{110}Zr_{70}$)

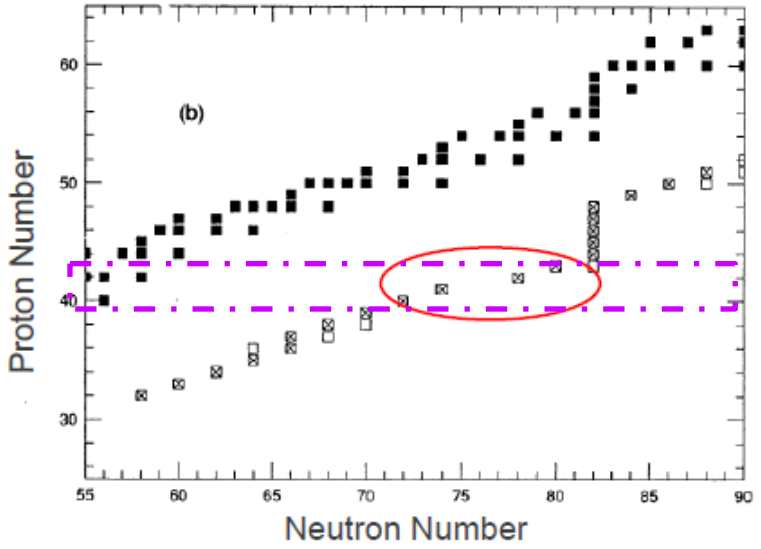
Path Moller

Mass model w/o quenching



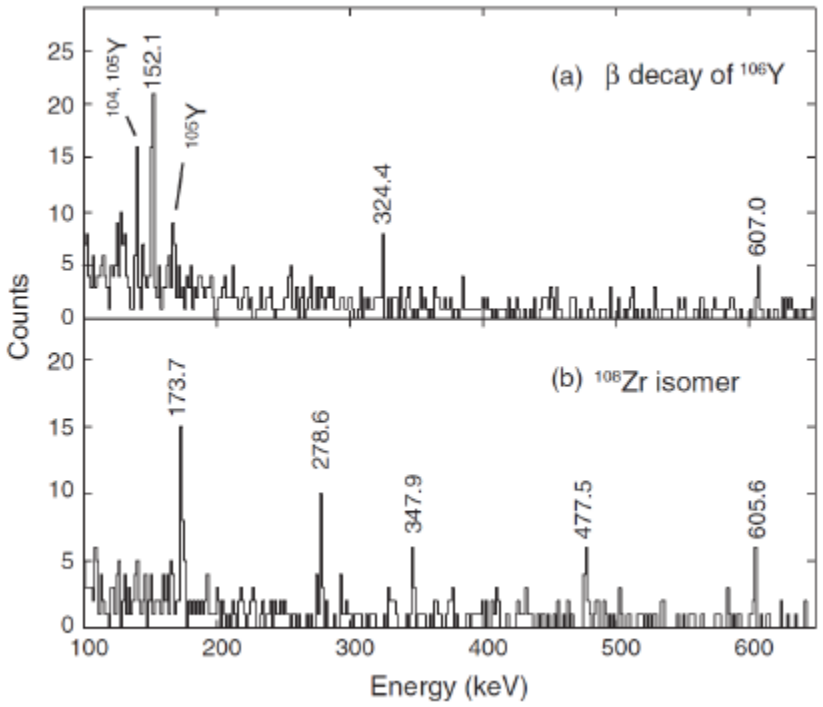

Zr, Nb : N=70 → 82

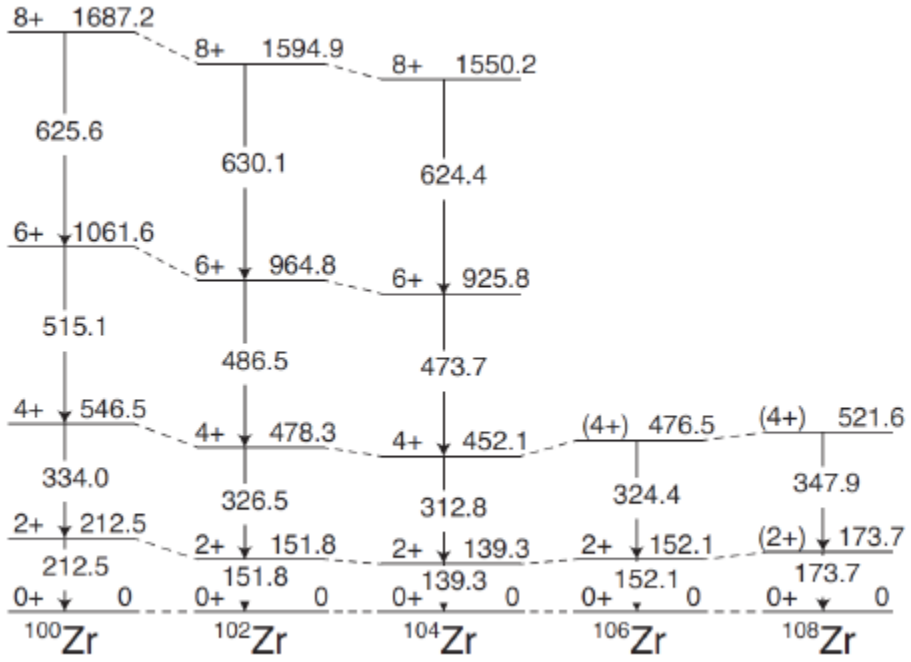
Mass model w/ quenching




110Zr → 128Pd

# Decay spectroscopy of $^{106,108}$Zr




Gamma-ray spectra measured

(a) in coincidence with b-rays detected within 200 ms after implantation of $^{106}$Y

(b) with a particle gate on $^{108}$Zr within 4 μs.

Ground state bands of neutron rich even-even Zr isotopes with N≥60

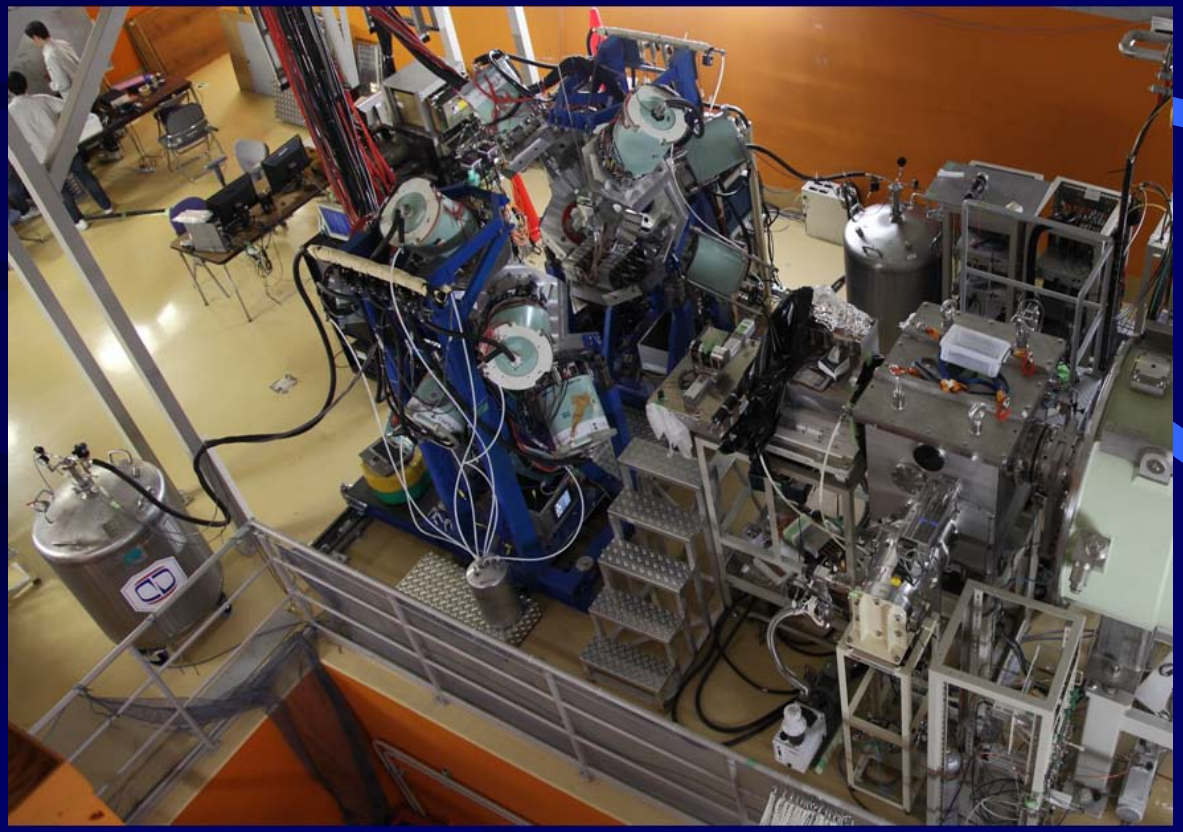
Results suggest a deformed sub-shell closure at N = 64

*T. Sumikama et al.*, PRL 106, 202501 (2011)

Isomerism in $^{108}$Zr could imply tetrahedral shape in low-energy states

EUROBALL RIKEN Cluster Array

# EURICA Project

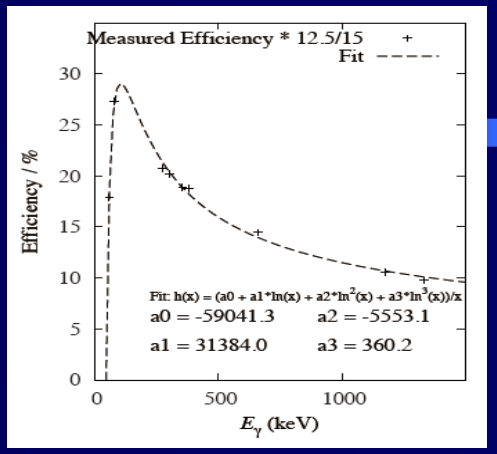


# RISING → EURICA


- Euroball Cluster detectors
- Support structure
- Readout electronics

RIKEN RIBF (Japan)

# Decay Spectroscopy : 2nd Phase




U-beam intensity

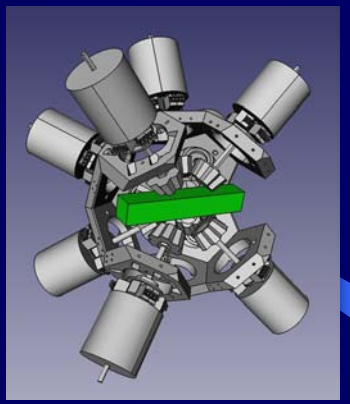
- 0.2 pnA → 3-5 pnA … x 15 – 25 times

Beam time …

- 0.3 - 2.5 days → 100 days … x 40 – 300 times

Beta counting system

- 16 x 16 pixels x 7 layers = 1792 pixels
  → 40x60 pixels x 8 layers = 19200 pixels … x 4-10 times
- Accept higher implantation rate for $T_{1/2}$ measurement
  → x 2 – 5 times

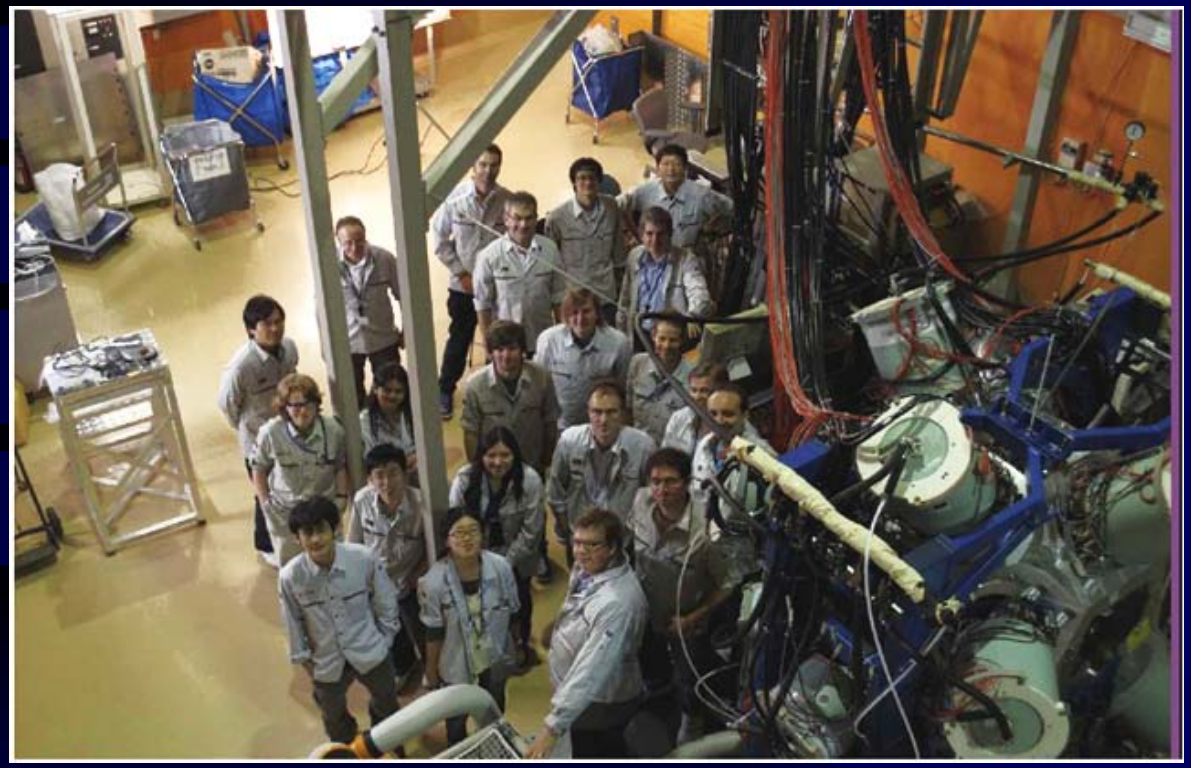


Gamma-ray detector

- 4 Clover detectors (Det. Effi. ~1.5% at 662 keV)
  → 12 Cluster detectors (Det. Eff. ~ 15 % at 662keV) … x 10 times
  ( → gamma-gamma coincidence … x 100 times )

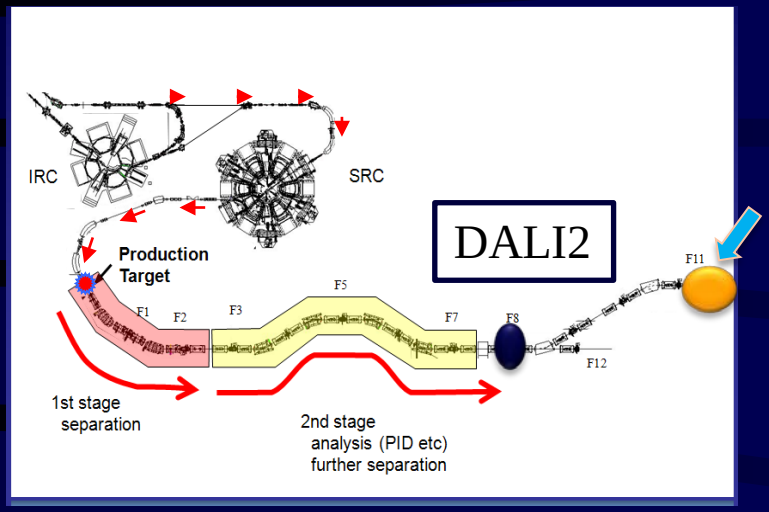
# First EURICA Exp.
## Online spectra

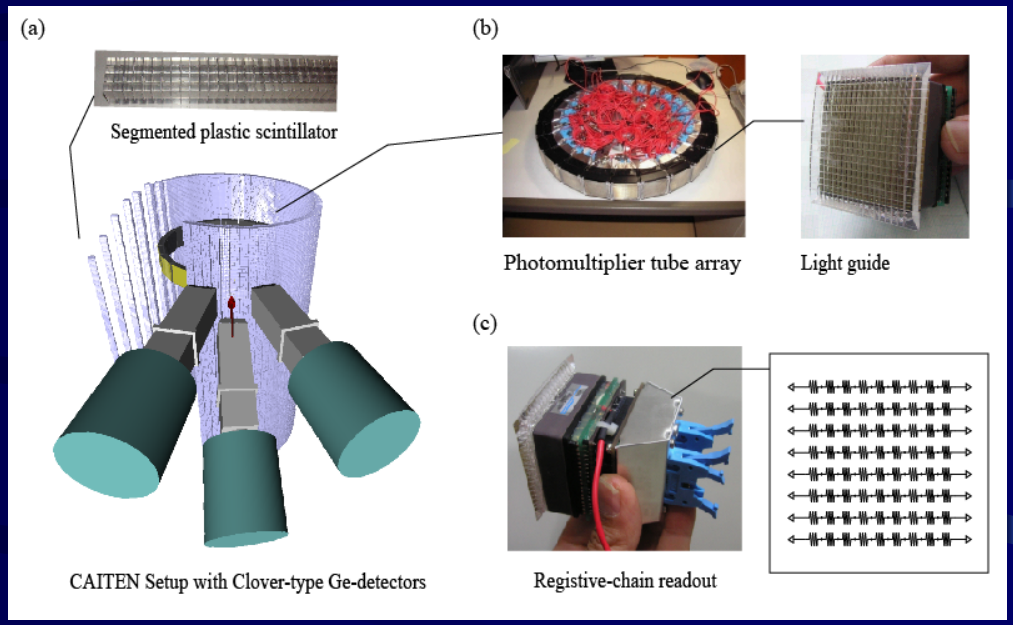
***Preliminary***
***RIBF-083***
***(P.Boutachkov)***

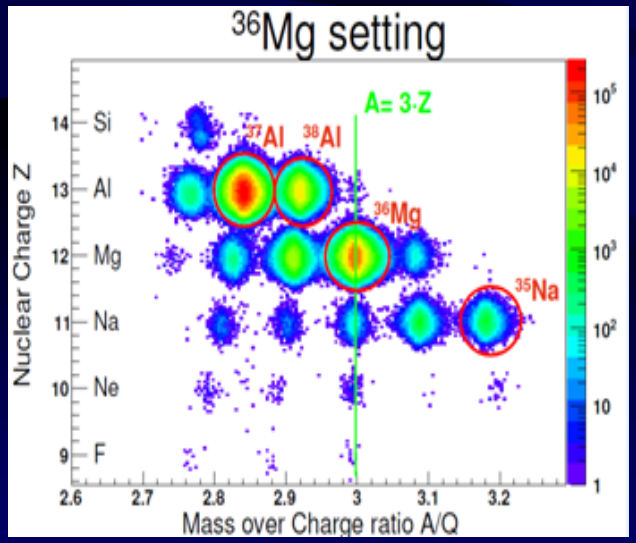


**Xe-beam  int. : 10 ~ 20 pnA**

# CAITEN: Test Experiment using $^{48}$Ca



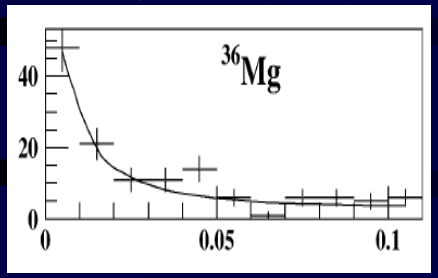



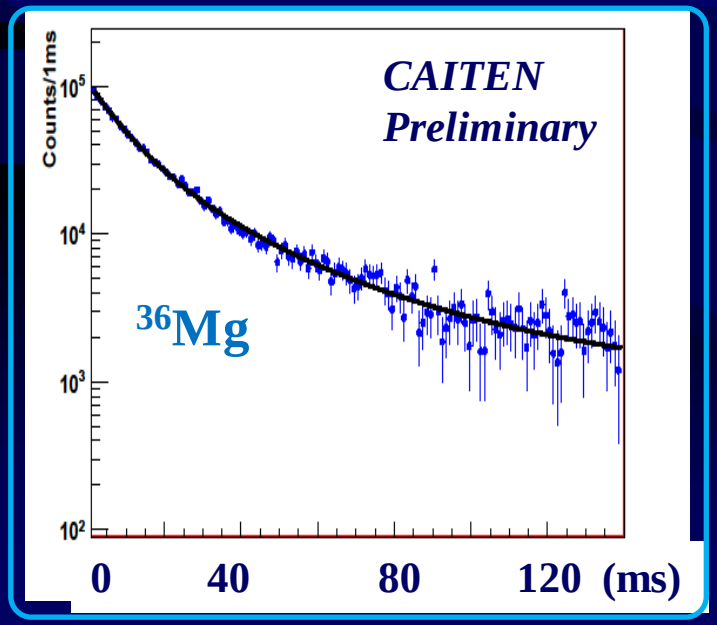
# CAITEN : $T_{1/2}$ measurement

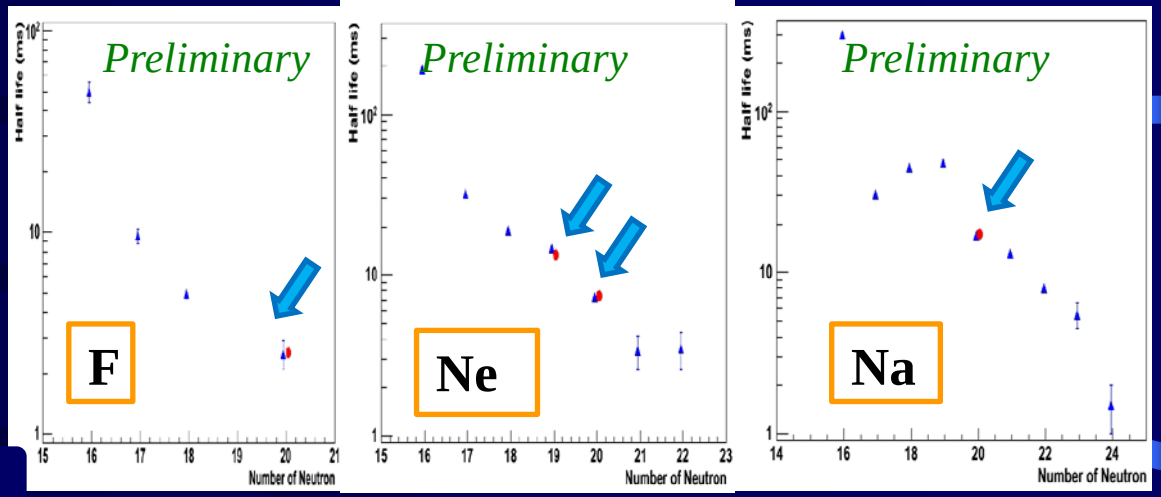
Z.Li@RNC, K.Steiger@TUM

S.Grevy, et al. (2004)




High statistic




**High precision $T_{1/2}$ measurement**
**( implantation rate ~ 1 kcps )**

# Summary

- Decay Spectroscopy at RIKEN:
  - Successful experiment around $^{110}$Zr region
    - 18 new half-lives on boundary of r-process path
      - Shorter half-lives for Zr and Nb with respective to FRDM+QRPA → Some impact to r-process abundance.
  - EURICA Campaign (2012.Mar. – 2013.June)
    - First EURICA Experiment in June: Completed. (Below 100Sn)
    - U-, Xe, Kr Campaigns in 2012 Fall & 2013 Spring
    - $^{238}$U beam intensity (x10) from 0.1 ~ 0.3 pnA → 3 pnA ~
    - High light of decay spectroscopy in 2012 -2013 :

      N = 50 $^{78}$Ni (N=50) → $^{110}$Zr (N=70) → $^{128}$Pd (N=82) → $^{170}$Dy ..

  – Fast timing (CAITEN), Neutron measurement (Pn), ..

# Collaboration in 2009

- RIKEN Nishina Center
  - S. Nishimura, H. Watanabe, Z. Li, H. Baba, M. Nishimura, T. Isobe, H. Scheit, P. Doornenbal, D. Steppenbeck, H. Sakurai
- Tokyo University of Science
  - T. Sumikama, K. Yoshinaga, Y. Miyashita, T. Nakano, K. Sugimoto, S. Takano, J. Chiba
- Osaka University
  - K. Yamaguchi, A. Odahara, A. Takashima, Y. Ito, K. Tajiri, T. Shimoda, H.J. Ong
- Tokyo Institute of Technology
  - N. Kobayashi, Y. Kawada, Y. Kondo, T. Nakamura
- CNS
  - E. Ideguchi, S. Go, S. Ota, S. Kubono, H. Yamaguchi, T. Hashimoto, S. Hayakawa
- Japan Atomic Energy Agency
  Y. Wakabayashi
- Kyushu University
  - T. Teranishi
- Technishe Universität München
  - C. Hinke, K. Steiger, R. Kruecken
- Michigan State University
  G. Lorusso,
- Lawrence Berkeley National Laboratory
  - J.S. Berryman
- INFN
  - O. Wieland, N. Blasi
- Università di Milano
  - A. Bracco, F. Camera
- University of Surrey
  - Zs. Podolyák, P.M. Walker

**48 collaborators**
**13 institutes**
**5 countries**

# CAITEN Collaboration in 2010

**CAITEN Collaboration:**

Shunji Nishimura[1], Zhihuan Li[1], Konrad Steiger[2],
Thomas Faestermann[2], Roman Gernhäuser[2],
Christoph Hinke[2], Reiner Krücken[2], Giuseppe Lorusso[1],
Yuki Miyashita[3], Mizuki Nishimura[1], Chen Ruijiu[1],
Hiroyoshi Sakurai[1], Kenichi Sugimoto[3], Toshiyuki Sumikama[3],
Hiroshi Watanabe[1] and Kenta Yoshinaga[3]

—

[1] RIKEN Nishina Center, Wako
[2] Technische Universität München
[3] Tokyo University of Science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