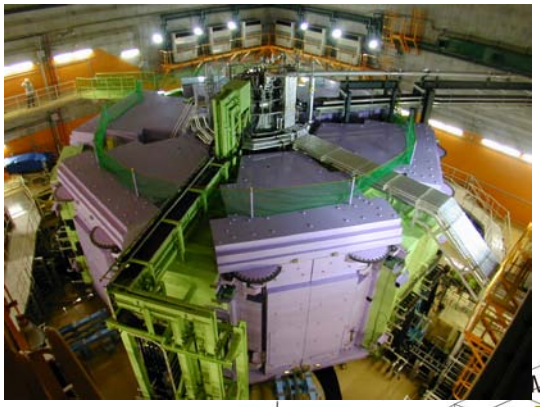
Beta Decay Experiment at the RIBF

High Intensity Beam Facility



Shunji Nishimura
RIKEN Nishina Center

Large acceptance beam line
Good Separation/Particle ID

^{238}U … 345 MeV/u

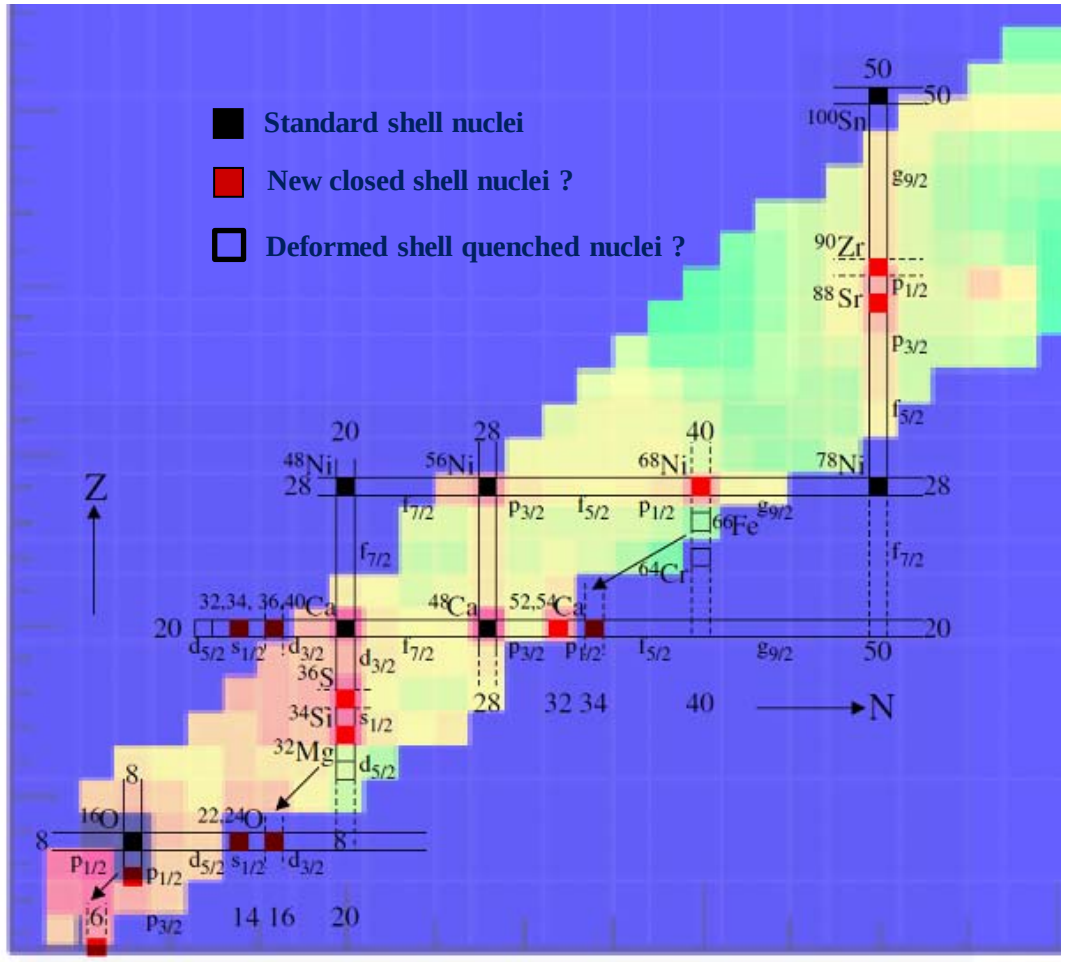
Decay Spectroscopy

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_β**
- **Neutron emission (P_n)**

Systematic Study



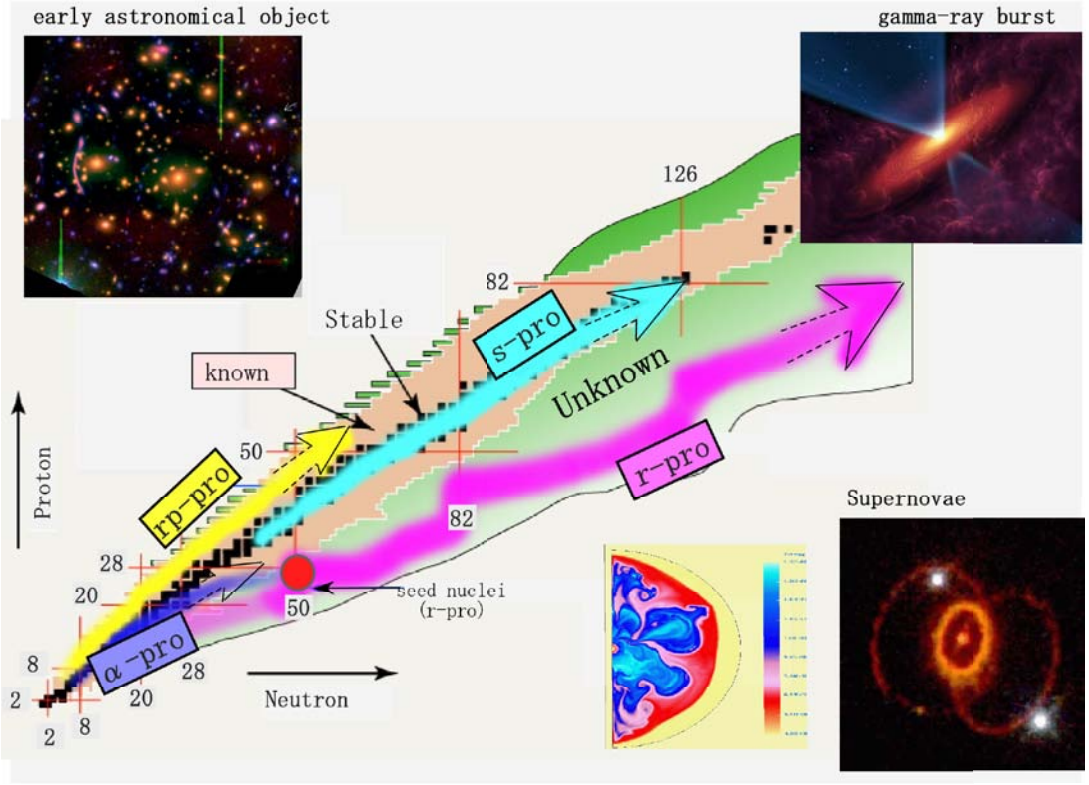
- Nuclear Structure
  - **New magic number ?**
  - **Disappearance?**
  - **Shell quenching?**
  - **Deformation?**

Inputs

Feedback to Nuclear Theory

Decay Spectroscopy

(Astrophysics Nucleosynthesis)



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

☆ Masses (A, Q_β, S_n)
→ location of the path

☆ β-delayed neutron (P_n)
→ final abundances

☆ ν ($\bar{\nu}$) catupures

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

Decay Spectroscopy Experiment around A = 110 at RIBF (2009/Dec.)

- [1]“β-Decay Half-Lives of Very Neutron-Rich Kr to Tc Isotopes on the Boundary of the r-Process Path: An Indication of Fast r-Matter Flow”, Phys.Rev.Lett.106,052502 (2011) 1-5., S.Nishimura, et al.

[2]“Structural Evolution in the Neutron-Rich Nuclei ^{106}Zr and ^{108}Zr”, Phys. Rev. Lett. 106, 202501 (2011) 1-4., T.Sumikama, et al.

[3]“Development of axial asymmetry in the neutron-rich nucleus ^{110}Mo”, Phys. Lett. B 704 (2011) 270-275., H.Watanabe, et al.

[4]“Low-lying level structure of the neutron-rich nucleus ^{109}Nb: A possible oblate-shape isomer”, Phys. Lett. B 696 (2011) 186-190., H.Watanabe, et al.

Decay Collaboration (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**
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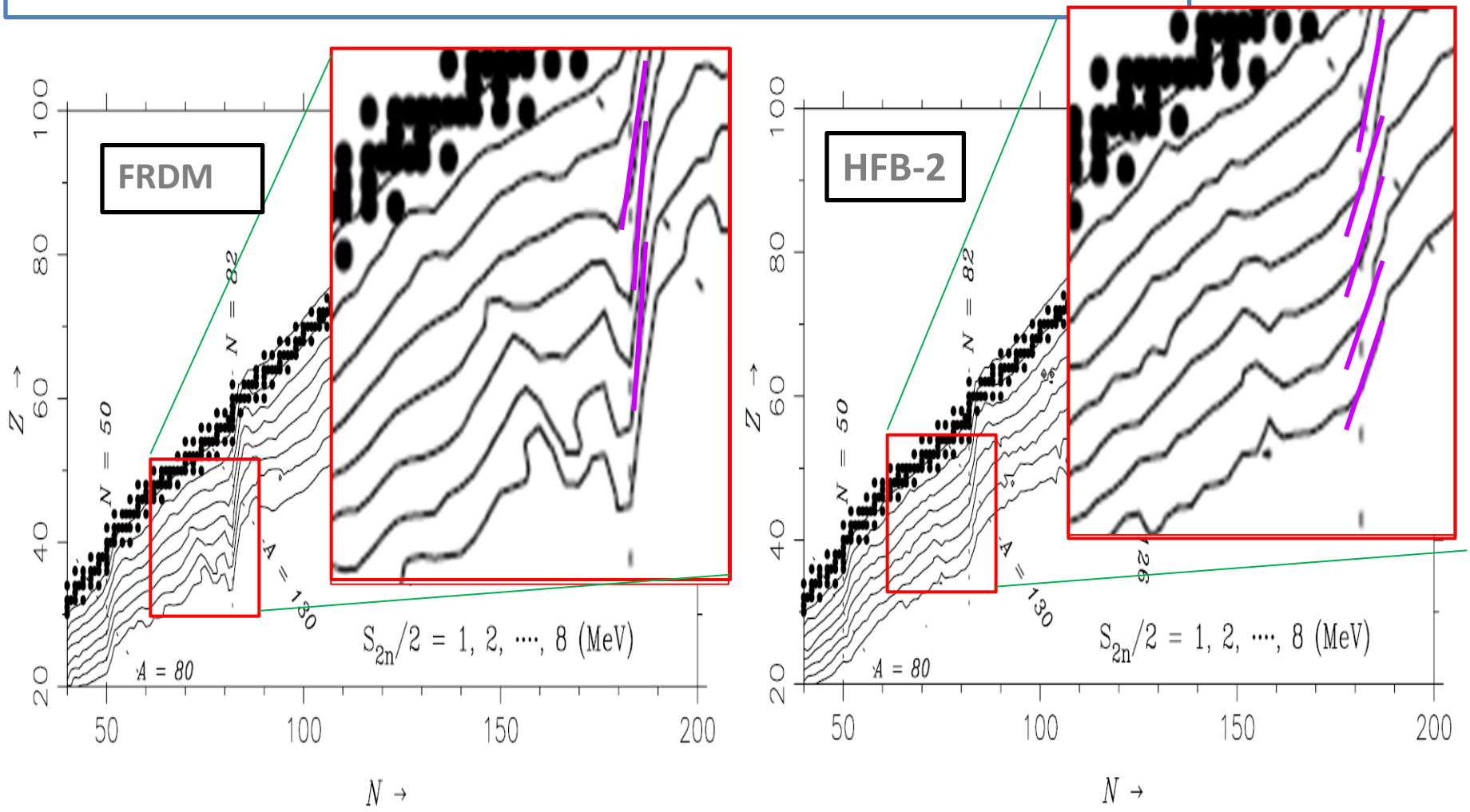
  Y. Wakabayashi
- Kyushu University
  - T. Teranishi
- Technishe Universität München
  - **C. Hinke, K. Steiger**, R. Kruecken
- Michigan State University
  G. Lorusso,
- Lawrence Berkeley National Laboratory
  - J.S. Berryman
- INFN
  - O. Wieland, N. Blasi
- Università di Milano
  - A. Bracco, F. Camera
- University of Surrey
  - Zs. Podolyák, P.M. Walker

***Students**

48 collaborators
13 institutes
5 countries

Neutron Separation Energies

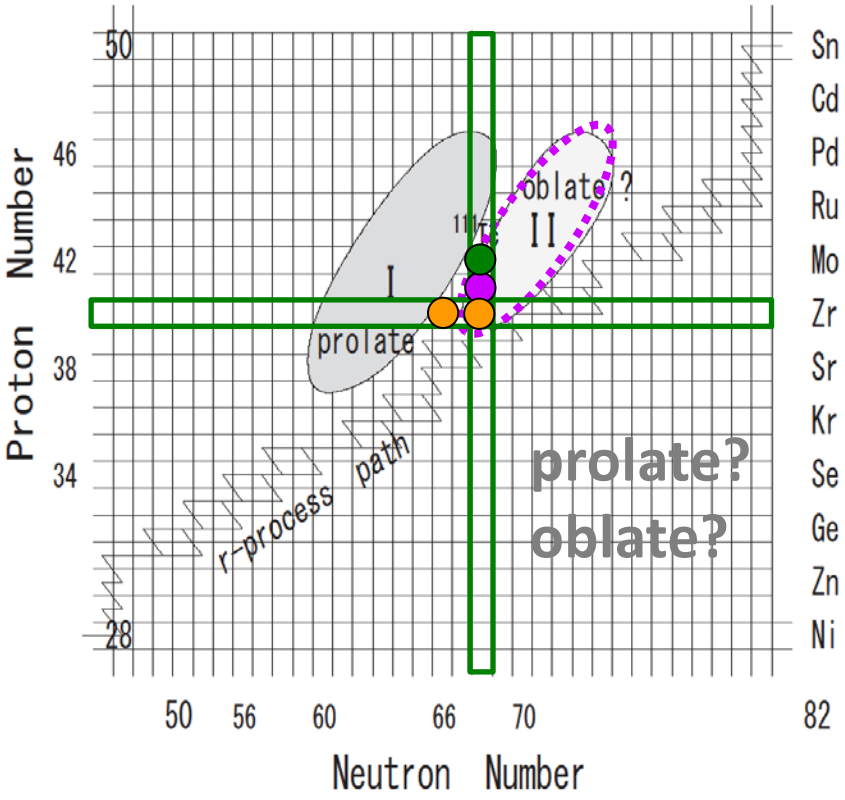
Location of r-process path depends on S_n (2 – 3 MeV)
(n,γ)-(γ,n) competition

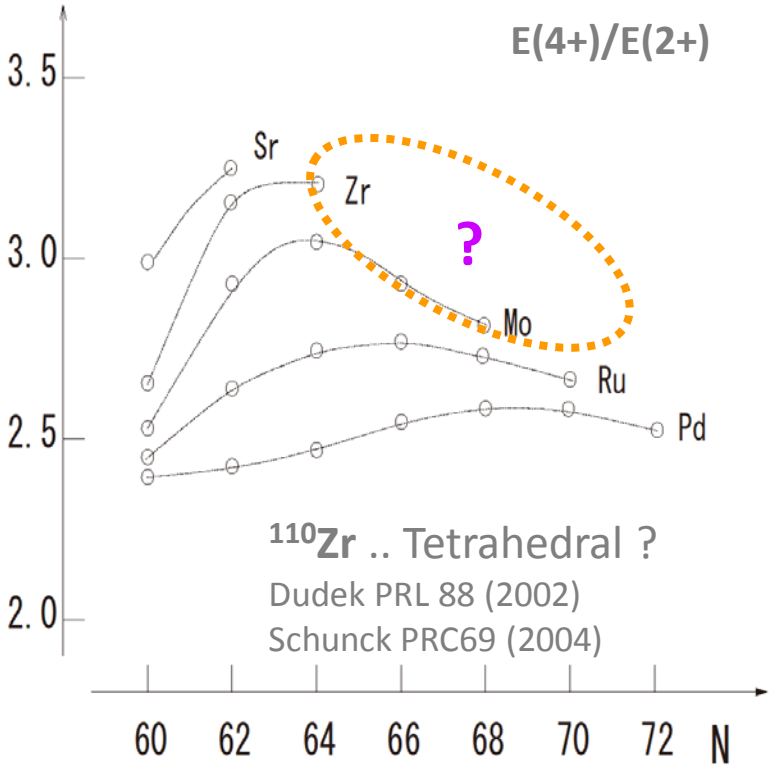


S.Wanajo, S.Goriely, M.Samyn, N.Itoh, Astro.J 606 (2004).

Deformation around Zr

- Oblate shape isomer for ^{109}Nb? by Watanabe, PLB 696 (2011)
- ^{106,108}Zr … K.Yoshinaga, T.Sumikama
- ^{110}Mo … H.Watanabe, K.Yamaguchi



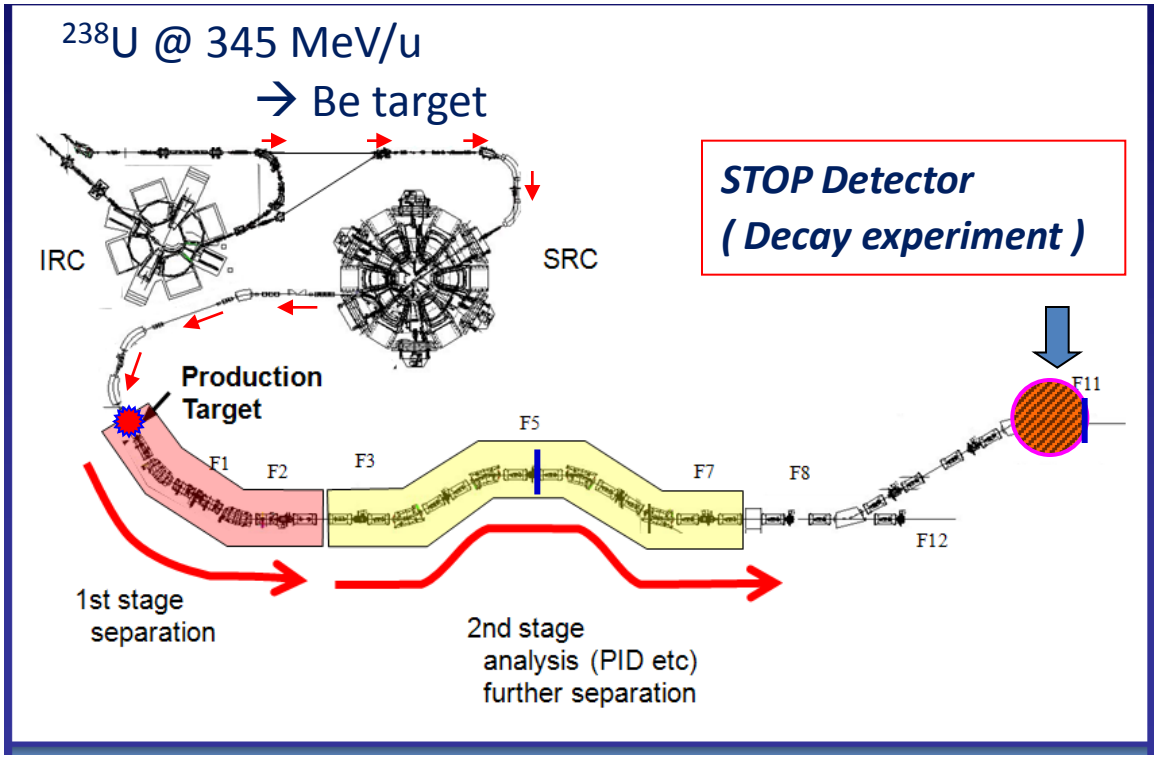


W.Urban, et al., EPJA 20 (2004), EPJA24 (2005)

- Beta-delayed gamma
- Isomeric states

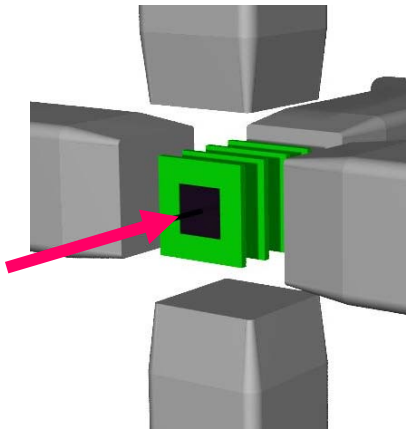
Influence of deformation on half-life ?

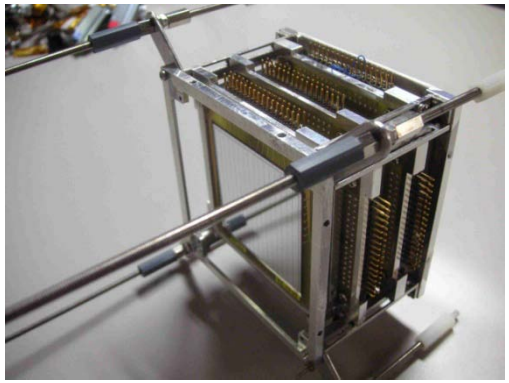
Beam Production



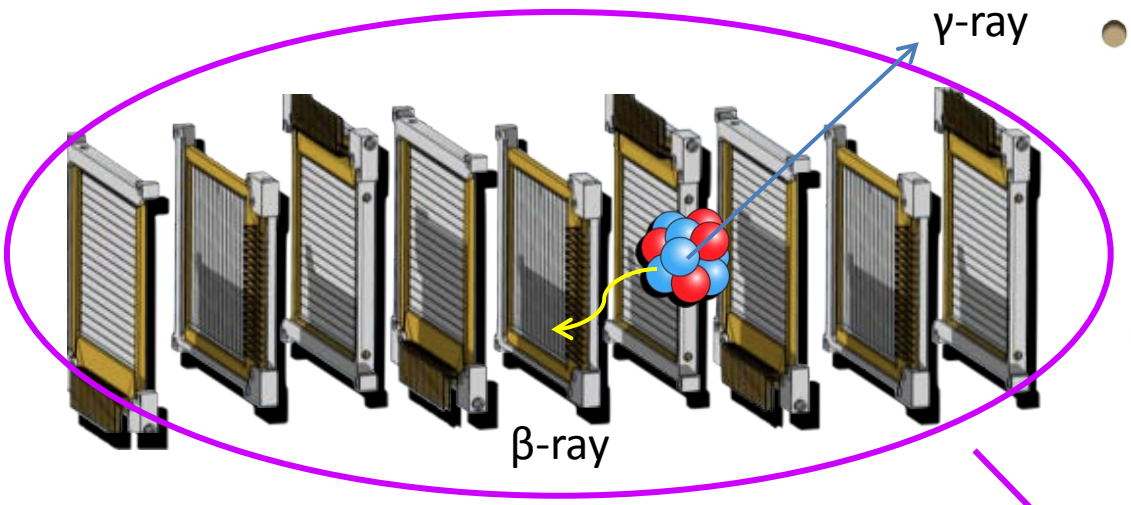
- **Charge stripper @ F5**
- **Degrader @ F11**

Silicon strip detector

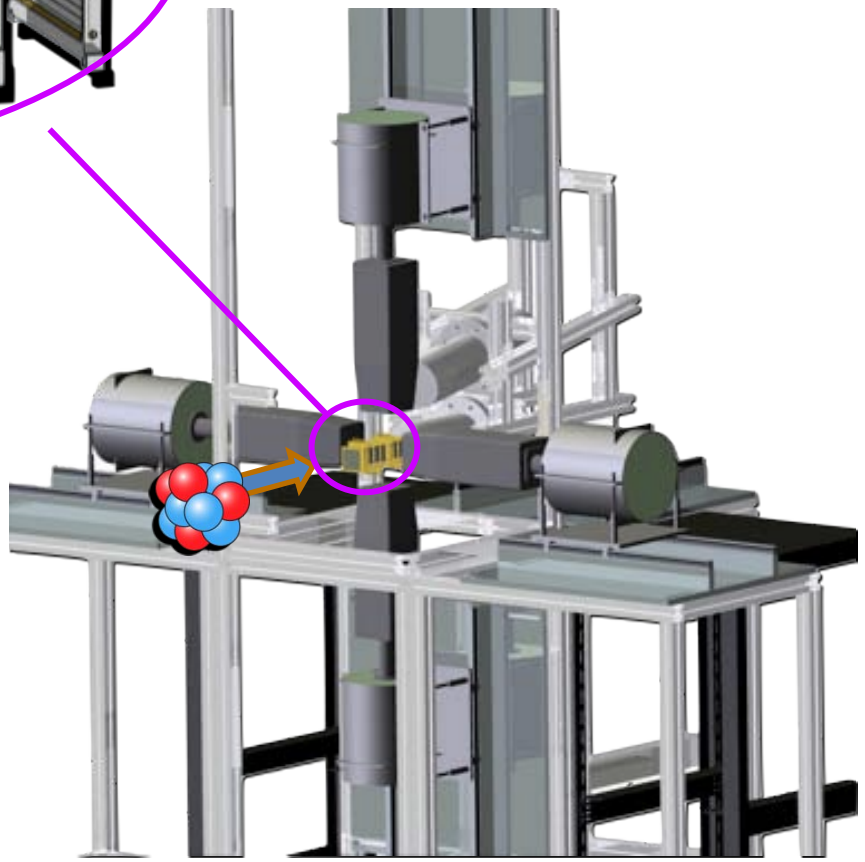




Experimental Setup



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



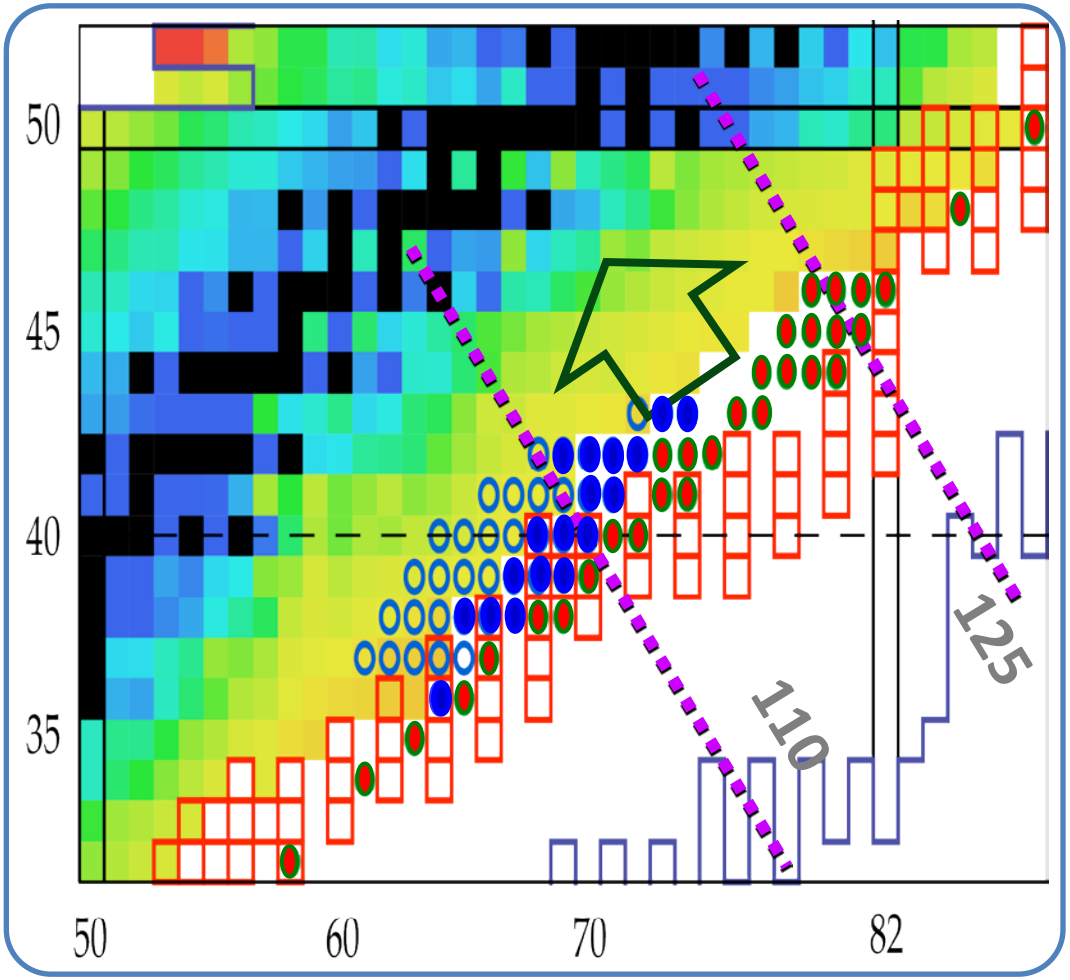
- The implantation of an identified RI is associated with the following β-decay events that are detected in the same DSSSD pixel

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

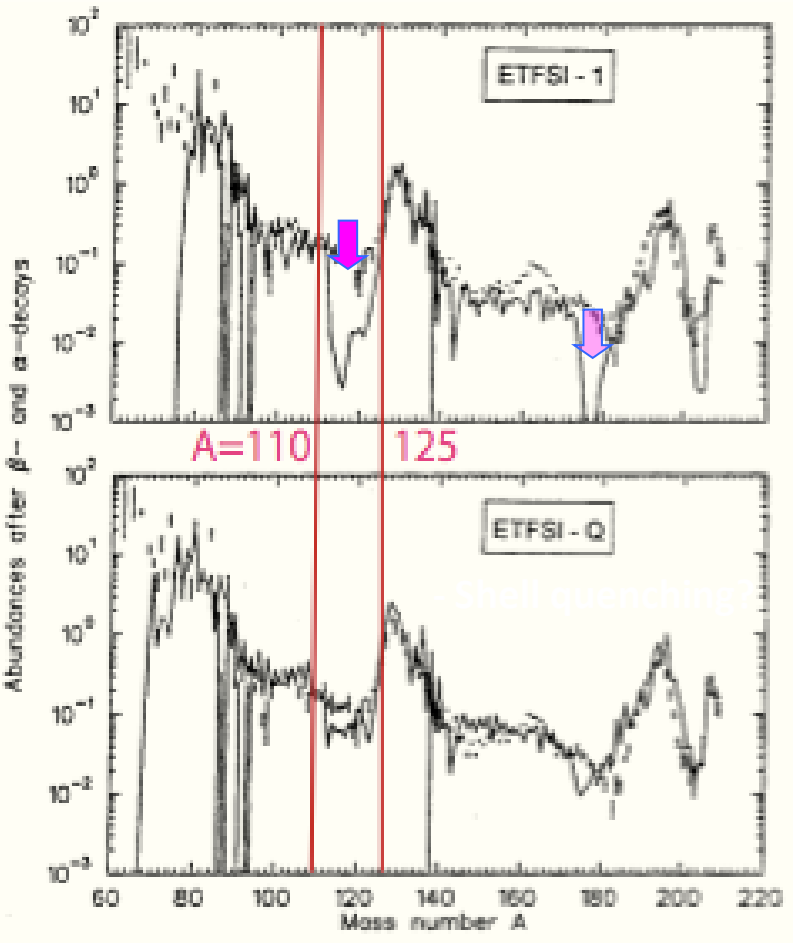
By Y. Miyashita

R-process Abundance around 2nd peak

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



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



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

~ 1989 : ***

1992 : J.Aysto
… ^{105}Zr, ^{107}Nb, ^{109}Mo, ^{113}Tc

1996 : M.Mehren
… ^{103}Y, ^{109,110}Nb

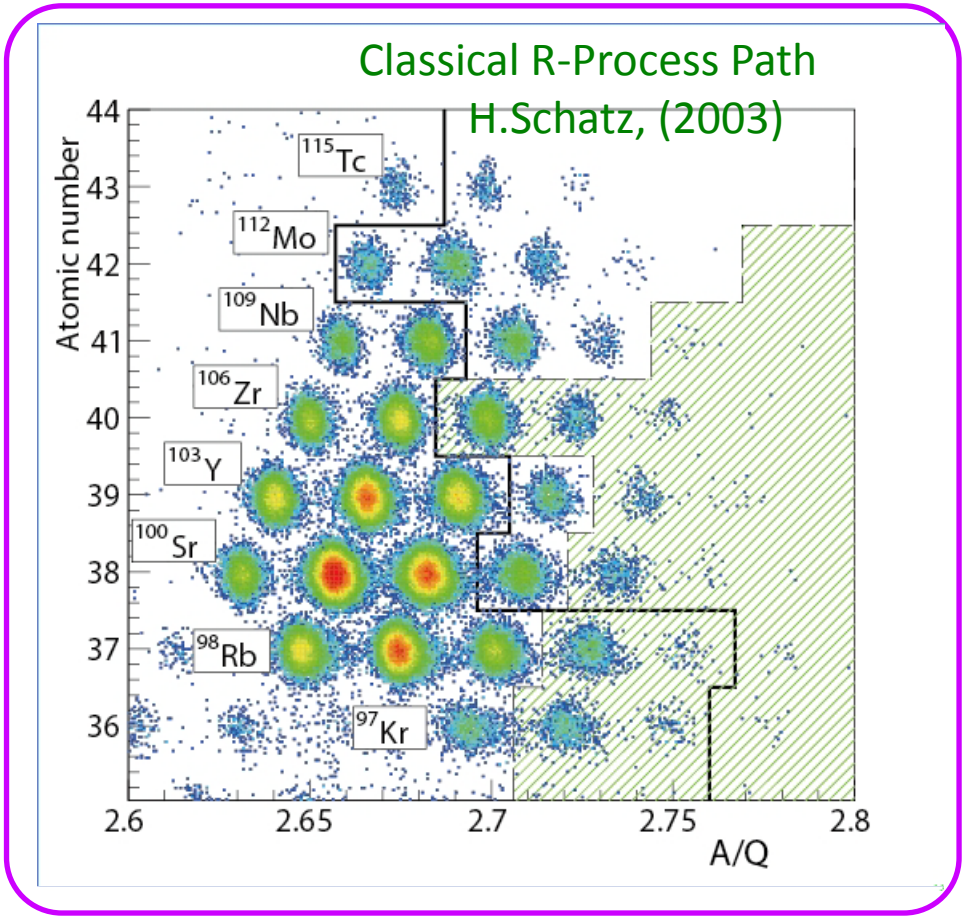
1999 : J.C.Wang
… ^{104}Y, ^{112,113,114}Tc

2003 : U.C.Bergmann
… $^{96\text{-}99}$Kr

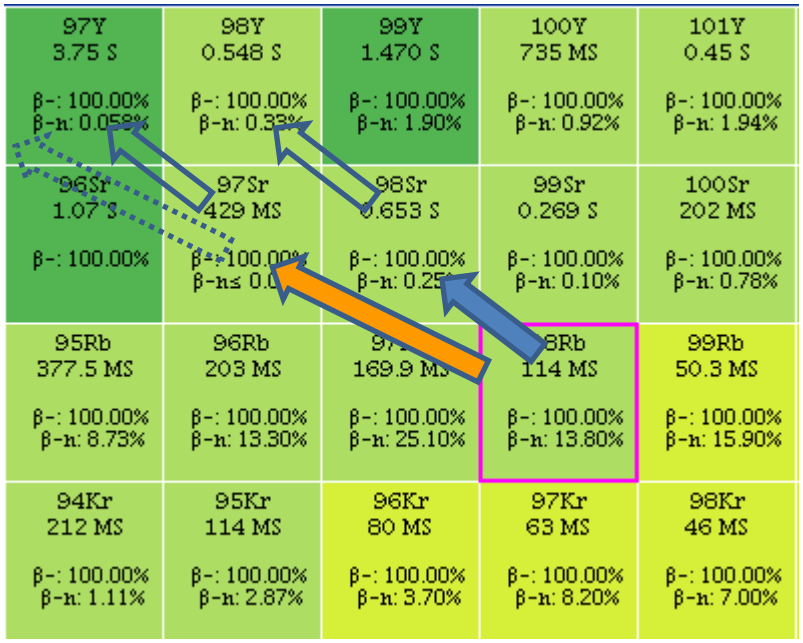
2006 : F.Montes
… ^{115}Tc

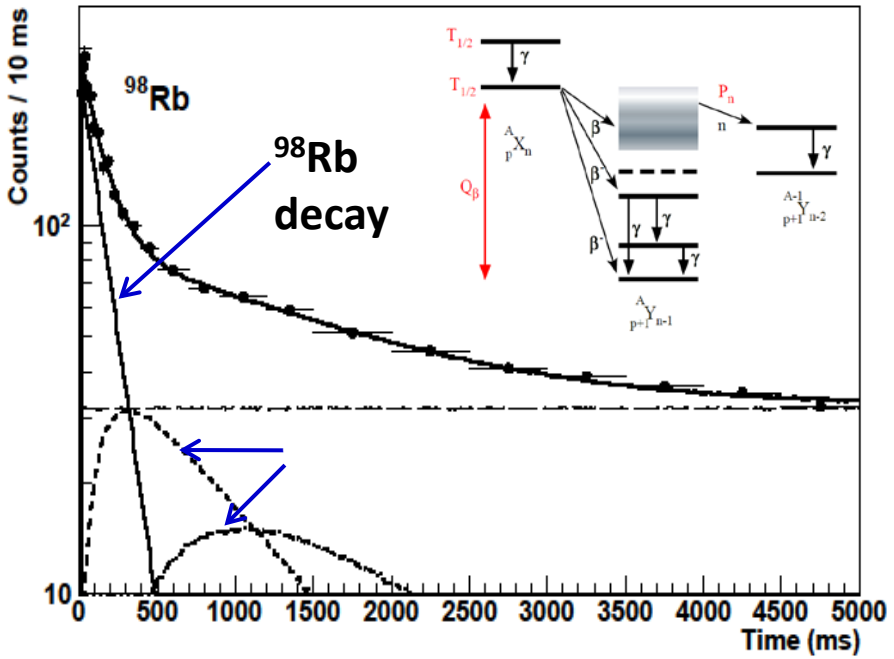
2009 : J.Pereira
… ^{105}Y, ^{106,107}Zr, ^{111}Mo

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



Decay curve and $T_{1/2}$





Likelihood method with 10ms bins (0 – 5 sec)

Free parameters for fitting

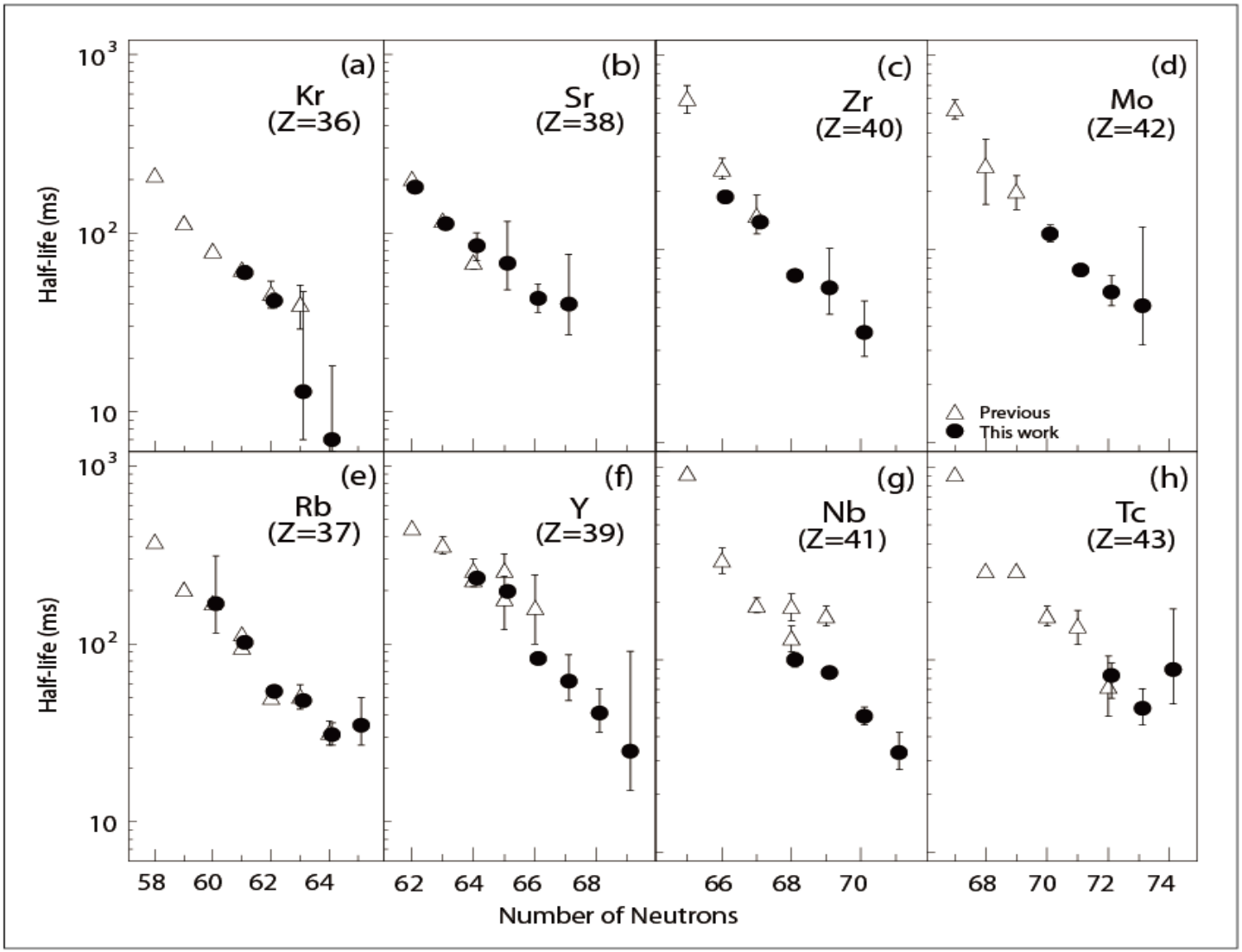
- Background … ~ 0.5 cps
- Neutron emission Probability (Pn)
- Detection efficiency (ε) … 40% - 80%

Consistency check

- Monte Carlo Simulation

$T_{1/2}$

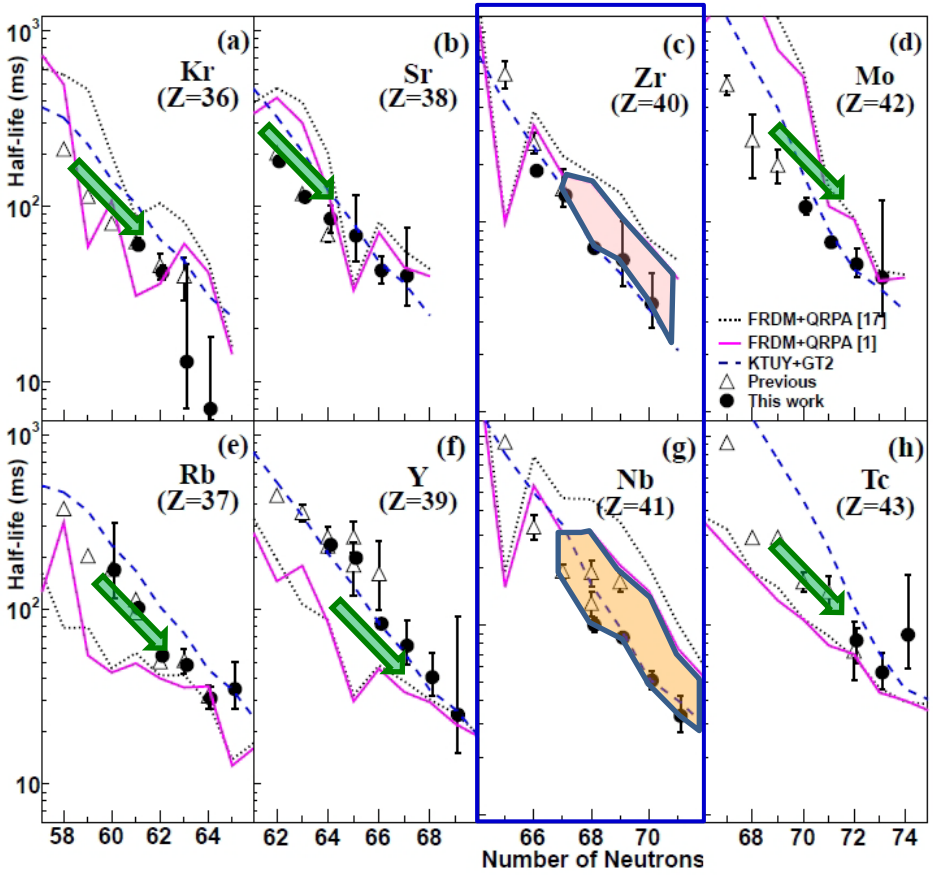
Neutron Number Dependence of $T_{1/2}$



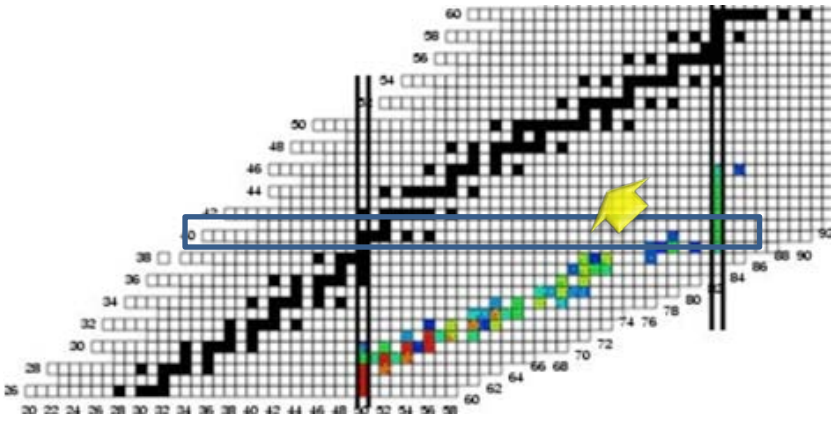
Significant improvement of $T_{1/2}$ information ! & 18 new half-lives !!

38 half-lives (18 half-lives are new!)

S.N, et al. PRL 106 (2011) 052502

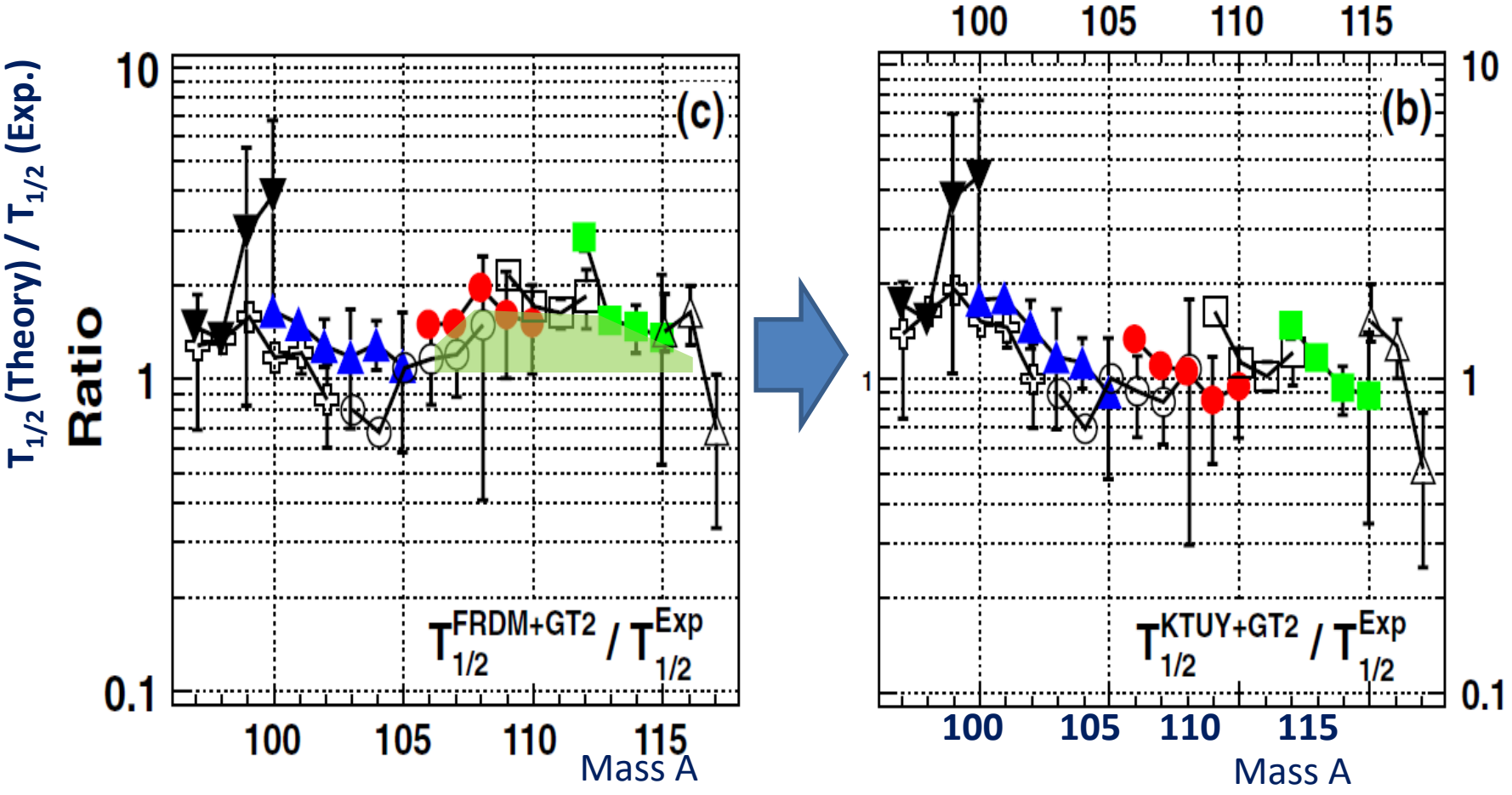


by JINA



Zr and Nb decay faster than expected by FRDM+QRPA (T1/2 : 1/2 ~ 1/3 ~)

(FRDM → KTUY) + GT2

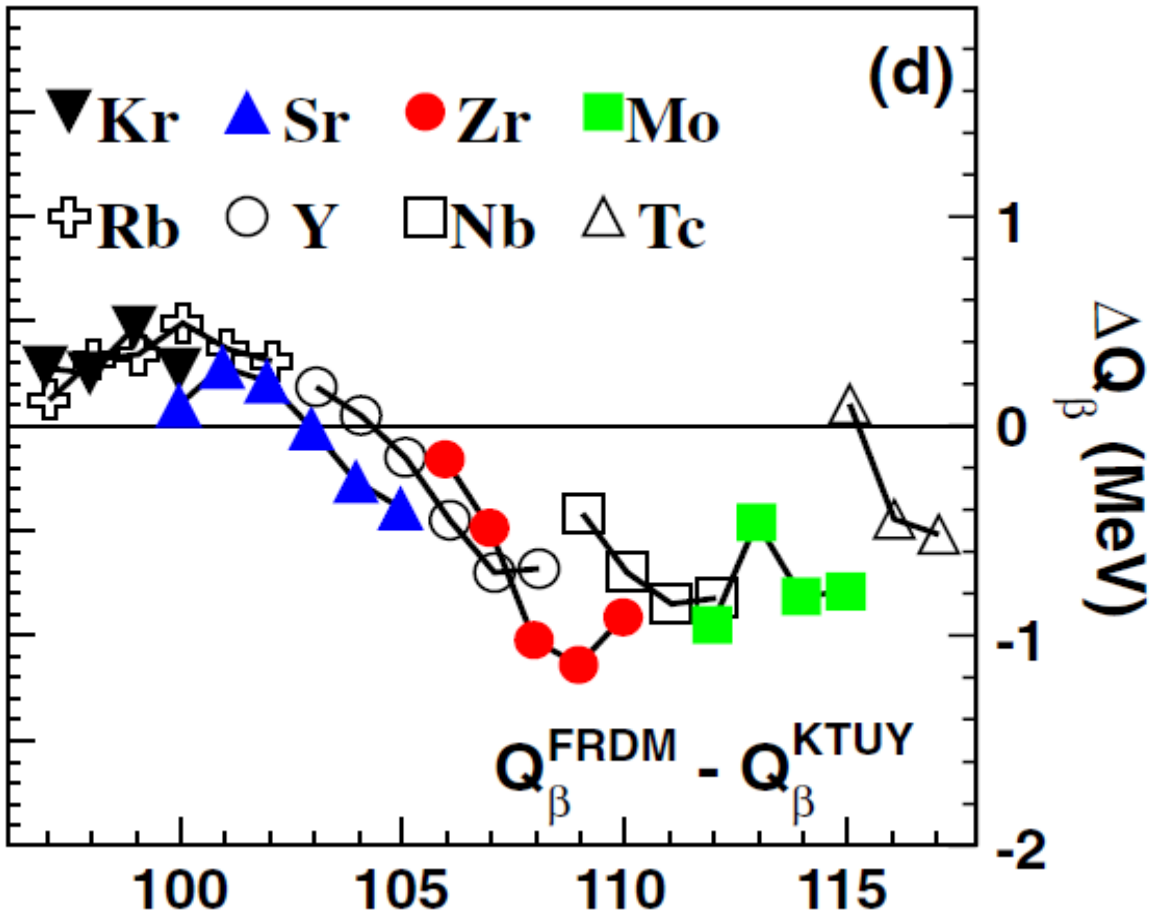


Overestimation of T1/2 by factor of ~ 2

Better agreement for KTUY !

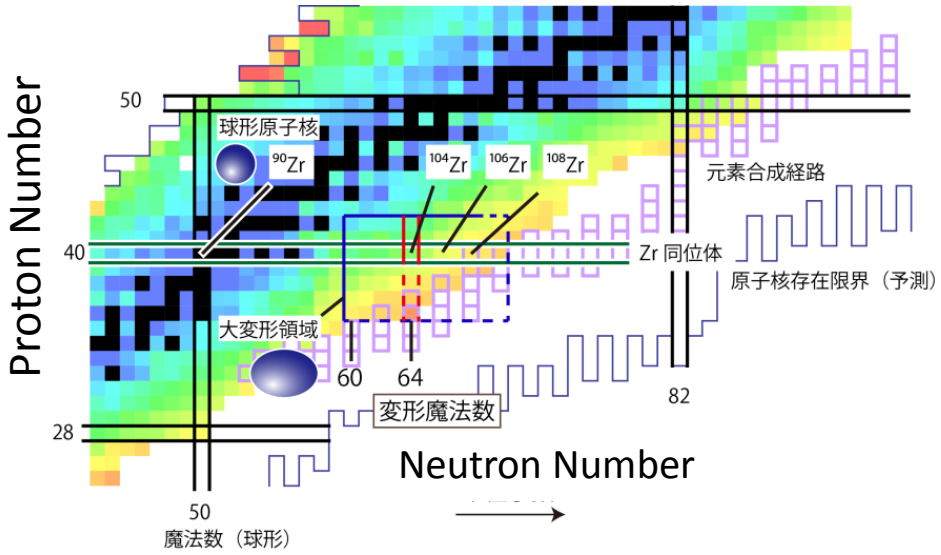
→ WHY ?!

Better prediction with KTUY (H.Koura)?

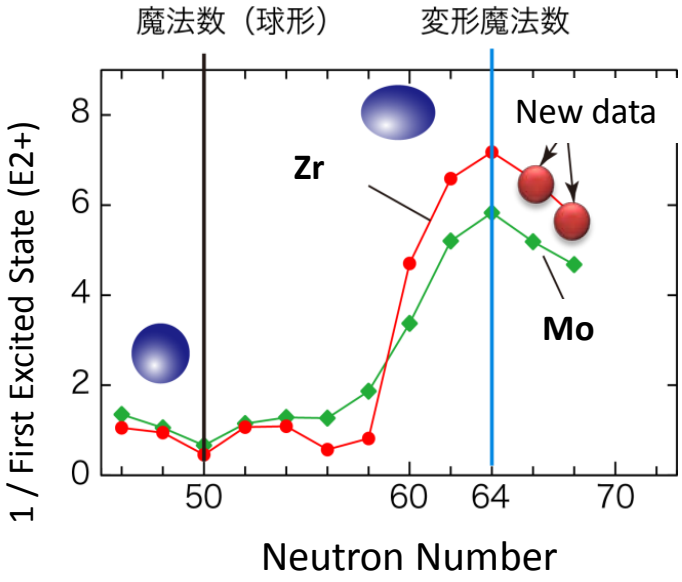


FRDM may underestimate the Q value :
dQ ~ 1 MeV @ A ~ 110.

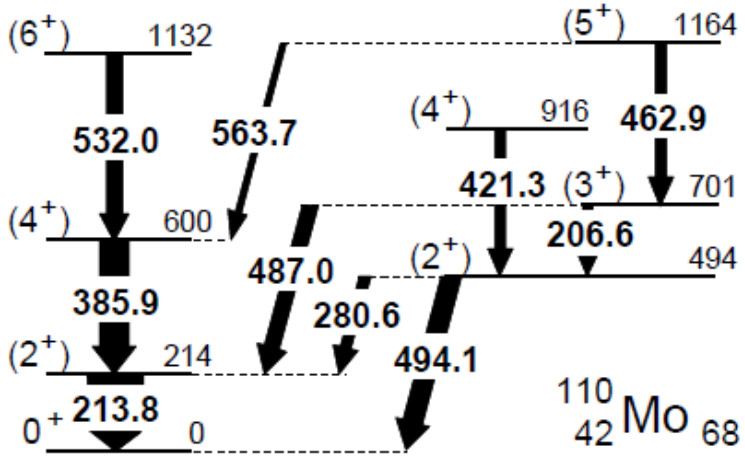
More Results



Structural evolution in 106,108Zr
T.Sumikama, PRL 106 (2011)



Development of axial asymmetry in 110Mo ,
H.Watanabe, PLB 704 (2011) 270.



In Future

CAITEN

(New type of beta-counting system)

CAITEN Collaboration (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], Kenichi Sugimoto[3], Toshiyuki Sumikama[3], Hiroshi Watanabe[1] and Kenta Yoshinaga[3]

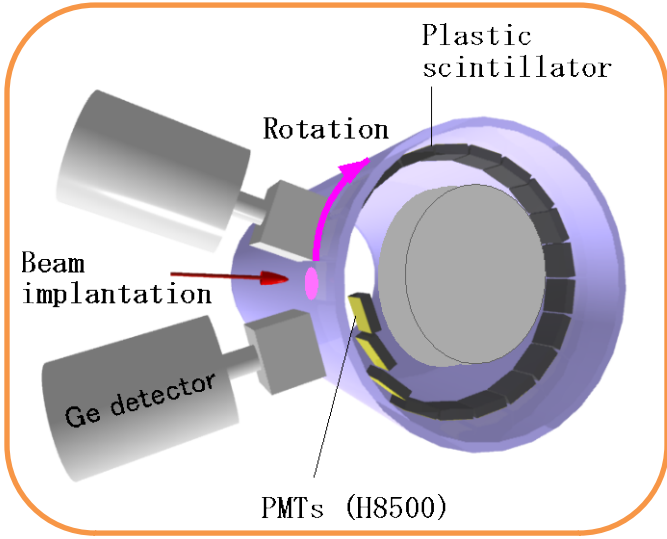
—

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

Special thanks to
S.Takeuchi, H.Scheit, T.Nakamura, M.Takechi, D.Bazin, P.Fallon

supported by RIKEN President Fund 2007 and BMBF (06MT9156) and DFG (EXC 153)

High counting rate beta counting system CAITEN



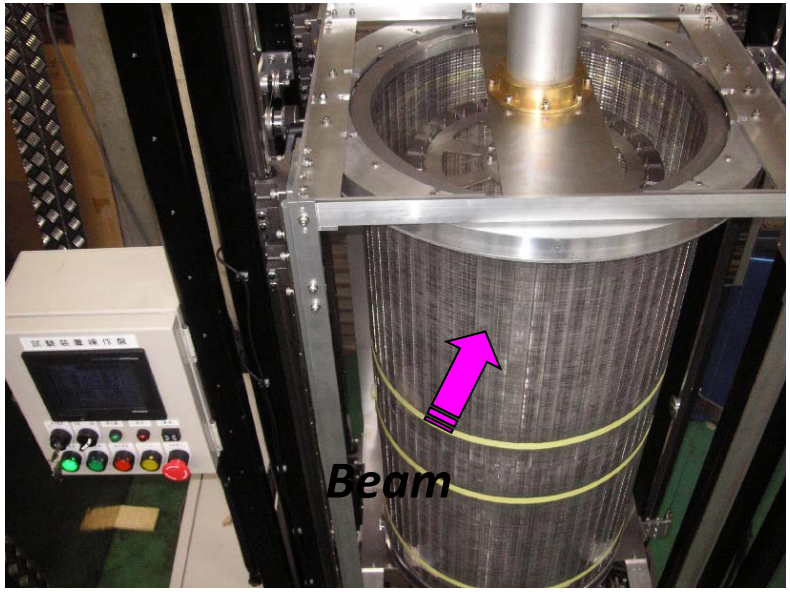
Cylindrical scintillator : (RP-408)

- **4x10^5 pixel scintillators**
- **ϕ50 cm x 100 cm**
- **Ration : ~ 60 rpm ~**
- **Vertical motion (up / down)**

- Air-coupling ~ 3mm gap

- **Position resolution**

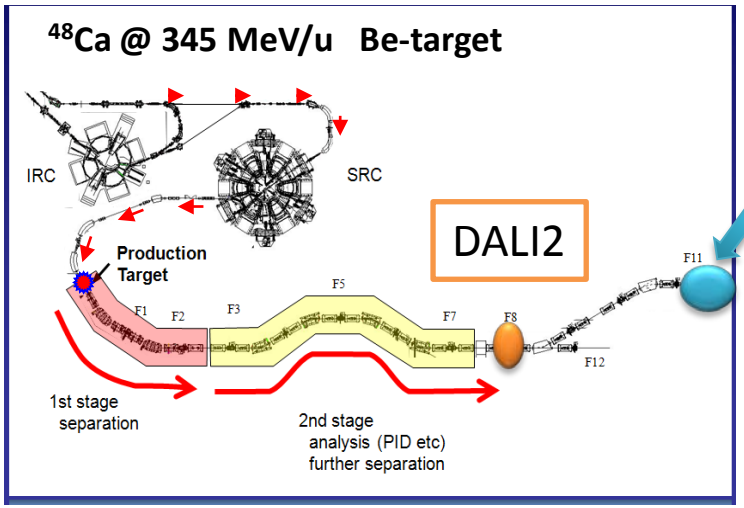
  σ~ 3.8 mm



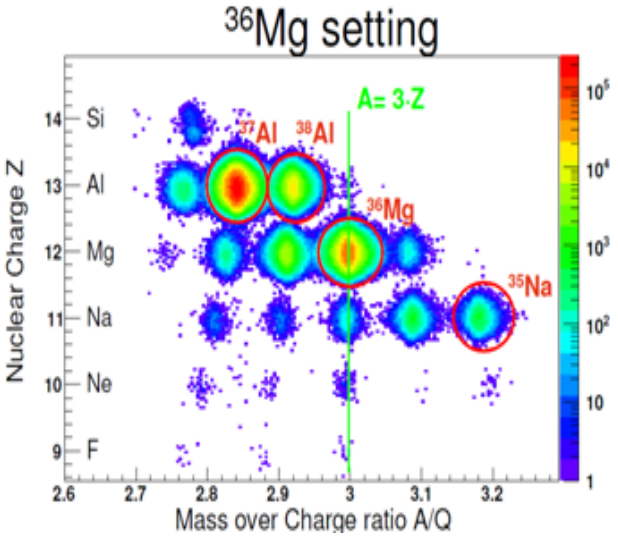
Decay experiment using CAITEN with in-beam gamma ?

CAITEN : Decay Spectroscopy

Spokesperson : S.Nishimura



CAITEN:
Position sensitive beta-ray detector
+
γ detectors :
3 clover Ge det.

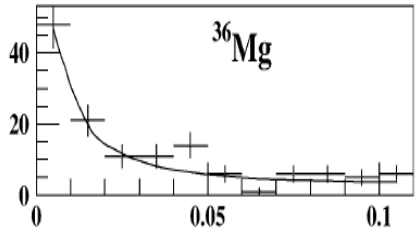


Implantation detector

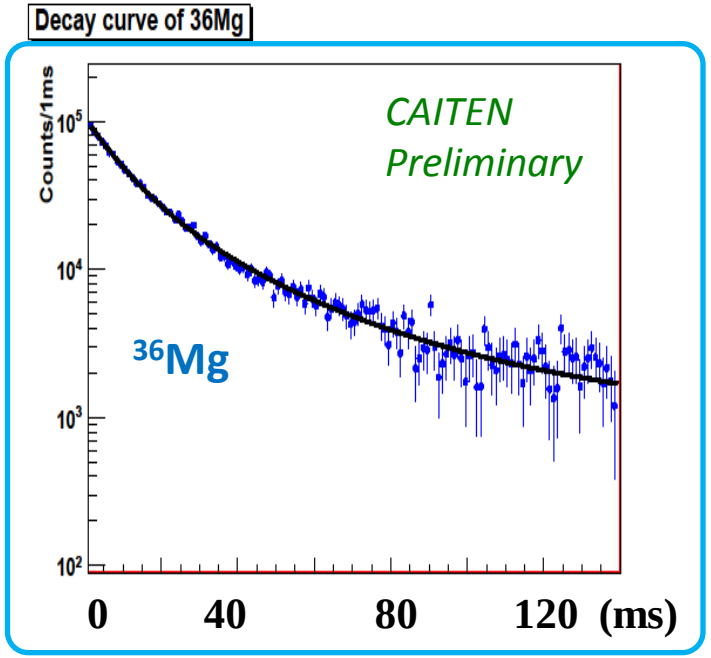
CAITEN : T1/2 measurement

Z.Li@RNC, K.Steiger@TUM

S.Grevy, et al. (2004)

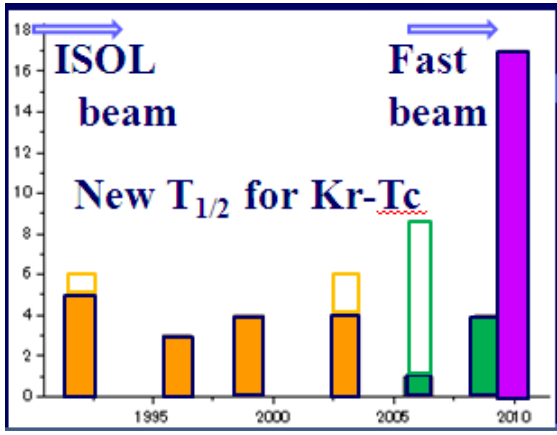


High statistic



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

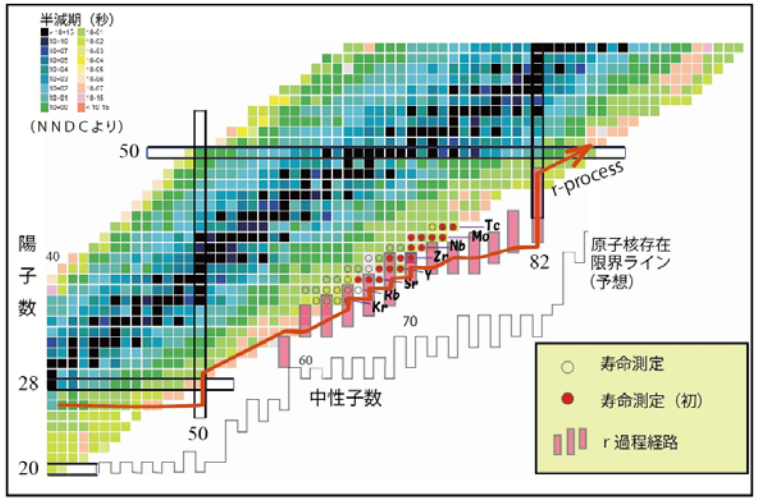
Summary



- Decay spectroscopy experiment (A ~ 110)
  - ^{238}U beam intensity : 0.1 ~ 0.3 pnA & **2.5** days
  - Mass A ~ 110 region (**Kr, Rb, Sr, Y, Zr, Nb, Mo, Tc**)
  - Half-lives of **18** neutron-rich isotopes are measured for the first time.
  - Half-lives of **37** isotopes from this work are compared with predictions of the deformed quasi-random-phase-approximation model (FRDM+QRPA) and gloss model (KTUY)
    - → FRDM + QRPA seems to overestimate the half-life around A = 108 ~ 114.
    - → Better agreement with KTUY gloss theory

- More detectors & physics cases
  - **EURICA Project !**
  - **CAITEN system**

Nuclear Structure & Nucleosynthesis

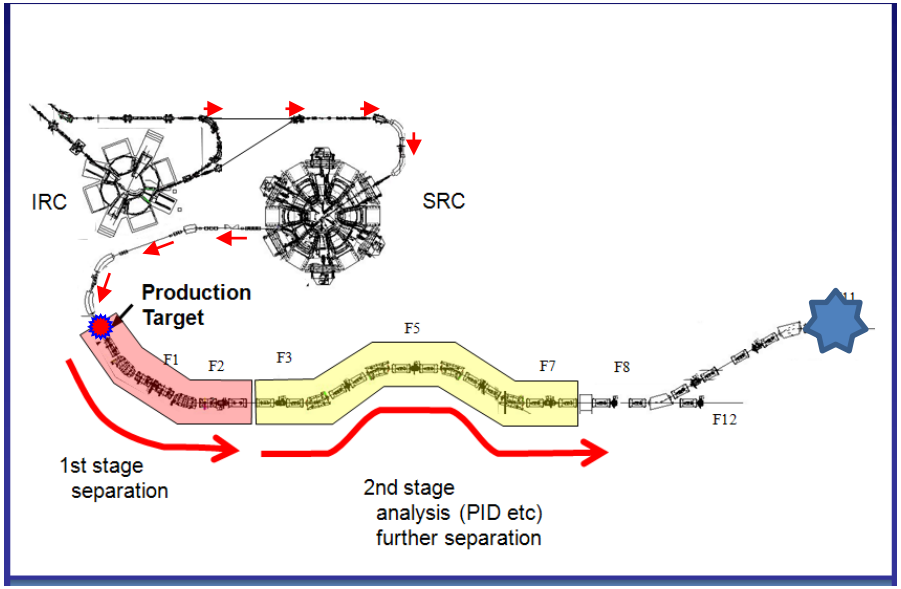


New Project

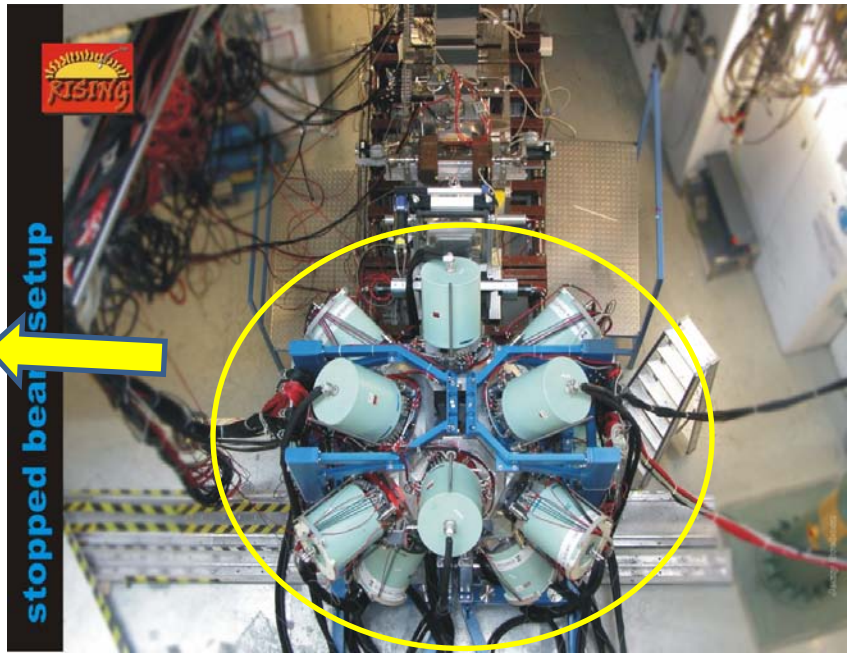
EURICA

Euroball RIKEN Cluster Array

EURICA Project (～ 2013.06)



RISING@GSI



Combinations of

- **Highest Beam Intensity : RIKEN RIBF**
- **Large Acceptance Beam Line : BigRIPS + ZeroDegree**
- **Highest performance : beta-counting system**

&

- **High Efficiency EUROBALL Cluster Array (RISING)**

Gamma-detection
1~2 % → 15%

γ–γ : ~ 2 orders higher effi.

EURICA Collaboration & Proposals

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Large international collaboration

- **170 people**
- **28 proposals**

→ More results are expected from RIBF decay exp.

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