RIBF討論会 (2012, May, 24)

r-process nucleosynthesis
(RIBF : Experimental Side)

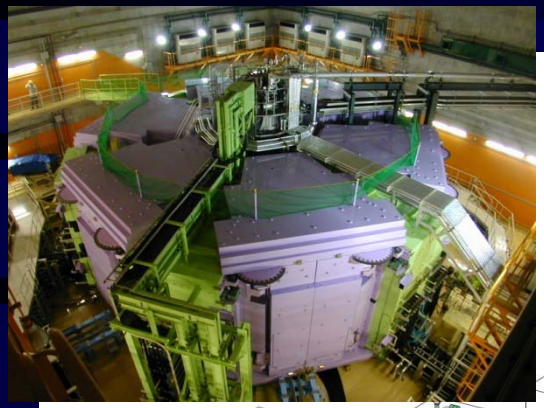
Shunji Nishimura
(RIKEN)

RIBF討論会: 核理論 RIBF実験 協力関係
→ 成果を最大限産み出す。

Status
(- 2011)

RIKEN RIBF

Nucleus	Beam Intensity / pnA	
	Achieved	Expected FY 2011/12
^{48}Ca	230	200
^{86}Kr	30	30
^{124,136}Xe	**10**	10
^{238}U	~~0.6~~ **3-4**	5

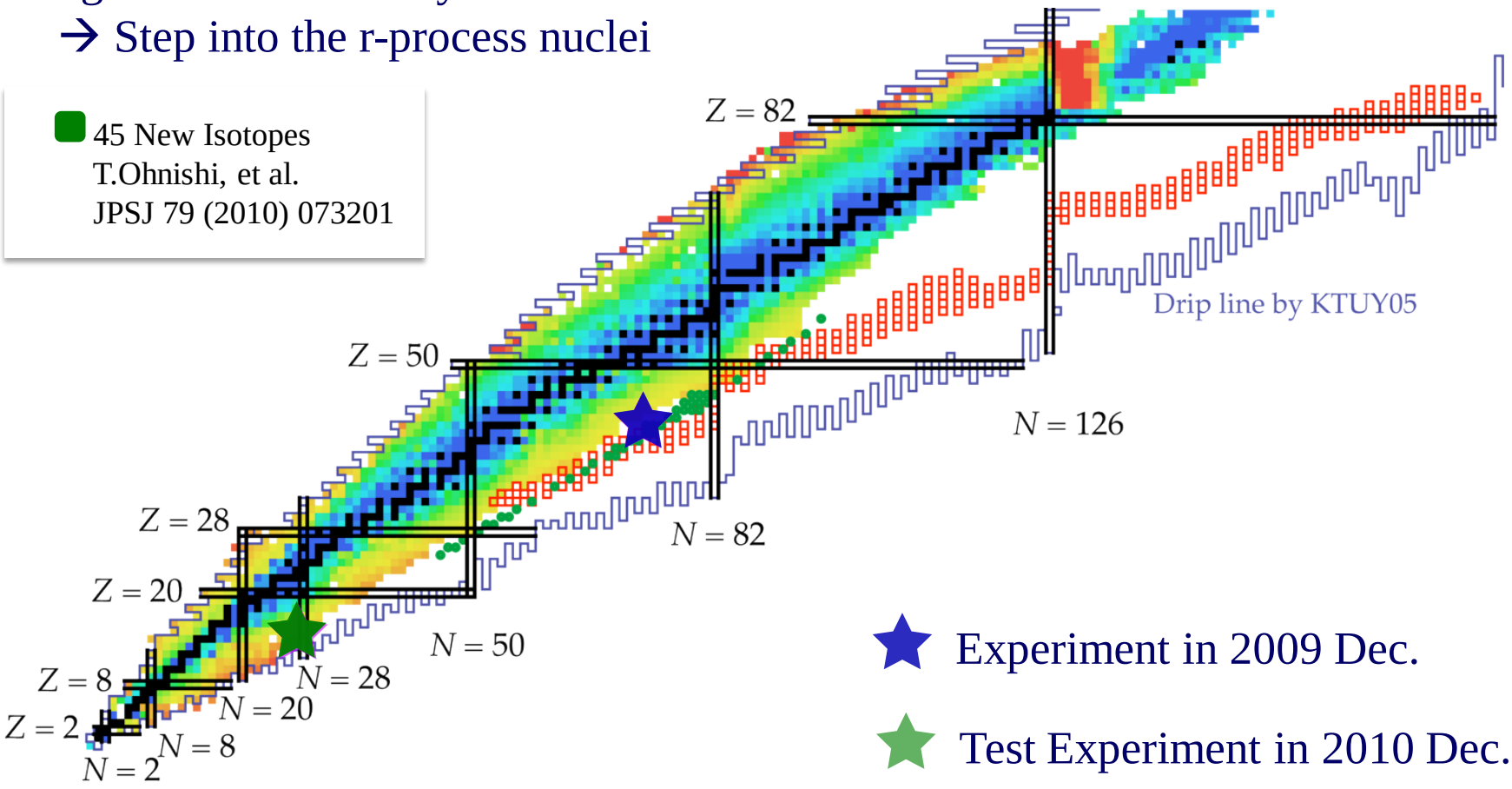


^{238}U … 345 MeV/u

Beta-Decay Experiments at RIBF

Highest beam intensity of ^{238}U-beam
→ Step into the r-process nuclei

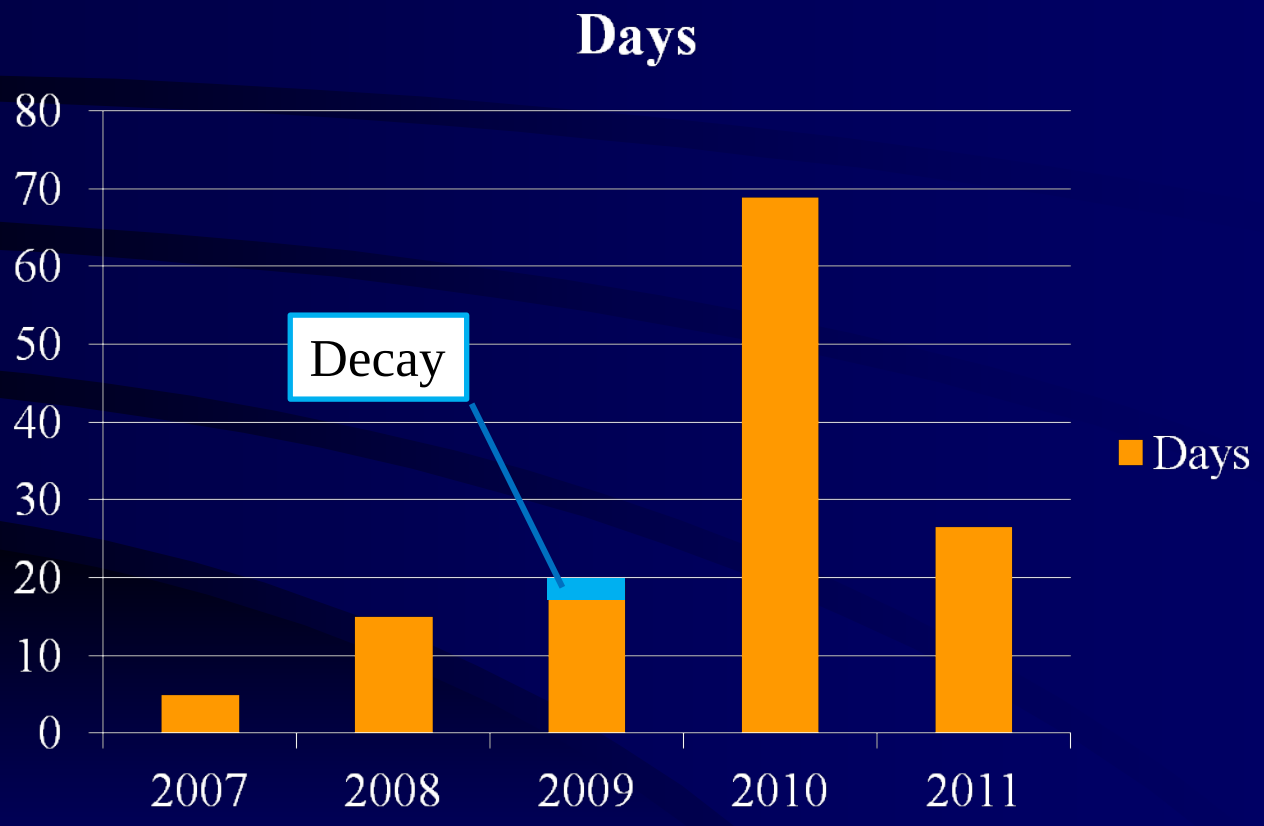
45 New Isotopes
T.Ohnishi, et al.
JPSJ 79 (2010) 073201



Experiment in 2009 Dec.

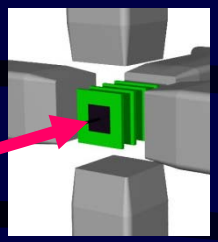
Test Experiment in 2010 Dec.

RIBF Experiments (Beam on Target)



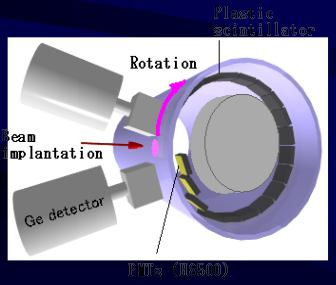
These days..

2009 2010 2011 2012 2013

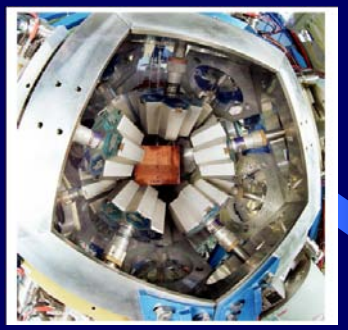


1st Decay Exp. (Si)
A ~ 110
(2.5-days)

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

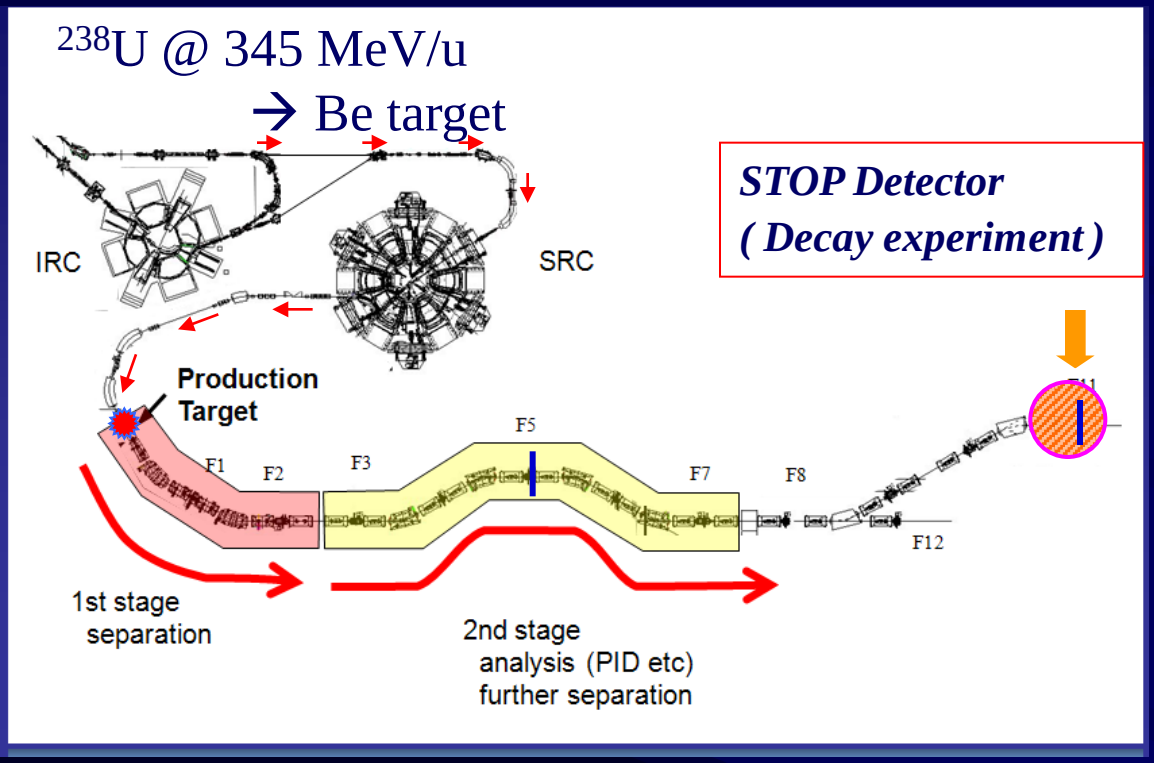


Test Exp. (CAITEN)
A = 30 ~ 40



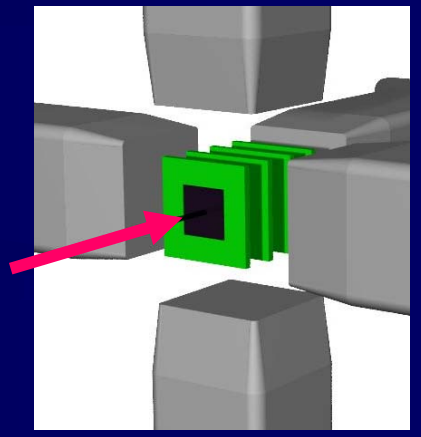
EURICA Project
(40 % of RIBF beam time)

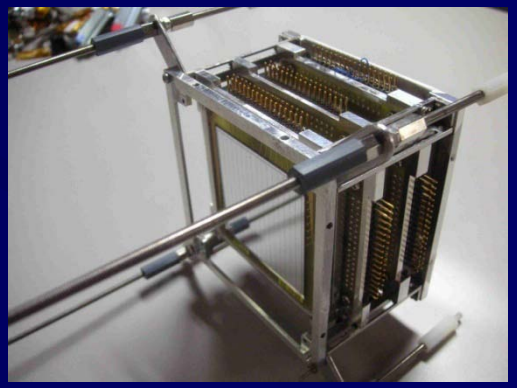
Beam Production



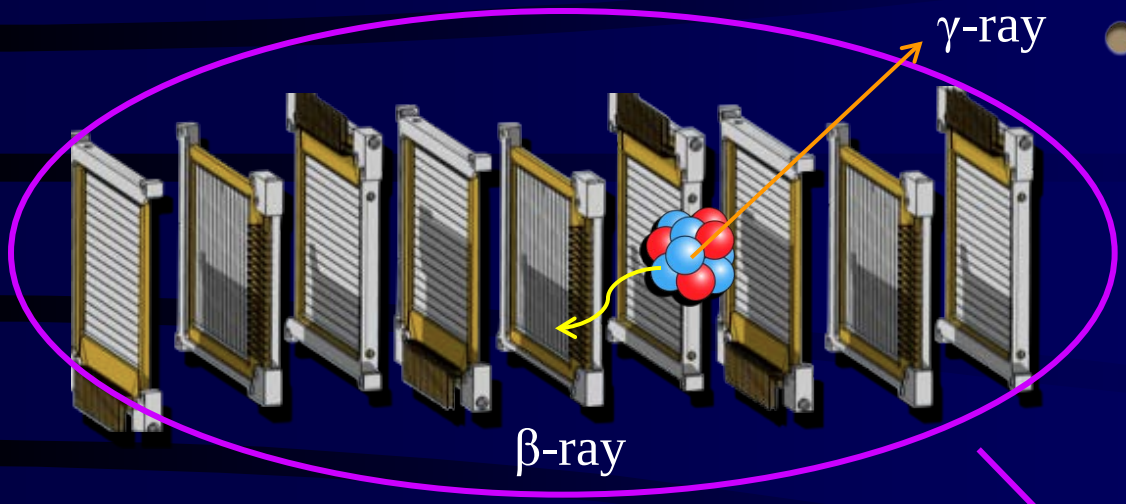
- Charge stripper @ F5
- Degrader @ F11

Silicon strip detector

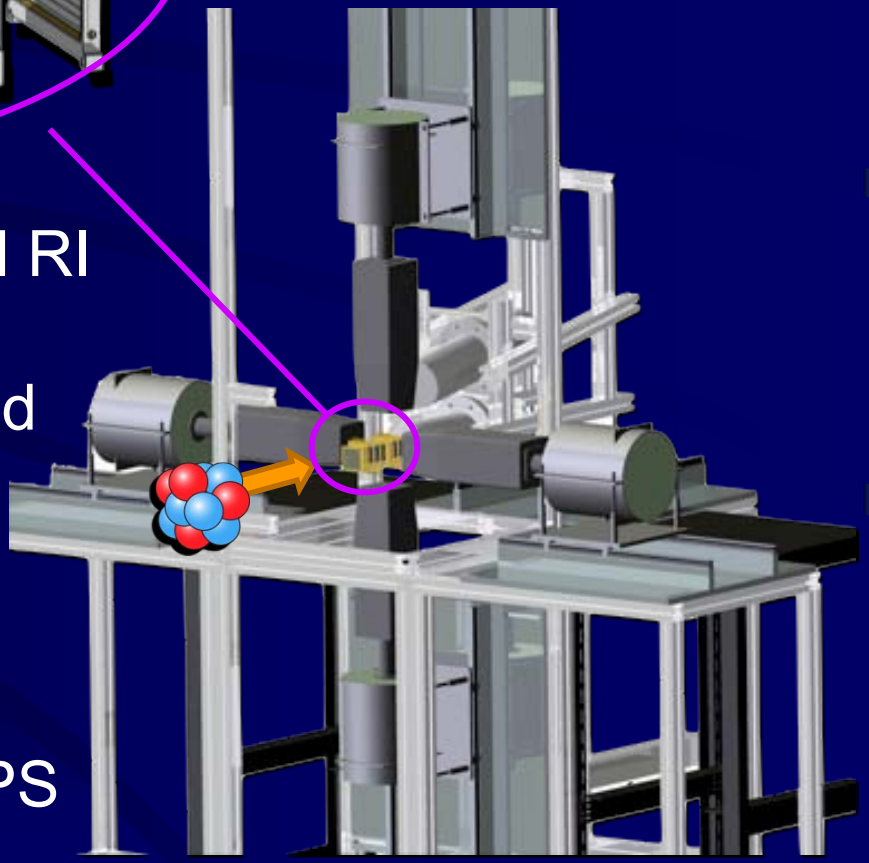




Experimental Setup



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

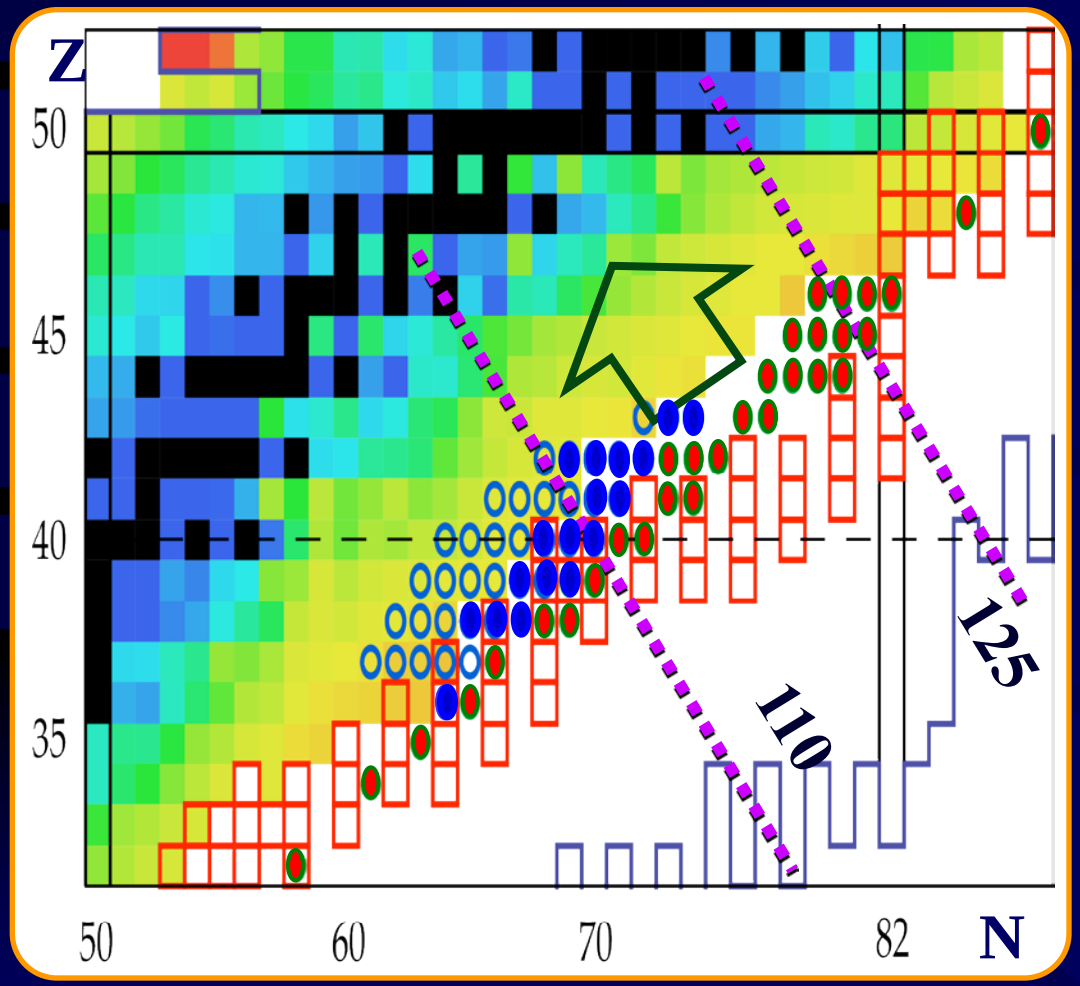


- The implantation of an identified RI is associated with the following β-decay events that are detected in the same DSSSD pixel

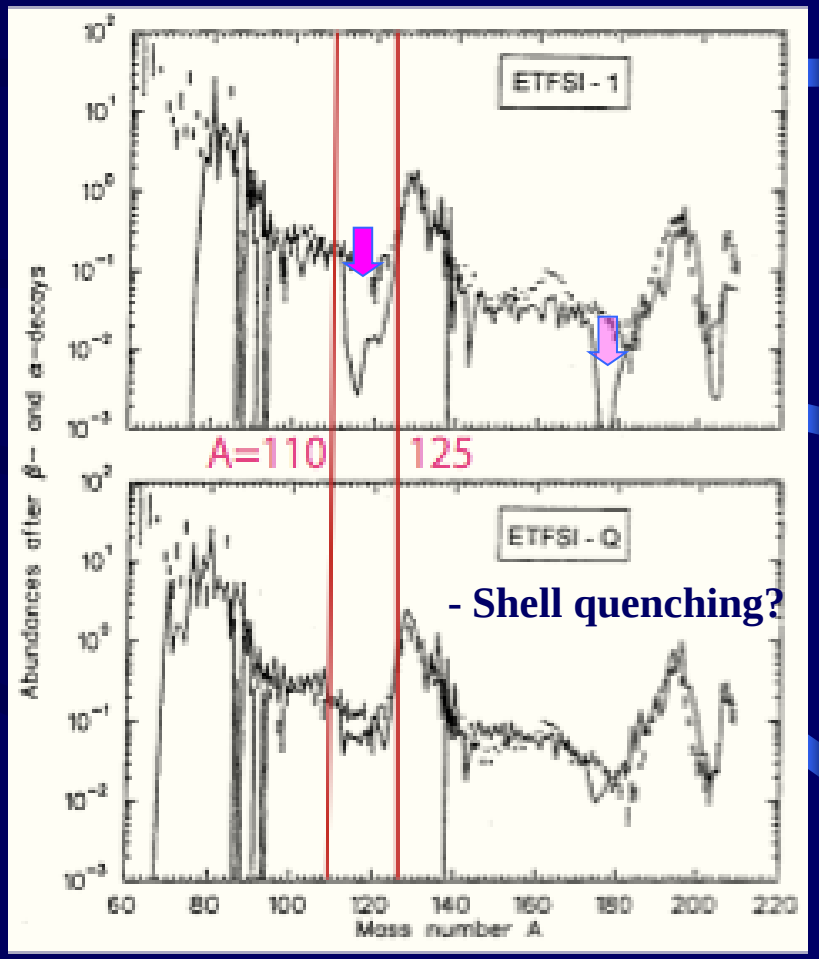
- ΔE-TOF-Bρ method using the focal plane detectors in BigRIPS

R-process Abundance around 2nd peak

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



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



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

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

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

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

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

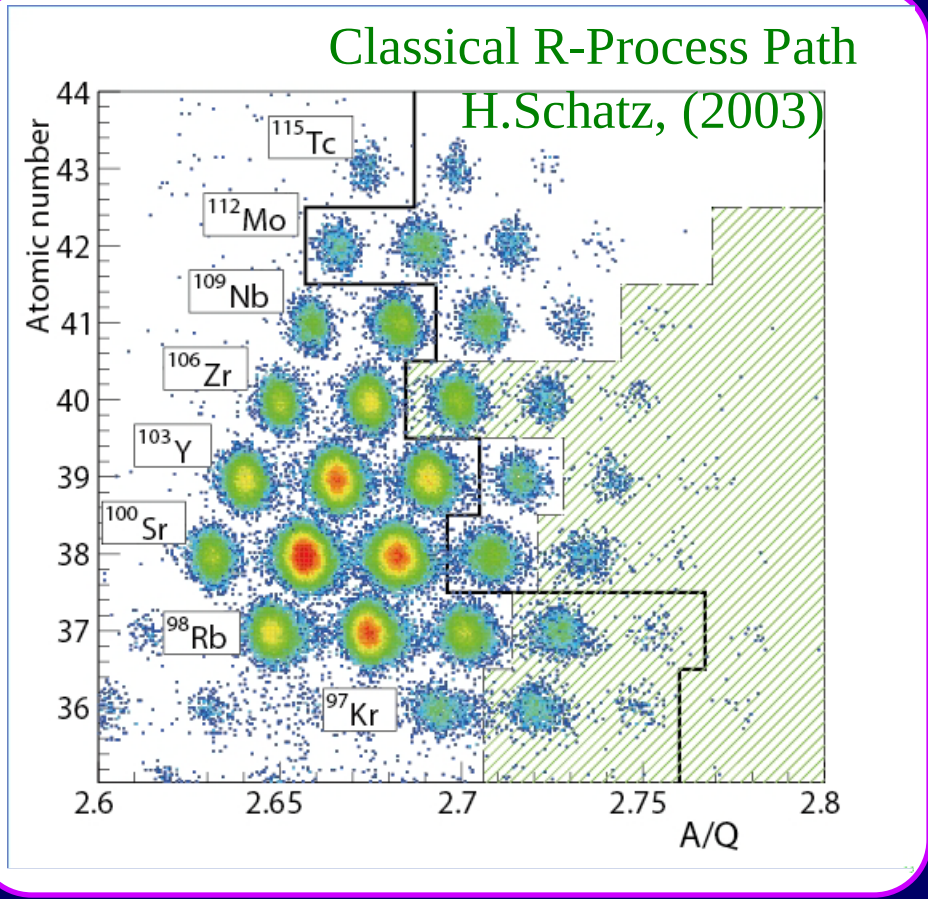
1999 : J.C.Wang
… ^{104}Y, ^{112,113,114}Tc

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

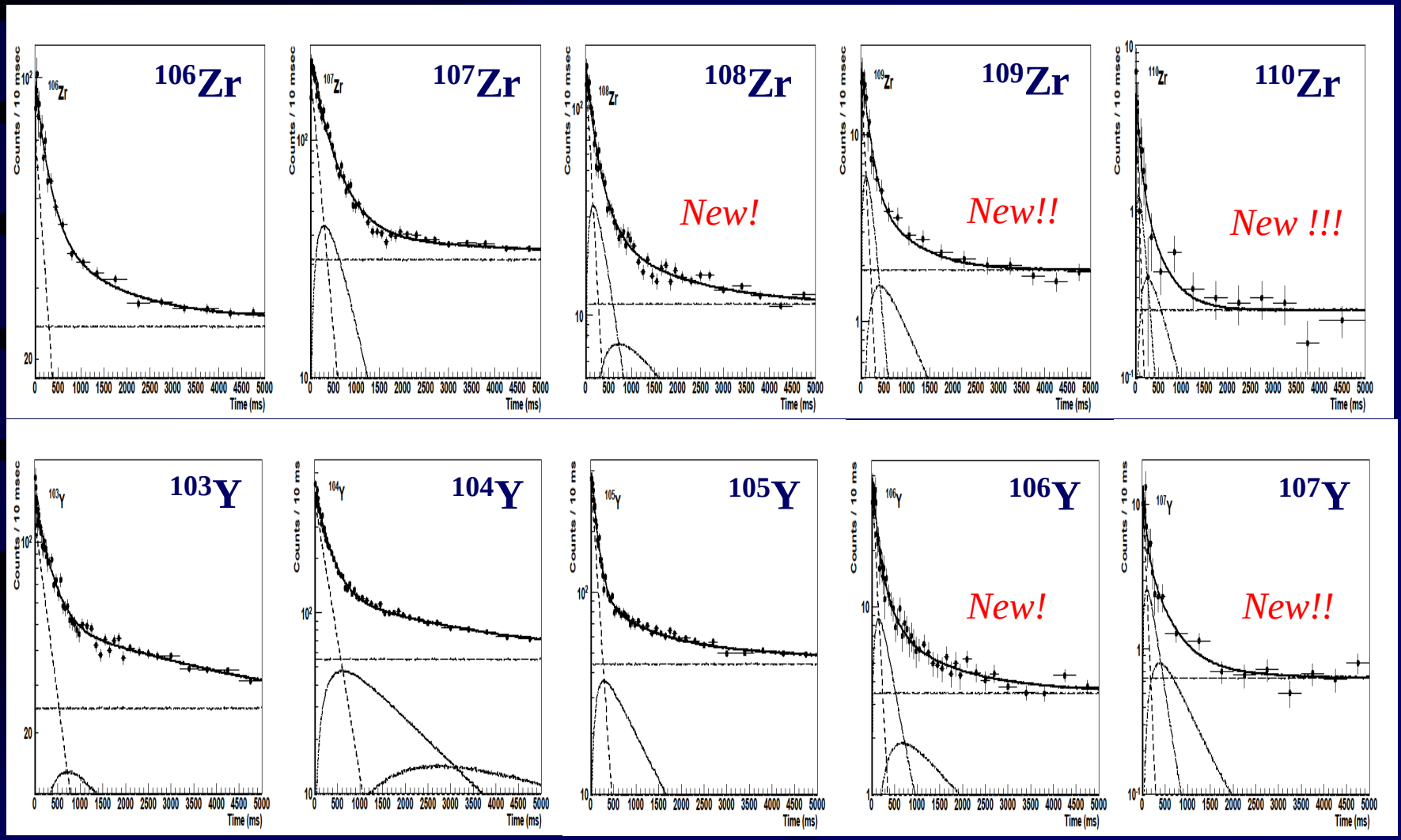
2006 : F.Montes
… ^{115}Tc

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

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

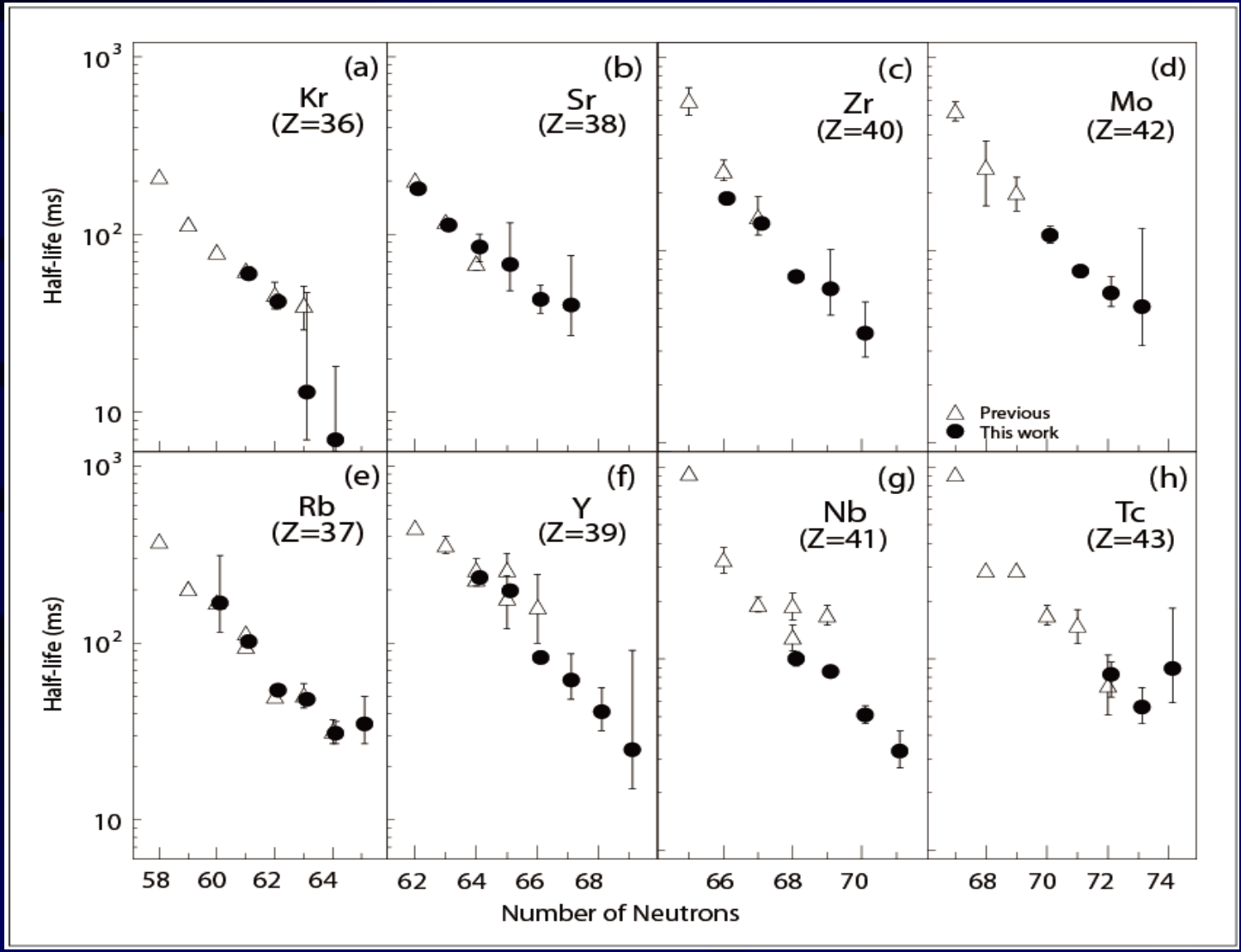


Y, Zr isotopes : Decay curves



And, more for Kr, Nb, Mo, and Tc isotopes !!

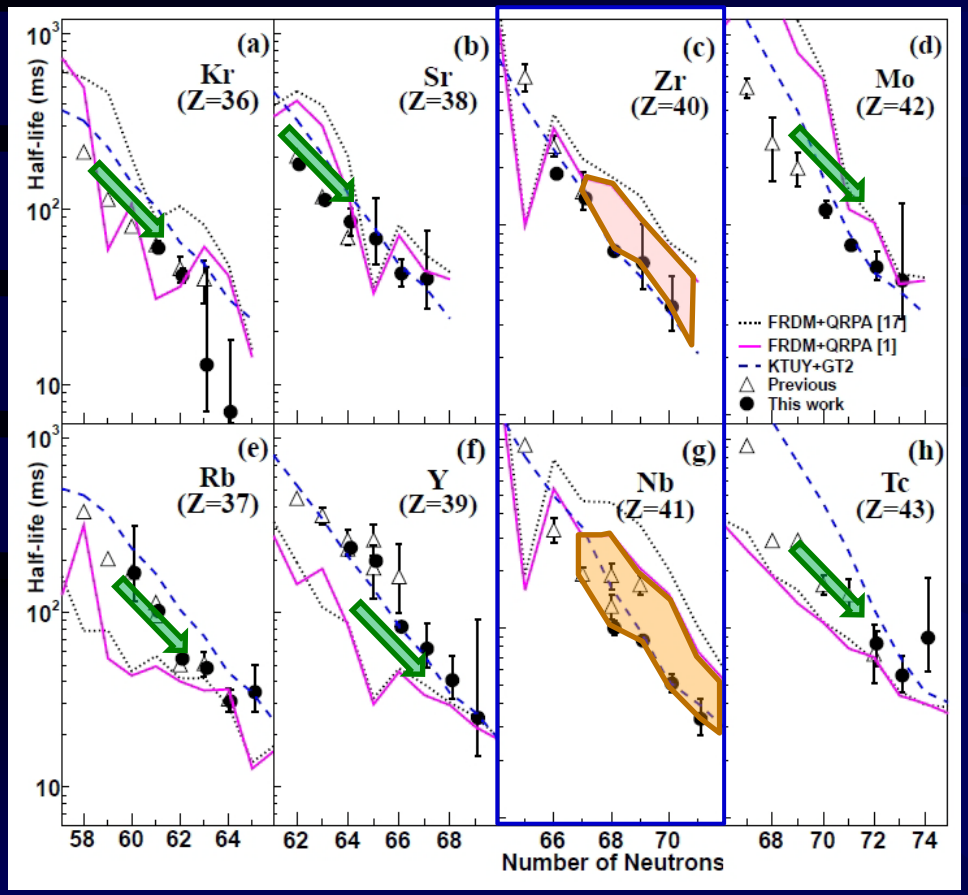
Neutron Number Dependence of $T_{1/2}$

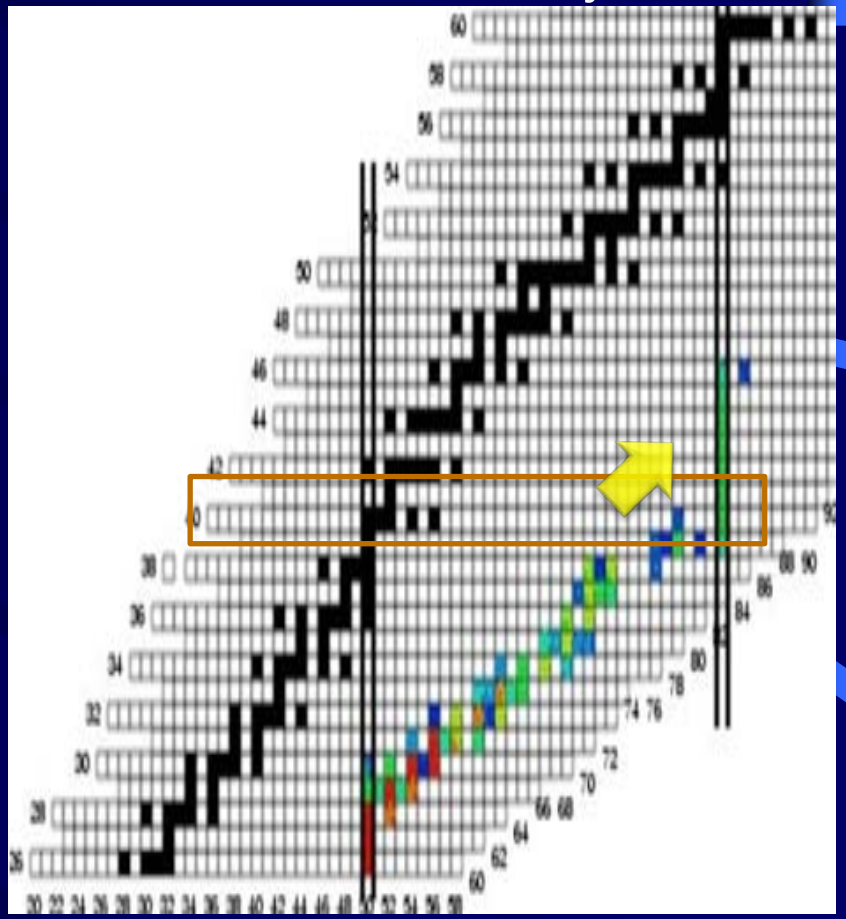


Significant improvement of $T_{1/2}$ information ! & 18 new half-lives !!

Very Neutron-Rich Zr and Nb

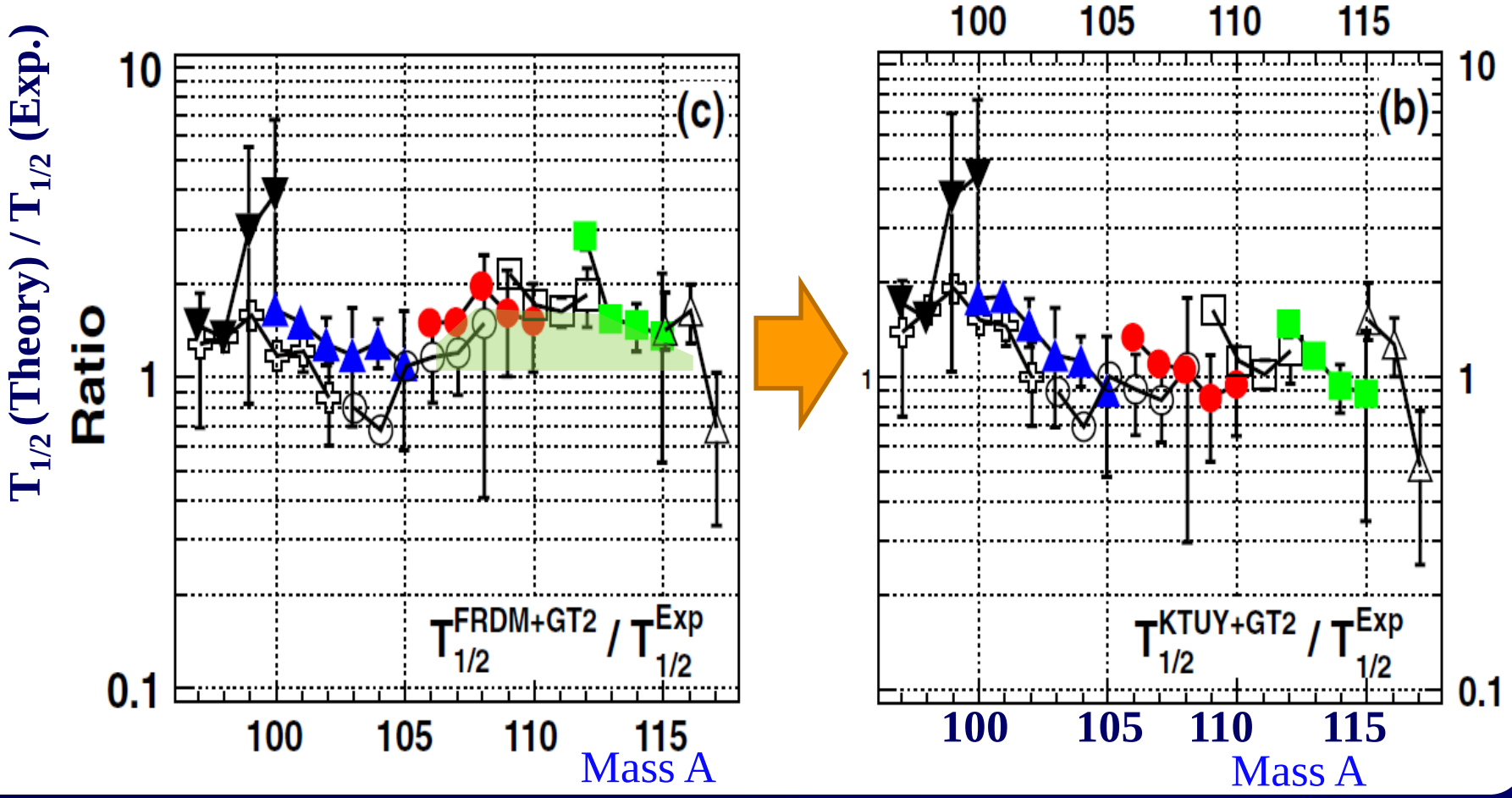
by JINA





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

(FRDM → KTUY) +GT2

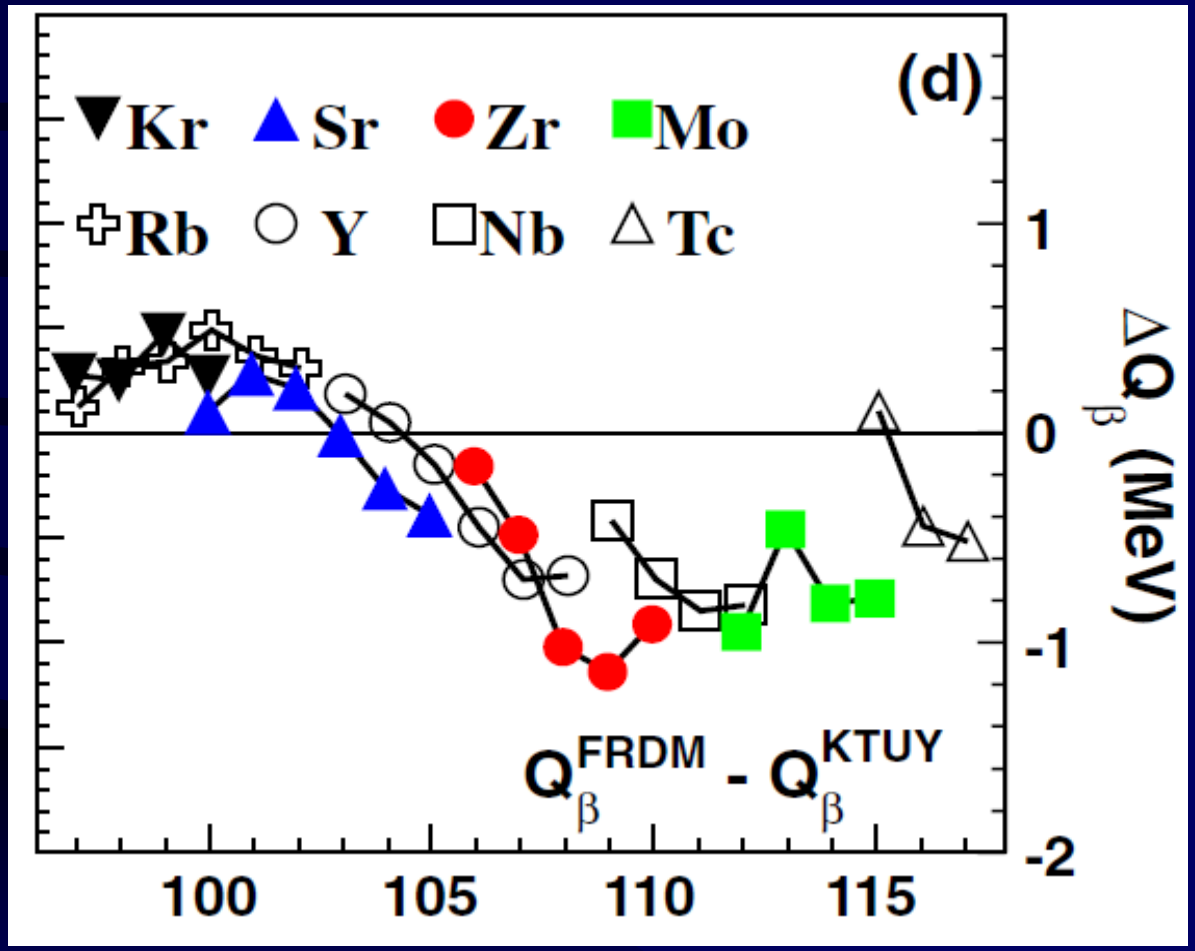


Overestimation of T1/2 by factor of ~ 2

Better agreement for KTUY !

→ WHY ?!

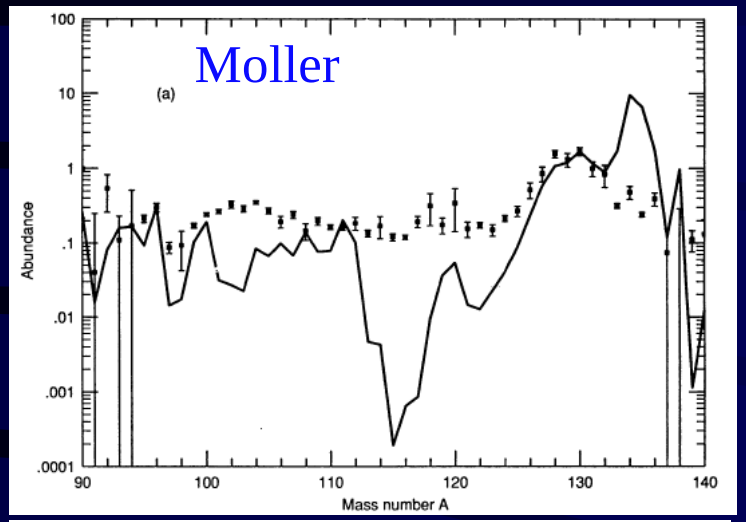
Better prediction with KTUY (H.Koura) ?

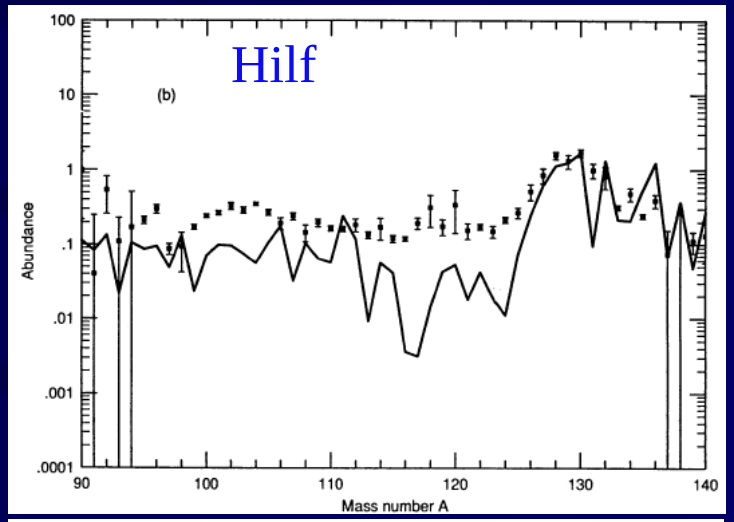


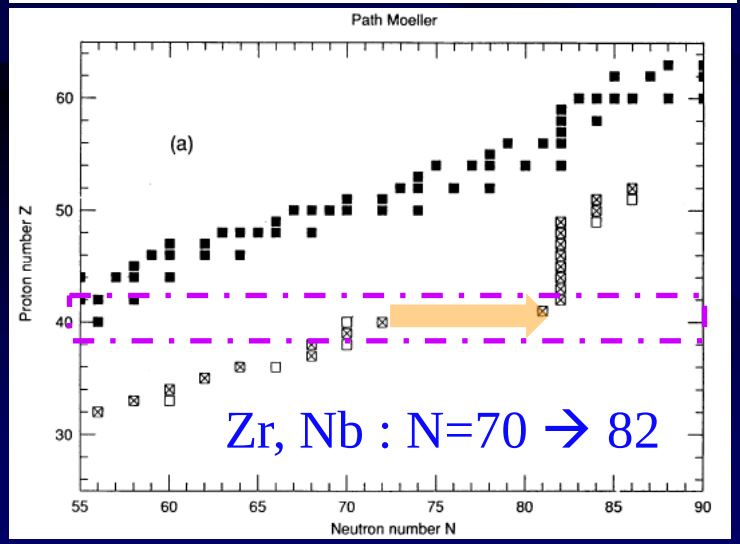
FRDM may underestimate the Q value : dQ ~ 1 MeV @ A ~ 110.

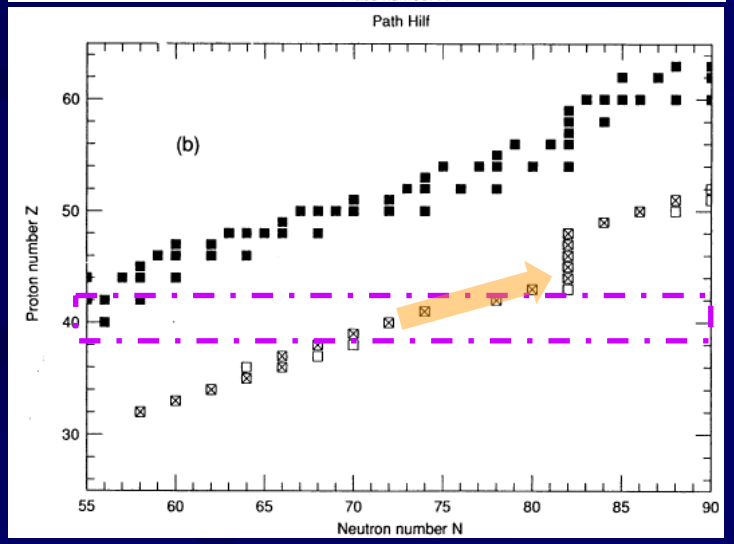
Mass Formula vs R-Process Path

K-L. Kratz APJ 403 (1993) 216



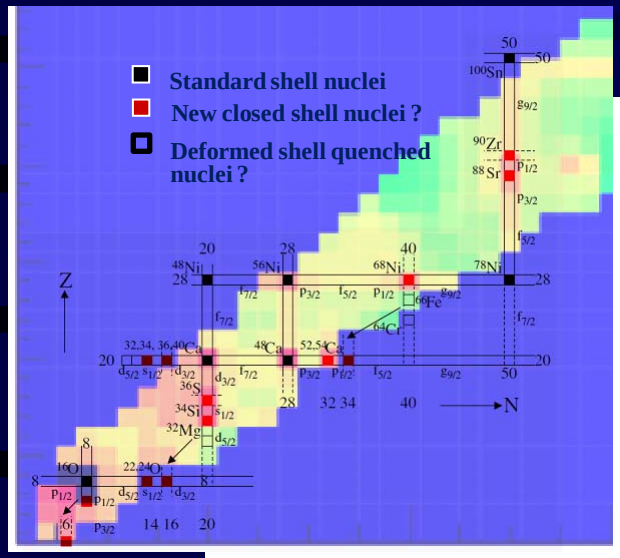






2nd Phase (2012 -)

Fast Beam Facilities



from NNDC

Approach to Heavier RI : Very important for r-process nucleosynthesis.

EURICA Project
for Stopped Beam Experiment

Idea of EURICA Project

~ 15 months ago,
this plan was just rumor.

- Euroball Cluster detectors
- Support structure
- Readout electronics

RIKEN RIBF
(Japan)

Time-line (2011 – 2013.06)

	Collaboration work	Construction work (GSI, RIKEN)
2011	04 .. Letter of Intent	04 ..
	05 .. Workshop @ RIKEN	05 ..
	06 .. Construction proposal	06 ..
	07 .. Proposal approval by O.C.	07 ..
	08 ..	08 ..
	09 .. Workshop @ GSI	09 .. Shipping (Support frame)
	10 .. Proposals submitted to RNC	10 .. Shipping (Cluster detectors, electronics)
	11 ..	11 .. Construction of Cluster detectors
2012	12 .. NP-PAC	12 .. Rail system & Cluster construction
	01 ..	01 .. Construction & Mounting Cluster detectors
	02 ..	02 .. Readout electronics
	03 .. Commissioning	03 .. Testing & Liq. N2 pipe line & buff. tank
	04 .. Commissioning	
	05 ..	
	06 .. Experiments (Xe-beam)	

~ 2013. June

EURICA Campaign (Xe, U, Kr)
(40 – 50 % of RIBF beam time)

Some Photos

Nov.02

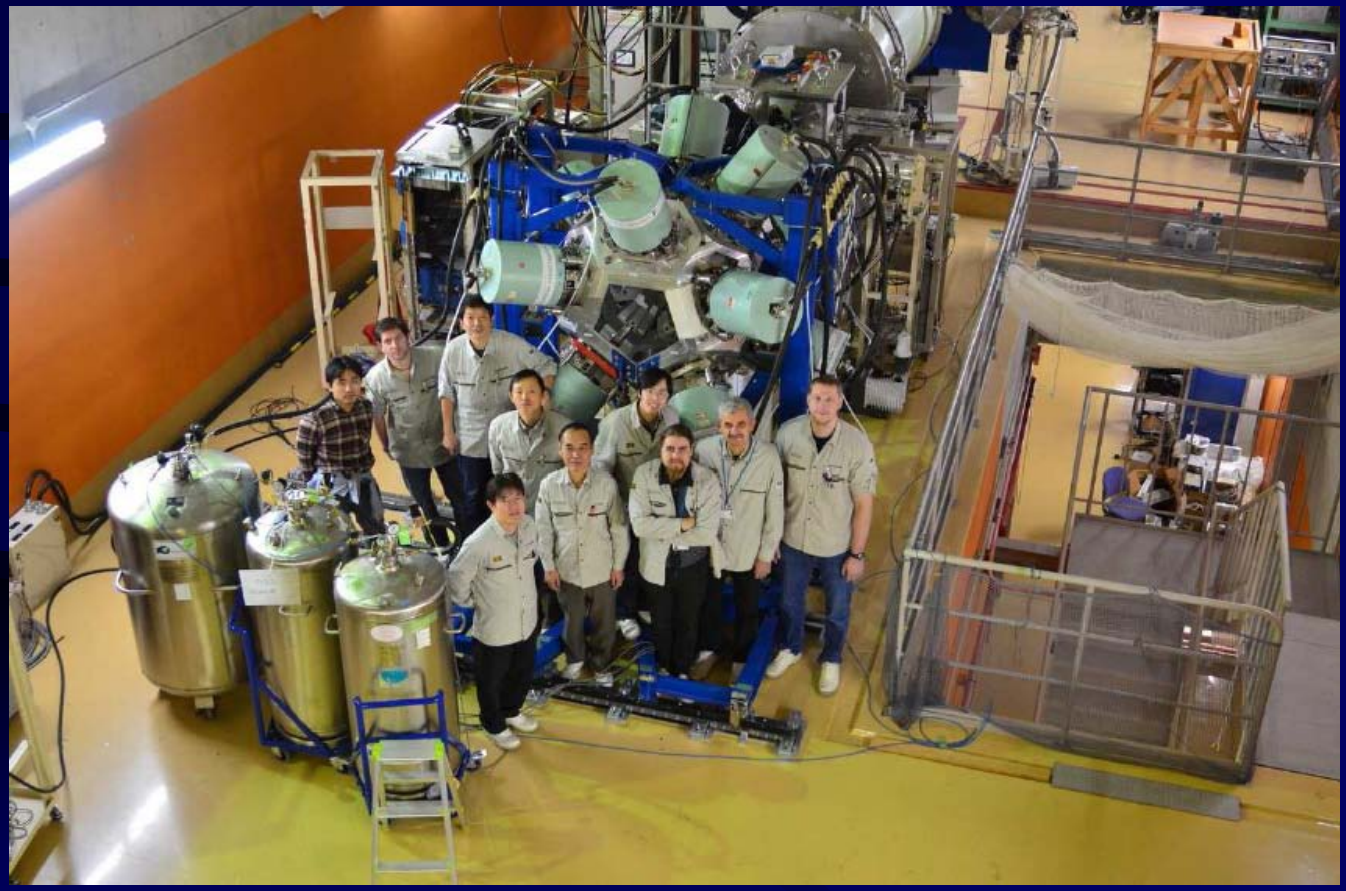
Jan.10

Jan.05

Feb.04

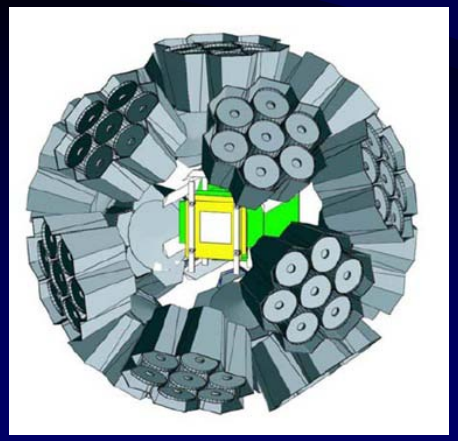
Installation : Completed

Jan. 15



RISING @ GSI ← → RIKEN

- In-beam γ-ray spectroscopy at relativistic energies about 100MeV/n
- g-factor measurements of isomeric stopped beams
- Isomer and β-delayed γ-ray spectroscopy of stopped beam



Gamma-detection
1~2 % → 15%

γ–γ : ~ 2 orders higher effi.

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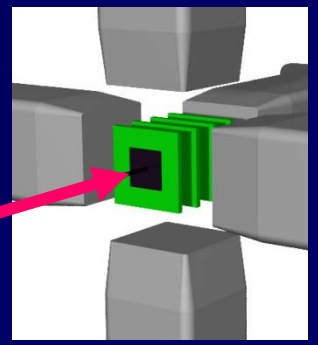
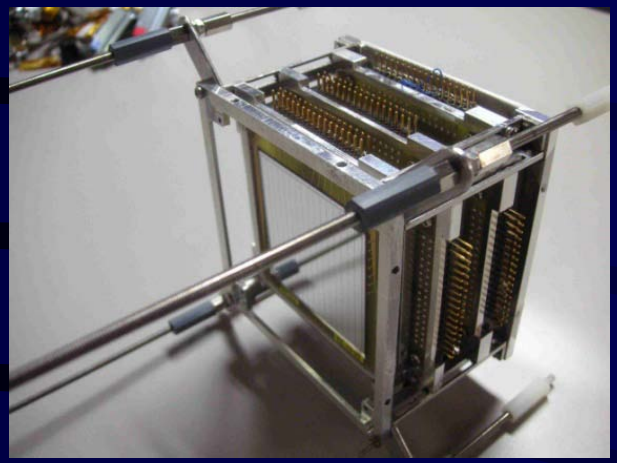


Beta Counting System

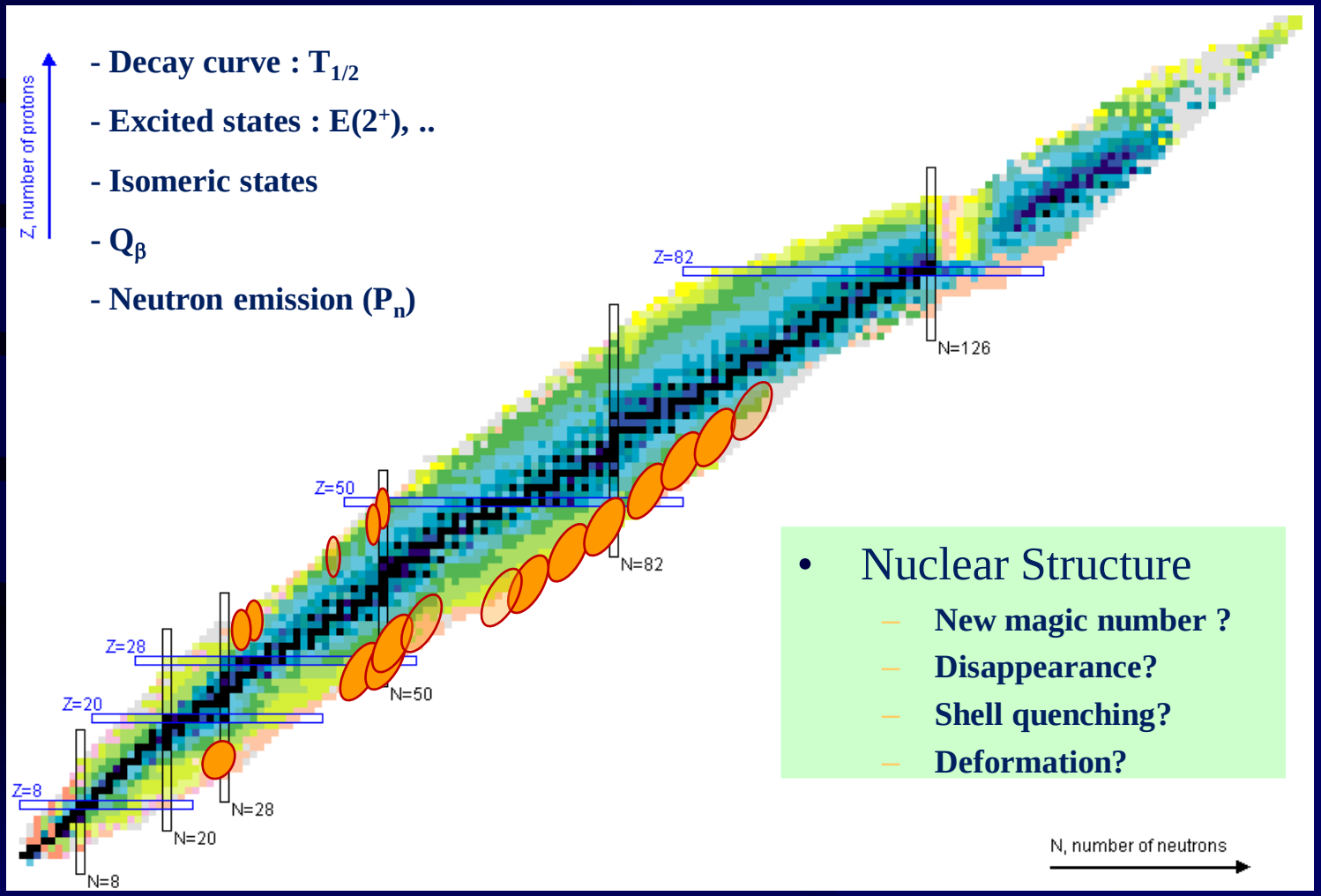


New version for EURICA

Size : 50x50mm
Strip : 16 x 16 strips
Thickness : 1mm^{t}

Size : 40x60mm
Strip : 40 x 60 strips
Thickness : 1mm^{t}
(supporting board from TUM)

Decay Spectroscopy



Decay campaigns : Scanning most of neutron-rich nuclei below A<170

Decay Spectroscopy : 2nd Phase

x 1000 higher production yield in the world ? (~ 110Zr)

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

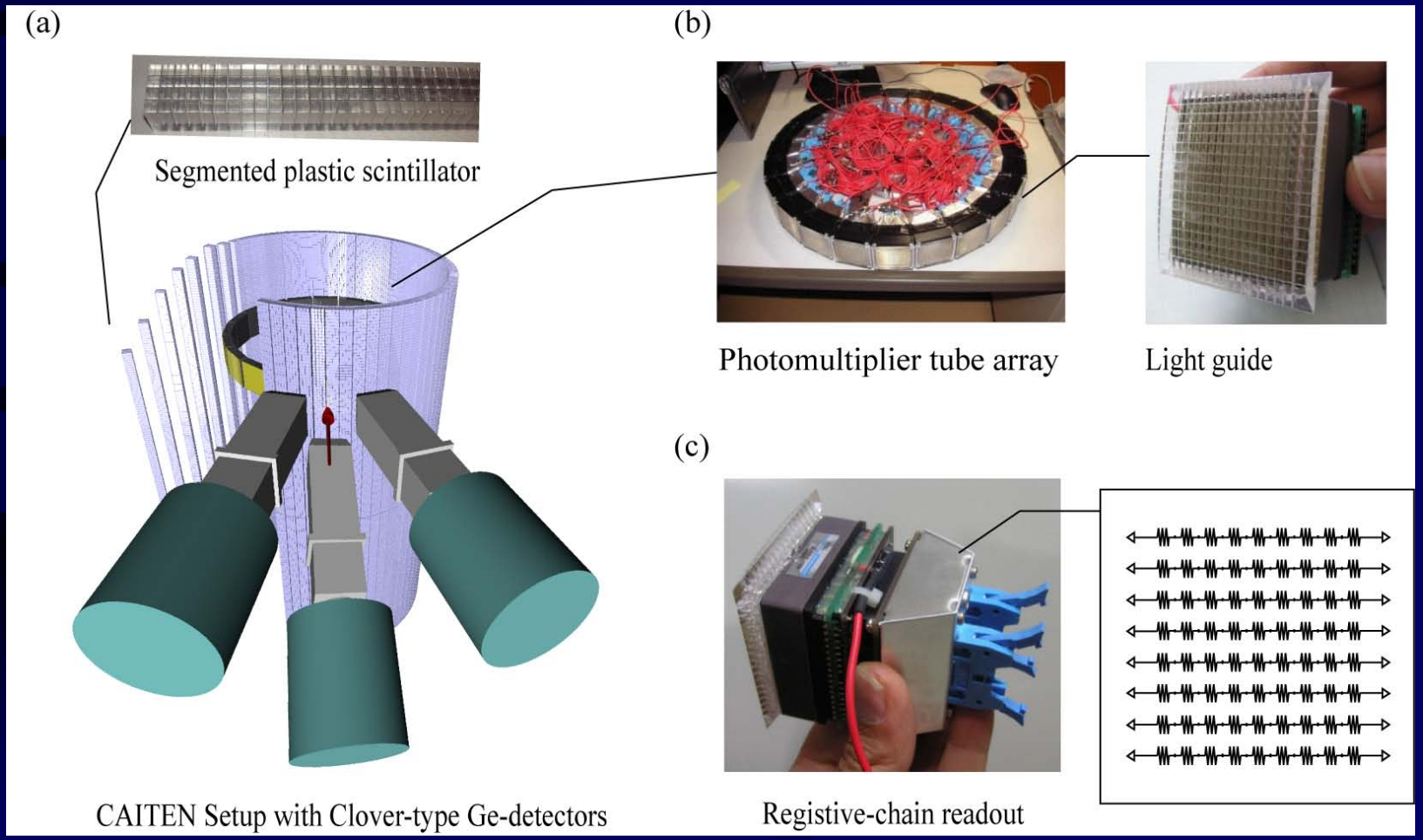
- 16 x 16 pixels x 7 layers = 1792 pixels
  → 40x60 pixels x 8 layers = 19200 pixels … x 4-10 times
- Accept relatively higher implantation rate for $T_{1/2}$ measurement
  → x 2 – 5 times

Gamma-ray detector

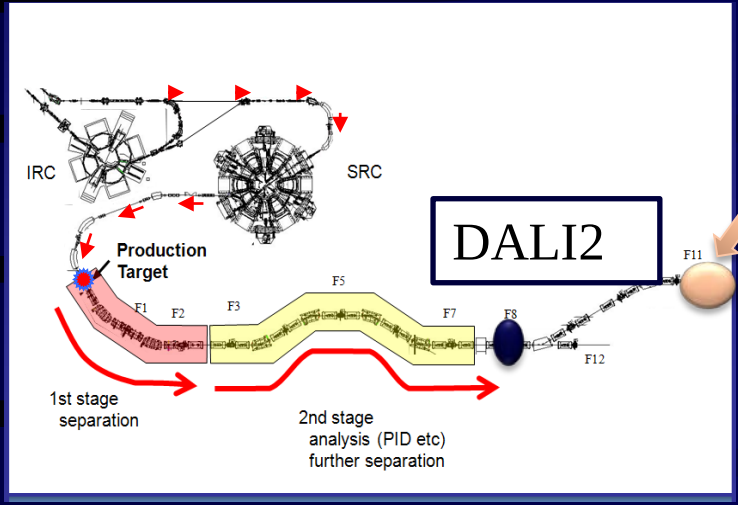
- 4 Clover detectors (Det. Effi. ~1.5% at 1 MeV)
  → 12 Cluster detectors (Det. Eff. ~ 15 % at 1MeV) … x 10 times
  (→ gamma-gamma coincidence … x 100 times)

3rd Phase

CAITEN

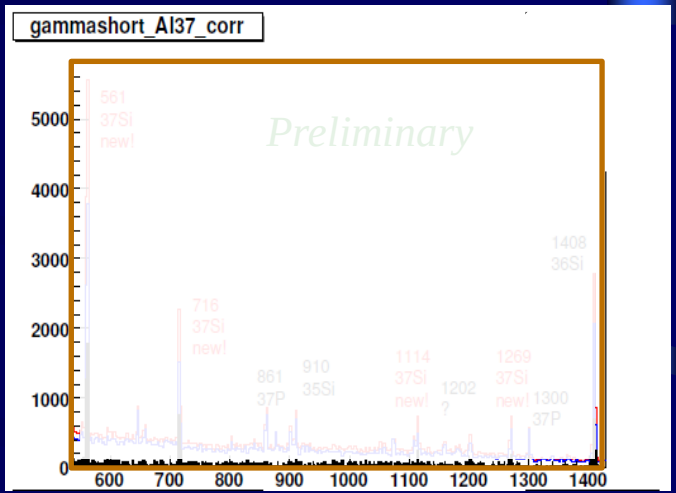

(a)
Segmented plastic scintillator
CAITEN Setup with Clover-type Ge-detectors
(b)
Photomultiplier tube array
Light guide
(c)
Registive-chain readout

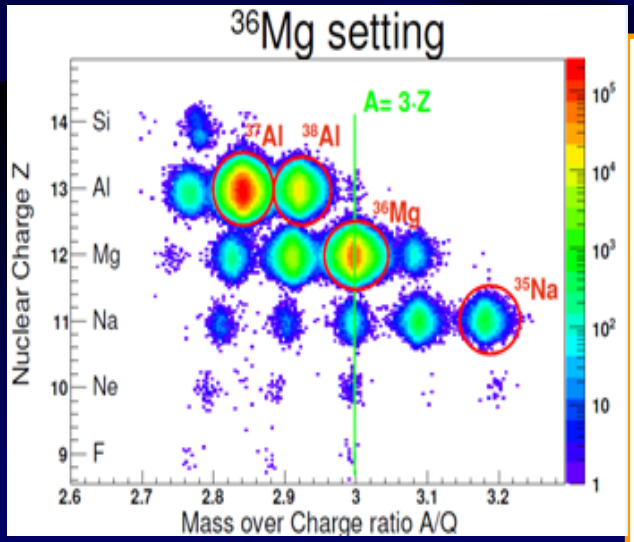
CAITEN : Decay Spectroscopy



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

Beta-delayed gamma of ^{37}Al





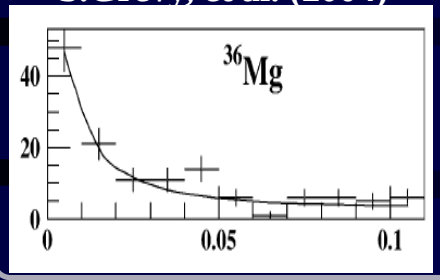
Implantation detector

K.Steiger Z.Li

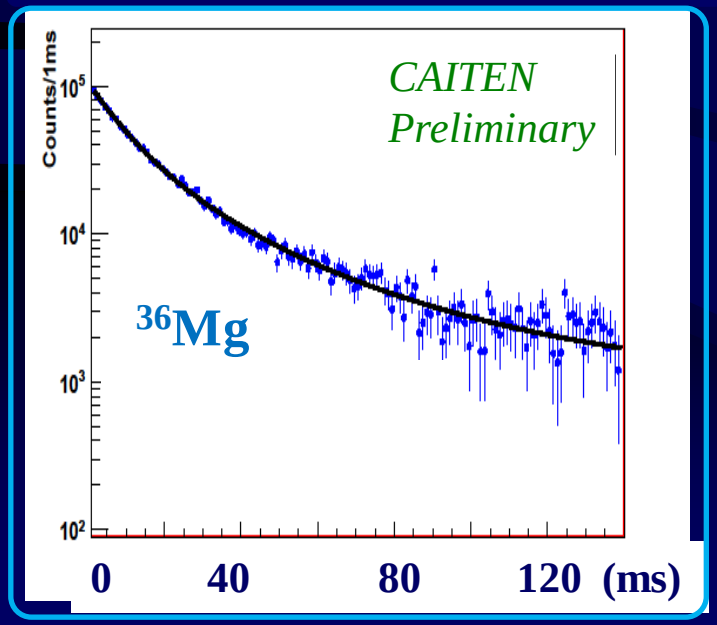
Possible level scheme

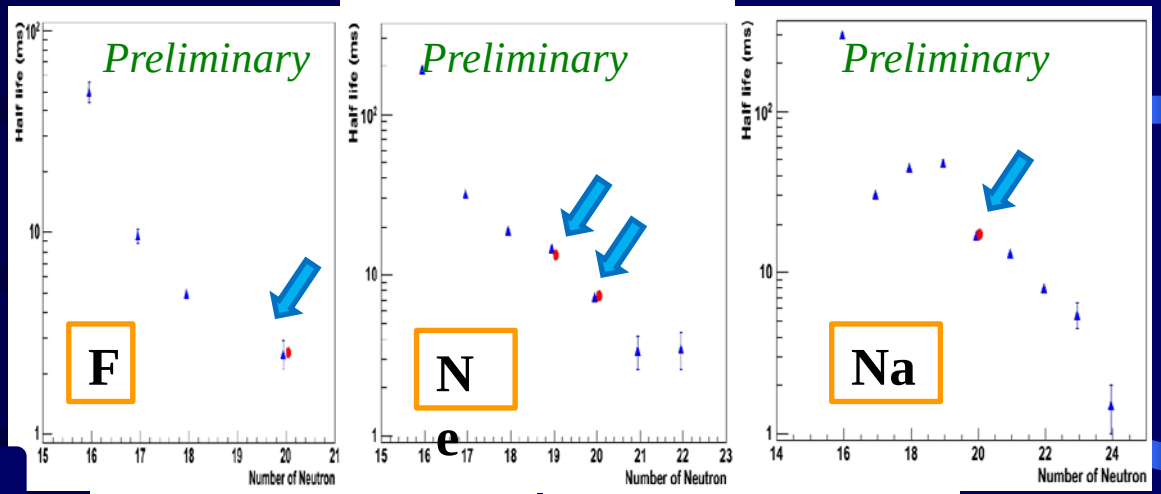
CAITEN : $T_{1/2}$ measurement

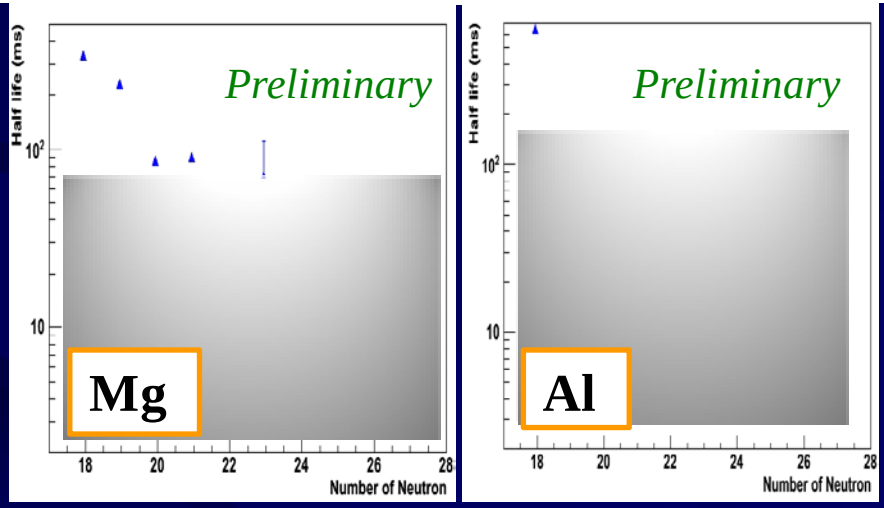
S.Grevy, et al. (2004)



High statistic



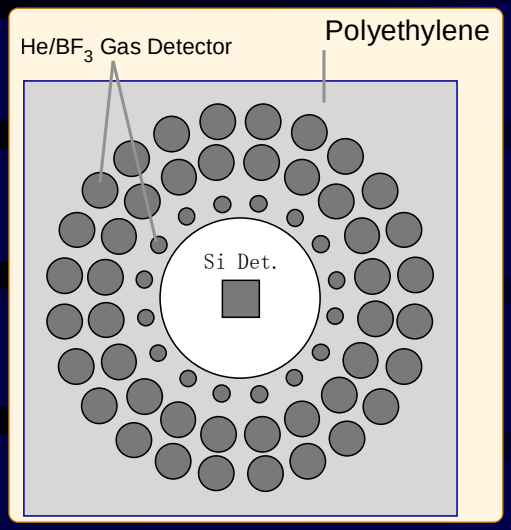




High precision $T_{1/2}$ measurement
(implantation rate ~ 1 kcps)

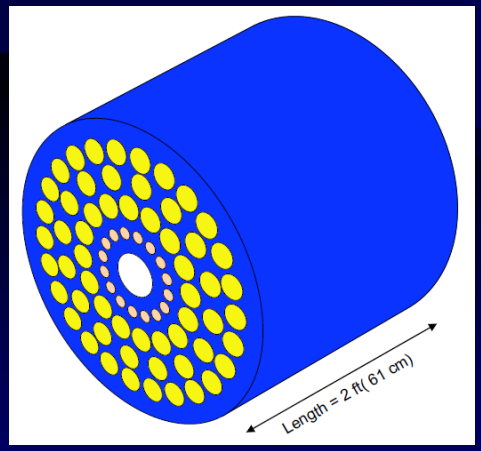
Neutron emission Pn

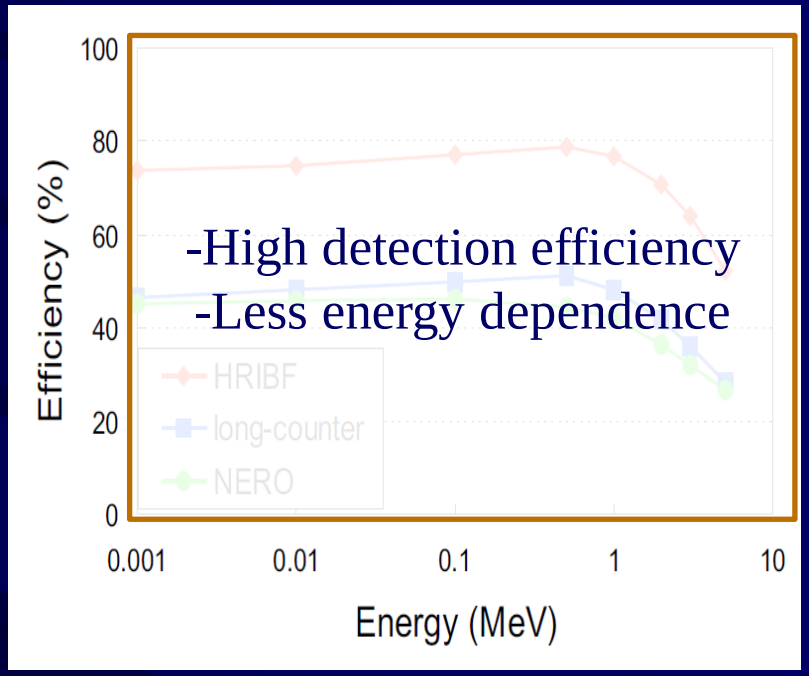
MSU



- n + ^{3}He → p(0.574MeV) + t (0.191MeV)
  σ=5333b
- n + ^{10}B → α(1.78MeV) + 7Li(1.02MeV)
  σ=3837b

HRIBF



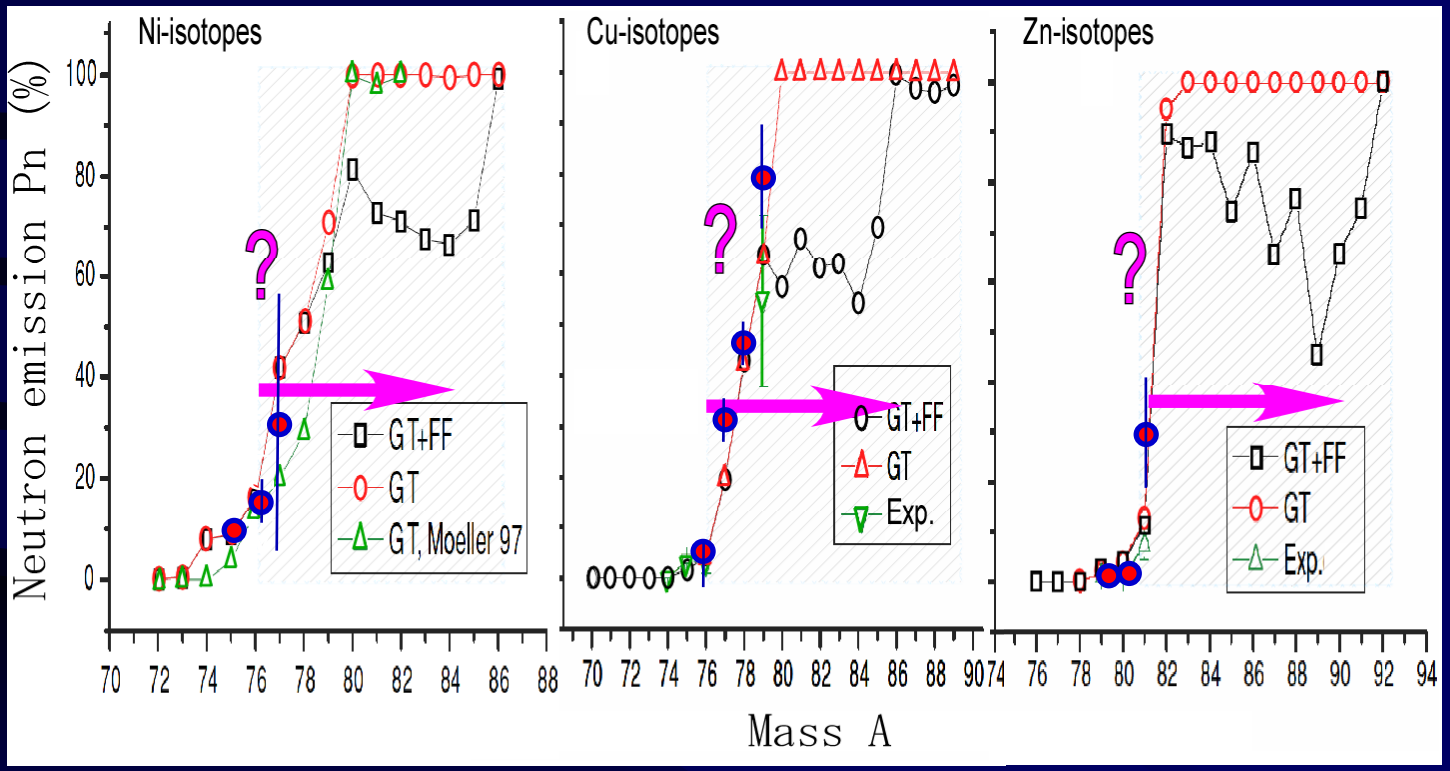


- Construction of neutron detectors
- Formation of new collaboration

Neutron Emission

I.N.Borzov Phys. Rev. C71 (2005) 065801

+ P.Hosmer, PRC82 (2010)

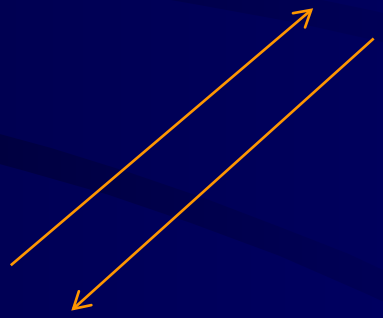


Neutron emission prob. (Pn) goes up dramatically ?

3He long counters will be feasible for this kind of measurement.

Evaluation of New RIBF Data → Impact to R-Process

Theory



Experiment

Mass Measurements

Hakala, et al., EPJA (2011) 47, 129

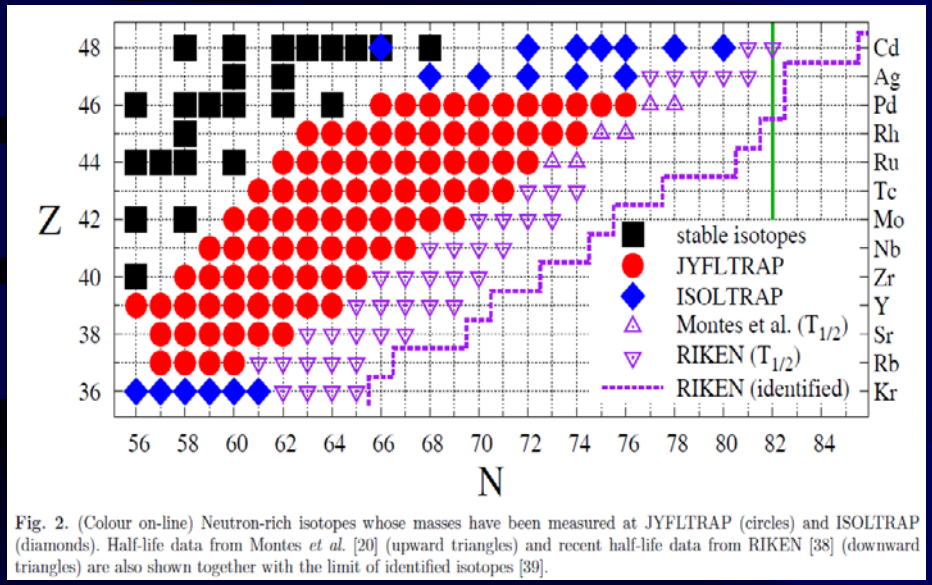


Fig. 2. (Colour on-line) Neutron-rich isotopes whose masses have been measured at JYFLTRAP (circles) and ISOLTRAP (diamonds). Half-life data from Montes *et al.* [20] (upward triangles) and recent half-life data from RIKEN [38] (downward triangles) are also shown together with the limit of identified isotopes [39].

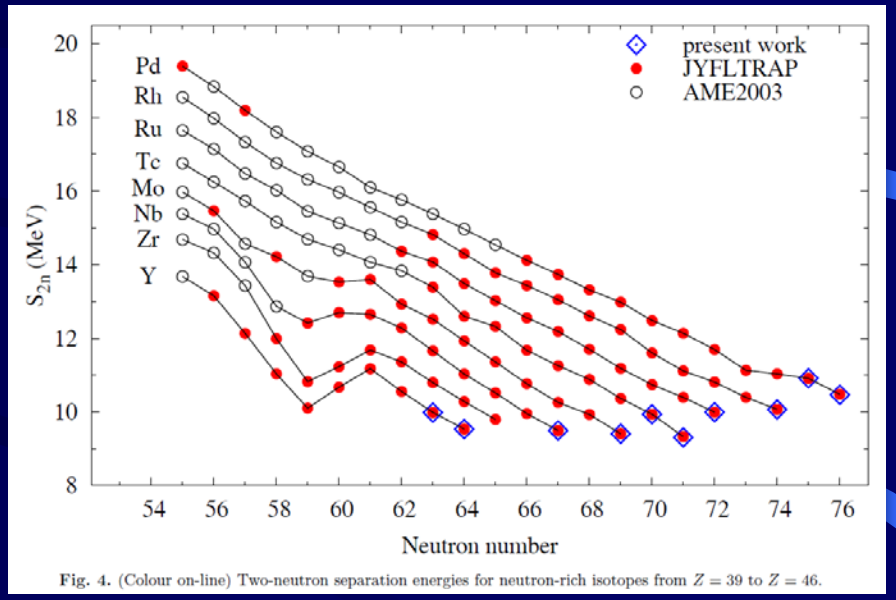
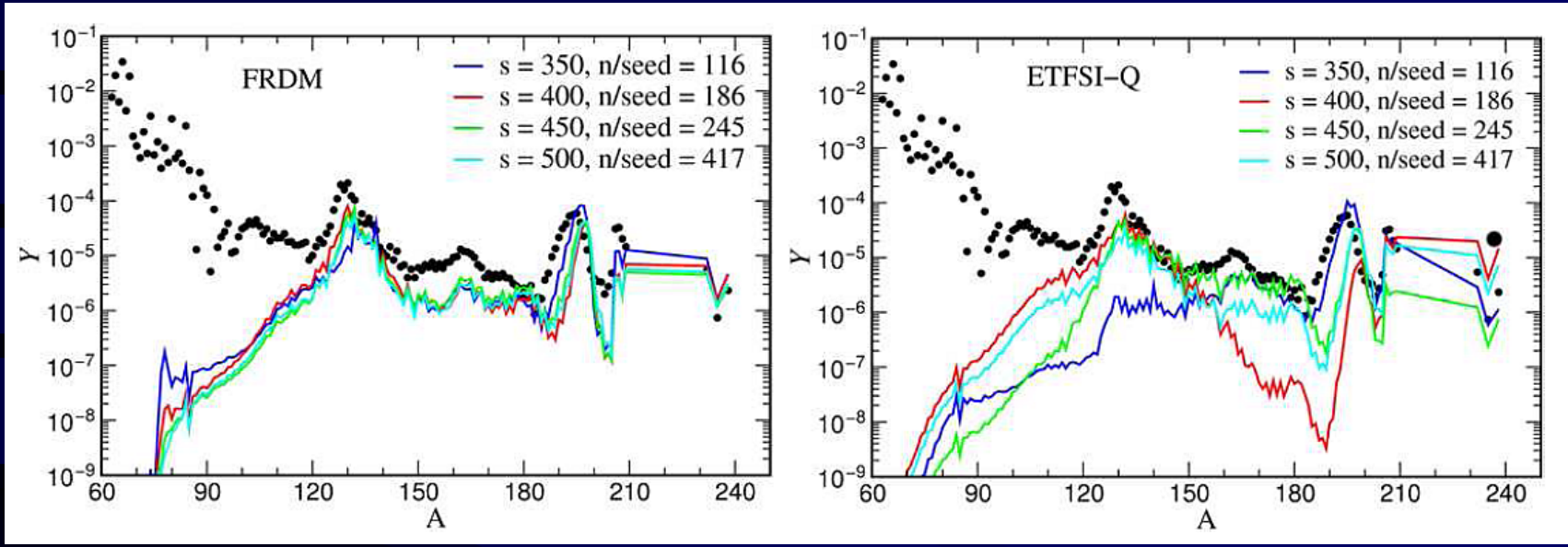


Fig. 4. (Colour on-line) Two-neutron separation energies for neutron-rich isotopes from $Z = 39$ to $Z = 46$.

First systematic check by decay spectroscopy

→ Direct mass measurement by SlowRI / Mass Ring

Mass formula dependence



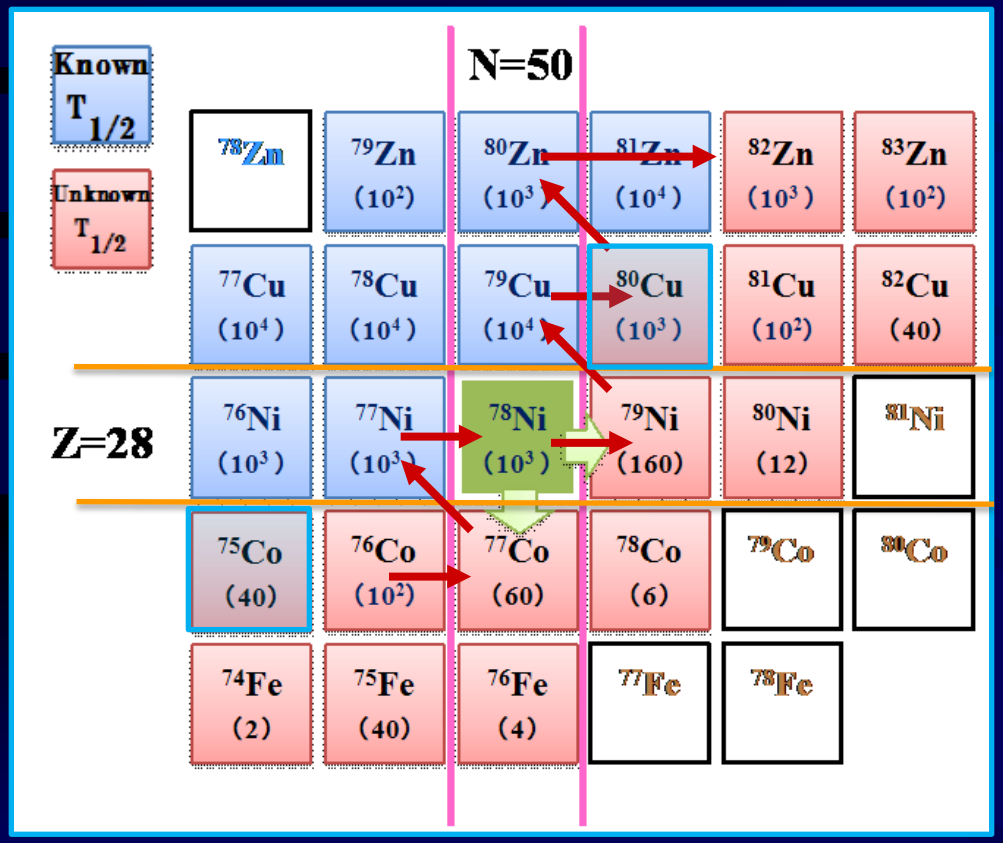
K.Langanke, Conf. Ser. 230 (2010) 012028

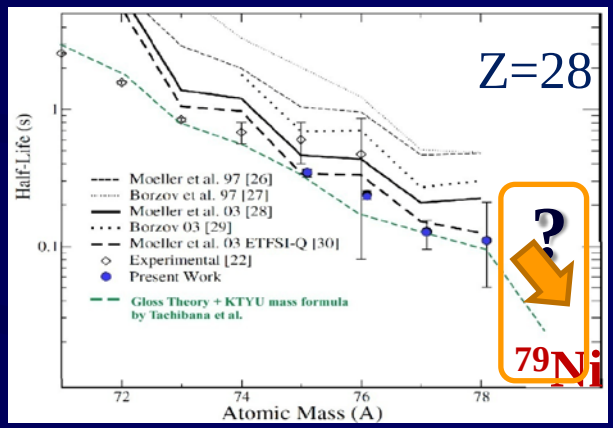
Mass measurement ← → Mass formula

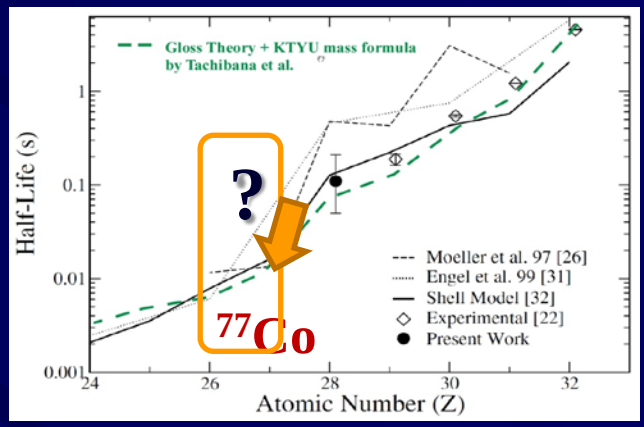
Evaluation is very important

Z=28, N=50 : 78Ni region

Magicity at Z=28 and N=50 ?



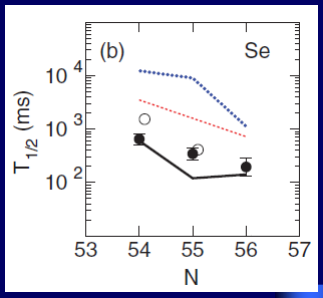




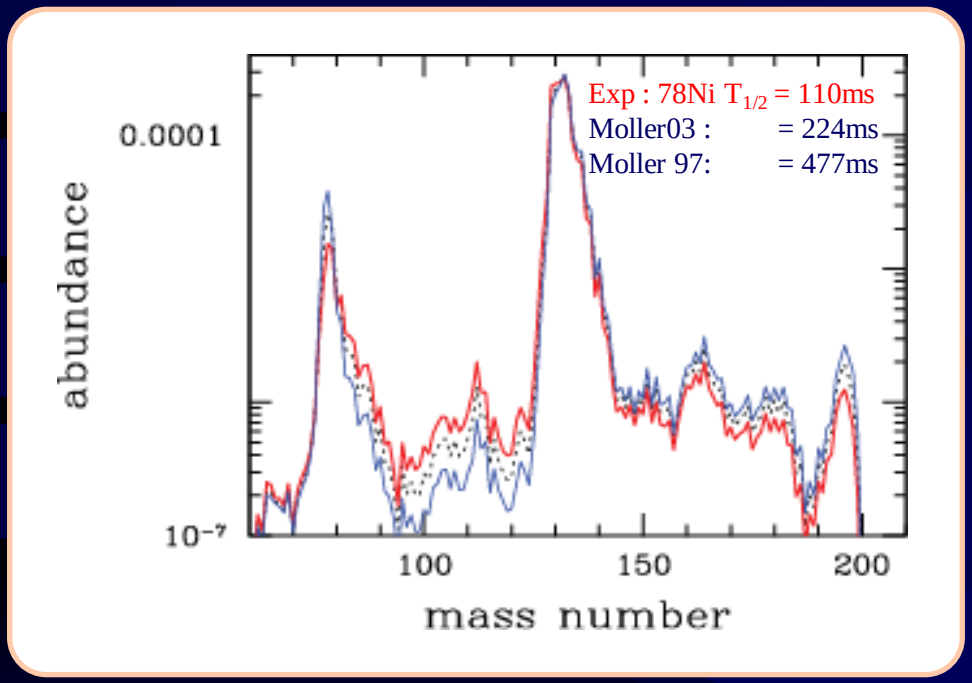
P.T.Hosmer et al., PRL 94, 112501(2005) mod.

If there is isomer in 78Ni, it is very interesting.

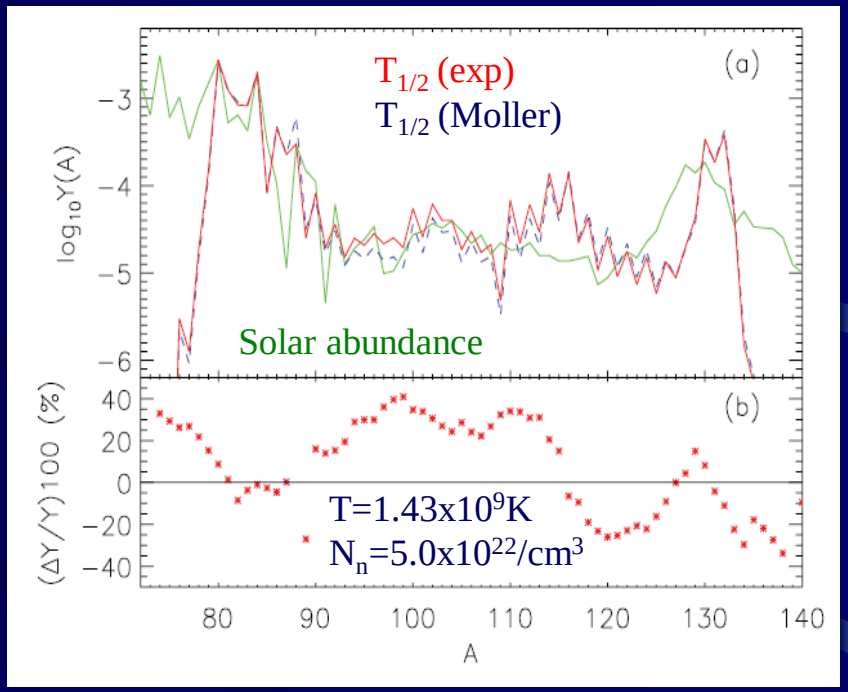
Half-lives around ^{78}Ni



P.Hosmer, PRC82 (2010)



N.Quinn, PRC85 (2012) 035807

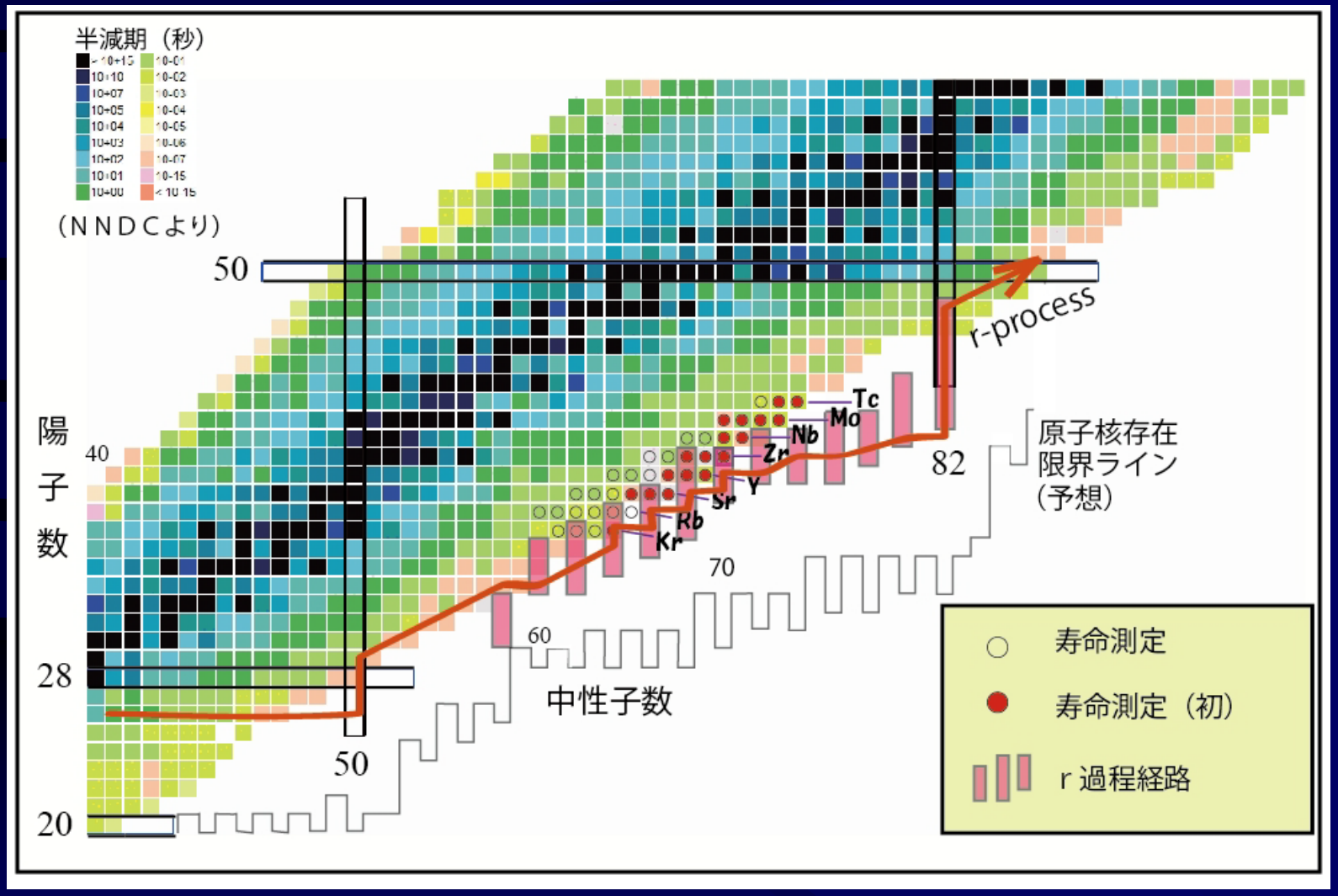


Half-lives of isotopes around the 78Ni are important !?

$^{74\text{-}75}$Fe, $^{76\text{-}78}$Co, $^{78\text{-}80}$Ni, $^{80\text{-}81}$Cu

^{90}Se half-life
(Z=34, N=56)

N = 50 ～ 82



RIBF New Data → Network r-process calculation

Summary

RIBF: Stepping into r-process area

- Decay Spectroscopy :
  - EURICA Campaign (2012.Mar. – 2013.June)
  - Commissioning (2012. Mar. & April.) : Ready !
  - First EURICA Experiment in June (Below 100Sn)
  - U-, Xe, Kr Campaigns in 2012 Fall & 2013 Spring
  - ^{238}U beam intensity (x10) from 0.1 ~ 0.3 pnA → 3 - 5 pnA
  - Last decay exp. (2009) γ–γ coincidence : 1 month → 40 mins.

- In future :
  - Decay spectroscopy in heavy region → N=126 region
  - Fast timing (CAITEN), Neutron measurement (Pn), ..
  - EOS, Low energy nuclear reactions, mass measurement …

- Theoretical calculation with “New” RIBF Data
  - Opening a door to reveal the mystery of “R-Process” nucleosynthesis

More communications ..

→ - Nuclear Structure
- Nuclear Astrophysics