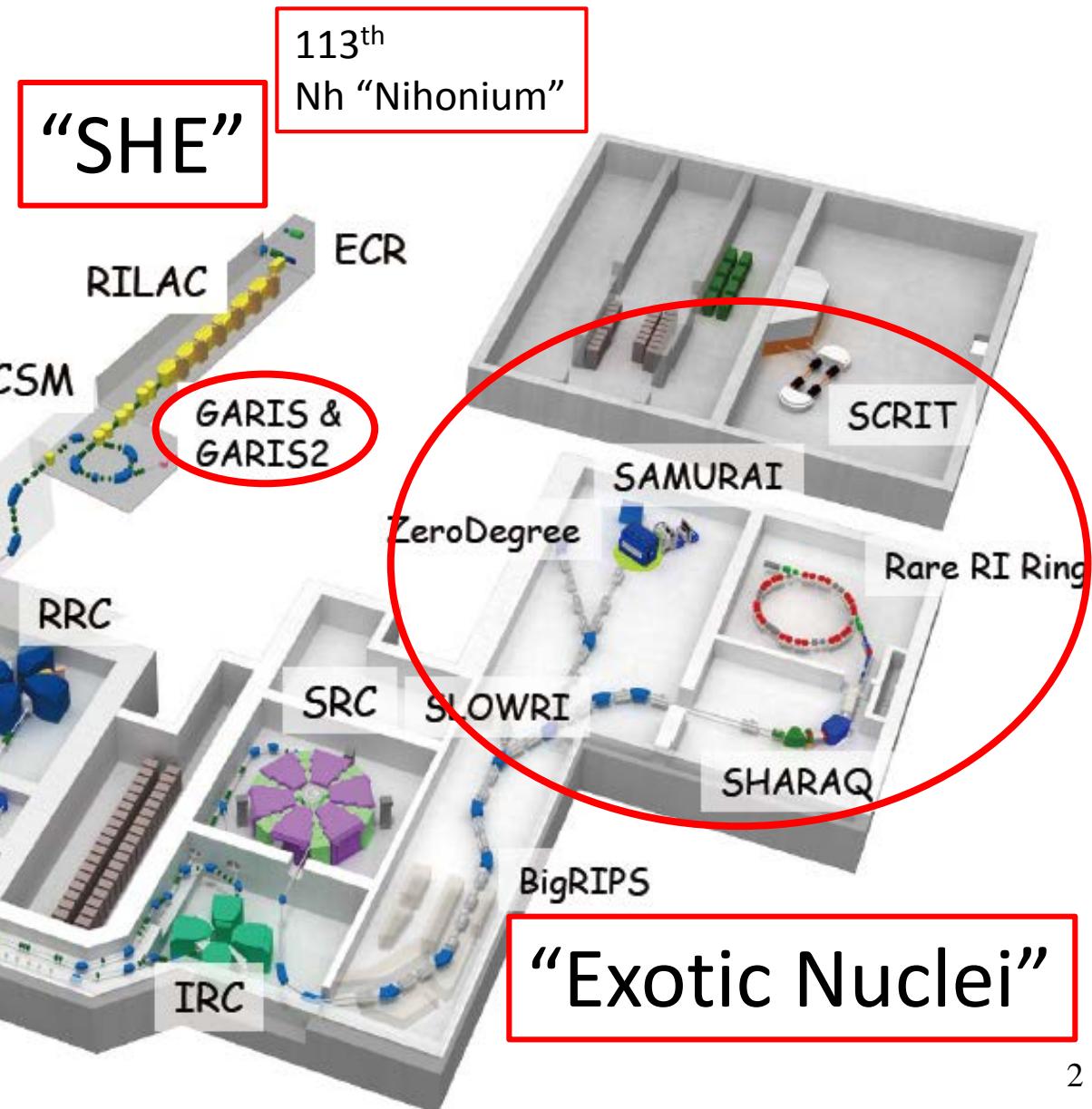


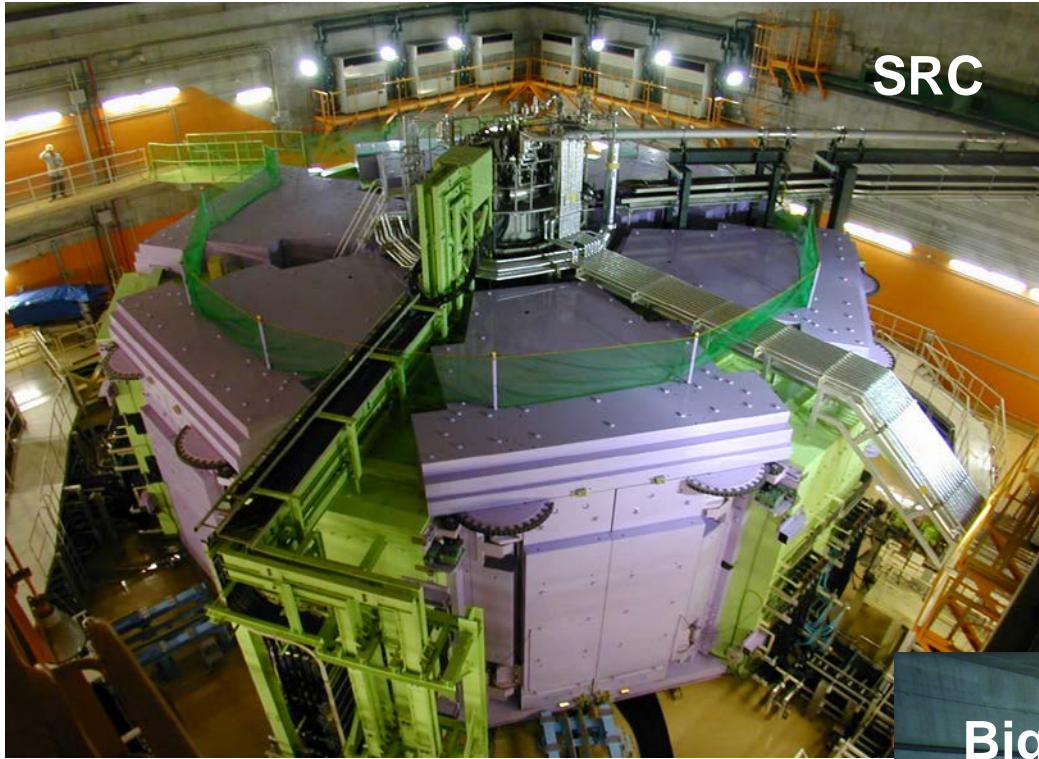
Recent highlights and future projects at RIBF

Hiroyoshi Sakurai
RIKEN Nishina Center / Univ. of Tokyo

RI Beam Factory

5 cyclotrons + 2 linacs
3 inflight separators
Experimental devices
coupled with BigRIPS
have been completed in FY13





**World's First and Strongest
K2600MeV
Superconducting Ring Cyclotron**

400 MeV/u Light-ion beam
345 MeV/u Uranium beam

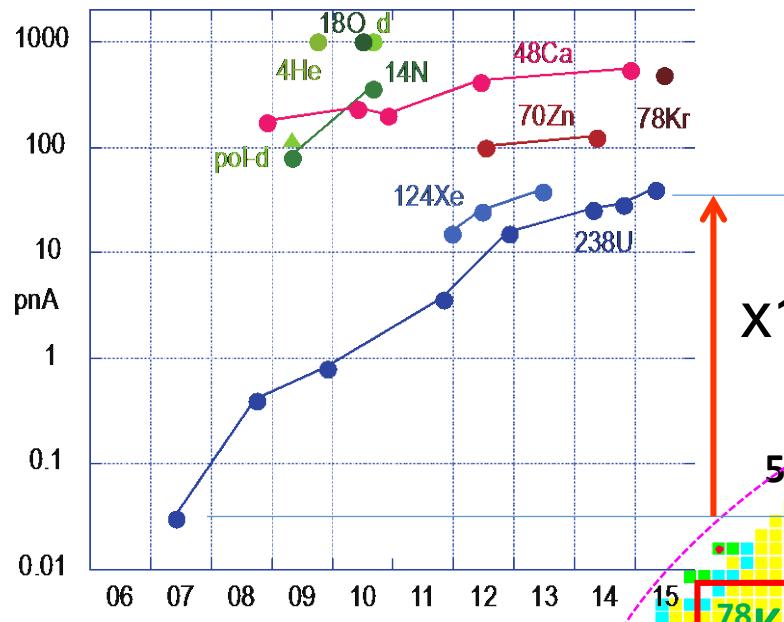
**World's Largest Acceptance
9 Tm
Superconducting RI beam Separator**

~250-300 MeV/nucleon RIB



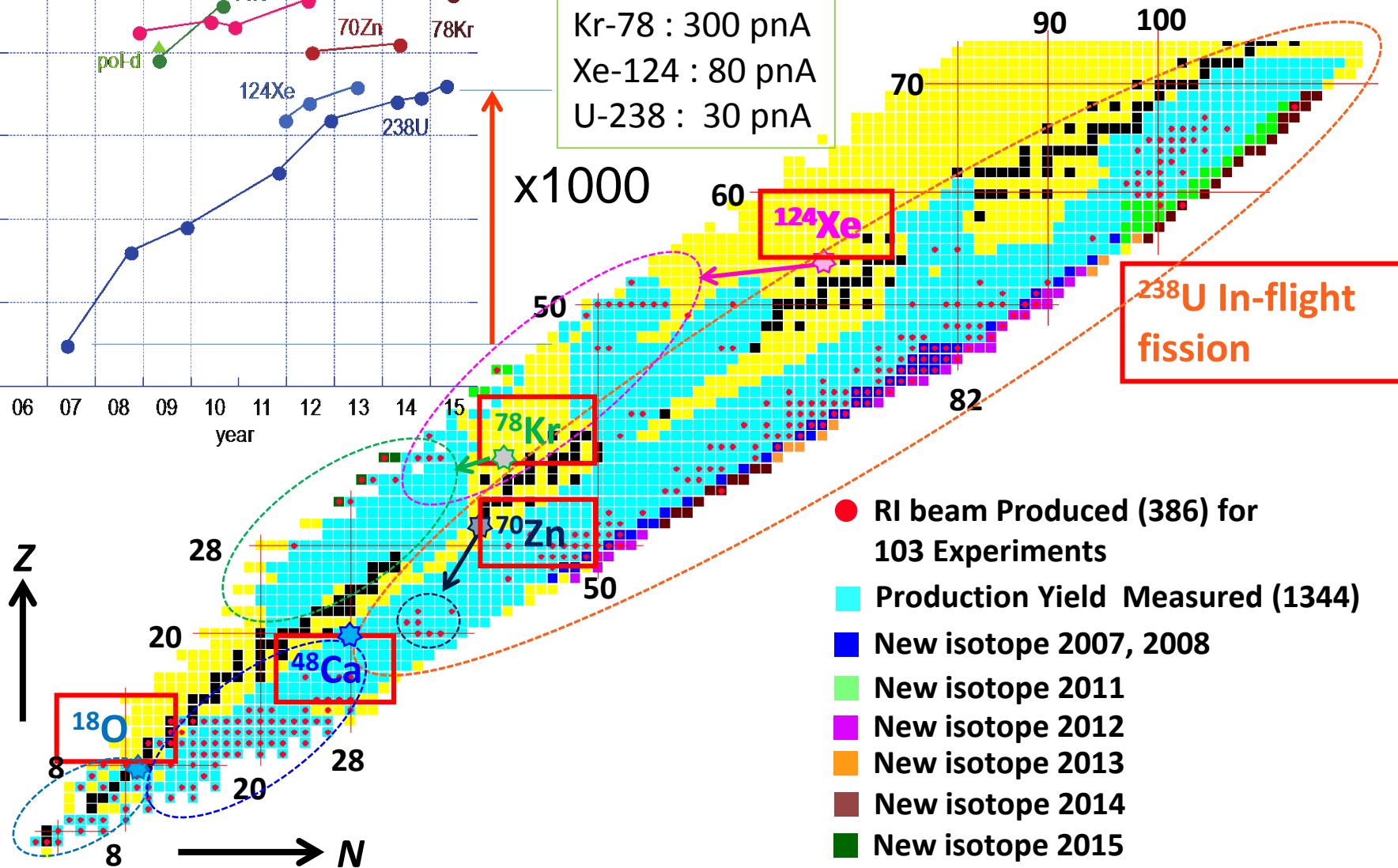
RI Beam Production at BigRIPS Since 2007

Primary beam intensity



2016
 Ca-48 : 400 pnA
 Zn-70 : 100 pnA
 Kr-78 : 300 pnA
 Xe-124 : 80 pnA
 U-238 : 30 pnA

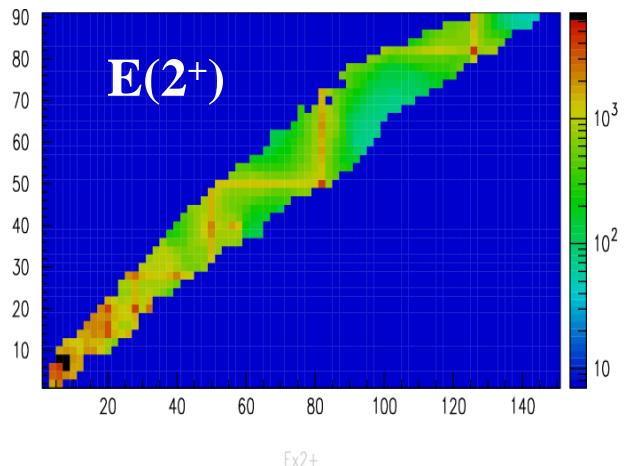
x1000



- RI beam Produced (386) for 103 Experiments
- Production Yield Measured (1344)
- New isotope 2007, 2008
- New isotope 2011
- New isotope 2012
- New isotope 2013
- New isotope 2014
- New isotope 2015

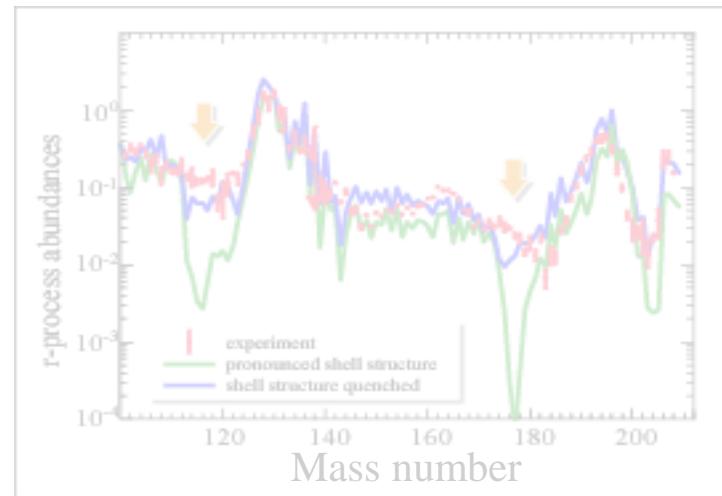
Physics with Exotic Nuclei

Shell Evolution : magicity loss and new magicity



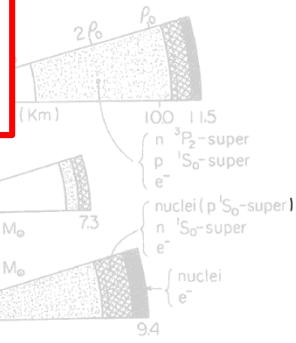
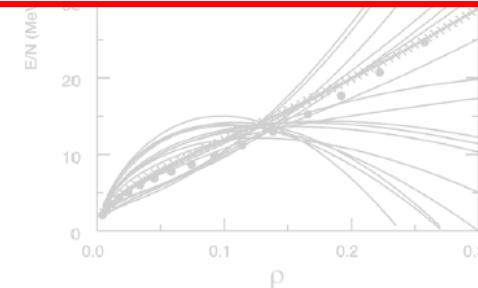
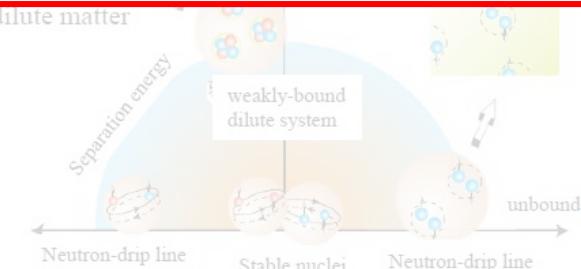
Ex2+
Neutron Correlation in the

R-process path: Synthesis up to U



EOS: asymmetric nuclear matter
SN explosion, neutron-star,

In-beam gamma “Sunflower” “SEASTAR”
Decay “EURICA”

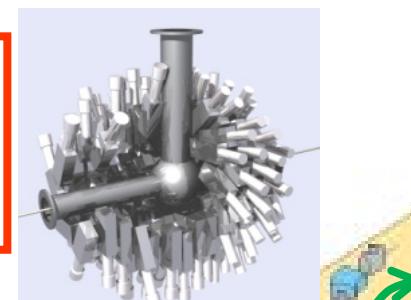


Spectroscopy via reactions with in-beam gamma method

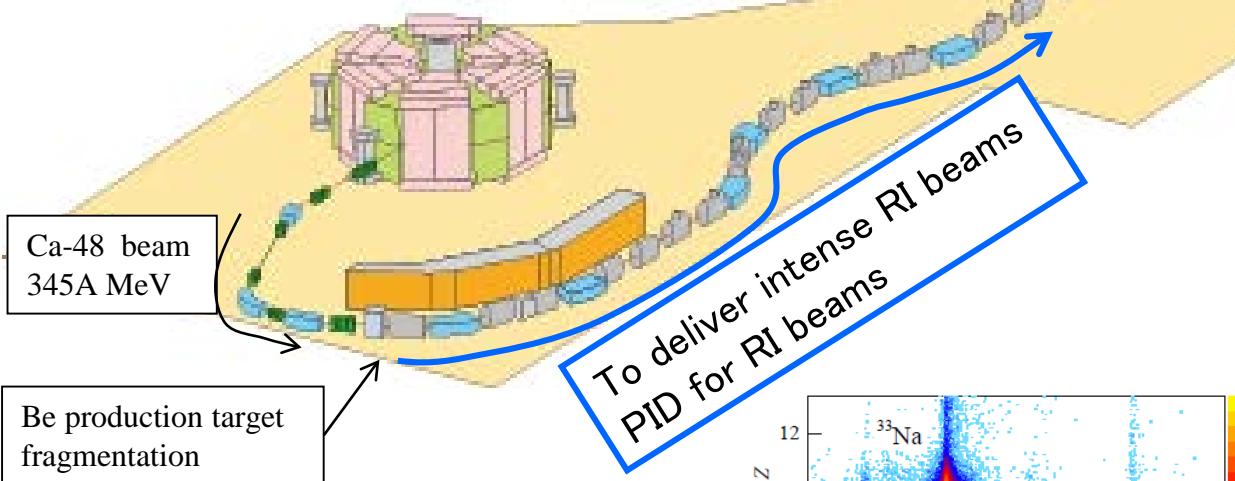
Secondary target: H₂, C, Pb....

Gamma-detectors : DALI2 NaI array
to measure de-excited gamma rays

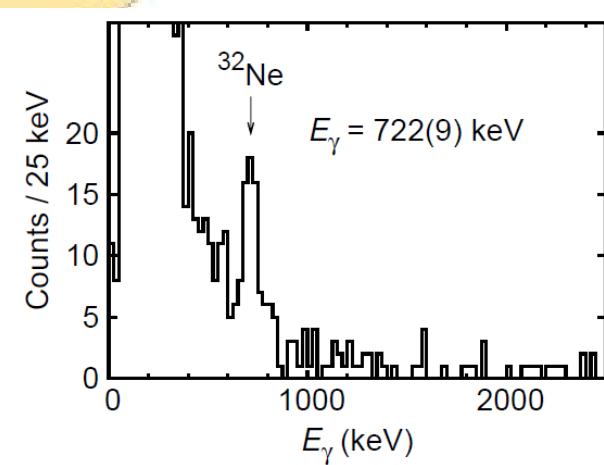
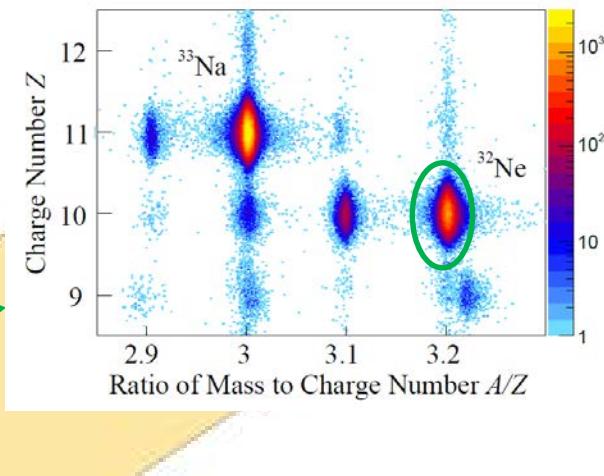
S.Takeuchi et al., NIM A 763, 596-603 (2014)



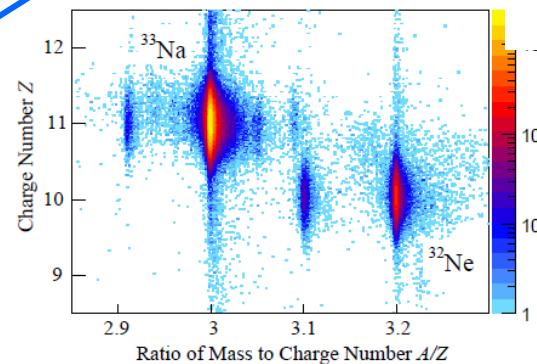
Ca-48 Acceleration
at Super-Conducting Cyclotron



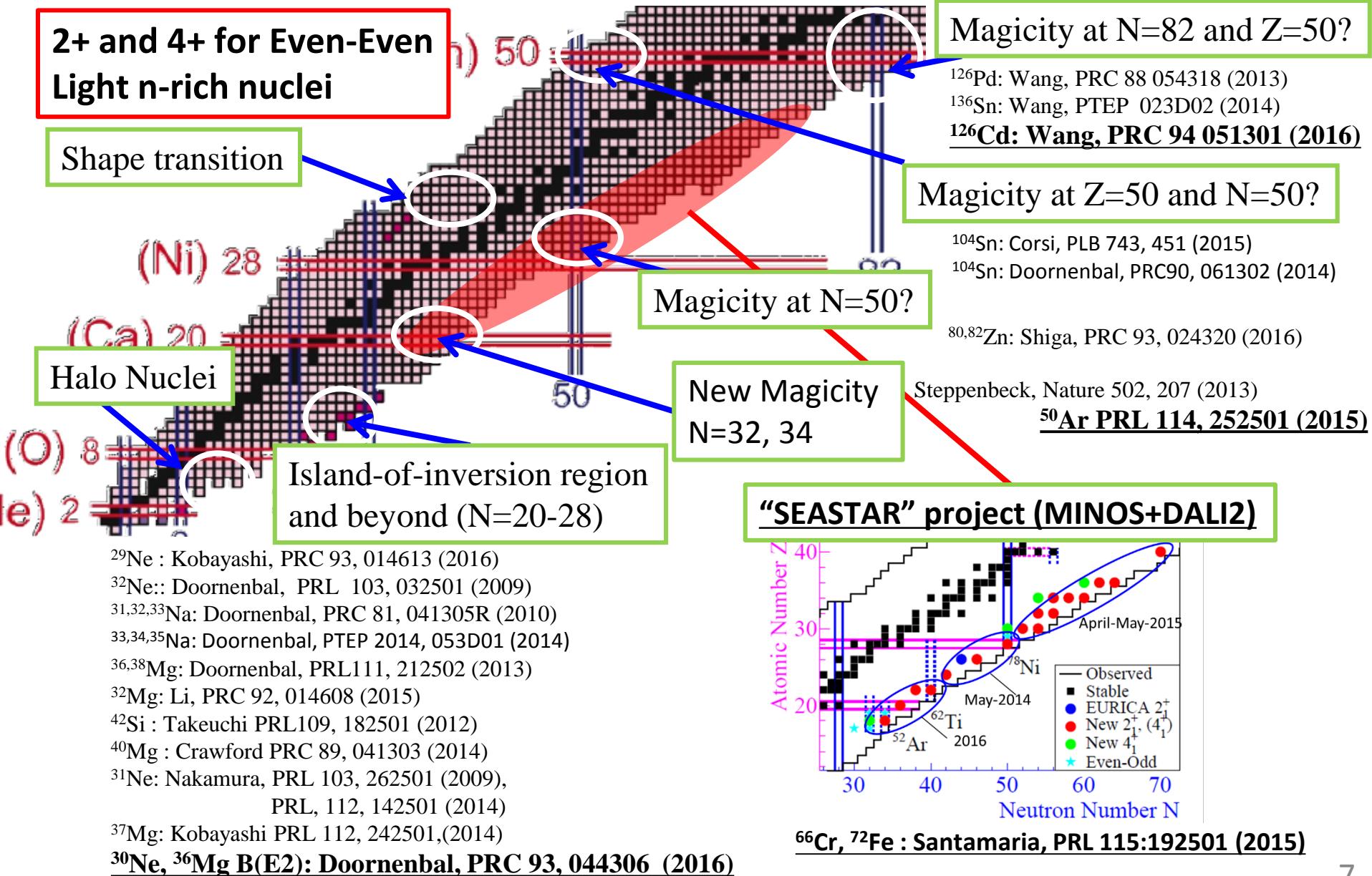
PID at ZeroDegree



Doornenbal, Scheit et al.
PRL 103, 032501 (2009)



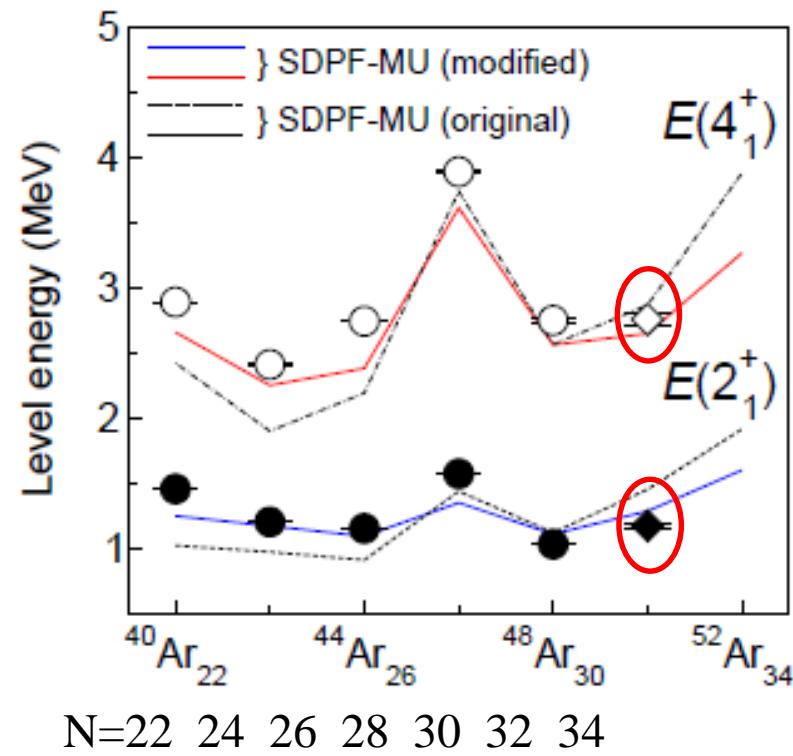
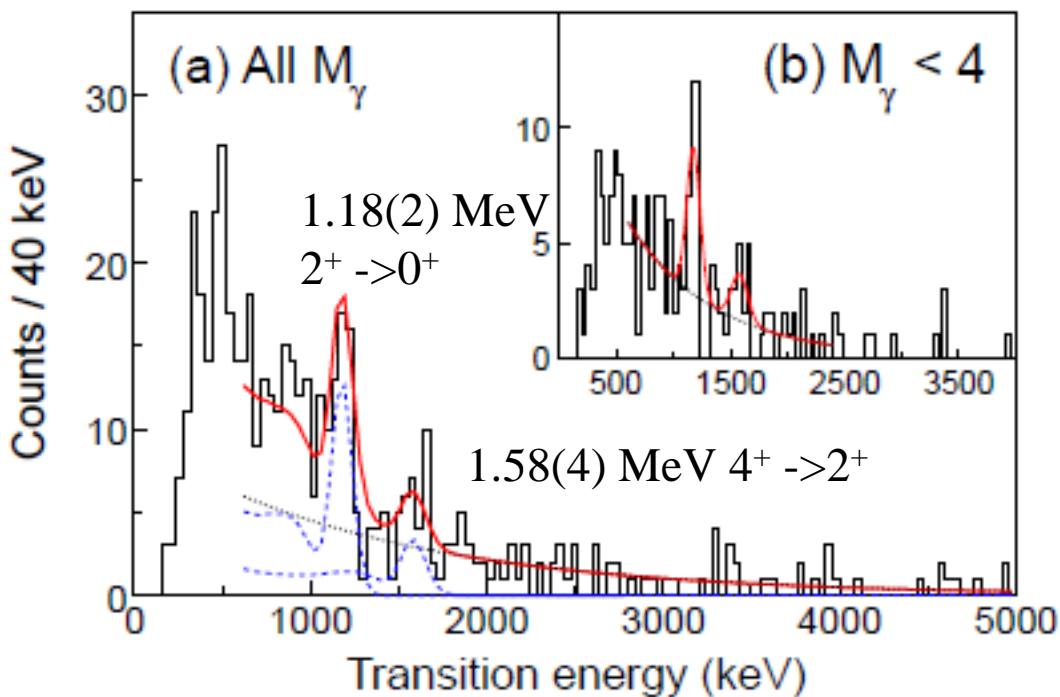
Achievements with DALI2 at ZD since 2009-



“Magicity” in the Ar isotopes : ^{50}Ar ($N=32$)

D. Steffenbeck et al., Phys. Rev. Lett. 114, 252501 (2015)

Sum of the reaction channels



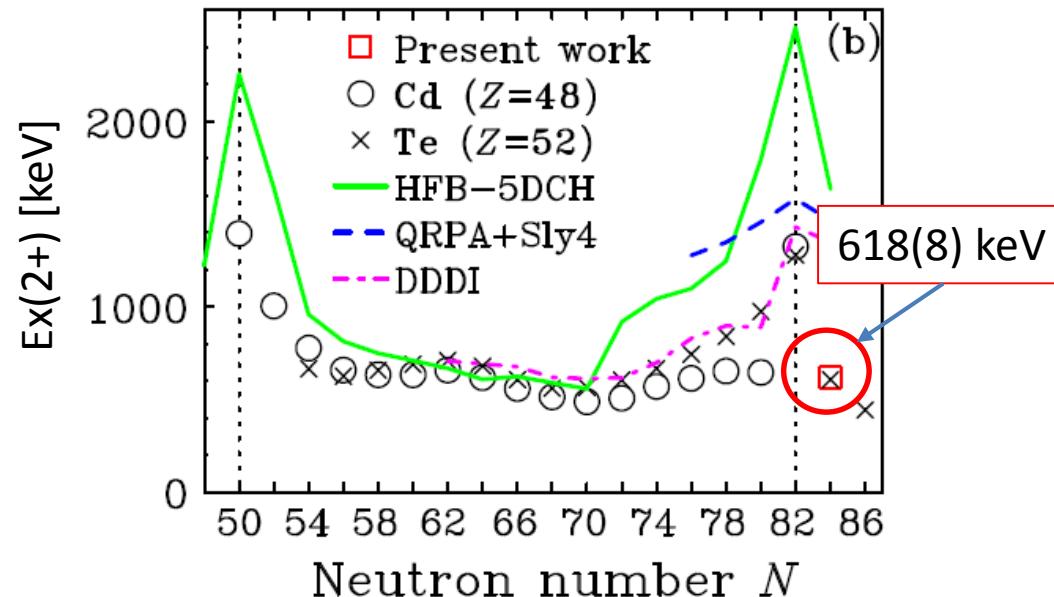
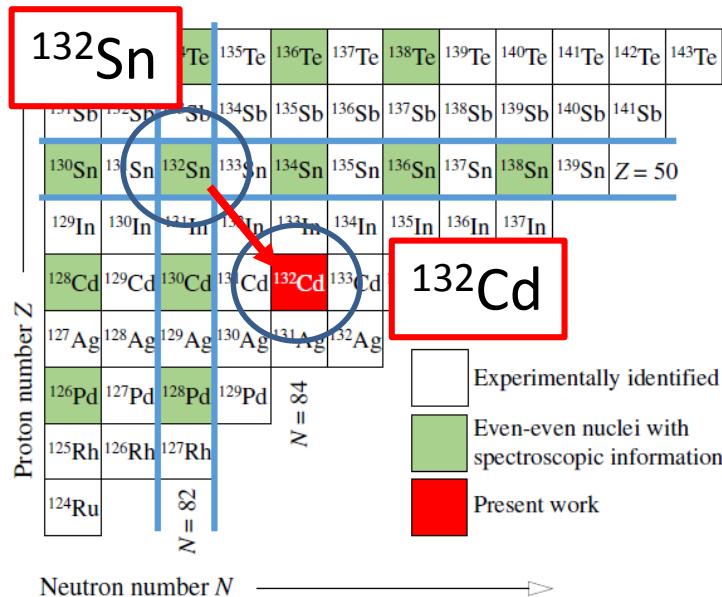
$N=32$ gap in Ar is similar at that in Ca and Ti...

How about Ar-52 ($N=34$)?
Ca-56 ($N=36$)?

First spectroscopic information on

“Southeast” of ^{132}Sn ; ^{132}Cd

Wang et al., PRC 94, 051301 (R), 2016



Neutron dominant excitation beyond $N=82$

$$\begin{aligned} \boxed{N=84} \quad & |2^+; {}^{132}\text{Cd}\rangle = (0.13)^{1/2} |\pi^- 2\rangle \pm (0.87)^{1/2} |\nu^2\rangle \\ & |2^+; {}^{136}\text{Te}\rangle = (0.15)^{1/2} |\pi^2\rangle \pm (0.85)^{1/2} |\nu^2\rangle \end{aligned}$$

Small $B(E2)$ of ${}^{136}\text{Te}$
Radford et al., PRL88, 222501 (02)

$$\begin{aligned} \boxed{N=80} \quad & |2^+; {}^{128}\text{Cd}\rangle = (0.46)^{1/2} |\pi^- 2\rangle \pm (0.54)^{1/2} |\nu^2\rangle \\ & |2^+; {}^{132}\text{Te}\rangle = (0.45)^{1/2} |\pi^2\rangle \pm (0.55)^{1/2} |\nu^2\rangle \end{aligned}$$

Precise mass measurement
Hakala et al., PRL 109, 032501 (12)
Neutron-pairing gap at $Z=50$
Is quenched beyond $N=82$... ?

Shell Evolution And Search for Two-plus energies At the RIBF (SEASTAR) – a RIKEN Physics Program

Spokespersons: P. Doornenbal (RIKEN), A. Obertelli (CEA, RIKEN)

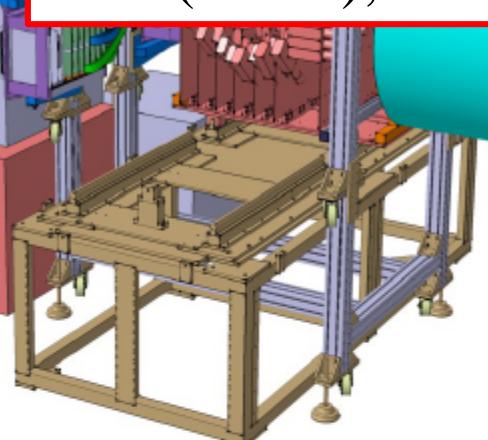
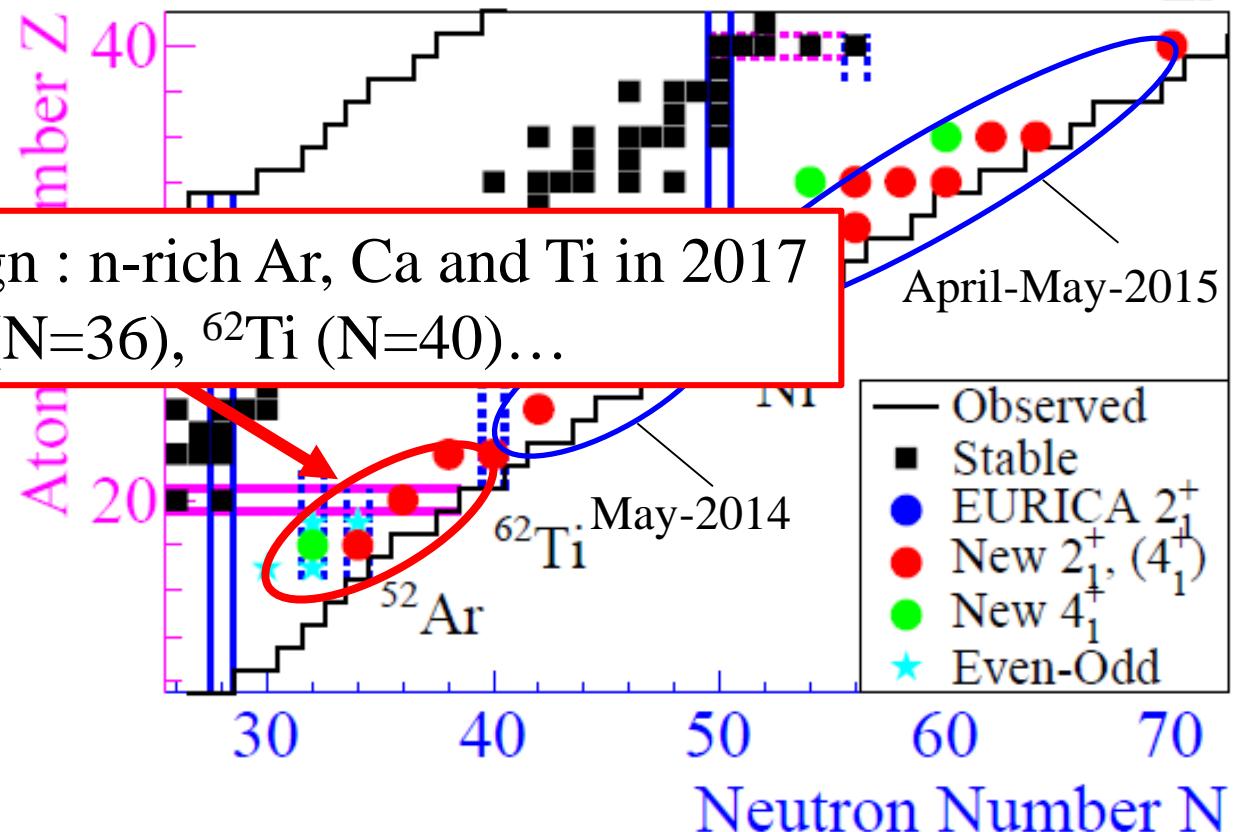
New collaboration scheme; Nuclear Physics News, 24 No2, 35

^{110}Zr



The Third Campaign : n-rich Ar, Ca and Ti in 2017

^{52}Ar ($N=34$), ^{56}Ca ($N=36$), ^{62}Ti ($N=40$)...



MINOS (100-mm thick Liq. H_2 target and TPC system, $\Delta\beta = 20\%$)

-> high luminosity and vertex position determination

DALI2 -> high efficiency

to access very neutron-rich nuclei



EURICA

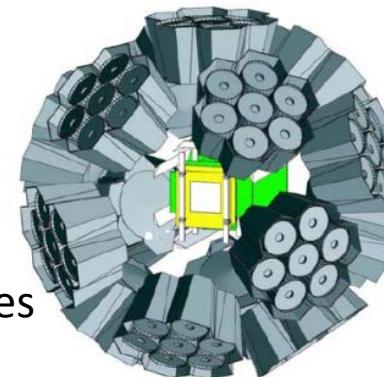
EUroball-RIKEN Cluster Array

2012-2016



12 Euroball Cluster detectors
Support structure
Electronics/daq used for RISING

RIBF: decay station
Active stopper: DS-SSD (WAS3ABI)
Liq. N₂ system, other infrastructures
+Additional detectors (LaBr₃, Plastic, AIDA...)



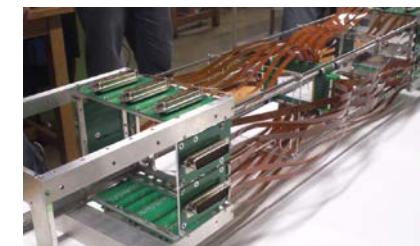
230 collaborators from 19 countries

About 100 days were approved for physics run

Commissioning March 2012 NIM B 317, 649 (2013)

Physics Run June 2012 – June 2016

WAS3ABI



Publication at this time (November 5th, 2016)

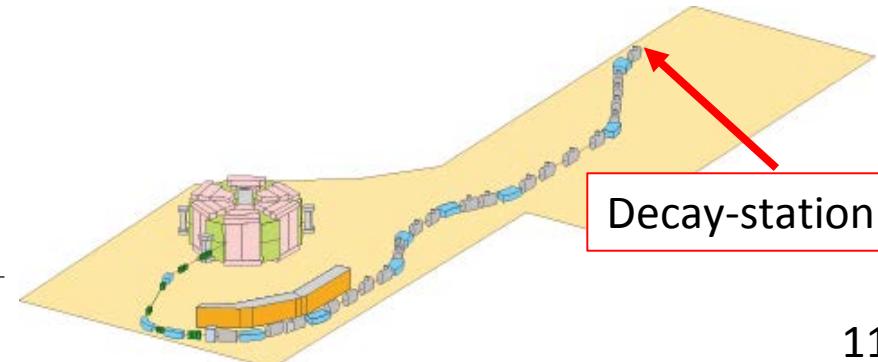
25 papers (9xPRL, 6xPLB, 3xPRC(R), 7xPRC)

10 PhD Thesis + 1 Master Thesis

33 proceedings

8 technical articles

“End-of-Campaign WS Sept.6-7th, 2016

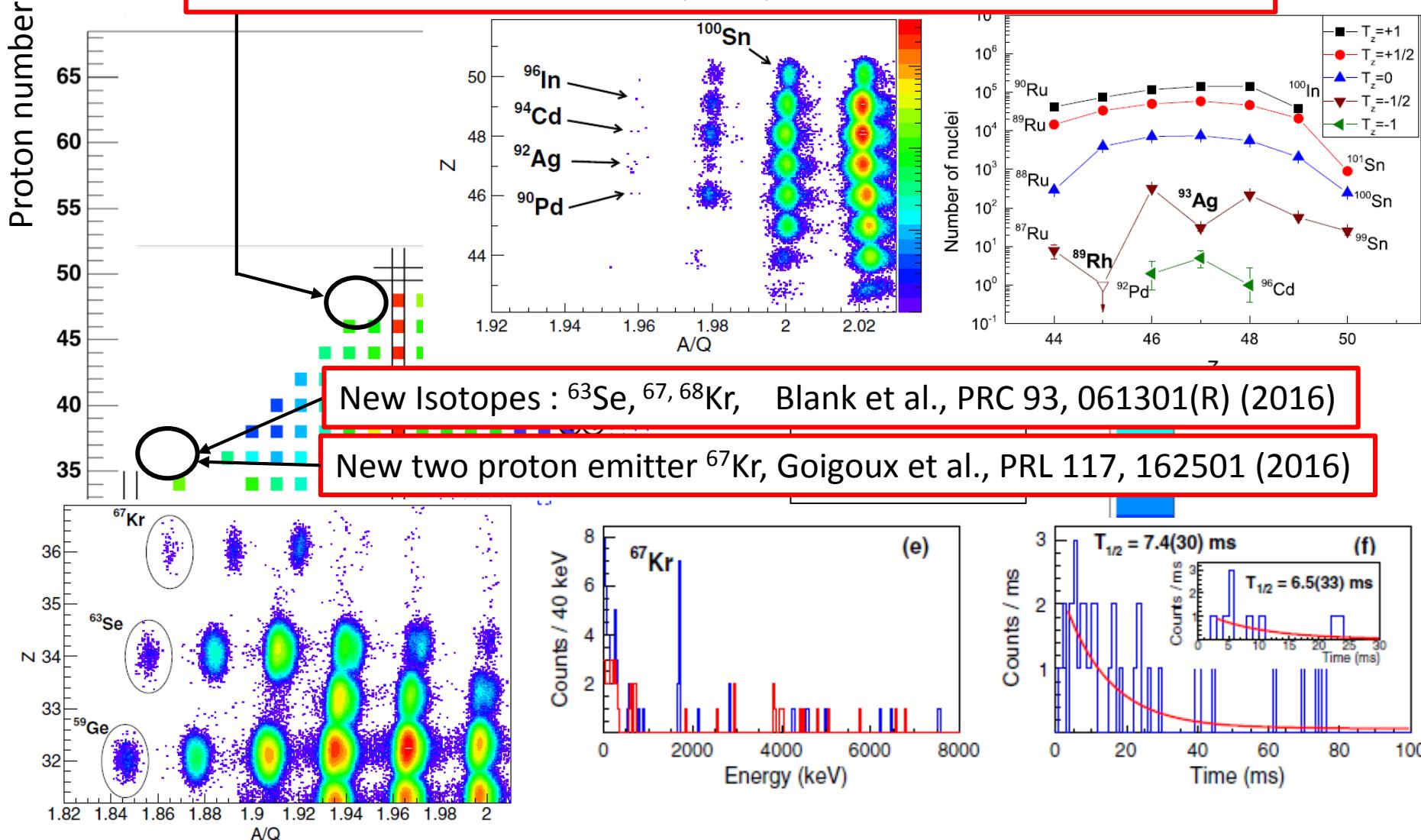


Decay-station



EURICA Achievements (2012-) new isotopes and proton emitters

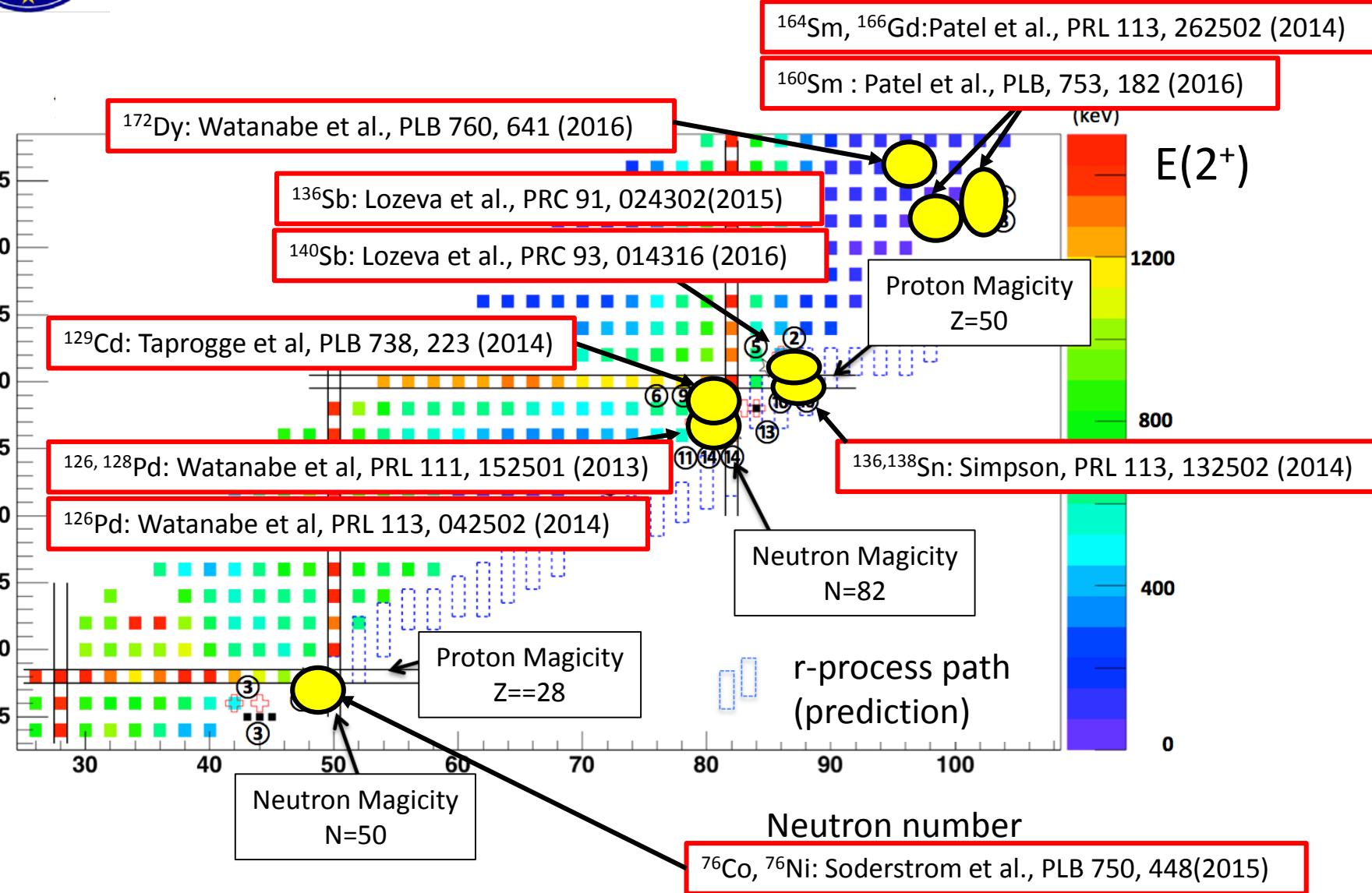
New Isotopes: ^{96}In , ^{94}Cd , ^{92}Ag , ^{90}Pd , New proton emitters: ^{89}Rh , ^{93}Ag
Celikovic et al., PRL 116, 162501(2016)





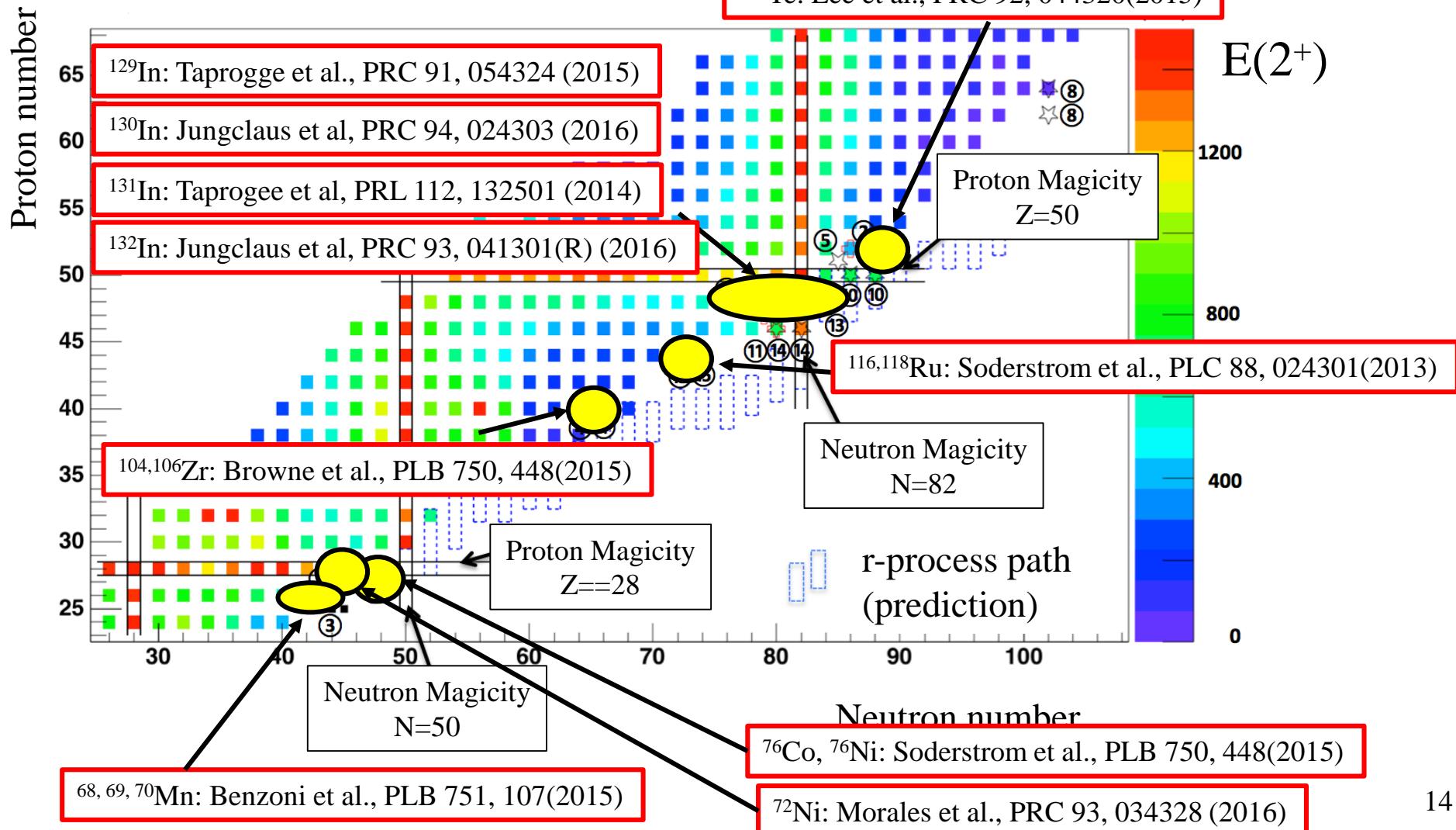
EURICA Achievements (2012-): isomers

Proton number





EURICA Achievements (2012-): Beta-gamma



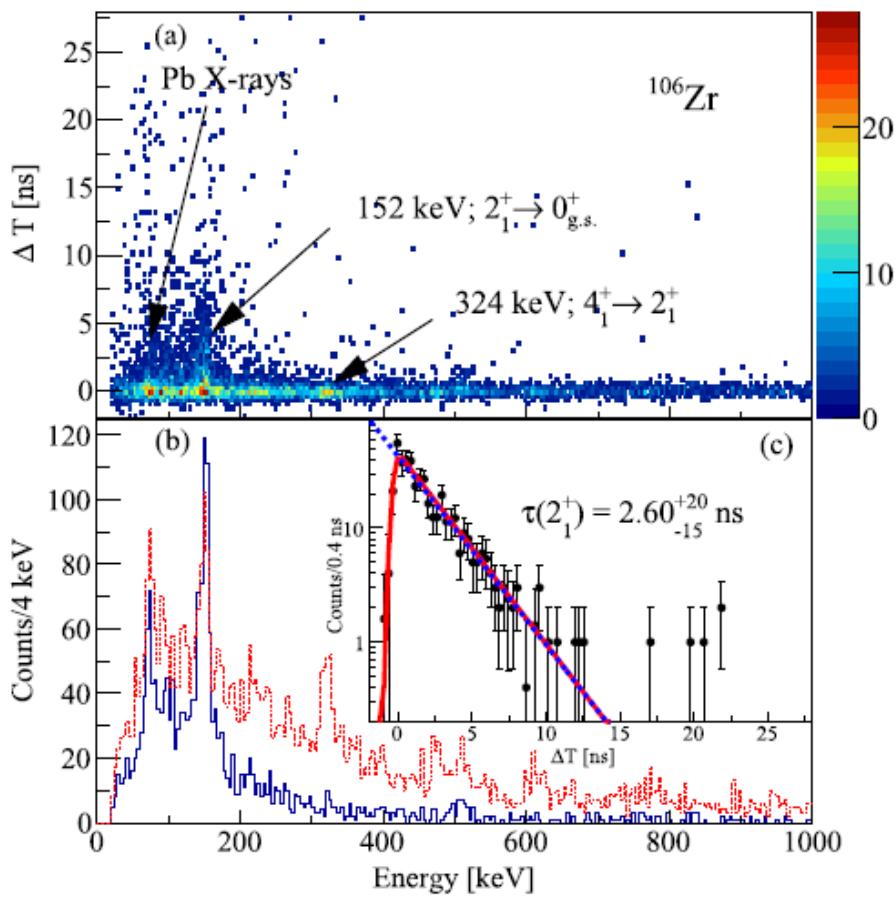
Lifetime of measurements of the first 2^+ states in $^{104,106}\text{Zr}$: Evolution of ground-state deformations



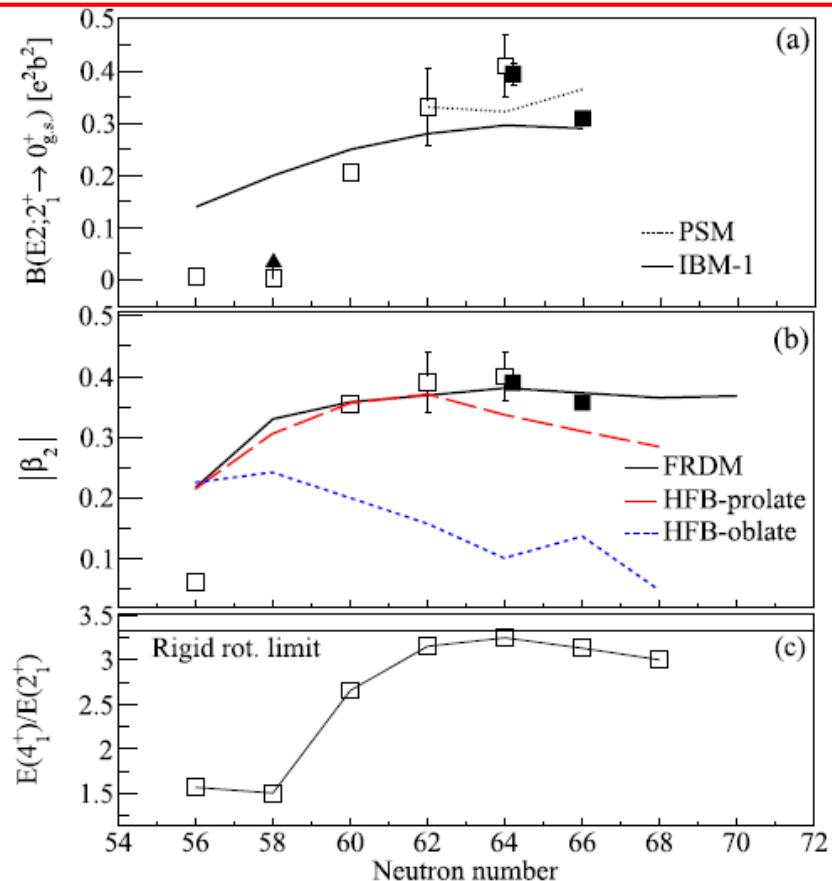
Browne et al., Phys. Lett. B 750 448-452 (2015)

LaBr₃(FATIMA) E and T resolution, 10% and 0.8 ns (FWHM), respectively for 150-170 keV gamma

EURICA Feeding analysis 50% from 4^+ , 20% from others

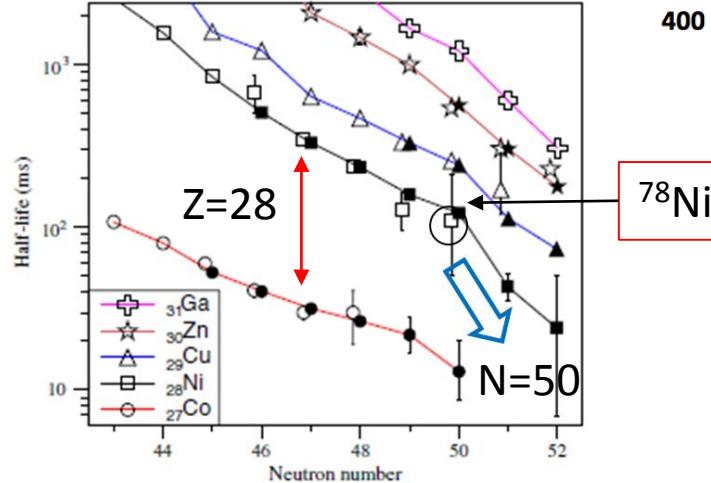
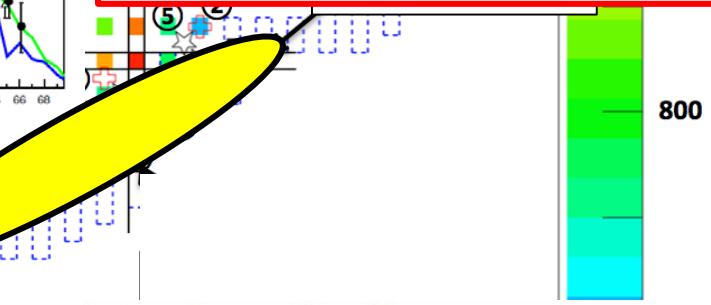
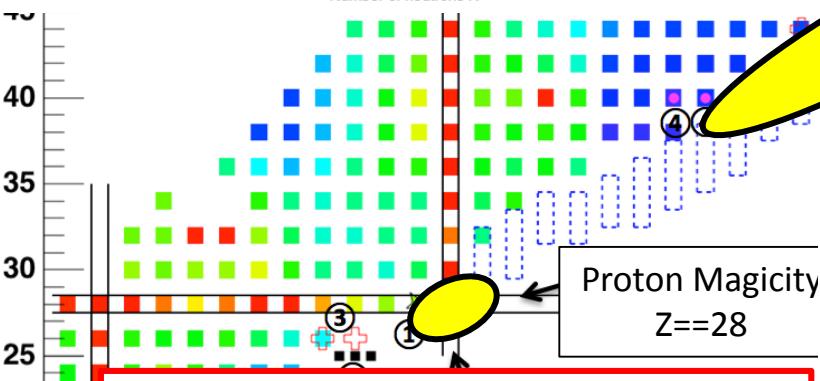
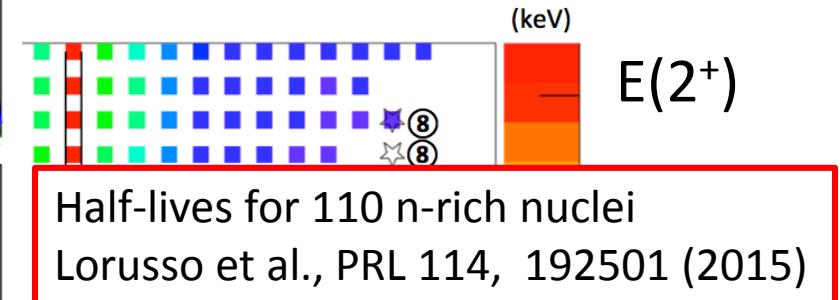
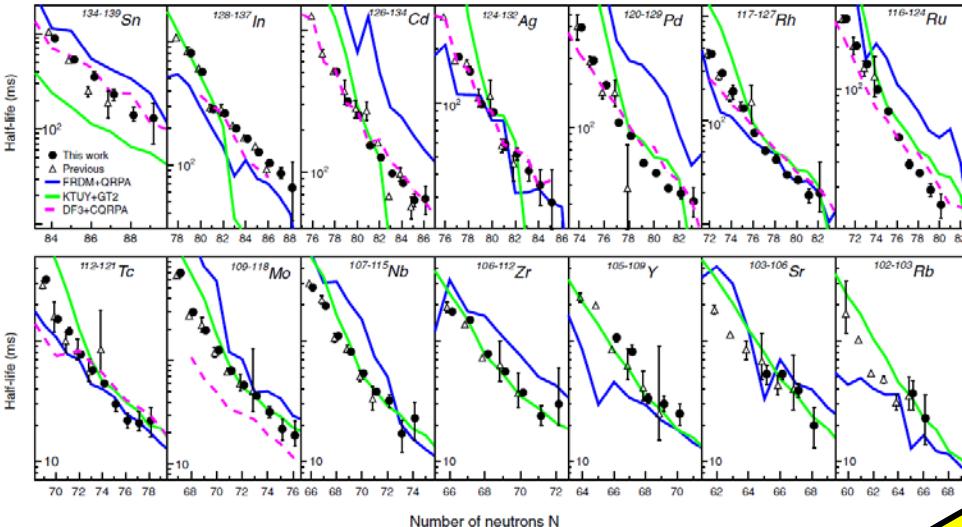


Confirmation of Deformed Magic of N=64





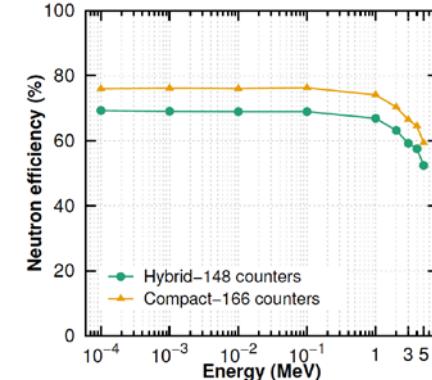
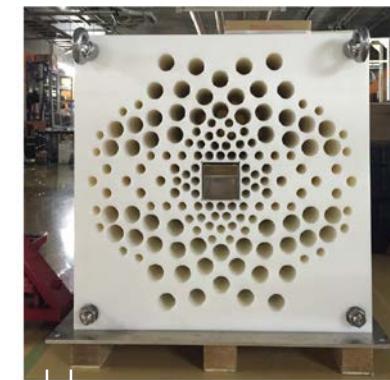
EURICA Achievements (2012-): Half-lives



Future: BRIKEN β-Delayed Neutron Study

166 He-3 tubes

ORNL-JINR-GSI-UPC-RIKEN

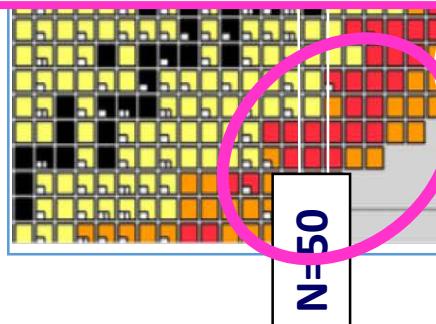


Systematics Study of
Decay Properties ($T_{1/2}$, P_n)

- (1) (unexpected) trends → Nuclear structure
(2) Study for r-process nucleosynthesis

2016 : Commissioning
2017- : physics run

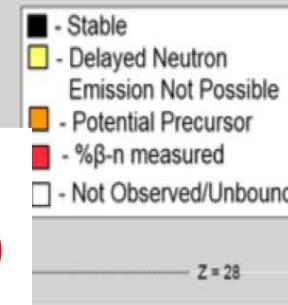
K. Rykaczewski, J. Tain,
R. Gryzwacz, I. Dillmann
- 20 new P_n values



S. Nishimura, A. Algora
- 125 P_n (63 ~ 96 new P_n)
- 36 ~ 47 New P_{2n}

N=82

G. Lorusso, A. Estrade, F. Montes
- 33 new P_n values



S. Nishimura
NIC-XIV June, 2016

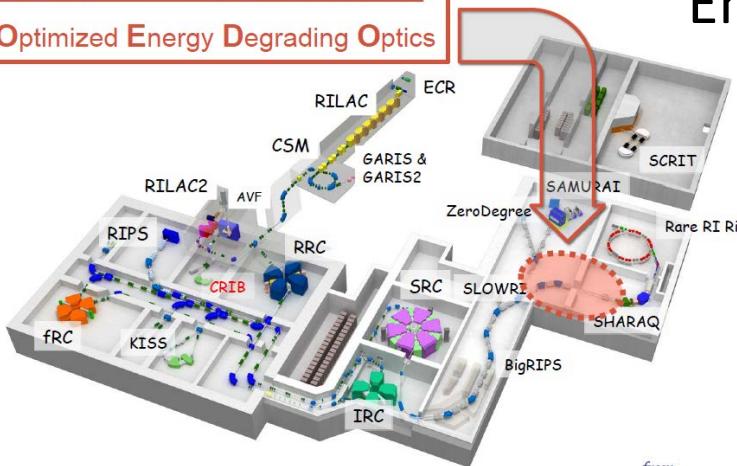


CNS-RIKEN: OEDO Project

Shimoura et al

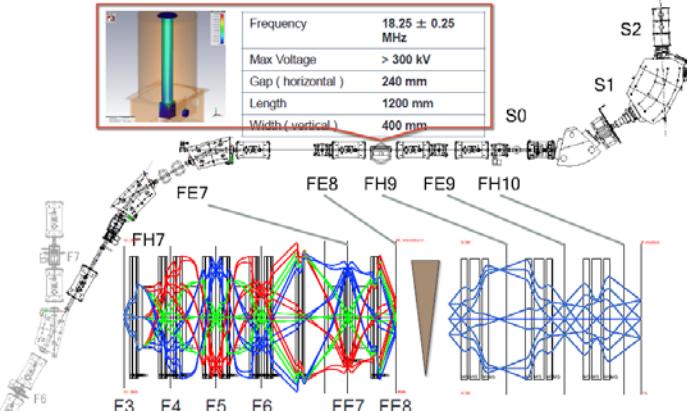
OEDO Beam-line

Optimized Energy Degrading Optics



Magnet configuration and optical condition

RF deflector



Operation will start in 2017
WS will be organized in 2017

Energy-degraded radioactive isotope beams

Nucleon transfer reactions (10A – 50A MeV)

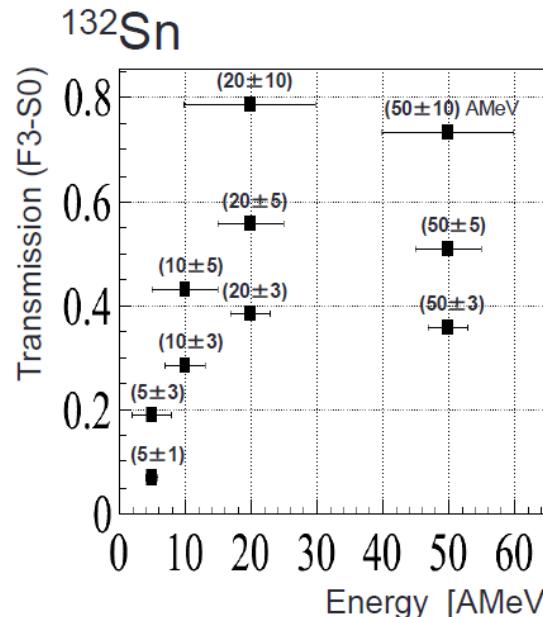
Pair transfer / Cluster transfer (10A – 20A MeV)

Deep inelastic collisions (incomplete fusion) (5A – 30A MeV)

Fusion reaction (~ 5A MeV)

Coulomb excitation reactions for low-energy gamma rays (~ 50A MeV)

Transmission and intensity



Transmission (F3 - S0)
x Intensity @ F3
|| Intensity @ OEDO (S0)

Typical example of ^{132}Sn

based on actual intensity in experiment by using 345 AMeV 30pnA U primary beam (Apr. 2015)

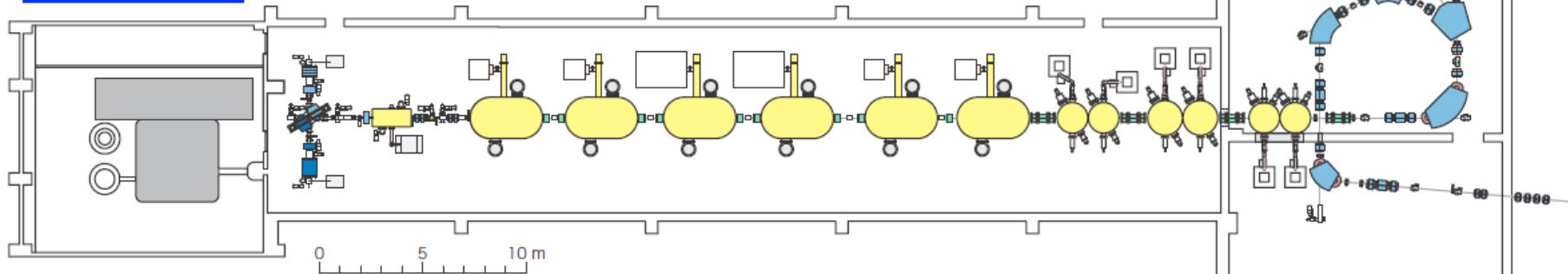
Intensity @ F3 (Apr. 2015)	2.5×10^6 [pps]
50 ± 5 AMeV @ S0	1.3×10^6
20 ± 3 AMeV @ S0	9.5×10^5
10 ± 3 AMeV @ S0	7.5×10^5
5 ± 1 AMeV @ S0	1.7×10^5

cf. 1.4×10^4 pps ^{132}Sn in CARIBU proposal

RILAC upgrade for SHE

Present

$E \sim 5 \text{ MeV/u}, M/q \sim 5$



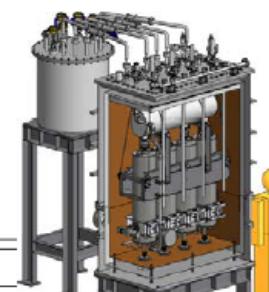
Upgrade plan

$E \sim 6 \text{ MeV/u}, M/q \sim 6$

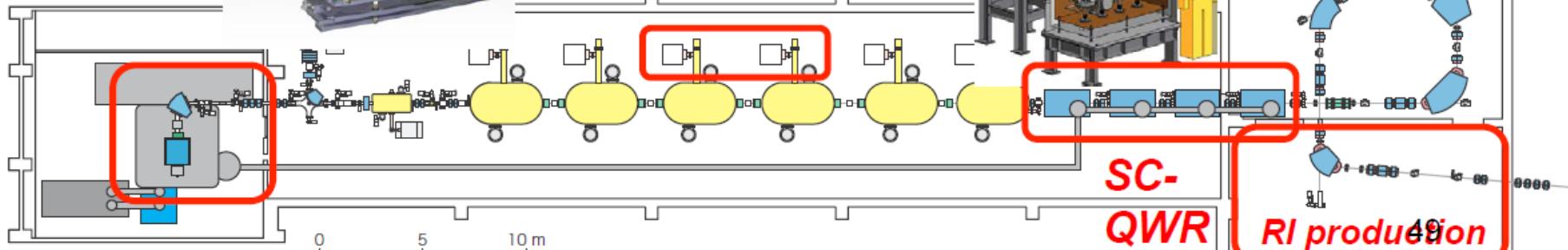
28GHz
SC-
ECRIS



2 Amps.
Renewal



2019-



(Ca, Zn)

SC-
QWR

RI production

Summary

In-beam gamma spectroscopy

Neutron-rich Ar, Ca and Ti will be investigated
with the SEASTAR setup in 2017

^{132}Cd -> neutron dominant excitation beyond N=82

Decay spectroscopy

EURICA has got bunch of data on
proton-emitters, isomeric states, excited-states, half-life...

A list of publication could be found in <https://ribf.riken.jp/EURICA>
The BRIKEN setup starts measuring T_{1/2} and P_n in 2017

Energy-degraded Radioactive Isotope Beams will be ready in 2017.

Transfer reactions for single-particle (hole) states

Higher spin / higher excited states

-> Workshop in next year...

RILAC upgrade will be completed in 2019.