Recent activities and perspectives at RIBF

H. Sakurai
RIKEN Nishina Center for Accelerator-based Science

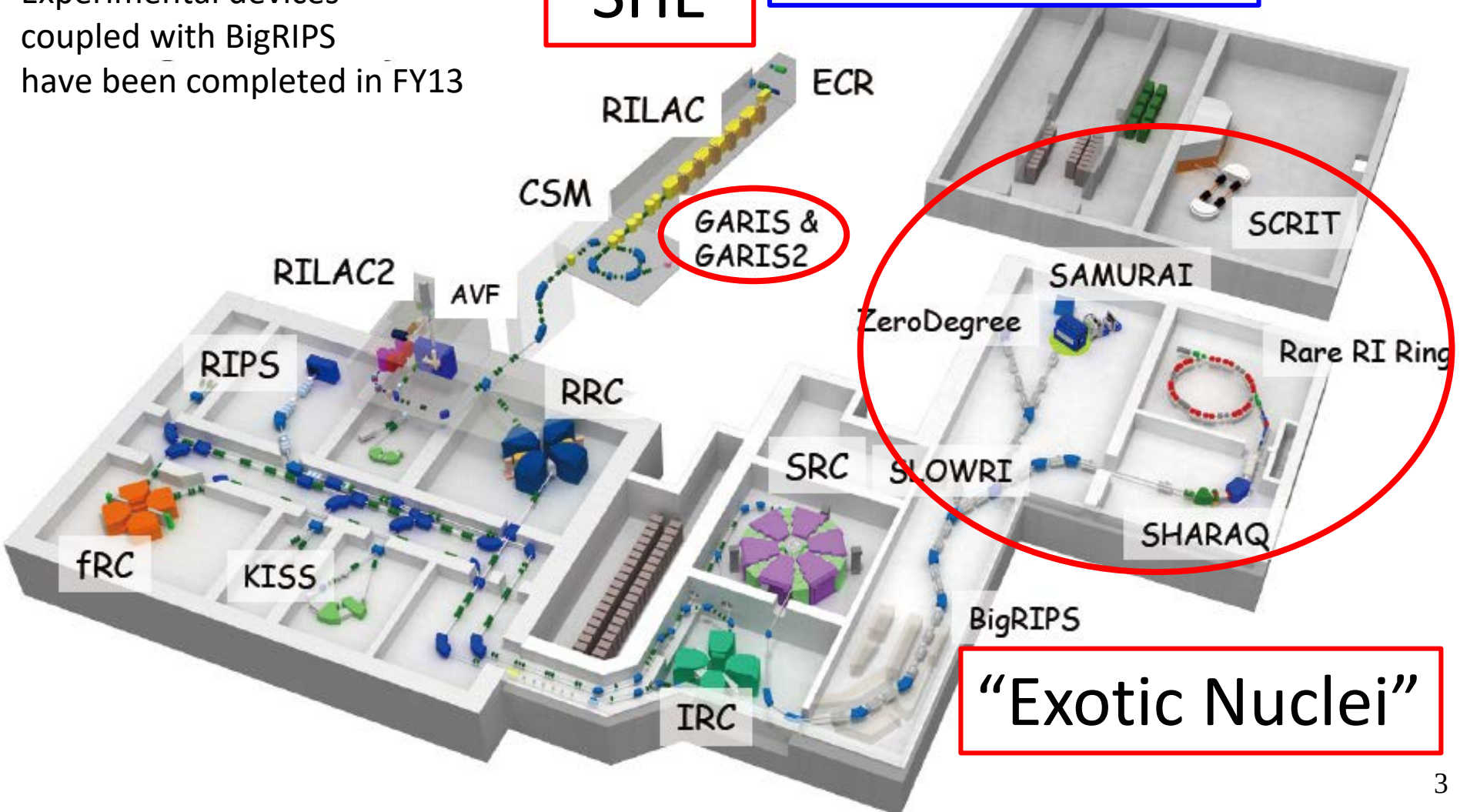
Press conference on the name of 113th, December 1st, 2016

RI Beam Factory

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

Toward 119th and 120th
via RILAC upgrade

"SHE"

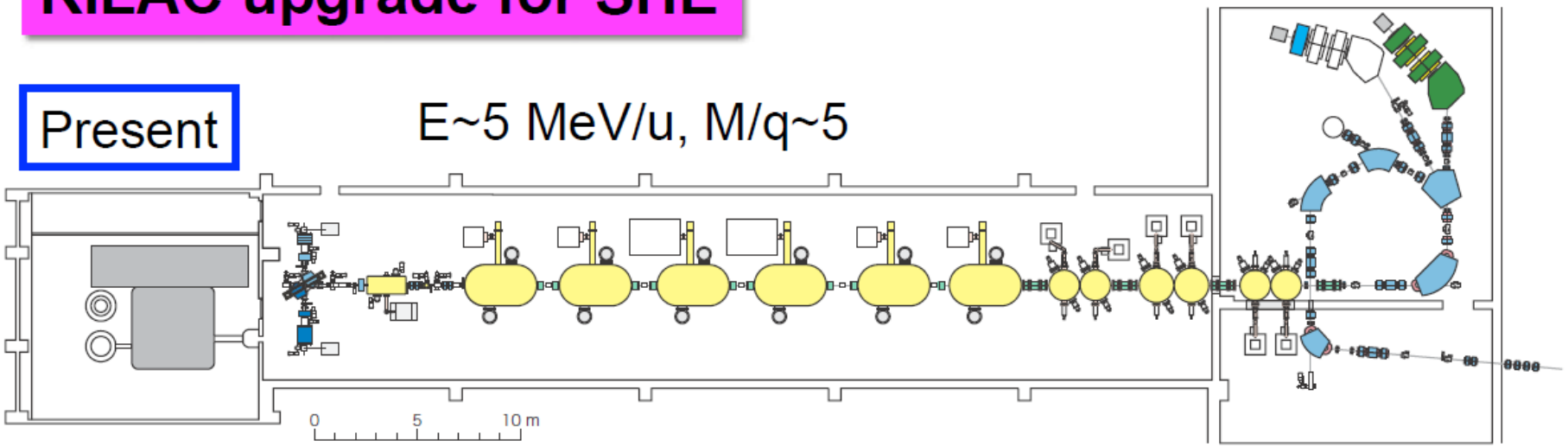


"Exotic Nuclei"

RILAC upgrade for SHE

Present

E~5 MeV/u, M/q~5



Upgrade plan

E~6 MeV/u, M/q~6

2019-

28GHz SC-ECRIS

2 Amps. Renewal

SC-QWR

RI production

(Ca, Zn)

RI Beam Factory

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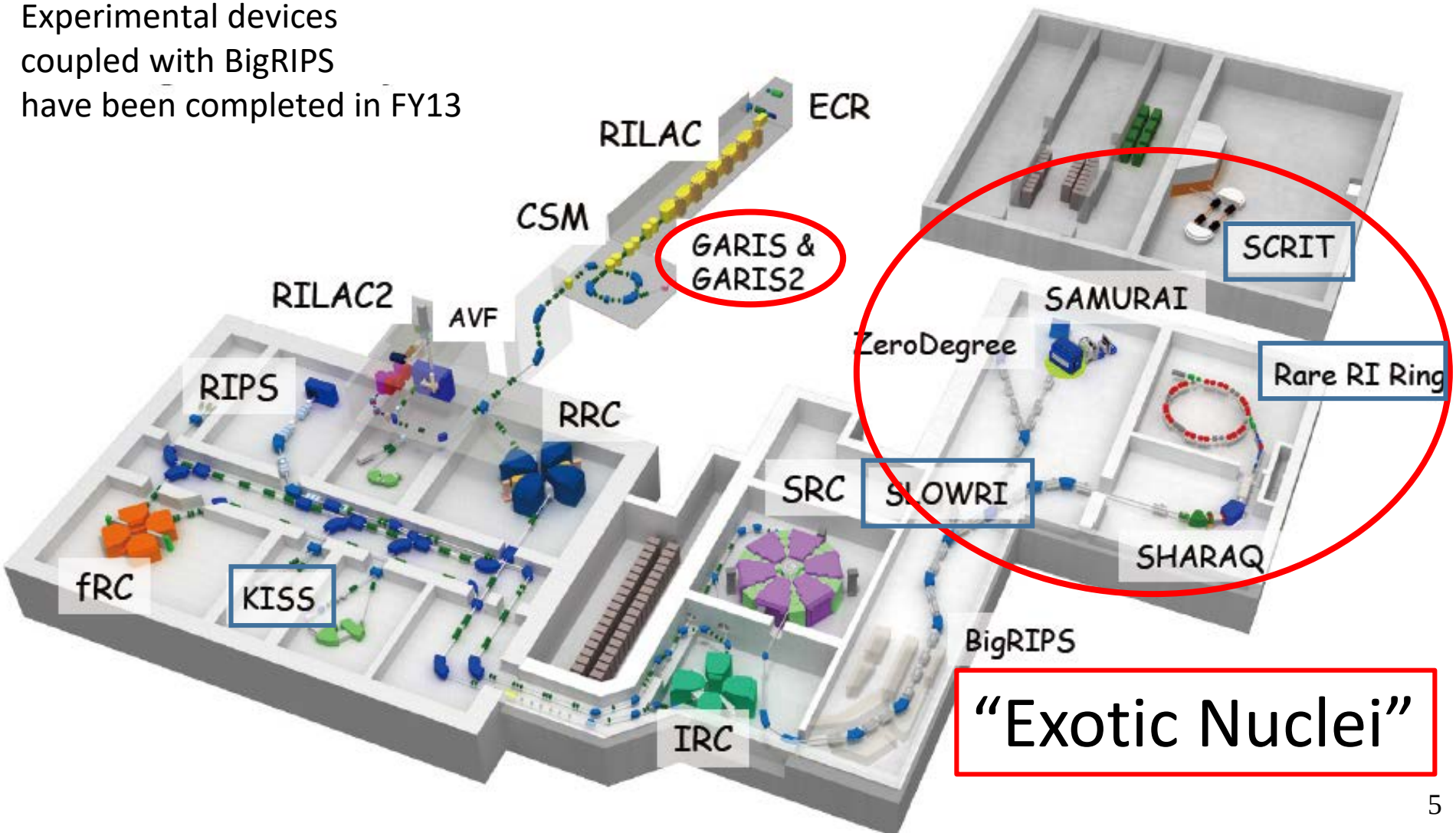
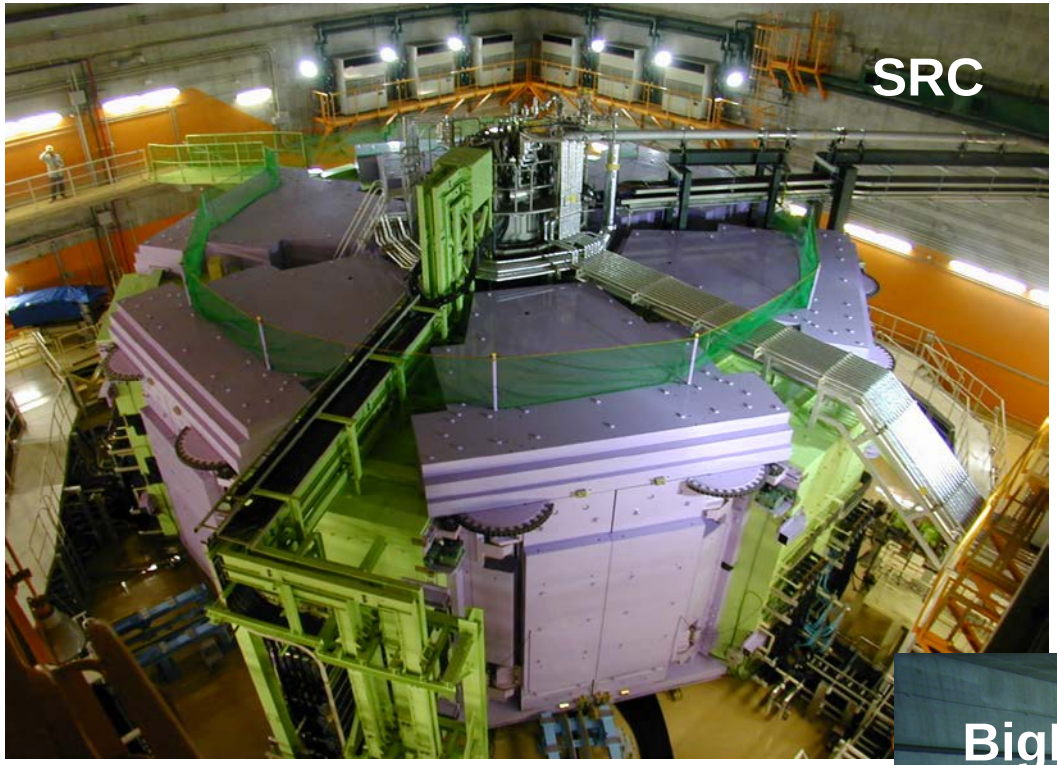
have been completed in FY13



"Exotic Nuclei"



World's First and Strongest
K2600MeV
Superconducting Ring Cyclotron

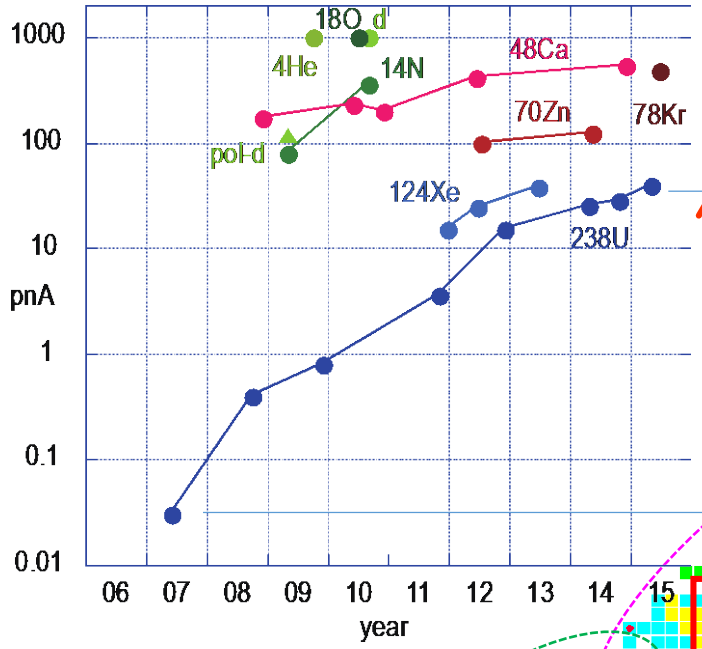
400 MeV/u Light-ion beam
345 MeV/u Uranium beam

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



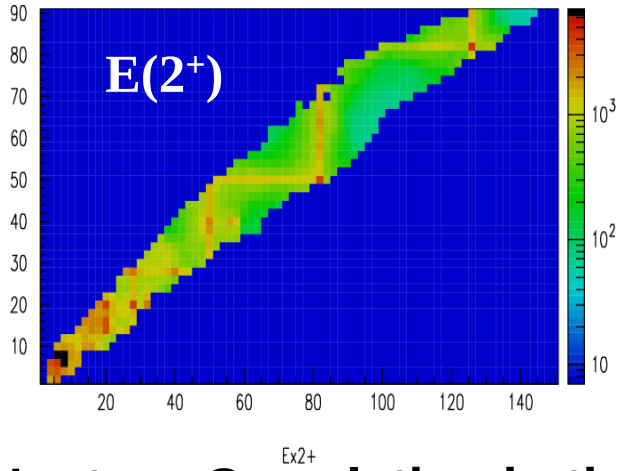
2016
Ca-48 : 400 pnA
Zn-70 : 100 pnA
Kr-78 : 300 pnA
Xe-124 : 80 pnA
U-238 : 30 pnA

x1000

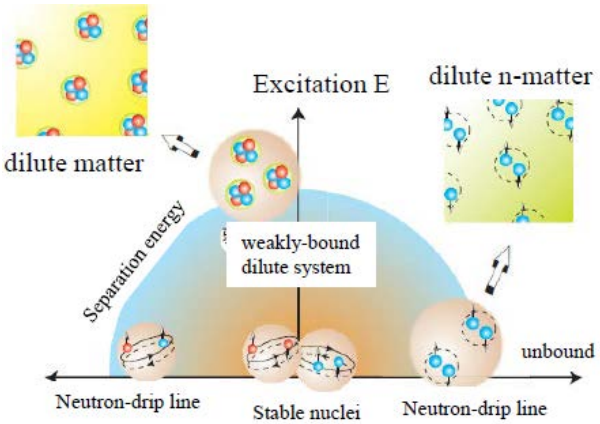
2017 Nov. U-238 67 pnA

Physics with Exotic Nuclei

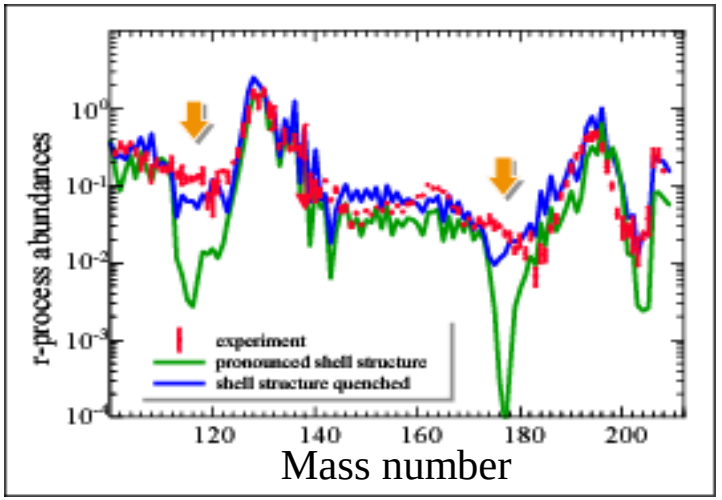
Shell Evolution :
magicity loss and new magicity



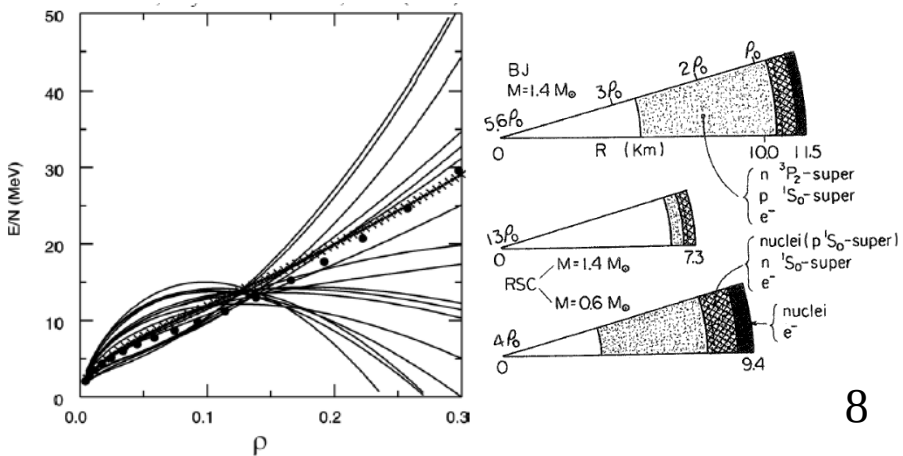
Neutron Correlation in the vicinity of the Drip-line



R-process path: Synthesis up to U



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



Physics with Exotic Nuclei

Shell Evolution :
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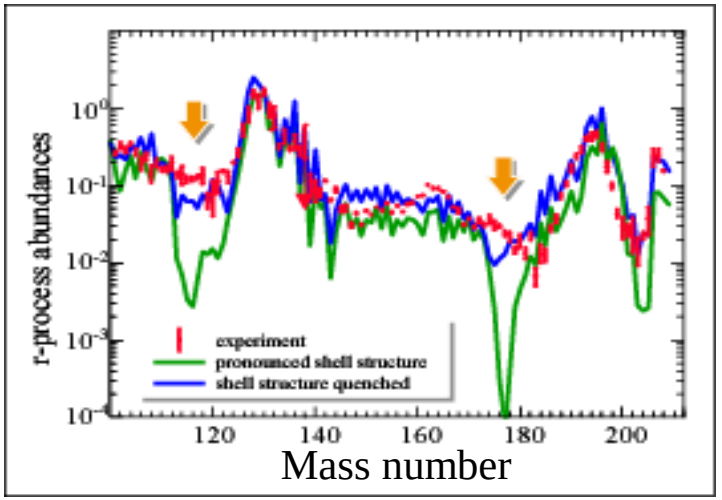

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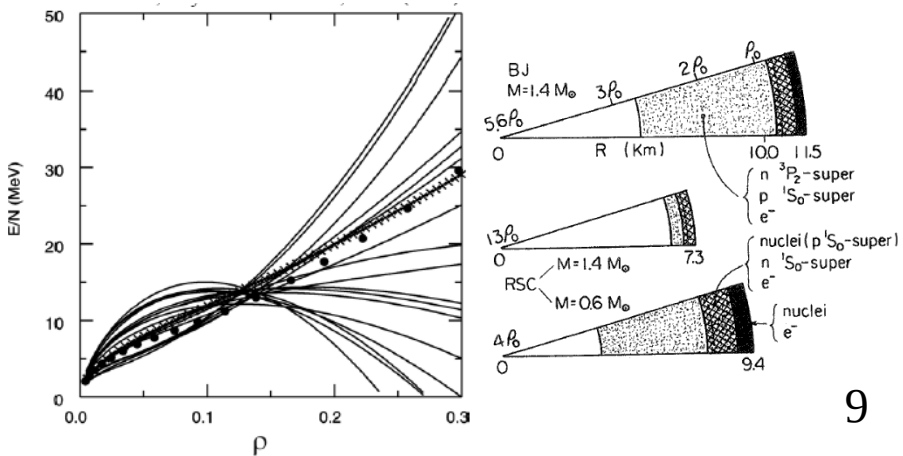


Isobe et al. at NIC2016

SπRIT

Heavy RI Collision program @RIKEN-RIBF

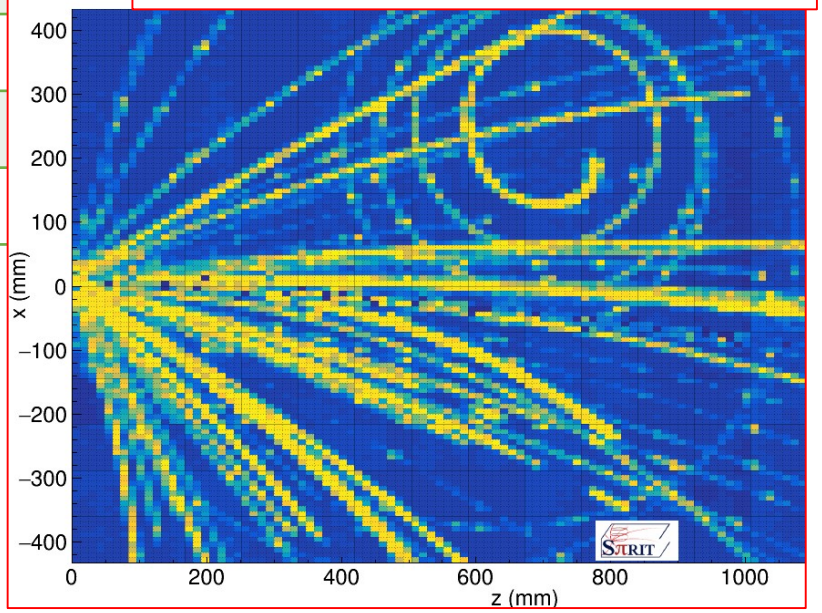
- Experimental project to give a constrain on the density dependent symmetry energy main for higher dense region.
- Systematic measurement in same *Z* but different *N* system realized with heavy RI beam.
  - $\rho \sim 2\rho_0$ nuclear matter at RIBF energy (E/A=300MeV).

Primary	Beam	Target	E_{beam}/A	$(N-Z/A)_{sys}$
^{238}U	^{132}Sn	^{124}Sn	300	0.22
	^{124}Sn	^{112}Sn	300	0.15
^{124}Xe	^{108}Sn	^{112}Sn	300	0.09
	^{112}Sn	^{124}Sn	300	0.15

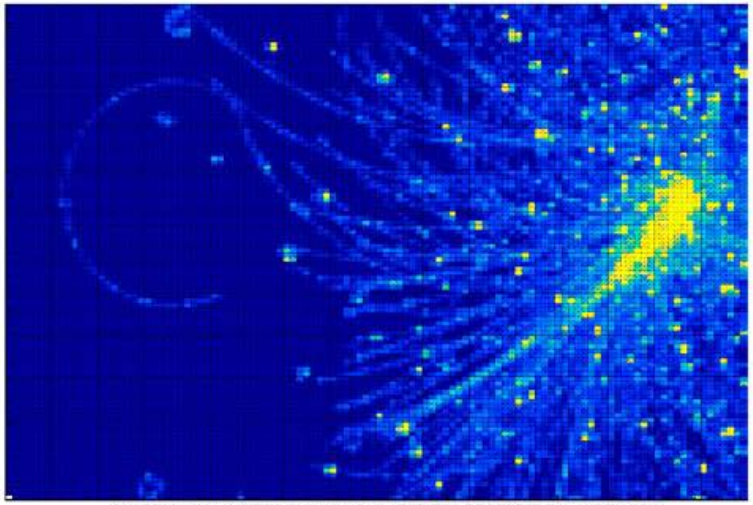
- Successfully finished.
  - 2016 Apr. – Jun.

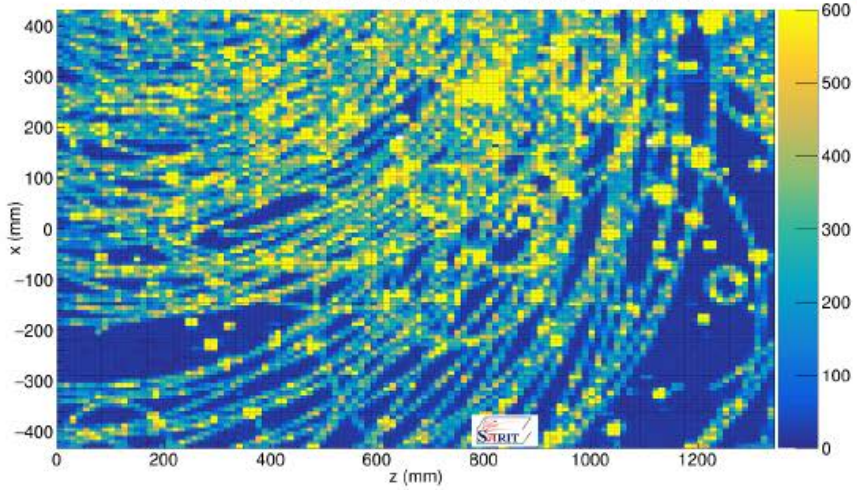
→ Analysis of data is ongoing.

$^{132}Sn + ^{124}Sn$ @E/A=300MeV
TPC Top view

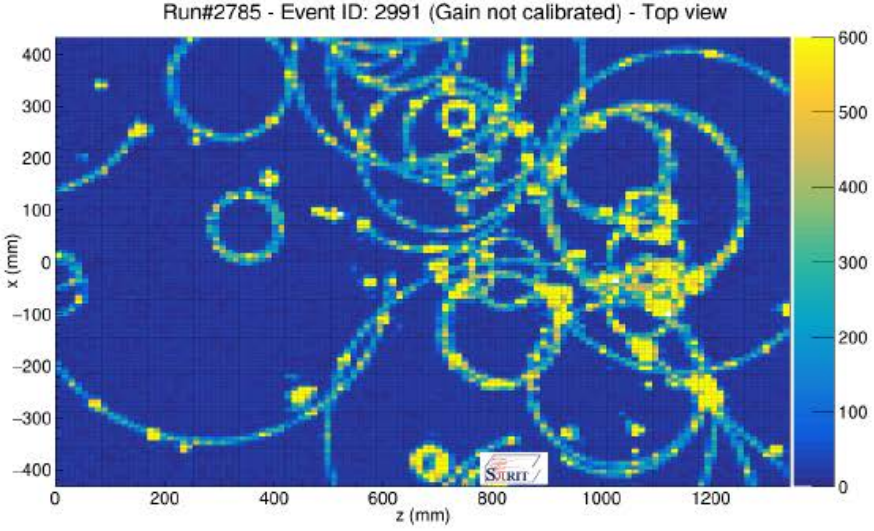


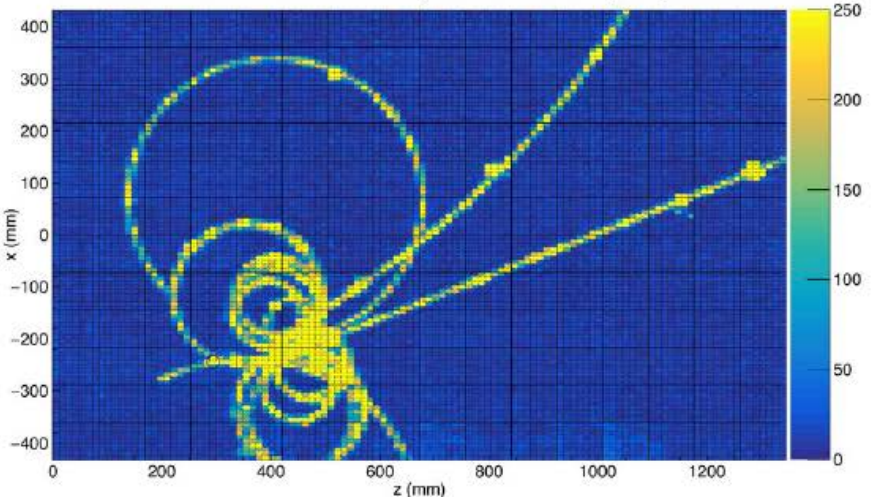
Art from Heaven SπRIT on Earth





https://groups.nscl.msu.edu/hira/NP1306_SAMURAI15/files/cosmicPics/phpshow.php?oldGD&0





Isobe et al. at NuSYM16

United States: C. Anderson, J. Barney, Z. Chajecki, G. Cerizza, P. Danielewicz, J. Estee, M. Famiano, U. Garg, W. Lynch, A. McIntosh, P. Morfouace, C. Santamaria, H. Setiawan, R. Shane, M. B. Tsang, T. Tsang, S. Tangwancharoen, G. Westfall, S. Yennello, M. Youngs

Japan: H. Baba, K. Ieki, T. Isobe, M. Kaneko, T. Murakami, Nakai, N. Nakatsuka, M. Nishimura, S. Nishimura, A. Taketani

China: F. Lu, R. Wang, Z. Xiao, Y. Zhang

United Kingdom: M. Chartier, R. Lemmon, W. Powell

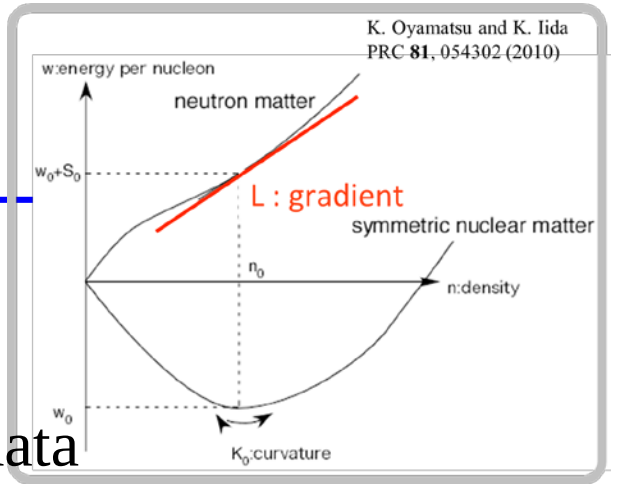
France: E. Pollacco

Italy: G. Verde

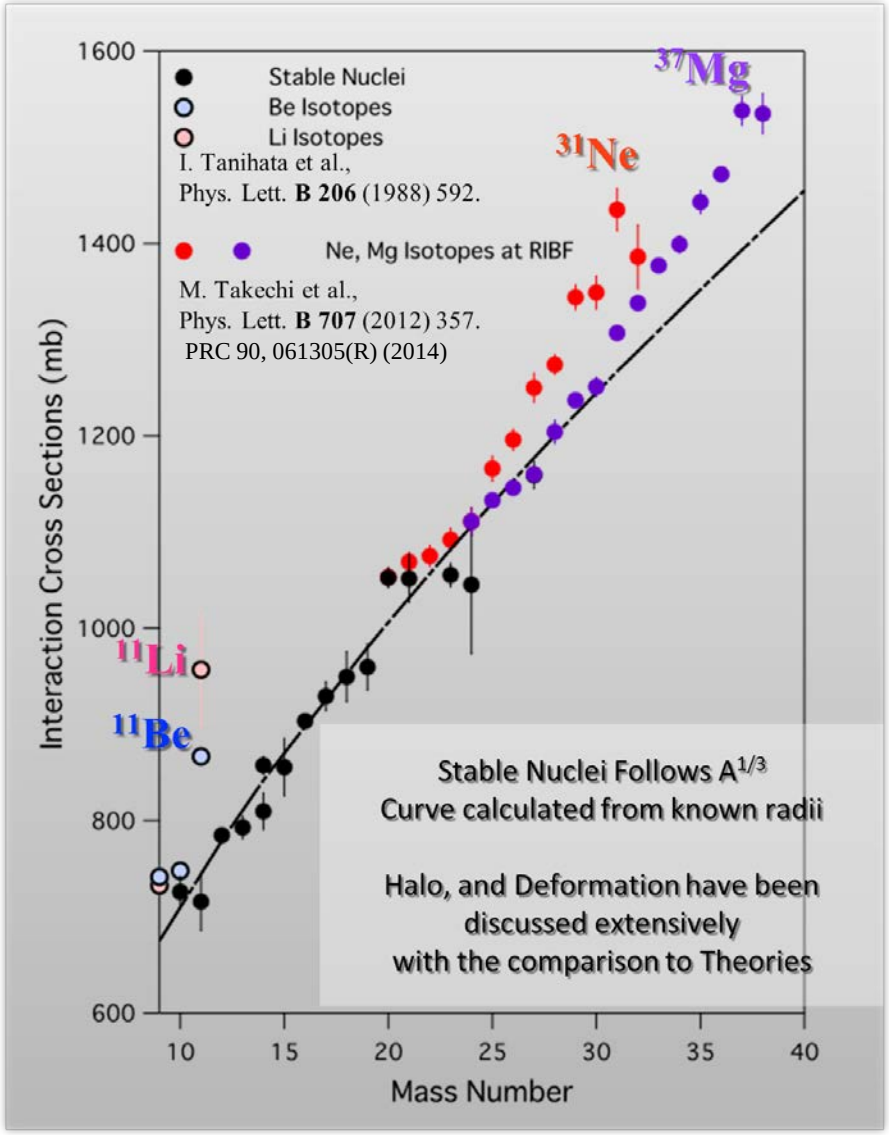
Korea: B. Hong, G. Jhang, Y. J. Kim, H. S. Lee, J. W. Lee

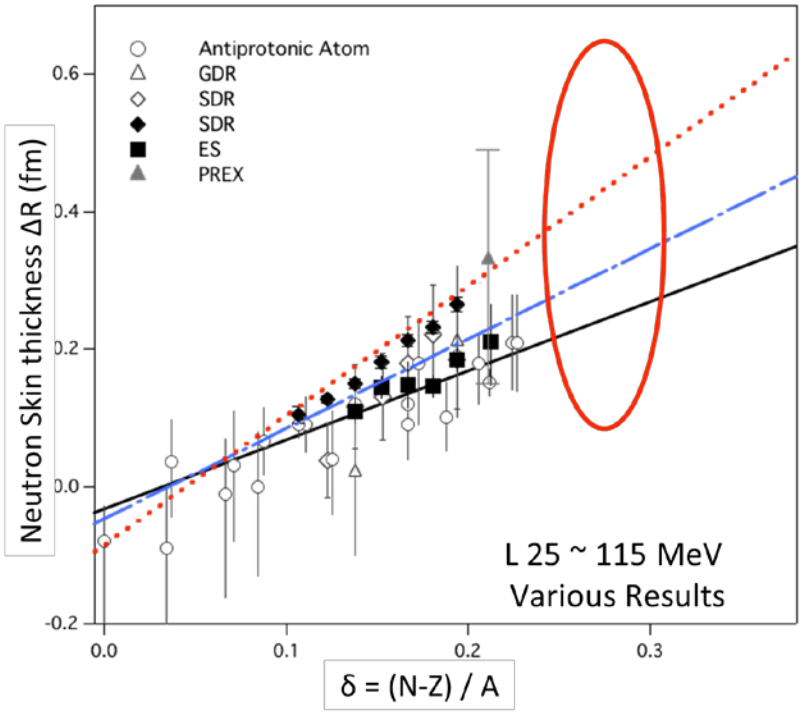
Poland: P. Lasko, J. Lukasik, P. Pawlowski, K. Pelczar

Total Interaction Cross Section Measurements at RIBF Takechi et al.



Ni isotope data are coming up soon !

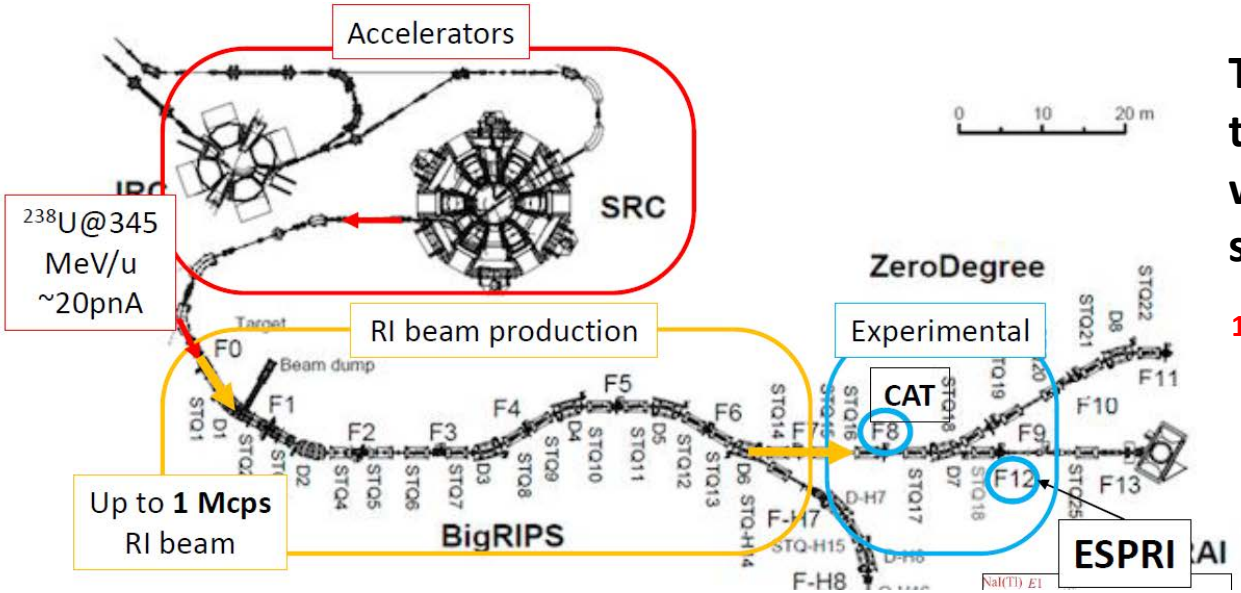




Anti Protonic Atom : A. Trzcinska et al., Phys. Rev. Lett. **87** 082501 (2001).
GDR : A. Krasznahorkay et al., Nucl. Phys. A 567 521 (1994).
SDR : A. Krasznahorkay et al., Phys. Rev. Lett. 82, 3216 (1999).
SDR : A. Krasznahorkay et al., Nucl. Phys. A 731 224 (2004).
ES : S. Terashima et al., Phys. Rev. C 77 024317 (2008).
ES : J. Zenihiro et al., Phys. Rev. C 82 044611 (2010).

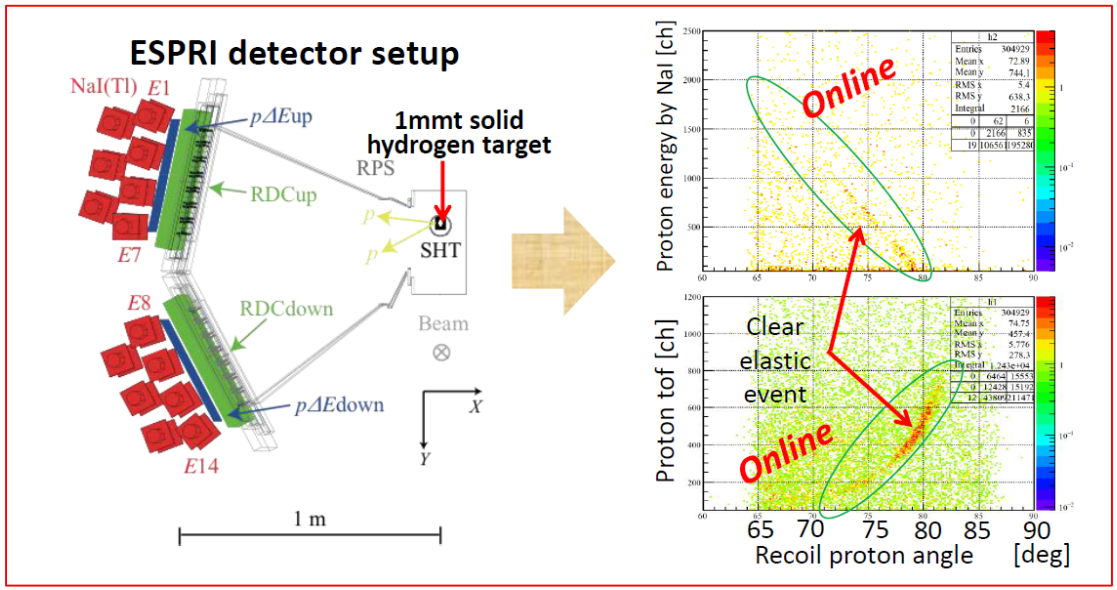
NP1512-RIBF79R1 Zenihiro et al
Proton elastic scattering of ^{132}**Sn** with ESPRI

BigRIPS

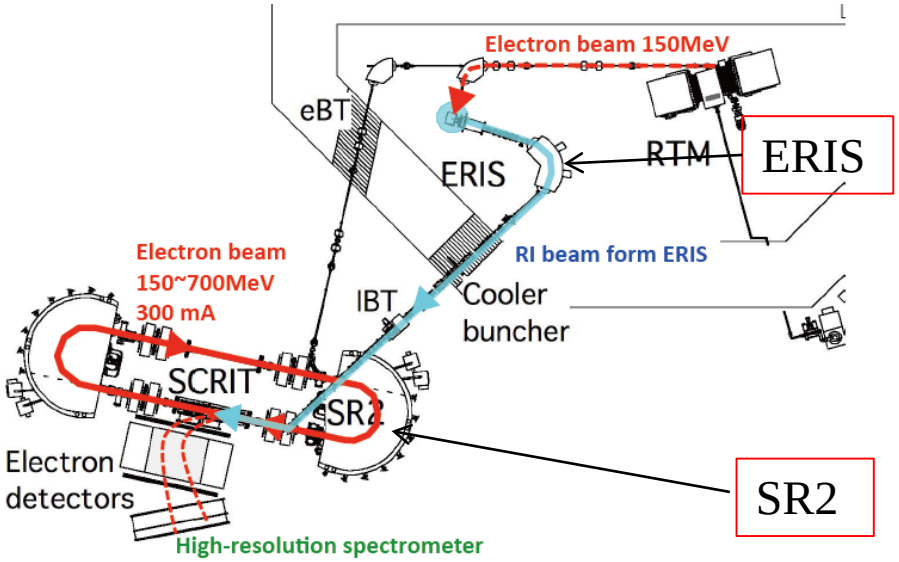


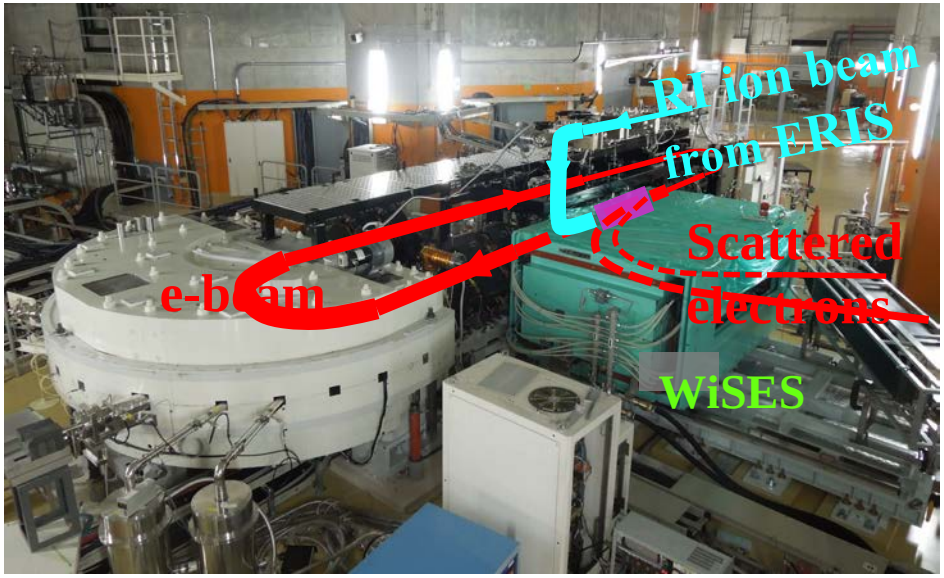
To extract the neutron skin thickness of unstable nuclei w/ large δ from proton elastic scattering in inverse kinematics

^{132}Sn (p, p) at 200 MeV/u



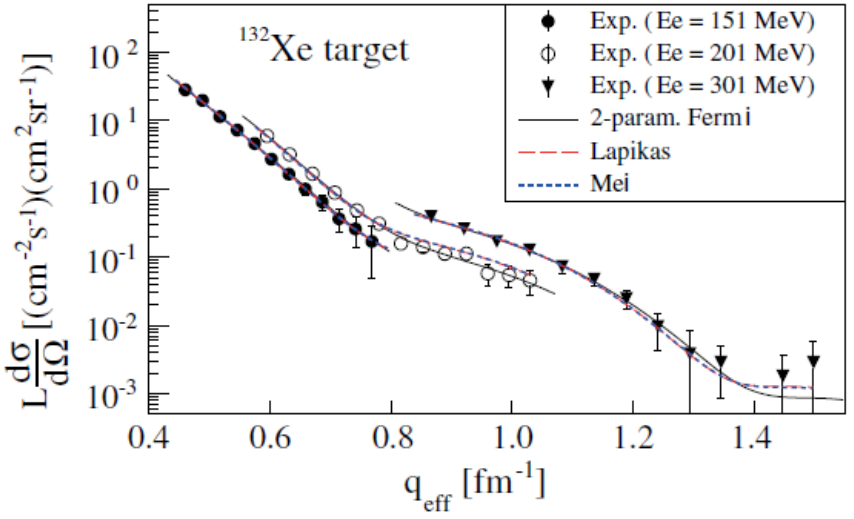
SCRIT Facility for e+RI scattering





First elastic scattering from ^{132}Xe

Tsukada et al., PRL118, 262501 (2017)



Luminosity of 10^{27}/(cm^{2}s) was achieved at the e-beam current of 250mA.

Efficiency improvement
More high power beam 10W->1kW
-> 10^{29}/cm^2/s

Measurement of Giant Monopole Resonance in 132Sn

BigRIPS

RIBF113: S. Ota et al.

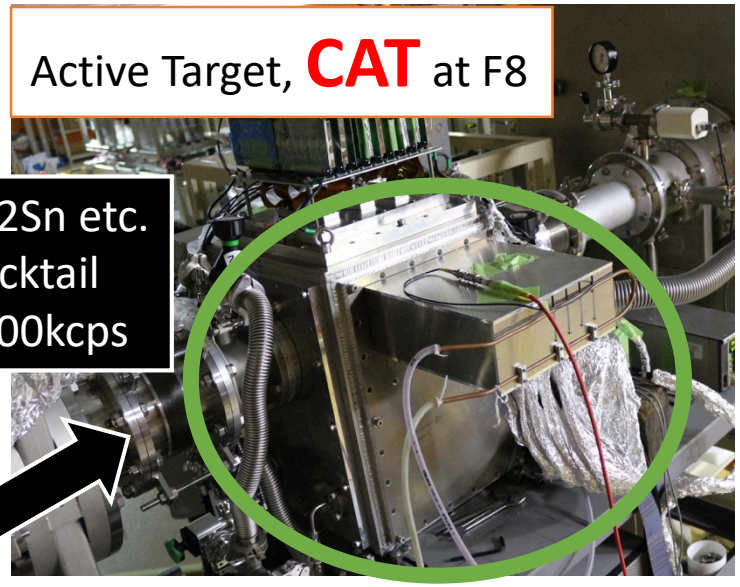
Is the neutron star soft?

<= symmetry term of EoS

<= isospin incompressibility K_τ as a baseline

Measurement of (d,d') was performed in April, 2016

Active Target, **CAT** at F8



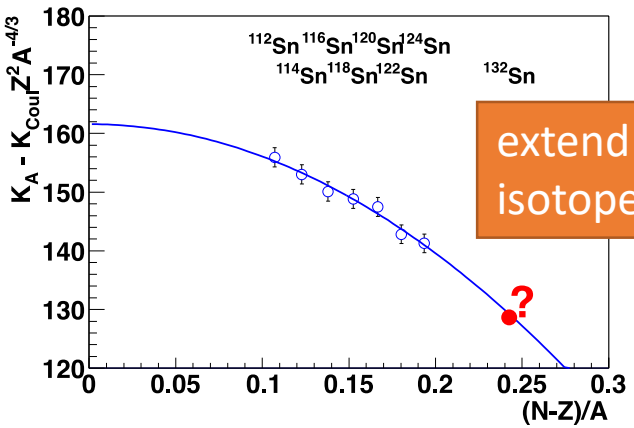
132Sn etc.
Cocktail
>300kcps

$$\mathcal{E}(\rho,\alpha) = \mathcal{E}(\bar{x}_0,\alpha) + \tfrac{1}{2}[(1+3\bar{x}_0)^2\mathcal{E}''(\bar{x}_0,\alpha)]\bar{x}^2 + \cdots$$
$$\equiv \varepsilon_0(\alpha) + \tfrac{1}{2}K_0(\alpha)\bar{x}^2 + \cdots,$$

$$K_0(\alpha) = K_0 + K_\tau\alpha^2 + \mathcal{O}(\alpha^4)$$

$$K_A \sim K_{\rm vol}(1+cA^{-1/3}) + K_\tau[(N-Z)/A]^2 + K_{\rm Coul}Z^2A^{-4/3},$$

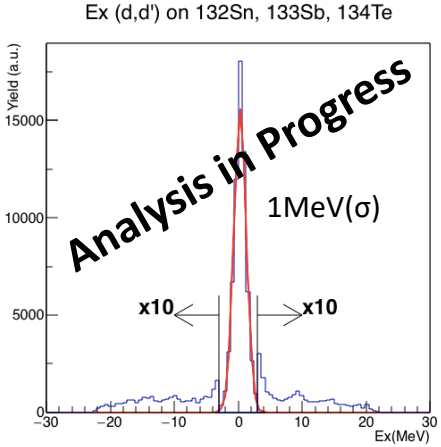
Measure K_A as a function of $[(N-Z)/A]^2$



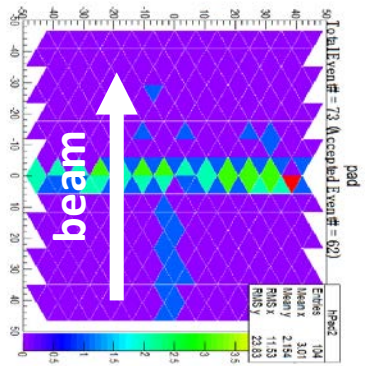
extend along the isotope chain to 132Sn

$$E_{\rm GMR} = \hbar\sqrt{\frac{K_A}{m<r^2>}},$$

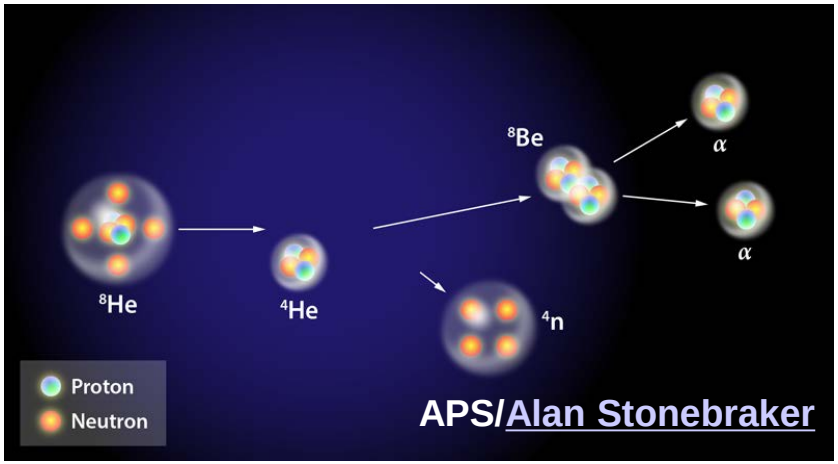
Excitation energy spectrum
(for cocktail beam of 132Sn,133Sb,133Te)

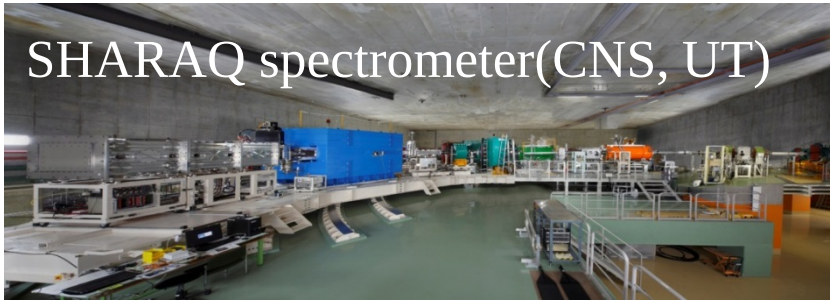


hit pattern in TPC

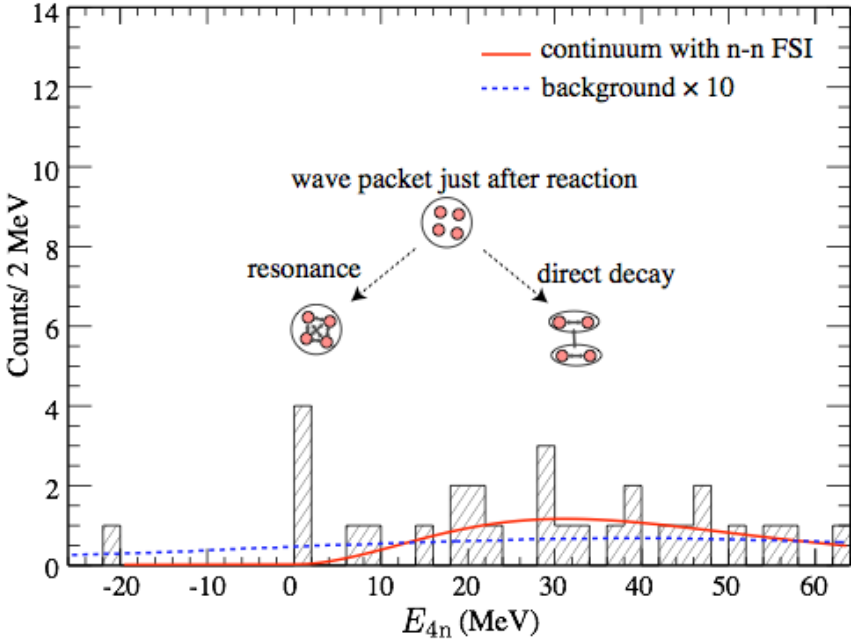


Element Number Zero: Tetra-neutron system





Kisamori, Shimoura et al.,
PRL 116, 052501 (2016)



"Nucleus made only of neutrons"
Benchmark for ab initio calculations
NN, NNN, NNNN… interactions
T=3/2, 2 interactions ??
T=1/2 d+p
K. Sekiguchi et al., Phys.Rev. C 83, 06100 (2011); Phys. Rev. C89, 064007 (2014)

A high statistics experiment was conducted June 2016.

Clear strength with 4.9σ significance level
E_{4n} = 0.83 ± 0.65 (stat.) ± 1.25 (syst.) MeV
Upper limit of Γ = 2.6 MeV (FWHM)
Cross section: 3.8 nb
(integrated up to θ_{CM} < 5.4 degree)
Energy resolution: 1.2 MeV
Uncertainty of calibration: ± 1.3 MeV
Background : 0.02 events/2MeV

Many-neutron systems: search for superheavy ^{7}H and its tetraneutron decay

SAMURAI

NP1512-SAMURAI34
July 2017

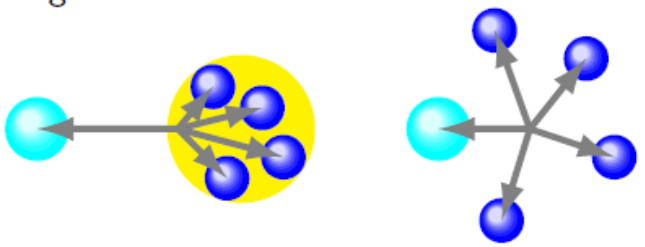
Yang and Marques, et al.

^{8}He(p,2p)^{7}H -> ^{3}H+^{4}n

- **MINOS** liquid H target :
  - → high luminosity (*statistics*)
  - → proton angles (*resolution*)
- **DALI** NaI crystals :
  - → proton energies (*efficiency*)
- **SAMURAI** :
  - → triton momentum (*resolution & correlations*)
- **NEBULA** + **NeuLAND** :
  - → 3/4 neutron momenta (*efficiency, resolution & correlations*)

$$\text{FWHM} \sim \begin{cases} 5 \text{ MeV} & (2p) \\ 150 \text{ keV} & (2p+t+3n) \\ 100 \text{ keV} & (t+4n)\ !!! \end{cases}$$

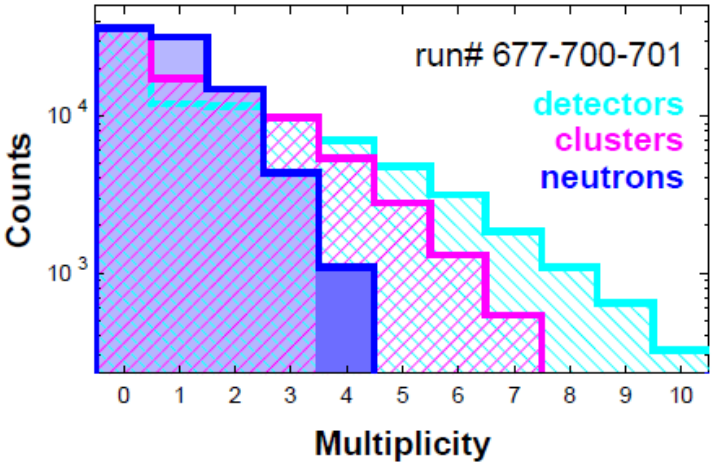
- Angular correlations :



(2-body PS) (5-body PS)

→ sensitive to $E_R(^4n)$ for any Γ !

- On-line [Revel] : ^{8}He (p,2p)^{3}H



→ complete events : 1k/90 min ≈ 10^5 !!!

E1 response of ^{52,50}Ca

NP1312 SAMURAI9 R1
April 2017
SAMURAI

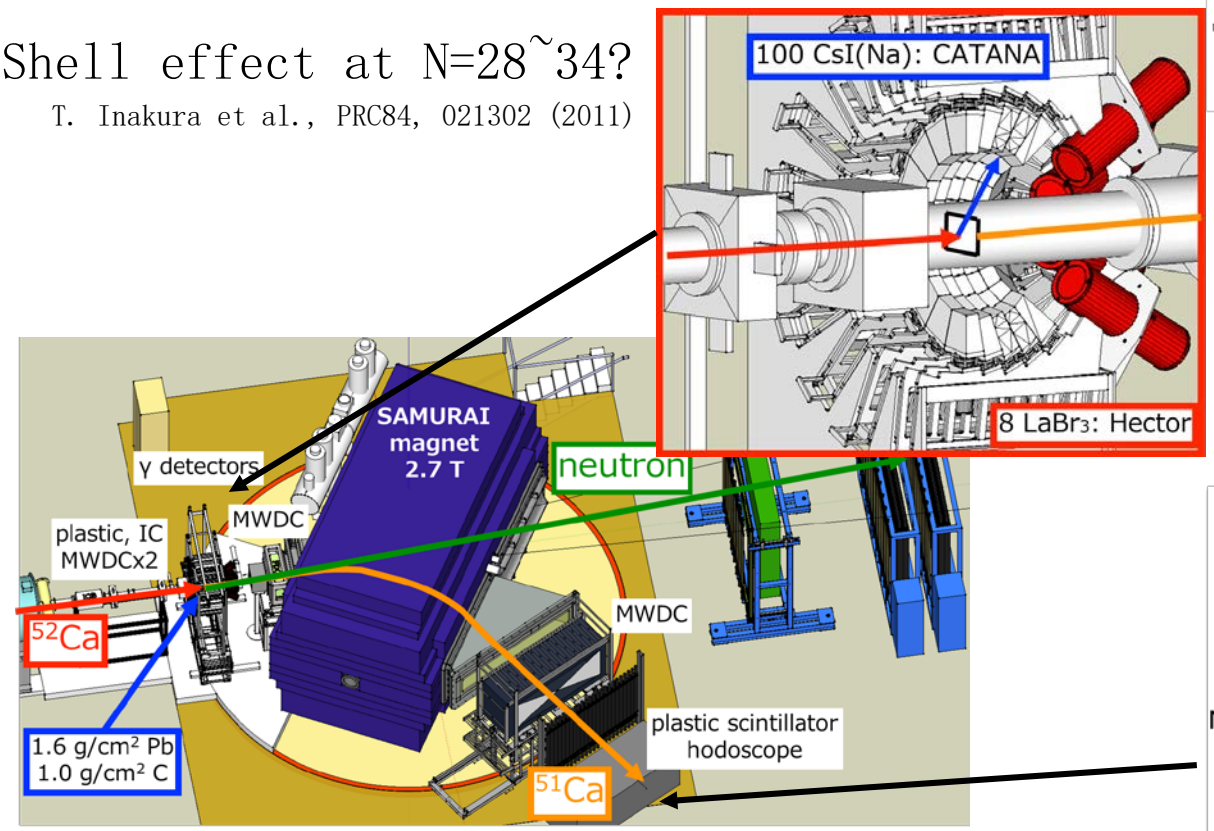
Togano and Kobayashi et al.

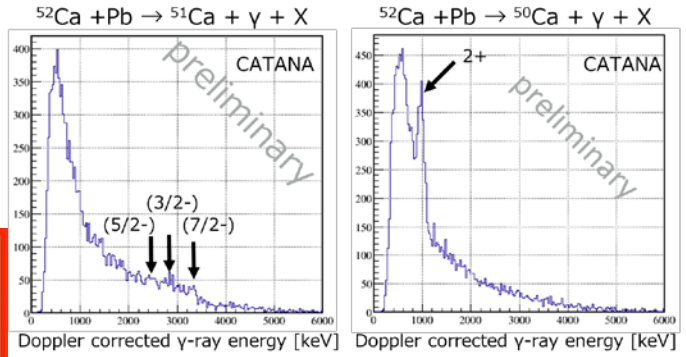
Investigation of skin through PDR

T. Inakura et al., PRC88, 051305 (2013)

Shell effect at N=28~34?

T. Inakura et al., PRC84, 021302 (2011)

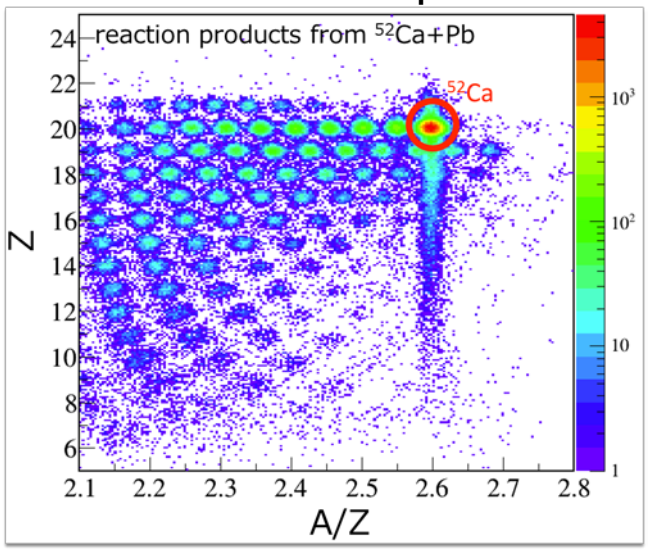




Known transitions were observed

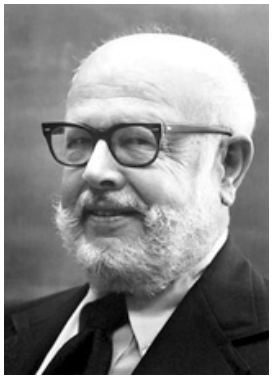
CsI + $LaBr_3$

PID for reaction products

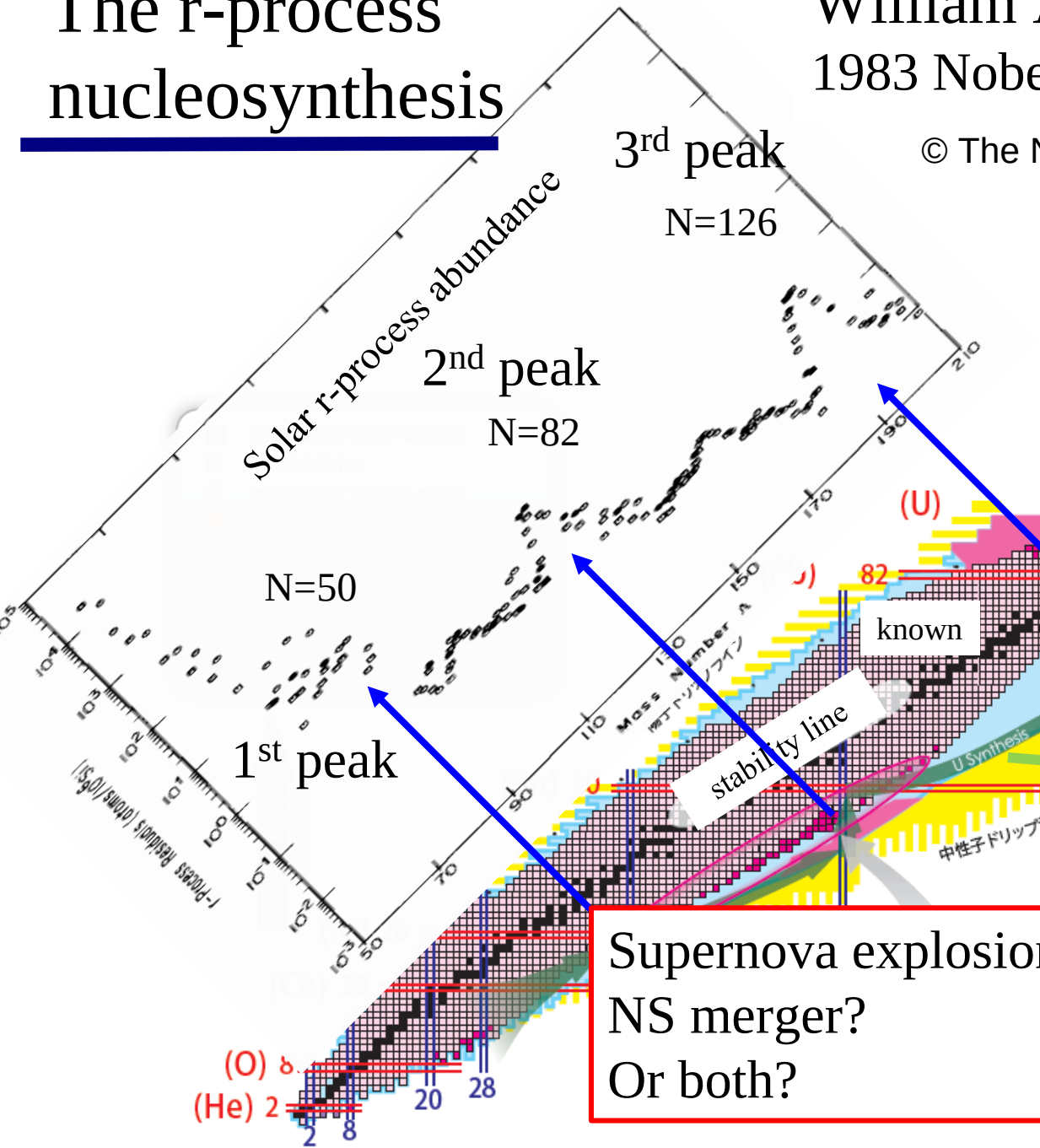


Primary beam: ^{70}Zn (~140 pnA)
^{52}Ca: 1 kcps, ^{50}Ca: 16 kcps

The r-process nucleosynthesis



William A. Fowler
1983 Nobel Prize Physics



r-process path

rapid neutron-capture
vs beta-decay
Mass -> path location
Half-life -> matter flow

Supernova explosion?
NS merger?
Or both?

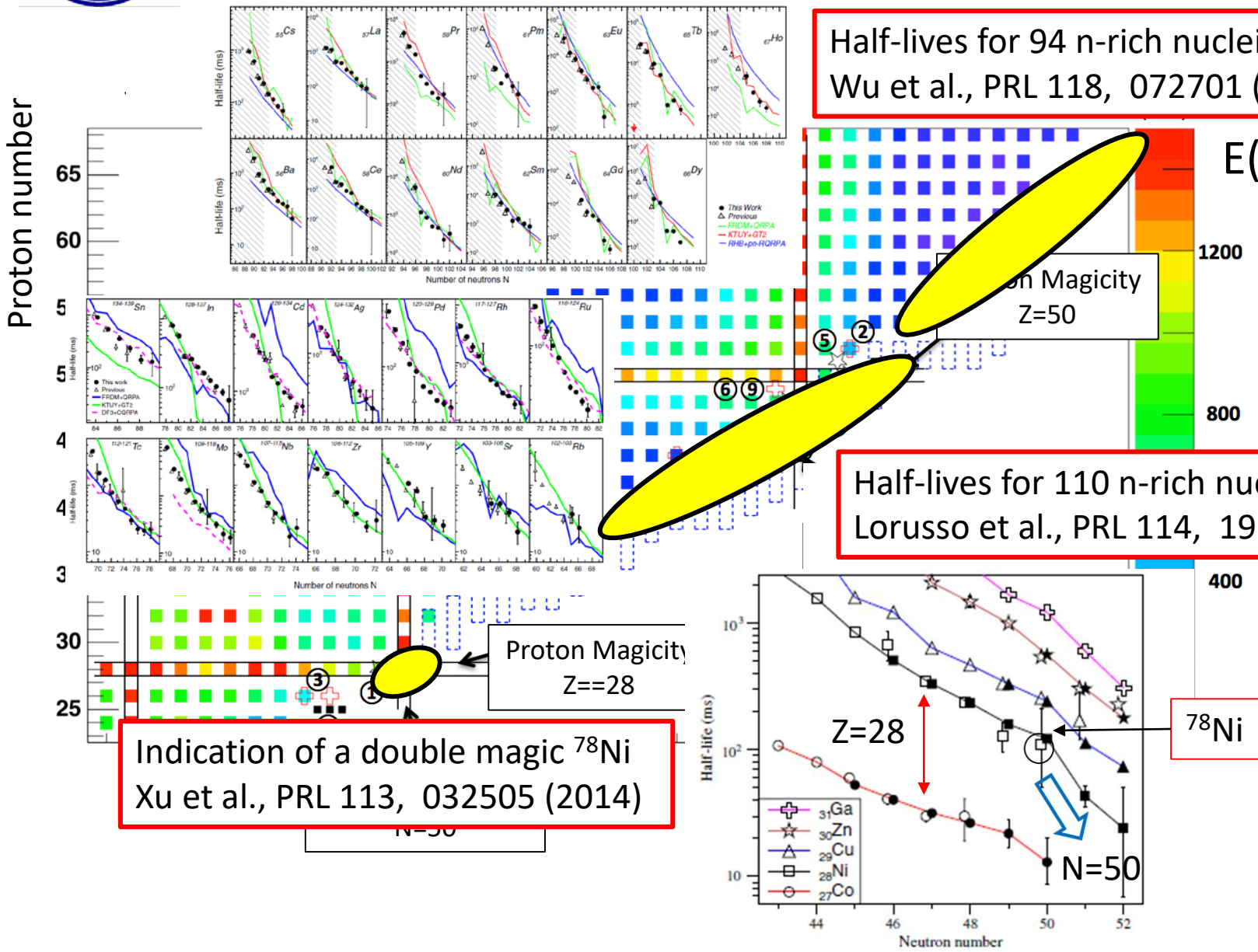
NS merger
Stiff EOS -> low T
Soft EOS -> high T

EURICA Achievements (2012-): Half-lives

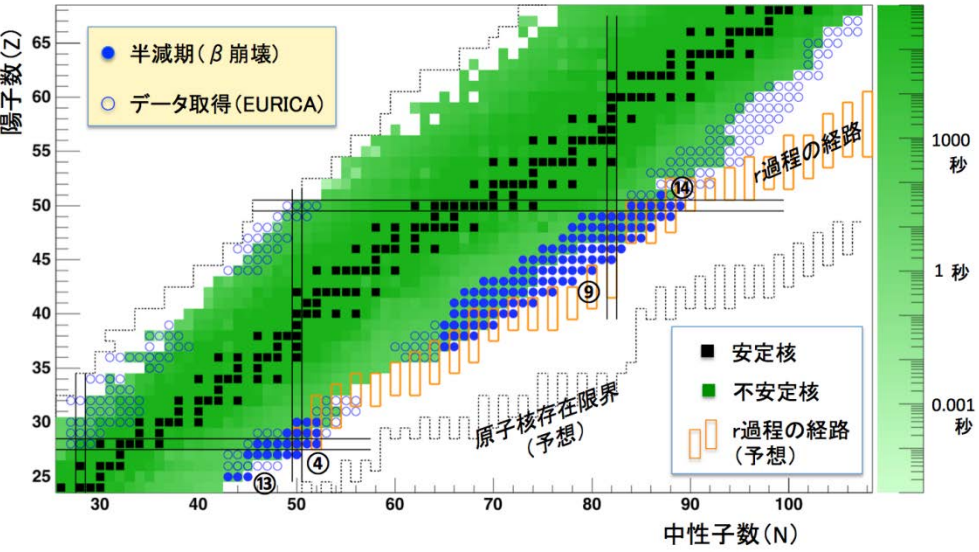
Half-lives for 94 n-rich nuclei
Wu et al., PRL 118, 072701 (2017)

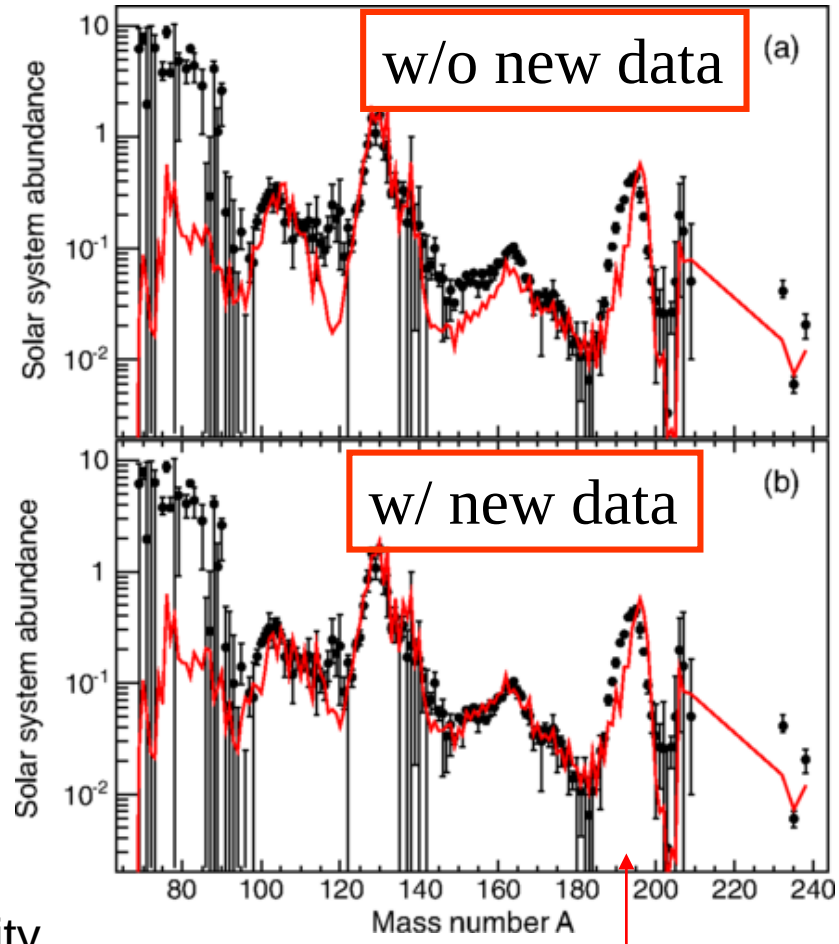
Half-lives for 110 n-rich nuclei
Lorusso et al., PRL 114, 192501 (2015)

Indication of a double magic ^{78}Ni
Xu et al., PRL 113, 032505 (2014)



“Revolution” in the r-process research





Bunch of T1/2 data for A~100
A standard model assuming (n,gamma) equilibrium reproduces the r-abundance up to rare-earth region

Mass, beta-delayed neutron emission probability measurement in future

G. Lorusso, S. Nishimura *et al. PRL*. 114, 192501 (2015)

Next step should be for the 3rd peak

S. Nishimura et al., PRL. 106, 052502 (2011)
Z. Y. Xu, S. Nishimura *et al.*: PRL. 113, 032505 (2014)
G. Lorusso, S. Nishimura *et al.*: PRL. 114, 192501 (2015)
G. Benzoni, A.I. Morales, H. Watanabe *et al.*: PRC 92, 044320 (2015)
P. Lee, C.-B. Moon, C. S. Lee, A. Odahara *et al.*: PLB 751, 107 (2015)

BRIKEN : β-Delayed Neutron Study 2017-

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

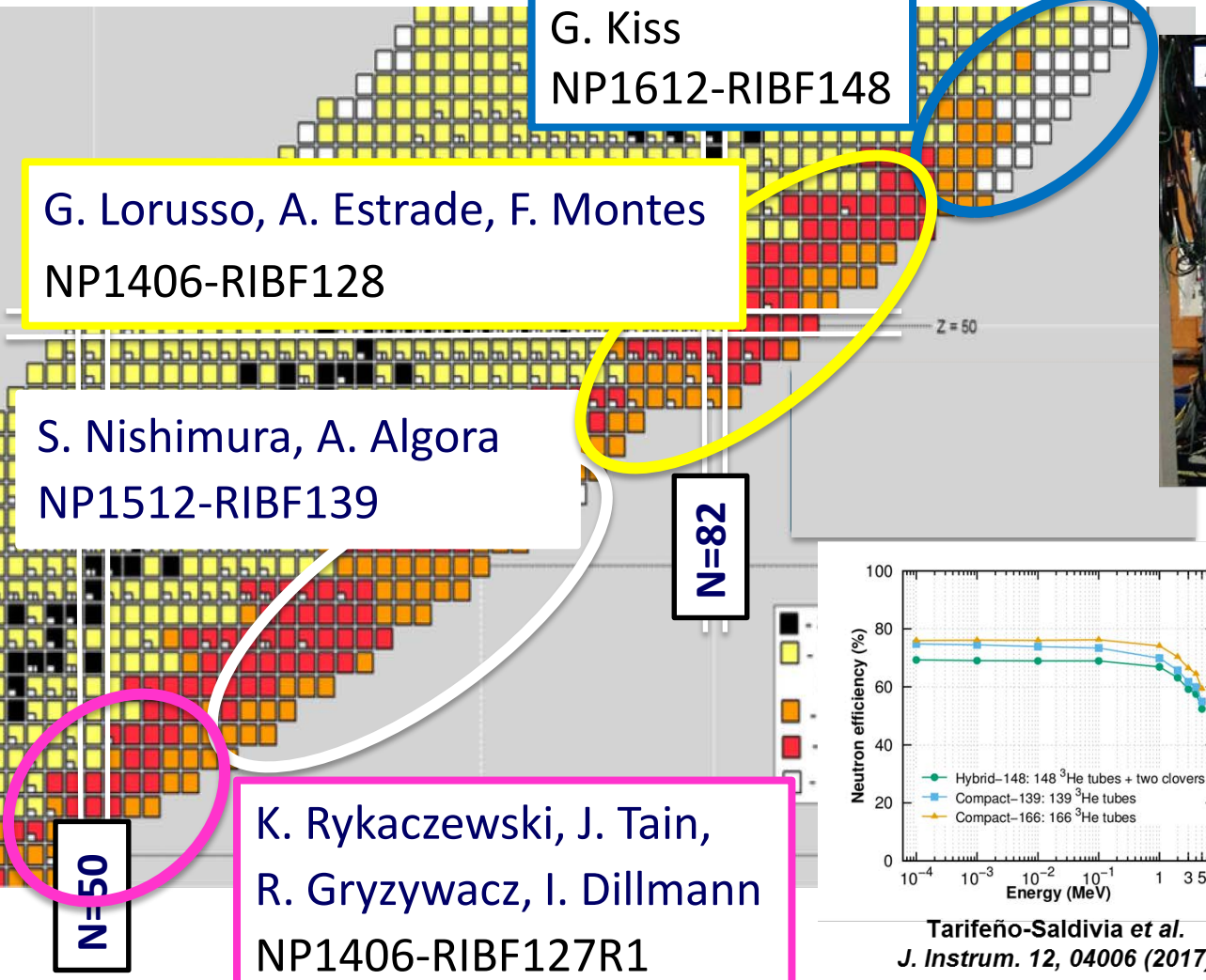
(1) (unexpected) trends → Nuclear structure
(2) Study for r-process nucleosynthesis

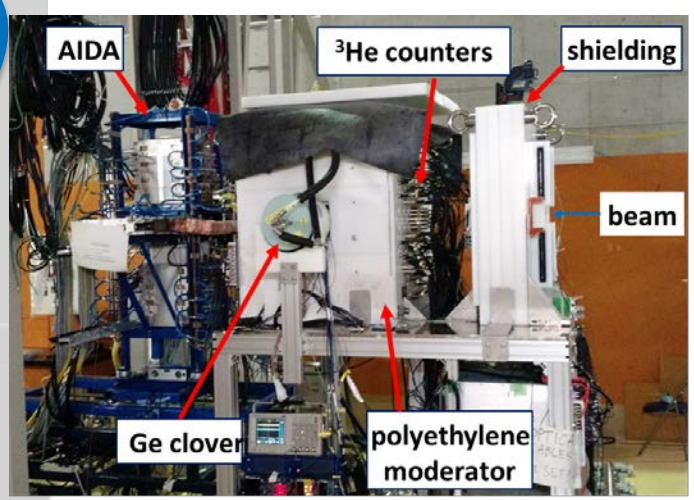
G. Kiss
NP1612-RIBF148

G. Lorusso, A. Estrade, F. Montes
NP1406-RIBF128

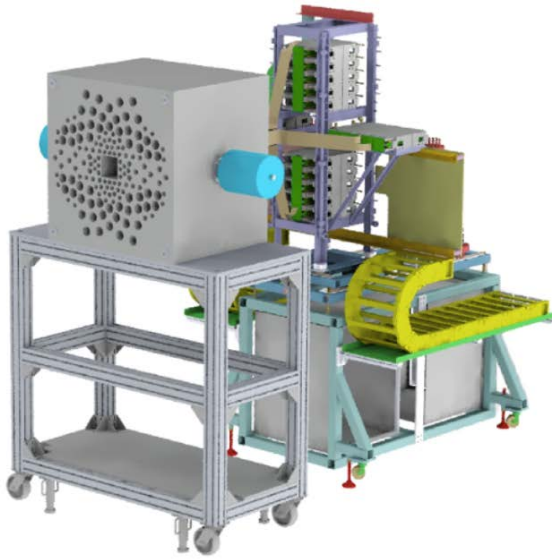
S. Nishimura, A. Algora
NP1512-RIBF139

K. Rykaczewski, J. Tain,
R. Gryzywacz, I. Dillmann
NP1406-RIBF127R1



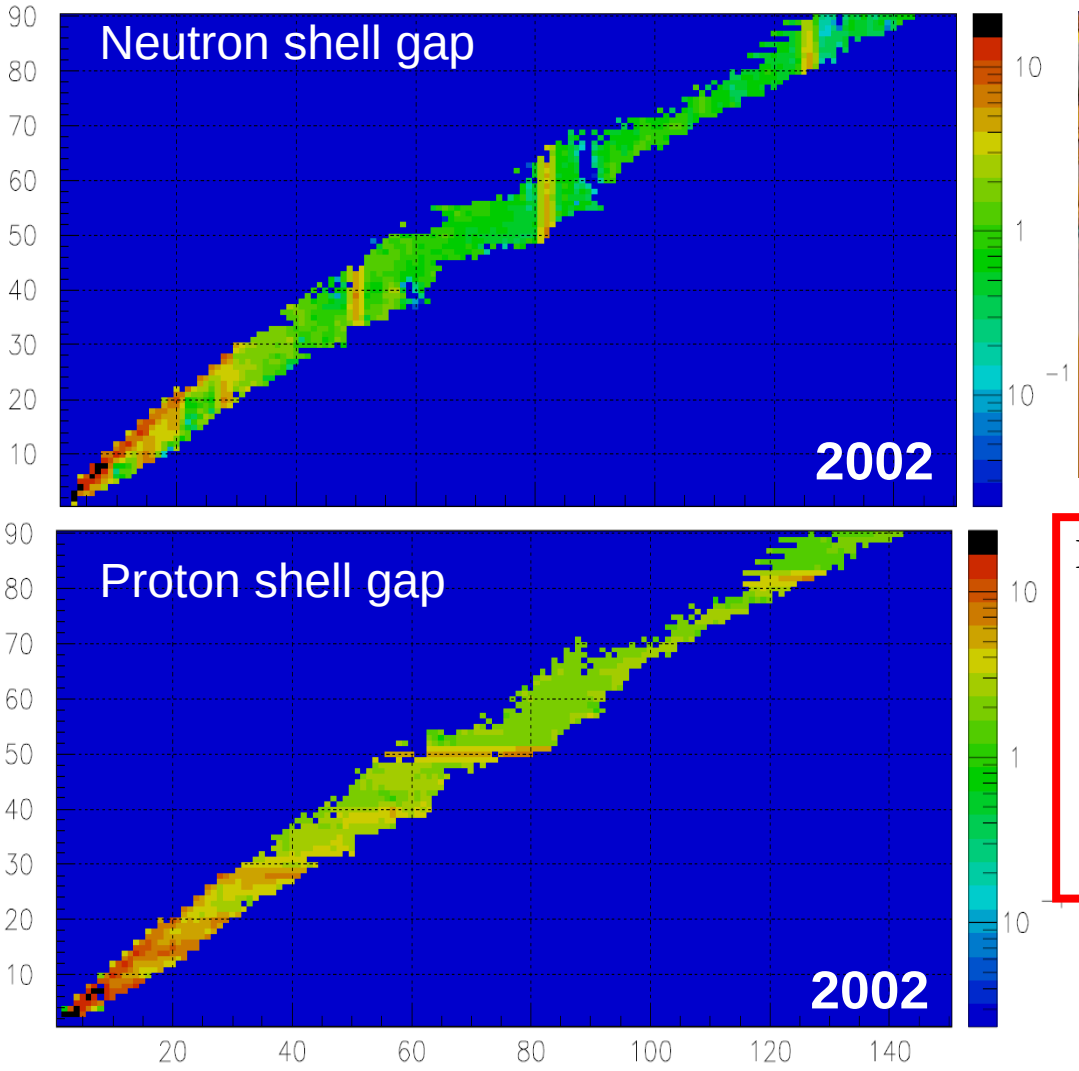


Tarifeño-Saldivia *et al.*
J. Instrum. 12, 04006 (2017)



Mass measurements for shell evolution

Yamaguchi (Saitama U.), Wakasugi (RIKEN), Uesaka (RIKEN), Ozawa (Tsukuba U.), et al.



Key technologies:
- Isochronous ring
  - $\Delta T/T < 10^{-6}$ for $\delta p/p = \pm 0.5\%$
- Individual injection triggered by a detector at BigRIPS
  - efficiency ~ 100%
  - even for a “cyclotron” beam

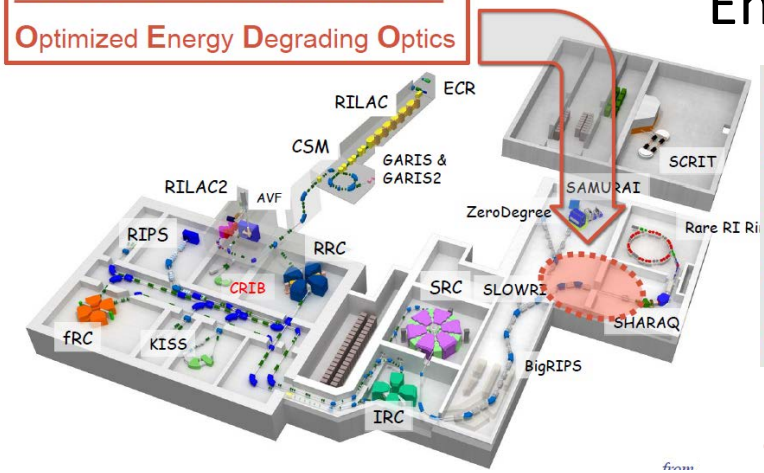
Schedule:
- **2015 Commissioning run**
- **2016~ Mass measurements of RI**

CNS-RIKEN: OEDO Project

Shimoura et al

OEDO Beam-line

Optimized Energy Degrading Optics



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)

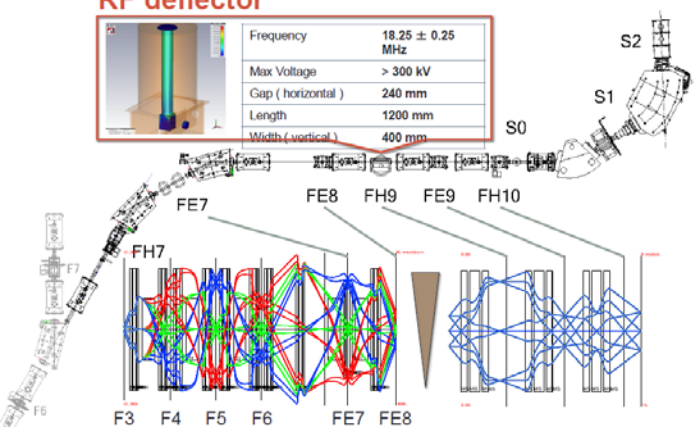
Coulomb excitation reactions for low-energy gamma rays (~ 50A MeV)

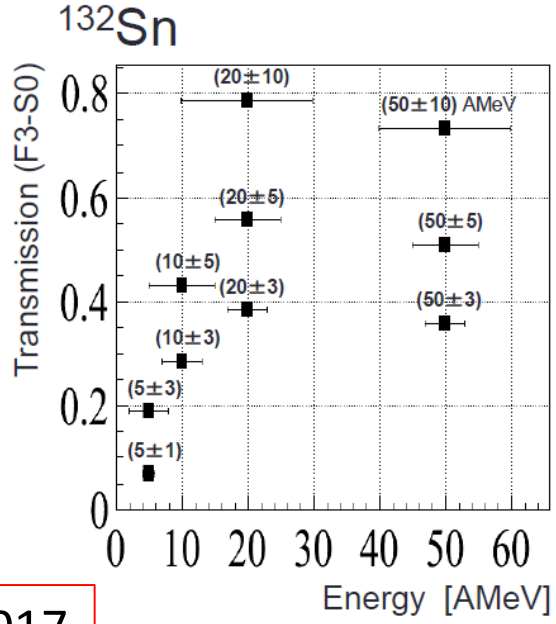
Transmission and intensity

Magnet configuration and optical condition

RF deflector

Frequency	18.25 ± 0.25 MHz
Max Voltage	> 300 kV
Gap (horizontal)	240 mm
Length	1200 mm
Width (vertical)	400 mm





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

Typical example of ^{132}Sn

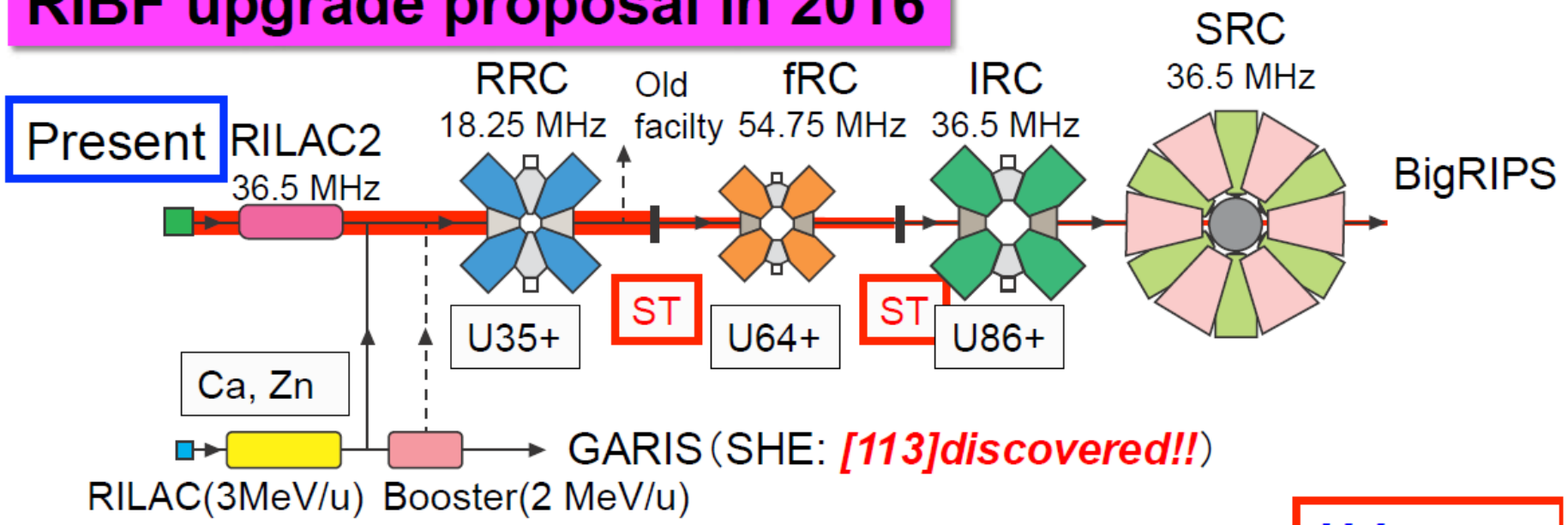
based on actual intensity in experiment by using 345 AMeV 30pnA U primary beam (Apr. 2015)

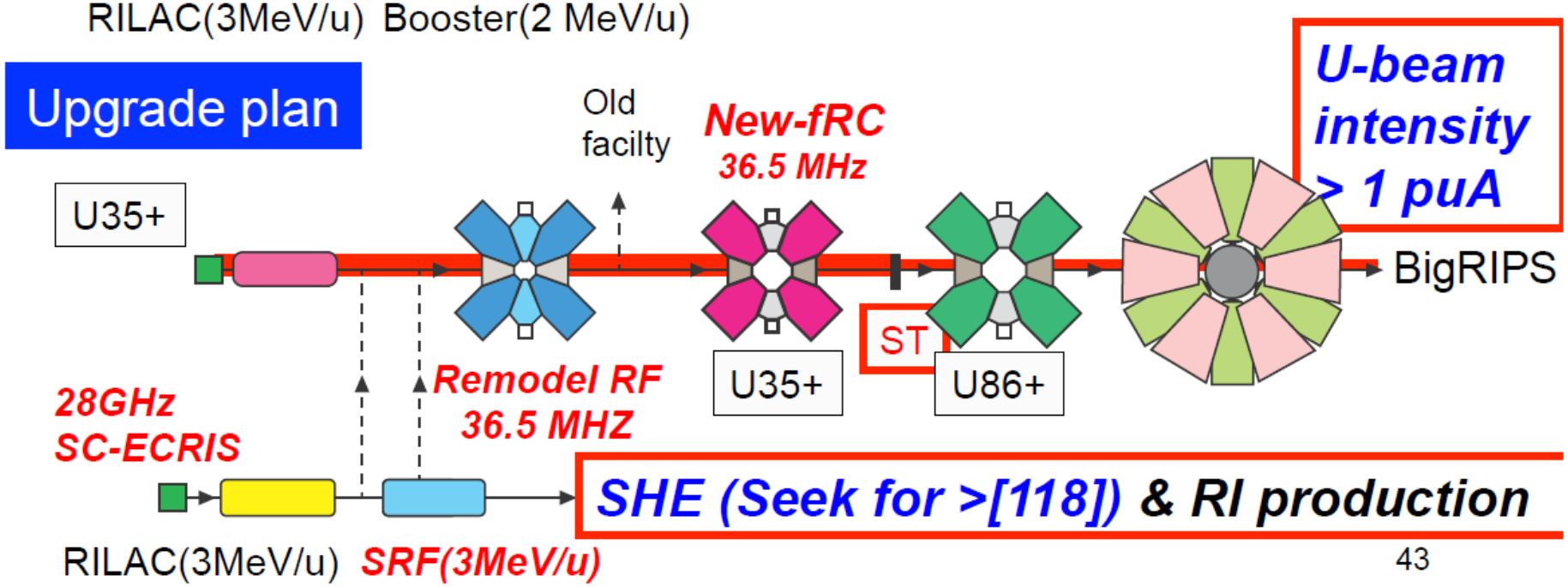
Intensity @ F3 (Apr. 2015)	2.5×10^6 [pps]
50 ± 5 AMeV @ S0	1.3×10^6
20 ± 3 AMeV @ S0	9.5×10^5
10 ± 3 AMeV @ S0	7.5×10^5
5 ± 1 AMeV @ S0	1.7×10^5

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

Operation started in autumn, 2017

RIBF upgrade proposal in 2016





Summary

On-going EOS Programs at RIBF

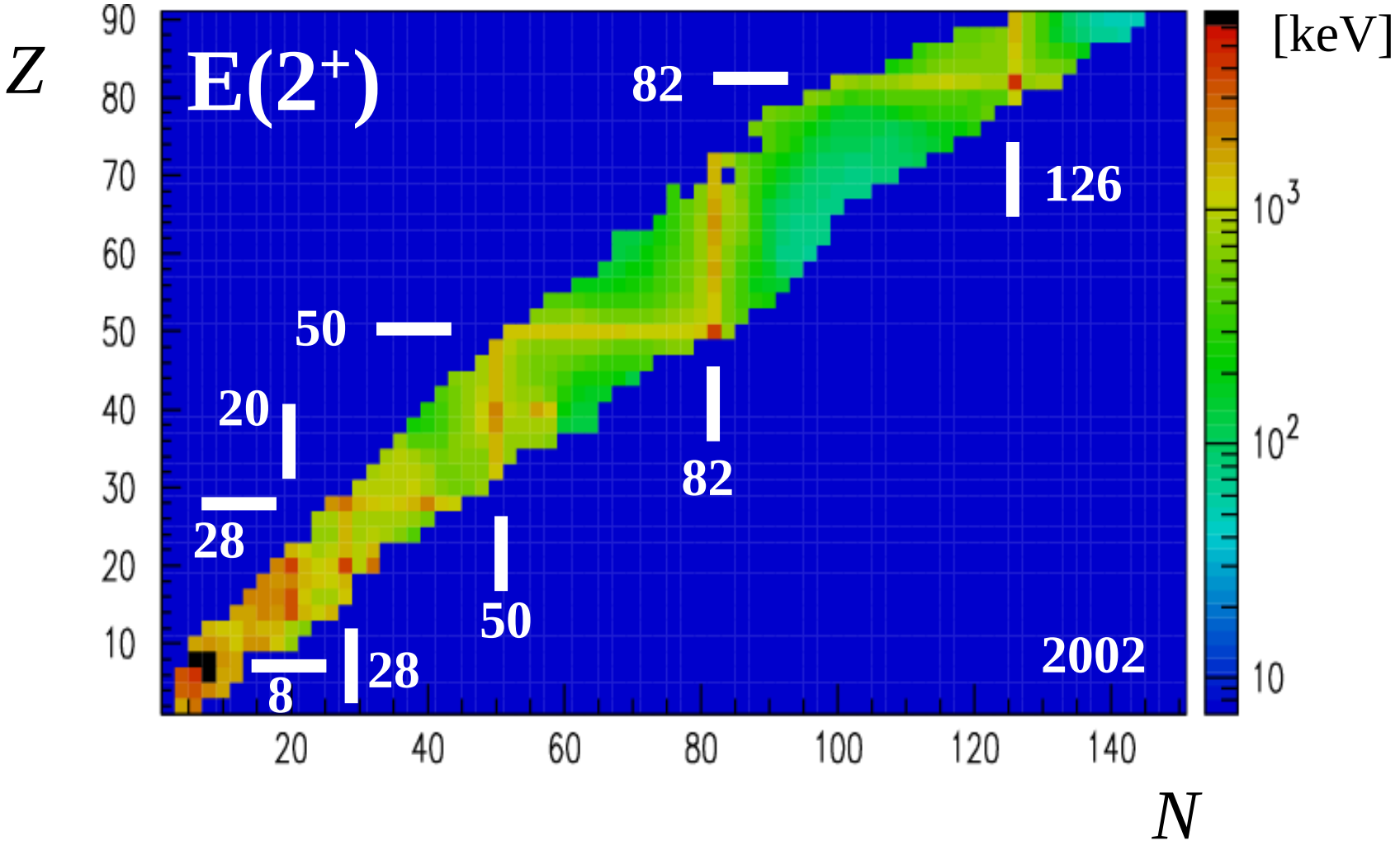
SAMURAI TPC SpiRIT Collaboration
Total interaction cross section measurements
Proton and Electron elastic scattering for matter and proton distribution
GMR and GDR measurements
Tetra neutron spectroscopy with missing mass and invariant mass
3NF study with d+p elastic scattering

r-process path

Bunch of data for Half-life and Pn
Mass information will be produced soon

The OEDO beam line is completed to start new projects with low energy reactions such as fusion, deep-inelastic.
RILAC upgrade will be completed in 2019. Ca and Zn beams at SRC will be increased
RIBF intensity upgrade for the U beam is waiting for green-sign by the government

Magicity and its loss through determining $E(2^+)$

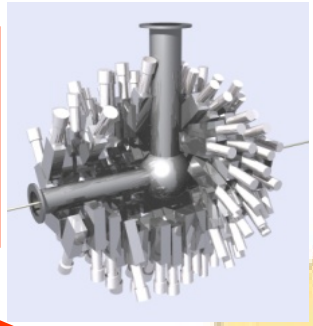


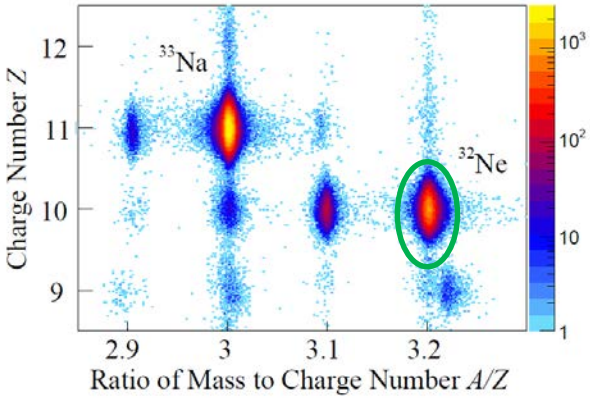
Spectroscopy via reactions with in-beam gamma method

Sunflower Collaboration

Secondary target: H_2, C, Pb….
Gamma-detectors : DALI2 NaI array
to measure de-excited gamma rays

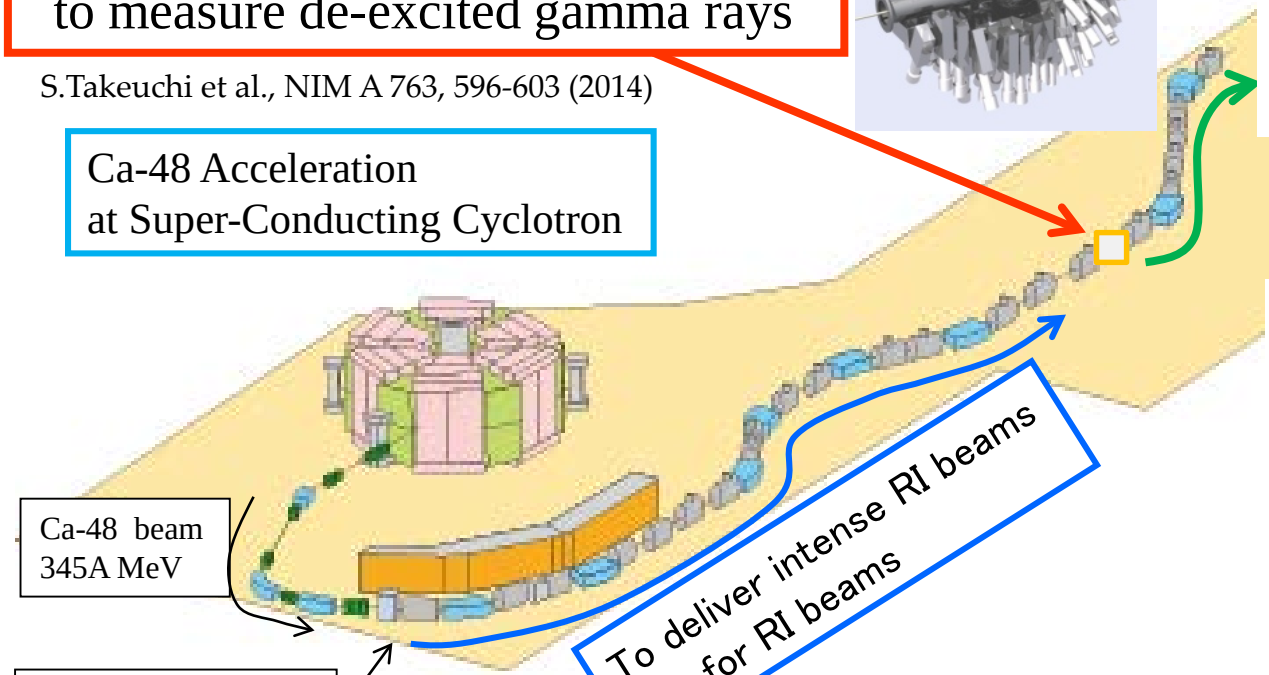
S.Takeuchi et al., NIM A 763, 596-603 (2014)

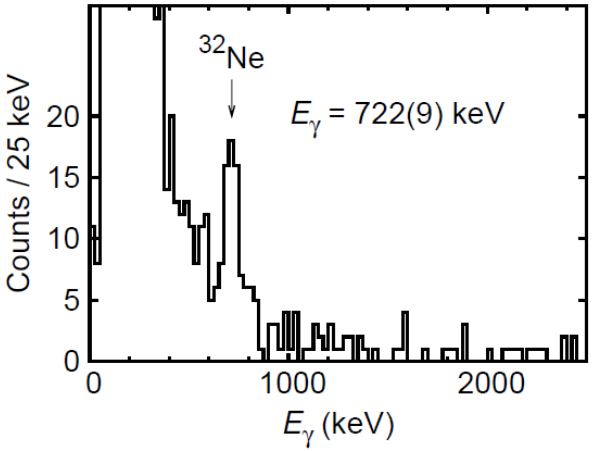




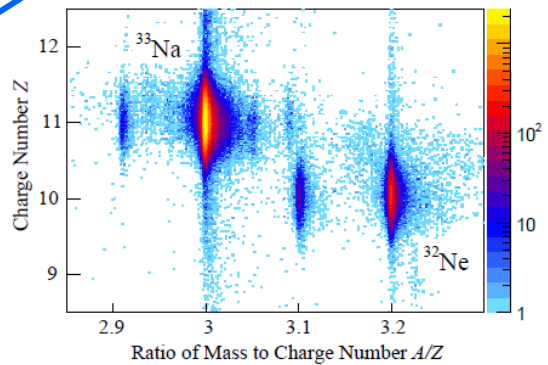
Ca-48 Acceleration
at Super-Conducting Cyclotron

PID at ZeroDegree





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



Achievements with DALI2 at ZD since 2008-

2+ and 4+ for Even-Even Light n-rich nuclei

Shape transition

Halo Nuclei

Island-of-inversion region and beyond (N=20-28)

Magicity at N=82 and Z=50?

^{126}Pd: Wang, PRC 88 054318 (2013)
^{136}Sn: Wang, PTEP 023D02 (2014)
^{126}Cd: Wang, PRC 94 051301 (2016)
^{133}Sn: Vaquero, PRL118 202502 (2017)

Magicity at Z=50 and N=50?

^{104}Sn: Corsi, PLB 743, 451 (2015)
^{104}Sn: Doornenbal, PRC90, 061302 (2014)

^{80,82}Zn: Shiga, PRC 93, 024320 (2016)

Magicity at N=50?

New Magicity N=32, 34

Steppenbeck, Nature 502, 207 (2013)
^{50}Ar PRL 114, 252501 (2015)

"SEASTAR" project (MINOS+DALI2)

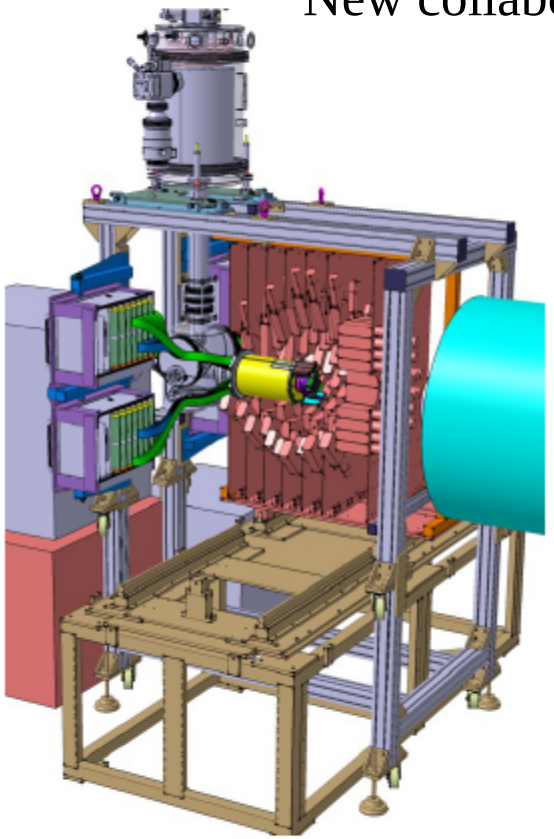
2014-2017

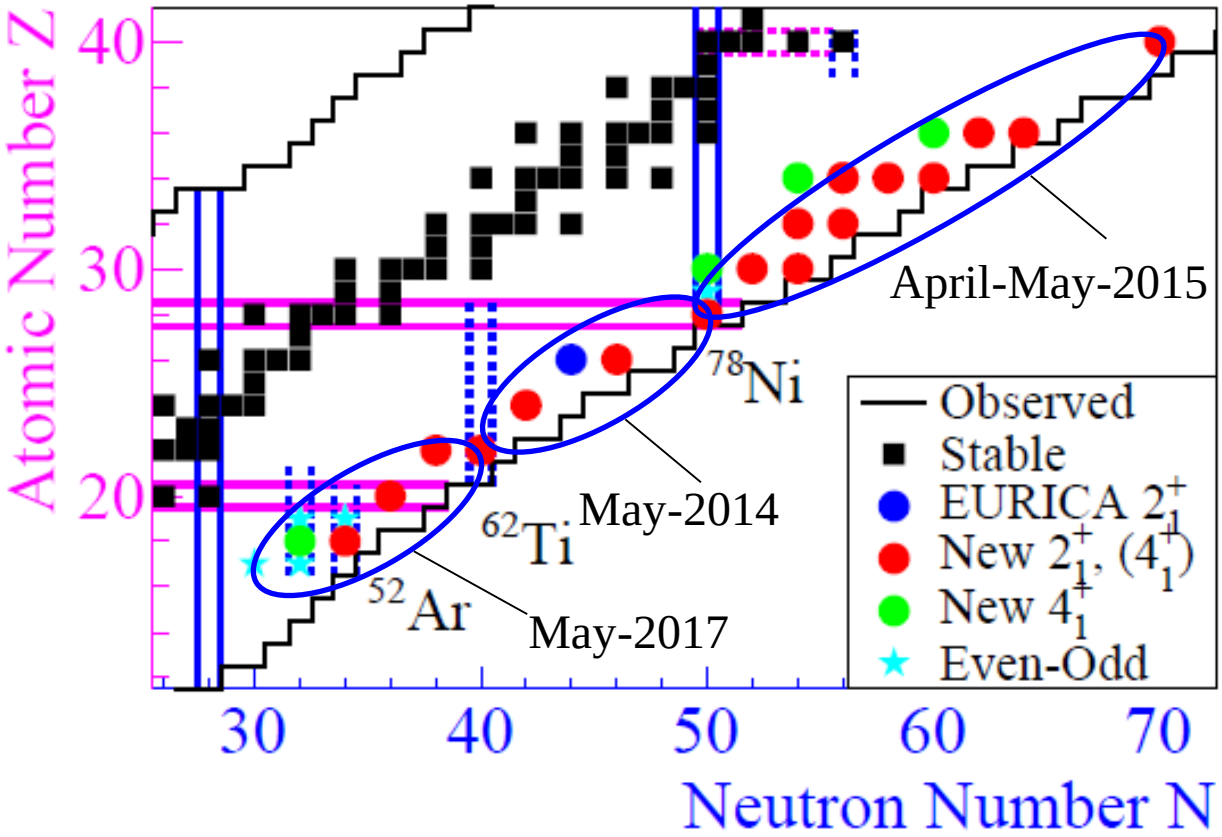
^{29}Ne : Kobayashi, PRC 93, 014613 (2016)
^{32}Ne:: Doornenbal, PRL 103, 032501 (2009)
^{31,32,33}Na: Doornenbal, PRC 81, 041305R (2010)
^{33,34,35}Na: Doornenbal, PTEP 2014, 053D01 (2014)
^{36,38}Mg: Doornenbal, PRL111, 212502 (2013)
^{32}Mg: Li, PRC 92, 014608 (2015)
^{42}Si : Takeuchi PRL109, 182501 (2012)
^{40}Mg : Crawford PRC 89, 041303 (2014)
^{31}Ne: Nakamura, PRL 103, 262501 (2009),
PRL, 112, 142501 (2014)
^{37}Mg: Kobayashi PRL 112, 242501,(2014)
^{30}Ne, ^{36}Mg B(E2): Doornenbal, PRC 93, 044306 (2016)

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





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

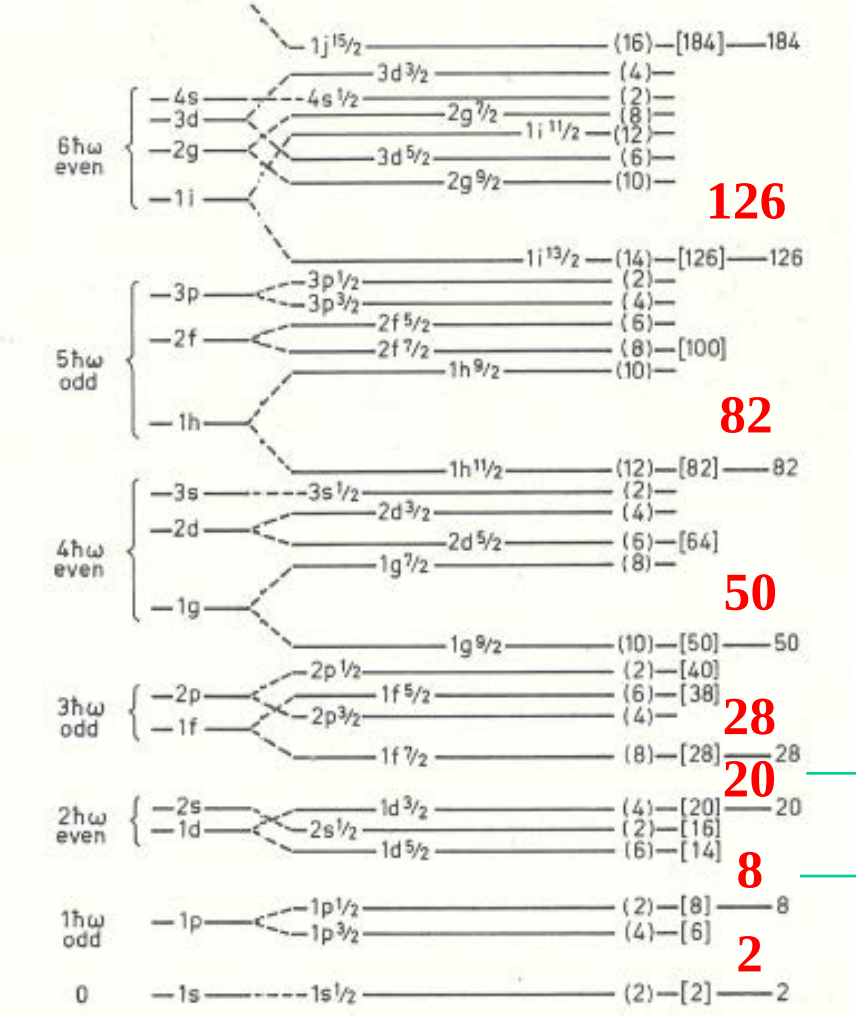
Nuclear Magic Numbers and Shell Evolution (1)

Stable nuclei

Neutron-rich nuclei

Mayer & Jensen

Nobel Prize 1963



? ? ? ?

→ loss

→ loss

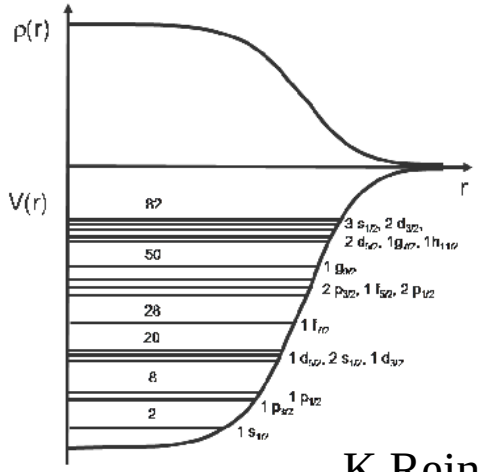
N=16

Shell Structure

One-body potential

Large LS term

(surface contribution)



K.Reiner

Magic numbers ->

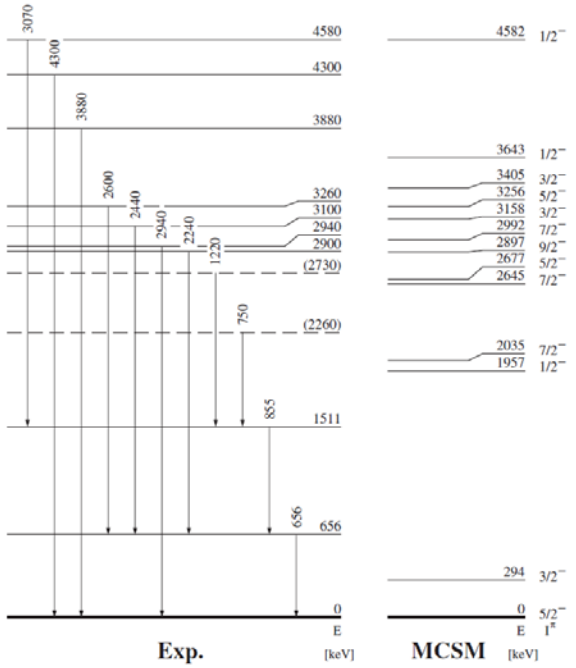
2, 8, 20, 28, 50 …

“Magic” Correlation between RIBF and ISOLDE

RIBF-SEASTAR

First Spectroscopy of ^{79}Cu

L. Olivier et al., PRL119, 192501 (2017)

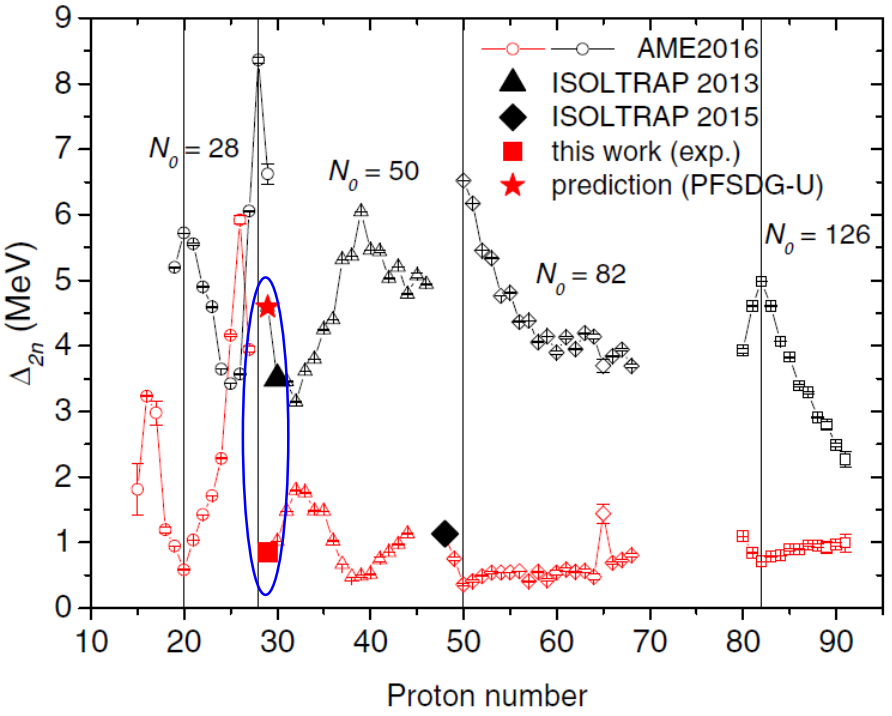


Large Z=28 gap at N=50

ISOLDE-ISOLTRAP

Binding Energy of ^{79}Cu

A. Welker et al., PRL119, 192502 (2017)

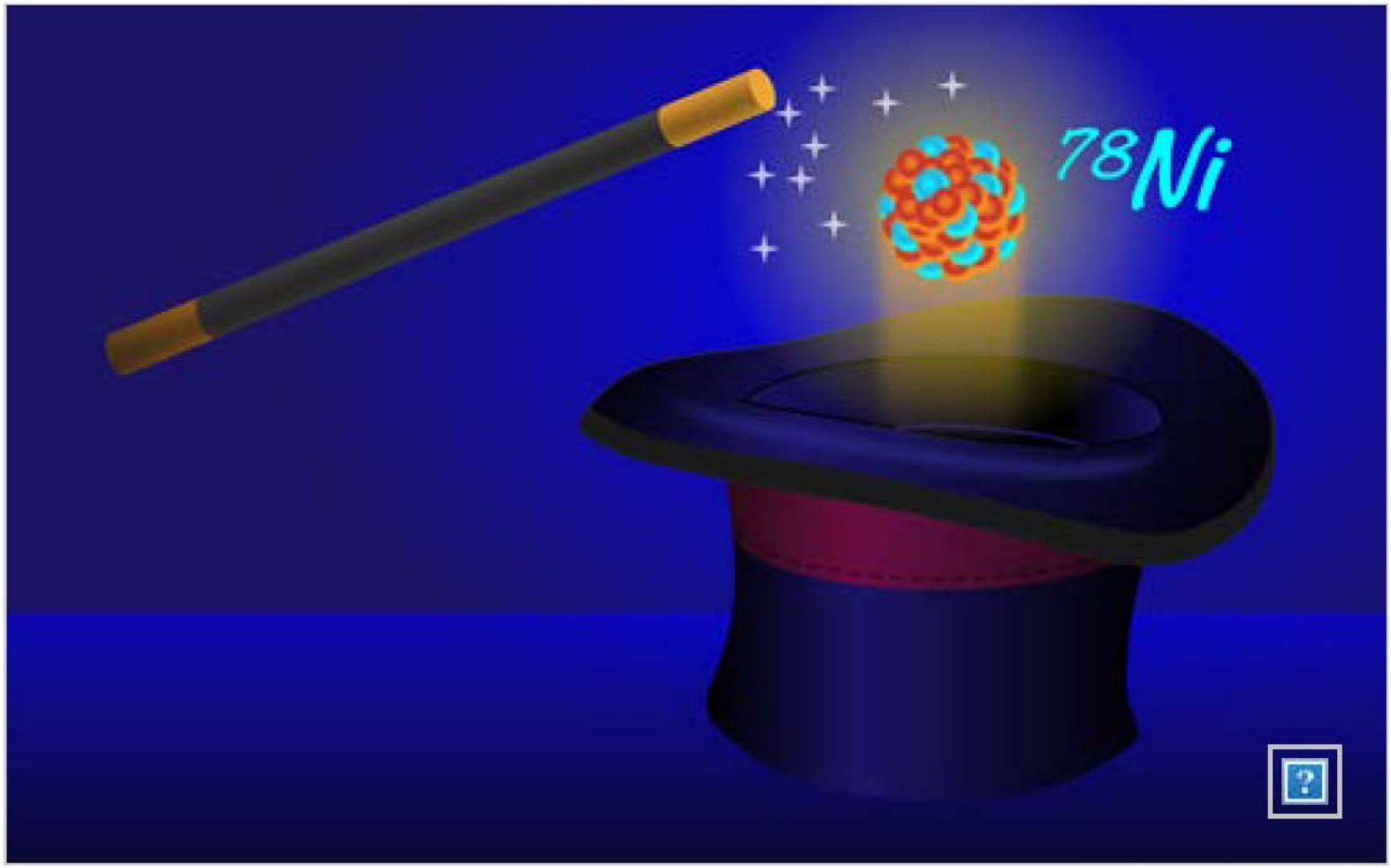


Large N=50 gap towards Z=28

Viewpoint: Doubly Magic Nickel

Daniel Bazin, National Superconducting Cyclotron Laboratory,
Michigan State University, East Lansing, MI 48824-1321, USA

November 6, 2017 • *Physics* 10, 121



APS/Alan Stonebraker

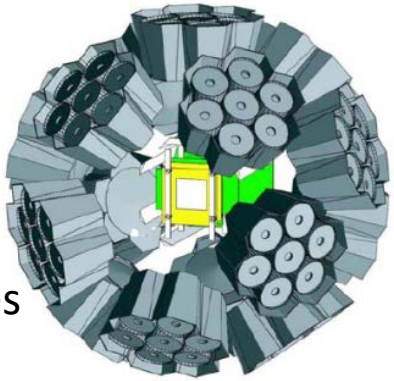
EURICA

EUroball-RIKEN Cluster Array 2012-2016

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

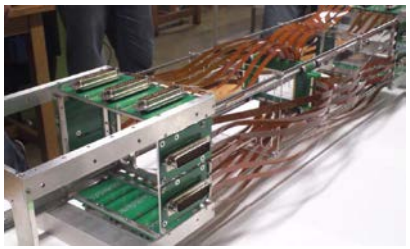
RIBF: decay station
Active stopper: DS-SSD (WAS3ABi)
Liq. N_2 system, other infrastructures

+Additional detectors ($LaBr_3$, Plastic, AIDA…)

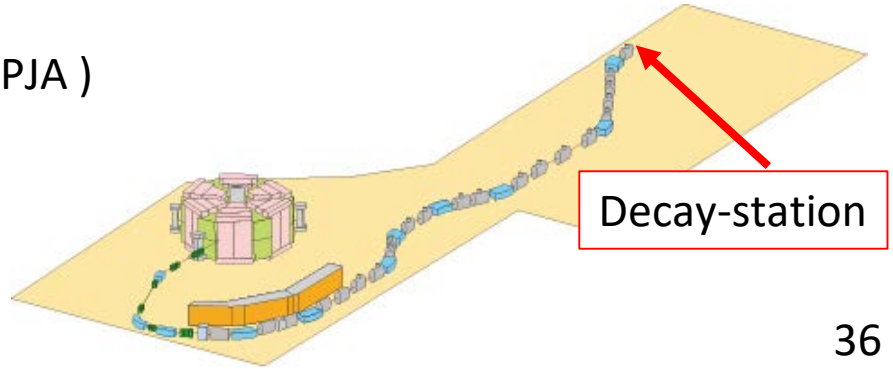


230 collaborators from 19 countries
About 100 days were approved for physics run
Commissioning March 2012 NIM B 317, 649 (2013)
Physics Run June 2012 – June 2016

WAS3ABi



Publication at this time (November 15th, 2017)
38 papers (12xPRL, 9xPLB, 4xPRC(R), 14xPRC, 1xEPJA)
12 PhD Thesis + 1 Master Thesis
38 proceedings
8 technical articles



"End-of-Campaign WS Sept.6-7th, 2016

EURICA Achievements (2012-)

New isotopes

P-Rich

^{96}In, ^{94}Cd, ^{92}Ag, ^{90}Pd: Celikovic et al., PRL 116, 162501(2016)

^{63}Se, ^{67,68}Kr: Blank et al., PRC 93, 061301(R) (2016)

^{67}Kr: Goigoux et al., PRL 117, 162501 (2016)

^{72}Rb: Suzuki et al., PRL 119, 192503 (2017)

N-rich

^{73}Mn, ^{76}Fe, ^{77,78}Co, ^{80,81,82}Ni, ^{83}Cu:
Sumikama et al., PRC95, 051601(R) (2017)

Isomers

^{76}Co, ^{76}Ni: Soderstrom et al., PLB 750, 448(2015)

^{102}Zr : Browne et al., PRC96, 024309 (2017)

^{126,128}Pd: Watanabe et al, PRL 111, 152501 (2013)

^{126}Pd: Watanabe et al, PRL 113, 042502 (2014)

^{92}Rh, ^{96}Ag, ^{98}Cd: Park et al., PRC 96, 044311 (2017)

^{96}Cd: Davied et al, PLB 767, 474 (2017)

^{128}Cd: Junclaus et al, PLB 772, 483 (2017)

^{129}Cd, ^{131}In: Taprogge et al, PLB 738, 223 (2014);
Eur.Phys.J.A.52, 347(2016)

^{136,138}Sn: Simpson et al., PRL 113, 132502 (2014)

^{158,160}Nd : Ideguchi et al., PRC94, 064322 (2016)

^{136}Sb: Lozeva et al., PRC 91, 024302(2015)

^{140}Sb: Lozeva et al., PRC 93, 014316 (2016)

^{164}Sm, ^{166}Gd:Patel et al., PRL 113, 262502 (2014)

^{160}Sm : Patel et al., PLB, 753, 182 (2016)

^{159,161,162}Sm : Patel et al., PRC95, 034305 (2017)

^{170}Dy: Soderstrom et al., PLB 762, 404 (2016)

^{172}Dy: Watanabe et al., PLB 760, 641 (2016)

Half-life

Indication of a double magic ^{78}Ni : Xu et al., PRL 113, 032505 (2014)

Half-lives for 110 n-rich nuclei: Lorusso et al., PRL 114, 192501 (2015)

Half-lives for 94 n-rich nuclei: Wu et al., PRL 118, 072701 (2017)

Beta-gamma

^{68,69,70}Mn: Benzoni et al., PLB 751, 107(2015)

^{60}Co, ^{70}Ni: Morales et al., PLB 765, 328(2017)

^{72}Ni: Morales et al., PRC 93, 034328 (2016)

^{76}Co, ^{76}Ni: Soderstrom et al., PRC 92, 051305(R) (2015)

^{77}Cu: Sahin et al., PRL118, 242502 (2017)

^{70}Br: Morales et al., PRC 95, 064327(2017)

^{104,106}Zr: Browne et al., PLB 750, 448(2015)

^{116,118}Ru: Soderstrom et al., PRC 88, 024301(2013)

^{129}In: Taprogge et al., PRC 91, 054324 (2015

^{130}In: Jungclaus et al, PRC 94, 024303 (2016)

^{131}In: Taproge et al, PRL 112, 132501 (2014)

^{132}In: Jungclaus et al, PRC 93, 041301(R) (2016)

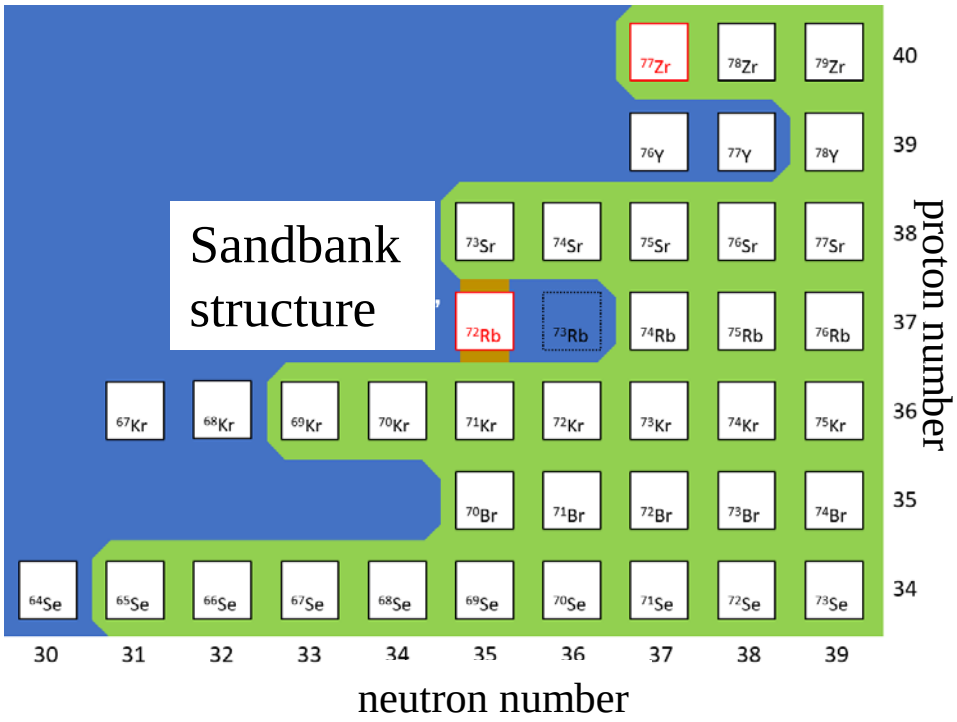
^{138}Te: Lee et al., PRC 92, 044320(2015)

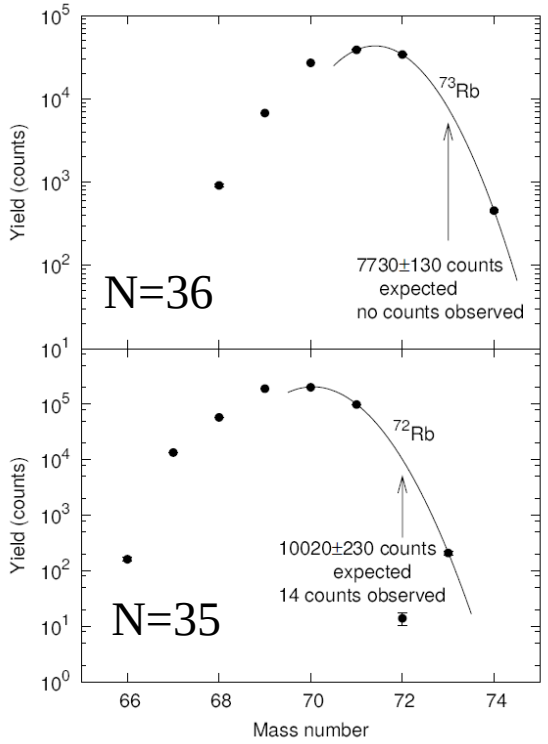
^{140}Te: Moon et al., PRC 95, 044322(2017)

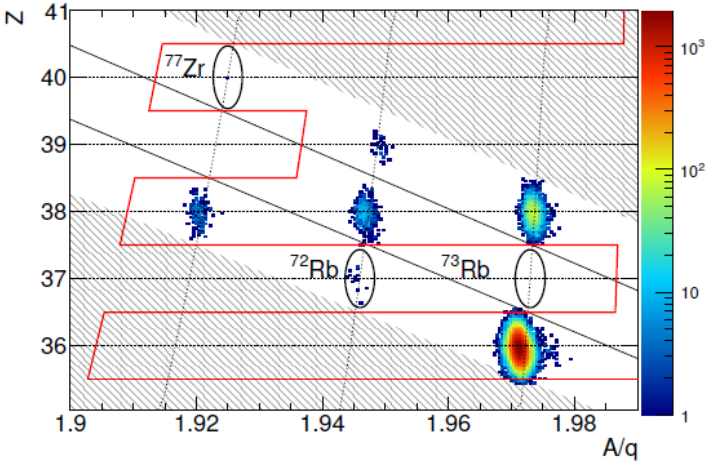
^{140}Te: Moon et al., PRC 96, 014325(2017)

Discovery of ^{72}Rb: A nuclear sandbank beyond the proton drip-line

H. Suzuki et al., PRL 119, 192503 (2017)







^{72}Rb : $T_{1/2}$ ~ 100 ns

^{73}Rb : no events

$T_{1/2}$ < 80ns

^{77}Zr : one event

Mechanism of stability enhancement for the odd-odd nucleus ?

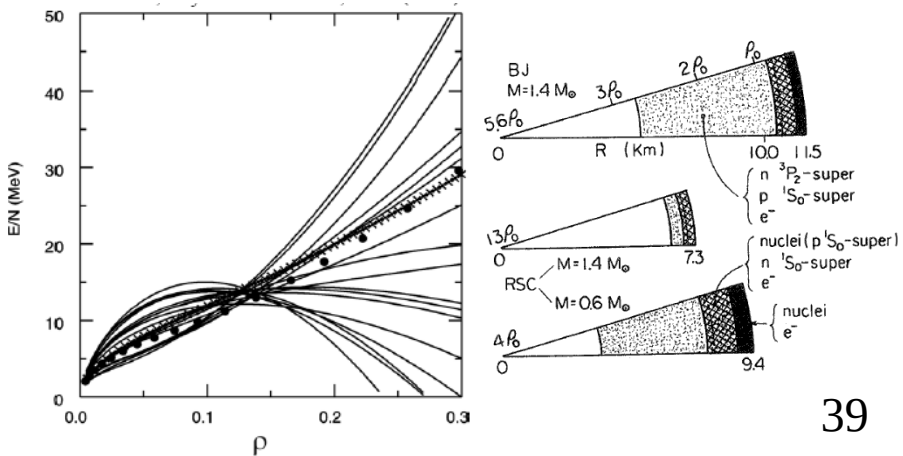
Physics with Exotic Nuclei

Shell Evolution : magicity loss and new magicity

R-process path: Synthesis up to U

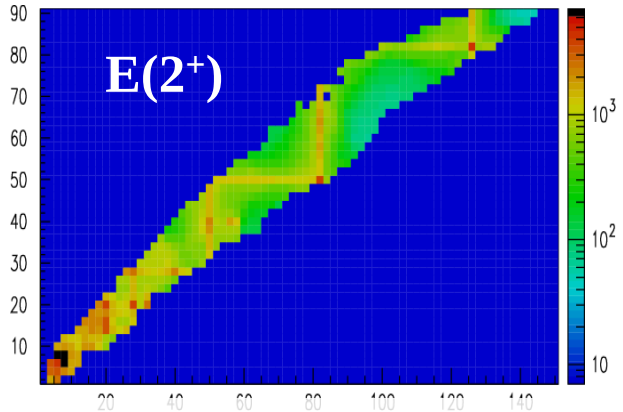
Neutron Correlation in the vicinity of the Drip-line

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

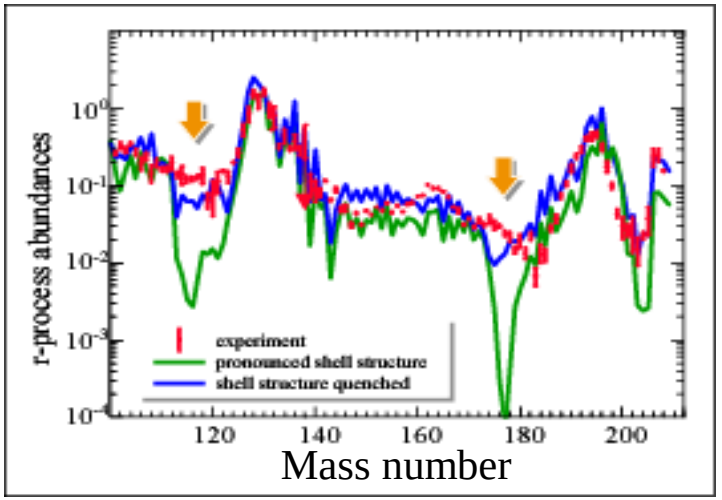


Physics with Exotic Nuclei

Shell Evolution :
magicity loss and new magicity



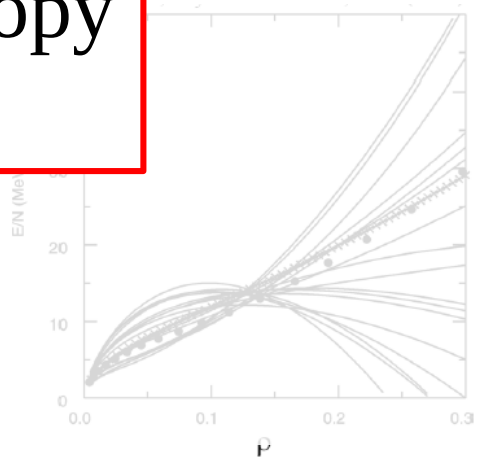
R-process path: Synthesis up to U



Neutron Correlation in the

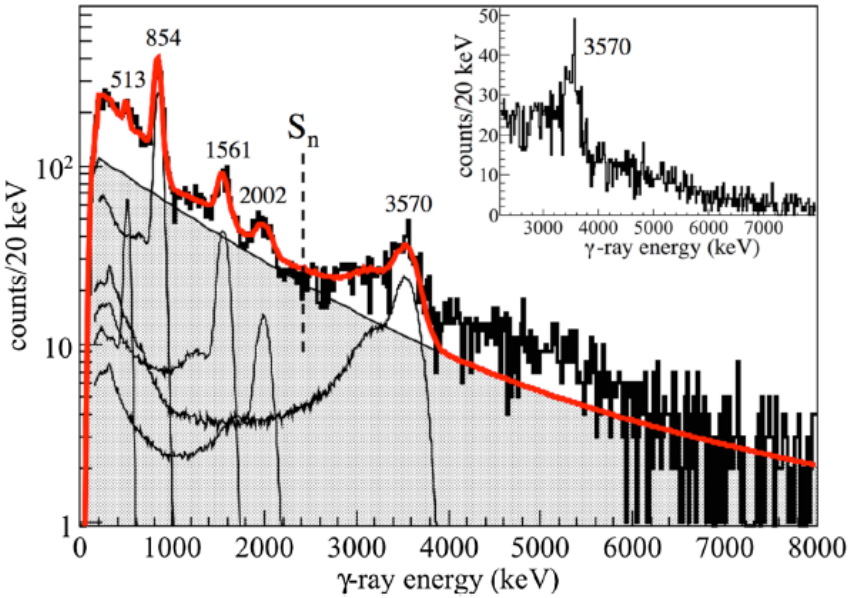
EOS: asymmetric nuclear matter
SN explosion, neutron-star,
vitational wave

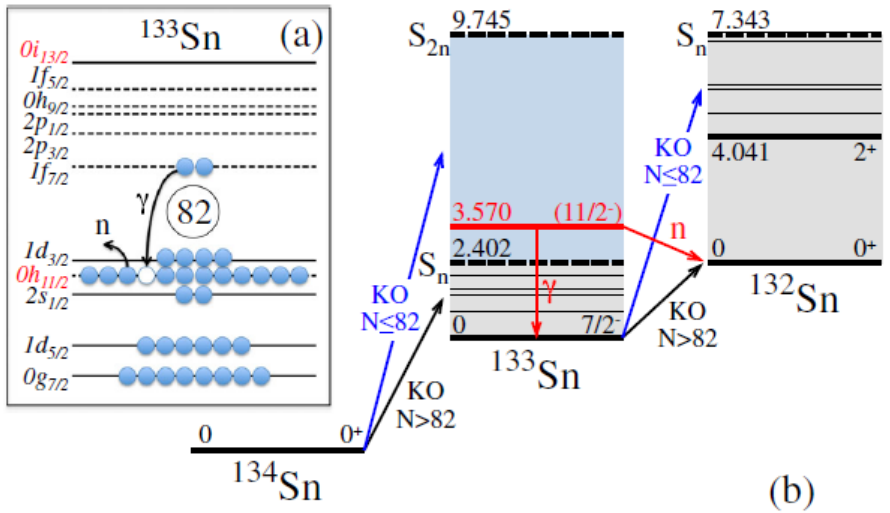
In-beam gamma spectroscopy
Decay spectroscopy



Gamma-decay of unbound neutron-hole states in ^{133}Sn

V. Vaquero, A. Jungclaus et al., PRL 118, 202502 (2017)





A gamma-decay of a neutron-hole unbound state at 3.57 MeV in ^{133}Sn is observed.

Neutron emission of a state at 3.66 MeV was observed at ISOLDE (PRL77, 1020, 1996)

Very small overlap between the state of ^{133}Sn and the ground state of ^{132}Sn, because of double magicity of ^{132}Sn

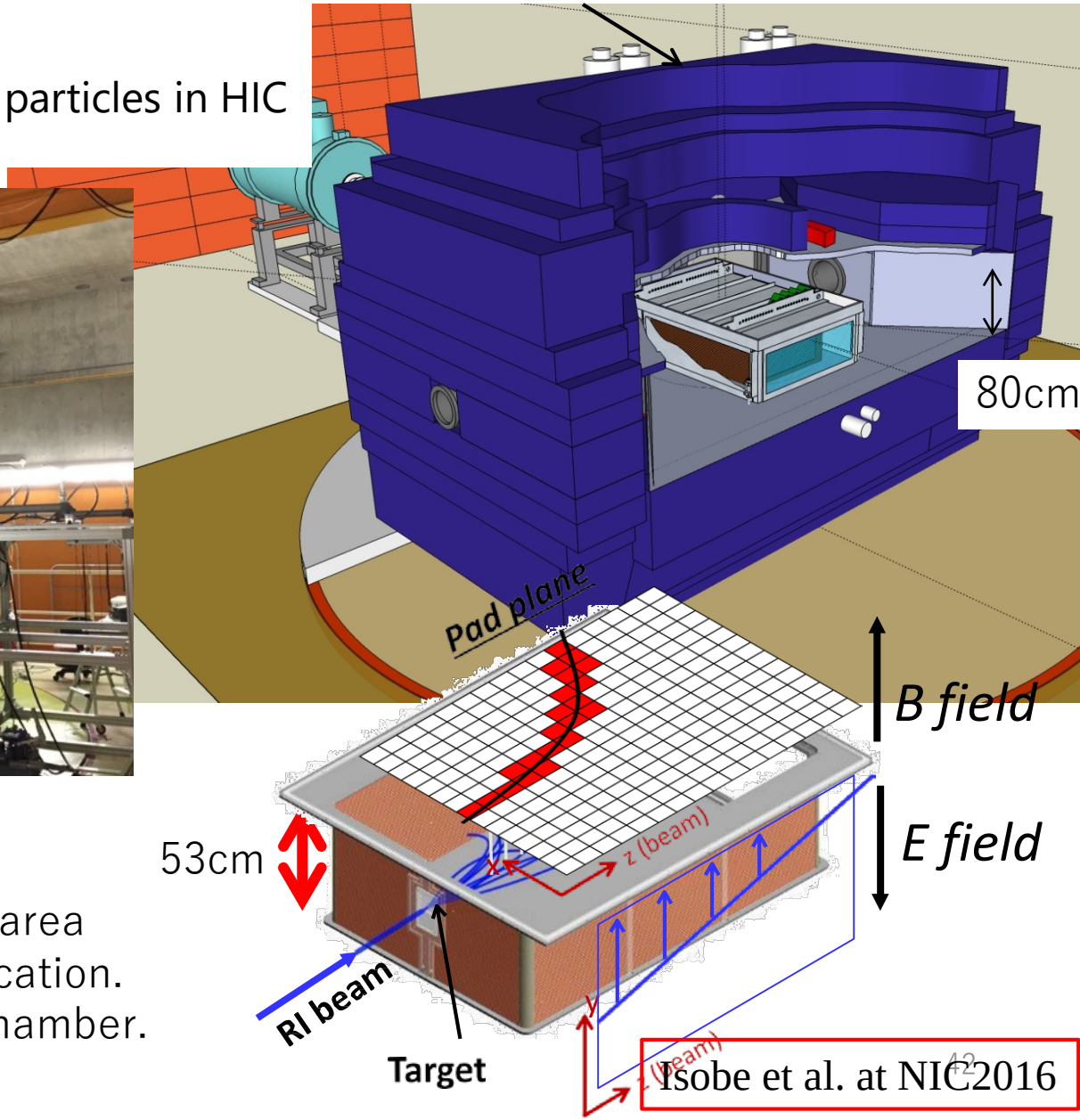
Concerning the r-process path, not only beta-delayed emission but also gamma-decay should be considered in network calculation

SPiRIT-Time Projection Chamber

for the measurement of charged particles in HIC

NIMA 784 (2015) 513

SAMURAI dipole magnet

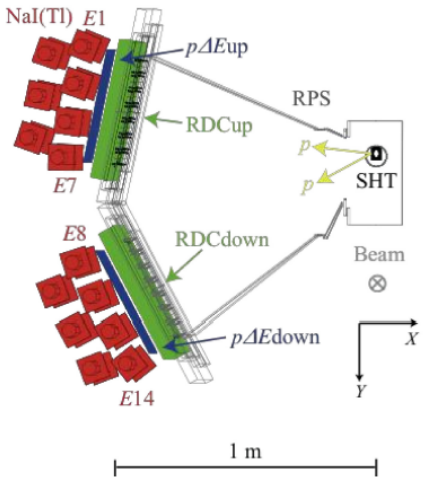


134 x 86 x 53 cm^3 effective area
dE/dX – Bρ particle identification.
Target at the entrance of chamber.
Readout with ~12000 pads.

Elastic scattering study for Exotic Nuclei with ESPRI

Terashima, Zenihiro, Sakaguchi et al.

Recoil Proton Spectrometer (RPS)



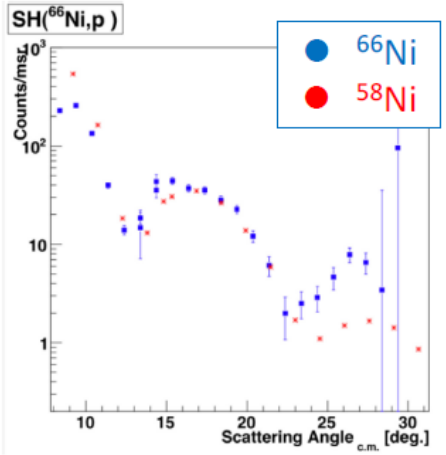
	Solid H_2 (SHT)	RDC	$p\Delta E$	E
material	Para H_2	Ar+C_2H_6	Plastic	NaI(Tl)
effective area	φ 30 mm	436 x 436 mm^2	440 x 440 mm^2	431.8 x 45.72 mm^2
thickness	1 mm	69.4 mm	2.53 / 3.09 mm	50.8 mm
Resolution		500 μm	TOF : 0.1 nsec	0.3 %(80 MeV)

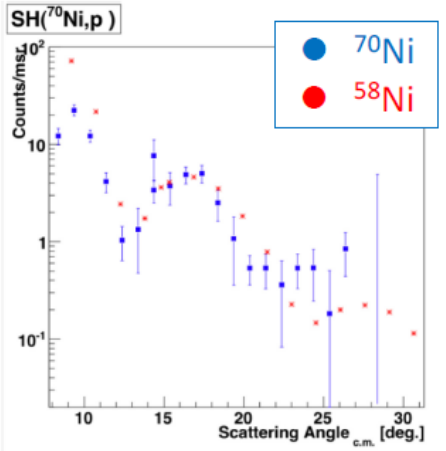
In 2006-2008

Experiments for C- and O-isotopes at HIMAC
9-11C, 20O at 300 MeV/u, 10^5 /s

In 2009-2010

Experiment for n-rich Ni isotopes at GSI





C-16 and Sn-132 at RIBF