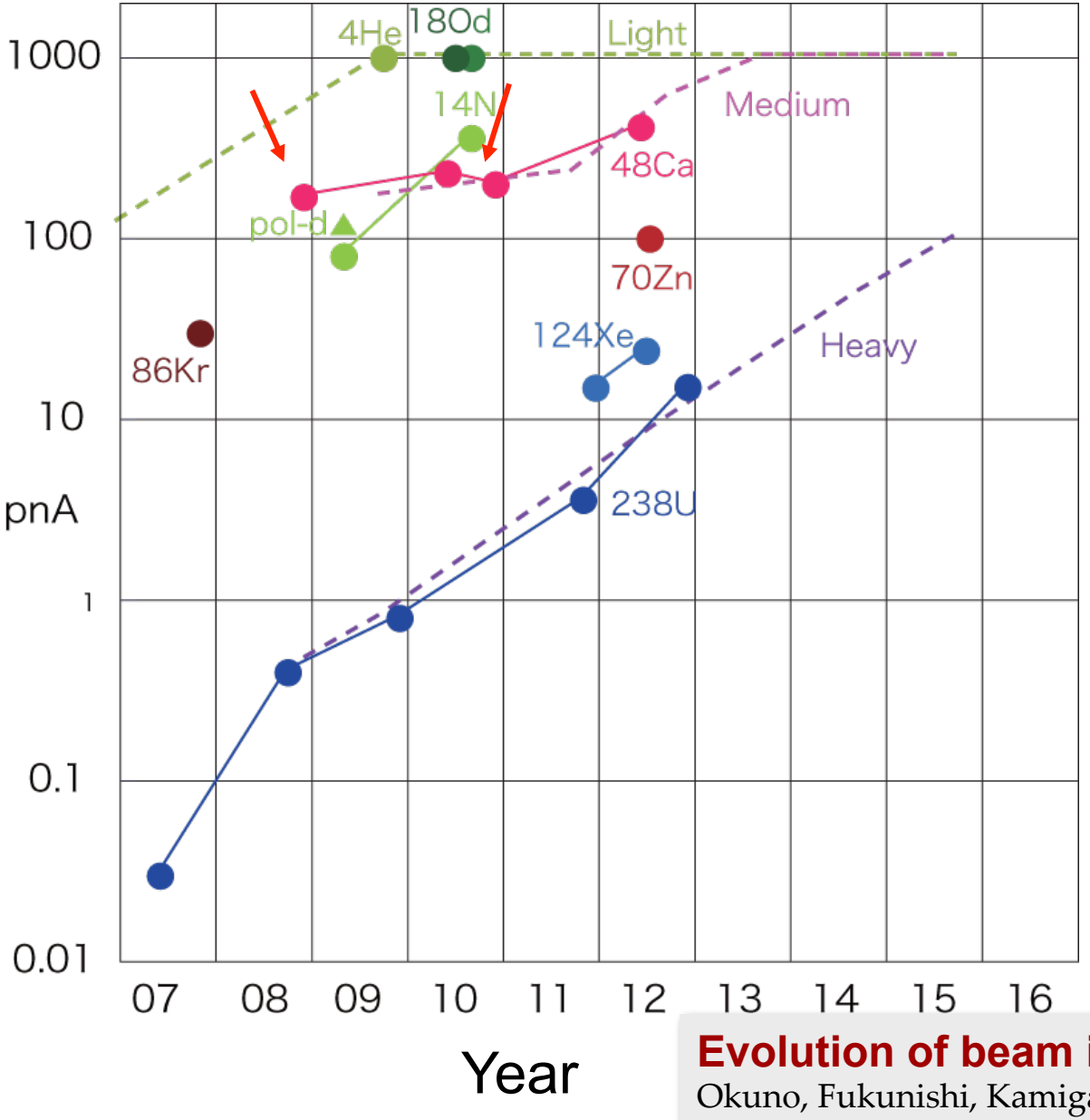
^{48}Ca Campaigns

- mission of RIBF (in its first period)

Tohru Motobayashi
RIKEN Nishina Center



Evolution of beam intensities at RIBF

Okuno, Fukunishi, Kamigaito, PTEP. 03C002 (2012).

Intensity increase at RIKEN RIBF --- old (1990-) *v.s.* new (2007-) facility

Secondary Beam Intensity with primary ^{48}Ca beams

	Previous (RIPS)	achieved (BigRIPS 2009)	gain
^{22}C	6 mcps	10 cps	1,700 ➔ 3,600 (2012)
^{30}Ne	0.2 cps	300 cps	1,500
^{31}Ne	20 c/4days	10 cps	1.7×10^{5}
^{32}Ne		5 cps	
^{42}Si		15 cps	
^{44}S		4×10^{4} cps	

Aoi

^{48}Ca	NP0702-RIBF-028	Magicity in ^{42}Si and ^{54}Ca	Satoshi Takeuchi	2010 (42Si) 2012 (54Ca)
	NP0702-RIBF-030	In-beam gamma spectroscopy of the doubly magic nucleus ^{78}Ni and its vicinity	Ken-ichiro Yoneda	2011
	NP0702-RIBF-031	Structure study of neutron-rich nuclei beyond ^{132}Sn	Nori Aoi	2011
^{48}Ca	NP0702-RIBF-032	Exploring the "Island of Inversion"	Heiko Scheit	2008

Four BigRIPS in-beam γ experiments* approved in the 1st PAC☆ in Mar. 2007

☆13 proposals (out of 16): approved

They are all for (very) neutron-rich nuclei.

Questions are on “up and down” of shell closure.

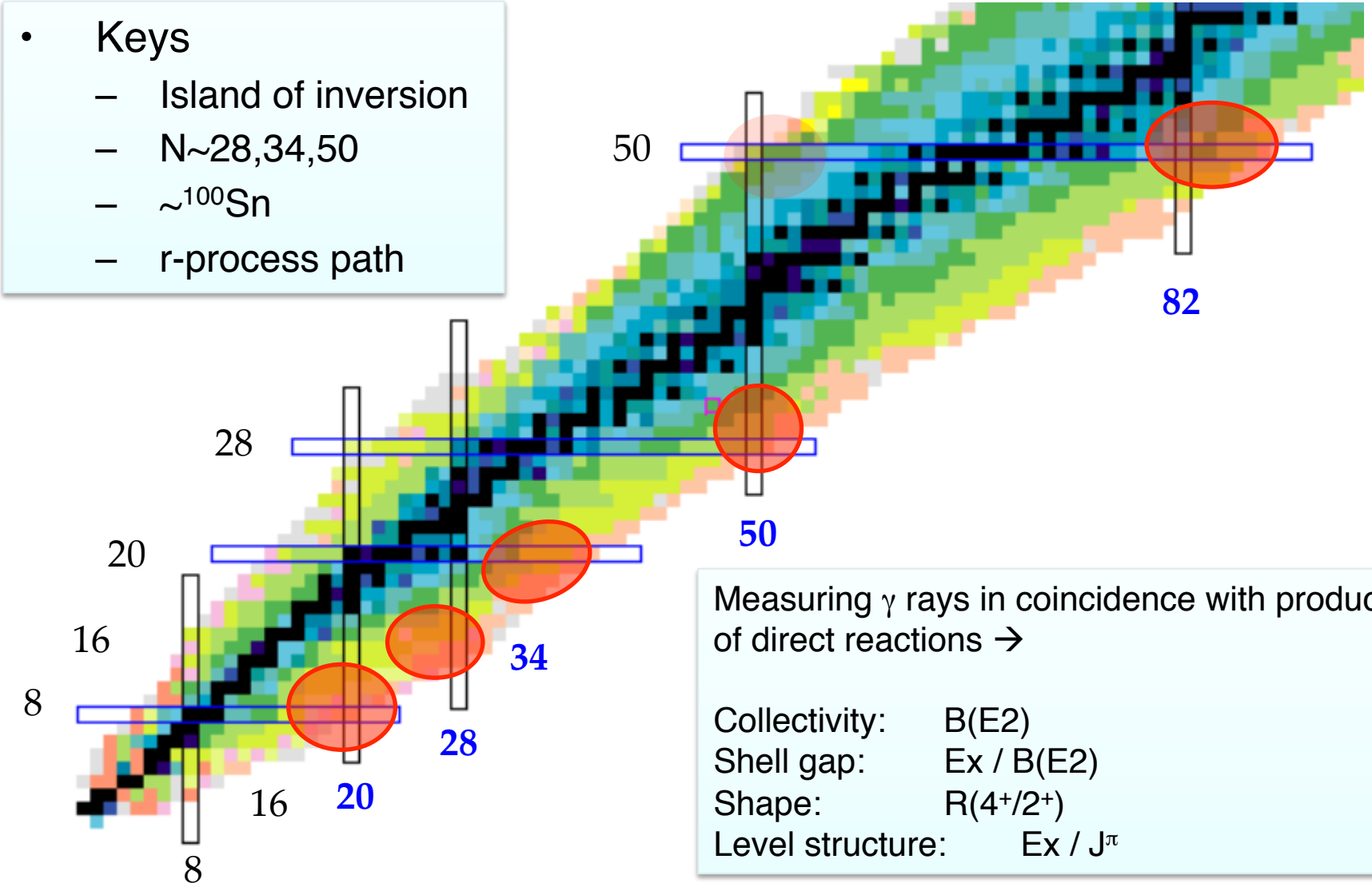
- Direct reaction study using fast RI beams with the help of γ-ray measurements

  c.f. “γ-tagging” (MSU)

  γ-ray spectroscopy associated with fast RI beam induced direct reactions

Questions regarding shell closure

- Keys
  - Island of inversion
  - N~28,34,50
  - ~^{100}Sn
  - r-process path



Measuring γ rays in coincidence with products of direct reactions →

Collectivity: B(E2)
Shell gap: Ex / B(E2)
Shape: R(4⁺/2⁺)
Level structure: Ex / Jᵖ

^{48}Ca	NP0702-RIBF-028	Magicity in ^{42}Si and ^{54}Ca	Satoshi Takeuchi	2010 (42Si) 2012 (54Ca)
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All the experiments were performed by 2012 (5 years!).

In-beam γ-ray spectroscopy performed at RIBF

- •2008 DayOne
  - ^{32}Ne, ^{31,33}Na — H. Scheit, P. Doornenbal — PRL 103:032501, 2009./PRC 81:041305, 2010.
- •2009 Test with U (0.3-0.6 pnA)
  - ~^{132}Sn — H. Wang, N. Aoi
- •2010 ^{48}Ca campaign
  - ^{38,40,42}Si — S. Takeuchi, M.Matsushita — PRL 109 (2012) 182501.
  - $^{A>36}$Mg — P. Doornenbal, H. Scheit — submitted
  - F isotopes — P. Doornenbal
  - ~Al, P — D. Steppenbeck
  - ^{33}Mg — D. Bazin
  - ^{40}Mg test — P. Fallon
- •2011 U beam campaign
  - ^{78}Ni — K. Yoneda, D. Steppenbeck
  - ~^{132}Sn — H. Wang, N. Aoi
- •2012 ^{124}Xe and ^{70}Zn beam campaign
  - ^{10x}Sn — A. Obertelli, P. Doornenbal
  - ^{54}Ca — D. Steppenbeck, S. Takeuchi

^{48}Ca campaigns

•2008	DayOne		
	^{32}Ne, ^{31,33}Na	H. Scheit, P. Doornenbal	
			PRL 103:032501, 2009./PRC 81:041305, 2010.
•2009	Test with U (0.3-0.6 pnA)		
	~^{132}Sn	H. Wang, N. Aoi	
•2010	^{48}Ca campaign		
	^{38,40,42}Si	S. Takeuchi, M.Matsushita	PRL 109 (2012) 182501.
	A>^{36}Mg	P. Doornenbal, H. Scheit	submitted (^{32}Mg: K. Li CPL)
	F isotopes	P. Doornenbal	in preparation
	~Al, P	D. Steppenbeck	
	^{33}Mg	D. Bazin	
	^{40}Mg test	P. Fallon	in preparation (H. H. Crawford)
•2011	U beam campaign		
	^{78}Ni	K. Yoneda, D. Steppenbeck	
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•2012	^{124}Xe and ^{70}Zn beam campaign		
	^{10x}Sn	A. Obertelli, P. Doornenbal	
	^{54}Ca	D. Steppenbeck, S. Takeuchi	

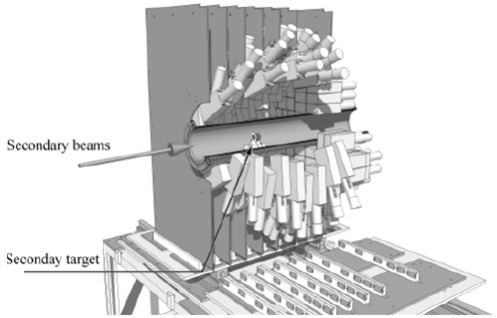
γ-ray spectroscopy setup @ BigRIPS/ZDS

PID of beam particles

PID of scattered particles

Reaction Target and DALI2

Observables:
- velocity
- γ–emission angle
- γ-ray energy

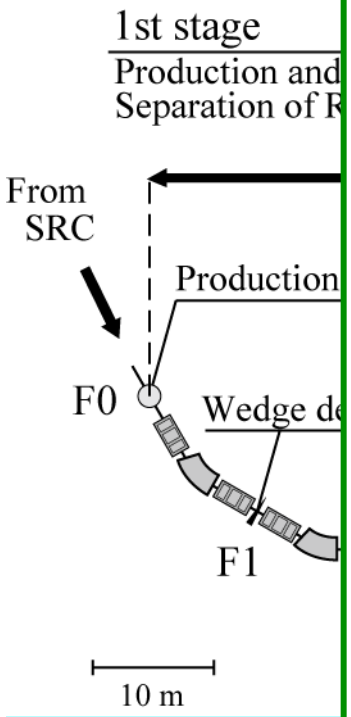


Determine reaction channel and correct Doppler shift effects.

γ-ray spec

PII

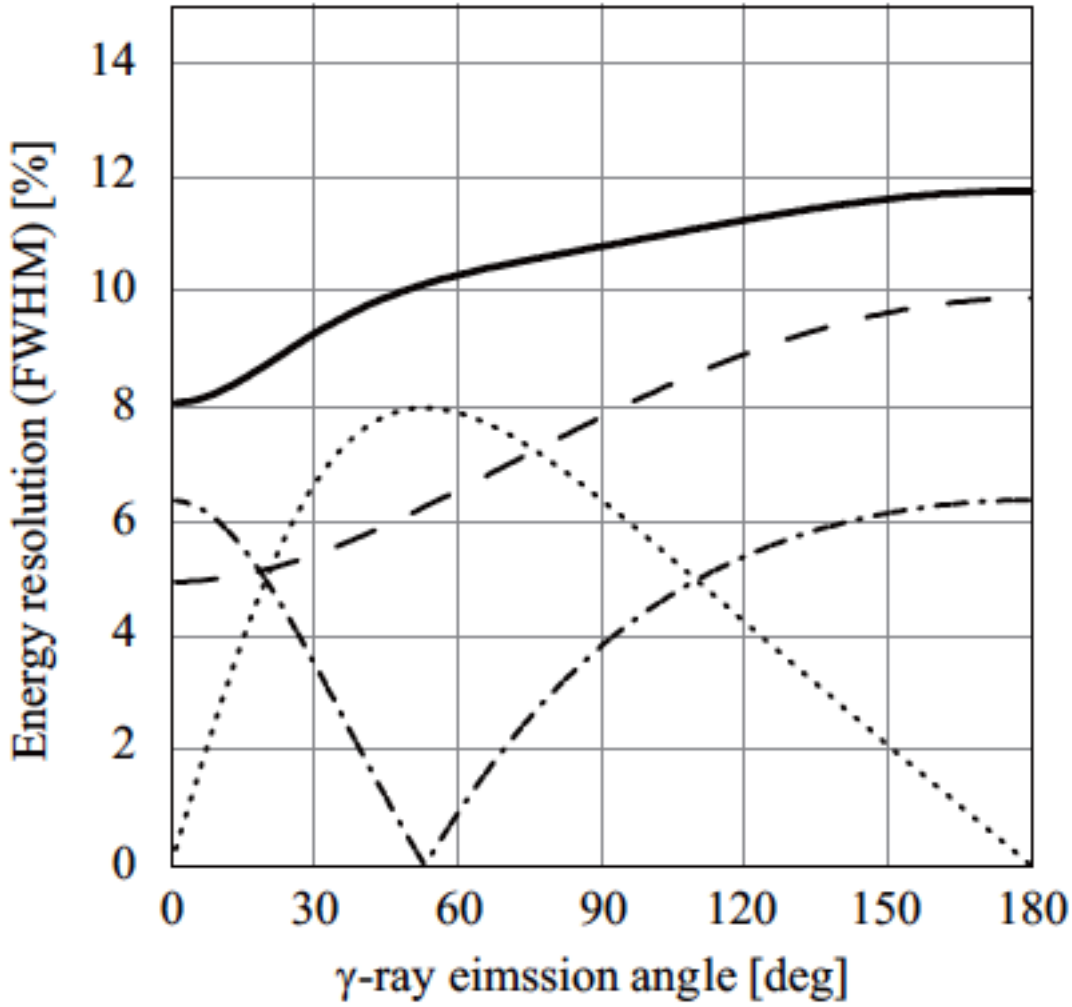
cles



Determin

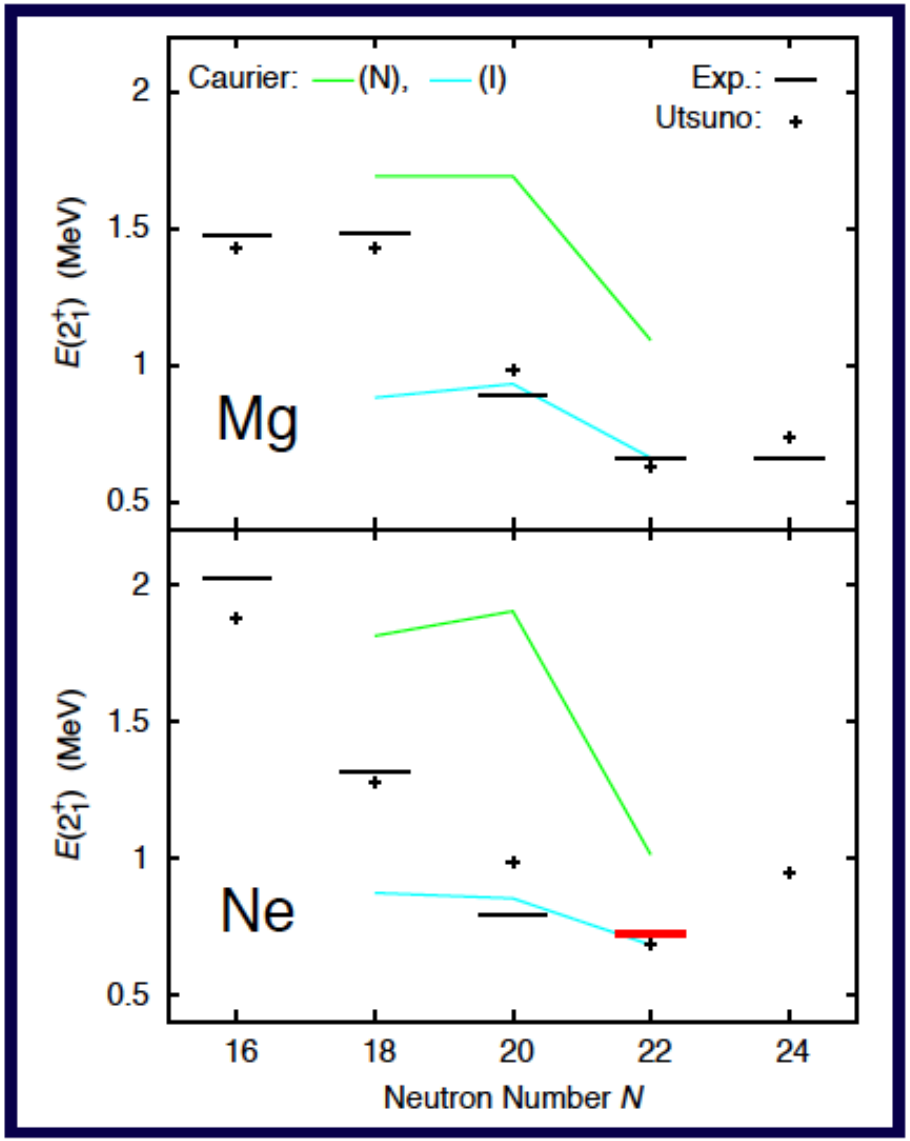
DALI2 performance

E_γ=1 MeV, β=0.6 (10% uncertainty)



^{32}Ne

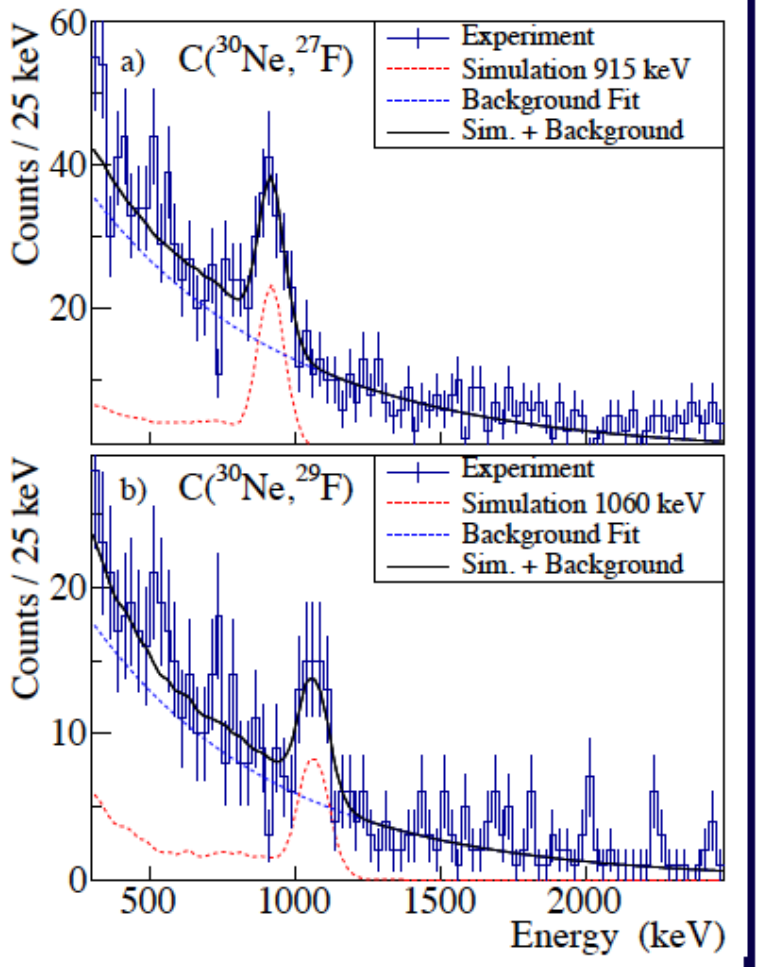
- Lowest $E(2^+)$ of Ne isotopes
- Very good agreement with Utsuno *et al.*, PRC 60, 054315 (1999)
- Very good agreement with Intruder calculation of Caurier *et al.*, NPA 693, 374 (2001)
- ^{32}Ne belongs to the "Island of Inversion"

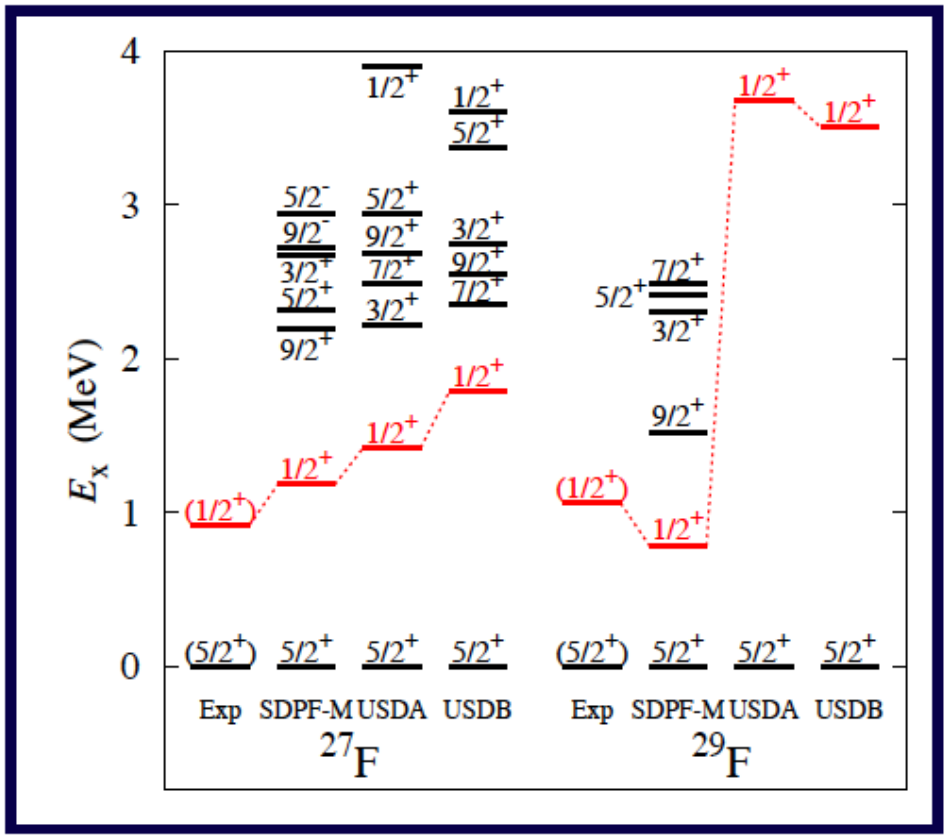


P. Doornenbal, H. Scheit *et al.*
Phys. Rev. Lett. 103, 032501 (2009)
arXiv:0906.3775

In-Beam γ-Ray Spectroscopy of ^{27,29}F

Doppler Corrected γ-Ray Energy

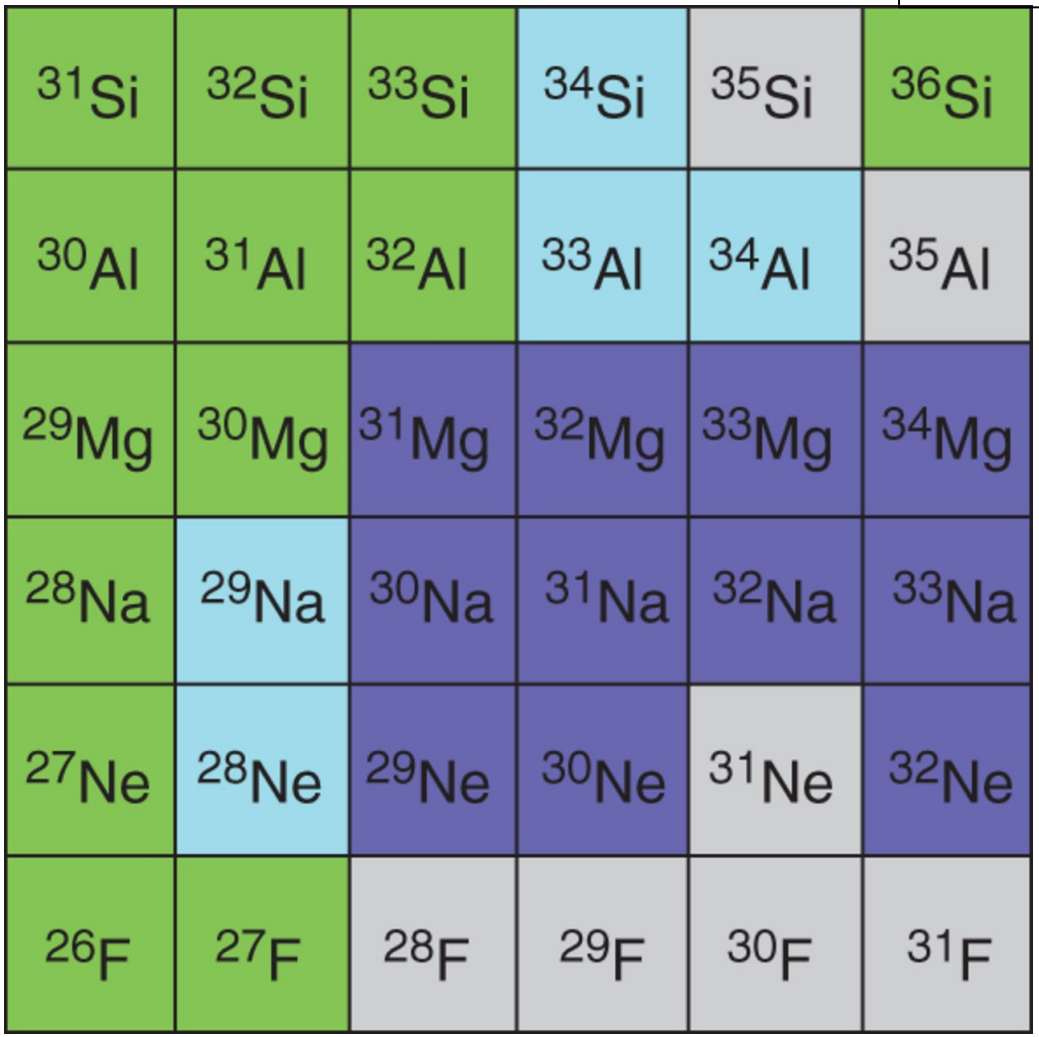




USDA/B: B. Alex Brown and W. A. Richter, Phys. Rev. C 74, 034315 (2006), no excitations to pf shell
SDPF-M: Y. Utsuno *et al.*, Phys. Rev. C 60, 054315 (1999), includes $sd - pf$ mixing

Nuclear chart around the island of inversion.

← E_x, B(E2), μ, Q, …

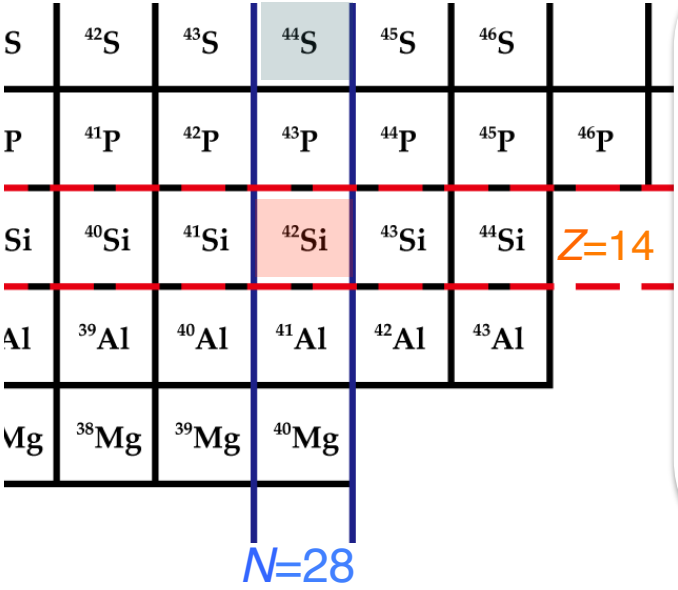


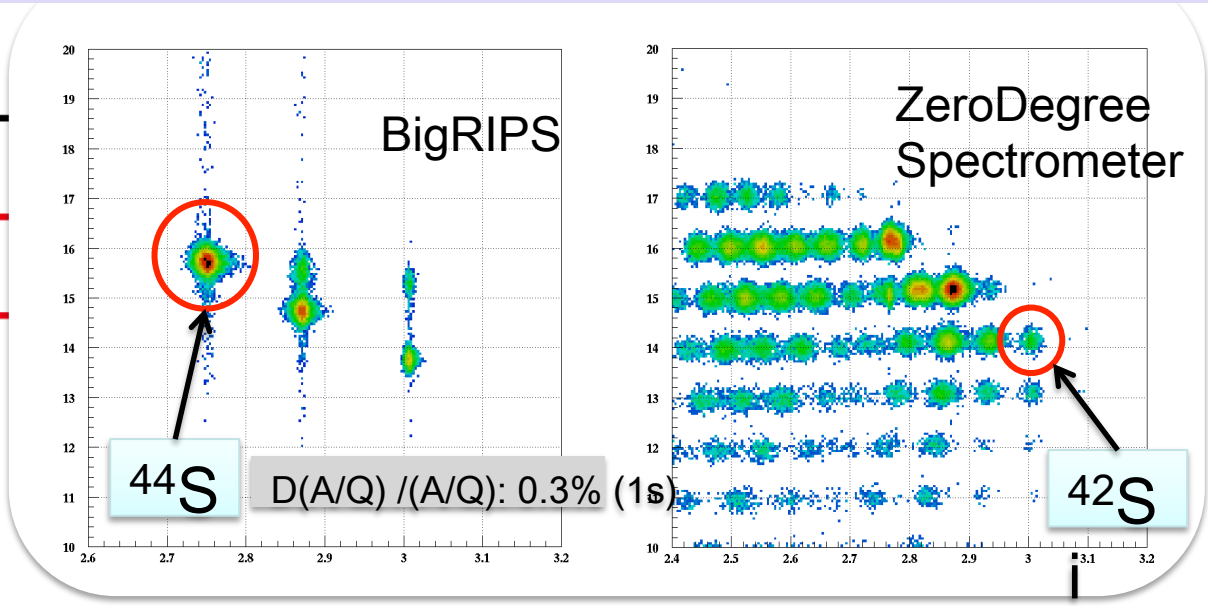
Motobayashi T , and Sakurai H Prog. Theor. Exp. Phys. 2012;2012:03C001

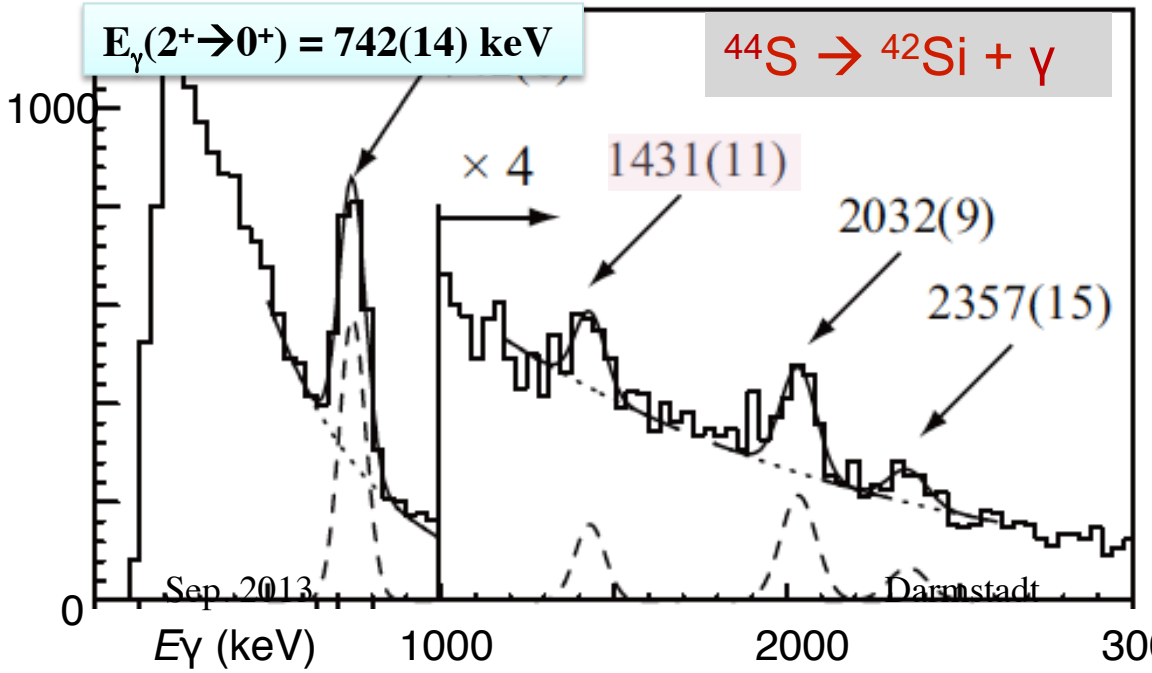
PTEP
Progress of Theoretical and Experimental Physics

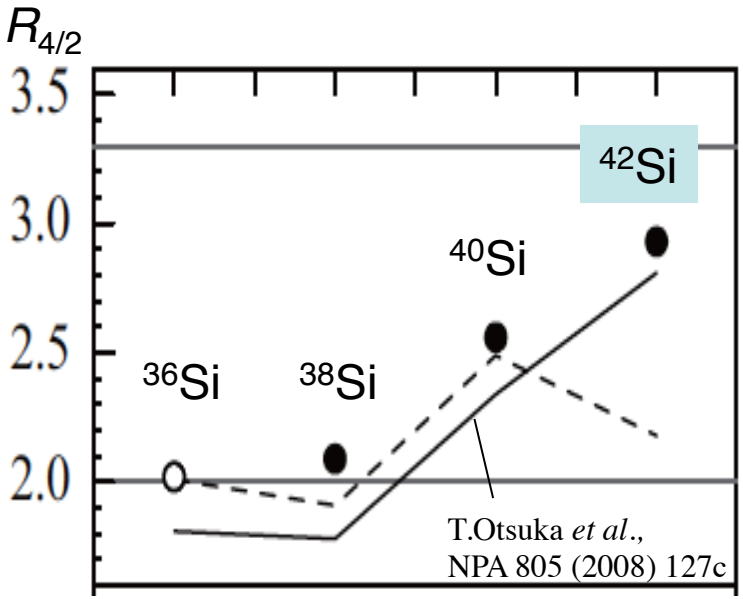
Well-developed deformation of 42Si

Takeuchi *et al.* (2012)









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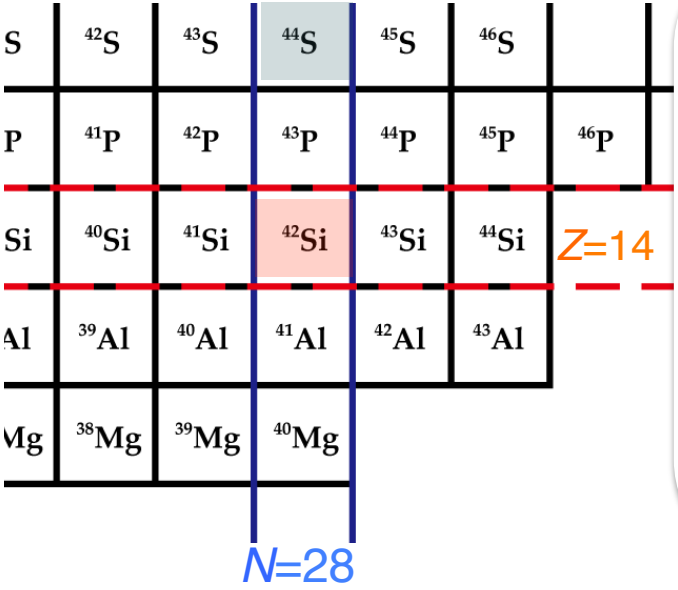
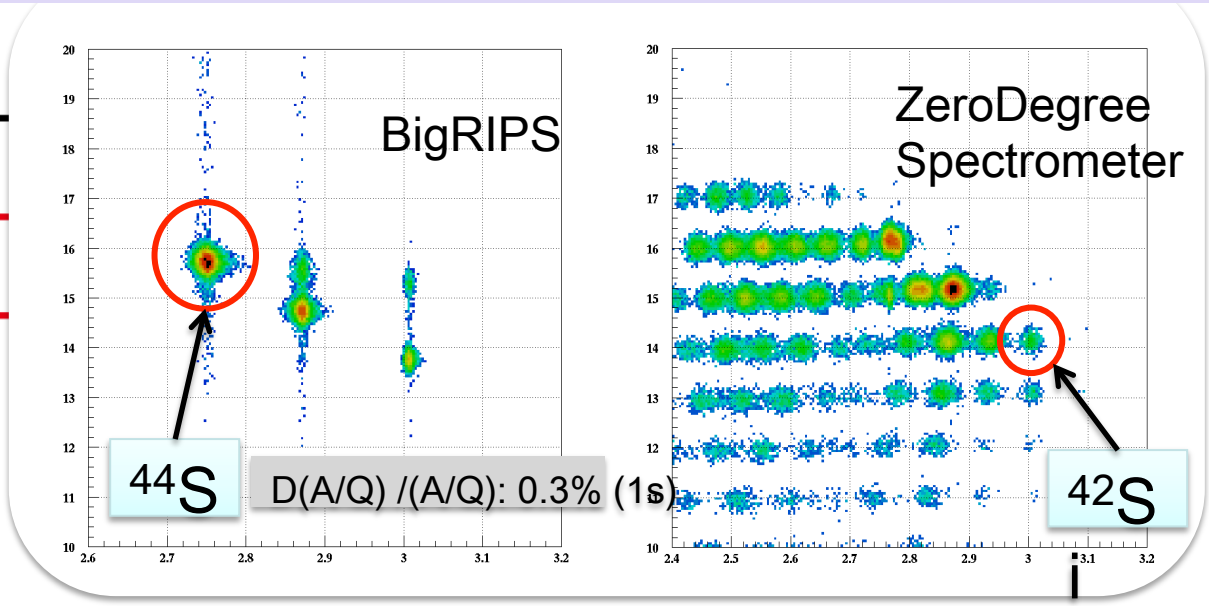
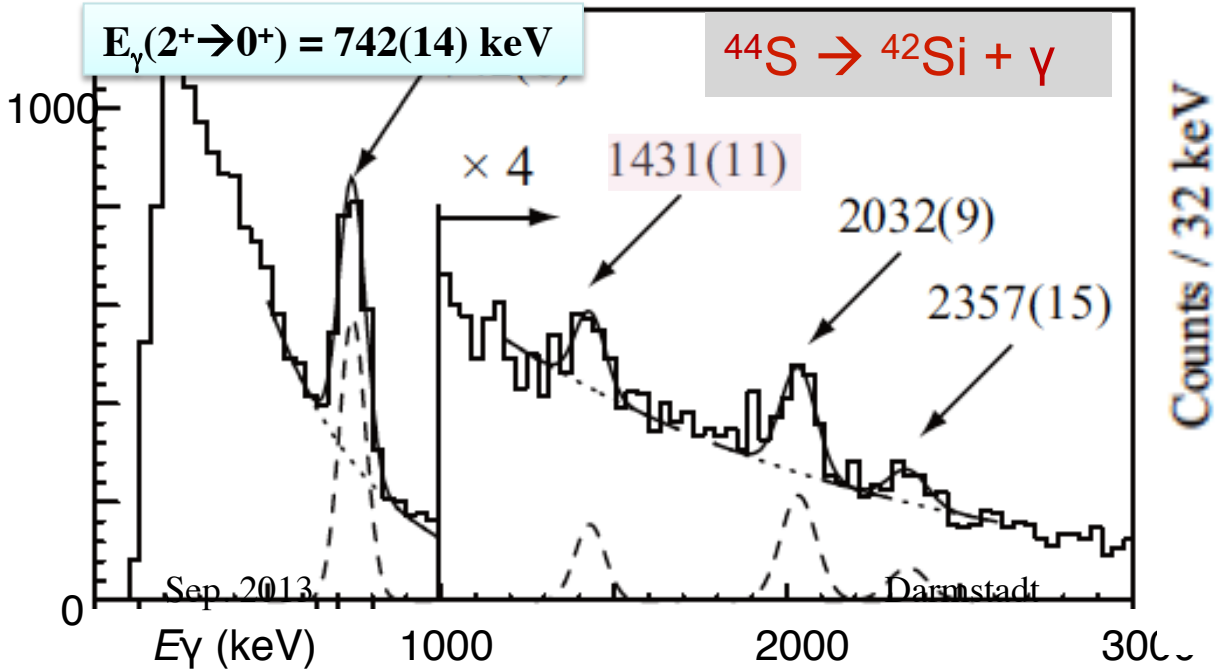
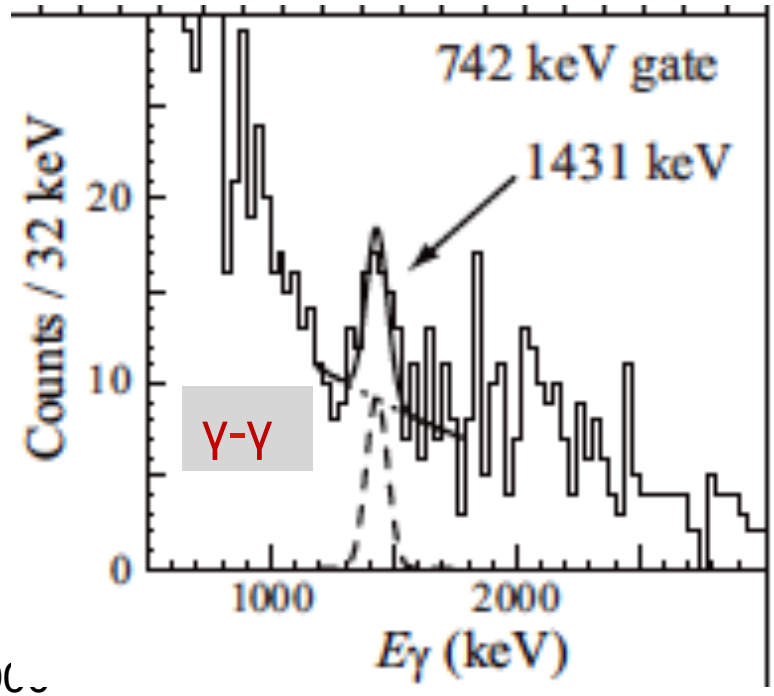


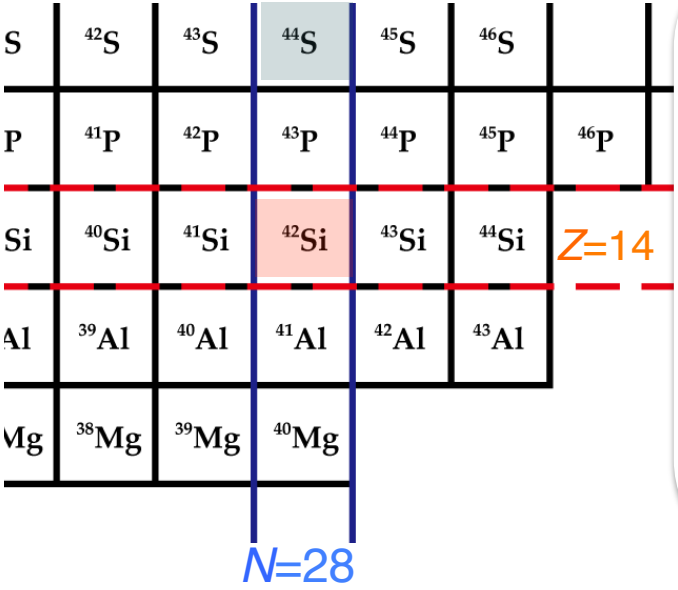


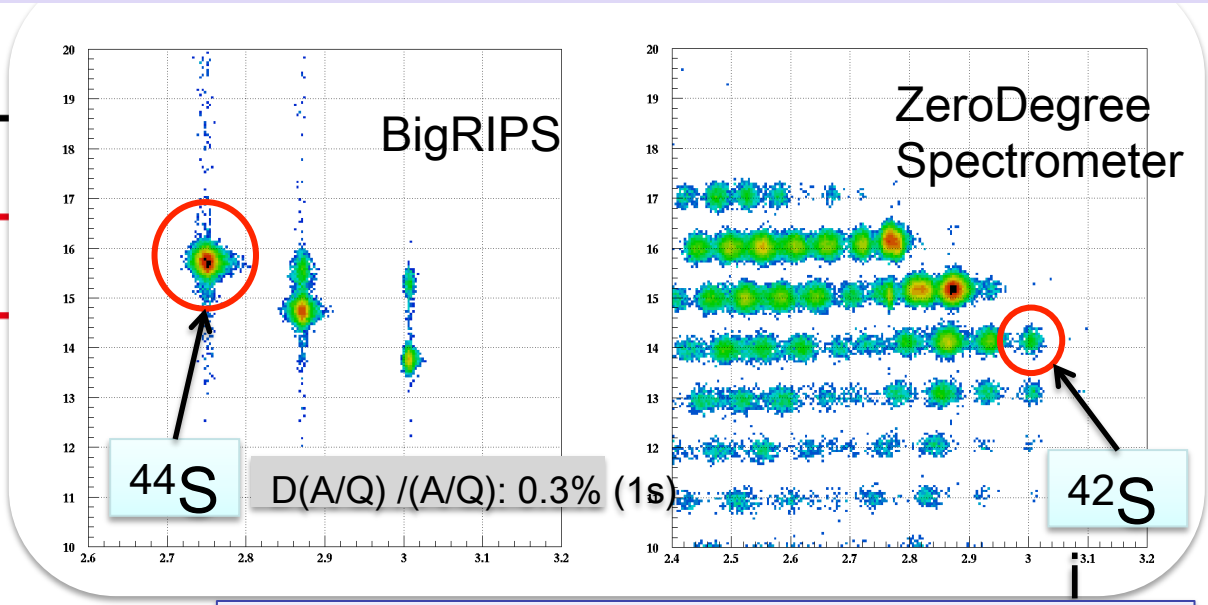




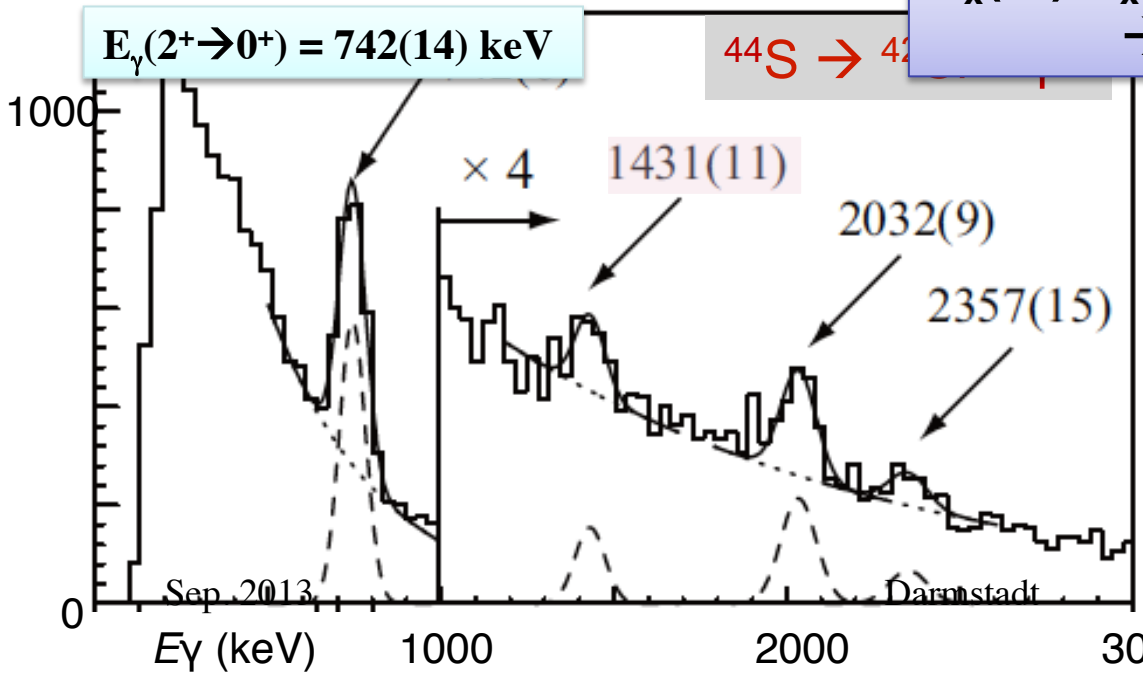
Well-developed deformation of 42Si

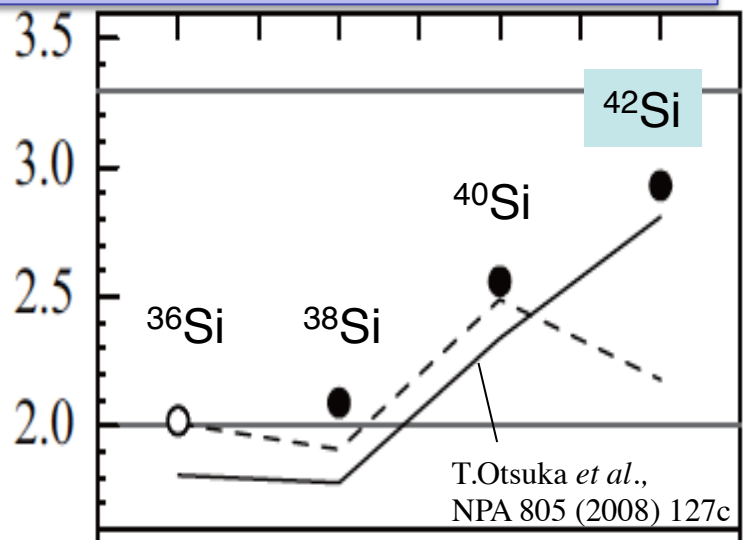
Takeuchi *et al.* (2012)





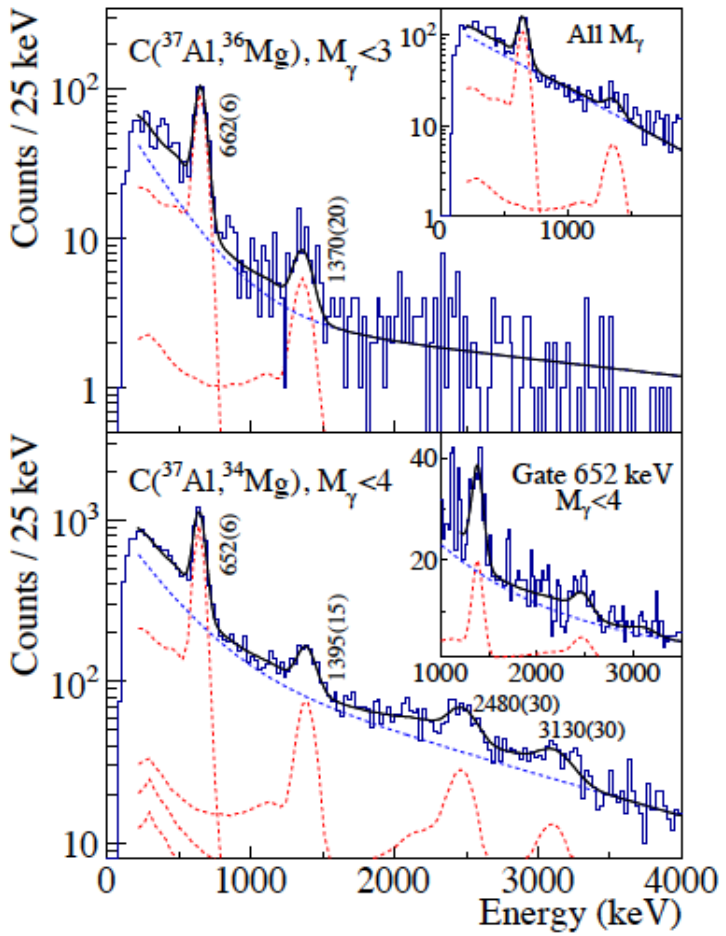
$E_x(4^+)/E_x(2^+) = 2.93$
→ well-developed deformation





Systematics in Mg Isotopes

Doppler Corrected γ-ray Energy



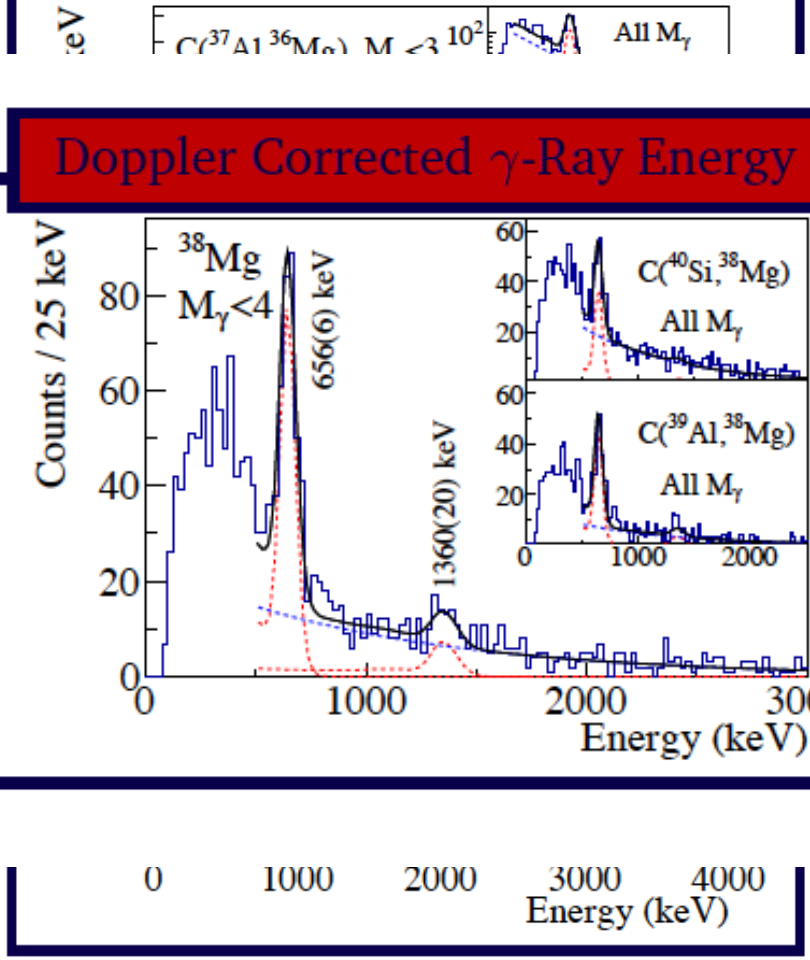
4^+ candidates are observed.

PD, H. Scheit, S. Takeuchi *et al.*, submitted

Systematics in Mg Isotopes

$R_{4/2}$ ~ rigid rotor

Doppler Corrected γ-ray Energy



Doppler Corrected γ-Ray Energy

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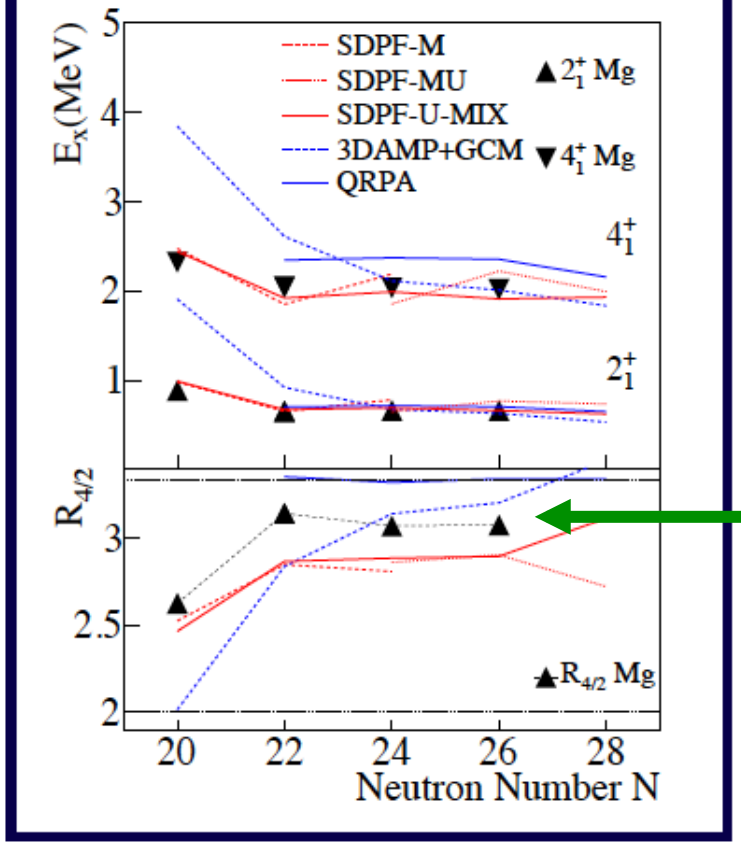
Comparison with Theory



M: Y. Utsuno *et al.*, PRC 60, 054315 (1999).
SDPF-MU: Y. Utsuno *et al.*, PRC 86, 051301 (2012).
SPPF-U-MIX: A. Poves *et al.*, PST 150, 014030 (2012).
3DAMP+GCM: J. M. Yao *et al.*, PRC 83, 014308 (2011).
QRPA: K. Yoshida, EPJ A 42, 583 (2009).

Next challenges?