

# Tardy results from EURICA@RIBF and the isospin dependence of effective charges

Andrea Jungclaus

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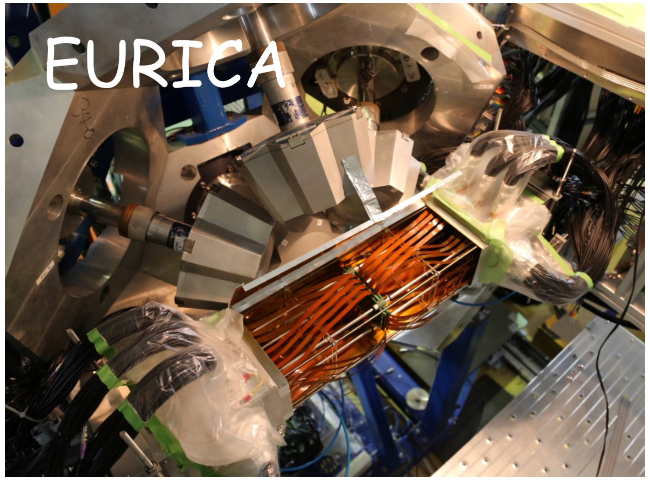
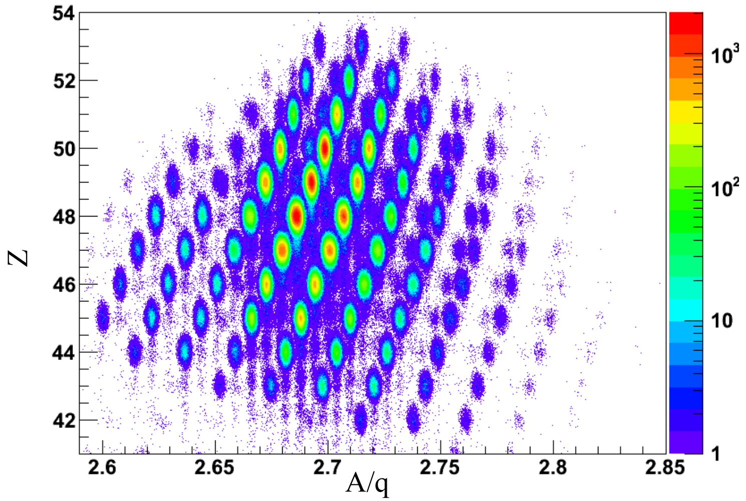


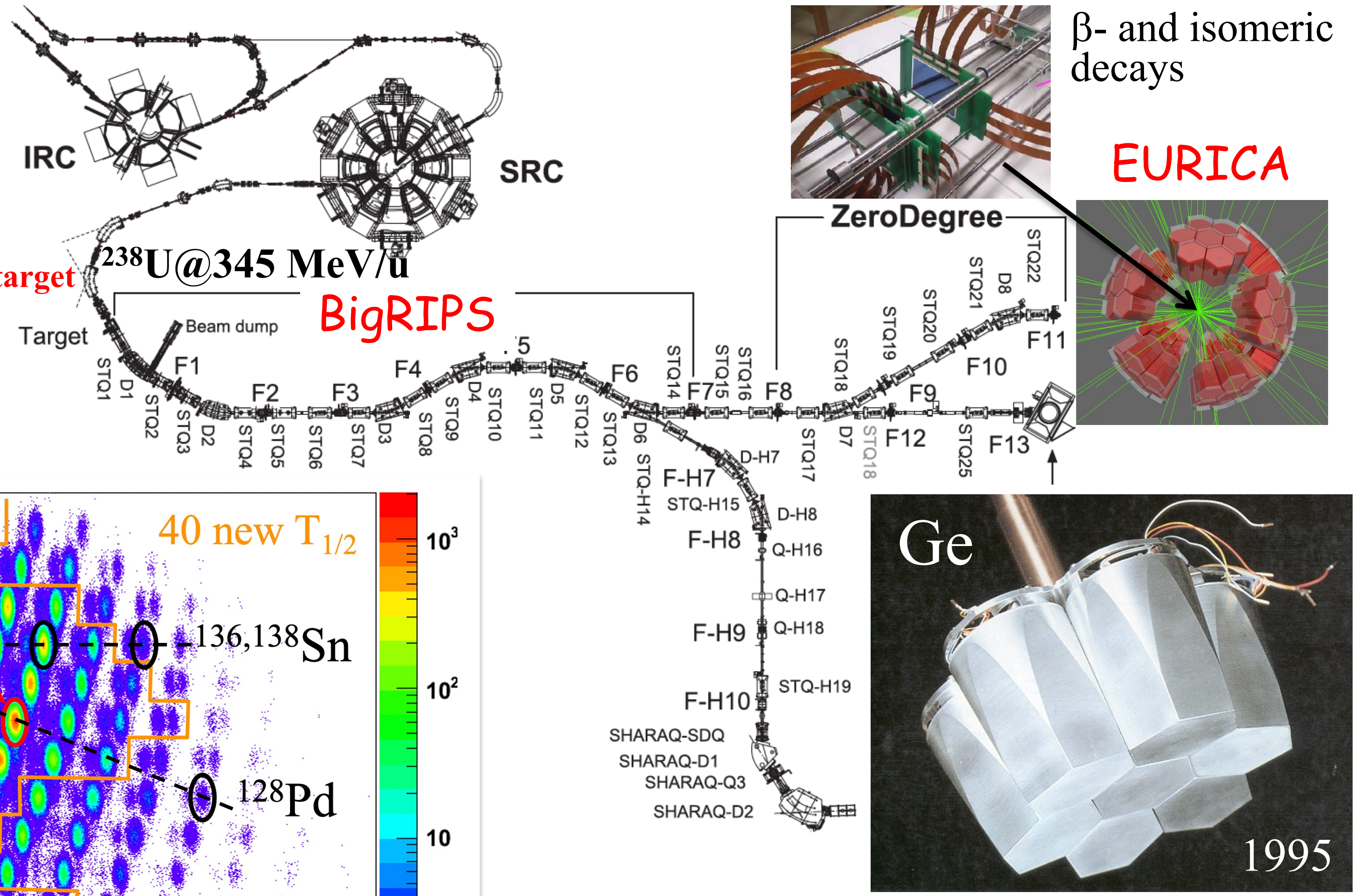




SSNET’24, November 5, 2024

# Decay spectroscopy: The EUroball-RIKEN Cluster Array

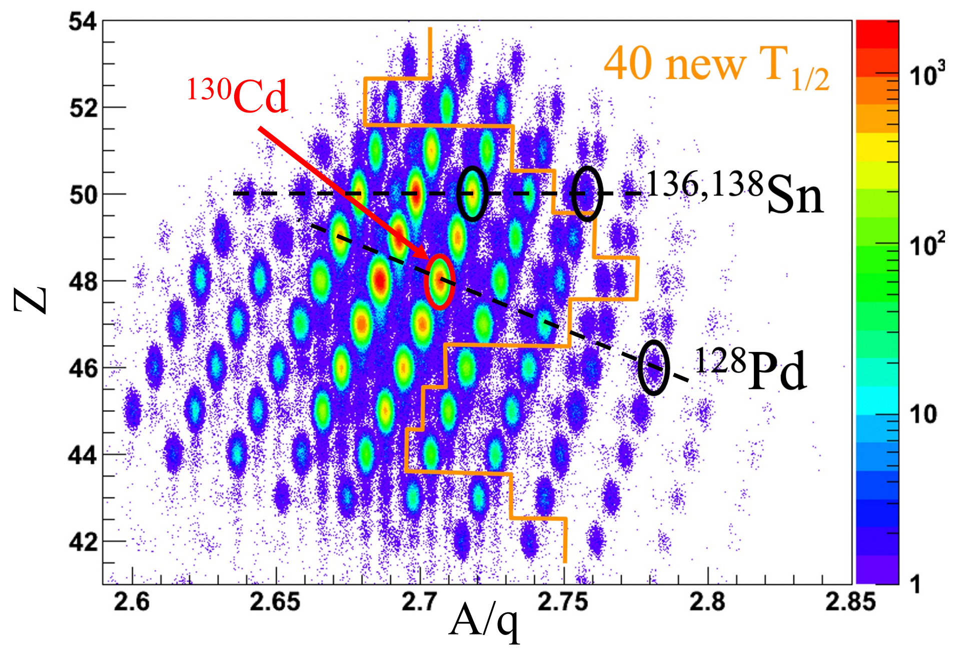
RIBF85, RIBF60&62R1
November 2012

*H. Watanabe et al., PRL 111, 152501 (2013)*
*G. Simpson et al., PRL 113, 132502 (2014)*
*G. Lorusso et al., PRL 114, 192501 (2015)*
………




*T. Kubo et al., PTEP 2012, 03C003*

ID plot from BigRIPS



# Decay spectroscopy: The EUroball-RIKEN Cluster Array

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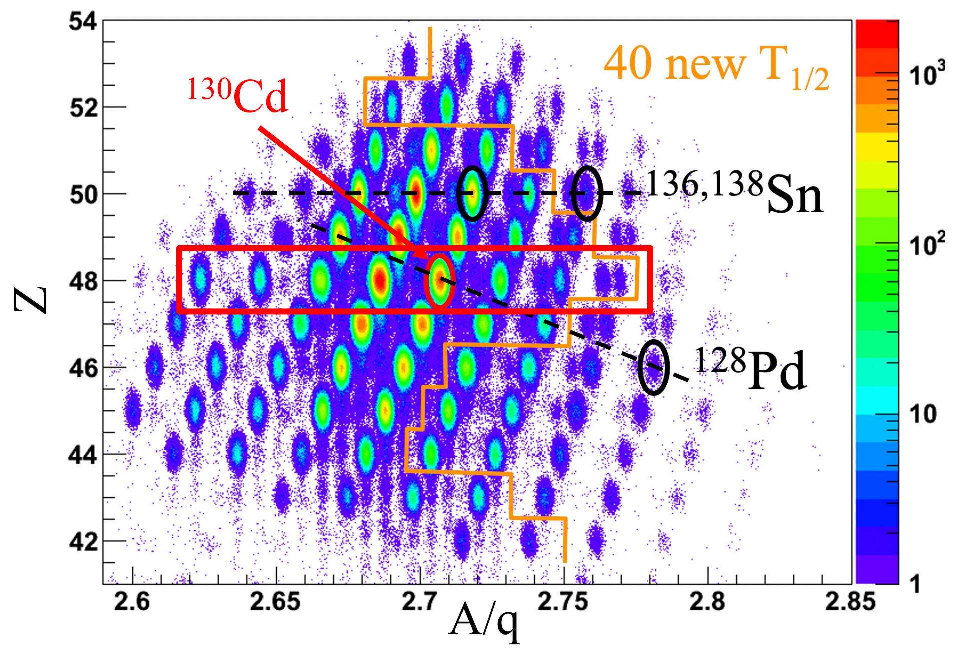
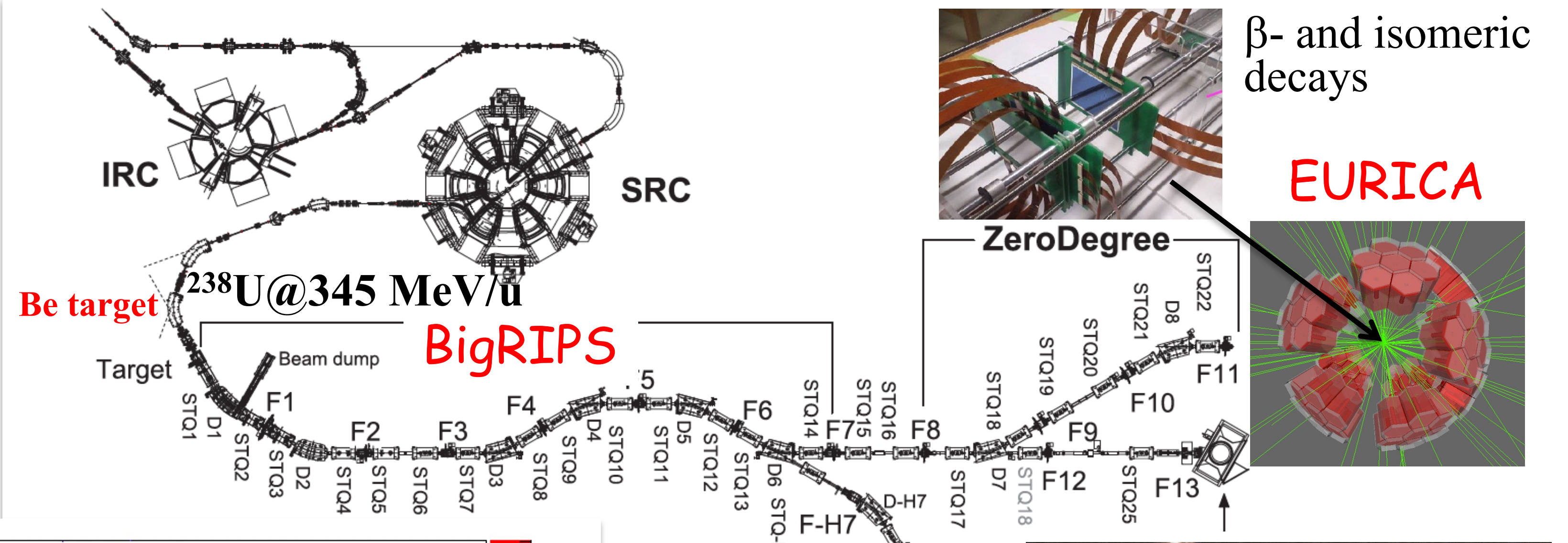
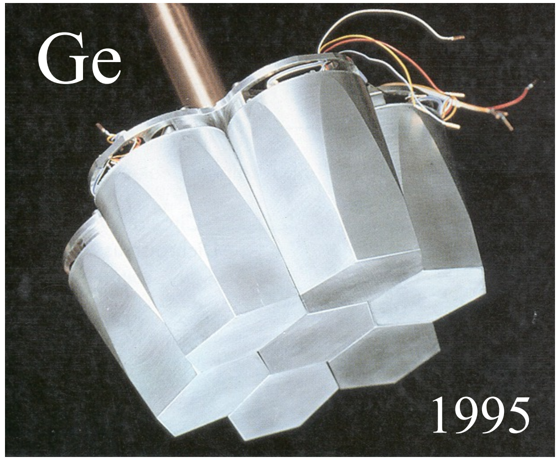


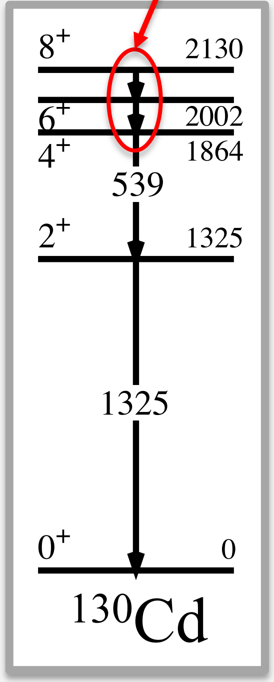



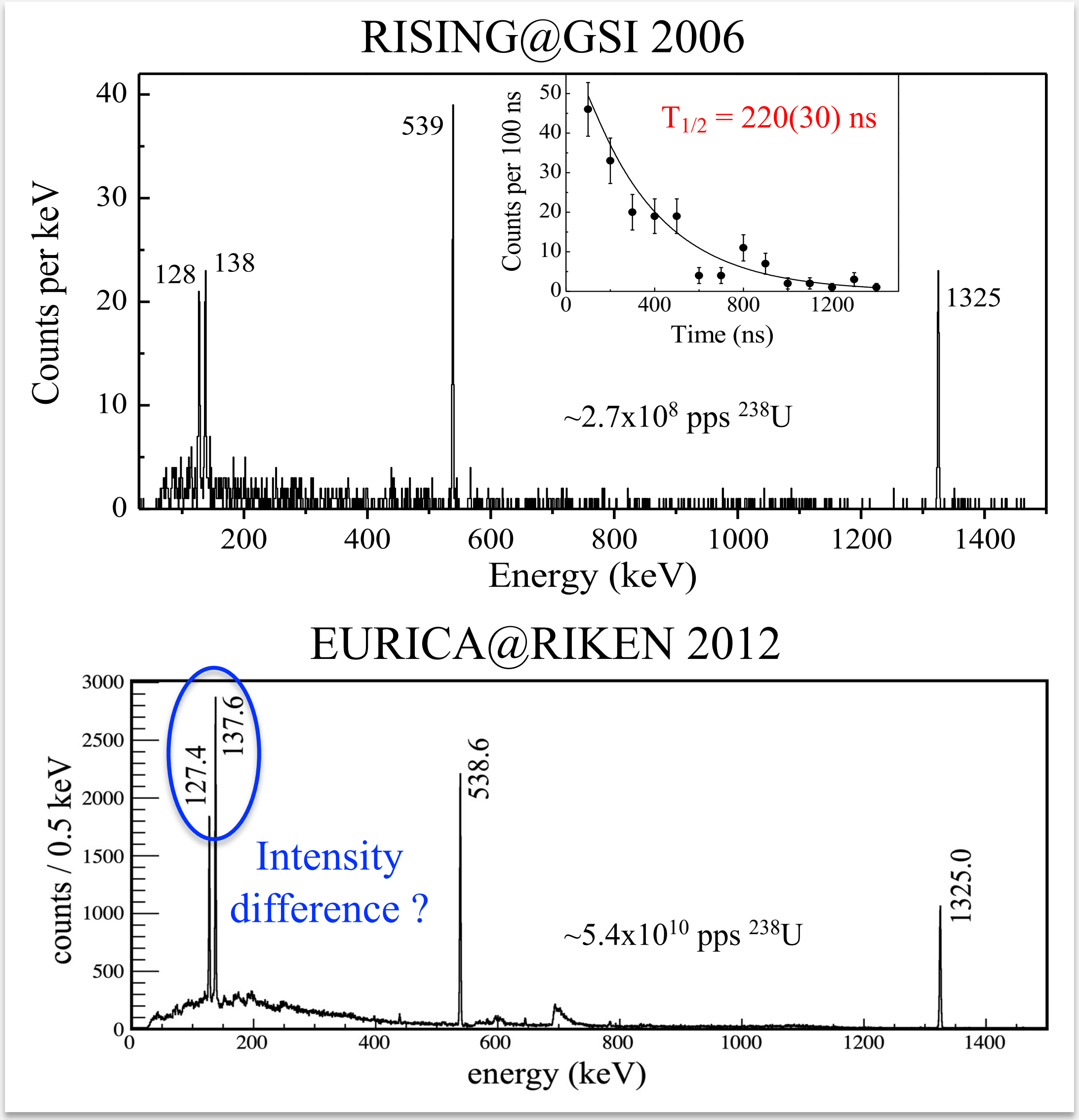

*T. Kubo et al., PTEP 2012, 03C003*

# An important remnant of Jan's PhD thesis …

Order ?

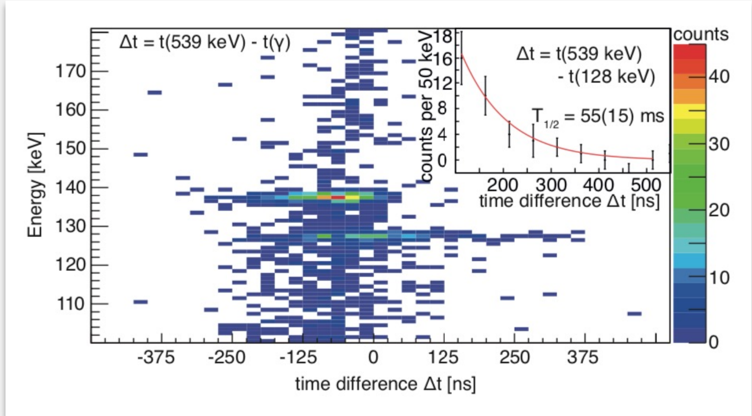



*A. Jungclaus et al.*
*PRL 99, 132501 (2007)*




Jan Taprogge, 2012-2015

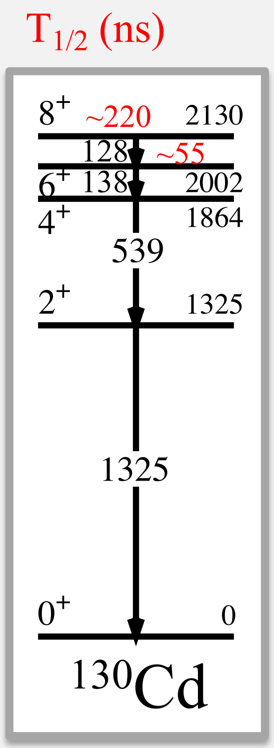
Order fixed !



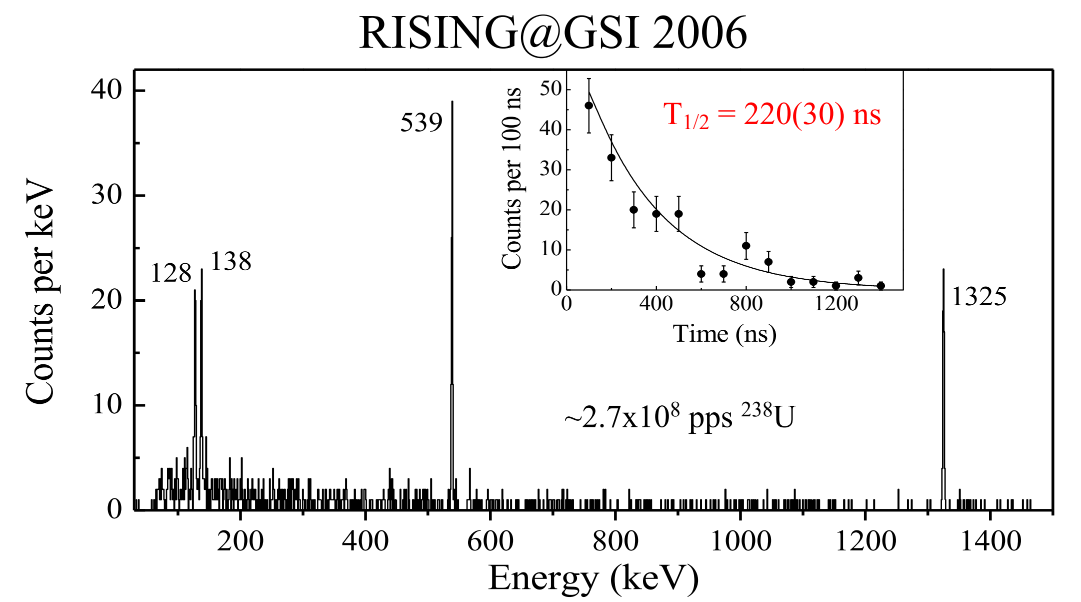

PhD thesis
UAM, 2015

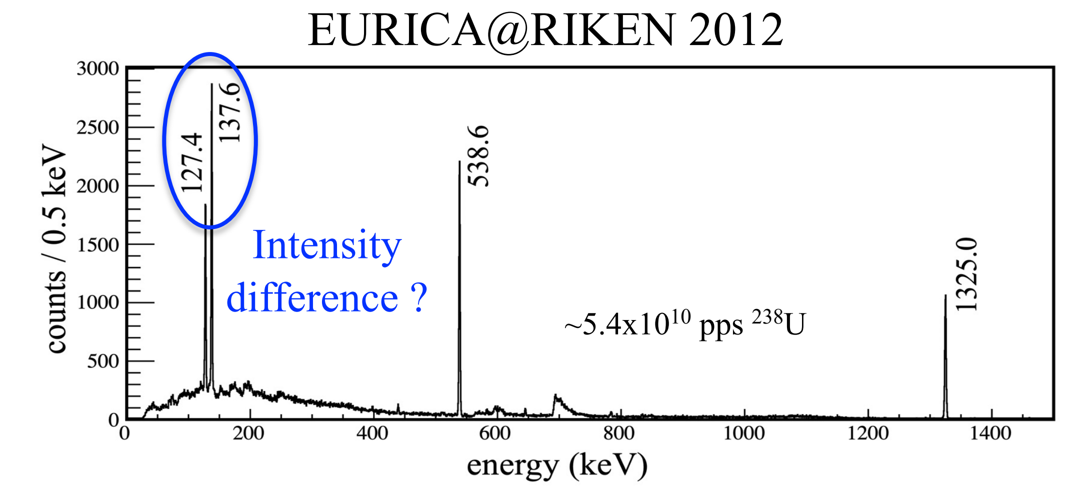
- J. Taprogge, *A. Jungclaus et al., Physical Review Letters 112, 132501 (2014)*
- J. Taprogge, *A. Jungclaus et al., Physics Letters B 738, 223 (2014)*
- J. Taprogge, *A. Jungclaus et al., Physical Review C 91, 054324 (2015)*
- *A. Jungclaus et al., Physical Review C 93, 041301(R) (2016)*
- *A. Jungclaus et al., Physical Review C 94, 024303 (2016)*
- J. Taprogge, *A. Jungclaus et al., European Physical Journal A 52, 347 (2016)*
- *A. Jungclaus et al., Physics Letters B 772, 483 (2017)*

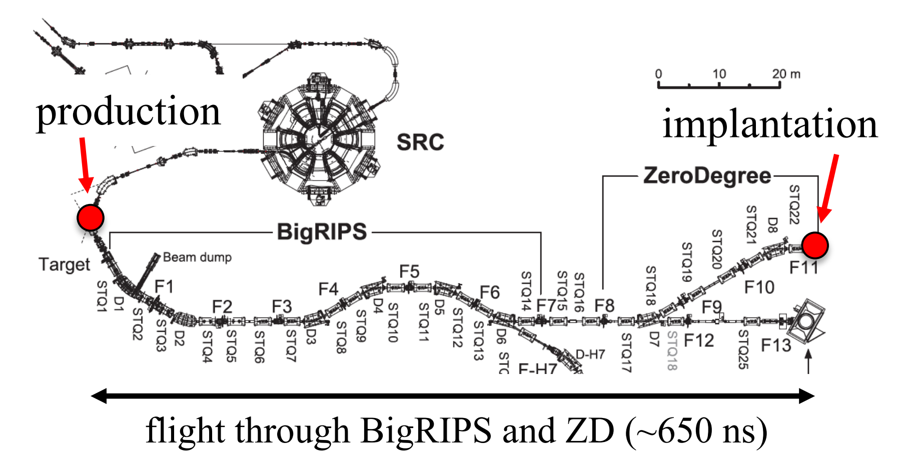
# … and the explanation ten years later !

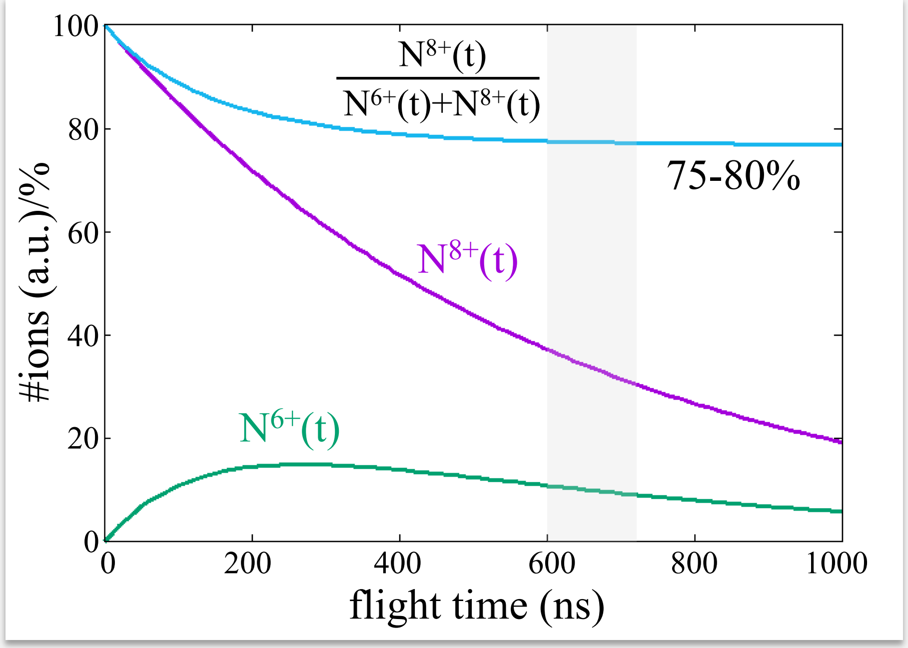



*A. Jungclaus et al.*
*PRL 99, 132501 (2007)*



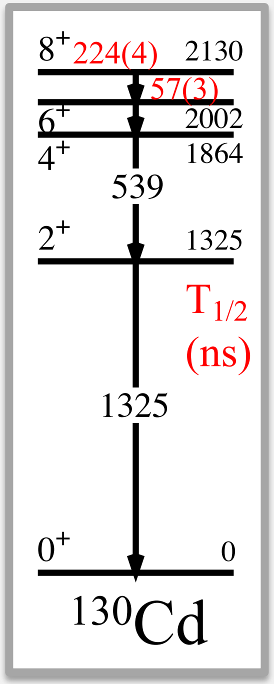



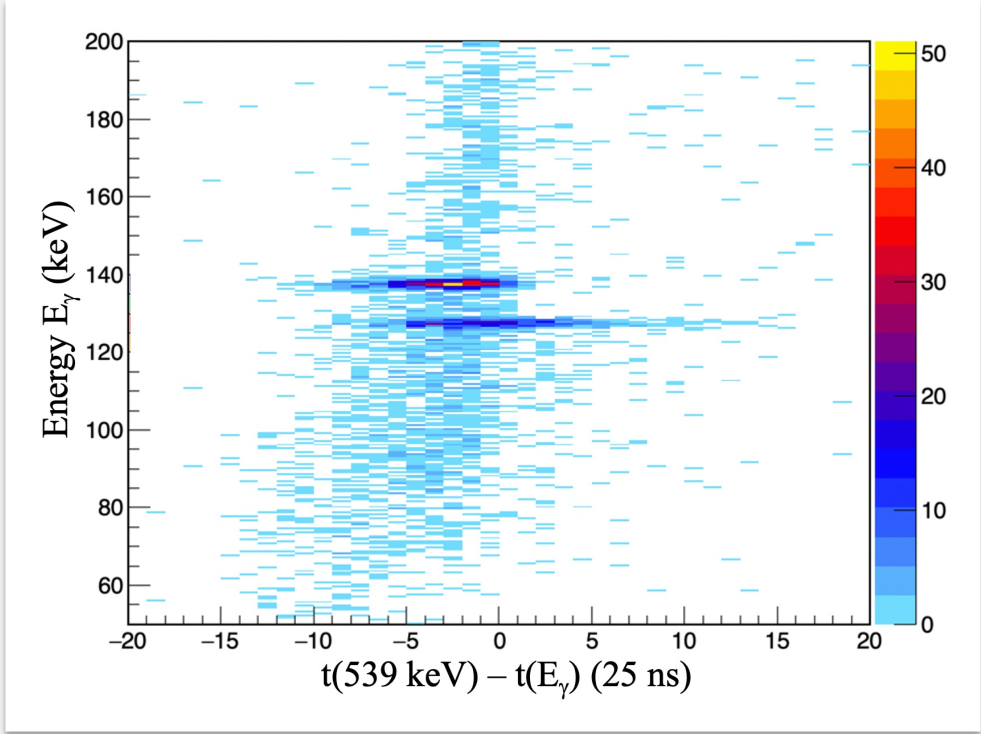
# Accurate experimental transition rates in $^{130}$Cd

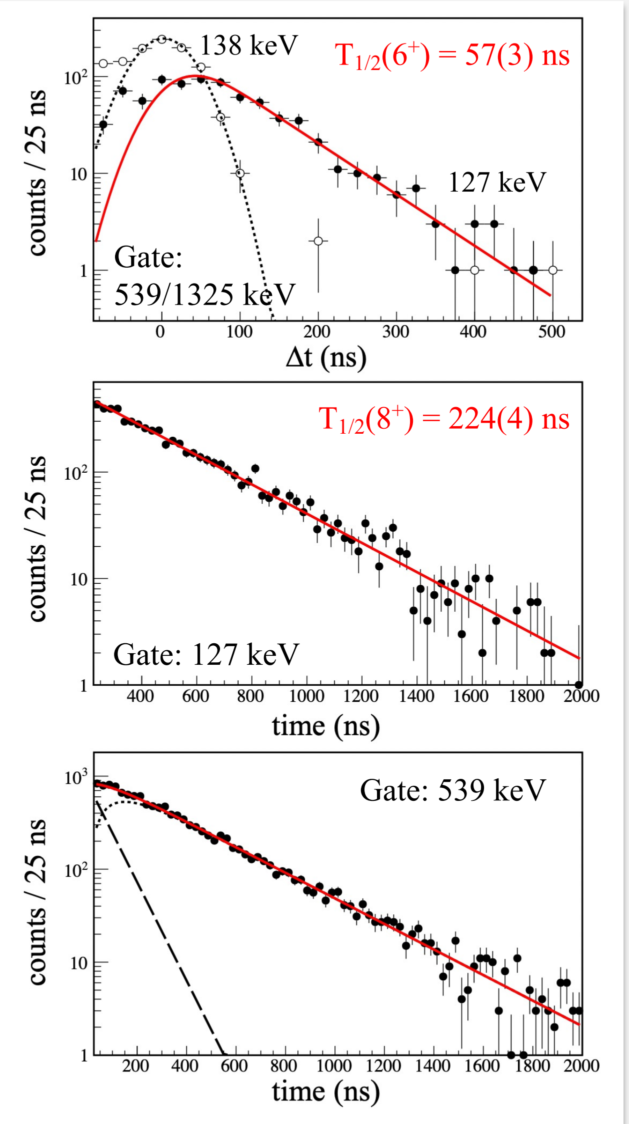
$\pi g_{9/2}^{-2}$ $8^+$ seniority isomer




*A. Jungclaus et al. PRL 99, 132501 (2007)*

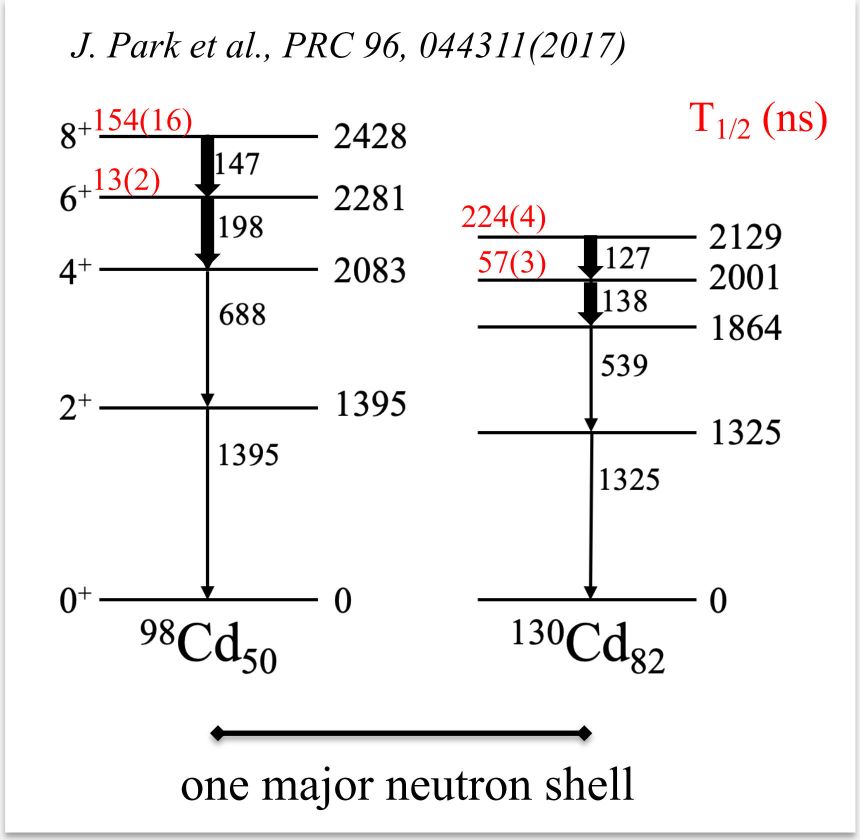
Careful new analysis:



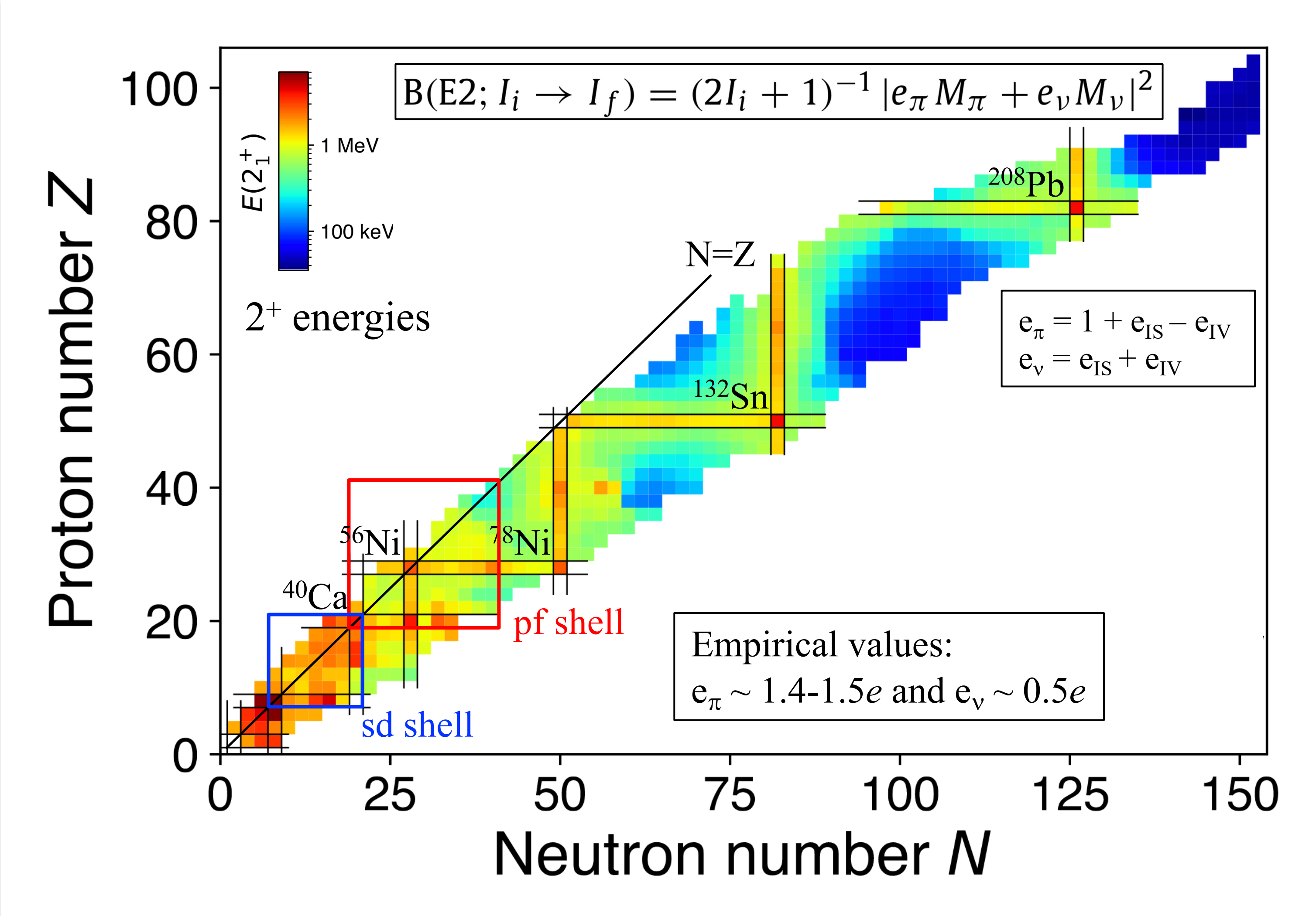

→ Accurate experimental B(E2; 8-6) and B(E2; 6-4) transition rates in $^{130}$Cd !

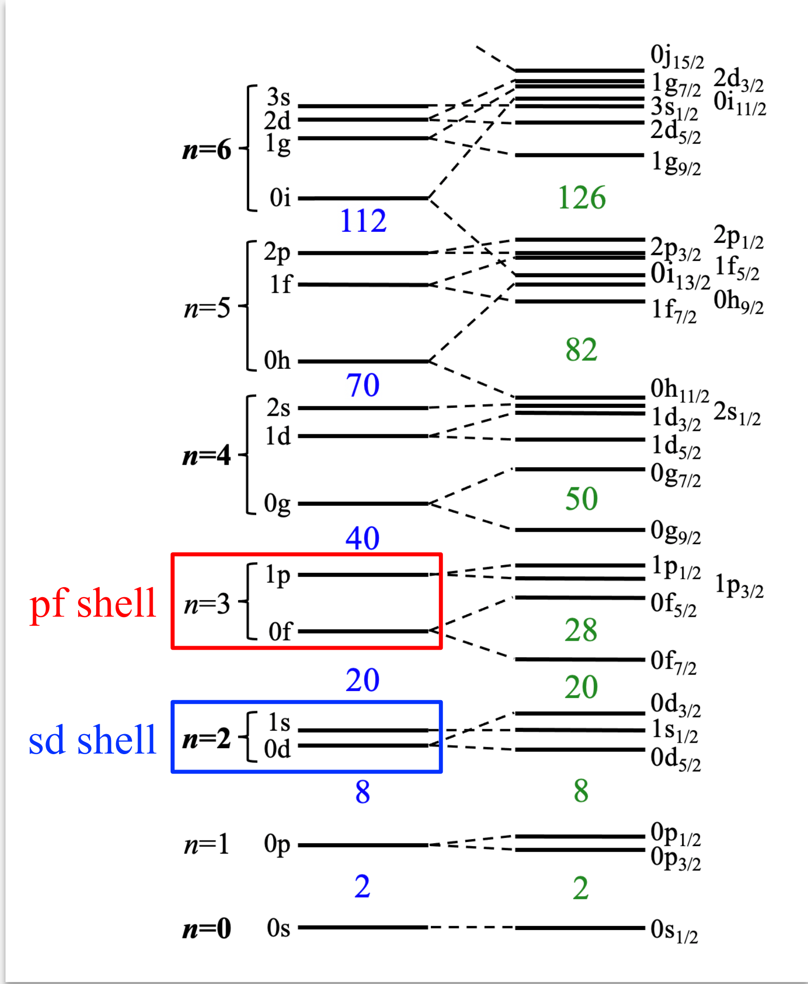
# Accurate experimental transition rates in $^{98}$Cd and $^{130}$Cd




Why is this important ?

# Effective charges in different regions of the chart




Effect of polarization is similar for both neutrons and protons, i.e., isovector contributions to the effective charges are small.

However, the assumption of constant effective charges is an approximation !

# Effective charges in the pf shell

PRL **93,** 222501 (2004) PHYSICAL REVIEW LETTERS week ending 26 NOVEMBER 2004

## Effective Charges in the $fp$ Shell

R. du Rietz,[1] J. Ekman,[1] D. Rudolph,[1] C. Fahlander,[1] A. Dewald,[2] O. Möller,[2] B. Saha,[2] M. Axiotis,[3] M. A. Bentley,[4] C. Chandler,[4] G. de Angelis,[3] F. Della Vedova,[5] A. Gadea,[3] G. Hammond,[4] S. M. Lenzi,[5] N. Mărginean,[3] D. R. Napoli,[3] M. Nespolo,[5] C. Rusu,[3] and D. Tonev[3]

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[2]*Institut für Kernphysik der Universität zu Köln, D-50937 Köln, Germany*
[3]*Instituto Nazionale di Fisica Nucleare, Laboratori Nazionali di Legnaro, I-35020 Legnaro, Italy*
[4]*School of Chemistry and Physics, Keele University, Keele, Staffordshire ST5 5BG, United Kingdom*
[5]*Dipartimento di Fisica dell'Università and INFN, Sezione di Padova, I-35141 Padova, Italy*

(Received 16 August 2004; published 22 November 2004)

Following the heavy-ion fusion-evaporation reaction $^{32}S + ^{24}Mg$ at 95 MeV beam energy the lifetimes of analogue states in the $T_z = \pm 1/2$ $A = 51$ mirror nuclei $^{51}Fe$ and $^{51}Mn$ have been measured using the Cologne plunger device coupled to the GASP $\gamma$-ray spectrometer. The deduced $B(E2; 27/2^- \rightarrow 23/2^-)$ values afford a unique opportunity to probe isoscalar and isovector polarization charges and to derive effective proton and neutron charges, $\varepsilon_p$ and $\varepsilon_n$, in the $fp$ shell. A comparison between the experimental results and several different large-scale shell-model calculations yields $\varepsilon_p \sim 1.15e$ and $\varepsilon_n \sim 0.80e$.

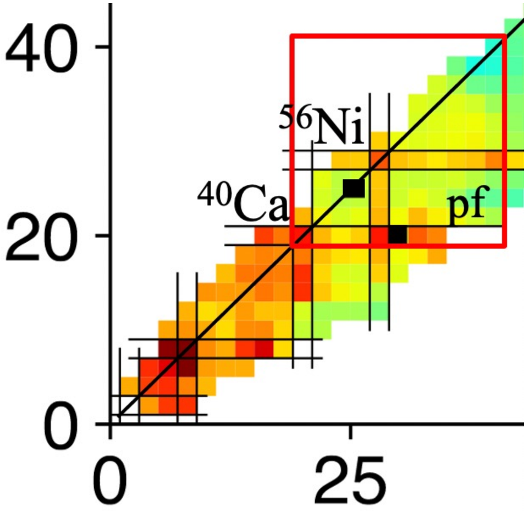
DOI: 10.1103/PhysRevLett.93.222501 PACS numbers: 21.10.Tg, 21.60.Cs, 27.40.+z

$^{51}$Fe, $^{51}$Mn

$f_{7/2}$ dominated

N~Z

$e_\pi \sim 1.15e$
$e_\nu \sim 0.80e$




PRL **102,** 242502 (2009) PHYSICAL REVIEW LETTERS week ending 19 JUNE 2009

## Lifetime Measurements of the Neutron-Rich $N = 30$ Isotones $^{50}$Ca and $^{51}$Sc: Orbital Dependence of Effective Charges in the $fp$ Shell

J. J. Valiente-Dobón,[1,*] D. Mengoni,[2] A. Gadea,[1,3] E. Farnea,[4] S. M. Lenzi,[2] S. Lunardi,[2] A. Dewald,[5] Th. Pissulla,[5] S. Szilner,[6] R. Broda,[7] F. Recchia,[1] A. Algora,[3,8] L. Angus,[9] D. Bazzacco,[4] G. Benzoni,[10] P. G. Bizzeti,[11] A. M. Bizzeti-Sona,[11] P. Boutachkov,[12] L. Corradi,[1] F. Crespi,[13] G. de Angelis,[1] E. Fioretto,[1] A. Görgen,[14] M. Gorska,[12] A. Gottardo,[1] E. Grodner,[1] B. Guiot,[1] A. Howard,[15] W. Królas,[7] S. Leoni,[13] P. Mason,[1] R. Menegazzo,[4] D. Montanari,[13] G. Montagnoli,[2] D. R. Napoli,[1] A. Obertelli,[14] T. Pawłat,[7] G. Pollarolo,[16] B. Rubio,[3] E. Şahin,[1] F. Scarlassara,[2] R. Silvestri,[1] A. M. Stefanini,[1] J. F. Smith,[9] D. Steppenbeck,[15] C. A. Ur,[4] P. T. Wady,[9] J. Wrzesiński,[7] E. Maglione,[2] and I. Hamamoto[17]

[1]*Istituto Nazionale di Fisica Nucleare, Laboratori Nazionali di Legnaro, Legnaro, Italy*
[2]*Dipartimento di Fisica dell'Università and INFN Sezione di Padova, Padova, Italy*
[3]*Instituto de Física Corpuscular, CSIC-Universidad de Valencia, Valencia, Spain*
[4]*Istituto Nazionale di Fisica Nucleare, Sezione di Padova, Padova, Italy*
[5]*Institut für Kernphysik der Universität zu Köln, Köln, Germany*
[6]*Ruđer Bošković Institute, Zagreb, Croatia*
[7]*Institute of Nuclear Physics, Polish Academy of Sciences, Cracow, Poland*
[8]*Institute of Nuclear Research of the Hungarian Academy of Sciences, Debrecen, Hungary*
[9]*School of Engineering and Science, University of Paisley, Paisley, Scotland, United Kingdom*
[10]*Istituto Nazionale di Fisica Nucleare, Sezione di Milano, Milano, Italy*
[11]*Dipartimento di Fisica dell'Università and INFN Sezione di Firenze, Firenze, Italy*
[12]*Helmholtzzentrum für Schwerionenforschung (GSI), Darmstadt, Germany*
[13]*Dipartimento di Fisica dell'Università and INFN Sezione di Milano, Milano, Italy*
[14]*CEA Saclay, IRFU/Service de Physique Nucléaire, Gif-sur-Yvette, France*
[15]*Schuster Laboratory, University of Manchester, Manchester, United Kingdom*
[16]*Dipartimento di Fisica Teorica, Università di Torino, Via Pietro Giuria I, I-10125 Torino, Italy*
[17]*Department of Mathematical Physics, Lund Institute of Technology at University of Lund, Lund, Sweden*

(Received 2 December 2008; published 16 June 2009; corrected 23 July 2009)

The lifetimes of the first excited states of the $N = 30$ isotones $^{50}$Ca and $^{51}$Sc have been determined using the Recoil Distance Doppler Shift method in combination with the CLARA-PRISMA spectrometers. This is the first time such a method is applied to measure lifetimes of neutron-rich nuclei populated via a multinucleon transfer reaction. This extends the lifetime knowledge beyond the $f_{7/2}$ shell closure and allows us to derive the effective proton and neutron charges in the $fp$ shell near the doubly magic nucleus $^{48}$Ca, using large-scale, shell-model calculations. These results indicate an orbital dependence of the core polarization along the $fp$ shell.

DOI: 10.1103/PhysRevLett.102.242502 PACS numbers: 27.40.+z, 21.10.Tg, 21.60.Cs, 23.20.−g

$^{50}$Ca, $^{51}$Sc

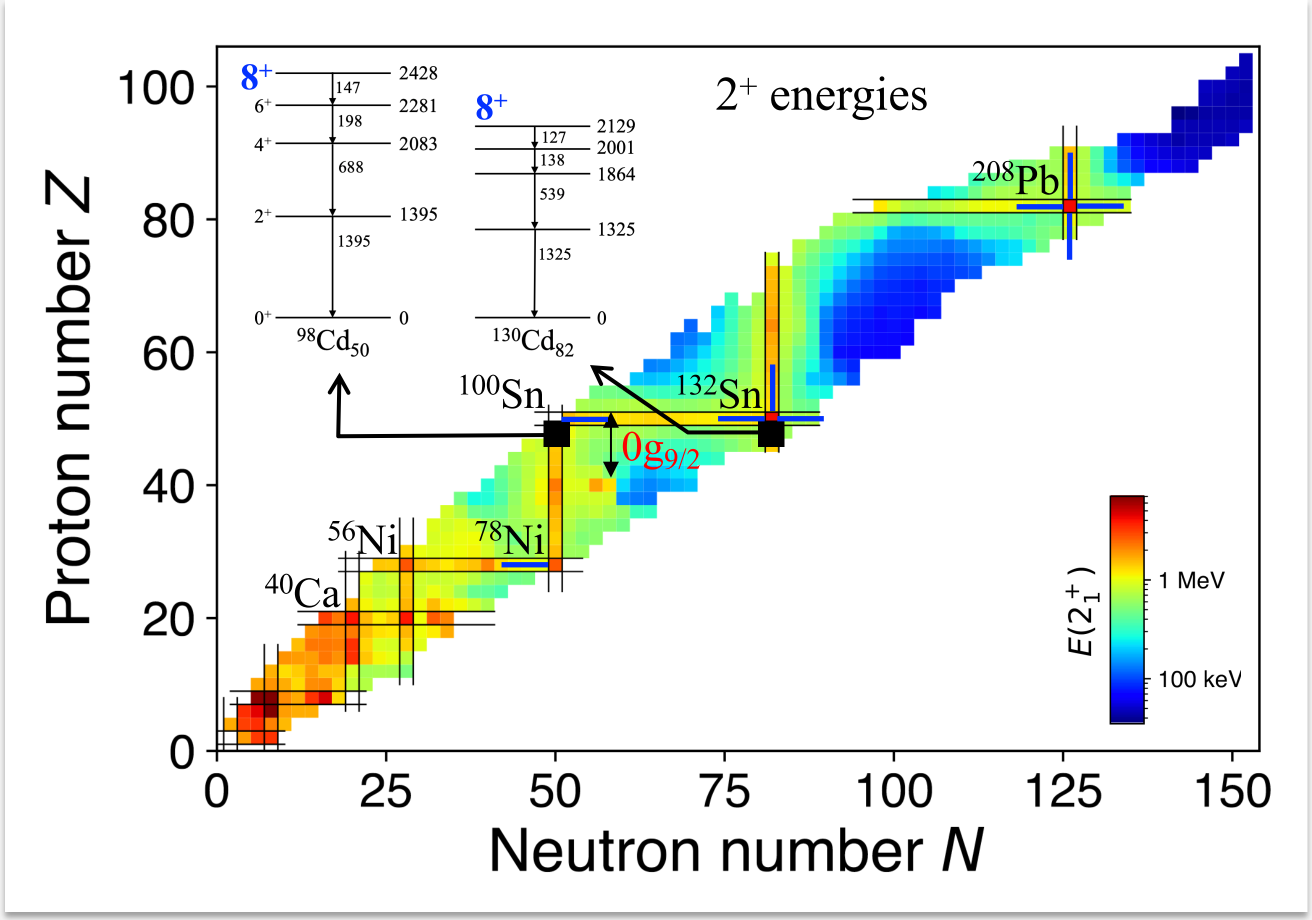
$p_{3/2}$ dominated

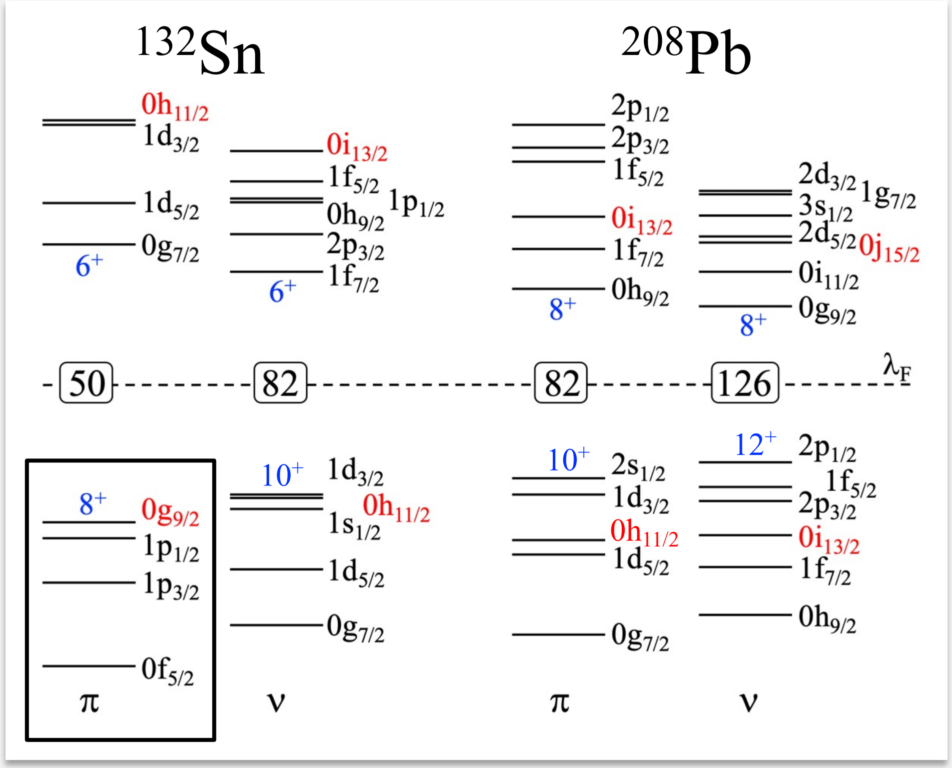
N/Z = 1.5

$e_\pi \sim 1.5e$
$e_\nu = 0.5e$

Isospin or orbital dependence ?

# Uniqueness of the $8^+$ seniority isomers in $^{98,130}Cd$



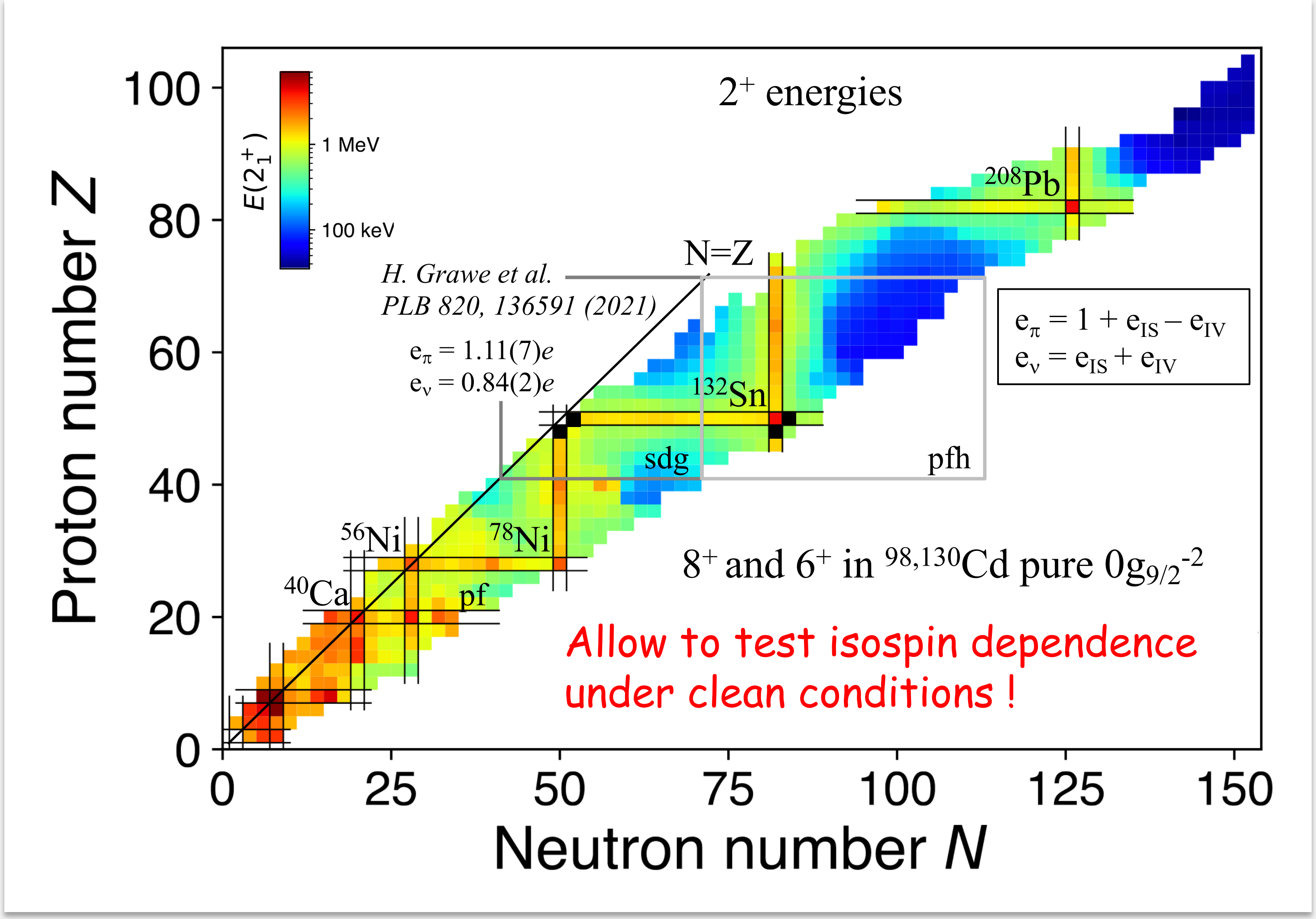



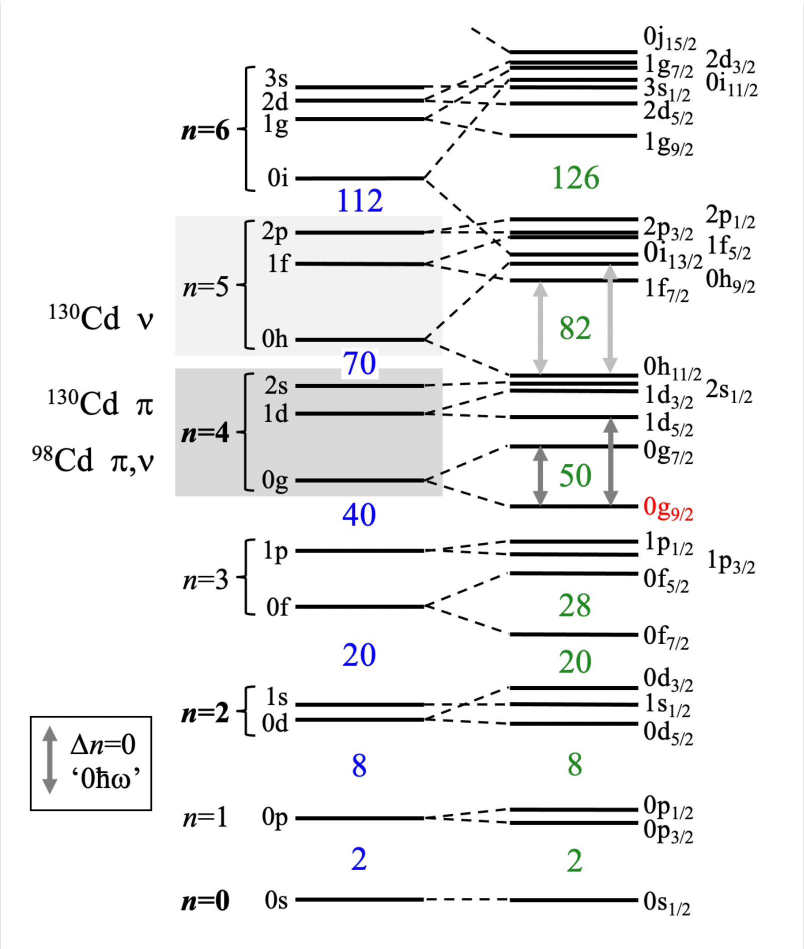

intruder orbitals     seniority isomers

Unique opportunity to study the evolution of the proton effective charge $e_\pi$ along an entire major neutron shell (1.04<N/Z<1.71) !

$8^+$ and $6^+$ in $^{98,130}Cd$ pure $0g_{9/2}^{-2}$, $4^+$ >99%

# Effective charges for $^{98,132}$Cd from 0ħω SM calculations




$^{98}$Cd: SDGN interaction

*M. Górska, Physics 4, 364 (2022)*

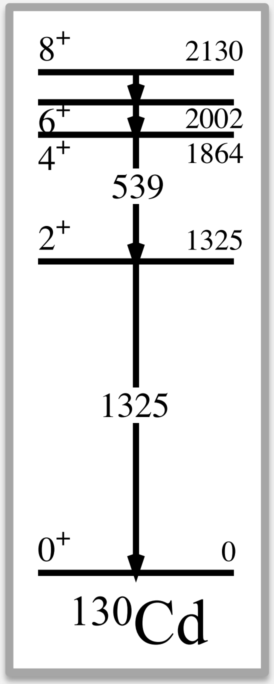
$^{130}$Cd: NNS110 interaction

*H. Naidja, F. Nowacki, and K. Sieja, Acta Phys. Pol. B 46, 669 (2015)*

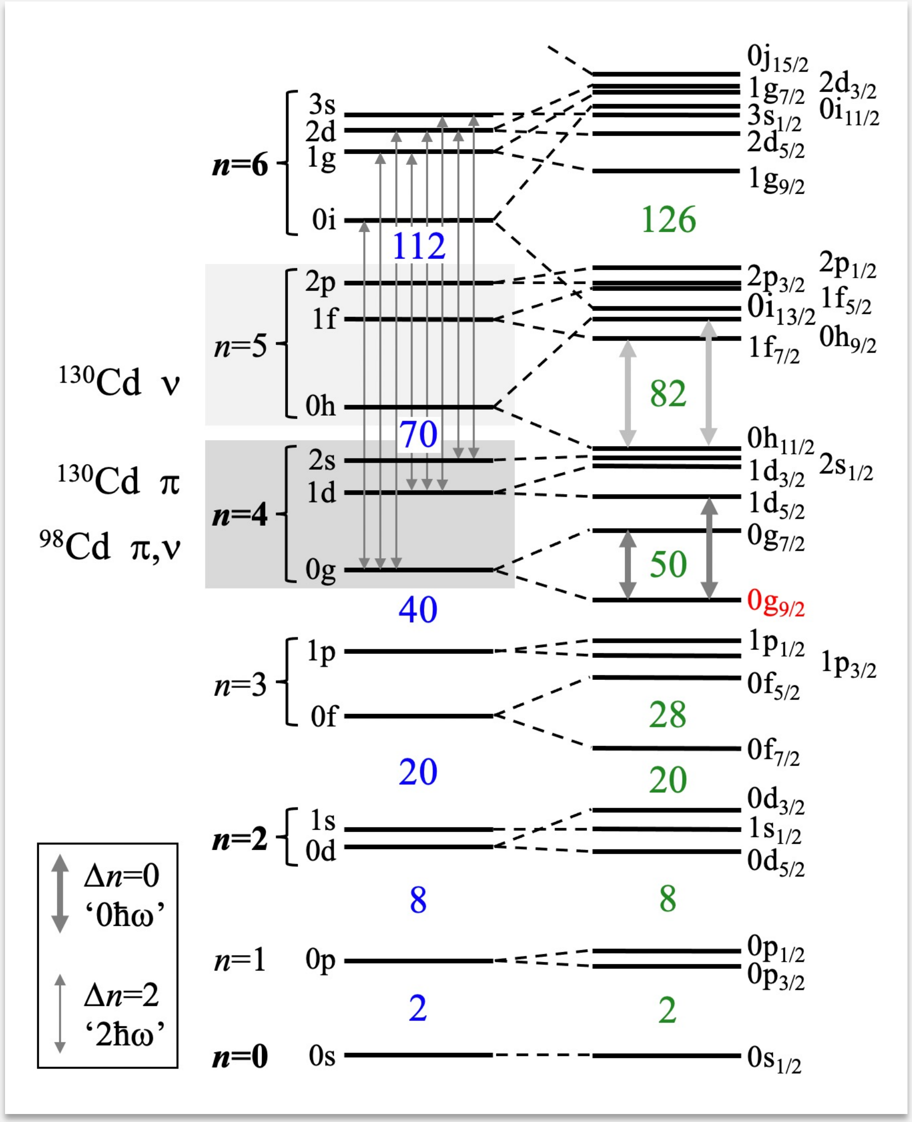
Full harmonic oscillator shells, include all $\Delta n$=0 excitations ("0ħω calculations").

# What is missing in 0ħω shell-model calculations ?

$\pi g_{9/2}^{-2}$ $8^+$
seniority isomer




*A. Jungclaus et al.*
*PRL 99, 132501 (2007)*




Full harmonic oscillator shell, includes all $\Delta n=0$ excitations (called "0ħω calculation").

Best we can do …

However, $\Delta n=2$ excitations are still outside the model space !

**Giant Quadrupole resonances (GQR)**

$E_x \approx 2\hbar\omega$, e.g., ≈16–17 MeV for $^{100,132}Sn$

The effective charges extracted from 0ħω shell-model calculations account for the neglect of the coupling to the GQR.

# Theoretical predictions of the isospin dependence

**NUCLEAR STRUCTURE**

**Volume II: Nuclear Deformations**

isoscalar

$$e^{\mathrm{std}}_{\mathrm{pol}}(E2,\Delta E=0) = \frac{Ze}{A}\chi(\tau=0,\Delta E=0)\left(1+\frac{V_1}{4V_0}\frac{N-Z}{A}\tau_z\right)$$

isovector

$$-\frac{e}{2}\chi(\tau=1,\Delta E=0)\left(\tau_z-\frac{N-Z}{A}\right) \qquad (6\text{-}386a)$$

$$= e\left(\frac{Z}{A}-0.32\frac{N-Z}{A}+\left(0.32-0.3\frac{N-Z}{A}\right)\tau_z\right) \qquad (6\text{-}386b)$$

+1 for ν
-1 for π


**Aage Bohr**
*The Niels Bohr Institute, University of Copenhagen*

**Ben R. Mottelson**
*Nordita, Copenhagen*


BM

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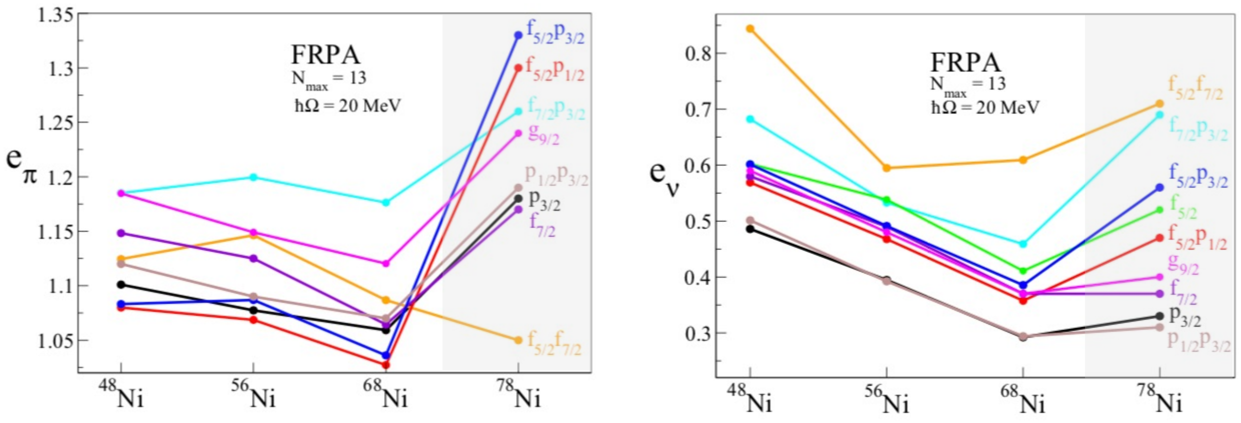
PHYSICAL REVIEW C **100**, 024317 (2019)


*ab-initio*

**Core-polarization effects and effective charges in O and Ni isotopes from chiral interactions**


Francesco Raimondi[1,2] and Carlo Barbieri[1]
[1]*Department of Physics, University of Surrey, Guildford GU2 7XH, United Kingdom*
[2]*ESNT, CEA, Université Paris-Saclay, 91191 Gif-sur-Yvette, France*

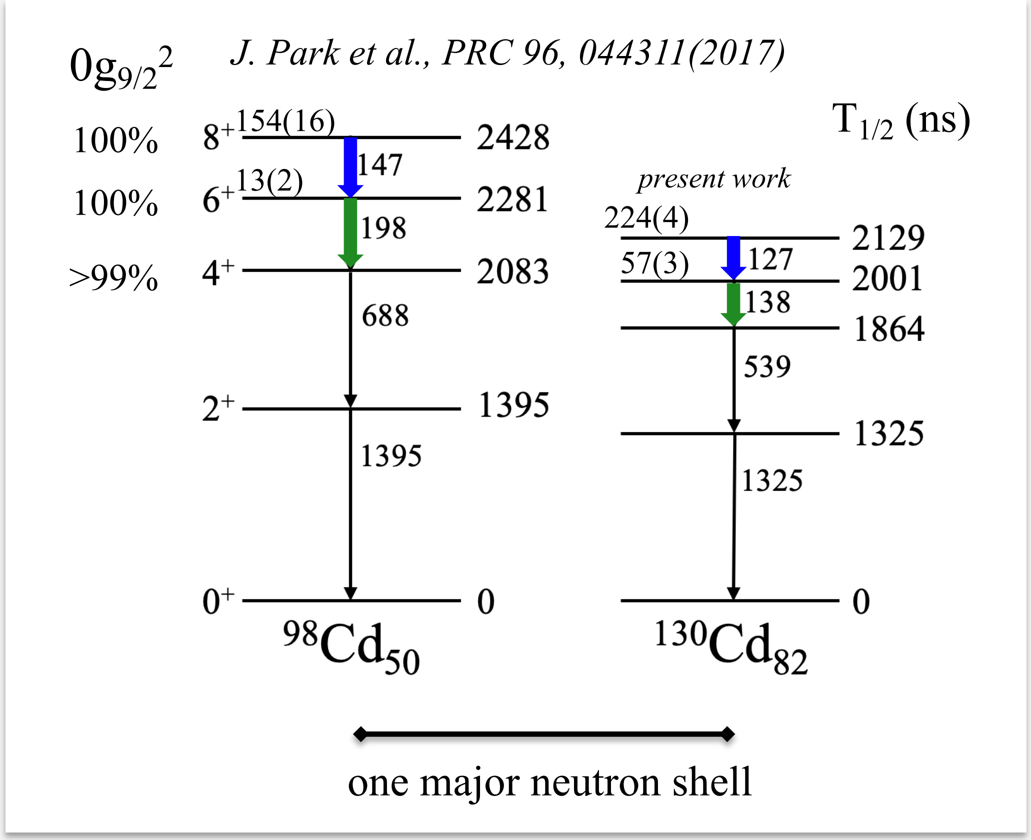

orbital-dependent proton and neutron effective charges $e_\pi$, $e_\nu$

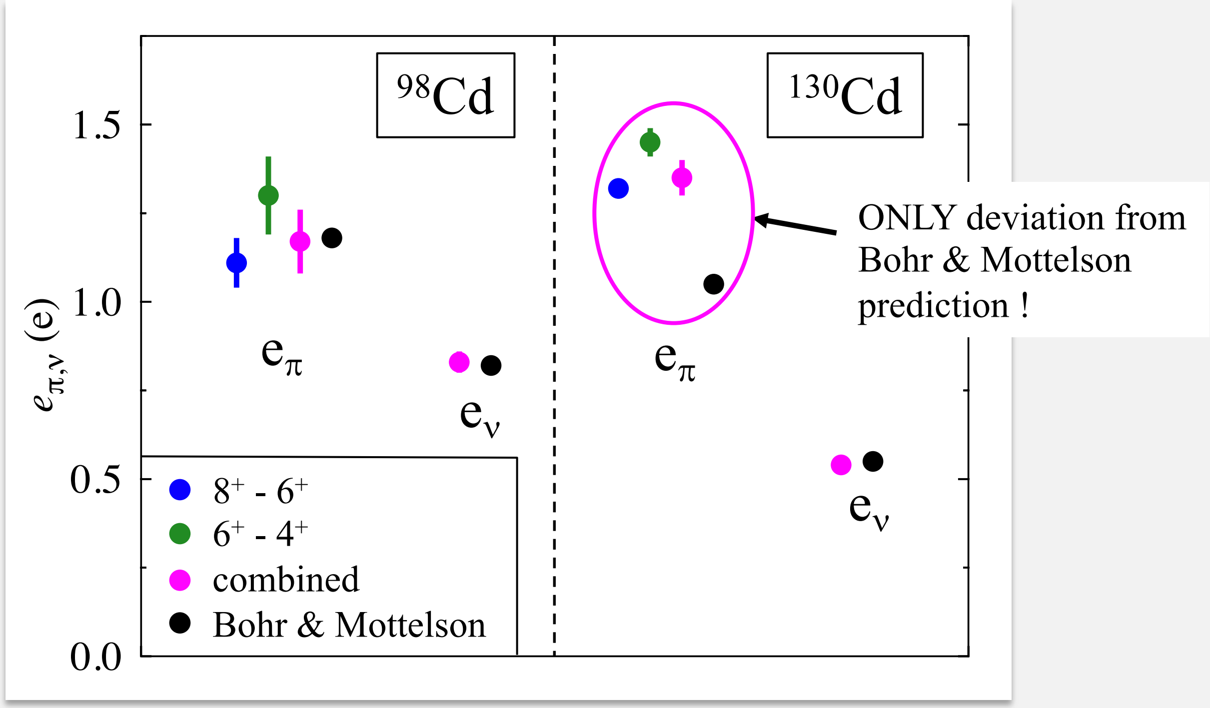



$^{78}$Ni maybe not fully converged

- harmonic oscillator model
- one collective GQR state exhausting 100% of the EWSR
- further simplifying assumptions to describe the coupling between the two modes (IS and IV)

# Effective charges for $^{98,132}$Cd from 0ħω SM calculations



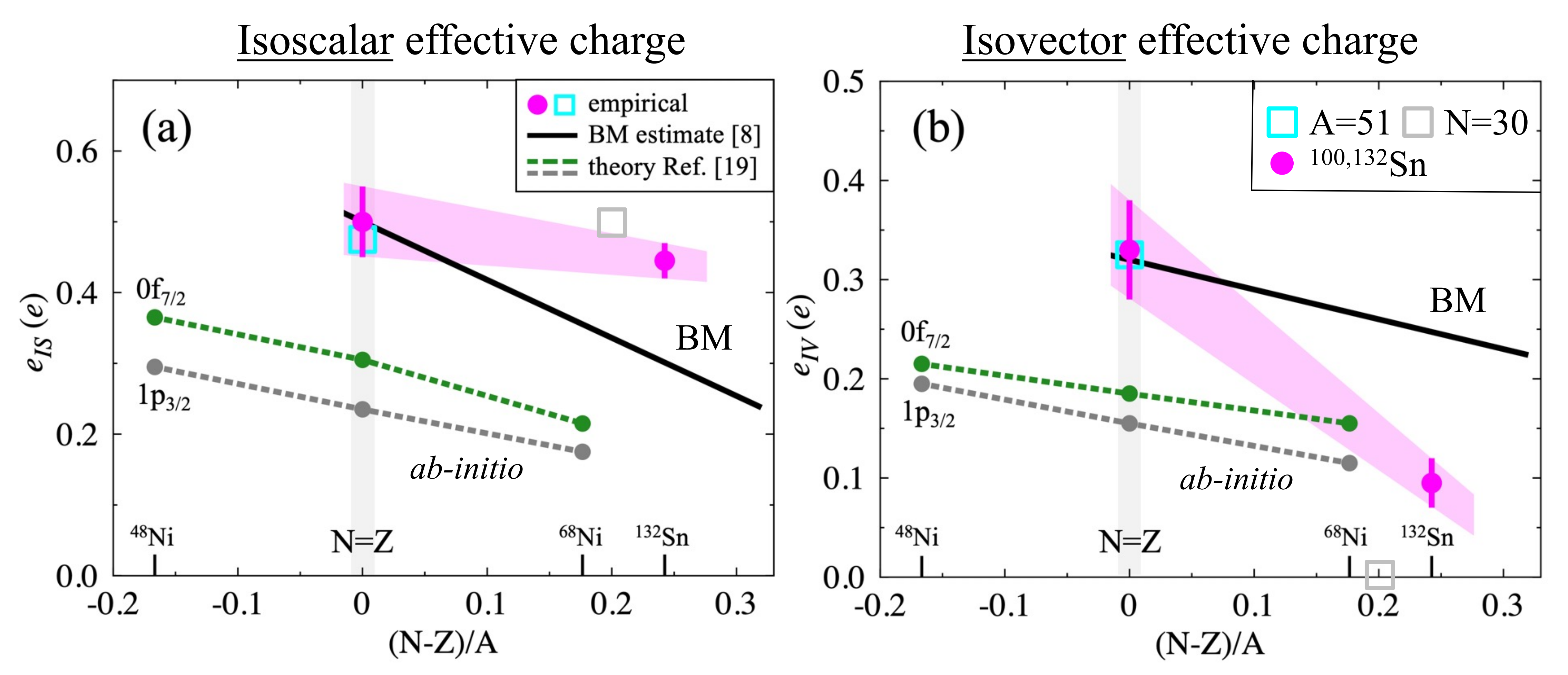




State-dependent effects are not understood: Consider both and increase the uncertainty !

From proton and neutron effective charges to isoscalar and isovector effective charges:

$$e_\pi = 1 + e_{IS} - e_{IV}$$
$$e_\nu = e_{IS} + e_{IV}$$

# Empirically extracted vs. calculated effective charges




- $e_{IS}$ decreases slower and $e_{IV}$ decreases faster than expected
- In general, too small values are obtained in the ab-initio calculations.
- Empirically extracted charges are rather consistent.

Strong isovector effects close to N=Z !

# Effective charges in recent large-scale SM calculations

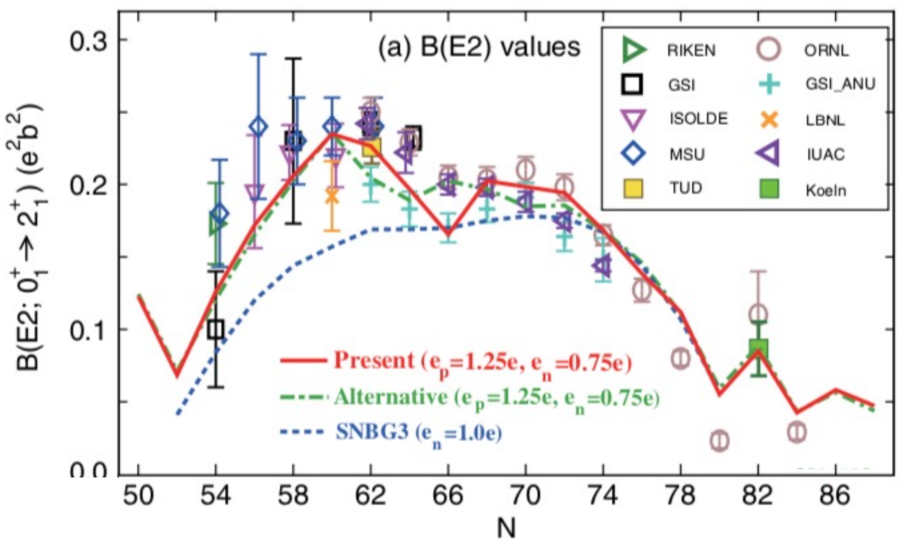
PHYSICAL REVIEW LETTERS **121,** 062501 (2018)

$e_\pi = 1.25e$, $e_\nu = 0.75e$

**Novel Shape Evolution in Sn Isotopes from Magic Numbers 50 to 82**

Tomoaki Togashi,[1] Yusuke Tsunoda,[1] Takaharu Otsuka,[2,1,3,4,5,*] Noritaka Shimizu,[1] and Michio Honma[6]
[1]*Center for Nuclear Study, University of Tokyo, Hongo, Bunkyo-ku, Tokyo 113-0033, Japan*
[2]*Department of Physics, University of Tokyo, Hongo, Bunkyo-ku, Tokyo 113-0033, Japan*
[3]*RIKEN Nishina Center, 2-1 Hirosawa, Wako, Saitama 351-0198, Japan*
[4]*Instituut voor Kern- en Stralingsfysica, KU Leuven, B-3001 Leuven, Belgium*
[5]*National Superconducting Cyclotron Laboratory, Michigan State University, East Lansing, Michigan 48824, USA*
[6]*Center for Mathematical Sciences, University of Aizu, Ikki-machi, Aizu-Wakamatsu, Fukushima 965-8580, Japan*

Monte Carlo shell model in huge spaces




Increase of B(E2) around $^{110}$Sn due to shape evolution driven by proton excitations from the $g_{9/2}$ orbital.

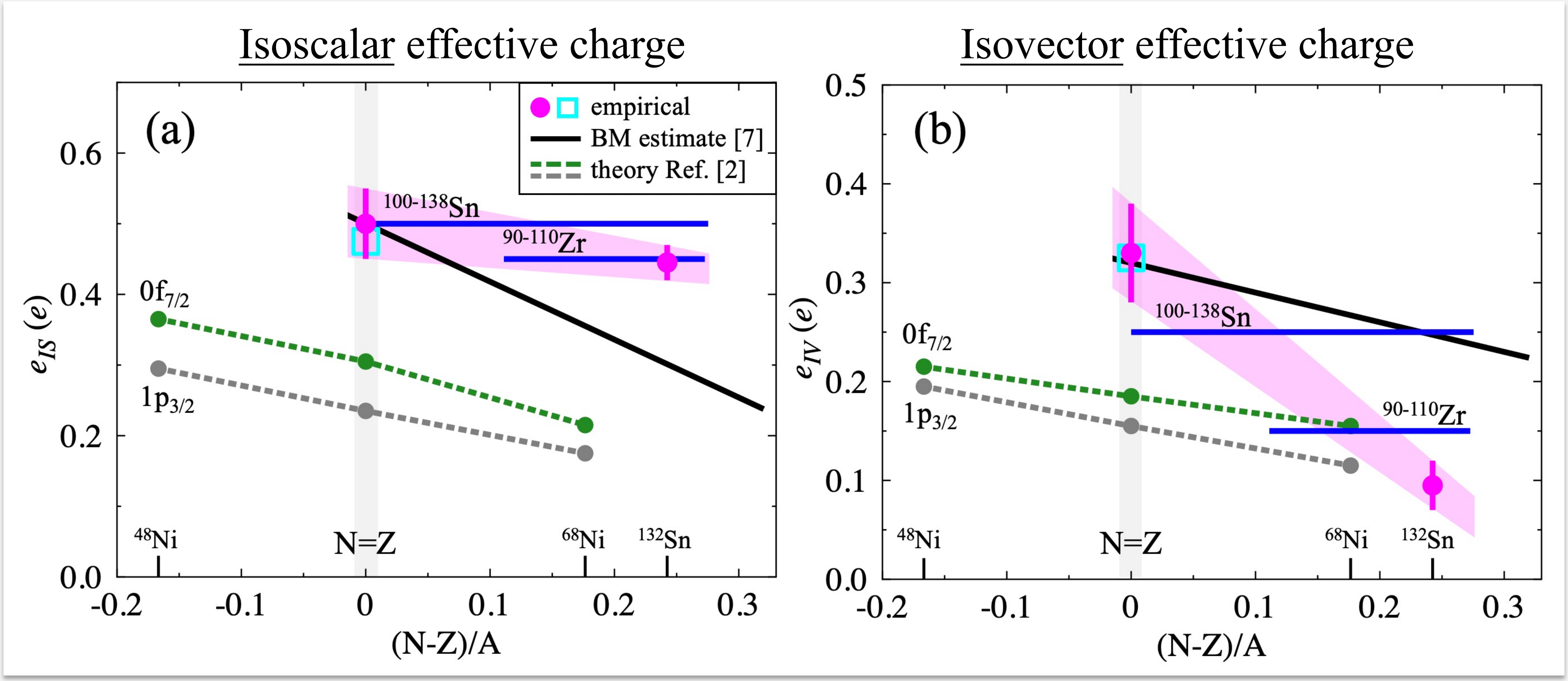
PRL **117,** 172502 (2016) PHYSICAL REVIEW LETTERS week ending 21 OCTOBER 2016

$e_\pi = 1.3e$, $e_\nu = 0.6e$

**Quantum Phase Transition in the Shape of Zr isotopes**

Tomoaki Togashi,[1] Yusuke Tsunoda,[1] Takaharu Otsuka,[1,2,3,4] and Noritaka Shimizu[1]
[1]*Center for Nuclear Study, University of Tokyo, Hongo, Bunkyo-ku, Tokyo 113-0033, Japan*
[2]*Department of Physics, University of Tokyo, Hongo, Bunkyo-ku, Tokyo 113-0033, Japan*
[3]*National Superconducting Cyclotron Laboratory, Michigan State University, East Lansing, Michigan 48824, USA*
[4]*Instituut voor Kern- en Stralingsfysica, KU Leuven, B-3001 Leuven, Belgium*

# Empirically extracted vs. calculated effective charges



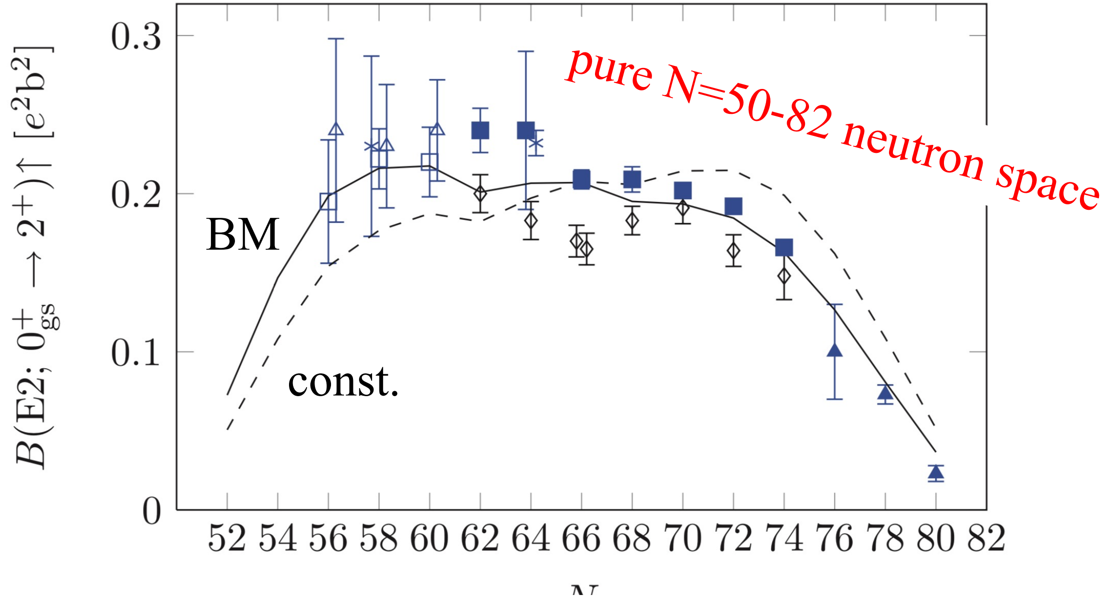

‘ad-hoc’ values close to the average values extracted from empirical dependence on neutron excess !

# Relevance of isospin-dependent effective charges

PHYSICAL REVIEW C **87**, 031306(R) (2013)

**Transition probabilities near $^{100}$Sn and the stability of the $N$, $Z$ = 50 shell closure**

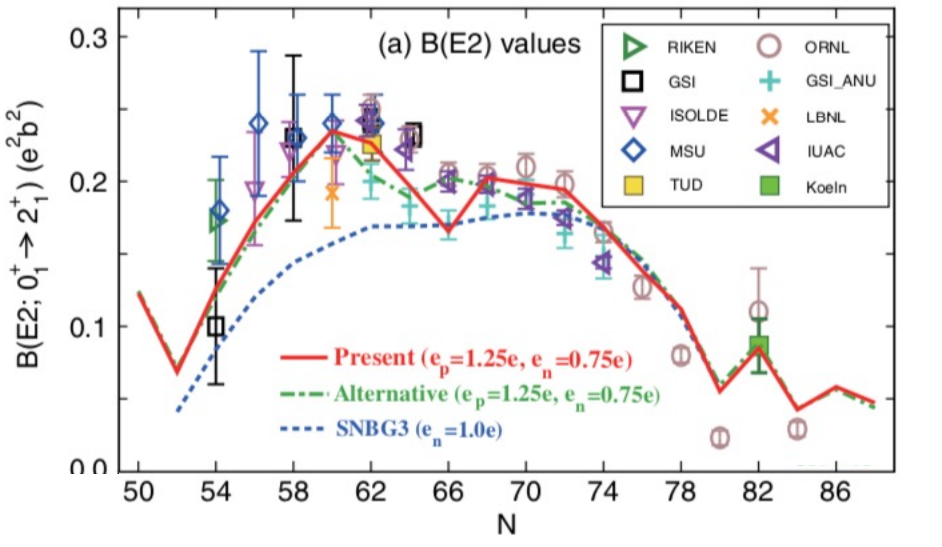
T. Bäck,[1,*] C. Qi,[1] B. Cederwall,[1] R. Liotta,[1] F. Ghazi Moradi,[1] A. Johnson,[1] R. Wyss,[1] and R. Wadsworth[2]
[1]*Royal Institute of Technology, SE-10691 Stockholm, Sweden*
[2]*Department of Physics, University of York, YO10 5DD York, United Kingdom*
(Received 12 April 2012; revised manuscript received 28 February 2013; published 22 March 2013)




The dashed model curve corresponds to a constant neutron effective charge, $e_n^{eff} = 1.0e$. The solid curve uses the isospin-dependent $e_n^{eff}$ from Bohr and Mottelson [31], normalized to $e_n^{eff} = 1.0e$ at $N = 66$.

Increase of B(E2) around $^{110}$Sn due to shape evolution driven by proton excitations from the $g_{9/2}$ orbital.

Monte Carlo shell model in huge spaces

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How would the use of isospin-dependent effective charges affect the trend in these MCSM calculations ?

# Twelve years after the experiment, finally thanks to …

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**Excited-State Half-Lives in $^{130}$Cd and the Isospin Dependence of Effective Charges**

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