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INSTITUT DE PHYSIQUE NUCLÉAIRE
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Proposal: Beta-delayed neutron spectroscopy of ^{54}Ca

Addendum of IS599

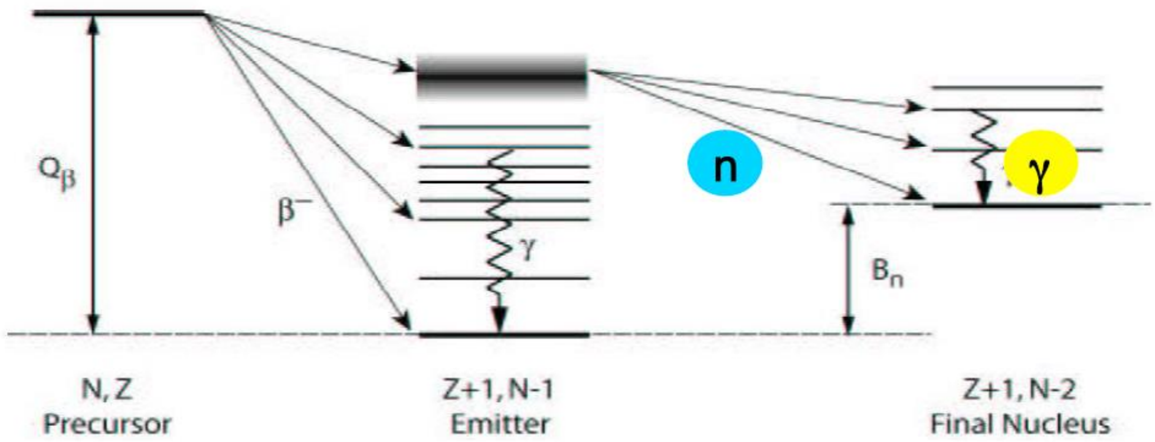
ISOLDE

Index

- Why beta-delayed neutron spectroscopy ?
- IS599: $^{51-53}K \rightarrow \; ^{51-53}Ca$
- Physics case for $^{54}K \rightarrow \; ^{54,53}Ca$
- Beam-time request

Beta-delayed neutron spectroscopy

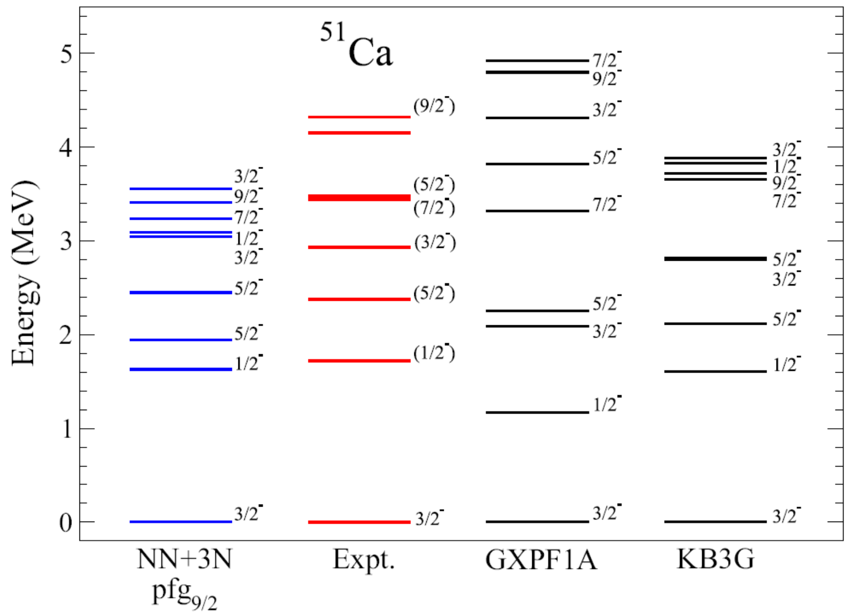
In exotic nuclei close to shell closures we can have very large Q values (15 MeV or more)

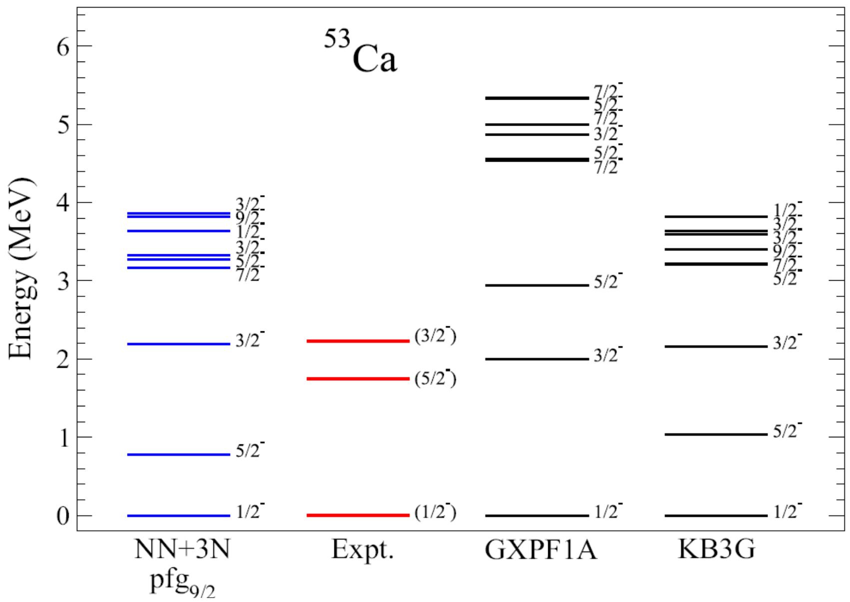


The beta decay can thus populate states below and above the neutron (and 2n) separation threshold

- Where does the beta strenght go through(GT, FF) ?
- Particle-hole to measure the shell energies in exotic nuclei

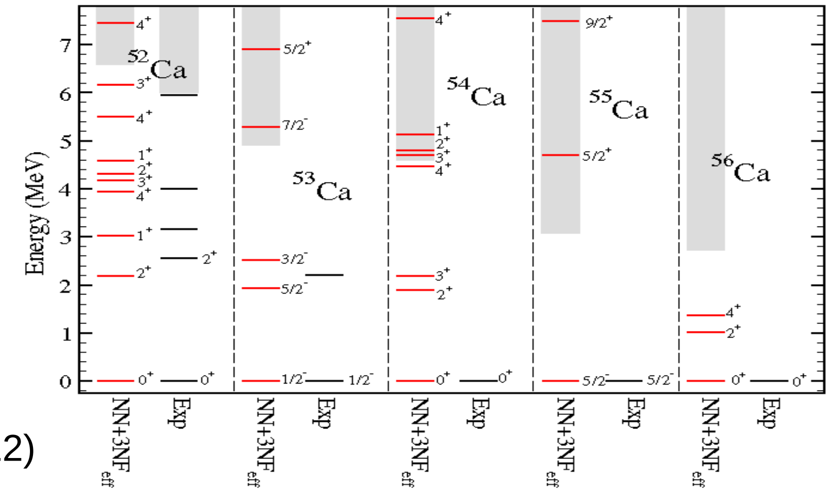
How are the ESPEs evolving in Ca isotopes?





J. D. Holt et al., PRC 90, 024312 (2014)

Different predictions going towards the N=34 for the $f_{7/2}$ gap (different 3N forces + coupling to continuum)



G. Hagen et al., Phys. Rev. Lett. 109, 032502 (2012)

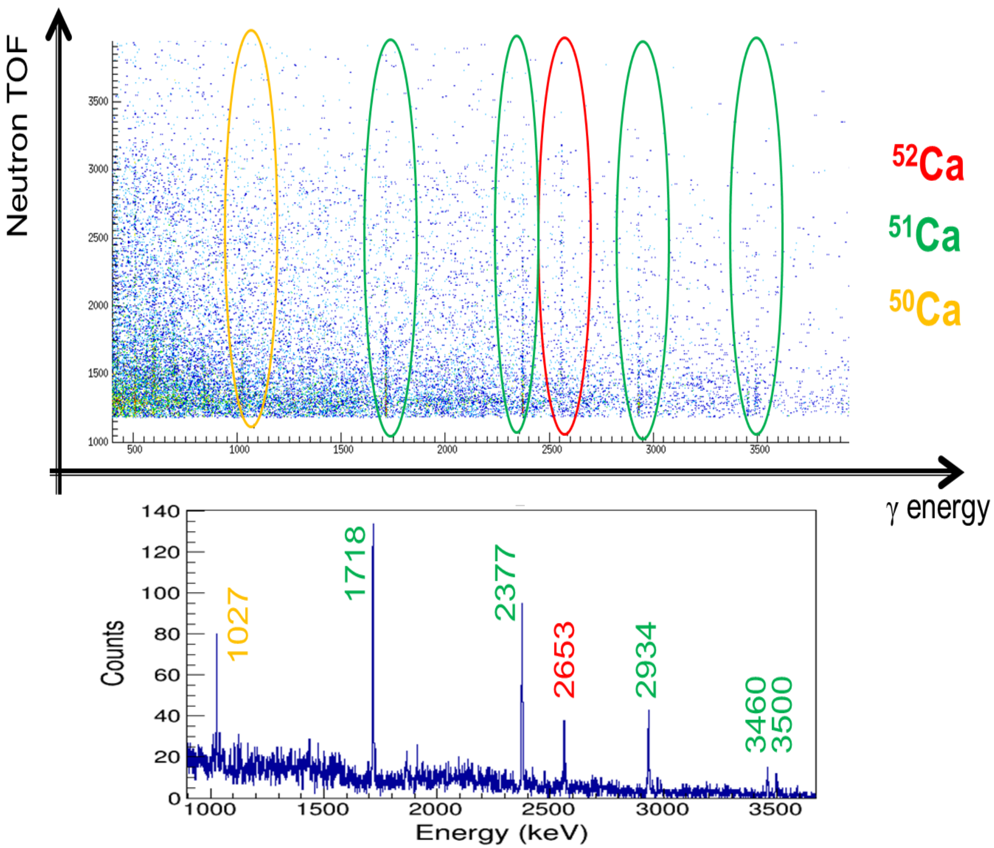
Experimental setup: VANDLE + IDS

VANDLE neutron array: ε: 10 %; σ: 80 keV (1 MeV)

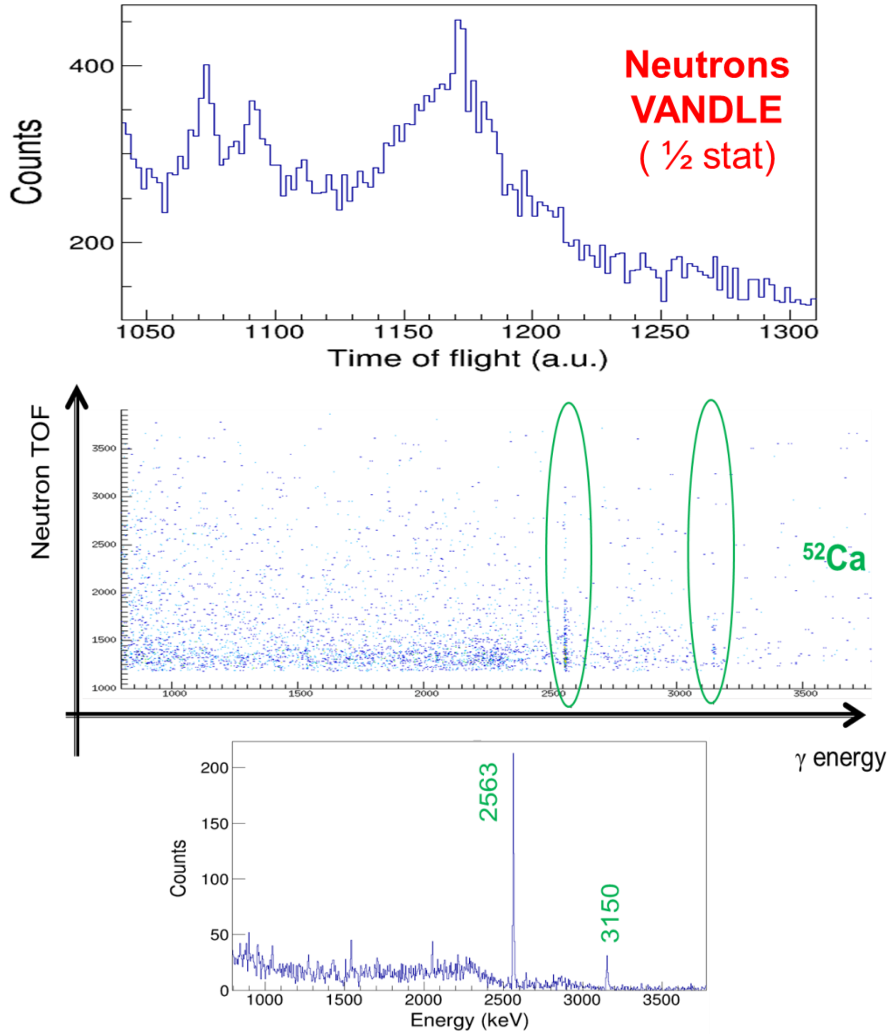
- Four clovers
- High-efficiency beta detector (>80 %)
- IDS tape
- 1 LaBr (Mr. Big)
- Low rates

Very preliminary IS599 results

^{52}K decay



^{53}K decay



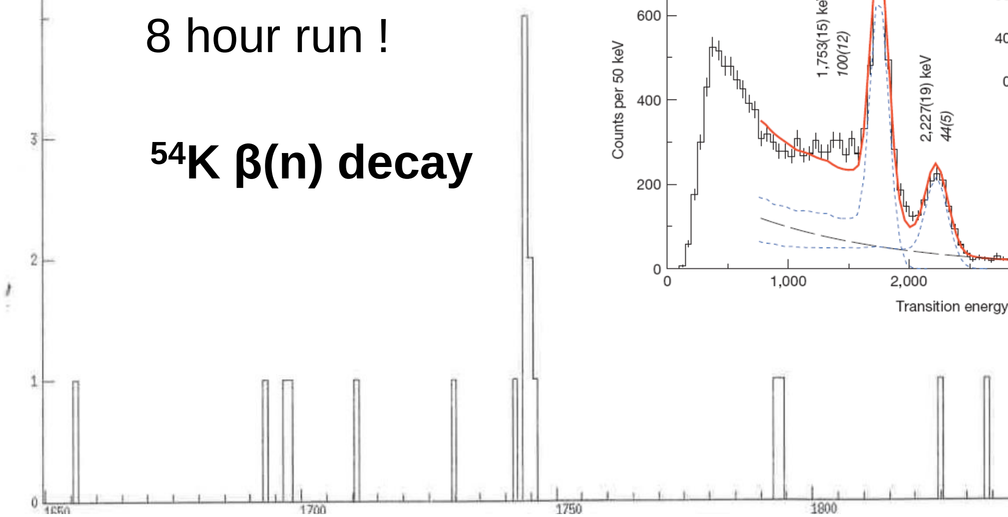
What we have observed: ^{54}K -> ^{54,53}Ca

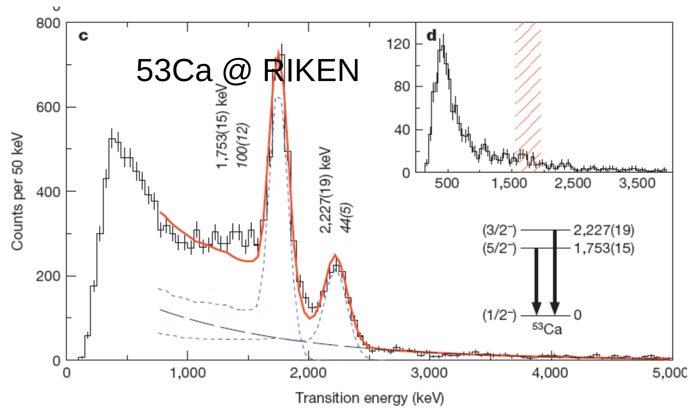
Q-value 20 MeV !

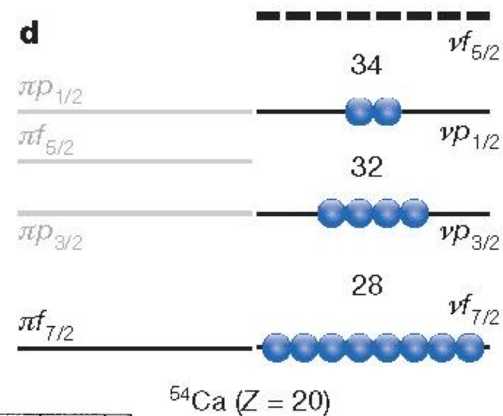
γ IDS – VANDLE

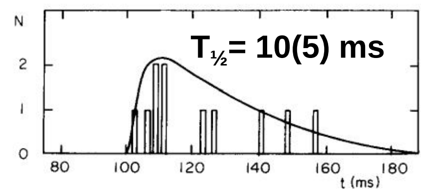
8 hour run !

^{54}K β(n) decay









M. Langevin et al., PLB 130, 251 (1983)

Only one γ ray observed: likely it is the 5/2$^-$ state already seen at RIKEN

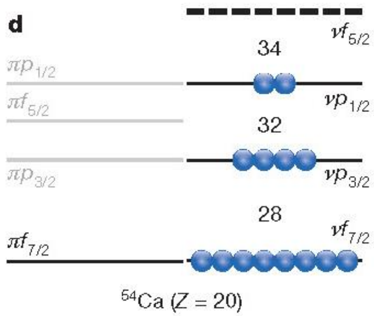
Gxpf1br intaraction in ^{53}Ca: 5/2$^-$ is 85% $(\upsilon p_{1/2})^0$ $(\upsilon f_{5/2})^1$

^{54}K: N=35 isotope. One neutron in $f_{5/2}$?

Paring $f_{5/2}$ = 1.2 MeV; Pairing $p_{1/2}$ = 0.2 MeV : strong pair scattering across N=34

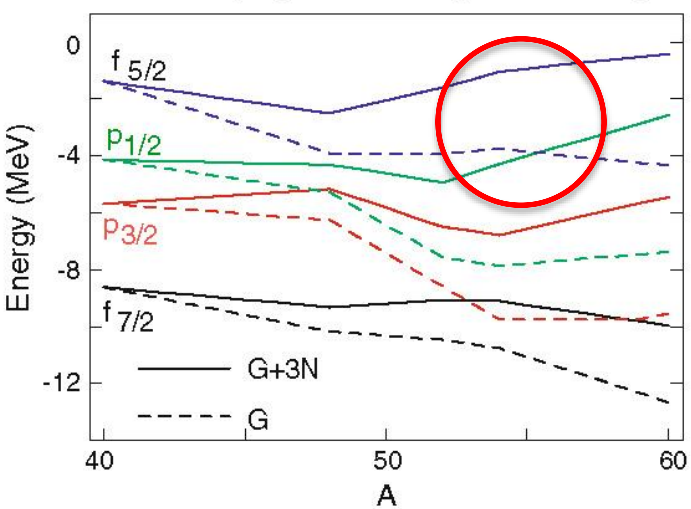
^{54}K 2$^-$ ground state: $\langle f_{5/2}\rangle$ = 3; $\langle p_{1/2}\rangle$ = 0.8

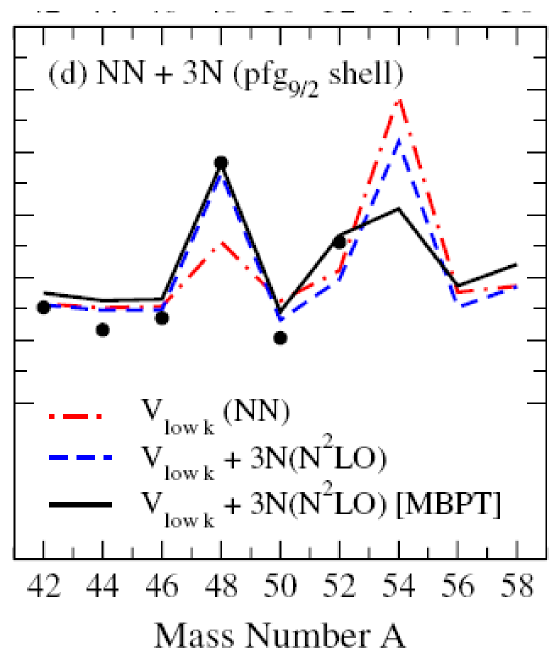
Three-body forces in Ca isotopes



Two-body forces cannot explain the N=28 SO shell closure

Neutron single-particle energy of Ca isotopes





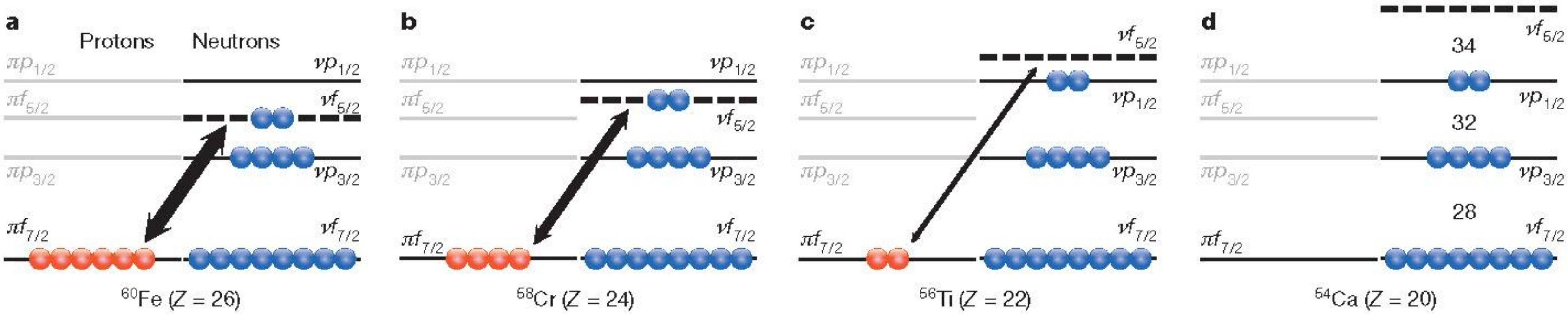
J. D. Holt et al., J. Phys. G: Nucl. Part. Phys. 39 (2012) 085111

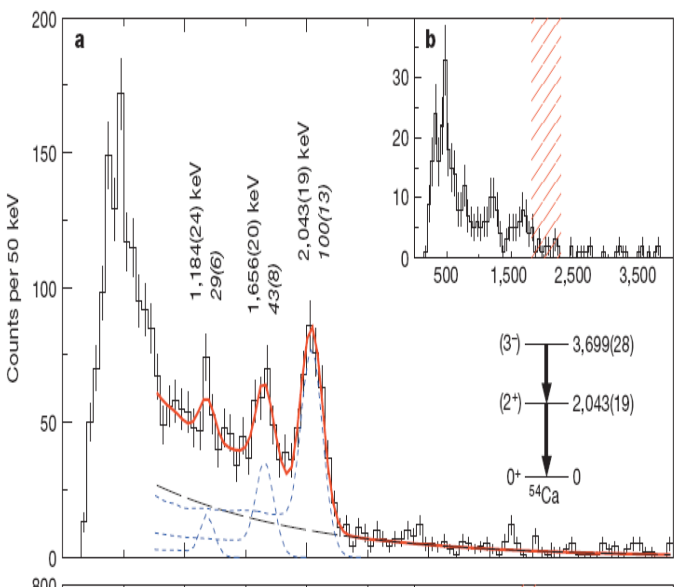
Three-body forces: repulsion between $f_{7/2}$ and $p_{3/2}$,$p_{1/2}$, $f_{5/2}$

T. Otsuka and T. Suzuki, Few-Body Syst (2013) 54:891–896

The N=34 subshell closure

The N=34 subshell gap is created by the tensor force





D. Steppenbeck et al., Nature 502, 207 (2013)

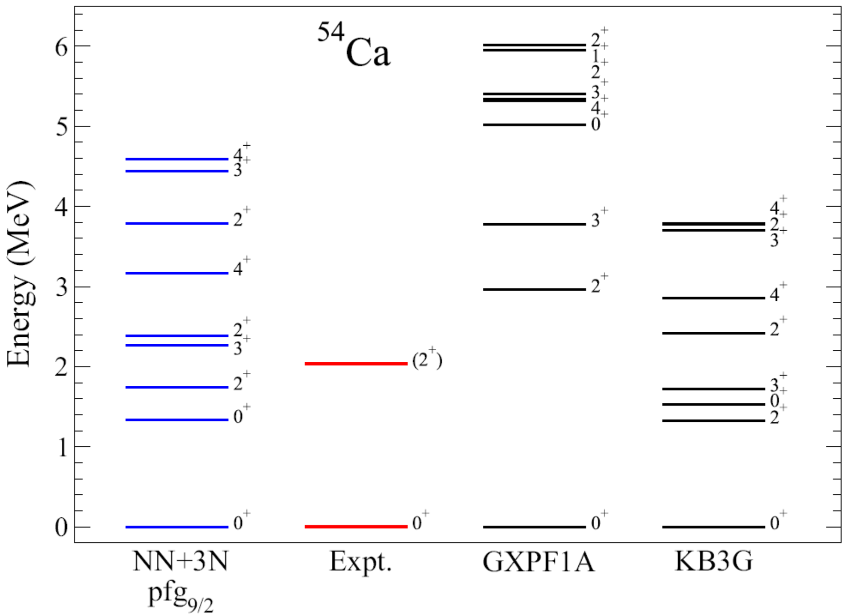
2^+ found at 2 MeV, consistent with the tensor + 3-body theory

F. Wienholtz et al., Nature 498, 346 (2013)

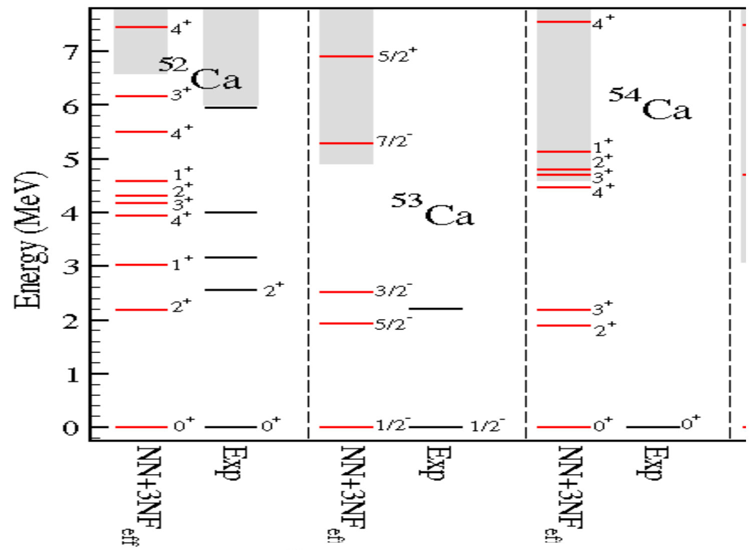
Three-body forces reduce the N=34 gap by adding repulsion to $p_{1/2}$ with respect to $f_{5/2}$

Physical motivation

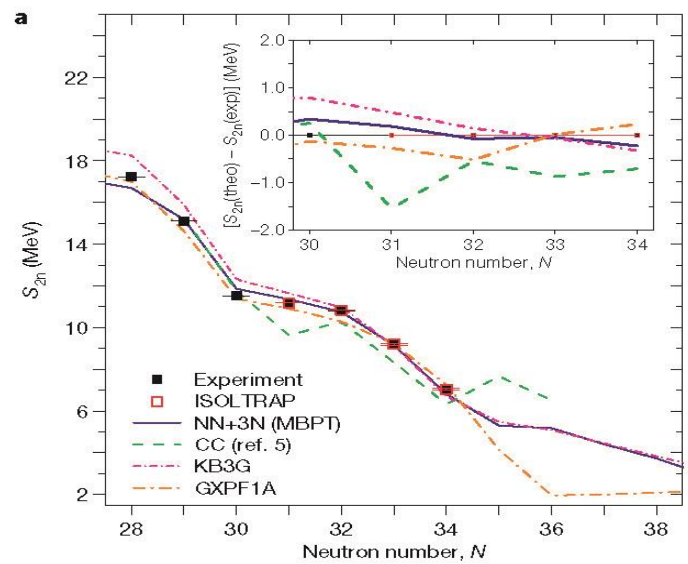
«first principle»



«renormalized to ^{40}Ca mass»



- 2^+ known, detailed spectroscopy: confirmation of 3^-, 4^+ (very different predictions for different 3-body force renormalization)
- Neutron emission towards ^{53}Ca: distribution of the GT (shell closures) and scattering across N=34.

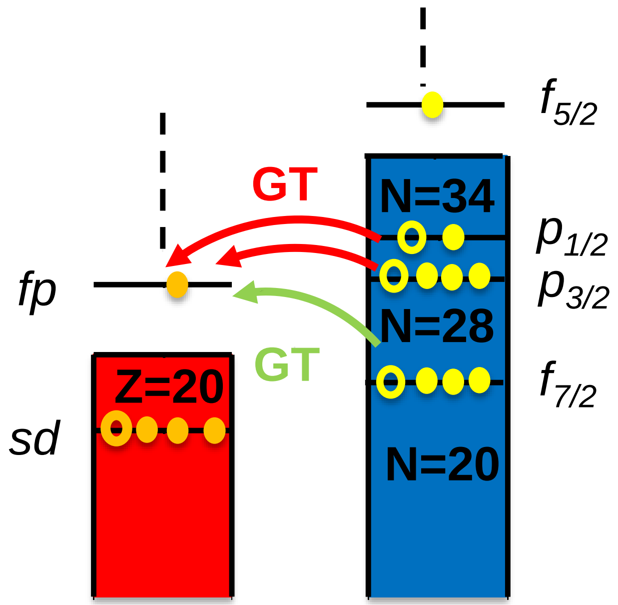


What we expect to see (1)

1. Calculations with the PSDPF interaction predict a 2^- ground state from ^{54}K (also from systematics)
2. Shell-model calculations also predict a strong population of 3^- states, close and above the S_n=4.4 MeV
3. After GT: holes in $f_{7/2}$, $p_{3/2}$, $p_{1/2}$, neutrons in $f_{5/2}$

In the n-emission daughter ^{53}Ca, which states populated ? What is the fragmentation ? -> observing 10-20 % branches

^{54}K β(GT) decay to ^{54}Ca



$$\text{GT: } \nu p_{1/2} \rightarrow \pi p_{1/2}$$
$$\nu p_{3/2} \rightarrow \pi p_{3/2}$$
} ^{48}Ca core

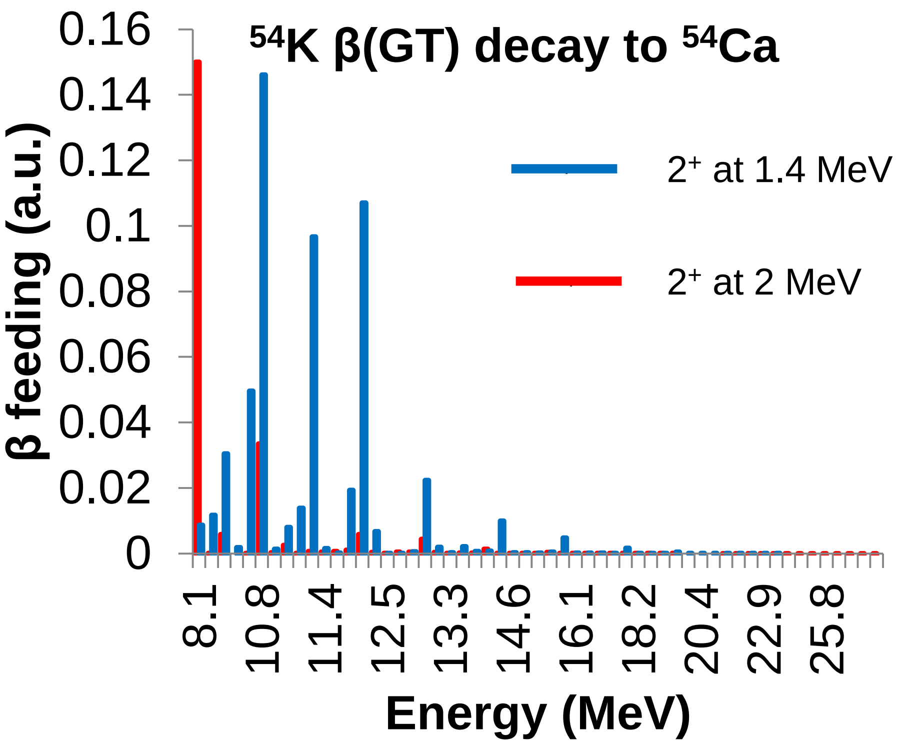
$$\nu f_{7/2} \rightarrow \pi f_{7/2}$$
^{40}Ca core

What we expect to see (2)

Large-scale shell-model calculation in the psdpf space with Antoine:

The most intense states are 3^-

	$\nu f_{7/2}$	$\nu p_{3/2}$	$\nu p_{1/2}$	$\nu f_{5/2}$
^{54}Ca after GT	**7.5**	**3.4**	**1**	**2**



Results:

- From ^{54}Ca γ-ray spectroscopy: more detailed level scheme, comparison with different 3-body models
- From neutron spectroscopy: GT distribution and neutron evaporation as a probe of N=34

Rates and spectroscopy

- ^{54}K rate (realistic, based on previous result plus some target improvements): 0.5 pps, (possible to improve with target optimized for fast release ?)
- 8% neutron efficiency, 90% β efficiency, 2 % γ efficiency
- 60-90 % neutron emission: around (1-2)·10^4 neutrons detected in 7 days
- 10% feeding to excited ^{54}Ca states: around 200 γ rays from ^{54}Ca in 7 days; mainly 2^+ and 3^-, likely also 4^+ states
- Lifetime from neutrons and gammas

In total, 21 shifts (seven days) are requested

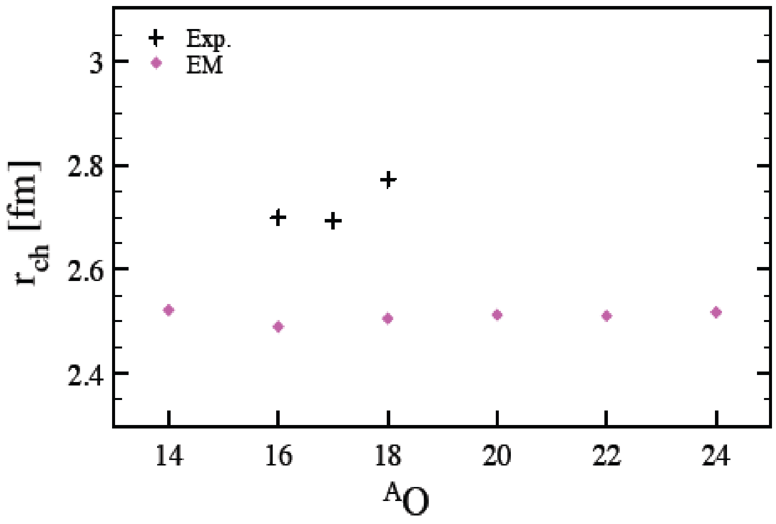
Collaboration

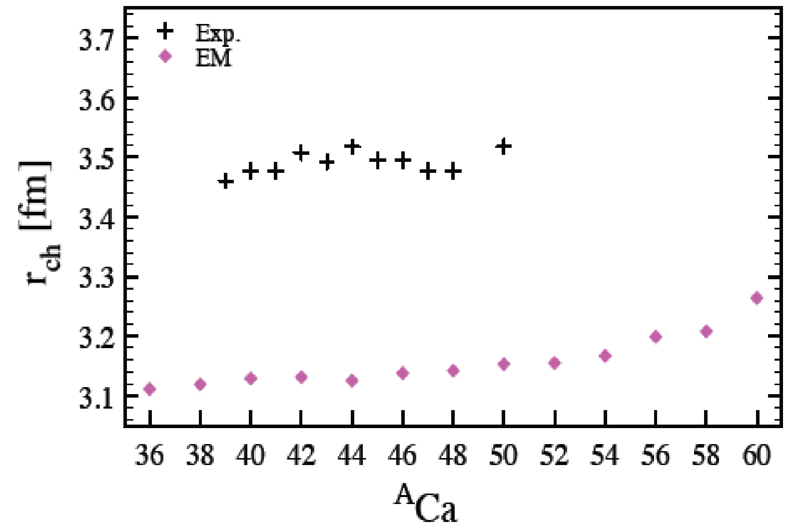
A. Gottardo[1], R. Grzywacz[2], M. Madurga[3],
G. de Angelis[4], F. Azaiez[1], D. Bazzacco[5], G. Benzoni[6], A. Boso[5], Y. Deyan[1], M.-C.Delattre[1], P. Van Duppen[7], A. Etilé[8], S. Franchoo[1], C. Gaulard[8], G. Georgiev[8], S. Go[2], A. Goasduff[4], F. Gramegna[4],K. Kolos[2], M. Kowalska[3], S. Ilyushkin[9], G. Jaworski[4], Y. Xiao[2], S.M. Lenzi[5], J. Ljungvall[7], P.R. John[5], R. Li[1], S. Lunardi[5], T. Marchi[4], I. Matea[1], D.Mengoni[5], V. Modamio[4], A.I. Morales[6], P. Morfouace[1], D.R. Napoli[4], S. Paulauskas[10], E.Rapisarda[3], S. Roccia[8], B. Roussier[1], C. Sotty[7], I. Stefan[1] , S. Taylor[2], J.J. Valiente-Dobón[4], D. Verney[1] , H. de Witte[7], A. Algora[11], K. Riisager[12], A. Negret[13], N. Marginean[13], R. Lica[13], C. Mihai[13], R.E. Mihai[13], R. Marginean[13], C. Costache[13], S. Nae[13], A. Turturica[13].

IDS collaboration

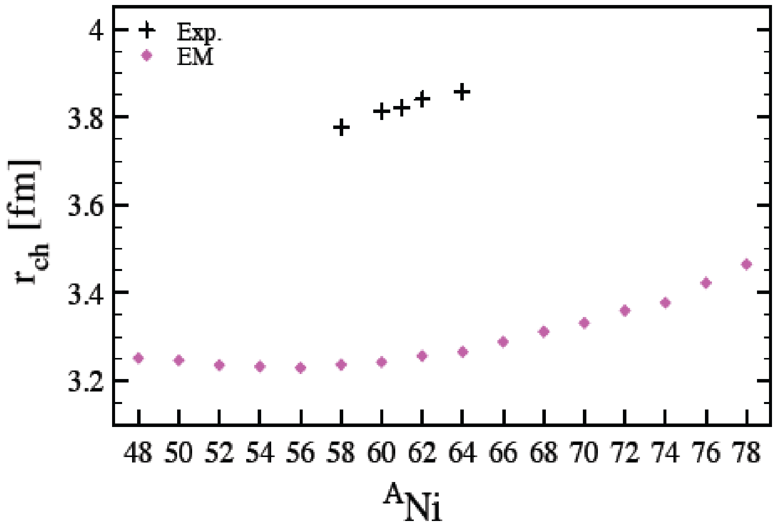
1 Institut de Physique Nucléaire Orsay, 2 University of Tennessee , 3 CERN, 4 INFN, Laboratori Nazionali di Legnaro
5 University of Padova and INFN Padova, 6 University of Milano and INFN Milano, 7 KU Leuven, 8 CSNSM Orsay, 9 Colorado School of Mines, 10 NSCL, 11 IFIC Valencia, 12 Aarhus University, 13 IFIN-HH, Bucharest

Charge radii





[Somà *et al.* in preparation]



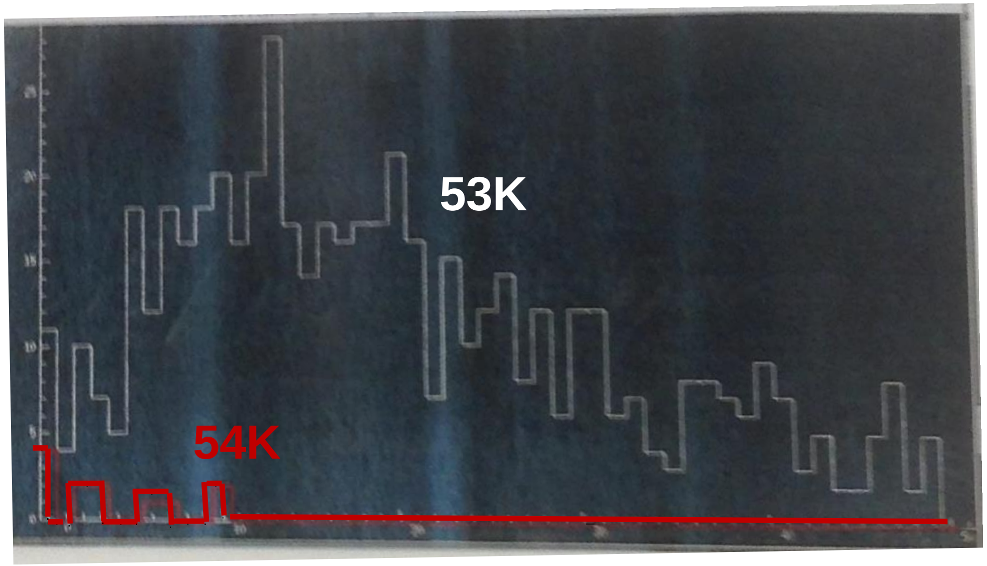
➟ Radii largely **underestimated**

➟ **Consistent with overbinding & spectra**

➟ Higher orders? 4NF? Hard core?

V. Somà

Our result from gamma rays



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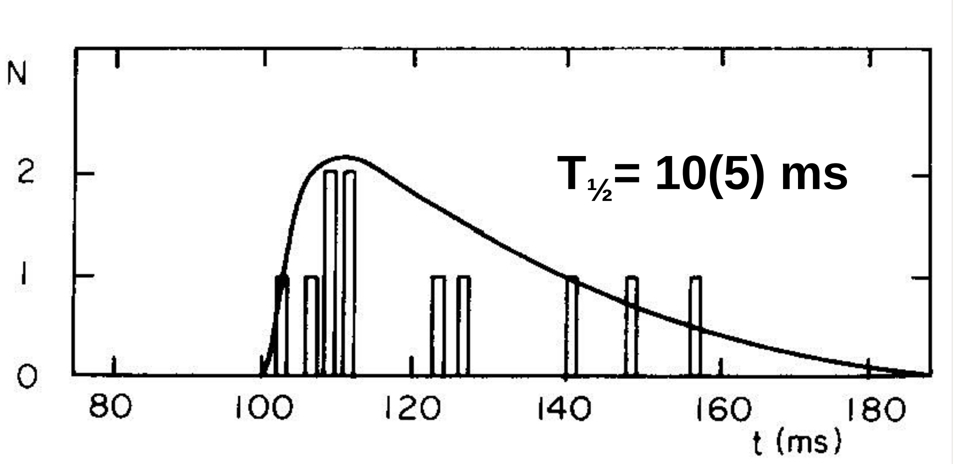
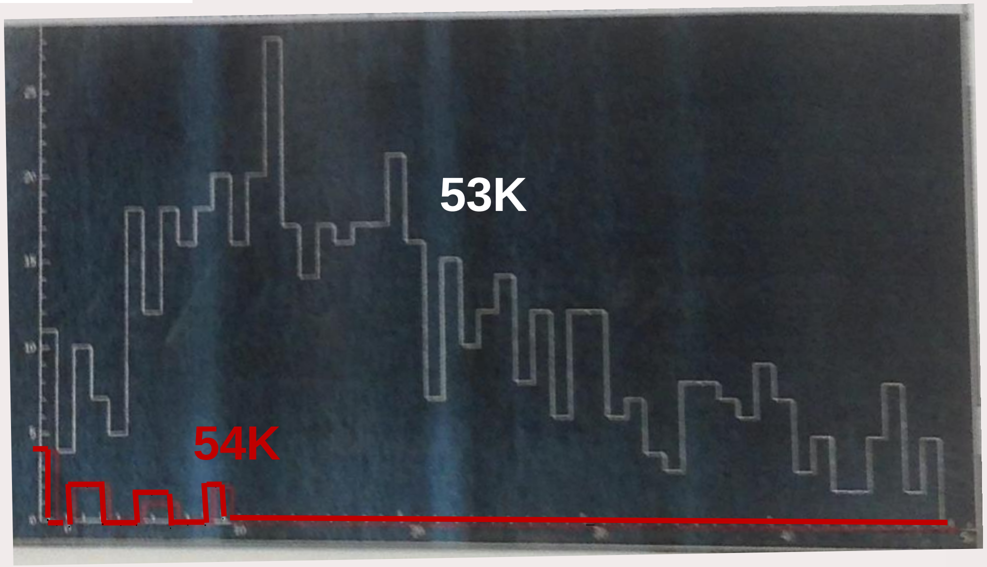
^{54}K -> ^{53}Ca: PRELIMINARY RESULTS (2)



Result from neutrons:
M. Langevin et al., PLB 130, 251 (1983)

Our result from gamma rays



New proposal for dedicated experiment !