Status report on addendum IS599: β-delayed neutron spectroscopy of $^{(52,53),54}K$

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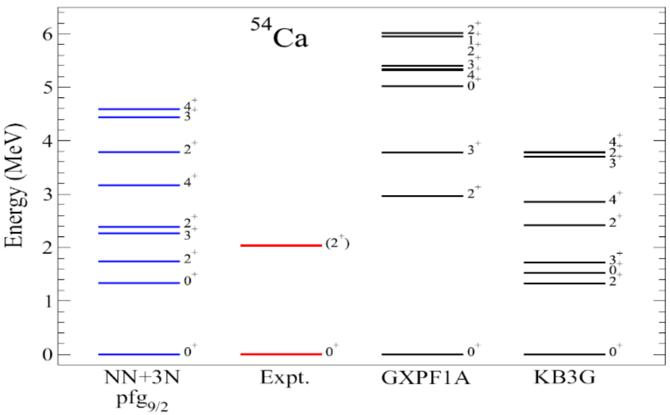
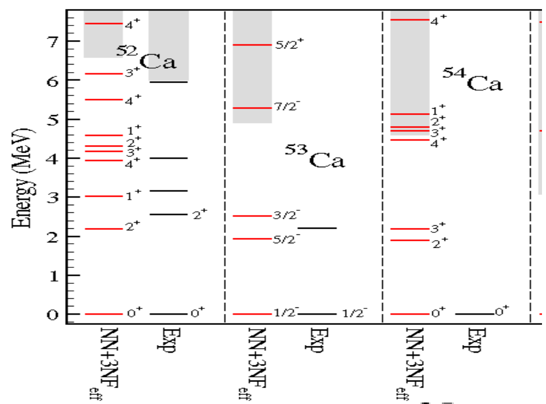
Neutron-rich Ca isotopes: a paradigm for shell-model

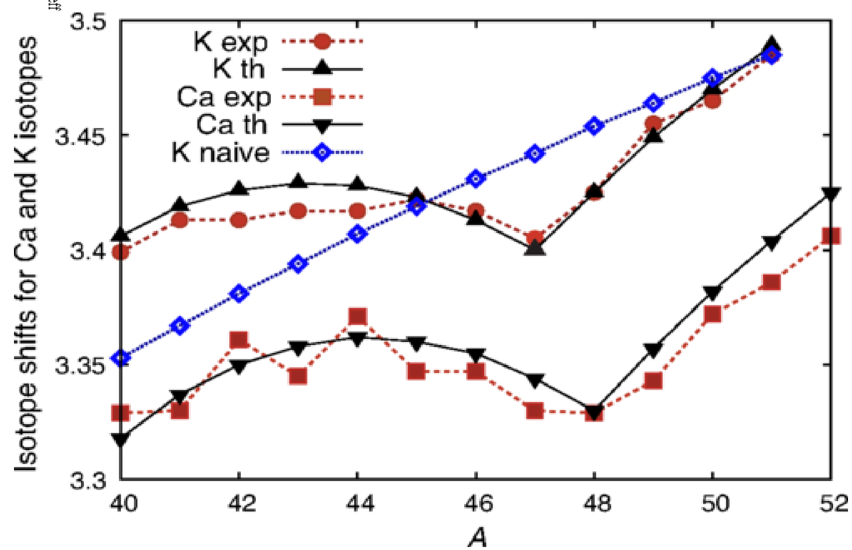
«first principle»



«renormalized to ^{40}Ca mass»



Large radii of Ca and K after N=28: large neutron p shell radii:

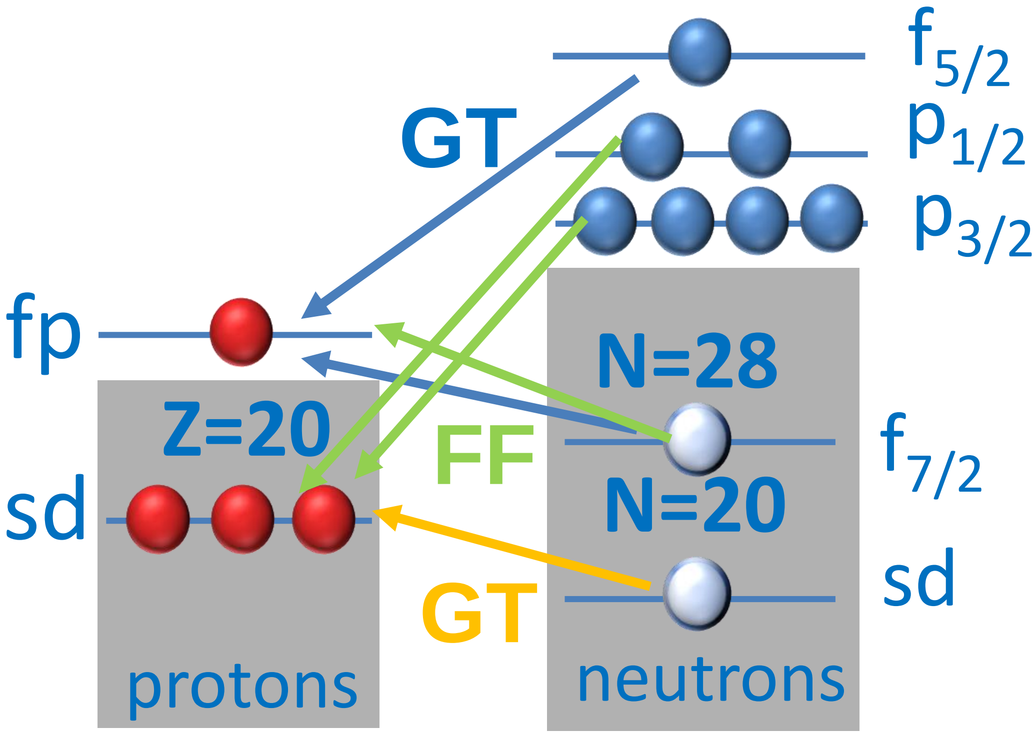


J. Bonnard, S. M. Lenzi, and A. P. Zuker Phys. Rev. Lett. 116, 212501 (2016)

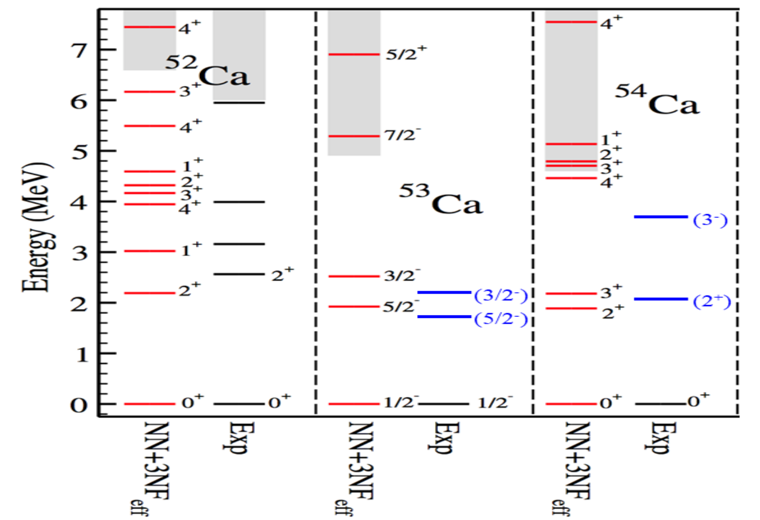
Many open questions for ^{54}Ca

- 2^+ known only, differences for other states
- Neutron emission towards ^{53}Ca: distribution of the GT (shell closures) and scattering across N=34.
- Same quenching in B(GT) as $^{49\text{-}53}$Ca ?

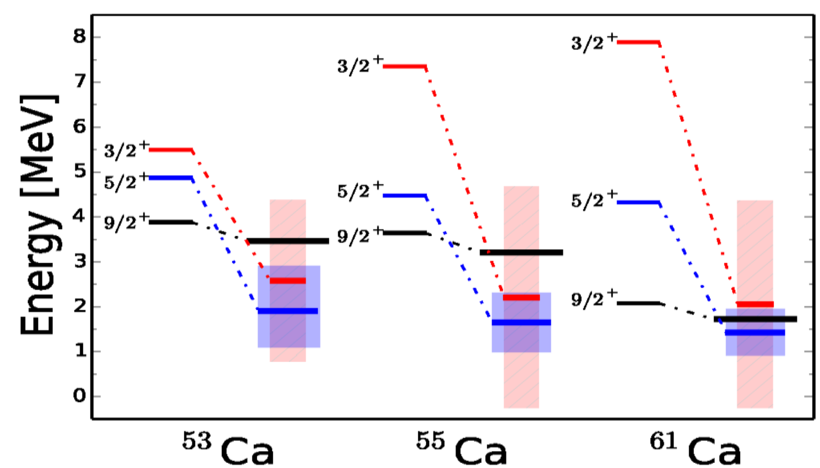
The n-rich Ca region: GT across shell closures



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



G. Hagen et al, Phys. Scr. **91**, 063006 (2016).

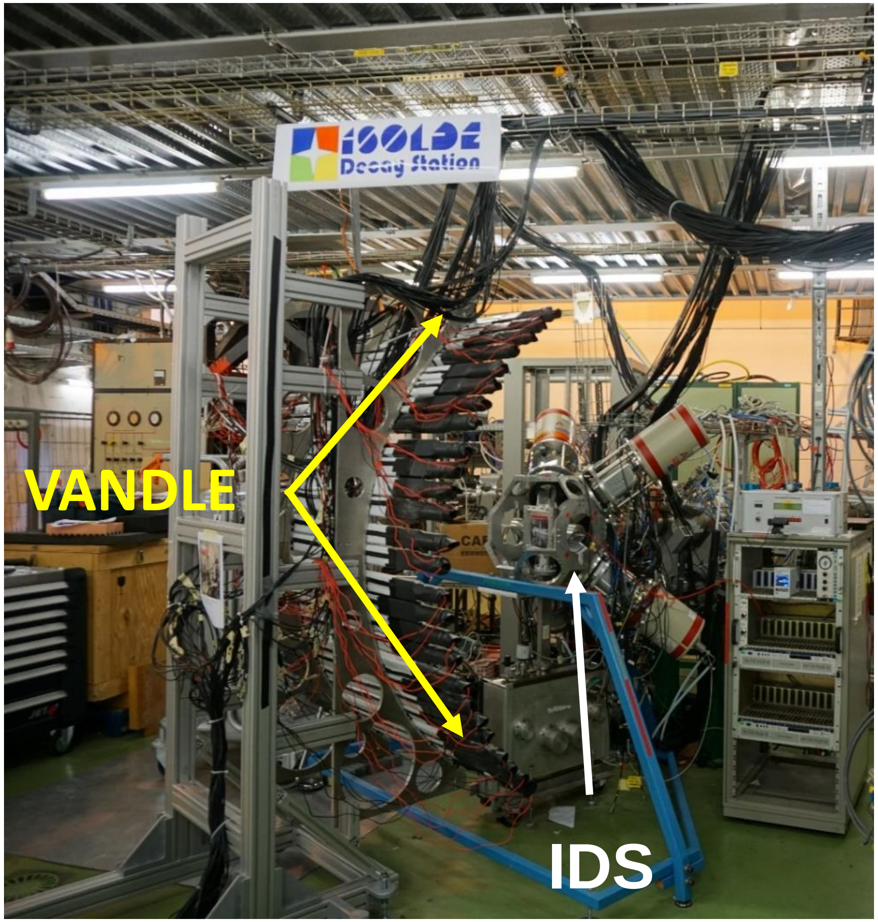


Very large Q values 10-20 MeV

The β decay populates states below and above the neutron (and 2n) separation energy

The IDS-VANDLE setup

VANDLE: Versatile Array of Neutron Detectors at Low Energy: ε: 8 %; σ: 80 keV (1 MeV)



- Neutron TOF EJ200 plastic scintillators
- Two - four clovers
- High-efficiency β detector (>80 %)
- IDS tape transport
- Sensitive even at low rates

ISOL beams

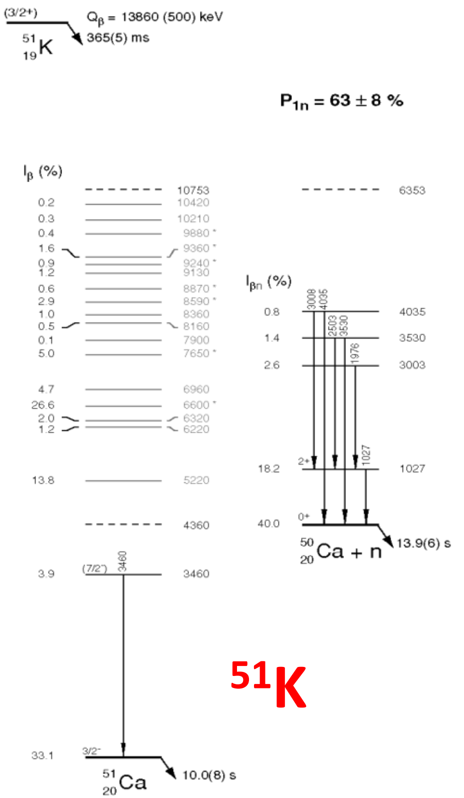
ISOL beams @ ISOLDE

$^{51,52,53,54}K$: surface ionization

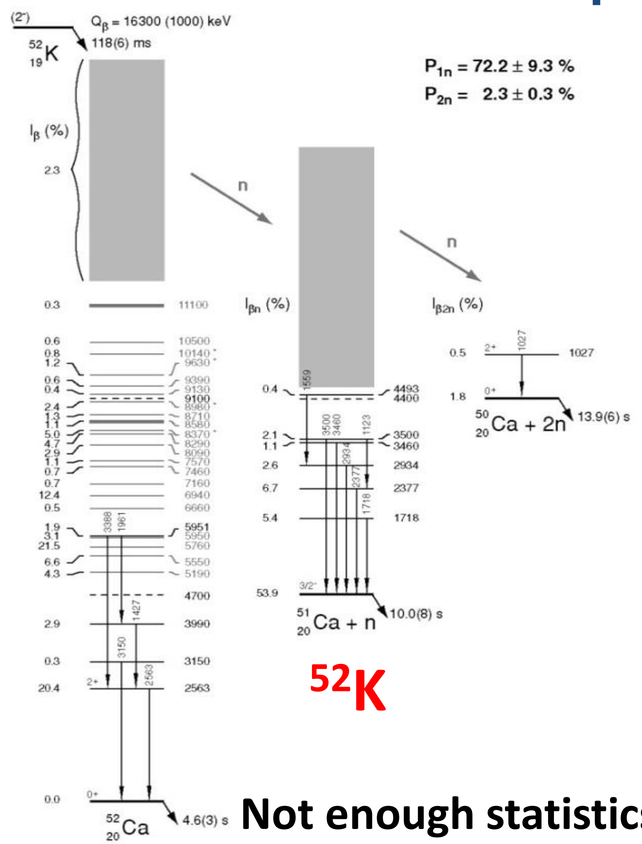
- Rates: 3-5 pps for ^{53}K, <1 pps for ^{54}K
- Main limiting factor: $T_{1/2}$: 30 ms for ^{53}K and 10 ms for ^{54}K

Previous Tonnere experiment

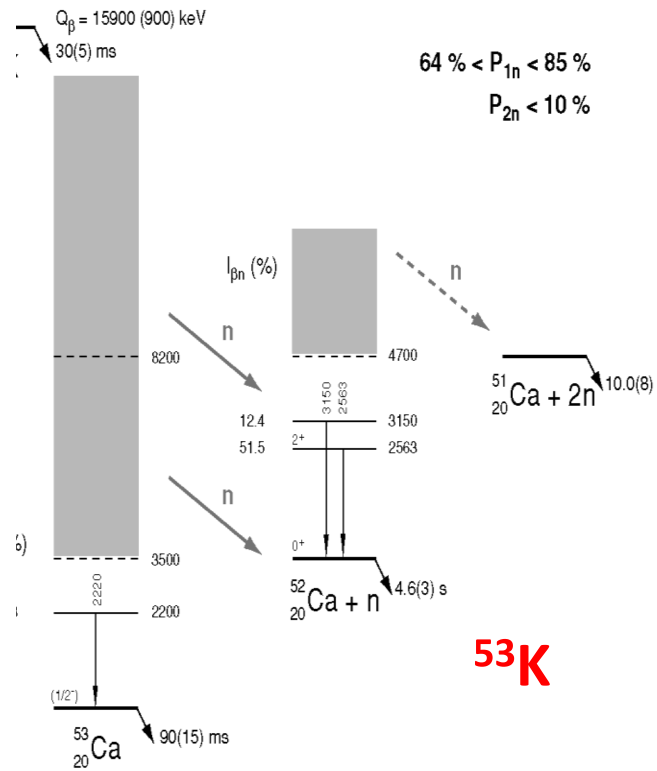
F. Perrot et al., Phys. Rev. C 74 014313 (2006)



^{51}K

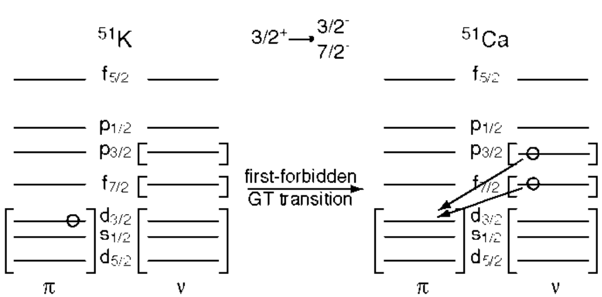


^{52}K

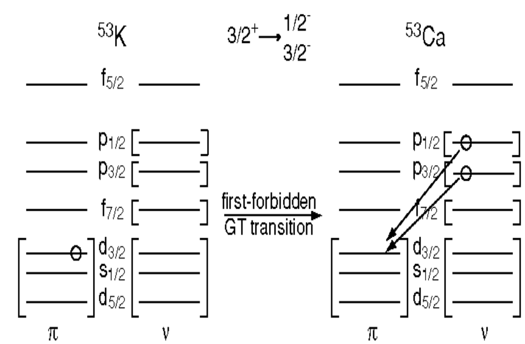


^{53}K

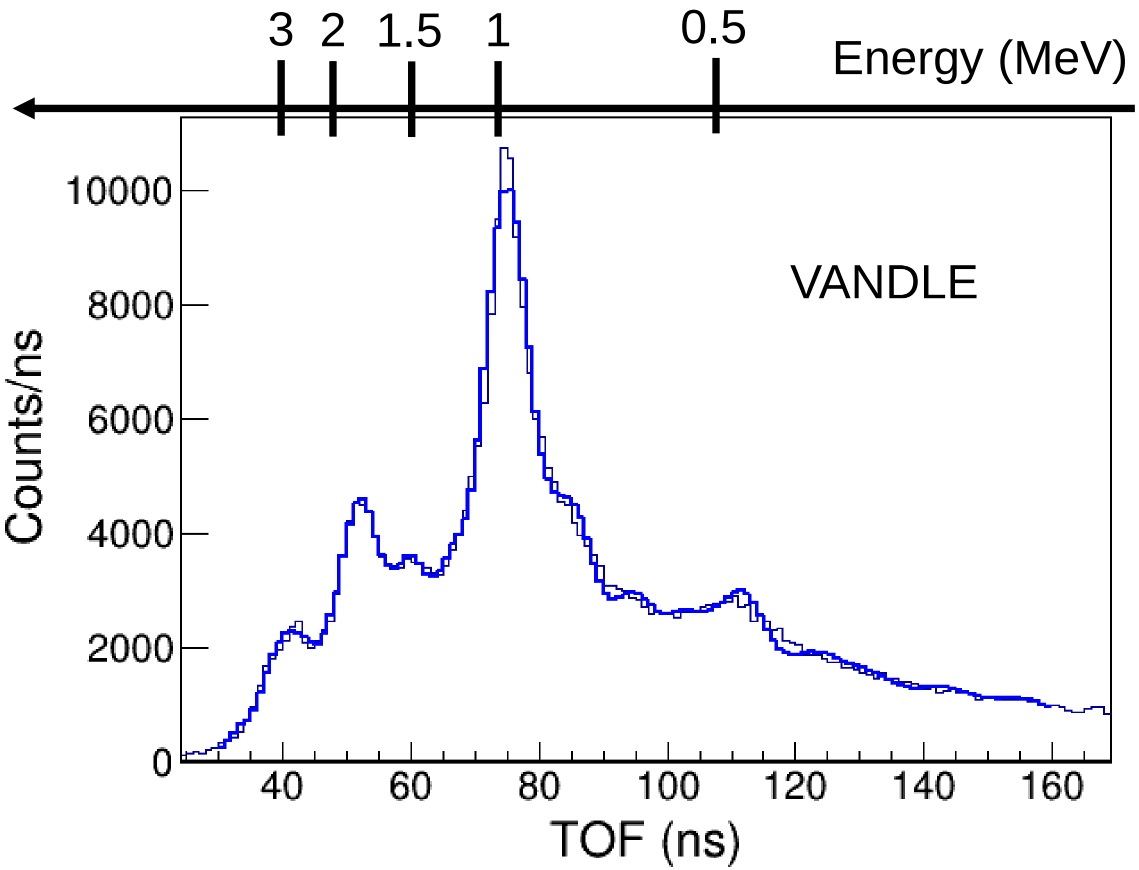
Not enough statistics for $^{(52),53}$Ca



Interpretation of spectra: FF due to parity-changing transitions

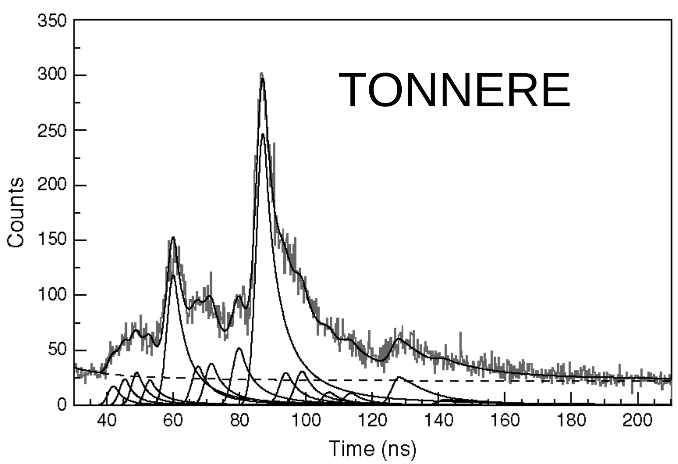


^{52}K results: neutron emission

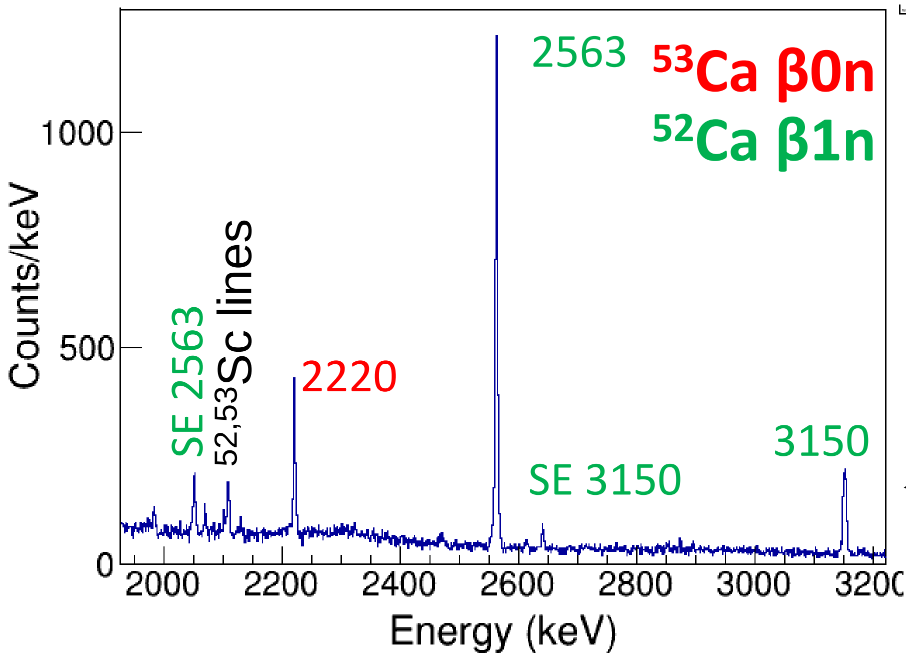


neutron spetrum

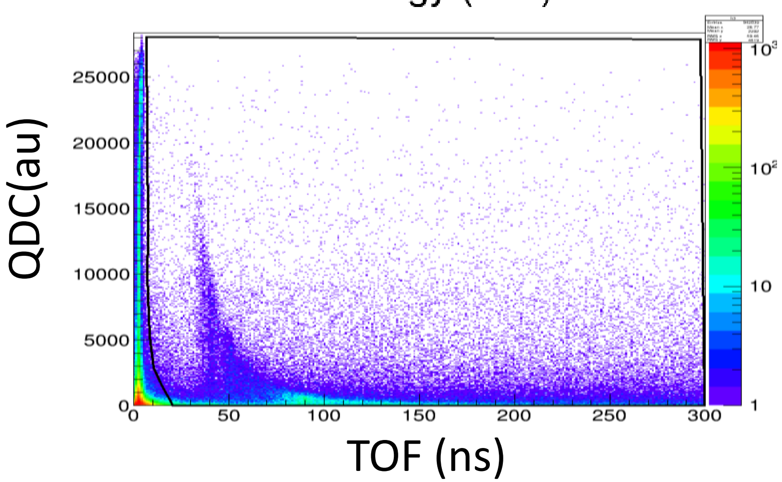
- Simulated response function
- Unfolding of the neutron TOF spectrum: deconvolution and then χ^2 fit

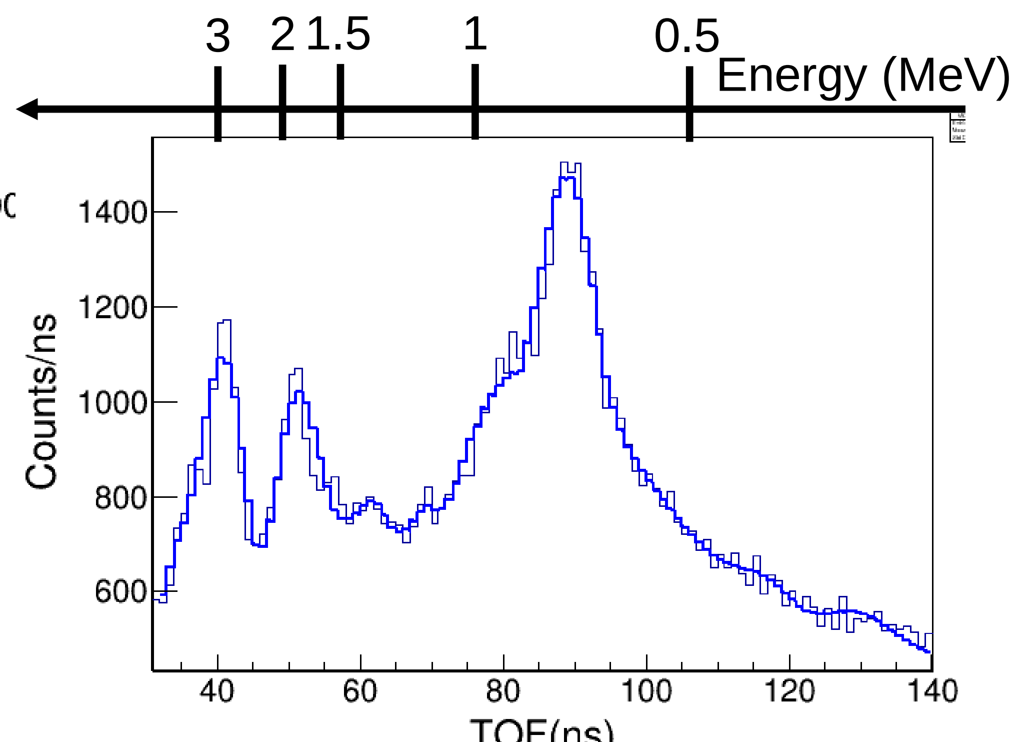


^{53}K results: γ and neutron emission

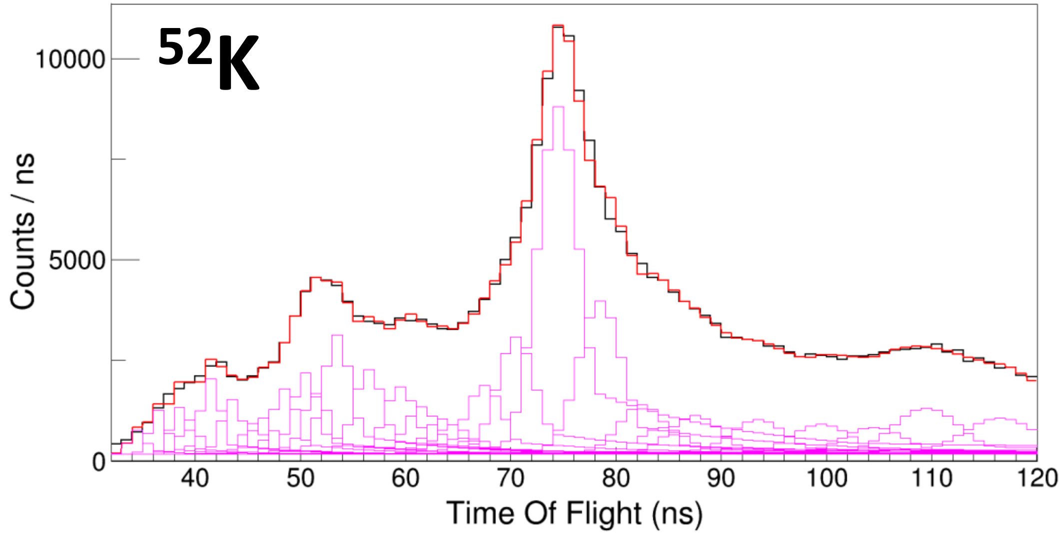


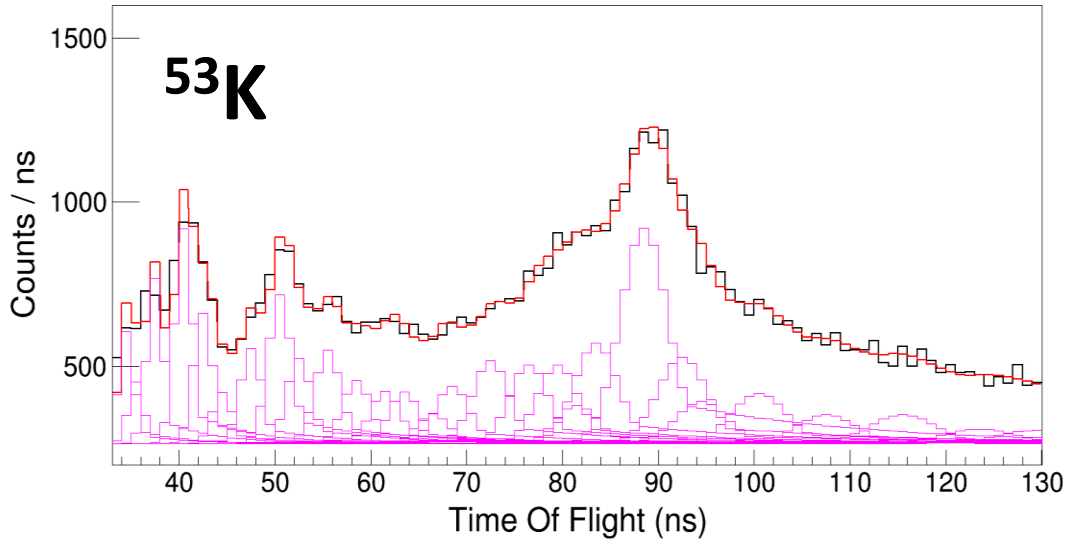
NO 2n emission observed from γ spectra (hint at 1541 keV, line not known in ^{51}Ca)





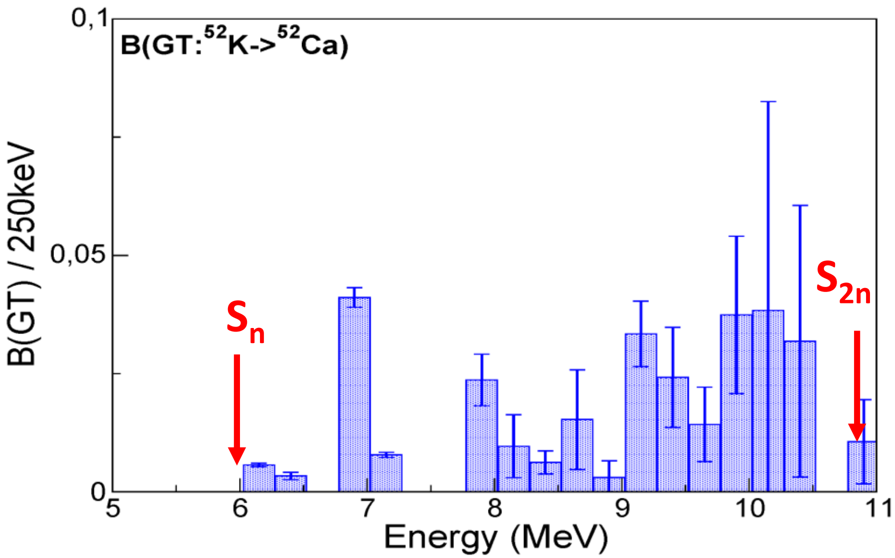
^{52,53}K results: neutron emission deconvoluted

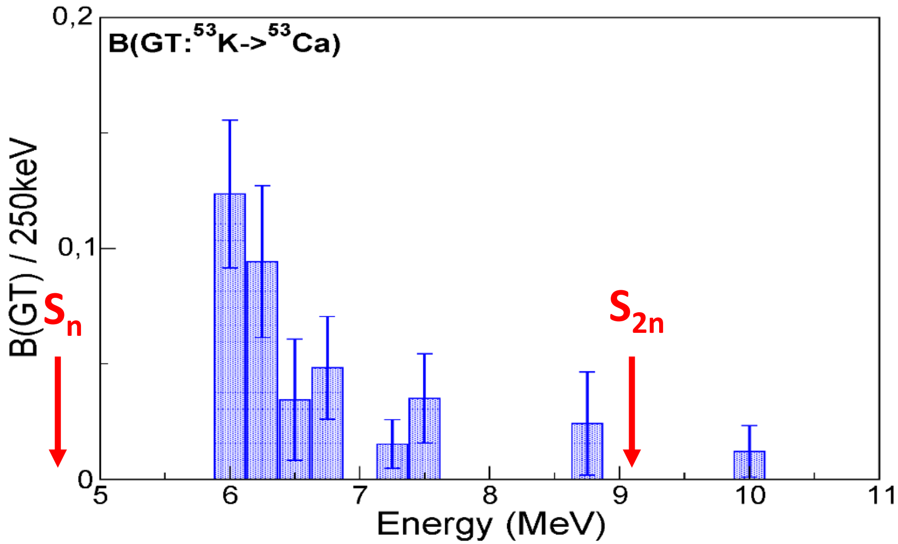




- Simulated TOF shape verified on experiment
- Fit with 20-30 peaks plus a constant background
- Number of neutrons consistent with P_n from γ rays in ^{52}Ca, a little higher for ^{53}Ca.

^{52}K-^{53}K results: B(GT) distribution

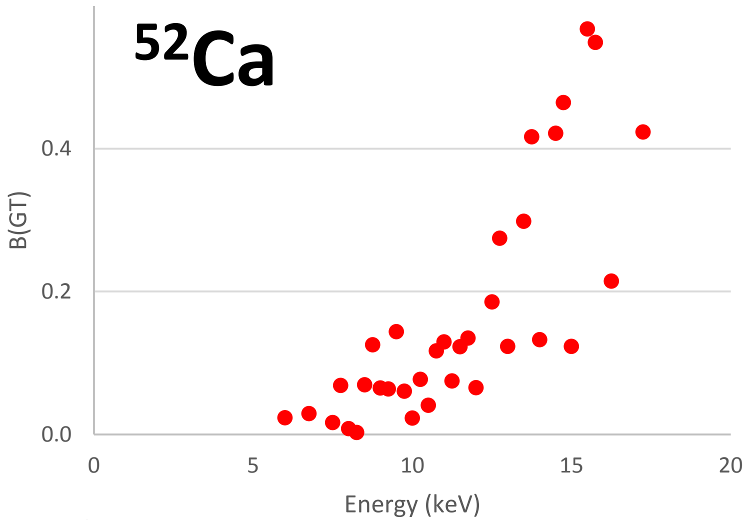


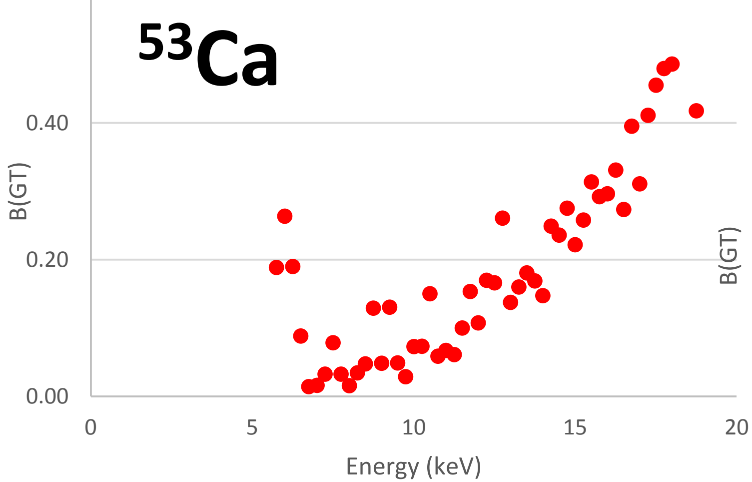


B(GT) distribution

- Some FF strength at low energies
- GT strength starts at around 6 MeV (logft < 6)
- Peak in the GT distribution at around 6.5-7 MeV
- Gradual decrease of strength towards 10 Mev

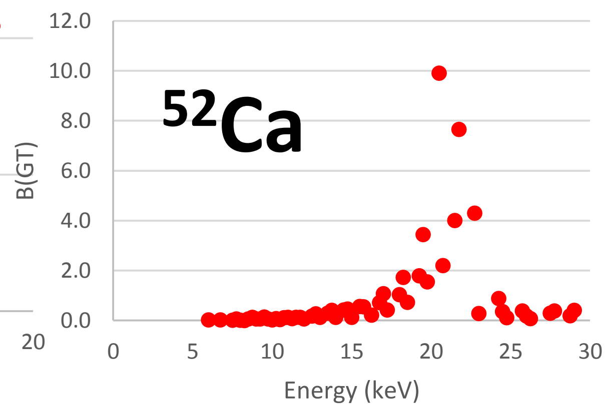
Shell-model calculations: sdpf space

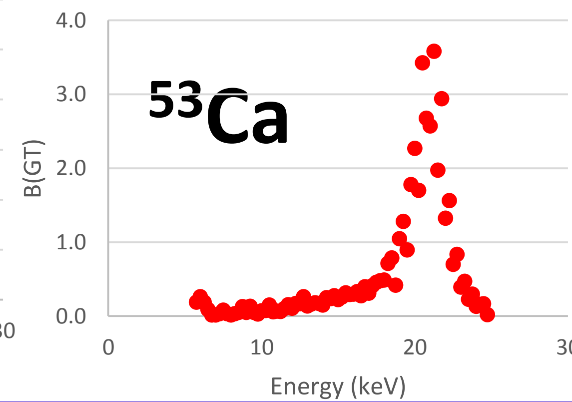




B(GT) and FF

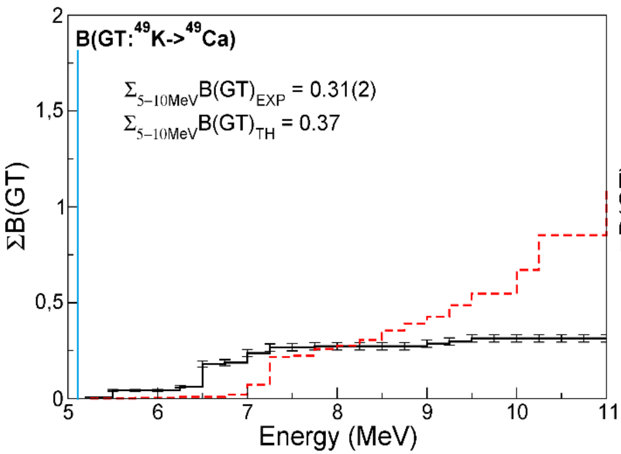
- sdpf-kb3g.a53 interaction by A. Poves, 1p-1h excitations
- GT distribution: low-energy feature at 6-7 MeV: $\nu f_{5/2} \to \pi f_{7/2}$ main component
- Small B(GT) values: N=34 closure

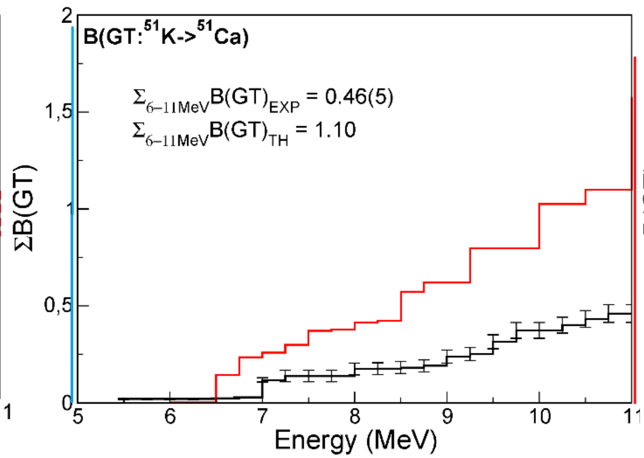


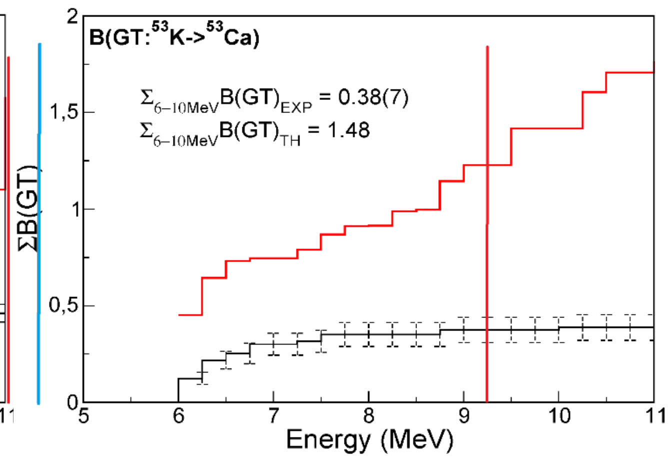


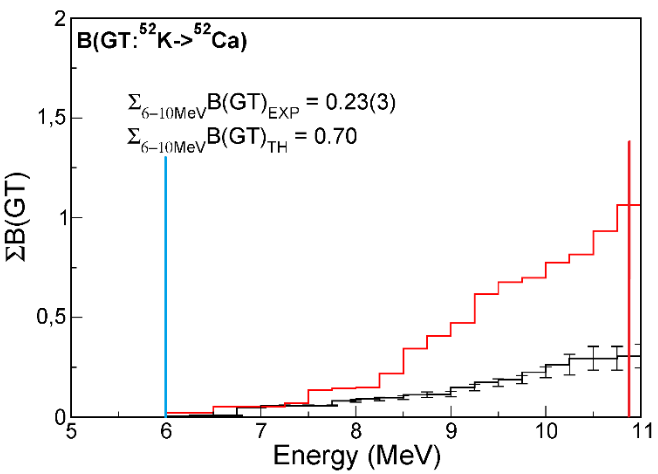
Comparison with theory

Theory
Exp.









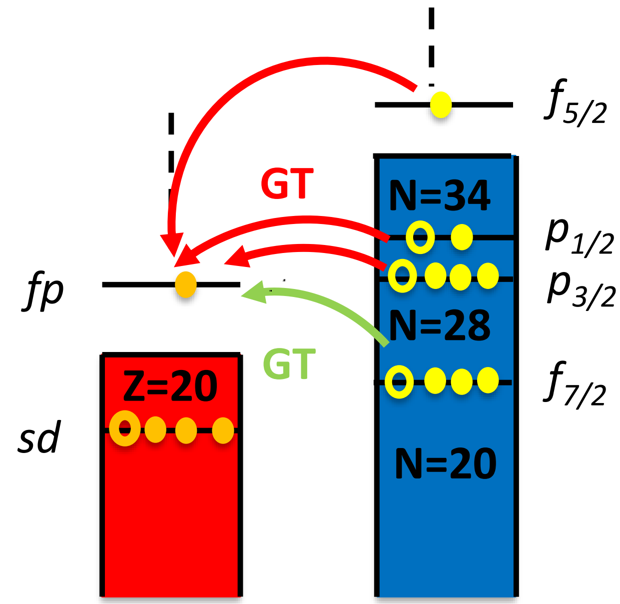
Very quenched B(GT)

- Large B(GT) quenching,
- GT $\nu f_{5/2} \rightarrow \pi f_{7/2}$ due to scattering across N=34: ^{53}K ~75% closed N=34 core (85% in ^{54}Ca). Maybe small GT linked with large radii ? Neutron sd shells from above N=50 ?

What we expect to see (1)

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

^{54}K β(GT) decay to ^{54}Ca



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

GT: $\upsilon p_{1/2} \rightarrow \pi p_{1/2}$

$\upsilon p_{3/2} \rightarrow \pi p_{3/2}$ } ^{48}Ca core

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

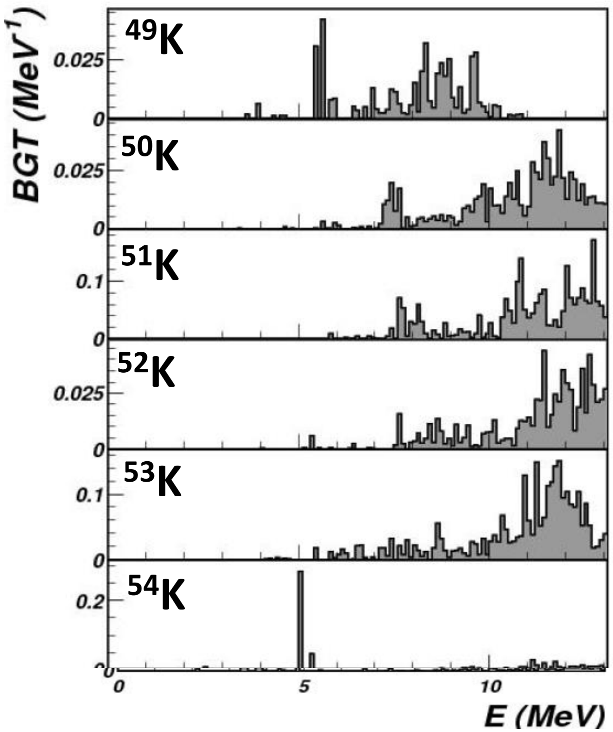
What we expect to see (2)

Shell-model predictions

- Large-scale shell-model calculations in the sdpf space with Antoine: intense 3^-
- Strong $\upsilon f_{5/2}$ -> $\pi f_{7/2}$ GT transition at 5-6 MeV

	$\upsilon f_{7/2}$ $\pi f_{7/2}$	$\upsilon p_{3/2}$ $\pi p_{3/2}$	$\upsilon p_{1/2}$ $\pi p_{1/2}$	$\upsilon f_{5/2}$ $\pi f_{5/2}$
^{54}Ca after GT	**6.7** **0.8**	**3.4** **0.1**	**1.6** **0.03**	**2.2** **0.004**

$^{49-54}$K β(GT) decay to $^{49-54}$Ca with GXPF1A



Results:

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

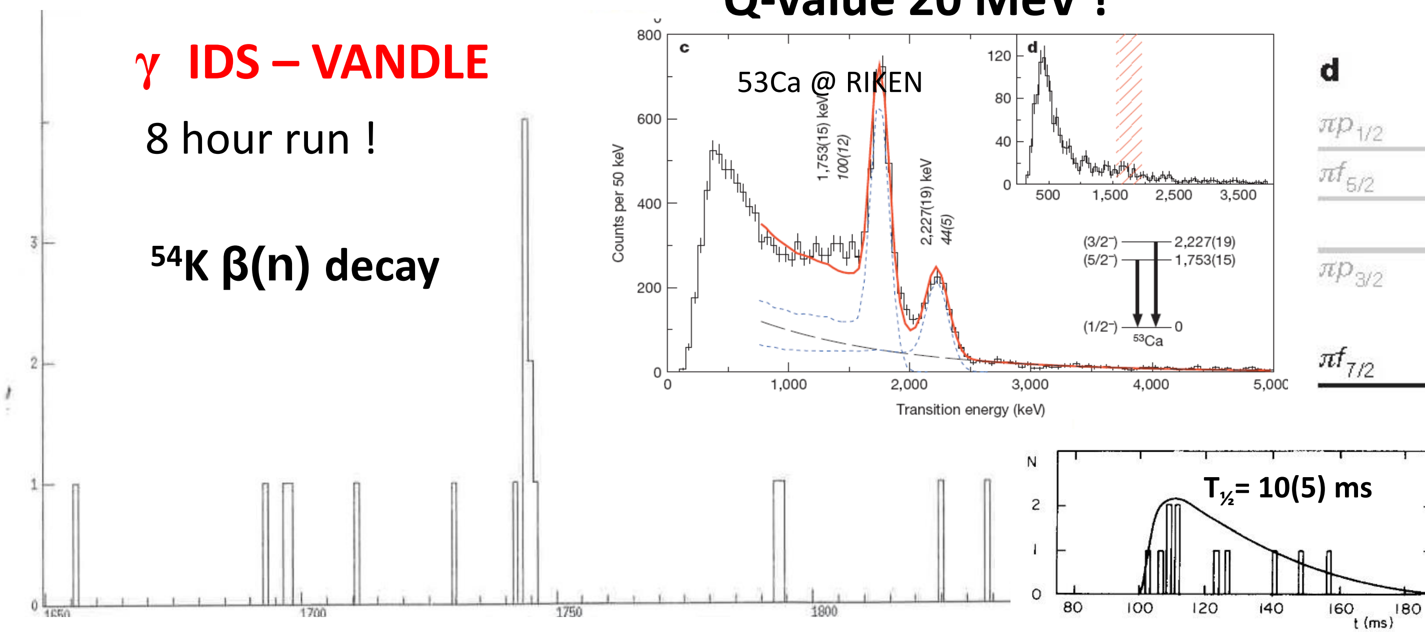
What we have observed: ^{54}K -> ^{54,53}Ca

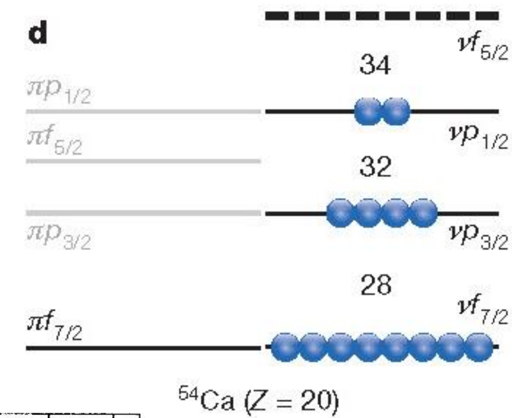
Q-value 20 MeV !

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

KB3G_POV interaction in ^{53}Ca: $5/2^-$ is 86% $(\upsilon p_{1/2})^0\ (\upsilon f_{5/2})^1$

^{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^- gs (GXPF1A-BR): $\langle f_{5/2}\rangle = 3$; $\langle p_{1/2}\rangle = 0.8$ ^{54}K 2^- gs (KB32_POV): $\langle f_{5/2}\rangle = 1.4$; $\langle p_{1/2}\rangle = 1.8$

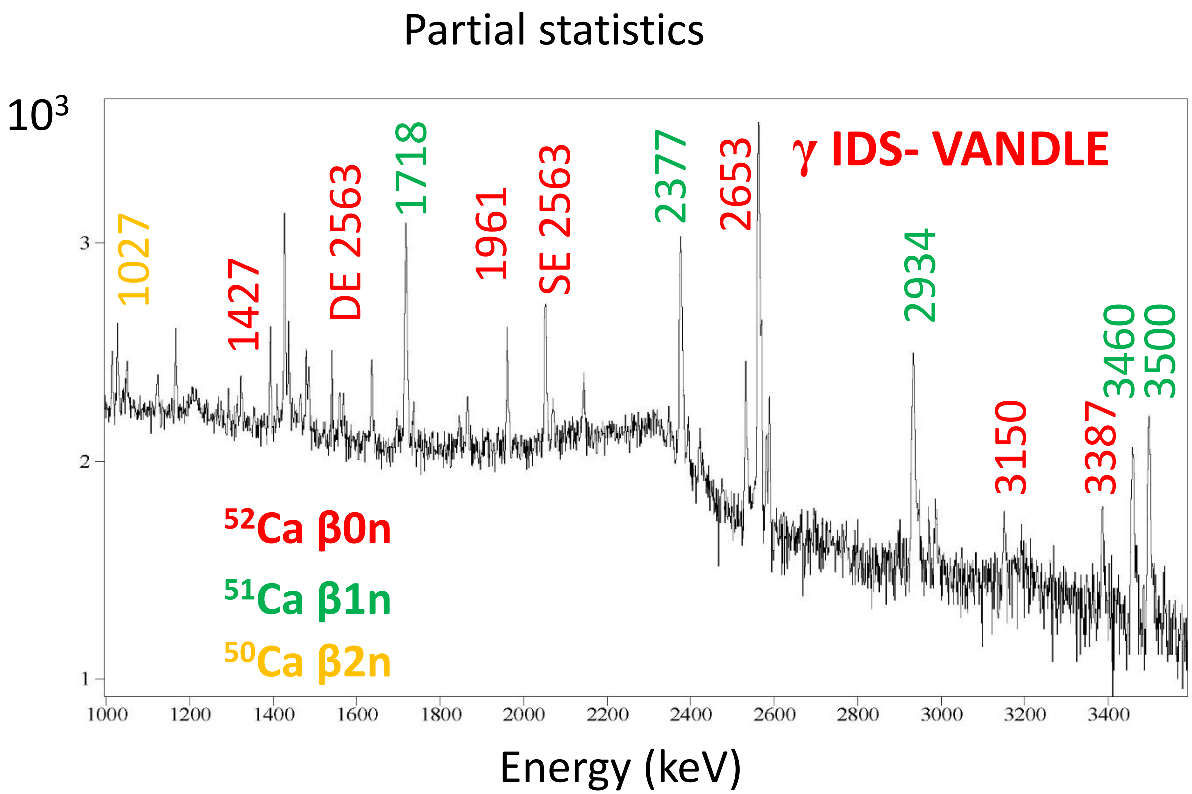
In total, 15 shifts (five days) were assigned

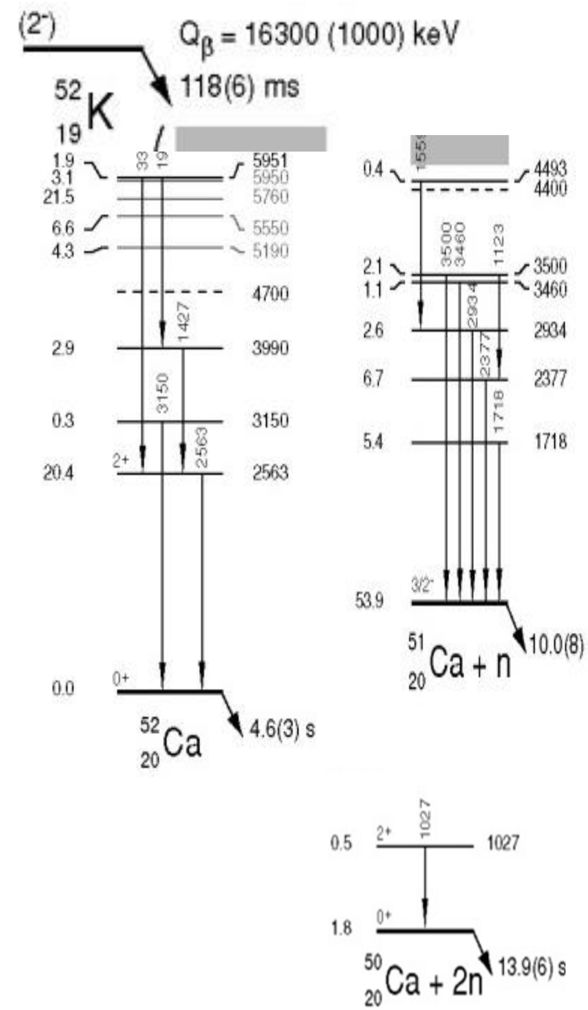
^{54}K rate (realistic, based on previous result plus some target improvements): **0.5 pps**, (possible to improve with target optimized for fast release ?):

- 8% neutron efficiency, 90% β efficiency, 2 % γ efficiency
- 60-90 % neutron emission: around **10^4 neutrons detected in 5 days** (assigned by INTC)
- 10% feeding to excited ^{54}Ca states: around 150 γ rays from ^{54}Ca in 5 days; mainly 2^+ and 3^-, likely also 4^+ states
- Lifetime from neutrons and gammas

A fast extraction needed for ^{54}K (10ms half life).
With nano-UCX this can be feasible but not guaranteed, fluctuations are possible.

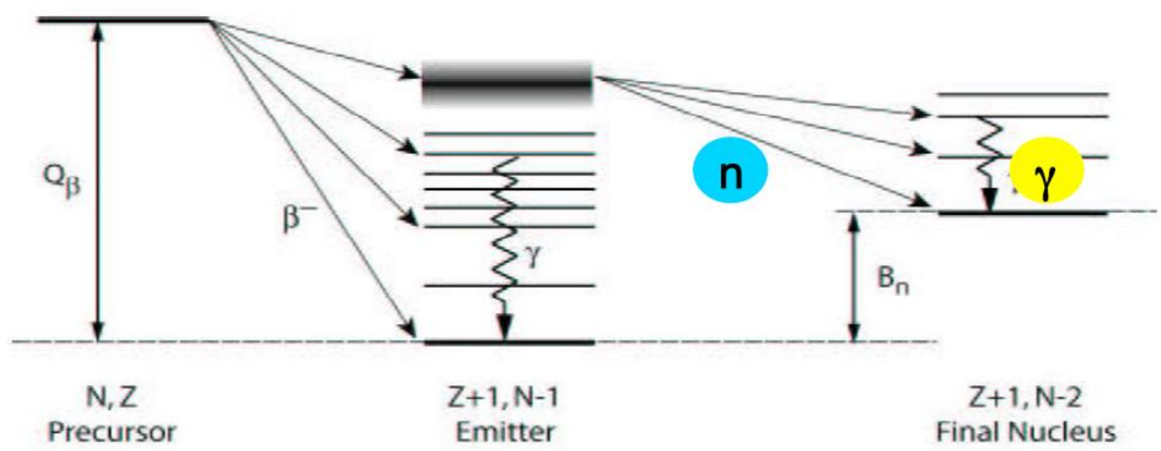
^{52}K results: γ-ray spectroscopy





Predominance of β-delayed neutron emission

In exotic nuclei close to shell closures one can have very large Q values (10-20 MeV)



The β decay can populate states below and above the neutron (and 2n) separation energy

- GT vs. FF transition competition caused by interplay of phase space and shell structure effects
- Particle-hole states may provide a measure of the shell energies in exotic nuclei