- Physics motivation
- Experimental setup
- Results and discussion
- Summary and outlook

Spectroscopic studies on the β-delayed neutron emission near ^{54}Ca

Zhengyu Xu

on behalf of the VANDLE group at UTK
and the IDS collaboration at ISOLDE-CERN

THE UNIVERSITY OF TENNESSEE KNOXVILLE

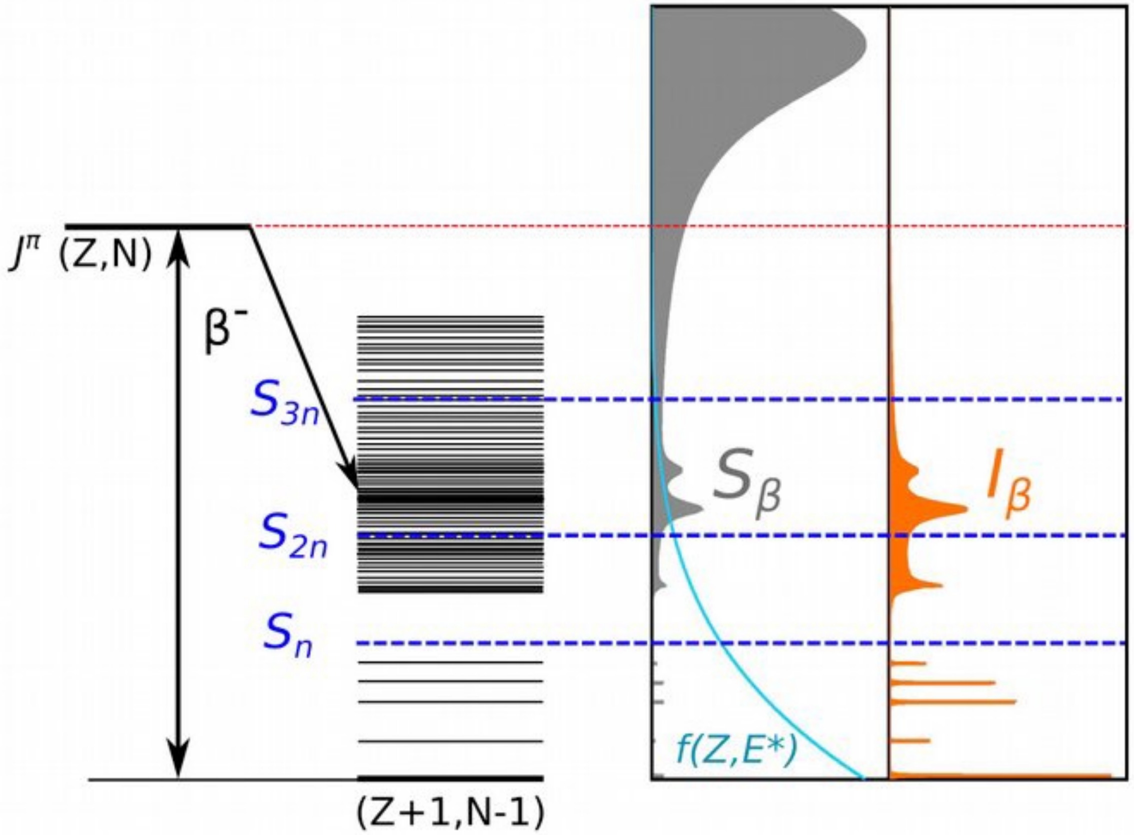
Nuclear Structure 2022
13-17 June 2022 Berkeley, CA

Beta decay, nuclear structure, and neutron emission

$$\frac{1}{T_{1/2}} = \sum_{E_i \geq 0}^{E_i \leq Q_\beta} S_\beta(E_i) \times f(Z, Q_\beta - E_i) \quad S_\beta(E_i) = \left| \langle \psi_f | \hat{O}_\beta | \psi_{mother} \rangle \right|^2$$

- S_β is determined by the nuclear structure in parent and daughter nuclei
- f (Z, Q_β - E_i) is the phase-space factor (Fermi integral)
- I_β is strongly modulated by f, which follows ~$(Q_\beta - E_i)^5$
- When states above neutron-separation energy (S_n) are populated, neutron emissions become the dominant decay process following beta decays

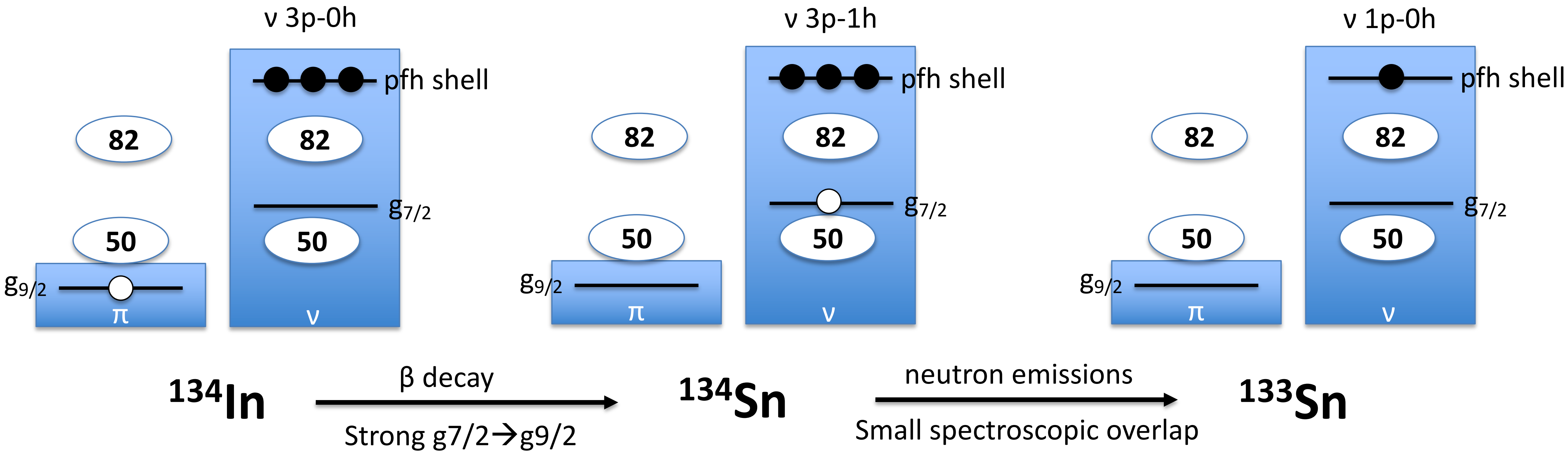
→ Neutron spectroscopy becomes more and more important in reconstructing S_β in more neutron-rich nuclei



A controversy in beta-delayed neutron emissions

- The mismatch between initial and final wavefunctions was seen in beta-delayed neutron emission (J. Heideman, R. Grzywacz et al., submitted for peer review)
- Microscopic calculations such as the shell-model calculation are difficult
- Hauser-Feshbach statistical model [1] is used to predict inclusive neutron-emission branching ratios (e.g., Ref. [2])

→ Exclusive neutron-emission branching ratios make a step forward and provide more insights



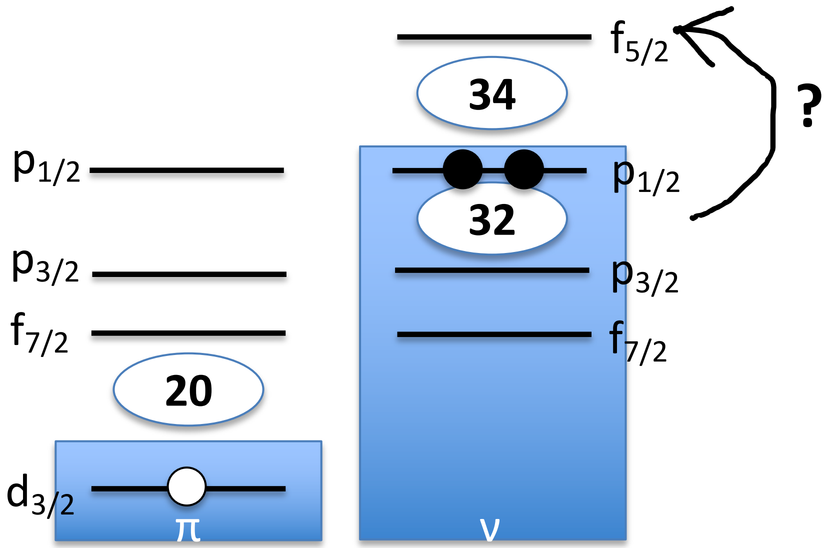
[1] T. Kawano et al., Phys. Rev. C 78, 054601 (2008)
[2] R.Yokoyama et al., Phys. Rev. C 100, 031302(R) (2019)

Beta decay around ^{54}Ca (^{52,53}K)

Is ^{54}Ca (Z=20, N=34) a doubly magic nucleus, like ^{132}Sn (?)

- How many neutrons occupy the $f_{5/2}$ orbital above N=34 in ^{52,53}K (i.e., is N=34 a strong shell gap)?

Z \ N	30	31	32	33	34
20	50Ca 13.9 S β-: 100.00%	51Ca 10000 MS β-: 100.00% β-n	52Ca 4600 MS β-: 100.00% β-n < 2.00%	53Ca 461 MS β-: 100.00% β-n: 40.00%	54Ca 107 MS β-: 100.00%
19	49K 1263 MS β-: 100.00% β-n: 86.00%	50K 472 MS β-: 100.00% β-n: 28.60%	51K 365 MS β-: 100.00% β-n: 65.00%	52K 110 MS β-: 100.0% β-n: 72.20%	53K 30 MS β-: 100.00% β-n: 75.00%
18	48Ar 424 MS β-: 100.00% β-n: 38.00%	49Ar 236 MS β-: 100.00% β-n: 29.00%	50Ar 106 MS β-: 100.00% β-n: 37.00%	51Ar >200 NS β-: 100.00%	52Ar >620 NS β-: 100.00% β-n

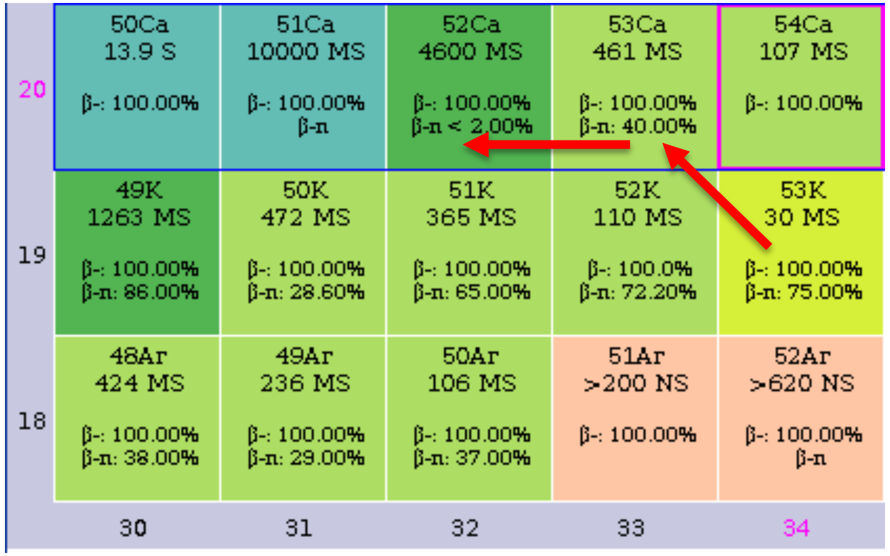


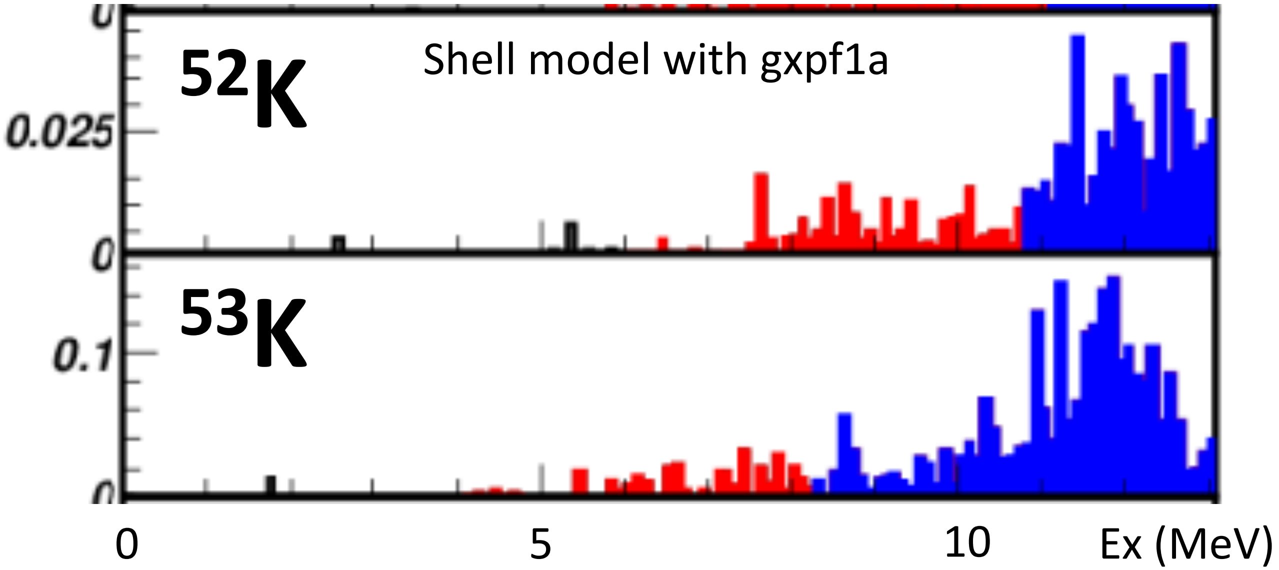
^{53}K

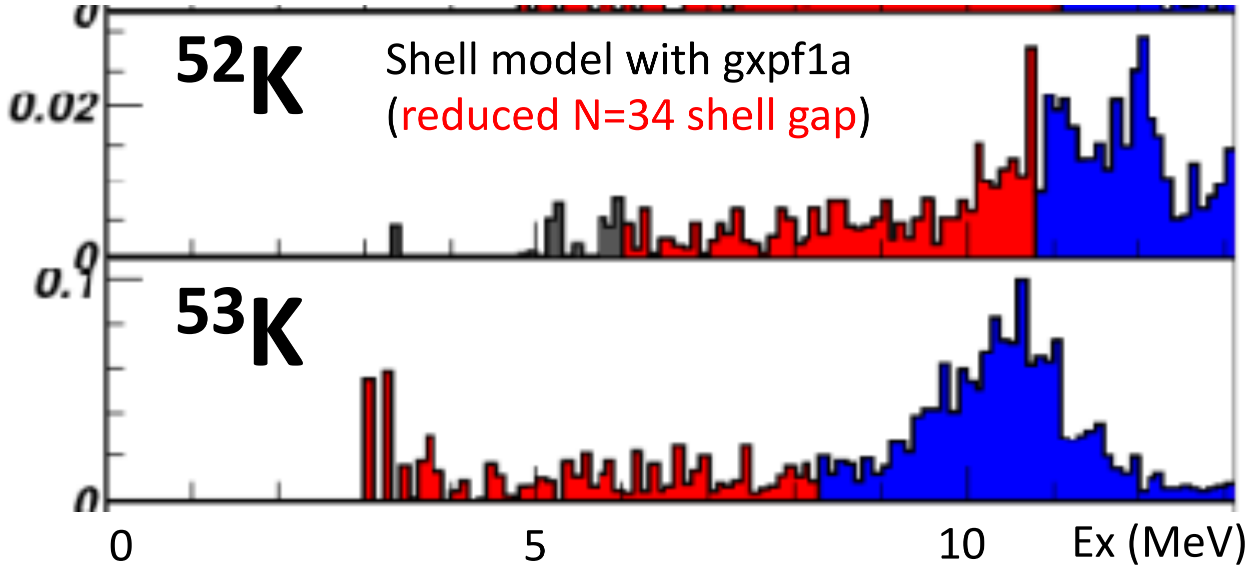
Beta decay around ^{54}Ca (^{52,53}K)

Is ^{54}Ca (Z=20, N=34) a doubly magic nucleus, like ^{132}Sn (?)

- How many neutrons occupy the $f_{5/2}$ orbital above N=34 in ^{52,53}K (i.e., is N=34 a strong shell gap)?
- → I_β is our probe to the shell gap



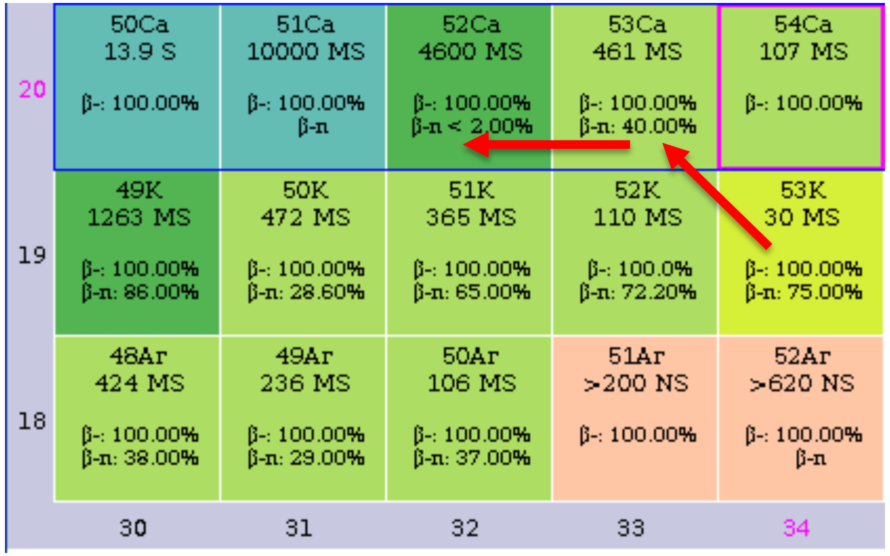


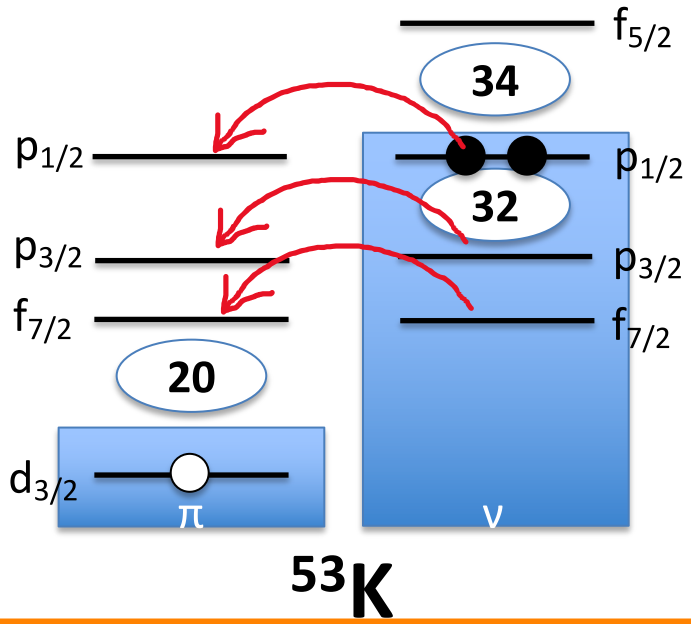


Beta decay around ^{54}Ca (^{52,53}K)

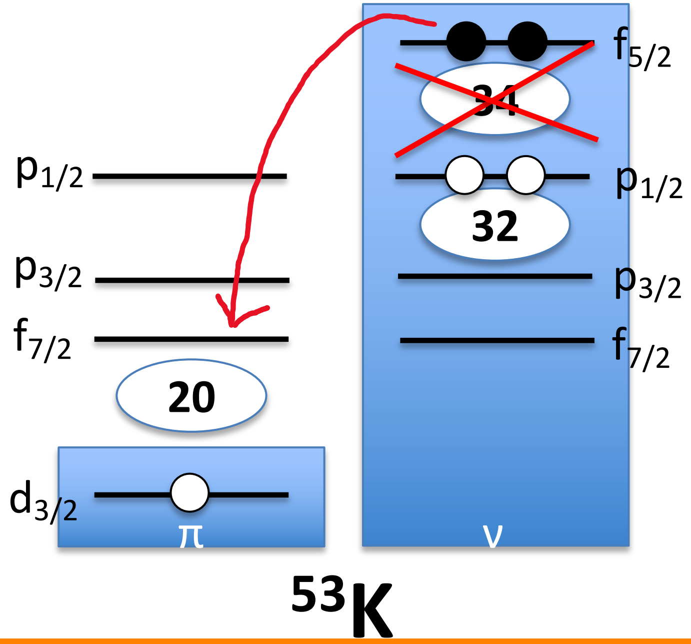
Is ^{54}Ca (Z=20, N=34) a doubly magic nucleus, like ^{132}Sn (?)

- How many neutrons occupy the $f_{5/2}$ orbital above N=34 in ^{52,53}K (i.e., is N=34 a strong shell gap)?
- → I_β is our probe to the shell gap

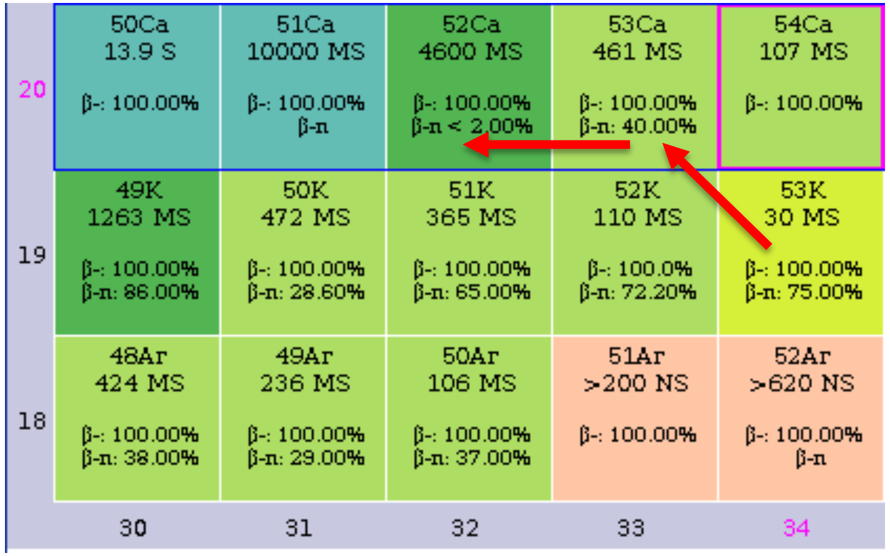




or

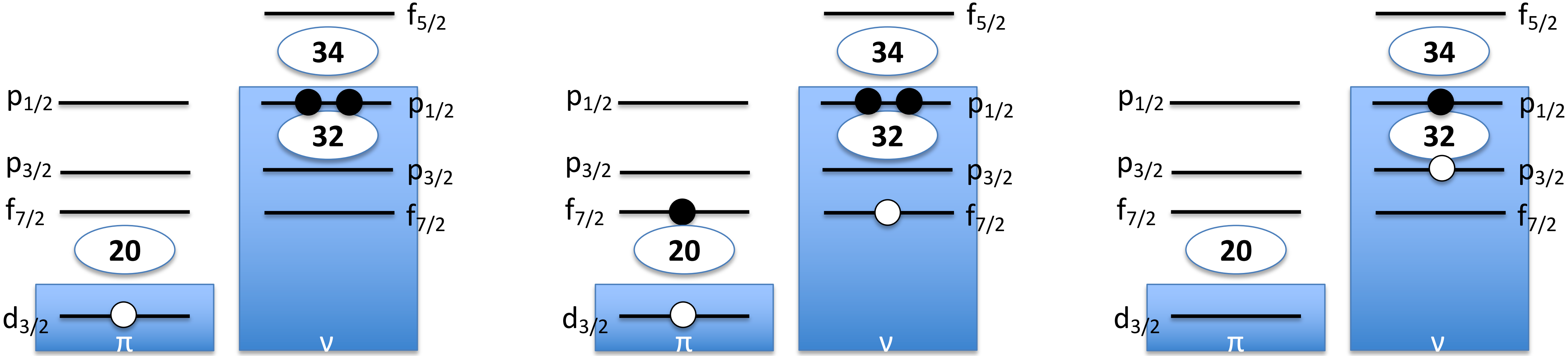


Beta decay around ^{54}Ca (^{52,53}K)



Is ^{54}Ca (Z=20, N=34) a doubly magic nucleus, like ^{132}Sn (?)

- How many neutrons occupy the $f_{5/2}$ orbital above N=34 in ^{52,53}K (i.e., is N=34 a strong shell gap)?
- → I_β is our probe to the shell gap
- → The exclusive neutron branching ratios around ^{54}Ca provide another valuable input to the statistical-model calculation



^{53}K ^{53}Ca ^{52}Ca

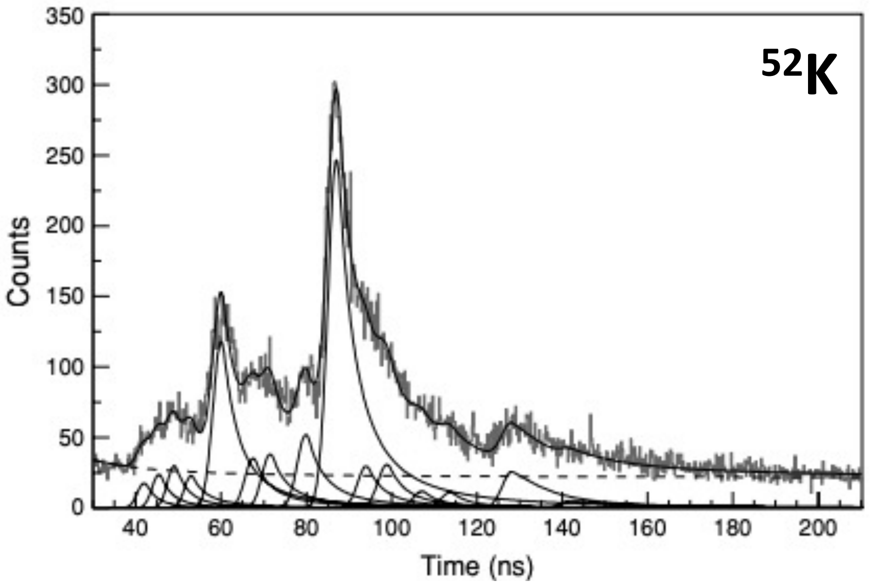
Beta decay around ^{54}Ca (^{52,53}K)

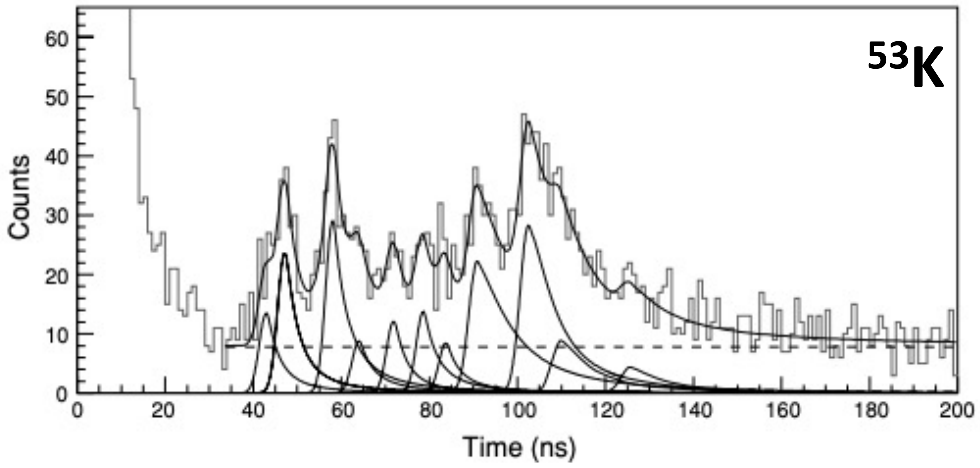
Previous work at ISOLDE Decay Station (MINIBALL+TONNERRE+LEND):
F. Perrot et al., Phys. Rev. C 74, 014313 (2006)

More statistics are needed for a decisive conclusion for ^{53}K (no β-γ-n analysis was performed in previous work)

This work:

- Remeasure the I_β of ^{52}K decay (confirmation)
- Establish the I_β ^{53}K for the first time

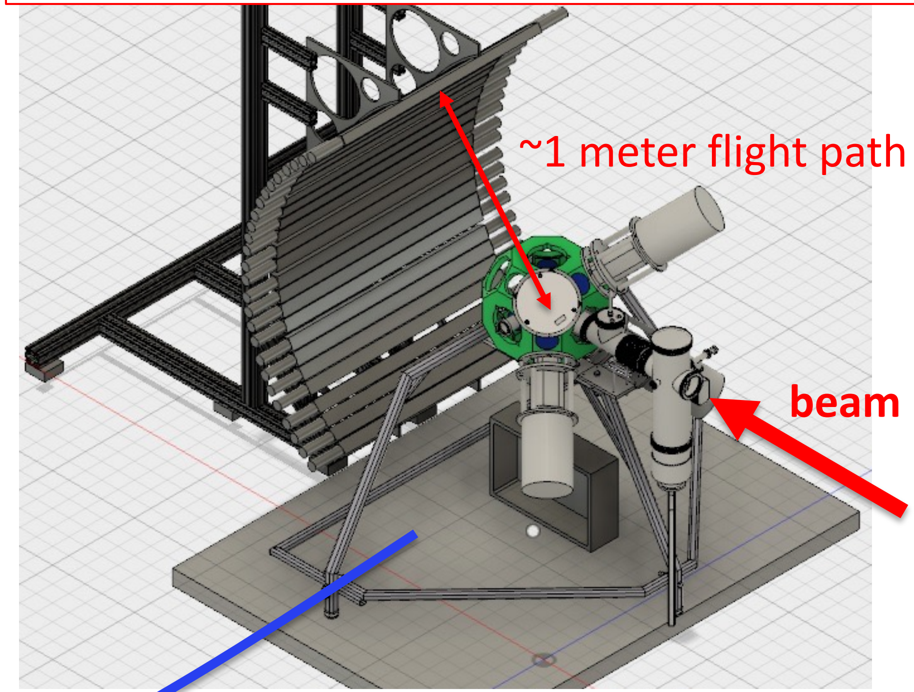




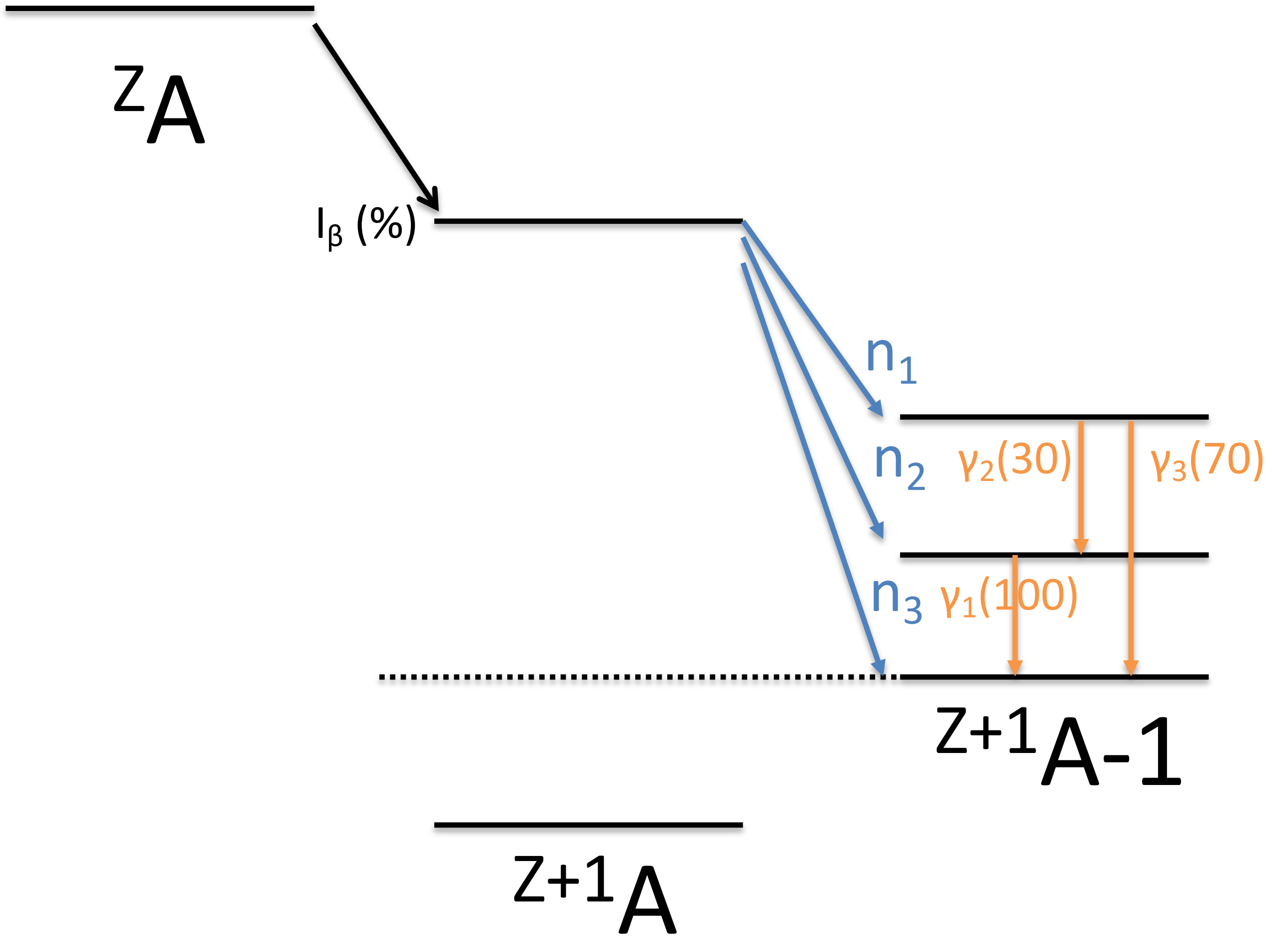
Experimental setup (IS599, PI: A. Gottardo, R. Grzywacz, M. Madurga)

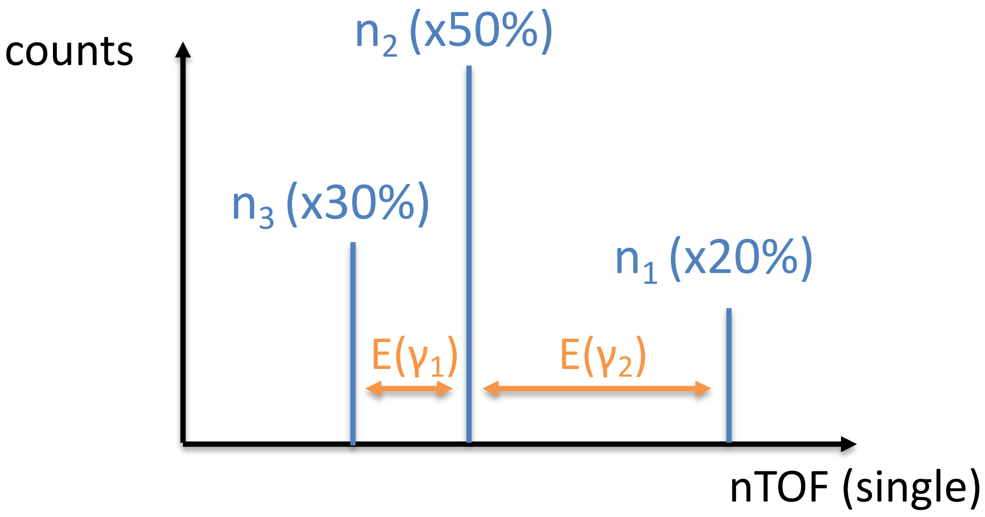
Proton beam current ~ 2uA
Isotopes were separated by general-purpose separator (GPS)
~500k 53K were collected in 4 days of beamtime

At ISOLDE Decay Station (IDS)
Tape system to remove long-lived activities
Two β detectors (front and back) with 80% efficiency
4 HPGe clovers + 26 Neutron detectors (INDiE*)
2% γ and 10% neutron efficiency at 1 MeV

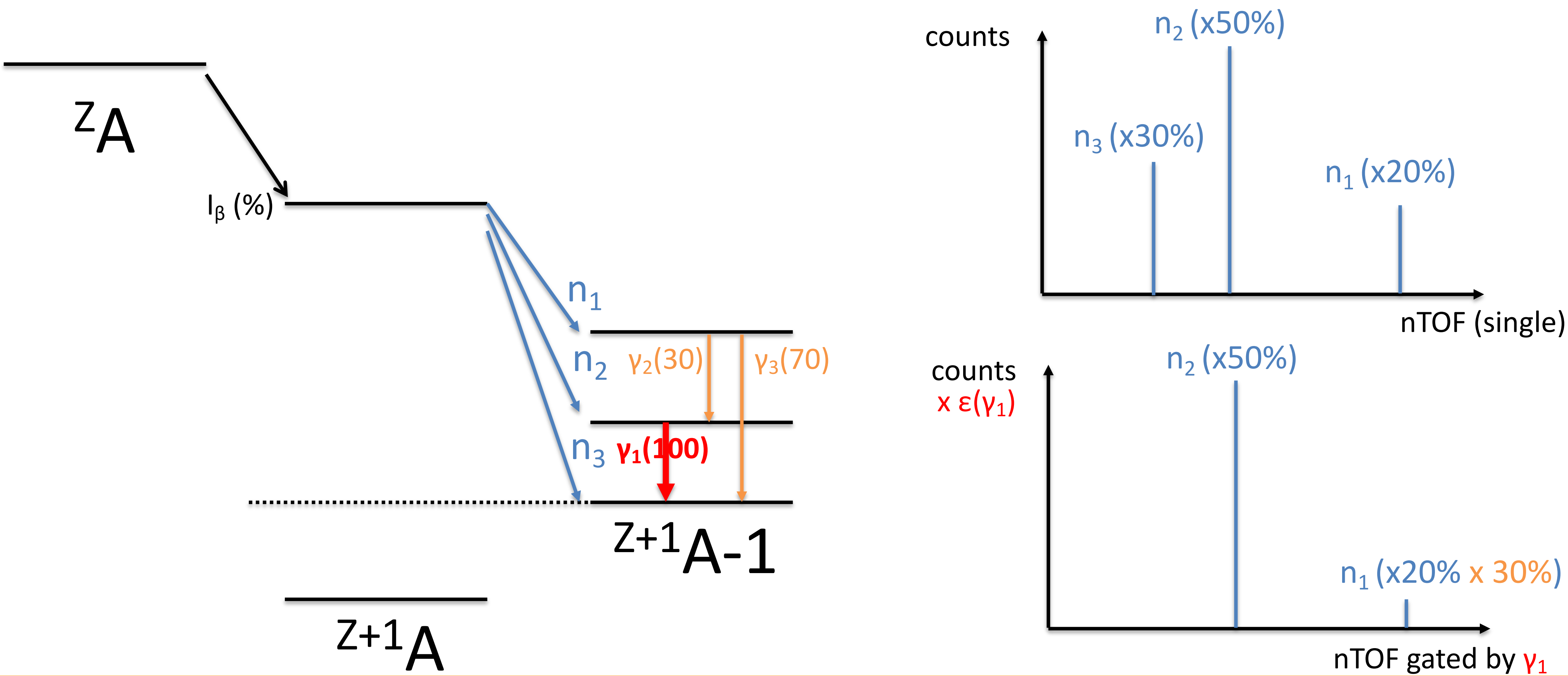


Data analysis with neutron & gamma spectra



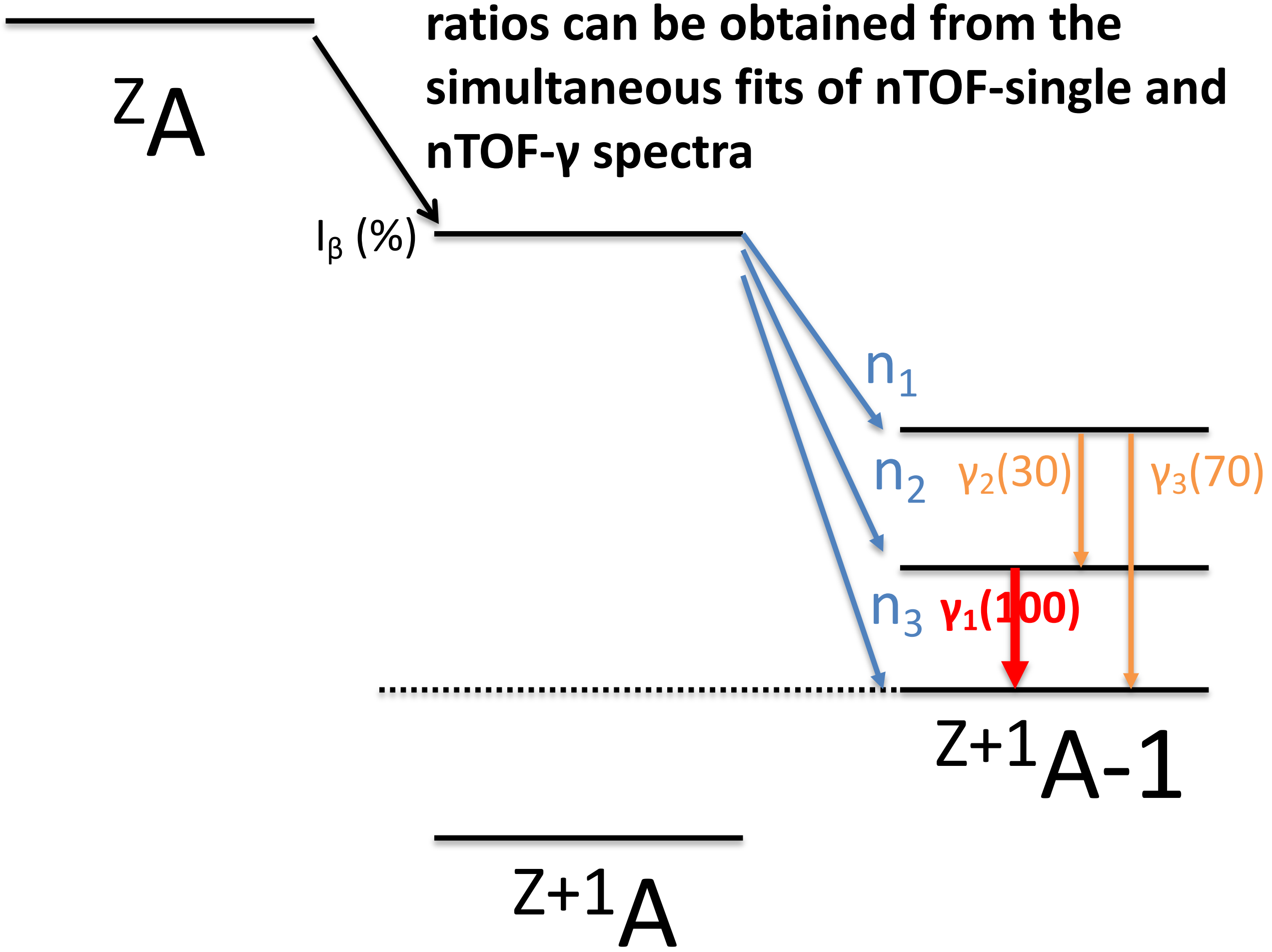


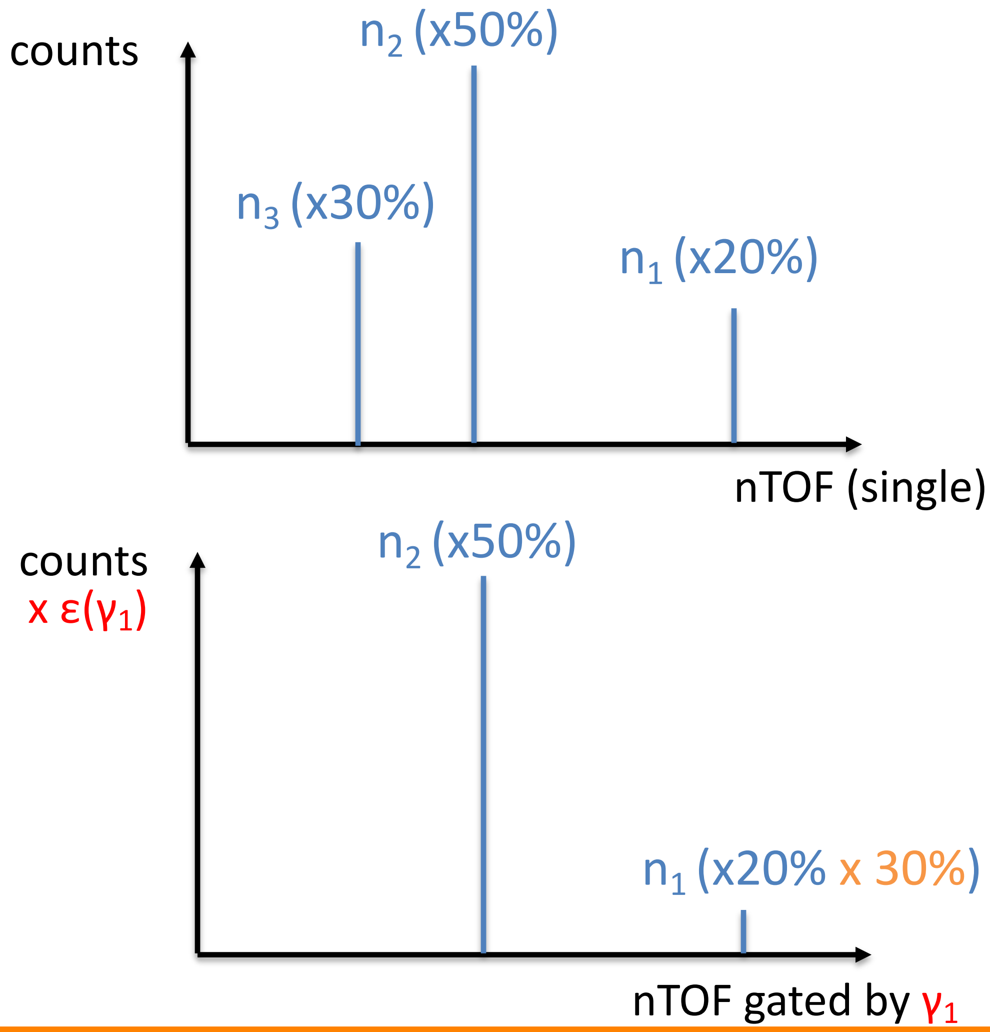
Data analysis with neutron & gamma spectra



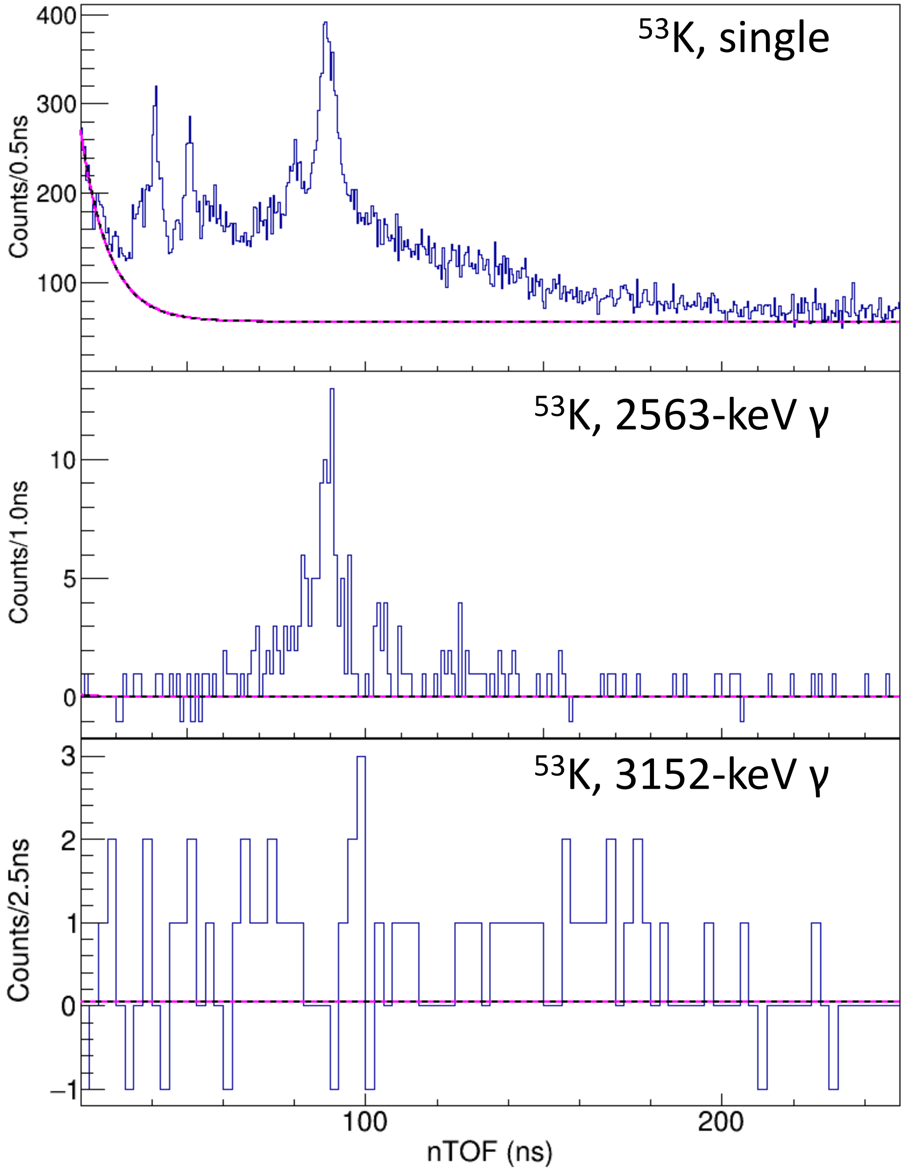
Data analysis with neutron & gamma spectra

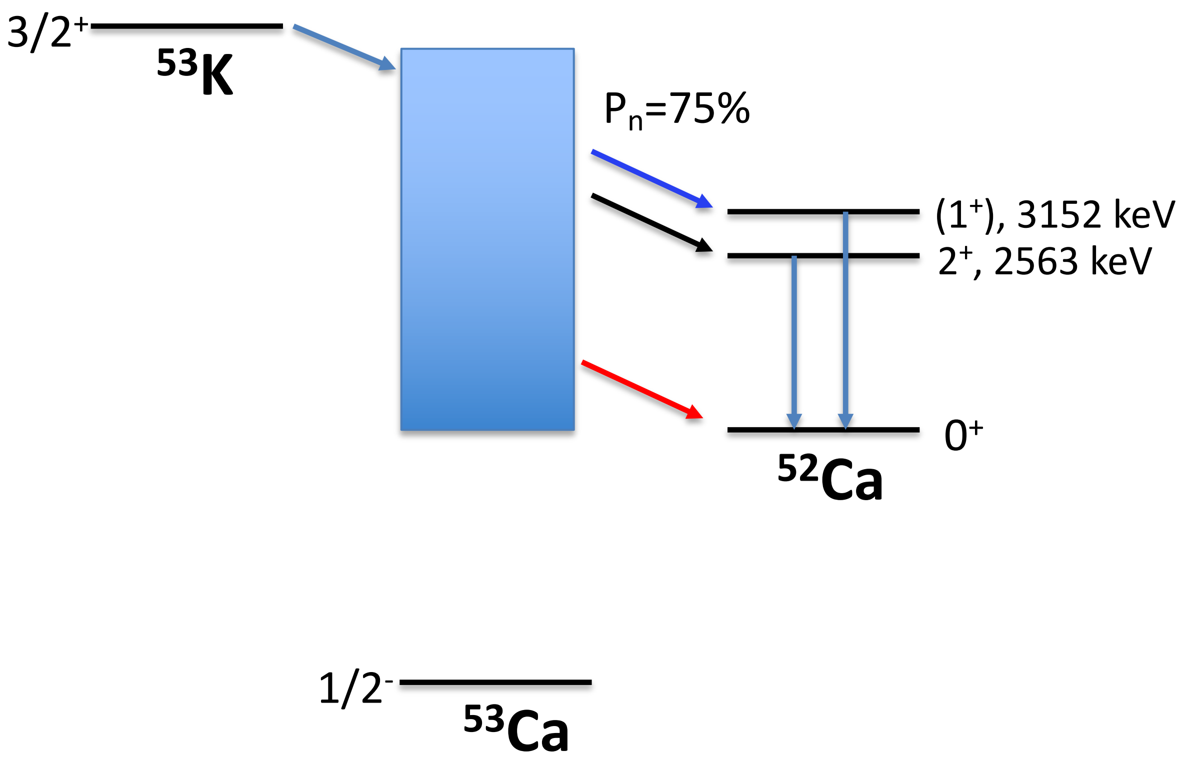
I_β and neutron exclusive branching ratios can be obtained from the simultaneous fits of nTOF-single and nTOF-γ spectra



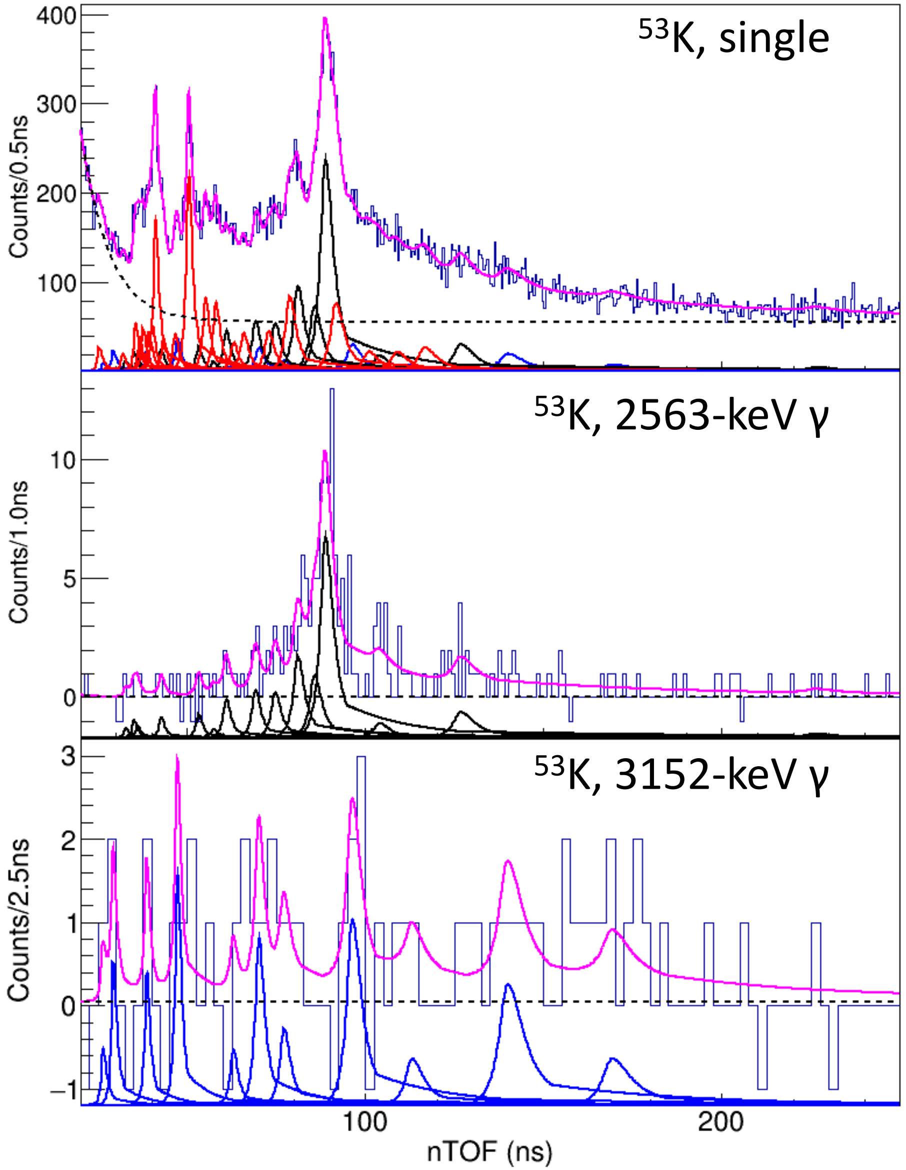


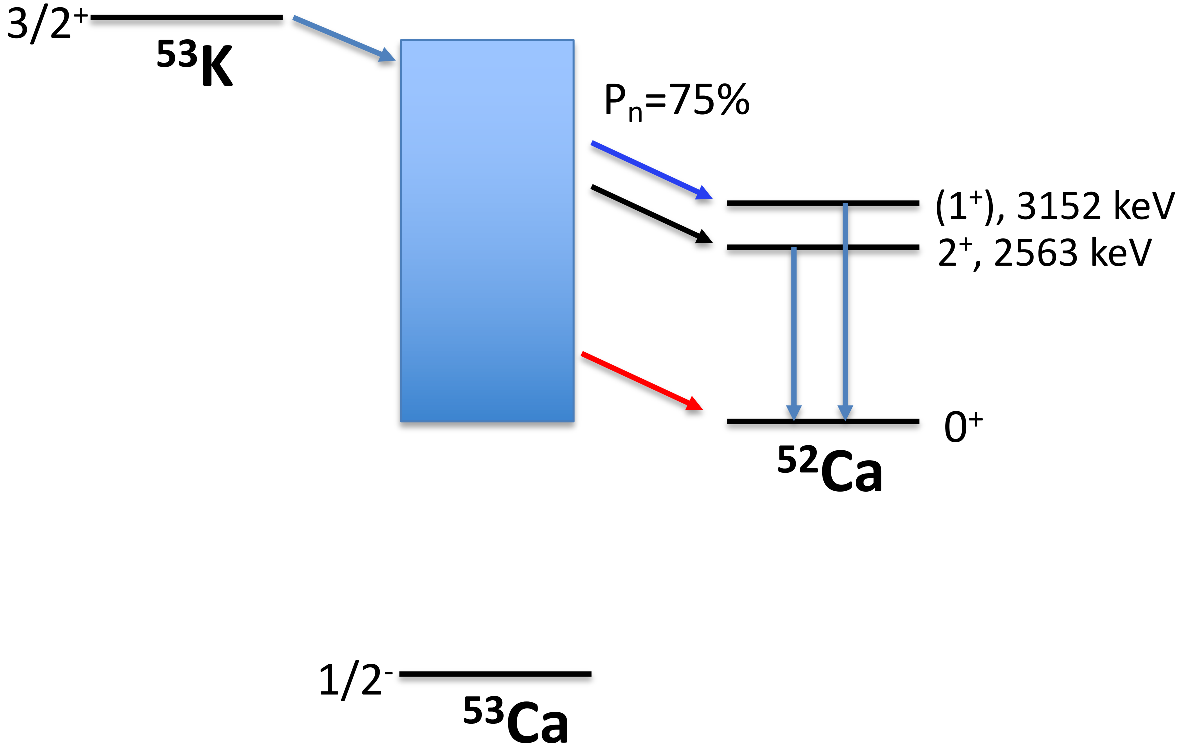
Experimental result: nTOF following the decay of ^{53}K



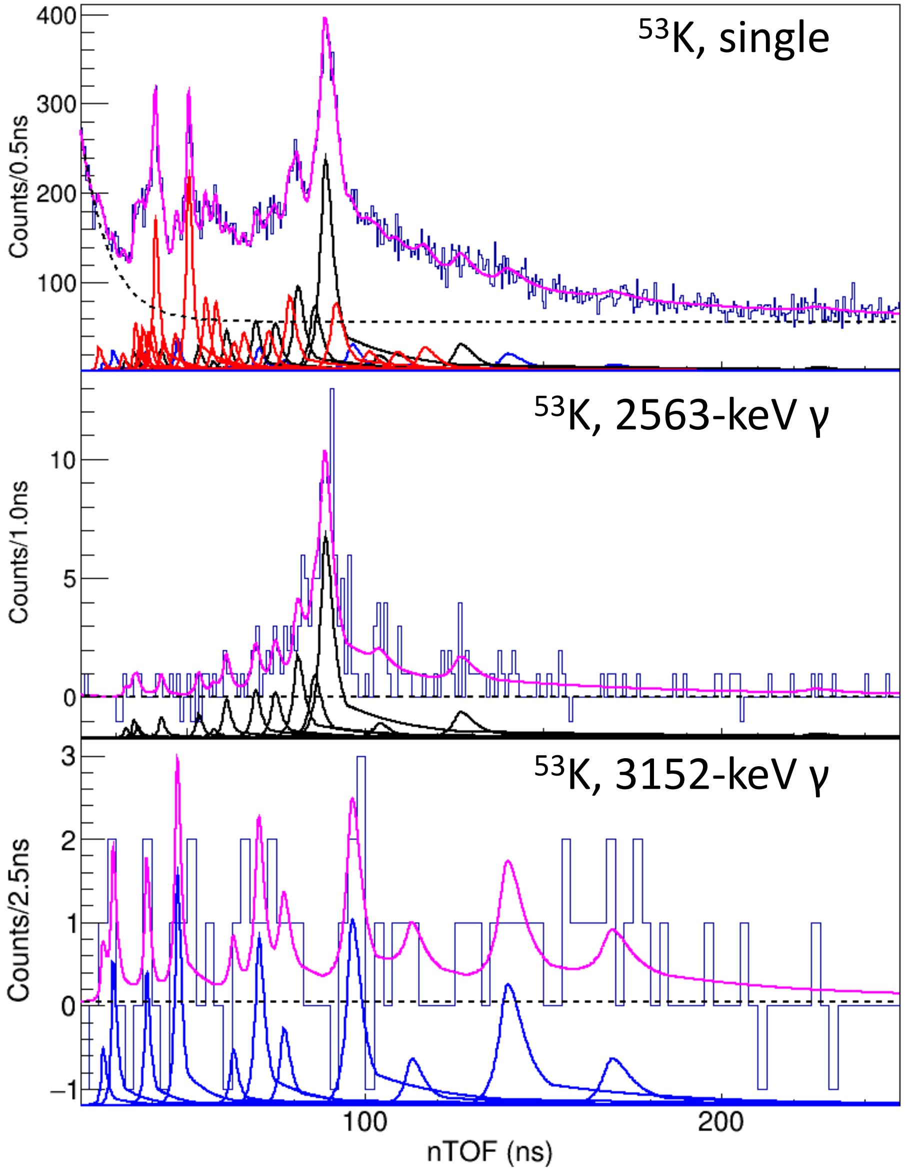


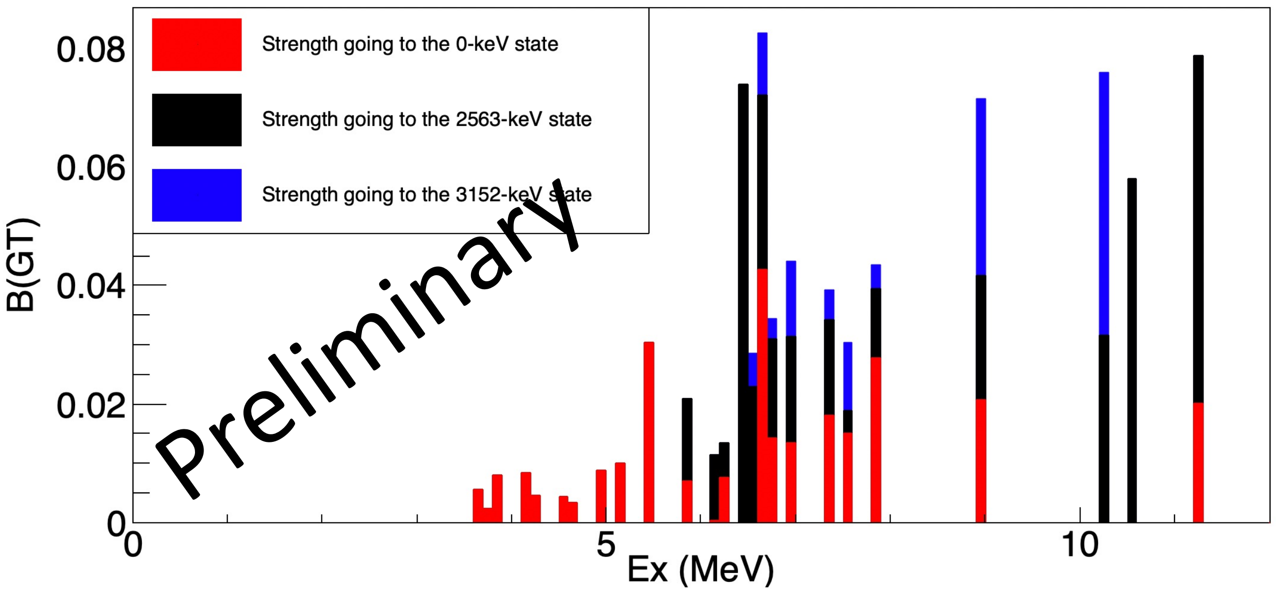
Experimental result: nTOF following the decay of ^{53}K





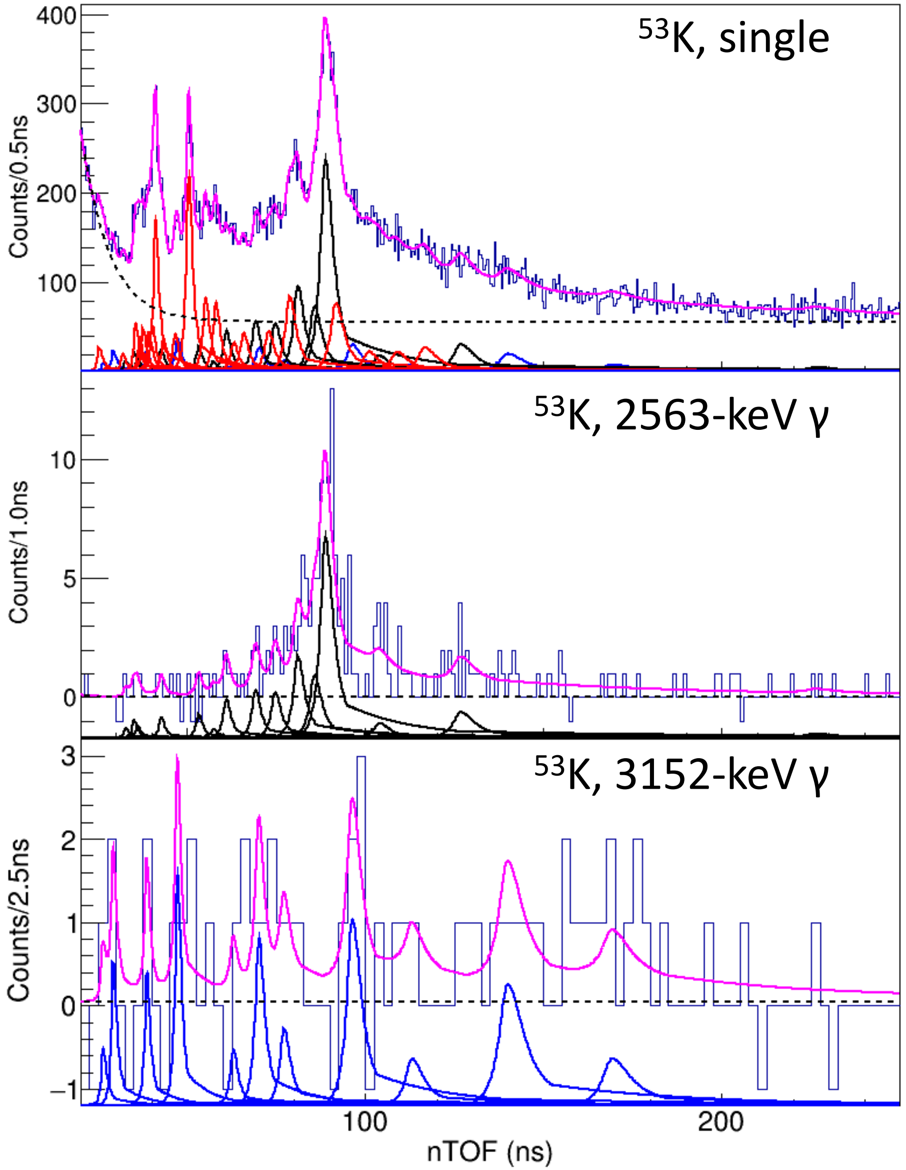
The B(GT) distribution indicates a strong N=34 shell gap

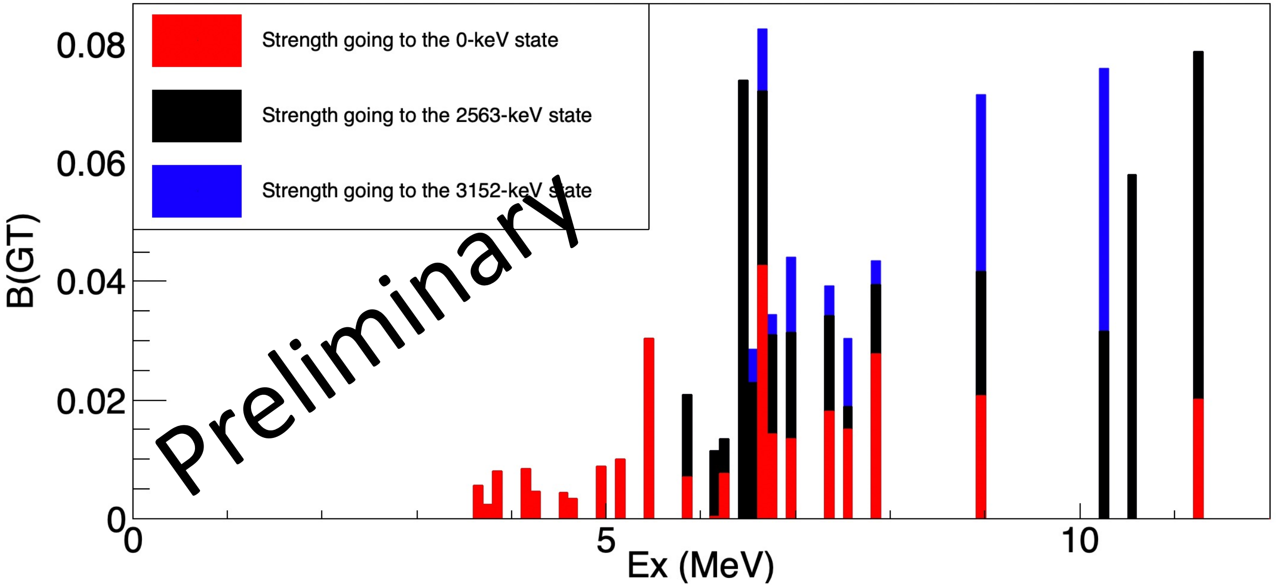


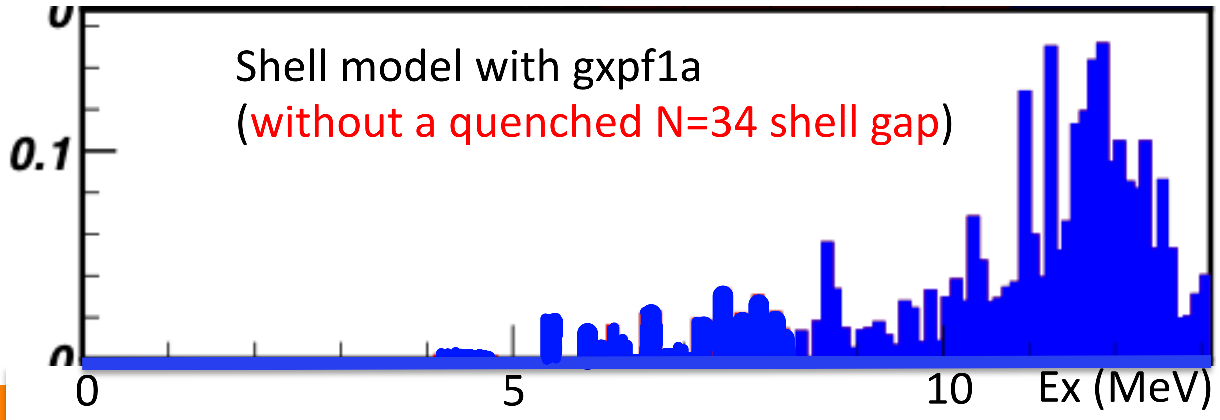


Each narrow bar corresponds to a virtual state (in the fitting analysis), of which the width is not yet included.

The B(GT) distribution indicates a strong N=34 shell gap

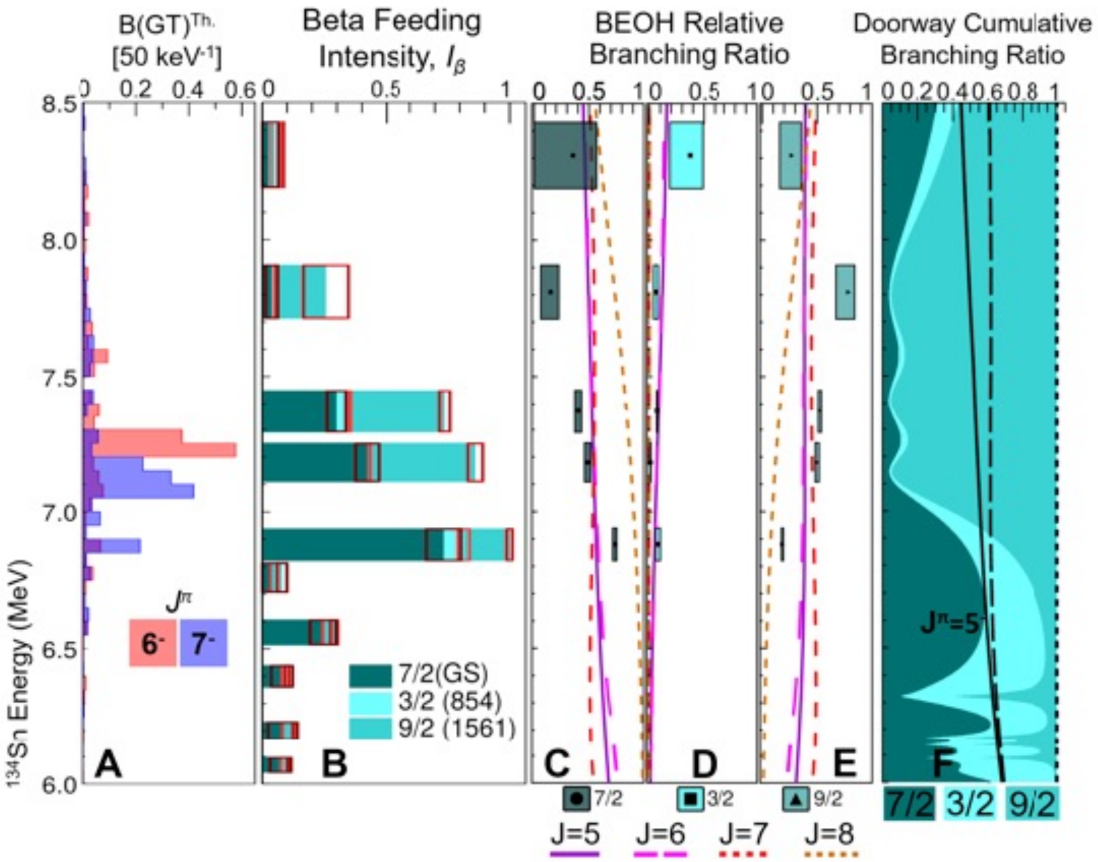




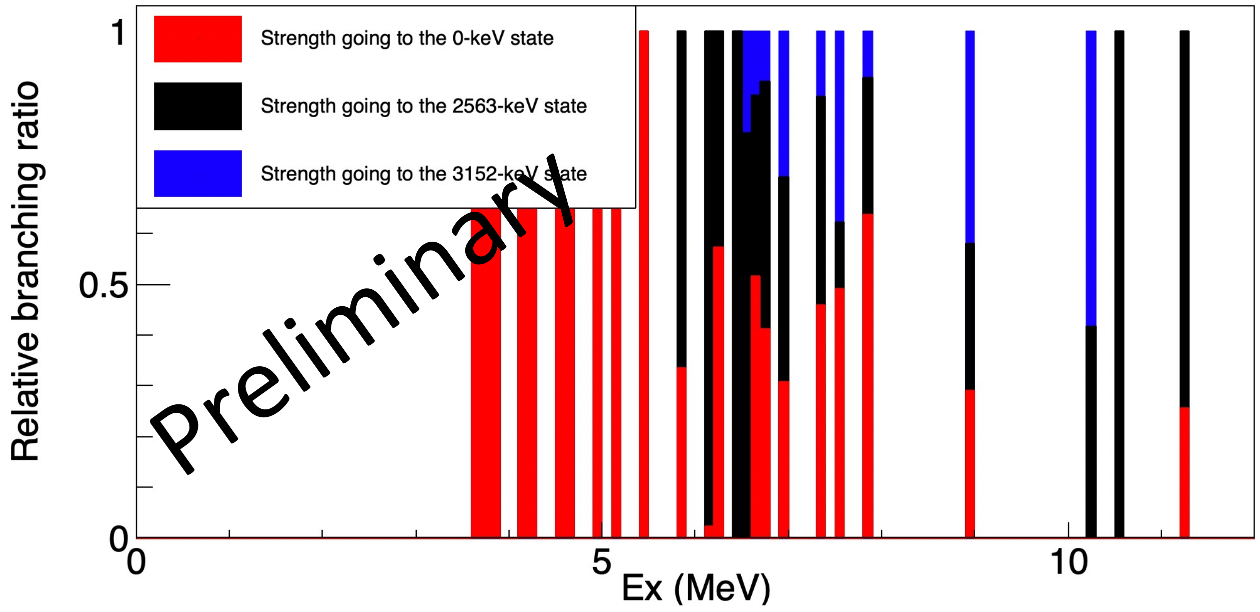


Exclusive neutron branching ratios matter

Non statistical neutron emissions were observed in $^{134}In \rightarrow {}^{134}Sn \rightarrow {}^{133}Sn$

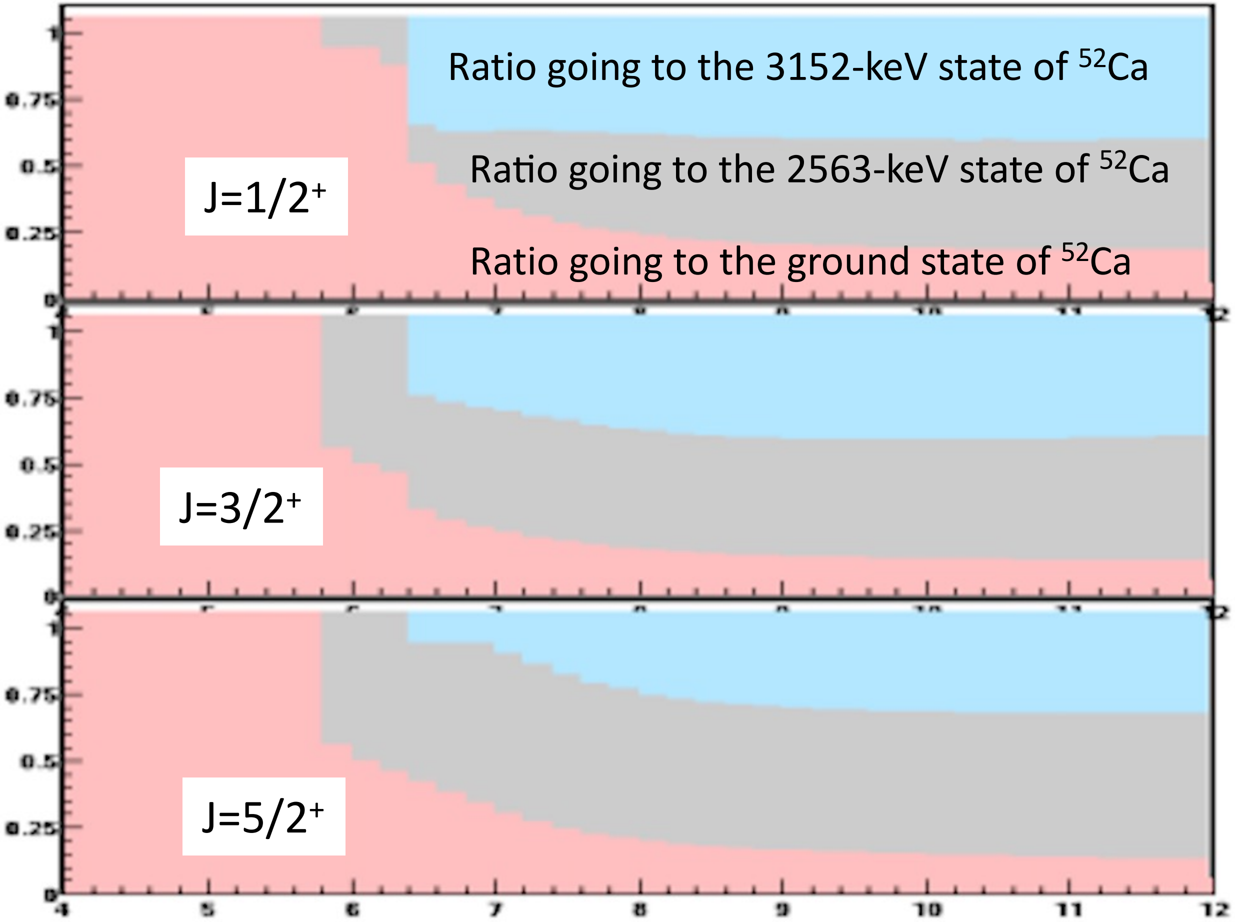


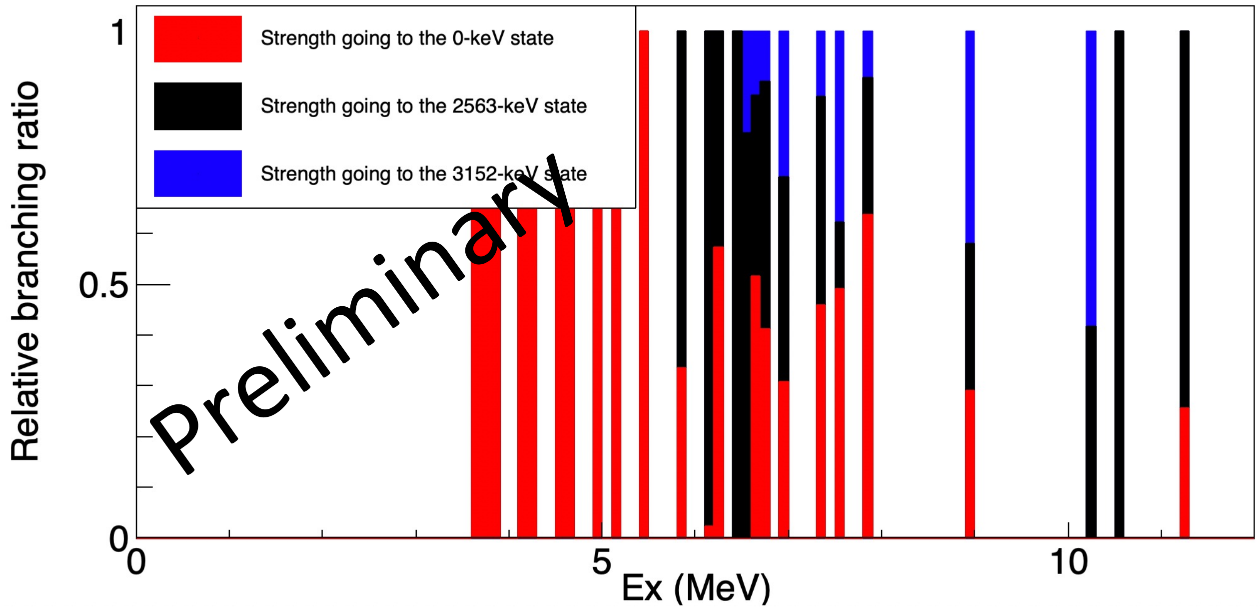
J. Heideman, R. Grzywacz et al., submitted for peer review



Exclusive neutron branching ratios matter

Hauser-Feshbach calculation on ^{53}K ($3/2^+$) decay





Summary and outlook

- Beta decays of $^{52,53}K$ were studied at ISOLDE Decay Station with a hybrid detection system (beta + gamma + neutron)
- Analysis methods were developed to obtain apparent beta feeding and neutron exclusive branching ratios simultaneously
- The results were compared with SM calculations, and we did not see the evidence of a reduced neutron shell gap at N=34 shell gap
- The comparison of the neutron exclusive branching ratios with the statistical model (HF) shows some spin-dependency and the possibility of model-dependent spin assignment
- So far, only allowed Gamow-Teller strength distribution has been calculated in the SM, which will be extended to include First-Forbidden transitions soon.

Collaboration of IS599

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].

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

Spokesperson(s): A. Gottardo (gottardo@ipno.in2p3.fr), R. Grzywacz (rgrzywac@utk.edu), M. Madurga (madurga@cern.ch)

Collaboration of IS599

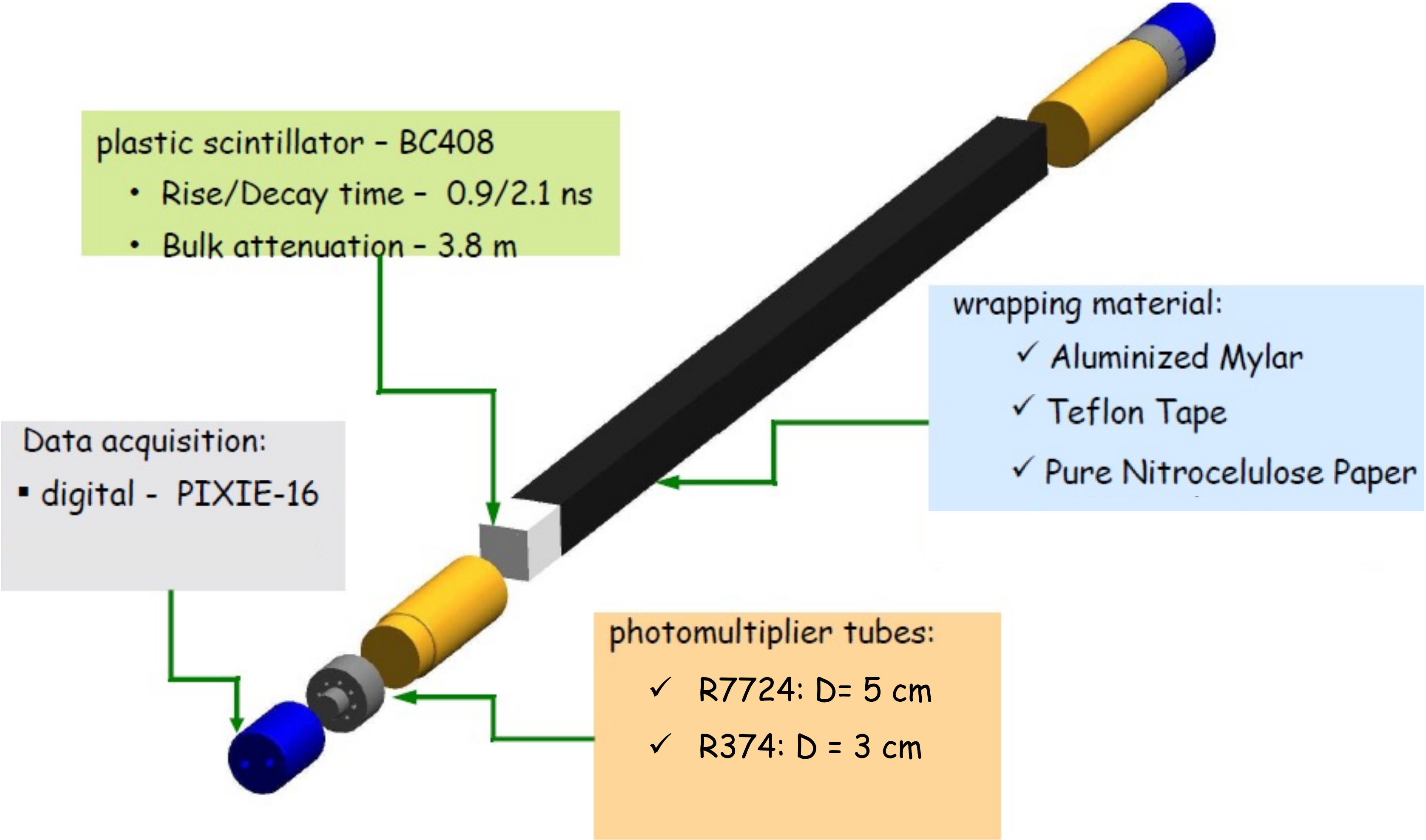
A. Gottardo[1], R. Grzywacz[2], M. Madurga[3], G. de Angelis[4], F. Azaiez[1], D. Bazzacco[5], G. Benzoni[6], A. Boso[5], Y. Deyan[1], M.-C.Delattre[1], P. Van Duppen[7], A. Etilé[8], S. Franchoo[1], C. Gaulard[8], G. Georgiev[8], S. Go[2], A. Goasduff[4], F. Gramegna[4],K. Kolos[2], M. Kowalska[3], 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].

Thanks for your attention!

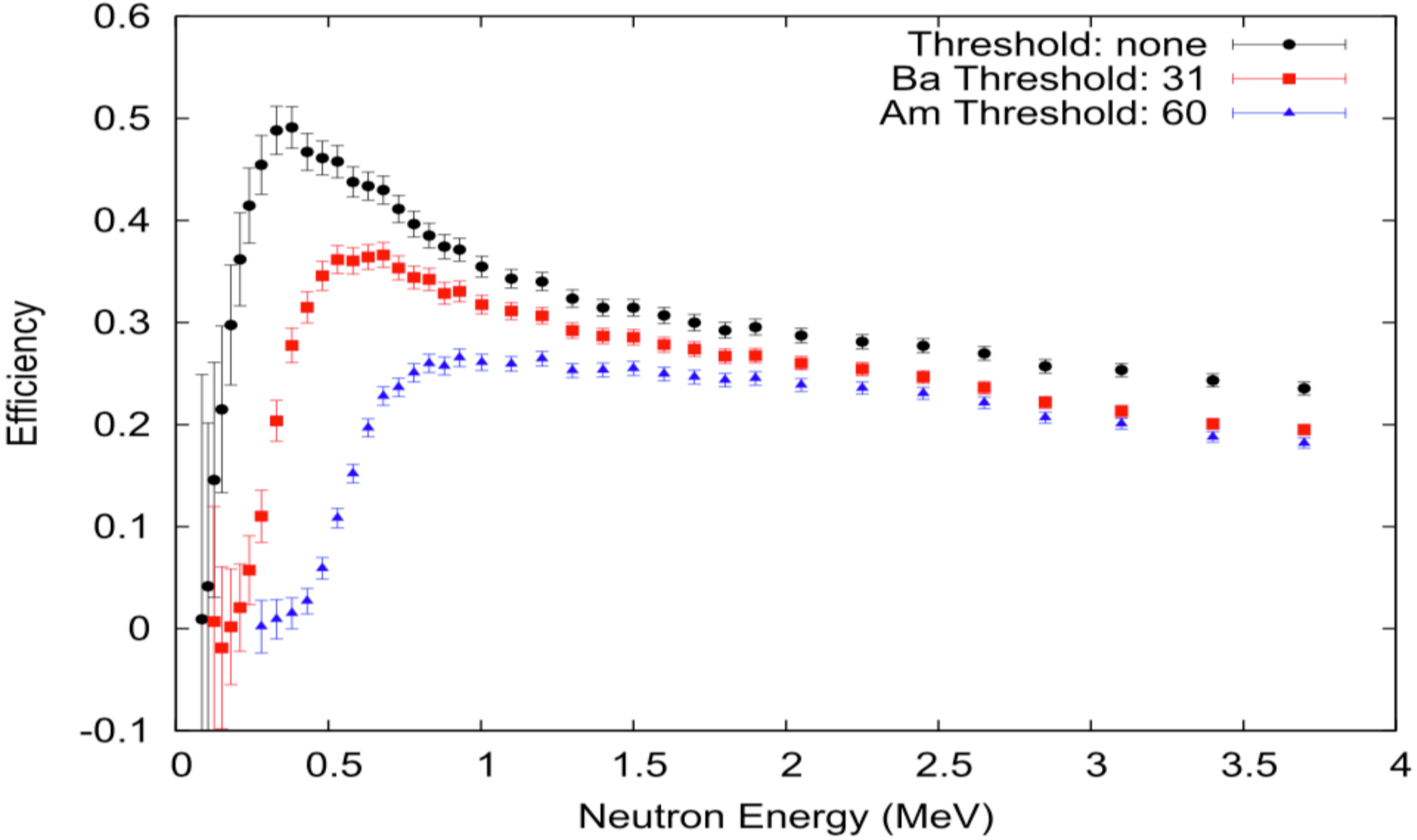
4 INFN, Laboratori Nazionali di Legnaro
5 University of Padova and INFN Padova
6 University of Milano and INFN Milano
7 KU Leuven
8 CSNSM Orsay
9 Colorado School of Mines
10 NSCL
11 IFIC Valencia
12 Aarhus University
13 IFIN-HH, Bucharest
Spokesperson(s): A. Gottardo (gottardo@ipno.in2p3.fr), R. Grzywacz (rgrzywac@utk.edu), M. Madurga (madurga@cern.ch)

Backup slides

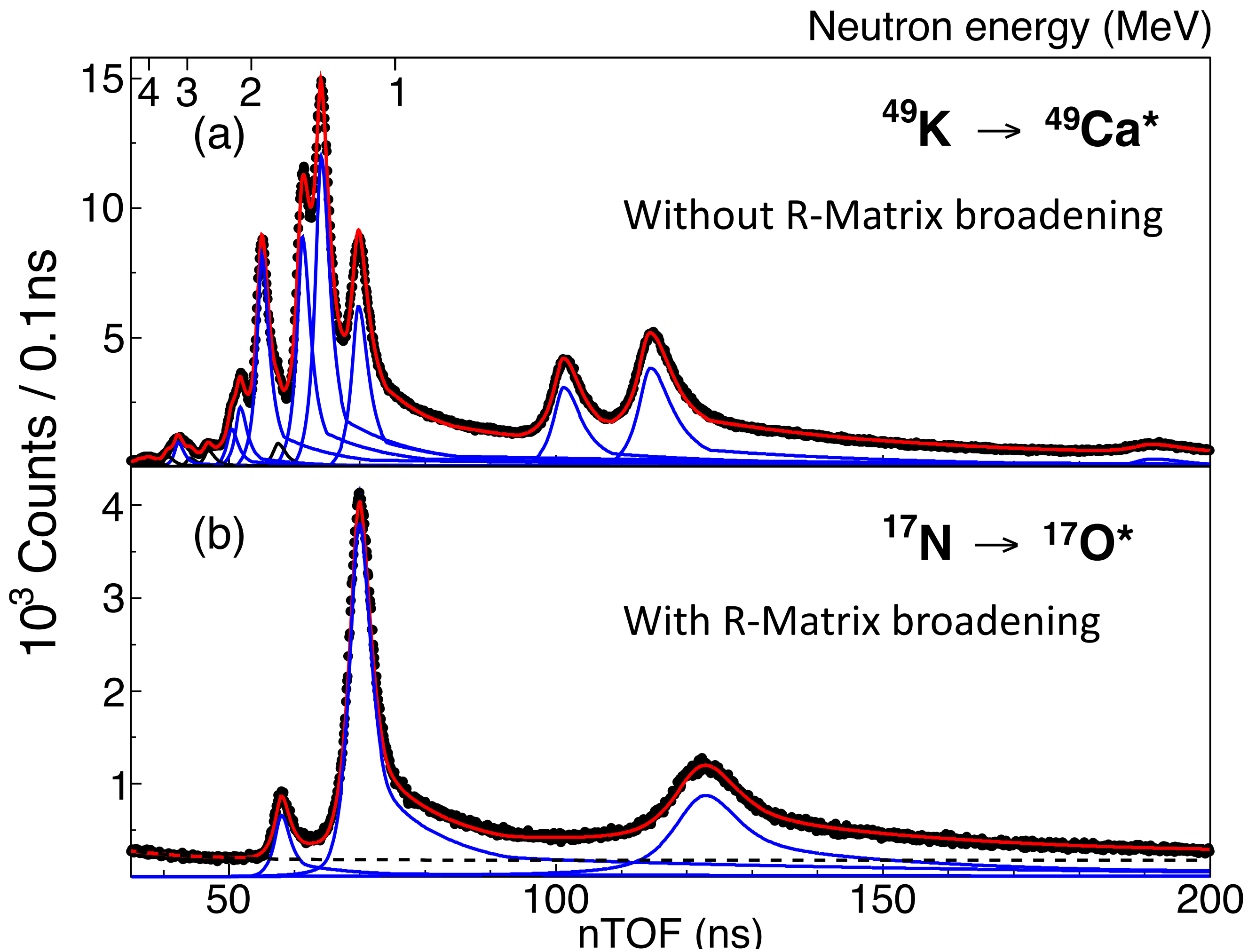
Detector components

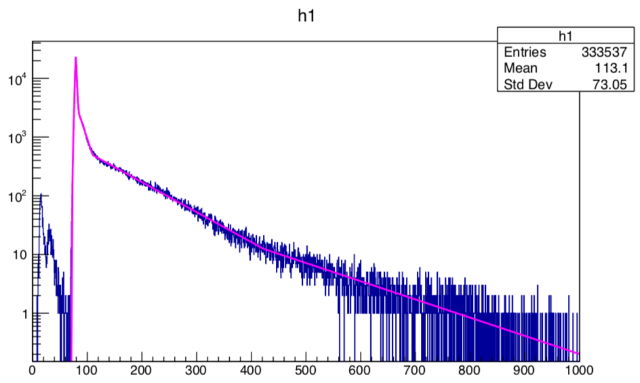


Neutron efficiency curve



Online calibration for INDiE





1-MeV neutrons in GEANT4

- Mono-energetic neutrons from GEANT4 (neutron scattering, time resolution)
- Convolution with the R-Matrix theory (with Lorentzian profile)
- Reproduce the *n*TOF spectra of ^{49}K and ^{17}N simultaneously