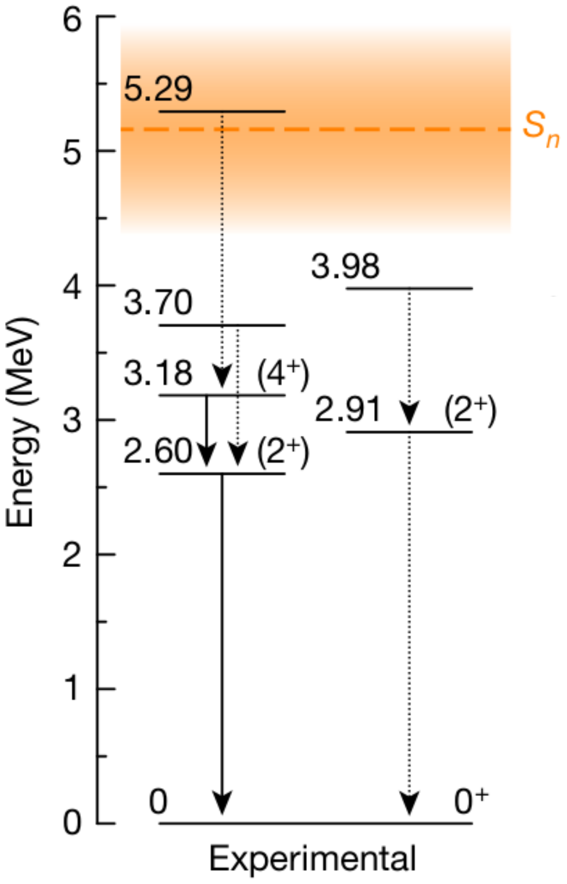
Beta-decay strength of ^{78}Ni to neutron-unbound states revealed by ^{79}Cu

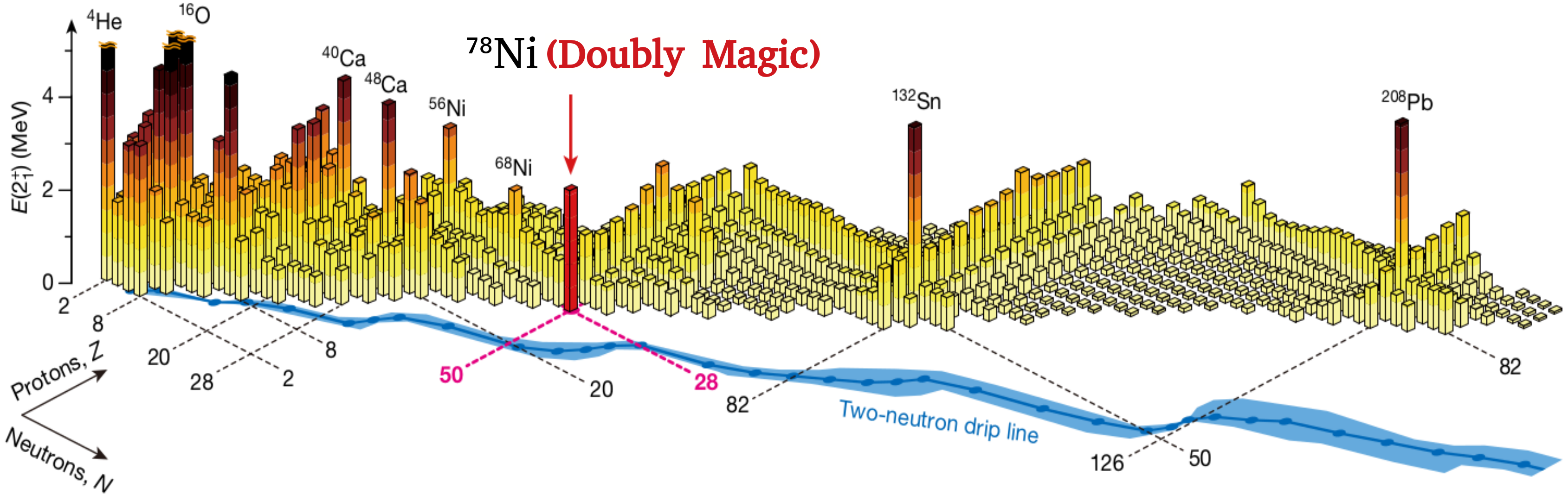
Maninder Singh

THE UNIVERSITY OF TENNESSEE KNOXVILLE

Nuclear Structure 2022-Berkeley

Doubly-Magic ^{78}Ni

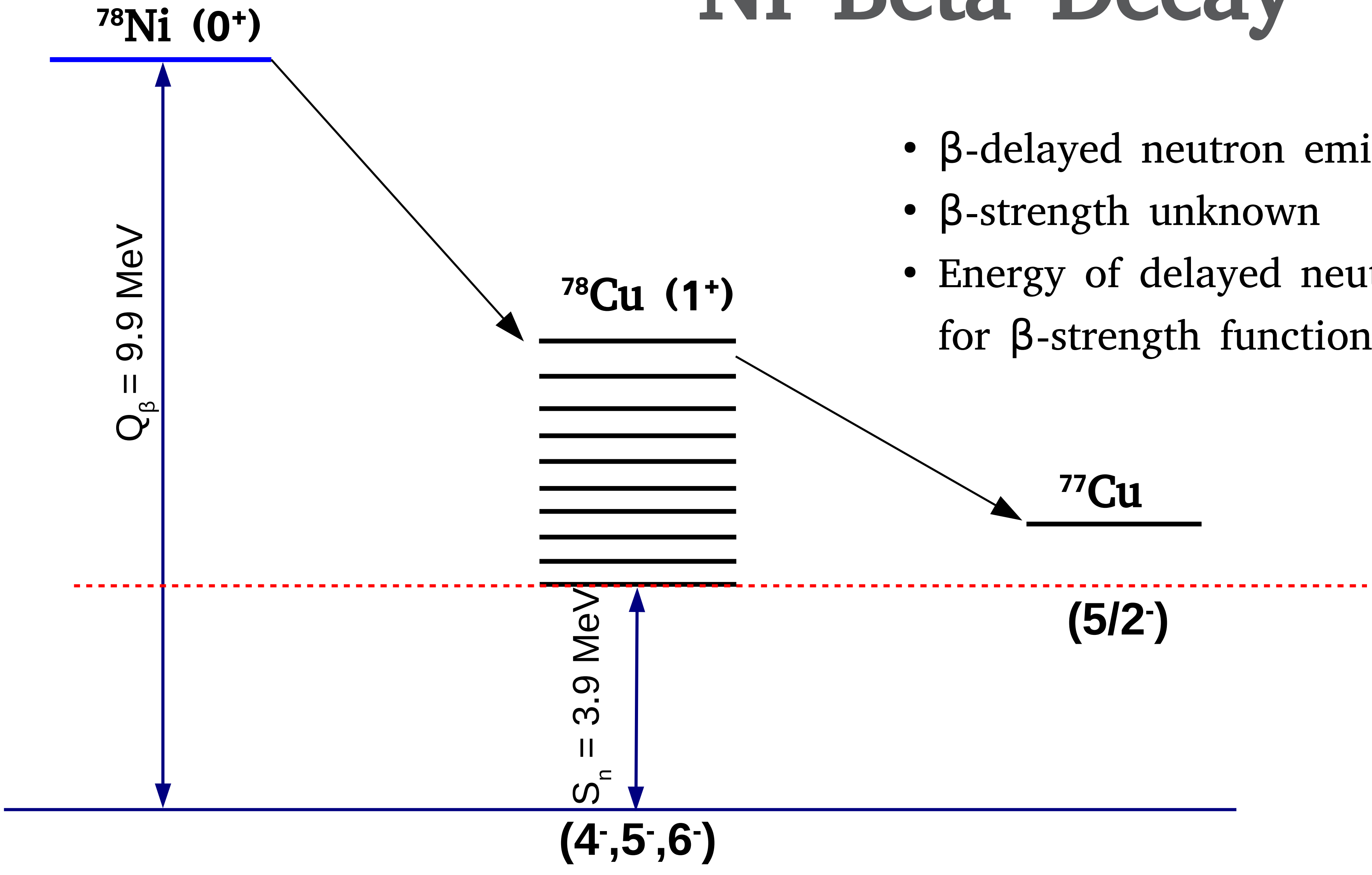




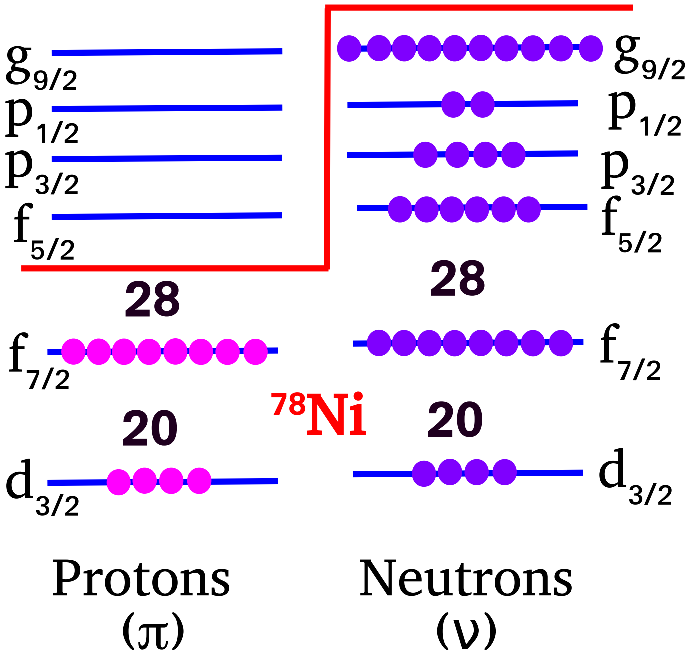
- Highly ***excited 2+ state*** in ^{78}Ni at 2.6 MeV
- Radioactive nucleus with ***Z=28 and N=50*** shell closure
- Rare example of doubly-magic shell ***far-off stability***

Figures: R. Taniuchi *et al.*, 2019

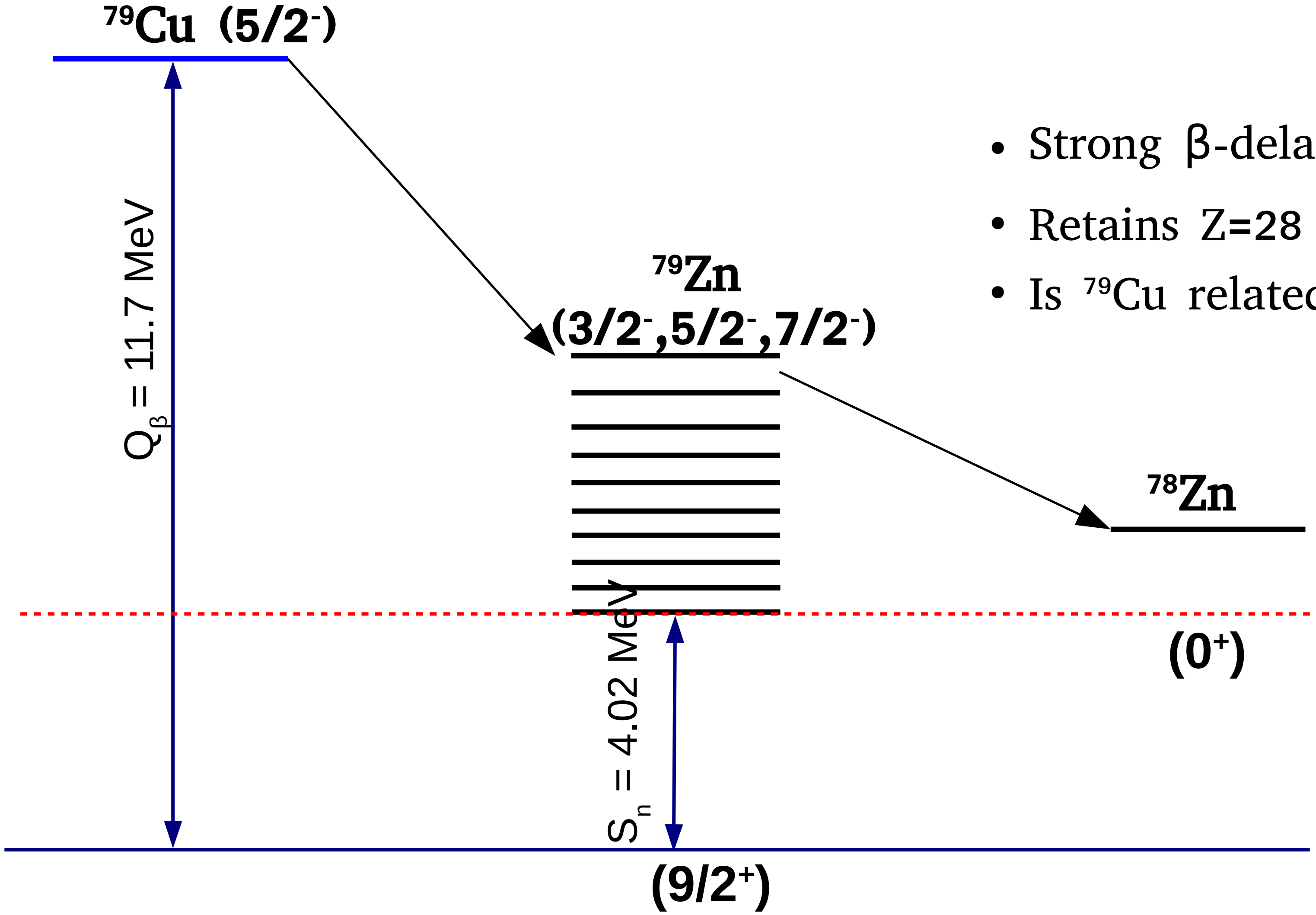
^{78}Ni Beta Decay



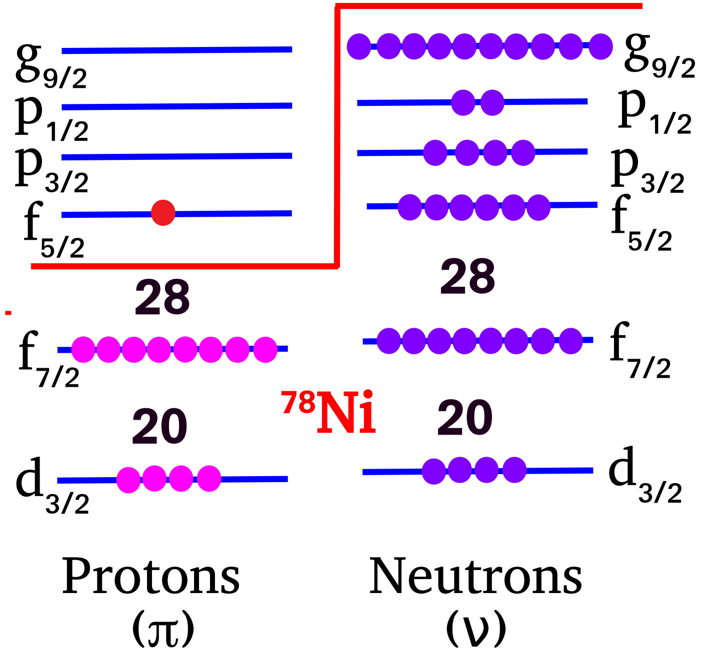
- β-delayed neutron emitter
- β-strength unknown
- Energy of delayed neutrons important for β-strength function determination



^{79}Cu (^{78}Ni + 1p) Beta Decay

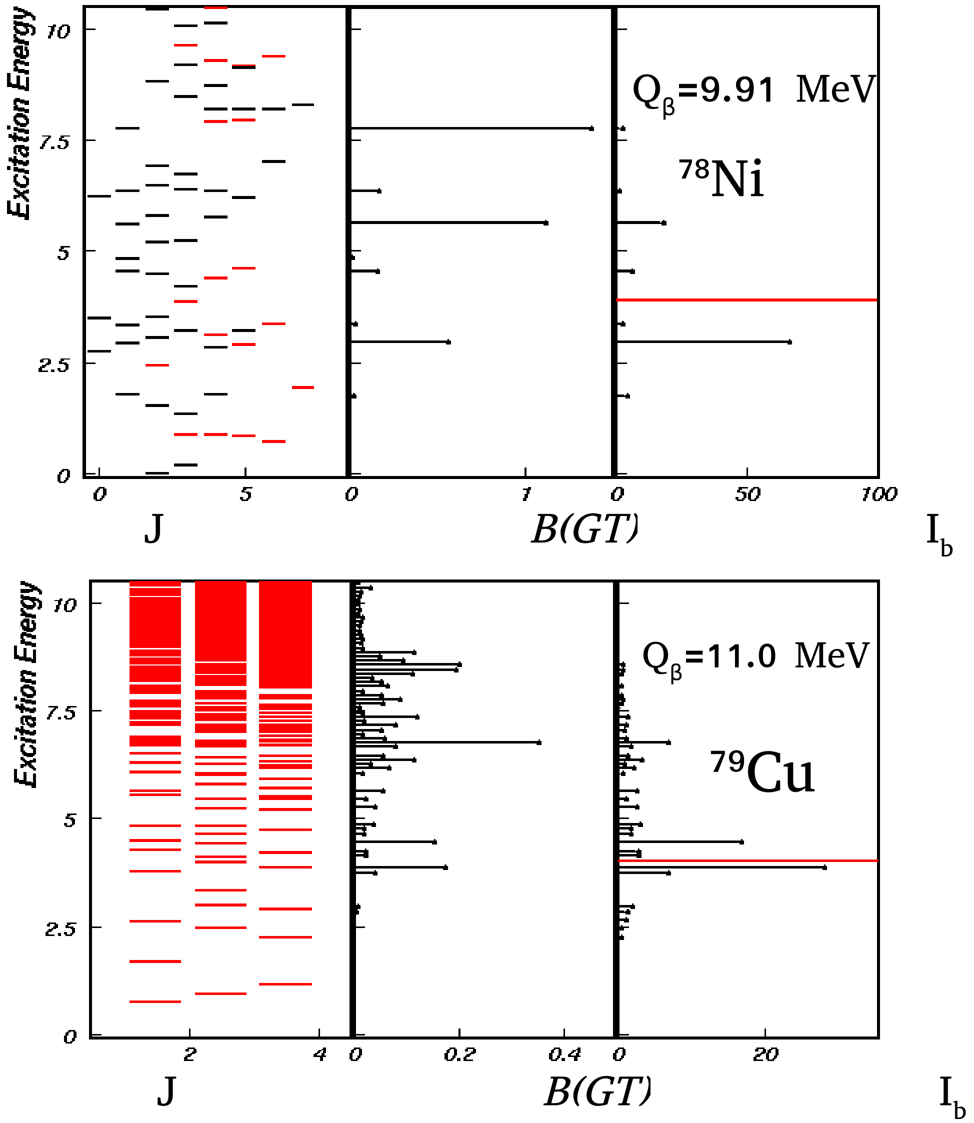


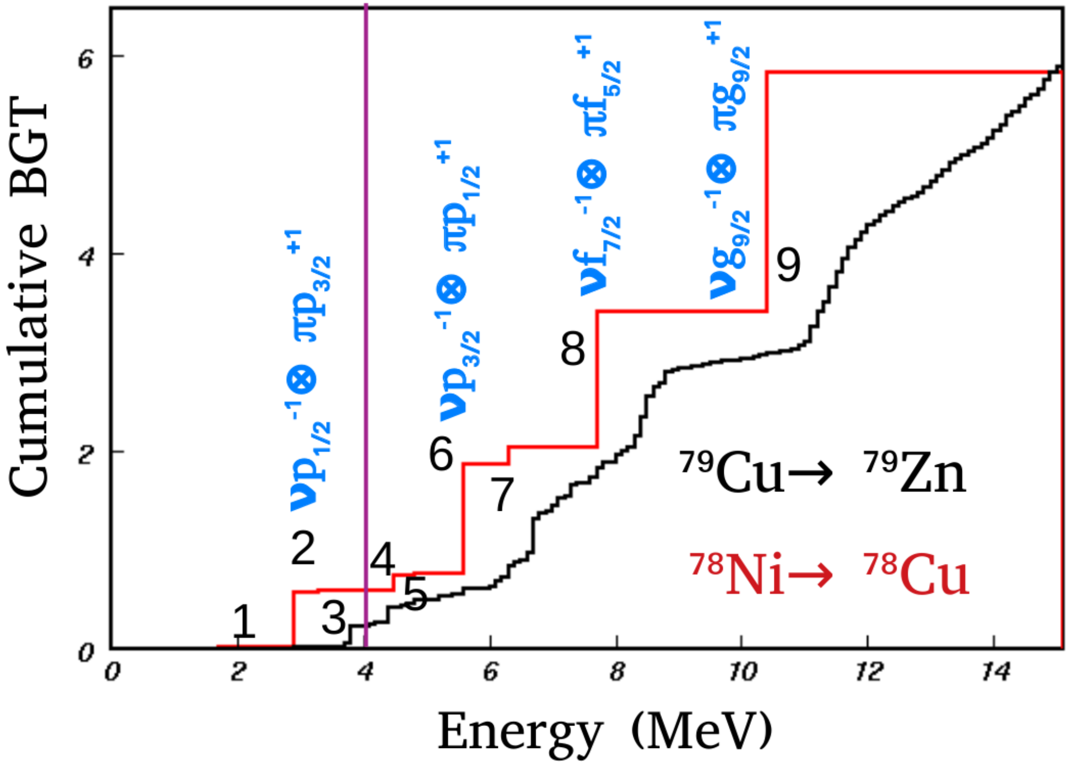
- Strong β-delayed neutron emitter (P_n~70%)
- Retains Z=28 shell gap
- Is ^{79}Cu related to ^{78}Ni decay?



P. Hosmer *et al.*, 2010, L. Olivier *et al.*, 2017

^{78}Ni / ^{79}Cu



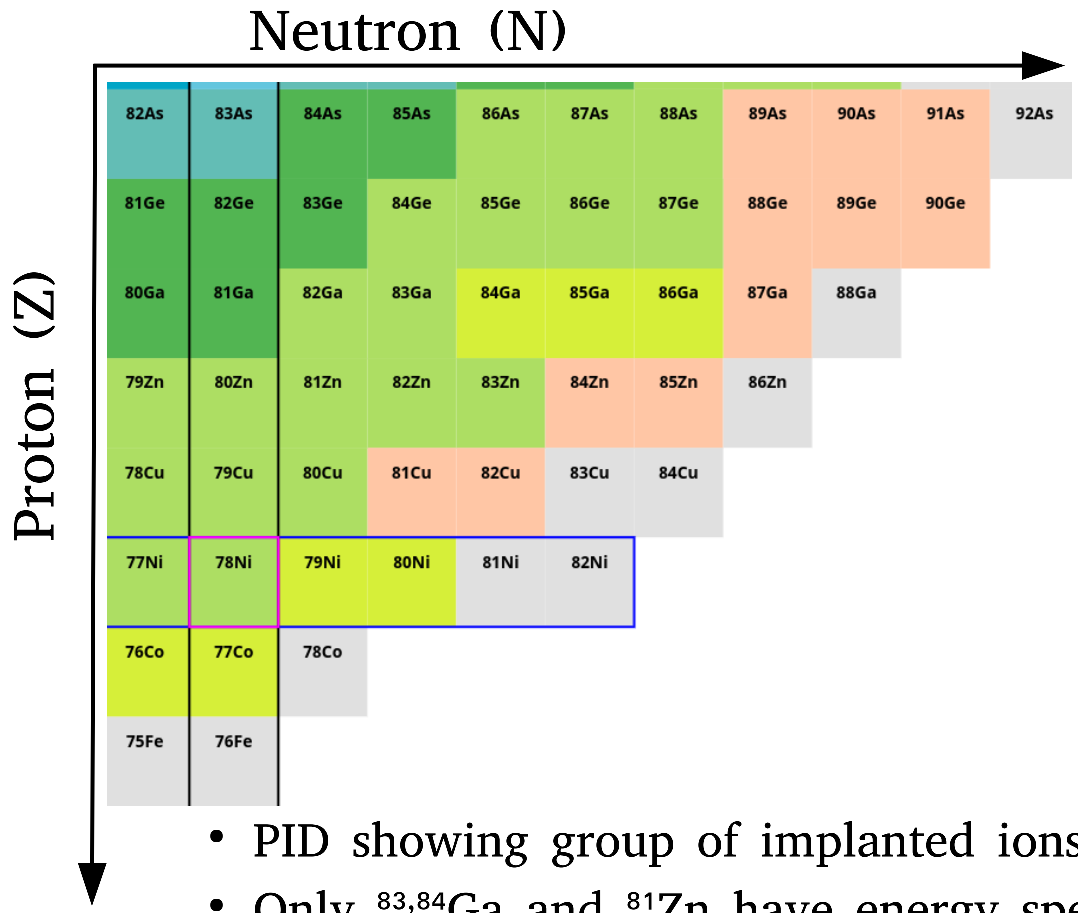


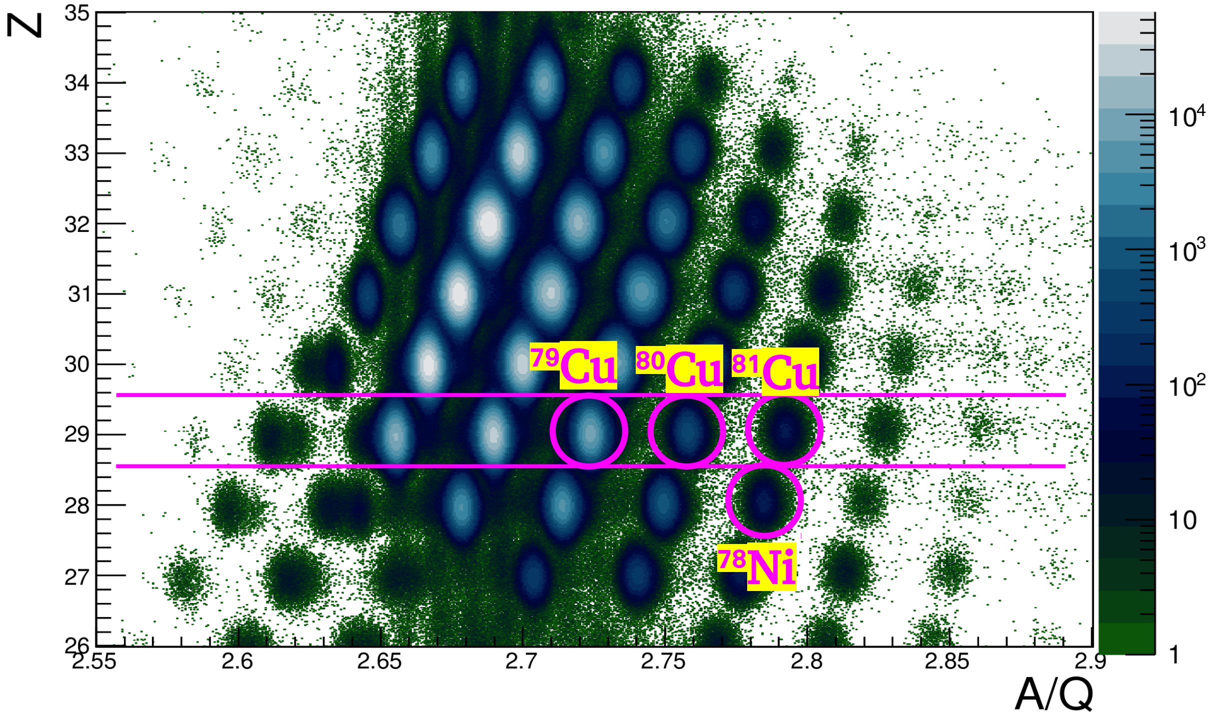
fpgpn interaction and ^{40}Ca core

Measurement of neutron energy crucial to establish the beta-strength above S_n

A. Spyrou *et al.*, 2016, NuShellX, W.D.M. Rae, http://www.garsington.eclipse.co.uk

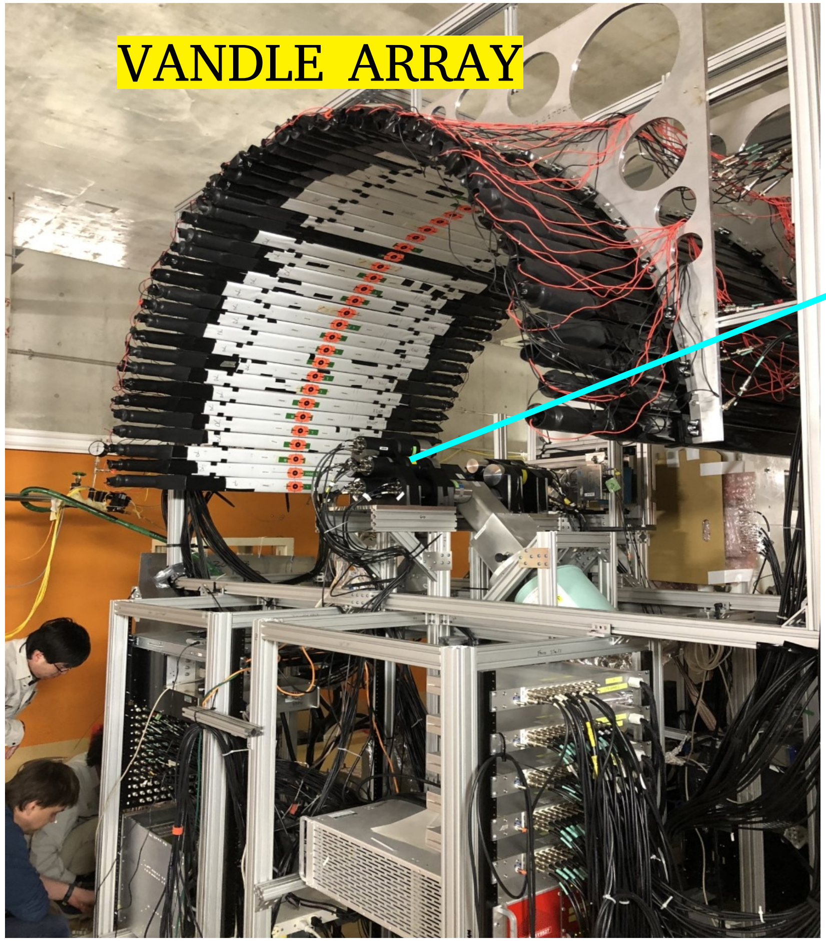
Experiment at Radioactive Ion Beam Factory

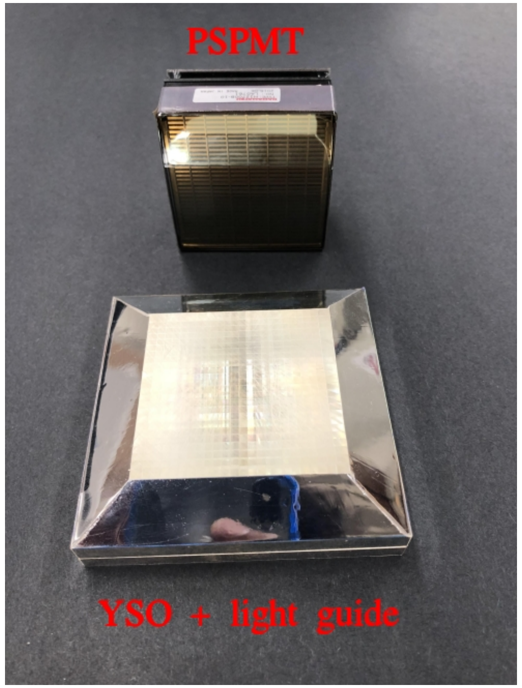


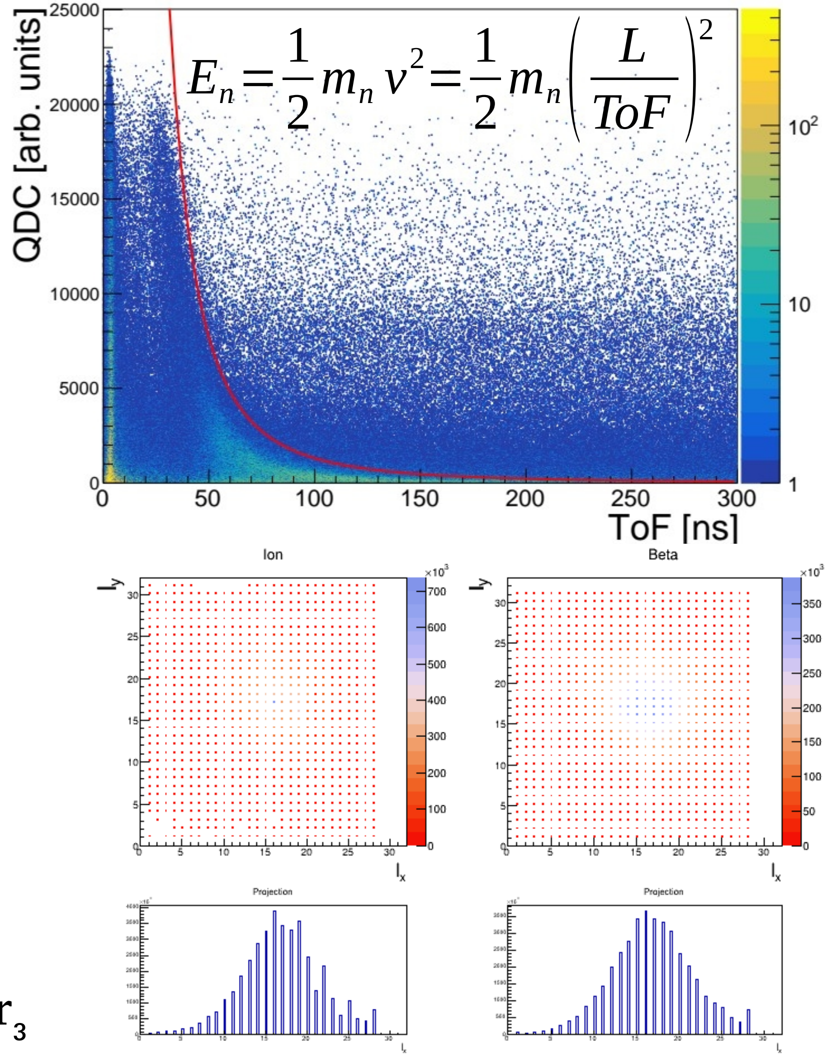


- PID showing group of implanted ions: Fe, Co, Ni, Cu, Co, Zn, Ga, Ge, As, and Se
- Only ^{83,84}Ga and ^{81}Zn have energy spectra of delayed neutrons previously measured

Neutron Spectroscopy using VANDLE



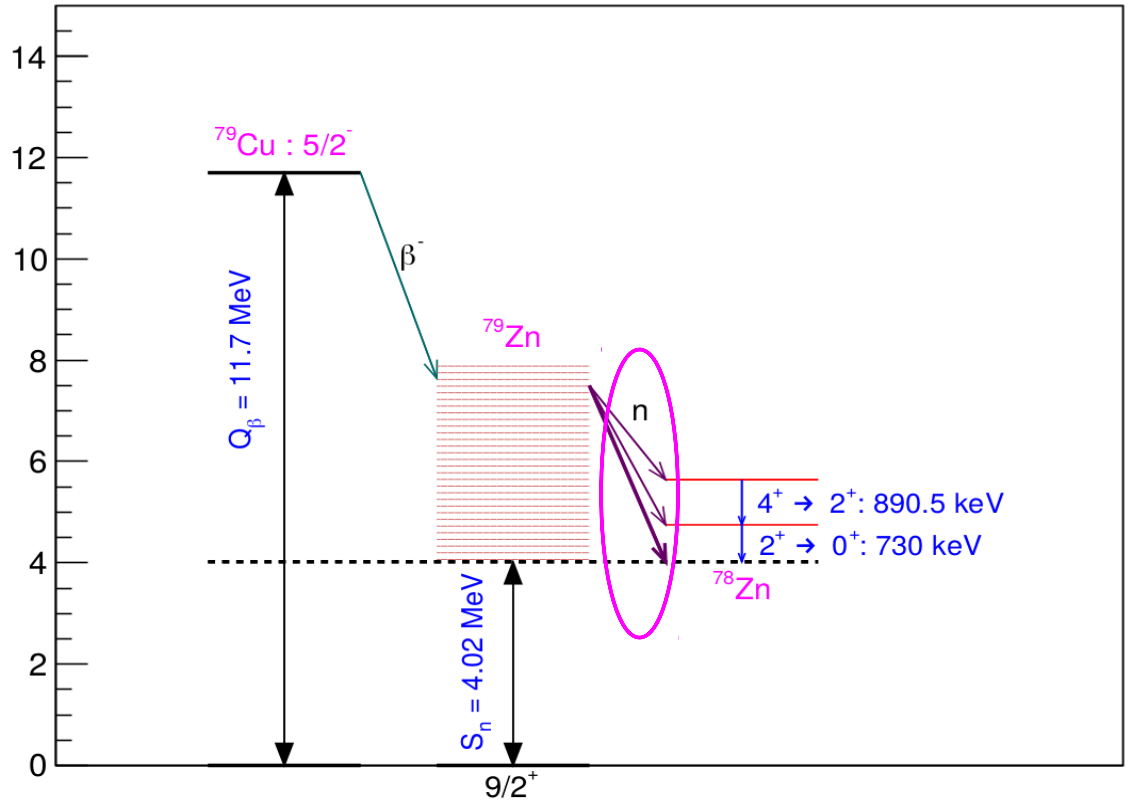


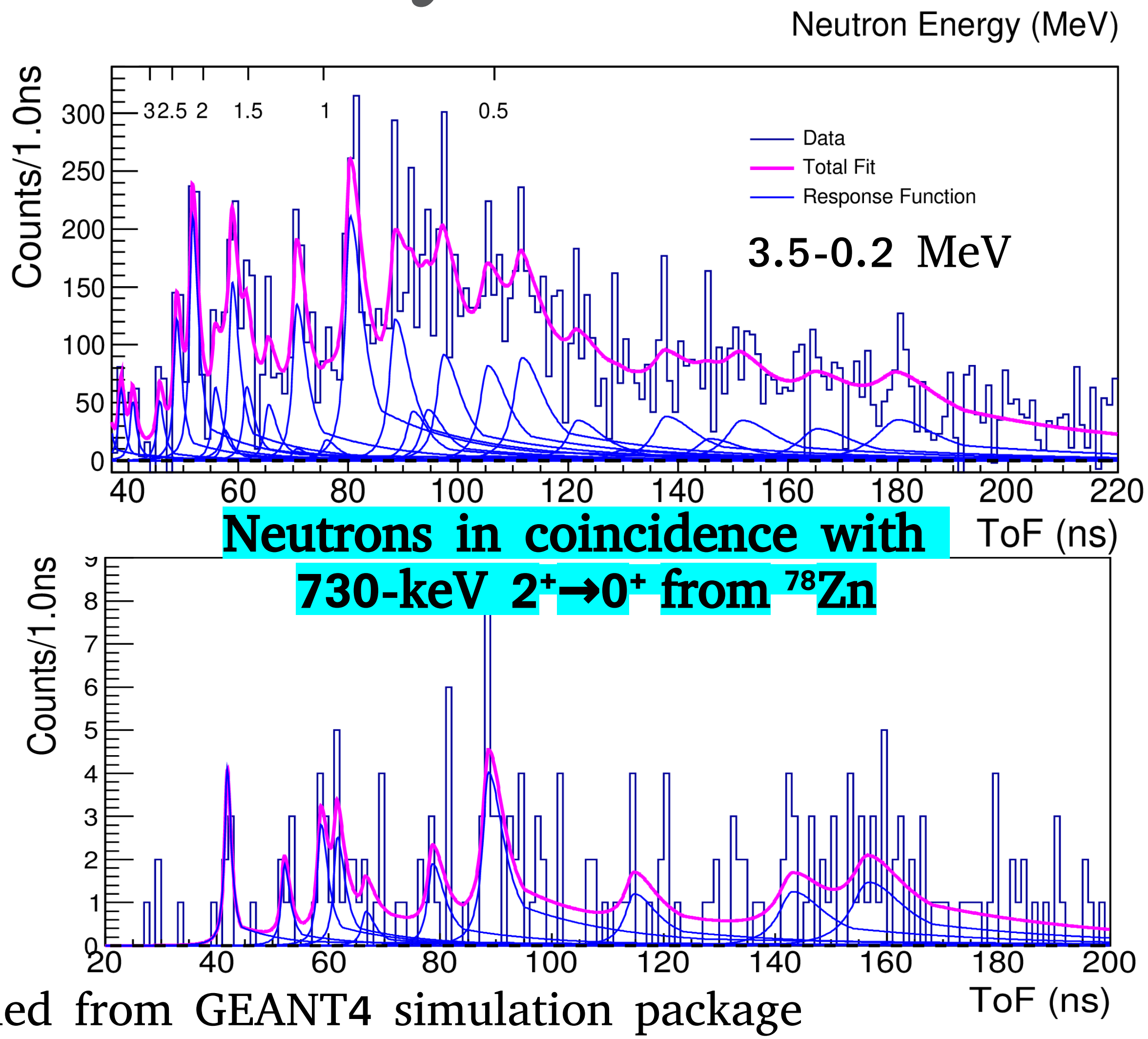


- Pixie-16 with custom triggering scheme
- 48 VANDLE Bars
- 2 high-purity germanium clovers
- 10 3'' x 3'' and 2 2'' x 2'' $LaBr_3$

VANDLE: W.A. Peters *et al.*, 2016
YSO: M. Singh *et al.* (to be submitted), R. Yokoyama *et al.*, 2019

^{79}Cu (N=50) Decay

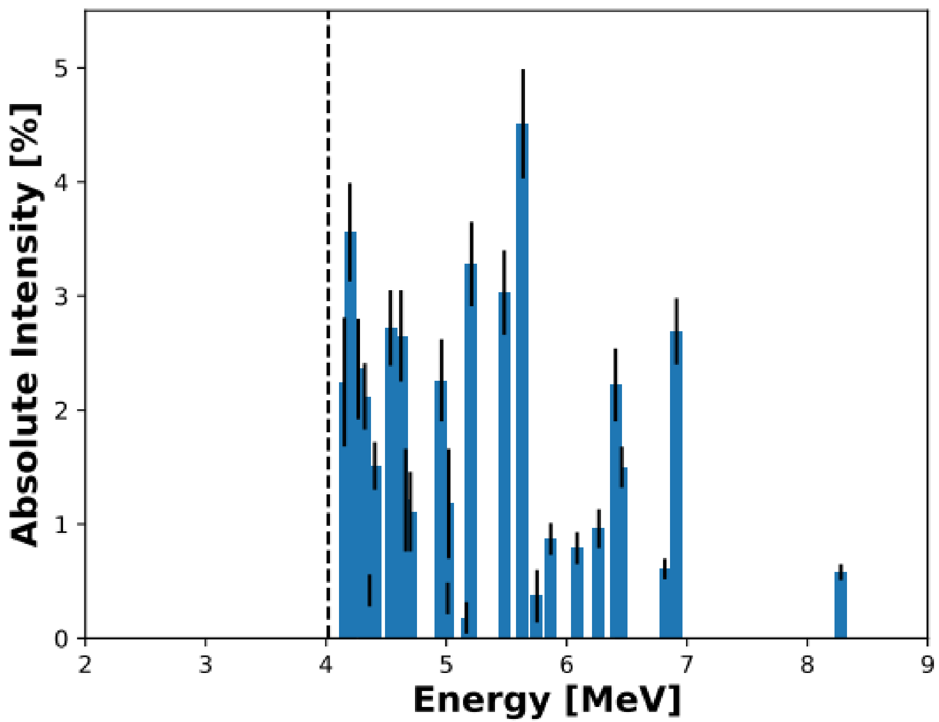


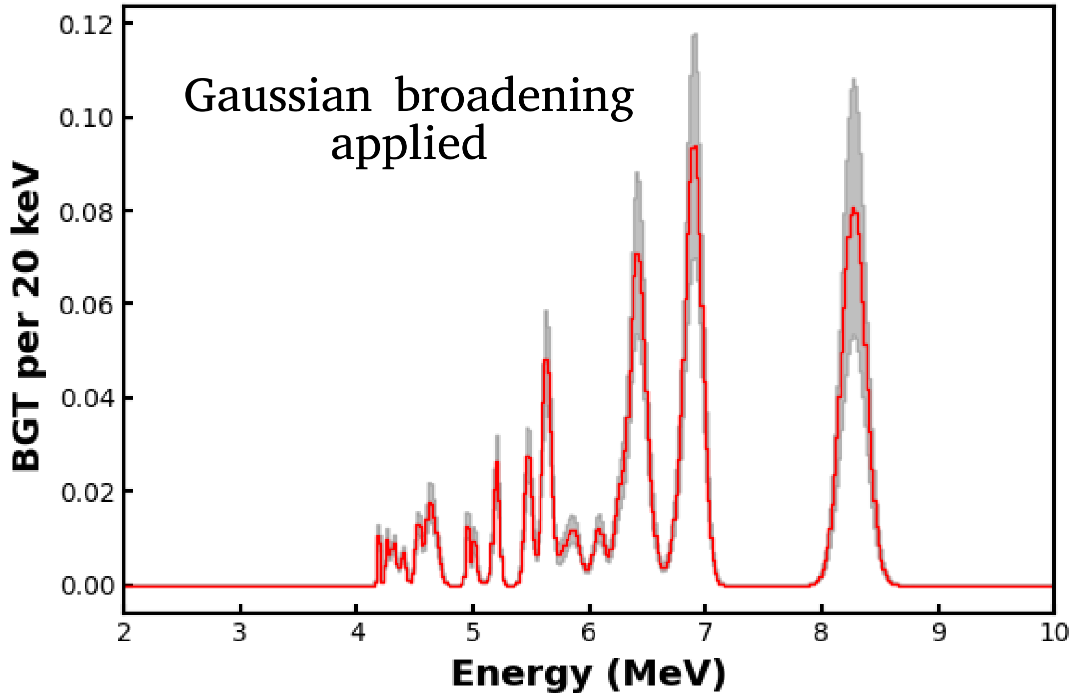


ToF spectrum fitted using response obtained from GEANT4 simulation package called NEXTSim, captures neutron scattering!

^{79}Cu decay scheme: A. Korgul *et al.*, 2012

Neutron Intensity and Beta-strength



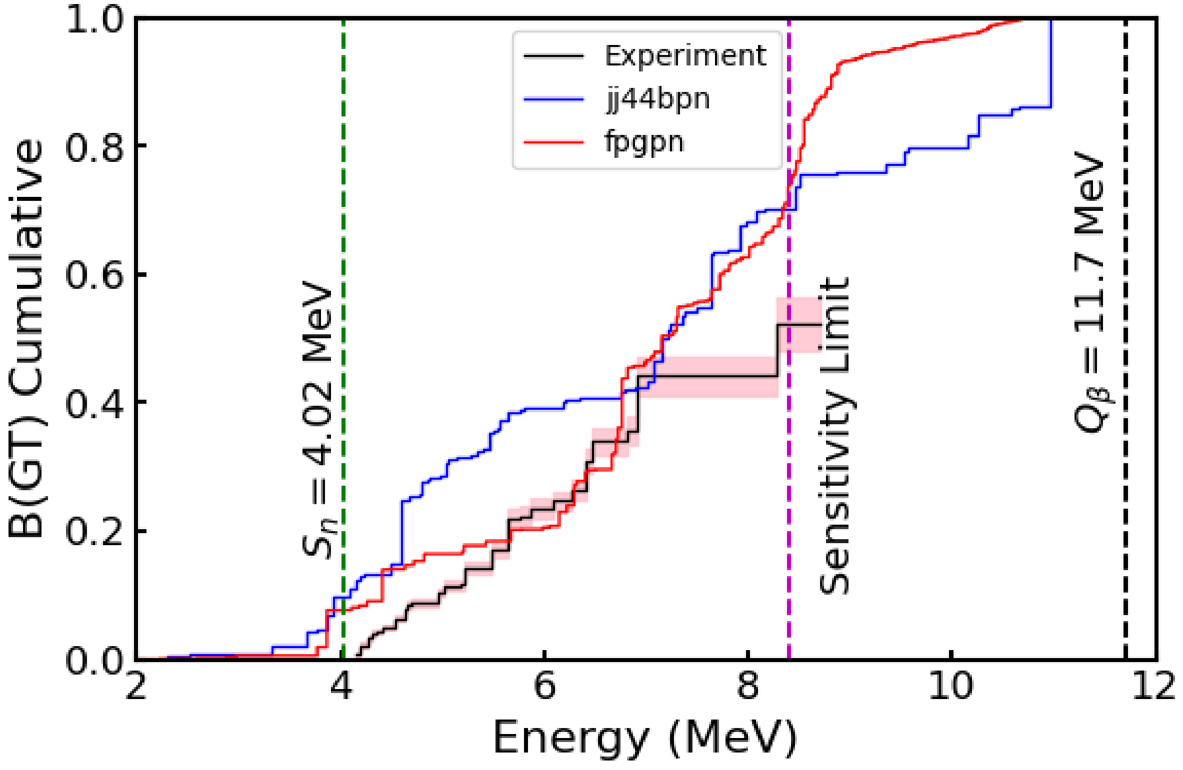


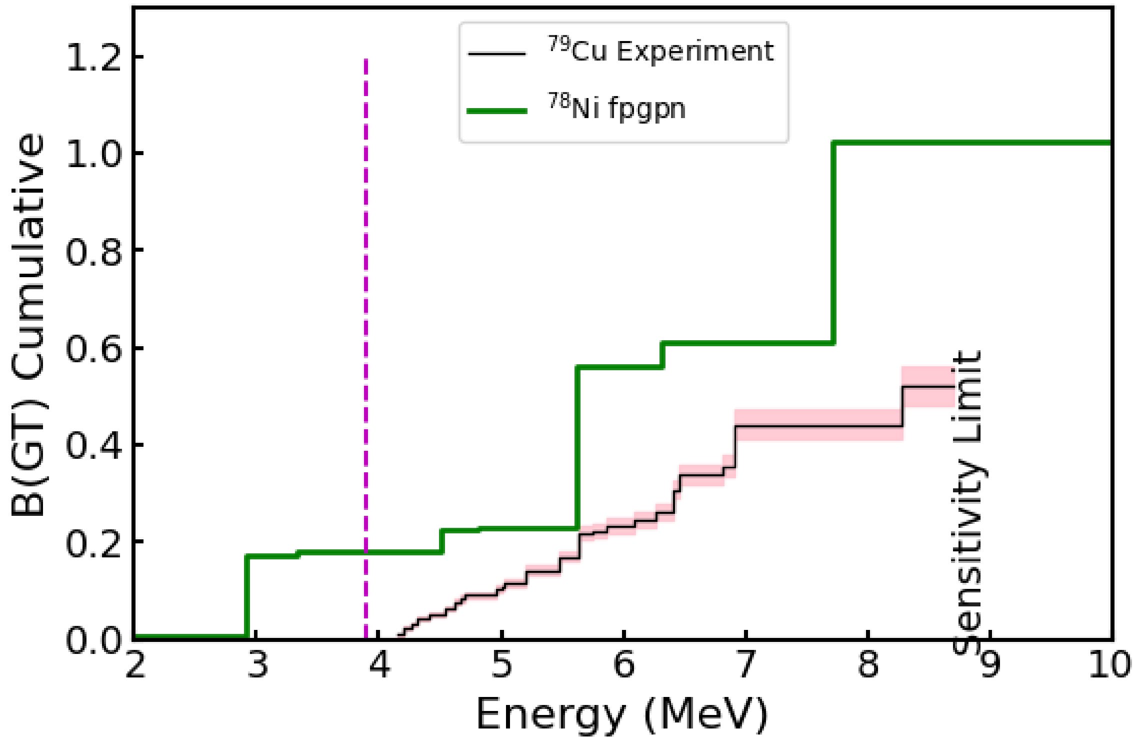
$$I(E_x) = \frac{\text{Efficiency-corrected neutron counts}}{\text{Number of correlated betas}}$$

$$BGT \propto S_\beta(E_x) = \frac{I(E_x)}{f(Z, Q_\beta - E_x) T_{1/2}}$$

Neutrons in coincidence with gammas used to adjust the branching ratios and strength distribution

^{79}Cu Beta-decay Strength

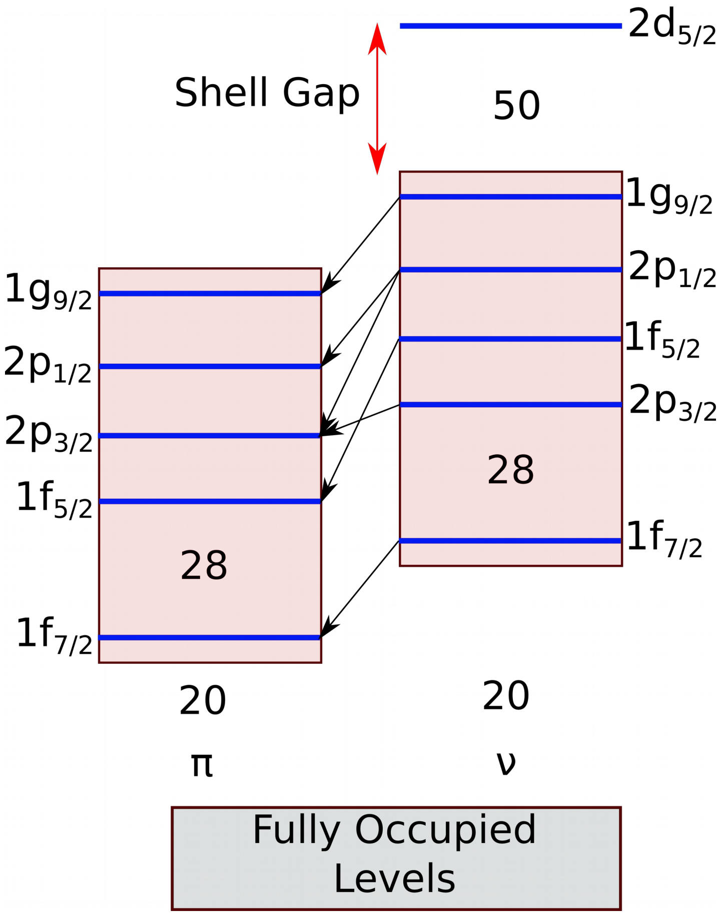


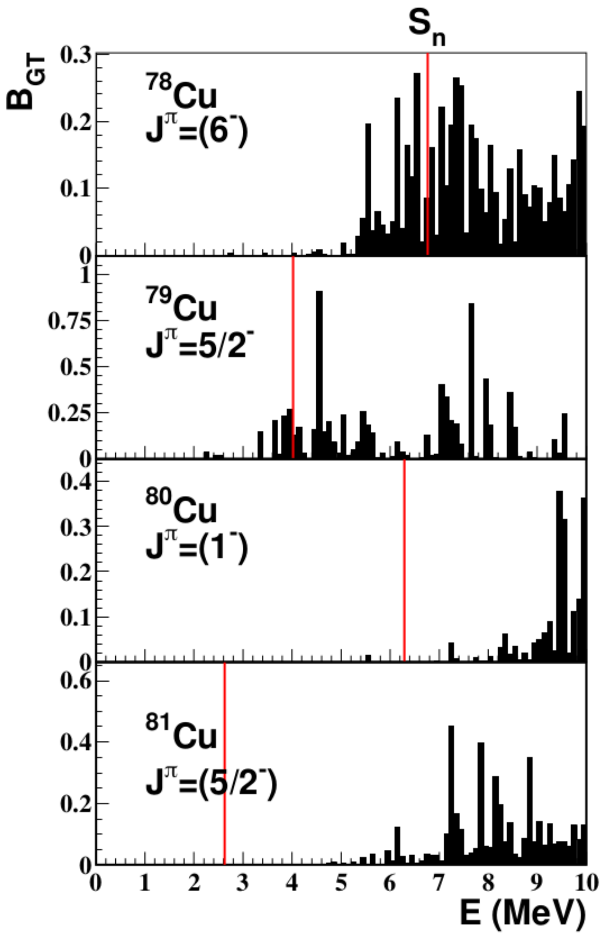


The experimental data agree with the *fpgpn* prediction with 5 MeV proton shell gap

A. Spyrou *et al.*, 2016, A. F. Lisetskiy *et al.*, 2004
NuShellX, W.D.M. Rae, http://www.garsington.eclipse.co.uk.

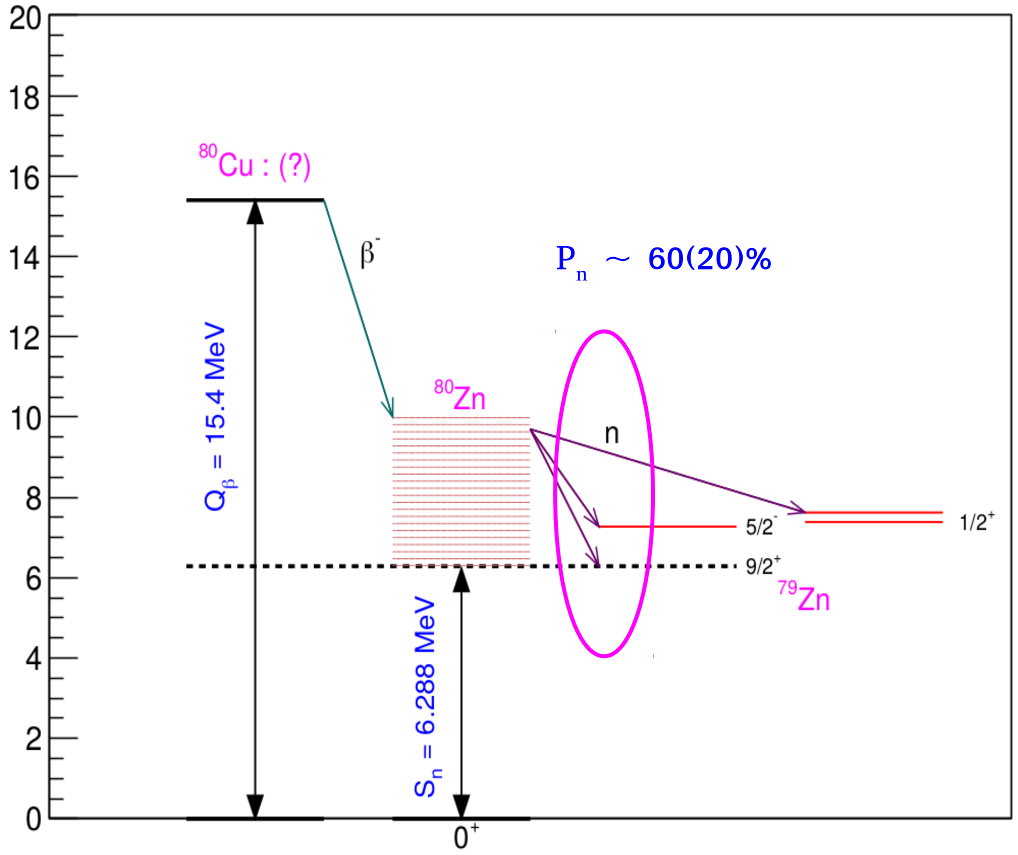
Beta decay beyond N=50

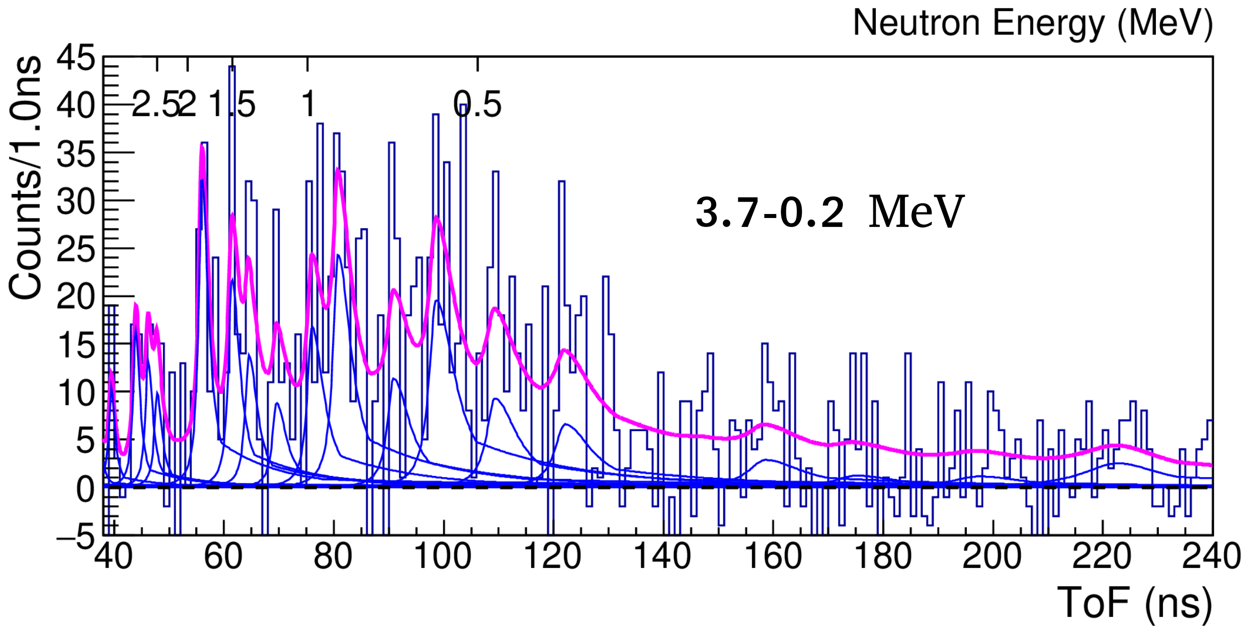




Allowed Gamow-Teller transitions transform neutron states below the **N=50** shell gap to proton spin-orbit partners above the **Z=28** gap

^{80}Cu（N=51）Decay



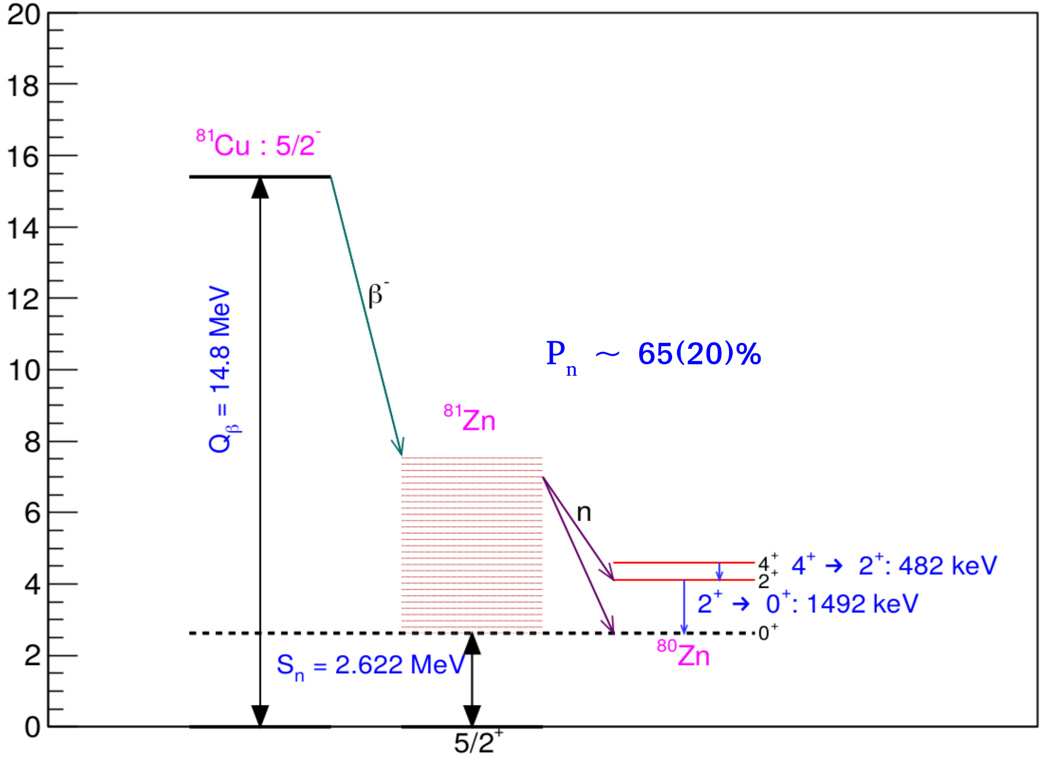


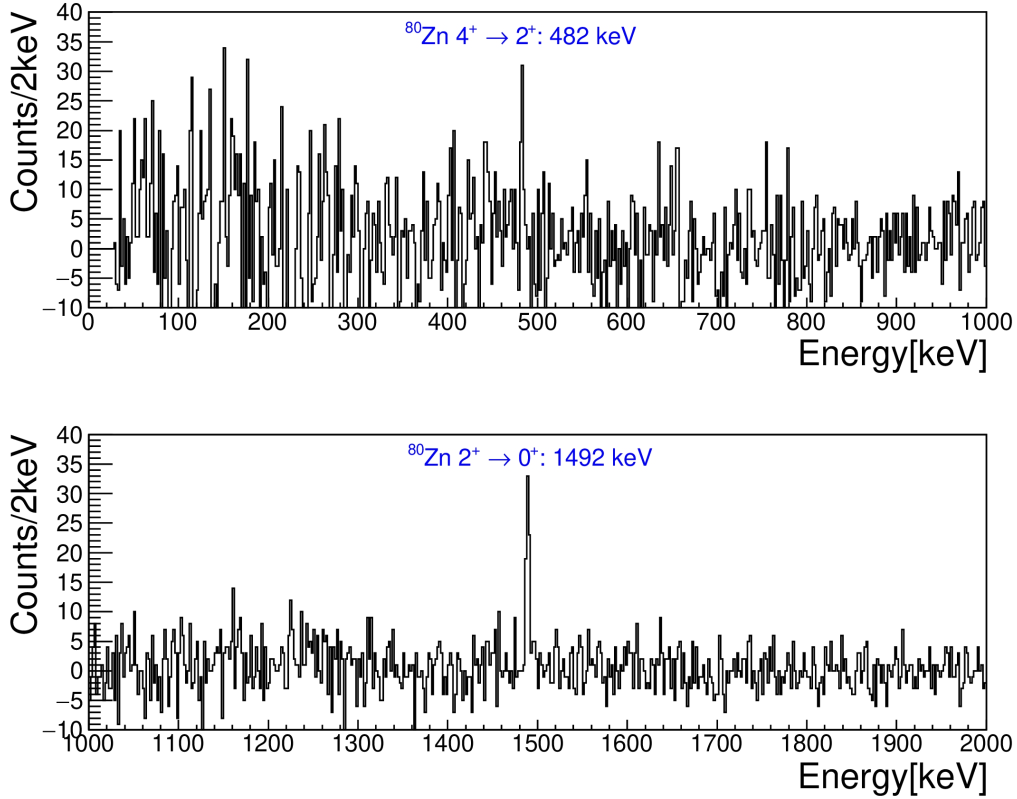
- Neutron emitting states identified in ^{80}Zn
- Neutron-gamma coincidences remain unidentified

P_n: Xu *et al.*, 2014

THE UNIVERSITY OF TENNESSEE KNOXVILLE

^{81}Cu (N=52) Decay

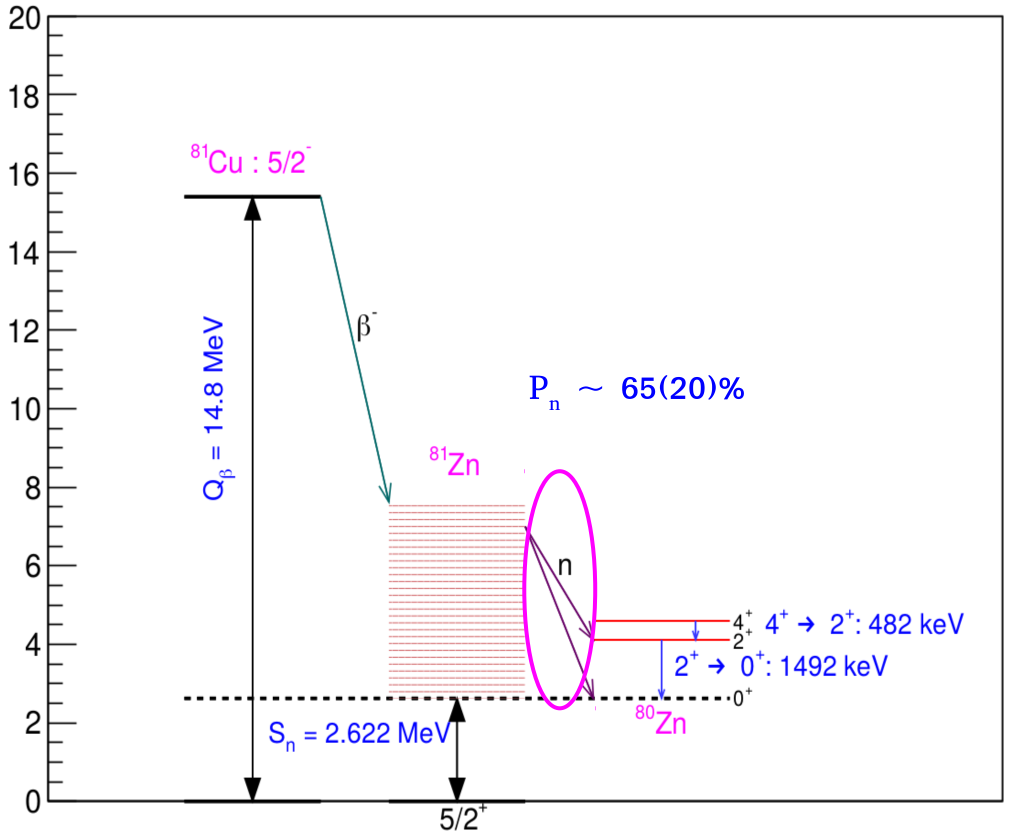


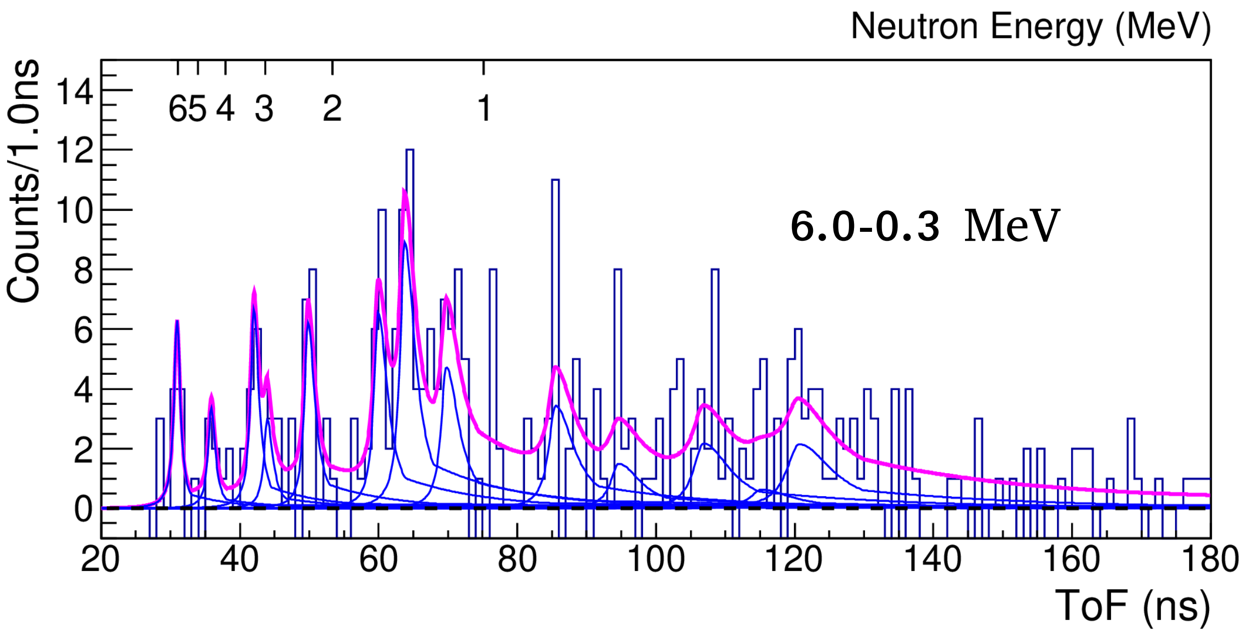


- Branching ratios: 482-keV, 9.4(3.8)% and 1492-keV, 26.7(4.8)%
- Presence of 1492- and 482-keV transitions → strong population of 2$^+$ and 4$^+$ excited state in N=50 ^{80}Zn by neutrons

P_n: Xu *et al.*, 2014
Gamma Lines in ^{80}Zn verified with J. Van de Walle *et al.*, 2009 and Y. Shiga, *et al.*, 2016

^{81}Cu (N=52) Decay

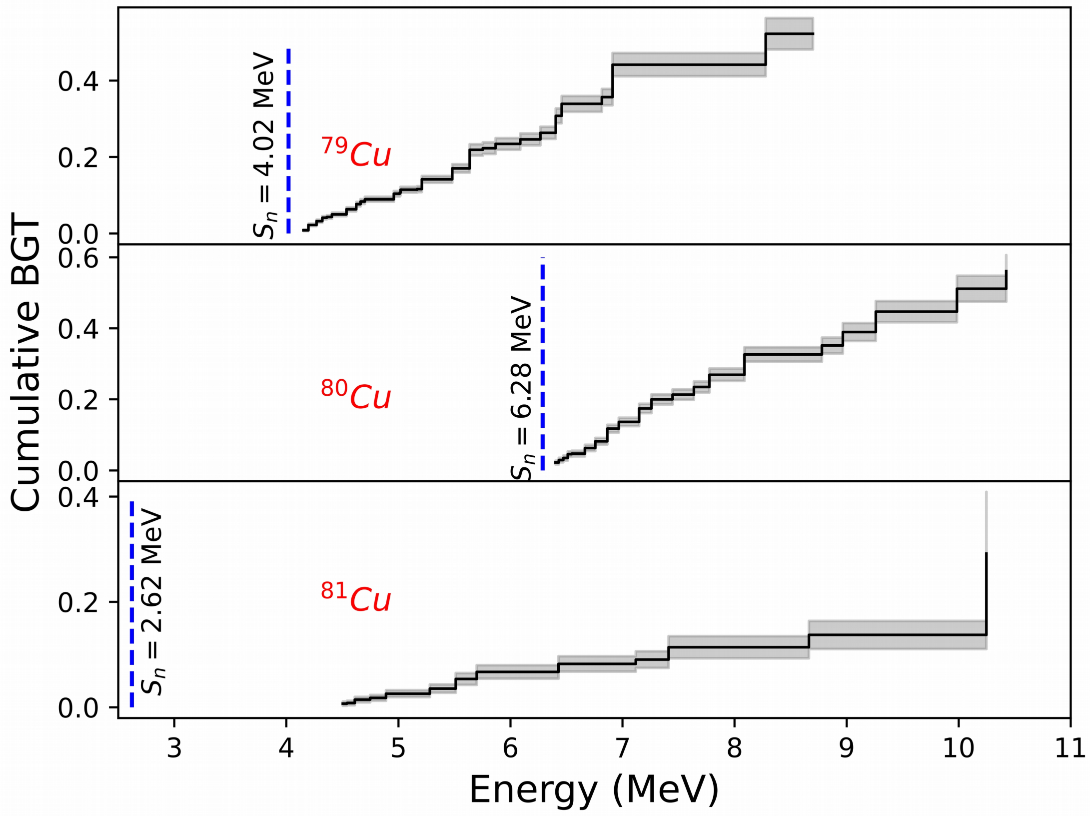


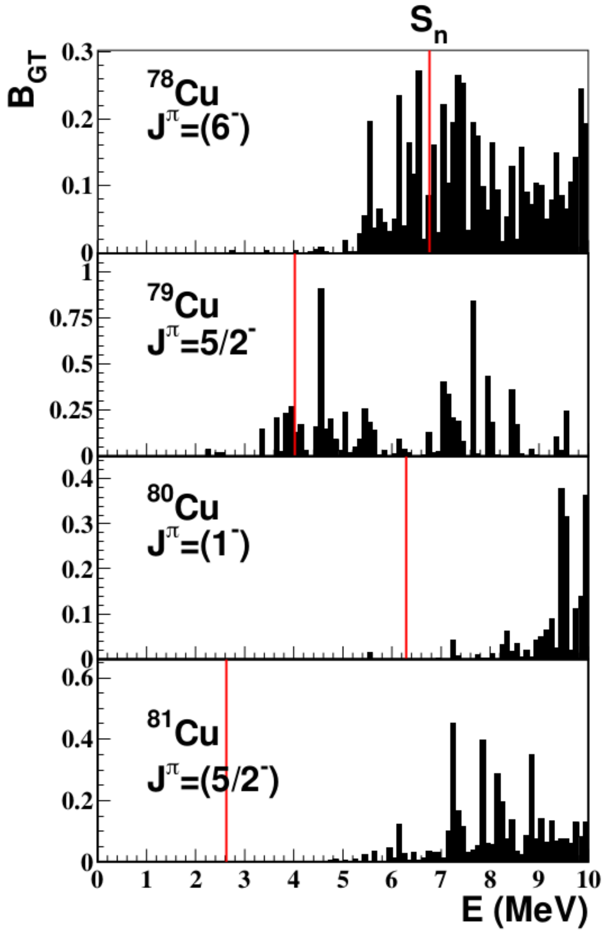


- Neutron-unbound states identified in ^{81}Zn
- Neutron-gamma coincidences remain unidentified

P_n: Xu *et al.*, 2014
Gamma Lines in ^{80}Zn verified with J. Van de Walle *et al.*, 2009 and Y. Shiga, *et al.*, 2016

Beta-decay Strength for N>50





Beta-decay strength shifted to higher excitation energy when crossing N=50 shell gap

Concluding Remarks

- Beta-delayed neutron emission is the dominant decay mode for investigated nuclei $^{79\text{-}81}$Cu
- Neutron energy measurement needed to establish the beta-strength distribution
- Experiment performed using VANDLE and YSO implant detector in ^{78}Ni region ($26 \leq Z \leq 34$)
- Neutron-emitting states identified in the β-decay of $^{79\text{-}81}$Cu
- Shell model predictions of B(GT) agree with the data for ^{79}Cu using *fpgpn* interaction
- Population 2^+ and 4^+ in ^{80}Zn by neutrons observed in the decay of ^{81}Cu
- Hauser-Feshbach statistical model predicts the sharing of neutron energy with gamma rays in the decay of ^{81}Cu
- **Decay-strength distributions shifted to higher excitation energy when crossing N=50 shell gap!**

Collaborators

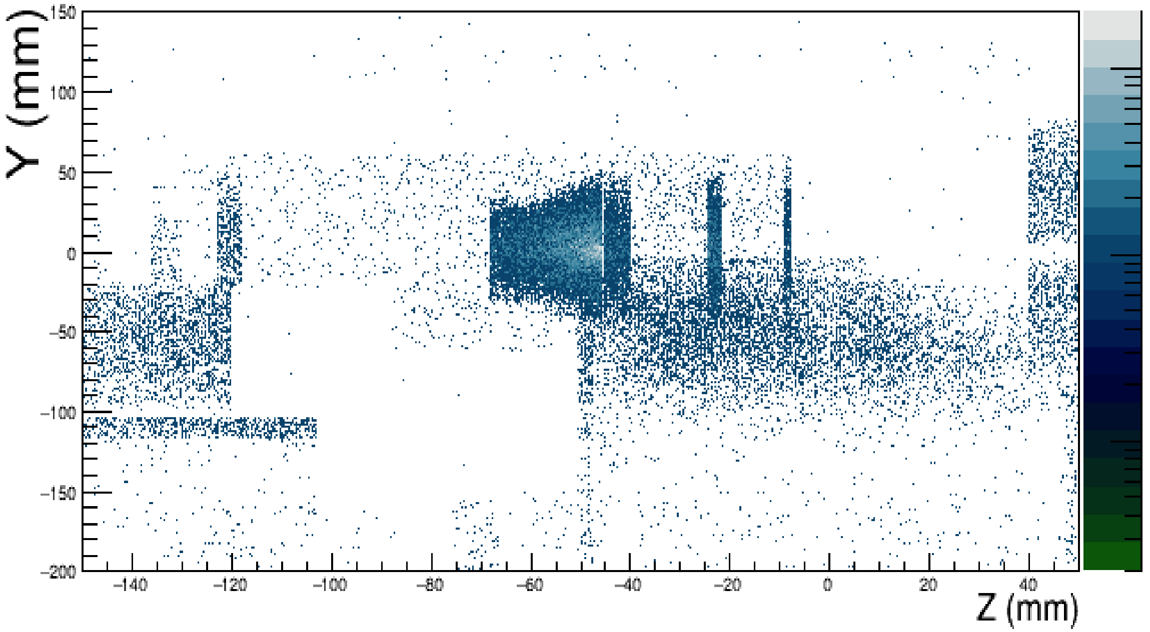
M. Singh[1], R. Yokoyama[2], R. K. Grzywacz[1,2], T. King[2], S. Nishimura[3], P. Brionnet[3], I. Cox[1], A. Fijalkowska[4], L M. Fraile[5], S. Go[6], A. Gottardo[7], M. Karny[4], A. Keeler[1], A. Korgul[4], M. Madurga[1], K. Miernik[4], S. Neupane[1], M. Niikura[8], M. Pfutzner[4], M. Piersa[4], M. Rajabali[9], B.C. Rasco[2], K.P.Rykaczewski[2], M. Silkowski[4], M. Stepaniuk[4], J.L. Tain[10], A. Delgado[10], Z. Xu[1], and M.W. Wolinska-Chichocka[4]

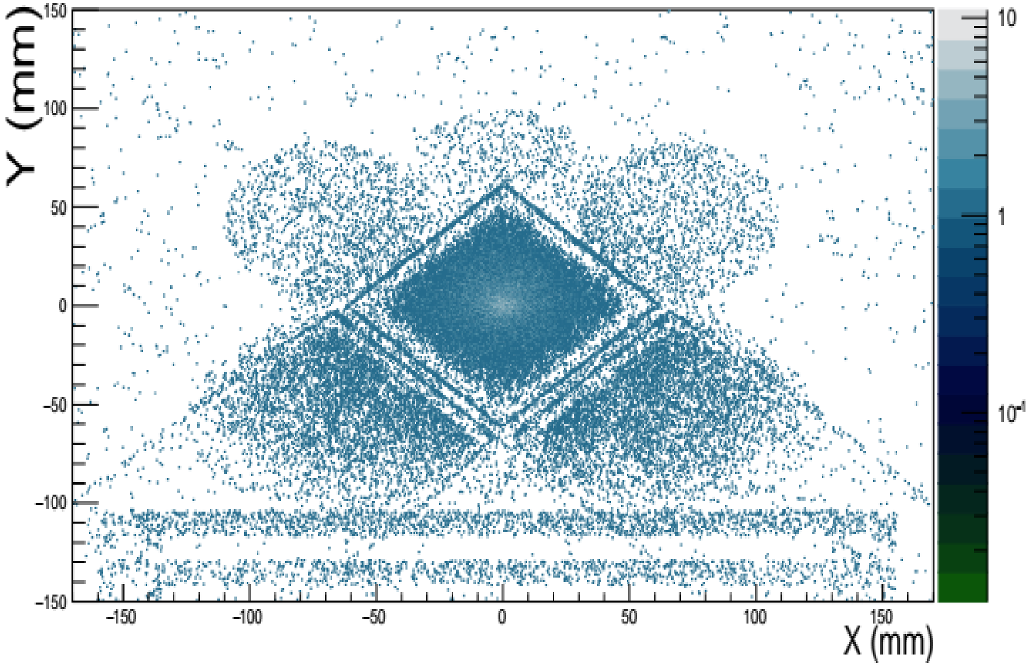
[1] Dept. of Physics and Astronomy, University of Tennessee
[2] Oak Ridge National Laboratory
[3] RIKEN Nishina Center
[4] University of Warsaw
[5] Complutense University of Madrid
[6] Kyushu University
[7] INFN-LNL
[8] University of Tokyo
[9] Tennessee Tech University
[10] Instituto de Fí sica Corpuscular

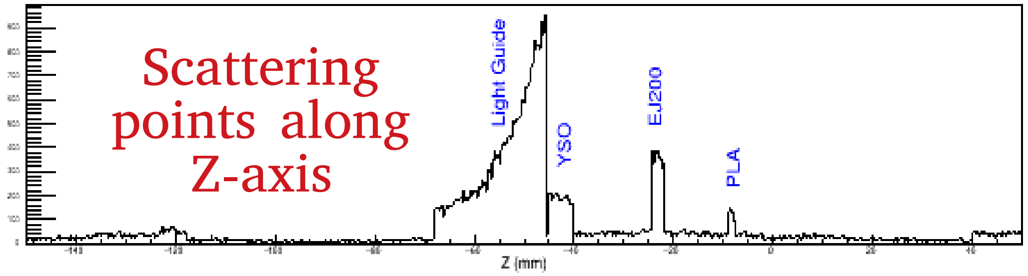
Thank You!!

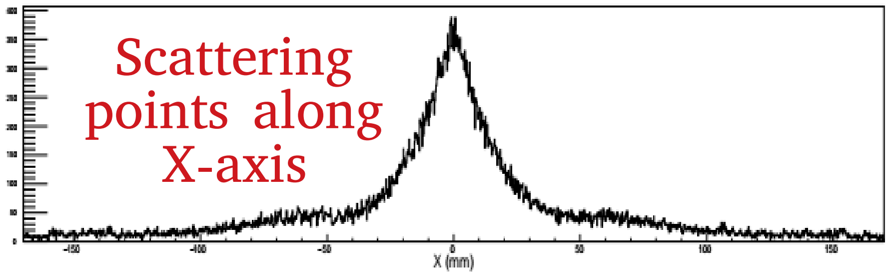
This research was sponsored in part by the Office of Nuclear Physics, U.S. Department of Energy under Award No. DE-FG02-96ER40983 (UTK)and DE-AC05-00OR22725 (ORNL), and by the National Nuclear Security Administration under the Stewardship Science Academic Alliances program through DOE Award No. DE-NA000213

Neutron Scattering Effects

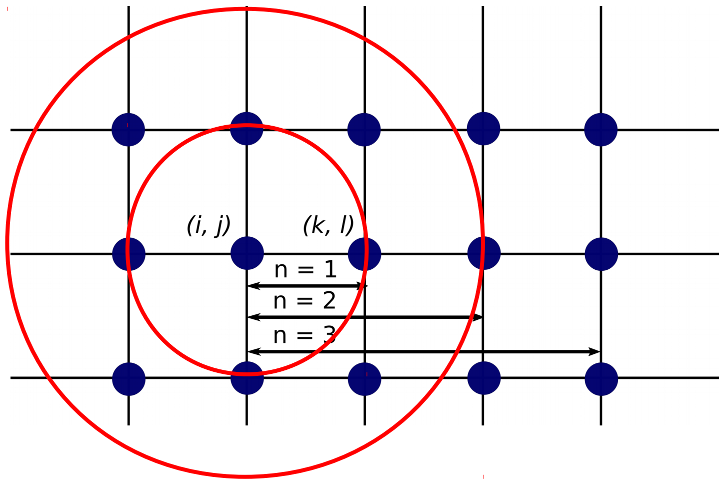




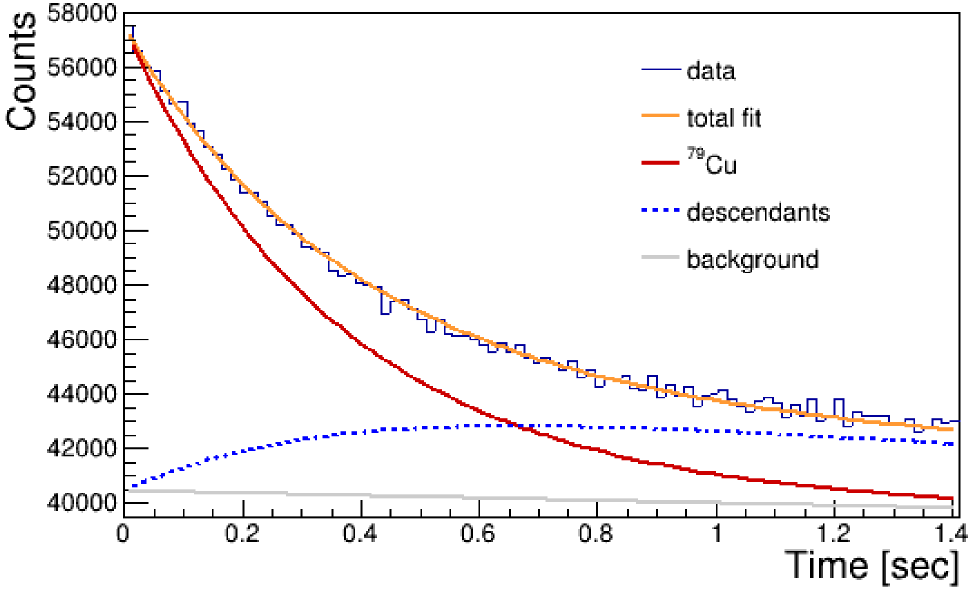


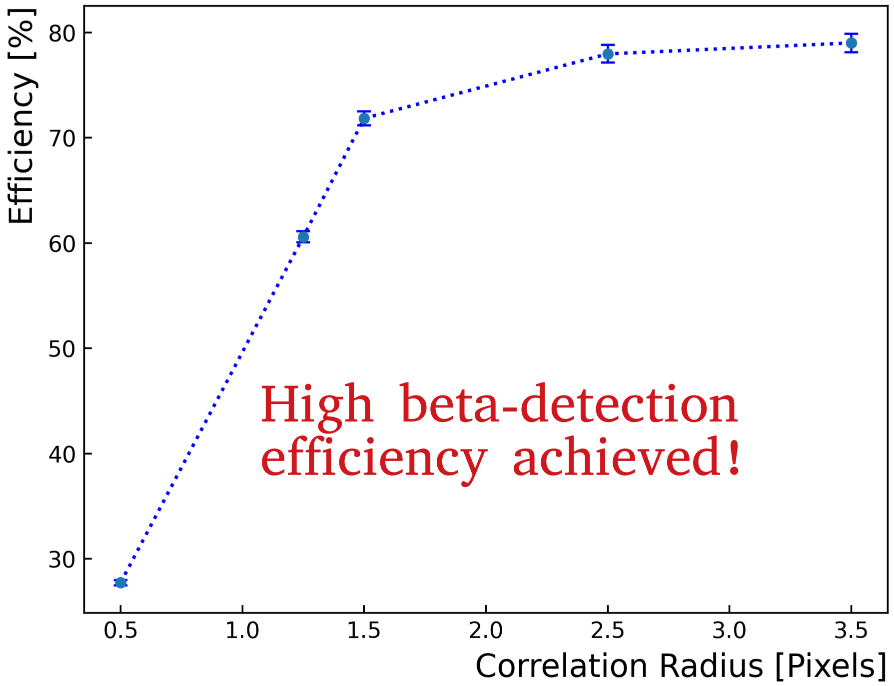


Ion-Beta Correlation using YSO



$$\sqrt{\left(I_{\beta,i}-I_{ion,k}\right)^2+\left(I_{\beta,j}-I_{ion,l}\right)^2}\leq n$$





M. Singh *et al.* (to be submitted) & R. Yokoyama *et al.*, 2019

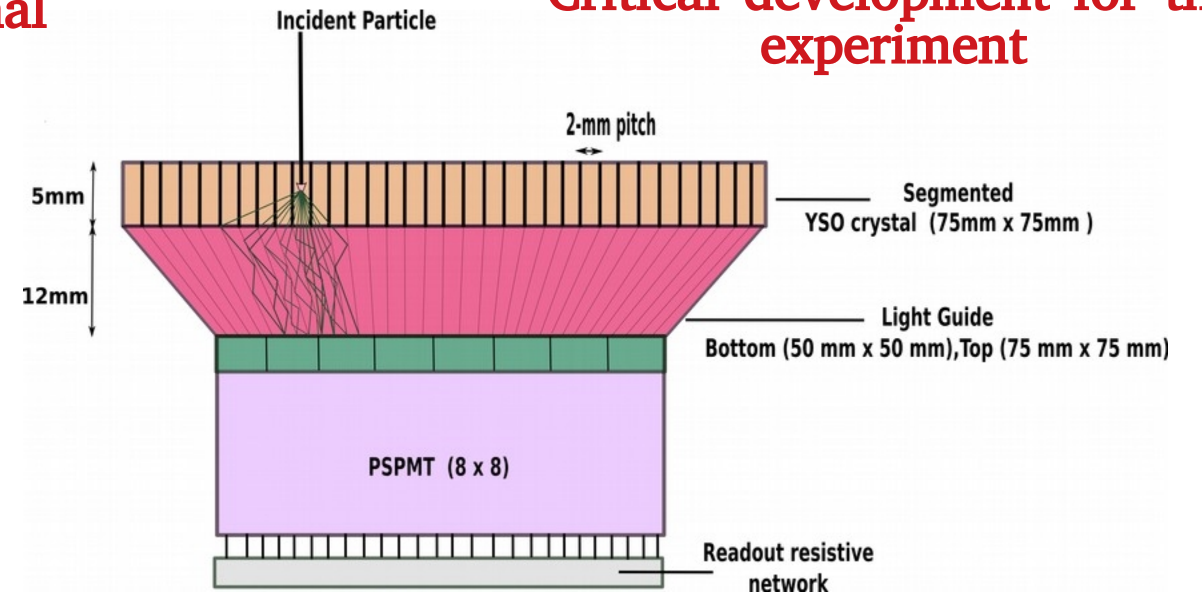
YSO Implant Detector

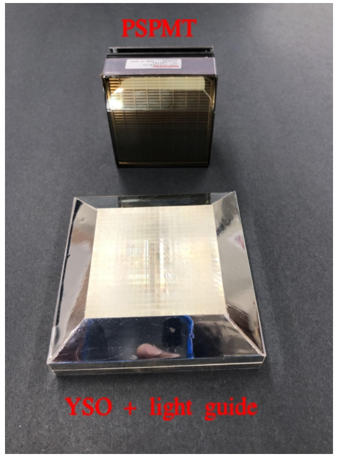
Properties

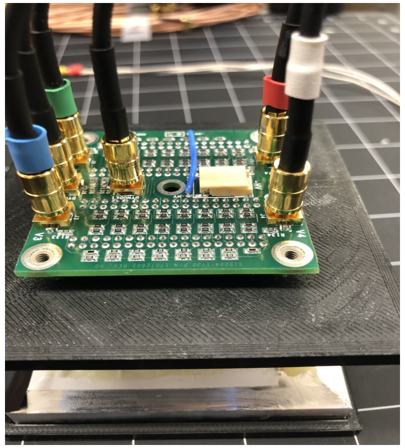
- Y_2SiO_5 (Ce)
- High stopping power (Z_{eff} = 35 & ρ = 4.5 g/cm³)
- High beta-detection efficiency
- Decay time of 50-70 ns
- Provides sub-nanosecond timing resolution

Cannot use conventional SiDSSD for nToF

Critical development for the experiment







Functions

- Correlate implanted ions and their beta decays
- Fast timing for time-of-flight-based neutron energy measurements
- Light quenching essential for mapping dynamic range of ions (~GeV) and electrons (~1-10 MeV) simultaneously

YSO: M. Singh *et al.* (to be submitted), R. Yokoyama, *et al.*, 2019