Gamow-Teller decays of beta delayed neutron emitters $^{82-86}$Ga and shell effects

Spokespersons: R. Grzywacz and M. Madurga

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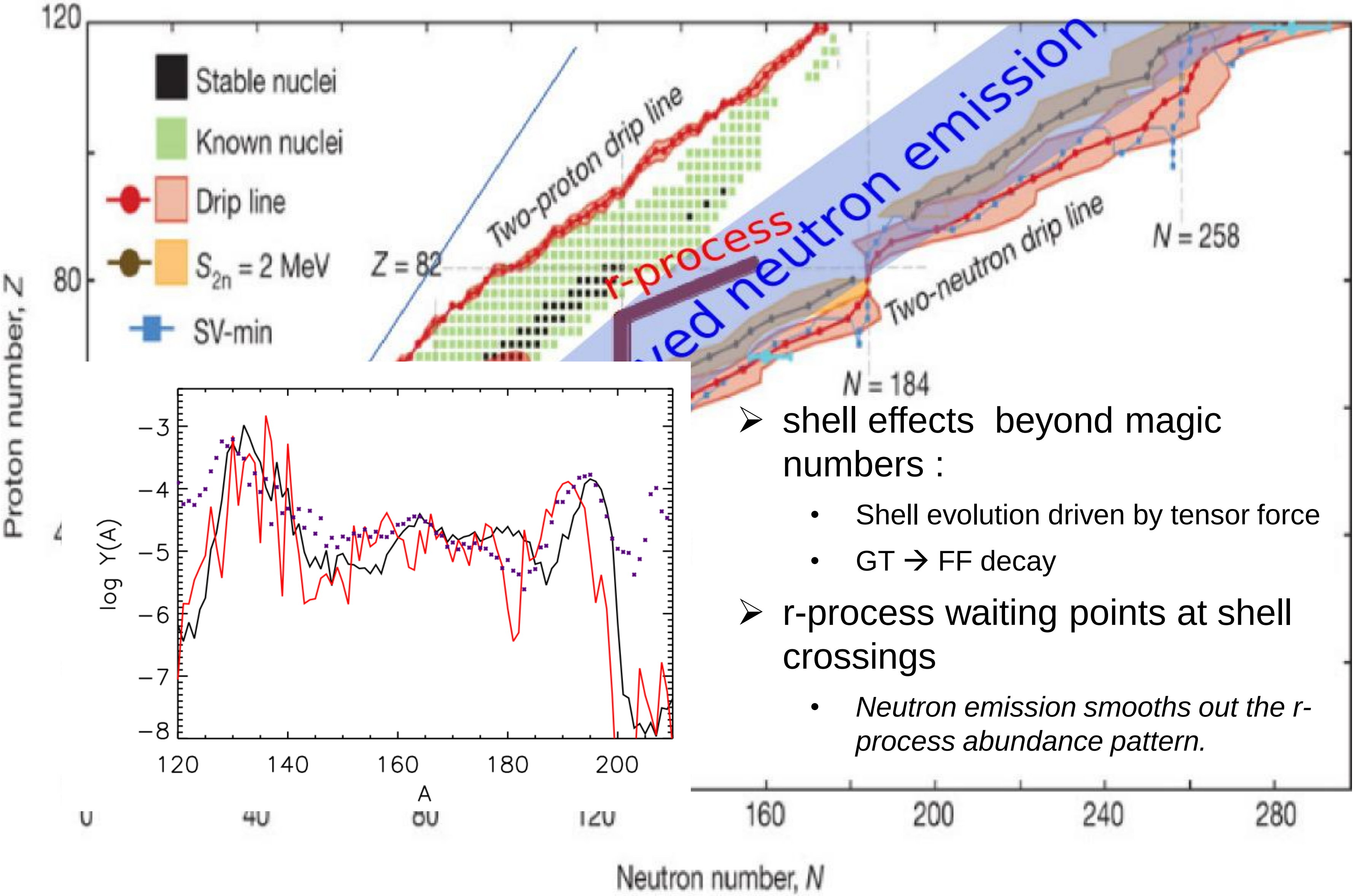
Beta-decay properties near major shell gaps for neutron rich nuclei

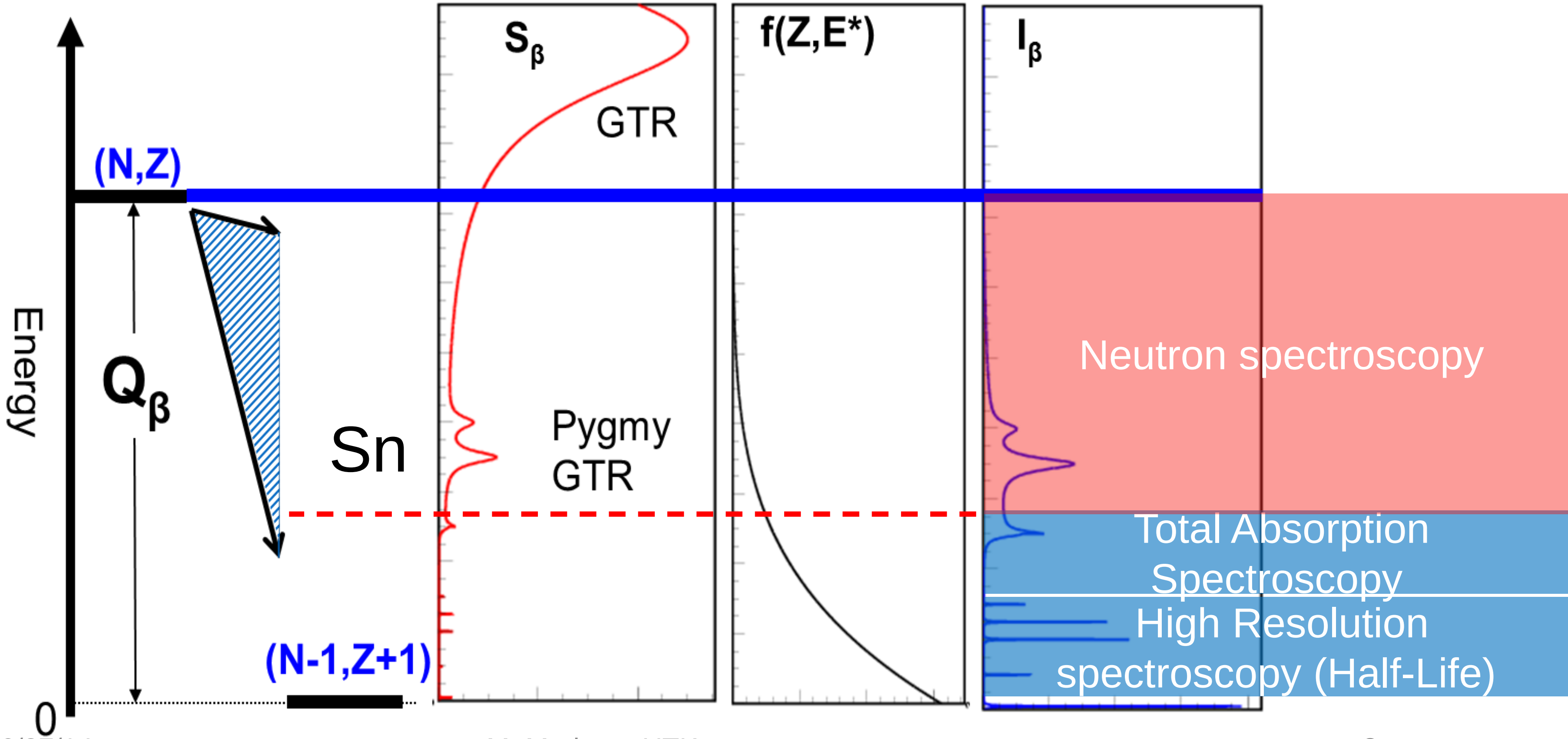


- shell effects beyond magic numbers :
  - Shell evolution driven by tensor force
  - GT → FF decay
- r-process waiting points at shell crossings
  - *Neutron emission smooths out the r-process abundance pattern.*

Beta decay of neutron rich nuclei: Comprehensive measurements

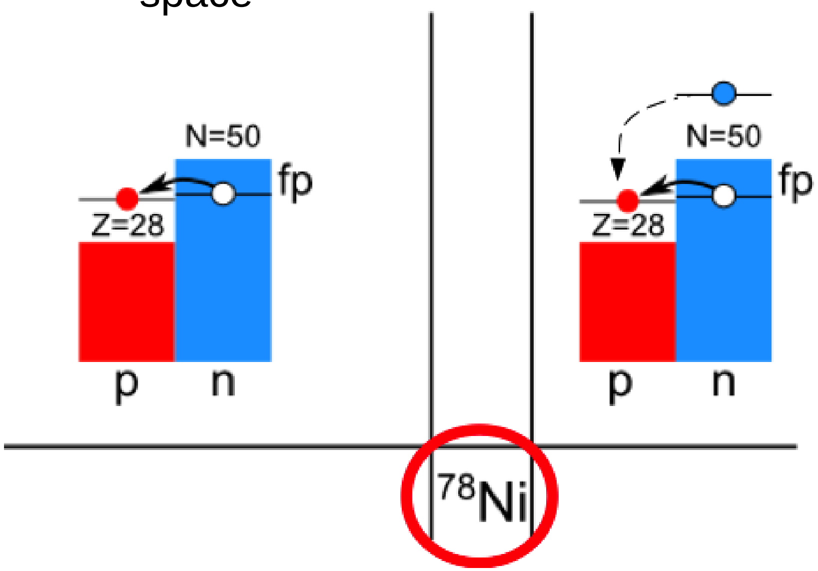
$$\frac{1}{T_{1/2}} = \sum_{E_i \geq 0}^{E_i \leq Q_\beta} S_\beta(E_i) \times f(Z, Q_\beta - E_i)$$

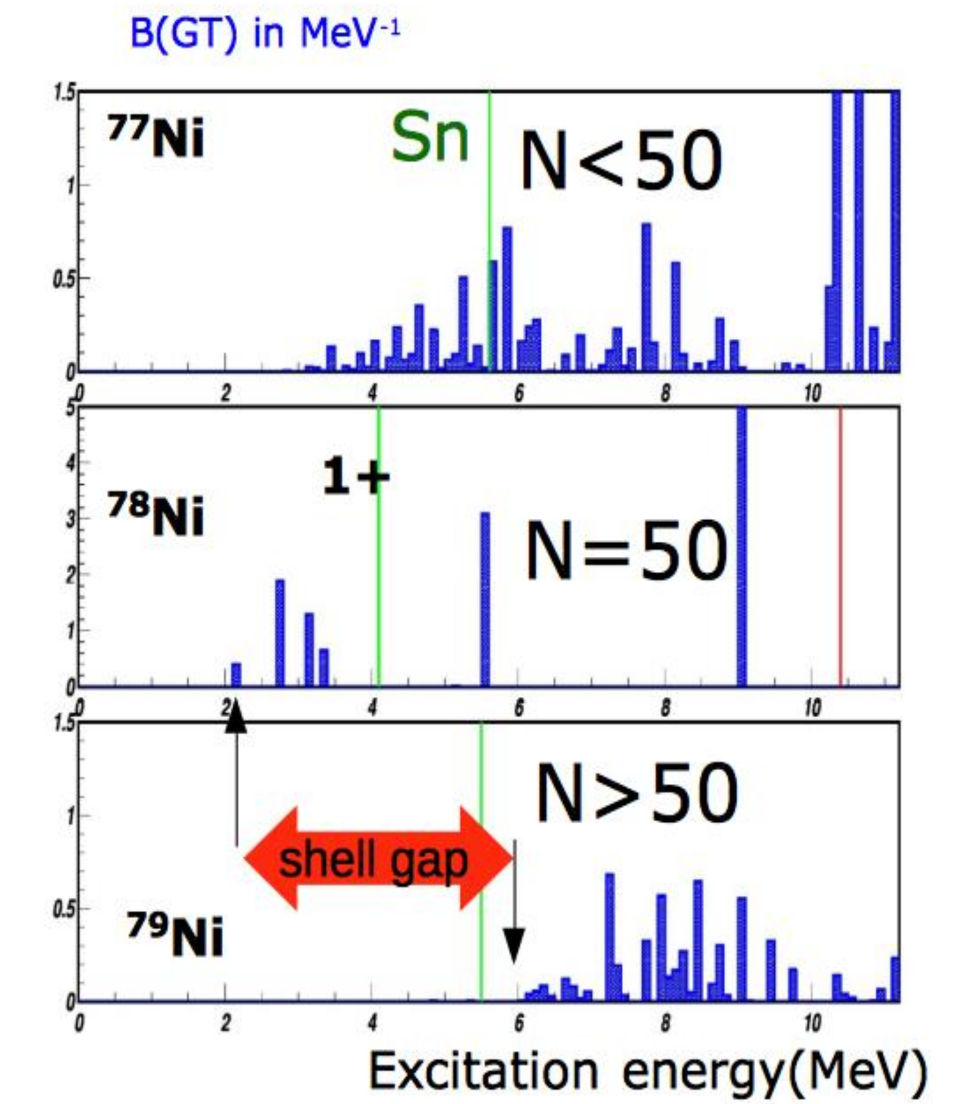
$$S_\beta(E_i) = \langle \psi_f | \hat{O}_\beta | \psi_{mother} \rangle$$



Effects of the shell gap on the decay of isotopes with N>50

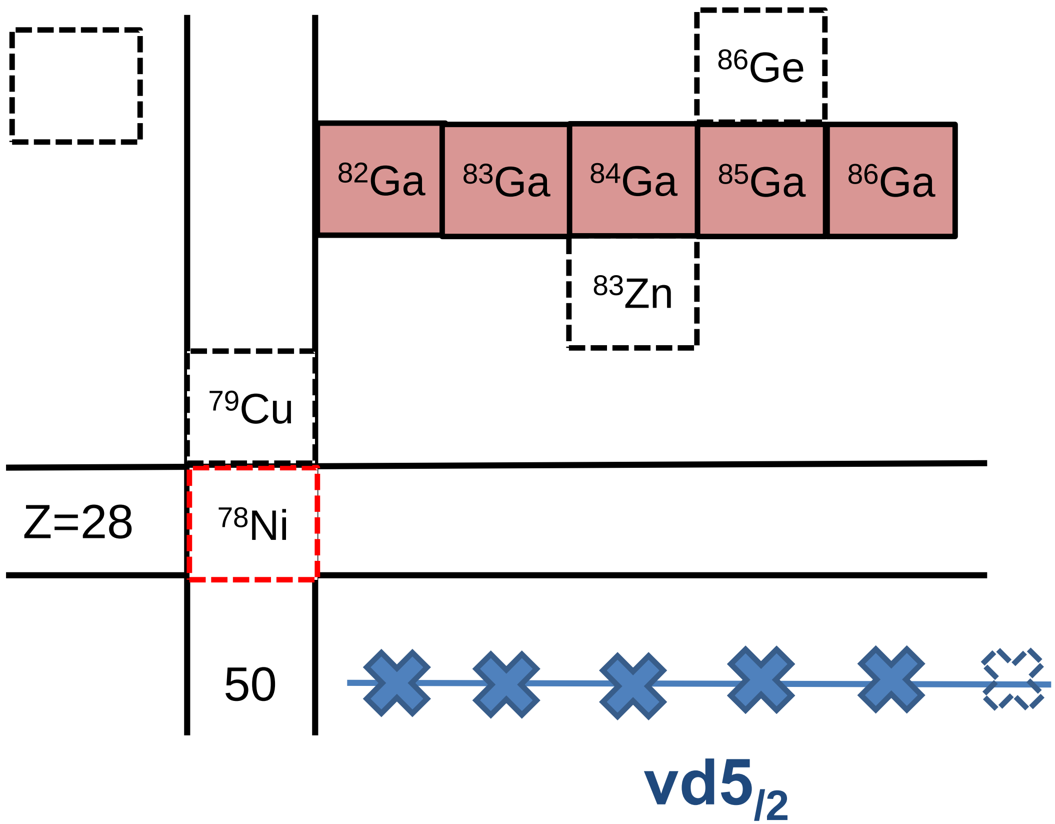
- Gamow-Teller operator can only connect spin orbit partners
- For N>50 competing decay types
  - Valence neutron decay is of forbidden type
  - GT decay of core neutrons is orders of magnitude stronger but suppressed by Fermi phase space





Why Ga?:
a sneak-peak beyond the N=50 shell closure

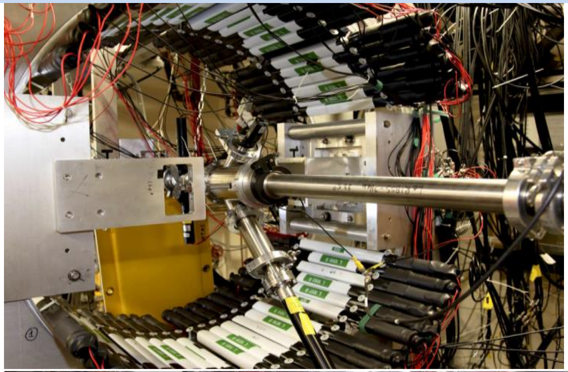
Furthest from stability at ISOLDE



- Ga isotopic chain offers a unique opportunity:
- Furthest from stability at Z~28
- Increasing $vd_{5/2}$ shell occupation for both mother and daughter

The Versatile Array of Neutron Detectors at Low Energy

- A highly modular array of plastic scintillators for neutron Time-of-Flight measurement
- Scientific goals: β-delayed neutrons and reaction studies.
- Bar Sizes:
  - Small : 3x3x60 cm3
  - Medium : 3x6x120 cm3
  - Large : 5x5x200 cm3
- Neutron Energies Covered:
  - Small/Med. : 0.1 - 6 MeV
  - Large : 1 - 20 MeV

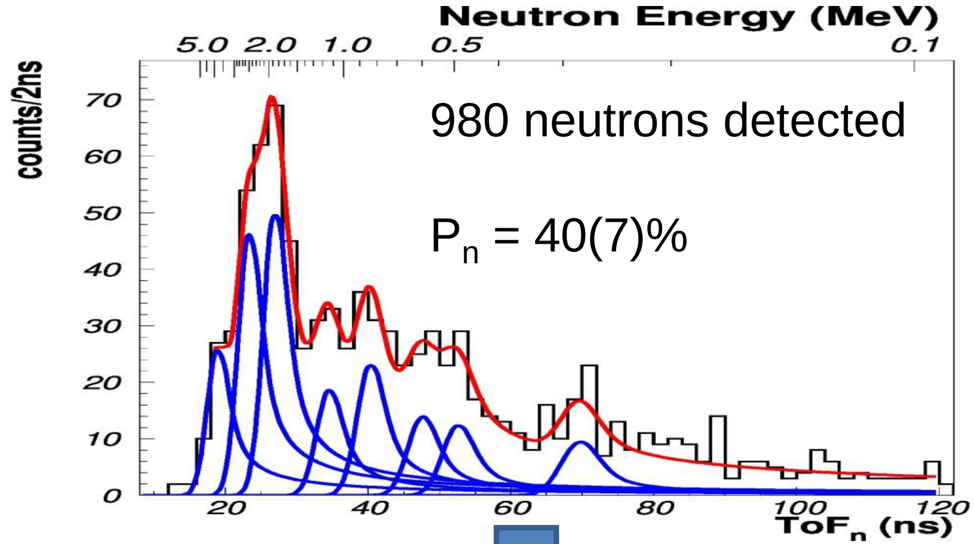


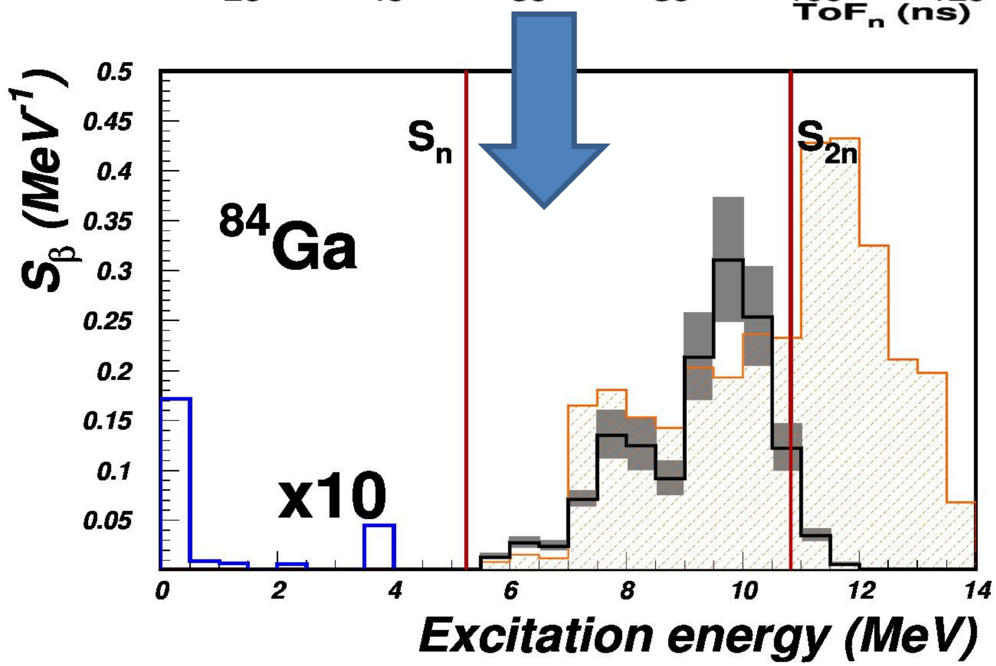
^{84}Ga @ ORNL with VANDLE

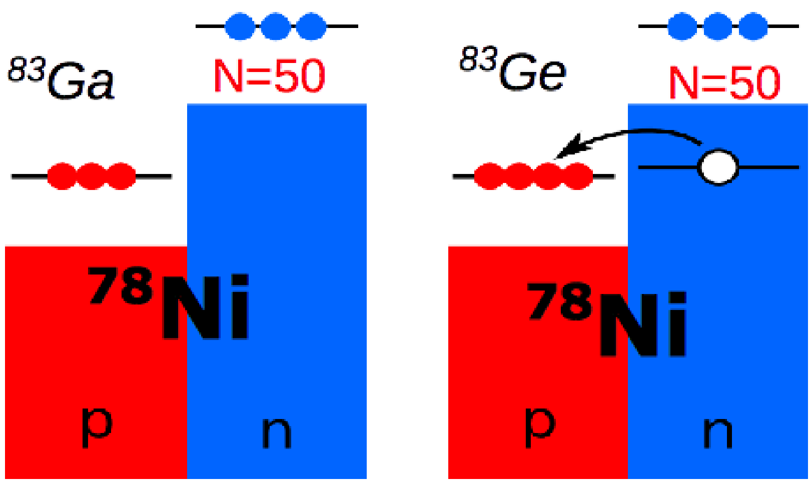
- Neutron branching ratio **<u>different</u>** from literature 70(13)% and 74(14)%

*[K.-L. Kratz et al., Z. Phys. A **340**, 419 (1991)]*
[J.A. Winger et al. PRC 81, 044303(2010)]

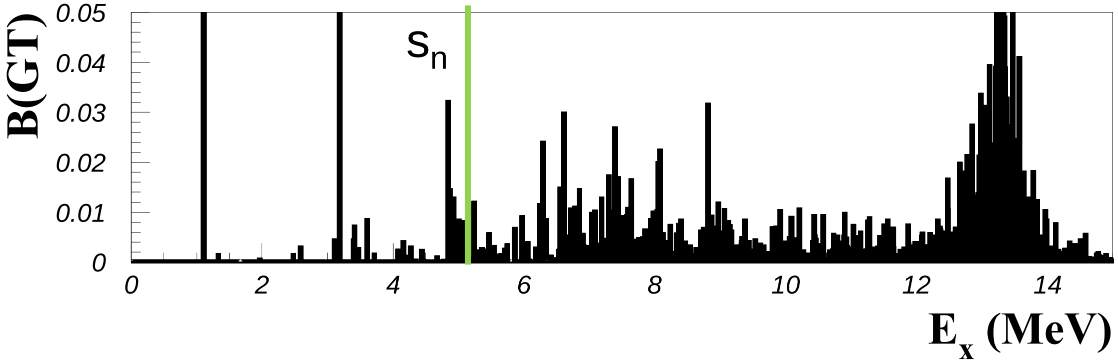
- Nushellx calculation with hybrid interactions in good accordance with data:
    - *jj44bpn* for fpg (^{56}Ni core, B.A. Brown),
    - Added matrix elements for neutrons in $d_{5/2}$ x protons and neutrons in fpg

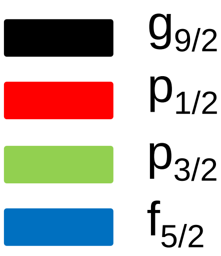






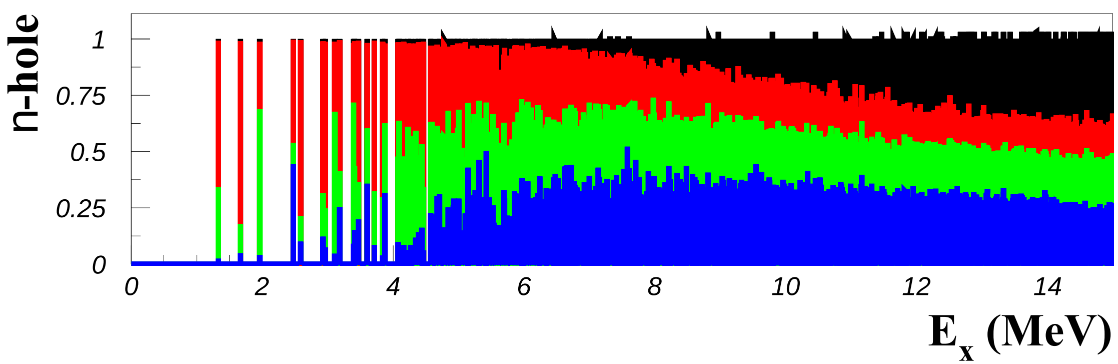
Shell Model Single Particle composition





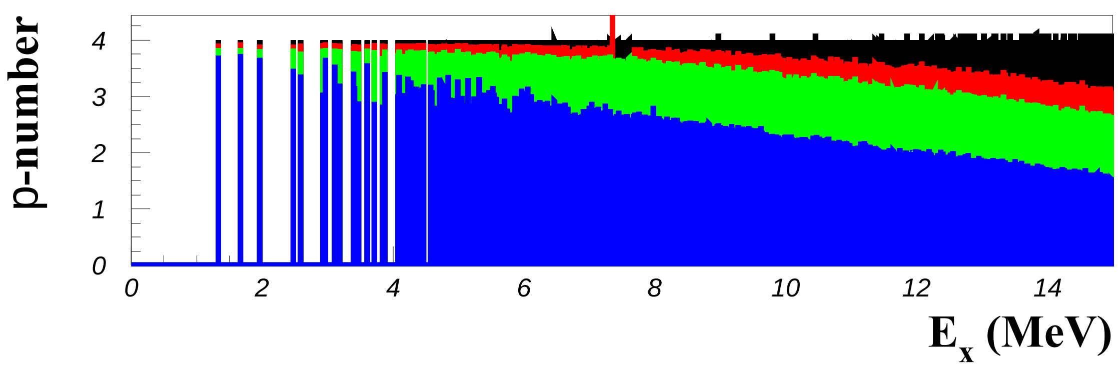
Neutron emission enhanced by

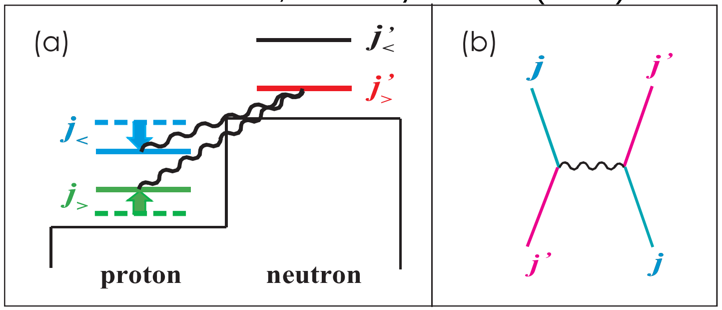
$\nu f^{(-1)}_{5/2} \rightarrow \pi f_{5/2}$



Isotopic evolution will be driven by filling the $d_{5/2}$ neutron shells

B. Cheal et al, PRL 104, 252502 (2010)
T. Otsuka et al., PRL **95,** 232502 (2005)

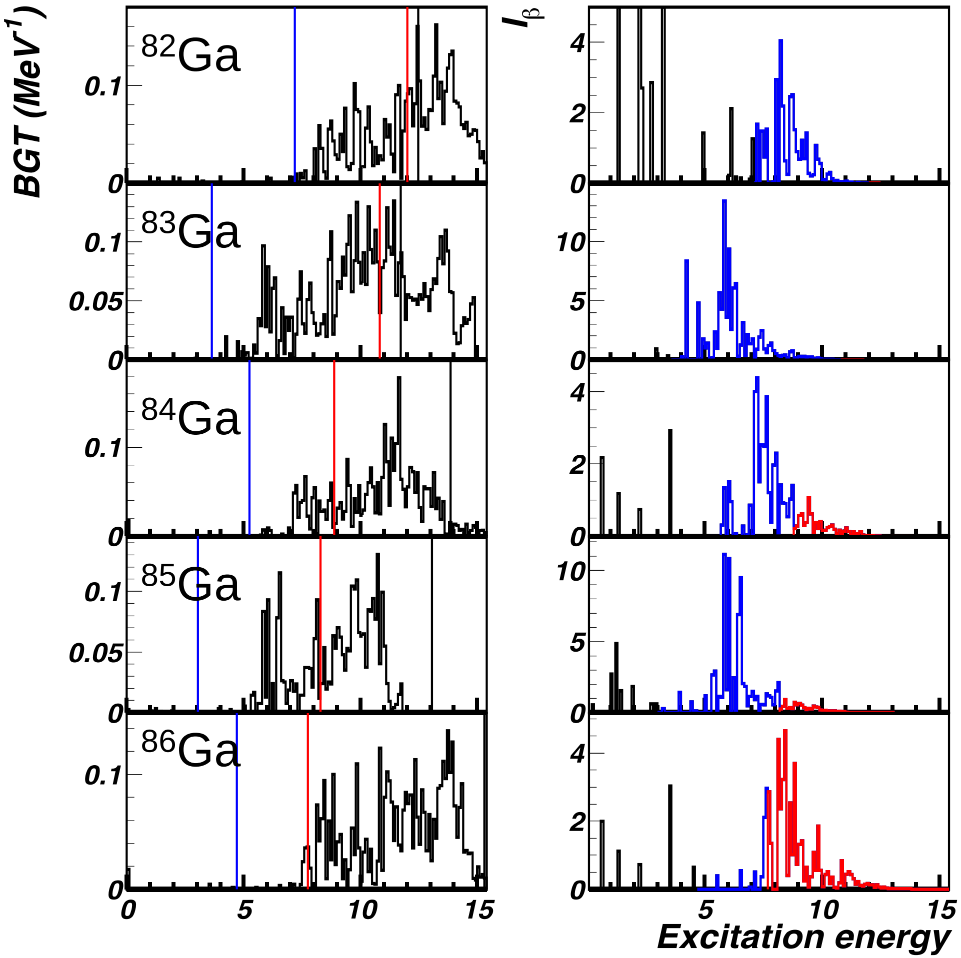


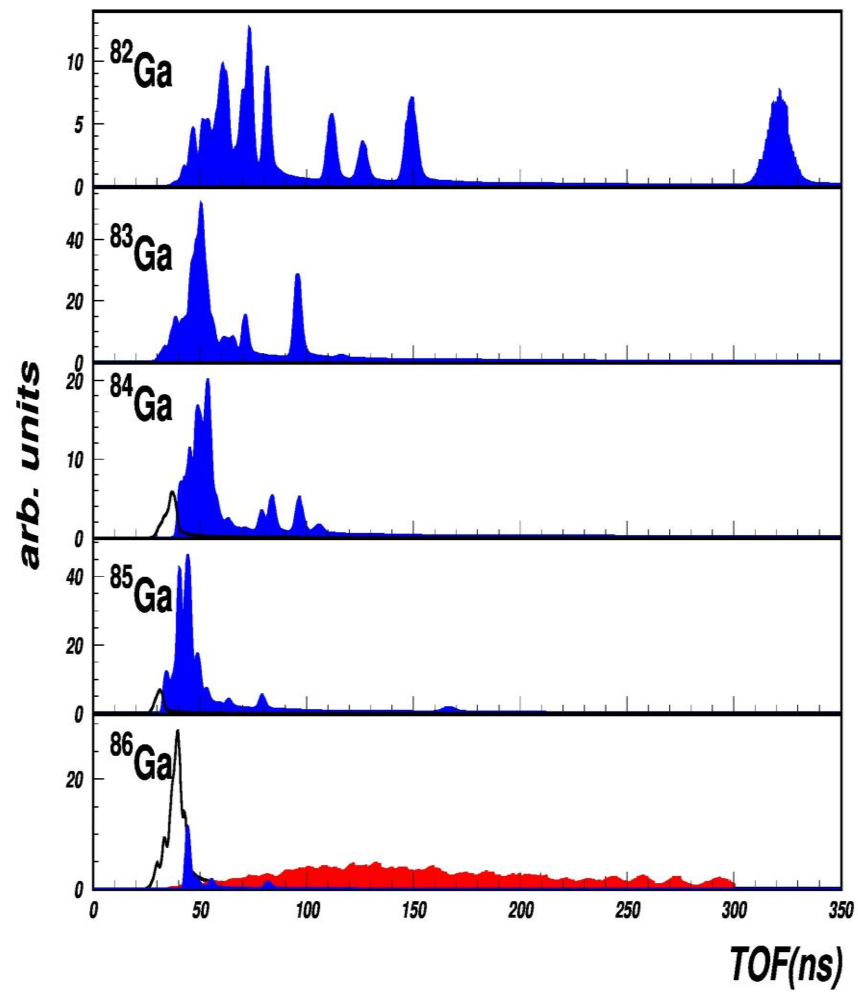


Experiment Goal:
Systematic study of shell effects on the decay strength in the Ga isotopic chain

Decay strength from jj4bpn SM (with $d_{5/2}$)
Introduced $\nu d_{5/2}$-πfpg interaction
→ No shell gap quenching in our model

Single neutron emission
Two neutron emission

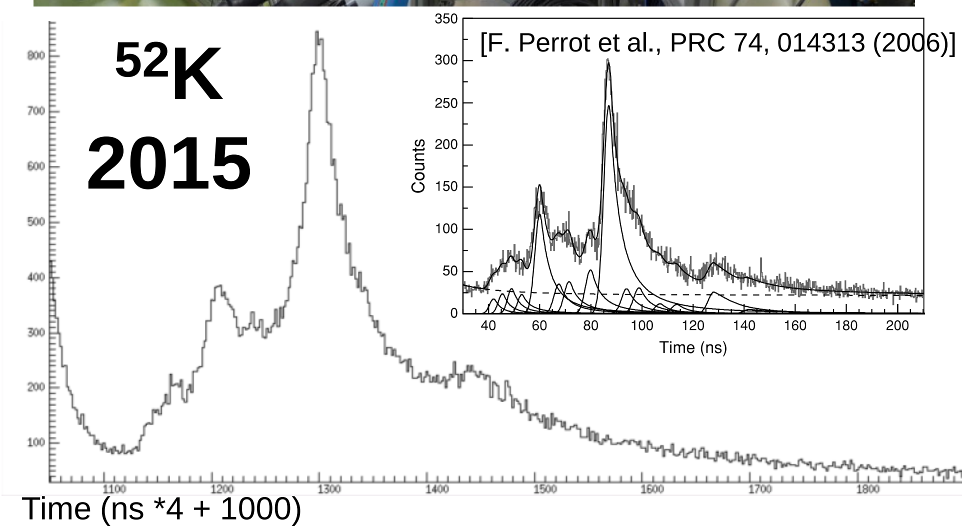


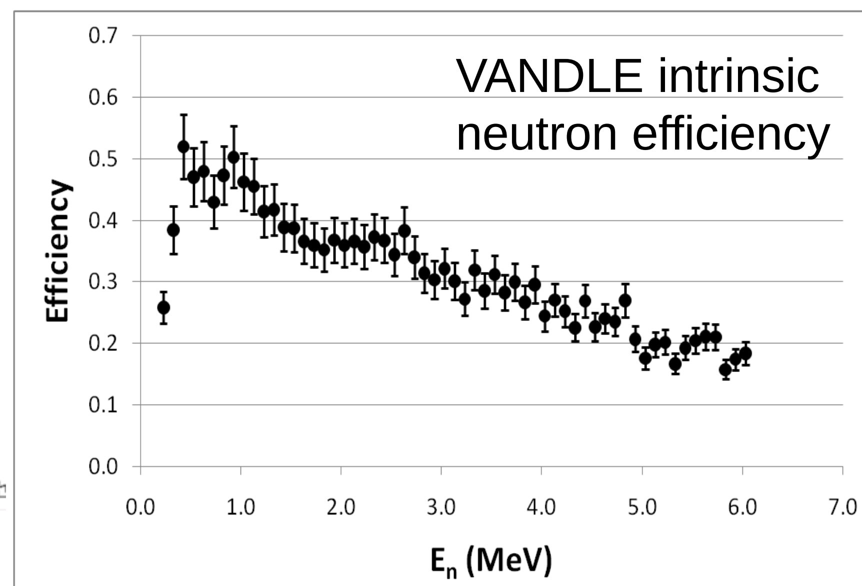


VANDLE @ IDS

- 4 clovers, 4% efficient @ 1MeV
- 26 x 120 cm VANDLE bars
  - •45% efficiency/bar @ 1MeV
  - •Ω = 14.9% of 4π
  - •90% β-trigger efficiency
  - •<u>6% total efficiency @ 1MeV</u>

    (possible efficiency increase to 9% in 2016)
- Greatly improved resolution demonstrated in 2015 (> ORNL)
  - •100 cm flight path
  - •1.5 ns time resolution (3 ns before)





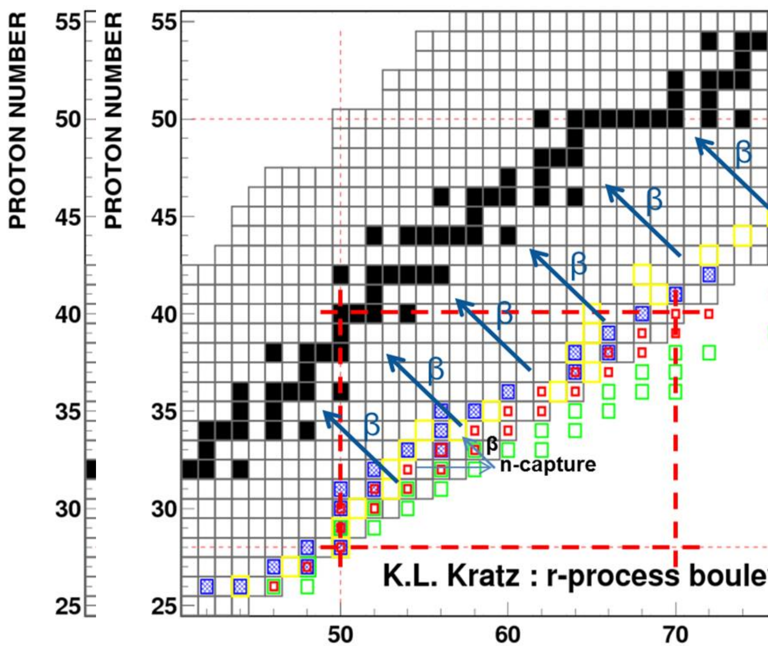
Beam request

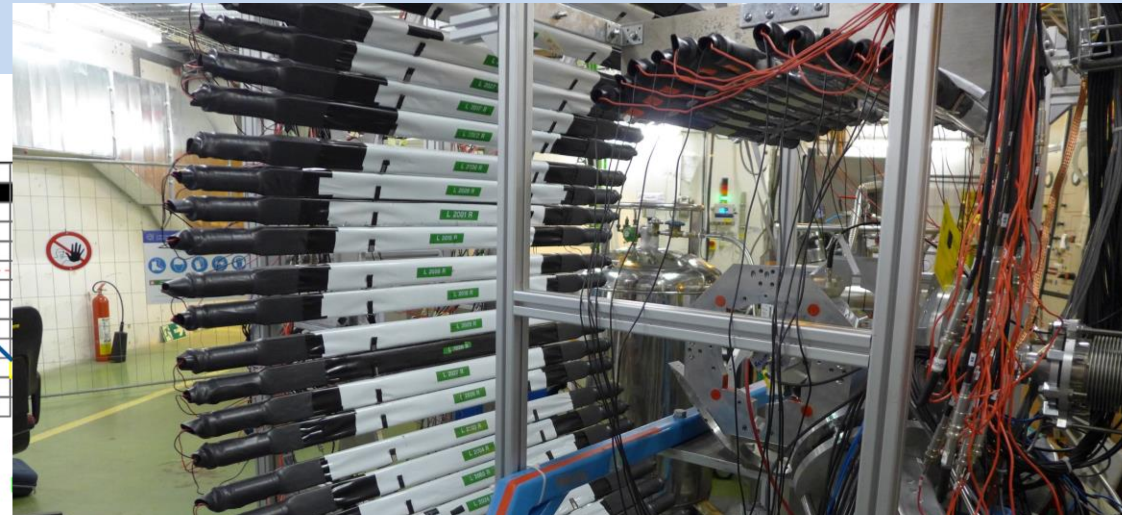
UC_x Target + neutron converter + RILIS

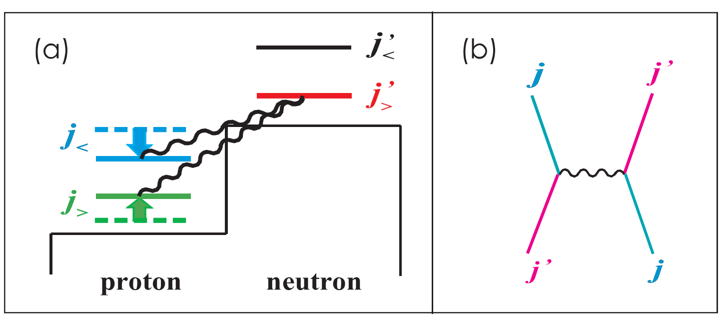
- Yields:
  - $^{82-86}$Ga produced and yields measured at ISOLDE [U. Köster, Eur. Phys. J. A 15, 255 (2002)]
  - Short test July 2015 (p on target): Yield(^{83}Ga) = 6.5 10^4 μC^{-1}
- Isobar contamination:
  - $^{85-86}$Rb n-converter yield: ~10^5 [A. Gottberg et al. NIM B 336, 143(2014)]
  - HRS offers enough suppression (2000 resolving power required, 5000 nominal)
    - Effective suppression of isobars using high resolution separator proven at ORNL for 85,86Ga [K. Miernik et al., PRL111, 132502 (2013)]

Isotope	P_n (%)	Beam (μC^{-1})	n/shift	Shifts	Total neutrons
^{82}Ga	20	5000	1.6 10^6	0.5	0.8 10^4
^{83}Ga	63	400	0.4 10^6	0.5	0.2 10^4
^{84}Ga	40	80	6.6 10^4	1	6.6 10^4
^{85}Ga	60	12	1.2 10^4	5	6.0 10^4
^{86}Ga	60	1.5	1.5 10^3	13	1.9 10^4
^{49}K	86	5 10^3	7.0 10^6	1	7.0 10^6

Summary





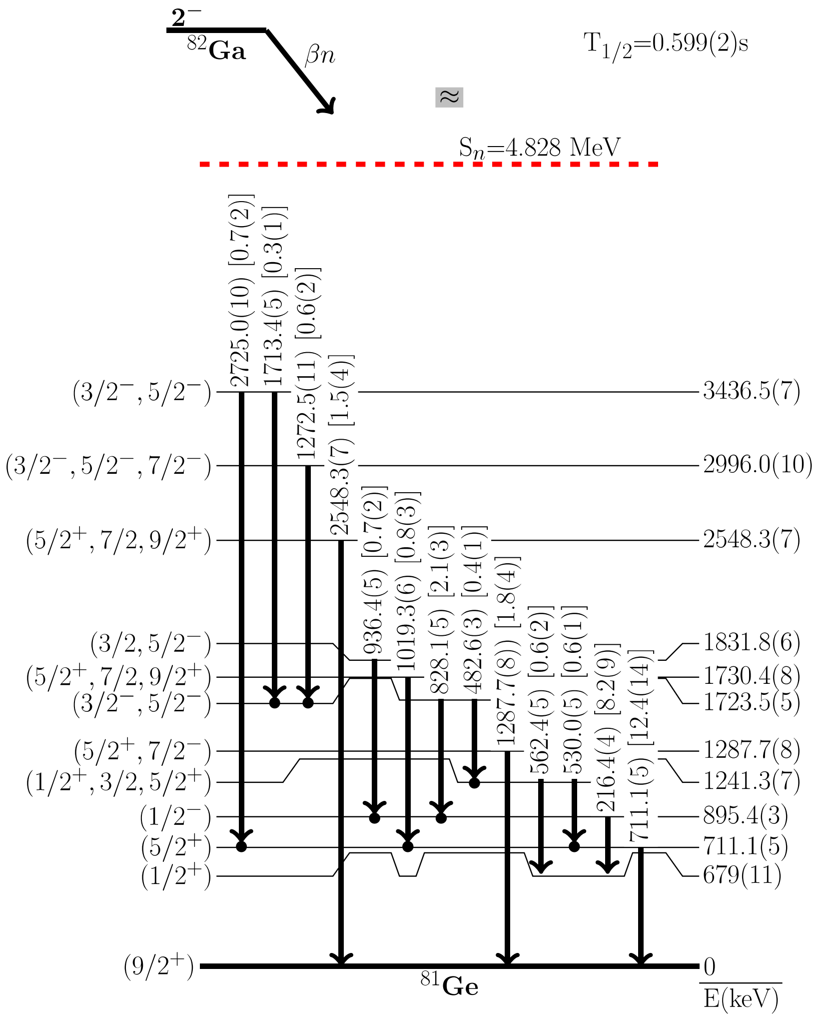


- ➢ Shell effects enhance neutron emission across major shell gaps
- ➢ Goal: Systematic study of neutron emission in N=51→55 Ga isotopes
  - Investigate relation of “core” decay to the large neutron emission probabilities in the region
  - Effect of proton-neutron interaction in decay strength (shell evolution)
- ➢ Beam request: 21 shifts (collect ~10^4 n)

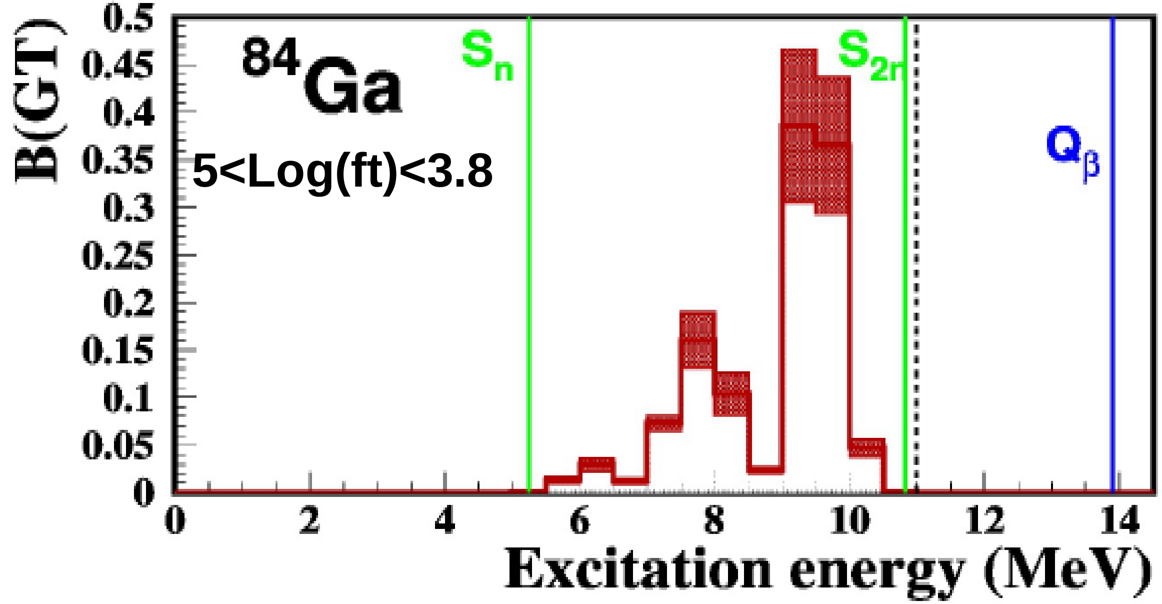
BACK UP SLIDES

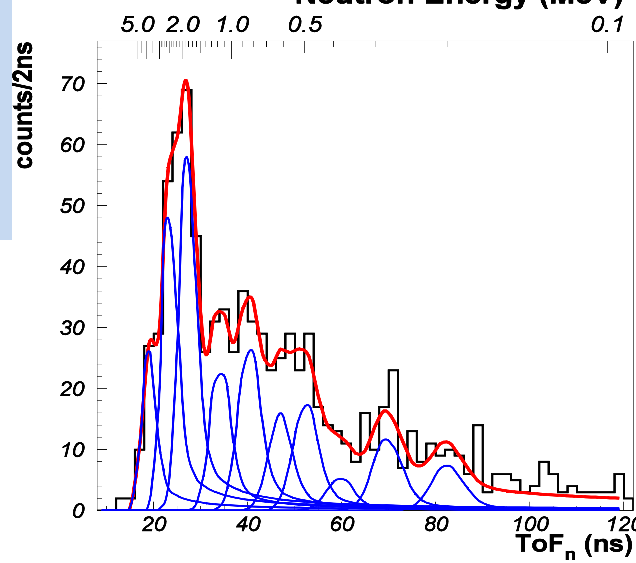
Beta decay of 82Ga

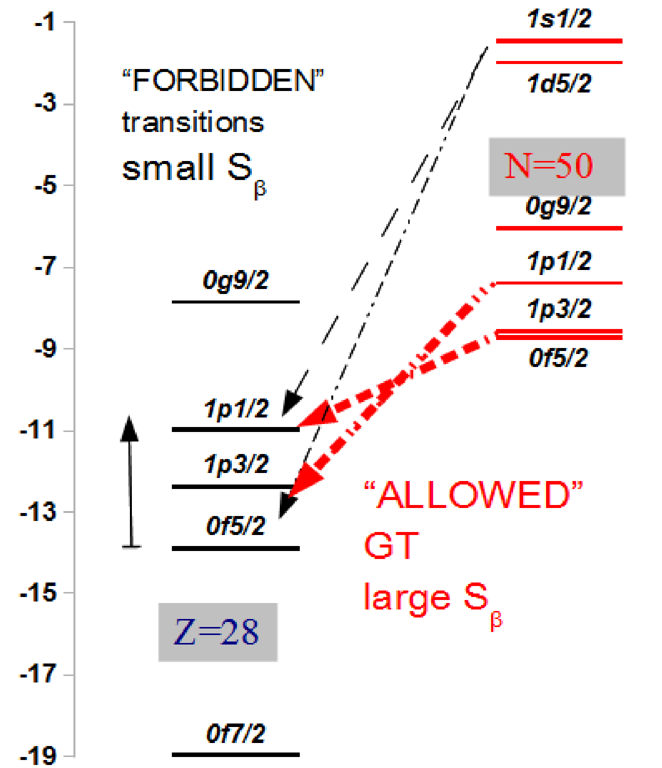
M. Al-shudifat et al., submitted to PRC

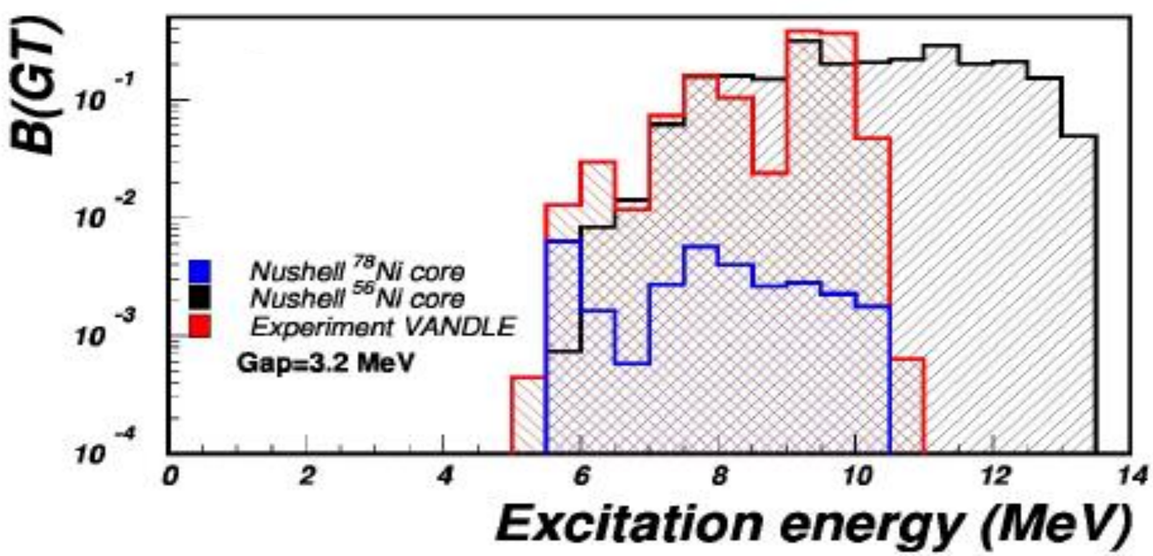


Core breaking states in ^{84}Ga



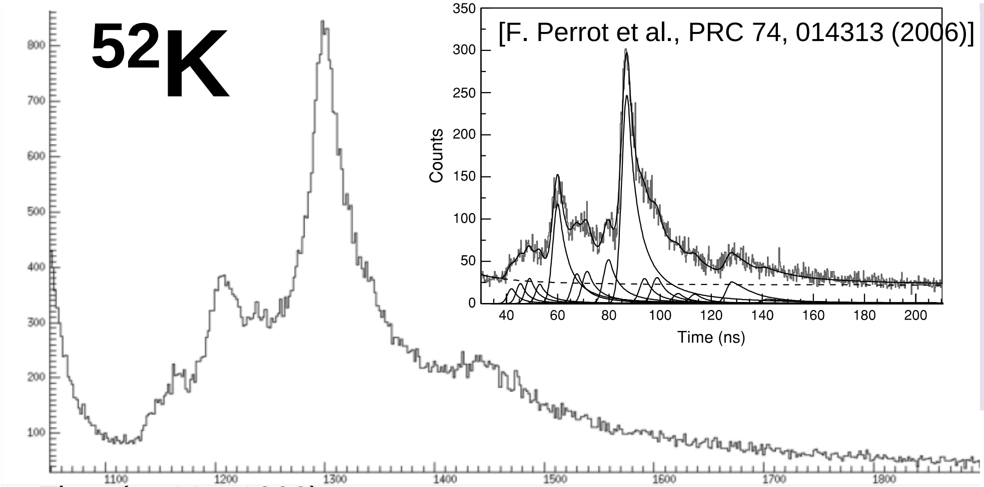




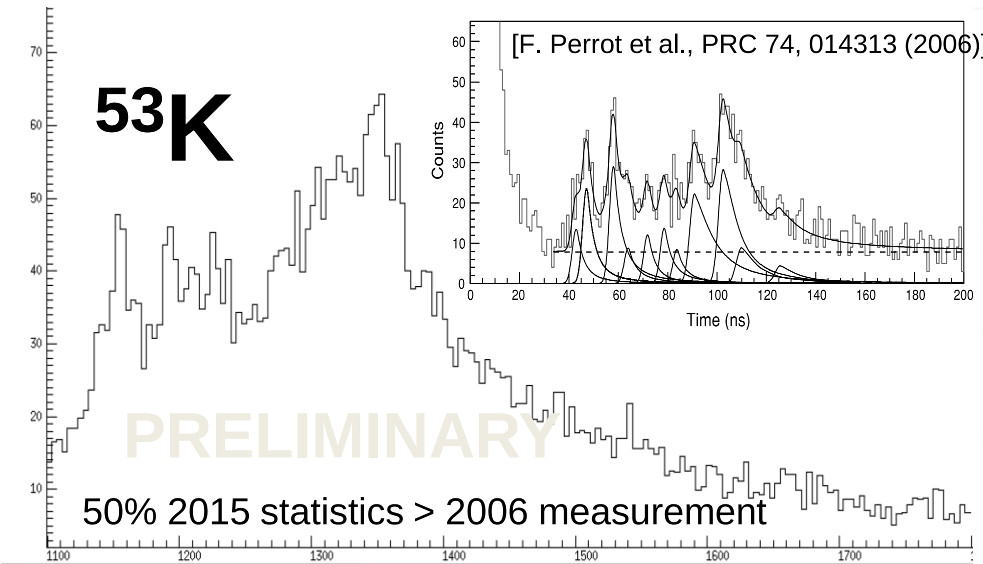


IS599: Study of neutron-rich 51-53Ca isotopes via beta-decay

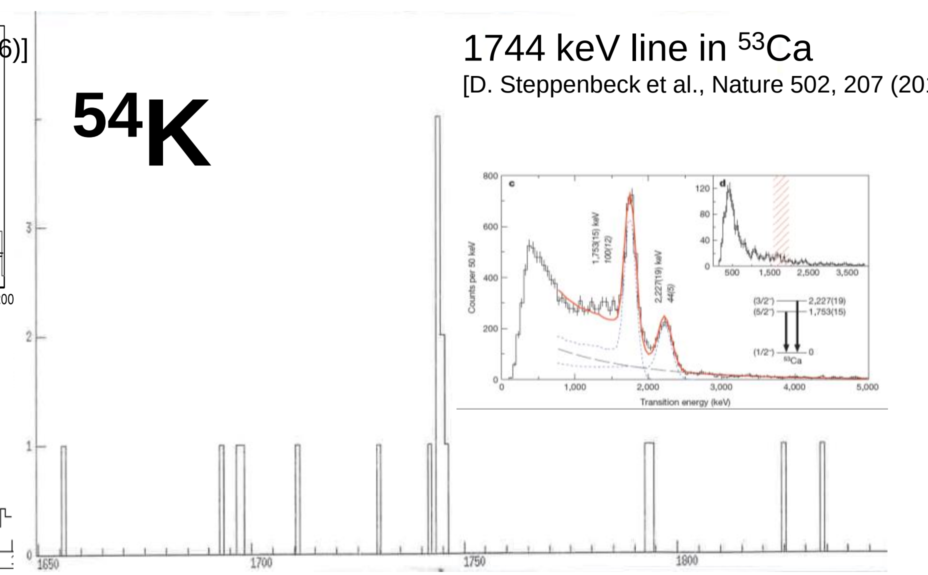
- Potassium isotopes @ IDS:
  - $^{51-53}$K improved statistics
  - First observation of ^{54}K decay



Time (ns *4 + 1000)



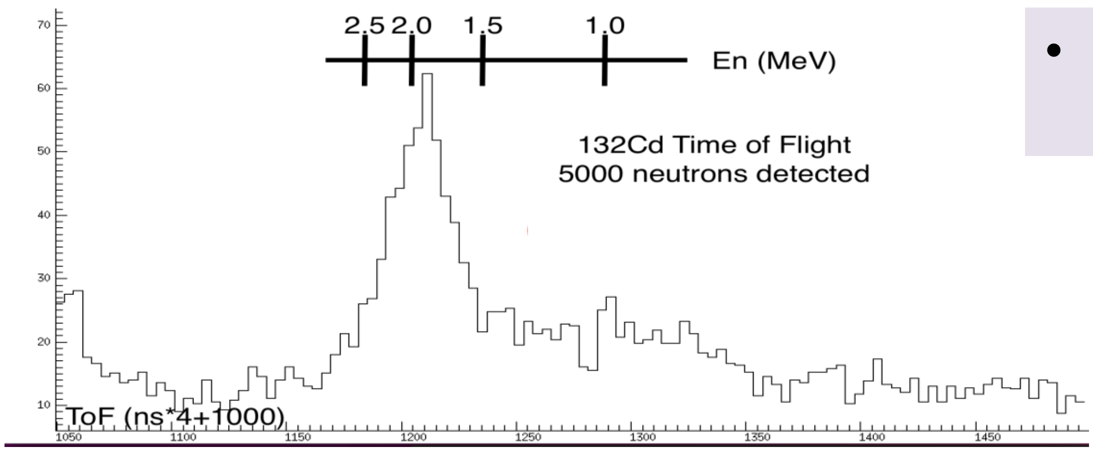
Time (ns *4 + 1000)

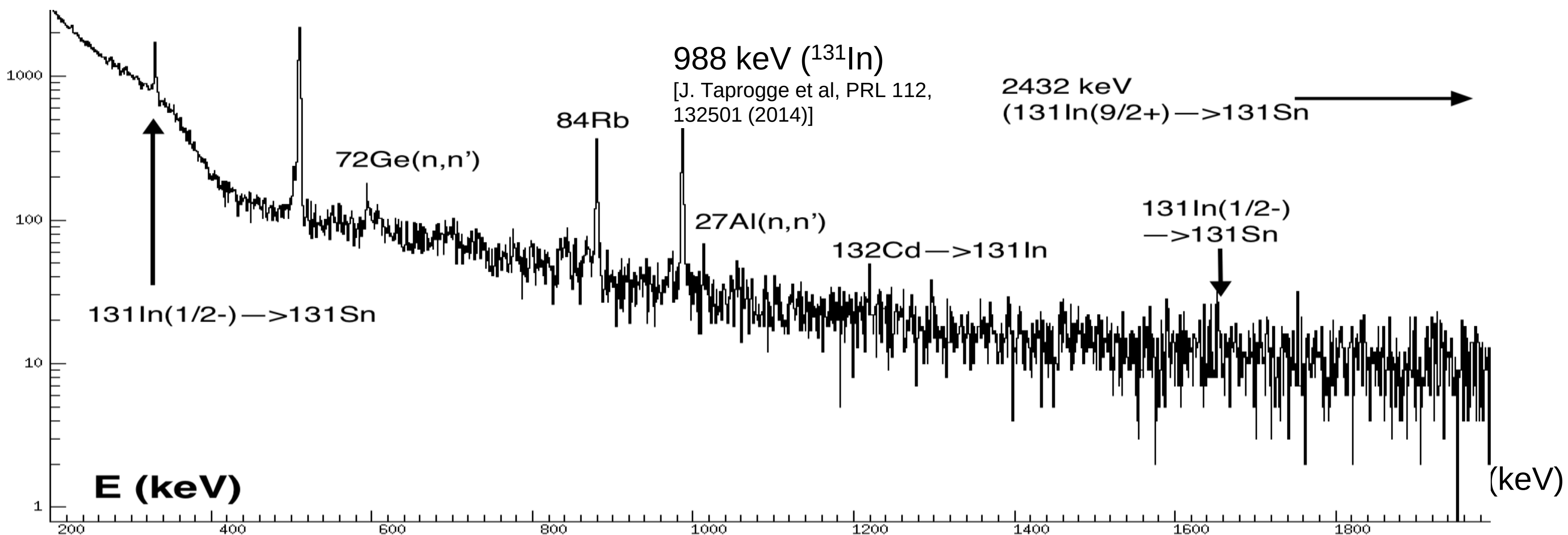


E_γ (keV)

IS600: Beta-delayed neutron emission in ^{132}Cd

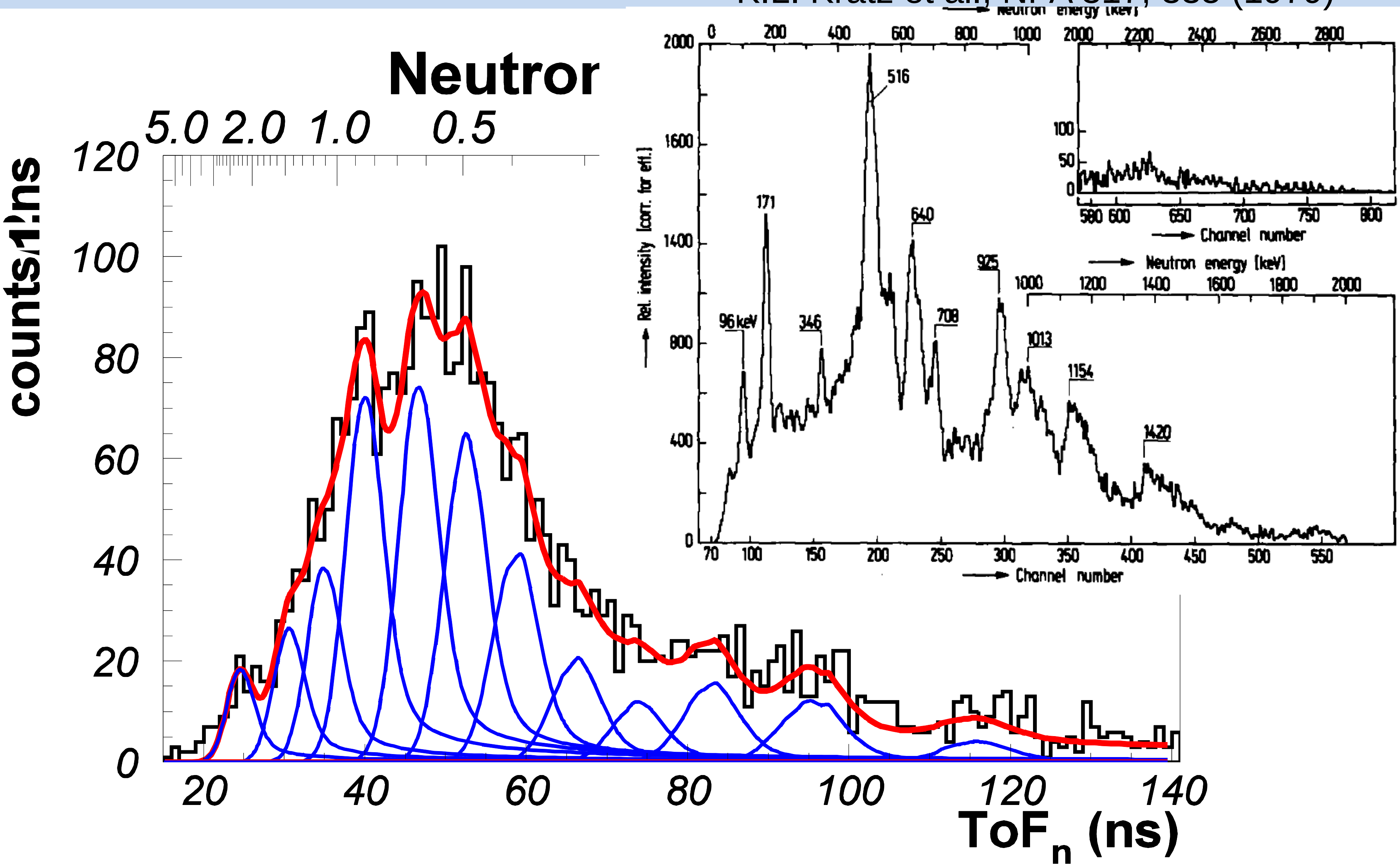
- Beta decay of ^{132}Cd:
  - 9 shifts with yield=0.5 μC^{-1}



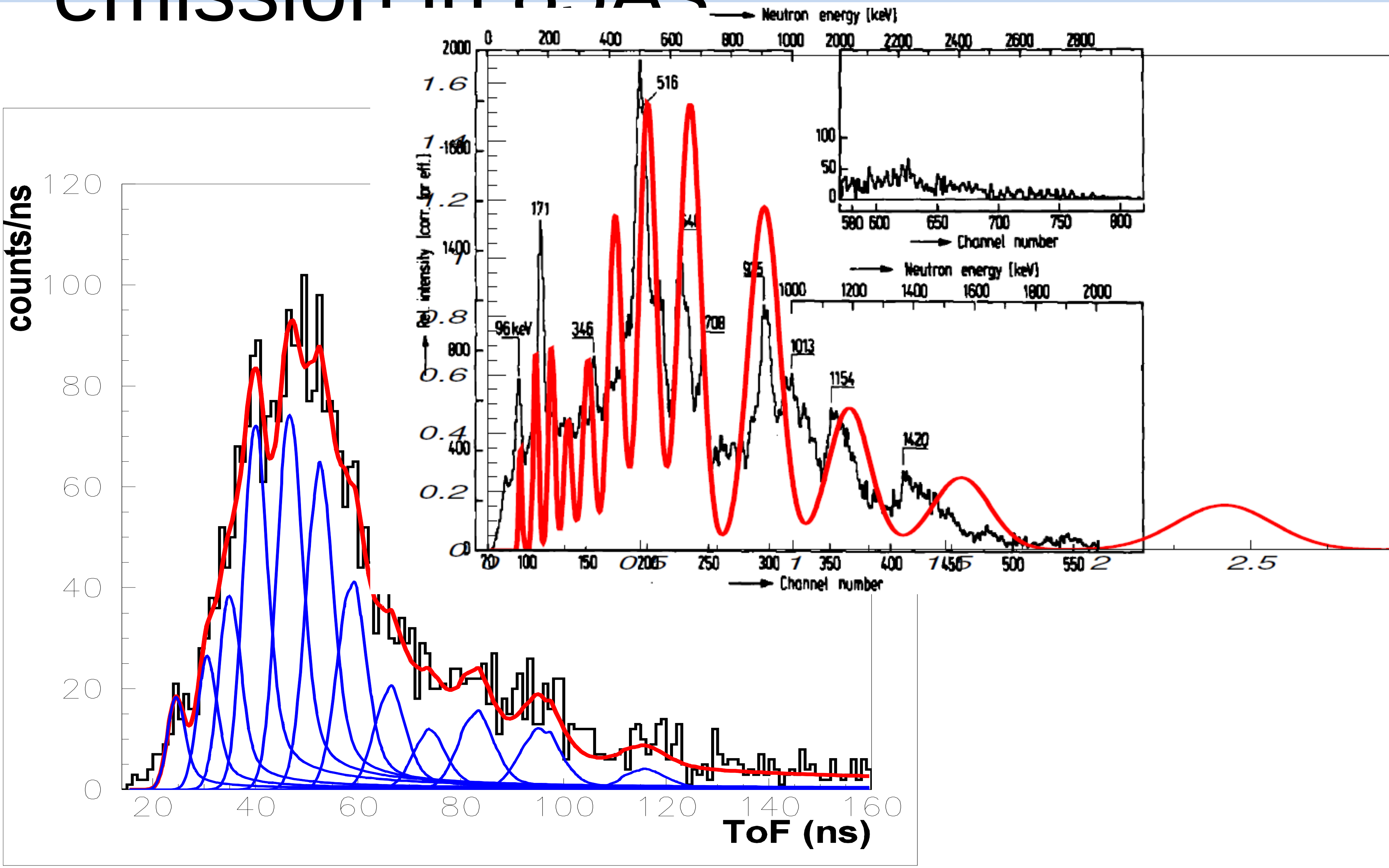


1-Neutron energy spectrum:
Beta-delayed neutron emission in ^{85}As

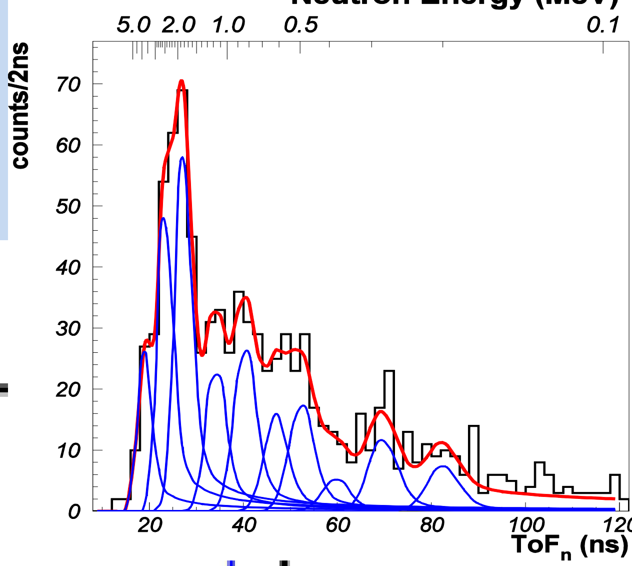
K.L. Kratz et al., NPA 317, 335 (1979)

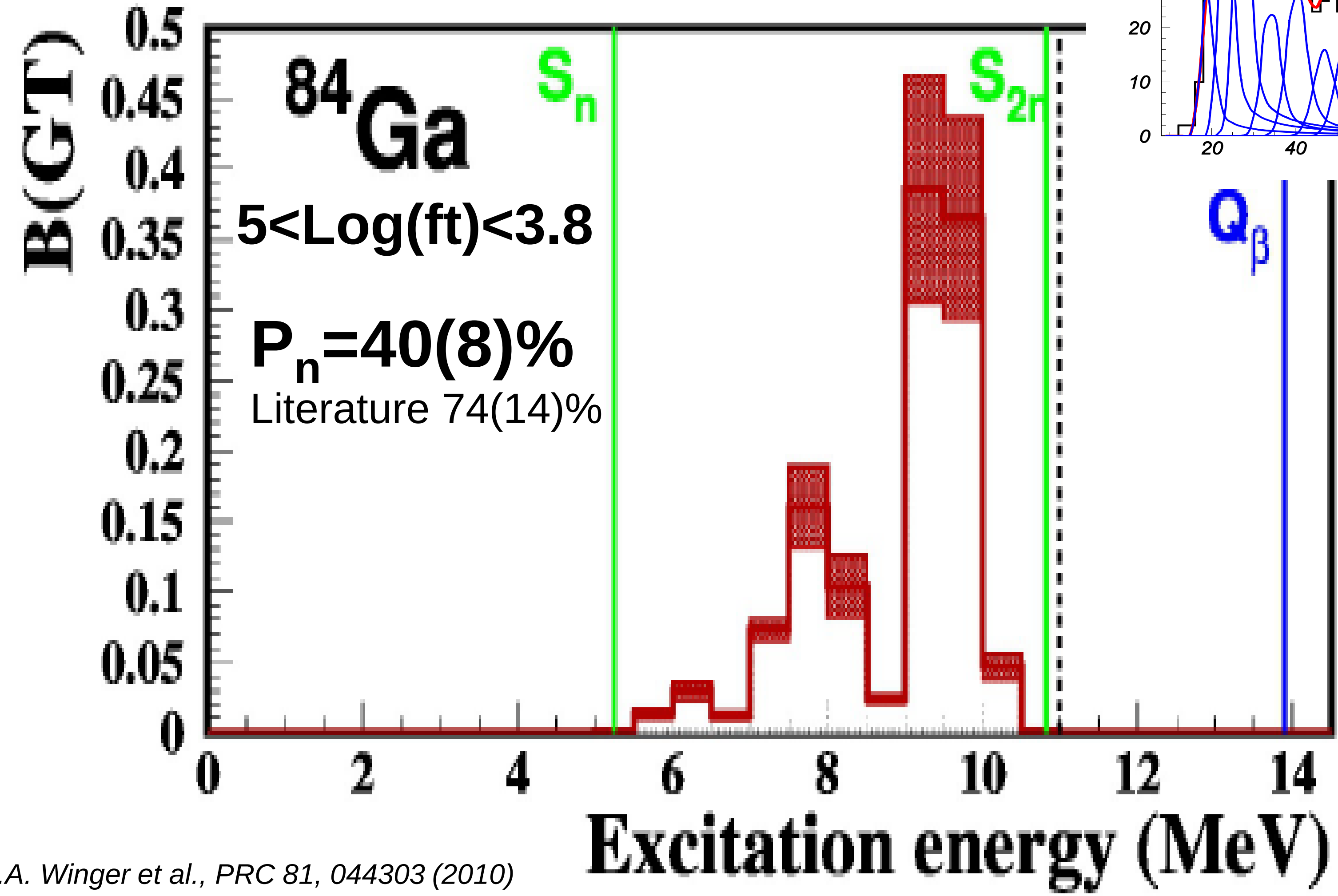


Low energy delayed neutron emission in 85As



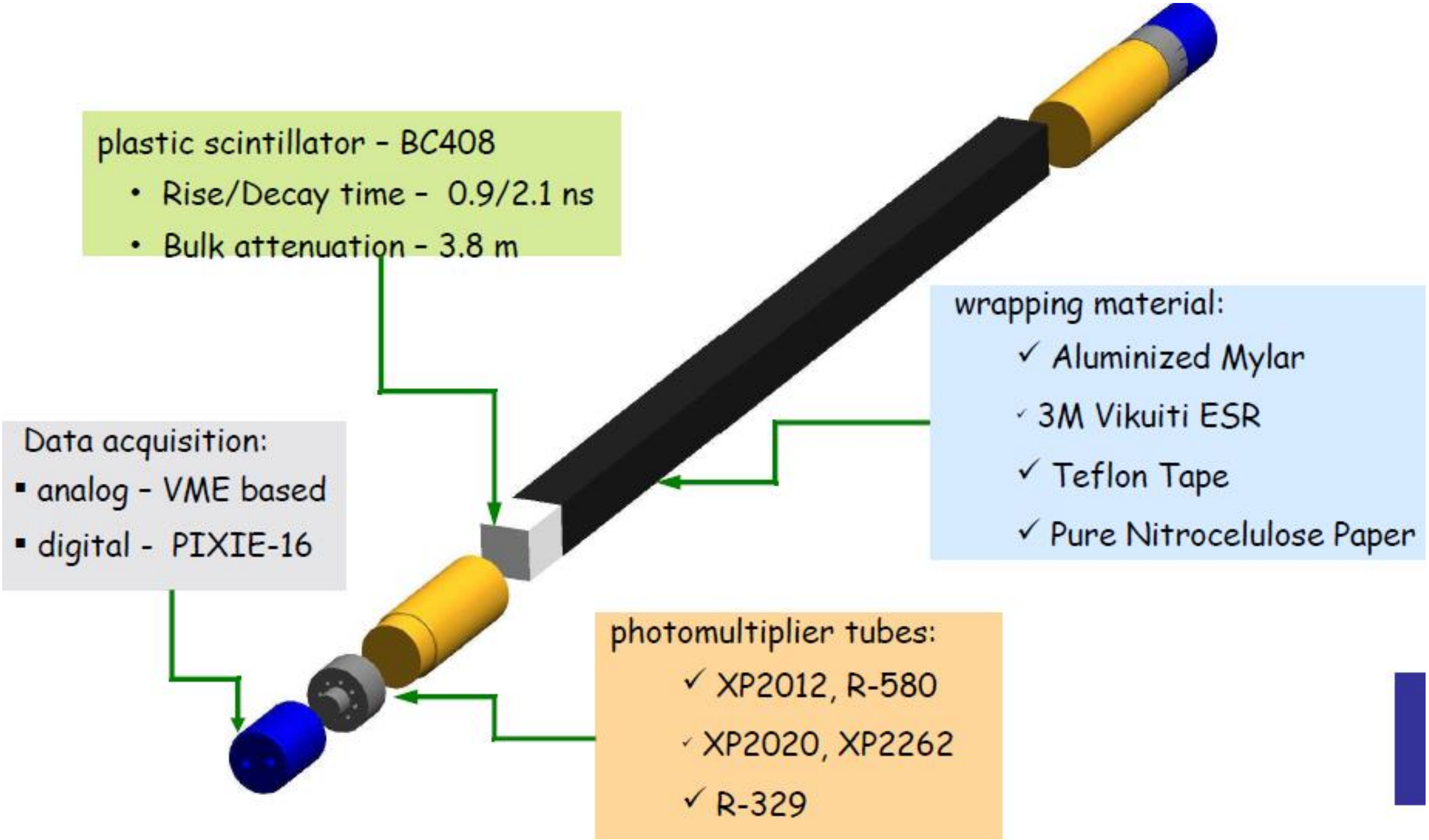
^{84}Ga B(GT) distribution



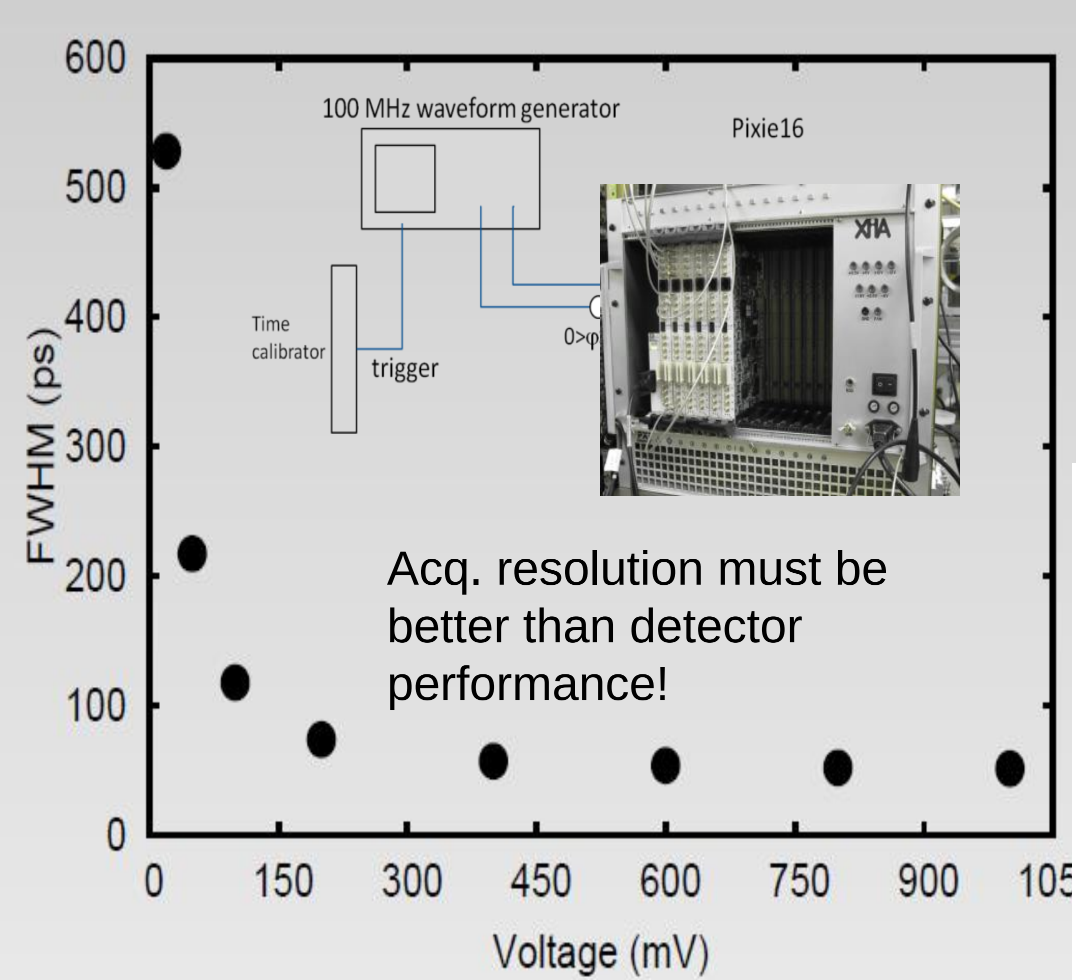


J.A. Winger et al., PRC 81, 044303 (2010)

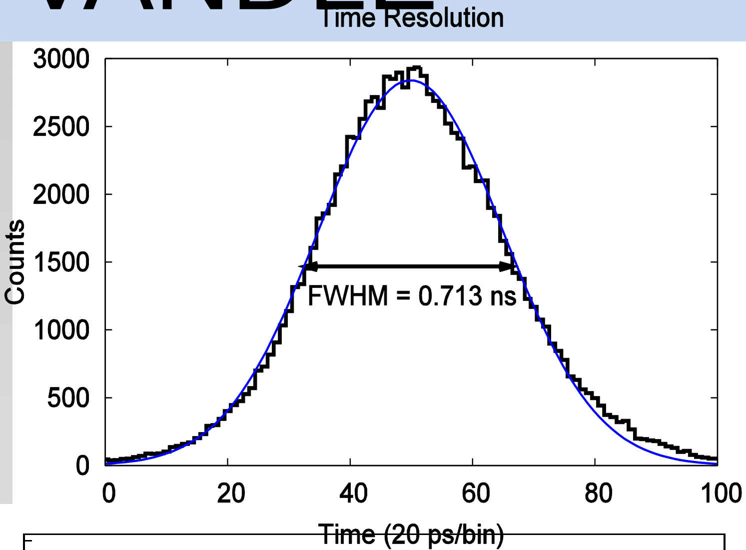
Detector components

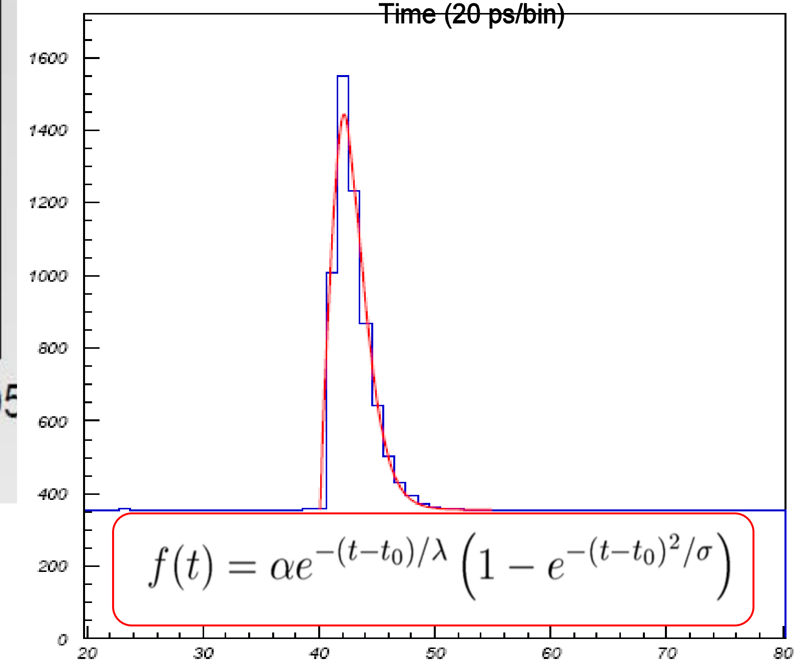


Low threshold/High Efficiency Digital electronics for VANDLE

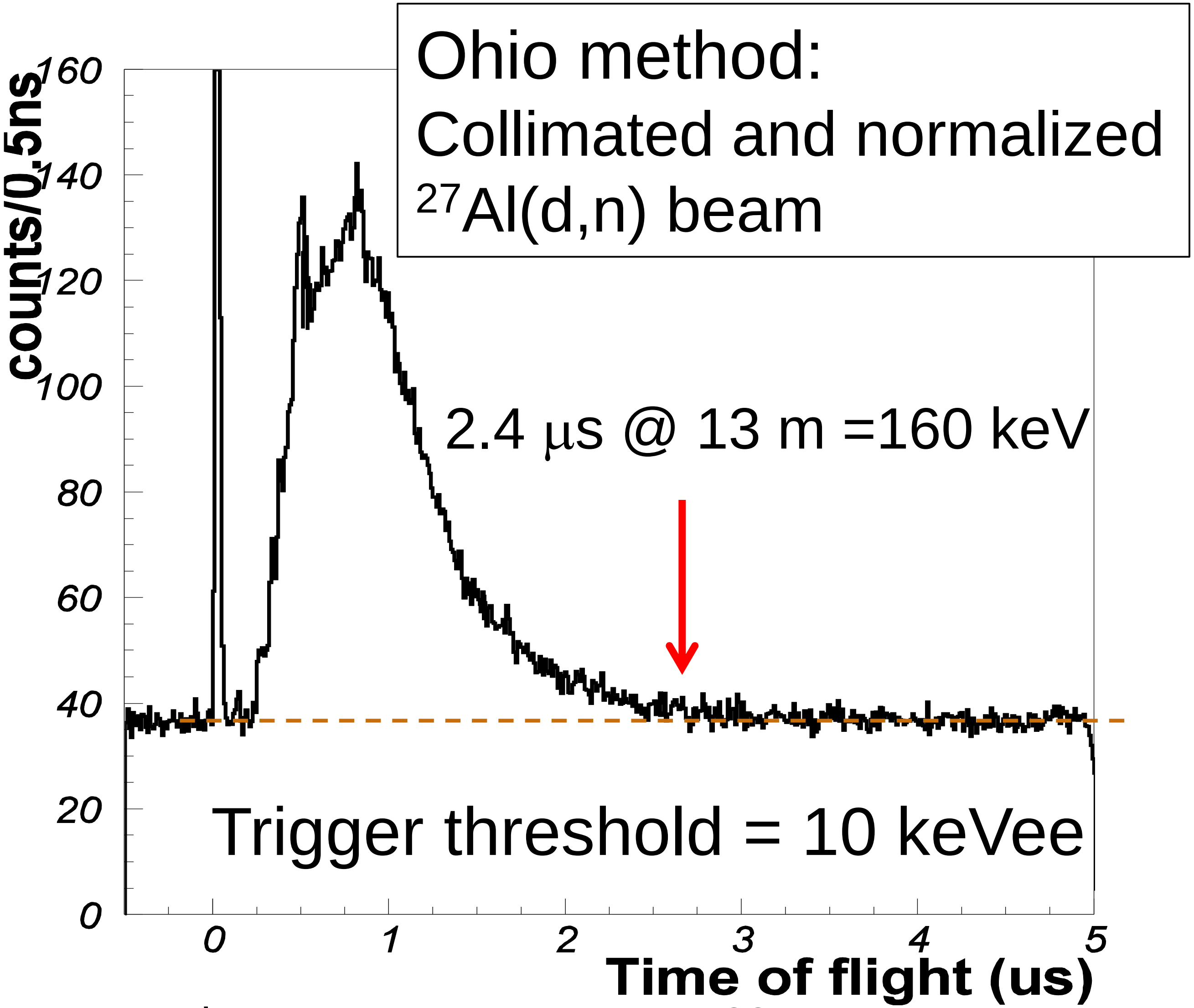


Acq. resolution must be better than detector performance!



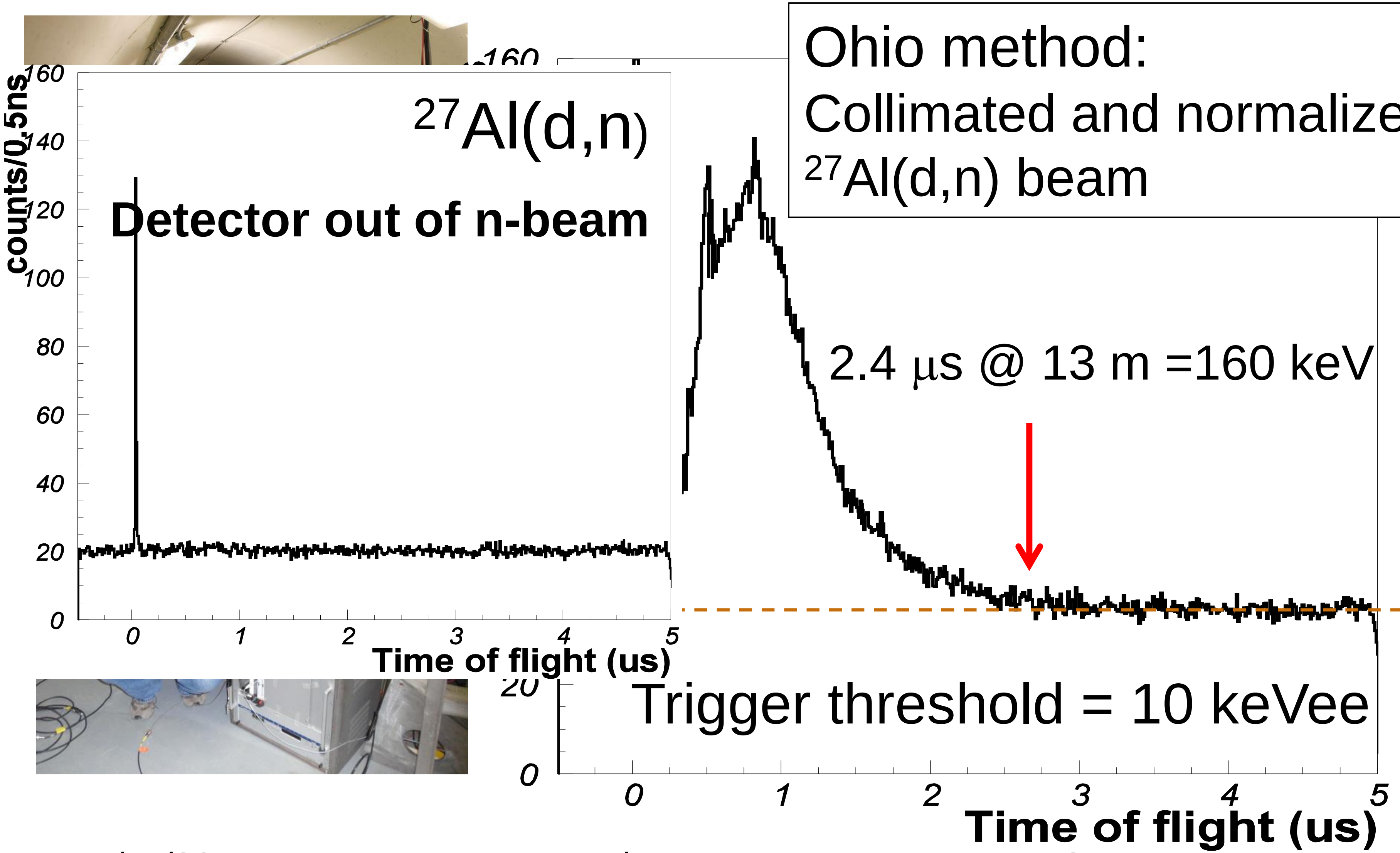


VANDLE efficiency measurement at Ohio U



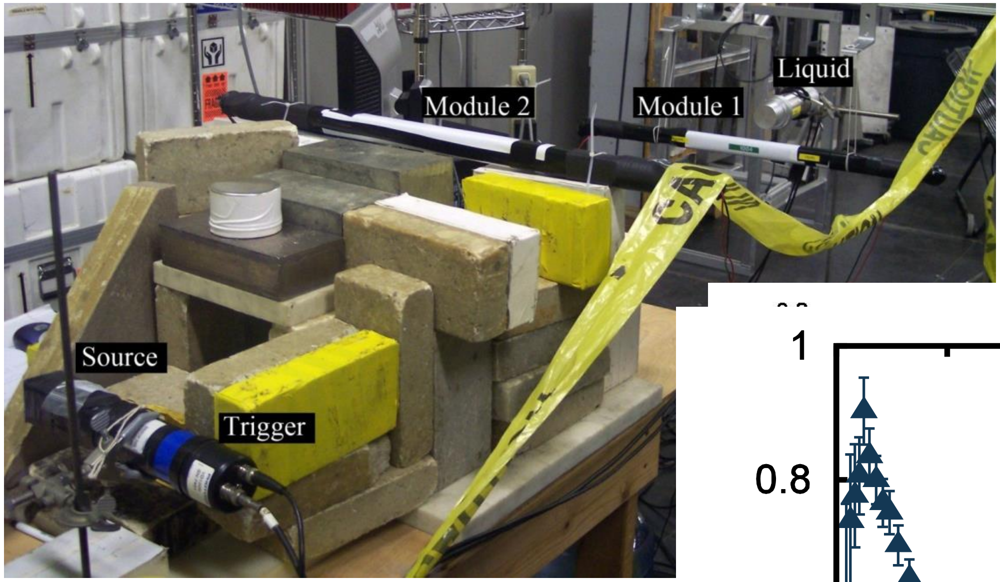
VANDLE efficiency measurement at Ohio University

Ohio method:
Collimated and normalized $^{27}Al(d,n)$ beam

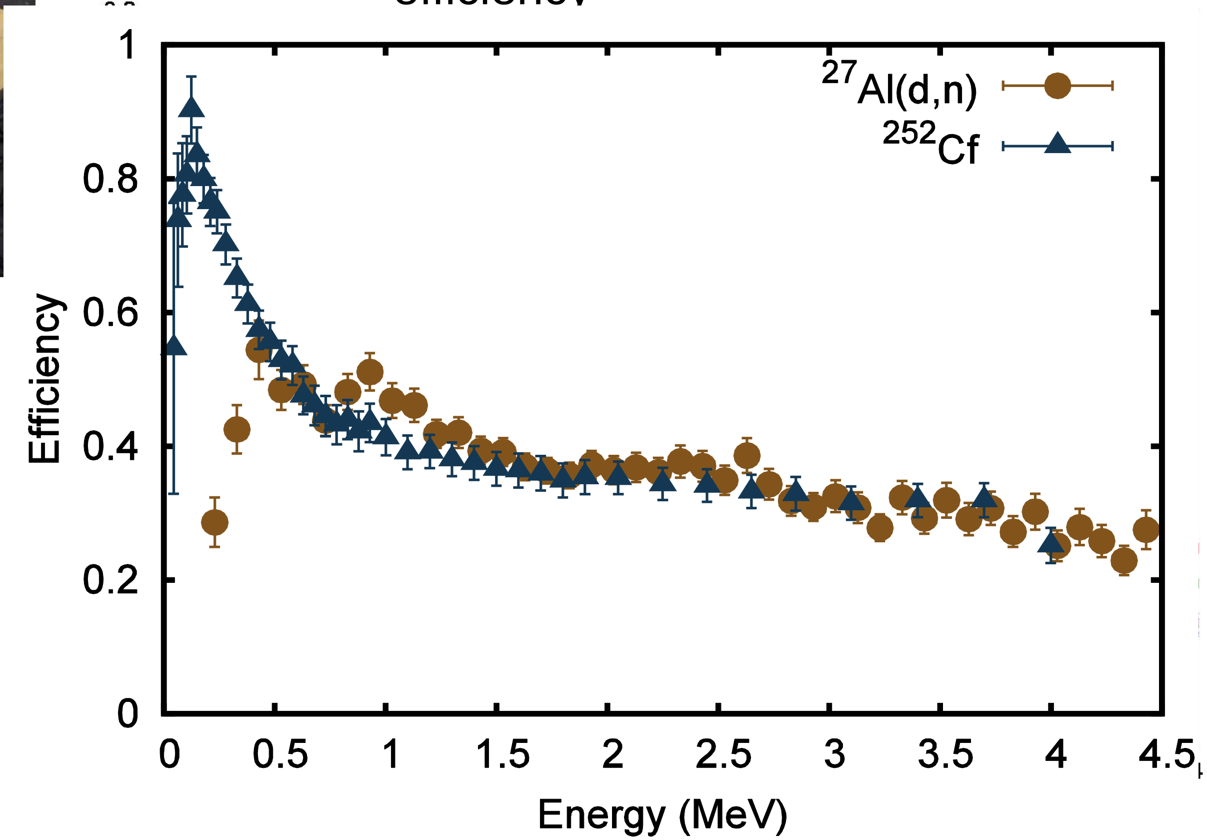


VANDLE efficiency @ ORNL

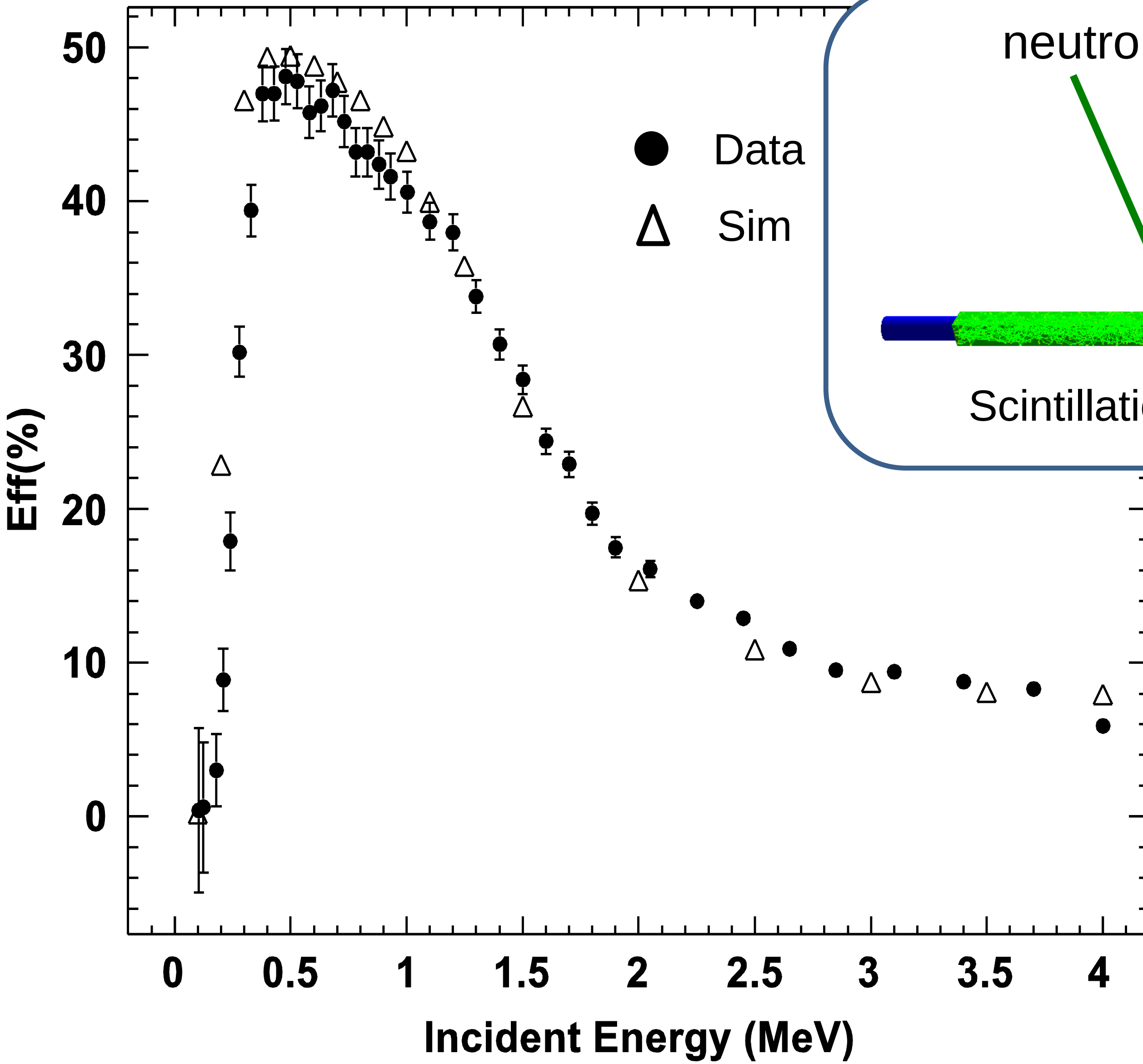
W.A. Peters & I. Spassova

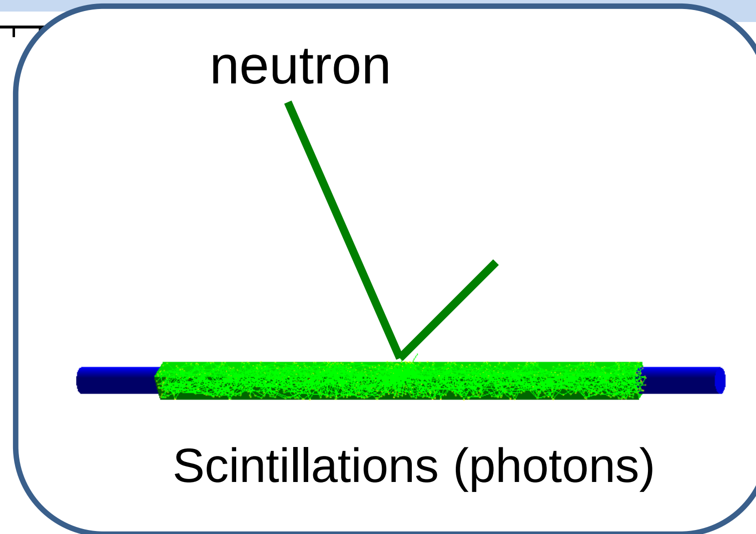


- Collimated ^{252}Cf source
- "shadowbar" measurement for scattered neutrons background
- Liquid scintillator normalized efficiency



Geant4 simulation of VANDLE bars

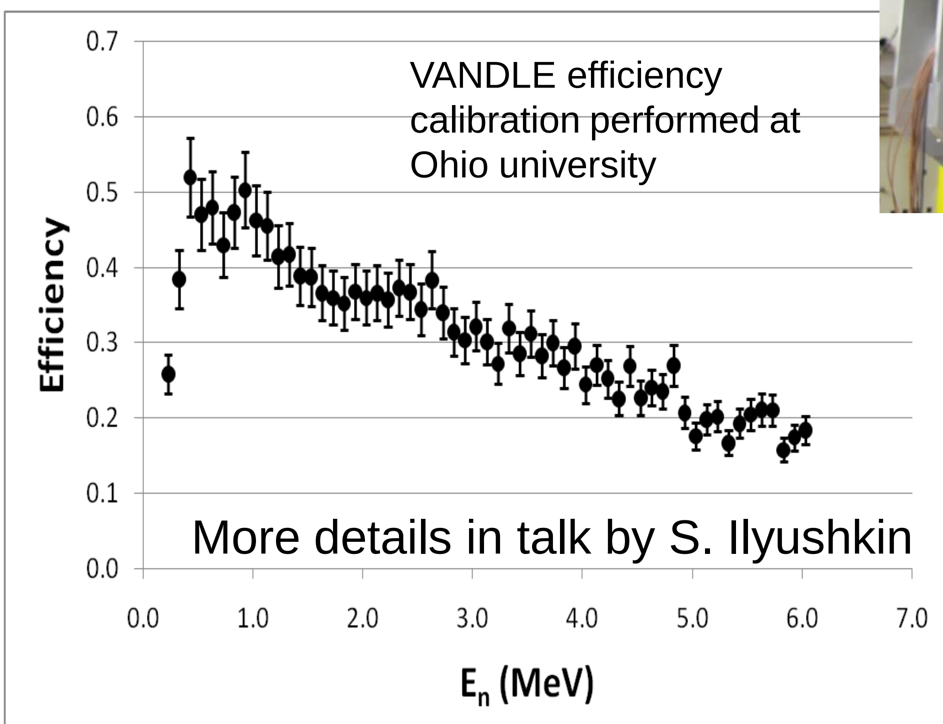


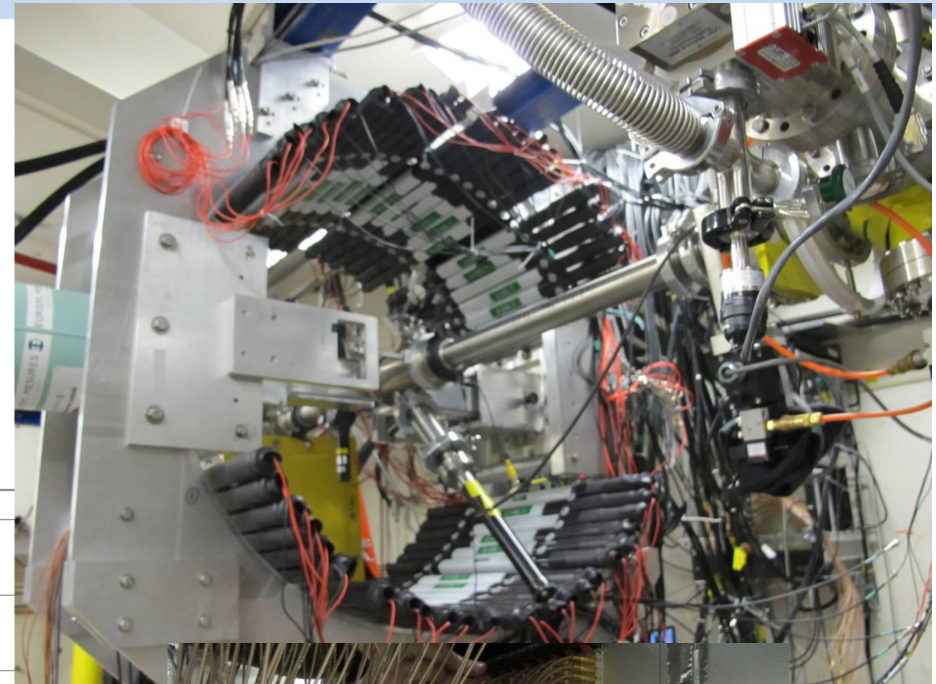


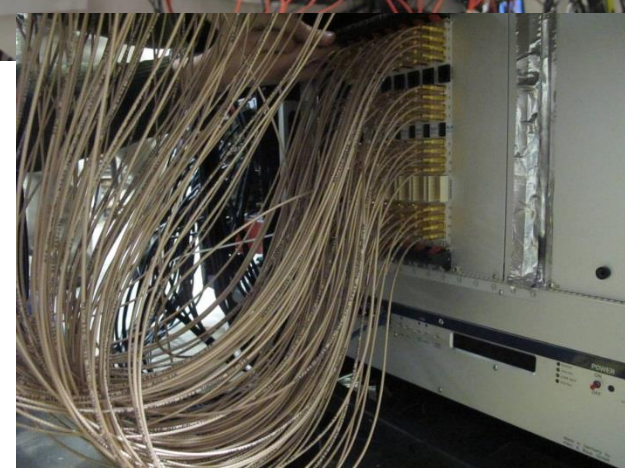
- 30 keVee threshold
- Geant4 Monte-Carlo includes:
  - Wrapping materials
  - Plastic scintillator
  - Photo-cathode acceptance

(III) Neutron Spectroscopy
The Versatile Array for Neutron Detection at Low Energies

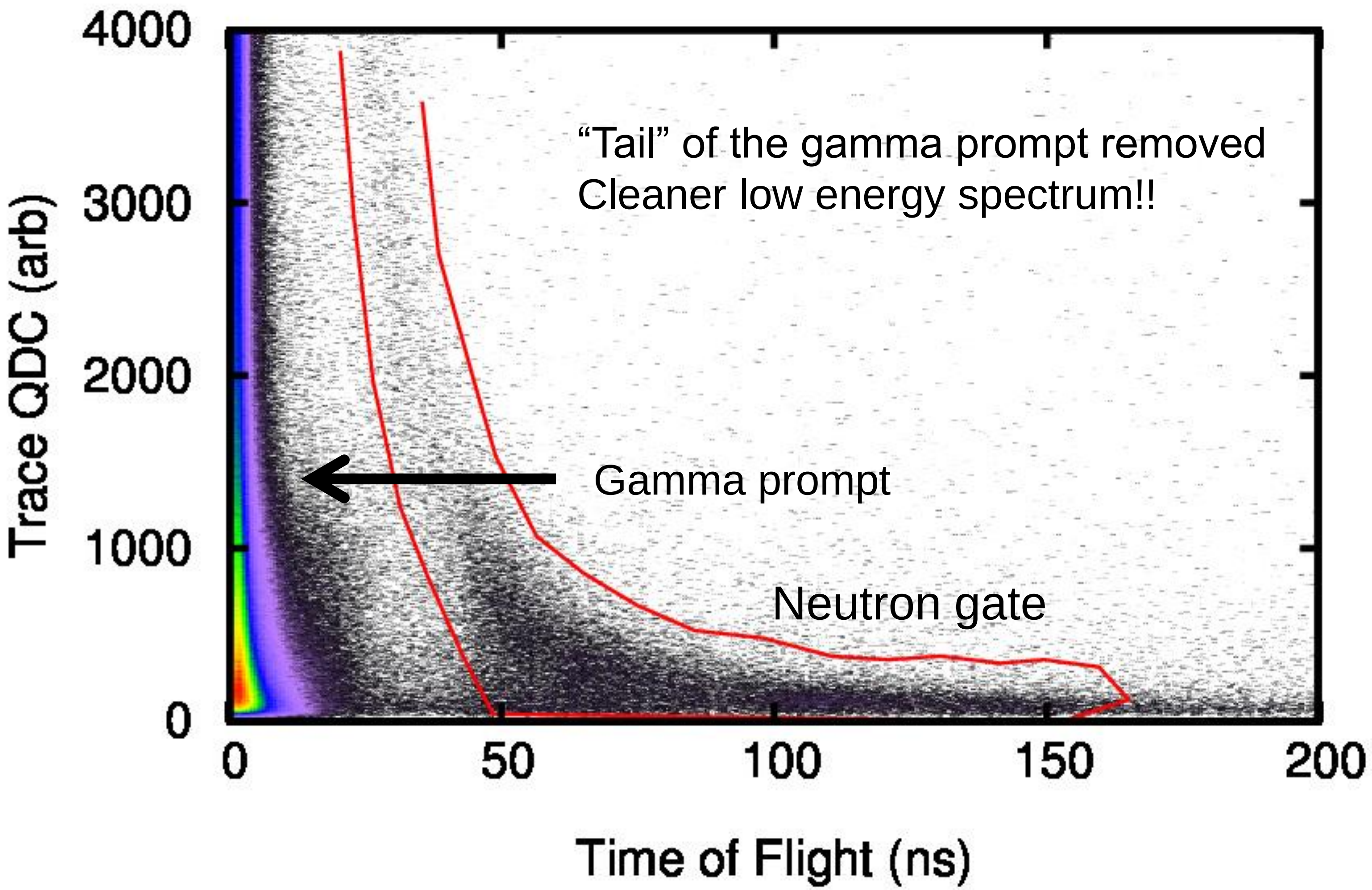
- 2 clovers, 3% efficient @ 1MeV
- 48 x 60 cm VANDLE bars
    - 45% efficiency/bar @ 1MeV
    - Ω = 10% (23%) of 4π
    - 40-60% β-trigger efficiency
    - <u>3% (6%) total efficiency @ 1MeV</u>
- Fully instrumented using XIA's Pixie 16 digitizers





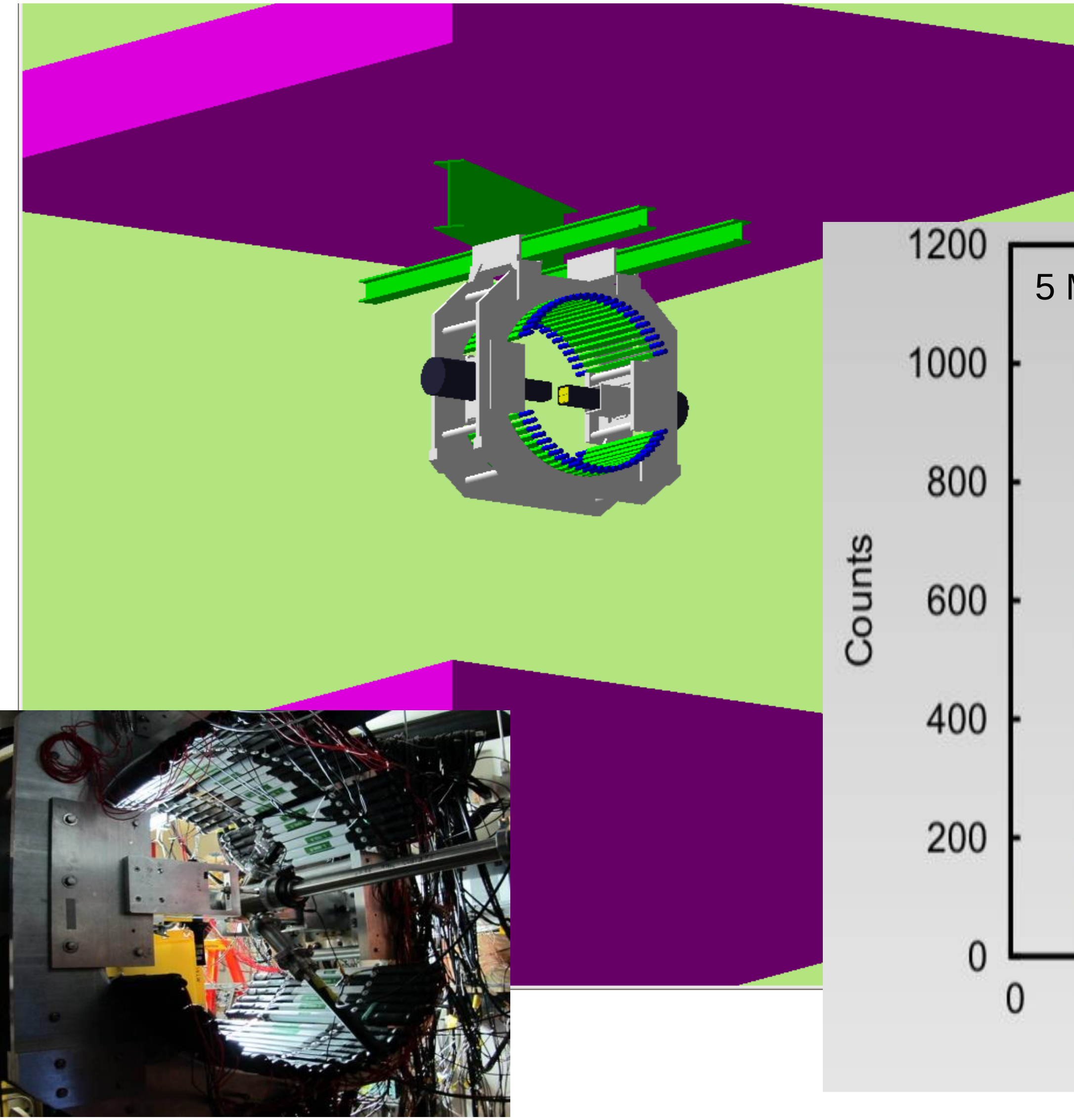


Light output vs Time of Flight: Neutron gate

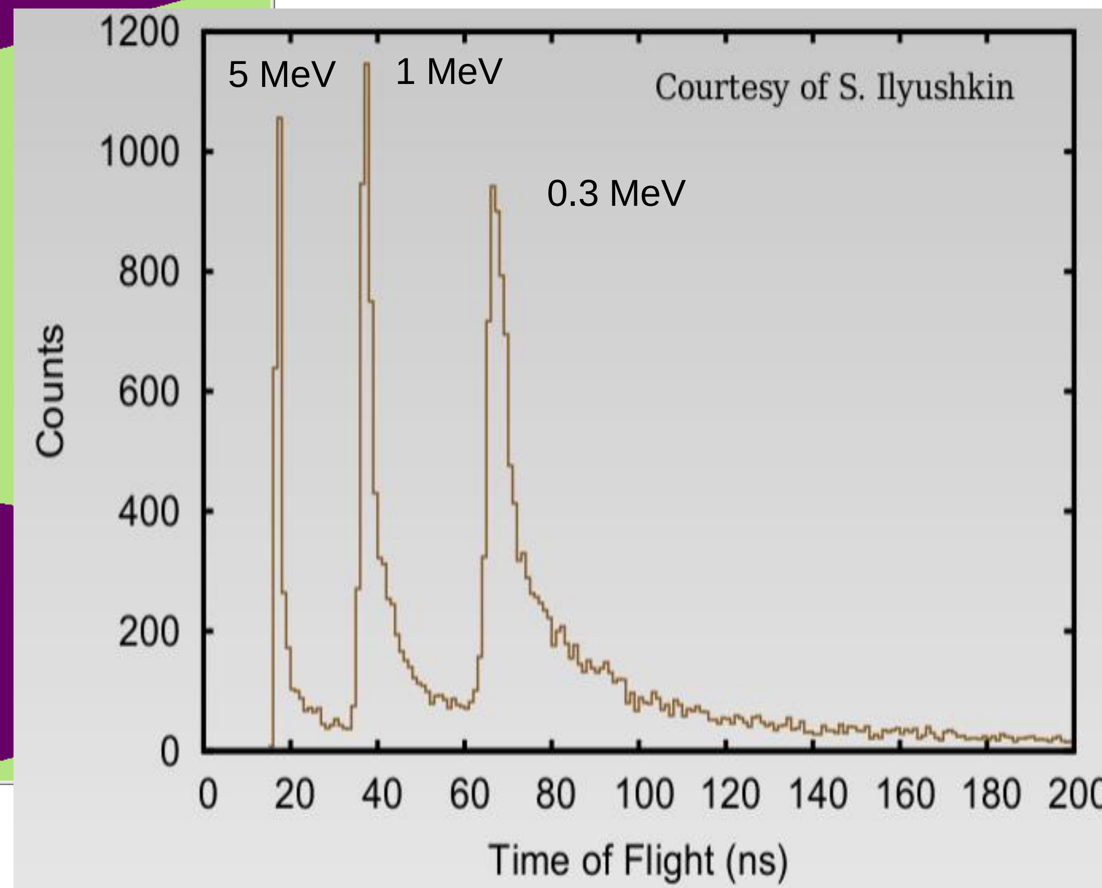


Monte Carlo simulation of LeRIBSS setup

S. Ilyushkin



Isotropic, mono-energetic neutron source



Neutron-gamma coincidences in ^{83}Ga beta decay