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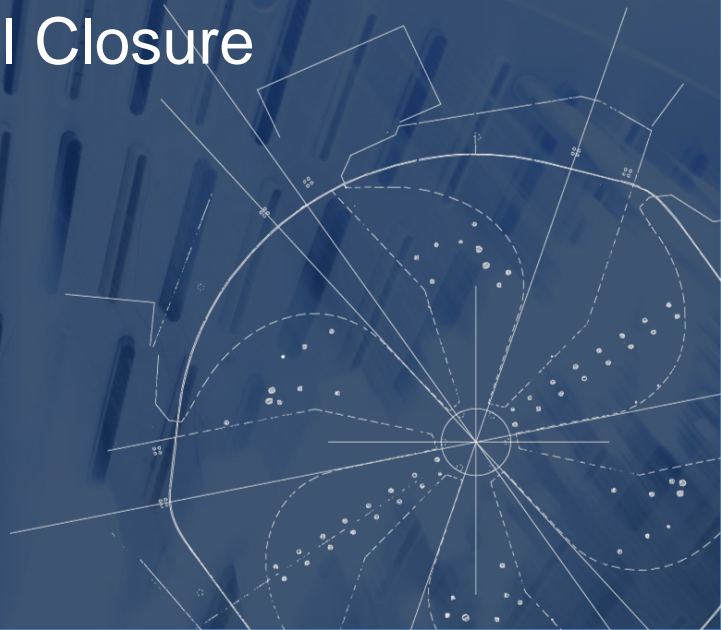
Laboratoire national canadien de physique  
des particules, de physique nucléaire et de  
science fondée sur les accélérateurs

# Decay Spectroscopy of Neutron-rich Cd Approaching the $N = 82$ Shell Closure

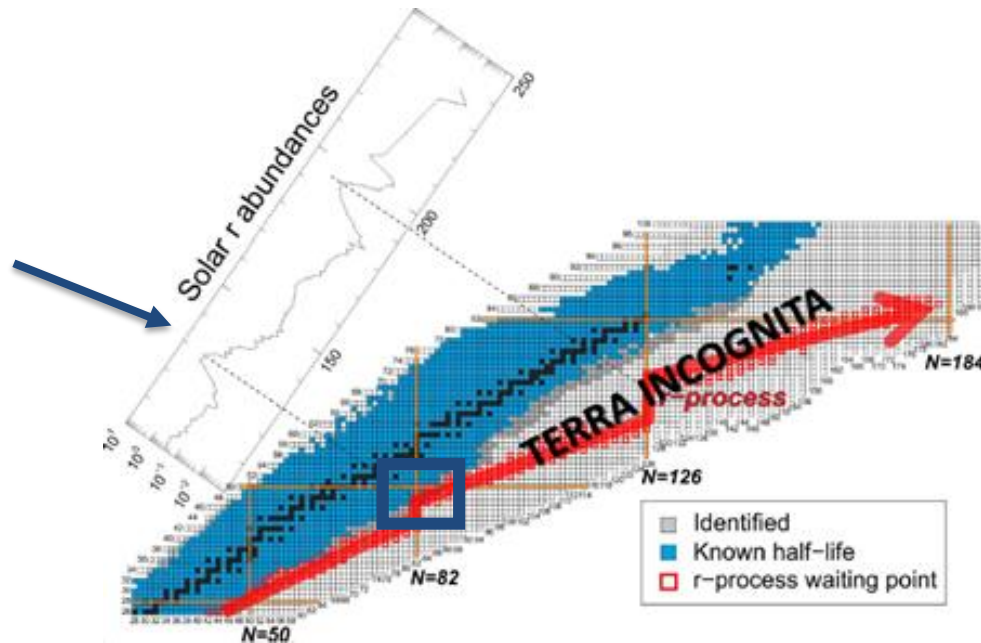
Nikita Bernier, UBC and TRIUMF  
For the GRIFFIN Collaboration

Winter Nuclear and Particle Physics Conference

February 16th, 2018.



- Rapid neutron capture (***r***-) **process** path formed by **waiting point** nuclei, where most of the *r*-process material within an isotopic chain accumulates and  $\beta$ -decays
- $N = 82$  isotope  $^{130}\text{Cd}$  provides critical information on the position and shape of the 2nd *r*-process **abundance peak** at  $A \sim 130$ .

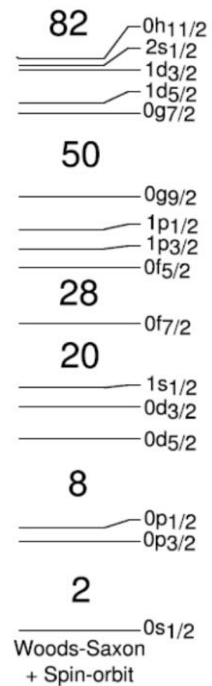




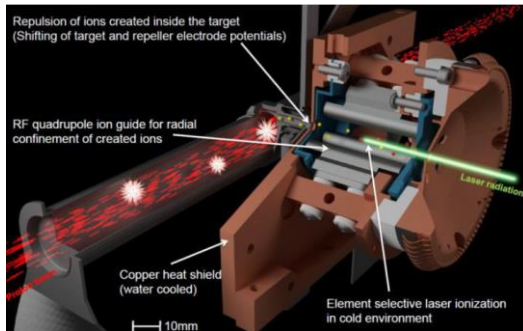
- Special interest for **nuclear structure** since  $^{128-132}\text{Cd}$  are neighboring the **doubly-magic**  $^{132}\text{Sn}$  which is central to shell model predictions:  $^{130}\text{Cd}$  is 2p hole,  $^{128}\text{Cd}$  is 2p-2n hole.

	$^{128}\text{Sn}$ 59.07 M	$^{129}\text{Sn}$ 2.23 M	$^{130}\text{Sn}$ 3.72 M	$^{131}\text{Sn}$ 56.0 S	$^{132}\text{Sn}$ 39.7 S	$^{133}\text{Sn}$ 1.46 S	$^{134}\text{Sn}$ 1.050 S	$^{135}\text{Sn}$ 530 MS	$^{136}\text{Sn}$ 0.25 S
Z	$\beta^-$ : 100.00%	$\beta^-$ : 100.00%	$\beta^-$ : 100.00%	$\beta^-$ : 100.00%	$\beta^-$ : 100.00%	$\beta^-$ : 100.00% $\beta^-n$ : 0.03%	$\beta^-$ : 100.00% $\beta^-n$ : 17.00%	$\beta^-$ : 100.00% $\beta^-n$ : 21.00%	$\beta^-$ : 100.00% $\beta^-n$ : 30.00%
	$^{127}\text{In}$ 1.09 S	$^{128}\text{In}$ 0.84 S	$^{129}\text{In}$ 0.61 S	$^{130}\text{In}$ 0.29 S	$^{131}\text{In}$ 0.28 S	$^{132}\text{In}$ 0.207 S	$^{133}\text{In}$ 165 MS	$^{134}\text{In}$ 140 MS	$^{135}\text{In}$ 92 MS
49	$\beta^-$ : 100.00% $\beta^-n$ : 0.03%	810 (30) ms	370 (10) ms	284 (10) ms	261 (3) ms	190 (2) ms	163 (7) ms	126 (7) ms	103 (5) ms
		$\beta^-n$ : 0.25%	$\beta^-n$ : 0.93%	$\beta^-n$ : 2.00%	$\beta^-n$ : 6.30%	$\beta^-n$ : 65.00%	$\beta^-n$ : 65.00%	$\beta^-n$ : 65.00%	$\beta^-n$
	$^{126}\text{Cd}$ 0.515 S	$^{127}\text{Cd}$ 0.7 S	$^{128}\text{Cd}$ 0.28 S	$^{129}\text{Cd}$ 0.2 S	$^{130}\text{Cd}$ 162 S	$^{131}\text{Cd}$ 68 MS	$^{132}\text{Cd}$ 97 MS	$^{133}\text{Cd}$ 57 MS	
48	$\beta^-$ : 100.00%	$\beta^-$ : 100.00%	245 (5) ms	151 (8) ms 151 (15) ms	127 (2) ms $\beta^-n$ : 3.00%	98 (2) ms $\beta^-n$ : 3.50%	82 (4) ms $\beta^-n$ : 60.00%	64 (8) ms $\beta^-n$	
	$^{125}\text{Ag}$ 166 MS	$^{126}\text{Ag}$ 107 MS	$^{127}\text{Ag}$ 100 MS	$^{128}\text{Ag}$ 58 MS	$^{129}\text{Ag}$ 46 MS	$^{130}\text{Ag}$ 350 MS			
47	$\beta^-$ : 100.00% $\beta^-n$	$\beta^-$ : 100.00% $\beta^-n$	$\beta^-$ : 100.00%	$\beta^-$ : 100.00% $\beta^-n$	$\beta^-$ : 100.00% $\beta^-n$	$\beta^-$ : 100.00% $\beta^-n$			
	$^{124}\text{Pd}$ 38 MS	$^{125}\text{Pd}$ >230 NS	$^{126}\text{Pd}$ >230 NS		$^{128}\text{Pd}$ >394 NS				
46	$\beta^-$ : 100.00%	$\beta^-n$ $\beta^-$	$\beta^-n$ $\beta^-$		$\beta^-n$ $\beta^-$				
	78	79	80	81	82	83	84	85	N

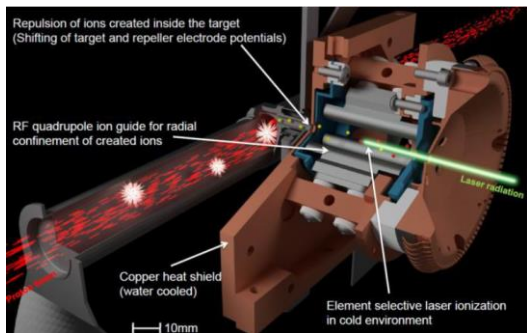
Recent  $t_{1/2}$  measurements:  
 Lorusso et al., PRL 114, 192501 (2015)  
 Taprogge et al., PRC 91, 054324 (2015)



- Selective ionization with the Ion Guide Laser Ion Source [IG-LIS]
  - Measured background suppression by factors  $10^5$ - $10^6$

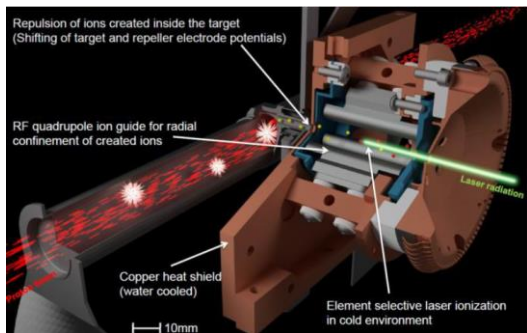


- Selective ionization with the **Ion Guide Laser Ion Source [IG-LIS]**
  - Measured background suppression by factors  **$10^5$ - $10^6$**
- High statistics  $\beta$ - $\gamma$ - $\gamma$  with **SCEPTAR** : SCintillating Electron Positron Tagging Array

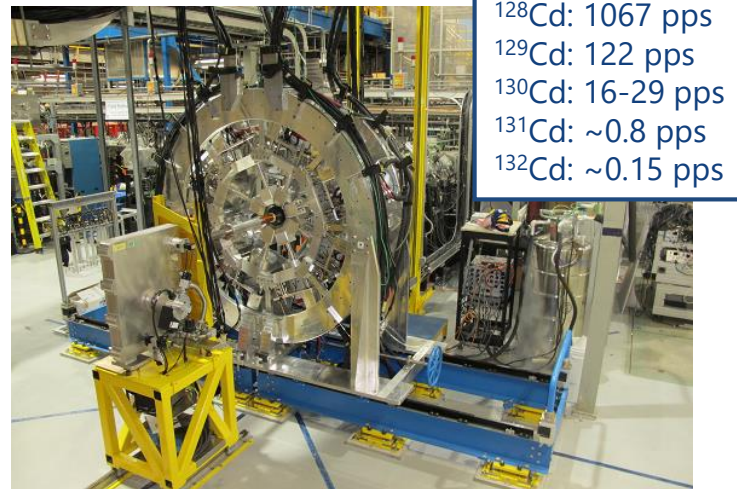


*In-vacuum moving tape collector system*

- Selective ionization with the **Ion Guide Laser Ion Source [IG-LIS]**
  - Measured background suppression by factors  **$10^5$ - $10^6$**
- High statistics  $\beta$ - $\gamma$ - $\gamma$  with **SCEPTAR** : SCintillating Electron Positron Tagging Array
- 16 large-volume High Purity Germanium clover **GRIFFIN** detectors dedicated to **decay spectroscopy** of the low-energy radioactive ion beams at TRIUMF.

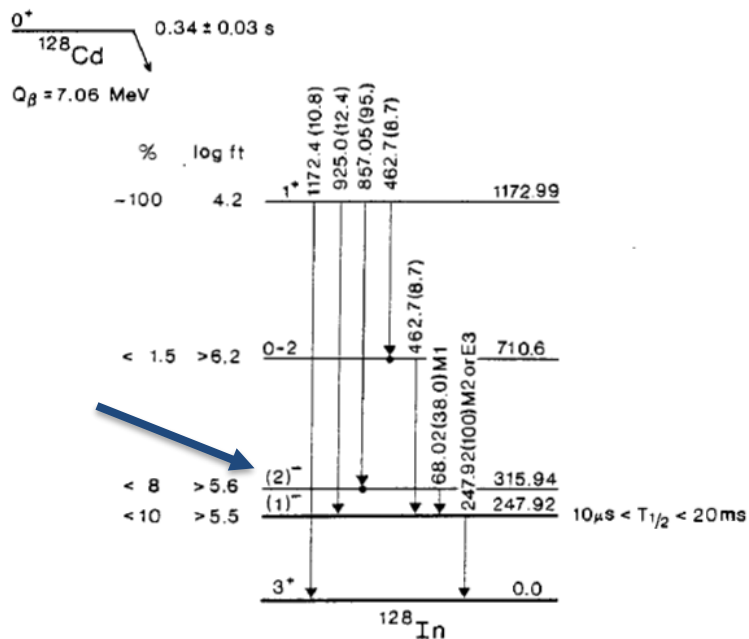


*In-vacuum moving tape collector system*



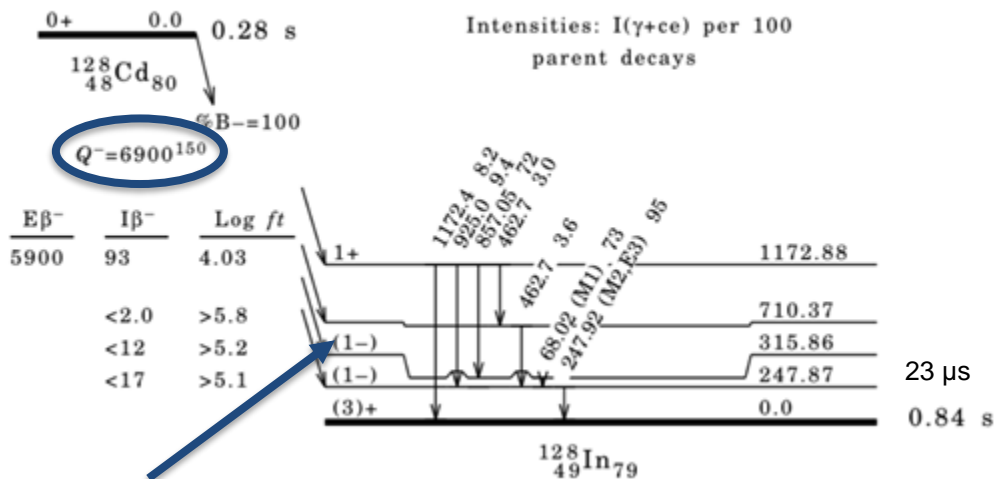
Measured
$^{128}\text{Cd}$ : 1067 pps
$^{129}\text{Cd}$ : 122 pps
$^{130}\text{Cd}$ : 16-29 pps
$^{131}\text{Cd}$ : ~0.8 pps
$^{132}\text{Cd}$ : ~0.15 pps

- 1988 experiment in Sweden: 7 transitions and 4 levels
- Multipolarities from conversion electron measurements.



Work by B. Ekstrom quoted in  
 B. Fogelberg, Nucl. Data for Sc. and Tech., **837** (1988)

$^{128}\text{In} S(n) = 5320 (150) \text{ keV}$

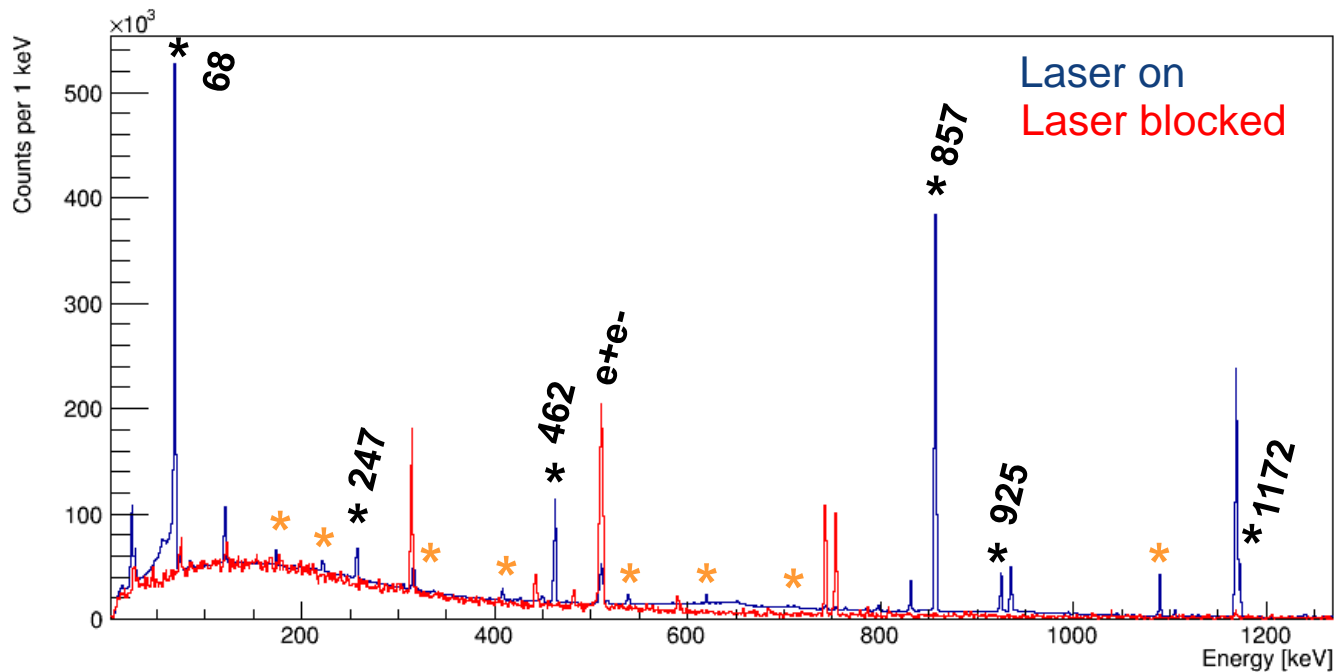


Z. Elekes and J. Timar, Nucl. Data Sheets **129**, 191 (2015)



### Further discrimination of **isobaric background**:

- Identification of transitions by comparing laser **on** (Cd + In) and laser **blocked** (mostly In)



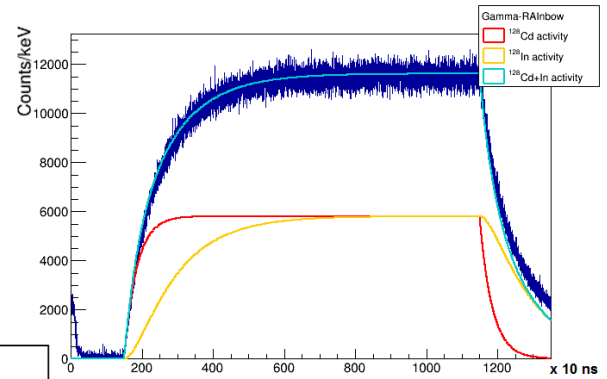
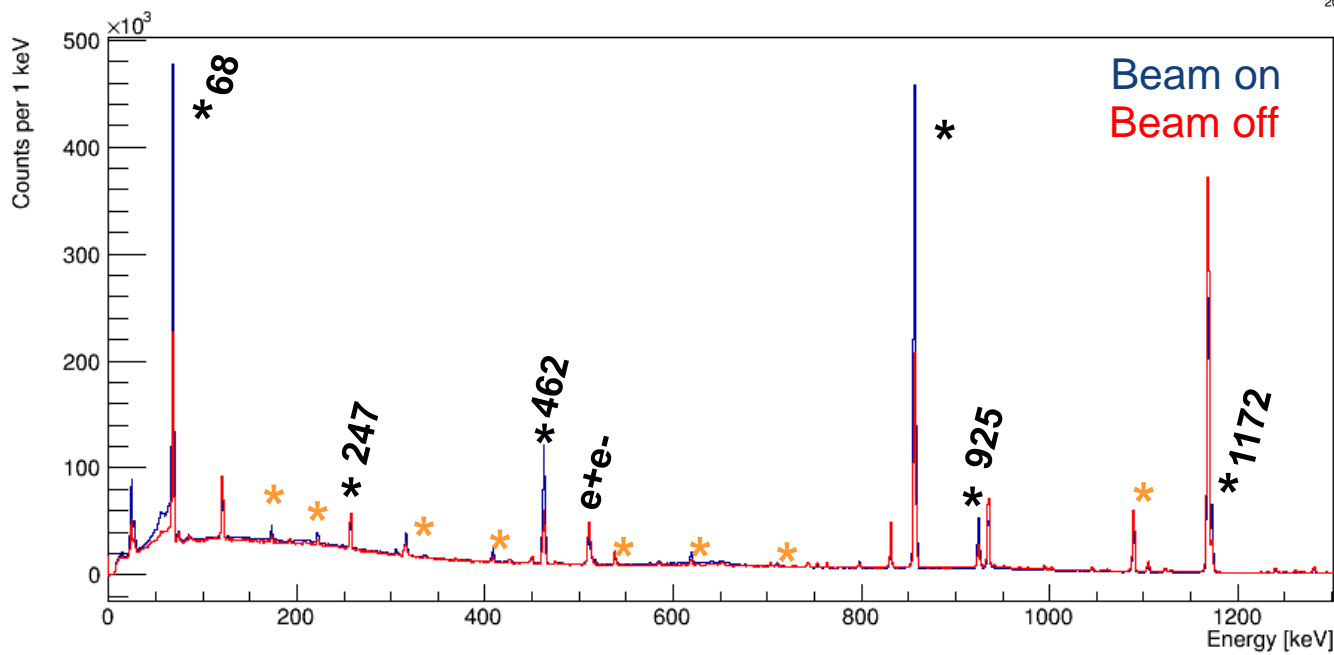
$\beta$ -gated  $\gamma$ -singles

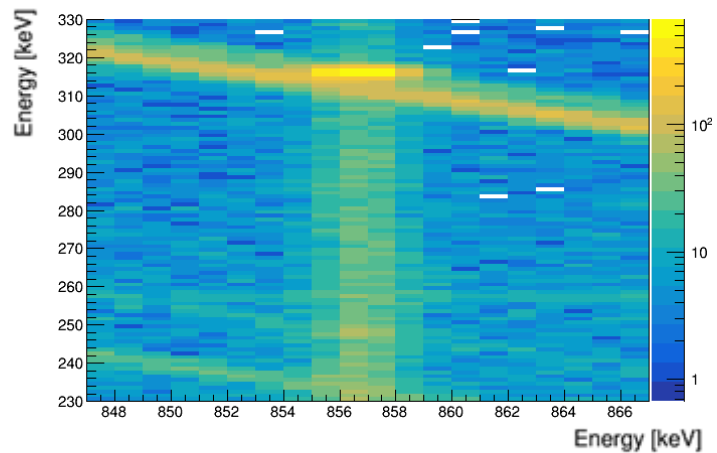
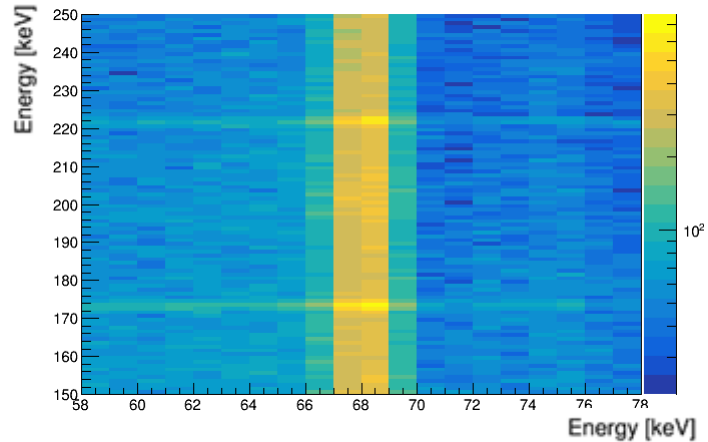
\* **Known**  $^{128}\text{Cd} \rightarrow ^{128}\text{In}$

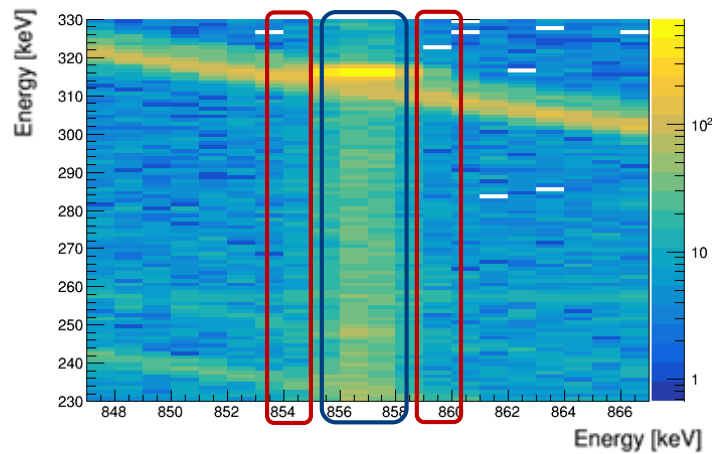
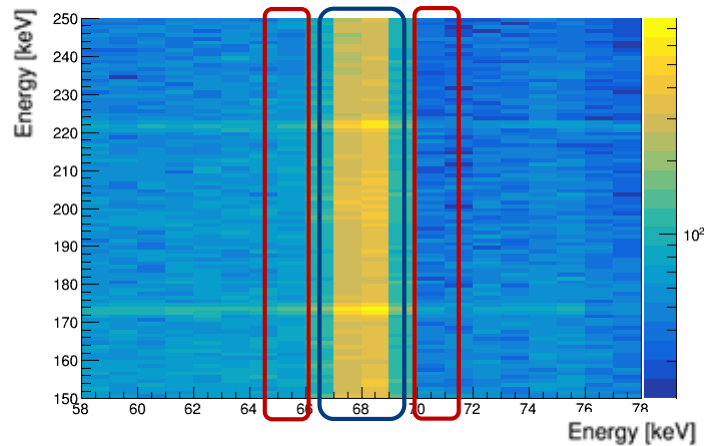
\* **New**  $^{128}\text{Cd} \rightarrow ^{128}\text{In}$

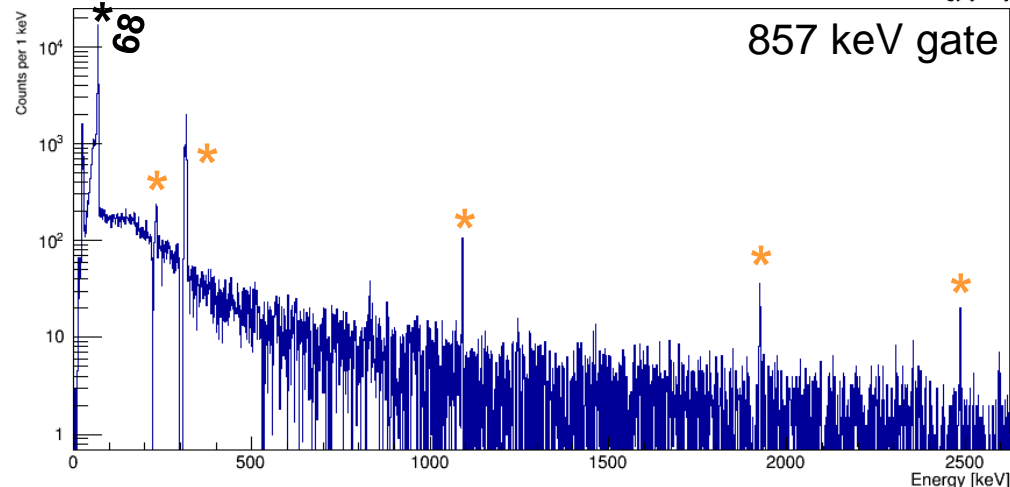
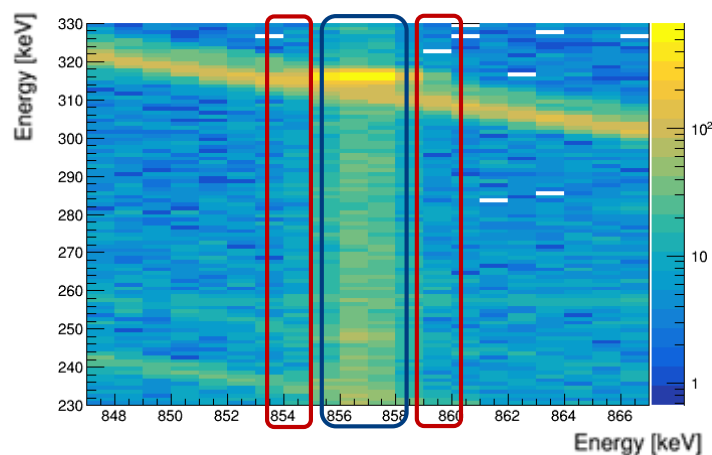
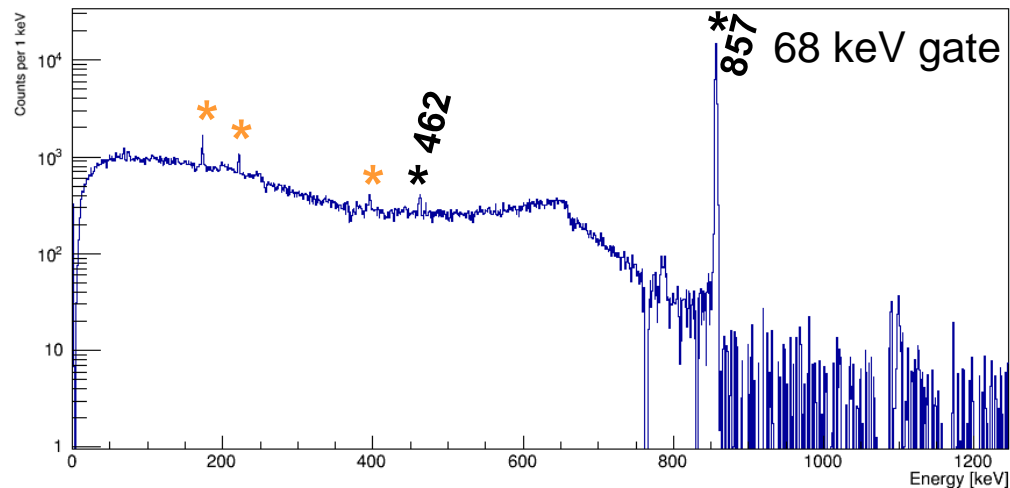
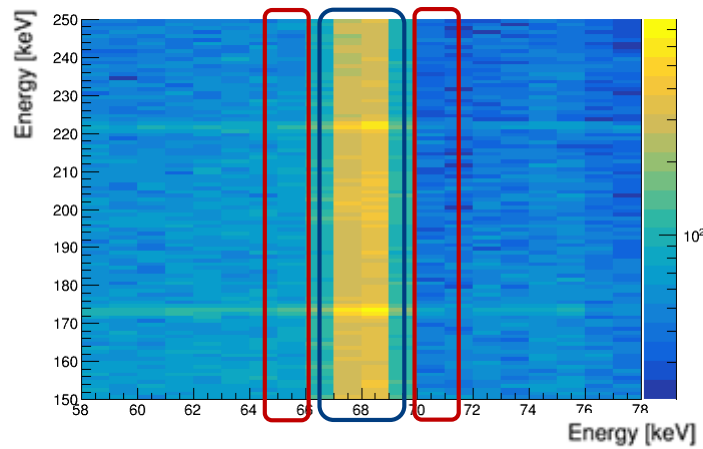
## Further discrimination of **decaying daughters**:

- Identification of transitions by comparing beam **on** data (Cd + In) and beam **off** data (mostly In)

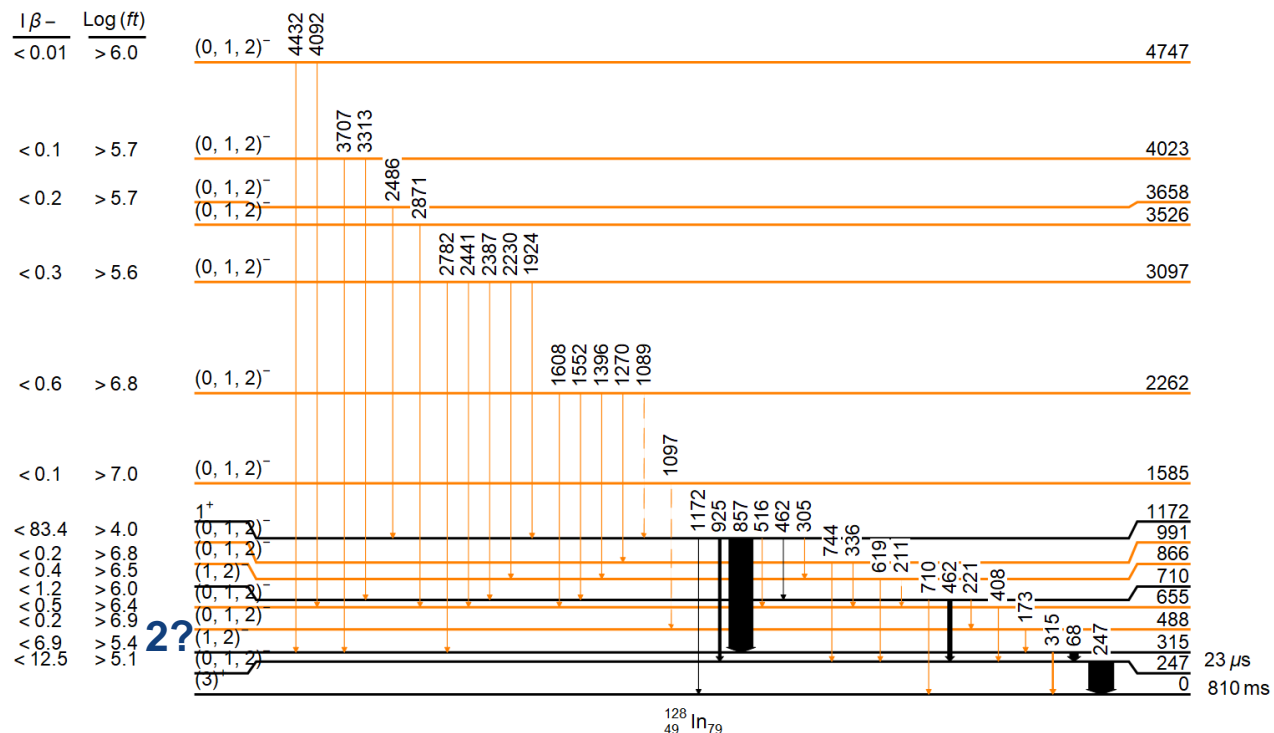








- 28 **new** transitions and 11 **new** states
- Spin assignments with **log(ft)** values and Shell Model predictions



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- Spin assignments with **log(ft)** values and Shell Model predictions

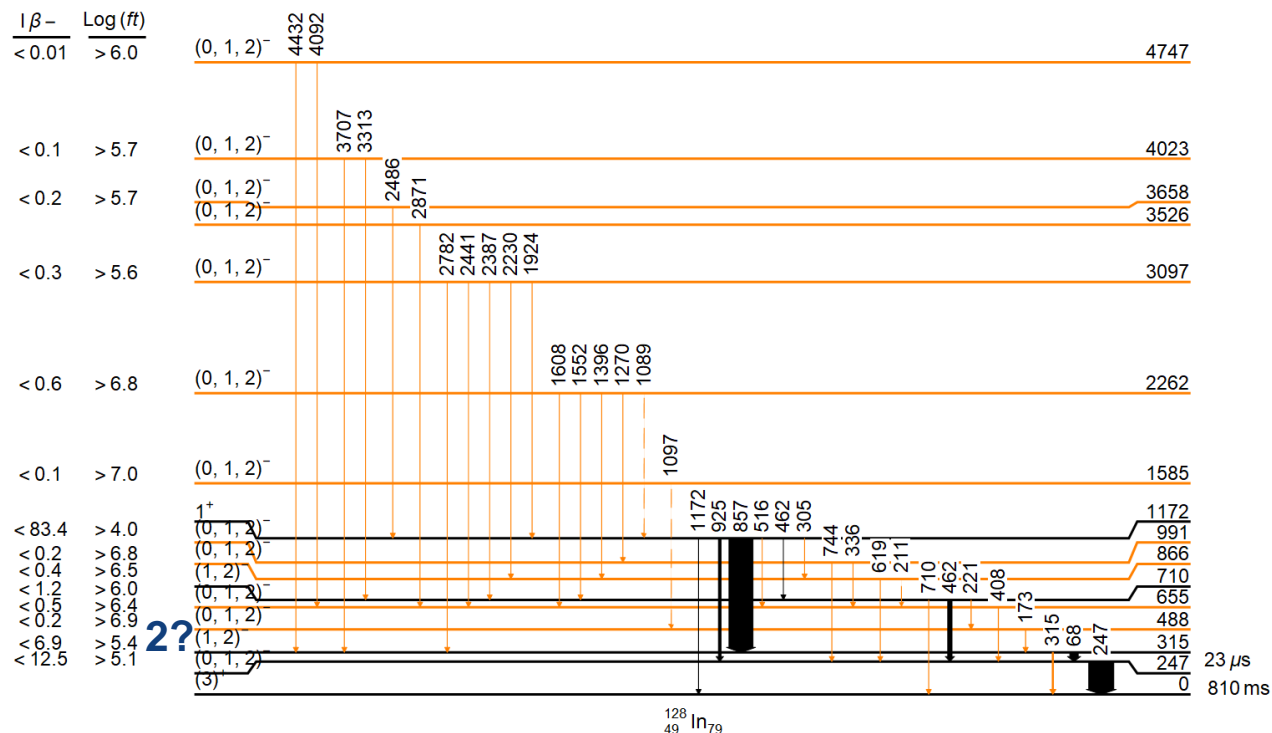
$$ft = \frac{f(Q_\beta - E_f, Z)T_{1/2}}{I_\beta(E_f)}$$

$$= \frac{k}{g_V^2 B(F) + g_A^2 B(GT)}$$

$$k = \frac{2 \ln 2 \pi^3 \hbar^7}{m_e^5 c^4}$$

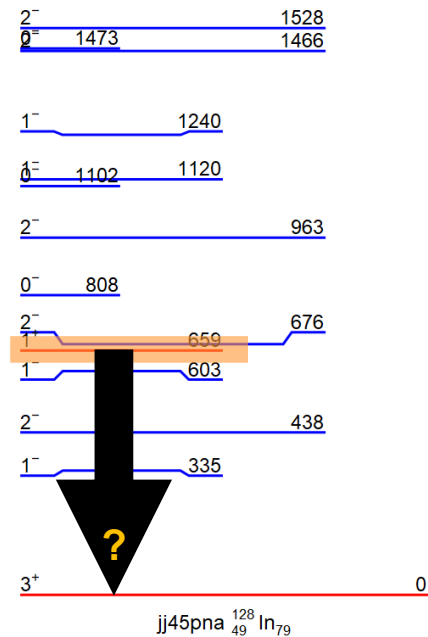
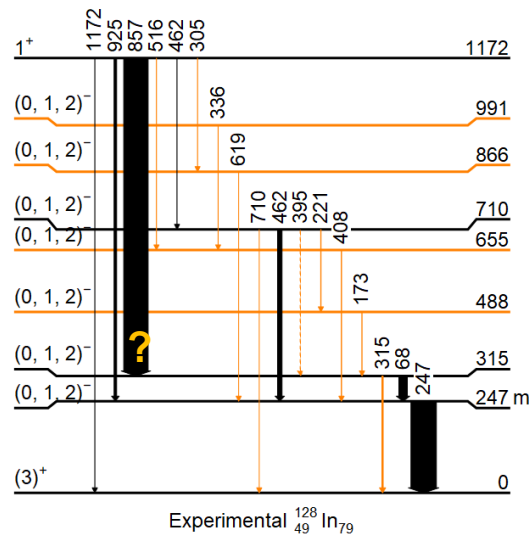
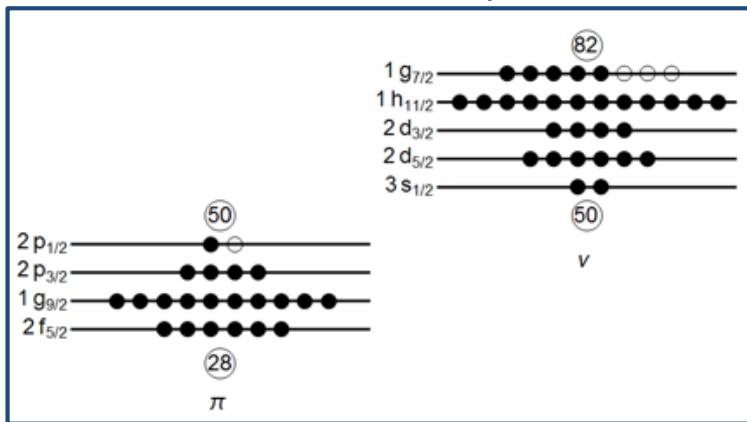
$$B(F) = |\langle \psi_f^* | \tau | \psi_I \rangle|^2$$

$$B(GT) = |\langle \psi_f^* | \sigma \tau | \psi_I \rangle|^2$$



- First 1+ decays ~100% to the ground state
- J. Holt from TRIUMF theory group is working on further calculations.

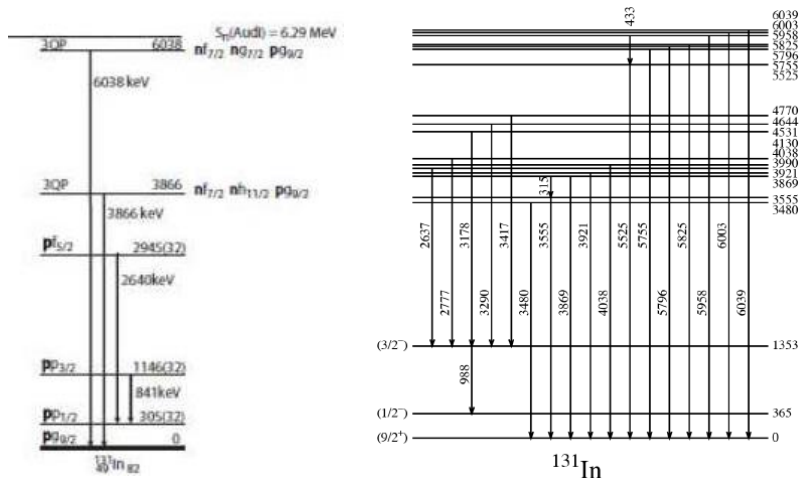
NuShellX model space



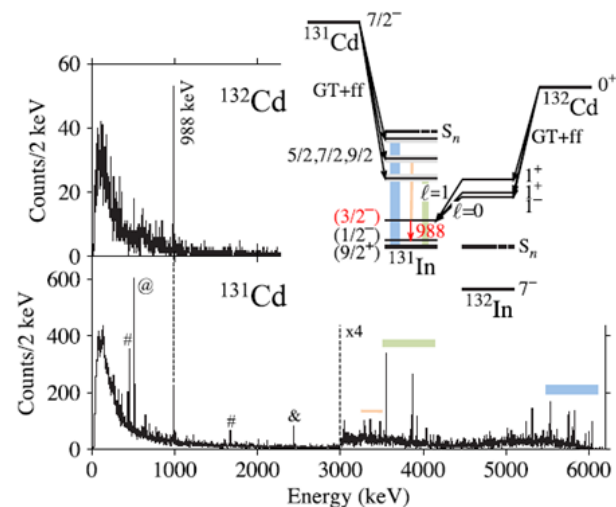


- 7 transitions observed in  $^{131}\text{In}$  at ISOLDE, **23** at RIKEN: only **3** transitions in common
- No  $\gamma$ -transitions observed from the  $\beta$ -decay of  $^{132}\text{Cd}$  to  $^{132}\text{In}$ .

$^{131}\text{Cd} Q(\beta^-) = 12700 (510) \text{ keV}$   
 $^{131}\text{In} S(n) = 6210 (40) \text{ keV}$



$^{132}\text{Cd} Q(\beta^-) = 12150 (510) \text{ keV}$   
 $^{132}\text{In} S(n) = 2450 (60) \text{ keV}$



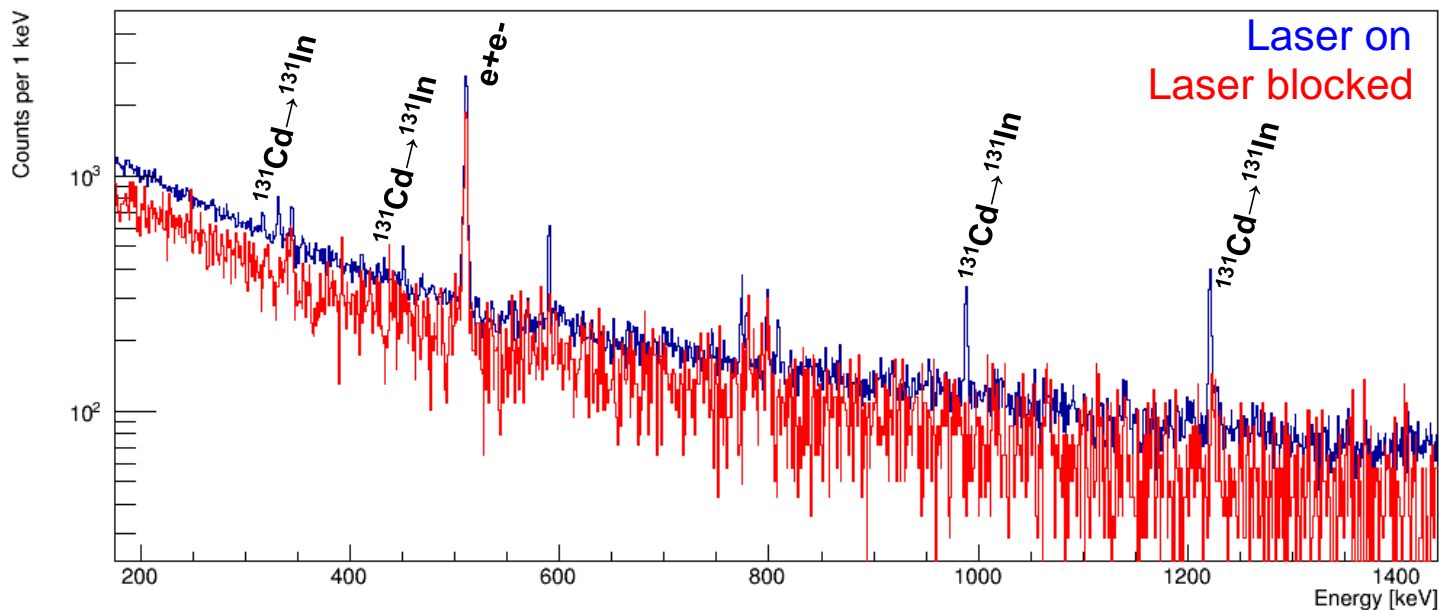
O. Arndt *et al.*, Acta Phys. Pol. B **40**, 437 (2009)

C. Jost, PhD thesis, U of Mainz (2010)

J. Taprogge *et al.*, Eur. Phys. J. A **52**, 347 (2016)

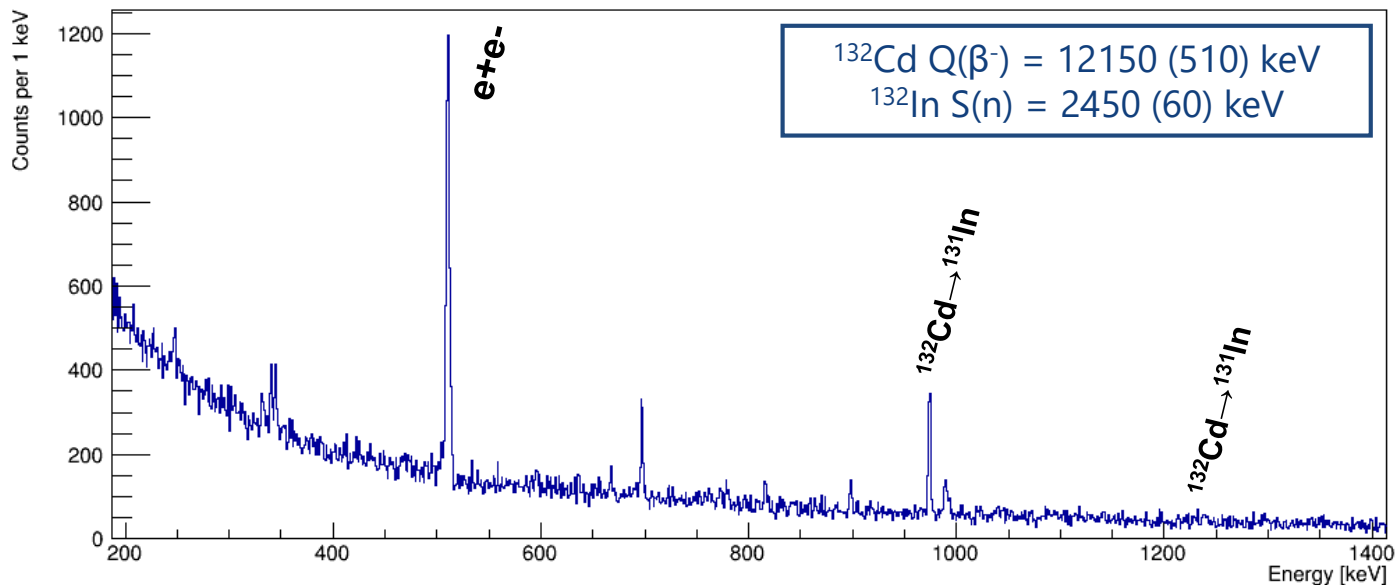
J. Taprogge *et al.*, Phys. Rev. Lett. **112**, 132501 (2014)

- 32 hours at ~0.8 pps, comparable to EURICA/RIKEN statistics
- Many transitions confirmed: **5/7** (O. Arndt *et al.*, Acta Phys. Pol. B **40**, 437, 2009)  
**22/23** (J. Taprogge *et al.*, Eur. Phys. J. A **52**, 347, 2016)



- Very low neutron separation energy  $\rightarrow$  large neutron branching ratio ( $P_n$ )
  - **988 keV** in both  $^{131-132}\text{Cd}$  datasets
  - No  $\gamma$ -transitions observed from  $\beta$ -decay of  $^{132}\text{Cd}$  into  $^{132}\text{In}$ , yet
  - $P_n$  closer to 100% than previously reported: **60(15) %**

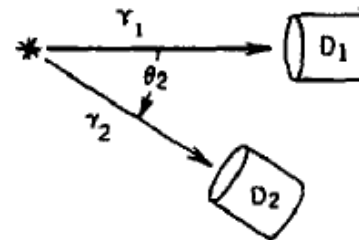
M. Hannawald *et al.*,  
Phys. Rev. C **62**, 054301 (2000).



18 hours at  $\sim 0.15$  pps:  
Lowest yield ever  
measured with 8 $\pi$  and  
GRIFFIN!

## Detailed $\gamma$ -spectroscopy of $^{128-132}\text{Cd}$ $\beta$ -decay in progress

- $^{128}\text{Cd}$  nuclear structure:
  - **28** new transitions and **11** new levels so far
  - More Shell Model calculations, angular correlations....
- $^{131-132}\text{Cd}$  analysis in progress
- $^{129-130}\text{Cd}$  analysis by Y. Saito [UBC/TRIUMF] and M. Bowry [TRIUMF]
- Half-lives of  $^{128-130}\text{Cd}$ : R. Dunlop *et al.*, Phys. Rev. C **93**, 062801(R) (2016).



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Montréal | Northern British Columbia | Queen's |  
Regina | Saint Mary's | Simon Fraser | Toronto |  
Victoria | Western | Winnipeg | York

# Merci ! Thank you!

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8 CSIC Madrid

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