# First Results from GRIFFIN Half-lives of Neutron Rich $^{128-130}Cd$ and $^{131}In$

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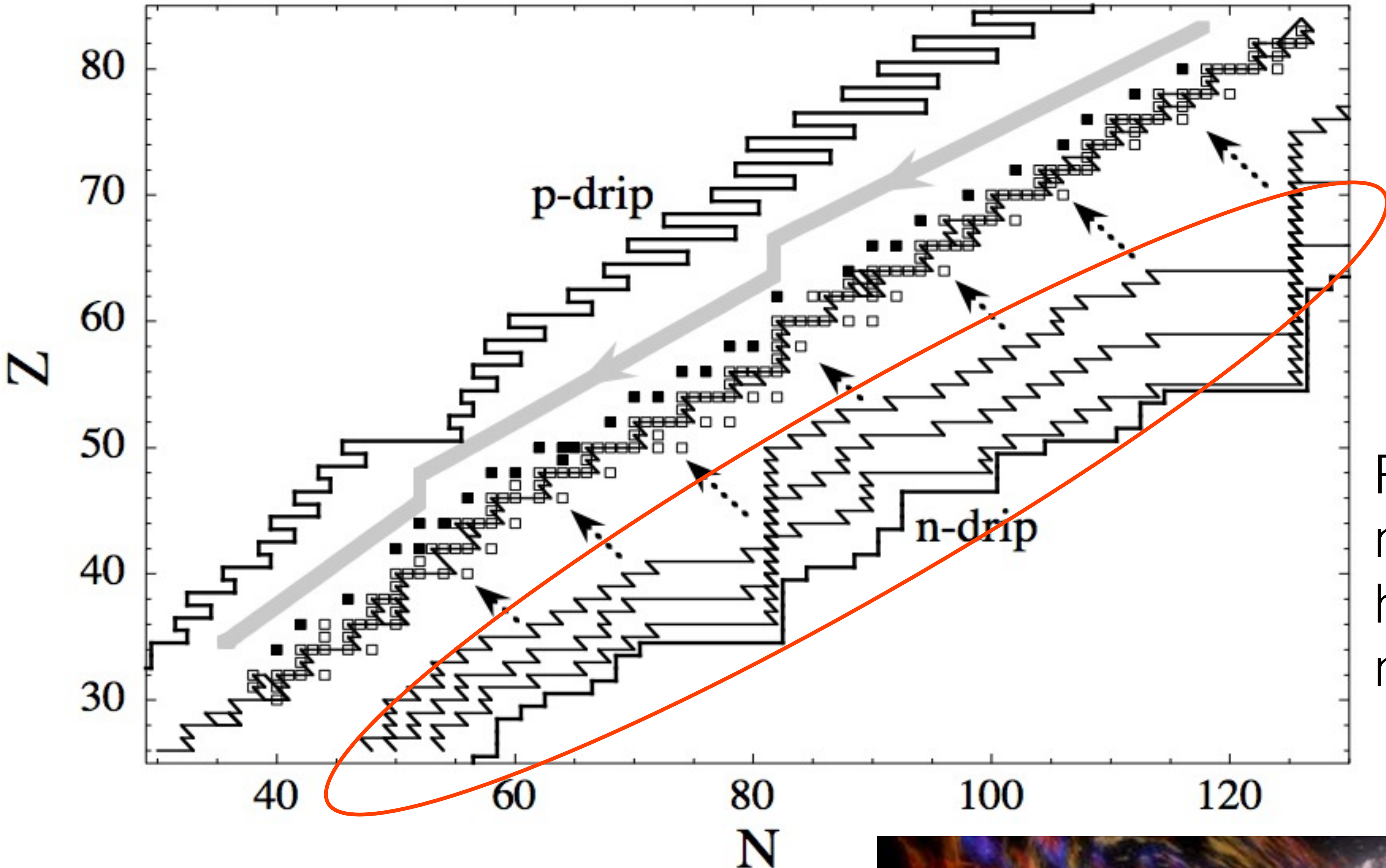
INPC 2016

# r-process




High n density
fast capturing

Produces many of the naturally occurring, heavy, neutron-rich nuclei

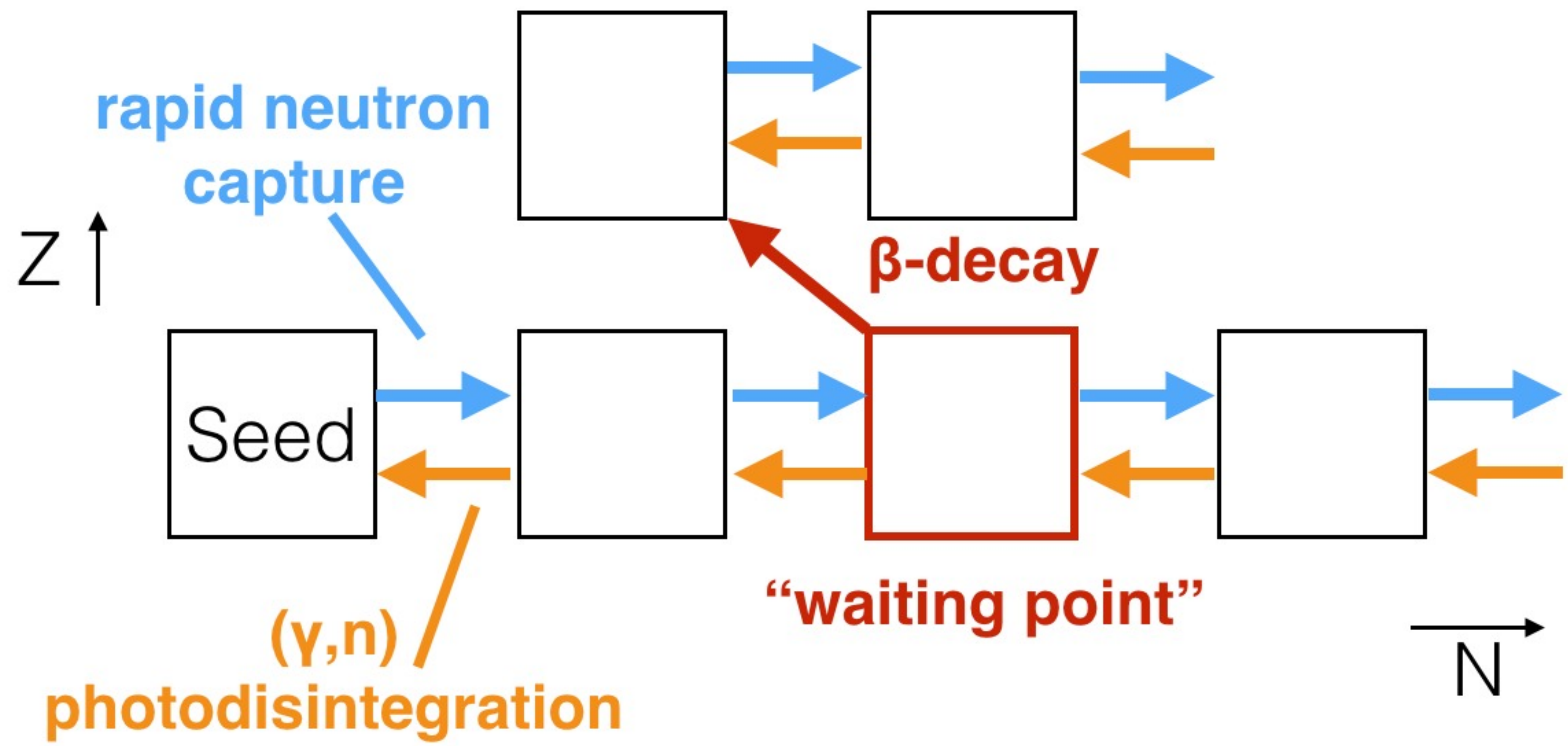
Site of r-process

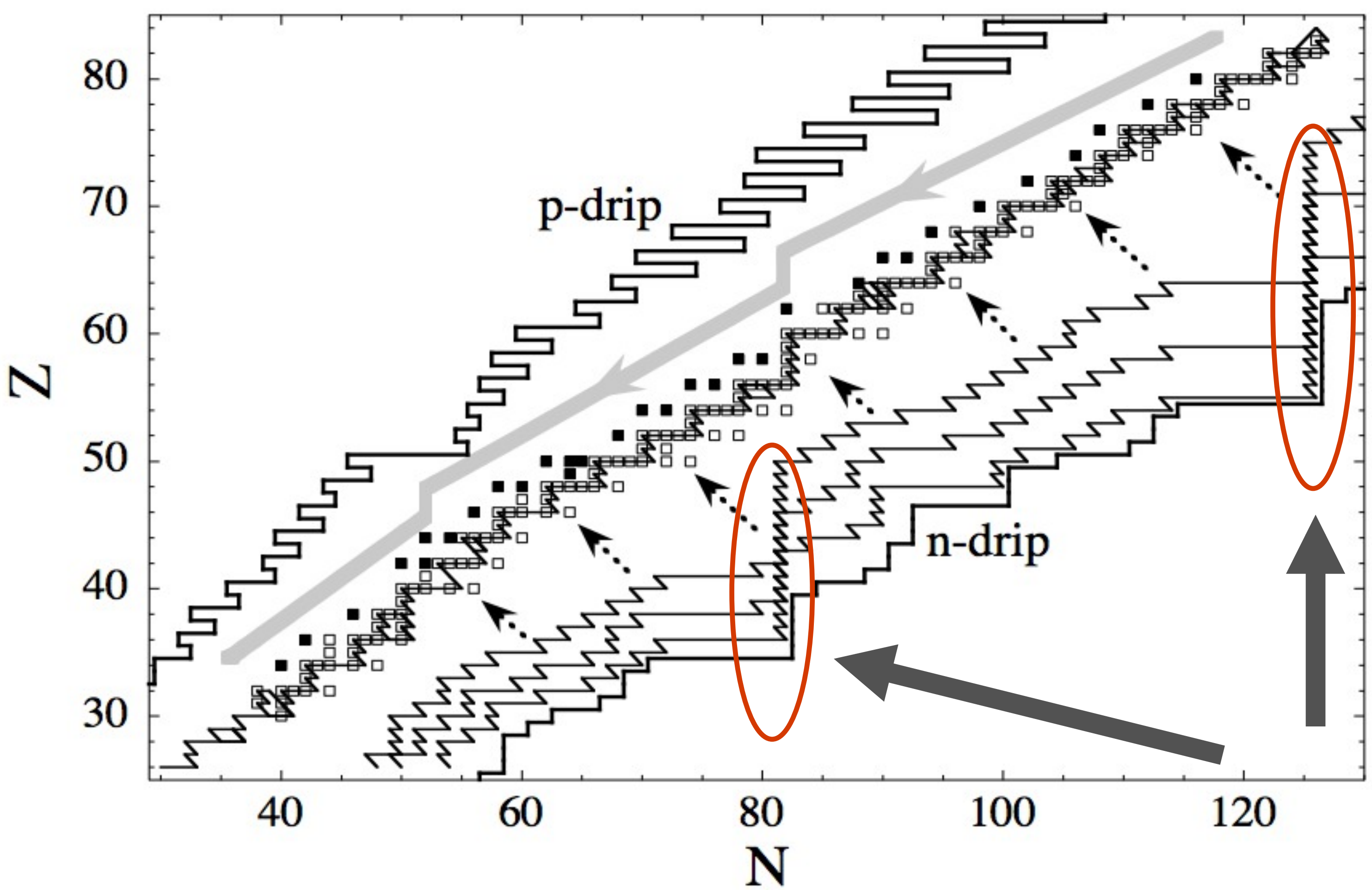
- Neutron star mergers
- Core-collapse Supernovae?

# r-process

Waiting-point approximation assumes:

- (n,γ)  (γ,n) equilibrium within isotopic chain
- β-flow equilibrium



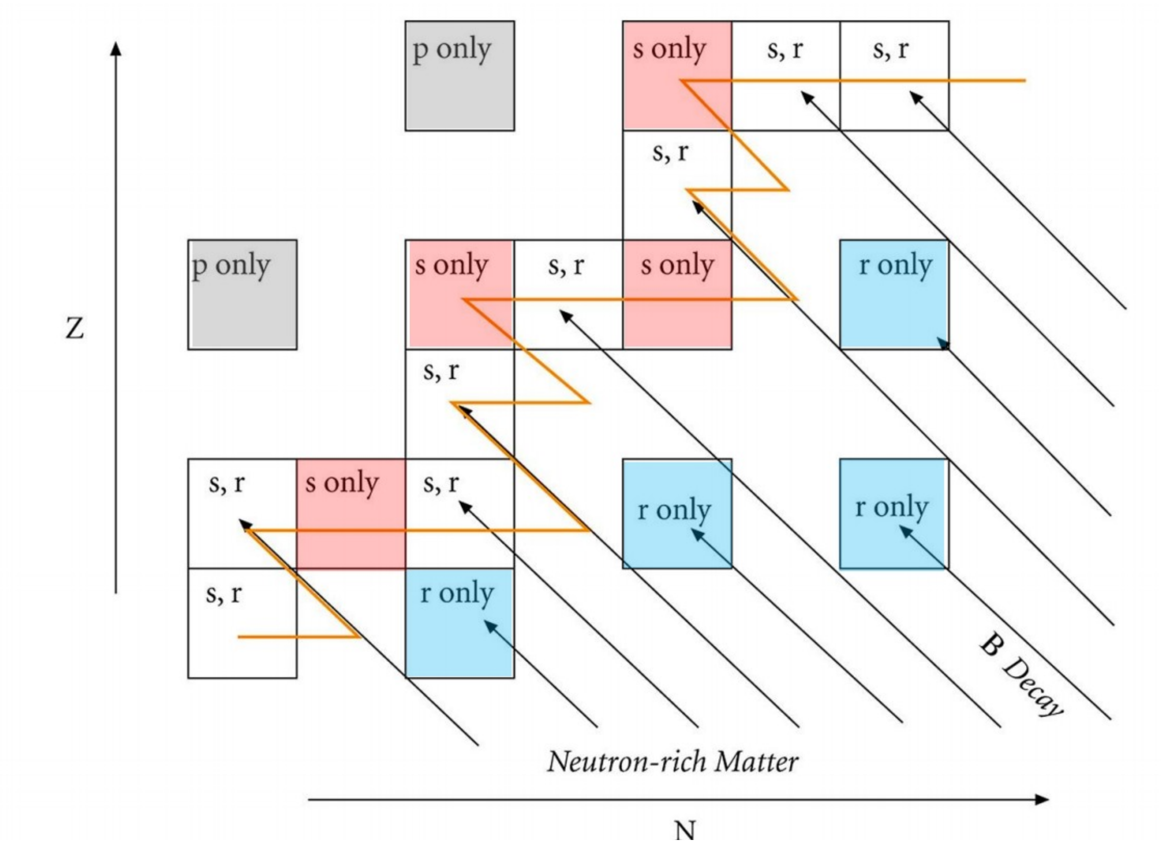



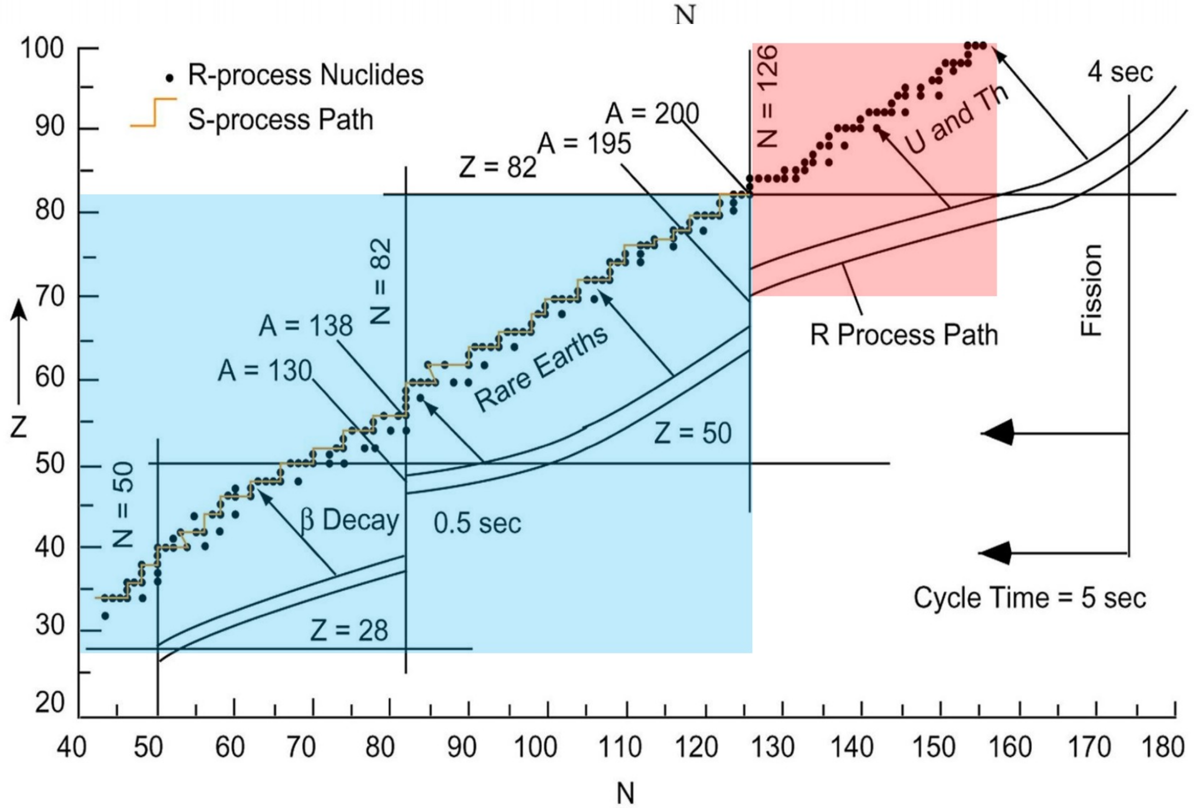

- Flow rate (and equilibrium population) is characteristic of waiting-point half-lives

Q(γ,n) small at closed n-shells, these nuclei are waiting points and r-process moves along them towards stability.

# r-process

## Freeze-out



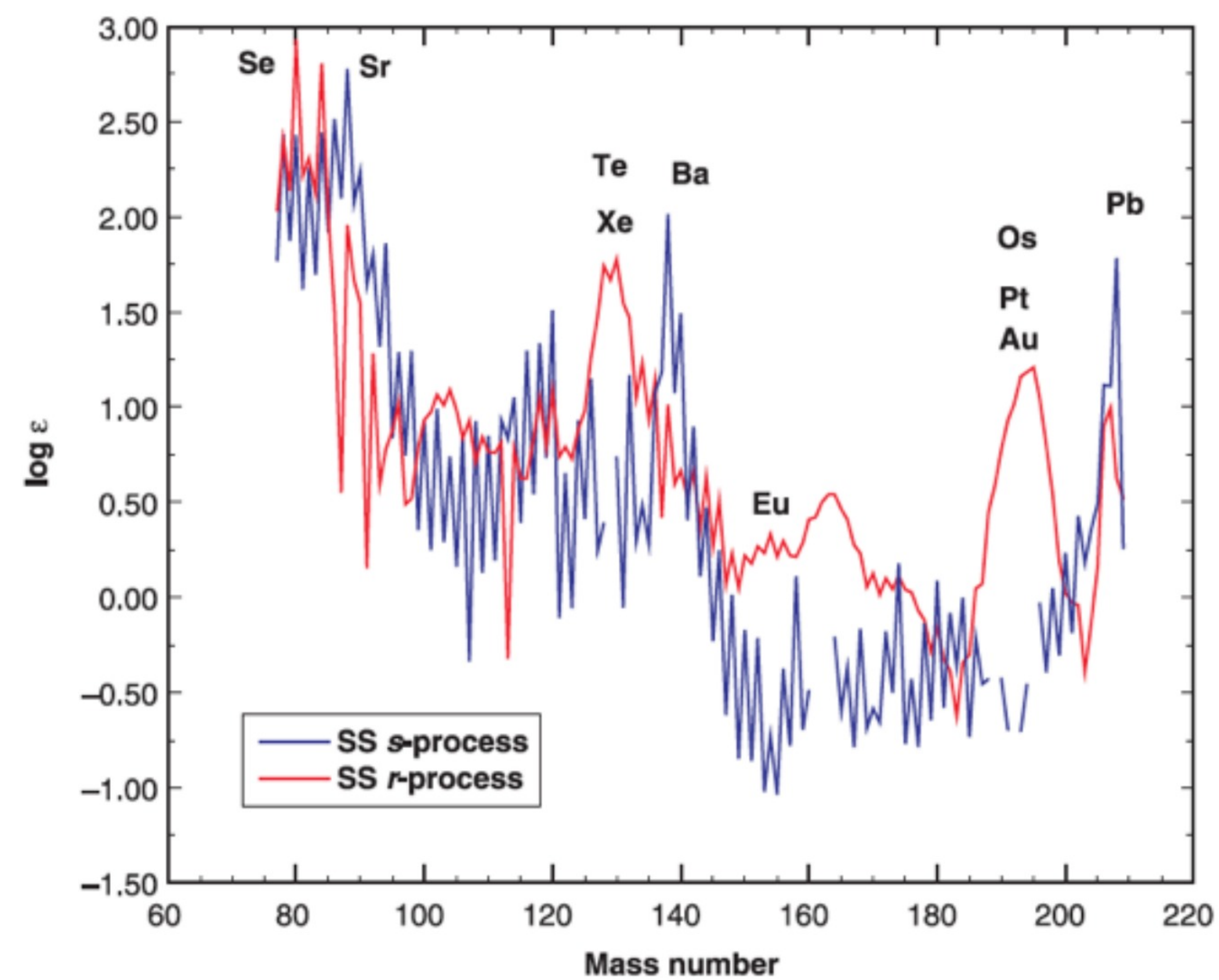

## r-process peaks:

1st peak: A≈80 → N=50

2nd peak: A≈130 → N=82

3rd peak: A≈195 → N=126

rare earth peak A≈165 → ?



# Sensitivity of r-process rate to $^{130}$Cd decay rate

$^{130}$Cd is responsible for the maximum of second r-abundance peak at N=82

Shell-model calculations for the half-lives of N=82 waiting point nuclei use a quenched GT operator that reproduces the $^{130}$Cd half-life.

Recent measurement at RIKEN by Lorusso et al. shortens half life by > 5σ.

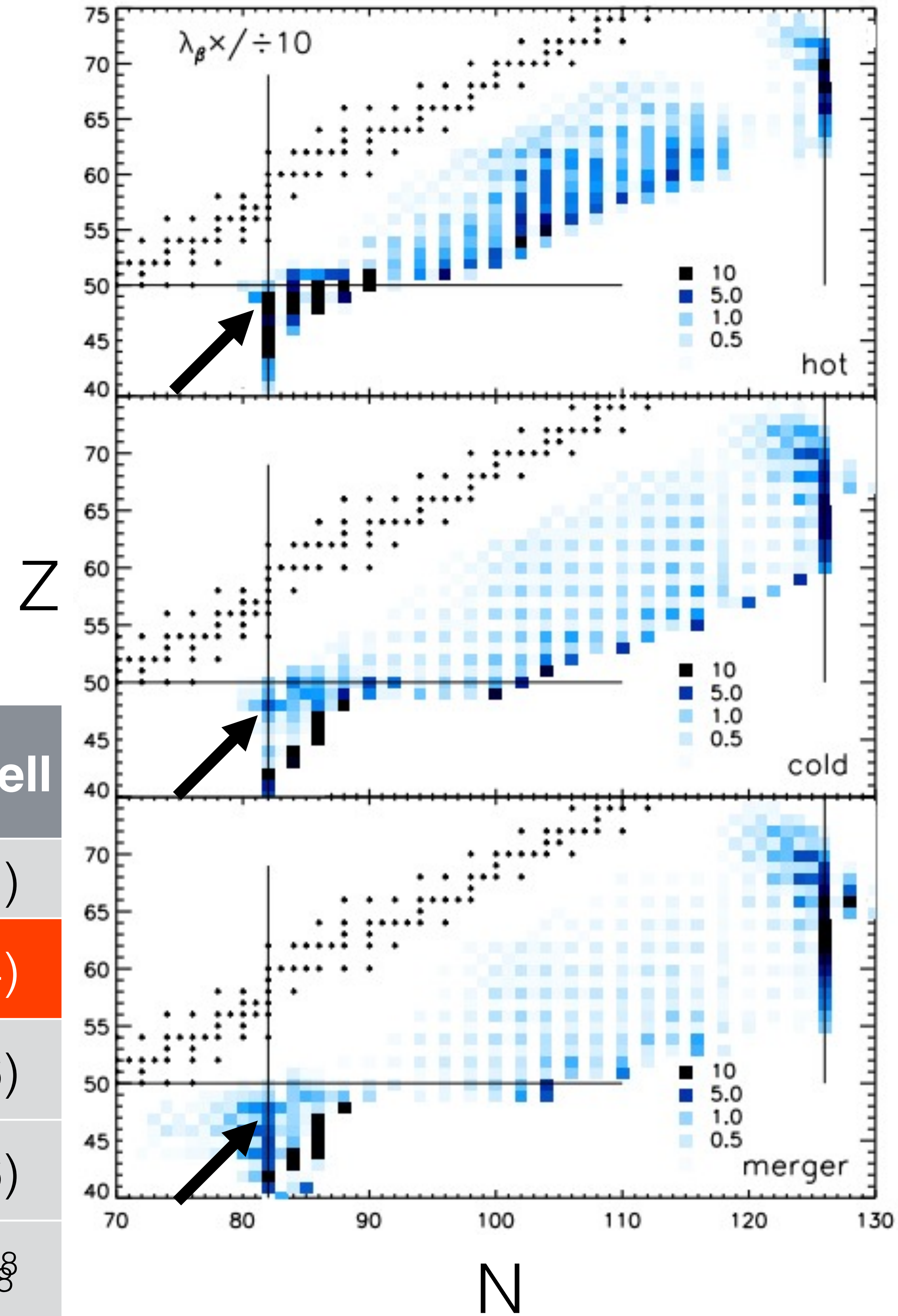
New: 127(2) ms

Old: 162(7) ms

Half Lives (ms) N=82

| | Exp | Shell Model | Exp/Shell |
|---|---|---|---|
| $^{131}$In | 261(3) | 247.53 | 1.06(1) |
| $^{130}$Cd | 162(7) | 164.29 | 0.99(4) |
| $^{129}$Ag | 52(4) | 69.81 | 0.74(6) |
| $^{128}$Pd | 35(3) | 47.25 | 0.74(6) |
| $^{127}$Rh | $20^{+20}_{-7}$ | 27.98 | $0.74^{+68}_{-28}$ |

G. Lorusso *et al.* PRL **114** 192501 (2015)

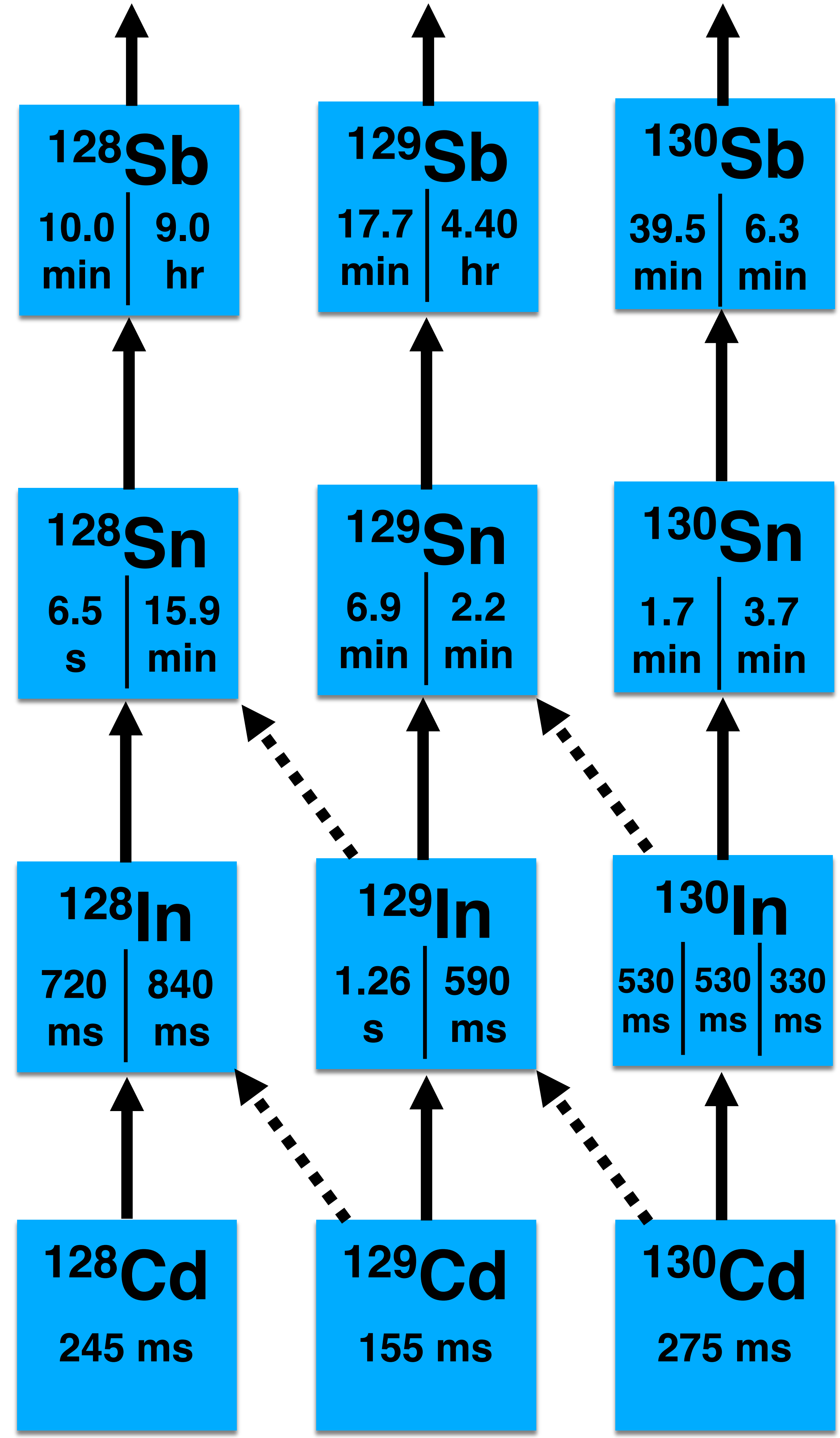



R. Surman *et al.* arXiv:1309.0059, 2013

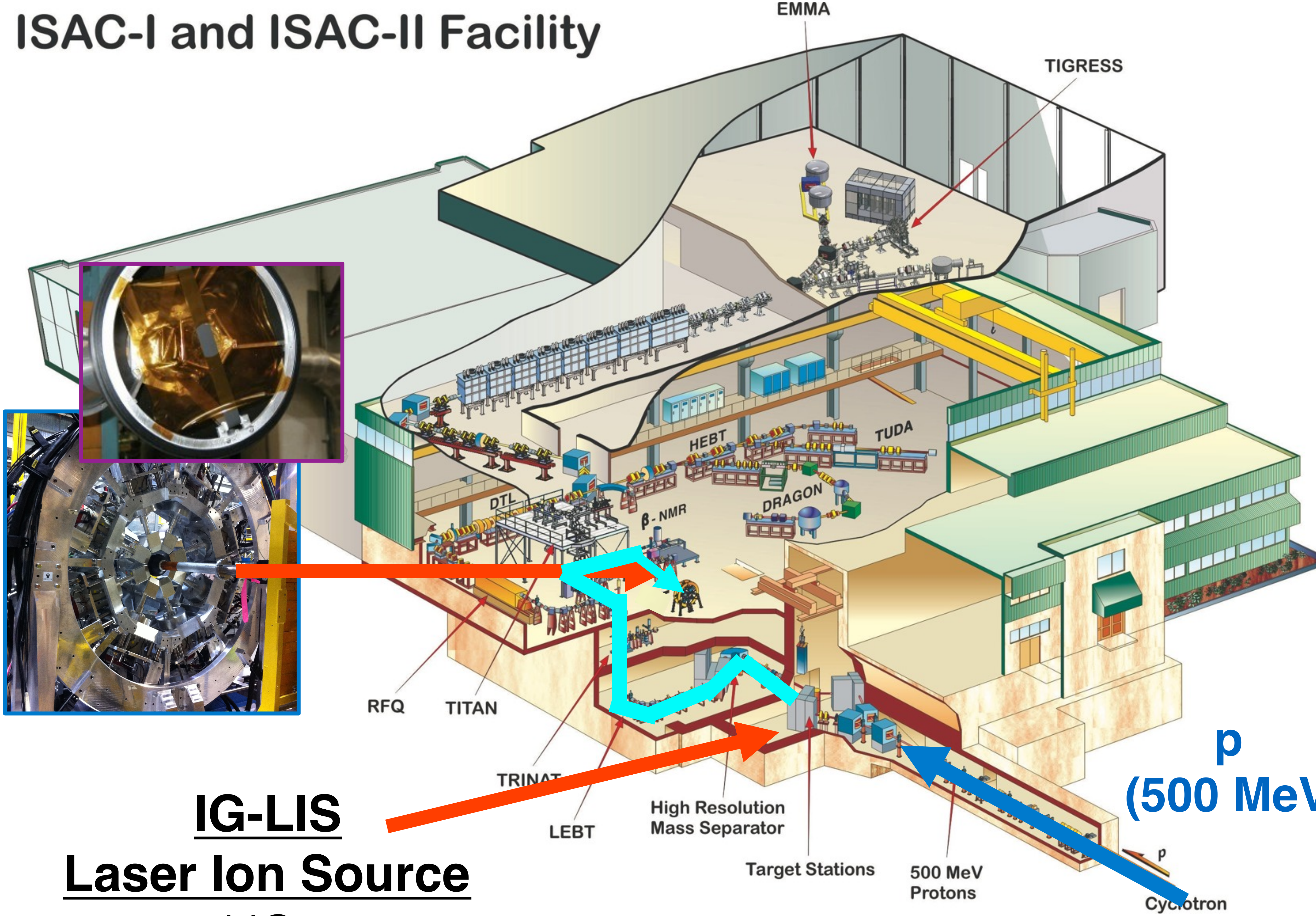
# Complicated Decay Chains

- Short-lived ground states
- isomers with comparable half-lives
- beta-n branches

- Fitting Charged particles is challenging
- Fit time distribution of characteristic gamma rays
- Need high-efficiency gamma-ray spectrometer



# ISAC-I and ISAC-II Facility




p
(500 MeV)

**<u>IG-LIS</u>**

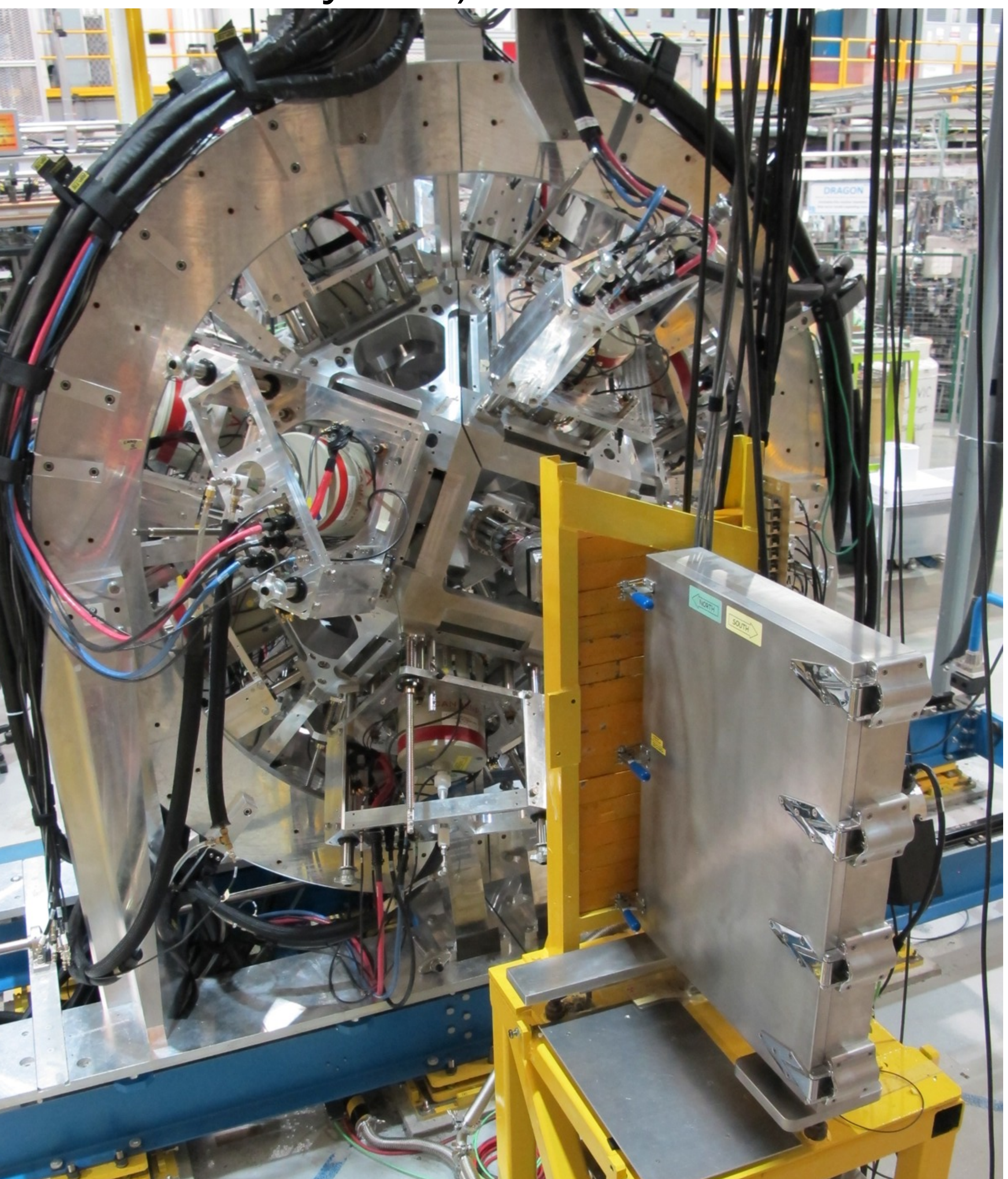
**<u>Laser Ion Source</u>**

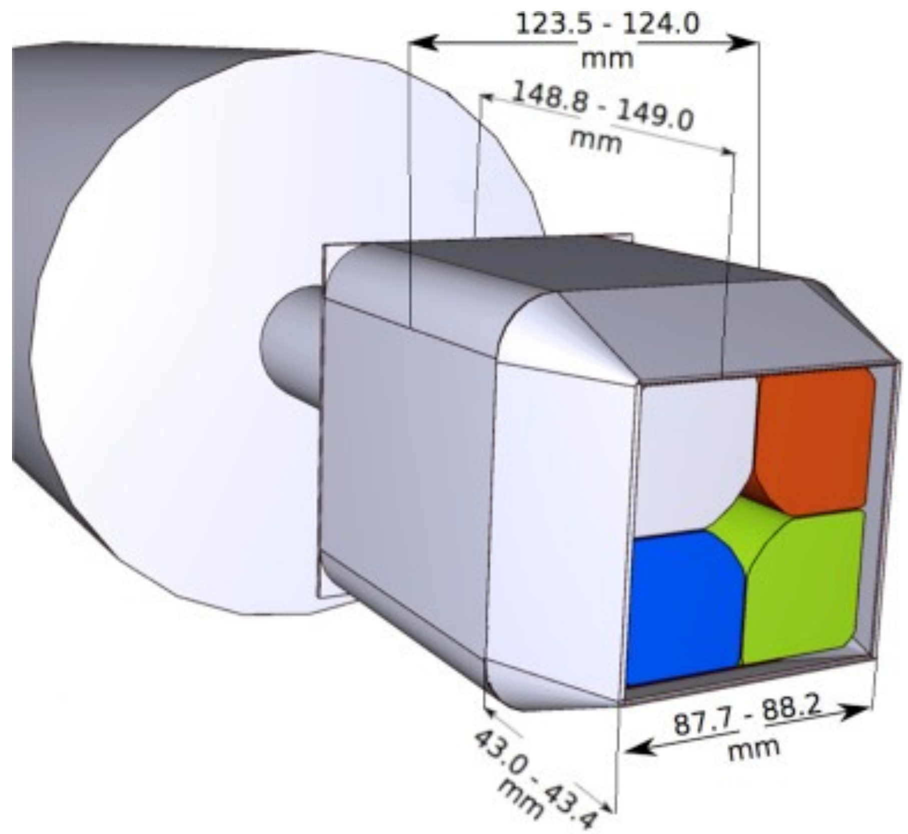
$UC_x$

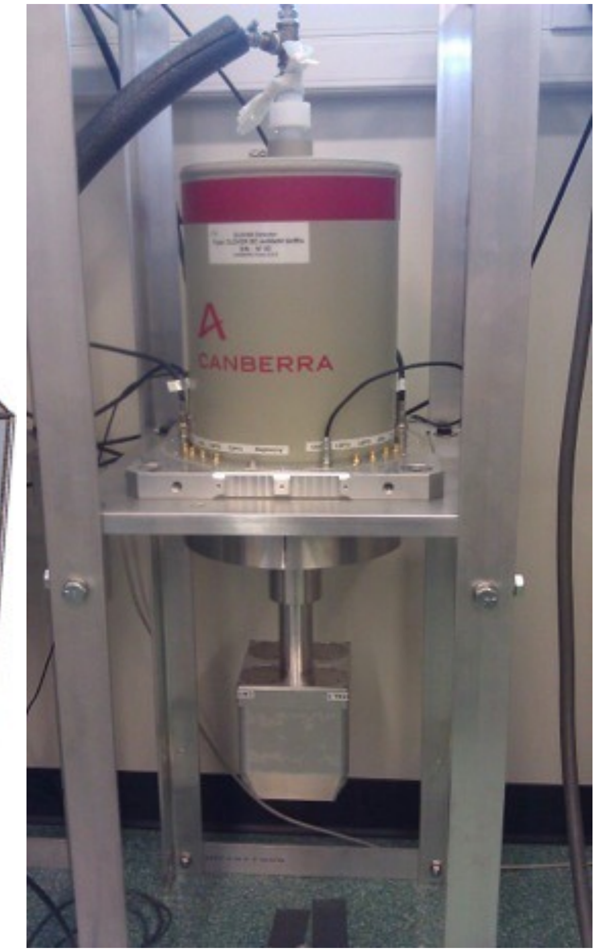
TRIUMF

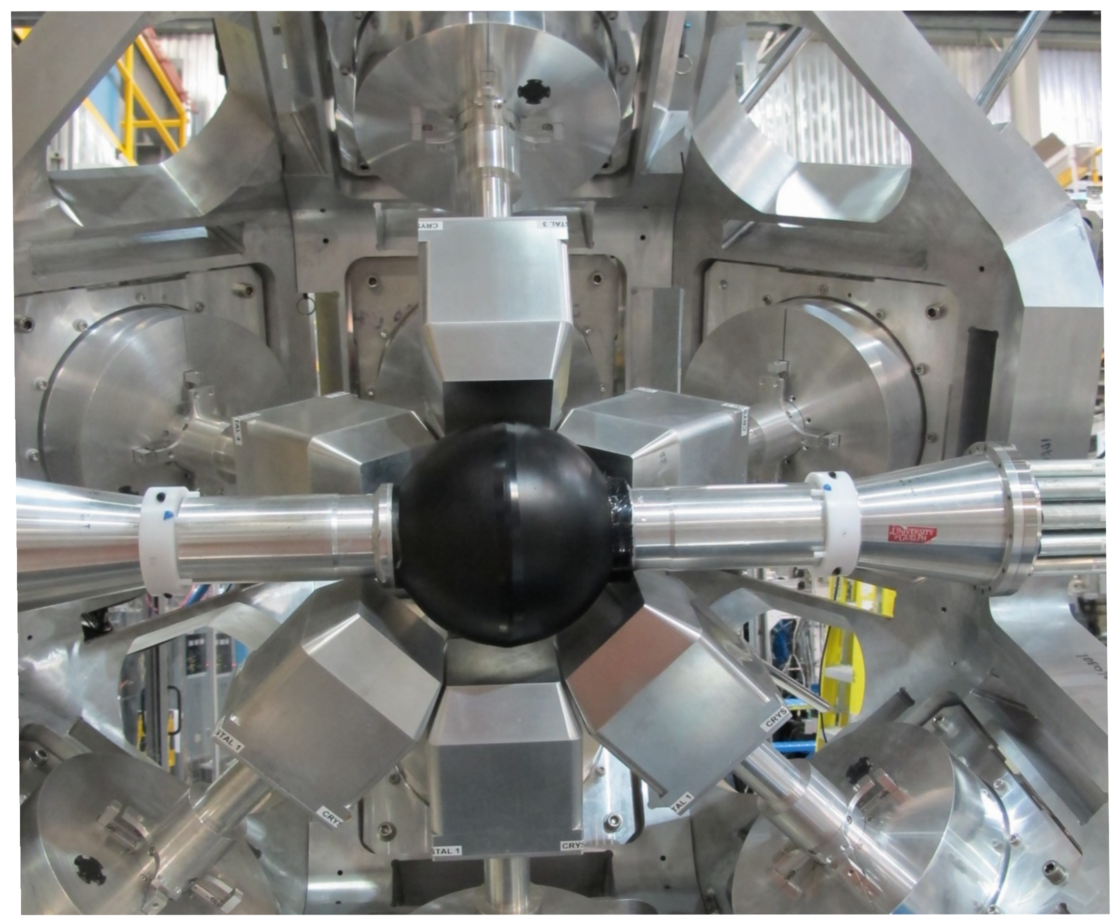
# GRIFFIN

- 16 large volume HPGe Clovers
- Used for studying beta decay at TRIUMF-ISAC
- Custom Digital electronics (50 kHz/crystal)

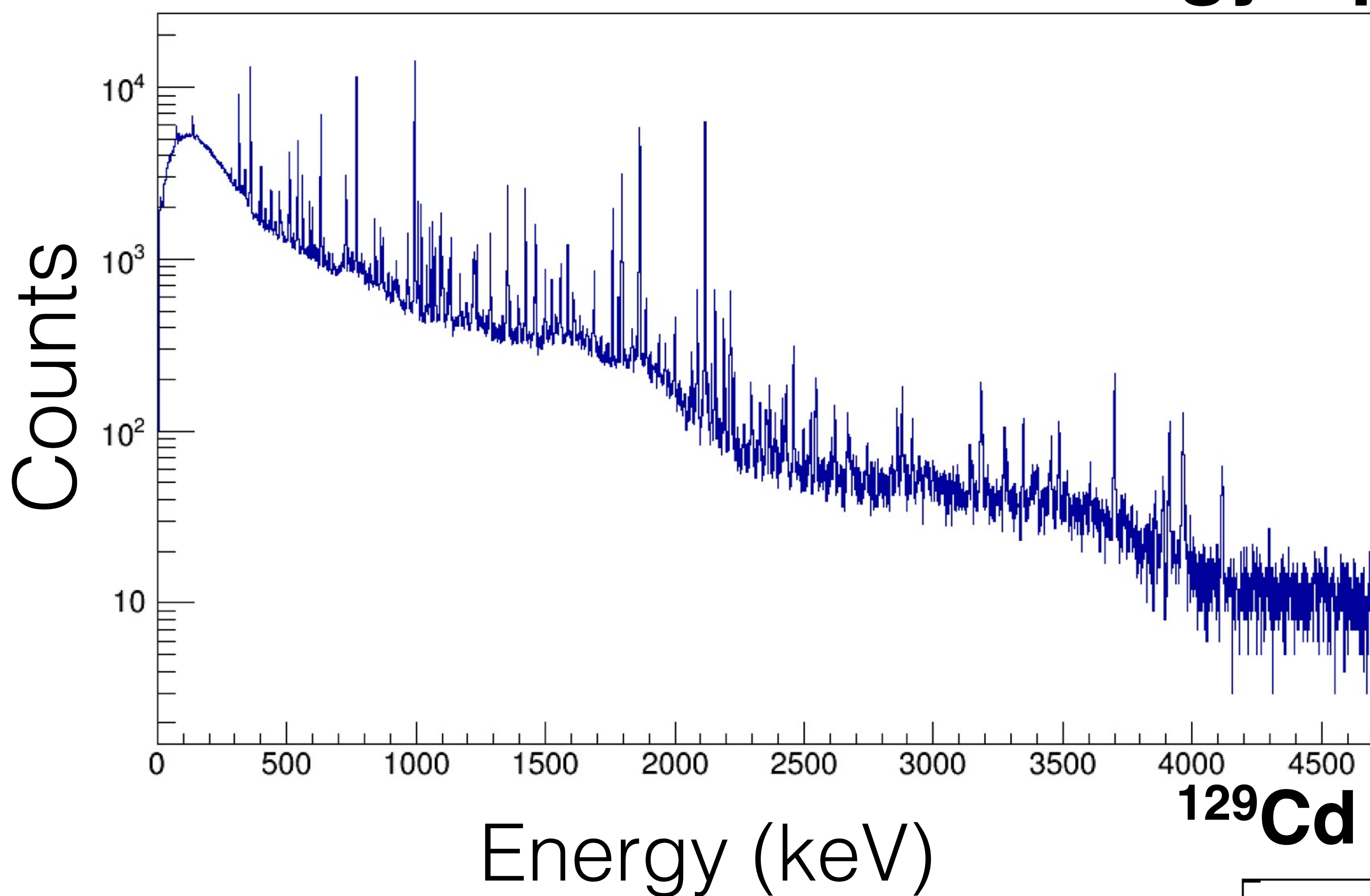




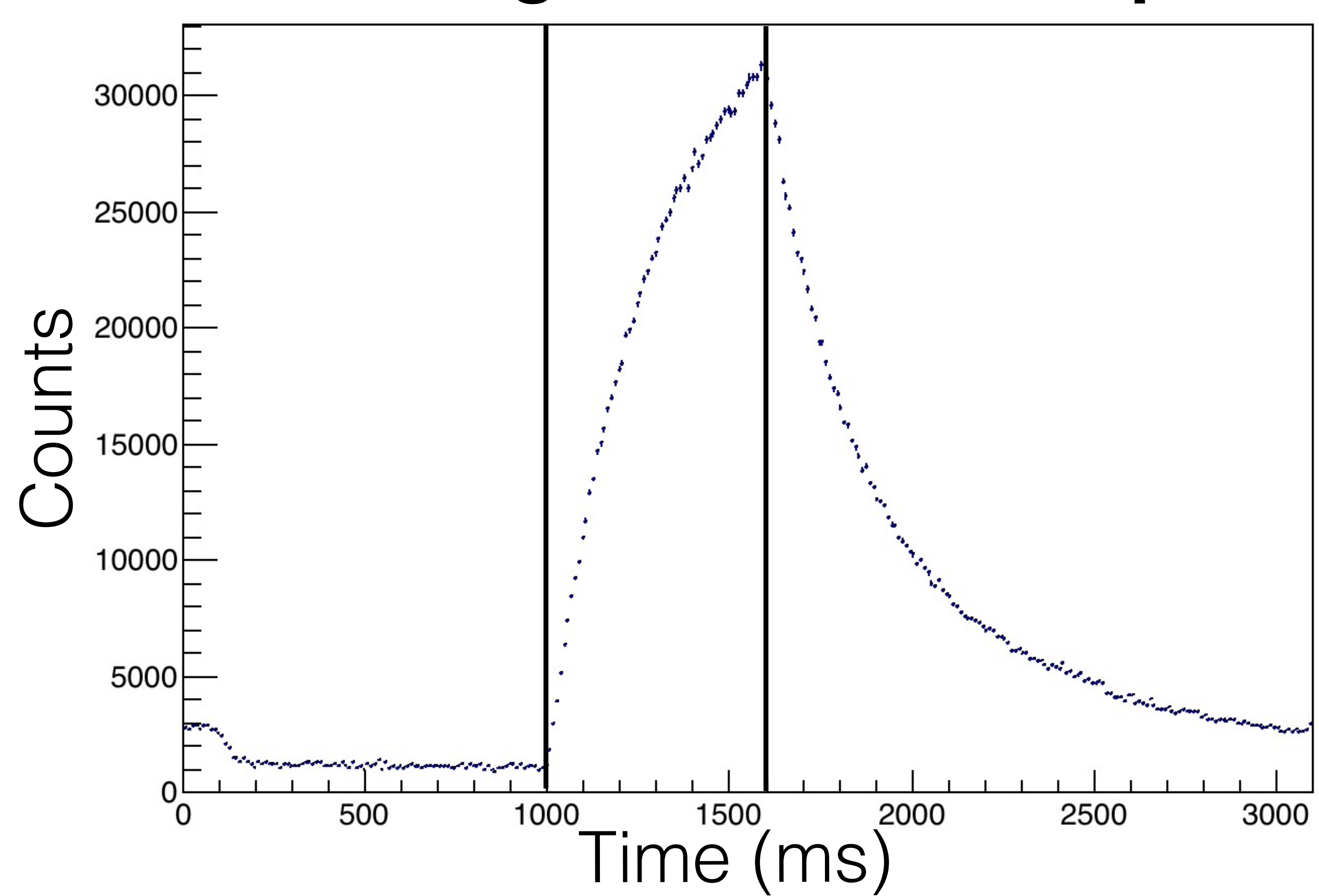



# $^{129}$Cd Beta coinc. Gamma Energy Spectrum




High Resolution
High Efficiency

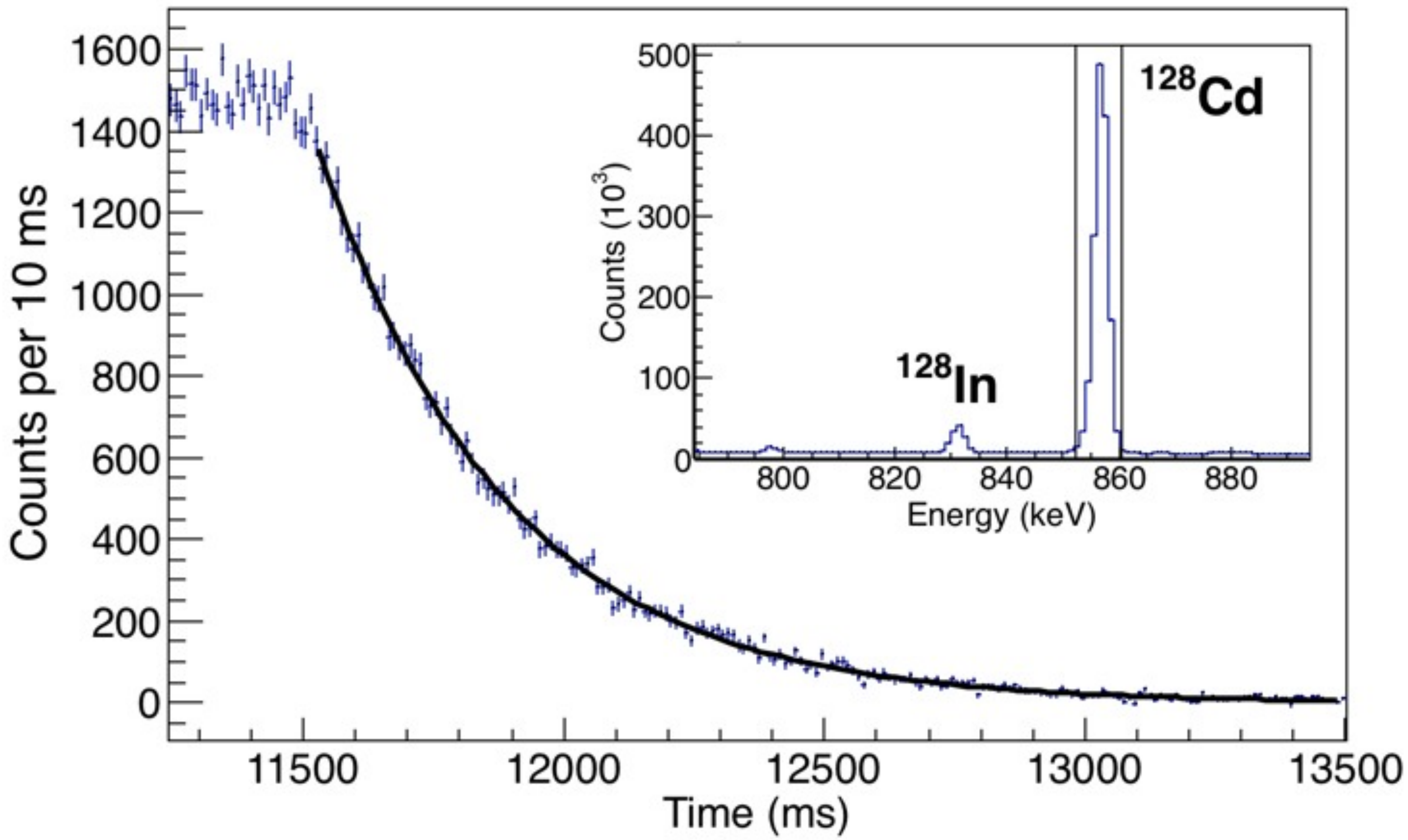
# $^{129}$Cd Beta-gamma timestamps




Cycles Mode:

- Tape Move 0 s to behind lead-shielded tape box
- Beam on 1 s
- Beam off 11 s

# $^{128}$Cd Half-Life




RD *et al.*, Phys Rev. C. **93**, 062801(R) (2016).

β-γ coincidences

857 keV γ ray

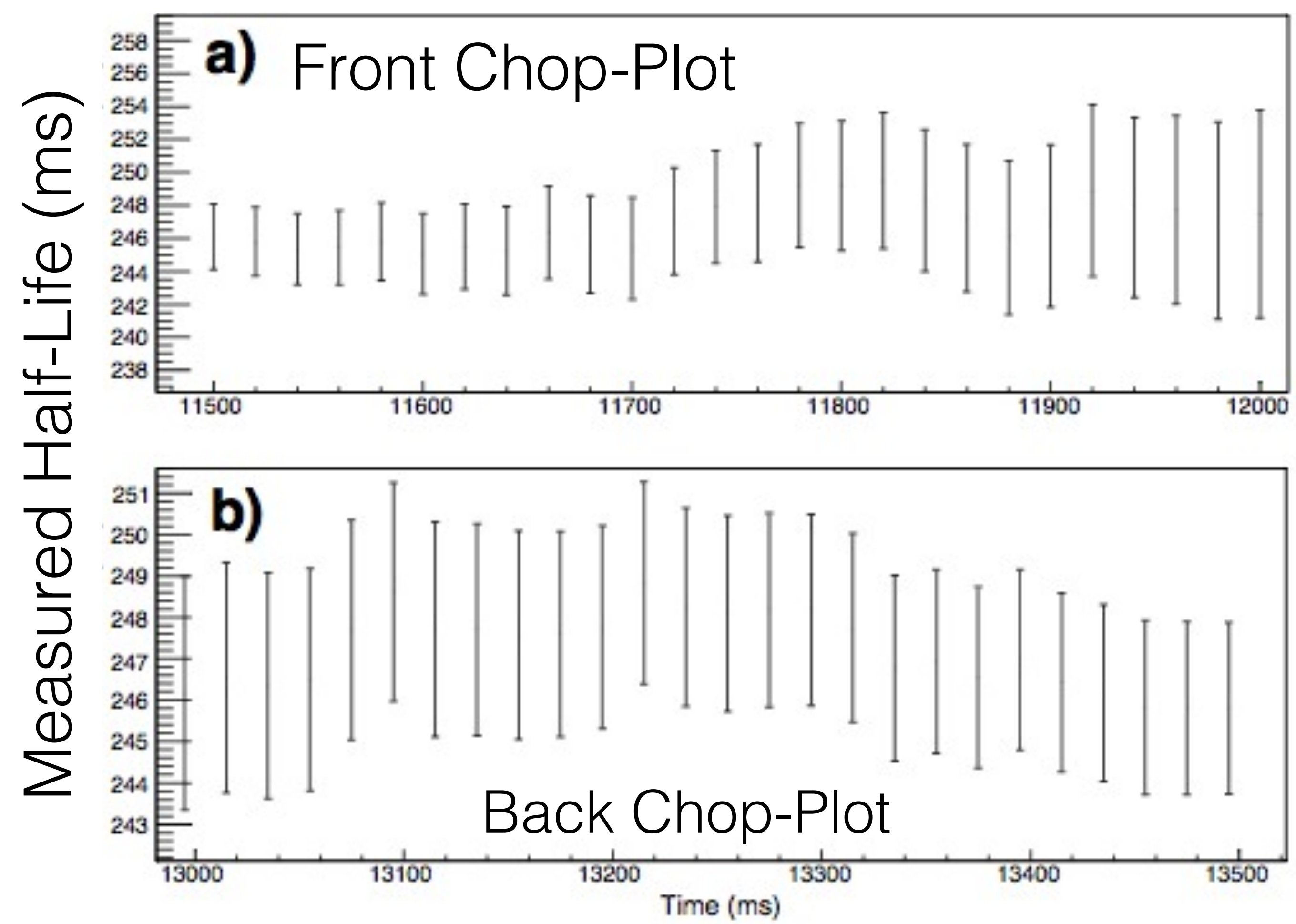
$T_{1/2} = 246.2(21)$ ms

Previous 245(5) ms

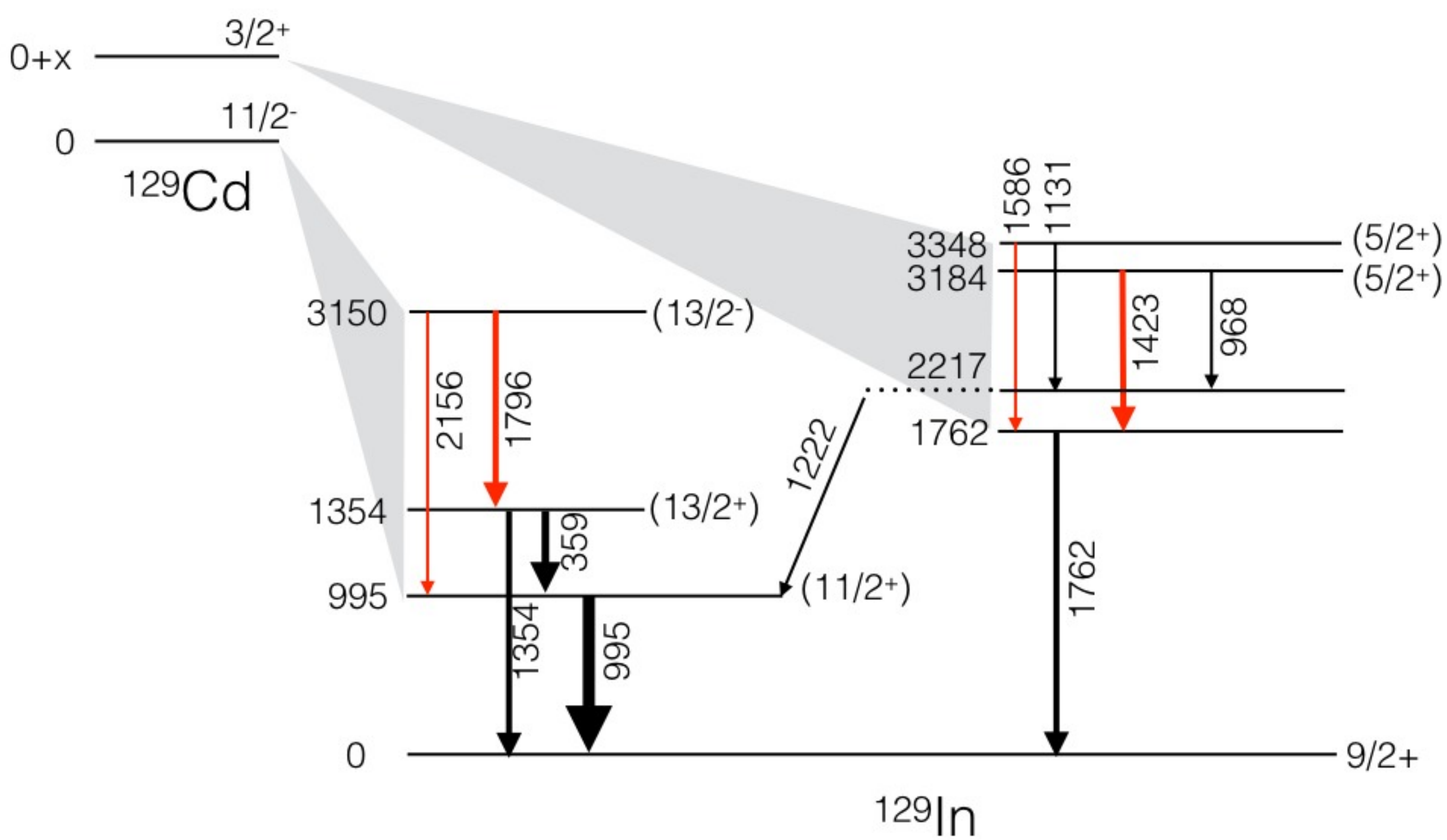
G. Lorusso *et al.* PRL **114** 192501 (2015)

**Systematic checks**

- Change the first bin included in the fit
- Change the last bin included in the fit
- Changed binning
- Fixed constant background parameter



# $^{129}$Cd Half-Life




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

- beta-delayed neutrons

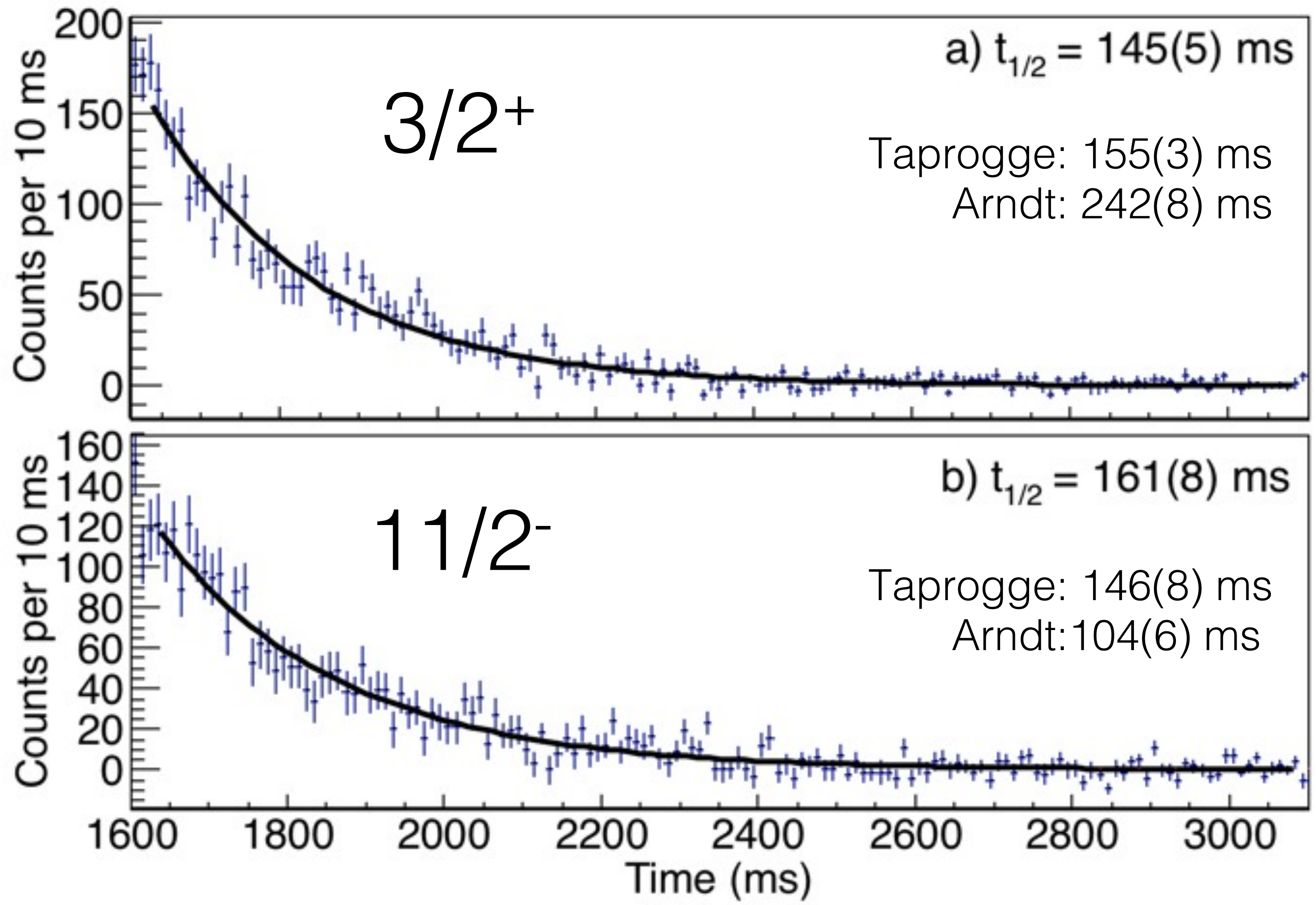
J. Taprogge et al., Phys. Rev. C 91, 054324 (2015)

- Gated on 1354 ($^{129}$Sn 2.2 min)
- Gated on 995 (mixed)

Gates:

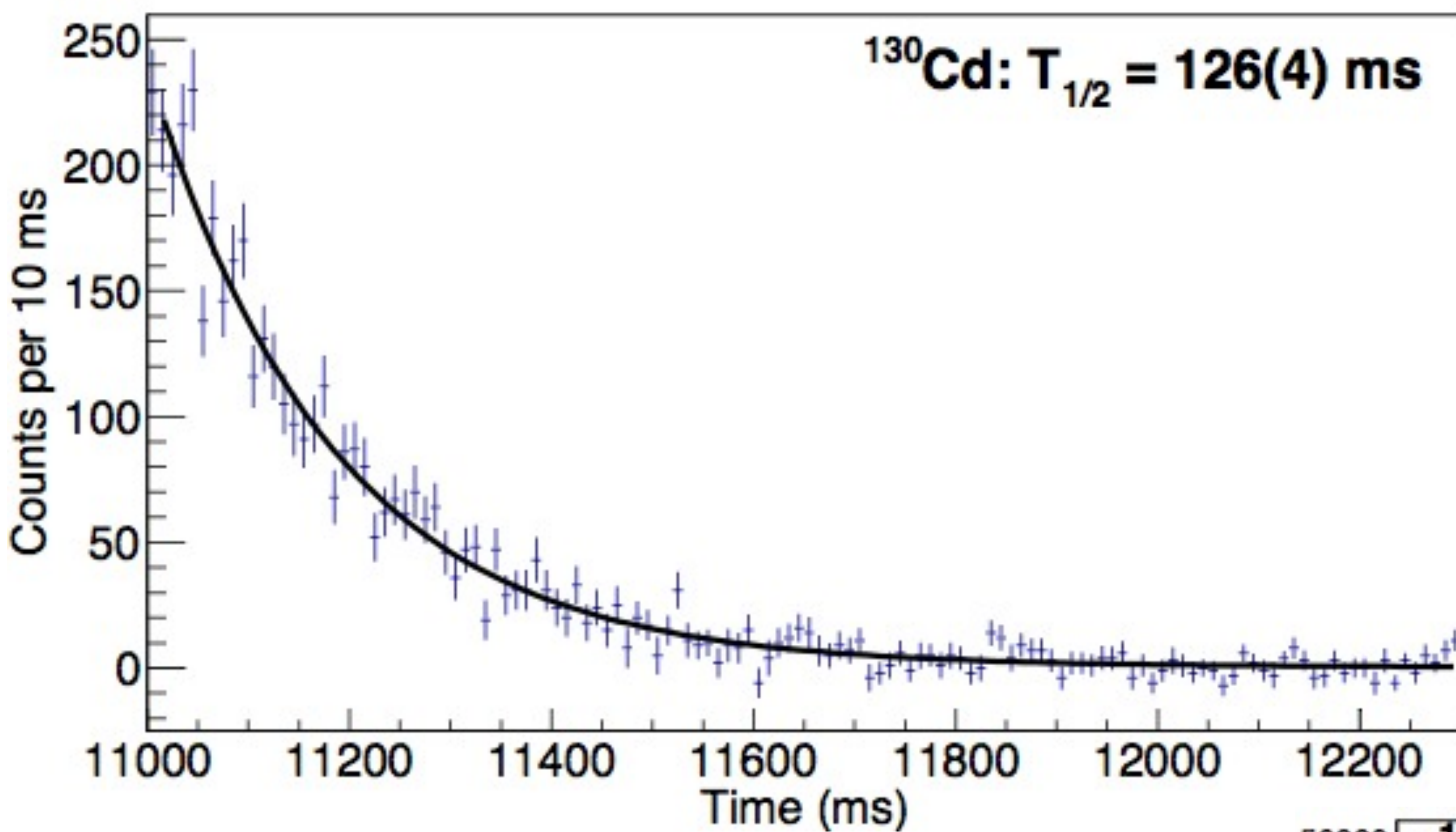
1422.9 and 1586.2 keV

1796.5 and 2155.6 keV



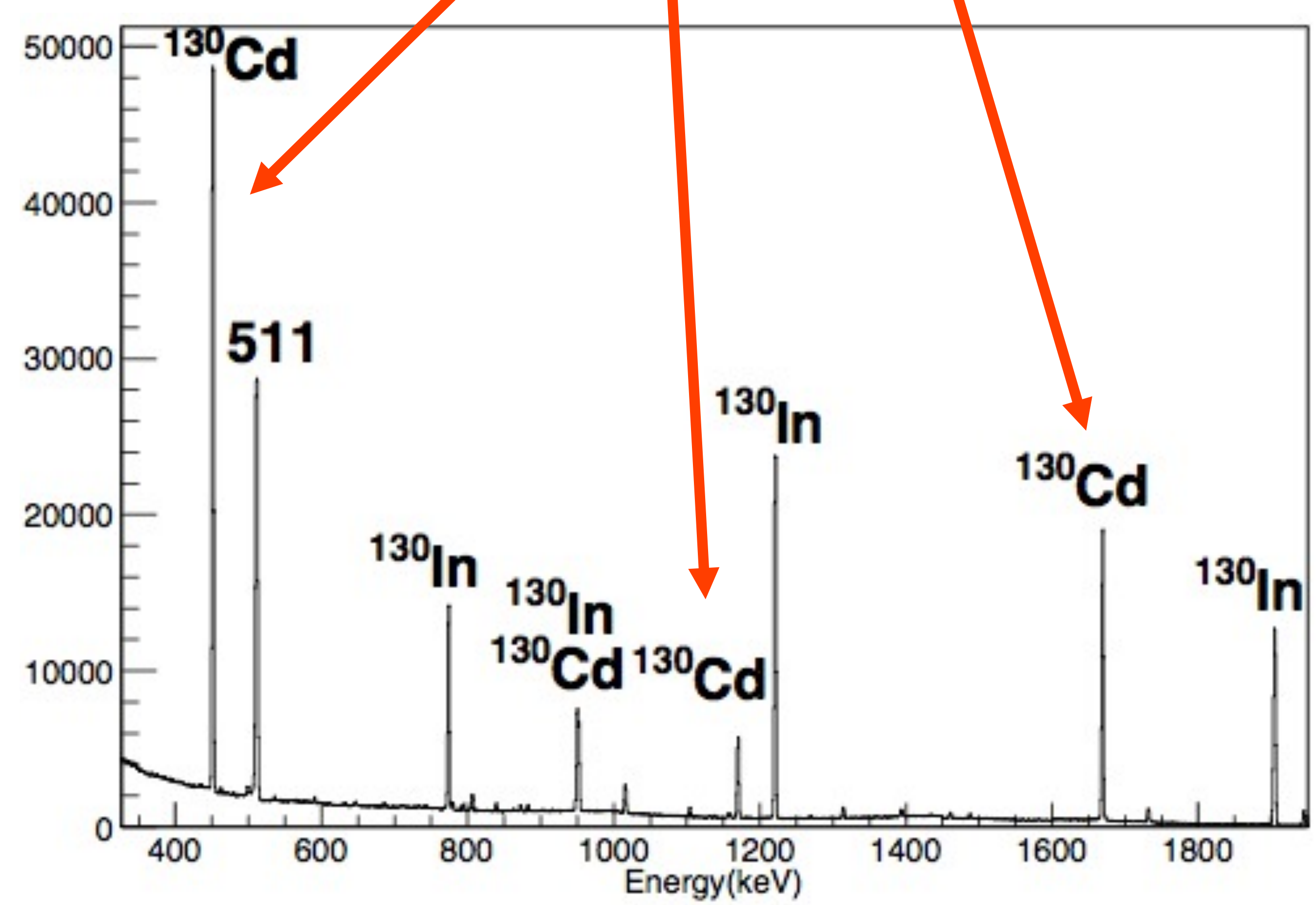

RD *et al.*, Phys Rev. C. **93**, 062801(R) (2016).

# $^{130}$Cd Half-Life




**Agreement with Lorusso (2015)**

Gated on 451.0, 1170.3, and 1669.2 keV gamma rays



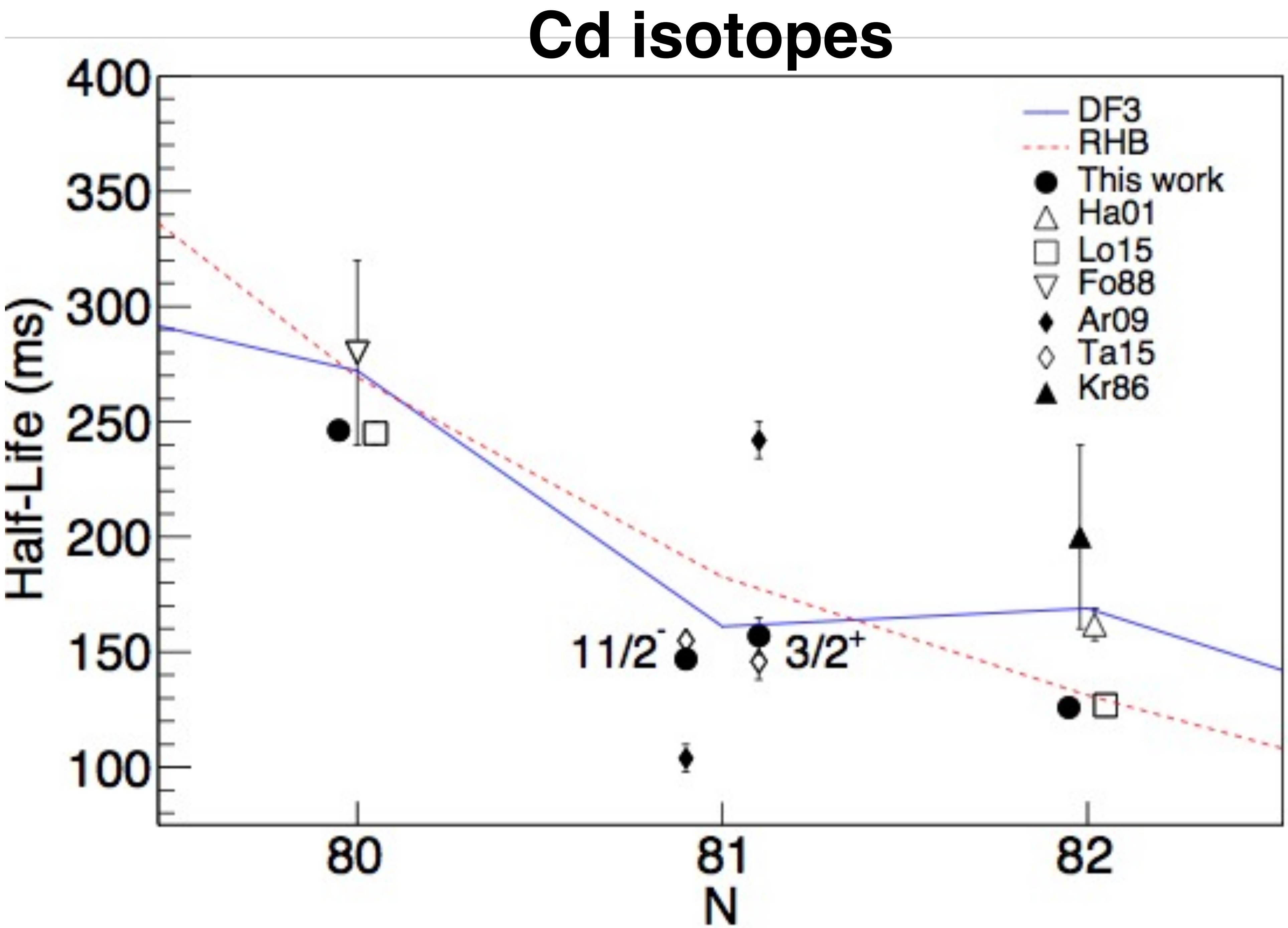

Previous: 127(2) ms and 162(7) ms

G. Lorusso *et al.* PRL **114** 192501 (2015)
M. Hannawald *et al.* Nucl. Phys. A **688** 578 (2001)

RD *et al.*, Phys Rev. C. **93**, 062801(R) (2016).

# Comparison to Theory

Theory is over-predicting $^{130}$Cd




Rescaling GT-quenching to new $^{130}$Cd half-life resolves this

# Comparison to Theory

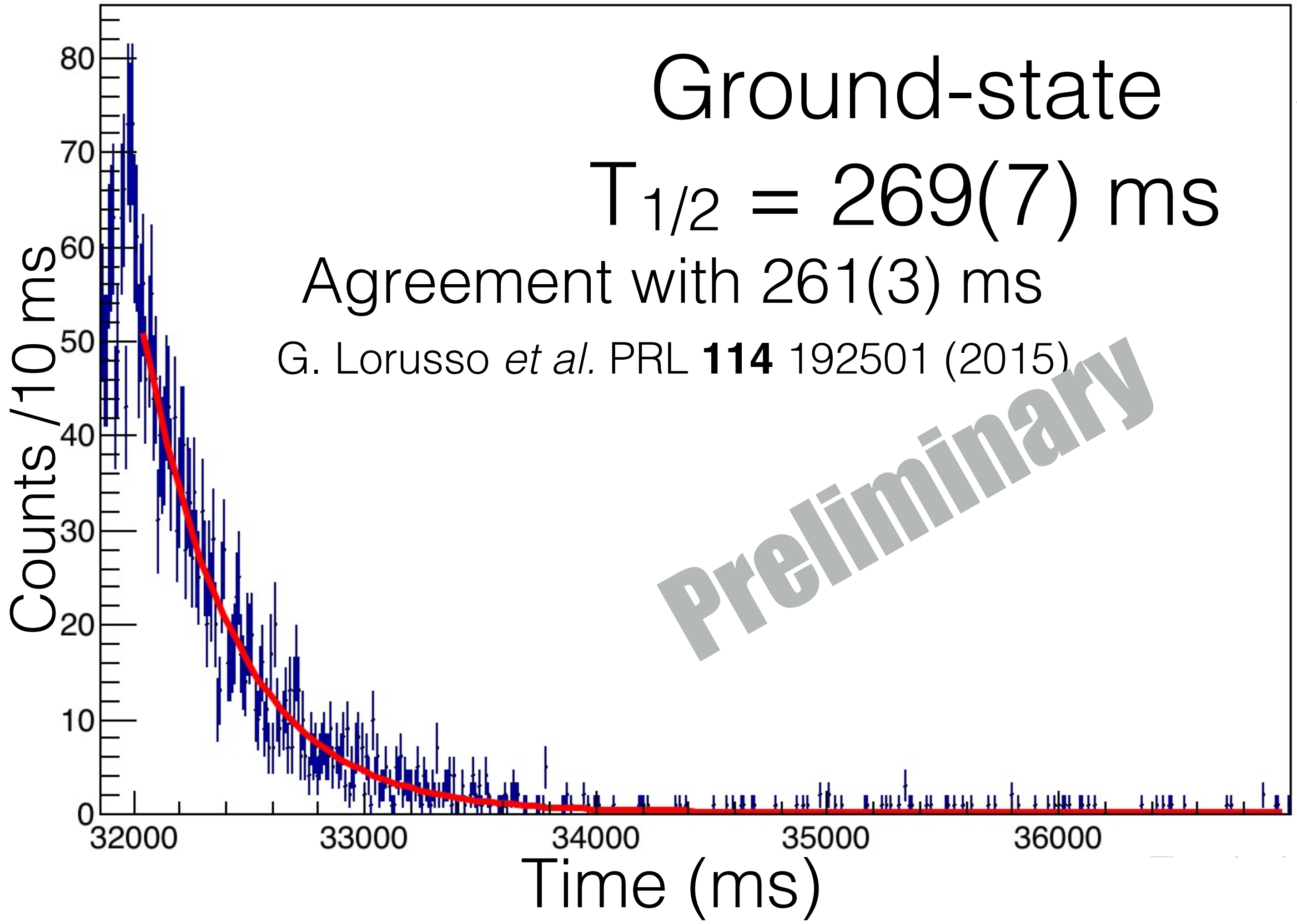
Half Lives (ms) of N = 82 waiting points

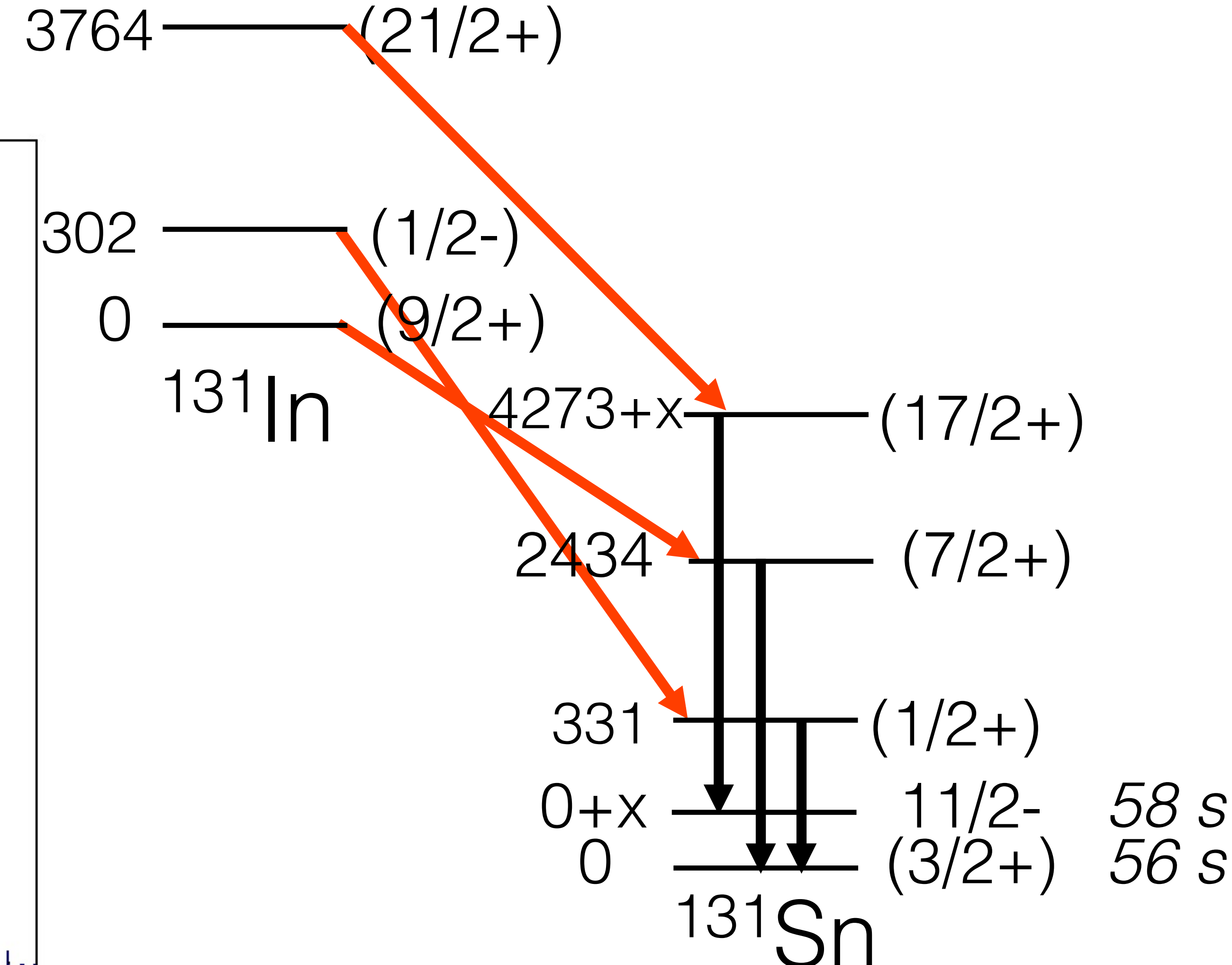
| | Exp | Scaled SM | Exp/ Scaled |
|---|---|---|---|
| $^{131}$In | 261(3) | 191.68 | 1.36(2) |
| $^{130}$Cd | 127(2) | 127 | 1.00 |
| $^{129}$Ag | 52(4) | 54.06 | 0.96(7) |
| $^{128}$Pd | 35(3) | 36.59 | 0.96(6) |
| $^{127}$Rh | $20^{+20}_{-7}$ | 21.66 | $0.92^{+92}_{-32}$ |

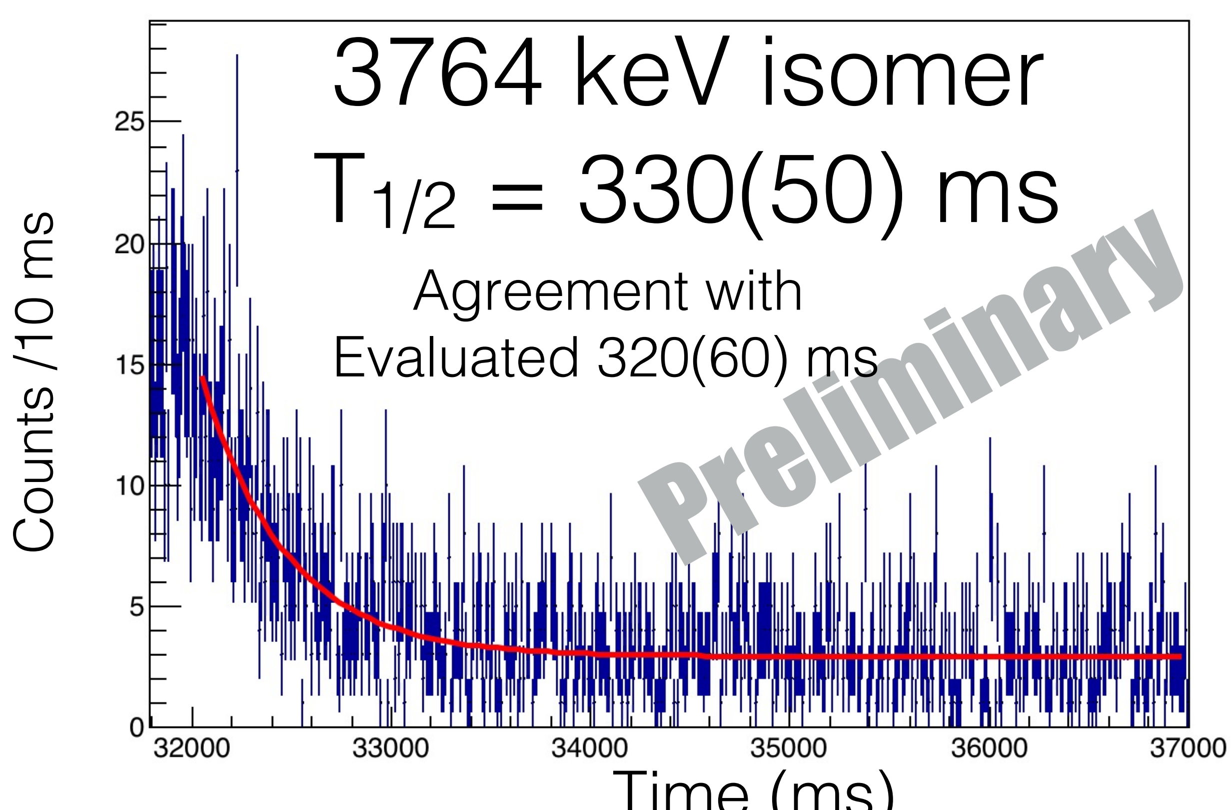
Shorter half-life resolves problem with GT quenched calculations

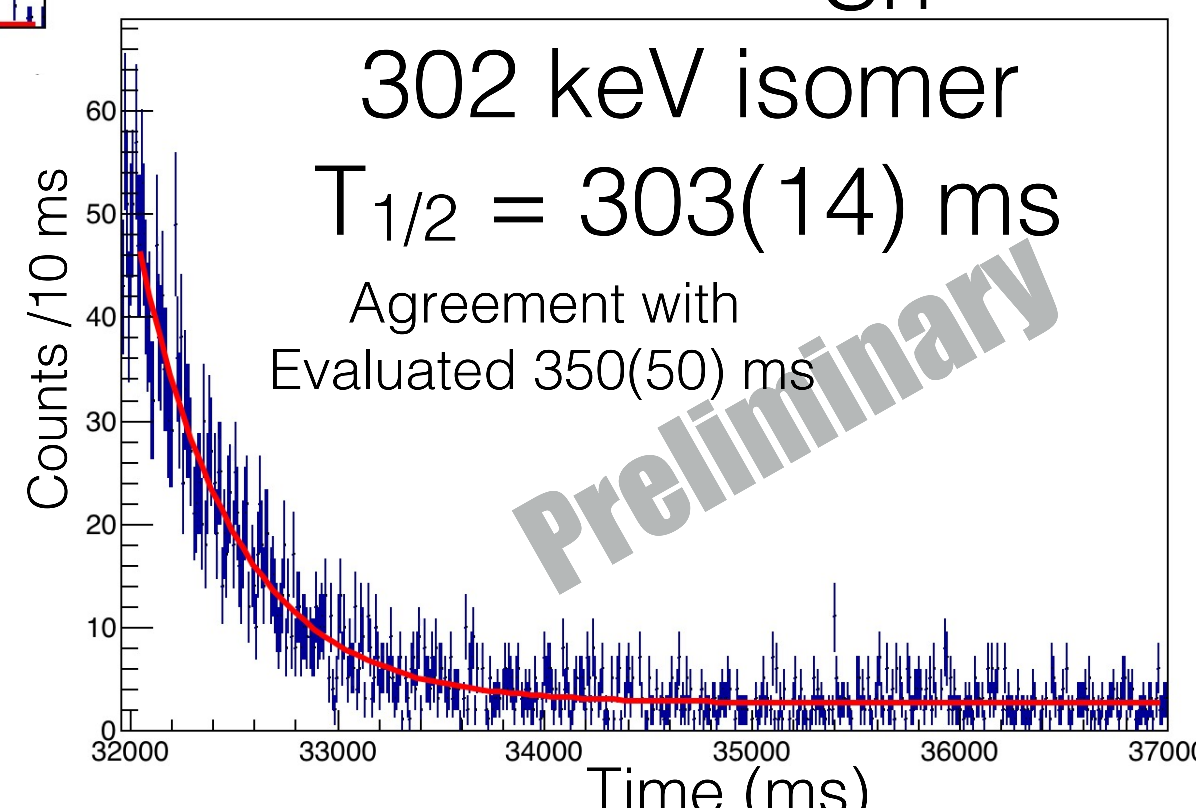
**What about $^{131}$In…?**

# $^{131}$In Half-Life



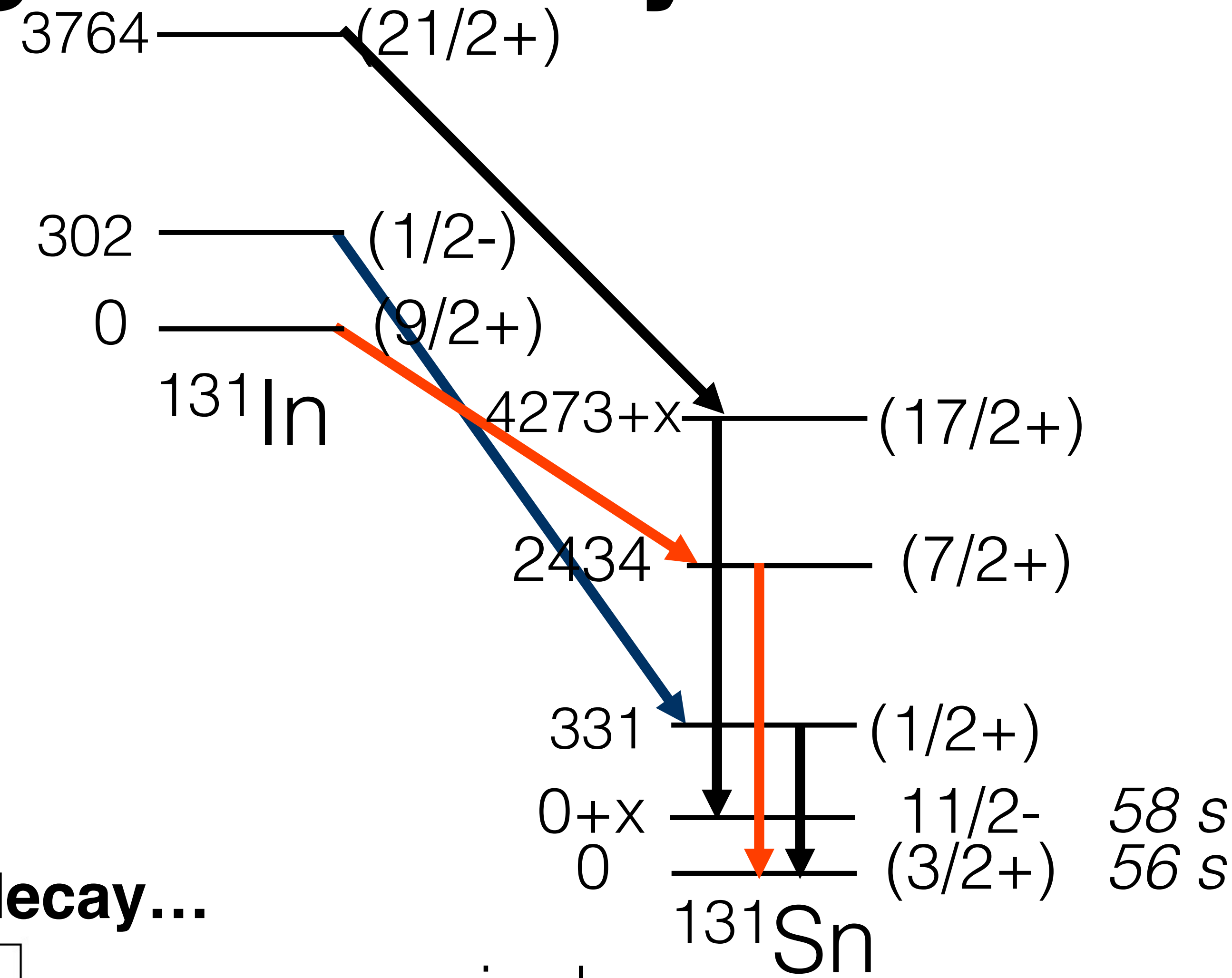




**$T_{1/2}$ is too large once scaled to new $^{130}$Cd half-life (192 ms)**

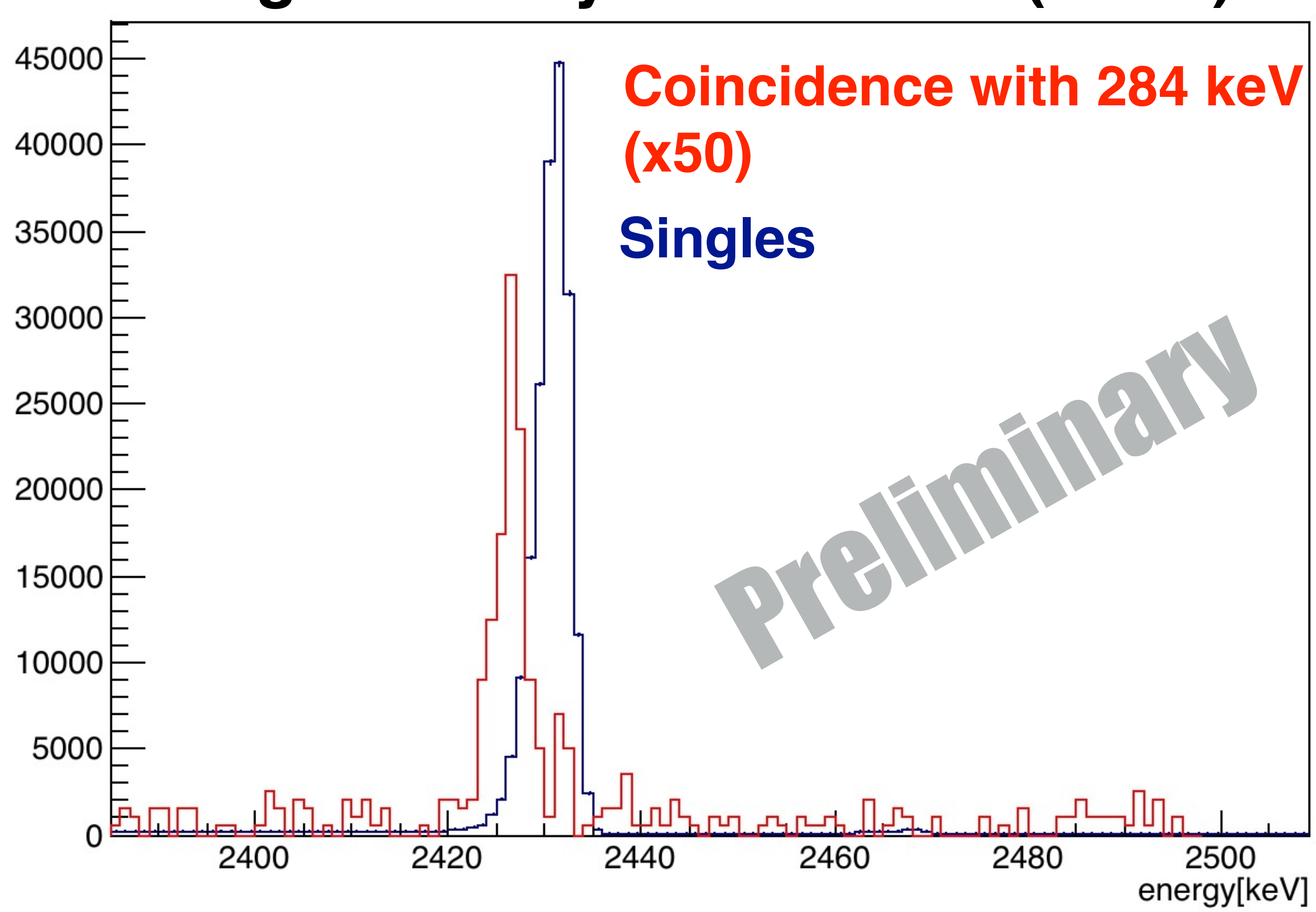
# $^{131}$Sn $\gamma$-rays following $^{131}$In Decay

Many gamma rays observed

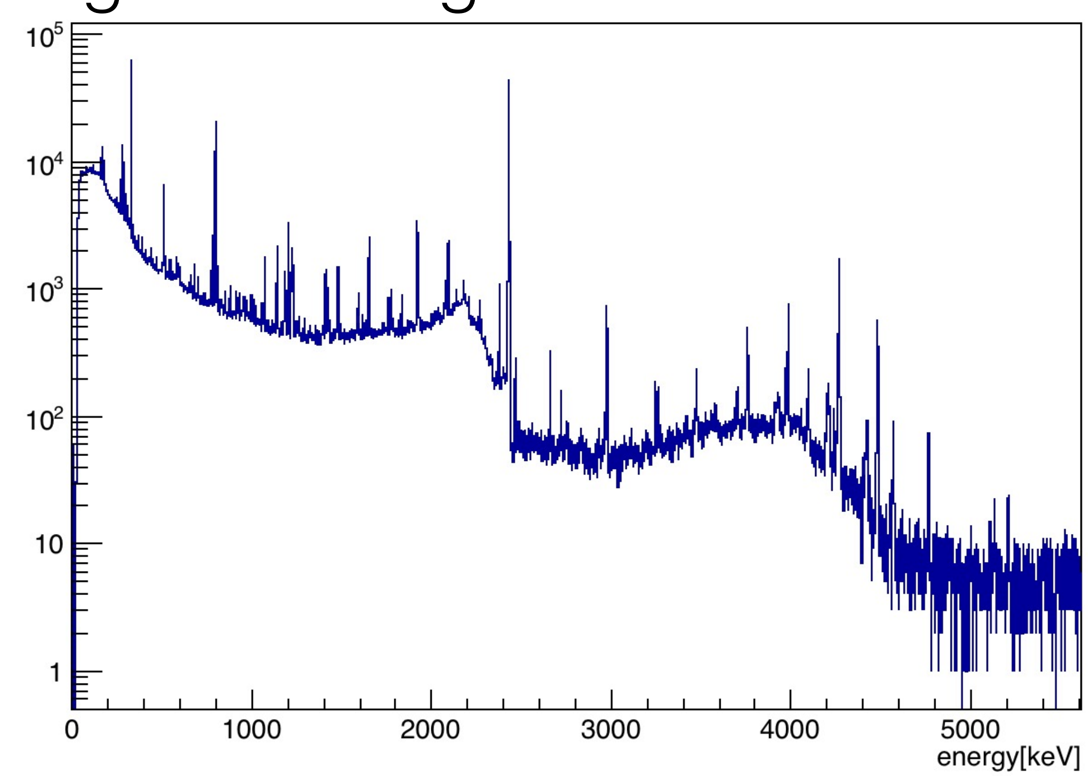
- Goal: Expand and confirm current level scheme
  - Large coincidence efficiency
  - Possibility to do angular correlations
- Goal: Solve the $^{131}$In half-life discrepancy




**284 keV gamma-ray comes from (21/2+) decay…**




gamma singles



# Summary

- The GRIFFIN spectrometer is on-line at TRIUMF-ISAC allowing for the study of rare isotopes beams with low production yields
- The recent discrepant half-life measurements of $^{129}$Cd and $^{130}$Cd have been confirmed.
- The new half-life of $^{130}$Cd resolves the problem of systematically short theoretical calculations of the half-life by providing a new Gamow-Teller quenching factor.
- A new theoretical outlier, $^{131}$In, exists with a half-life that is 40% too large. An analysis of the decay of $^{131}$In is underway in conjunction with an analysis of the decay of $^{131}$Cd in order to understand this discrepancy.

# Collaborators

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Thank you