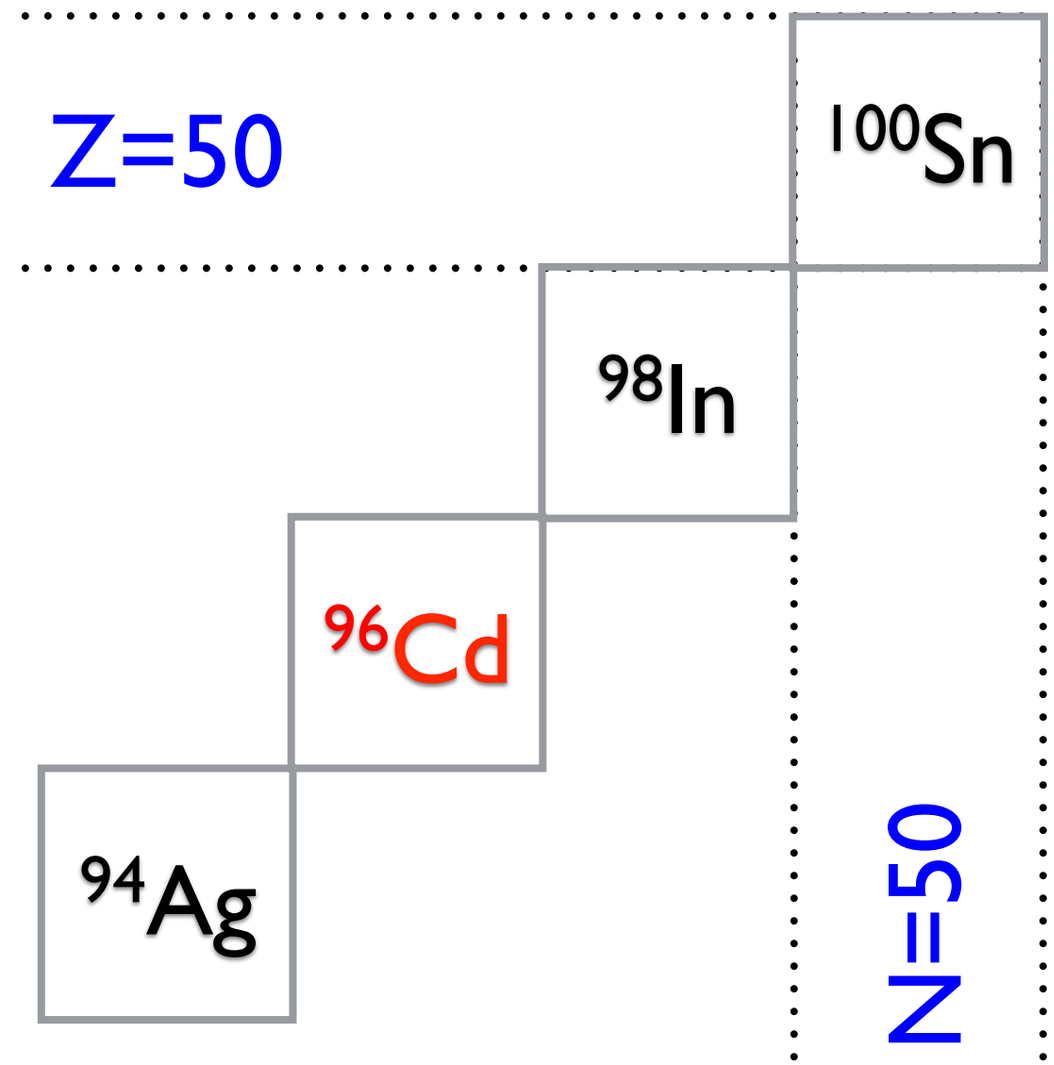
Isomers in ^{96}Cd populated via Fragmentation

Bob Wadsworth

- Motivation
- Experiment
- Results
- Summary



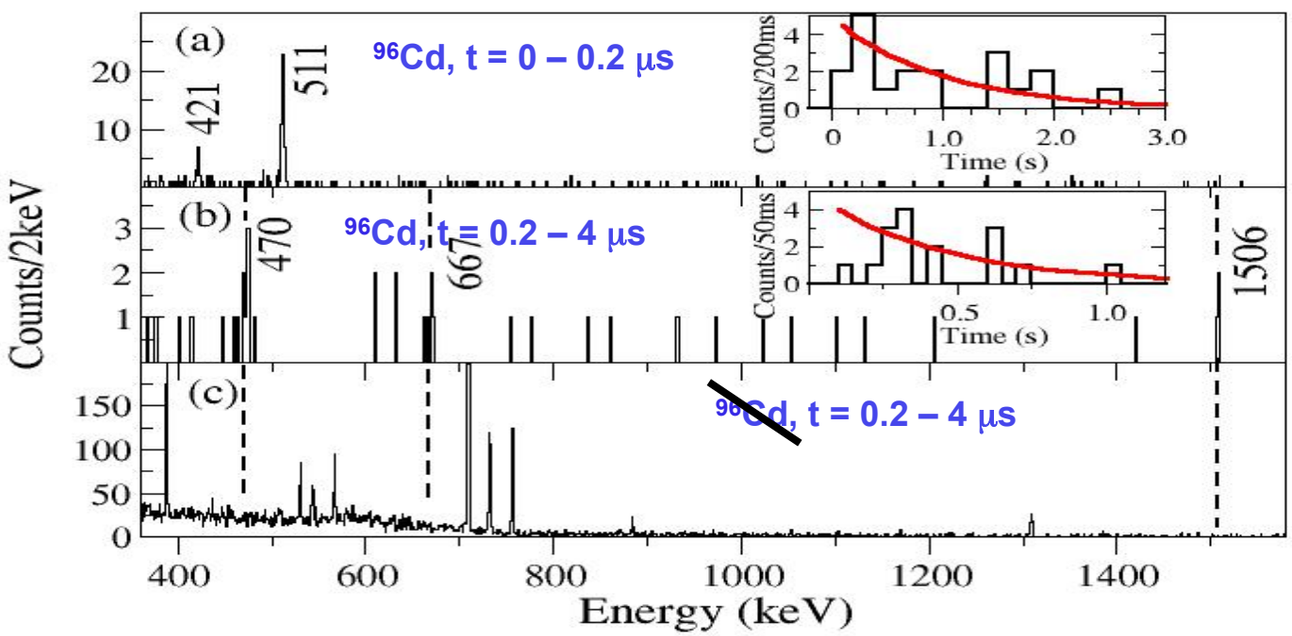
Motivation – ^{96}Cd

- **Long standing SM predictions for the presence of 16^+ spin-gap isomer in ^{96}Cd:**

  K Ogawa, Phys Rev C 28, 958 (1983)

⇒ First evidence: GSI via β-delayed γ's

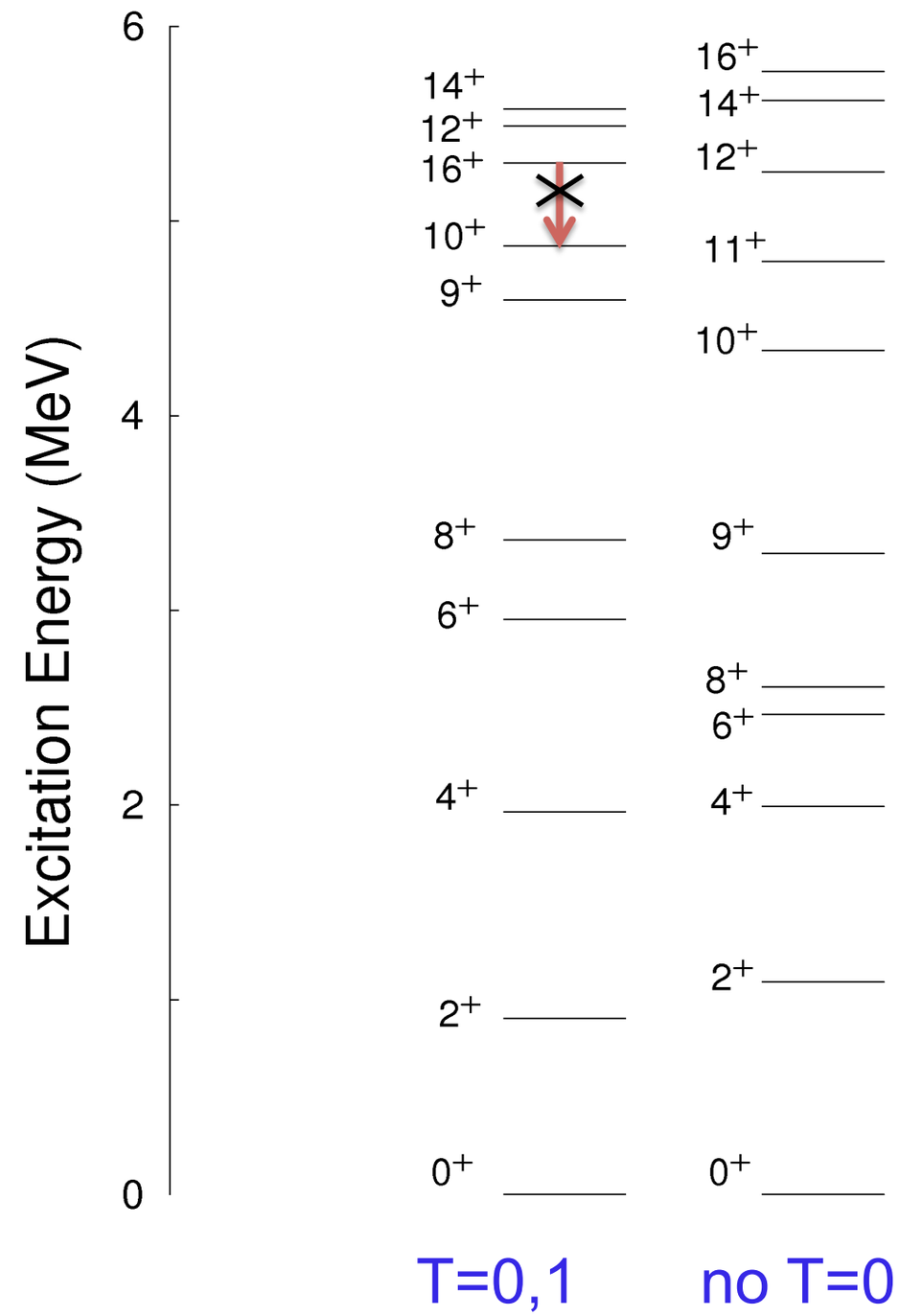
⇒ Nara Singh et al PRL 107, 172502 (2011)



^{96}Ag: P. Boutachkov et al, PRC 84 044311 (2011)

⇒ Existence of isomer provides evidence for the importance of the T = 0 np interaction at high-spin

Cf ^{92}Pd results – B Cederwall et al., Nature 469, 68 (2011)



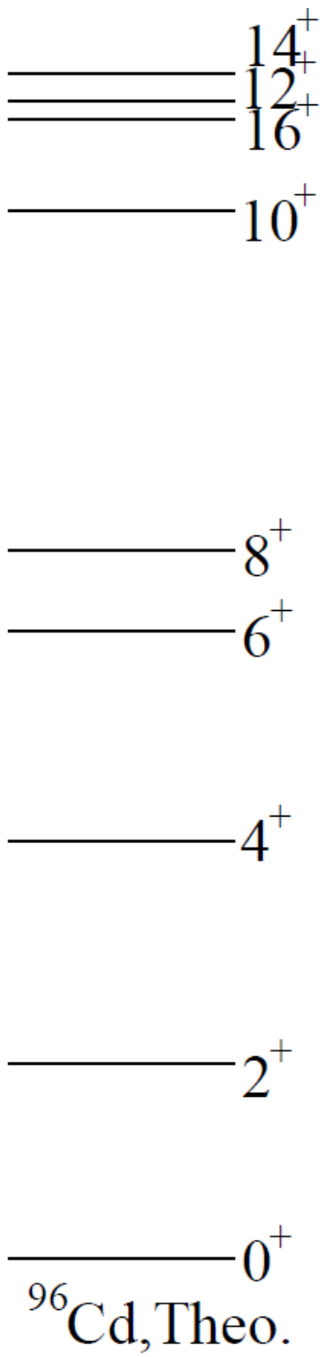
SM Calculations by H Grawe

GF int., $g_{9/2}$, $p_{1/2}$ model space

Motivation – ^{96}Cd

GSI expt: → Insufficient data to provide detailed tests of SM predictions…

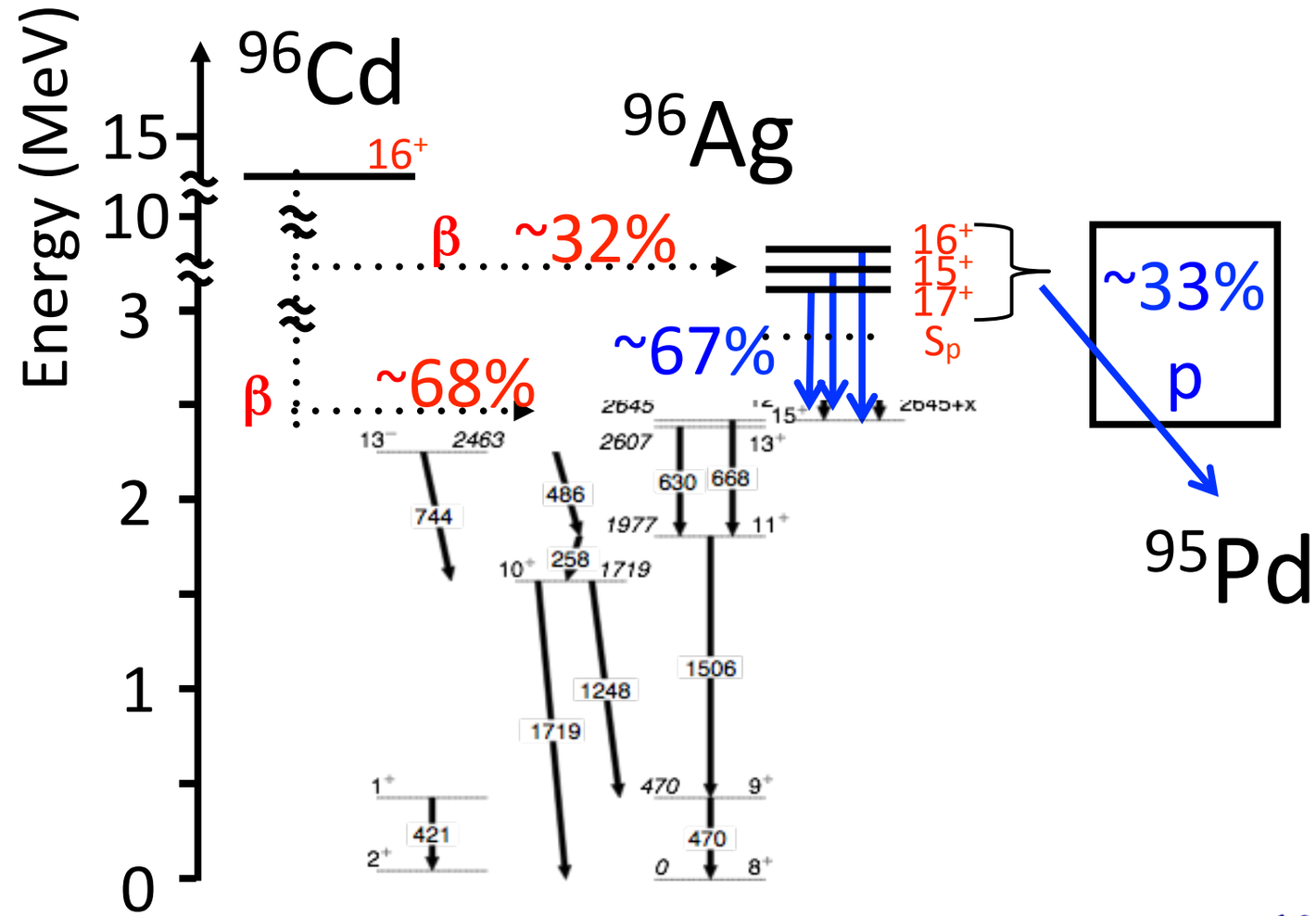
SM calcs: hint at existence of γ decaying isomer(s)



LSSM calcs - υπ(gds) model space + ^{80}Zr core

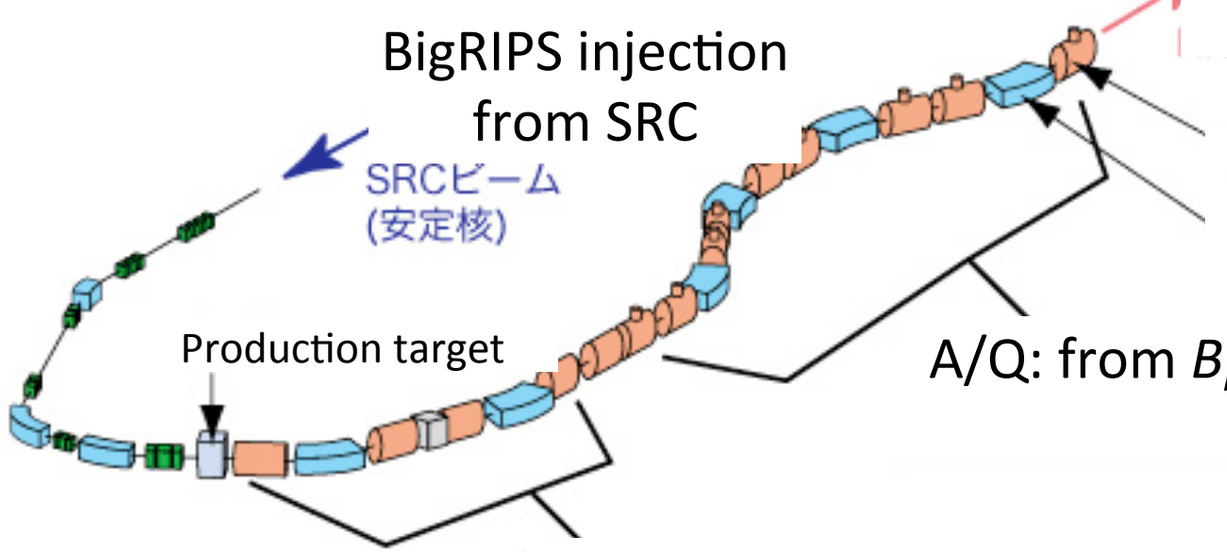
⇒ predict 16⁺ state β-decays to 3 resonance states above the p thres that have significant core excited wavefn components + direct pop. of 15⁺ isomer in ^{96}Ag.

⇒ Using simple WKB estimates, 15⁺,16⁺,17⁺ states were estimated to have large proton decay branches



Experiment: Radioactive Ion Beam Factory - RIKEN

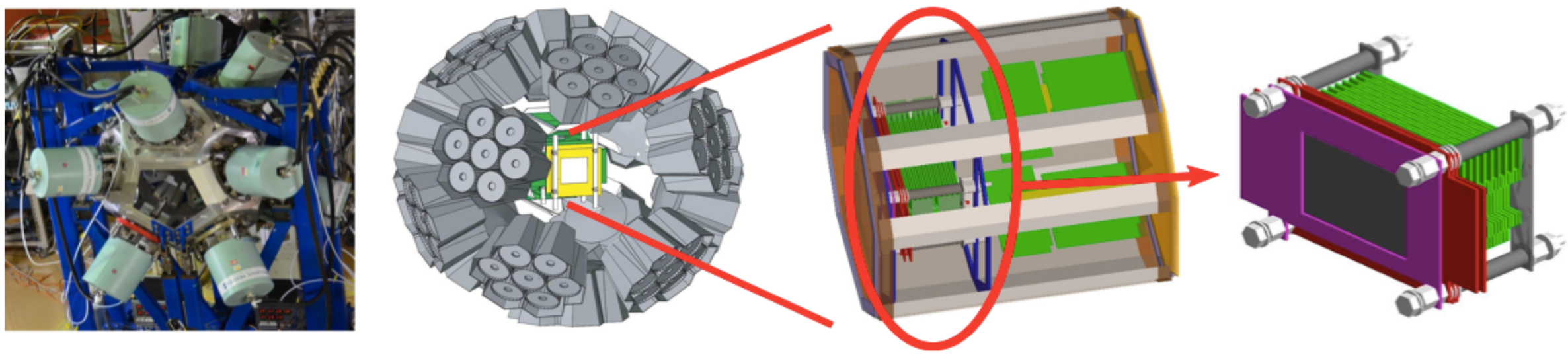
RIBF83: ^{124}Xe: 345 MeV/u, average of ~15 pnA on ^{9}Be target



RIBF83: P Boutachkov. A Blazhev, RW Isomer studies of ^{98}In, ^{96}Cd, ^{94}Ag

RIBF9: R Krucken, M. Lewitowicz, R. Gernhauser, S. Nishimura ^{100}Sn decay expt

Modified SIMBA: Silicon IMplantation Beta Absorber



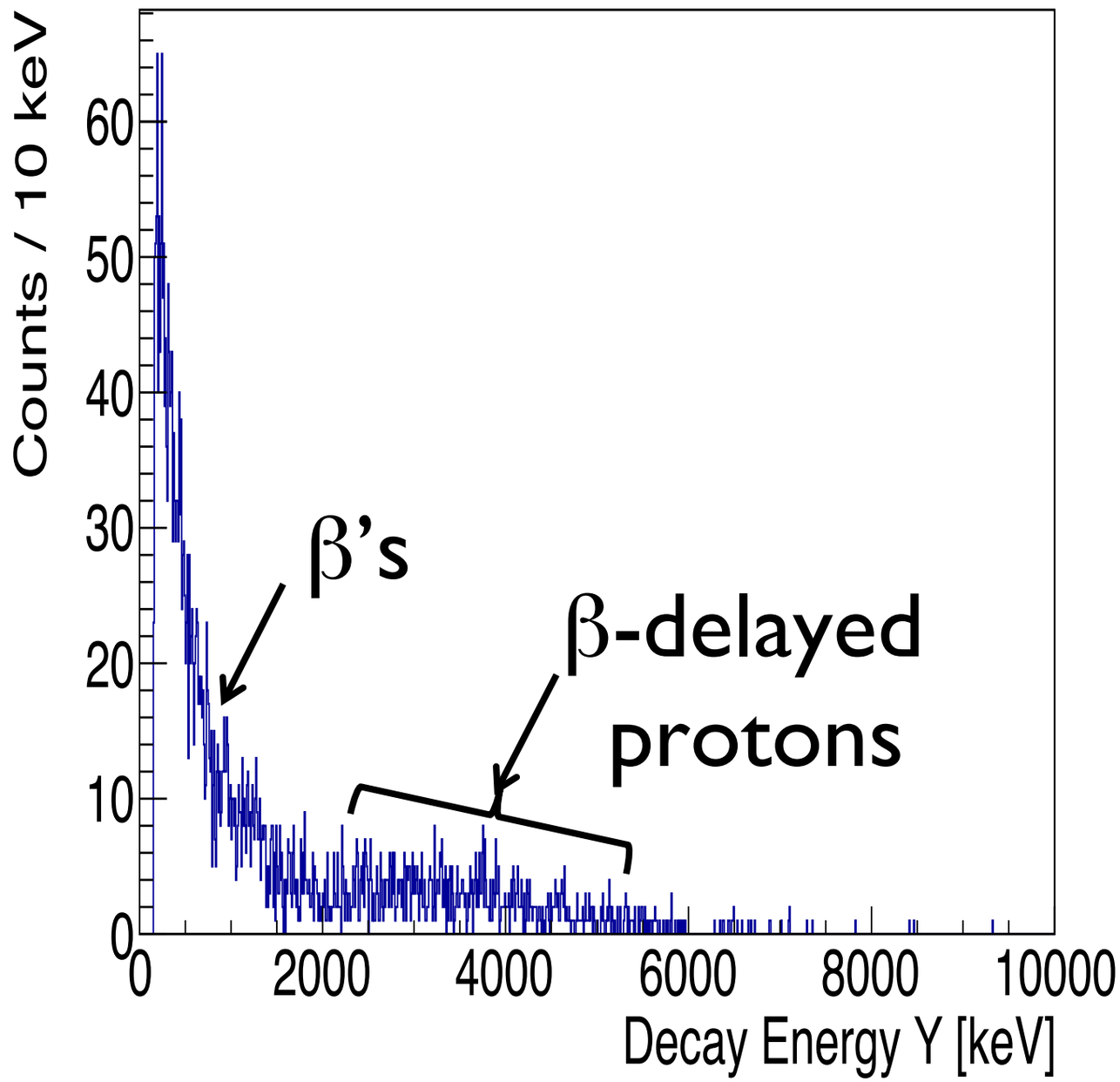
12 EB clusters, ε_γ ~ 8% @1.3 MeV

1 Si-DSSD 0.3 mm, 60x40 x-y strips for X-Y posn. + 3 Si-DSSSD, 1mm thick, 60 by 40 x-y strips for implantation

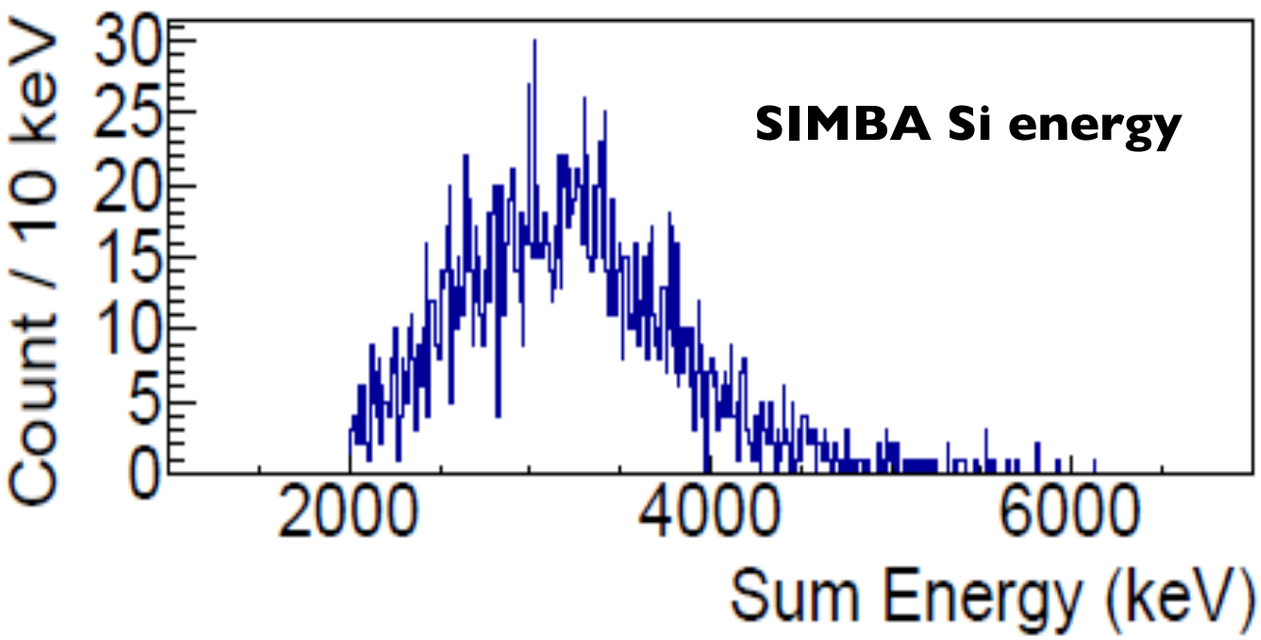
16 Si-DSSSD, 1mm thick, for β calorimetry +2 up- and 2 down-stream SSSSD for x,y pos.

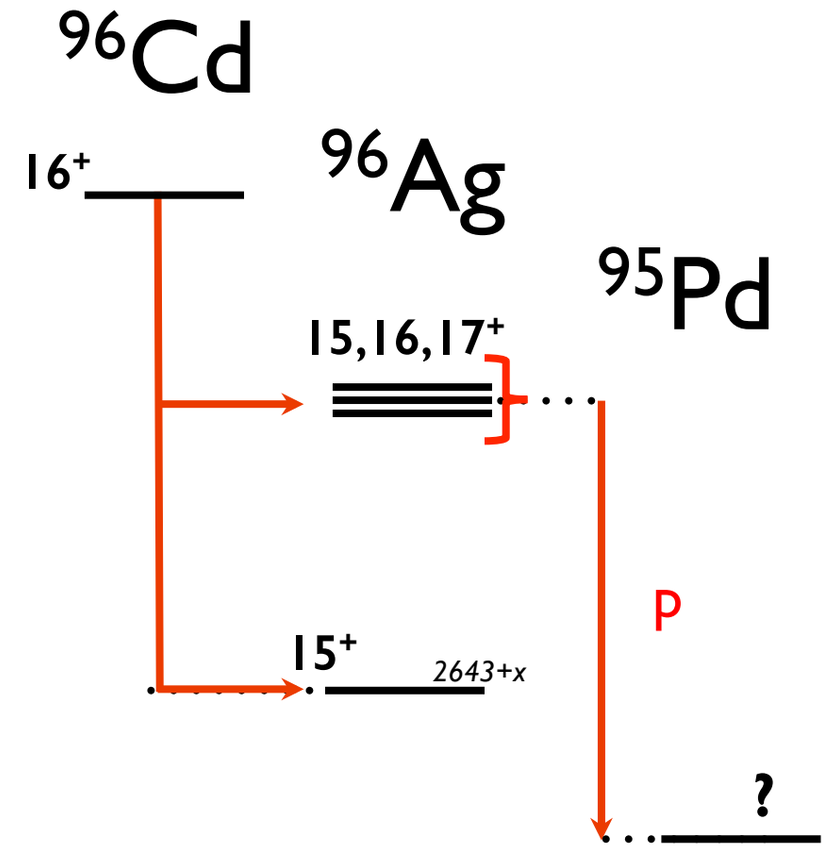
Results: ^{96}Cd 16^+ isomer decay

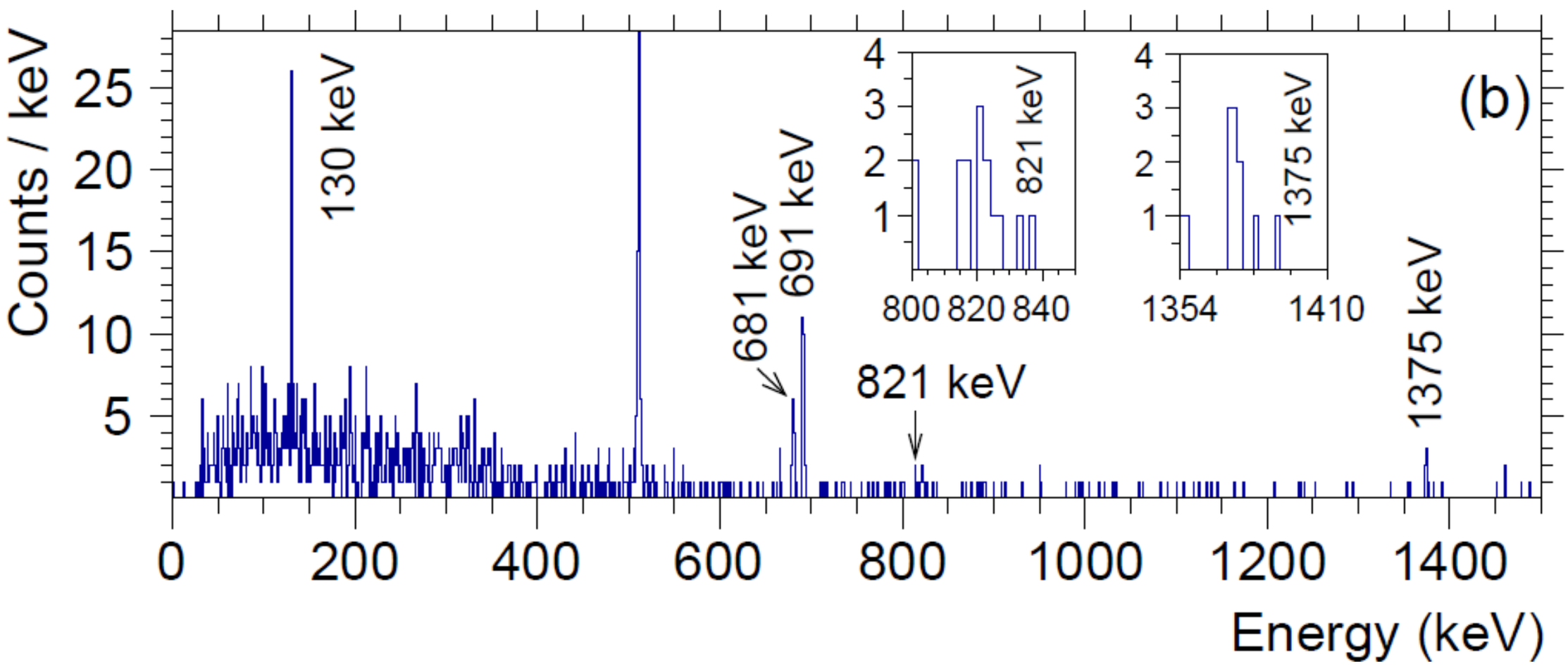
SIMBA spectrum following ^{96}Cd ion implants



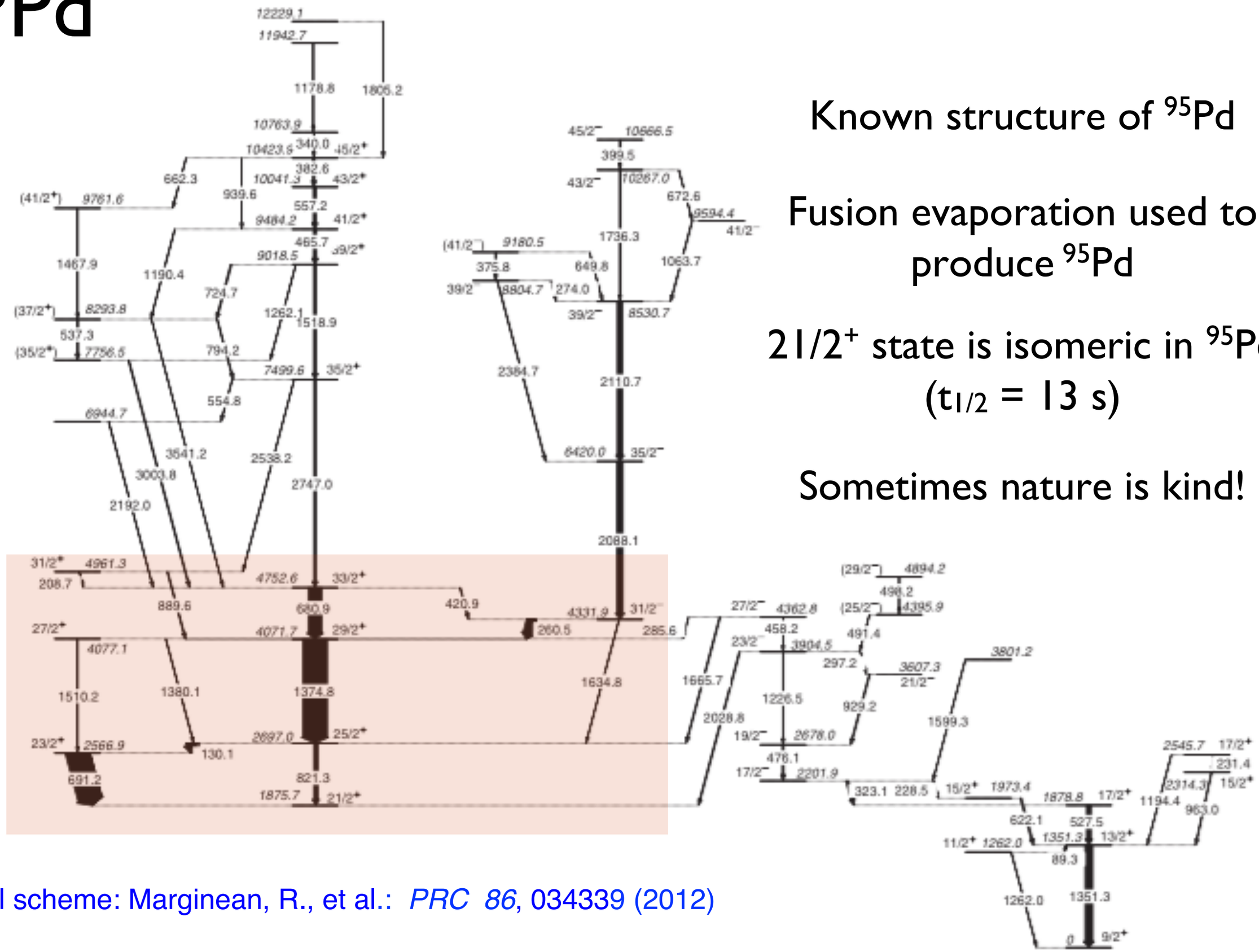
^{96}Cd ions + β-del. protons







^{95}Pd



Known structure of ^{95}Pd

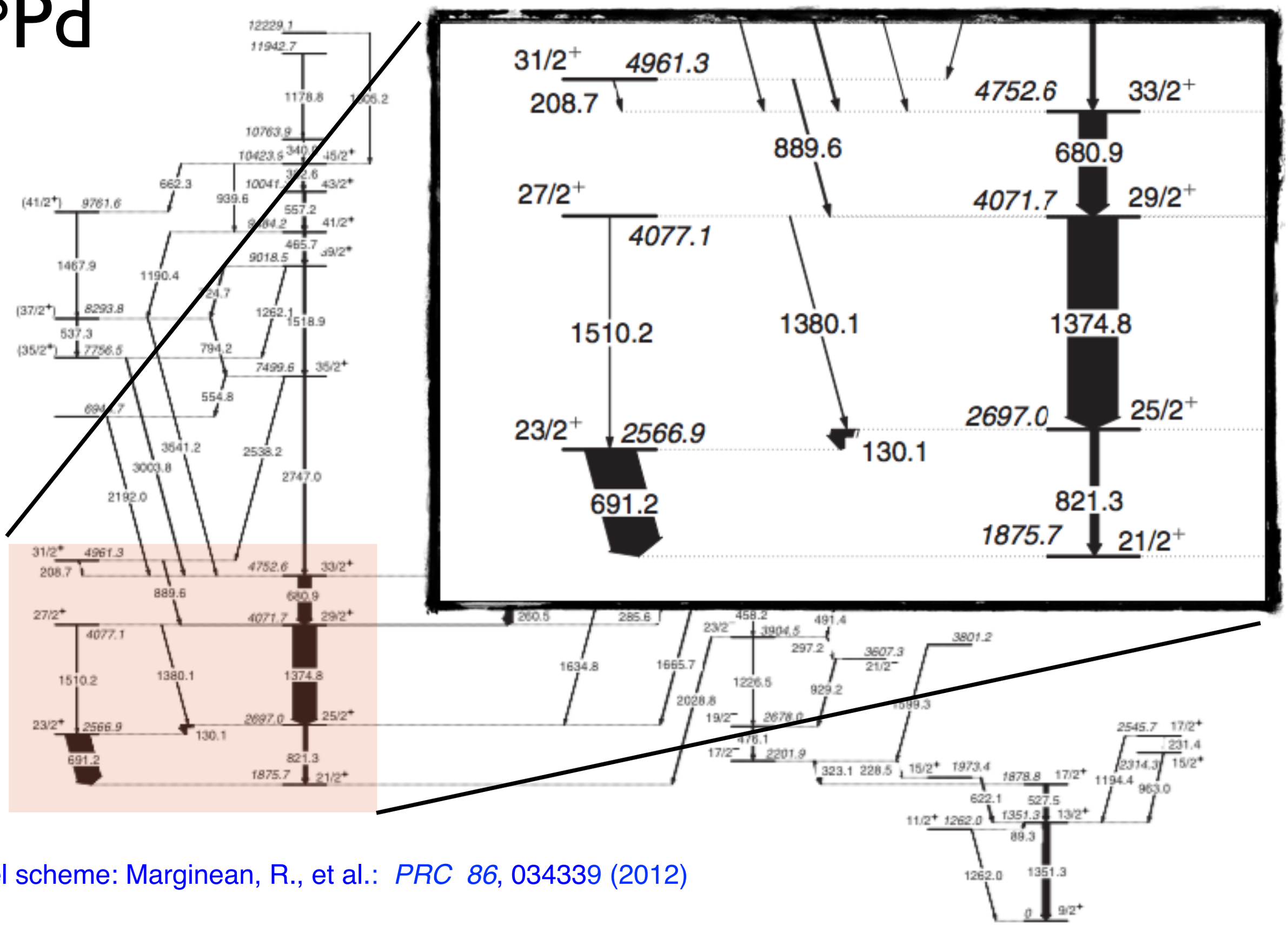
Fusion evaporation used to produce ^{95}Pd

$21/2^+$ state is isomeric in ^{95}Pd ($t_{1/2}$ = 13 s)

Sometimes nature is kind!

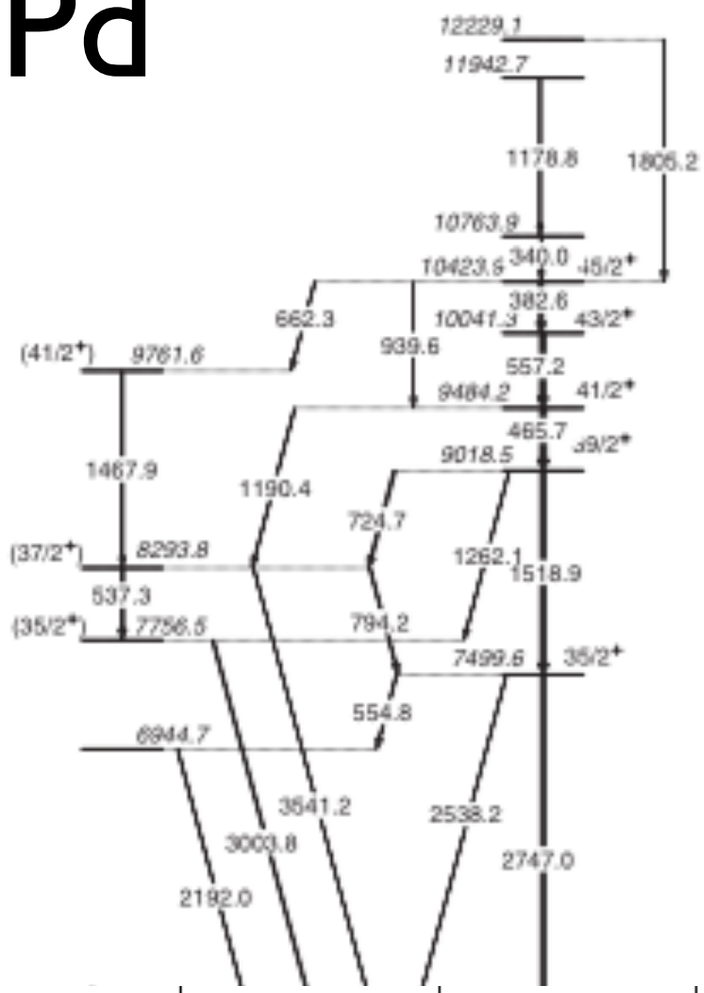
Level scheme: Marginean, R., et al.: *PRC 86*, 034339 (2012)

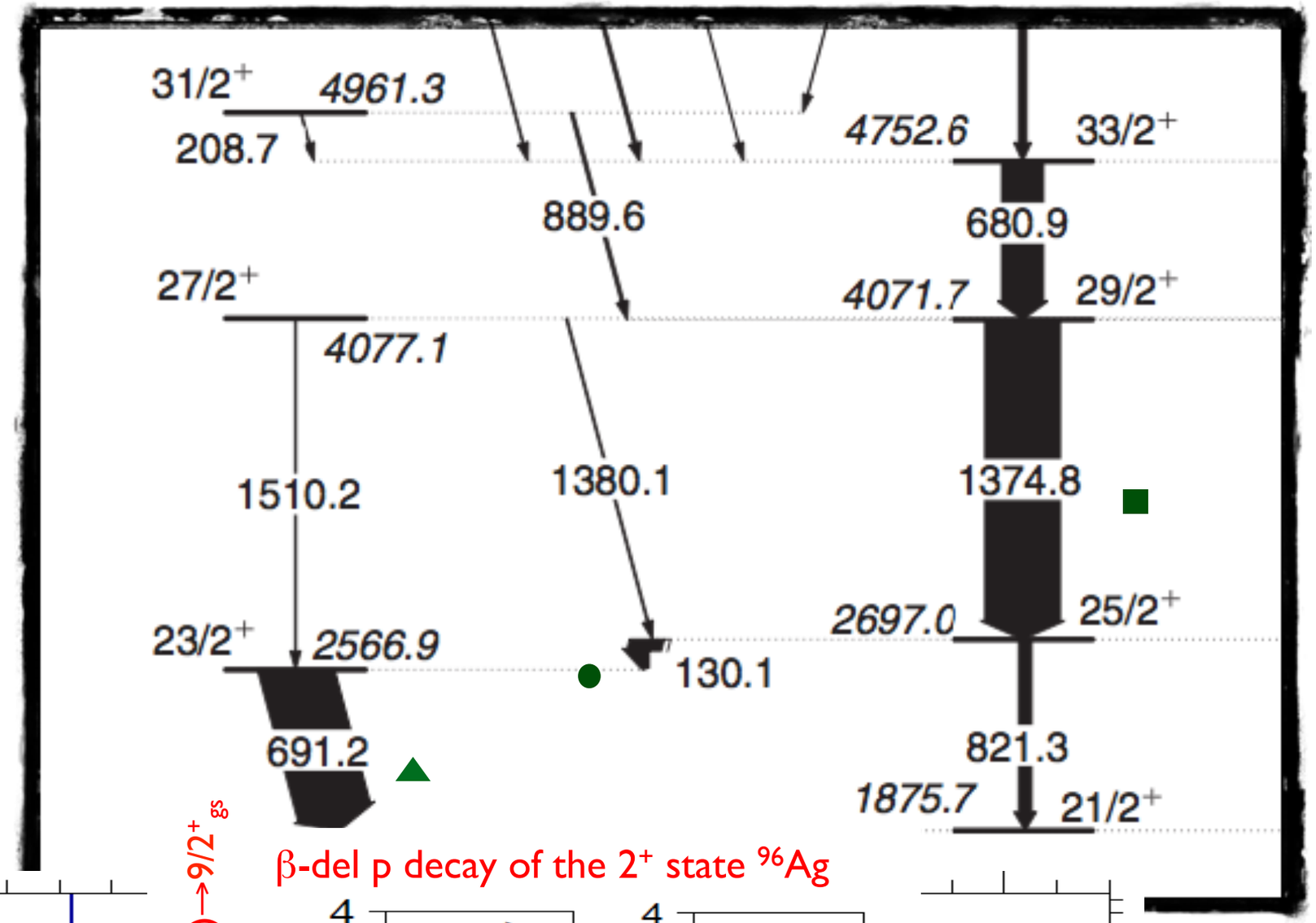
^{95}Pd



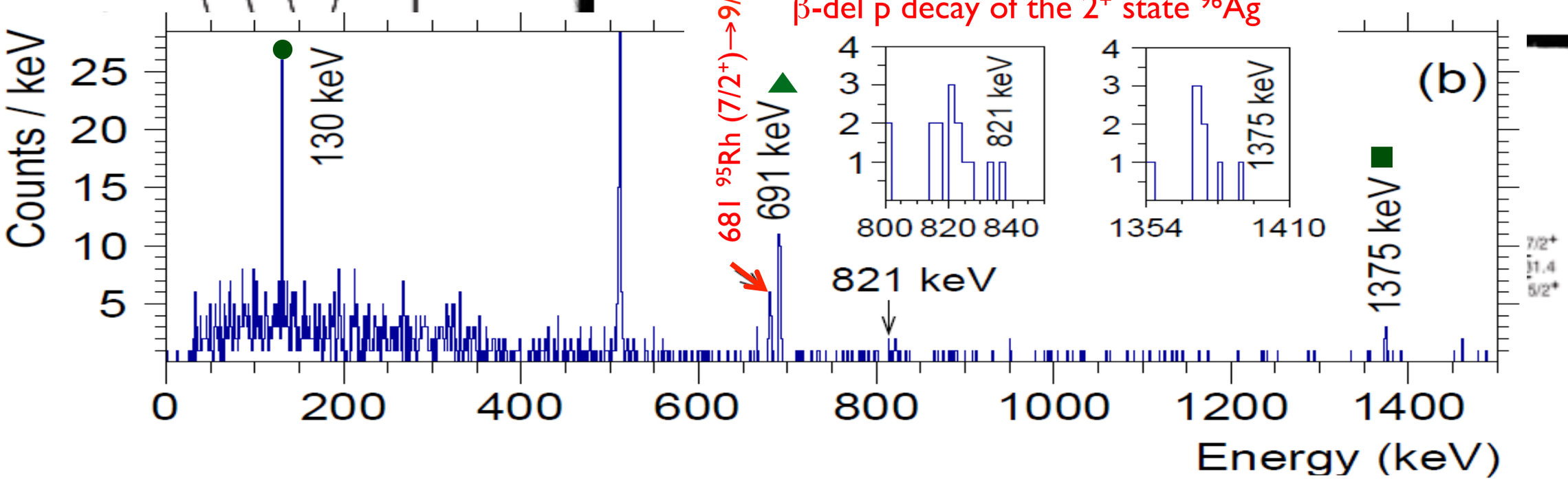
Level scheme: Marginean, R., et al.: *PRC 86*, 034339 (2012)

^{95}Pd



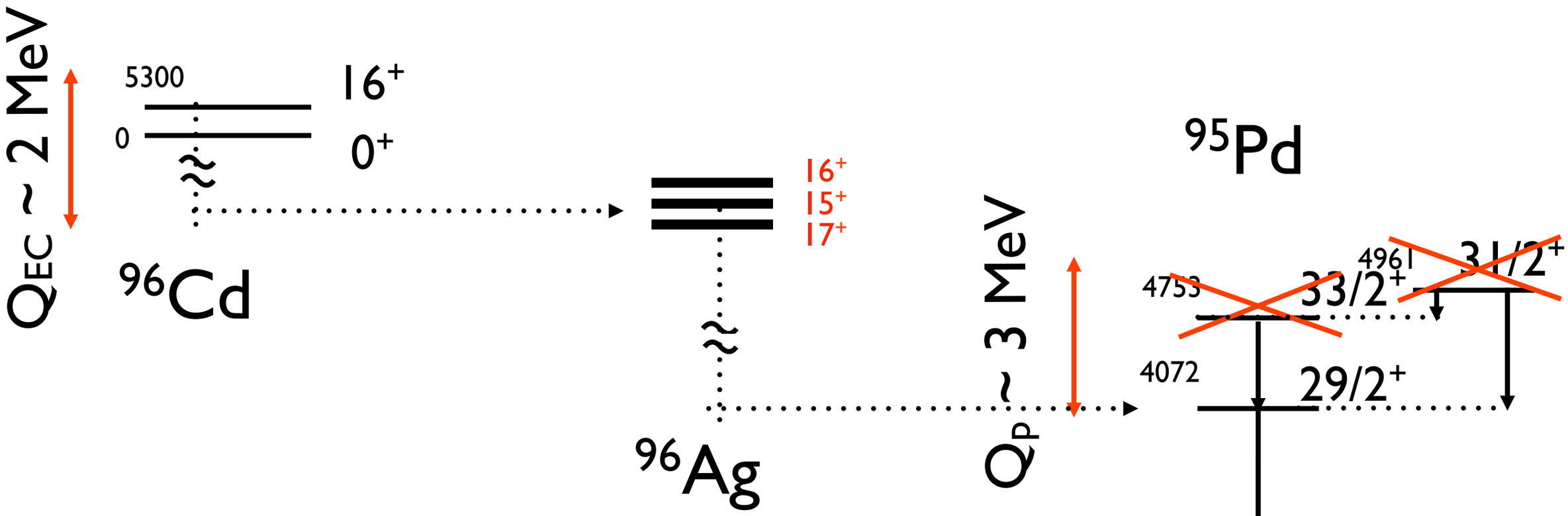


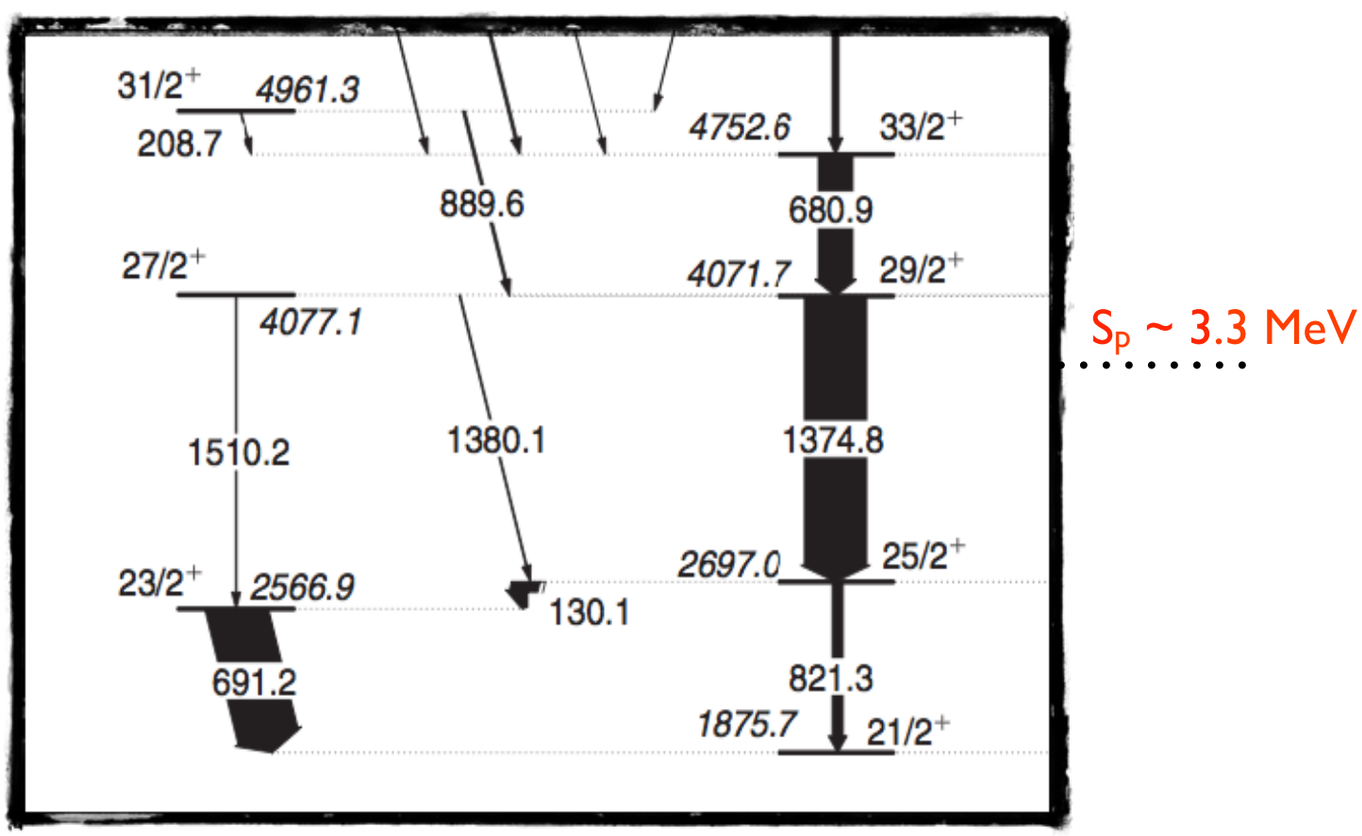
β-del p decay of the 2+ state ^{96}Ag



681 grows with ½ life consistent with the 6.9 sec decay ½ life of the 2+ state in ^{96}Ag

^{96}Cd 16$^+$ isomer decay





^{96}Cd 16^+ isomer decay

LSSM (*gds* space)/ WKB (ℓ = 0,2,4 barrier penetration) calcs have been made by H. Grawe/ T. Faestermann to investigate the population and decay of the 15^+,16^+,17^+ resonance states in ^{96}Ag.

Calculations still being checked, but prelim conclusions are:

1) Resonance population intensity is confirmed at ~30%
2) Population 15^+ / 17^+ states favoured mainly for decay energy reasons.

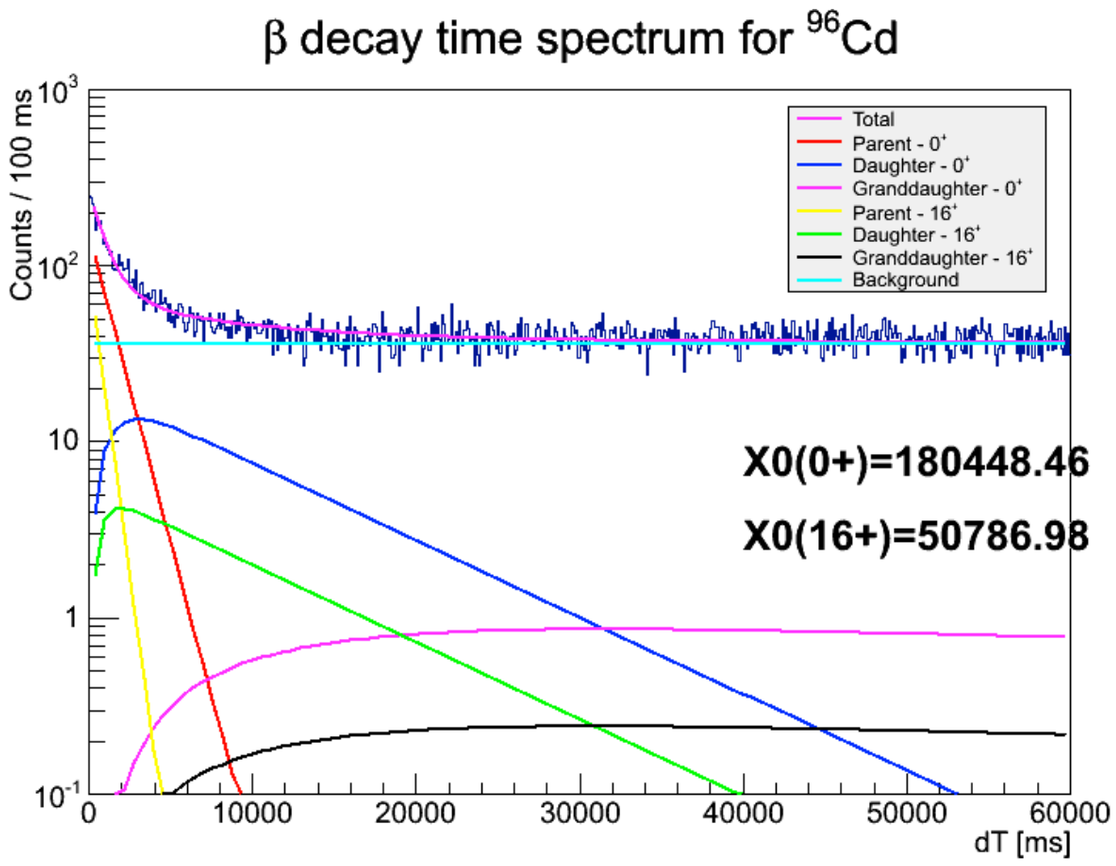
E_{res} (MeV)	I^{π}	I_{β} (%)
9.34	16^+	6.0
9.11	15^+	9.7
8.82	17^+	14.5

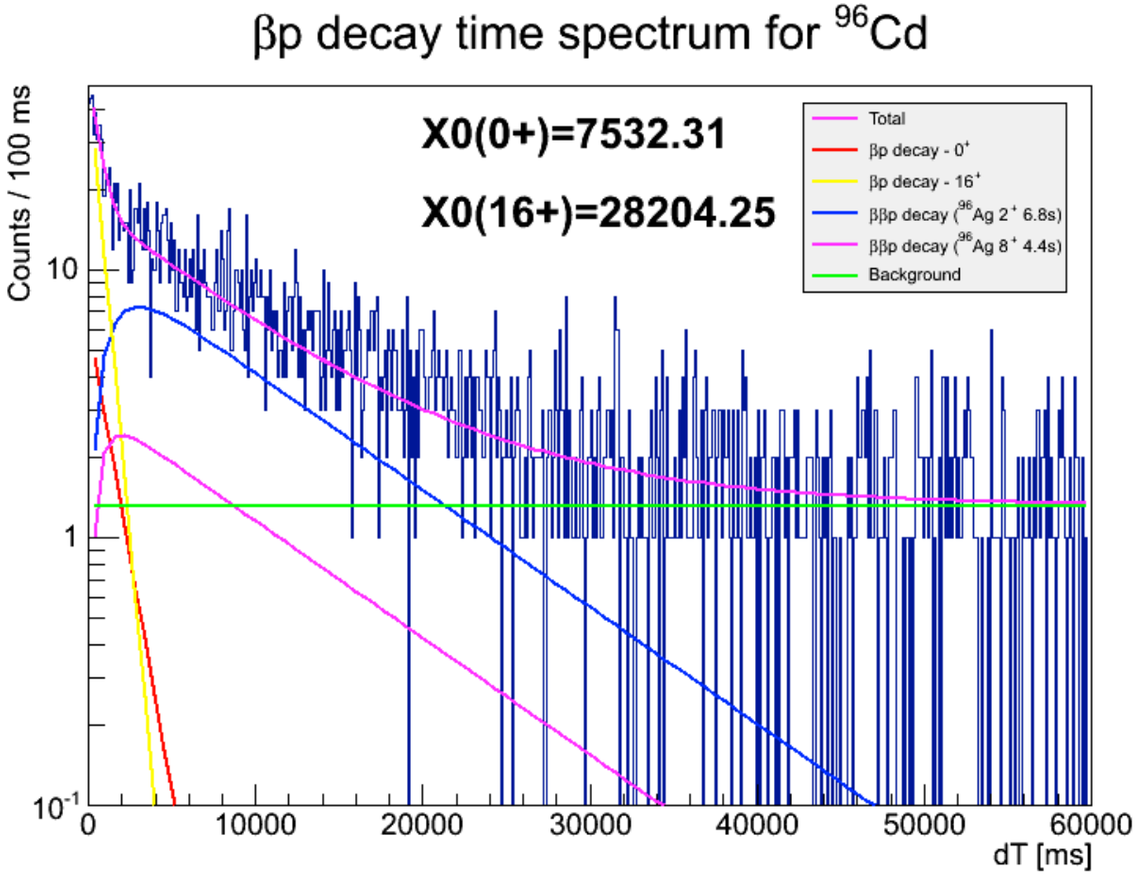
~ 30%

3) p-emission is strongest for ℓ = 2 decays. Indications that β-p decay comes mainly from core excited configurations.
4) $29/2^+$, $25/2^+$ states favoured by decay energy, Q_p, and WKB barrier penetration
   $\Rightarrow$ ℓ = 2 favoured over ℓ = 4 by the lower centrifugal barrier
   $\Rightarrow$ ℓ = 2 favoured over ℓ = 0 because of low Spec. Factors's for the latter

Calcs consistent with exptl obs. – i.e: no substantial evidence of decays from $27/2^+$, $31/2^+$ or $33/2^+$ states

β-delayed proton - branching ratios





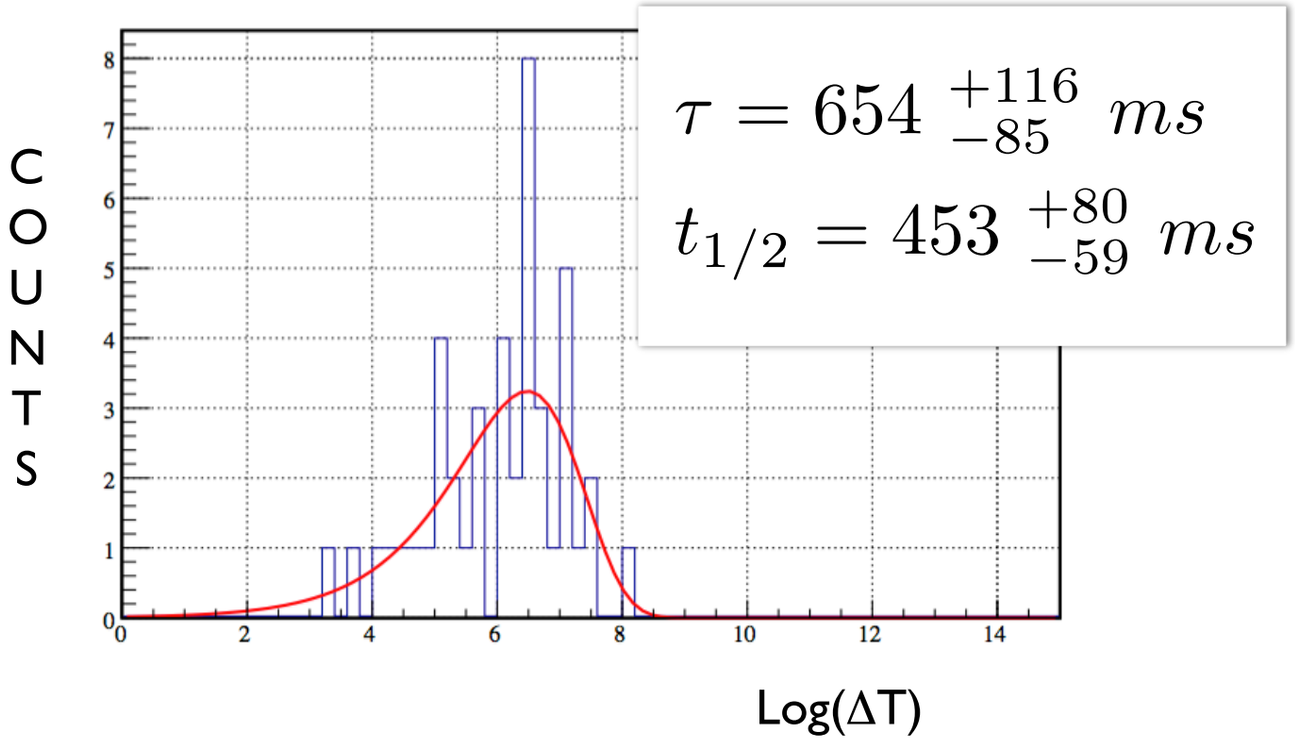
Fitting: two exponentials for ^{96}Cd, background (daughter+time-random)

Proton-Beta branching ratio extracted:

16^+ isomer: 11(3)%
Ground state: 1.5(5)% cf 5(4)%*

* G. Lorusso et al, PRC 86, 014313 (2012)

Lifetimes



Schmidt method:
K. H. Schmidt , Z. Phys A316, 19 (1984)

16^+ isomer:

Sum of 470, 668 and 1506 keV γ's in ^{96}Ag

Prev. result:

$\tau_{1/2}$ = 290+110-100 ms ,
Nara Singh et al PRL 107, 172502

$$\tau = 1397(130)\ ms$$

$$t_{1/2} = 968(90)\ ms$$

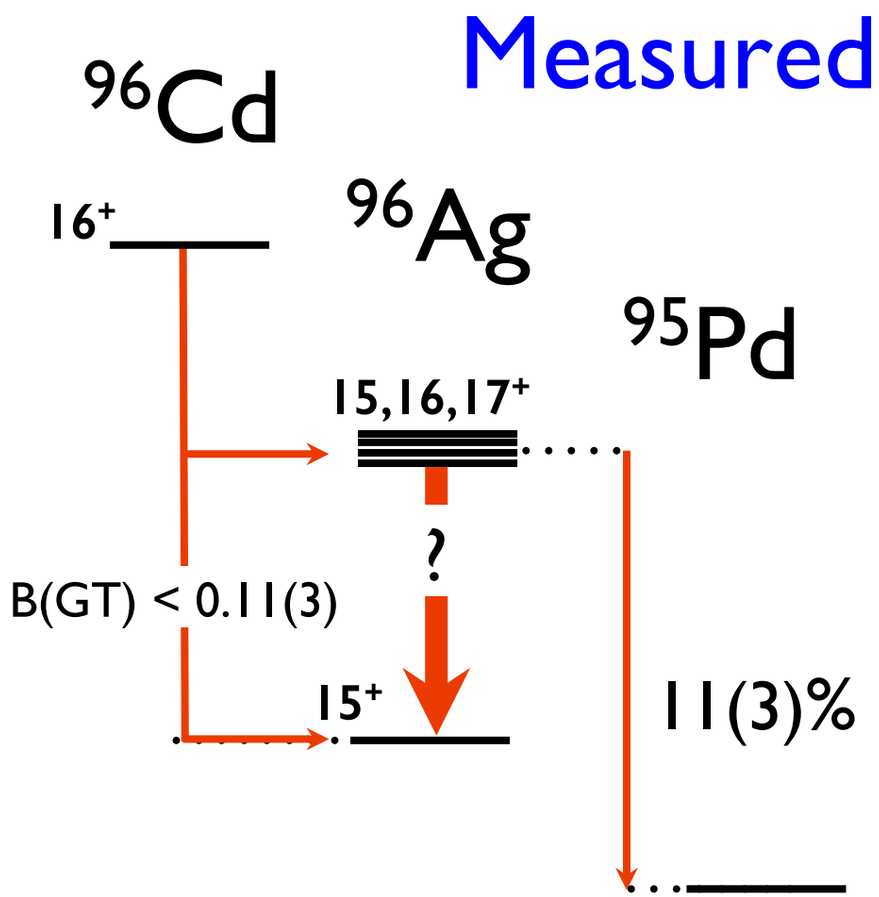
Ground state:

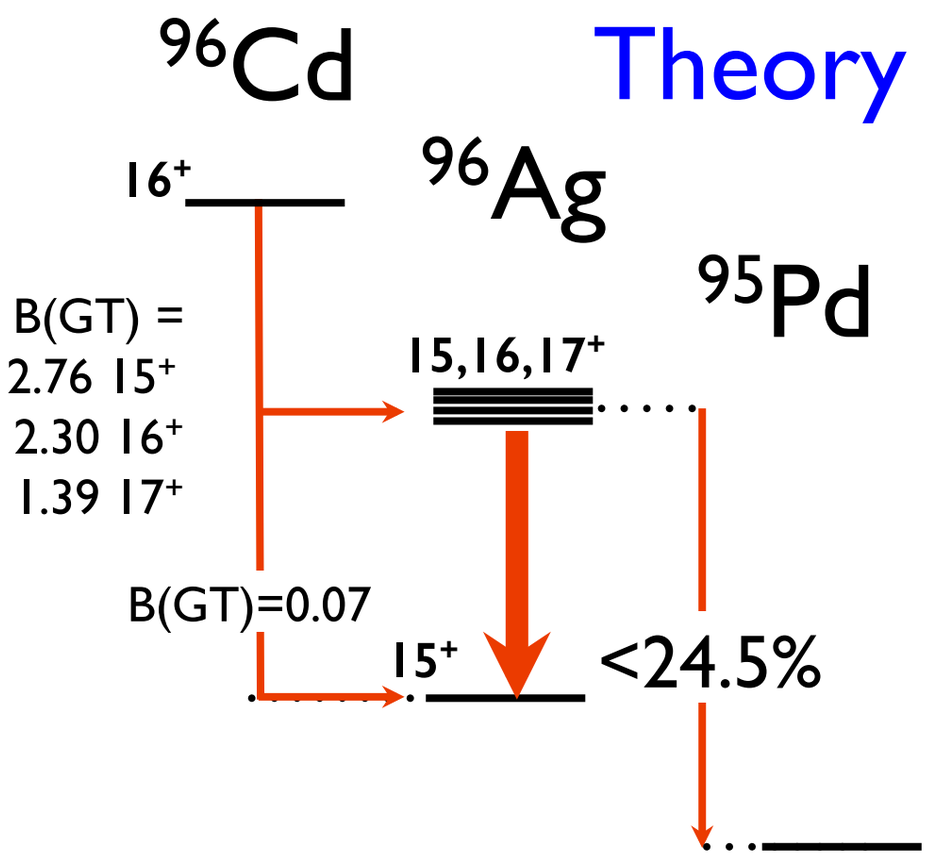
From fit of β-decay data with gs lifetime as free parameter

Prev. results:

$\tau_{1/2}$ = 1030+240-210 ms,
D Bazin et al PRL 101, 252501
$\tau_{1/2}$ = 670+/-150 ms,
Nara Singh et al PRL107, 172502

B(GT) + β del p values



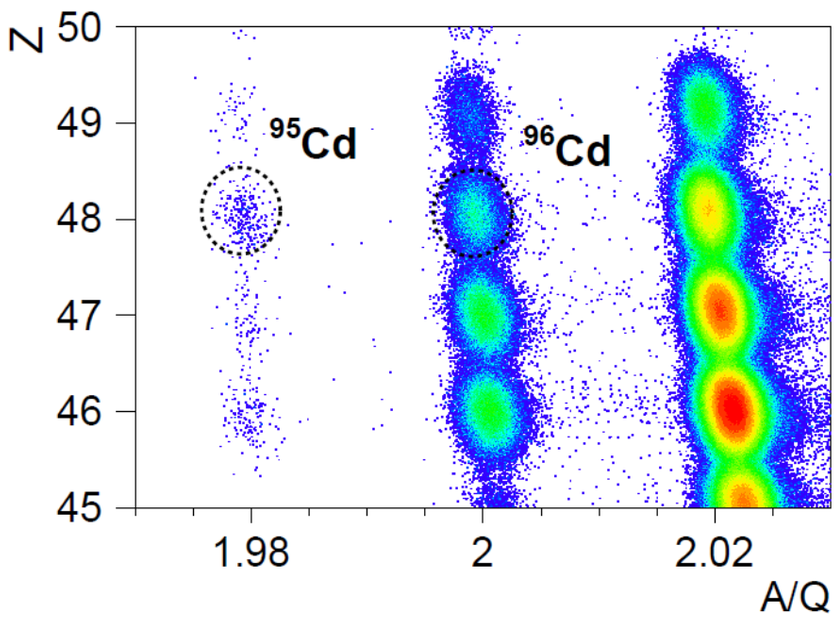


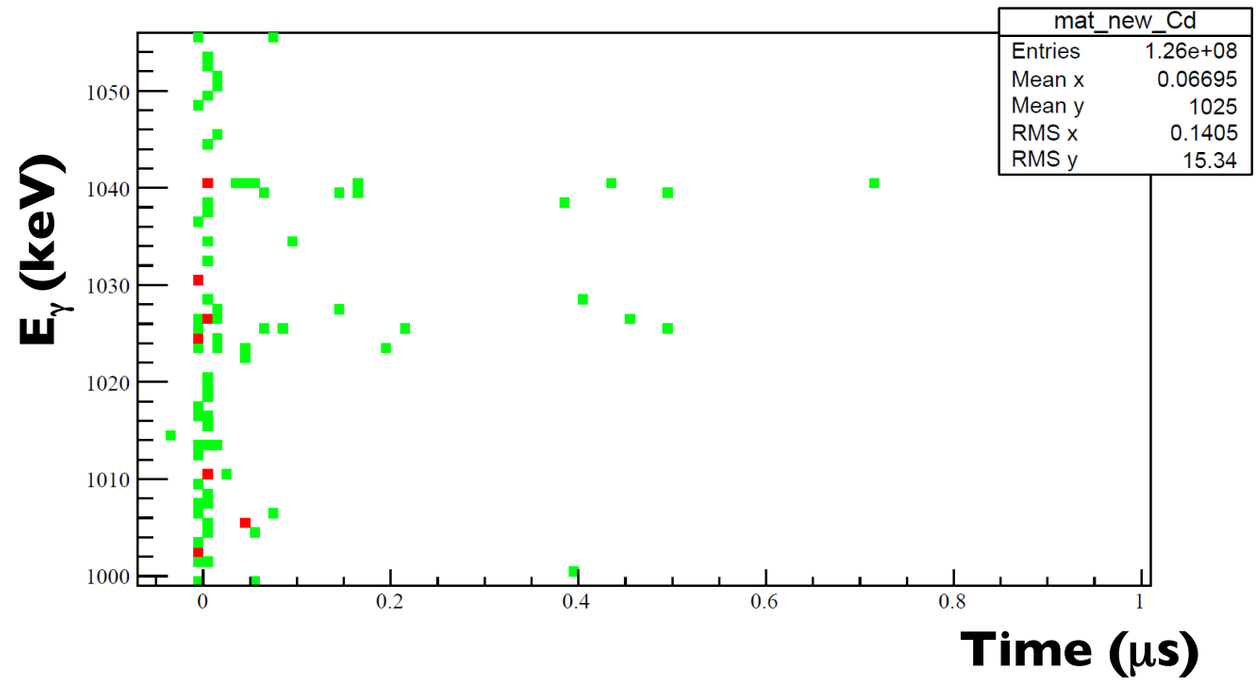
Pandemonium effect: Unable to extract the exclusive B(GT) strengths

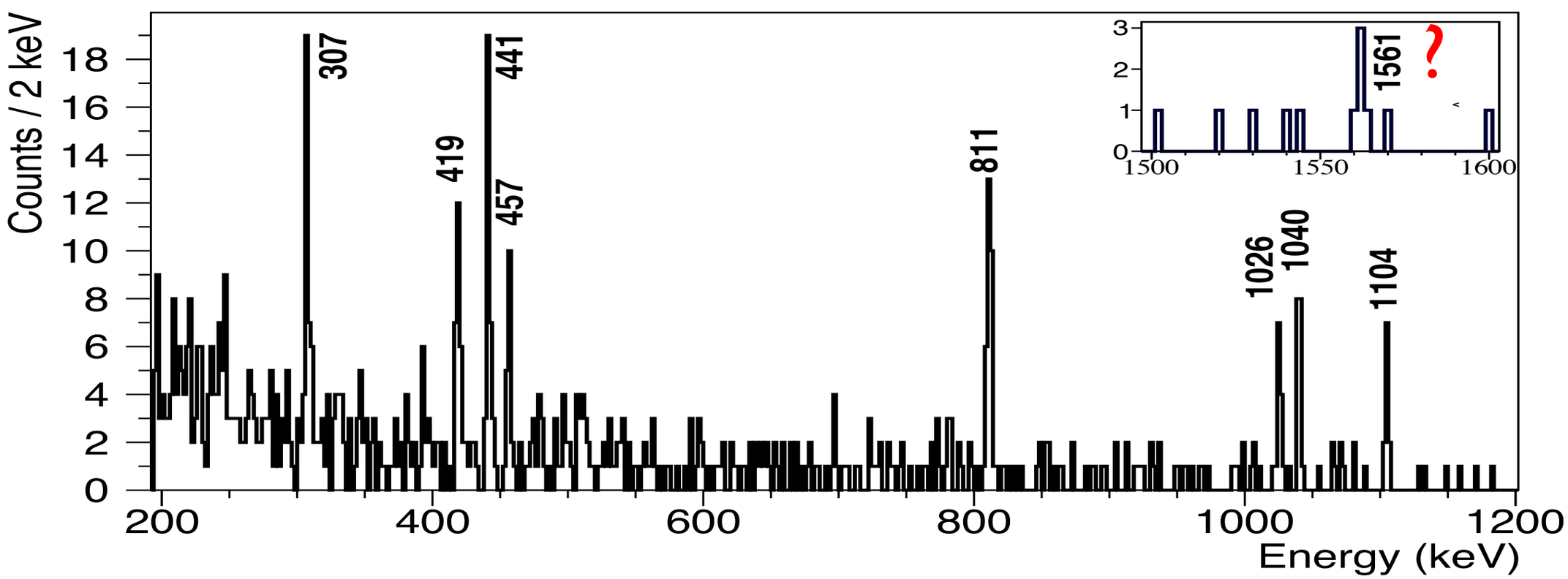
$$B(GT) = \frac{3860(18)\, I_\beta}{f\, T_{1/2}}$$

See Nara Singh et al., PRL 107, 172502 for details

Gamma decaying isomer in ^{96}Cd: RIBF9,83



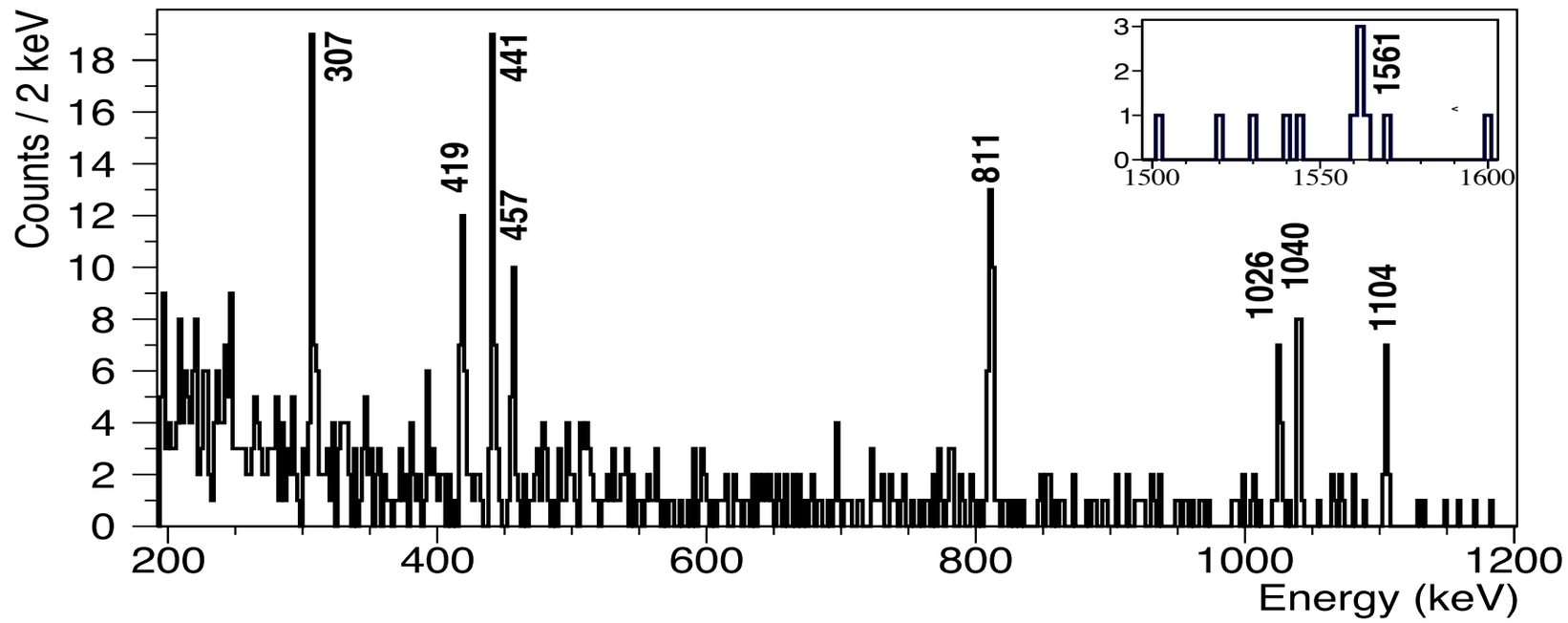


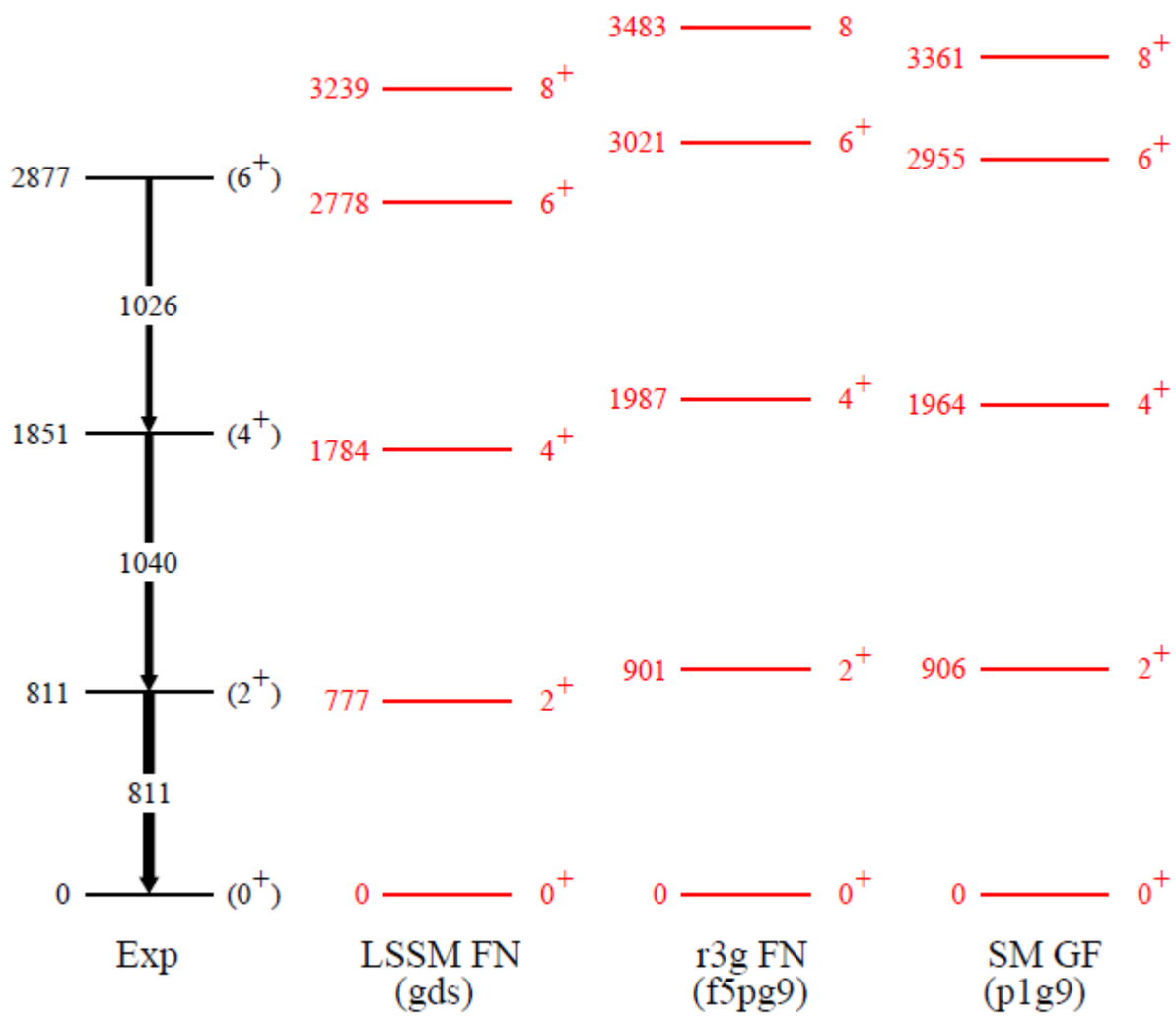


γ rays within ~50 - 900 ns of the ion being implanted

Sum of RIBF9 and RIBF83 expt data

Gamma decaying isomer in ^{96}Cd



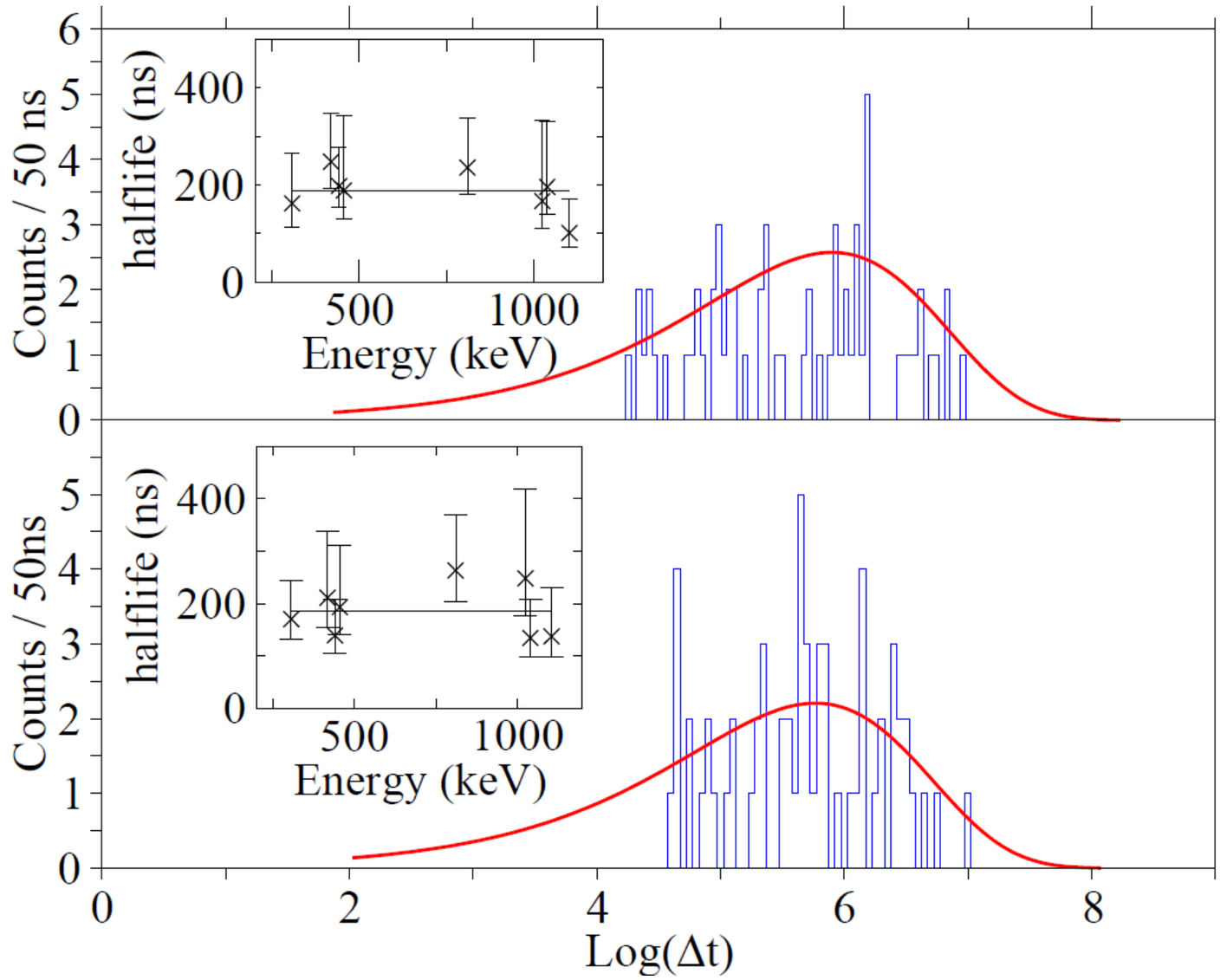


Shell model calculations give us some clue to what we are seeing

<u>$8^+ \rightarrow 6^+$ transition: assuming 1 W.u.</u>

E_γ	τ_m(ns)
307	11
419	2.3
441	1.8

Lifetime of γ decaying isomer



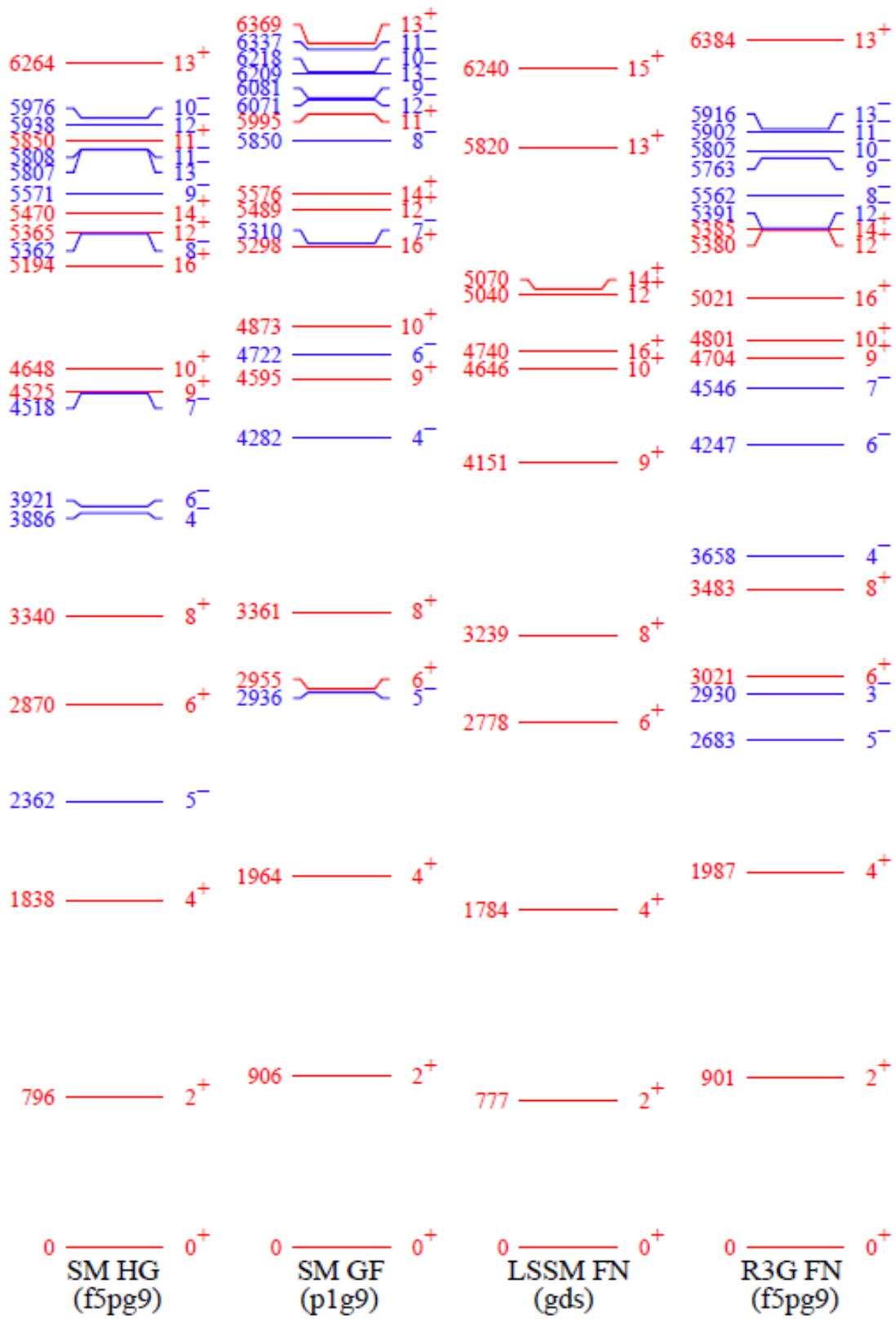
$$\text{York}: \quad t_{1/2} = 195^{+27}_{-21}\ \text{ns}$$
(RIBF83)
$$\tau = 281^{+39}_{-30}\ \text{ns}$$

$$\text{UBC}: \quad t_{1/2} = 198(26)\ \text{ns}$$
(RIBF9)
$$\tau = 286(37)\ \text{ns}$$

Δt = time diff. between γ and ^{96}Cd implant

K H Schmidt (Z. Phys A. 316, 19 (1984)): - sum events in the 8 γ transitions.

Nature of ^{96}Cd γ decaying isomer?



Possible options:

1) 14^+ - probably not!

All 8 γ's have coincs with 1 or more of the others

2) Negative parity state, 12^- or 13^-?

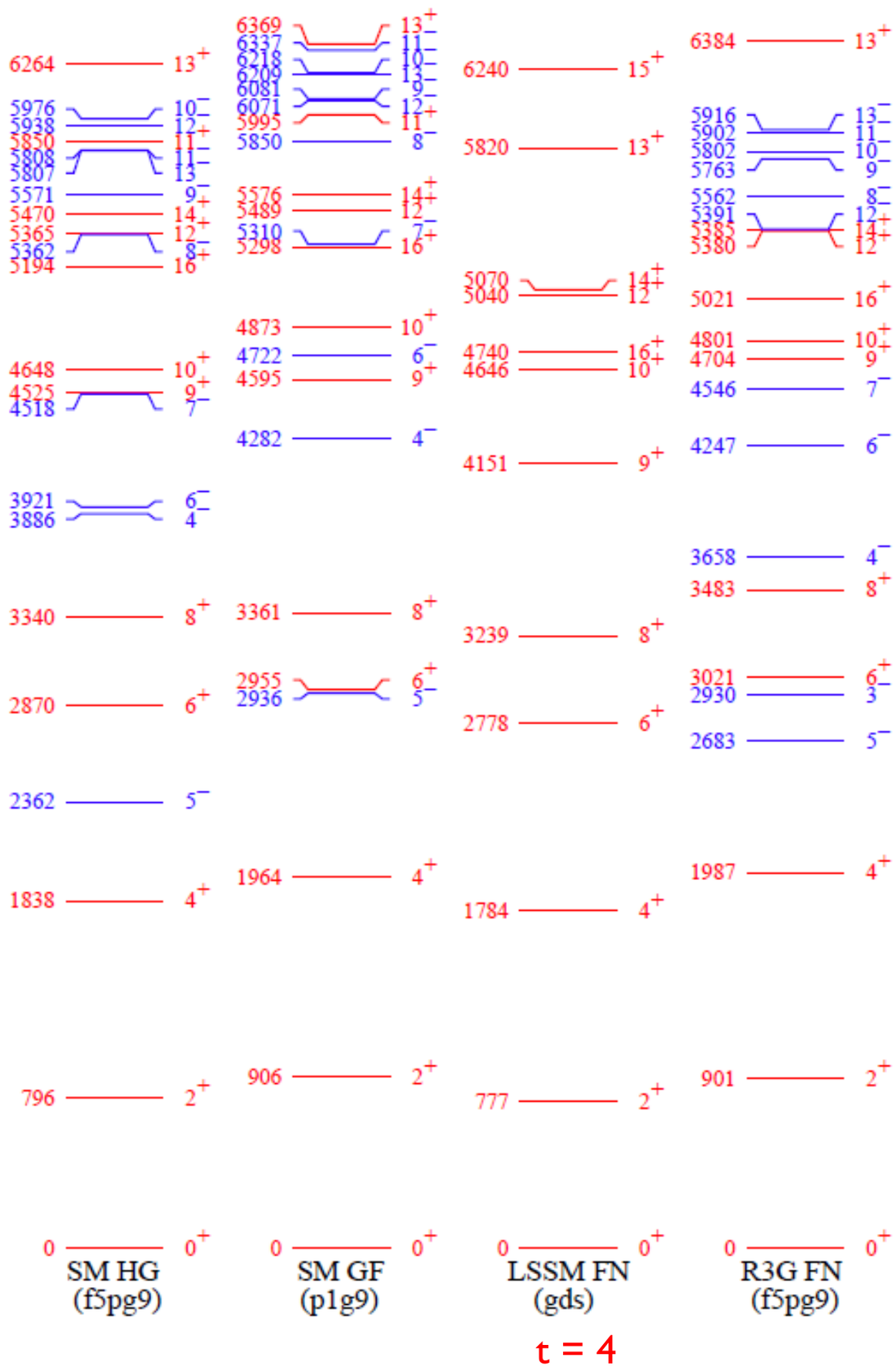
For 307, 419, 441 keV trans.

B(E1) ~ few x 10^{-8} W.u. OK

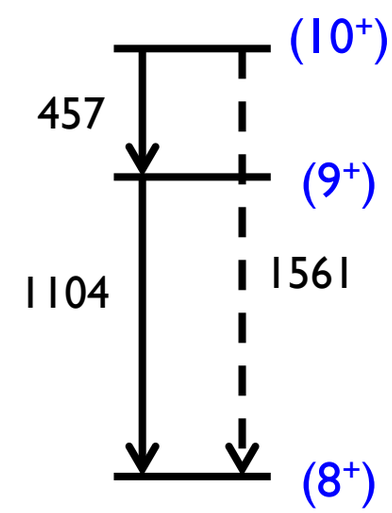
B(M2) ~ 0.5 – 2.5 W.u. X

B(E3) ~ few thousand W.u. X

Other comparisons



10^+ predicted to be 1.3 – 1.6 MeV ab ove the 8^+



T = 1 state in t = 4 LSSM + GF Calcs !!

Strong M1 pred. for 10 → 9 in GF space, BR (M1/E2) = 77/23 % for 457/1561

In a pair approx the T=1 9^+ state →
Energetically favoured coupling of a 9^+,T=0 pair to a 0^+, T=1, pair, which are the lowest states in ^{98}In.....

Further SM calculations underway!!
H. Grawe/ F Nowacki

RIBF83 + RIBF9 Collaborations

GSI: P. Boutachkov, M.Górska, H. Grawe, F. Ameil, I. Mukha, J. Gerl, I. Kojouharov, N. Kurz, H. Schaffner, N. Goel
York: P.J. Davies, L.F. Sinclair, D.G. Jenkins, M. A. Bentley, S. Valder, R. Wadsworth
UBC/ TRIUMF: R. Krucken, J. Park, M.M. Rajabali, Z. Wang
IPHC Strasbourg: F. Nowacki and K. Sieja
GANIL: M. Lewitowicz, I. Celikovic, G. deFrance
IKP Koln: A. Blazhev, M. Dewald, J. Jolie, K. Moschner, N. Warr, J. Thole
RIKEN: S. Nishimura, P. Doornenbal, H. Watanabe, Z. Li, G. Lorusso, T. Nakao, T. Isobe, H. Baba, P.-A. Soderstrom, K. Yoshinaga, Z. Xu, D.S. Ahn, N. Fukuda, N. Inabe, K. Kameda, T. Kubo, D. Murai, Y. Shimizu, H. Suzuki, H. Takeda
TU Munich: T. Faestermann R. Gernhaeuser, D. Lubos, L. Maier, K. Steiger
CEN Bordeaux: B. Blank, J. Giovinazzo
Brighton: F. Browne
Edinburgh: Z. Lui, P. J. Woods
Univ of Tokyo: S. Go, H. Hotaka, D. Nishimura, H. Soon Jung, Z.Y. Zhu, S. Sakurai
Tohoku: T. Sumikama, T. Nishizuka,
Surrey: Z. Patel, S. Rice
Madrid: A. Jungclaus
Daejeon: G.D. Kim, Y.-K. Kim
KTH: B. Cederwall and T. Back
Padova: F. Recchia
Osaka: Y. Ayumi, H. Nishibata, Y. Fang
Uppsala: A. Gengelbach
TU Darmstadt: E. Merchan, E. Gregor, N. Pietralla, S. Ilieva,
Yale: V. Werner, F. Naqvi
Beihang U: H. Watanabe
IEM: J. Taprogge
Peking U: J. Wu

Summary

- ⇒ LSSM calcs suggest that the 16^+ isomer populates 3 (15^+,16^+,17^+) "resonance-like" states above the p threshold in ^{96}Ag. β - p decays obs.
  Confirms 16^+ has core excited wavefn components

  ⇒ LSSM +1-D WKB estimates suggest ℓ = 2 p decay to $29/2^+$ ($25/2^+$) states in ^{95}Pd dominates : Consistent with exptl. obs.

  ⇒ B(GT) limit extracted for (^{96}Cd) $16^+ \rightarrow$ (^{96}Ag) 15^+ isomer compares well with LSSM - pandemonium problems remain to determining exclusive B(GT) values.

- ⇒ Evidence for new γ-decaying isomer in ^{96}Cd with half-life of ~200 ns: Nature still to be confirmed: 12^-, 13^- good candidates

  ⇒ First tentative identification of 2^+ 4^+ and 6^+ states

  ⇒ SM calcs suggest indicate that the yrast T=0 10^+ state should feed a T=1 9^+ state. Tentative exptl evidence for this.