Interplay between collective and single particle excitations around neutron-rich doubly-magic nuclei

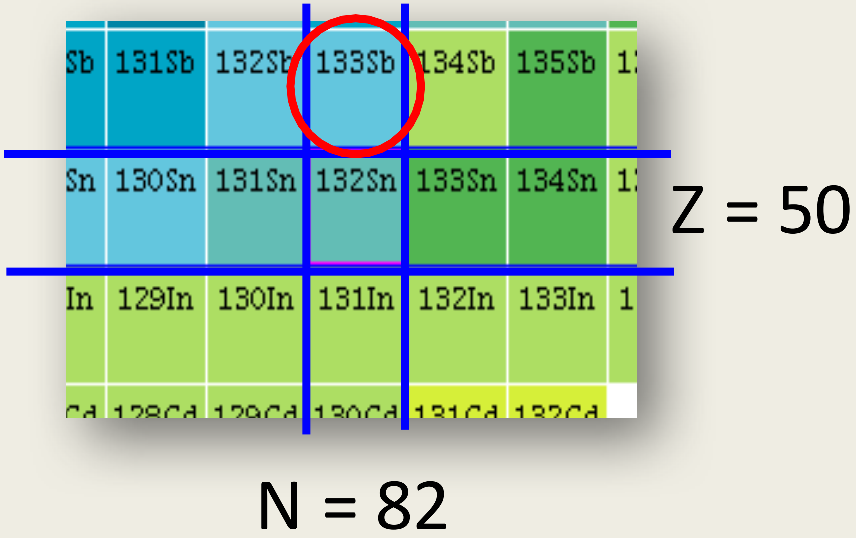
NUSPIN 2016 Workshop on the Nuclear Spectroscopy Instrumentation Network and AGATA Physics Workshop

Giovanni Bocchi
Venezia - 2016

Physics Motivation

^{133}**Sb:** $^{132}\mathrm{Sn} + 1\pi$

One-valence-proton nucleus



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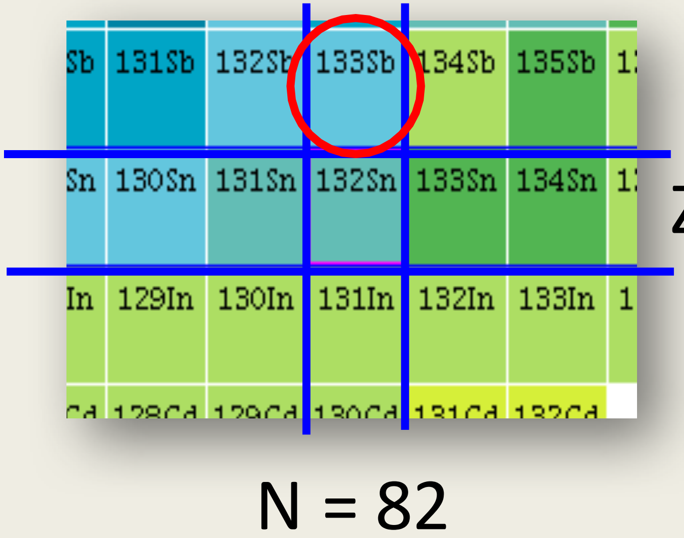
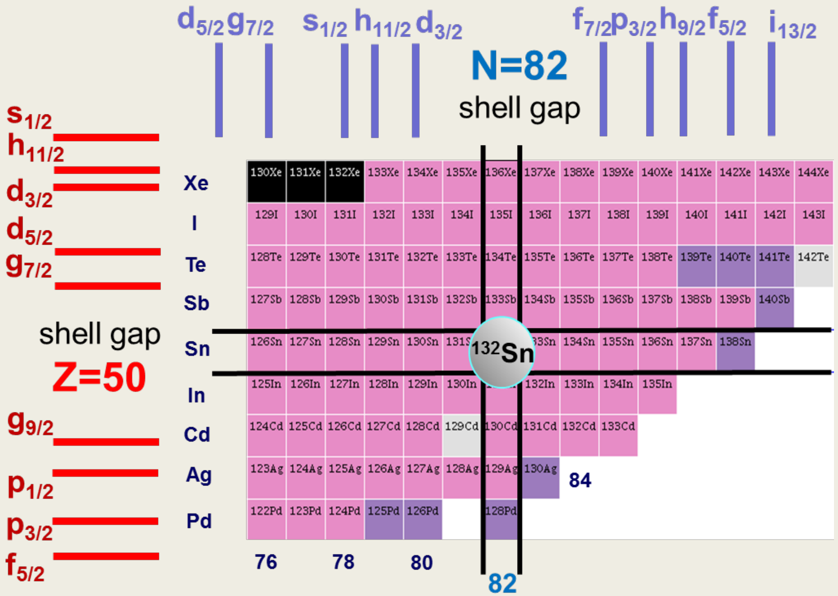


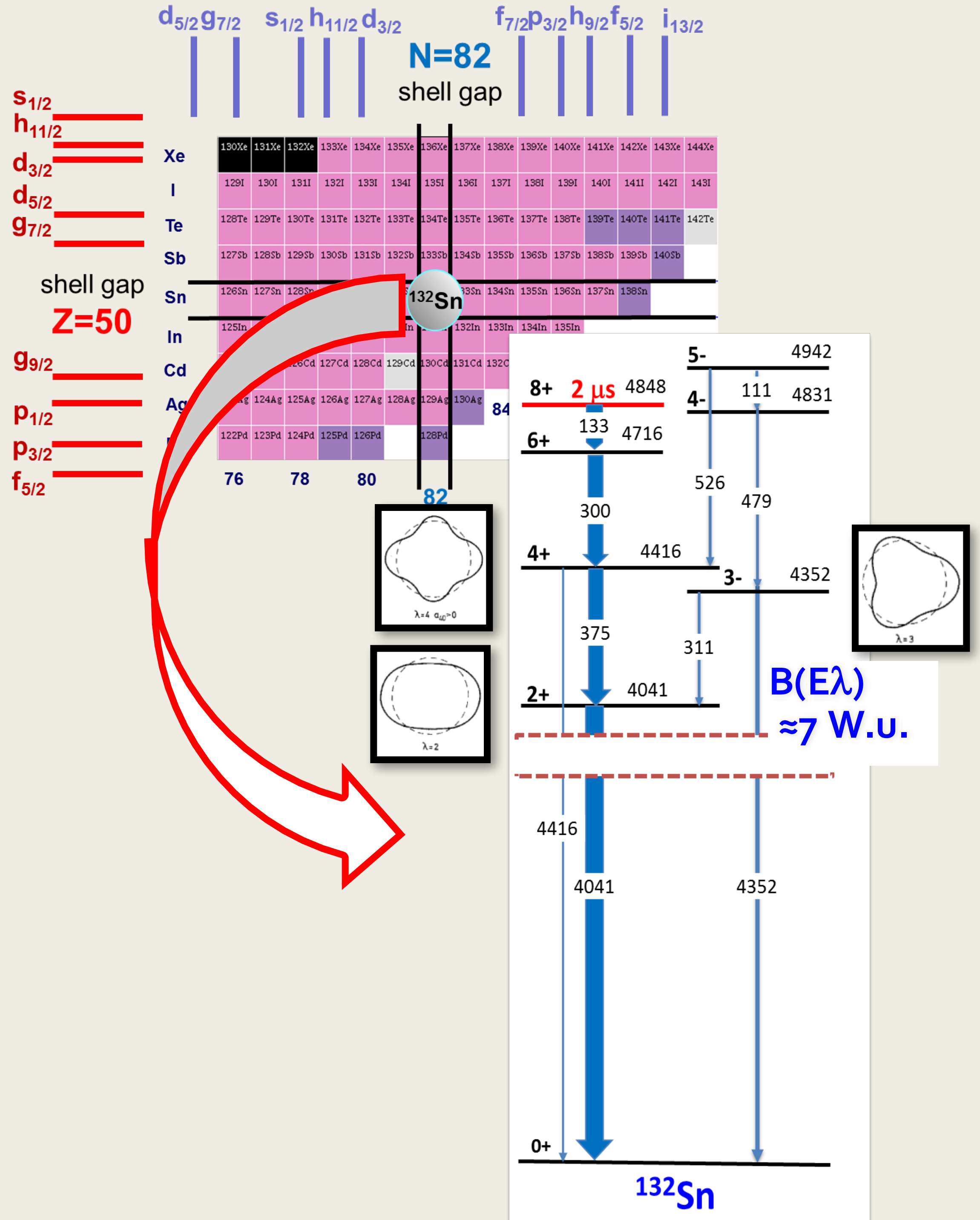
An ideal system to investigate both:

- Single particle excited states
- Coupling between valence particle and core excitations **collective (phonons)** and **non-collective (pure 1p-1h)**



^{133}Sb

- ***Single*** *particle levels*
- ***Couplings*** *between particle and core excitations*



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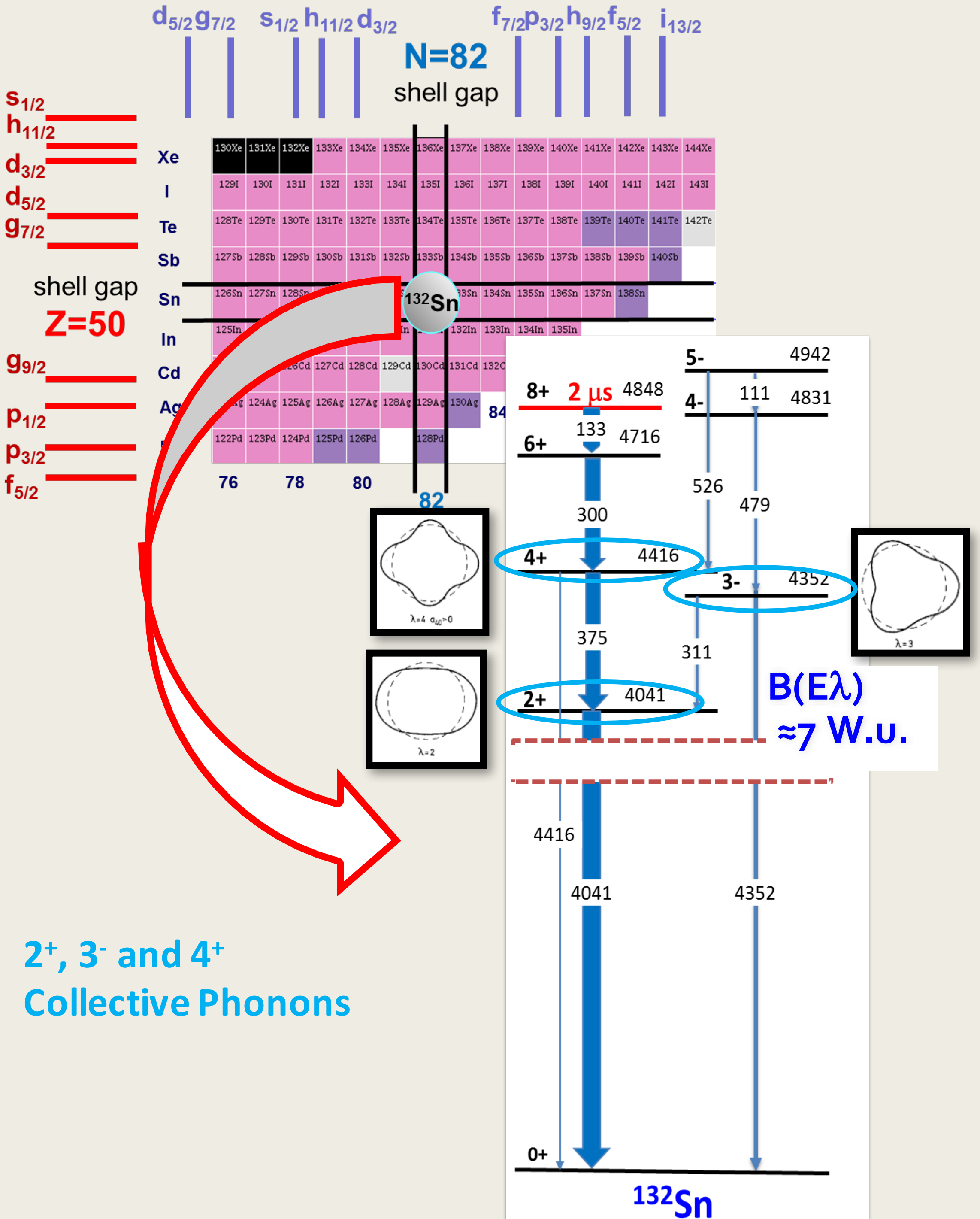
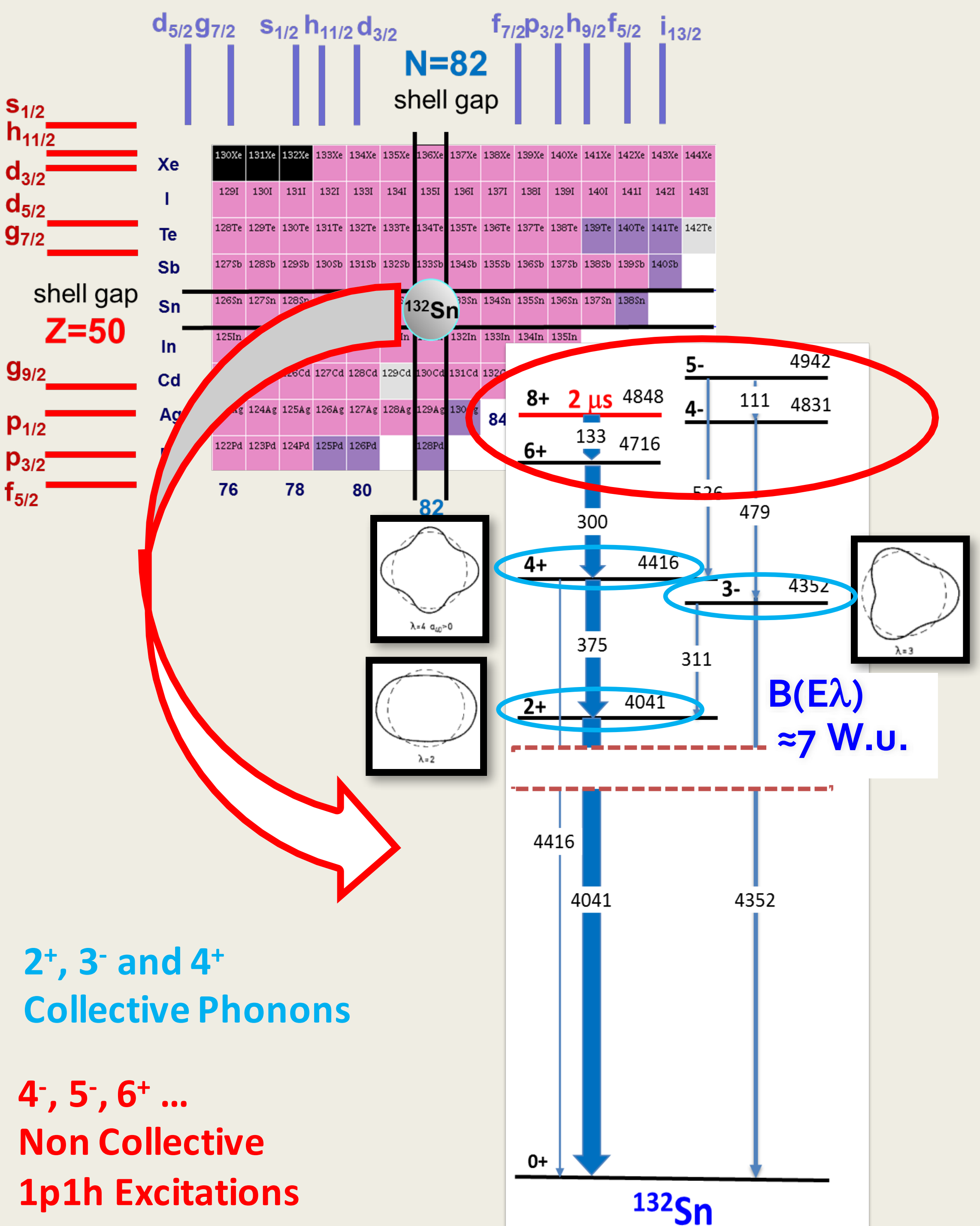


2^+, 3^- and 4^+ Collective Phonons



^{133}Sb

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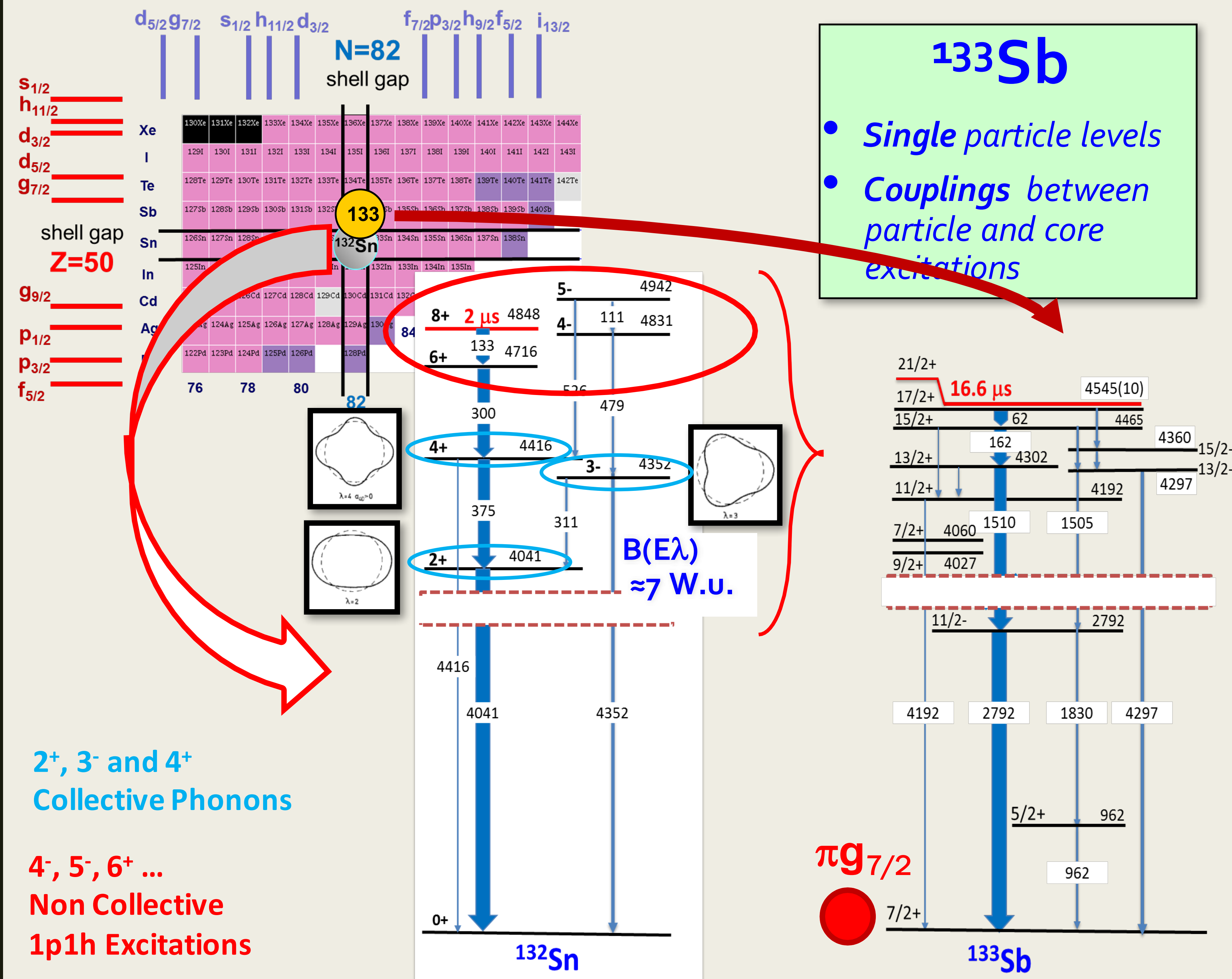
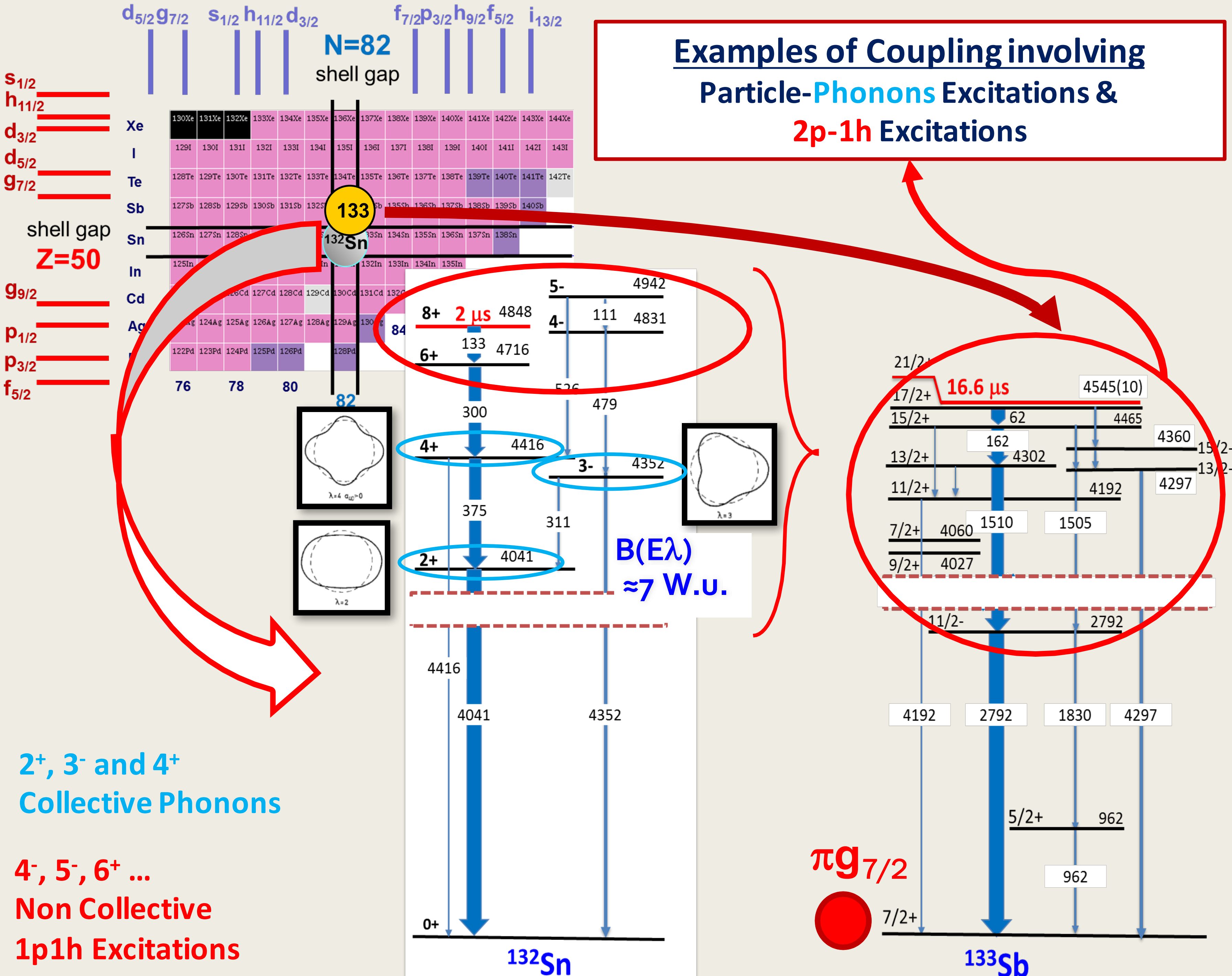

133Sb
Single particle levels
Couplings between particle and core excitations
N=82
shell gap
d5/2 g7/2 s1/2 h11/2 d3/2 f7/2 p3/2 h9/2 f5/2 i13/2
s1/2
h11/2
d3/2
d5/2
g7/2
shell gap
Z=50
g9/2
p1/2
p3/2
f5/2
Xe
I
Te
Sb
Sn
In
Cd
Ag
76
78
80
82
84
133
132Sn
8+ 2 μs 4848
6+ 133 4716
5- 4942
4- 111 4831
300
479
4+ 4416
3- 4352
375
311
2+ 4041
B(Eλ) ≈7 W.u.
4416
4041
4352
0+
132Sn
21/2+
17/2+ 16.6 μs 4545(10)
15/2+ 62 4465
162
13/2+ 4302
4360
15/2-
13/2-
11/2+ 4192
4297
7/2+ 4060 1510
1505
9/2+ 4027
11/2- 2792
4192
2792
1830
4297
5/2+ 962
962
πg7/2
7/2+
133Sb
2+, 3- and 4+
Collective Phonons
4-, 5-, 6+ …
Non Collective
1p1h Excitations

Examples of Coupling involving Particle-Phonons Excitations & 2p-1h Excitations



2^+, 3^- and 4^+

Collective Phonons

4^-, 5^-, 6^+ …

Non Collective

1p1h Excitations

NEW experimental data on ^{133}Sb

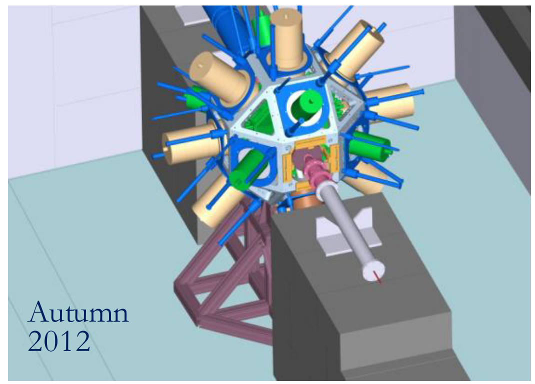
→ n-induced fission on ^{235}U and ^{241}Pu @ILL (Grenoble)

EXILL + FATIMA

SETUP 1

γ – spectroscopy

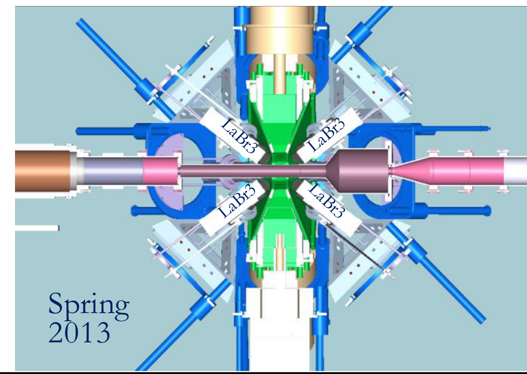
10 EXOGAM – Clovers + 6 Ge GASP
6% efficiency



SETUP 2

Lifetime Measurement

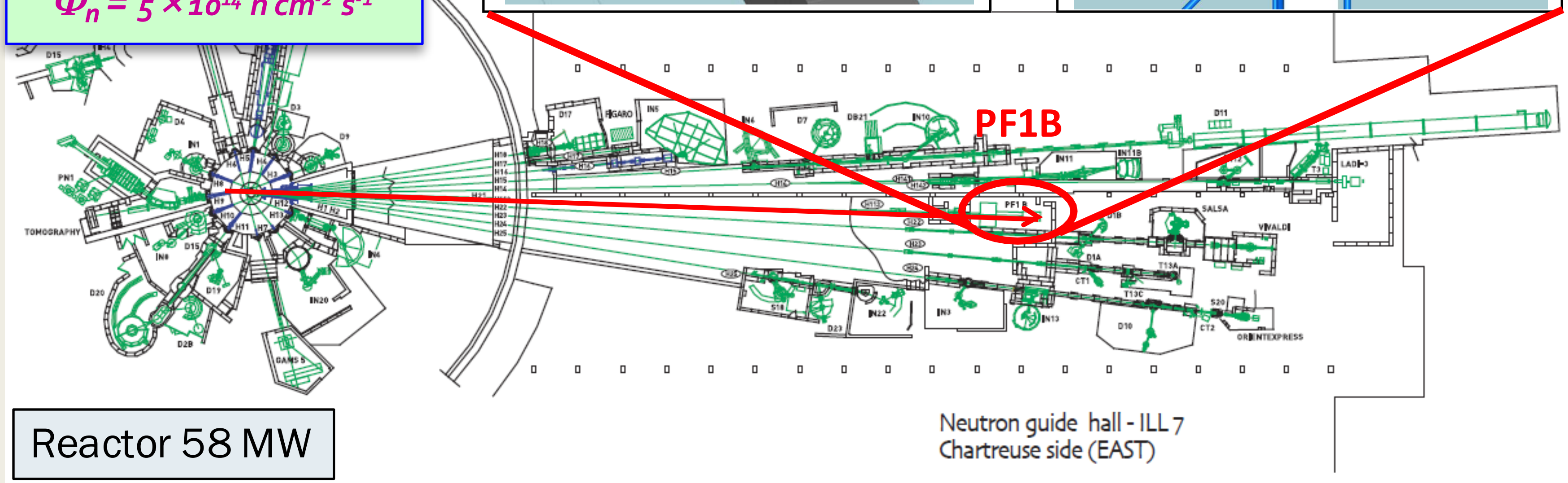
8 EXOGAM – Clovers + 16 LaBr3
Fast Timing



World Brightest Continuum neutron source

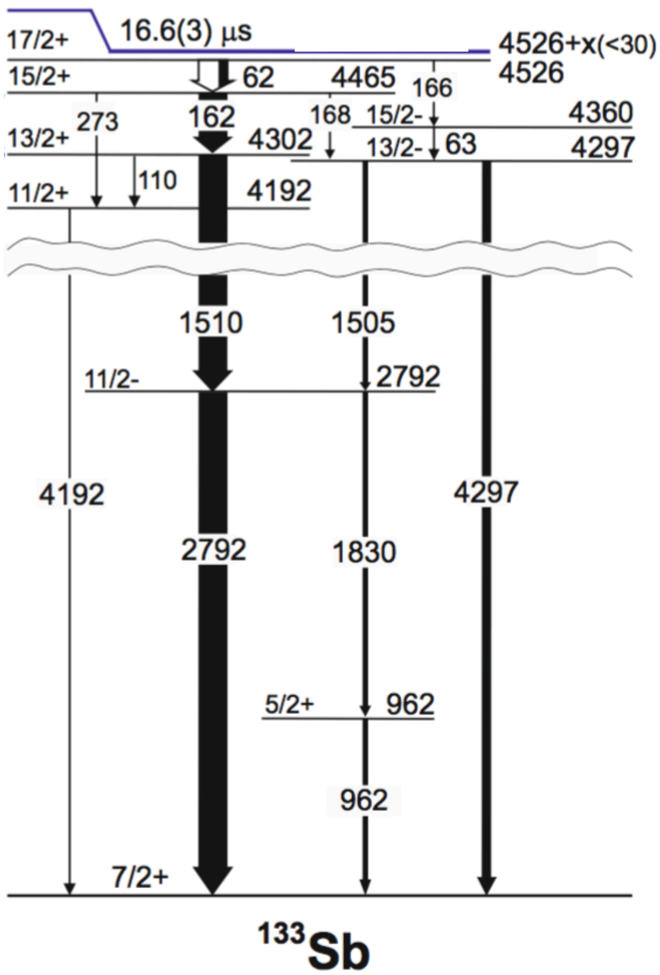
In pile

$\Phi_n = 5 \times 10^{14}\ n\ cm^{-2}\ s^{-1}$



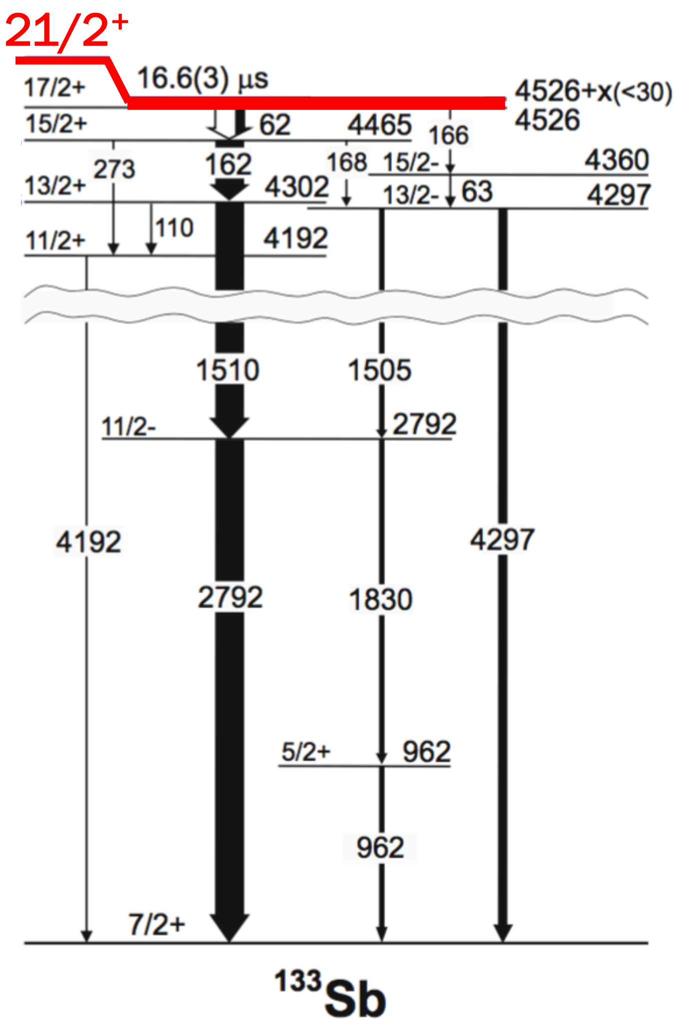
Reactor 58 MW

W. Urban et al., PRC79(2009)037304



Isomer Decay Measured at the focal plane of LOHENGRIN separator (ILL)

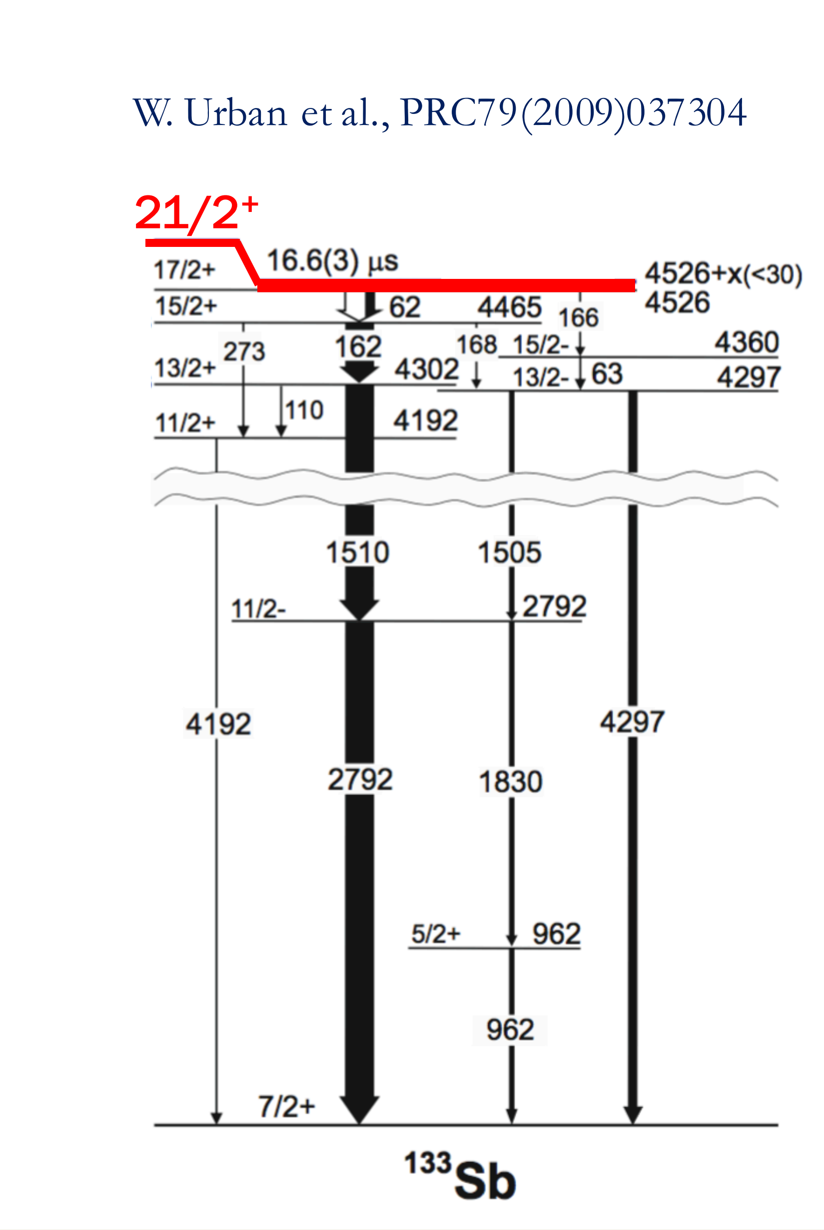
W. Urban et al., PRC79(2009)037304



Isomer Decay Measured at the focal plane of LOHENGRIN separator (ILL)

Starting Point

- Isomeric state @ 4.5 MeV with a lifetime of 16.6 μs
- No information above $21/2^{+}$



Isomer Decay Measured at the focal plane of LOHENGRIN separator (ILL)

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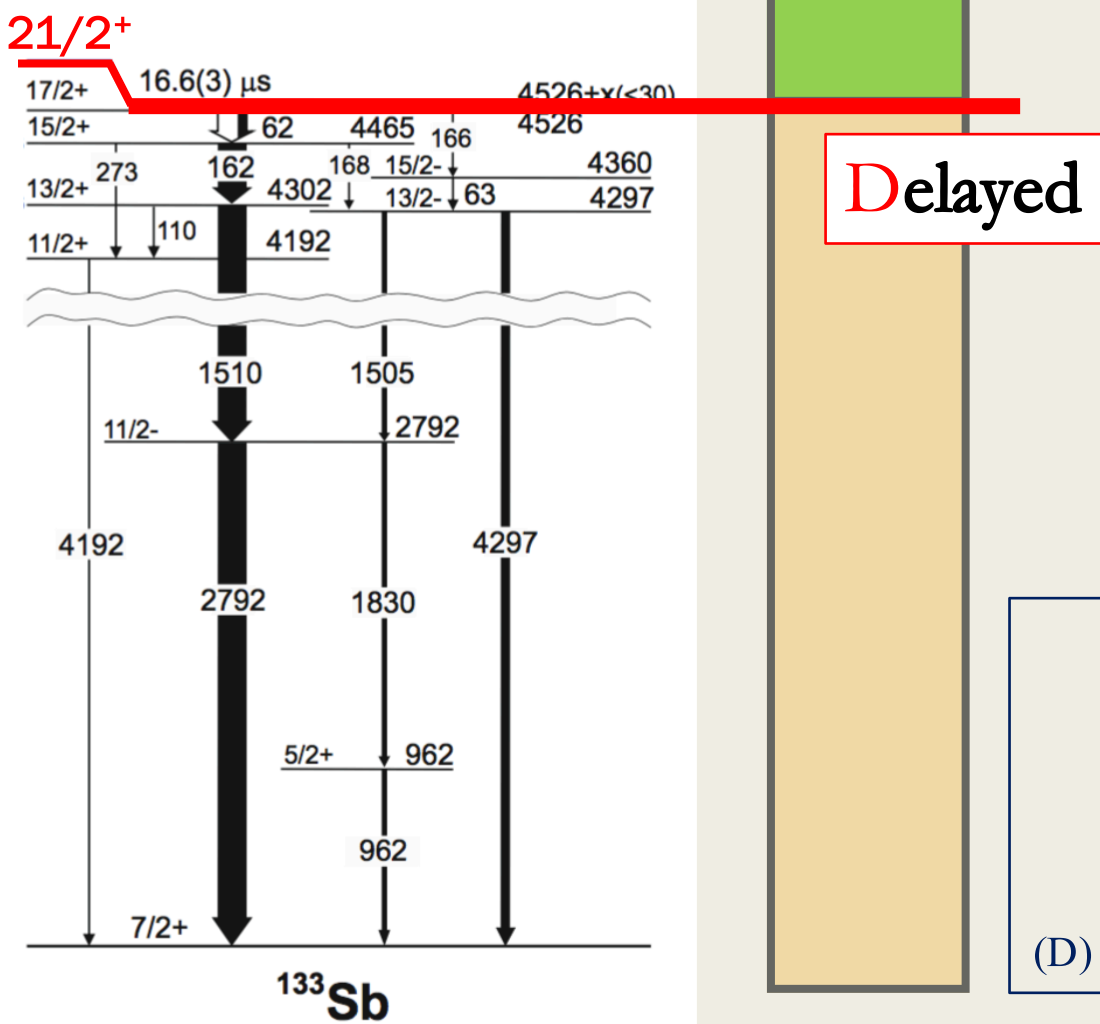
Goal

New high spin yrast states above the long-lived 16.6 μs isomer

W. Urban et al., PRC79(2009)037304



$\Delta T_{Prompt} = 200$ ns

$\gamma_{mult} > 3$

$\Delta T_{Delayed} \leq 20$ μs

$\gamma_{mult} \leq 3$

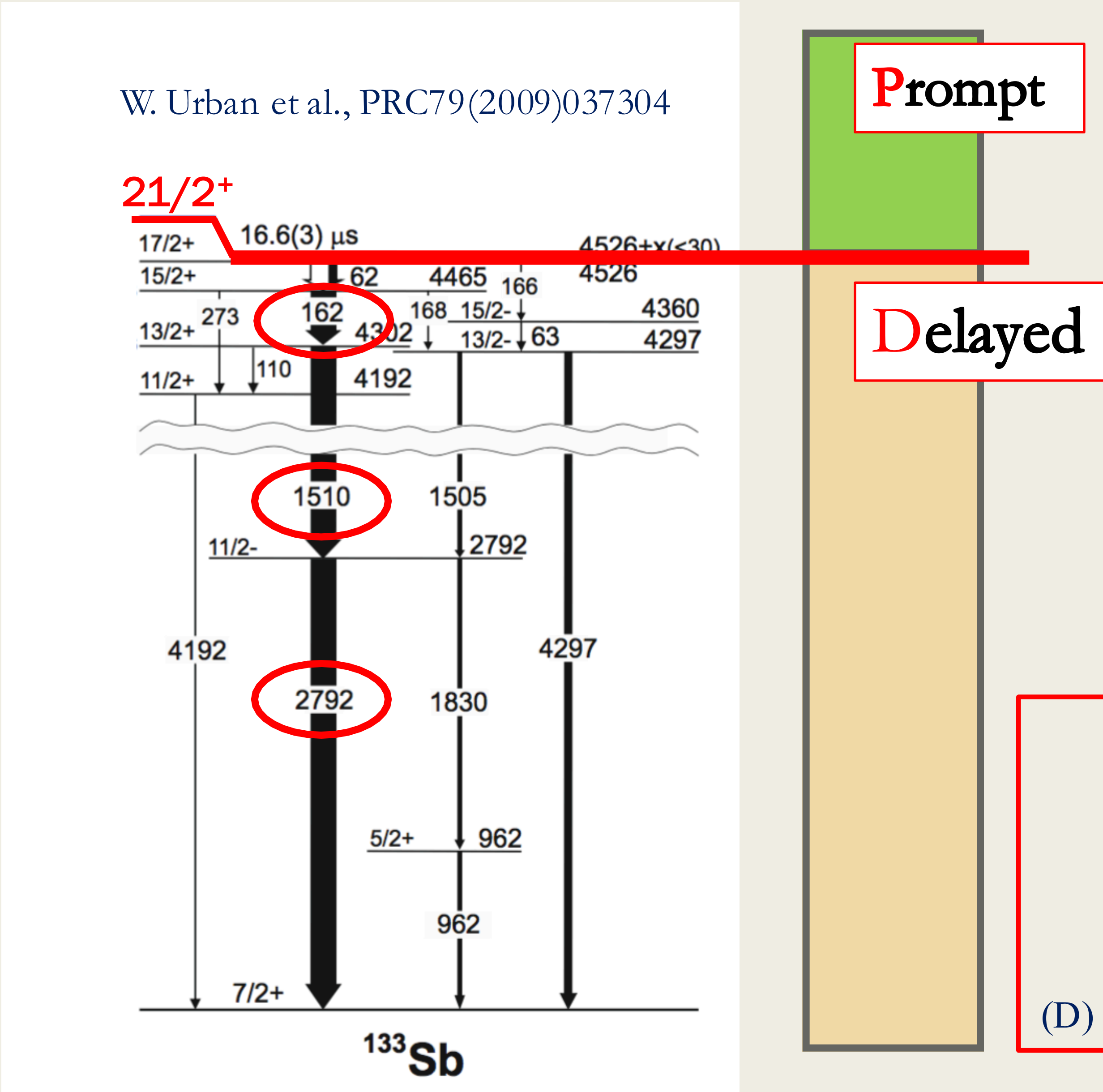
Matrices

P – P – (D)

P – D – (D)

(D) = 2792, 1510 and 162 keV

A Fully Digital Approach, TRIGGERLESS acq.



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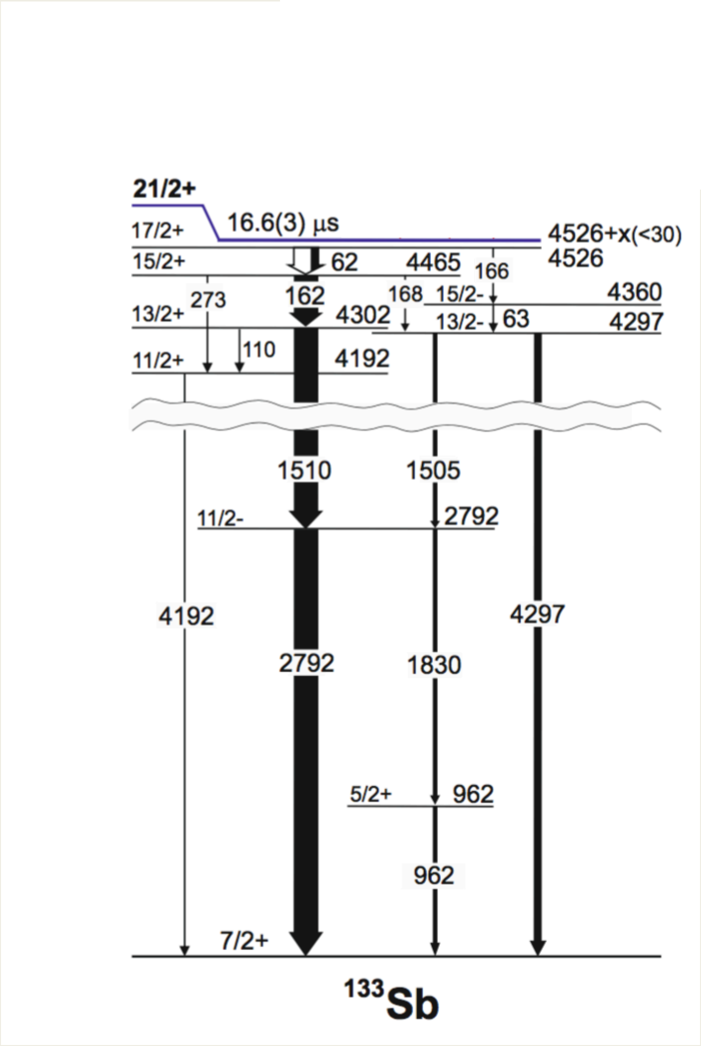
P – P – (D)

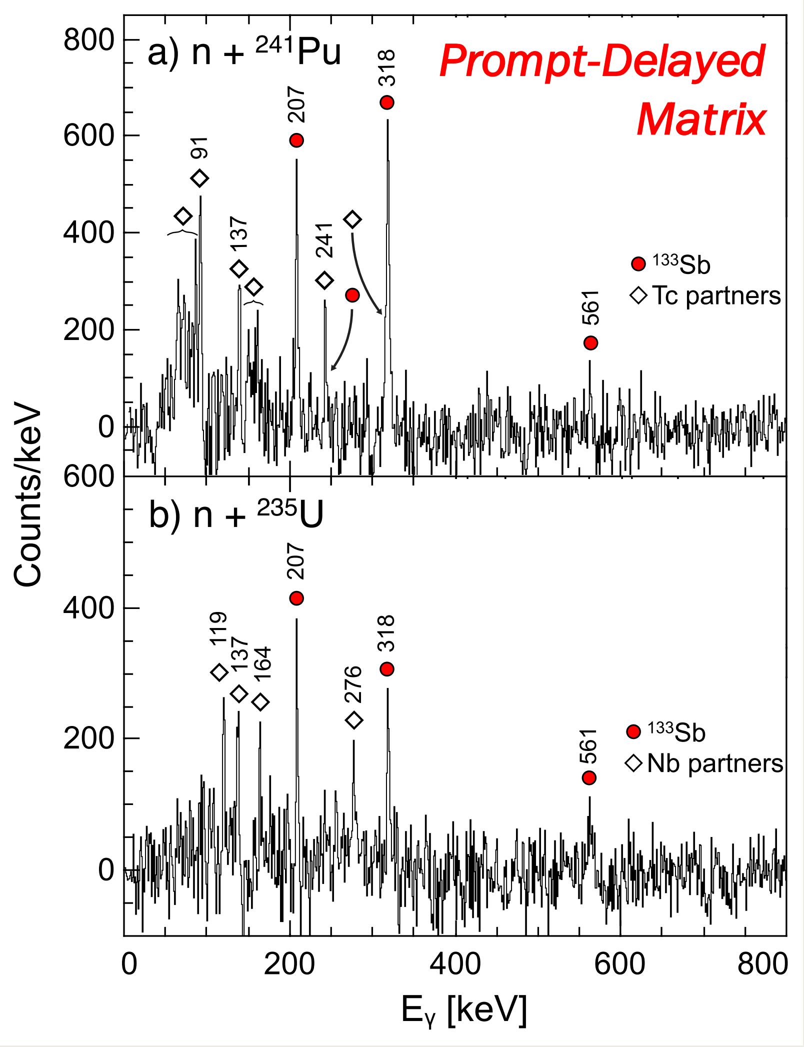
P – D – (D)

(D) = **2792**, **1510** and **162** keV

Results

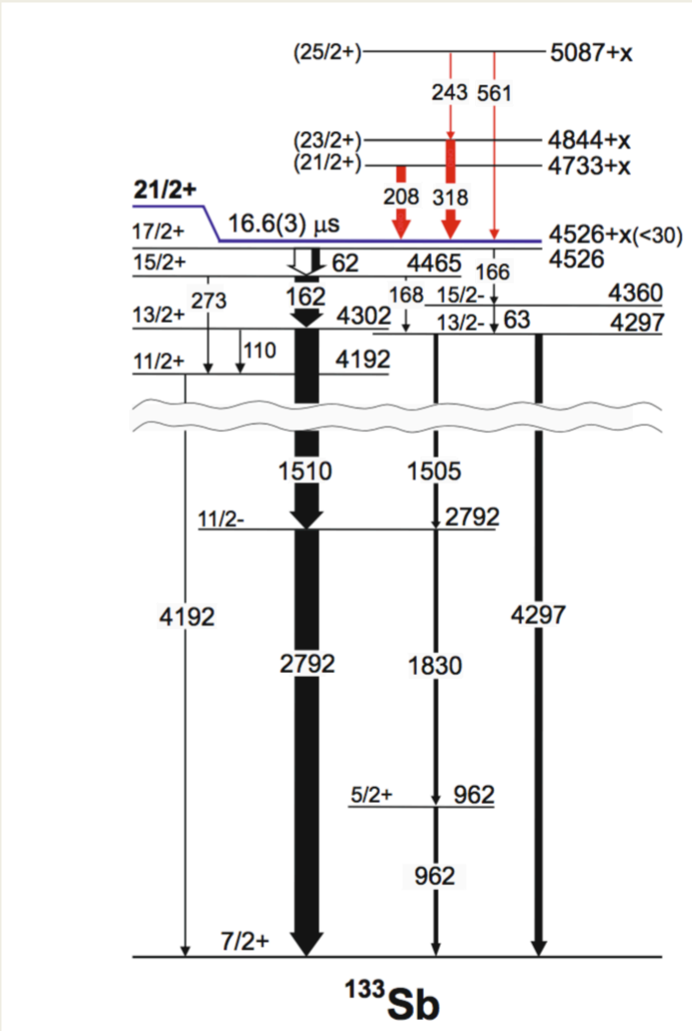


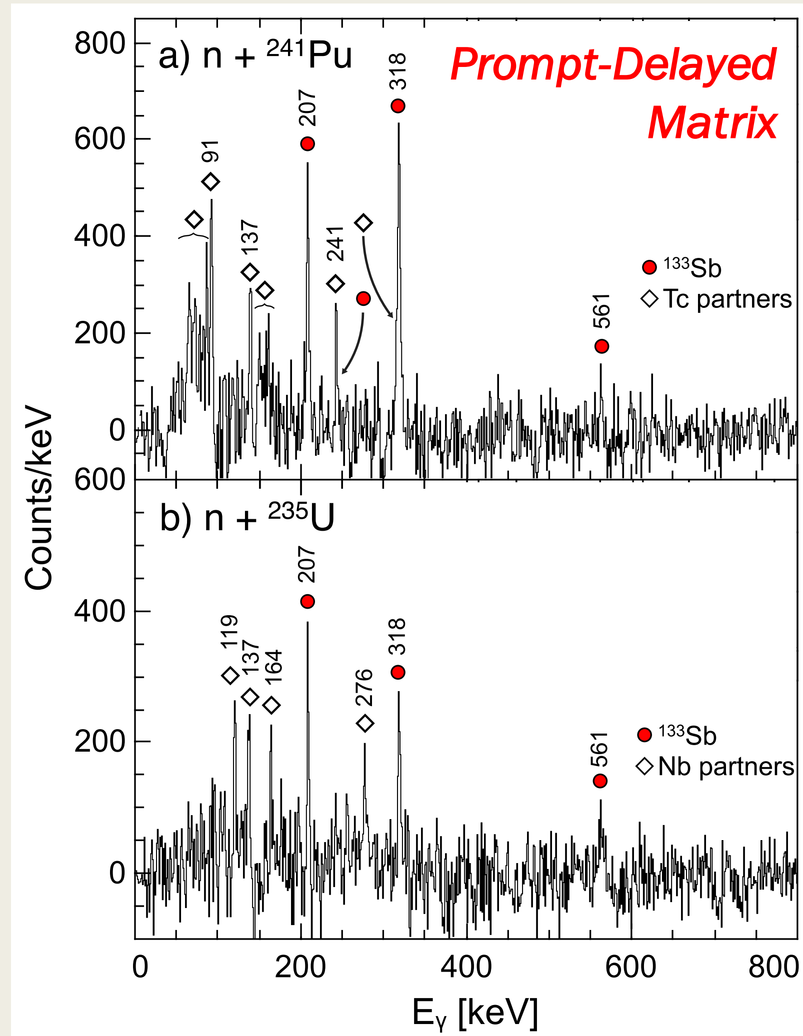
21/2+
17/2+
16.6(3) μs
4526+x(<30)
15/2+
62
4465
166
4526
13/2+
273
162
168
15/2-
4360
4302
13/2-
63
4297
110
11/2+
4192
1510
1505
11/2-
2792
4192
4297
2792
1830
5/2+
962
962
7/2+
133Sb



a) n + 241Pu
Prompt-Delayed Matrix
91
137
207
241
318
561
133Sb
Tc partners
b) n + 235U
119
137
164
207
276
318
561
133Sb
Nb partners
Counts/keV
Eγ [keV]

Results

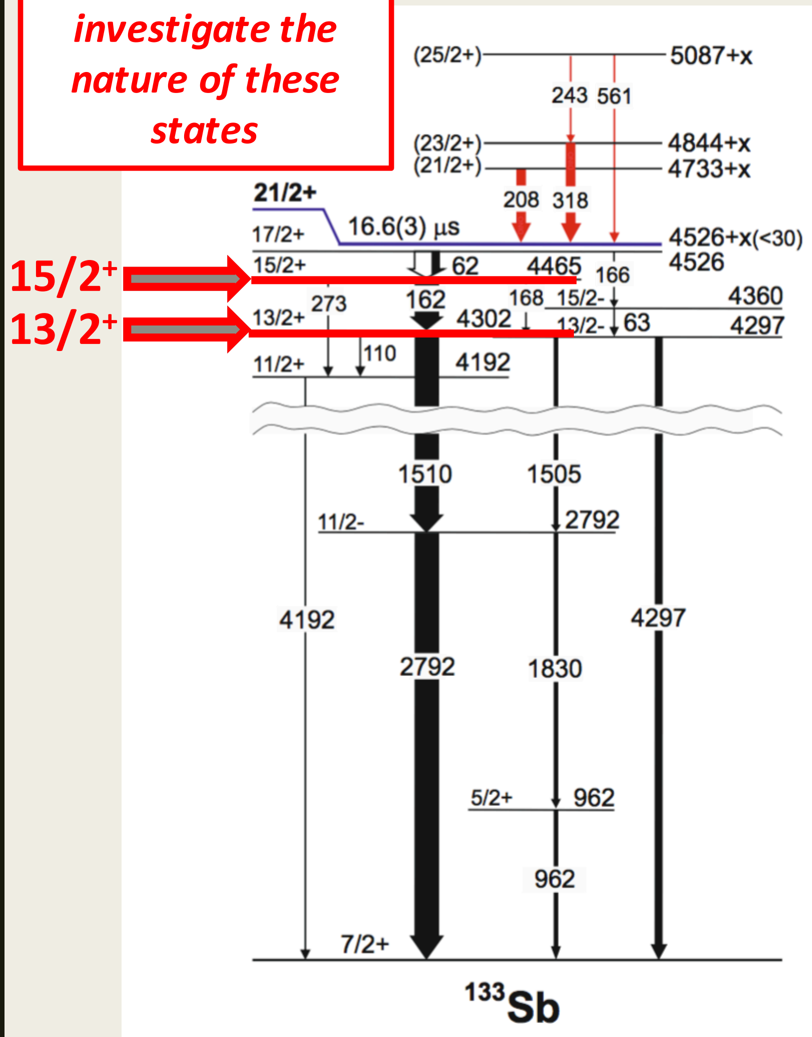


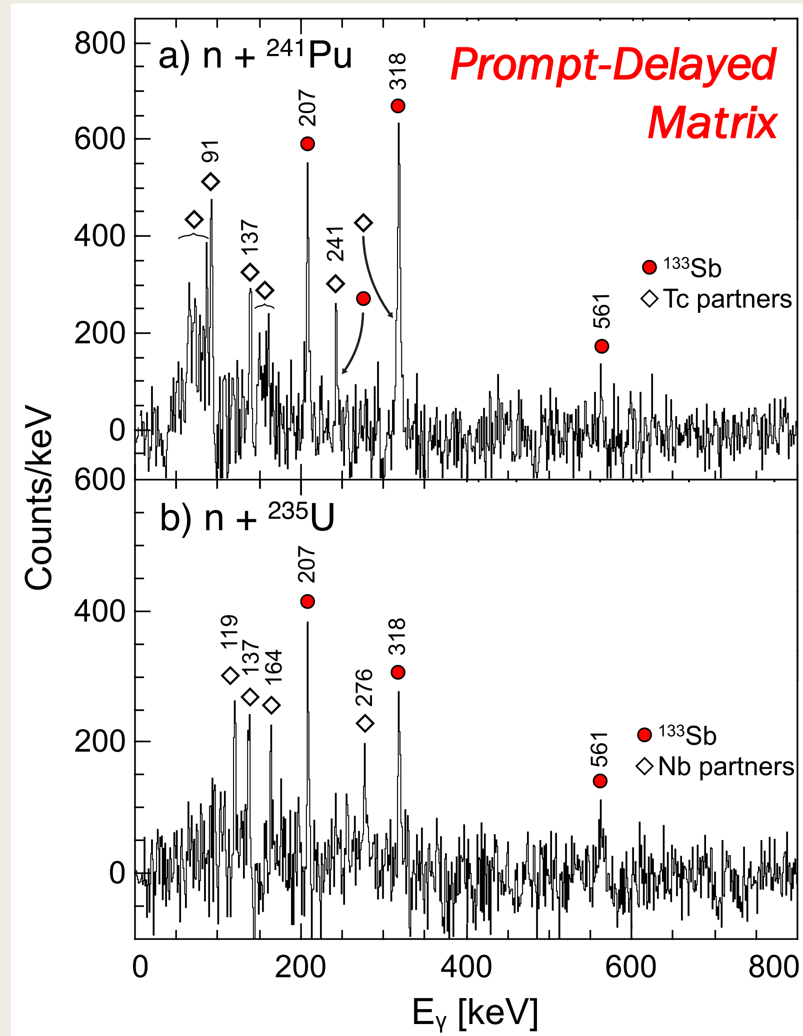


2 targets play a **crucial rule** in order to confirm new γ-transitions

Results

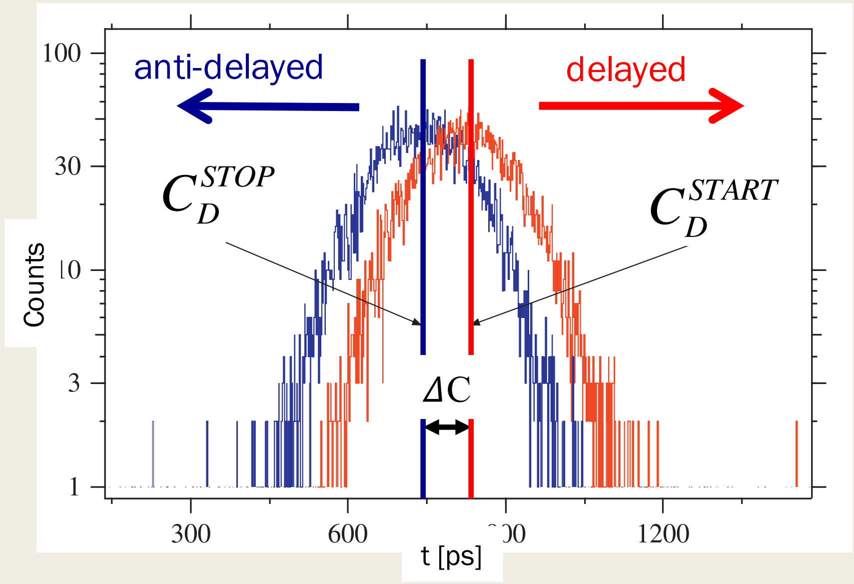
Lifetime Analysis via fast timing in order to investigate the nature of these states

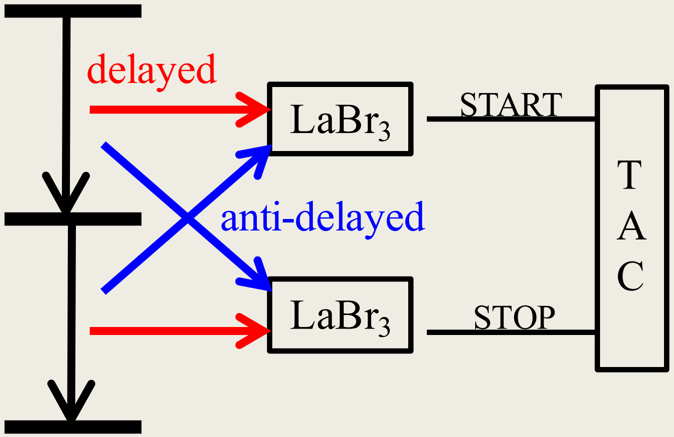




2 targets play a **crucial rule** in order to confirm new γ-transitions

Lifetime Analysis: Generalized Centroid Difference Method (GCD) with $LaBr_3(Ce)$





$$C^D{}_{start} = C^P{}_{start} - \tau$$

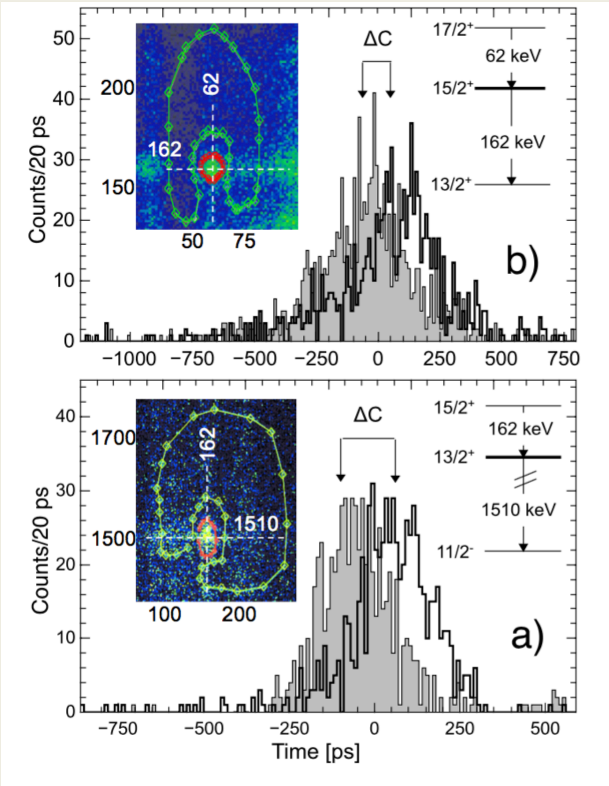
$$C^D{}_{stop} = C^P{}_{stop} + \tau$$

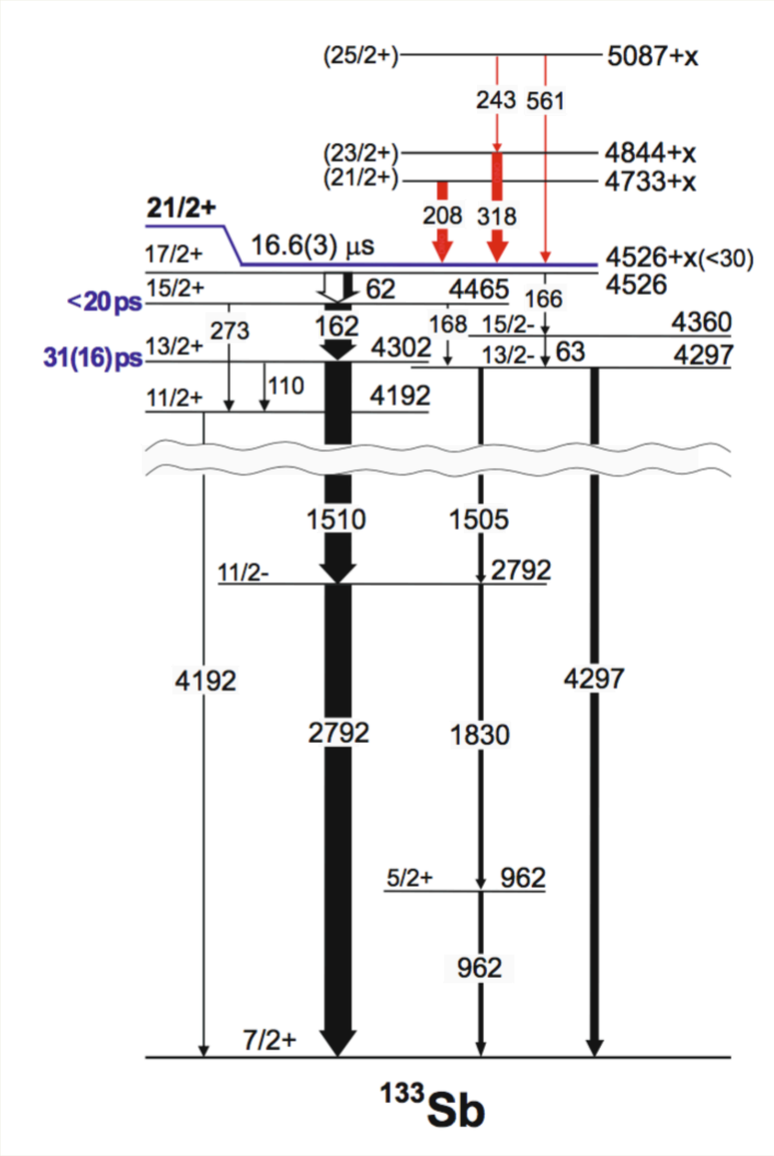
$$\Delta C = C^D{}_{stop} - C^D{}_{start} = C^P{}_{stop} - C^P{}_{start} + 2\tau$$

$$2\tau = \Delta C - PRD$$

Régis, J. M. et al. Nucl. Instr. and Meth. in Phys. Rev. A 763, 210–220 (2014)

Lifetimes Analysis by FAST-TIMING:
Nature of particle-CORE coupled states





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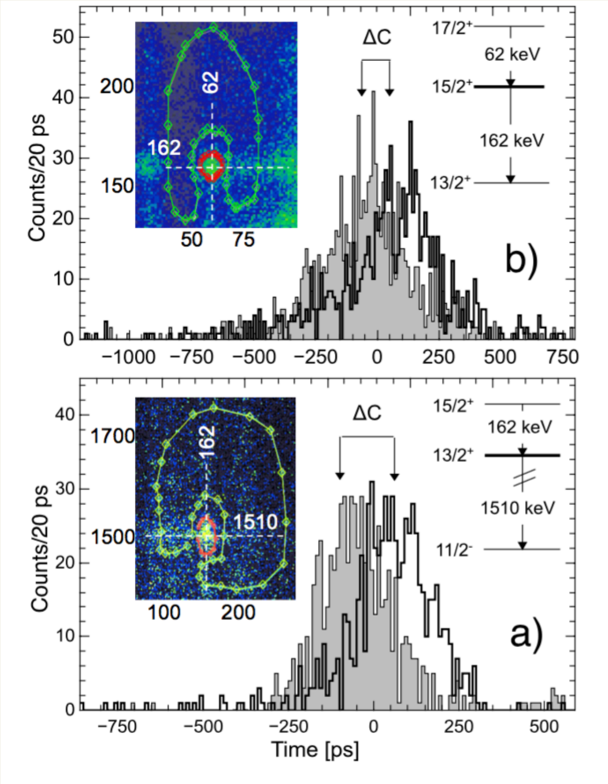

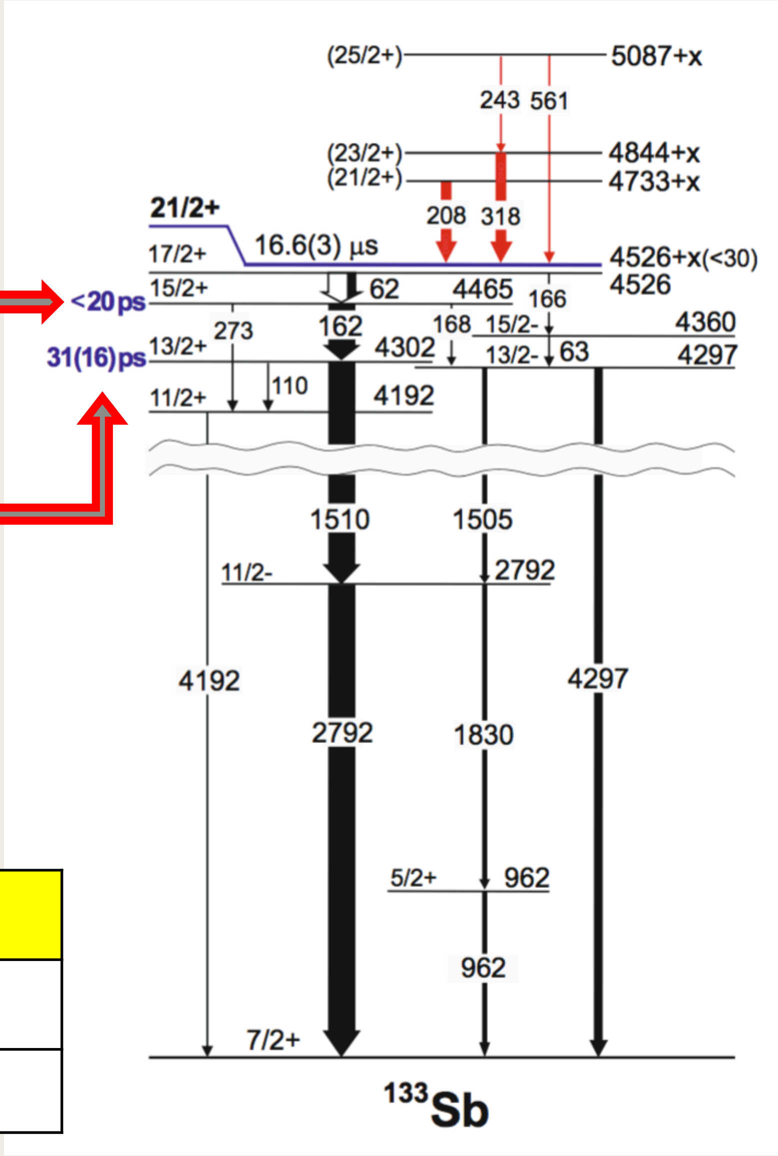

	τ_{EXP}	B(M1,I→I-1)
$15/2^+ \rightarrow 13/2^+$	< 20 ps	0.24 W.u.
$13/2^+ \rightarrow 11/2^+$	31 ps	0.004 W.u.

Accepted: Physics Letters B.

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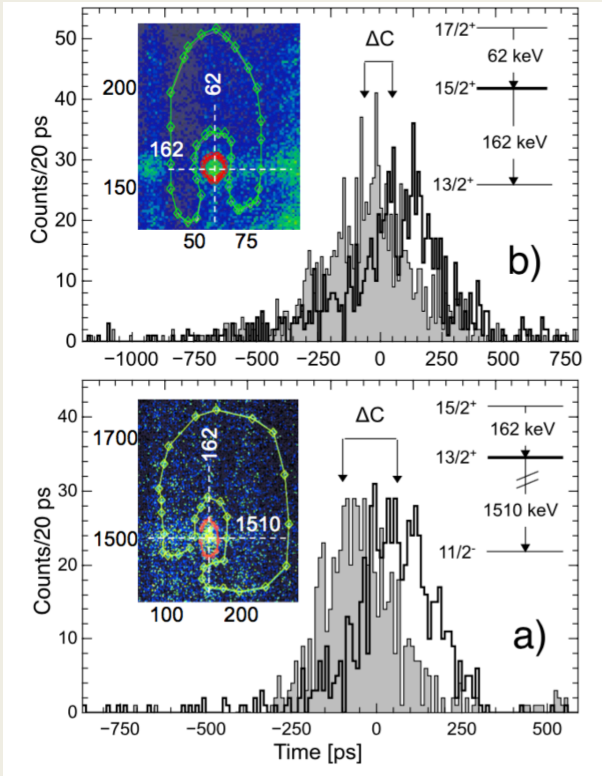

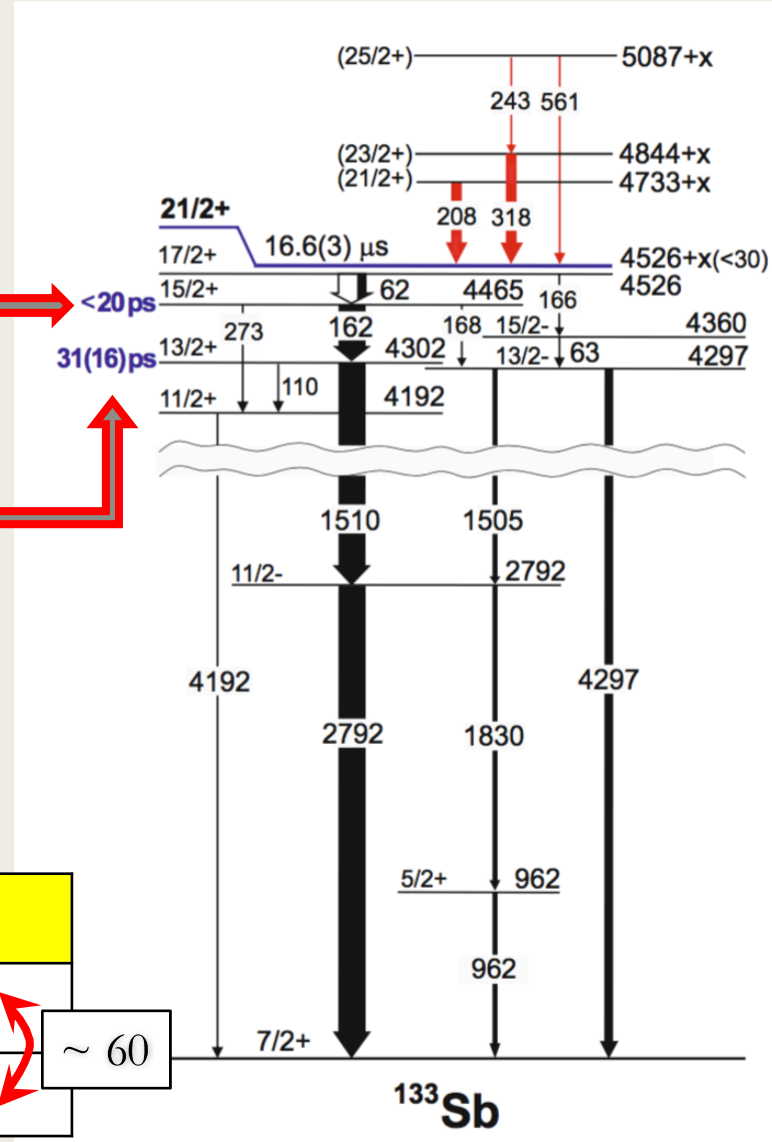

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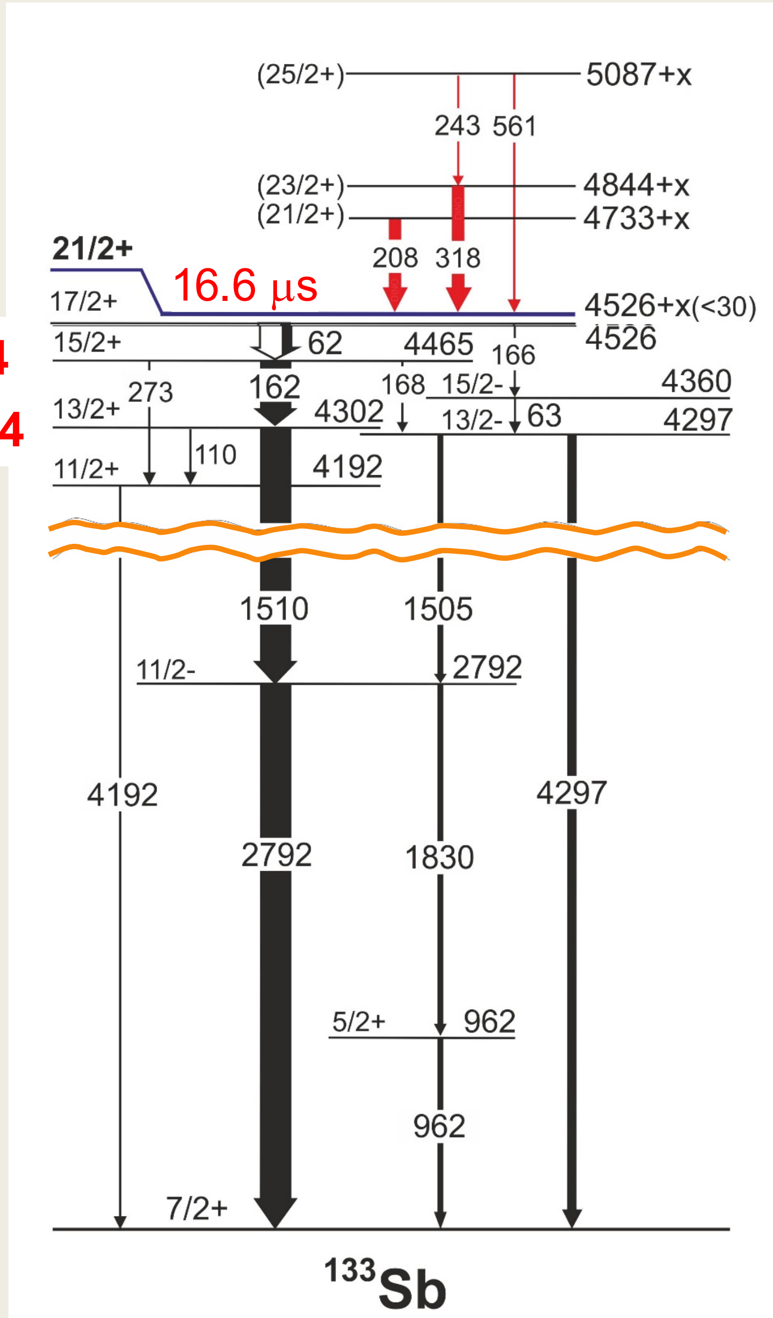
~ 60

Indication of Different Nature of Excitations!

Theoretical interpretation

0.24

0.004



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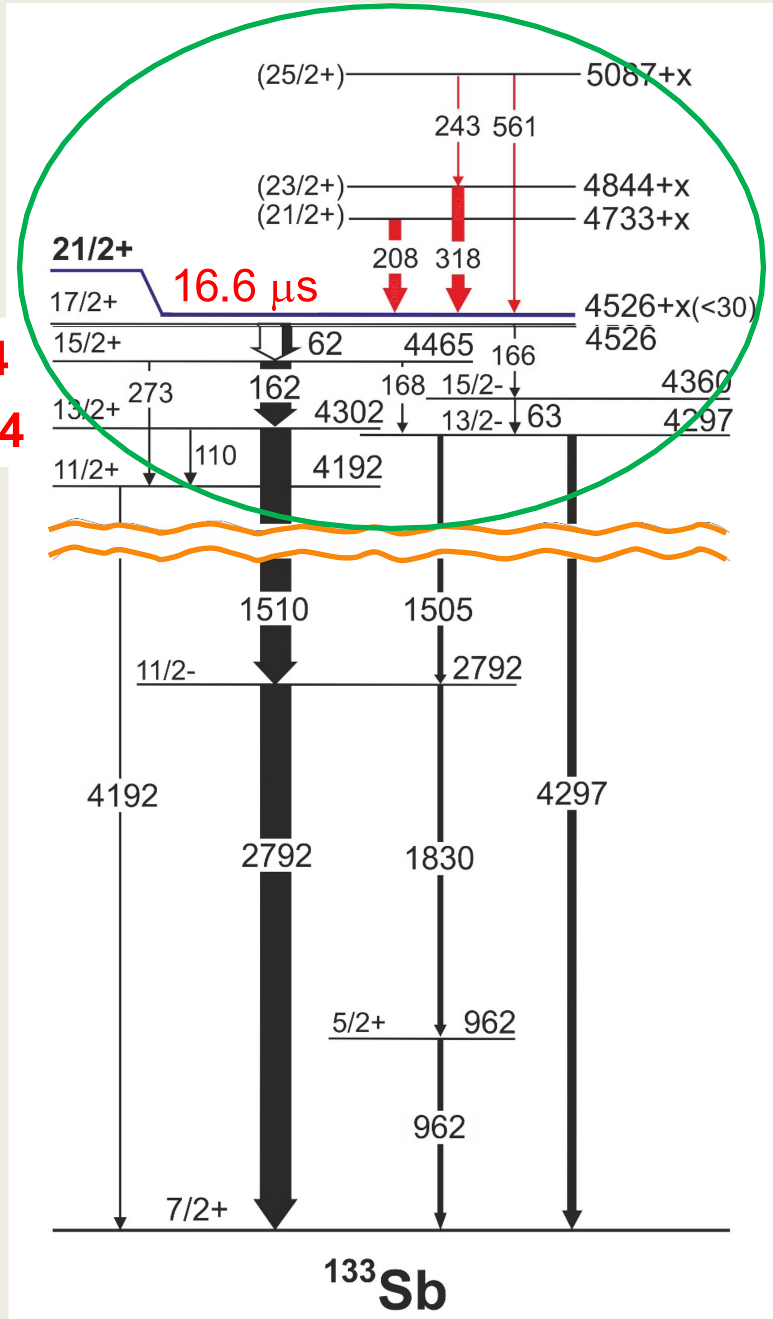
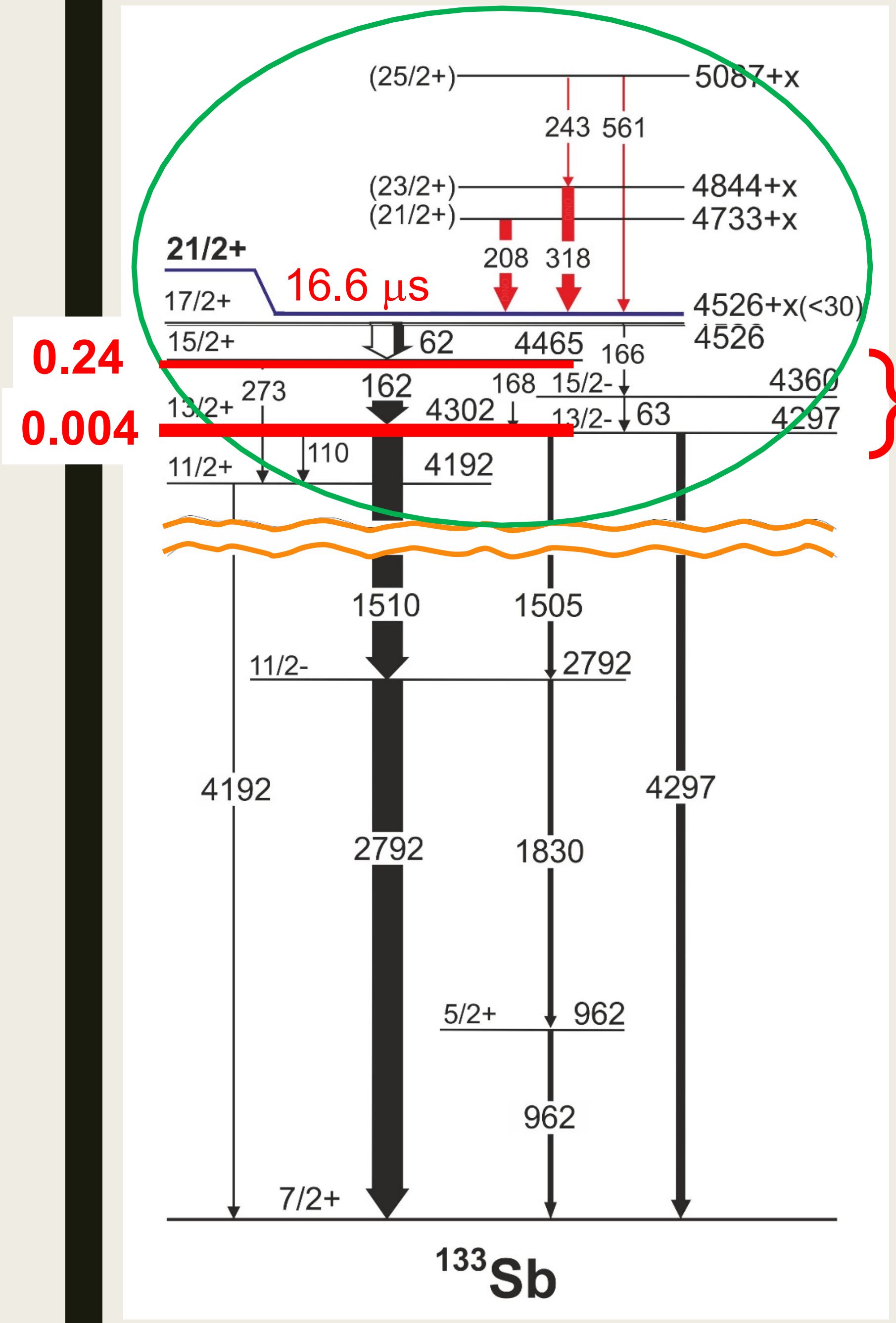


Restricted SHELL Model Calculations

considering only $\pi g_{7/2} \otimes f_{7/2} h^{-1}_{11/2}$

reproduce the energy sequence of states



Theoretical interpretation

Restricted SHELL Model Calculations

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reproduce the energy sequence of states

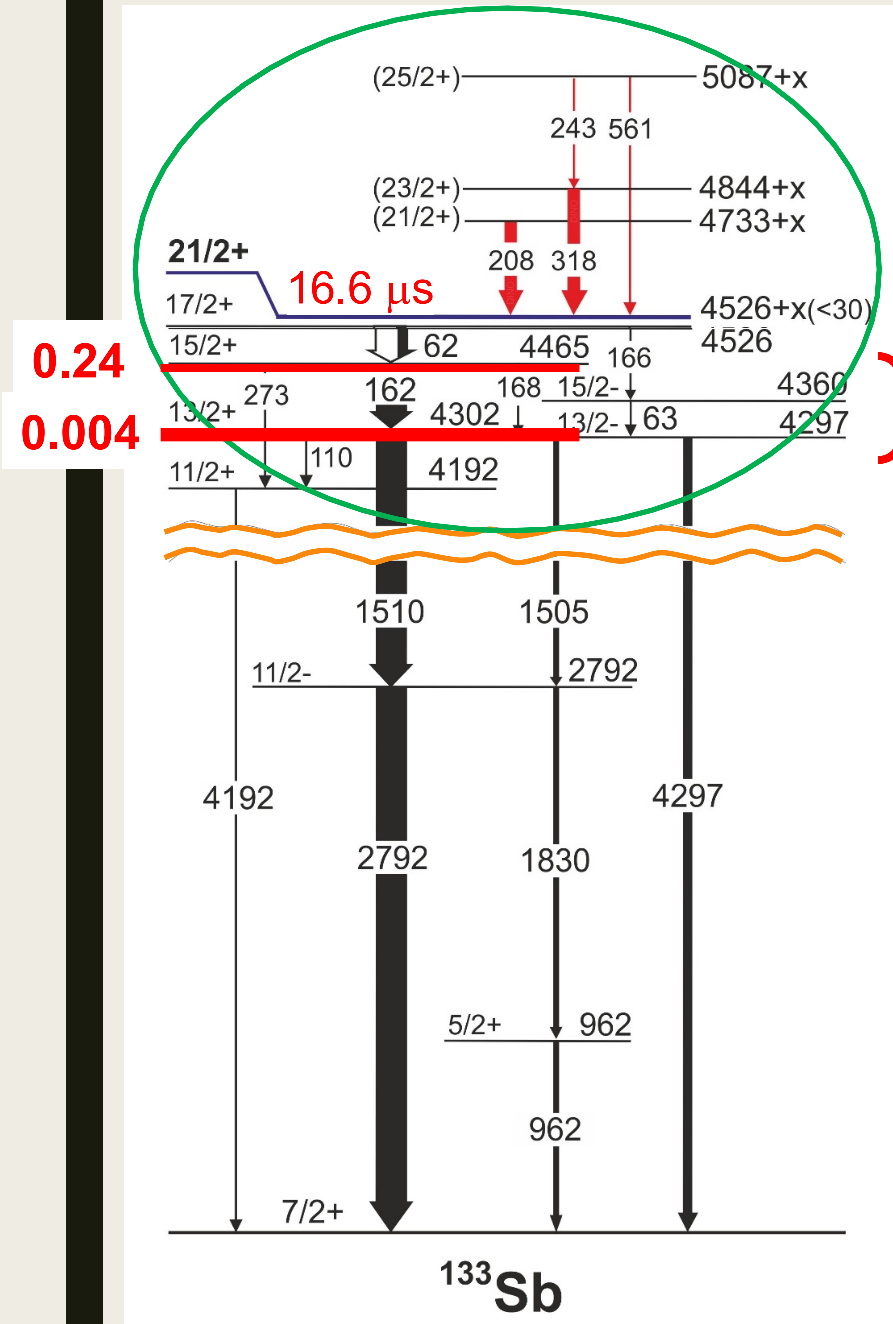
Experiment: Breaking of the core

LARGE SHELL Model Calculations

Involving complex **CORE-excitations**

are NOT possible !

→ 3p – 3h excitations take weeks with **10⁶** processors



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Involving complex **CORE-excitations**
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A new approach: HYBRID Model
G. Colò, P.F. Bortignon (Milano)

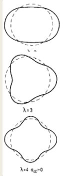
Core excitations of ^{132}Sn (RPA)
&
Proton States (HF)

HYBRID Model – Main ingredients

^{132}Sn

CORE Excitations

$E^* < 5.5$ MeV
$J^\pi < 11^{(+,-)}$



	Energy Exp.	Energy Theory (RPA)	Transition strength Exp.	Transition strength Theory (RPA)	Main components Theory (RPA)
Phonons					
2^+	4.041	3.87	7	4.75	$\nu h^{-1}_{11/2} f_{7/2}$ (0.56), $\pi g^{-1}_{9/2} d_{5/2}$ (0.19), $\pi g^{-1}_{9/2} g_{7/2}$ (0.14)
3^-	4.352	5.02	> 7.1	9.91	$\nu s^{-1}_{1/2} f_{7/2}$ (0.40), $\nu d^{-1}_{3/2} f_{7/2}$ (0.12), $\pi p^{-1}_{1/2} g_{7/2}$ (0.12)
4^+	4.416	4.46	7	5.10	$\nu h^{-1}_{11/2} f_{7/2}$ (0.63), $\pi g^{-1}_{9/2} g_{7/2}$ (0.21)
Other Excitations					
6^+	4.716	4.73		1.65	$\nu h^{-1}_{11/2} f_{7/2}$ (0.86), $\pi g^{-1}_{9/2} g_{7/2}$ (0.11)
4^-	4.831	5.68		0.16	$\nu s^{-1}_{1/2} f_{7/2}$ (0.91)
8^+	4.848	4.80		0.28	$\nu h^{-1}_{11/2} f_{7/2}$ (0.98)
5^+	4.885	4.77		0.61	$\nu h^{-1}_{11/2} f_{7/2}$ (0.99)
7^+	4.942	4.80		0.81	$\nu h^{-1}_{11/2} f_{7/2}$ (0.98)
5^-	4.919	5.98		0.96	$\nu d^{-1}_{3/2} f_{7/2}$ (0.96)
(9^+)	5.280	4.99		0.16	$\nu h^{-1}_{11/2} f_{7/2}$ (0.99)
2^-		5.44		1.77	$\nu d^{-1}_{3/2} f_{7/2}$ (0.79)

Phonons

^{133}Sb

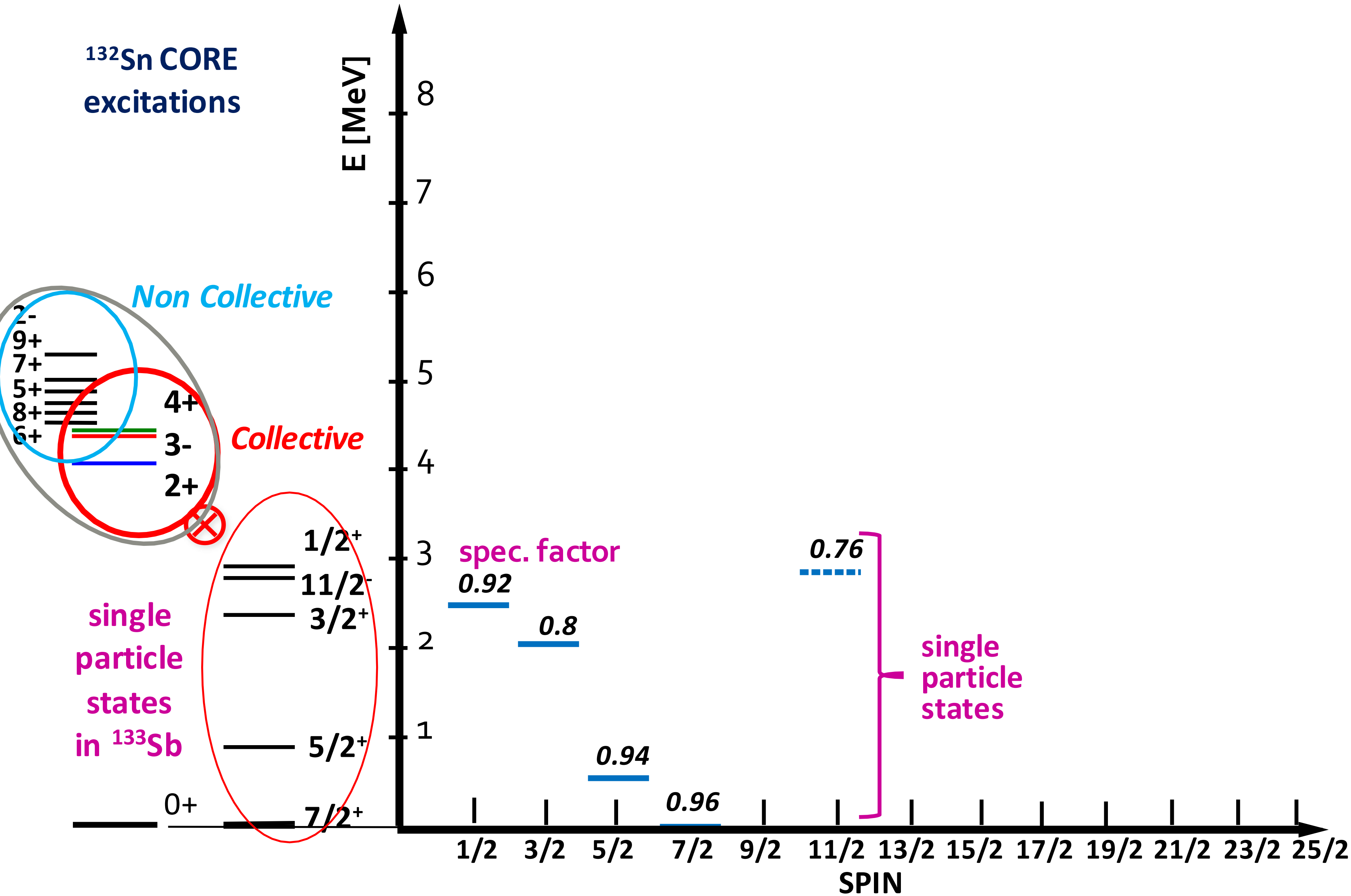
Single Particle states

$g_{7/2}$	$d_{5/2}$	$d_{3/2}$	$h_{11/2}$	$s_{1/2}$	
0	0.587	2.439	2.831	2.97	[MeV]

→ **Coupling matrix elements** between **single particle** and **RPA states** are consistently calculated with the **same SkX interaction**

[B. A. Brown, Phys. Rev. C 58, 220 (1998)]

HYBRID Model – ^{133}Sb spectrum



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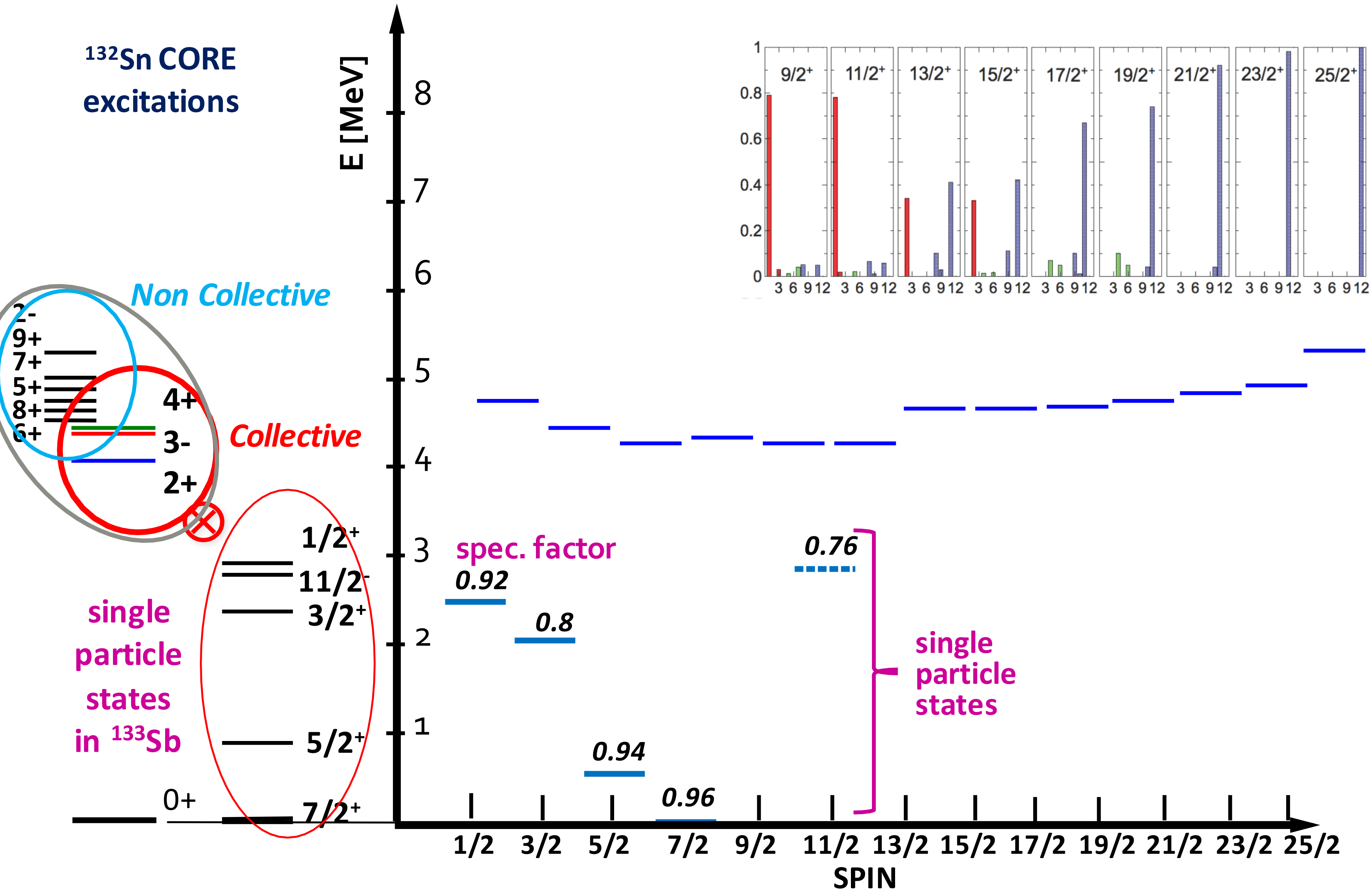
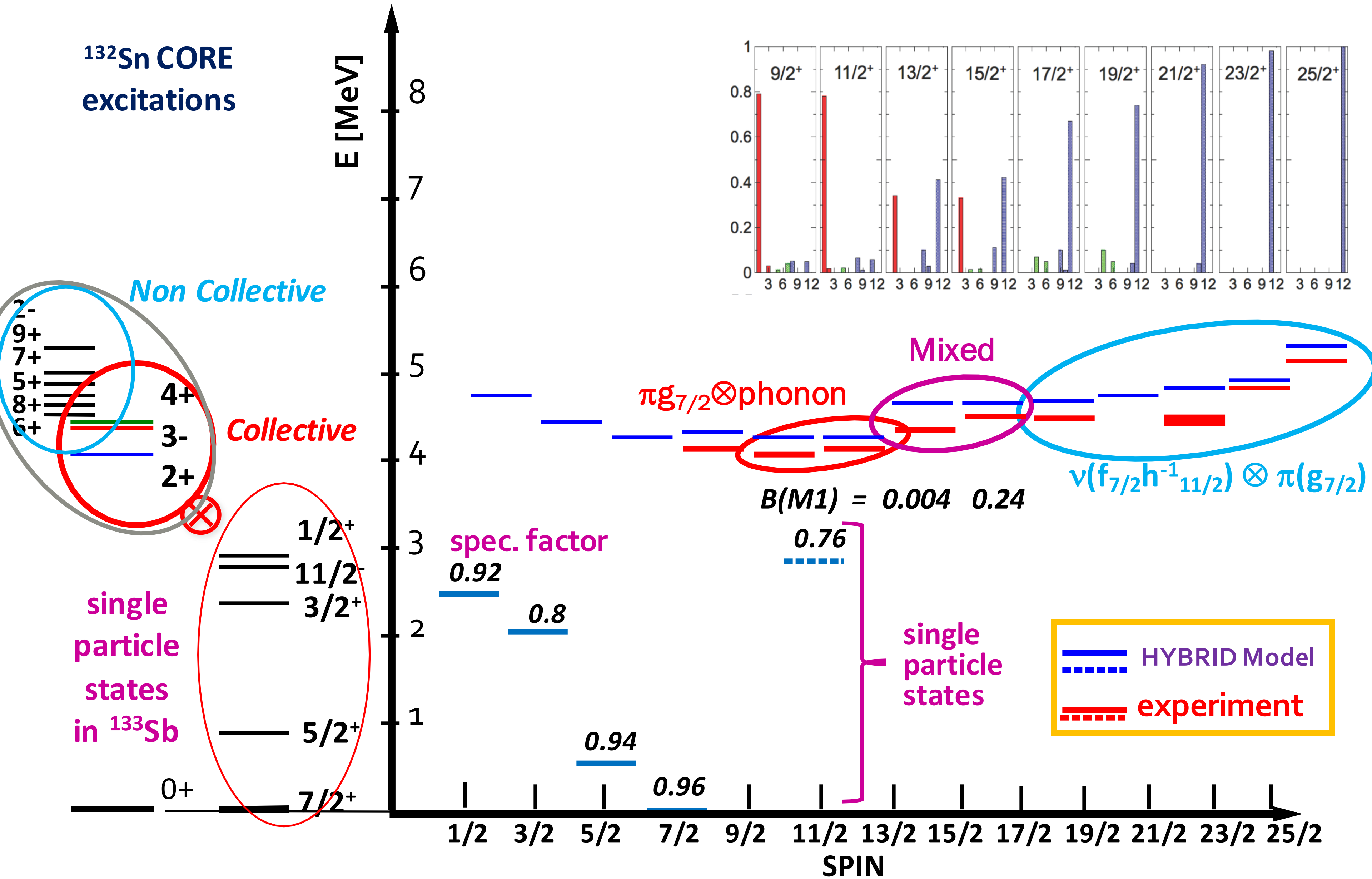


HYBRID Model – ^{133}Sb spectrum



Conclusion

1. **EXPERIMENT** provides evidence for **MIXED** configurations of **YRAST STATES**

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Conclusion

1. **EXPERIMENT** provides evidence for **MIXED** configurations of **YRAST STATES**

2. **The HYBRID Model (just developed) describes this observation (for the YRAST STATES) very satisfactorily** (in terms of the coupling of different types of CORE excitations (phonons or particle – hole excitations) to the valence particle.

3. **This might be the way to describe sistematically structures involving core excitations in nuclei around doubly magic cores.**

…Thanks

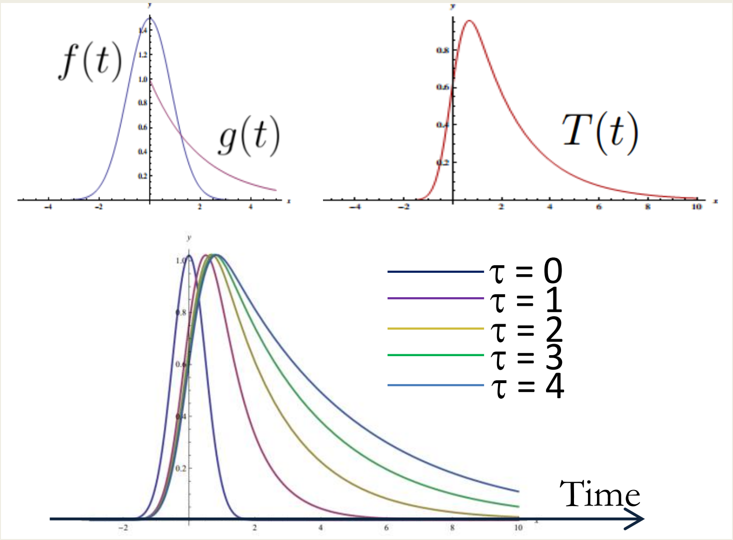
Il Generalized Centroid Difference method (GCD)

Time distribution: Gaussian * Exponential

Gaussian → Experimental Apparatus

Exponential → $e^{-t/\tau}$

τ = lifetime



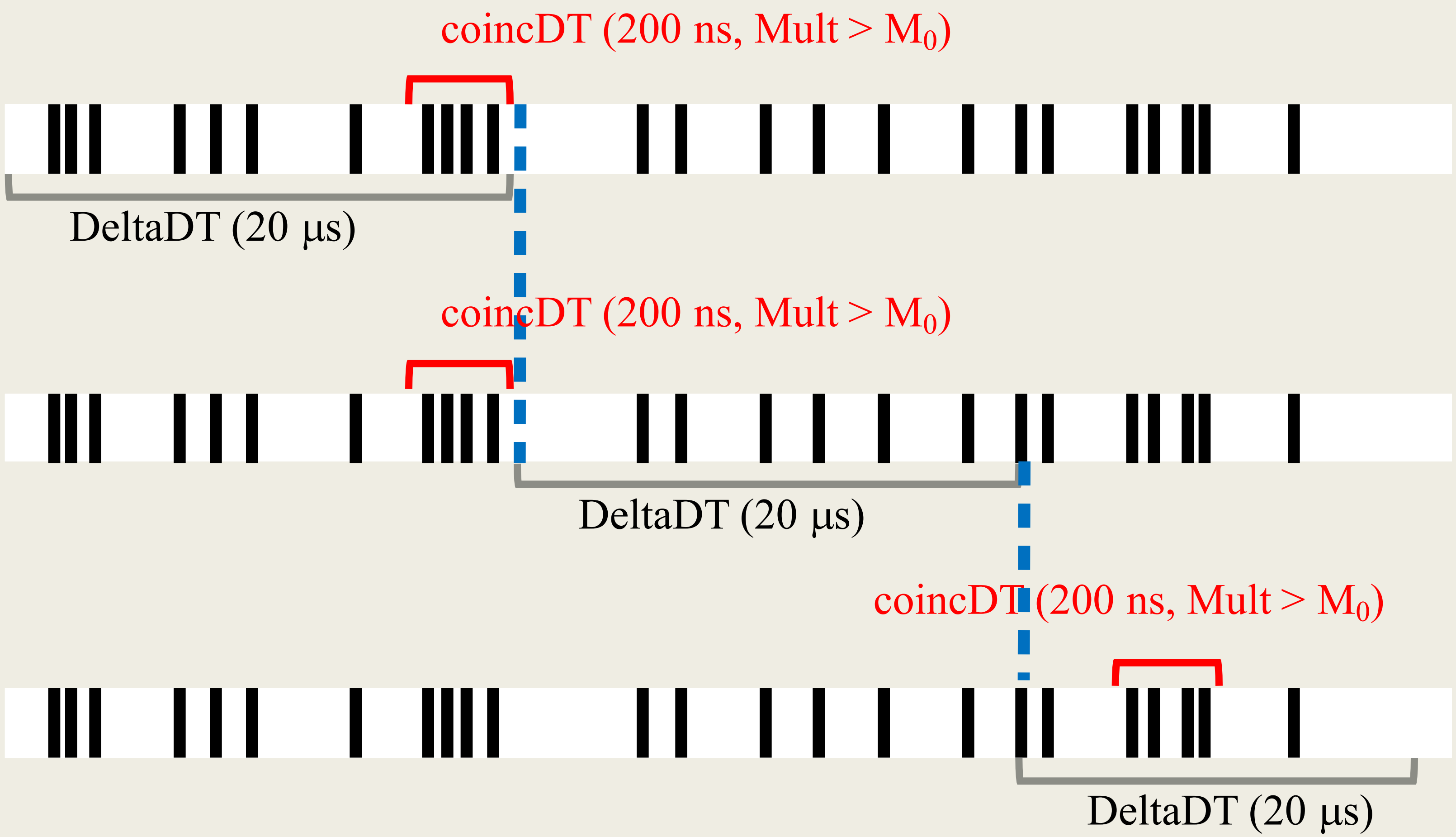
$\tau \approx 0$	Prompt	C_P
$\tau > 0$	Delayed	C_D

$C_D = C_P + \tau \longrightarrow \boxed{\tau = C_D - C_P}$

Event Building for μs ISOMER studies
Need to define a "Fission" Trigger

Critical Parameter to identify FISSION: **$M_0 = 3$**

Determination of **Prompt** & **Delayed** events



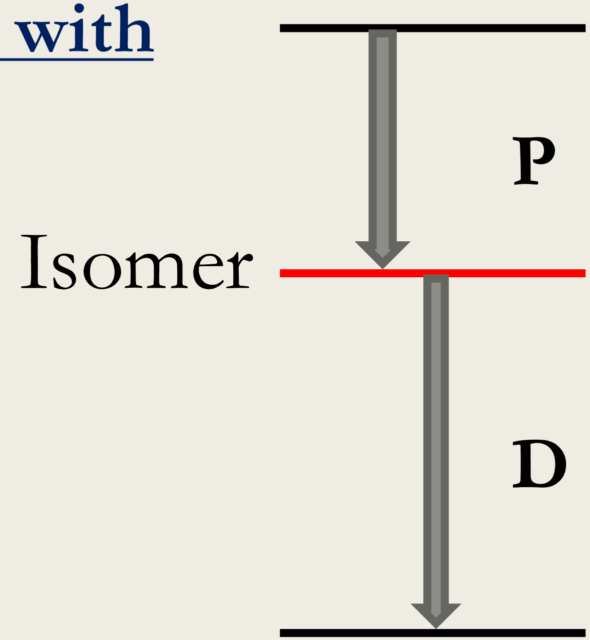
Event Building for μs ISOMER studies

$\Delta T_{Prompt} = 200$ ns with $\gamma_{mult} > 3$

$\Delta T_{Delayed} \leq 20$ μs with $\gamma_{mult} \leq 3$

Possibility to create 3 matrices with a gate condition

1) P – P
2) P – D
3) D – D



Base

$$|jm\rangle = a^{\dagger}_{jm}|0\rangle, \qquad |[j' \otimes NJ]_{jm}\rangle$$

S.P. S.P x PHONON

Hamiltonian

$$\begin{aligned} H &= H_0 + V, \\ H_0 &= \sum_{jm} \varepsilon_j a^{\dagger}_{jm} a_{jm} + \sum_{NJM} \hbar\omega_{NJ} \Gamma^{\dagger}_{NJM} \Gamma_{NJM}, \\ V &= \sum_{jmj'm'} \sum_{NJM} h(jm; j'm', NJM) a_{jm} \left[a^{\dagger}_{j'} \otimes \Gamma^{\dagger}_{NJ} \right]_{jm}, \end{aligned}$$

$$H = \begin{pmatrix} \varepsilon_{n_1 lj} & 0 & \frac{\langle n_1 lj||V||n_1' l_1' j_1' N_1 J_1\rangle}{\hat{j}} & \frac{\langle n_1 lj||V||n_2' l_2' j_2' N_2 J_2\rangle}{\hat{j}} \\ 0 & \varepsilon_{n_2 lj} & \frac{\langle n_2 lj||V||n_1' l_1' j_1' N_1 J_1\rangle}{\hat{j}} & \frac{\langle n_2 lj||V||n_2' l_2' j_2' N_2 J_2\rangle}{\hat{j}} \\ \frac{\langle n_1 lj||V||n_1' l' j_1' N_1 J_1\rangle}{\hat{j}} & \frac{\langle n_2 lj||V||n_1' l' j_1' N_1 J_1\rangle}{\hat{j}} & \varepsilon_{n_1' l_1' j_1'} + \hbar\omega_{N_1 J_1} & 0 \\ \frac{\langle n_1 lj||V||n_2' j_2' N_2 J_2\rangle}{\hat{j}} & \frac{\langle n_2 lj||V||n_2' l' j_2' N_2 J_2\rangle}{\hat{j}} & 0 & \varepsilon_{n_2' l_2' j_2'} + \hbar\omega_{N_2 J_2} \end{pmatrix}$$

HYBRID Model – Main ingredients

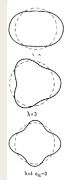
^{132}Sn

CORE Excitations

$E^* < 5.5$ MeV

$J^{\pi} < 11^{(+,-)}$

RPA (Skyrme X)



	Energy Exp.	Energy Theory (RPA)	Transition strength Exp.	Transition strength Theory (RPA)	Main components Theory (RPA)
Phonons					
2^+	4.041	3.87	7	4.75	$\nu h^{-1}_{11/2} f_{7/2}$ (0.56), $\pi g^{-1}_{9/2} d_{5/2}$ (0.19), $\pi g^{-1}_{9/2} g_{7/2}$ (0.14)
3^-	4.352	5.02	> 7.1	9.91	$\nu s^{-1}_{1/2} f_{7/2}$ (0.40), $\nu d^{-1}_{3/2} f_{7/2}$ (0.12), $\pi p^{-1}_{1/2} g_{7/2}$ (0.12)
4^+	4.416	4.46	7	5.10	$\nu h^{-1}_{11/2} f_{7/2}$ (0.63), $\pi g^{-1}_{9/2} g_{7/2}$ (0.21)
Other Excitations					
6^+	4.716	4.73		1.65	$\nu h^{-1}_{11/2} f_{7/2}$ (0.86), $\pi g^{-1}_{9/2} g_{7/2}$ (0.11)
4^-	4.831	5.68		0.16	$\nu s^{-1}_{1/2} f_{7/2}$ (0.91)
8^+	4.848	4.80		0.28	$\nu h^{-1}_{11/2} f_{7/2}$ (0.98)
5^+	4.885	4.77		0.61	$\nu h^{-1}_{11/2} f_{7/2}$ (0.99)
7^+	4.942	4.80		0.81	$\nu h^{-1}_{11/2} f_{7/2}$ (0.98)
5^-	4.919	5.98		0.96	$\nu d^{-1}_{3/2} f_{7/2}$ (0.96)
(9^+)	5.280	4.99		0.16	$\nu h^{-1}_{11/2} f_{7/2}$ (0.99)
2^-		5.44		1.77	$\nu d^{-1}_{3/2} f_{7/2}$ (0.79)

Phonons

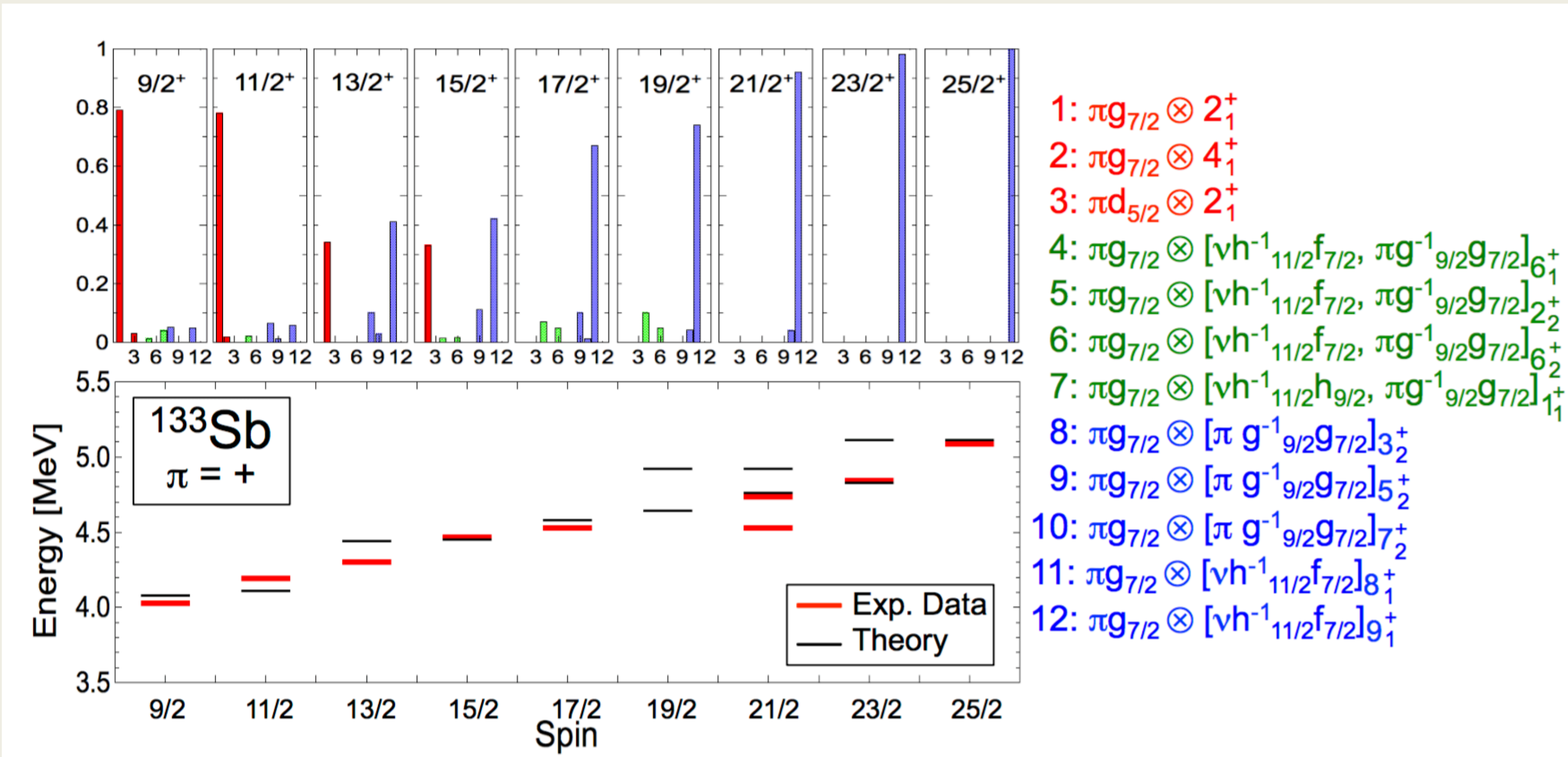
^{133}Sb

Single Particle states

Hartree-Fock (Skyrme X)

$g_{7/2}$	$d_{5/2}$	$d_{3/2}$	$h_{11/2}$	$s_{1/2}$	
0	0.587	2.439	2.831	2.97	[MeV]

→ **Coupling matrix elements** between **single particle** and **RPA states** are consistently calculated with the **same SkX interaction**



^{133}Sb
$\pi = +$
9/2$^+$ 11/2$^+$ 13/2$^+$ 15/2$^+$ 17/2$^+$ 19/2$^+$ 21/2$^+$ 23/2$^+$ 25/2$^+$
1 0.8 0.6 0.4 0.2 0
3 6 9 12
Energy [MeV]
5.5 5.0 4.5 4.0 3.5
Exp. Data
Theory
9/2 11/2 13/2 15/2 17/2 19/2 21/2 23/2 25/2
Spin
1: $\pi g_{7/2} \otimes 2^+_1$
2: $\pi g_{7/2} \otimes 4^+_1$
3: $\pi d_{5/2} \otimes 2^+_1$
4: $\pi g_{7/2} \otimes [\nu h^{-1}_{11/2} f_{7/2}, \pi g^{-1}_{9/2} g_{7/2}]_{6^+_1}$
5: $\pi g_{7/2} \otimes [\nu h^{-1}_{11/2} f_{7/2}, \pi g^{-1}_{9/2} g_{7/2}]_{2^+_2}$
6: $\pi g_{7/2} \otimes [\nu h^{-1}_{11/2} f_{7/2}, \pi g^{-1}_{9/2} g_{7/2}]_{6^+_2}$
7: $\pi g_{7/2} \otimes [\nu h^{-1}_{11/2} h_{9/2}, \pi g^{-1}_{9/2} g_{7/2}]_{1^+_1}$
8: $\pi g_{7/2} \otimes [\pi g^{-1}_{9/2} g_{7/2}]_{3^+_2}$
9: $\pi g_{7/2} \otimes [\pi g^{-1}_{9/2} g_{7/2}]_{5^+_2}$
10: $\pi g_{7/2} \otimes [\pi g^{-1}_{9/2} g_{7/2}]_{7^+_2}$
11: $\pi g_{7/2} \otimes [\nu h^{-1}_{11/2} f_{7/2}]_{8^+_1}$
12: $\pi g_{7/2} \otimes [\nu h^{-1}_{11/2} f_{7/2}]_{9^+_1}$

Reduced Transition Probabilities

$$B(X\lambda) \equiv \frac{1}{2j_f+1} |\langle \alpha_f j_f \| \hat{O}(X\lambda) \| \alpha_i j_i \rangle|^2,$$

$$\begin{aligned}
\langle \alpha_f j_f \| \hat{O}(X\lambda) \| \alpha_i j_i \rangle &= \sum_{if} X_i^{\alpha_i} X_f^{\alpha_f} \langle f j_f \| \hat{O}(X\lambda) \| i j_i \rangle \\
&= \sum_{if} X_i^{\alpha_i} X_f^{\alpha_f} \langle j_f \| \hat{O}(X\lambda) \| j_i \rangle + \\
&+ \sum_{if} X_i^{\alpha_i} X_f^{\alpha_f} \langle \left[j'_f \otimes J'_f \right]_{j_f} \| \hat{O}(X\lambda) \| j_i \rangle + \\
&+ \sum_{if} X_i^{\alpha_i} X_f^{\alpha_f} \langle j_f \| \hat{O}(X\lambda) \| \left[j'_i \otimes J_i \right]_{j_i} \rangle + \\
&+ \sum_{if} X_i^{\alpha_i} X_f^{\alpha_f} \langle \left[j'_f \otimes J'_f \right]_{j_f} \| \hat{O}(X\lambda) \| \left[j'_i \otimes J_i \right]_{j_i} \rangle,
\end{aligned}$$

$$\begin{aligned}
\langle \alpha_f j_f \| \hat{O}(X\lambda) \| \alpha_i j_i \rangle = & \sum_{if} \xi_i^{\alpha_i} \xi_f^{\alpha_f} \langle j_f \| \hat{O}(X\lambda) \| j_i \rangle + \\
& + \sum_{if} \xi_i^{\alpha_i} \xi_f^{\alpha_f} \delta(J'_f, \lambda) \delta(j'_f, j_i) \frac{\hat{j}_f}{\hat{\lambda}} \langle J'_f \| \hat{O}_{ph} \| 0 \rangle + \\
& + \sum_{if} \xi_i^{\alpha_i} \xi_f^{\alpha_f} \delta(J'_i, \lambda) \delta(j'_i, j_f) \frac{\hat{j}_i}{\hat{\lambda}} \langle J'_i \| \hat{O}_{ph} \| 0 \rangle (-)^{j_i - j_f + \lambda + \binom{+1}{+0}} + \\
& + \sum_{if} \xi_i^{\alpha_i} \xi_f^{\alpha_f} \hat{j}_f \hat{j}_i \Bigg\{ (-)^{j_f + J'_i + \lambda + j'_i} \begin{Bmatrix} j_i & j_f & \lambda \\ J'_f & J'_i & j'_f \end{Bmatrix} \delta(j'_f, j'_i) \times \\
& \times \sum_{ph, p'h'} \left[X^f_{ph} X^i_{p'h'} + (-)^{J'_f - J'_i + \lambda} Y^f_{ph} Y^i_{p'h'} \right] \times \\
& \quad \times \Bigg(\delta(h, h') \hat{J}'_f \hat{J}'_i (-)^{j_h + j_p + J'_i + \lambda} \begin{Bmatrix} j_h & J'_i & j_{p'} \\ \lambda & j_p & J'_f \end{Bmatrix} \langle j_p \| \hat{O}_{sp} \| j_{p'} \rangle + \\
& \quad - \delta(p, p') \hat{J}'_f \hat{J}'_i (-)^{j_h + j_p + J'_f} \begin{Bmatrix} j_p & J'_i & j_{h'} \\ \lambda & j_h & J'_f \end{Bmatrix} \langle j_{h'} \| \hat{O}_{sp} \| j_h \rangle \Bigg) + \\
& + (-)^{j_i + j'_f + \lambda + J'_f} \begin{Bmatrix} j_f & j_i & \lambda \\ j'_i & j'_f & J'_f \end{Bmatrix} \delta(J'_f, J'_i) \langle j'_f \| \hat{O}_{sp} \| j'_i \rangle \Bigg\}.
\end{aligned}$$

Reduced Transition Probabilities

$$\langle j_2 \| i^{\lambda}\mathcal{M}(E\lambda) \| j_1 \rangle$$

$$= e(-1)^{j_1-j_2+\lambda}\, i^{l_1-l_2+\lambda} \left(\frac{(2\lambda+1)(2j_1+1)}{4\pi}\right)^{1/2} \langle j_2 | r^{\lambda} | j_1 \rangle \langle j_1 \tfrac{1}{2} \lambda 0 | j_2 \tfrac{1}{2} \rangle \qquad (l_1 + \lambda - l_2 \text{ even}) \tag{3C-33}$$

$$\langle j_2 \| i^{\lambda-1}\mathcal{M}(M\lambda) \| j_1 \rangle$$

$$= \frac{e\hbar}{2Mc}(-1)^{j_1-j_2+\lambda-1}\, i^{l_1-l_2+\lambda-1}\left(\frac{(2j_1+1)(2\lambda+1)}{4\pi}\right)^{1/2} \langle j_2 | r^{\lambda-1} | j_1 \rangle$$

$$\times \left\{ \left(g_s - \frac{2}{\lambda+1} g_l\right) \frac{\lambda}{2} \langle j_1 \tfrac{1}{2} \lambda 0 | j_2 \tfrac{1}{2} \rangle \left[1 + \frac{1}{\lambda}(-1)^{l_1+1/2-j_1}\{(j_1+\tfrac{1}{2}) + (-1)^{j_1+j_2-\lambda}(j_2+\tfrac{1}{2})\} \right] \right.$$

$$+ (-1)^{j_1+j_2+\lambda} \frac{2g_l}{\lambda+1} (\lambda(2\lambda-1)(2\lambda+1)j_1(j_1+1)(2j_1+1))^{1/2} \langle j_1 \tfrac{1}{2}\, \lambda-1\, 0 | j_2 \tfrac{1}{2} \rangle$$

$$\left. \times \begin{Bmatrix} j_1 & 1 & j_1 \\ \lambda-1 & j_2 & \lambda \end{Bmatrix} \right\} \tag{3C-36}$$

$$\langle n_1' j_1' n_2' j_2' j' m' | \{\hat{\mathbf{P}}_a(1) \otimes \hat{\mathbf{Q}}_b(2)\}_{c\gamma} | n_1 j_1 n_2 j_2 j m \rangle$$

$$= (-1)^{2c} \prod_{cj} C^{j'm'}_{jmc\gamma} \begin{Bmatrix} a & b & c \\ j_1' & j_2' & j' \\ j_1 & j_2 & j \end{Bmatrix} \langle n_1' j_1' \| \hat{\mathbf{P}}_a(1) \| n_1 j_1 \rangle \langle n_2' j_2' \| \hat{\mathbf{Q}}_b(2) \| n_2 j_2 \rangle ,$$

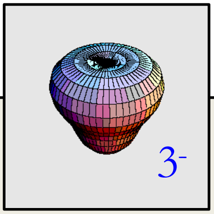
D.A. Varshalovich, World Scientific Publishing Company, Incorporated, 1988

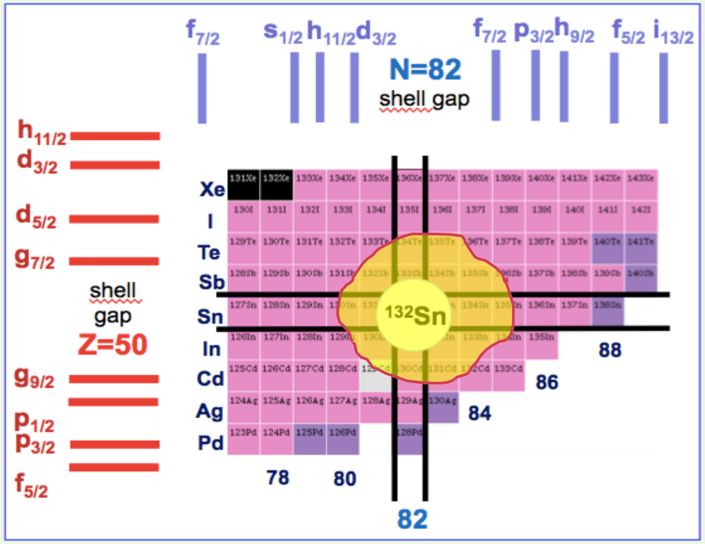
A. Bohr, B.R. Mottelson, Nuclear Structure, I and II, W.A. Benjamin, 1975

Physics Motivation

Low lying excited states in **DOUBLY MAGIC** Nuclei are dominated by complex, collective excitations

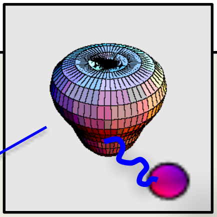
2^+, 3^-, 4^+, … **PHONONS**





The Structure of Nuclei with **one** or **two valence particles** is influenced by

Particle-Phonon couplings



excited core (phonon)

Key Ingredient for:

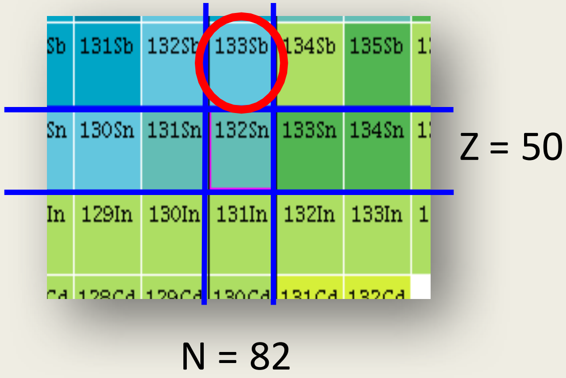
- Quenching of Spectroscopic Factors,
- Anharmonicity of vibrational spectra
- Damping of Giant Resonances, …

PHENOMENOLOGICAL (Bohr-Mottelson)
MICROSCOPIC (Colò, Bortignon, Sagawa, Dabaczewski, Vretenar, …)

→ ***VERY limited EXPERIMENTAL Information on Particle-PHONON Couplings around DOUBLY MAGIC NUCLEI***

Outline

$^{132}Sn + 1\pi$



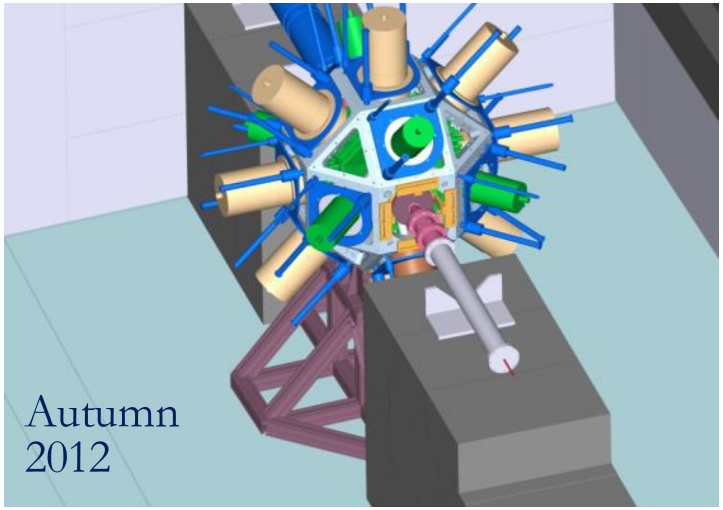
- Physics Motivation:
- EXILL e FATIMA Campaign
- Experimental Setup
- Analysis
- Theory

First time a large HPGe array (52 Ge crystals) installed around a highly collimated cold-neutron beam

SETUP 1

γ – spectroscopy

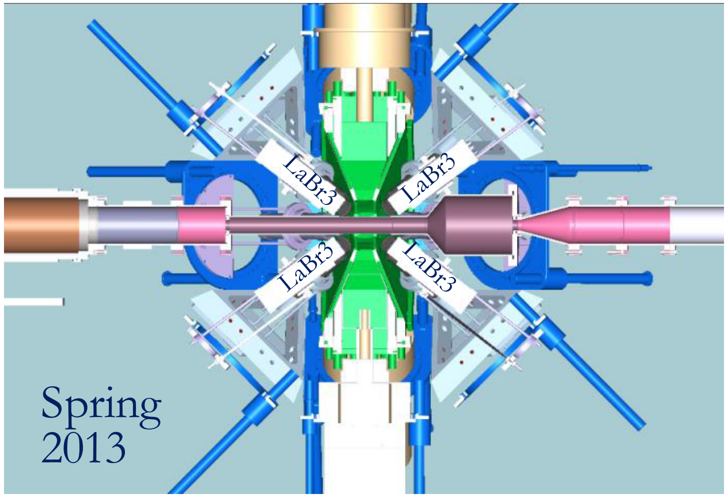
10 EXOGAM – Clovers + 6 Ge GASP
6% efficiency



SETUP 2

Lifetime Measurement

8 EXOGAM – Clovers + 16 LaBr3
Fast Timing



The ACQUISITION SYSTEM

A Fully Digital Approach, TRIGGERLESS

>10 kHz/crystal, >600 kHz total, 10 ns clock
Unique opportunity for g-coincidences over several ms time window

→ n-induced fission on ^{235}**U** and ^{241}**Pu** and (n,γ) on several targets

2 target play a **crucial rule** in order to identify partners!!!

EXILL

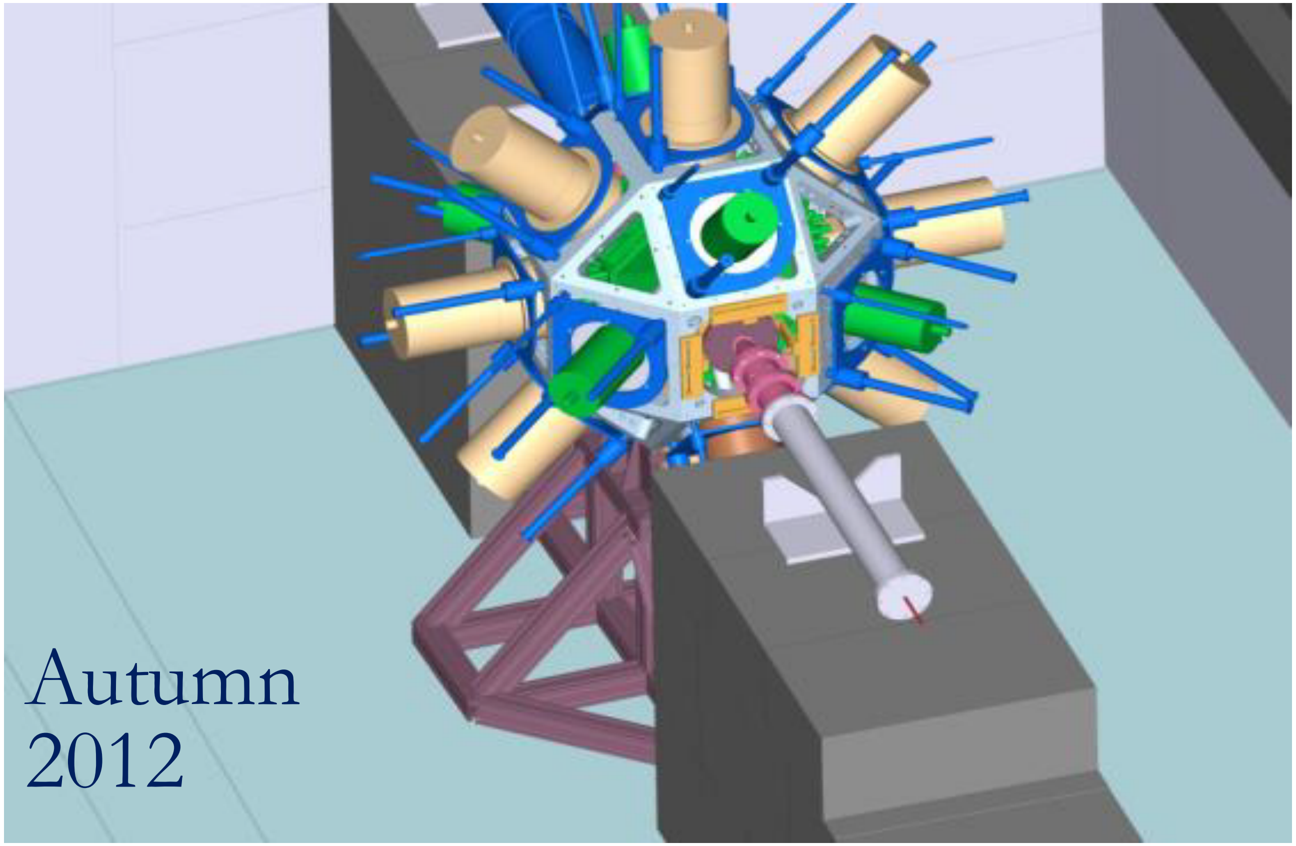
(EXOgam @ ILL)

SETUP 1

γ – spectroscopy

8 EXOGAM – Clovers + 6 Ge GASP + 2 Lohengrin

6% efficiency



Autumn
2012

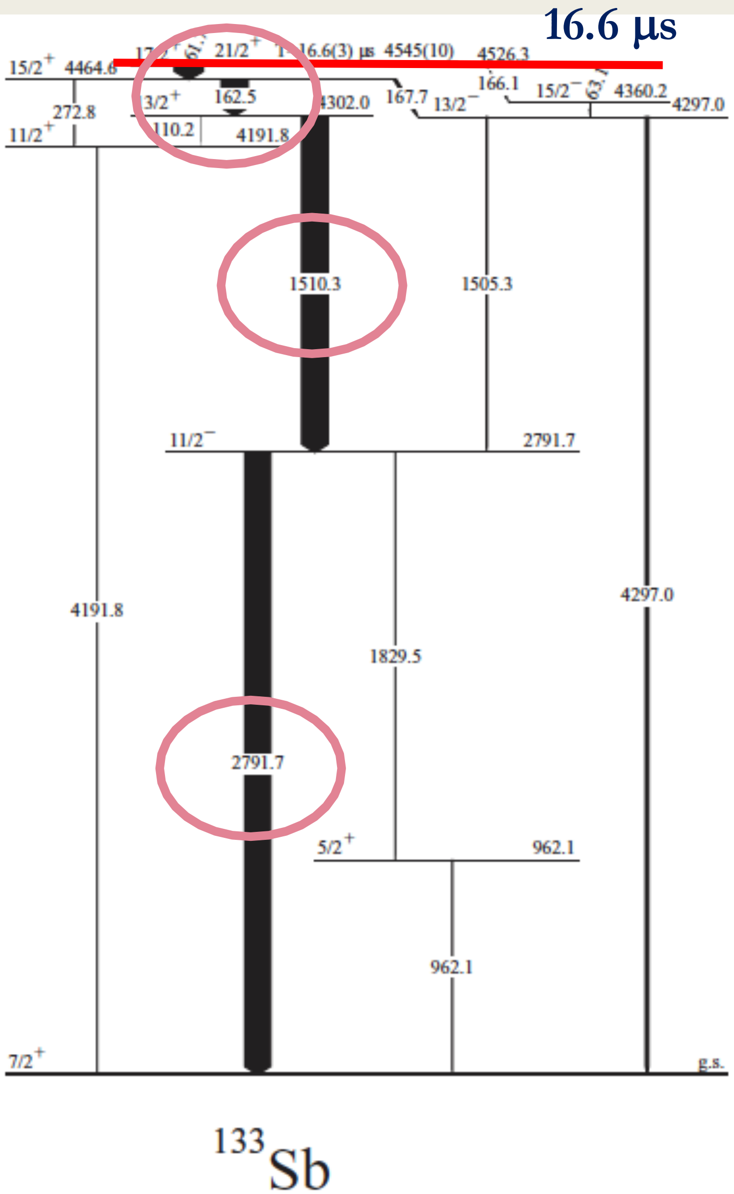


FIG. 5. Partial level scheme of ^{133}Sb as obtained in the present work. Excited levels and γ transitions are labeled with energies given in keV.

Isomer Decay Measured at the focal plane of LOHENGRIN separator (ILL)

W. Urban et al., PRC79(2009)037304

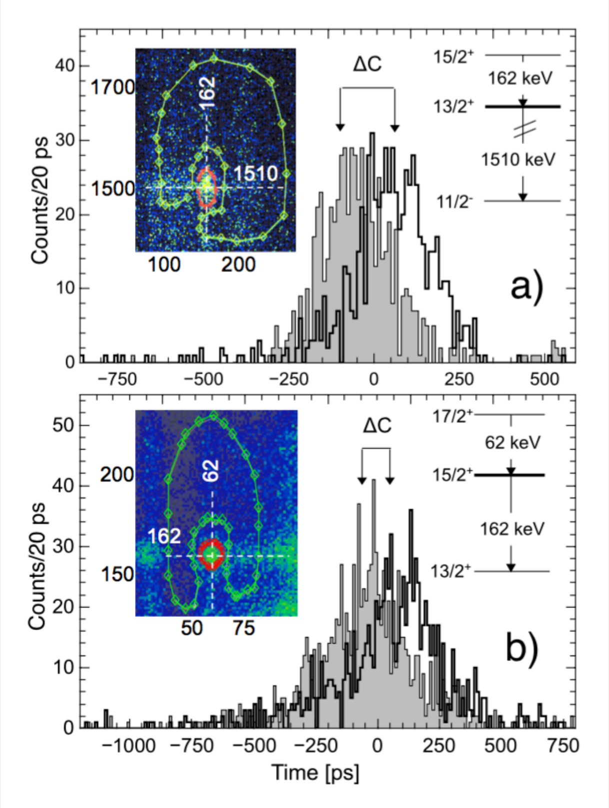
Matrices

P – P – (D)

P – D – (D)

(D) = 2792, 1510 and 162 keV

Lifetimes Analysis by FAST-TIMING:
Nature of particle-CORE coupled states



13/2+ @ 4302 keV

$$T_{1/2} = 31(16)\ \text{ps}$$

15/2+ @ 4464 keV

$$T_{1/2} < 20\ \text{ps}$$

INTERPRETATION

Multiplet of states

$11/2^+, 13/2^+, \ldots 25/2^+$

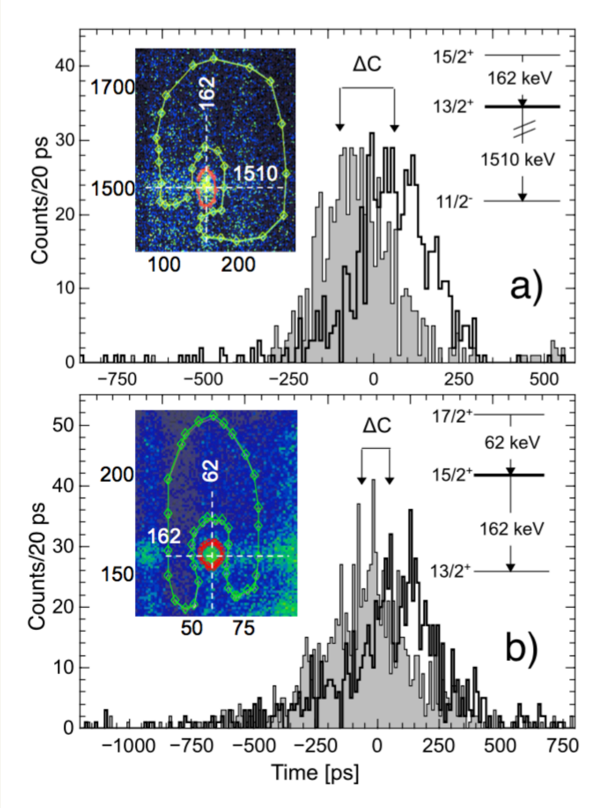
Lifetimes Analysis with Scintillators

	τ_{EXP}	B(M1,I→I-1)
$15/2^+ \rightarrow 13/2^+$	≈10 ps	0.7 W.u.
$13/2^+ \rightarrow 11/2^+$	≈40 ps	0.005 W.u.

> 100

Not Simple Configurations !

Lifetimes Analysis by FAST-TIMING:
Nature of particle-CORE coupled states



INTERPRETATION

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Lifetimes Analysis with Scintillators

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> 100

<u>$13/2^+$ @ 4302 keV</u>

$$T_{1/2} = 31(16)\ \text{ps}$$

<u>$15/2^+$ @ 4464 keV</u>

$$T_{1/2} < 20\ \text{ps}$$

Not Same Configurations !

Hybrid Configuration Mixing

(G. Colò & P.F. Bortignon)

We start from a **basis** made up with **particles** (or holes) around a core, and with **excitations** of the same core (RPA "phonons").

$$|jm\rangle = a^{\dagger}_{jm}|0\rangle, \qquad |[j' \otimes NJ]_{jm}\rangle$$

Hamiltonian

$$\begin{aligned} H &= H_0 + V, \\ H_0 &= \sum_{jm} \varepsilon_j a^{\dagger}_{jm} a_{jm} + \sum_{NJM} \hbar\omega_{NJ} \Gamma^{\dagger}_{NJM} \Gamma_{NJM}, \\ V &= \sum_{jmj'm'} \sum_{NJM} h(jm; j'm', NJM)\, a_{jm} \left[a^{\dagger}_{j'} \otimes \Gamma^{\dagger}_{NJ} \right]_{jm}, \end{aligned}$$