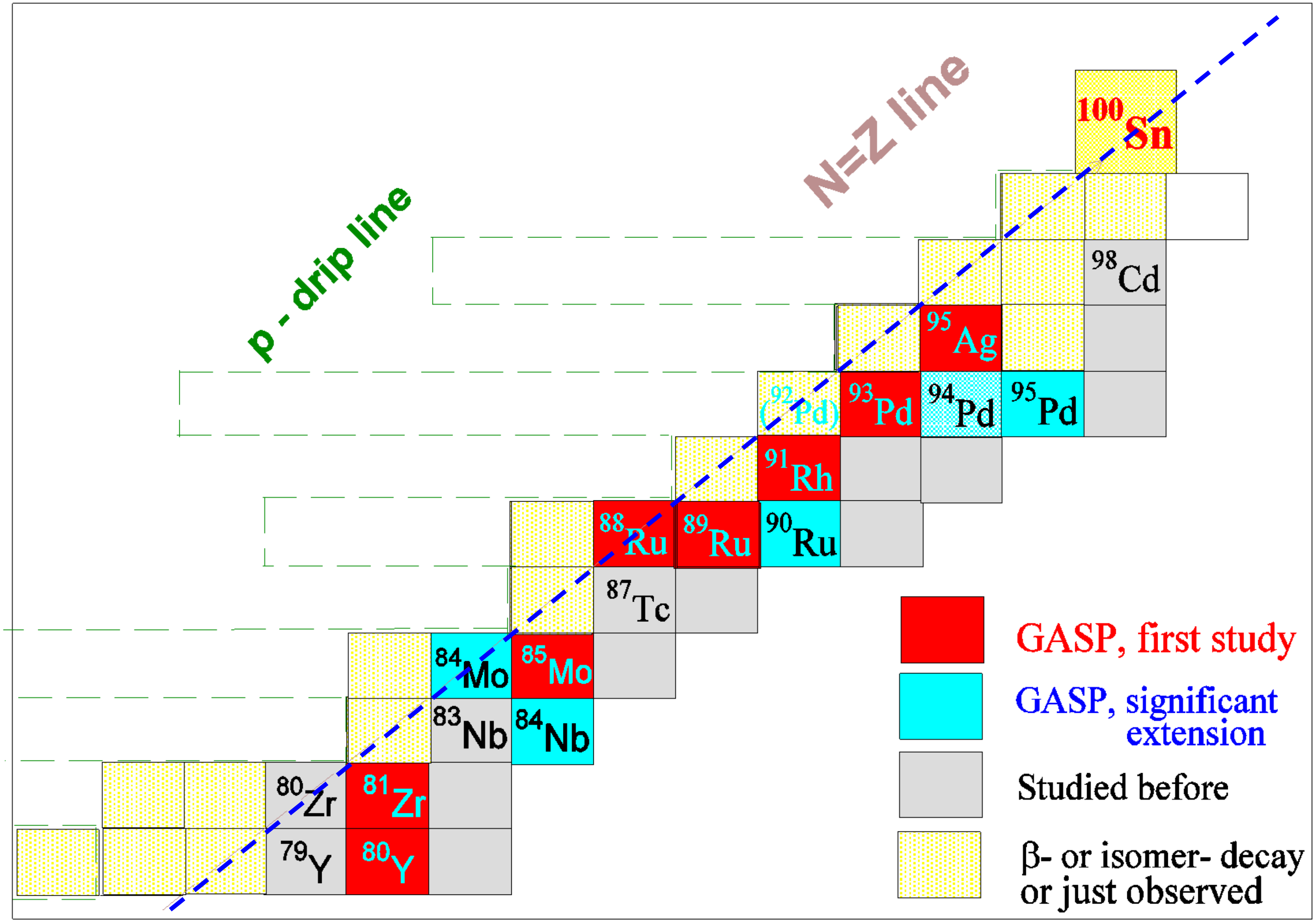
From GASP to ROSPHERE: Gamma-ray spectroscopy at NIPNE – Bucharest

Dorel Bucurescu

IFIN-HH, Bucharest

Padova 9-12 June 2013

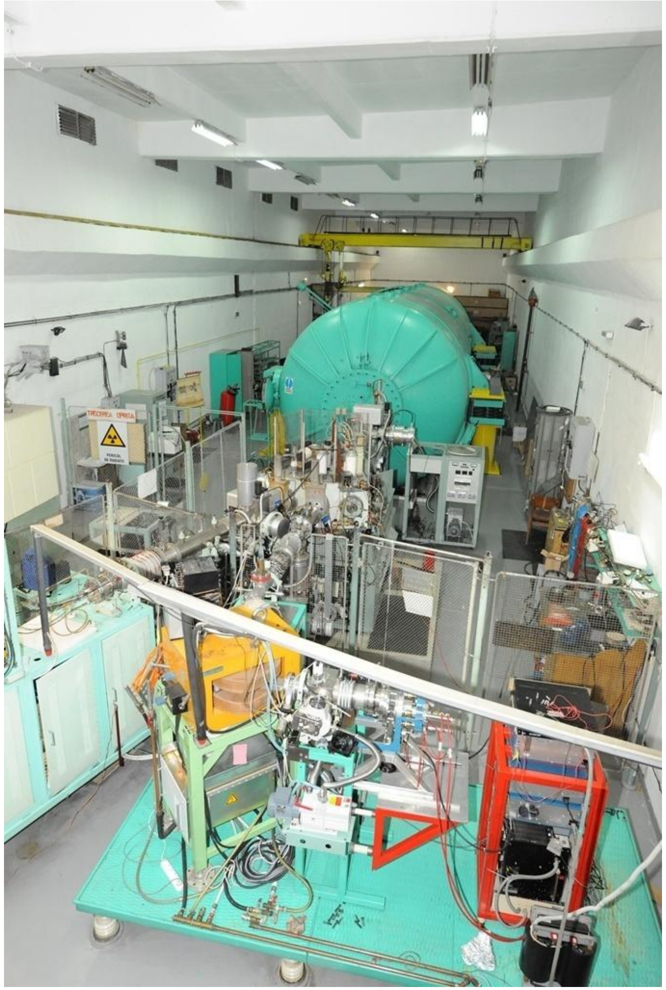
N≈Z nuclei at GASP - Laboratori Nazionali di Legnaro



p-drip line: G.A.Lalazissis et al, Nucl. Phys. A719,209c(2003): Rel. HB calc.

TANDEM Accelerator Laboratory at IFIN-HH

- 9 MV TANDEM accelerator, completely modernized
- Duoplasmatron alpha particle source (Li-exchange)
- Sputtering source
- “Fast” (nanoseconds) pulsing system (200 ns)
- “Slow” (~ms to hundreds of sec.) pulsing system
- Very good transmission (>98%)



Infrastructure for experiments

The major investments since ~2000 had in mind to:

- identify and exploit valuable “niche” research topics
- create an *international user community* for the national facilities
- add value to the Romanian contribution in major experimental nuclear physics collaborations
- make local nuclear physics experiments more attractive for students and provide good quality local training

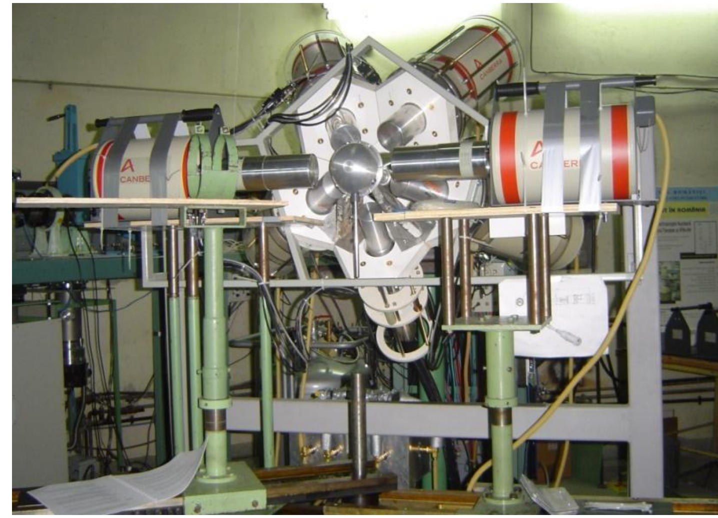
"Niche" example: *Wide-range timing*

Lifetimes have been measured only for a small fraction of the known nuclear levels

The transition matrix elements give important information about the structure of the states involved

- DSAM : $T_{1/2}$: n · 10 fs - ~2 ps
- Plunger : $T_{1/2}$: ~ ps - n · 10 ps
- Electronic fast timing : n · 10 ps – ~10 ns
- Fast beam pulsing : 10 ns – 1 µs
- Slow beam pulsing : $T_{1/2}$ > 1 ms

~1993



~2007

~2010

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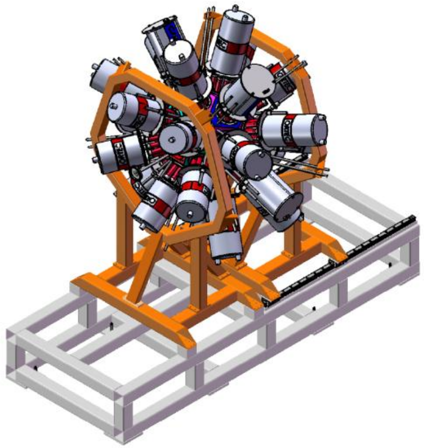
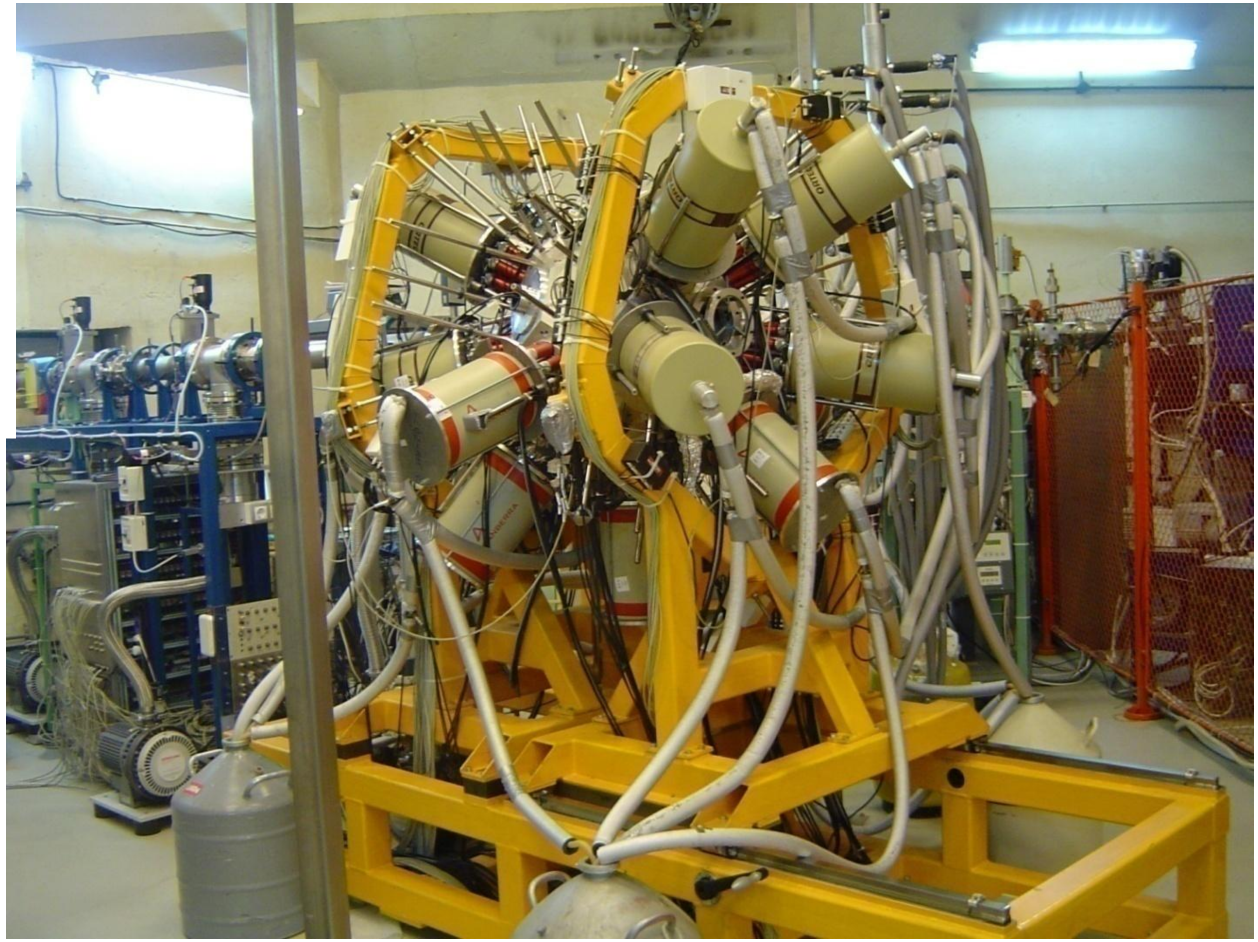




IFIN-HH Nuclear Physics Department

ROSPHERE

ROmanian array for SPectroscopy in HEavy ion REactions (June 2012)

25 detector positions

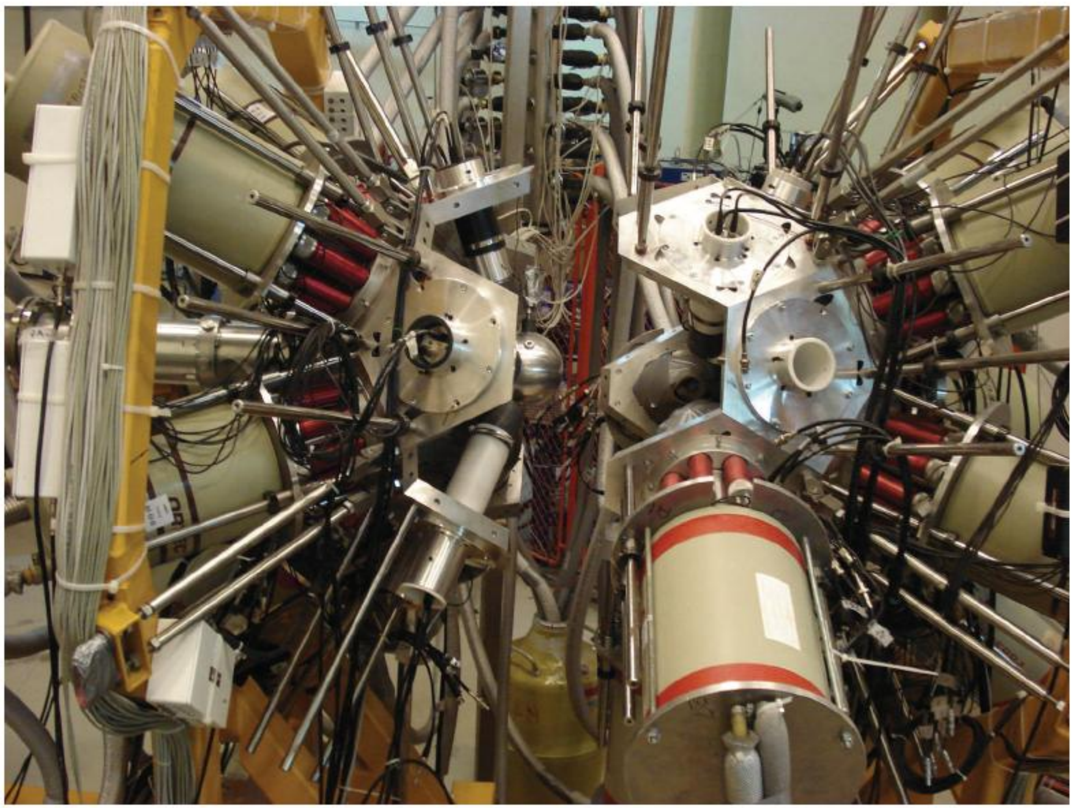
(5 rings: 90, +/- 60, +/- 43 degrees)

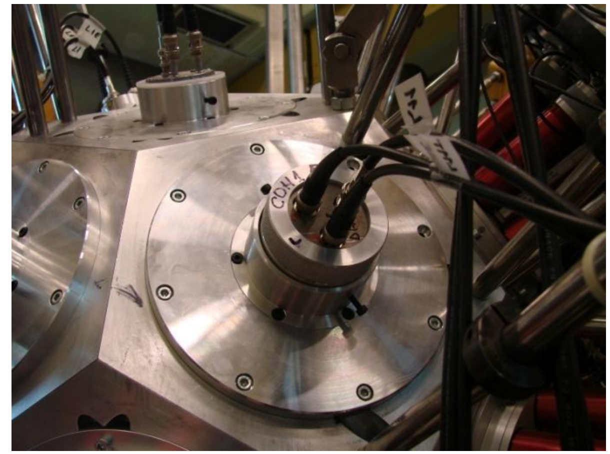
- **~ 55% HPGe with BGO anticompton shields**
- **planar Ge detectors (LEP)**
- **$LaBr_3$:Ce scintillator detectors**

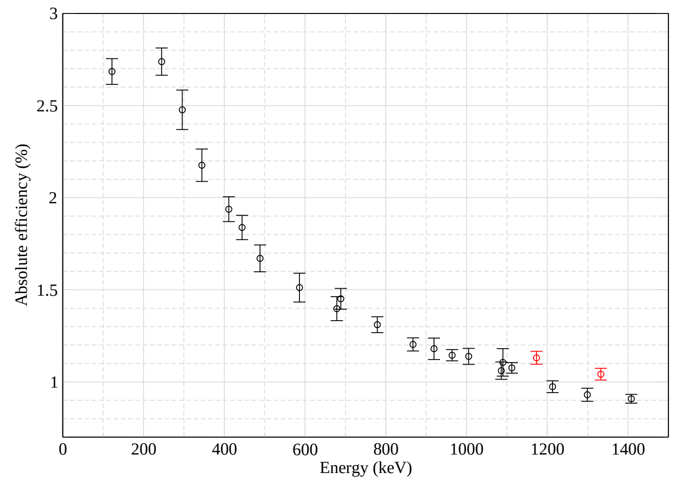
ROSPHERE with $LaBr_3$(Ce)

July 2012

14 HPGe detectors
11 $LaBr_3$(Ce) detectors





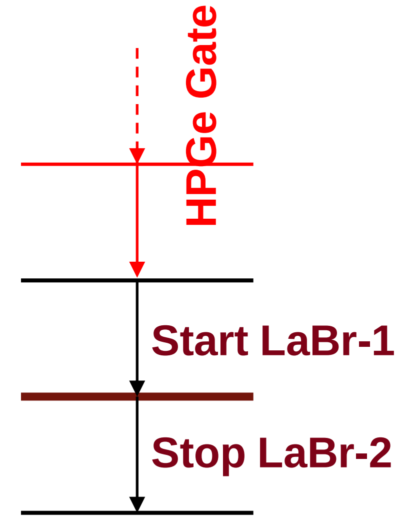


In-beam fast timing method

- Direct measure of time decay of excited levels:
range: tens of ps ---- ns

IFIN-HH method : *In-beam γ-ray* measurements with a mixed detector array : HPGe (good energy resolution) + $LaBr_3$:Ce scintillators (fast timing and reasonably good energy resolution):

- off-line correction for the CFD time walk
- triple coincidences : Ge – $LaBr_3$ – $LaBr_3$
- weak channels (fusion-evaporation, transfer)

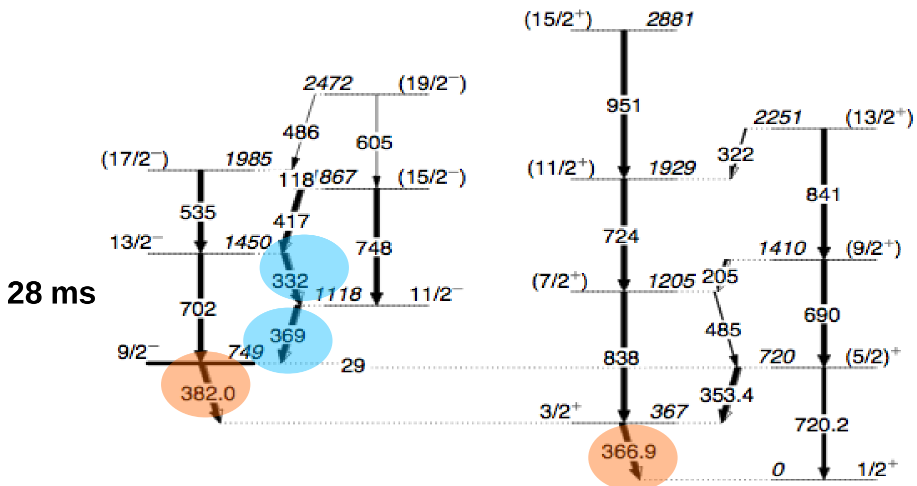


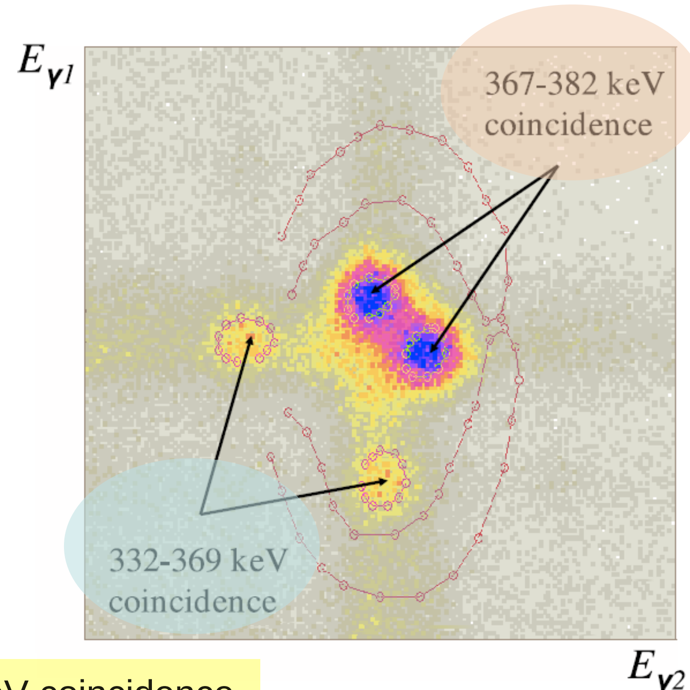
$$LaBr_3 : E_{\gamma 1} - E_{\gamma 2} - \Delta t_{12}$$

N.Mărginean *et al.*, Eur. Phys. J. A46(2010)329

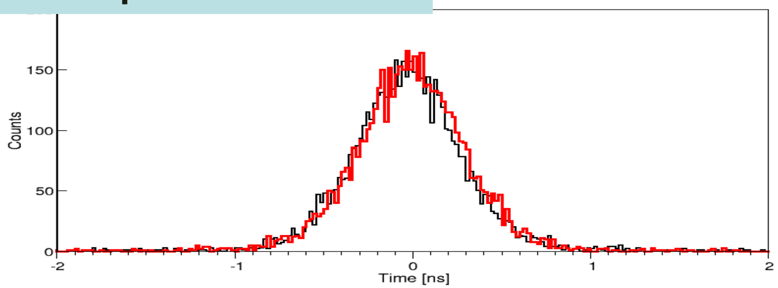
Accuracy of *In-Beam Fast Timing* measurements: example of ^{199}Tl

$^{197}Au(\alpha,2n)^{199}Tl$ @ 24 MeV

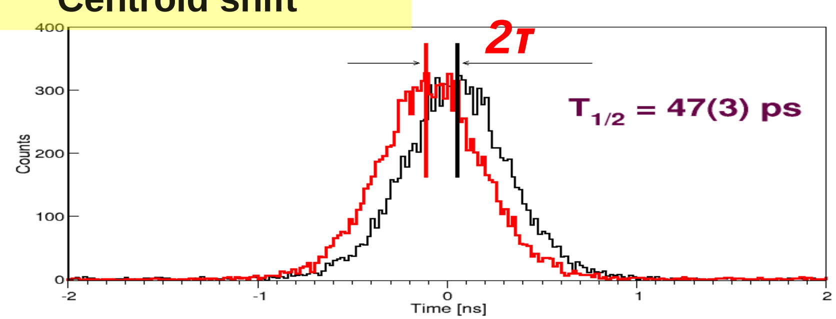




332-369 keV coincidence
“Prompt” coincidence



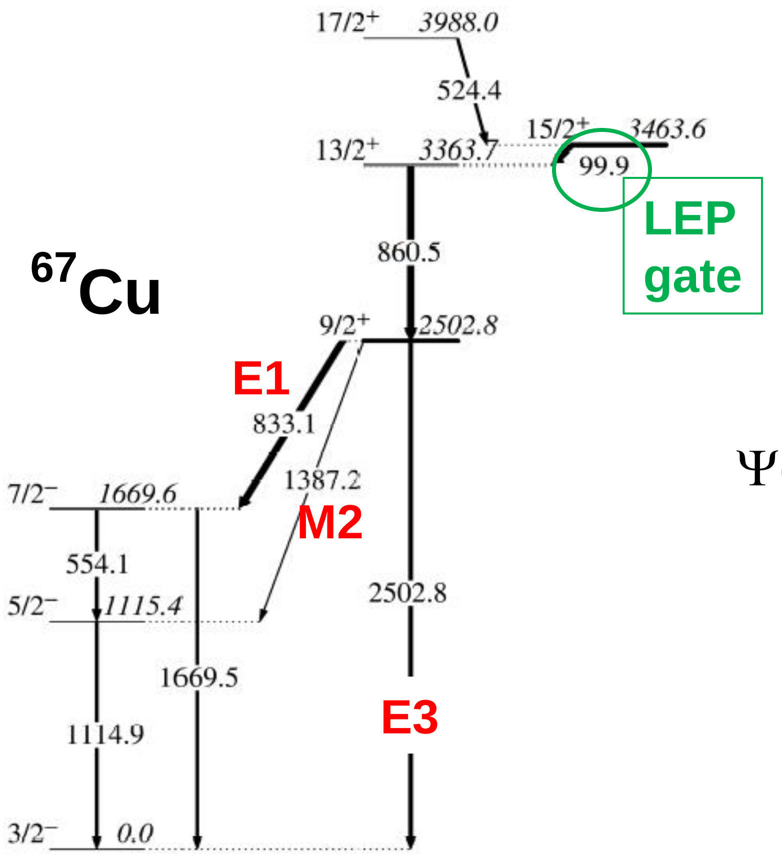
367-381 keV coincidence
Centroid shift



N.Mărginean *et al.*, Eur. Phys. J. A46(2010)329

Lifetime measurements in ^{67}Cu

C. Niţă, N. Mărginean, *et al.* *preliminary*



from (α,p) reaction:
Bucurescu *et al.* NPA189(1972)577

$$\Psi(9/2^+) = \alpha \cdot (0^+ \otimes \pi g_{9/2}) + \beta \cdot (3^- \otimes \pi p_{3/2}) + \ldots$$

$$\Psi(3/2^-) \approx 0^+ \otimes \pi p_{3/2}$$

E3: $\left\{ \begin{array}{l} 3^- \rightarrow 0^+ \\ \pi g_{9/2} \rightarrow \pi p_{3/2} \end{array} \right.$

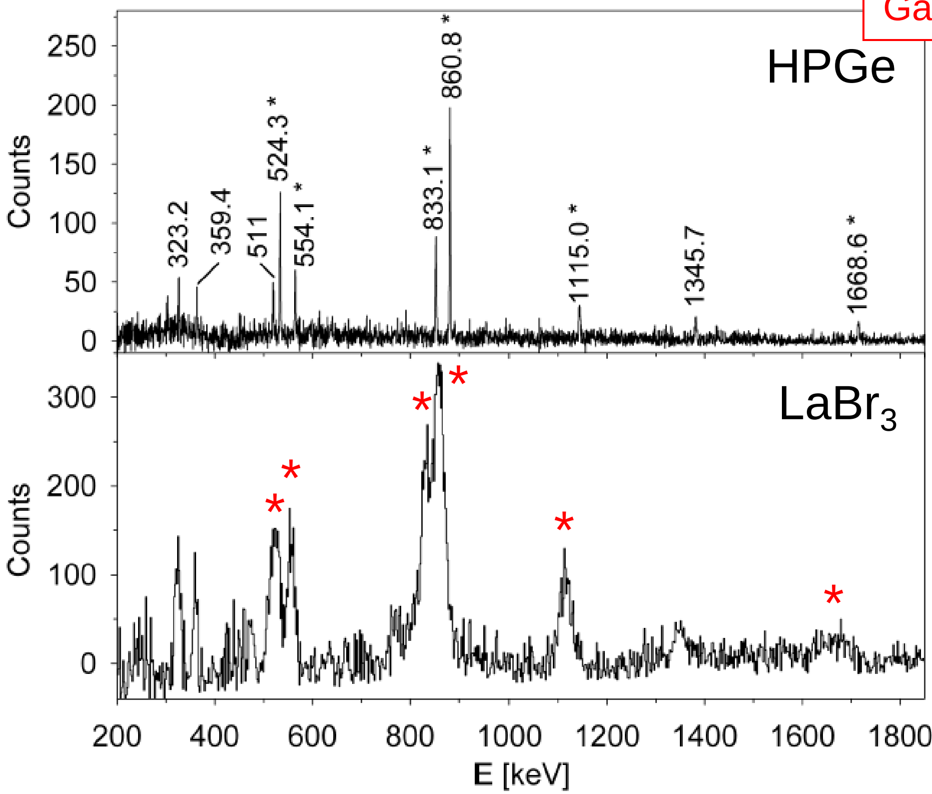
Asai et al. PRC62(2000)054313:

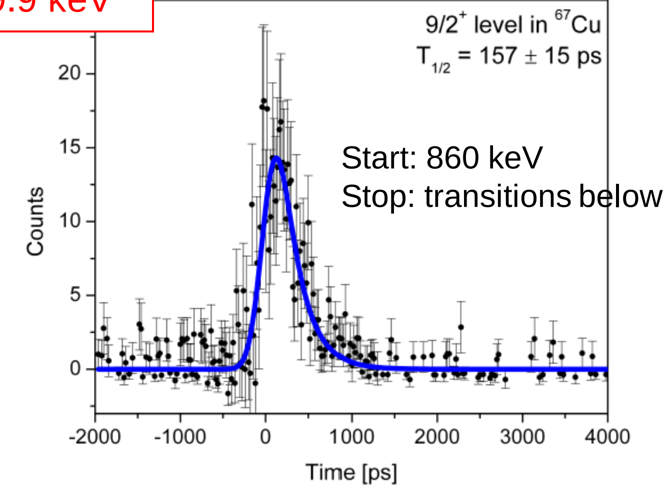
T(9/2$^+$) < 0.3 ns → if B(E1) ~ 10^{-5} W.u., like in lighter isotopes, then B(E3) >> 11 W.u. ***!***
0.6 ns < T(15/2$^+$)<2.4 ns

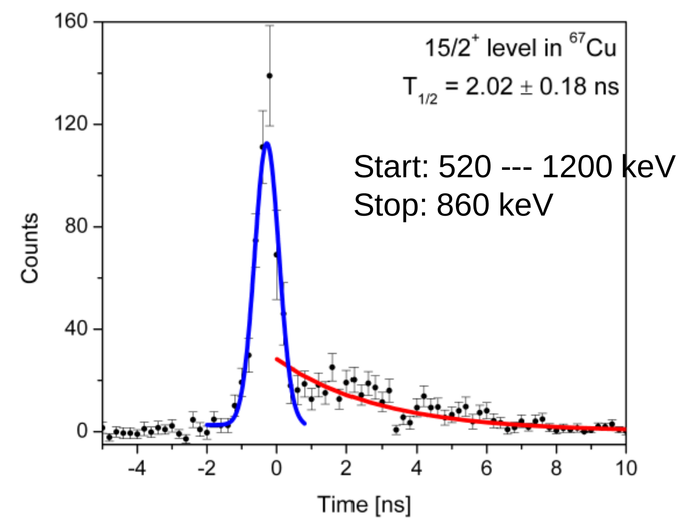
Lifetimes ^{67}Cu

$^{64}Ni(\alpha,p)$ @ 18 MeV; 5HPGe +4 HPGe LEP + 8 $LaBr_3(Ce)$

Gated by 99.9 keV







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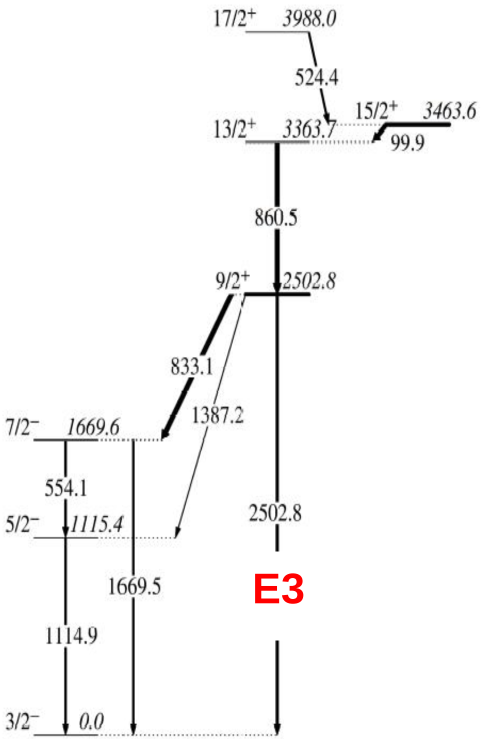
Lifetimes ^{67}Cu

$B(E1;9/2^{+} \rightarrow 7/2^{-}_{1}) = 2.6(3) \times 10^{-6}$ W.u.



Exp.: $B(E3;9/2^{+} \rightarrow 3/2^{-})$= 16.8(1.7) W.u.

^{64}Ni: $3^{-} \rightarrow 0^{+}$: 10.8(0.6) W.u.

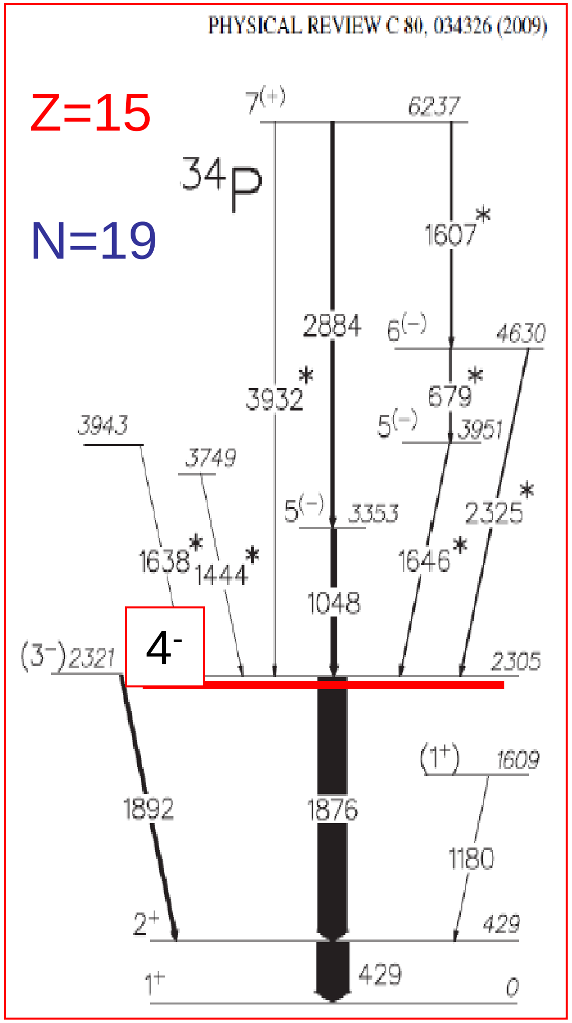
SM (NUSHELL) ($f_{5/2}p_{3/2}p_{1/2}g_{9/2}$) space, ***jj44b*** resid. inter.:

$$\Psi(9/2^{+}) \sim 39\% \,|\, J_{\nu} = 3^{-};(\pi p_{3/2})^{1} > +32\% \,|\, J^{\nu} = 0^{+};(\pi g_{9/2})^{1} > +\ldots$$

$$\Psi(3/2^{-}) \sim 89\% \,|\, J_{\nu} = 0^{+};(\pi p_{3/2})^{1} >$$

e_{π}=1.5e, e_{ν}=0.5e **B(E3)= 8.6 W.u.**

In Beam Fast-Timing Studies in ^{34}P



Collaboration with Surrey Univ.
(P. Regan, P. Mason, *et al.*)

Experiment at IFIN-HH:

50 mg/cm^2 $Ta_2{}^{18}O_5$ enriched target; 36 MeV ^{18}O beam

$$4^- : \pi s_{1/2} \otimes \nu f_{7/2}$$

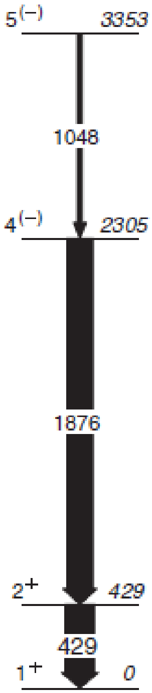
$$2^+ : \pi s_{1/2} \otimes \nu d_{3/2}{}^{-1}$$

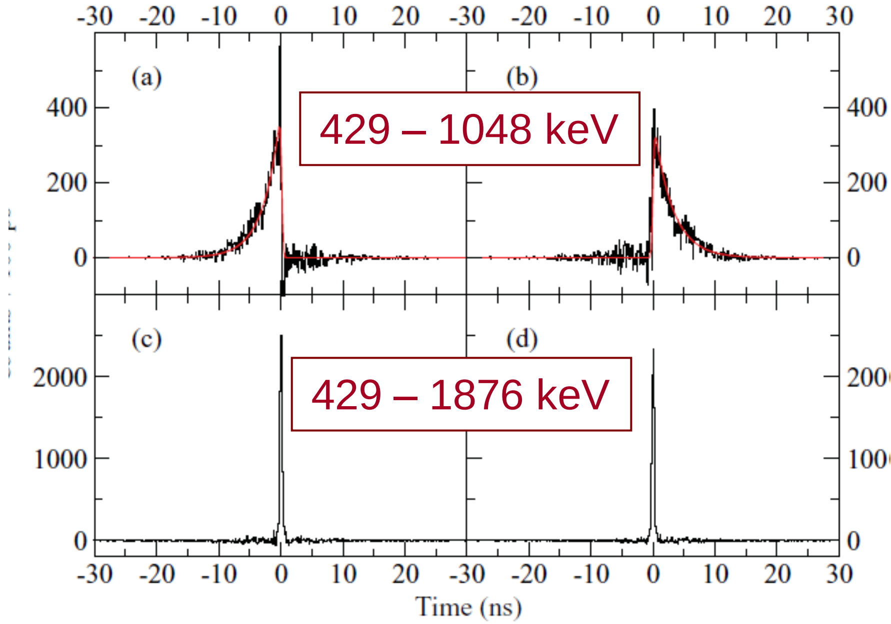
- $4^- \rightarrow 2^+$ EM transition: M2 + E3
- M2 and E3 decays can proceed by
  - M2 : => $\nu f_{7/2} \rightarrow \nu d_{3/2}$
  - E3 : => $\nu f_{7/2} \rightarrow \nu s_{1/2}$
- Lifetime and mixing ratio information gives direct values of M2 and E3 transition strength
  - Direct test of shell model wavefunctions

$$(4^-) = \alpha_1\phi_1 + \beta_1\phi_2 + \gamma_1\phi_3 \ldots$$

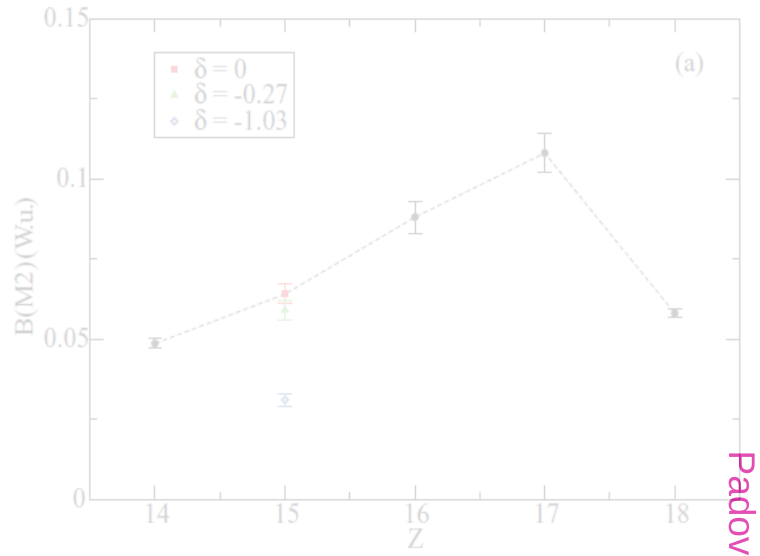
$$(2^+) = \alpha_2\phi_{1'} + \beta_2\phi_{2'} + \gamma_2\phi_{3'} \ldots$$

^{34}P





T = 2.0(1) ns



$4^- \rightarrow 2^+$ = M2 decay, consistent with δ=0.0(1) of Bender, PRC85(2012)044305
'Pure' ν$f_{7/2}$ → ν$d_{3/2}$ transition, B(M2) = 0.064(3) W.u.
Precision test of nuclear shell model: OXBASH, ^{16}O core, WBP interaction:
B(M2) = 0.139 W.u., B(E3) = 0.127W.u.

P. Mason et al., Phys. Rev. C85(2012)064303

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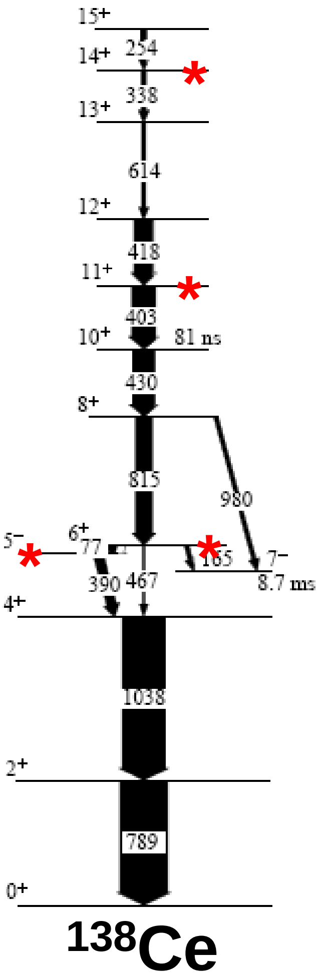
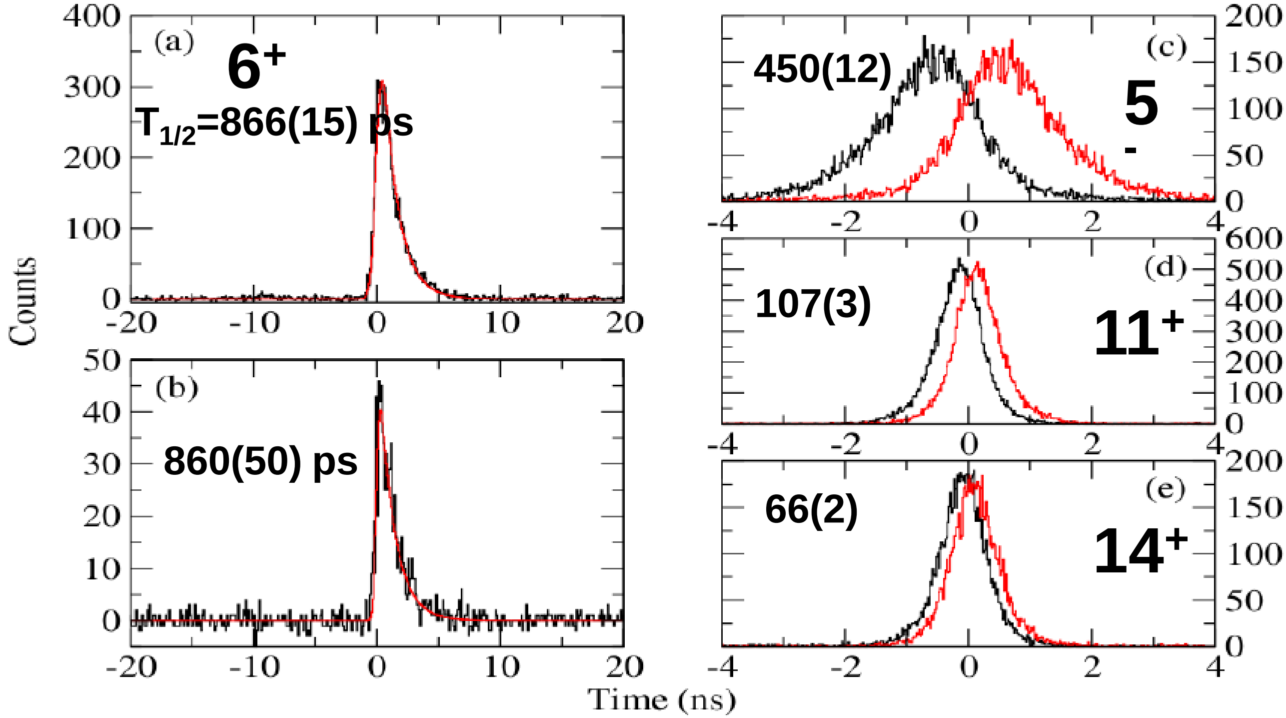
^{138}Ce: wide-range timing technique

^{130}Te(^{12}C,4n)^{138}Ce @ 56 MeV
Tandem + det. array IFIN

Collaboration with Surrey Univ.
(P. Regan, T. Alharbi, *et al.*)



Z=58,N=80



B(E2; 6+→4+) = 0.101(24) W.u.
Shell model: 0.967 W.u.

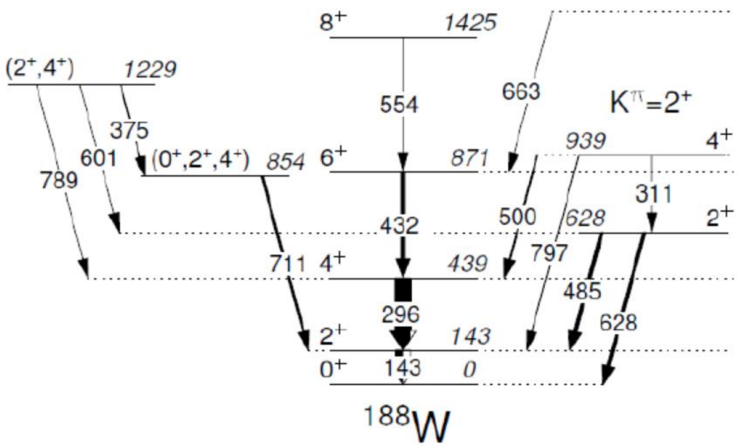
T.Alharbi et al., Phys. Rev. C87(2013)014323

Lifetime of first excited 2^+ state in ^{188}W

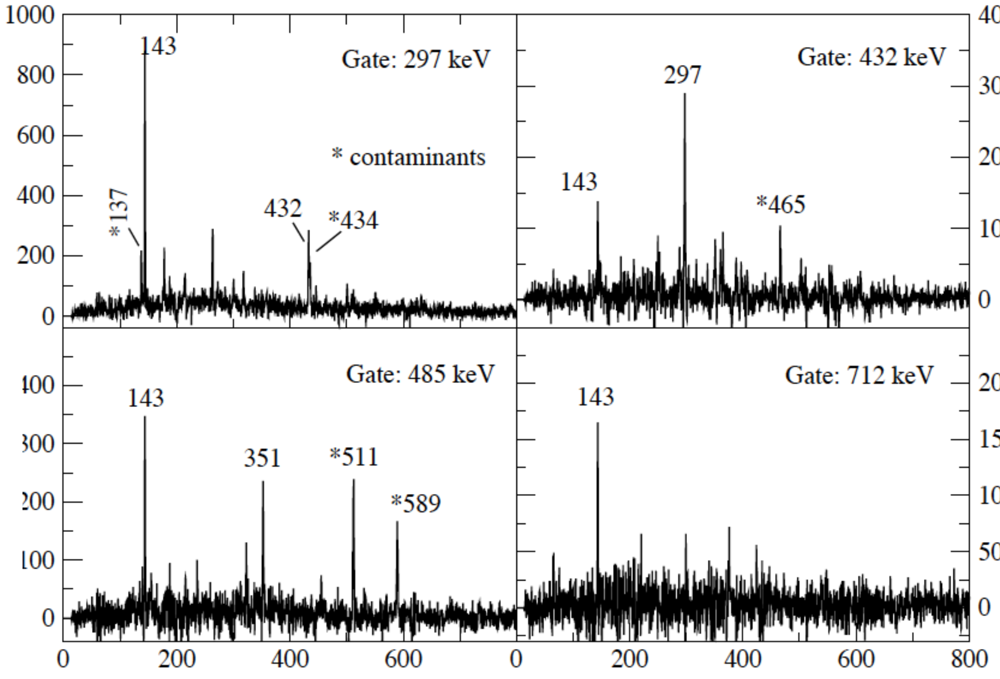
Collaboration with Surrey Univ.
(P. Mason *et al.*)

8 HPGe

11 $LaBr_3(Ce)$ Bucharest/Surrey



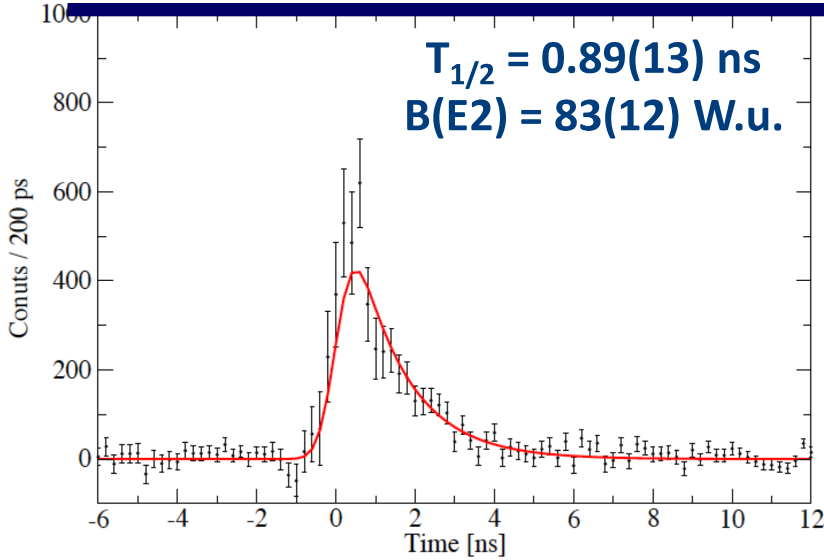
T. Shizuma et al. Eur. Phys. J. A30, 391 (2006)



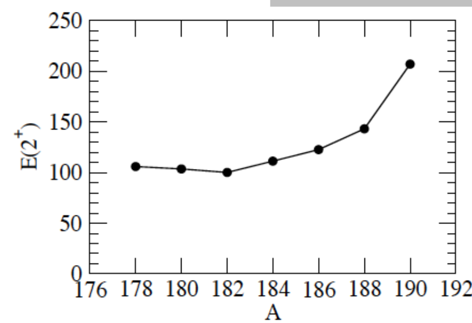
- **$^{186}W(^{7}Li,\alpha p)^{188}W$**, 31 MeV
- Reaction mechanism is a mix of incomplete fusion and low-energy transfer

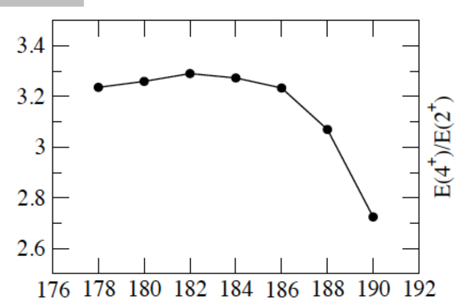
P.J.R. Mason et al., presented at EuNPC 2012 and submitted to PRC

2^+ state in ^{188}W

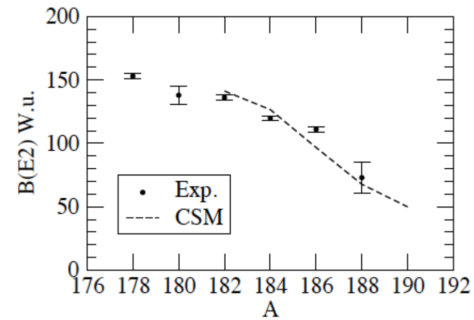


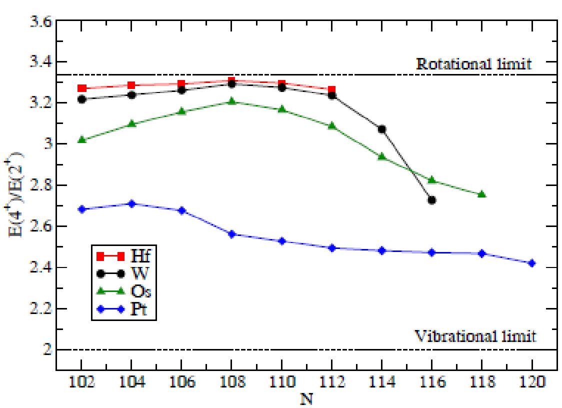
Δt - between 143-keV transition and higher lying feeding transitions.

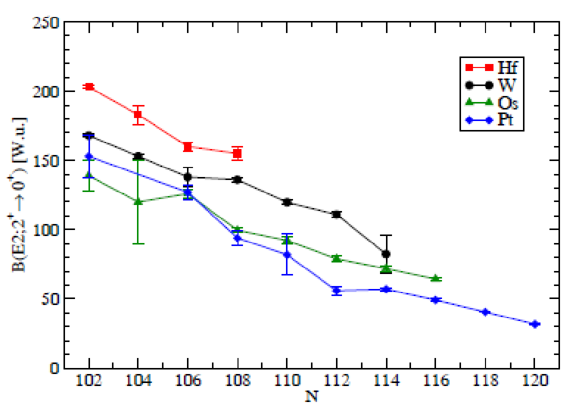




Systematics of W isotopes







Coherent State Model (CSM) calculations (Răduță *et al.*, 1981) reproduce reduction in $B(E2{:}2^+ \rightarrow 0^+)$ observed for ^{188}W.

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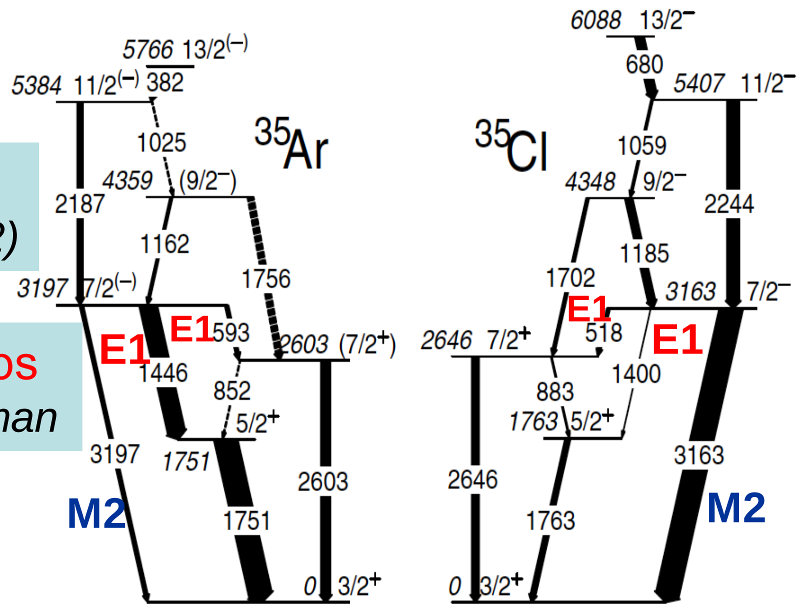
P.J.R. Mason et al., submitted to Phys. Rev. C

The ^{35}Ar – ^{35}Cl mirror pair

i-spin conservation:
E1 transitions in mirrors should be equal.

τ ≈ 7 ps
Equal B(M2)

τ ≈ 350 ps
Pattabiraman



τ = 45.3(6) ps

J. Ekman et al. PRL 92(2004) 132502
F. Della Vedova, PRC 75(2007)034317

1) Equal M2's (0.25 W.u. in ^{35}Cl): i-spin mixing (T=1/2 and 3/2) cancels E1 in ^{35}Cl , and enhances it in ^{35}Ar: **τ(7/2$^-$) = 7 ps**; but too large i-spin mixing: ~ 5% !

2) ≈ E1's: B(M2) ~ 1.5 10^{-4} W.u. in ^{35}Ar: **τ(7/2$^-$) ≈ 11 ns. Exp: < 1 ns:** M2's are not so different either.

3) Pattabiraman et al, PRC78(2008)024301: B(M2) ~ 0.0032 W.u. (calcul. Prosser & Harris, PRC4(1971)1611) and 1% i-spin mixing for A~35: ^{35}Ar: **τ(7/2$^-$) ≈ 350 ps**.

Lifetime of the 7/2$^-$ state in ^{35}Ar

N. Mărginean, C.A. Ur, *et al.*

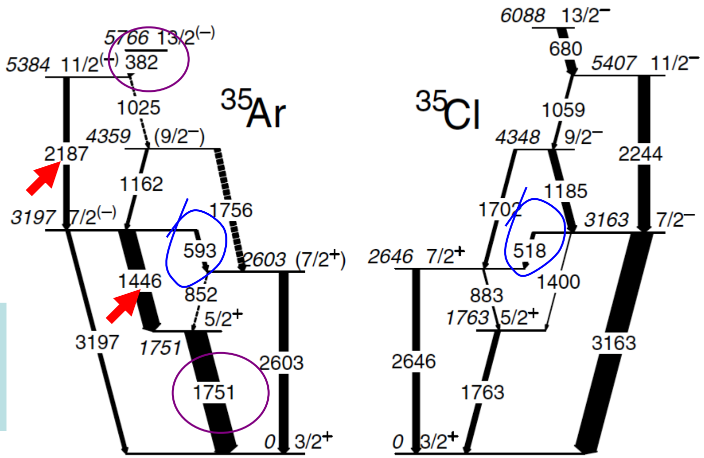
^{12}C (50 MeV) + ^{28}Si ROSPHERE

14 HPGe and 11 LaBr$_3$(Ce)

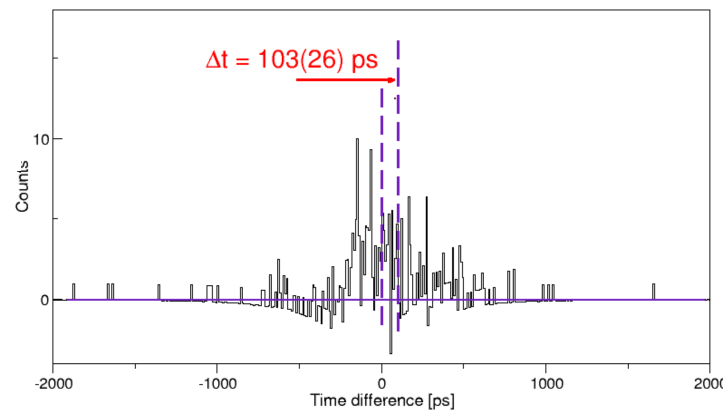
τ ≈ 7 ps
Equal B(M2)s

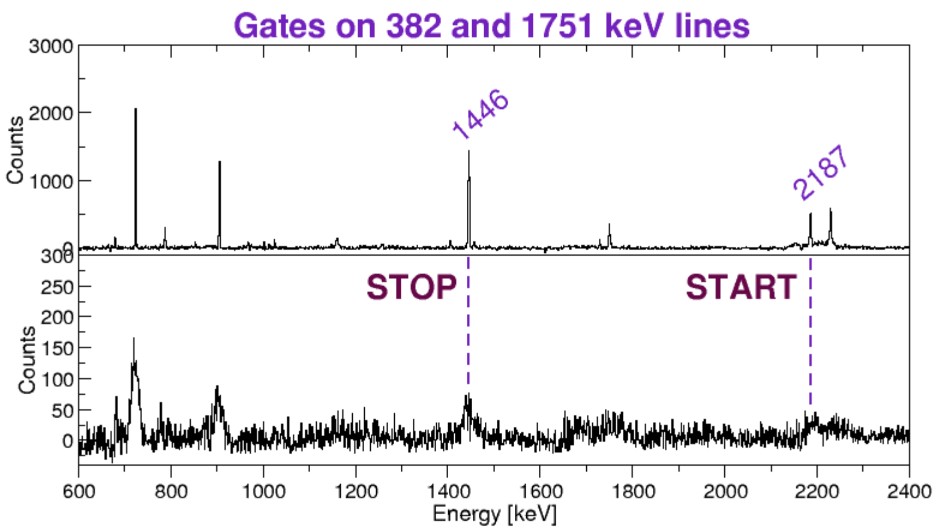
τ = 103(26) ps

τ ≈ 350 ps
Pattabiraman



τ = 45.3(6) ps



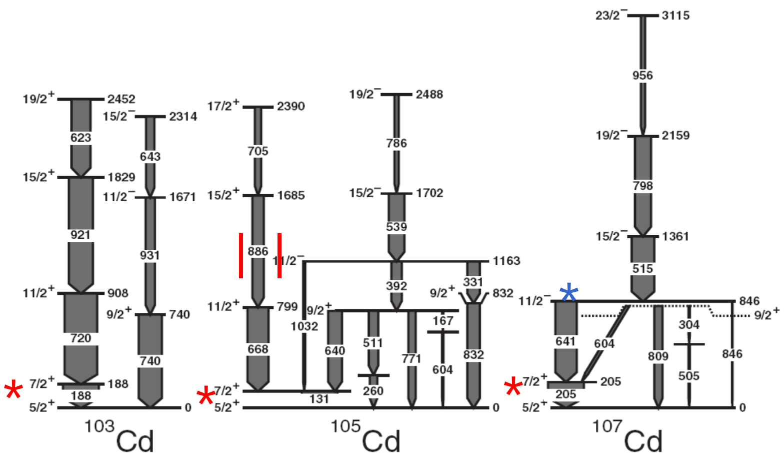


^{35}Cl: B(E1;7/2$^-$ → 7/2$^+$) = 1.30 (8)·10^{-5} W.u.

^{35}Ar: B(E1;7/2$^-$ → 7/2$^+$) = 0.49 (15)·10^{-5} W.u.

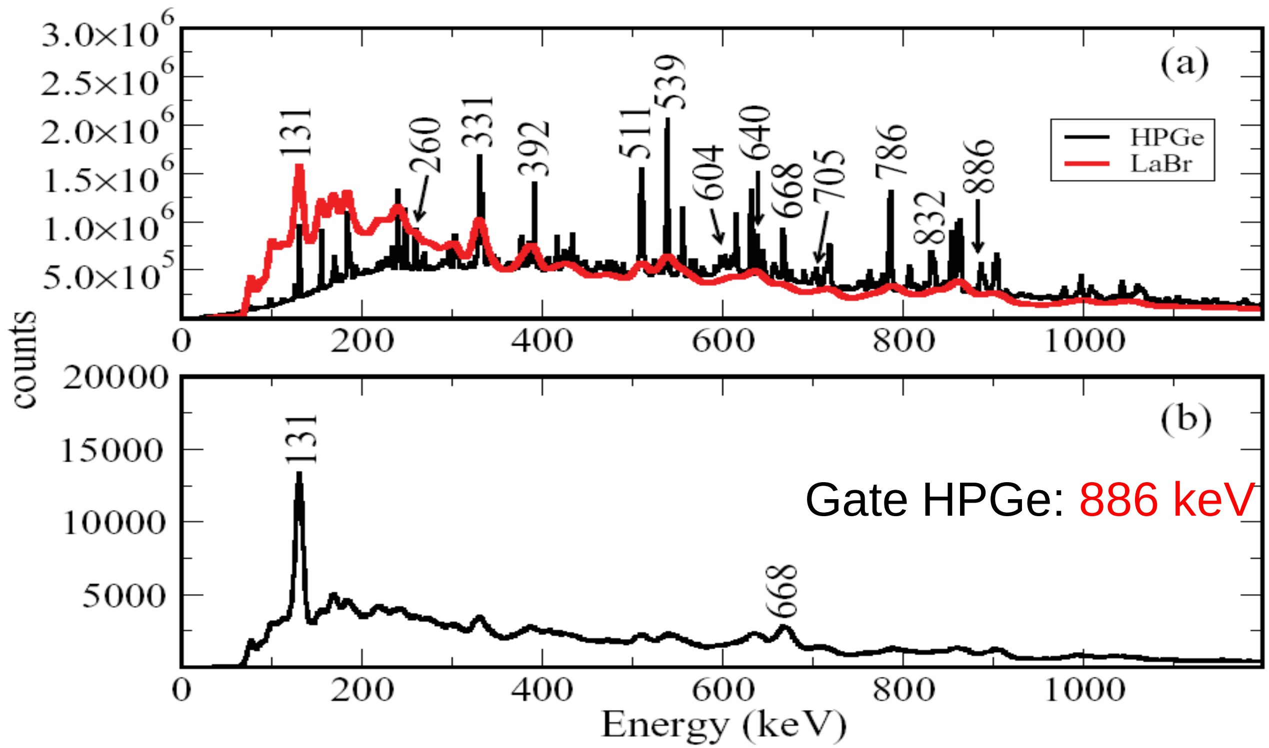
In Beam Fast-Timing of ^{103,105,107}Cd

Collaboration with Sofia Univ.
(S. Kisyov, *et al.*)

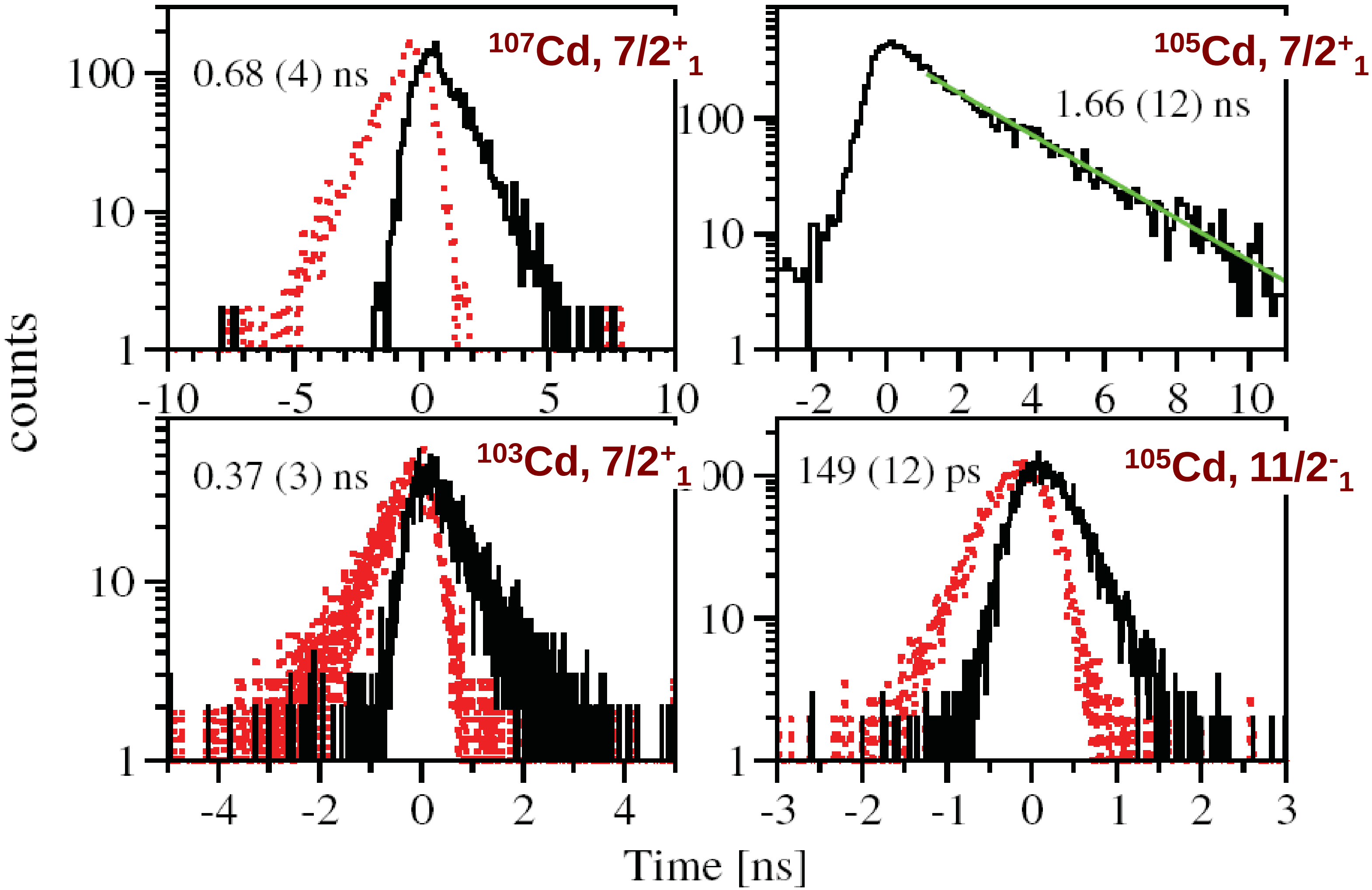


$7/2^+_1$ state:

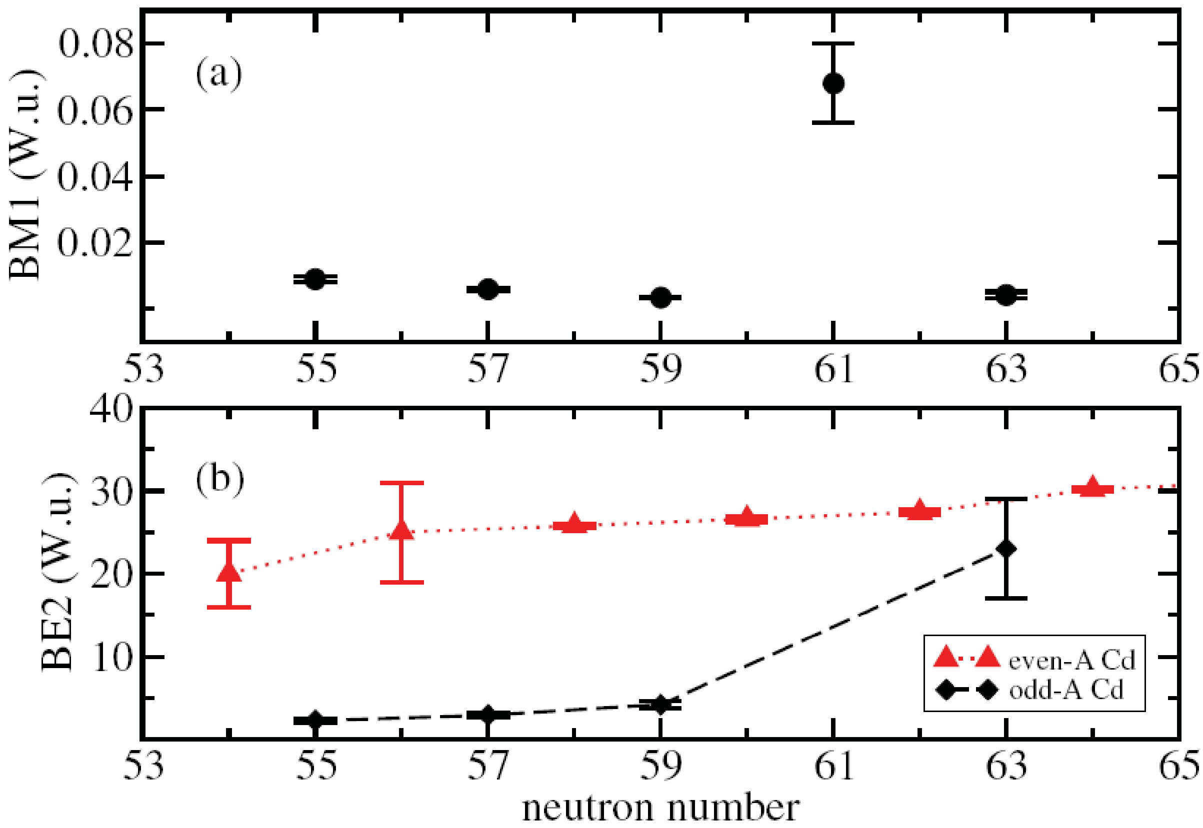
$0^+ \times g_{7/2}$
$2^+ \times d_{5/2}$



^{103,105,107}Cd



^{103,105,107}Cd



$7/2^+_1$ state in ^{103,105,107}Cd: s.p. state ($g_{7/2}$)

S. Kisyov et al., Phys. Rev. C84(2011)014324

Conclusions

- Investing in the “wide-range timing spectroscopy” proved to be a successful approach for creating our specific “niche” and complement research at large scale facilities

- There is now a well established international user community at the Bucharest TANDEM

- The good local research infrastructure allows high-quality training of young researchers