The mixed HPGe-$LaBr_3$(Ce) array ROSPHERE and selected physics results

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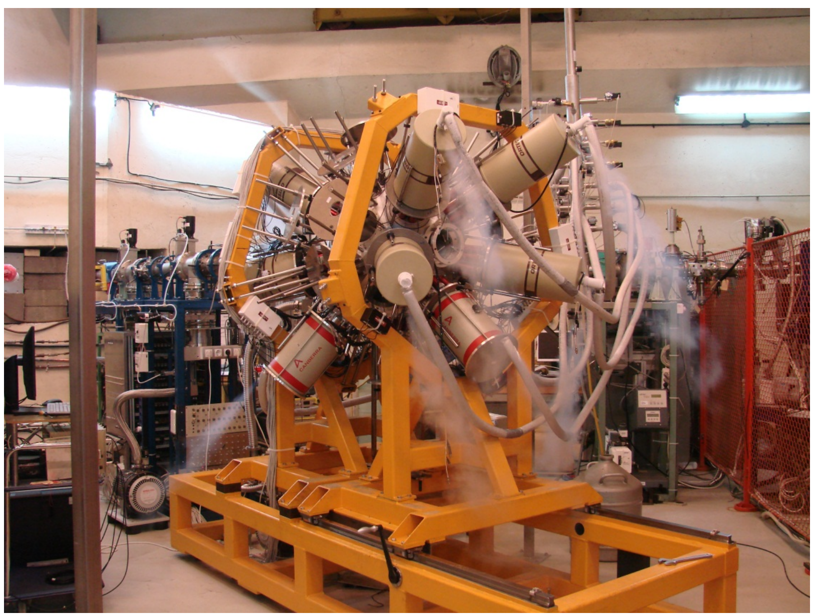
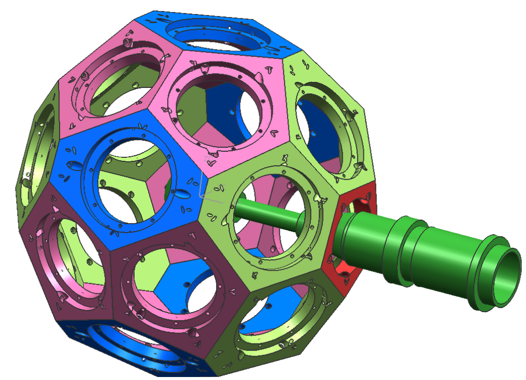
ROmanian array for SPectroscopy in HEavy ion REactions

Mixed array with

- **14 50% HPGe detectors** with BGO shields (IFIN-HH)
- **11 $LaBr_3$(Ce) scintillators**: currently 7 of 2”x2” (IFIN-HH) and 4 of 1.5”x2” (UK)

25 positions, 5 symmetric rings of 5 detectors



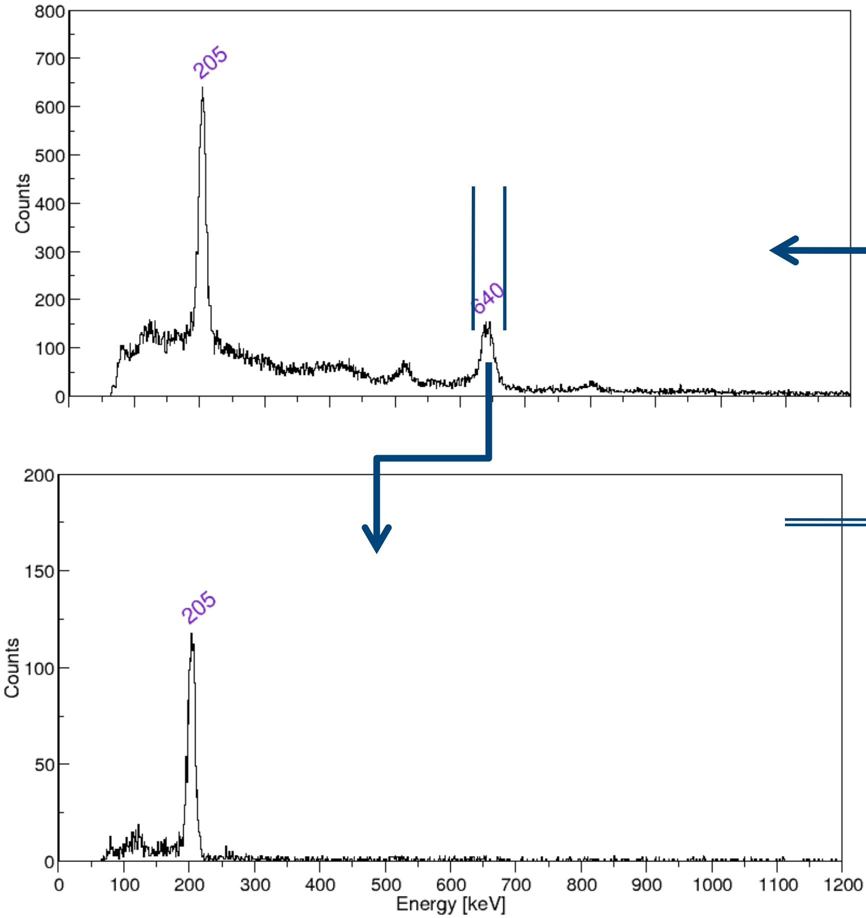


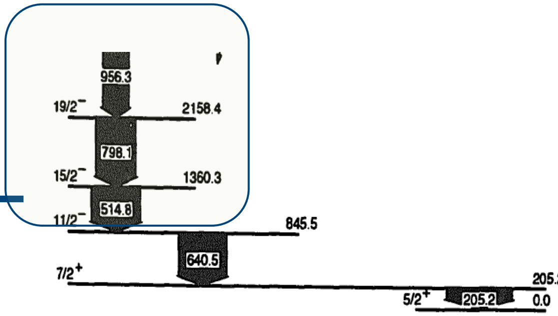
Absolute HPGe efficiency: ~ 1.1%

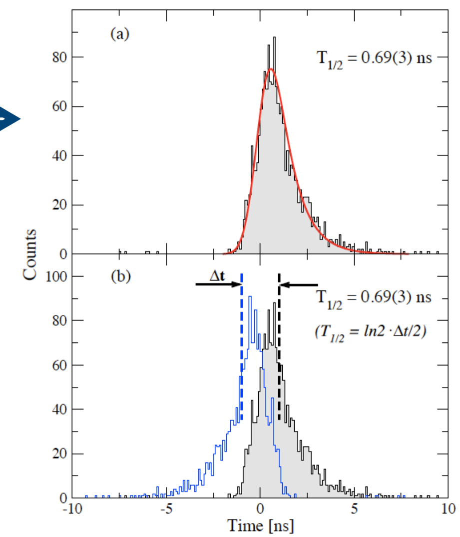
$LaBr_3$(Ce) efficiency ~ 1.75%

In-beam Fast-Timing : the principle

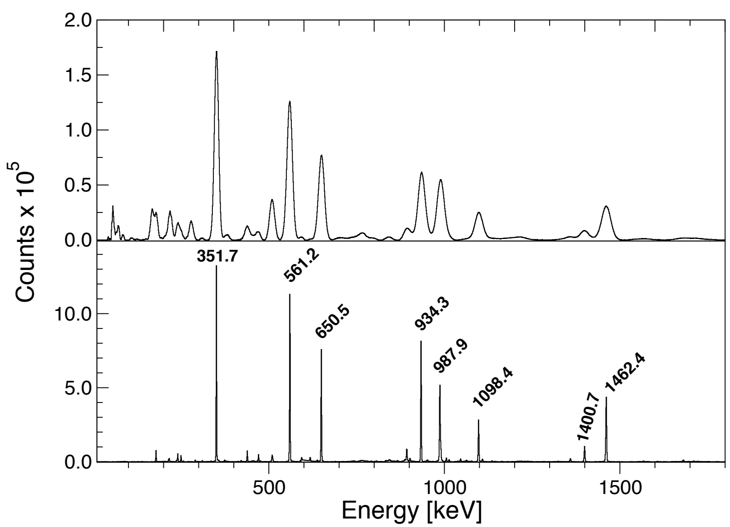
The START and STOP lines in $LaBr_3$:Ce detectors are cleanly selected by setting gates on the HPGe detectors

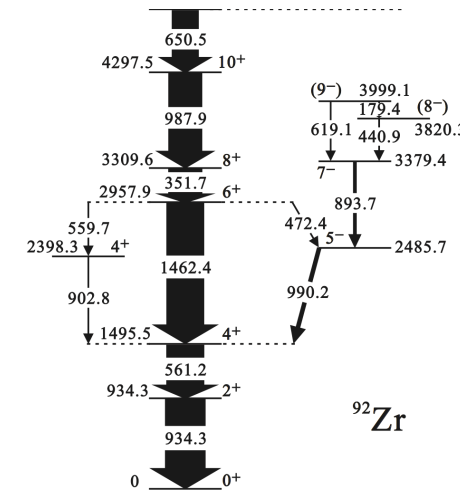


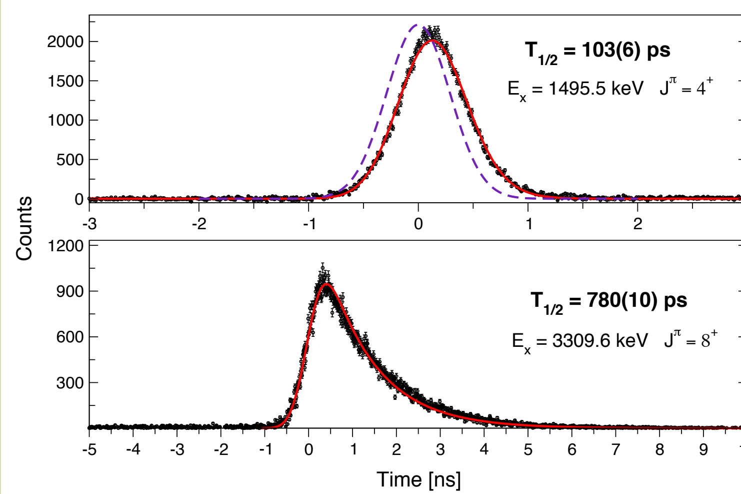




Accuracy of *In-Beam Fast Timing* measurements: example of ^{92}Zr



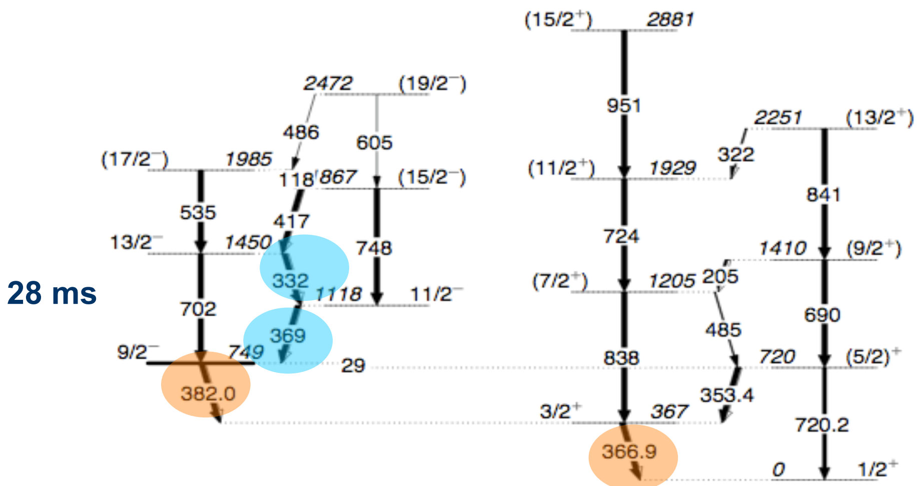


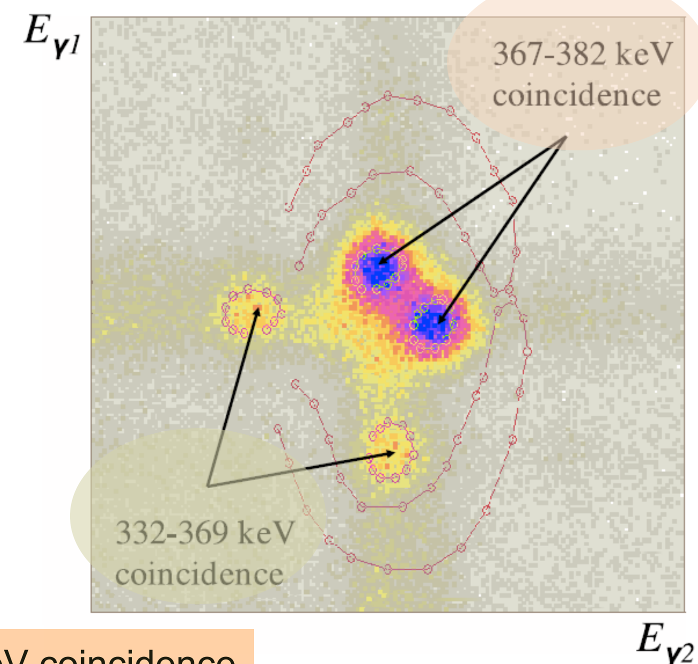


^{83}Se(^{13}C,3n)^{92}Zr @ 42 MeV

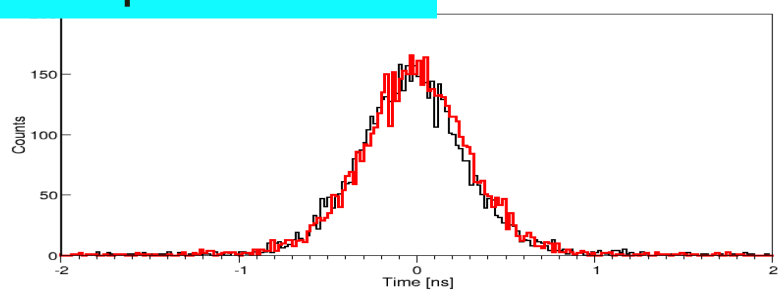
Accuracy of *In-Beam Fast Timing* measurements: example of ^{199}Tl

^{197}Au(α,2n)^{199}Tl @ 24 MeV

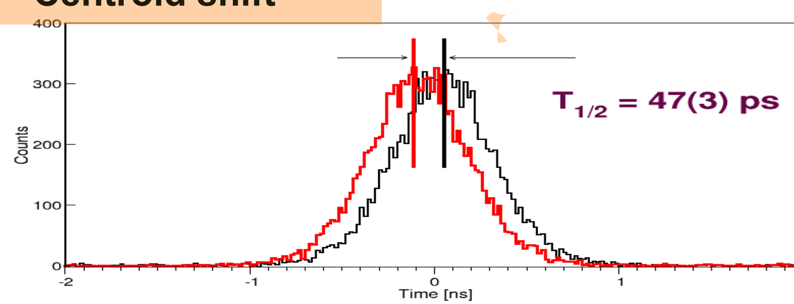




332-369 keV coincidence
"Prompt" coincidence



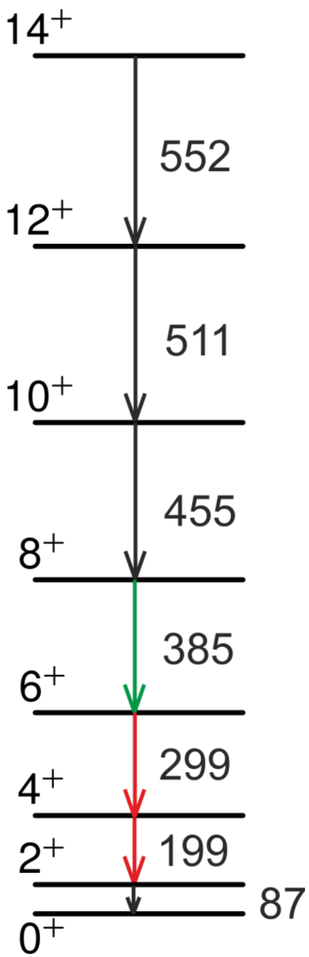
367-381 keV coincidence
Centroid shift

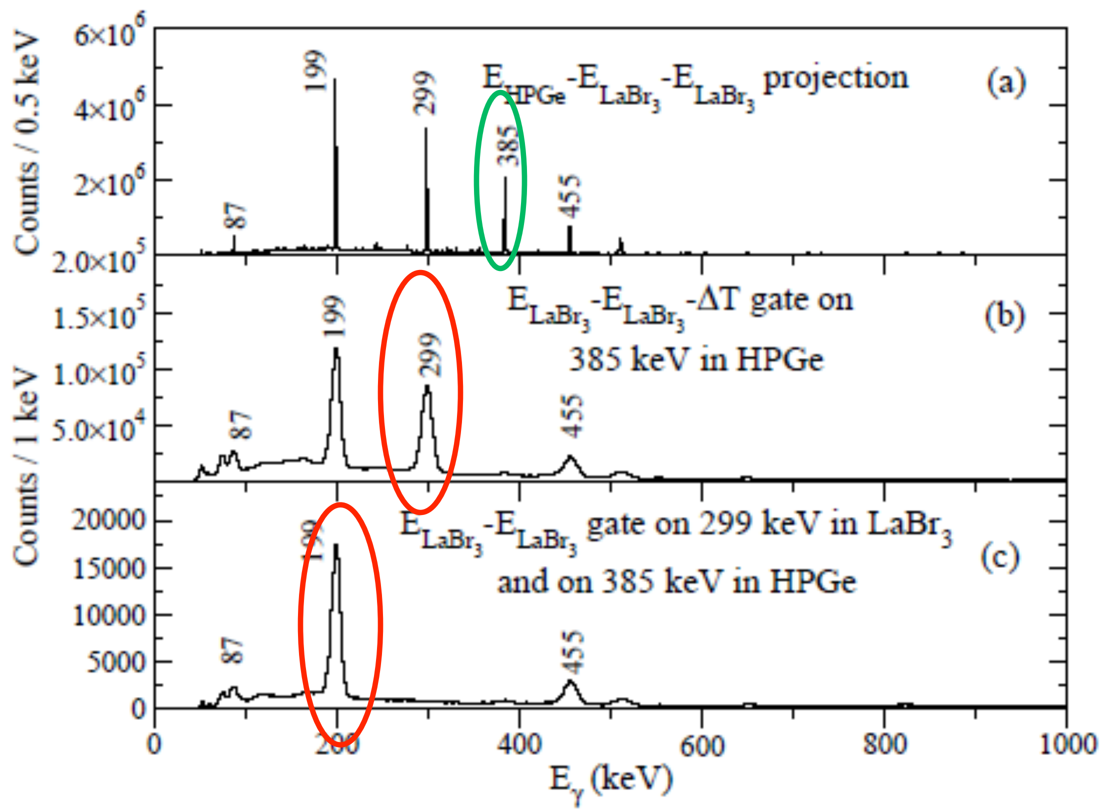


N.Mărginean *et al.*, Eur. Phys. J. A46(2010)329

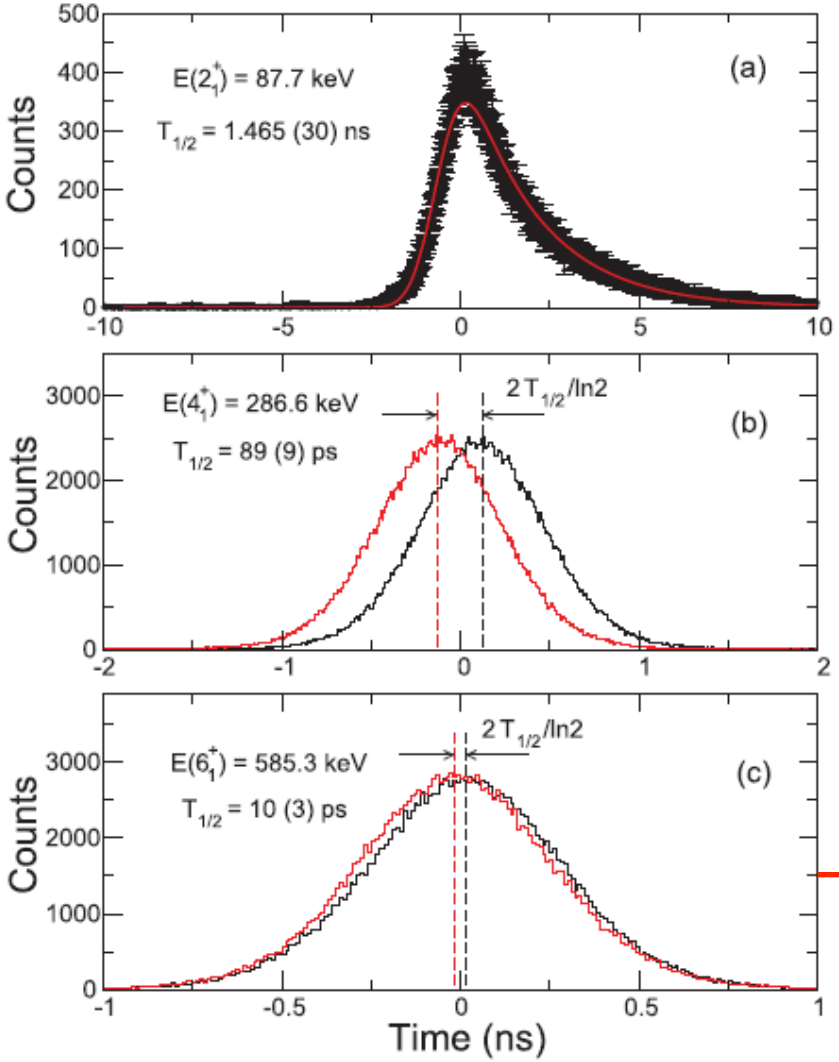
Lifetime measurements in ^{168}Yb

Sorin Pascu et al. *Phys. Rev. C 91 034321*





Wide-Range Timing Technique



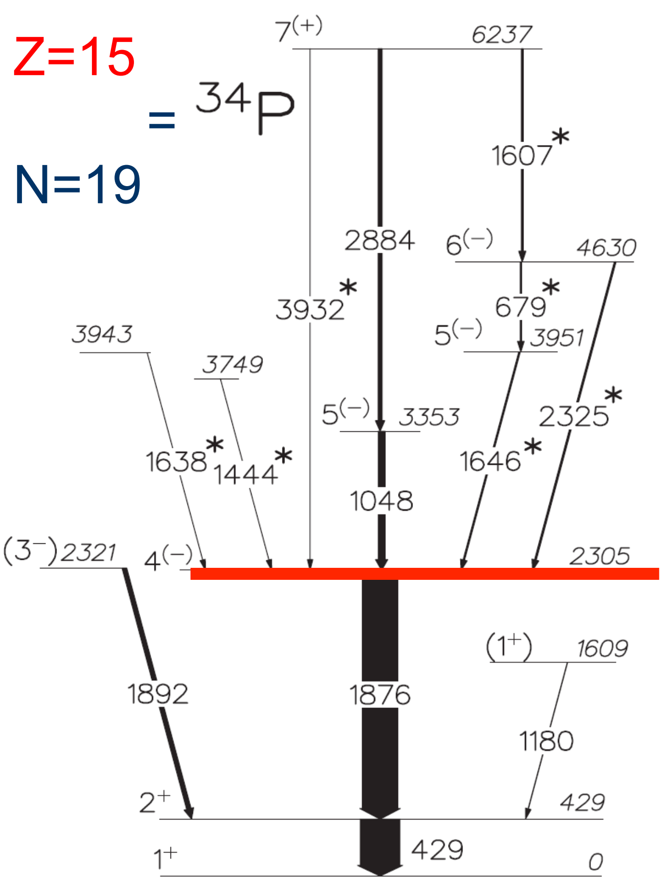
E_{level} (keV)	J_i^π	K_i^π	$T_{1/2}$ (ps)	$B(E2; J_i \rightarrow J_i - 2)$ (W.u.)
87.73(1)	2_1^+	0_1^+	1465(30)	213(5)
286.55(2)	4_1^+	0_1^+	89(9)	290(30)
585.25(5)	6_1^+	0_1^+	10(3)	400(120)

Very short lifetime for the fast-timing method

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

IFIN-HH

P.H. Regan, P.J.R. Mason (University of Surrey, UK)



R. CHAKRABARTI *et al* PHYSICAL REVIEW C **80**, 034326 (2009)

P. C. BENDER *et al.* PHYSICAL REVIEW C **80**, 014302 (2009)

- $^{34}P_{19}$ has $I^{\pi}=4^{-}$ state at E=2305 keV.
- *Aim to measure a precision lifetime for 2305 keV state.*

WHY?

- *A* $\Delta I^{\pi}=4^{-} \rightarrow 2^{+}$ EM transition is allowed to proceed by M2 or E3 multipole gamma-rays.
- M2 and E3 decays can proceed by
  - $\nu f_{7/2} \rightarrow \nu d_{3/2}$ => M2 multipole
  - $\nu f_{7/2} \rightarrow \nu s_{1/2}$ => E3 multipole
- Lifetime and mixing ratio information gives direct values of M2 and E3 transition strength
  - Direct test of shell model wfs…

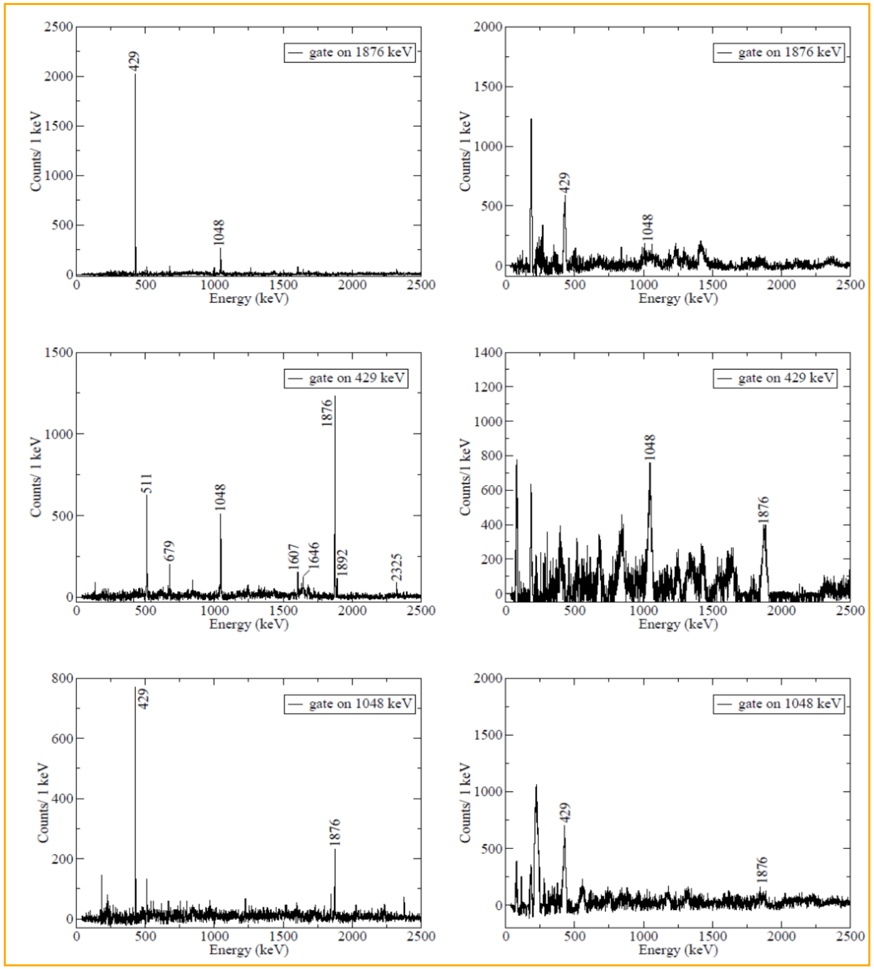
$$\Psi(4^{-}) = \alpha_1\phi_1 + \beta_1\phi_2 + \gamma_1\phi_3 \ldots$$

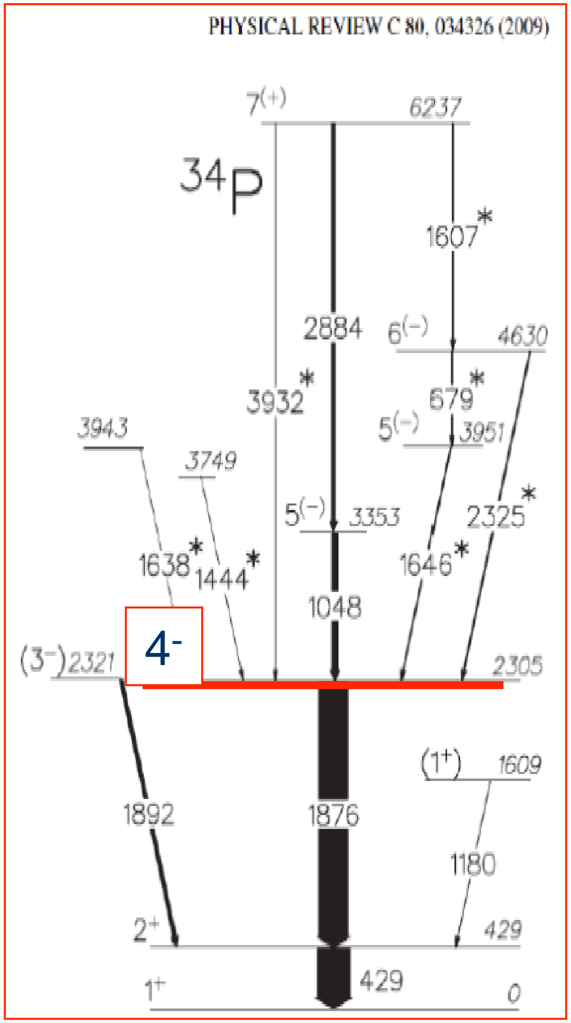
$$\Psi(2^{+}) = \alpha_2\phi_{1'} + \beta_2\phi_{2'} + \gamma_2\phi_{3'} \ldots$$

Fast-Timing experiment for ^{34}P

50 mg/cm^2 $Ta_2{}^{18}O_5$ enriched target

36 MeV ^{18}O, typical beam current ~20 pnA

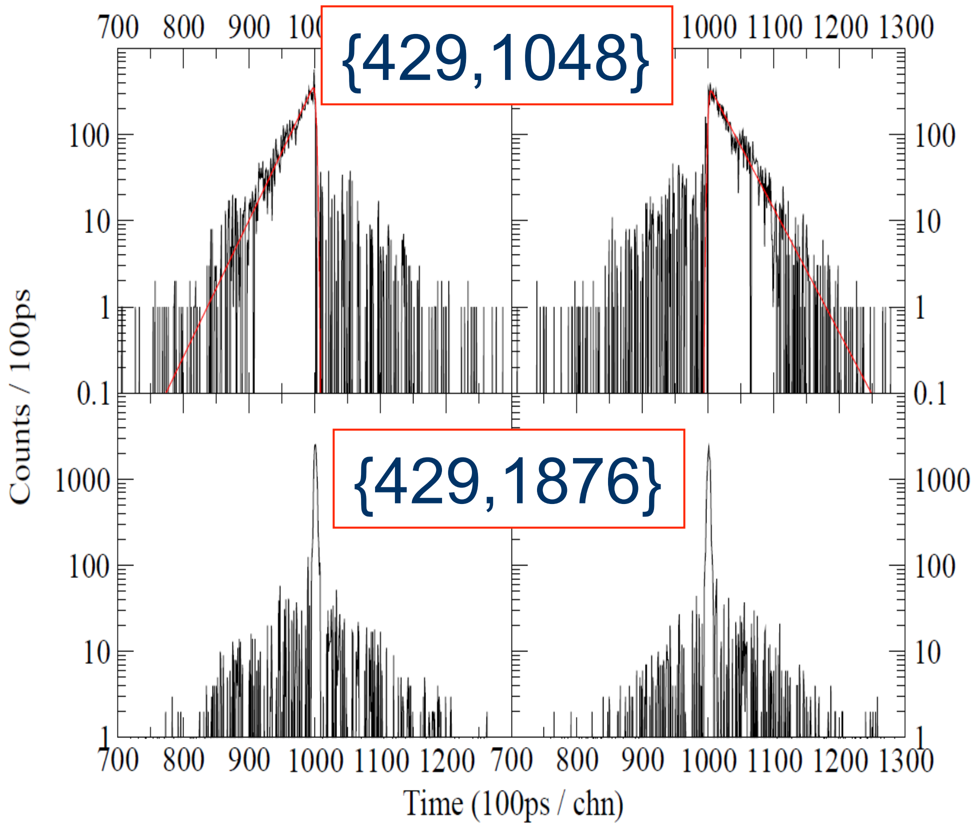


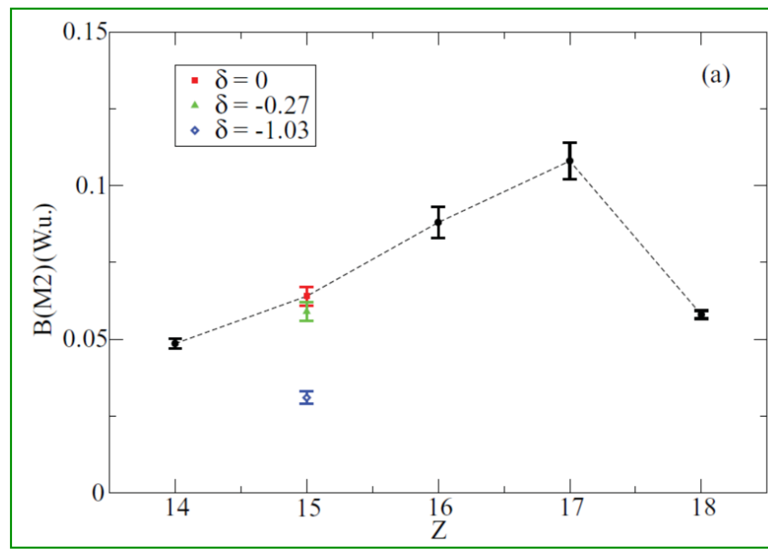


PHYSICAL REVIEW C **85**, 064303 (2012)

Half-life of the $I^{\pi} = 4^{-}$ intruder state in ^{34}P: $M2$ transition strengths approaching the island of inversion

P. J. R. Mason,[1] T. Alharbi,[1,2] P. H. Regan,[1] N. Mărginean,[3] Zs. Podolyàk,[1] E. C. Simpson,[1] N. Alkhomashi,[4] P. C. Bender,[5] M. Bowry,[1] M. Bostan,[6] D. Bucurescu,[3] A. M. Bruce,[7] G. Căta-Danil,[3] I. Căta-Danil,[3] R. Chakrabarti,[8] D. Deleanu,[3] P. Detistov,[9] M. N. Erduran,[10] D. Filipescu,[3] U. Garg,[11] T. Glodariu,[3] D. Ghiţă,[3] S. S. Ghugre,[8] A. Kusoglu,[6] R. Mărginean,[3] C. Mihai,[3] M. Nakhostin,[1] A. Negret,[3] S. Pascu,[3] C. Rodríguez Triguero,[7] T. Sava,[3] A. K. Sinha,[8] L. Stroe,[3] G. Suliman,[3] and N. V. Zamfir[3]

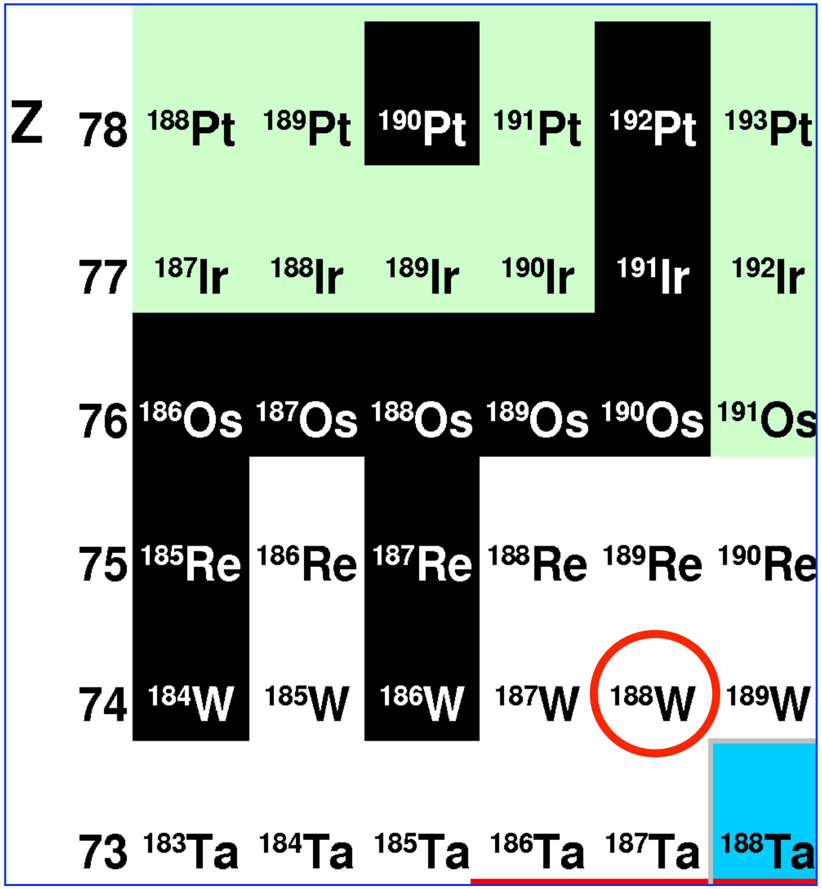




$T_{1/2}(4^-)$ = 2.0(2) ns ; $4^- \rightarrow 2^+$ = M2 decay. Consistent with ‘pure’ $\pi f_{7/2} \rightarrow \pi d_{3/2}$ transition.

Precision test of nuclear shell model at N=20

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



2 neutrons more than heaviest stable Tungsten (Z=74) isotope (^{186}W).

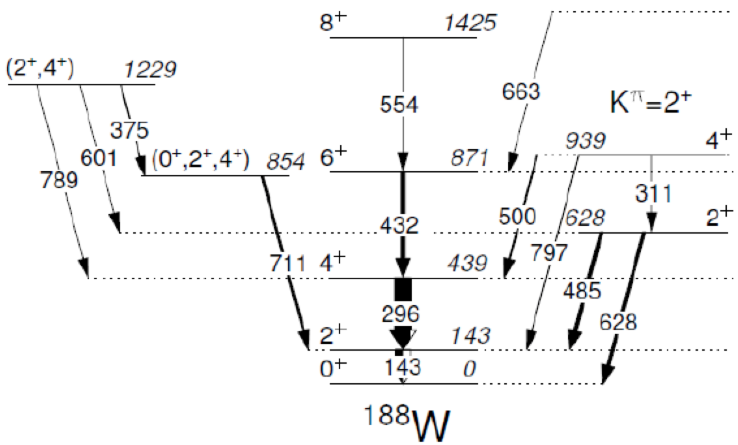
Populate ^{188}W using $^{186}W(^7Li,ap)^{188}W$ 'incomplete fusion' reaction.

(Not really a fusion-evap reaction, but populates medium spin states).

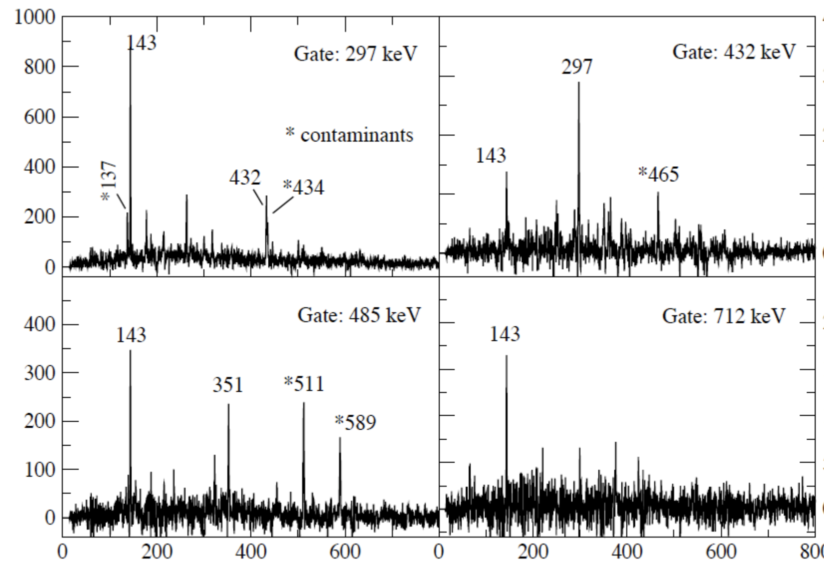
See e.g.,
Dracoulis et al., J. Phys. G23 (1997) 1191-1202

P.J.R. Mason, Zs. Podolyak (University of Surrey, UK)

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



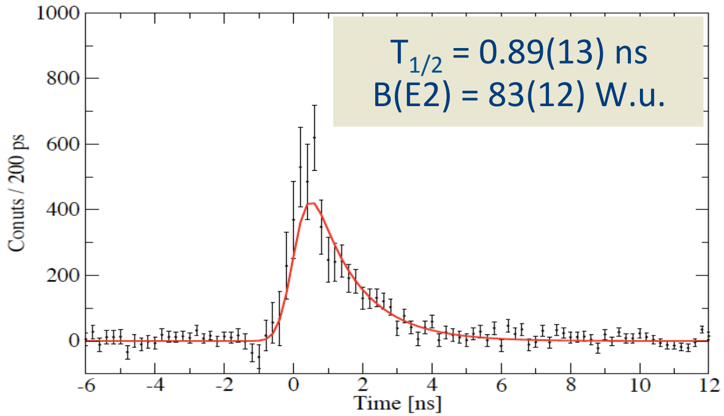
T. Shizuma et al. Eur. Phys. J. A30, 391 (2006)



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

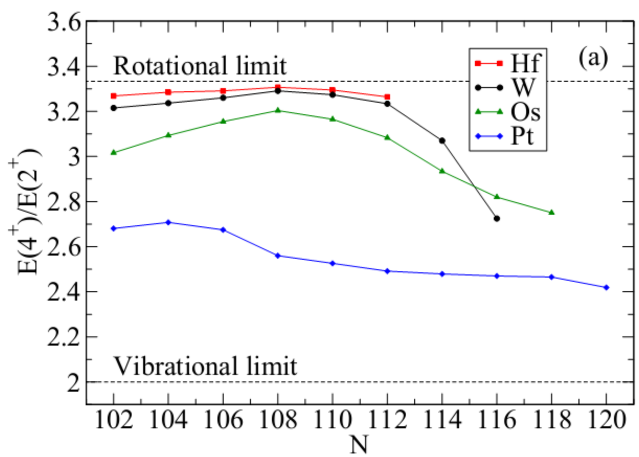
- The production cross section is small, thus one have to separate an 10^{-3} good signal from a huge background
- Time response and walk correction are difficult to handle for low-energy gamma rays

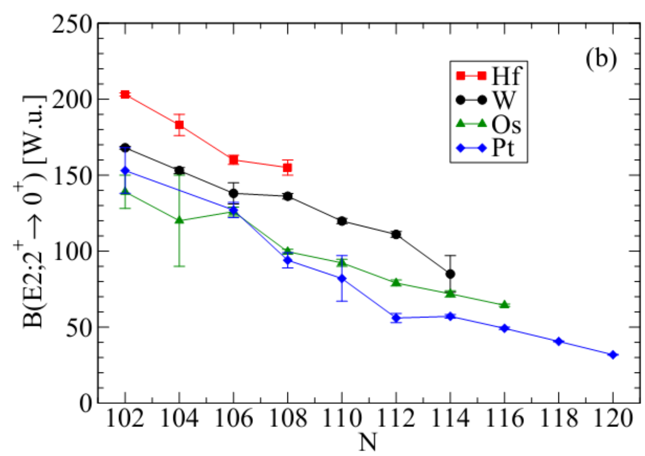
Lifetime of first-excited 2^+ in ^{188}W



P.J.R Mason et al. Phys. Rev. C ***88*** *044301(2013)*

Sum of time differences between 143-keV transition and any higher lying feeding transition (assumes negligible half-life for intermediate states.



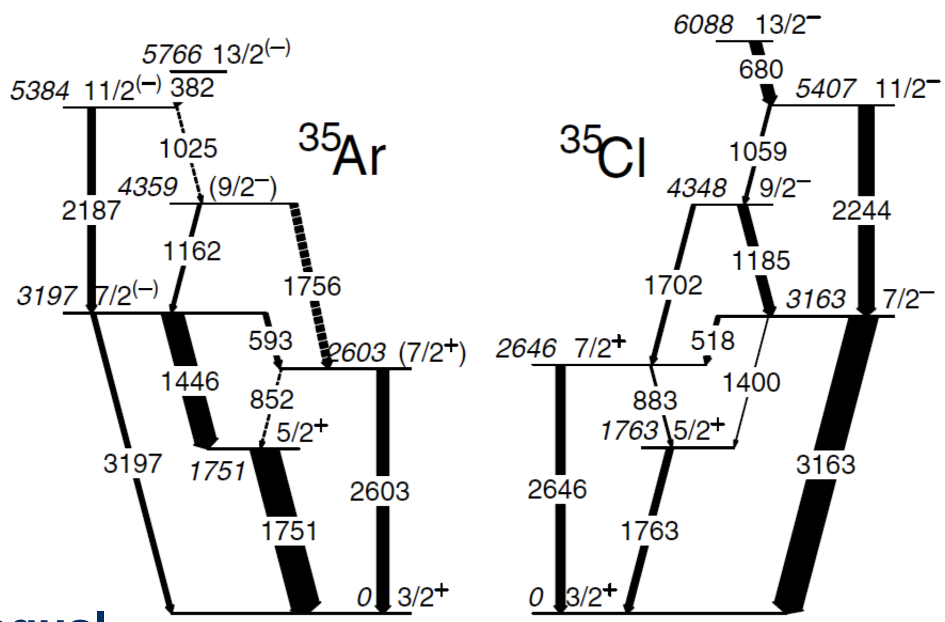


- Rapid drop in collectivity for W isotopes compared to Os and Pt chains.
- Overall relatively linear decrease in B(E2) with increasing N.

The ^{35}Ar – ^{35}Cl mirror pair

J. Ekman et al. Phys. Rev. Letters 92(2004) 132502

The decay pattern of the yrast 7/2^{-} state is very different for the mirror partners



If the B(M2) are equal

- almost exact cancellation of T=1/2 and T=3/2 E1 strength in ^{35}Cl
- isospin mixing larger than 5%

Electromagnetic transition matrix elements in $|T_z| = ½$ mirror nuclei

Isoscalar $\Delta T = 0$ — *independent of* $\mathbf{T_z}$

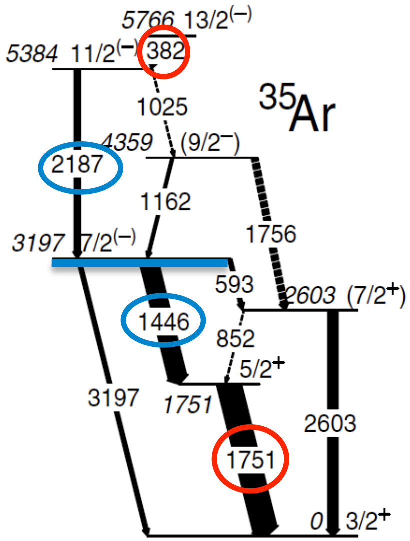
Isovector $\Delta T = \pm 1$ ~ $(T_>^2 - T_z^2)^{1/2}$

Isovector $\Delta T = 0$ ~ $\mathbf{T_z}$

The matrix elements do not change sign by changing T_z from -1/2 to 1/2

The matrix elements change sign by changing T_z from -1/2 to 1/2

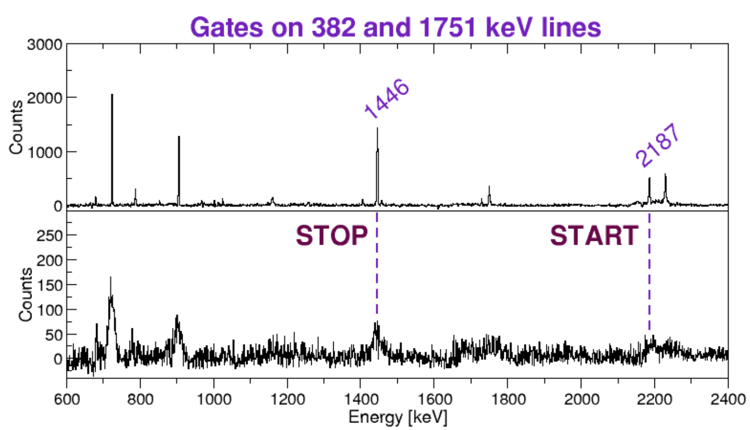
Lifetime of the first 7/2$^-$ state in ^{35}Ar

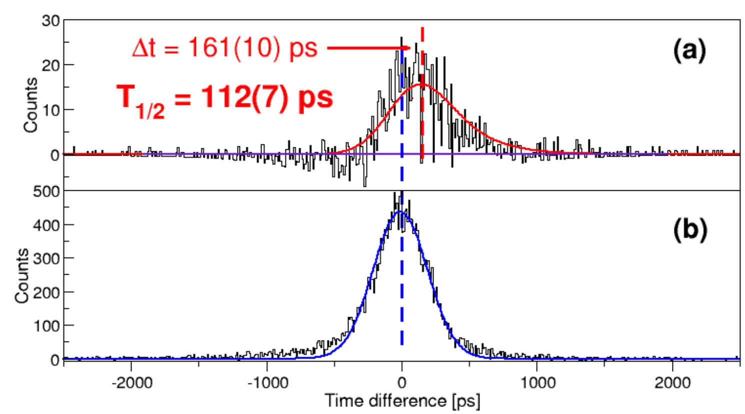


^{12}C (^{28}Si,αn) ^{35}Ar @50MeV

ROSPHERE: 14HPGe + 11 $LaBr_3$:Ce

Transition	^{35}Ar		^{35}Cl	
7/2$^-$ →	B(E1)[W.u]	B(M2)[W.u.]	B(E1)[W.u]	B(M2)[W.u.]
7/2$^+$ (1)	0.49(15)×10^{-5}	-	1.30(8)×10^{-5}	-
5/2$^+$ (1)	2.1(5)×10^{-6}	-	1.8(4)×10^{-8}	0.008(4)
3/2$^+$ (gs)	-	<0.021(7)	-	0.258(6)





Isospin mixing: E1 transitions

Considering **isospin mixing** in both initial and final state (major component T=1/2, minor component T=3/2):

Diagonal *Non-diagonal* *Measured matrix element*

$$\begin{cases} M(E1;1) + M(E1;2) = \pm\sqrt{B(E1;T_z)} & \text{(eg: } ^{35}\text{Cl)} \\ M(E1;1) - M(E1;2) = \pm\sqrt{B(E1;-T_z)} & \text{(eg: } ^{35}\text{Ar)} \end{cases}$$

$$M(E1;1) = \frac{\sqrt{B(E1;Tz)} + \sqrt{B(E1;-Tz)}}{2}$$

$$M(E1;2) = \frac{\sqrt{B(E1;Tz)} - \sqrt{B(E1;-Tz)}}{2}$$

Reduced matrix elements for pure transitions (ΔT=0 or ΔT=1) (no mixing):

E1 transition	B(E1;1)[W.u.]	B(E1;2)[W.u.]
$7/2^- \longrightarrow 7/2^+$	$8.5(10)\times10^{-6}$	$4.8(25)\times10^{-7}$
$7/2^- \longrightarrow 5/2^+$	$6.3(14)\times10^{-7}$	$4.3(11)\times10^{-7}$

We can assume B(E1; ΔT=1) ≈ $5\text{-}6\times10^{-7}$ W.u.

Isospin mixing: M2 transition

Sign changing: **ΔT=0 isovector** *(expected to be larger)*

Sign invariant: **ΔT=0 isoscalar** and **ΔT=1 isovector** *(expected to be smaller)*

M(M2;1) = ±0.326(12) ⟶ sign changing

M(M2;2) = ±0.182(12) ⟶ sign invariant

$$\frac{M(ML;\Delta T=0;IS)}{M(ML;\Delta T=0;IV)} = \frac{\mu_- - \frac{1}{L+1}}{\mu_+ + \frac{1}{L+1}}$$

⟹

B(M2;ΔT=0;IS) = 1.3(1) × 10^{-3} W.u.

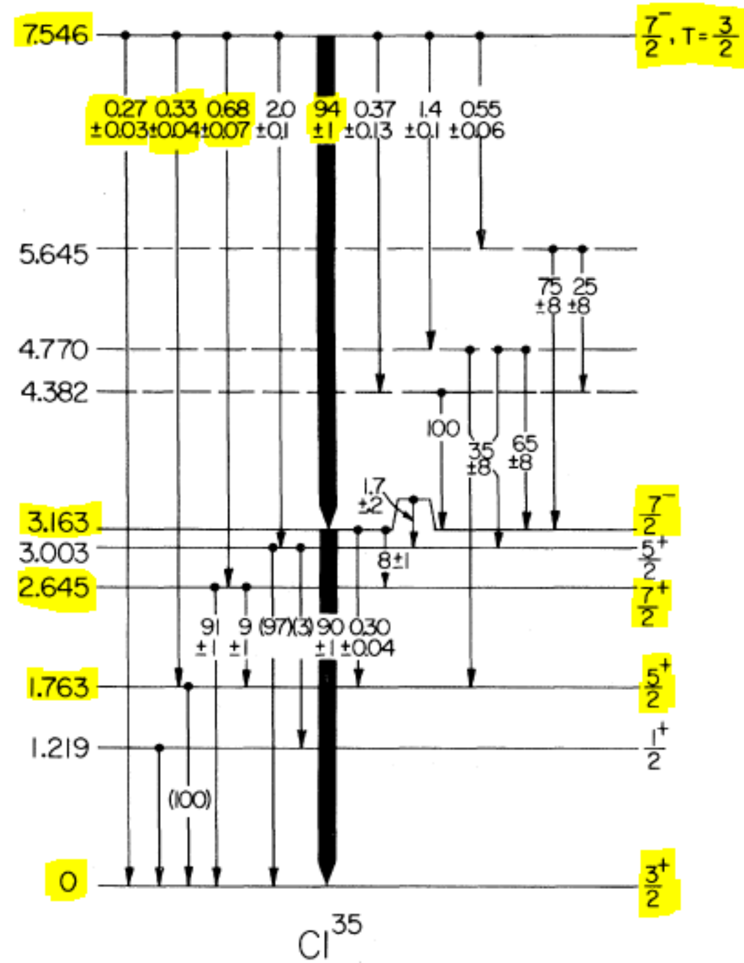
B(M2;ΔT=0;IV) = 0.107(8) W.u

B(M2;ΔT=1;IV) = 2.1(4) × 10^{-2} W.u

Upper limits of the isospin mixing

An **upper limit** of the integral isospin mixing of initial and final states can be obtained scaling the B(E1) and B(M2) values to the corresponding ones from the decay of the well-known 7/2⁻ analog state of ^{35}Cl

Transition	Type	α^2 %
$7/2^- \longrightarrow 7/2^+$	E1	0.41(23)
$7/2^- \longrightarrow 5/2^+$	E1	1.9(6) or 1.3(4)
$7/2^- \longrightarrow 3/2^+$	M2	1.9(7)

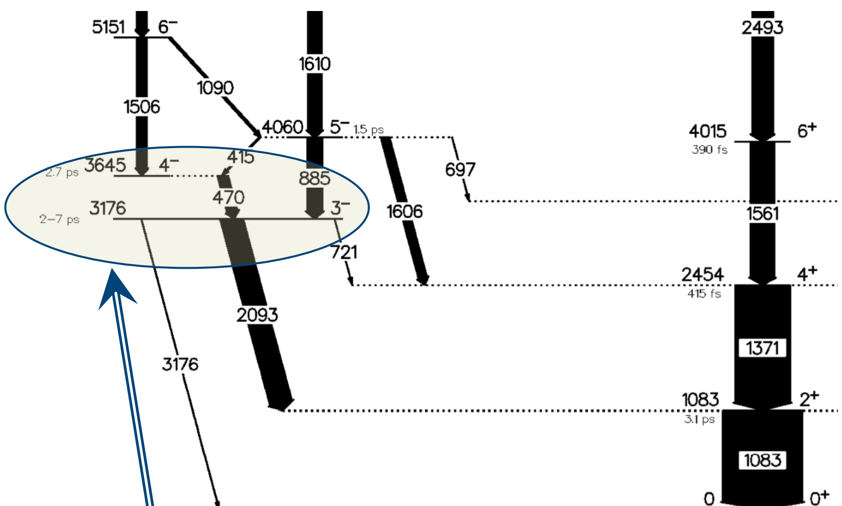


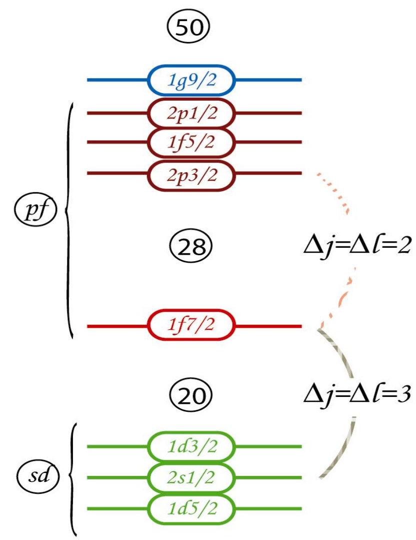
F.W. Prosser, Jr., and Gale I. Harris, Phys. Rev. C4, 1611 (1971)

Octupole correlations and the 3$^-$ state of ^{44}Ti

ROSPHERE plunger + fast-timing experiment

Spokesperson: C.A. Ur (INFN Padova and ELI-NP Bucharest)





$K^{\pi} = 1/2^{+}$
^{45}Ti, ^{49}Cr

If $\tau(3^-) = 10$ ps
⇓
B(E3) = 20 W.u.

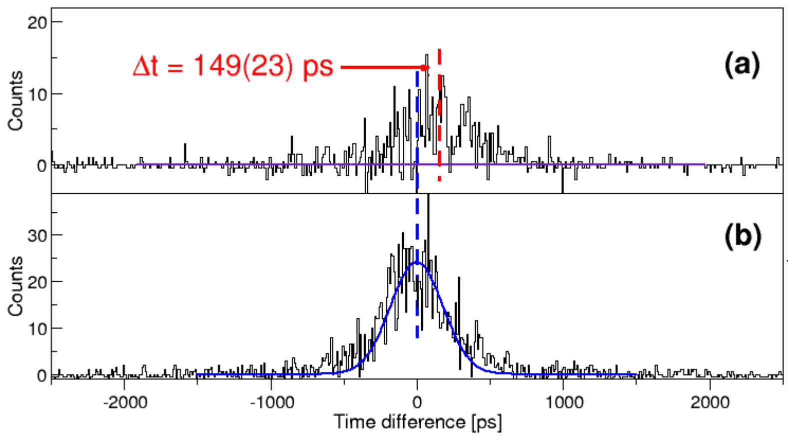
Isoscalar M1

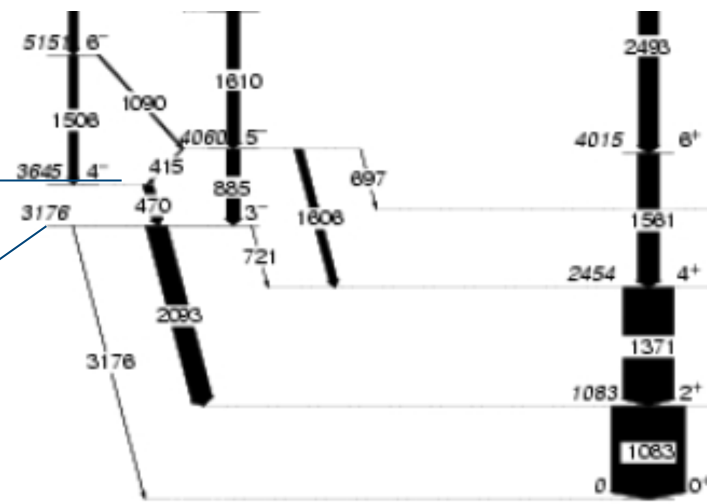
→ **reduced hindrance ??**

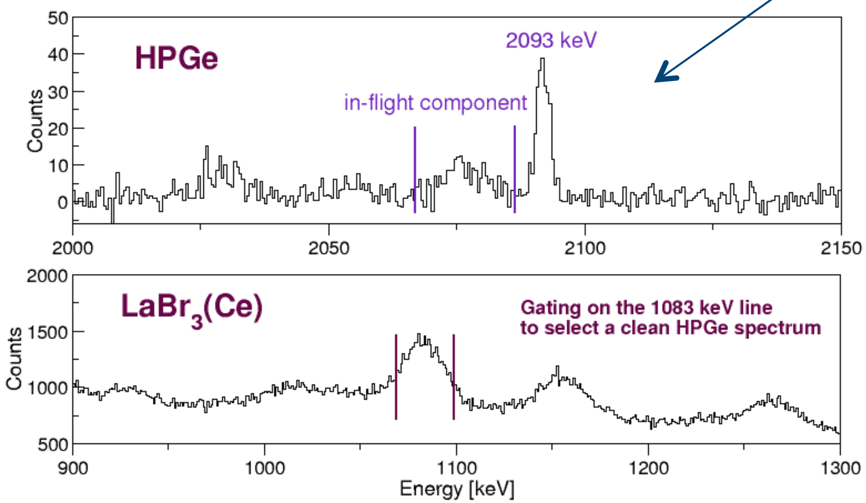
Forbidden E1

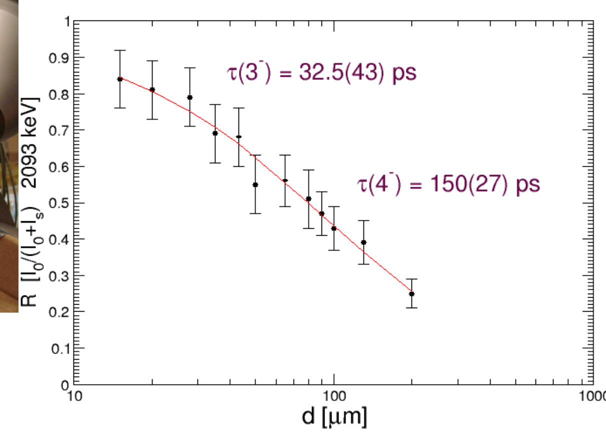
^{44}Ti – Combined plunger-fast timing experiment

C.A. Ur , preliminary analysis







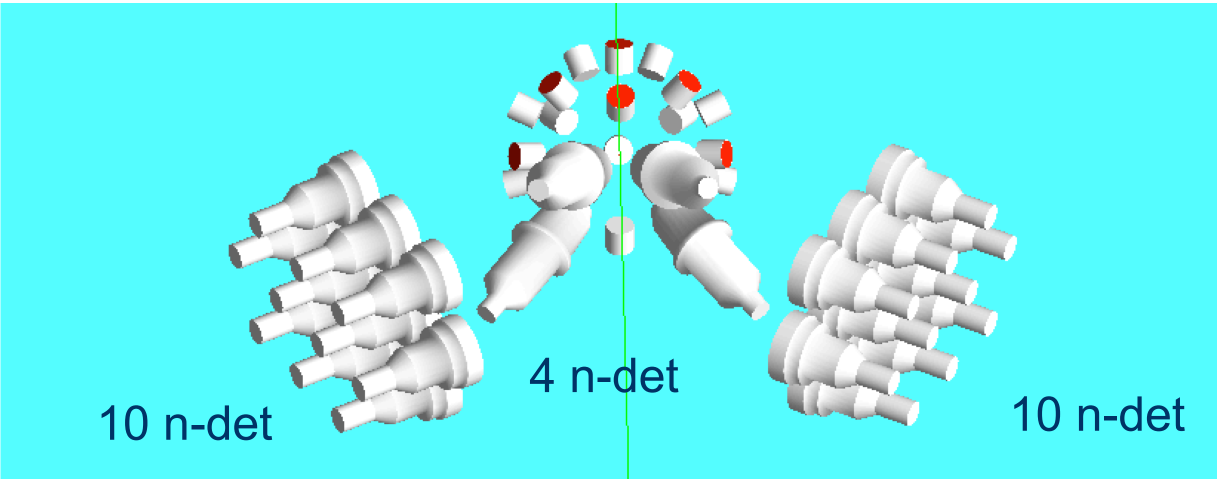


ROSPHERE and neutron detectors

^{6}Li (22 MeV) + ^{58}Ni ⟶ ^{62}Ga + 2n *at this energy is the only two-neutron channel*

ROSPHERE with 10 HPGe *(5 at 90^{o} and 5 at 143^{o})* and 11 $LaBr_3$(Ce)

Three sub-arrays of neutron detectors *20 from ELI-NP, 24 elements in total*



- Resolve clean two-neutron coincidences ⇒ "pure" ^{62}Ga spectra
- Provide a reasonably good start for the $LaBr_3$(Ce) timing

Conclusions

The mixed HPGe-$LaBr_3$(Ce) array ROSPHERE

- Fully functional, running with open access and establishing an international user community
- Fills a gap on the lifetime measurements techniques using large gamma spectroscopy arrays
- Suitable for approaching many nuclear structure problems
- Provides know-how for the building of new arrays at large nuclear physics facilities which are now under construction (e.g. FAIR, ELI-NP)

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