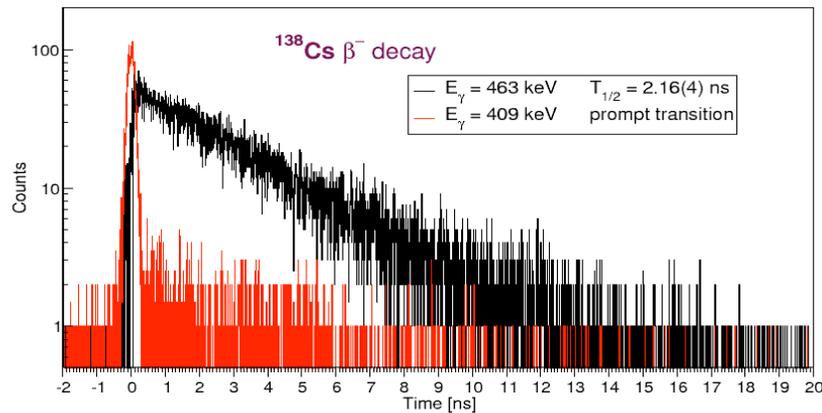

In-Beam Fast-Timing Experiments

N. Marginean

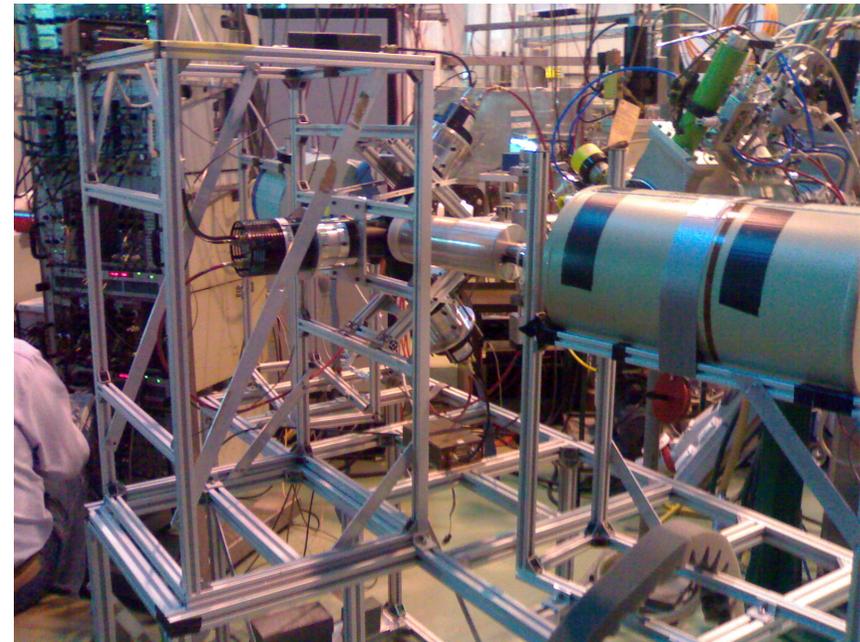
IFIN-HH Bucharest

“Classical” fast-timing in beta decay experiments

β - γ - γ coincidence technique developed by H. Mach



- ◆ One NE111 scintillator as β^- detector
- ◆ Two BaF_2 detectors in tight geometry
- ◆ Two large-volume HPGe detectors

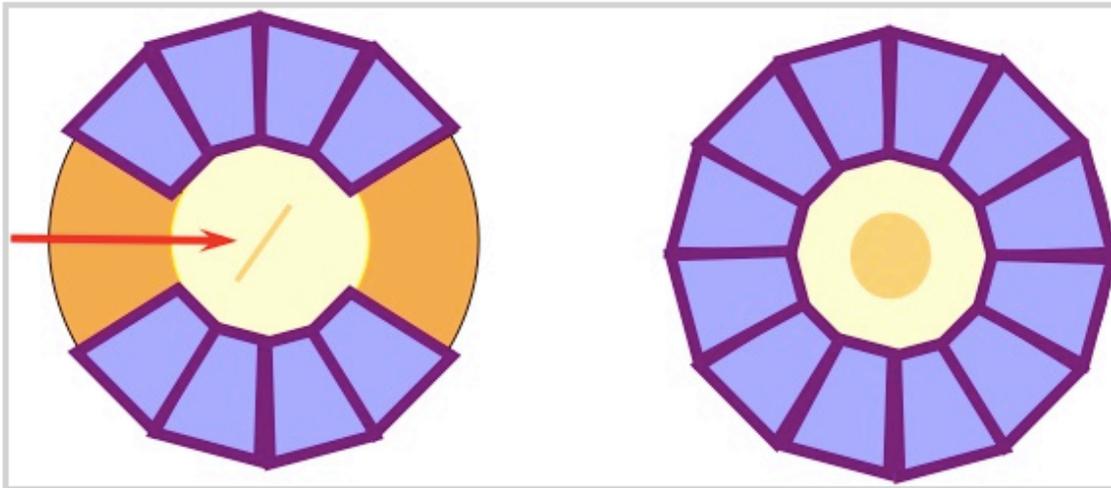


NUSTAR → DESPEC → Fast Timing

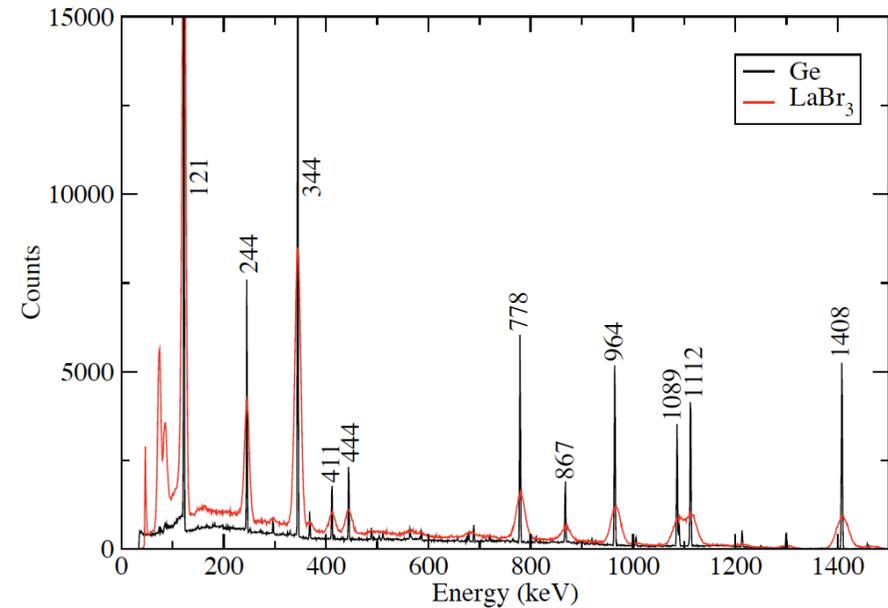
Bulgaria, France, Germany, Romania, Spain, Sweden, UK

FATIMA - A FAST TIMING Array for DESPEC

The objective of this project is to design a new modular high-efficiency FAST TIMING array designed for measurements at DESPEC. The ultra fast timing method using fast response scintillation detectors, is a well-established method to measure level lifetimes in the range from a few picoseconds to several nanoseconds [1]. Its main application is for the exotic nuclei populated in beta-decay and via de-excitation of microsecond isomers at DESPEC. High precision results can be obtained at the level of intensity as low as 1-5 particles/s for exotic nuclei.



LaBr₃:Ce detectors



- ◆ Best energy resolution achievable with scintillators
- ◆ Timing comparable with BaF₂ : 100-300 ps depending on the crystal size
- ◆ Might be used to measure lifetimes in the 50ps – few ns range

Suitable for in-beam experiments

LaBr₃(Ce) Fast Timing Array ...

... means

- ◆ Many detection elements which must **behave identically**
- ◆ Fix **saturation problems** induced by the high light output
- ◆ Speed up the careful tuning with **preserving the time resolution**
- ◆ **Coupling with other kind of detectors**

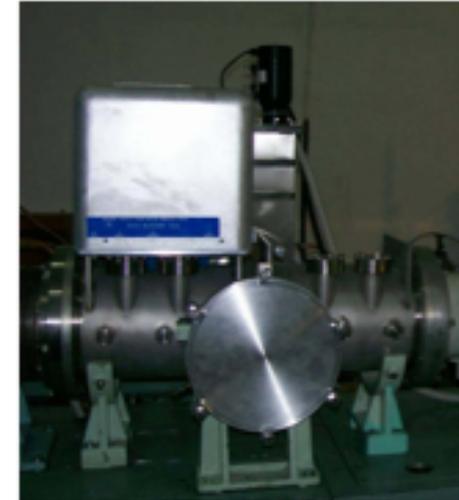
R&D , Learning ...

... and good physics results

TANDEM Accelerator at IFIN-HH

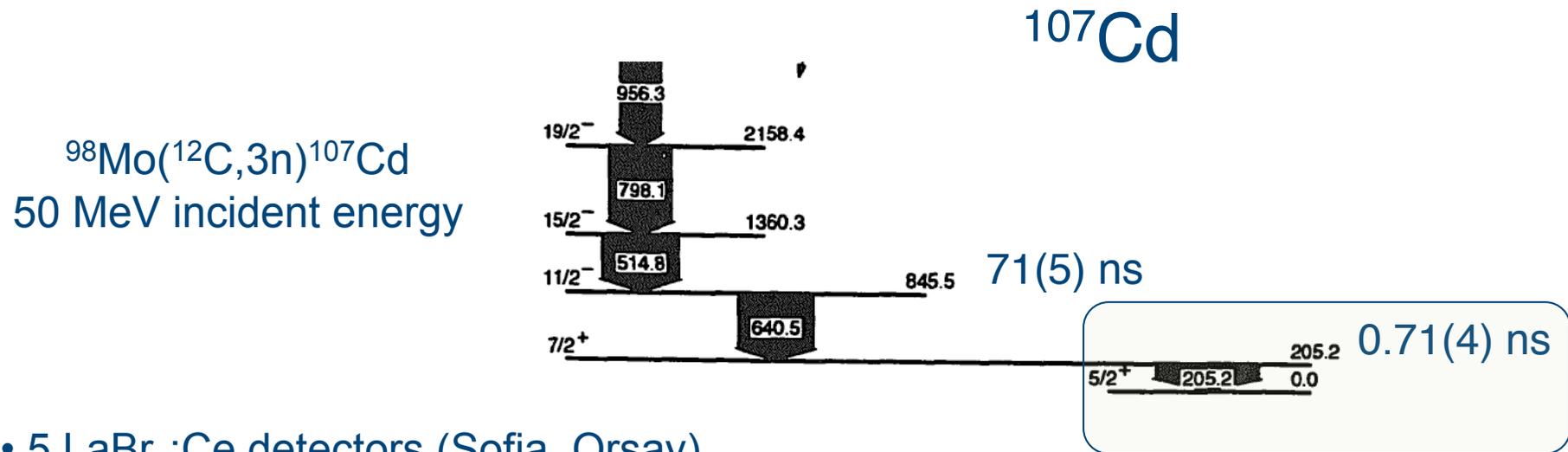
- ◆ 9 MV TANDEM accelerator, completely modernized
- ◆ Duoplasmatron alpha particles source (Li-exchange)
- ◆ Sputtering source
- ◆ “Fast” (nanoseconds) pulsing system
- ◆ “Slow” (>millisecond) pulsing system
- ◆ Very good transmission (>98%)

5000 hours of beam time per year



In-beam Fast-Timing : test experiment

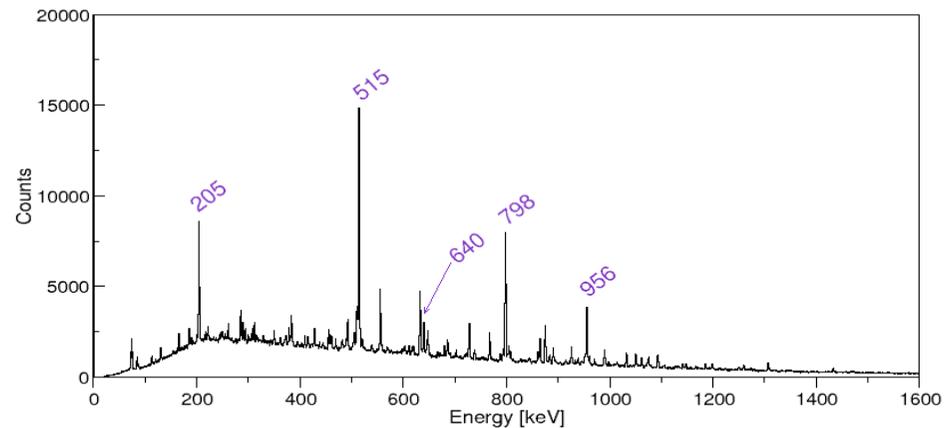
Experiment proposed by D. Balabaski (INRNE-BAS Sofia)



- 5 LaBr₃:Ce detectors (Sofia, Orsay)
- 7 HPGe detectors (Bucharest)

January 2009

Trigger condition
Ge \geq 1 AND LaBr₃:Ce \geq 2



Detection systems

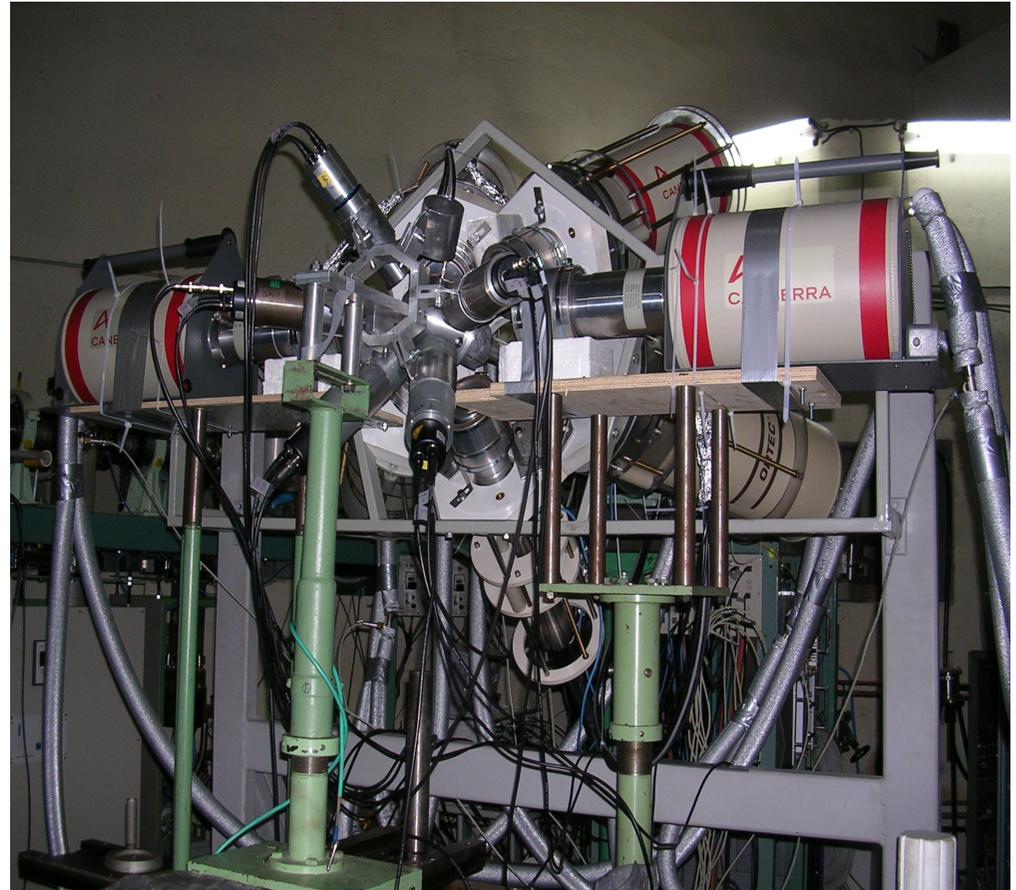
Present infrastructure:

- 18 HPGe detectors with 55% efficiency
- two clover detectors
- scintillation detectors: 12 LaBr₃:Ce,
 - 3 : 2"x2"
 - 3 : 1.5"x1.5"
 - 6 : 1.5" conical
- charged-particle detectors
- neutron detectors

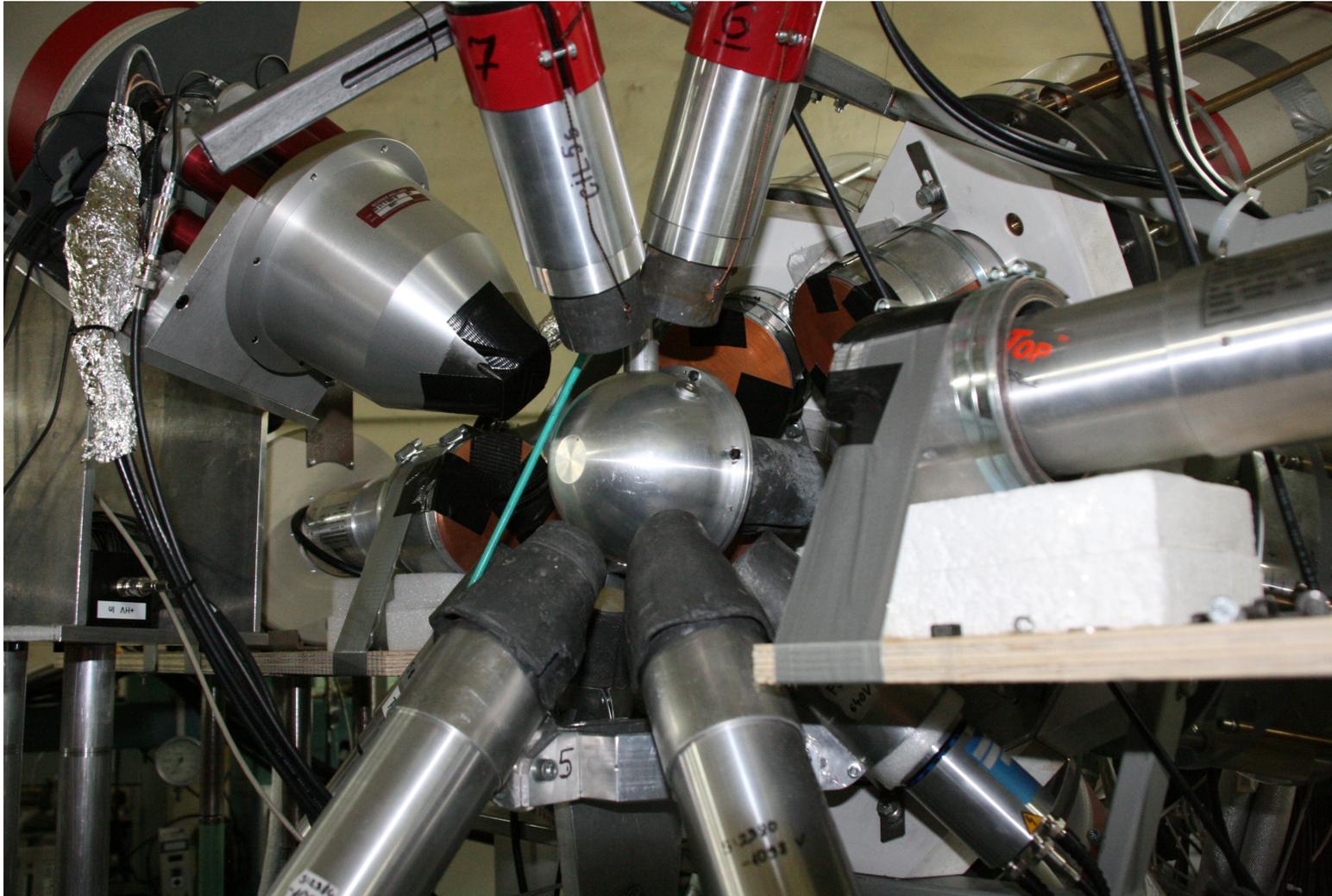
Permanent gamma detection array

7-8 55% HPGe detectors

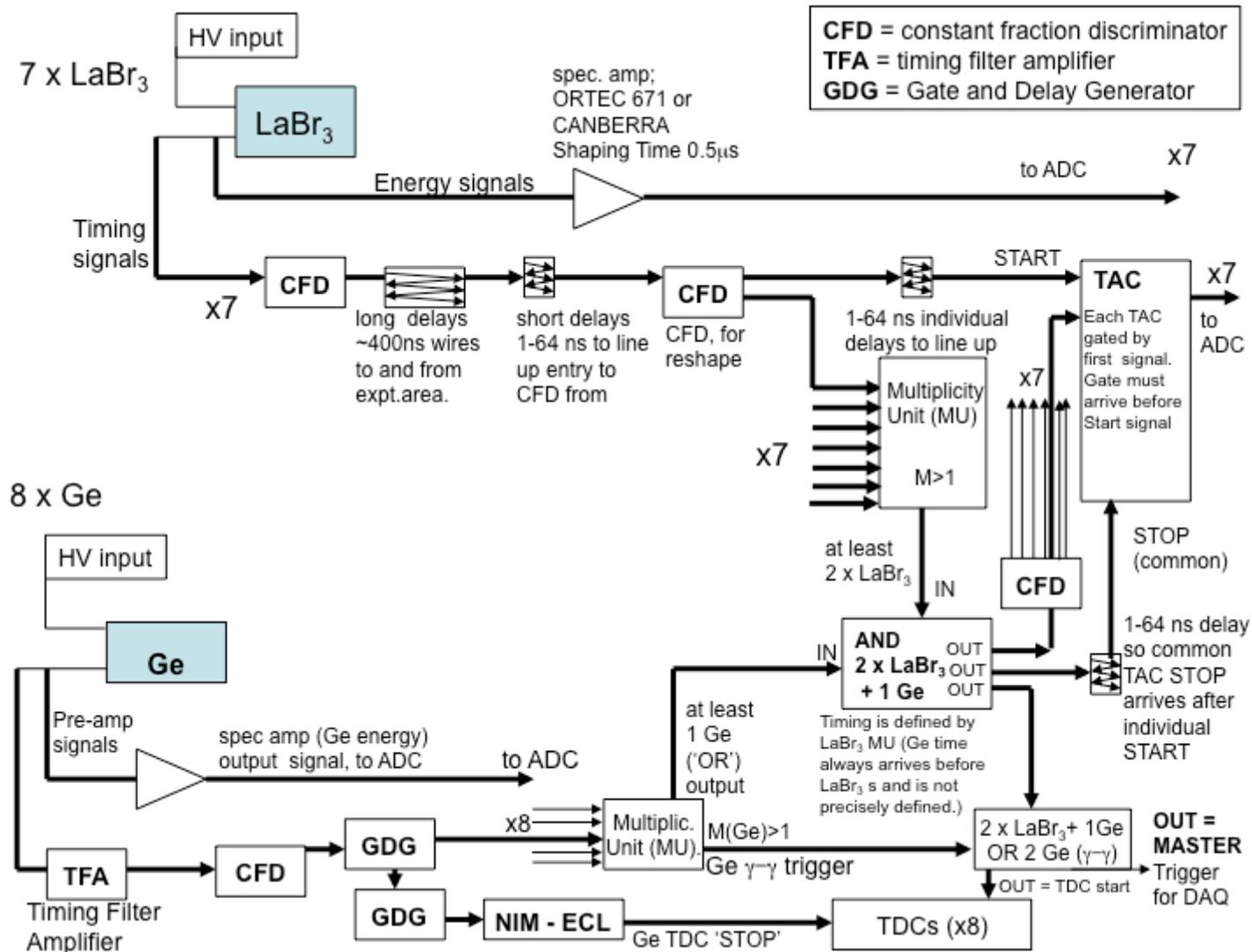
8-12 LaBr₃:Ce detectors



Present “in-beam fast timing” setup



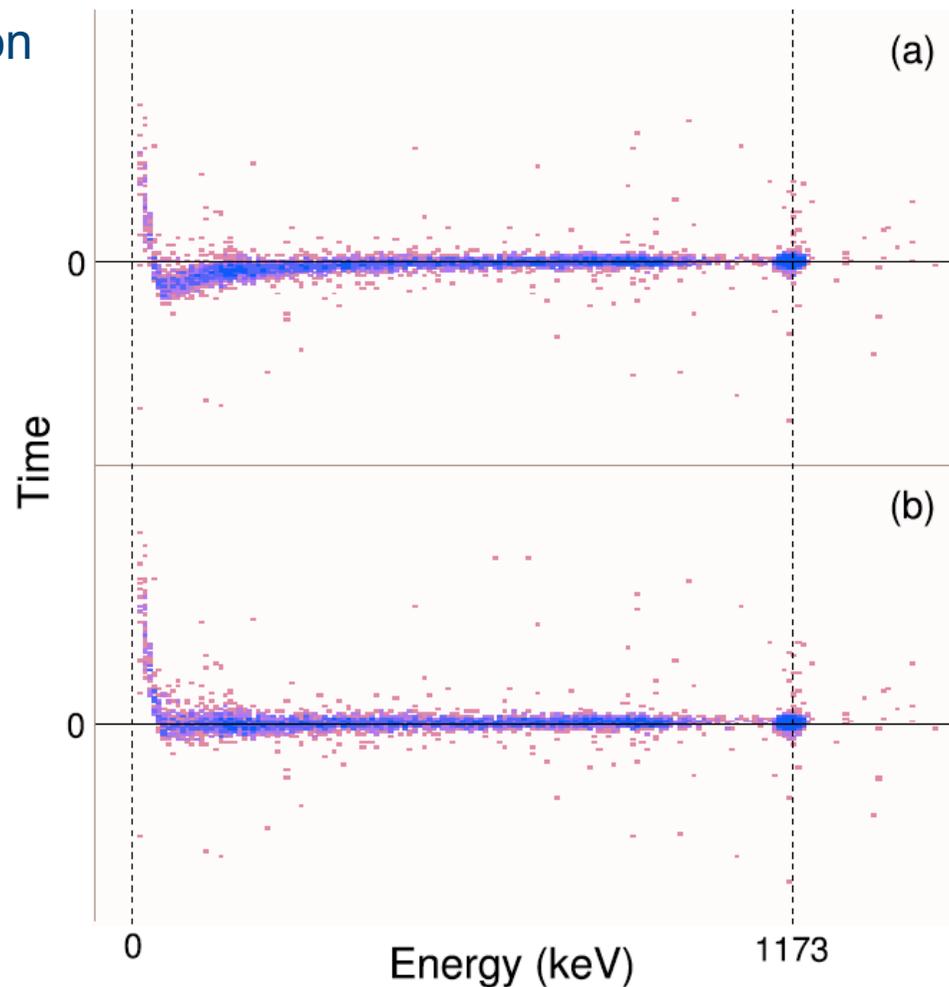
In-Beam Fast Timing Electronic Diagram



CFD walk correction

- ^{60}Co source placed in target position
- One $\text{LaBr}_3:\text{Ce}$ detector taken as time reference
- Voltage close to the linear regime for energy
- Time reference detector gated on the 1332 keV full-energy peak

The CFD walk dependence on amplitude is removed using offline corrections, in order to insure similar time response for all elements of the detection system

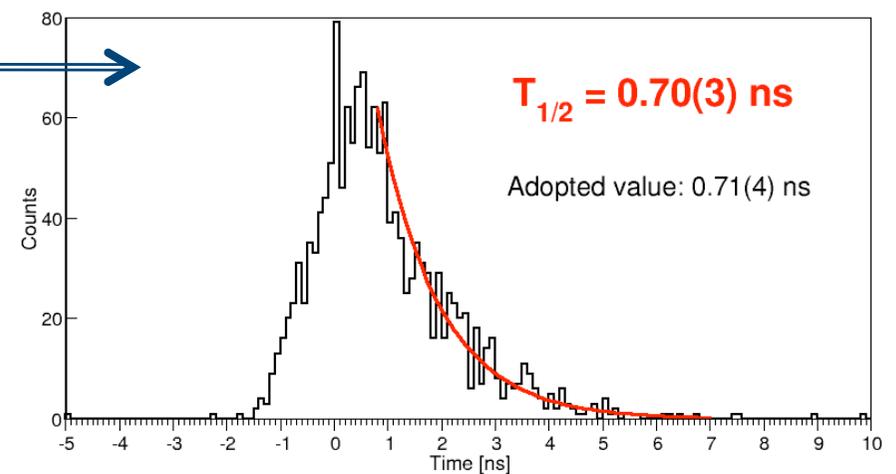
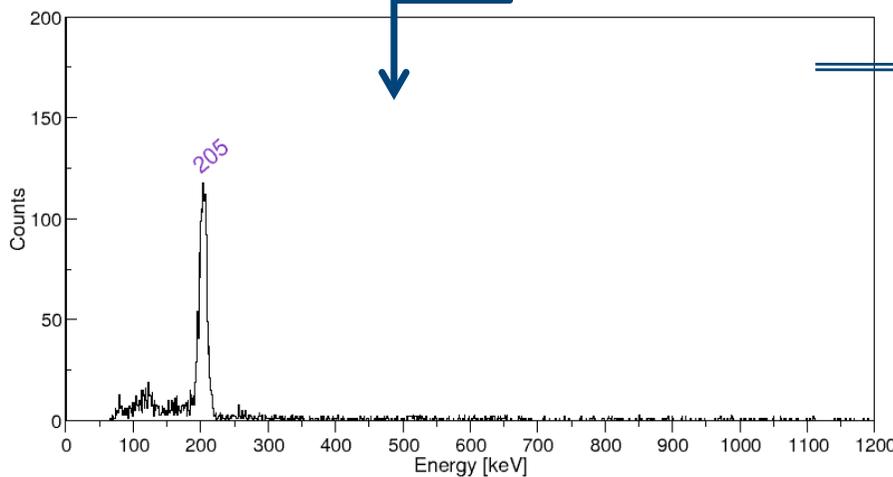
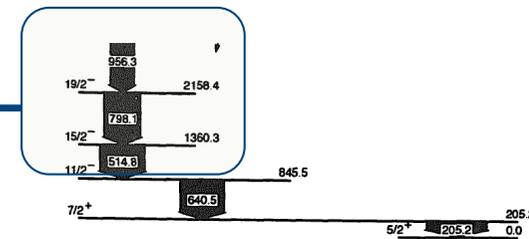
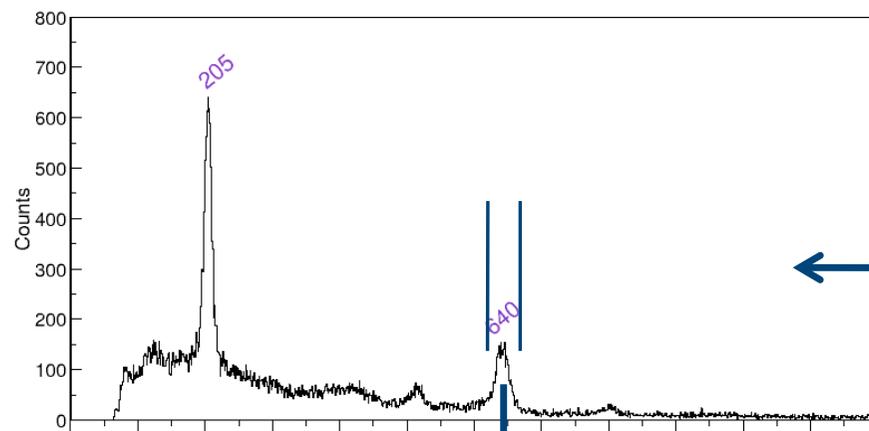


In-beam Fast-Timing : ^{107}Cd test case

640-205 coincidence in $\text{LaBr}_3:\text{Ce}$ detectors

selected gating with HPGe detectors

on yrast transitions of ^{107}Cd



In-beam Fast-Timing : ^{107}Cd test case

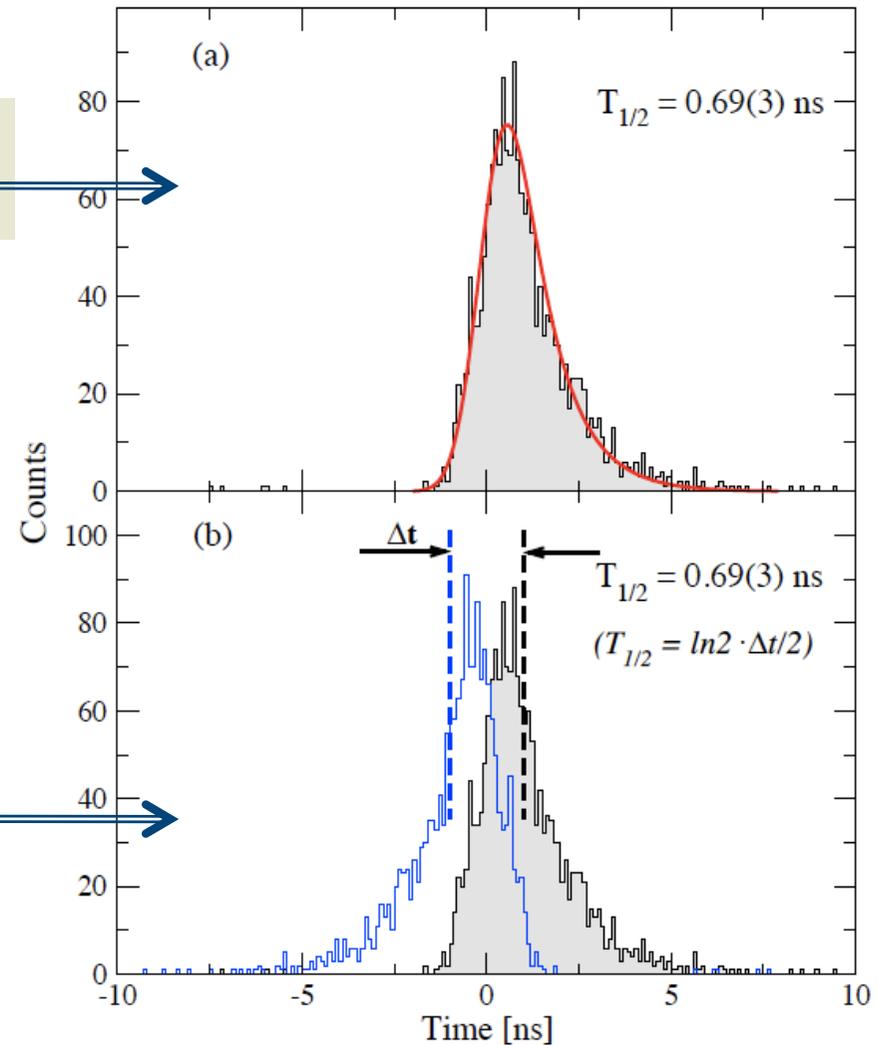
Fit of the decay curve convoluted with effective detector response



Consistent result using both methods



Centroid shift method

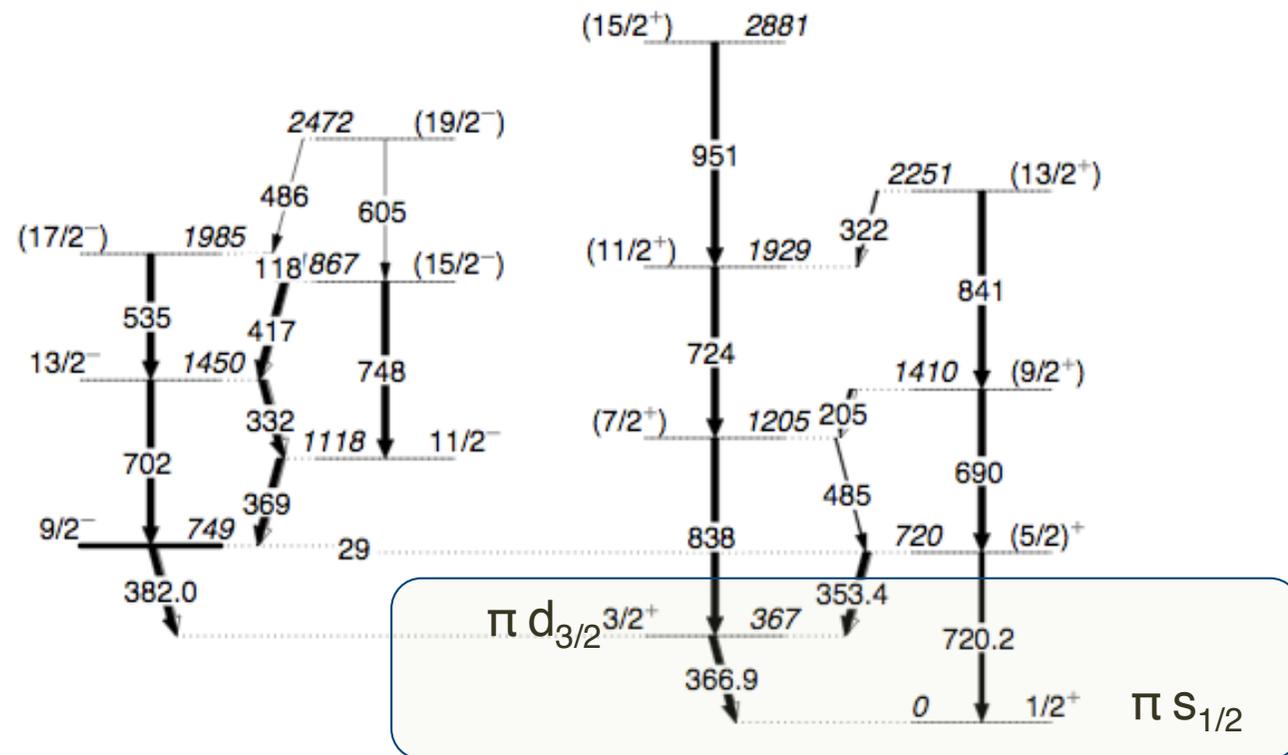


Spectroscopy of ^{199}Tl

- ◆ $^{197}\text{Au}(\alpha,2n)^{199}\text{Tl}$ at 24 MeV beam energy

8 HPGe and 5 LaBr₃:Ce detectors

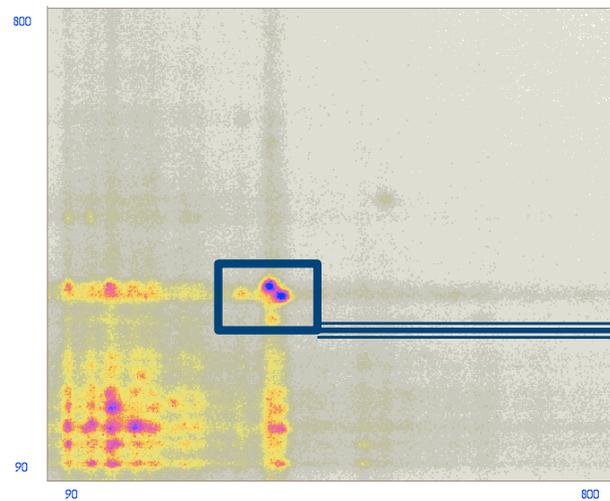
$T_{1/2} = 28.4(2)$ ms



If these states have pure single-particle configurations, one expects lifetime of several hundreds of picoseconds for the 367 keV level

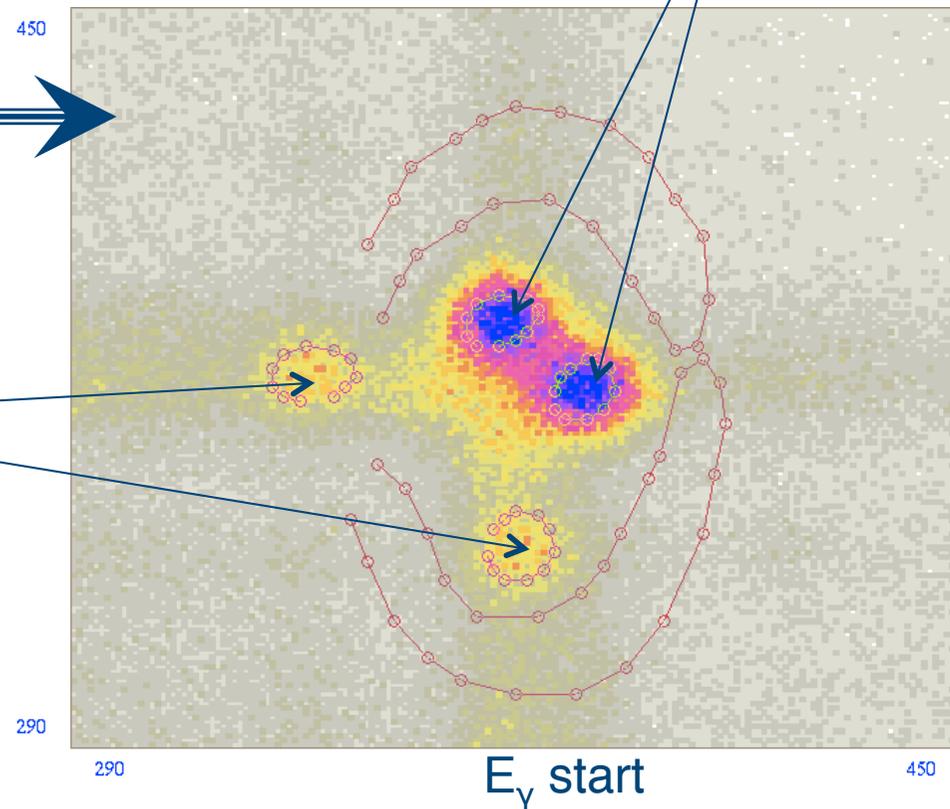
Lifetime of the 367 keV level

γ - γ - Δt cube with LaBr₃:Ce detectors



332 keV – 369 keV
coincidence

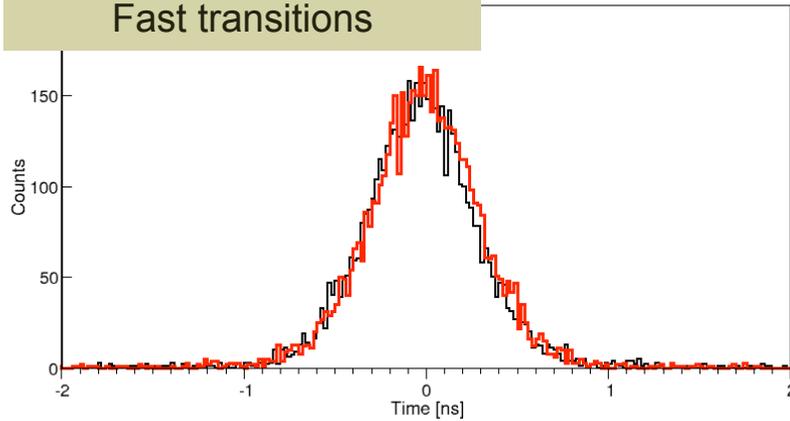
381 keV – 367 keV
coincidence



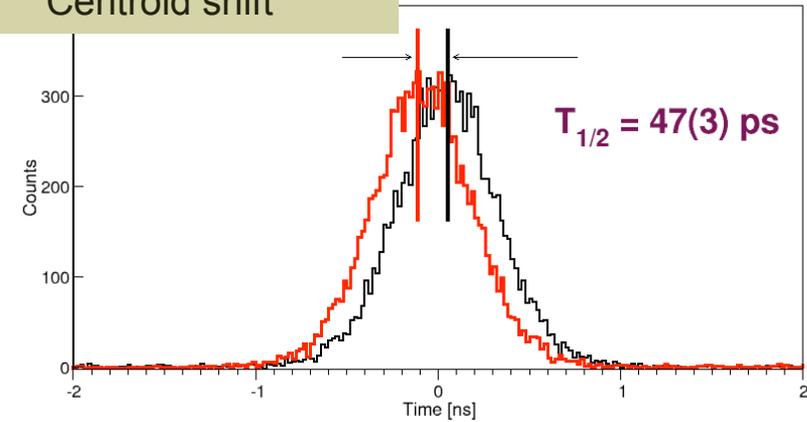
E_γ stop

Lifetime of the 367 keV level

332-369 keV coincidence
Fast transitions



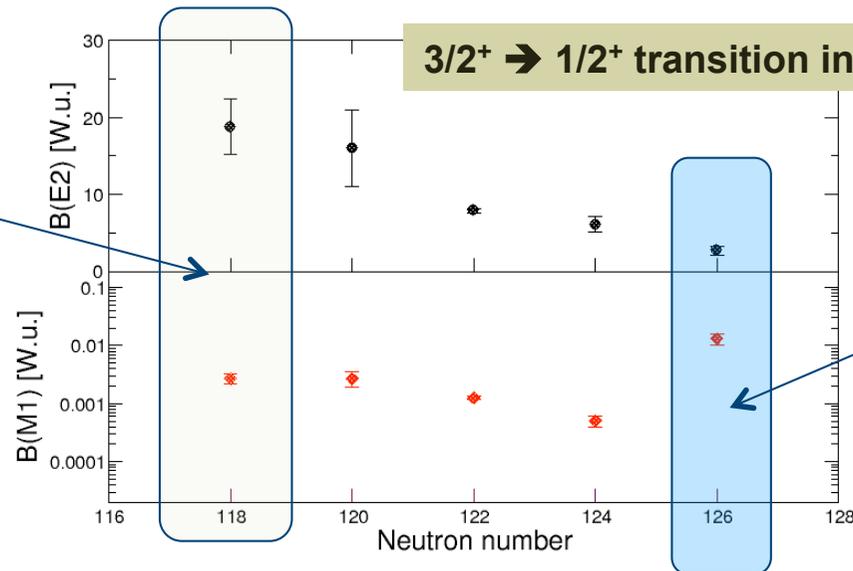
367-381 keV coincidence
Centroid shift



$3/2^+ \rightarrow 1/2^+$ transition in odd-A TI isotopes

Present data

Increased collectivity
of the two states



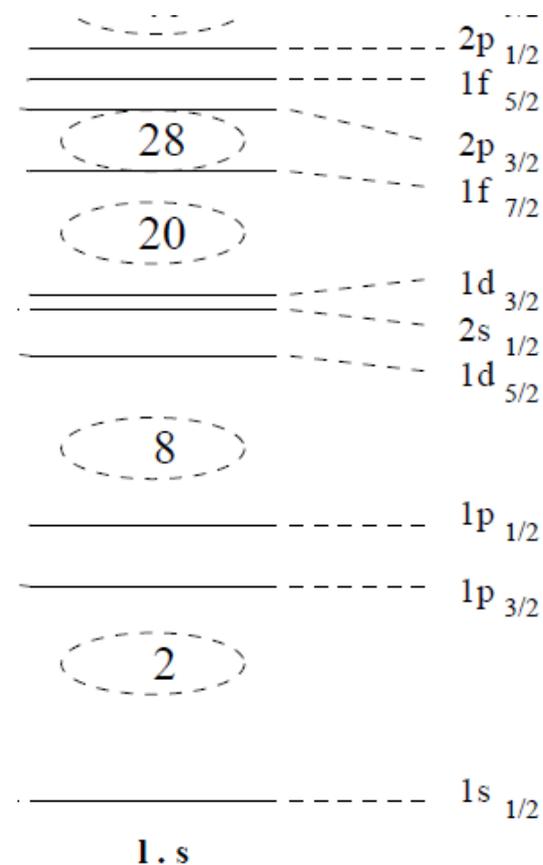
One hole in doubly-magic ^{208}Pb
Single-particle states

Lifetime of the $I^{\pi}=4^{-}$ “intruder” state in ^{34}P using in-beam fast-timing technique

- ◆ Experiment at the Bucharest TANDEM, Spokesperson P.H. Regan (Surrey University, UK)
- ◆ *Surrey Uni., Brighton Uni. (UK)*
- ◆ *UGC-DAE Kolkata*
- ◆ *IFIN-HH Bucharest*
- ◆ *Uni. Notre Dame, Florida State Uni. (USA)*
- ◆ *Istanbul University (Turkey)*
- ◆ *Sofia (Bulgaria)*
- ◆ *KACST (Saudi Arabia)*

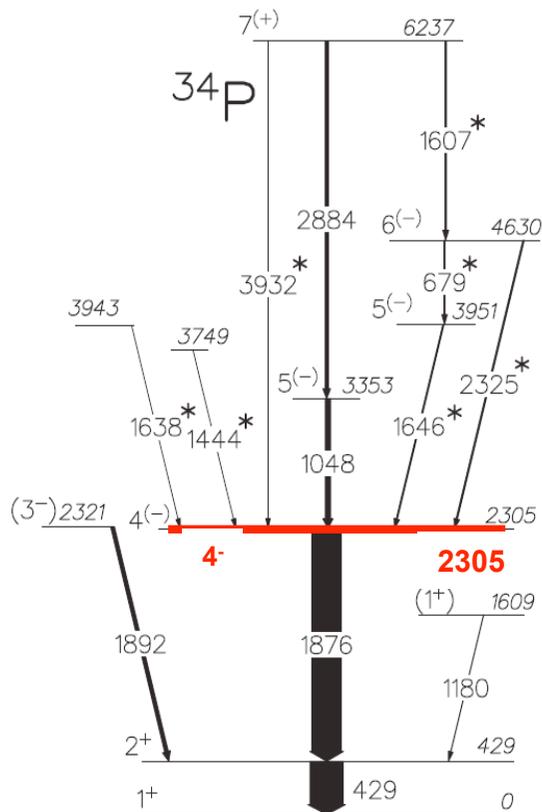
^{34}P N=19, Z=15, close the ‘Island of Inversion’ (e.g. ^{32}Mg).

Negative parity states requires excitations from positive parity (sd) orbitals to negative parity (f,p) states. $f_{7/2}$ is the ‘intruder’ orbital in this region.



High-spin states in ^{34}P

PHYSICAL REVIEW C 80, 034326 (2009)



- Recent study of neutron-rich, N=19 nucleus ^{34}P identified low-lying $I^\pi=4^-$ state at $E_x=2305$ keV.
- Spin and parity assigned on basis of γ -ray DCO and polarization measurements.
- $I^\pi=4^- \rightarrow 2^+$ transition can proceed by M2 and/or E3.
- Previous studies limit half-life to $0.3 \text{ ns} < t_{1/2} < 2.5 \text{ ns}$

Lifetime gives a direct comparison with sdfp-shell model calculations, i.e., including (intruder) negative parity (neutron) $f_{7/2}$ and $p_{3/2}$ orbitals.

Gamma decay of the 4⁻ “intruder” state

Shell model calculations (see table below) suggest that 4⁻ → 2⁺ decay arises mainly from the:

$$\begin{aligned} \nu f_{7/2} &\rightarrow (\nu d_{3/2})^{-1} \quad (\text{M2}) \text{ and} \\ \nu f_{7/2} &\rightarrow \nu s_{1/2} \quad (\text{E3}) \quad \text{‘pure’ transitions.} \end{aligned}$$

TABLE III. Subshell occupancies of states in ³⁴P calculated in the shell model with the WBP-a interaction, as discussed in the text.

E_x (keV)	J^π	Neutrons					Protons				
		$0d_{5/2}$	$1s_{1/2}$	$0d_{3/2}$	$0f_{7/2}$	$1p_{3/2}$	$0d_{5/2}$	$1s_{1/2}$	$0d_{3/2}$	$0f_{7/2}$	$1p_{3/2}$
0	1 ⁺	5.96	1.91	3.13			5.73	1.04	0.24		
363	2 ⁺	5.97	1.95	3.07			5.72	1.04	0.25		
1408	1 ⁺	5.95	1.40	3.65			5.56	1.06	0.38		
2216	2 ⁺	5.97	1.96	3.08			5.71	0.17	1.12		
2757	3 ⁺	5.93	1.95	3.13			5.69	0.26	1.05		
3788	4 ⁺	5.98	1.99	3.03			4.85	1.88	0.26		
2175	3 ⁻	5.81	1.68	2.52	0.90	0.09	5.43	0.98	0.58	0.01	0.00
2249	4 ⁻	5.80	1.71	2.49	0.96	0.04	5.45	1.07	0.48	0.00	0.00

PHYSICAL REVIEW C **80**, 014302 (2009)

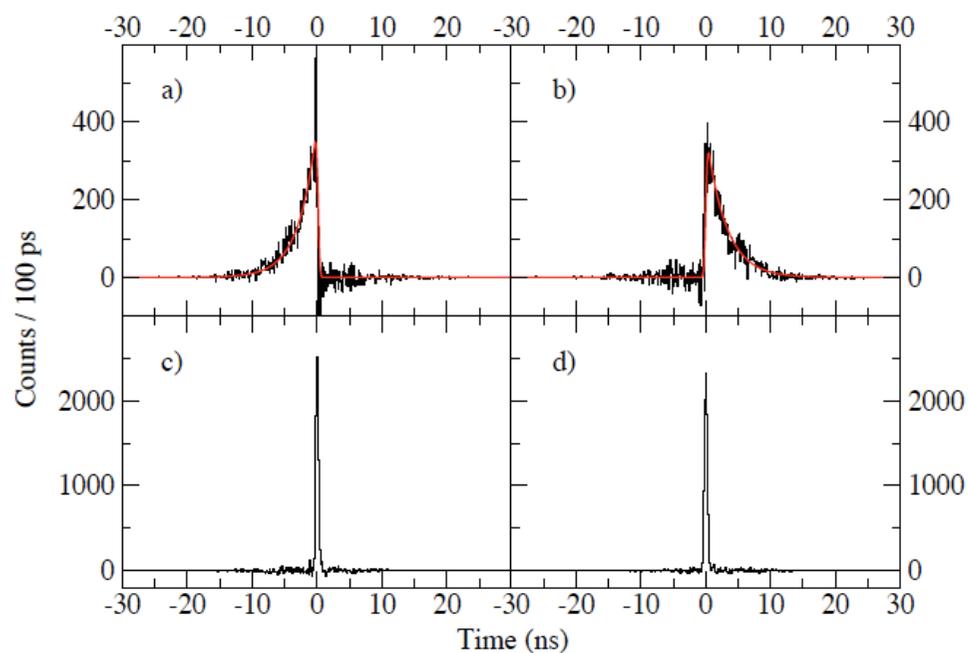
Fast-Timing experiment for ^{34}P

50 mg/cm² Ta₂¹⁸O₅ enriched target

36 MeV ¹⁸O beam from Bucharest TANDEM,
typical beam current ~20 pA

8 HPGe

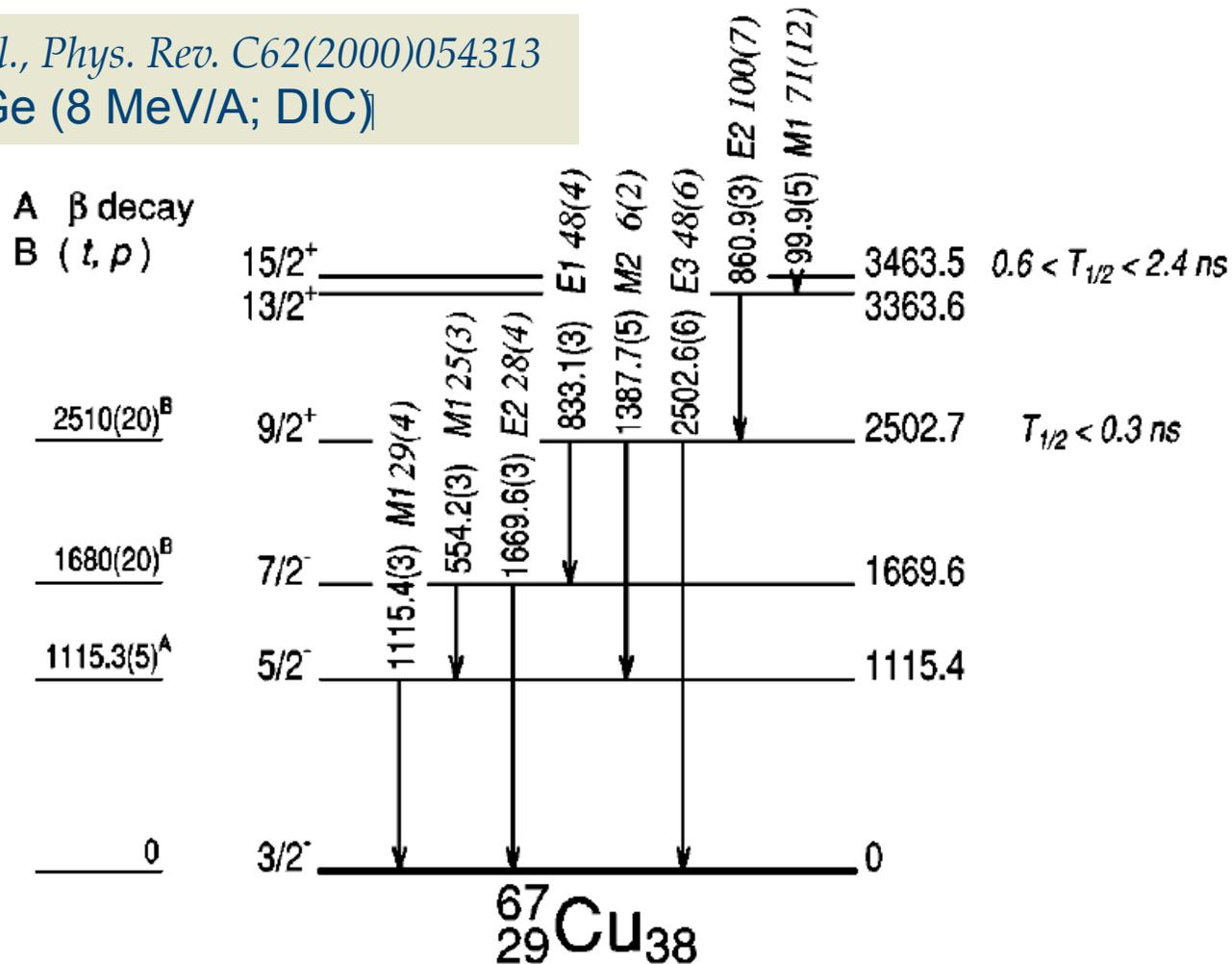
7 LaBr₃(Ce)



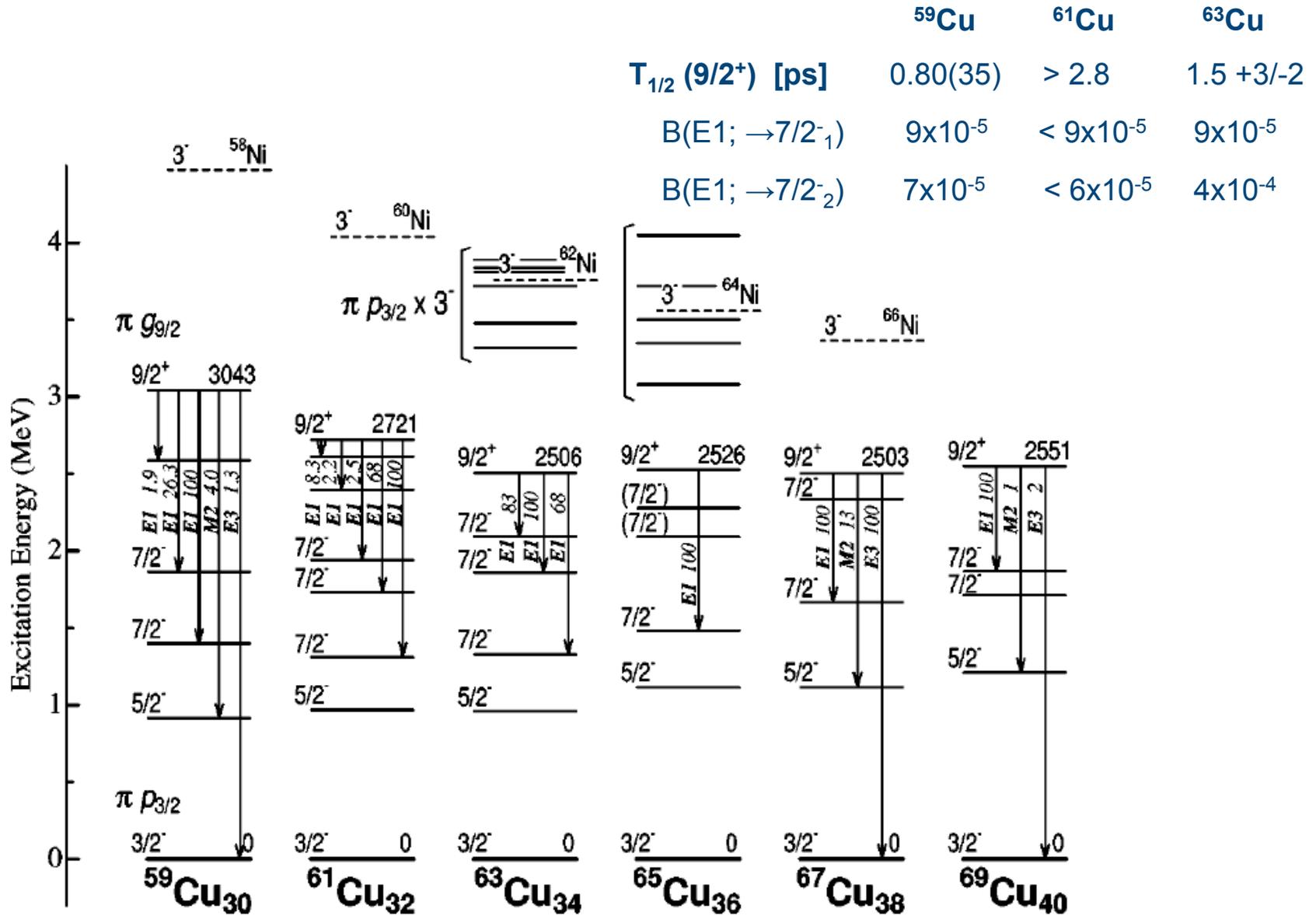
P.J. Mason et al. submitted to Phys. Lett. B

Yrast isomers in ^{67}Cu

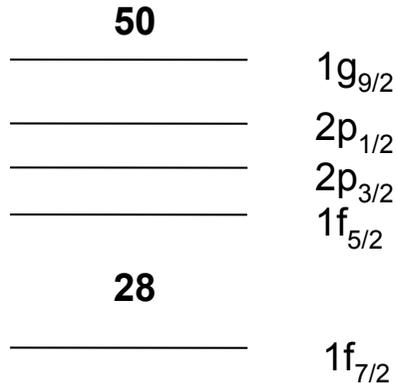
M. Asai et al., *Phys. Rev. C* 62(2000)054313
 $^{198}\text{Pt} + ^{76}\text{Ge}$ (8 MeV/A; DIC)



E1 transitions in Cu isotopes



E3 strength in Cu isotopes



^{67}Cu : $T_{1/2}(9/2^+) < 300$ ps

$B(E3; 2503 \text{ keV}) > 11 \text{ W.u.}$

$B(E1; 833 \text{ keV}) > 1.1 \times 10^{-6} \text{ W.u.}$

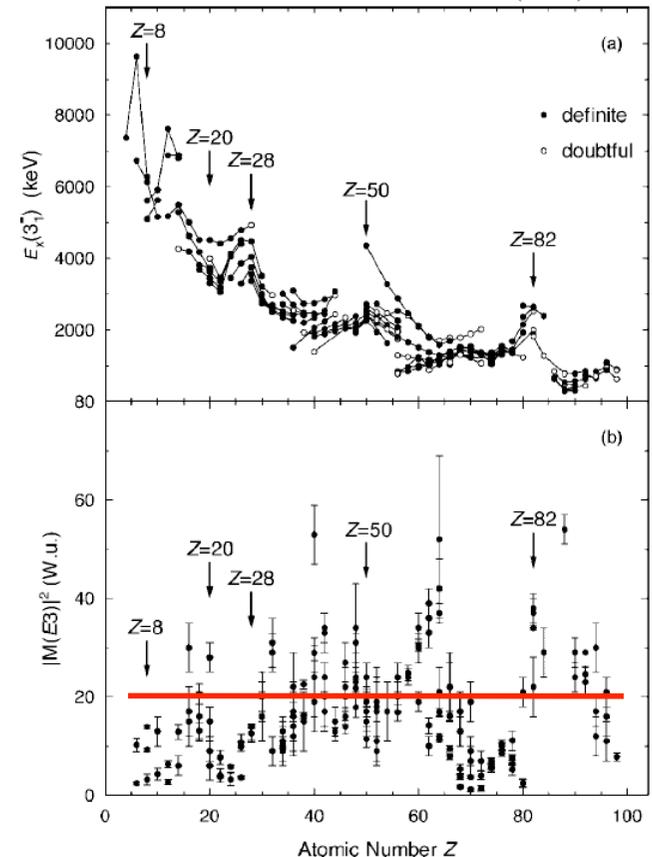
If $B(E1)$ in ^{67}Cu is $\sim 10^{-5} \text{ W.u.}$, then $B(E3) \gg 11 \text{ W.u.}$

In $^{63,65}\text{Cu}$, $B(E3; 9/2^+ \rightarrow 3/2^-) \approx 20 \text{ W.u.}$ (from (α, α') , (p, p') , (e, e')).

^{67}Cu : $9/2^+$ has large $\pi g_{9/2}$ component (from transfer reactions)

E3 $\pi g_{9/2} \rightarrow \pi p_{3/2}$ enhanced by particle-octupole vibration coupling?

T. Kibédi and R.H. Spear
Atomic Data and Nuclear Data Tables 80(2002)35-82



Fast-timing measurement for ^{67}Cu

Experiment proposed by D. Bucurescu and D. Pantelica

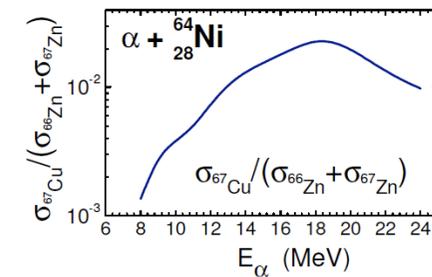
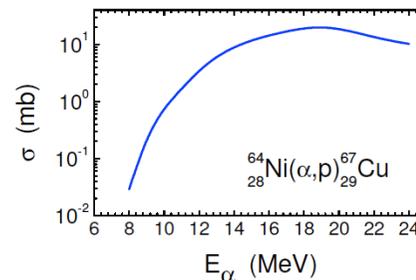
$^{64}\text{Ni}(\alpha, p)^{67}\text{Cu}$ $E_\alpha = 18 \text{ MeV}$

5 HP-Ge (55% rel. eff.)

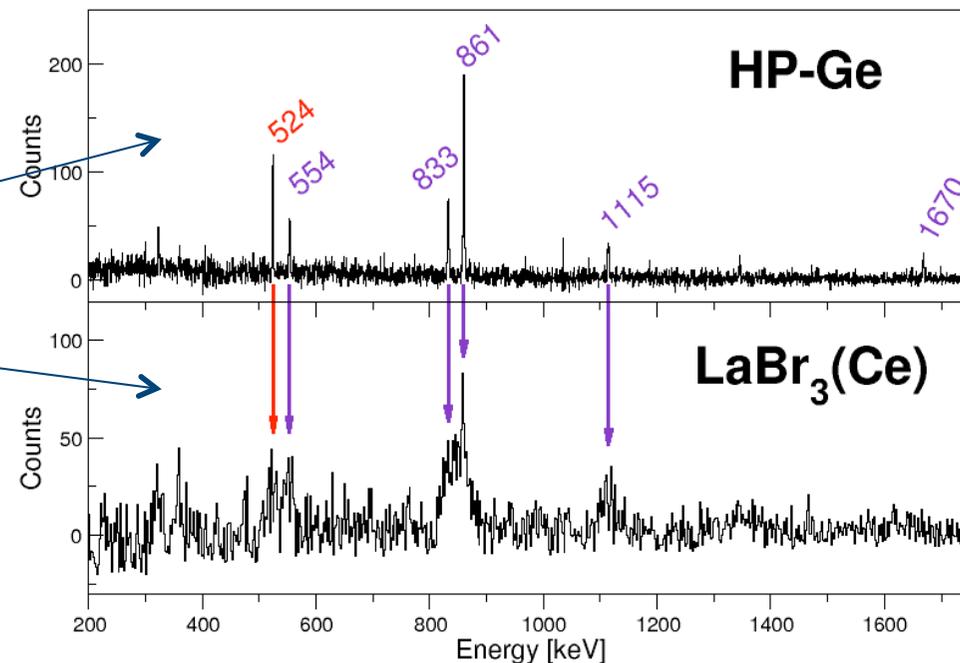
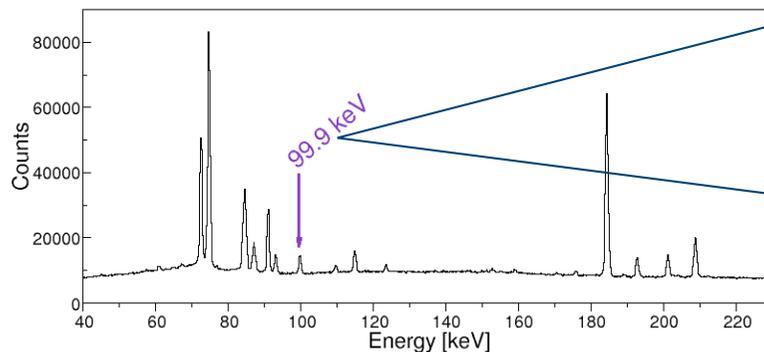
4 HP-Ge planars

8 LaBr₃(Ce)

$\alpha + ^{64}_{28}\text{Ni}$ (TALYS-1.2)

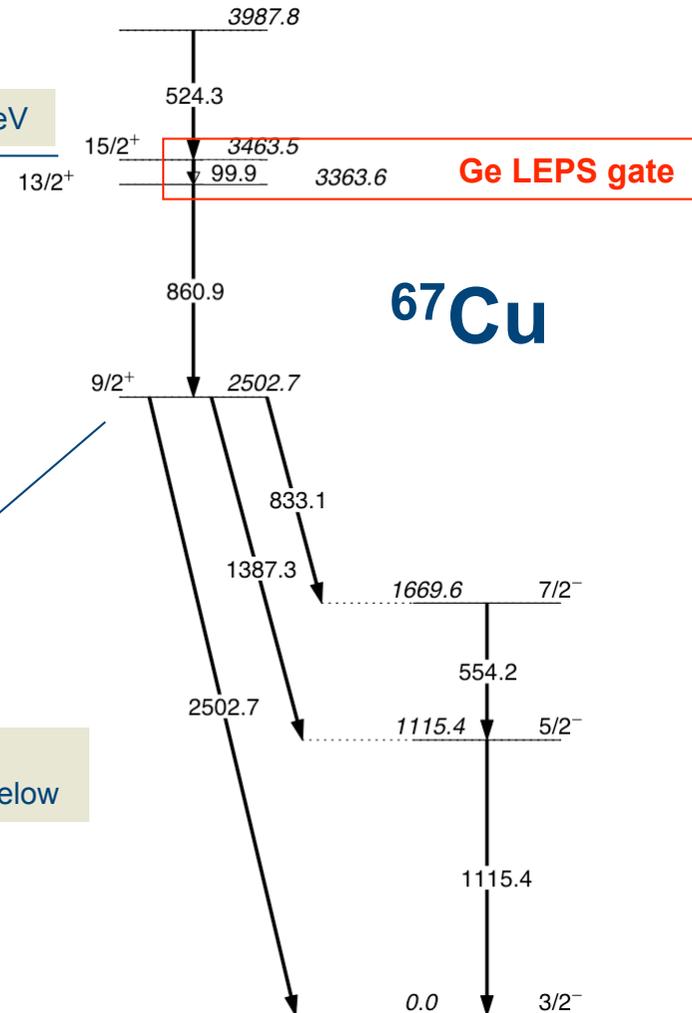
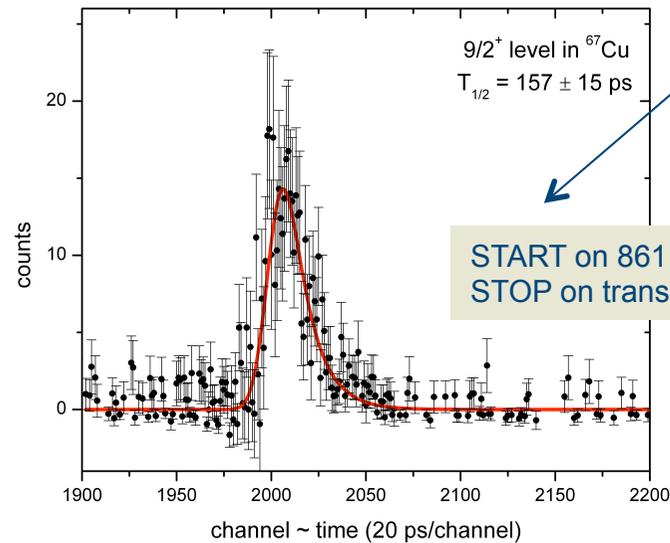
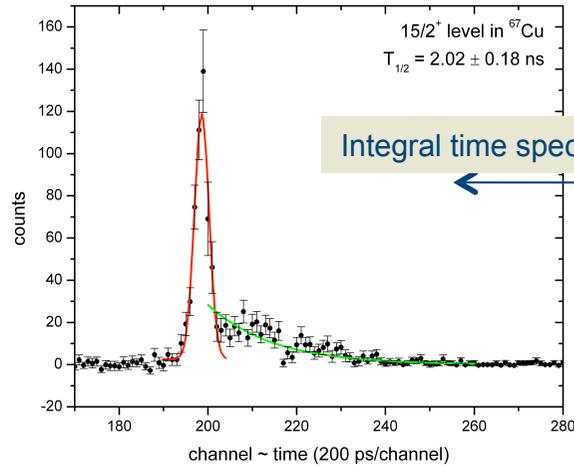


^{67}Cu selected by gating on the 99.9 keV line observed with the HP-Ge LEPS



Lifetime of positive-parity states in ^{67}Cu

C. Nita et al. (to be published)



E1/E3 transition strengths in ^{67}Cu

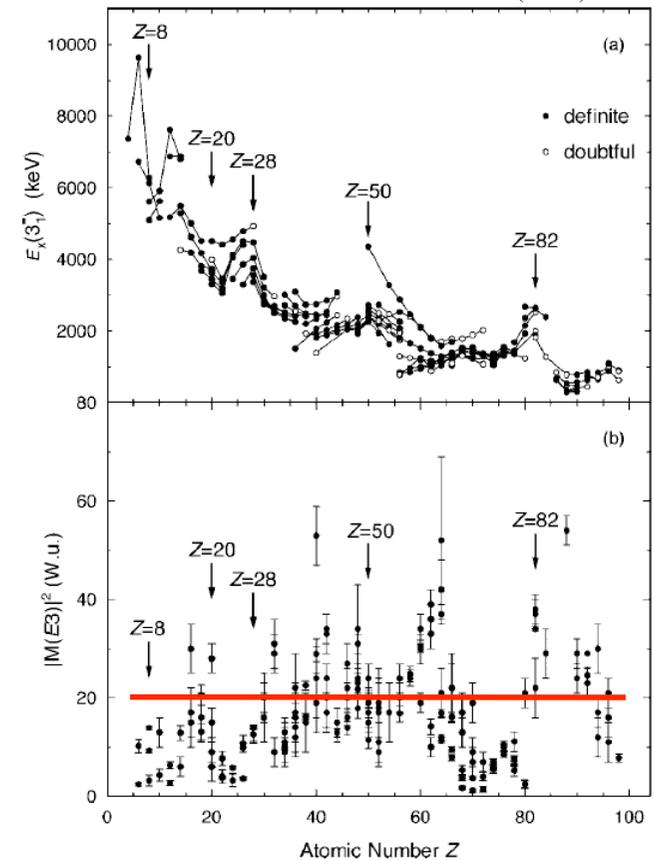
	^{59}Cu	^{61}Cu	^{63}Cu
$T_{1/2} (9/2^+) [\text{ps}]$	0.80(35)	> 2.8	1.5 +3/-2
$B(E1; \rightarrow 7/2^-_1)$	9×10^{-5}	$< 9 \times 10^{-5}$	9×10^{-5}
$B(E1; \rightarrow 7/2^-_2)$	7×10^{-5}	$< 6 \times 10^{-5}$	4×10^{-4}

$^{67}\text{Cu} \quad B(E1; \rightarrow 7/2^-_1) = 2.2(4) \times 10^{-6} \text{ W.u.}$

$^{67}\text{Cu} \quad B(E3; 9/2^+ \rightarrow 3/2^-) = 23(4) \text{ W.u.}$

In $^{63,65}\text{Cu}$, $B(E3; 9/2^+ \rightarrow 3/2^-) \approx 20 \text{ W.u.}$ (from (α, α') , (p, p') , (e, e')).

T. Kibédi and R.H. Spear
Atomic Data and Nuclear Data Tables 80(2002)35-82

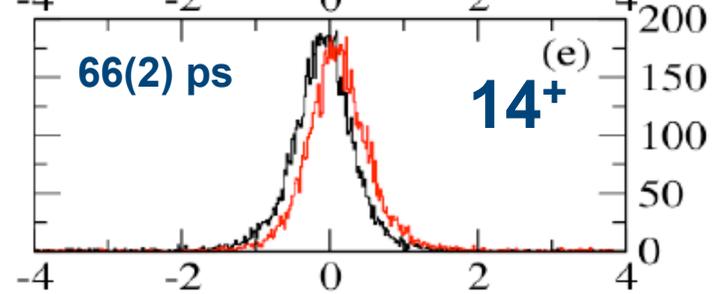
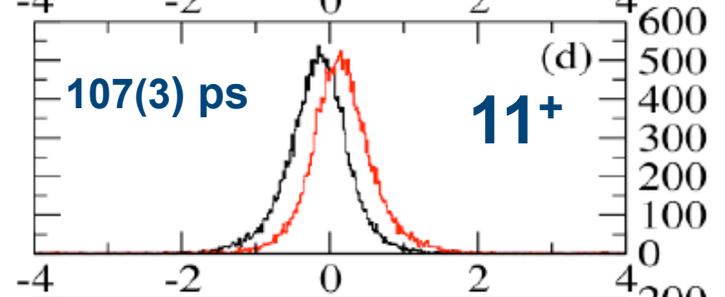
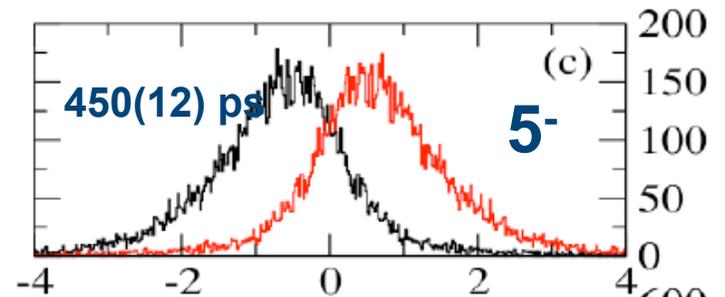
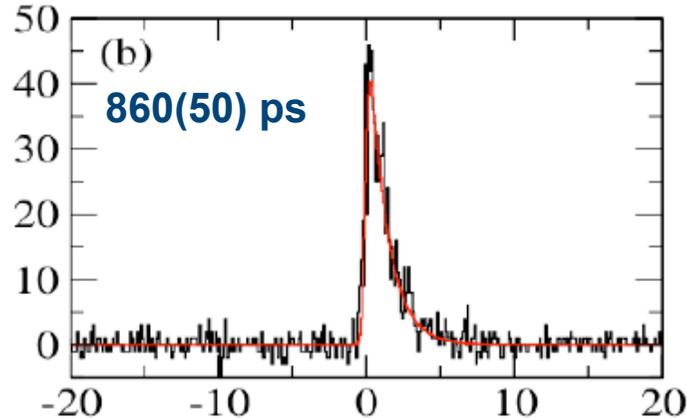
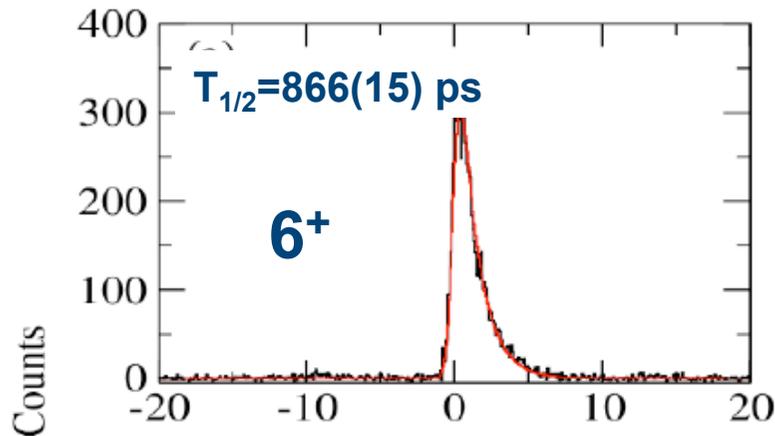
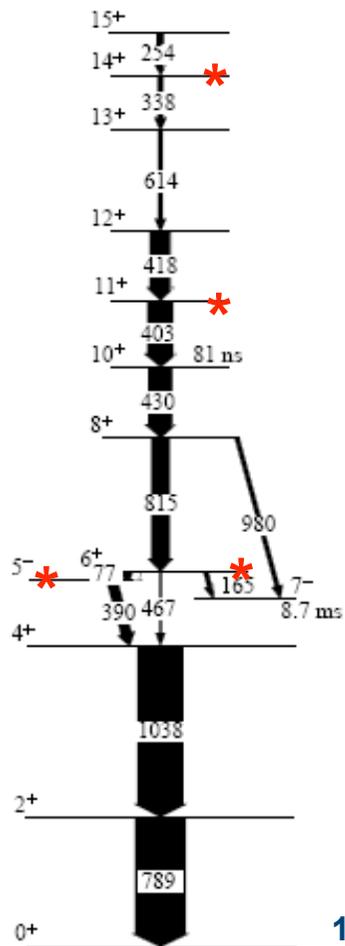


Wide-range timing technique

^{138}Ce

T. Alharbi et al.

Rutherford Centennial Conference, August 2011



$^{130}\text{Te}(^{12}\text{C},4n)^{138}\text{Ce}$ @ 56 MeV

Tandem + γ array IFIN-HH

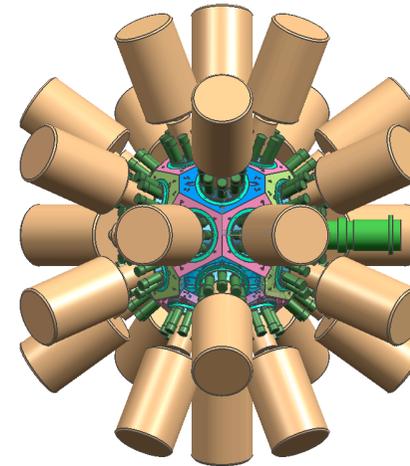
Forthcoming developments

Array of 25 HPGe 55% detectors with BGO anti-Compton shields

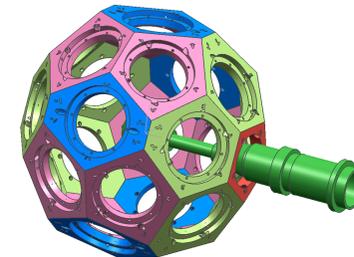
- May accommodate $\text{LaBr}_3(\text{Ce})$ detectors
- Increase granularity
- Increase P/T ratio
- Increase detection efficiency

Absolute detection efficiency (1.33 MeV) ~ 1%

Expected commissioning : summer of 2012



TFR-TRI WORK



TFR-TRI WORK

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L. Stroe
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