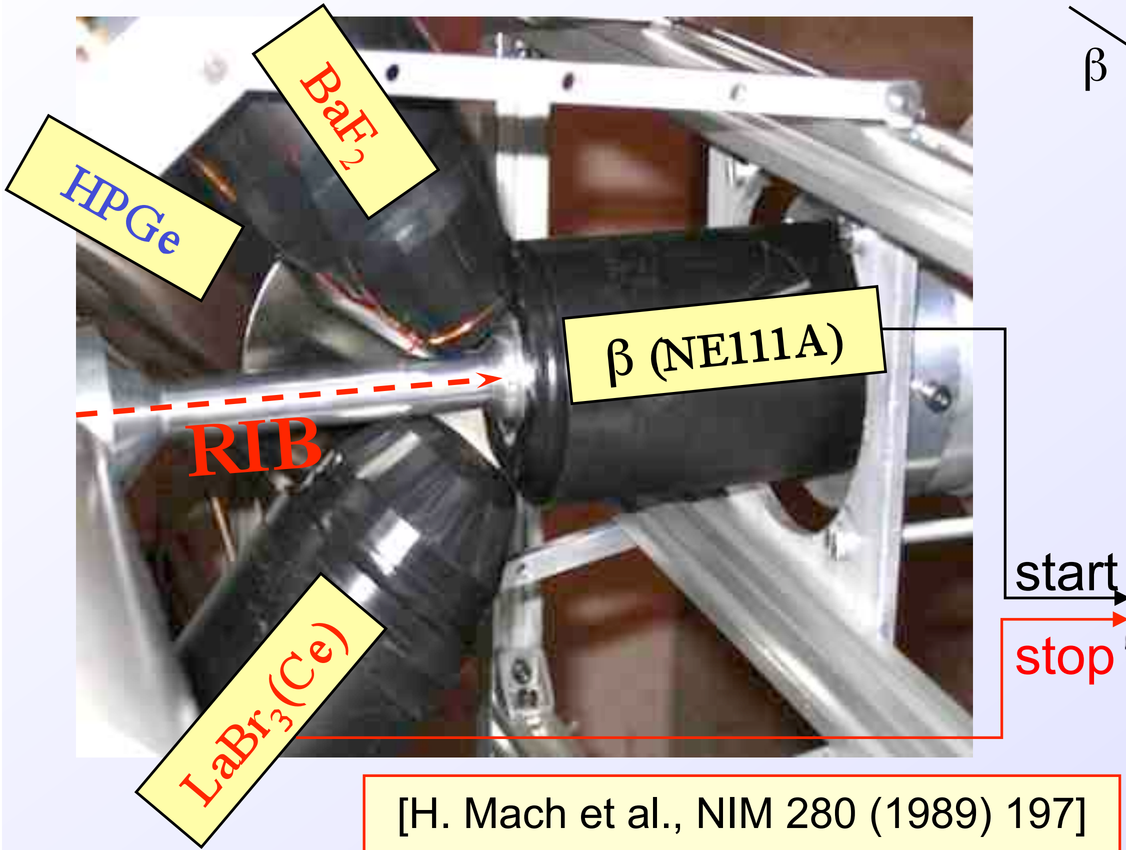
Fast timing meeting measurements

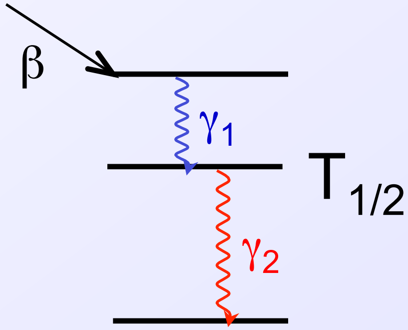
Brighton 13 Jan 2011

L.M. Fraile, UCM

Beta decay

The Advanced Time Delayed $\beta\gamma\gamma(t)$ method





TAC

[H. Mach et al., NIM 280 (1989) 197]
[H. Mach et al., NPA 523 (1991) 45]

HPGe: BRANCH SELECTION
High energy resolution
Poor time response

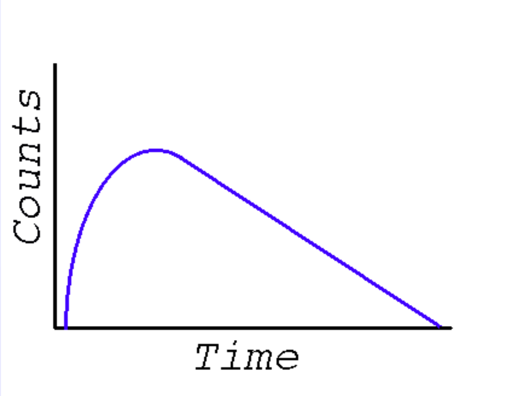
Plastic β scintillator: TIMING
Fast response
Efficient start detector

$LaBr_3(Ce)/BaF_2$: TIMING
Fast response γ-detectors
Poor energy resolution
Stop detectors

The Advanced Time Delayed $\beta\gamma\gamma(t)$ method

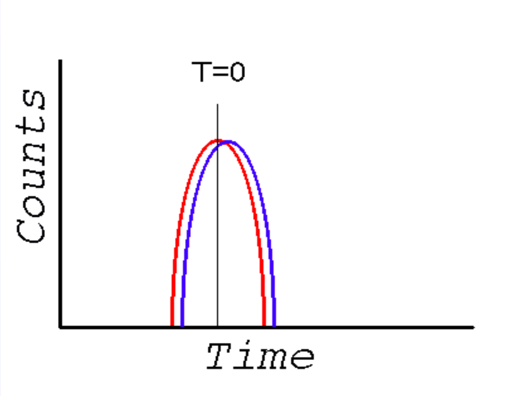
β–BaF_2–HPGe / β–$LaBr_3$–HPGe: lifetime measurements

TAC



De-convolution of slope

- Slope = $T_{1/2}$
- Range: 30 ps to 30 ns (or longer)



Centroid shift

- Shift in centroid position = τ
- Range: down to ~5-10 ps

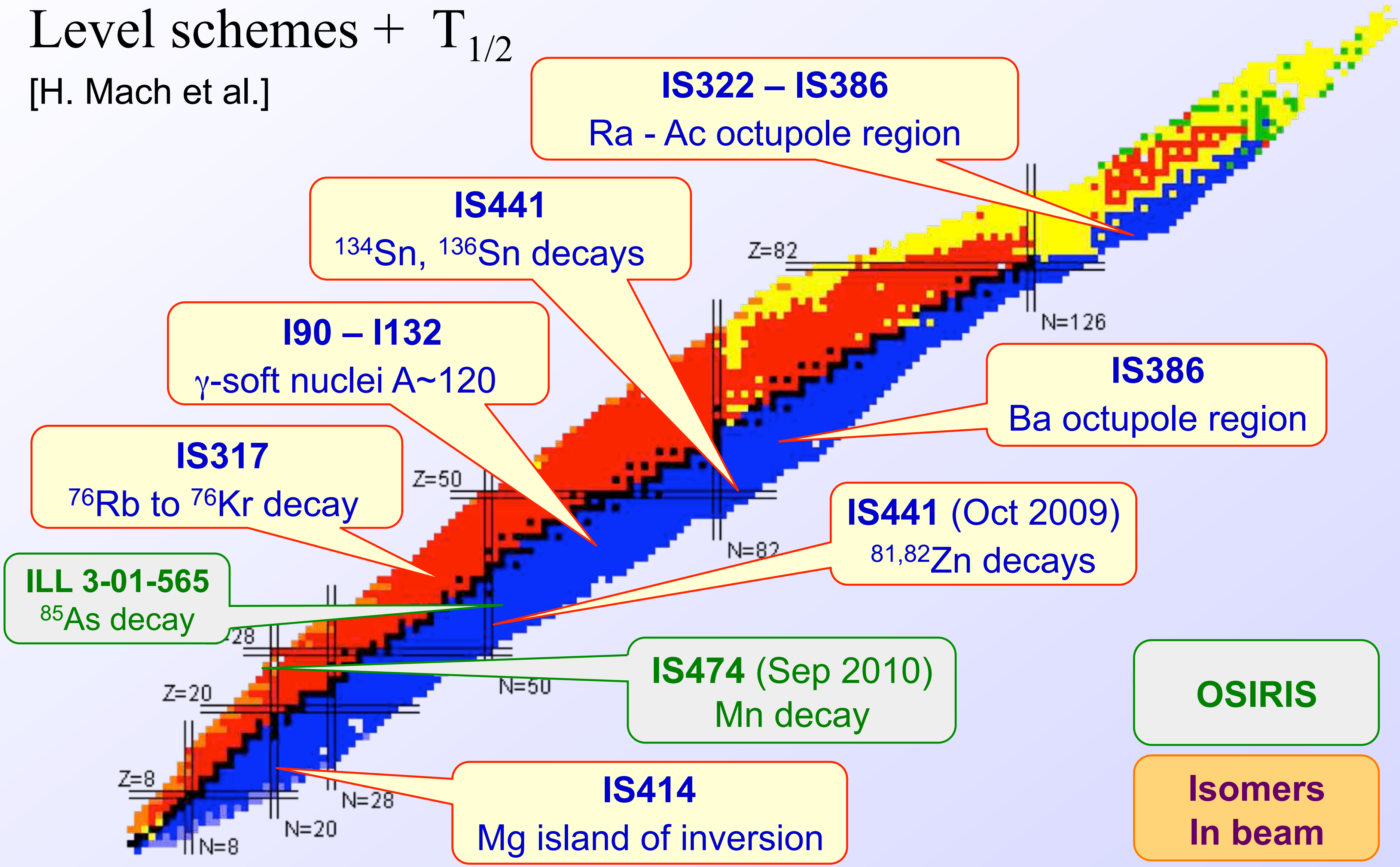
Precise Time calibrations

β–HPGe–HPGe: coincidences, level scheme, branchings

ATD βγγ(t) studies

Level schemes + $T_{1/2}$

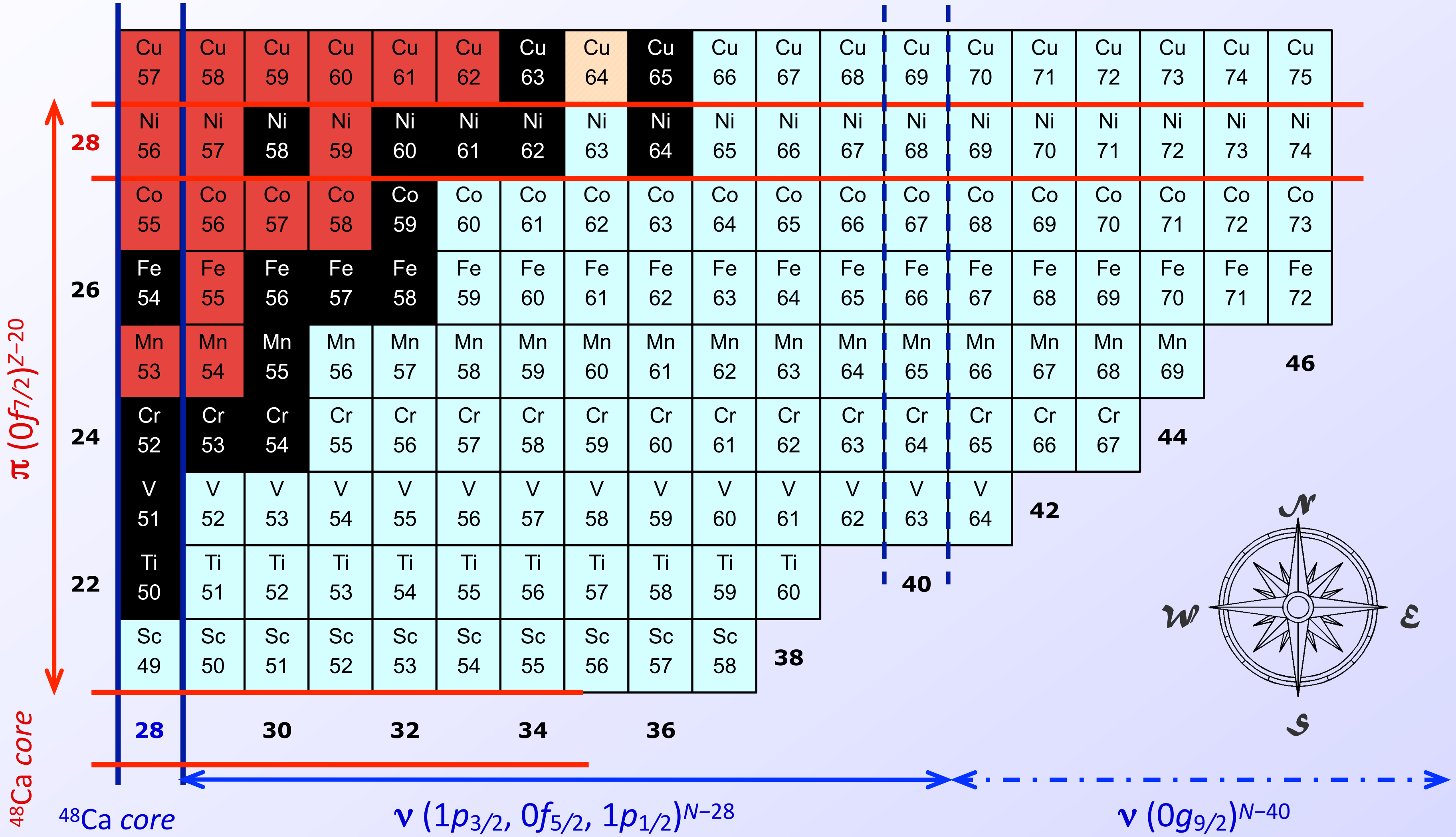
[H. Mach et al.]



OSIRIS

Isomers
In beam

Nuclear chart below ^{68}Ni



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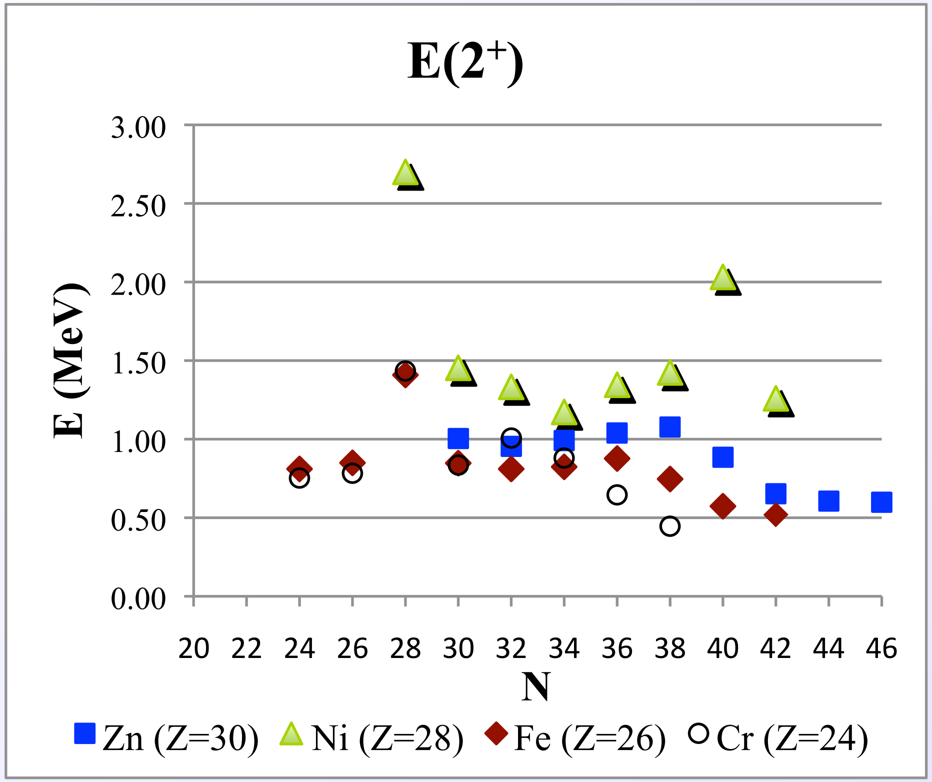
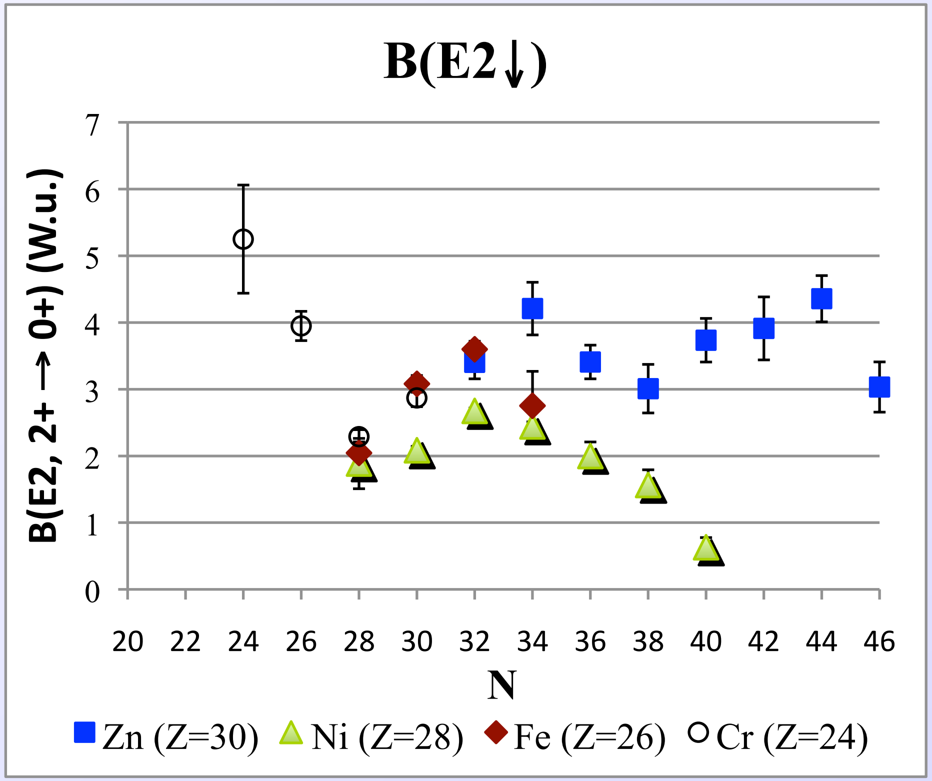
Prospects: nuclei below ^{68}Ni



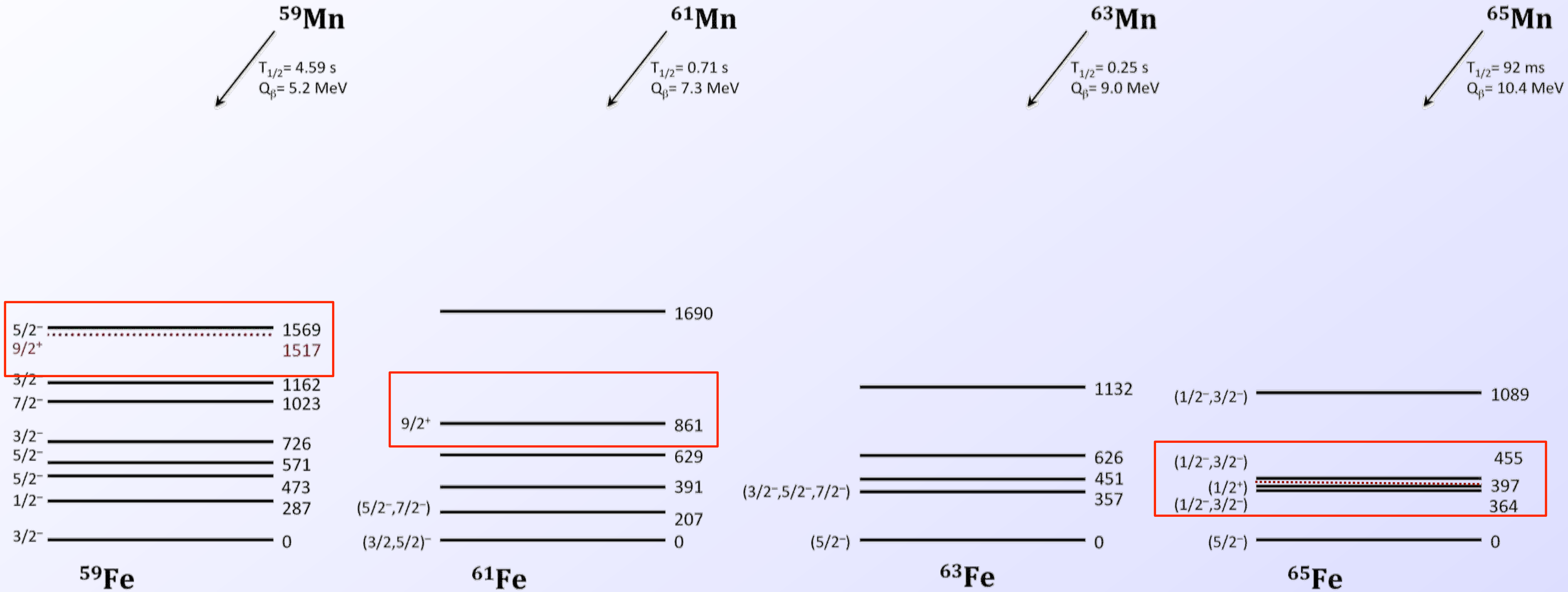


^{64,66}Fe, 2^+ states (most intense transitions), M. Hannawald et al., PRL 82, 1391 (1999)

S. Lunardi et al., PRC 76, 034303 (2007)

^{68}Fe $E(2^+)$ = 522 keV, J.M. Daugas et al., FINUSTAR, AIP Conf Proc 831, 427 (2006)

Odd-A Fe isotopes

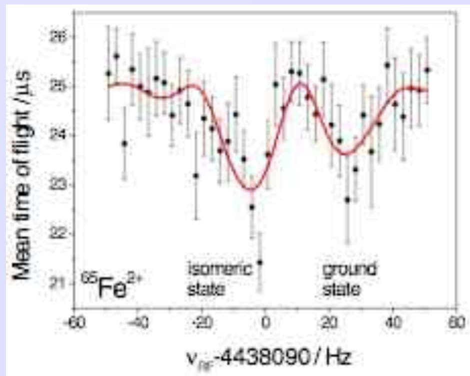


^{57}Fe E(9/2^{+}) = 2455 keV, A. Deacon et al., PRC 76, 054303 (2007)

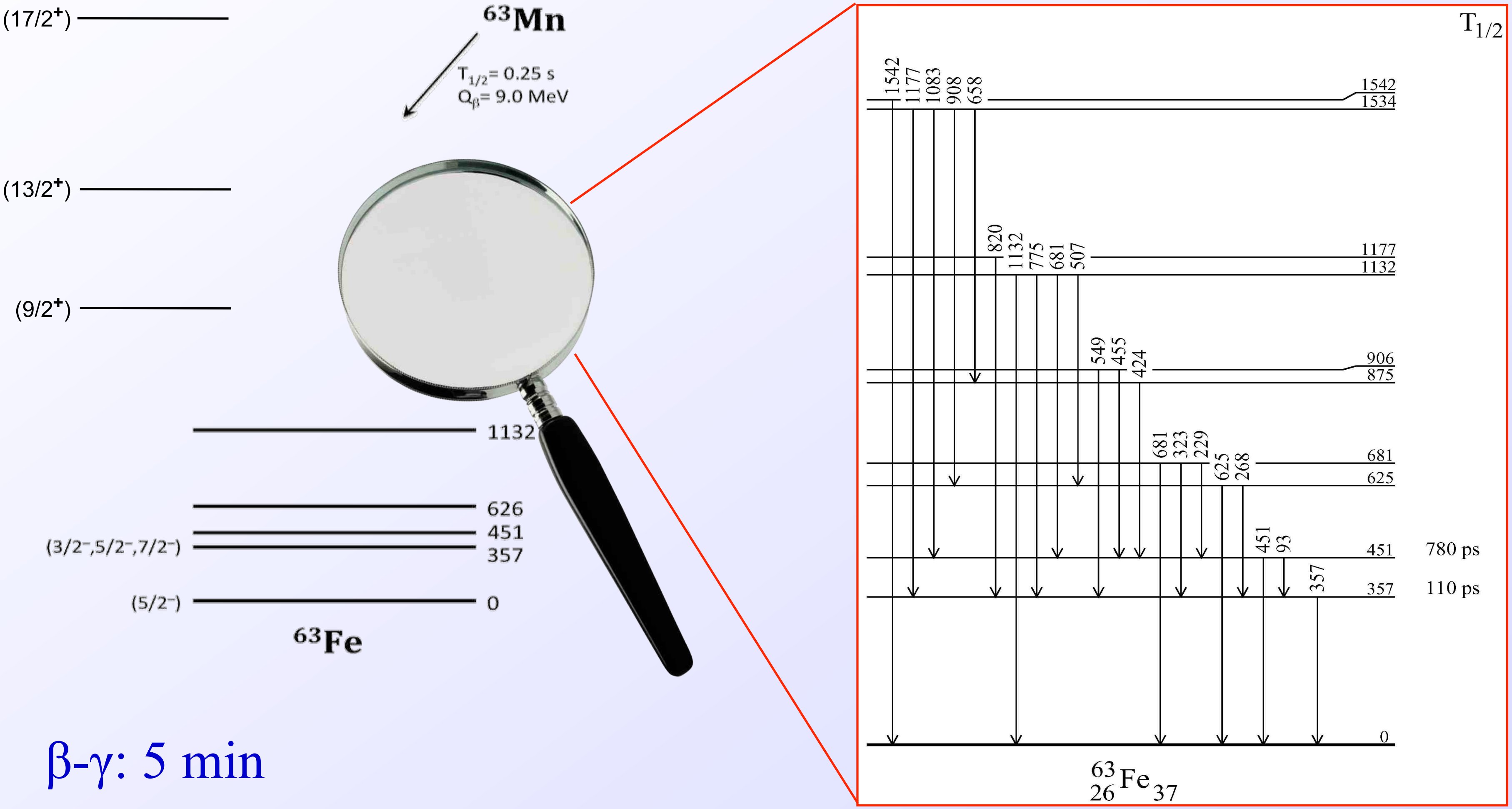
^{65}Fe E(9/2^{+}) = 402(5) keV, $T_{1/2} \geq 150$ ms

M. Block et al., PRL 100, 132501 (2008)

^{67}Fe $T_{1/2} \sim 75$ μs, J.M. Daugas et al. AIP Conf Proc 831, 427 (2006)



Pre-analysis ^{63}Mn decay [before Sep run]



β-γ: 5 min

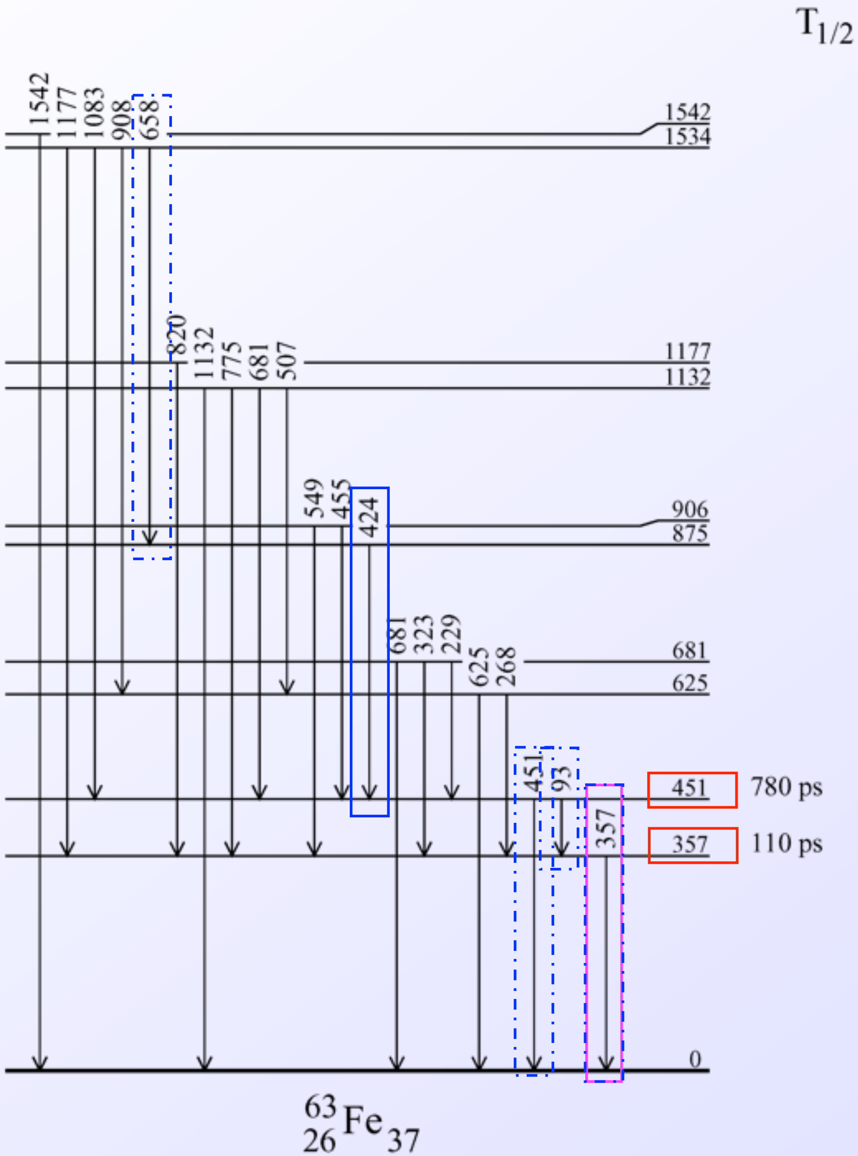
β-γ-γ: 17 min

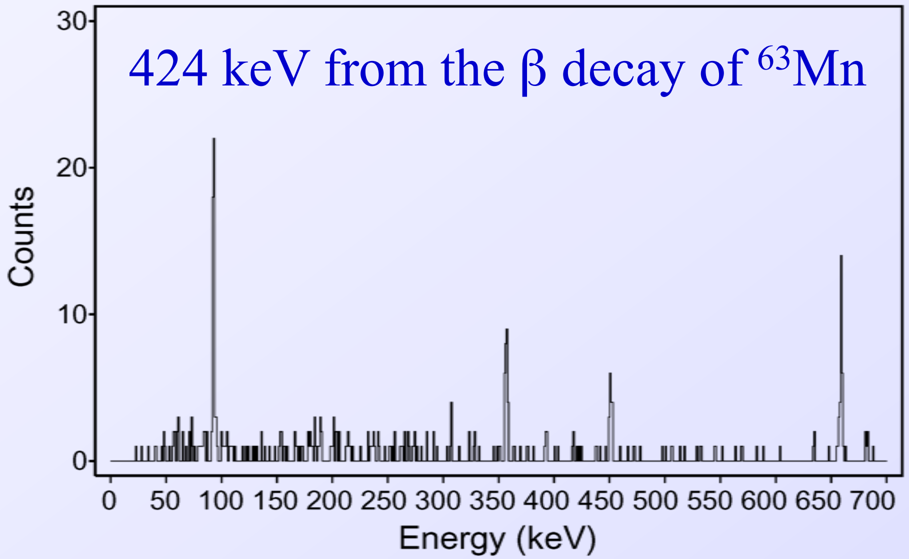
(in saturation)

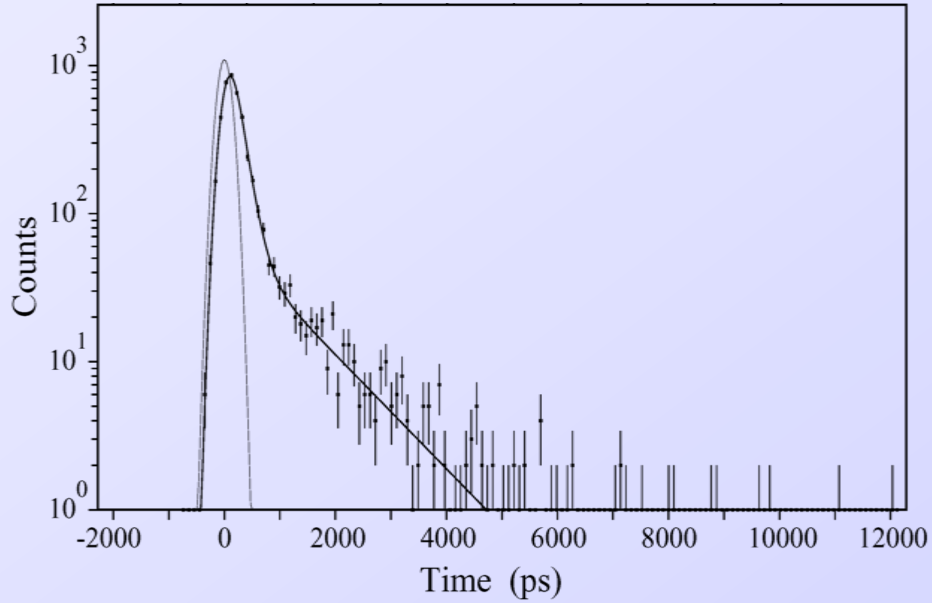
[H. Mach]

Strong beta-feeding to 357, 451 and 1132 keV states, very weak g.s. feeding

Pre-analysis ^{63}Mn decay







Transitions in ^{63}Fe

✓ 357 keV level, $T_{1/2}$ = 110 ps

→ 357 keV transition (neglecting conversion coefficient)

- E1 not expected: $1/2^-$, $3/2^-$, $5/2^-$ states or $9/2^+$ (long lifetime)
- B(E2)~60 W.u. (too high)
- B(M1)=0.0079 μ_N^2

✓ 451 keV level, $T_{1/2}$ = 780 ps

→ 93 keV transition

- Similar for E1 and E2
- B(M1)=0.028 μ_N^2

→ 451 keV transition

- B(E1)=3.2×10^{-6} e^2fm^2 (low)
- B(M1)=2.9×10^{-4} μ_N^2 (low)
- B(E2)=1.4 W.u. (nicely fits systematics)

Low-lying levels in ^{63}Fe

- ✓ Two dipole M1 and one E2 transition
  - → Either $1/2^-$, $3/2^-$, $5/2^-$
  - → or $5/2^-$, $3/2^-$, $1/2^-$
- ✓ Beta feeding from $5/2^-$
  - → 357 and 451 keV
  - → not to ground state
- ✓ Similar to ^{57}Fe

$1/2^-$ is the ground state
$3/2^-$ is the 357 keV state
$5/2^-$ is the 451 keV state

New data **$^{59-66}$Mn** decay to elucidate structure at higher E
Similar situation expected in odd-A Fe isotopes
Role of the $9/2^+$ orbital

Nuclear chart below ^{68}Ni @ PRESPEC

UCM
Grupo de Fisica Nuclear

	Cu 57	Cu 58	Cu 59	Cu 60	Cu 61	Cu 62	Cu 63	Cu 64	Cu 65	Cu 66	Cu 67	Cu 68	Cu 69	Cu 70	Cu 71	Cu 72	Cu 73	Cu 74	Cu 75
28	Ni 56	Ni 57	Ni 58	Ni 59	Ni 60	Ni 61	Ni 62	Ni 63	Ni 64	Ni 65	Ni 66	Ni 67	Ni 68	Ni 69	Ni 70	Ni 71	Ni 72	Ni 73	Ni 74
	Co 55	Co 56	Co 57	Co 58	Co 59	Co 60	Co 61	Co 62	Co 63	Co 64	Co 65	Co 66	Co 67	Co 68	Co 69	Co 70	Co 71	Co 72	Co 73
26	Fe 54	Fe 55	Fe 56	Fe 57	Fe 58	Fe 59	Fe 60	Fe 61	Fe 62	Fe 63	Fe 64	Fe 65	Fe 66	Fe 67	Fe 68	Fe 69	Fe 70	Fe 71	Fe 72
	Mn 53	Mn 54	Mn 55	Mn 56	Mn 57	Mn 58	Mn 59	Mn 60	Mn 61	Mn 62	Mn 63	Mn 64	Mn 65	Mn 66	Mn 67	Mn 68	Mn 69		46
24	Cr 52	Cr 53	Cr 54	Cr 55	Cr 56	Cr 57	Cr 58	Cr 59	Cr 60	Cr 61	Cr 62	Cr 63	Cr 64	Cr 65	Cr 66	Cr 67	44		
	V 51	V 52	V 53	V 54	V 55	V 56	V 57	V 58	V 59	V 60	V 61	V 62	V 63	V 64	42				
22	Ti 50	Ti 51	Ti 52	Ti 53	Ti 54	Ti 55	Ti 56	Ti 57	Ti 58	Ti 59	Ti 60		40						
	Sc 49	Sc 50	Sc 51	Sc 52	Sc 53	Sc 54	Sc 55	Sc 56	Sc 57	Sc 58	38								
	28		30		32		34		36										

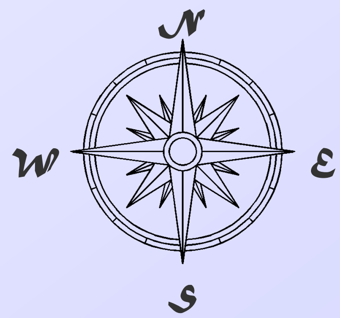
$\pi\ (0f_{7/2})^{Z-20}$

^{48}Ca core

^{48}Ca core

$\nu\ (1p_{3/2}, 0f_{5/2}, 1p_{1/2})^{N-28}$

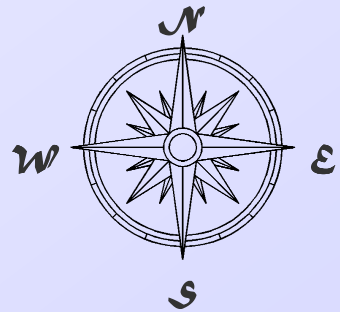
$\nu\ (0g_{9/2})^{N-40}$



gfn UCM Grupo de Fisica Nuclear

The region NE of ^{132}Sn

	Cs 127	Cs 128	Cs 129	Cs 130	Cs 131	Cs 132	Cs 133	Cs 134	Cs 135	Cs 136	Cs 137	Cs 138	Cs 139	Cs 140	Cs 141	Cs 142	Cs 143	Cs 144	Cs 145	Cs 146	Cs 147	Cs 148	Cs 149	Cs 150	Cs 151	Cs 152
54	Xe 126	Xe 127	Xe 128	Xe 129	Xe 130	Xe 131	Xe 132	Xe 133	Xe 134	Xe 135	Xe 136	Xe 137	Xe 138	Xe 139	Xe 140	Xe 141	Xe 142	Xe 143	Xe 144	Xe 145	Xe 146	Xe 147	94		96	
	I 125	I 126	I 127	I 128	I 129	I 130	I 131	I 132	I 133	I 134	I 135	I 136	I 137	I 138	I 139	I 140	I 141	I 142	I 143	I 144	92					
52	Te 124	Te 125	Te 126	Te 127	Te 128	Te 129	Te 130	Te 131	Te 132	Te 133	Te 134	Te 135	Te 136	Te 137	Te 138	Te 139	Te 140	Te 141	Te 142							
	Sb 123	Sb 124	Sb 125	Sb 126	Sb 127	Sb 128	Sb 129	Sb 130	Sb 131	Sb 132	Sb 133	Sb 134	Sb 135	Sb 136	Sb 137	Sb 138	Sb 139		90							
50	Sn 122	Sn 123	Sn 124	Sn 125	Sn 126	Sn 127	Sn 128	Sn 129	Sn 130	Sn 131	**Sn 132**	Sn 133	Sn 134	Sn 135	Sn 136	Sn 137										
	In 121	In 122	In 123	In 124	In 125	In 126	In 127	In 128	In 129	In 130	In 131	In 132	In 133	In 134	In 135		88									
48	Cd 120	Cd 121	Cd 122	Cd 123	Cd 124	Cd 125	Cd 126	Cd 127	Cd 128	Cd 129	Cd 130	Cd 131	Cd 132		86											
	Ag 119	Ag 120	Ag 121	Ag 122	Ag 123	Ag 124	Ag 125	Ag 126	Ag 127	Ag 128	Ag 129	Ag 130	84													
46	Pd 118	Pd 119	Pd 120	Pd 121	Pd 122	Pd 123	Pd 124		80		82															
	72		74		76		78																			



$\pi\,(0g_{7/2}, 1d_{5/2}, 1d_{3/2}, 2s_{1/2}, 0h_{11/2})^{Z-50}$

^{132}Sn *core*

^{132}Sn *core*

$\nu\,(1f_{7/2}, 0h_{9/2}, 1f_{5/2}, 2p_{3/2}, 2p_{1/2}, 0i_{13/2})^{N-82}$

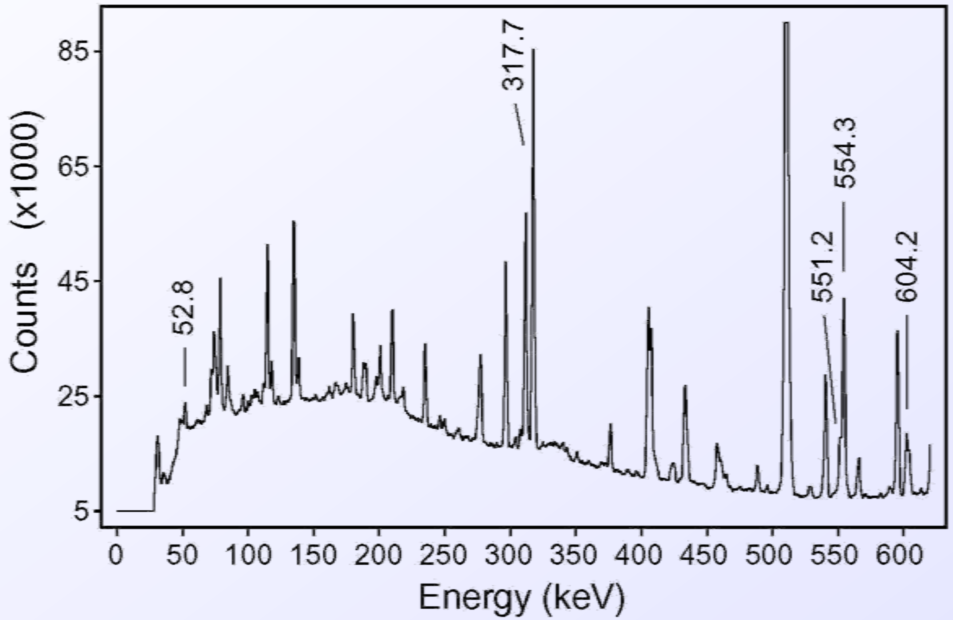
Simple nuclei above ^{132}Sn

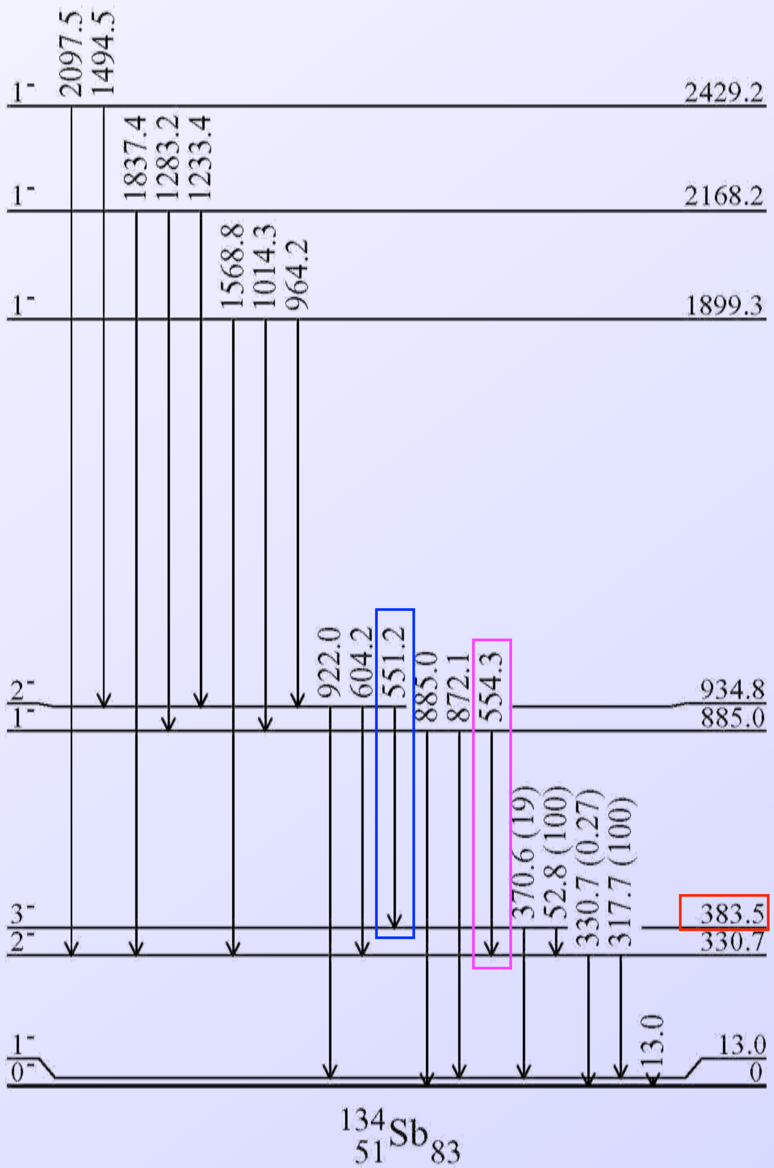
- ✓ Nuclear structure close to the N=82 Z=50 double shell closure
  - → Understanding of the effect of large N/Z
  - → Transition rates required to constraint calculations (^{135}Sb)
  - → Experimental information needed to define better the M1 operator parameters north-east of ^{132}Sn
  - → Evolution of collectivity
- ✓ Topical region for r-process
  - → Nuclear input for modeling
  - → Waiting points
- ✓ IS441 fast-timing experiment at ISOLDE
  - → Sn separated using molecular beams of SnS+
  - → Application of $LaBr_3(Ce)$ to timing

Fast timing RESULTS on ^{134}Sb, ^{135}Sb and ^{136}Te

^{134}Sb (^{132}Sn ⊕ p ⊕ n) results

✓ Strong production of ^{134}Sn



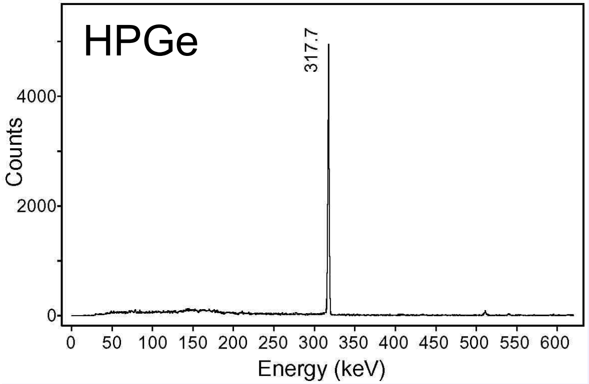


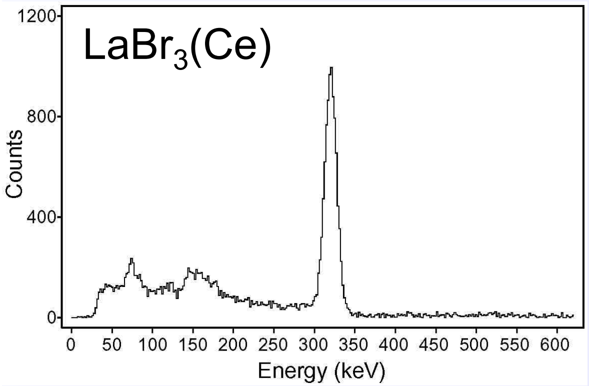
→ Clean spectra

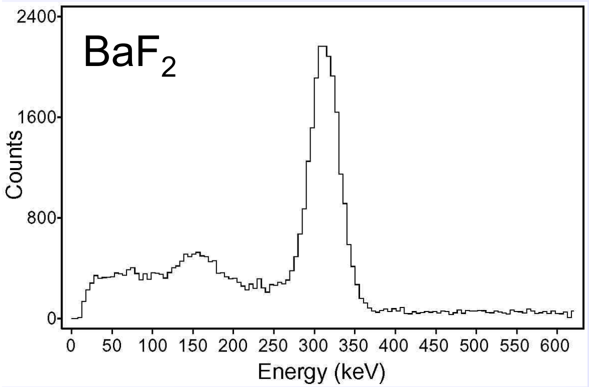
→ Weak branches

→ Fast timing

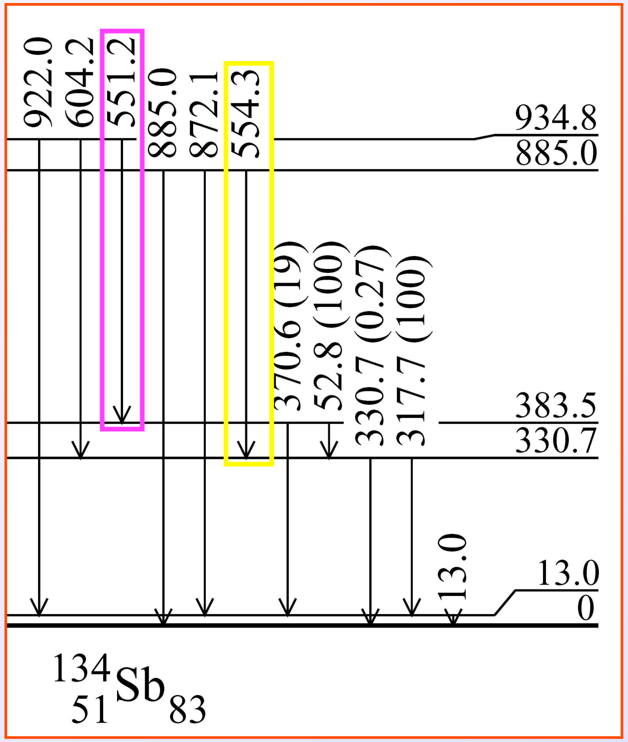
^{134}Sb results: lifetime of 383 keV level



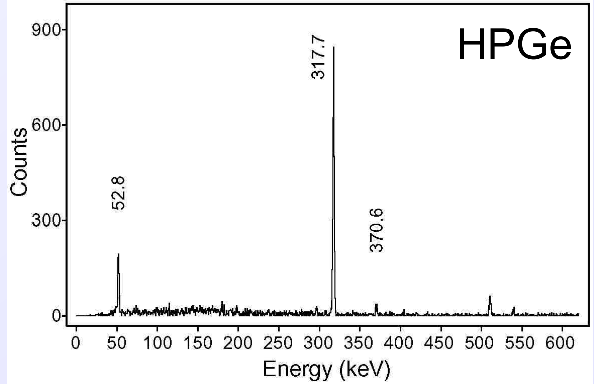


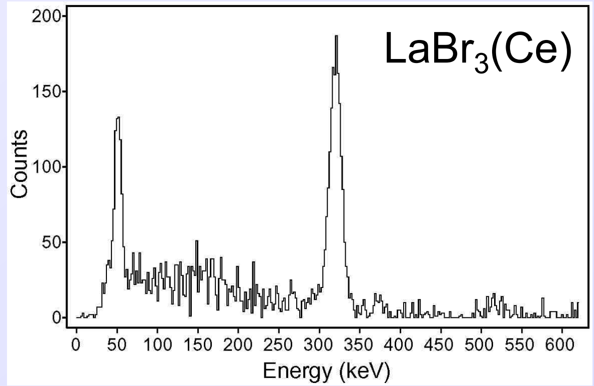


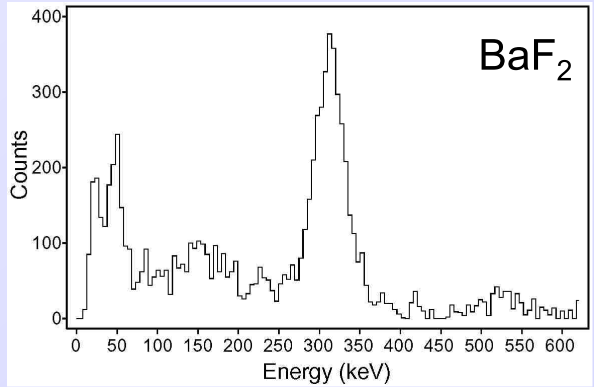
554 keV gate



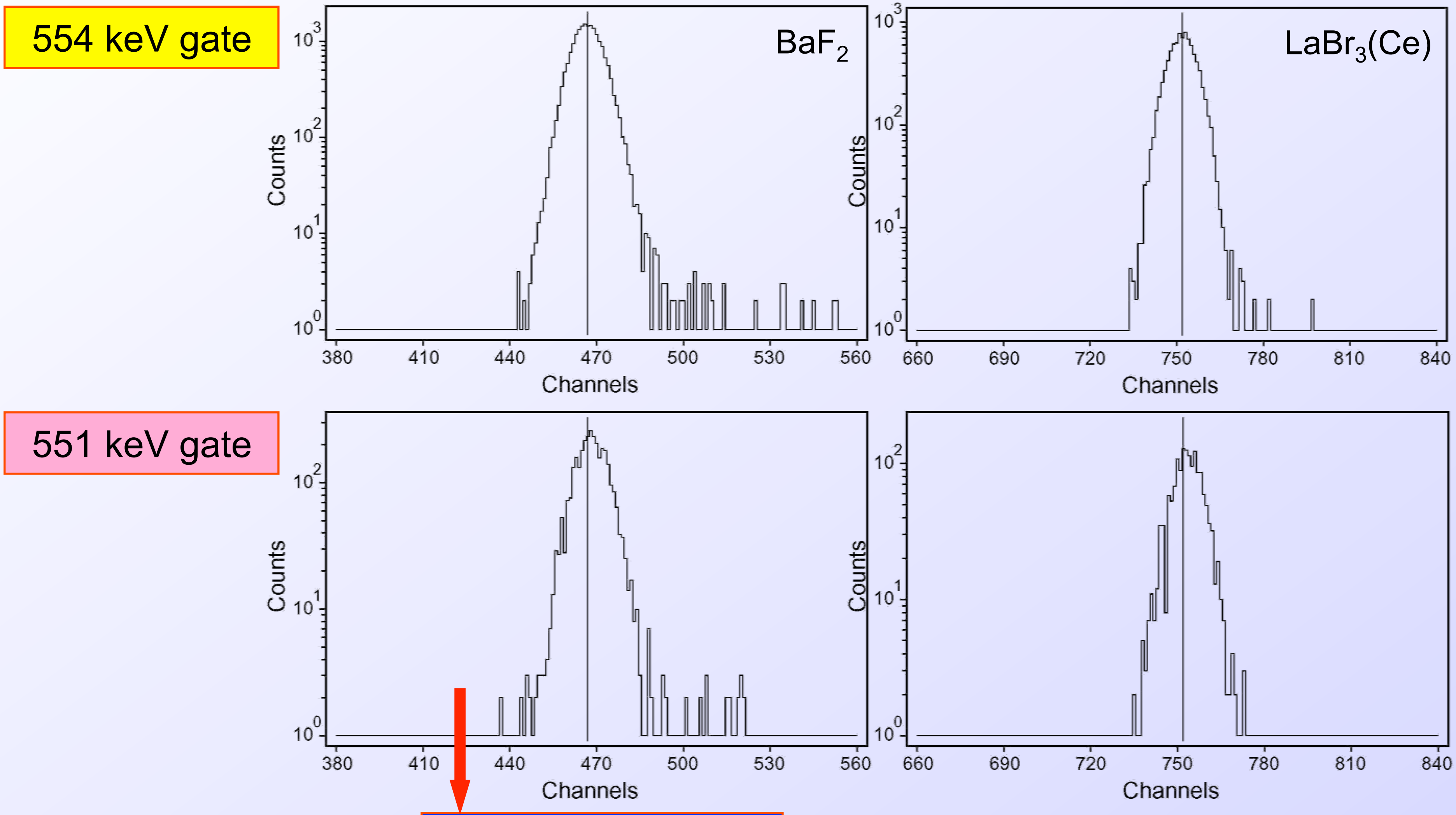
551 keV gate







^{134}Sb results: lifetime of 383 keV level



$T_{1/2}$=26(5) ps

Preliminary!

^{134}Sb results: comparison to shell model

Levels $\pi g_{7/2} \nu f_{7/2}$	Exp (keV)	Brown (keV)	Covello & Gargano (keV)
0^-	0	0	0
1^-	13	333	52
2^-	331	404	385
3^-	383	587	429

Transition	Exp (keV)	Brown* (keV)	Covello Gargano (keV)
$3^- \rightarrow 2^-$	B(M1) = 2.0(0.4) μ_N^2	1.60	1.39
$3^- \rightarrow 1^-$	B(E2) = 118(26) e^2fm^4	84	115

B(M1) is one of the fastest in all known nuclei at the excitation energy below 3 MeV

The region below ^{132}Sn @ PRESPEC

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$\pi\ (0g_{7/2}, 1d_{5/2}, 1d_{3/2}, 2s_{1/2}, 0h_{11/2})^{Z-50}$

^{132}Sn *core*

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54	Xe 126	Xe 127	Xe 128	Xe 129	Xe 130	Xe 131	Xe 132	Xe 133	Xe 134	Xe 135	Xe 136	Xe 137	Xe 138	Xe 139	Xe 140	Xe 141	Xe 142	Xe 143	Xe 144	Xe 145	Xe 146	Xe 147	94		96	
	I 125	I 126	I 127	I 128	I 129	I 130	I 131	I 132	I 133	I 134	I 135	I 136	I 137	I 138	I 139	I 140	I 141	I 142	I 143	I 144	92					
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	72		74		76		78																			

N W E S

^{132}Sn *core*

$\nu\ (1f_{7/2}, 0h_{9/2}, 1f_{5/2}, 2p_{3/2}, 2p_{1/2}, 0i_{13/2})^{N-82}$

Fast-timing elements

Time resolution vs efficiency

- Opposite requirements
- Precision = Resolution (FWHM) / $N^{1/2}$

✓ Photosensors (if PMs)

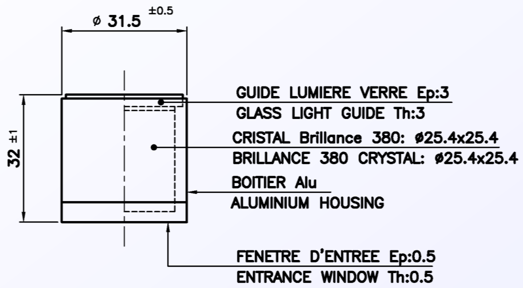
- Best time response phototubes are 2" tubes
- Effective diameter is about 44-46 mm

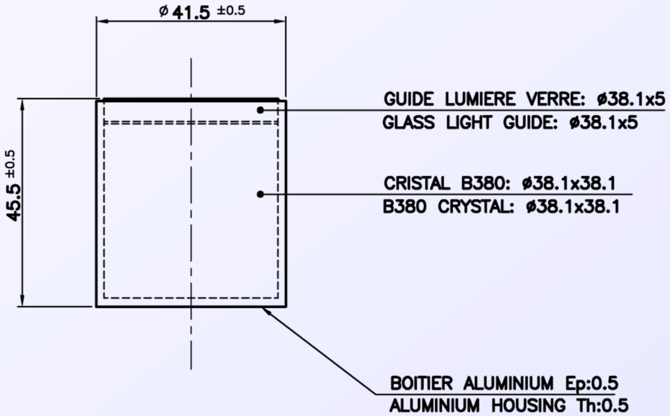
XP20D0
8 stage

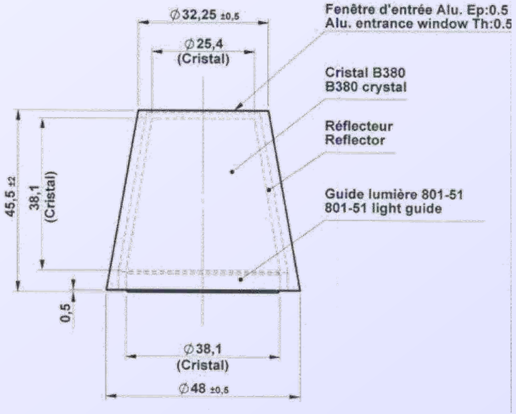
✓ Detectors:

- Experience gained with BaF2 over 20 years applies to LaBr3
- Size ("as small as possible" ;-)
- Shape (but 44-46 mm diamter at base for coupling)

$LaBr_3(Ce)$ detectors







25.4 x 25.4 mm (10%) Ce doping since 2005

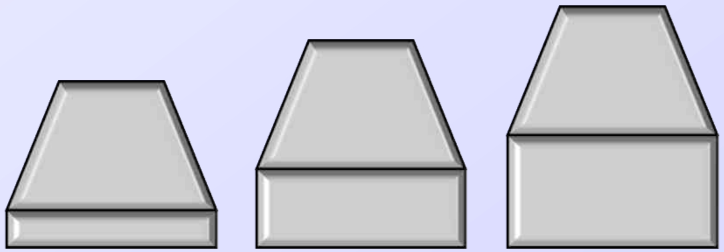
123(5) ps FWHM (@1.3 MeV)

38.1 x 38.1 mm 5% Ce doping since 2007

150(10) ps FWHM

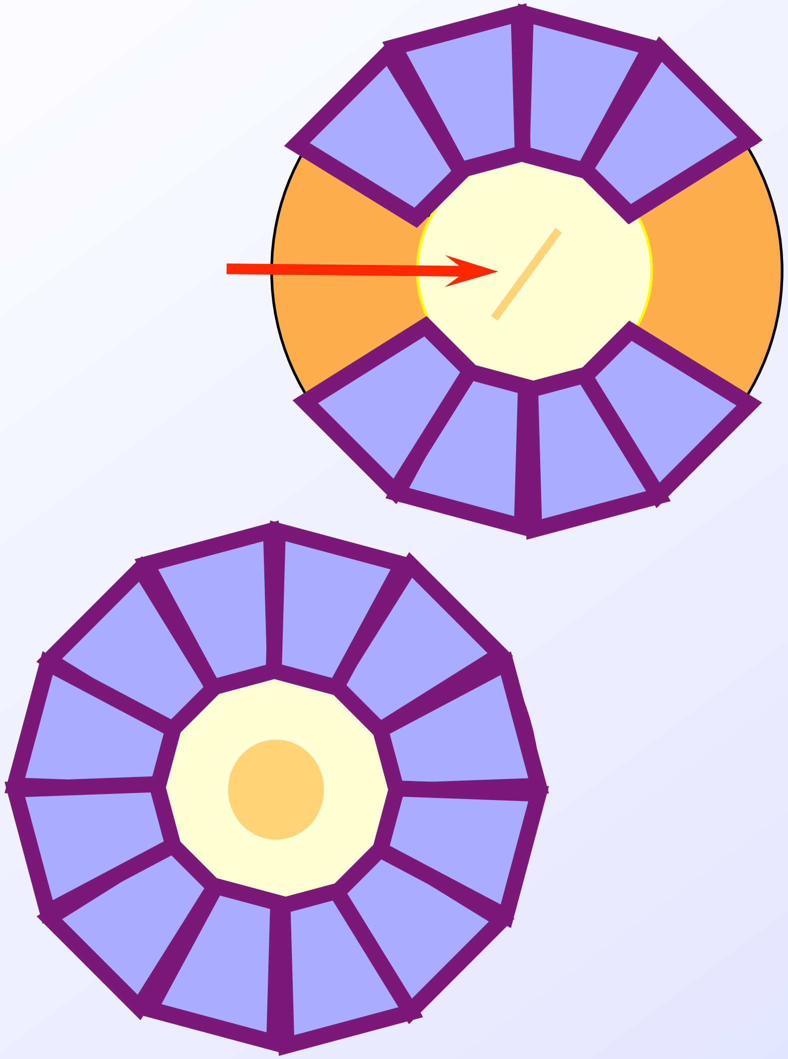
38.1/25.4 x 38.1 mm 5% Ce (2009)

Time resolution 140-145 ps FWHM at 1.3 MeV - Tested ISOLDE



30% better for BaF_2

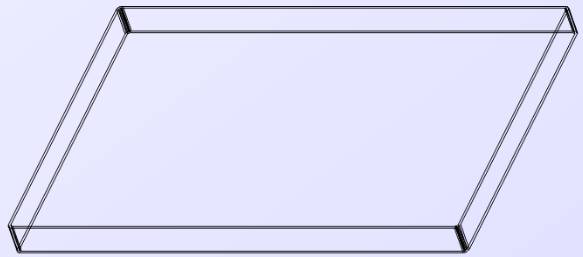
Basic array at DESPEC



✓ Beta decay

→ AIDA DSSSD too slow

→ Needs "few" 100 ps instead



→ Segmentation

✓ Isomeric decays

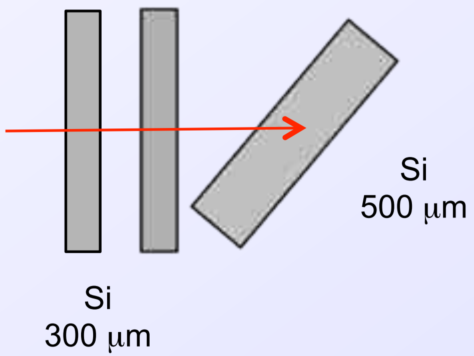
→ Coupling with AIDA ?

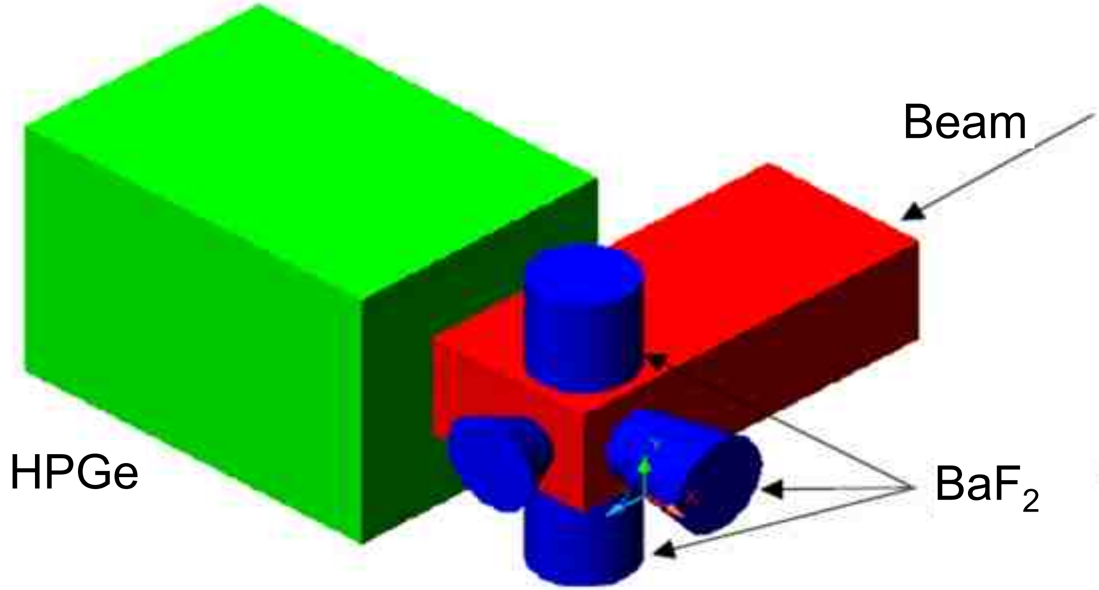
- 36-48 $LaBr_3(Ce)$ detectors in rings around the target
- using 9-12 clusters of 4 individually-shielded crystals

Isomeric decays

Fast timing $\gamma\gamma(t)$: isomers at GANIL

✓ Experiments at LISE (GANIL)





L.M. Fraile

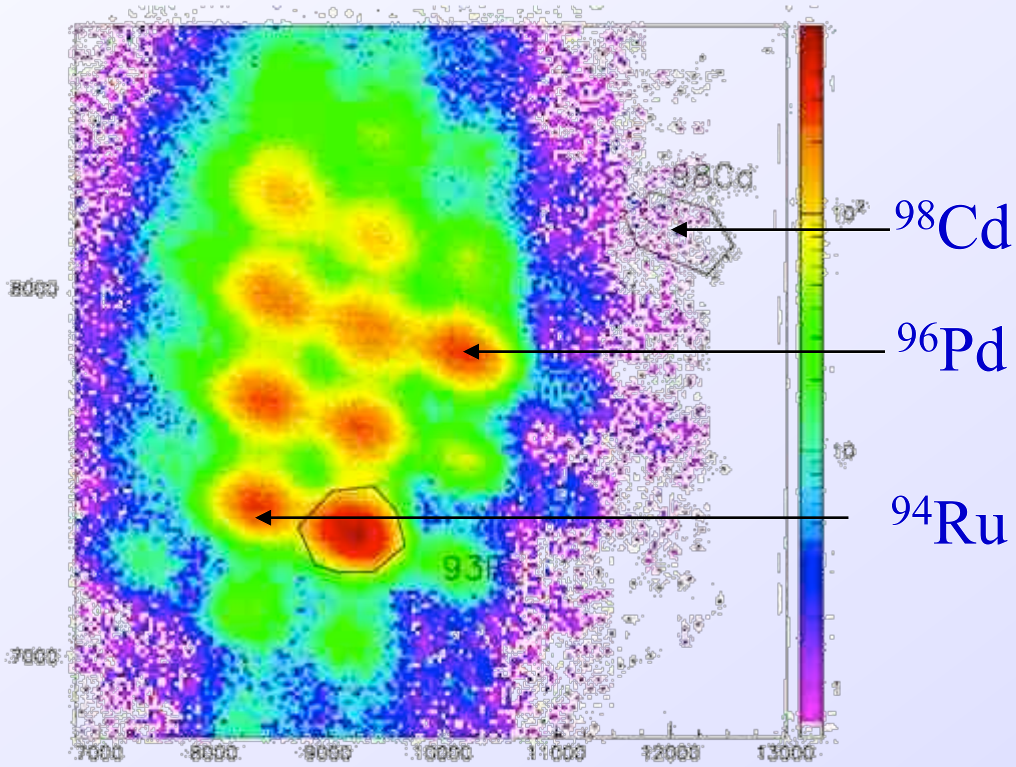
Fast timing γγ(t): isomers at GANIL

1 EXOGAM clover Ge and 4 large fast timing BaF_2 detectors.

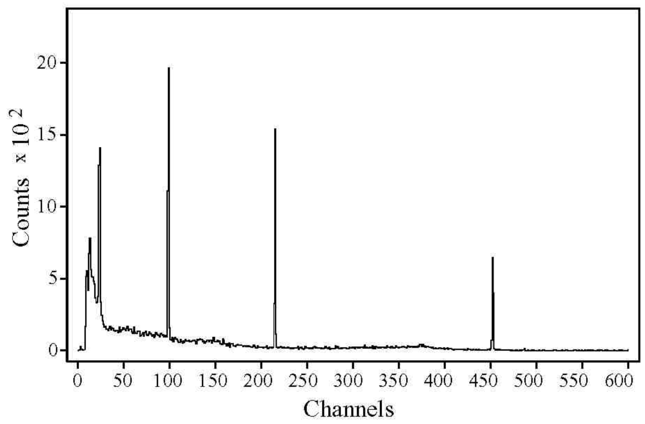
[H. Mach et al.]

Trigger on arriving ion

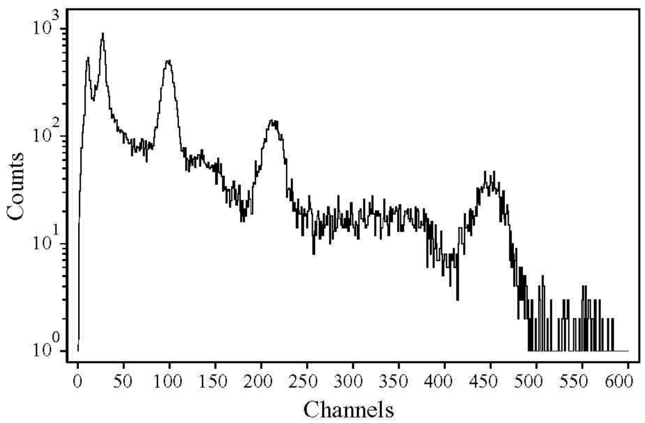
Long lifetimes of the 8^+ isomers



States below 8^+ in ^{96}Pd

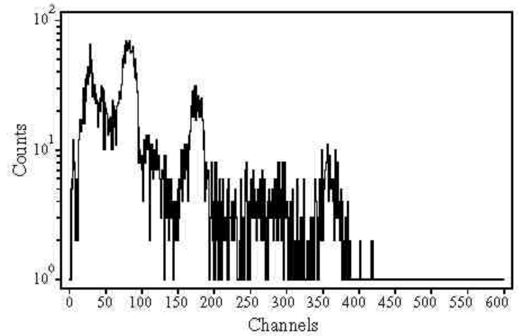


^{96}Pd: gamma-ray spectrum observed in the clover Ge detector, one observes the 106, 325, 684, and 1415 keV transitions, but no 511 e+e-.

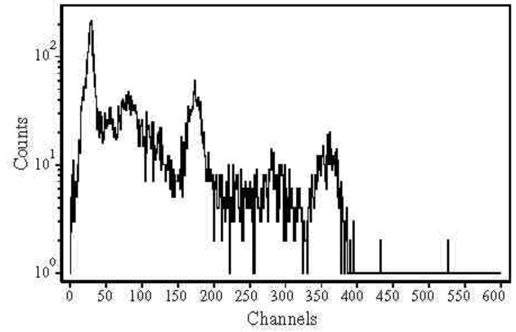


The same as above but in the BaF2 detector

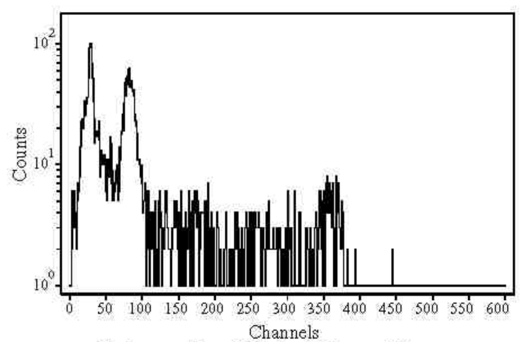
Ordering gamma rays below isomers: BaF_2.



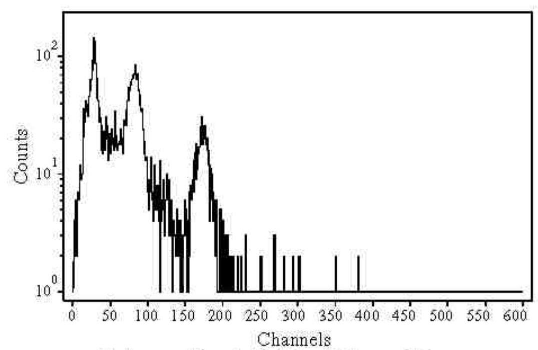
Gate on the 106 keV transition



Gate on the 325 keV transition



Gate on the 684 keV transition



Gate on the 1415 keV transition

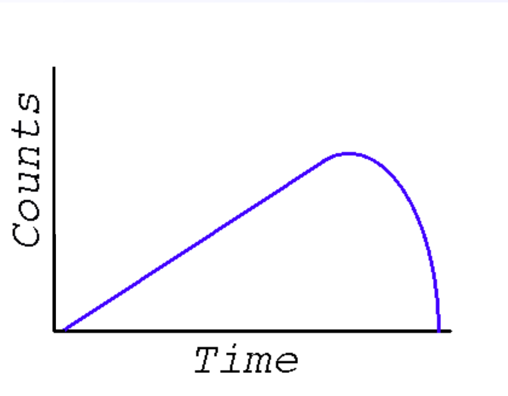
^{96}Pd: 8^+ seniority isomer, BaF_2-BaF_2 coincidences

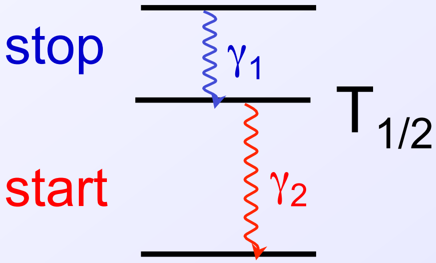
Good statistics – rate of about 2 isomers/s.

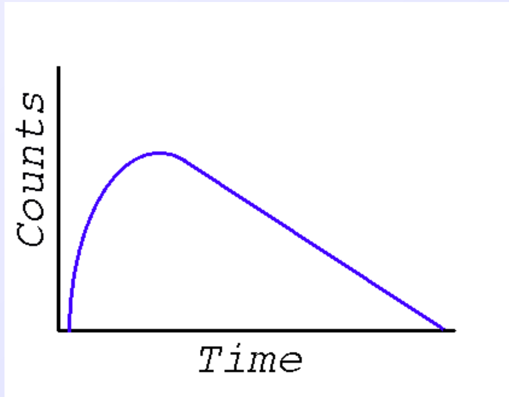
[H. Mach et al.]

The $\gamma\gamma(t)$ method (isomers)

BaF_2–BaF_2 / $LaBr_3$–$LaBr_3$: lifetime measurements







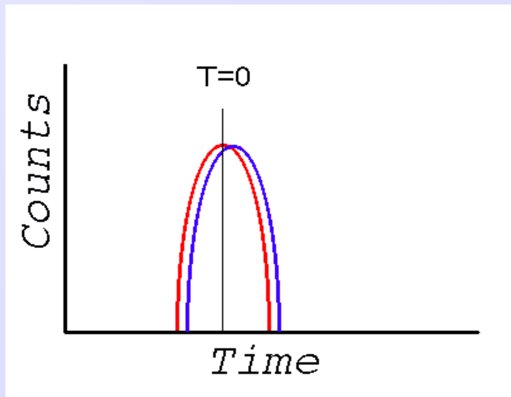
TAC

De-convolution of slope

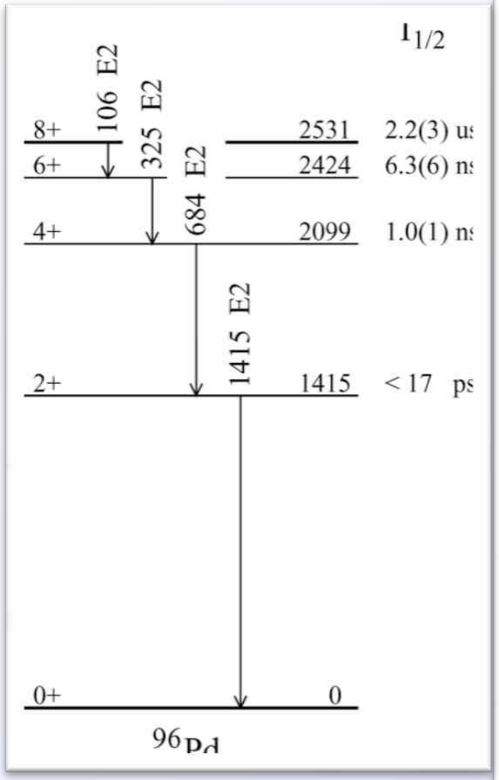
- Slope = $T_{1/2}$
- Range: 30 ps to 30 ns (or longer)

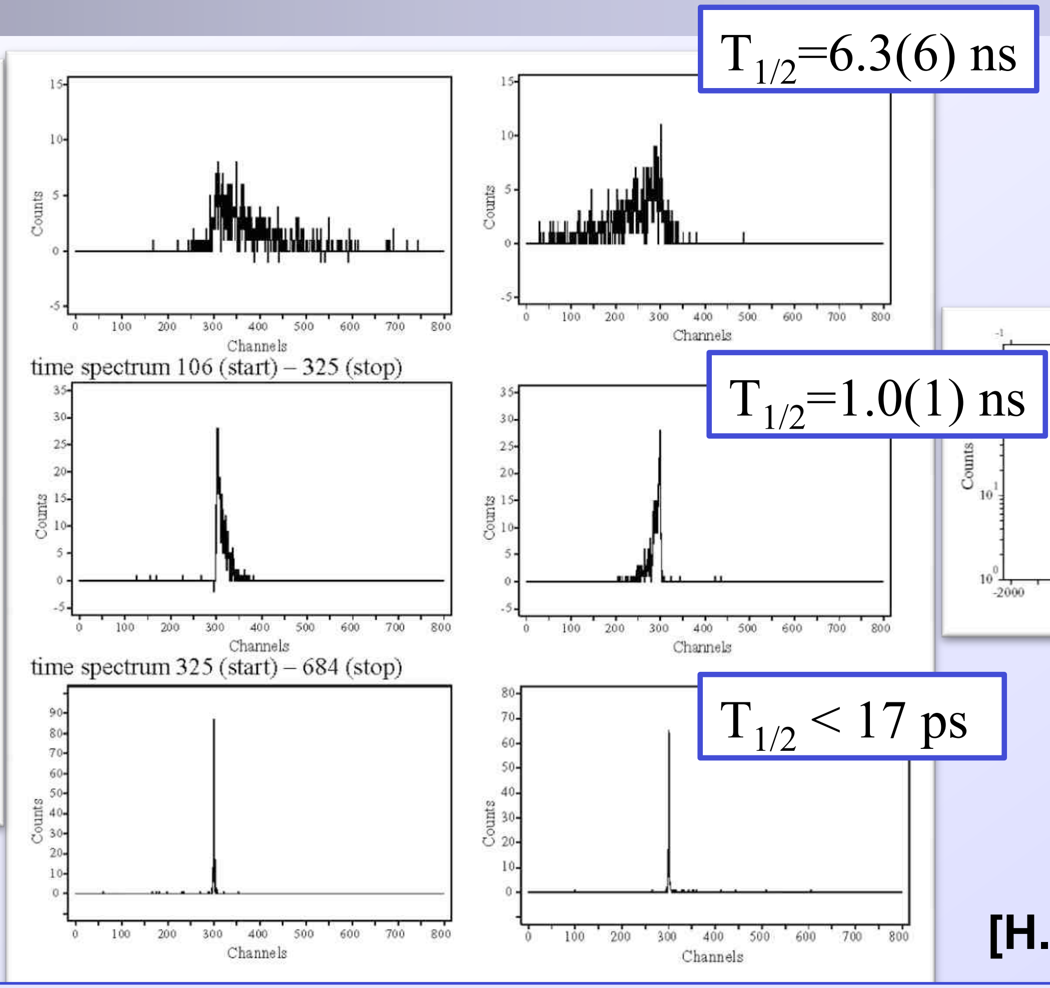
Centroid shift

- Shift in centroid position = 2τ
- Range: down to ~5-10 ps

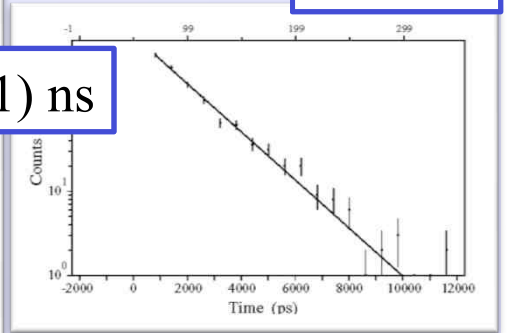


^{96}Pd results – ^{98}Cd PRESPEC





summed

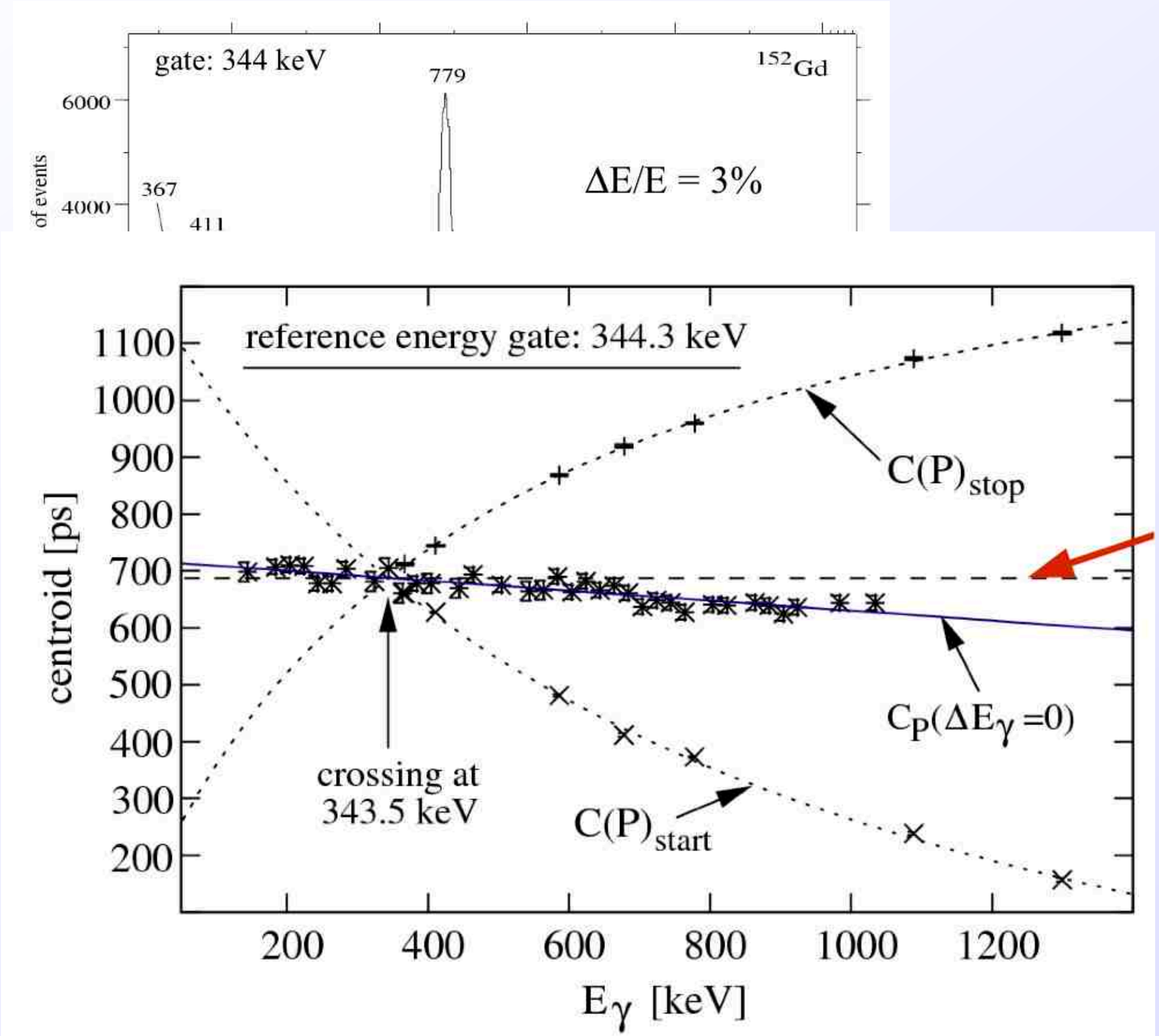


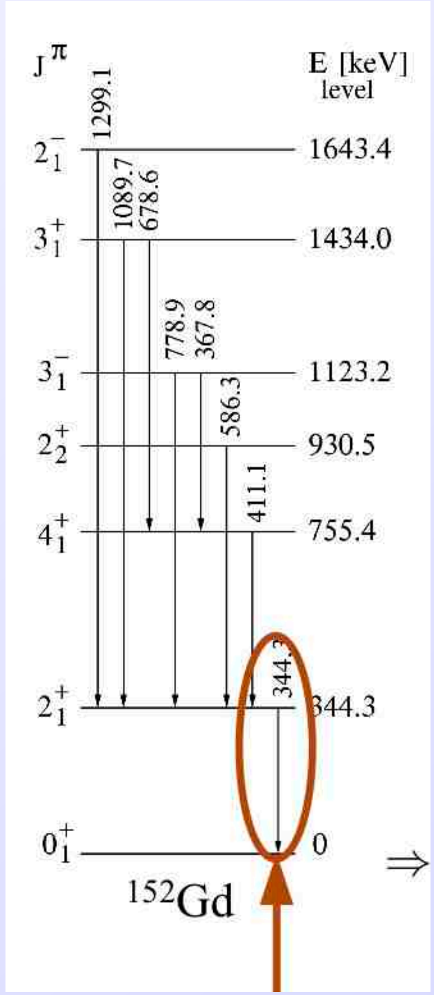
[H. Mach et al.]

Time-delayed spectra due to the 6+, 4+ and 2+ states in ^{96}Pd from the BaF_2-BaF_2(t) coincidences plotted on the same time scale.

Note a unique assignment of gamma-rays into the sequence in the cascade.

Prompt calibration with $LaBr_3(Ce)$





[J-M Régis, NIM A 622 (2010) and PhD thesis to come soon]

FINIS