β-decay studies of neutron rich $^{61-70}$Mn isotopes with the new LISOL β-decay setup

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U. Koster, *ILL, Grenoble, France*
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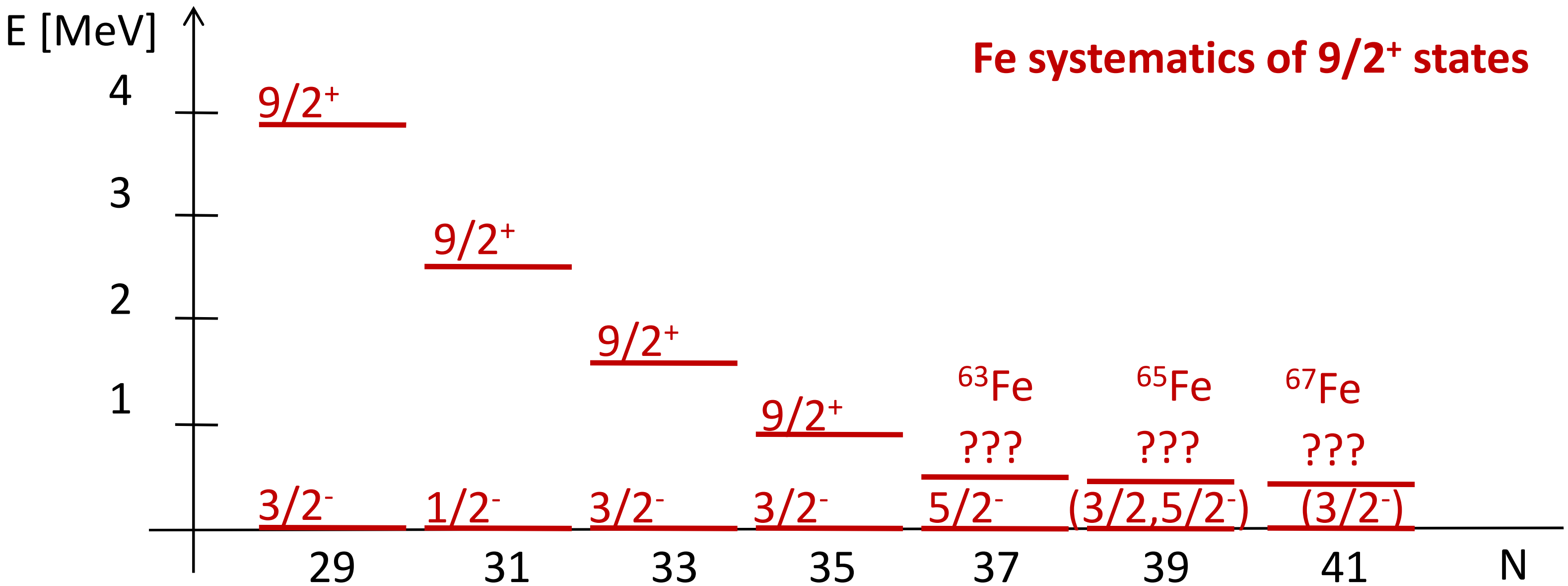
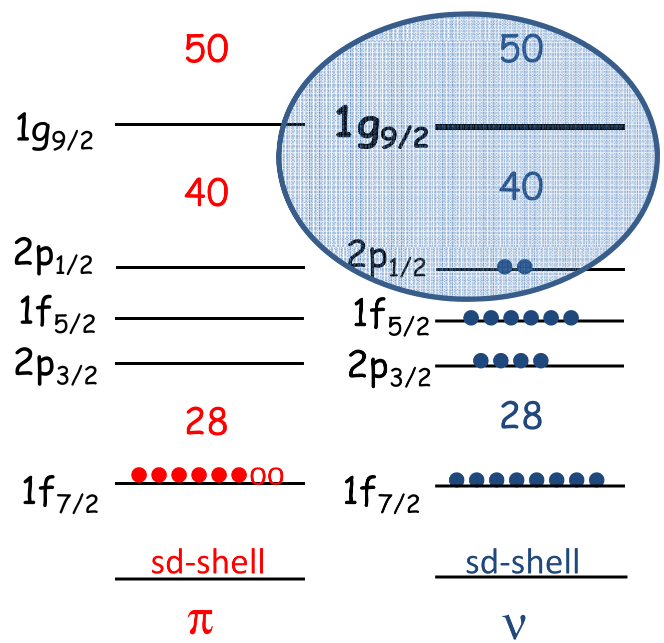
2. Previous and proposed experiment
3. The LISOL β-decay setup
4. Contamination and Yields
5. Conclusions

Fe systematics of 9/2⁺ states





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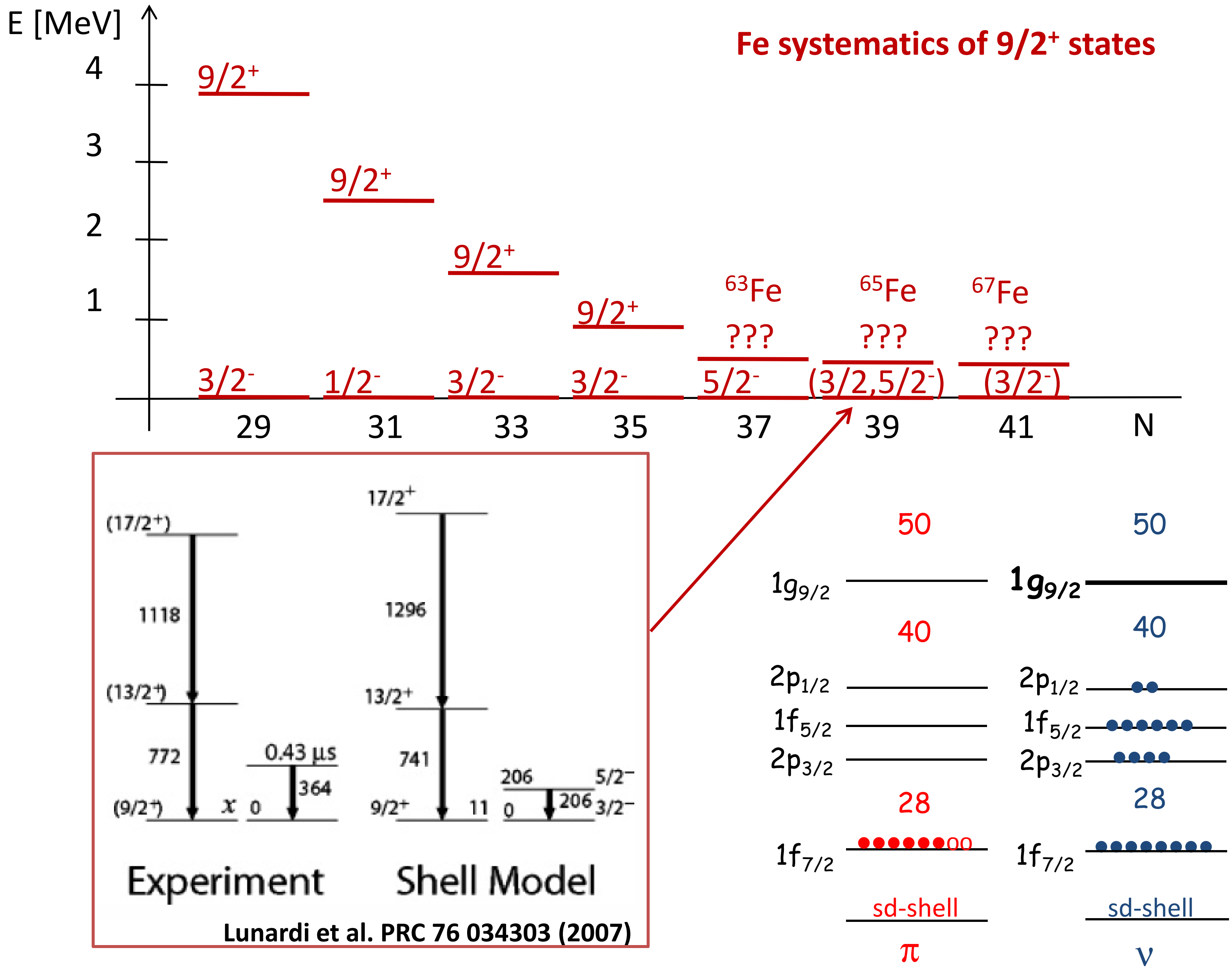

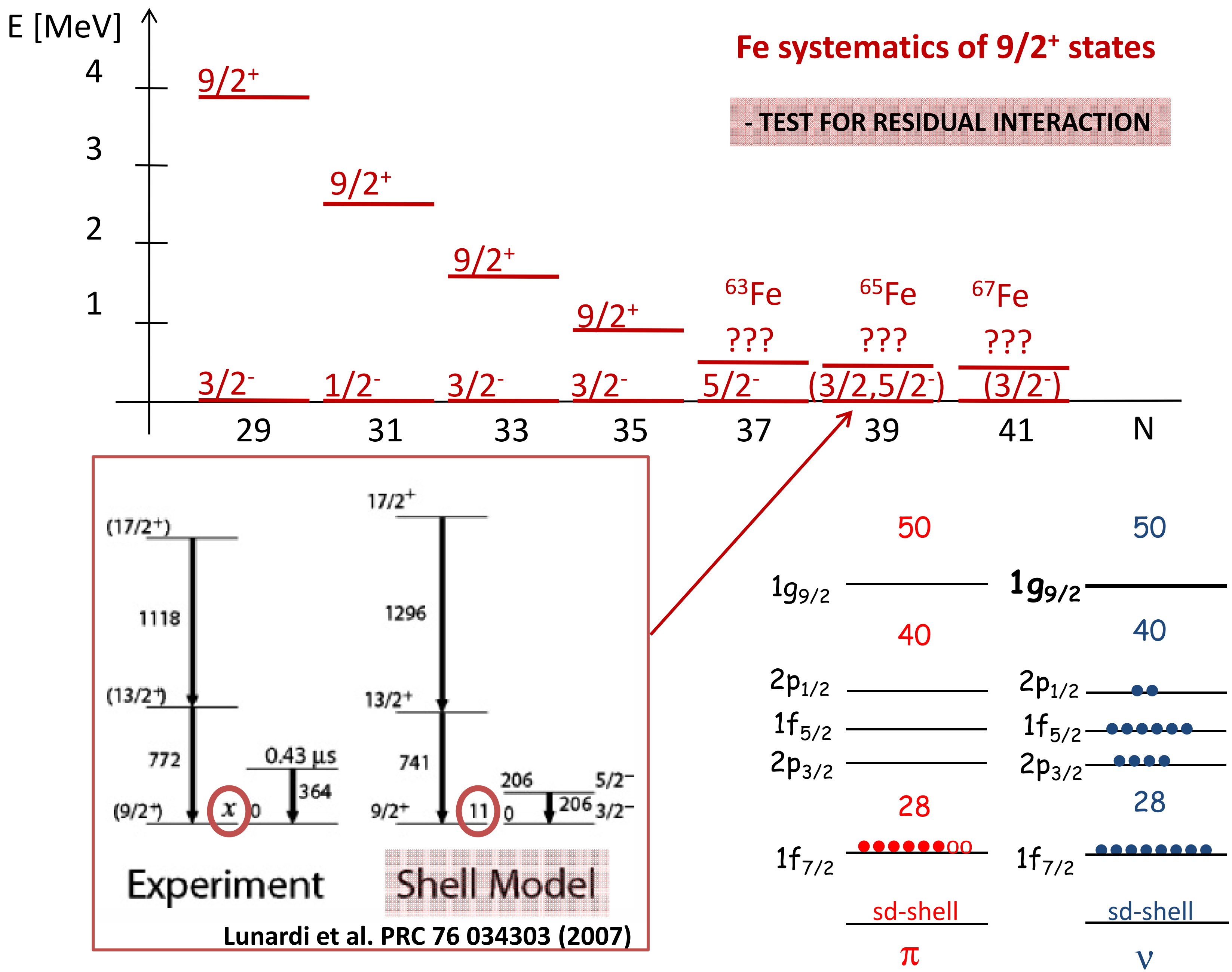
Fe systematics of 9/2+ states
- TEST FOR RESIDUAL INTERACTION
E [MeV]
4
3
2
1
9/2+
9/2+
9/2+
9/2+
3/2-
1/2-
3/2-
3/2-
63Fe
???
5/2-
65Fe
???
(3/2,5/2-)
67Fe
???
(3/2-)
29
31
33
35
37
39
41
N
(17/2+)
1118
(13/2+)
772
(9/2+)
x
0
0.43 µs
364
17/2+
1296
13/2+
741
9/2+
11
0
206
5/2−
206
3/2−
Experiment
Shell Model
Lunardi et al. PRC 76 034303 (2007)
50
1g9/2
40
2p1/2
1f5/2
2p3/2
28
1f7/2
sd-shell
π
50
1g9/2
40
2p1/2
1f5/2
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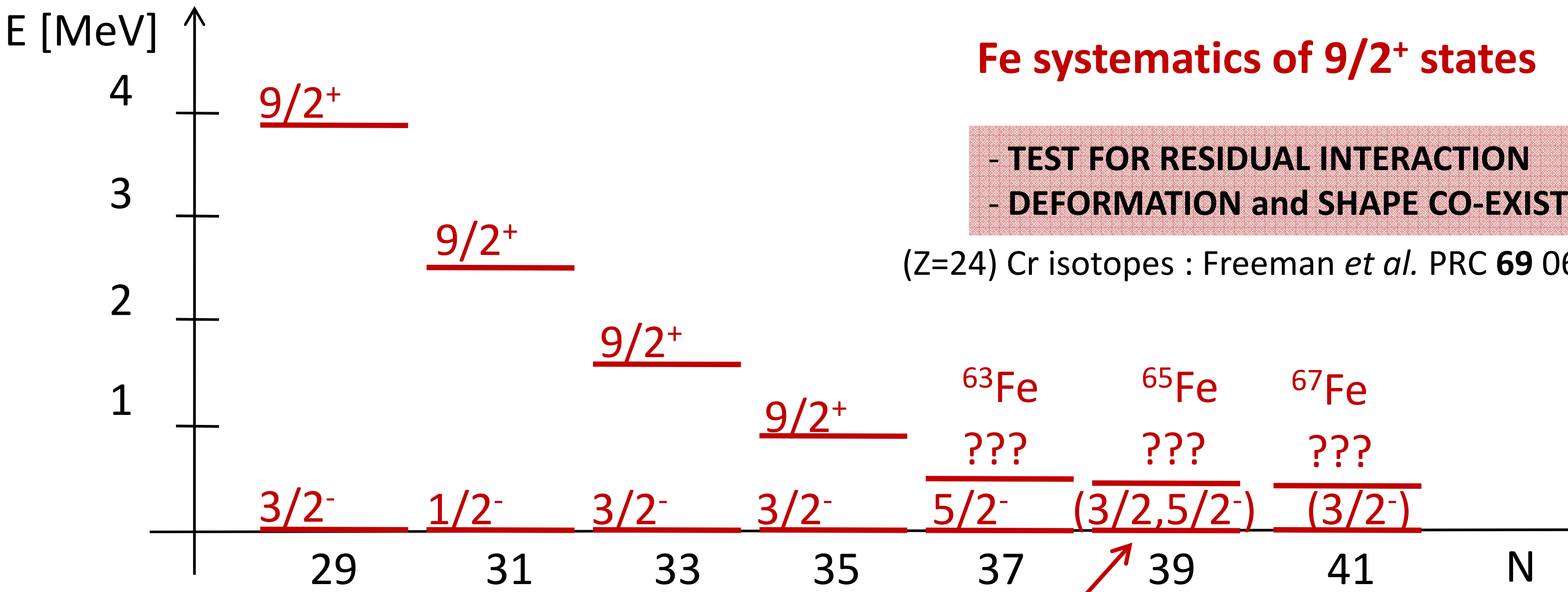
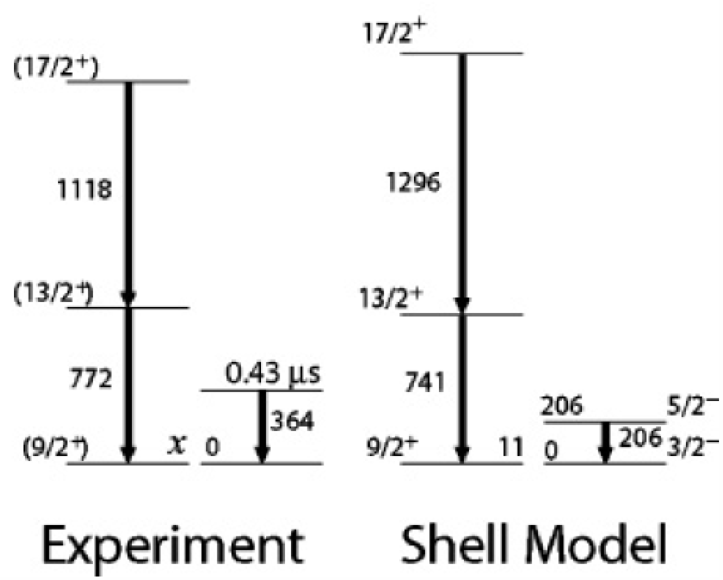
28
1f7/2
sd-shell
ν

Fe systematics of 9/2+ states

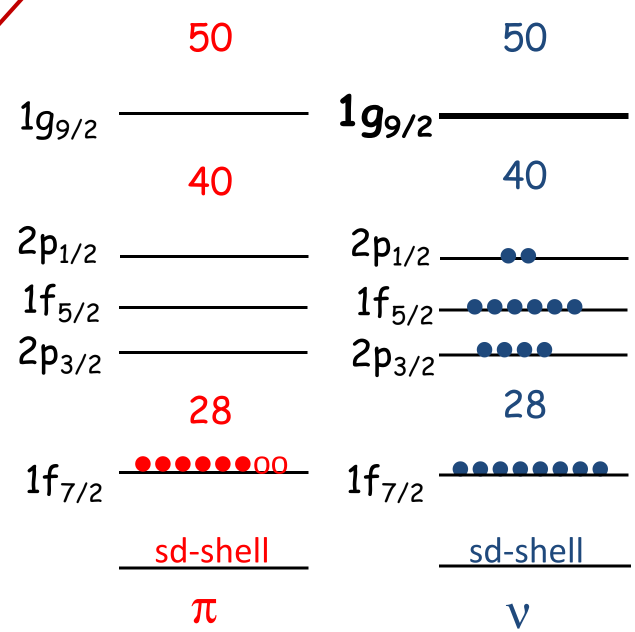
- TEST FOR RESIDUAL INTERACTION
- DEFORMATION and SHAPE CO-EXISTENCE

(Z=24) Cr isotopes : Freeman *et al.* PRC **69** 064301 (2004)



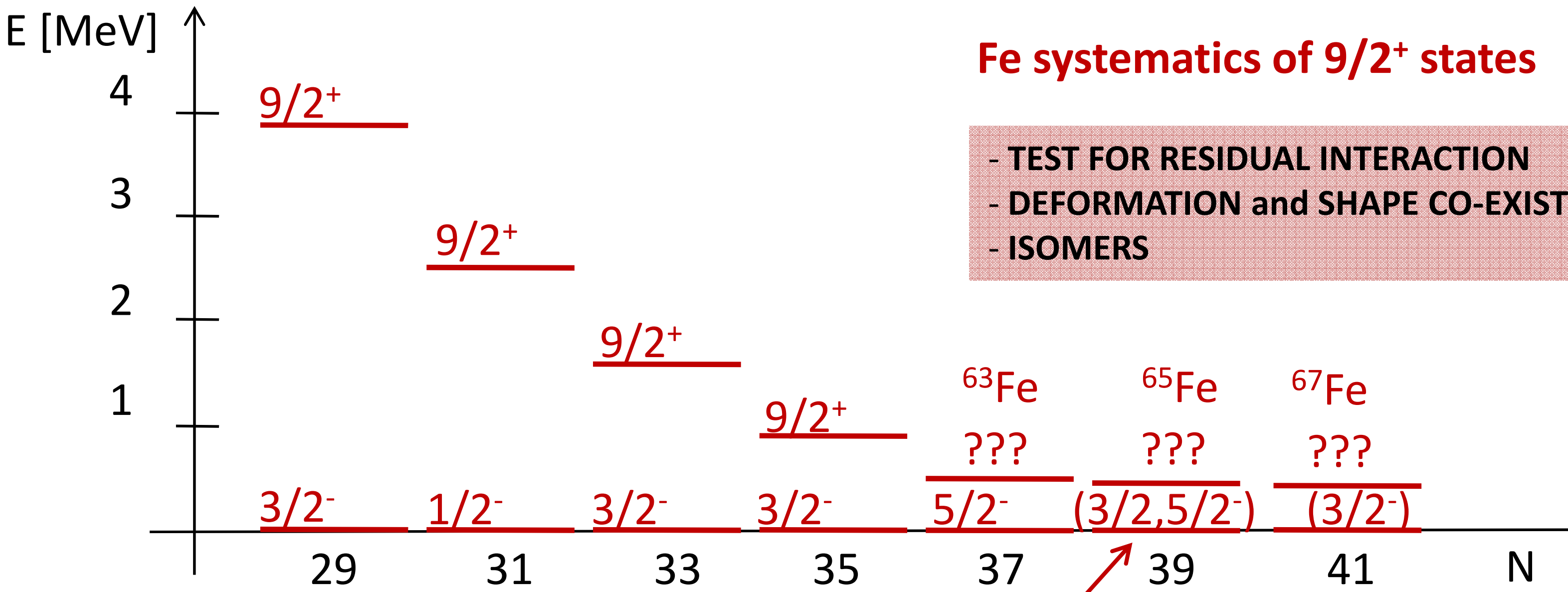


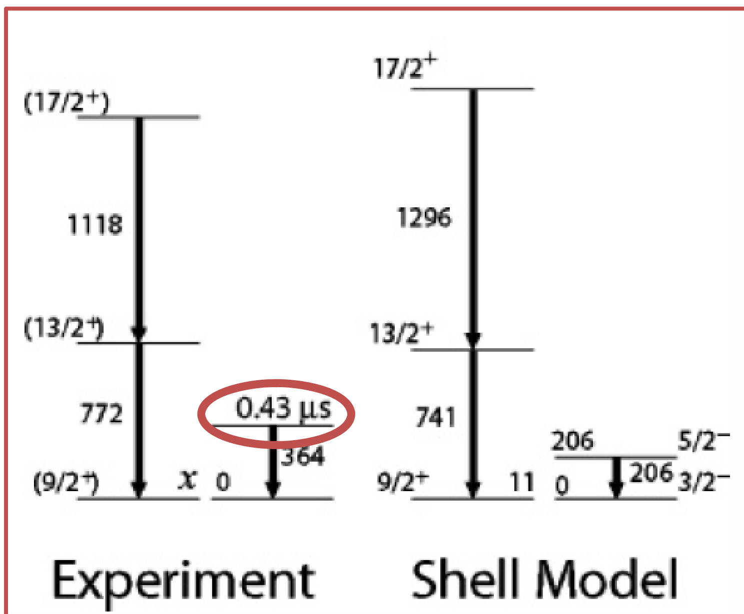
Lunardi et al. PRC 76 034303 (2007)



Fe systematics of $9/2^+$ states

- TEST FOR RESIDUAL INTERACTION
- DEFORMATION and SHAPE CO-EXISTENCE
- ISOMERS





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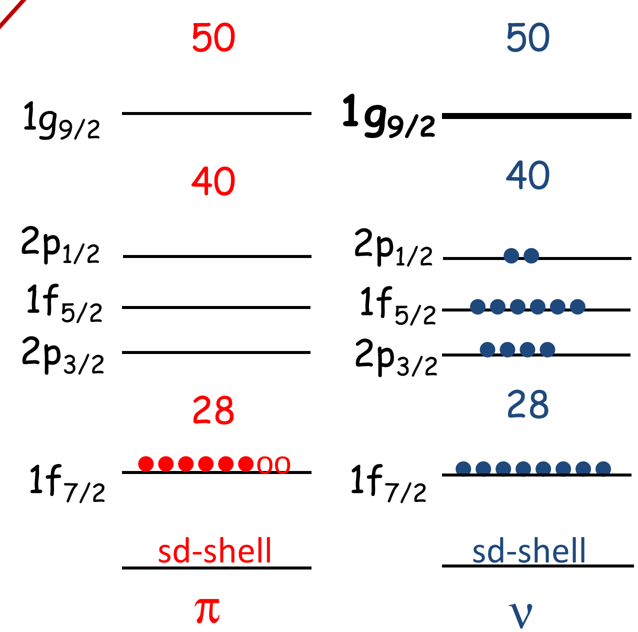
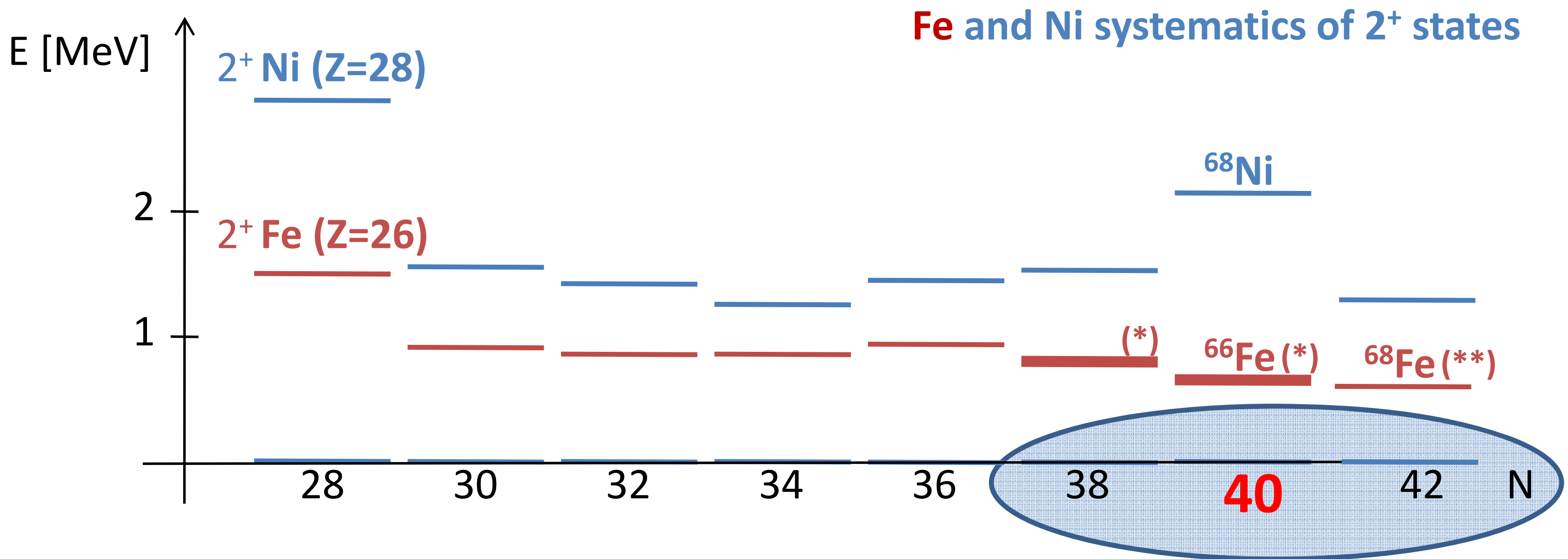
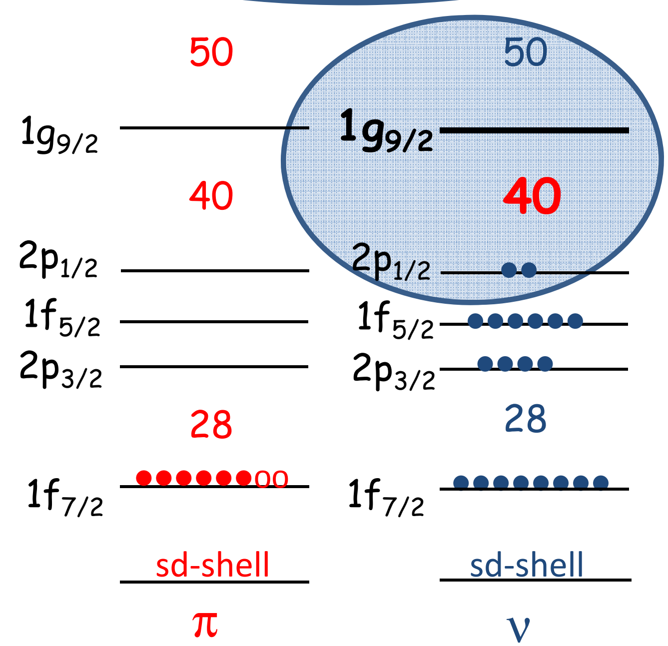


Fe and Ni systematics of 2^+ states



(**) β-decay study ^{68}Mn at GANIL (2006)
J.M. Daugas et al., AIP Conf Proc 831 p 427-429

(*) β-decay study ^{64,66}Mn at ISOLDE (1998)
Hannawald et al. PRL 82 1391 (1999)



1998 : "EXTENDED TARGET TEST" …

yielding surprisingly interesting physics !!!

β-decay study at ISOLDE of ^{64,66}Mn
M. Hannawald, PhD dissertation Mainz universitat 1999

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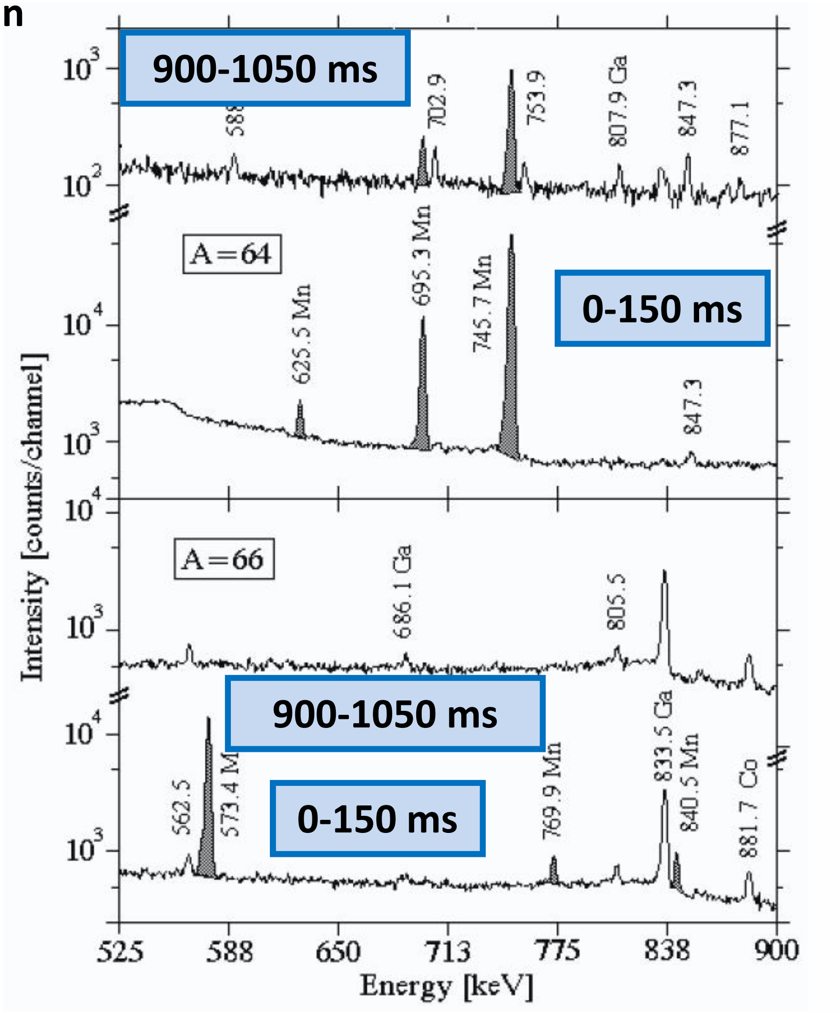

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PROPOSAL 2008 : extended β-decay study at ISOLDE of $^{61-70}Mn$

- **Singles AND β-gated γ-ray spectra**
- **NEW TECHNOLOGY :**
  - **Two segmented MINIBALL cluster detectors**
  - **Digital electronics : TOTAL DATA READOUT**
- **Use the unique Mn beams at ISOLDE again :**
  - **one of the highest laser ionization efficiencies**
  - **"standard" beam with UC_x target since 1998**
- **Physics :**
  - **Search for isomeric states ;**
  - **Spin and parity assignments in $^{61-70}Fe$;**
  - **Probe deformation and shape co-existence in this region ;**

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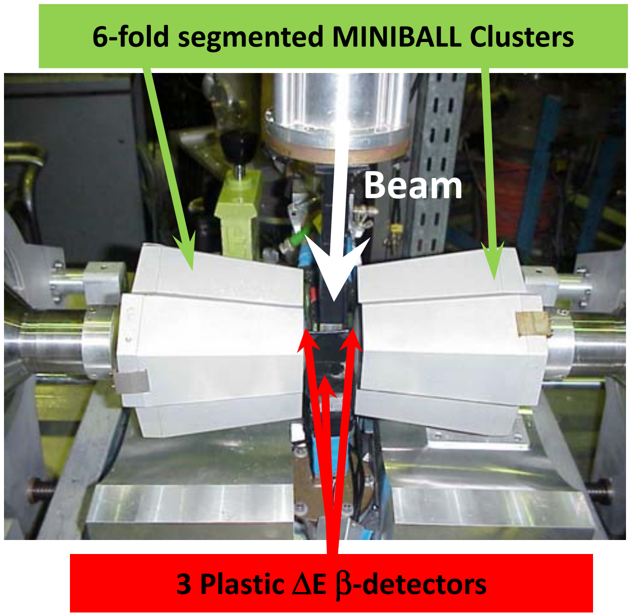
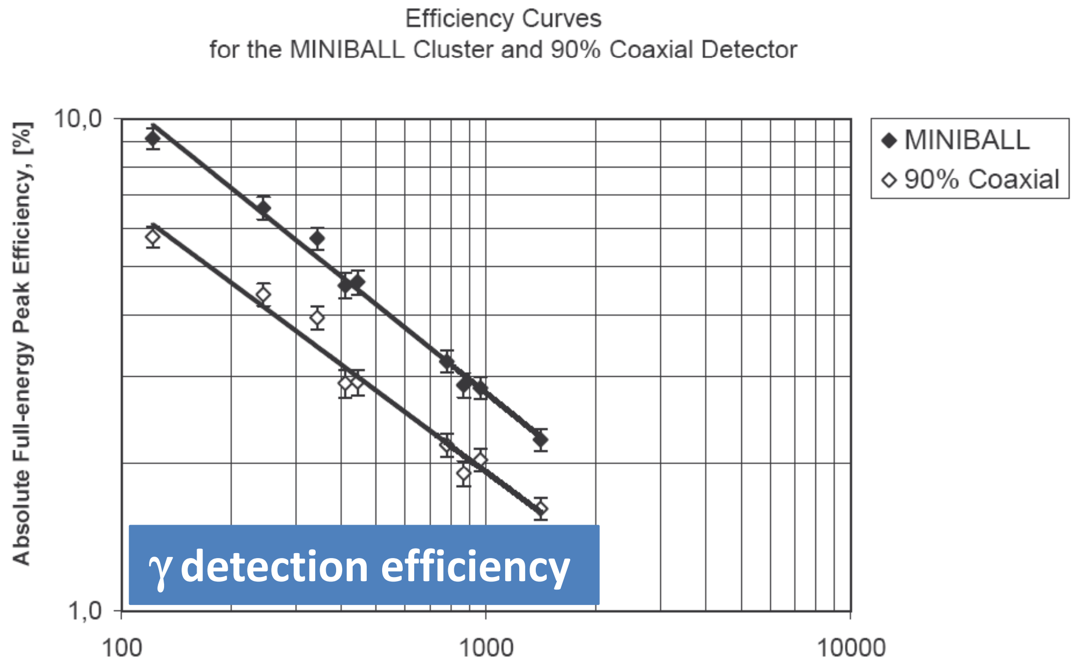
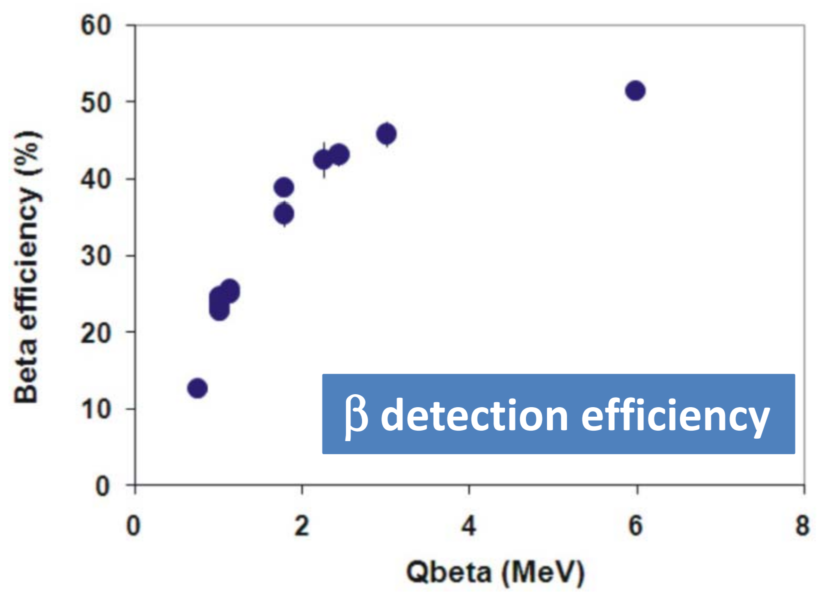
Pictures taken from O. Ivanov, PhD Thesis, KU Leuven, 2007







✓shielding (polyethylene-borax-Cu-Lead)
✓digital electronics readout
✓high segmentation (6 cores, 36 segments) reduces "true coincidence summing effects"

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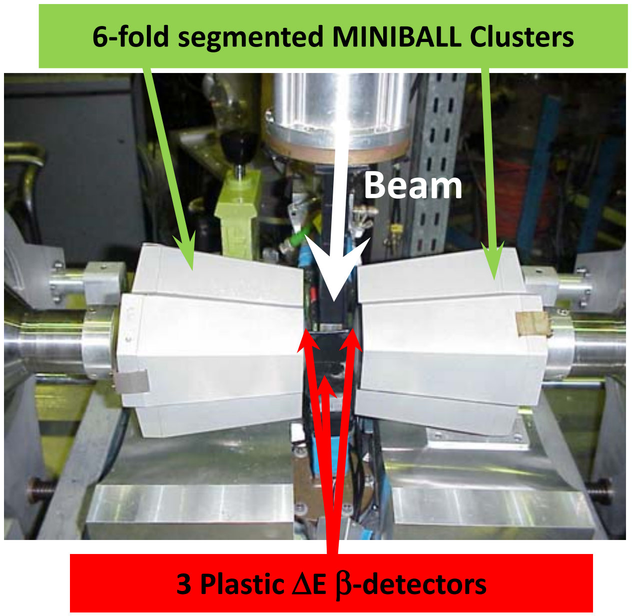
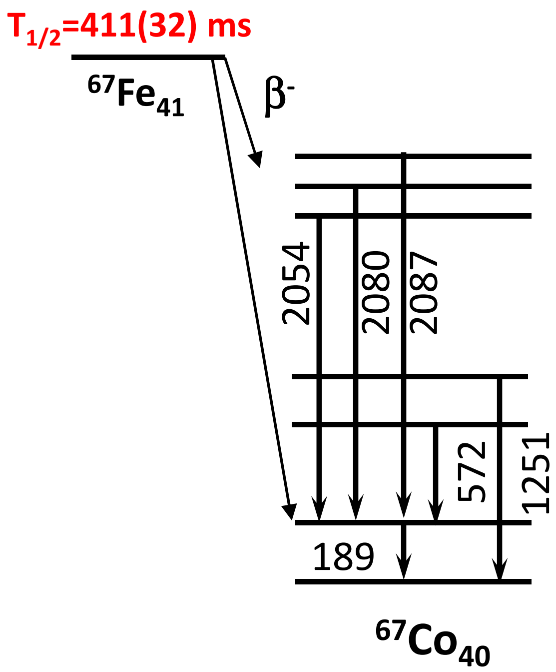


✓shielding (polyethylene-borax-Cu-Lead)
✓digital electronics readout
✓high segmentation (6 cores, 36 segments) reduces "true coincidence summing effects"

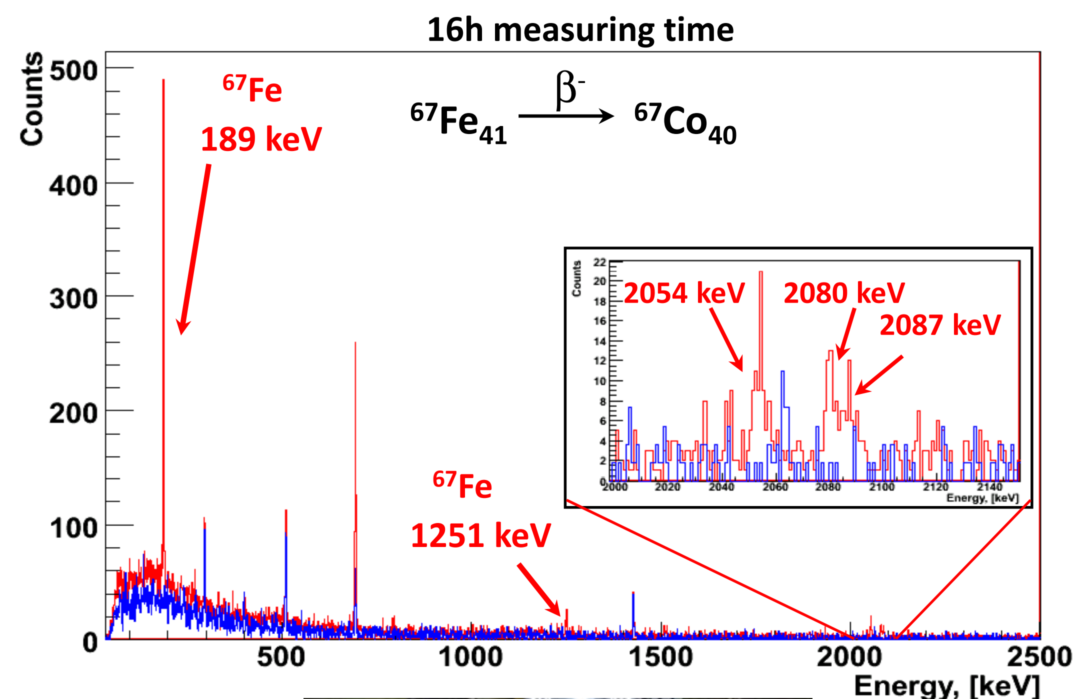
⇒Coincidences and Correlations (γ-γ, βγ-γ, …) are performed OFFLINE
⇒ TOTAL DATA READOUT

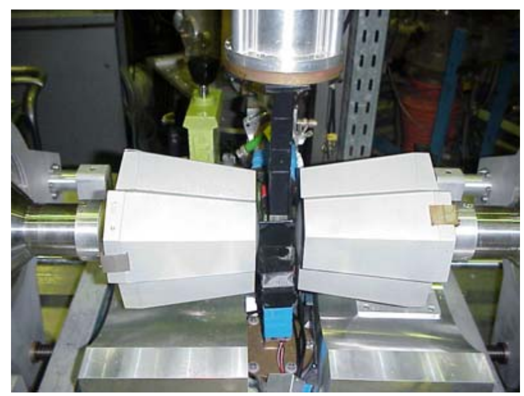
^{67}Fe-^{67}Co-^{67}Ni decay chain

D. Pauwels, NIM B, to be published 2008



β-gated γ-spectra: Red: Laser ON Blue: Laser OFF





Pictures Courtesy D. Pauwels O. Ivanov, KU Leuven (2007)

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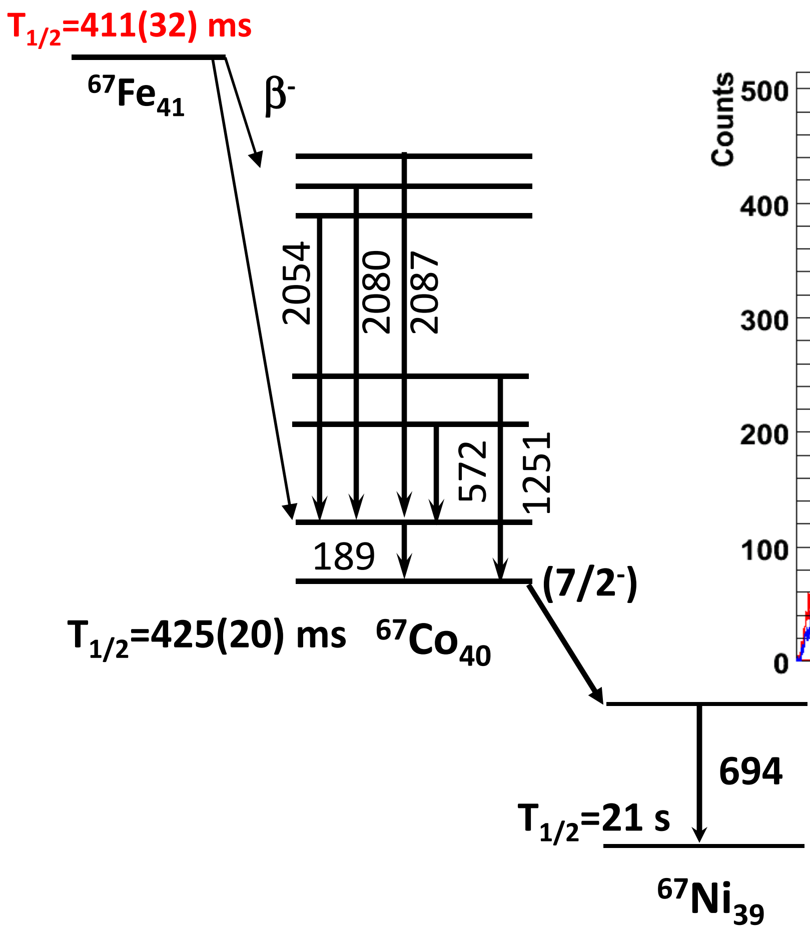
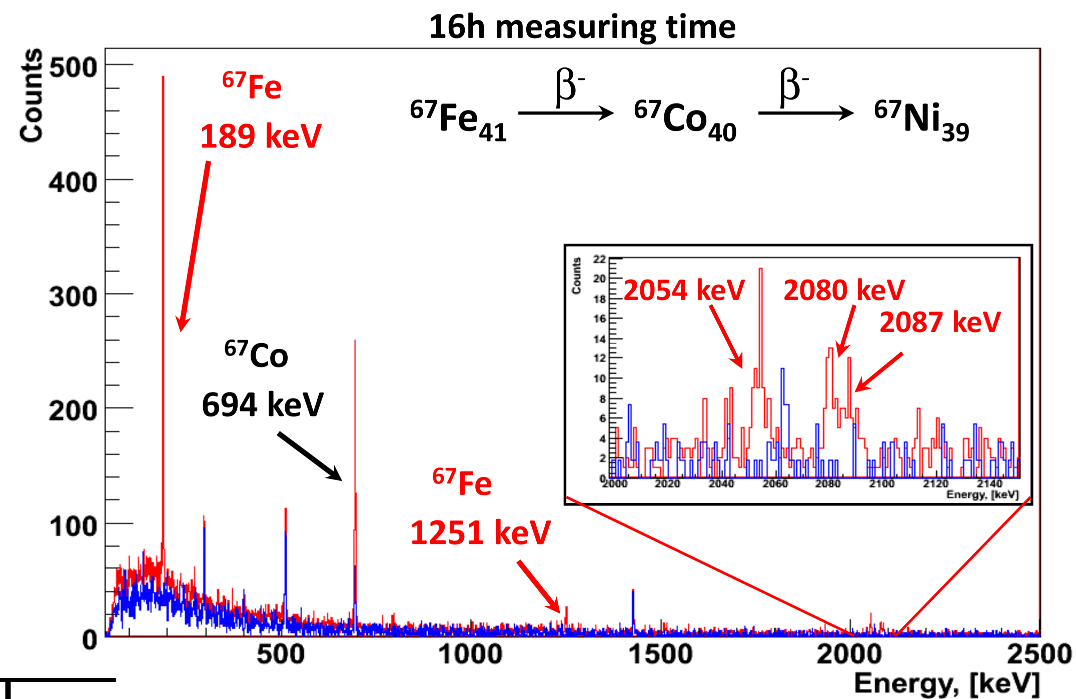
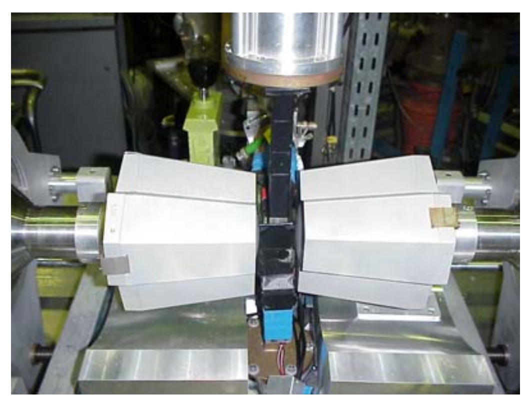


L. Weissman et al., PRC 59, 2004(1999).

β-gated γ-spectra: Red: Laser ON Blue: Laser OFF





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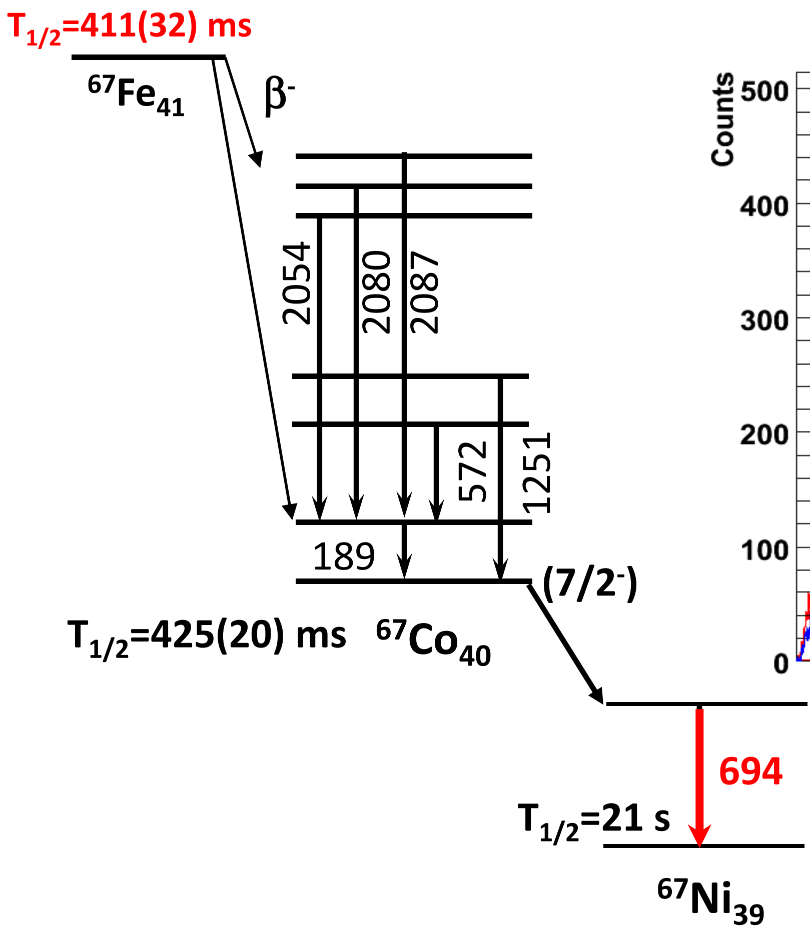

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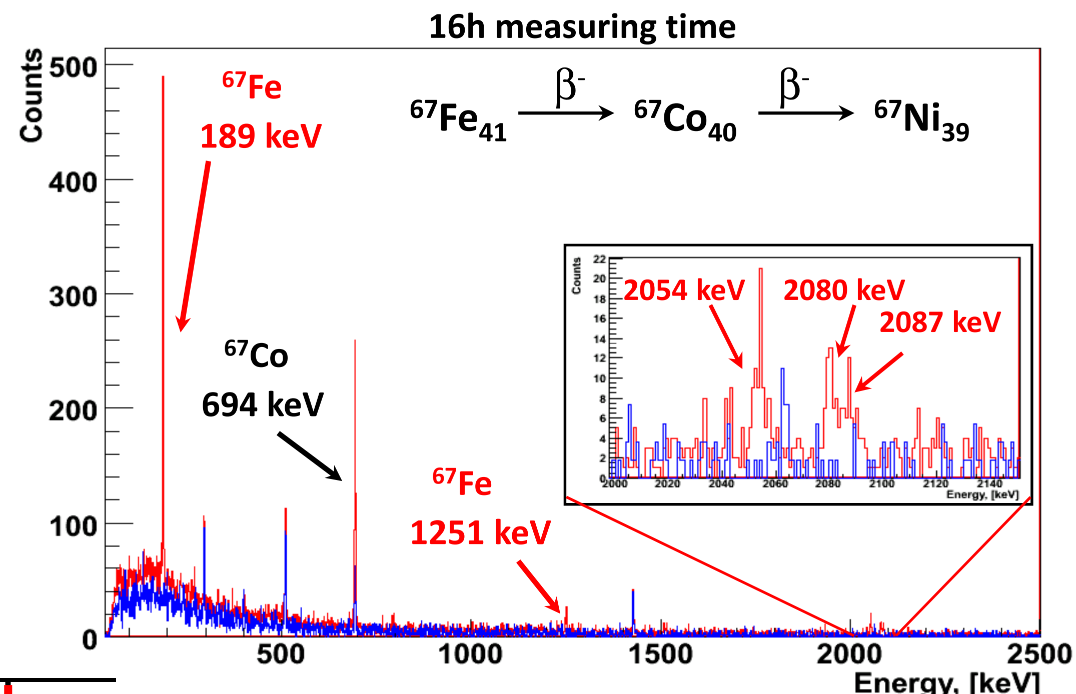

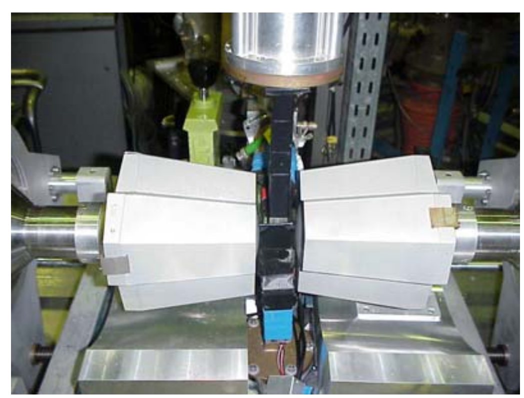

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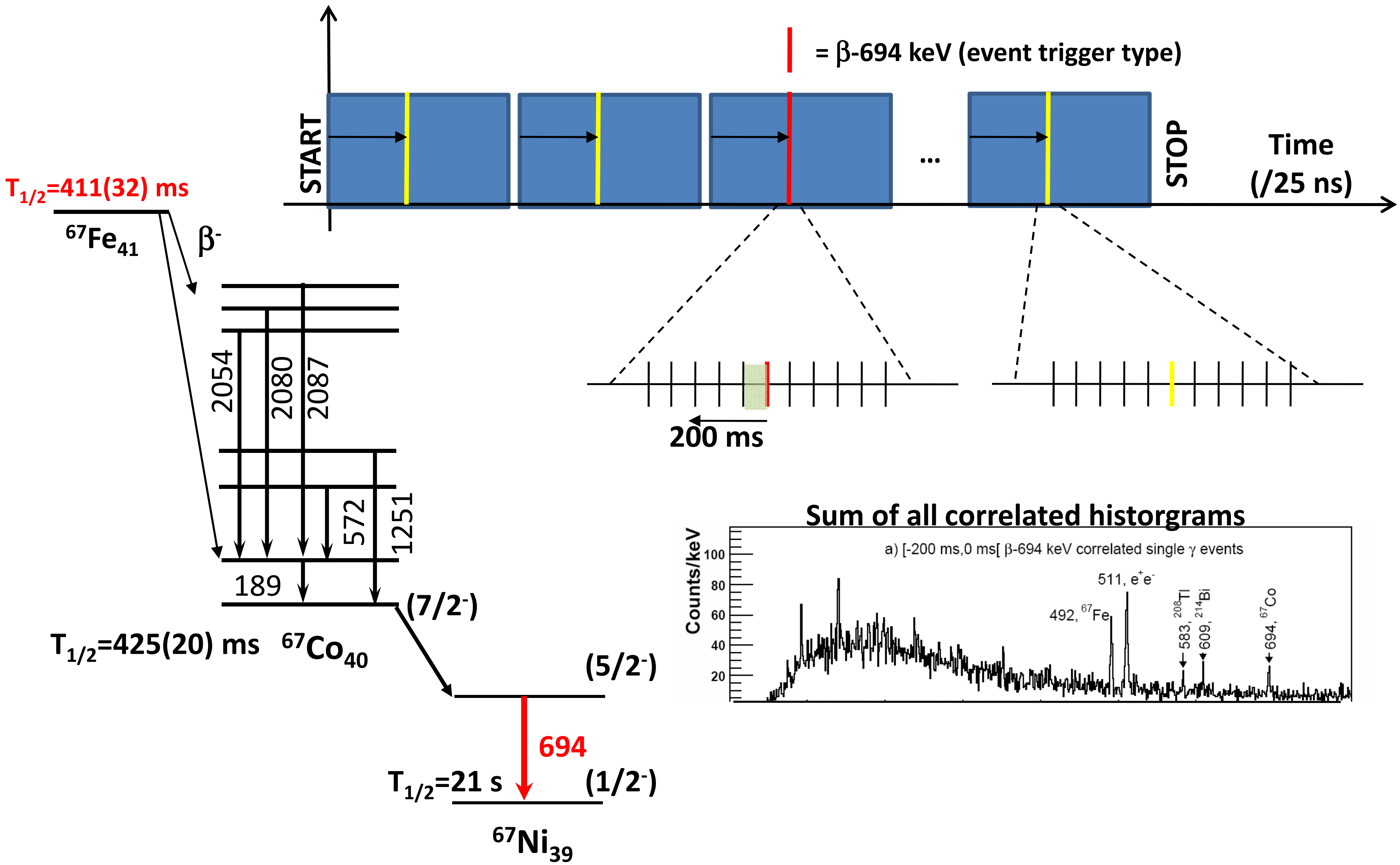

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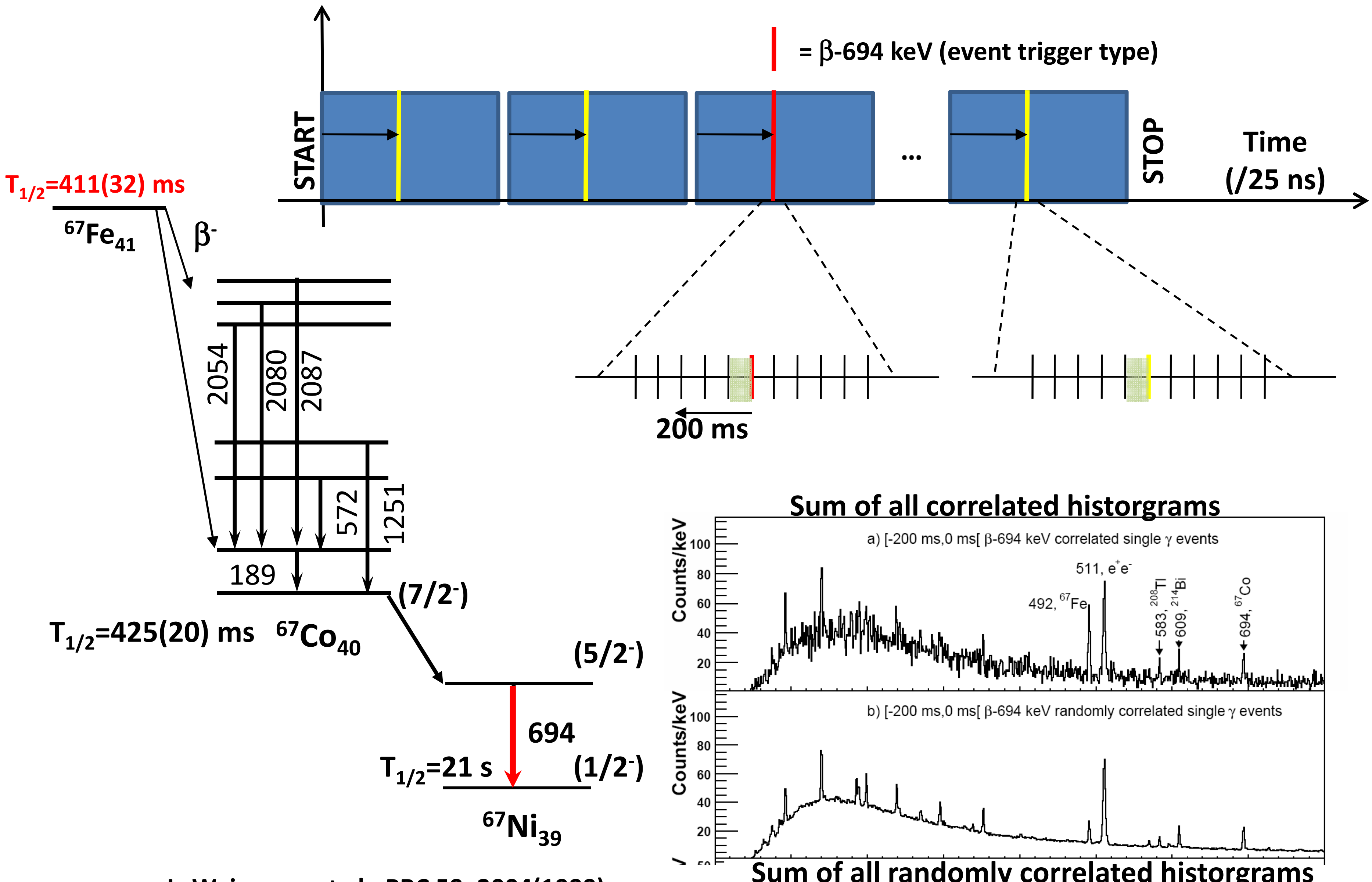

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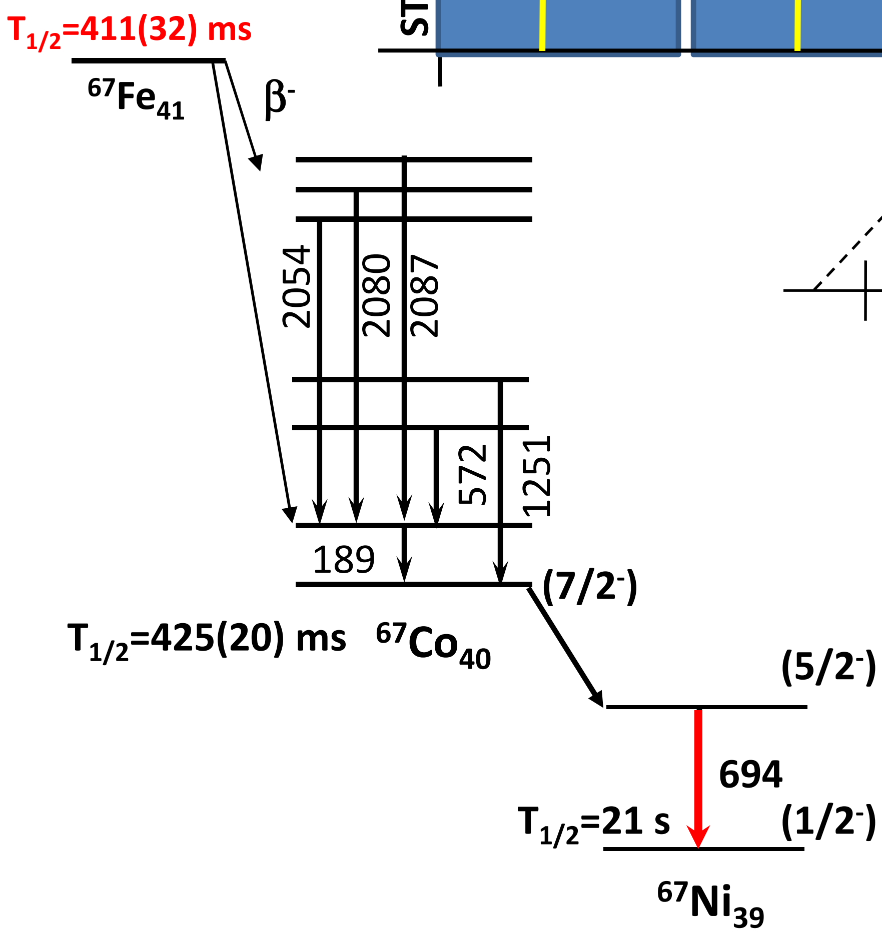

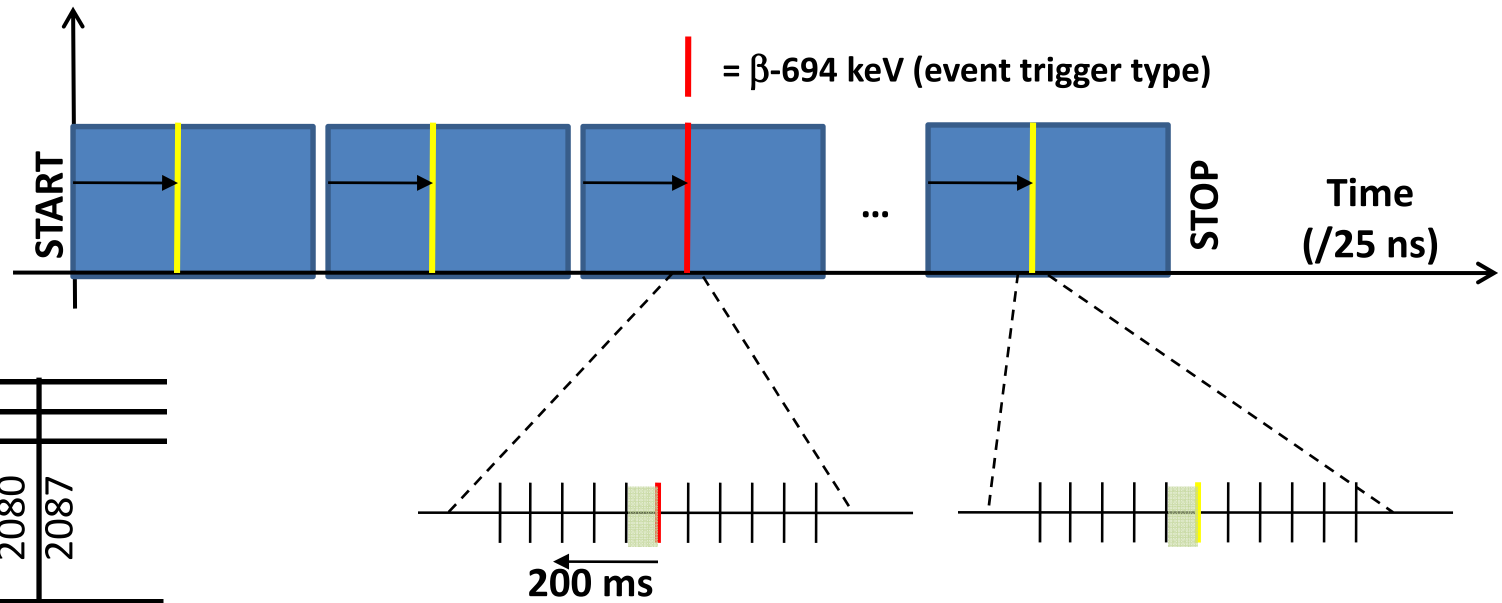

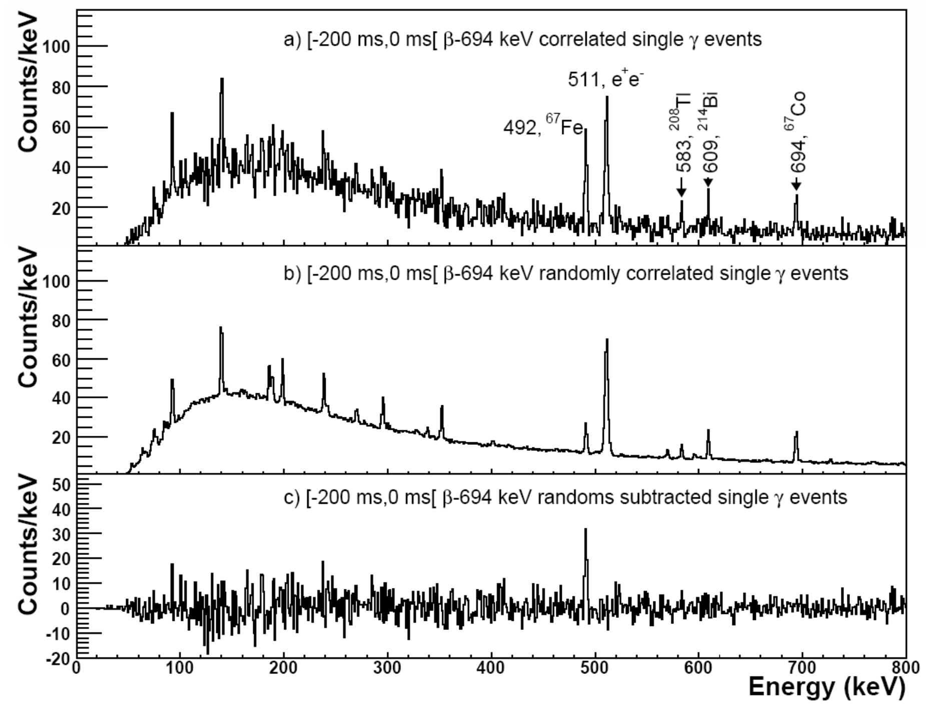

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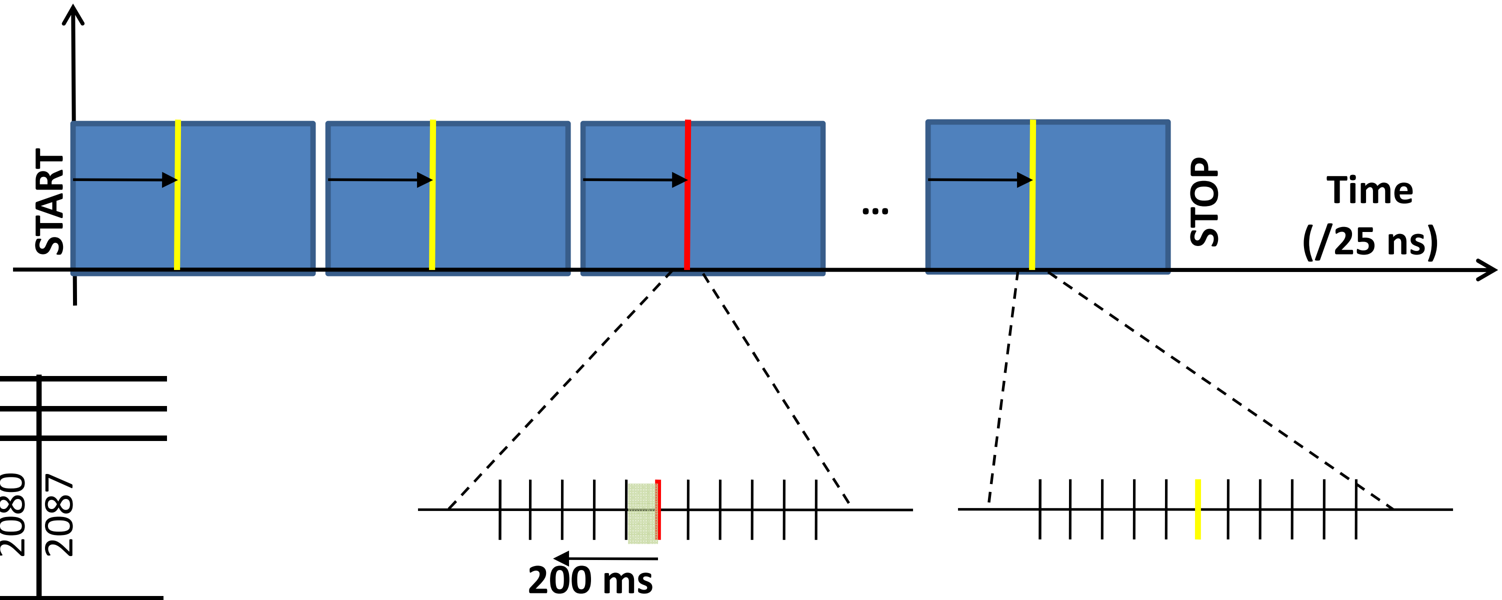

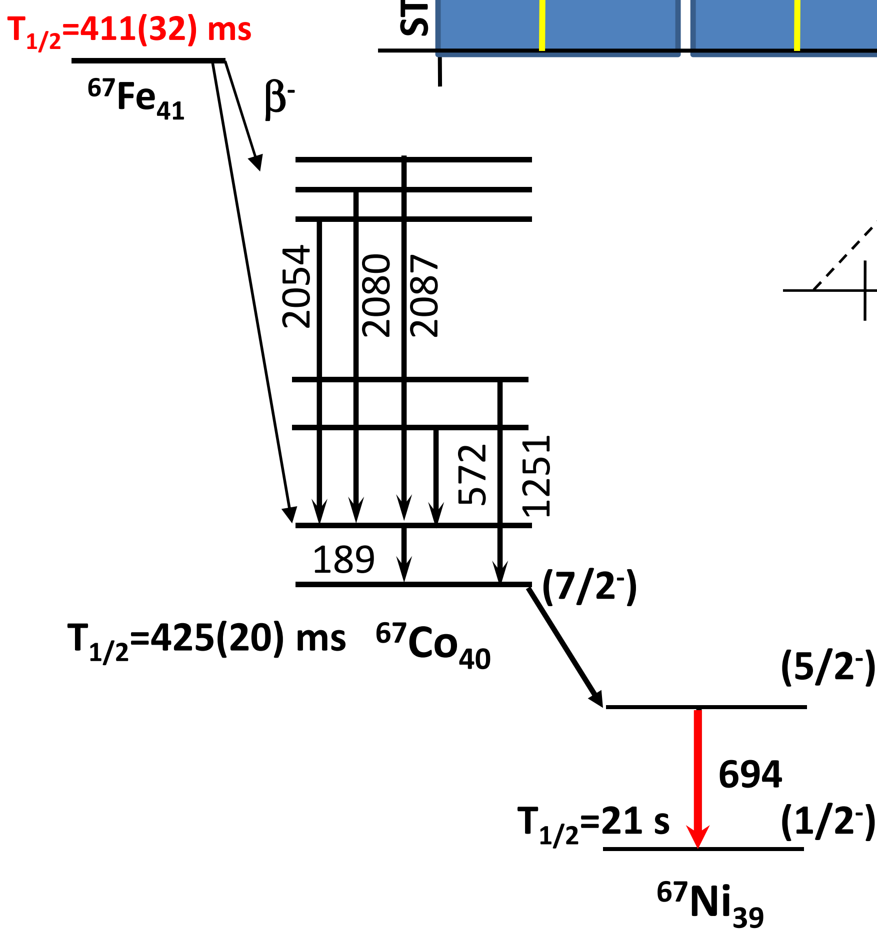

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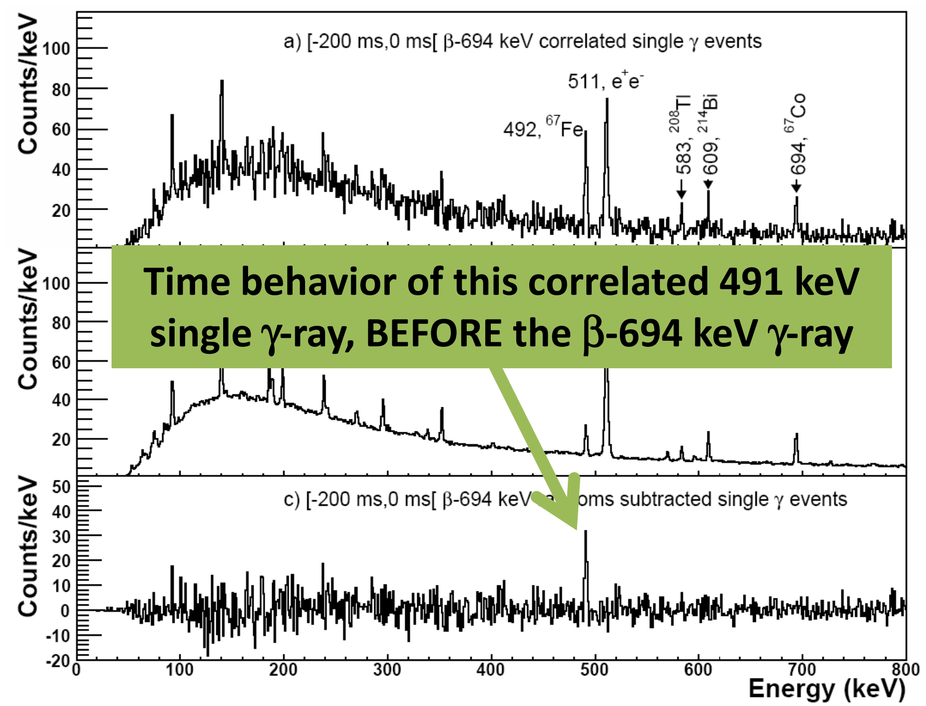

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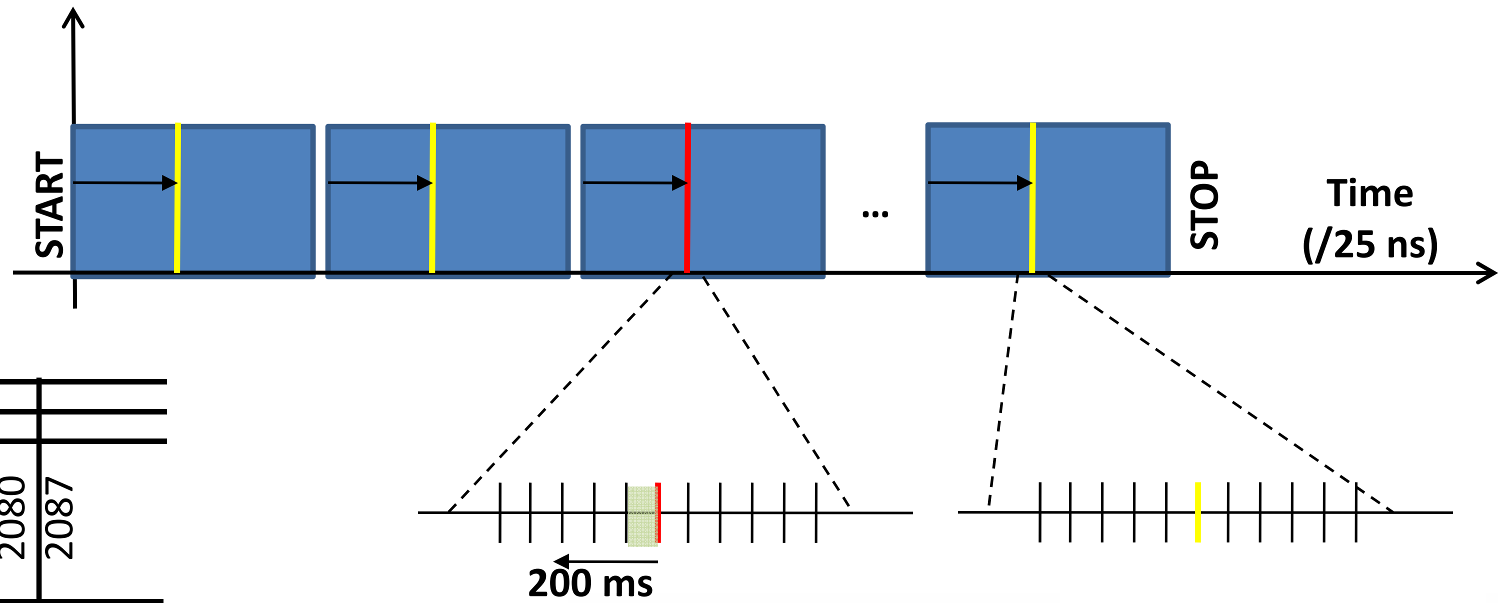

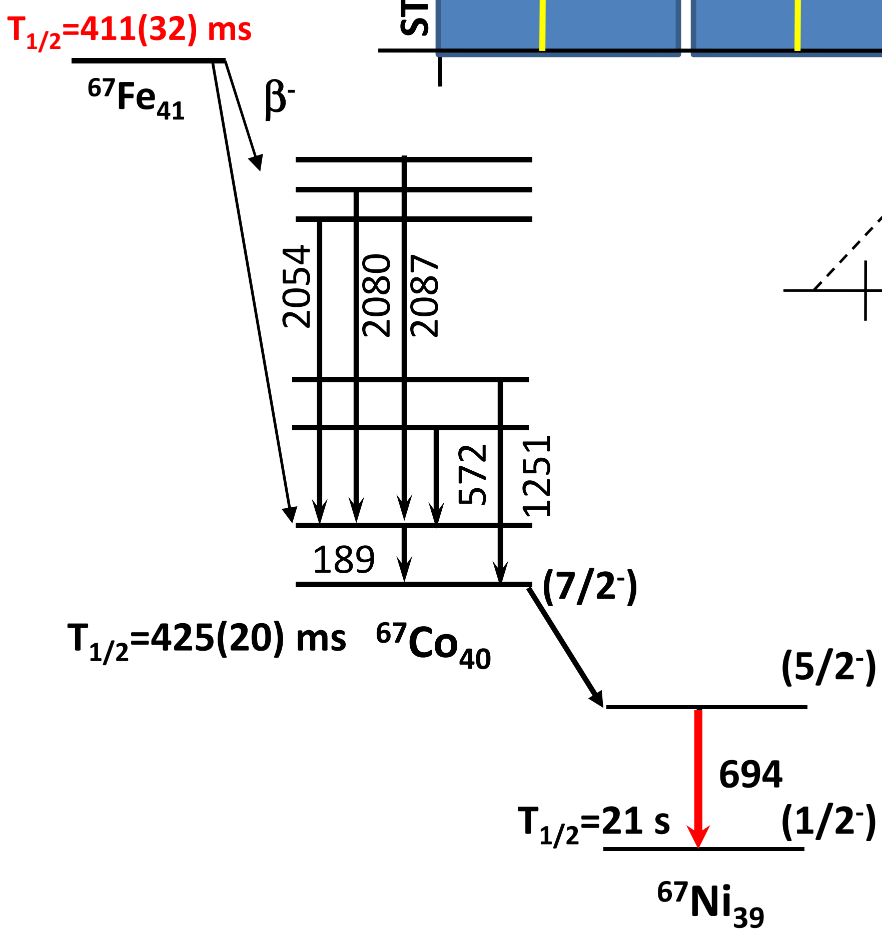

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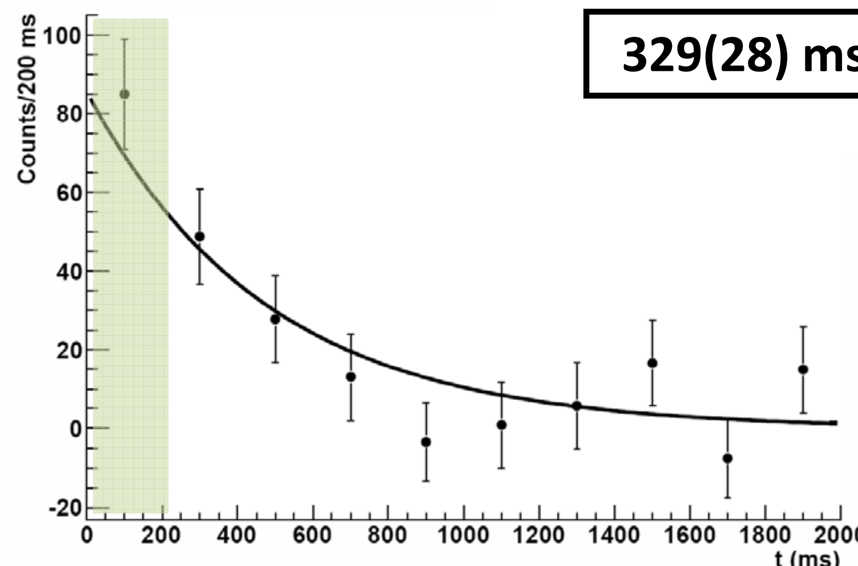
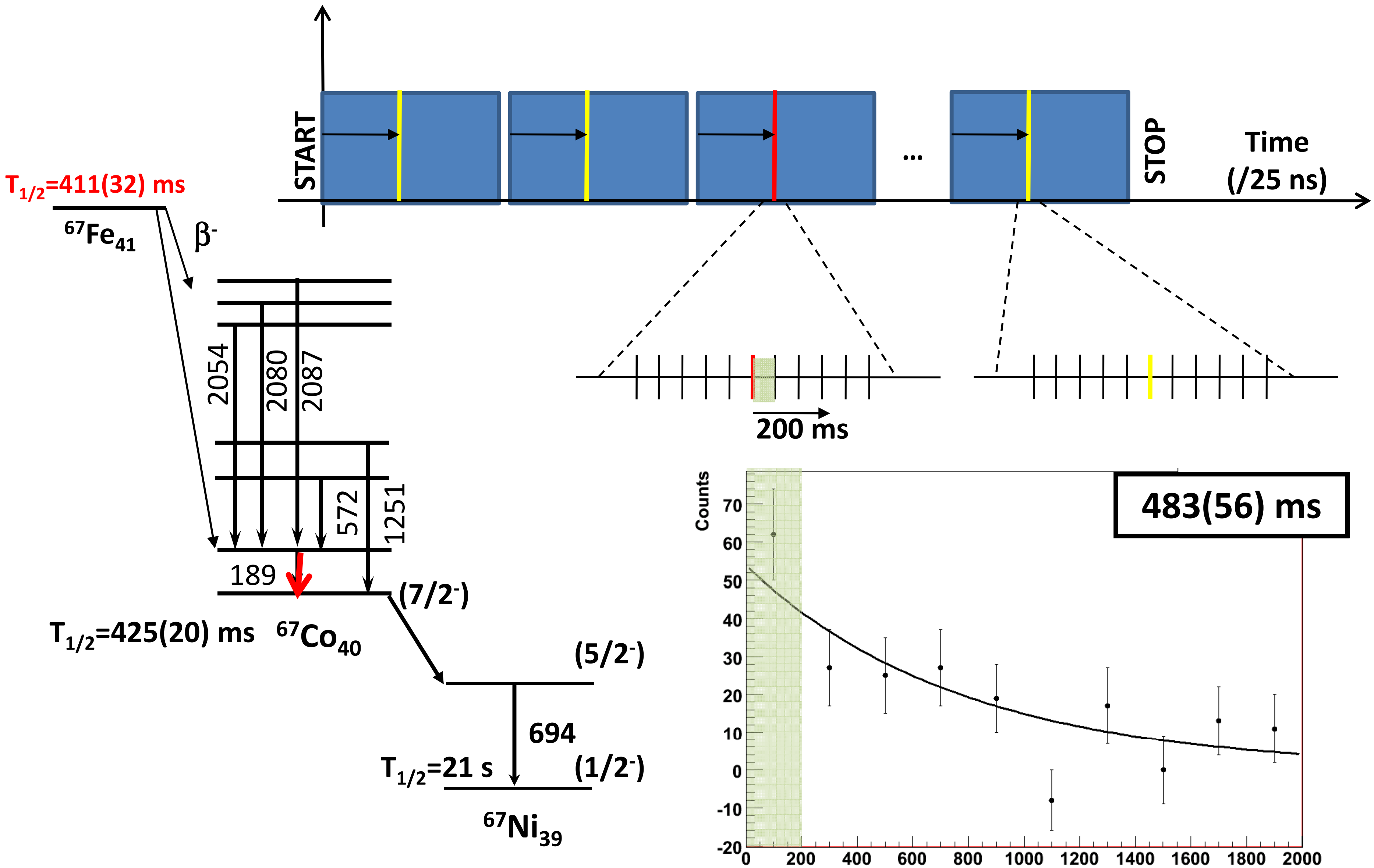
329(28) ms



Time behavior of this correlated 491 keV single γ-ray, BEFORE the β-694 keV γ-ray

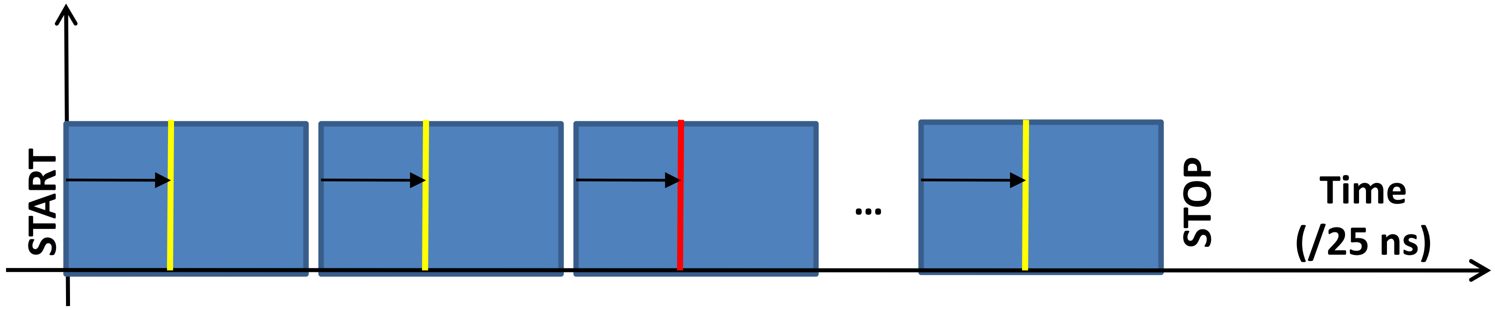
Pictures Courtesy D. Pauwels O. Ivanov, KU Leuven (2007)

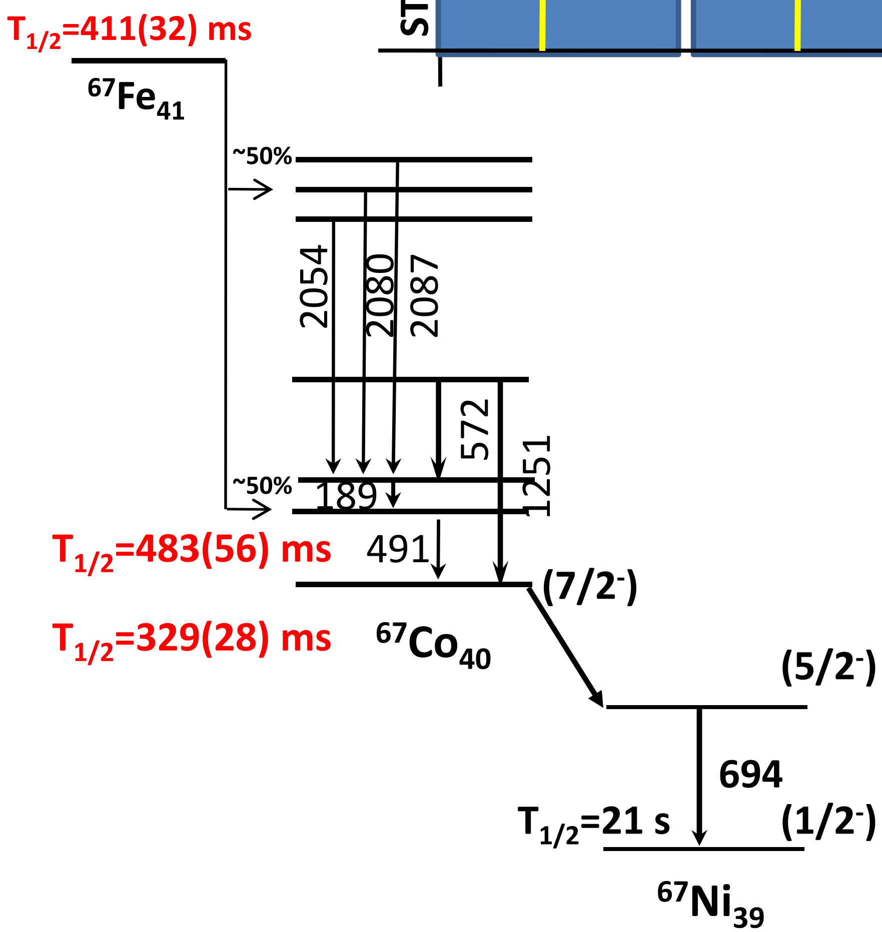


L. Weissman et al., PRC 59, 2004(1999).

Time behavior of this correlated 491 keV single γ-ray, AFTER the β-189 keV γ-ray

Pictures Courtesy D. Pauwels O. Ivanov, KU Leuven (2007)





An isomeric state was discovered thanks to the possibility to correlate events offline with digital electronics readout.

L. Weissman et al., PRC 59, 2004(1999).

Pictures Courtesy D. Pauwels O. Ivanov, KU Leuven (2007)

Conditions for applicability :

-pure sources of radioactive ions
-element selectivity
-low background
-efficient detection system
-low count rate

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Laser ON and laser OFF measurements with RILIS

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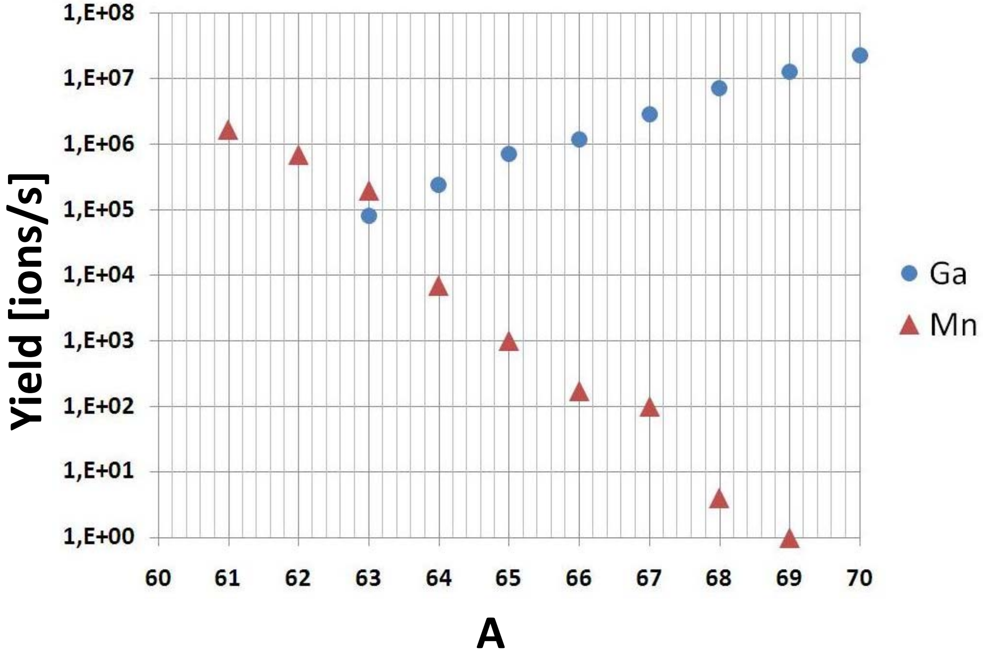
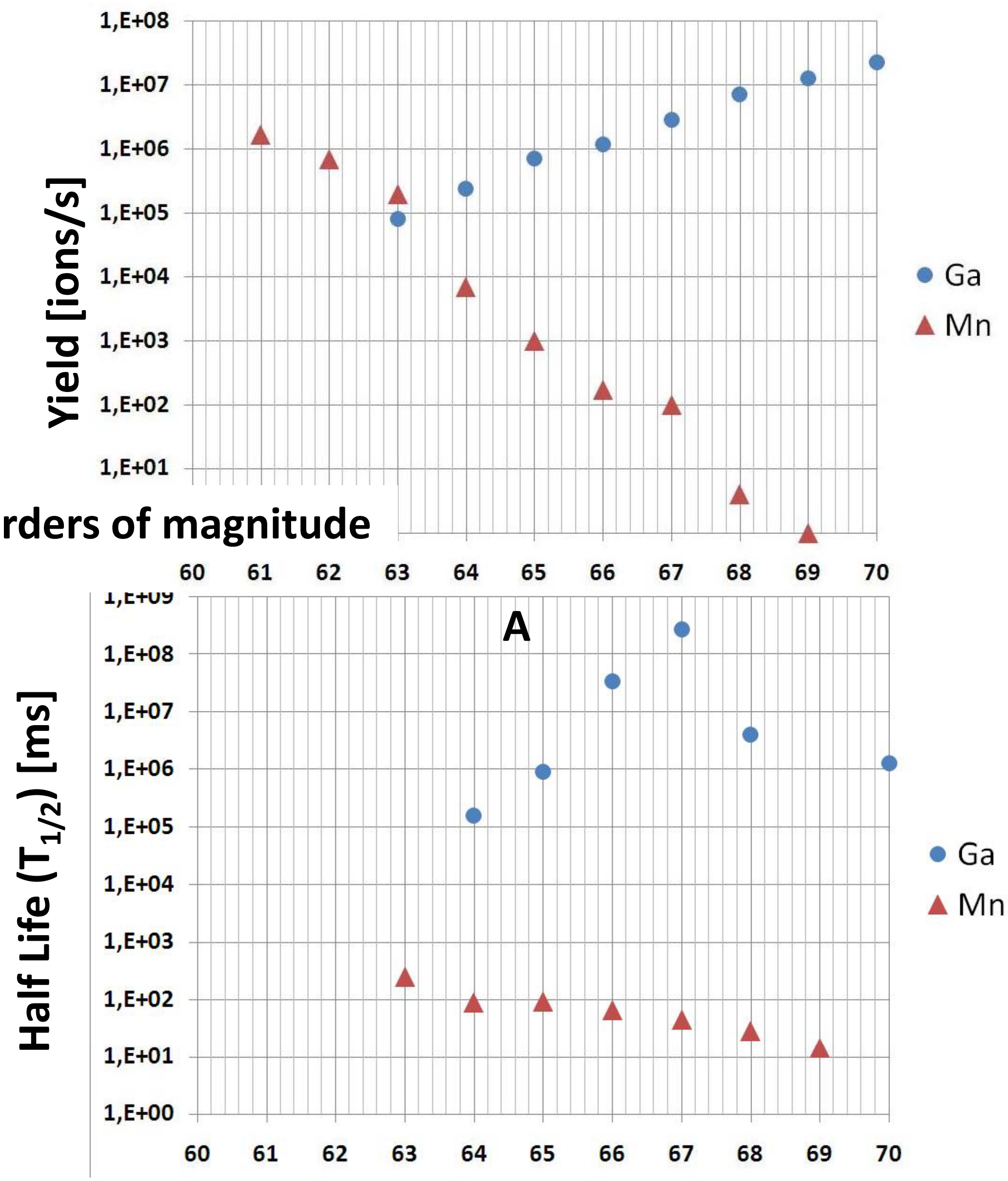
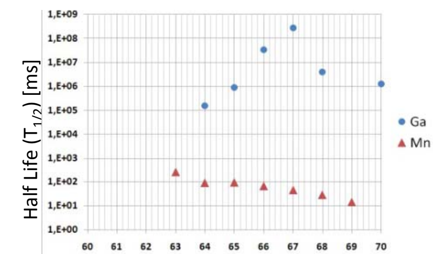
Ga production yields from fission cross section measurements of ^{238}U with 1 GeV protons
http://www-w2k.gsi.de/charms/data-arb04.htm or
M. Bernas *et al.* Nucl. Phys. A 725 213 (2003) + 1% ionization efficiency
Mn yields from ISOLDE Yield database



1/ Half Lives differ orders of magnitude





1/ **Half Lives** differ orders of magnitude ;

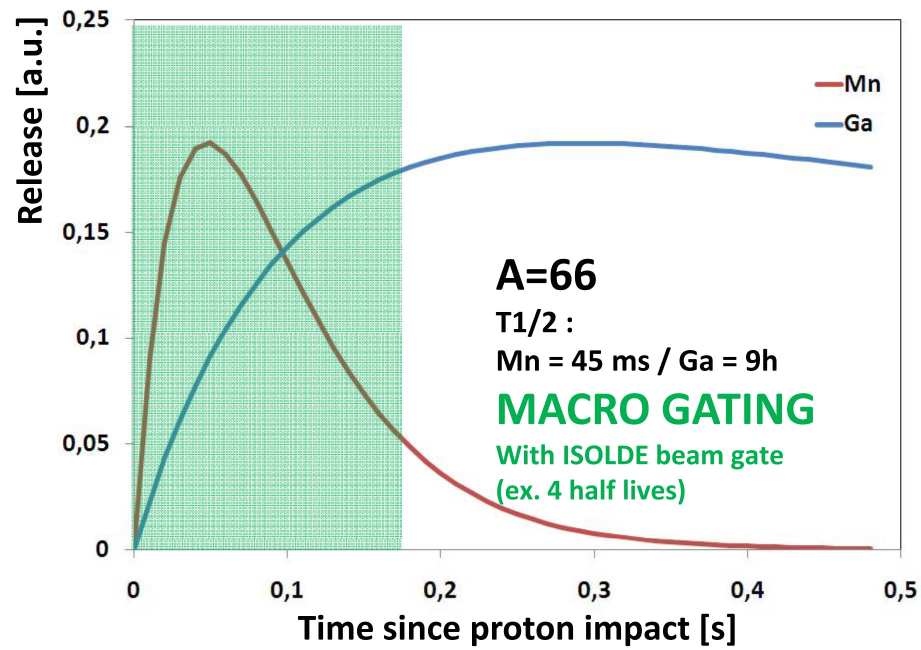
2/ Different release times (**macro gating**) ;

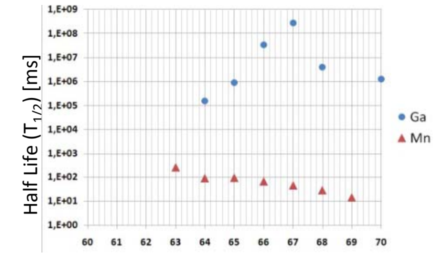
Release Curves : $C(1-e^{-t/\tau r}).[\alpha e^{-t/\tau f}+(1-\alpha)e^{-t/\tau s}].e^{-t/\tau}$

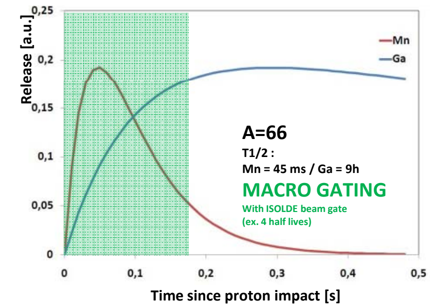
T=2000˚C

Parameters taken from U. Koester, These 1999, TU Munchen

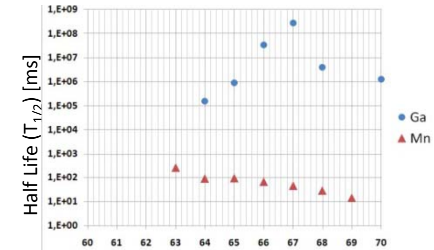
+ additional life time factor

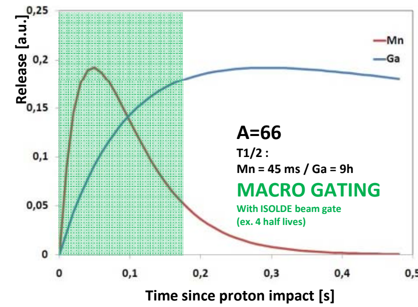






1/ Half Lives differ orders of magnitude ;
2/ Different release times (macro gating) ;
3/ Micro gating of laser ionized isotopes ;





1/ Half Lives differ orders of magnitude ;
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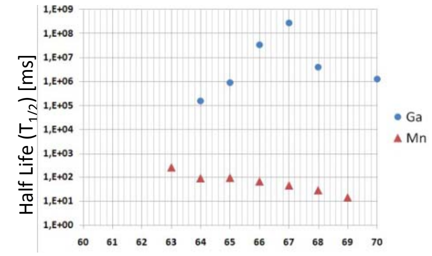
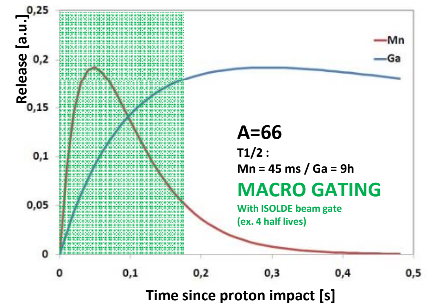
3/ Micro gating of laser ionized isotopes ;
4/ Tape transport after each measuring cycle ;





<u>Conditions for applicability :</u>

- ✓pure sources of radioactive ions
- ✓element selectivity
- ✓low background
- ✓efficient detection system
- ✓low count rate

1/ Half Lives differ orders of magnitude ;

2/ Different release times (macro gating) ;

3/ Micro gating of laser ionized isotopes ;

4/ Tape transport after each measuring cycle ;

5/ Good beam steering

CONCLUSION

ISOLDE provides the UNIQUE possibility to combine

1/ the new technology utilized with the LISOL β-decay setup
2/ the laser ionized neutron rich Mn beams at ISOLDE

1/ search for isomeric states in Iron and Manganese isotopes ;
2/ complement the knowledge of the nuclear structure below (neutron rich) Nickel isotopes (Co, Fe and Mn)

Nr of Shifts

Example ^{67}Fe LISOL

1.25 ions/s on tape
58h (or 7 shifts) measurement

Nr of Shifts

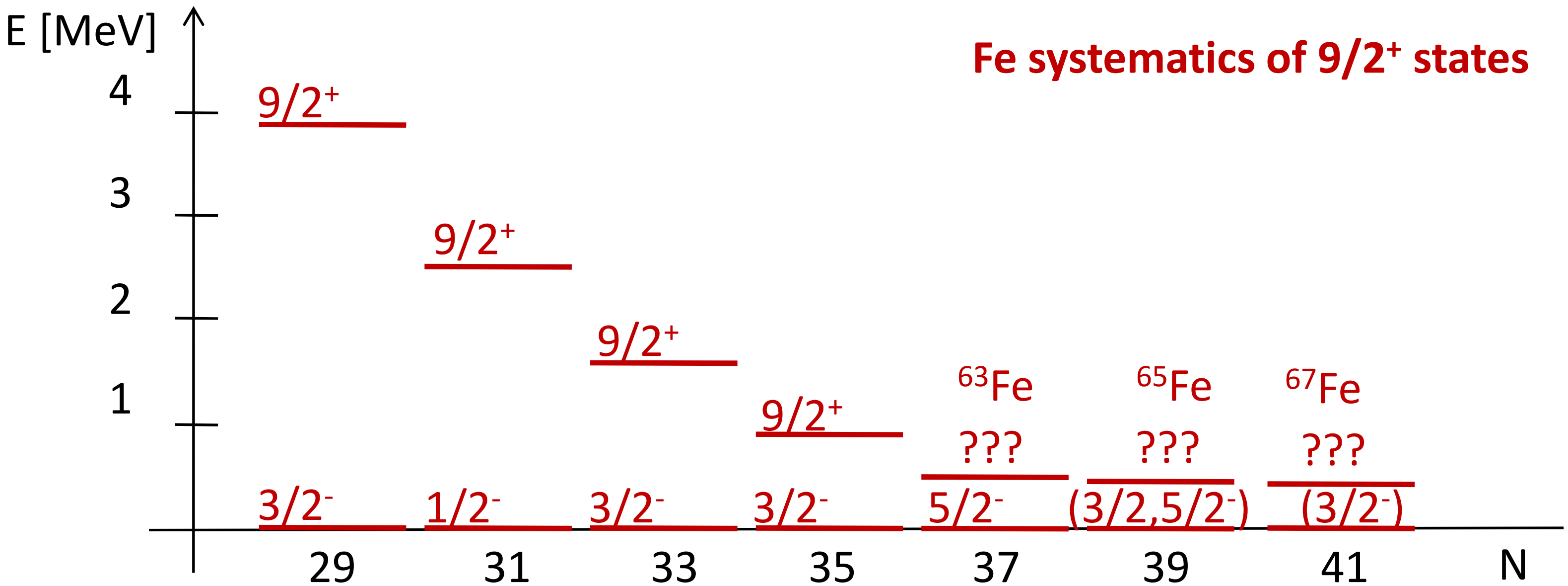
Example ^{67}Fe LISOL

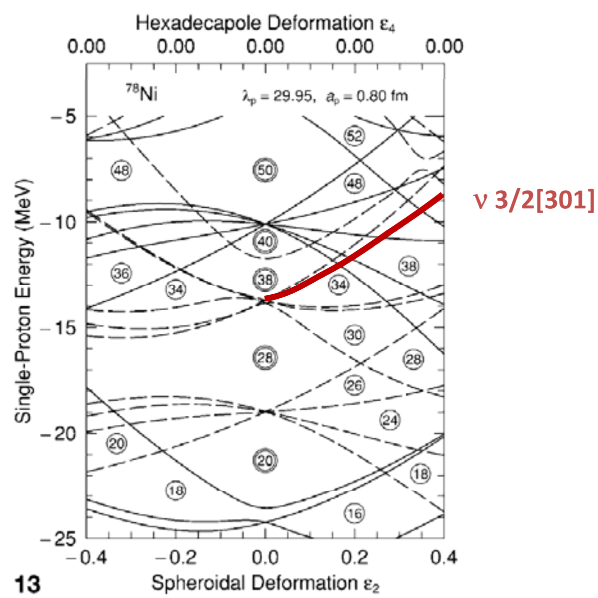
1.25 ions/s on tape
58h (or 7 shifts) measurement

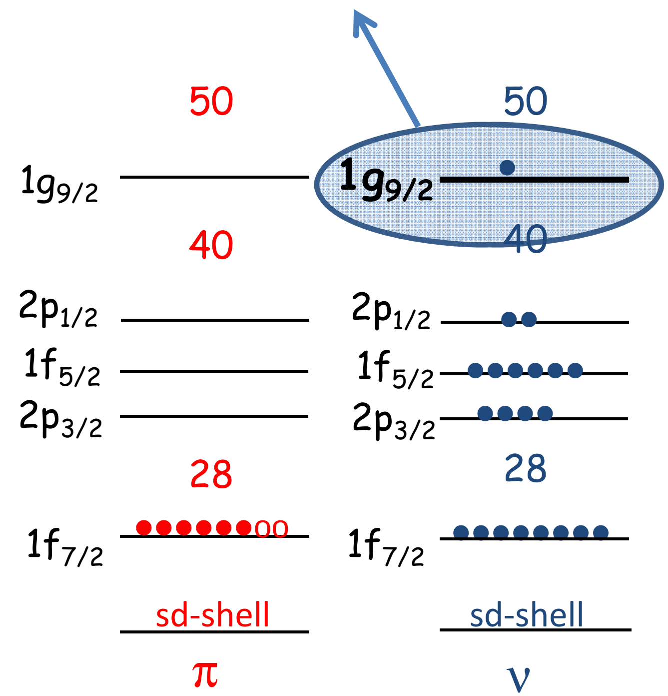
Similar for ^{68,69}Mn : 7 shifts / isotope
(6 laser on, 1 laser off)
$^{61-67}$Mn : average 1 shift / isotope
^{70}Mn : 2 shifts

<u>24 SHIFTS</u>

Fe systematics of 9/2⁺ states

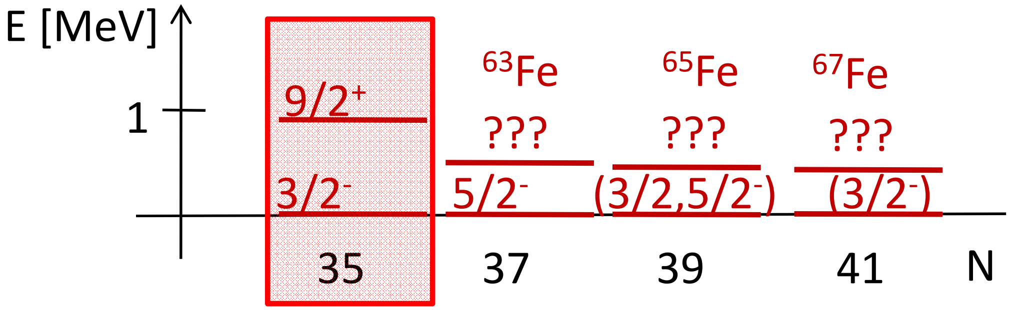


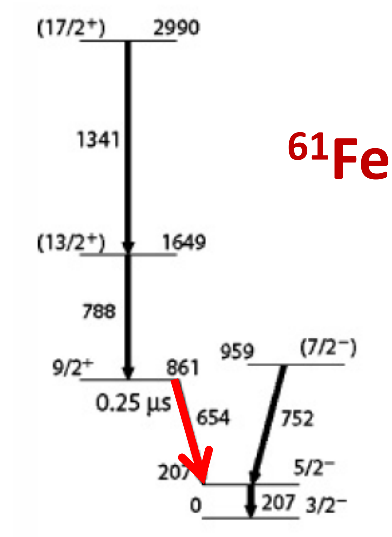




g.s. = 3/2⁻ state from β-decay feeding to ^{67}Co

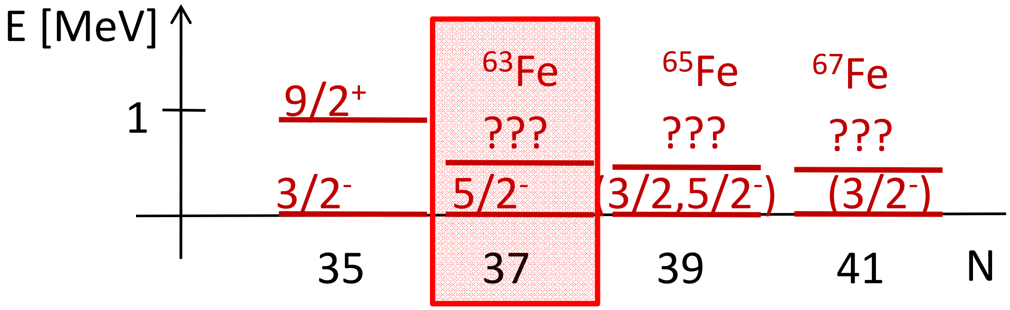
D. Pauwels et al., to be published





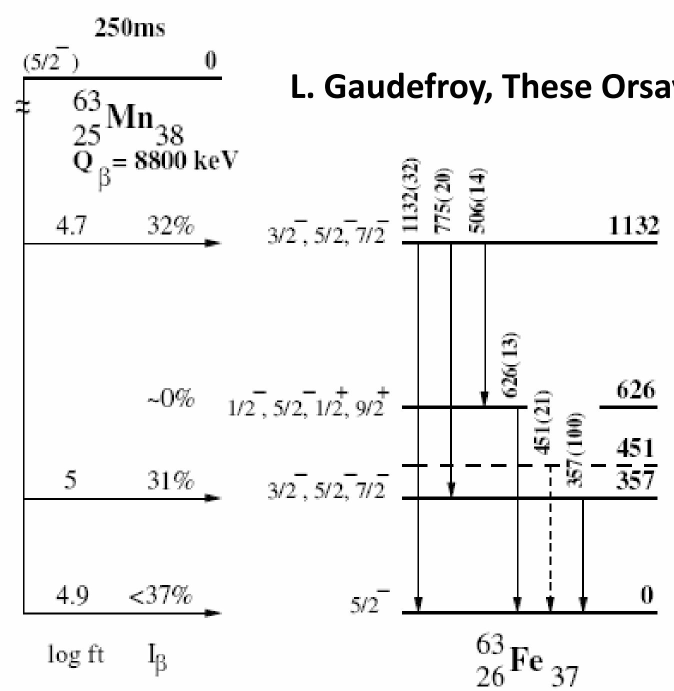
Lunardi et al. PRC 76 034303 (2007)

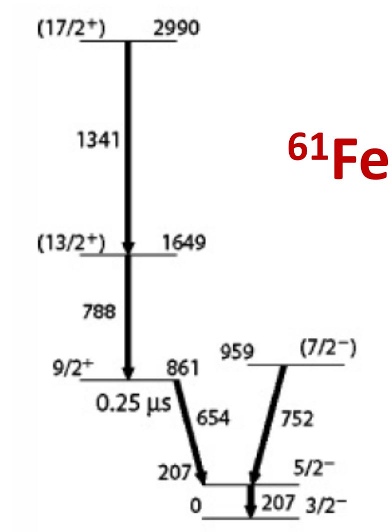
M2 654 keV 9/2^{+}⟶5/2^{-} : 239(5) ns



1st forbidden GT transition 5/2- → 9/2-+

L. Gaudefroy, These Orsay 2005





Lunardi et al. PRC 76 034303 (2007)

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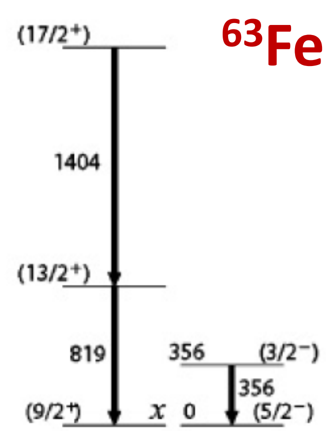
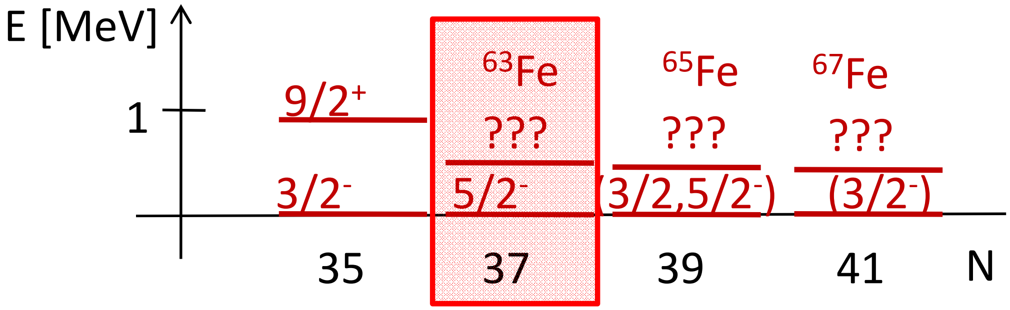
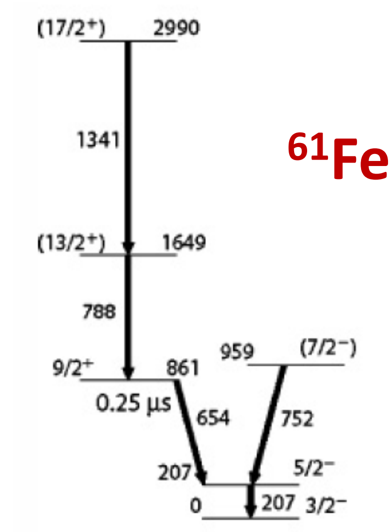


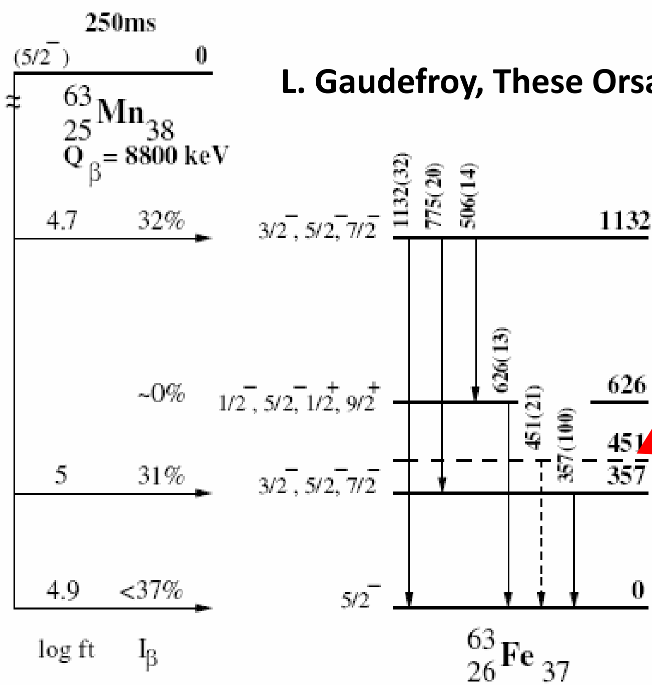
Lunardi et al. PRC 76 034303 (2007)



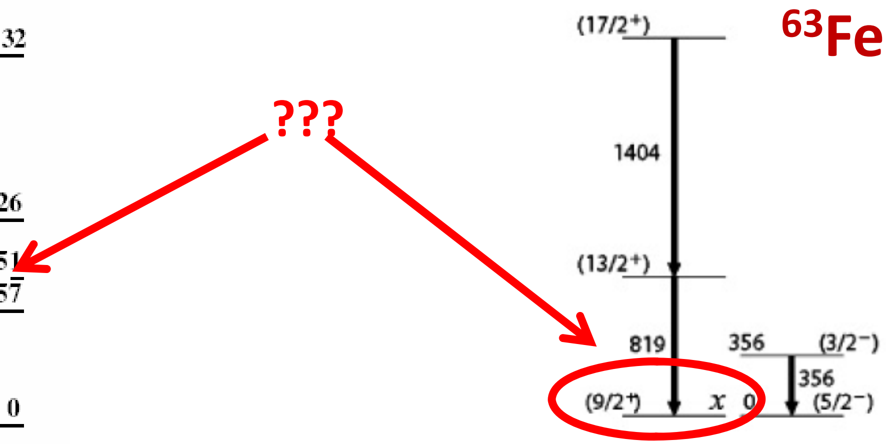


Lunardi et al. PRC 76 034303 (2007)
M2 654 keV $9/2^+ \rightarrow 5/2^-$: 239(5) ns

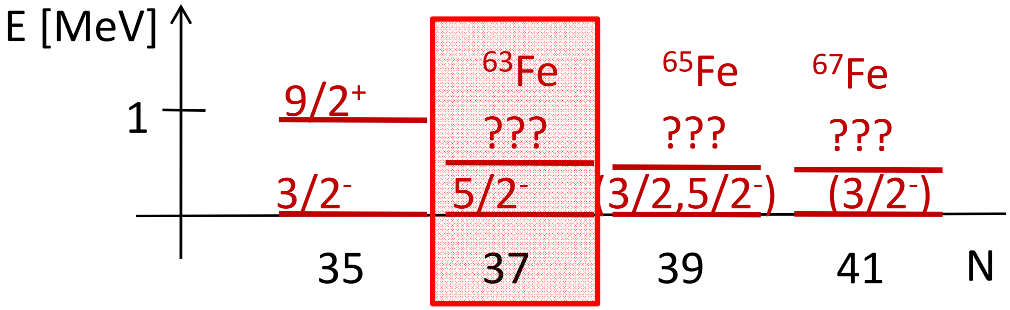
1st forbidden GT transition $5/2^- \rightarrow 9/2^{-+}$

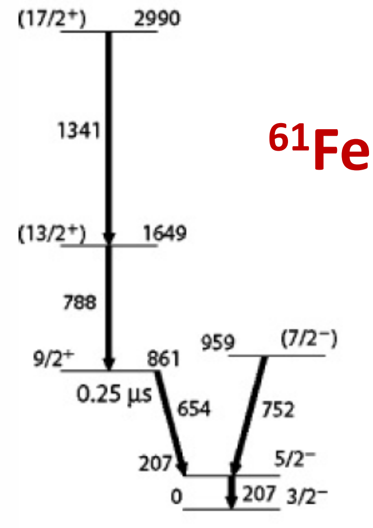


L. Gaudefroy, These Orsay 2005



Lunardi et al. PRC 76 034303 (2007)





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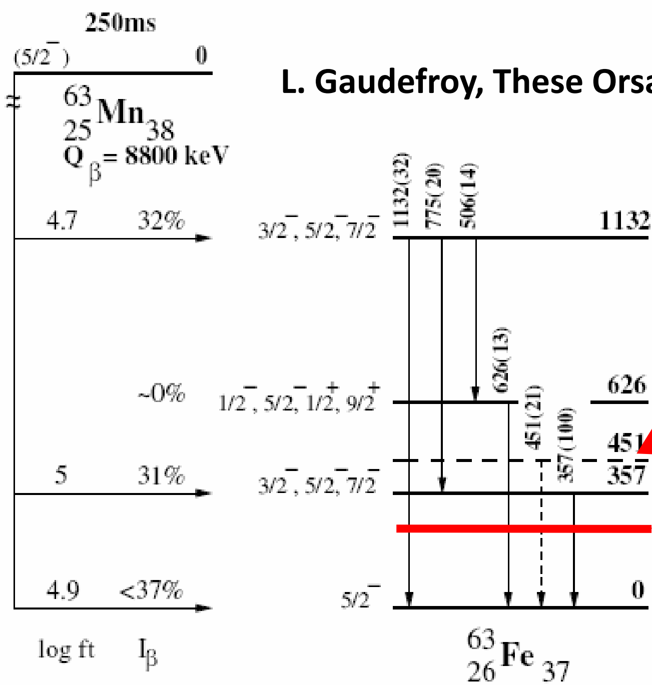
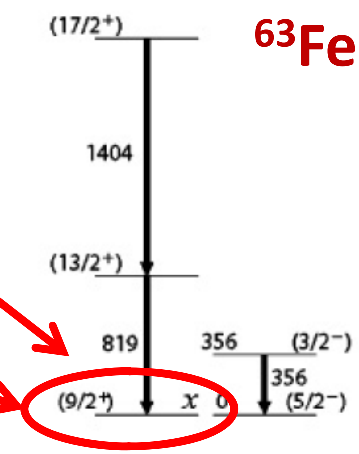


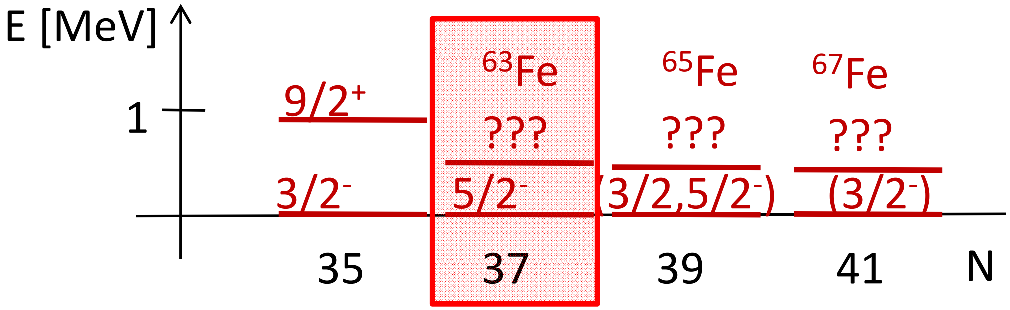
???

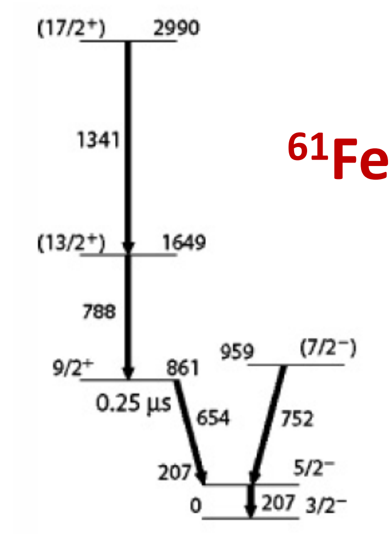
< 350 keV ???

From deep-inelastic data
(W.B. Walters, priv. comm.)



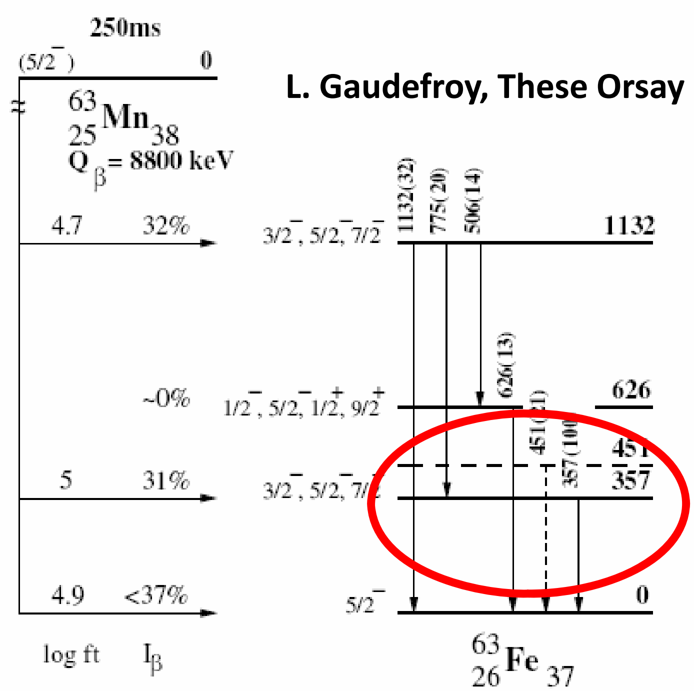
Lunardi et al. PRC 76 034303 (2007)





61Fe

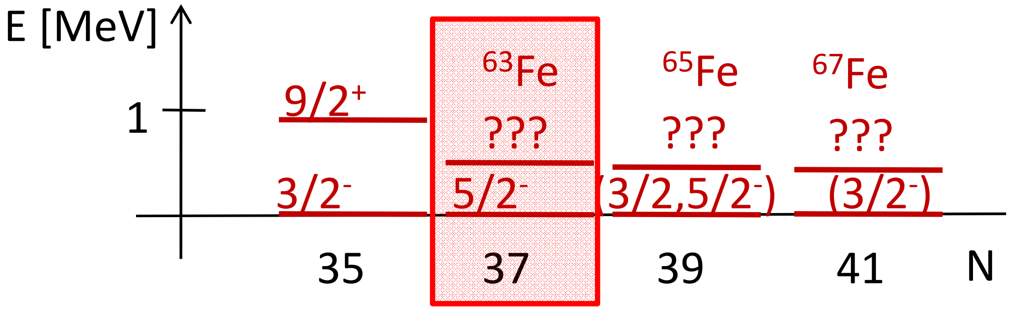
1^{st} forbidden GT transition $5/2^- \rightarrow 9/2^{-+}$

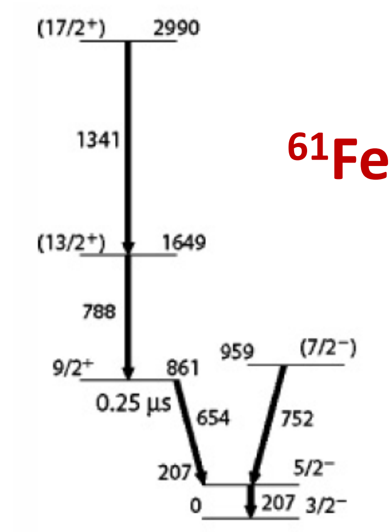


L. Gaudefroy, These Orsay 2005

Lunardi et al. PRC 76 034303 (2007)
M2 654 keV $9/2^+ \rightarrow 5/2^-$: 239(5) ns

$9/2^+ \rightarrow 5/2^-$ = µs isomer ...
lost in prompt β-γ coincidences,
re-gained with the digital readout !





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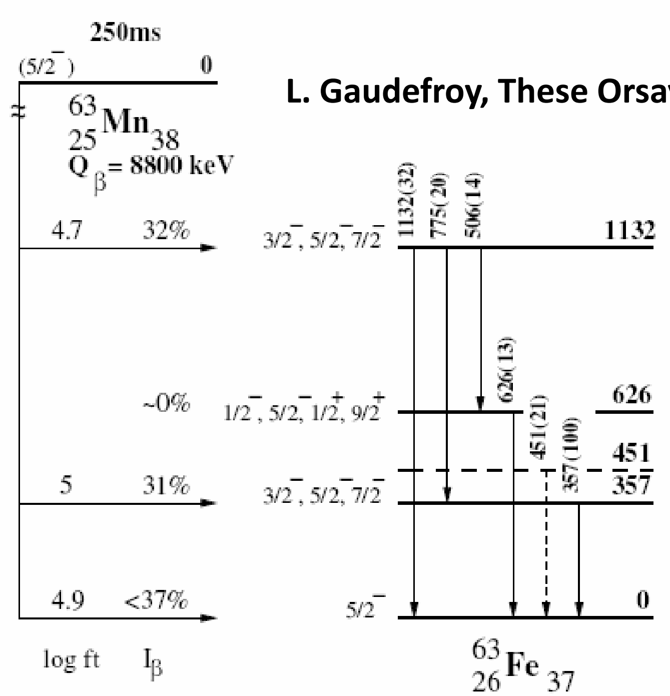
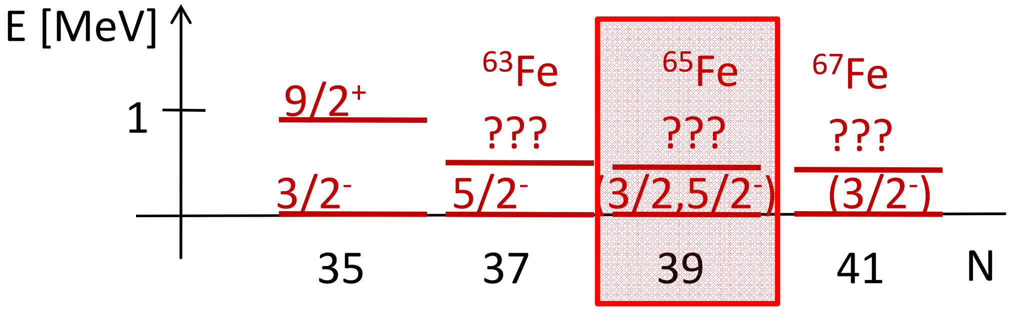


L. Gaudefroy, These Orsay 2005

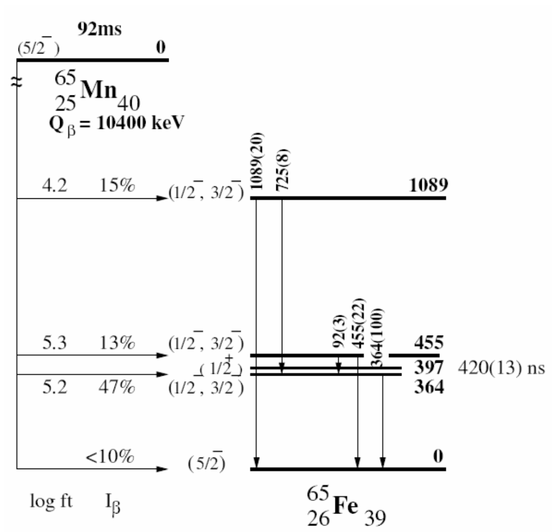
^{64}Mn decay :

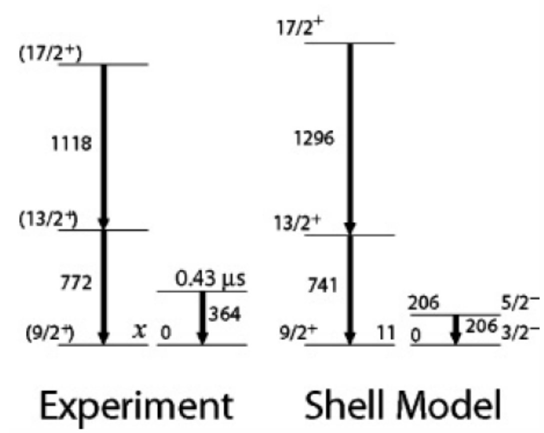
33(2)% β-delayed neutron branch

⇒Feeding of low-spin states in ^{63}Mn !!!



L. Gaudefroy, These Orsay 2005

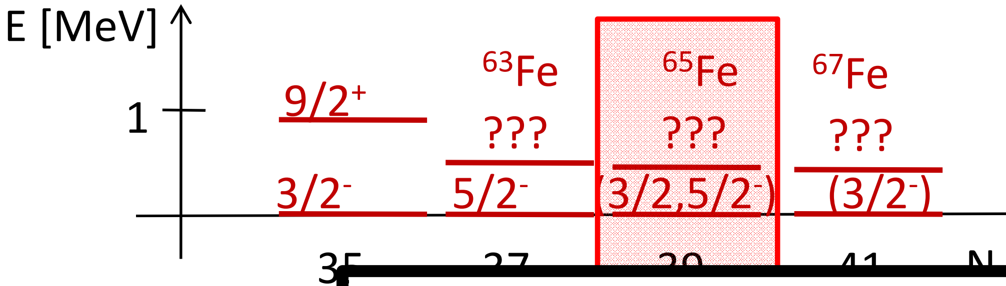




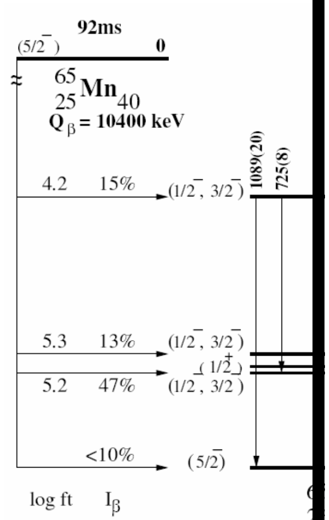
Lunardi et al. PRC 76 034303 (2007)

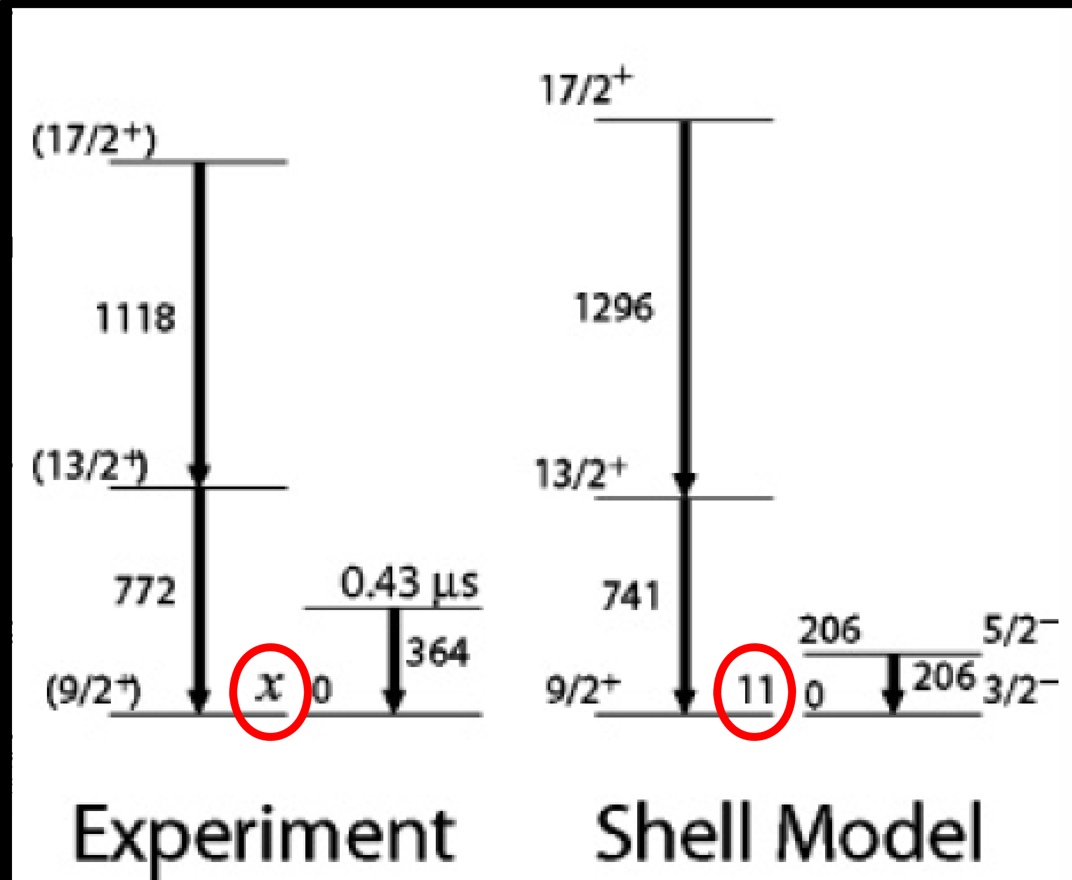
+ MSU mass measurements :
isomer around 400 keV
Block *et al.* (MSU)

+ LISOL β-decay ^{65}Fe
Indication for β-decaying isomer
D. Pauwels *et al.* (KU Leuven)



L. Gaudefroy, These

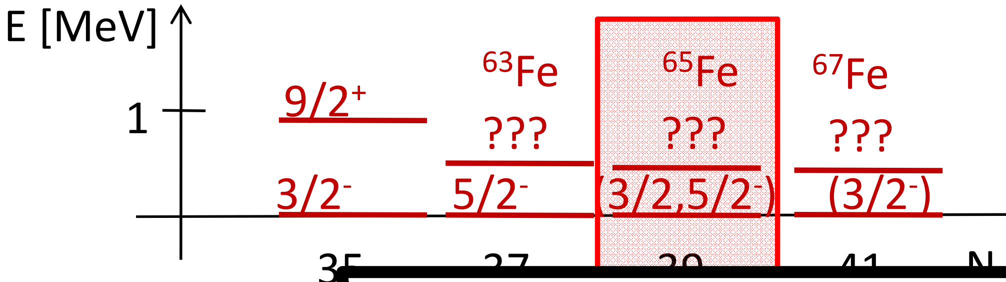




Lunardi et al. PRC 76 034303 (2007)

ass measurements :
round 400 keV
al. (MSU)

-decay ^{65}Fe
n for β-decaying isomer
els *et al.* (KU Leuven)



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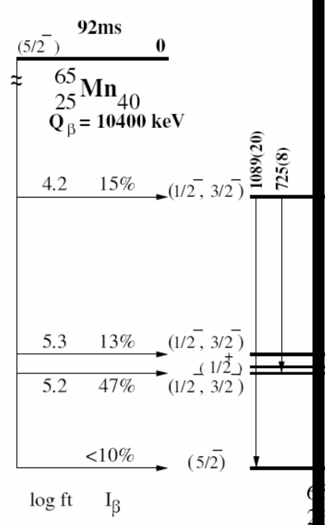

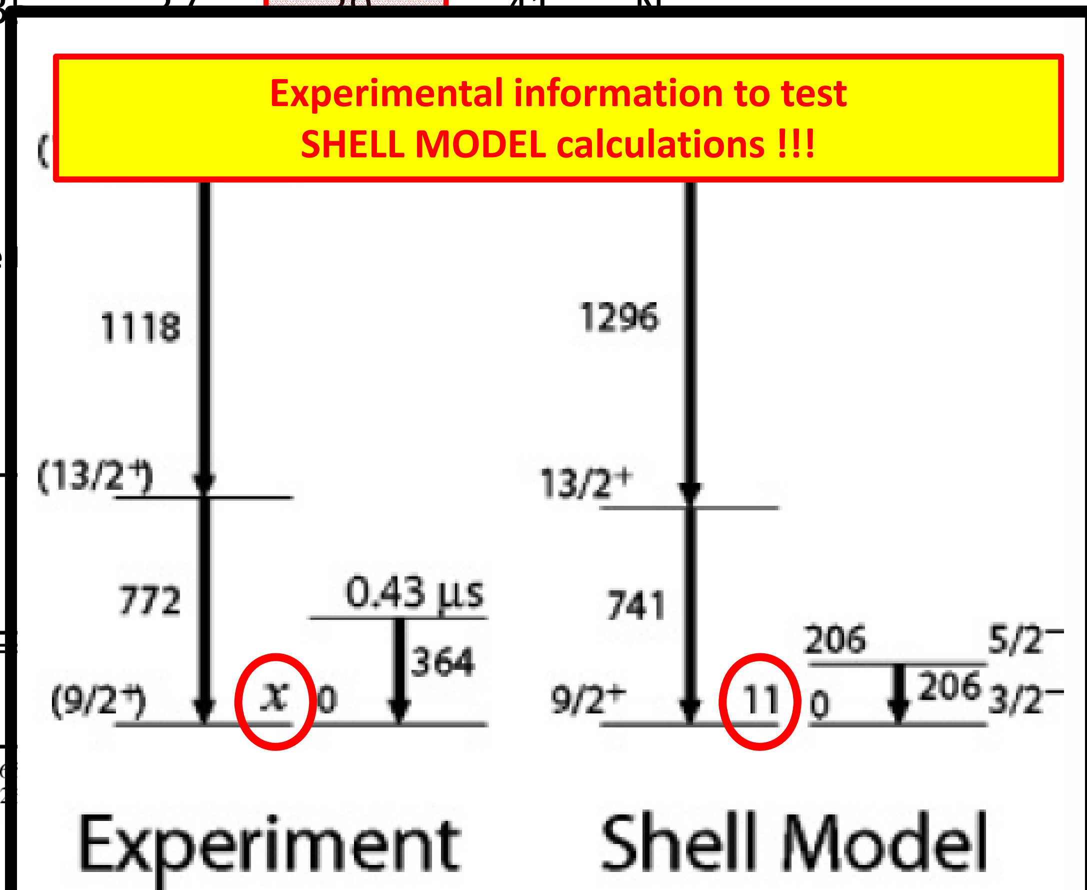

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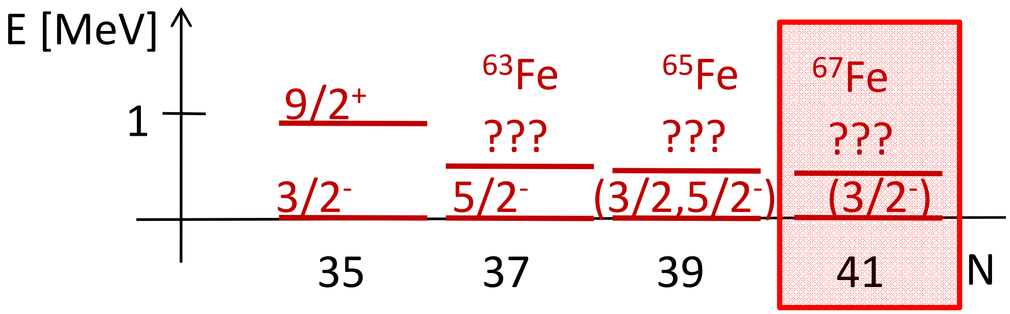
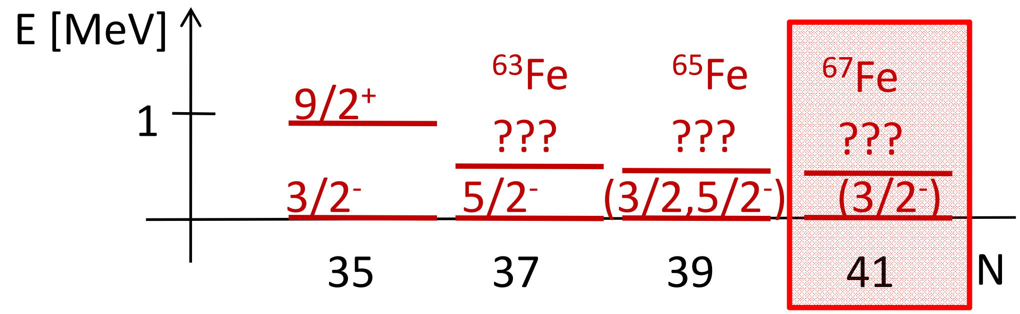
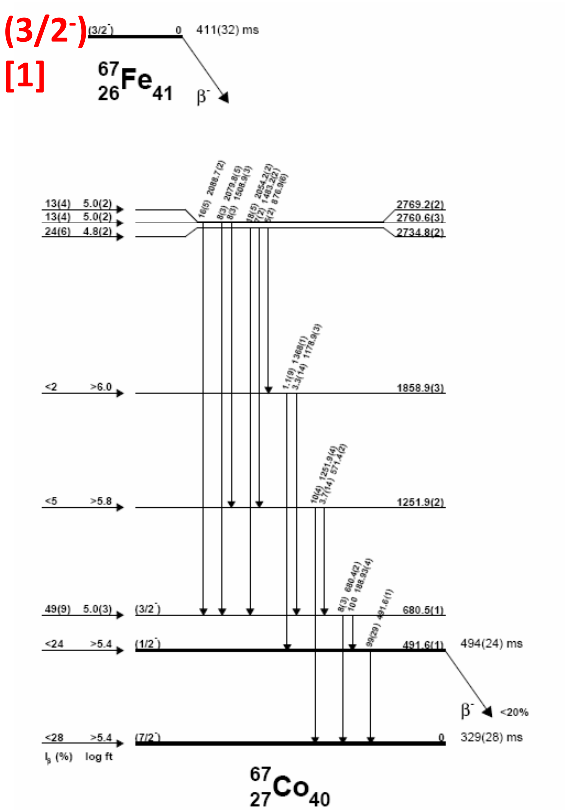

E [MeV]
1
9/2+
3/2-
63Fe
???
5/2-
65Fe
???
(3/2,5/2-)
67Fe
???
(3/2-)
35
37
39
41
N

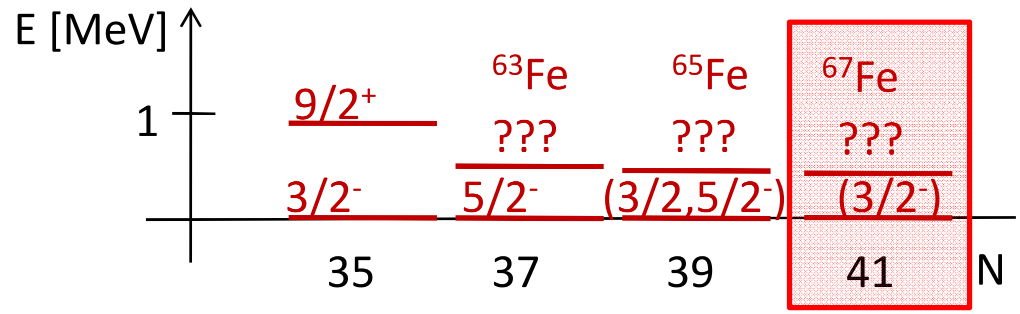


β-decay study of ^{67}Fe at LISOL (2007)

D. Pauwels et al., These KU Leuven 2008

(to be published) [1]





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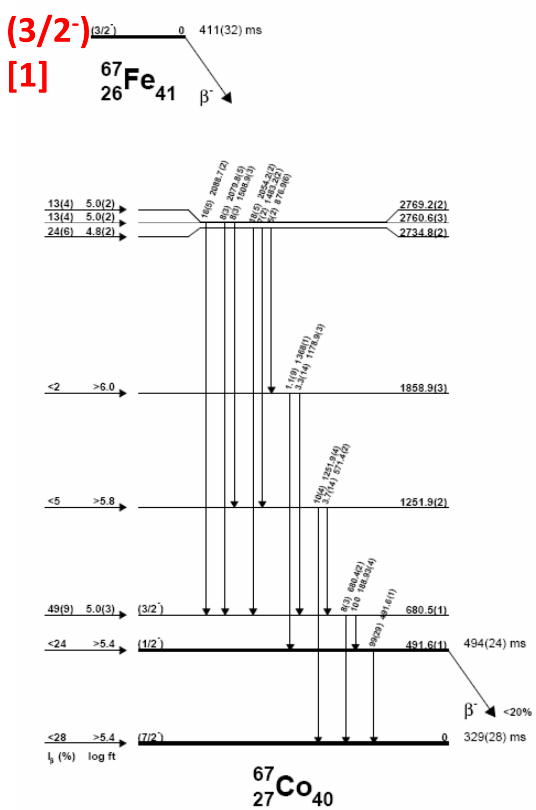
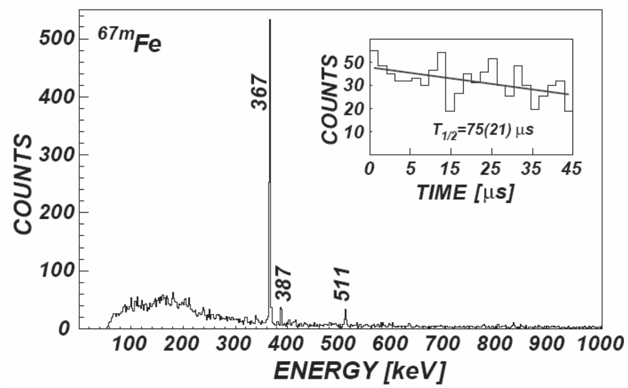
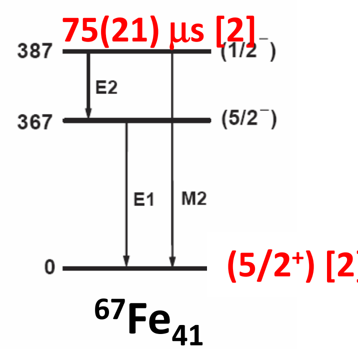
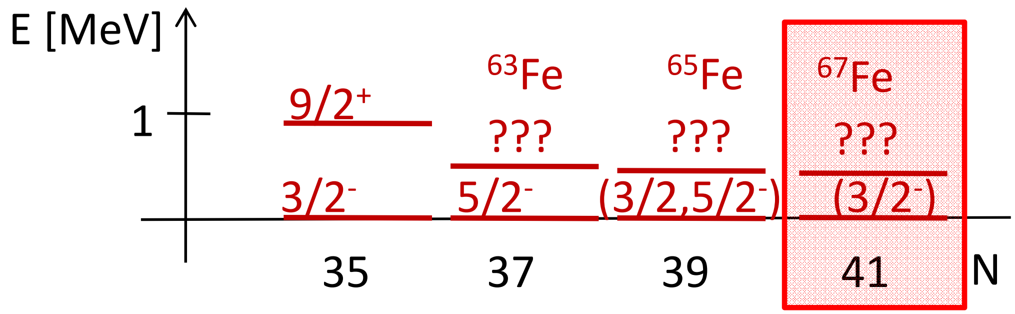






In-flight separation and isomeric decay study at GANIL
M. Sawicka et al. EPJA 16 51-54 (2003) [2]



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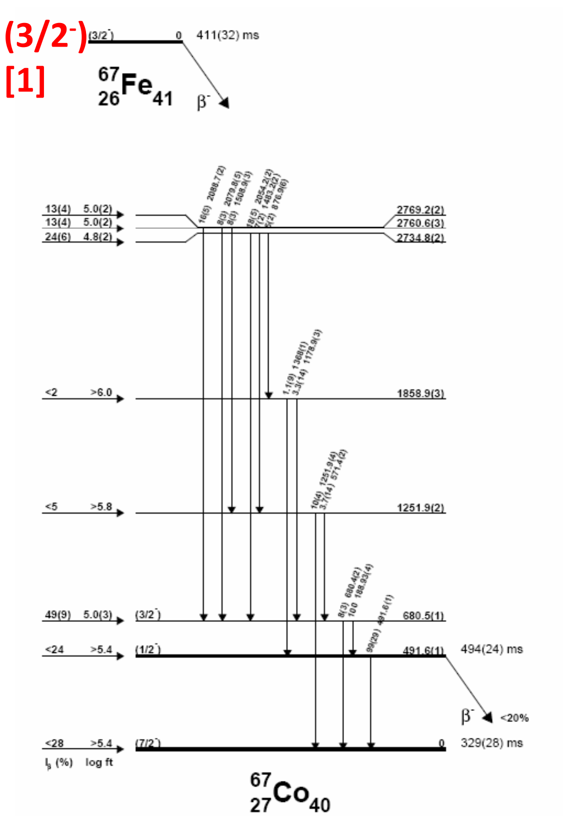
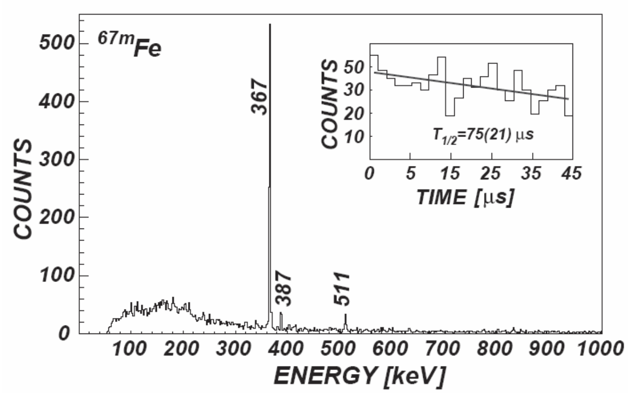
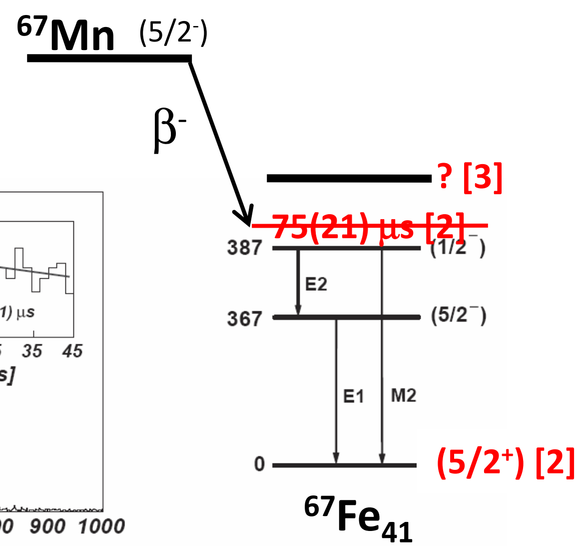


[3] = β-decay study of ^{67}Mn at GANIL
J.M. Daugas et al., AIP Conf Proc 831 p 427
No spin assignments (!)





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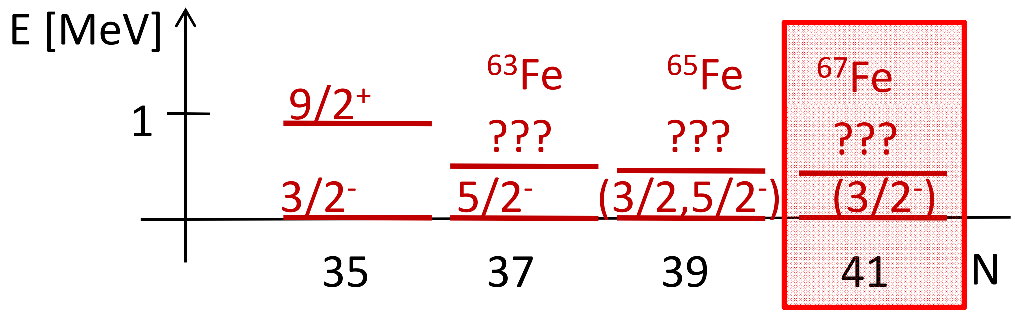

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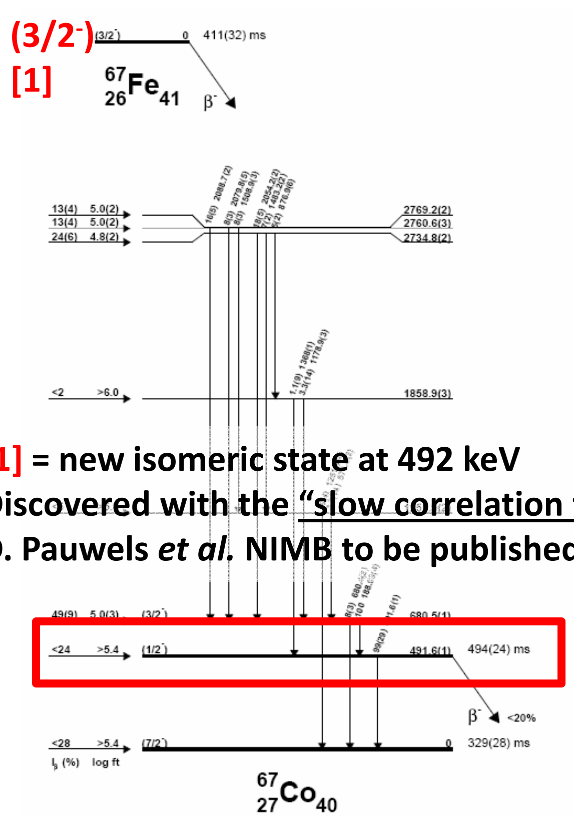
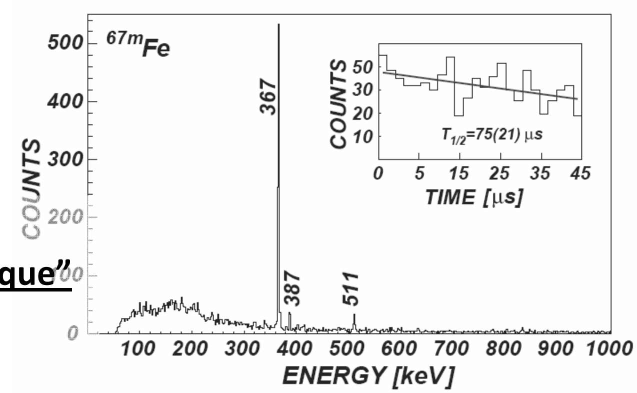
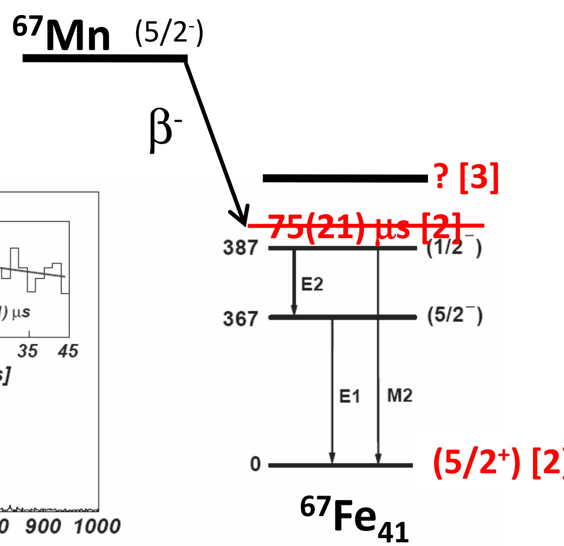


[1] = new isomeric state at 492 keV
Discovered with the "slow correlation technique"
D. Pauwels *et al.* NIMB to be published





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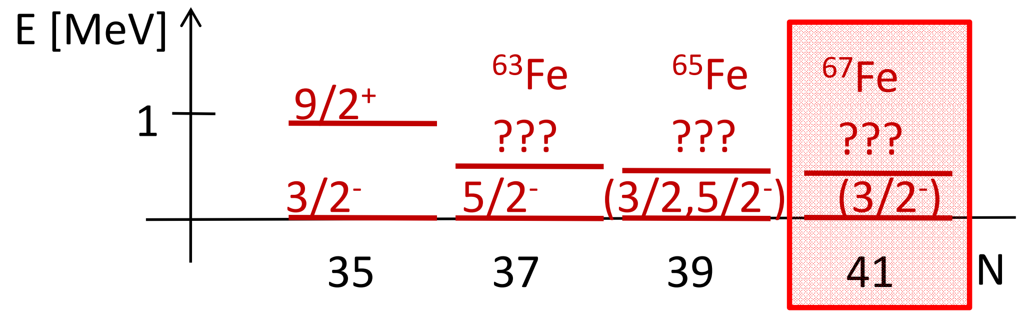
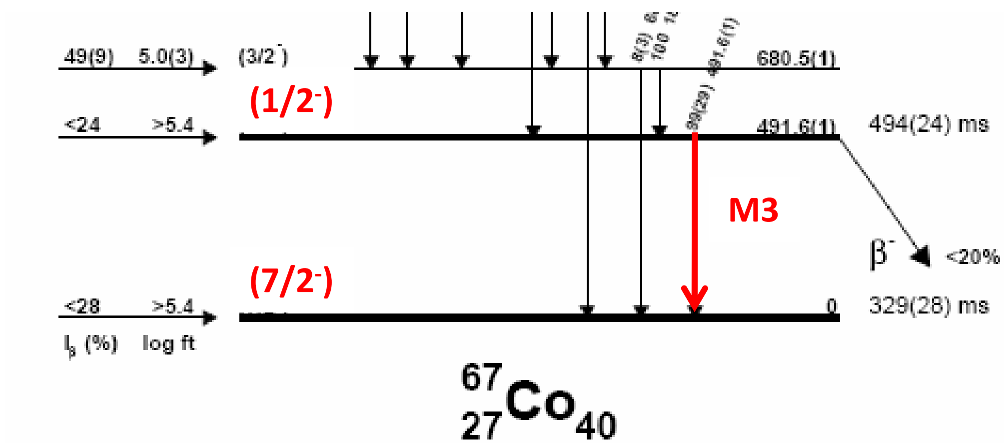
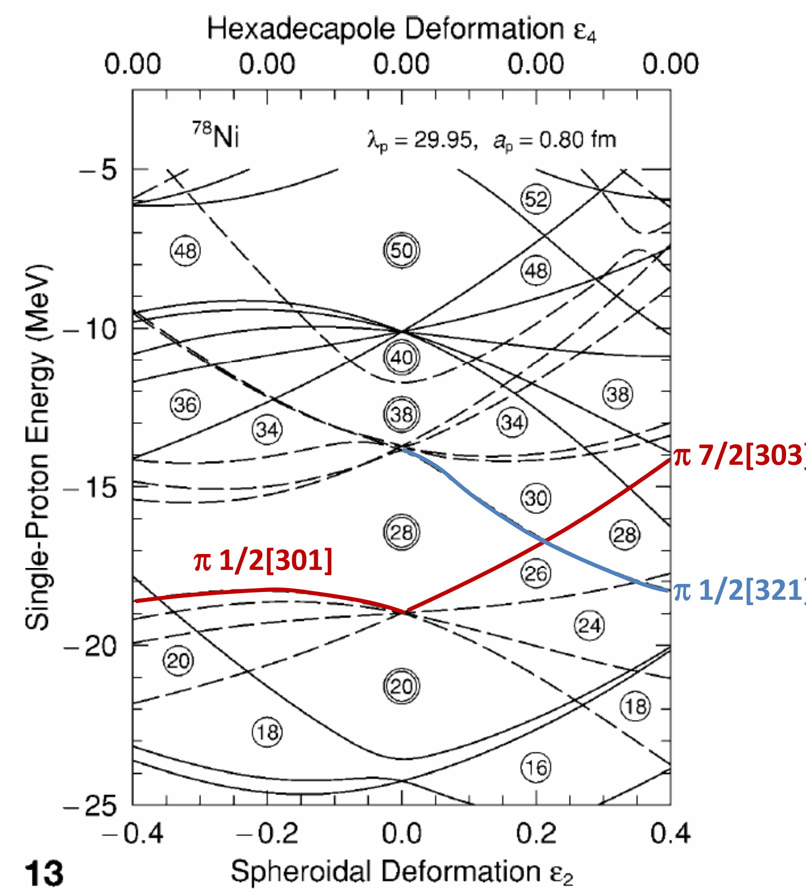


Preliminary interpretation, related to shape coexistence and deformation

D. Pauwels et al., These KU Leuven 2008

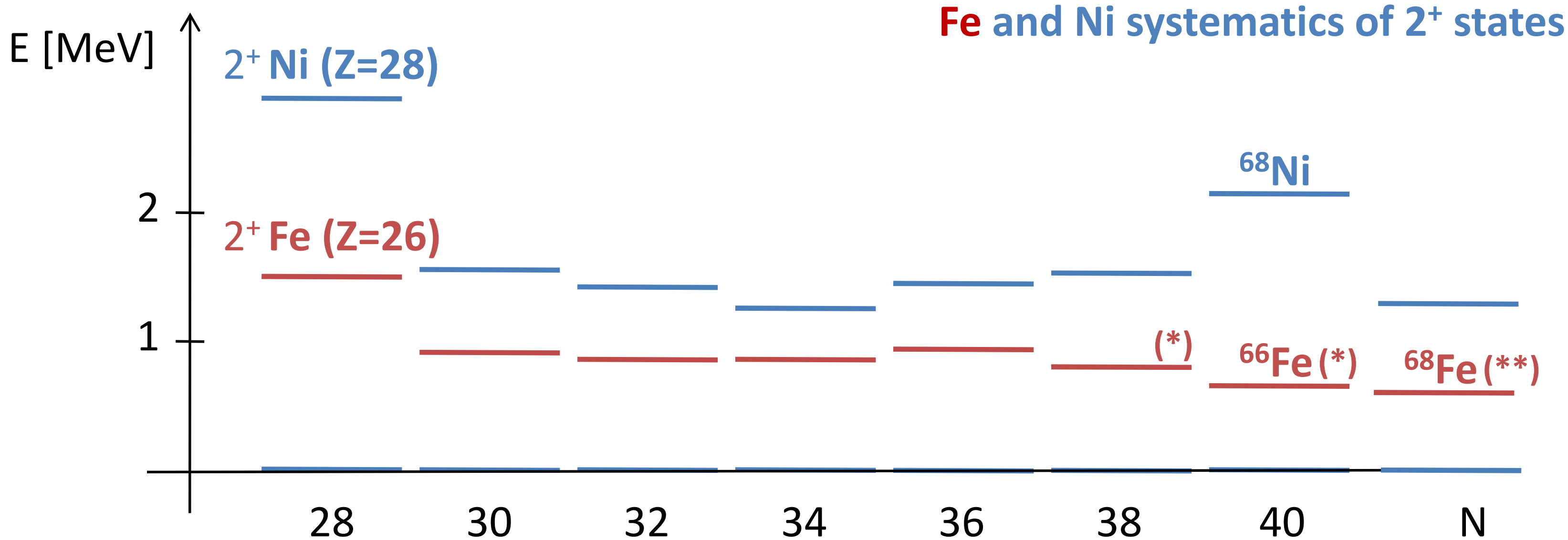
(to be published) [1]





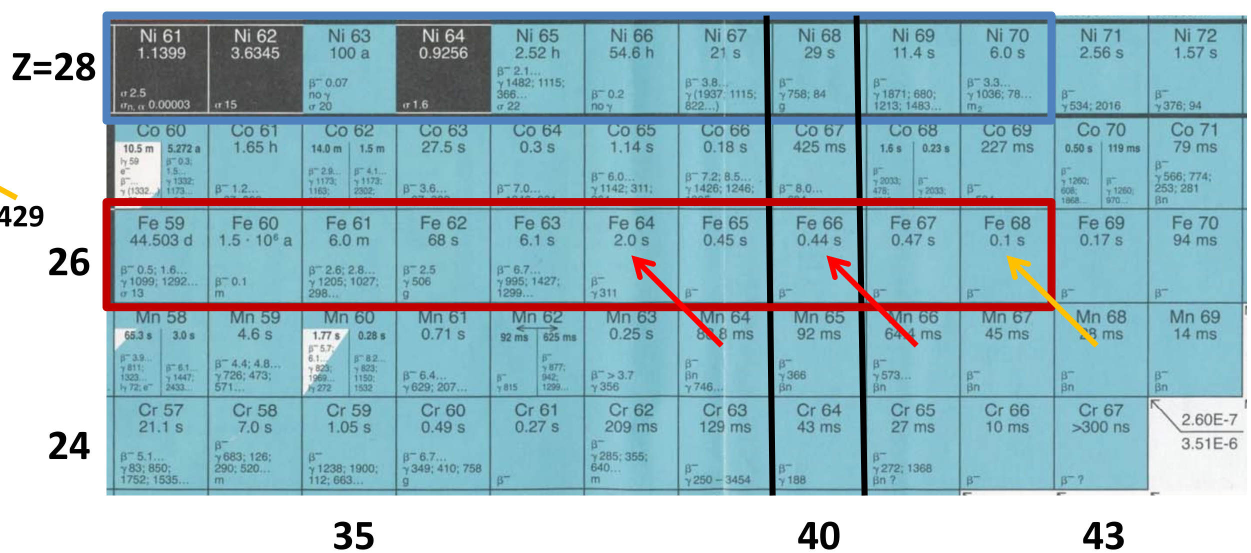
1. General Physics Motivation

Fe and Ni systematics of 2^+ states



(**) β-decay study ^{68}Mn at GANIL (2006)
J.M. Daugas et al., AIP Conf Proc 831 p 427-429

(*) β-decay study ^{64,66}Mn at ISOLDE (1998)
Hannawald et al. PRL 82 1391 (1999)



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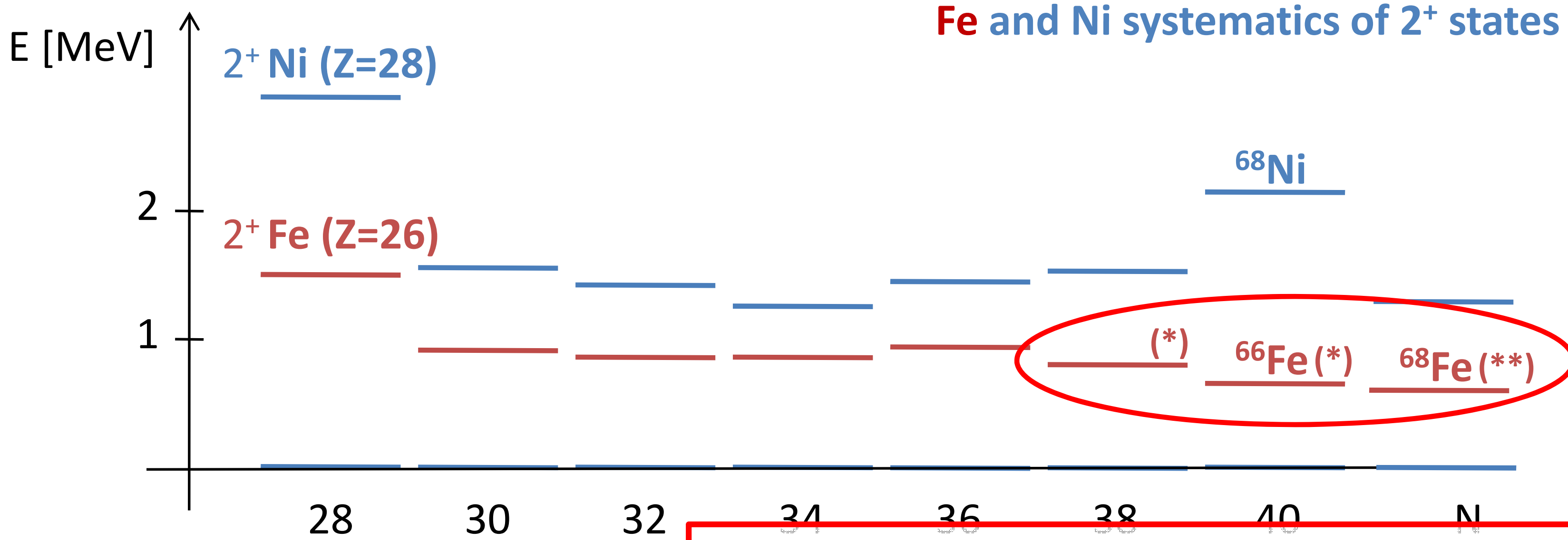
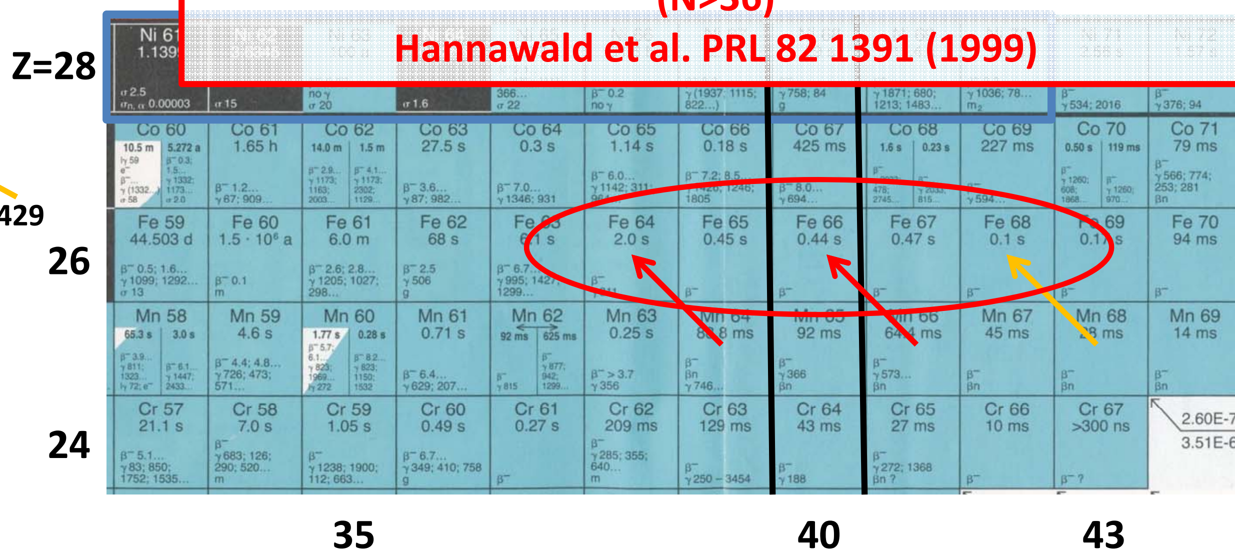


ONSET TO DEFORMATION IN NEUTRON RICH Fe ISOTOPES (N>36)

Hannawald et al. PRL 82 1391 (1999)



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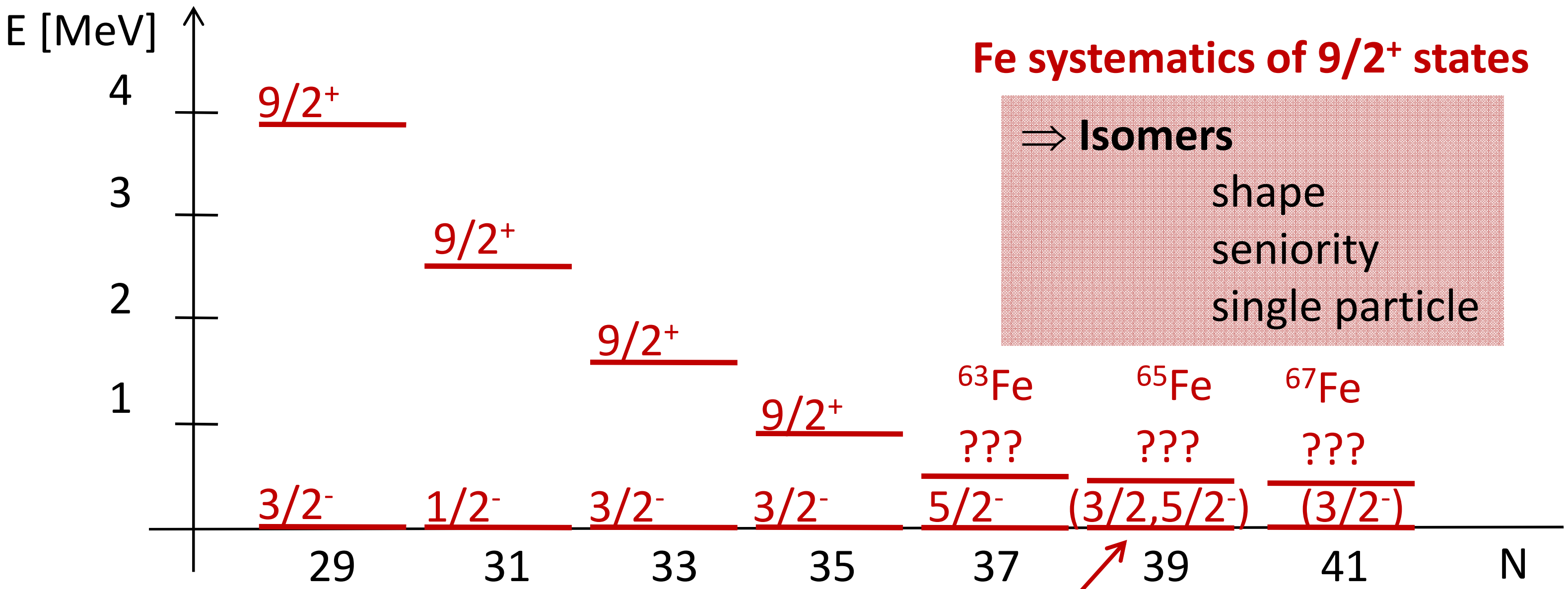
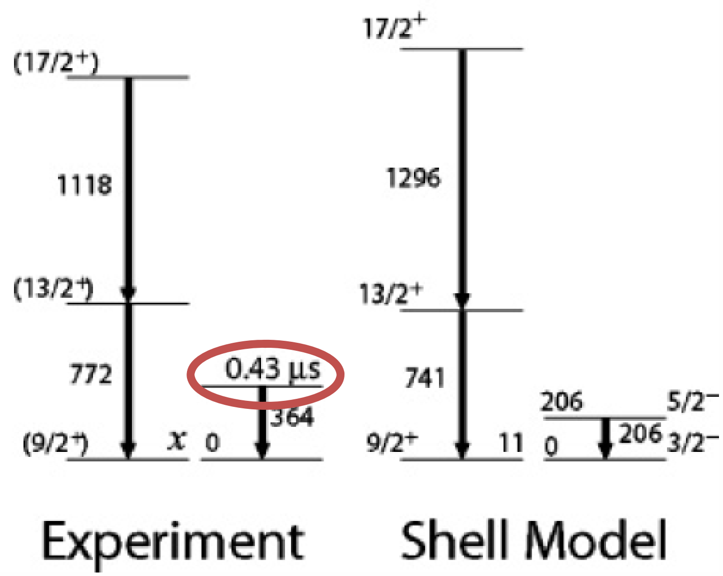


Fe systematics of 9/2+ states

⇒ **Isomers**
shape
seniority
single particle



Lunardi et al. PRC 76 034303 (2007)

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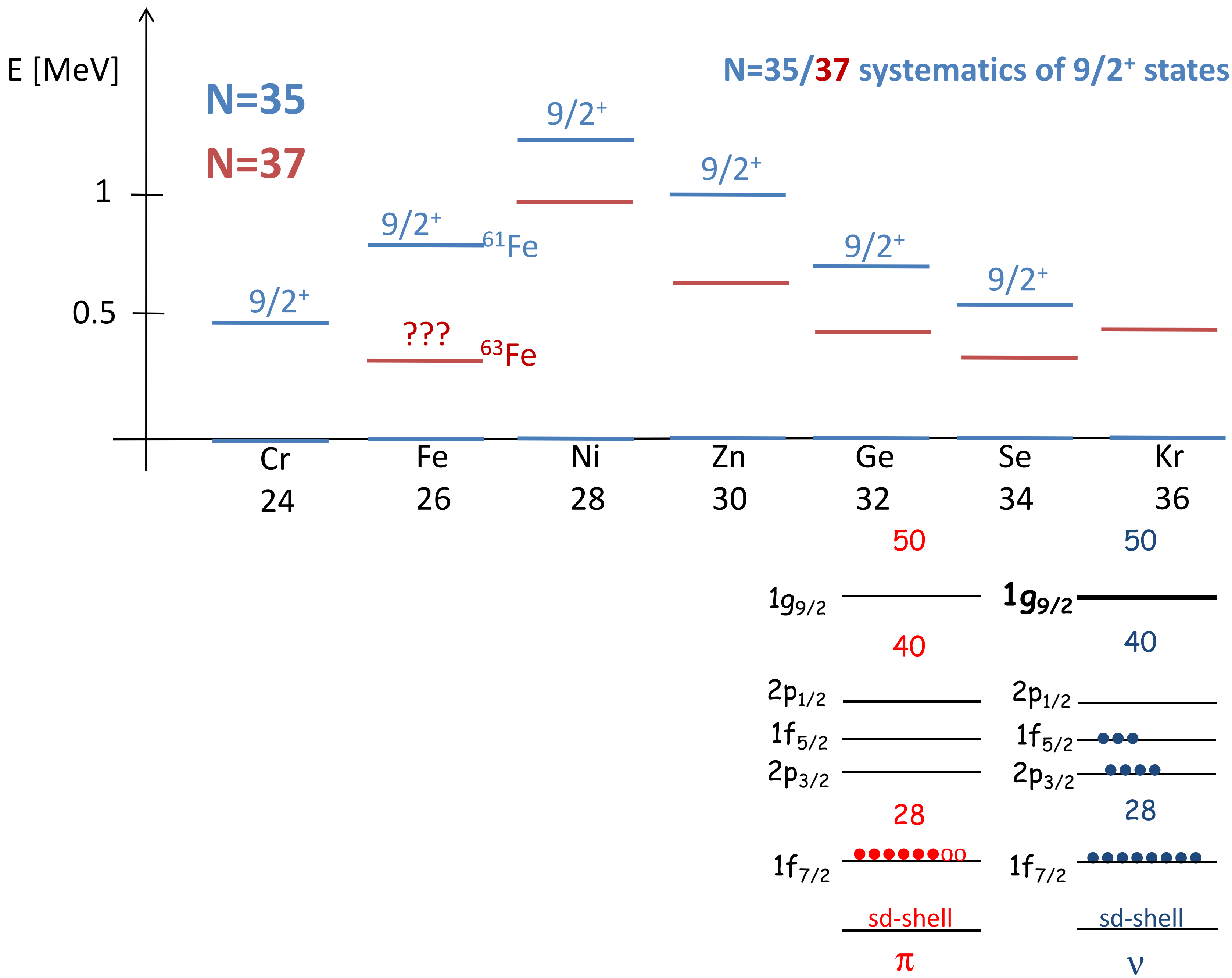
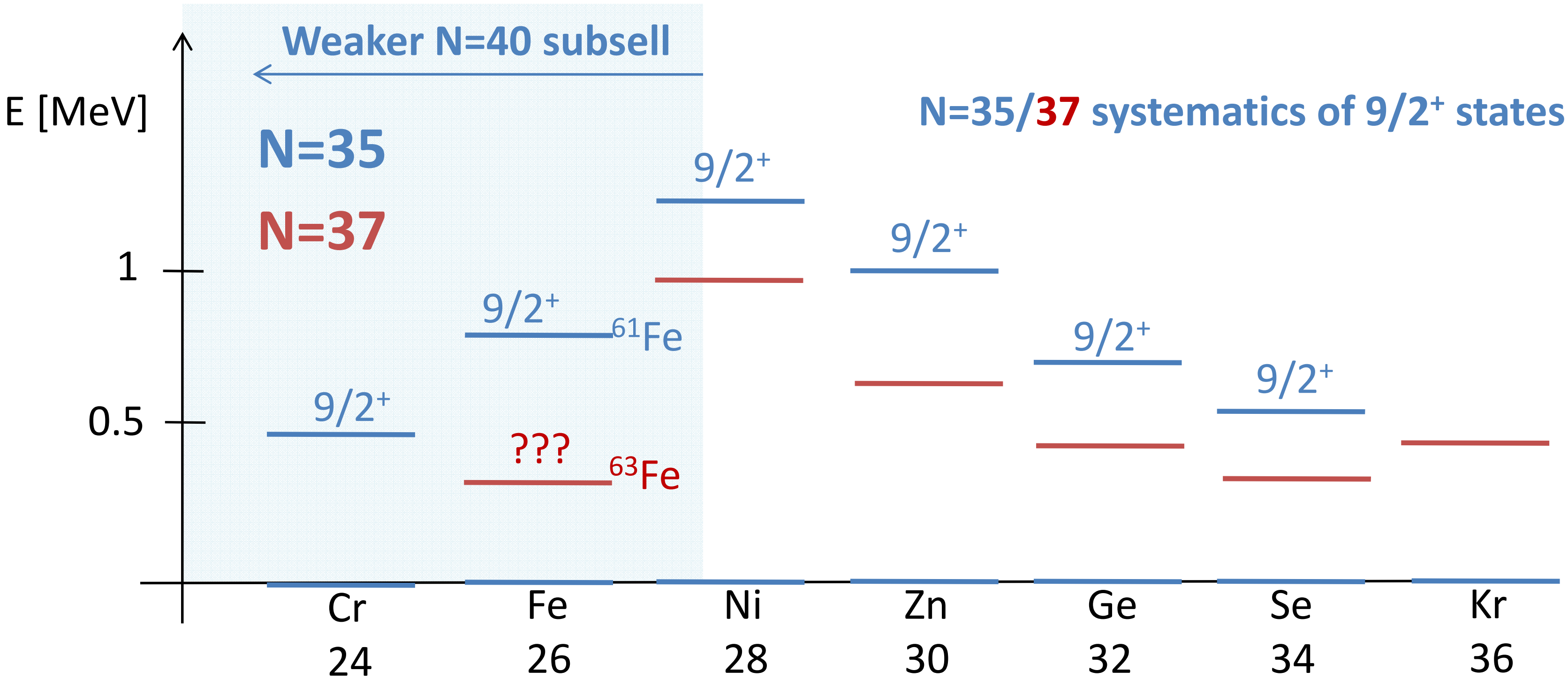
Indication for β-decaying isomer
D. Pauwels *et al.* (KU Leuven)

+ GANIL : 397 keV 420(13) ns


E [MeV]
N=35
N=37
N=35/37 systematics of 9/2+ states
1
0.5
9/2+
9/2+
61Fe
???
63Fe
9/2+
9/2+
9/2+
9/2+
Cr 24
Fe 26
Ni 28
Zn 30
Ge 32
Se 34
Kr 36
50
1g9/2
40
2p1/2
1f5/2
2p3/2
28
1f7/2
sd-shell
π
50
1g9/2
40
2p1/2
1f5/2
2p3/2
28
1f7/2
sd-shell
ν

1. General Physics Motivation



9/2$^+$ excitation energy drops to low energy region dominated by pf orbitals

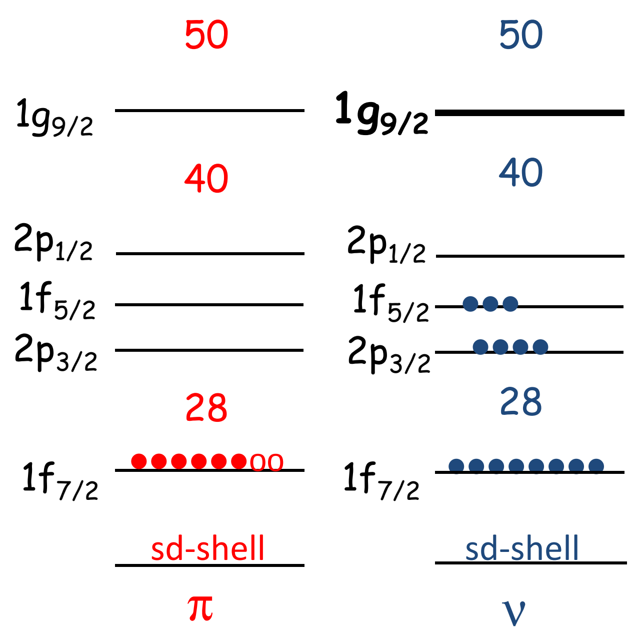
⇒ Deformation

⇒ Shape co-existence

Ex. High spin study $^{59}Cr_{35}$

Freeman *et al* PRC **69** 064301 (2004)

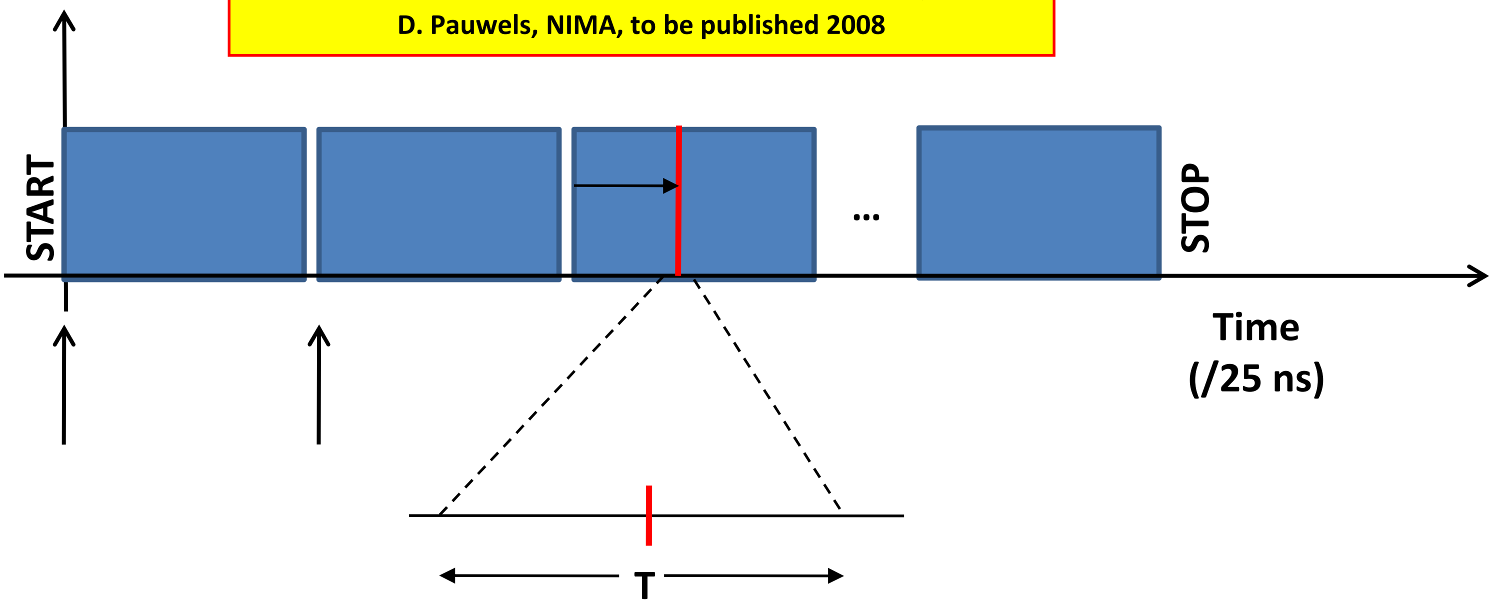
Sorlin *et al* NPA **669** 351-367 (2000)



-Single γ-rays and β's are individually "timestamped"
-Only the energy of the γ-ray is registered
-No hardware conditions are implied on the raw data !

⇒ Coincidences and Correlations (γ-γ, βγ-γ, …) are performed OFFLINE

THE "SLOW CORRELATION TECHNIQUE"
D. Pauwels, NIMA, to be published 2008



1- Event type definition : β-γ / single γ / … + time window definition (T)

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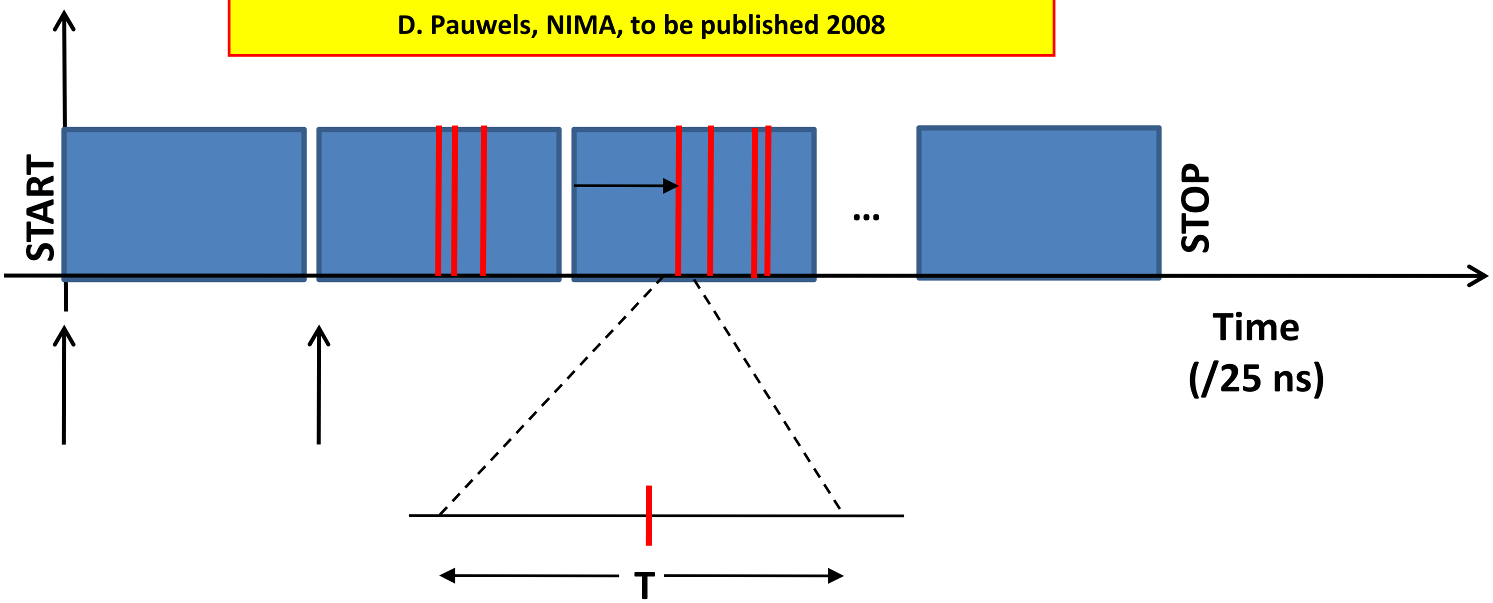

1- Event type definition : β-γ / single γ / … + time window definition (T)

(scan over full data set for these event types)

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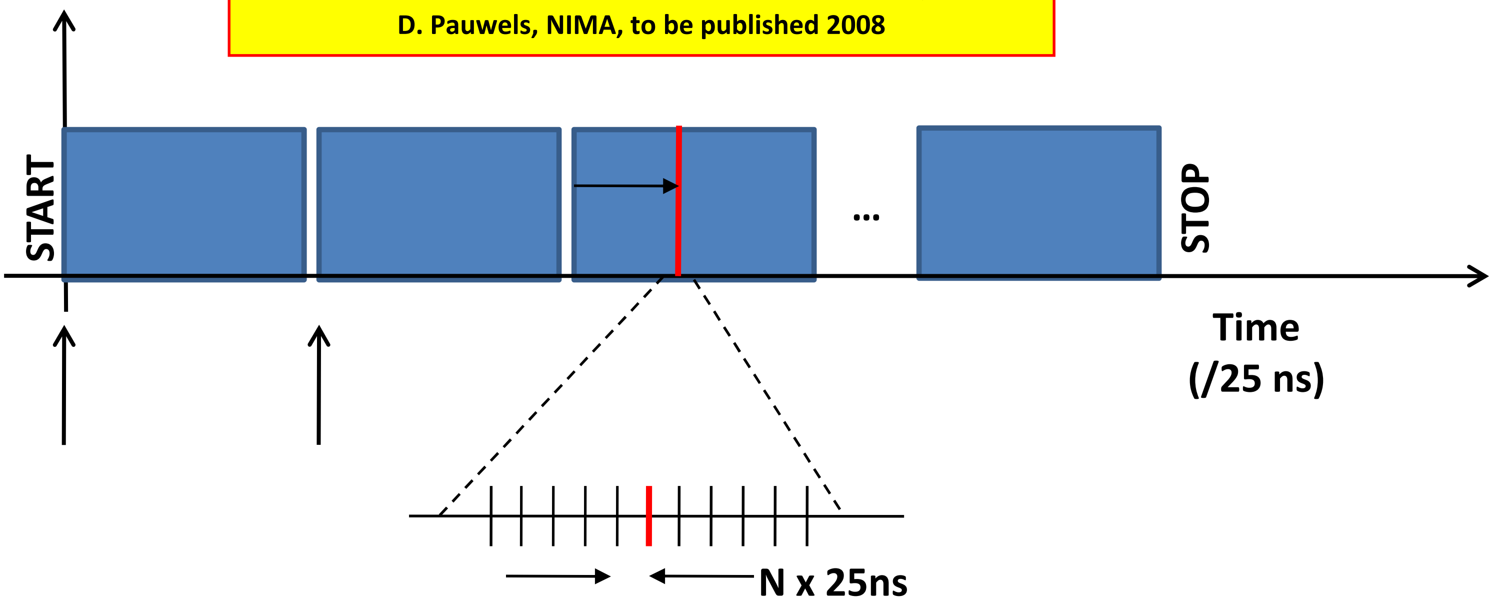

1- Event type definition : β-γ / single γ / ... + time window definition (T)
2- Single γ-ray histograms in time slices (N x 25ns) before and after the detected "event type" = *CORRELATED HISTOGRAMS*

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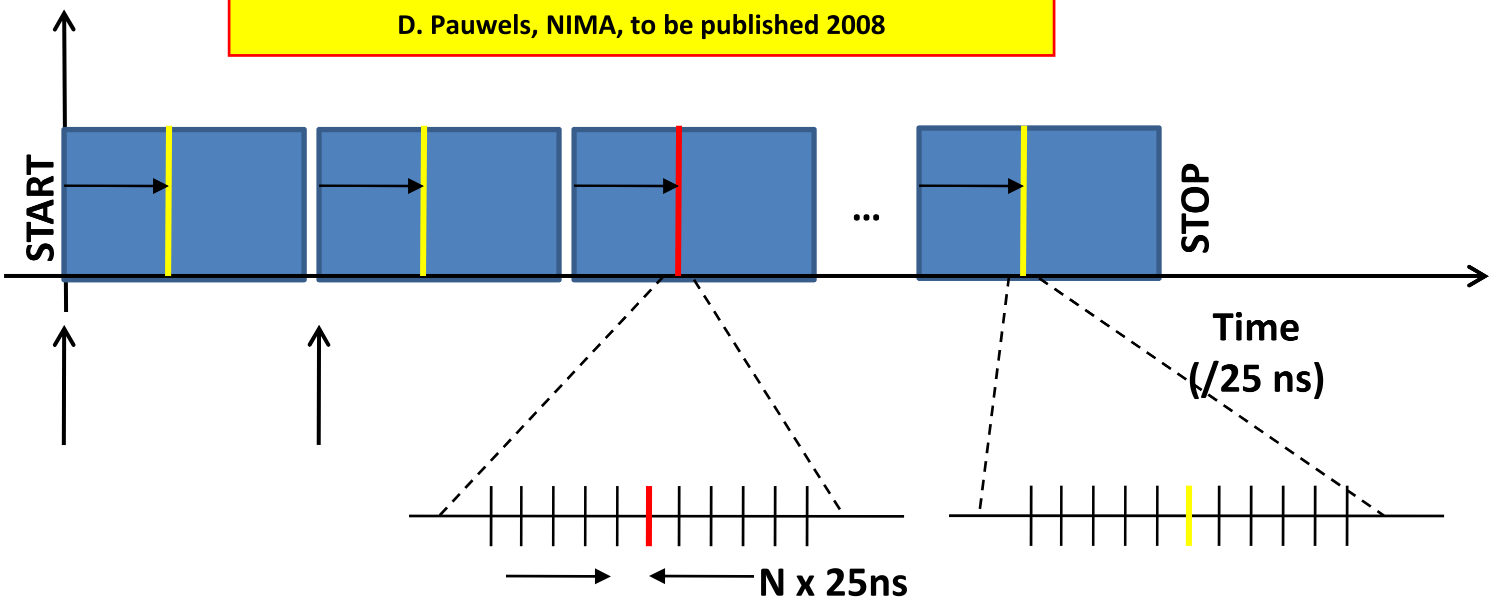
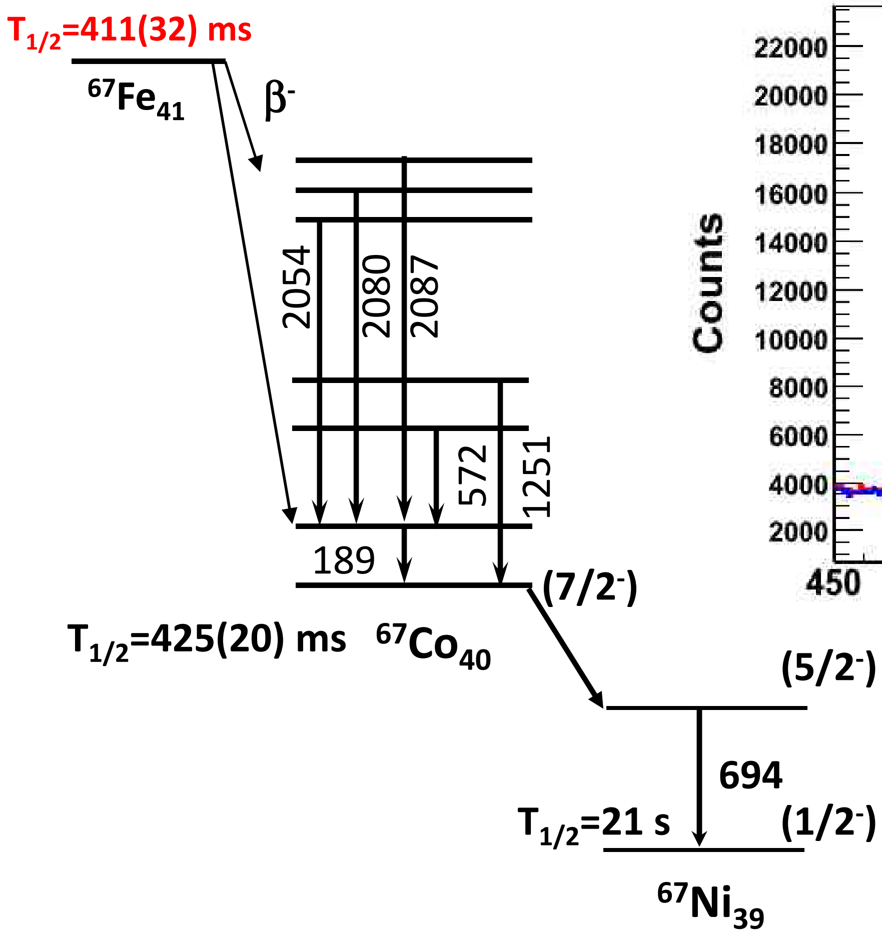


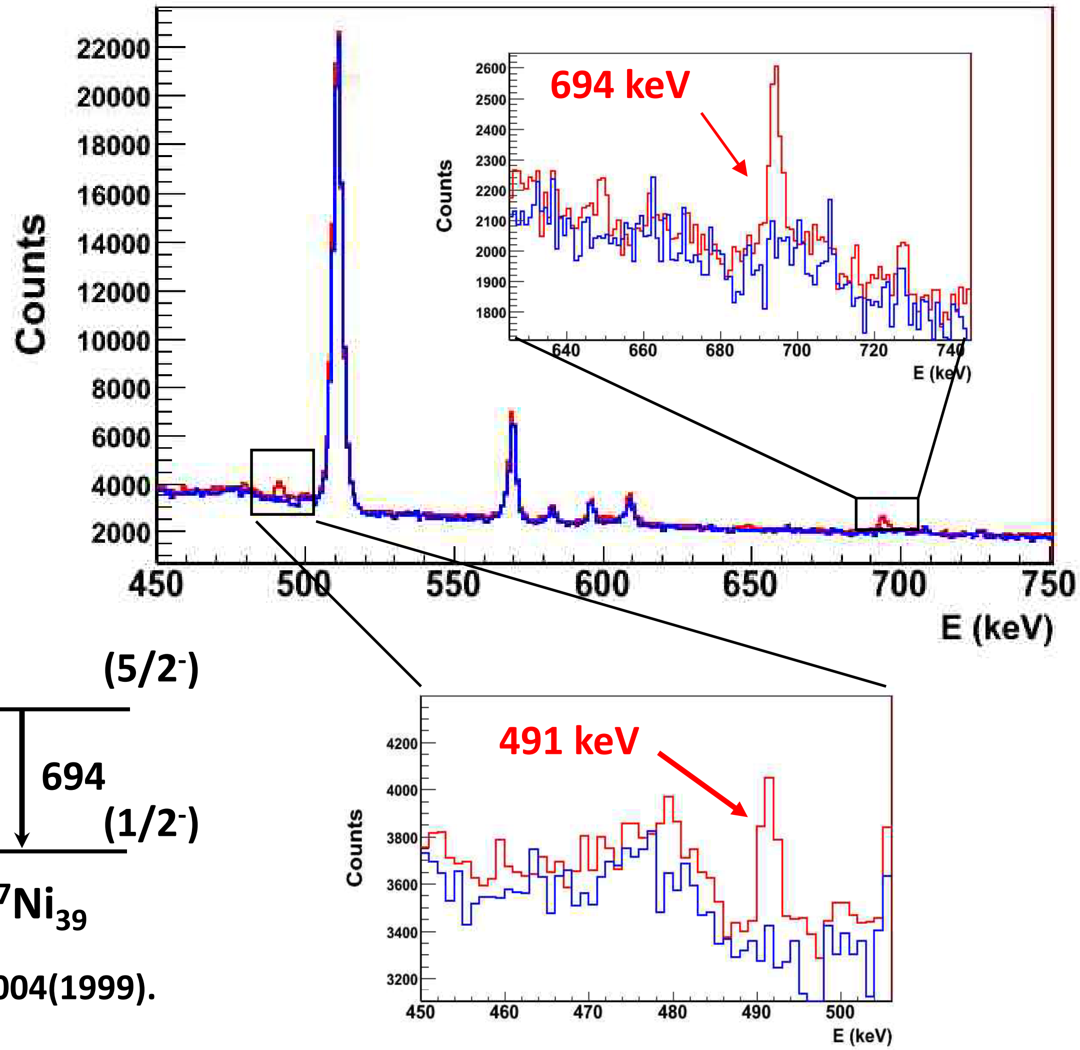
1- Event type definition : β-γ / single γ / …
2- Single γ-ray histograms in time slices (N x 25ns) before and after
the detected "event type" = *CORRELATED HISTOGRAMS*
3- Single γ-ray histograms in the same time windows relative to the start of each cycle
= *RANDOMLY CORRELATED HISTOGRAMS*

3. The LISOL β-decay setup



L. Weissman et al., PRC 59, 2004(1999).

Singles γ-spectra : Red: Laser ON Blue: Laser OFF



Pictures Courtesy D. Pauwels O. Ivanov, KU Leuven (2007)

2. Conditions for applicability :

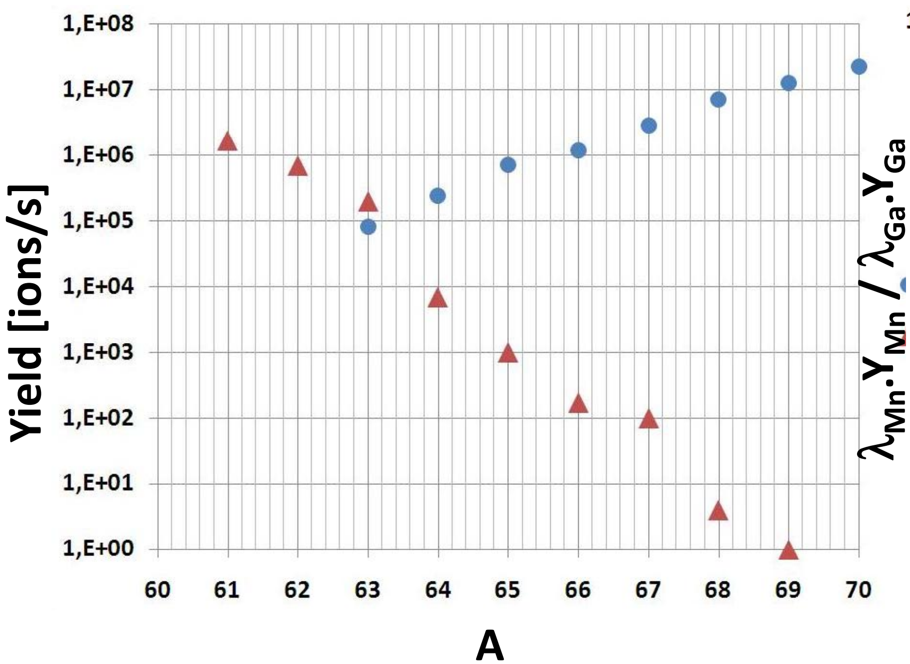
? pure sources of radioactive ions

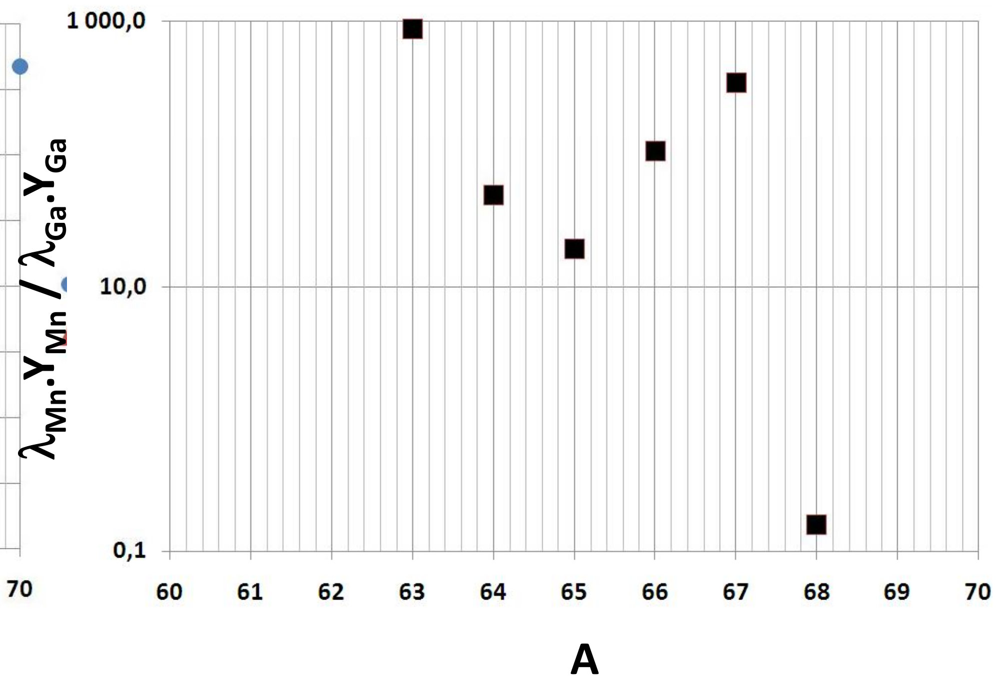
✓element selectivity

✓low background

✓efficient detection system

? low count rate





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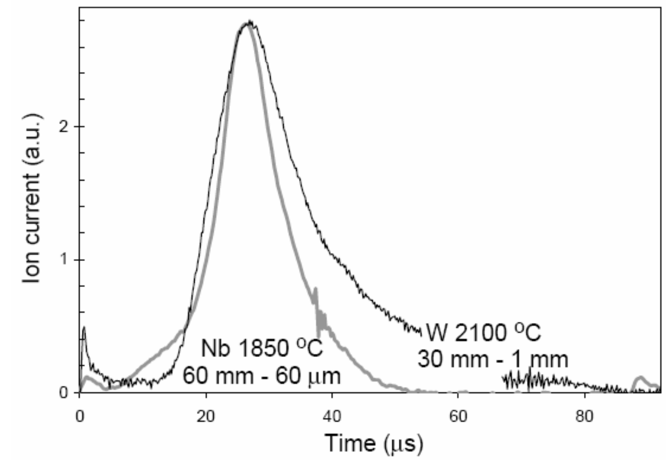
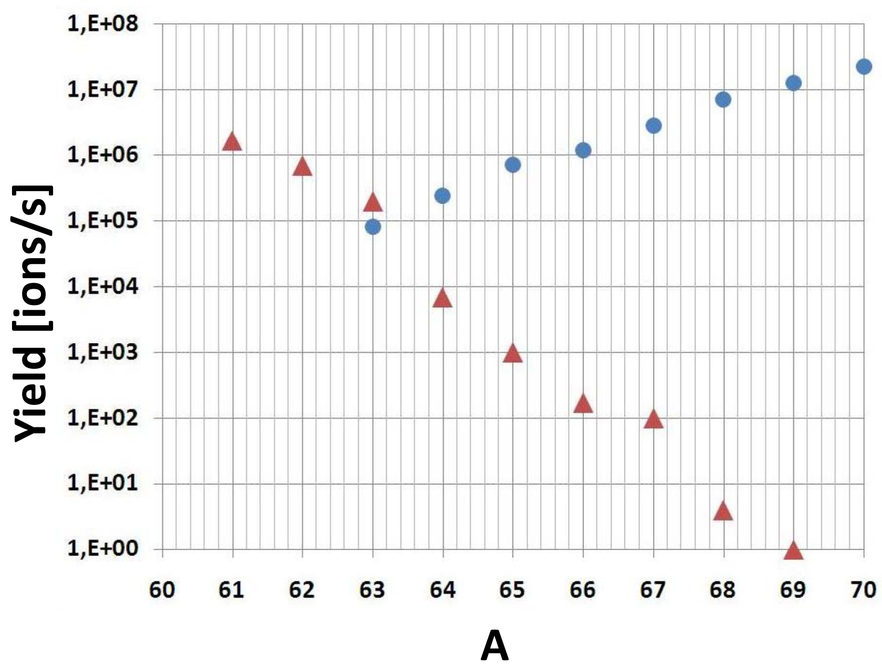
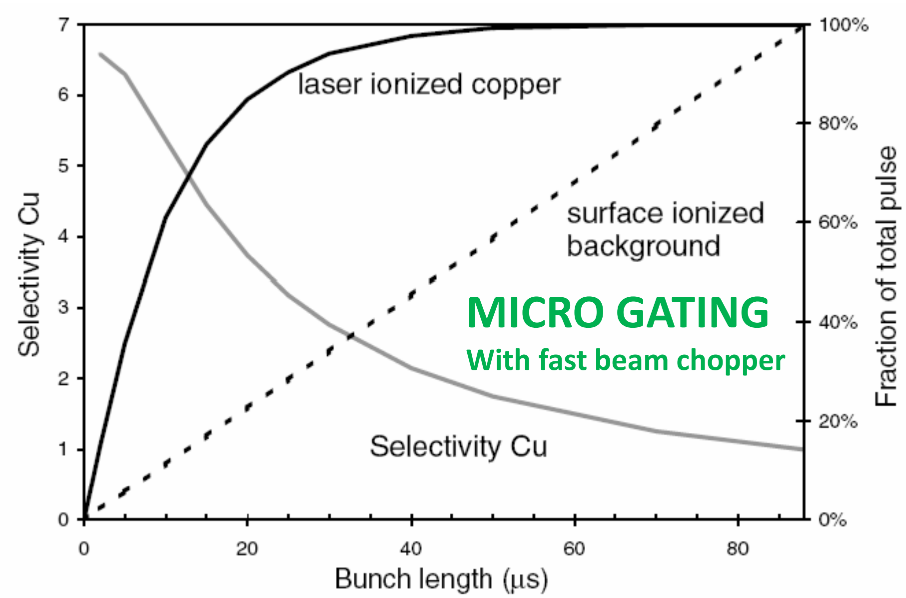


Pictures taken from U. Koester, These 1999, TU Munchen
Method is exemplified for 67Co isotopes





2. Previous experiment (1998) and Proposed experiment (2008)

1998 : β-decay study at ISOLDE of $^{64,66}Mn$

M. Hannawald, PhD dissertation Mainz universitat 1999

- -Only Single γ's in time slices of 150 ms after proton impact
- -No β-gated γ-ray spectra
- -Two coaxial Germanium detectors
- -Only γ's from $^{64,66}Mn$ were measured (experiment was an "extended target test")