Nuclear moments of excited states in neutron-rich Sn isotopes studied by on-line PAC (IS673)

Addendum: Request for an additional off-line run using Sb sources

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•**Spokespersons:** H. Haas, G. Georgiev

- Our aim: Test the additivity rule for moments of two-particle states in a chain of semi-magic (Sn) nuclei
- The best candidates: The 5^- states of (pure ?) configuration $\{1h11/2^-, 3s1/2^+\}$
- These states are isomers with suitable half-life from ^{116}Sn to ^{130}Sn
- Most moments of the single-particle states in the neighboring odd isotopes have been determined
- Does the simple shell-model picture work or what could it teach us?

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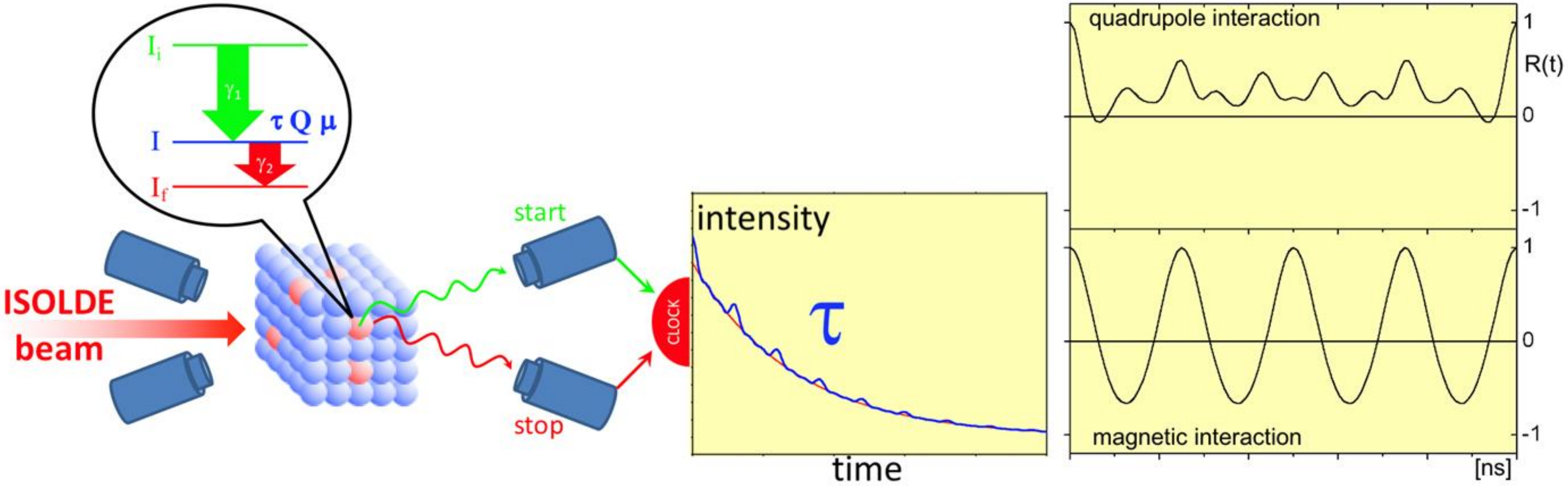
The γ-γ PAC technique for pure interactions:



From the experimental perturbation pattern one extracts

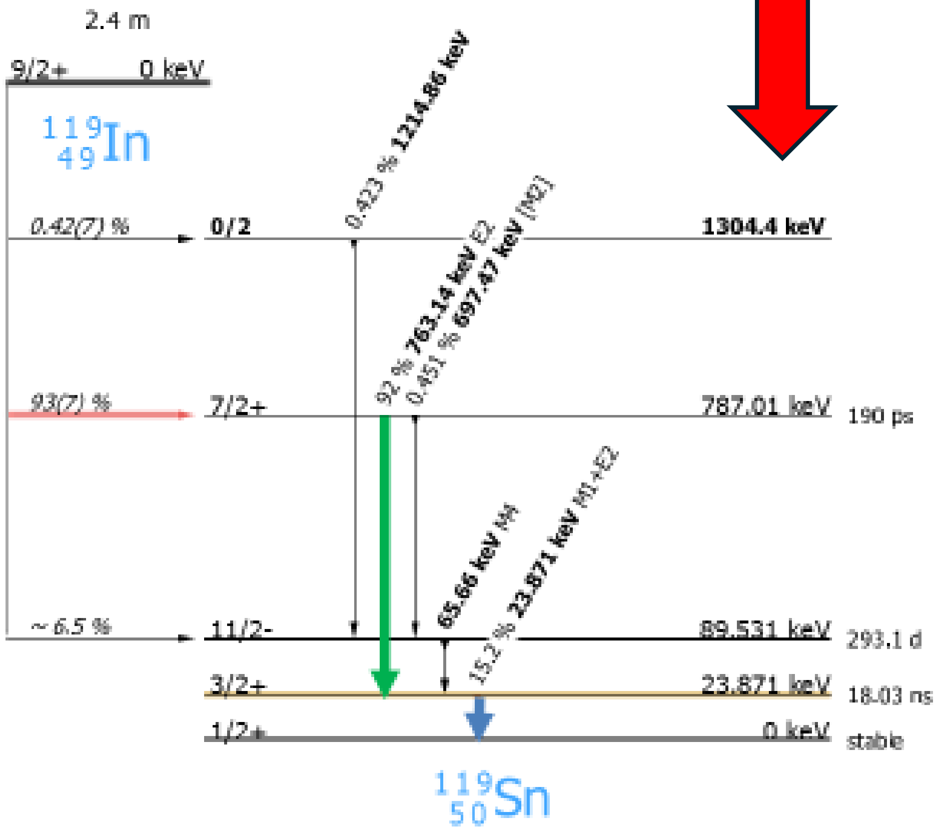
ν_Q = e Q * Vzz / h

Electric field gradient Vzz in non-cubic solid (from theory!) or reference isotope

ν_L = μ/I * B / h

Magnetic field B from external magnet or ferromagnetic solid

Simple decay scheme: ^{119}In to ^{119}Sn

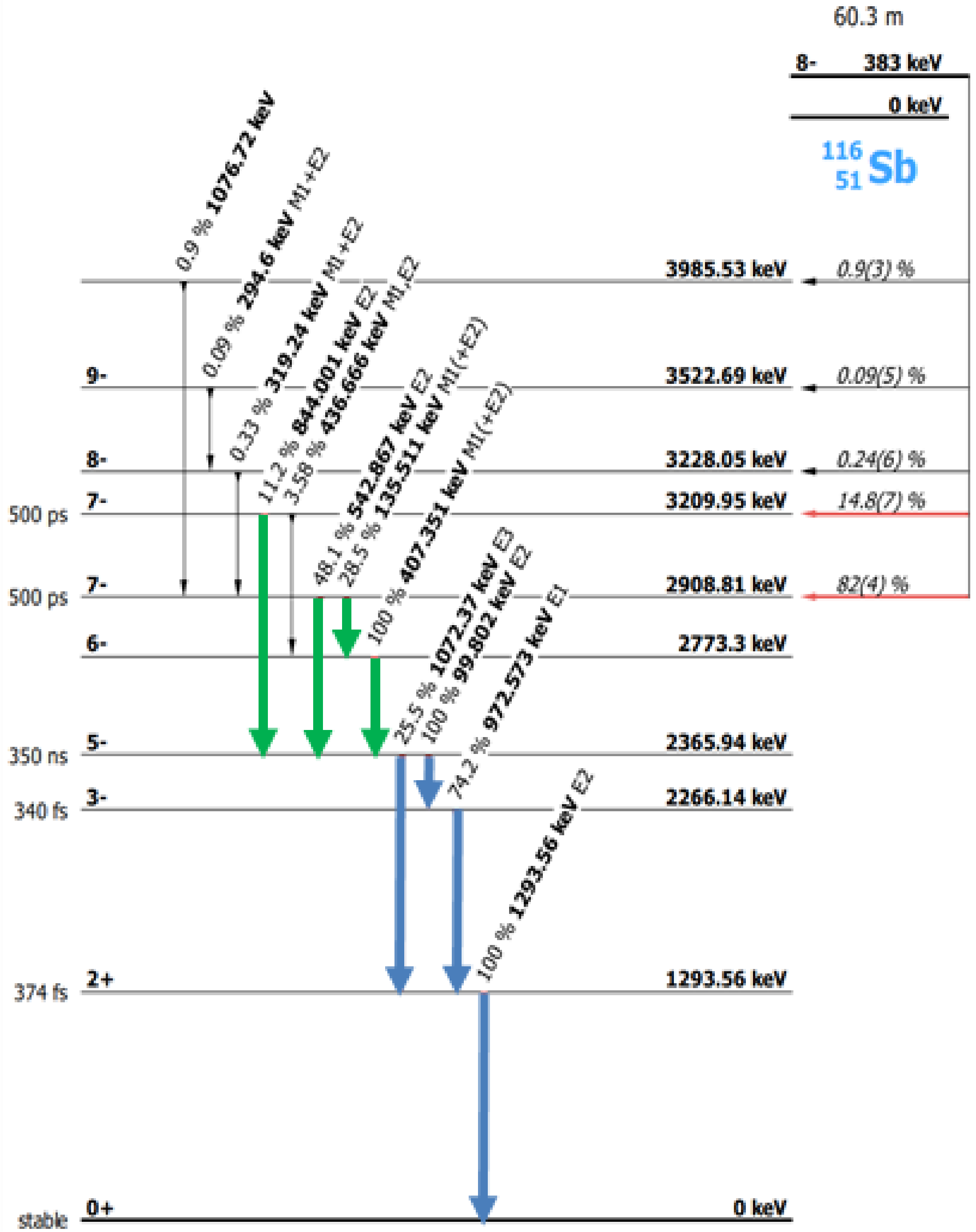


Complex decay scheme: ^{116}Sb to ^{116}Sn

4 start transitions, 4 stop transitions

Result: 16 R(t) functions

Add all up (recalibrated) to improve statistics



Off-line run in October 2021

using 3 different PAC spectrometers

What we have measured:

^{116m}Sb(1hr) to ^{116}Sn (5^-,350ns) in Fe — accurate data, μ agrees with PAD

^{116m}Sb(1hr) to ^{116}Sn (5^-,350ns) in Zn — expected spectrum not seen, failed annealing!

^{118m}Sb(5hr) to ^{118}Sn (5^-,22ns) in Fe — good data for polarized Fe foil give μ

^{118m}Sb(5hr) to ^{118}Sn (5^-,22ns) in Zn — annealing results in strong damping! Hope!

^{118m}Sb(5hr) to ^{118}Sn (5^-,22ns) in Graphite — good data for QI, reference?, annealing studied

^{120}Sb(5.8d) to ^{120}Sn (5^-,5.6ns) in Graphite — precision spectra give Q relative to ^{118}Sn

Difficulties encountered:

Annealing of Sb implanted in Zn at 200C apparently resulted in segregation at surface

Spectra for ^{118}Sn confirm this, preliminary data without annealing acceptable!

For ^{118,120}Sn measurement in Gd or high external field needed for precision μ

On-line run in June 2023

using fully digital PAC spectrometer ($LaBr_3$)

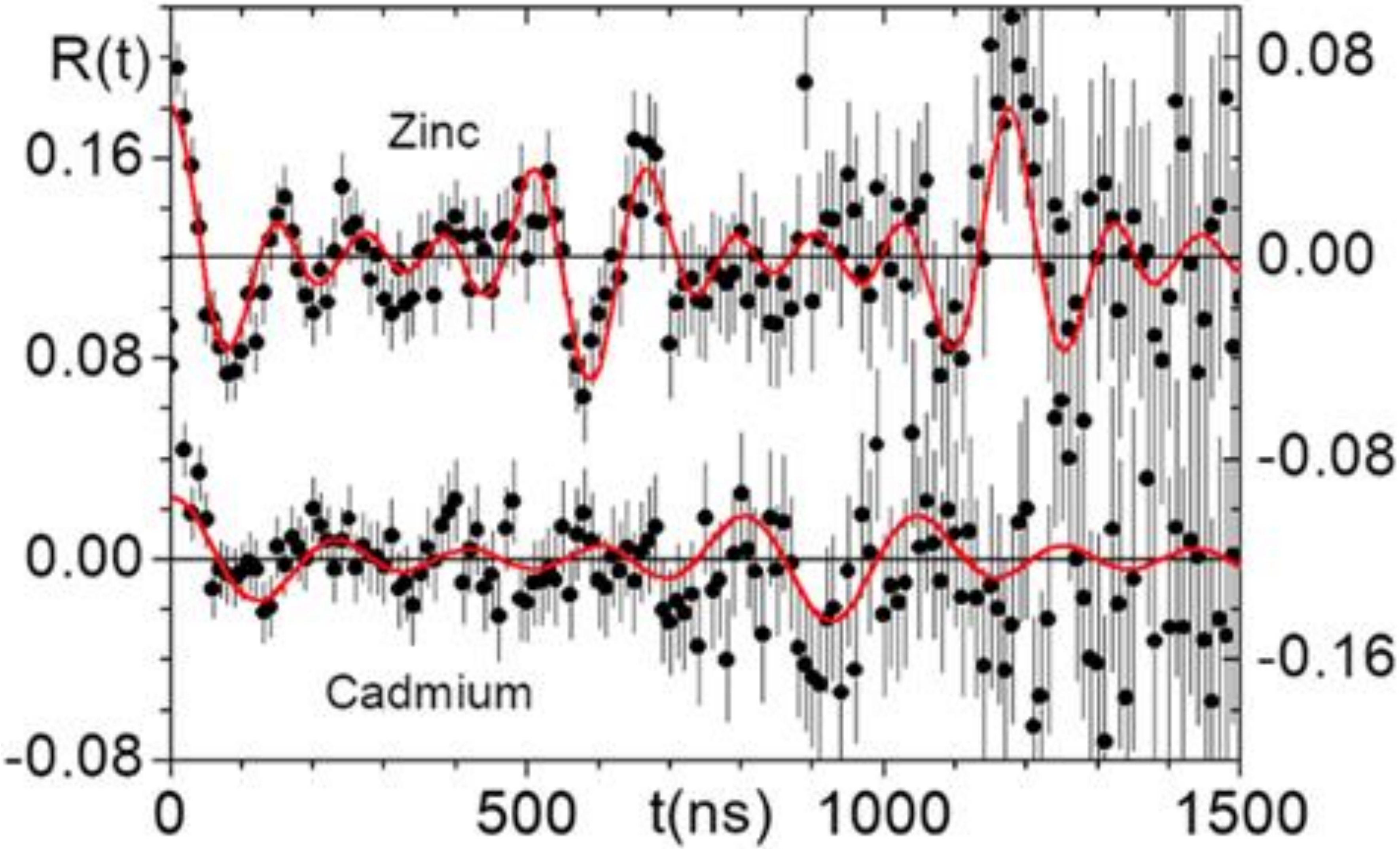
What we have measured:

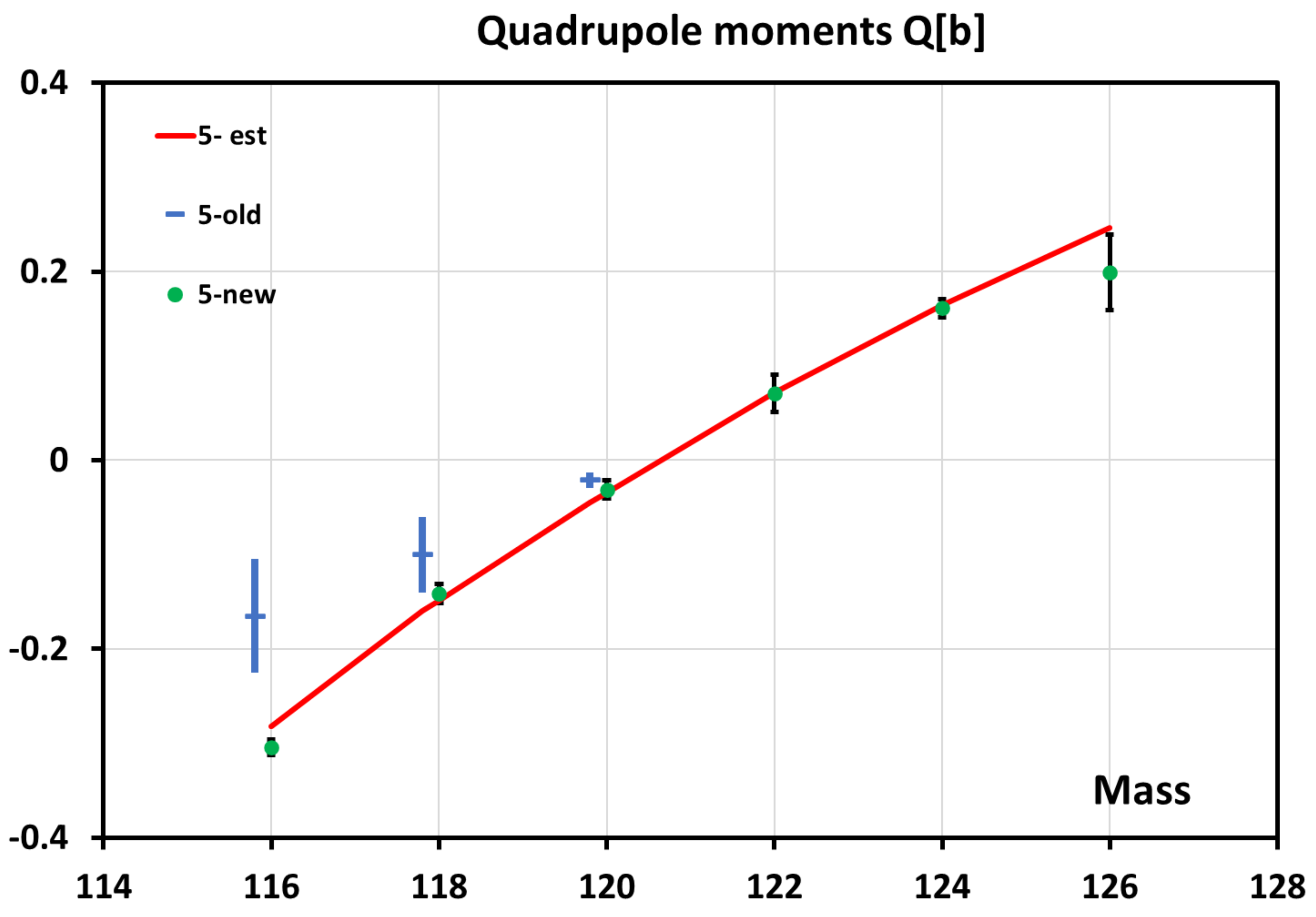
^{119}In(2.4m) to ^{119}Sn($3/2^+$,18ns) in Zn undamped spectrum at RT, ν_Q agrees with MS
^{122}In(10.8s) to ^{122}Sn (5^-,7.9ns) in Graphite acceptable data for QI
^{122}In(10.8s) to ^{122}Sn (5^-,7.9ns) in Fe approximate value for μ
^{124}In(3.7s) to ^{124}Sn (5^-,520ns) in Zn good data! Q determined
^{124}In(3.7s) to ^{124}Sn (5^-,520ns) in Cd acceptable data, efg ratio Zn/Cd determined!
^{124}In(3.7s) to ^{124}Sn (5^-,520ns) in Fe very good data for μ, damping similar to ^{116}Sn
^{126}In(1.6s) to ^{126}Sn (5^-,10.8ns) in Graphite preliminary data for QI

Difficulties encountered:

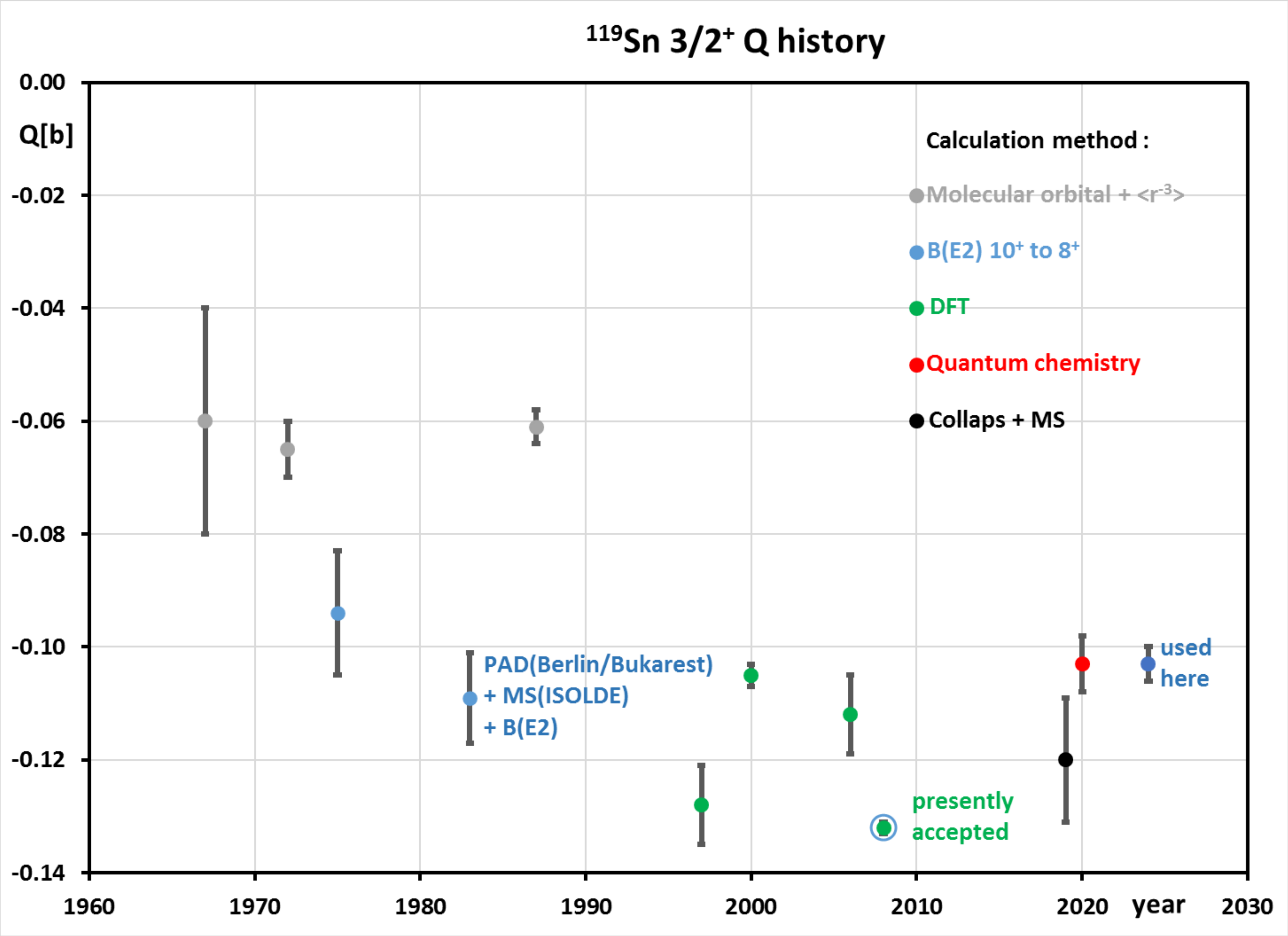
For T1/2<10s isotopes time-structure of ISOLDE beam makes measurement inefficient!
Suggested solutions: Including time in data system, replace photomultipliers with semiconductors, use staggered ISOLDE beam, use selective laser ionization
Better interpretation of data in Graphite call for a (technically demanding) reference measurement with ^{118}In implantation
For states with T1/2 below 50ns Gd matrix (cooled) needed for accurate μ

The key result: PAC for $^{124}Sn(5^-)$ in Zn and Cd



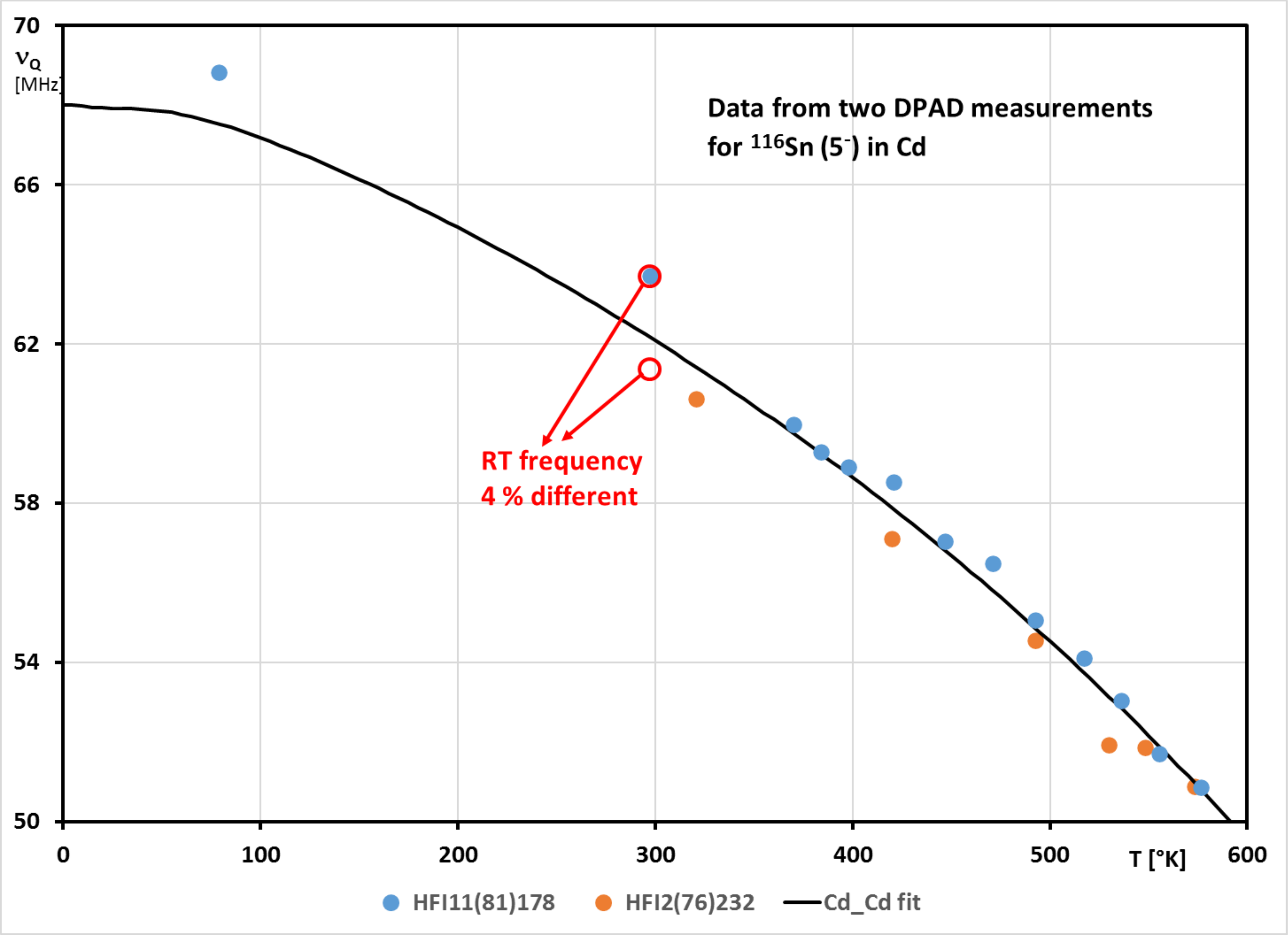


Quadrupole moments Q[b]
5- est
5-old
5-new
0.4
0.2
0
-0.2
-0.4
Mass
114
116
118
120
122
124
126
128



119Sn 3/2+ Q history
Q[b]
0.00
-0.02
-0.04
-0.06
-0.08
-0.10
-0.12
-0.14
1960
1970
1980
1990
2000
2010
2020
year
2030
Calculation method :
Molecular orbital + <r-3>
B(E2) 10+ to 8+
DFT
Quantum chemistry
Collaps + MS
PAD(Berlin/Bukarest)
+ MS(ISOLDE)
+ B(E2)
presently
accepted
used
here

The necessary reference: ν_Q for $^{116}Sn(5^-)$ in Cd at RT



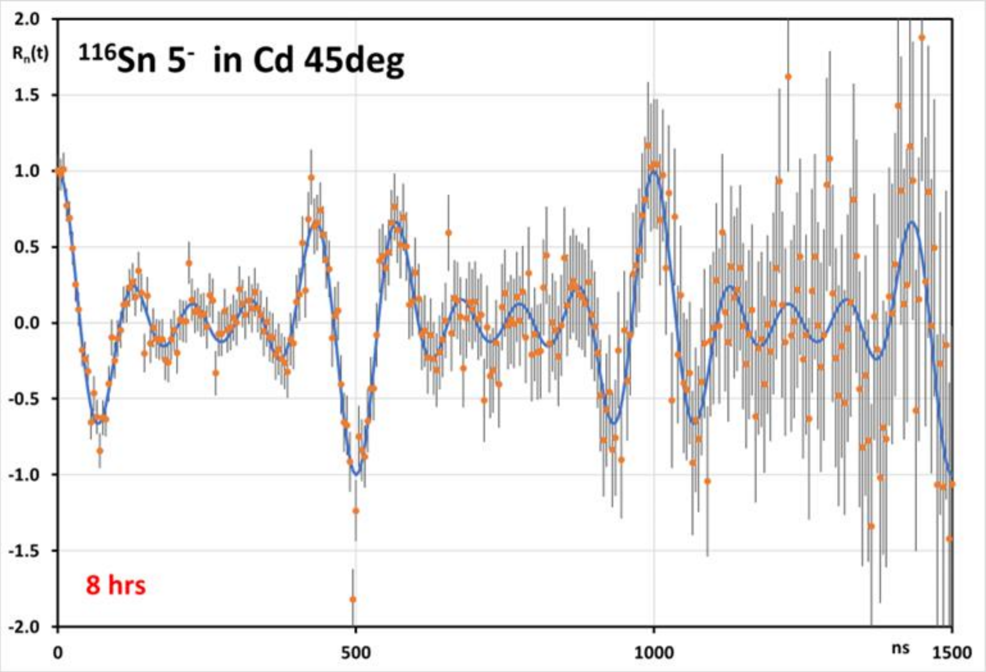
The quest for precision quadrupole moments:

- Missing data:

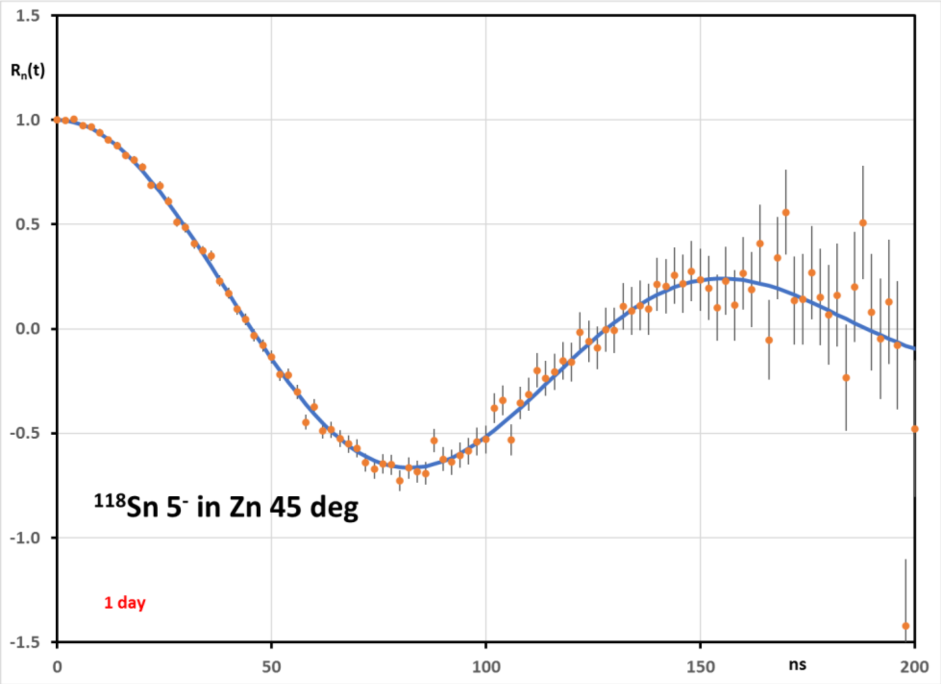
1) Accurate ν_Q for $^{116}Sn(5^-)$ in Cd at RT
2) Reliable value of ν_Q for $^{118}Sn(5^-)$ in Zn
3) Independent determination of Q(116) to Q(118) ratio
4) Relate the Q of $^{119}Sn(3/2^+)$ to the values obtained here

- Proposed solution:

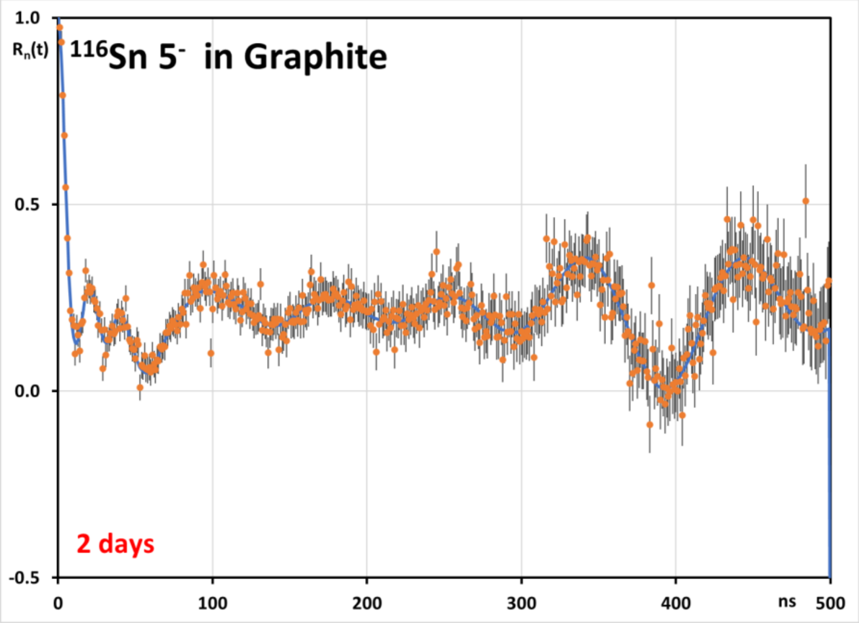
1) Measure ν_Q for ^{116}Sn in Cd (single crystal or foil)
2) High statistics PAC spectrum for ^{118}Sn in Zn(SC, annealing?)
3) High statistics PAC spectrum for ^{116}Sn in graphite(annealed)
4) Moessbauer spectrum for ^{119}Sn in graphite(annealed)



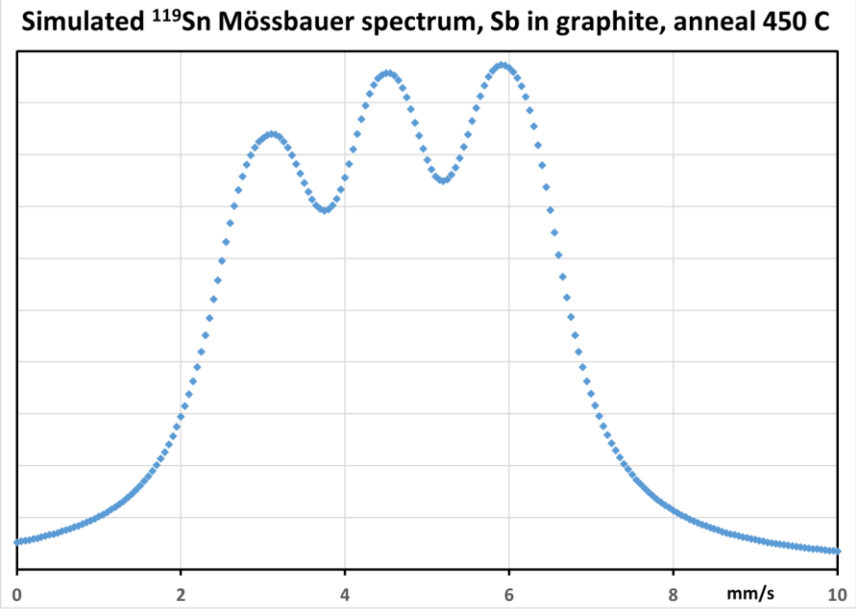
116Sn 5- in Cd 45deg
Rn(t)
8 hrs
ns
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
0
500
1000
1500



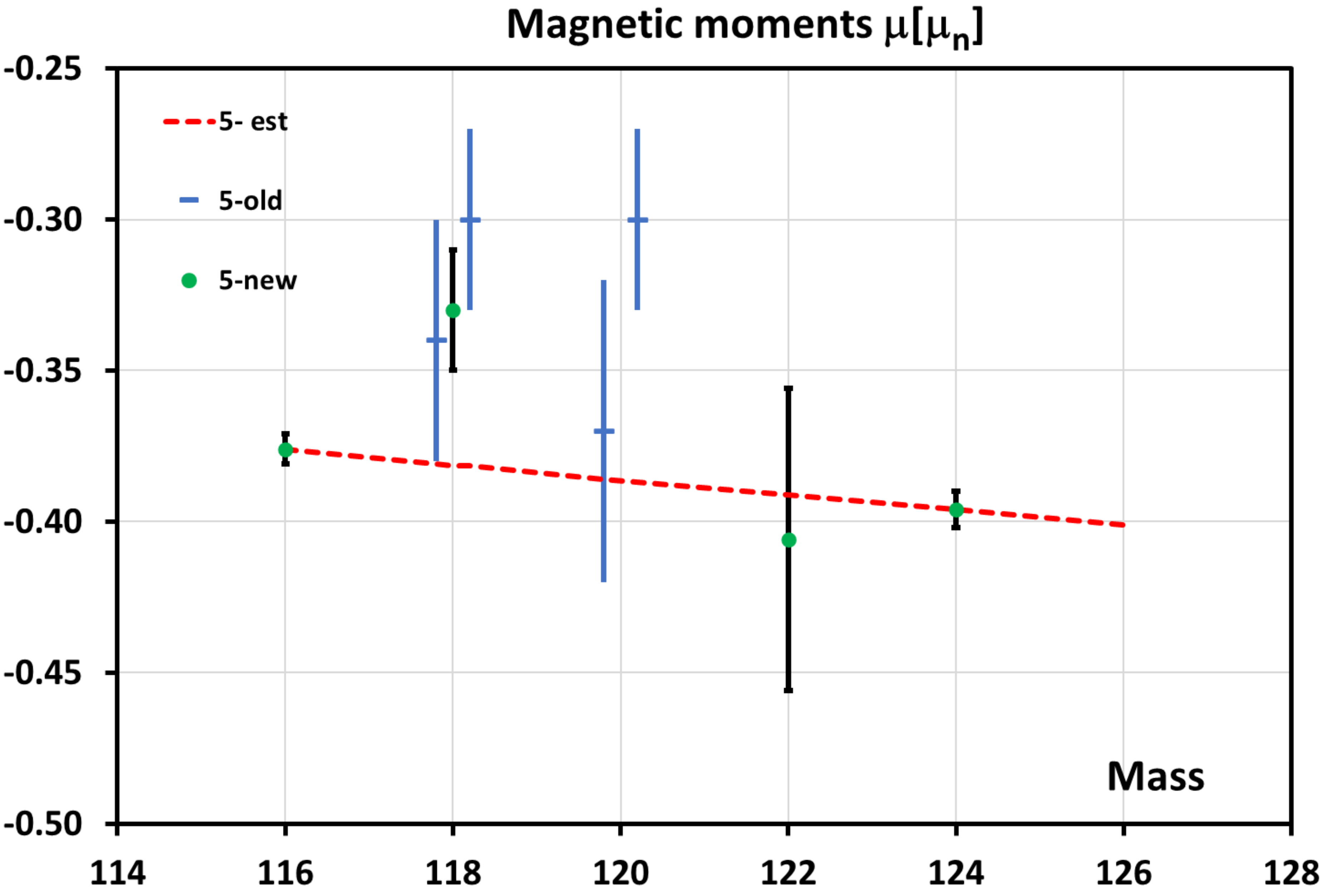
118Sn 5- in Zn 45 deg
Rn(t)
1 day
ns
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
0
50
100
150
200



116Sn 5- in Graphite
Rn(t)
2 days
ns
1.0
0.5
0.0
-0.5
0
100
200
300
400
500

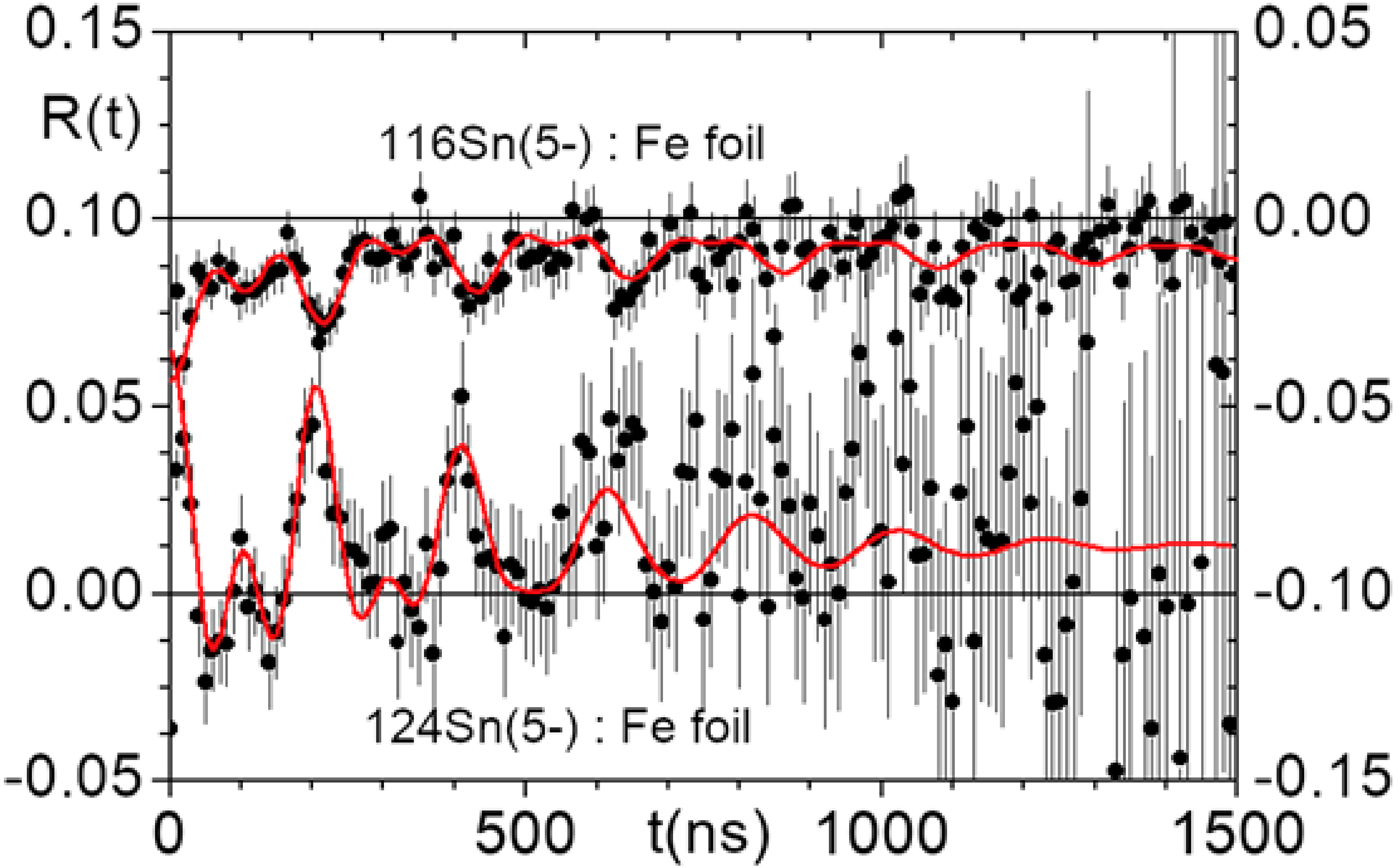


Simulated 119Sn Mössbauer spectrum, Sb in graphite, anneal 450 C
mm/s
0
2
4
6
8
10



Magnetic moments μ[μn]
5- est
5-old
5-new
-0.25
-0.30
-0.35
-0.40
-0.45
-0.50
114
116
118
120
122
124
126
128
Mass

The unexpected result: PAC for $^{116,124}Sn(5^-)$ in Fe



The way to more accurate magnetic moments:

- Present data:

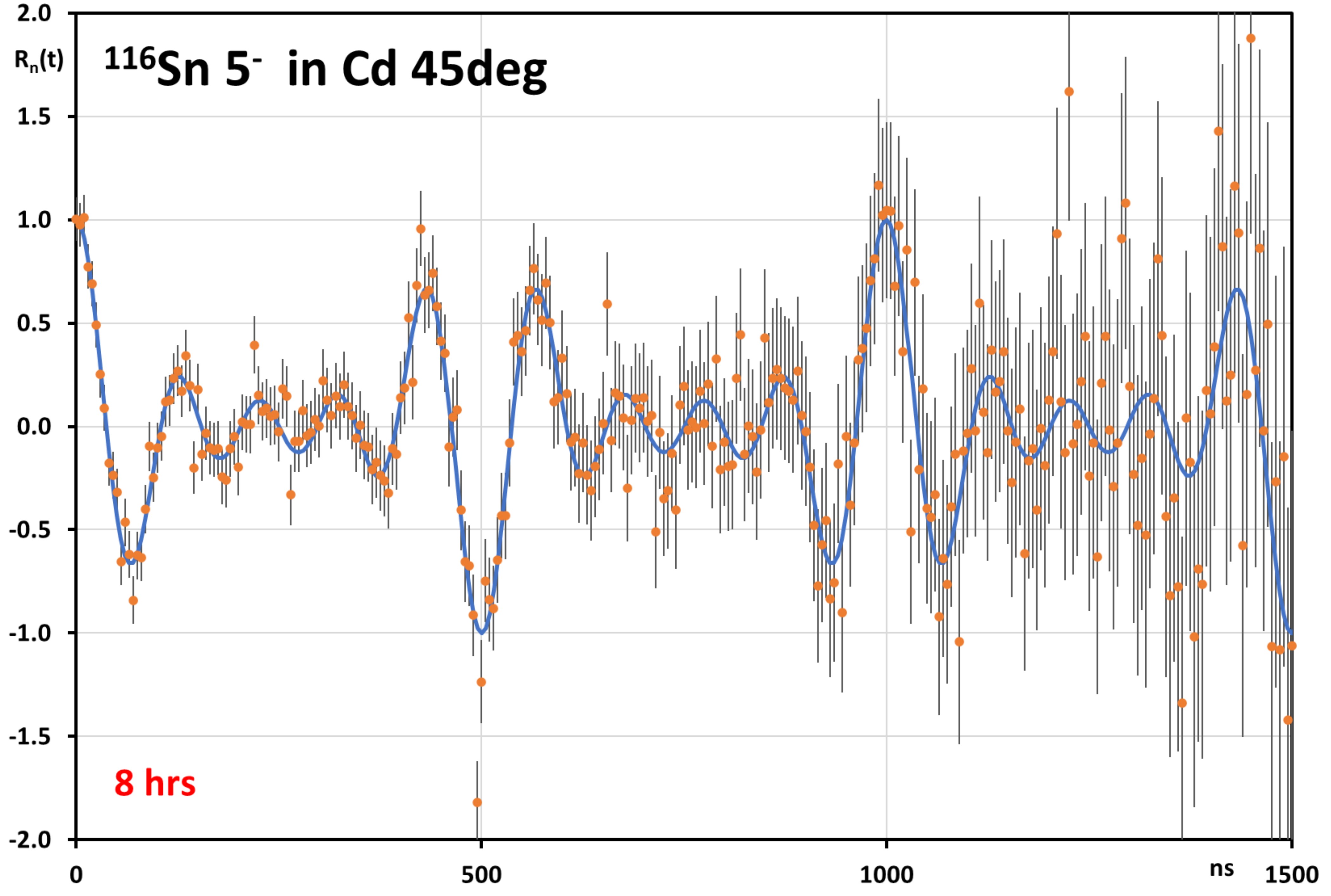
1) Earlier measurements suggested a decrease of μ with mass
2) Our measurement for ^{118}Sn also indicates a decrease
3) Our precision result slightly increases from ^{116}Sn to ^{124}Sn !

- Proposed solution:

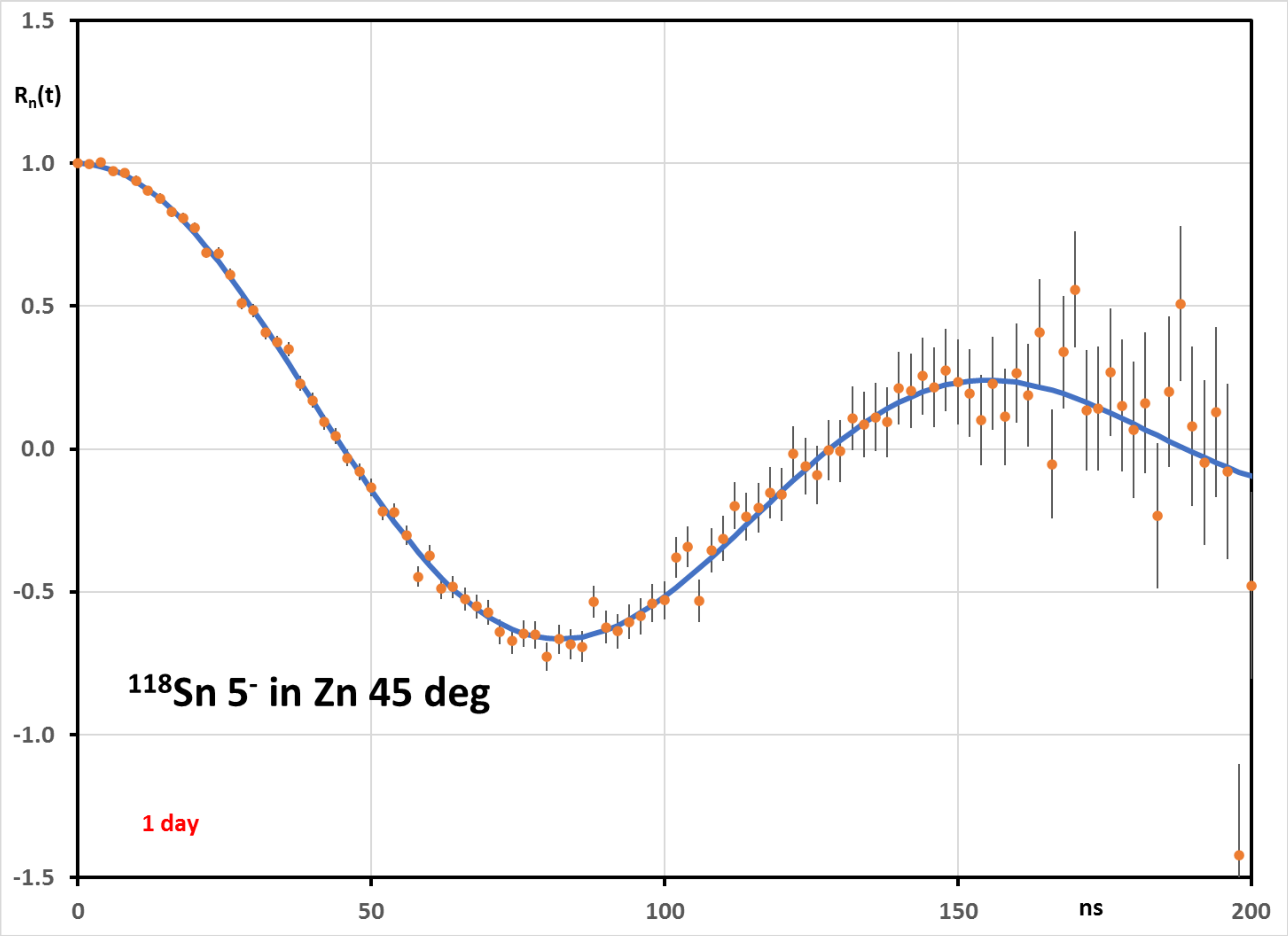
1) Measure μ for ^{118}Sn in liquid (Ga or water) at high field
2) Measure μ for ^{118}Sn in Gd (at low T)
3) Measure μ for ^{120}Sn in Gd (at low T)

Summary of proposed measurements

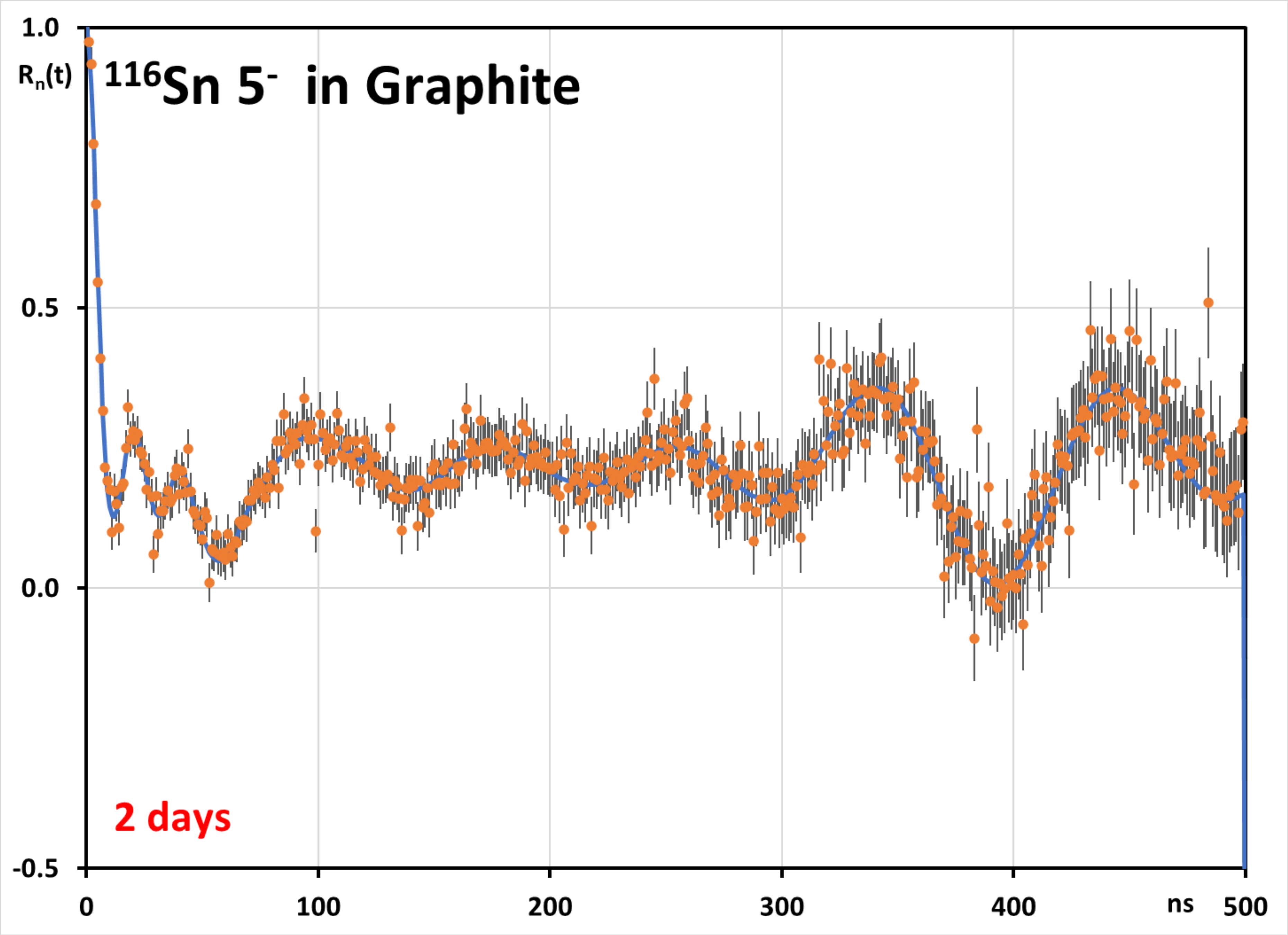
ISOLDE Beam, UC/RILIS						State of interest			Experiment		
	I^{π}	$t_{1/2}$	Int [at/μC]	Req [at/samp]	t_{coll} [min]		I^{π}	$t_{1/2}$ [ns]	meas	host	Nr sa
^{116m}Sb	8^-	1 h	$5\ 10^7$	$1\ 10^{10}$	6	^{116}Sn	5^-	320	ν_Q	Gra	16
									ν_Q	Cd	8
^{118m}Sb	8^-	5.1 h	$1\ 10^8$	$4\ 10^{10}$	30	^{118}Sn	5^-	22	ν_Q	Zn	2
									ν_L	Ga?	3
									ν_L	Gd	3
^{120}Sb	8^-	5.8 d	$2\ 10^8$	$2\ 10^{11}$	120	^{120}Sn	5^-	8	ν_L	Gd	1
^{119}Sb	$3/2^+$	38 h	$2\ 10^8$	$1\ 10^{11}$	60	^{119}Sn	$3/2^+$	18	ν_Q	Gra	2
									ν_L	Fe	2
^{119m}In	$1/2^-$	18 min	$2\ 10^8$		on line	^{119}Sn	$3/2^+$	18	ν_L	Fe	4hrs
									ν_Q	Gra	4hrs



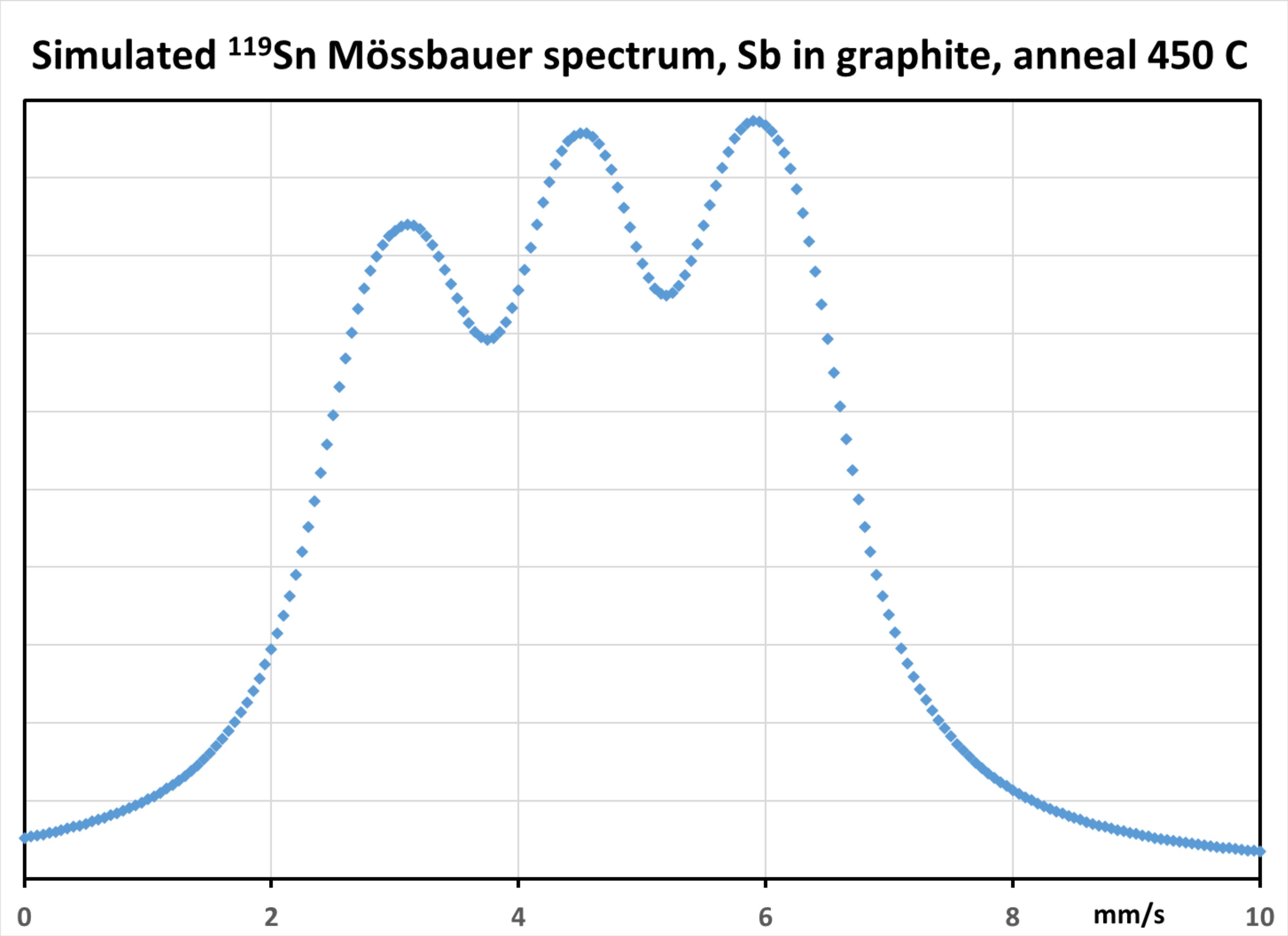
116Sn 5- in Cd 45deg
Rn(t)
8 hrs
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
0
500
1000
1500
ns



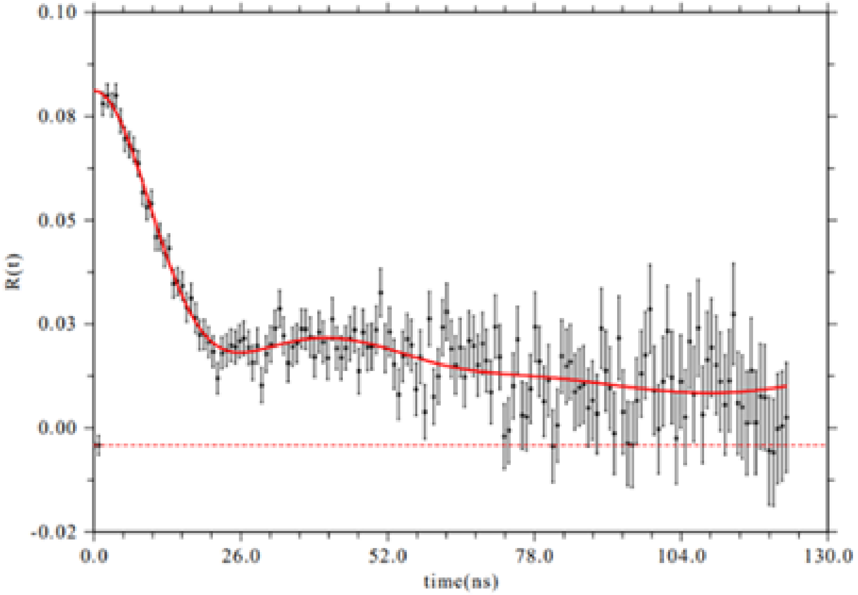
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
Rn(t)
118Sn 5- in Zn 45 deg
1 day
0
50
100
150
ns
200

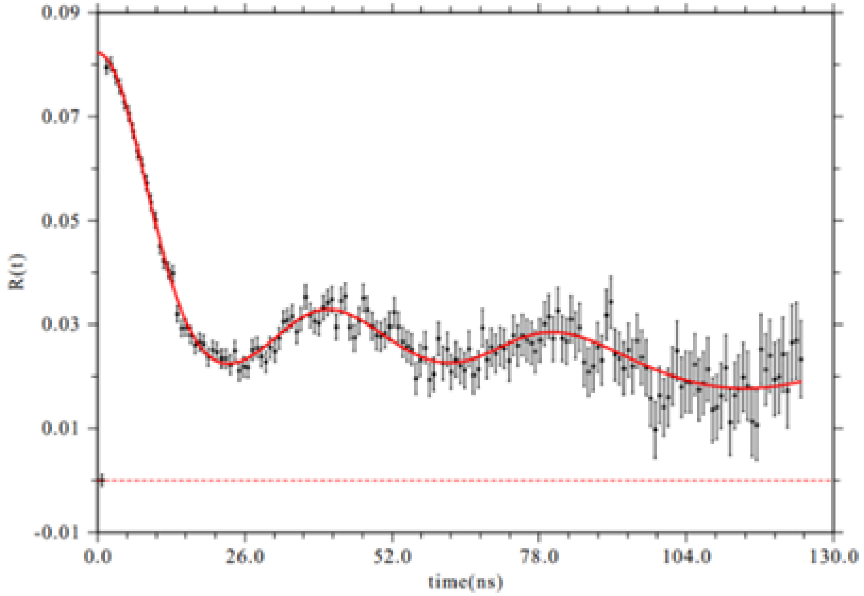


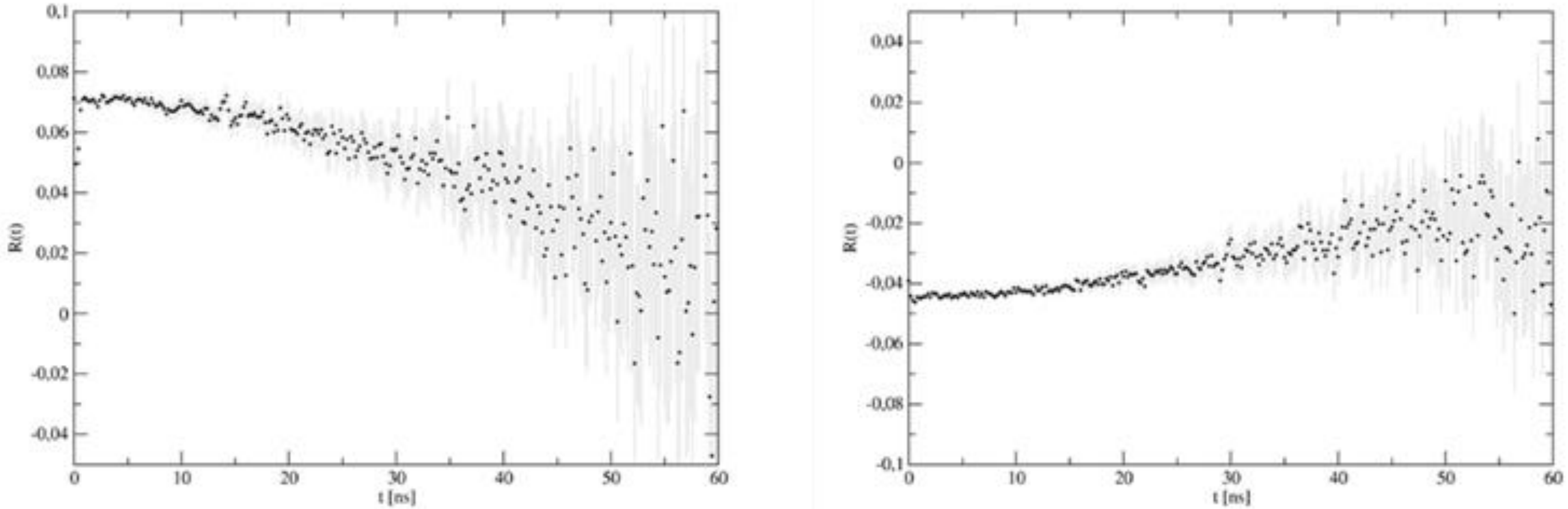
^{116}Sn 5^{-} in Graphite
$R_n(t)$
1.0
0.5
0.0
-0.5
0
100
200
300
400
ns
500
2 days

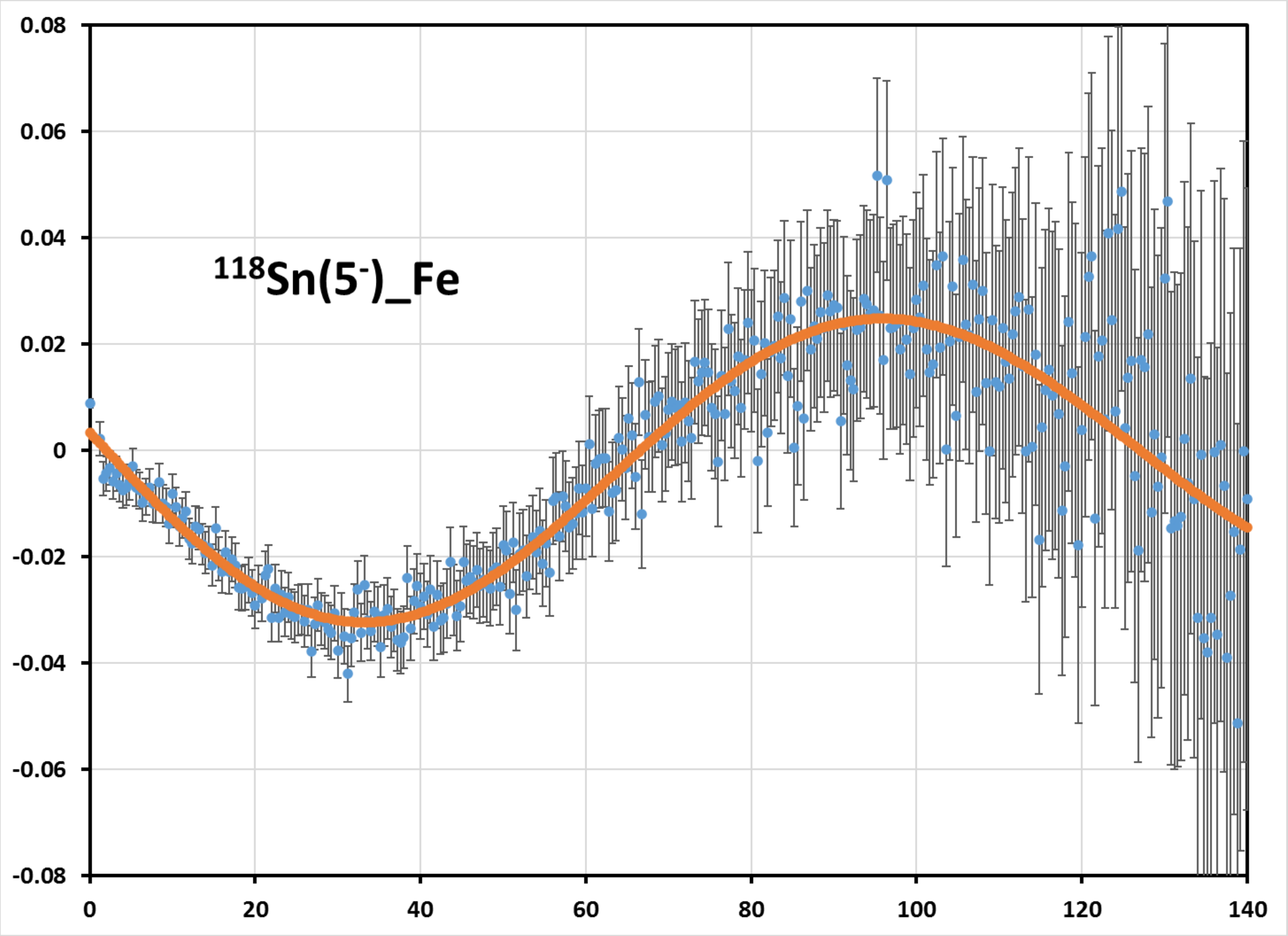


Simulated ¹¹⁹Sn Mössbauer spectrum, Sb in graphite, anneal 450 C
0
2
4
6
8
mm/s
10

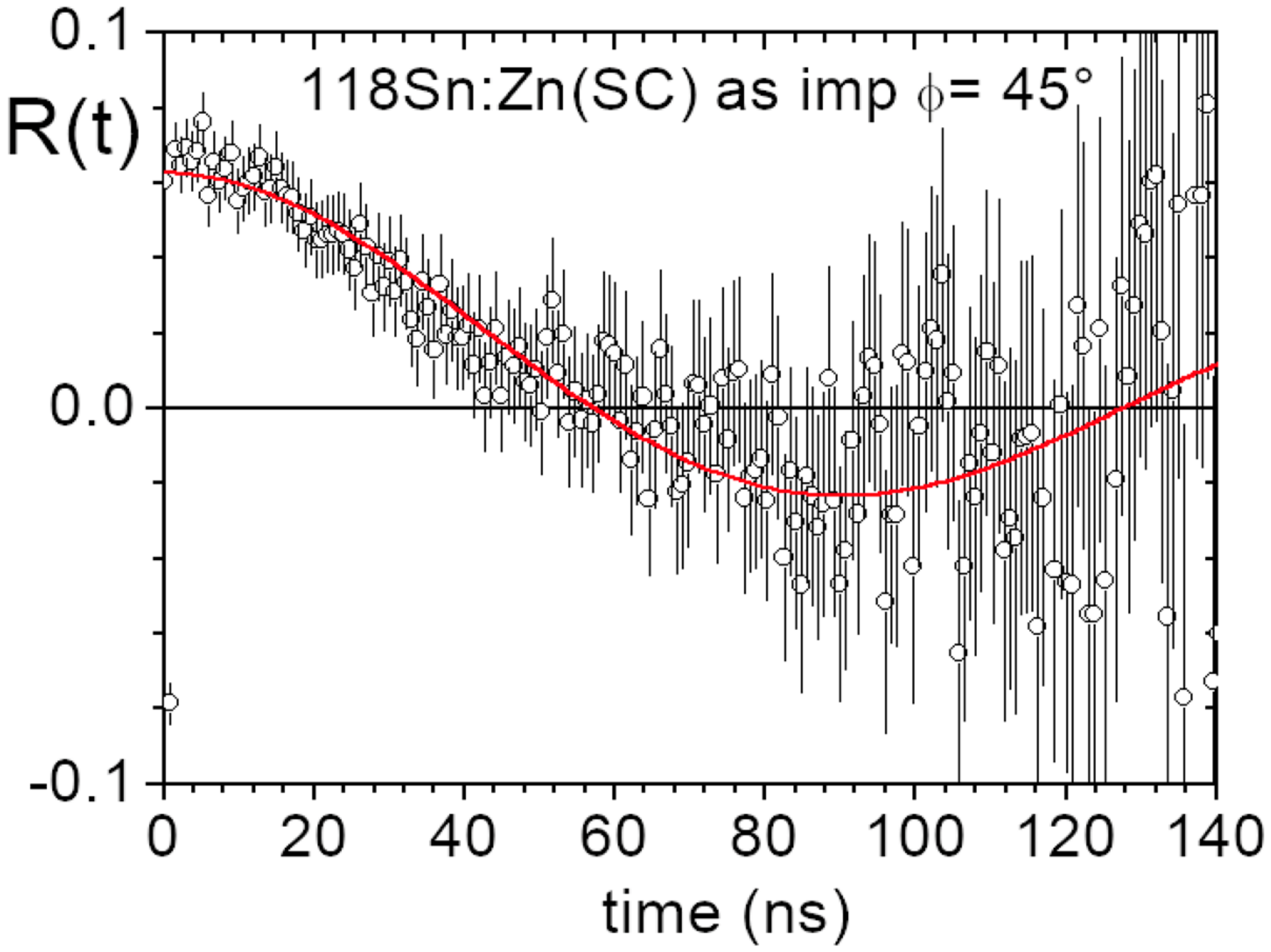

0.10
0.08
0.05
0.03
0.00
-0.02
R(t)
0.0
26.0
52.0
78.0
104.0
130.0
time(ns)

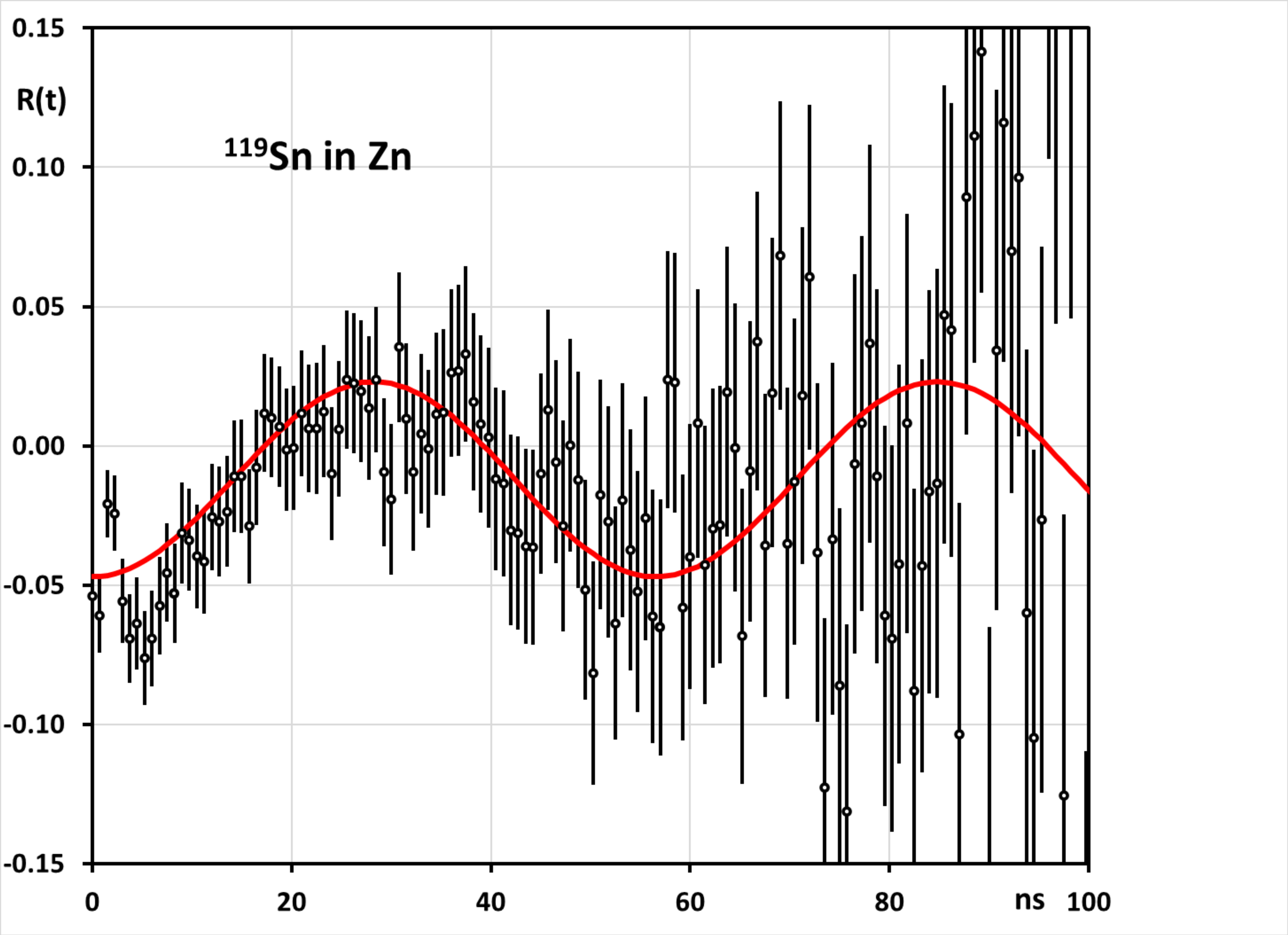

0.09
0.07
0.05
0.03
0.01
-0.01
R(t)
0.0
26.0
52.0
78.0
104.0
130.0
time(ns)


0,1
0,08
0,06
0,04
0,02
0
-0,02
-0,04
R(t)
0
10
20
30
40
50
60
t [ns]
0,04
0,02
0
-0,02
-0,04
-0,06
-0,08
-0,1
R(t)
0
10
20
30
40
50
60
t [ns]



^{118}Sn(5$^-$)_Fe
0.08
0.06
0.04
0.02
0
-0.02
-0.04
-0.06
-0.08
0
20
40
60
80
100
120
140


118Sn:Zn(SC) as imp ϕ= 45°
R(t)
0.1
0.0
-0.1
0
20
40
60
80
100
120
140
time (ns)



R(t)
119Sn in Zn
0.15
0.10
0.05
0.00
-0.05
-0.10
-0.15
0
20
40
60
80
ns
100