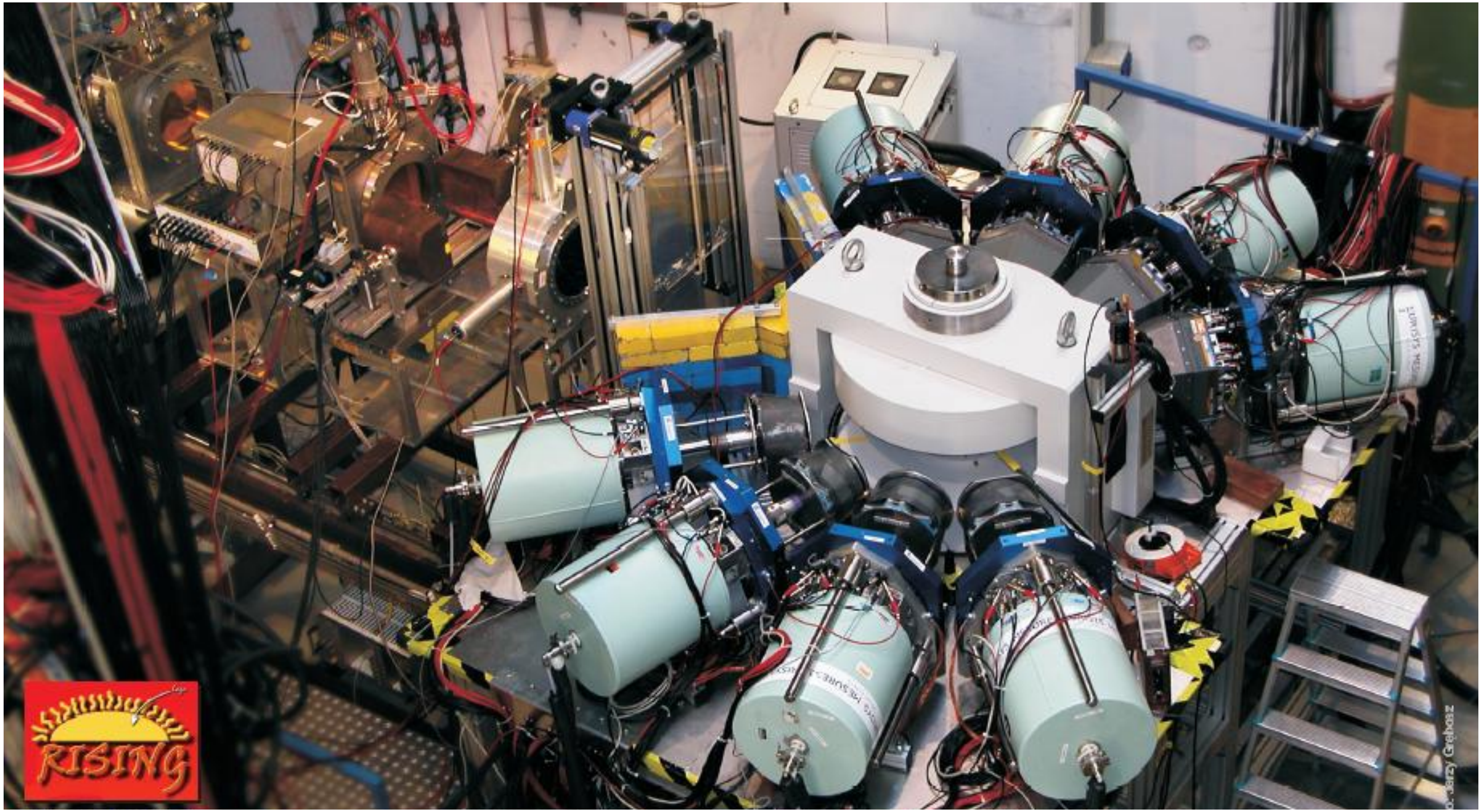
ACHIEVEMENTS WITH g-RISING @ GSI

Radomira Lozeva
IPHC, CNRS/IN2P3

on behalf of the g-RISING collaboration



E(U)RICA Workshop, RIKEN RIBF, 22-23.05.2011

Why measure g-factors at the FRS with RISING

REQUIREMENT for measuring nuclear moments

→ **need spin-oriented nuclear ensemble**

➔ produced in the nuclear reactions (fragmentation, pick-up, transfer, fusion-evaporation, spontaneous fission , relativistic fission ?, …)

→ **challenge with in-flight selection:**
maintain reaction-induced nuclear spin-orientation up to implantation point !

➔ need fully-stripped fragments along the flight path !
(no interaction with randomly-oriented atomic electrons)

➔ **requires E ~ 300 MeV/u up to implantation point for isotopes with A > 100**

$\mu = g.I$

GOALS OF THE g-FACTOR CAMPAIGN

GOAL 1:

➔ demonstrate that **fully-stripped isomeric beams of heavy elements** (A~200) produced by **fragmentation of a relativistic ^{238}U beam**, remain fully stripped and thus preserve their reaction-induced spin- alignment up to the implantation point.

GOAL 2:

➔ demonstrate that **isomeric beams of neutron-rich fission fragments**, produced by **relativistic fission of a ^{238}U beam**, are spin-aligned.

GOAL 3:

➔ study **g-factors of isomeric states towards doubly-magic ^{132}Sn**, in order to test shell model interactions and to study the evolution of shell structure far from stability.

➔ **compare** the spin-alignment from fission and fragmentation

GOAL 4:

➔ **search for new isomers** – structure in the neutron **^{132}Sn isotopes produced by fission and fragmentation**

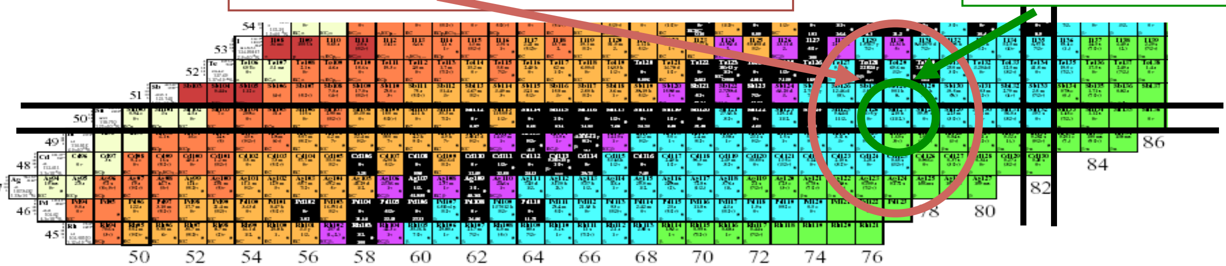
g-factor CAMPAIGN: October & December 2005 @ GSI

1. **Spin-alignment in projectile fission and g-factors around ^{132}Sn**
   (Gerda Neyens and Gary Simpson)

^{238}U-fission at 750 MeV/u

^{136}Xe-fagmentation at 700 MeV/u

Sn



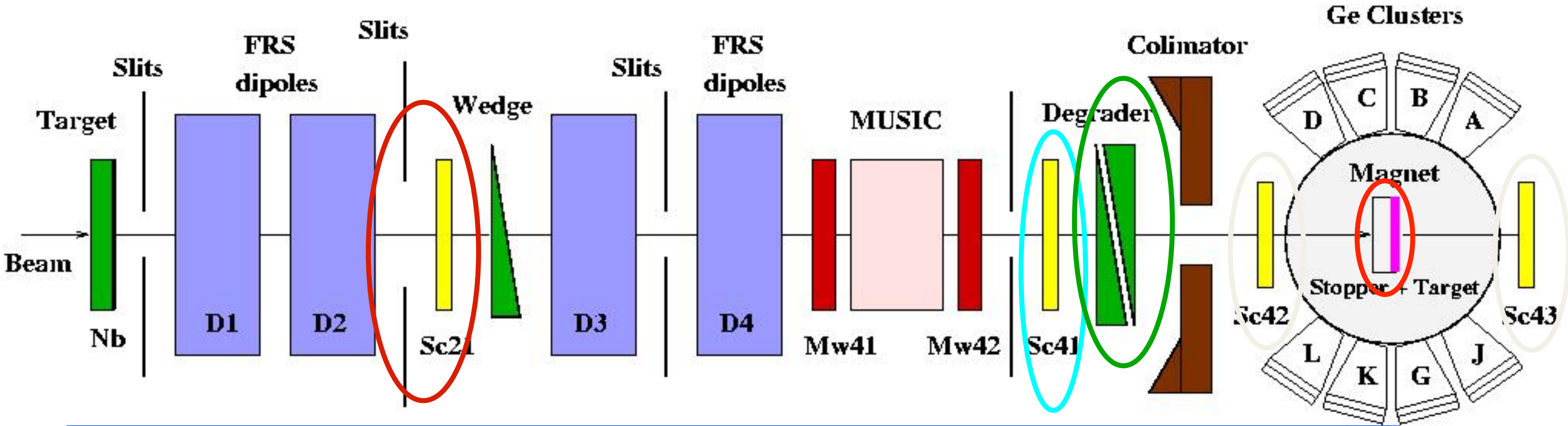
2. **Spin-alignment and g-factors of isomers in ^{127,128}Sn from fragmentation of a ^{136}Xe beam.** (Dimiter Balabanski and Michael Hass)

3. **Spin-alignment and g-factor of isomers in the neutron deficient Pb-region.**
   (Adam Maj and Juergen Gerl)

^{238}U-fragmentation at 1 GeV/u

Pb

Experimental set-up at FRS @ GSI



Spin-aligned secondary beam selected
(S2 slits + position selection in **SC21**)

SC41 gives t=0 signal for γ-decay time measurement

Beam energy after Al degrader > 300 MeV/u → to remain fully stripped

Implantation: plexiglass degrader + 2 mm Cu (annealed)

SC42 and SC43 validates the event

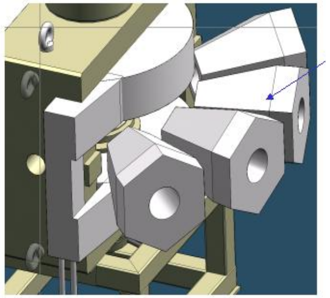
G. Neyens et al., Act. Phys. Pol. B38, 1237 (2007)

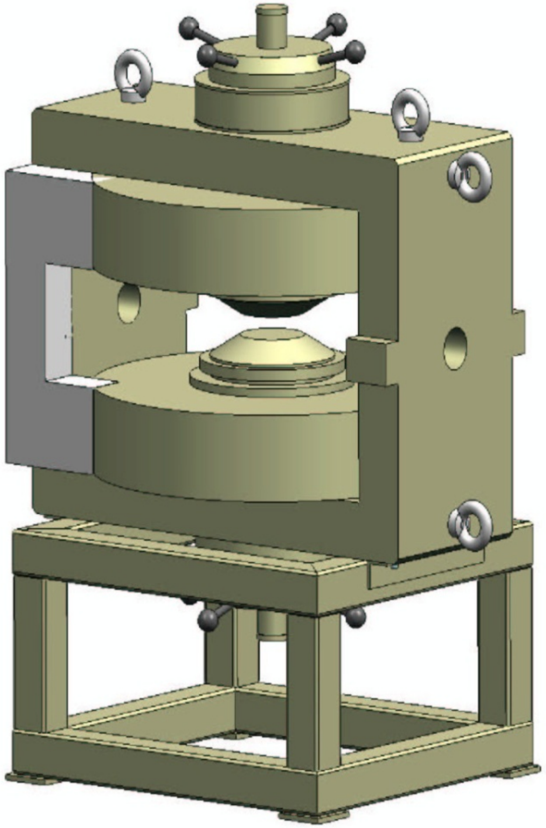
Experimental set-up and method:
Time Differential Perturbed Angular Distribution (TDPAD)

For g factor measurement:

- static magnetic field (vertical) up to 1 Tesla
- 8 Ge Clusters detectors from RISING in horizontal plane
- degrader/stopper sandwich
  (slow-down and stop ions in a perturbation free environment)

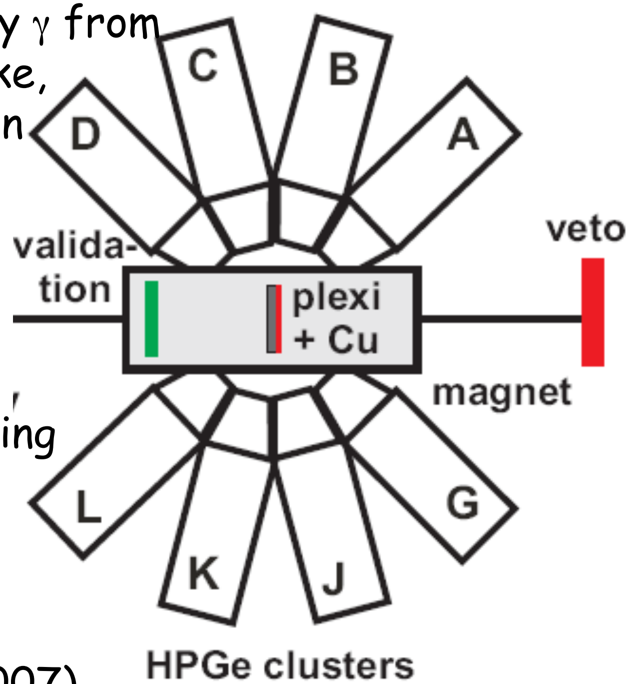
RISING clusters detectors positions





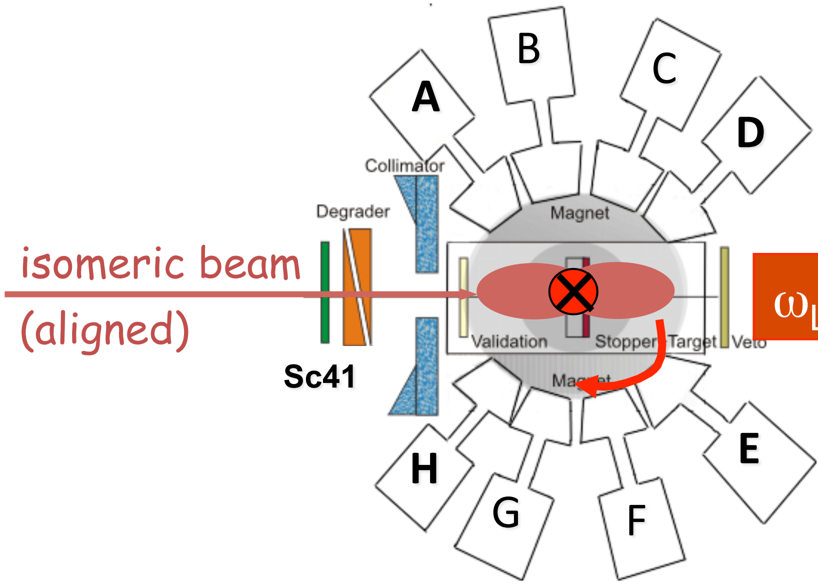
- validation scintillator (accept only γ from ions that pass through hole in yoke, reduces possibility of registration of unwanted reactions)

- veto scintillator (reject non-stopped events, clean up from light particles, punching trough)



G. Neyens et al, Act. Phys. Pol. B38, 1237 (2007)

Experimental set-up and method: Time Differential Perturbed Angular Distribution (TDPAD)

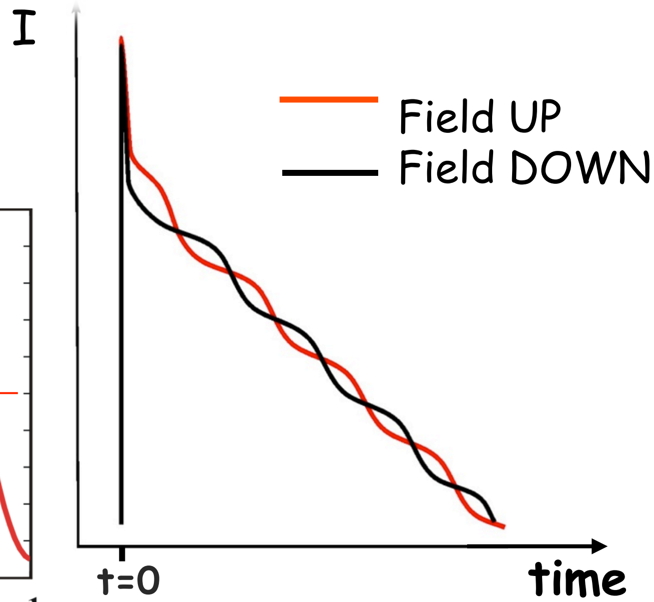


$\omega_L = -\,g\mu_N B/\hbar$

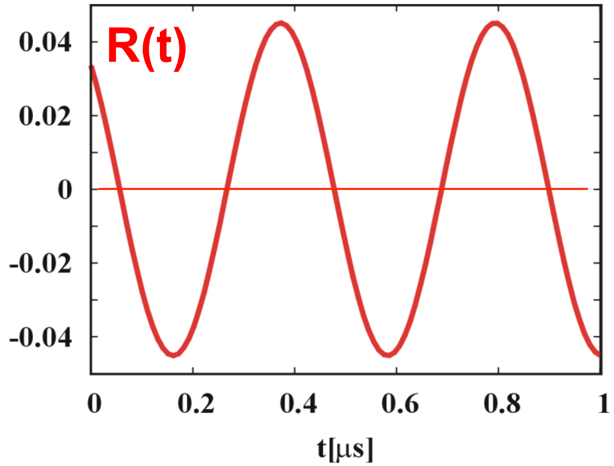
Measure isomeric γ–decay

$I(\theta,t) \sim e^{-t/\tau}(1-A\,P_2[\cos(\theta-\omega_L t)])$

Start (t=0): ion arrives in Sc41
Stop: γ detected in 1 … 8
time range: 15 μs



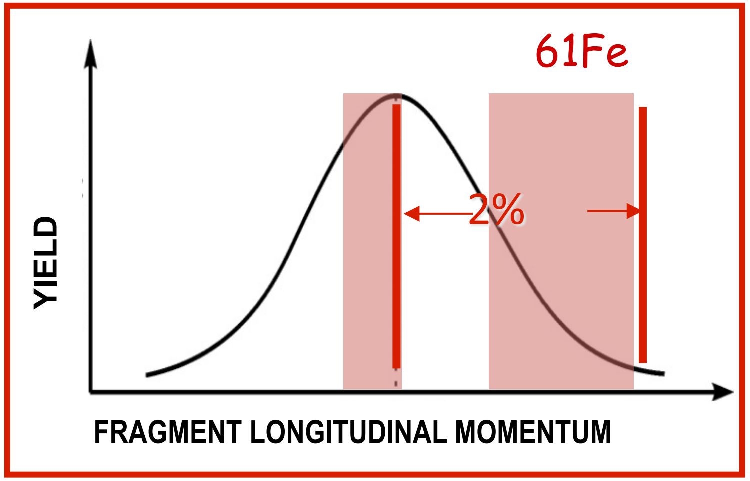
Combine field up/down spectra
→ eliminate exponential decay
(= R(t) curve)

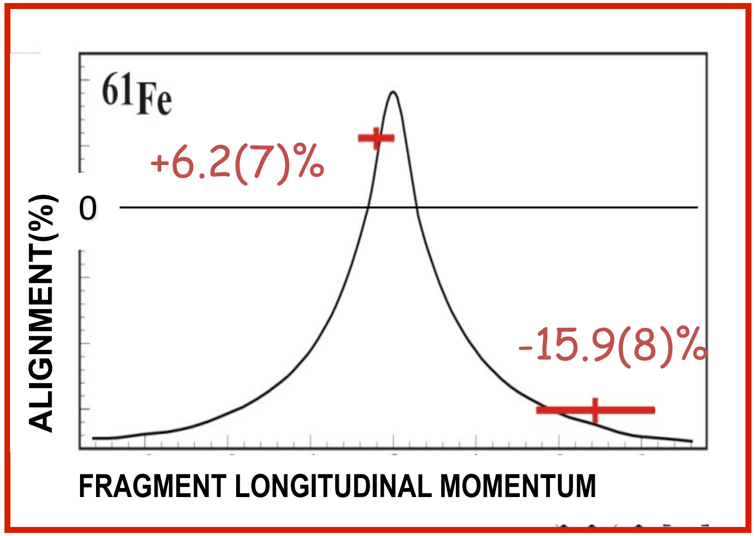


Amplitude ~ alignment
Period ~ ω_L ~ g

Challenge: spin-alignment in fragmentation → based on reaction kinematics !

In fragmentation:





K. Asahi et al., PRC43 (1991) 456
W.D. Schmidt-Ott et al., Z. Phys. A350 (1994) 215
I. Matea et al., PRL 93 (2004) 142503
G. Georgiev et al., JPG 28 (2002) 2993

Spin-alignment is obtained by a selection in longitudinal fragment momentum distribution
- center: positive (prolate) alignment
- wings: negative (oblate) alignment

Acceptance of FRS ~ 2 %

→ momentum selection with
- FRS momentum slits
- or event-by-event correlation with ion position at intermediate plane (S2)

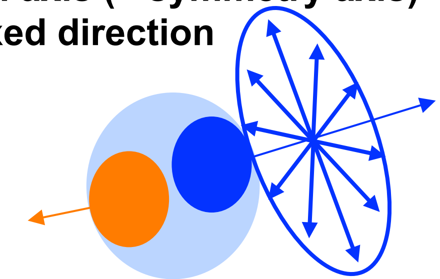
We confirmed !

L. Atanasova et al, EPL **91** (2010) 42001

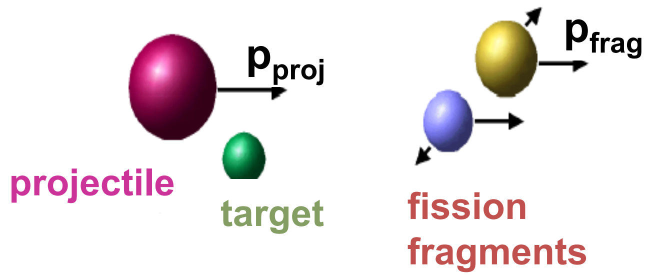
Challenge: spin-alignment in relativistic fission : never observed

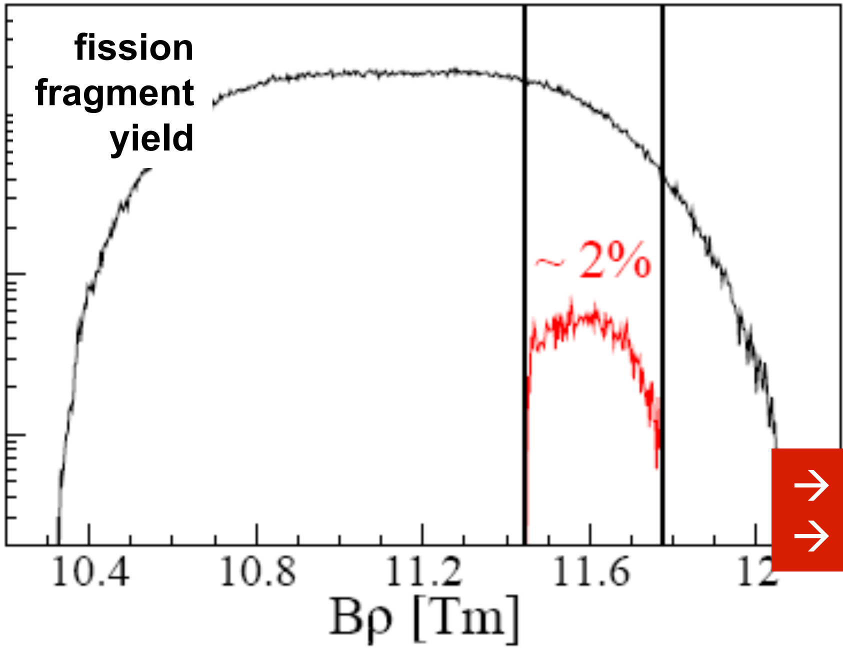
In spontaneous fission: Wilhelmy et al, PRC5 (1972)

- → **spins perpendicular to emission axis (= symmetry axis)**
- → **selection of emitted ions in a fixed direction**
- → **alignment up to 50%**



In relativistic fission FRS:
Moving projectile is fissioning:





Fragments with higher/lower velocity
= fission fragment emitted
along beam axis

→ Oblate alignment expected

→ broad momentum spread in fission (~ 10%)
→ FRS momentum slits can remain fully open

We established !

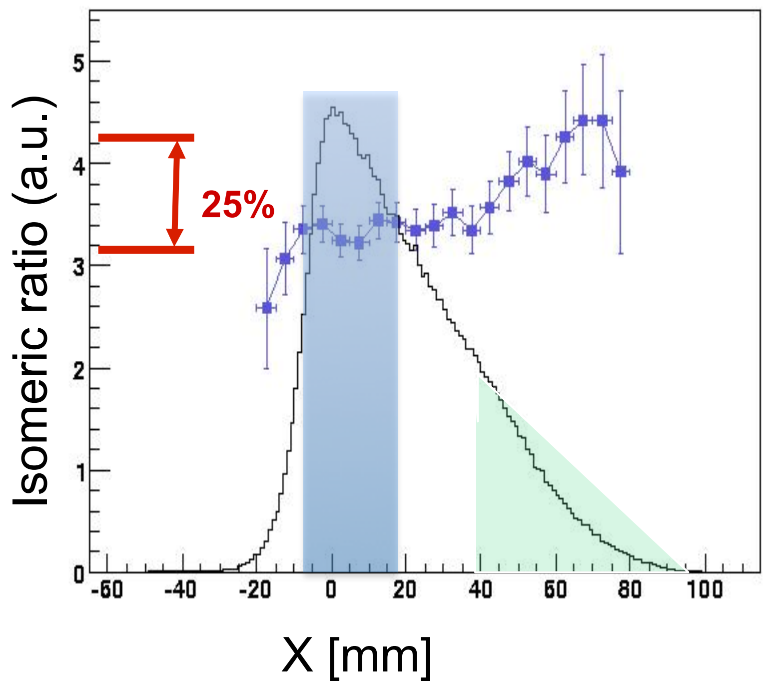
G. Ilie et al., PLB 687 (2010) 305

Momentum selection in fragmentation/ fission

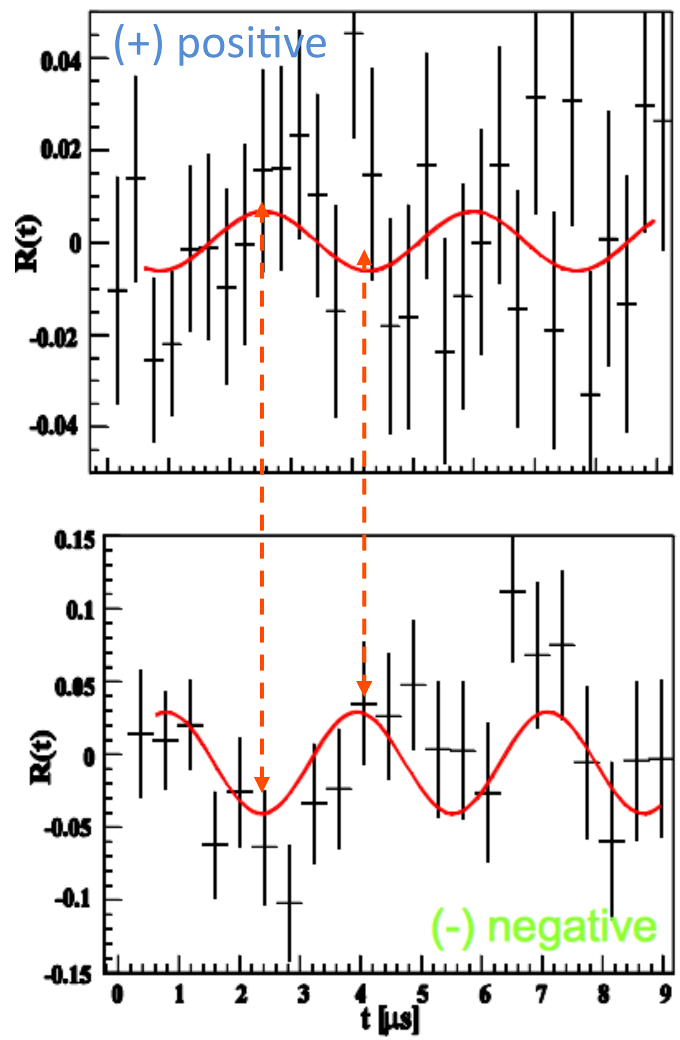
Momentum spead is narower < 3% ($\Delta p/p$)
-the selection is done by slits or by ion correlation
-measured by position sensitive scintillator

@ FRS using **relativistic fragmentation**:
^{136}Xe (600 MeV/u) → ^{127}Sn

Momentum selection in fragmentation is crucial for the alignment !



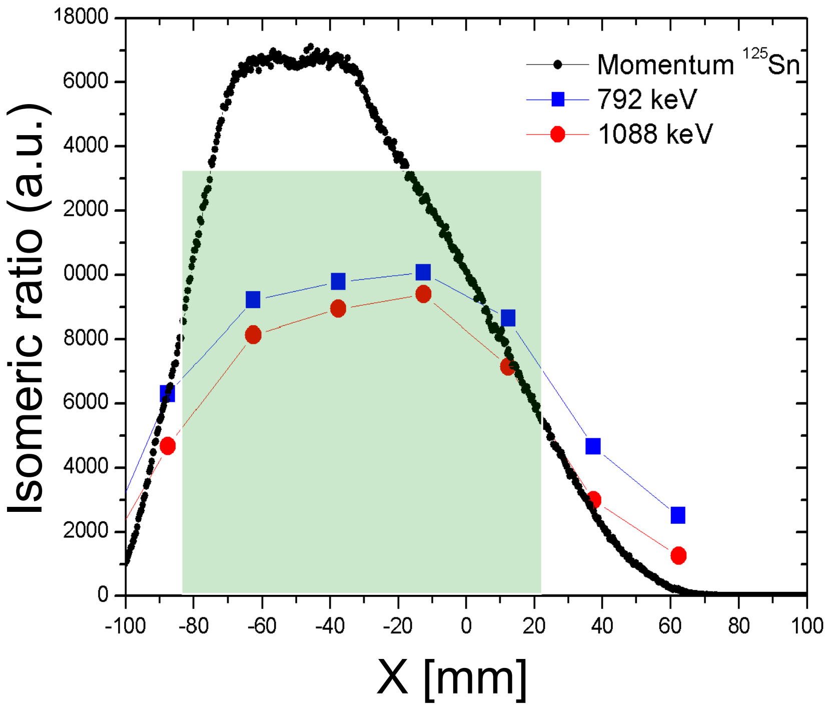
L. Atanasova

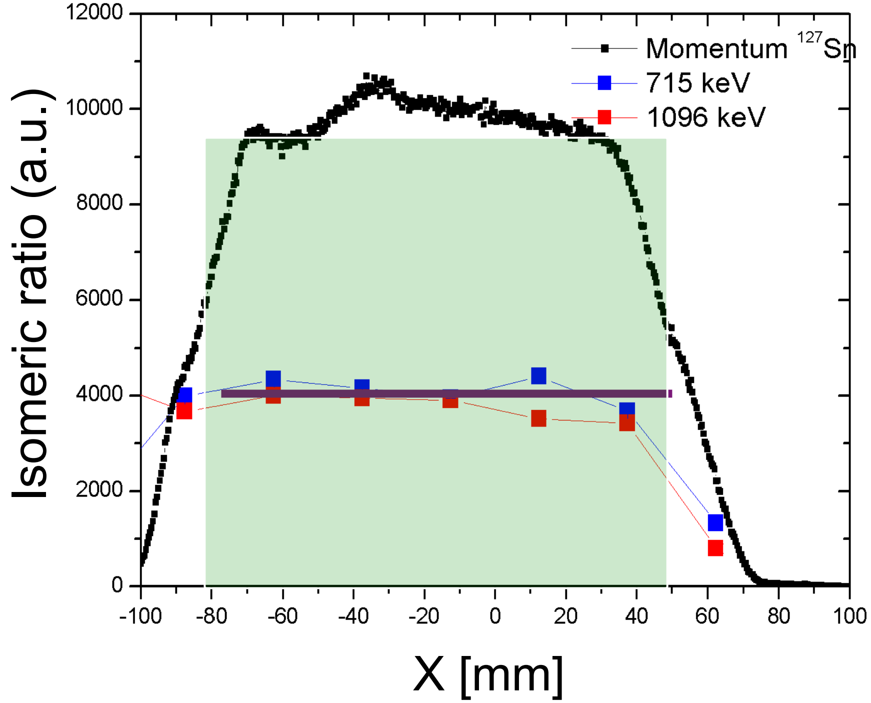


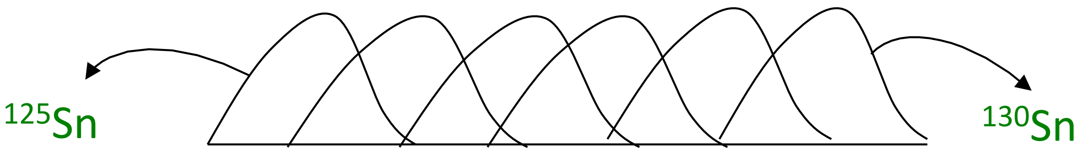
Momentum selection in fission

relativistic fission:
^{238}U (750 MeV/u) → ^{127}Sn

R. Lozeva







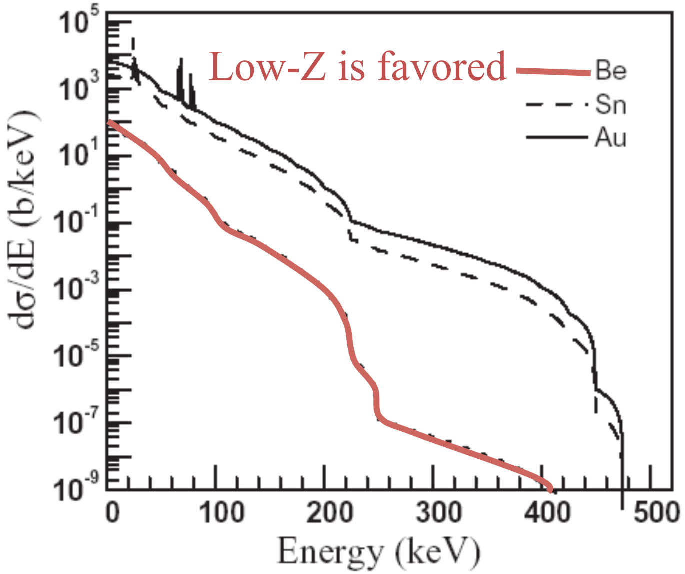
Momentum selection in FISSION also possible in order to improve the alignment

LESSONS LEARNED

(1) What is the best material to use - for slowing down the ions ?
- for stopping the ions ?

Disadvantage of high-Z energy degrader → produces 10^2-10^4 times more background photons (γ-flash)

Wollersheim et al NIM A 537(2005) 637



Host in which isomers are stopped needs to have cubic lattice structure, without electric field gradients
→ high-purity (99.995) **2 mm Cu**, annealed

Make it thicker to slow down the ions from 300 MeV/u → 50 MeV/u
by fixing to this
→ another **2 mm Cu plate**
or
→ **2 cm plexiglass**

BUT: in low-Z energy degrader → more interactions of isomeric beam with degrader material → loss of isomers due to reactions

LESSONS LEARNED

(1) What is the best material to use - for slowing down the ions ?
- for stopping the ions ?

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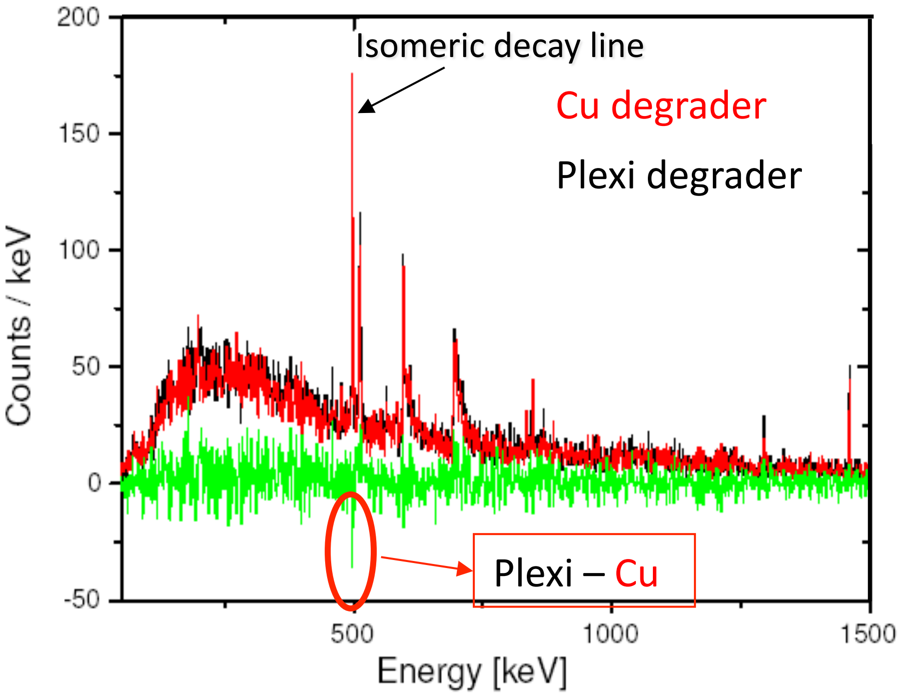


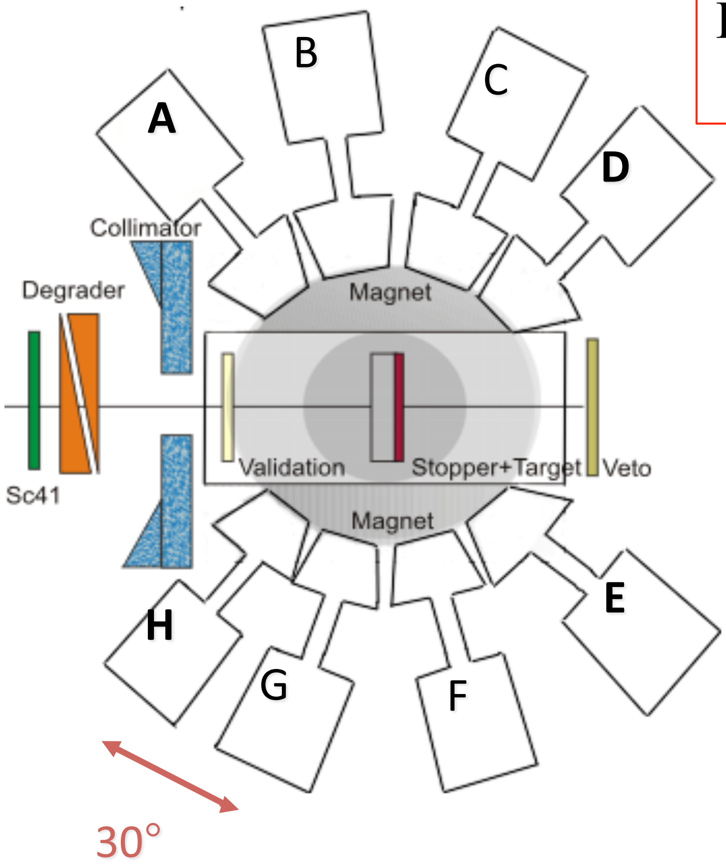
Isomer is best produced with **Cu as degrader** !
and the background radiation is acceptable if the trigger is made by **a delayed gamma ray**

With a **low-Z** material, **20% of isomers are lost** due to reaction in the degrader

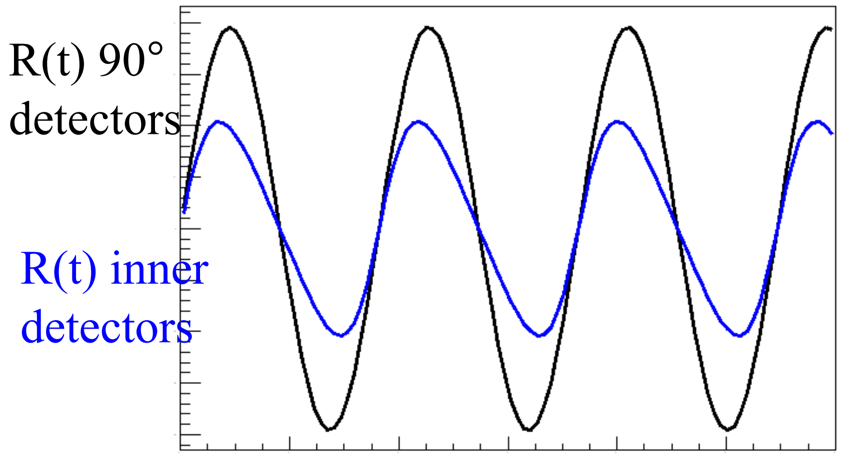
Particle-gamma trigger
+ particle trigger reduced by 2^8

LESSONS LEARNED

(2) What is the most efficient TDPAD set-up for g-factor studies ?



Present set-up: 8 detectors at 42 cm from stopper
→ total efficiency : 2 % (at 1 MeV)

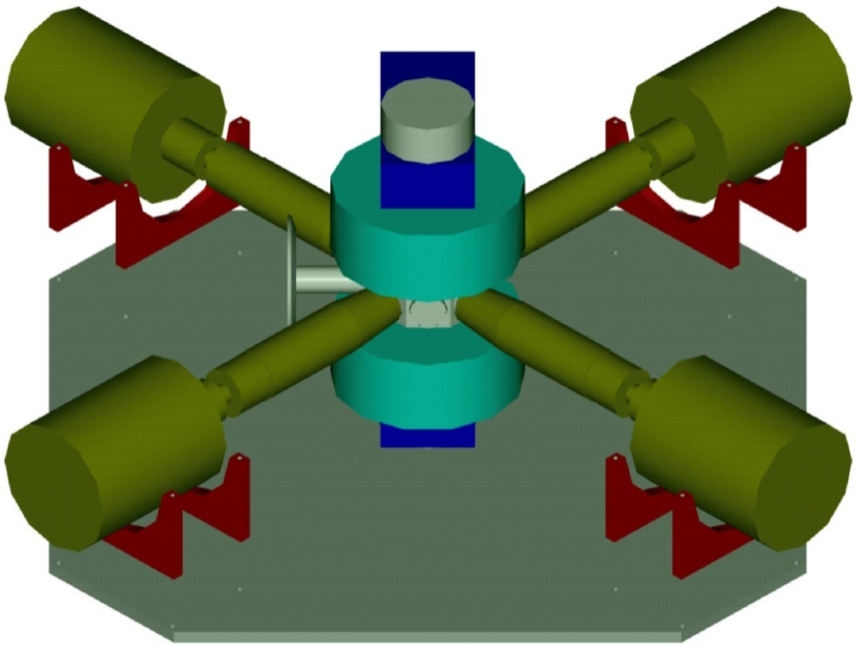


BUT ONLY half of our detection efficiency is useful for R(t) analysis !!!

LESSONS LEARNED

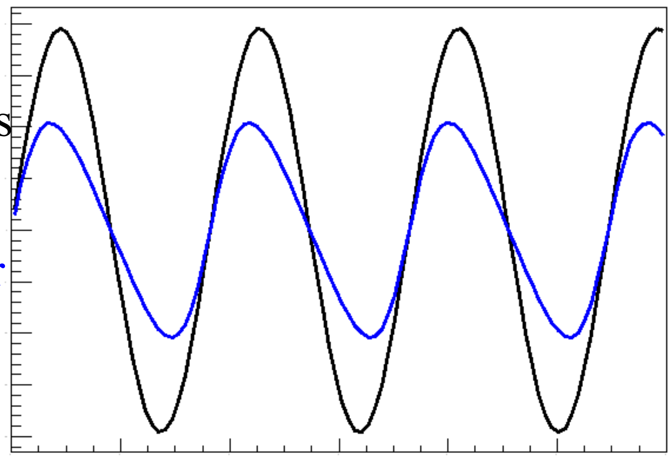
(2) What is the most efficient TDPAD set-up for g-factor studies ?

4 Clover detectors,
placed as close as possible to the stopper



R(t) 90° detectors

R(t) inner detectors

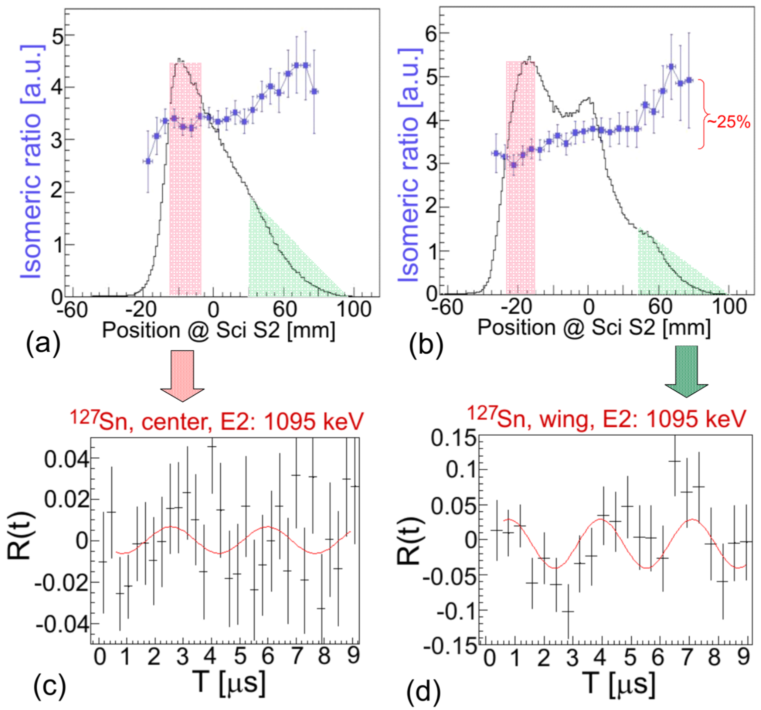


IMPROVED SET-UP:
4 detectors in closer geometry
→ GAIN of factor 2-3 in useful efficiency

LESSONS LEARNED

(3) Can we use 'event-by-event' ion selection for selecting aligned beam ?

(1) In Xe-fragmentation run: event-by-event software selection



PROBLEMS:

- position sensitive detector in S2 can handle a limited rate (~ 10^5/s)

- the detector deteriorates with increasing dose (from 2.10^{10} onwards)

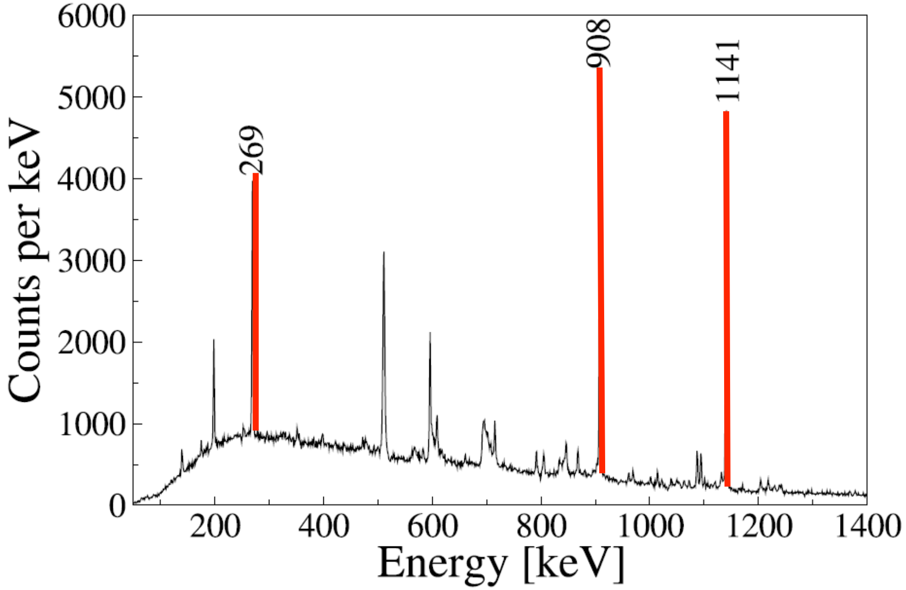
RL, LA, INTAG reports 2006-2007

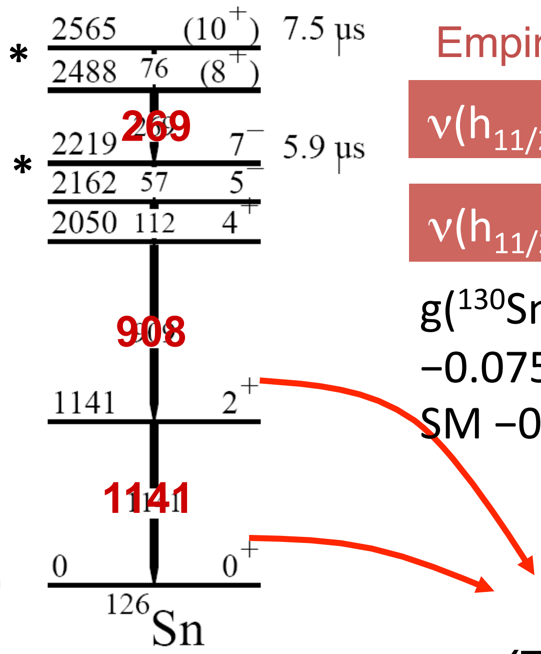
(2) No momentum selection performed in fission run (and slits open)

(3) In the ^{238}U fragmentation run: hardware selection of the tail in the momentum distribution

RESULTS: ^{126}Sn: R(t) analysis from fission experiment

G. Ilie et al., PLB 687 (2010) 305



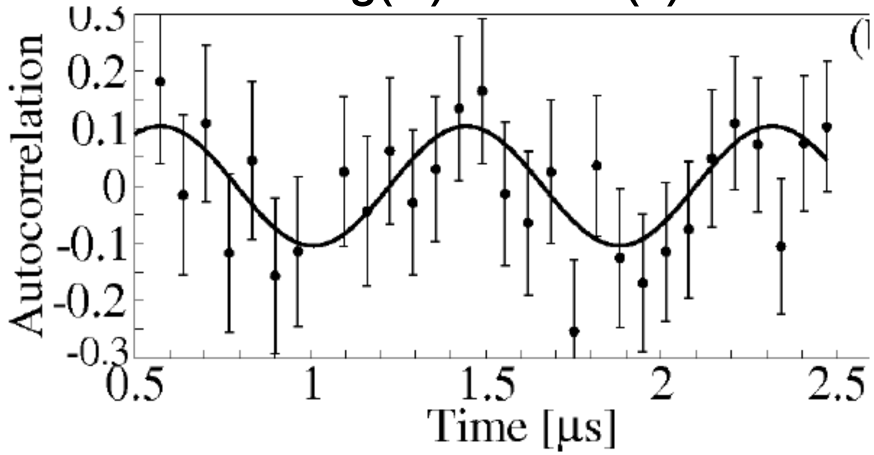


Empirical g-factors :

$\nu(h_{11/2})^{-2}$	$g(10^+) \sim -0.24$
$\nu(h_{11/2}^{-1}d_{3/2}^{-1})$	$g(7^-) \sim -0.11$

$g(^{130}Sn,3/2-)$	$g(^{126}Sn,11/2-)$
−0.0756(10)	−0.0826(10)
SM −0.076	−0.077
	additivity

$g(7^-) = -0.098(7)$

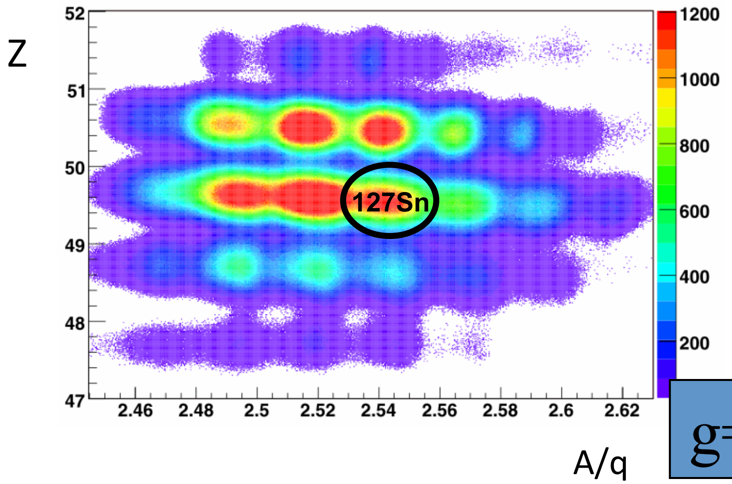


→g-factor very sensitive to mixing with particular configurations

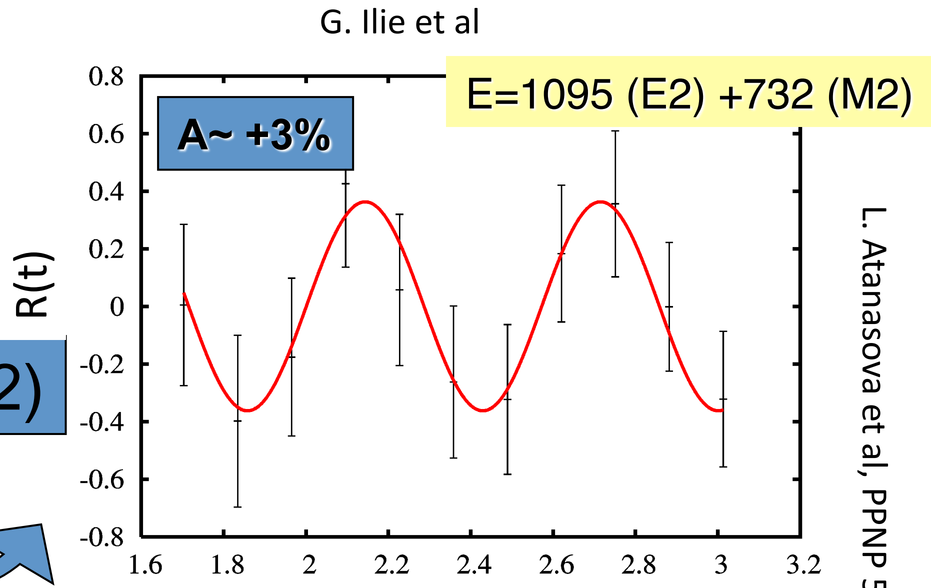
➔ Alignment of 18(8)% observed !

First observation of spin-alignment in relativistic fission !

RESULTS: ^{127}Sn: 19/2^{+} isomer : ^{136}Xe fragmentation / ^{238}U fission

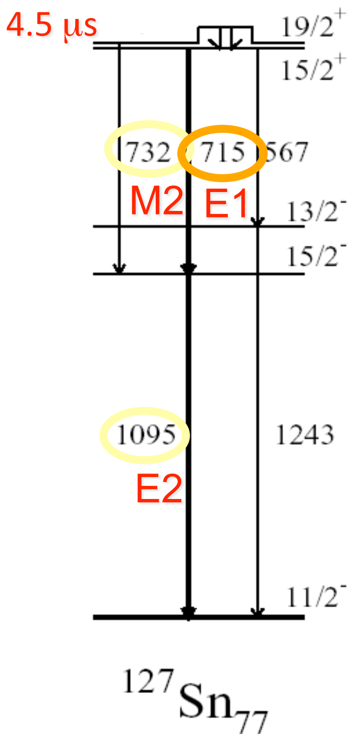


g=0.163(2)



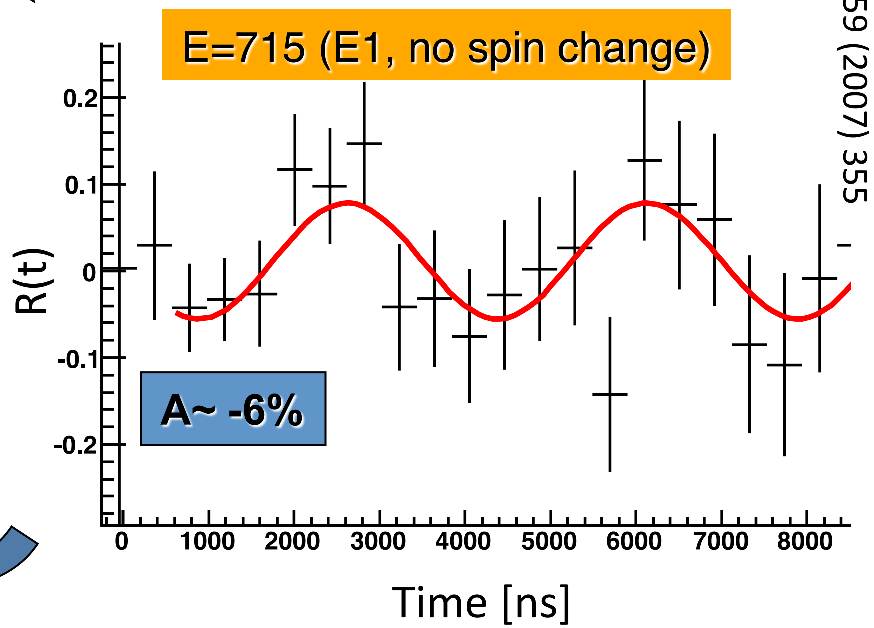
L. Atanasova et al, PPNP 59 (2007) 355

J. Pinston et al, PRC61 (2000) 024312



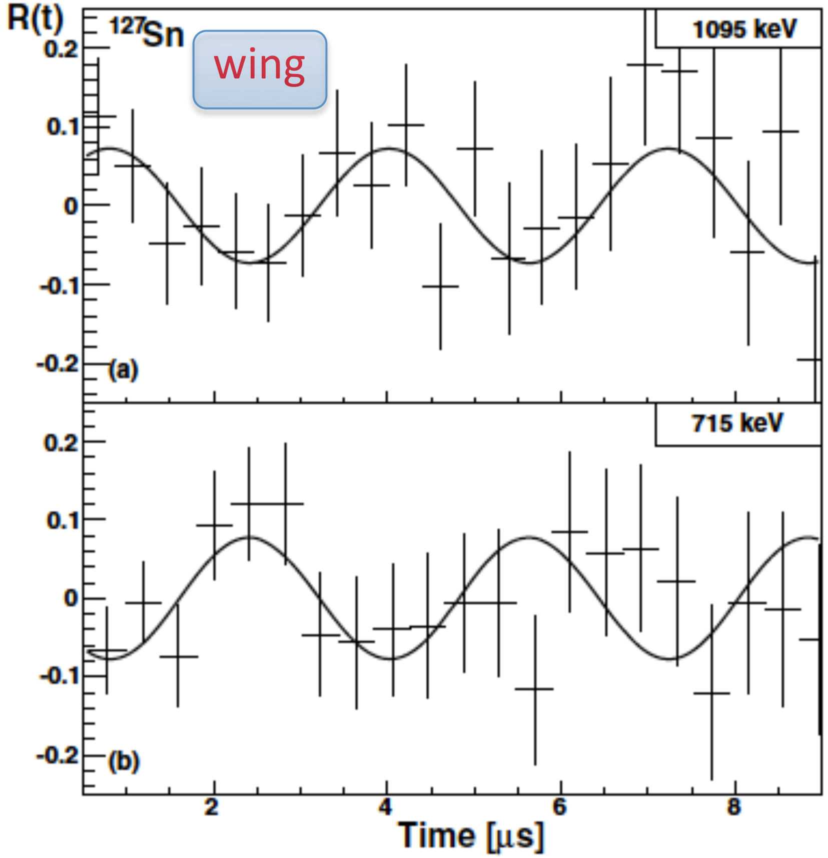
The same result in fission and fragmentation !

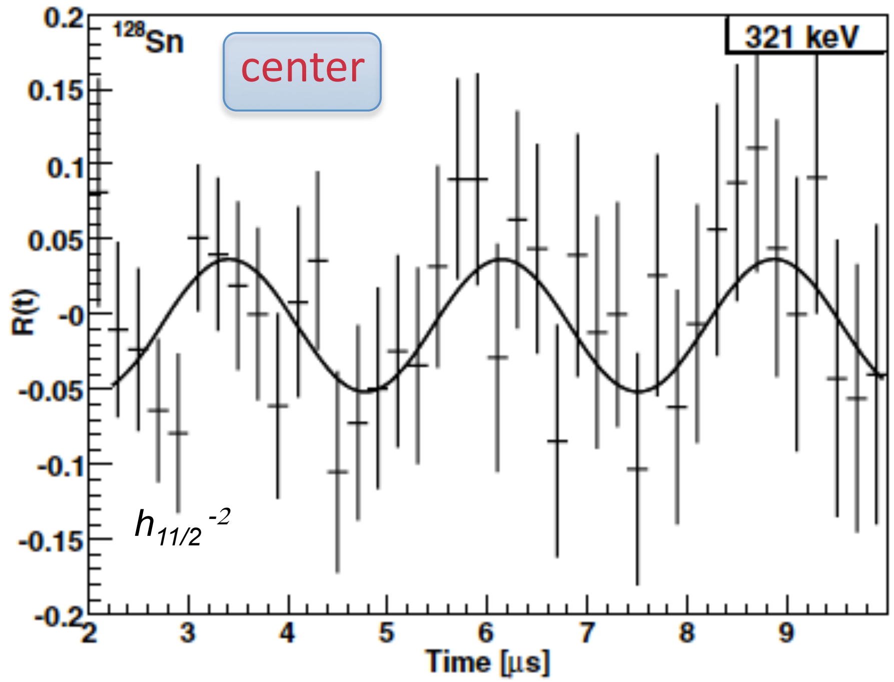
g=0.168(3)



RESULTS: Study of g-factors in isomers approaching ^{132}Sn using fragmentation reactions

L. Atanasova et al, Eur.Phys. Lett. **91** (2010) 42001



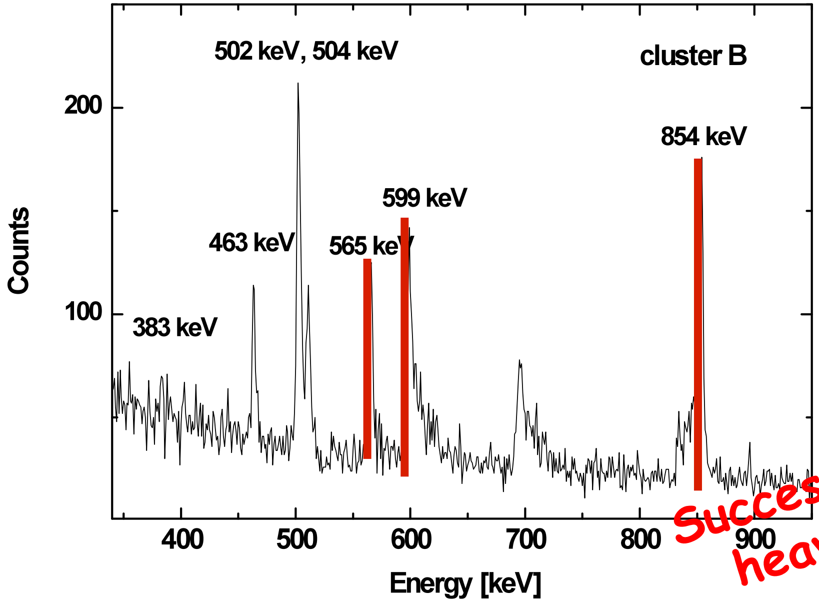


−19(5)% $g(19/2^+;\ ^{127}Sn)=-0.17(2)$
SM: g-free : −0.212 g-eff: −0.148

+12(4)% $g(10^+;\ ^{128}Sn) =-0.20(4)$
SM: g-free : −0.359 g-eff: −0.251

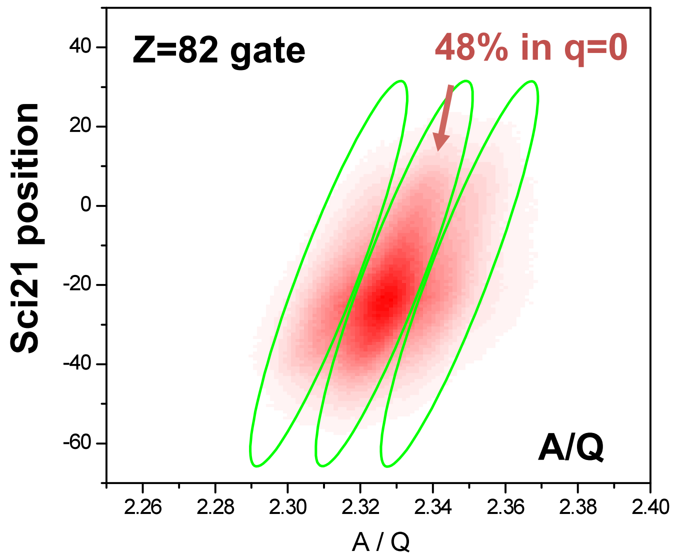
s.p. config.	g_{exp}	$19/2^+$ config.	g_{emp}
$\nu(1h_{11/2}^{-1})$	−0.242(1) [21]		
$\nu(3s_{1/2}^{-1})$	−2.05 [22]	$\nu(3s_{1/2}^{-1}1h_{11/2}^{-2})$	−0.156
$\nu(2d_{3/2}^{-1})$	+0.505(3) [21]	$\nu(2d_{3/2}^{-1}1h_{11/2}^{-2})$	−0.266
$\nu(2d_{5/2}^{-1})$	−0.432(2) [23]	$\nu(2d_{5/2}^{-1}1h_{11/2}^{-2})$	−0.241
$\nu(1g_{7/2}^{-1})$	+0.195(3) [22]	$\nu(1g_{7/2}^{-1}1h_{11/2}^{-2})$	−0.230

RESULTS: ^{192}Pb: R(t) analysis from U-fragmentation

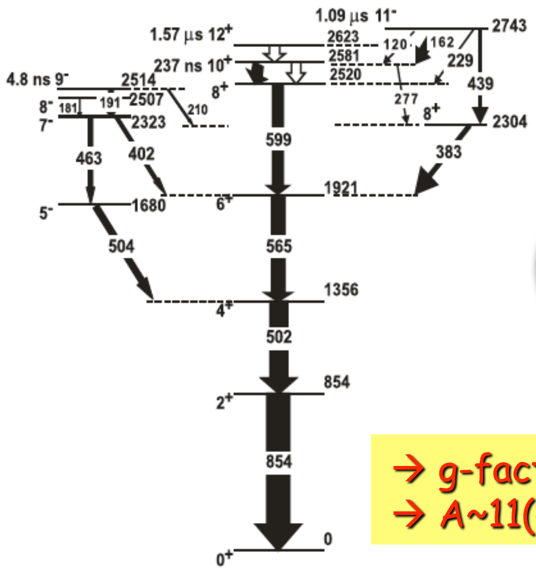


Success to maintain heavy ions fully stripped !

M. Kmiecik et al., EPJA 45, 153–158 (2010)

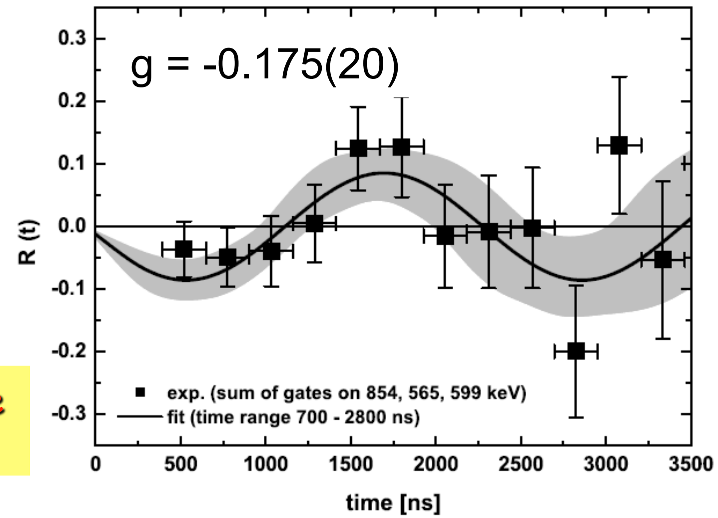


Improve result: gate on q=0 fragments only !



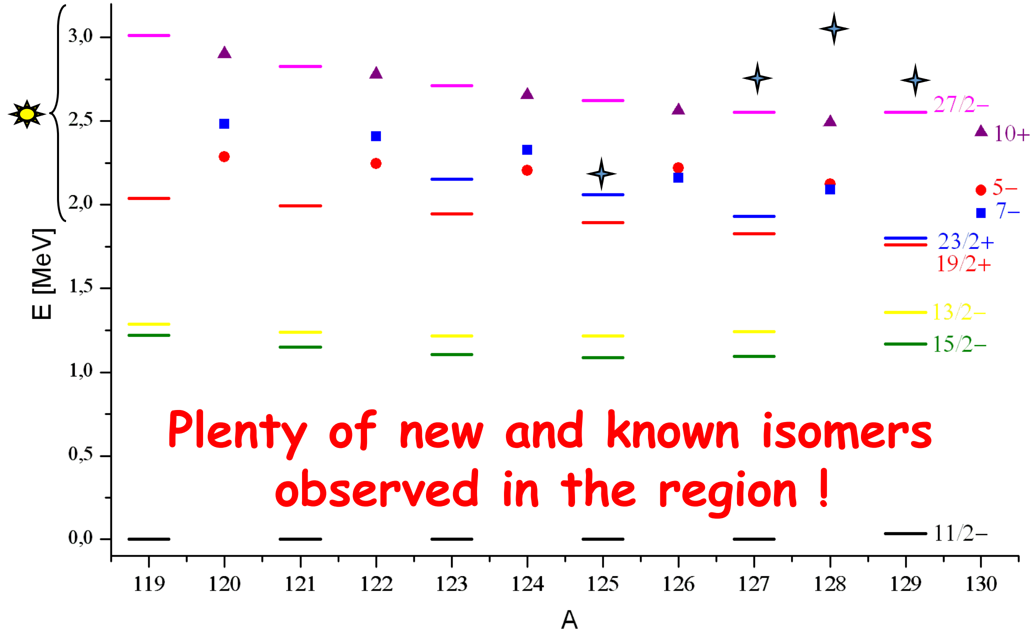
$i_{13/2}^{-2}$

$I^{\pi}=12^{+}$ isomer
$T_{1/2}$= 1.6 µs
g = -0.173(2)



→ g-factor in agreement with earlier value
→ A~11(4)% → FEASIBILITY PROVEN

RESULTS: Study of isomers approaching ^{132}Sn



R. Lozeva et al, PRC **77** (2008) 064313

Even Sn

admixture from other configurations

5^- $\nu s_{1/2}^{-1} h_{11/2}^{-1}$ 7^- $\nu d_{3/2}^{-1} h_{11/2}^{-1}$

almost pure configuration

10^+ $h_{11/2}^{-2}$

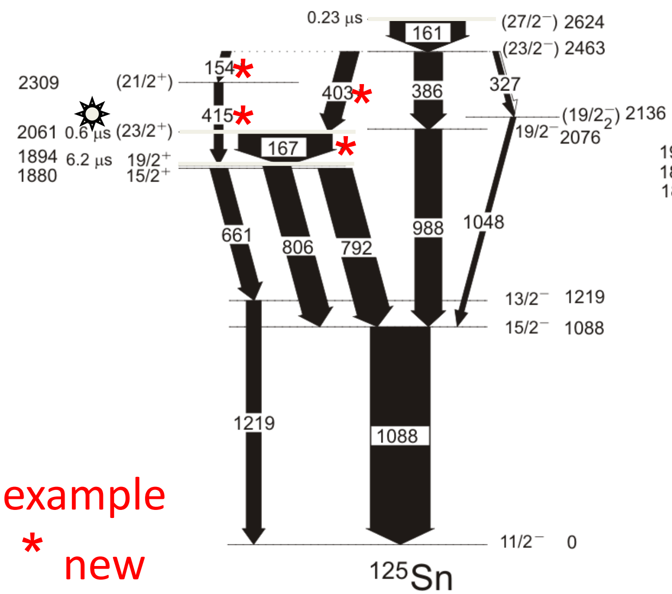
Odd Sn

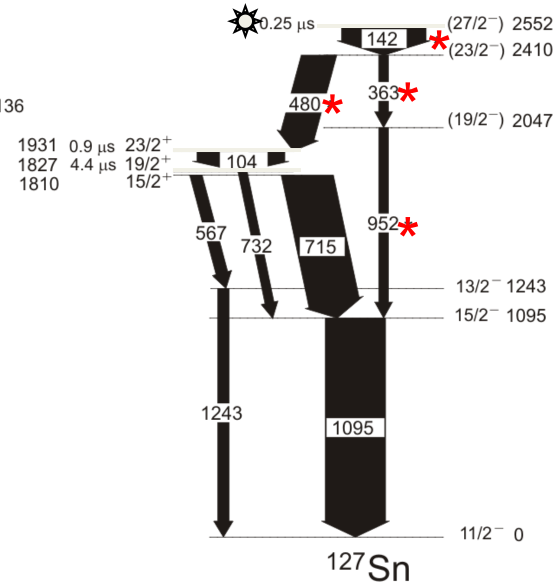
$19/2^+$ $\nu s_{1/2}^{-1} h_{11/2}^{-2}$ $23/2^+$ $\nu d_{3/2}^{-1} h_{11/2}^{-2}$

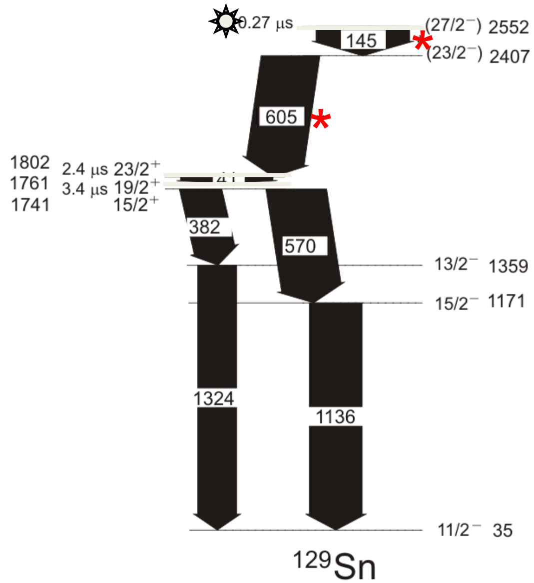
$\nu h_{11/2}$ x 5^- core $\nu h_{11/2}$ x 7^- core

$27/2^-$ $h_{11/2}^{-3}$

$h_{11/2}^{\nu}$, ν=2,3



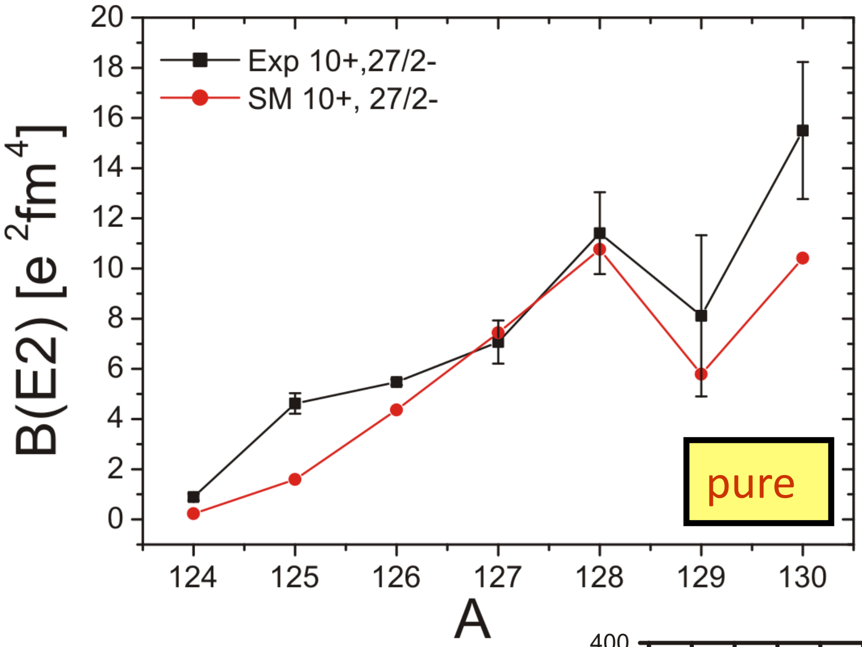


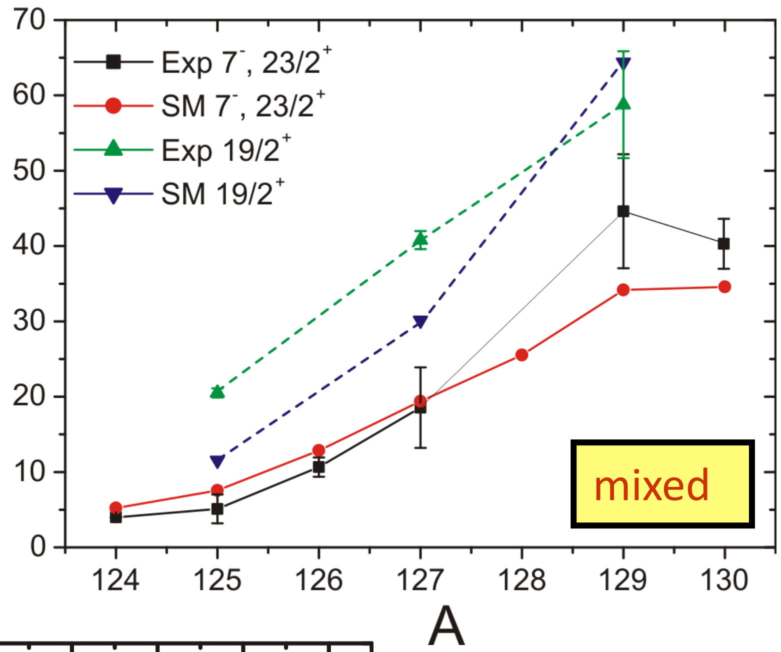


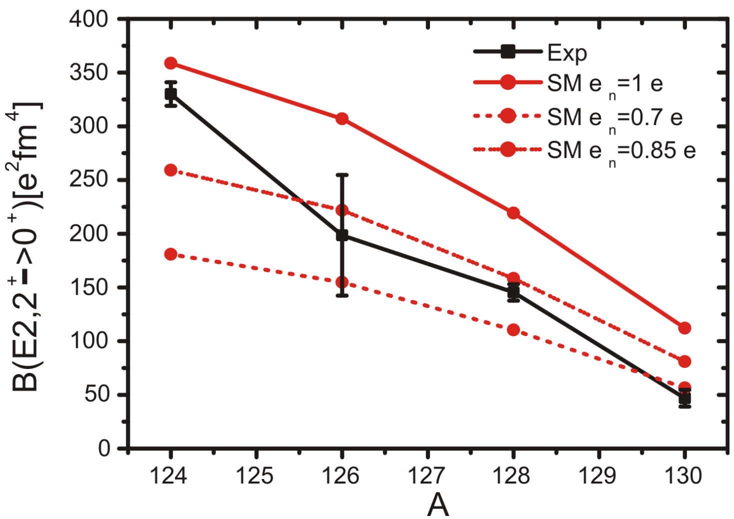
example

* new

RESULTS: Systematics of Sn isotopes with N<82







Very valuable nuclear structure information obtained !

Experimental vs Theoretical BE(2)

R. Lozeva et al, PRC **77** (2008) 064313

CONCLUSIONS / Outcome

(1) PROVEN the PRESENCE of spin-alignment

- in relativistic fission
- in projectile fragmentation for high-Z beams

→ neutron-rich nuclei & heavy nuclei become accessible for moment studies

(2) Measured g factors for few isomers

→ determine isomeric structure, confirm assigned spin/parity

(3) New isomers identified and B(E2) determined → structure towards ^{132}Sn

Outlook

Improvements needed for a future campaign:

(1) a position sensitive detector in intermediate plane (S2) that can handle **high rates** (> 10^6/s) as well as **high doses !**

(2) improve **efficiency of the set-up**: use only 4 detectors but in closer geometry → gain of factor 2-3 in efficiency is possible !!

(3) ACQ that can handle **higher event-rate**

what next: g-E(U)RICA @ RIKEN ?!...

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