Decay Spectroscopy at GSI and FAIR - II

J. Gerl

GSI Darmstadt, Germany

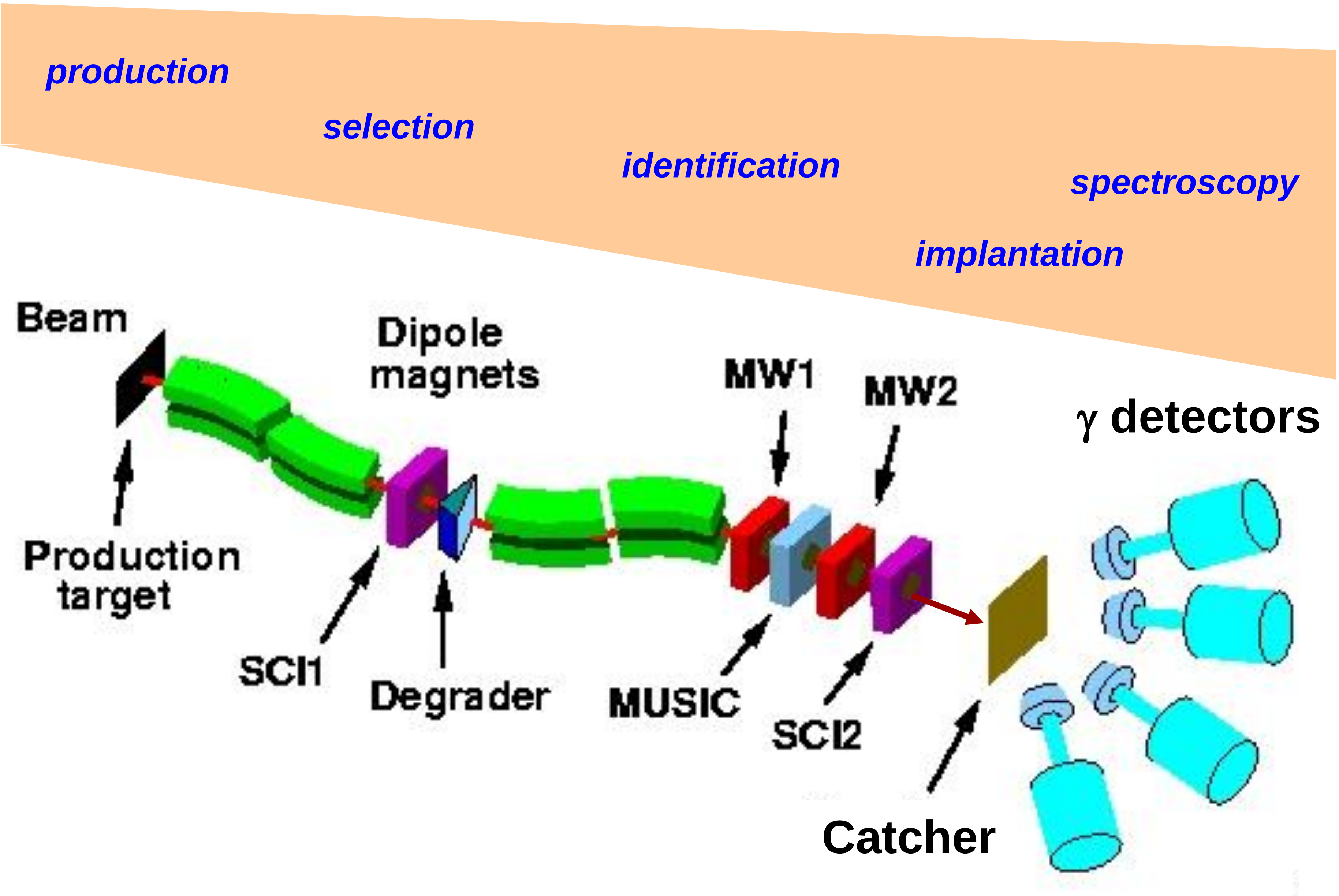
presented at

INUP 2011

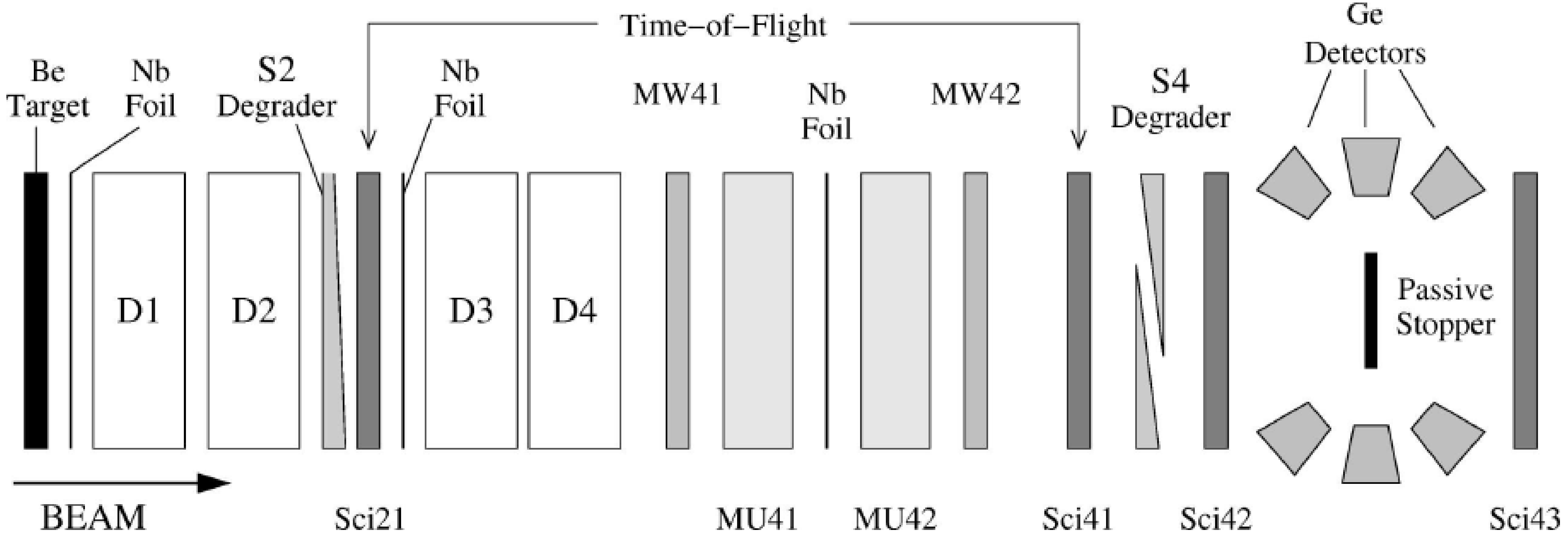
Goa, India,

NOVEMBER 9 – 11, 2011

Decay Spectroscopy

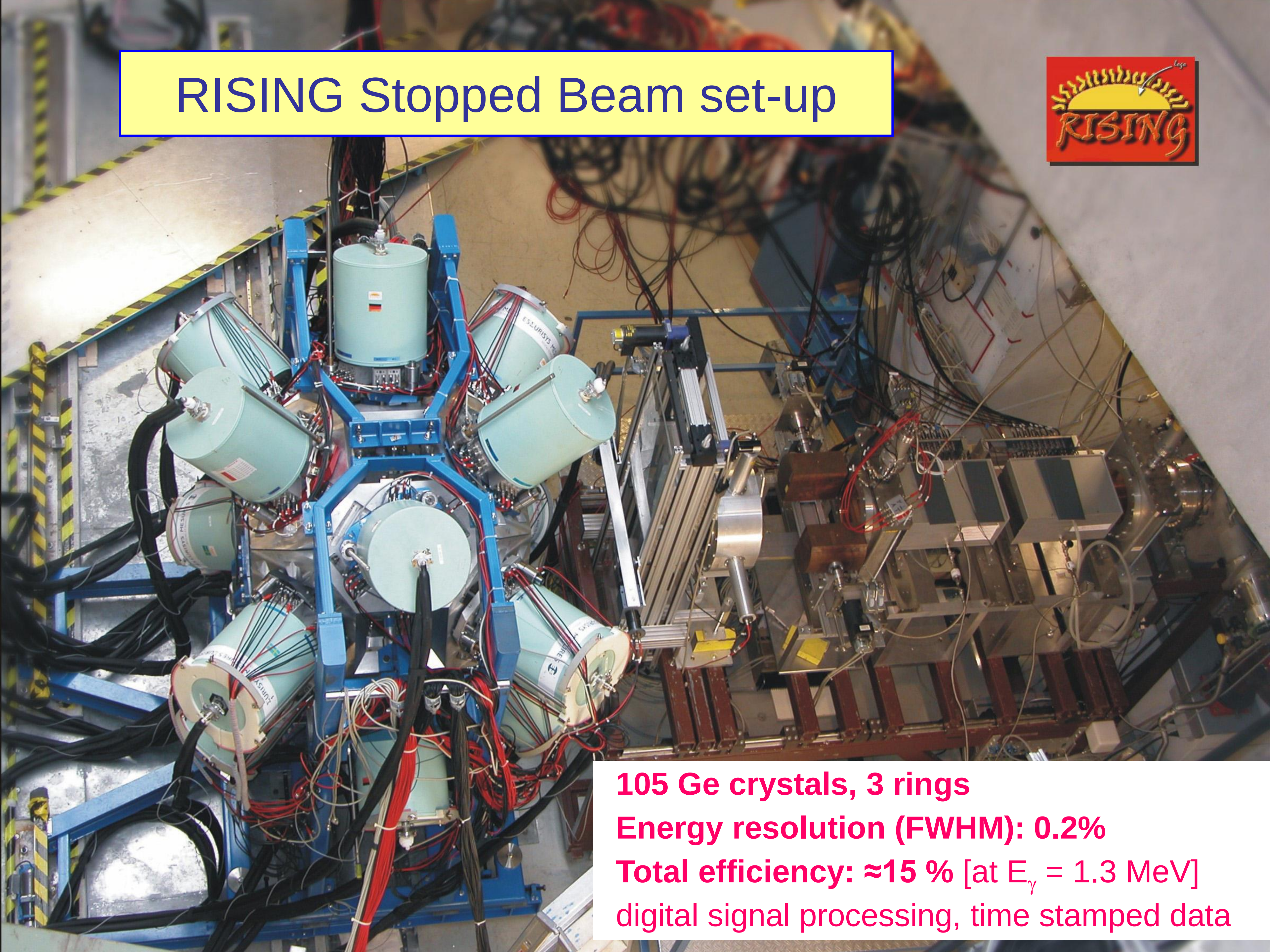


FRS calibration

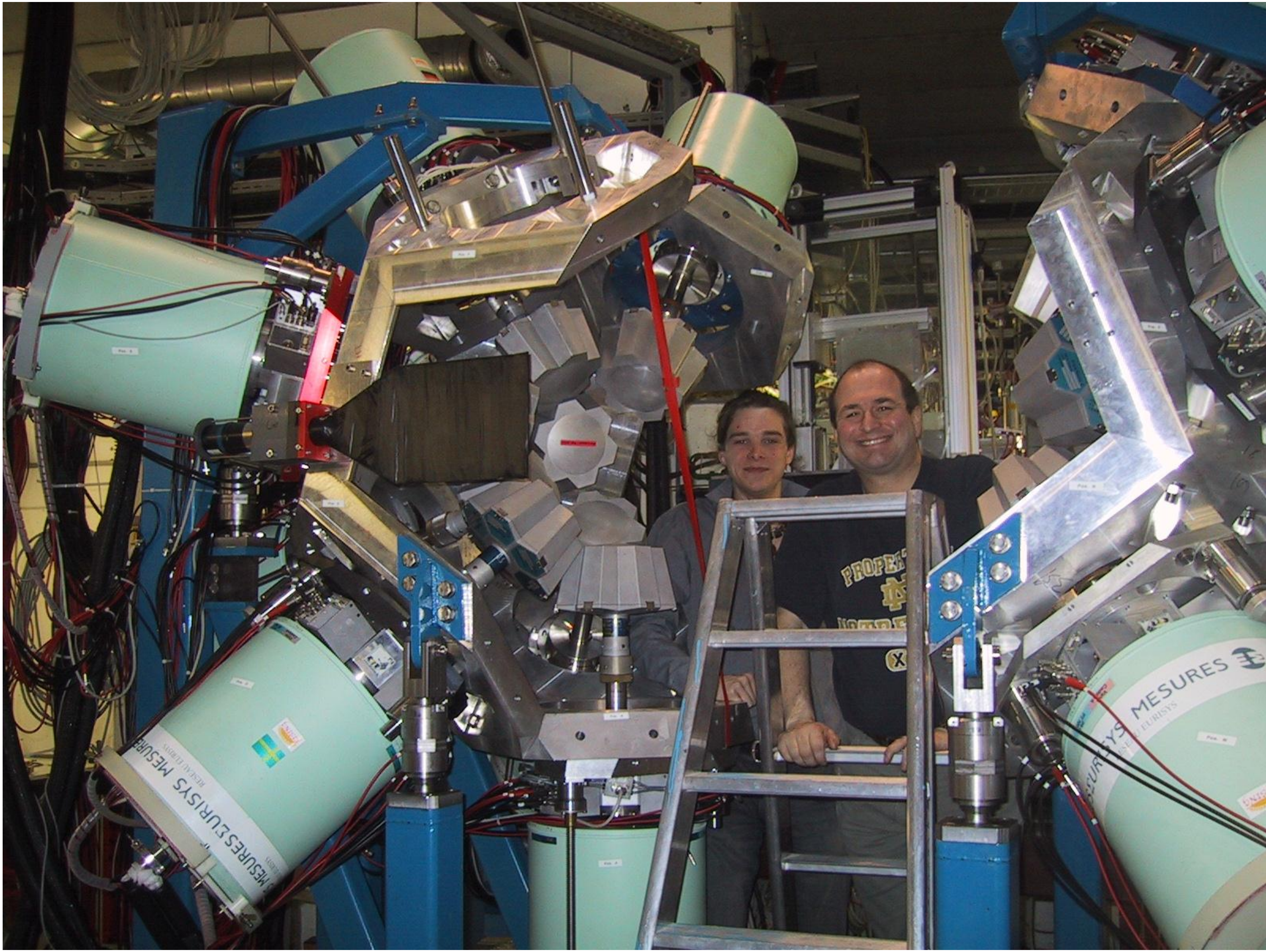


1. Calculate setting with LISE++ and MOCADI (target and degrader thicknesses, fragment distribution, Eloss, magnetic fields)
2. Center reduced intensity primary beam at final focus using calculated parameters
3. Check and calibrate all particle tracking detectors
4. Calibrate degrader thicknesses and ToF
5. Center fragment using calculated parameters or scaled values of previous runs
6. Control isotope identification with known isomers

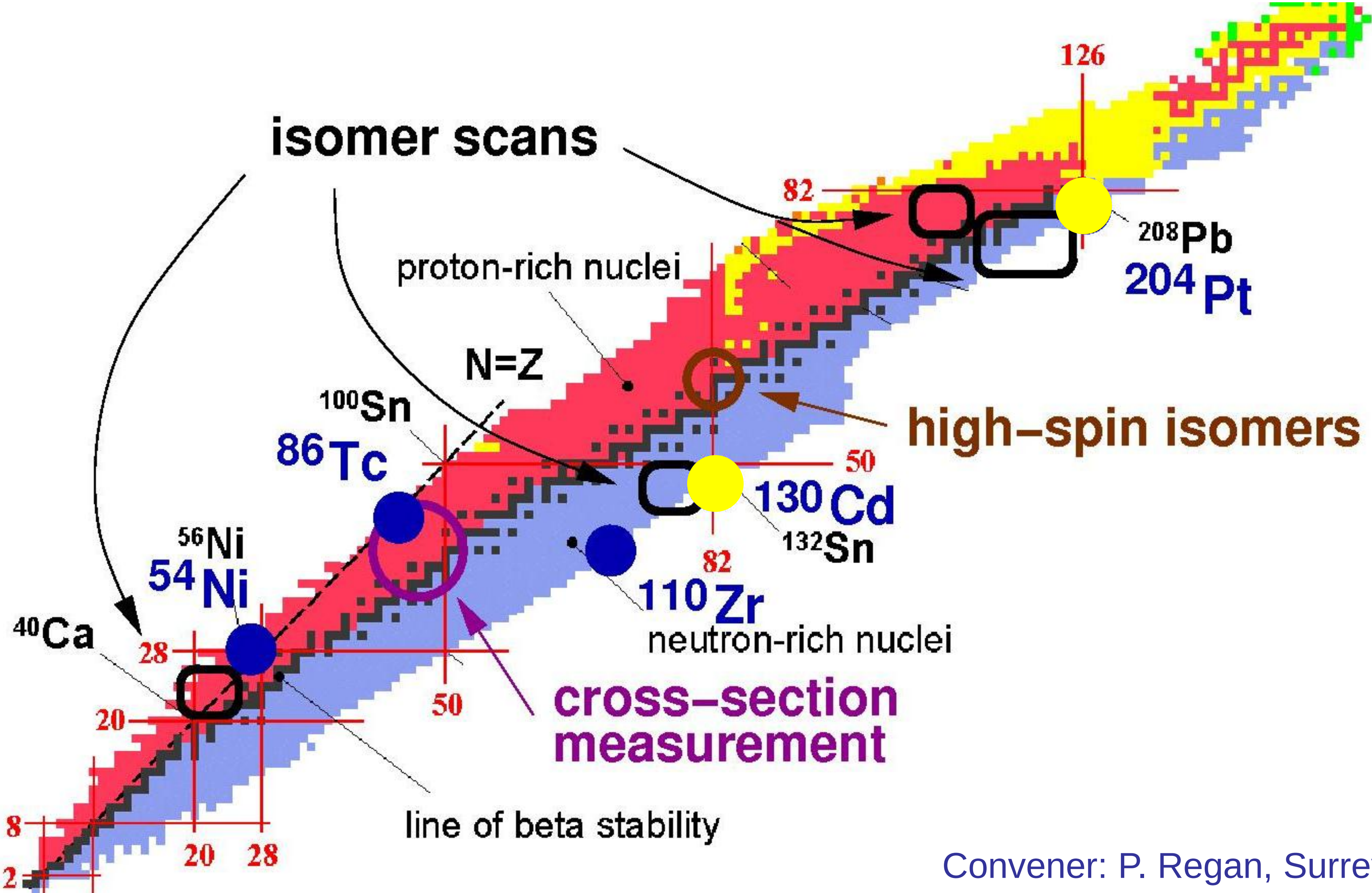
RISING Stopped Beam set-up



105 Ge crystals, 3 rings
Energy resolution (FWHM): 0.2%
Total efficiency: ≈15 % [at E_γ = 1.3 MeV]
digital signal processing, time stamped data


MESURES

RISING: Stopped beam – physics focus **2006**



Convener: P. Regan, Surrey

Isospin symmetry in ^{54}Ni

Goals:

Investigate isospin symmetry near the p-dripline

Constrain large-scale fp shell model calculations

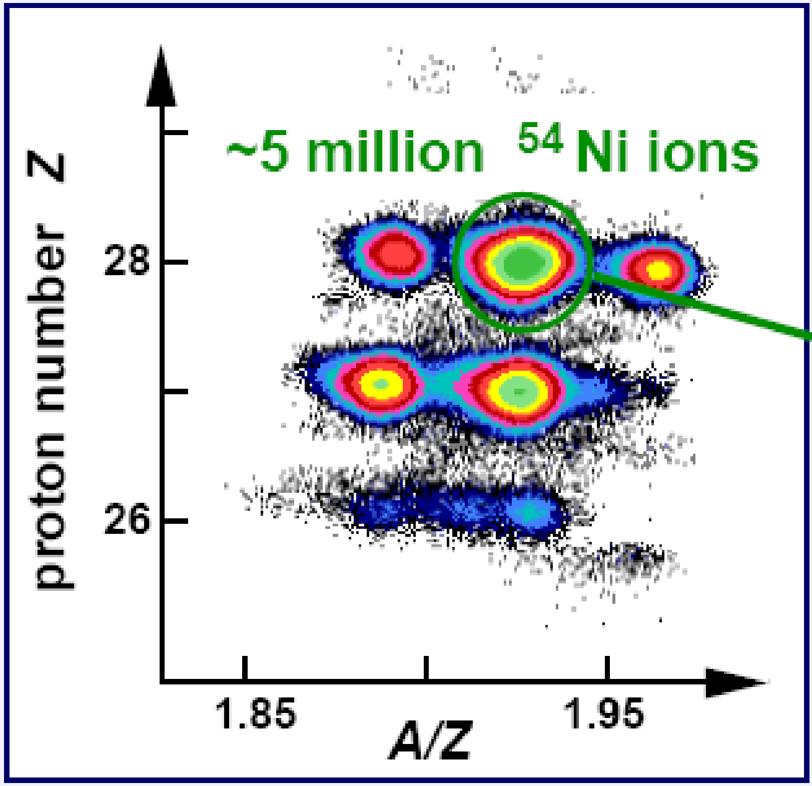
Experiment:

Find 10^+ isomer as isobaric analog state of ^{54}Fe

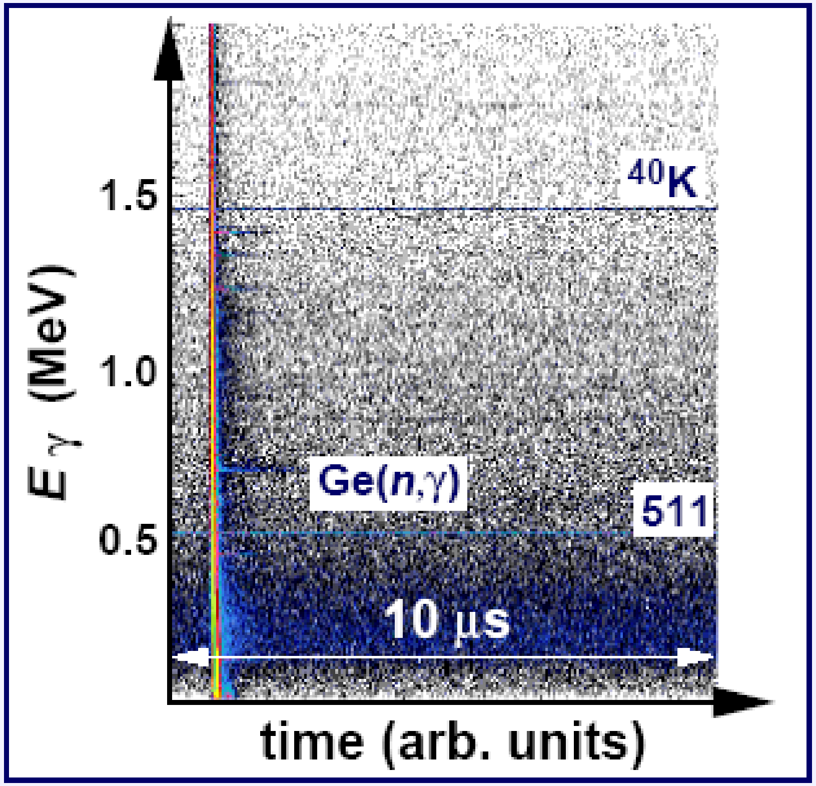
Determine isomer lifetime

Determine spin dependent mirror energy differences (MED)

Gamma Energy-Time Correlations



^{54}Ni: DGF–timing

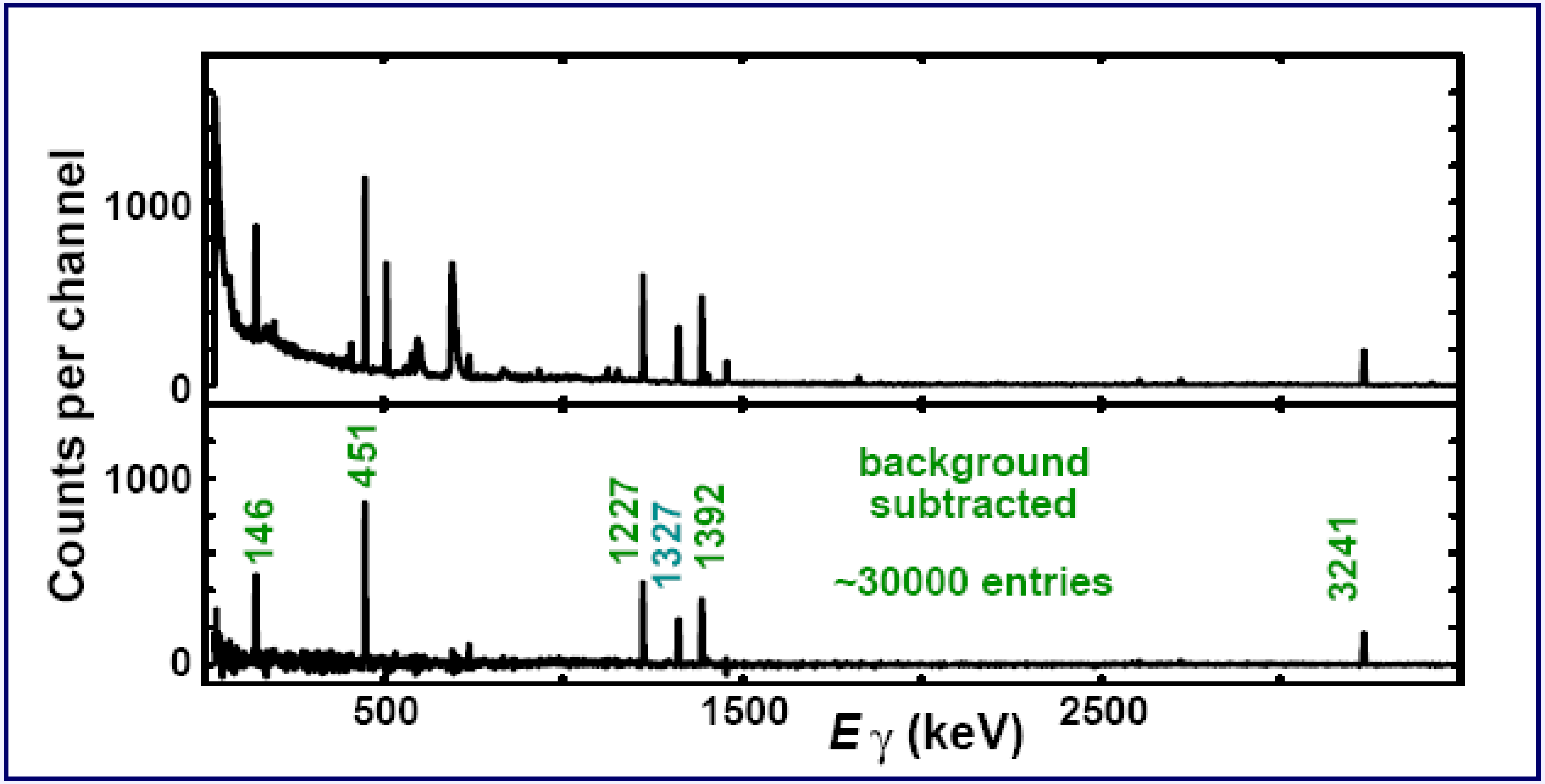


~ 0.9 million entries

D. Rudolph, Lund University

Ge Single Spectra

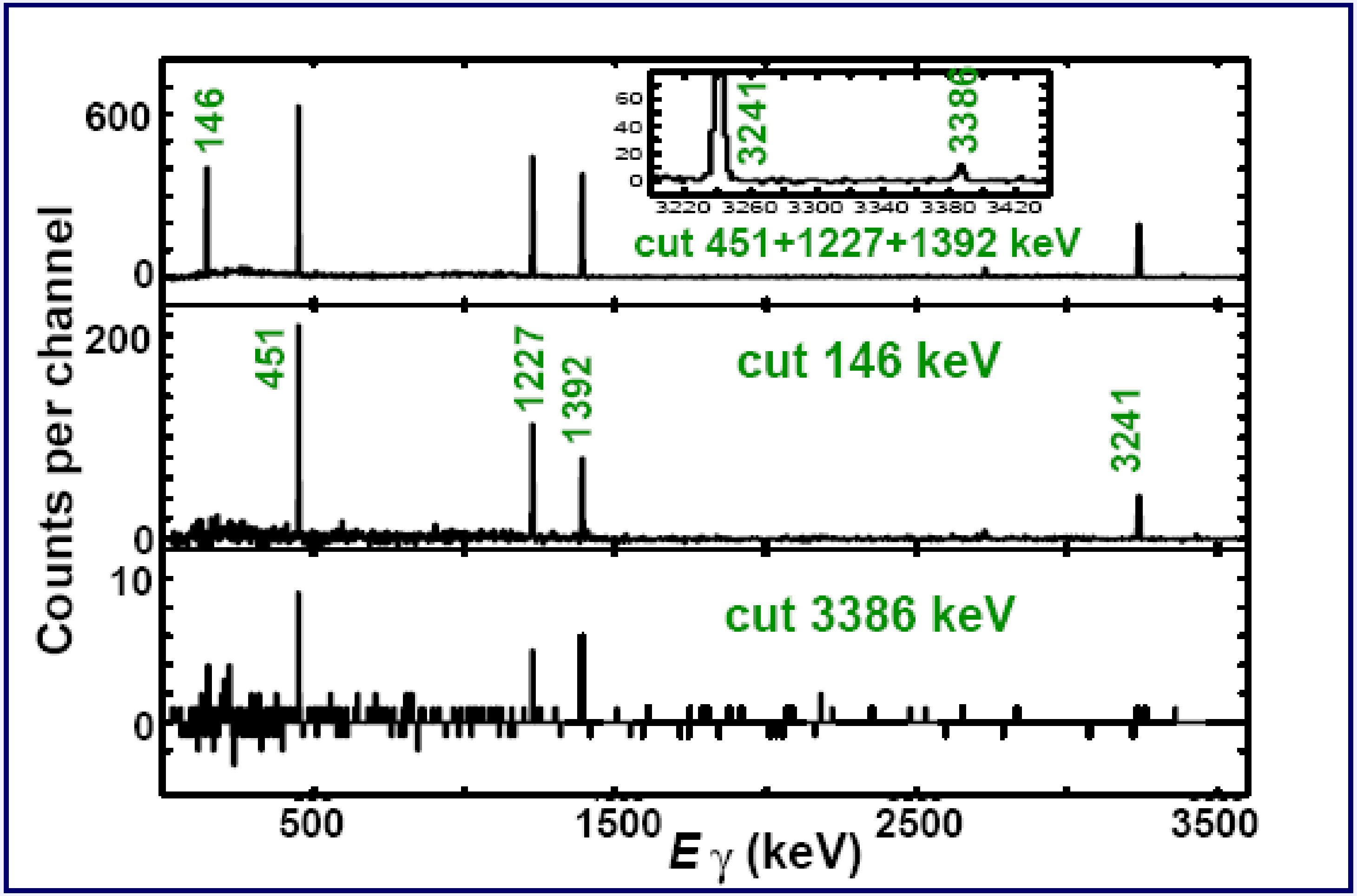
^{54}Ni gated, time range 0.05 – 1.00 μs after implantation



D. Rudolph

γγ Coincidence Spectra

Ni gated
0.05 – 1.00μs

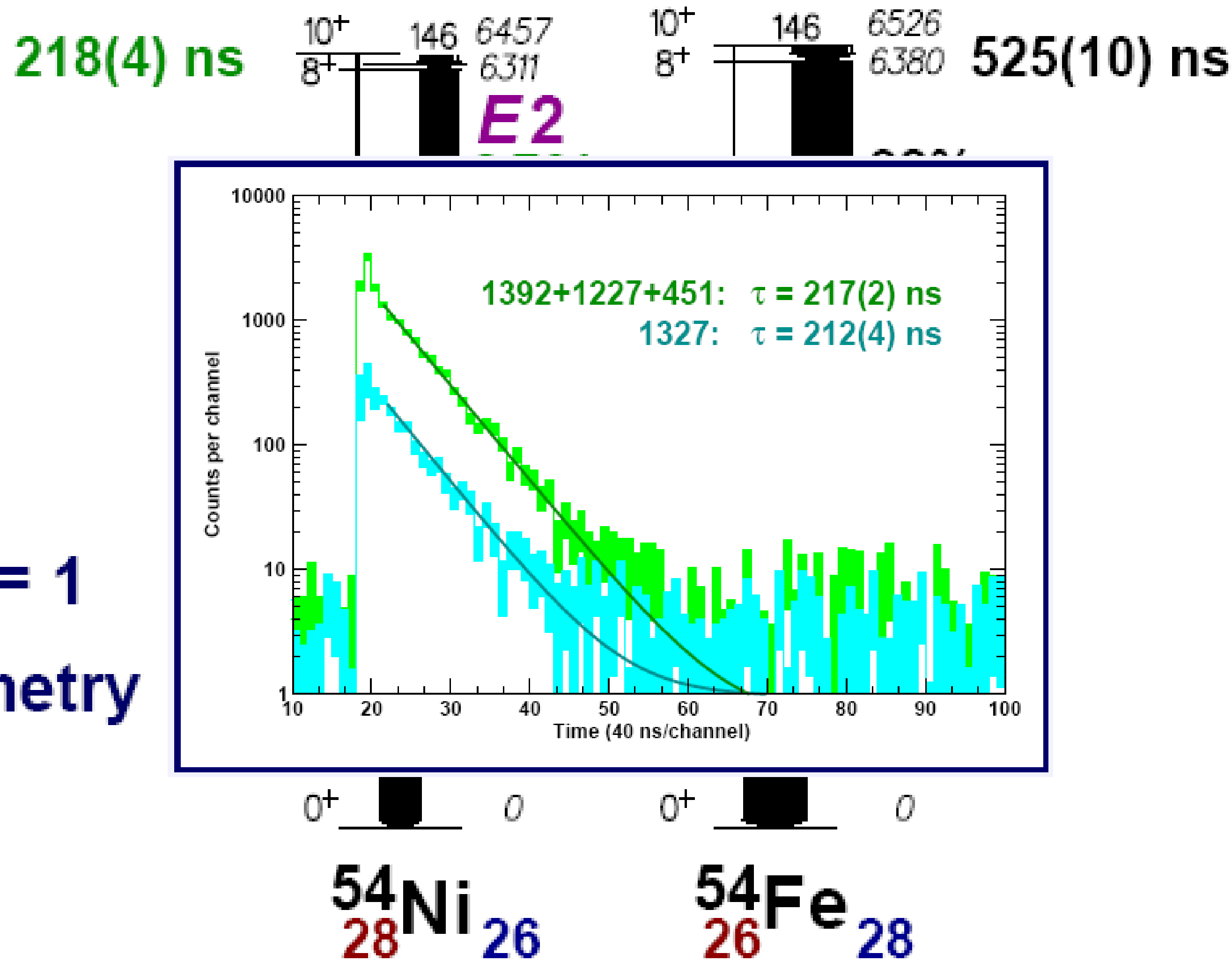


D. Rudolph

Decay Scheme of ^{54}Ni

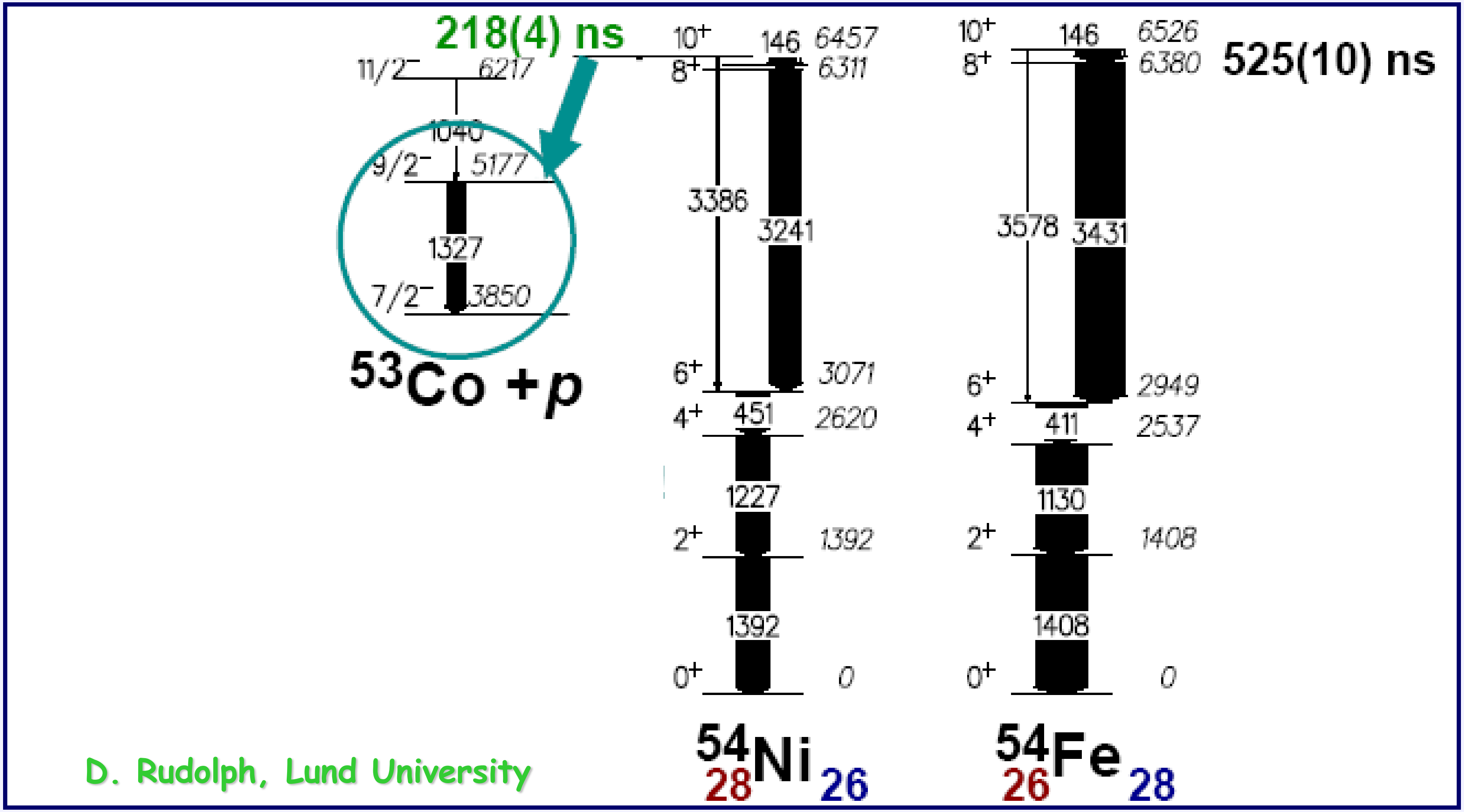
A = 54, T = 1

Isospin Symmetry

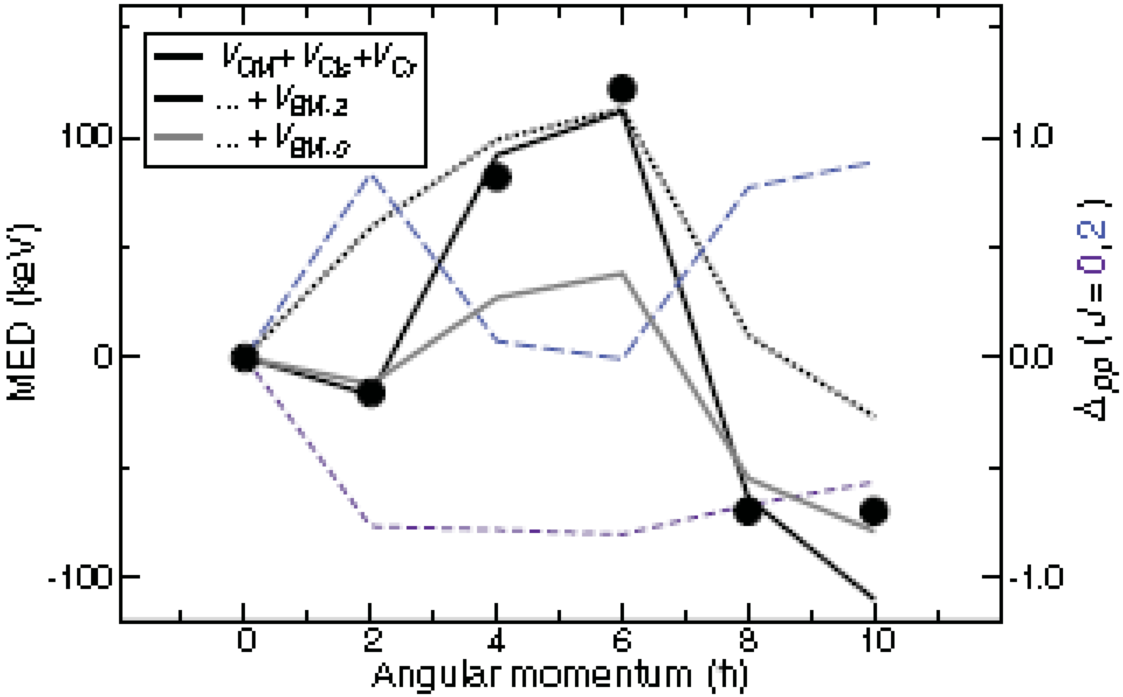


D. Rudolph

Decay Scheme of ^{54}Ni



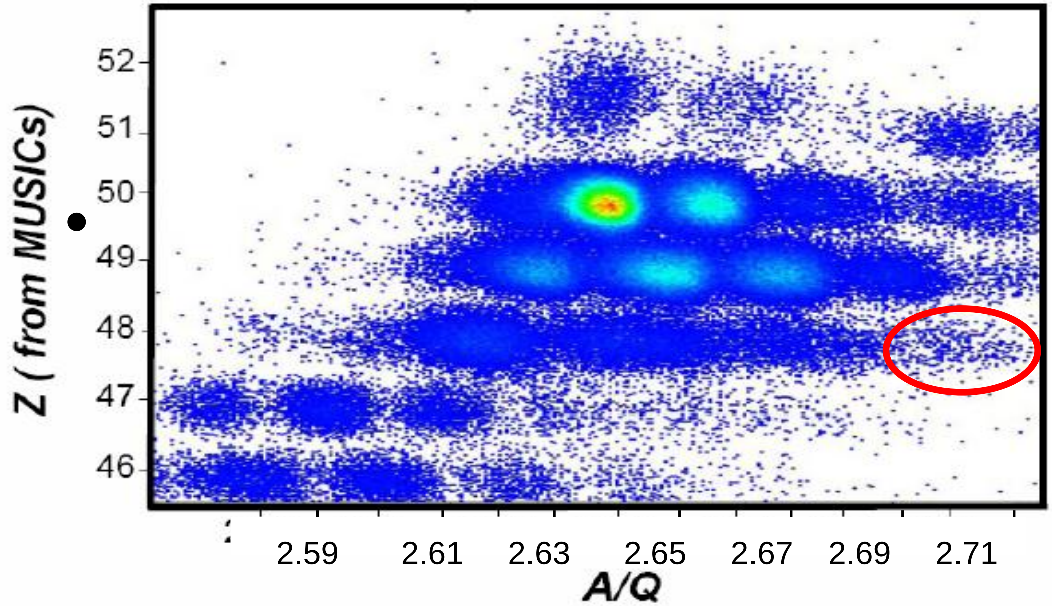
Results

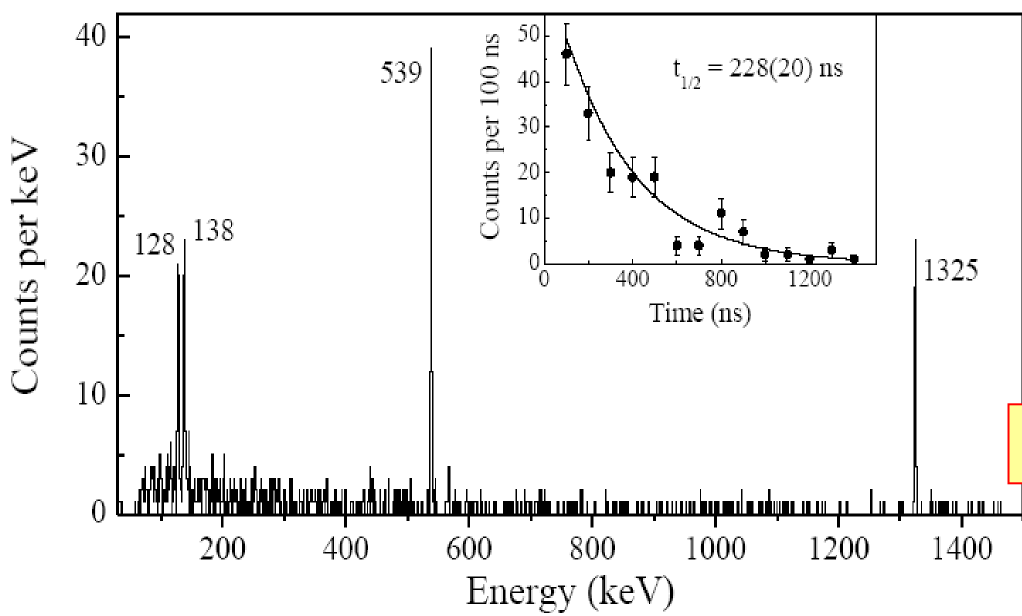


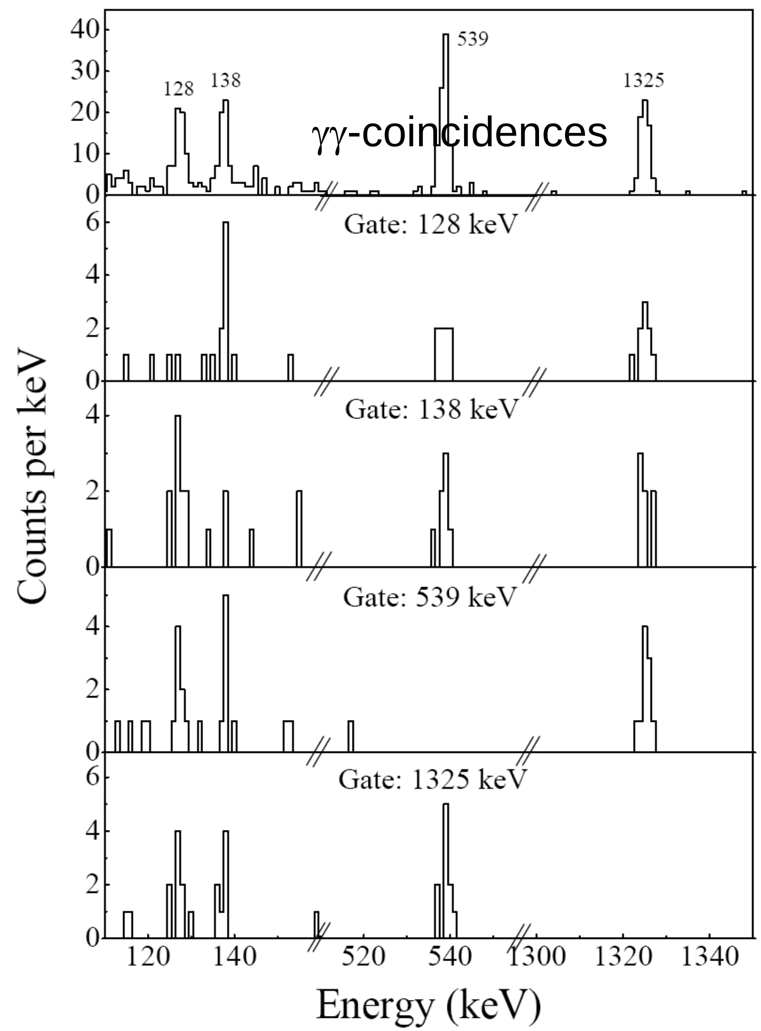
Shell model with KB3G interaction can describe symmetry breaking (assuming a 25% p-decay contribution to the 10^+ isomer lifetime)

	54Fe		54Ni	
	Exp.	KB3G	Exp.	KB3G
$T_{1/2}(10^+)$ (ns)	364(7)	308	296(8)	286

^{130}Cd from fission and fragmentation





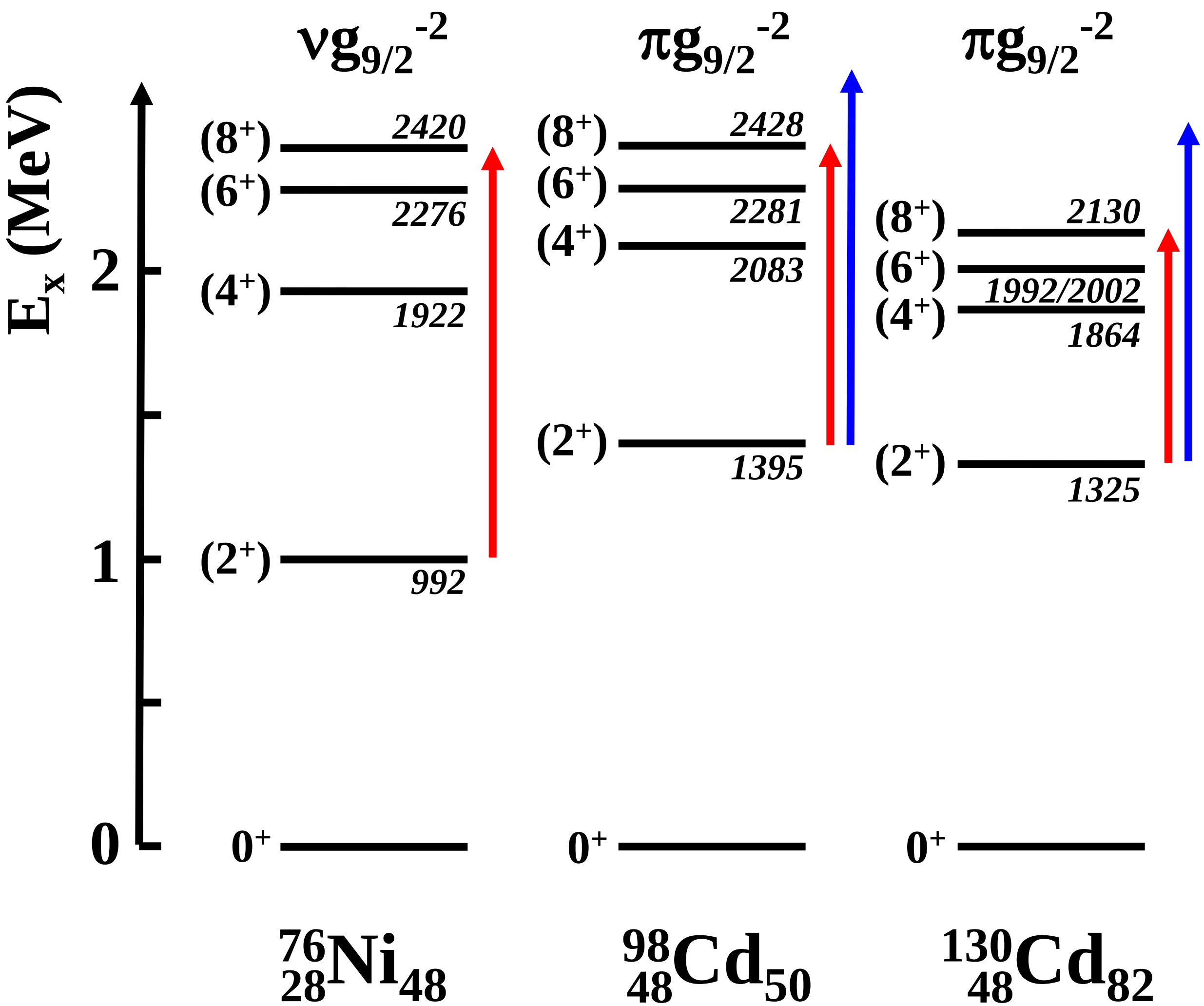


No evidence for shell quenching

Andrea Jungclaus, Madrid

Lucia Caceres, PhD thesis

Unexpected scaling of $(g_{9/2})^{-2}$ two-body interaction



*C. Mazzocchi et al., PLB **622** (2005) 45*

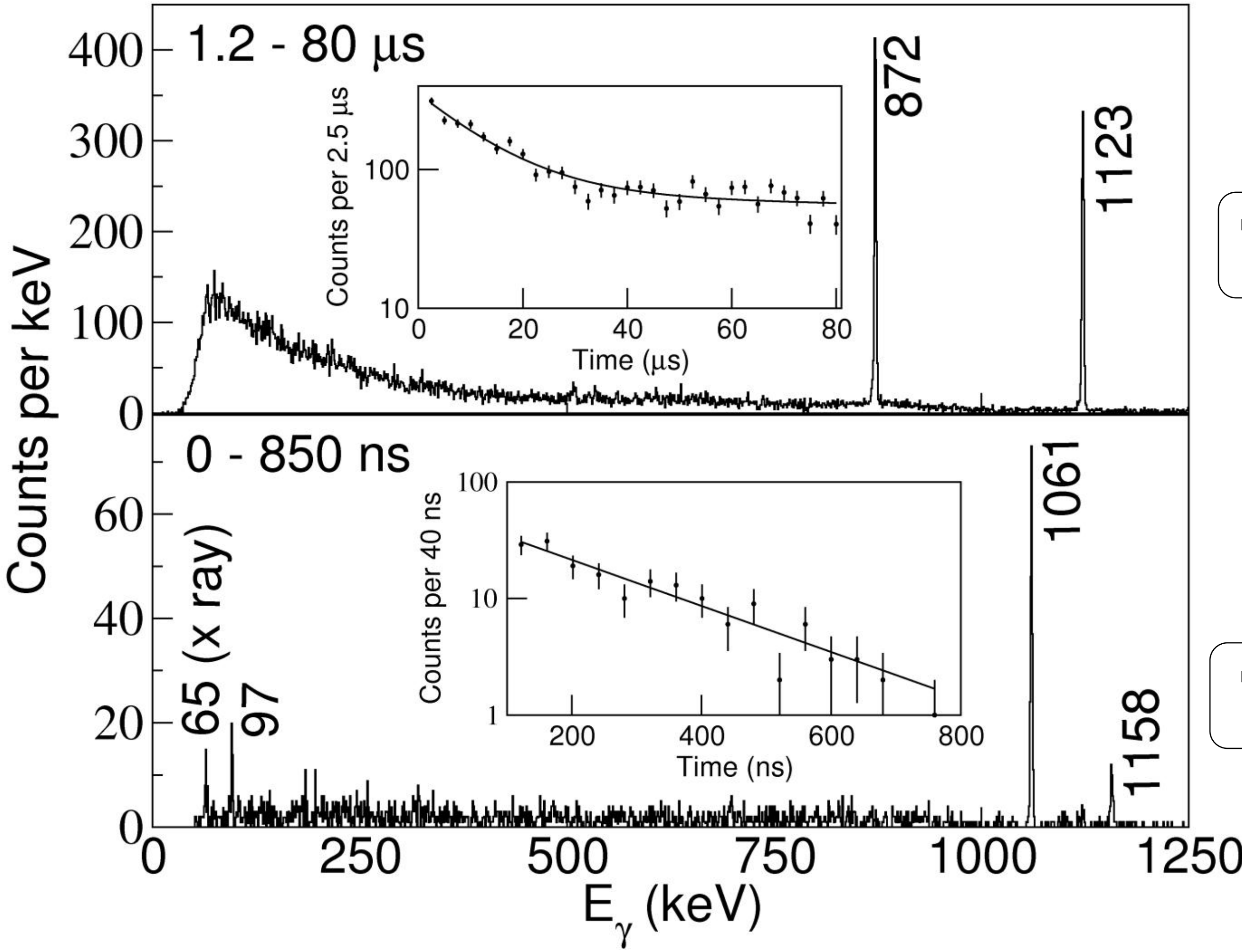
2^+-8^+ levels are pure $(g_{9/2})^{-2}$ states

2^+-8^+ energy spread scales with A^{-1}

not with $\hbar\omega = 41 \cdot A^{-1/3}$ as commonly assumed

idea of H. Grawe

^{204}Pt populated via 4-proton-knockout from ^{208}Pb



long isomer:

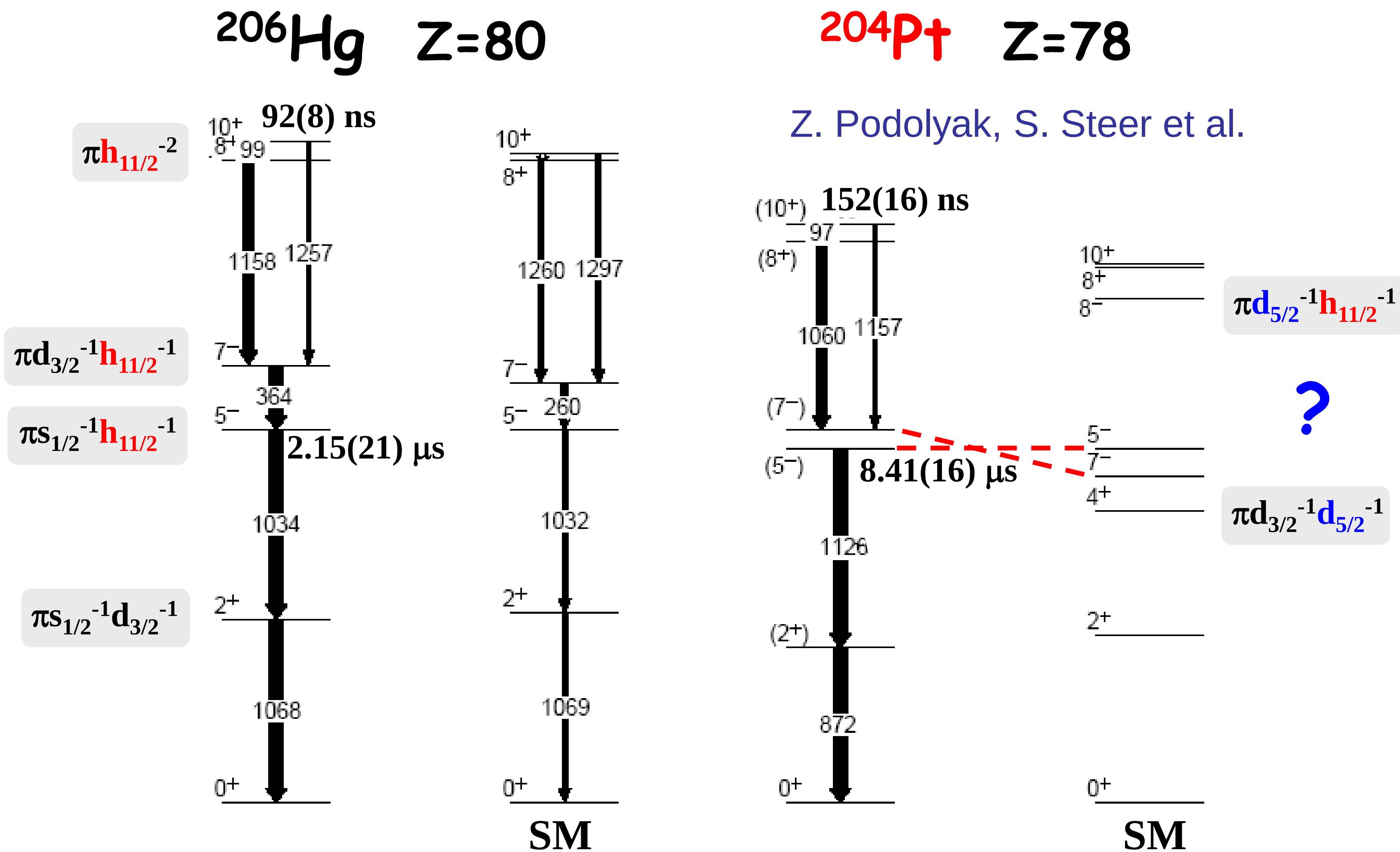
$T_{1/2}$=8.41(16) µs

short isomer:

$T_{1/2}$=152(16) ns

N=126 isotones: $(\pi h_{11/2})^{-2,4}$ $I^{\pi}=10^{+}$ isomers

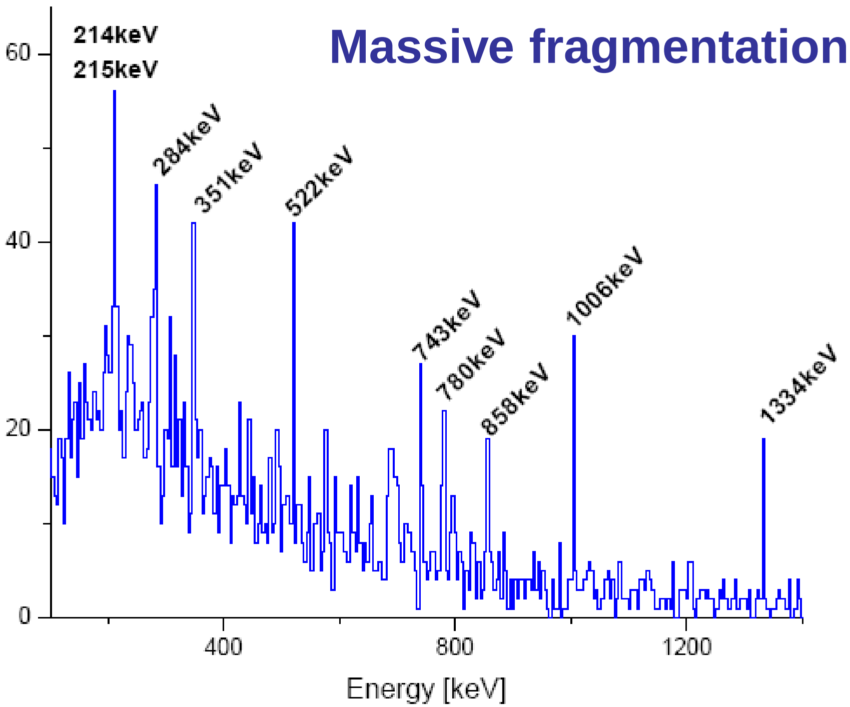
Z. Podolyak, S. Steer et al.

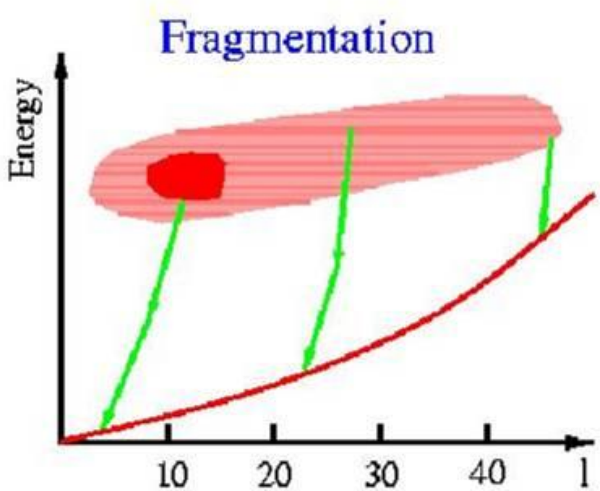


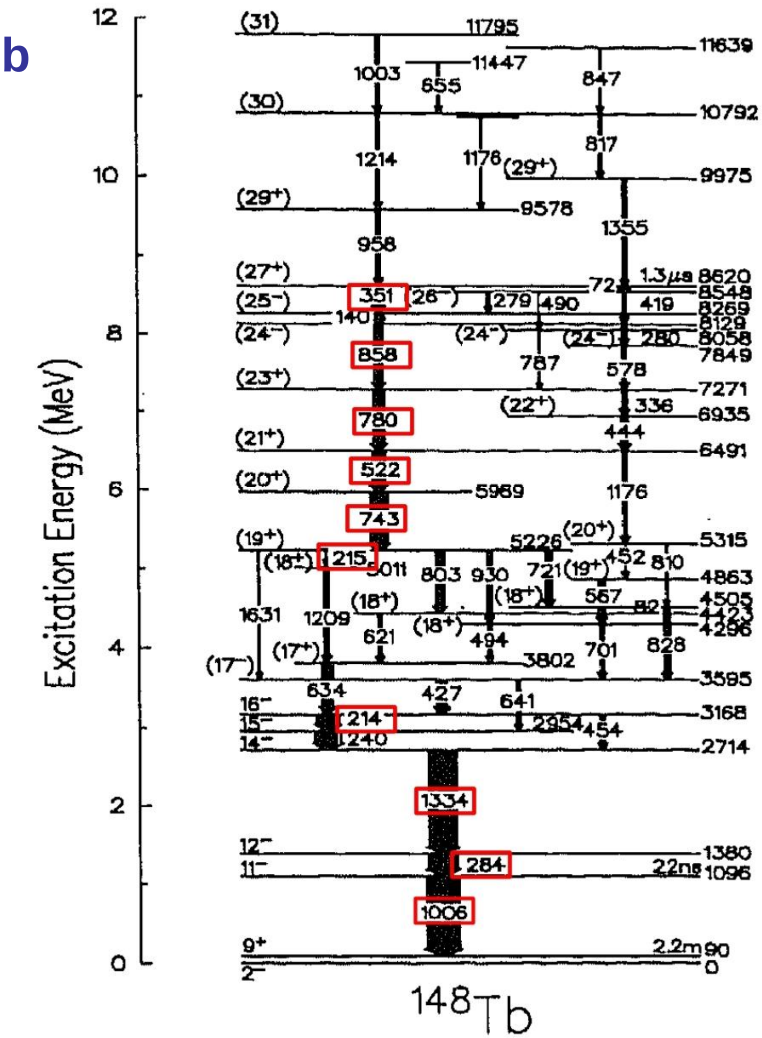
B. Fornal et al.
PRL 87 (2001)212501

➡ Results require modification of SPE and/or interactions !

27^+ state populated in ^{148}Tb



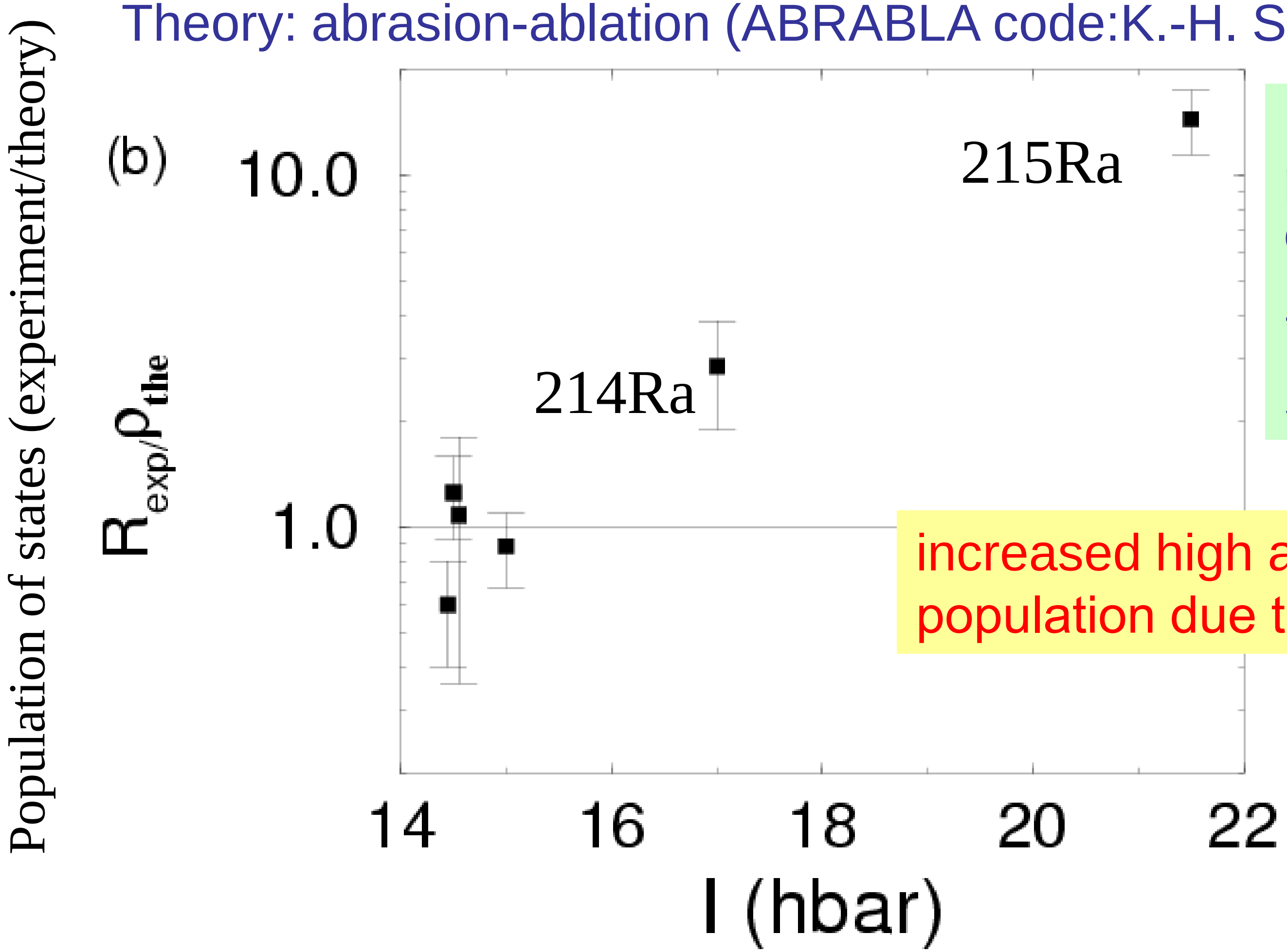




Fragmentation populates high spin states

Theoretical explanation

Theory: abrasion-ablation (ABRABLA code:K.-H. Schmidt et al.)



Rupture of nucleon pairs -> high spin orbitals

\+

Statistical decay

increased high angular momentum population due to ‘**collective**’ ***I***

Zs. Podolyák *et al*., Phys. Lett. B632 (2006) 203.

Isomeric ratios in massive fragmentation

Fragmentation of ^{238}U

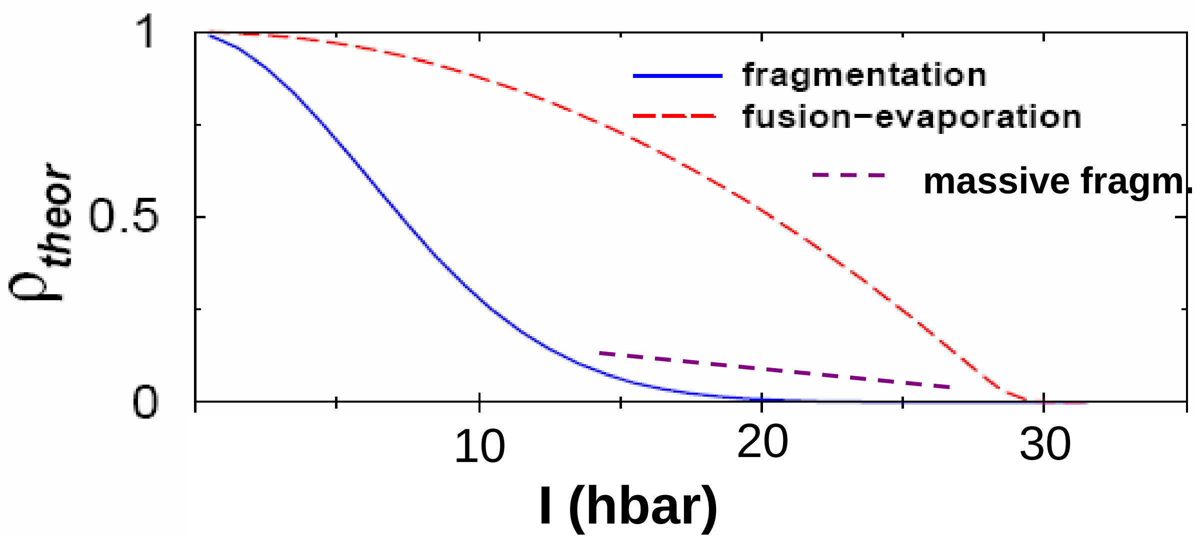
Isomeric ratios

	I	R [%]
^{211}Fr	$29/2^+$	5.7 (2)
^{212}Fr	15^-	7.5 (2)
^{213}Fr	$29/2^+$	12.0 (8)
^{214}Ra	17^-	6.8 (2)
^{215}Ra	$43/2^-$	3.1 (6)

Fragmentation of ^{208}Pb

Isomeric ratios

	I	R [%]
^{148}Tb	27^+	3.0 (6)



Improving the set-up

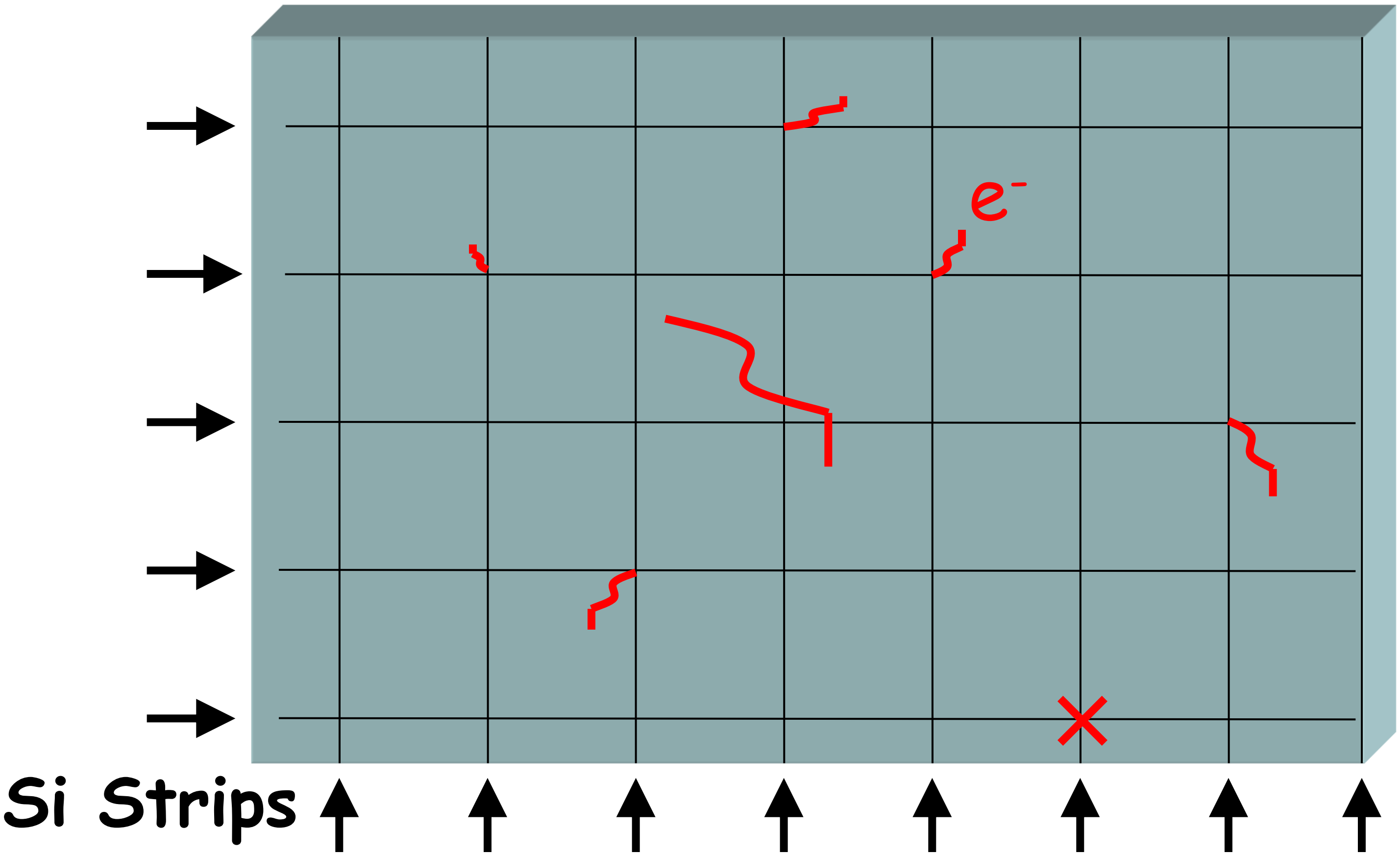
Limitation

Passive stopper limited to lifetimes < 1 ms
and implantation rates < 1 kHz

Way out
Active stopper

The Principle of the Active Stopper

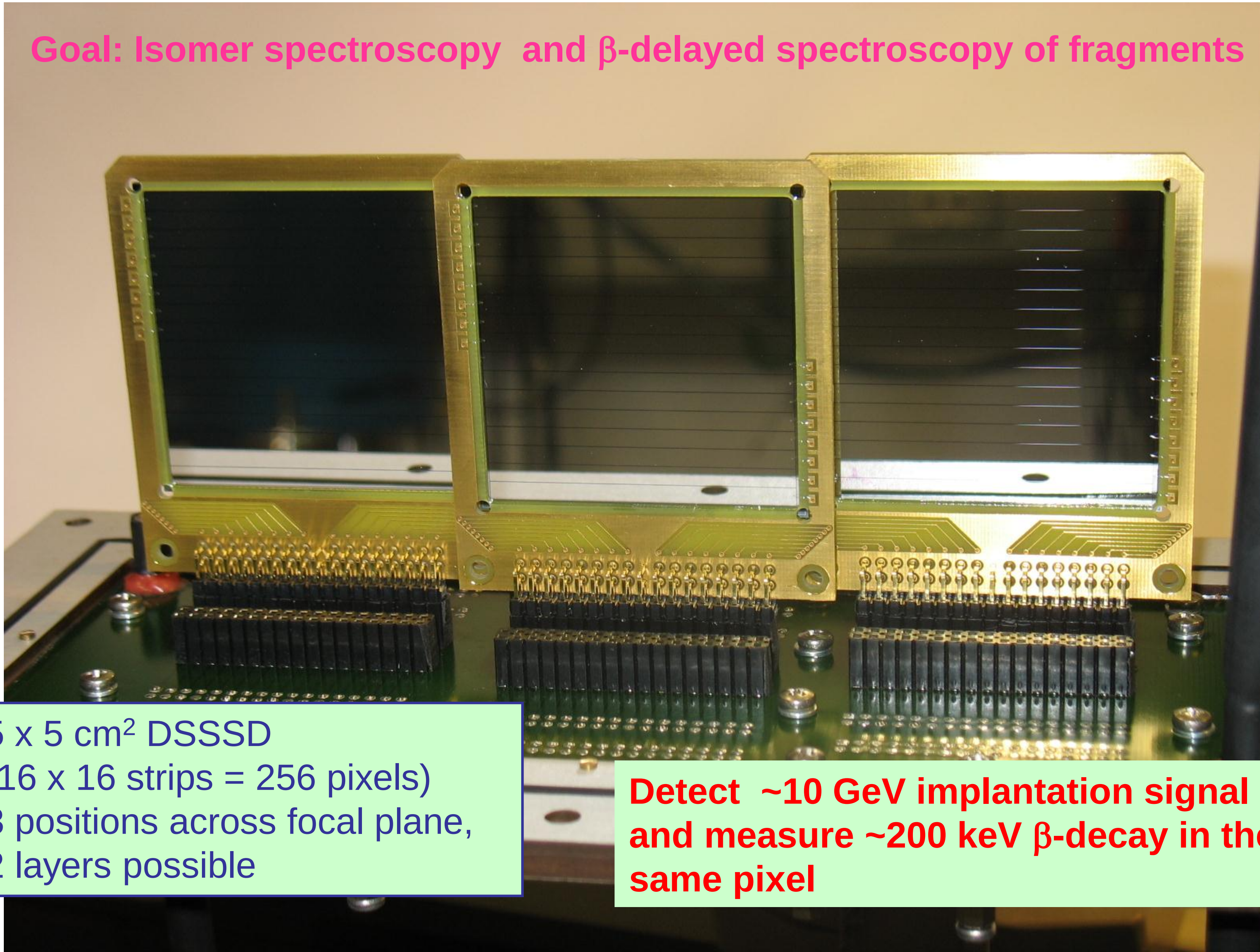
Focal plane implantation detector sensitive to electron emission



The waiting time between particle implantation and β-particle (or i.c. electron) emission is a measure of the decay half-life. Gamma rays emitted following these decays are detected by the RISING array.

Active Stopper RISING

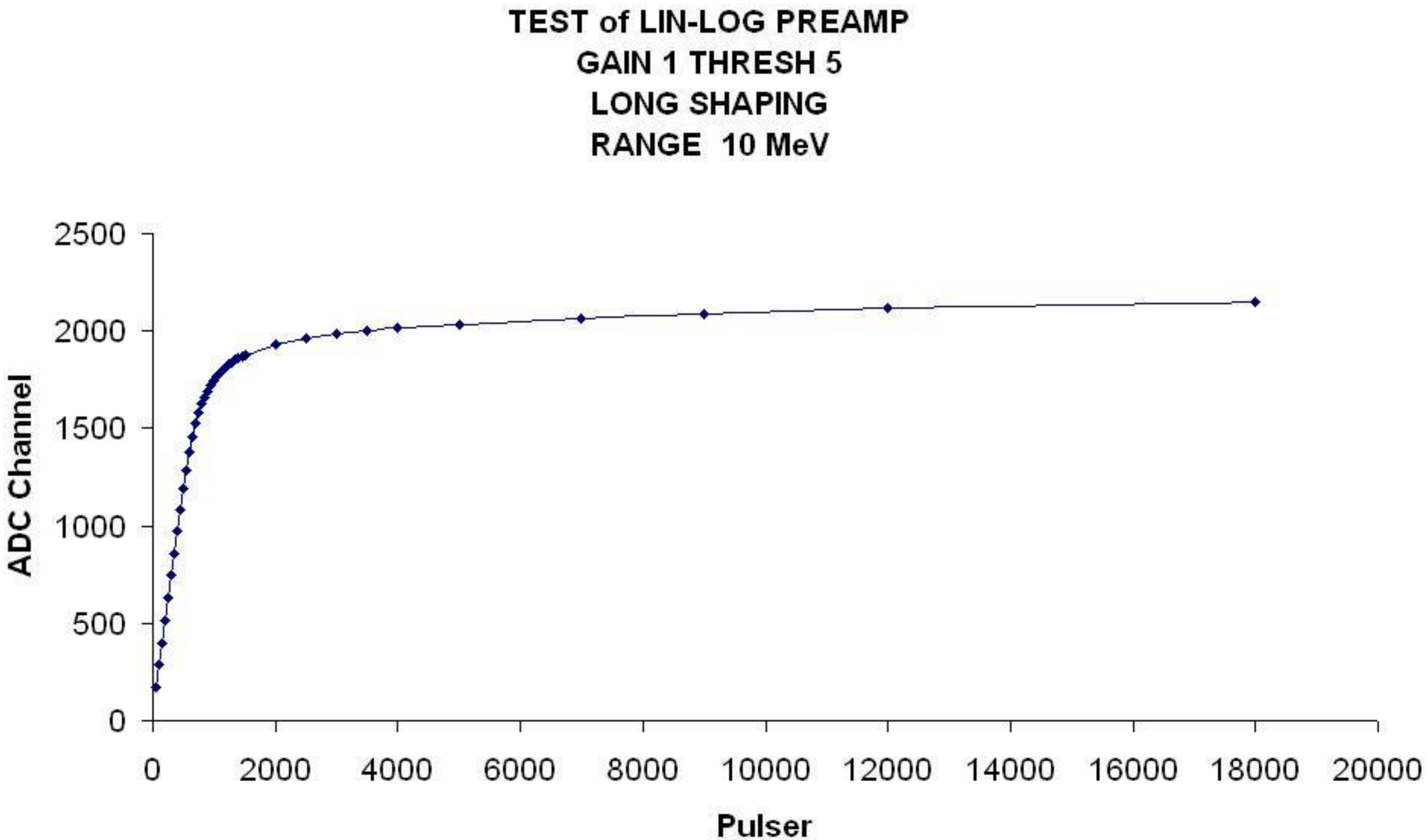
Goal: Isomer spectroscopy and β-delayed spectroscopy of fragments



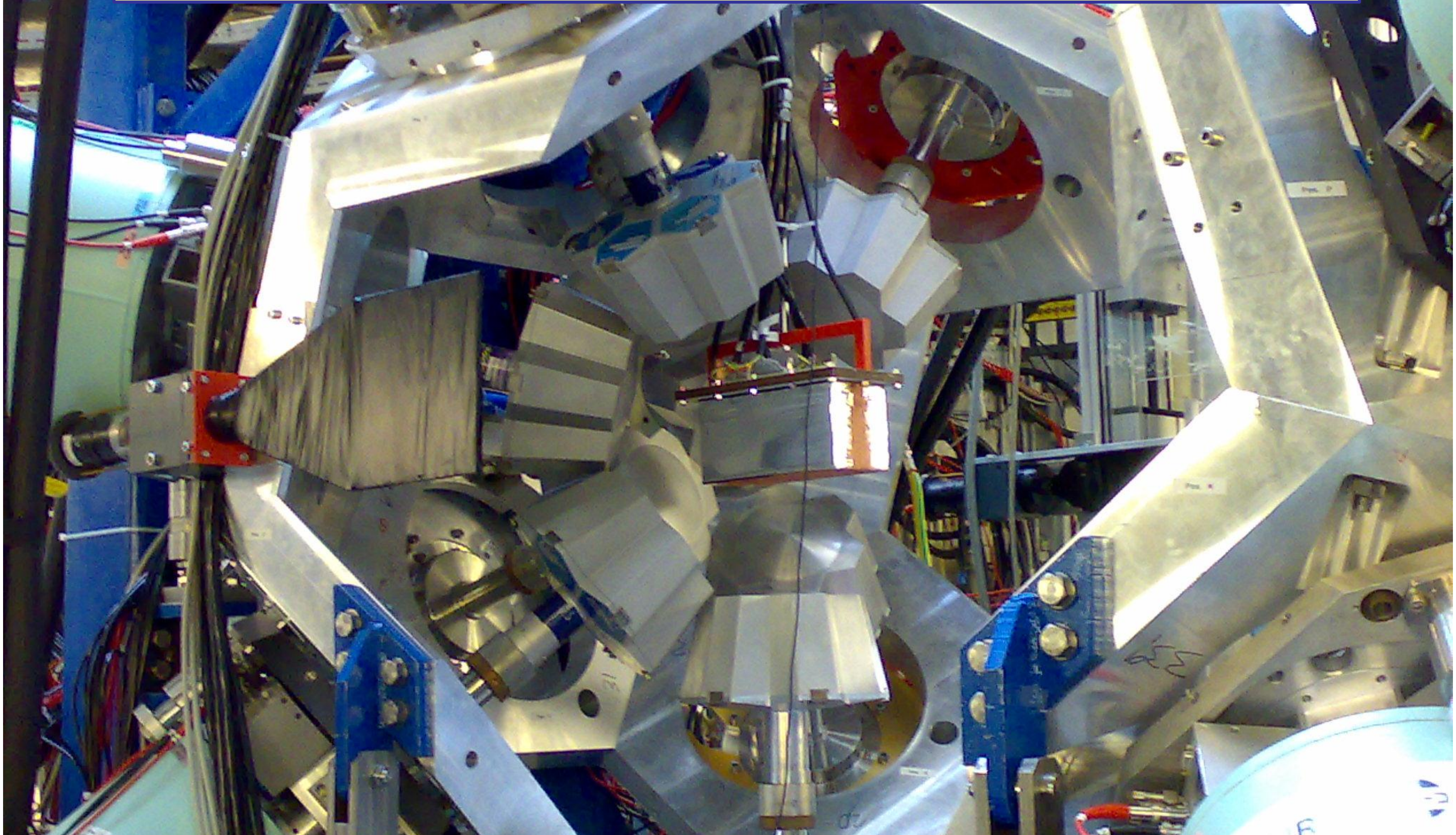
5 x 5 cm^2 DSSSD
(16 x 16 strips = 256 pixels)
3 positions across focal plane,
2 layers possible

Detect ~10 GeV implantation signal and measure ~200 keV β-decay in the same pixel

How do you measure signals with 0.1 MeV & 20 GeV in the same detector ?



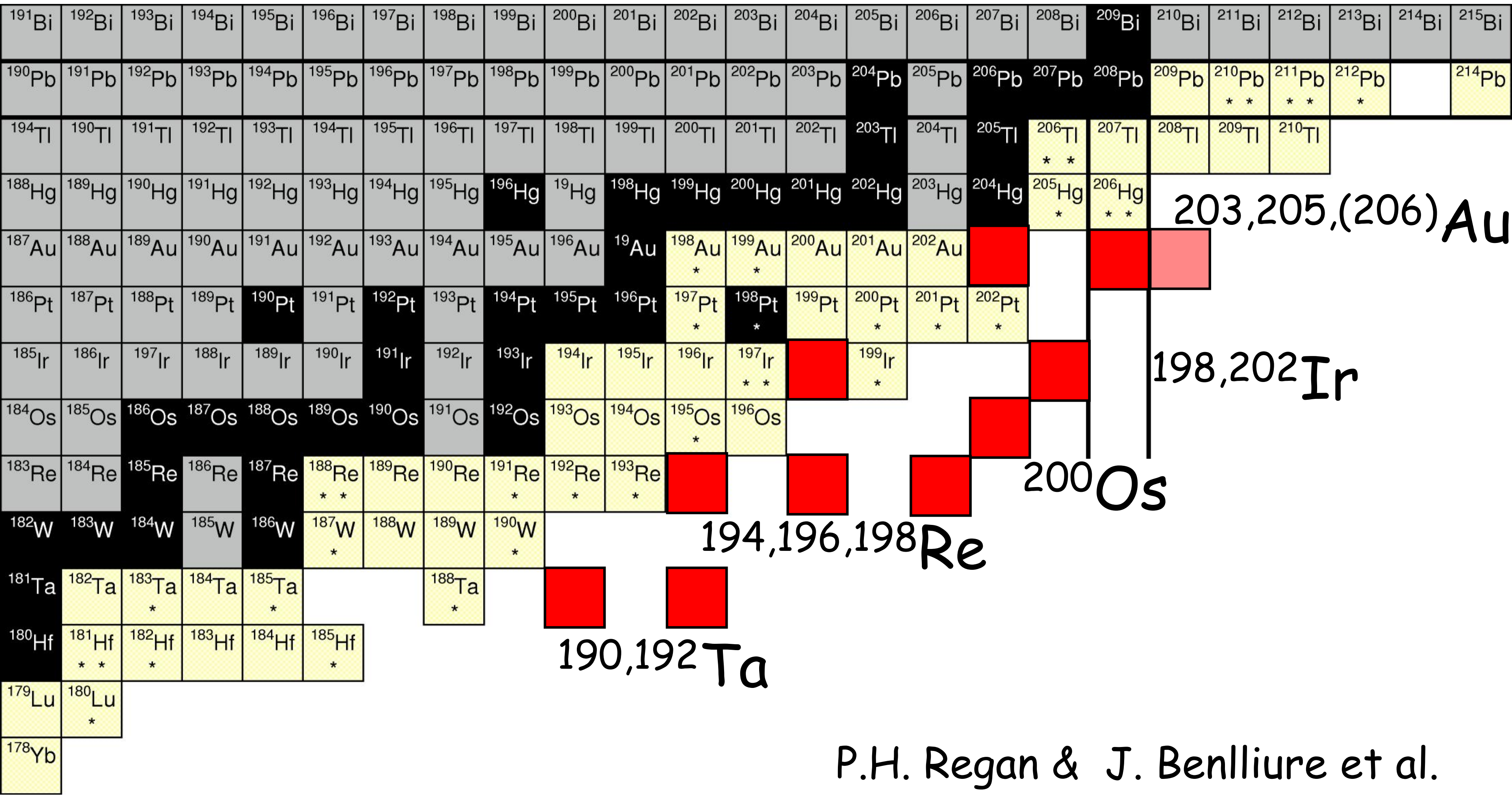
Active stopper in place



Passive Stopper measurements: γ rays from isomer with $T_{1/2}$ for 10 ns → 1 ms.

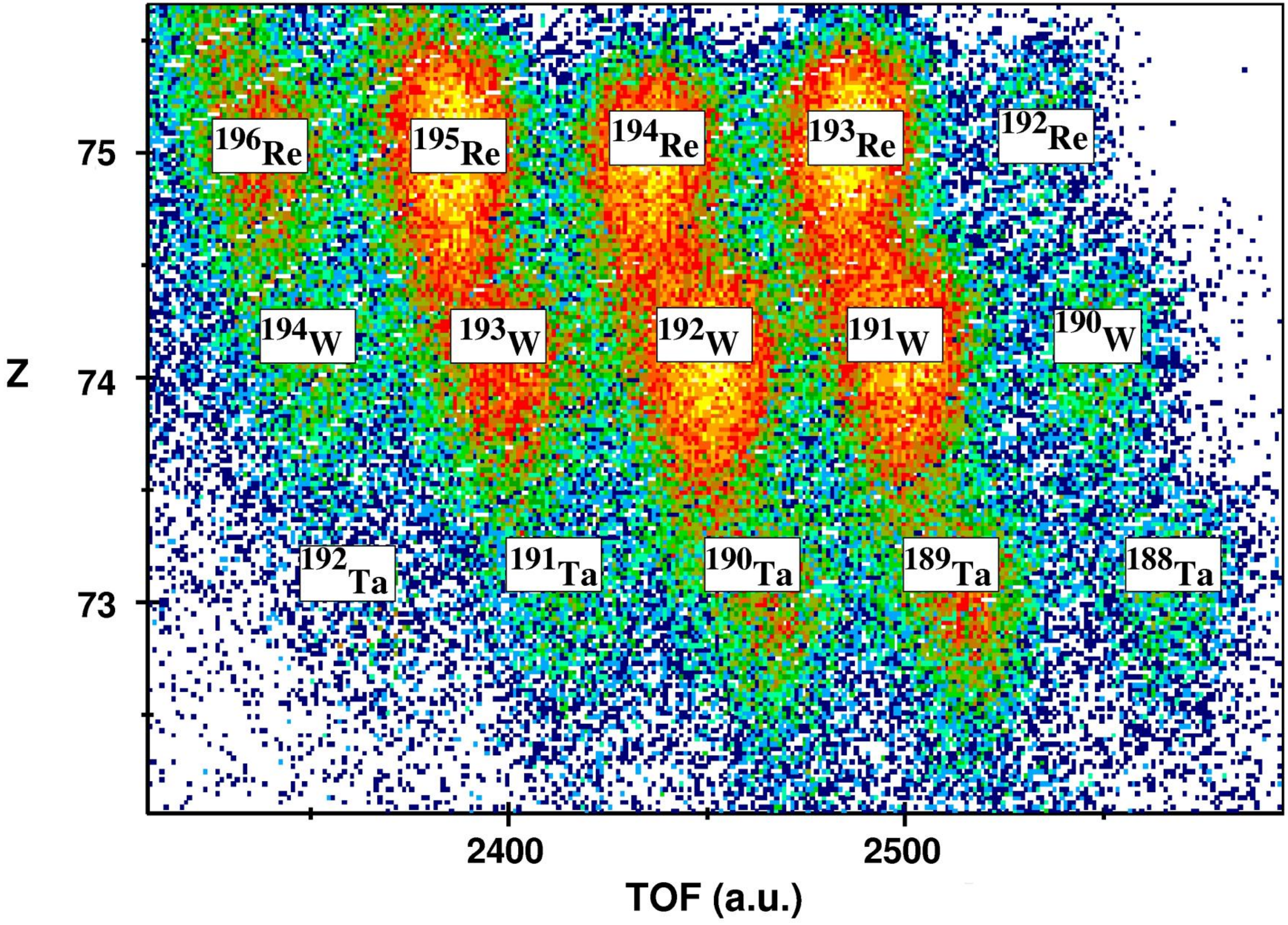
Active Stopper measurements: β *particles*, *i.c.* electrons, $T_{1/2}$ ms →mins

A~190-200 Structure Studies

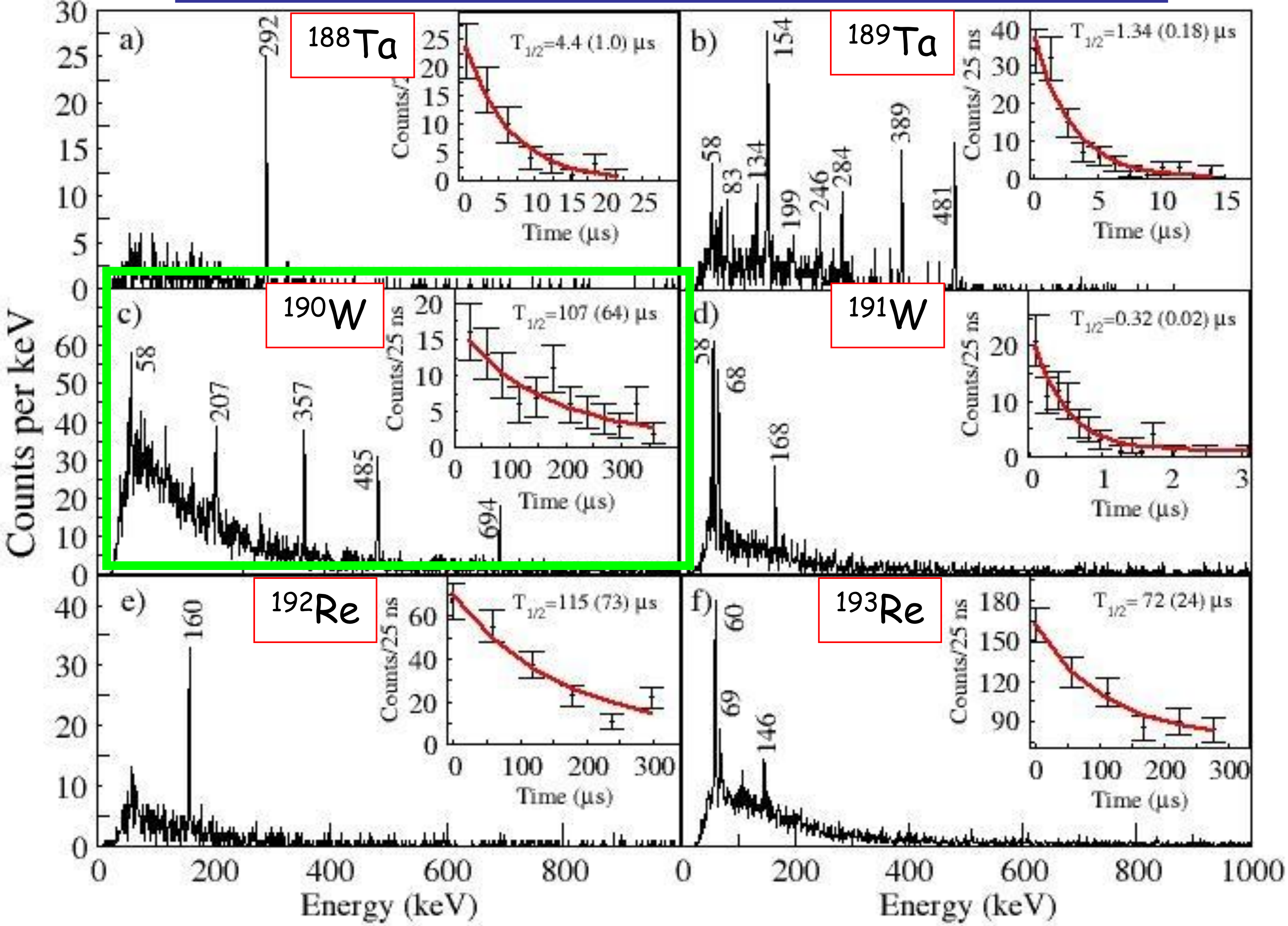


P.H. Regan & J. Benlliure et al.

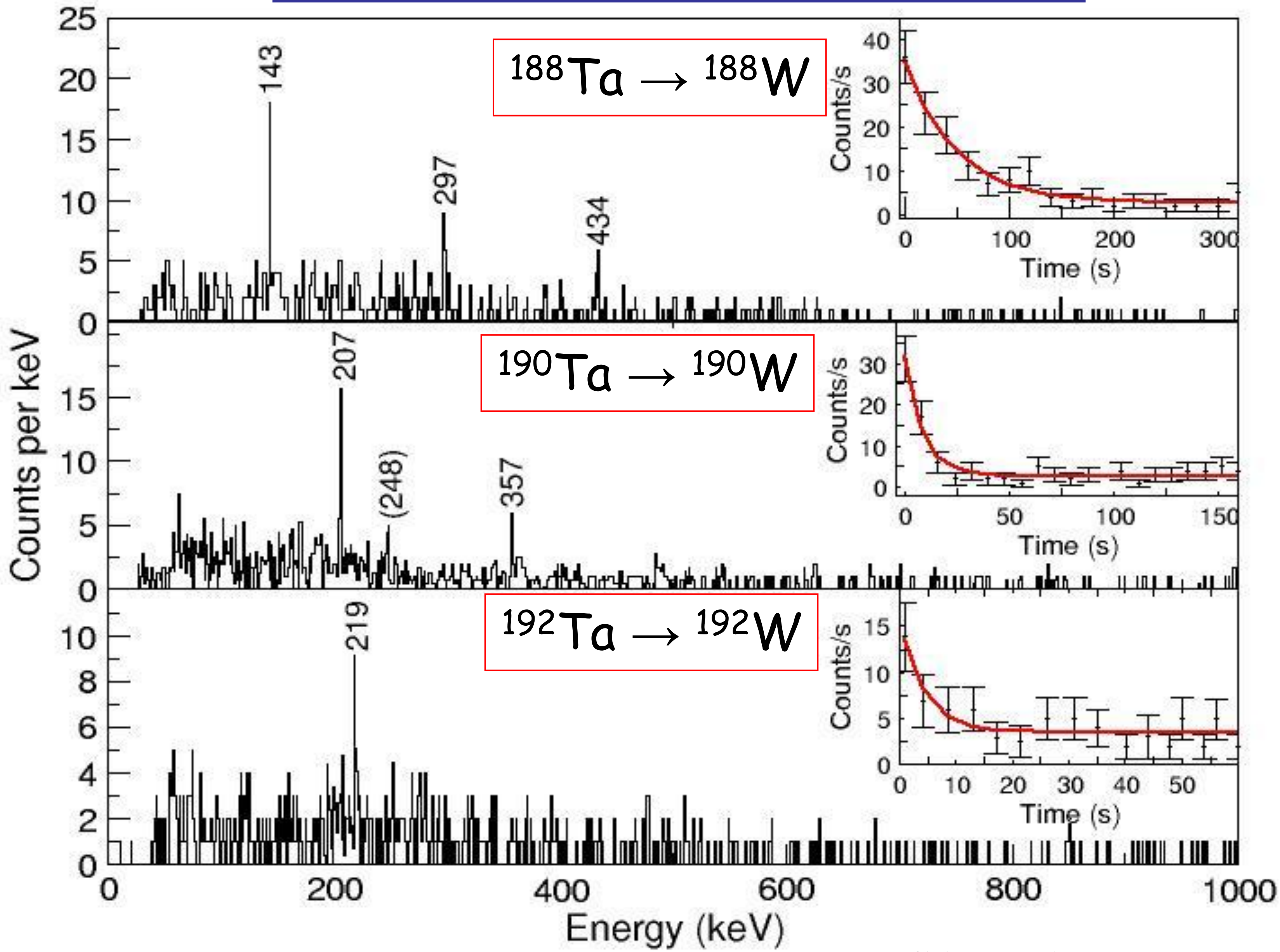
Implanted cocktail beam



Decays from known isomeric states prove correctness of particle ID

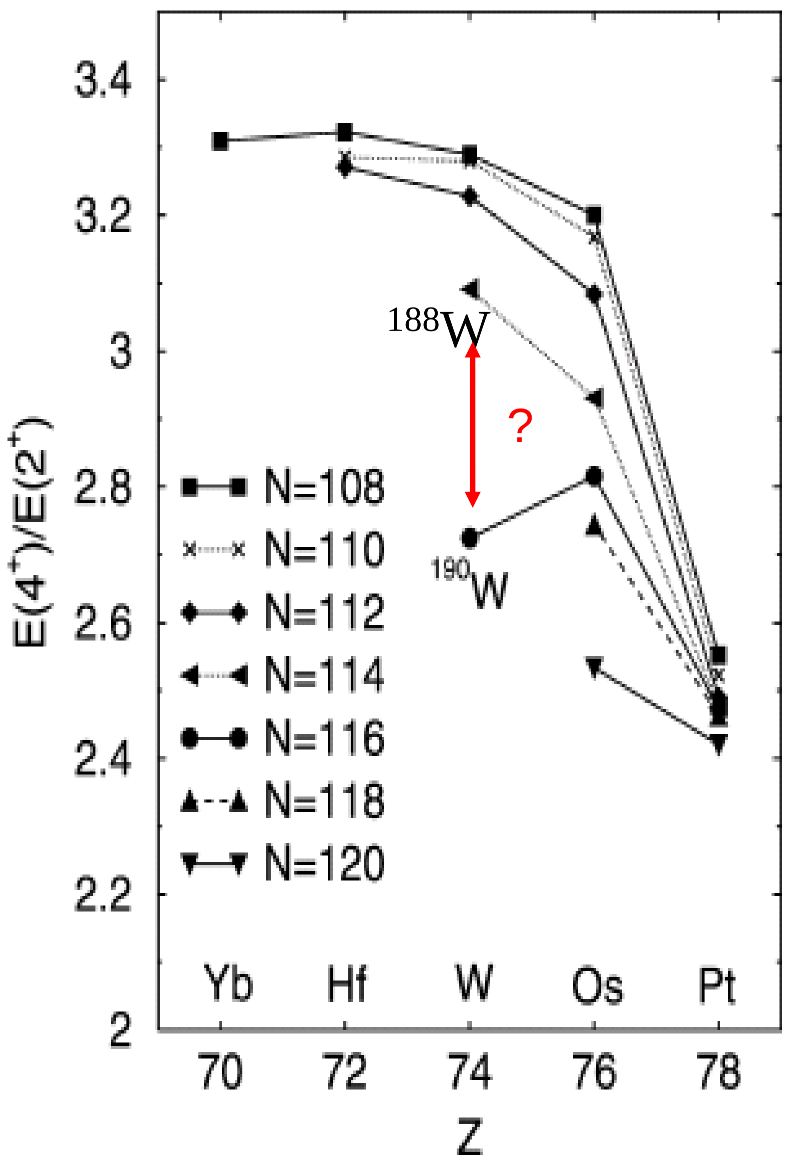


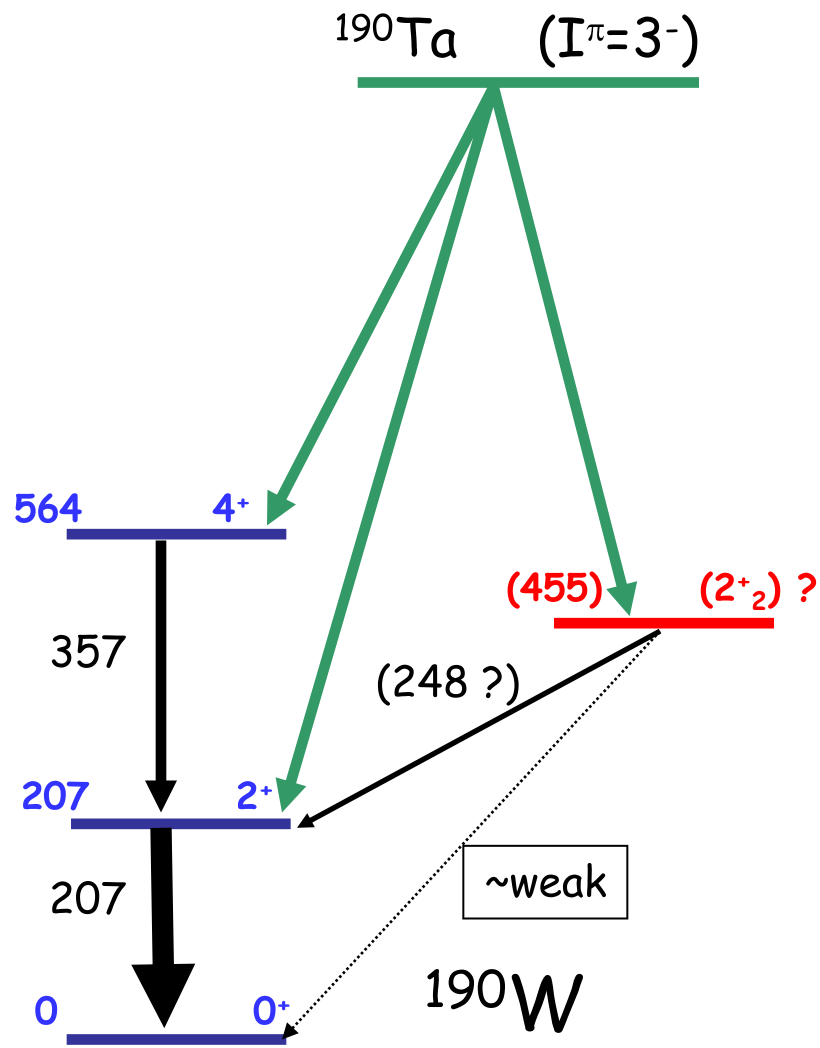
β decay into W isotopes



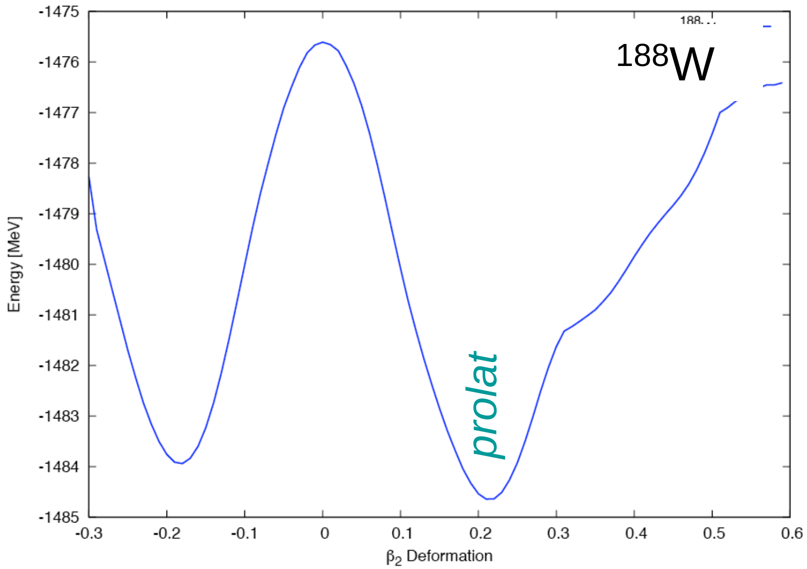
N. Alkhomashi, P.H. Regan et al.,

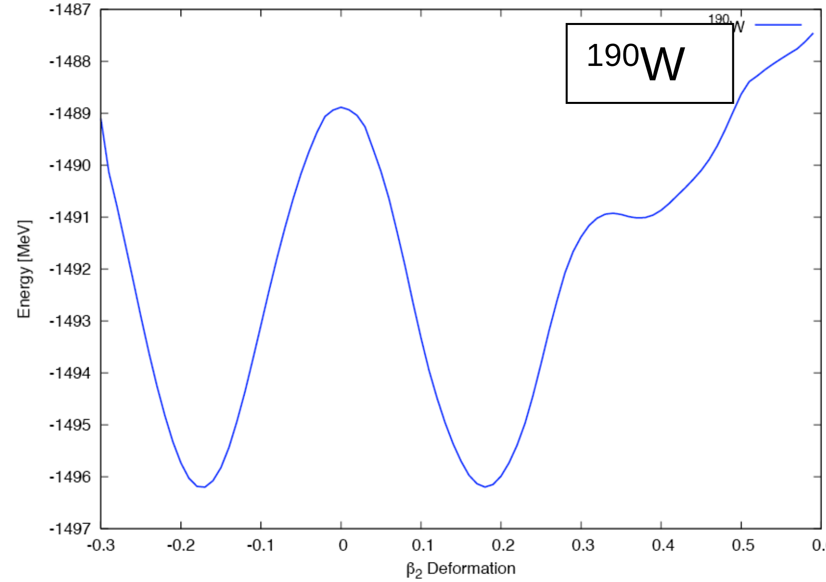
Results for ^{190}W



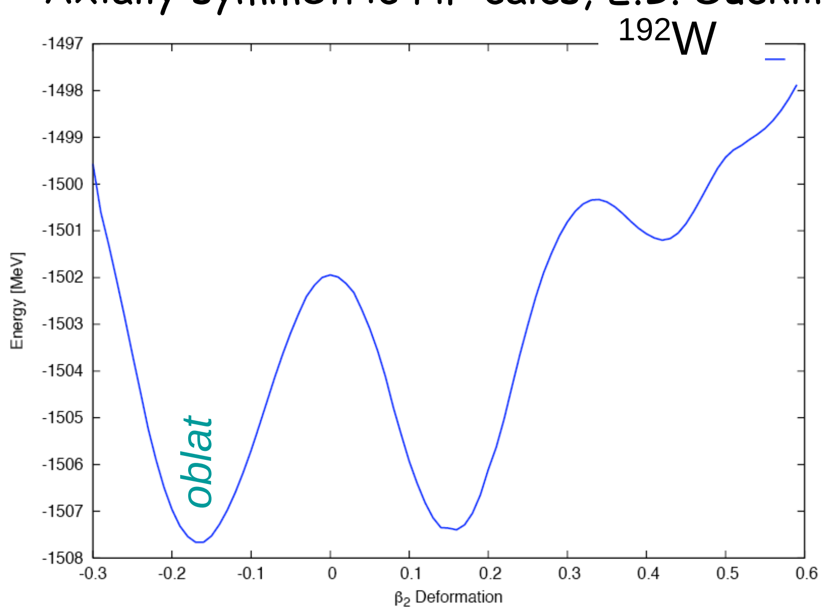


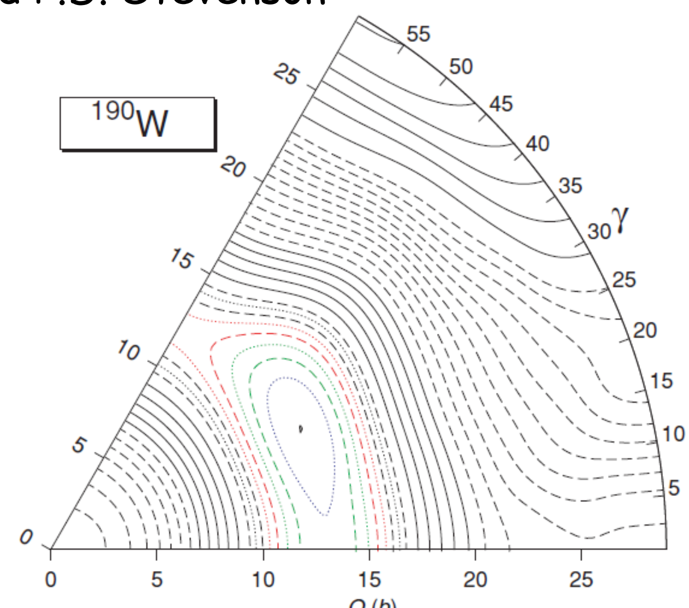
^{190}W: a nice transitional nucleus



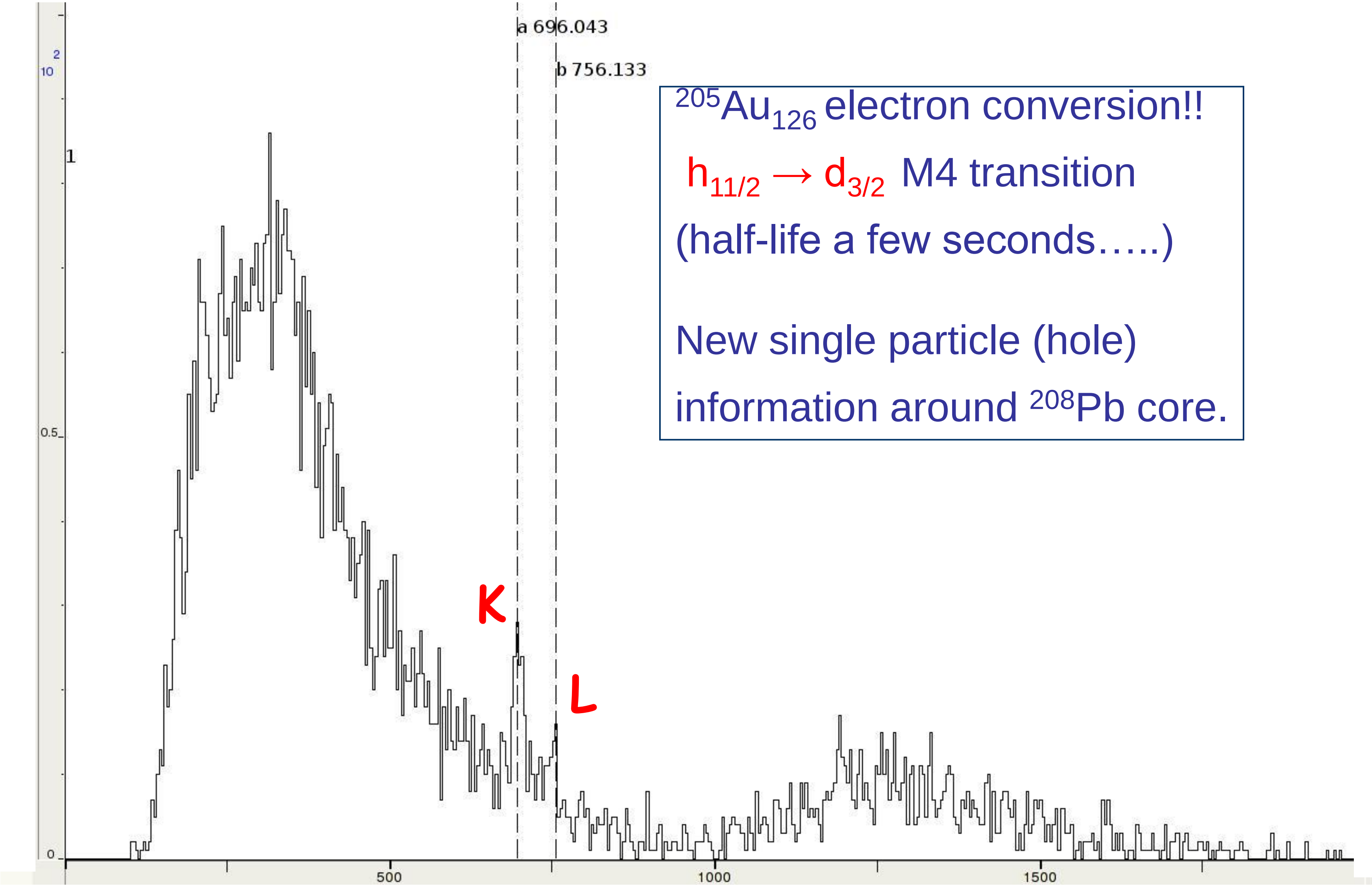


Axially symmetric HF calcs, E.B. Suckling and P.D. Stevenson





Conversion electron spectroscopy in ^{205}Au



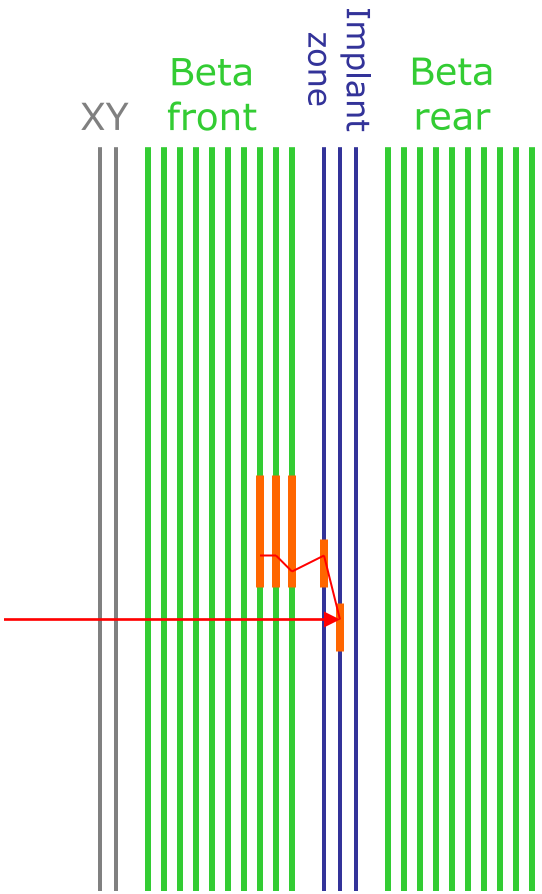
$^{205}Au_{126}$ electron conversion!!

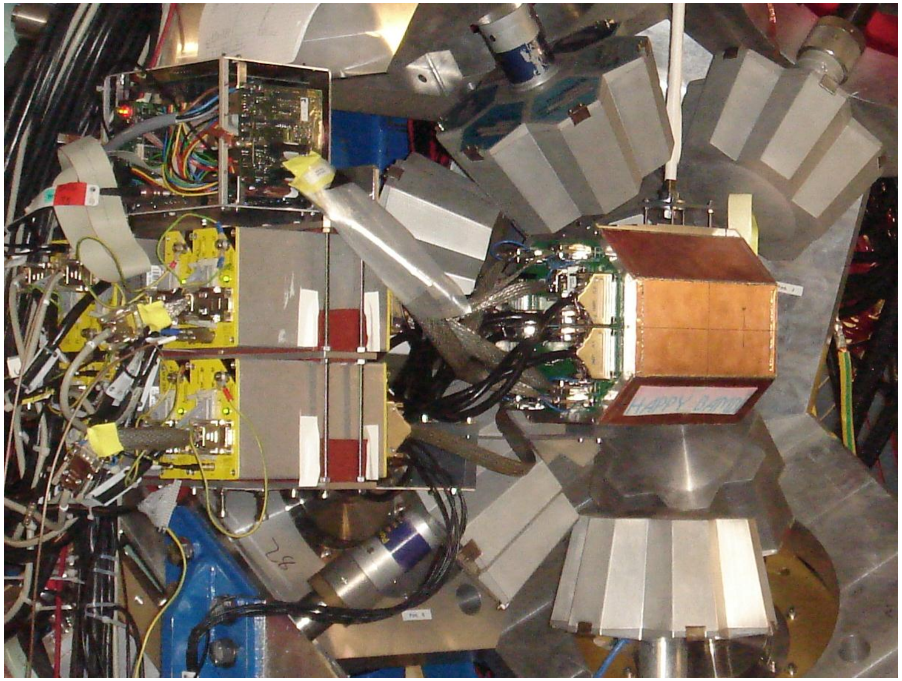
$h_{11/2} \rightarrow d_{3/2}$ M4 transition

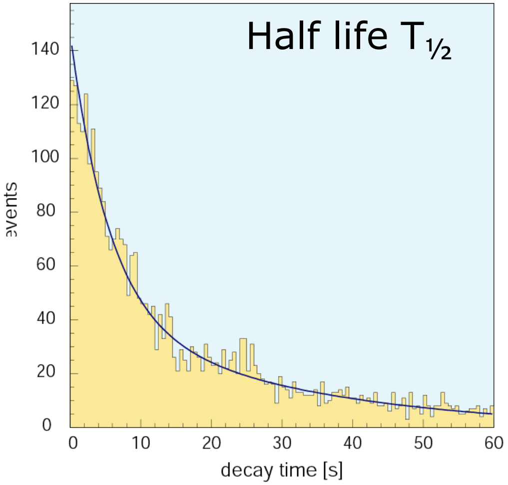
(half-life a few seconds…..)

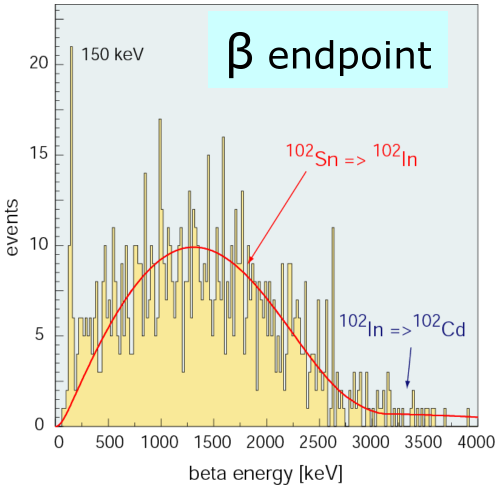
New single particle (hole) information around ^{208}Pb core.

Implantation detector SIMBA (TU München)



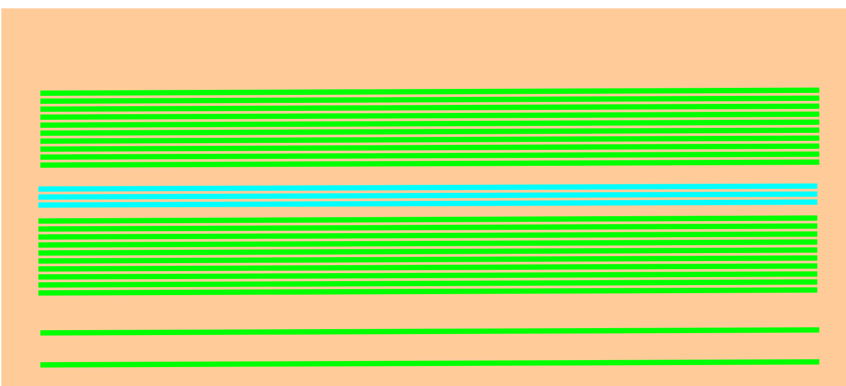


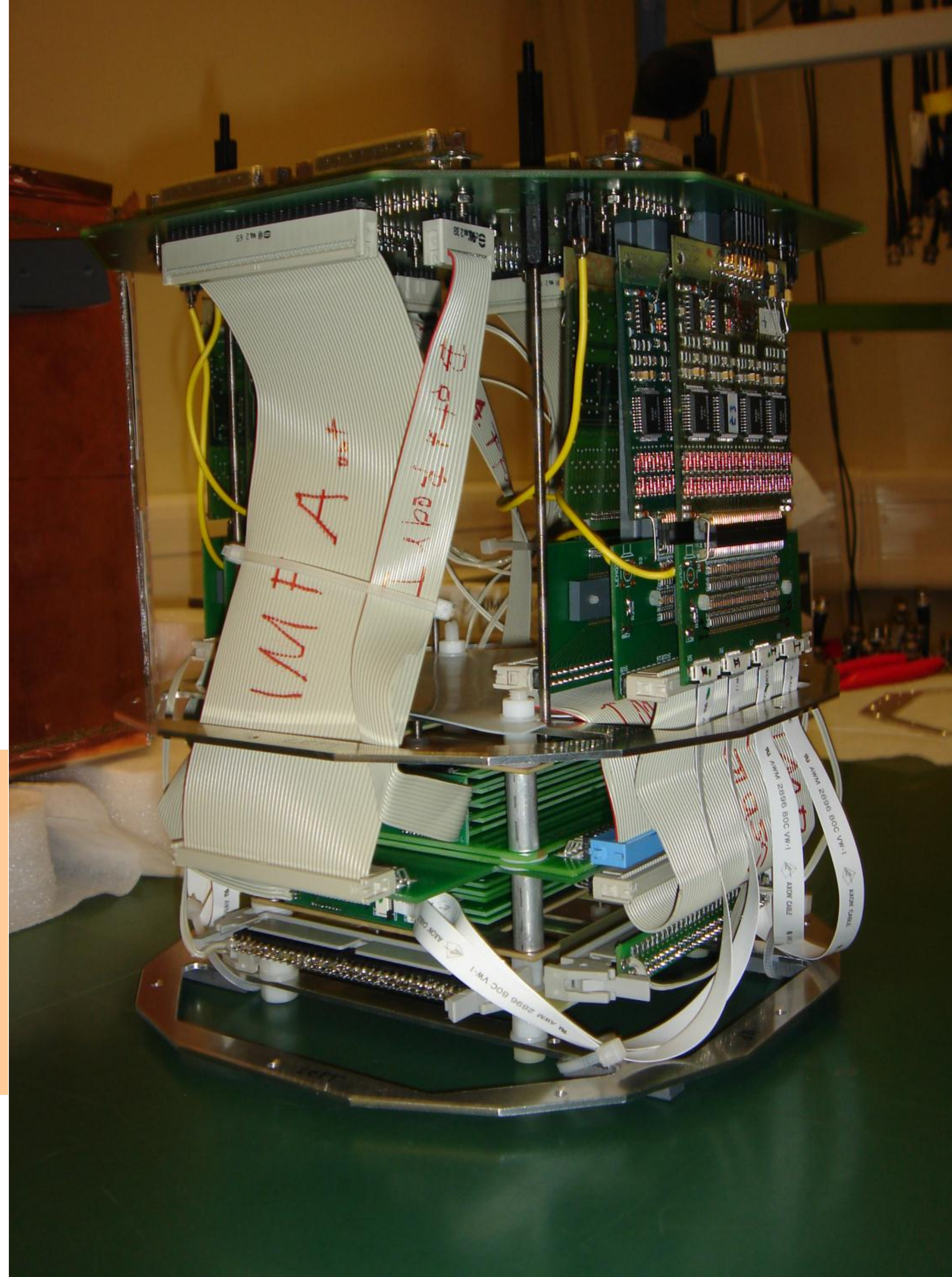




Implantation zone
3 x 60 x 40 = 7200 pixels
Calorimeter for decay particles
2 x 10 layers + x,y layer

and how it looks inside



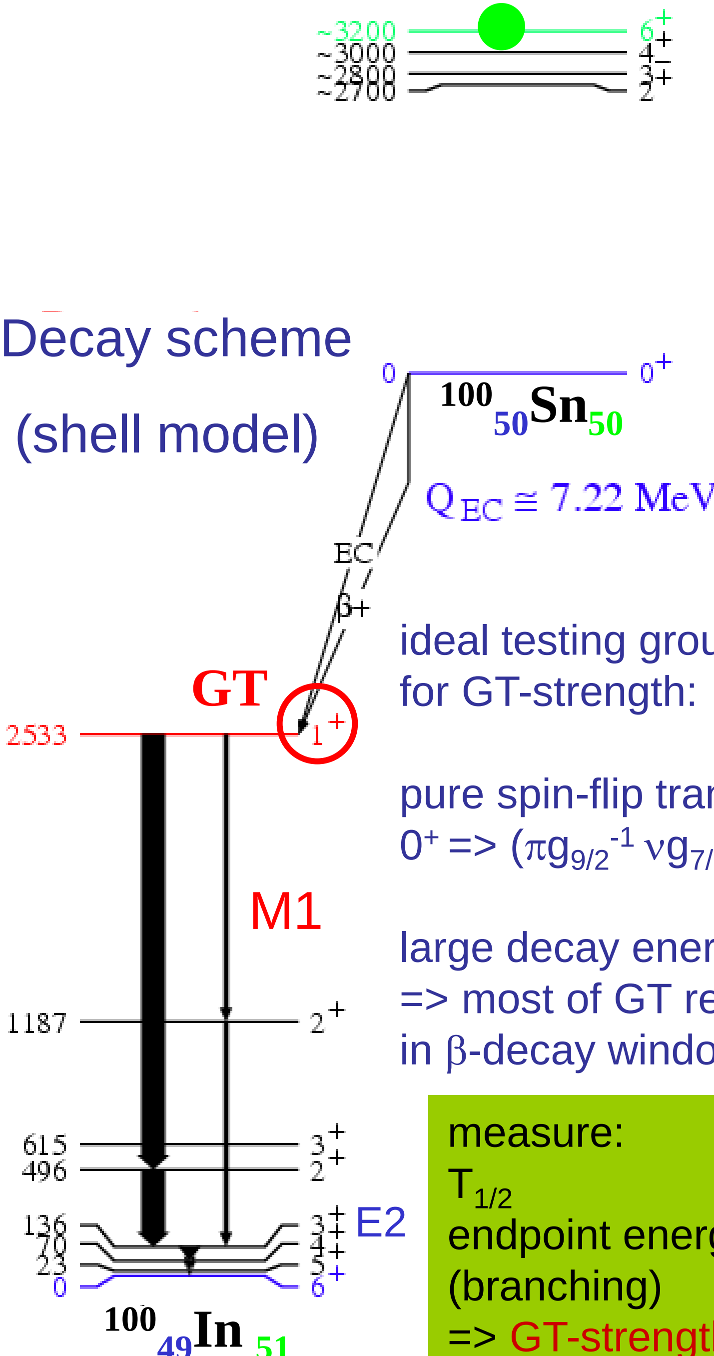


^{100}Sn

- GT strength in the decay
- rp process end point
- 6^+ spin gap isomer
- particle stability of neighbours

Decay scheme

(shell model)



ideal testing ground for GT-strength:

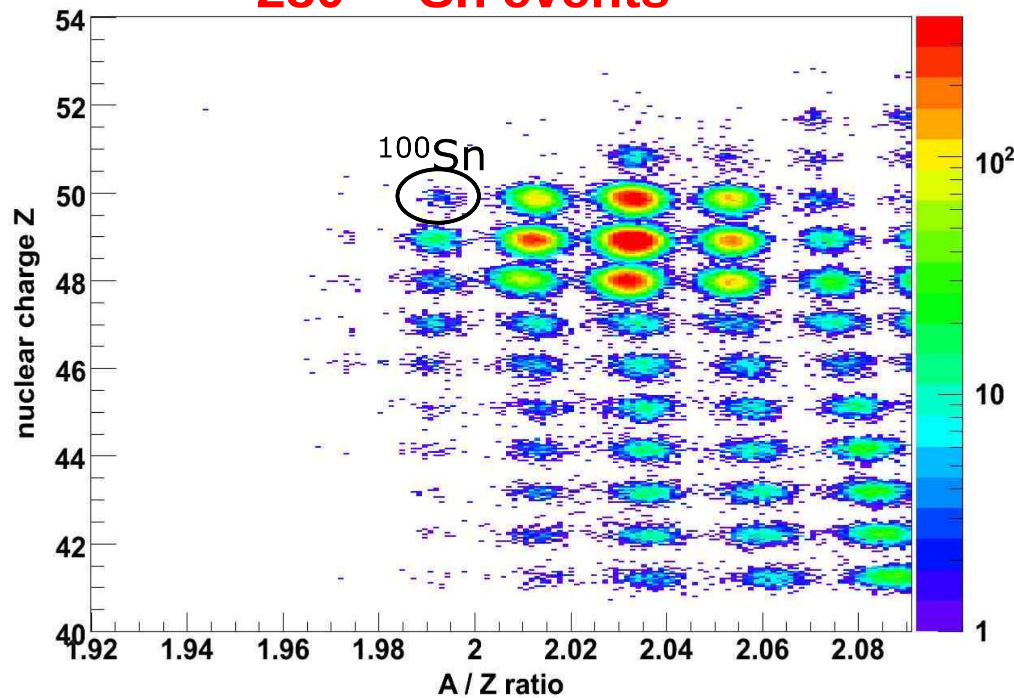
pure spin-flip transition
$0^+ \Rightarrow (\pi g_{9/2}^{-1}\ \nu g_{7/2})1^+$

large decay energy
=> most of GT resonance
in β-decay window

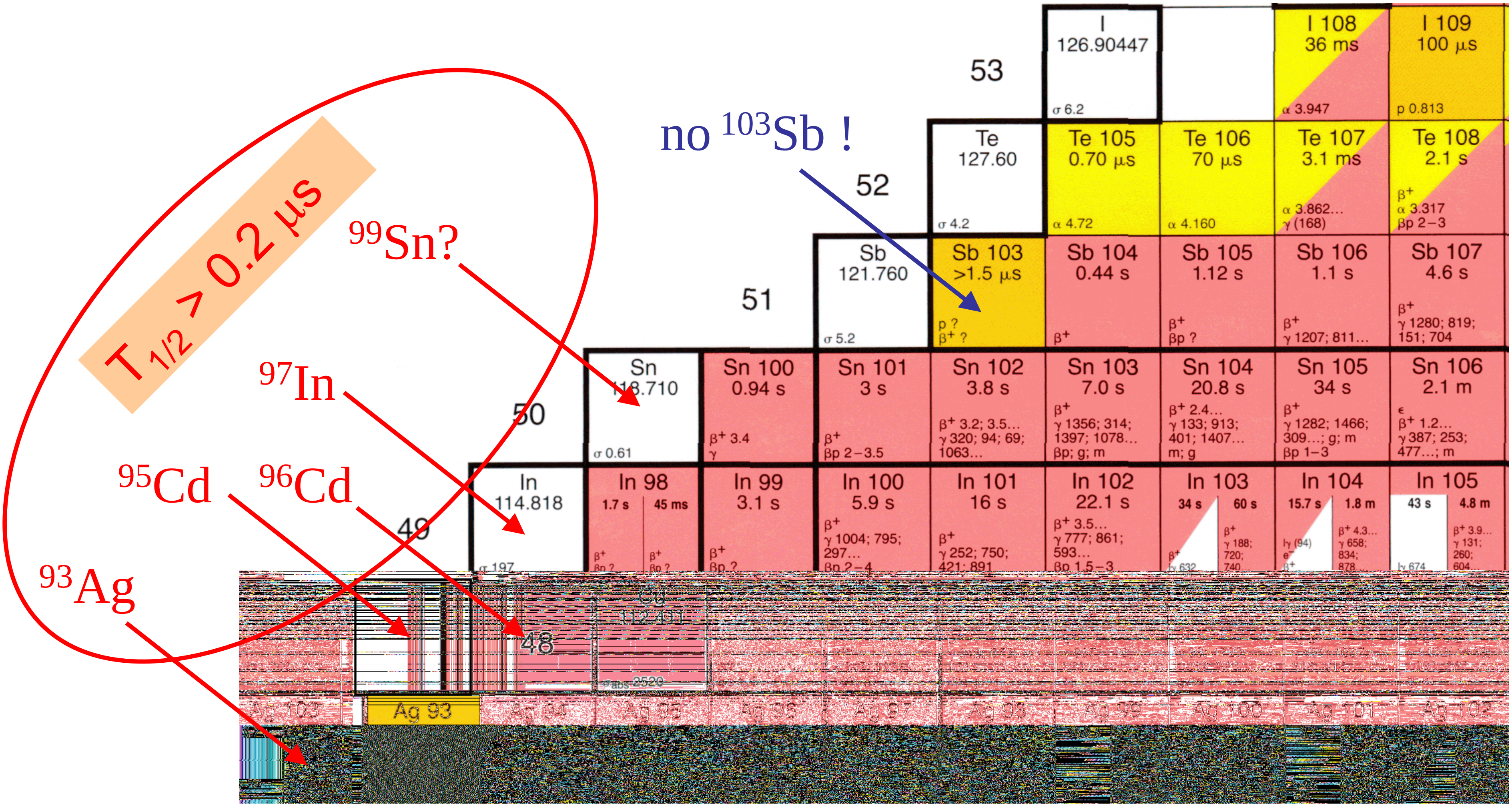
measure:
$T_{1/2}$
endpoint energy
(branching)
=> GT-strength

^{124}Xe fragmentation, 1 evt/h

≈280 ^{100}Sn events

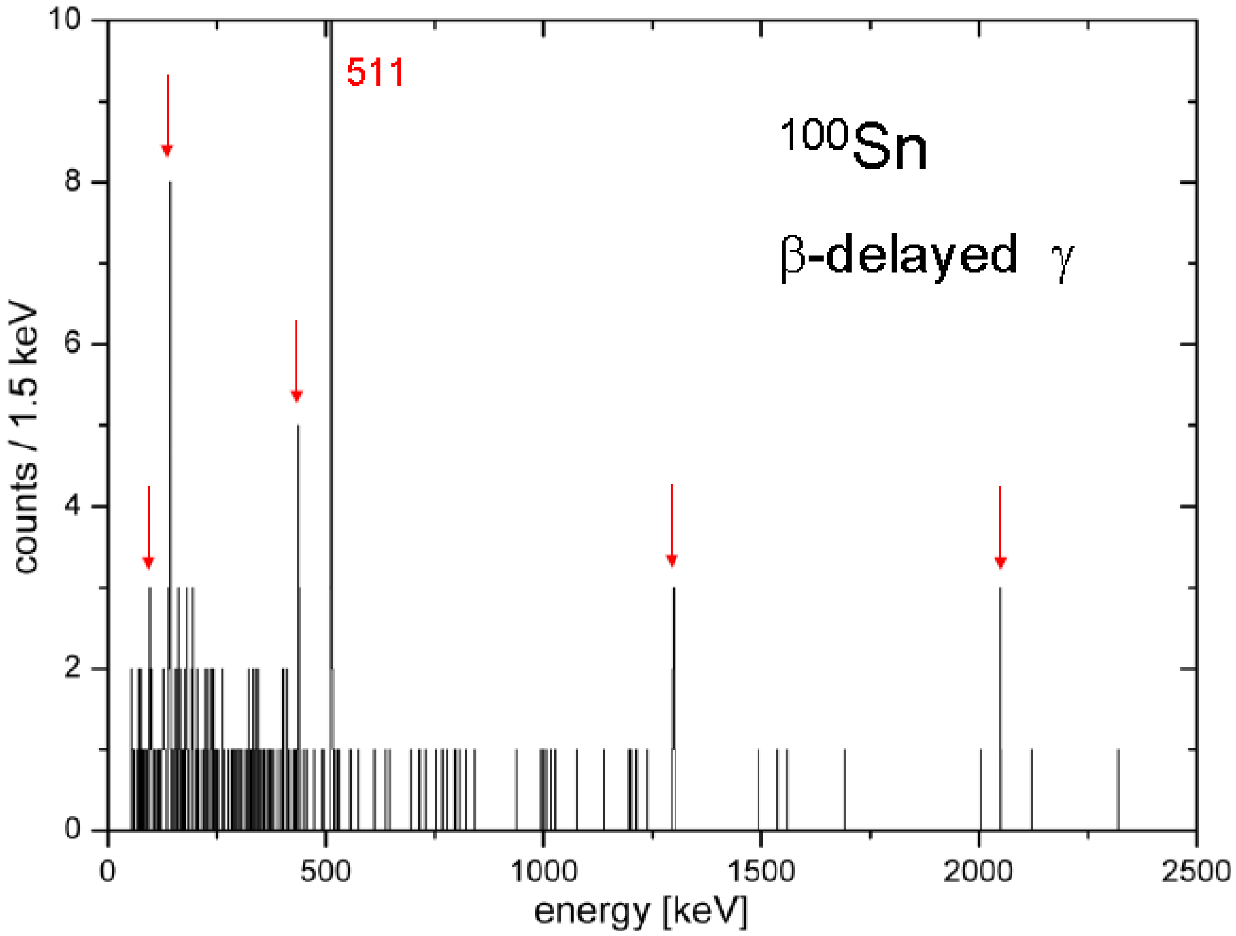


what‘s new?



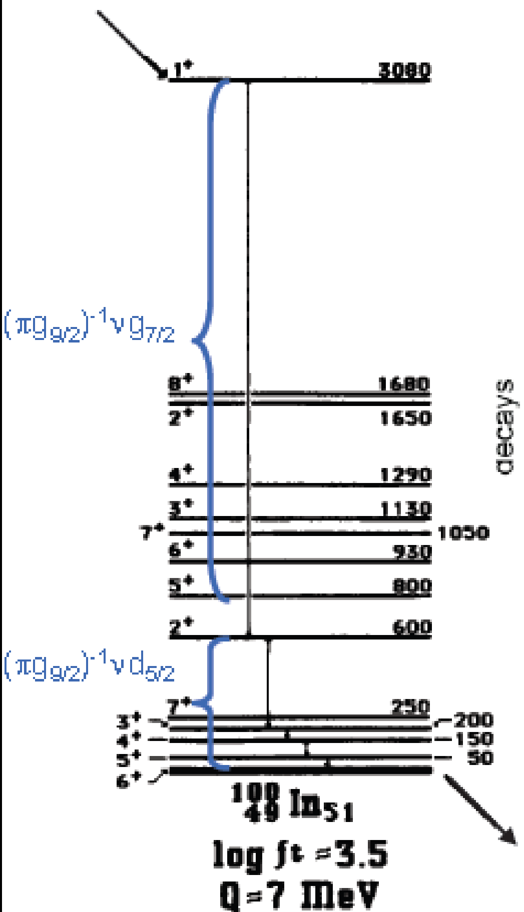
$T_{1/2}$ > 0.2 µs
^{99}Sn?
^{97}In
^{95}Cd
^{96}Cd
^{93}Ag
no ^{103}Sb !
53
52
51
50
49
48
I 126.90447
I 108 36 ms
I 109 100 µs
Te 127.60
Te 105 0.70 µs
Te 106 70 µs
Te 107 3.1 ms
Te 108 2.1 s
Sb 121.760
Sb 103 >1.5 µs
Sb 104 0.44 s
Sb 105 1.12 s
Sb 106 1.1 s
Sb 107 4.6 s
Sn 118.710
Sn 100 0.94 s
Sn 101 3 s
Sn 102 3.8 s
Sn 103 7.0 s
Sn 104 20.8 s
Sn 105 34 s
Sn 106 2.1 m
In 114.818
In 98
In 99 3.1 s
In 100 5.9 s
In 101 16 s
In 102 22.1 s
In 103
In 104
In 105
Ag 93

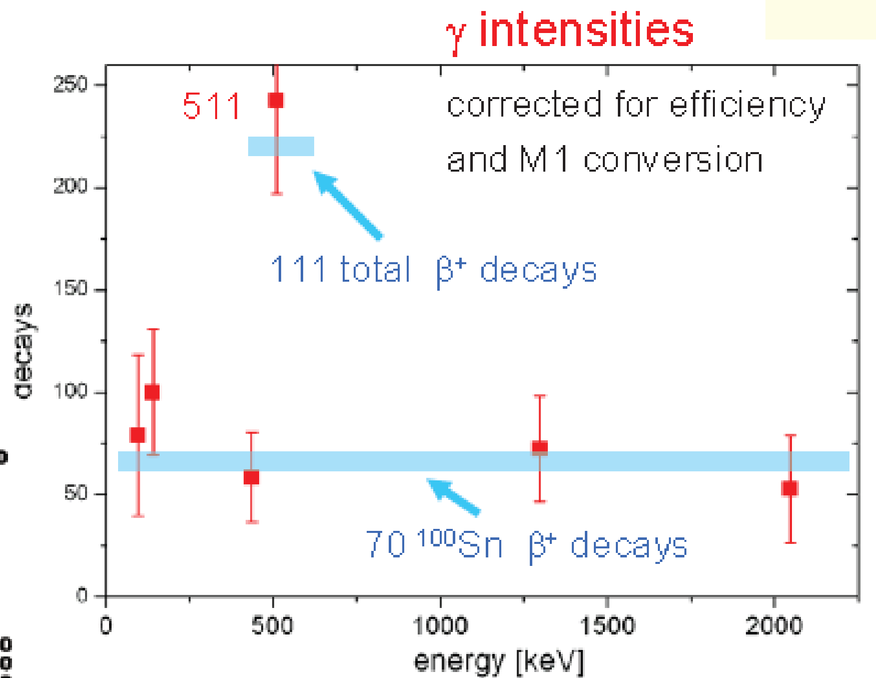
γ spectrum after β decay of ^{100}Sn

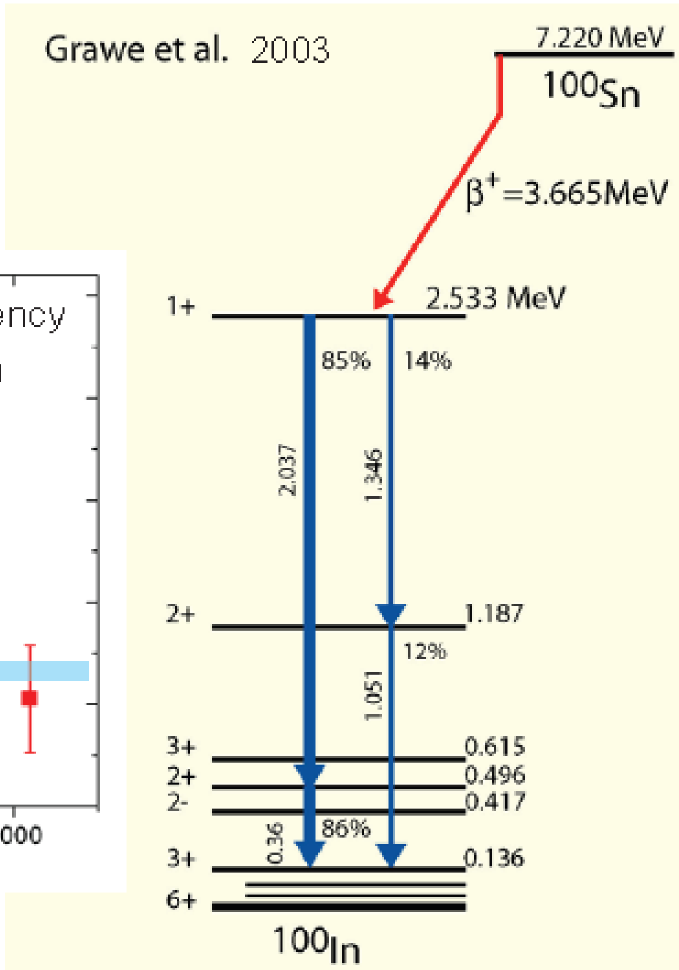


γ intensities

Stone, Walters 1985

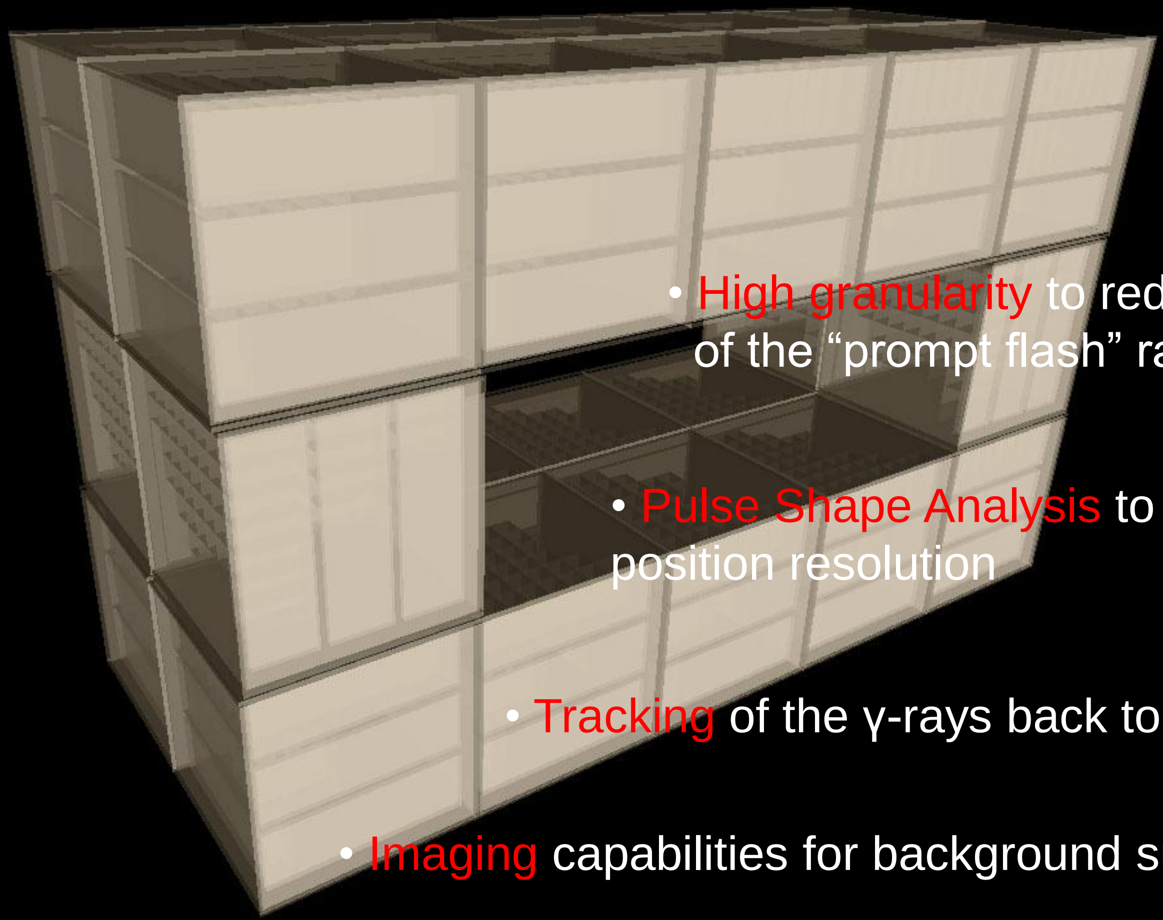






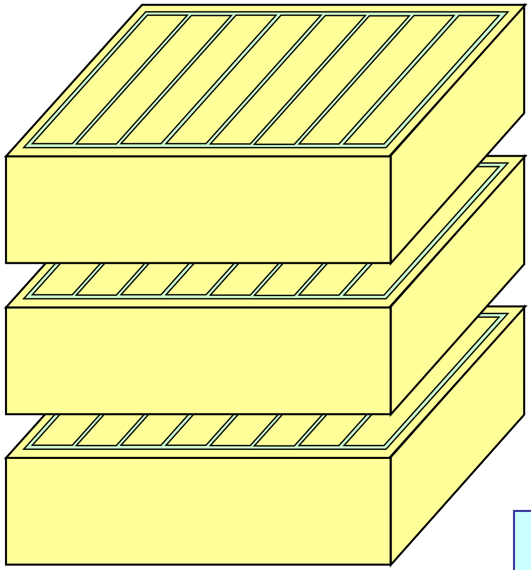
5 lines add up to
4018 keV ???

DESPEC γ-tracking/imaging array



- High granularity to reduce the effect of the “prompt flash” radiation
- Pulse Shape Analysis to improve the position resolution
- Tracking of the γ-rays back to the origin
- Imaging capabilities for background suppression
- Polarization sensitivity

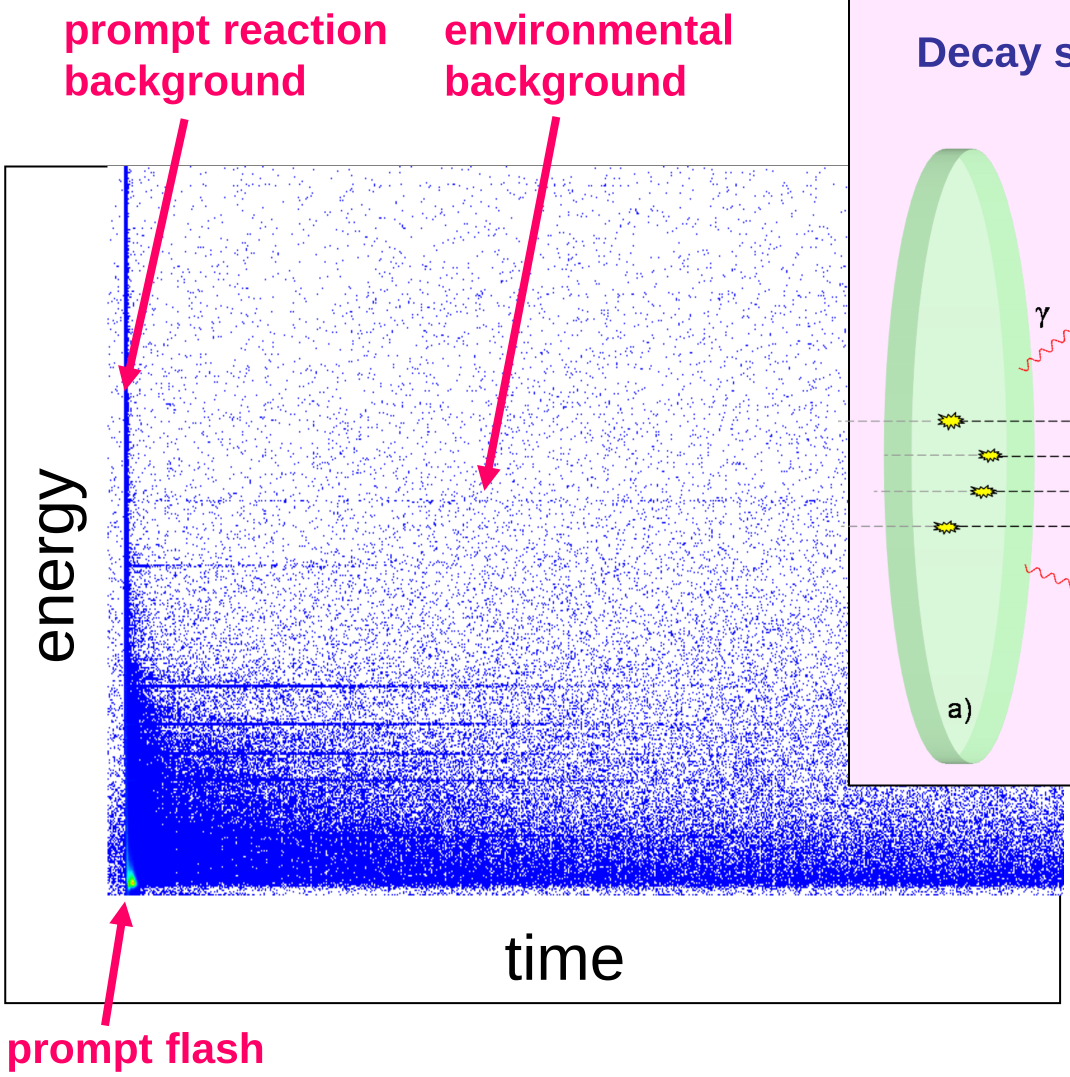
Detector Module

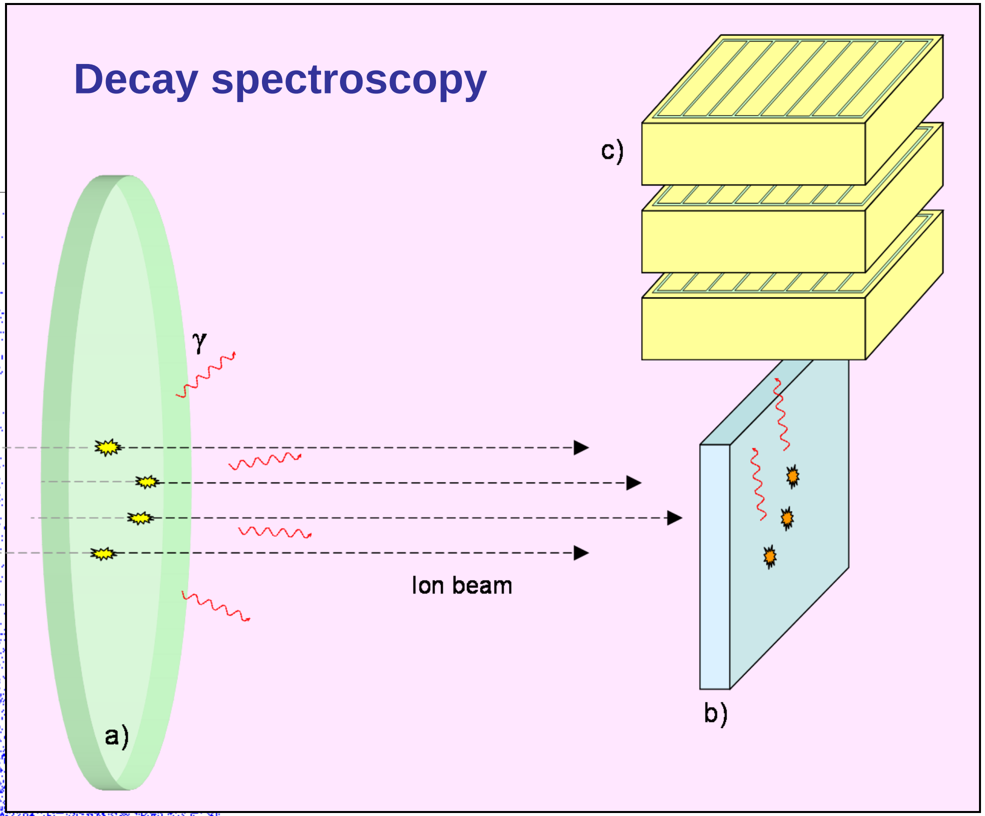


- Stack of 3 planar 2D stripe Ge detectors
- $68mm^2$ x $68mm^2$ x $20mm^2$ + 2mm guard ring
- 6mm gap between crystals
- 8x8 segmentation
- 1 – 3 mm 3D position resolution with PSA
- Energy resolution: 0.2%

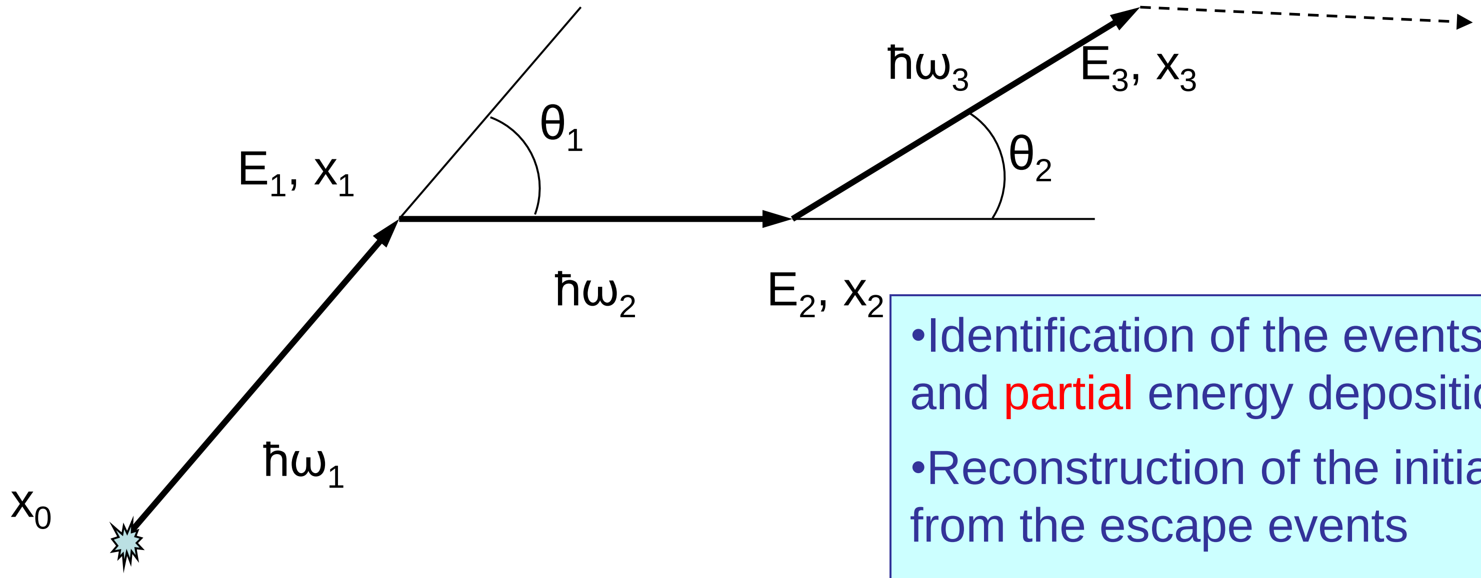
- Increase of correlation time range between implantation and decay for isomers
- Distinction of gamma events from background sources
- Suppression of Compton escape background (software anti-Compton shield)
- Increase of absolute efficiency by reconstruction of incomplete events

Motivation: background suppression





Tracking algorithms



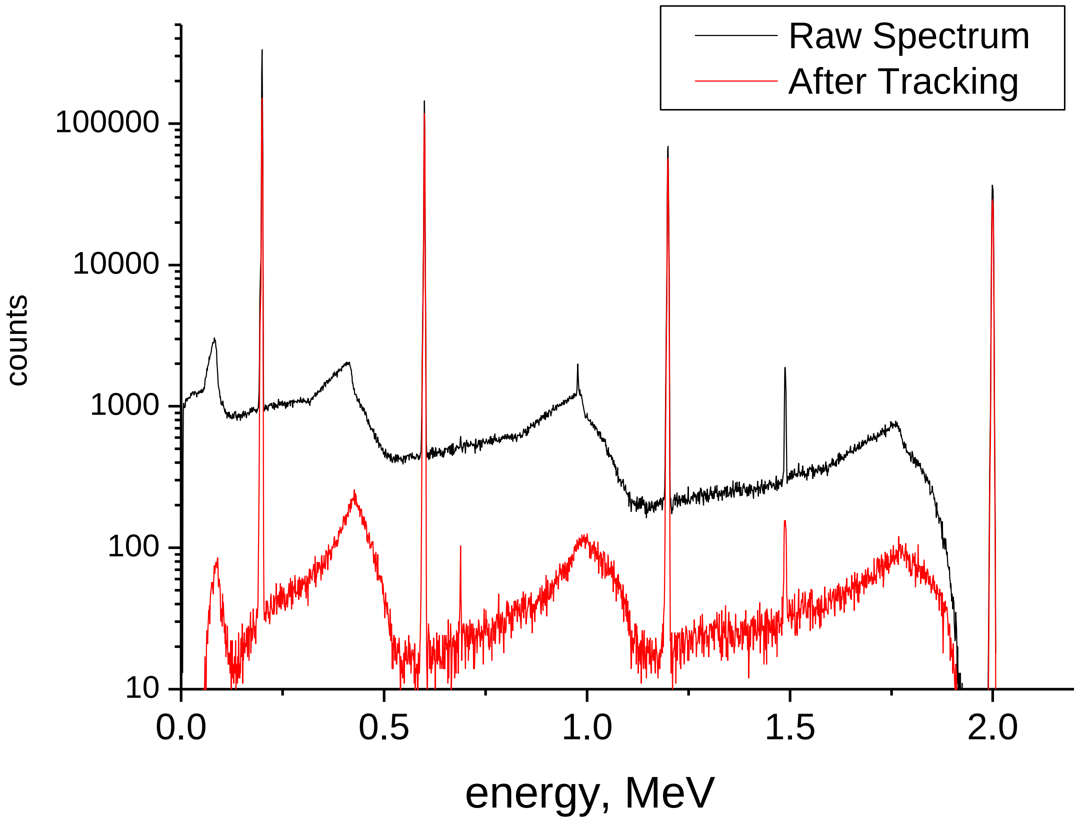
- Identification of the events with total and partial energy depositions
- Reconstruction of the initial energy from the escape events
- Rejection of the events from background sources

Construction of the “Figure of Merit”

- for each possible order of interactions
- for the case of total and partial energy deposition

Selecting the case with the maximum Figure of Merit

Results of tracking:
events, identified as total energy deposition

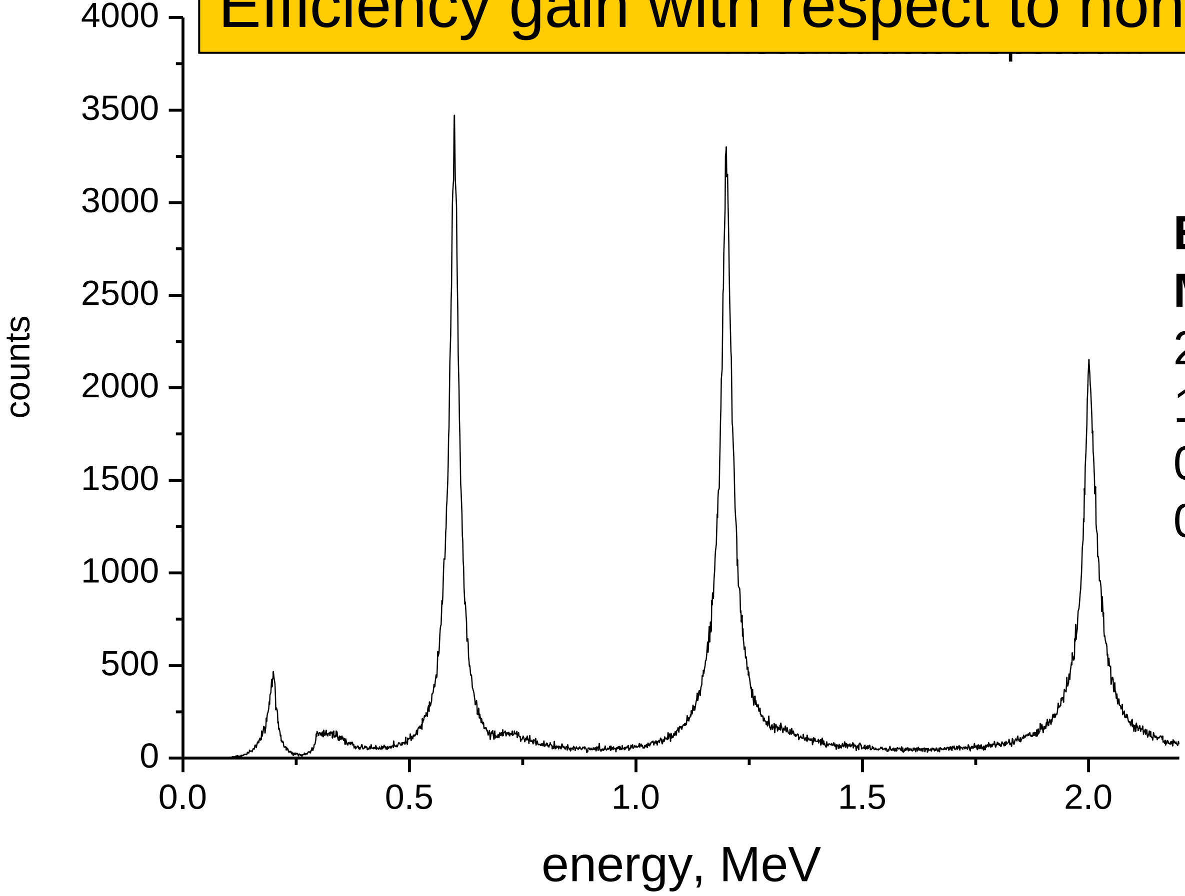


Energy MeV	Tracking Efficiency	Compton Background Suppression
2	0.79	7.5
1.2	0.81	13
0.6	0.82	13
0.2	0.51	57

GEANT4 simulation

Results of tracking:
events, identified as partial energy deposition (escapes)

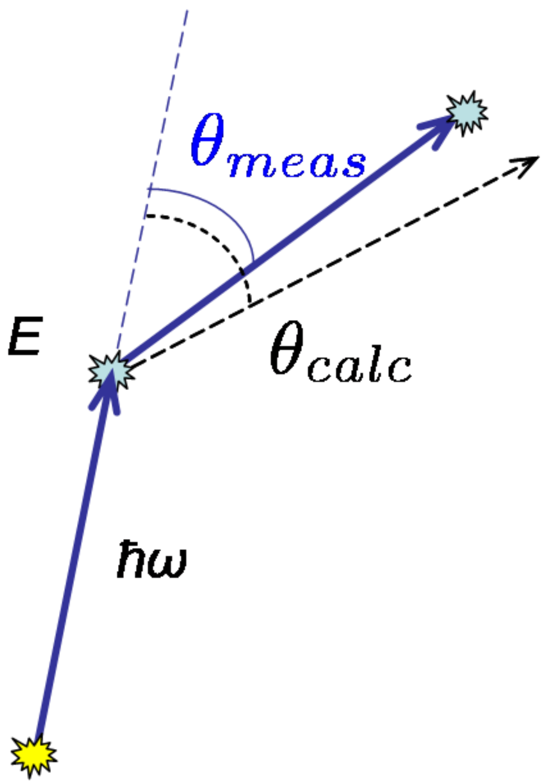
Efficiency gain with respect to non-tracking detectors

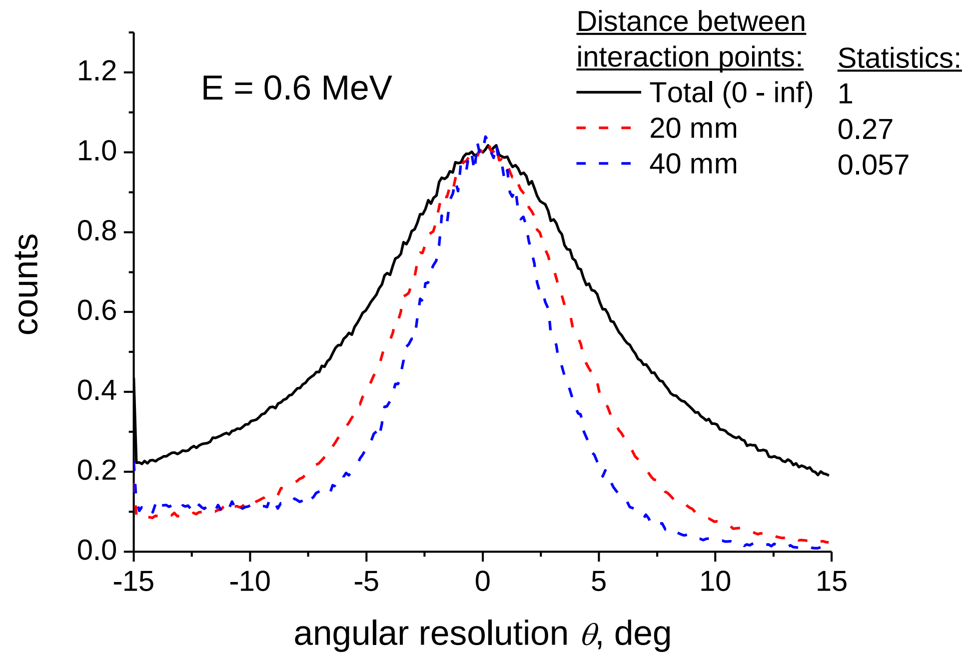


Energy MeV	Tracking Efficiency (escape)	Tracking Efficiency (total)
2	0.7	1.5
1.2	0.65	1.5
0.6	0.35	1.2
0.2	0.02	0.5

Energy Resolution:
FWHM: ~1.5%
Lorentzian Profile

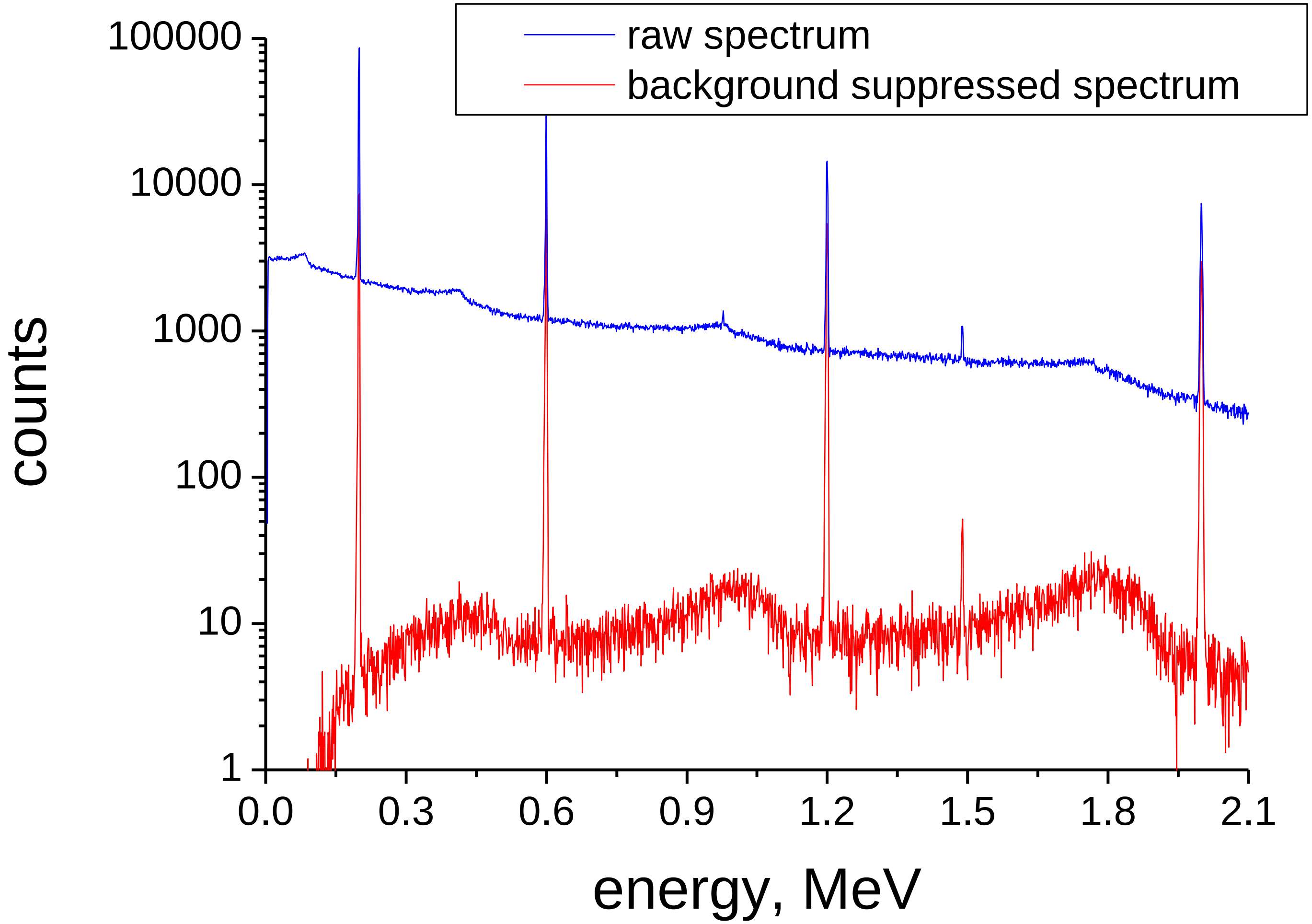
Background suppression via Imaging





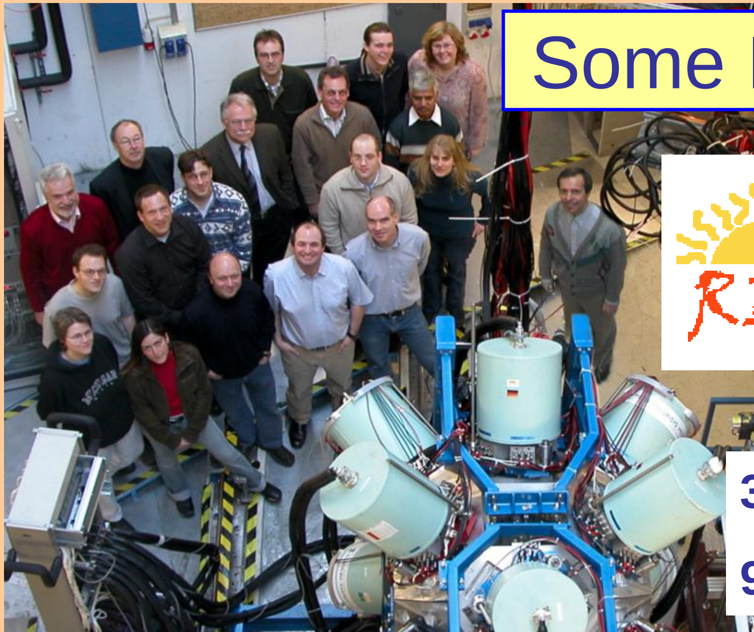
$$\Delta\theta = \theta_{meas} - \theta_{calc}$$

Environmental background suppression



"Ideal" (100% efficient) tracking was assumed for simulations

Some RISING collaborators



RISING

39 groups

9 countries

... has been a great time!!!

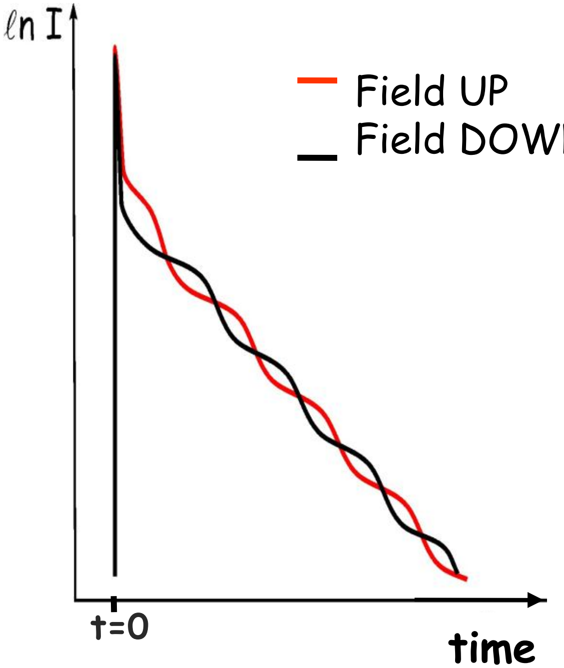
g-factor measurements at RISING

(a) g-factors → reveal information about the nuclear single particle structure:
wave function, spin, magnetic dipole operator, …
→ unique probe to study changes in nuclear shell structure far from stability
→ second step: quadrupole moments (deformation)

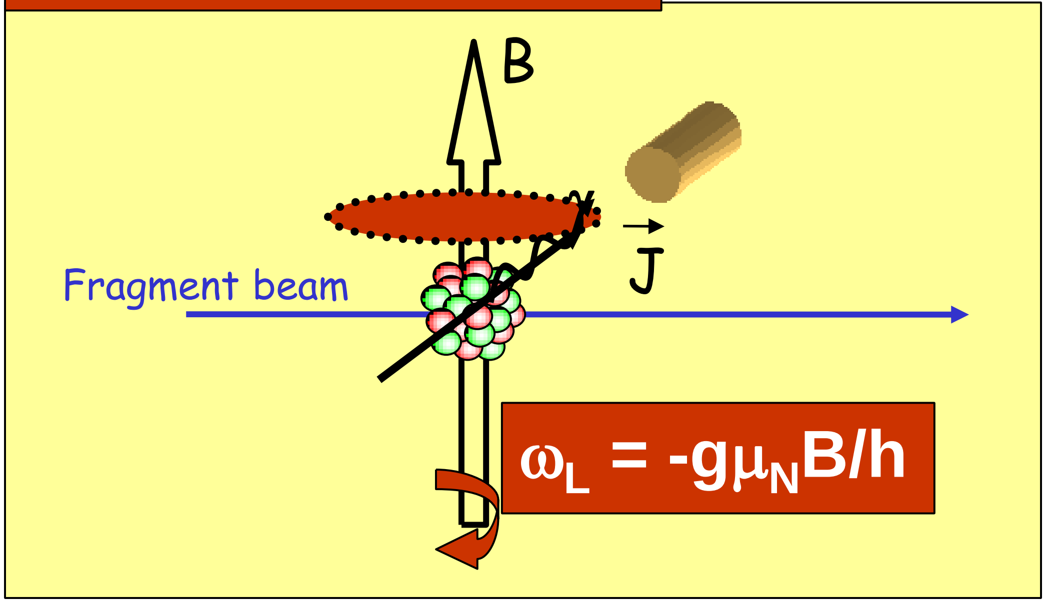
(b) spin-alignment in relativistic fission
→ never experimentally proven !
→ exotic neutron rich nuclei become accessible for moments studies

WHY AT THE FRS ?
= unique facility to study *g*-factors and quadrupole moments of spin-aligned isomeric beams not accessible at other places:
- lifetime range 100 ns – 100 μs (not at ISOL facilities)
- in neutron rich nuclei with mass A>70
(not with intermediate energy fragmentation)
(not with fusion-evaporation)

Time Differential Perturbed Angular Distribution



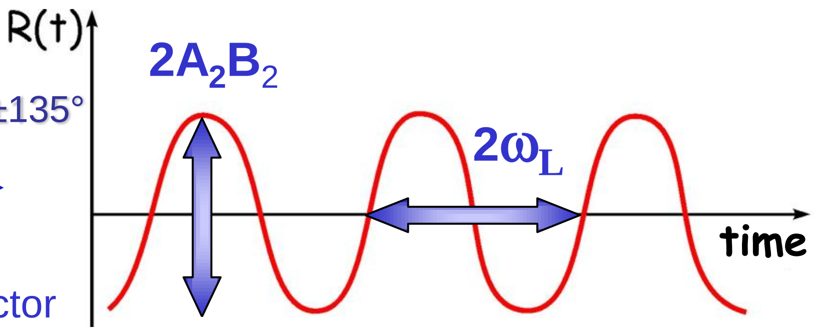
Measure Larmor precesion and decay I(θ,t)



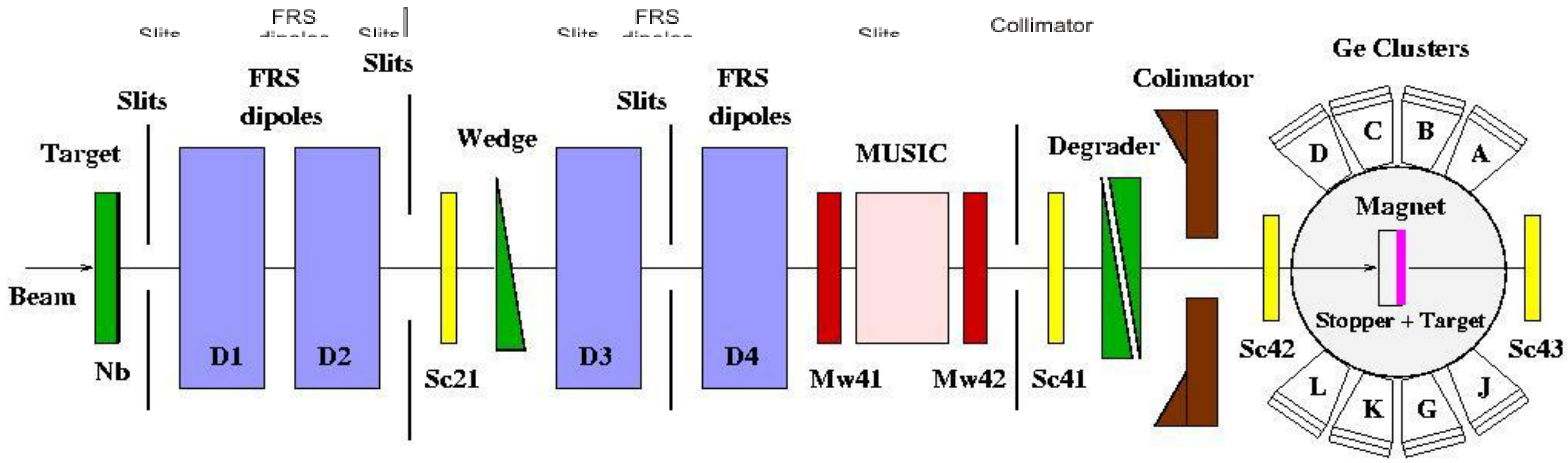
$$R(t) = \frac{I_1 - \varepsilon I_2}{I_1 + \varepsilon I_2}$$

detectors at ±45° and ±135°

the relative phases depend on the g-factor



THE EXPERIMENTAL SET-UP AT GSI: g-RISING

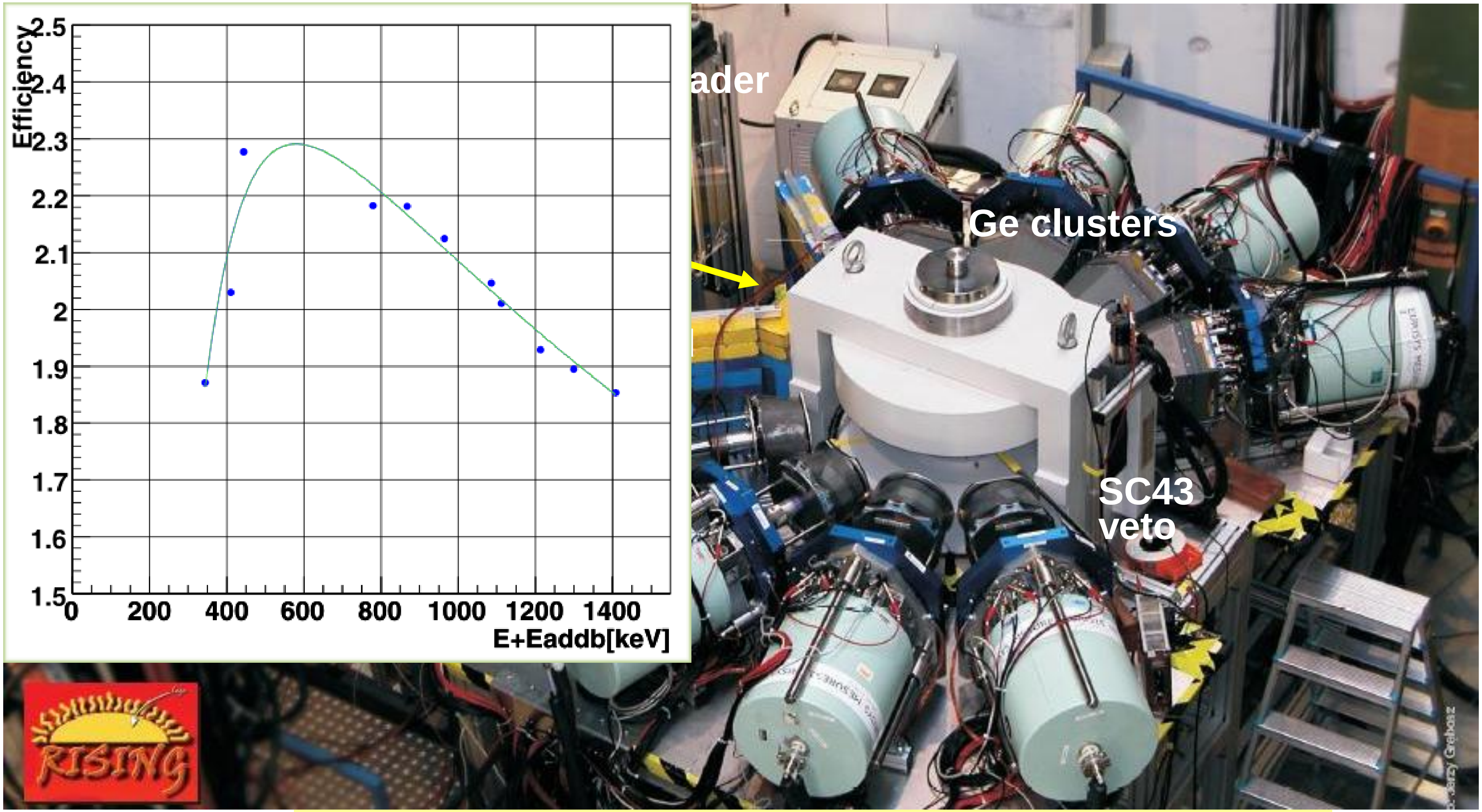


Spin-aligned secondary beam selected
(S2 slits + position selection in **SC21**)

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

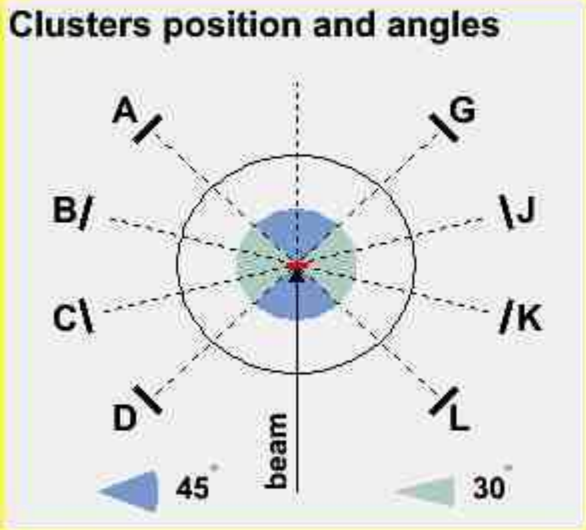
Implantation: plexiglass degrader + 2 mm Cu (annealed)

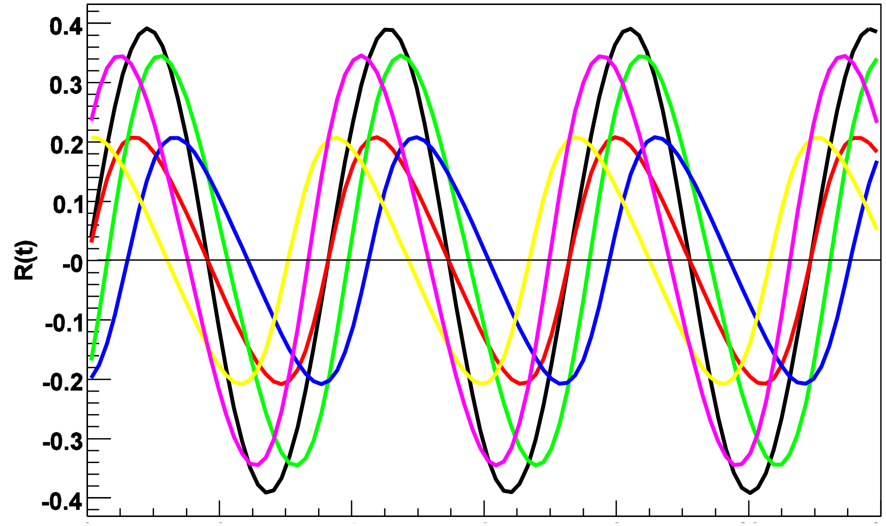
SC42 and SC43 validates the event



4 clusters with BGO anticompton shields and short collimators
4 clusters with the former RISING shields
Total efficiency (Eu source) = 1.9 – 2.3 % (from Liliya Atanosova, Sofia)

RISING collaborators are committed and highly motivated ....



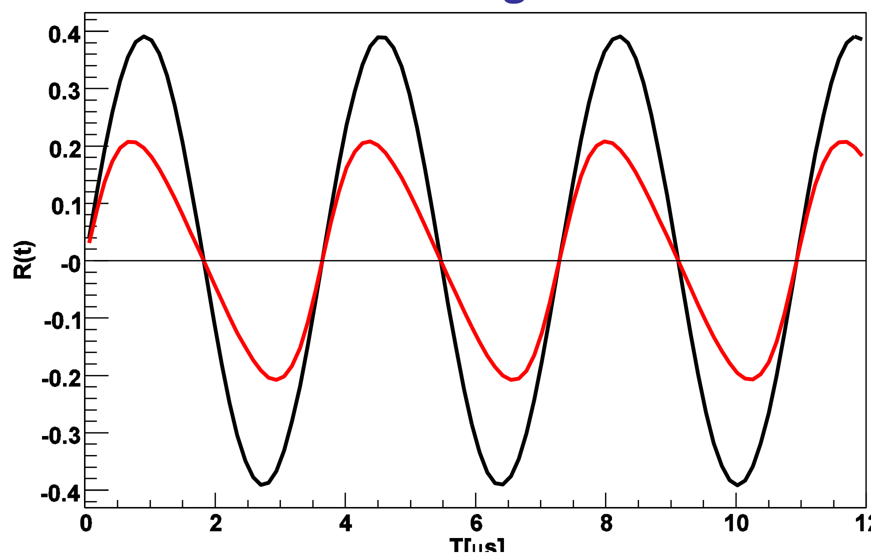


***g* = 0.16**

$$R(t) = \frac{I_1 - \varepsilon I_2}{I_1 + \varepsilon I_2}$$

I_1 = (A+L)↑ + (D+G)↓

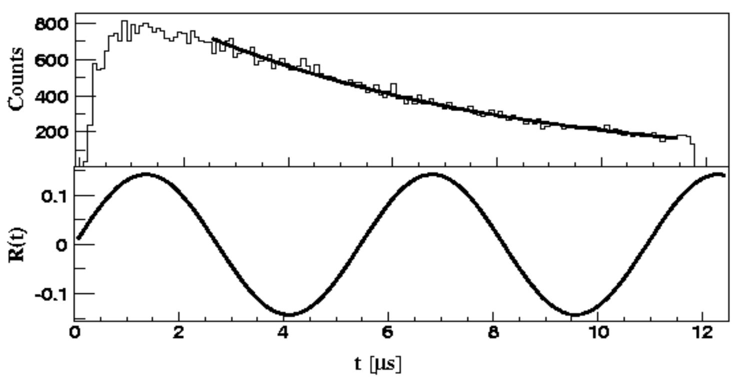
I_2 = (A+L)↓ + (D+G)↑



Choice of the magnetic field

B = 0.12 T

***g* = - 0.1**



$$R(t, \pm B) = \frac{3A}{4+A}\sin(2\omega_L t)$$

Structure of 127Sn investigated