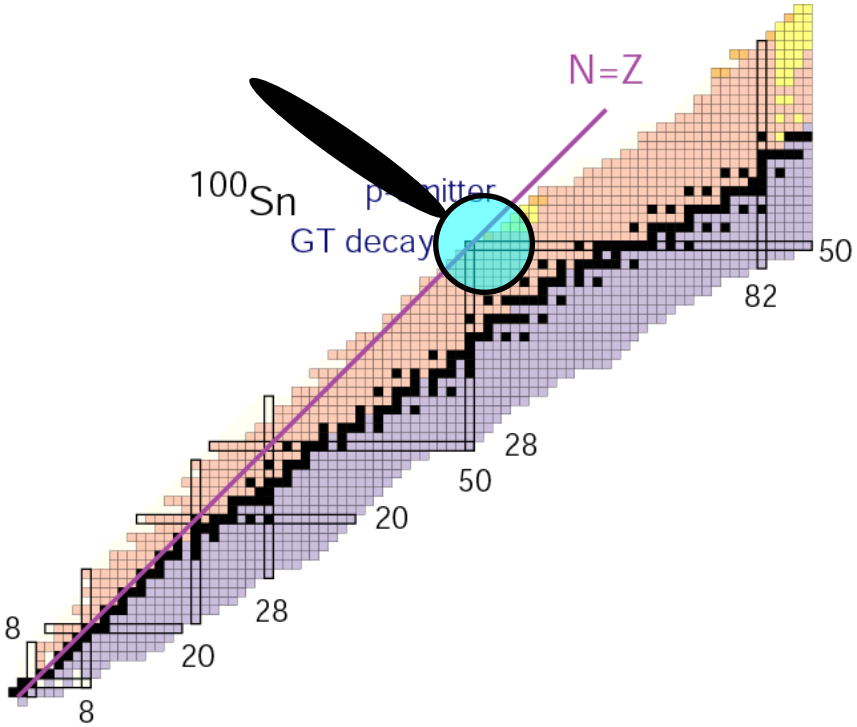
Spectroscopy of the doubly magic nucleus ^{100}Sn and its neighbourhood with RISING

Lehrstuhl E12



RISING

LMU Excellence Cluster Universe

GSI

C. Hinke, EURICA Workshop, RIKEN, 23-24 May 2011

Outline

- Physical Motivation
- Experimental Setup
- Selected Results

Physical Motivation

^{100}Sn β-Decay – GT Strength

→ ^{100}Sn is an ideal testing ground to investigate the GT-strength:

Pure GT Spin-Flip Transition:

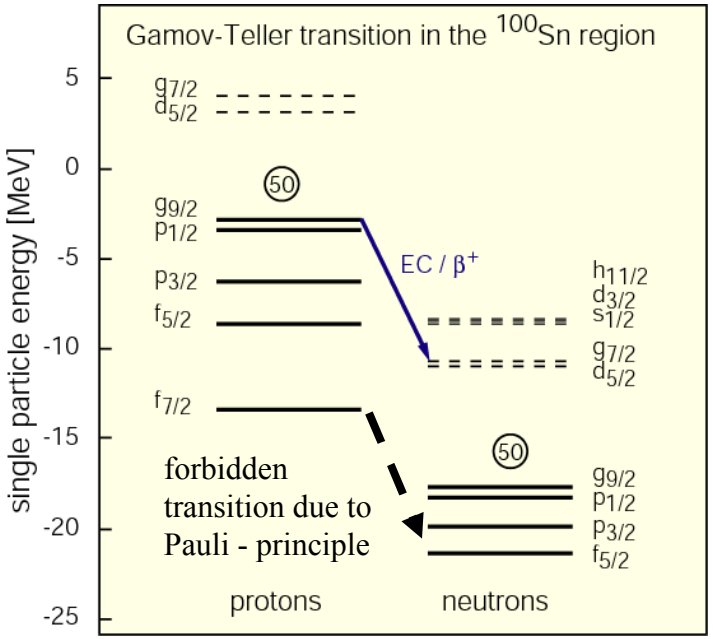
$$0^+ \Rightarrow (\pi\, g_{9/2}^{-1}\ \nu\, g_{7/2})\ 1^+$$

→ Almost the whole strength of the GT resonance is covered by the energy window of the β-decay

Calculation of the distribution of the GT strength:

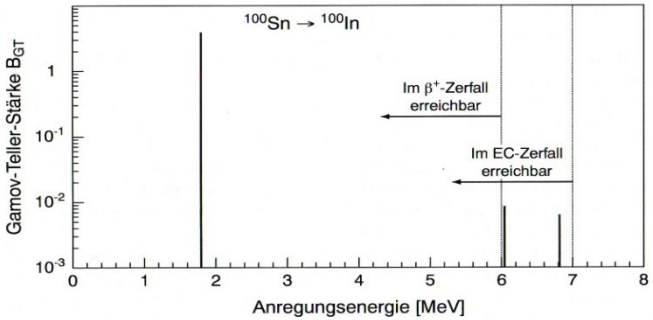
97 % of the whole strength is concentrated in a single state, which is accessible in the beta-decay

Single particle energies for shell model orbitals in ^{100}Sn



β+: $Q = M(Z+1)c^2 - M(Z)c^2 - 2m_e c^2$

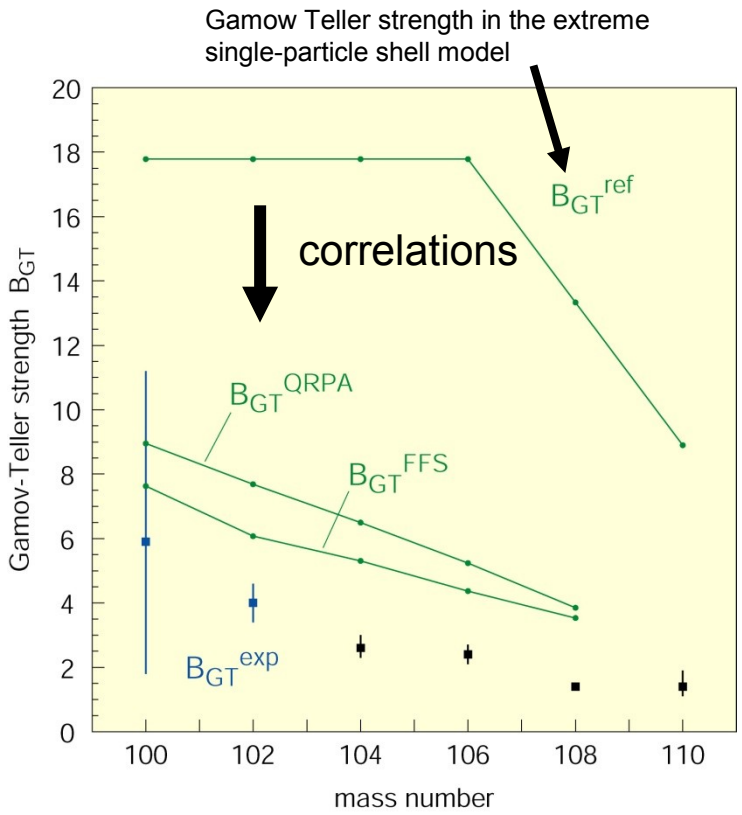
EC: $Q = M(Z+1)c^2 - M(Z)c^2 - BE(K\text{-Electron})$



B. A. Brown and K. Rykaczewski, Phys. Rev. C 50 (1994) R2270.

^{100}Sn β-Decay – GT Strength II

Theoretical (green) and experimental values (blue) of the GT strength of some even-even tin isotopes



Calculation of the GT strength in the case of a pure Gamow-Teller Decay, which populates exactly one excited state in the daughter nucleus, using measured values:

$$B_{GT} = |M_{GT}|^2 = \left|\langle \Psi_f | \vec{\sigma}\tau_{\pm} | \Psi_i \rangle\right|^2 = \frac{6142.8\,s}{(g_A/g_V)^2 \cdot f(Z,E_0) \cdot T_{1/2}}$$

β end point energy

half-life

$g_A / g_V = -1.2695$ ratio of the axial-vector to the vector coupling constant

$f(Z,E_0) \propto E_0^5$ Fermi integral (phasespace!) – strong energy dependence

A. Stolz et al., 2001 A. Bobyk & W. Kaminski, 2000

^{100}In: Test of p-n interaction

Shell model calculation of excited states in ^{100}In

CD Bonn Nucleon-Nucleon potential

Model space for neutrons d5/2, g7/2, s1/2, d3/2, h11/2

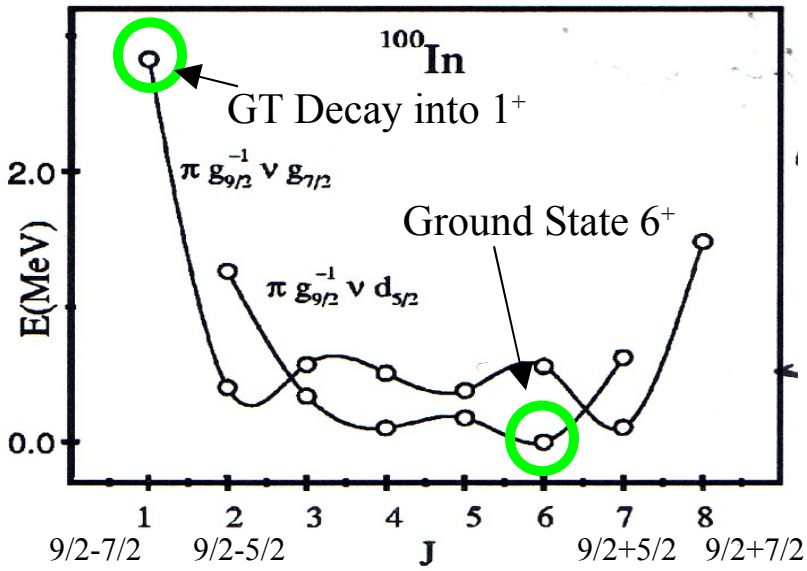
Model space for protons g9/2, p1/2, p3/2 and f5/2

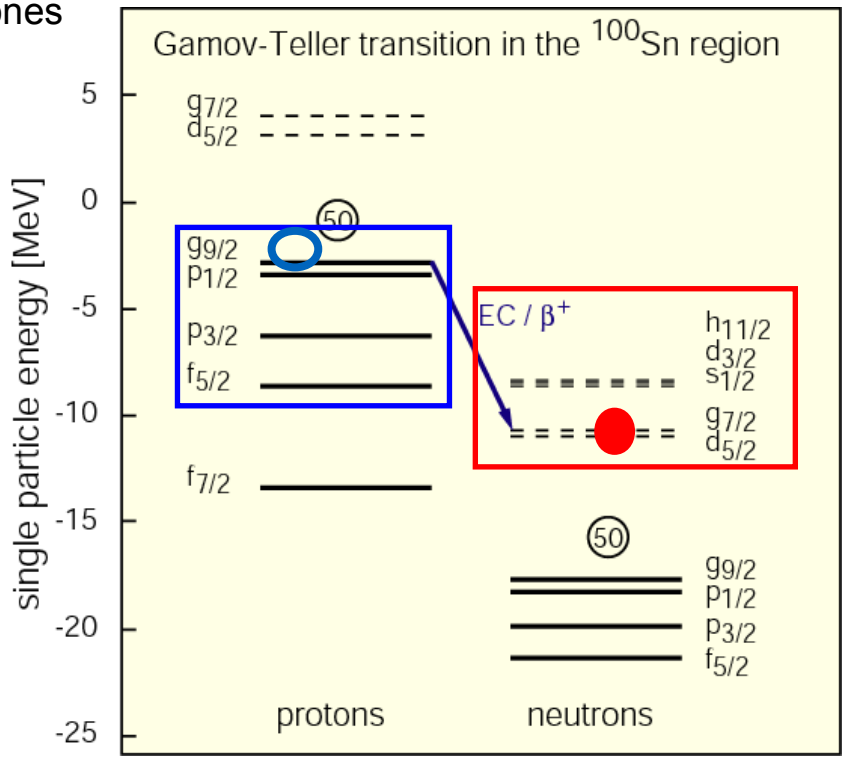
Single particle energies: odd tin isotopes, odd N=50 isotones

Neutron d5/2, g7/2 almost degenerate

→ splitting of multiplets depends on the different strength of p-n interaction of Pg9/2 Nd5/2, Pg9/2 Ng7/2

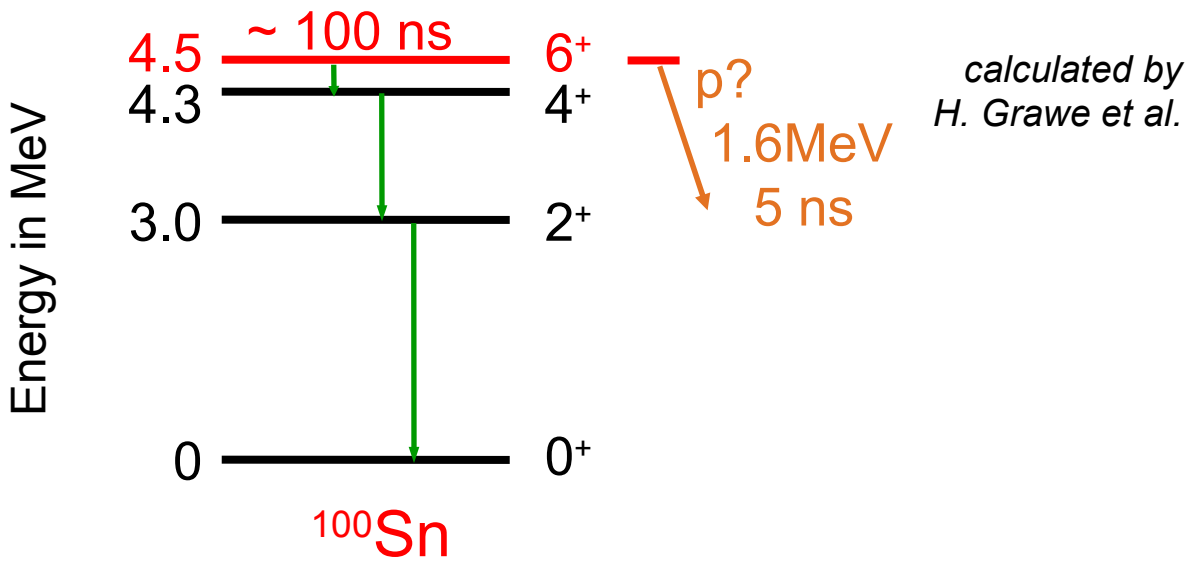
Phys. Rev. C 70, 034310 (2004)





^{100}Sn Isomer

Theoretical predictions for the ^{100}Sn level scheme



Former ^{100}Sn Experiments

year	where	production	events	quantity			
1994	GSI	fragm. ^{124}Xe	7	$T_{1/2}$	E(β)	E(γ)	S139
1994	GANIL	fragm. ^{112}Sn	11		ident.		
1996	GANIL	fusion	11		Δ m		
1998	GSI	fragm. ^{112}Sn	1	$T_{1/2}$	E(β)	E(γ)	S192
2007	MSU	fragm. ^{112}Sn	14	$T_{1/2}$			
2008	GSI	fragm. ^{124}Xe	259	$T_{1/2}$	E(β)	E(γ)	S330

Half life $T_{1/2}$ = 1.0 (+0.54 –0.26) s

Beta-endpoint energy

$E(\beta_0)$ = 3.8 (+0.7 –0.3) MeV

Gamow-Teller-strength

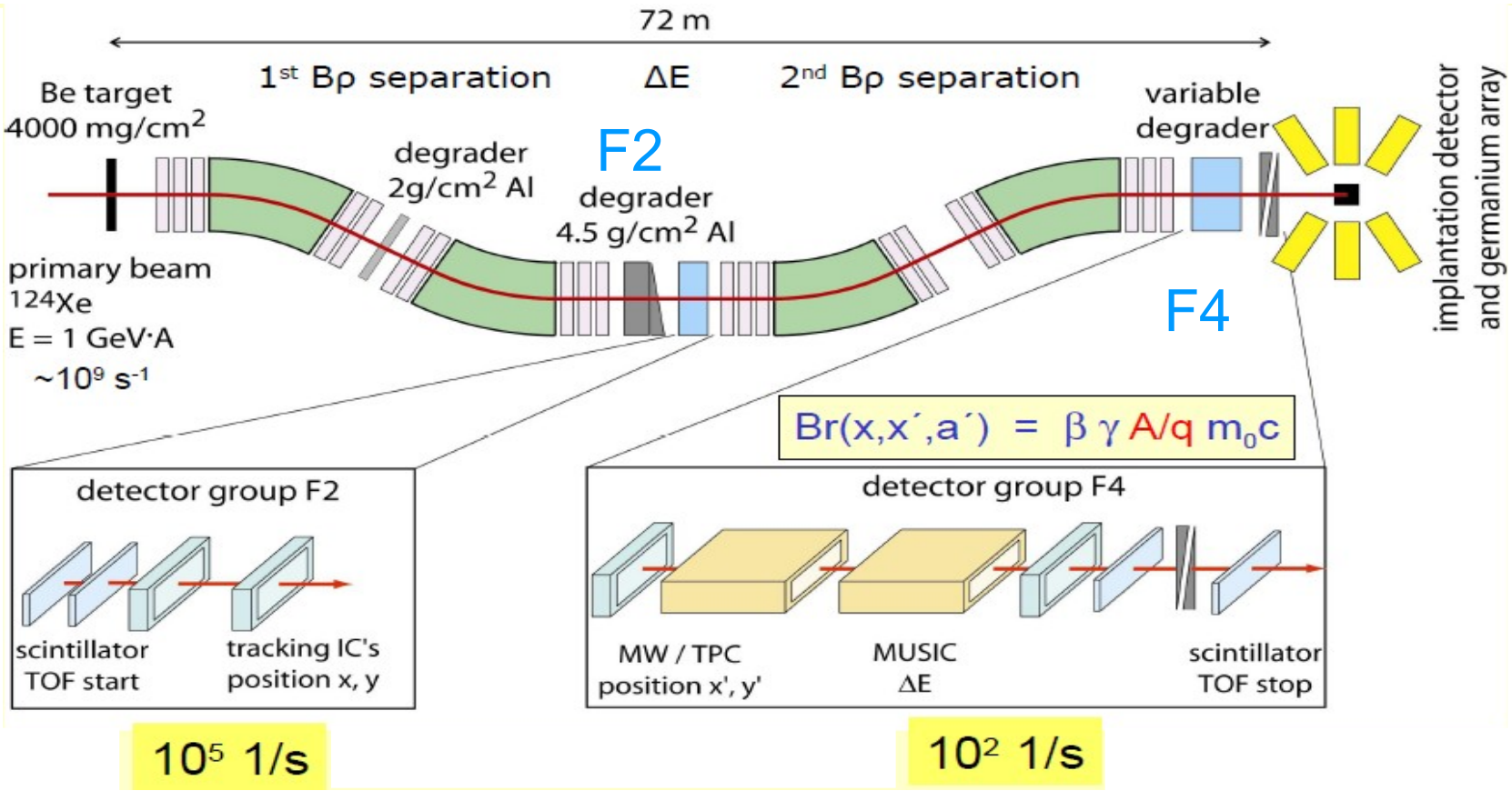
B_{GT} = 5.8 (+5.3 –4.1)

Q_{EC}-value g.s. to g.s.

Q_{EC} = 7.2 (+0.8 –0.5) MeV

Experimental Setup

Particle Identification



identification F2-F4:

resolution ^{100}Sn setting:

$\Delta A = 0.42$ (FWHM)

$\Delta Z = 0.32$ (FWHM)

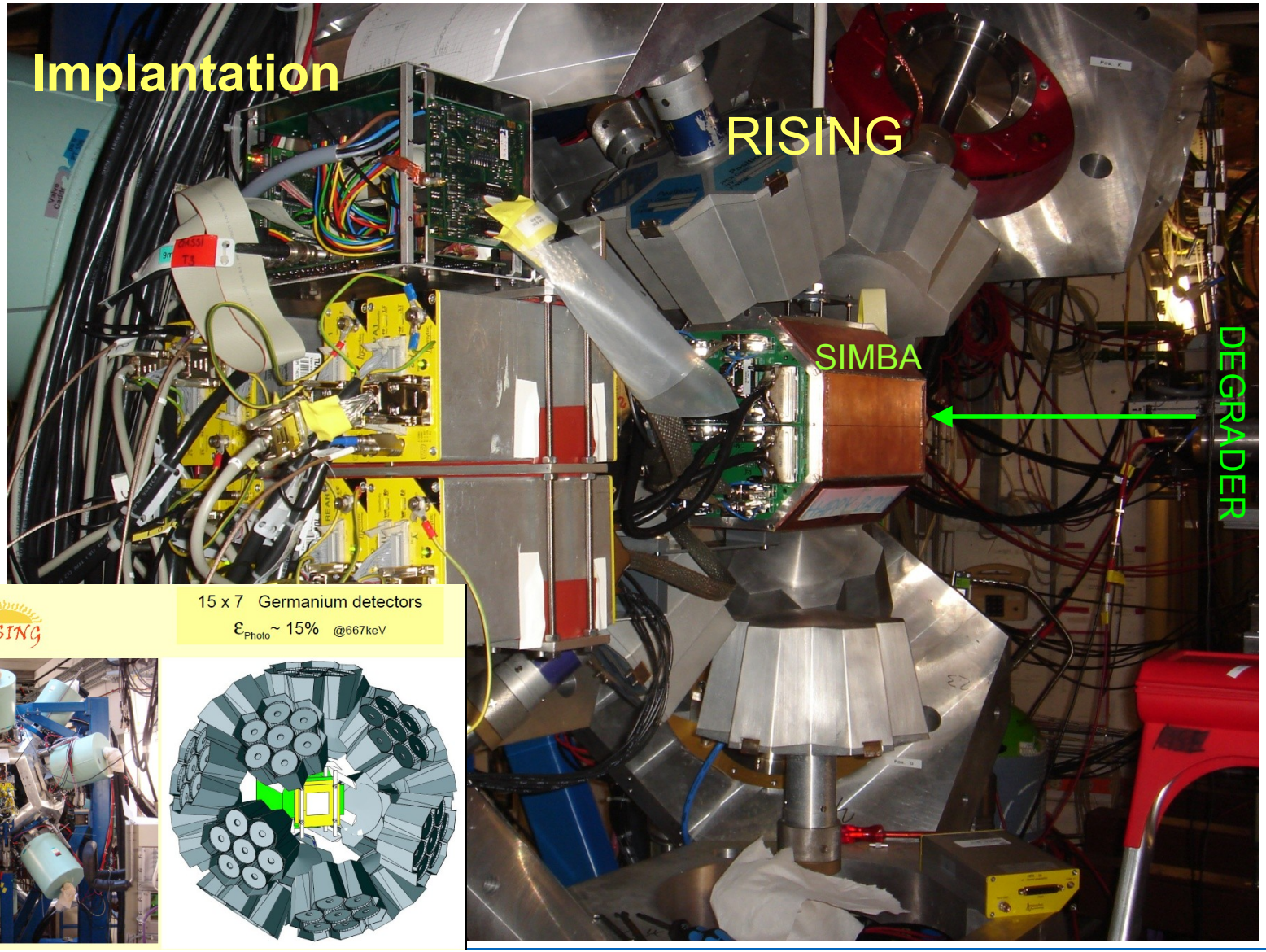
$\Delta E \Rightarrow Z$

$B\rho(x,x',\alpha') = \beta\gamma A/q\, m_0 c$

$q = Z$

TOF $\Rightarrow \beta$

Implantation Detector

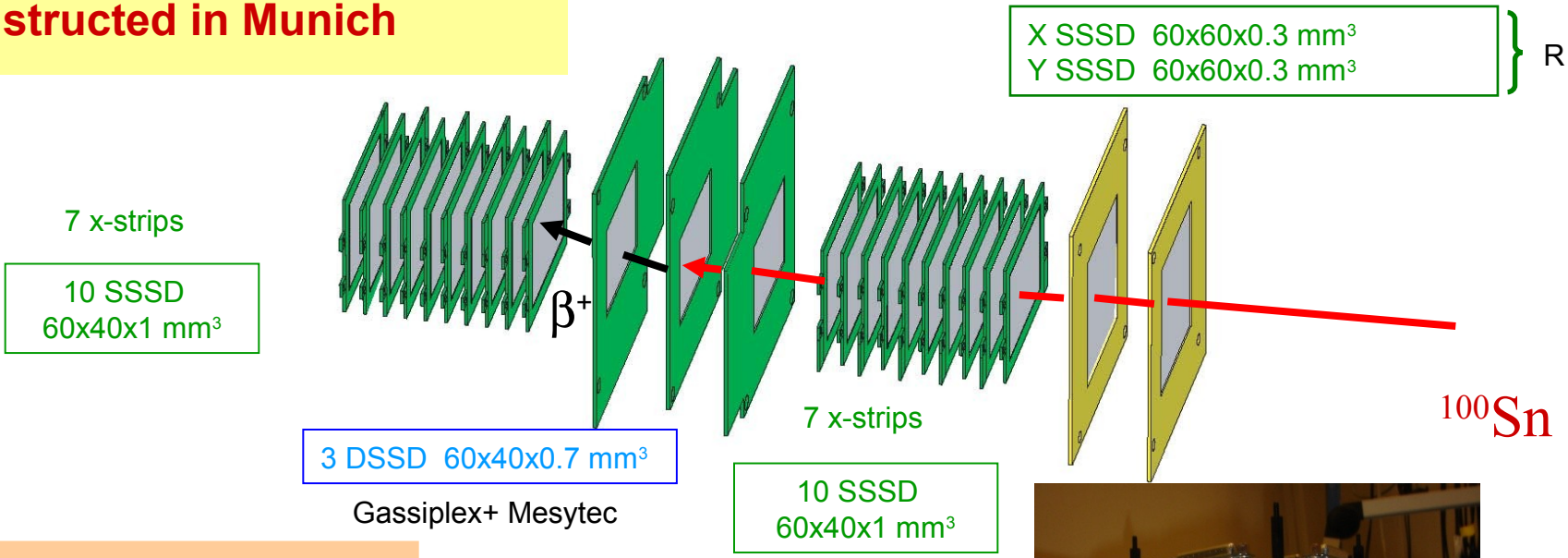


RISING

15 x 7 Germanium detectors

ε_{Photo} ~ 15% @667keV

Silicon Implantation Detector and Beta Absorber SIMBA constructed in Munich

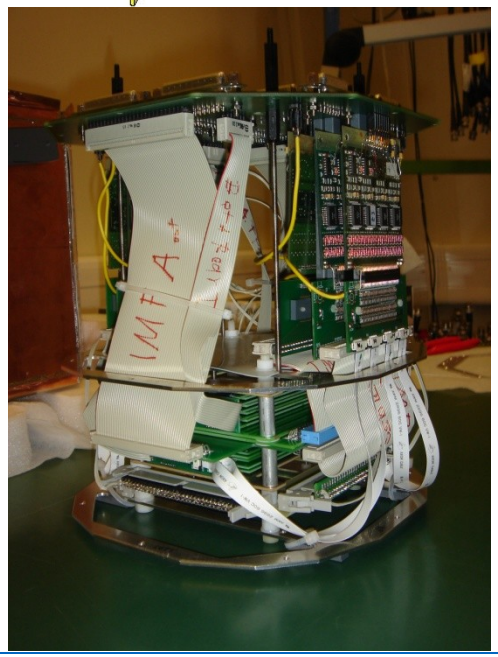


Number of pixels in the implantation zone: 3x60x40 = 7200

4π - Detector for
- α - decay
- β - decay
- proton emission

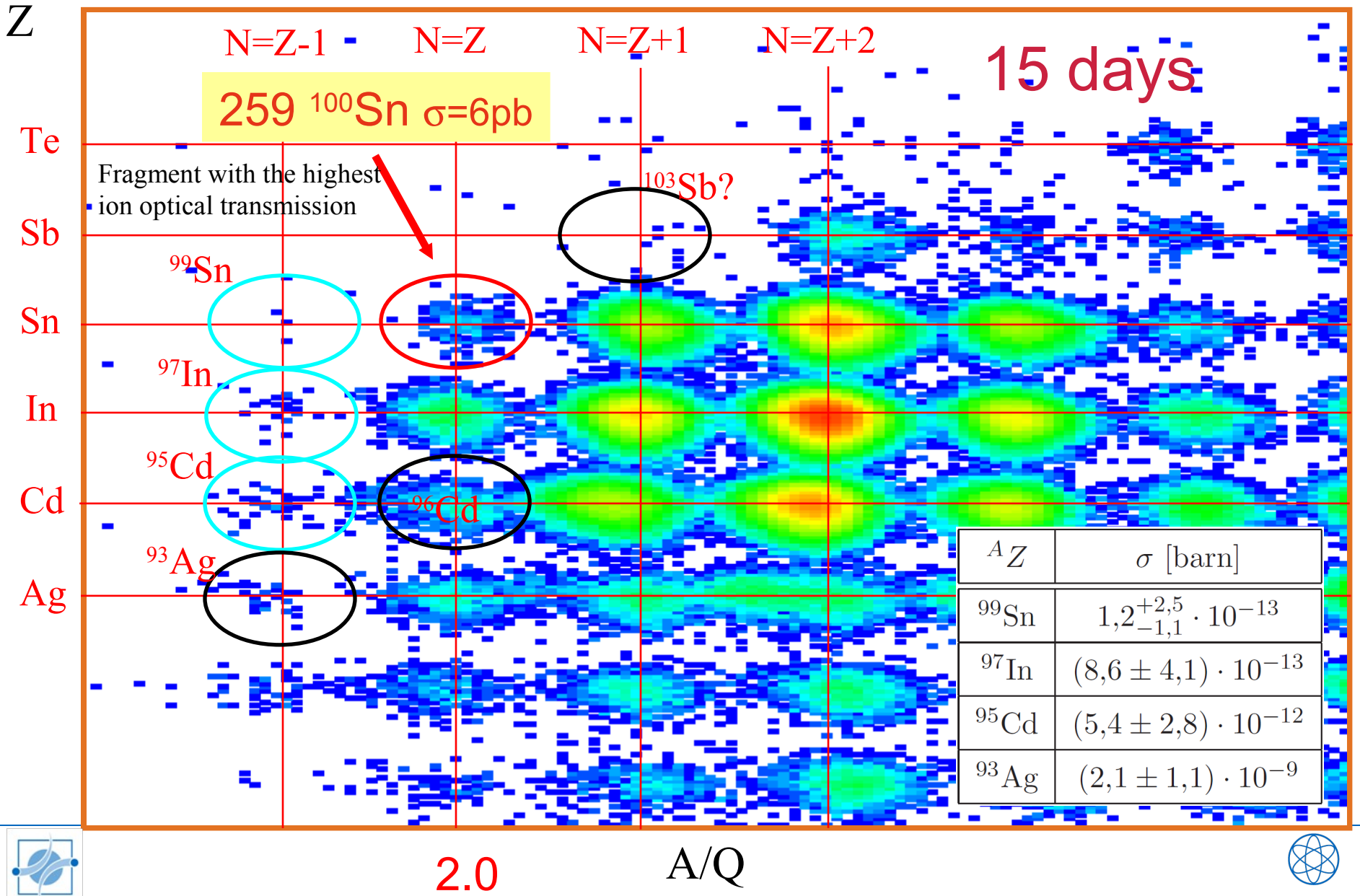
5MeV positrons stop in 10mm silicon

Half life between a few ms and at least some seconds depending on the background



Selected Results

^{100}Sn Setting (full statistics)



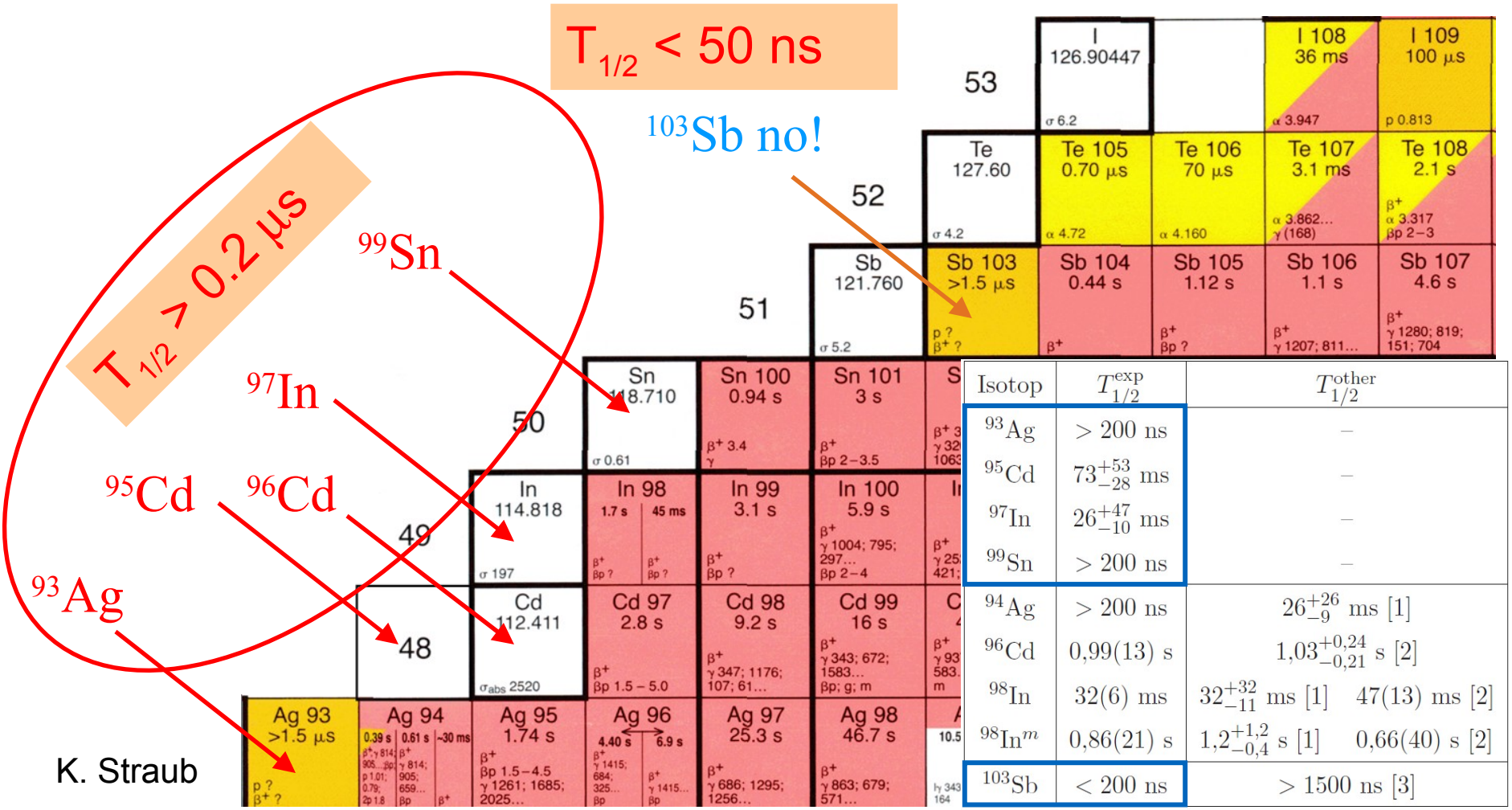
^{A}Z	σ [barn]
^{99}Sn	$1{,}2^{+2{,}5}_{-1{,}1} \cdot 10^{-13}$
^{97}In	$(8{,}6 \pm 4{,}1) \cdot 10^{-13}$
^{95}Cd	$(5{,}4 \pm 2{,}8) \cdot 10^{-12}$
^{93}Ag	$(2{,}1 \pm 1{,}1) \cdot 10^{-9}$

Discovery of exotic nuclei

^{103}Sb: dominant p-decay

^{97}In: dominant β-decay

^{93}Ag: persumably p-decay

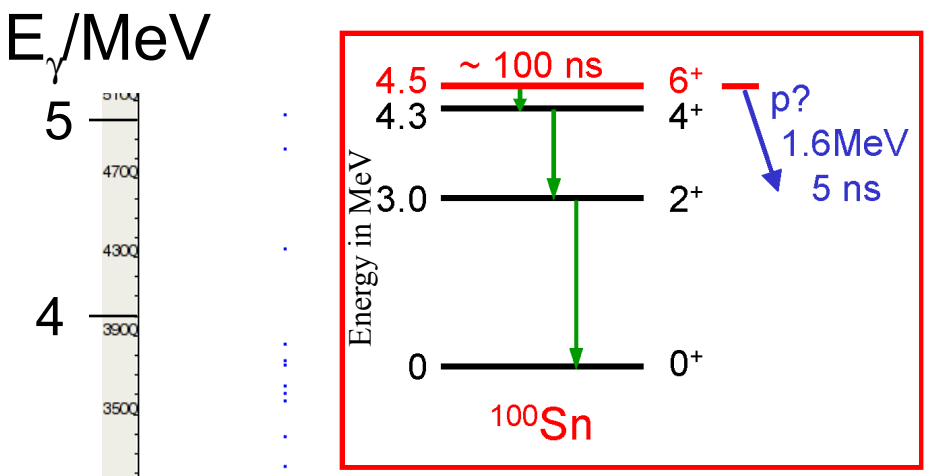


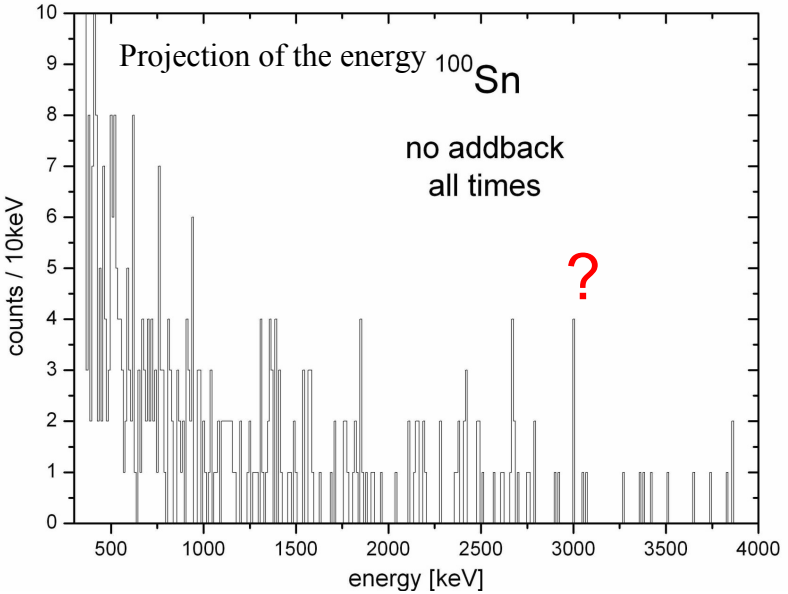
Isotop	$T_{1/2}^{exp}$	$T_{1/2}^{other}$
^{93}Ag	> 200 ns	–
^{95}Cd	73^{+53}_{-28} ms	–
^{97}In	26^{+47}_{-10} ms	–
^{99}Sn	> 200 ns	–
^{94}Ag	> 200 ns	26^{+26}_{-9} ms [1]
^{96}Cd	0,99(13) s	$1{,}03^{+0,24}_{-0,21}$ s [2]
^{98}In	32(6) ms	32^{+32}_{-11} ms [1] 47(13) ms [2]
^{98}In^{m}	0,86(21) s	$1{,}2^{+1,2}_{-0,4}$ s [1] 0,66(40) s [2]
^{103}Sb	< 200 ns	> 1500 ns [3]

K. Straub

Search for the 6^+ ^{100}Sn Isomer

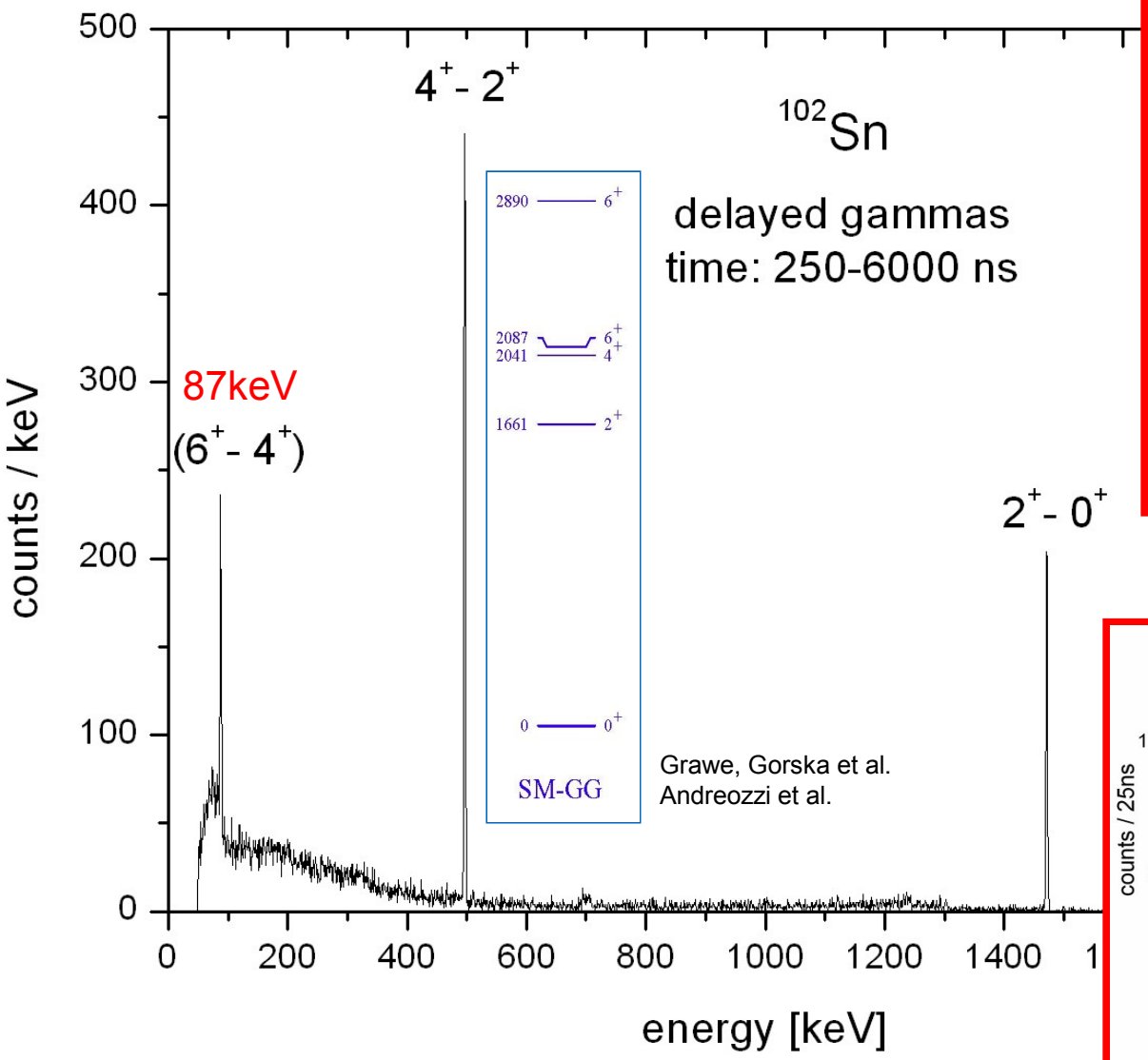
200 ^{100}Sn implanted → Isomeric Ratio 50% → $T_{1/2}$ ~ ToF → Efficiency 10%-15%: 5-8 Gamma rays

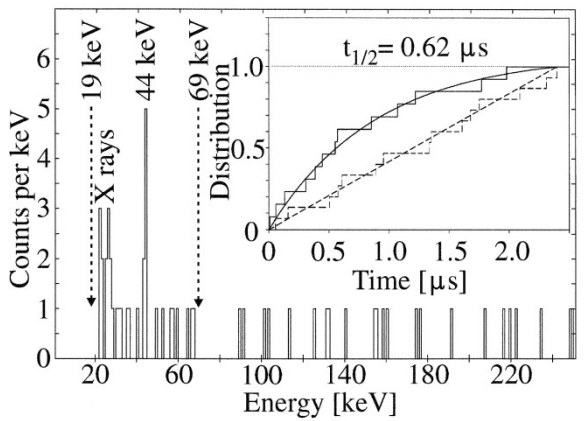




4 isomer decays after ToF=200ns decaying within 25 ns ?

6^+ Isomer in ^{102}Sn

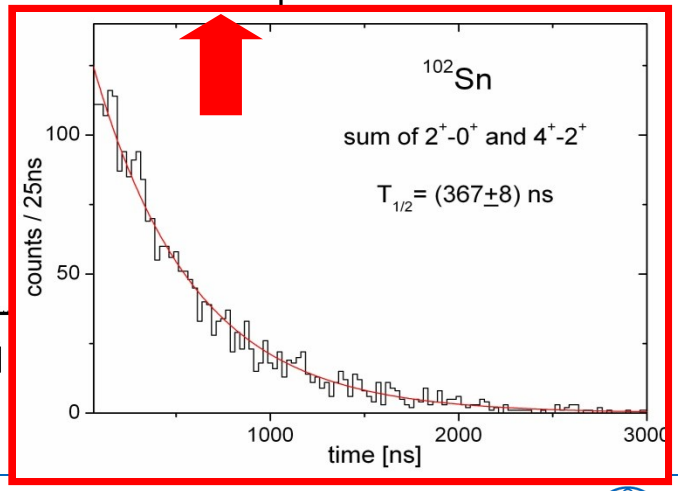




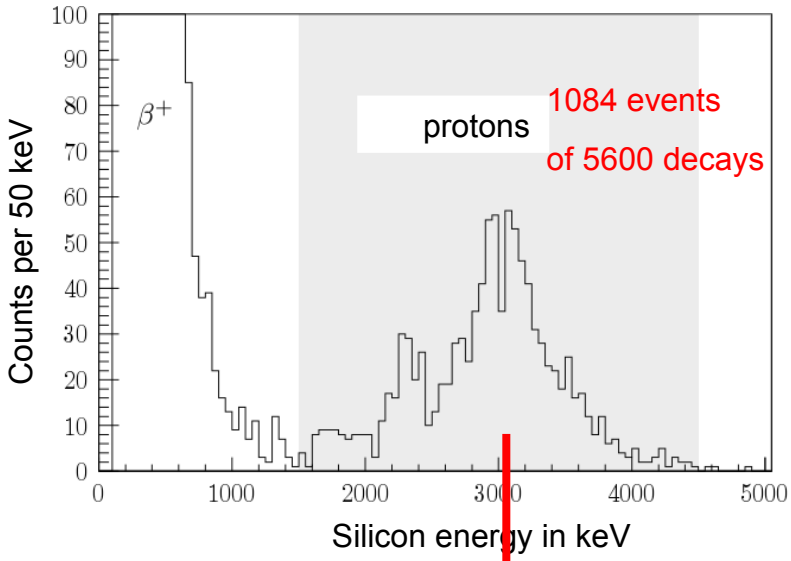
Lipoglavsek et al., PLB 1998

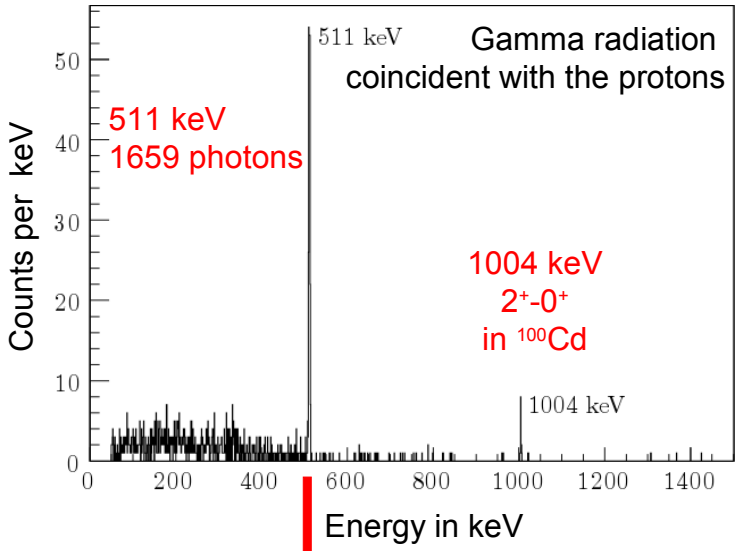
E(6-4) = 48keV

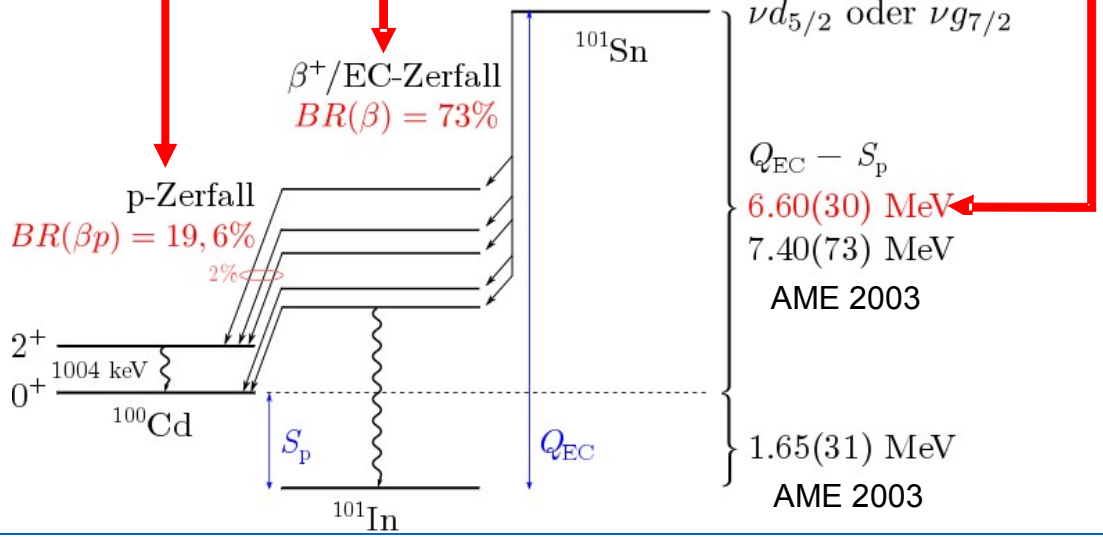
B(E2)=3.2(1) W.u.



^{101}Sn β-delayed Protons







K. Straub

^{100}Sn Decay Analysis $T_{1/2}$

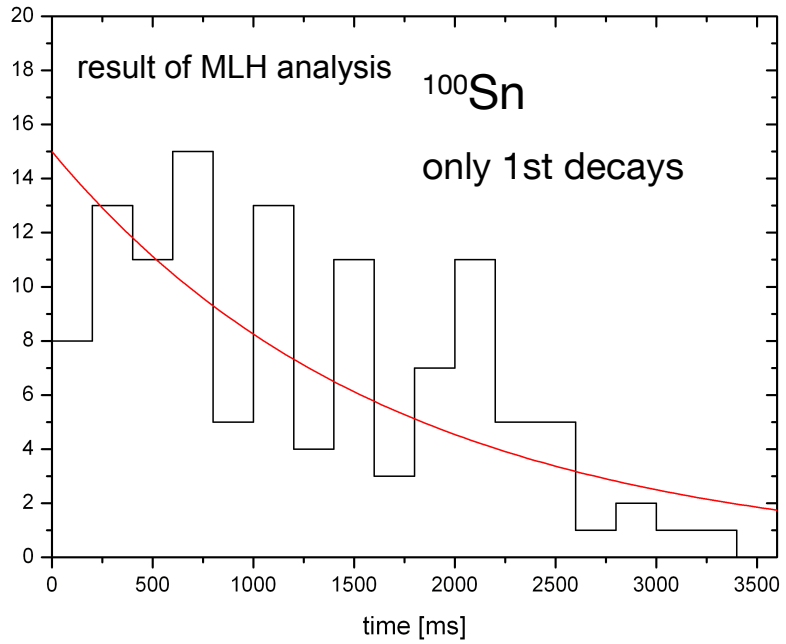
Correlation of Implantation and Decay

require same position within ± 1mm in x,y,z

record all decay triggers within 15 s (β^+ of 3 generations)

Maximum Likelihood analysis

varying the 100Sn half-life
with known: daughter decays,
efficiencies, dead times, background



T1/2 = 1.16 ± 0.20 s

Comparison:

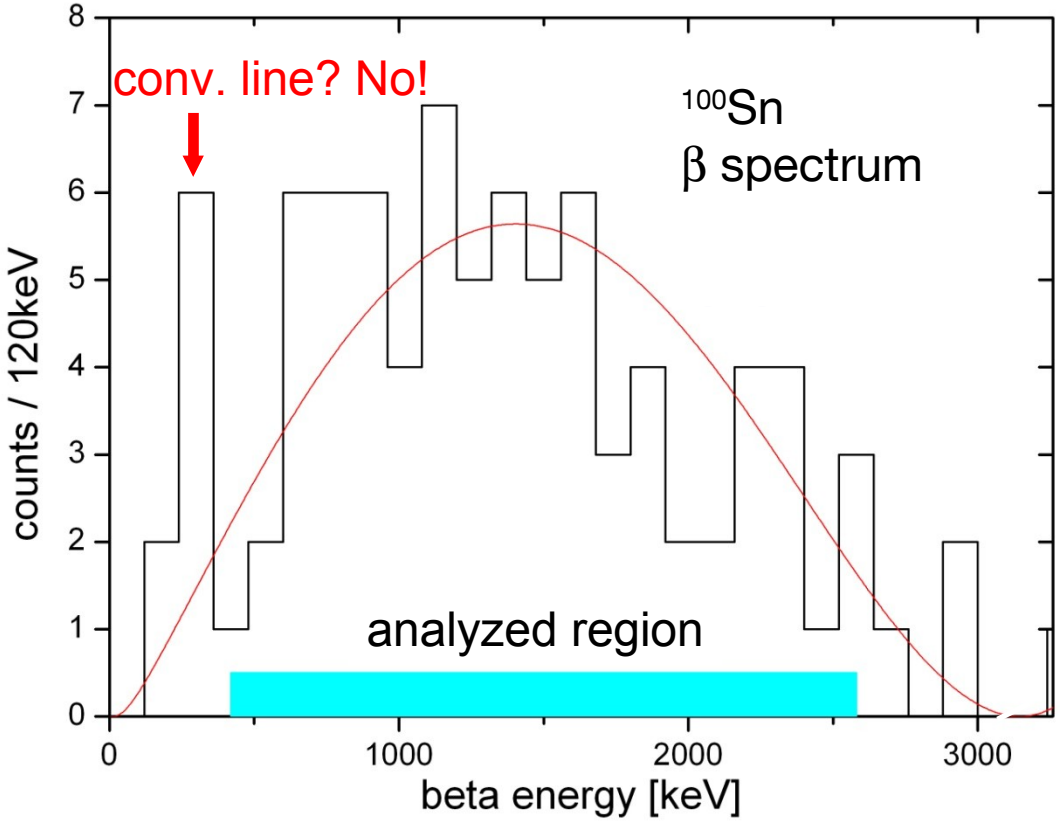
MSU 2007	$0.55^{+0.70}_{-0.31}$ s
GSI 1997	$0.94^{+0.54}_{-0.26}$ s

^{100}Sn Beta Endpoint Energy

Extraction of Beta Spectrum

Sum over total energy within 3 s after implantation in implantation zone + calorimeter

Tracking of decay positrons in each silicon detector



from centroid

E_{max} = 3.29 ± 0.20 MeV

Q_{EC} = 4.31 ± 0.20 MeV

to excited state

=> I_{β^+} = 87%

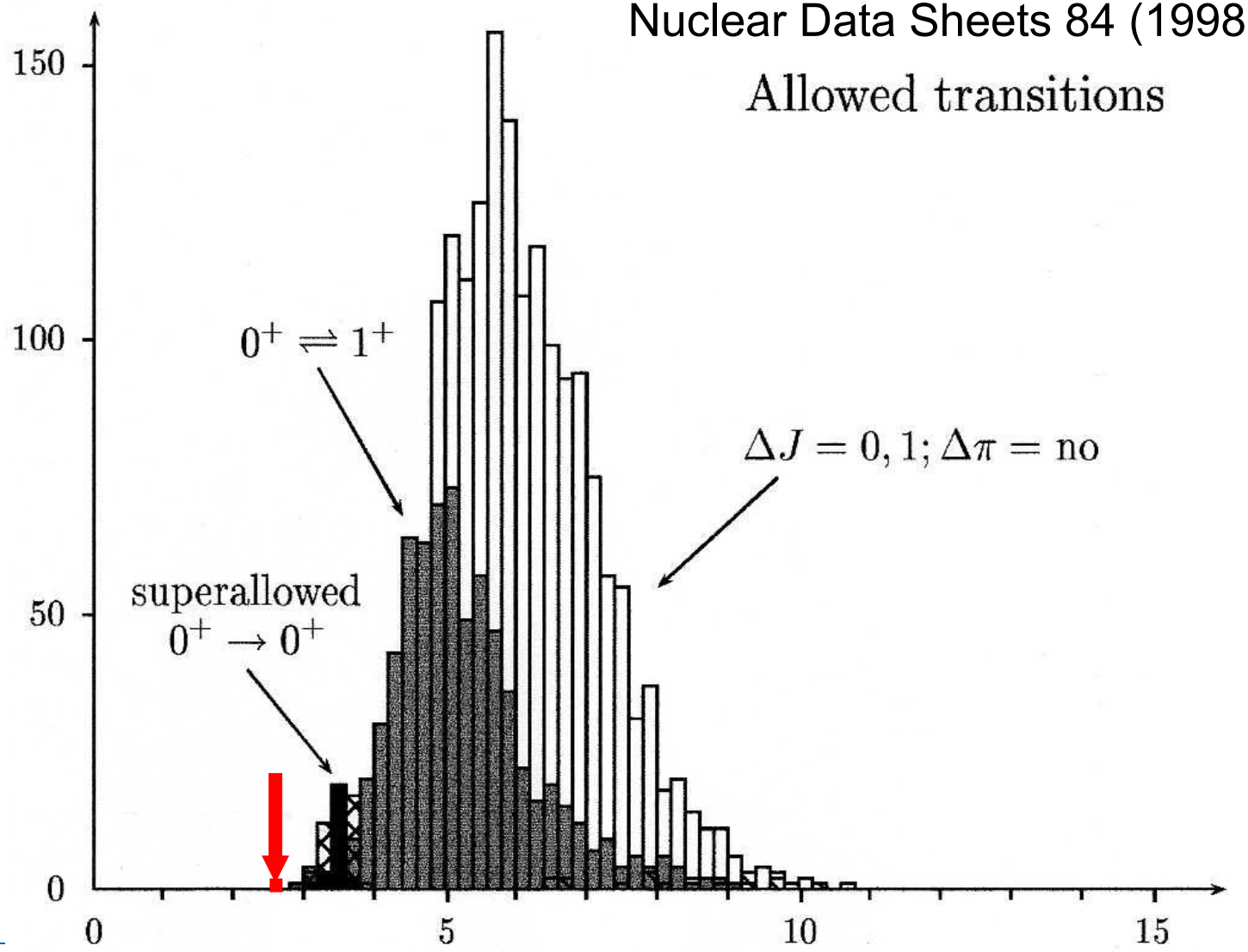
log ft = 2.62 ± 0.14

that's record

Assumption: Only one final state in the daughter nucleus is populated

Known log-ft values

Nuclear Data Sheets 84 (1998) 487



^{100}Sn Gamow Teller Strength

B_{GT} > 3 to a single state: Super Gamow Teller transition in ^{100}Sn

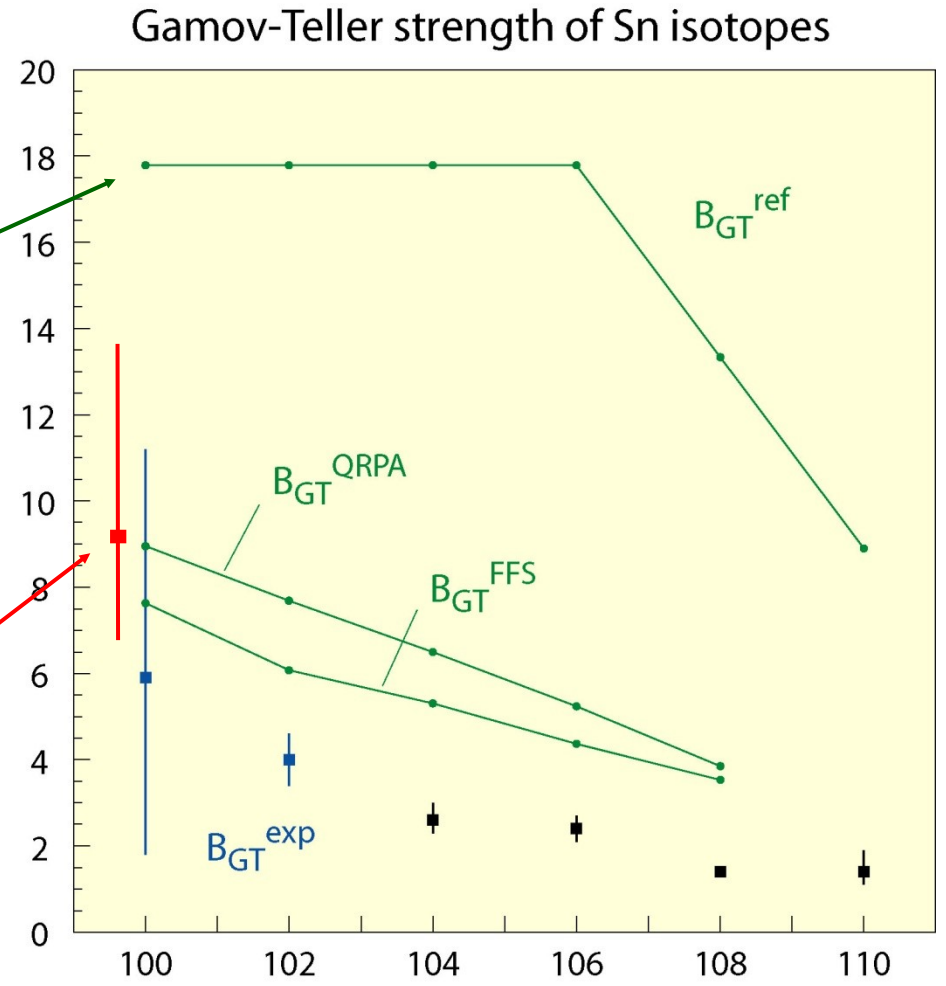
$$B_{GT}^{ref} = \frac{4l}{2l+1} \cdot N_{\pi\, g9/2} \cdot \left(1 - \frac{N_{\nu\, g7/2}}{8}\right)$$

$$B_{GT}^{ref} = 17.8$$

$$B_{GT}^{exp} = \frac{2Ft}{(g_A/g_V)^2\, ft} = \frac{6142.8s}{1.2695^2 \cdot ft}$$

$$B_{GT}^{exp} = 9.1^{+4.8}_{-2.3}$$

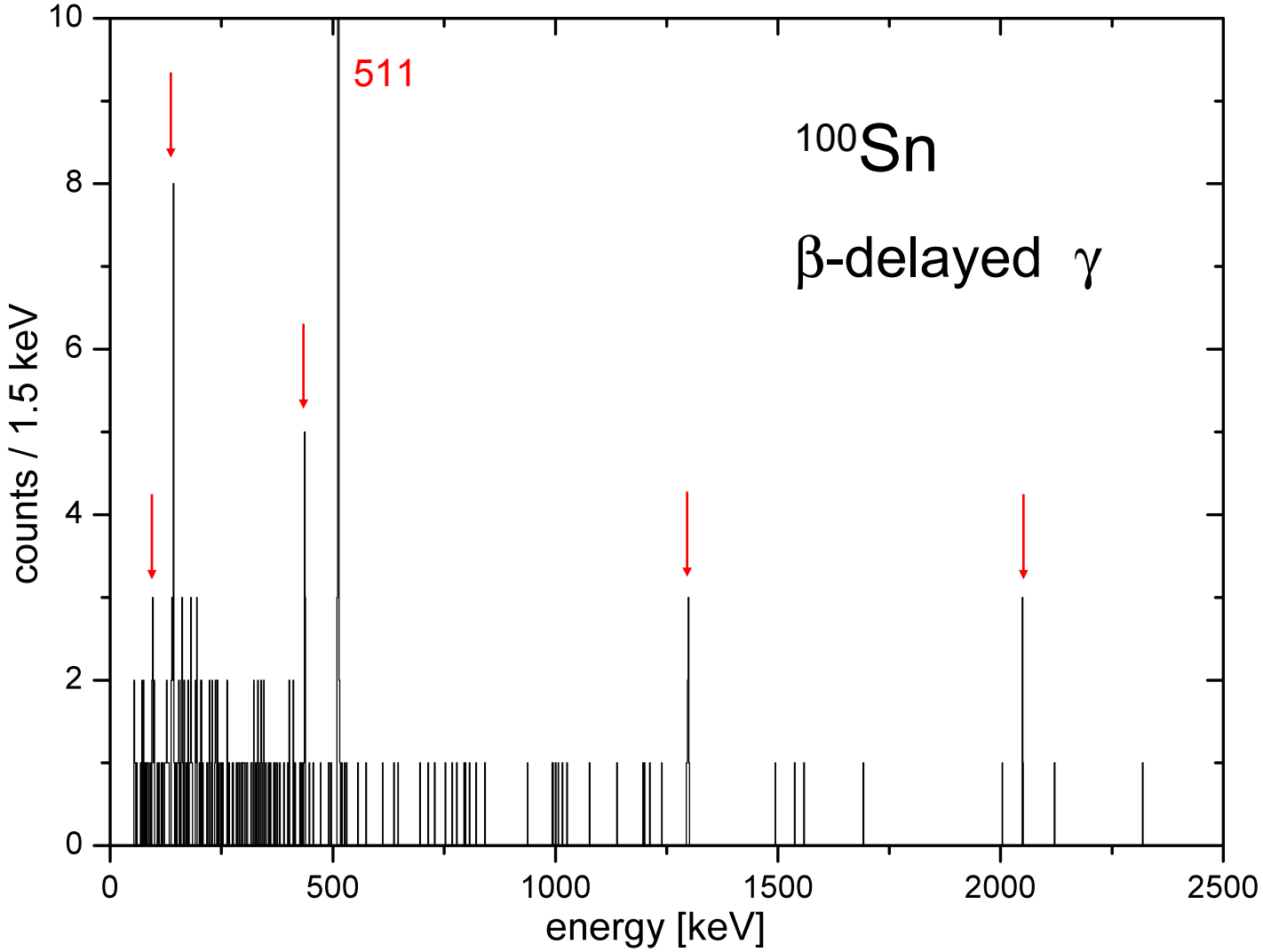
LSSM Calculation
reproduces the measurement well



^{100}Sn Decay Gammas I

Gamma Spectrum after Beta Decay of 100Sn

all events within 4 s after implantation



^{100}Sn Decay Gammas II

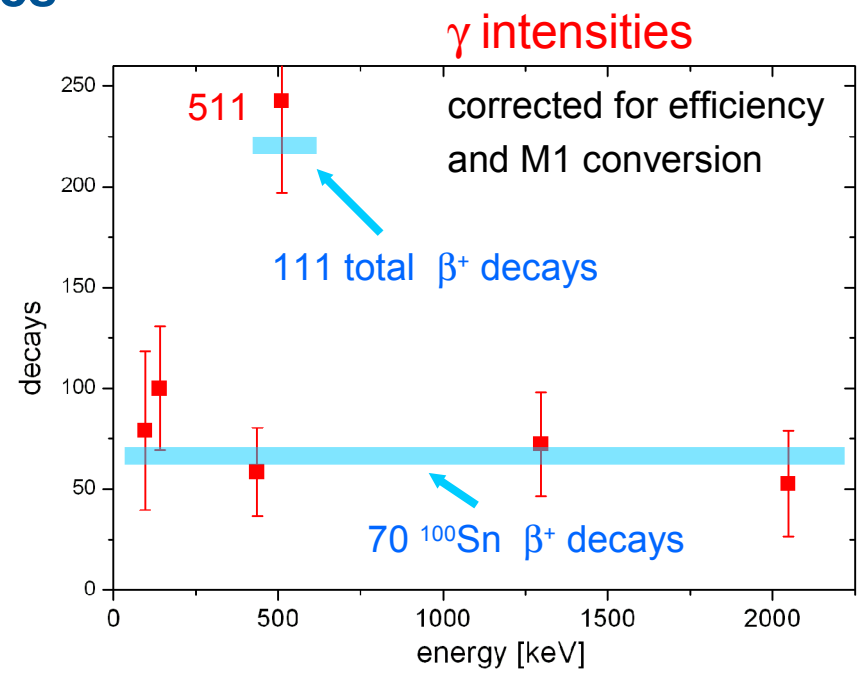
Gamma Spectrum after Beta Decay of 100Sn

all events within 4 s after implantation

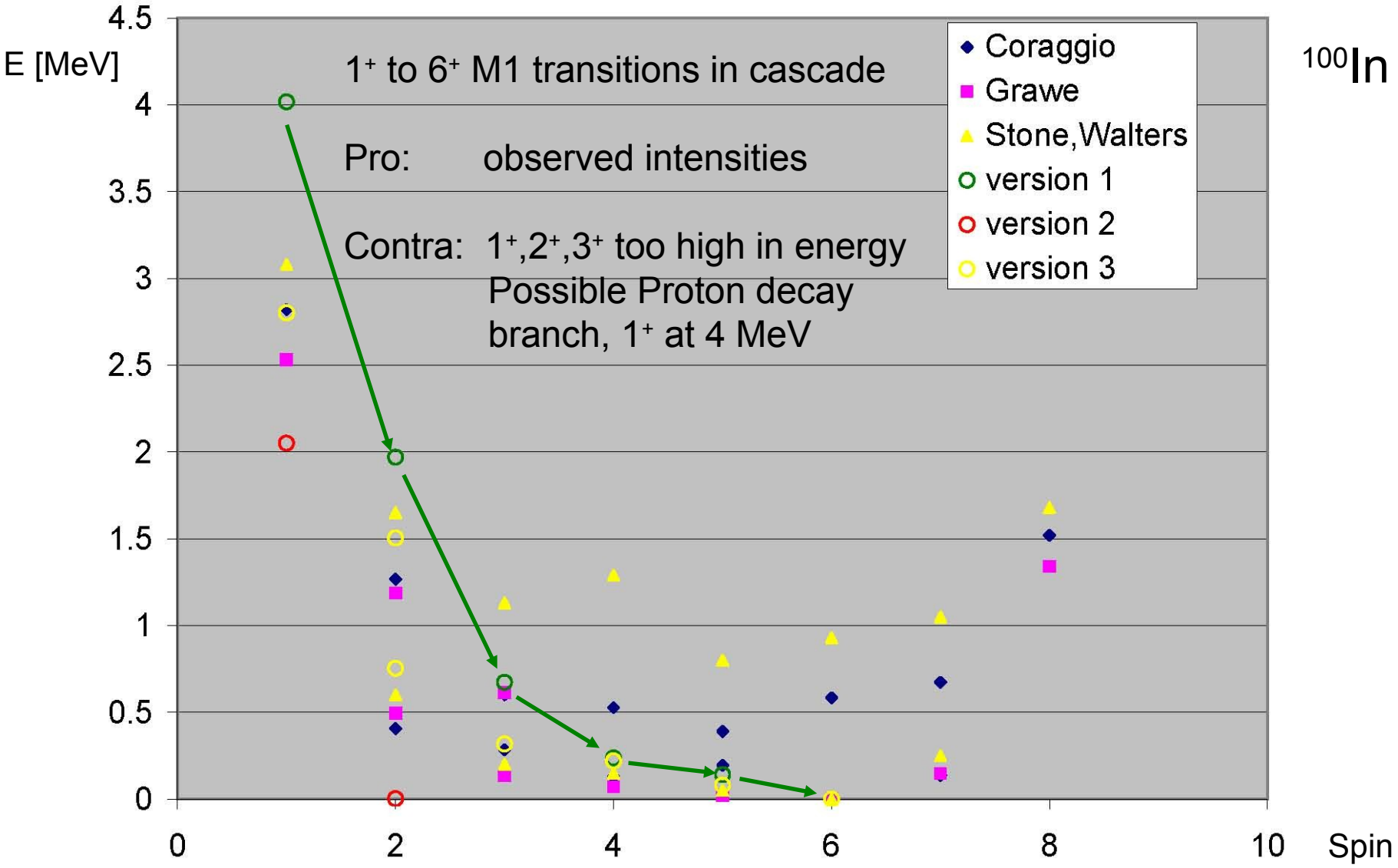
^{100}Sn

β-delayed γ

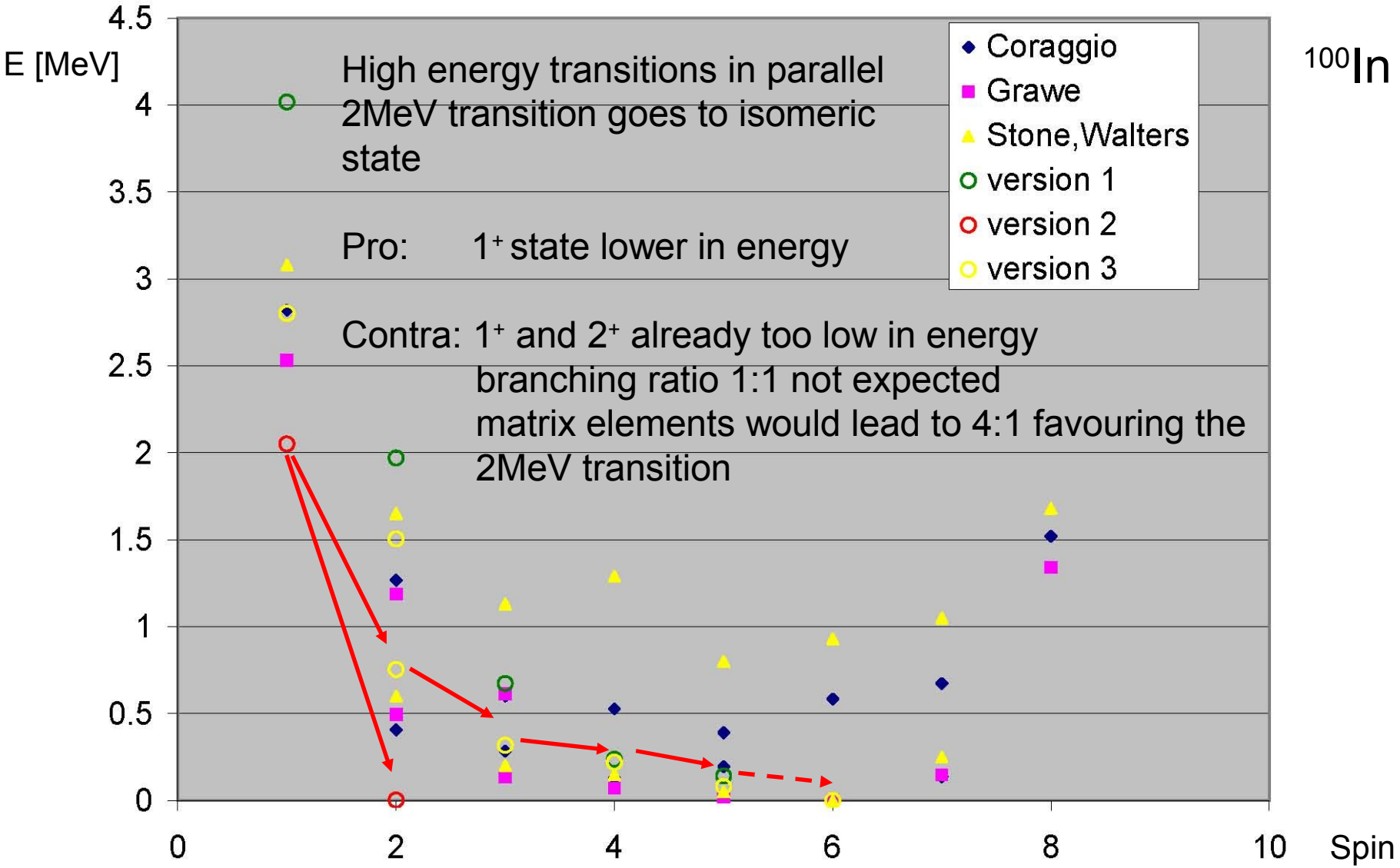
Gamma Intensities



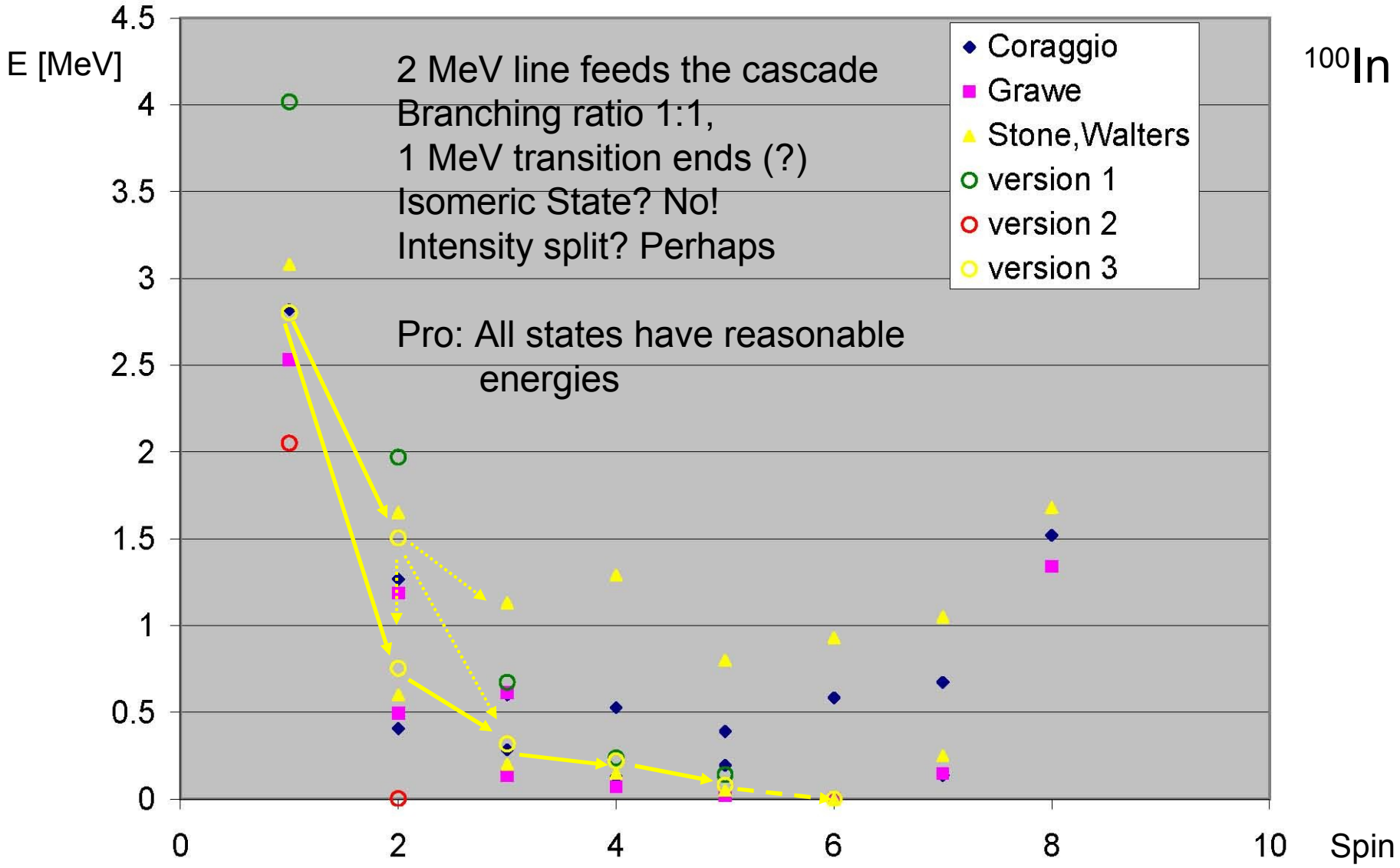
Possible Placements I



Possible Placements II



Possible Placements III



Conclusion and Outlook

Already today possible at GSI: 1 ^{100}Sn / hour

First observation of ^{95}Cd, ^{97}In, und ^{99}Sn

Non-observation of ^{103}Sb: $T_{1/2} < 50$ ns

New Isomeric Transition in ^{102}Sn

^{101}Sn: Details about the beta delayed proton decay

Concerning ^{100}Sn: $T_{1/2}$, E^{β}_{max}, E_{γ}, B_{GT}

^{100}Sn – remarkable Results:

→Super GT decay, smallest log-ft value
→LSSM calculations: successful description of the nucleus
→Shell closure is well pronounced

Excitation structure of ^{100}In remains unclear → better statistics is necessary

^{100}Sn at RIBF + RISING

More precise value of GT-strength in the decay of ^{100}Sn as a precision test of LSSM calculations

Clarify excitation structure of ^{100}In (Gamma-gamma coincidences)

Spectroscopy of ^{99}Sn ?

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N.Al-Dahan (5), N.Alkhomashi (5), A.Atac (6), A.Blazhev (7), N.Braun (7),
I.Čeliković (8), T.Davinson (3), I.Dillmann (1), C.Domingo-Pardo (2), P.Doornenbal (9),
G.de France (10), G.Farelli (5), F.Farinon (2), J.Gerl (2), N.Goel (2), T.Habermann (2),
R.Hoischen (2), R.Janik (11), M.Karny (12), A.Kaskas (6), I.Kojouharov (2), Th.Kröll (1),
M.Lewitowicz (10), Y.Litvinov (2), S.Myalski (4), F. Nebel (1), S.Nishimura (9),
C.Nociforo (2), J.Nyberg (13), A.Parikh (1), A.Procházka (2), P.H.Regan (4),
C.Rigollet (14), H.Schaffner (2), C.Scheidenberger (2), S.Schwertel (1),
P.-A.Söderström (13), S.Steer (4), A.Stolz (15), P.Strmeň (11), H.J.Wollersheim (2),
and the RISING collaboration

(1) TU München, (2) GSI, (3) U of Edinburgh, (4) IFJ PAN Krakow, (5) U of Surrey,
(6) U of Ankara, (7) U of Köln (8) Inst. Vinca Belgrade, (9) RIKEN, (10) GANIL,
(11) U of Bratislava, (12) U of Warsaw, (13) U of Uppsala, (14) KVI - U of Groningen, (15) MSU

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