Spectroscopy of ^{99}Cd and ^{101}In: challenges and new approaches

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Preface

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Spectroscopy of ^{99}Cd and ^{101}In from β decays of ^{99}In and ^{101}Sn

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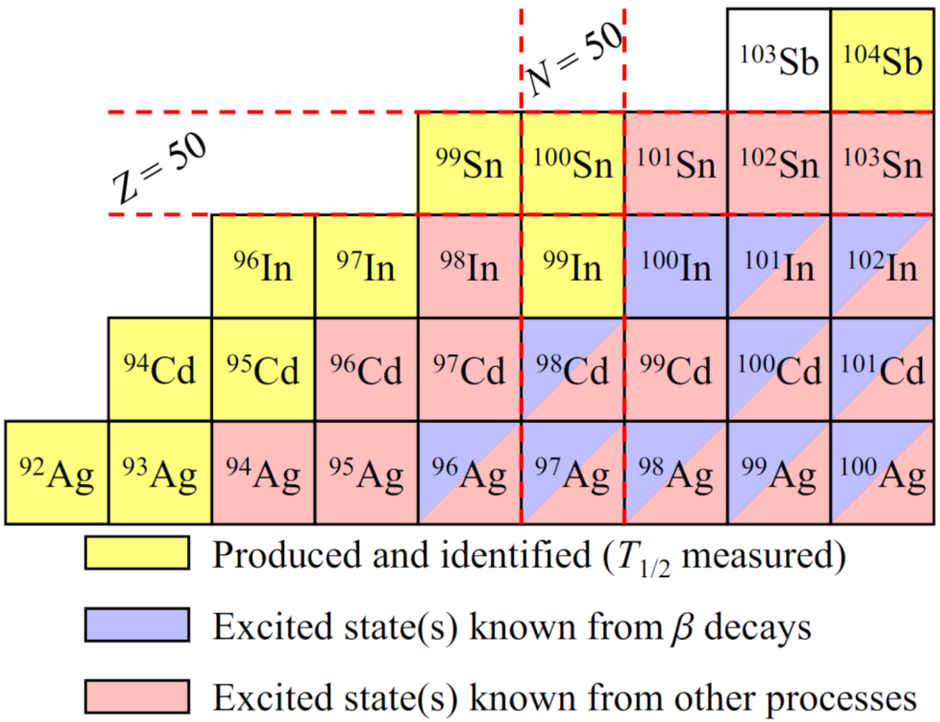
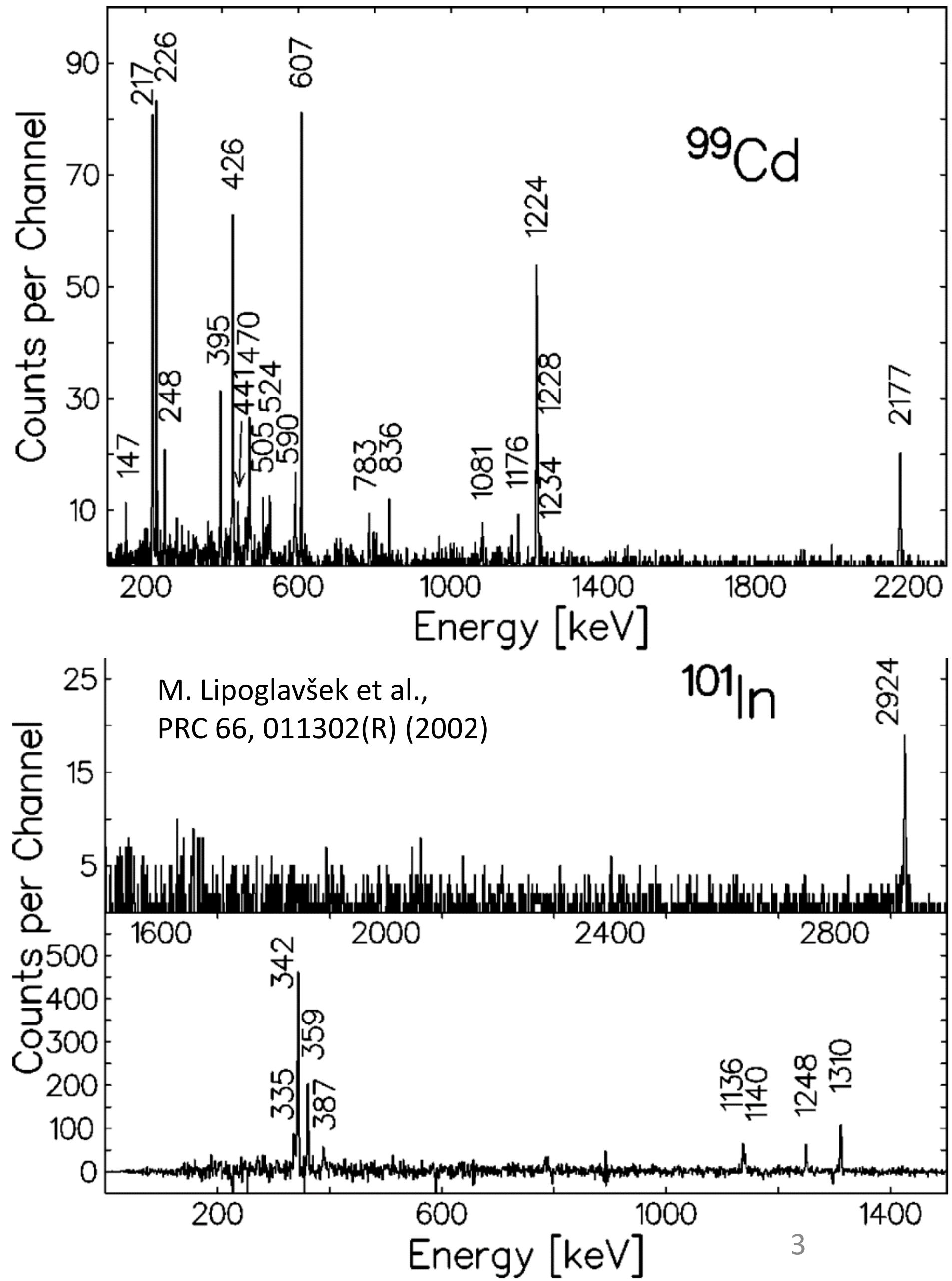
Most figures in this talk are taken from this article unless otherwise specified

Introduction



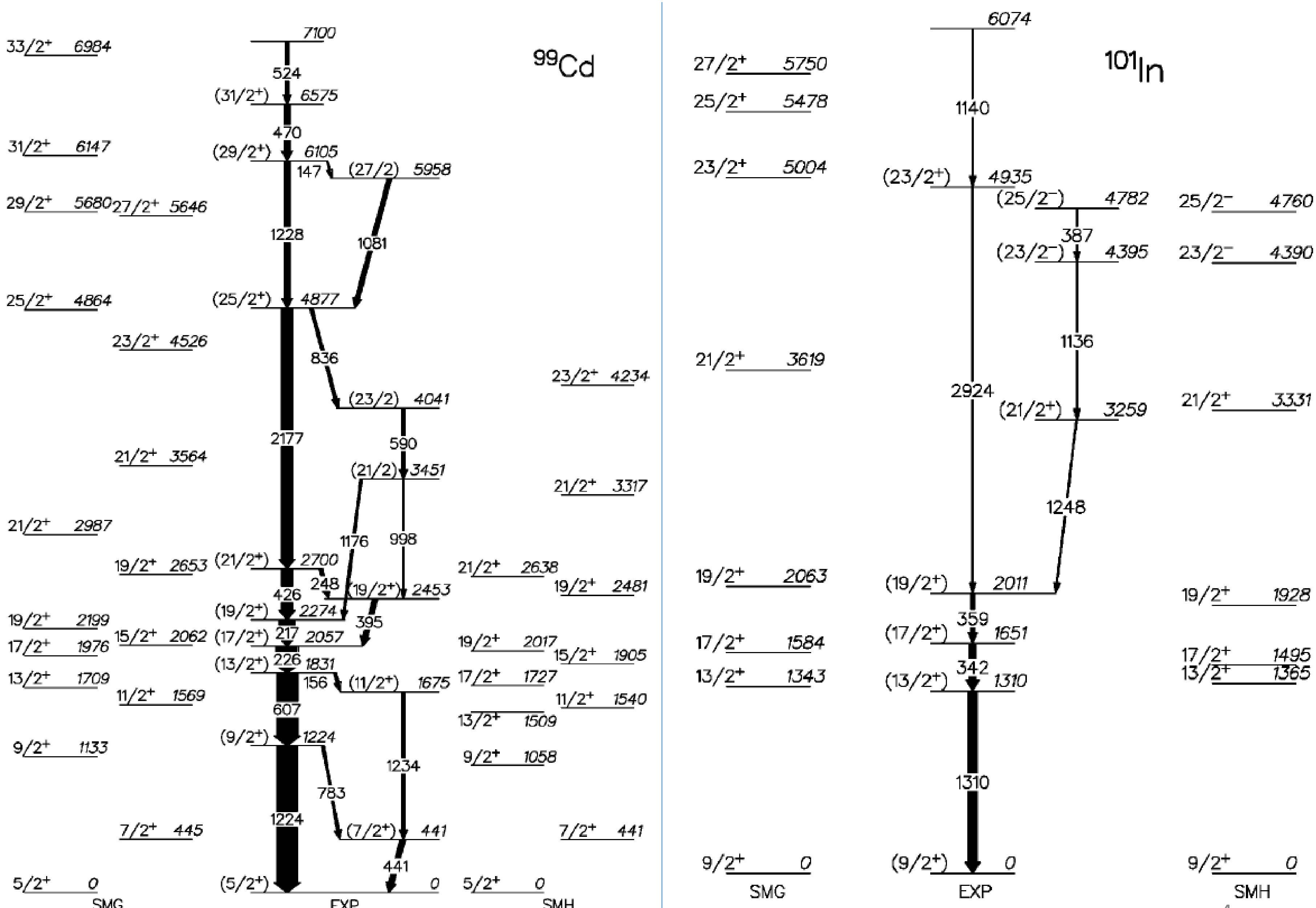


Beta decays of semi-magic nuclei
^{99}In: N = 50, ^{101}Sn: Z = 50

Ground state spin of ^{101}Sn: $5/2^+$ or $7/2^+$?
Magnitude of tensor force?

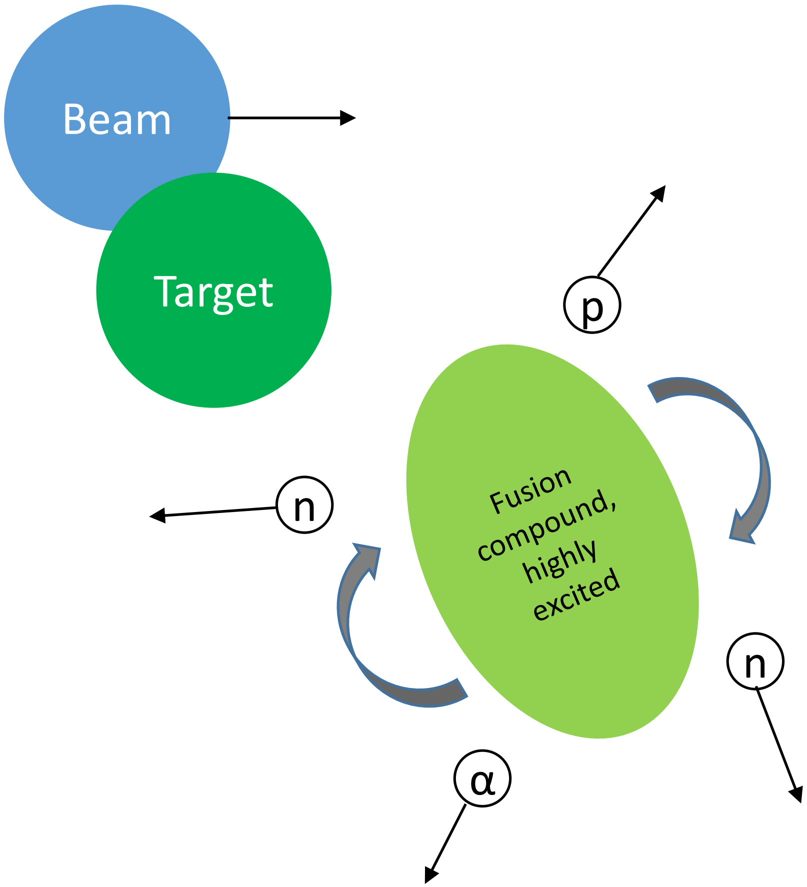
γ-ray spectroscopy of ^{99}Cd and ^{101}In
from fusion evaporation only until 2020

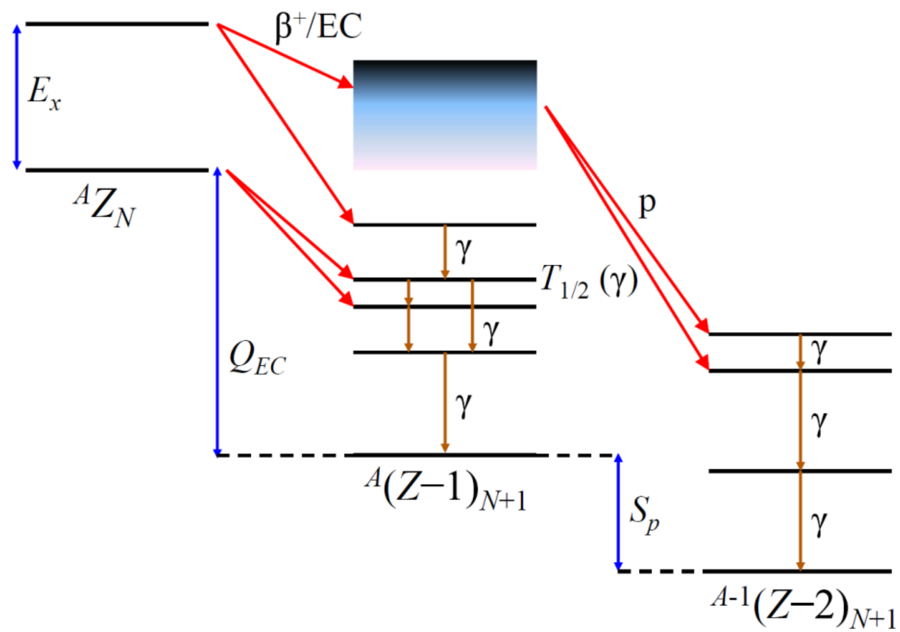
First level schemes of ^{99}Cd and ^{101}In



M. Lipoglavšek et al., PRC 66, 011302(R) (2002)

Fusion evaporation vs decay spectroscopy





$$ft = \frac{K}{G_V^2 B_F + G_A^2 B_{GT}}$$

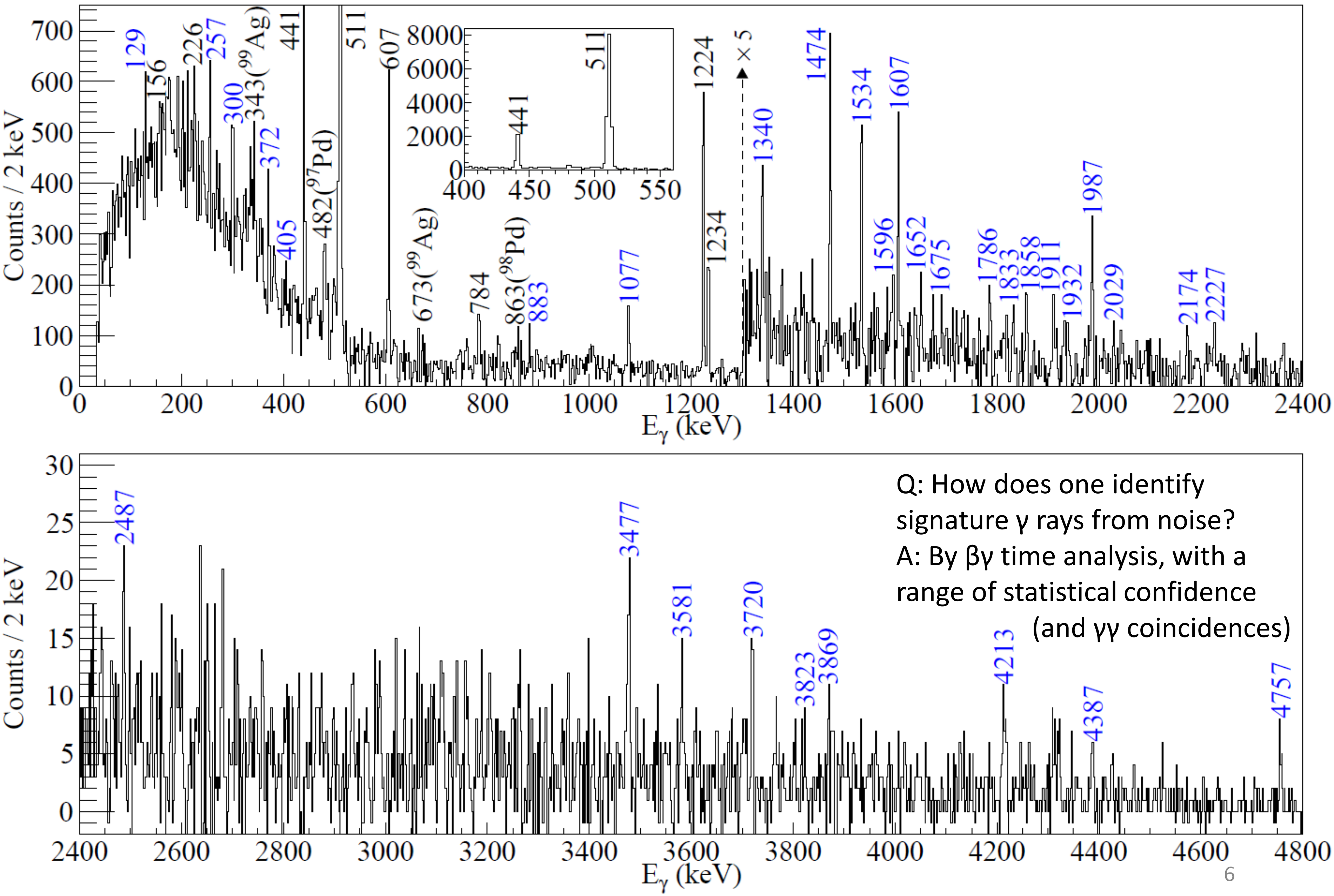
$f(Q_\beta)$ — Partial $T_{1/2}$ (weighted by intensity) — Structure info.

Both beam and target are ≈ A/2 nuclei,
grazing reactions → high-spin states populated

Allowed GT decays populate
ΔJ ≤ 1, Δπ = 0 states

<u>Population of different states in residual/daughter nuclei</u>

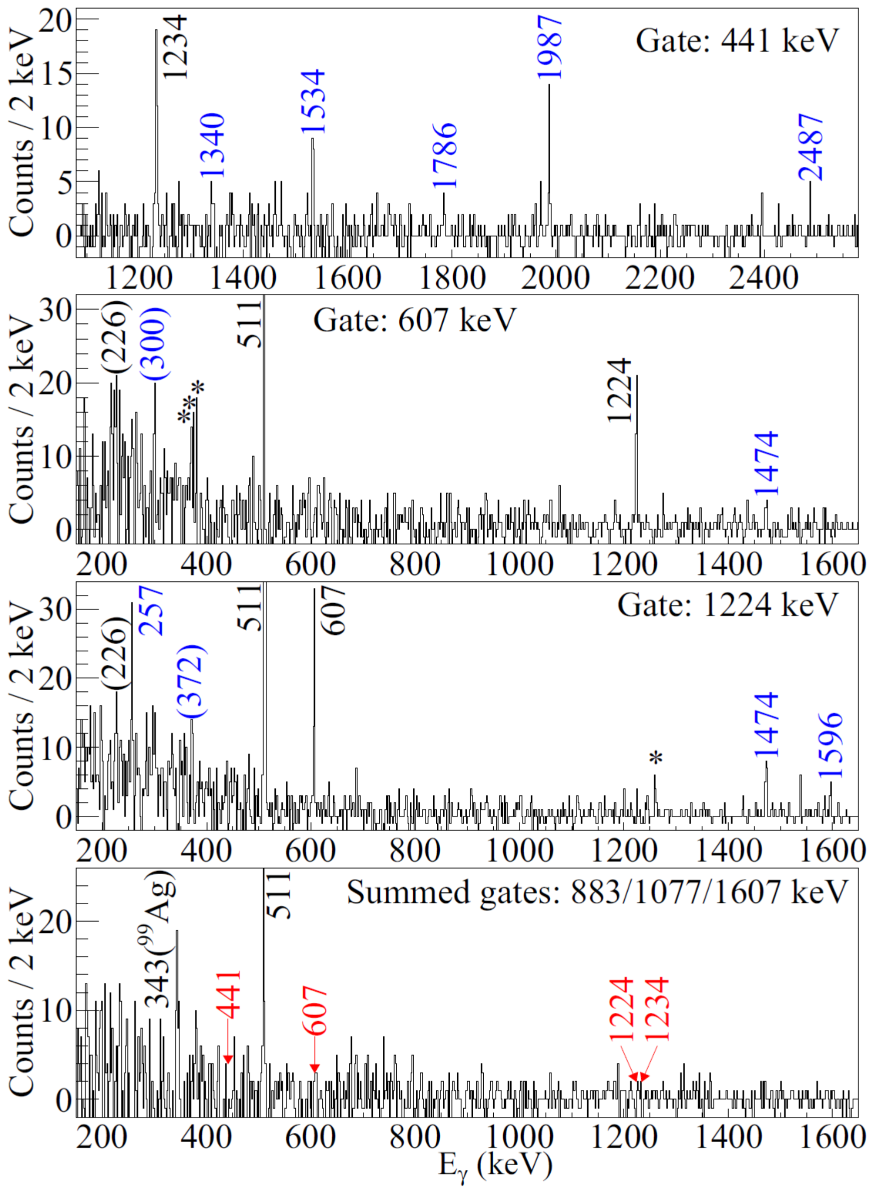
βγ spectra ($^{99}In \rightarrow {}^{99}Cd$), this work

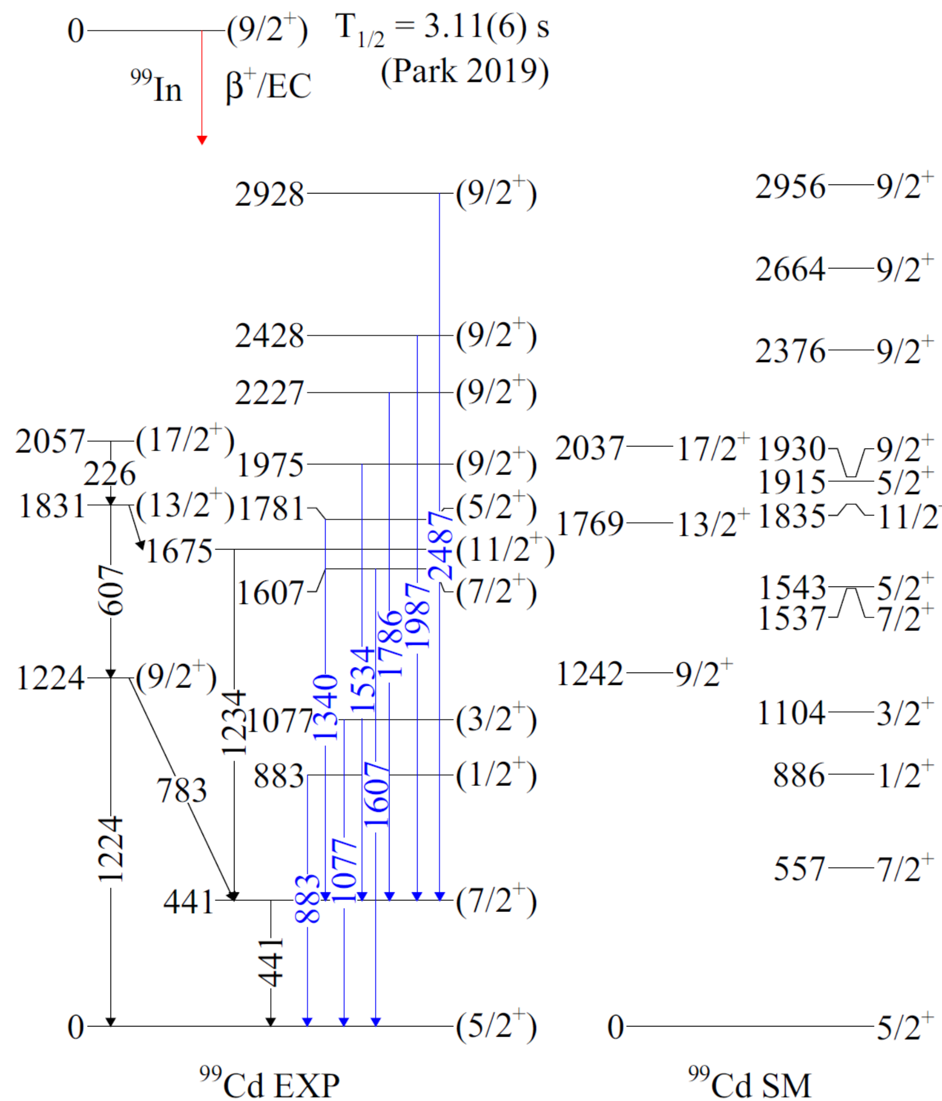


Q: How does one identify signature γ rays from noise?

A: By βγ time analysis, with a range of statistical confidence (and γγ coincidences)

γγ coincidences and level scheme of ^{99}Cd





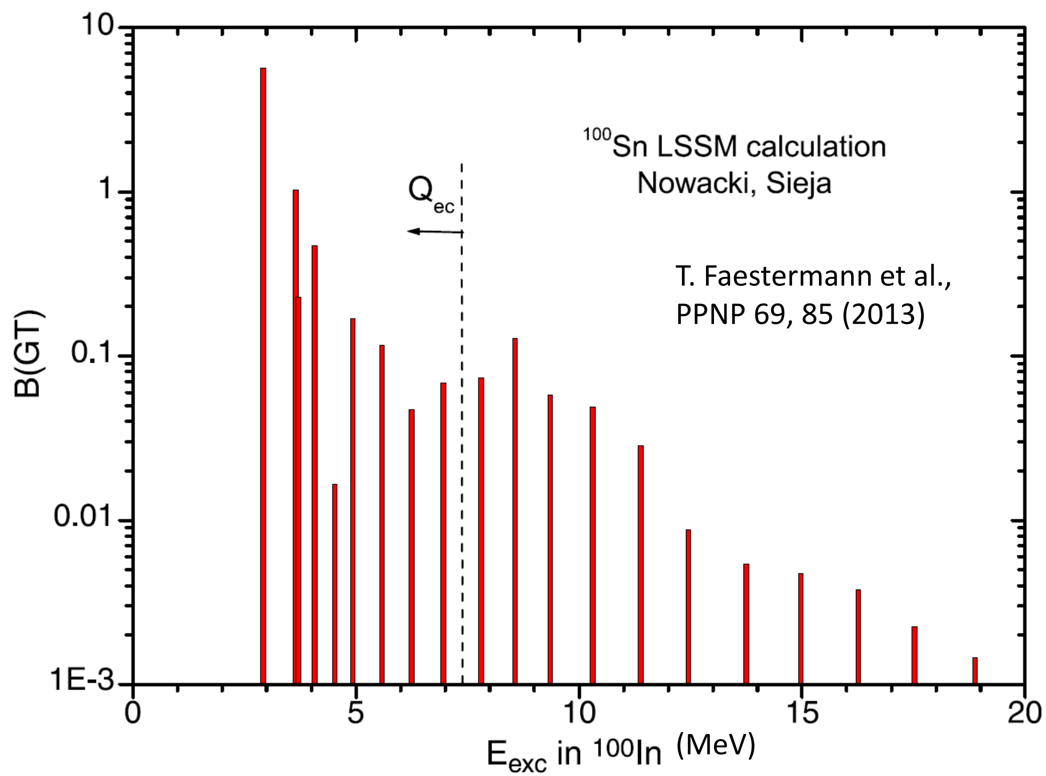
All tentative assignments, many left out

Any other supporting evidence?

Comparing experiment and theory

In β-decay and γ-ray spectroscopy experiments for nuclear structure, the ideal observables are transition strengths. For Gamow-Teller decays:

$$B_{GT} = | < \psi_f | \vec{\sigma}\tau_{\pm} | \psi_i > |^2 = \sum_i \frac{3811.5s}{f_i \cdot t_i}$$



The main difficulty lies with measurements of t_i, the partial decay half-lives (see next)

The Pandemonium effect

Volume 71B, number 2 PHYSICS LETTERS 21 November 1977

THE ESSENTIAL DECAY OF PANDEMONIUM:
A DEMONSTRATION OF ERRORS IN COMPLEX BETA-DECAY SCHEMES

J.C. HARDY *, L.C. CARRAZ, B. JONSON ‡ and P.G. HANSEN ‡
CERN, Geneva, Switzerland

Monte-Carlo simulation of decay of a hypothetical nucleus “Pandemonium” with controllable inputs revealed flaws in βγ experiments

Finite γ-ray detection efficiency and small branching ratios inevitable
→ Biased beta-decay intensities of the strongest branches, and thus B_{GT}

Possible remedy via total absorption spectroscopy (TAS) with higher sensitivity and efficiency

Challenges of TAS: background contamination, energy resolution, etc

Extrapolating theory down to $I_{\beta\gamma}$

Part A:

Theoretical B_{GT} values + mass difference (Q_{EC}) + final states' E_x
→ $T_{1/2}$ value, b_β distribution

Some of the masses of the most exotic isotopes have to be taken from SM, mass models, etc

Uncertainty estimates using RMS deviation of final state energies of models, typically on the order of 100 keV or 10% for empirical SM on the most exotic nuclei

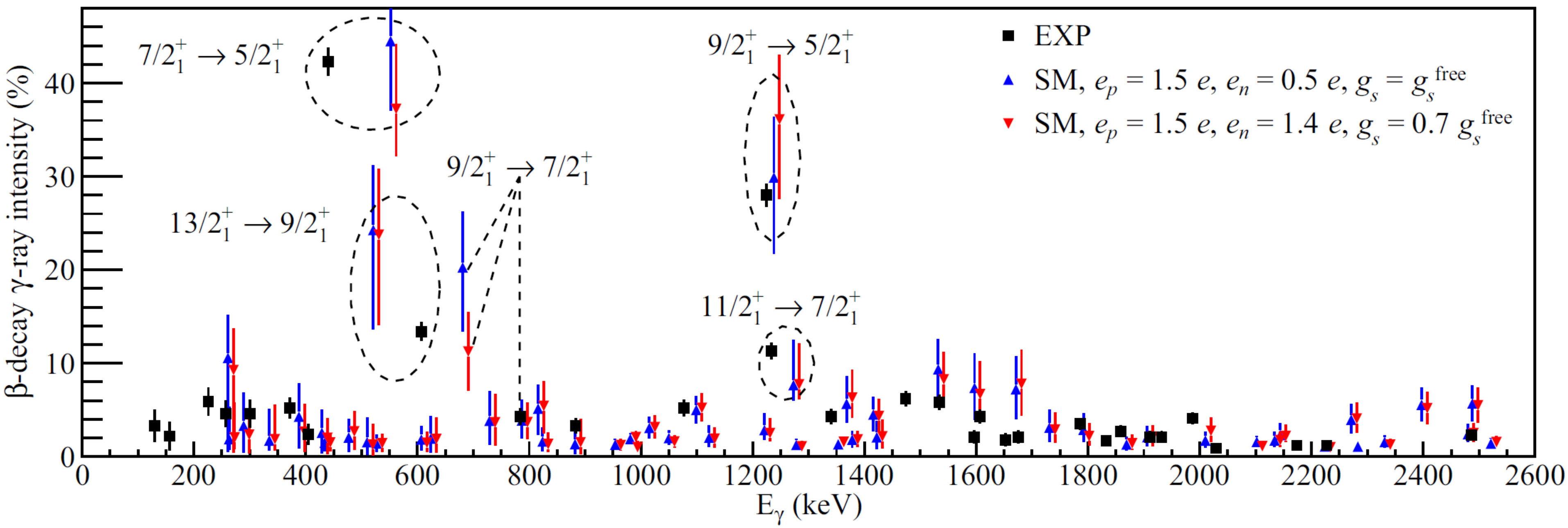
Part B:

Theoretical B(EL), B(ML) values of inter-state transitions + energies of γ rays
→ Distribution of γ-ray branches from state A to states B_i, already implemented in most calculations

Uncertainties also calculated via $\Delta|E_i - E_f|$ perturbation, and variations in effective charges

Combine parts A and B by funneling theoretical β and γ branches down to the ground state, with proper uncertainty propagation

γ-ray intensity comparison, ^{99}Cd



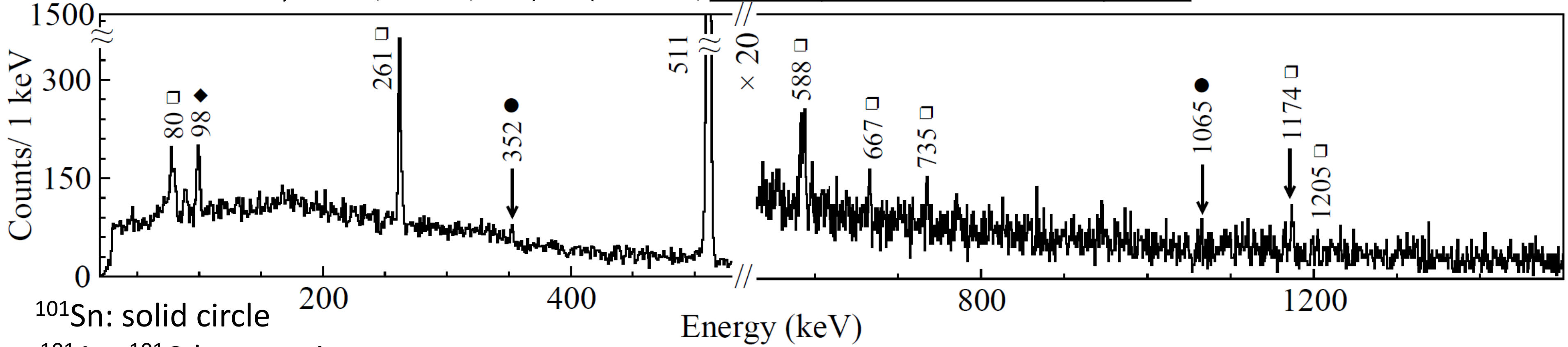
General agreement of the strongest γ-ray intensities from β decays from SM calculations:

- ^{88}Sr core (Z = 38, N = 50)
- Proton $p_{1/2}$, $g_{9/2}$ and neutron $d_{5/2}$, $g_{7/2}$, $d_{3/2}$, $s_{1/2}$, $h_{11/2}$ orbitals as valence space

No significant disagreements of the weaker γ-ray branches

βγ spectra ($^{101}Sn \rightarrow {}^{101}In$), literature

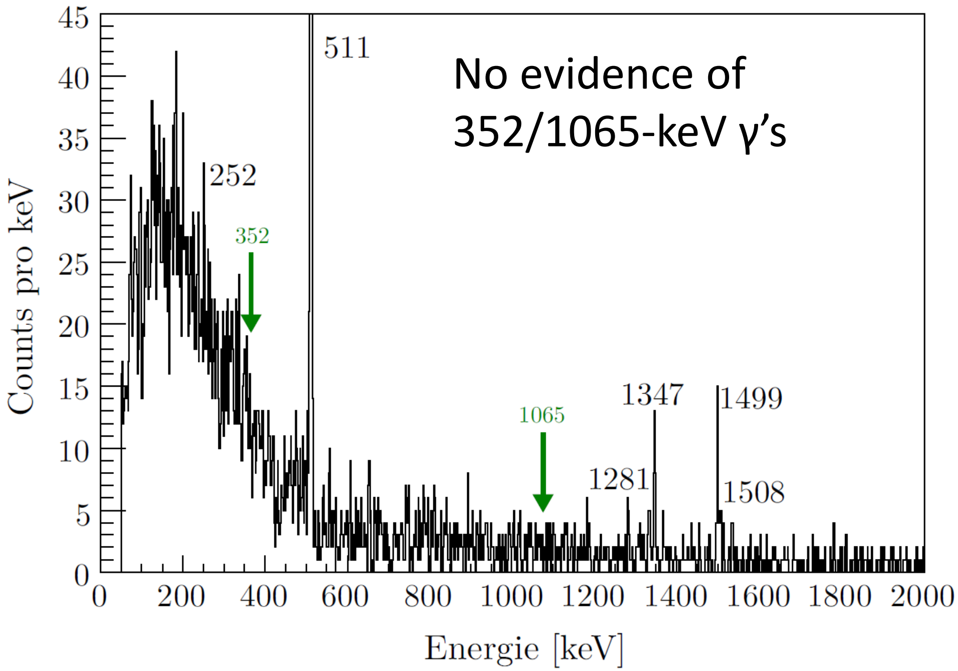
O. Kavatsyuk et al., EPJA 31, 319 (2007) from GSI, fusion evaporation and ion source separation

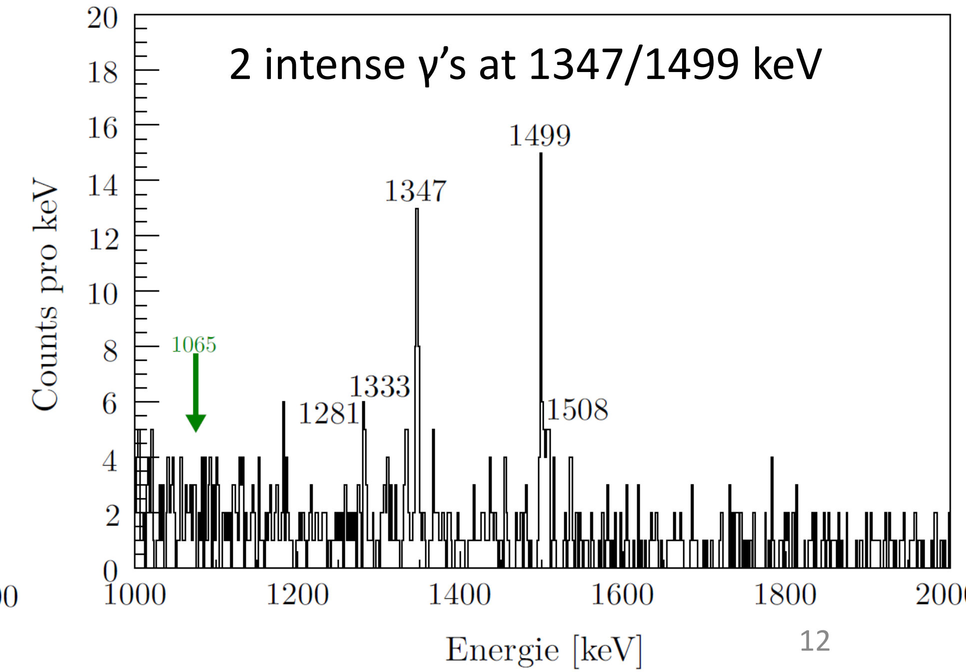


^{101}Sn: solid circle

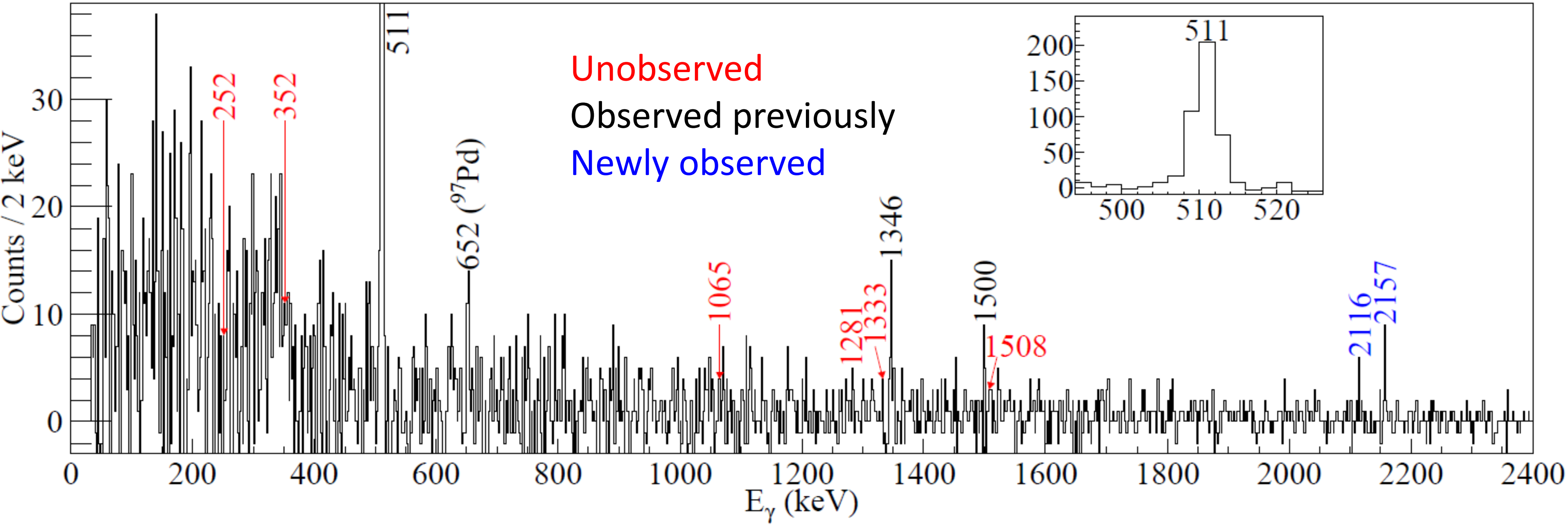
^{101}Ag, ^{101}Cd contaminants

K. Straub, PhD thesis (TU Munich, 2010) from GSI RISING campaign for ^{100}Sn, fragment separation for PID; much cleaner separation!





βγ spectra ($^{101}Sn \rightarrow ^{101}In$), this work



Affirmed two γ rays at 1346 and 1500 keV and two new γ rays at higher energies

Inconclusive on many other transitions, 252-keV γ belongs to the granddaughter ^{101}Cd

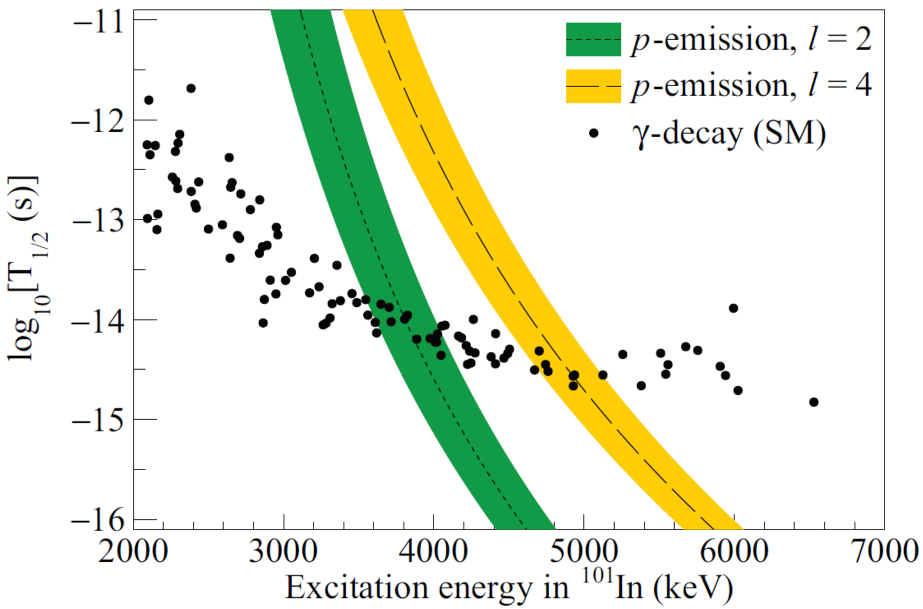
[M. Huyse et al., ZPA 330, 121 (1988)]

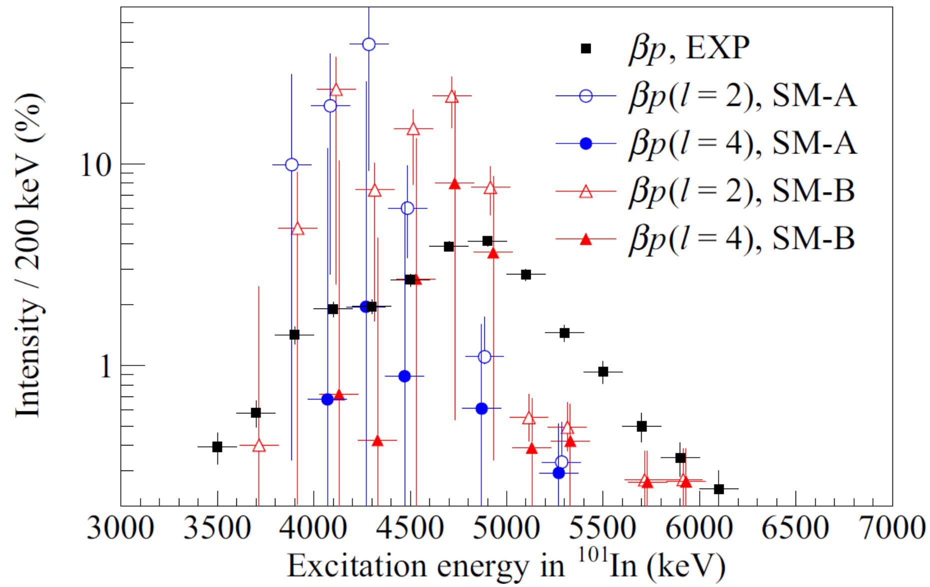
Statistically challenging even more than the prized ^{100}Sn, despite having been produced at least 4 times more… Why?

Combination of:

- Non-negligible β-delayed proton emission branch (~20%) to ^{100}Cd instead
- Fragmented β-decay branches
- Absence of low-energy γ rays, where EURICA efficiency is reasonably high

Reproducing βp spectrum from theory





For states with $E_x > S_p$, γ-decay competes with proton emission

Robust theory should be able to reproduce the experimental βp spectrum and branching ratio of ^{101}Sn, which also affects I_γ calculation

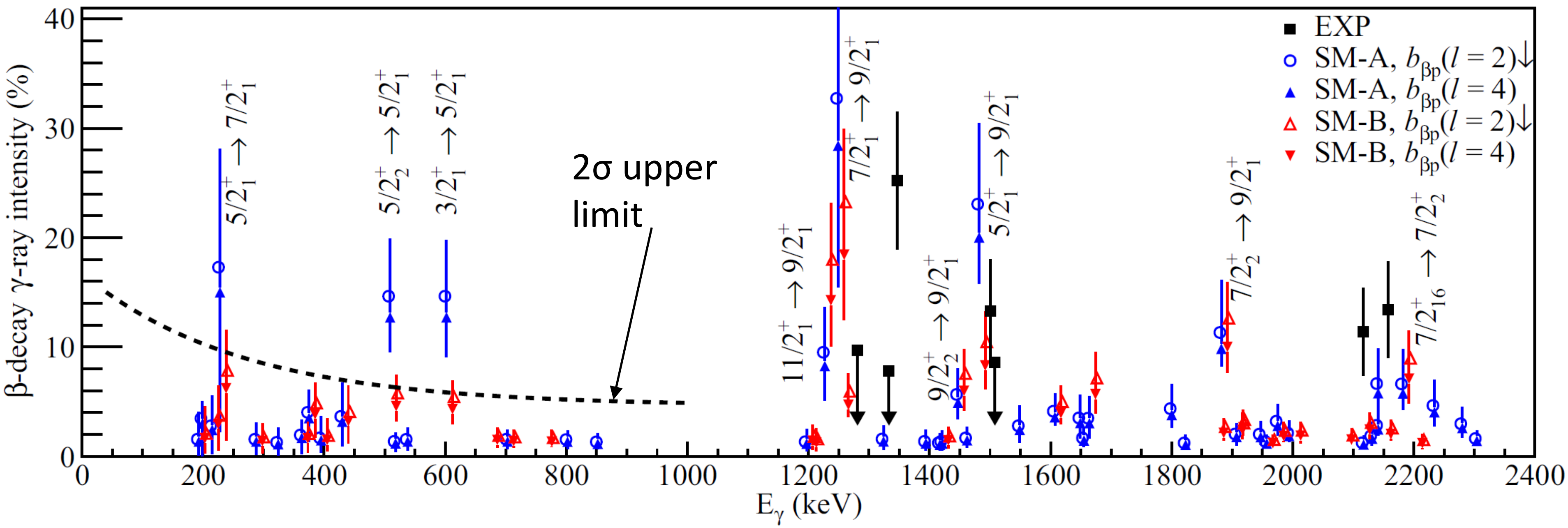
Theories on proton emission by Delion, Liotta and Wyss [Phys. Rep. 424, 113 (2006)] predict partial half-lives as a function of proton energy and angular momentum, etc.

In gds model space above *N* = *Z* = 50, dominant emission from g(*l* = 4) or d(*l* = 2) orbitals

[P. J. Davies et al., PLB 767, 474 (2017)]

Branching ratios predicted within ~50%, distribution at higher energies missing

γ-ray intensity comparison, ^{101}In

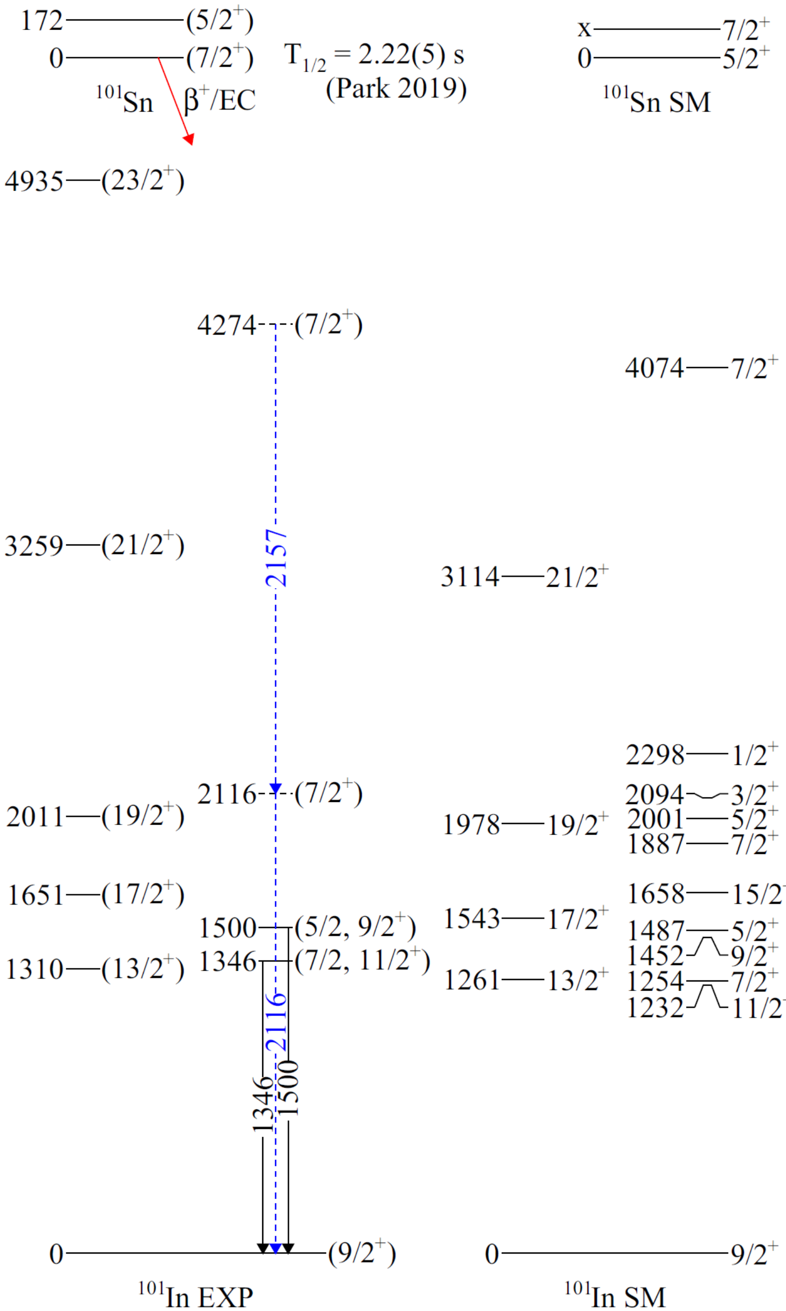


Strongest γ-ray intensities reproduced by theories, taking into account βp branching

SM-A: $J^{\pi}(^{101}Sn) = 5/2^{+}$, SM-B: $J^{\pi}(^{101}Sn) = 7/2^{+}$ assumptions to probe ground state dependence on γ-ray distribution

Some differences, but not convincing enough to accept or reject either scenario; slight favor to the $7/2^{+}$ case based on non-observation of low-energy γ's

Proposed level scheme of ^{101}In



2157-2116 cascade is tentative, only based on SM (coincidence predicted)

Multiple spin candidates for 1346, 1500-keV gamma rays formed by 2-neutron configurations above *N* = 50 shell

Still very uncertain

Summary

Extending theory to compare to limited experimental results in exotic decay spectroscopy of ^{99}In and ^{101}Sn

- From B_{GT} distribution to βp energy spectra
- From excitation energies to γ-cascade schemes
  → infer J^{π} from theory and γγ coincidence relationships
- Theoretical uncertainty estimation crucial

Key requirements on studying the rarest isotopes, when statistics are limited:

- High-purity data → high suppression of background and contaminants
- High-efficiency detector systems → γγ coincidences, for instance
- Capability to distinguish multiple excitation and decay/exit channels:
  β vs βp, βn, β2n, etc