Complete Gamma-Gamma Spectroscopy of ^{152}Tb: a Diagnostic Component of the Terbium Theragnostic Toolbox

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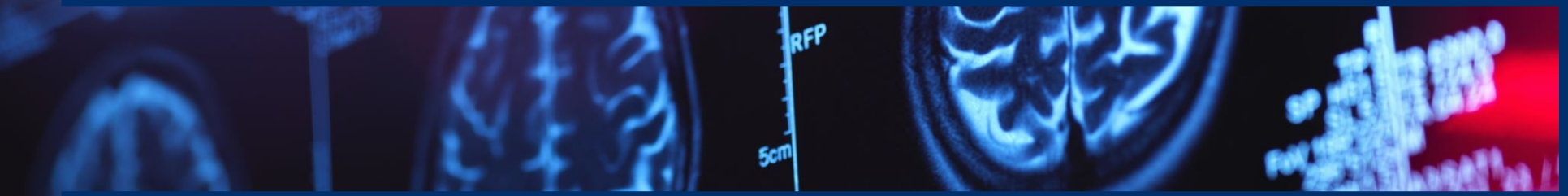
^{152}Tb: Medical Imaging

- β^+ / EC decay to ^{152}Gd – **Positron Emitter**
- Q_{EC} = 3990 keV
- $T_{1/2}$ = 17.8784(95) h
- $I_{\beta+}$ = 20.3% [1]
- Clinical trials show promise in **PET imaging**: 152Tb-DOTATOC and 152Tb-PSMA-617 used successfully in **human patients** [2,3]
- Terbium isotope – applications in **theragnostics**



1) Nuclear Data Sheets for A = 152, M.J. Martin
2) Preclinical investigations and first-in-human application of 152Tb-PSMA-617 for PET/CT imaging of prostate cancer, C. Müller et. al
3) Clinical evaluation of the radiolanthanide terbium-152: first-in-human PET/CT with 152Tb-DOTATOC, R.P. Baum et. al

Theragnostics: Therapy + Diagnostics

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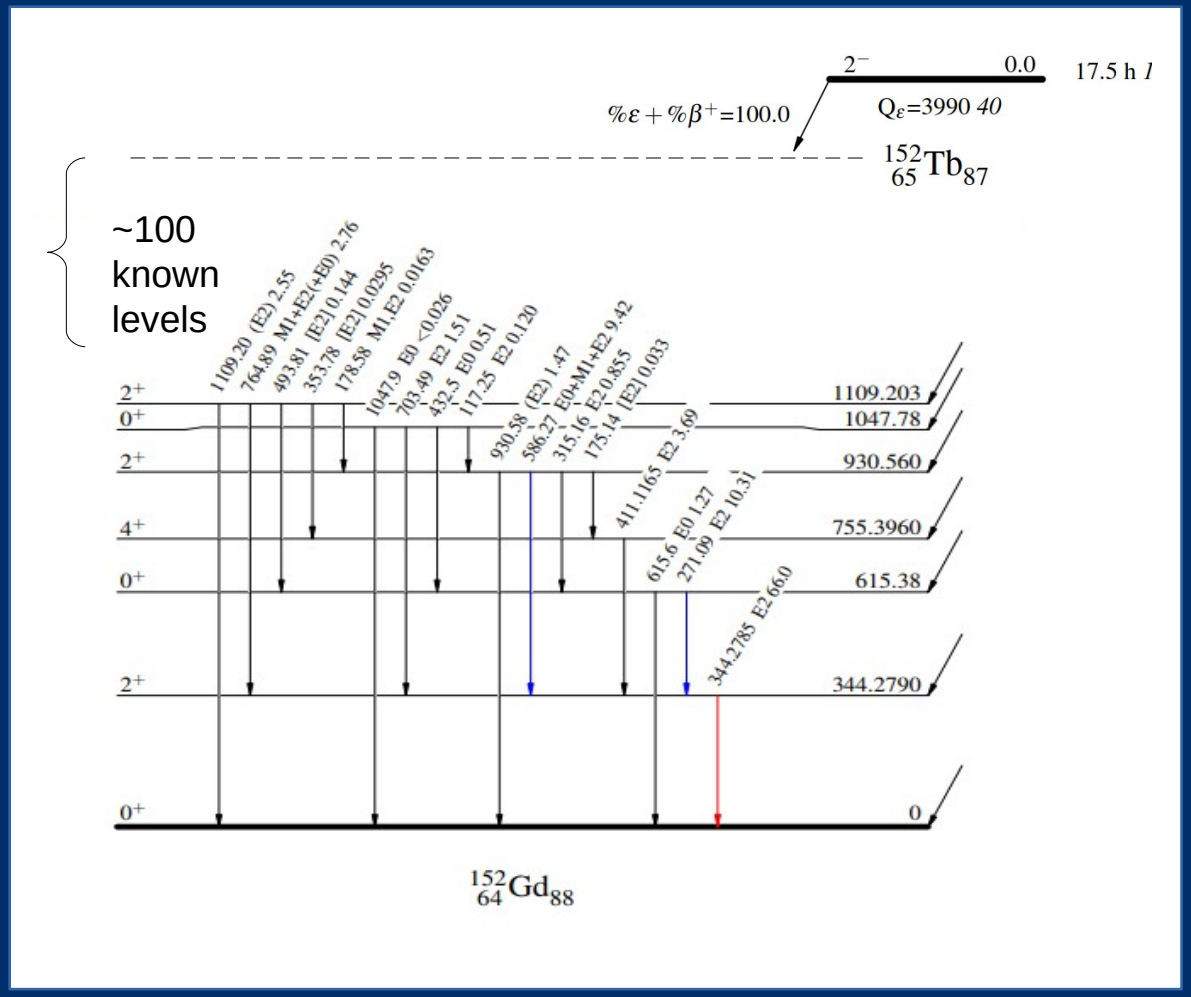
- **Terbium theragnostic quartet**: four different medical uses
- Shared chemistry – compatible with the **same delivery mechanism**
- **Personalised medicine** – dose tailored to individual patients

Isotope	$T_{1/2}$	Decay	Use
^{149}Tb	4.118(25) h [4]	Alpha	Radionuclide Therapy
^{152}Tb	17.8784(95) h [5]	Beta+ / EC	PET Imaging
^{155}Tb	5.2346(36) d [6]	EC	SPECT Imaging
^{161}Tb	6.9637(29) d [7]	Beta-	Radionuclide Therapy

4) PRISMAP Radionuclide Portfolio, https://www.prismap.eu/radionuclides/portfolio/149Tb
5) Determination of the Terbium-152 Half-Life from Mass-Separated Samples from CERN-ISOLDE and Assessment of the Radionuclide Purity, S.M. Collins et. al
6) Half-life determination of 155Tb from mass-separated samples produced at CERN-MEDICIS, S.M. Collins et. al
7) Determination of the 161Tb half-life, S.M. Collins et. al

Nuclear Data: ^{152}Gd

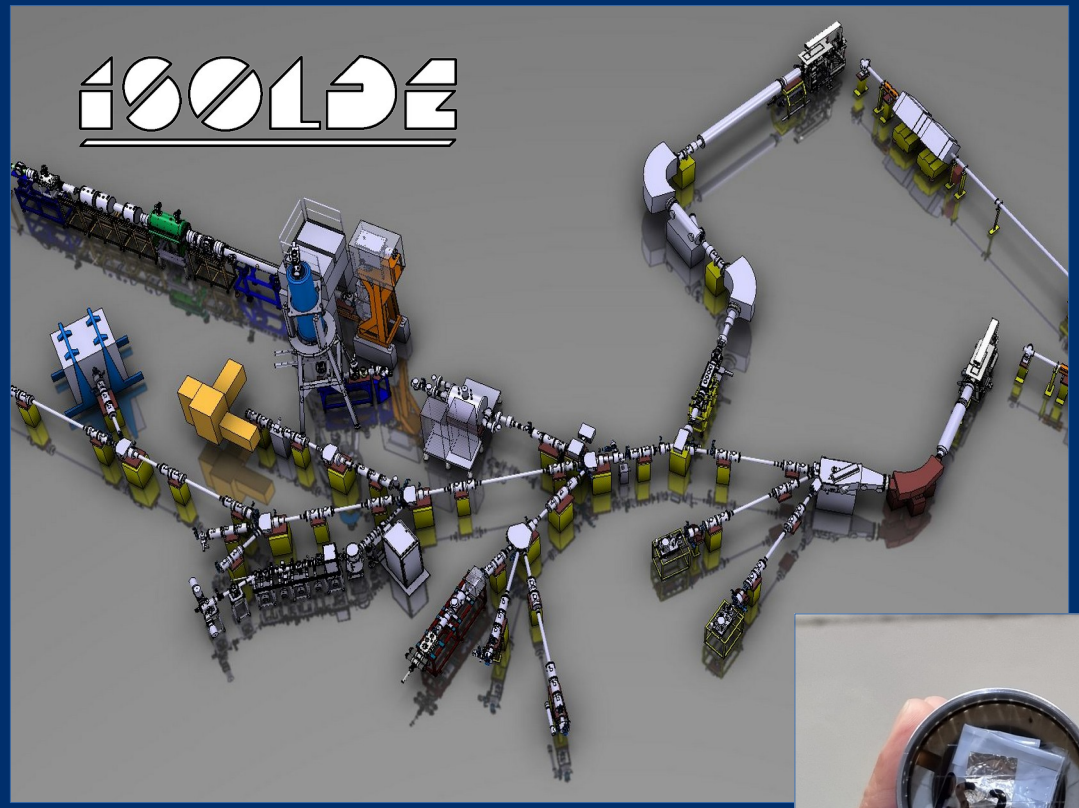
- ^{152}Tb → ^{152}Gd decay **last studied in 2003,** using a **pair of HPGe detectors** [8]
- Highest energy level identified at 3358 keV – **600 keV below Q_{EC}**
- 248 out of 635 known transitions **unplaced**
- Pandemonium effect: unknown high energy states leads to **overestimate of beta dose**, for example in ^{86}Y [9].



8) Properties of 152Gd Collective States, J. Adam et. al
9) State-of-the-art γ-ray assay of 86 Y for medical imaging, A.C. Gula et. al.

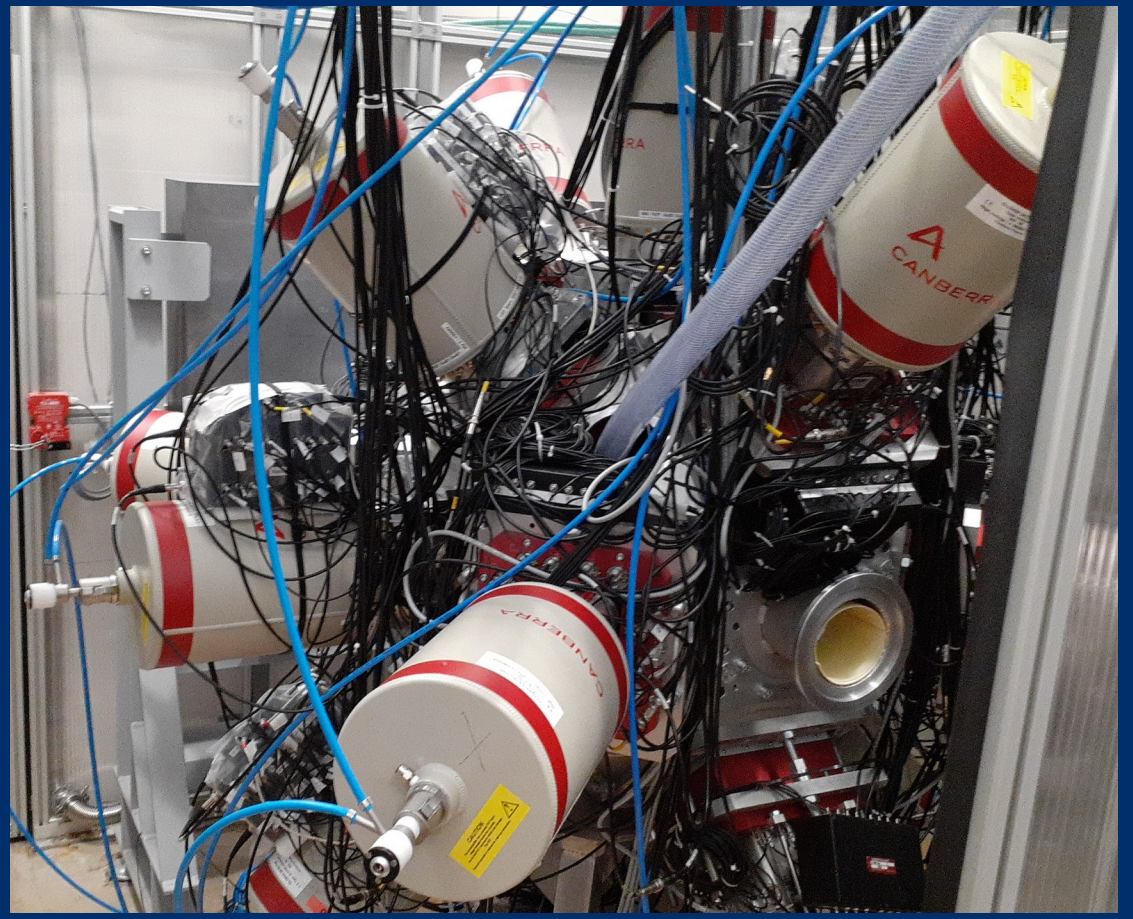
^{152}Tb Decay Spectroscopy

- Sources prepared at CERN ISOLDE: **1.4 GeV proton beam** on a tantalum target
- Samples purified by **mass separation** and implanted onto a pair of Al/Mylar foils
- Delivered to ILL Grenoble for measurement: **111 kBq** at start of experiment (3rd May 2023)



Gamma-Gamma Spectroscopy

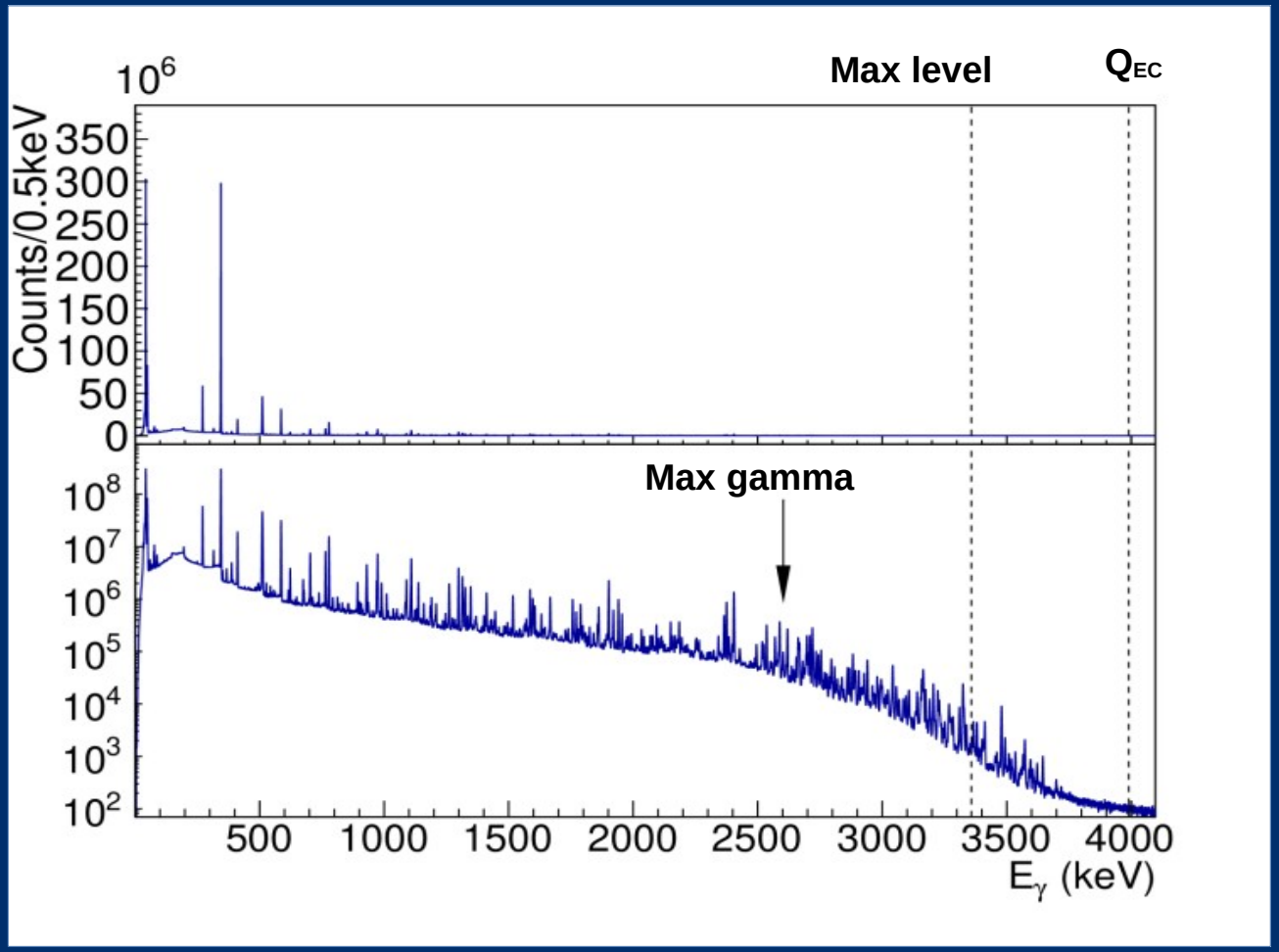
- FIssion Product Prompt Gamma-Ray Spectrometer (FIPPS) [10]
- **64 HPGe crystals**, 16 clovers with BGO shielding (14 crystals excluded)
- Absolute efficiency ~5.6% at 344 keV
- **48 hours** measurement time
- (Electron-Gamma spectroscopy carried out in parallel – PN1)



10) FIPPS (FIssion Product Prompt γ-ray Spectrometer) and its first experimental campaign, C. Michelagnoli et. al

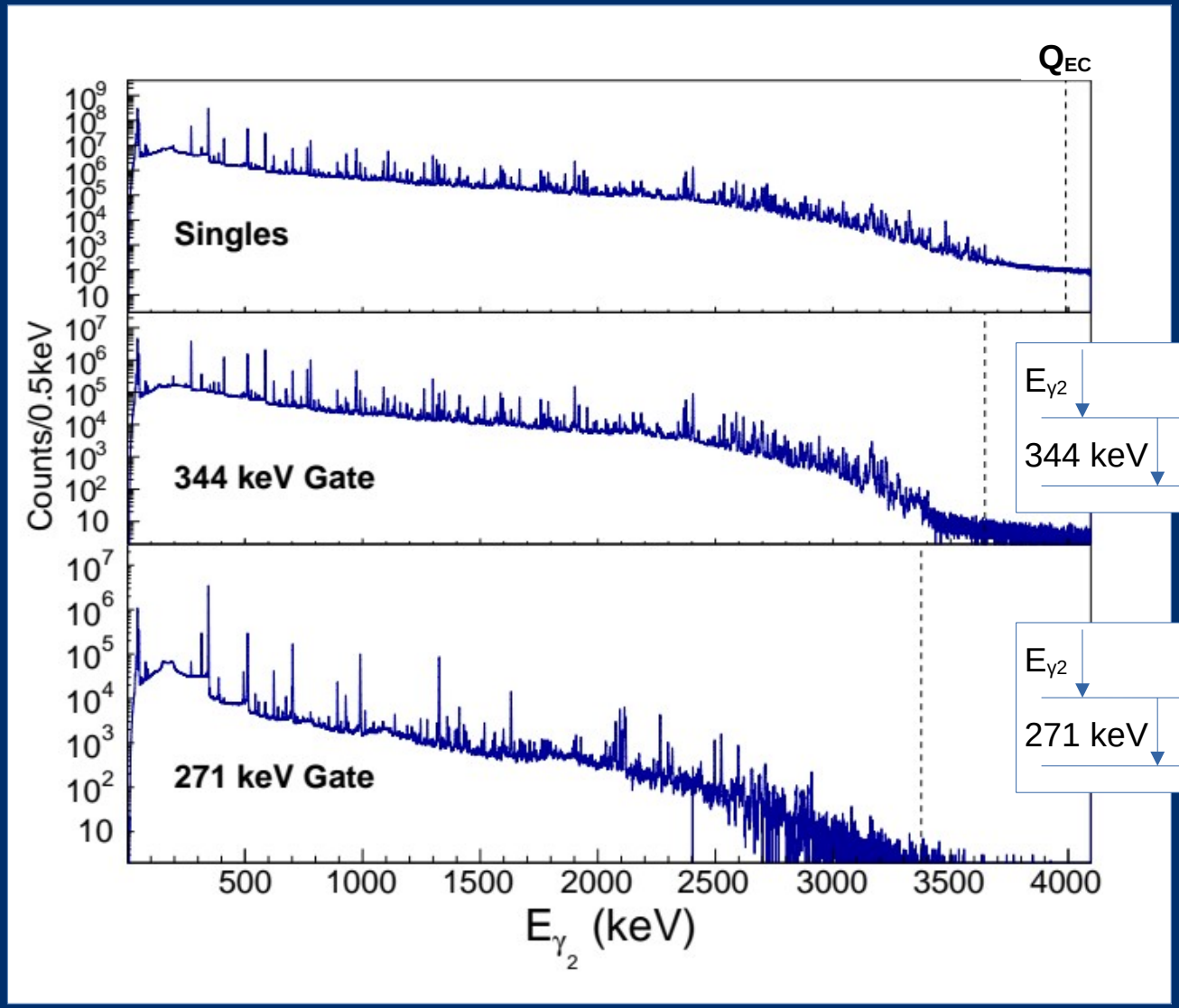
Singles Spectra

- **1.5e10 single events** collected from source 2 (~70% of the total)
- Highest energy gamma previously placed: **2603 keV**
- Highest energy state previously identified: **3358 keV**
- Q_{EC} = **3990 keV**



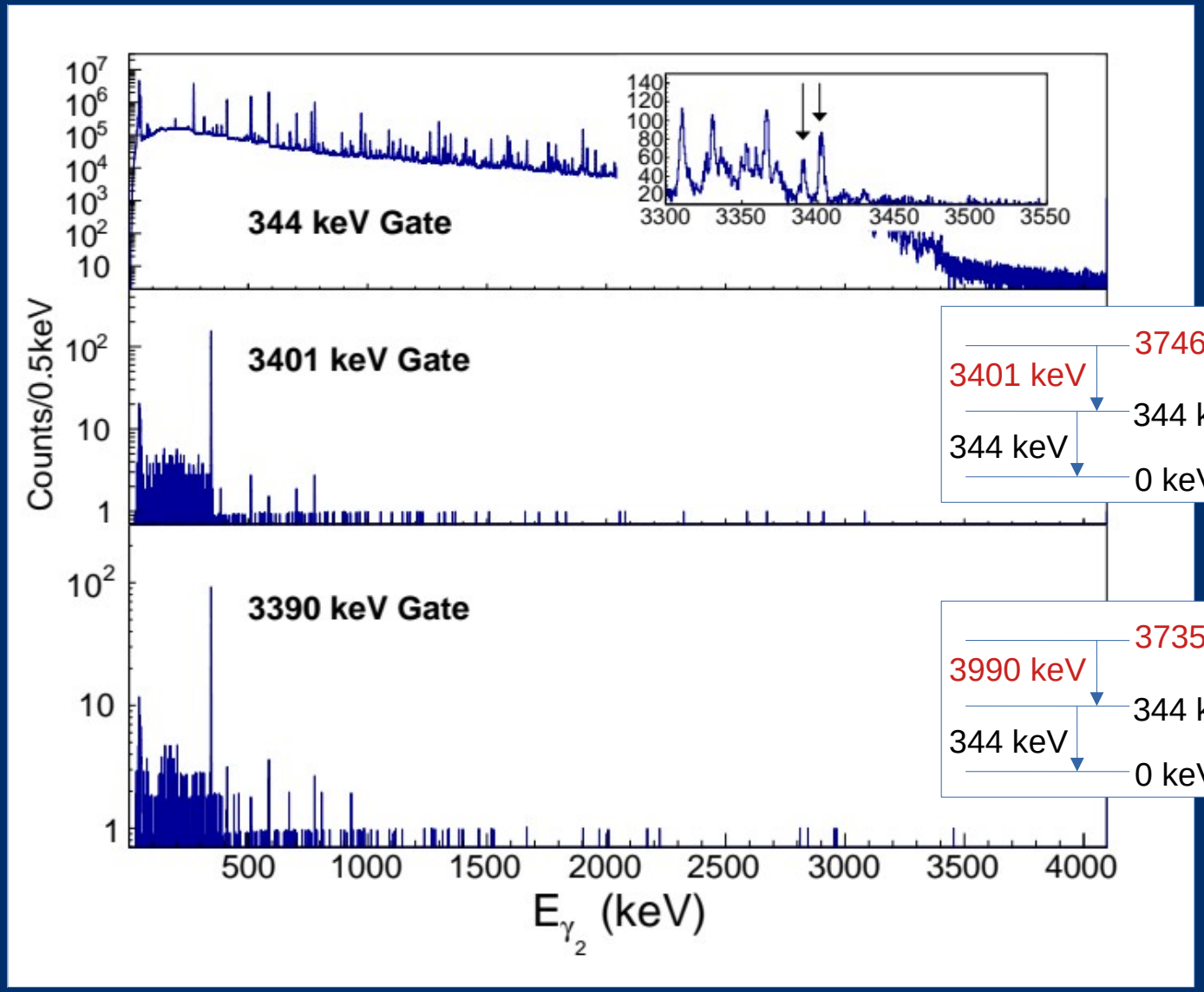
Coincidence Analysis

- **4.5e9 coincident events** (window of 120 ns)
- New levels identified by **“gating from below”**
- **Compton background subtracted** from gates



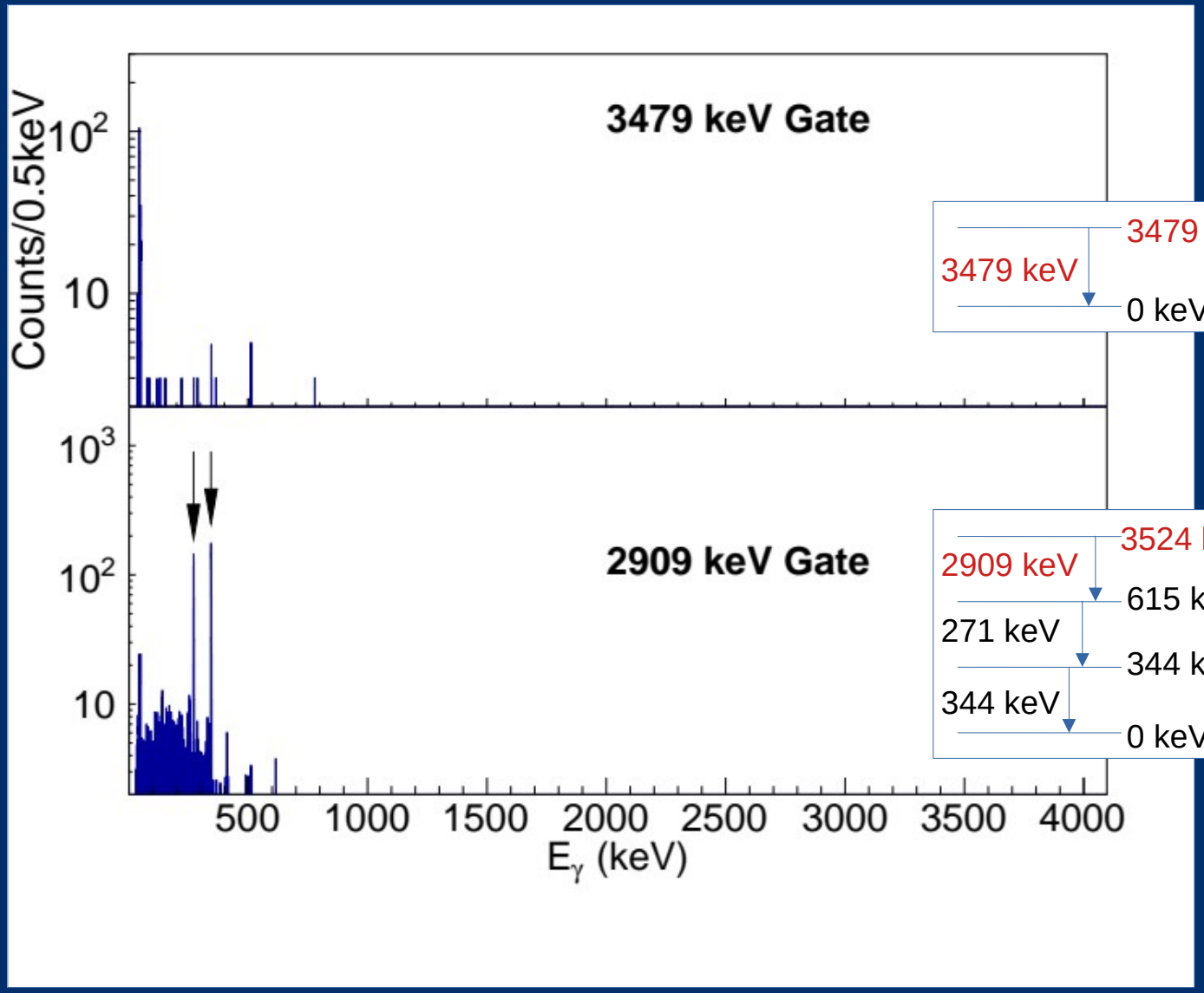
Placing New Transitions

- Verify placement of previously unidentified transitions by **reversing the gating**
- The **entire de-excitation cascade** should appear in the coincidence gate
- Highest energy state previously identified: 3358 keV



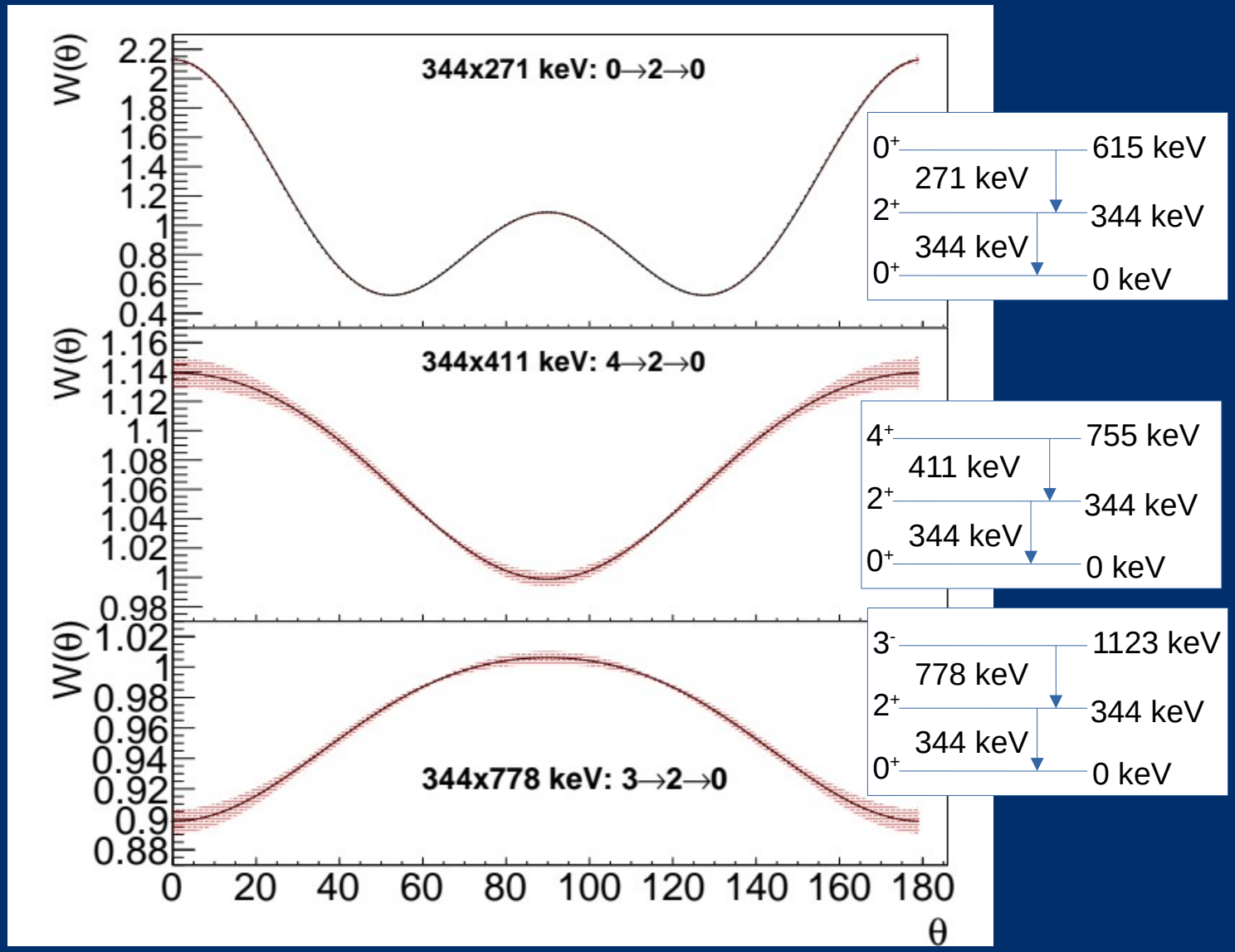
Placing New Transitions

- Straight to ground transitions only in coincidence with x-rays
- Cascades may involve intermediate levels



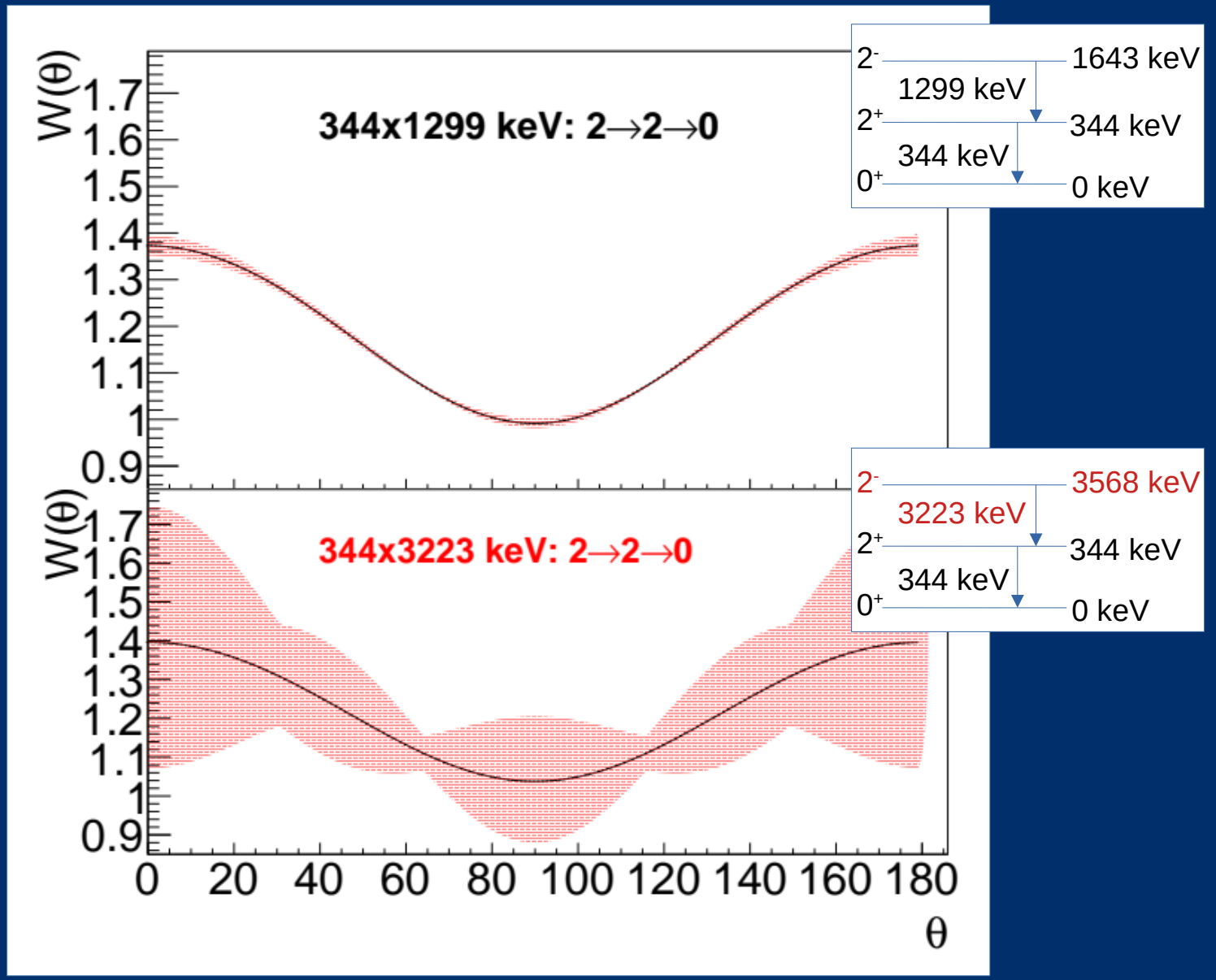
Angular Correlation Analysis

- Use angular correlations to **assign spin and parity** to previously unidentified levels
- Angular momentum transfer in the decay determines **angular distribution** of emitted gamma rays
- Probe this distribution using coincidences between **different detector pairs**



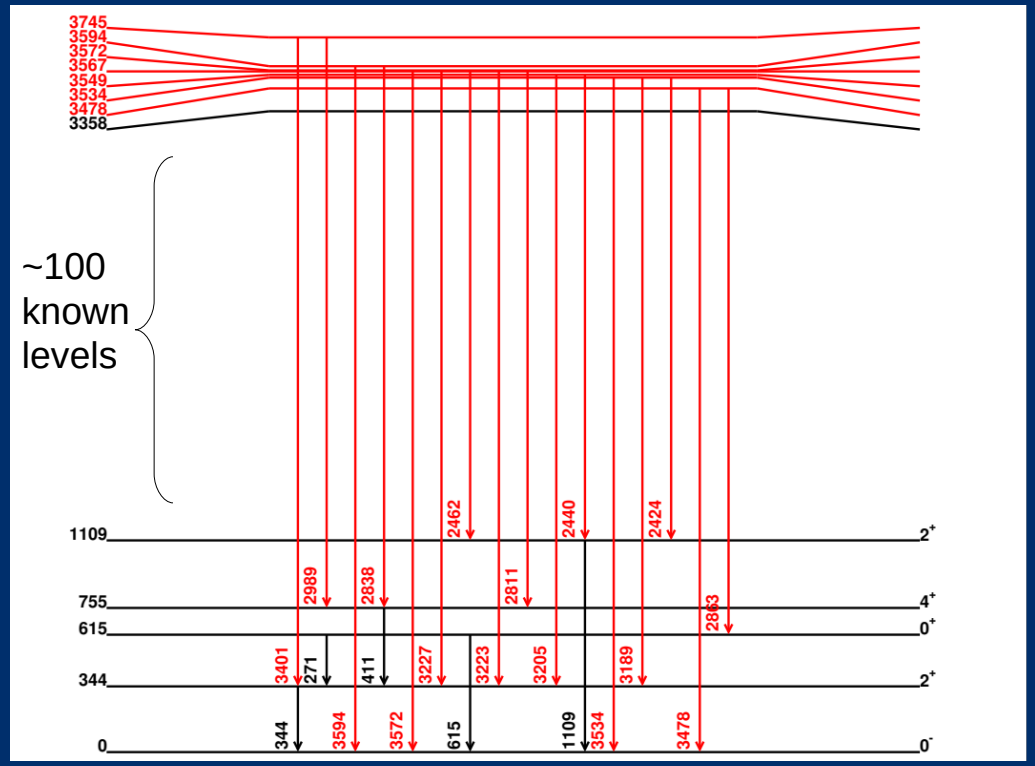
Spin/Parity of New States

- ^{152}Tb ground state has $J^{\pi}=2^-$
- “Allowed” beta decays populate $1^-,2^-,3^-$ in ^{152}Gd
- 2^- to 0+ ground state **M2**
- 2+ to 0+ **E2**
- **No ground state transition** (3568 keV) seen: assign negative parity



Preliminary Results + Future Work

- Over **50 new transitions** placed so far, including to **19 previously unidentified levels**
- Further preliminary placements not reported – only **multiply placed levels** included
- Transition intensities require **Monte Carlo simulations** to validate efficiency curve
- **Electron-Gamma data**: measurements of internal conversion coefficients and E0 transitions – supports spin/parity assignments and measures “missing” intensity



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References:

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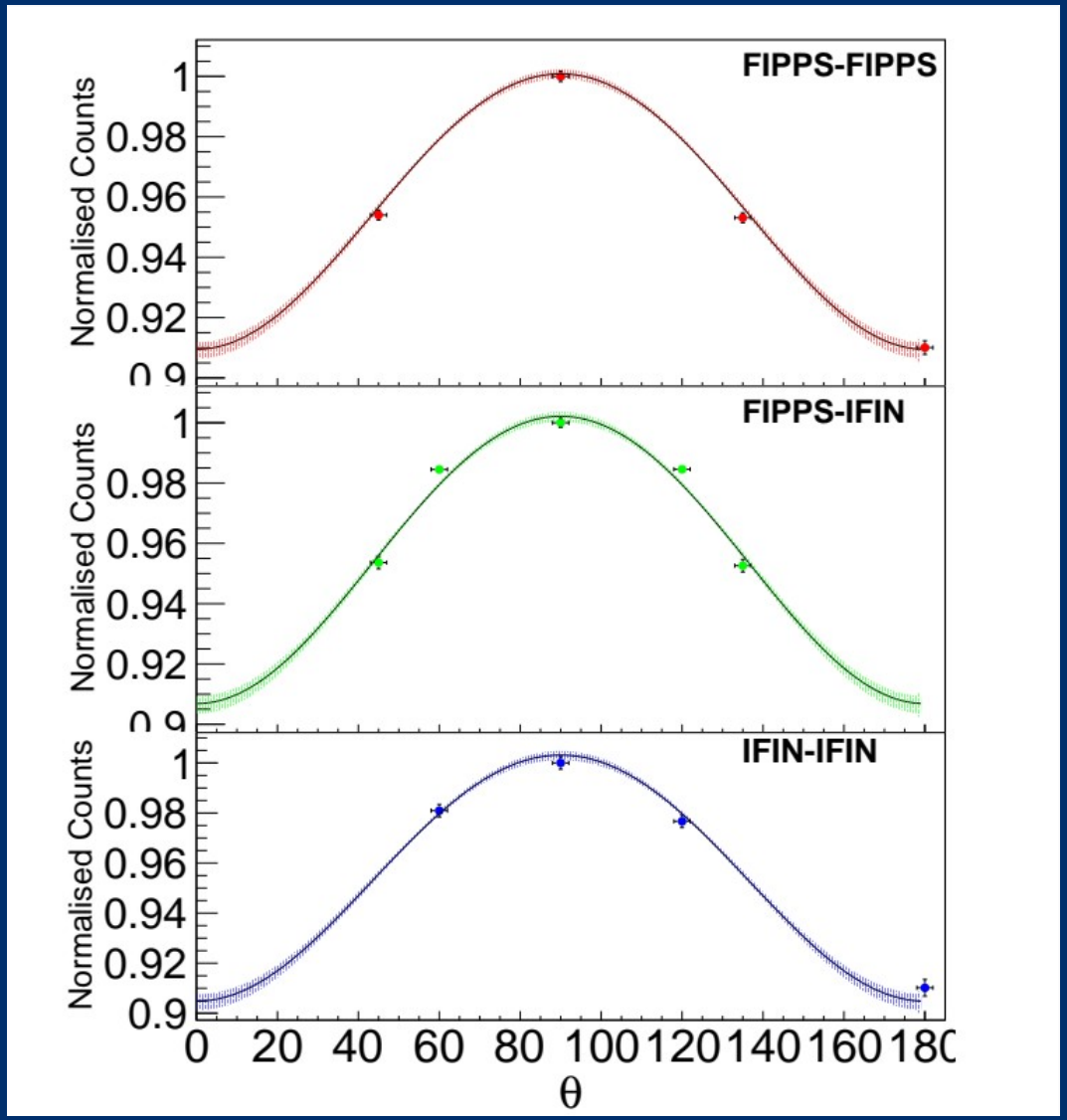
NEUTRONS FOR SOCIETY

ISOLDE

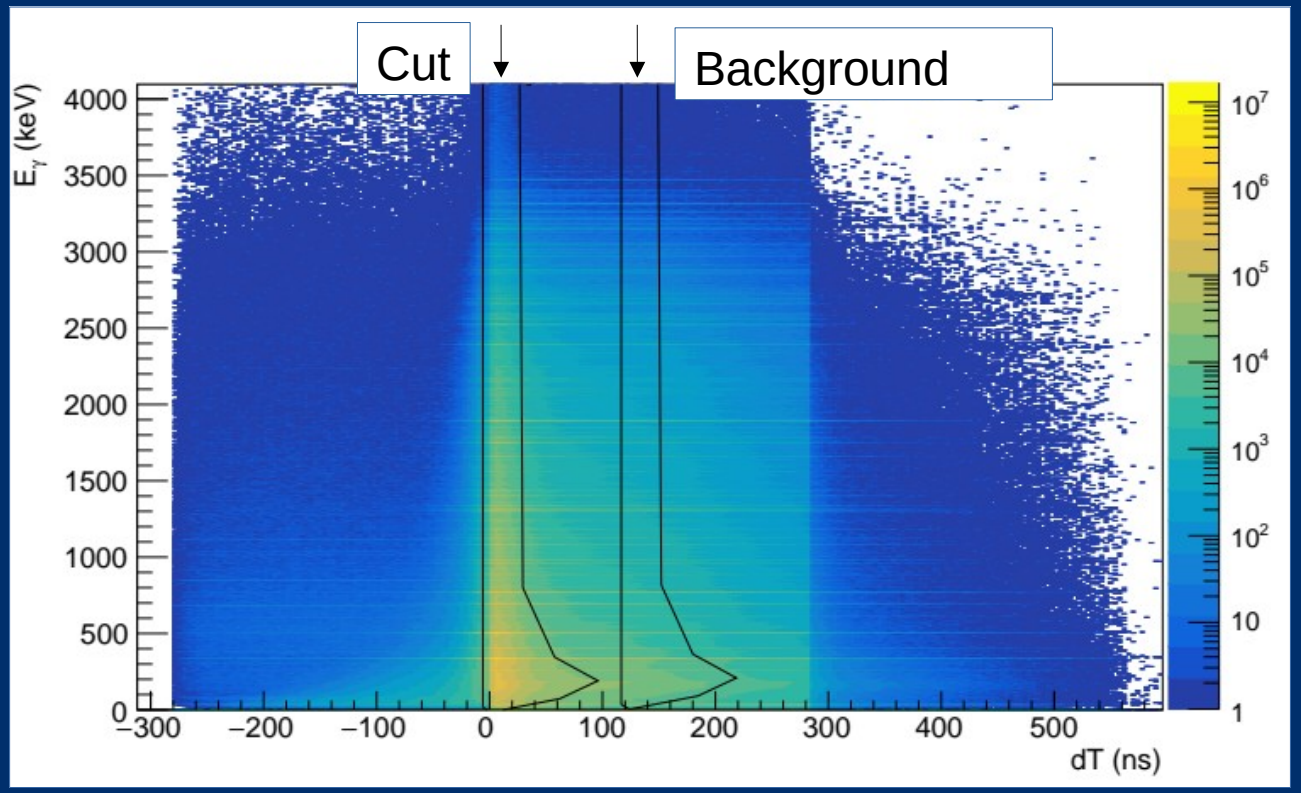
27 EU PRISMAP Medical Radionuclides

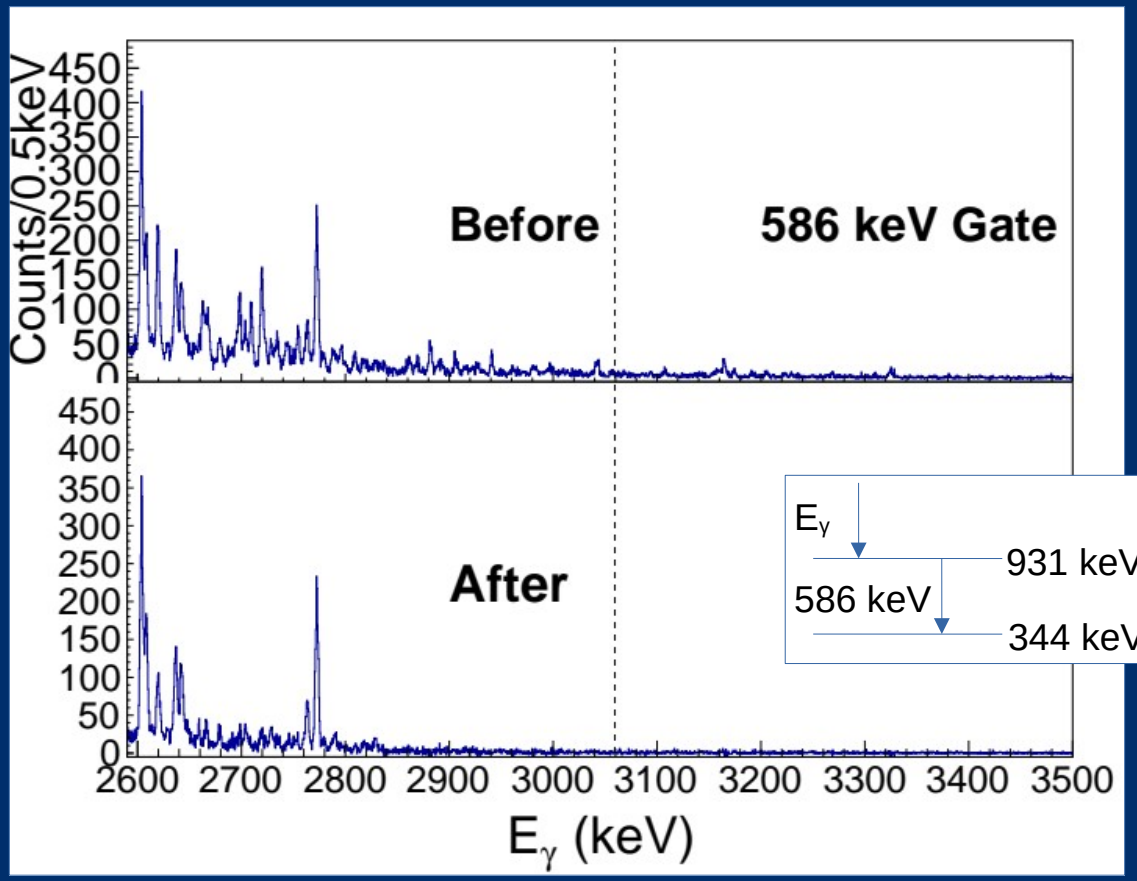
Extra Slide: Angular Correlation Minimisation

- Two HPGe detector types – three possible pairings, 6 possible angles
- Fit overall angular correlation function by simultaneously minimising three distributions



Extra Slide: Prompt Time Cut





- Select only gammas within 40 ns window – **emitted from same nucleus**
- Offset window 100 ns to **sample background** for subtraction
- **Random coincidences removed**