Physics Opportunities and Functional Requirements for “Offline” γ-ray spectrometers

C.J. Lister
Argonne National Laboratory

Even at an “Equipment” meeting….Physics First !

What will we be measuring with RIA?

Current examples of “Offline” γ-spectroscopy

Functional Requirements for the future

Conclusions

What are the physics challenges at RIA?

Determine Spin-Orbit splitting.

Quantify Residual Interactions / Correlations

Measure Wavefunction Purity

Determine Strength Functions

Properties of poorly-bound states.

Devil is in the detail:

Look for NON YRAST states

Need DETAILED investigation of state wavefunctions.

Usually with very low intensity beams

Fine structure at the proton dripine

Proton decay spectroscopy has evolved from a dripline curio to a precise and detailed tool for probing nuclear wavefunctions

Theory has evolved to cover

Spherical

Deformed

Vibrational

Odd-odd

Triaxial Nuclei.

More complicated cases (e.g. odd-odds) need more than groundstate decay for clear interpretation

Often, the combination of groundstate and excited state decays can allow the parent to be unambiguously identified

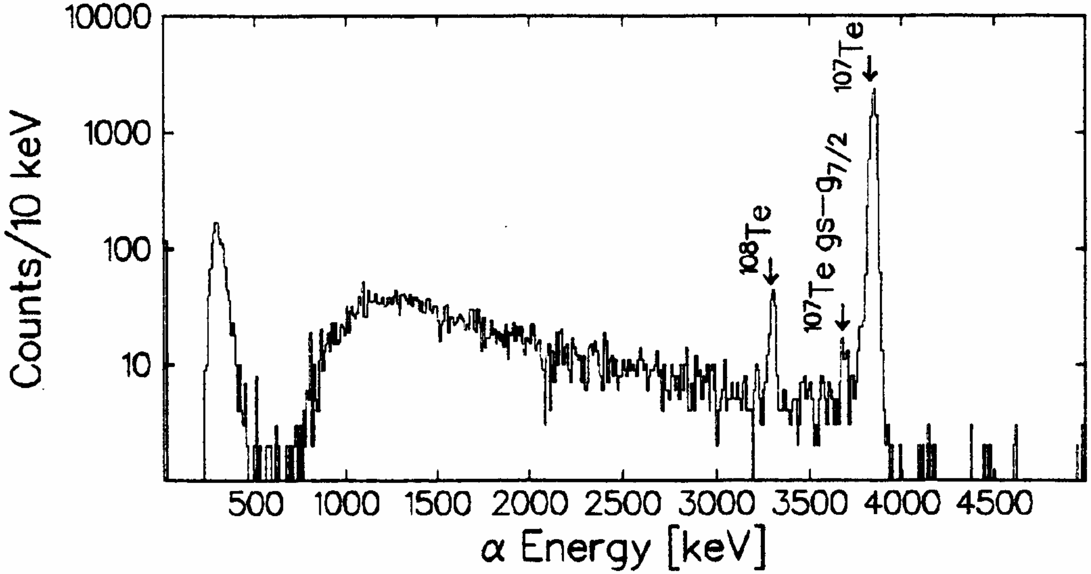
Fine structure following alpha decay

RAPID COMMUNICATIONS

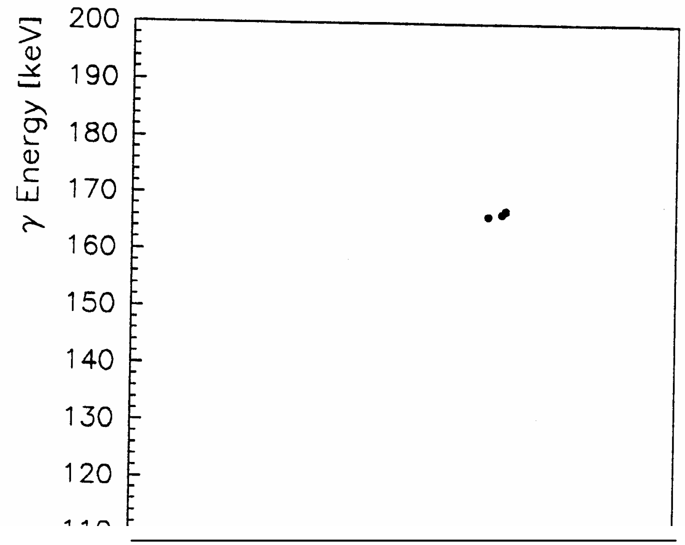
PHYSICAL REVIEW C **66**, 051307(R) (2002)

Population of the 168-keV ($g_{7/2}$) excited state in ^{103}Sn in the α decay of ^{107}Te

D. Seweryniak,[1] W. B. Walters,[2] A. Woehr,[2] M. Lipoglavsek,[3] J. Shergur,[2] C. N. Davids,[1] A. Heinz,[1] and J. J. Ressler[2]



Complicated α- and γ-
"singles spectra



α-energy

"Background-free" α–γ correlation allows absolutely unambiguous assignment.

Very Heavy Elements (Z > 100)

What can we learn about nuclear structure when the production cross-section is nb (10^{-37} m^2) or even pb?

Even with GRETA, “In-Beam” spectroscopy becomes VERY difficult.

But many of the decays have α-decay “Fine-structure”.

Which can be detected quite efficiently.

And α–γ correlations, together with α-hindrance factors, can pin down the identification of Nilsson states near the Fermi Level.

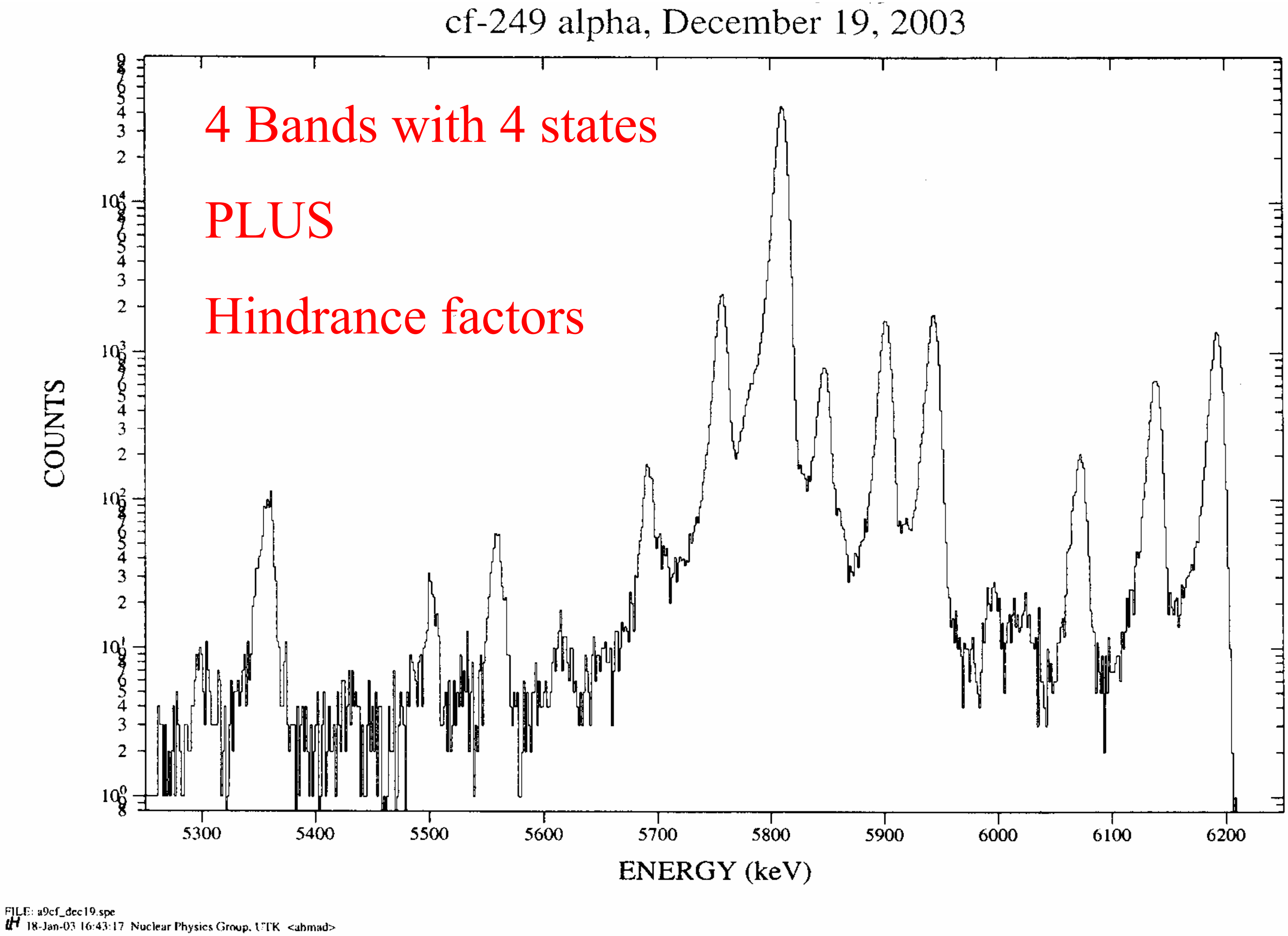
The Case of ^{249}Cf Decay

(I. Ahmad et. al. ANL 2003)

4 Bands with 4 states

PLUS

Hindrance factors



Beta Decay

A powerful though recently quite neglected tool.

A beautiful complement to “In-Beam” spectroscopy.

Populates “Non Yrast” states well

Low spin (Δ J = 0,1) Selection rules favored

Range of accessible states INCREASE as you move away from stability

Technical Drawback for very low production channels:

Finding an efficient and channel-specific trigger.

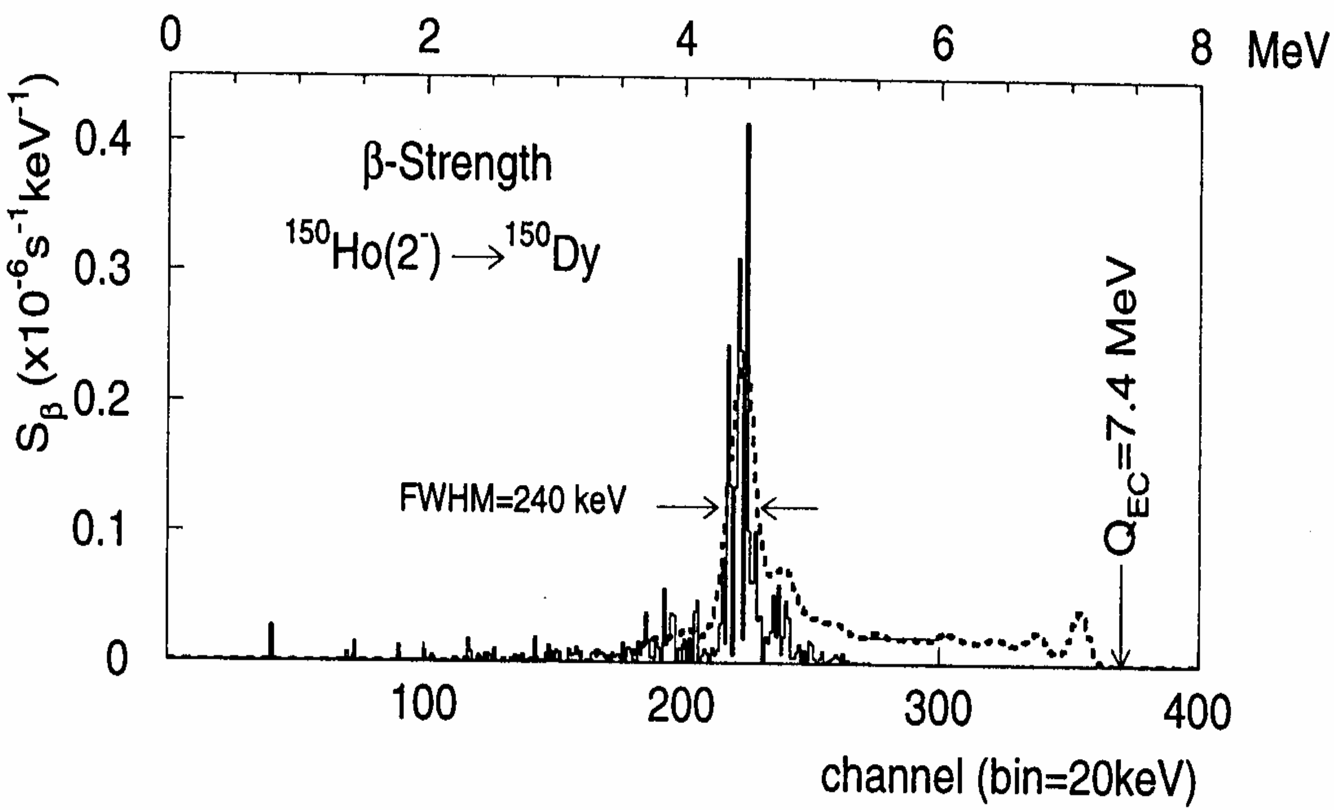
(β-spectrum is continuous)
(Lifetimes relatively long ~ seconds)

Beta Decay Example: Decay of ^{150}Ho

J. Agramunt et. al. (Valencia) in Nuclear Structure '98 from Gatlinburg Meeting

Experiments at GSI after mass separation. Data collected using Na(I) calorimetry….the Total Absorption Spectrometer (TAS) AND using the "Cluster Cube".

Result: $h_{11/2}$ to $h_{9/2}$ "spin flip" Gammow-Teller decay DOMINATES. Cluster cube has fantastic sensitivity to mixing of this into other states (>1000 g-rays !!)



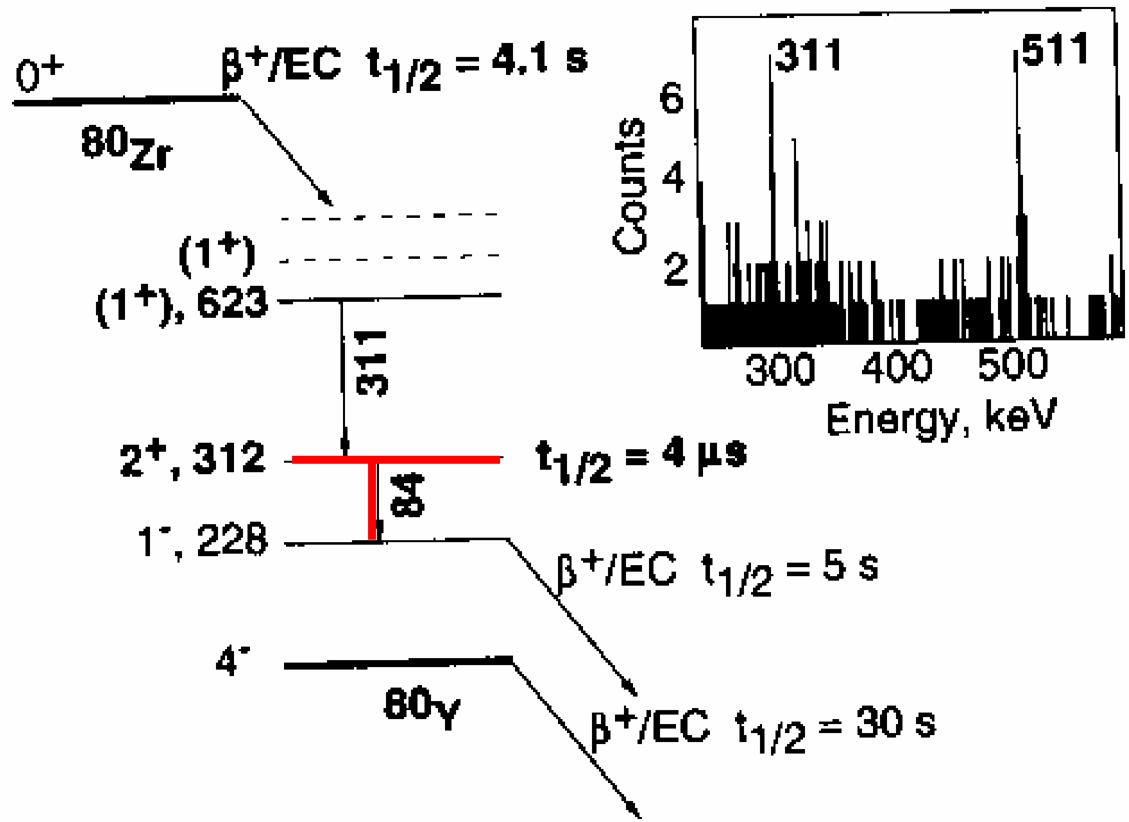
GSI Cluster Cube Array

β-decay of ^{80}Zr

VOLUME 84, NUMBER 10 PHYSICAL REVIEW LETTERS 6 MARCH 2000

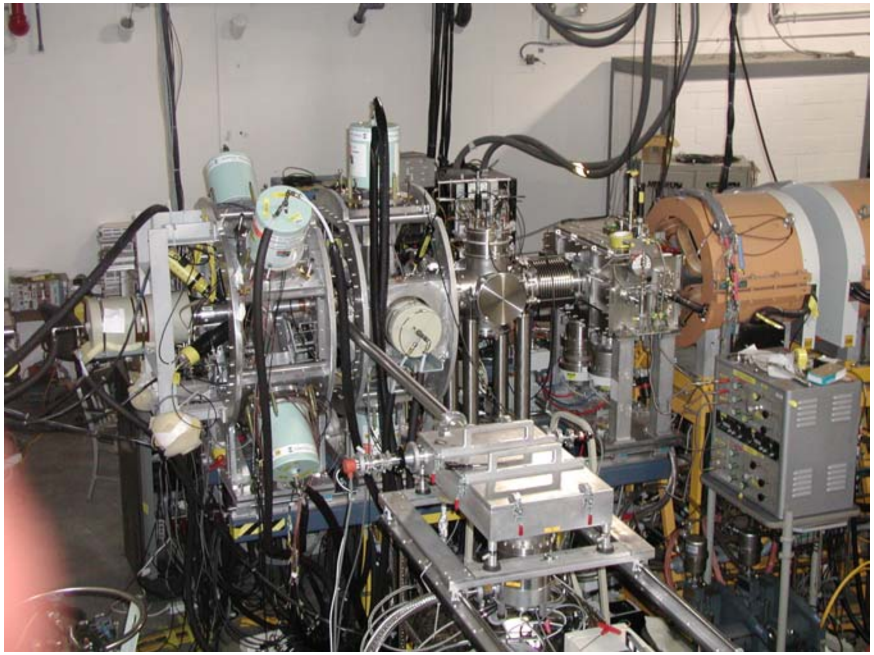
Half-Life Measurement for the *rp*-Process Waiting Point Nuclide ^{80}Zr

J. J. Ressler,[1] A. Piechaczek,[2] W. B. Walters,[1] A. Aprahamian,[3] M. Wiescher,[3] J. C. Batchelder,[4] C. R. Bingham,[5,6] D. S. Brenner,[7] T. N. Ginter,[8] C. J. Gross,[4,6] R. Grzywacz,[5] D. Kulp,[9] B. MacDonald,[9] W. Reviol,[5] J. Rikovska,[1] K. Rykaczewski,[6,10] J. A. Winger,[11] and E. F. Zganjar[2]



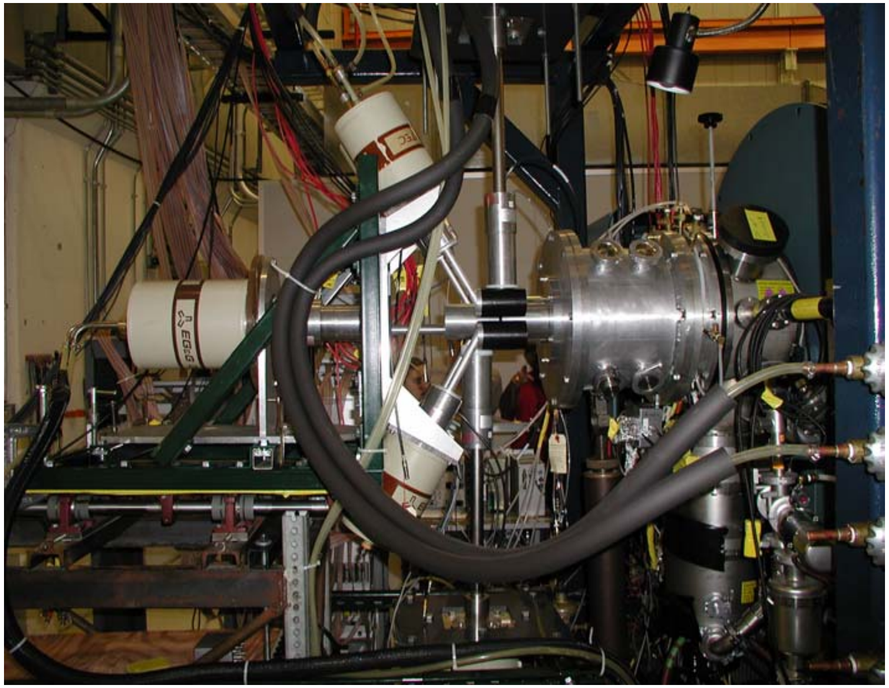
4 μs isomer trigger is the key that picks out this beta decay from the A=80 "background that is 5000 times stronger

Isomer Physics: Example of ^{140}Dy



At ORNL at the back of the RS using "cluster" detectors

And at ANL at the back of the FMA using a motley array



^{140}Dy Data

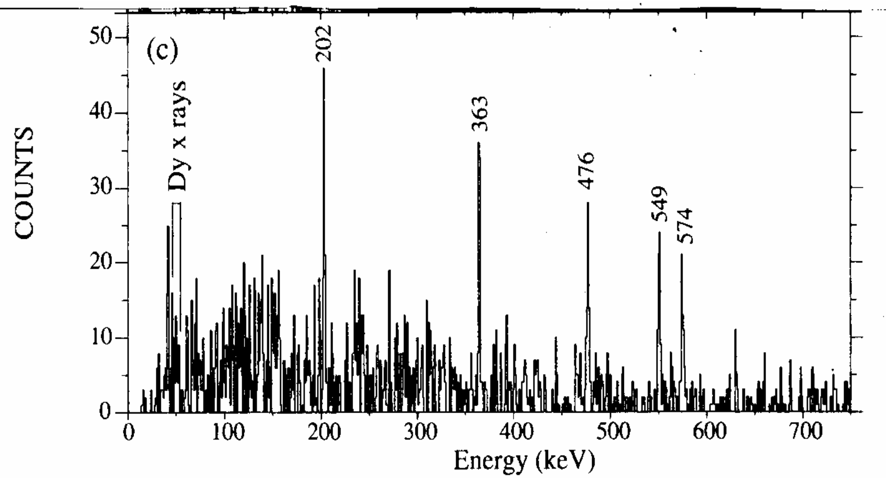
PHYSICS LETTERS B

ELSEVIER

Physics Letters B 529 (2002) 42–49

www.elsevier.com/locate/npe

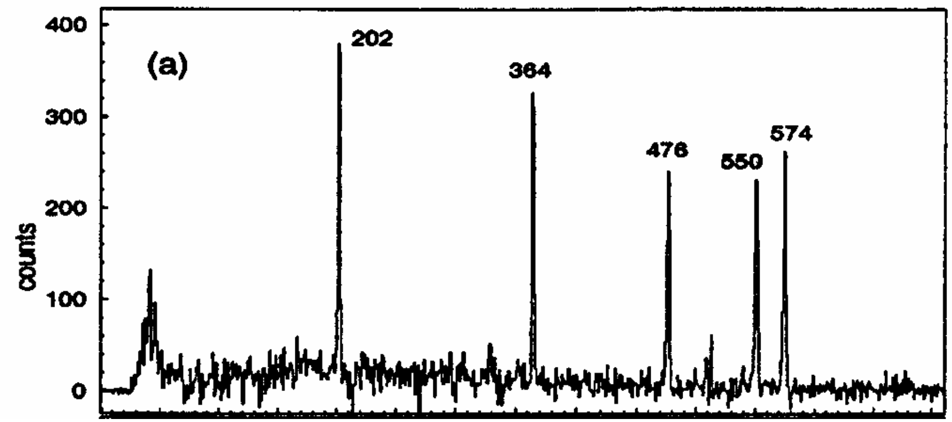
Identification of excited states in ^{140}Dy

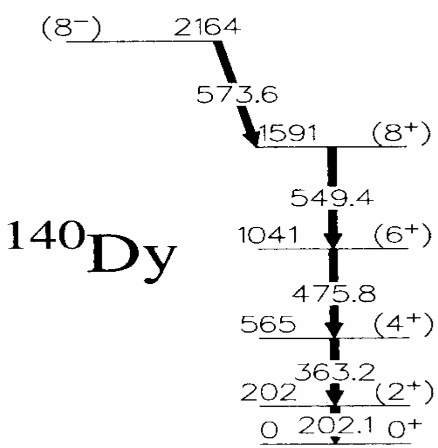


RAPID COMMUNICATIONS

PHYSICAL REVIEW C, VOLUME 65, 031303(R)

First observation of the drip line nucleus ^{140}Dy: Identification of a 7 μs K isomer populating the ground state band





Happily, in the end, everyone agreed!!

Functional requirements for “offline” arrays

Detection Efficiency is VERY VERY important as:

Mass Separation,
Selection Rules
Temporal Correlations (RDT, RBT, IT)

May have allowed the selection of the nucleus, AND state of interest

Energy and Time Resolution are VERY important for:

Signal-to-noise
Cases of “Many Gammas” (resolving multiplets)
Isomer identification and measurement

Dynamic Range is VERY important

From	X-Rays	(for identification and C.E. measurement)
To	~10MeV	(for the highest β-decays)

Polarization and Angular Correlation Measurements

Generally, in "Offline" studies the γ-multiplicity is low, and thus high segmentation may not appear very important. Also, all the reaction-induced alignment or polarization of magnetic substates have been lost.

BUT

Of course it can be regained by establishing a preferred "Z-direction"

From direction of emitted proton, or alpha particle ("Box" detector)

From first photon in γ–γ angular correlation. (Pixel detector)

SO

Good SPATIAL RESOLUTION may be very useful

BONUS

"Directionality" helps reject background radiation

The X-Array: A step forward

Compact Three Layer Concept:

A) Inner array for efficiently detecting (α,p,β,CE) decays

Highly segmented silicon DSSDs

Thin Wall Vacuum Envelope

B) Array of large area planar detectors for efficiently detecting X-rays, and for polarization and correlation studies.

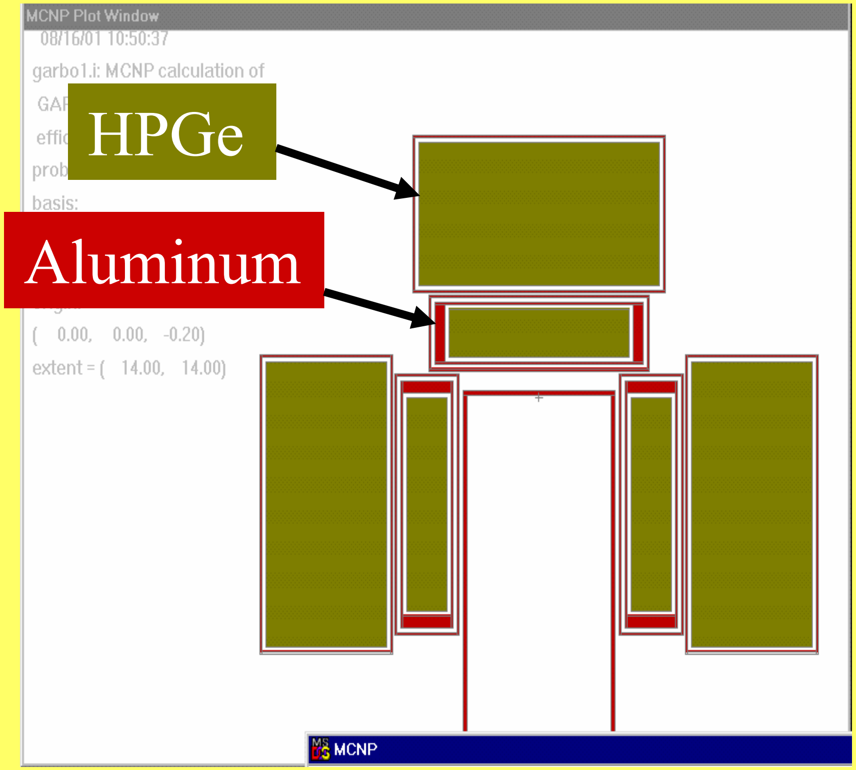
Highly segmented planar germanium DSSDs

C) Calorimeter of low-segmentation large germanium detectors for efficient absorption of total gamma ray flux.

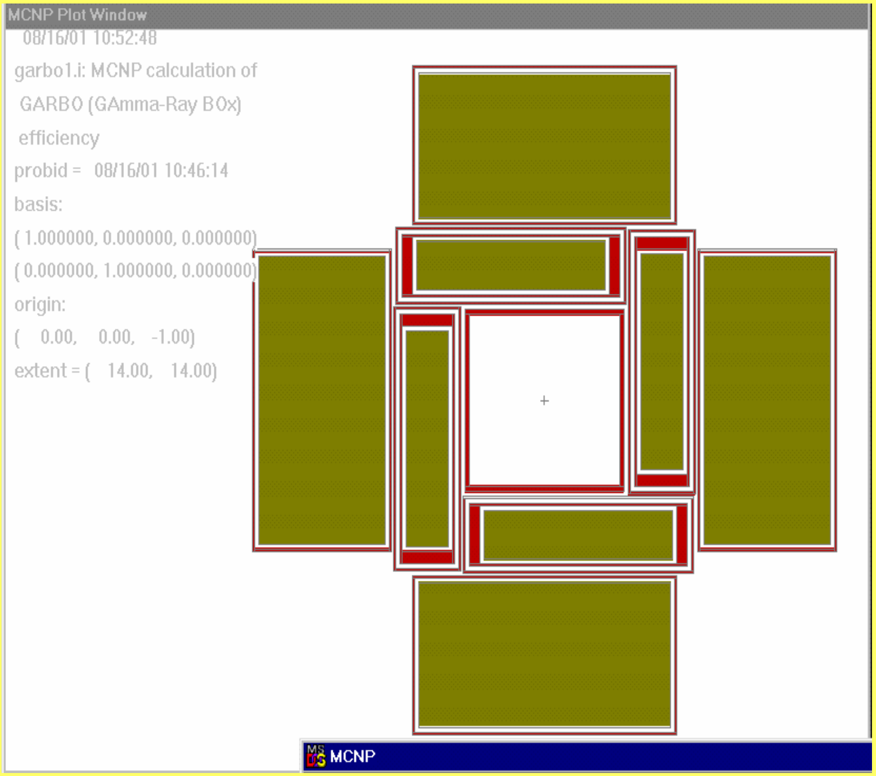
Large Volume non-segmented “clover” detectors

GARBO MCNP Geometry

Horizontal cross section

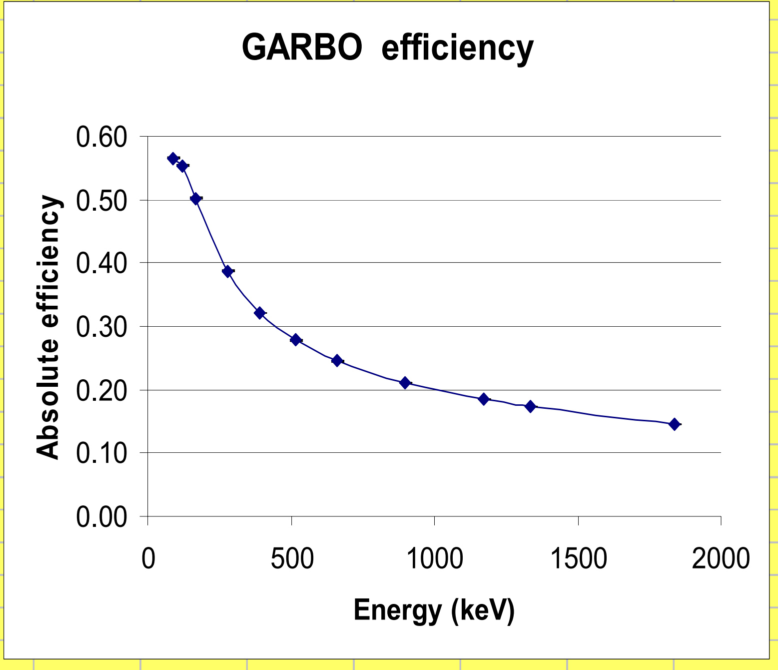


Vertical cross section

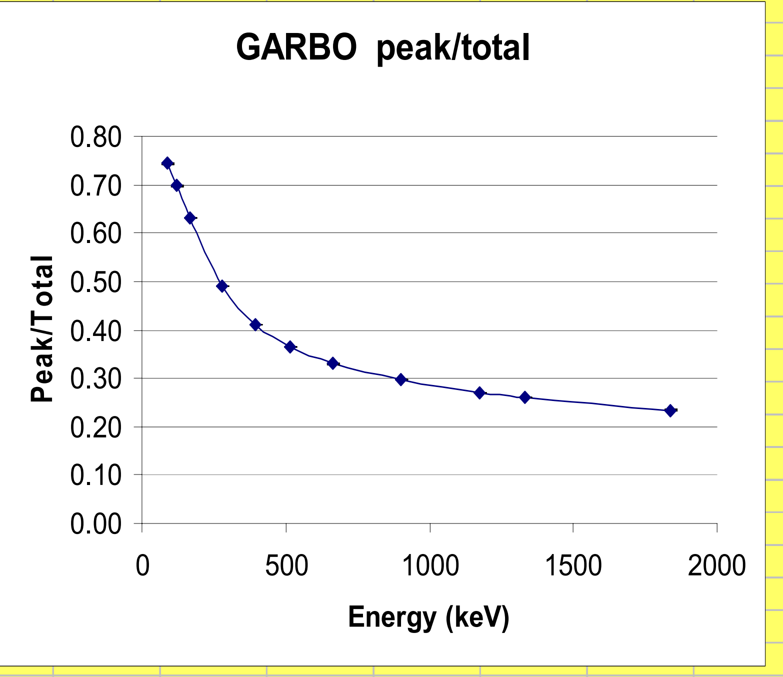


MCNP Results

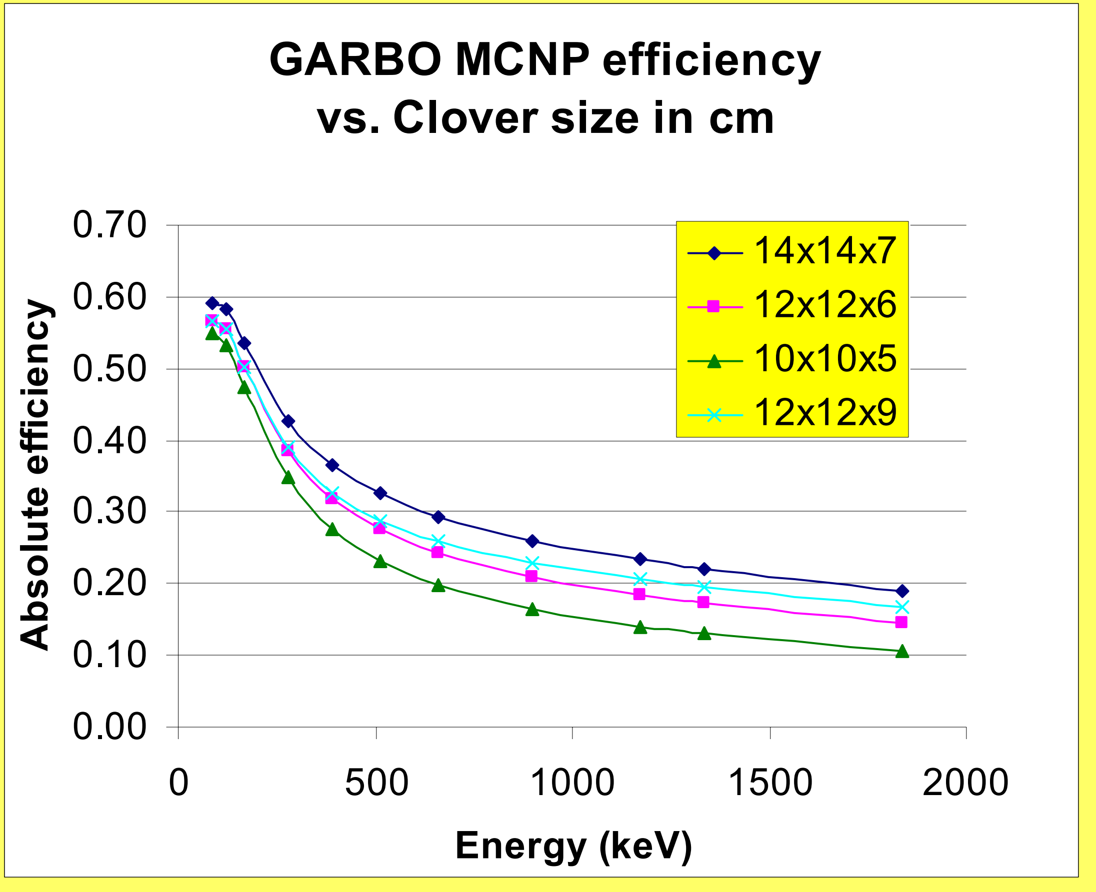
Photopeak efficiency



Peak to Total (E > 30 keV)



MCNP Results



Conclusions

New physics challenges will need new techniques.

Access to non-yrast states will be very important.

Combining the selection rules of (α,β,p,e^-) decay, with the power of γ-spectroscopy, can give UNIQUE insight into nuclear wavefunctions.

The technological sophistication of "in-beam" γ-arrays have fantastic (and relatively unexplored) potential for decay spectroscopy.

High Efficiency for "offline" γ-decay is critical.

Excellent Energy and Time resolution are very important.

Spatial Resolution (Pixels or "Tracking") is a big PLUS