Review of (in-beam) Electron Spectroscopy

(Over the past decade or so)

Paul Greenlees

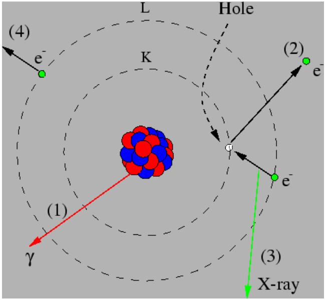
Department of Physics
University of Jyväskylä
and
Collaborators

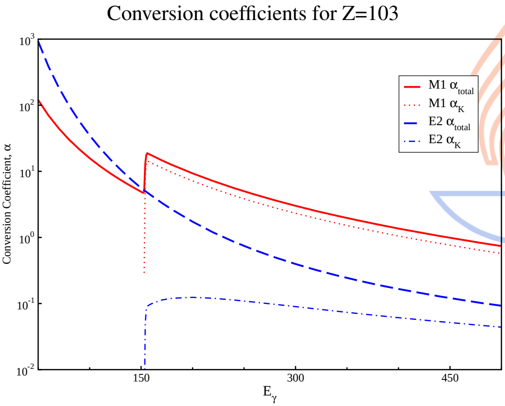
EGAN 2012 Workshop
25.-28.06.2012
Orsay, France

Outline

Internal Conversion

- $E_i = E_\gamma - B_i$;
  $i = K, L_I, L_{II}, .., M_V, ..$
- $\alpha_{tot} = \frac{N_e}{N_\gamma} = \alpha_K + \alpha_L + ...$
- $\alpha \propto \frac{Z^3}{n^3 E_\gamma^{2.5}}$
- α increases strongly with multipolarity
- α larger for magnetic transitions

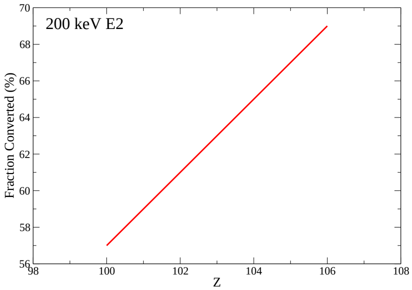


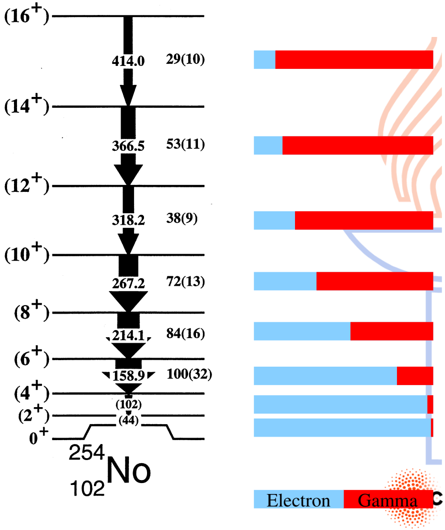


Internal Conversion

Fraction of 200 keV E2 converted

$$f = \frac{\alpha}{1+\alpha}$$

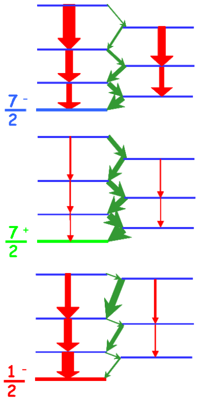




Electromagnetic Properties

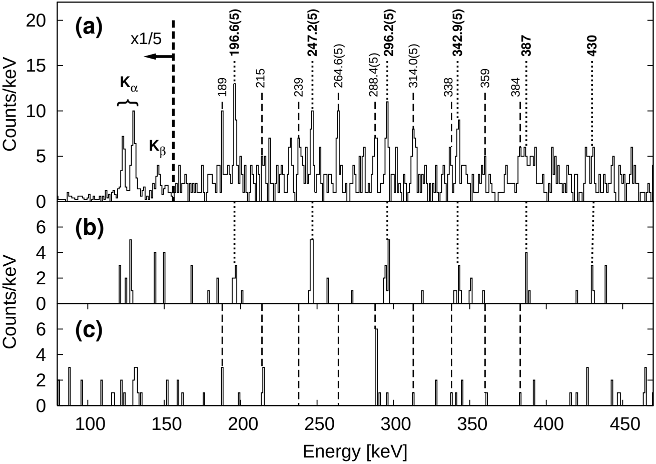
- Odd-proton orbitals in ^{251}Md
- B(M1)/B(E2) depends on $(g_K - g_R / Q_0)$

[514] $\frac{7}{2}^-$	$g_K \sim 0.7$	Mainly E2	⇨
[633] $\frac{7}{2}^+$	$g_K \sim 1.3$	Mainly M1	⇨
[521] $\frac{1}{2}^-$	$a \sim 0.9$: $g_K \sim -0.55$	Mainly E2	⇨



In-beam γ-ray Spectroscopy of ^{255}Lr

$^{48}Ca + ^{209}Bi \Rightarrow ^{255}Lr + 2n$, $\sigma \simeq 300$ nb, S. Ketelhut et al., PRL **102** 212501 (2009



Spectrometer Design Considerations

Efficiency

Broad Range
Typically 0-1 MeV
Backscattering - normal incidence

Magnetic Field

Profile
Strength

Detector

Thickness
Size
Granularity

Resolution

Intrinsic
Doppler Broadening

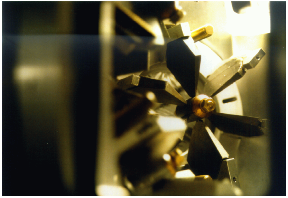
Delta Electron Suppression

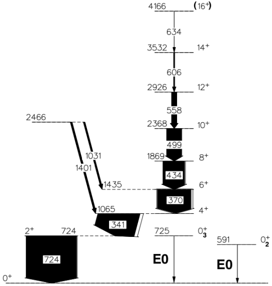
Kinematics
Biased Target
Physical Block
HV Barrier
High Counting Rate Capability
Tagging Techniques

Combination with Ge

Maintain Ge Efficiency
Maintain P/T
Effect of stray field

ICEMOS - ^{188}Pb

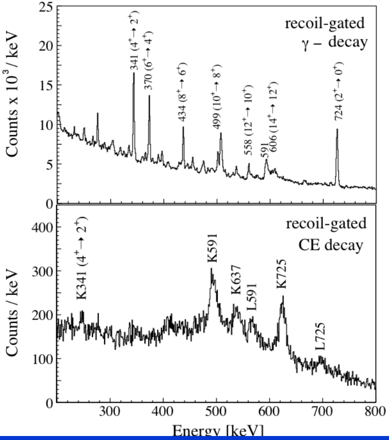




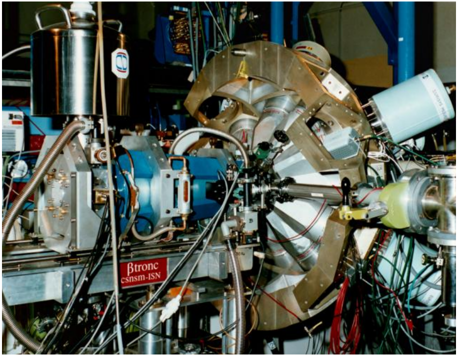
EPJdirect A3, 1–6 (1999)
DOI 10.1007/s101059900a0003
EPJdirect
electronic only

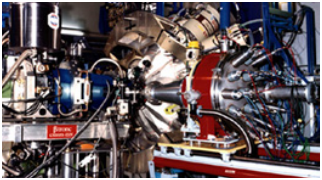
Evidence of Multiple Shape-Coexistence in ^{188}Pb

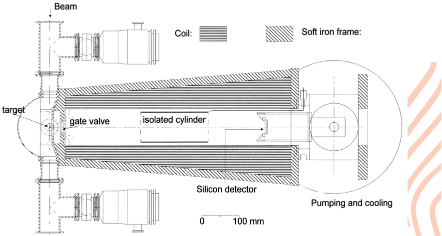
Y. Le Coz[1*], F. Becker[1], H. Kankaanpää[2], W. Korten[1], E. Mergel[3], P.A. Butler[4], J.F.C. Cocks[2], O. Dorvaux[2], D. Hawcroft[4], K. Helariutta[2], R.D. Herzberg[4], M. Houry[1], H. Hübel[3], P. Jones[2], R. Julin[2], S. Juutinen[2], H. Kettunen[2], P. Kuusiniemi[2], M. Leino[2], R. Lucas[1], M. Muikku[2], P. Nieminen[2], P. Rahkila[2], D. Rossbach[3], A. Savelius[2], Ch. Theisen[1]

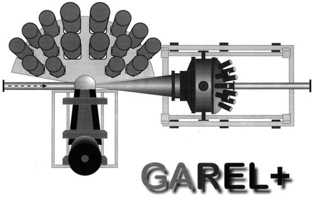


GAREL+ at the Vivitron









P.Paris et al., NIM A451, 662 (2000)
Betatronc constructed in Orsay
Coupled to RFD and 15 Tapered Ge

GAREL+ at the Vivitron

Eur. Phys. J. A 4, 103–105 (1999)

THE EUROPEAN PHYSICAL JOURNAL A

Short note

Investigation of prolate-oblate shape-coexistence in ^{74}Kr

F. Becker[1], W. Korten[1], F. Hannachi[2], P. Paris[2], N. Buforn[1,a], C. Chandler[4], M. Houry[1], H. Hübel[3], A. Jansen[3], Y. Le Coz[1], C.F. Liang[2], A. Lopez-Martens[5], R. Lucas[1], E. Mergel[3], P. H. Regan[4], G. Schönwasser[3], Ch. Theisen[1]

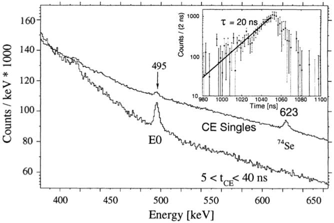


Fig. 1. Conversion-electron singles spectrum obtained in the reaction ^{58}Ni(^{19}F,p2n)^{74}Kr compared with the corresponding normalised time-gated spectrum ($5 < t_{CE} < 40$ ns). In the inset the time spectrum for the 495 keV E0 transition is shown

Pulsed beam 4ns on, 480ns off
^{58}Ni(^{19}F,p2n)^{74}Kr
Carbon Catcher Foil

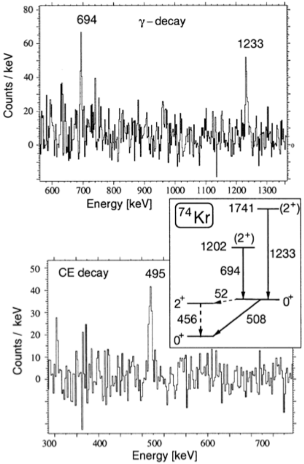
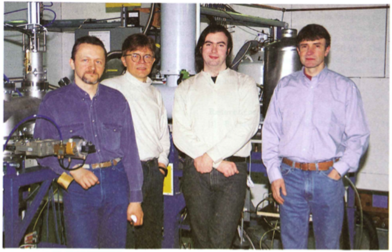


Fig. 2. γ-CE coincidence spectra: γ-ray spectrum gated by the 495 keV CE line (top) and CE spectrum gated by the γ-ray lines at 694 and 1233 keV (bottom), together with the proposed partial level scheme of ^{74}Kr (the dotted transitions were not seen in coincidence with the feeders of the 0_2^+ state)

The *Original* SACRED Electron Spectrometer

3.6. Studies using electron spectroscopy with SACRED

P.M. Jones, P.A. Butler[1], J.F.C. Cocks[1], G.D. Jones[1], R. Julin, J.F. Smith[1] and W. Trzaska
1) Oliver Lodge Laboratory, Department of Physics, University of Liverpool, L69 3BX, UK



From left: Wladyslaw Trzaska, Rauno Julin, Peter Jones, Peter Butler

1. Electron spectroscopy group

The tradition of in-beam electron spectroscopy at JYFL will be continued in the new accelerator laboratory as a joint effort by the Liverpool and the local JYFL group. The aim is to develop more powerful in-beam methods for conversion-electron studies of heavy nuclei.

2. Report on Progress

The superconducting solenoid was installed at the Accelerator Laboratory in its dedicated experimental cave in April 1994. The magnet was cooled during this period and was immediately able to support its maximum field of 2 T. The multi-element silicon array for conversion electron detection (SACRED) was sited at the end of the solenoidal field, the electrons being transported to it through the solenoid.

The cave was commissioned with beam from the cyclotron during May 6-8 and we were able to take data throughout this period. In these initial test experiments the spectrometer was operated in recoil shadow mode, using the reaction 85 MeV ^{170}Er(^{18}O, 4n) to populate the 20 ns 10^+ isomeric state in ^{184}Os [1]. Electron-electron coincidences from the 13 element PIN array were collected using the Liverpool VME-based data acquisition system. The matrix and subsequent gated spectra shown in figure 1 shows clearly the E_{e^-}-E_{e^-} correlations expected from the decay structure.

Tests of prompt electron detection were also carried out during May 24-26 and August 8-14. As expected the largest background in this type of measurement arises from the delta electrons produced with atomic cross-sections. In these first experiments we employed several techniques to reduce this background:

i) a stopper disc placed on the target-detector axis.
ii) electrostatic potential applied to the target (+5 kV).
iii) division of the total rate over the individual elements of the array.

The best data were obtained using the reaction ^{170}Er(α, 4n)^{170}Yb at 42 MeV, using the same techniques as employed for the recoil shadow mode. From the rotational band structure, transitions were observed down 70 keV, although the background remains high. The electron energy peaks observed are notably characteristic of the regular structure. Several reactions were also tried with Th targets, but the background from the backing foils was too high for these targets.

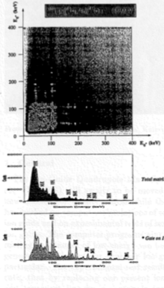


Fig. 1. ^{184}Os electron-electron matrix and coincidence spectra.

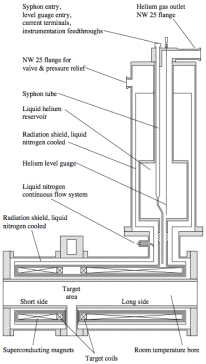
3. Prospects

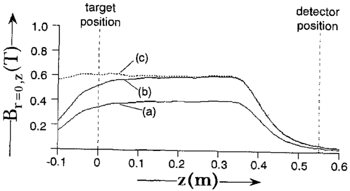
To make further progress for the in-beam mode, we intend to replace the stopper disc / HV combination by a single high voltage deflector plate alone. Difficulties were experienced in aligning the beam spot, magnetic axis and stopper disc and in any case the beam profile for an inclined target is perhaps too large to allow effective low energy suppression using this method. The new electrostatic deflector will be rated to a higher voltage (30-50 kV). Deltas with energy sufficient to pass this barrier are emitted but with cross-sections of less than a few barns.

References

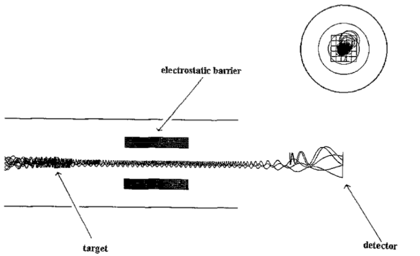
[1] P. Chowdhury et. al., Nucl. Phys. A485 (1988) 136

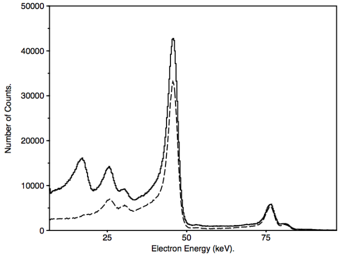
The *Original* SACRED Electron Spectrometer



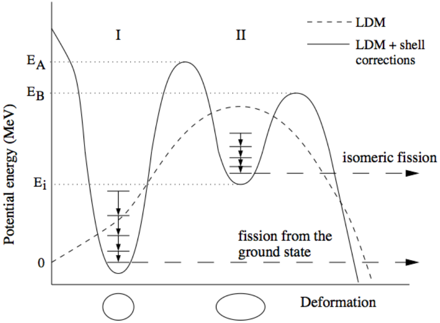


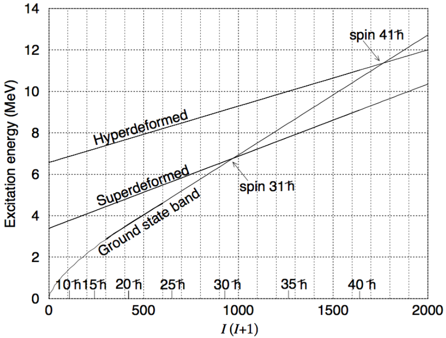
P.A. Butler et al./Nucl. Instr. and Meth. in Phys. Res. A 381 (1996) 433–442



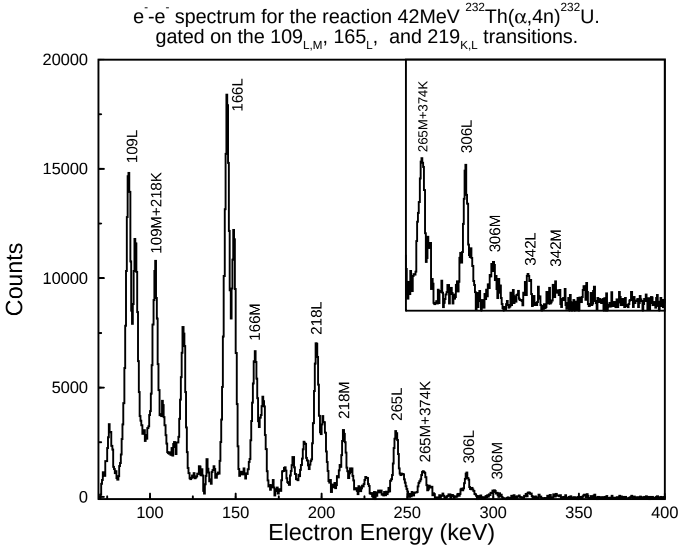


The *Original* SACRED - Holy Grail

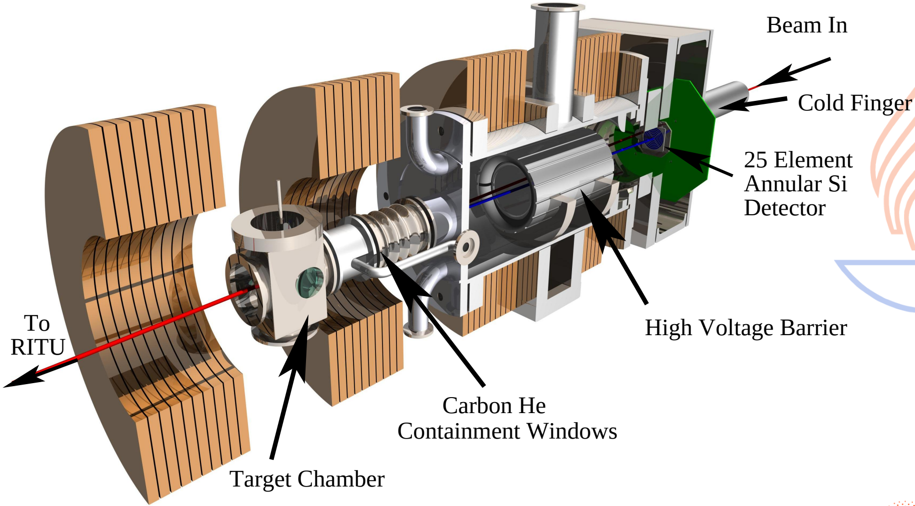




The *Original* SACRED - Some Results



The SACRED Electron Spectrometer

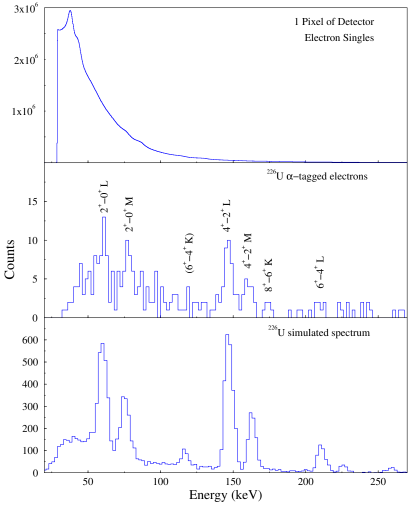


H. Kankaanpää et al., NIM A534, 503 (2004)
P. A. Butler et al., NIM A381, 433 (1996)

THE UNIVERSITY of LIVERPOOL

UNIVERSITY OF JYVÄSKYLÄ

Recoil-Decay Tagging with SACRED



δ electrons produced with atomic cross sections!

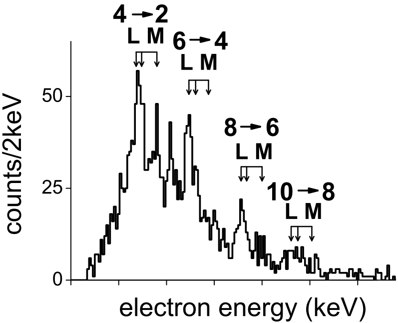
H. Kankaanpää et al., NIM A534, 503 (2004)
see also:
R.D. Humphreys et al., PRC69, 064324 (2004)

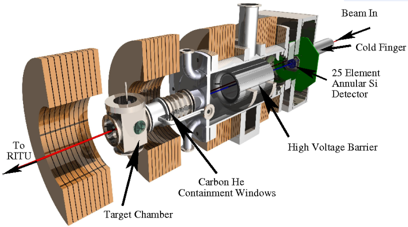
Conversion-Electron Spectroscopy of ^{254}No

VOLUME 89, NUMBER 20 PHYSICAL REVIEW LETTERS 11 NOVEMBER 2002

Conversion Electron Cascades in $^{254}_{102}$No

P. A. Butler,[1] R. D. Humphreys,[1] P. T. Greenlees,[2] R.-D. Herzberg,[1] D. G. Jenkins,[1] G. D. Jones,[1] H. Kankaanpää,[2] H. Kettunen,[2] P. Rahkila,[2] C. Scholey,[1,2] J. Uusitalo,[2] N. Amzal,[1] J. E. Bastin,[1] P. M. T. Brew,[1] K. Eskola,[3] J. Gerl,[4] N. J. Hammond,[1] K. Hauschild,[5] K. Helariutta,[4] F.-P. Heßberger,[4] A. Hürstel,[5] P. M. Jones,[2] R. Julin,[2] S. Juutinen,[2] A. Keenan,[2] T.-L. Khoo,[6] W. Korten,[5] P. Kusiniemi,[2] Y. Le Coz,[5] M. Leino,[2] A.-P. Leppänen,[2] M. Muikku,[2] P. Nieminen,[2] S. W. Ødegård,[7] T. Page,[1] J. Pakarinen,[2] P. Reiter,[8] G. Sletten,[9] Ch. Theisen,[5] and H.-J. Wollersheim[4]





University of Lodz ICE Spectrometer

Available online at www.sciencedirect.com
ScienceDirect
Nuclear Instruments and Methods in Physics Research A 585 (2008) 155–164
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A
www.elsevier.com/locate/nima

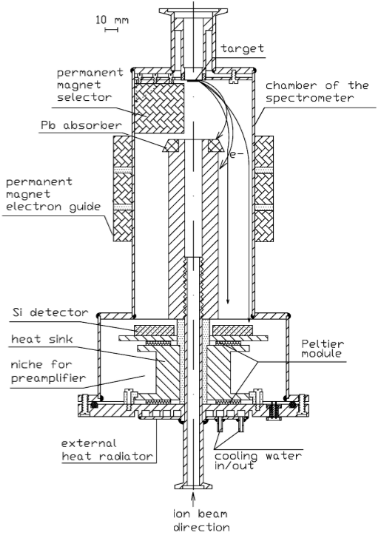
Electron spectrometer for "in-beam" spectroscopy

J. Andrzejewski[a], A. Król[a,*], J. Perkowski[a], K. Sobczak[a], R. Wojtkiewicz[a], M. Kisieliński[b], M. Kowalczyk[b], J. Kownacki[b], A. Korman[c]

[a]Institute of Physics, University of Lodz, Pomorska 149/153, 90-236 Lodz, Poland
[b]Heavy Ion Laboratory, Warsaw University, Pasteura 5a, 02-093 Warsaw, Poland
[c]The Andrzej Soltan Institute for Nuclear Studies, 05-400 Świerk-Otwock, Poland

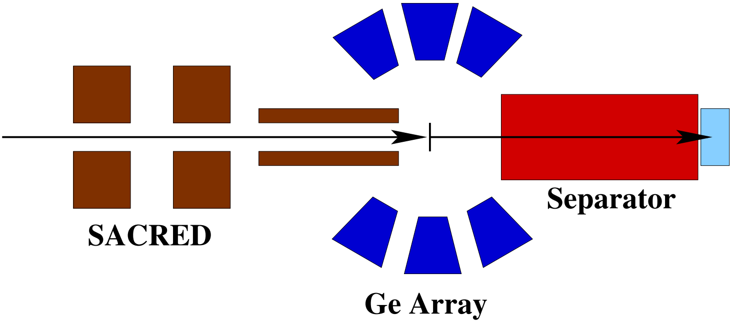
Received 6 June 2007; received in revised form 5 November 2007; accepted 10 November 2007
Available online 19 November 2007

- See talk of J. Perkowski



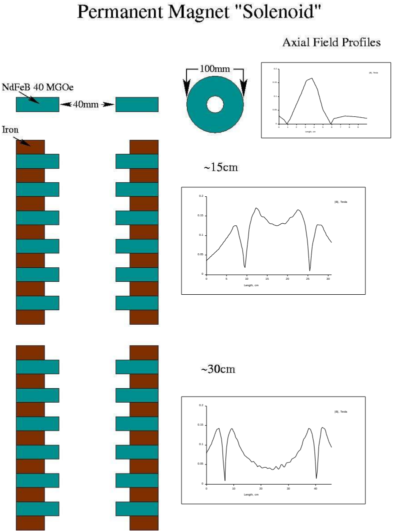
The SAGE Spectrometer - Vision 2004

The Future? ...SAGE
Combined Electron–Gamma Spectroscopy

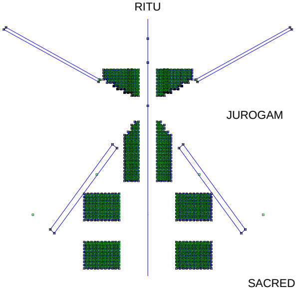


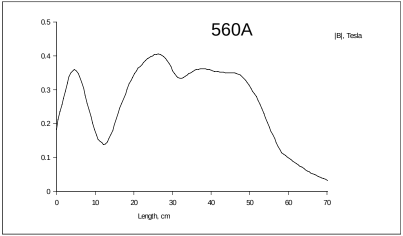
Electron Efficiency ~ 10%
Gamma Efficiency ~ 4%

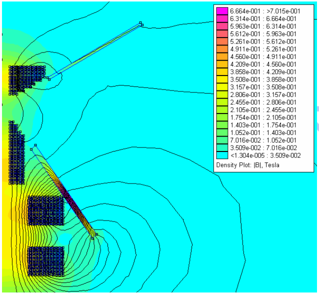
The SAGE Spectrometer - Vision 2004



The SAGE Spectrometer - Vision 2005

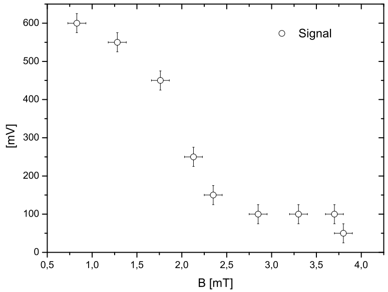


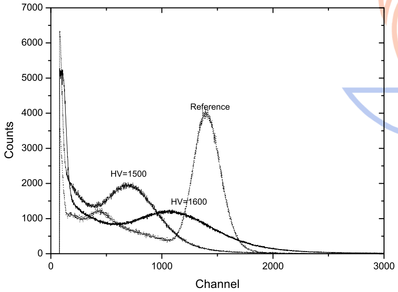




The SAGE Spectrometer - Vision 2005

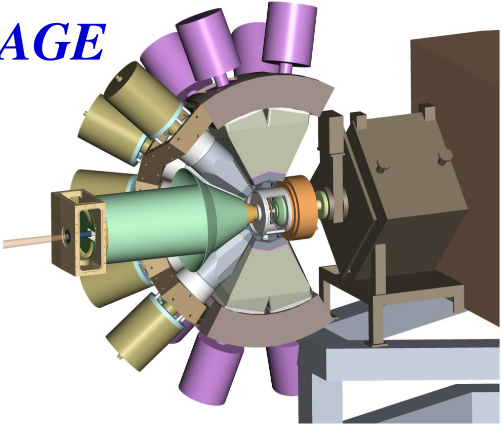
Effect of Stray Field on BGO Signal

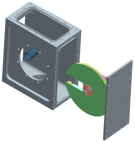


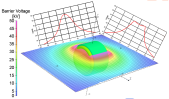


The SAGE Spectrometer

SAGE



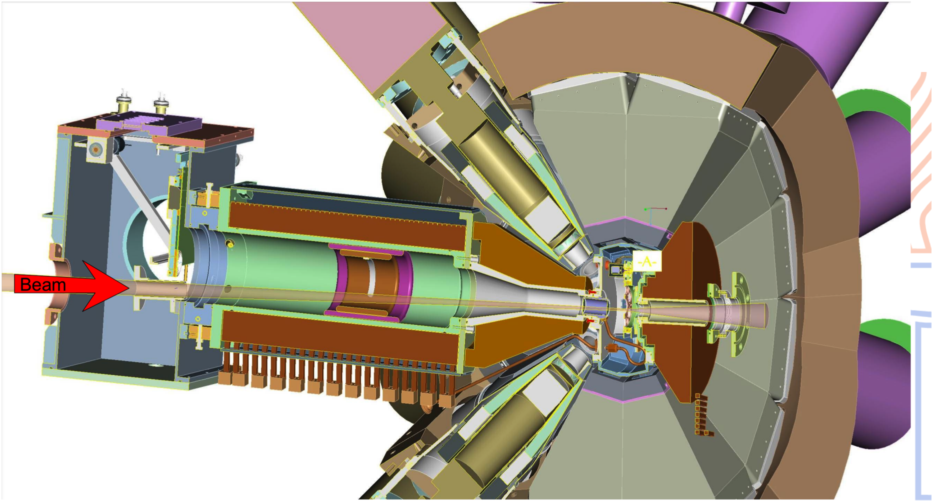




UNIVERSITY OF LIVERPOOL | Science & Technology Facilities Council | UNIVERSITY OF JYVÄSKYLÄ | erc

erc

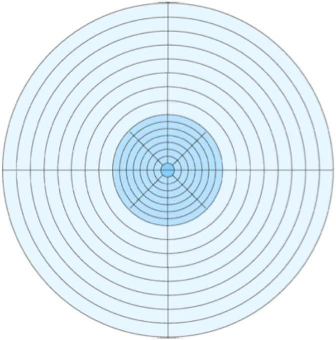
Anatomy of the SAGE Spectrometer



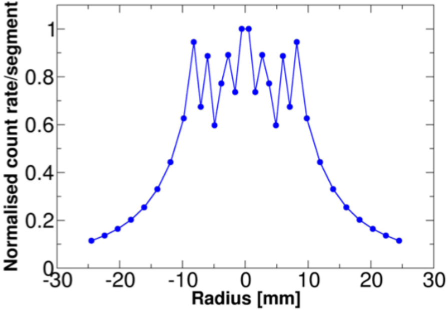
P. Papadakis et al., AIP Conf. Proc. **1090**, 14 (2009)

SAGE - Silicon Detector

- 90 segments
- 51 mm diameter
- 1 mm thick



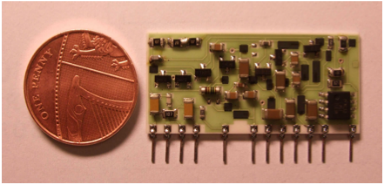
Simulated normalised count rate distribution using data from SACRED experiments

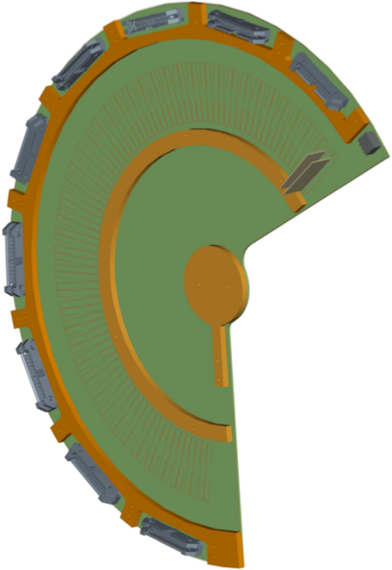


SAGE - Silicon Detector

C.A.E.N. A1422 charge sensitive hybrid preamplifiers

- 400 mV/MeV
- Low noise
- Suitable for high count-rates



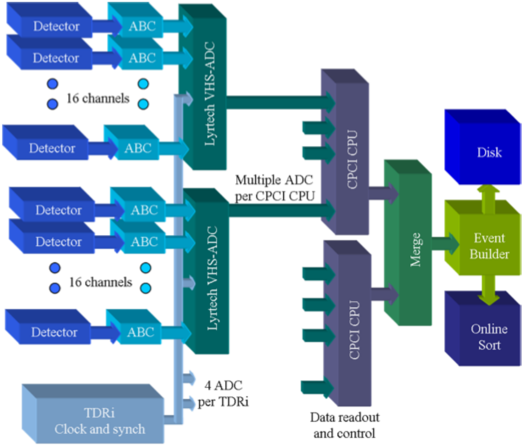


SAGE - Electronics

201 Fully digital channels

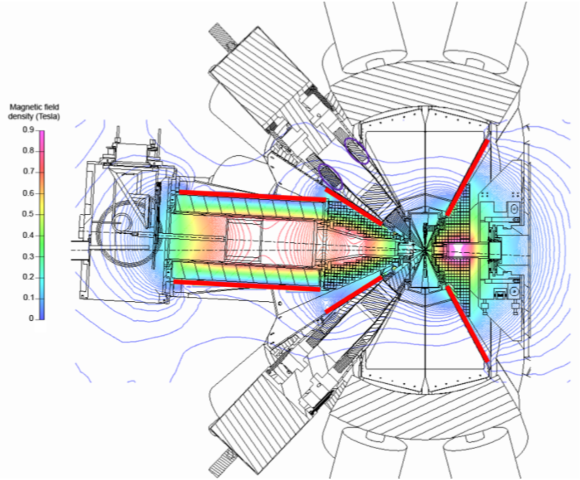
- 90 Si channels
- 111 Ge channels

Lyrtech VHS-ADC

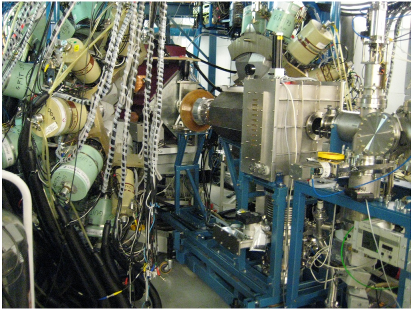


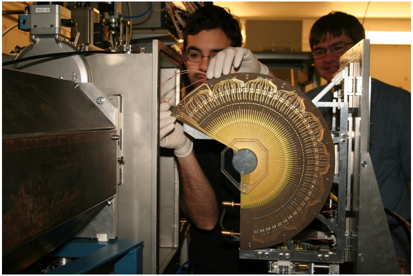
SAGE - Shielding

- Photomultiplier tubes are sensitive to magnetic fields
- Shields: Weaken and redirect stray magnetic field



The SAGE Spectrometer





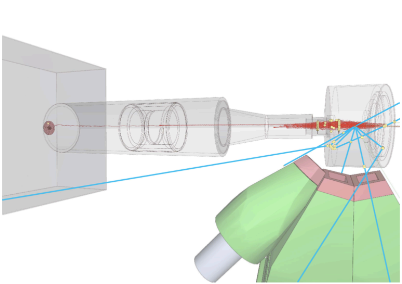
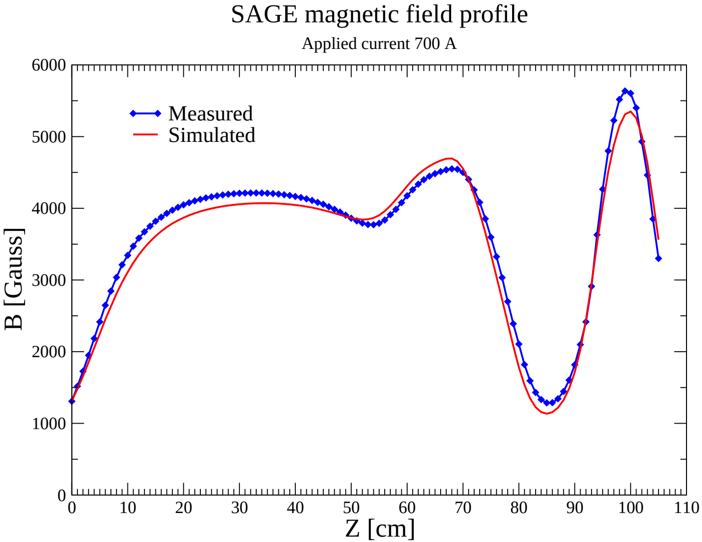


Figure 4.5: An example drawing of simulated events visualised in Geant4. Electrons are presented with red lines and gamma rays with blue. Only some of the electrons reach the detector while the others either interact with the surrounding materials (open circles) or are reflected back by the HV barrier. Note also the magnetic bottle effect of electrons being trapped in the magnetic field.

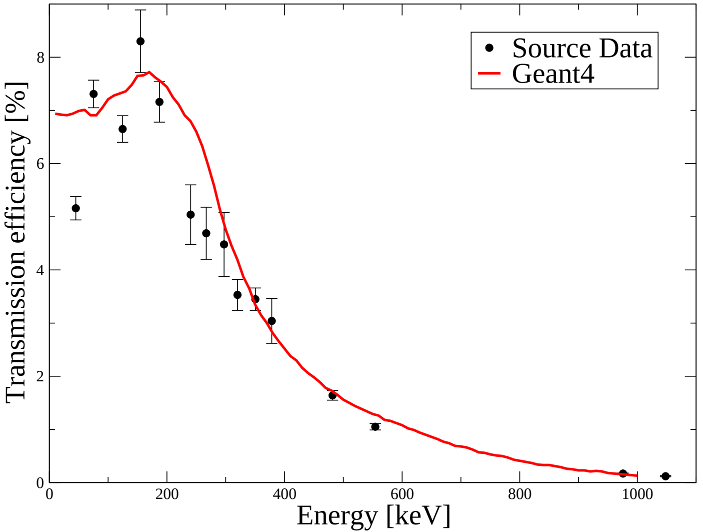
Full Geant4 Simulation

P.Papadakis, D.Cox, J.Konki, K.Hauschild, P. Rahkila

SAGE - Field Profile



SAGE- efficiency



SAGE experiments to date

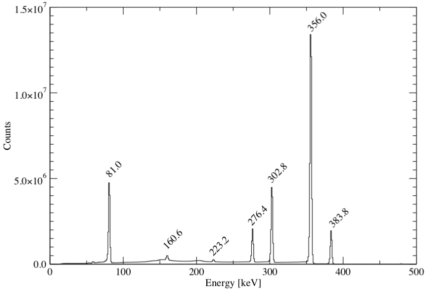
Campaign 2010

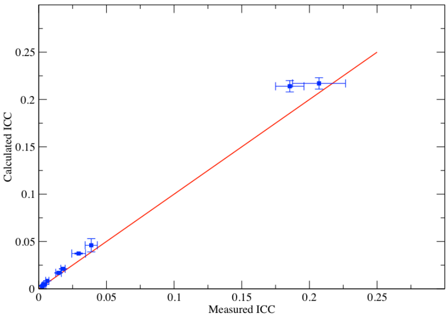
- S01: Commissioning of the SAGE spectrometer, R.-D. Herzberg
- S02: Simultaneous conversion-electron and gamma-ray spectroscopy using SAGE; an in-beam study of ^{253}No, R.-D. Herzberg
- S04: Exploring shape co-existence in ^{202,204}Rn, D.Jenkins, A.P.Robinson, P.Rahkila
- S05: Shape co-existence in $^{182-188}$Hg, P.A.Butler, P.Rahkila, P. Van Duppen

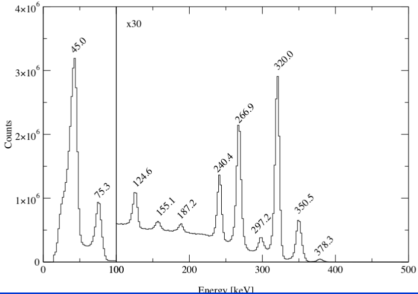
Campaign 2011/2012

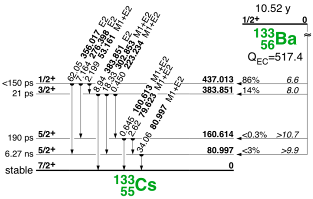
- S11: Commissioning of the SAGE spectrometer through in-beam investigation of ^{177}Hg , P.Papadakis
- S06: Exploring nuclear shapes in the transitional region of N 90: Coulomb excitation of ^{152,154}Sm to study E0 transitions with SAGE, P.Davies, C.Barton
- S07: Probing E0 transitions in ^{188}Pb using the SAGE spectrometer, J.Pakarinen
- S10: Spectroscopy of the odd-proton ^{249,251}Md, Ch.Theisen
- S08: Simultaneous conversion-electron and gamma-ray spectroscopy using SAGE; an in-beam study of ^{253}No, R.-D. Herzberg
- S09: Complete spectroscopy of the transfermium nucleus ^{255}Lr, M.Sandzelius, K.Hauschild, A.Lopez-Martens

ICC determination with SAGE- ^{133}Ba





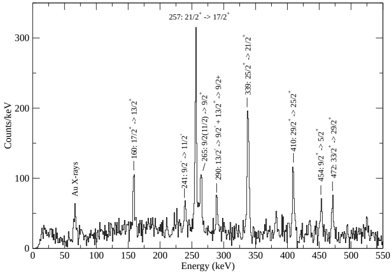




ICC determination with SAGE- ^{177}Au Preliminary!

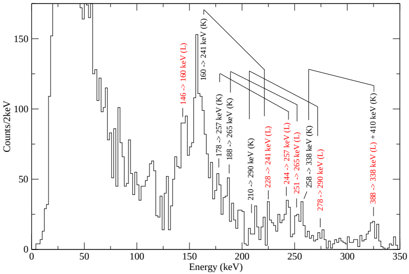
177Au Gamma Spectrum

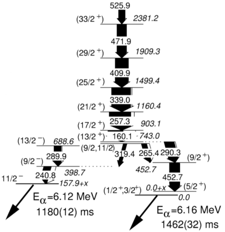
Gamma-Gamma Gates on 160,289,453



177Au Electron spectrum

Gates on 160,453 gammas -> 160 electrons - > all subsequent gammas





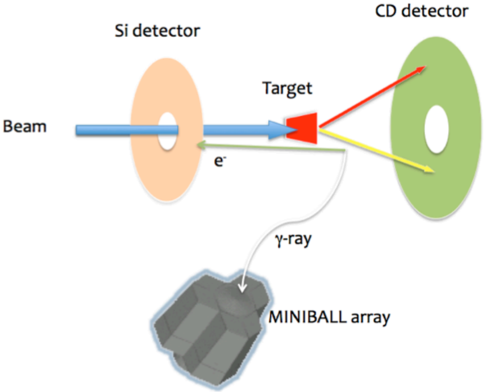
265 keV 9/2,11/2->9/2+
K:182.5keV L:254keV

ICC	Value	Error
K ICC Exp	0.132	0.037
K ICC BRICC	0.090	0.007
L ICC Exp	0.082	0.002
L ICC BRICC	0.050	0.001
K/L Exp	1.610	0.400
K/L BRICC	1.82	0.04

257 keV 21/2->17/2+
K: 176.5keV L: 243keV

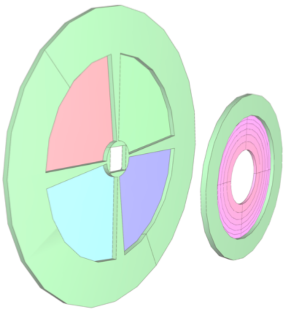
ICC	Value	Error
K ICC Exp	0.088	0.024
K ICC Theo	0.091	0.004
L ICC Exp	0.062	0.014
L ICC BRICC	0.051	0.001
K/L Exp	1.421	0.508
K/L BRICC	1.644	0.04

SPEDE Concept

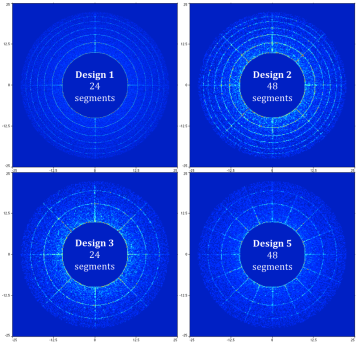


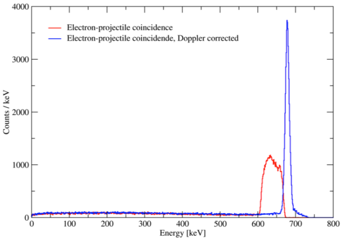
- HIE-ISOLDE
- Measure ICE in Coulex experiments
- J. Pakarinen - Marie Curie Funding

SPEDE Simulations



- Geant4
- J. Konki (JYFL)

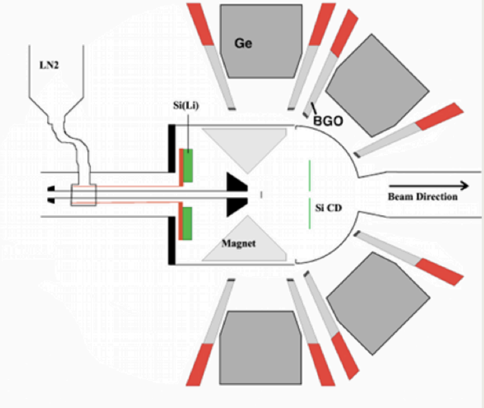




SPICE - A. Garnsworthy TRIUMF

TRIUMF

Main Features of SPICE with TIGRESS



NdFeB magnetic lens in backward angle geometry

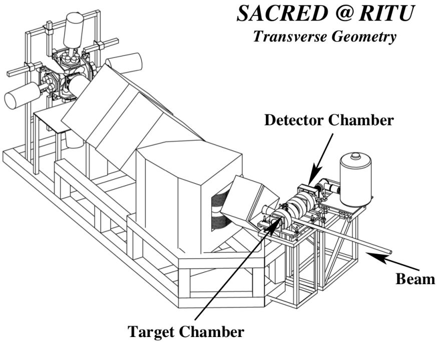
LN_2-cooled 16-fold segmented Si(Li) detectors (38x38x5mm)

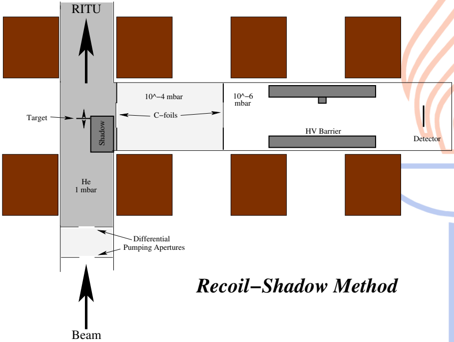
Heavy-Met photon and charged-particle shield

12 Compton-Suppressed TIGRESS Clovers
12.5% Singles Eff. @ 1.3MeV

Downstream CD for coincidence charged particle or Heavy ion

Recoil-Shadow Mode at JYFL





Summary

- In-beam electron spectroscopy is a challenge!
- Combined electron-gamma spectroscopy an even greater challenge!
- Essential part of spectroscopy of heavy nuclei
- Essential in study of E0 transitions
- Steady progress over past 10-15 years
- Can now run with beam intensities of 10 pnA or so
- Combined electron-gamma spectroscopy possible at 200 nb level
- Improvement still possible to lower limit further
- New devices being developed for use with radioactive beams

Thanks! - SAGE Team

Paul Greenlees, Rodi Herzberg, Mikael Sandzelius, Rauno Julin, Andrew Mistry, Janne Pakarinen, Panu Rahkila
Juha Sorri, Philippos Papadakis, Joonas Konki, Danny Cox

Internal Conversion - E0 Transitions

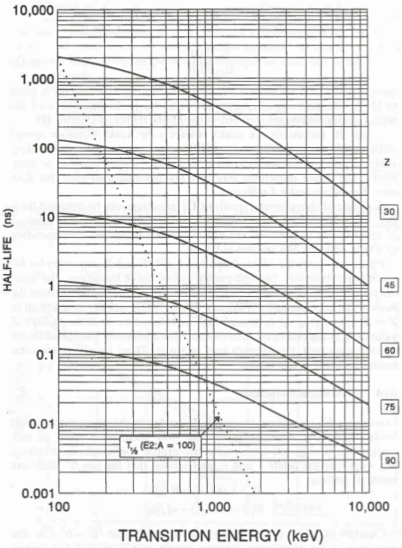


Figure 6-8 Speeds of E0 transitions with $\rho^2 = 0.010$. For comparison, the Weisskopf estimate half-life for E2 ($A = 100$) is also shown.

Monopole Strength Parameter

$$\rho^2 = \frac{ln2}{(T_{1/2})_K} \times \Omega_K$$

Ω_K electronic factor, analogous to ICC

Simple Two-Level Model

Two levels: spherical and deformed

$|0_i^+\rangle = a|sph\rangle + b|def\rangle$

$|0_f^+\rangle = -b|sph\rangle + a|def\rangle$

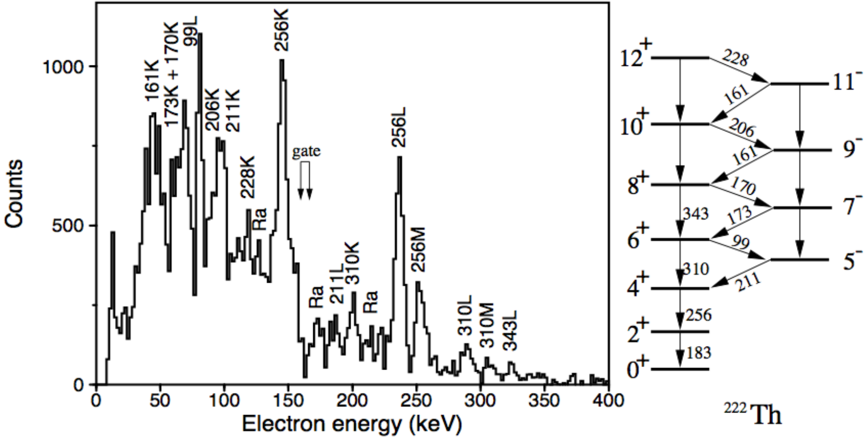
$$\langle 0_f^+|m(E0)|0_i^+\rangle \simeq abk\beta^2$$

$$k = \frac{3}{4\pi} ZeR^2[1 + \frac{4\pi^2}{3}(\frac{a_0}{R})^2]$$

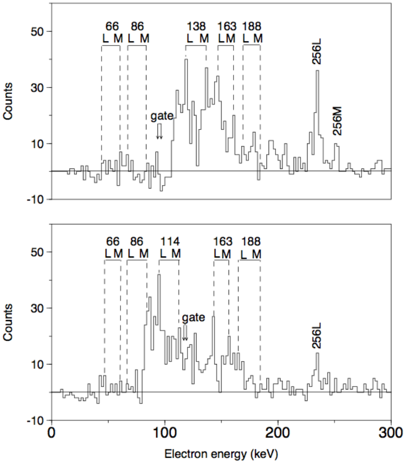
$$\rho^2 \propto a^2(1 - a^2)\beta^4$$

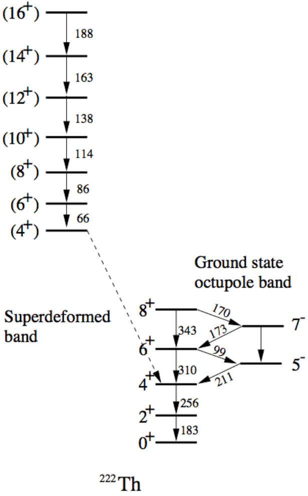
In this model: large ρ^2 values imply the presence of sizeable deformation, as well as mixing of components with different r^2 (Kantele)

The *Original* SACRED - Some Results

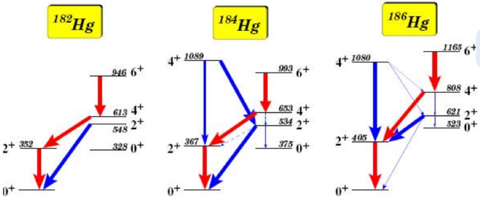


The *Original* SACRED - Some Results

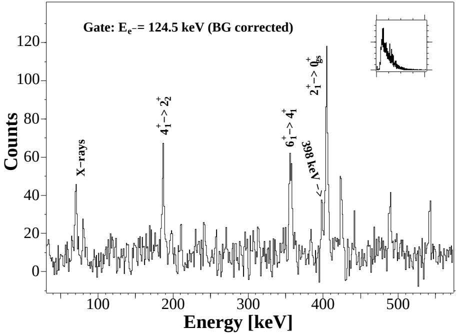


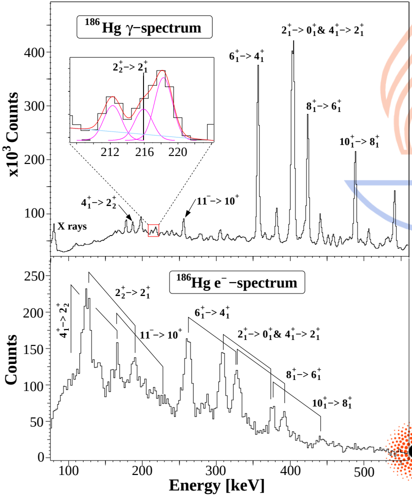


SAGE - First Results

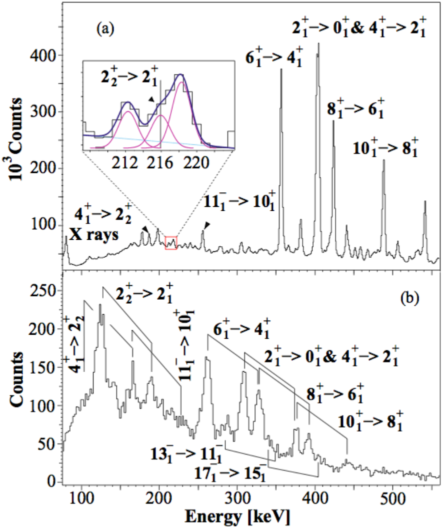


M.Scheck et al., To be published





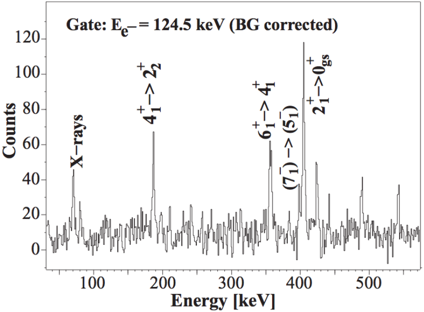
SAGE - First Results



PHYSICAL REVIEW C **83**, 037303 (2011)

Combined in-beam electron and γ-ray spectroscopy of ^{184,186}Hg

M. Scheck,[1] P. A. Butler,[1] L. P. Gaffney,[1] N. Bree,[2] R. J. Carrol,[1] D. Cox,[1] T. Grahn,[3] P. T. Greenlees,[3] K. Hauschild,[3,4] A. Herzan,[3] M. Huyse,[2] U. Jakobsson,[3] P. Jones,[3] D. T. Joss,[1] R. Julin,[3] S. Juutinen,[3] S. Ketelhut,[3] R.-D. Herzberg,[1] M. Kowalczyk,[5] A. C. Larsen,[6] M. Leino,[3] A. Lopez-Martens,[3,4] P. Nieminen,[3] R. D. Page,[1] J. Pakarinen,[7] P. Papadakis,[1] P. Peura,[3] P. Rahkila,[3] S. Rinta-Antila,[3] P. Ruotsalainen,[3] M. Sandzelius,[3] J. Saren,[3] C. Scholey,[3] J. Sorri,[3] J. Srebrny,[5] P. Van Duppen,[2] H. V. Watkins,[1] and J.Uusitalo[3]



SAGE Collaboration

University of Liverpool, UK
R.-D. Herzberg, P. Papadakis,
J. Pakarinen, P.A. Butler, R.D. Page,
E. Parr, J.R. Cresswell, D.A. Seddon,
J. Thornhill, D. Wells

University of Jyväskylä, Finland
P.T. Greenlees, P. Jones, R. Julin,
P. Peura, P. Rahkila, J. Sorri

STFC Daresbury Laboratory, UK
J. Simpson, P.J. Coleman-Smith,
I.H. Lazarus, S.C. Letts, V.F.E. Pucknell

UNIVERSITY OF LIVERPOOL

UNIVERSITY OF JYVÄSKYLÄ

Science & Technology Facilities Council

SPICE - A.Garnsworthy TRIUMF