Total Absorption Spectroscopy at Isolde; Past, Present and Future

Berta Rubio
IFIC-Valencia

Lucrezia Borgia

ohn Matin ´ s 1825 engraving "Pandemonium".

Volume 71B, number 2 PHYSICS LETTERS 21 November 1977

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

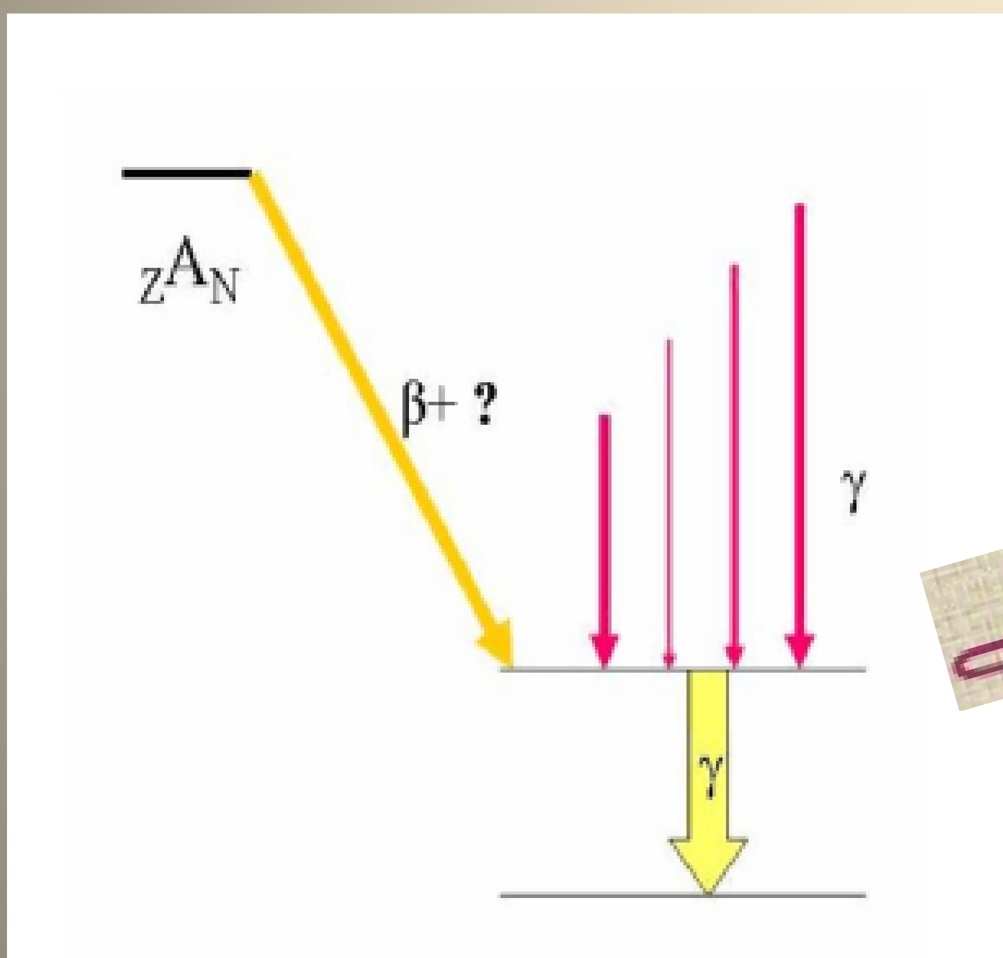
J.C. HARDY *, L.C. CARRAZ, B. JONSON ‡ and P.G. HANSEN ‡
CERN, Geneva, Switzerland

Milton, *Paradise Lost, Book I (1667)*

ISOLDE Workshop and Users meeting 2010
Wednesday 08 December 2010 - Friday 10 December 2010

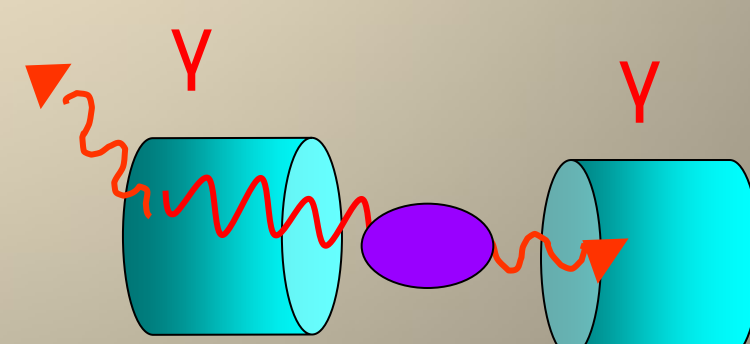
The problem we want to solve is the systematic errors often appearing in the beta feeding measurements of complex decay schemes due to the missing gamma intensity

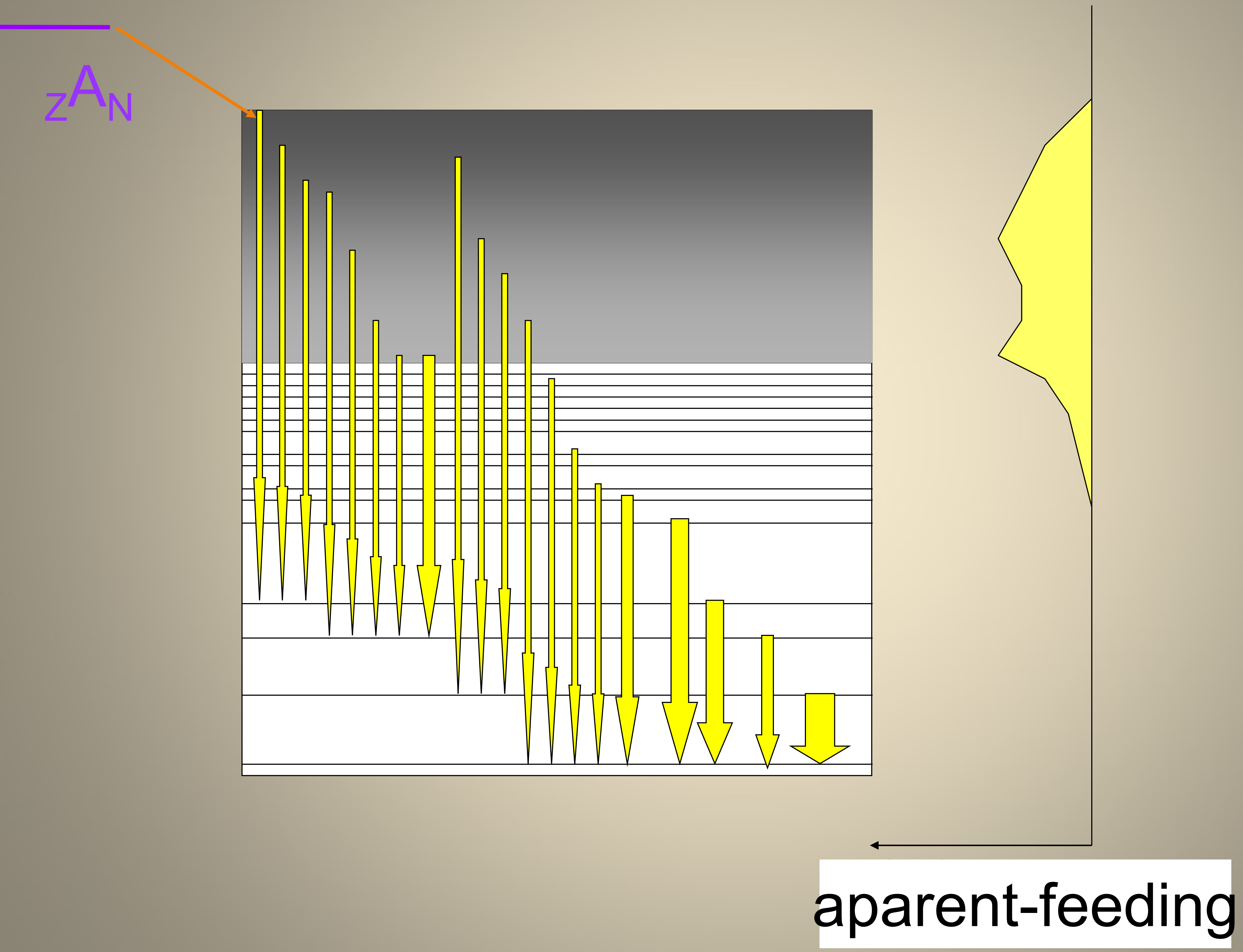
$$B(GT) = \left| \left\langle \psi_f \right| \sum_k \sigma_k \tau_k^{\pm} \left| \psi_i \right\rangle \right|^2$$



$$B(GT) = k \frac{I_\beta(E)}{f(Q_\beta - E, Z) T_{1/2}}$$

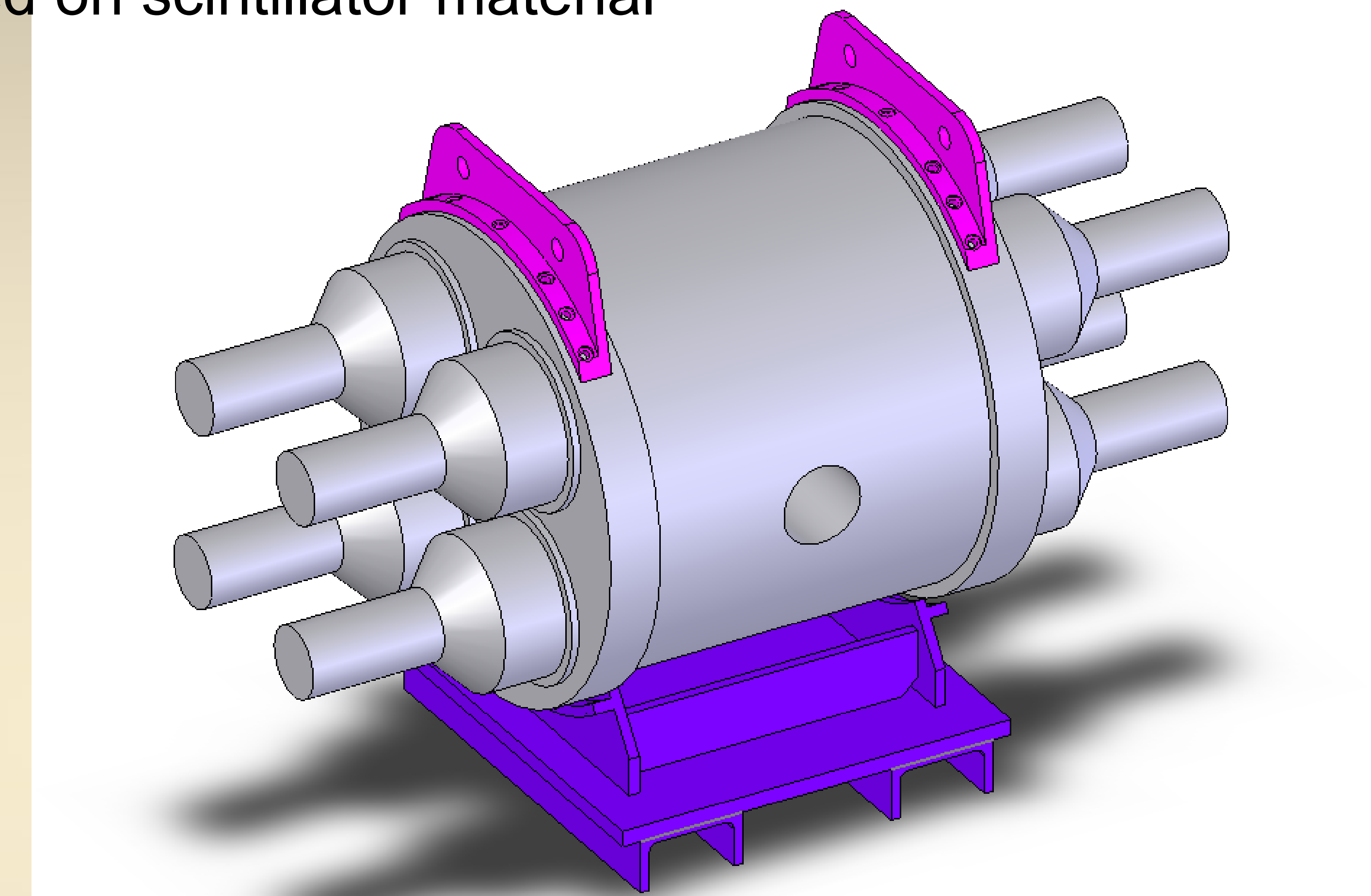
$$I_\beta(E)$$



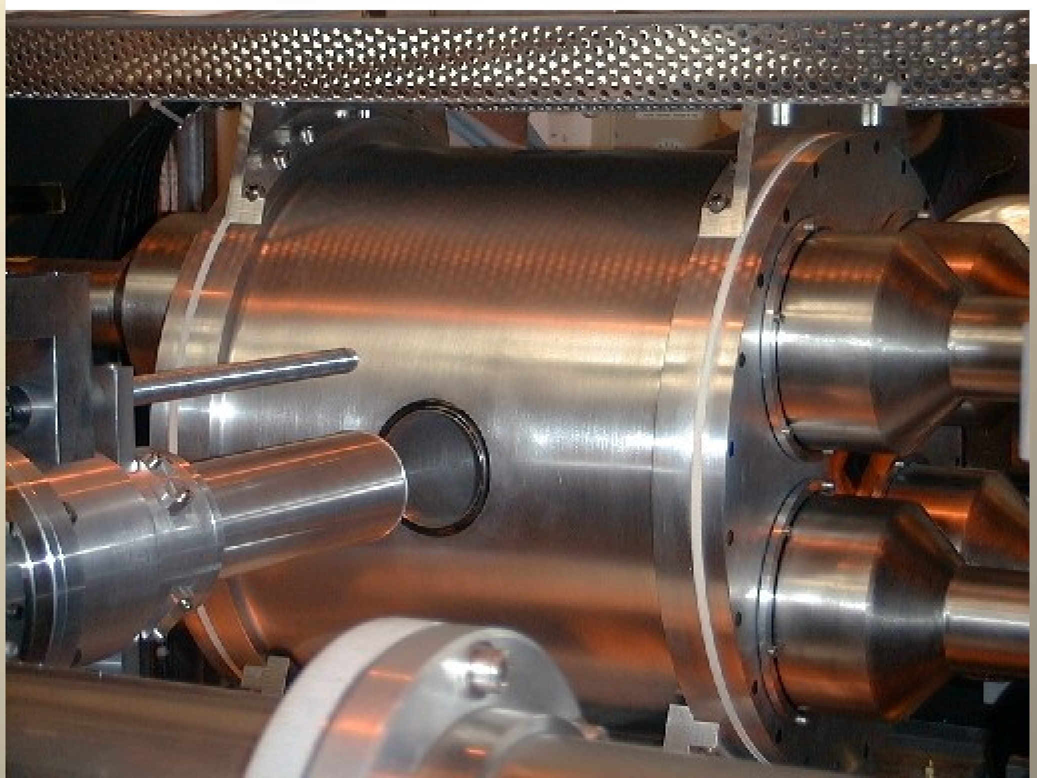


$_ZA_N$
aparent-feeding

The solution is a Total Absorption Spectrometer
for gamma-rays
A gamma calorimeter based on scintillator material

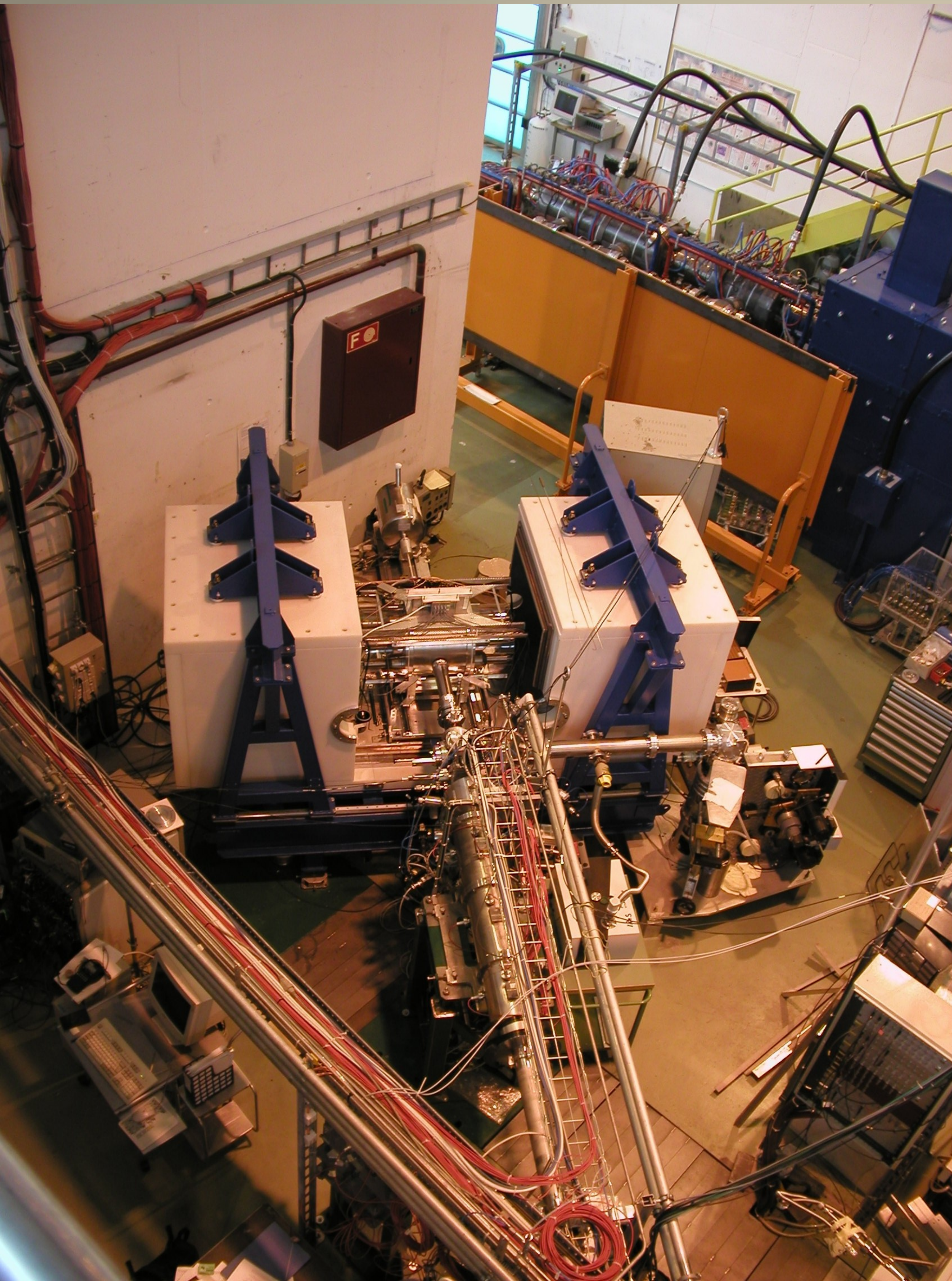


The Lucrecia TAS at Isolde
is a NaI single-crystal Φ38cm x 38cm
(+ ancillary detectors)Ge for X-rays
and plastic for β particles



Valencia-
Surrey
Madrid
Strasbourg

The data analysis is not trivial, but today we have the necessary algoritms and analysis programs

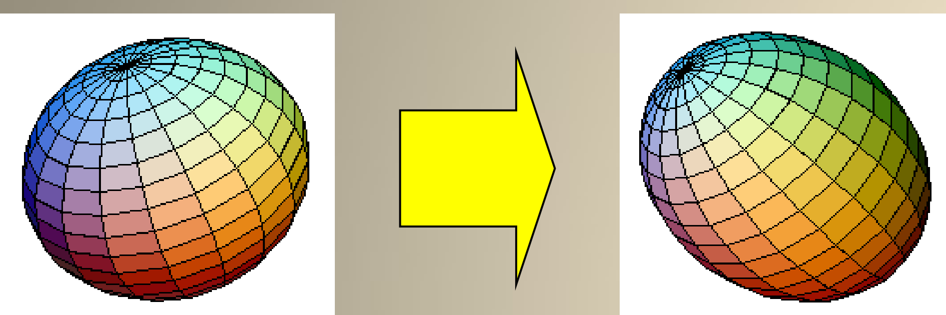


Taín and Cano-Ott
NIM A 571, 710 (2007)
NIM A 571, 728 (2007)

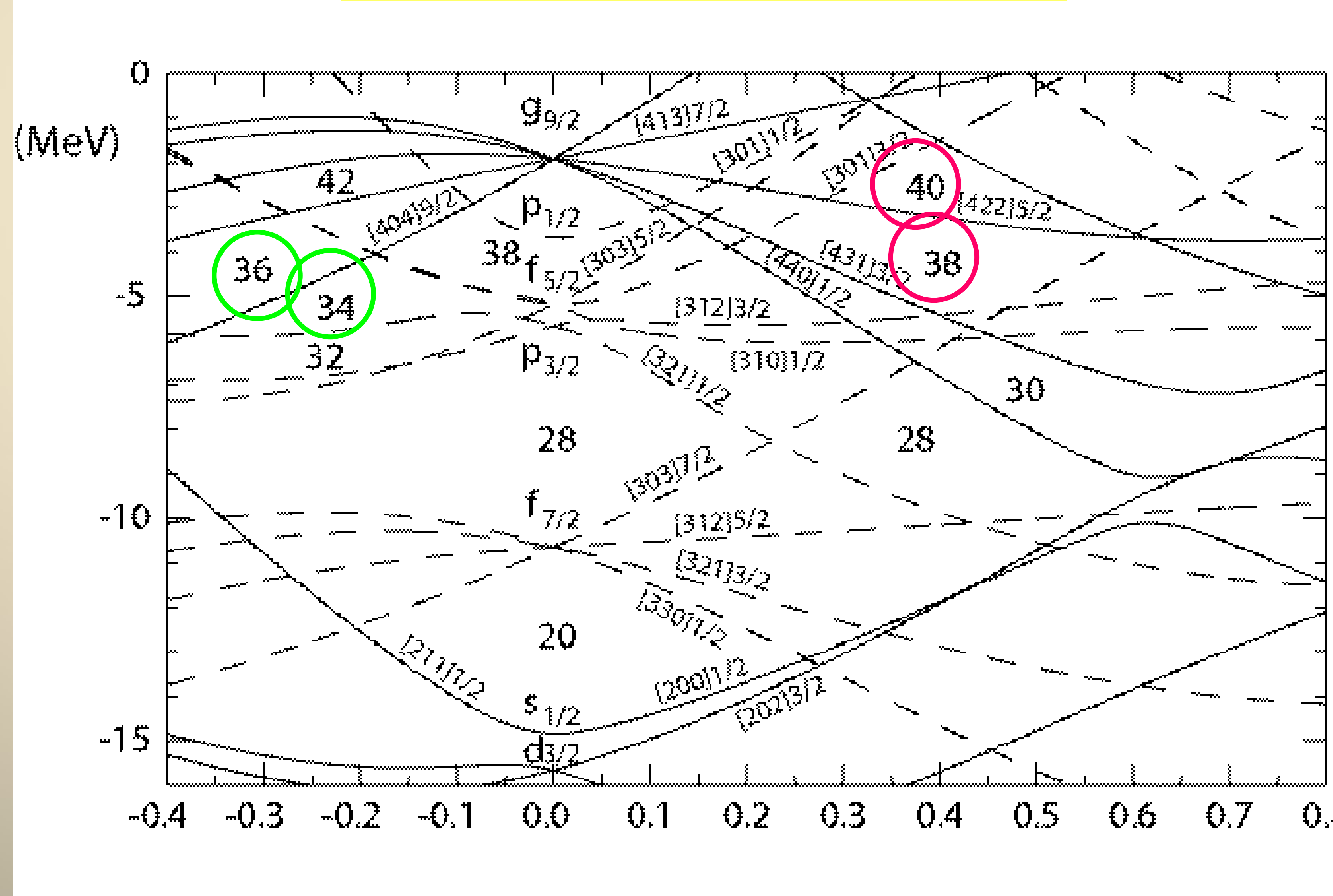
$$f_k(j) = \frac{1}{\sum_i R(i,j)} \sum_i \frac{R(i,j)\, f_{k-1}(j)\, d(i)}{\sum_j R(i,j)\, f_{k-1}(j)}$$

**The first two proposals IS370 and IS398,
Were focused in deducing the deformation of the
Ground state of neutron deficient Sr (Z=38) and Kr (Z=36) isotopes from
the B(GT) distribution of their ß+ decay**

Strong oblate-prolate competition and rapid shape changes

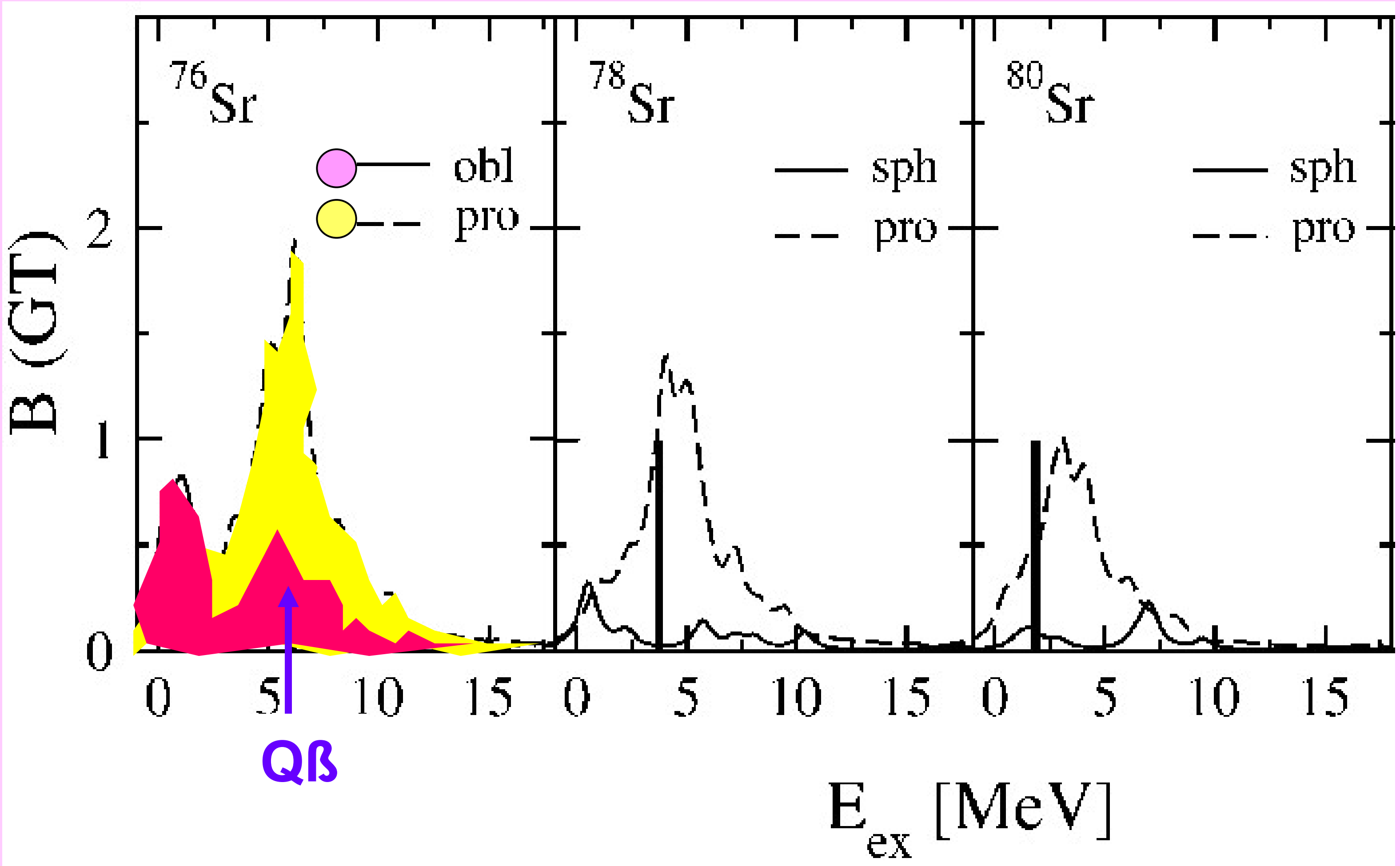


To extract information on the sign of the deformation is not easy



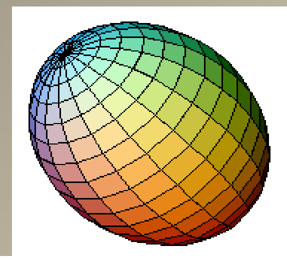
Rememeber C. Buer contribution to this workshop

P. Sarriguren *et al*., Nuc. Phys. A635 (1999) 13

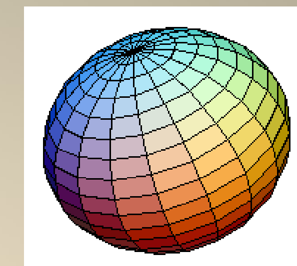


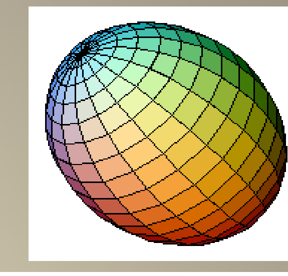
Theoretical calculations predict different B(GT) distributions for oblate, prolate and spherical shape of the ground state.
[Original idea I. Hamamoto *et al*., Z. Phys. A353 (1995) 145]
Followed up by Sarriguren and collaborators and Petrovici and collaborators

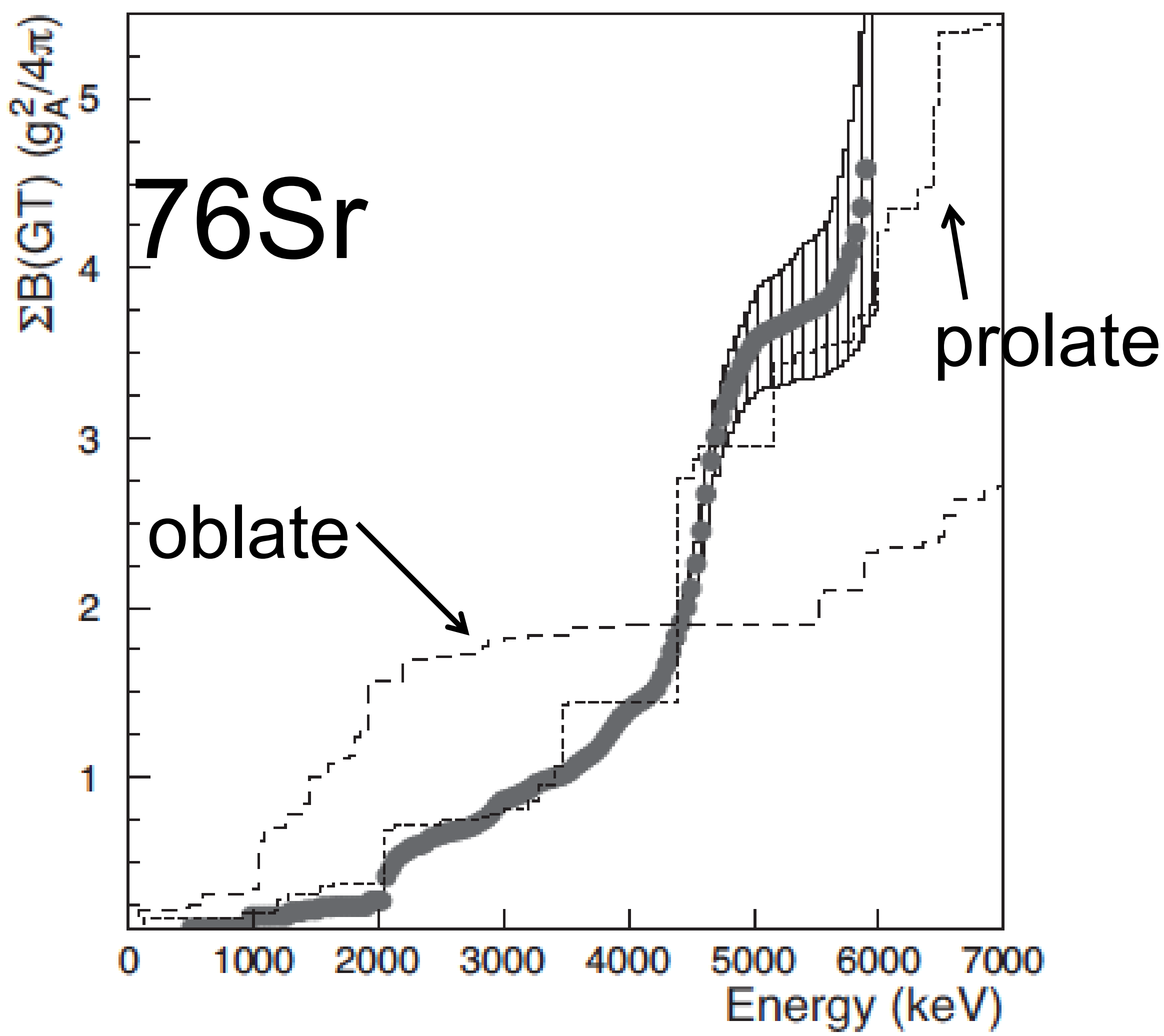
Clarly prolate

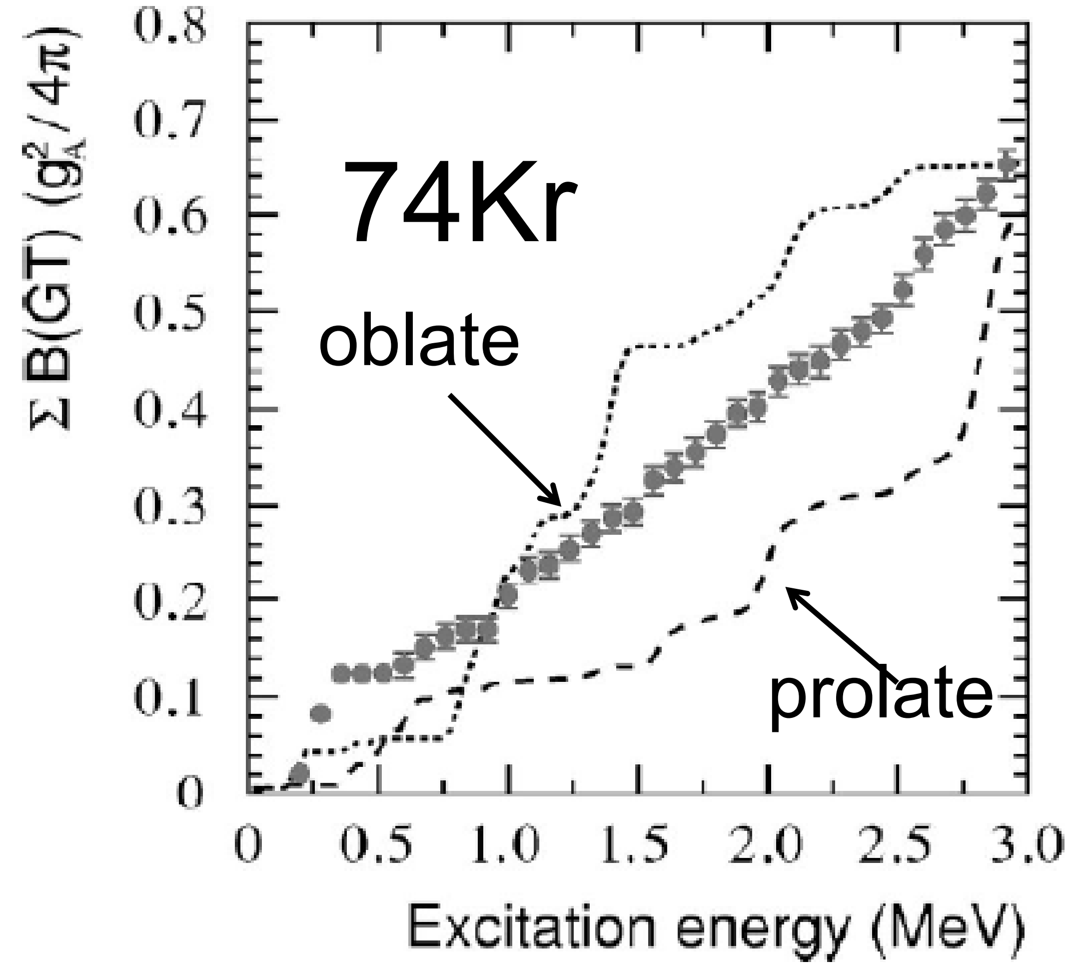


Mixture of prolate and oblate





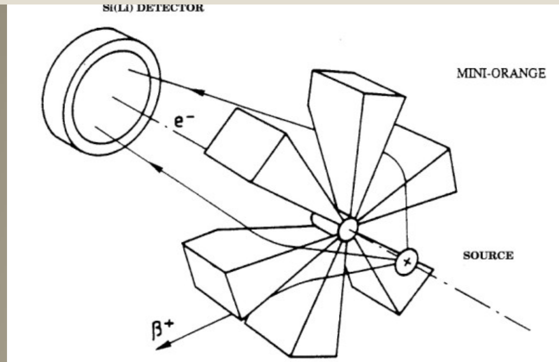




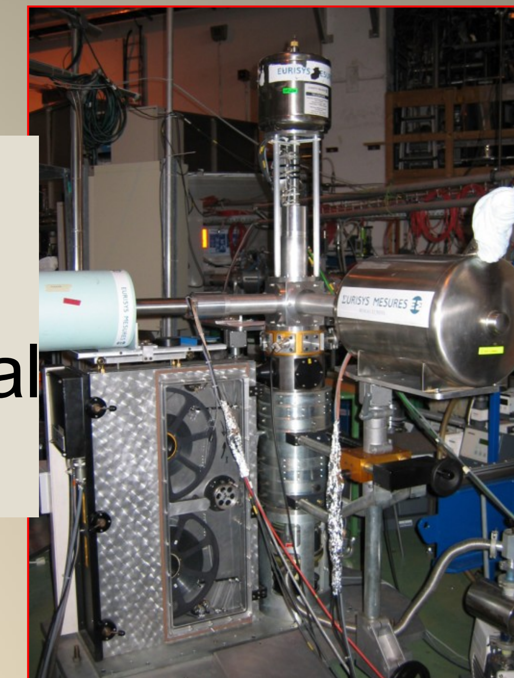
E. Nacher *et al., Phys. Rev. Lett. 92, 232501 (2004)*
Ph.D thesis Valencia

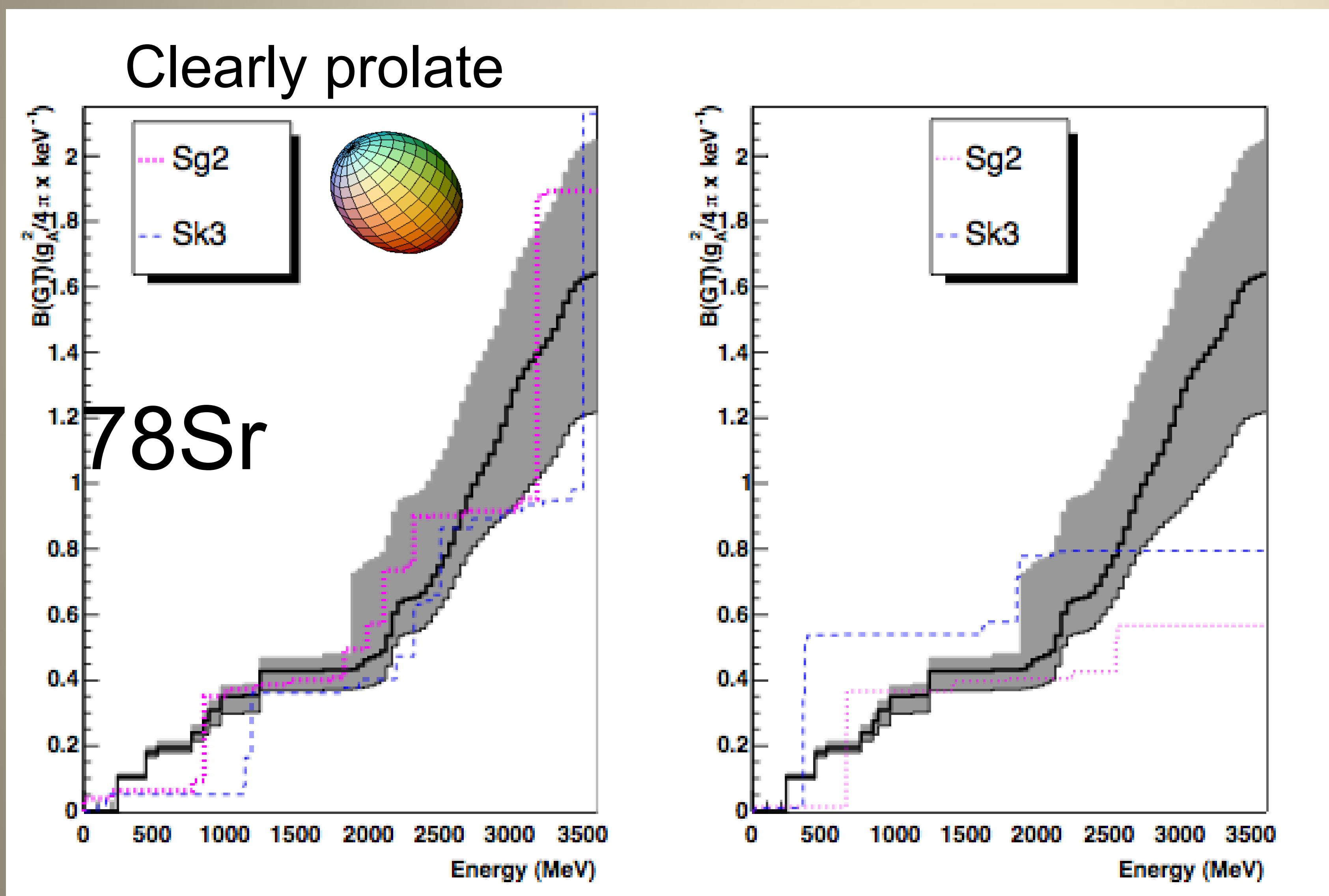
E. Poirier *et al., Phys. Rev. C 69, 034307 (2004)*
Ph. D thesis Starsbourg

In order to properly analyse Tas data
One needs some high resolution data
And the electron conversion information



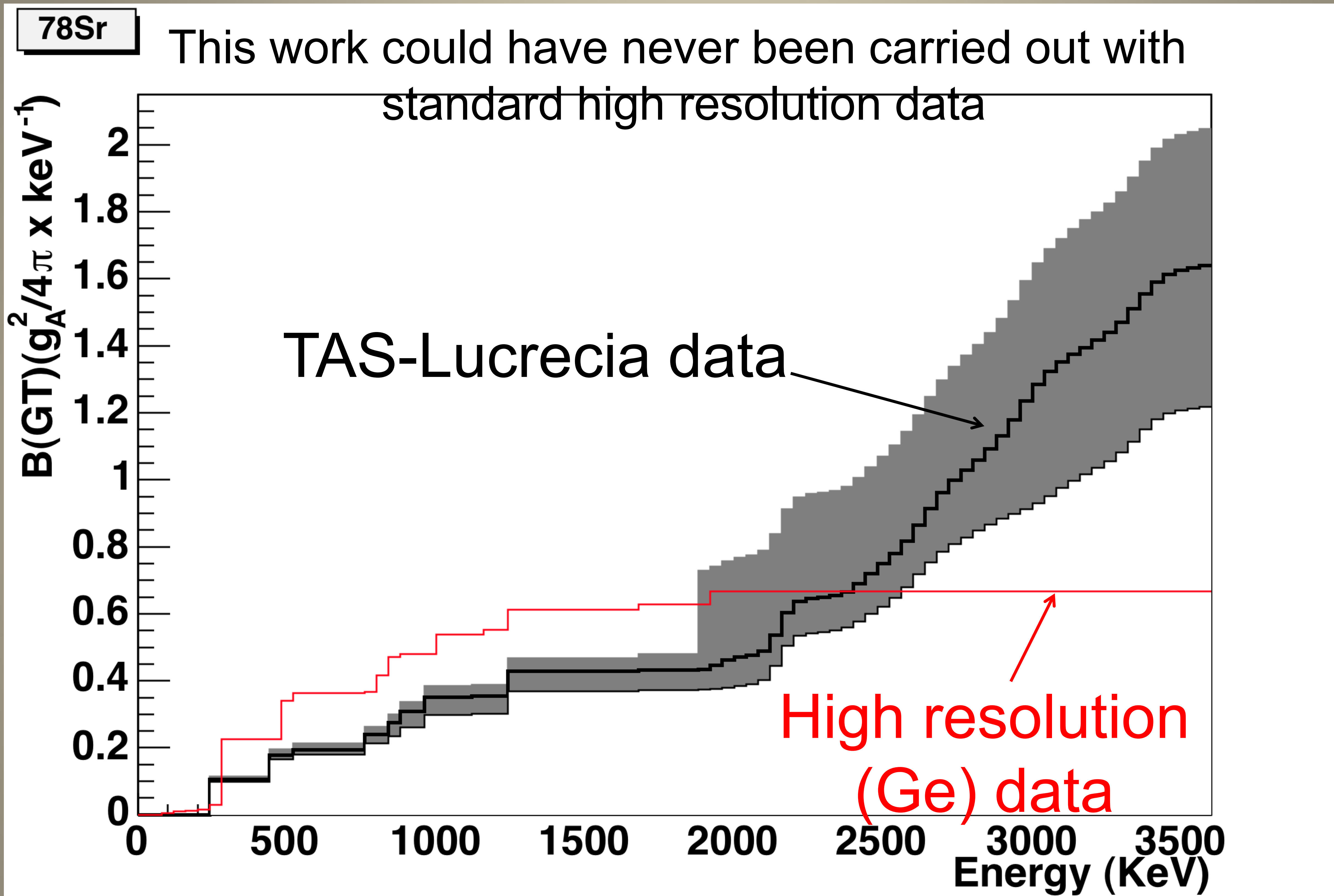
78Sr needed a
larger effort due
to the lack of experimental
information

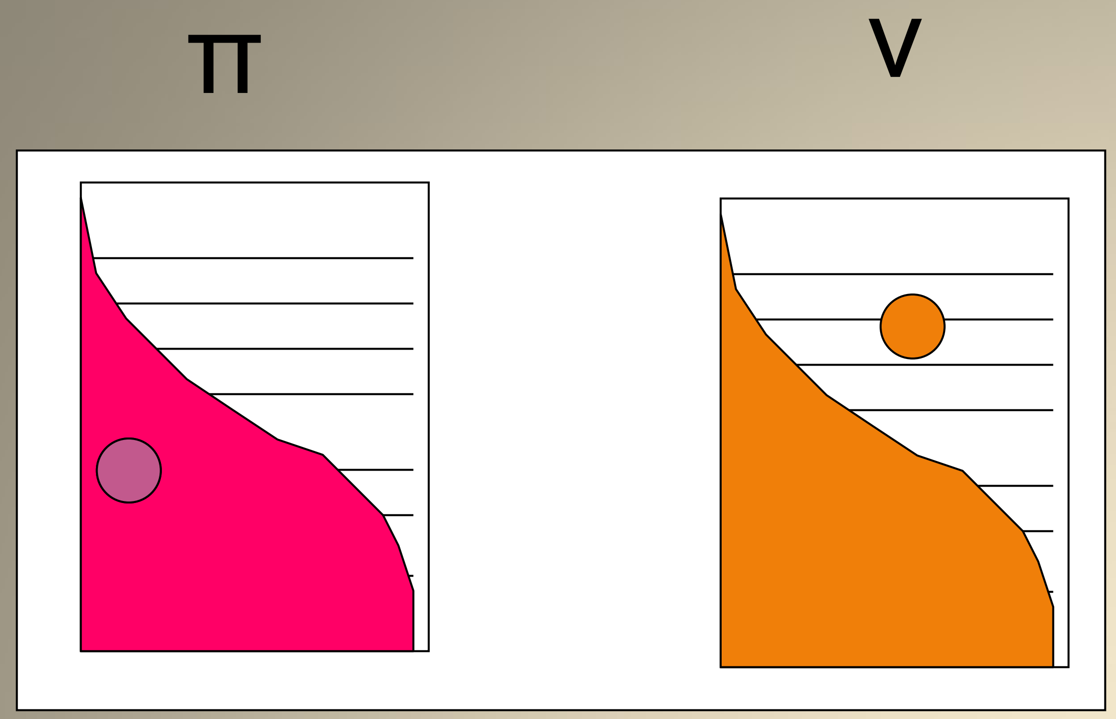




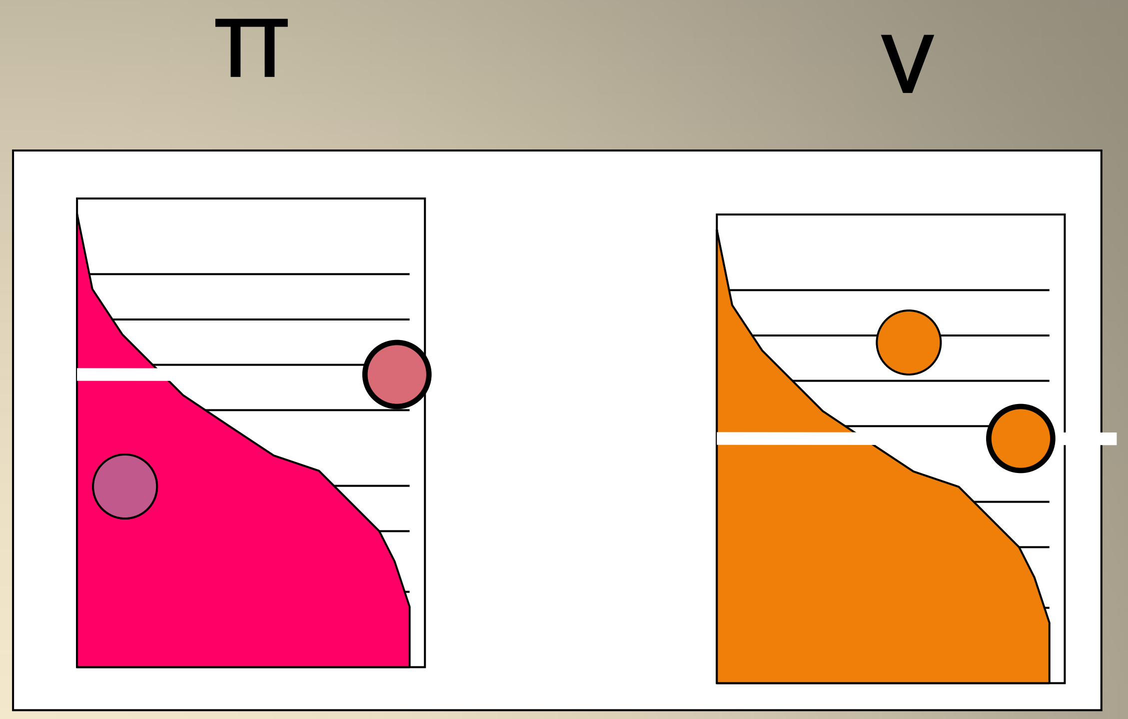
Similarly 72Kr analysis,
needed camplementary
information
and the analysis is still
in progrees
J.A Briz
Ph.D thesis Madrid

A. Pérez
Ph. D thesis Valencia (almost finisched)

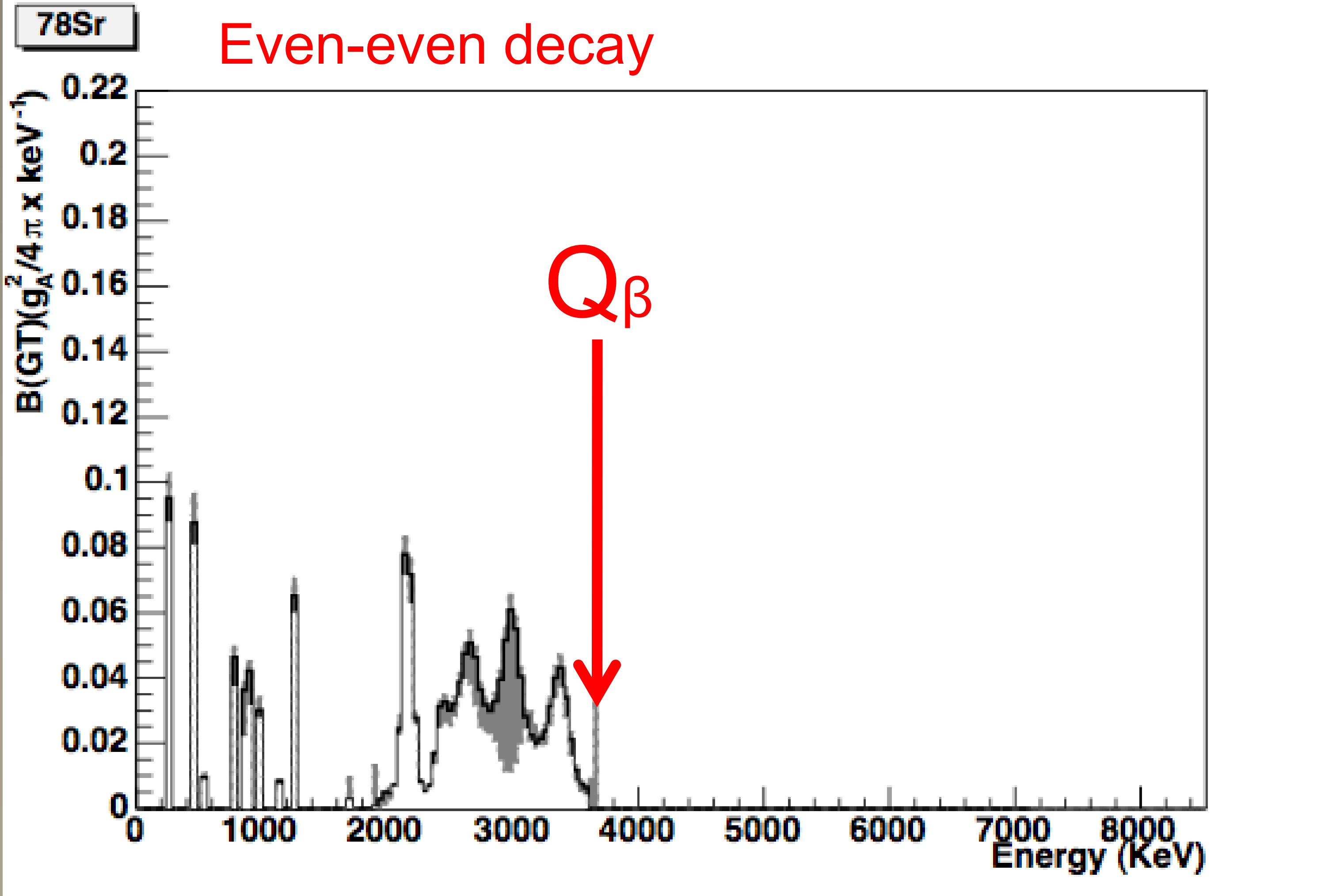

78Sr
This work could have never been carried out with standard high resolution data
B(GT)(g_A^2/4π x keV^-1)
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
TAS-Lucrecia data
High resolution (Ge) data
0
500
1000
1500
2000
2500
3000
3500
Energy (KeV)

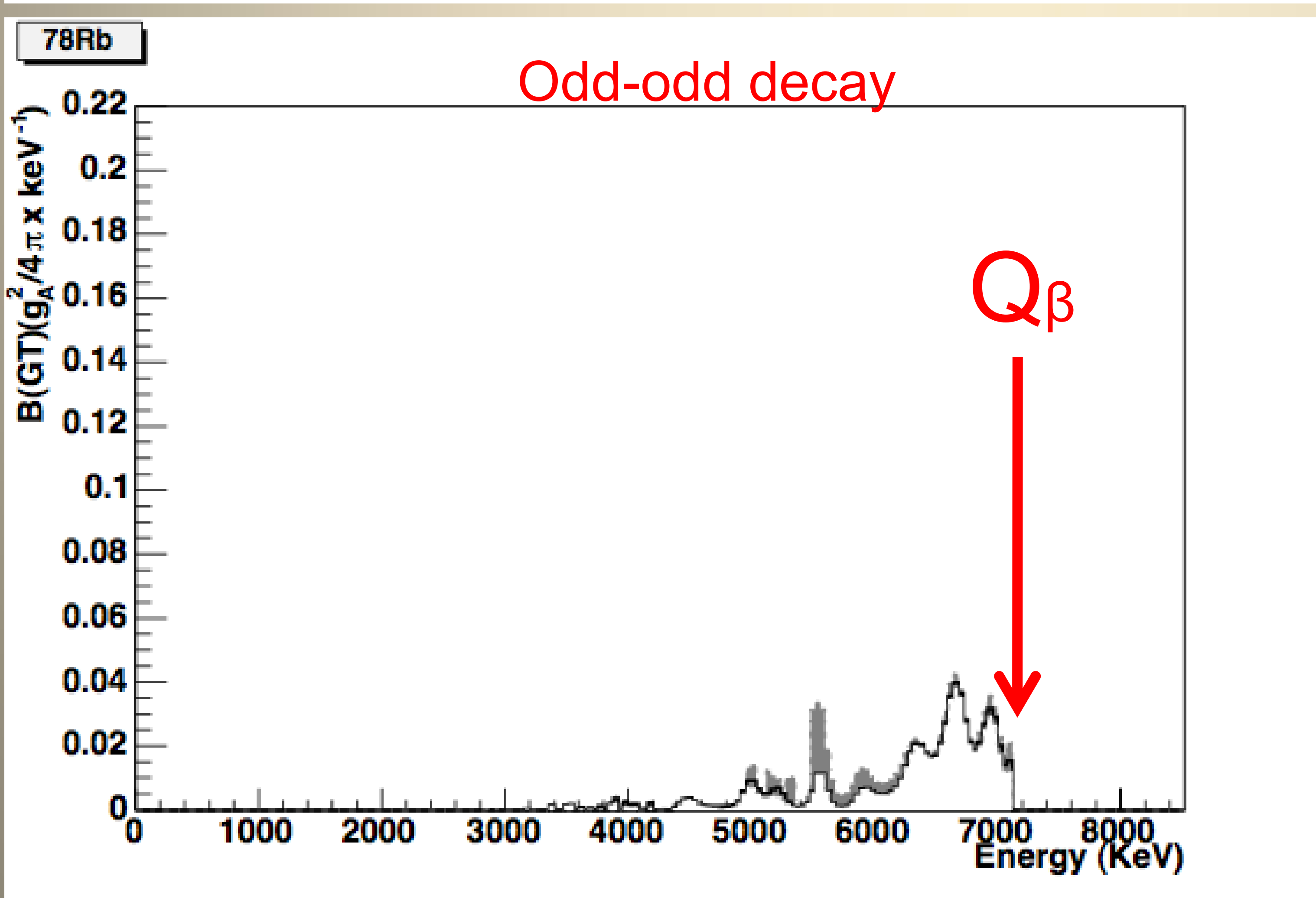


even-even →odd-odd

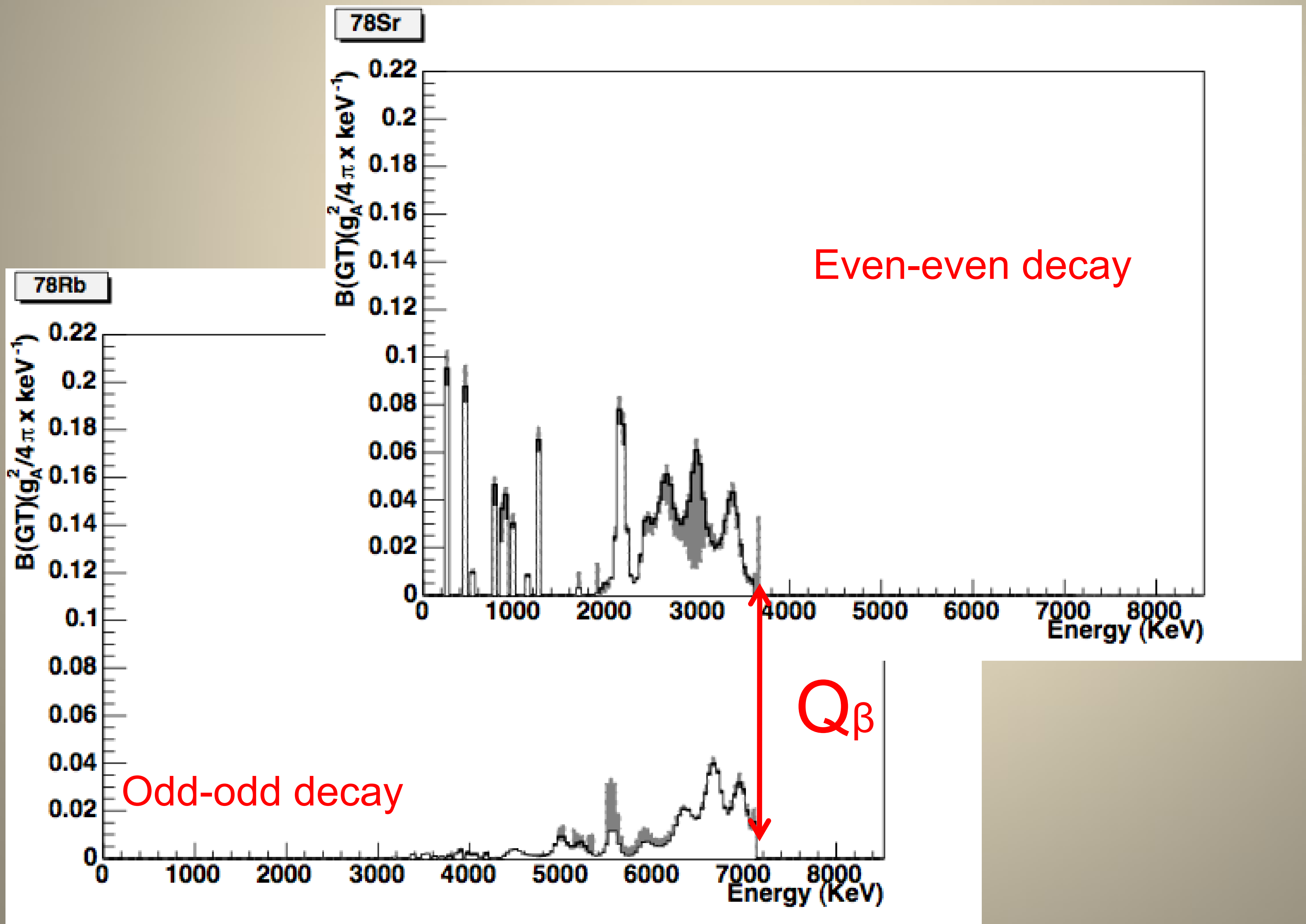


odd-odd →even-even


78Sr
Even-even decay
Qβ
B(GT)(g_A^2/4π x keV^-1)
0.22
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0
1000
2000
3000
4000
5000
6000
7000
8000
Energy (KeV)


78Rb
Odd-odd decay
Qβ
B(GT)(g_A^2/4π x keV^-1)
0.22
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0
1000
2000
3000
4000
5000
6000
7000
8000
Energy (KeV)

e might infer from the BGT distribution of parent and daughter decays
if the two ground states have have similar deformation

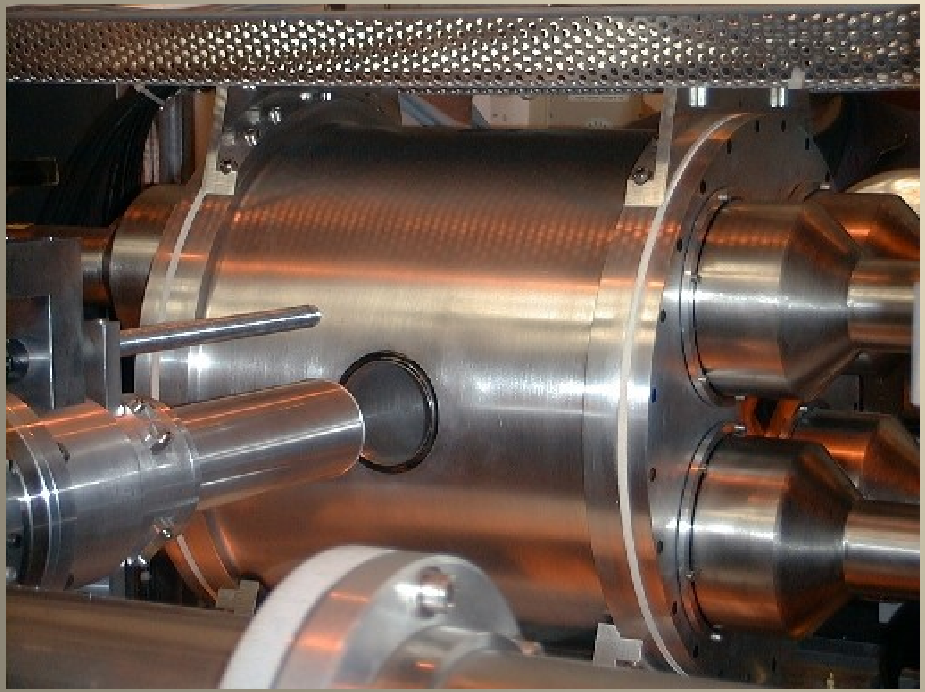


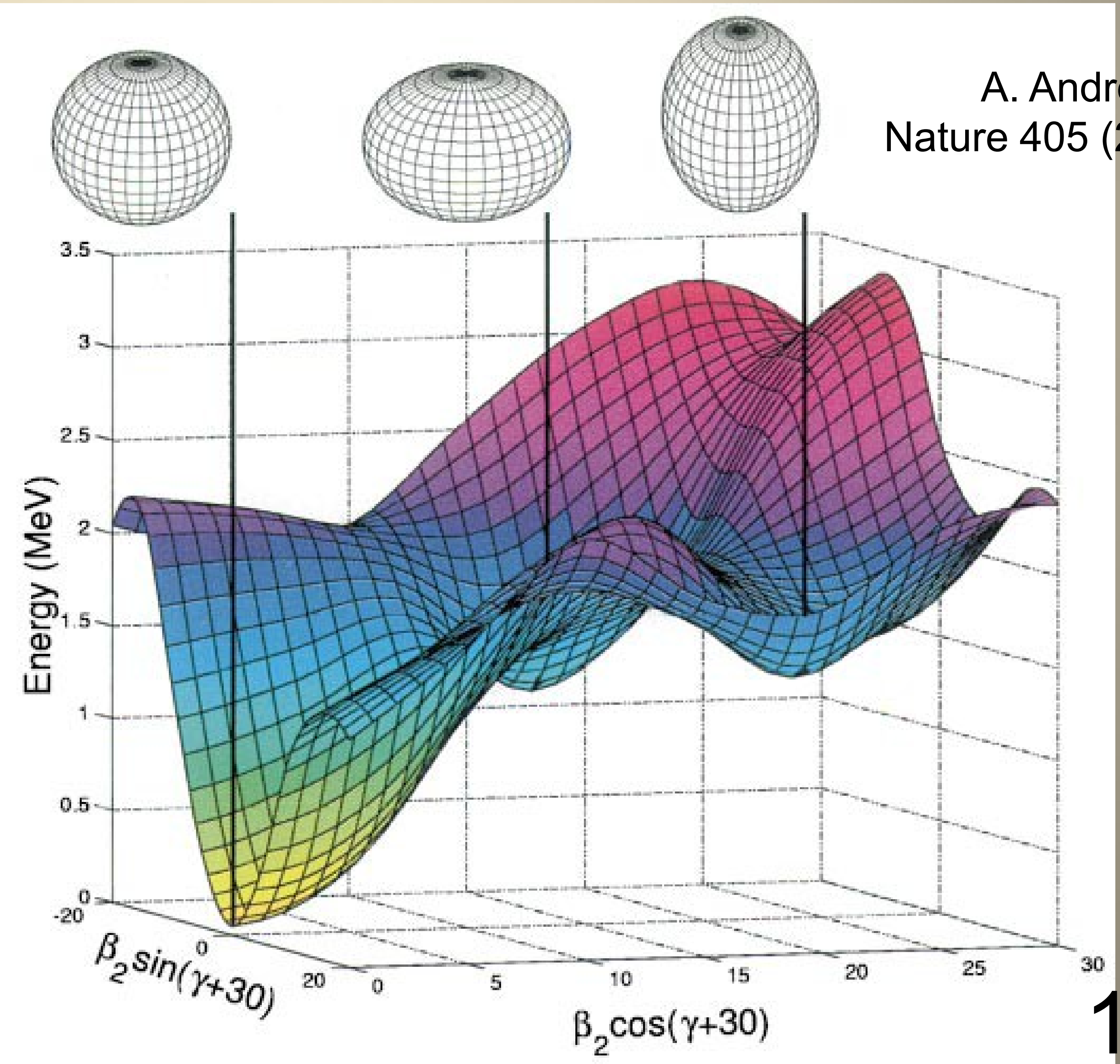
Shape effects along the Z=82 line: study of the beta decay of $^{188,190,192}Pb$ using total absorption spectroscopy

Spokespersons: A. Algora, B. Rubio

ISOLDE Experimental Proposal

CERN-INTC-2005-027, INTC-P-199, IS 440

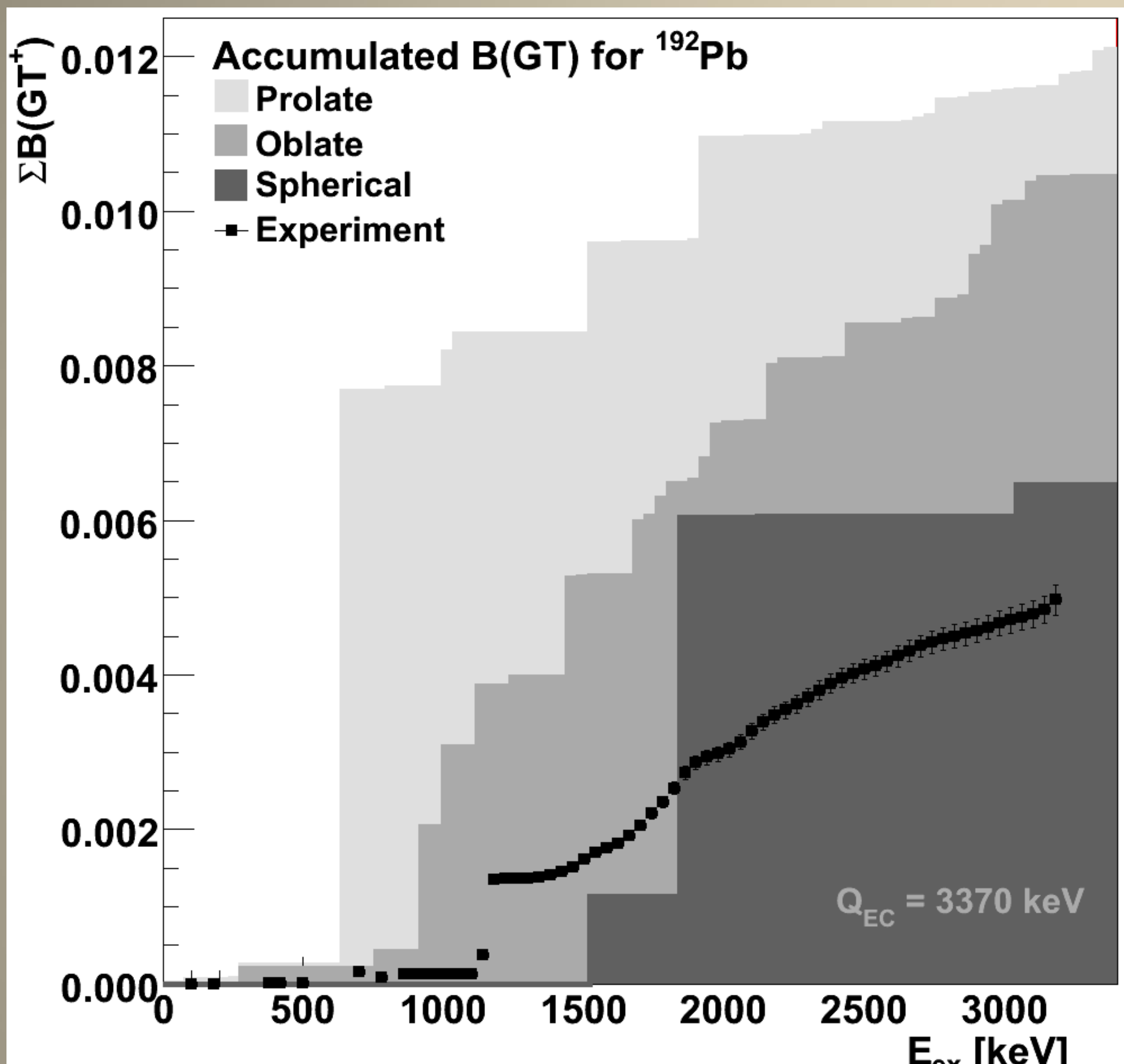


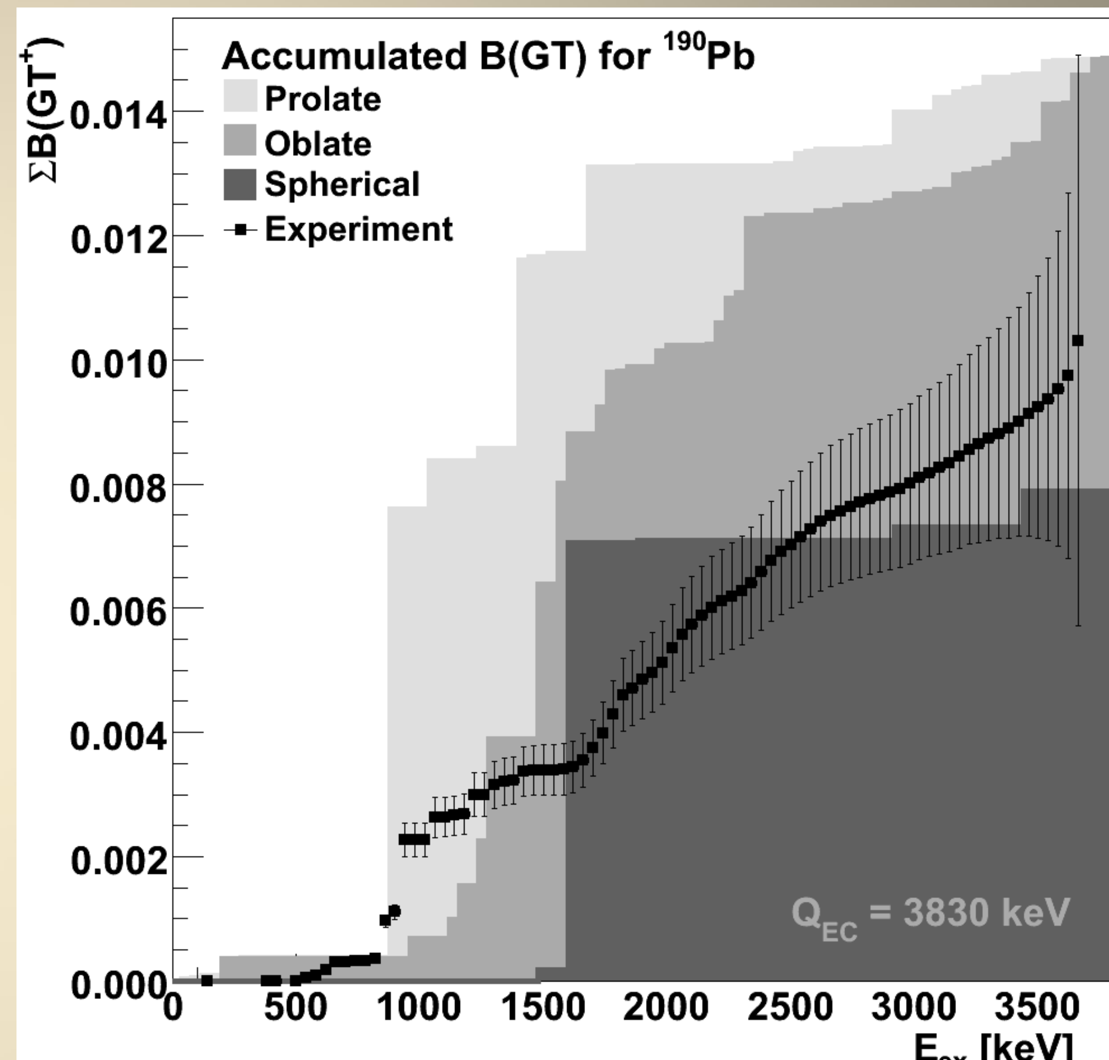


A. Andreyev
Nature 405 (2000) 430

186Pb

Preliminary results: $^{190,192}Pb$





Thesis work of E. Estevez, in preparation. Theory from PRC 72, 054317 (2005)

Preliminary results consistent with spherical picture. Calculations may require fine-tuning

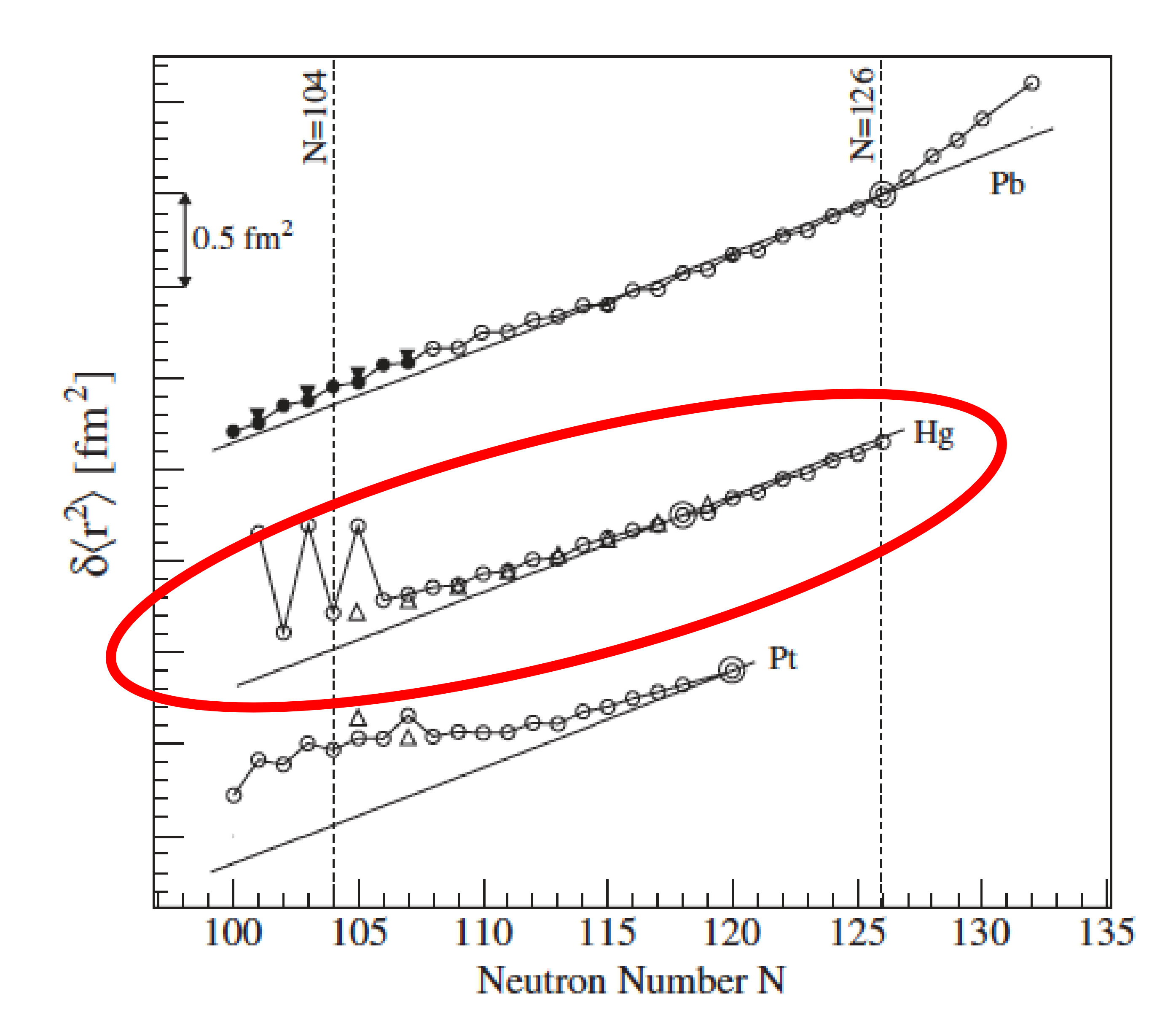
Addendum planned to study the beta decay of ^{186}Pb with the TAS, high resolution studies of $^{188,186}Pb$ (A. Algora *et al. in preparation*)

Additional studies planed in the region ($^{182,184,185,186}Hg$) with the TAS based on new calculations of P. Sarriguren and O. Moreno PRC 73, 054302 (2006). Possible extension of studies to Po (theoretical calculations exist), Pt isotopes (calculations

PRL 98, 112502 (2007) PHYSICAL REVIEW LETTERS week ending 16 MARCH 2007

Nuclear Charge Radii of Neutron-Deficient Lead Isotopes Beyond $N = 104$ Midshell Investigated by In-Source Laser Spectroscopy

H. De Witte,[1] A. N. Andreyev,[2,3] N. Barré,[4] M. Bender,[5,6] T. E. Cocolios,[1] S. Dean,[1] D. Fedorov,[7] V. N. Fedoseyev,[8] L. M. Fraile,[8] S. Franchoo,[4,8,9] V. Hellemans,[10] P. H. Heenen,[5] K. Heyde,[10] G. Huber,[9] M. Huyse,[1] H. Jeppessen,[8] U. Köster,[5,*] P. Kunz,[9] S. R. Lesher,[1,†] B. A. Marsh,[8,11] I. Mukha,[1,‡] B. Roussière,[4] J. Sauvage,[4] M. Seliverstov,[7,9] I. Stefanescu,[1] E. Tengborn,[12] K. Van de Vel,[1,§] J. Van de Walle,[1] P. Van Duppen,[1] and Yu. Volkov[7]

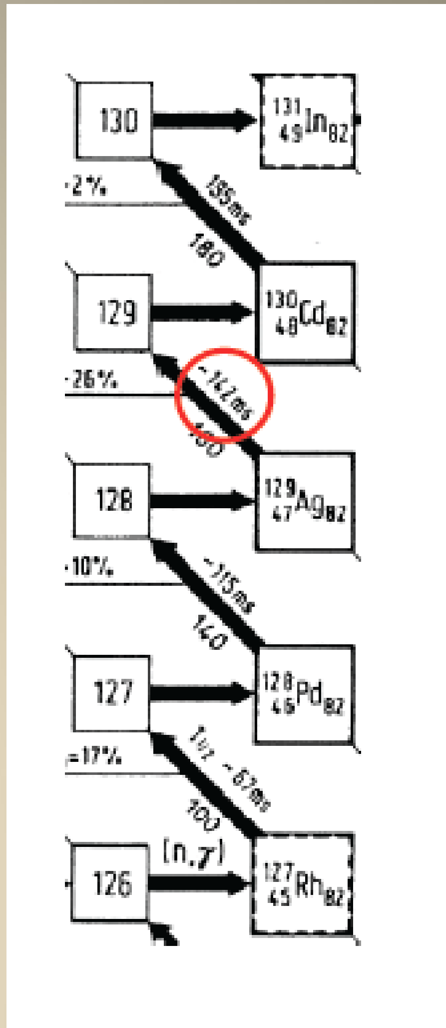


Neutron deficient Hg isotopes also look very promesing

The **impact** of
15 years of RILIS at ISOLDE
and
25 years of r-process research at ISOLDE
“ recognition of the efforts of K.-L. Kratz”

William B. Walters

Department of Chemistry and Biochemistry
University of Maryland



Most of the nuclei in the r-process path are not experimentally available

Half-life estimates are based on BGT (and other contributions) lculations. Experimental BGT strength in accesible close by nuclei are very important to check our models

PHYSICAL REVIEW C, VOLUME 62, 054301

Selective laser ionization of very neutron-rich cadmium isotopes: Decay properties of $^{131}Cd_{83}$ and $^{132}Cd_{84}$

M. Hannawald,[1] K.-L. Kratz,[1,*] B. Pfeiffer,[1] W. B. Walters,[2] V. N. Fedoseyev,[3] V. I. Mishin,[3] W. F. Mueller,[4] H. Schatz,[5] J. Van Roosbroeck,[4] U. Köster,[6] V. Sebastian,[7] H. L. Ravn,[8] and the ISOLDE Collaboration[8]
[1]*Institut für Kernchemie, Universität Mainz, D-55128 Mainz, Germany*
[2]*Department of Chemistry, University of Maryland, College Park, Maryland 20742*
[3]*Institute of Spectroscopy, Russian Academy of Sciences, RU-142092 Troitzk, Russia*
[4]*Instituut for Kern- en Stralingsfysica, University of Leuven, B-3001 Leuven, Belgium*
[5]*Gesellschaft für Schwerionenforschung, D-64291 Darmstadt, Germany*
[6]*Physik Department, TU München, D-85748 Garching, Germany*
[7]*Institut für Physik, Universität Mainz, D-55128 Mainz, Germany*
[8]*CERN, CH-1211 Geneva 23, Switzerland*
(Received 4 May 2000; published 25 September 2000)

A chemically selective laser ion source has been applied in a decay study of the very neutron-rich isotopes ^{131}Cd and ^{132}Cd at CERN/ISOLDE. For the β^- decay of the $N=83$ nuclide ^{131}Cd a surprisingly short half-life of (68 ± 3) ms and a weak delayed-neutron branch of $P_n=(3.5\pm1.0)\%$ were observed. For the $N=84$ nuclide ^{132}Cd a half-life of (97 ± 10) ms and a P_n value of $(60\pm15)\%$ were obtained. Schematic features of both decay schemes are developed. We find that our new data are not reproduced by current global models used for *ab initio* calculations of β-decay properties without significant changes.

^{131}Cd: 68(3) ms **^{132}Cd 97 (10) ms** **^{133}Cd 57(10)**

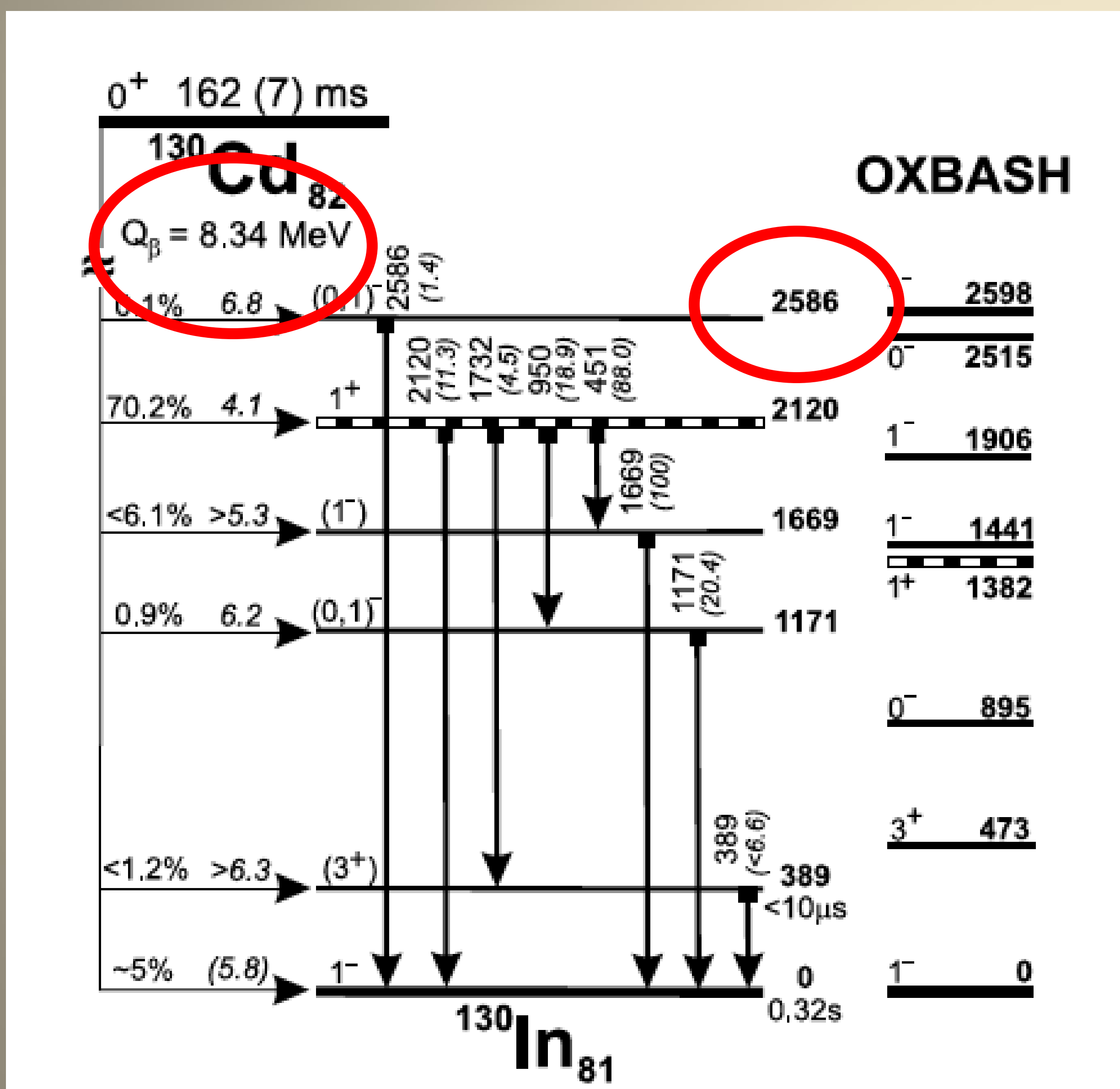
The 68 (3) ms half-life and 3.5% P_n values for ^{131}Cd remain somewhat anomalous and deserve more attention.

Taken from Prof. WALTERS, William
Prof. KRATZ, Karl-Ludwig contribution to this workshop

VOLUME 91, NUMBER 16 PHYSICAL REVIEW LETTERS week ending 17 OCTOBER 2003

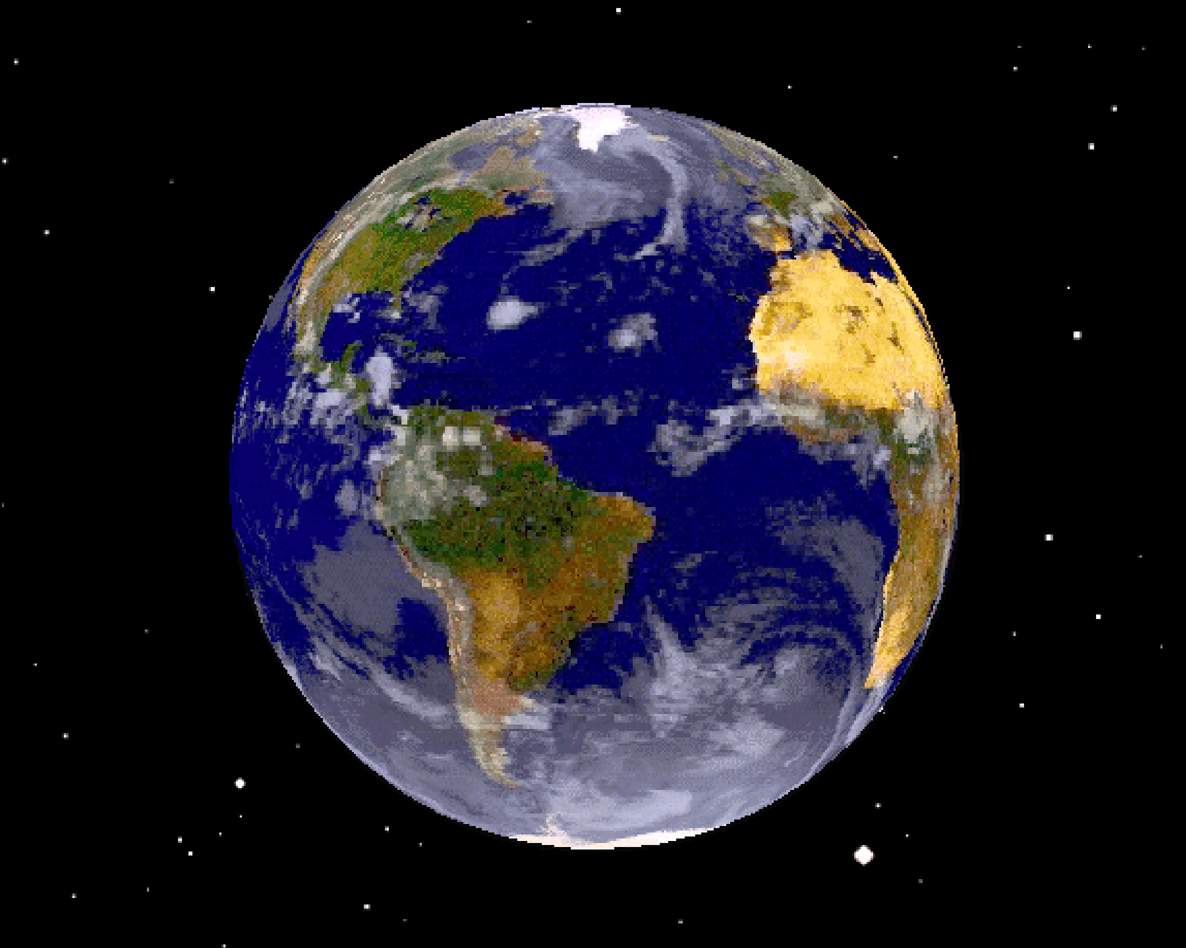
$N = 82$ Shell Quenching of the Classical r-Process "Waiting-Point" Nucleus ^{130}Cd

I. Dillmann,[1,2] K.-L. Kratz,[1,*] A. Wöhr,[3,4] O. Arndt,[1] B. A. Brown,[5] P. Hoff,[6] M. Hjorth-Jensen,[7] U. Köster,[8] A. N. Ostrowski,[1] B. Pfeiffer,[1] D. Seweryniak,[9] J. Shergur,[3,9] W. B. Walters,[3] and the ISOLDE Collaboration[8]



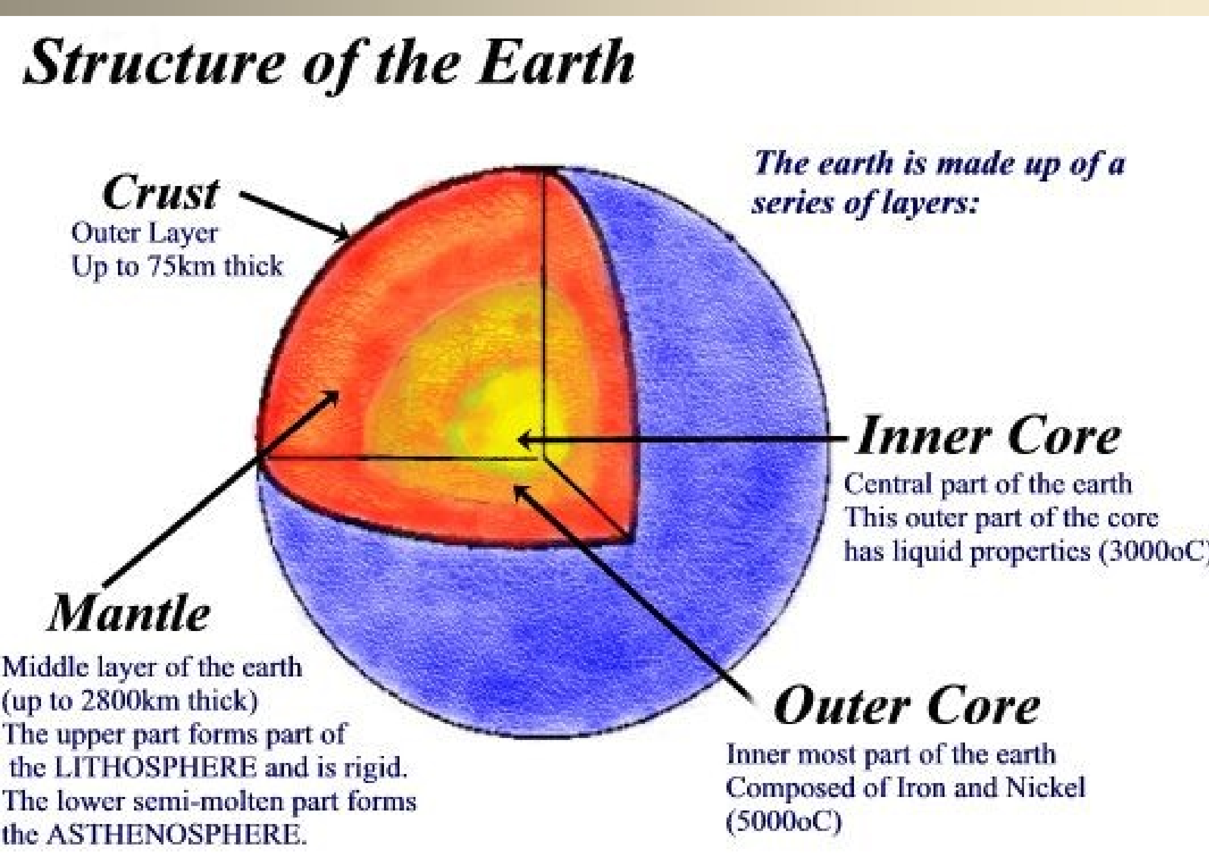
The beta-delayed gammas of 130Cd, with 8.3 MeV Q-beta value, and last observed level at 2.6 MeV, plus some "indication" at 4.4 MeV, deserves an experimetal effort using Total Absorption Technique. Isolde is today the place to do it

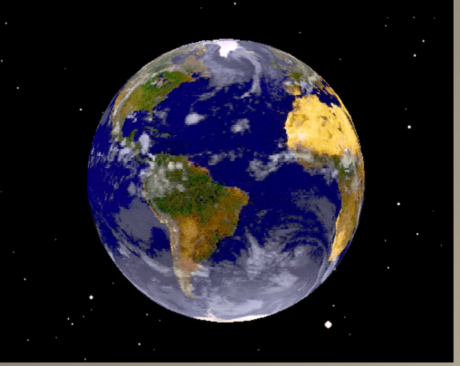
ıeory [17]. The log ft values for a cluster of seven levels above 4.4 MeV (not included in Fig. 1) clearly suggest GT feeding. These levels have a total β feeding



The Structure and Composition of the Earth

- Deepest borehole – 12 km
- Seismology gives us a density profile but nothing about composition
- We then have models which do not tell us about the composition in detail
- Without detail it is very hard to know how much of Earth's heating comes from radiogenic sources
- Indeed we have a very limited knowledge the sources of heating of the Earth's interi





An important piece of information comes from the Geo-Neutrinos

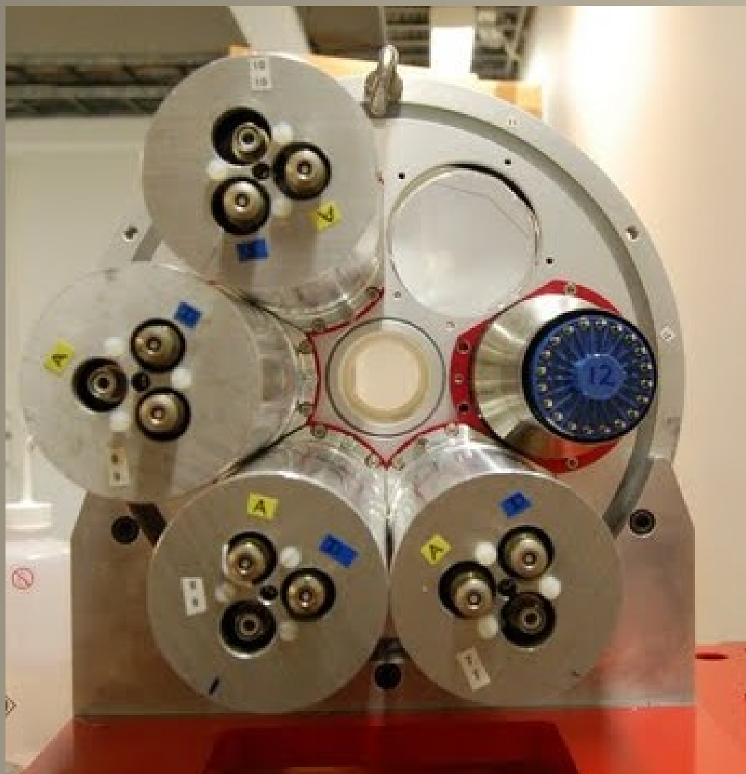
They tell us about 238U, Th, 235U, 40K and 87Rb the main sources of radioactive decay in the Earth

- Neutrino detectors are now sensitive enough that we can expect to measure υ_e spectra in the next few years.

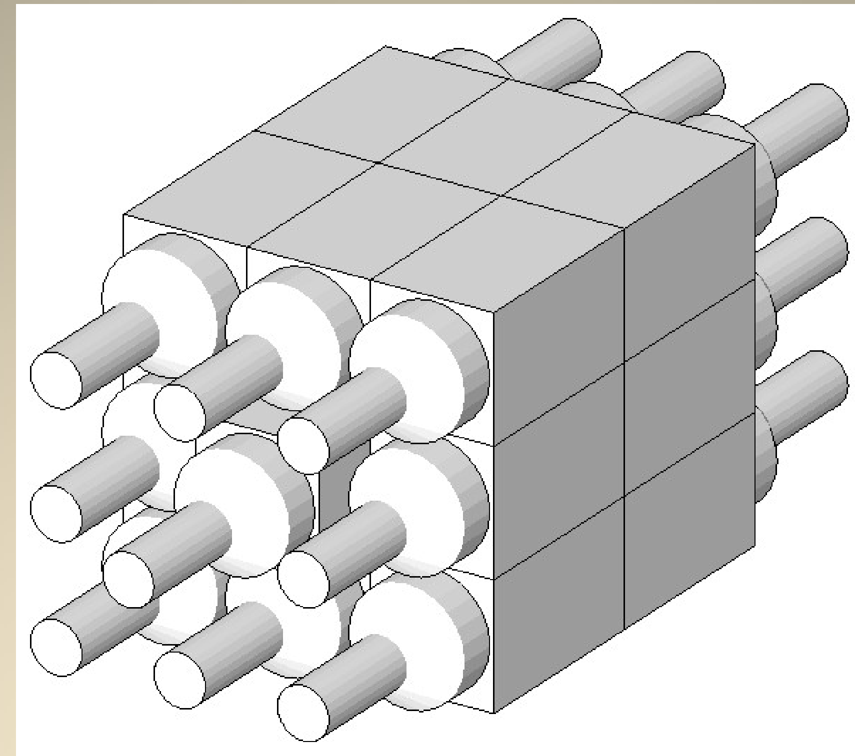
But in order to extract the information of the neutrino spectra we have to know very well the decay scheme of the nuclei involved in particular 214Bi (originating 60% of the antineutrinos produced by U) should be revised.

Excellent candidate for an experiment at Isolde using the Lucrecia TAS
The gs to gs transition could be determined using the subsequent alpha decay

Fiorentini et al.,PRC81(2010)034602
Fiorentini et al., Phys.Reports453(2007)117

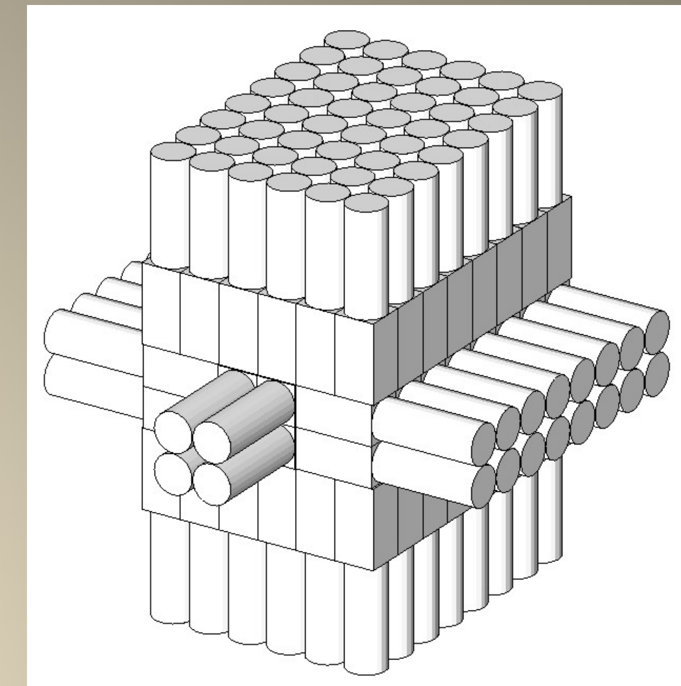


BaF_2 TAS Valencia-Surrey
Now at Juväskylä
In the future at DESIR



Total Absorption Spectrometer for DESPE
(FAIR), under construction

16 + 1 modules:
15×15×25 cm^3 **NaI(Tl)**
+ 5” PMT (50% light col.)
V= 95 L, M= 351 kg



128 + 4 modules:
5.5×5.5×11 cm^3 **$LaBr_3$:Ce**
+ 2” PMT (60% light col.)
V= 44 L, M= 223 kg

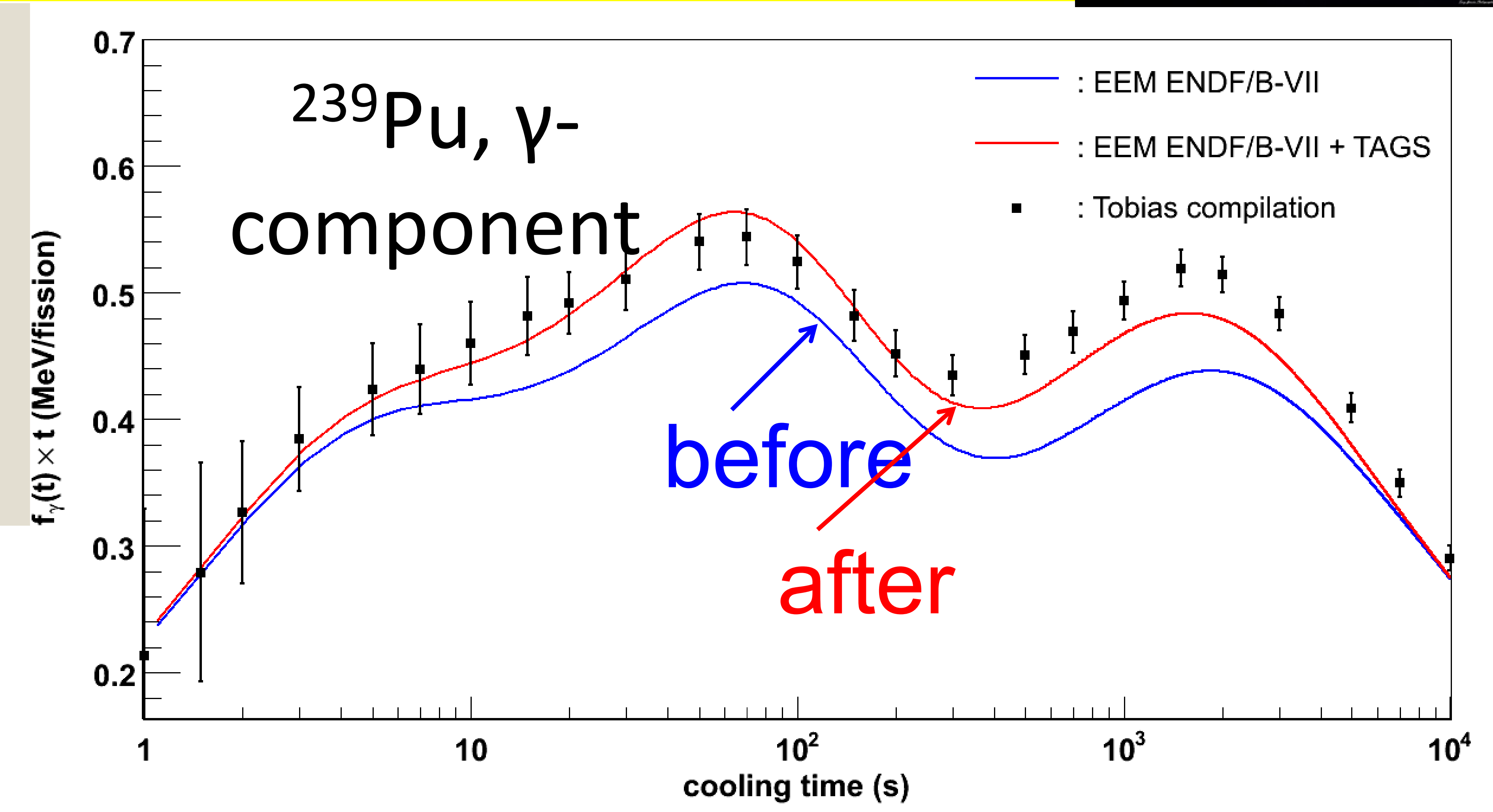
Modular Total Absorption Spectrometer (MTAS)
to be constructed at the HRIBF

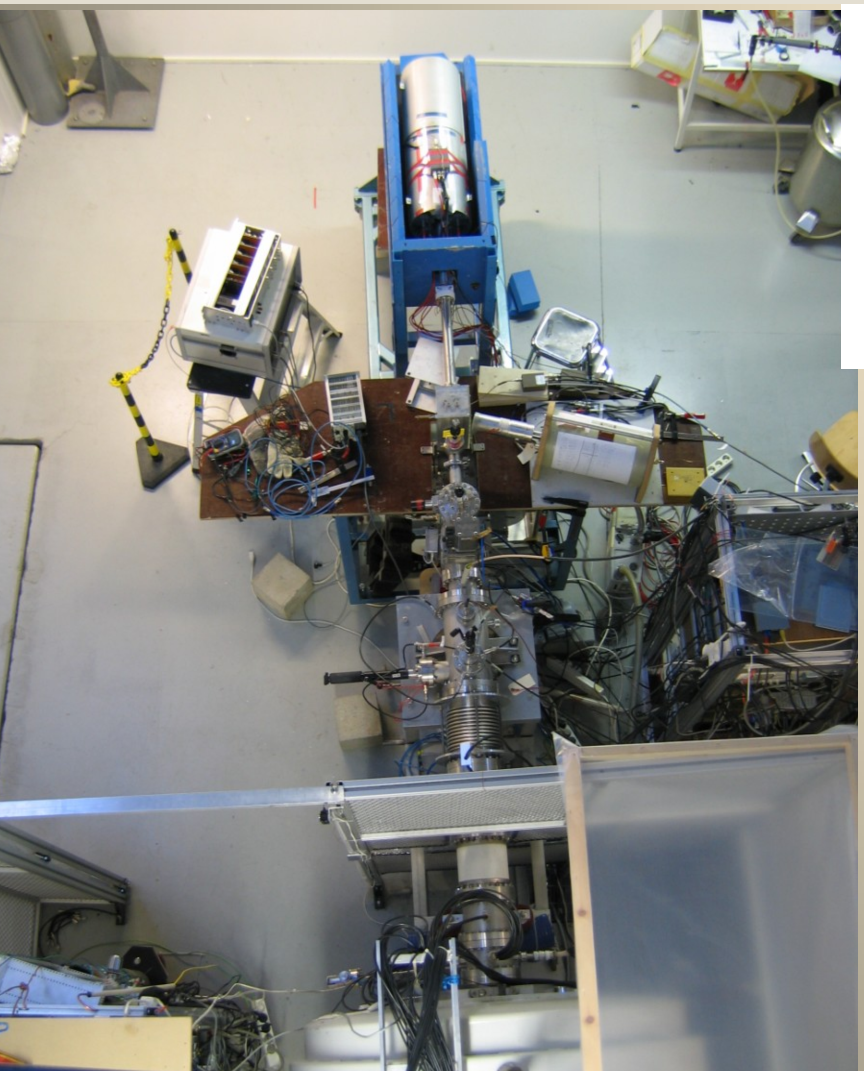
Another one is planned in CALIBU Argonne
National Laboratoty

Decay heat

IFIC, ATOMKI, Univ. Jyvaskyla.,Univ. Surrey, GSI, PNPI, Tokio City Univ. ,NNDC, STUK

A. Algora et al. **PRL** 105, 202501 (2010) (viewpoint in **Physics** 3, 94 (2010))





Measurement of the beta decay of ^{101}Nb, ^{105}Mo, ^{102,104,105,106,107}Tc isotopes

Combination of techniques: IGISOL + JYFLTRAP+ TAS

Summary

• Lucrecia at ISOLDE remains the largest single-crystal Total Absorption Spectrometer in the World

•TAS spectroscopy is the only way to measure beta-delayed gammas fre of Pandemonium effect (systematic error) and consequently to obtain relaibile BGT values

•Two experimental campaigns at ISOLDE are finished now.
They were aimmed at extracting information on nuclear deformation from the BGT distribution

•ISOLDE remains a unique place to carry out decay studies of many nuc

•We are planning to extend the deformation studies to leighter Pb and H

• To study the r-process nuclei 130Cd and 131Cd

•To study nuclei of interest for Geoneutrinos

•We are happy to extend our experience to other collaborators

•Meanwhile similar activities are carried out or planned at other laboratories

The **Borgias** or **Borjas** were
a Valencia(Spanish)-Italian noble family
ho became prominent during the Renassens

EURISOL User Group

Topical Meeting Valencia

Neutron deficient exotic nuclei and
the Physics of the "proton rich side" of the nuclear chart

http://ific.uv.es/~eug-valencia/

February 21st. to 23rd. 2011

Month	Feb
Average high °C (°F)	17.2 (63)
Daily mean °C (°F)	12.6 (54.7)
Average low °C (°F)	7.9 (46.2)

Isospin symmetry and N~Z nuclei.
Superallowed decays
Rp-process
100Sn region
One and Two-proton radioactivity
Exotic decays in light nuclei
Shape coexistence and shape mixing
Dynamical symmetries

Descriptions beyond mean-field
Alpha clusters
Spectroscopy of Super Heavy or
very heavy nuclei, decay tagging
np pairing in N=Z nuclei
Exotic modes of excitation
Nucleosynthesis
Nuclear reactions

Geo-Neutrinos

- Neutrino detectors are now sensitive enough that we can expect to measure υ_e spectra in the next few years even although signal will be small and, in some places reactor antineutrinos will create a problem background.

- All antineutrino detectors based on hydrocarbons rely on the reaction

- $v + p \rightarrow e+ + n – 1.806$ MeV

- As a result only a small number of transitions contribute to the antineutrino spectrum

- 238U, Th, 235U, 40K and 87Rb are the main sources of radioactive decay in the Earth

- In the 238U chain it is 234Pa and 214Bi that deliver most of these neutrinos.

- 214Bi is our main target. We want to measure the branching ratios including the *gs* → *gs* transition.

- The experiment will involve the use of an alpha detector to measure the alphas from the daughter 214Po (half life 164.3 μs) in coincidence with gammas detected in *Lucrecia*

- The no. of alphas will give the total number of decays and the alpha-gamma coincidence will allow us to determine the branching ratios from the spectrum in the TAS.

Earth:

~1890 Kelvin: ~20-40 Myears

radioactivity

1905 Rutherford => billions of years

[age: 4.55 billion years (radioactive dating)]

Radioactivity ~ 40% of heating of Earth at pre

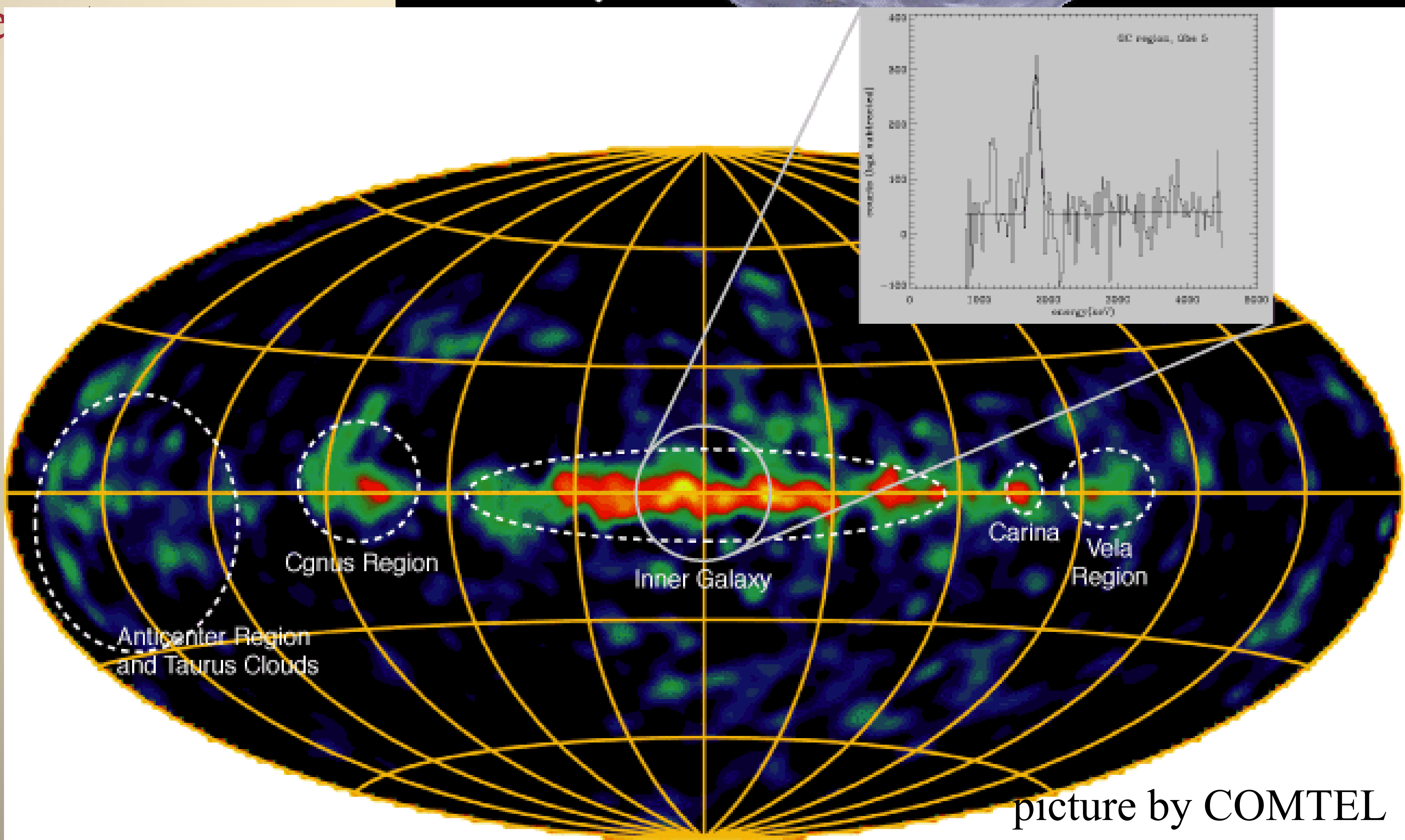
Heaven:

^{26}Al all-sky map:

$T_{1/2}$=0.74 My

E_γ =1.8 MeV

⇒ continuous nucleosynthesis



picture by COMTEL

Geo-Neutrinos

- Neutrino detectors are now sensitive enough that we can expect to measure ν_e spectra in the next few years even although signal will be small and, in some places reactor antineutrinos will create a problem background.

- All antineutrino detectors based on hydrocarbons rely on the reaction

$$\bar{\nu}_e + p \longrightarrow n + e^- - 1.806 \text{ MeV}$$

- As a result only a small number of transitions contribute to the antineutrino spectrum

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Letter to Ana, nov 23th 2010

First item: "usefulness of TAS data"
For that I need:
For 78Sr
a)beta feeding Lucrecia results compared with hi. resolution (already done)
b) the same but with the strength
c) the same, but accumulative sum, and comparison with theory

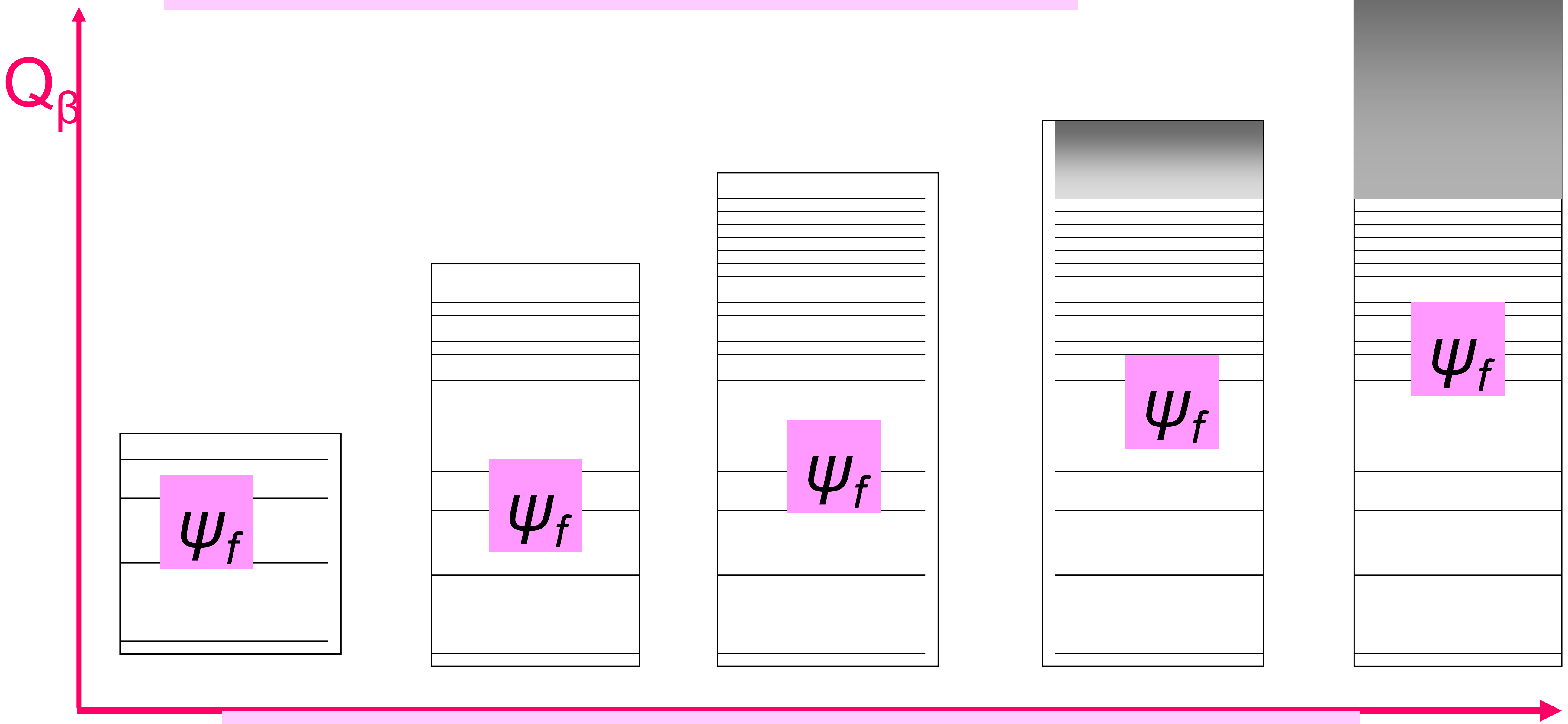
This is to show (hopefully) how wrong the conclusion would have been if hi. resol. was used.

Second item: "looking at the parent and the daughter activity one can gather extra information"

For that I would like to construct a picture along the lines we discussed last time. I attach the draft. Pleas send me the ingredients, namelly the four spectra, same x and y scale. I also need the total BGT for the four cases.

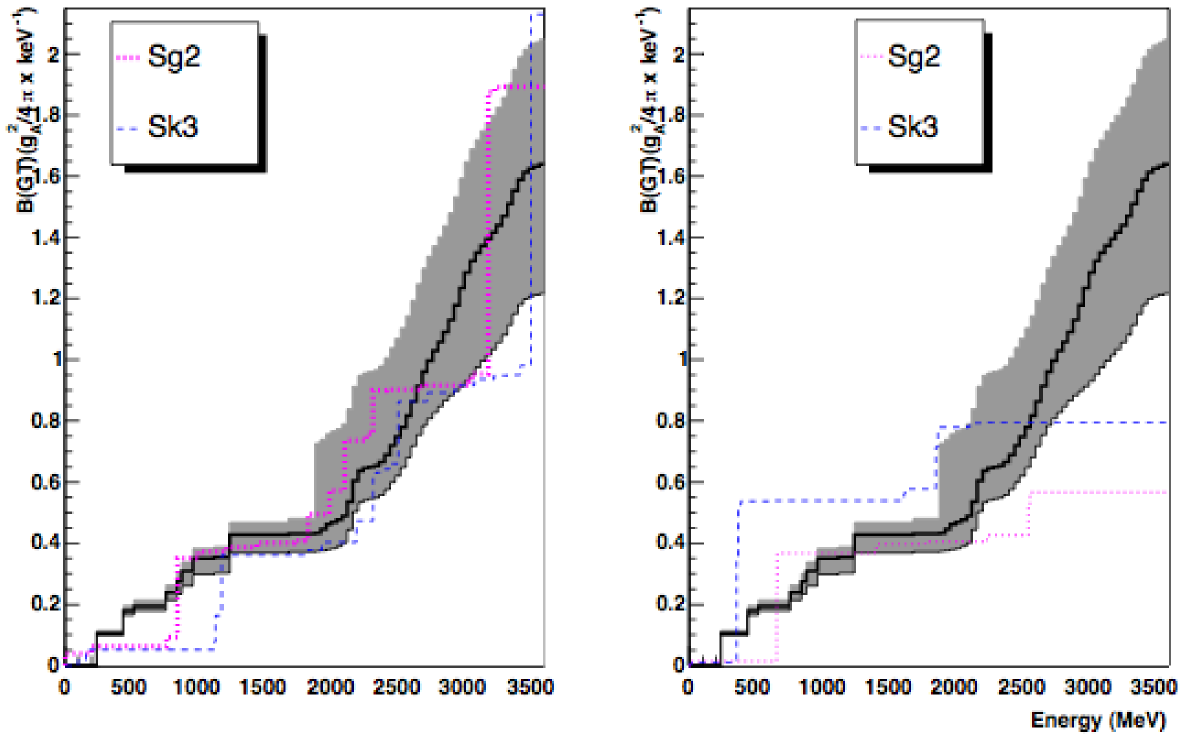
Far from the satability decay schemmes are in general very complex

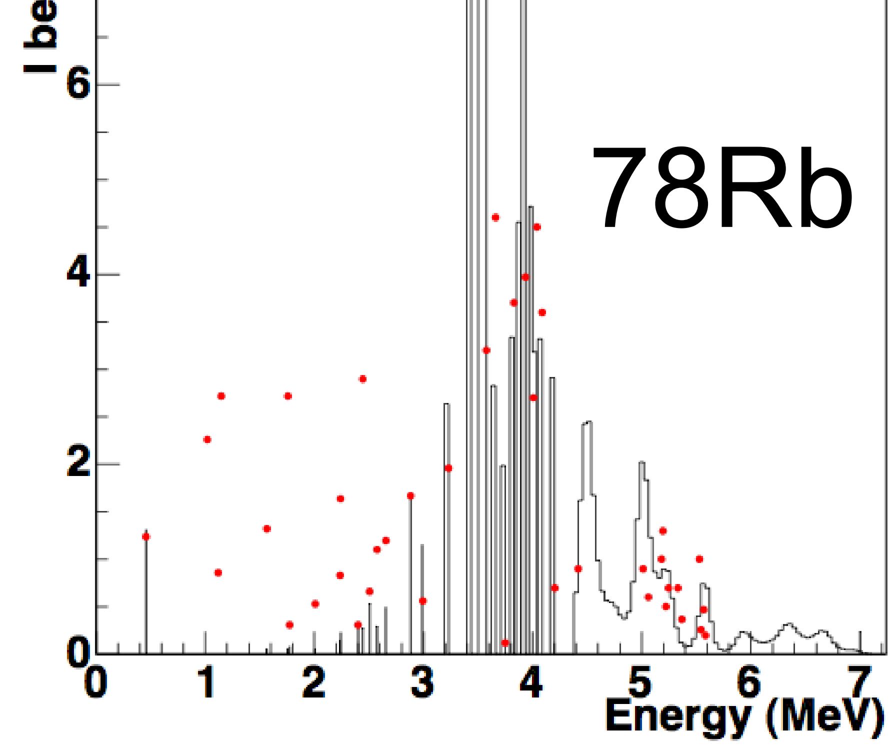
$$B(GT) = \left| \left\langle \psi_f \right| \sum_k \sigma_k \tau_k^{\pm} \left| \psi_i \right\rangle \right|^2$$

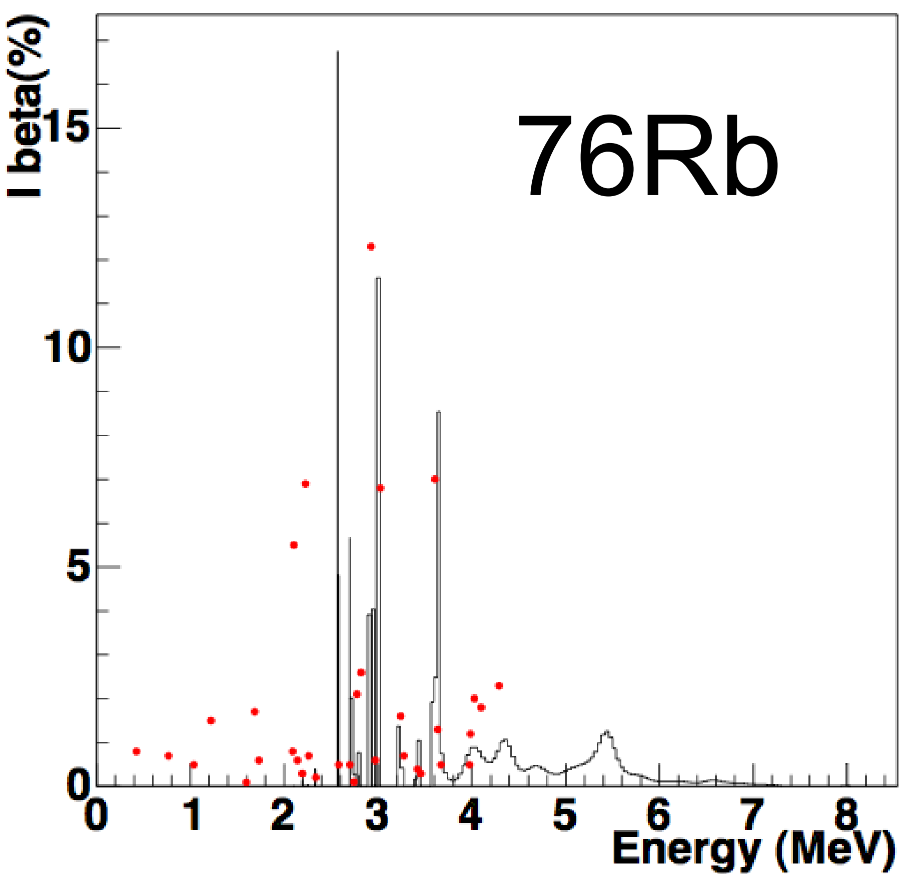


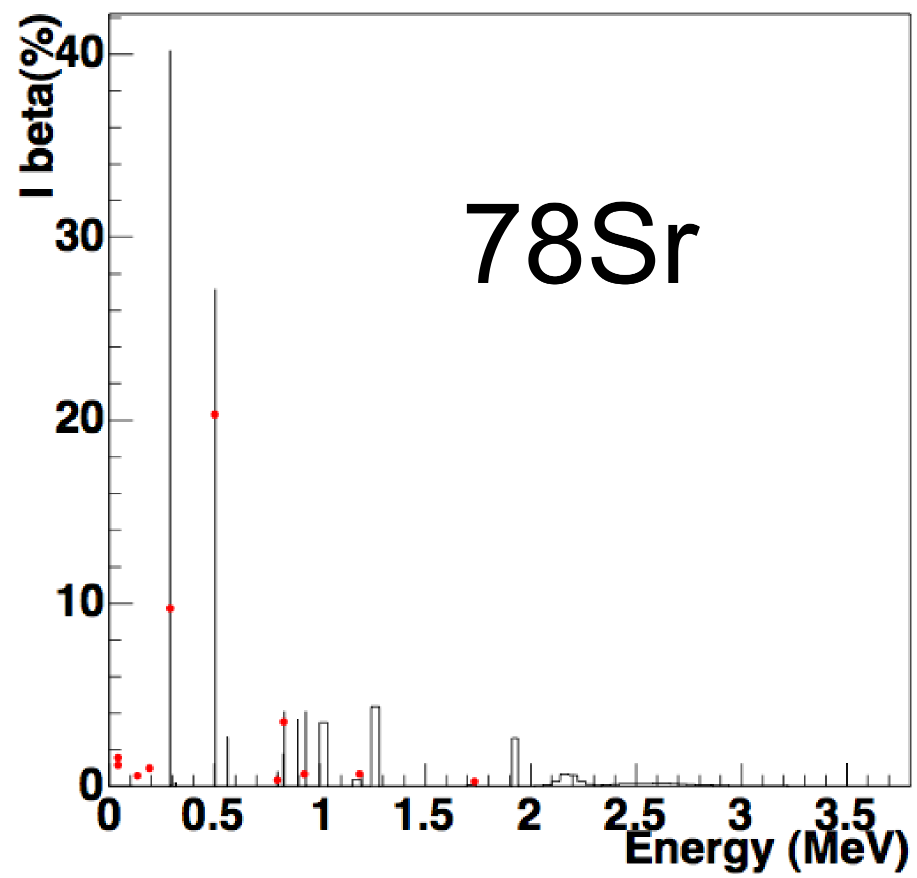
Further from stability, higher Q_β-values


TAS Tape Station


Sg2
Sk3
Energy (MeV)


78Rb
Energy (MeV)


I beta(%)
76Rb
Energy (MeV)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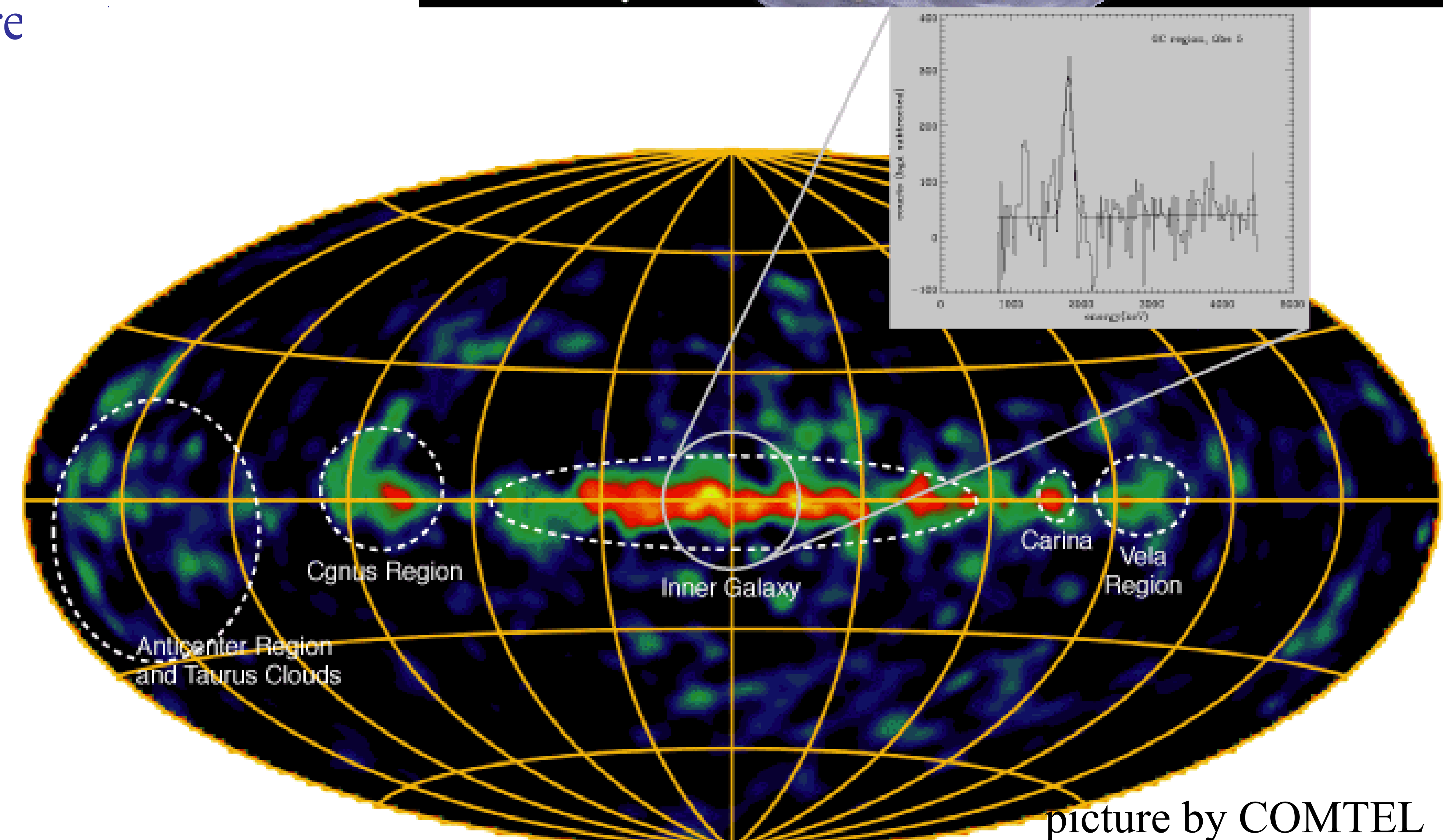


picture by COMTEL

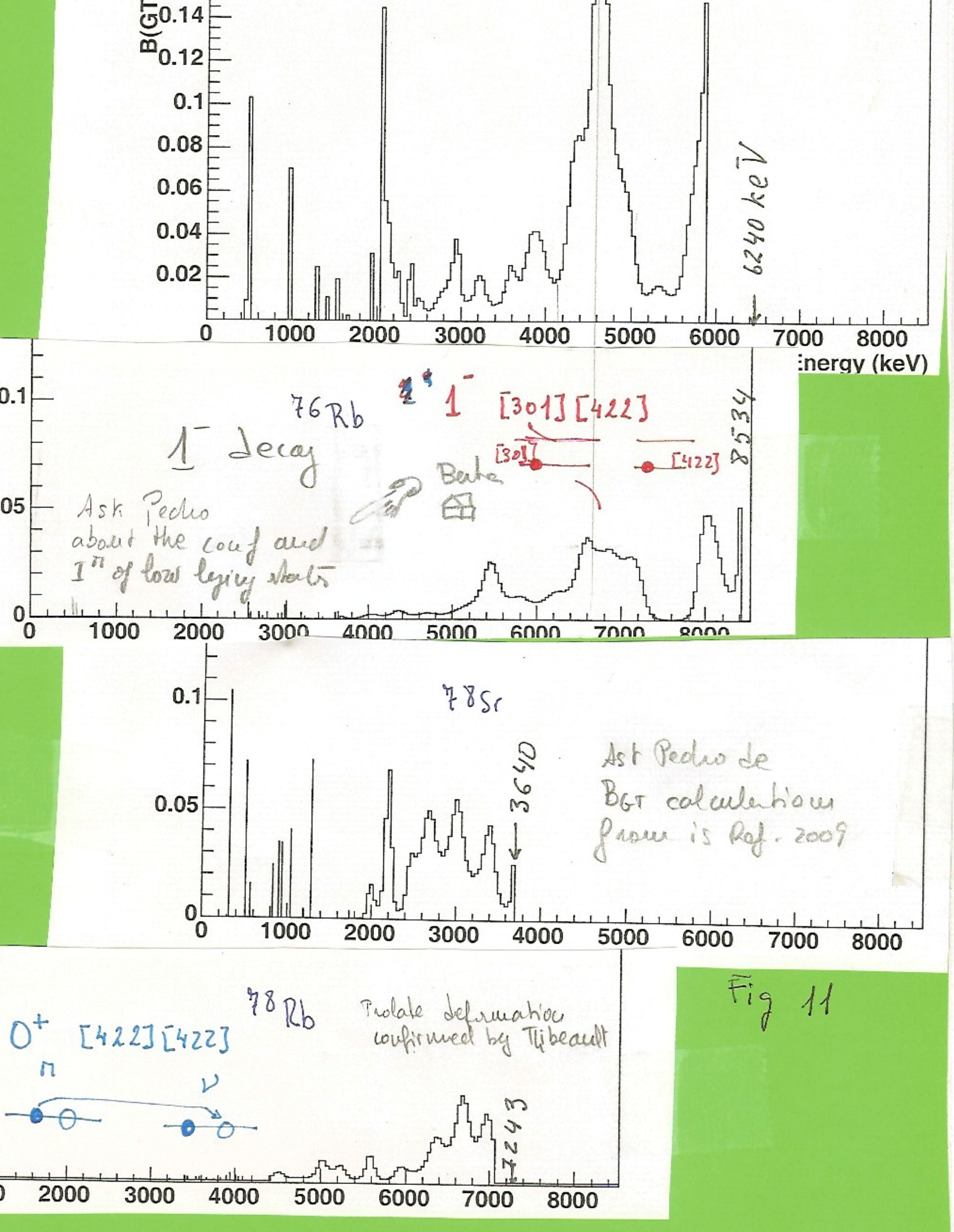
Early onset of deformation in the neutron-deficient polonium isotopes identified by in-source resonant ionization laser spectroscopy

T.E.~Cocolios, W.~Dexters, M.D.~Seliverstov, A.N.~Andreyev, S.~Antalic, B.~Bastin, A.~Barzakh, M.~Bender, J.~B{\"u}scher, I.G.~Darby, D.~Fedorov, V.N.~Fedosseyev, K.T.~Flanagan, S.~Franchoo, S.~Fritzsche, P.-H.~Heenen, G.~Huber, M.~Huyse, M.~Keupers, U.~K{\"o}ster, Yu.~Kudryavtsev, E.~Man{\'e}, B.A.~Marsh, P.~Molkanov, R.D.~Page, M.A.~Sjoedin, I.~Stefan, J.~Van de Walle, P.~Van Duppen, M.~Venhart, S.~Zemlyanoy

The technique of resonant ionization spectroscopy is well known for its selectivity in the production of RIB at ISOL facilities. This feature is now also used for atomic spectroscopy on weakly-produced isotopes (<1 atom/s), otherwise not accessible by conventional laser spectroscopy techniques.

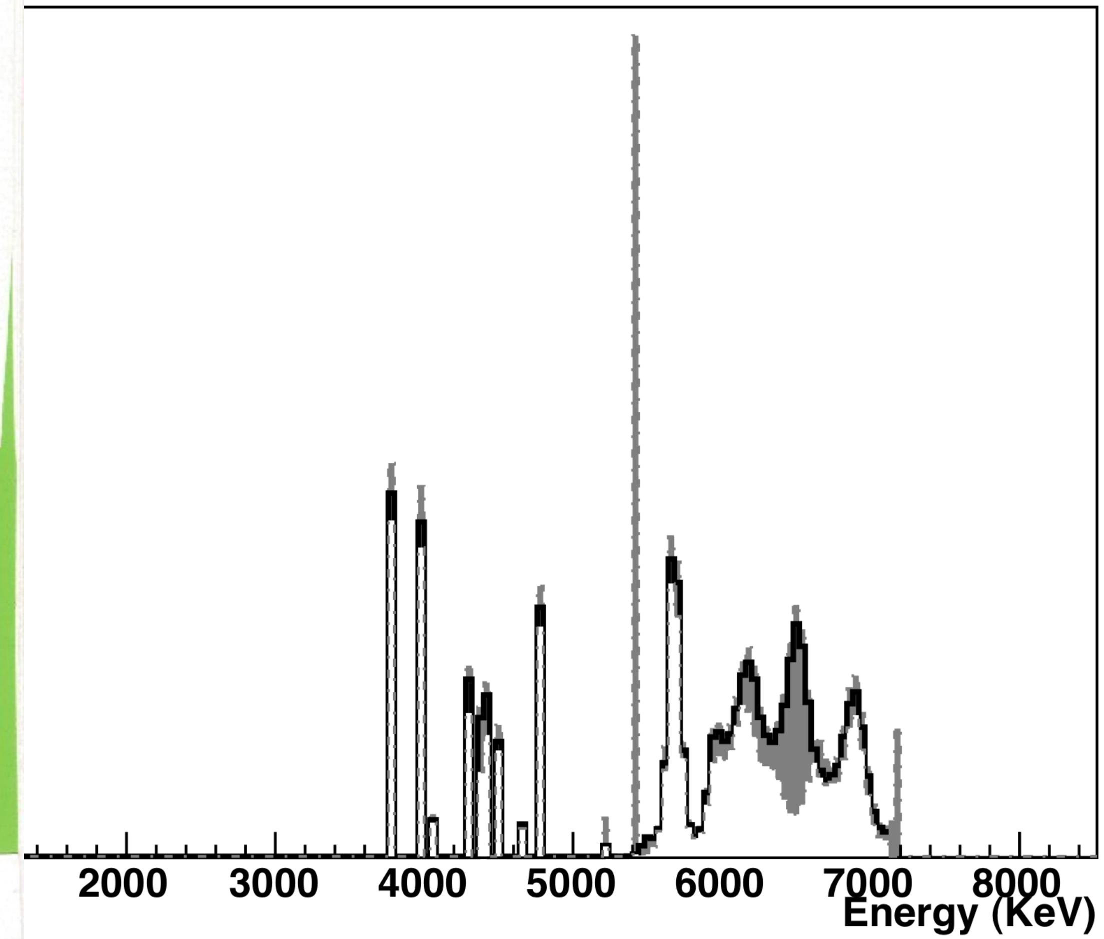
With two protons outside the lead (Z=82) closed core, the polonium isotopes (Z=84) exhibit shape coexistence on the neutron-deficient side of the nuclear chart. The influence of intruding deformed configurations on the ground state and long-lived isomers from 191Po up to the N=126 (210Po) shell closure and beyond has thus been investigated by means of in-source resonant ionization laser spectroscopy over two campaigns at CERN ISOLDE using the lsaer ion source. The isotope shifts between all the isotopes have been extracted and large-scale atomic calculations have been used to determine the electronic parameters necessary to deduce changes in the mean-square charge radii (mscr). The extracted changes in the mscr deviate much earlier than predicted by nuclear models and point towards a well-deformed ground state from 198Po downwards, much earlier than suggested by alpha-decay and in-beam studies of those isotopes.

After briefly introducing the technique and the challenges posed by the atomic calculations, we report in this contribution on the nuclear structure observables extracted (charge radii and electromagnetic moments) and their impact on our understanding of the shape coexistence phenomenon in this region of the nuclear chart.

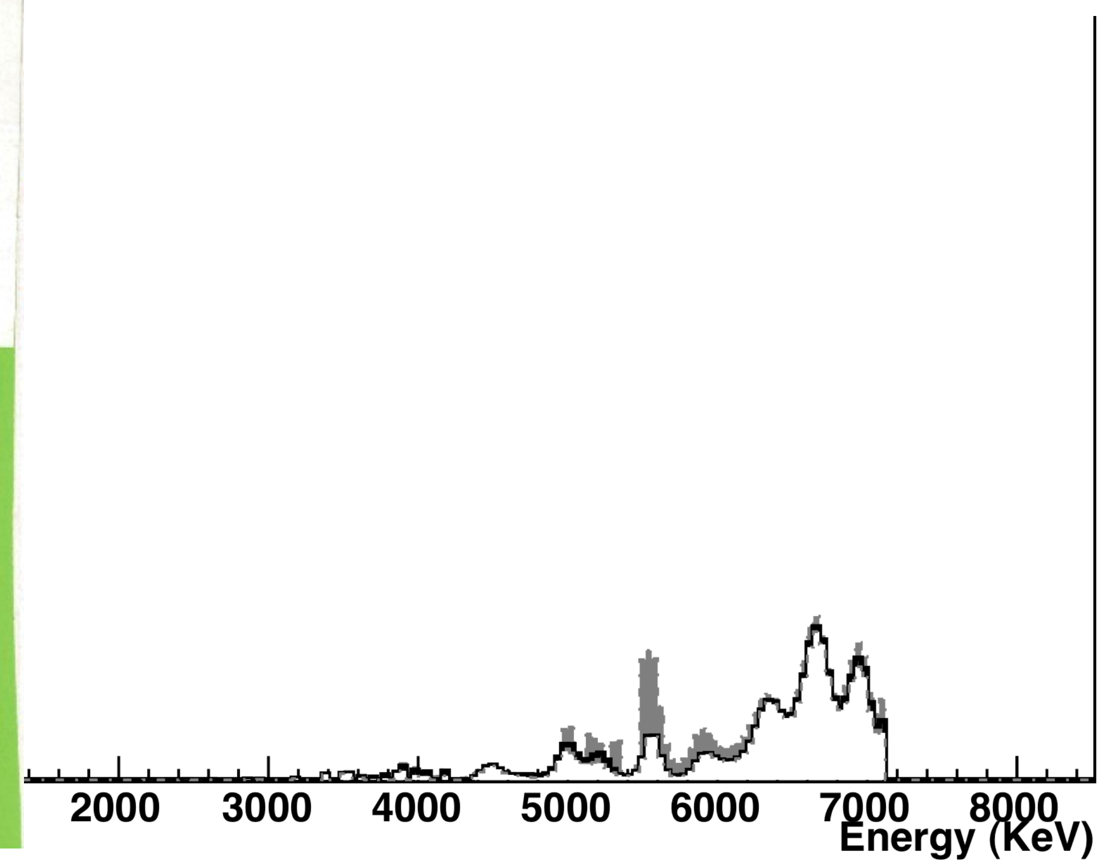


B(GT)
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0 1000 2000 3000 4000 5000 6000 7000 8000
Energy (keV)
6240 keV
76Rb
1⁻ Decay
1⁻ [301] [422]
[301]
[422]
8534
Ask Pedro
about the conf and
I^π of low lying states
78Sr
3640
Ask Pedro de
BGT calculations
from is Ref. 2009
78Rb
Prolate deformation
confirmed by Tibeault
0⁺ [422] [422]
7243

Fig 11



2000 3000 4000 5000 6000 7000 8000
Energy (KeV)



2000 3000 4000 5000 6000 7000 8000
Energy (KeV)