

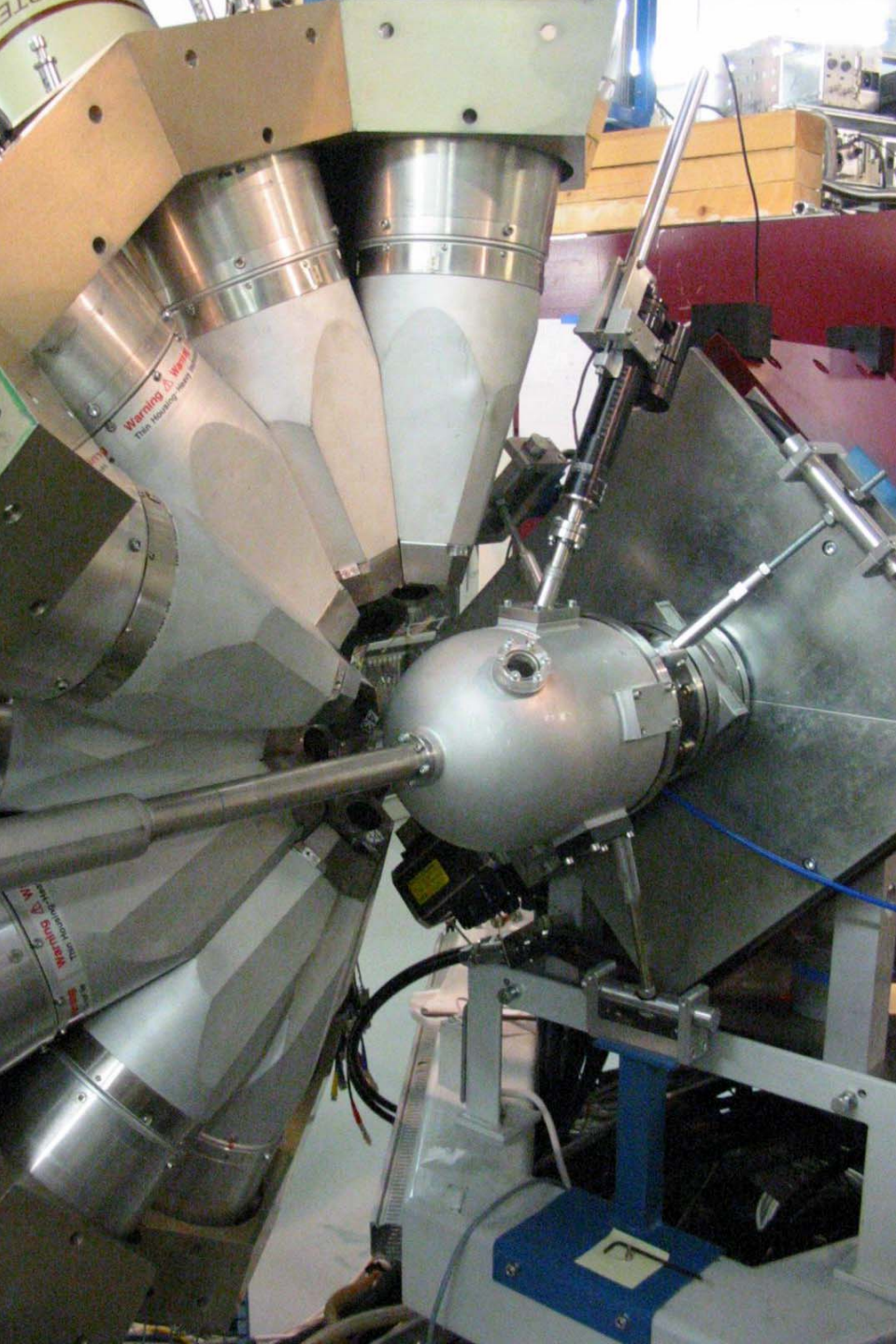
JUROGAM



JYFL
DEPARTMENT OF PHYSICS
UNIVERSITY OF JYVÄSKYLÄ
FINLAND

- **RDT- METHOD AND INSTRUMENTATION**
- **PRACTICAL THINGS**
- **PRINCIPLES OF TAGGING EXPERIMENTS**
- **TRIPLE-SHAPE COEXISTENCE IN LIGHT PB REGION**





JUROGAM ~ EUROGAM 1 (Daresbury)

- 43 EUROGAM Phase 1 Ge detectors + BGO shields
- Eff. at 1.3 MeV 4%

At JYFL:

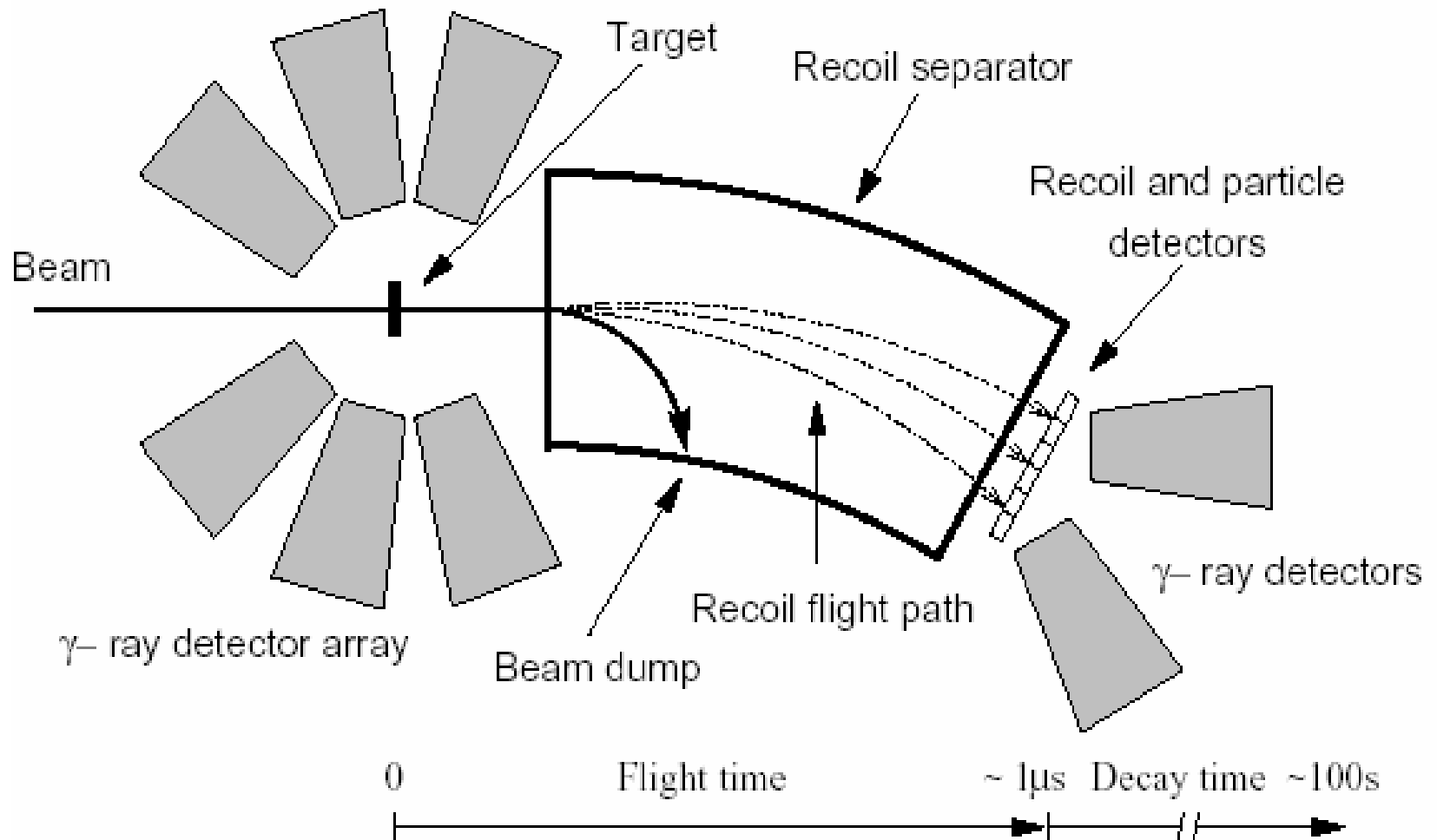
- 39 EoC pool + 10 UK-France pool Ge detectors
- 30 EoC shields + 15 UK-F shields
- Successor of JUROSPHERE – Eff. 1.5 %

At JYFL:

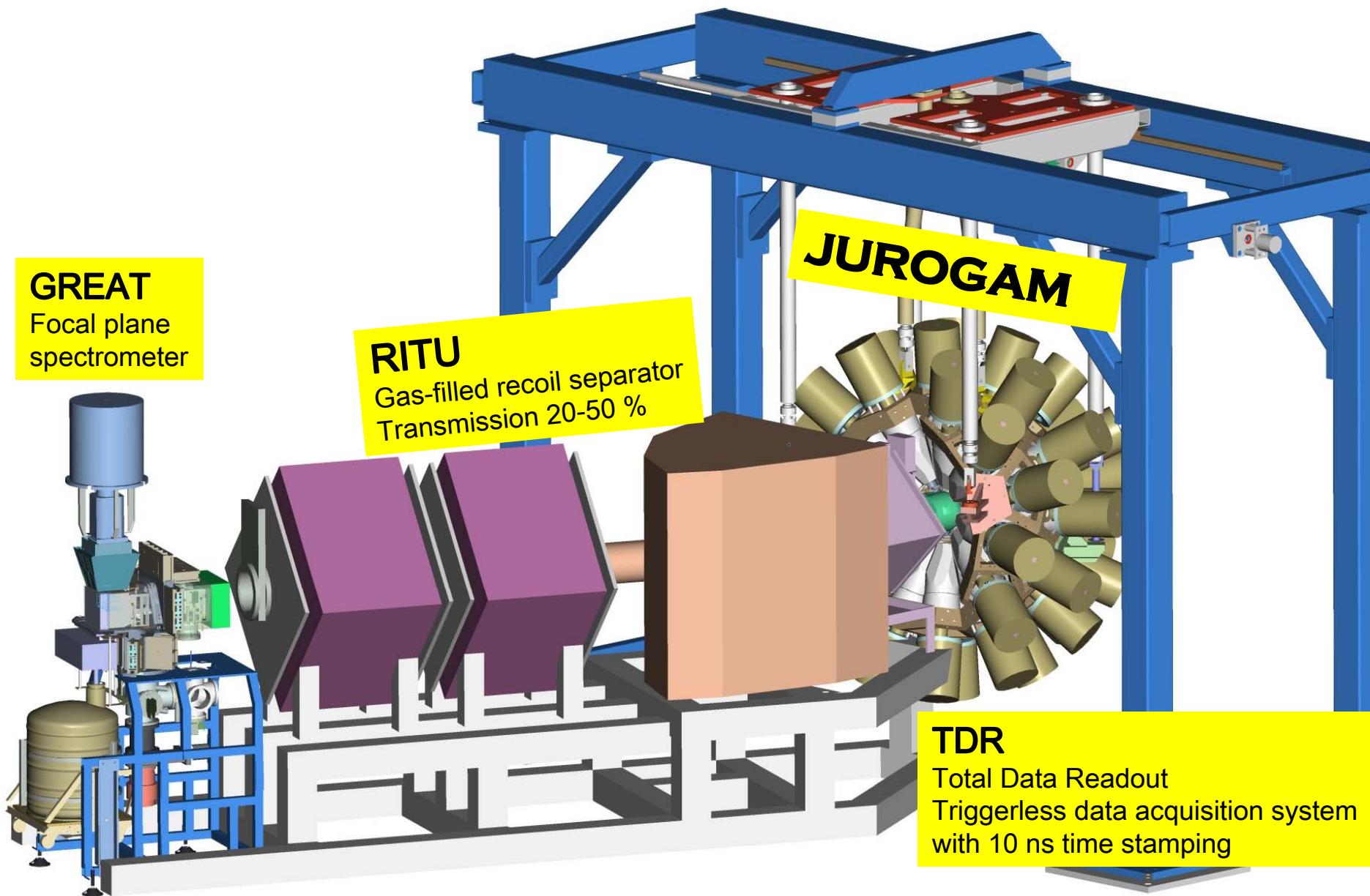
- **Large variety of HI beams**
- **2500 hours of beam time per year for tagging experiments**
- **EU – FP5 and FP6 Access support for users**
- **Part of the FP5-EXOTAG and FP6-INTAG projects**
- **Training site for young researchers and PhD students**
- **Local γ -RITU group: 7 seniors + 7 PhD students**
- **Annealing, preamp + FET repairs**
- **~ 120 k€/year for running costs and equipment investments (JYU budget)**

JUROGAM used in tagging experiments for studies of very neutron deficient and very heavy nuclei

Recoil – Decay – Tagging (RDT) method



RDT INSTRUMENTATION AT JYFL



GREAT
Focal plane spectrometer

RITU
Gas-filled recoil separator
Transmission 20-50 %

JUROGAM

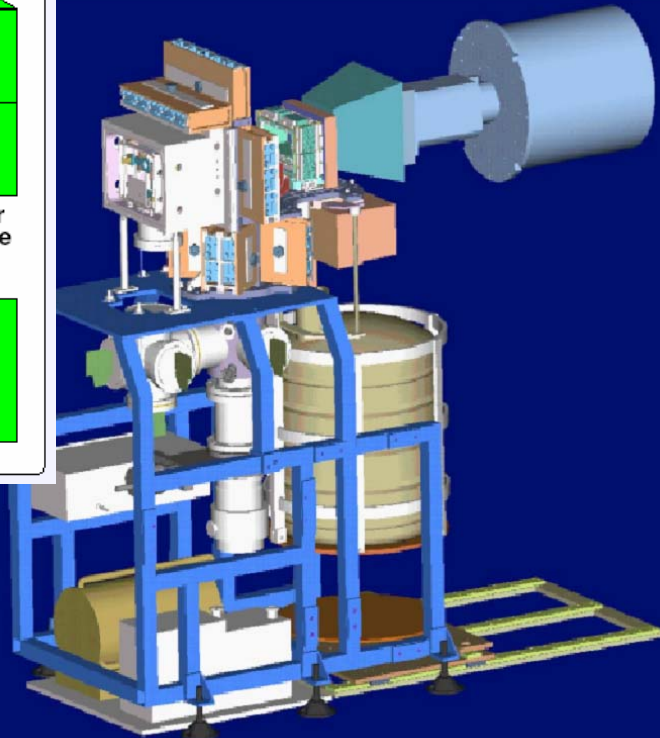
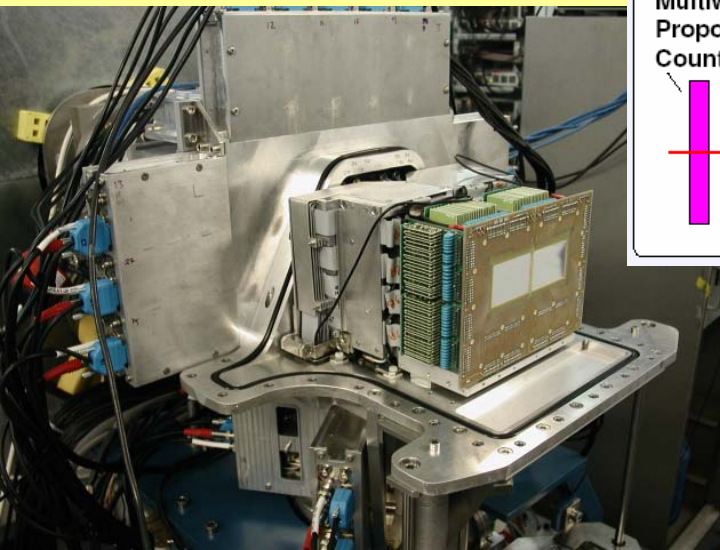
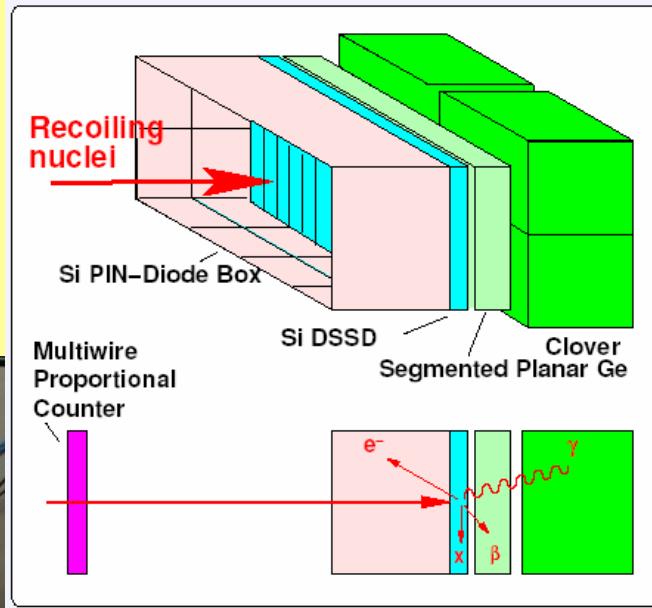
TDR
Total Data Readout
Triggerless data acquisition system
with 10 ns time stamping

THE GREAT FOCAL-PLANE SPECTROMETER FOR

γ -ray, e^- -, β -, p - and α - particle detection

UK INVESTMENT

- 2 x 60mm x 40mm DSSD (4800 pixels)
- 28 x 40mm x 40mm PIN Diodes
- 24 x 12 Segmented Planar Ge
- Compton-Suppressed Segmented Ge Clover
- Position-Sensitive MWPC



TDR : TOTAL DATA READOUT

- Triggerless Data Acquisition System
- Rates up to 850 kHz without deadtime
- 380 channels timestamped data
- 10 ns resolution
- Time-of-Day clock with 32 day rollover
- Flexible + Easily Scalable

UK INVESTMENT



**EVENT RECONSTRUCTION AND
ANALYSIS SOFTWARE PACKAGE**

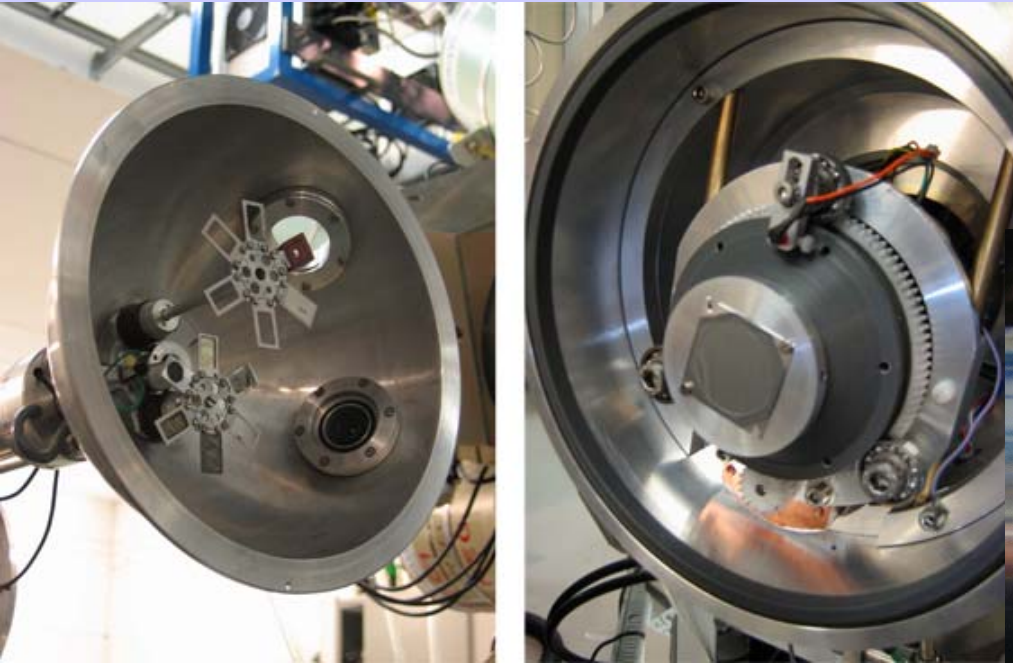
Designed by Panu Rahkila

Grain



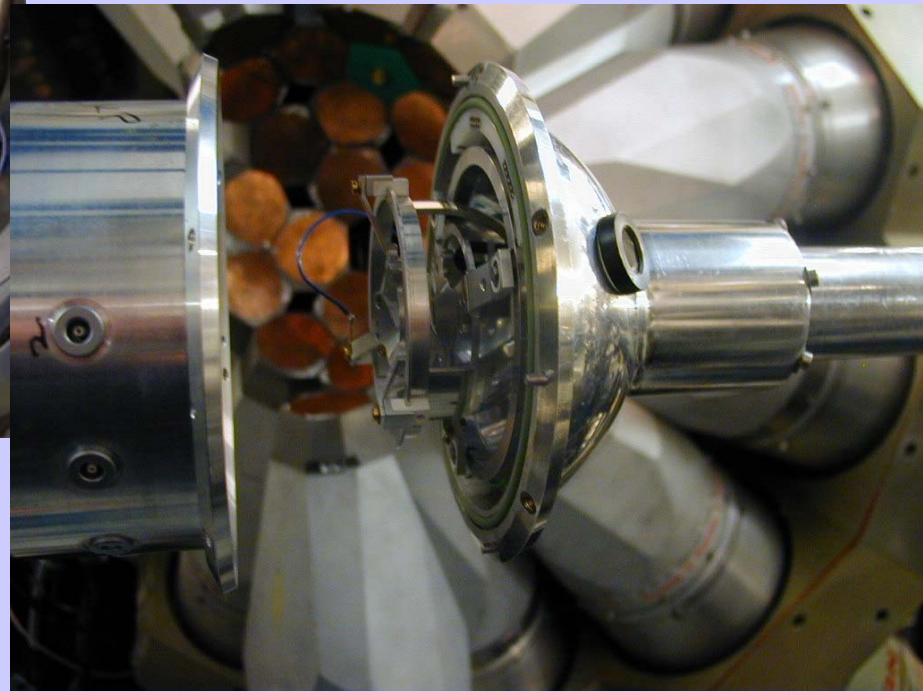
The Analyser

TARGET AREA



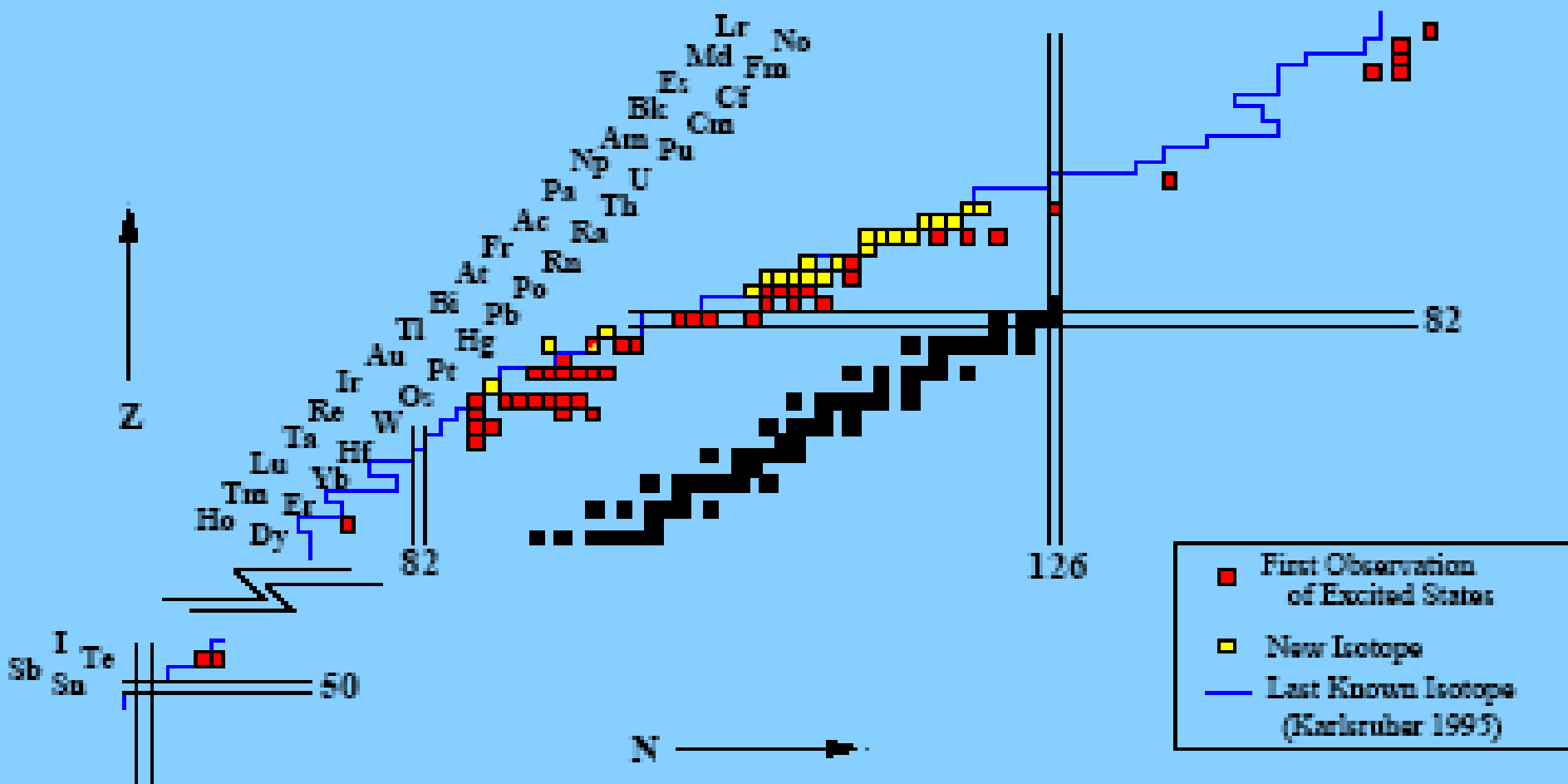
IRES – Target chamber

KÖLN Plunger



SPECTROSCOPY OF VERY NEUTRON DEFICIENT AND HEAVY NUCLEI

- + Can be produced via fusion evaporation with stable-ion beams and stable targets
- + Short-living alpha or proton emitters → tagging methods
- Cross-sections down to 1 nb
- Only levels near the yrast line populated



JUROGAM CAMPAIGNS 2003-2006

Campaign 1	4/2003 – 12/2003 : 9 months	14 experiments
Campaign 2	4/2004-6/2004 10/2004-3/2005 : 9 months	13+1 experiments
Campaign 3	9/2005 – 9/2006 : 12 months	13 experiments

Expt. No	Title	Spokeperson(s)
JR01	Search for triple shape coexistence in ^{190}Po	A.N. Andreyev
JR01		
JR04	A recoil-gated plunger lifetime measurement of ^{188}Pb with JUROGAM and the RITU separator	A. Dewald
JR05	Recoil-decay tagging employing the alpha-decaying nuclei produced in deep inelastic reactions	J. Uusitalo
JR07	Rotational band structures in the odd-Z fermium ^{251}Md nucleus studied by prompt gamma spectroscopy	A. Chatillon P.T. Greenlees R.-D. Herzberg
JR09	The structure of K-isomers at the proton drip-line: ^{140}Dy	D.M. Cullen
JR11	Yrast structure of the neutron-deficient nucleus ^{170}Pt	D.T. Joss
JR12	Alpha-decay tagging of ^{106}Te and ^{107}Te	B. Cederwall
JR12		
JR13	Search for spherical, deformed oblate and isomeric states in ^{184}Pb	R. Wadsworth R.D. Page R. Julin
JR16	Nuclear structure of the extremely neutron deficient nuclides ^{161}Re and ^{162}Os	K. Lagergren D.T. Joss
JR19	In-beam gamma-spectroscopy study of ^{254}No	M. Leino
JR21	Identification of excited states in the first proton-unbound $N=77$ isotope ^{146}Tm using recoil-isomer and proton-decay tagging	C. Scholey
JR23	Spectroscopy ^{223}Pa ($Z=91$): A step towards octupole deformation studies of high-Z nuclei	B.J.P. Gall
JR25	Gamma-ray spectroscopy of ^{192}Po with JuroGam	P. Rahkila
JR26	Search for an oblate band in ^{186}Pb	J. Pakarinen

Expt. No	Title	Spokeperson(s)
JR02	Gamma-ray spectroscopy of the very neutron-deficient nucleus ^{188}Po	P.T. Greenlees S. Juutinen A.N. Andreyev
JR18	Ground state and excited bands in ^{250}Fm	R.-D. Herzberg
JR24	A plunger lifetime measurement of low-lying yrast states in ^{194}Po	T. Grahn
JR27	Spectroscopy of the deformed ground-state proton emitter ^{113}Cs	J.F. Smith
JR29	Spectroscopy of ^{176}Hg : shape coexistence at the extremes	J. Simpson R. Julin
JR30	High-spin states in the $N=84$ isotones ^{156}Hf , ^{157}Ta and ^{158}W	D.T. Joss J. Uusitalo
JR31	In-beam gamma-spectroscopy study of ^{253}No	R.-D. Herzberg P. Reiter
JR32	Detailed spectroscopy of ^{191}Bi	S. Juutinen
JR33	A recoil-decay tagged plunger lifetime measurement for the yrast levels of ^{186}Pb	T. Grahn A. Dewald
JR34	In-beam gamma-ray spectroscopy of the fermium nucleus ^{255}Lr	P.T. Greenlees R.-D. Herzberg Ch. Theisen
JR35	Identification of excited states in the proton unbound nucleus ^{166}Ir	C. Scholey

Expt. No	Title	Spokeperson(s)
JR10	Proof-of-principle for recoil-beta tagging	D. Jenkins
JR15	Gamma-ray spectroscopy of ^{195}At	H. Kettunen
JR36	Recoil-decay tagging of exotic light neutron-rich ($N \leq 28, Z \leq 18$) nuclei employing the alpha-decaying nuclei produced in deep-inelastic reactions	J. Uusitalo
JR37	Shape co-existence in very neutron-deficient ^{189}Bi	S. Juutinen Y. Le Coz
JR39	Identification of excited states in the deformed proton emitter ^{117}La using recoil-decay tagging with JUROGAM, GREAT and RITU	J.F. Smith
JR40	RDDS lifetime measurements of yrast states in $^{180,182}\text{Hg}$	T. Grahn
JR41	Coulex-plunger lifetime measurements with Xe beams and test of inverse kinematics for future coulex-plunger experiments	S. Harissopolis
JR42	Search for deformed excitations in ^{185}Pb	A.N. Andreyev D.M. Cullen
JR43	Commissioning of the second multi-wire proportional counter for GREAT	D.M. Cullen
JR44	Search for $N=82$ shell quenching for neutron-rich nuclei	X. Liang
JR45	In-beam gamma-ray spectroscopy of heavy elements: ^{256}Rf	P.T. Greenlees R.-D. Herzberg Ch. Theisen B. Gall
JR46	Gamma spectroscopy of ^{256}No using a radioactive ^{238}U target	B. Gall R.-D. Herzberg Ch. Theisen P.T. Greenlees
JR47	Alpha-decay tagging spectroscopy of ^{119}Xe	B. Cederwall
JR48	Structure of high-K states in ^{254}No	R.-D. Herzberg P.-E. Greenlees
JR50	The changing structure of the light Re isotopes: Recoil-decay tagging of the neutron-deficient nucleus ^{152}Re	D.T. Joss
JR51	Search for magnetic rotation and superdeformation in ^{206}Po	A. Wilson
JR52	Identification of low-lying $T=0,1$ states in the $N=Z$ nucleus ^{78}Y	S.N.S. Bondili R. Wadsworth
JR53	Investigation of K-isomerism in ^{259}Fm	P.T. Greenlees R.-D. Herzberg
JR55	Ground state band of ^{248}Fm	R.-D. Herzberg
JR56	Probing the onset of collectively in ^{170}Po by means of RDDS lifetime measurements	T. Grahn
JR58	Evolution of single-particle states near the $N=82$ shell gap: spectroscopy of ^{168}Pt and neighbouring isotopes	M. Boden Gomez
JR59	Recoil-Decay Tagging spectroscopy of $^{172-176}\text{Au}$	B. Cederwall
JR60	Decay studies of the isomers in the proton emitter ^{151}Lu and its daughter nucleus ^{150}Yb	Z. Liu

Three campaigns in 2003 – 2006

43 Experiments so far

Costs:

EUROBALL: ~ 10 repairs at CANBERRA-EURISYS + transport ≈ 80 k€

UK- France pool rent 3×13 k€ ≈ 40 k€

Components ≈ 10 k€

LN2 $\sim 3 \times 60$ k€ ≈ 180 k€

Total in 3 years ≈ 300 k€

General idea:

Combining of

In-beam RDT or RG (Recoil Gating) experiments and
Focal plane decay experiments

→

- SHE- nuclei near ^{254}No ($Z=102$) – Talk: Paul Greenlees
- Shape-coexistence in the light Pb region – Talk: Alfred Dewald
- Competing structures in light W – Pt nuclei – Talk: David Joss
- Isomer – spectroscopy of light Eu – Hf nuclei – David Cullen
- Towards light $Z \approx 50$ nuclei – Talk: Bo Cederwall
- NEW: β – tagging of odd-odd $N = Z$ nuclei – David Jenkins



SHE nuclei

Produced in asymmetric cold-fusion reaction – $X(^{48}\text{Ca}, 2n)Y$

→ ideal for RITU

→ Only one reaction channel open

→ Total compound cross-section down to 50 mb

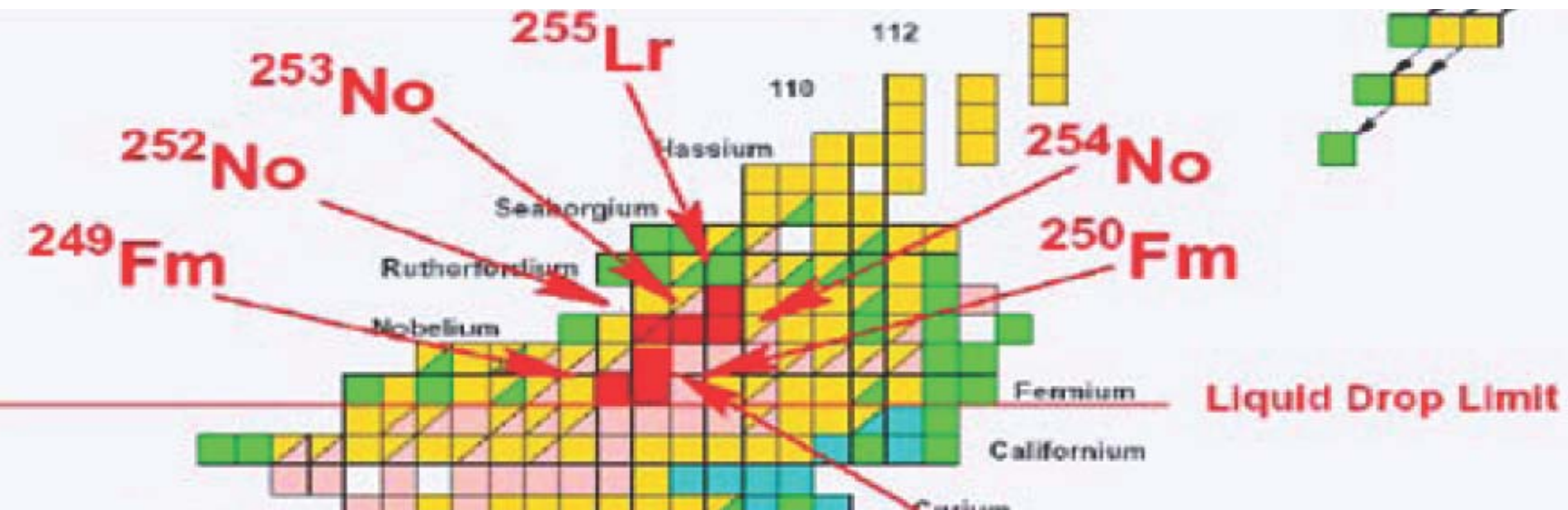
→ I_{beam} up to 30 pA on a $0.5\text{mg}/\text{cm}^2$ target in in-beam runs

Fission dominates: 100000 : 1

→ I_{beam} limited by the Ge rate

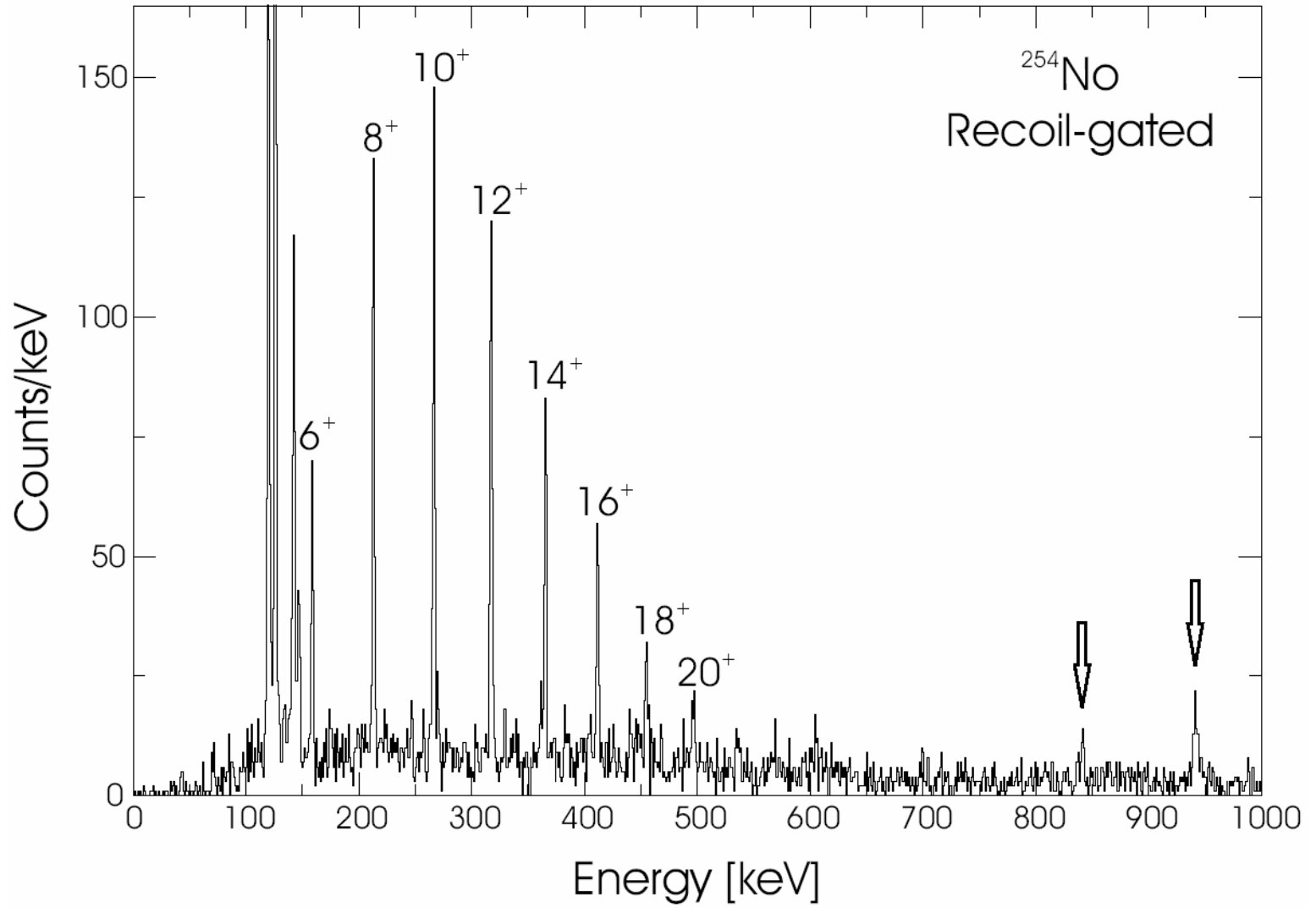
→ Very low focal-plane rate

→ Enables long $t_{1/2}$ – α – tagging



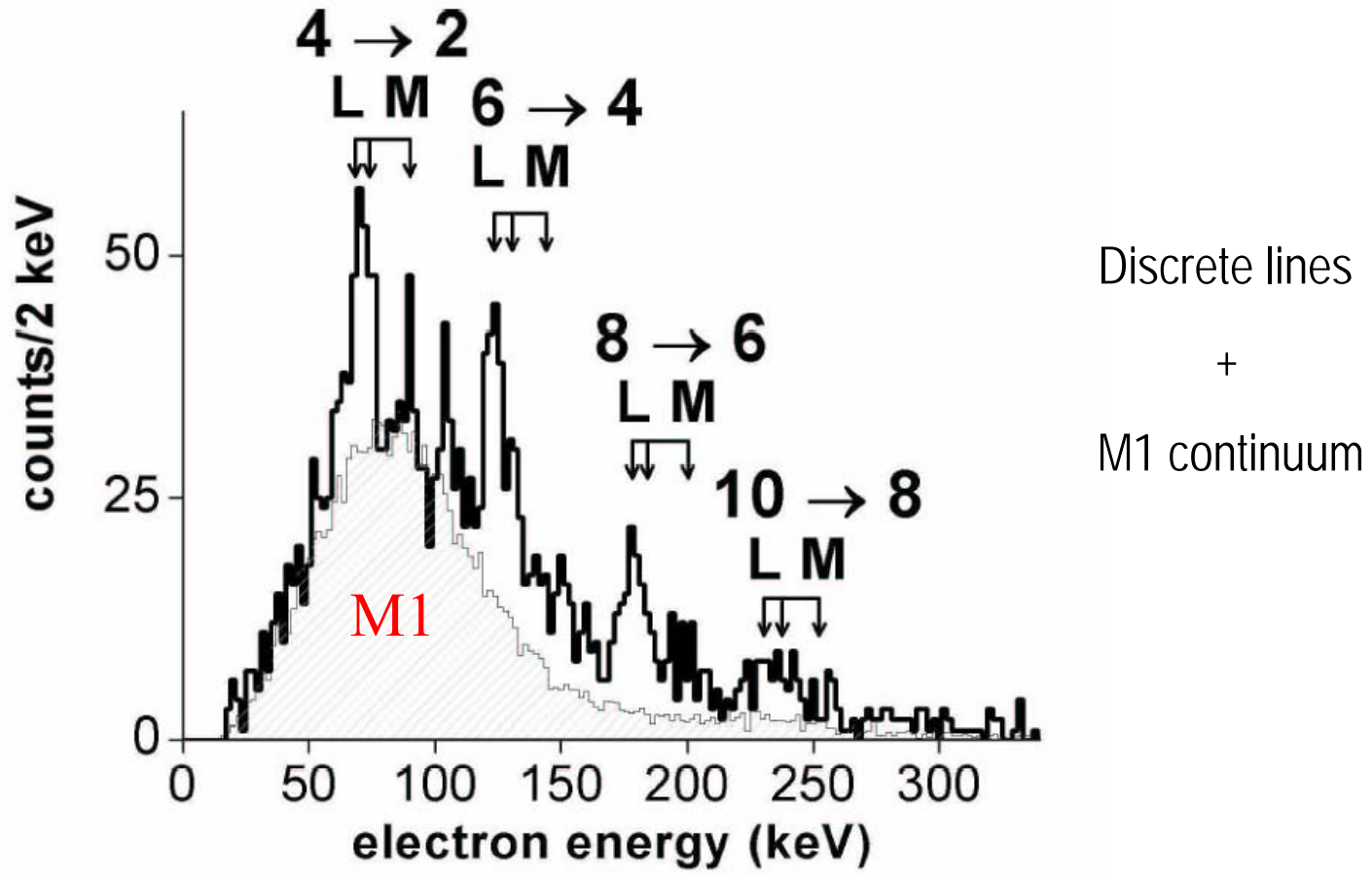
^{254}No

Gamma-rays from $^{208}\text{Pb}(^{48}\text{Ca},2n)^{254}\text{No}$ JUROGAM + RITU



SACRED + RITU data

²⁵⁴No-recoil gated in-beam conversion electrons
from ²⁰⁸Pb(⁴⁸Ca,2n) ²⁵⁴No



Medium-heavy and light nuclei

Produced in symmetric fusion-evaporation reactions

→ Difficulties with a gas-filled separator (separation of scattered beam)

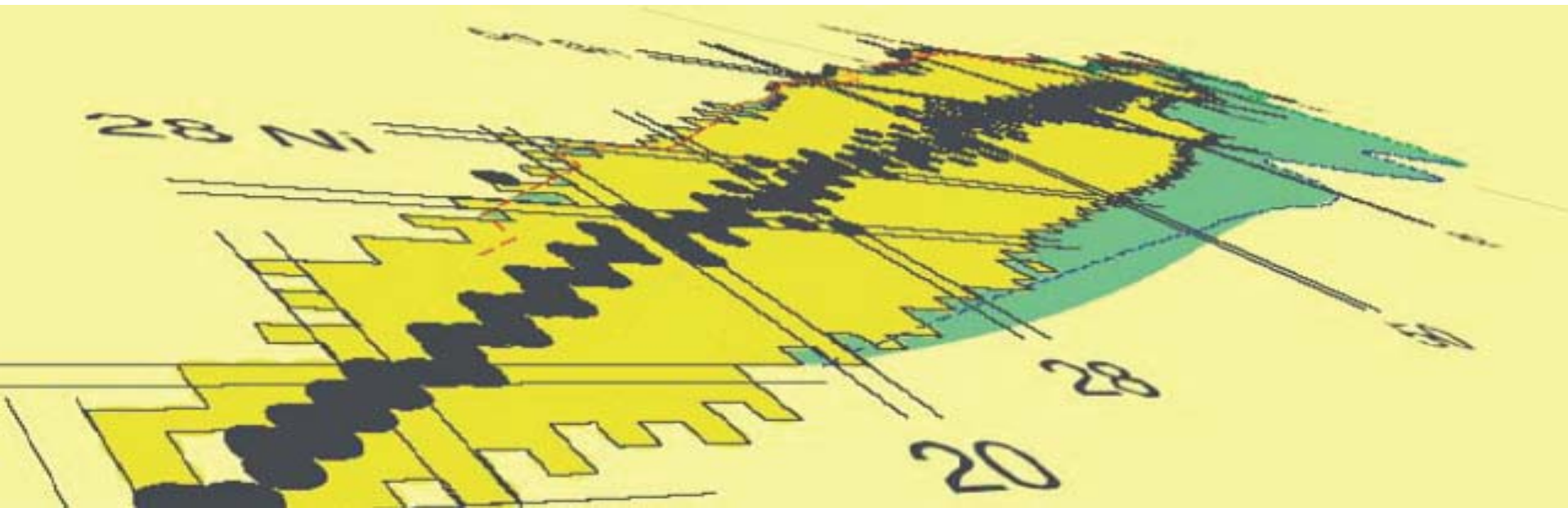
No fission – large number of fusion ev. reaction channels $\sigma \leq 1\text{mb}$

→ High recoil rate focal-plane - $\sim 1\text{kHz}/1\text{pA}$ on a $0.5\text{mg}/\text{cm}^2$ target

→ Limited possibilities for short- $t_{1/2}$ p- or α - tagging

→ Need mass-selectivity → vacuum recoil-separator

β - tagging !?

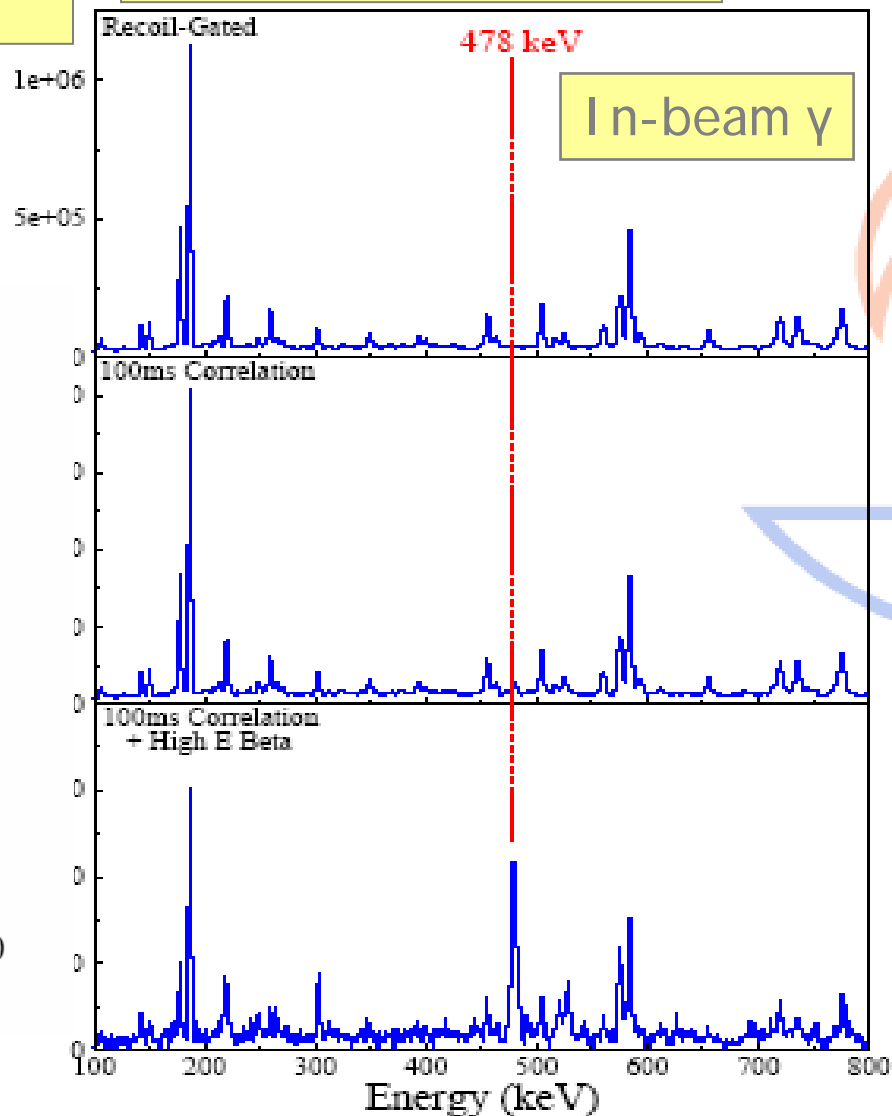
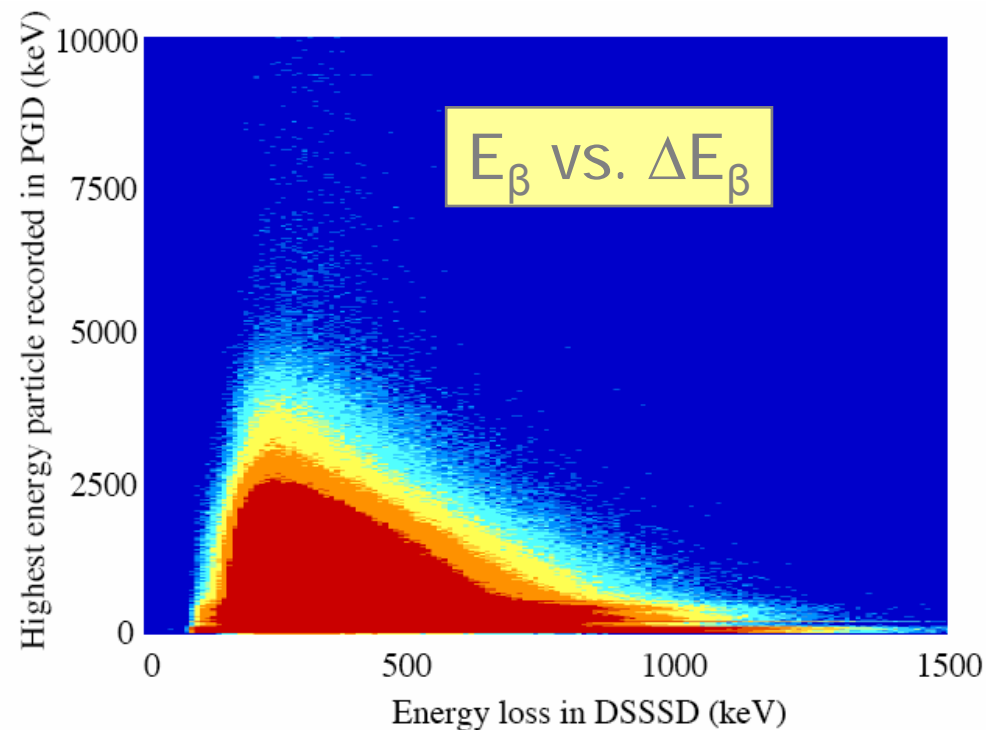


Recoil- β – tagging:

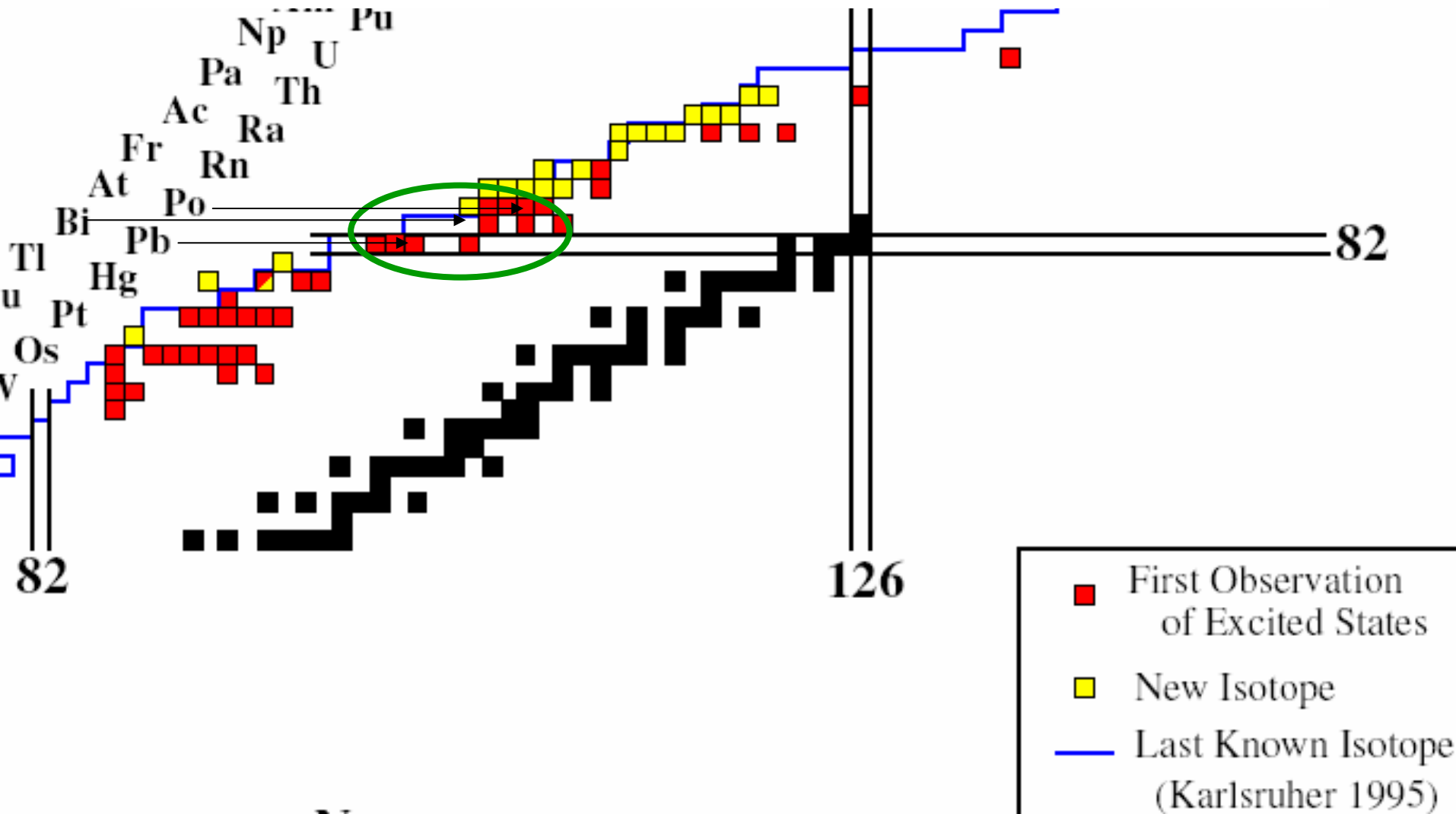
Proof-of-principle experiment:

Access to excited state structure of N=Z
superallowed β -emitters

$^{40}\text{Ca}(^{36}\text{Ar},pn)^{74}\text{Rb}$ Z=N=37

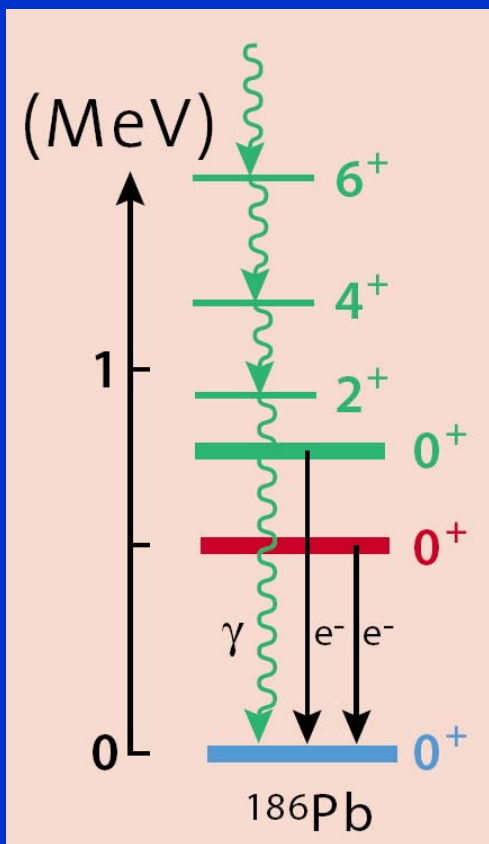


TRIPLE - SHAPE COEXISTENCE PB, BI AND PO ISOTOPES CLOSE TO THE PROTON DRIP-LINE



Three low-lying 0^+ states in ^{186}Pb observed in the α -decay of ^{190}Po

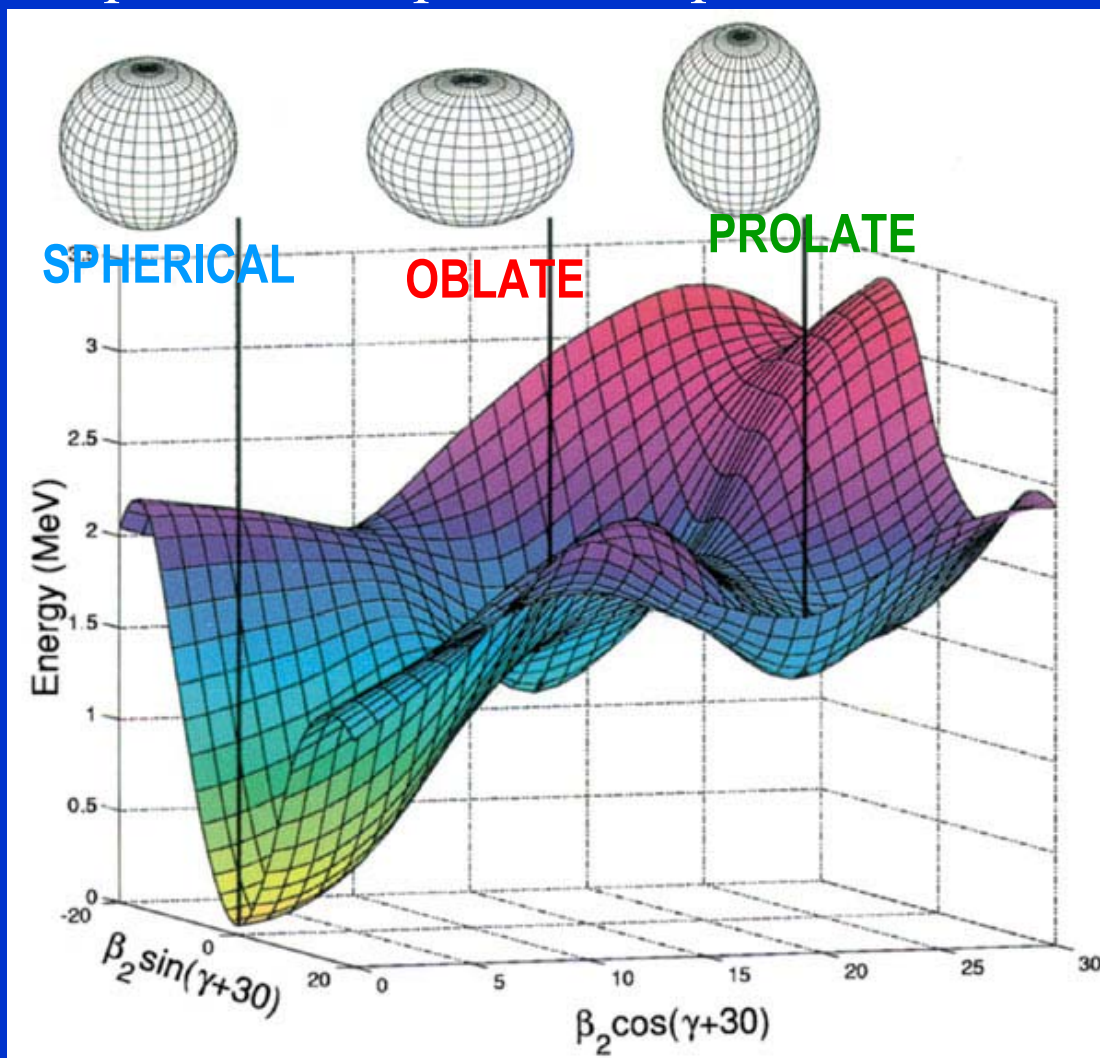
Where is the
OBLATE band?



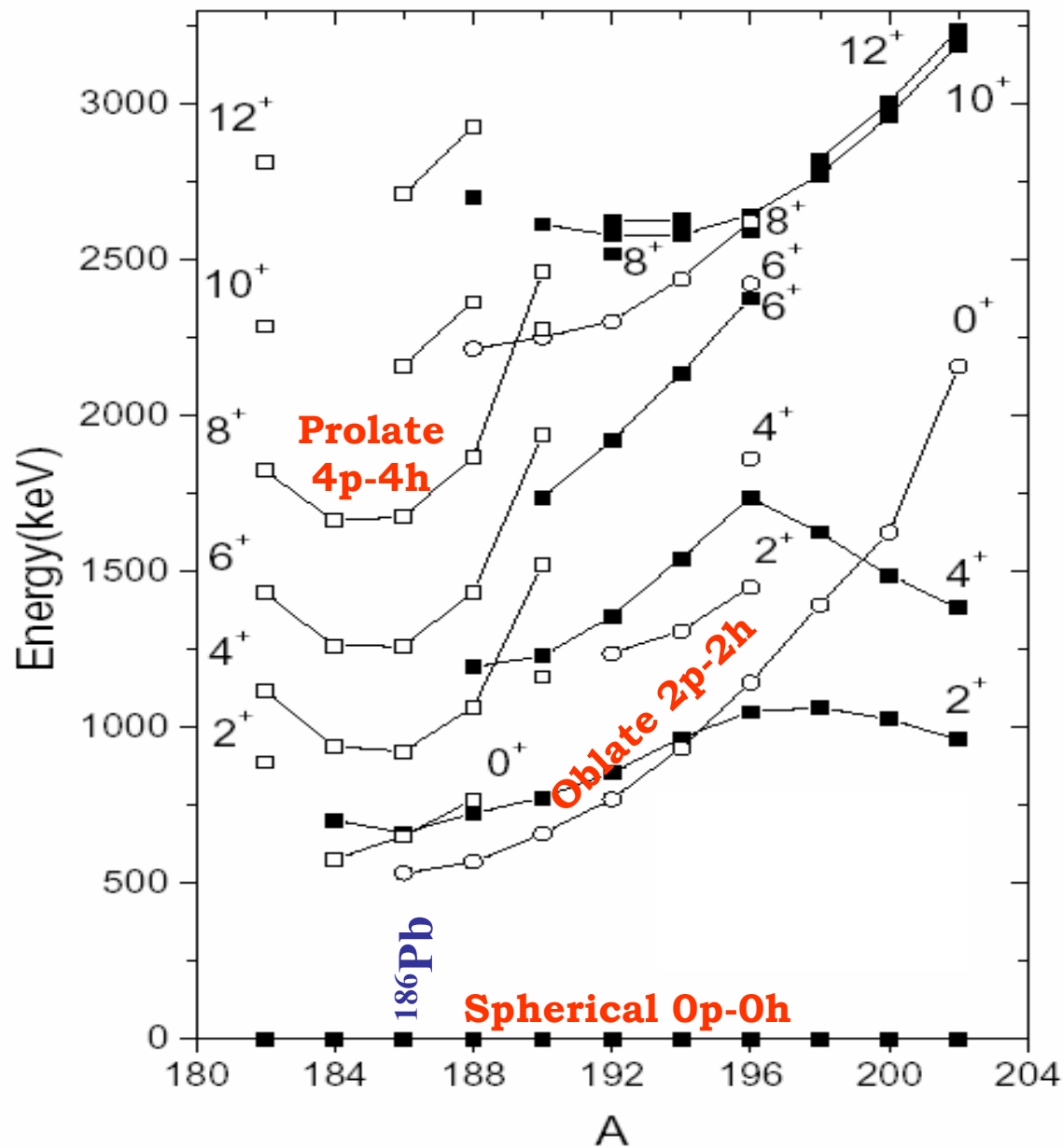
0p-0h

2p-2h

4p-4h



Pb

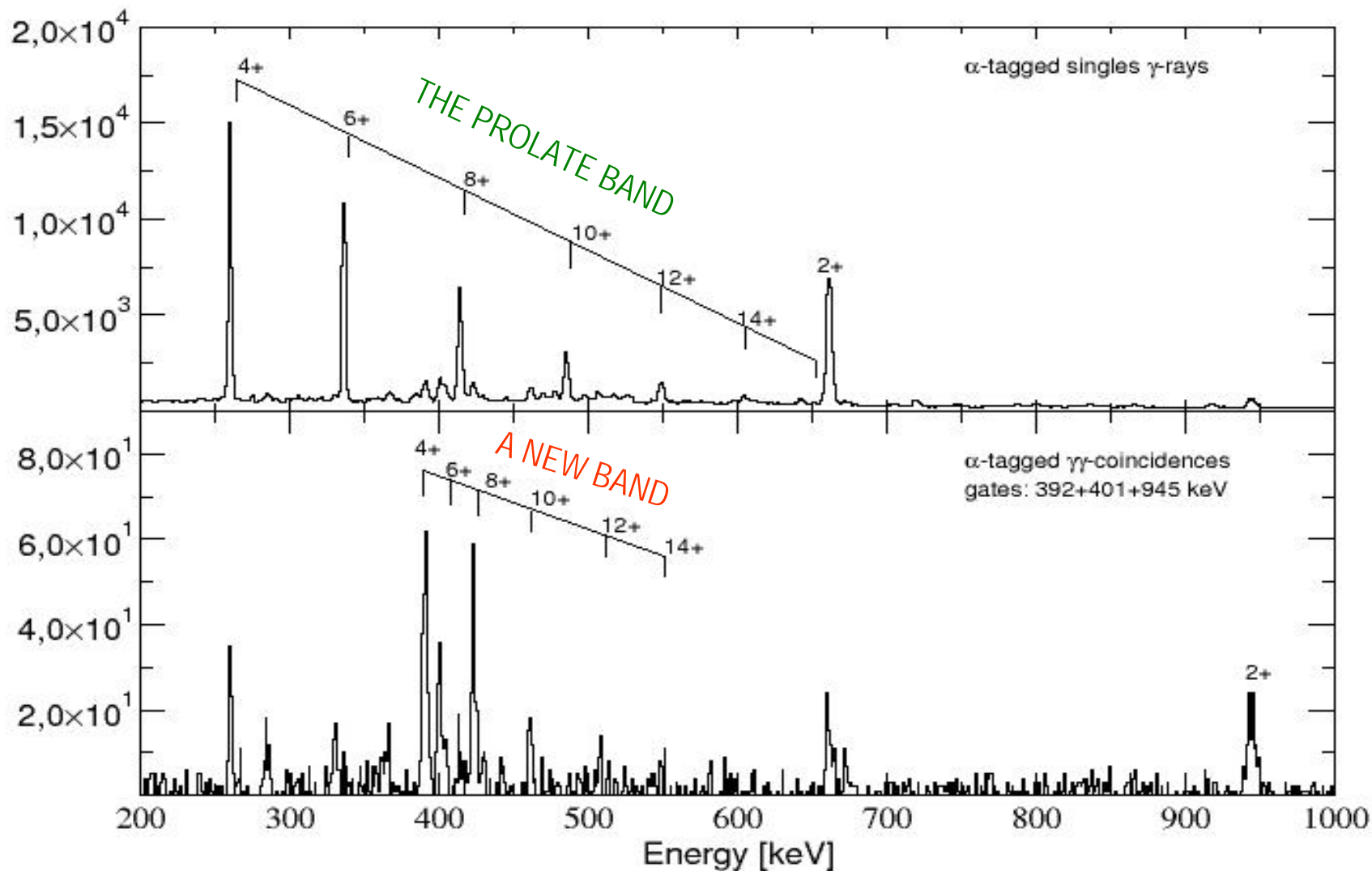


Even-mass
Pb isotopes
level systematics

RDT experiment for ^{186}Pb with JUROGAM+RITU+GREAT

$^{106}\text{Pd}(^{83}\text{Kr},3n)^{186}\text{Pb}$

^{186}Pb



PROLATE

Band I

(20⁺) (5308)

(673)

(18⁺) (4635)

(868)

(16⁺) 3968

652.2

(14⁺) 3316

605.6

12⁺ 2710

549.6

10⁺ 2160

485.8

8⁺ 1675

414.8

6⁺ 1260

337.1

4⁺ 923

280.6

2⁺ 862

662.2

OCTUPOLE

Band III

(17⁻) (4341)

498.4

(15⁻) 3843

461.3

(13⁻) 3381

419.5

(11⁻) 2962

389.1

(9⁻) 2593

(7⁻) (306) 2287

(643)

(384) (307)

GAMMA

Band IV

3409

543

2866

705.5

(11⁺) 3046

527

(9⁺) 2519

469.5

(7⁺) 2049

405.3

(5⁺) 1644

(3⁺) 337 1307

(645) (384) 362

0⁺ 650

0⁺ 532

0⁺

OBLATE

Band II

(14⁺) 3684

551.3

(12⁺) 3133

507.6

(10⁺) 2625

462.7

(8⁺) 2162

424.1

(6⁺) 1738

401.3

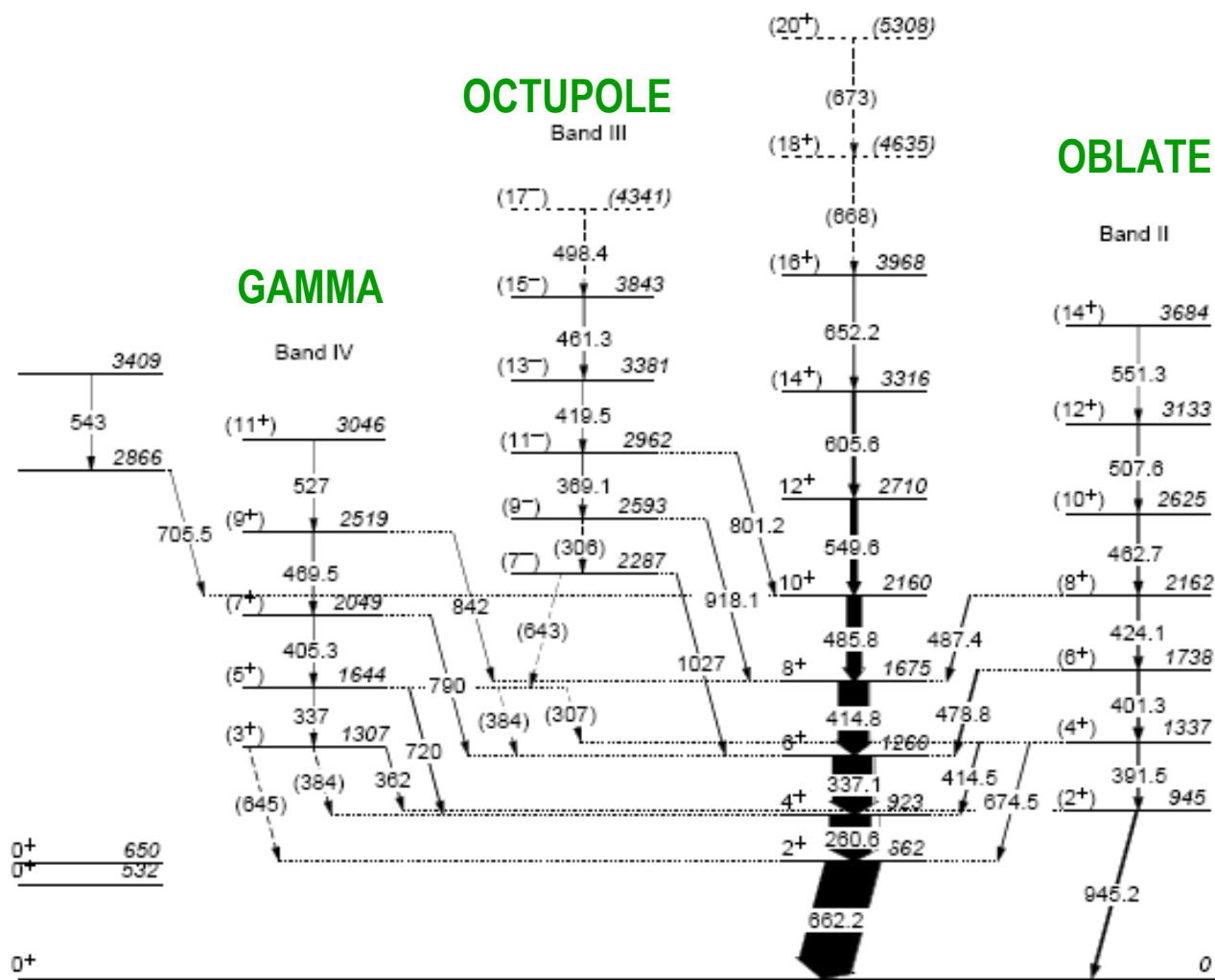
(4⁺) 1337

391.5

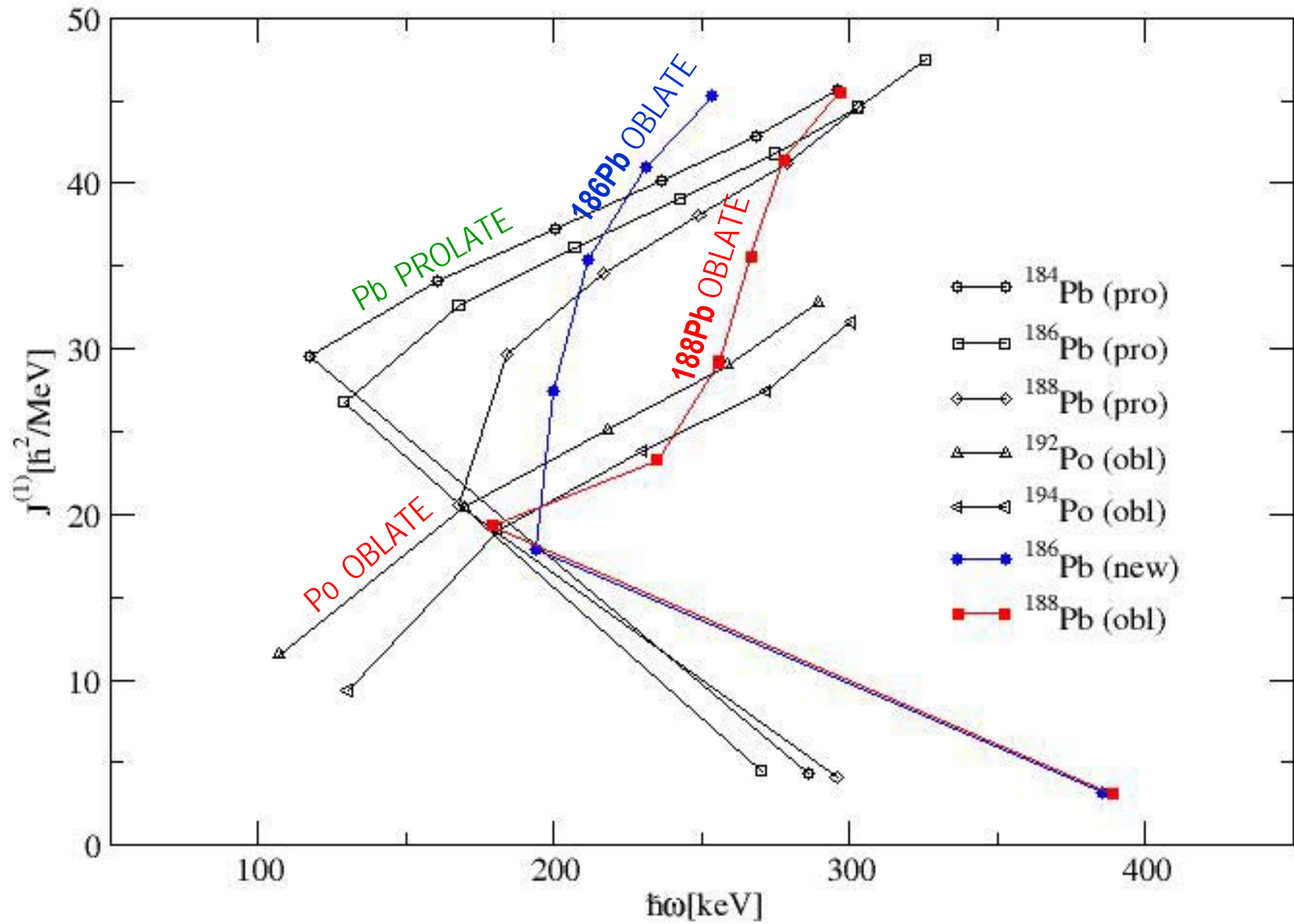
(2⁺) 945

945.2

¹⁸⁶Pb



Kinematic moment of inertia

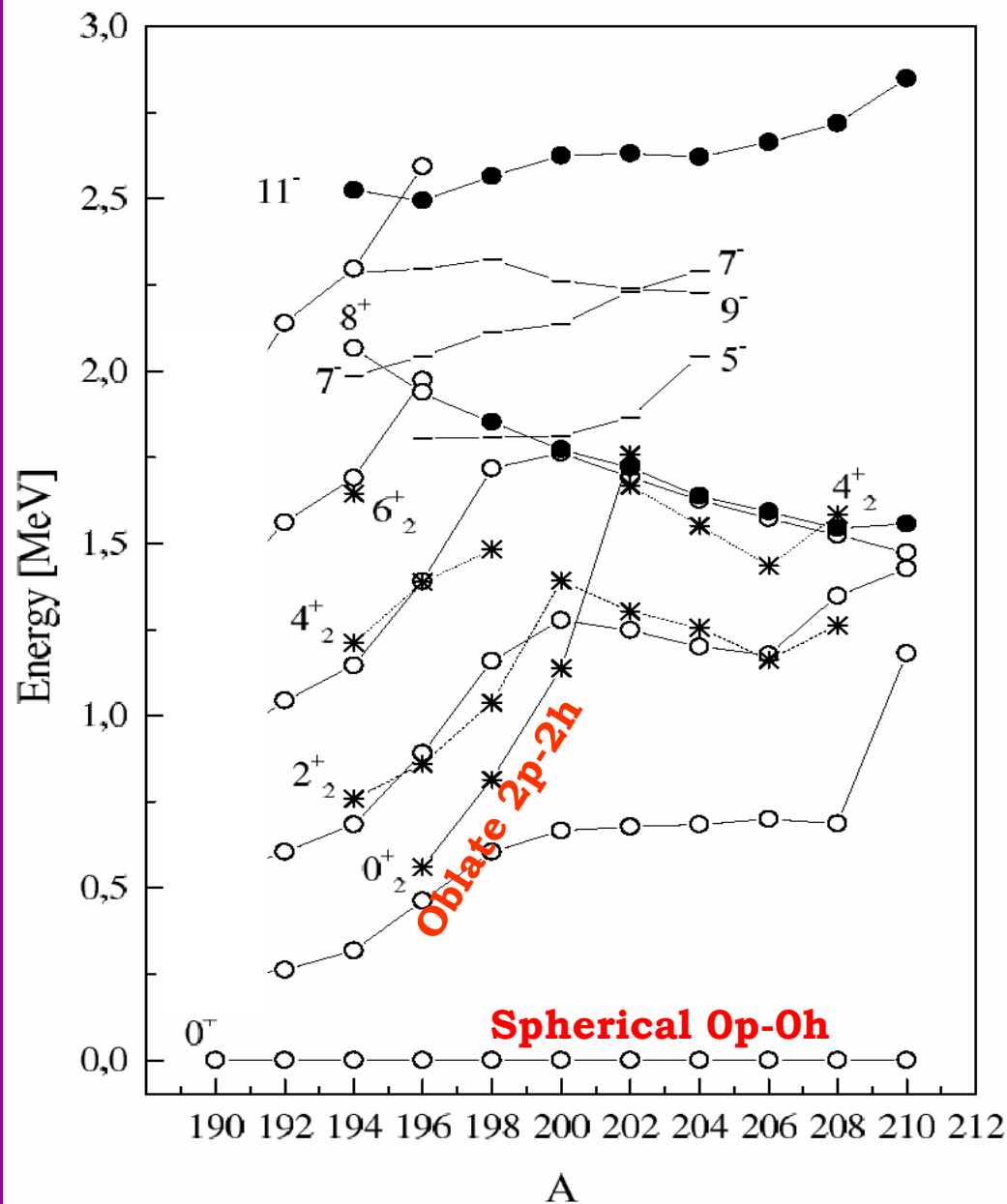


Po

Sudden onset
deformation in light
Polonium isotopes

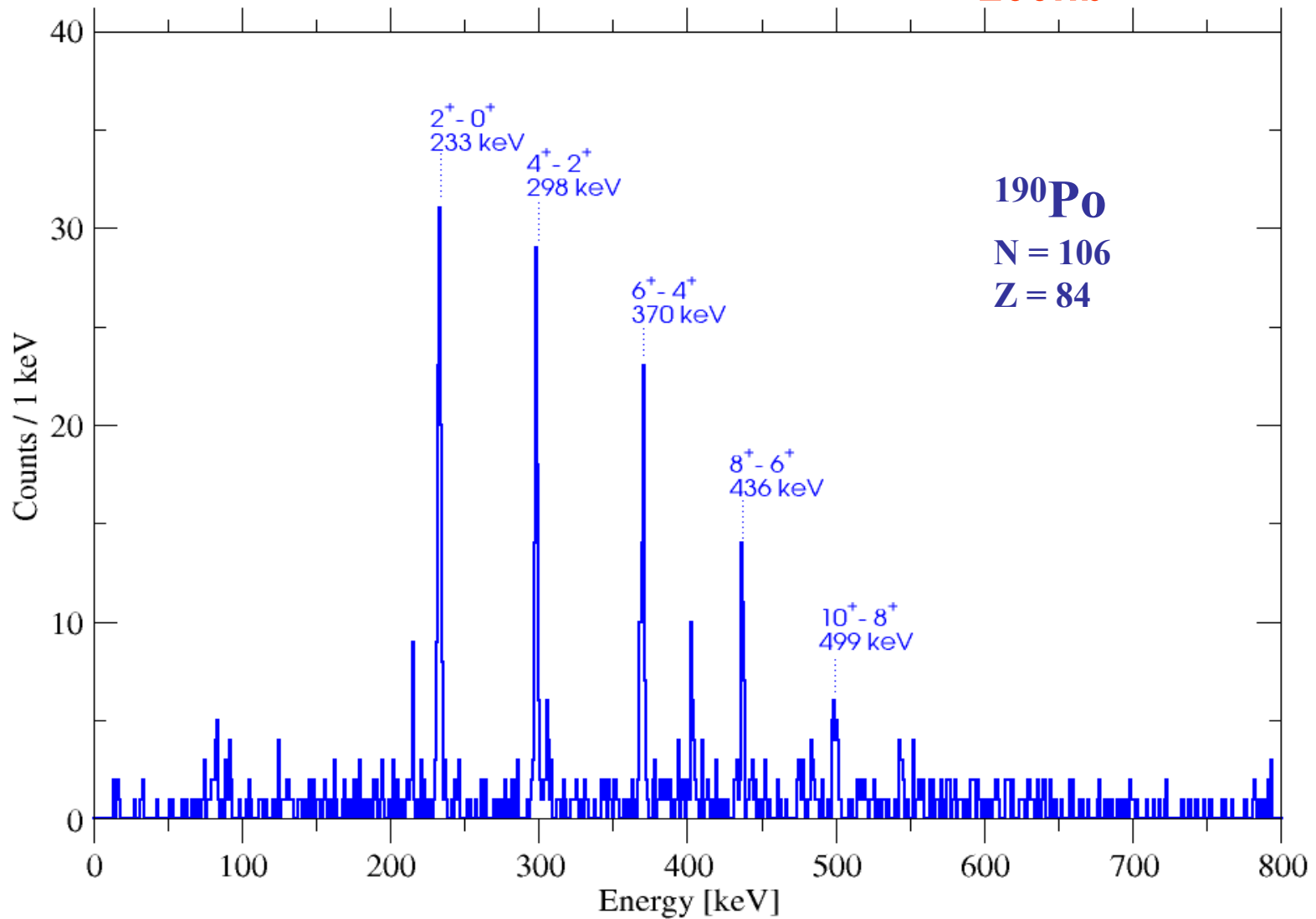
A = even, Z = 84

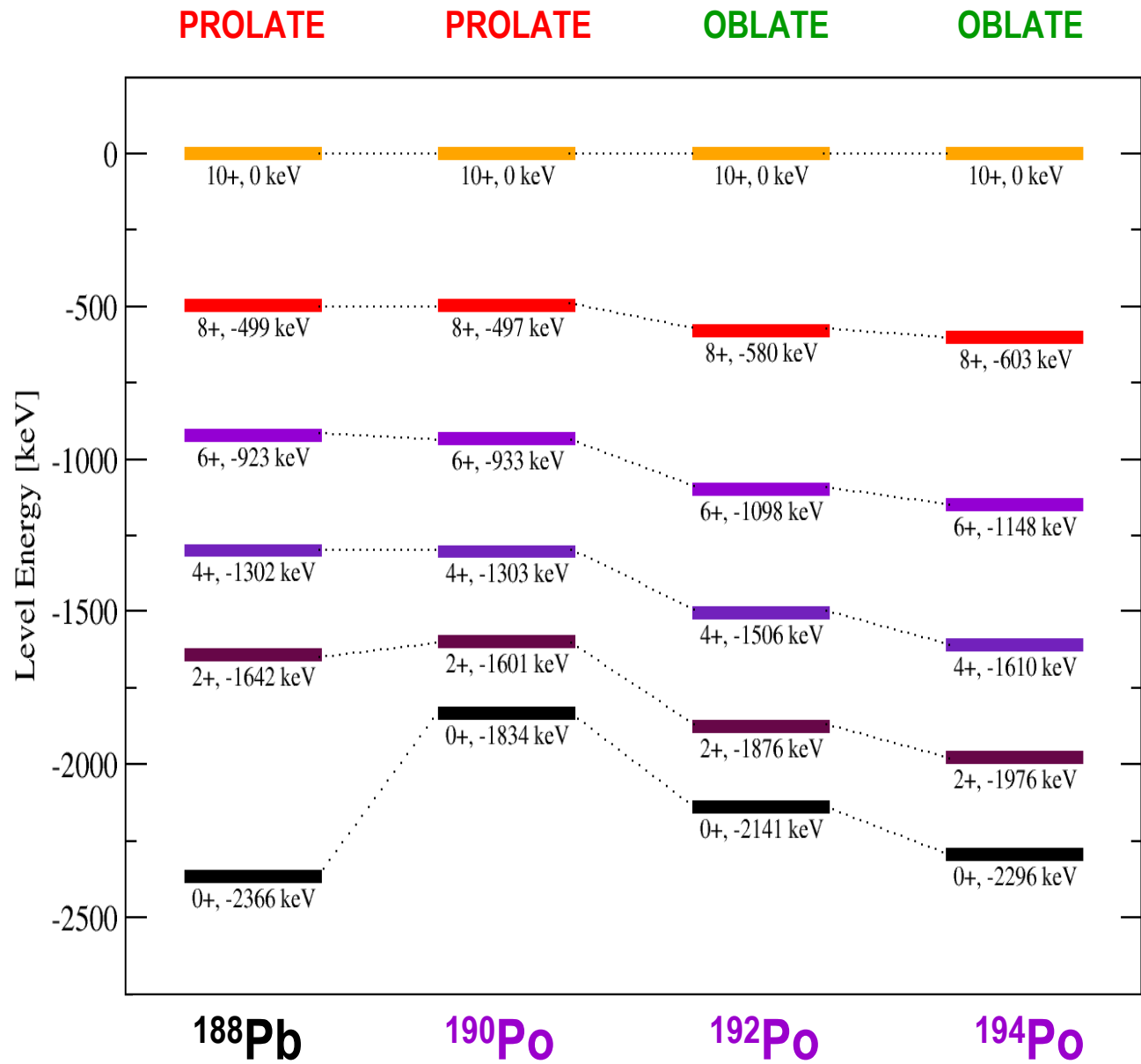
Level energies



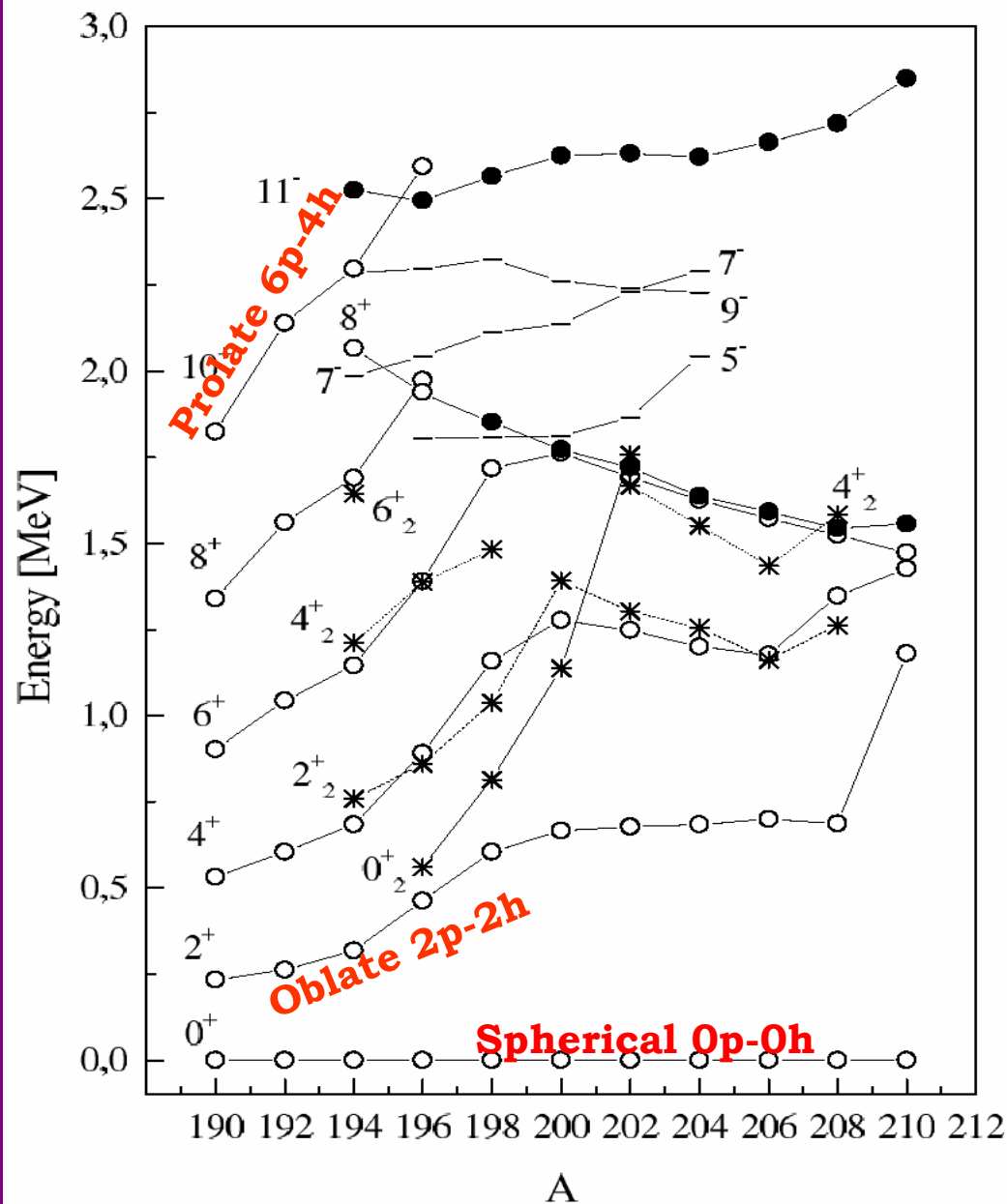
Alpha tagged singles gamma-rays from $^{144}\text{Sm}(^{49}\text{Ti},3n)^{190}\text{Po}$

200nb





Po



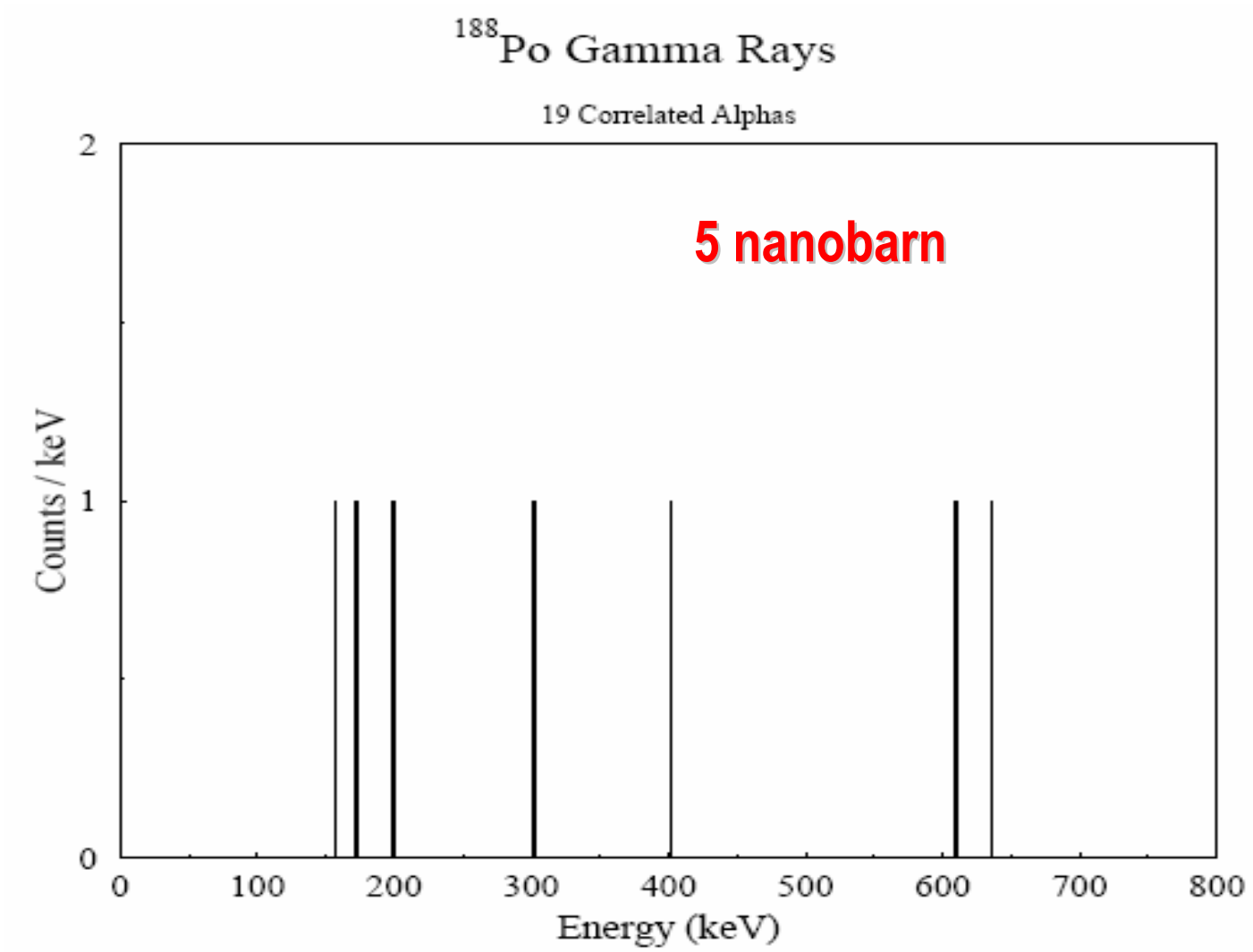
Sudden onset
deformation in light
Polonium isotopes

A = even, Z = 84

Level energies

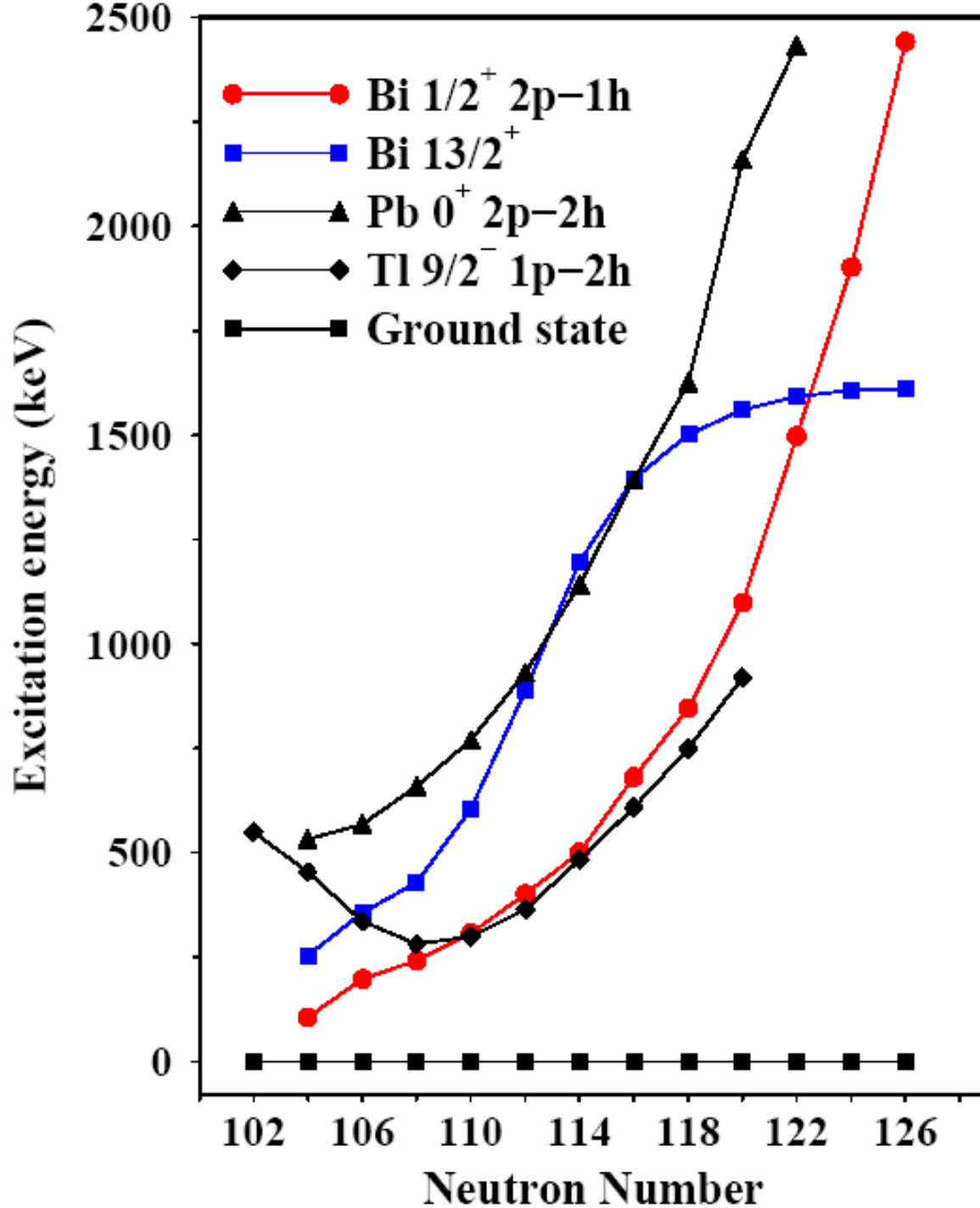
^{188}Po -alpha-tagged gamma-rays from $^{47}\text{Ti} + ^{144}\text{Sm}$

^{188}Po



Odd-mass
Bi
nuclei

$Z = 83$



^{191}Bi

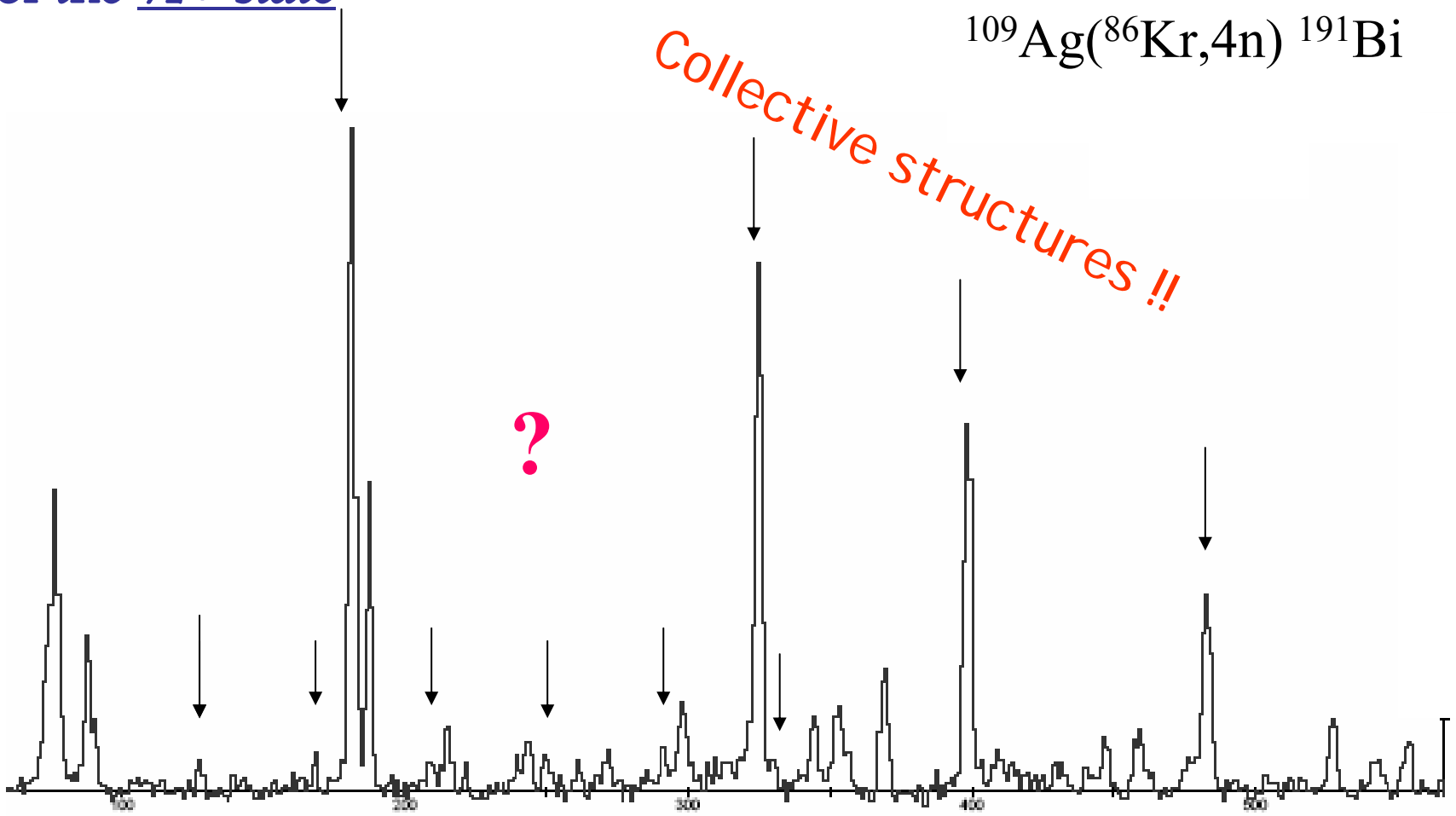
Prompt γ rays
tagged with the α decay
of the $\frac{1}{2}^+$ state

PRELIMINARY

$^{109}\text{Ag}(^{86}\text{Kr},4n)^{191}\text{Bi}$

Collective structures !!

?

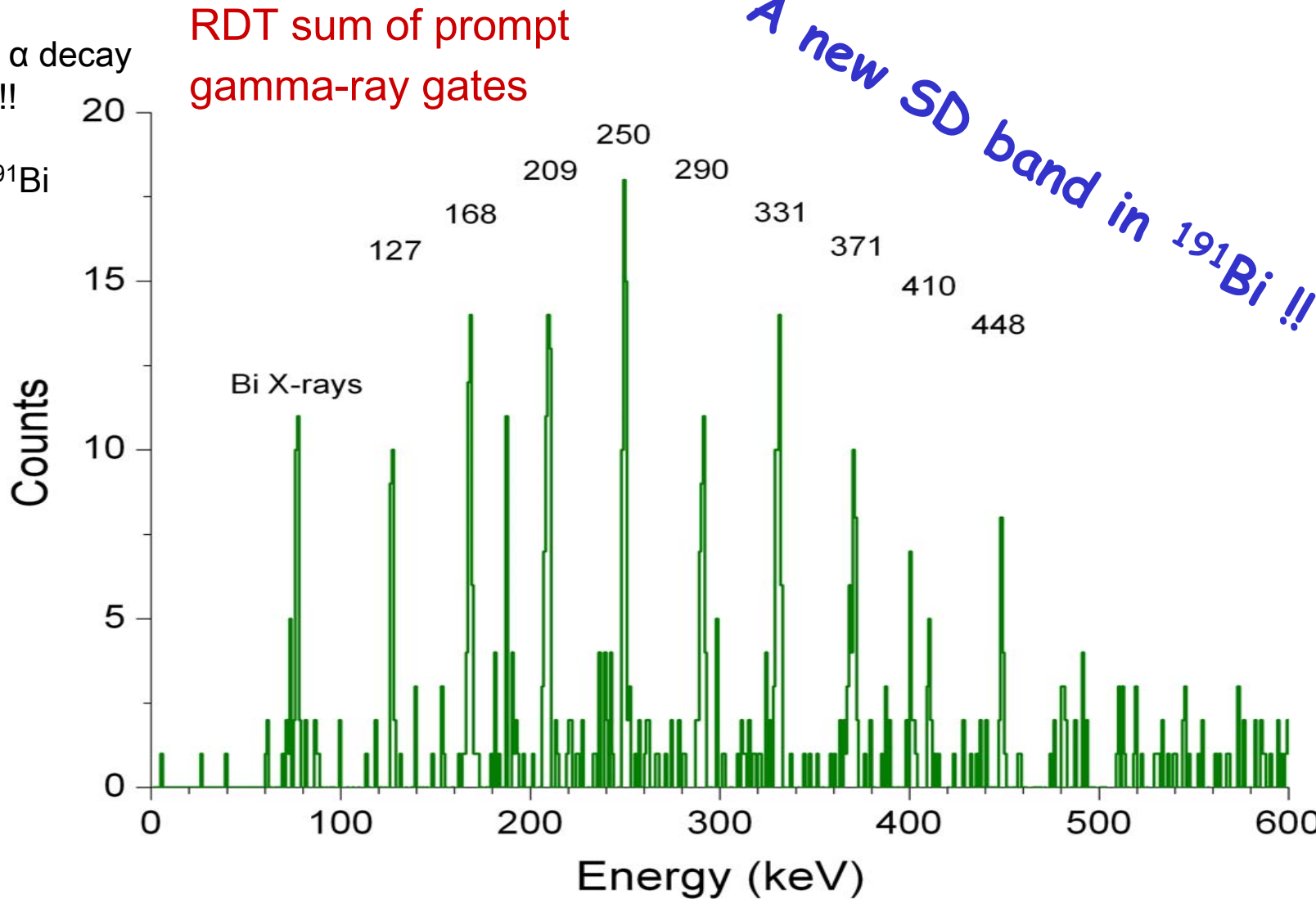


SD BAND DECAYING TO THE α DECAYING $1/2^+$ ISOMER BUT NOT TO THE α DECAYING $9/2^-$ ISOMER IN ^{191}Bi

^{191}Bi

Prompt γ rays
tagged with the α decay
of the $1/2^+$ state !!

$^{109}\text{Ag}(^{86}\text{Kr},4n)^{191}\text{Bi}$



PERSPECTIVES

Improved sensitivity:

- Digital signal processing → Higher counting rates
- Large variety of high-intensity beams

In-beam gamma - electron coincidences for SHE:

- Combined gamma-ray and electron spectrometer - SAGE

RDT for lighter nuclei - β - tagging

- Design for a new recoil separator

A new system for detection of ultra-fast proton emitters – LISA

INTAG JRA of EURONS –

Further development of tagging methods

Institutes Collaborating in the Experiments Presented:



UNIVERSITY OF JYVÄSKYLÄ



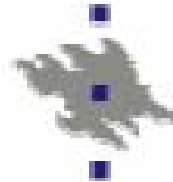
THE UNIVERSITY
of LIVERPOOL



NATIONALE UNIVERSITEIT
LEUVEN



GANIL



HELSINKI VLED-FISIO



THE UNIVERSITY *of* York



IN2P3

