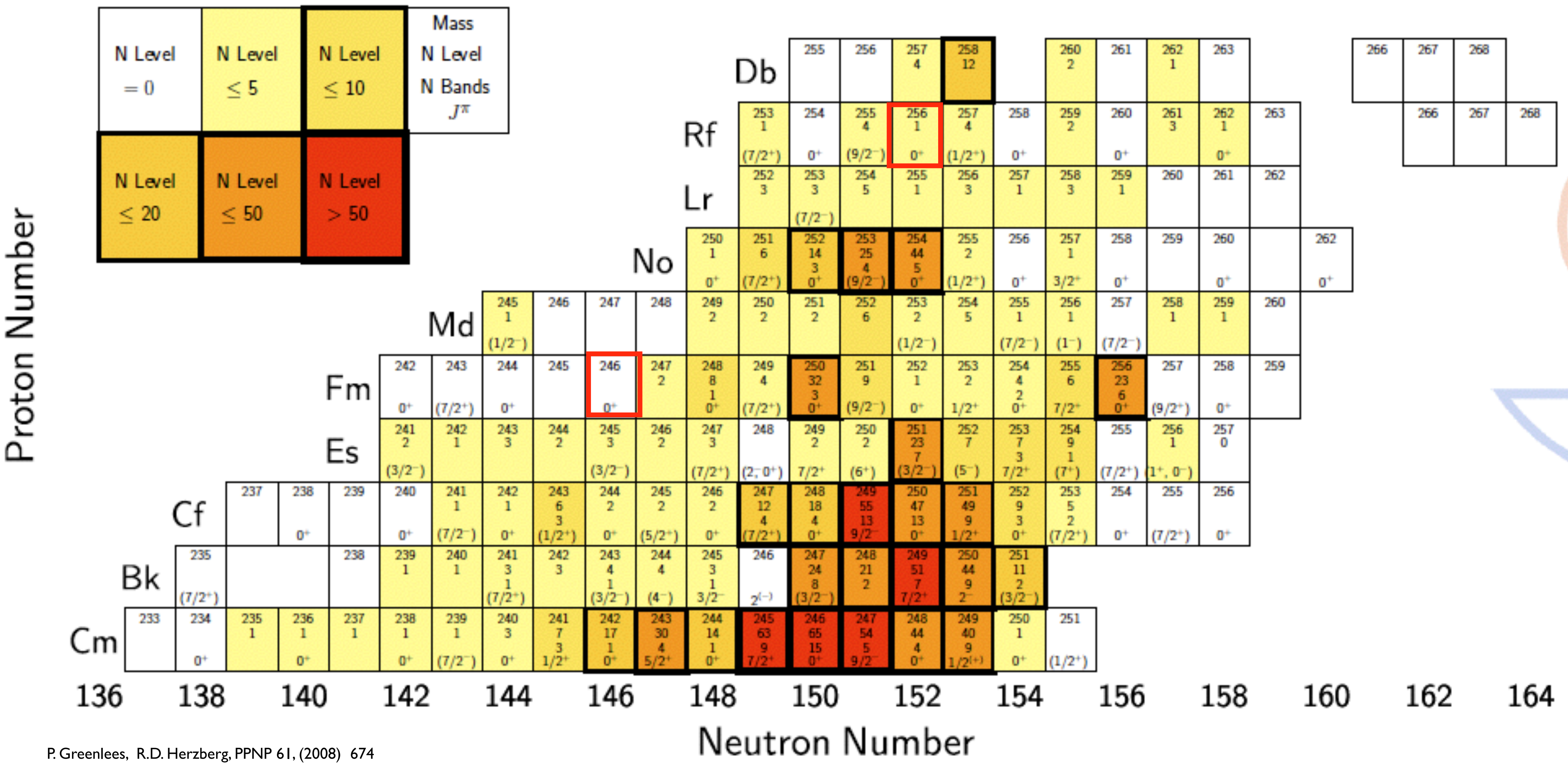
Investigation on the collectivity in the transfermium region

Julien Piot

ESNT Workshop November 16th-19th 2015

Advances in experimental and theoretical studies of heavy, very heavy and super-heavy nuclei

Knowledge of the transfermium region



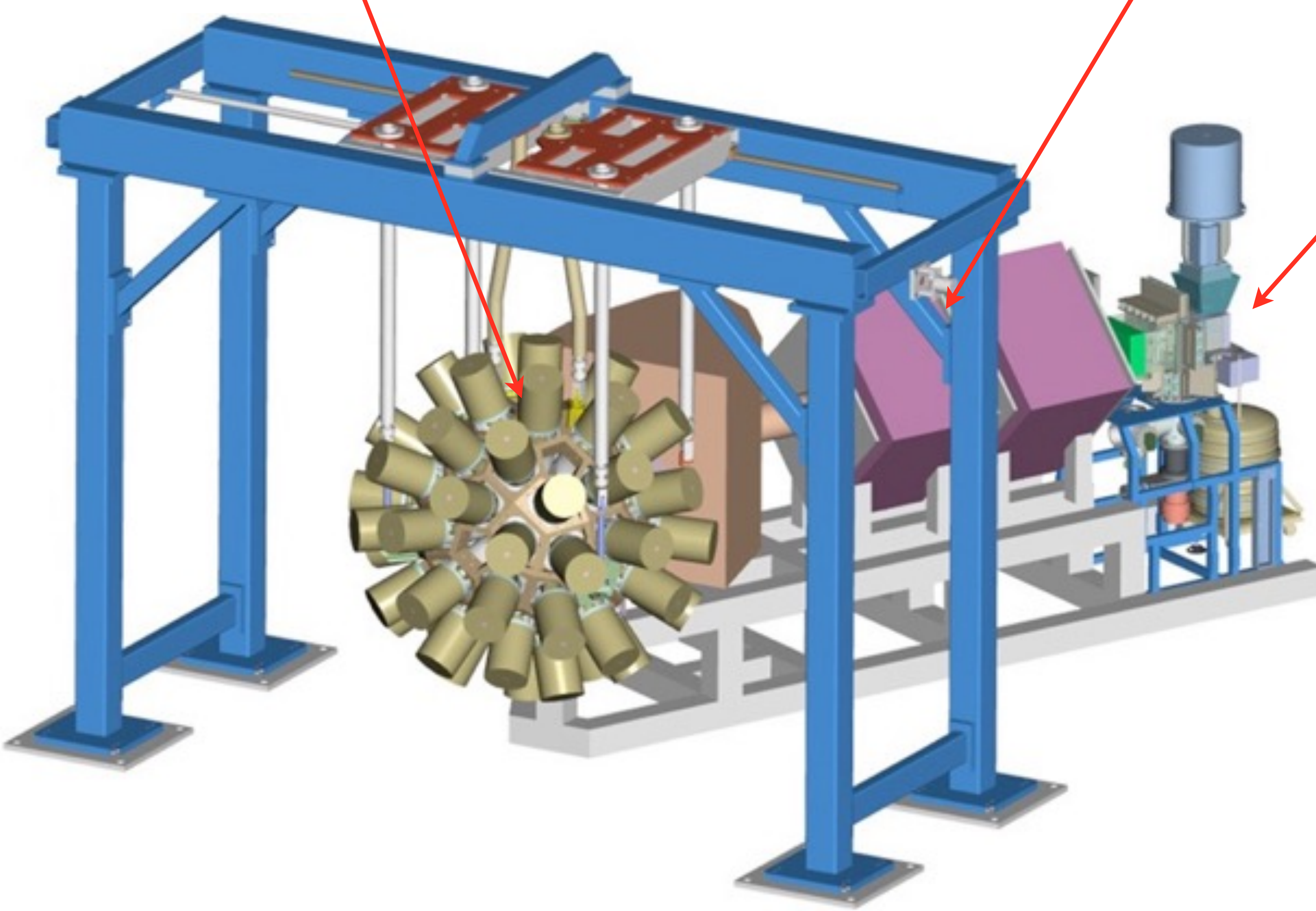
P. Greenlees, R.D. Herzberg, PPNP 61, (2008) 674

Spectroscopy at the University of Jyväskylä

JUROGAM 2 :
24 Germanium Clovers
15 Ge Phase 1
4π
Anti-Compton

RITU :
Gas-filed separator
QDQQ

GREAT :
Focal Plane
Implantation Si
Planar Germanium
Internal conversion



Prompt γ spectroscopy

Collective excitation detection

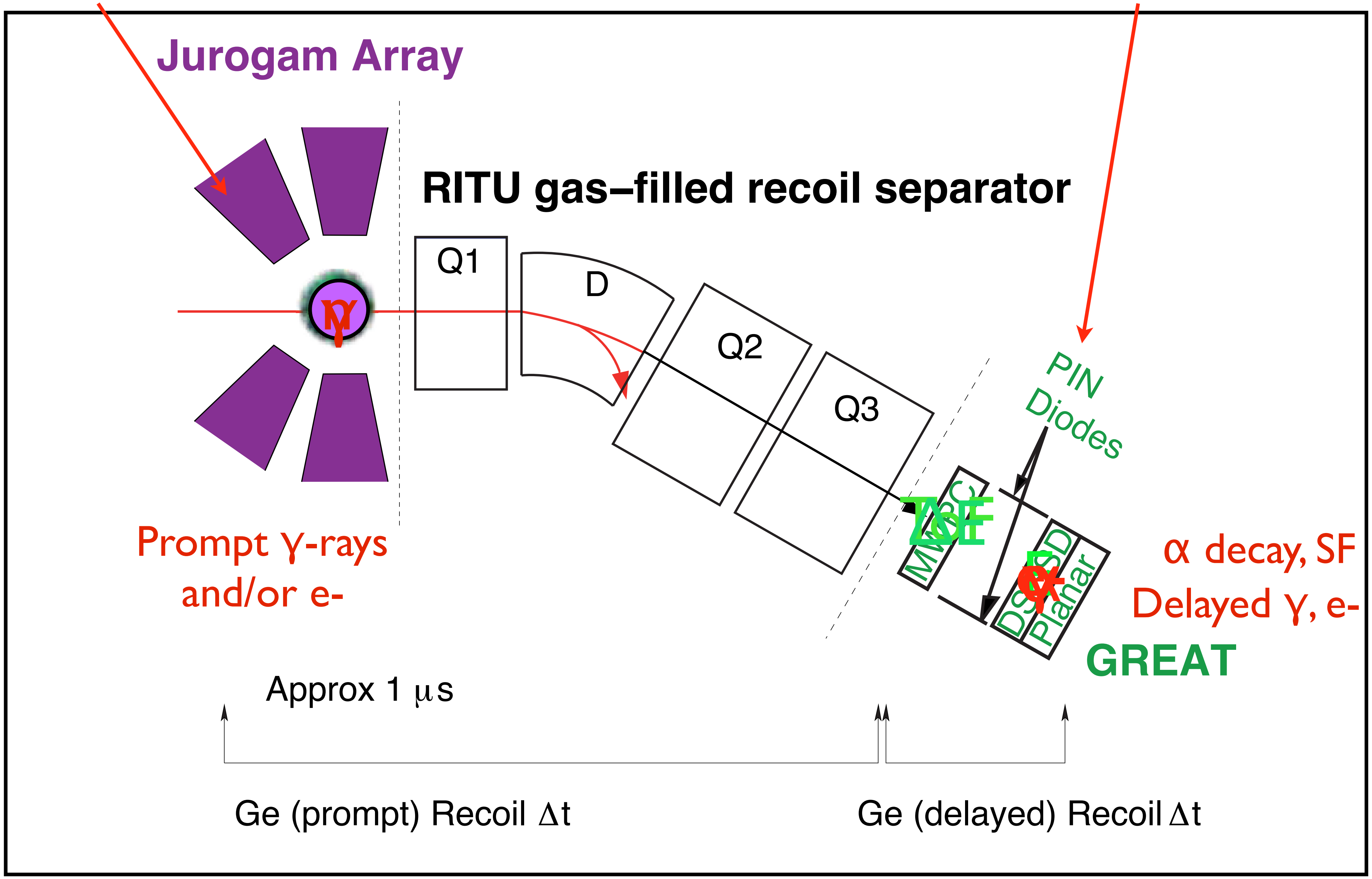
(rotation, vibration)

Delayed Spectroscopy : α, γ and e-

Recoil Decay Tagging for low cross-sections

Prompt γ-ray spectroscopy
Sustain high counting rates

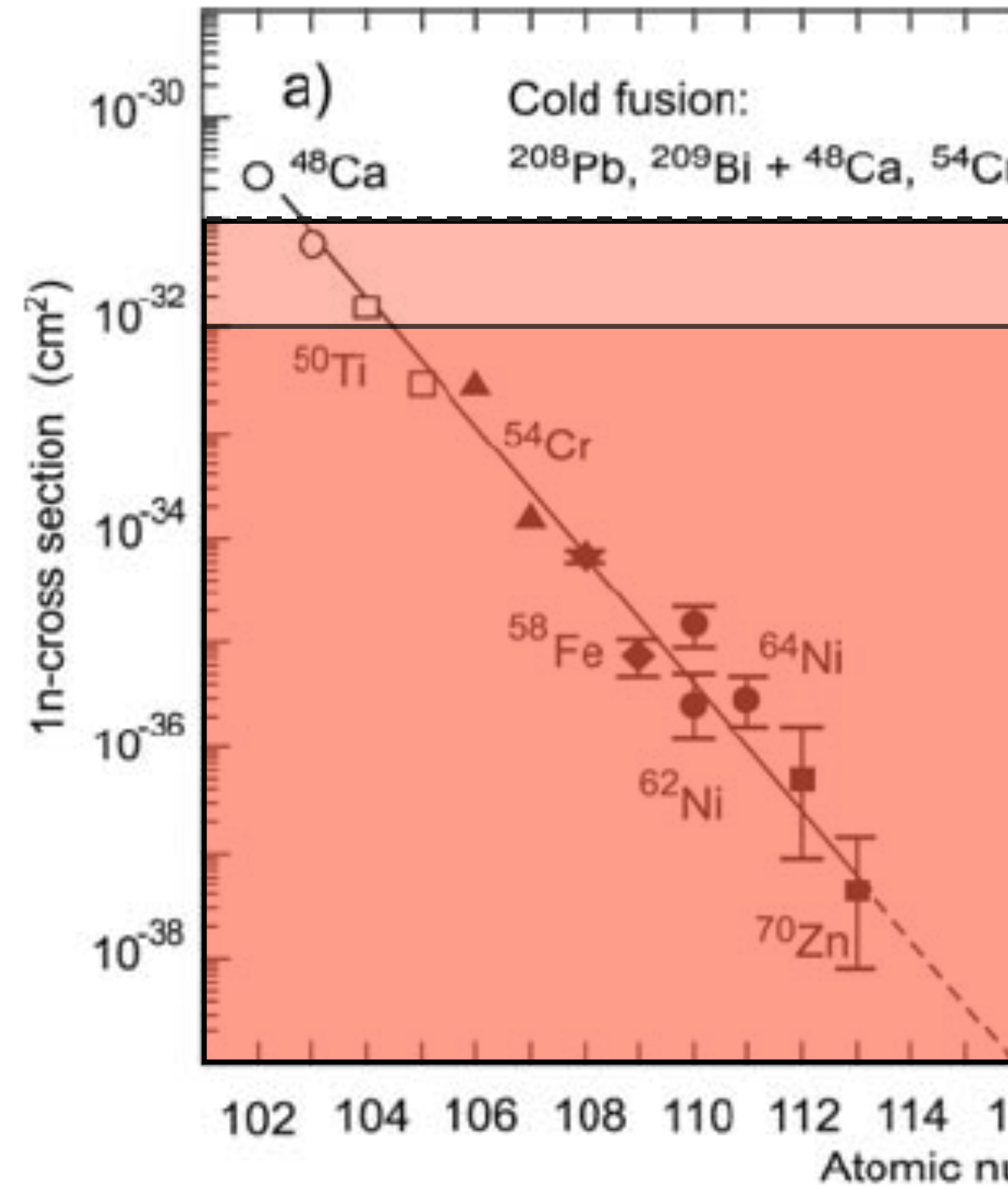
Focal Plane
Recoiling nuclei identification - tagging
Delayed α, γ and e- spectroscopy



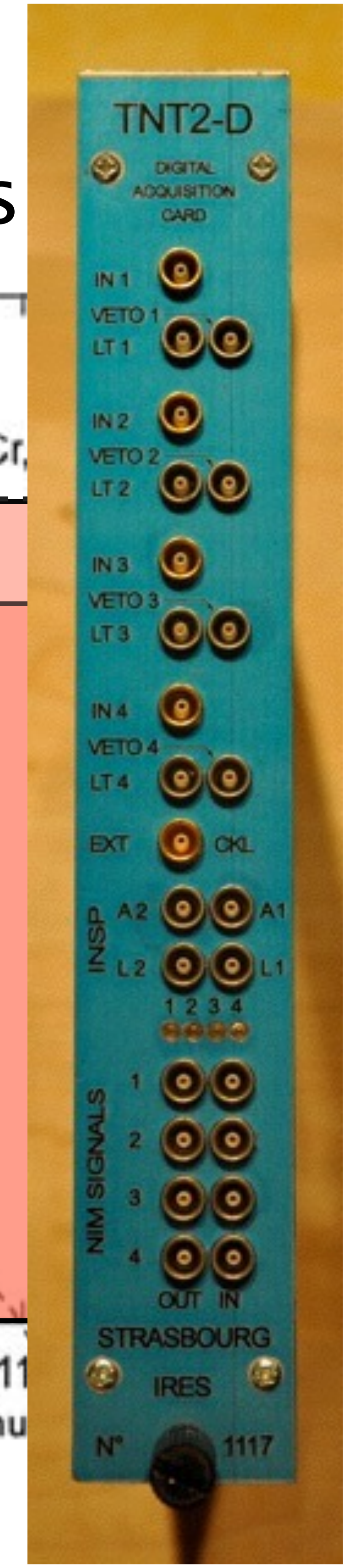
Detection limits for spectroscopy

γ–ray spectroscopy requires important statistics

- Cold Fusion
  - + Low E*
  - - Neutron deficient nuclei
- Hot Fusion
  - + More nuclei accessible
  - - High E*
- Cross section drops with A
- Analogue electronics is overwhelmed above 20kHz i.e. 100 nb

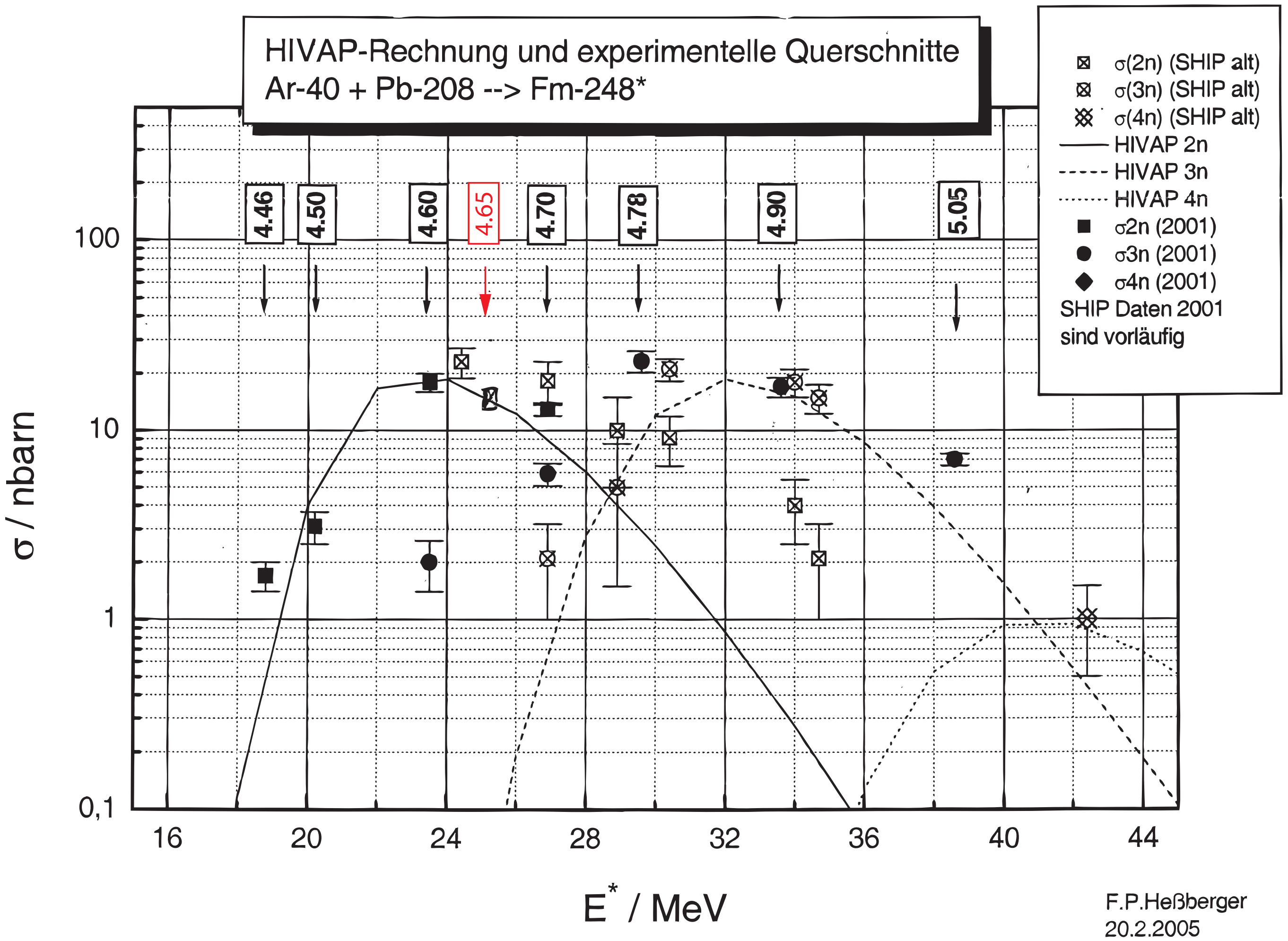


Yu.Ts. Oganessian, EPJA 42, 361



Faster electronics required

Prompt Spectroscopy of ^{246}Fm



J. Piot et al, Phys. Rev. C 85, 041301

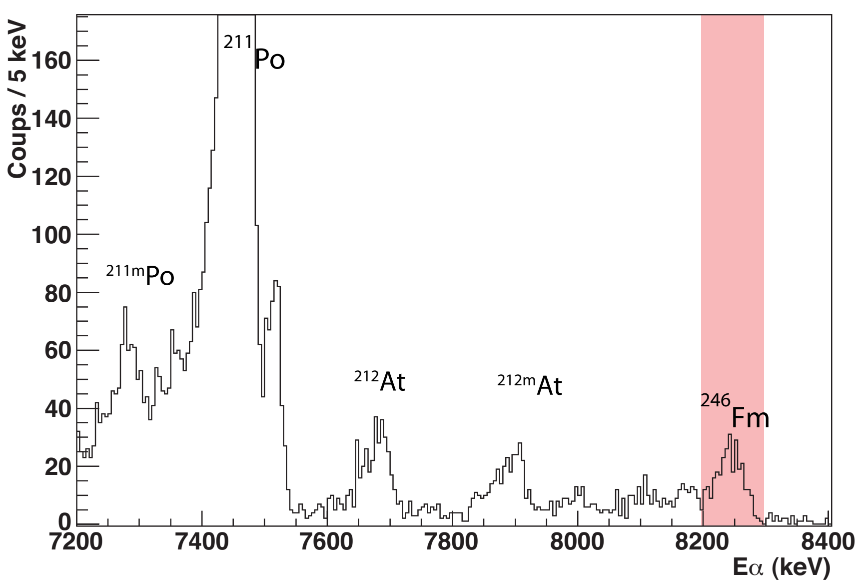
- ^{208}Pb(^{40}Ar,2n) ^{246}Fm
- Measured cross-section 11 nb
- Experiment ran in dec. 2009 in Jyväskylä on JUROGAM 2 RITU GREAT
- Rotating target
- Full digital electronics for JUROGAM 2
- Record 71 pnA beam on target for prompt spectroscopy

Prompt Spectroscopy of ^{246}Fm

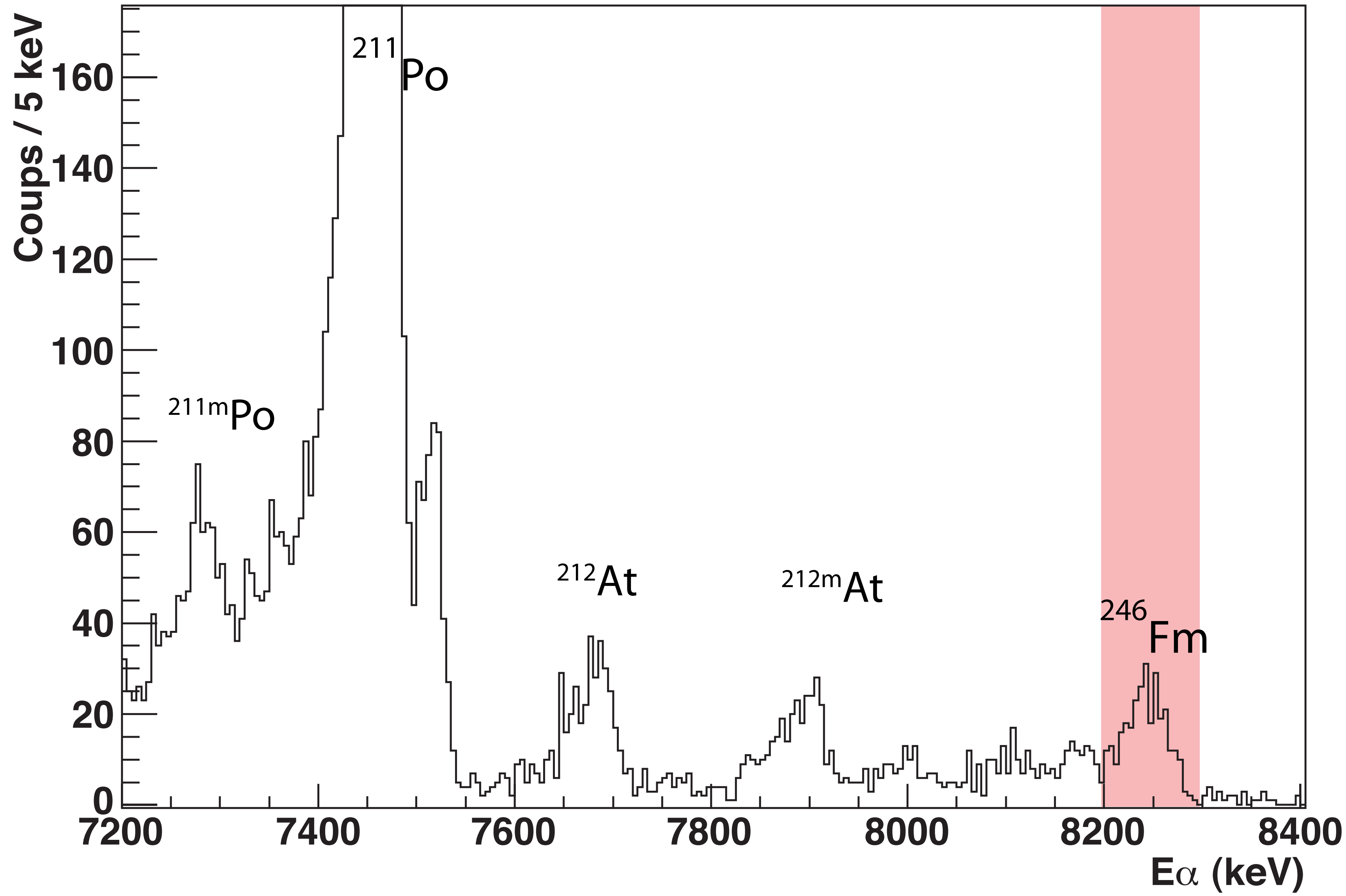
276 correlated α

E_{α} = (8244 ± 15) keV

$T_{1/2}$ = (1,6 ± 0,2) s



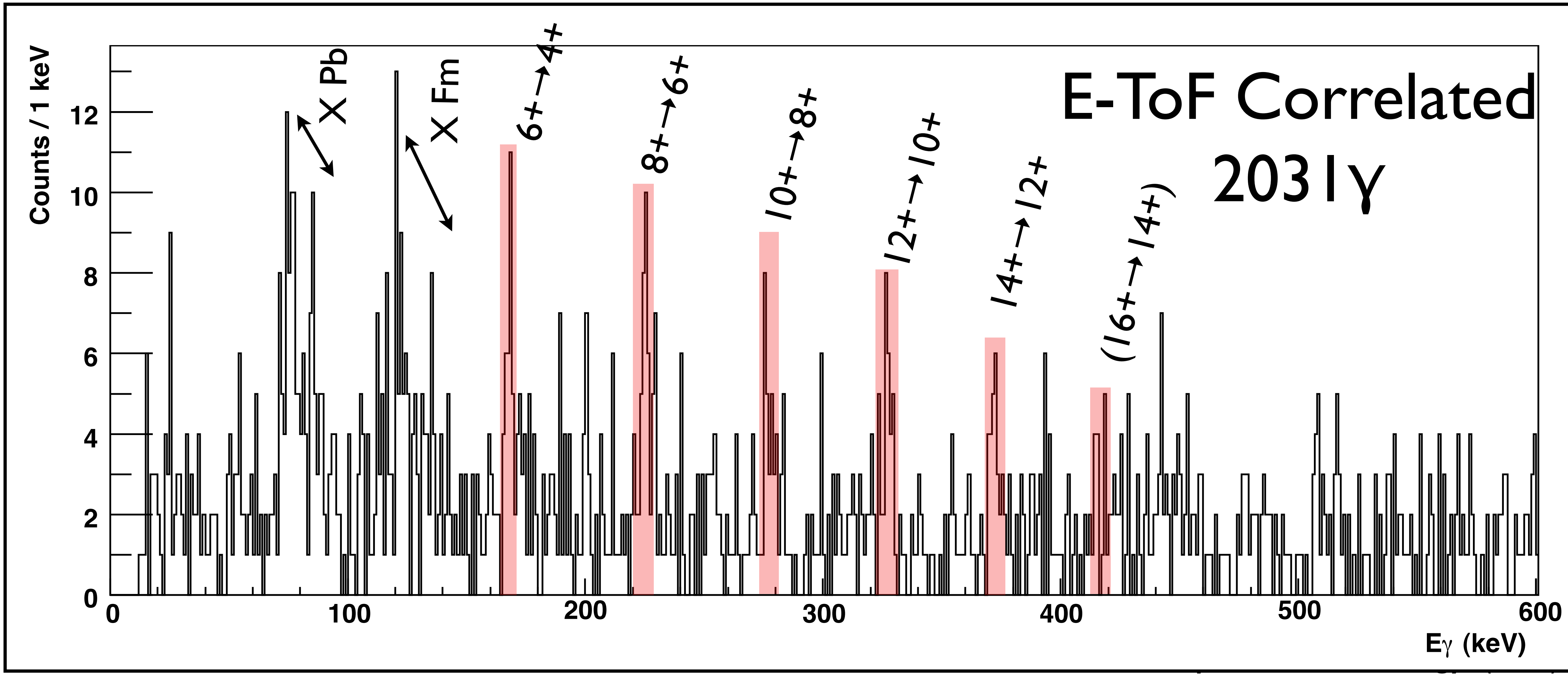
First evidence of a rotationnal band in ^{246}Fm



BUT Insufficient statistics

⇒ Enlarge selection

Prompt Spectroscopy of ^{246}Fm

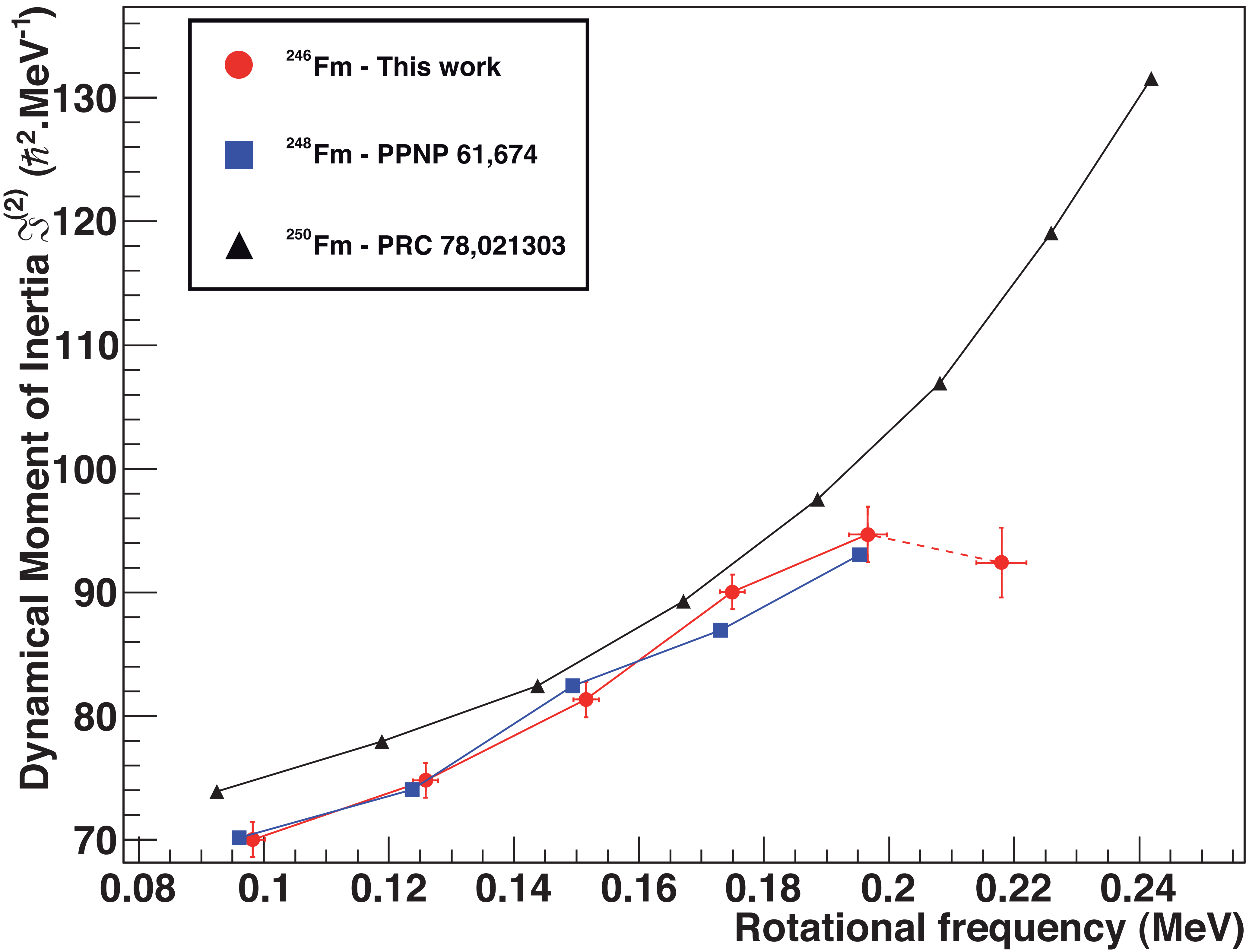


Rotationnal Band up to 16ħ

Prompt Spectroscopy of ^{246}Fm

$\Im^{(2)} =$

$\hbar\omega =$



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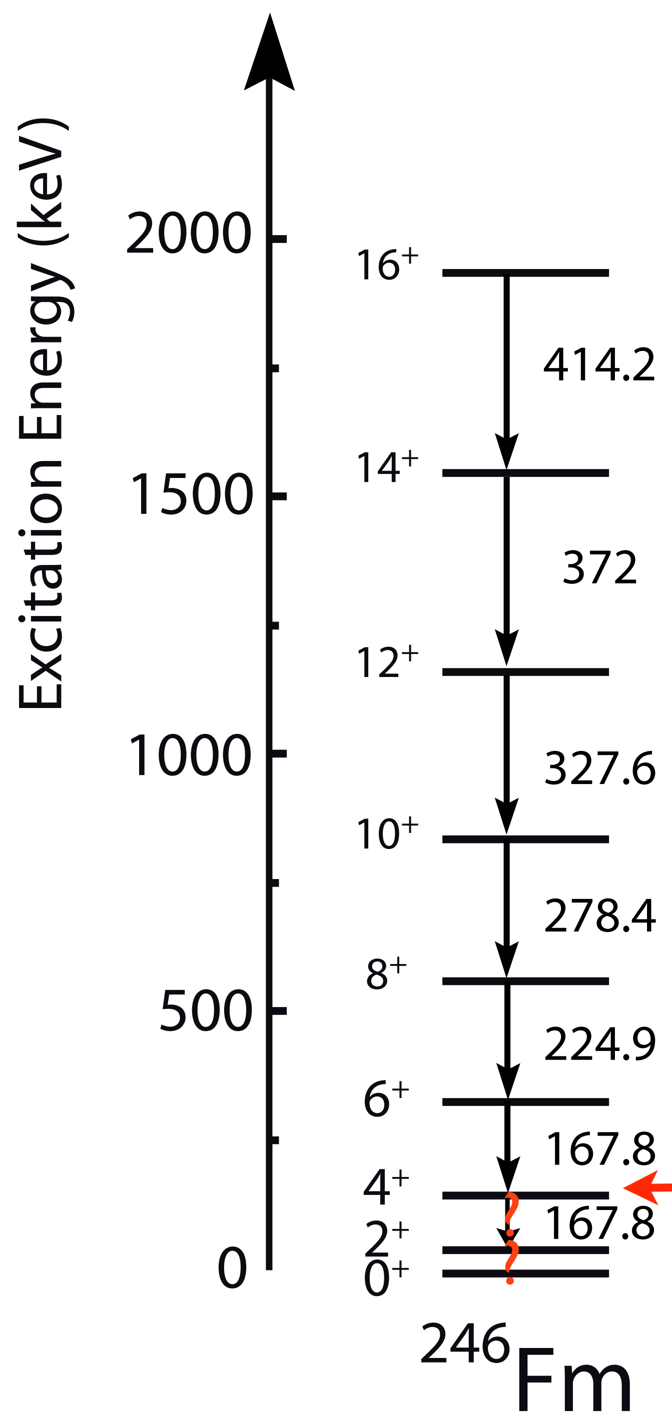
Prompt Spectroscopy of ^{246}Fm

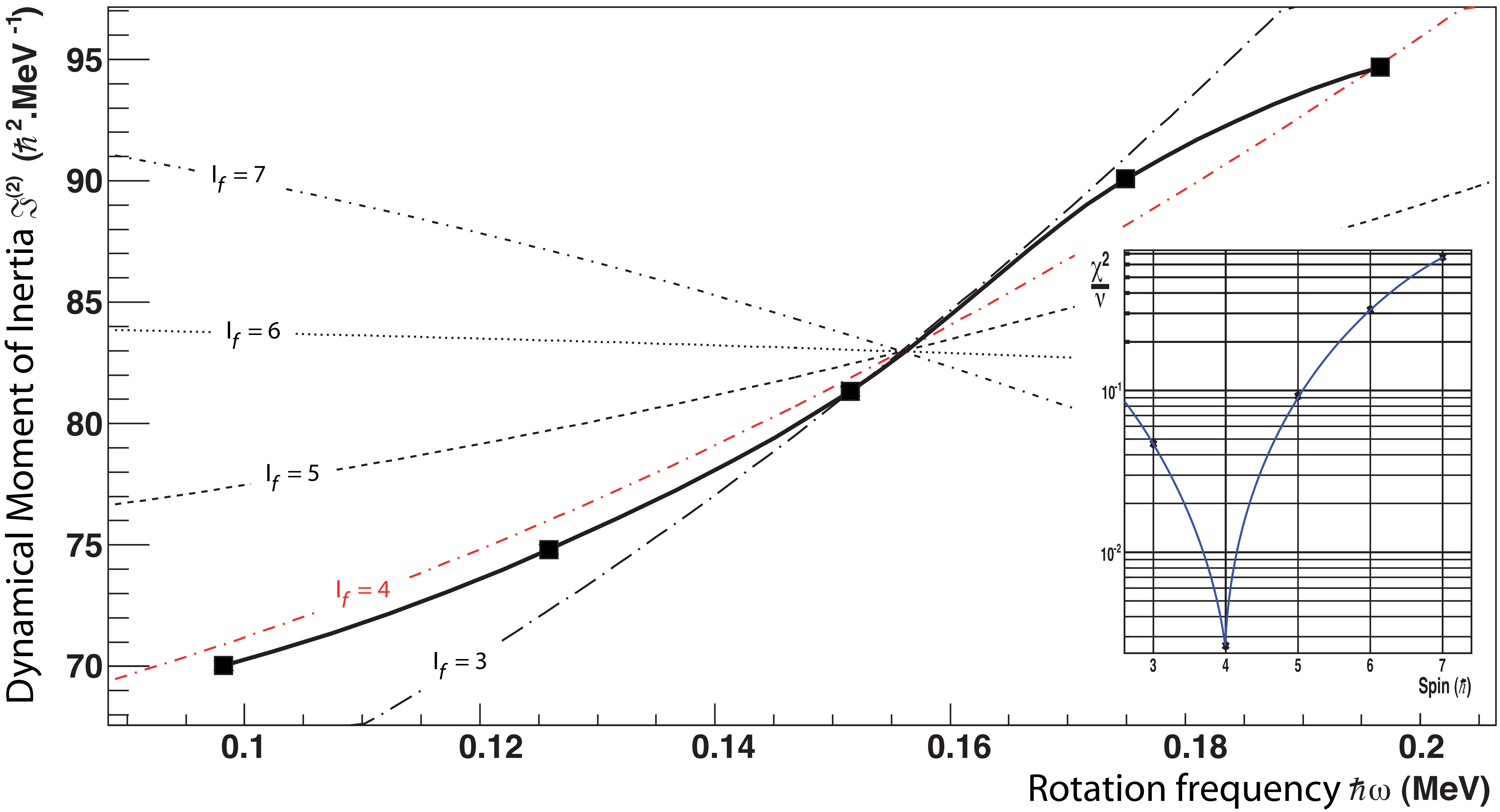


Confirm the spin assignement ?

Missing two transitions ?

I_f

Prompt Spectroscopy of ^{246}Fm



[1] Harris PR **138** (1965) 509 & insp. from "Becker et al. PRC **46** (1992) 889"

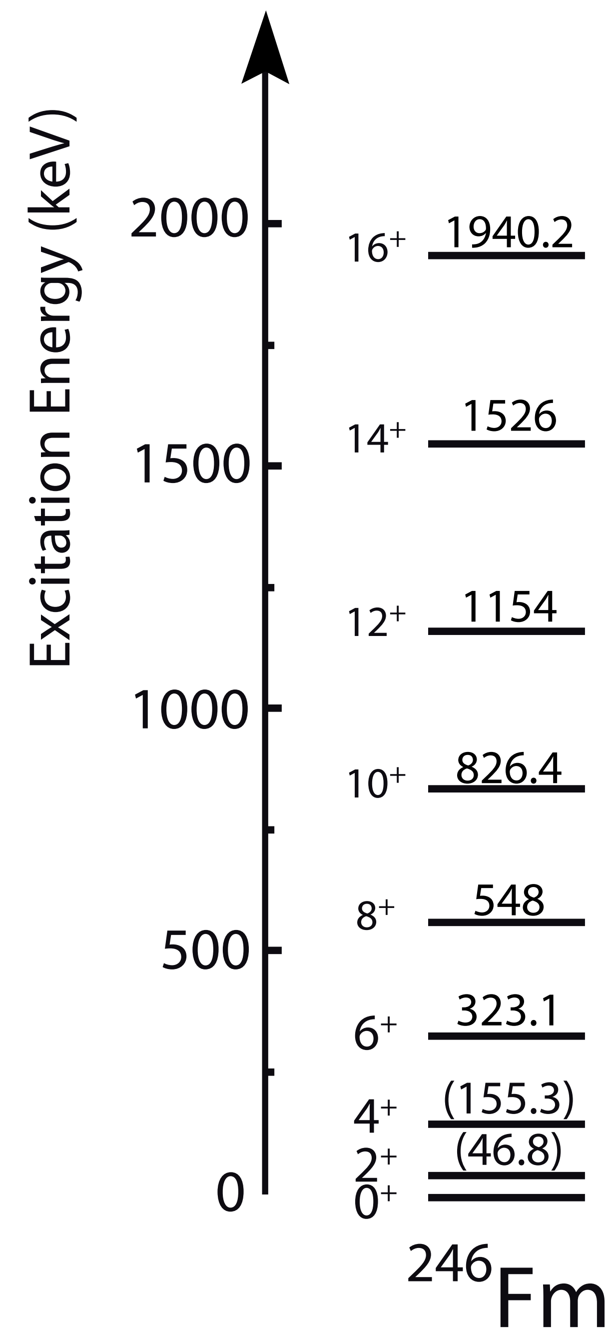
Prompt Spectroscopy of ^{246}Fm

$$\frac{E\gamma}{2} = \hbar\omega$$

$$I = J_1\omega + J_0\omega^3 + 1/2$$ [1]

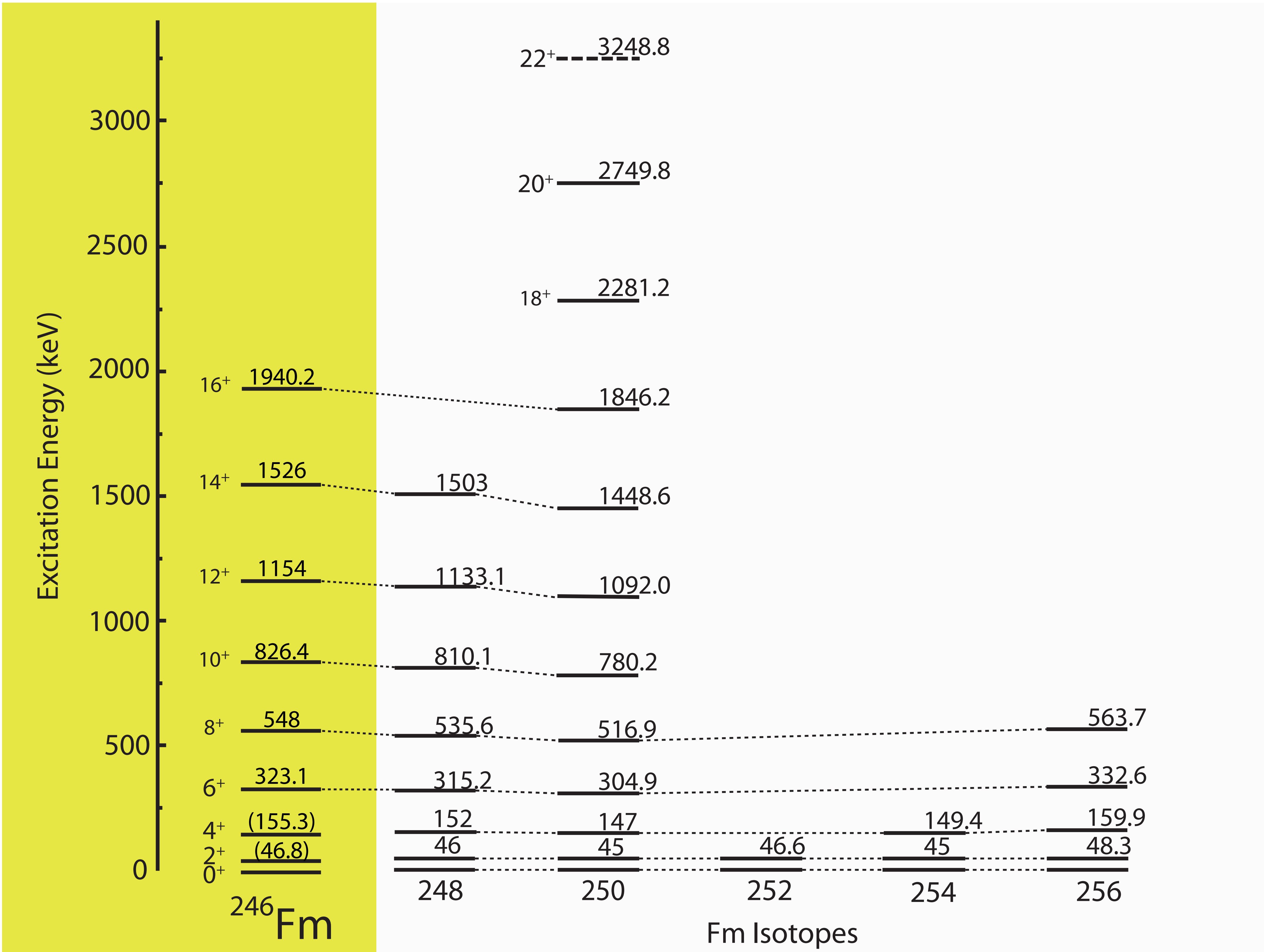
Fit for I = 4 (4+→2+)
and I = 2 (2+→0+)

Transition	Energy (keV)
$4^+ \rightarrow 2^+$	108,5
$2^+ \rightarrow 0^+$	46,8



[1] P. Reiter *et al.* PRL **82**, (1999) 509

Prompt Spectroscopy of ^{246}Fm



* from R.-D. Herzberg & P.T. Greenlees, PPNP 61, 674

A difficult nucleus to produce

${}^{50}_{22}Ti_{28}$ + ${}^{208}_{82}Pb_{126}$ => ${}^{258}_{104}Rf_{154}$(CN) => ${}^{256}_{104}Rf_{152}$ + 2n

$\sigma_{fus\text{-}evap} = 17$ nb

➡Increase the beam intensity

Higher heat deposition in the target

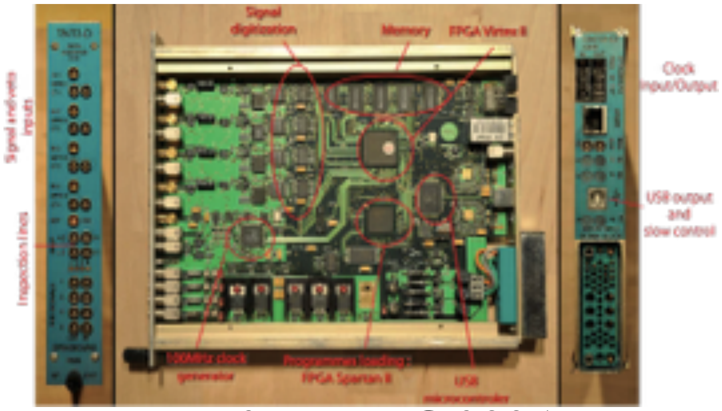
Rotating target

Increased count rates in HPGe

Digital ADCs

➡Produce ^{50}Ti beam

IPHC 2007

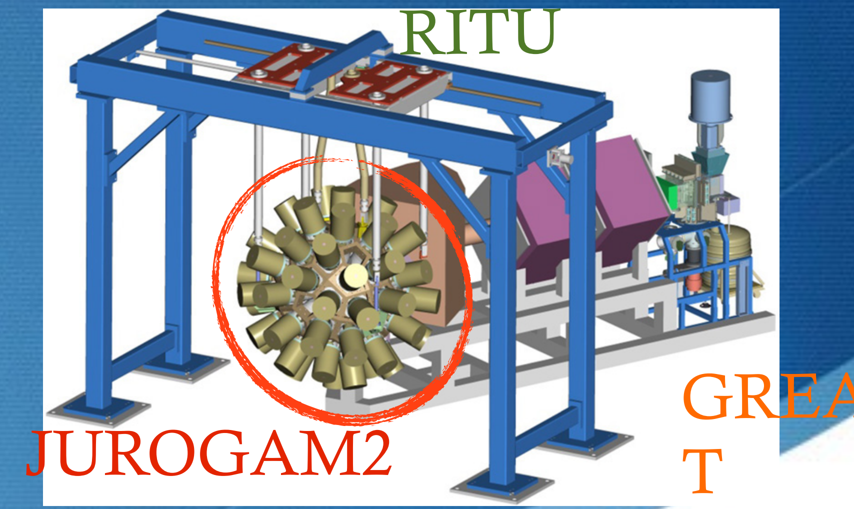


TNT2D, IPHC 2006

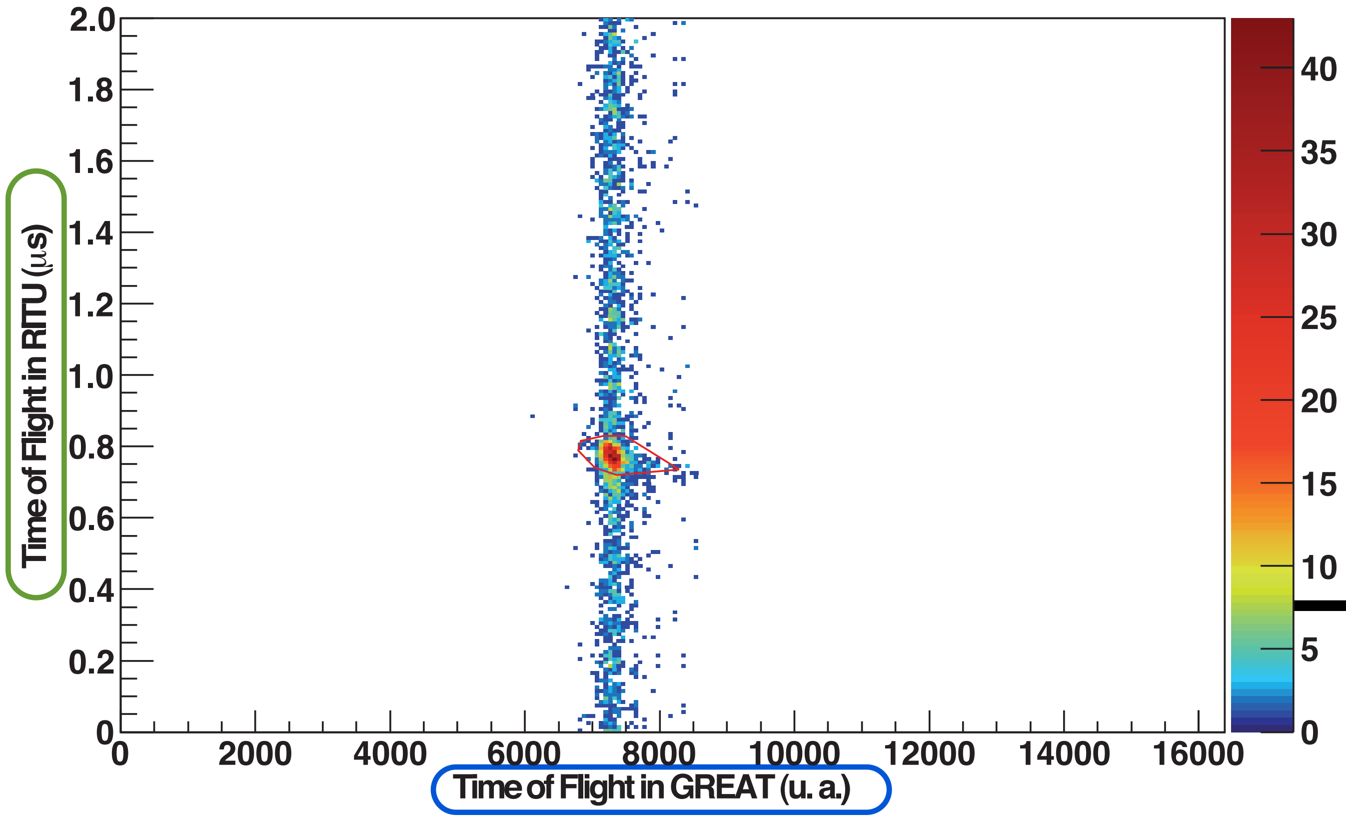
L. Arnold et al. IEEE TNS 53, 723 (2006)

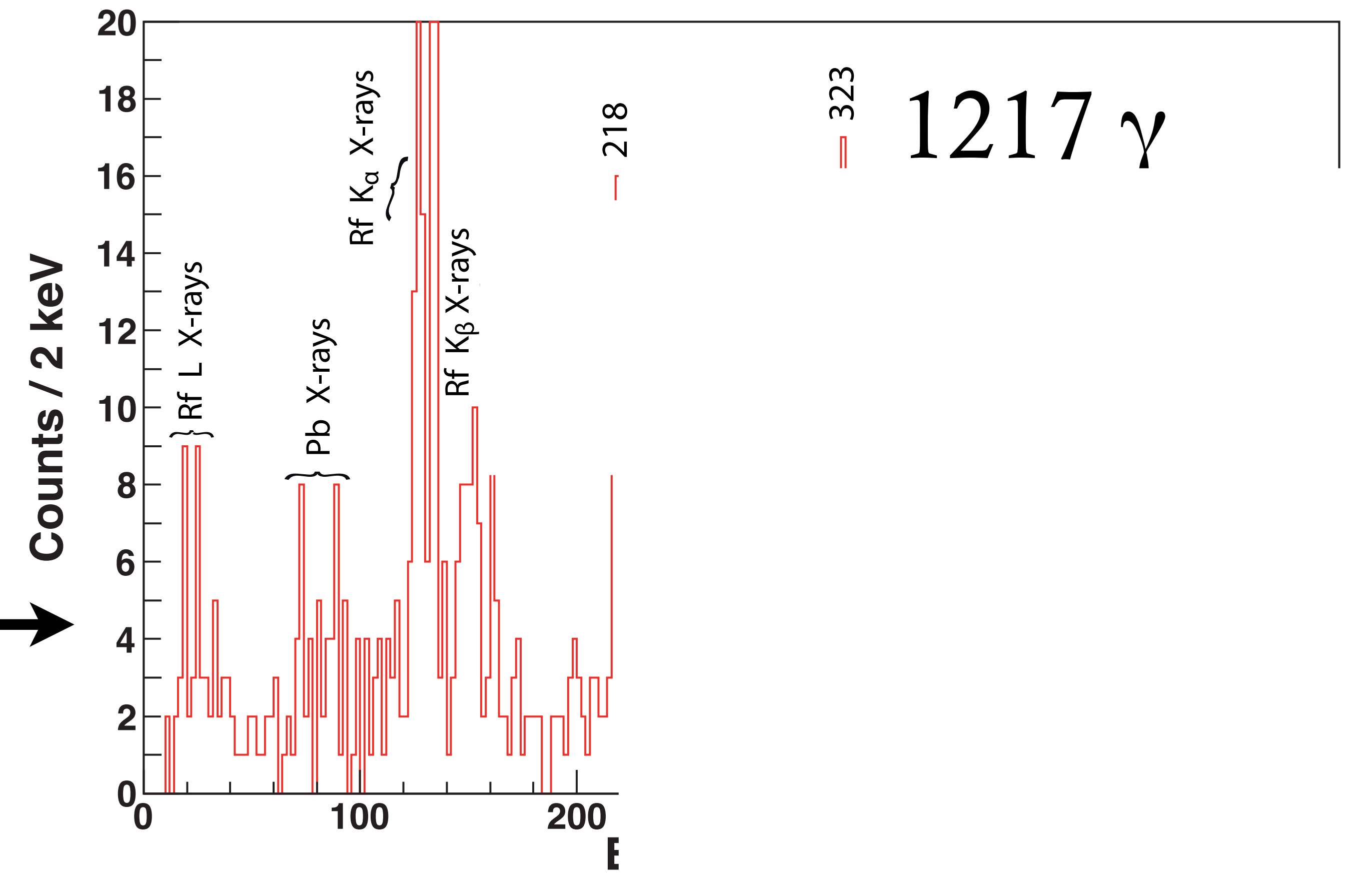
Lyrtech, 2010

Step 2 : Prompt gamma-ray spectrum



With the 2210 identified ^{256}Rf nuclei… a **R-F-γ** selection

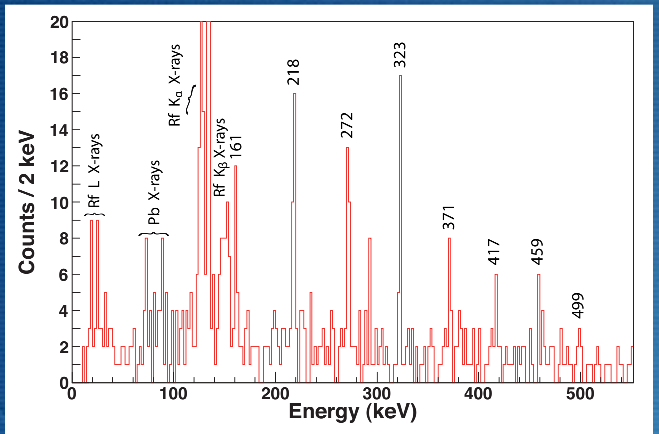


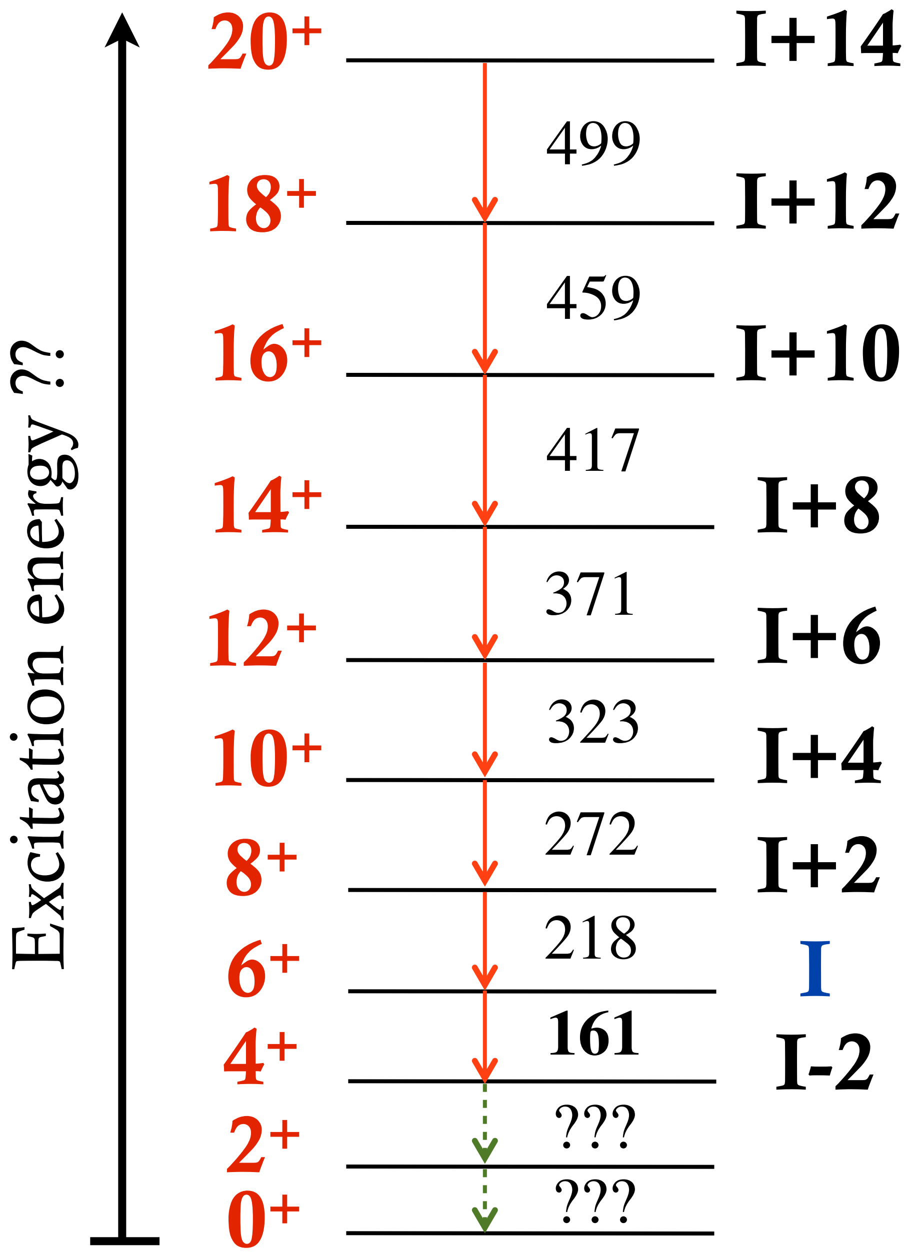


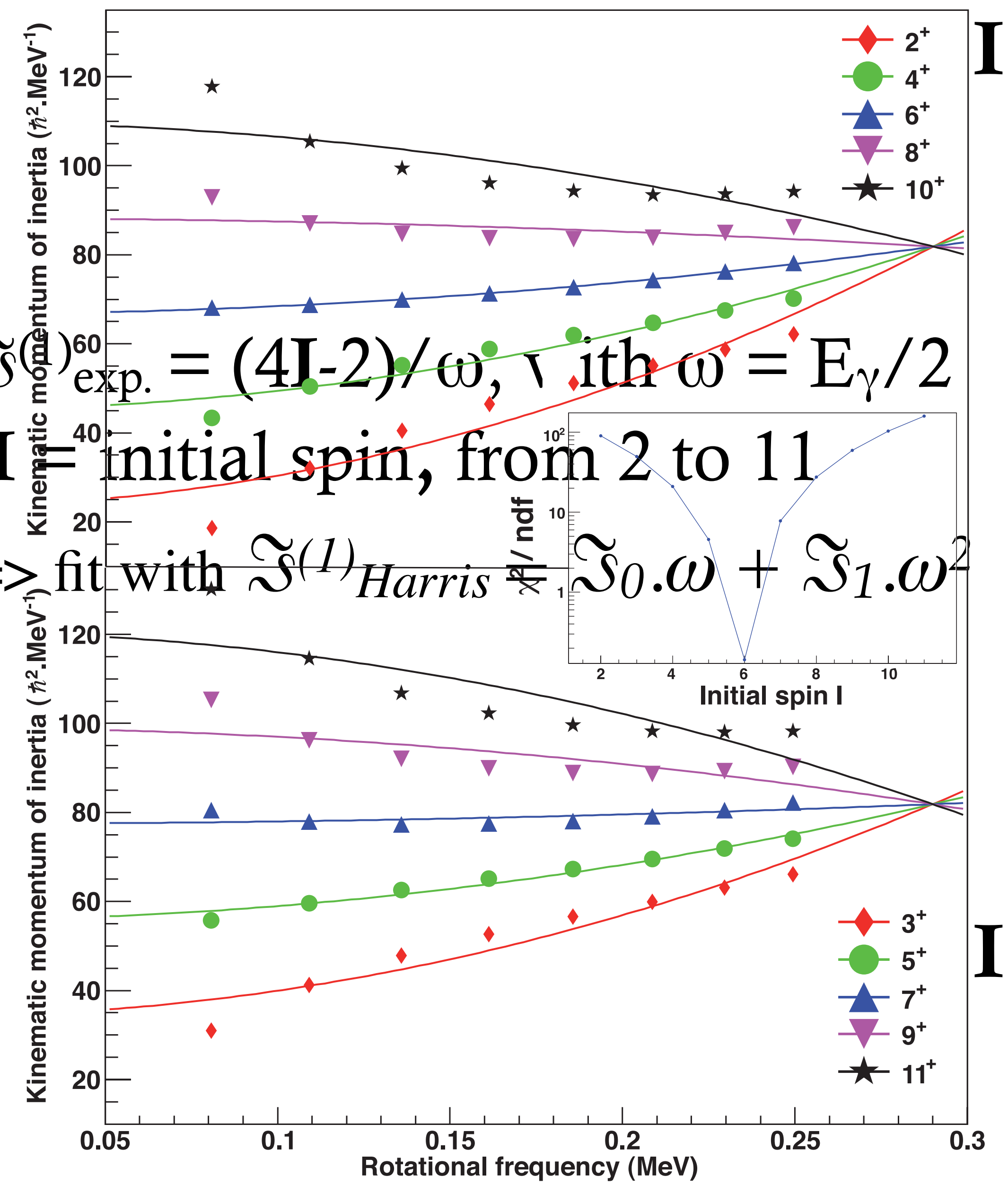
Calculated and measured
Time of Flight in RITU : ~0.8 μs

8 regularly spaced peaks

Characterisation of the rotational band using the **Harris method**







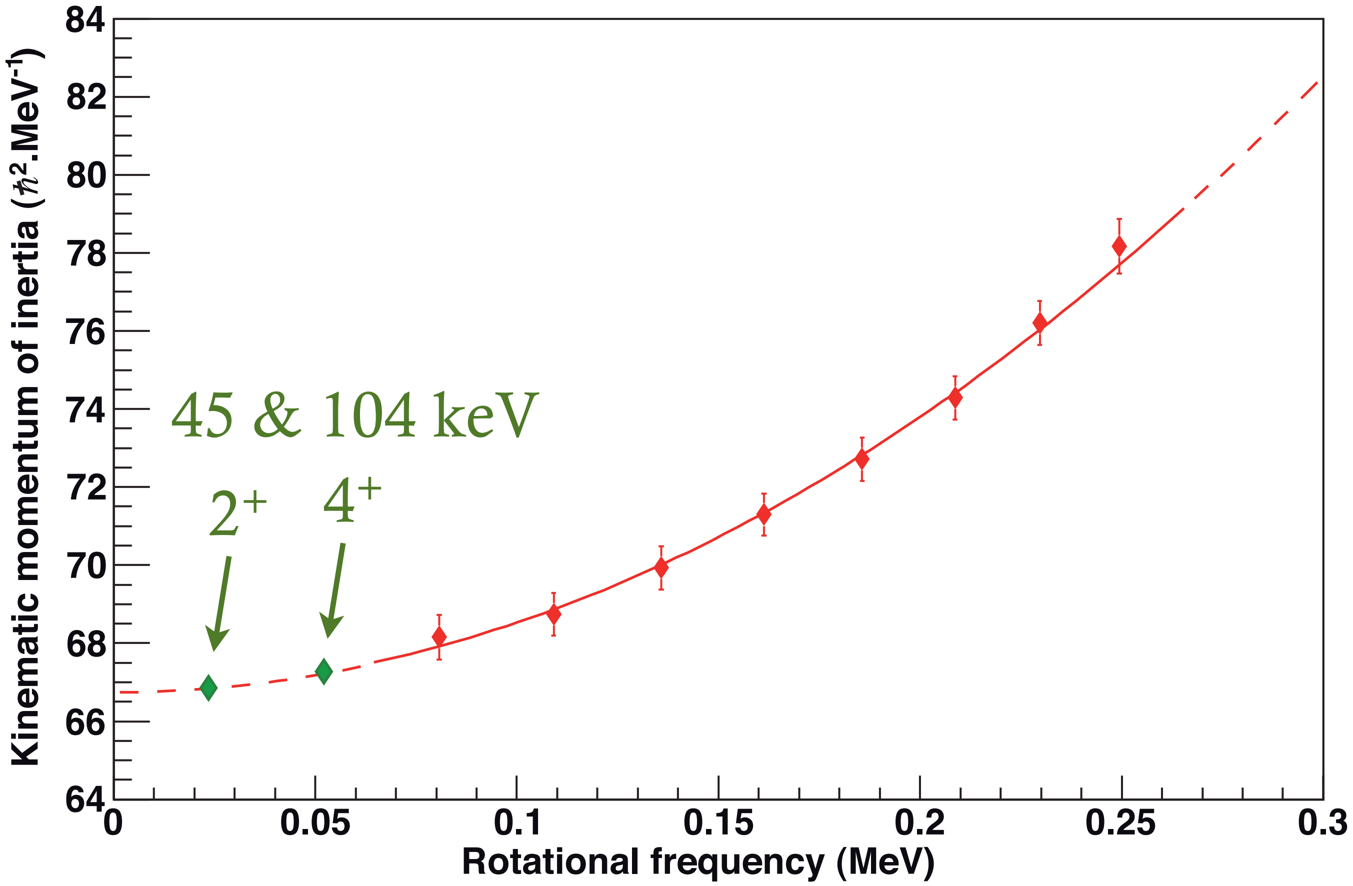
$\Im^{(1)}_{exp.} = (4I\text{-}2)/\omega$, \ ith $\omega = E_\gamma/2$

I = initial spin, from 2 to 11

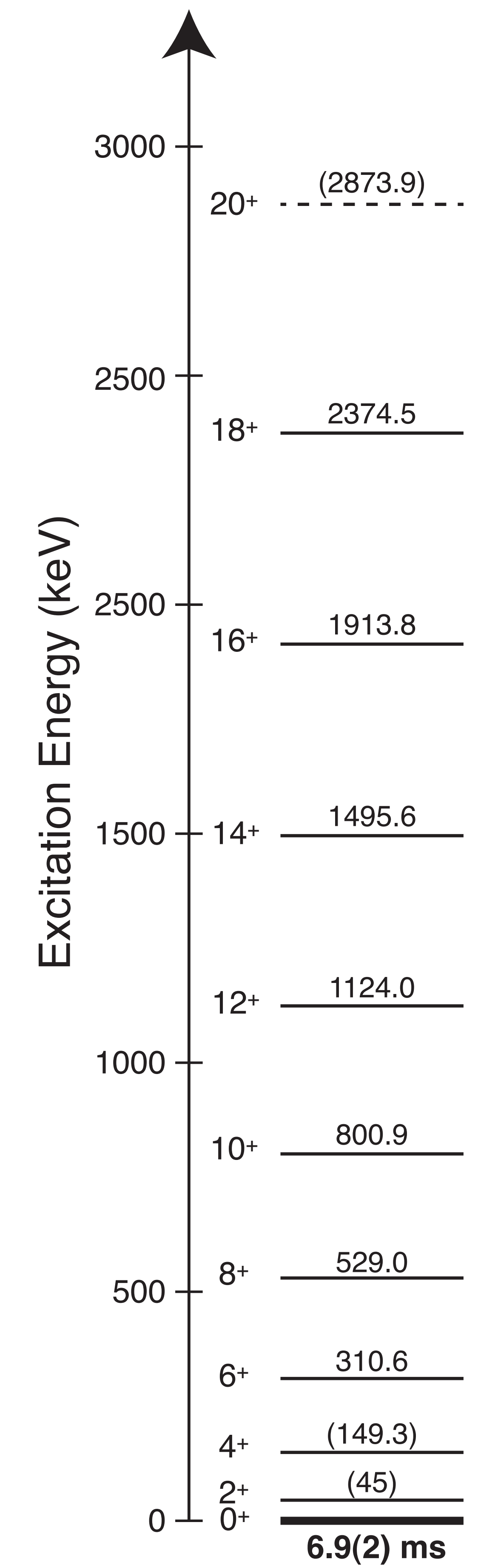
=> fit with $\Im^{(1)}_{Harris} = \Im_0.\omega + \Im_1.\omega^2$

Missing transitions: convertion electrons

Transition	Conv. Coef. (Bricc Calc.)
4+ → 2+	31.5 (15)
2+ → 0+	1640 (19)

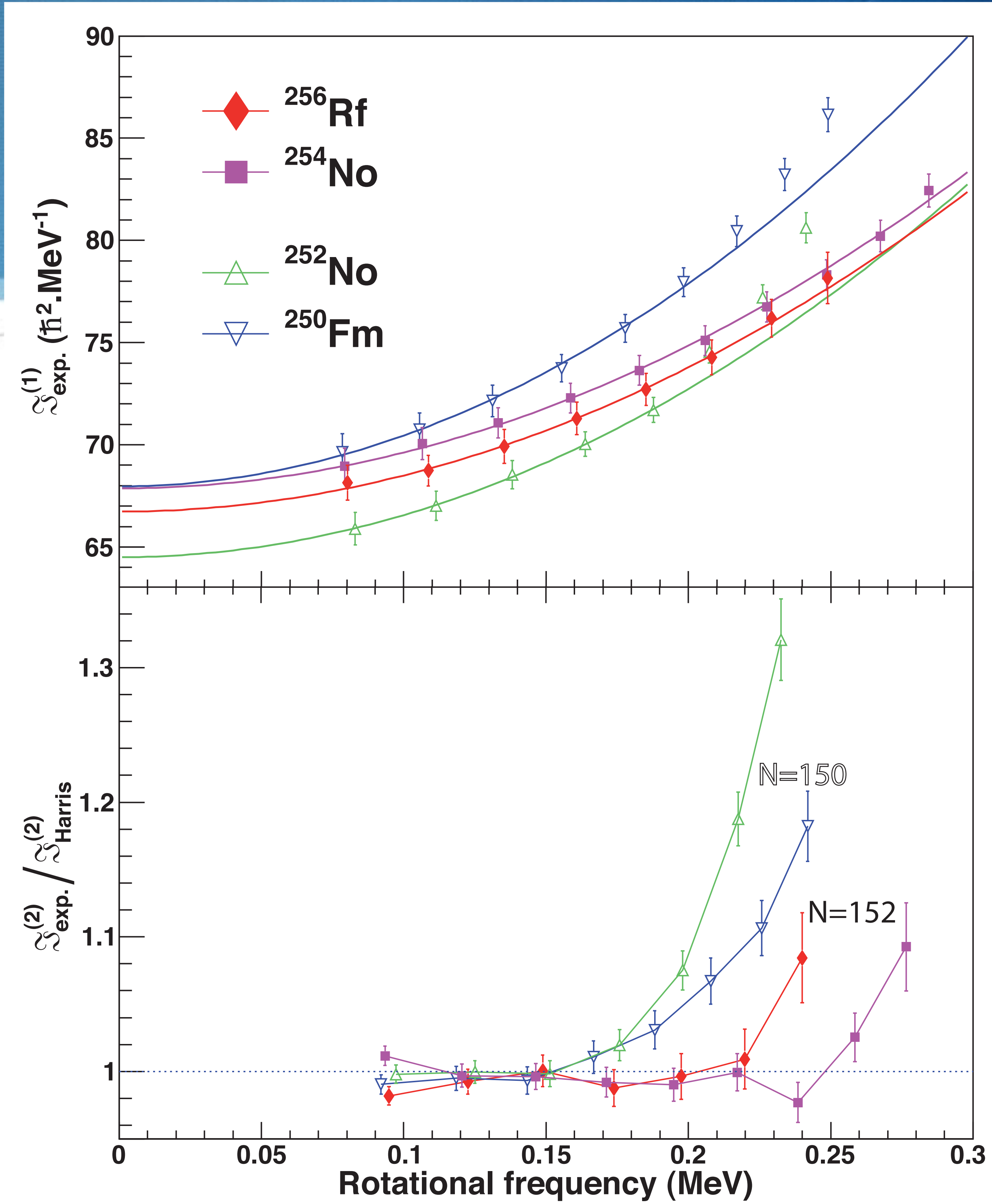


$$I = \mathfrak{I}_0.\omega + \mathfrak{I}_1.\omega^3 + 1/2$$



Comparison in transfermia region

	Z	N
^{256}Rf	104	152
^{254}No	102	152
^{252}No	102	150
^{250}Fm	100	150



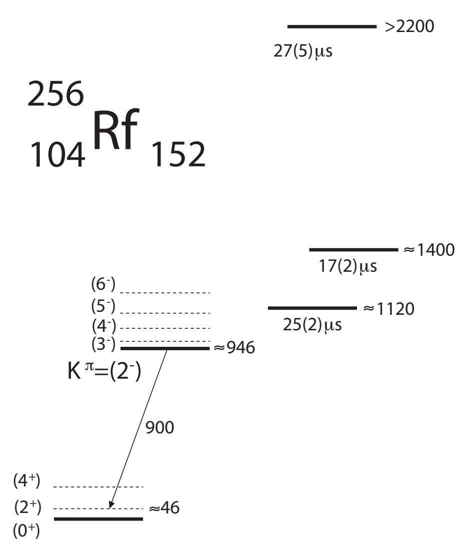
=> in agreement with gaps @ N=152 and Z=100

=> suggest no significant shell gap @ Z=104

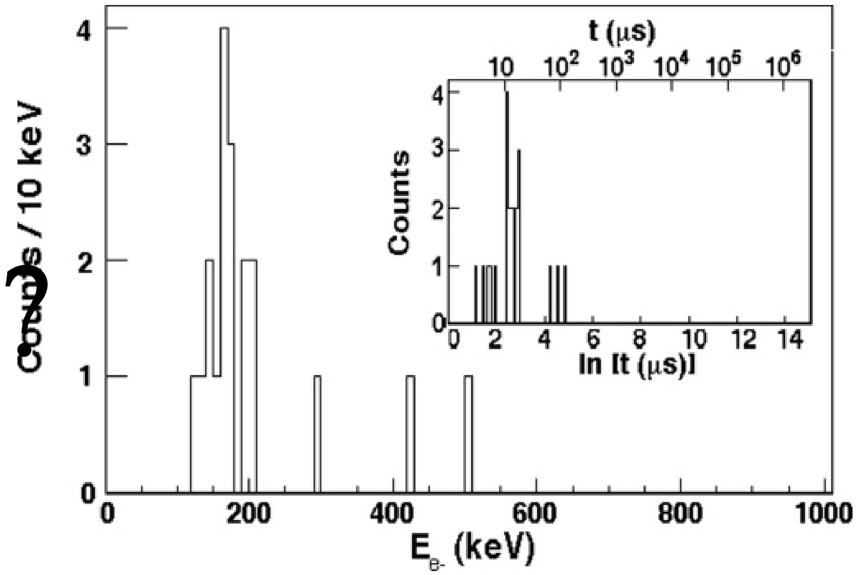
P.T. Greenlees, J. Rubert, J. Piot et al.
PRL **109** 012501 (2012)

Conclusion & Outlook

- A rotational band in 256Rf has been observed
- The data does not support the Z = 104 gap
- There is evidence for isomeric states …



What next ?



H.B. Jeppesen et al. PRC 79, 031303(R) (2009)

A.P. Robinson et al. PRC 83, 064311 (2011)

Where do we go now ?

- How do we improve these measurements ?

Conversion electrons, Higher selectivity, Better tagging

- What observable can we look for ?

I, Q0, μ, S2n, Mass

- Which nuclei can we access ?

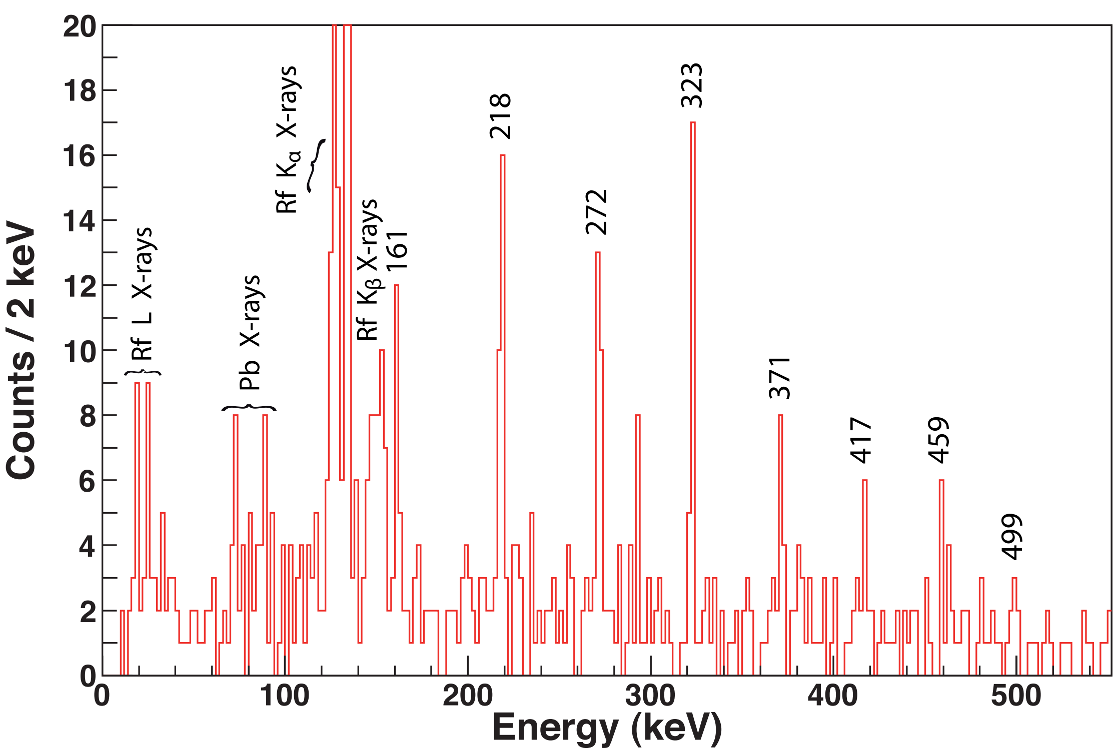
Up to Z=115, more neutron rich

Prompt Spectroscopy of Rf isotopes with AGATA & VAMOS

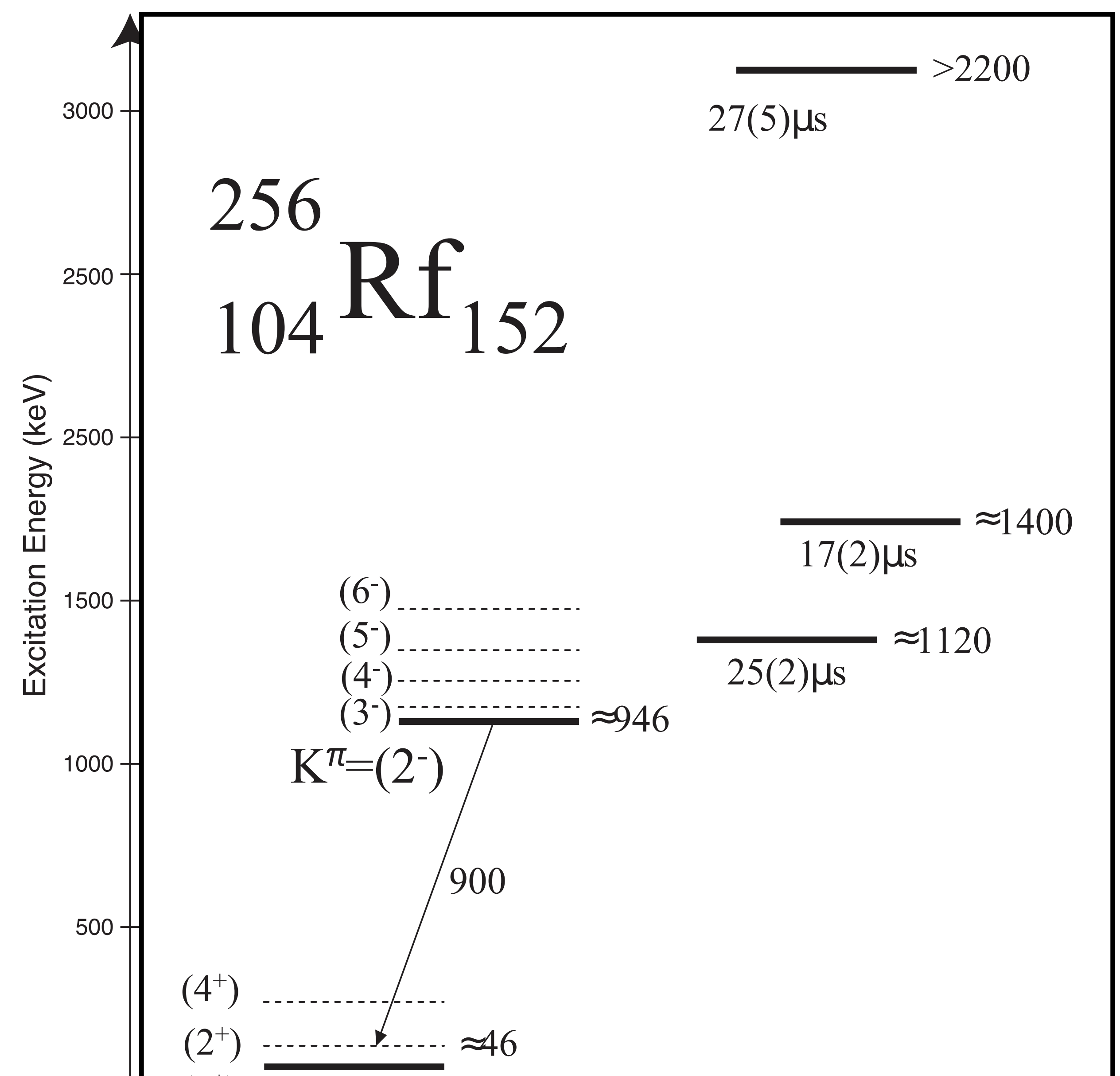
- Look for prompt excited states in isomeric bands and ground state bands in Rf isotopes
- Consolidate Level schemes for $^{256,257}Rf$
- Search isomeric levels in $^{254,255}Rf$

Spectroscopy of ^{256}Rf

- Rotational band observed
- Evidence for 3 K-isomer



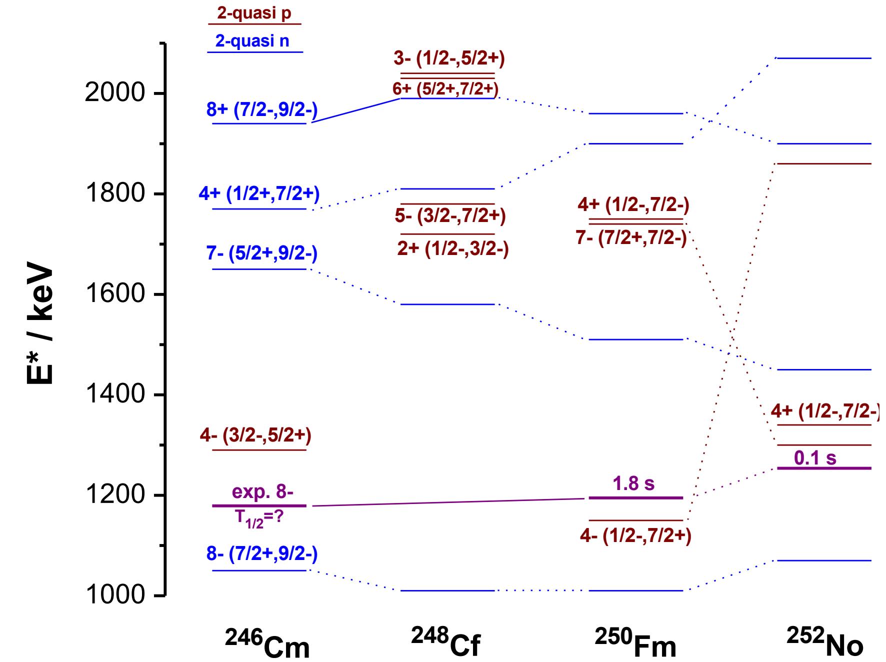
P.T. Greenlees et al., PRC 109 (2012) 012501



H.B. Jeppessen et al., PRC 79 (2009) 031303

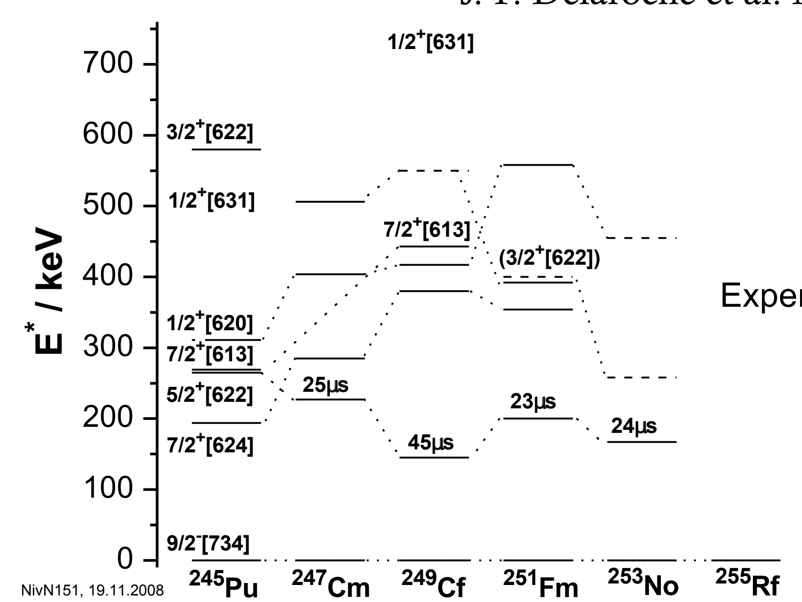
Spectroscopy of ^{254,255}Rf

- Other N=150 and 151 nuclei show isomers
- Do they exist in ^{254,255}Rf ?
- Is there collective excitation in these nuclei ?



N = 150

J.-P. Delaroche et al. NPA 771 (2006) 103

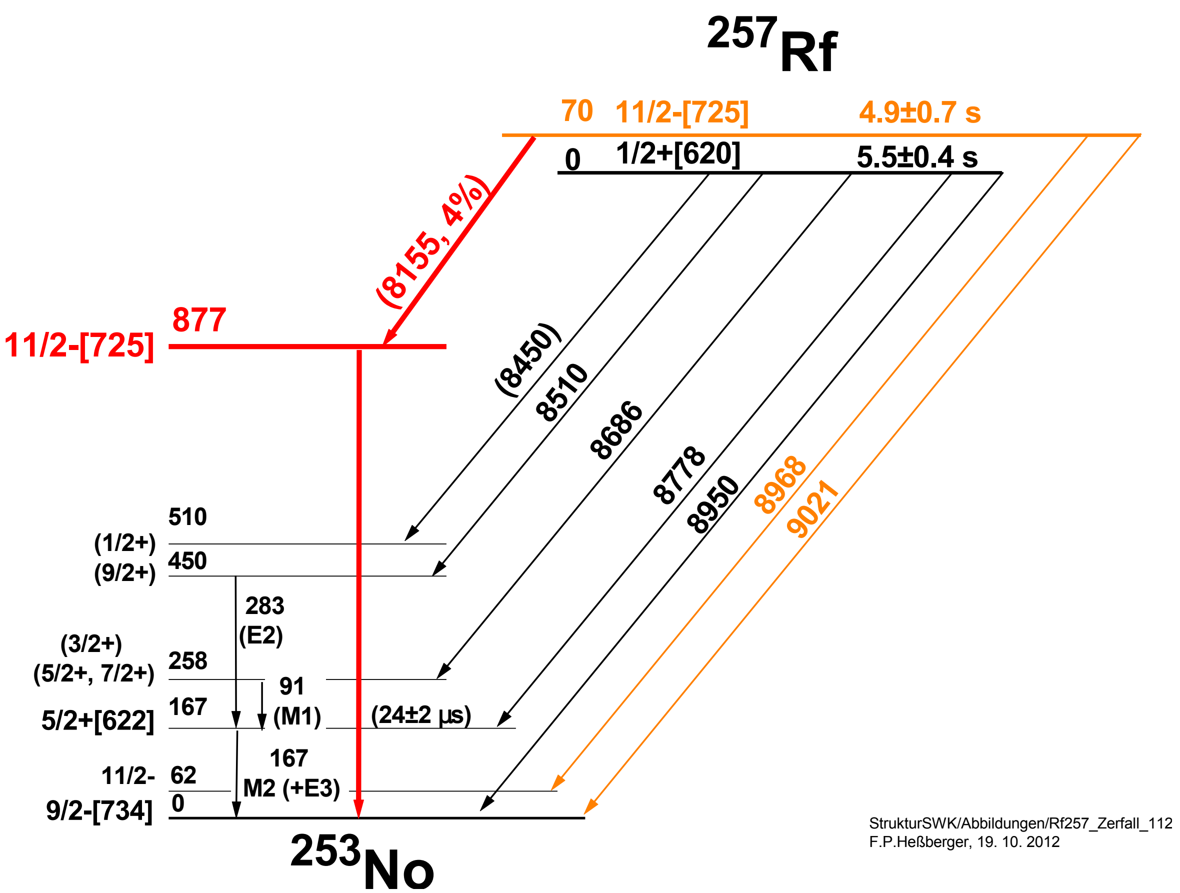


Experiment N = 151

A. Parkhomenko et al. APPB 36 (2005) 3115

Spectroscopy of ^{257}Rf

- Evidence for 11/2- isomeric state
- Are there others K-isomers ?
- How does the ground state band behave ?



B. Streicher et al. EPJA 45 (2010) 275

Experimental Setup

- Fusion-evaporation ^{50}Ti on ^{206,207,208}Pb
- AGATA + EXOGAM in pulled configuration
- VAMOS in gas-filled mode
- MUSETT modified for isomer tagging
- Beam intensity up to 100 pnA if possible (more likely 70 pnA)
- Rotating target for cooling + Gas cooling if differential pumping is available

Production

	b_{SF}	b_{α}	γ-Recoil for 21 UT	σ (nb)
$^{208}Pb(^{50}Ti,2n)^{256}Rf$	99.7%	0.3%	27000	17
$^{206}Pb(^{50}Ti,2n)^{254}Rf$	100%	-	3811	2.4
$^{207}Pb(^{50}Ti,2n)^{255}Rf$	48%	52%	20700	12
$^{208}Pb(^{50}Ti,n)^{257}Rf$	-	100%	14850	10

2 weeks of beam time at 100 pnA for each nucleus

Physics for VHE-SHE with S^3

- Improve data in the transactinide region
- Decay spectroscopy up to Z=115
- Access I, Q0 and μ through LASER spectroscopy
- Accurate Masses and Separation energies through Penning traps measurements
- Further ?