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# Gamma spectroscopy in the fermium region at SHIP


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# Collaboration

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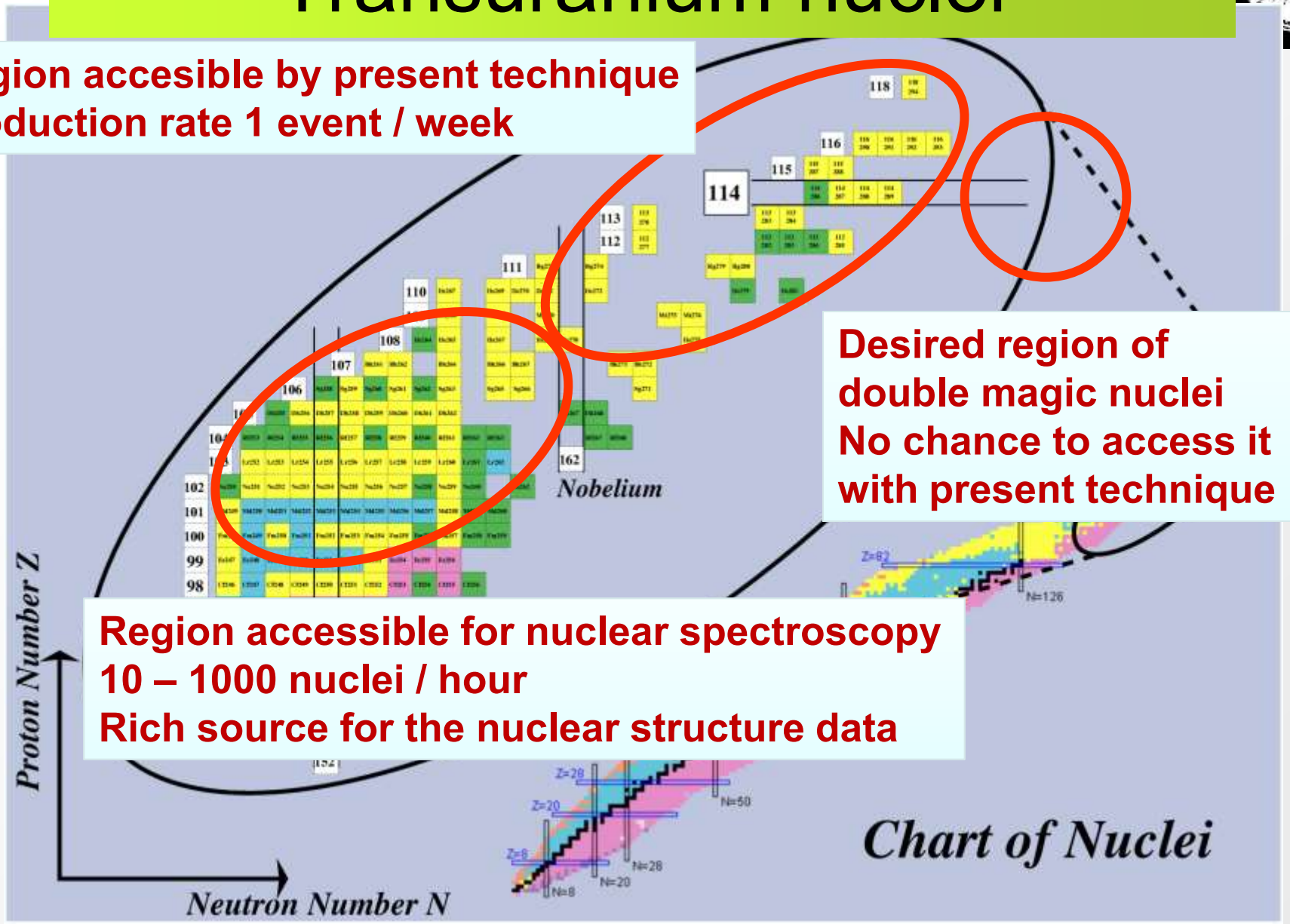
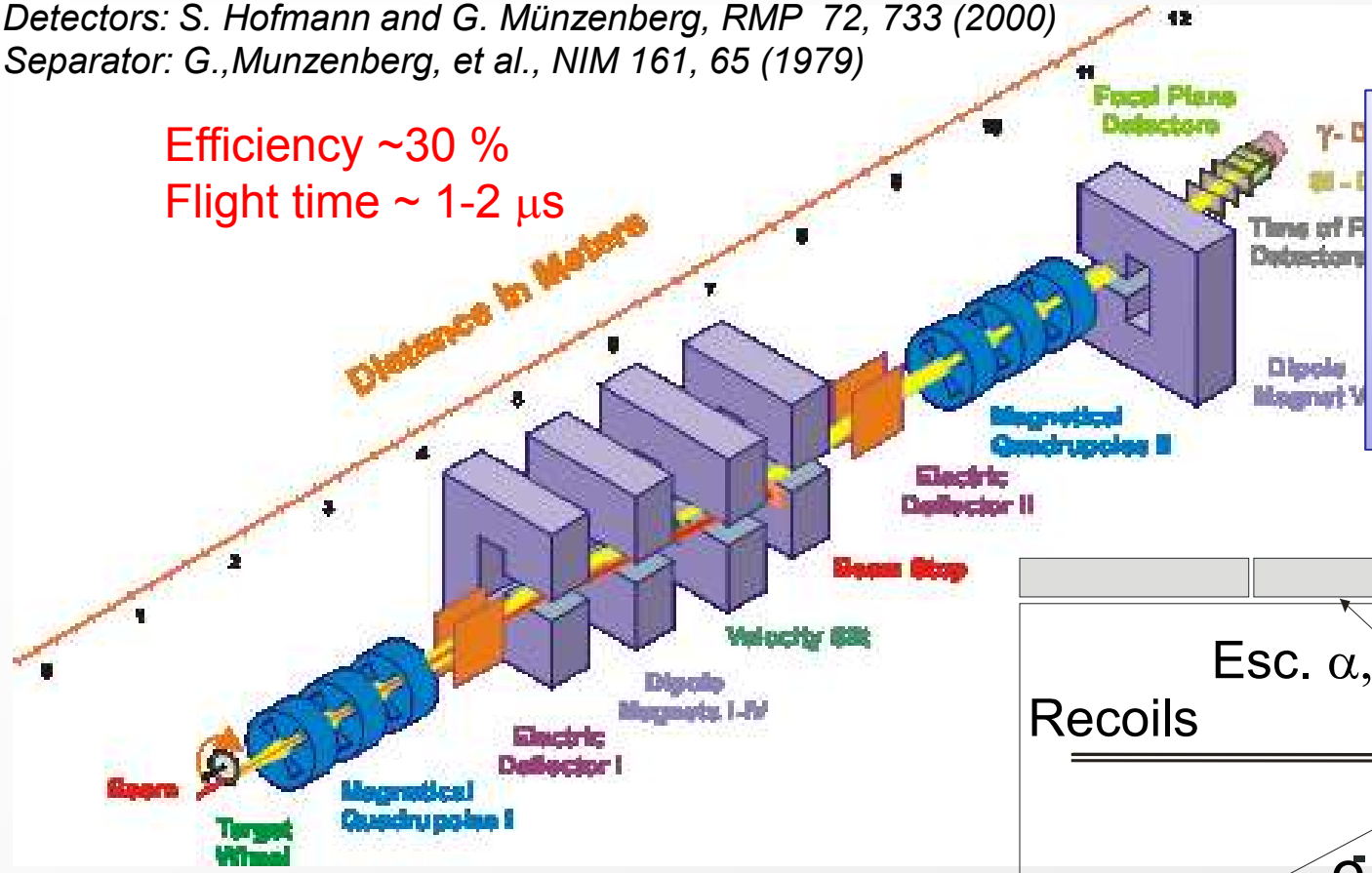
# Transuranium nuclei



# SHIP separator

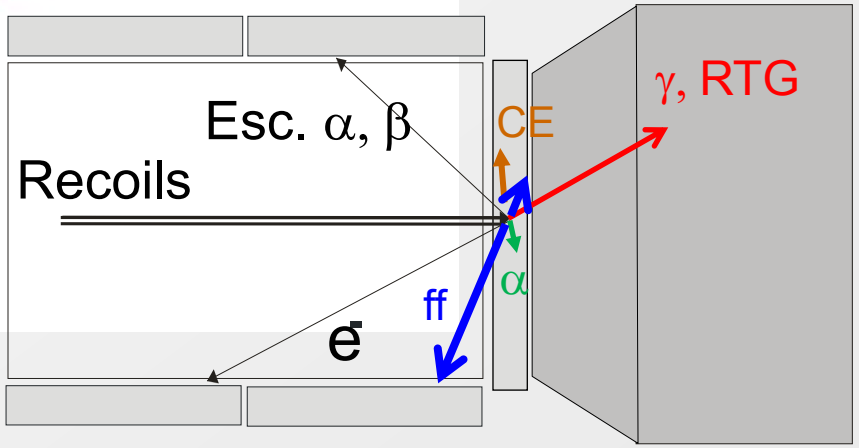
*Detectors: S. Hofmann and G. Münzenberg, RMP 72, 733 (2000)*
*Separator: G.,Munzenberg, et al., NIM 161, 65 (1979)*

Efficiency ~30 %
Flight time ~ 1-2 μs




+ high intensity beam
+ reliable setup
+ low background

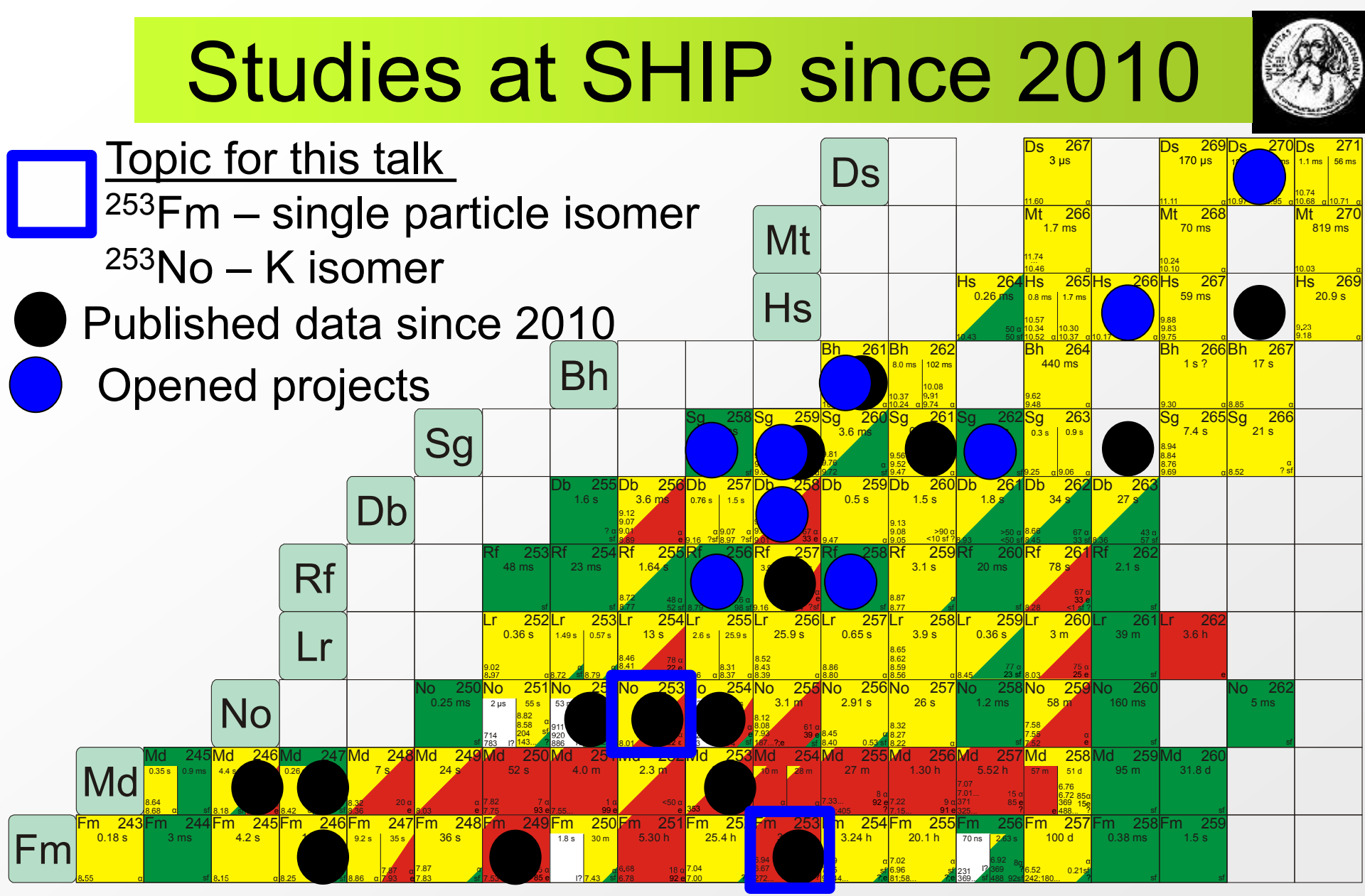
- Low granularity
- Lack of beamtime




$^{48}Ca$ ~ 1200 pnA

$Bi_2O_3$, PbS target – 400 μg/cm$^2$
Rotating wheel – 31 cm diameter
*B. Kindler et al. NIM A561,107 (2006)*

# Studies at SHIP since 2010

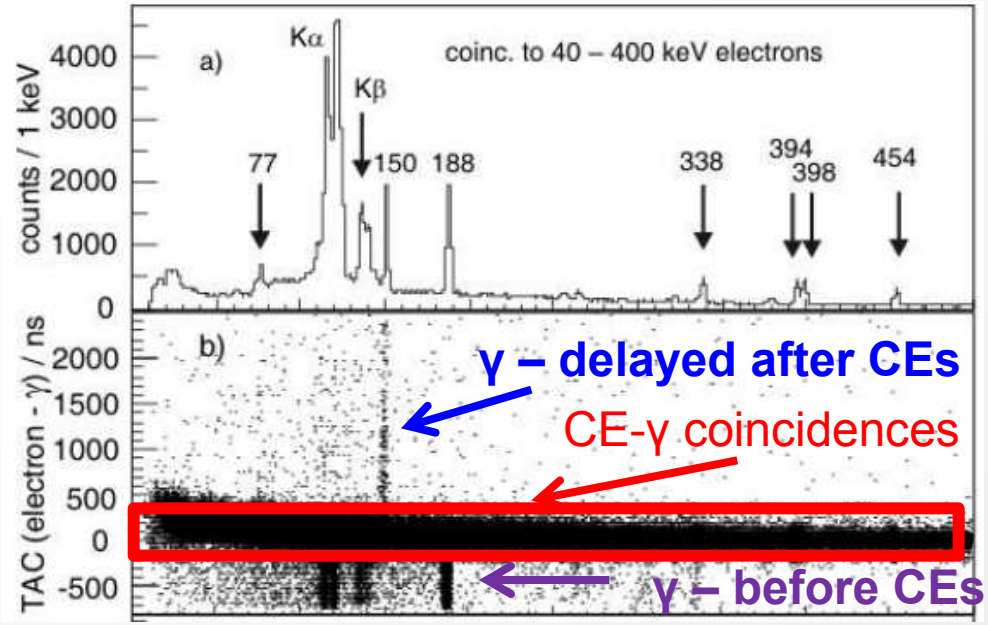


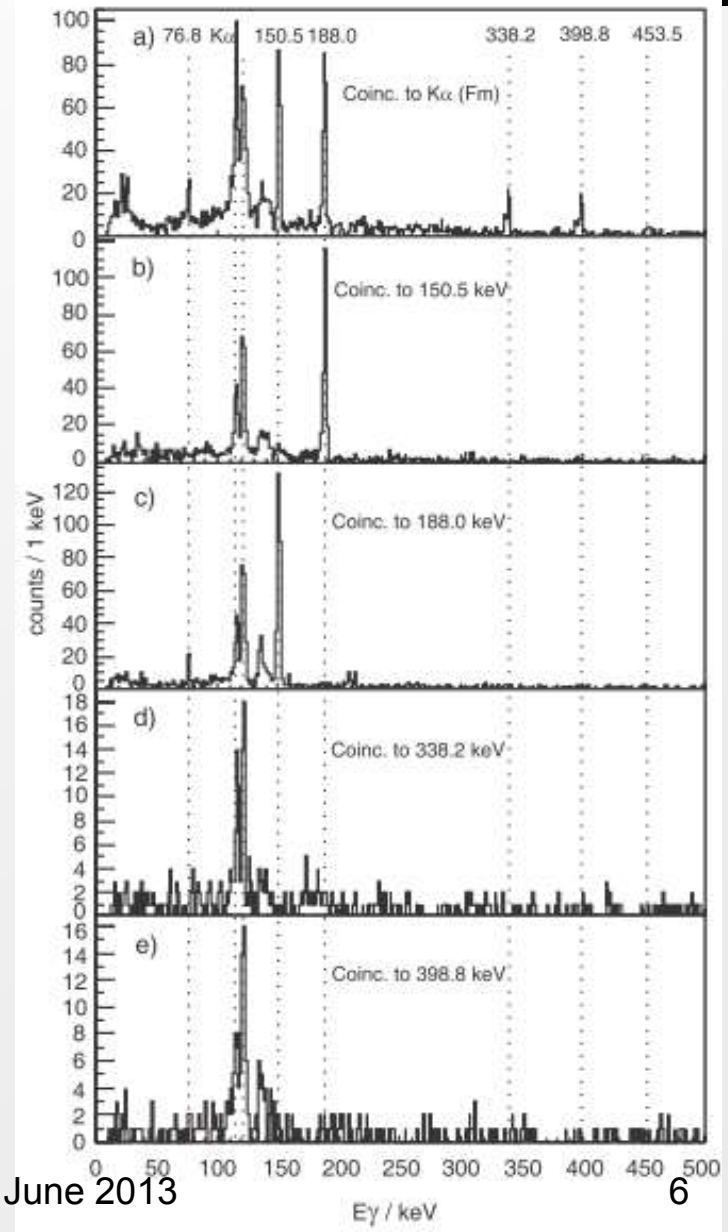
# $^{253}$Fm – single particle isomer

Applied reaction $^{48}$Ca+$^{207}$Pb → $^{253}$No + 2n
(1.8 x $10^6$ nuclei)

$^{253}$Fm Produced via 45% beta decay of $^{253}$No and beta decay of $^{253}$Md

Electron - γ coincidences

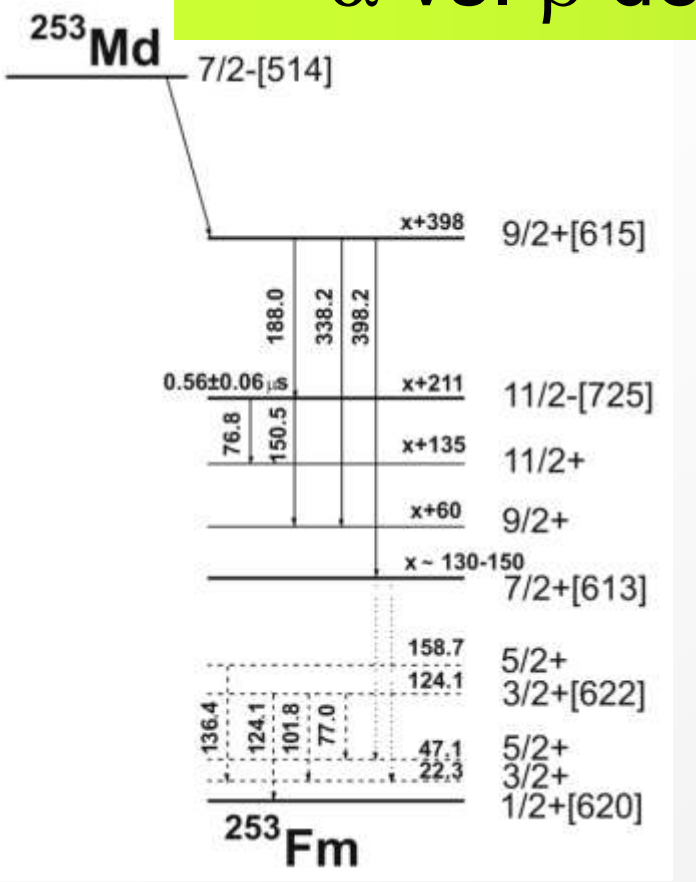



*S. Antalic et al. EPJ A47, 62 (2011)*

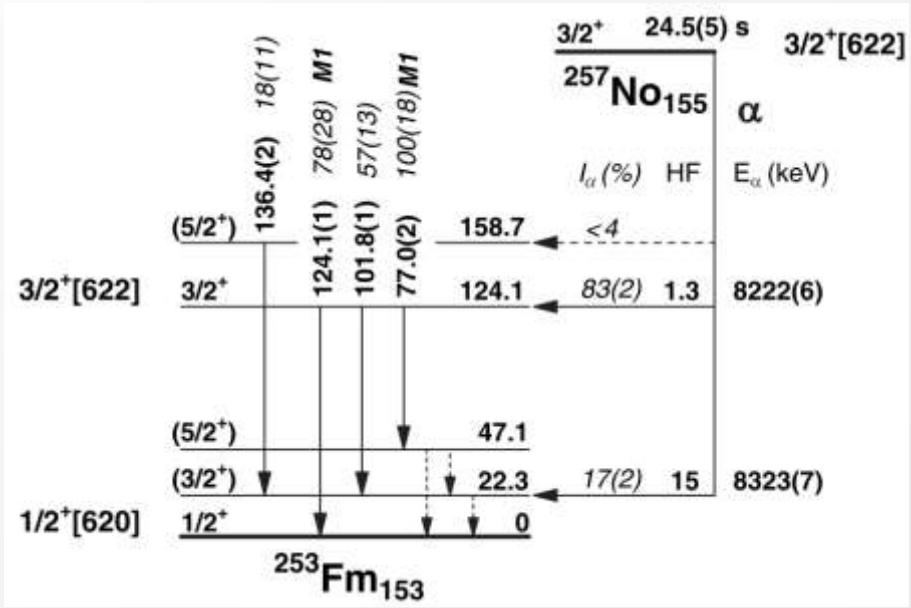
***First beta decay data in region Z>100***

# α vs. β decay production of $^{253}$Fm




S. Antalic et al. EPJ A47, 62 (2011)

$^{253}$Fm produced via α decay of $^{257}$No at JAERI

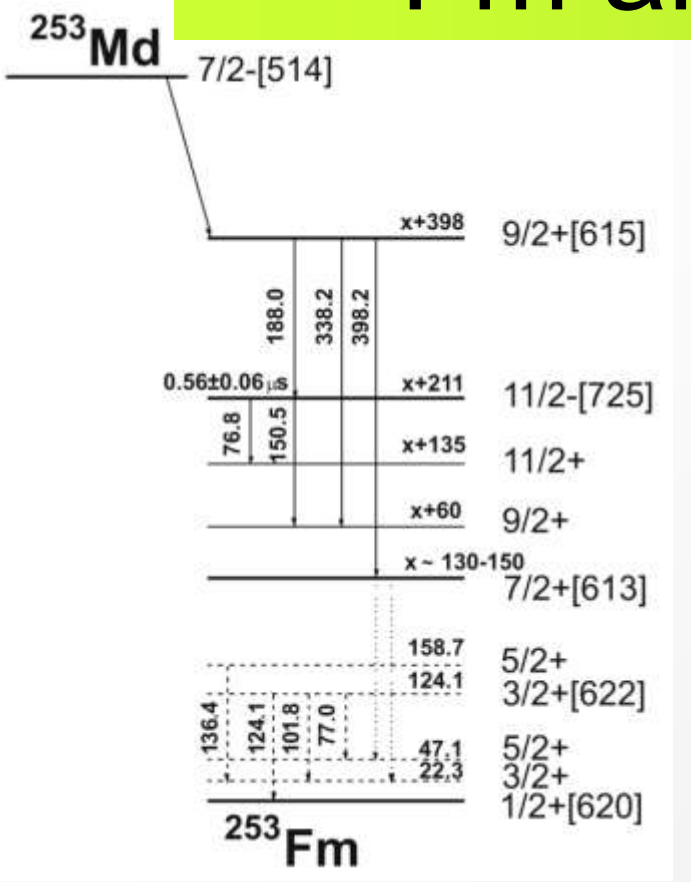



M. Asai et al. PRL 95, 102502 (2005)

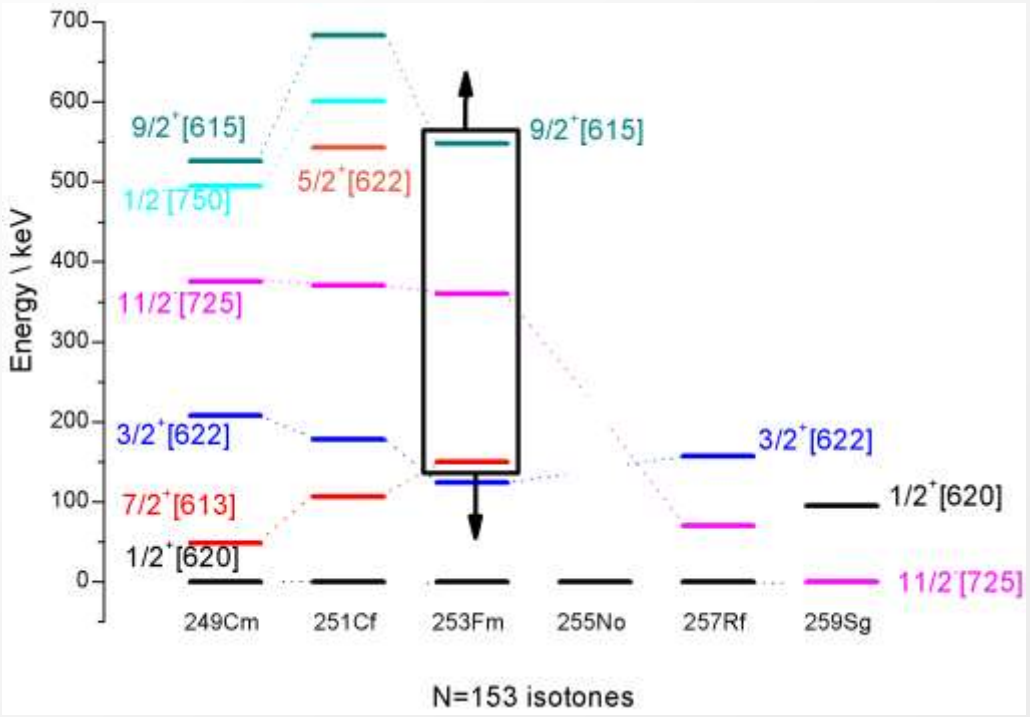
How is isomer connected to g.s.?

Opened problem:
How to connect upper part populated by beta decay of $^{253}$Md, with the lower part populated by $^{257}$No alpha decay *[M. Asai et al., PRL 95, 102502 (2005)]*?

# $^{253}$Fm and N=153 isotones




S. Antalic et al. EPJ A47, 62 (2011)

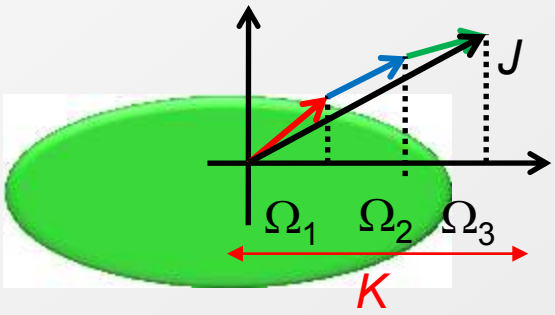



How is isomer connected to g.s.?

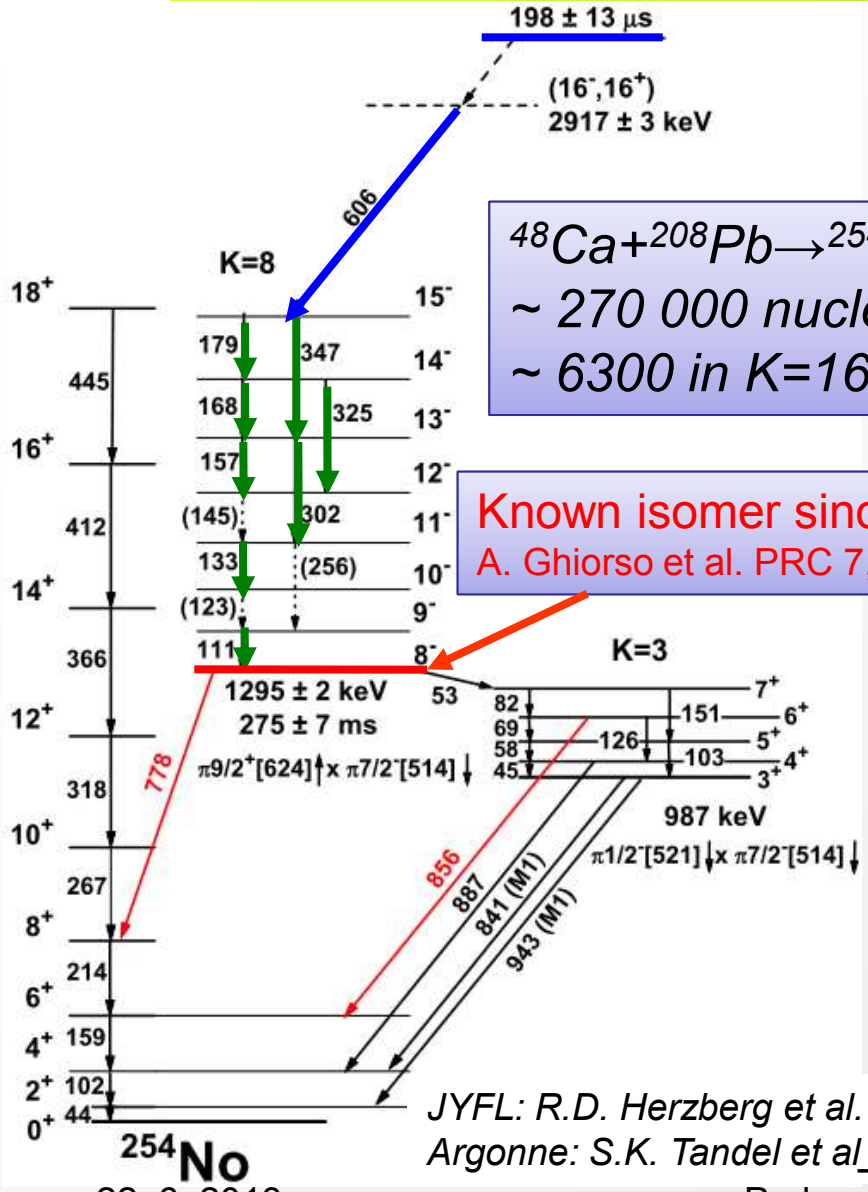
Opened problem:
How to connect upper part populated by beta decay of $^{253}$Md, with the lower part populated by $^{257}$No alpha decay *[M. Asai et al., PRL 95, 102502 (2005)]*?

# K isomers

- Multi-quasiparticle states are located typically above 1 MeV. Very complex decay schemes
- Rich source of data on the structure (chance to populate many low lying levels)
- K-isomers might have additional hindrance against radioactive decay and might play a important role for enhanced stability of superheavy nuclei.
  In some cases lifetime of the isomer exceeds the g.s. lifetime. (see e.g. $^{270}$Ds or $^{250}$No.)
  *[experiment: S. Hofmann et al., Eur. Phys. J. A 10, 5 (2001) and* D. Peterson et al., (2006). Phys. Rev. C74 014316*]*



# $^{254}$No – complex decay scheme




$^{48}Ca+^{208}Pb \rightarrow ^{254}No+2n$

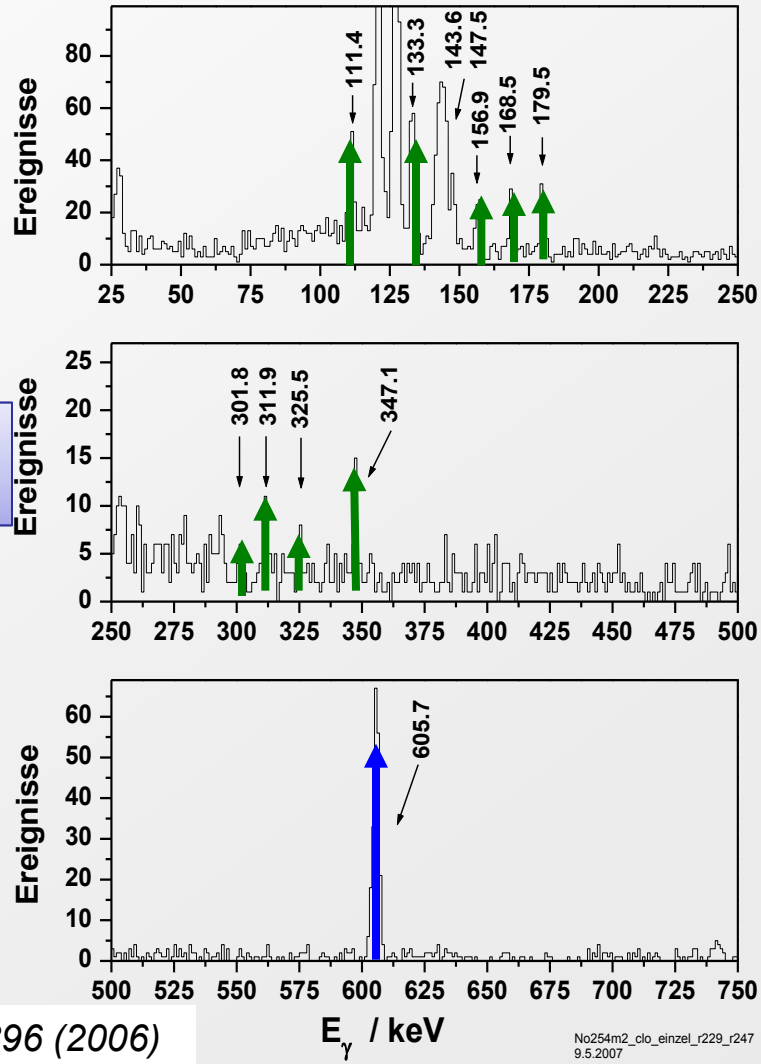
~ 270 000 nuclei

~ 6300 in K=16 isomer

Known isomer since 1973

A. Ghiorso et al. PRC 7, 2032 (1973)

*F.P. Hessberger et al., EPJ A43, 55 (2010)*



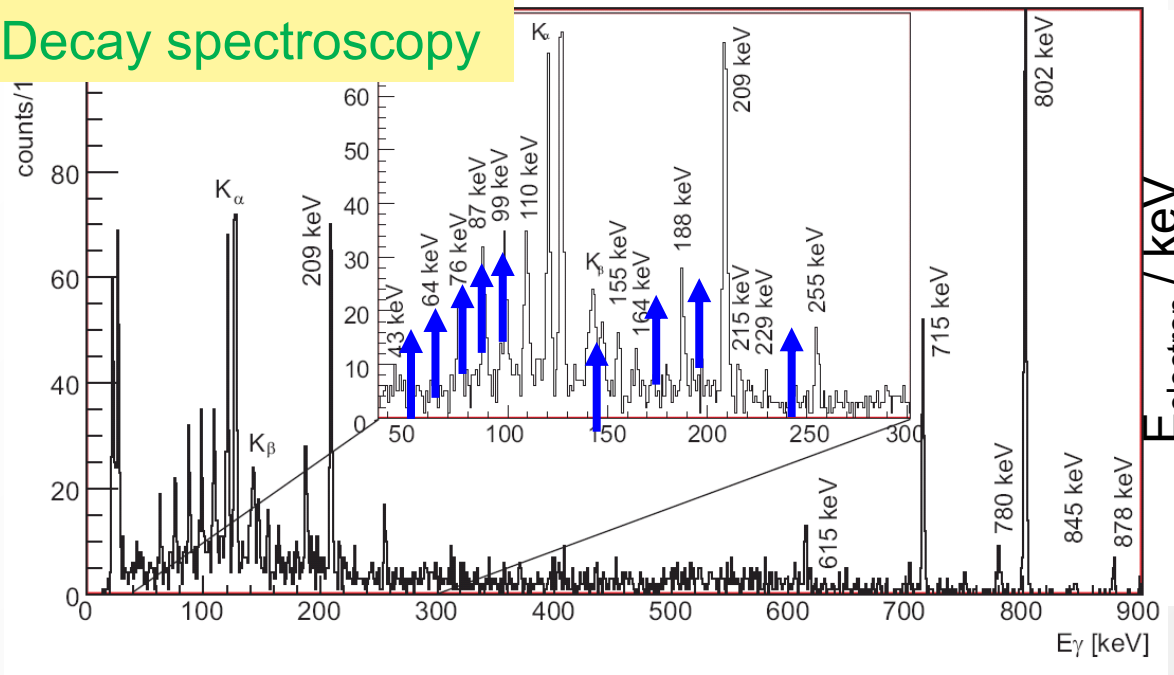

*JYFL: R.D. Herzberg et al. Nature 442, 896 (2006)*

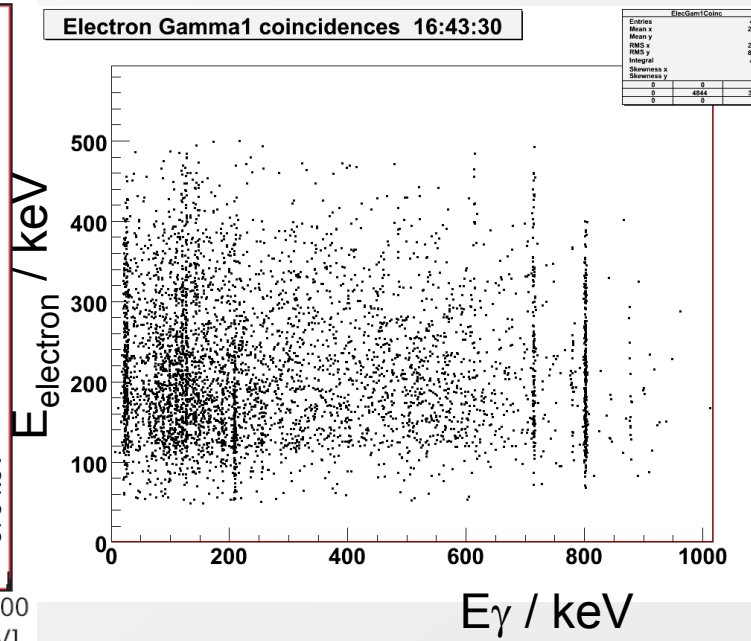
*Argonne: S.K. Tandel et al_PRL97, 082502 (2006)*

# $^{253}$No –K isomer

Back to the $^{48}$Ca+$^{207}$Pb → $^{253}$No + 2n

Decay spectroscopy




*S. Antalic et al. EPJ A47, 62 (2011)*

*F.P. Hessberger , Phys. At. Nucl. 70, 1445 (2007)*

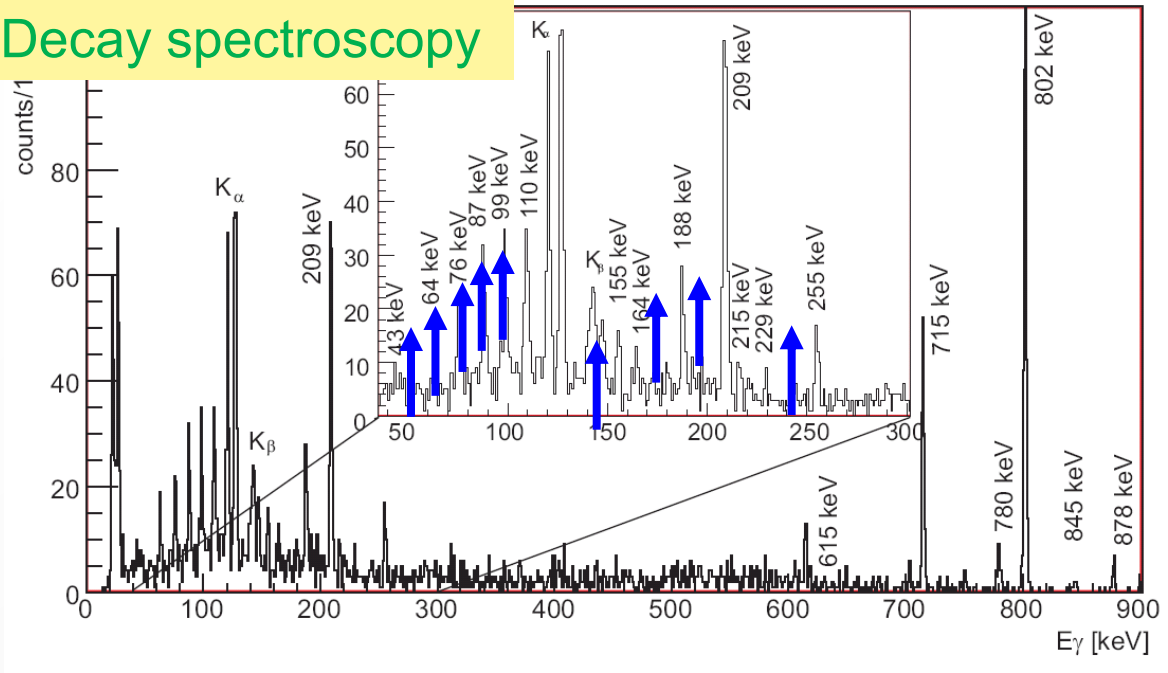
Crucial requirement: We need low background to see low-energy electron- γ coincidences!

# $^{253}$No

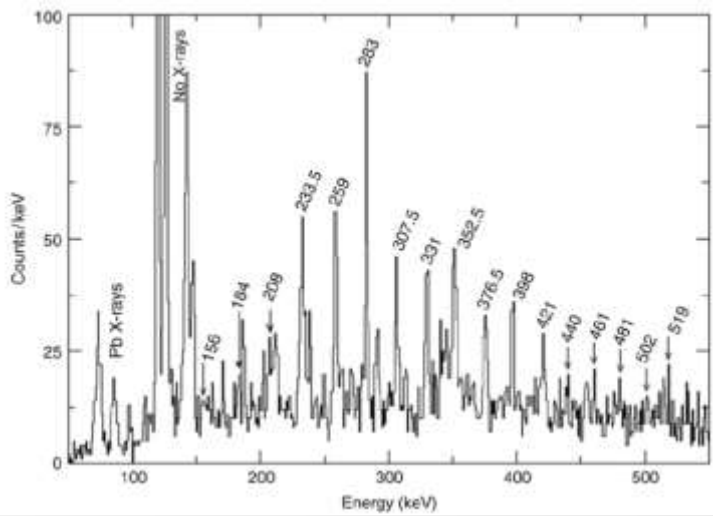
Produced in rection $^{48}Ca+^{207}Pb \rightarrow {}^{253}No + 2n$ (1.8 x $10^6$ nuclei)

Delayed $e^-$-$\gamma$ coincidences showed the presence of second isomer with many $\gamma$ lines

## Decay spectroscopy




## In-beam spectroscopy




*S. Antalic et al. EPJ A47, 62 (2011)*

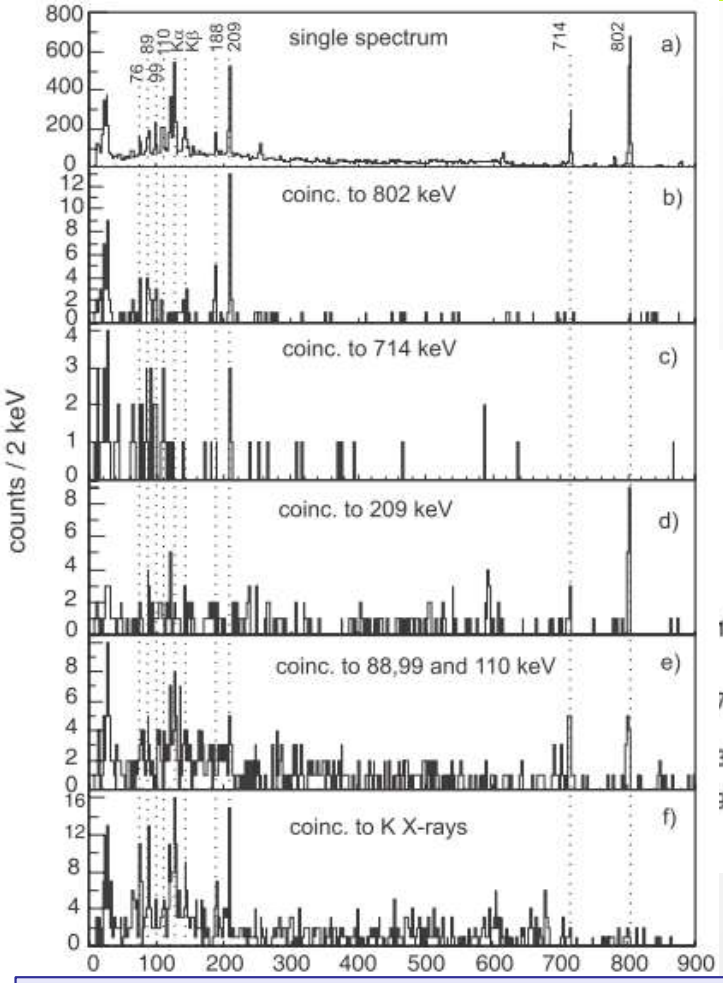
*F.P. Hessberger , Phys. At. Nucl. 70, 1445 (2007)*

*9/2-[734]: R.D. Herzberg et al., EPJ A42, 333 (2009)*

*7/2+[624]: P. Reiter. et al, PRL 95, 032501 (2005) 032501*

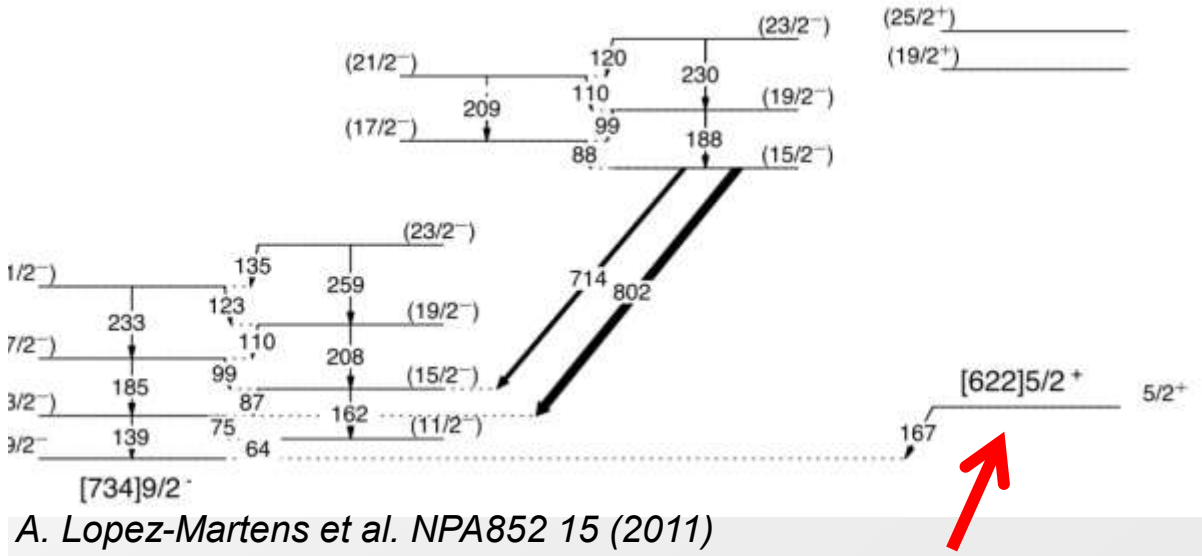
Isomer helped to detect rotational band
and provide independent information about its assignment.

# Possible decay scheme




Suggested decay scheme from VASSILISSA@JINR Dubna

Multi-quasi particle isomer




*A. Lopez-Martens et al. NPA852 15 (2011)*

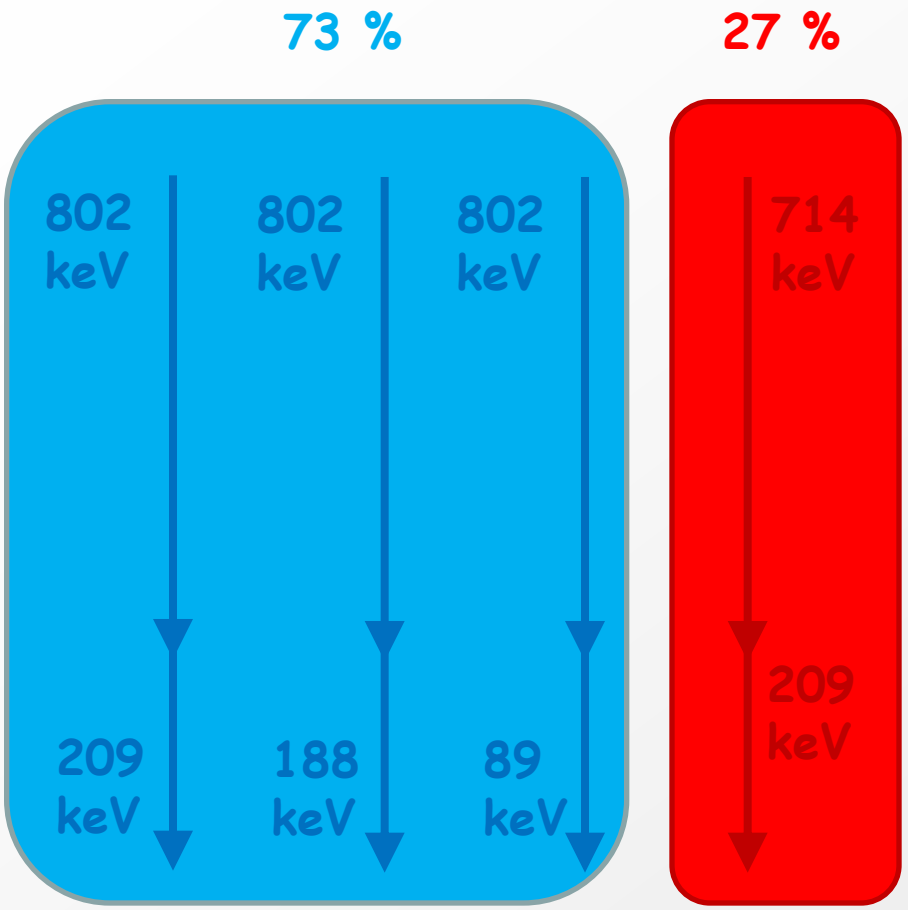
Single-particle isomer

Opened problem:
Despite of high statistics (1.8 x $10^6$ nuclei) very weak $\gamma$- $\gamma$ coincidences.

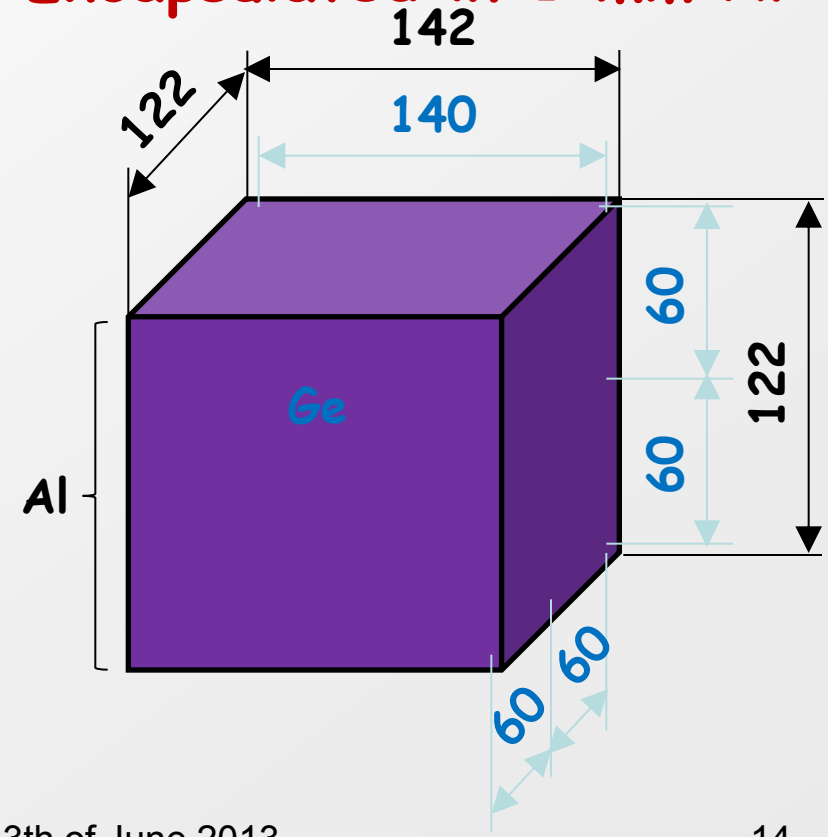
To confirm the decay scheme, more detailed $\gamma$ spectroscopy data are necessary.

# Geant simulations for present setup

## How important is the detector granularity?

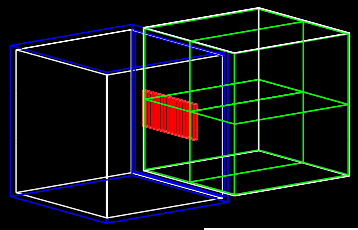



**Germanium clover:**
**60 x 60 x 140 mm**
**Encapsulated in 1 mm Al**

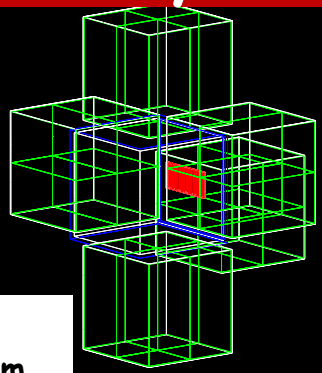


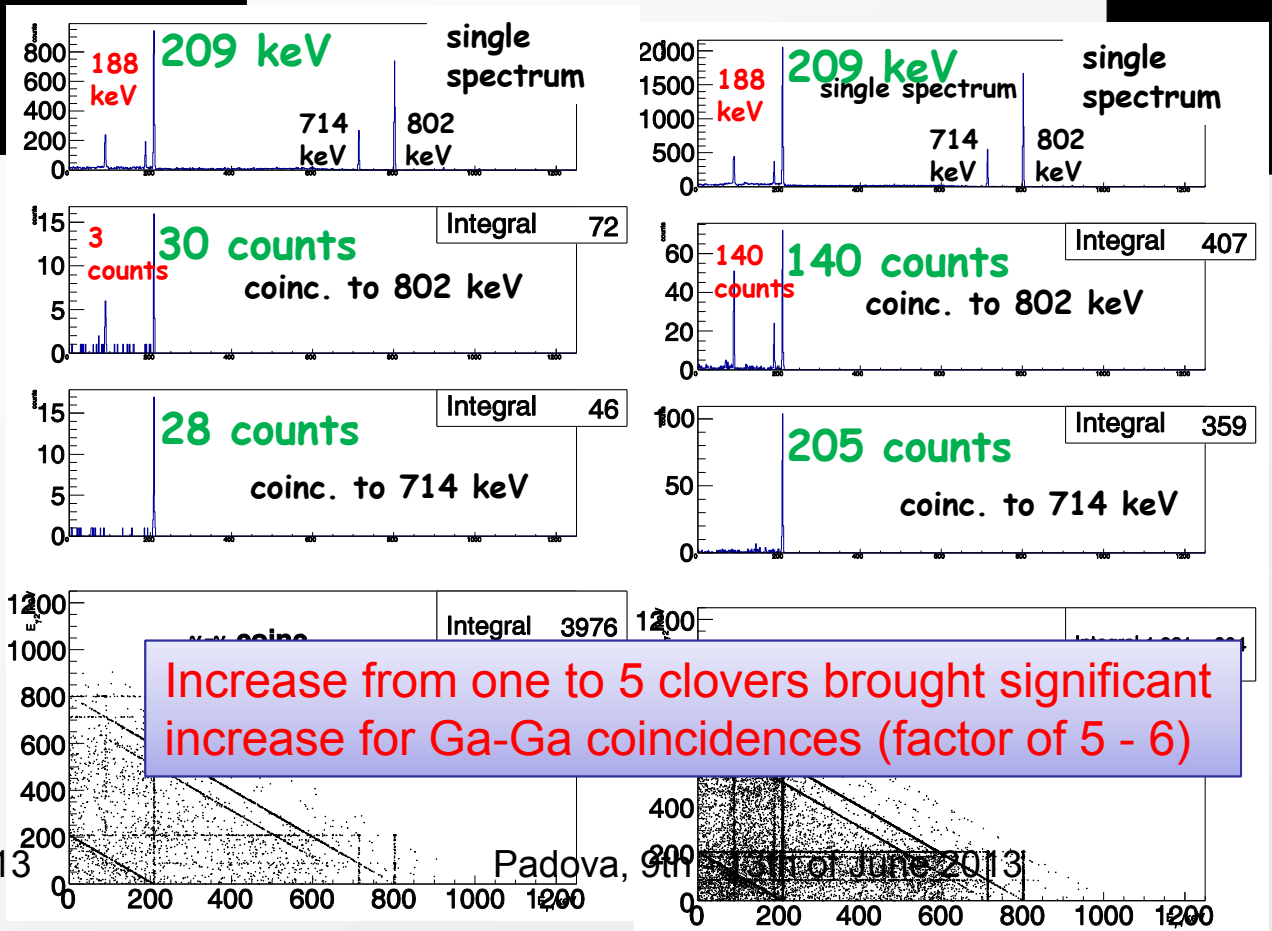
# GEANT simulation (40 000 events)

## 4 crystals



## 20 crystals






Increase from one to 5 clovers brought significant increase for Ga-Ga coincidences (factor of 5 - 6)

# Conclusion

- Interesting new data are on the way (see examples $^{253}$No and $^{253}$Fm)
- Present limit for $\gamma$ spectroscopy is Sg (Z = 106), however already for Rf (Z = 104) its challenging.
- Requirements for these measurements:
  - High intense beam (1 p$\mu$A and more)
  - low background (low energy electrons and gammas delayed after ER implantation)
  - high-sensitivity $\gamma$ detectors (granularity is critical)
- Still lot of work is waiting for us and we need to do many small steps to understand superheavy elements!

# Thank you