Studies of K isomers in Trans-fermium Nuclei Near the N=152 Subshell Closure

- Introduction & motivation
  - ✓ brief introduction of the trans-fermium region & K-isomers
- Results from recent experiments with emphasis on ^{254}Rf at Argonne & Berkeley using the implant-decay technique & a new digital DAQ
- Conclusions

CPC(HEP & NP), 2012, **36**(12): 1603–2014 **Chinese Physics C** Vol. 36, No. 12, Dec., 2012

The AME2012 atomic mass evaluation *

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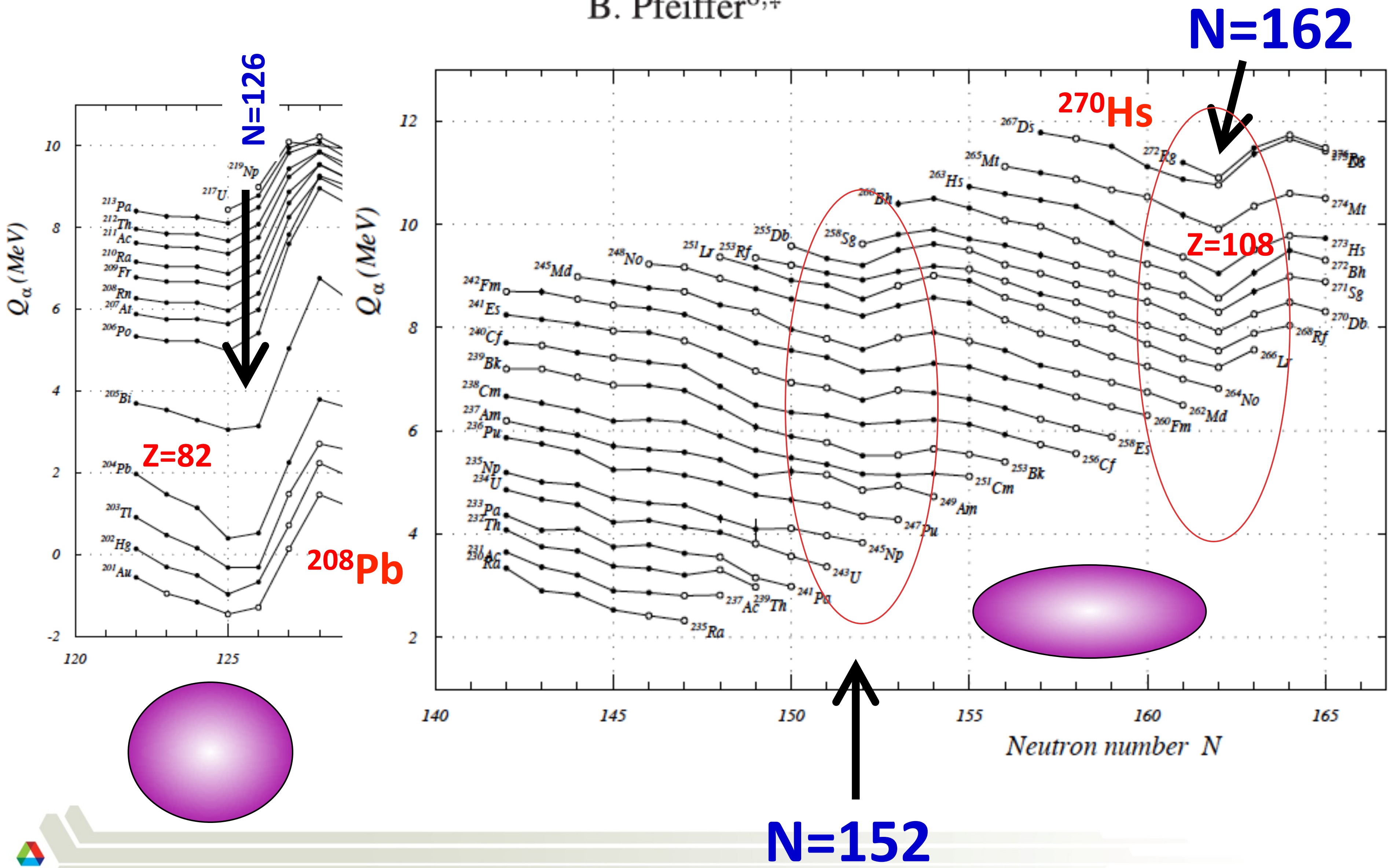
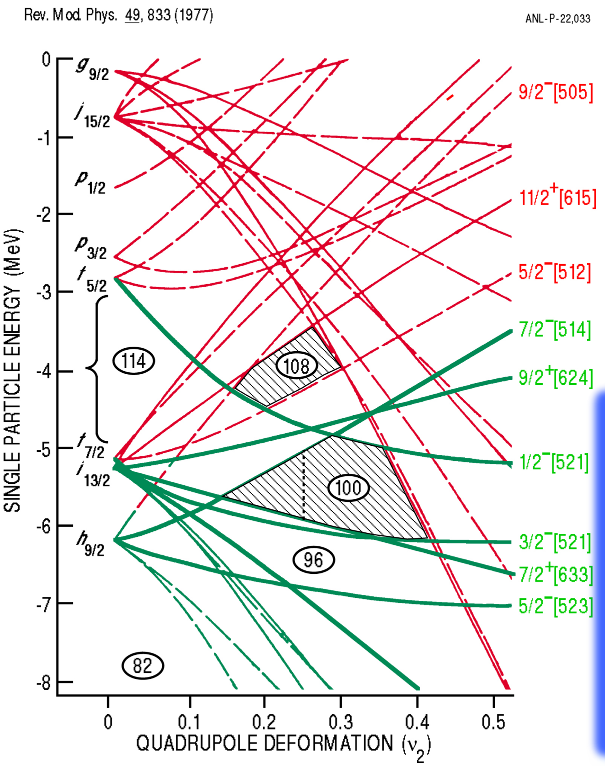
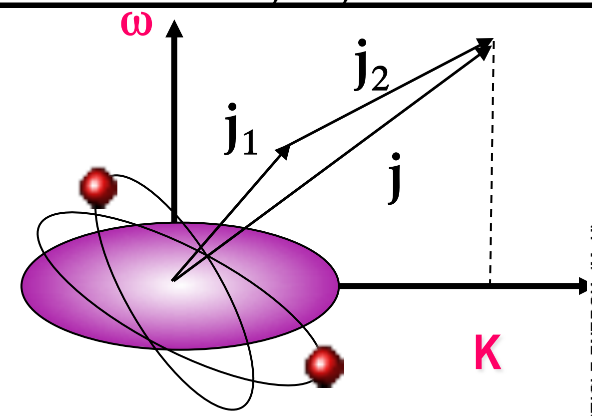
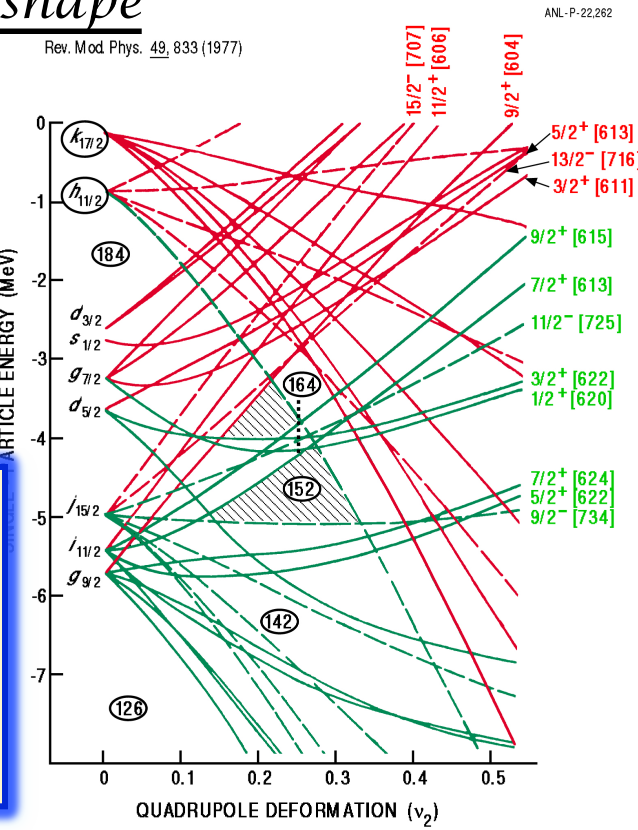


K Isomers & Trans-fermium region

Well-deformed nuclei with axially-symmetric shape







single-particle structure & subshell closures

collective properties, pairing and residual nucleon-nucleon interactions

High-K orbitals near the Fermi surface

N=150-152: ν 7/2[624], 9/2[734] – K^{π}=8-

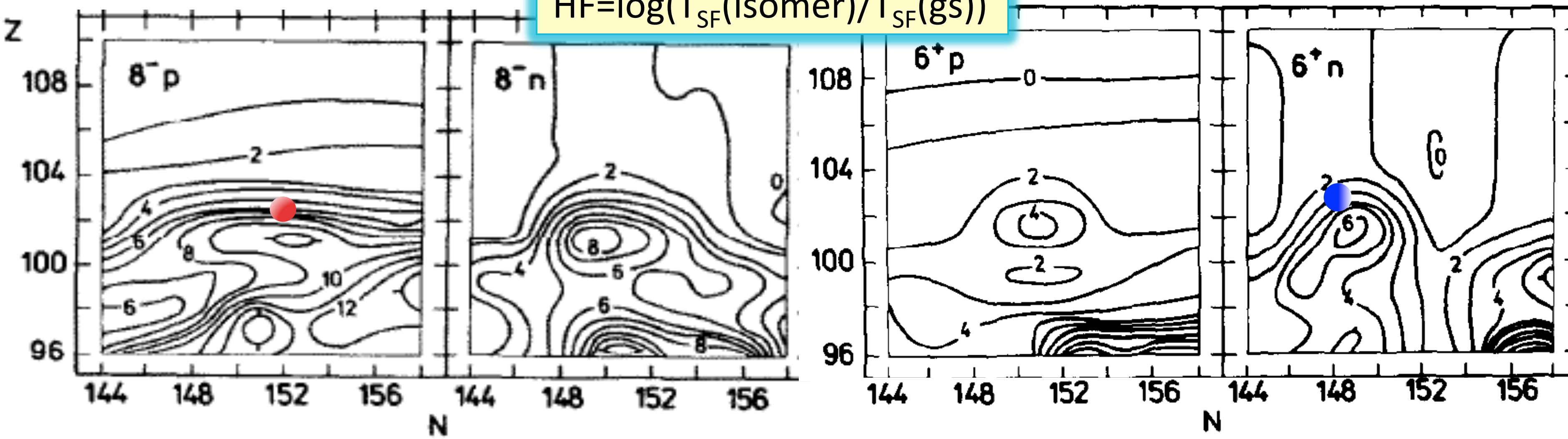
Z=100-104: π 7/2[514],9/2[624] – K^{π}=8-

competing 2-qp (8-) and a favored 4-qp (16+) states

K-Isomers and enhanced stability of SHE?

HF=log(T_{SF}(isomer)/T_{SF}(gs))

A. Baran, Z. Lojewski, NPA475 (1987) 327



HF$_{exp}$(^{254}No) = **-1.2** - > HF$_{th}$(^{254}No) ~ **+6**

F. Hessberger et al., Eur. Phys. A43 (2012) 55.

HF$_{exp}$(^{250}No) = **+1** - > HF$_{th}$(^{250}No) ~ **+3**

D. Peterson et al., Phys. Rev. C74 (2006) 014316.

Is the fission process inhibited in K-Isomers decays? – one needs $T_{1/2}$(SF) for IS

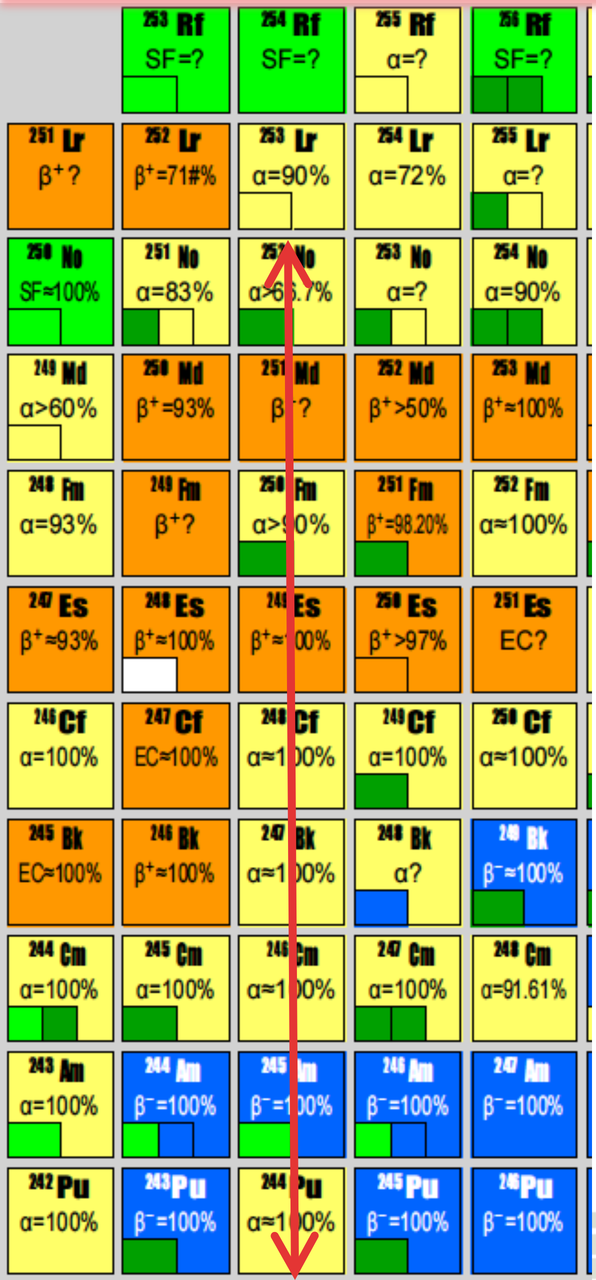
✓ simplified PES calculations based on the macroscopic-microscopic method & WKB approximation for the barrier penetration: A. Baran & Z. Lojewski, Nucl. Phys. A 475 (1987) 327

✓ role played by γ deformation (K->K ±2 mixing) and reduced pairing (blocking) – can affect not only B_f (“specialization energy”), but also the effective mass: Y. Lazarev et al. Phys. Scr. 39 (1989) 422

Experimental data are very scarce:

only a handful of cases – ^{250}Fm, ^{256}Fm, ^{250}No and ^{254}No …

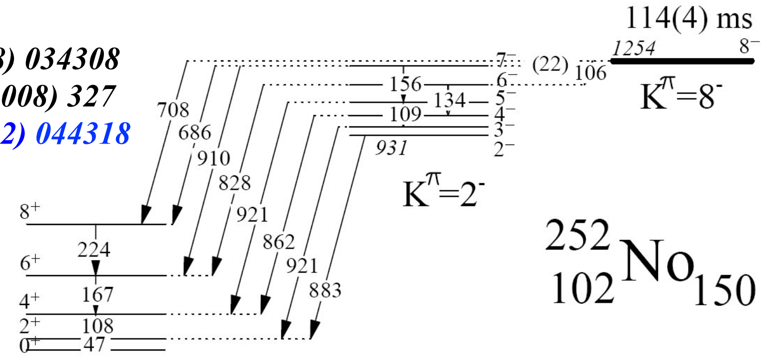
$\mathcal{N}$=150 Isotones
Z=94, 96, (98), 100 & 102



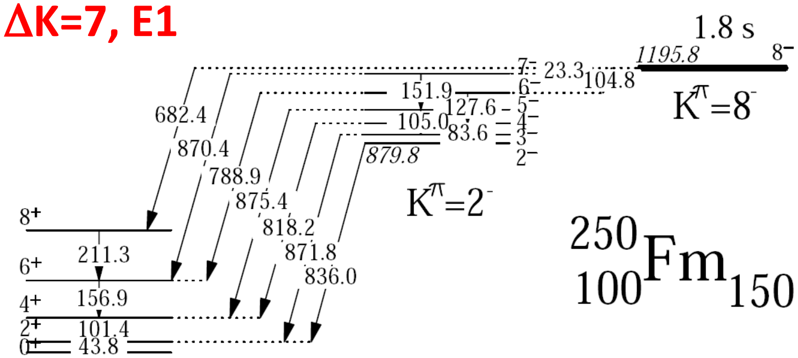
$K^{\pi}=8^{-}$, 2-qp state

ν^2(7/2+[624],9/2-[734])

A. Robinson et al., Phys. Rev. C78 (2008) 034308
B. Sulignano et al., Eur. Phys. J. A33 (2008) 327
B. Sulignano et al., Phys. Rev. C86 (2012) 044318

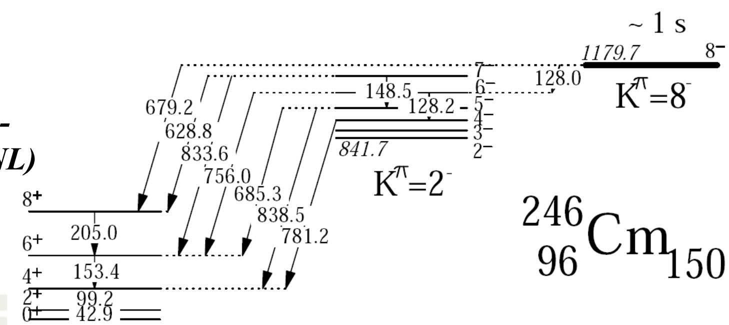


ΔK=7, E1

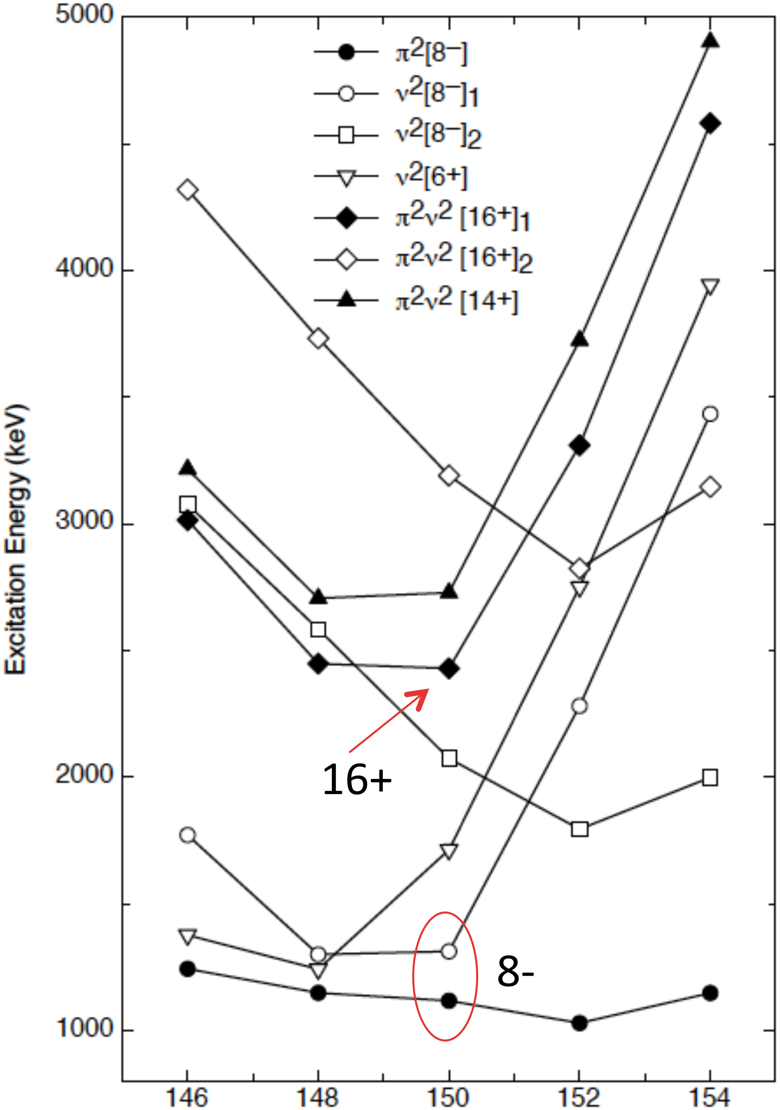


P.T. Greenlees et al., Phys. Rev. C78 (2008) 021303(R)

U. Tandel, U. Mass. Lowell, PhD Thesis -
(^{244}Pu target, MNT & pulsed beam @ ANL)



What about ^{254}Rf (N=150)?



F.G. Kondev et al., Int. Conf. Nuclear Data for Science & Technology, Nice, France, 2007;

http://dx.doi.org/10.1051/ndata:07775

- ground state decay mode: SF=100 %
- half-life:
  - ✓**29.6 (+0.7-0.6) μs** – I. Dragojevic et al. (2008) (LBNL)
  - ✓**23 (3) μs** - F. Hessberger et al. (1997) (GSI)
  - ✓**500 (200) μs** - G. Ter-Arkopyan et al. (1975) (JINR)

multi-quasiparticle calculations

- ✓ WS with "universal" parameterization
- ✓ Lipkin-Nogami pairing method – includes particle number conservation & blocking

N=150

- ✓ two competing **K^{π}=8$^-$**, 2-qp states:

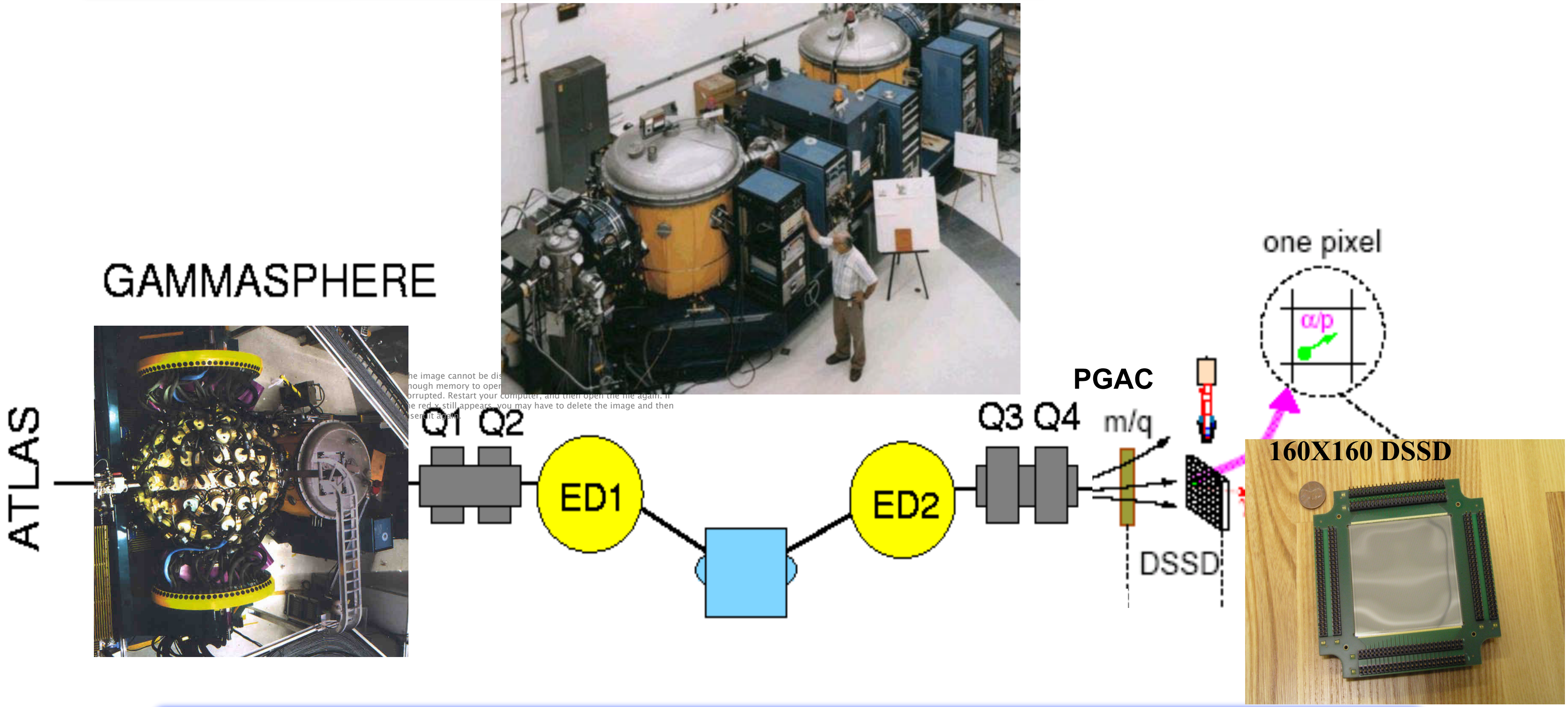
  $\nu^2 8_1^-$: ν^2(7/2[624],9/2[734])

  $\pi^2 8^-_2$: π^2(7/2[514],9/2[624])

- ✓ a favored **K^{π}=16$^+$**, 4-qp state:

  π^2(8-) x ν^2(8^-_1) – could be long-lived

FMA Experiment at ATLAS



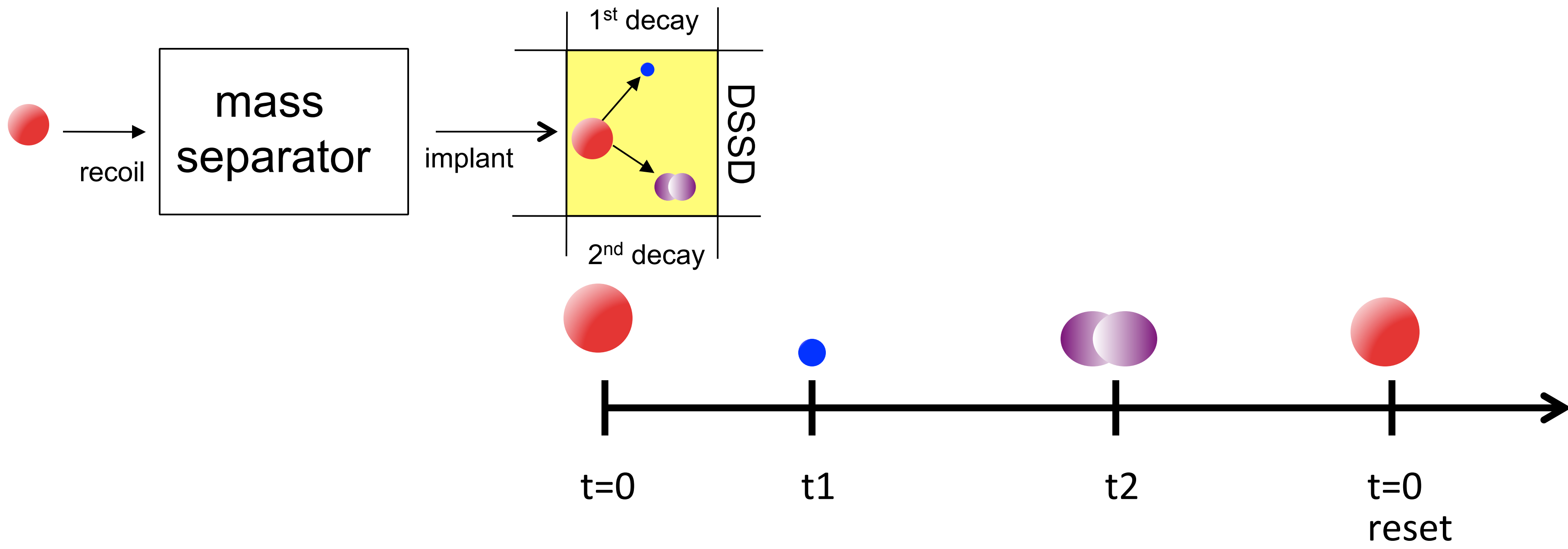
$^{50}Ti+^{206}Pb$ -> $^{254}Rf+2n$ @ 242.5 MeV

✓target: 500 μg/cm^2 on a rotating wheel, 98.93 (11)% enriched in ^{206}Pb (^{207}Pb=0.34 (1)% and ^{208}Pb=0.72 (12)%);

✓average (wobbled) beam current: ~150 pnA (over ~200 hrs)

✓production σ=2.4 (2) nb - F. Hessberger et al., Z. Phys. A359, 415 (1997)

Implant-decay correlation technique



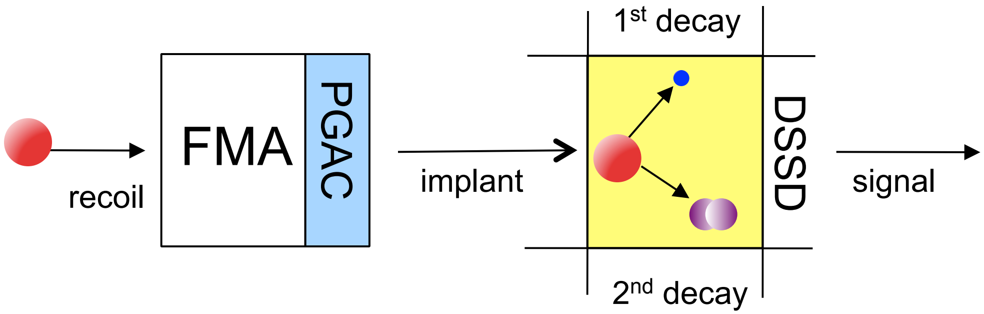
Correlations:

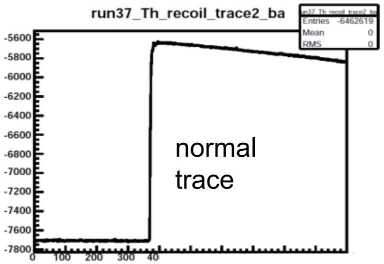
- ✓ spatial (within a single pixel)
- ✓ time (implant – decays)
- ✓ energy – e- (~1 MeV), α (~10 MeV), fission (150 MeV)

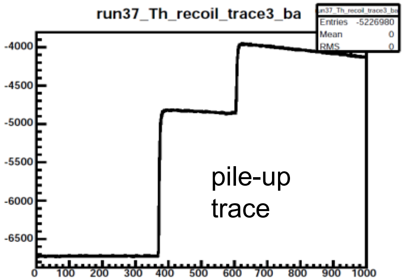
Limitations:

- ✓ long-lived cases – longer than 100's seconds

Implant-decay correlation technique

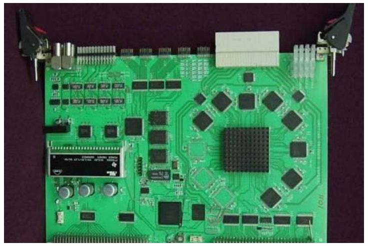






However, there are other limitations:

✓ short-lived case – shorter than ~ 20 μs



Trigger and Time control module

J.T. Anderson et al., 2007, IEEE Nuclear Science Symposium Conference Record, p. 1751

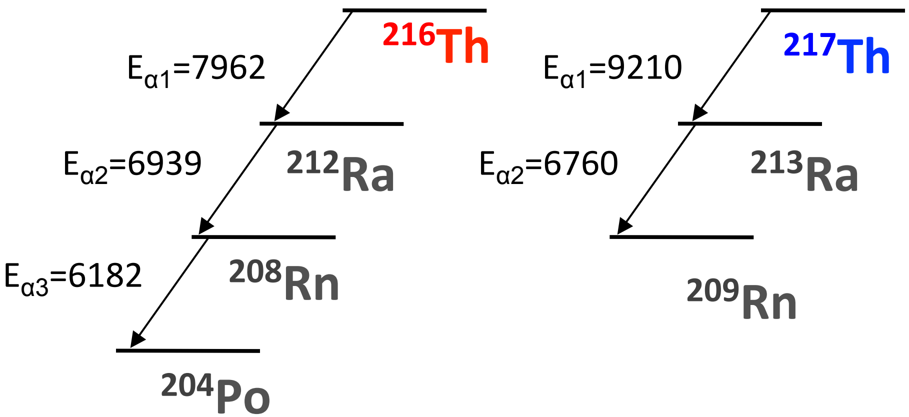
100MHz, 14-bit Digitizer

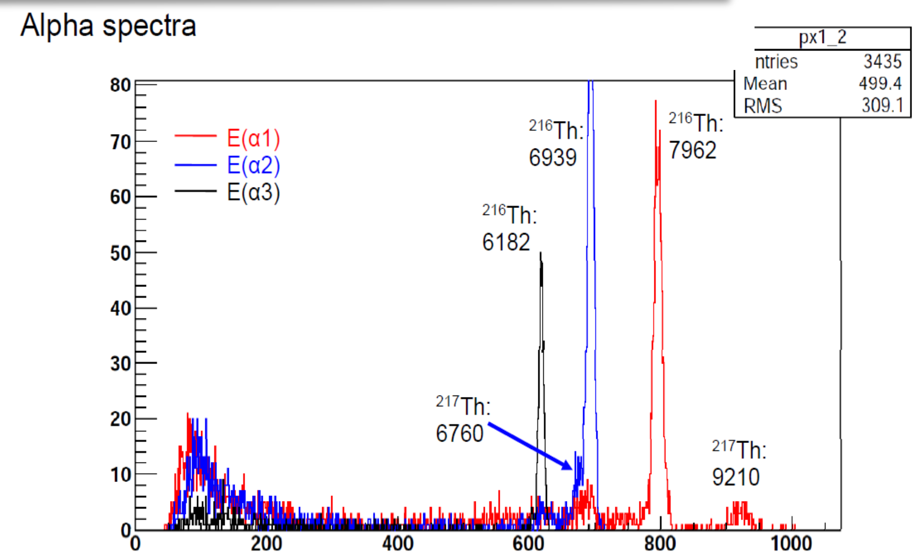
M. Cromaz et al., A 597 (2008) 233–237

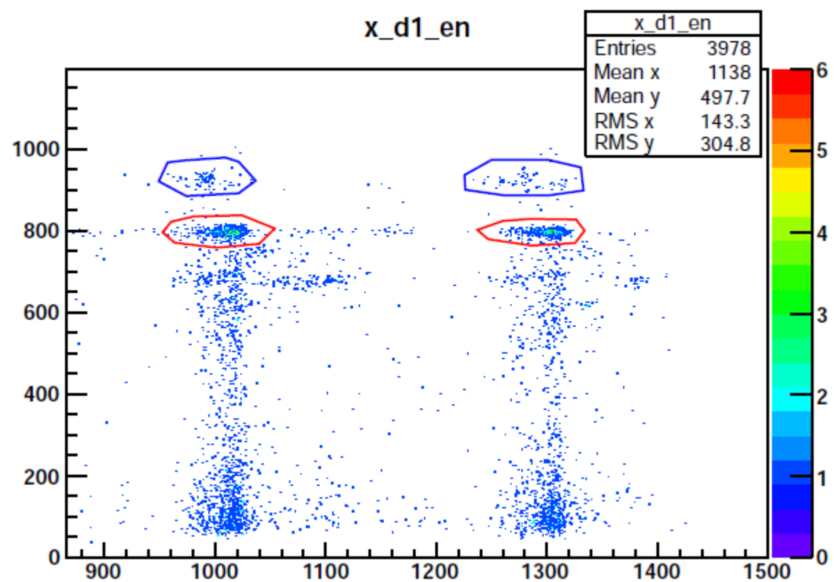
new (trigger-less) FMA digital DAQ

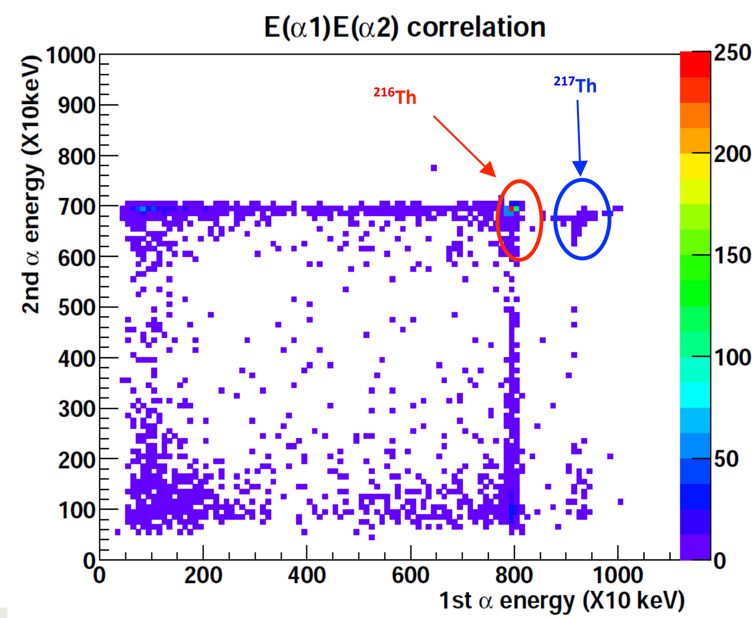
- ✓ developed in parallel with DGS
- ✓ based on GRETINA
- ✓ ~400 channels
- ✓ pulse shape analysis

Set-up experiment ^{50}Ti+^{170}Er ->^{216,217}Th + 4n(3n)



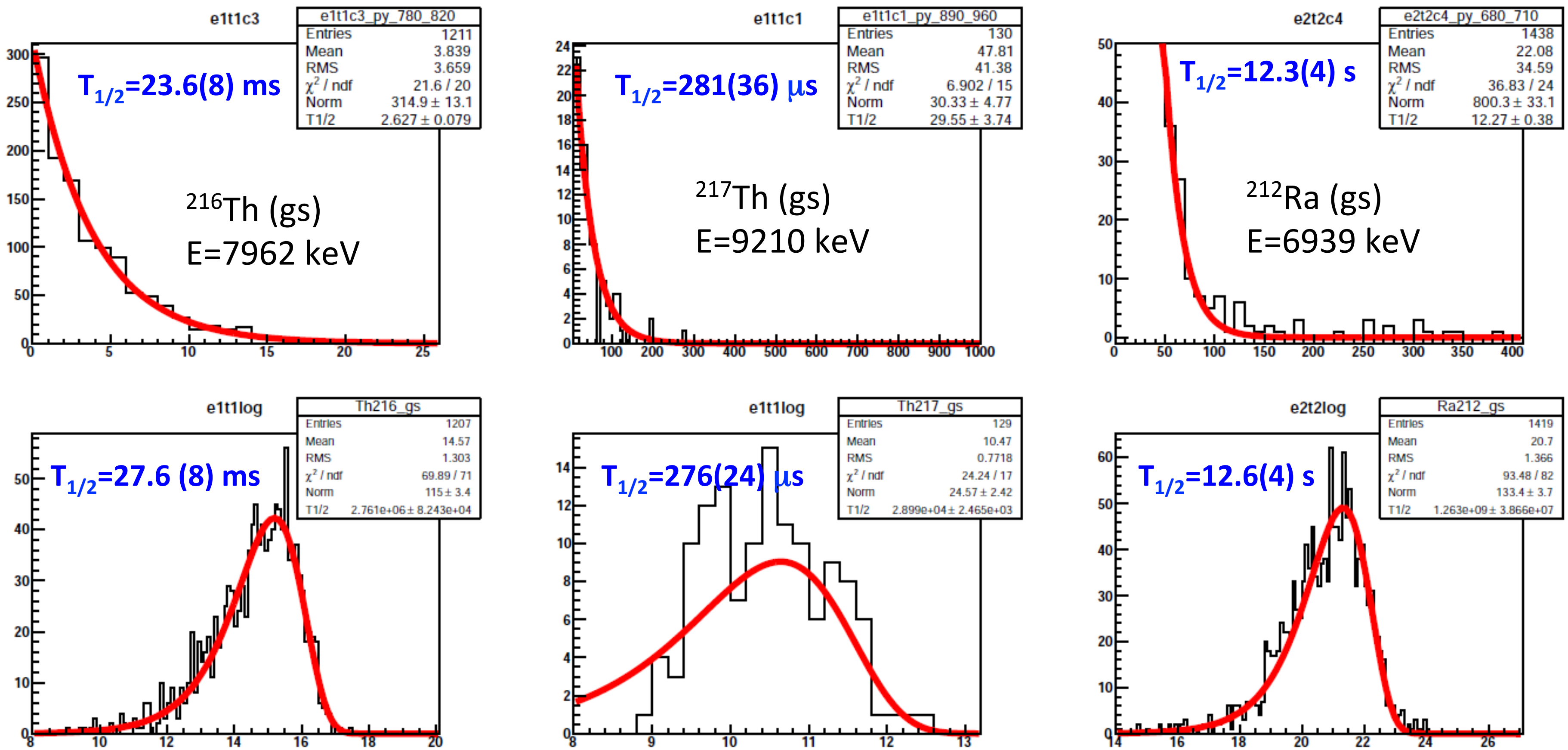






Lifetimes

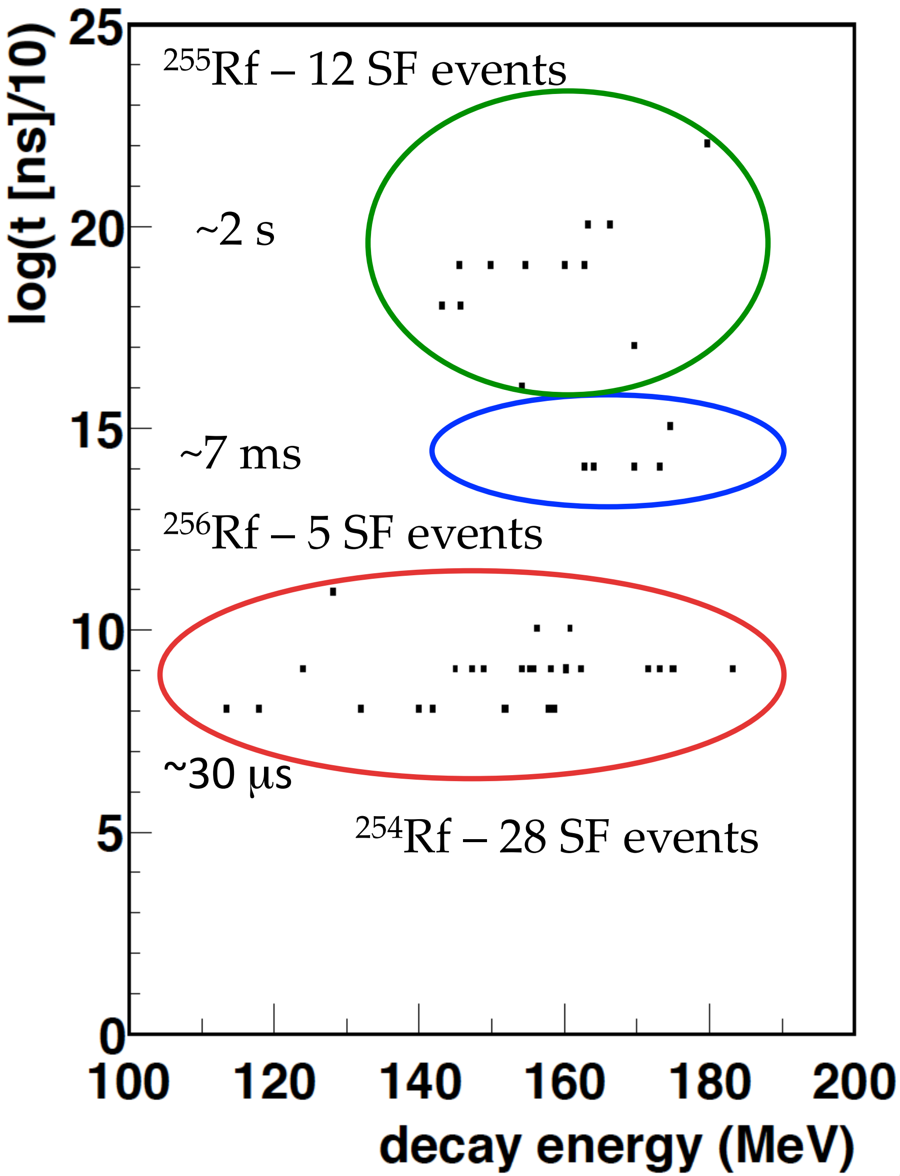
implant-$E_{\alpha1}(\Delta t)$ | implant-$E_{\alpha1}(\Delta t)$ | $E_{\alpha1}$-$E_{\alpha2}(\Delta t)$

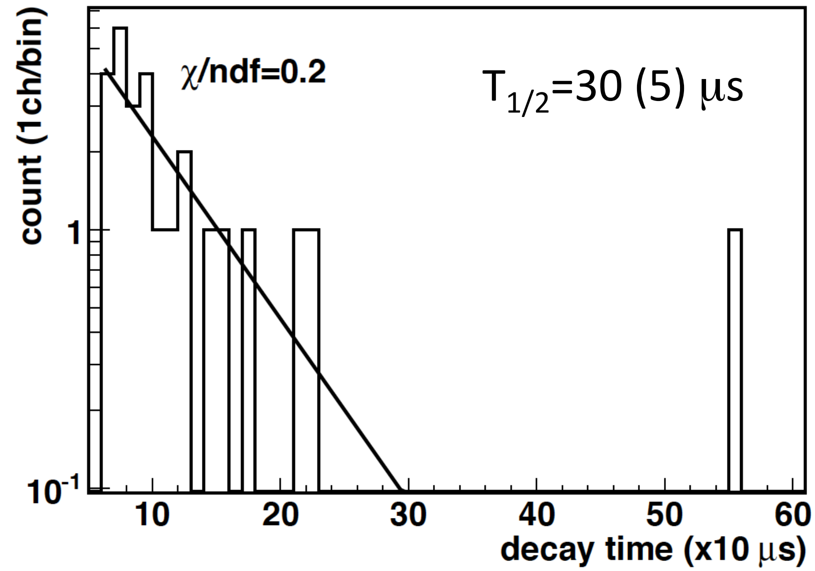


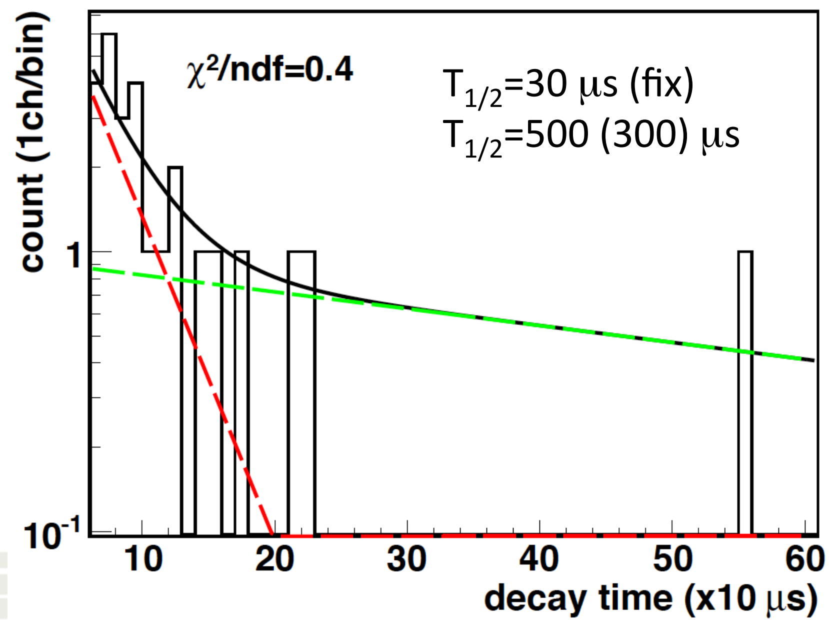
$T_{1/2}$=26.0 (2) ms | $T_{1/2}$=241 (5) μs | $T_{1/2}$=13.0 (2) s

ENSDF : www.nndc.bnl.gov/ensdf

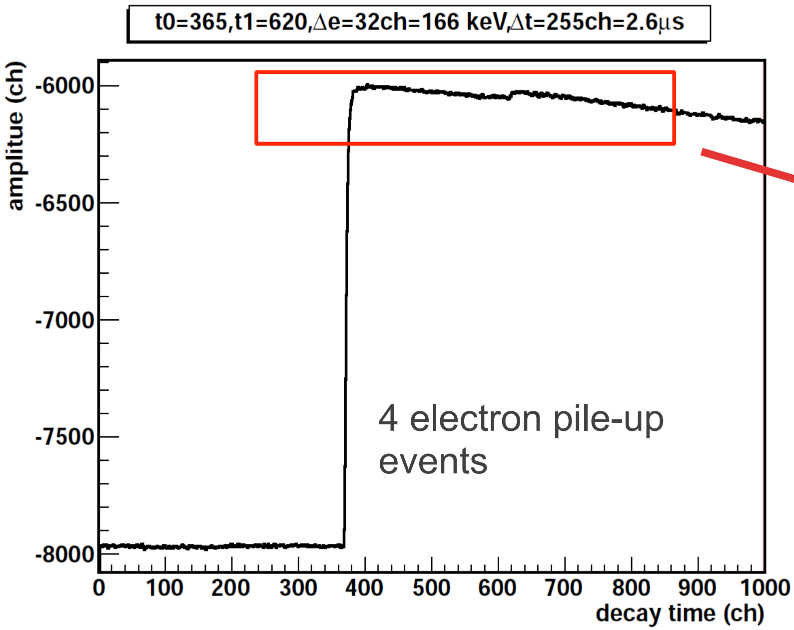
^{254}Rf spontaneous fission events

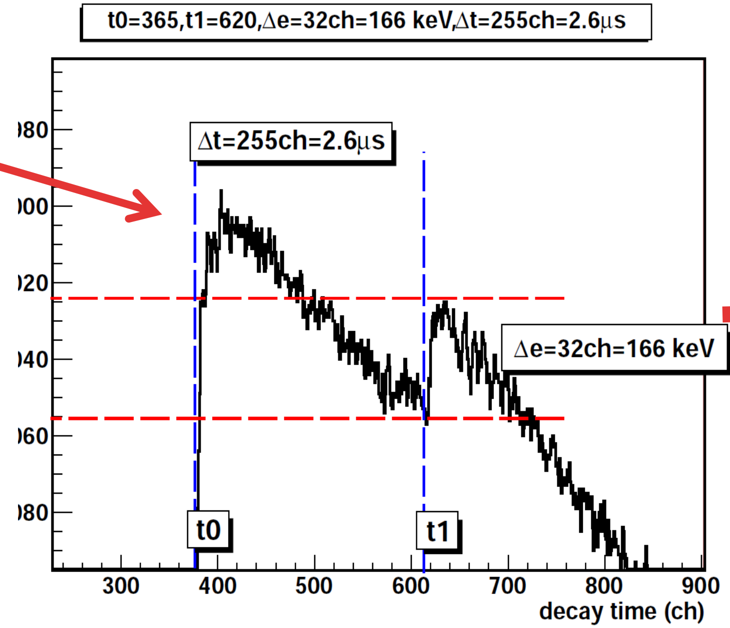


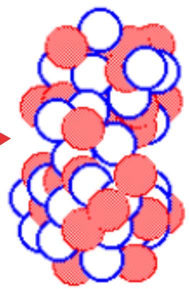




Electron-fission correlations

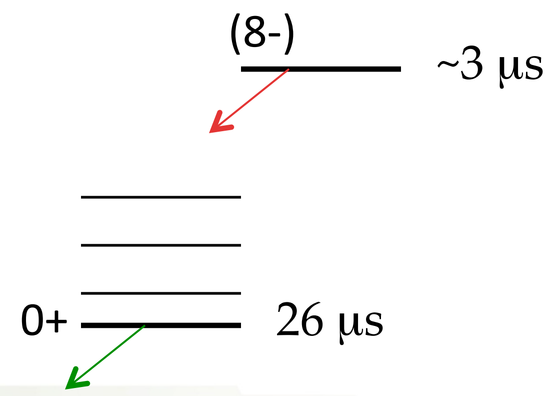




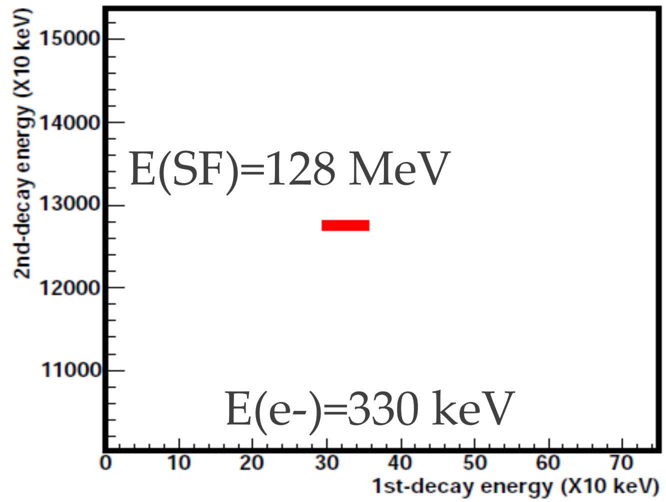


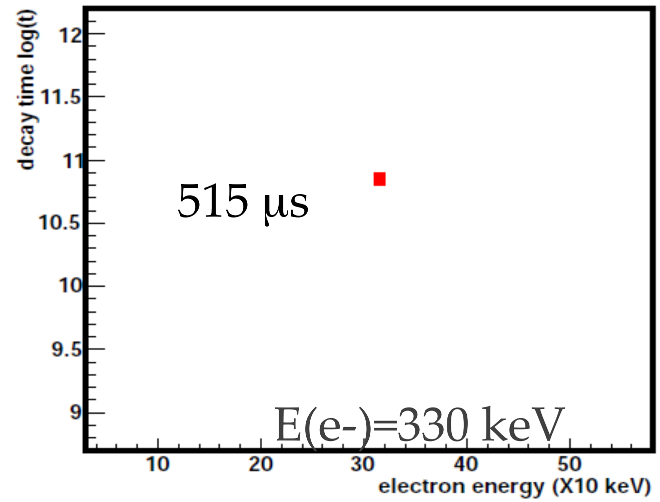
run #	E(e-) (keV)	$\Delta t_1 = \lvert t_{e-} - t_i \rvert$ (μs)	E(SF) (MeV)	$\Delta t_2 = \lvert t_{SF} - t_{e-} \rvert$ (μs)
51	166	2.6	161	78
188	150	0.7	146	94
190	200	2.5	158	74
198	270	2.8	183	128

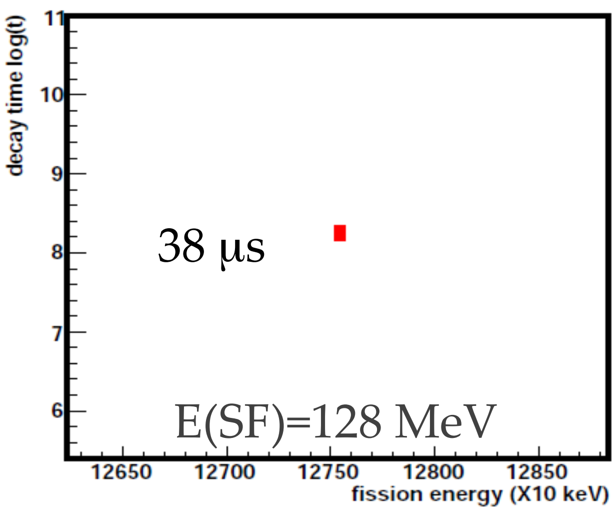
candidate for the 8- isomer



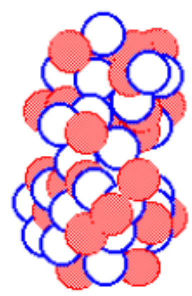
Electron-fission correlations – cont.

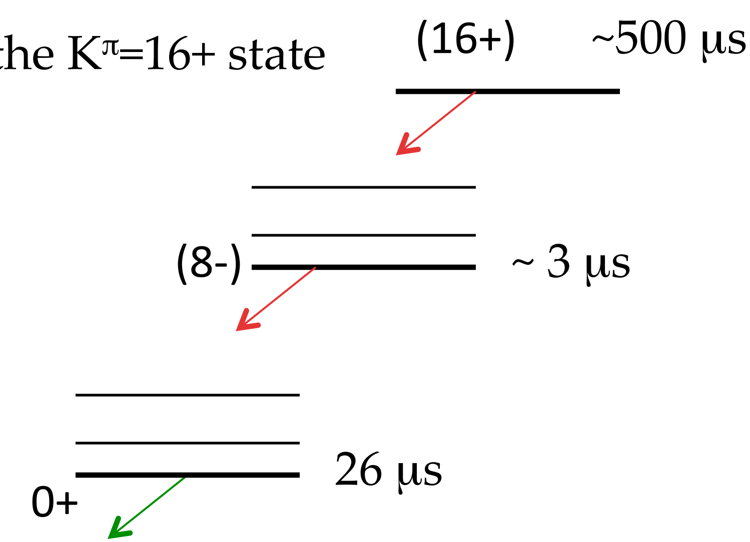






candidate for the K^{π}=16+ state





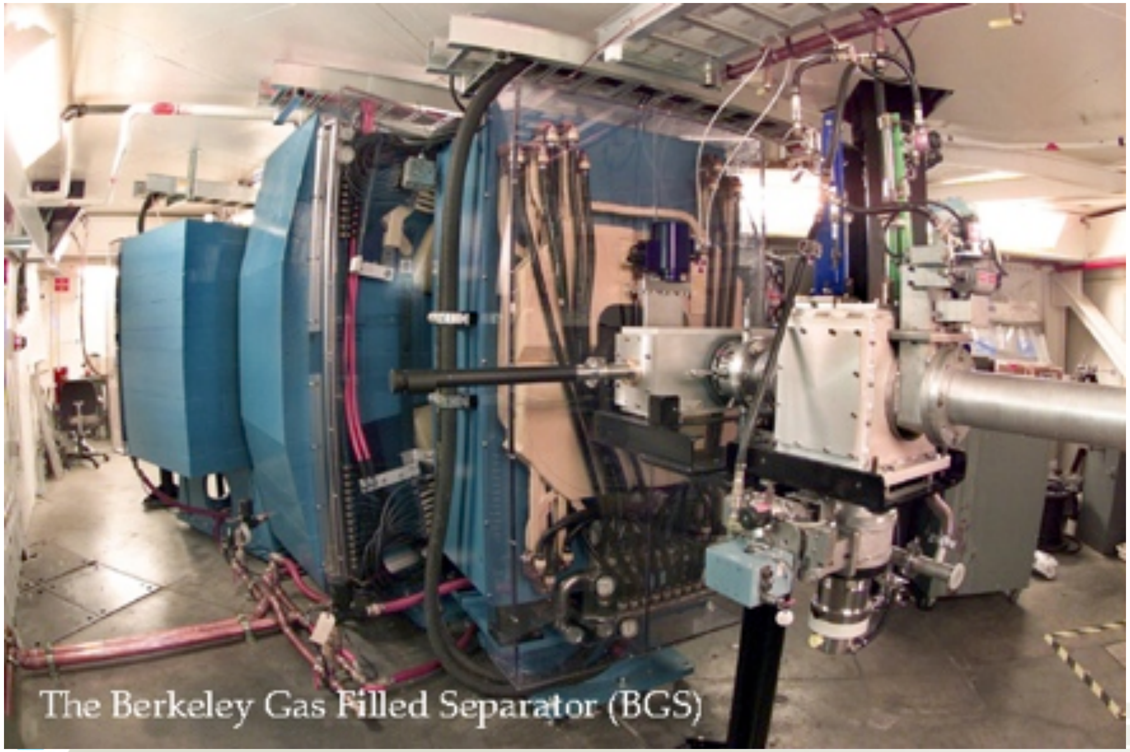
What about fission events from the isomers?

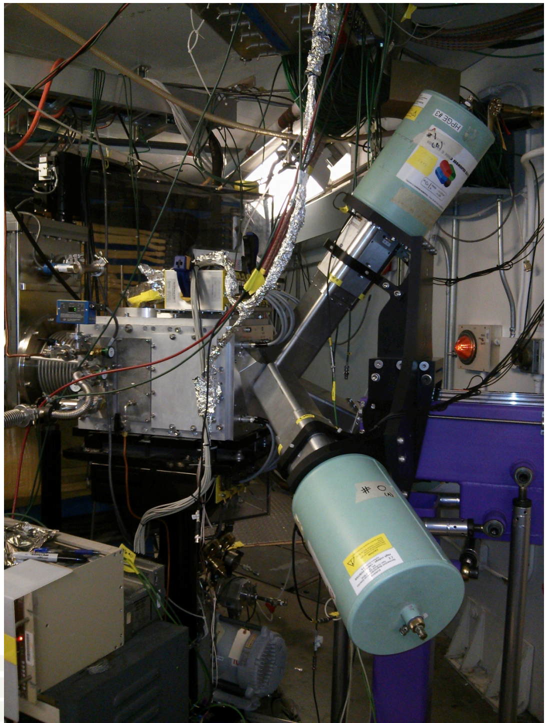
- none observed, but … with $T_{1/2}$=30 μs for the ^{254}Rf ground state, one may expect 23 % of all ^{254}Rf ground state decays to occur within the first 10 μs …
- the amount of ^{254}Rf fission events was somewhat smaller than that we have expected
- the new digital DAQ did not perform, as expected – it looks like that the system operated in a pile-up rejection mode for high-energy (fission-like) signals, despite that it was switched off in the software
- the DAQ firmware was redesigned and new tests showed good performance – we had 11 additional days of beam time approved by the ATLAS PAC to continue the experiment, but then the lightening struck …

LBNL experiment – March 2014

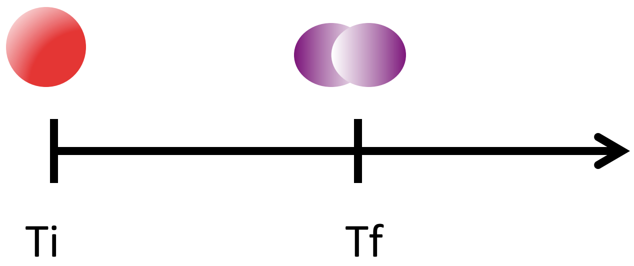
$^{50}Ti + ^{206}Pb \rightarrow ^{254}Rf + 2n$ @ 242.5 MeV

✓target: 500 μg/cm^2 on a rotating wheel, 99% enriched in ^{206}Pb
✓average beam current: ~**250 pnA** (over ~250 hrs)
✓ BGS efficiency ~**50%** (compared to 8% FMA)
✓ DSSD surrounded by 4 Ge CLOVER detectors





^{254}Rf ground state - SF decay

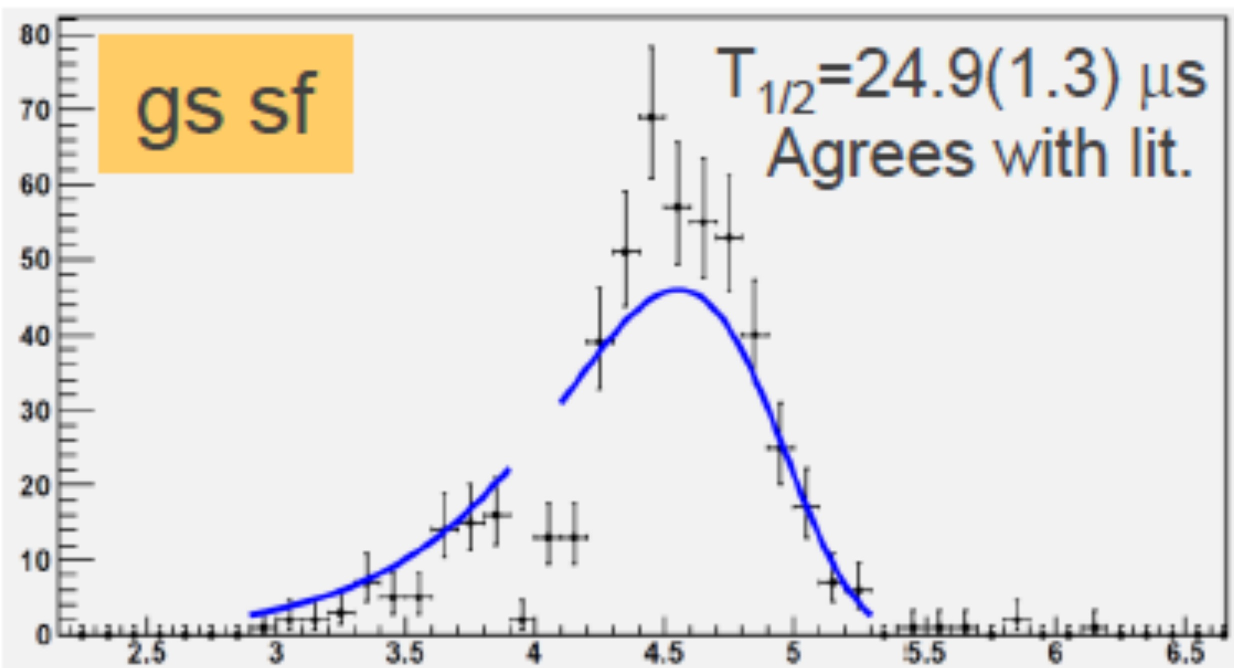


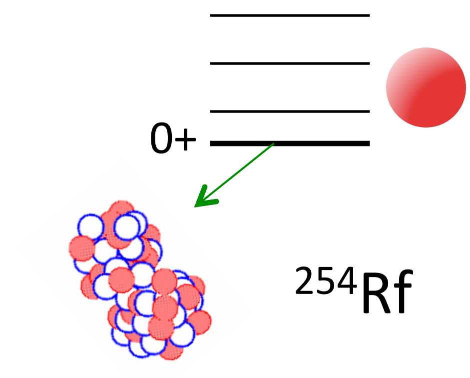
previous $T_{1/2}$:

✓**29.6 (+0.7-0.6) μs** – I. Dragojevic et al. (2008) (LBNL)
✓**23 (3) μs** - F. Hessberger et al. (1997) (GSI)
✓**500 (200) μs** - G. Ter-Arkopyan et al. (1975) (JINR)

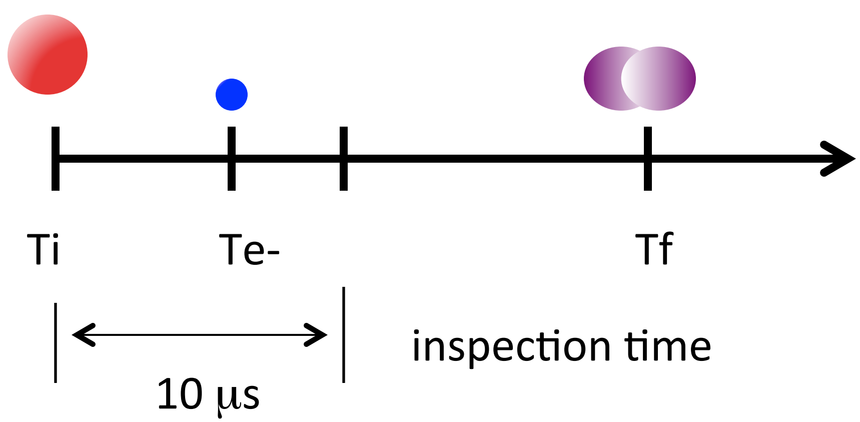
present $T_{1/2}$:

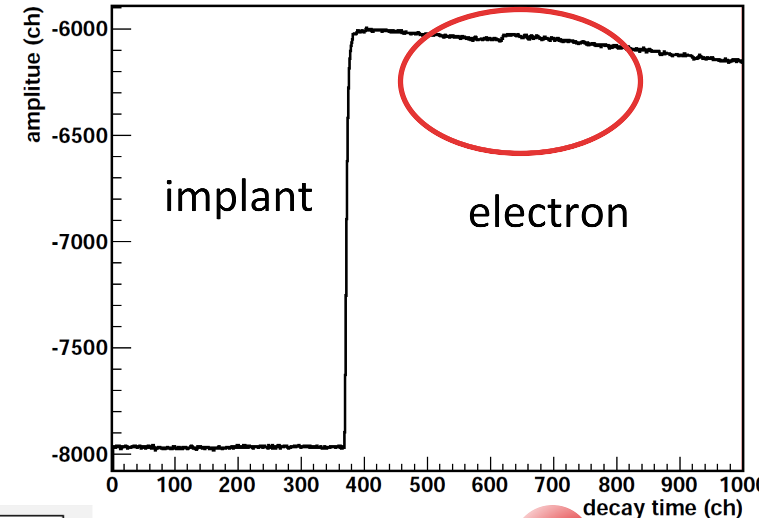
24.9 (13) μs (LBNL) / 30(5) μs (FMA)

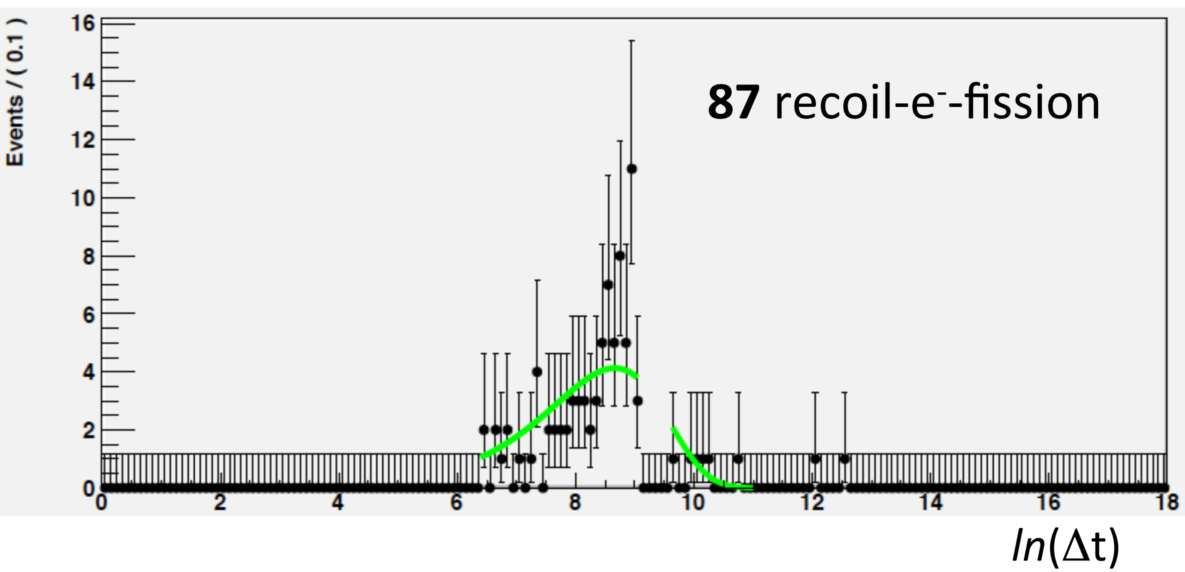


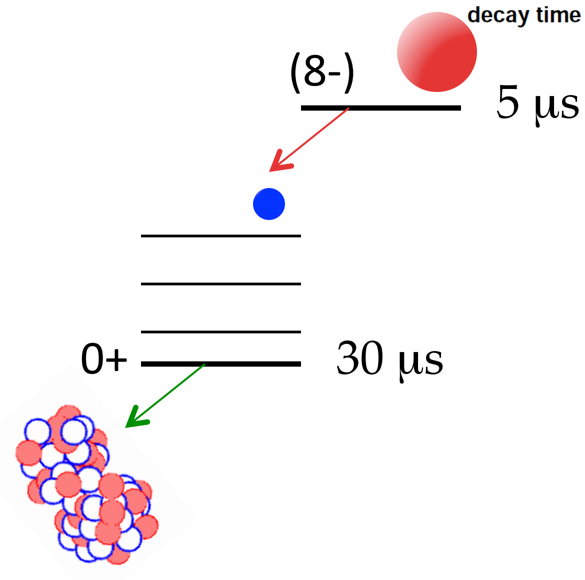


Gamma-ray decaying isomer



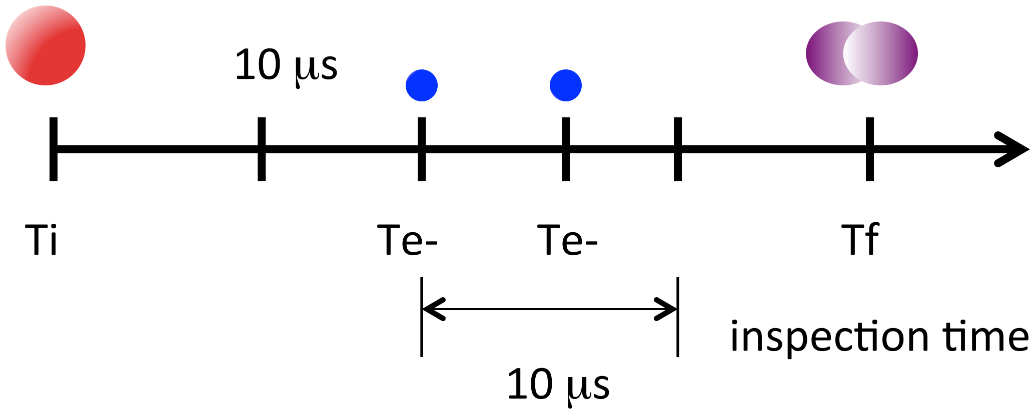


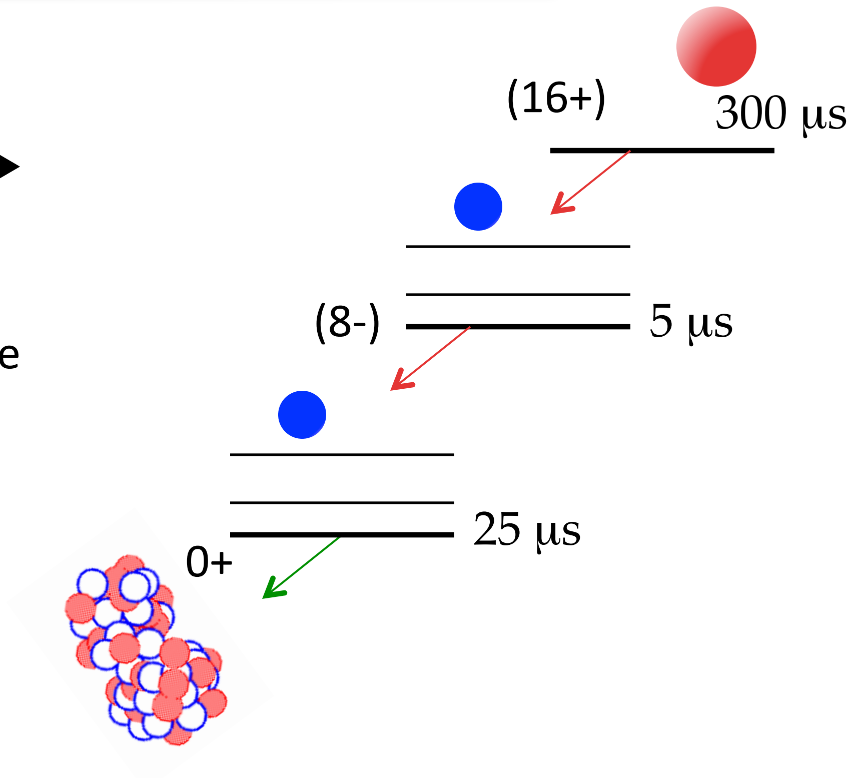


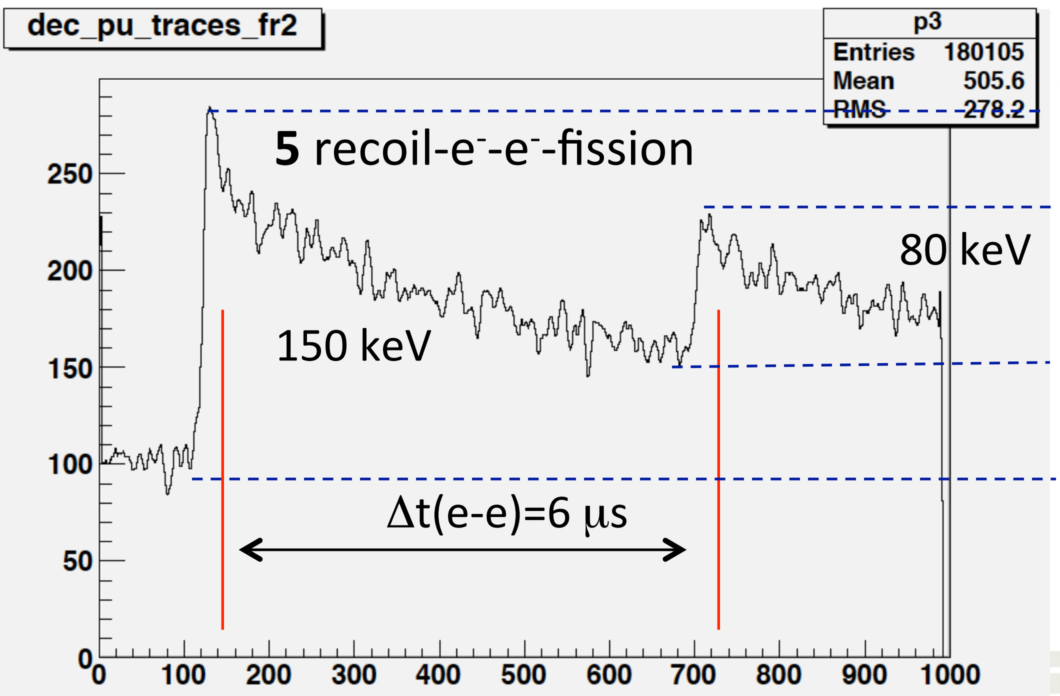


- ✓ confirm the existence of a short-lived isomer in ^{254}Rf – candidate for the Kπ=8-
- ✓ no fission events associated with the isomer were observed

Second gamma-ray decaying isomer







- ✓ candidate for the 4-qp, 16+ state
- ✓ no fission observed – partial fission lifetime much longer than that for the ground state
- ✓ $T_{1/2}$(iso) > $T_{1/2}$(gs)!

Conclusions

- a wealth of complementary data are needed to understand the structure of heavy elements – K isomers provide complementary (useful) information on single-particle structures, pairing, deformation,
- we studied ^{254}Rf (N=150) using both FMA & BGS and new digital DAQ - we found evidences for existence of two high-K isomers – one was short-lived (~5 μs) and the second one was long-lived (~300 μs); tentatively associate with predicted $K^{\pi}=8^{-}$ and 16^{+} states
- the digital DAQ & PSA very useful when exploring short lifetimes
- no fission was observed from the isomers
- the half-life of the 4-qp isomer was found to be much longer than that for the ground state, BUT one needs to know the transition strengths … future spectroscopy information is needed – theoretical support in predicting the fission half lives would also be valuable

Collaborators

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