# Fission isomer studies at IGISOL and FRS

- Introduction
- $^{240,242}$Am studies at IGISOL
- $^{235,236}$U and $^{237}$Np studies at FRS
- Summary

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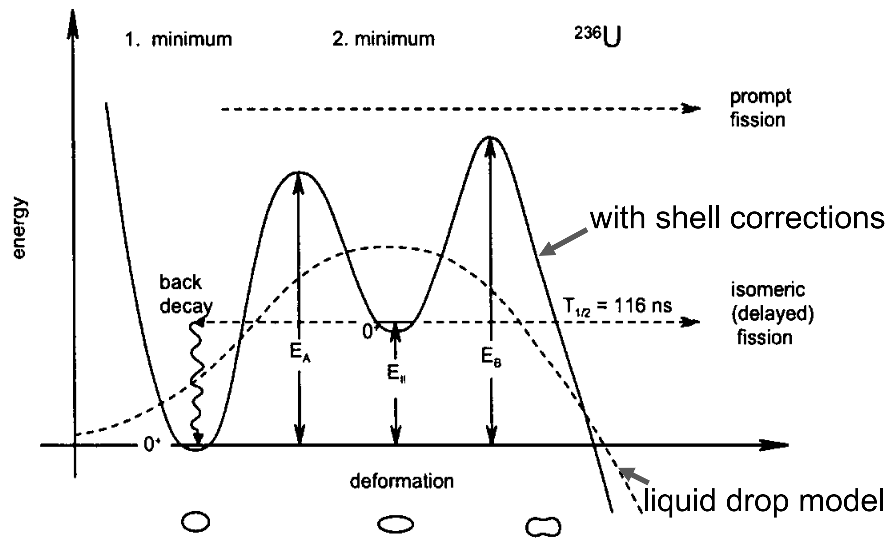
# Introduction: fission isomers

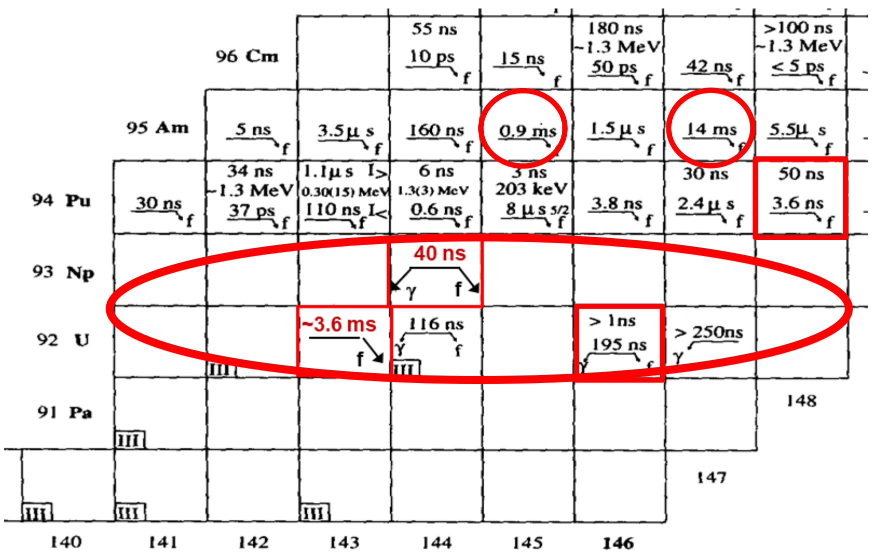
**Fission isomers**: excited metastable nuclear states decay by spontaneous fission.




(Superdeformed) second minimum in the potential energy surface appears in actinides → fission isomers

Ideal testing ground for strongly deformed low-spin nuclei and shell corrections in very heavy systems

P. Thirolf, D. Habs, Prog. Part. Nucl. Phys. 49, 325–402 (2002)
H. J. Specht, et al. , Phys. Lett. B. 41, 43–46 (1972)

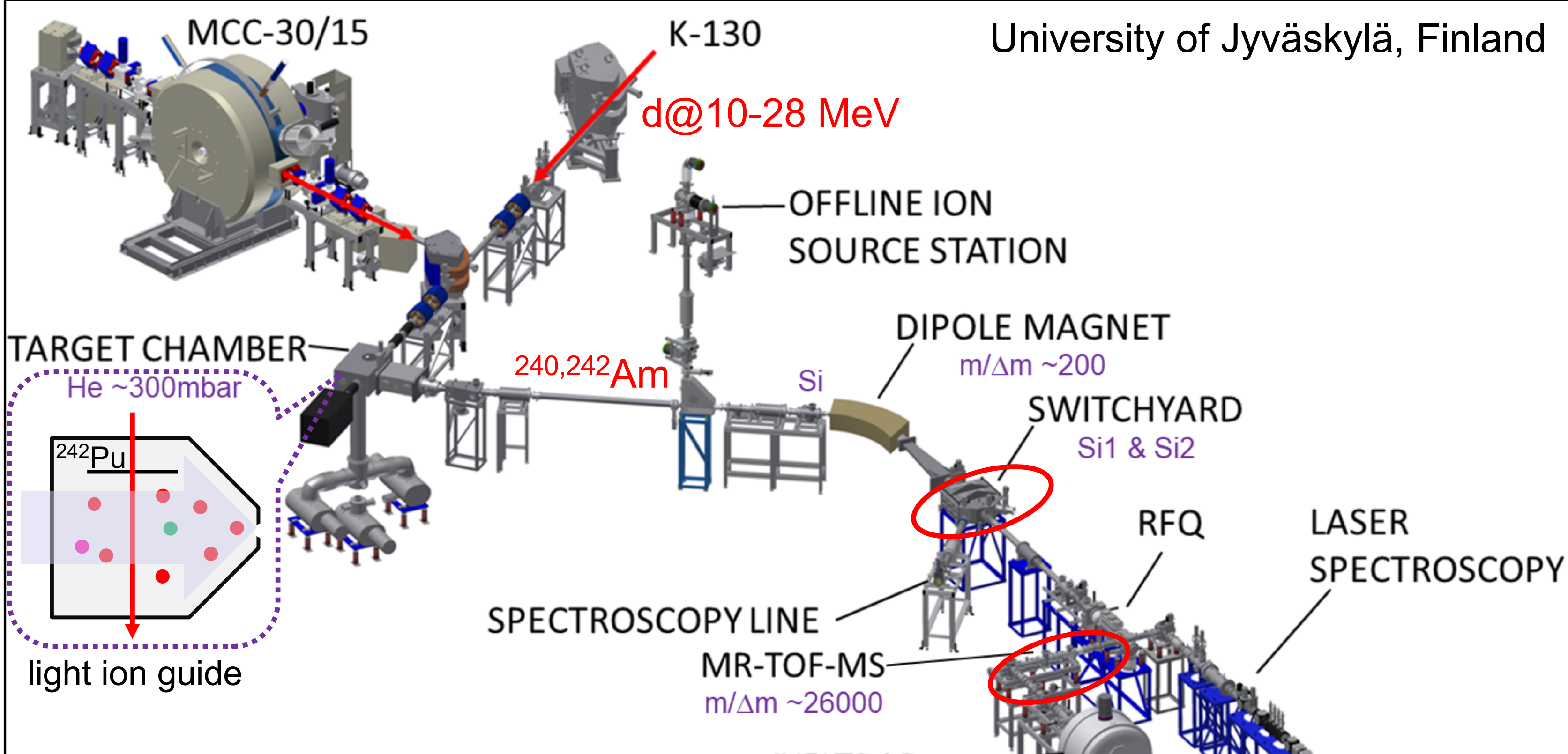



Studies in the past by n, p, d, α-induced reactions

**Difficulties:**

- Huge prompt fission background
- Low excitation energy and population probability ( ~ μbarn)
- Challenging to get targets to study U and Np

# Fission isomers $^{240f,242f}$Am studies at IGISOL



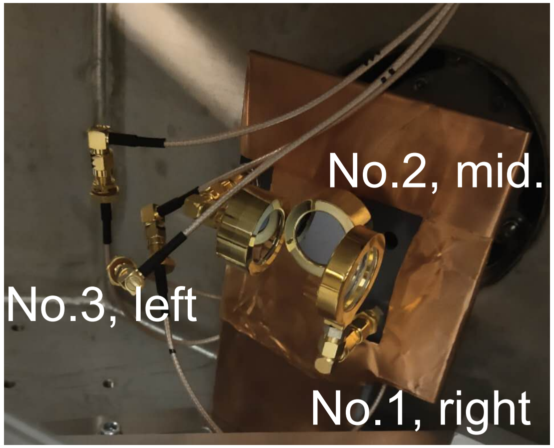

$^{242}$Pu($^{2}$d,2n) $^{242,f}$Am, 14 ms, 2.2 MeV

$^{242}$Pu($^{2}$d,4n) $^{240,f}$Am, 0.94 ms, 3.0 MeV

**Experimental goals:**

- Isomer yields vs. beam energy (10,14, 20, 25, 30 MeV)
- Isomer-to-ground state ratios
- Excitation energy of the fission isomer state in $^{242}$Am

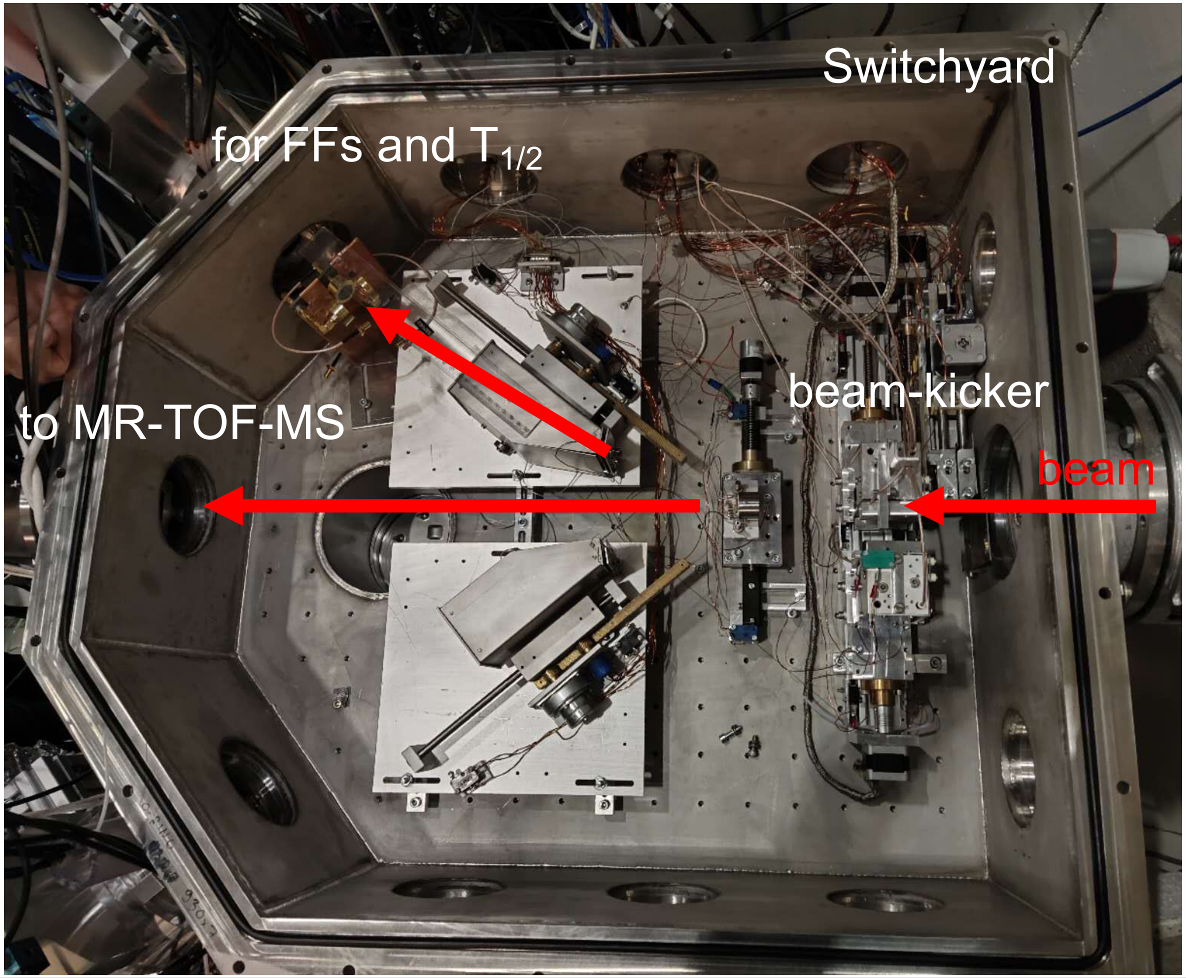
# 3 Si det. installation for $T_{1/2}$ measurement




| Si det. | Active area ($mm^2$) |
|---|---|
| No.1 | 200 |
| No.2 | 300 |
| No.3 | 100 |

Switchyard

- Pulsed beam with beam-kicker
- Si detectors for FFs measurement

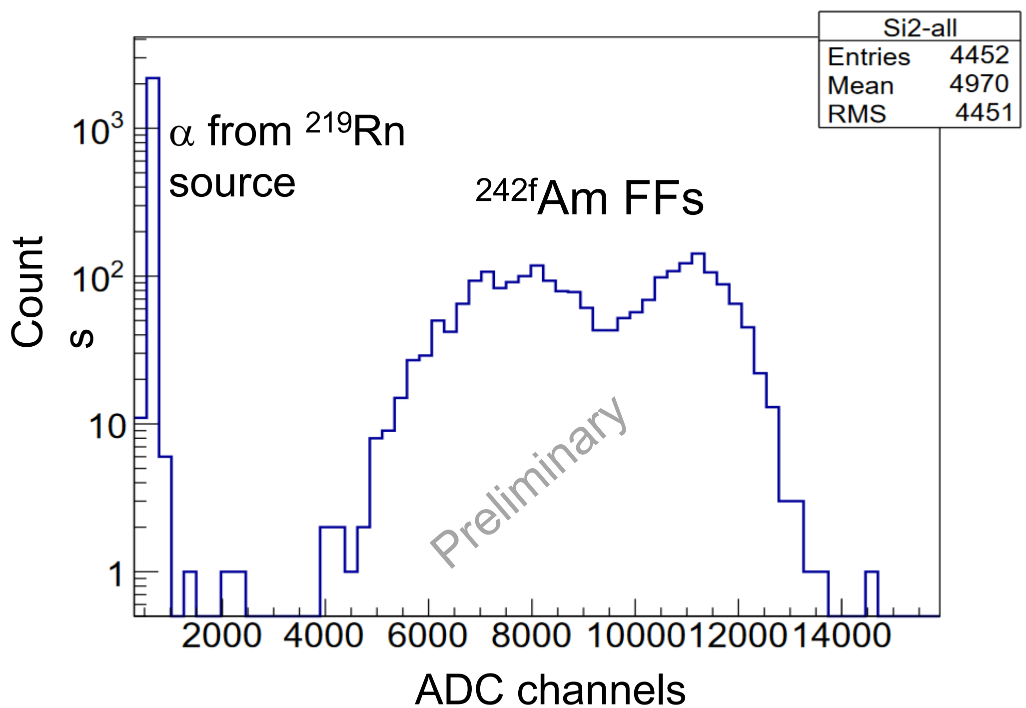


# FFs of $^{242f}$Am measured with Si detectors

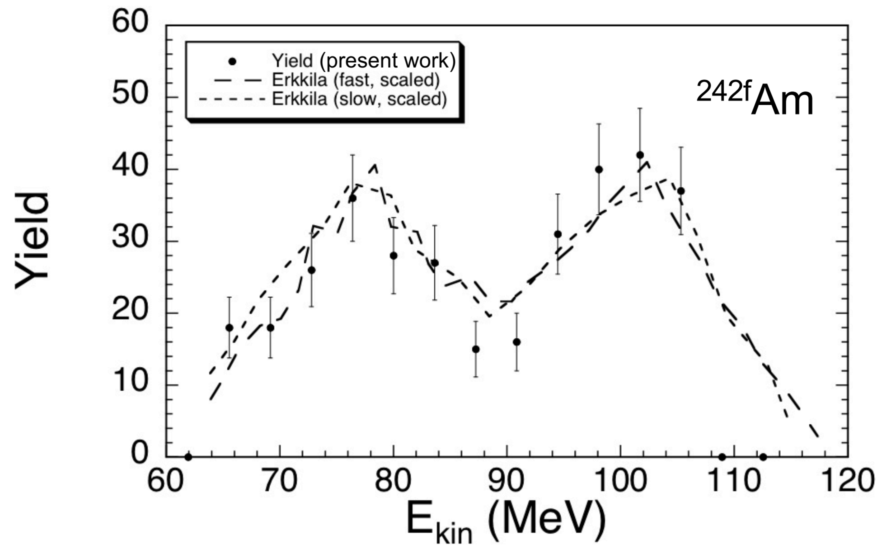
- $^{242f}$Am was successfully produced at IGISOL
- $^{242}$Am was extracted as singly charged ions
- Two types of $^{242}$Pu targets were tested

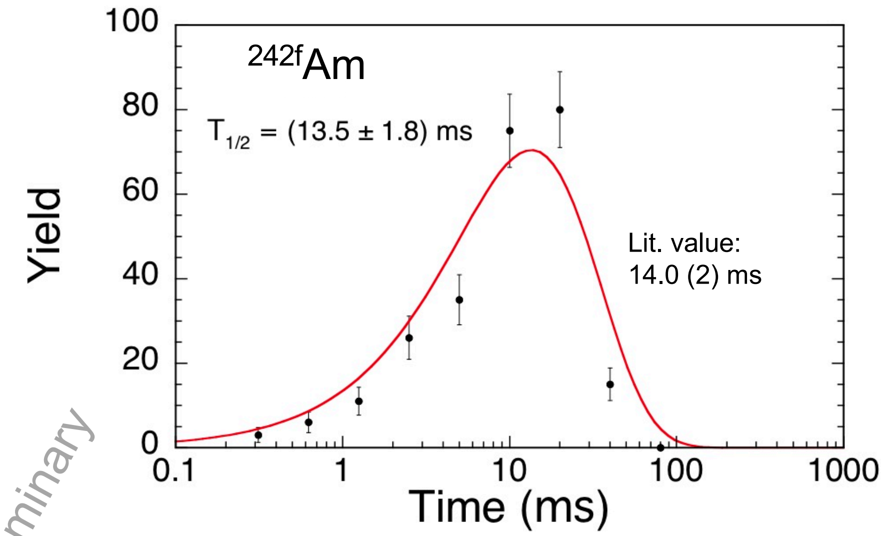
  (from Mainz Univ., Dennis Renisch, Christoph E. Düllmann)
  - drop-on-demand inkjet printing target → higher yield
  - molecular plating $^{242}$Pu target → lower yield

R. Haas et al., Nucl. Inst. and Methods A 874, 43 (2017)



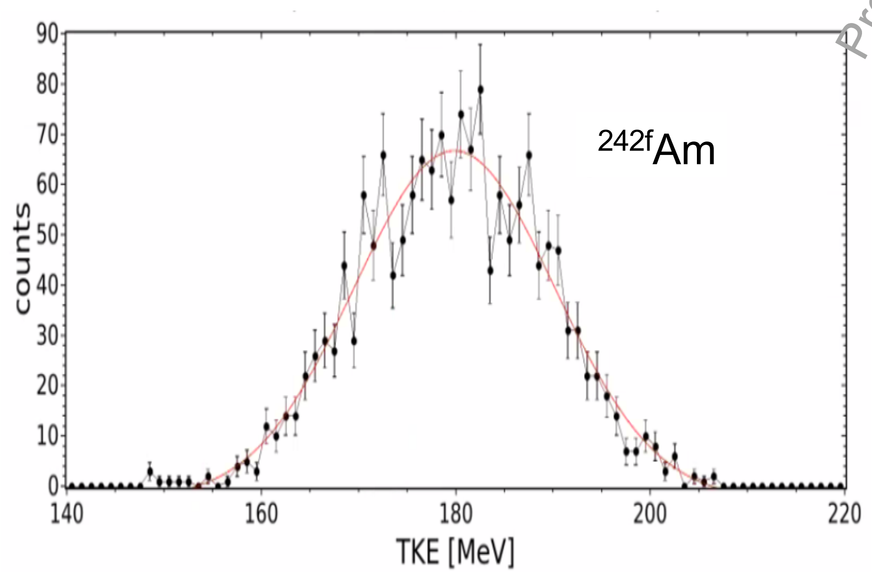
# Important proof: FFs yields and $T_{1/2}$ of $^{242f}Am$




A. Oberstedt and S. Oberstedt, Phys. Rev. C **104** (2021) 024611

Preliminary



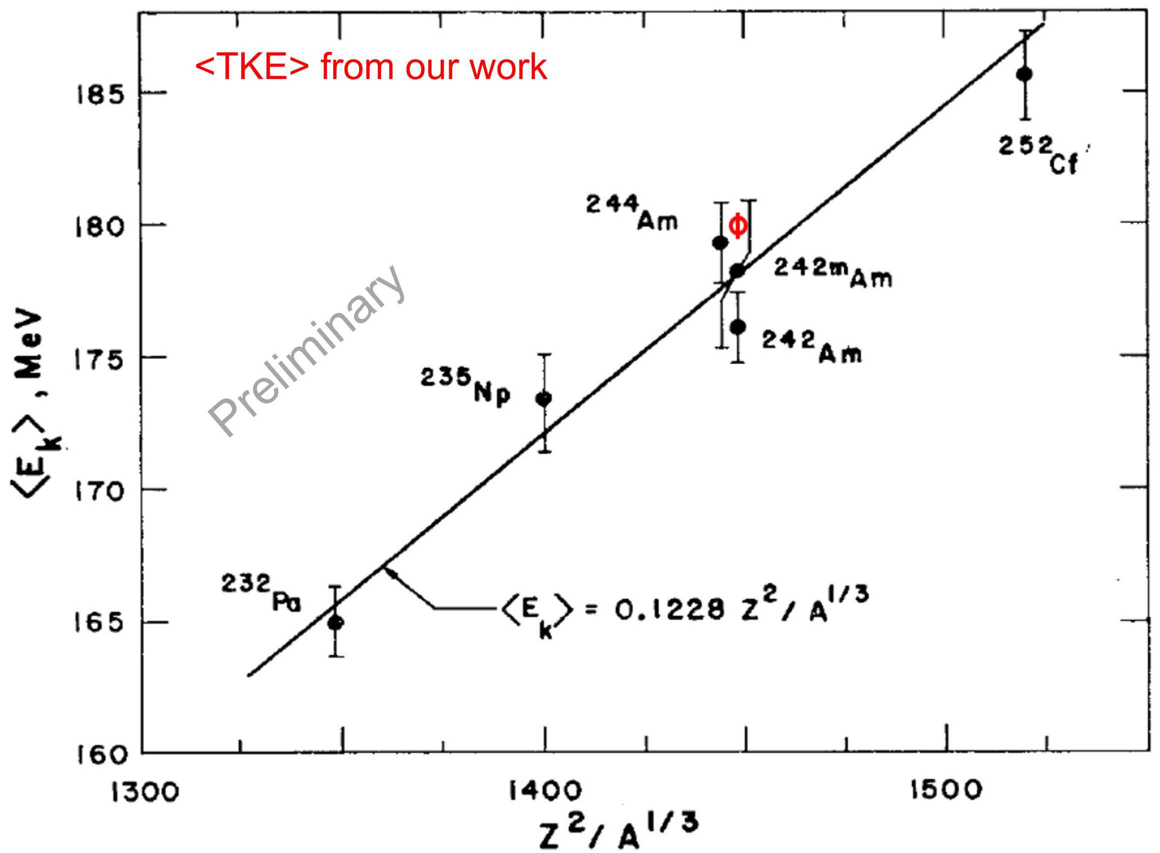

B. H. Erkkila and R. B. Leachman, Nucl. Phys. A **108** (1968) 689

- Half-lives of $^{240f}Am$ and $^{242f}Am$
- $\mathbf{E_{kin}}$ of two FFs of $^{242f}Am$
- $\mathbf{E_{kin}}$ of single FFs of $^{240f}Am$
- <TKE> of FFs → barrier parameters

- New method (separation of the production and detection) works fine

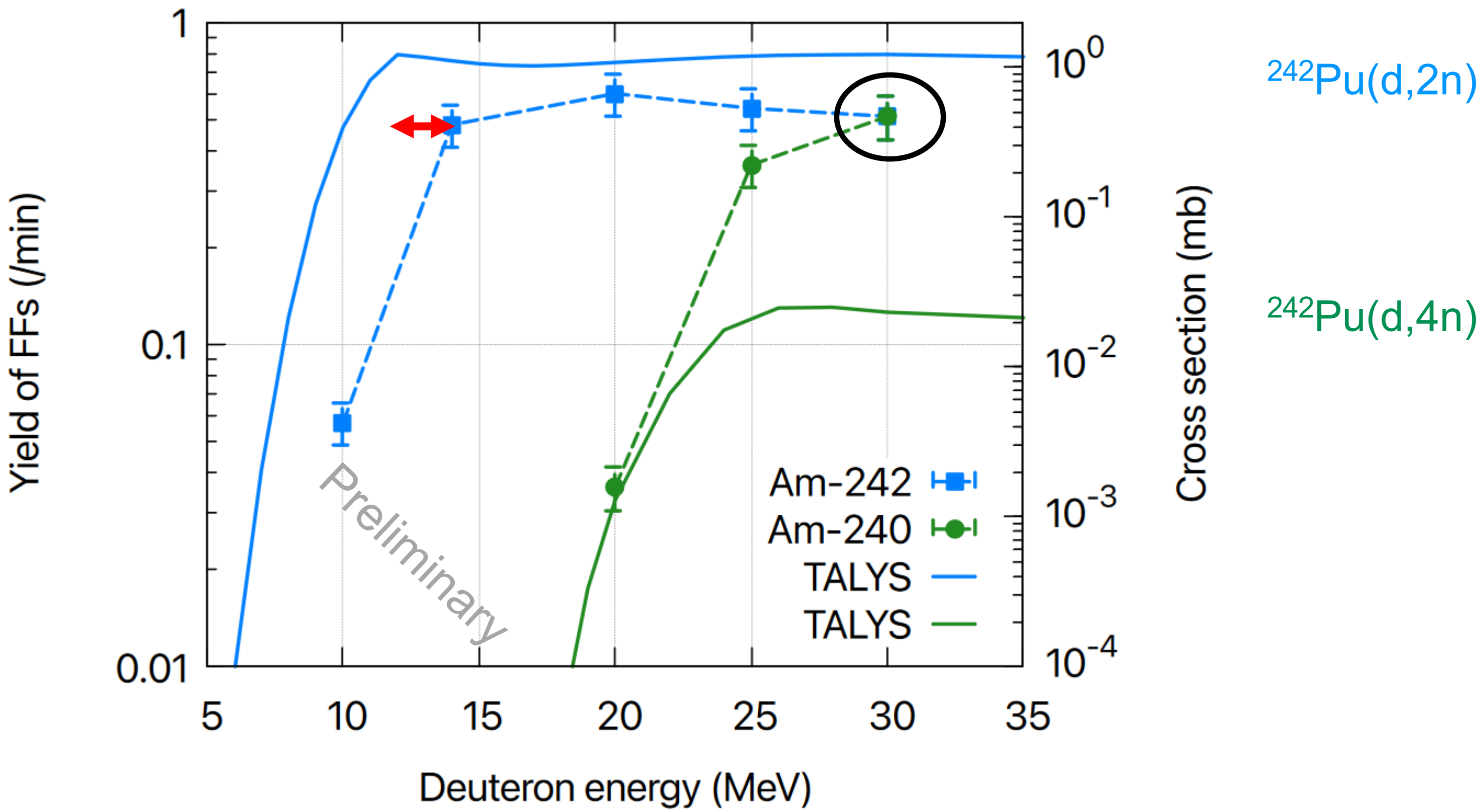
# New <TKE> of $^{242f}$Am FFs

- <TKE> of $^{242f}$Am FFs has been measured with a better precision
- It agrees with the systematics of <TKE> in the actinides




B.H. Erkkila and R.B. Leachman, Nucl. Phys. A **108**, 689 (1968)

# Preliminary results for excitation functions



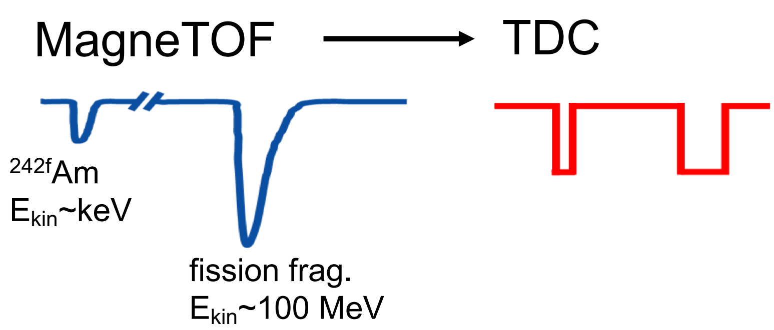

- Peak production energies are higher than TALYS prediction
- Production yields of $^{240f}$Am and $^{242f}$Am appear to be the same at 30 MeV (needs further investigations!)

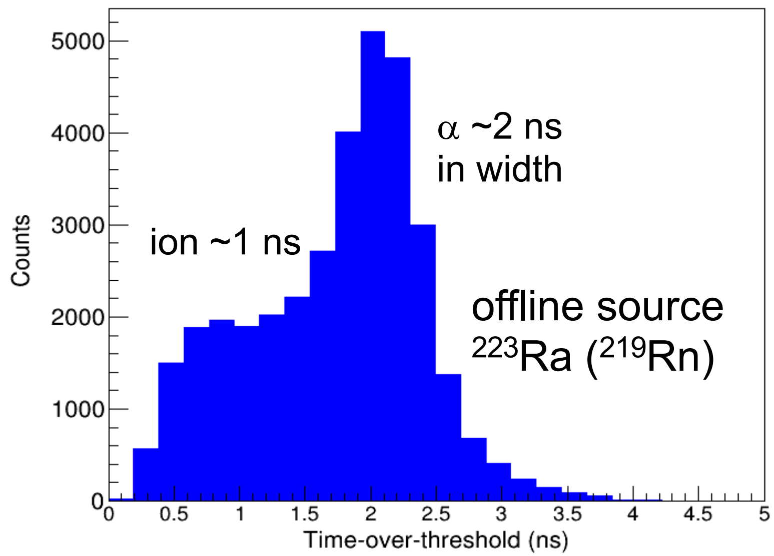
# MR-TOF-MS: excitation energy of $^{242f}$Am

Direct measurement of the excitation energy (2.20(8) or 2.9(2) MeV) of $^{242f}$Am

- Half-life ~ 14 ms
- Huge background: $^{242}$Am, $^{242}$Pu
- Bkg. suppression: by recording the fission fragments with time-over-threshold

S. Bjgrnholm, J.E. Lynn, Rev. Mod. Phys. 52, 725 (1980)
A.K. Jain, et al. , Nucl. Data Sheets 182, 1 (2015)



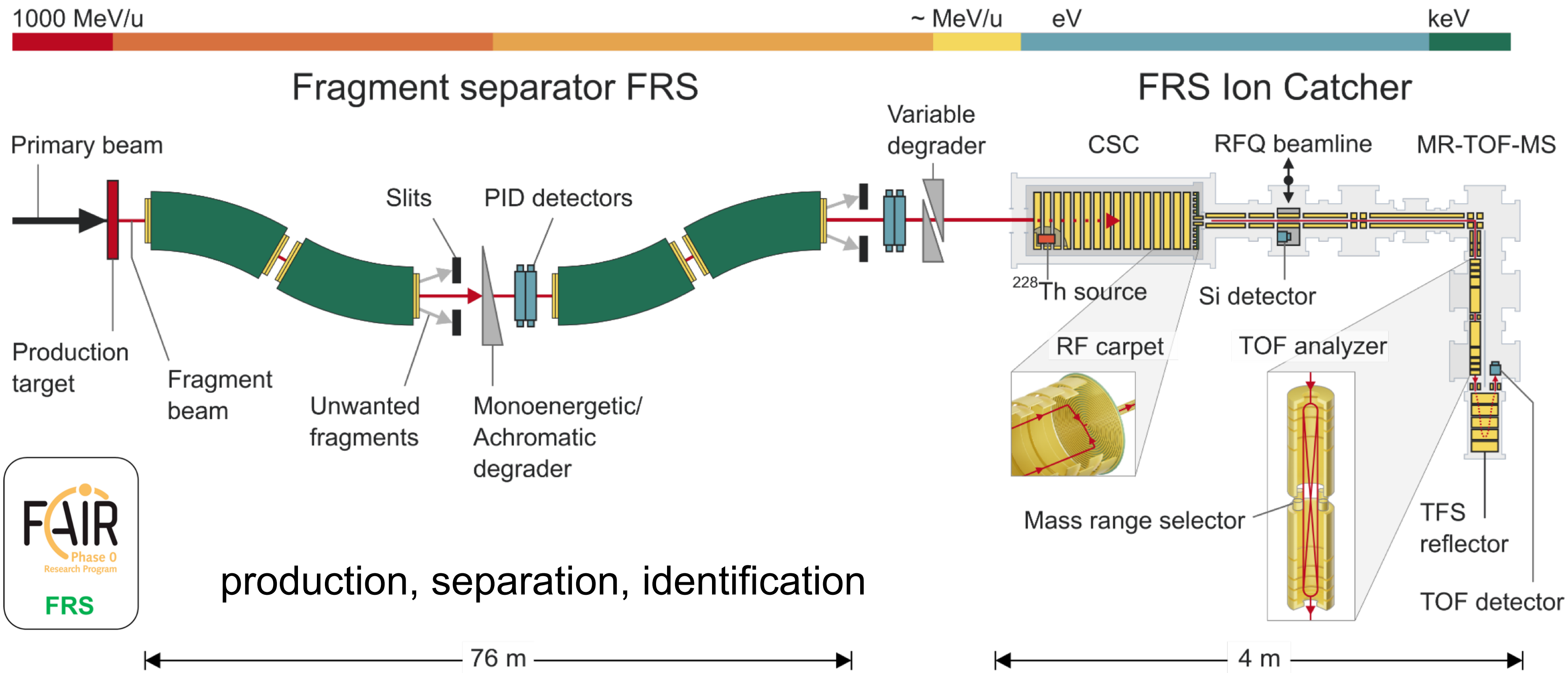




Two type of information:

1. TOF for mass measurements
2. Time-over-threshold information for identifying fission fragments

- Method demonstrated by the offline source
- Data analysis ongoing

# Fission isomer studies at FRS, GSI




- Isomers population via $^{238}$U fragmentation → is it possible? If so, how efficient?
- Fast production and separation → give access to isomers with short half-lives
- Event-by-event identification → background suppression
- $^{235f}$U, U and Np isotopes that are so far not well studied

Nazarena Tortorelli, PhD thesis, LMU

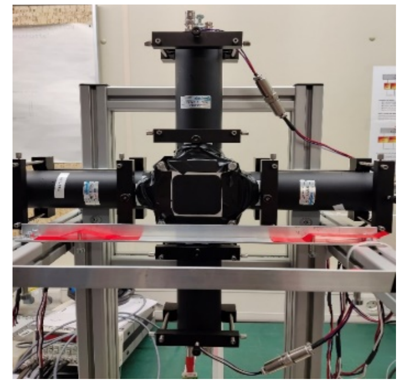
J. Zhao et al. PoS 419 (FAIRness2022) 063

# Detector systems used to cover wide half-lives

## Fast implanter

- ns to μs half-lives (e.g., $^{236f}U$)
- Background suppression
  → by event-by-event particle identification
  → by position correlation
- Rate capability: MHz

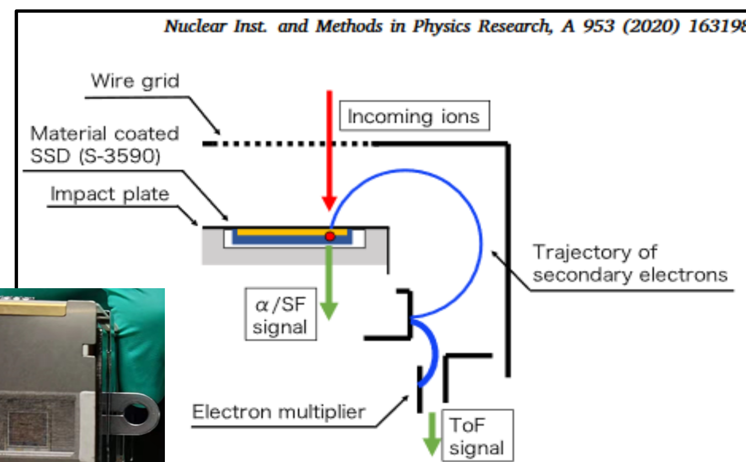
5 mm$^t$ plastic sci. + 4 fast PMTs

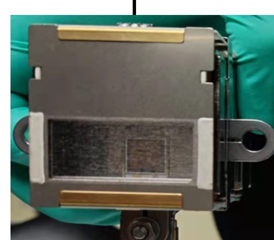


## FRS-Ion-Catcher

- ms and longer half-lives (e.g., $^{235f}U$)
- Measurement time ~10 ms
  → shorter DC-cage for faster extraction
  → MR-TOF-MS running with 200Hz
- Background suppression
  → α-ToF detector (mass & decay)
- Rate capability: 0.1 MHz

α-ToF detector



T. Niwase et al., NIM. A 953, 163198 (2020)

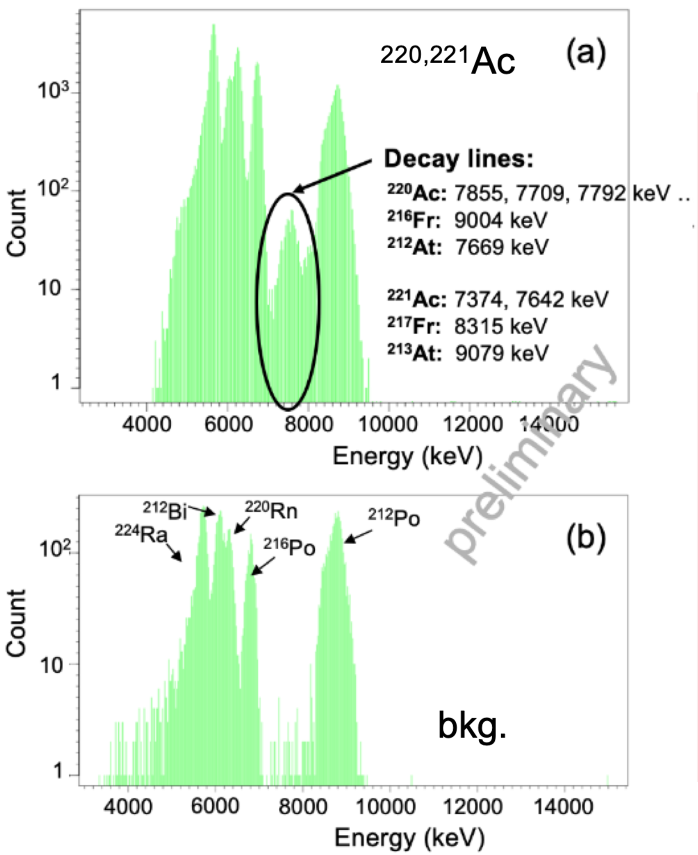
# Prelim. results and new experiments

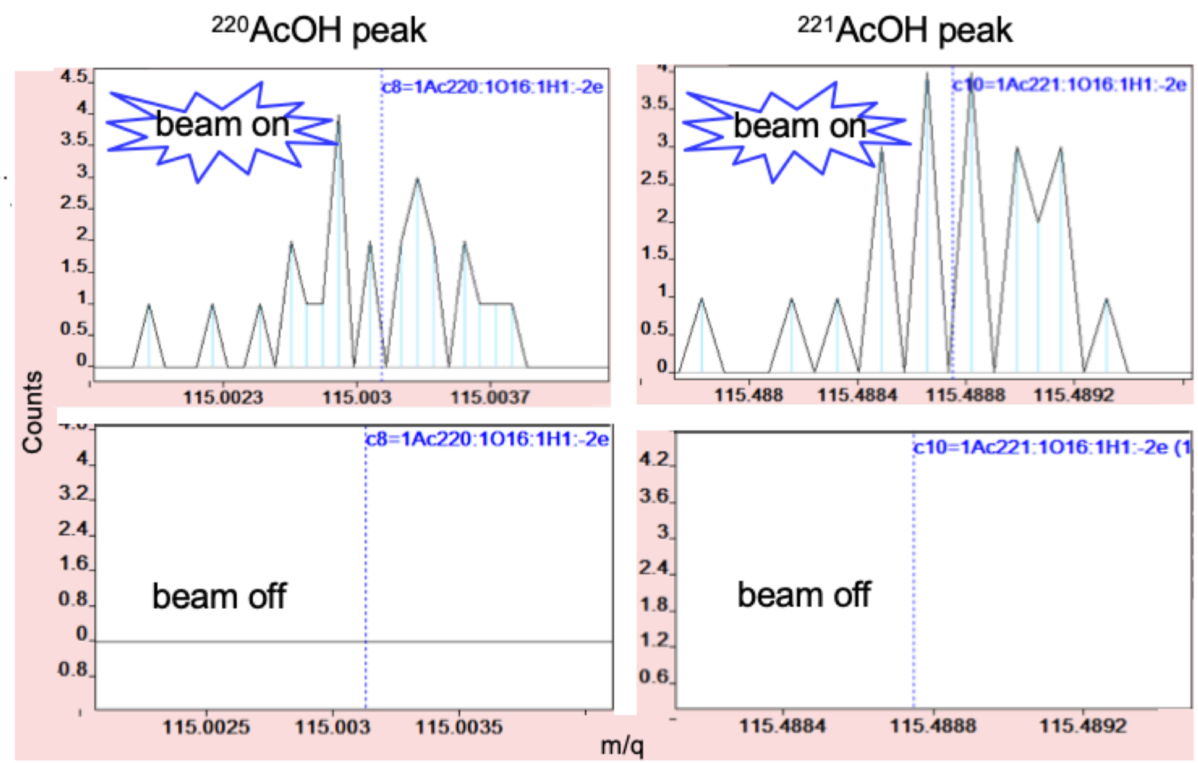
**From the α-TOF detector:**

- beam related decay & mass lines are seen
- further analysis ongoing

Nazarena Tortorelli, PhD thesis, LMU

J. Zhao et al. PoS 419 (FAIRness2022) 063

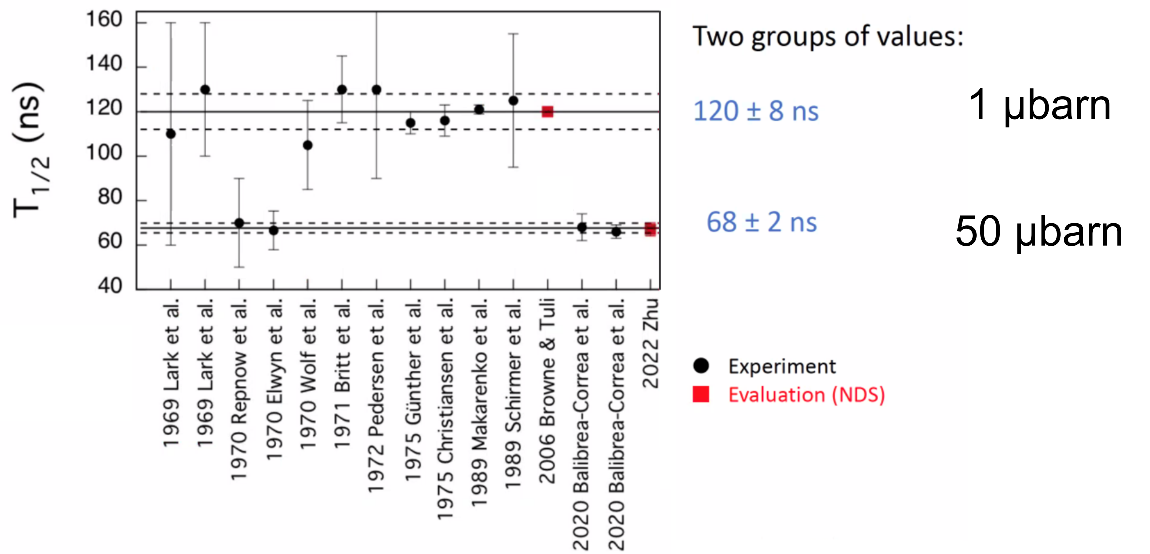


# Prelim. results and new experiments

**Preliminary knowledge learned for $^{236f}U$:**

- $1 \times 10^7$ $^{236}U$ (produced by a Be target) implanted into the fast scintillator
- Only 10 events identified as $^{236f}U$ → an upper limit of production (1 or 50 μbarn)
- Uncertainty in $T_{1/2}$ (120 ns or 68 ns) of $^{236f}U$ leads to a factor 50 different loss in the FRS




**Follow-up experiment for $^{236f}U$, $^{237f}Np$ in 2025:**

- with an improved implantation detector
  (better bkg. suppression, shorter deadtime)

# Summary



- Background free experiments on fission isomers have been performed
- Production of fission isomers in $^{240,242}$Am at IGISOL, Finland
  - Measurement of half-lives and fission fragments of $^{240f,242f}$Am
  - Measurement of excitation energy of $^{242f}$Am with MR-TOF-MS
- Exploration of the new production method with $^{238}$U fragmentation at FRS, GSI
  - Small number of possible $^{236f}$U have been observed
  - Follow-up experiment on $^{236f}$U, $^{237f}$Np scheduled in 2025

Spokesperson: T. Dickel[1,2] , Co-Spokespersons: M. P. Reiter[3], P. G. Thirolf[4], M. Wada[5]
A. Al-Adili[6], D. Amanbayev[2], S. Ayet[1], S. Bagchi[1], D. Balabanski[7], S. Beck[2], T. Cap[8], P. Constantin[7], L. Csige[9], D. Curien[10], O. Charviakova[8], T. Davinson[3], I. Dedes[11], F. Didierjean[10], G. Duchene[10], J. Dudek[10], H. Geissel[1,2], J. Gerl[1], T. Grahn[12,13], M. Gorska[1], M. Gupta[14], E. Haettner[1], O. Hall[3], M. Harakeh[15], C. Hornung[2], J.-P. Hucka[16], P. Jachimowicz[17], A. Kankainen[12], N. Kalantar-Nayestanaki[15], M. Kowal[8], A. Krasznahorkay[9], G. Kripko-Koncz[2], N. Kuzminzuk[1], M. Lantz[6], S. Lalkovski[18], I. Mardor[19,20], V. Metag[2], N. Minkov[21], I. Miskun[2], I. Moore[12,13], G. Münzenberg[1], A. Oberstedt[7], S. Oberstedt[22], Z. Patyk[8], S. Pietri[1], I. Pohjalainen[12], S. Pomp[6], W. R. Plaß[1,2], S. Purushothaman[1], C. Scheidenberger[1,2], P. Schury[5], J. Skalski[8], A. Solders[6], Y. Tanaka[1,23], M. Vencelj[24], H. Weick[2], P. Woods[3], J. Zhao[1,25] and the Super-FRS Experiment Collaboration

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# Thanks!

I290@IGISOL, Nov. 2023