Total kinetic energy distribution for spontaneous fission of Rf isotopes

54th ASCR International Workshop

JAEA Tokai, 2019

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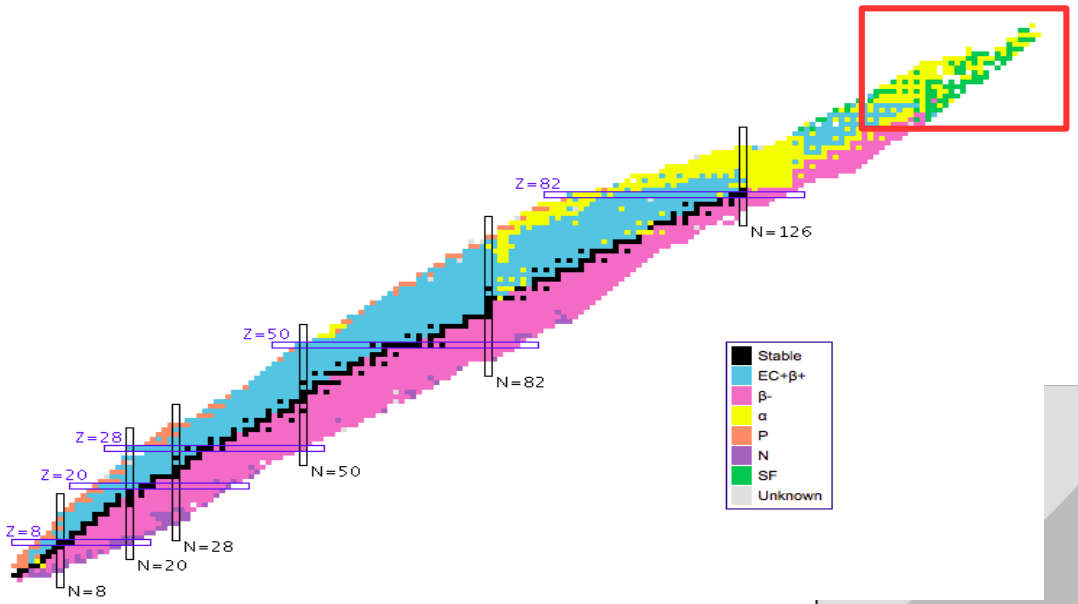
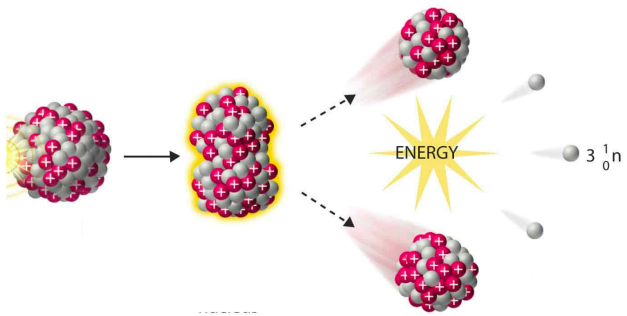
on behalf of SHIP collaboration

Outline

- Spontaneous fission properties
- Synthesis and identification
- Total kinetic energies of ^{255}Rf, ^{256}Rf and ^{258}Rf

Trans-fermium region



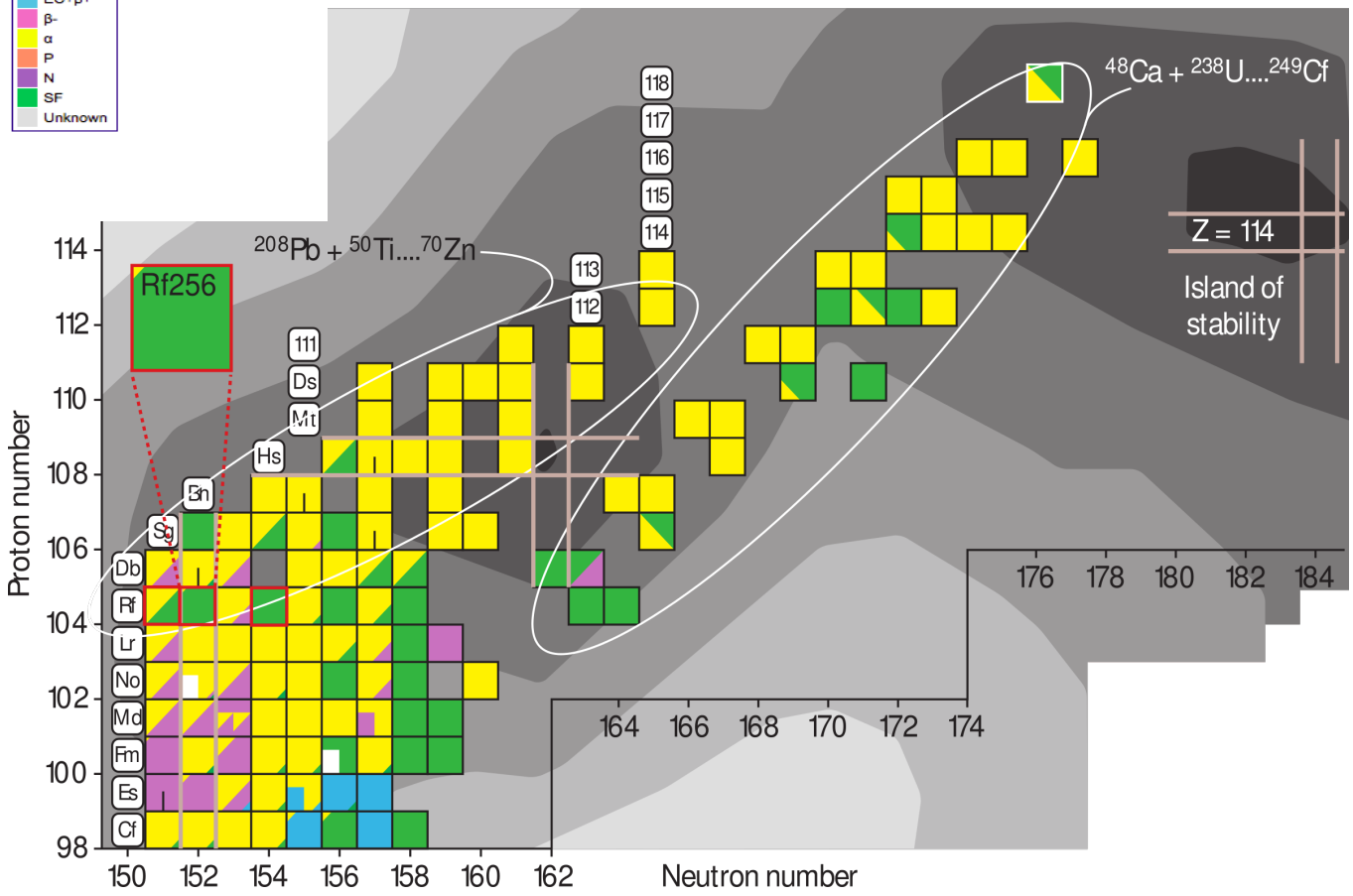


^{255}Rf: $T_{1/2}$=1.68(9) s
SF: 58.00%

^{256}Rf: $T_{1/2}$=6.67(10) ms
SF: 99.68 %

^{258}Rf: $T_{1/2}$=10.1(1.1) ms
SF : 95.00 %

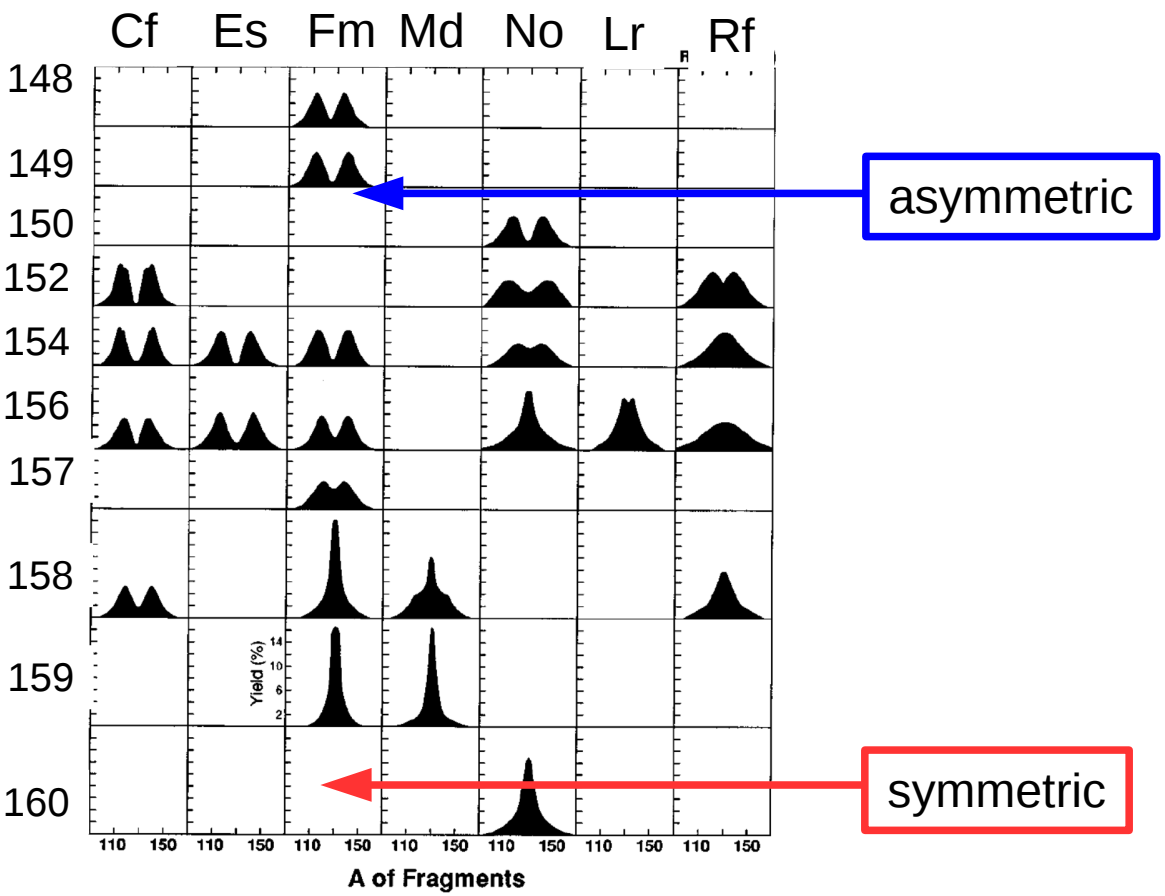
[NNDC]



M. A. Stoyer, Nature 442, 876 (2006).

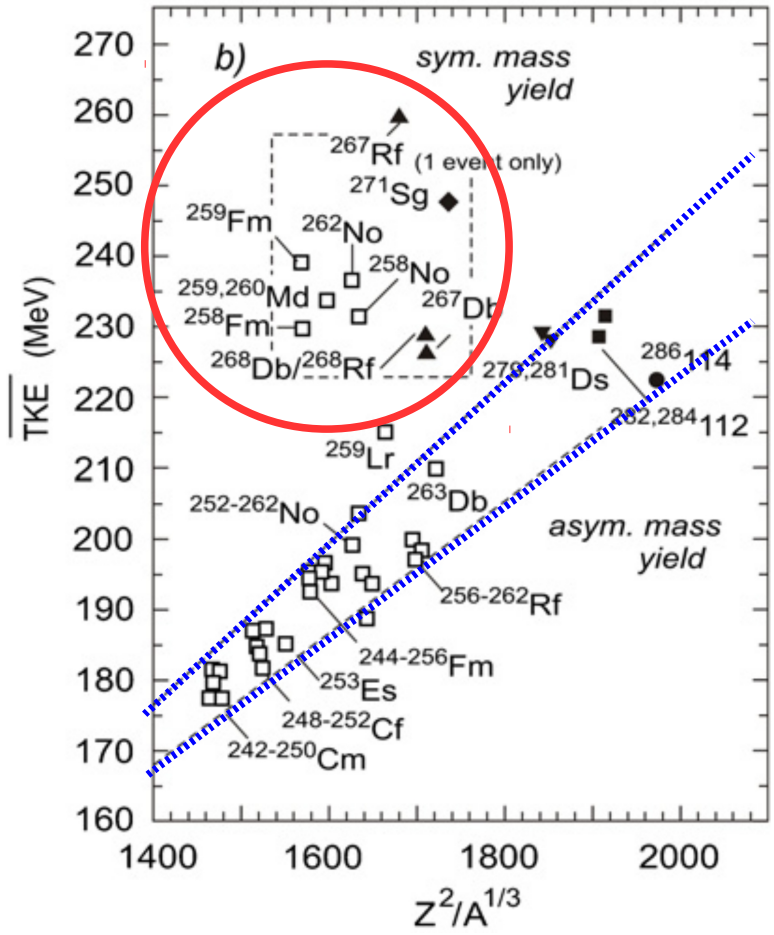
Fission characteristics

Mass distribution of fragments



D.C. Hoffman, Nucl. Phys. A. 502, 21c-40c (1989).

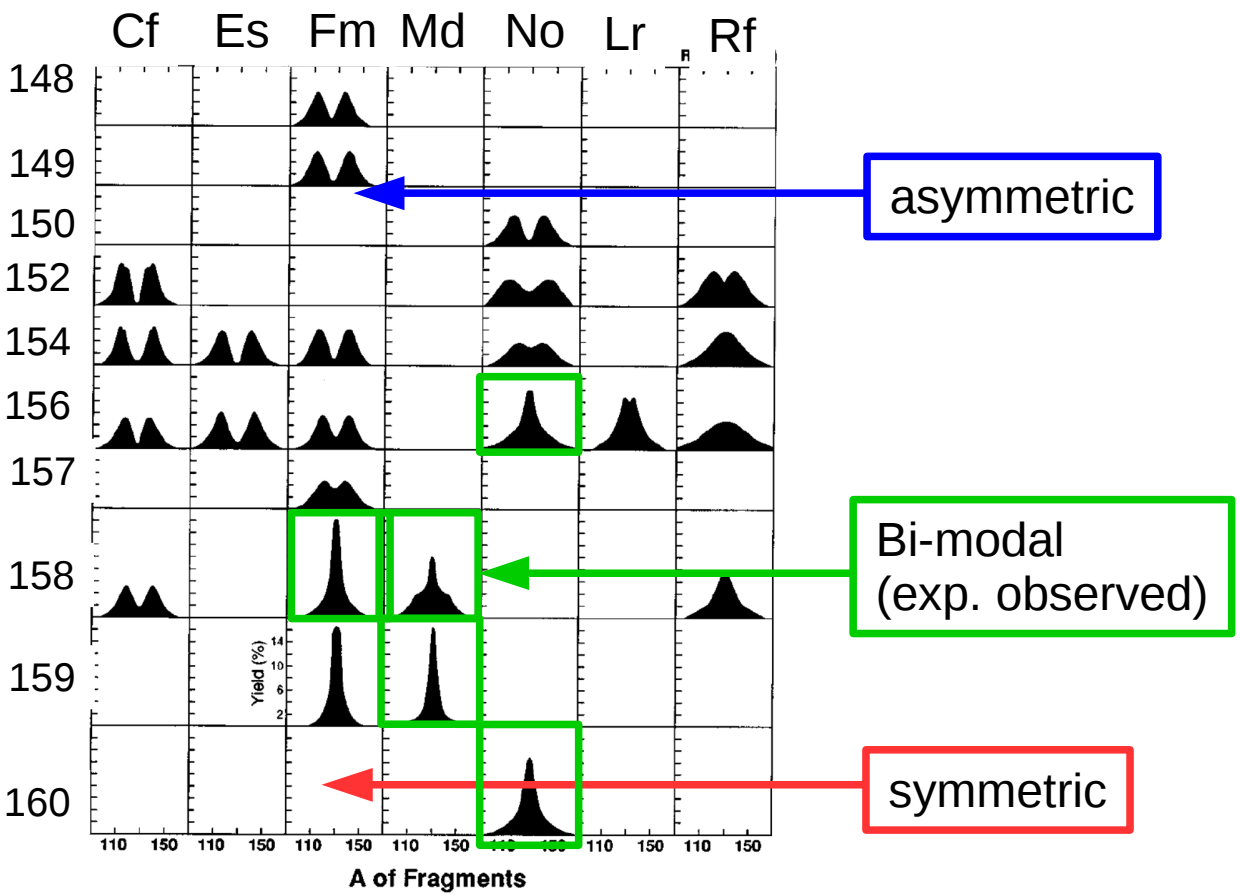
Total kinetic energy



Yu. Ts. Oganessian, J. Phys. G, Nucl. Part. Phys. 34, R165 (2007)

Fission characteristics

Mass distribution of fragments



D.C. Hoffman, Nucl. Phys. A. 502, 21c-40c (1989).

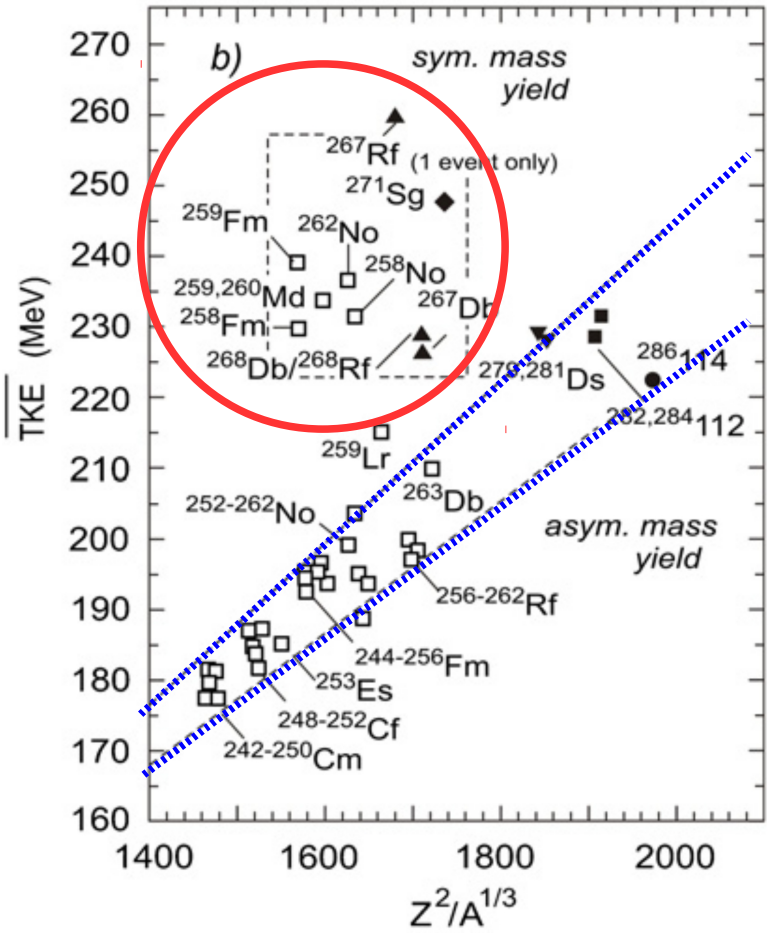
Bimodal fission “classical cases”

^{258}Fm, ^{259,260}Md or ^{258,262}No

E.K. Hulet et al., Phys.Rev.Lett. 56, 313 (1986)

J. F. Wild, et al., J. Alloy. Comp. 213, 86 (1994)

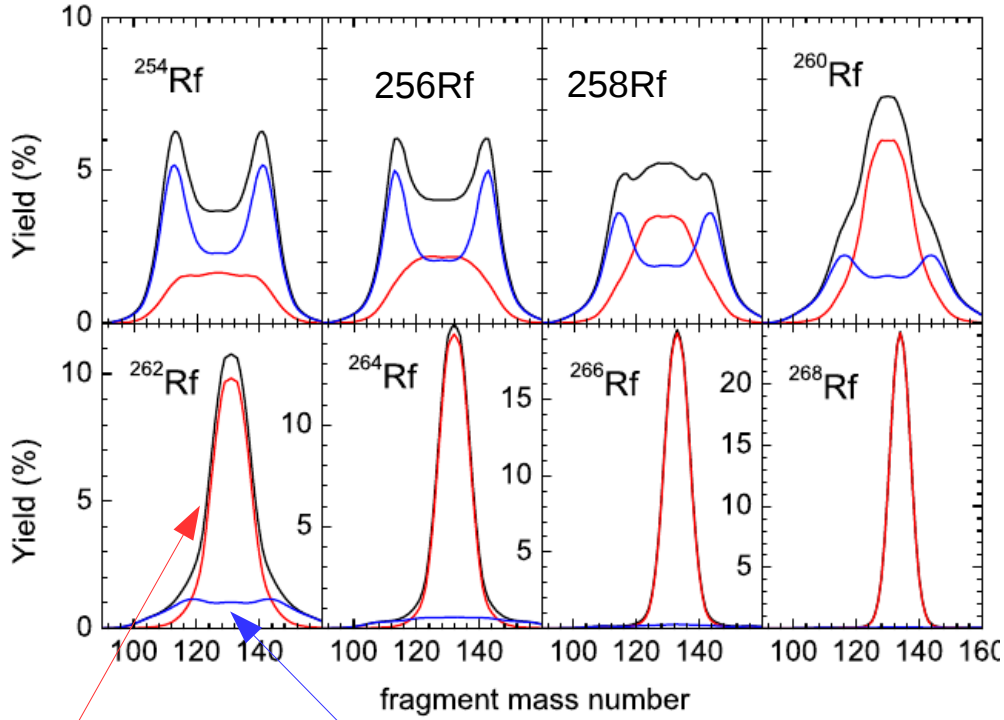
Total kinetic energy



Yu. Ts. Oganessian, J. Phys. G, Nucl. Part. Phys. 34, R165 (2007)

TKE vs. mass distribution

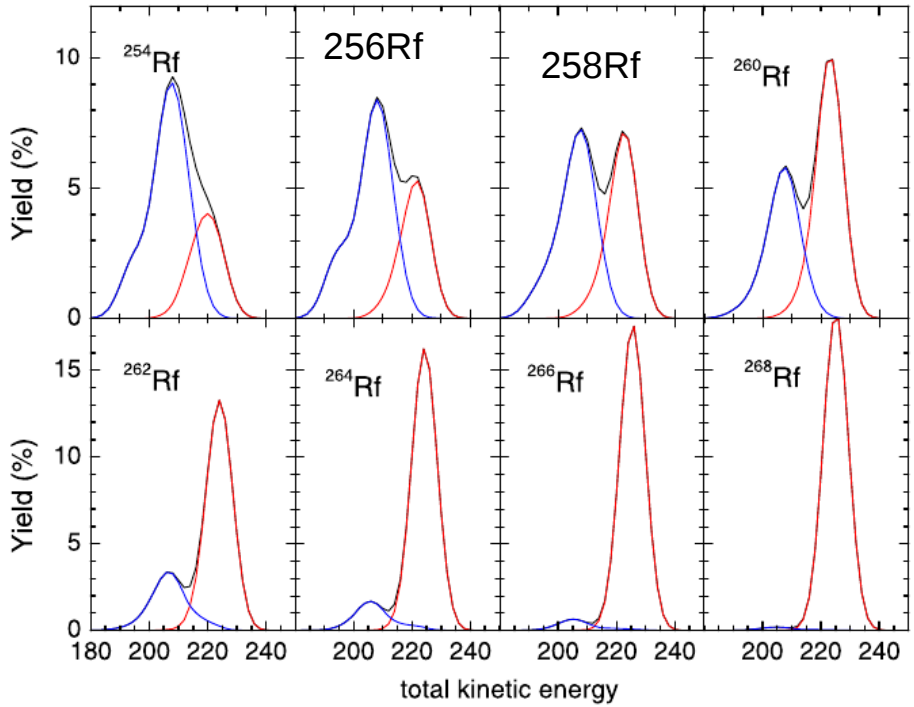
Mass distribution of fragments



compact

elongated

Total kinetic energy

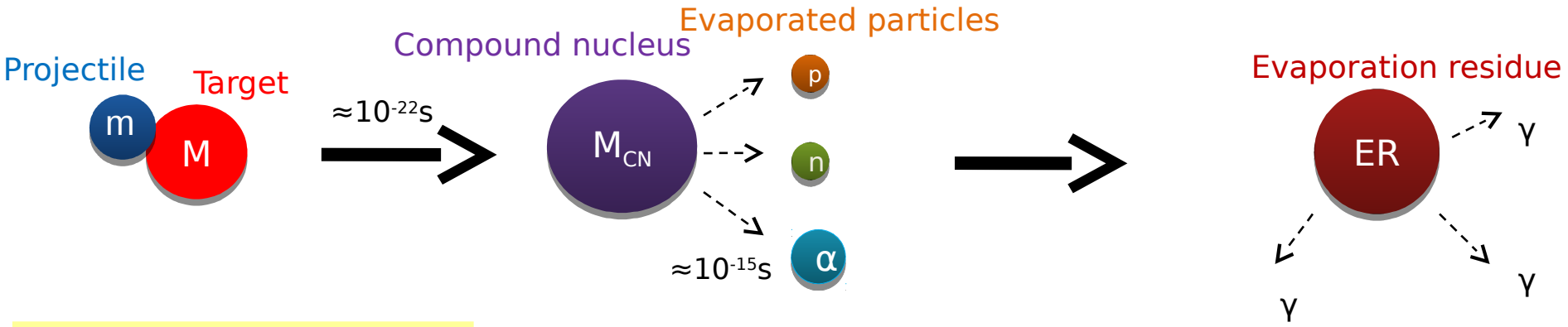


N. Carjan et al., Nucl. Phys. A 942, 97 (2015).

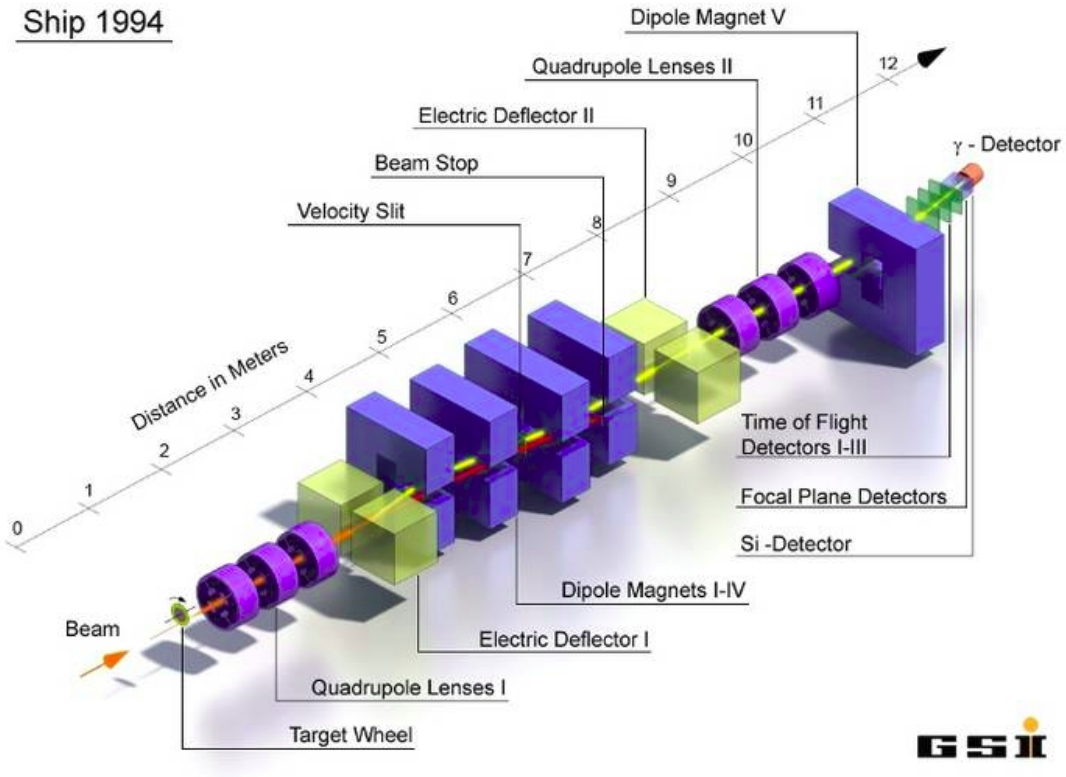
We have **improved experimental data** on SF of ^{255,256,258}Rf

- Do we see any sign of change in fission mode?
  - Study of TKE can give us a hint

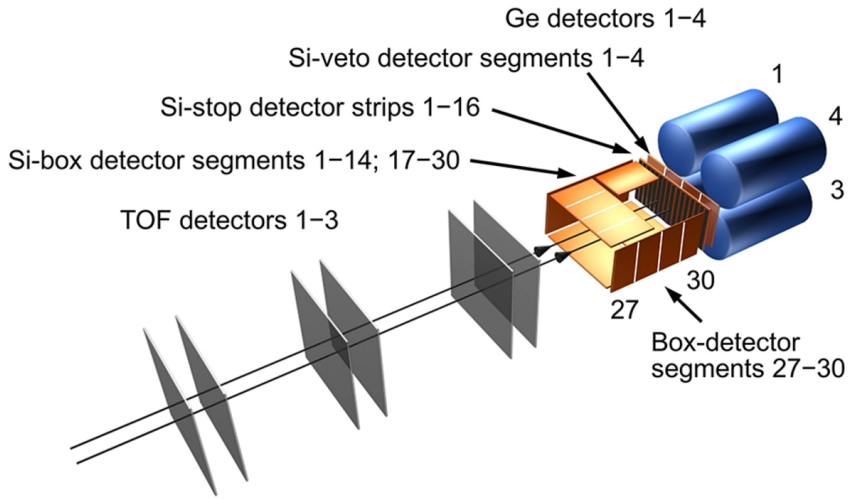
Production and detection

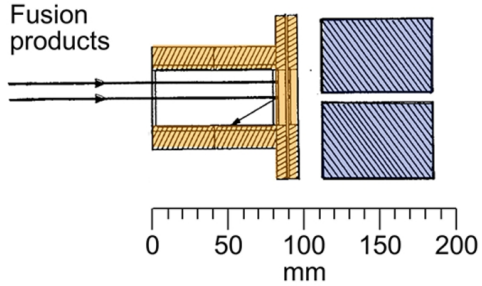


Separator for Heavy Ion reaction Products

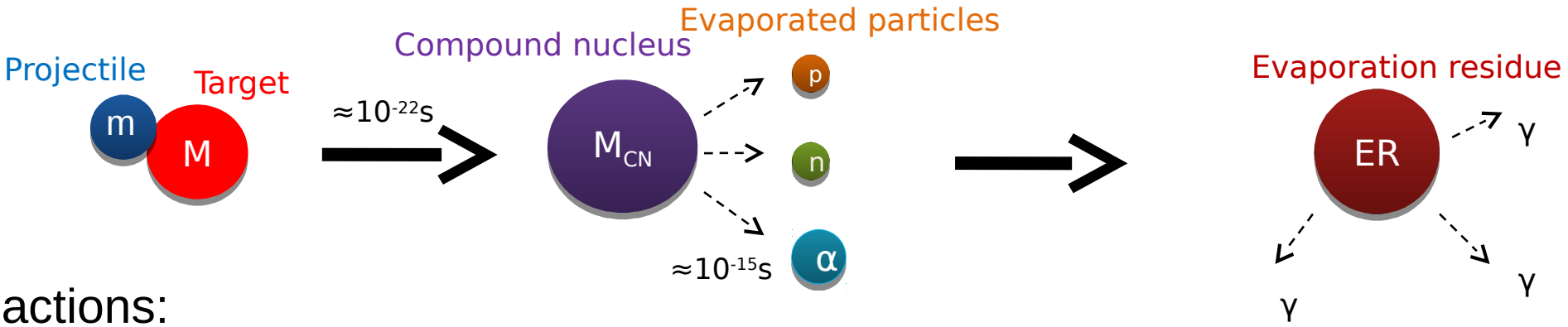


Detectors





Production and detection

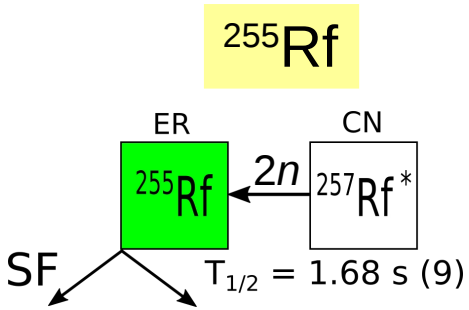


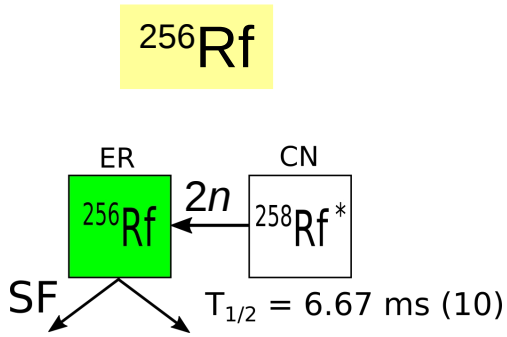
Reactions:

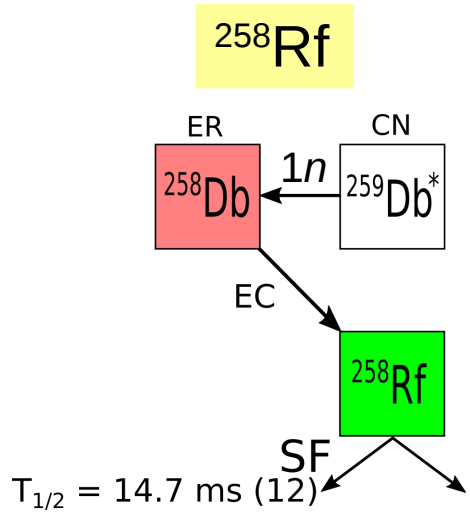
$^{50}Ti + {}^{207}Pb \rightarrow {}^{257}Rf^{*} \rightarrow {}^{255}\mathbf{Rf} + (2n)$

$^{50}Ti + {}^{208}Pb \rightarrow {}^{258}Rf^{*} \rightarrow {}^{256}\mathbf{Rf} + (2n)$

$^{50}Ti + {}^{209}Bi \rightarrow {}^{259}Db^{*} \rightarrow {}^{258}Db + (1n) \xrightarrow{EC} {}^{258}\mathbf{Rf}$



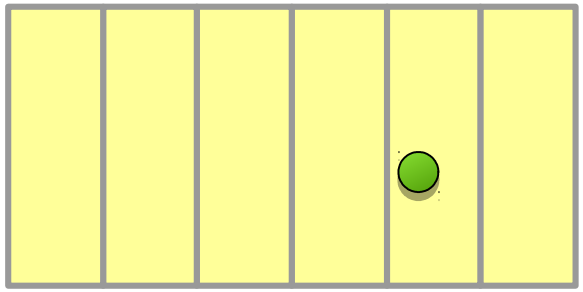




(gated on CEs and X-rays)

Range of fragments

Implantation of ER to STOP detector



“beam” view

Side view

Implantation depth
(6–7µm)

ER Implantation direction

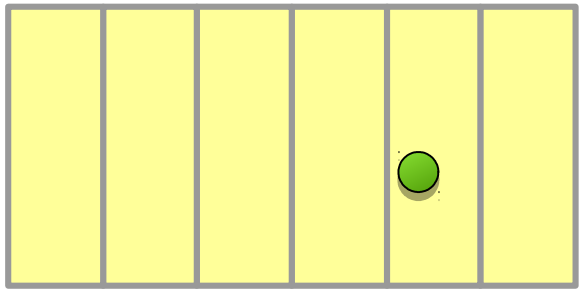
STOP detector

Dead layer
(11.6 µg/cm^2)

Range of fragments
(~20µm)

Range of fragments

Implantation of ER to STOP detector



“beam” view

Side view

How to reconstruct the energy of escaped fragments?

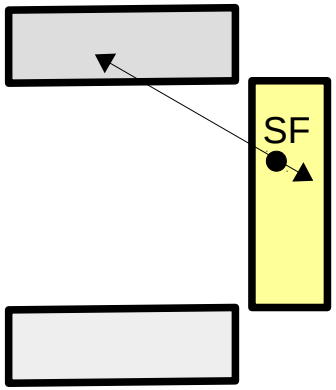
ER Im

Dead layer
(11.6 μg/cm^2)

Range of fragments
(~20μm)

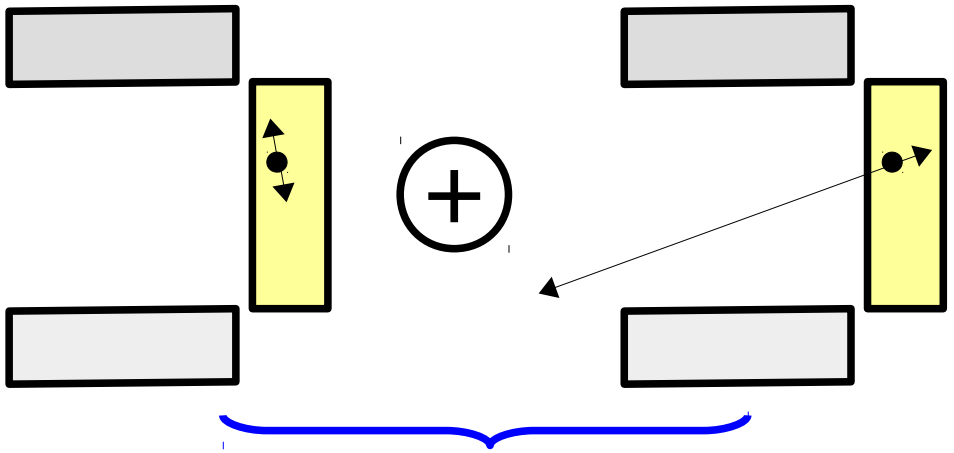
3 possible cases

Escape to BOX detector



Both fragments in STOP

One fragment complete escape



Impossible to separate !!

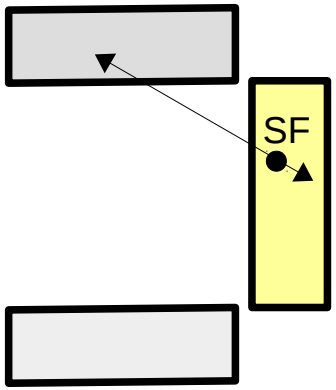
- 30% of all events
- Two dead layers
- Energy reconstruction possible

➔ STOP + BOX

- 70% of all events (50+20)
- 20% events with incomplete energy

3 possible cases

Escape to BOX detector



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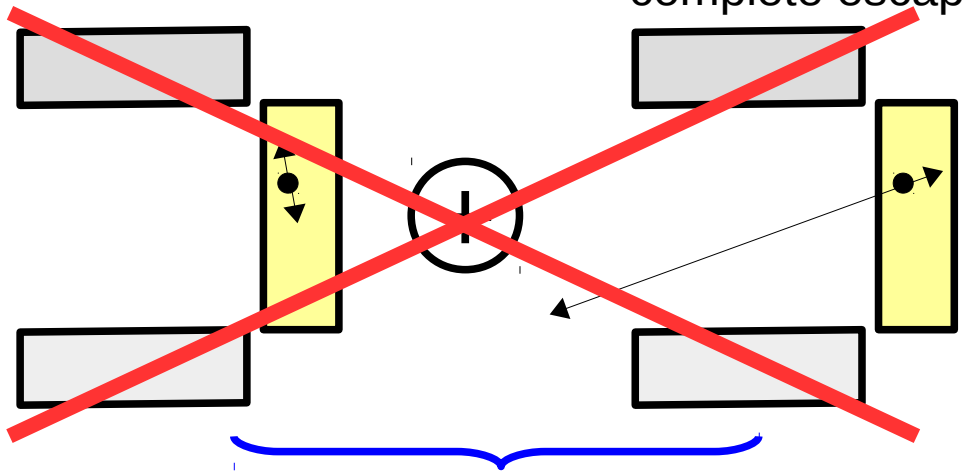

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  ➔ STOP + BOX amplitude

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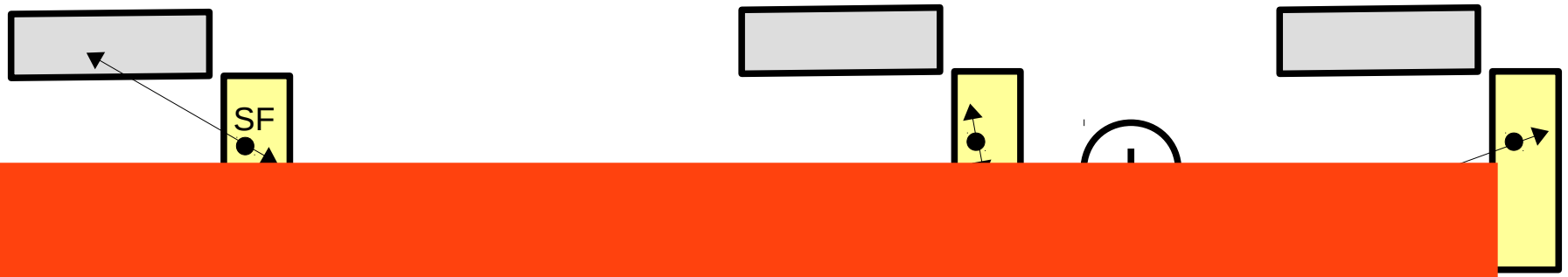
3 possible cases

Escape to BOX detector

Both fragments in STOP

One fragment complete escape



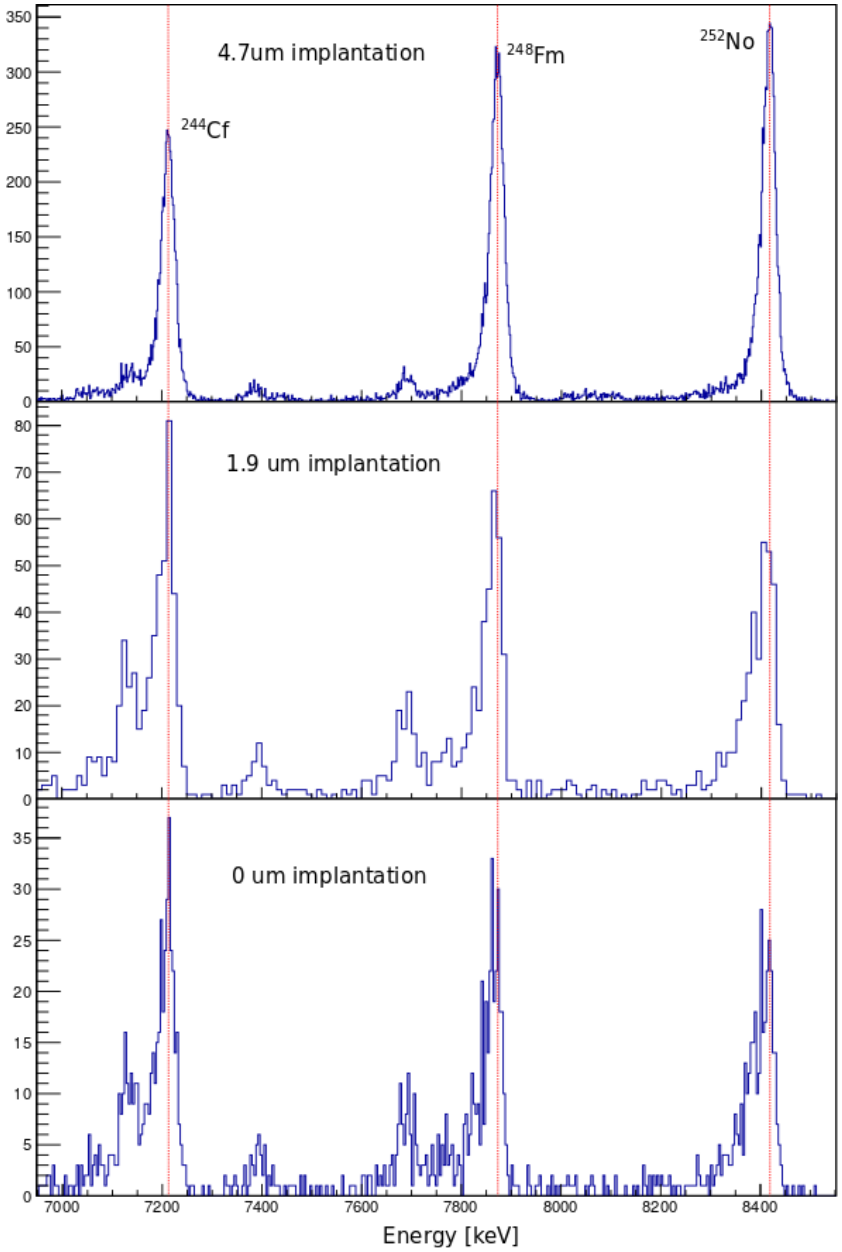
What about the detector response?

- 30% of all events
- Two dead layers
- Energy reconstruction possible

  ➔ STOP + BOX amplitude

- 70% of all events (50+20)
- 20% events with incomplete energy

Detected TKE



Calibration by **alpha lines =**

= Energy deficit in detected fragments' TKE

Pulse height defect

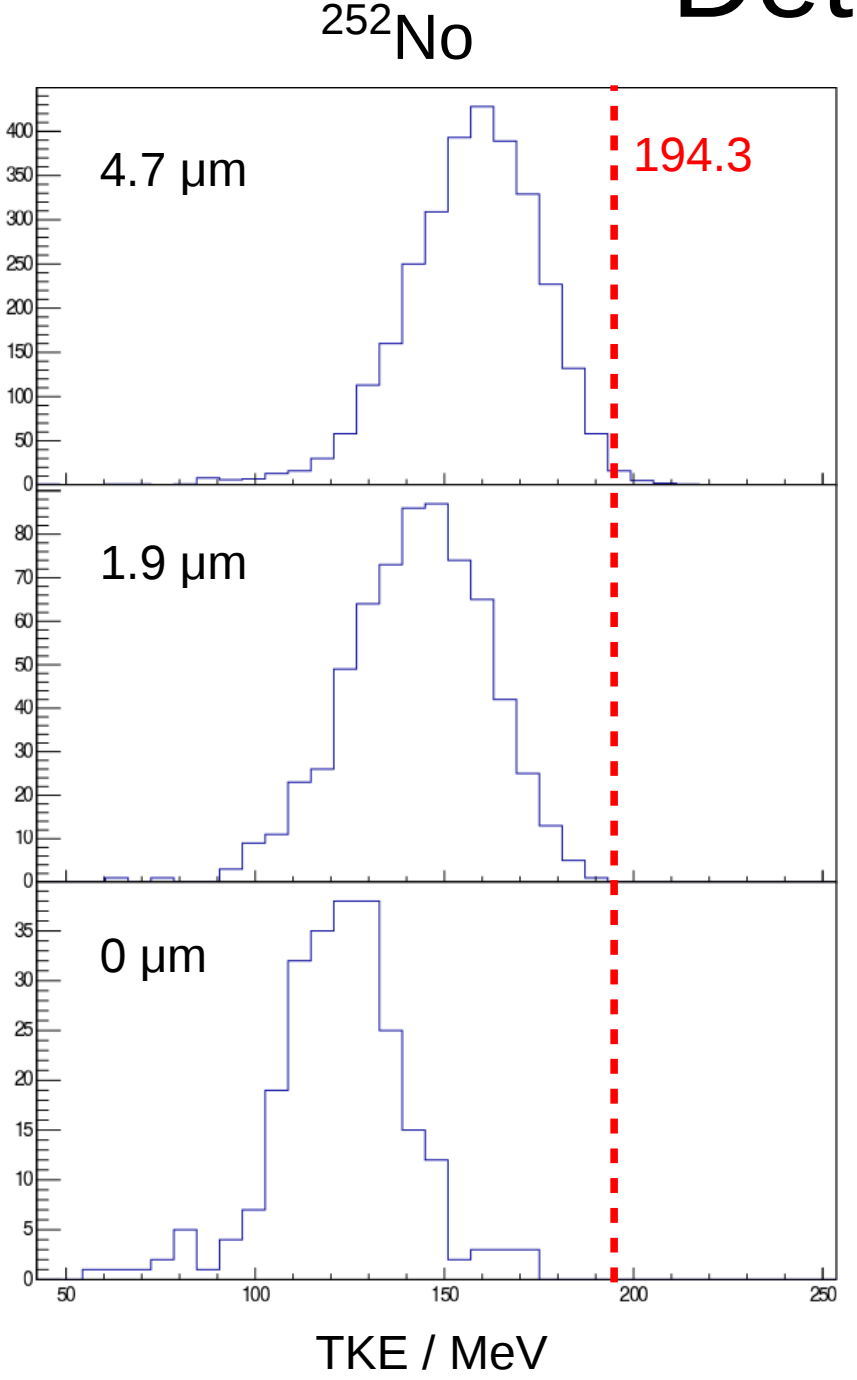
Difference in detected energy between light (e.g. alphas) and heavy ions (e.g. fragments) with the same kinetic energy

- Dead layer losses
- Not-ionizing interactions with atoms in detector
- Recombination of e-h

➔ **strongly depends on implantation depths**

Corrections needed!!!

Detected TKE



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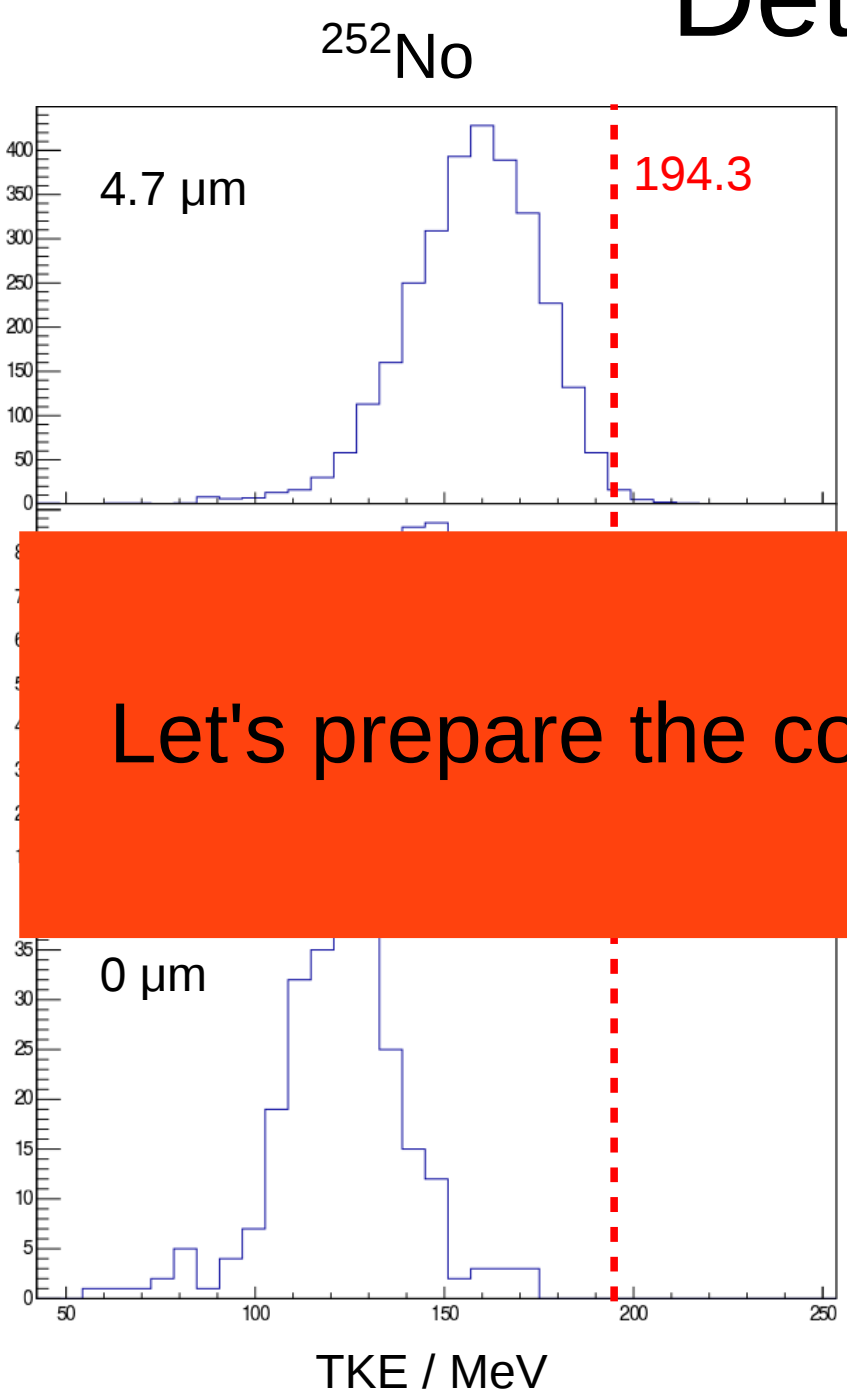


Calibration by **alpha lines =**

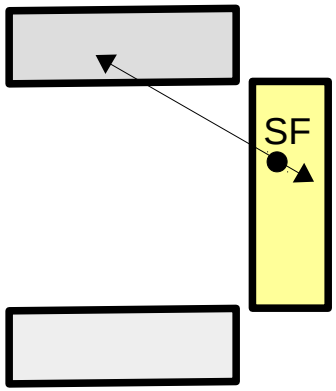
= Energy deficit in detected fragments' TKE

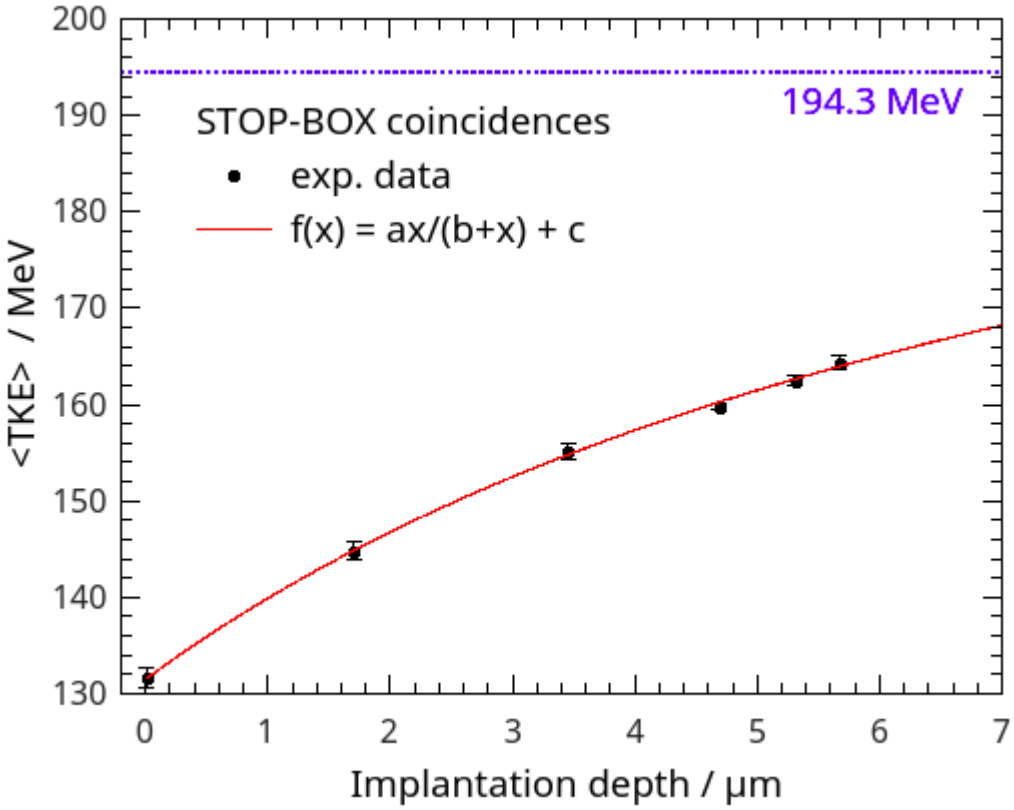
Let's prepare the correction to this energy deficit!

- Recombination of e-h
  - ➔ **strongly depends on implantation depths**

Corrections needed!!!

Energy deficit in detected TKE (^{252}No)





P. Mosat, et al., Acta Phys. Pol. B49, 605 (2018)

Effect already studied on ^{252}No in 2006 at SHIP*

- Why ^{252}No?
  - Relatively high production cross-section
  - Known <TKE> = 194.3 MeV
  - Close to Rf isotopes in Z and N
  - Implanted in 6 different depths to STOP detector
  - TKE vs. impl. depth

We evaluated previously measured data on ^{252}No from 2006 and used LISE++ for impl. depths.

*K. Nishio, et al., AIP Conf. Proc. 891, 71 (2007)

*S. Hofmann, et al., Eur. Phys. J. A 32, 251 (2007)

*implantation depths calculated by **LISE++** (O. B. Tarasov and D. Bazin., Nucl. Instr. Meth. B 266, 4657 (2008).

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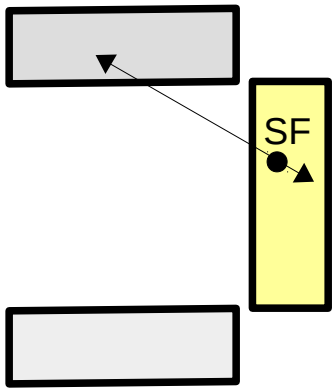

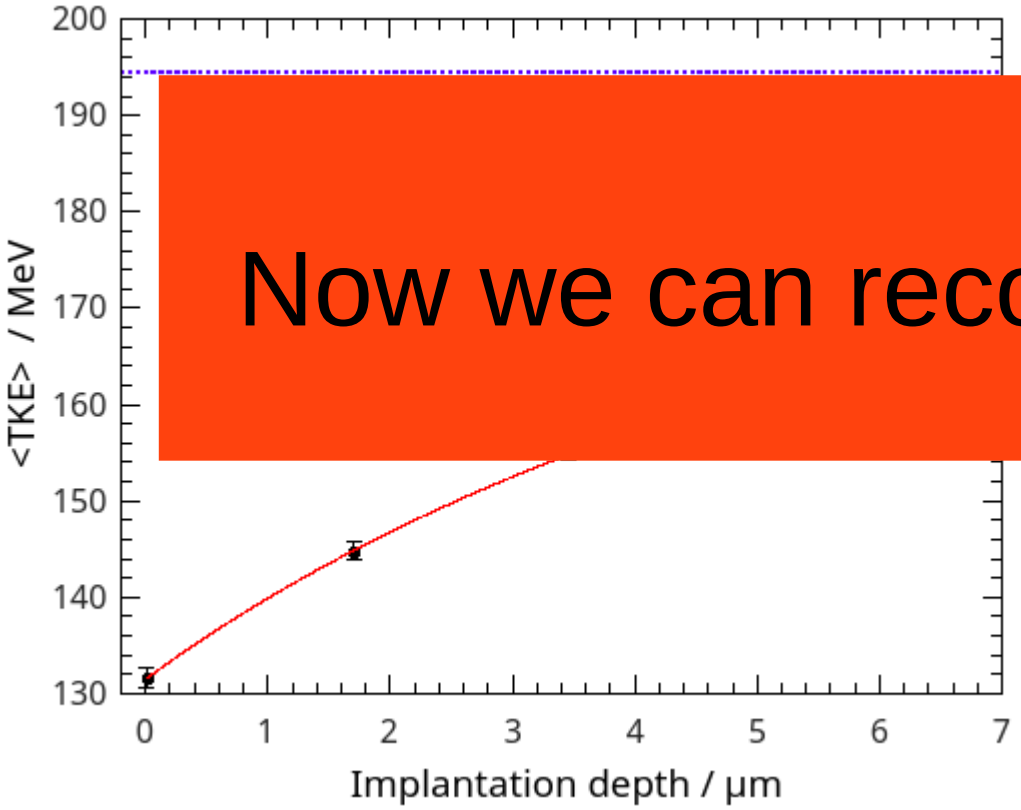

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  - Relatively high production cross-section
  - Known TKE = 194.3 MeV

etector

ata on impl.

Now we can reconstruct the TKE!

*K. Nishio, et al., AIP Conf. Proc. 891, 71 (2007)

*S. Hofmann, et al., Eur. Phys. J. A 32, 251 (2007)

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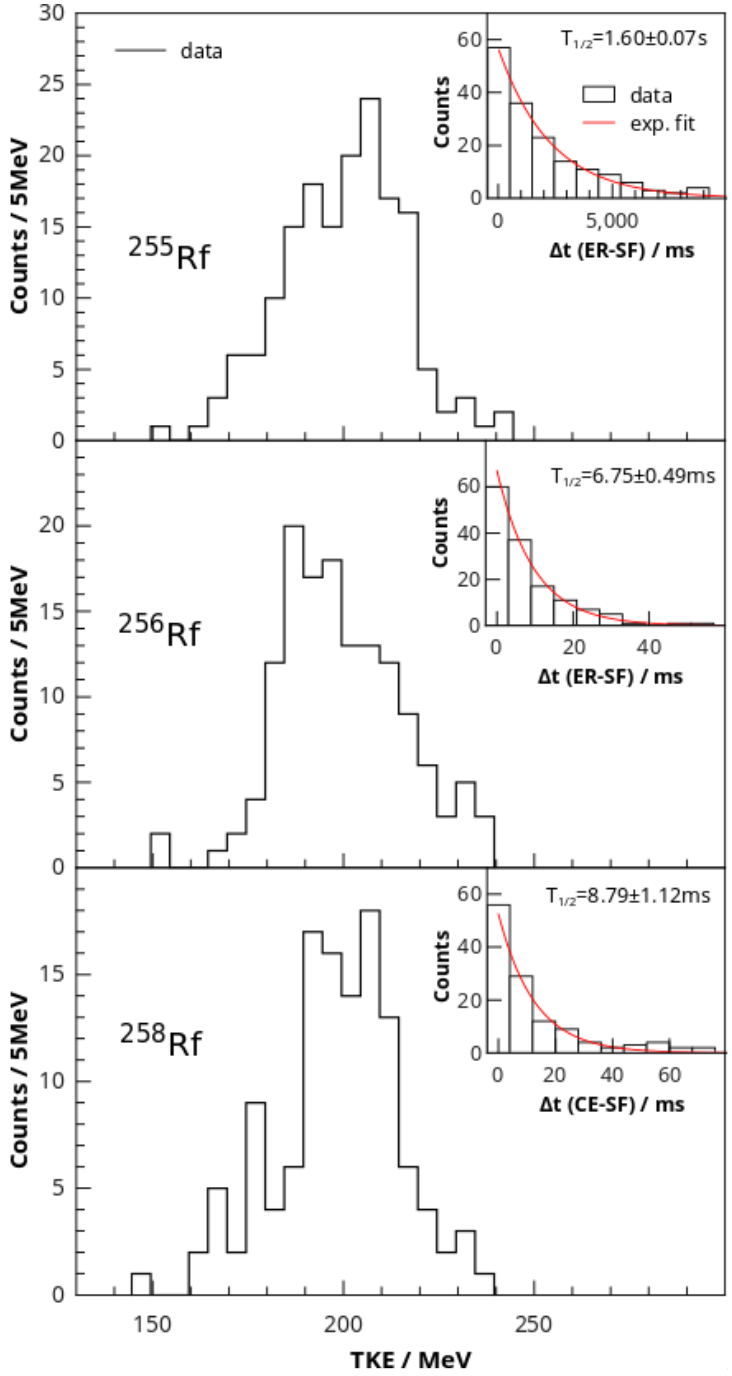
Total kinetic energy of ^{255,256,258}Rf



Total kinetic energy of ^{255,256,258}Rf

^{255}Rf

<TKE> = 201.2 ± 0.9 MeV

FWHM = 31.3 ± 1.7 MeV

^{256}Rf

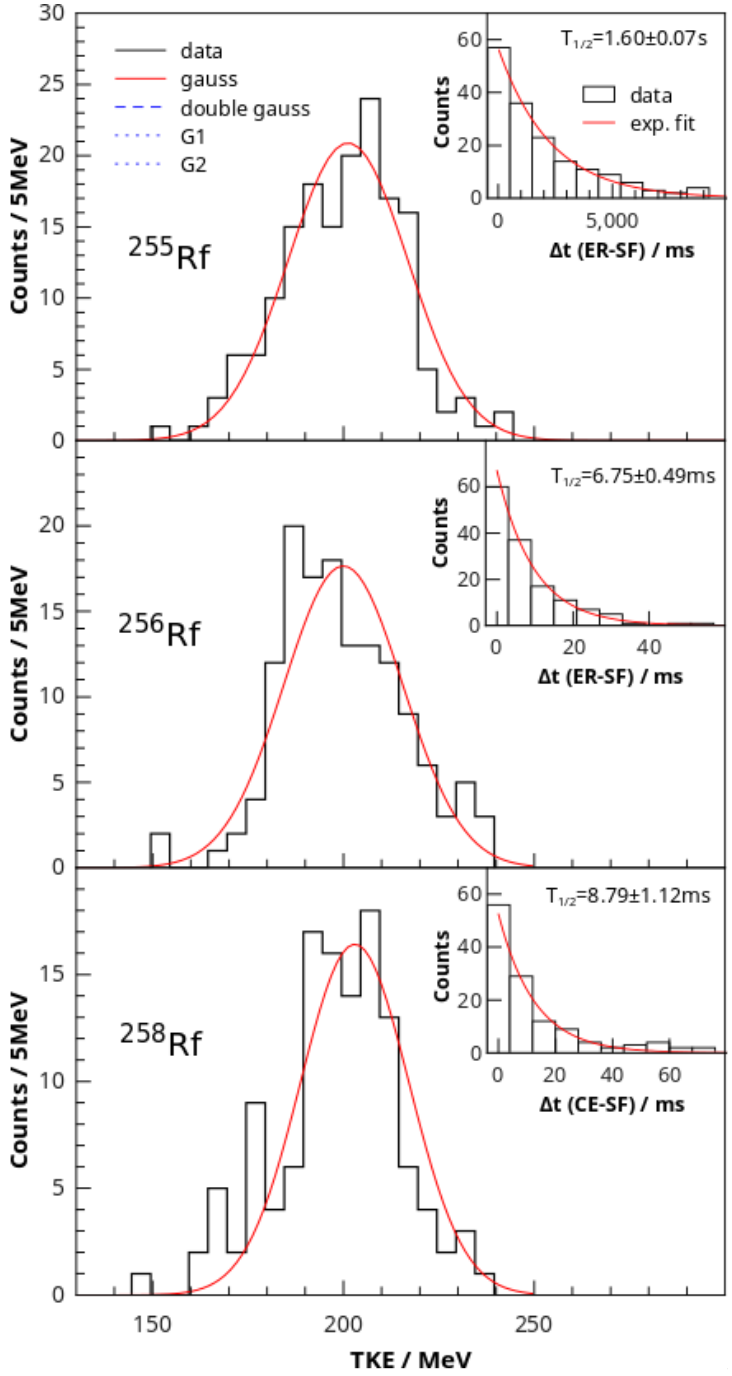
<TKE> = 197.5 ± 1.0 MeV

FWHM = 31.2 ± 2.0 MeV

^{258}Rf

<TKE> = 198.5 ± 1.1 MeV

FWHM = 28.4 ± 2.2 MeV



Total kinetic energy of ^{255,256,258}Rf

^{255}Rf

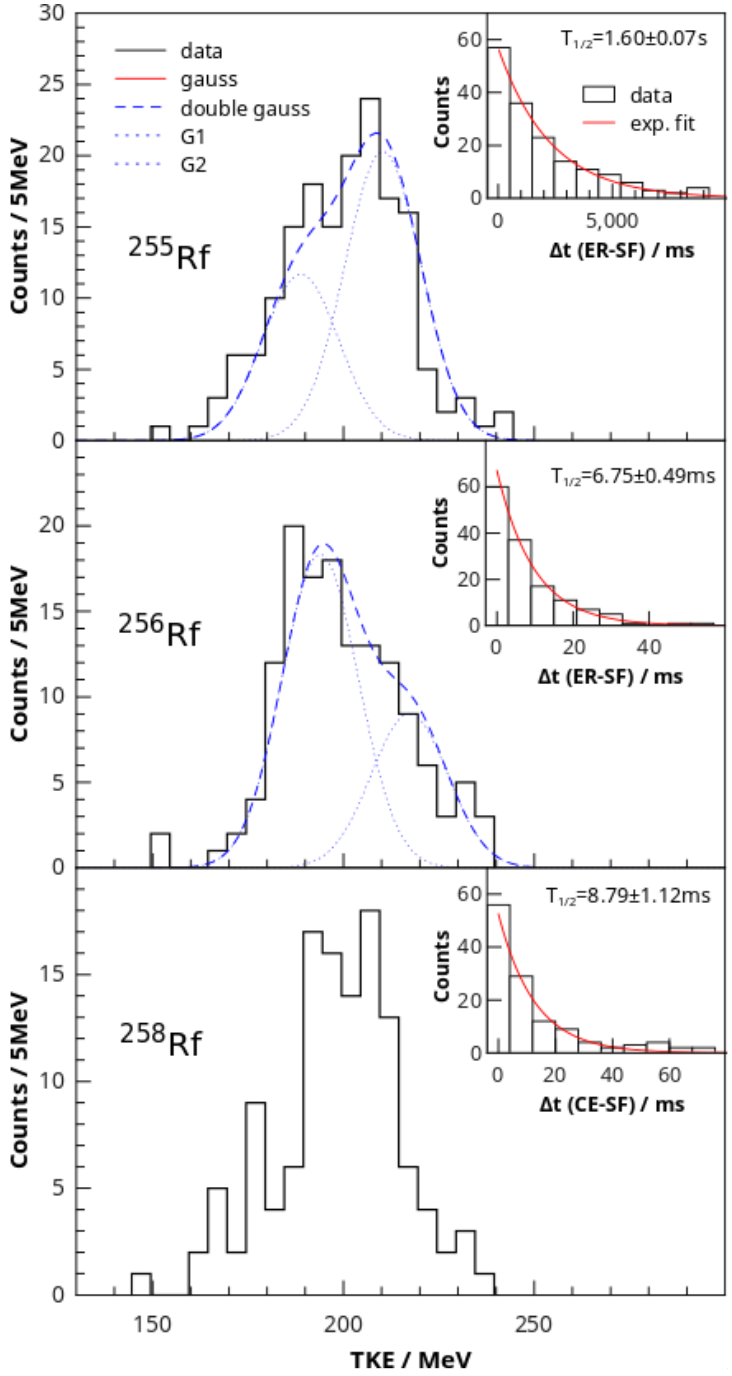
$\langle TKE \rangle_L$ = 188 ± 10 MeV $\langle TKE \rangle_H$ = 210 ± 4 MeV

$FWHM_L$ = 20 MeV (fixed) $FWHM_H$ = 20 MeV (fixed)

^{256}Rf

$\langle TKE \rangle_L$ = 194 ± 3 MeV $\langle TKE \rangle_H$ = 217 ± 4 MeV

$FWHM_L$ = 20 MeV (fixed) $FWHM_H$ = 20 MeV (fixed)



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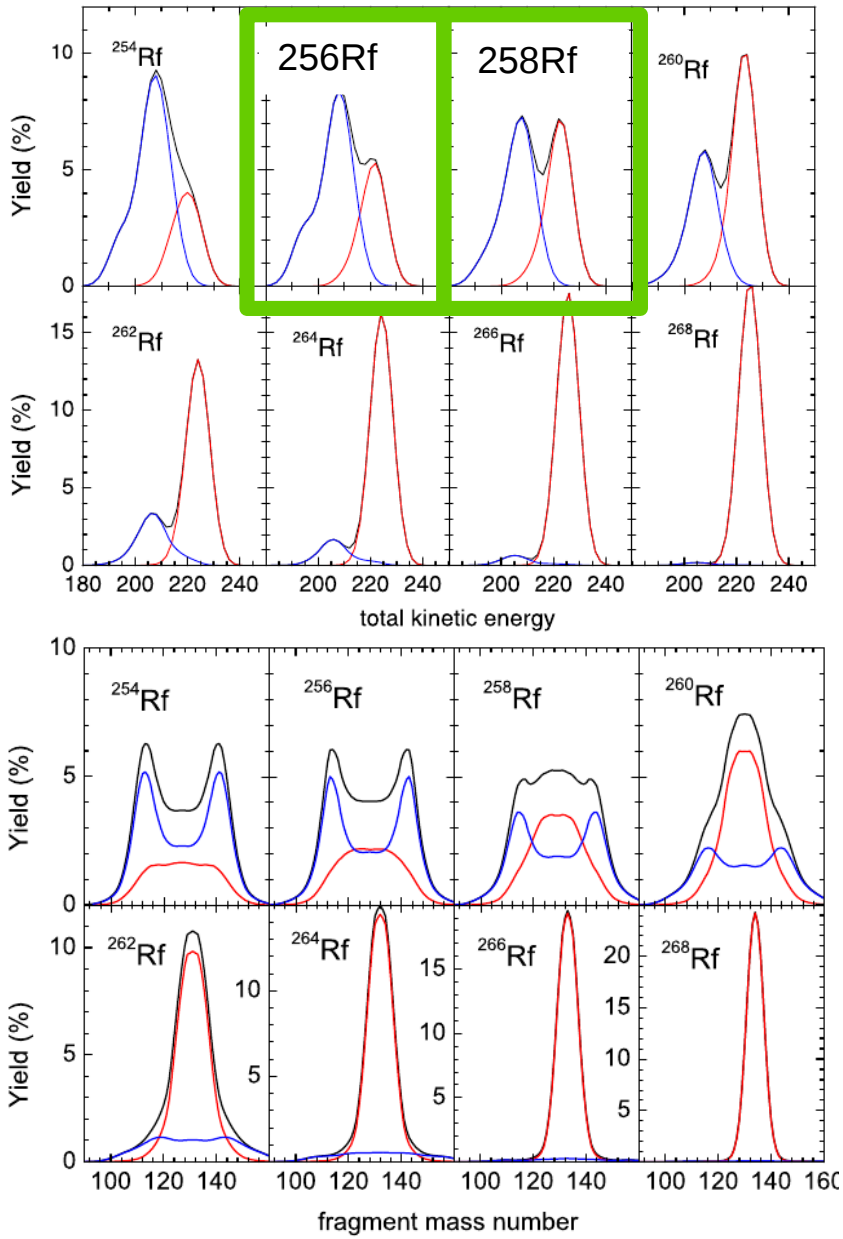
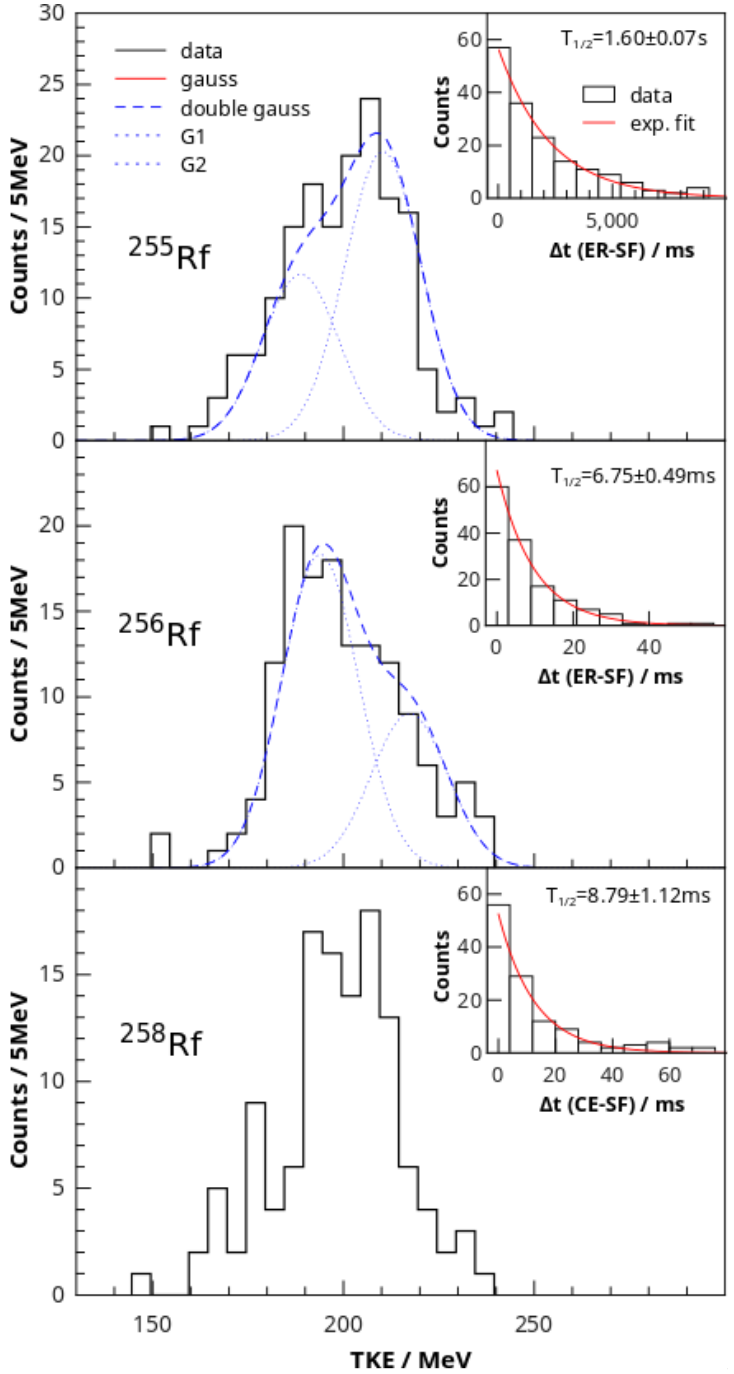




N. Carjan et al., Nucl. Phys. A 942, 97 (2015).

Summary

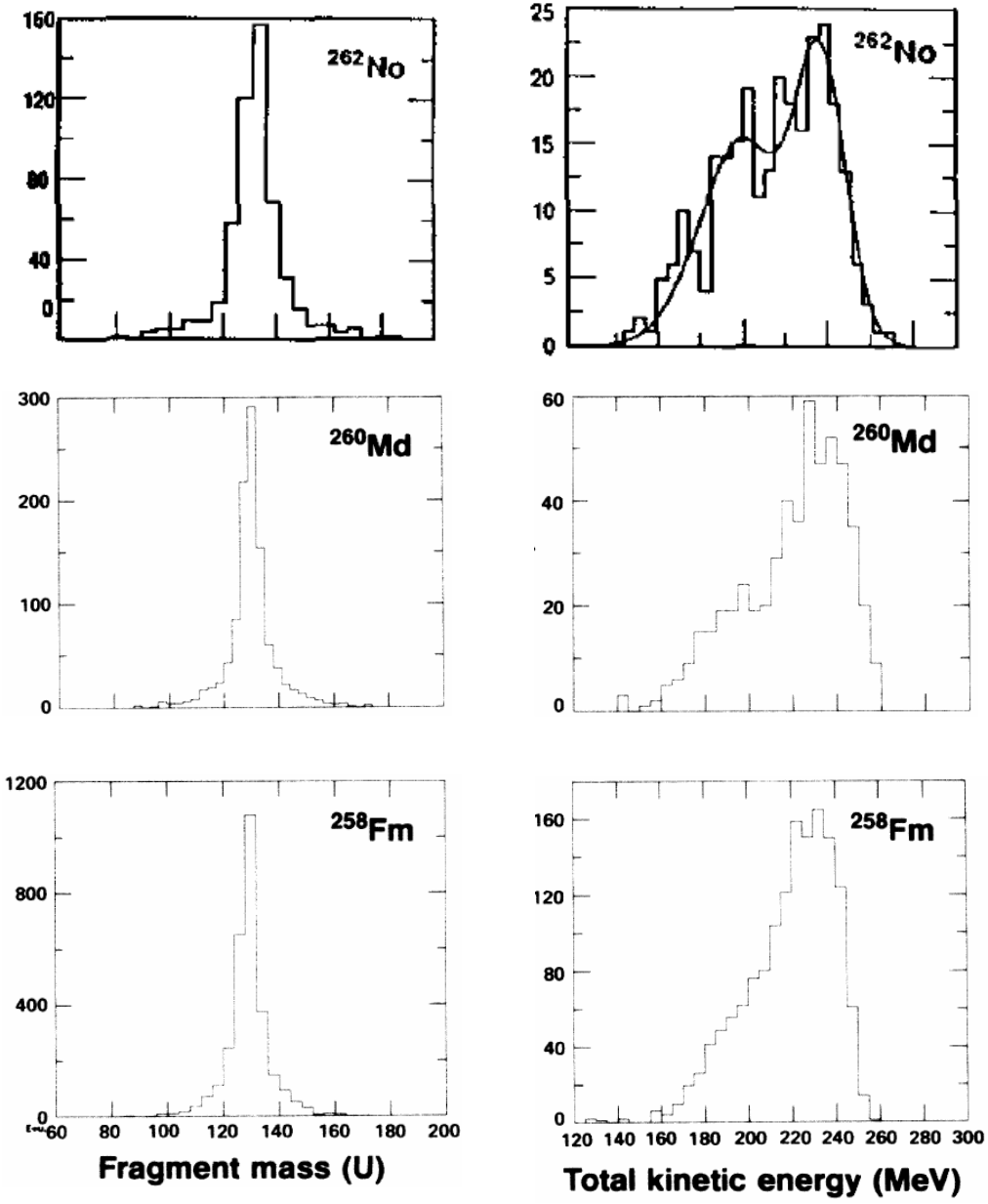
- $^{255, 256, 258}$Rf produced in fusion-evaporation reactions with ^{50}Ti beam and $^{207, 208}$Pb and ^{209}Bi targets

- Correction to pulse-height-defect determined using exp. data for TKE of ^{252}No and ER implantation calculation by LISE++

- Evaluation of <TKE> and study of TKE distributions for $^{255, 256, 258}$Rf

Thank you

Bi-modal fission



"classical cases"

^{258}Fm, ^{259,260}Md or ^{258,262}No

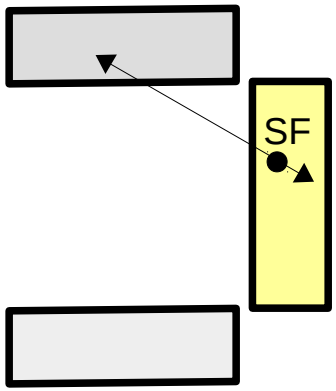
E.K. Hulet et al., Phys.Rev.Lett. 56, 313 (1986)

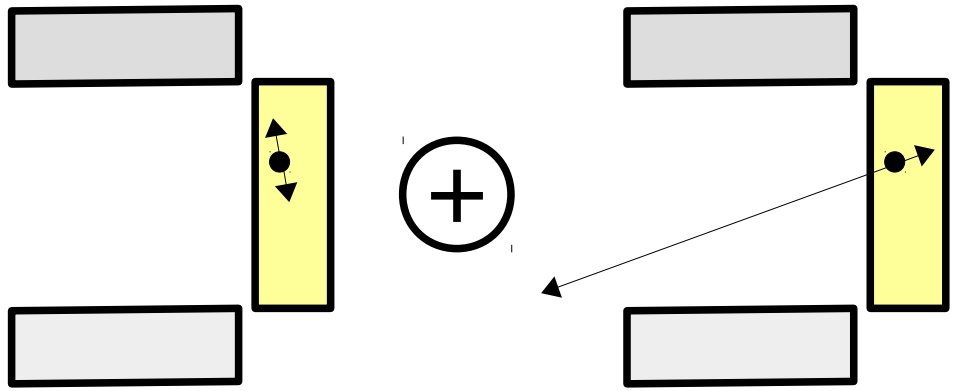
J. F. Wild, et al., J. Alloy. Comp. 213, 86 (1994)

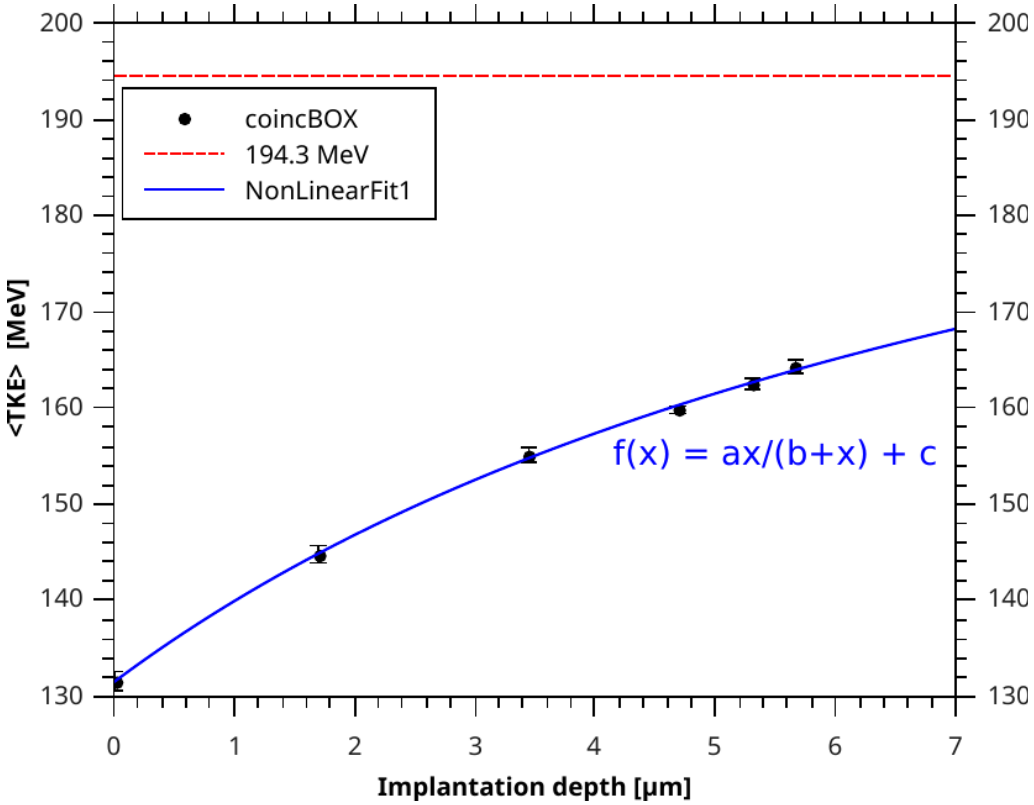
TKE distributions for Rf isotopes:

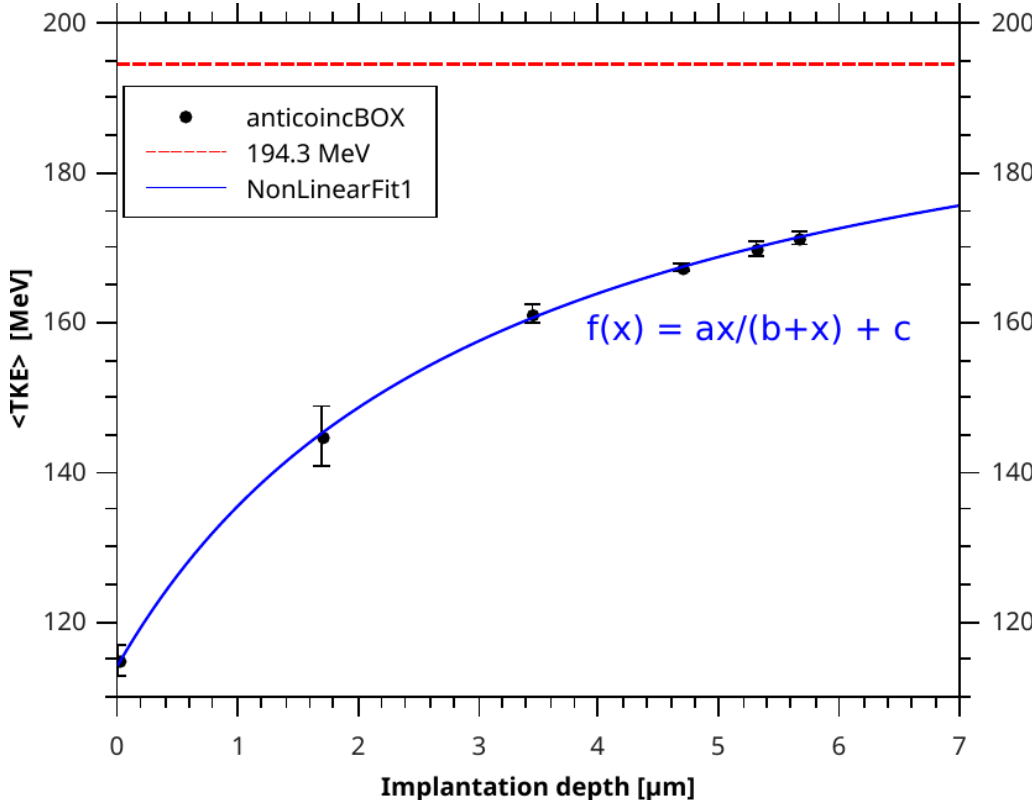
- ^{260}Rf, ^{258}Rf – reasonable statistics (no bi-modal fission clearly observed)
- ^{255}Rf, ^{256}Rf – very limited statistics (<30 counts)

Energy deficit in detected TKE (^{252}No)





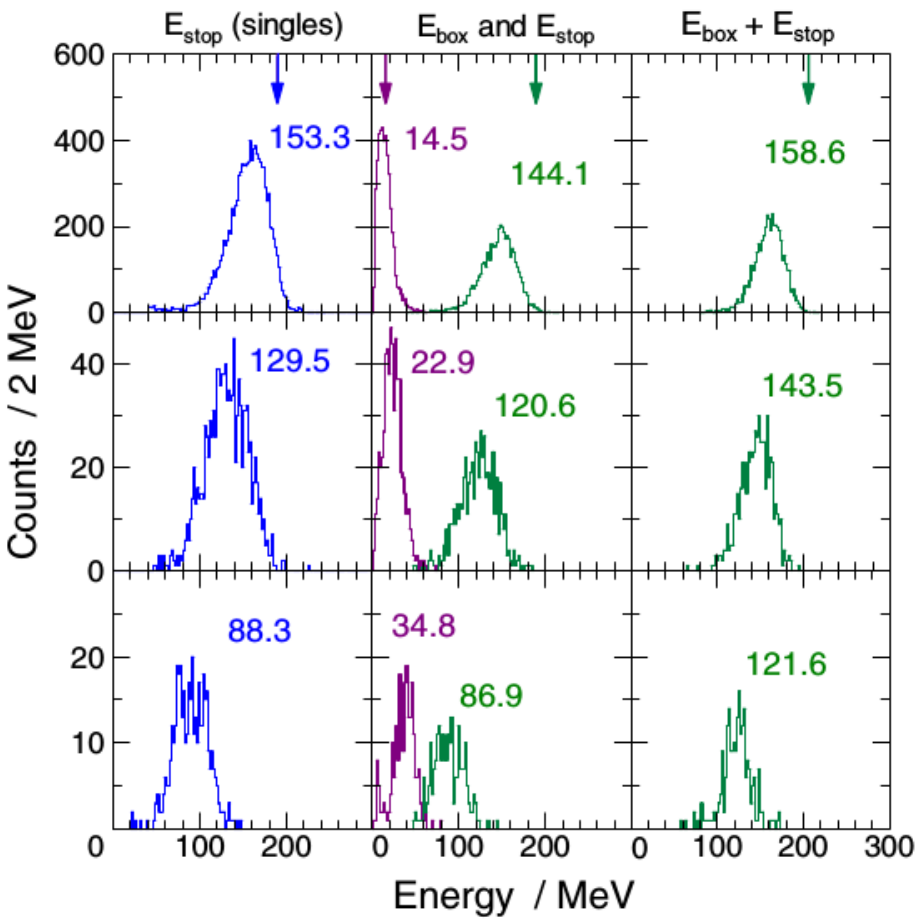


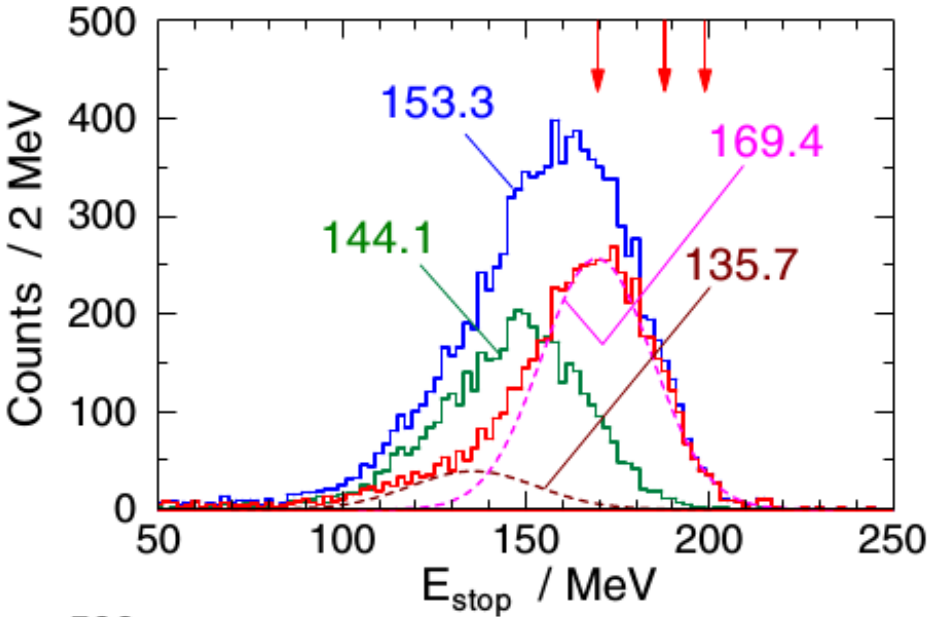


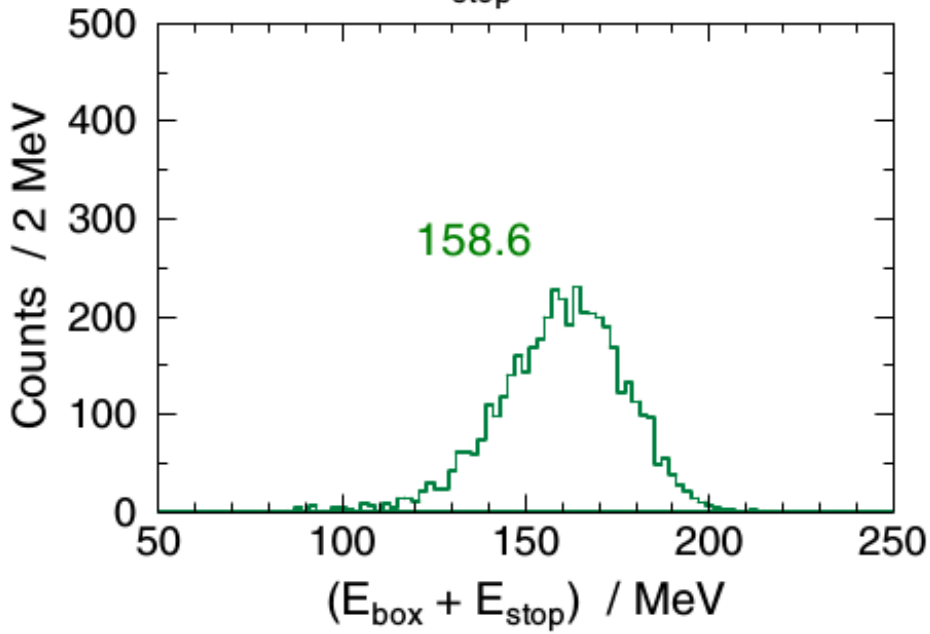
*implantation depths calculated by **LISE++** [O. B. Tarasov and D. Bazin. In: Nucl. Instr. Meth. B 266 (2008), p. 4657].

P. Mosat, et al., Acta Phys. Pol. B 49, 605 (2018)

252No







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