



FISSION 2026

7th Workshop
on Nuclear
Fission and
Spectroscopy
of Neutron-
Rich Nuclei



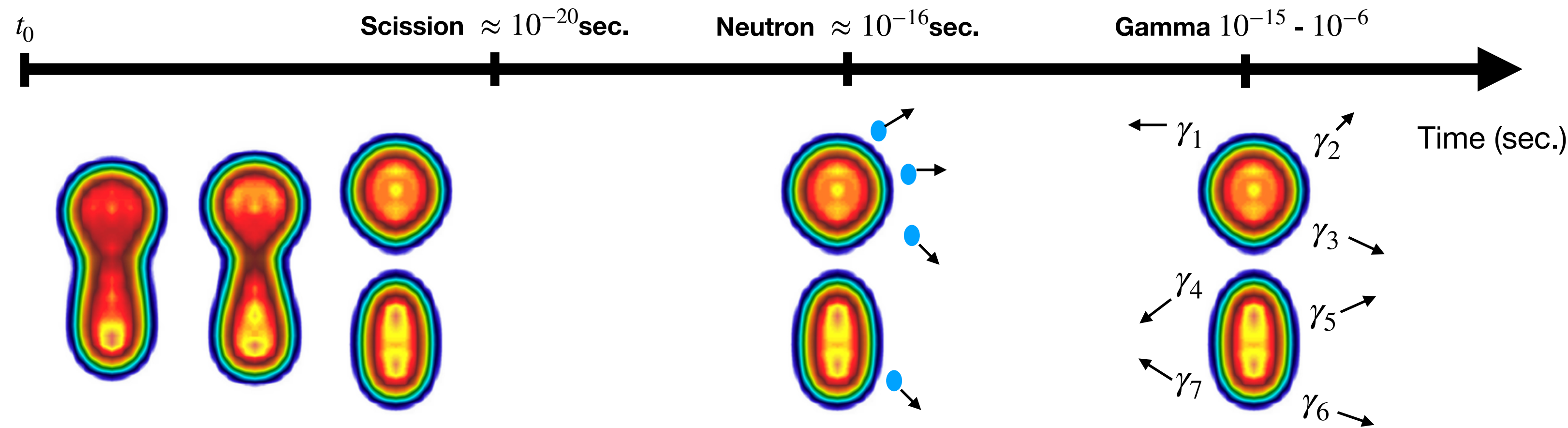
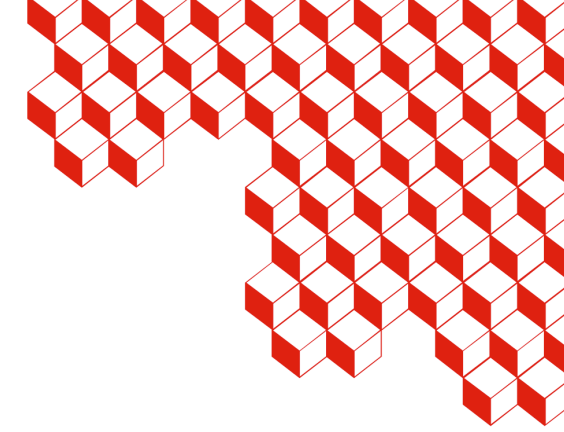
Excitation energy, angular momentum and deformation of fission fragments

L. Gaudefroy - CEA - Saclay

A. Francheteau, O. Roig, G. Scamps, V. Méot, A. Ebran, S. Hilaire, J.-F. Lemaître

March 2026

Studying the decay of the fragments?



A. Bulgac et al., PRL **116**, 122504 (2016)

Fission numbers for ^{252}Cf

$$\bar{Q} \sim 218 \text{ MeV}$$

$$\overline{\text{TKE}} = 184 \text{ MeV}$$

$$\overline{\text{TXE}} = \bar{Q} - \overline{\text{TKE}} \sim 34 \text{ MeV}$$

$$\bar{E}_n = \bar{\nu} * (\bar{B}_n + \bar{\eta}) = 27 \text{ MeV}$$

$$\bar{M}_\gamma = 8.4 \gamma / \text{fis}$$

$$\bar{J}_l + \bar{J}_H \sim 10 - 15 \hbar$$

An experimental challenge to :

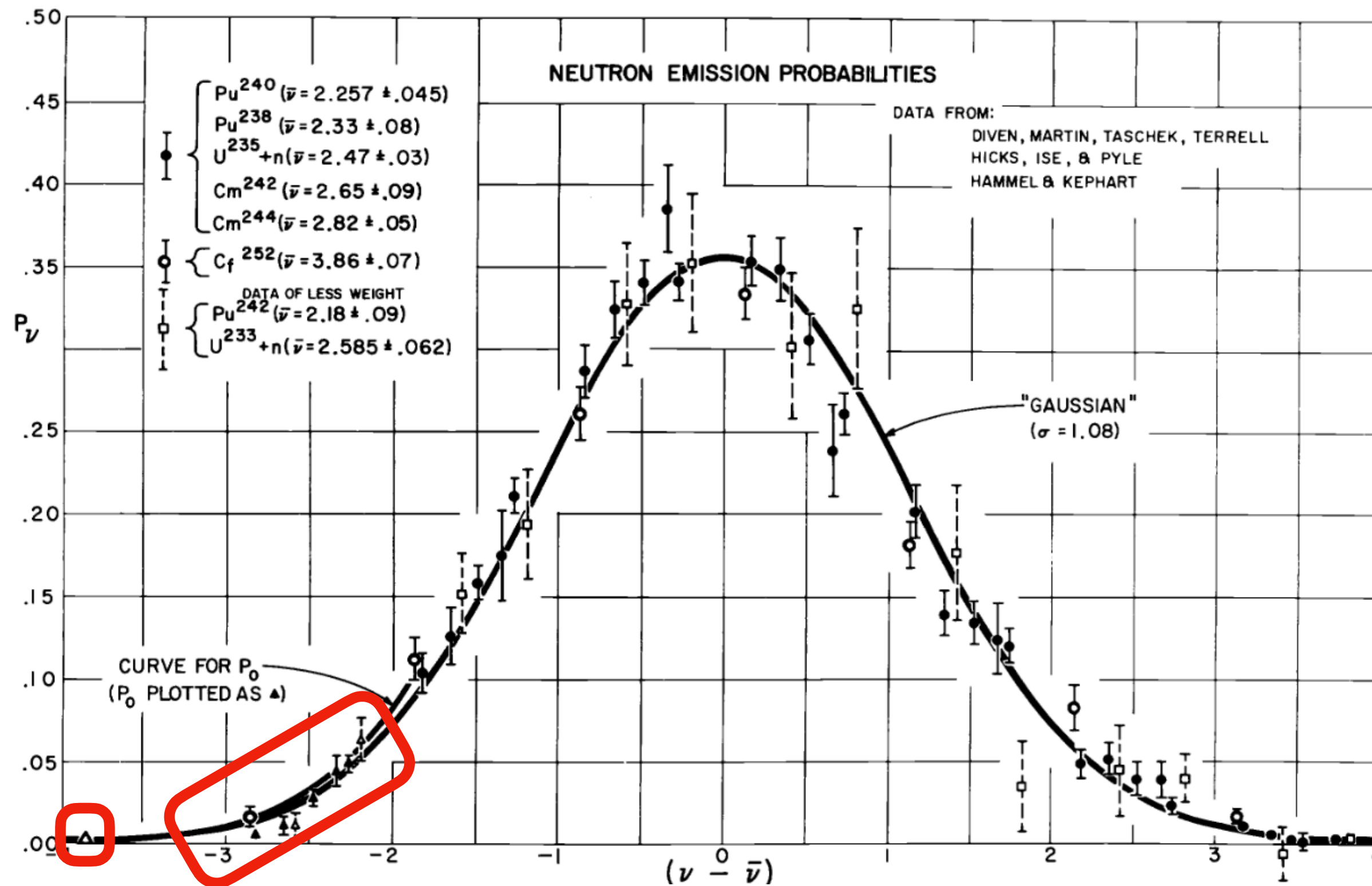
- Identify the fragments
- Correctly measure their decay



The neutronless side of fission



J. Terrell, Phys. Rev. **108** 783 (1957)

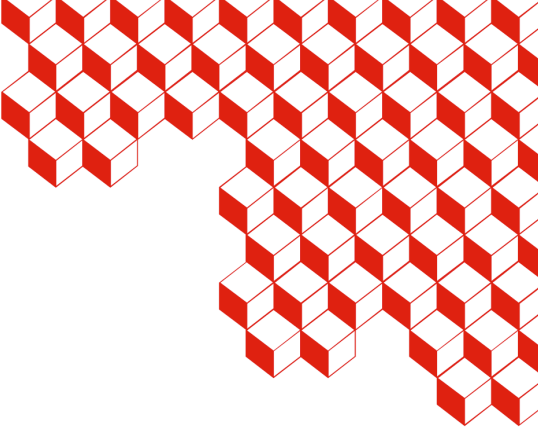


Huge experimental simplification for fragment ID

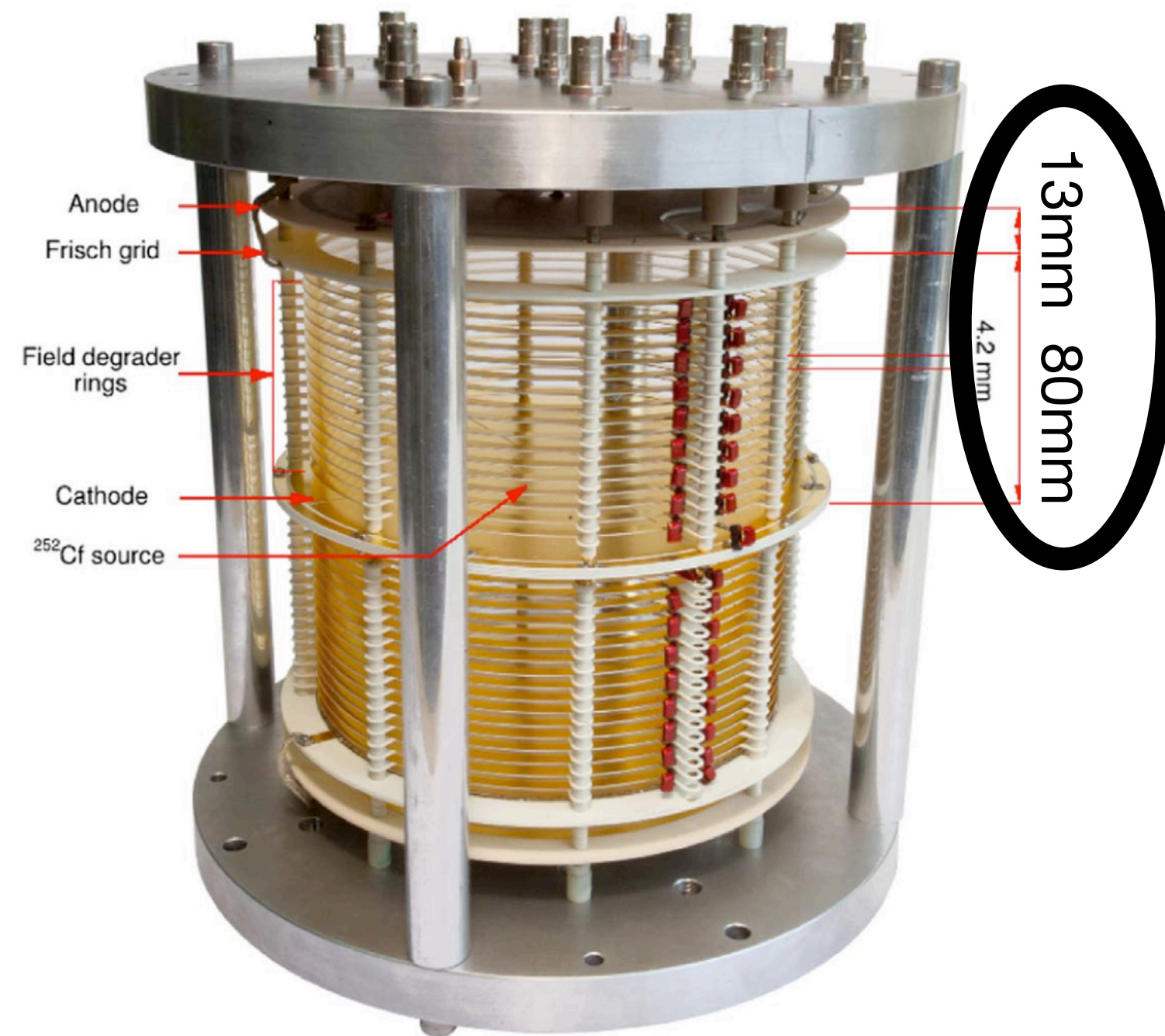
- ⇒ Possibility of compact FF detector
- $KE_L/KE_H = A_H/A_L$
- ⇒ Decay = only gamma rays
- ⇒ Highly efficient gamma array

$P_{\nu=0}$: Small Probability of occurrence

Studying neutronless fission



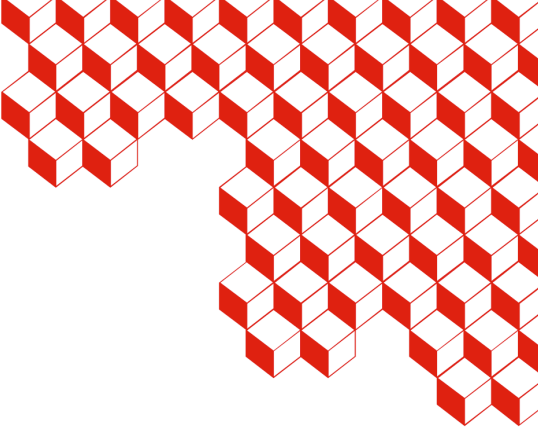
A fragment detector...



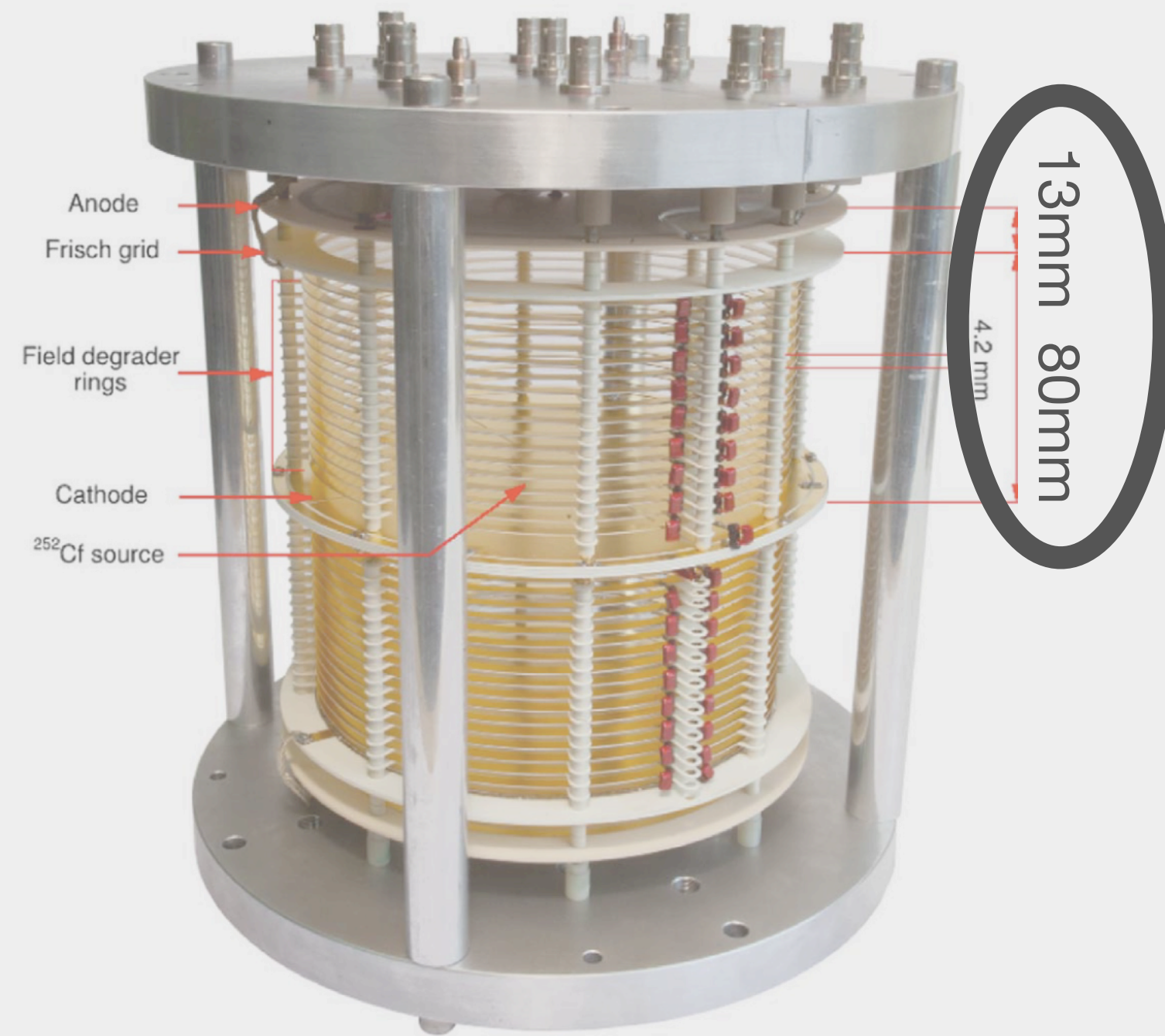
Twin Frisch Ionization Chamber ($\sigma_{KE} \approx 250\text{keV}$)

L. G. et al., NIMA **855**, 133 (2017)

Studying neutronless fission



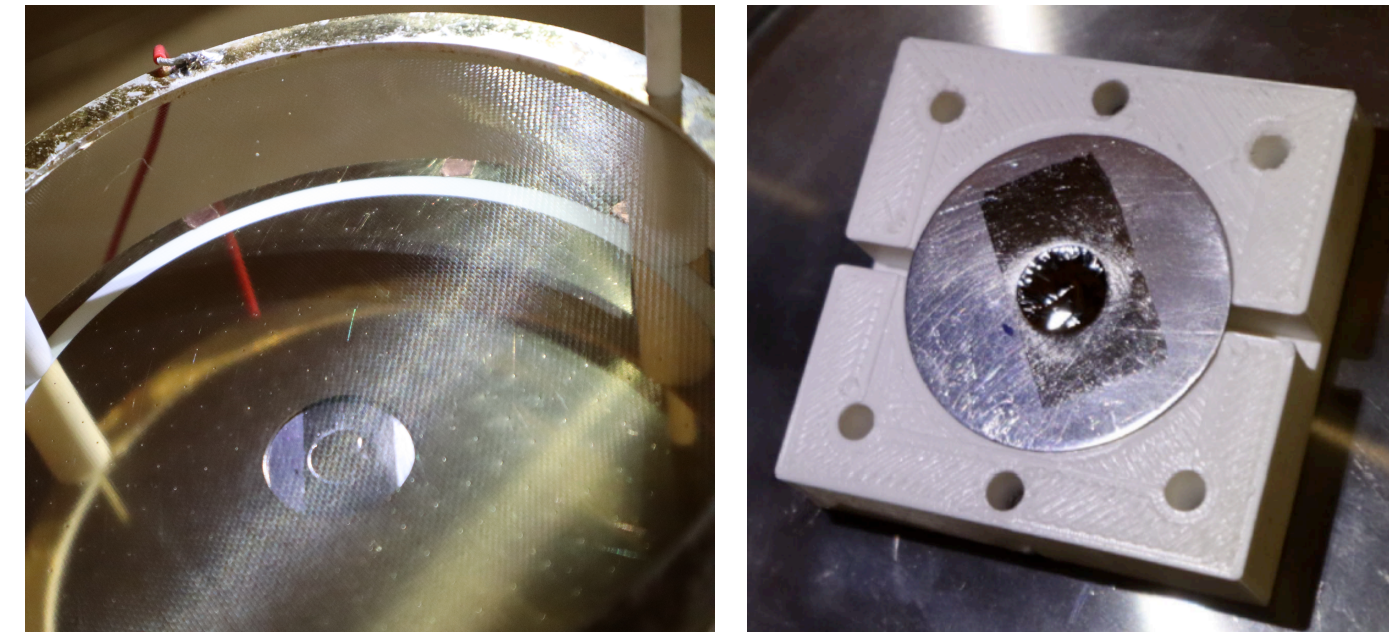
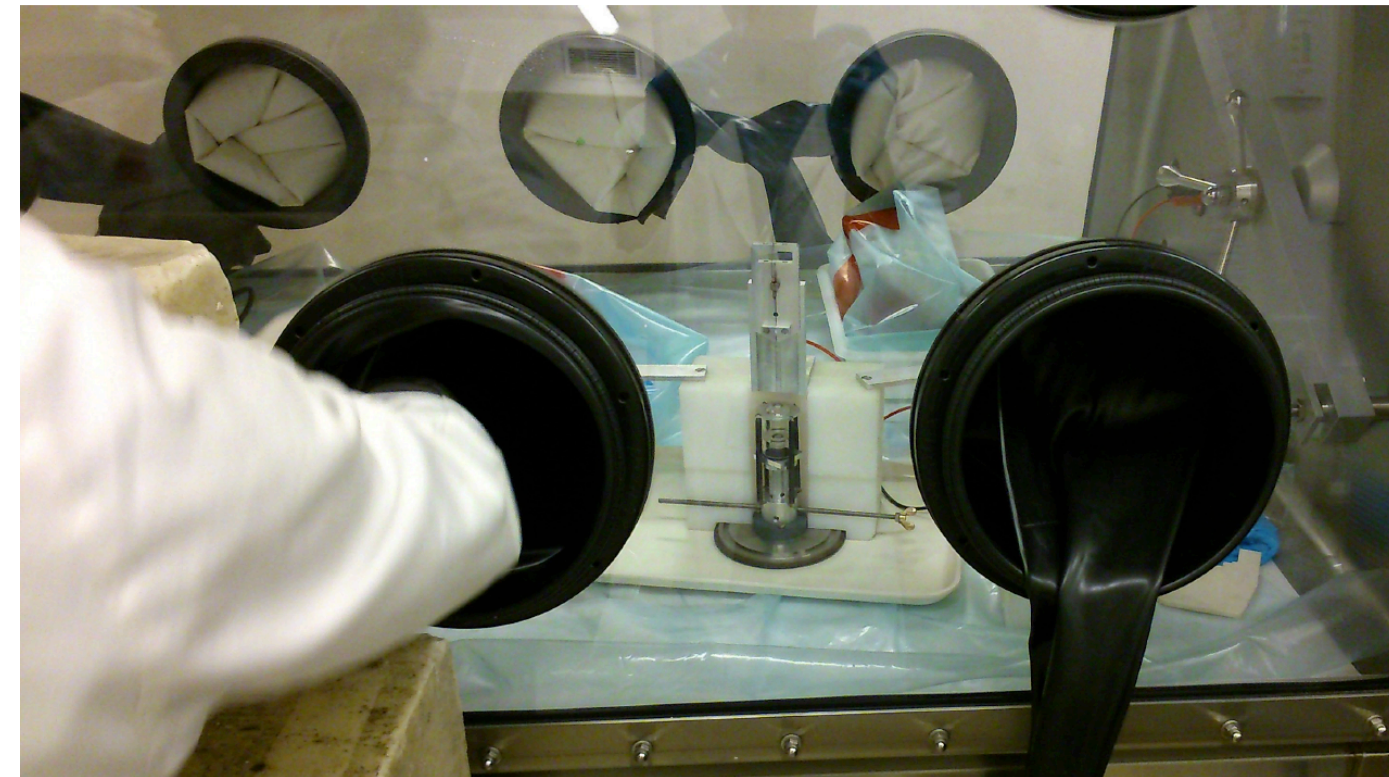
A fragment detector...



Twin Frisch Ionization Chamber ($\sigma_E = 400\text{keV}$)

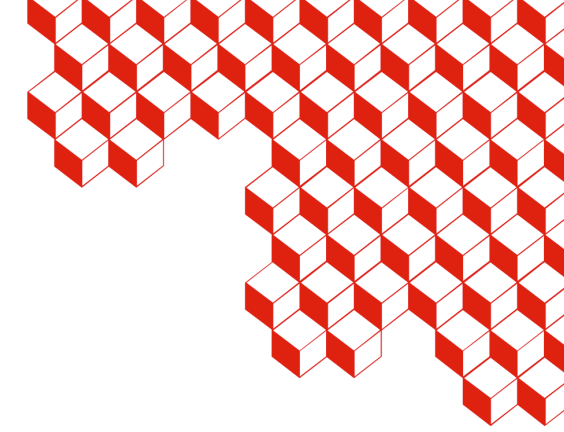
L. G. et al., NIMA 855, 133 (2017)

... loaded with an high quality fission sample ...

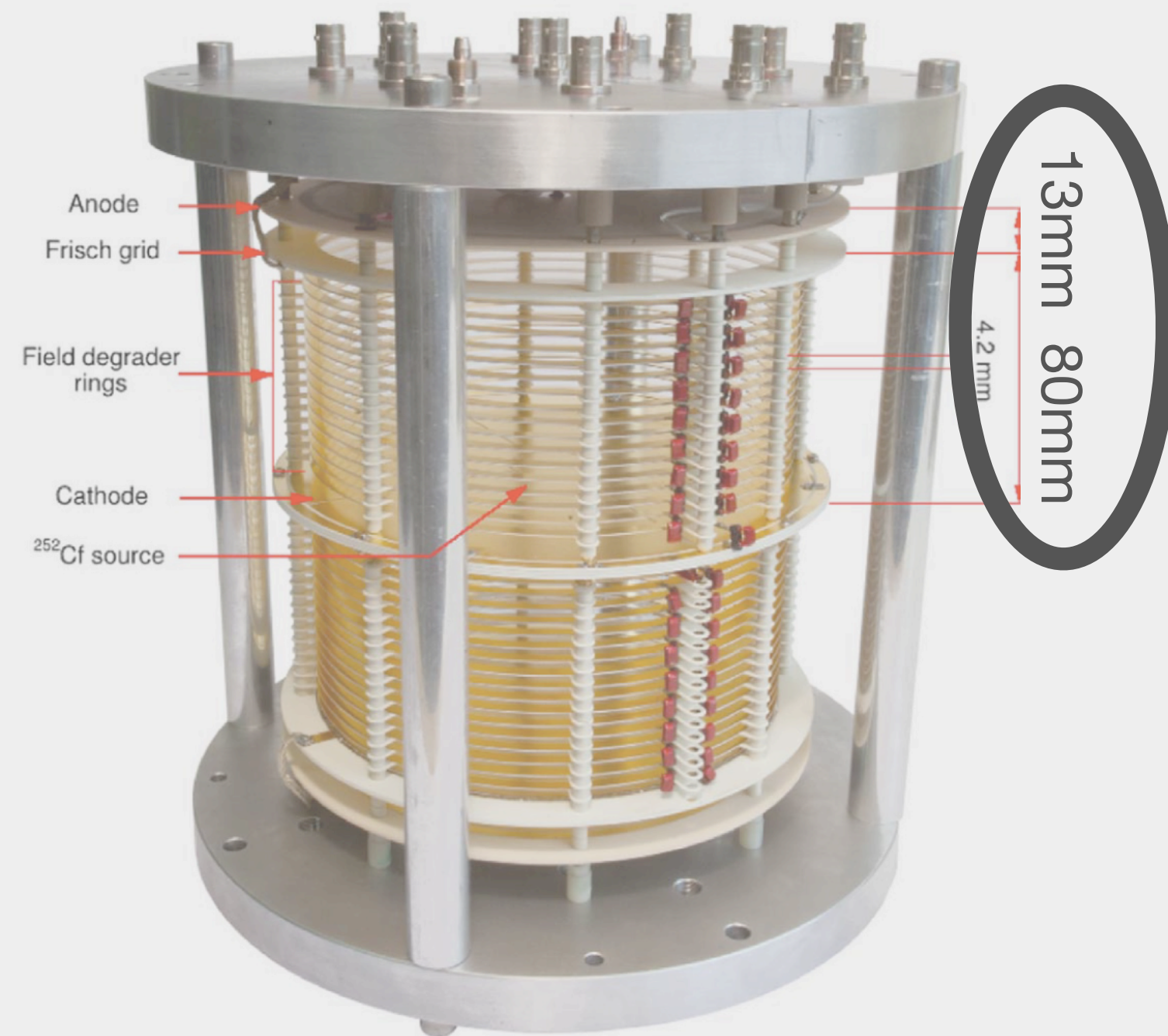


1200 Bq ^{252}Cf sample
on a 25nm ultra-thin C-backing

Studying neutronless fission



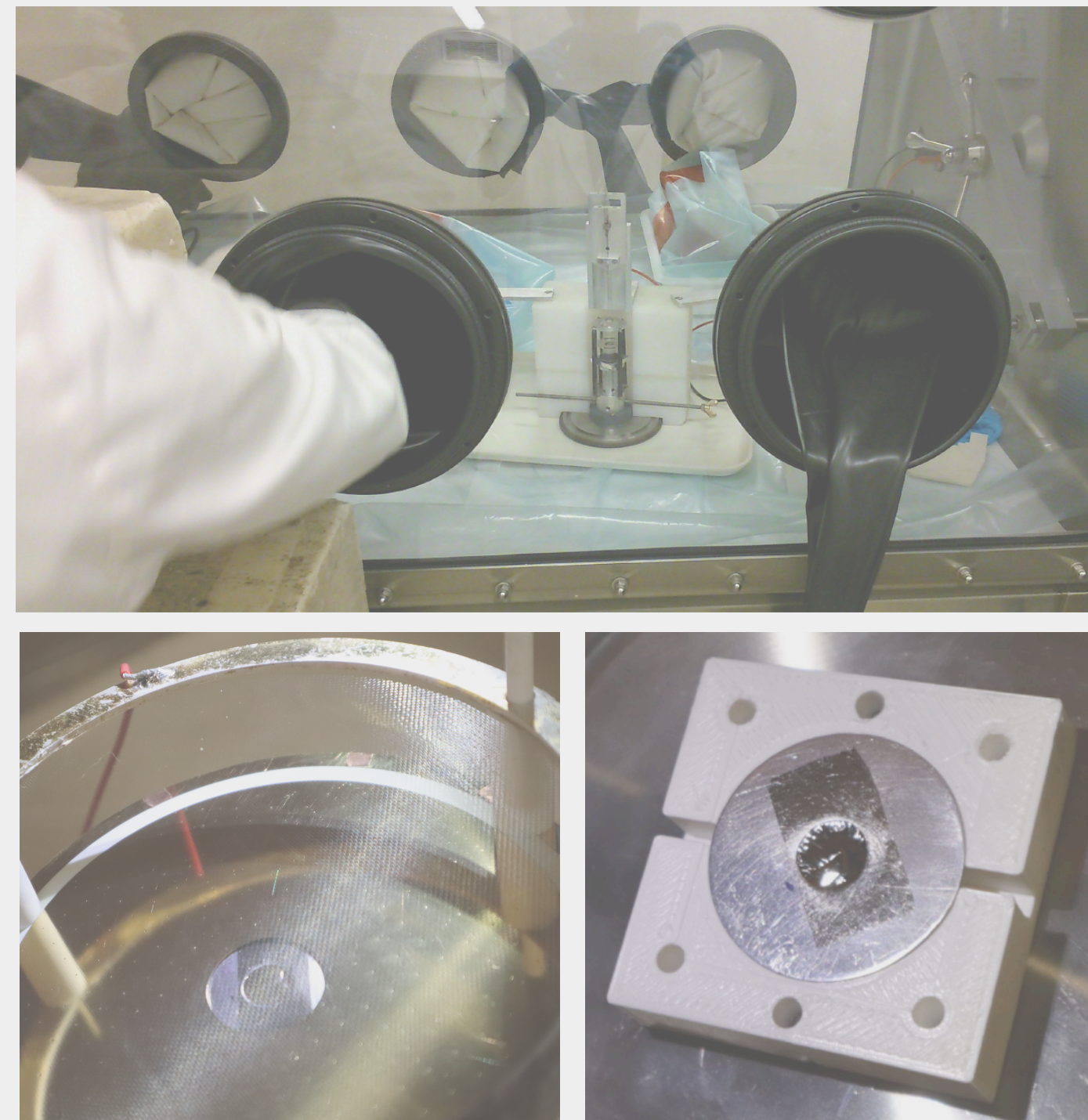
A fragment detector...



Twin Frisch Ionization Chamber ($\sigma_E = 400keV$)

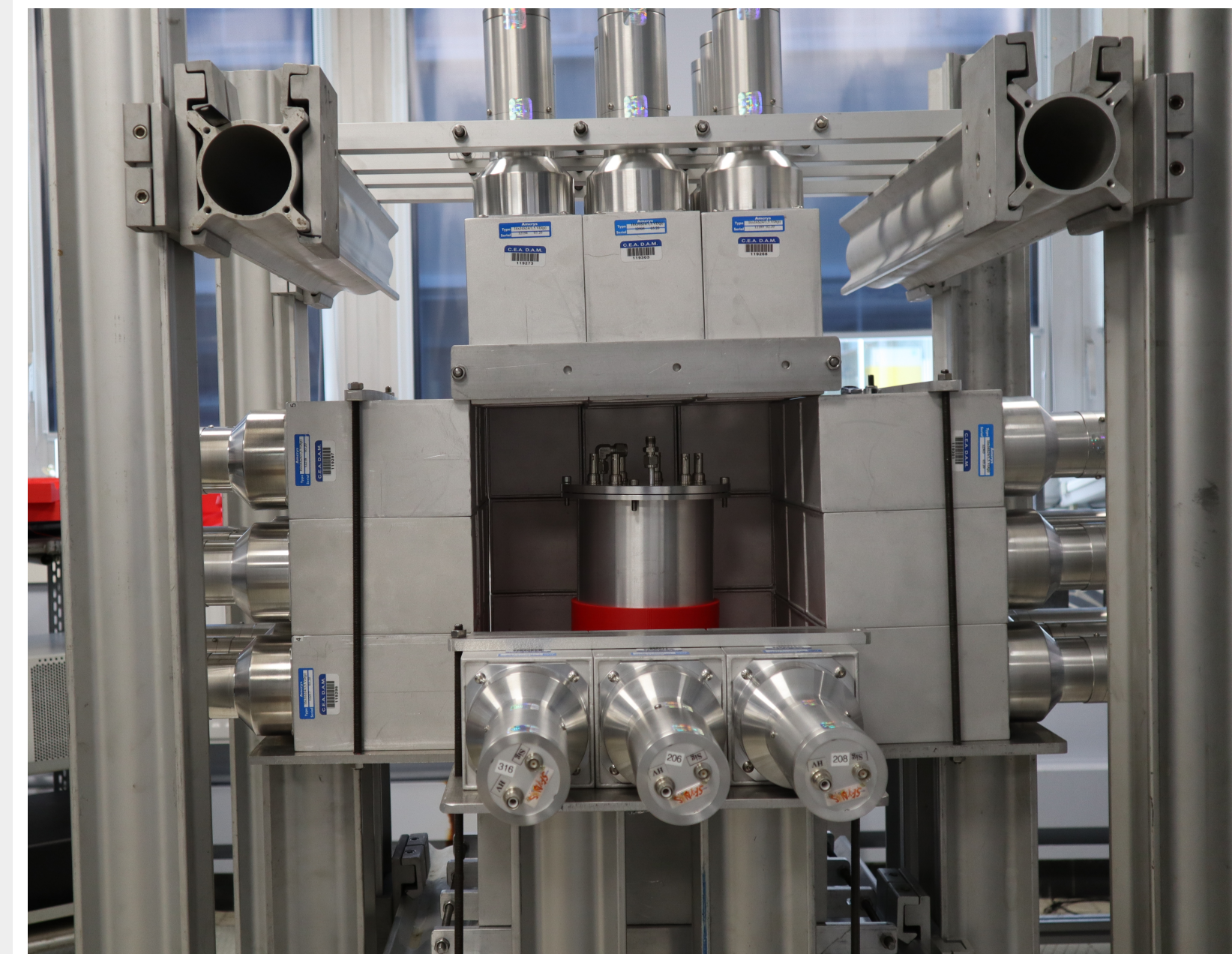
L. G. et al., NIMA **855**, 133 (2017)

... loaded with an high quality fission sample ...



1200 Bq ^{252}Cf sample
on a 25nm ultra-thin C-backing

...surrounded by a gamma array.



O.Roig et al., NIM A **1073**, 170243 (2025)

54 large Volume NaI detectors

$$\epsilon_{Geo} = 92\%$$

$$\epsilon_{tot} = 50\% @ 300keV$$

$$\epsilon_{tot} = 30\% @ 1300keV$$

Achievements

Our previous similar works

Detection system

L. G. et al., NIMA **855**, 133 (2017)

Spectroscopy of Fission Fragments

L. G. et al., PRC **97**, 064317 (2018)

Isomer Production

L. G. et al., EPJ Web Conf. **242**, 01003 (2020)

From this measurement

Fission/Fragments Properties

A. Francheteau et al., PRL 132, 142501 (2024)

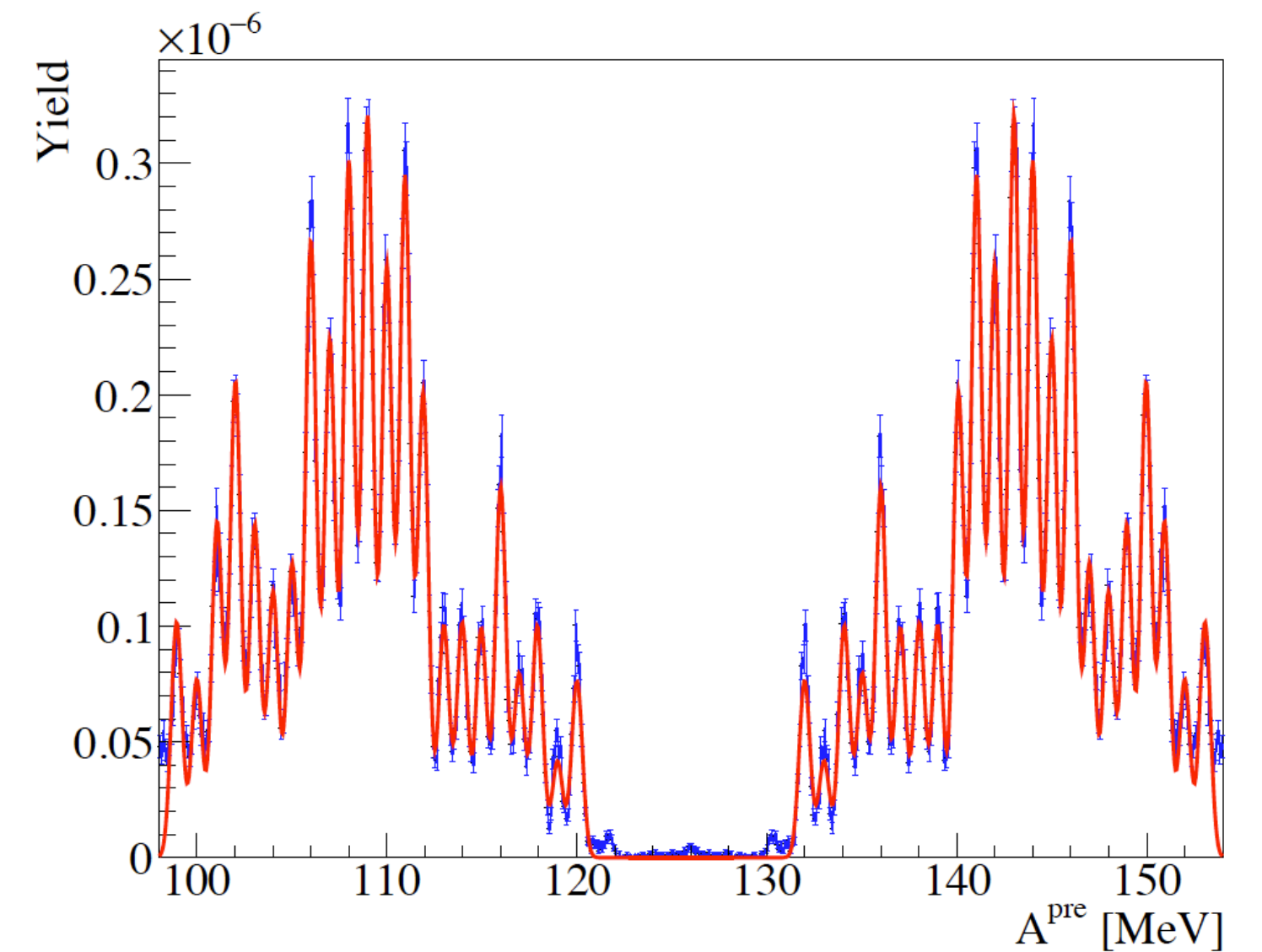
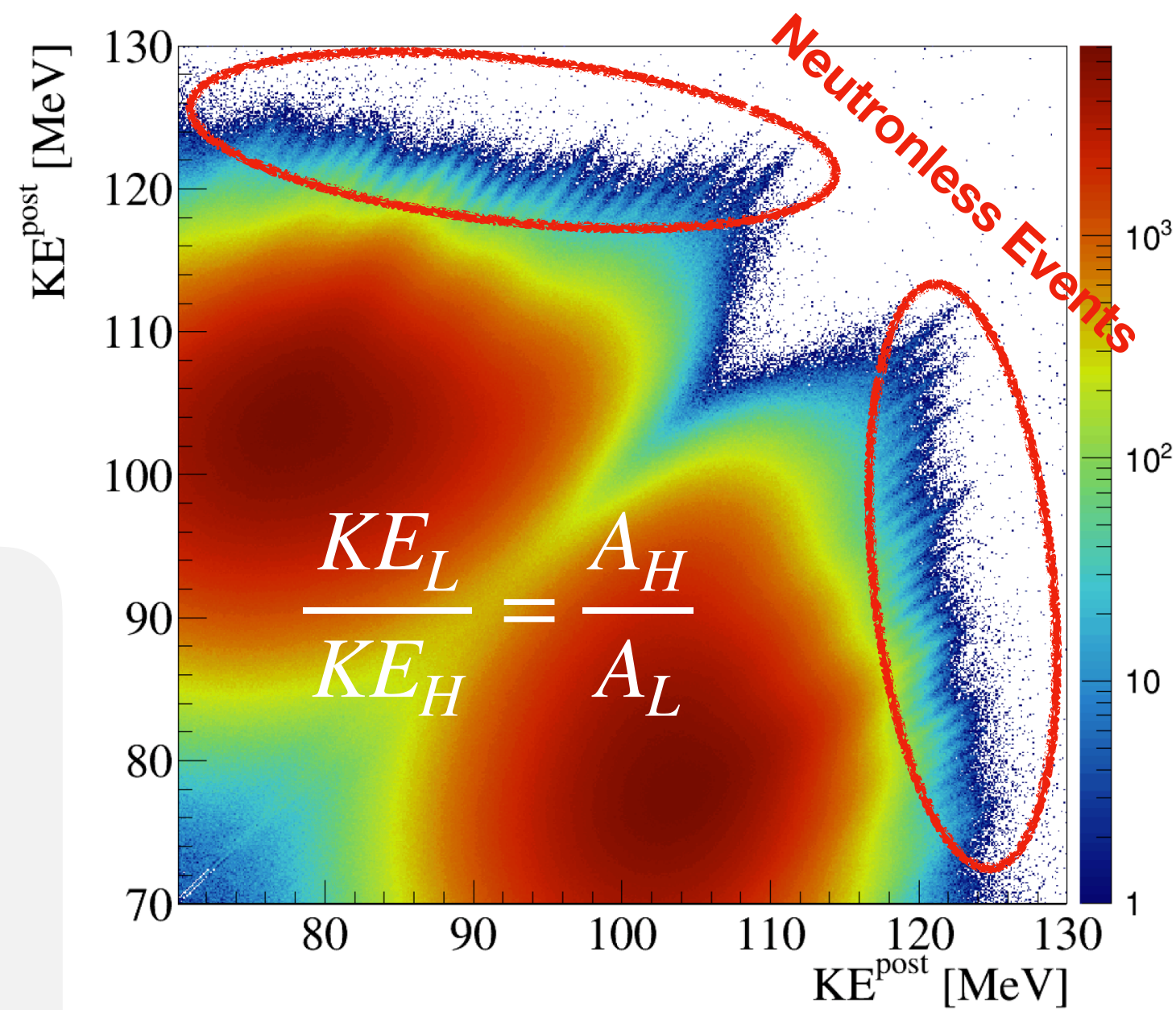
⇒ The exceptional $^{132}\text{Sn}/^{120}\text{Cd}$ case!

A. Francheteau et al., PRC 111, 034608 (2025)

⇒ Discussing the origin of the (4-6MeV) γ -bumps.

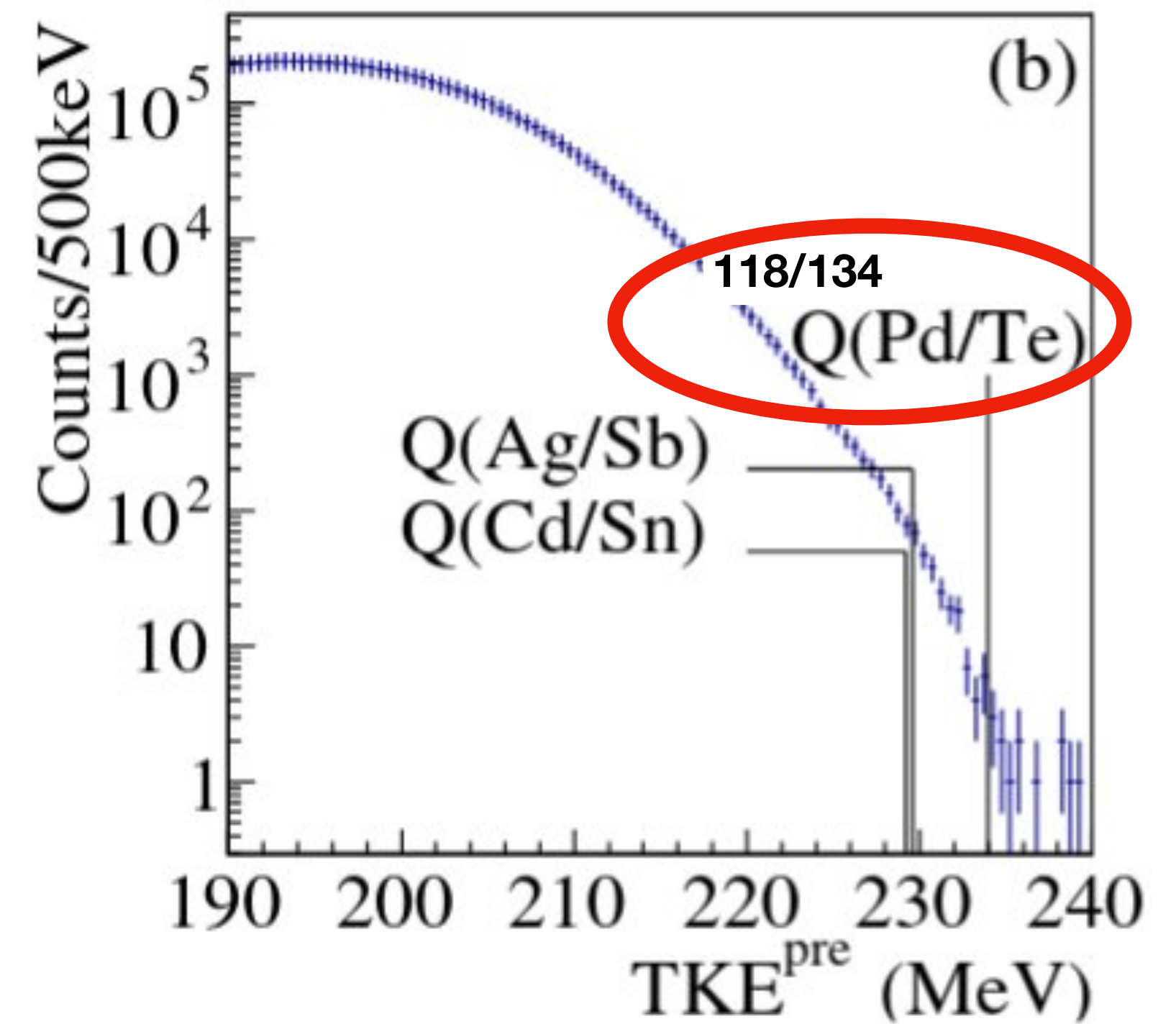
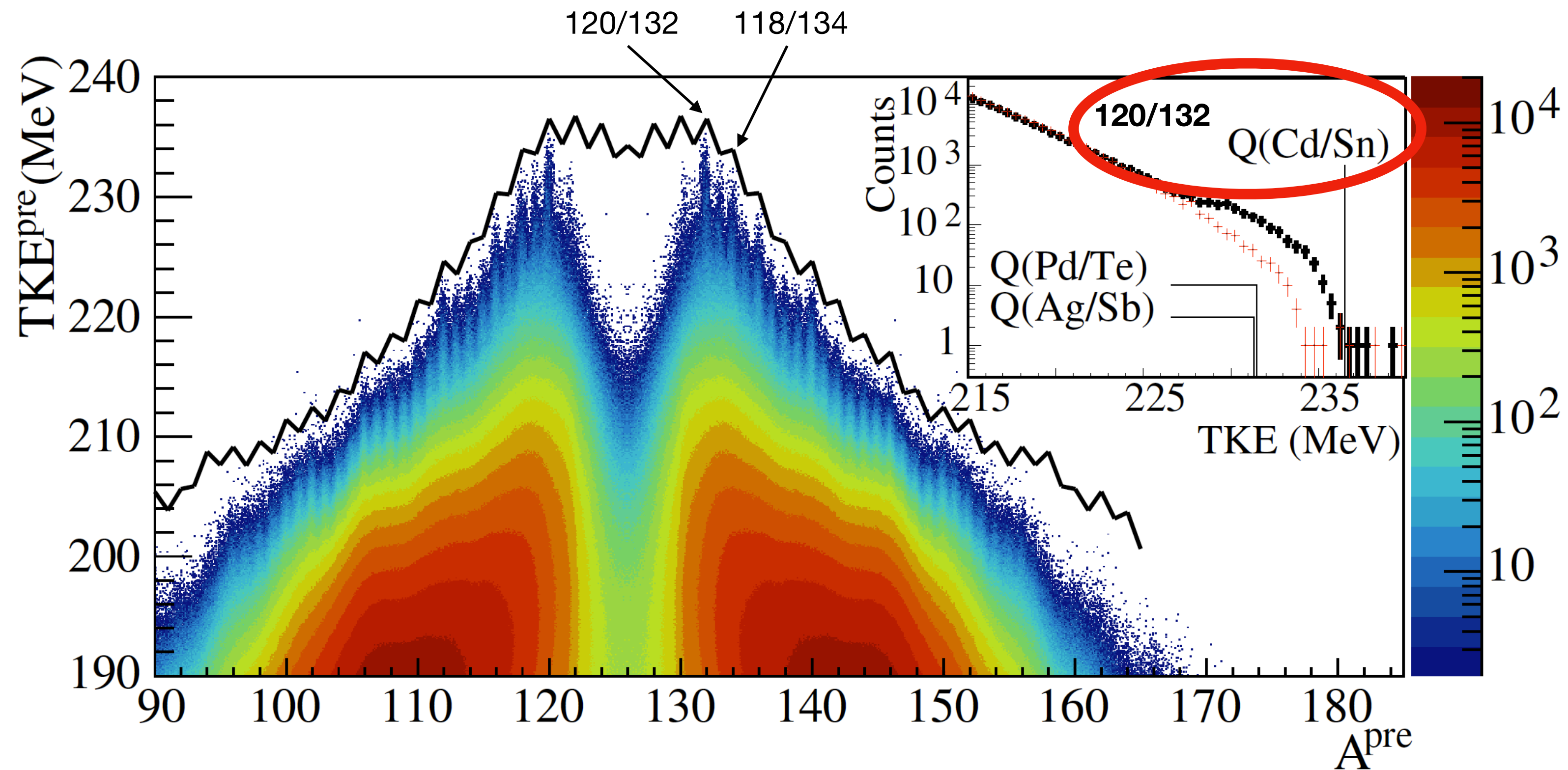
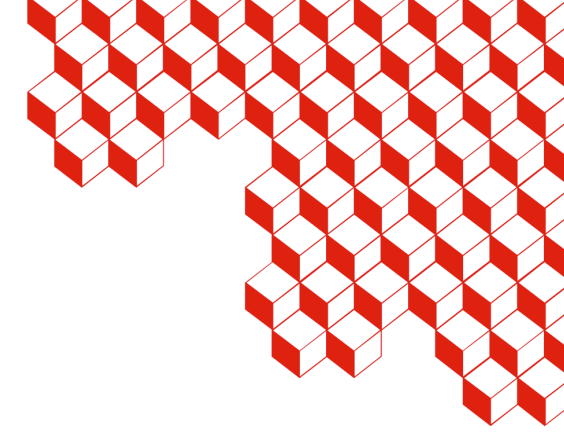
A. Francheteau et al., Accepted in PRC

⇒ Excitation energy, Angular momentum & Deformation.



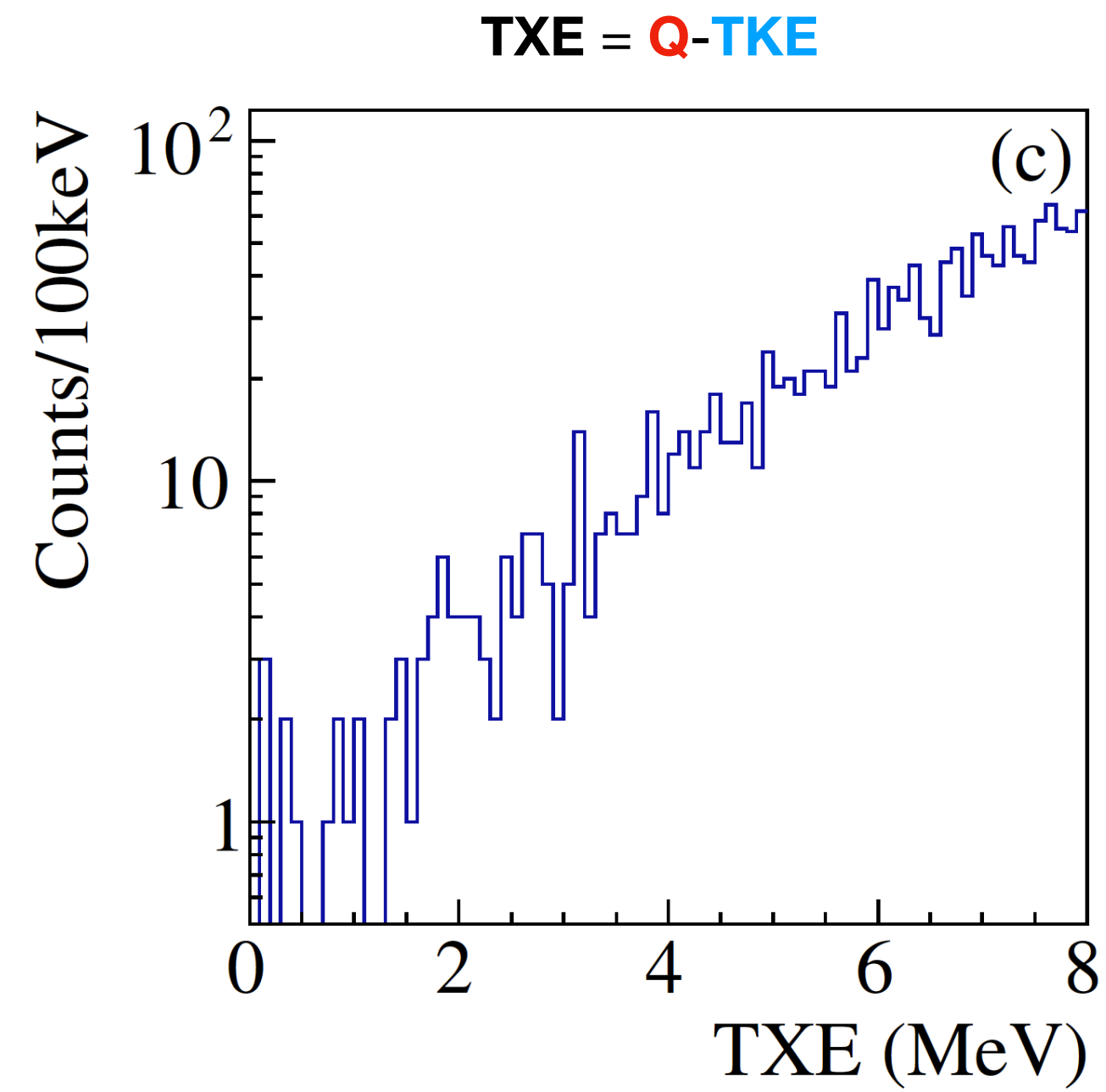
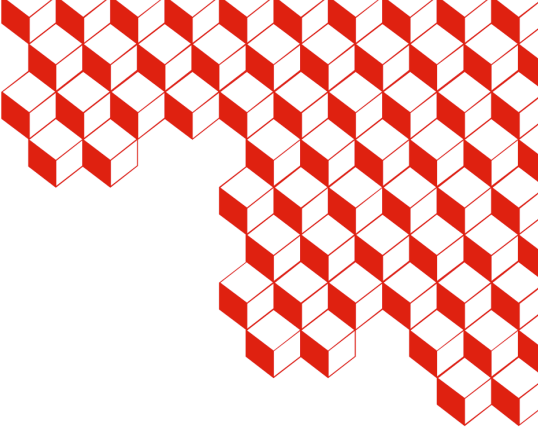
Mass Resolution : 0.6-0.7 amu FWHM

When Shell Closures help us!



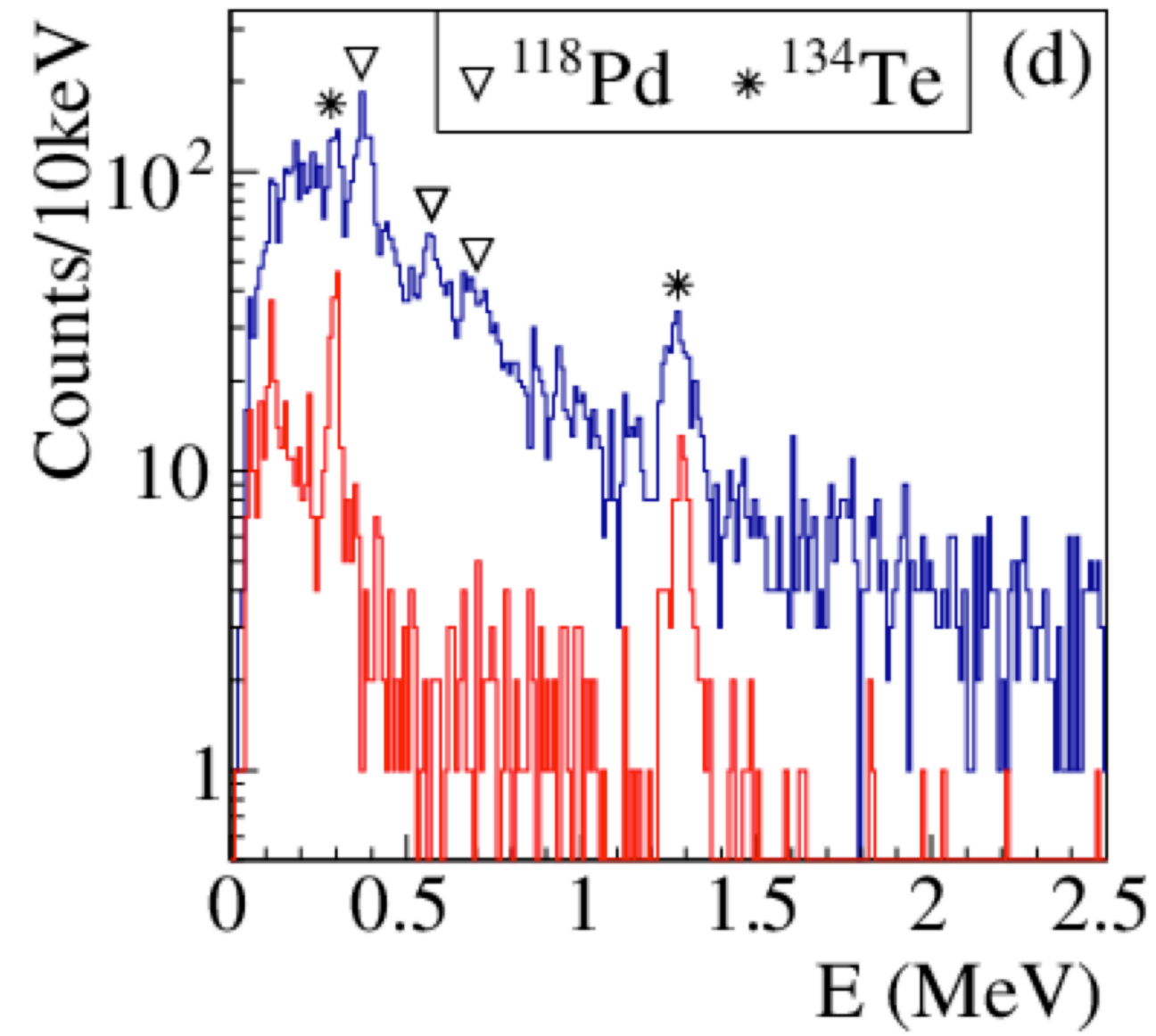
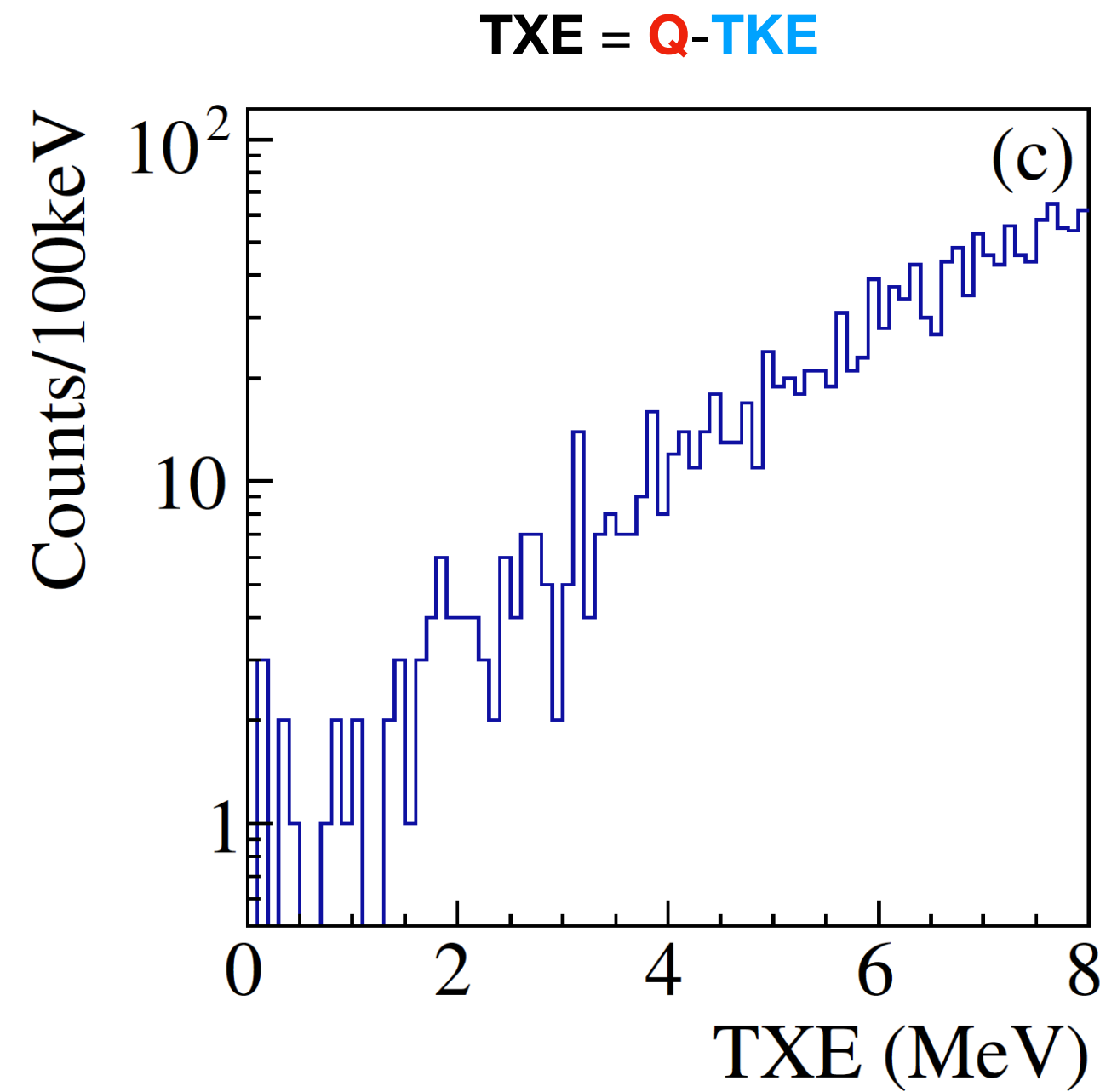
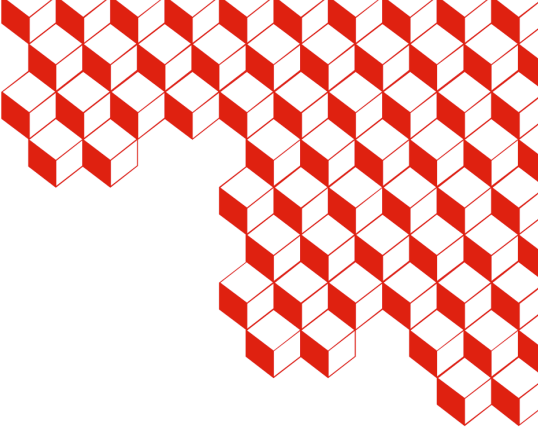
Simple TKE Selection = 90% purity on Fragment selection

What did we measure? 1/3



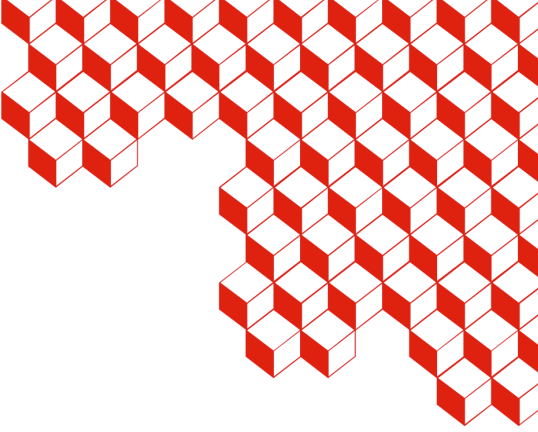
- $TXE = E_x^H + E_X^L$

What did we measure? 2/3

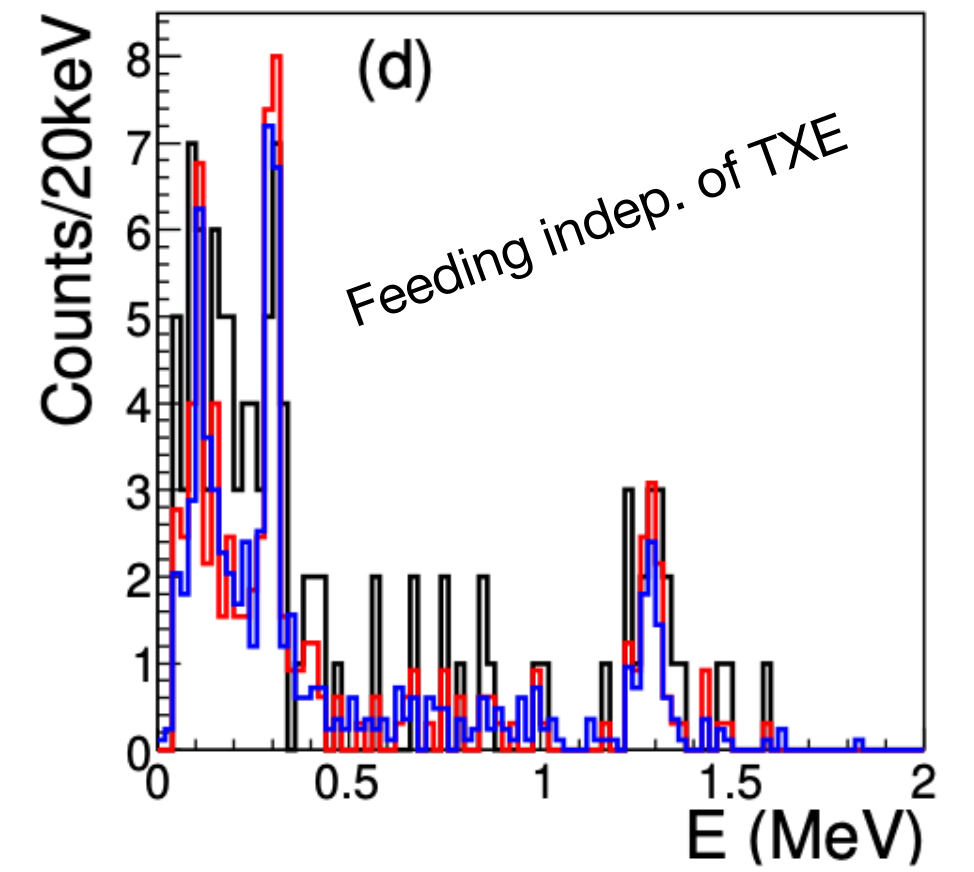
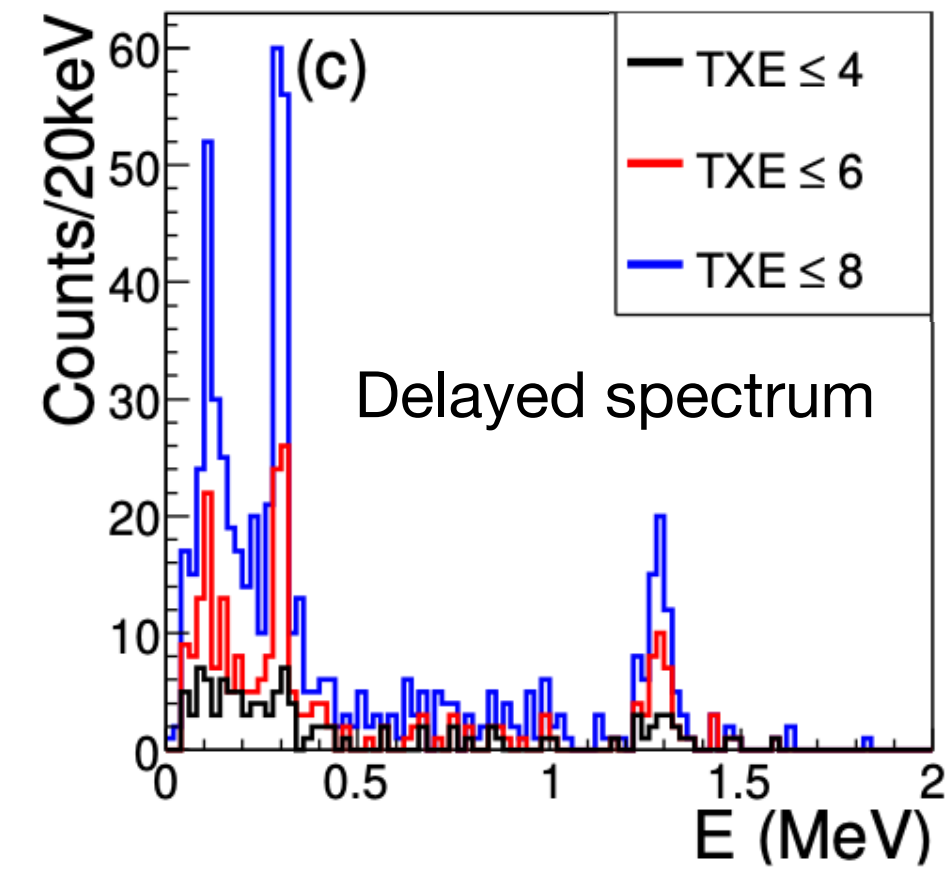
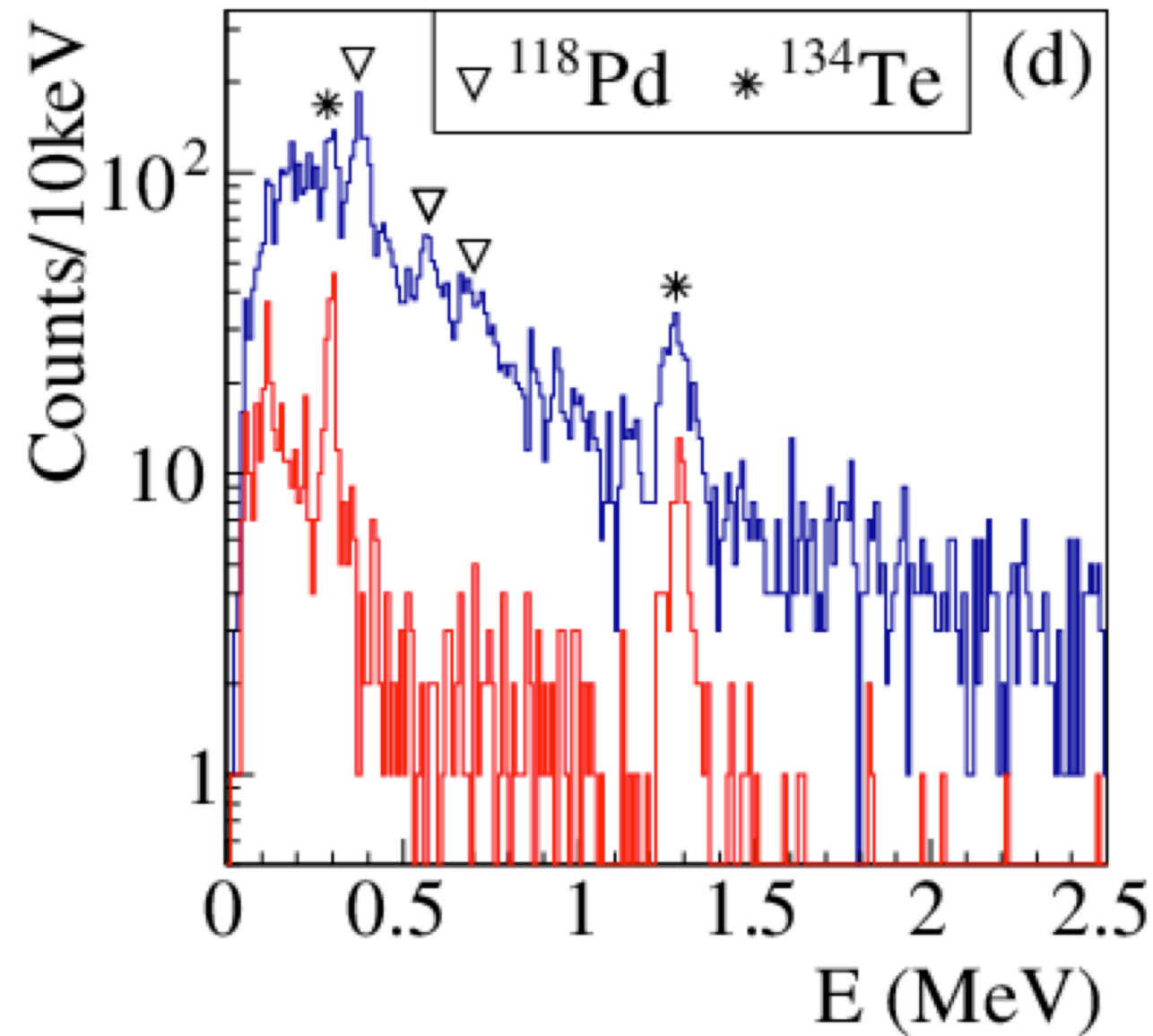
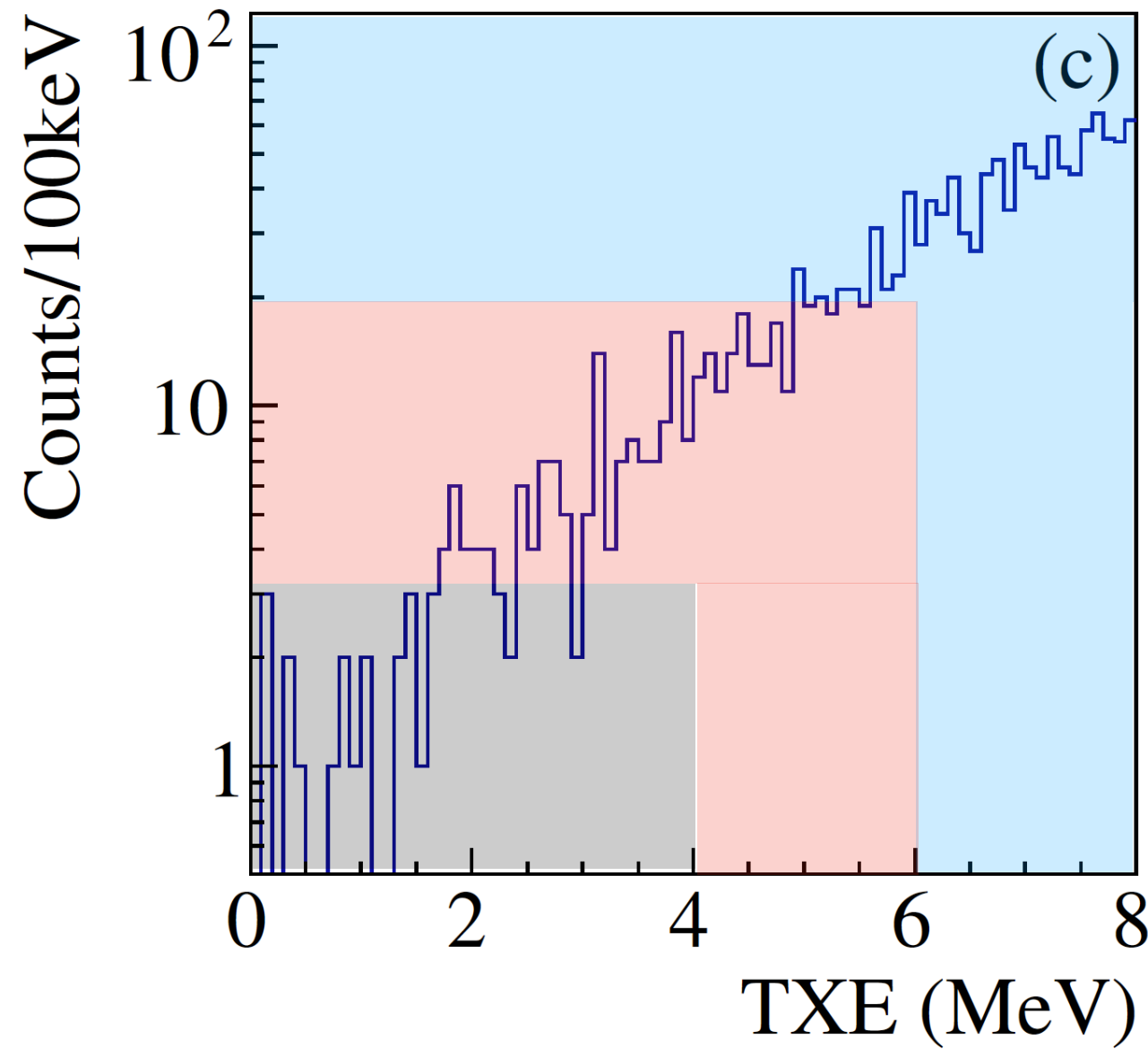


- $TXE = E_x^H + E_X^L$
- $^{118}Pd \Rightarrow I(2_1^+) = 75(7)\%$ and $I(4_1^+) = 22(8)\%$
- $^{134}Te \Rightarrow I(2_1^+) = 46(8)\%$, $I(4_1^+) = 36(6)\%$ and $I(6_1^+) = 14(2)\%$

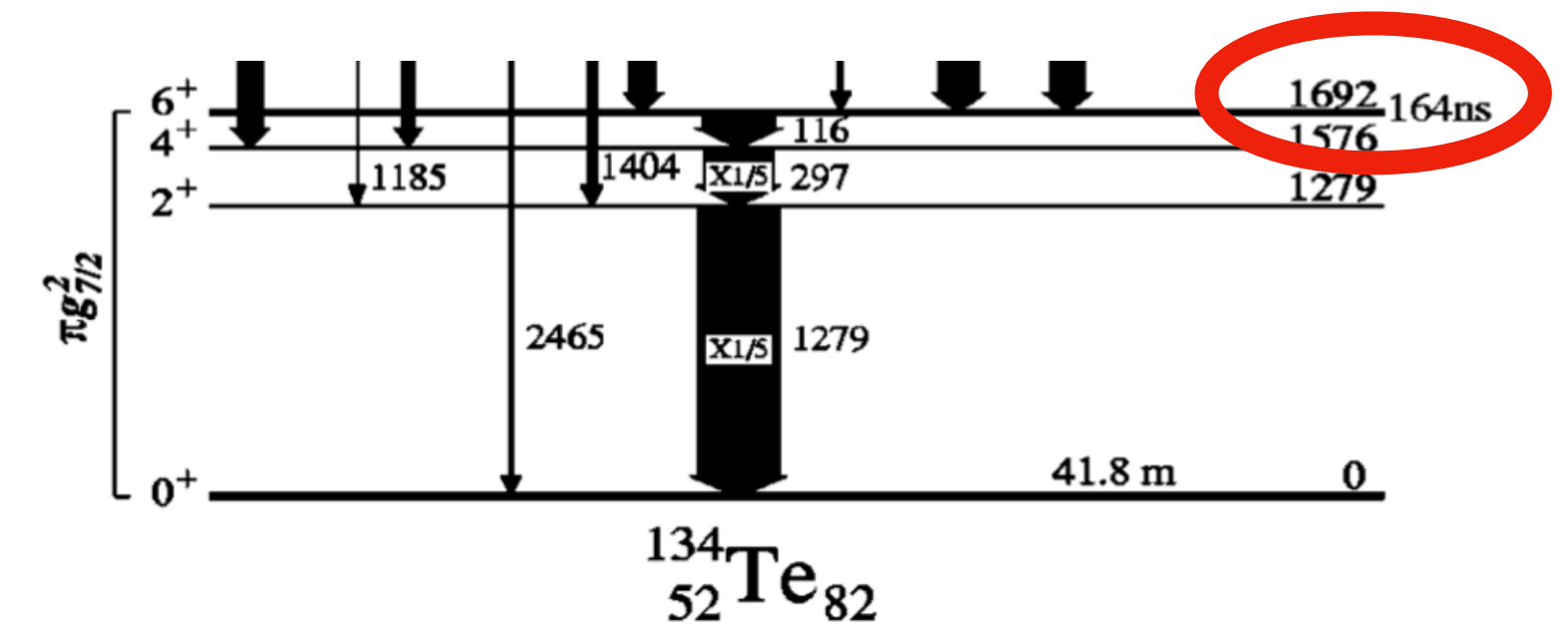
What did we measure? 3/3



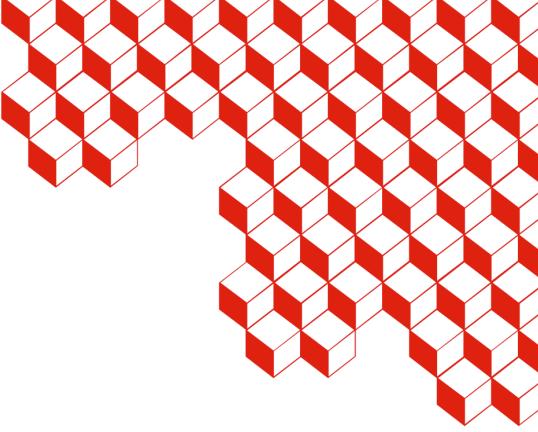
TXE = Q - TKE



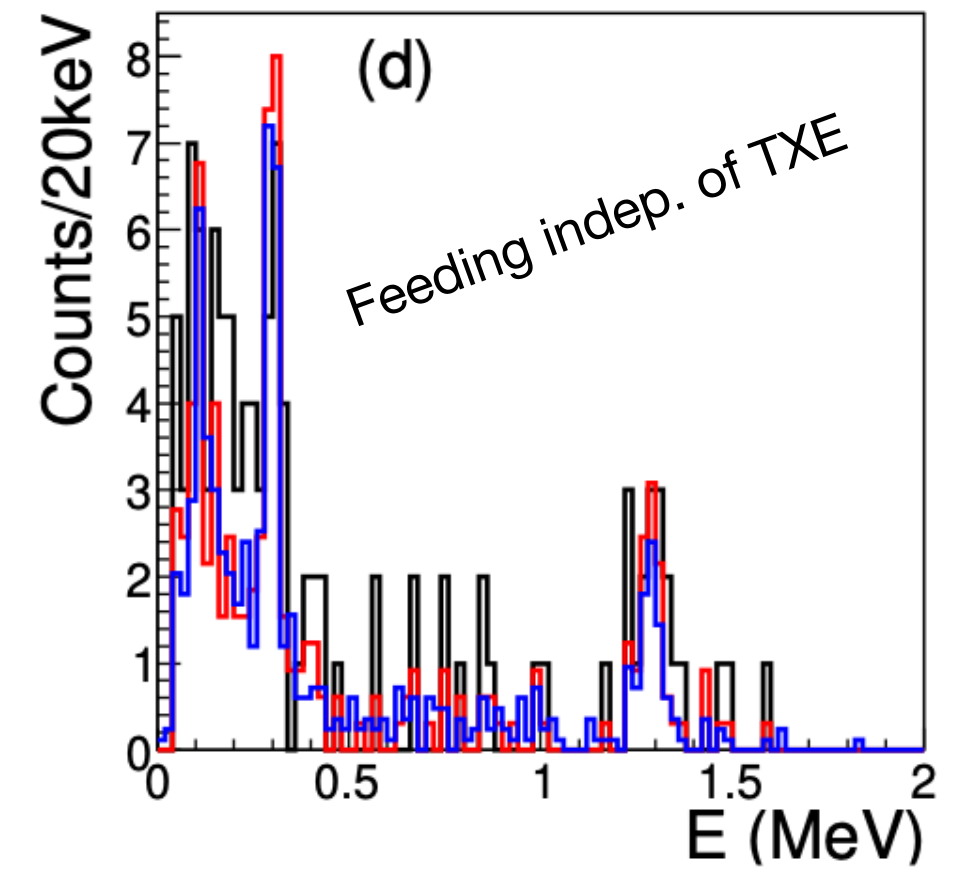
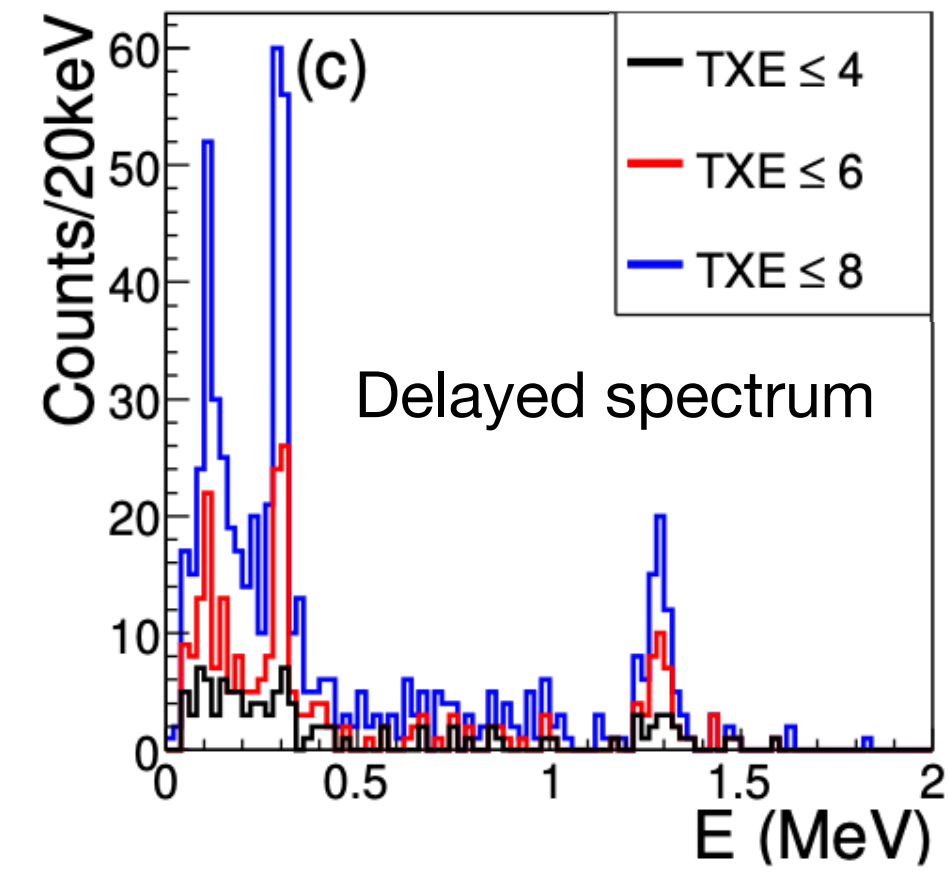
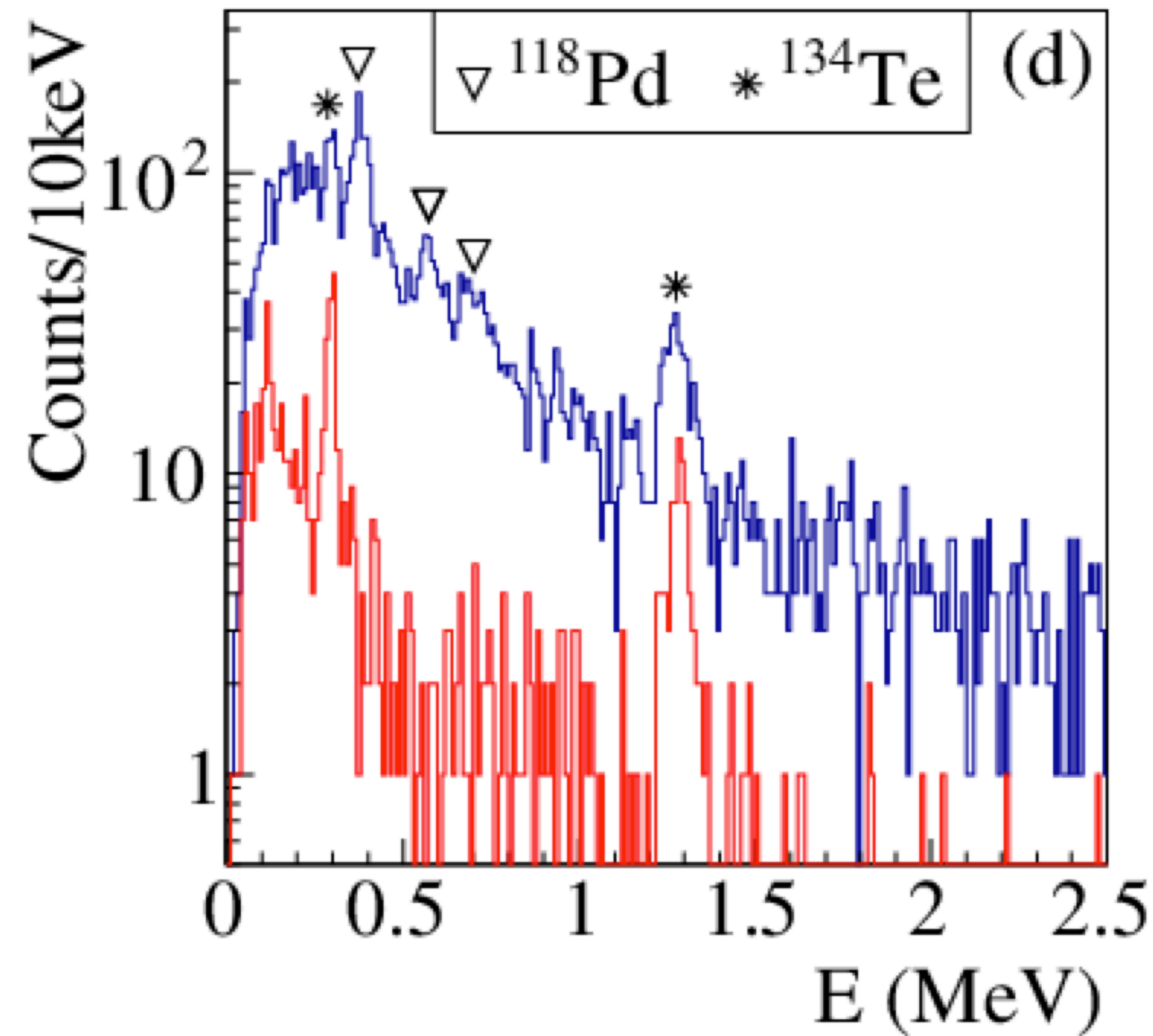
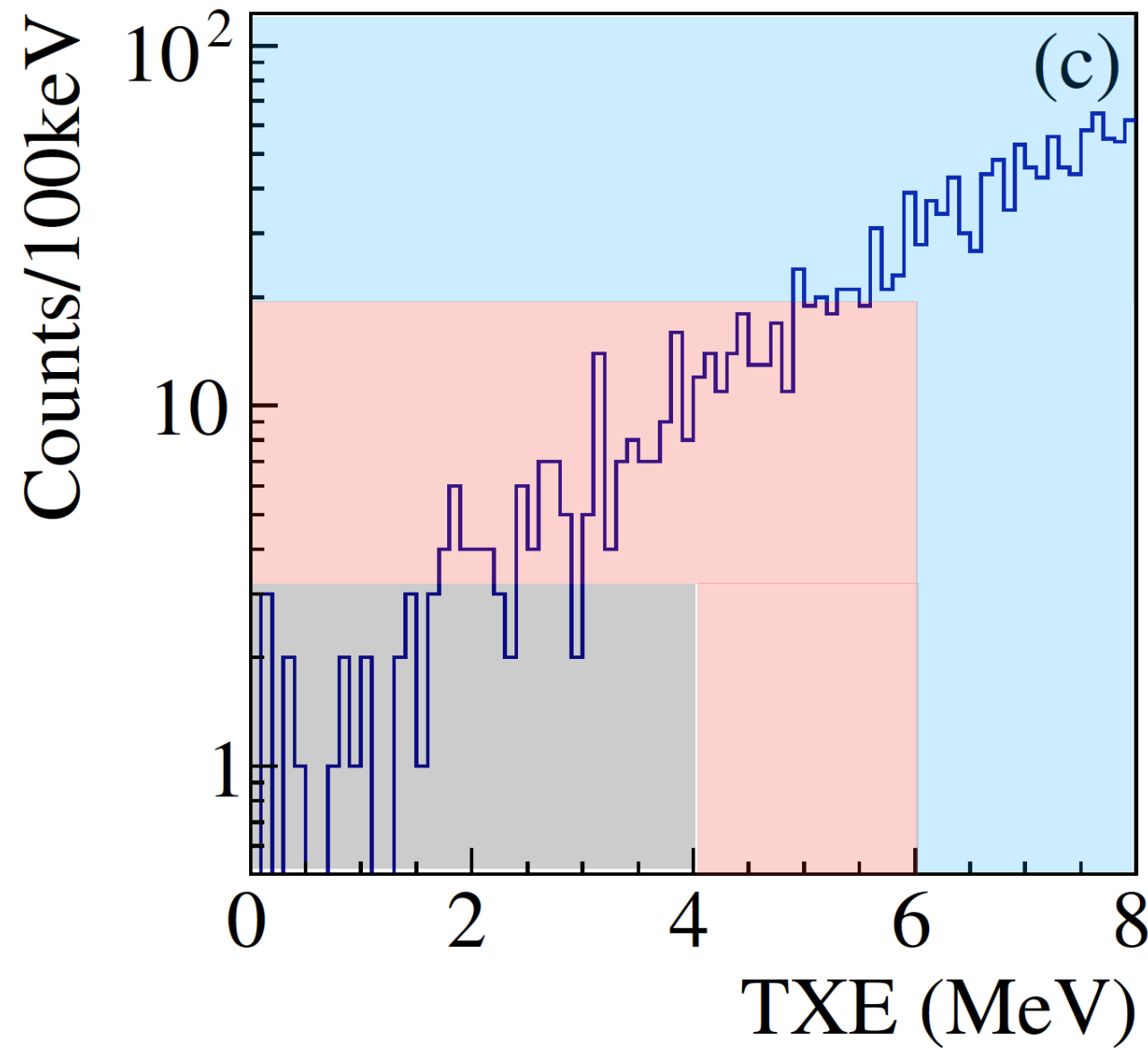
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- $^{134}Te \Rightarrow$ Feeding 6_1^+ @ 1.7MeV independent of TXE gate



What did we measure? 3/3



TXE = Q - TKE



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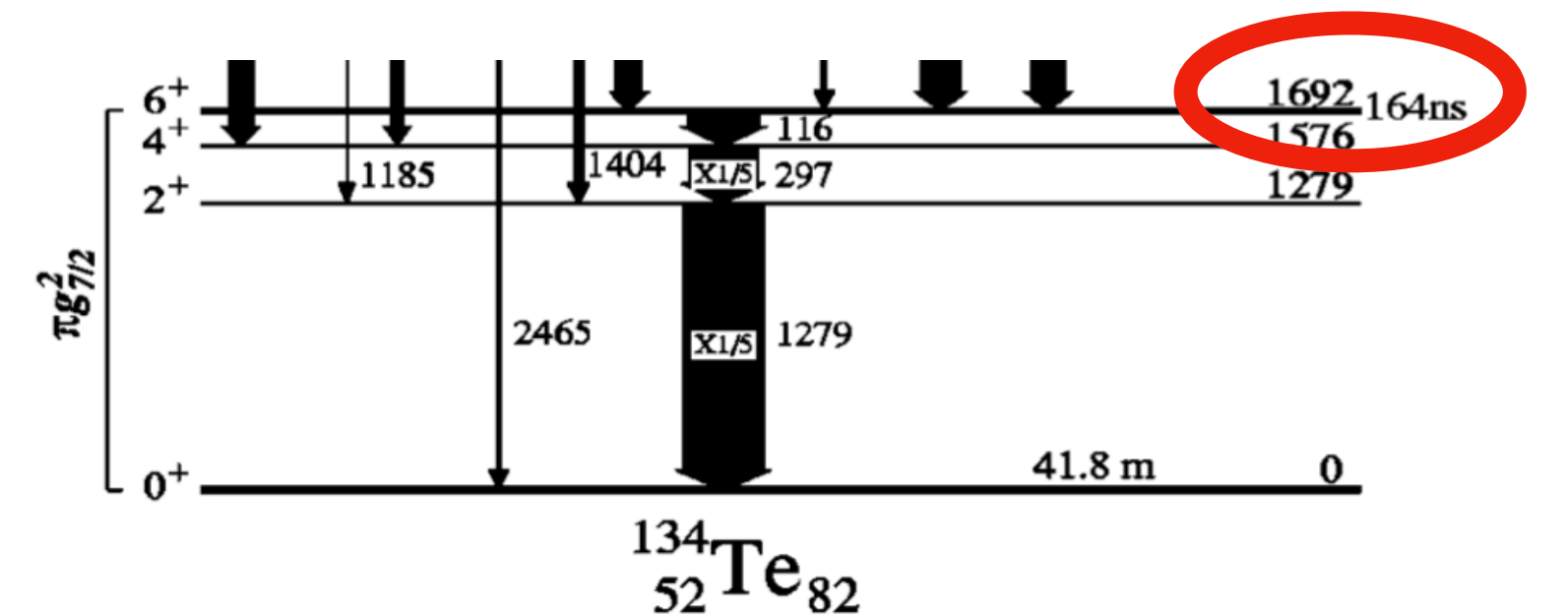
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Missing 2_1^+ intensity \approx GS direct feeding.

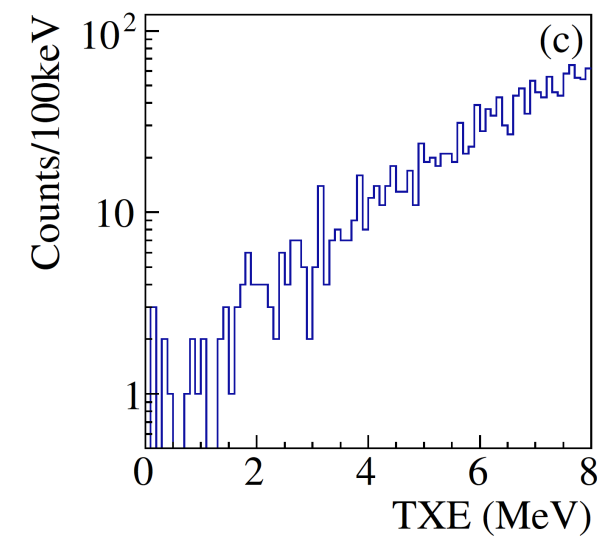
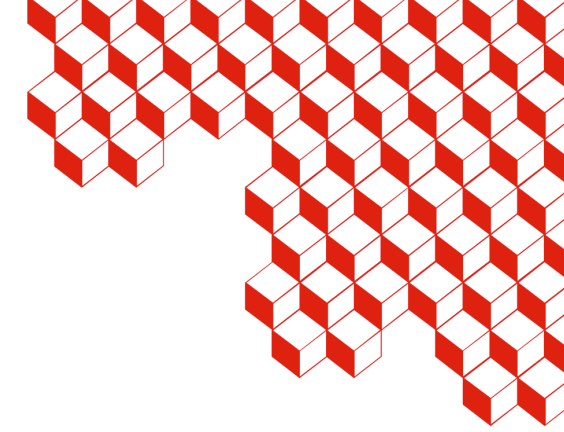
$I(GS) \sim 50\%$ for $^{134}Te_{82}$.

Similar to $^{120}Cd/^{132}Sn_{82}$ with ^{132}Sn always in its GS.

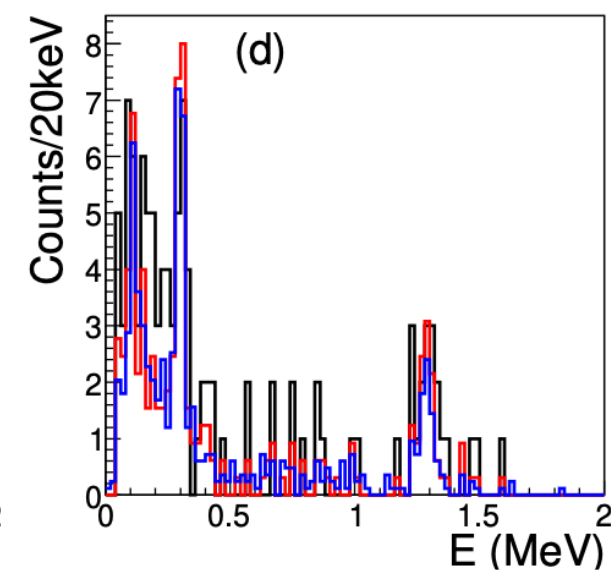
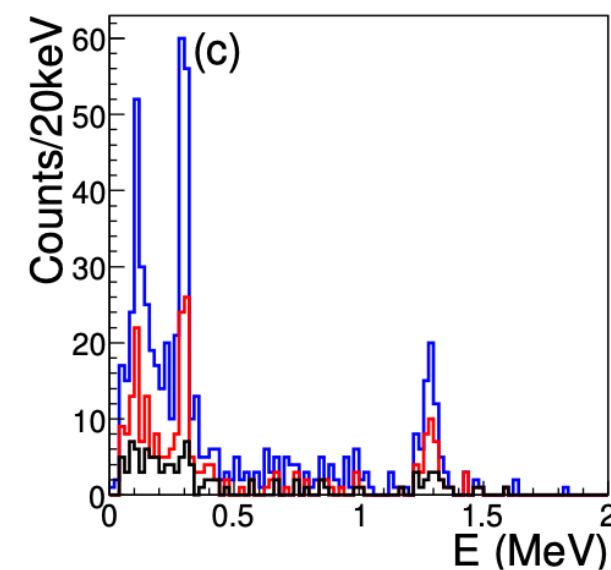
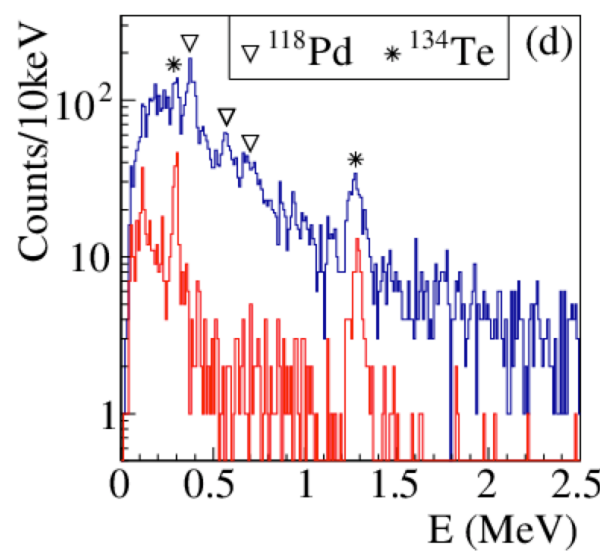
\Rightarrow PRL 132, 142501 (2024)



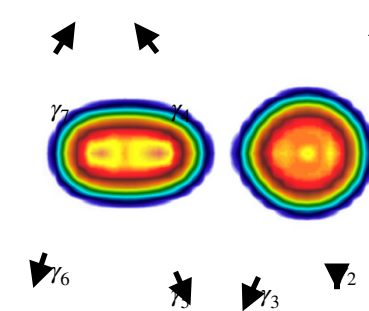
Reproducing what we measured



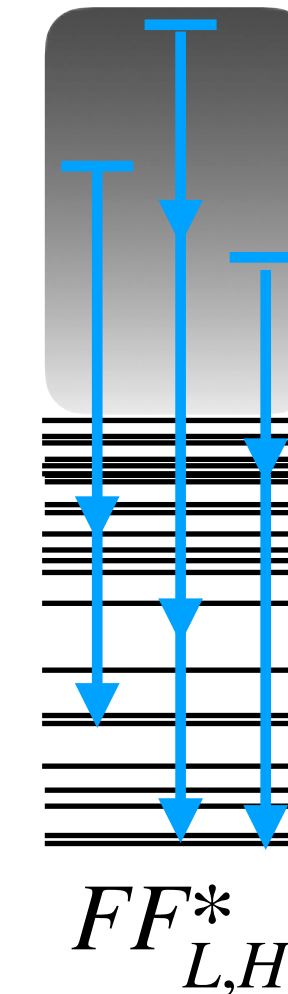
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Simulation of γ -ray spectrum



TXE and its sharing
Angular momentum



+ Statistical inputs for Hauser-Feschbach description of cascades:

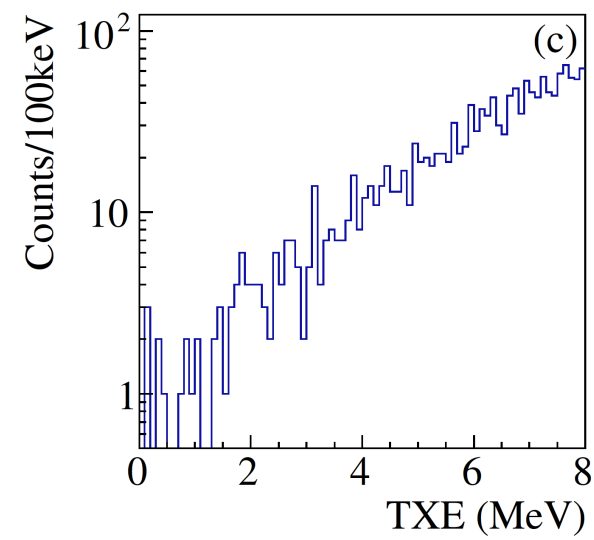
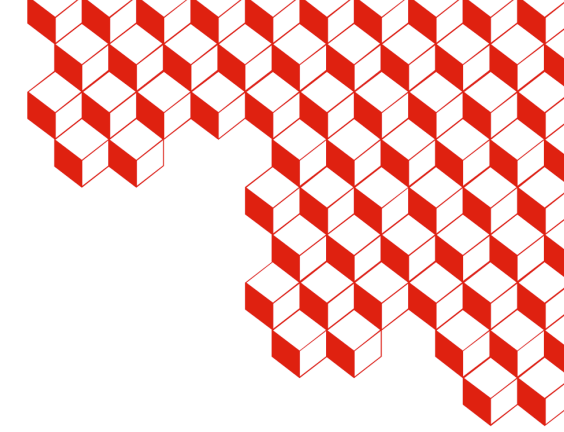
=> HFB+combinatorial with Gogny force NLD

S. Hilaire, M. Girod, S. Goriely and A. J. Konig, Phys. Rev. C 86, 064317 (2012)

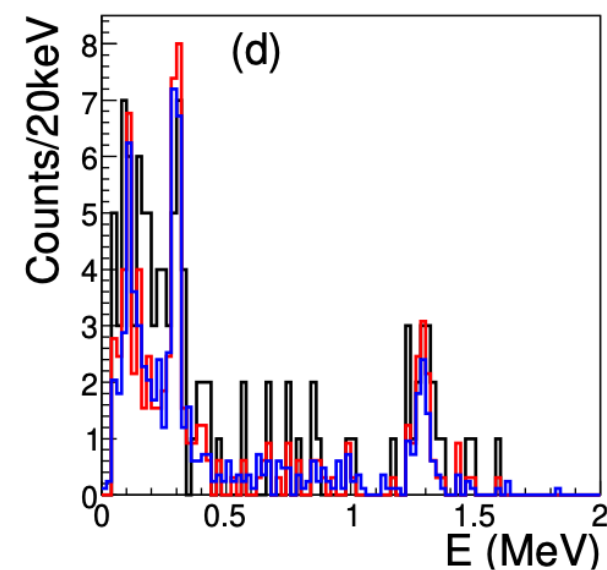
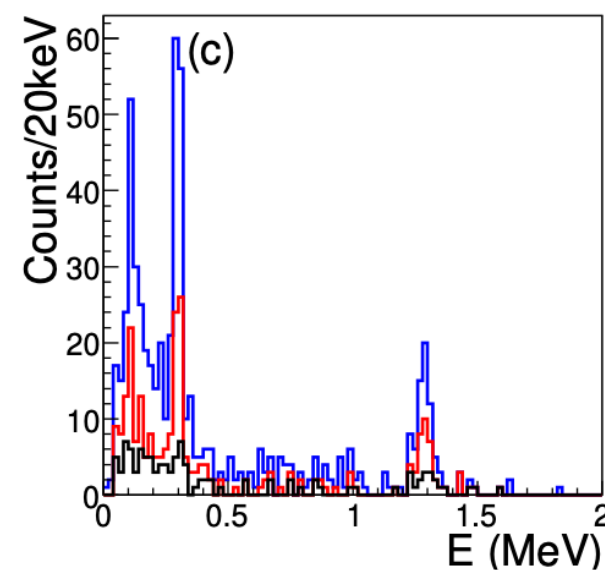
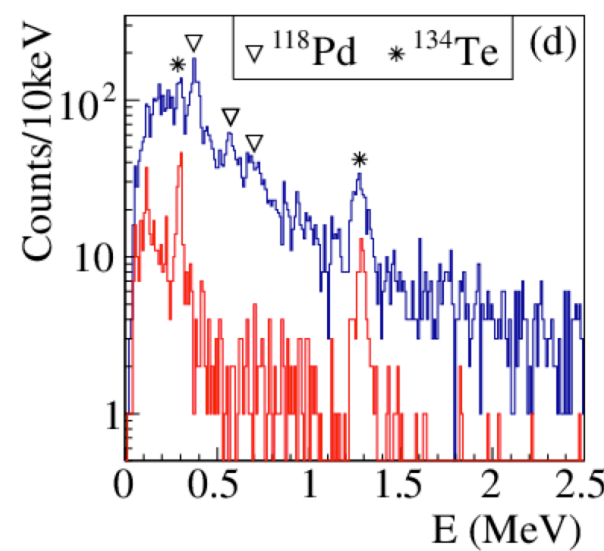
=> E1 & M1 BSk27 gSF

Y. Xu, S. Goriely and E. Khan, Phys. Rev. C 104, 044301 (2021)

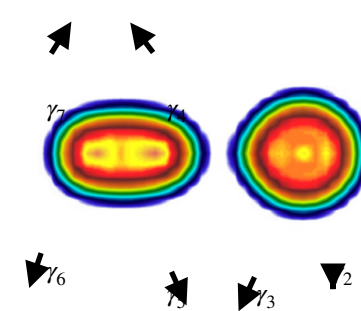
Reproducing what we measured



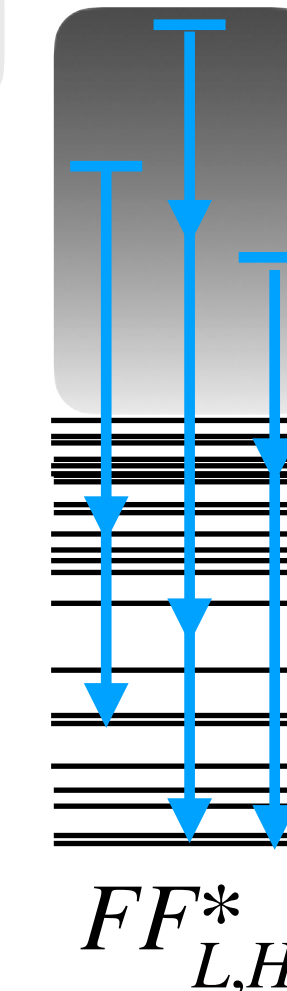
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Simulation of γ -ray spectrum



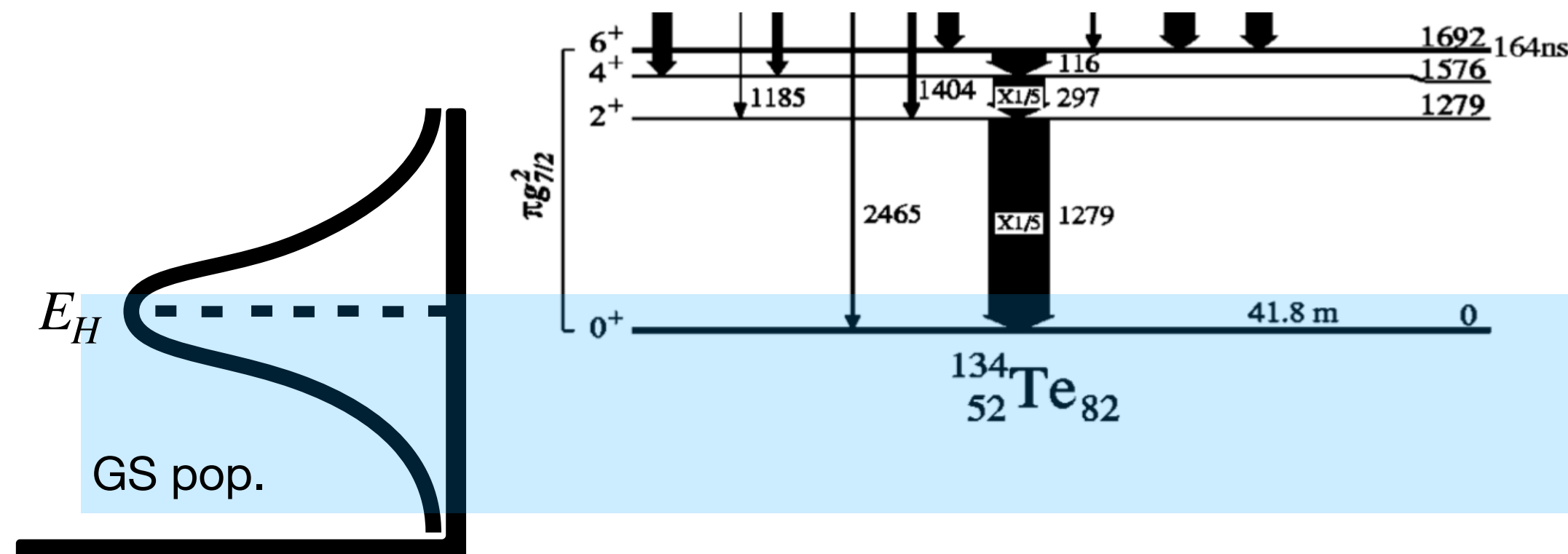
TXE and its sharing
Angular momentum



Main assumption :

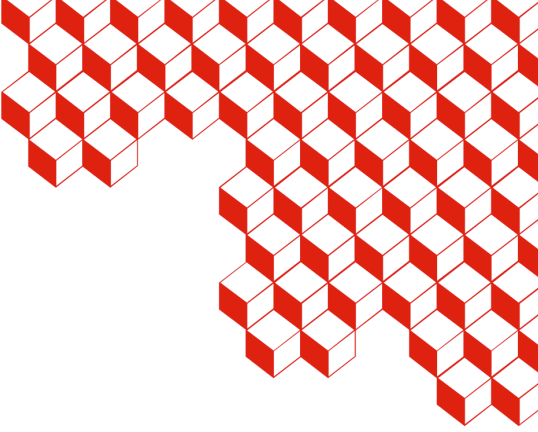
$$E_{L,H}^* \propto e^{-\left(\frac{[x - E_{L,H}(TXE)]^2}{2\sigma^2}\right)}, E_L^* + E_H^* = TXE$$

- $E_{L,H}$: a function of TXE
- σ common to both fragments and independent of TXE



\Rightarrow Natural explanation for experimental observations if $E_H \approx 0$ MeV and $\sigma \approx E(6_1^+)$

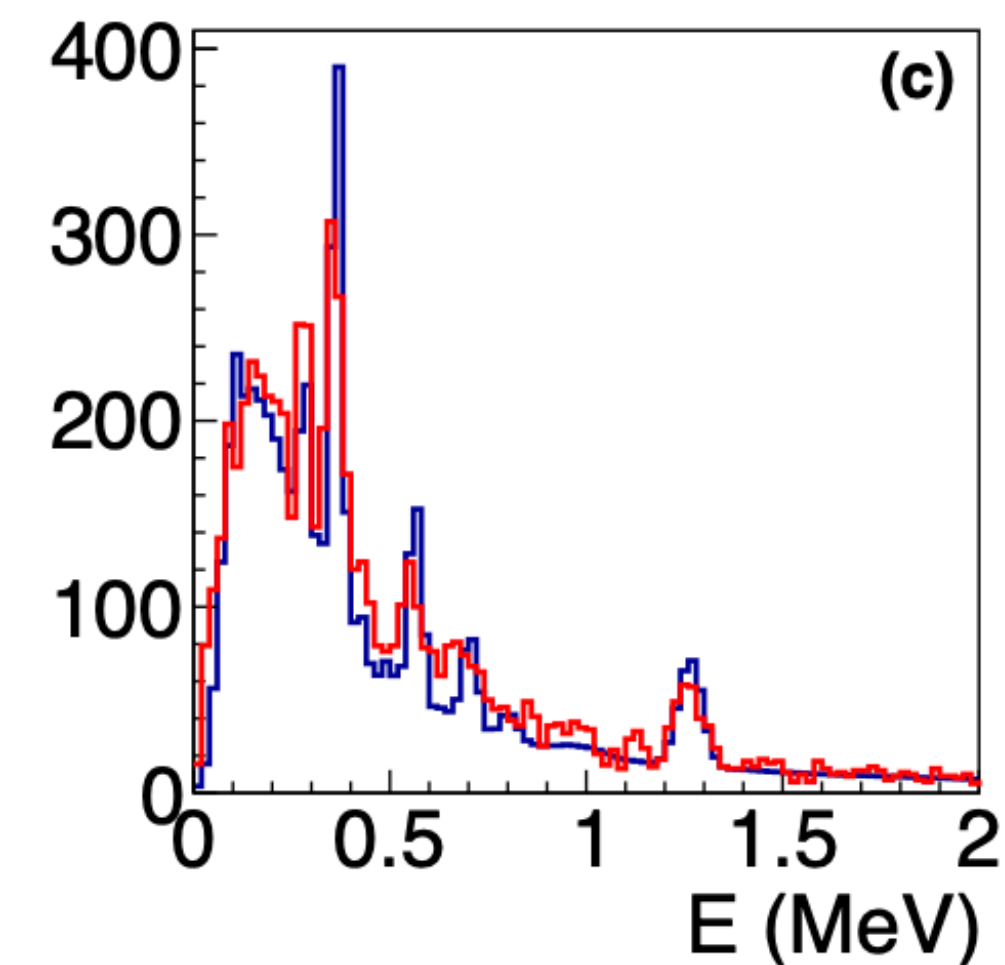
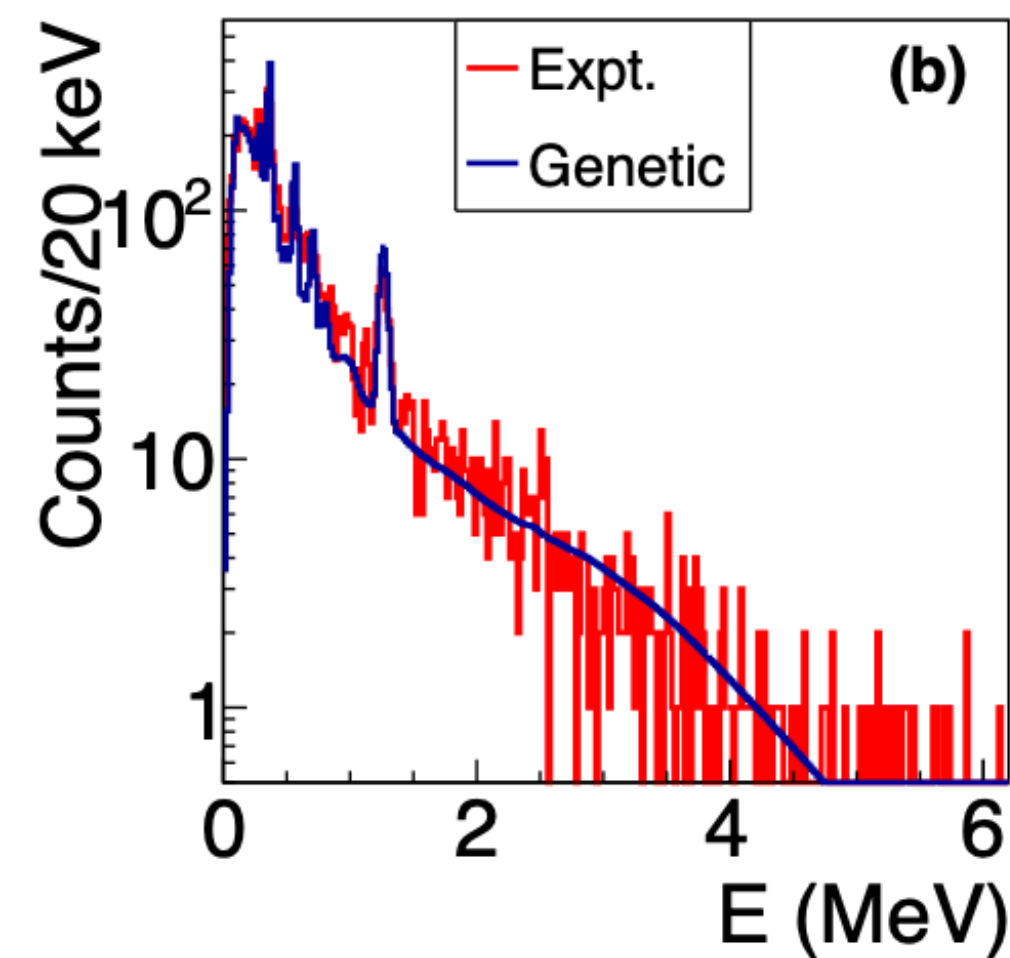
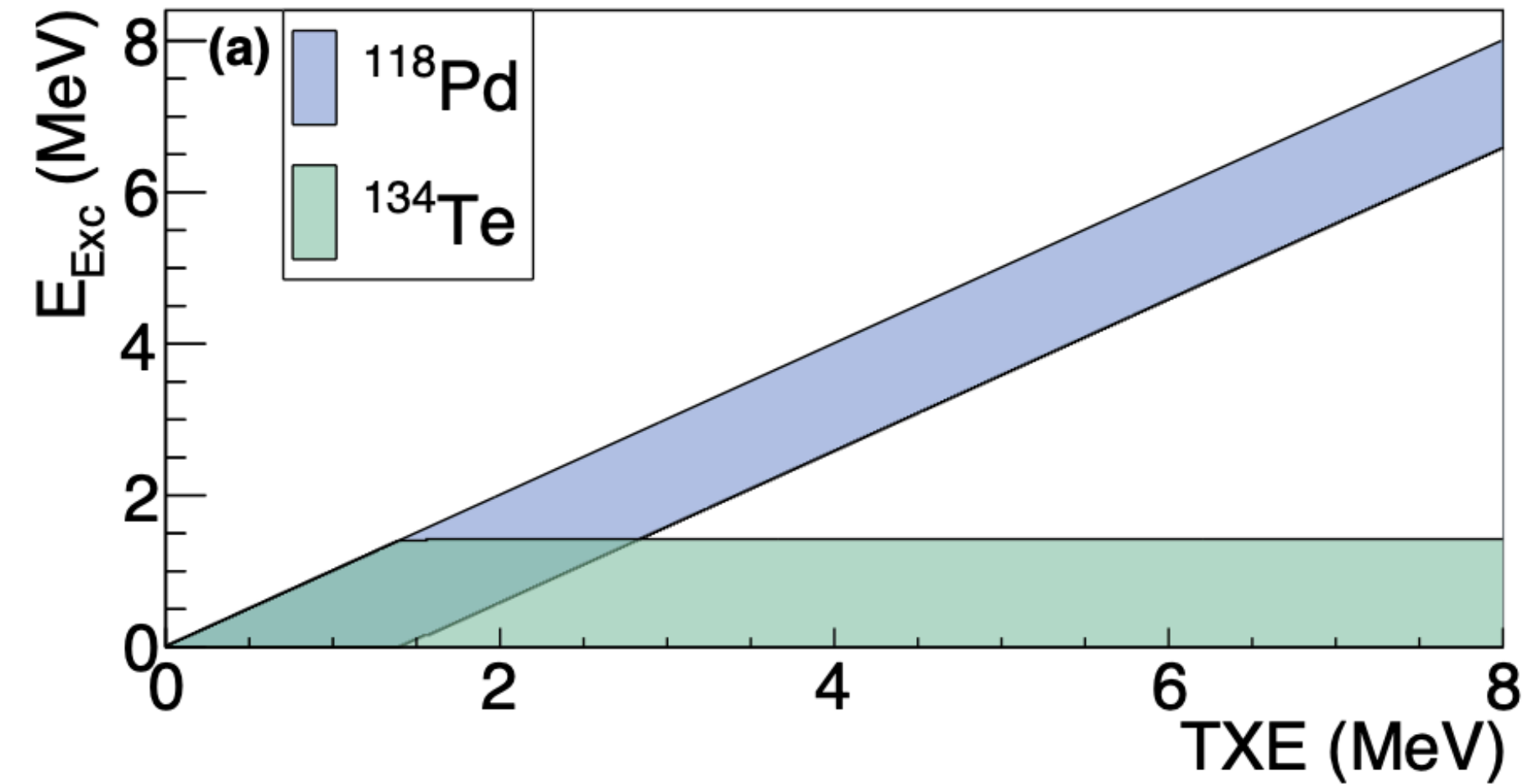
Optimization with Genetic algorithm



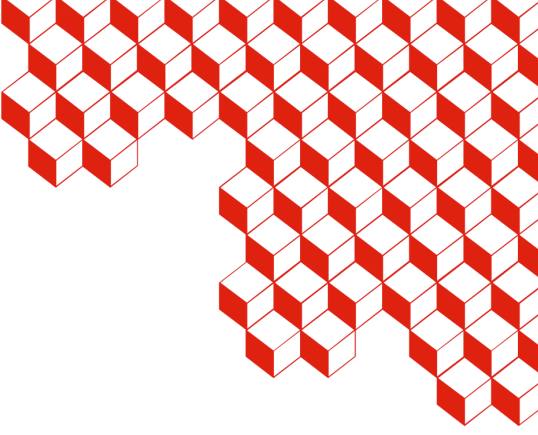
Genetic Algorithm :

⇒ determines $E_{L,H}(TXE)$ and σ as well as the spin-cutoff parameters providing the best description of the measured spectrum.

1. ^{134}Te weakly excited $\Rightarrow I(GS) \approx 50\%$.
2. $\sigma \approx 1.3 \text{ MeV} \Rightarrow I(6_1^+) \approx 15\% + \text{indep. TXE}$
3. Spin cutoff $B^{Te} \sim 3\hbar$ and $B^{Pd} \sim 4.5\hbar$
 \Rightarrow Global normalisation + $I(2_1^+)$ and $I(4_1^+)$



Comparison with Standard fission



- For ^{252}Cf standard fission J.N. Wilson et al. Nature 590, 566 (2021) :

$$B^{\text{Te}} \sim 2.9\hbar \text{ similar to our } B^{\text{Te}} \sim 3\hbar \Rightarrow \text{Ratio} \approx 1.0$$

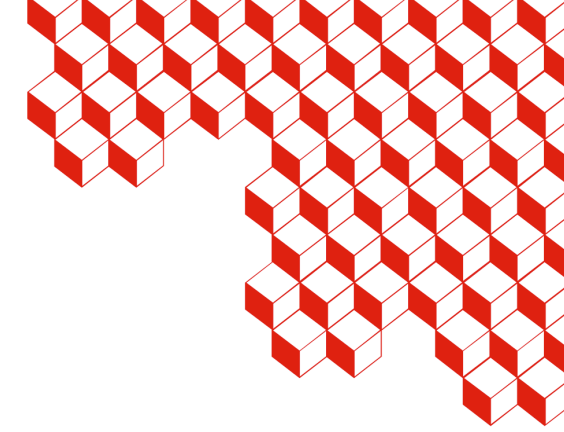
$$B^{\text{Pd}} \sim 6\hbar \text{ larger than our } B^{\text{Pd}} \sim 4.5\hbar \Rightarrow \text{Ratio} \approx 1.3$$

- Well accounted for by the relation $B^2 \propto \mathcal{F} \frac{a}{\tilde{a}} T$

- Mean pre-neutron excitation energies

$$\text{Wilson et al. : } \bar{E}_x^{\text{Te}} \sim 12 \text{ MeV and } \bar{E}_x^{\text{Pd}} \sim 21 \text{ MeV (}\Leftarrow \text{ GEF)}$$

$$\text{Our work : } \bar{E}_x^{\text{Te}} \sim 0 \text{ MeV and } \bar{E}_x^{\text{Pd}} \sim 6 \text{ MeV}$$



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- Using Talys to estimate nuclear Temperatures

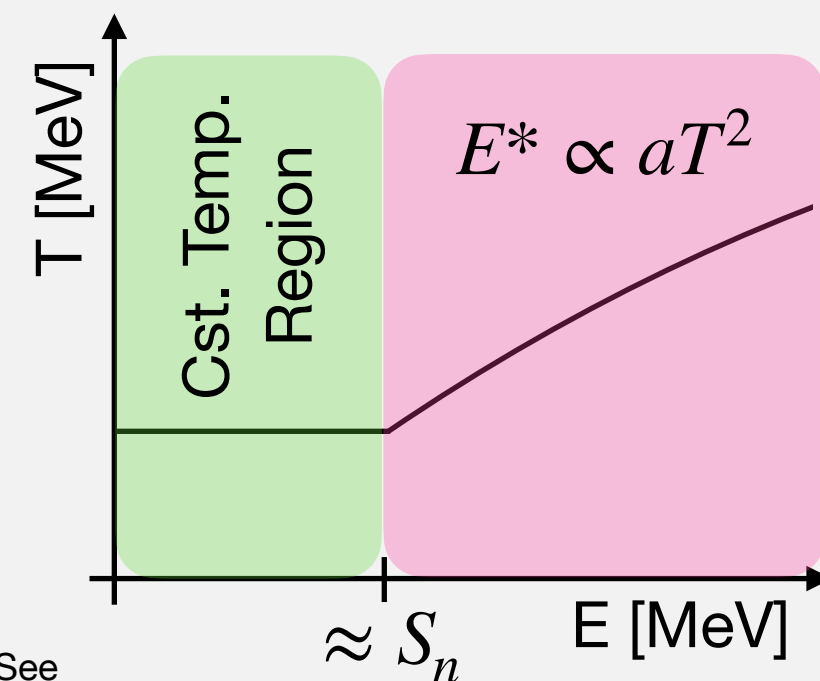
$$\bar{E}_x^{\text{Te}} \sim 12 \text{ MeV} \Rightarrow T^{\text{Te}} \sim 0.99 \text{ MeV}$$

$$\bar{E}_x^{\text{Te}} \sim 0 \text{ MeV} \Rightarrow T^{\text{Te}} \sim 0.78 \text{ MeV} \Rightarrow \text{Ratio} \approx 1.12$$

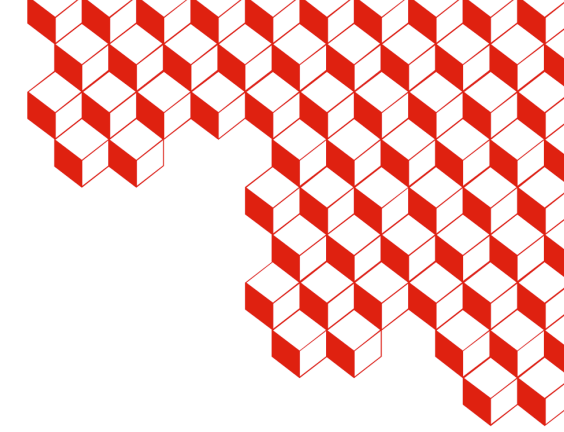
$$\bar{E}_x^{\text{Pd}} \sim 21 \text{ MeV} \Rightarrow T^{\text{Pd}} \sim 1.1 \text{ MeV}$$

$$\bar{E}_x^{\text{Pd}} \sim 6 \text{ MeV} \Rightarrow T^{\text{Pd}} \sim 0.58 \text{ MeV} \Rightarrow \text{Ratio} \approx 1.38$$

From excitation energy to Temperature



See
S. Goriely et al., PRC **106**, 044315 (2022)
V. Zelevinsky et al. PLB **783**, 428 (2018)



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- For ^{252}Cf standard fission J.N. Wilson et al. Nature 590, 566 (2021) :

$$B^{\text{Te}} \sim 2.9\hbar \text{ similar to our } B^{\text{Te}} \sim 3\hbar \Rightarrow \text{Ratio} \approx 1.0$$

$$B^{\text{Pd}} \sim 6\hbar \text{ larger than our } B^{\text{Pd}} \sim 4.5\hbar \Rightarrow \text{Ratio} \approx 1.3$$

- Well accounted for by the relation $B^2 \propto \mathcal{F} \frac{a}{\tilde{a}} T$

- Mean pre-neutron excitation energies

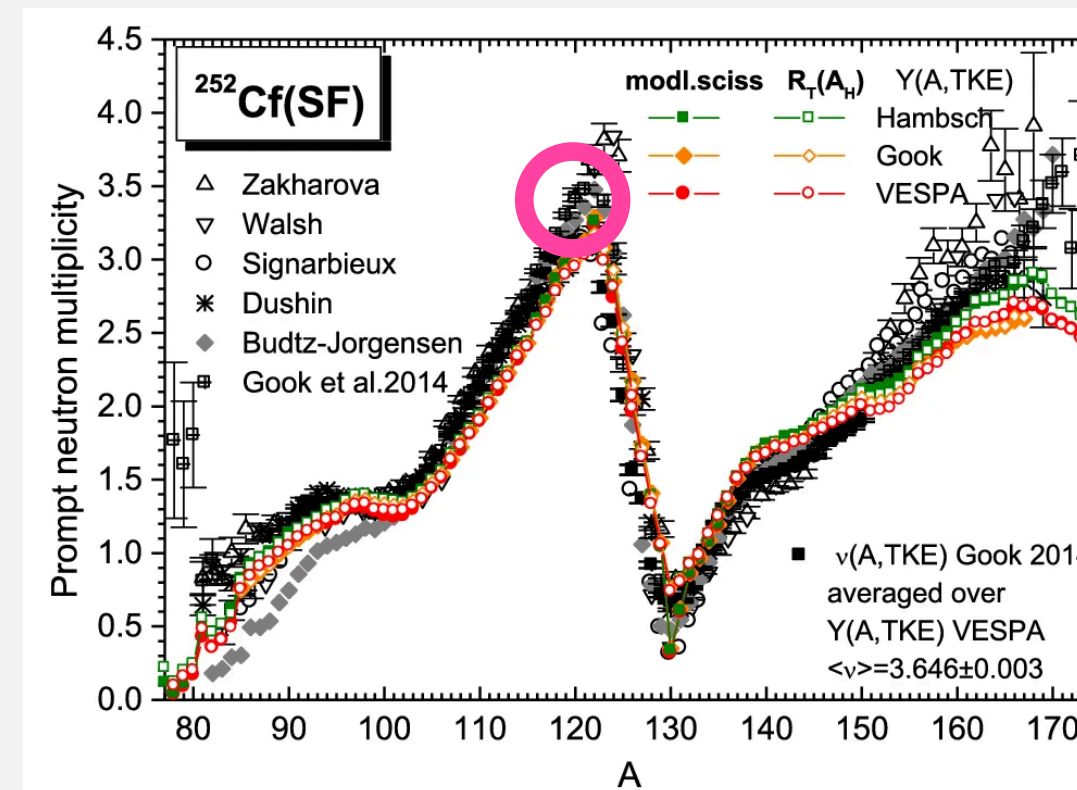
$$\text{Wilson et al. : } \bar{E}_x^{\text{Te}} \sim 12 \text{ MeV and } \bar{E}_x^{\text{Pd}} \sim 21 \text{ MeV (}\Leftarrow \text{ GEF)}$$

$$\text{Our work : } \bar{E}_x^{\text{Te}} \sim 0 \text{ MeV and } \bar{E}_x^{\text{Pd}} \sim 6 \text{ MeV}$$

Spin distribution differences explained without a third-party effect.

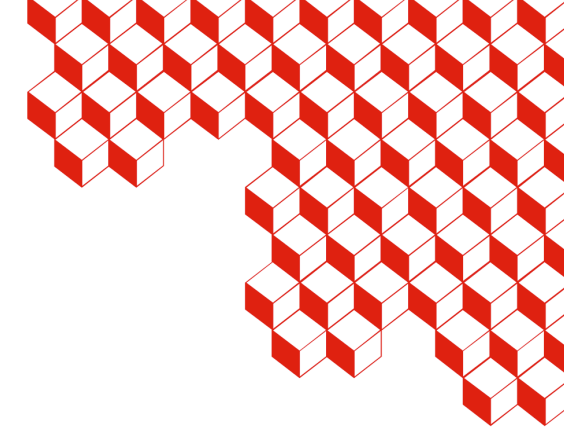
\Rightarrow Neglect angular momentum removal by neutrons.

I. Stetcu et al., PRL **127**, 222502 (2021)



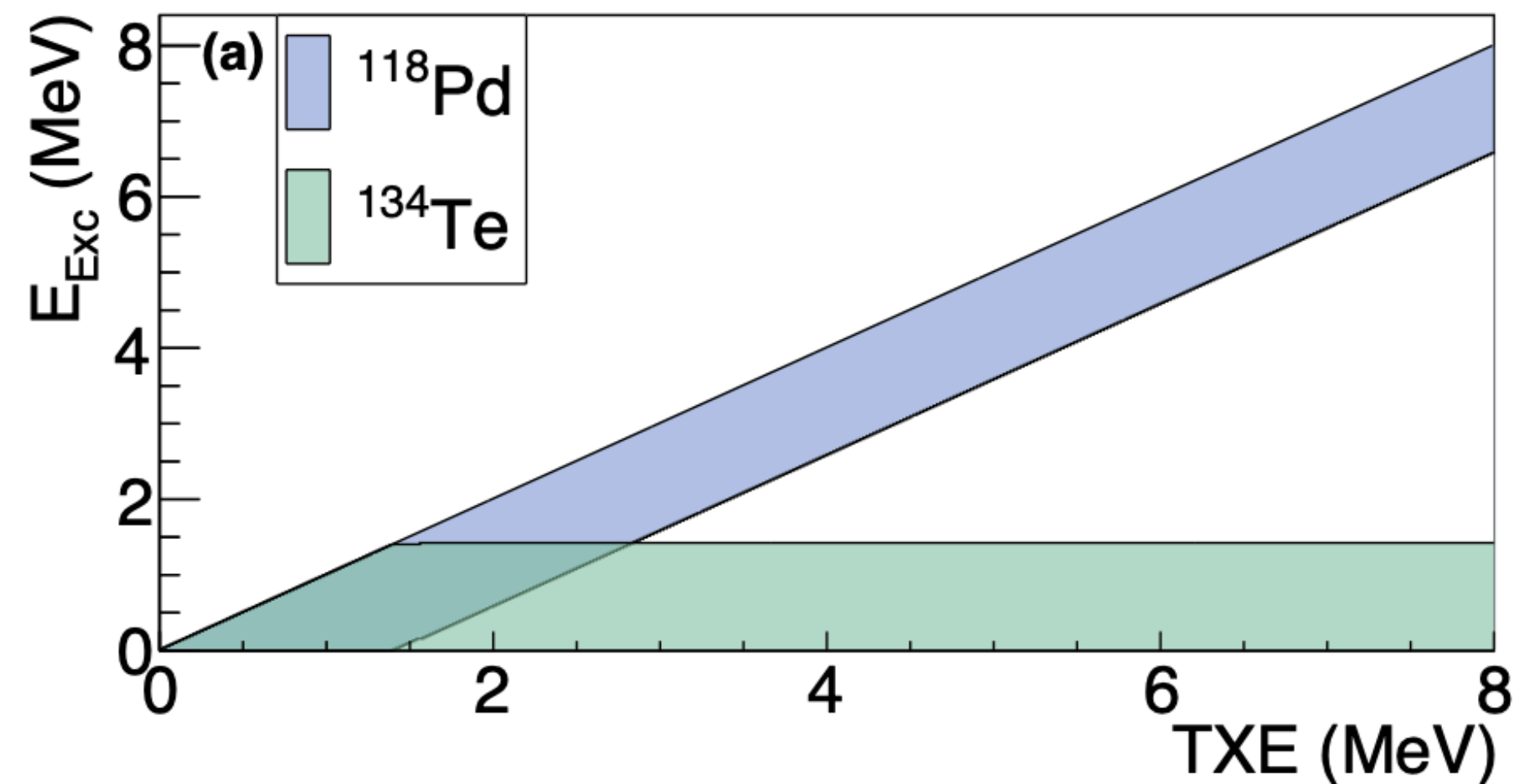
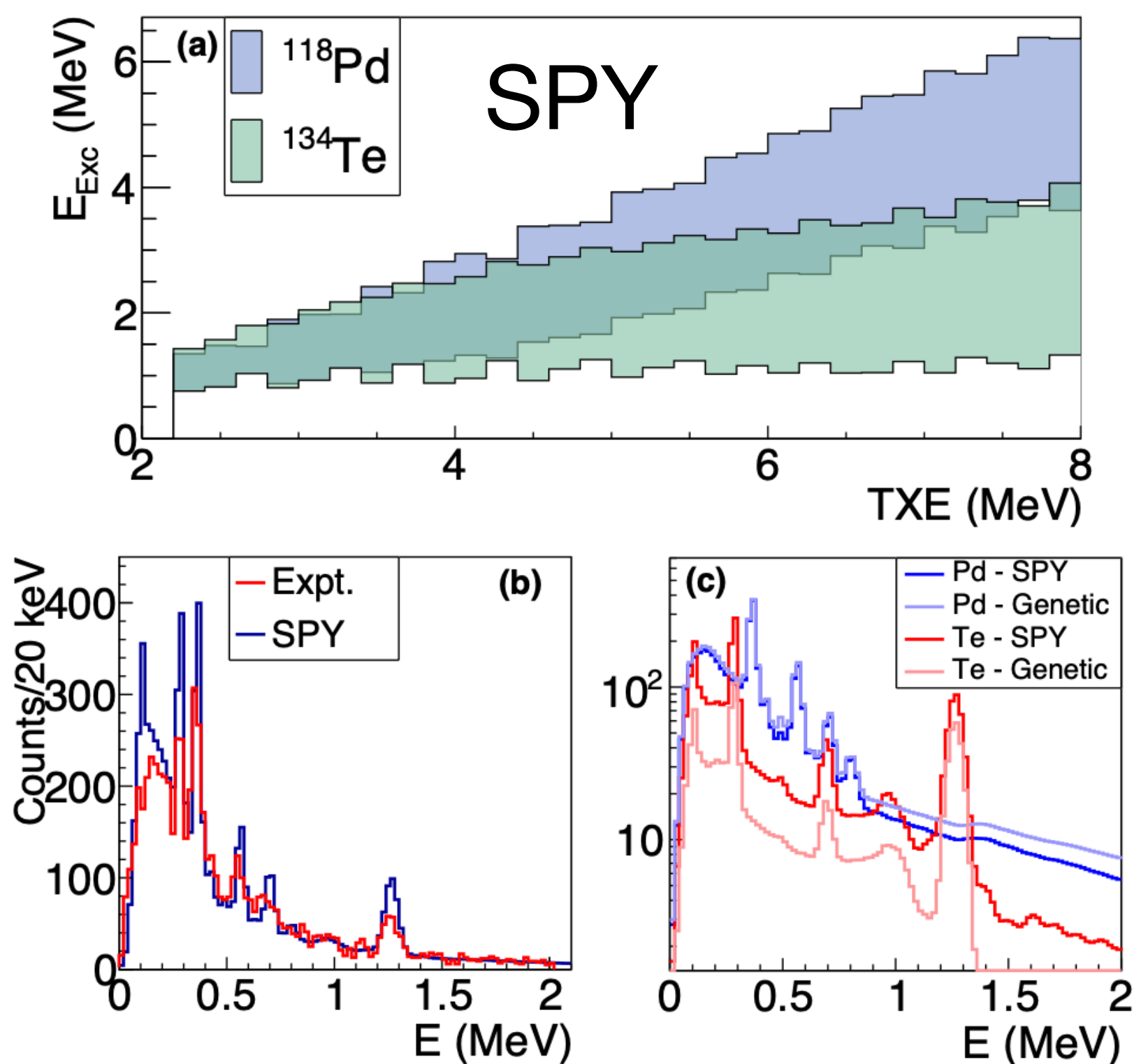
^{118}Pd : The best place to see the effect if it exists.

Comparison with SPY



SPY, a microscopic scission-point model, taking into account pairing, shell effect and deformation

J.-F. Lemaître et al., PRC 99, 034612 (2019)



SPY : too much E^* in ^{134}Te .

^{118}Pd :

- SPY $\Rightarrow \beta_L \approx 0.04$
- Orientation-pumping mechanism $\Rightarrow \beta_L \approx 0.4$
[see PRL 132, 142501 (2024)]

At fixed TXE :

- Lower $\beta_L \leftrightarrow$ lower E_L^*
- Lower $E_L^* \leftrightarrow$ higher E_H^* , since $(E_H^* = \text{TXE} - E_L^*)$

\Rightarrow SPY underestimates β_{Pd} .

\Rightarrow Indirect confirmation of the O-P mechanism.

Summary

Study of neutronless fission channel in ^{252}Cf

Identification of fragments

Study of their γ decay

Determination of TXE distribution

Reproduction of measured gamma spectrum

Determination of E_x distribution ($\sigma \sim 1.3\text{MeV}$)

\Rightarrow Heavy fragment weakly excited.

Determination of spin cutoff parameters

\Rightarrow Link with J-removal by neutrons...

Comparison with SPY

High $E_x^{Te} \Leftrightarrow$ disagreement on γ spectrum.

Potential link with too low β_{Pd} .

Indirect confirmation of orientation-pumping mechanism