# Fission Dynamics 2026

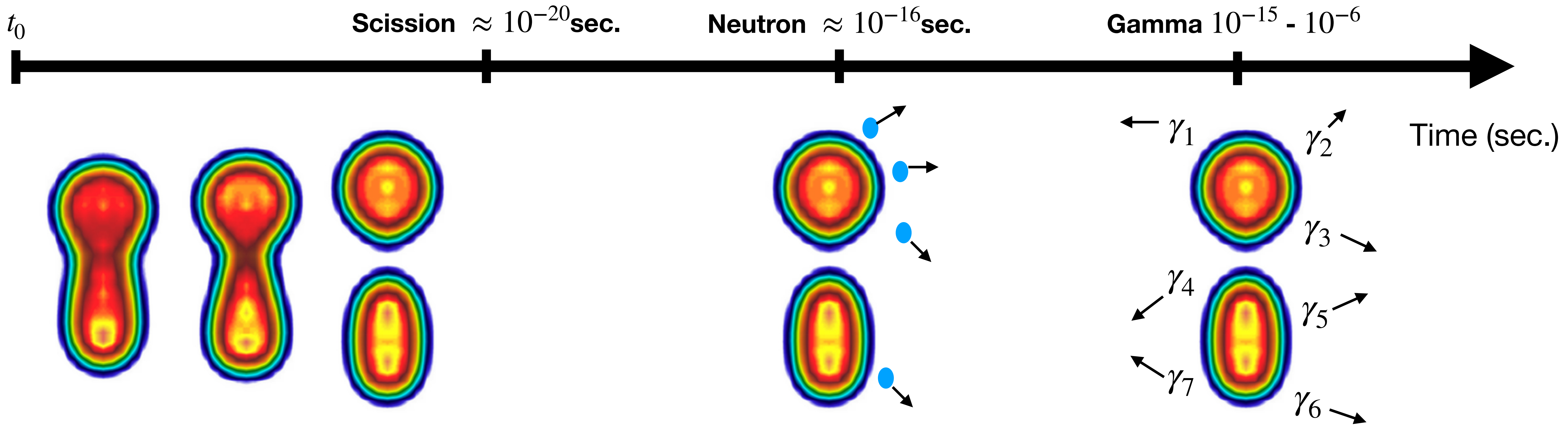
May 11-15, 2026
Chongqing - China

## Fission Fragments' Properties from the Neutronless Channel in $^{252}Cf(sf)$

L. Gaudefroy - CEA/Saclay

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

# Studying  the decay of the fragments?




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

Fission numbers for $^{252}Cf$

$\overline{Q}$~218 MeV

$\overline{TKE}$=184MeV

$\overline{TXE} = \overline{Q} - \overline{TKE}$ ~34 MeV

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

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

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

An experimental challenge to :

Identify the fragments
Correctly measure their decay

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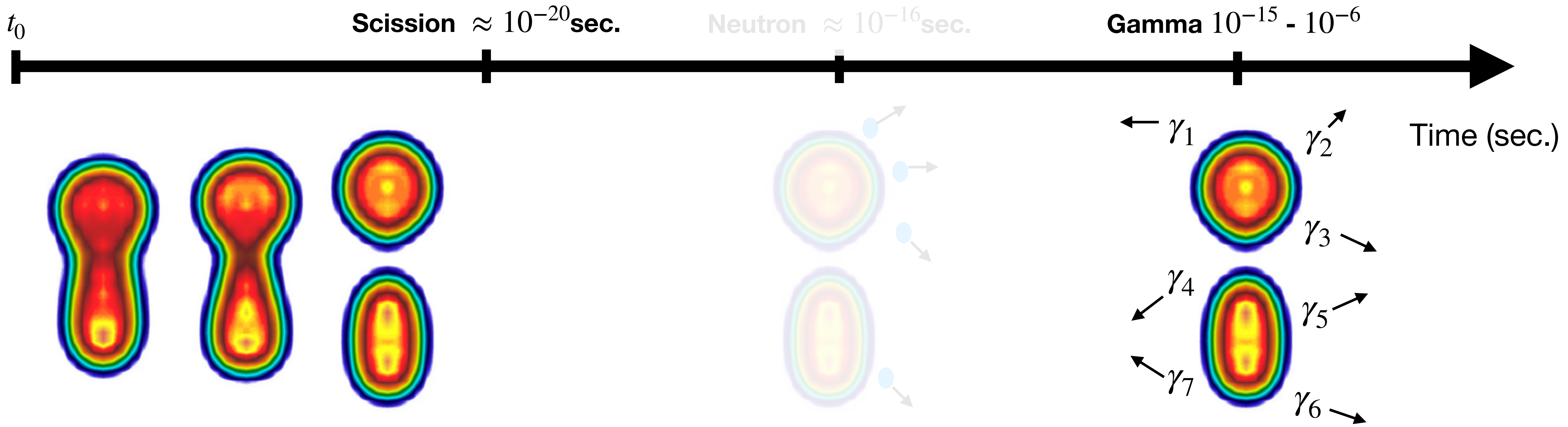


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An experimental challenge to :

Identify the fragments
Correctly measure their decay

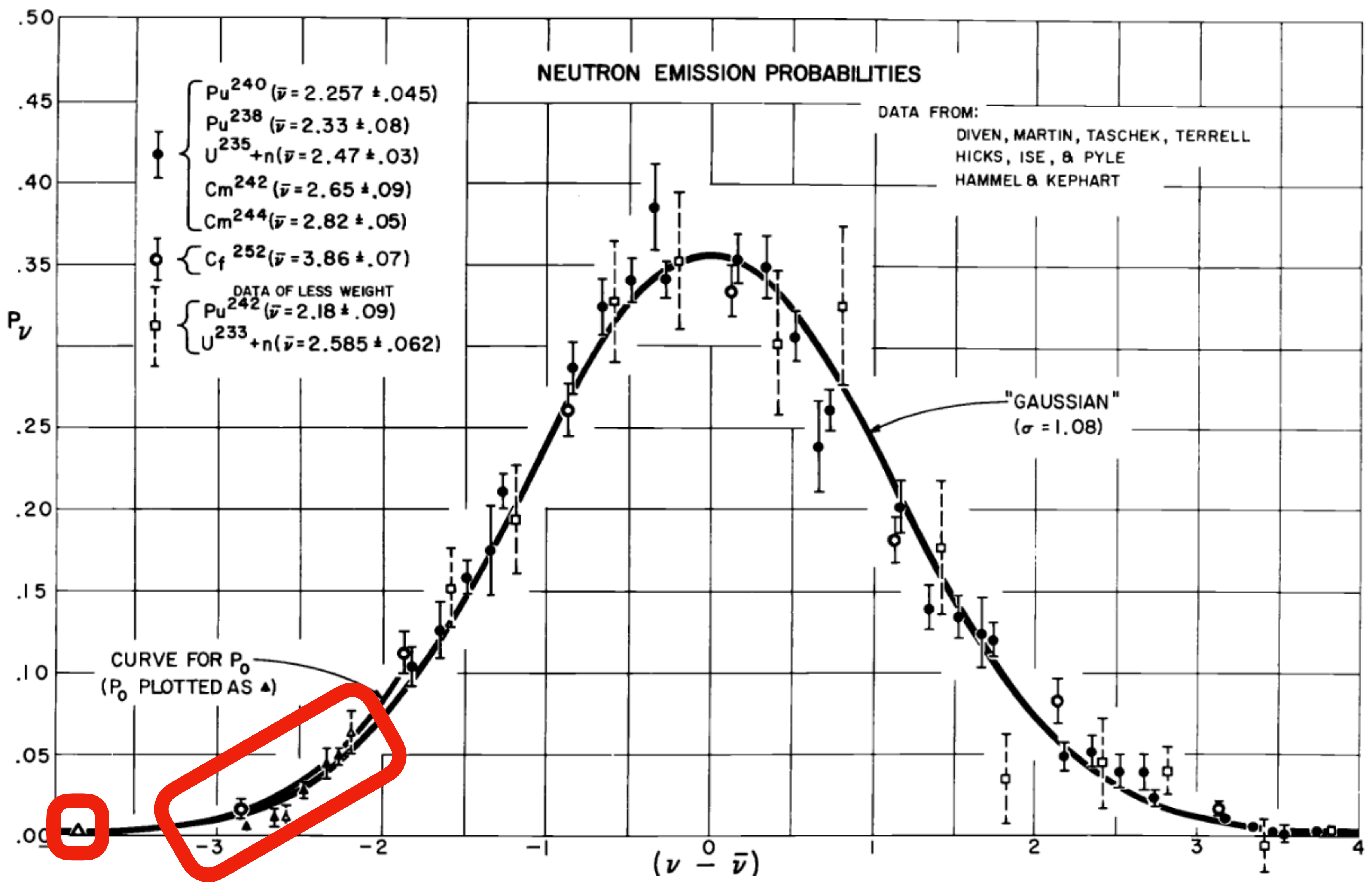
Neutronless fission simplifies fragment ID

⇒Possibility of compact FF detector

$$KE_L/KE_H = A_H/A_L$$

⇒Decay = only gamma rays

⇒ Highly efficient gamma array

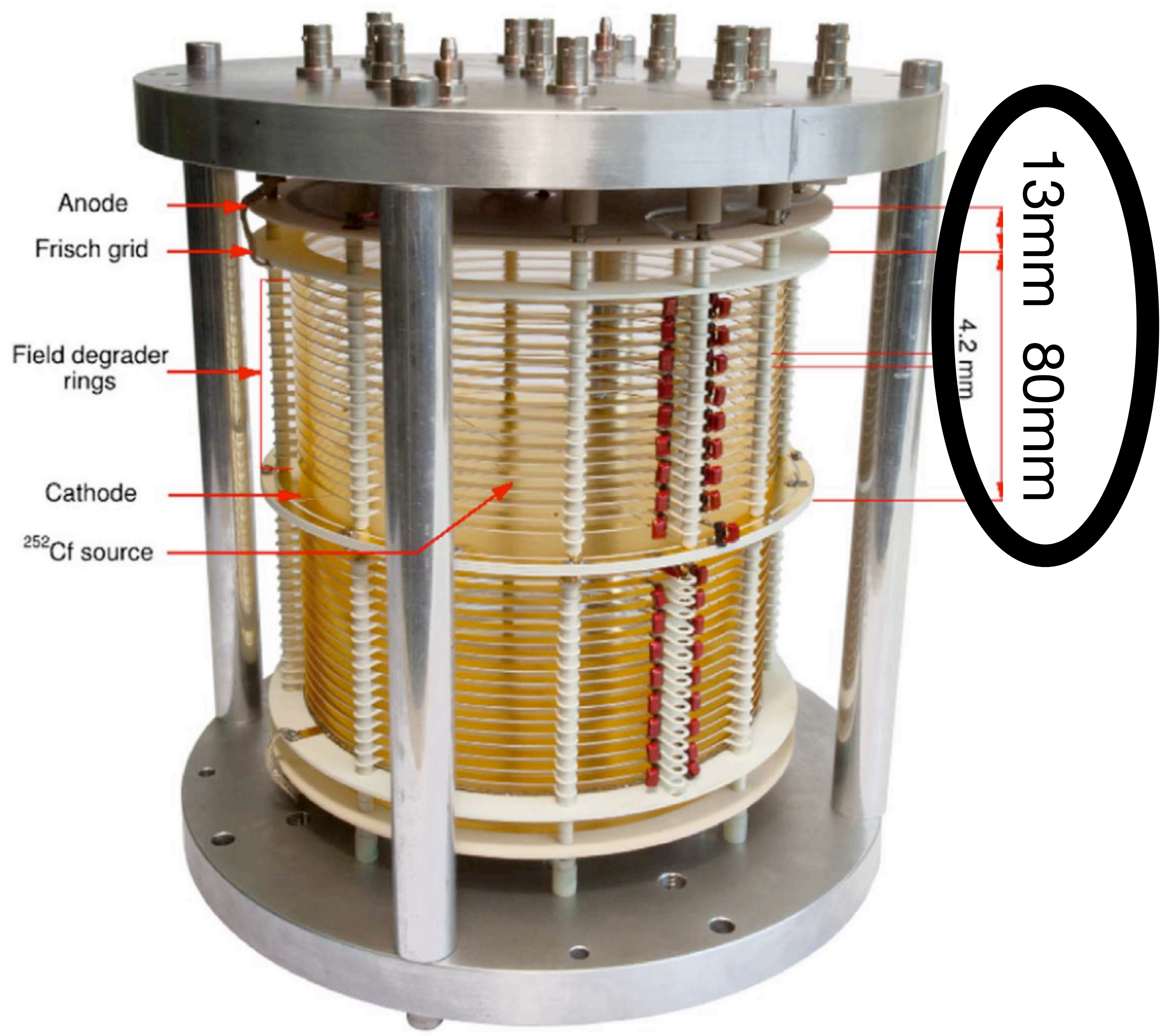



J. Terrell, Phys. Rev. **108** 783 (1957)

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

# Studying neutronless fission

A fragment detector…




Twin Frisch Grid Ionization Chamber ($\sigma_{KE} = 250 keV$)

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

# Studying neutronless fission

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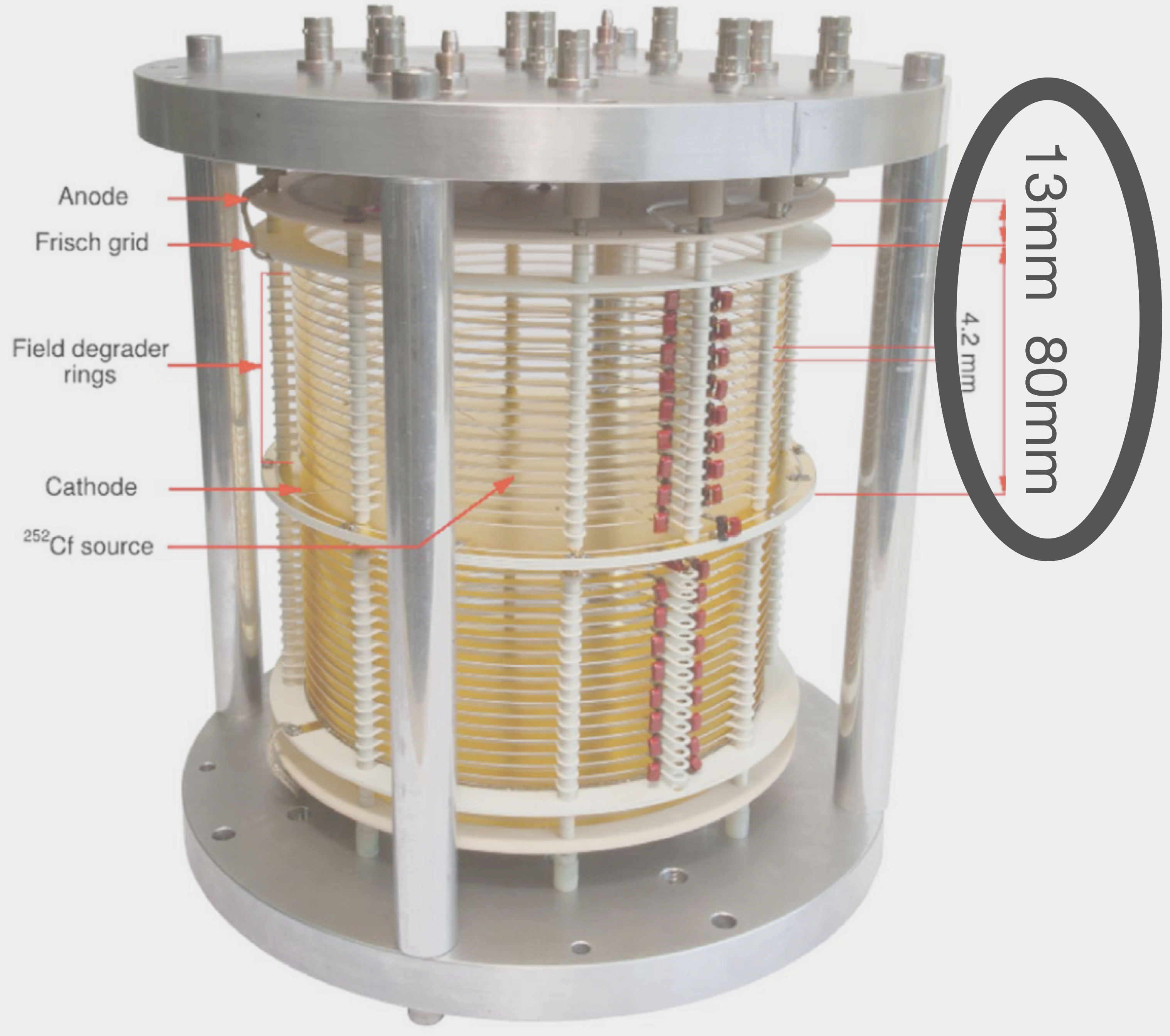


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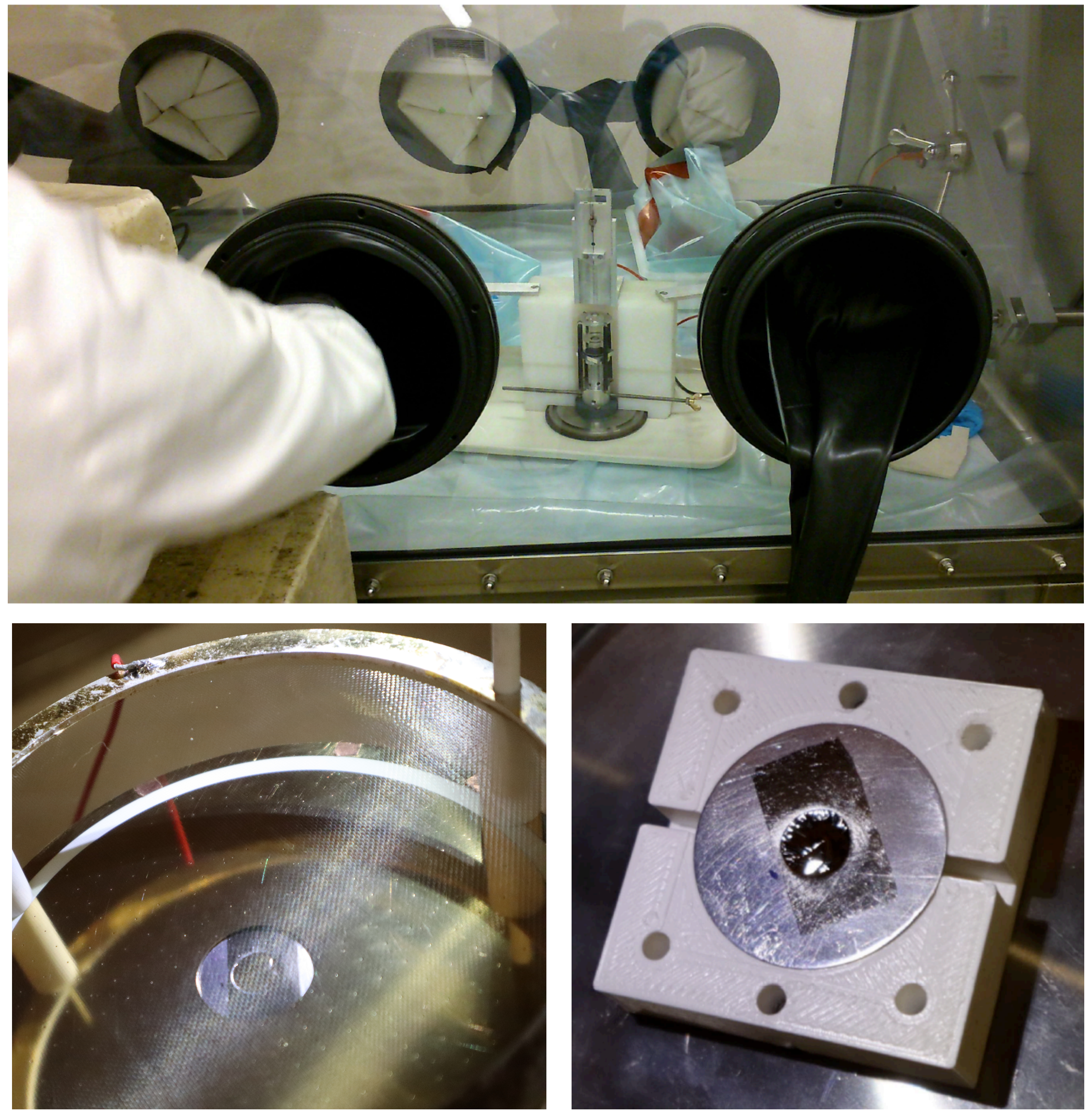
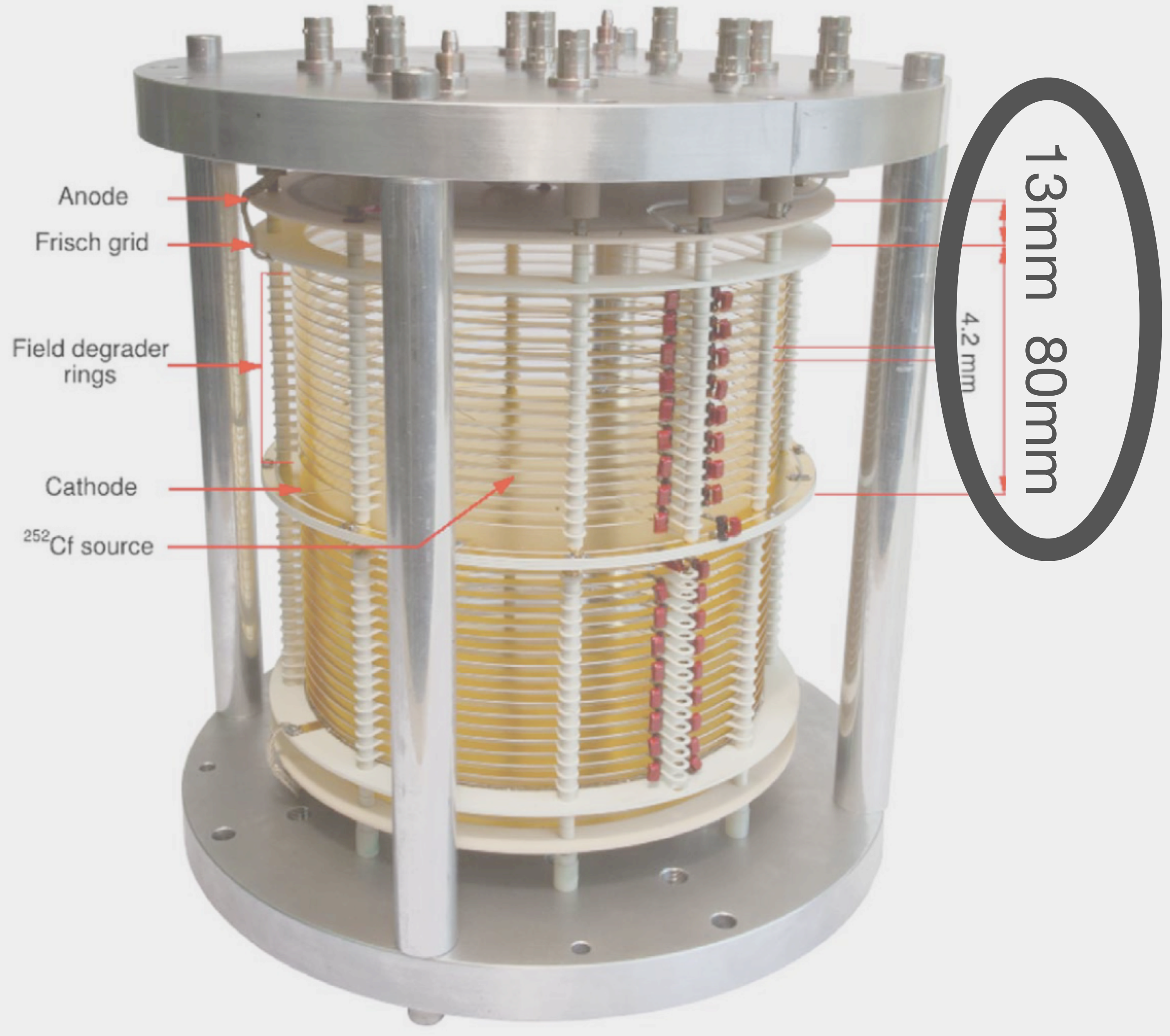
… loaded with an high quality fission sample …



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

# Studying neutronless fission

A fragment detector…

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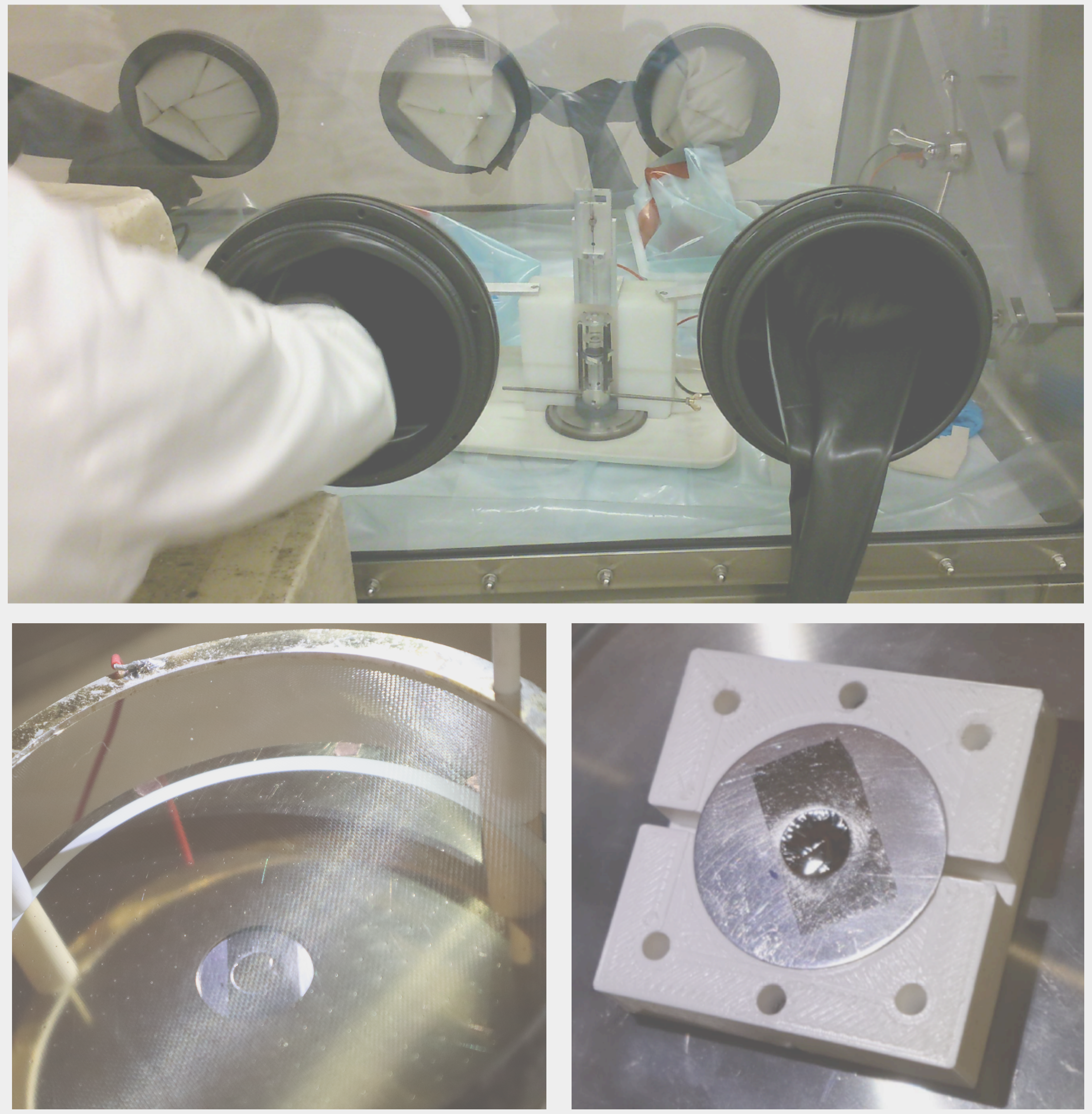
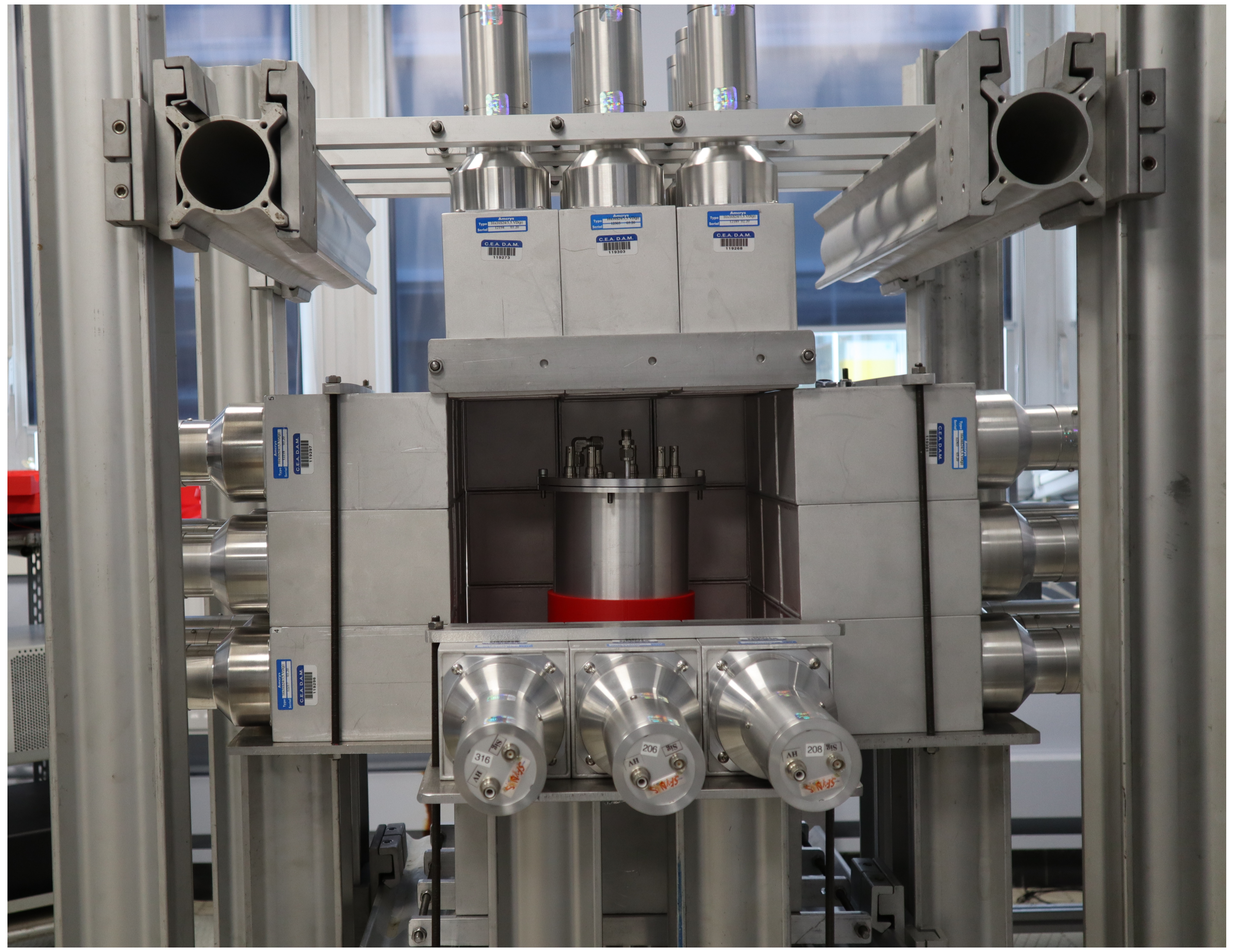


1200 Bq $^{252}Cf$ sample
on a 25nm ultra-thin C-backing

…surrounded by a gamma array.



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

54 large Volume (10x10x15cm) 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)

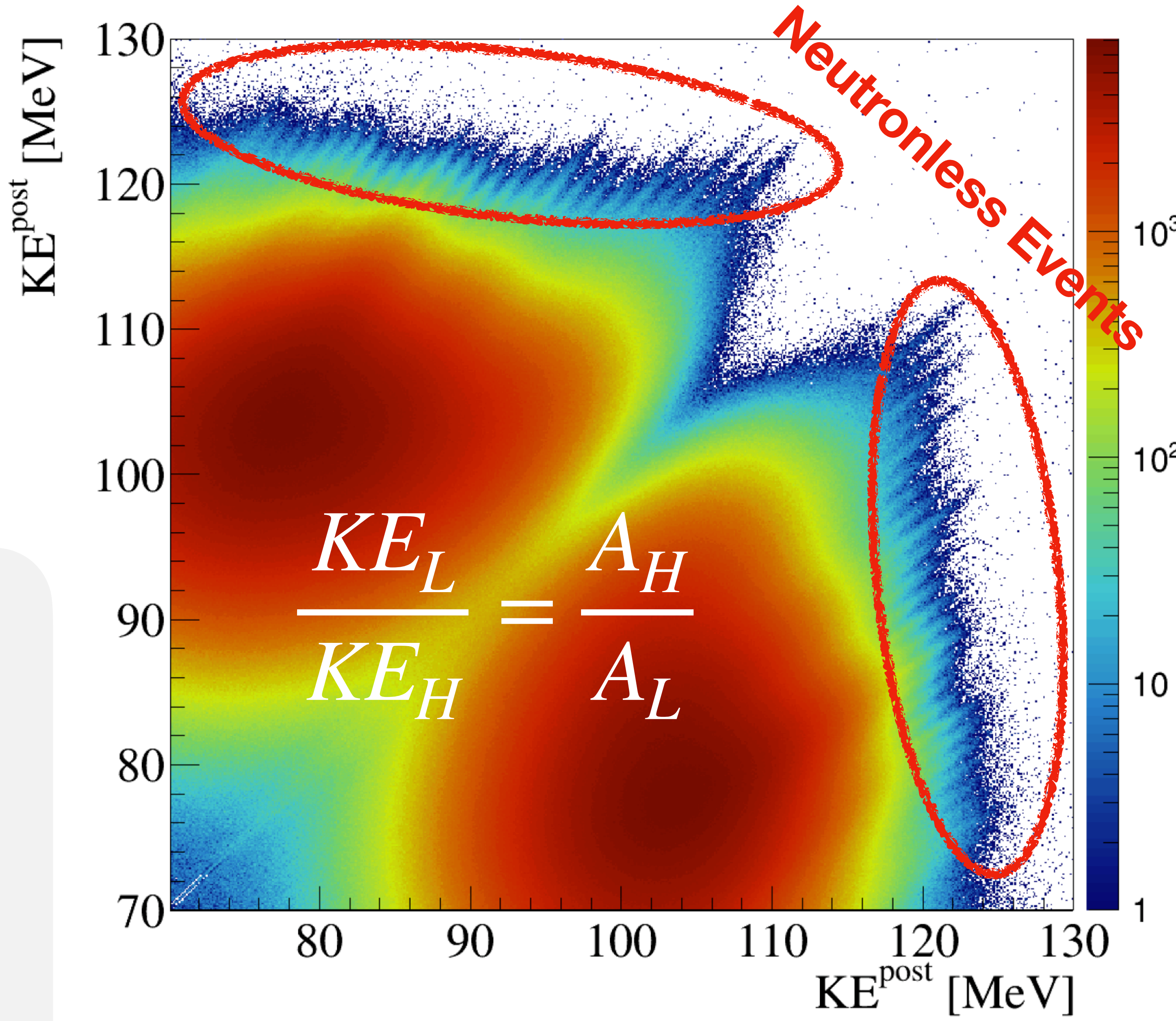
Isomer Production
L. G. et al., EPJ Web Conf. **242**, 01003 (2020)

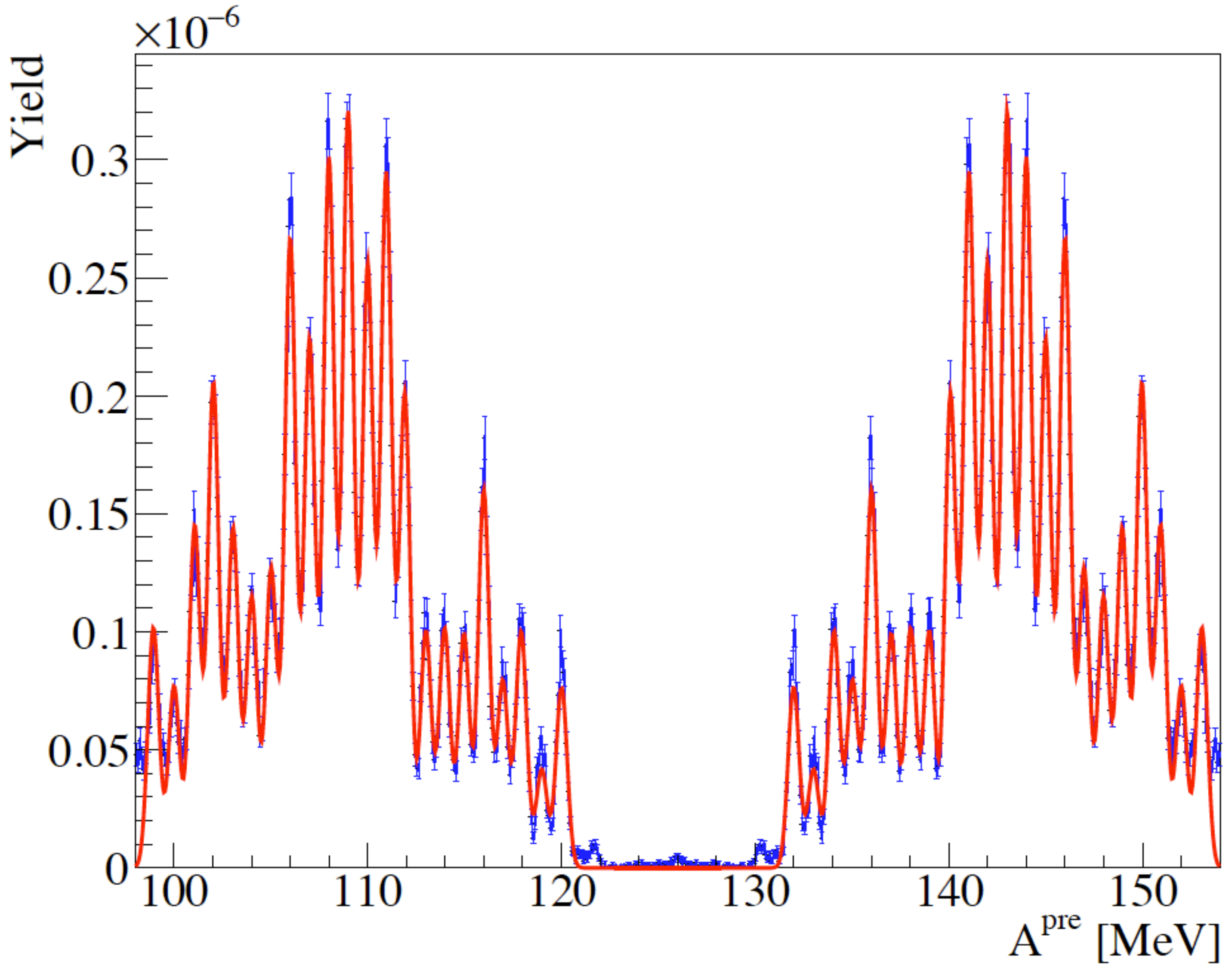
From this measurement

Fission/Fragments' Properties
A. Francheteau et al., PRL 132, 142501 (2024)
⇒ The exceptional $^{132}Sn/^{120}Cd$ case!

A. Francheteau et al., PRC 111, 034608 (2025)
⇒ Discussing the origin of the (4-6MeV) $\gamma$-bumps.

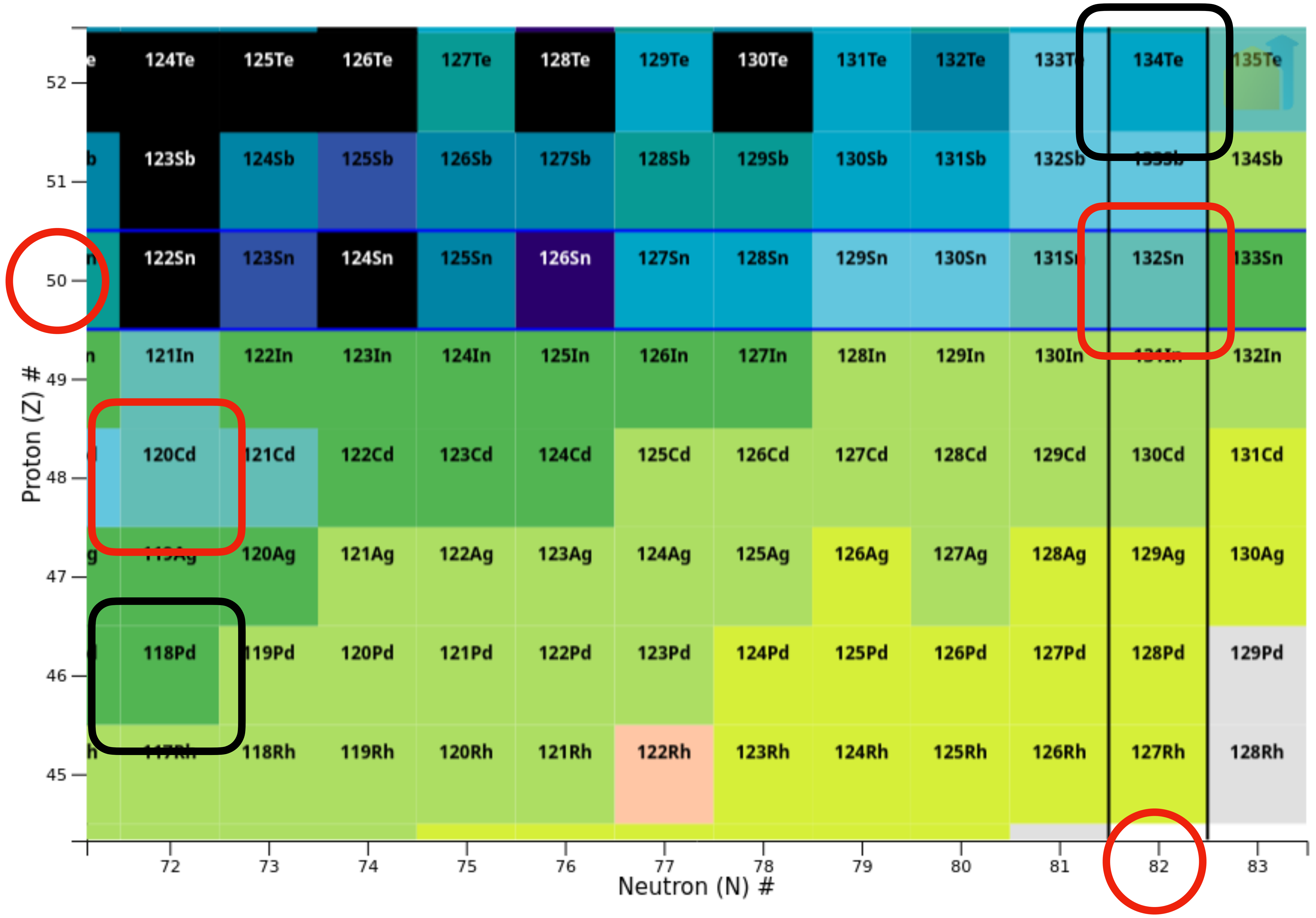
A. Francheteau et al., PRC 113, 034610 (2026)
⇒ $^{118}Pd/^{134}Te$ : Excitation energy, Angular momentum & Deformation.

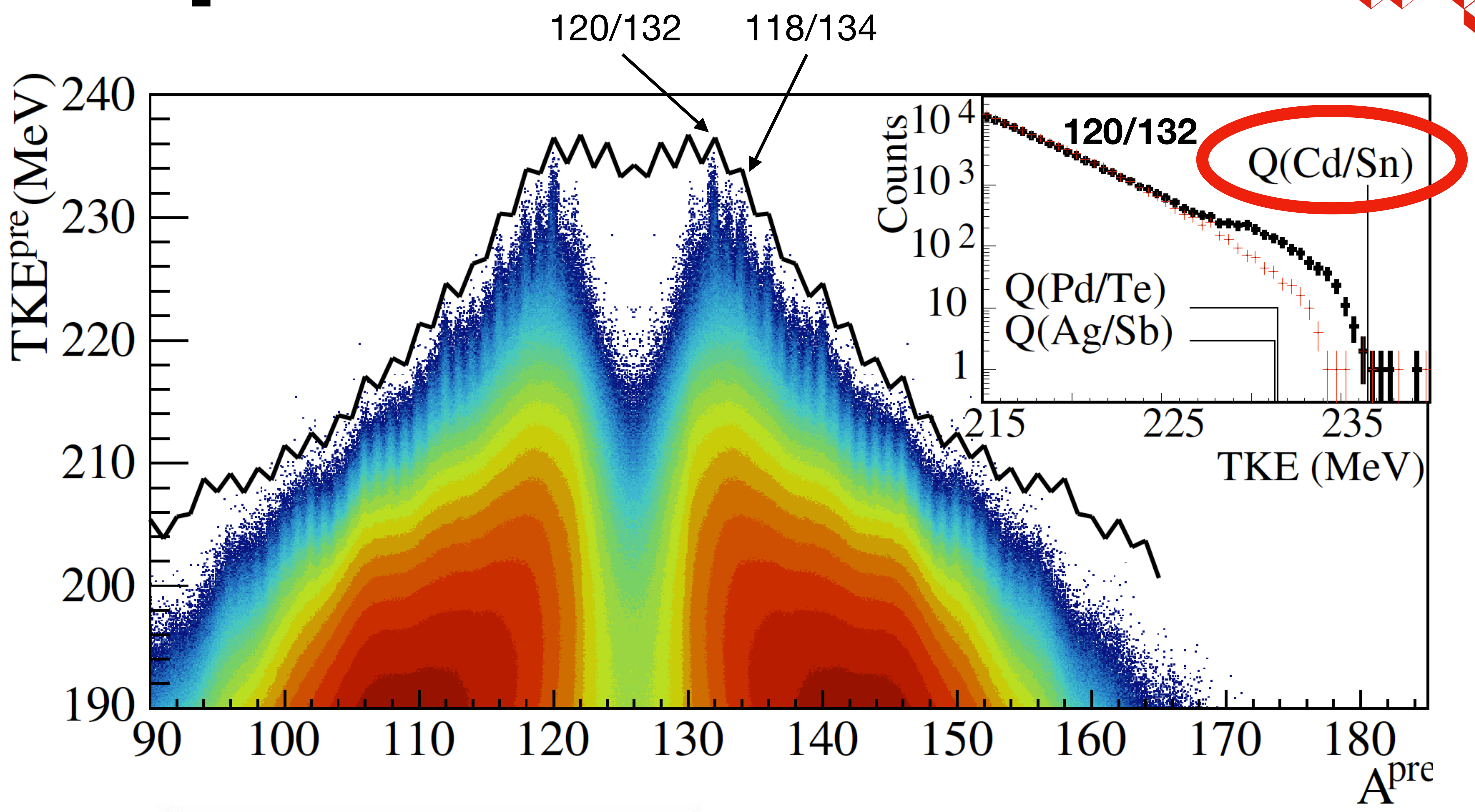


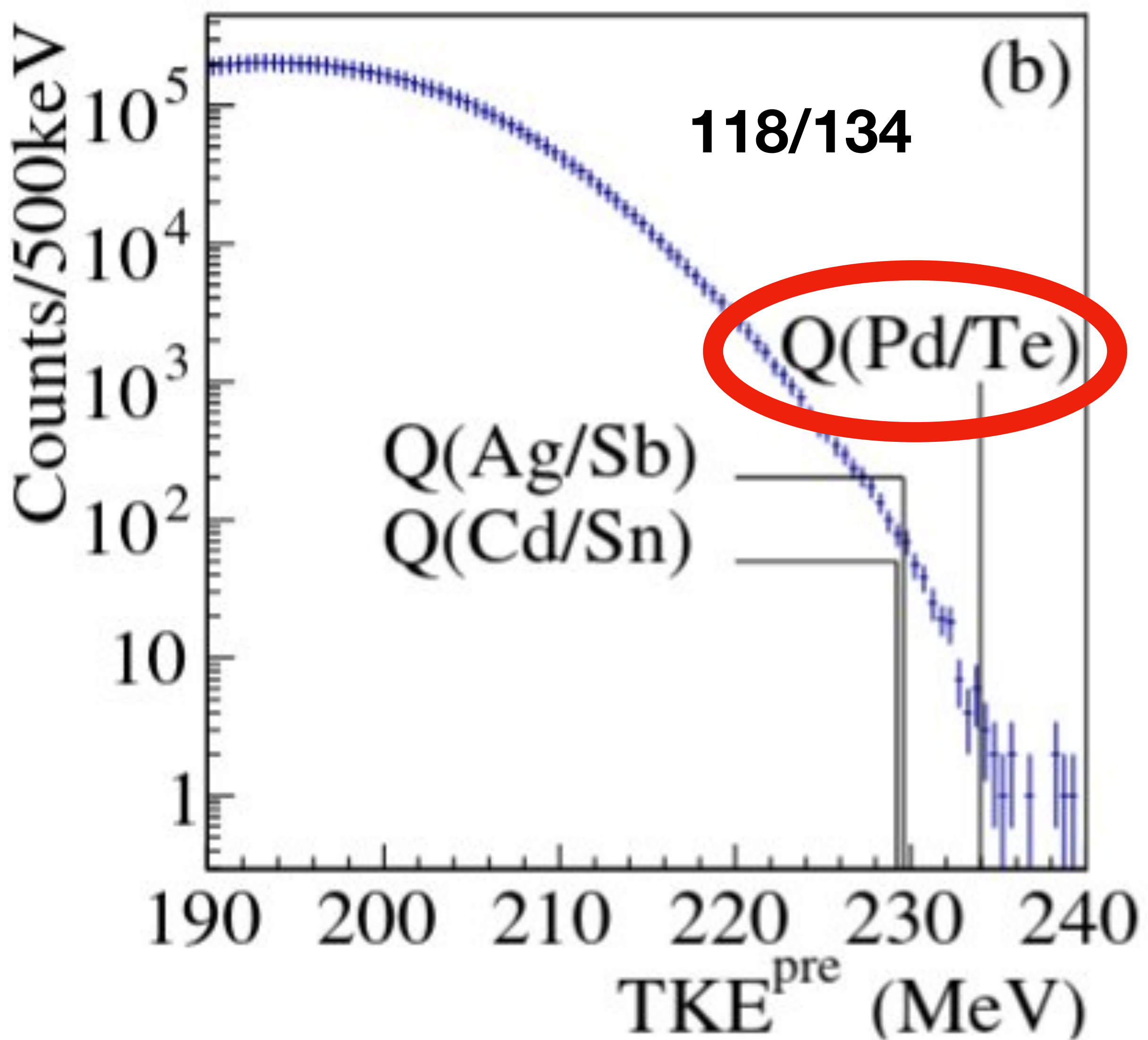




Mass Resolution : 0.6-0.7 amu FWHM!!

# When Shell Closures help us!



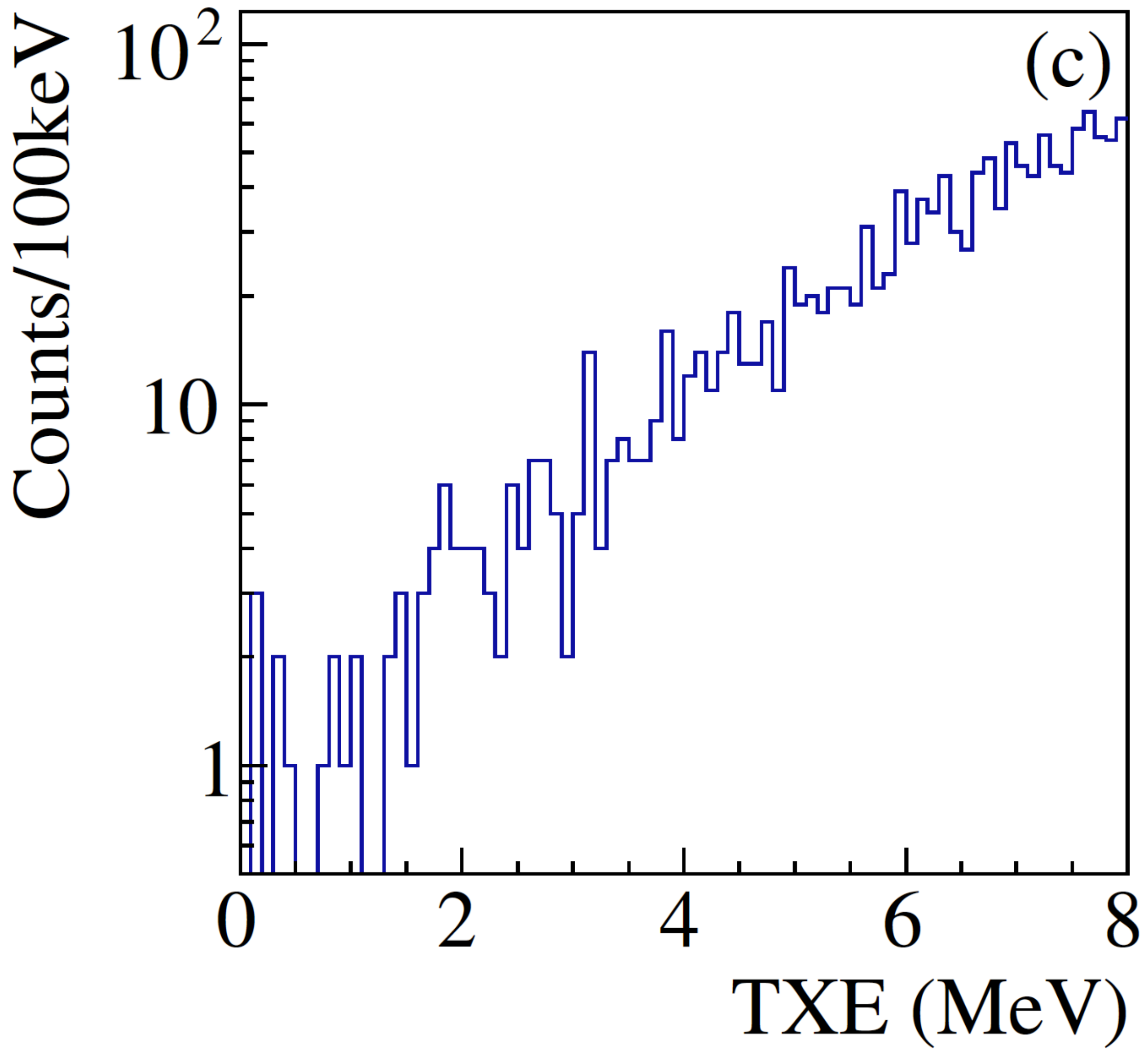




Simple TKE Selection
⇒ 90% purity on fragment selection

# What did we measure? 3/3

**TXE** = **Q**-**TKE**




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

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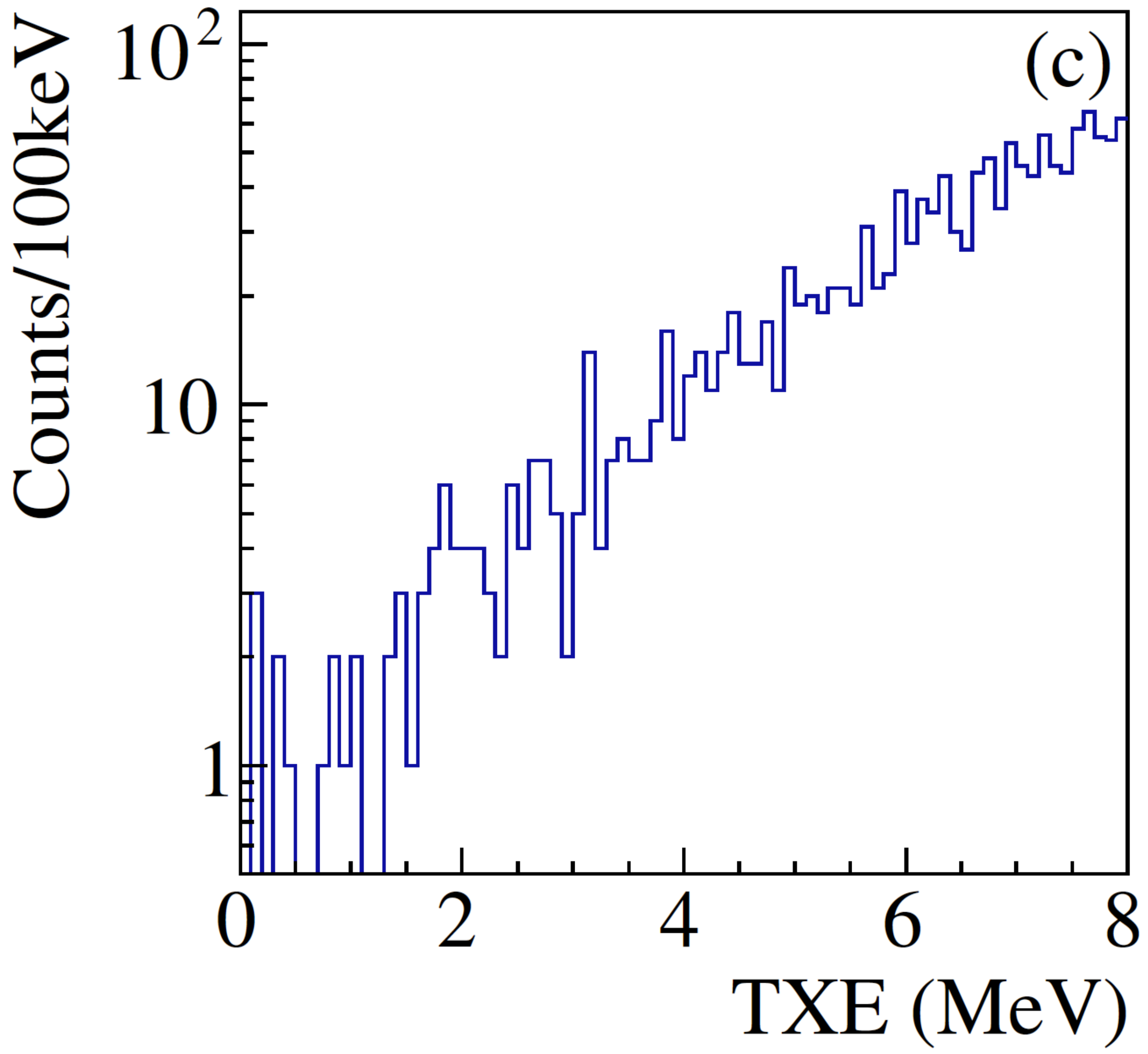


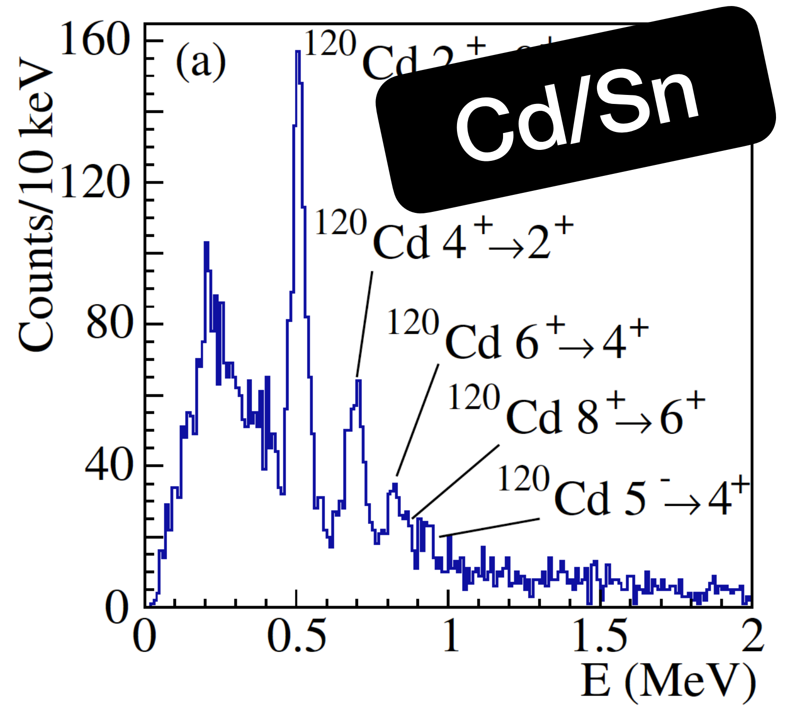


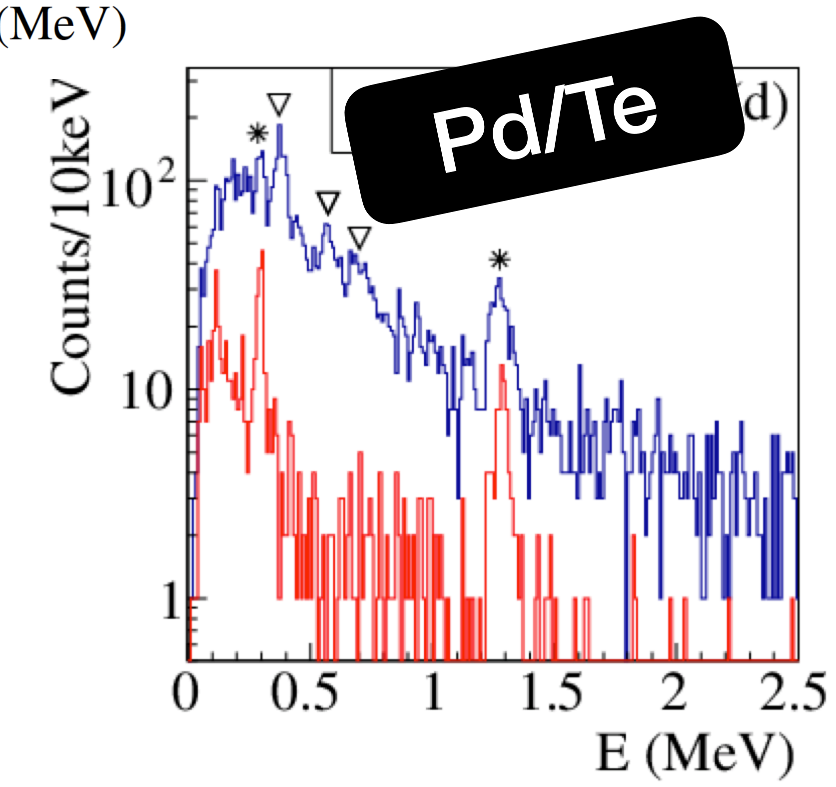


- TXE = $E_x^H + E_X^L$
- Prompt + delayed $\gamma$-spectrum; intensities/normalisation $\Rightarrow E_x$ distribution; spin distribution and multiplicity of the $\gamma$-cascade

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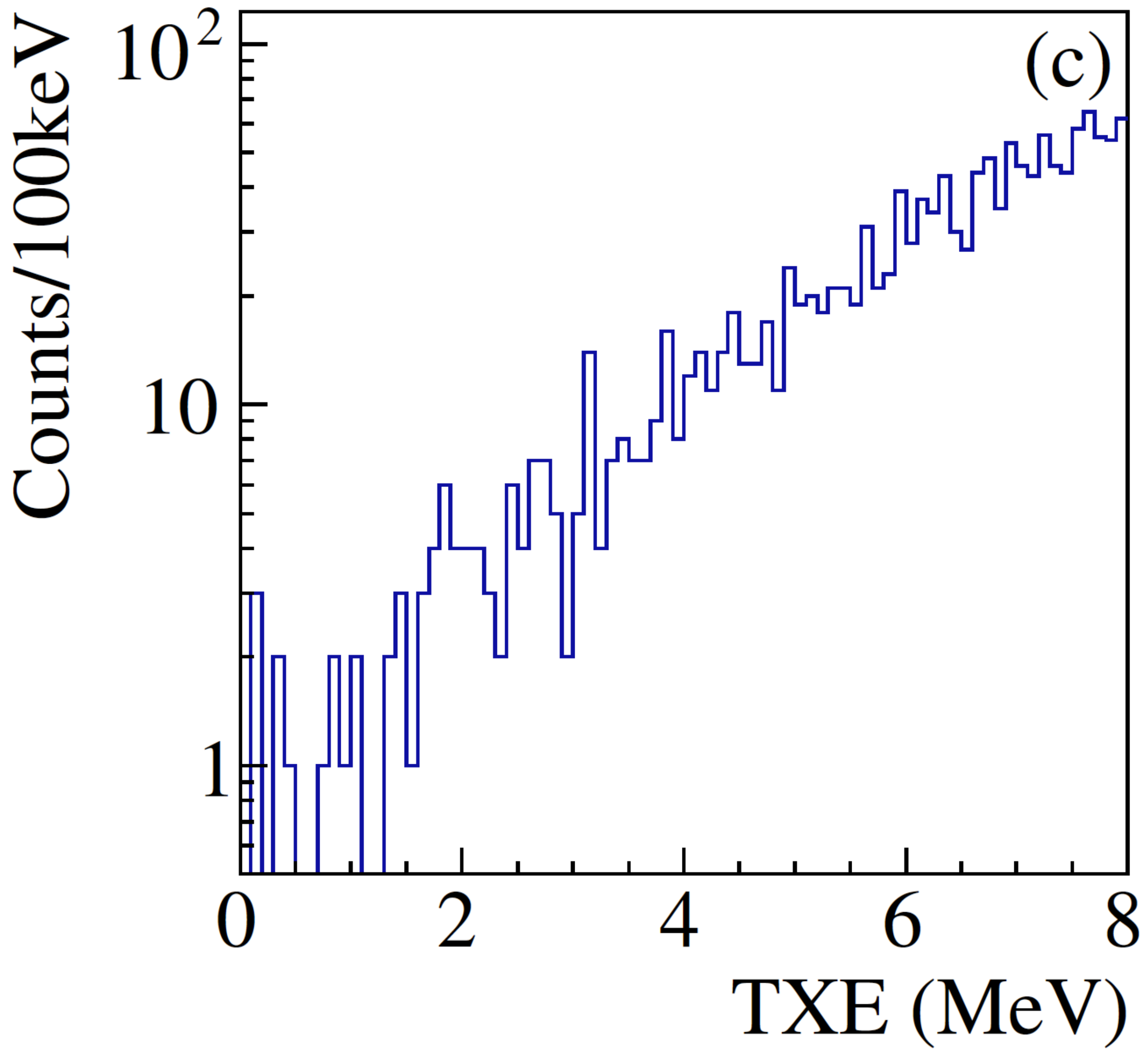
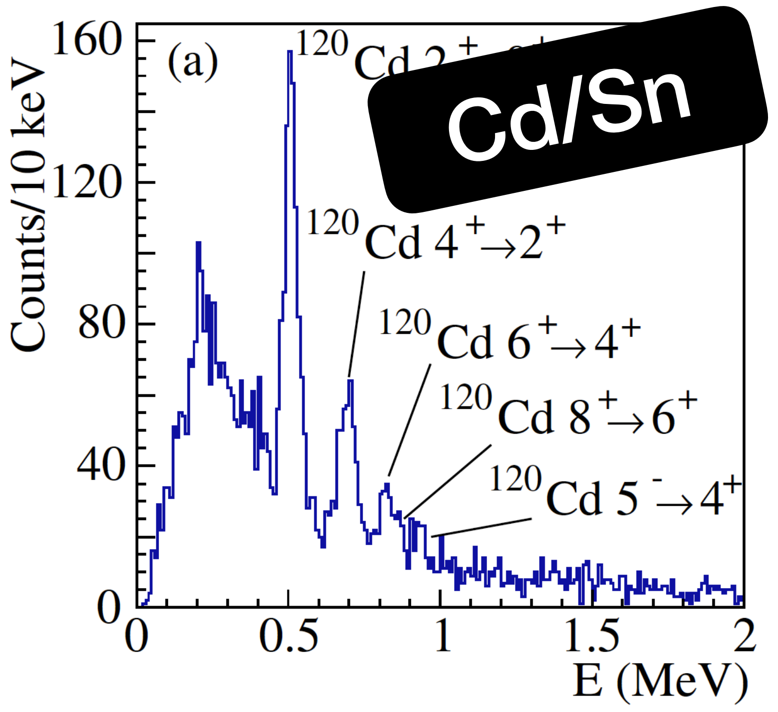
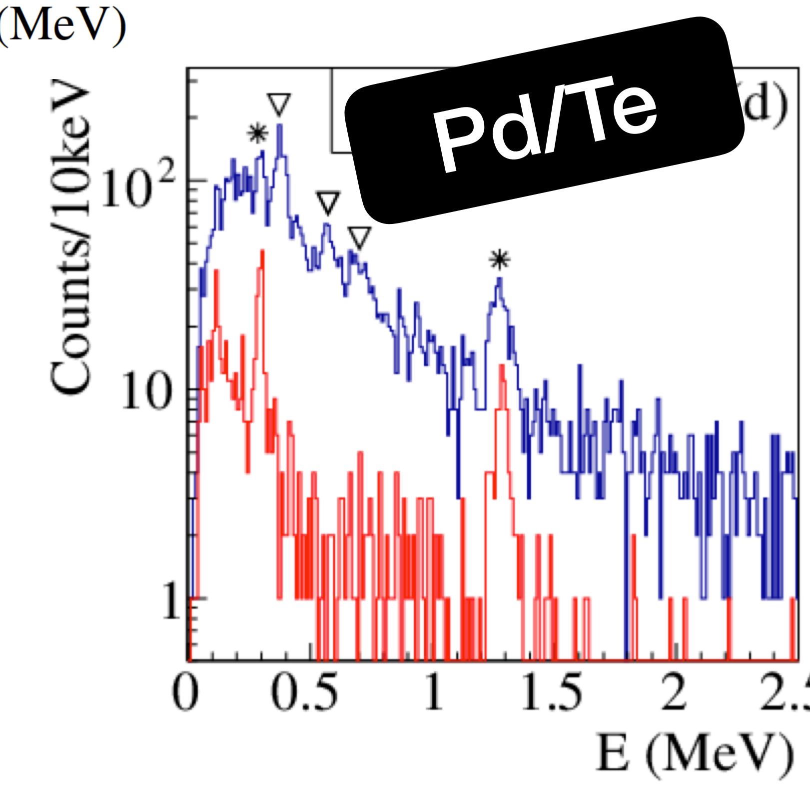
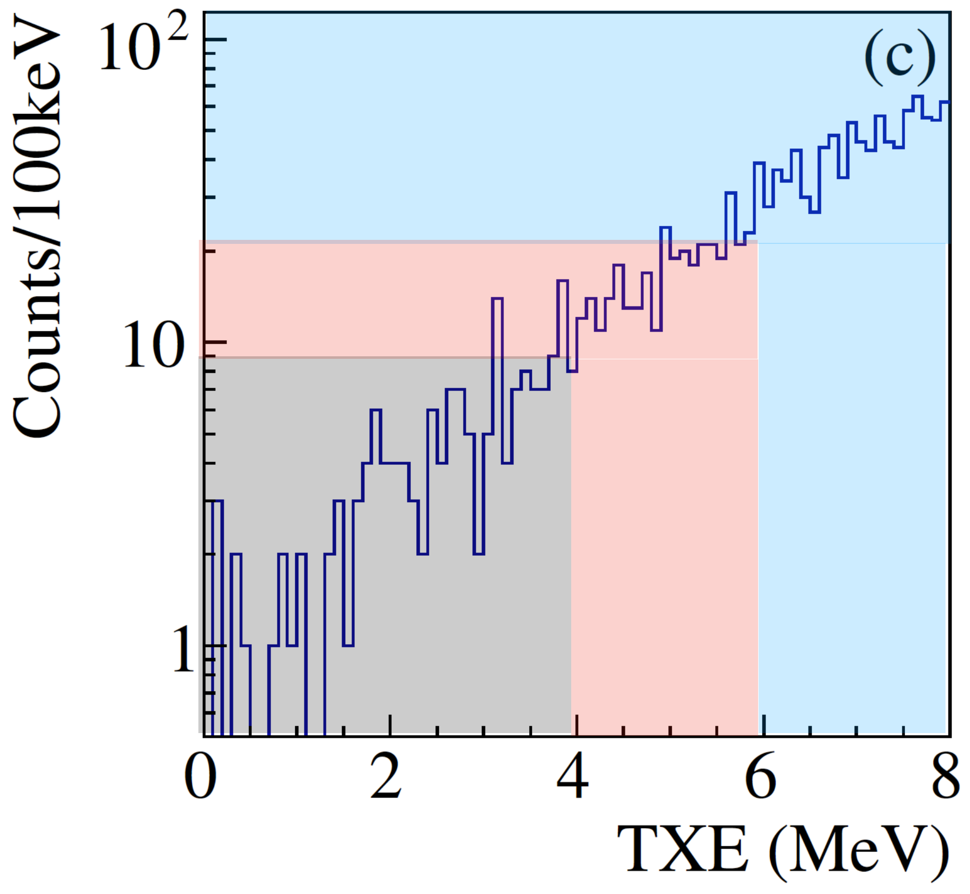
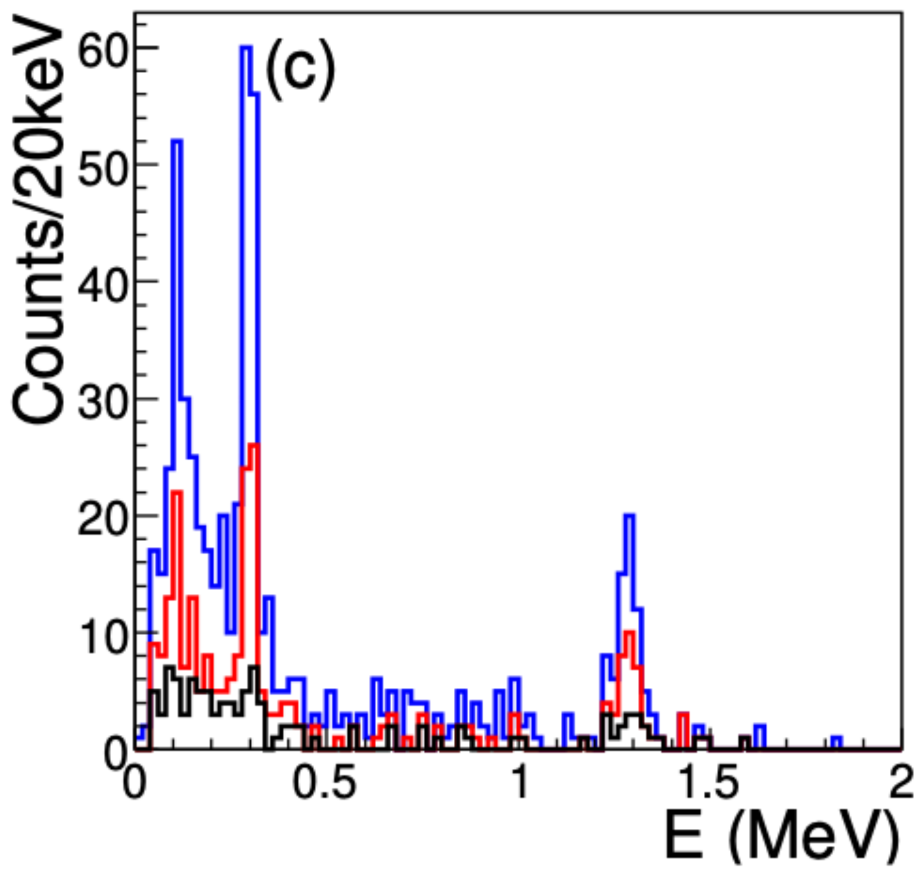


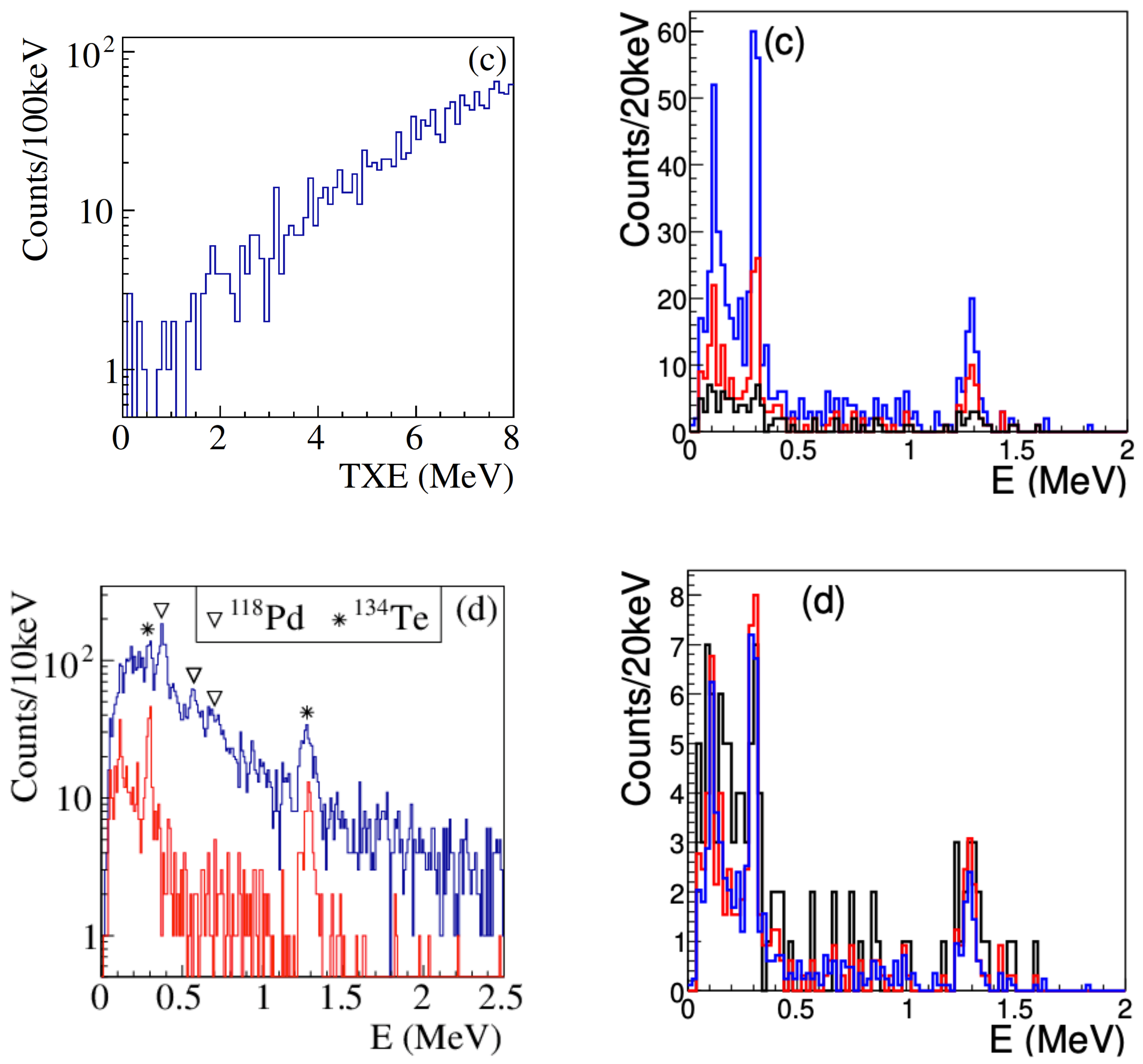



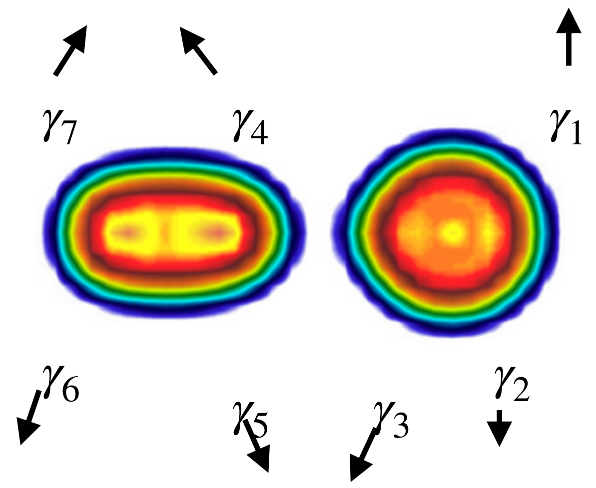



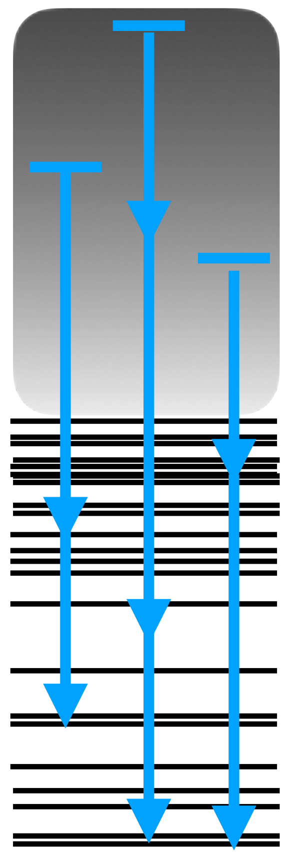

- TXE = $E_x^H + E_X^L$
- Prompt + delayed $\gamma$-spectrum; intensities/normalisation $\Rightarrow E_x$ distribution; spin distribution and multiplicity of the $\gamma$-cascade
- TXE gated $\gamma$-spectra

# Reproducing what we measured




Simulation of $\gamma$-ray spectrum



$FF^*_{L,H}$

Statistical inputs for Hauser-Feschbach 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)

⇒ Or extrapolated experimental data for (Cd, Pd, Sn)

Oslo group : PRC 87, 014319 (2013);
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Use DEcay GAmma (DEGA) code to simulate the cascade.

LG and V. Méot, Proceeding of the ND2025 Conference (2026).

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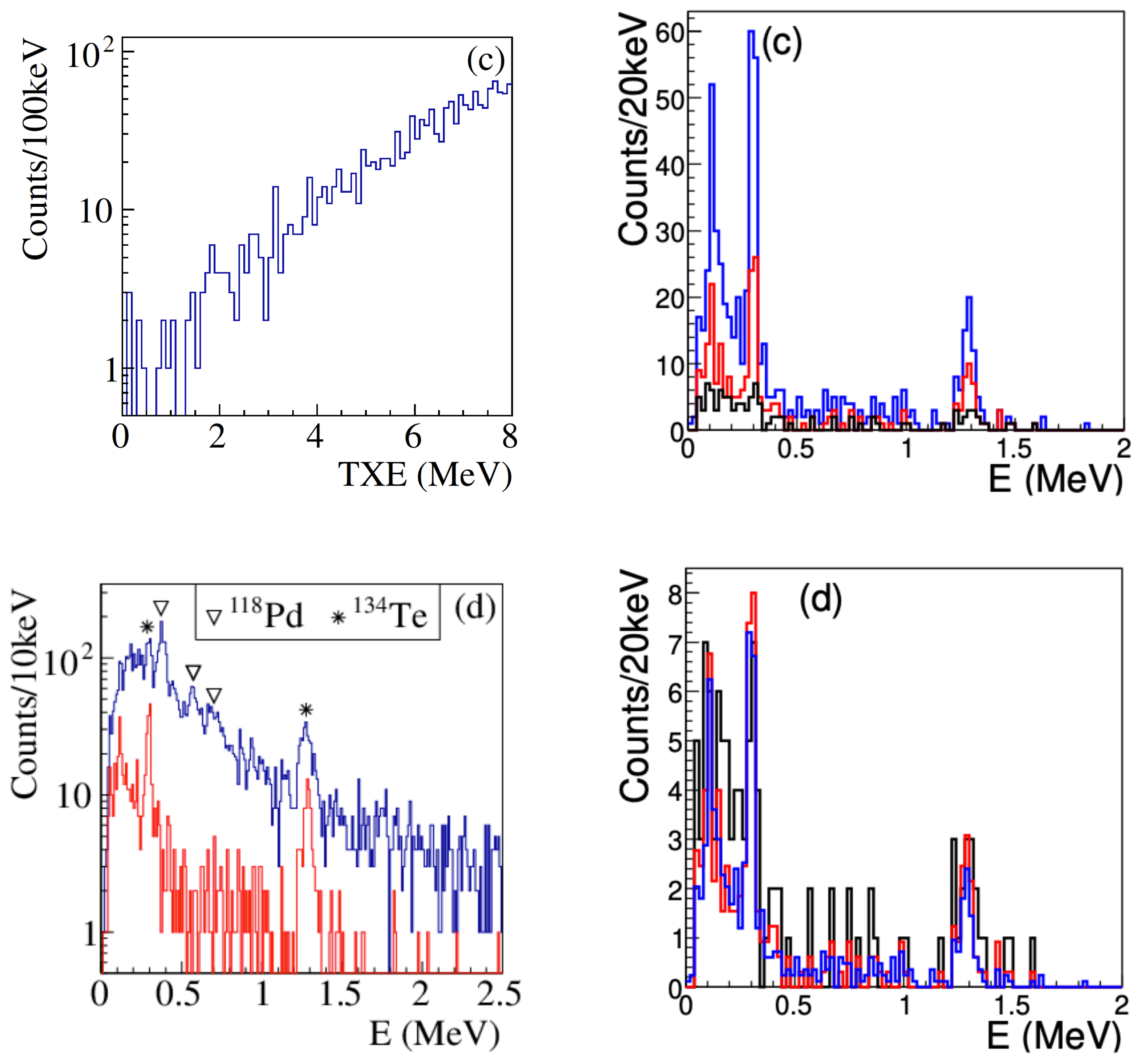


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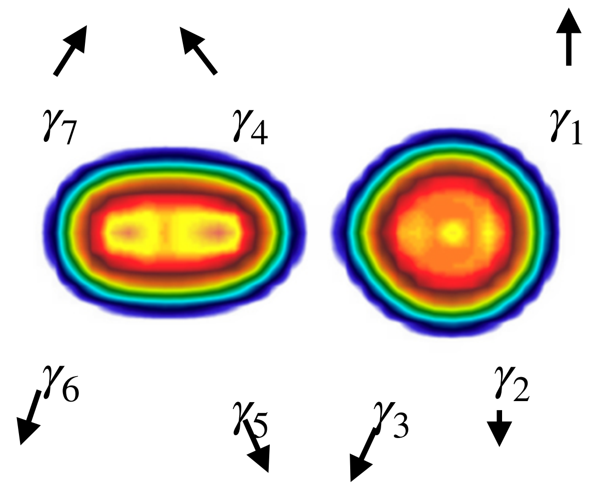


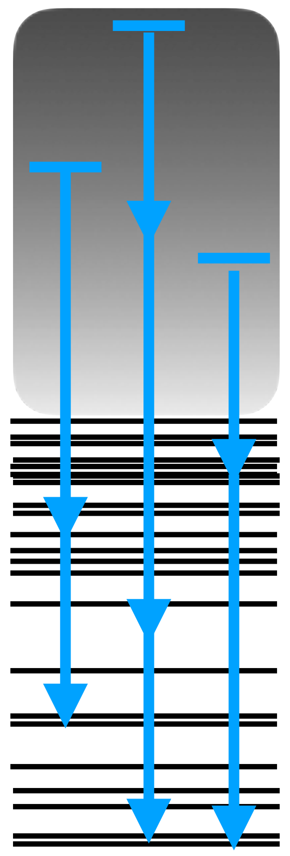

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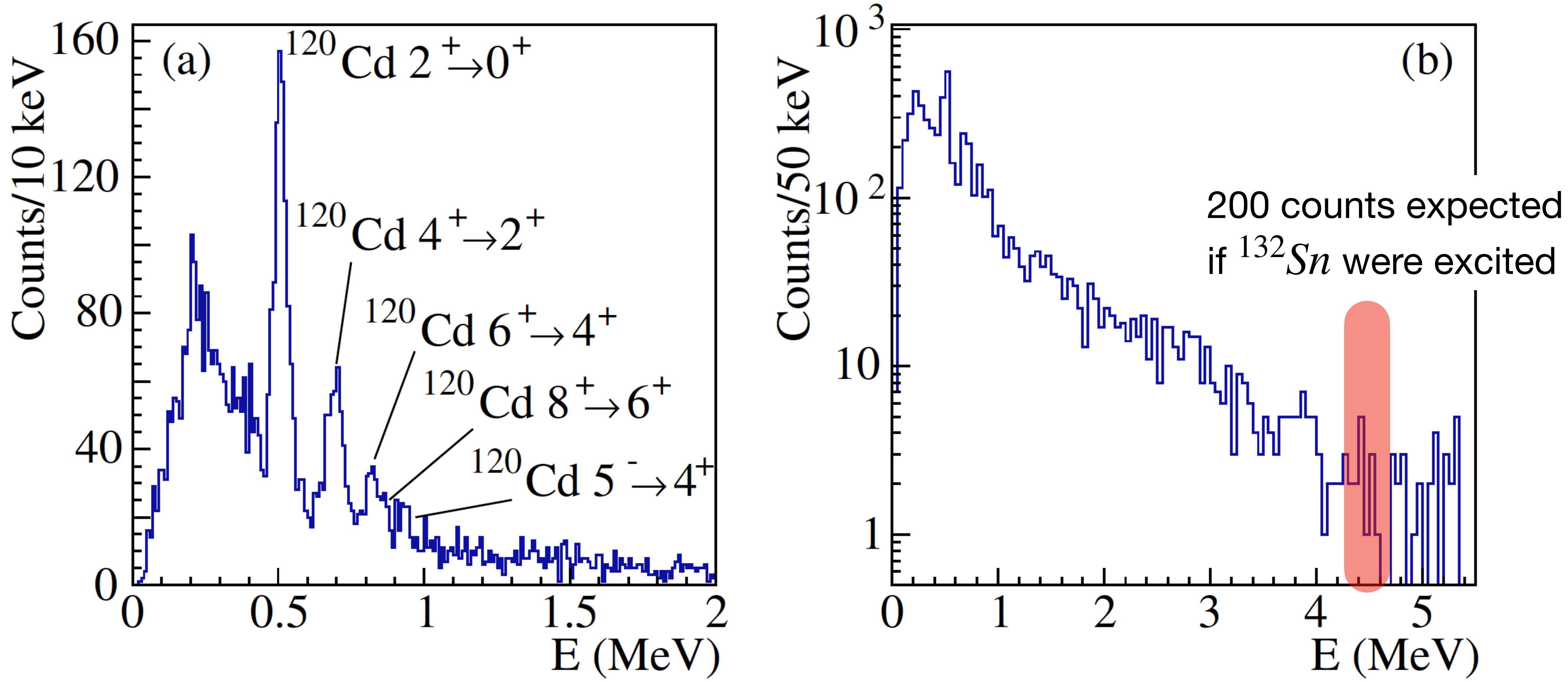
Needed/Tested inputs :

✦TXE and its sharing

✦Angular momentum distribution

# The exceptional $^{120}Cd/^{132}Sn$ fragmentation



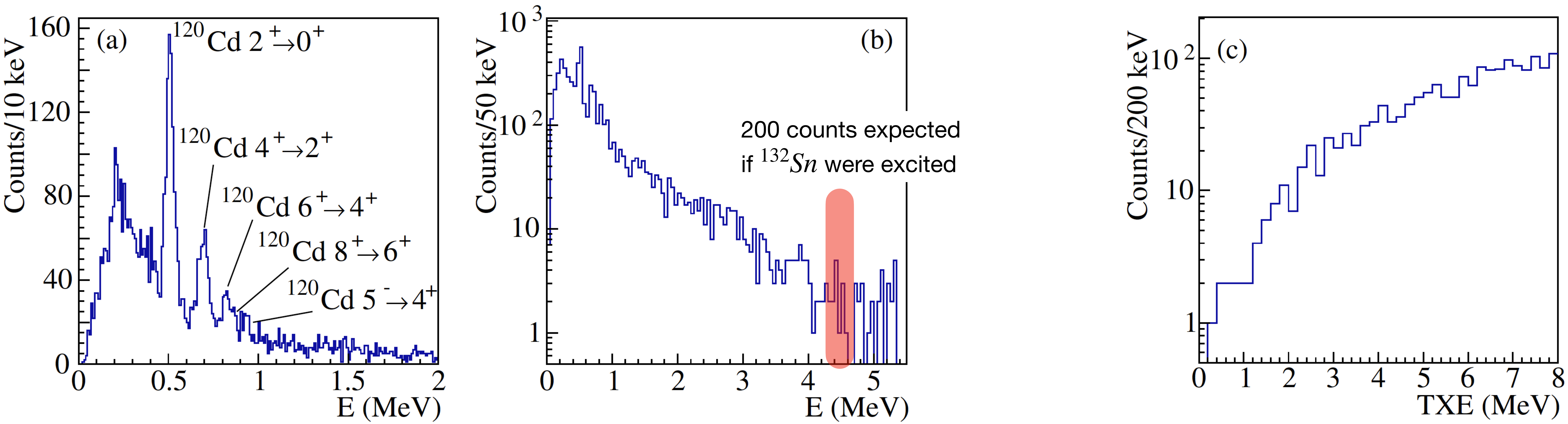

Only $\gamma$-rays from the light fragment.
$\Rightarrow$ $^{132}Sn$ in its GS for at least 95% of selected events.

**By-product**

$$\mathbf{J}(^{252}\mathrm{Cf}) = \mathbf{J}(^{120}\mathrm{Cd}) + \mathbf{J}(^{132}\mathrm{Sn}) + \mathbf{\Lambda}$$
$$\mathbf{0} = \mathbf{J}(^{120}\mathrm{Cd}) + \mathbf{\Lambda}$$

The fragment angular momentum is perpendicular to the fission axis.

# The exceptional $^{120}Cd/^{132}Sn$ fragmentation



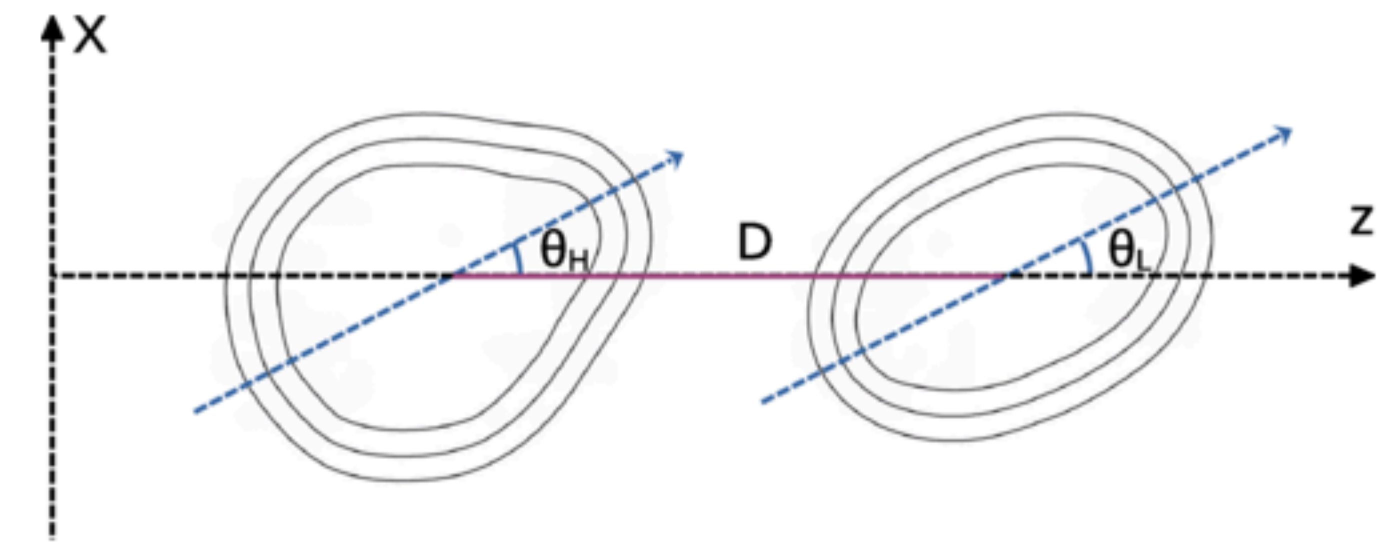

Only $\gamma$-rays from the light fragment.
$\Rightarrow$ $^{132}Sn$ in its GS for at least 95% of selected events.

TXE = $E^*(Cd) + E^*(Sn) = E^*(Cd)$

Angular momentum distribution needed to reproduce the measured spectrum.

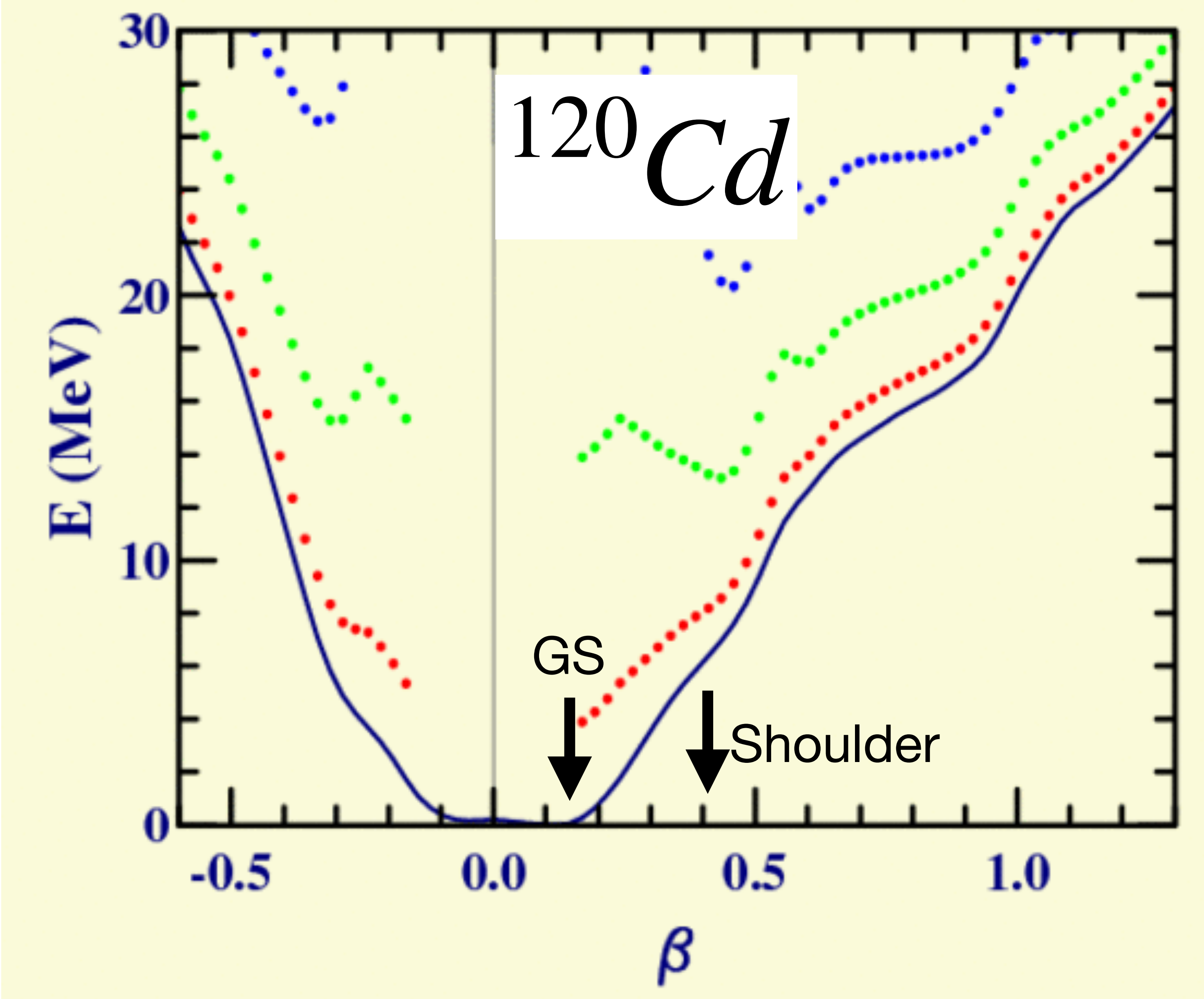
# Angular momentum and deformation

FIG. 1.




*Schematic view of the model in the x-z plane in the case of $\varphi_H = 0$ and $\varphi_L = 0$. The blue dashed line shows the principal axis of deformation of each fragment.*

**Orientation/pumping mechanism for AM generation.**
**G. Scamps and G. Bertsch, Phys. Rev. C 108, 034616 (2023).**
**See next Talk.**



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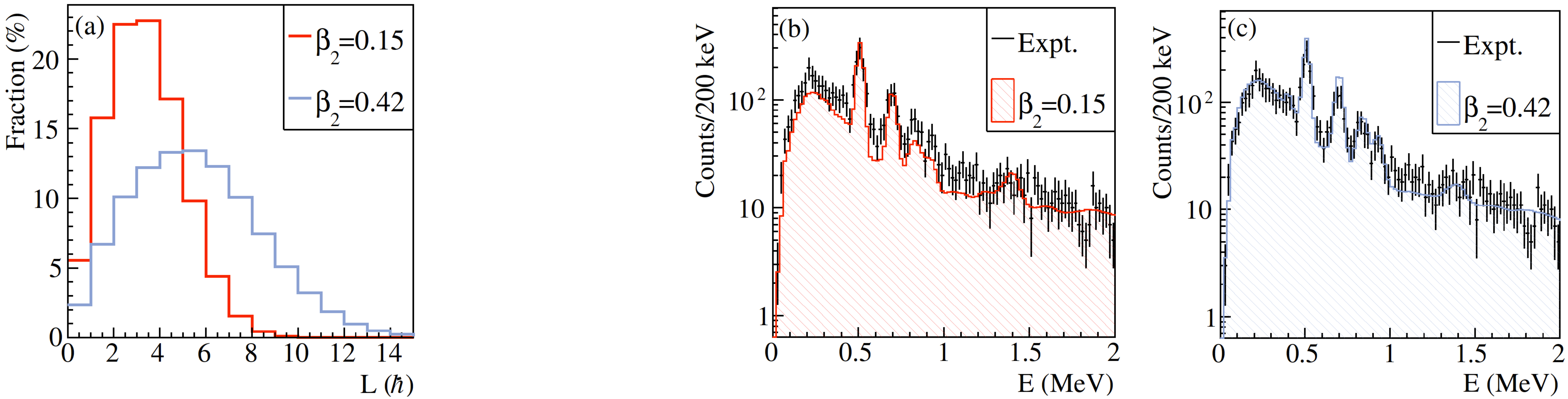


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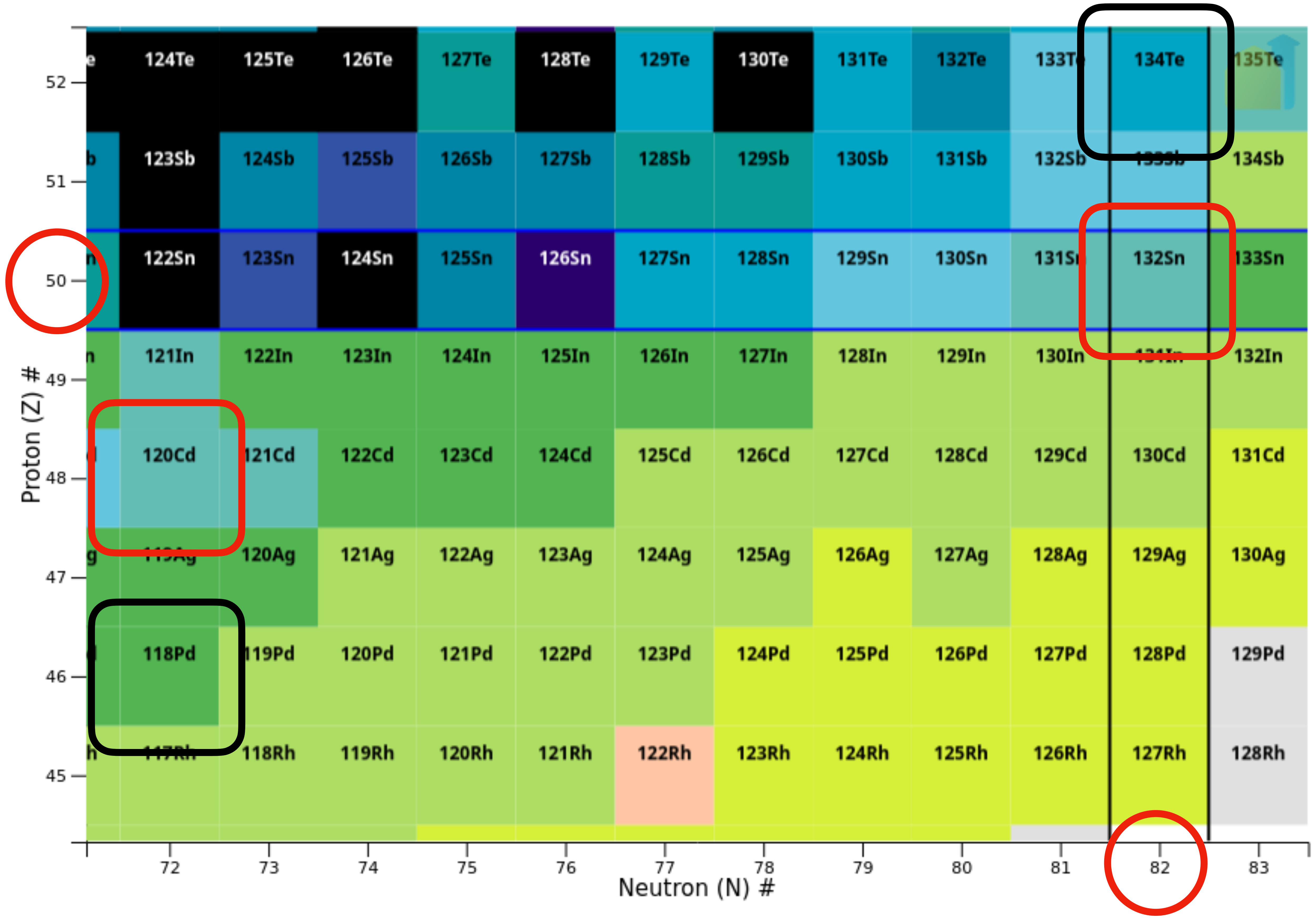
Good agreement for $\beta = 0.42$
Reproduces :

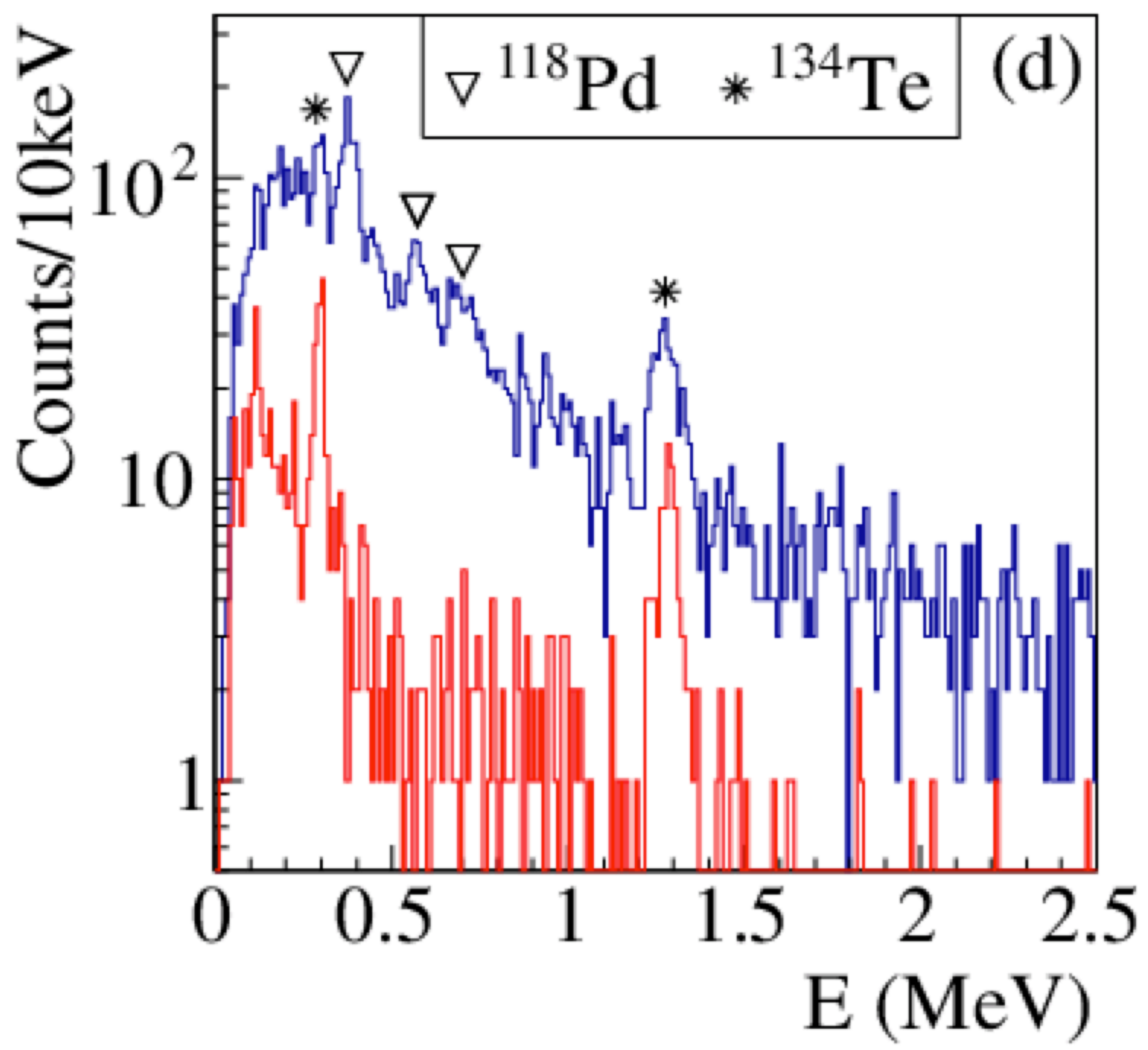
$\Rightarrow$ $\gamma$-ray intensities

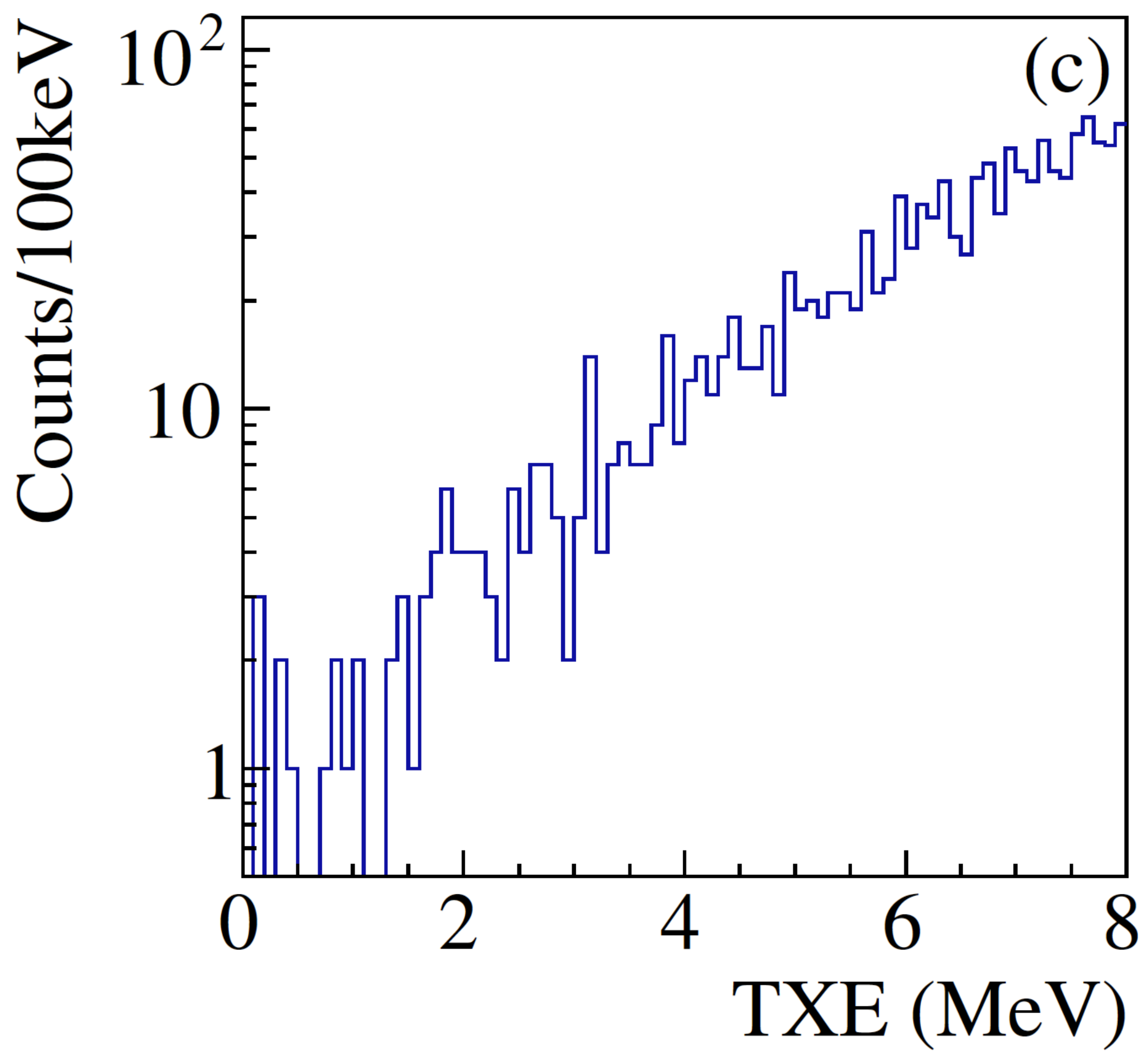
$\Rightarrow$ Global normalization = $\gamma$ Multiplicity

A. Francheteau *et al.*, Phys. Rev. Lett. **132**, 142501 (2024)

# Excitation Energy Sharing : Pd/Te




Which sharing of TXE allows to reproduce the properties of the $\gamma$-ray spectrum?

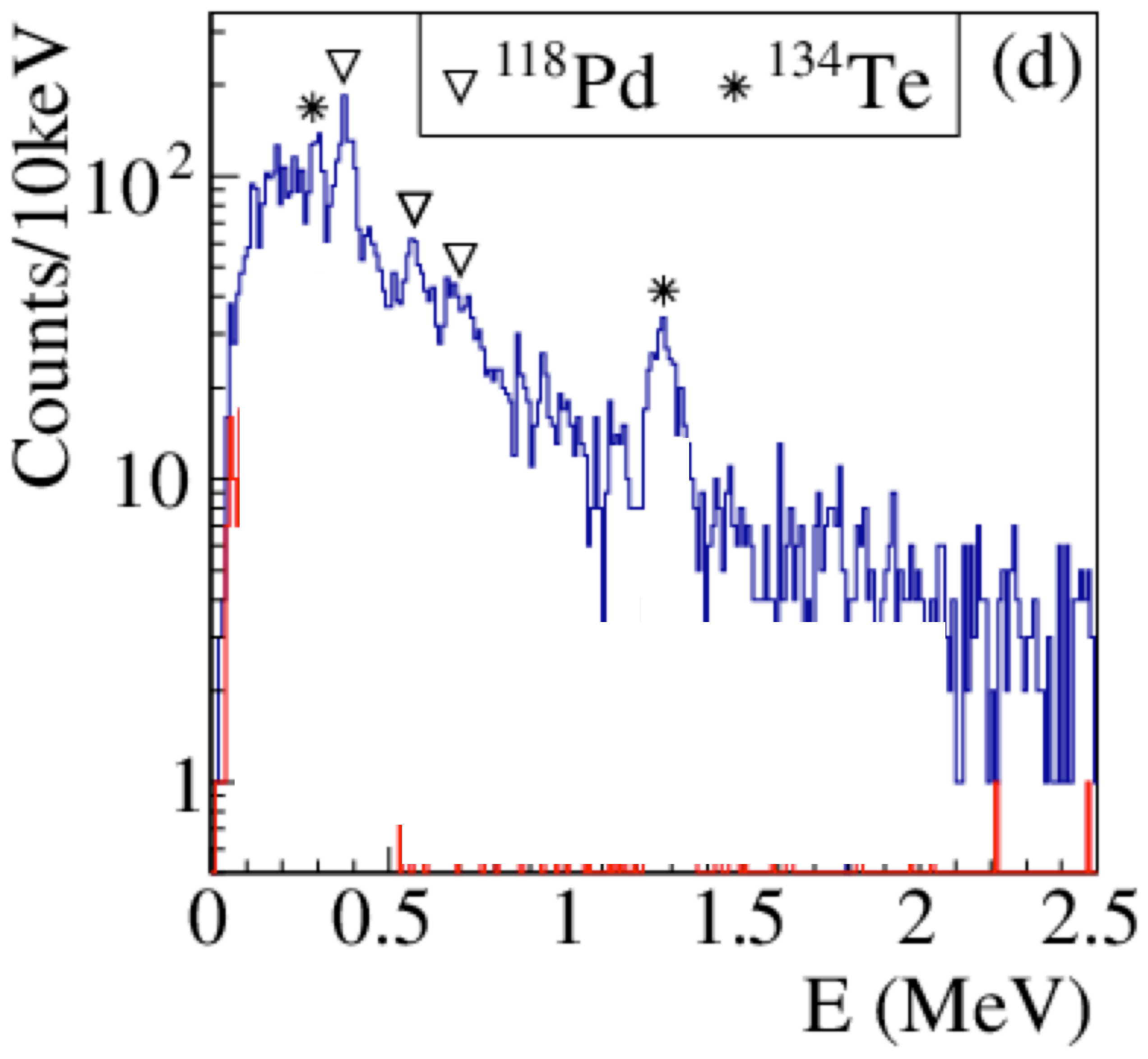
Neighboring fragmentation : expected similar behavior

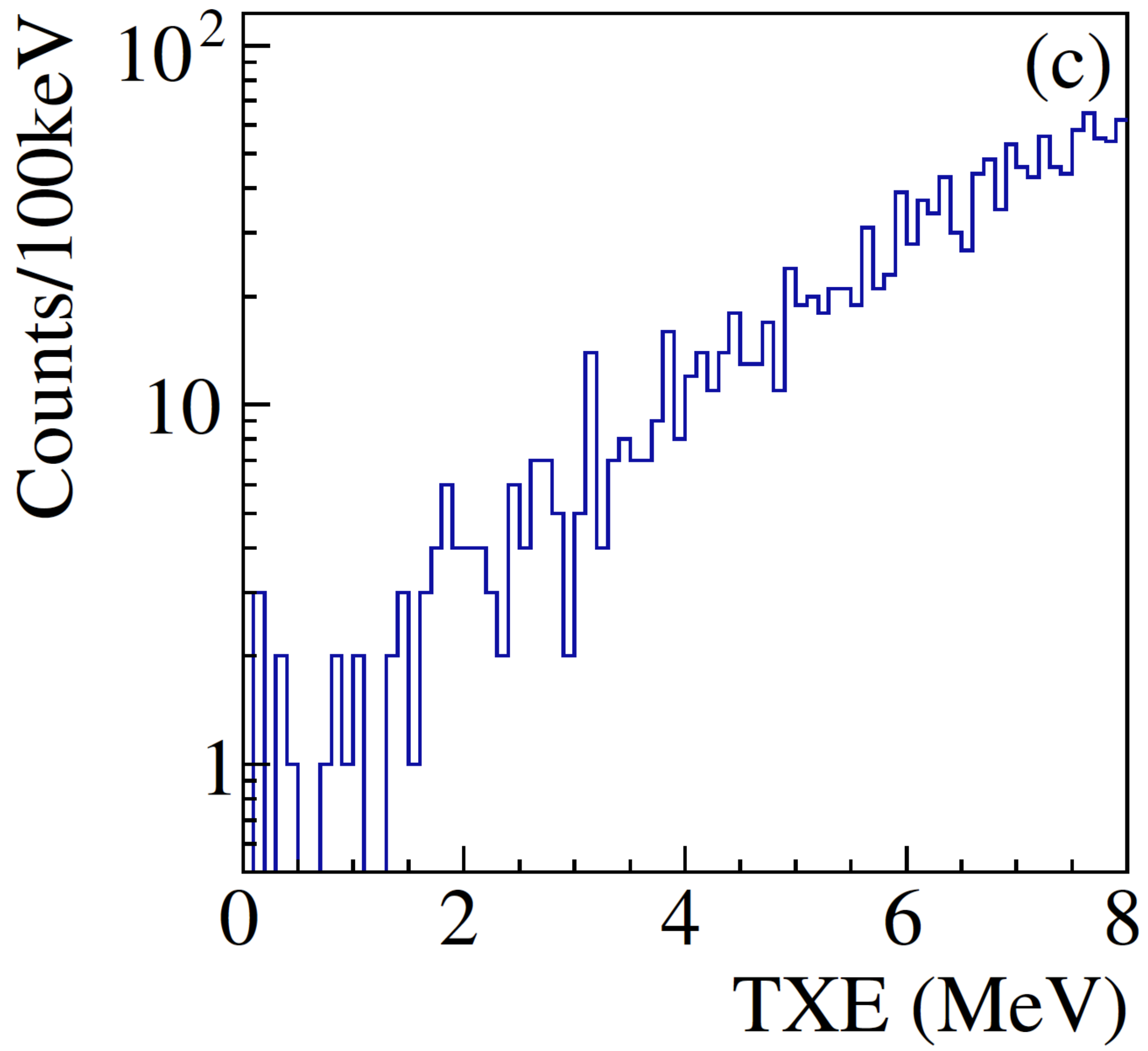
But :

-both fragments are excited.

# Measured properties to reproduce

TXE = Q-TKE




- 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)%

Where is the missing $2^+$ intensity?

⇒Similar to Cd/Sn? Large GS direct population?

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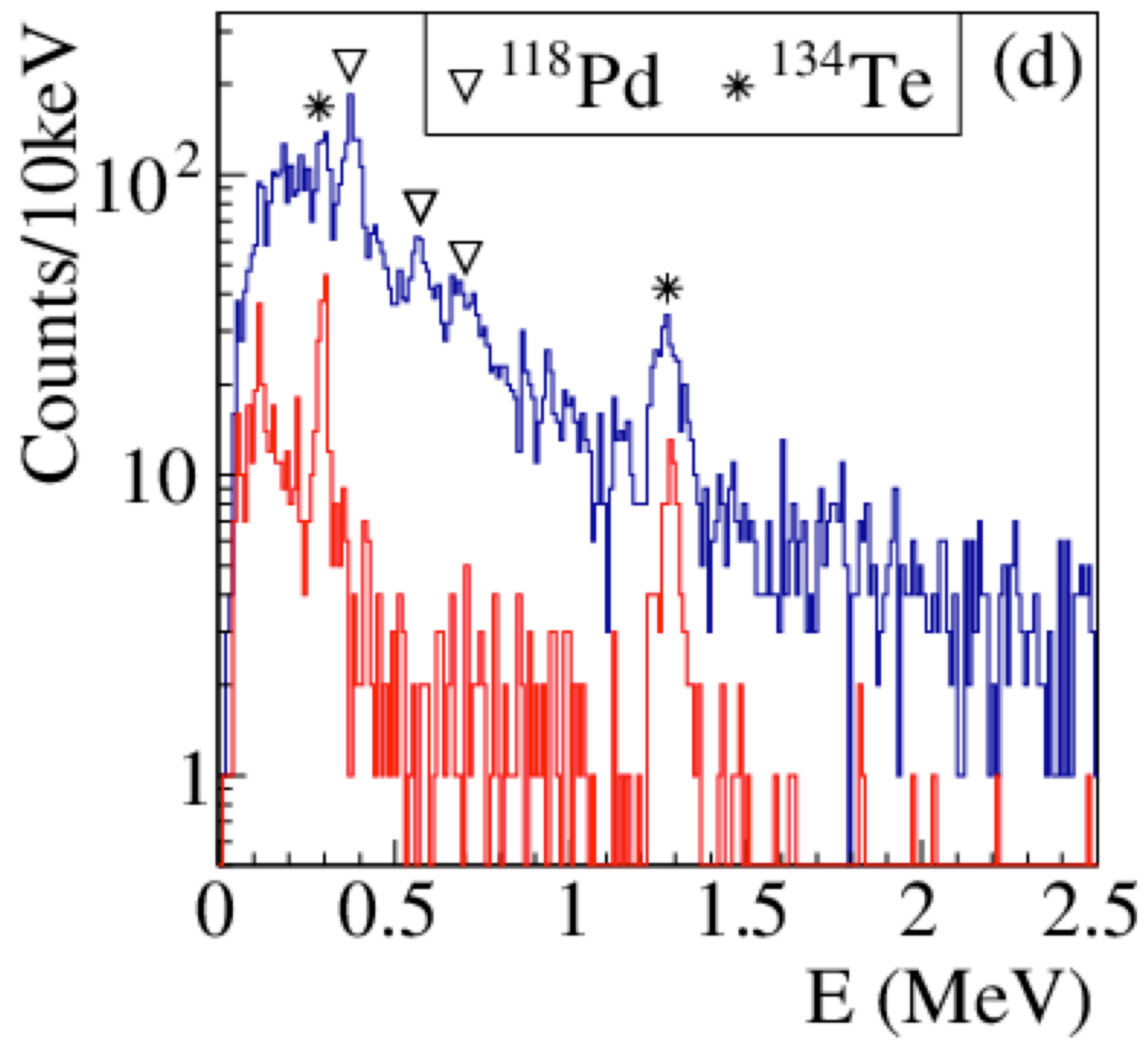


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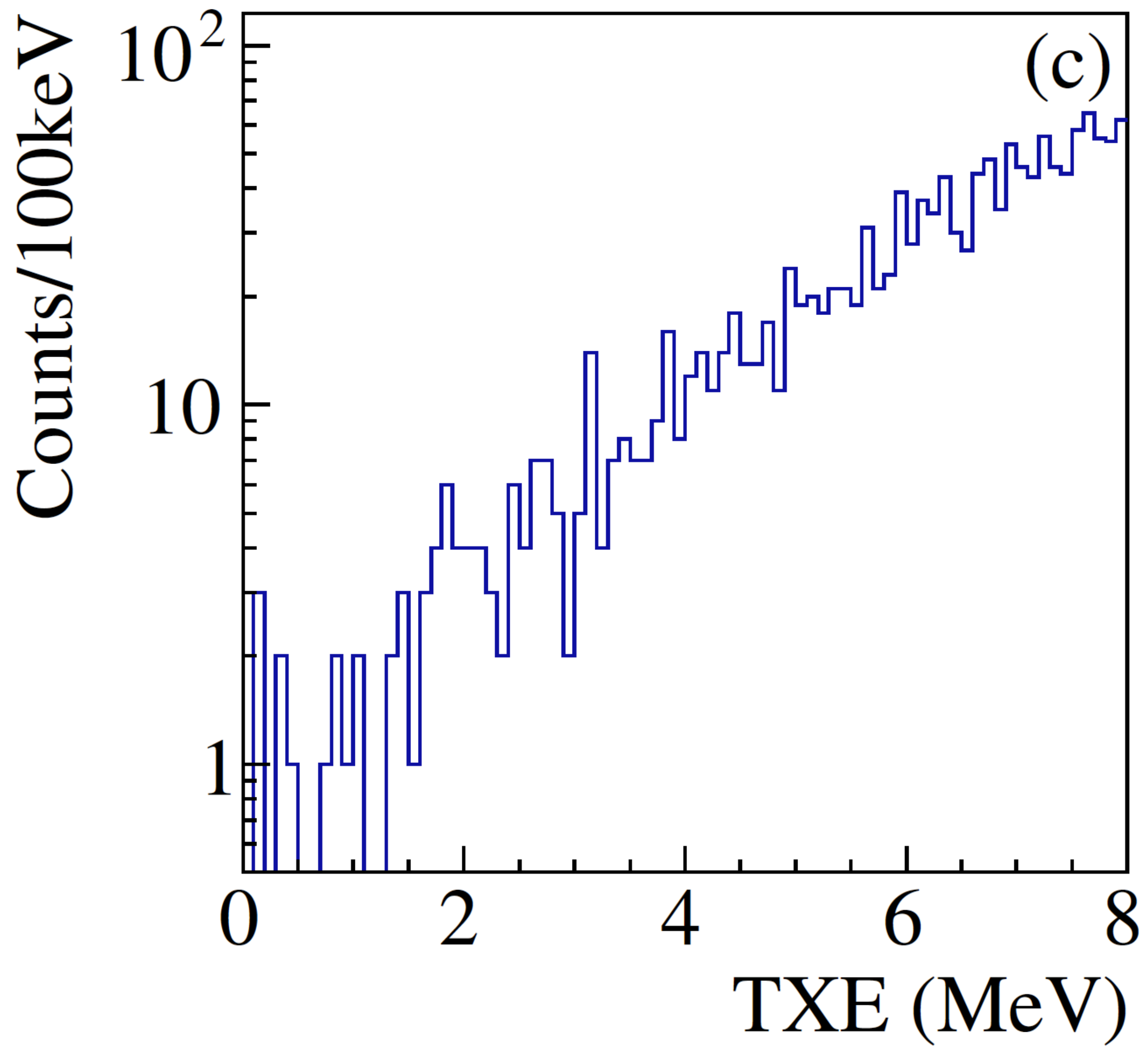


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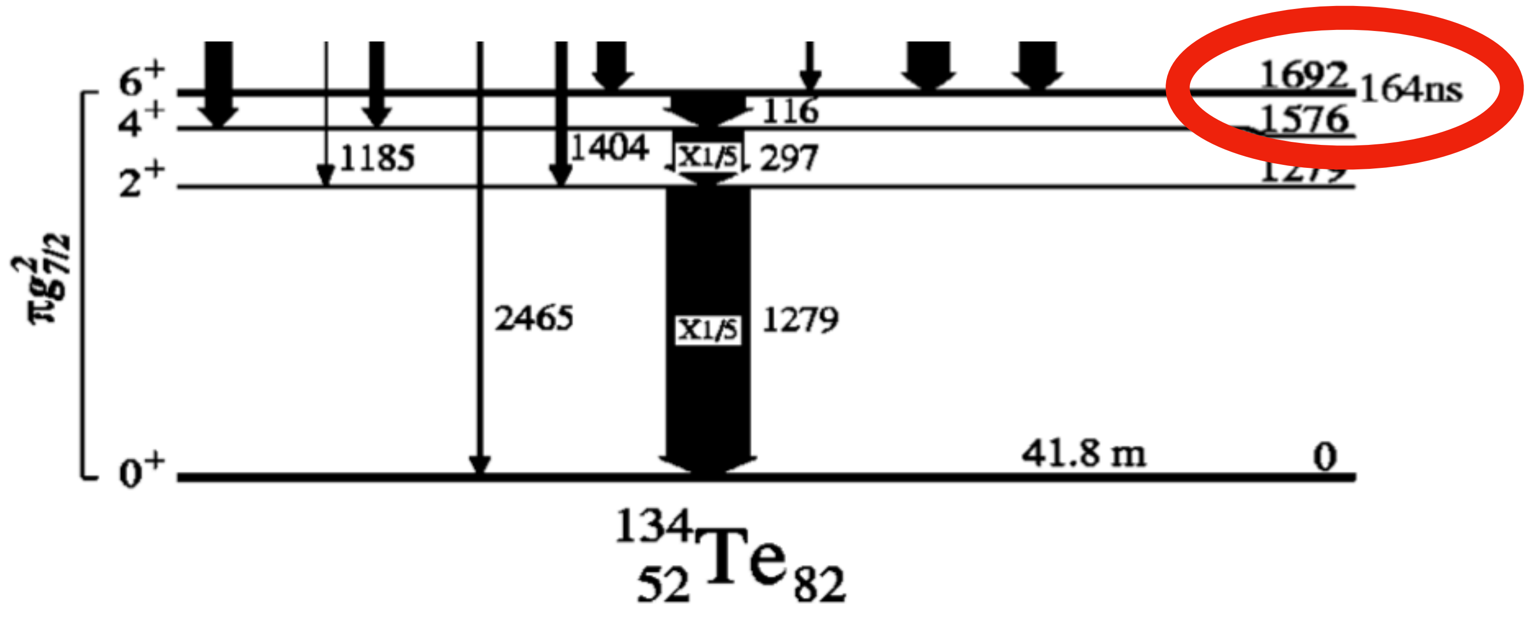

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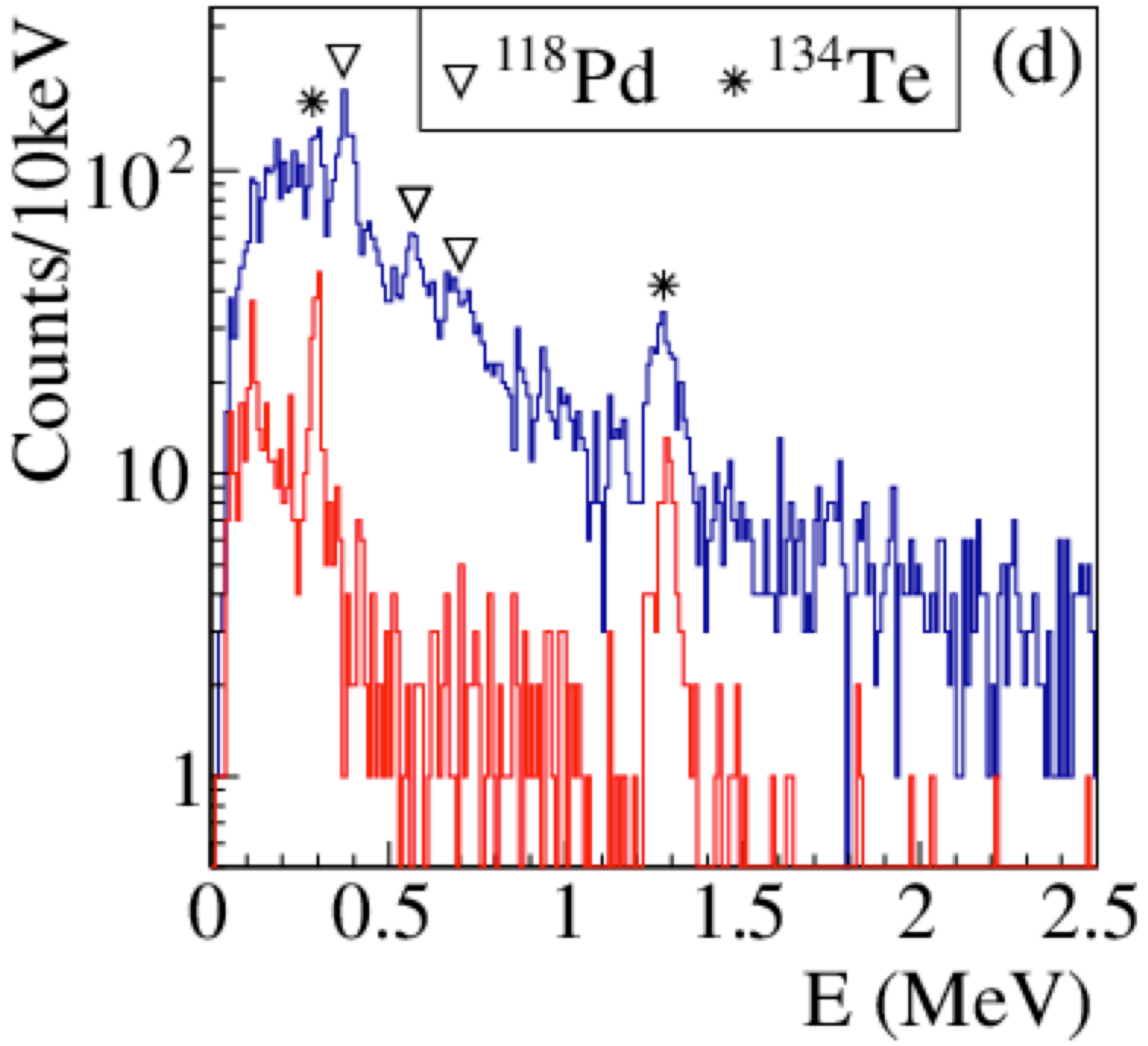


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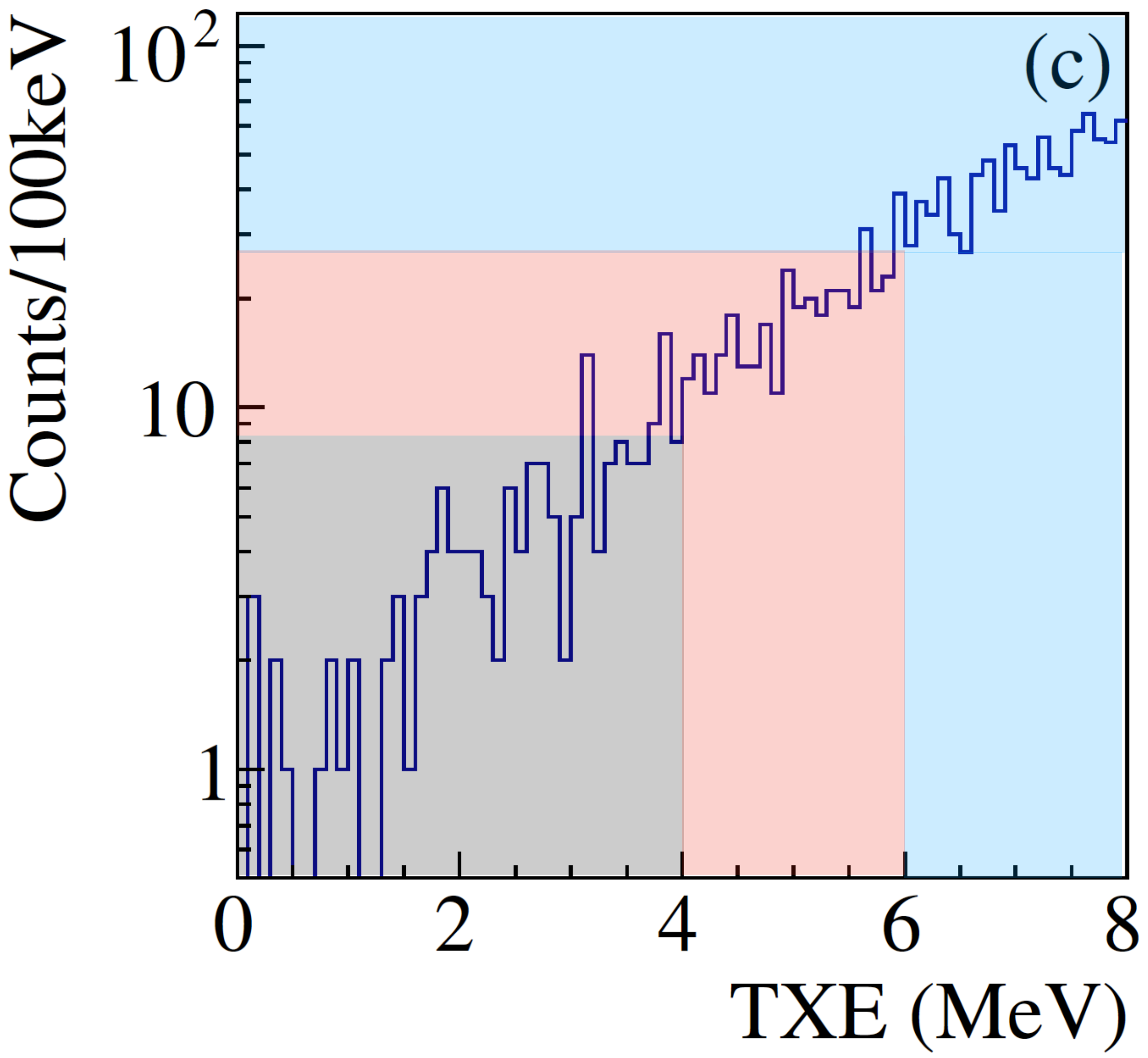


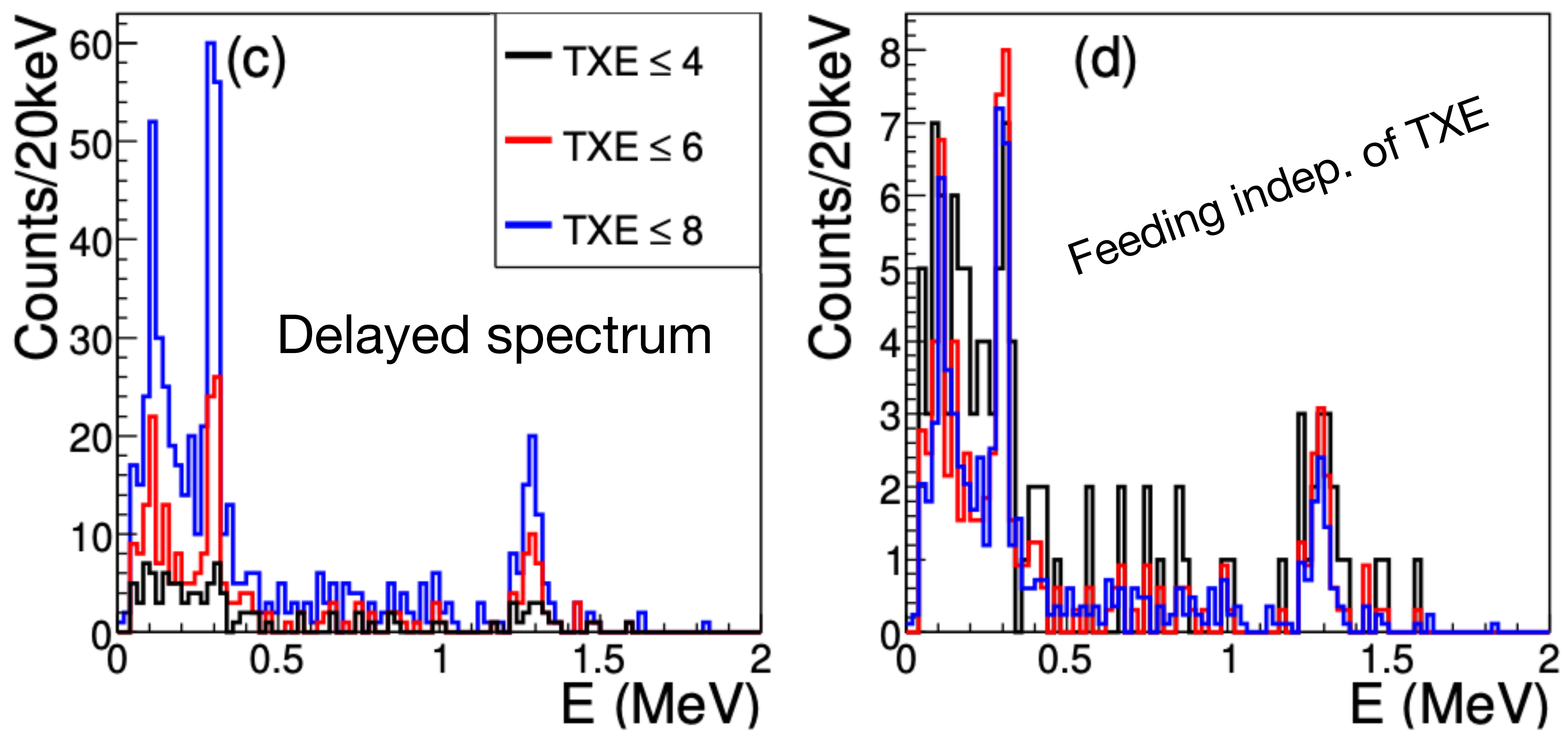


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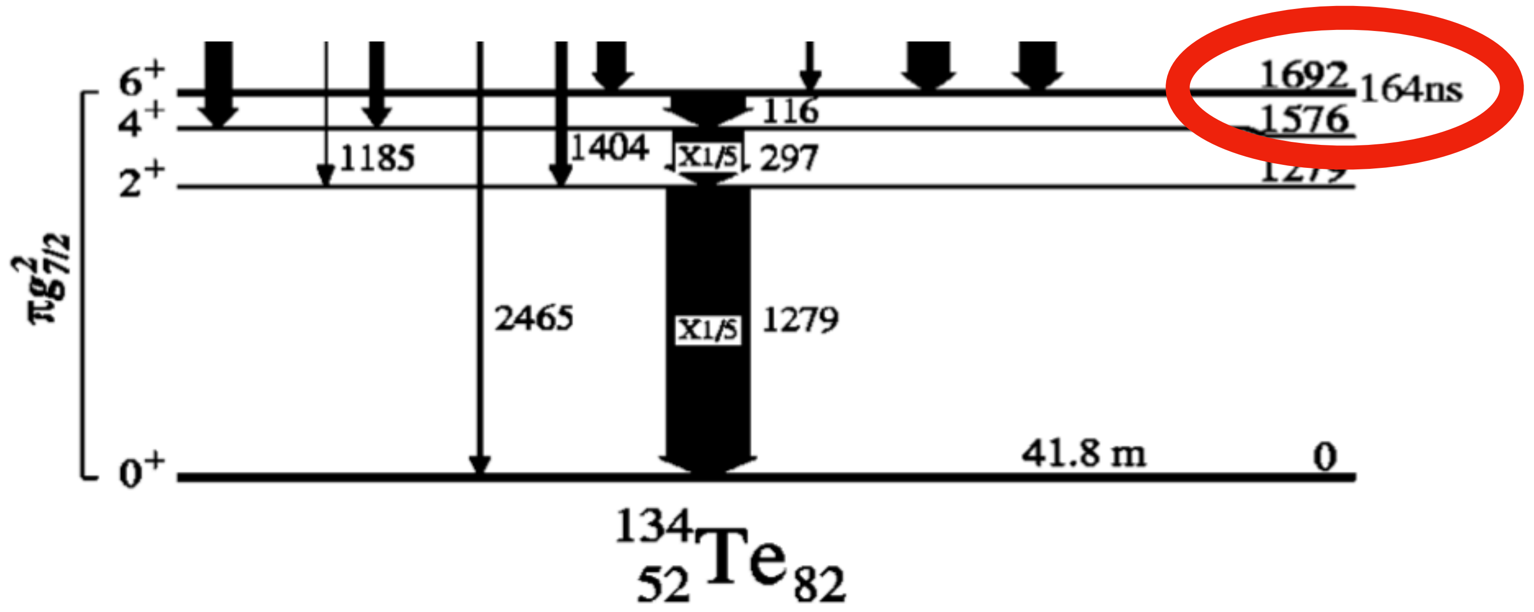
⇒Similar to Cd/Sn? Large GS direct population?



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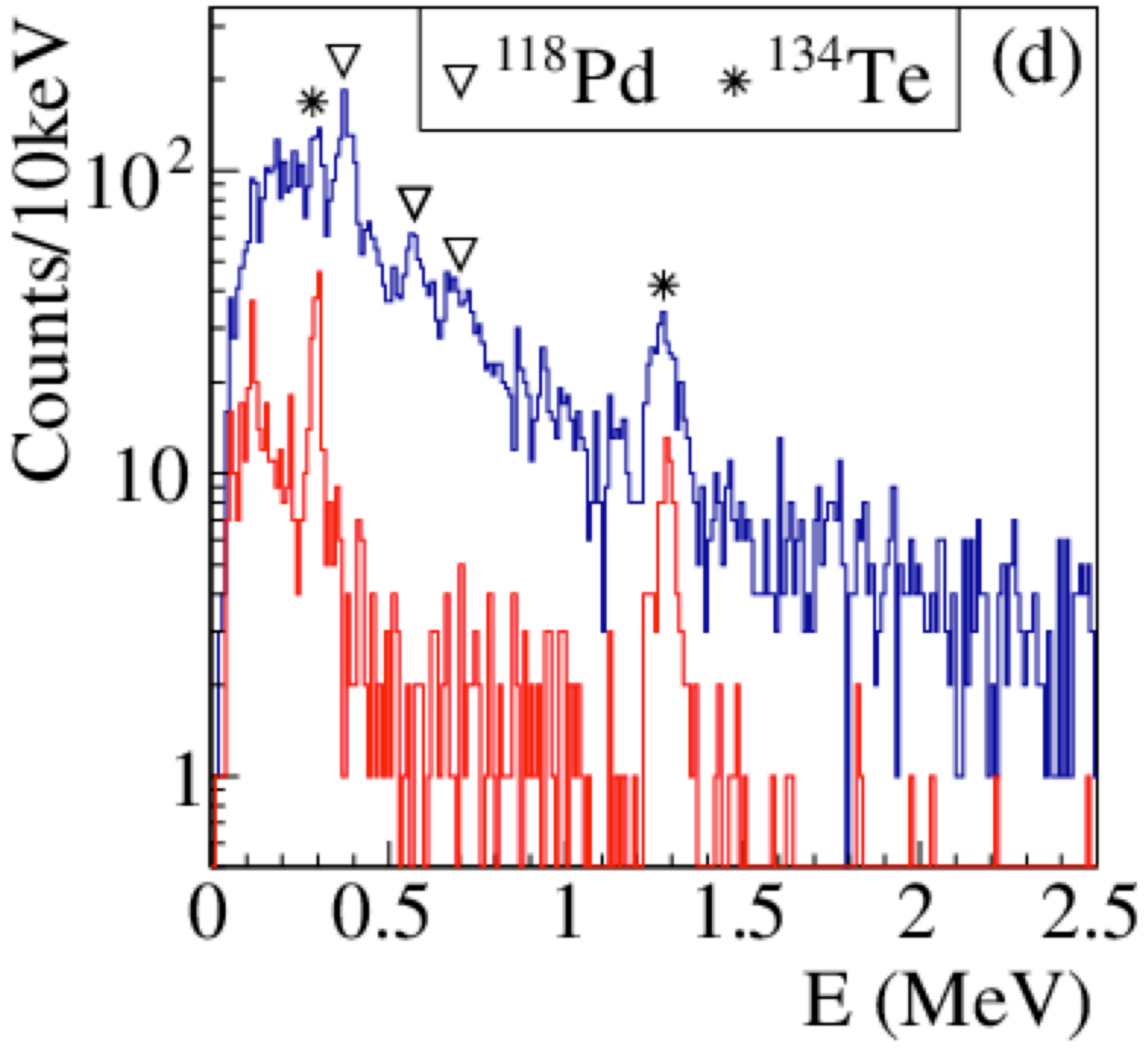


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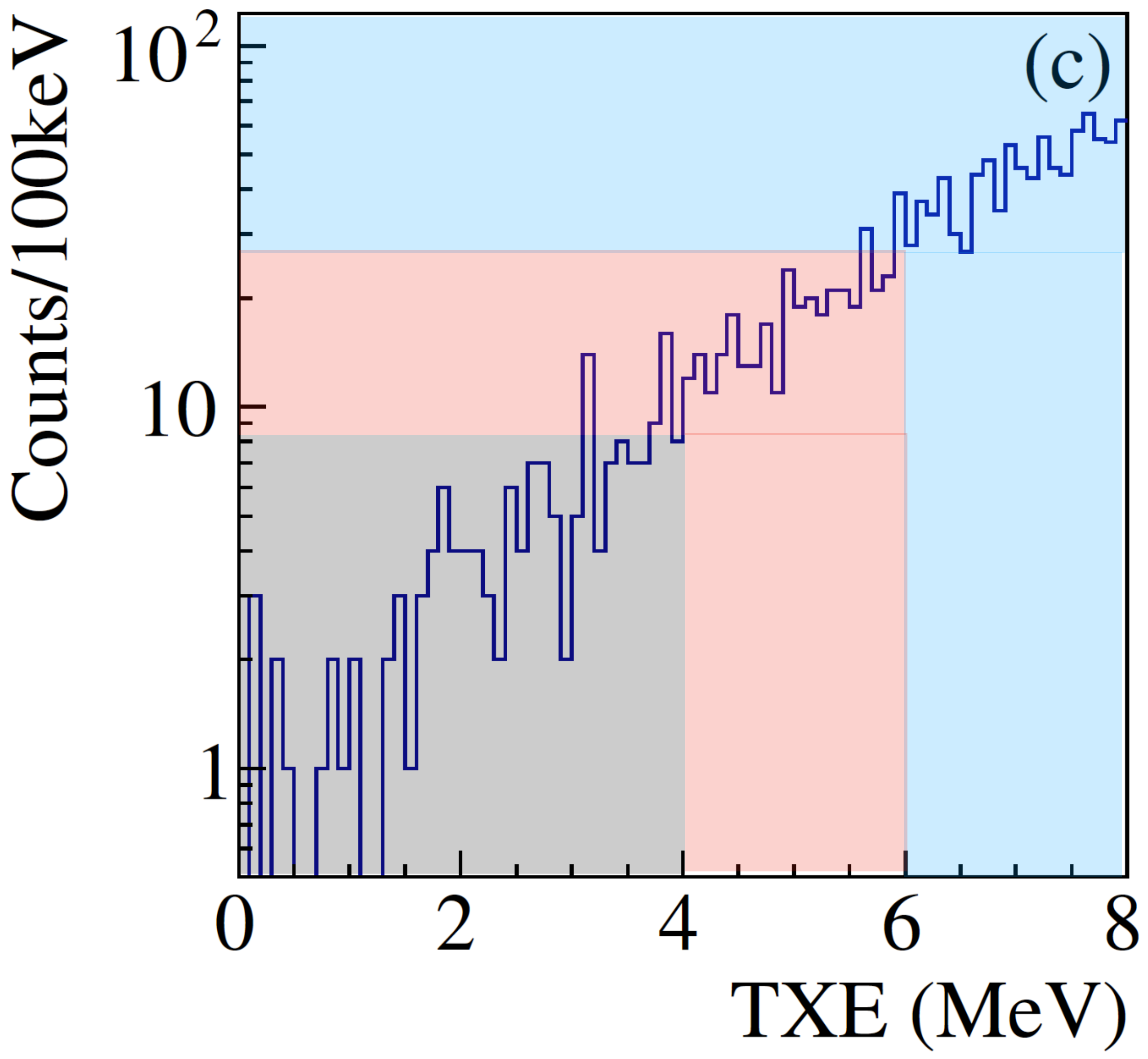


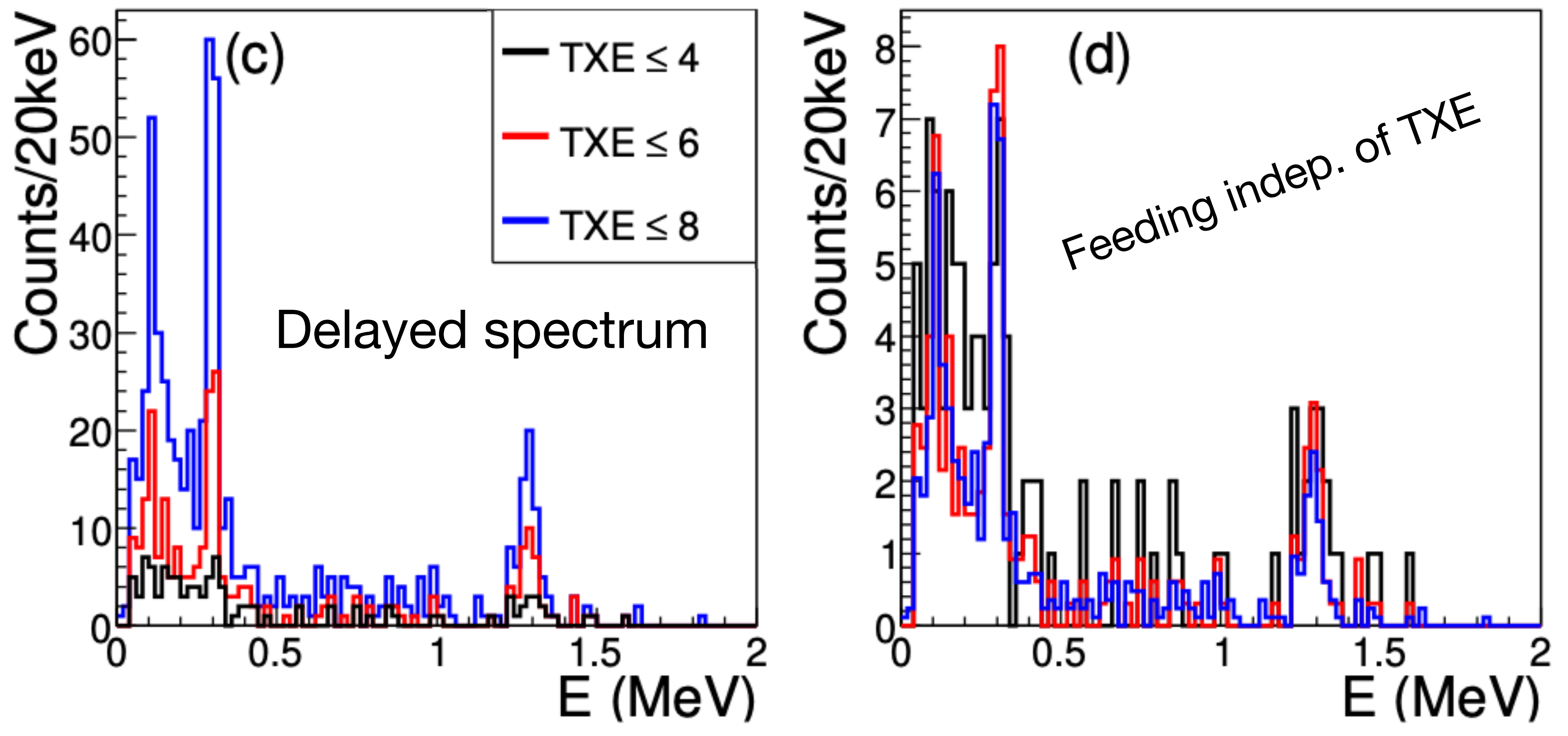


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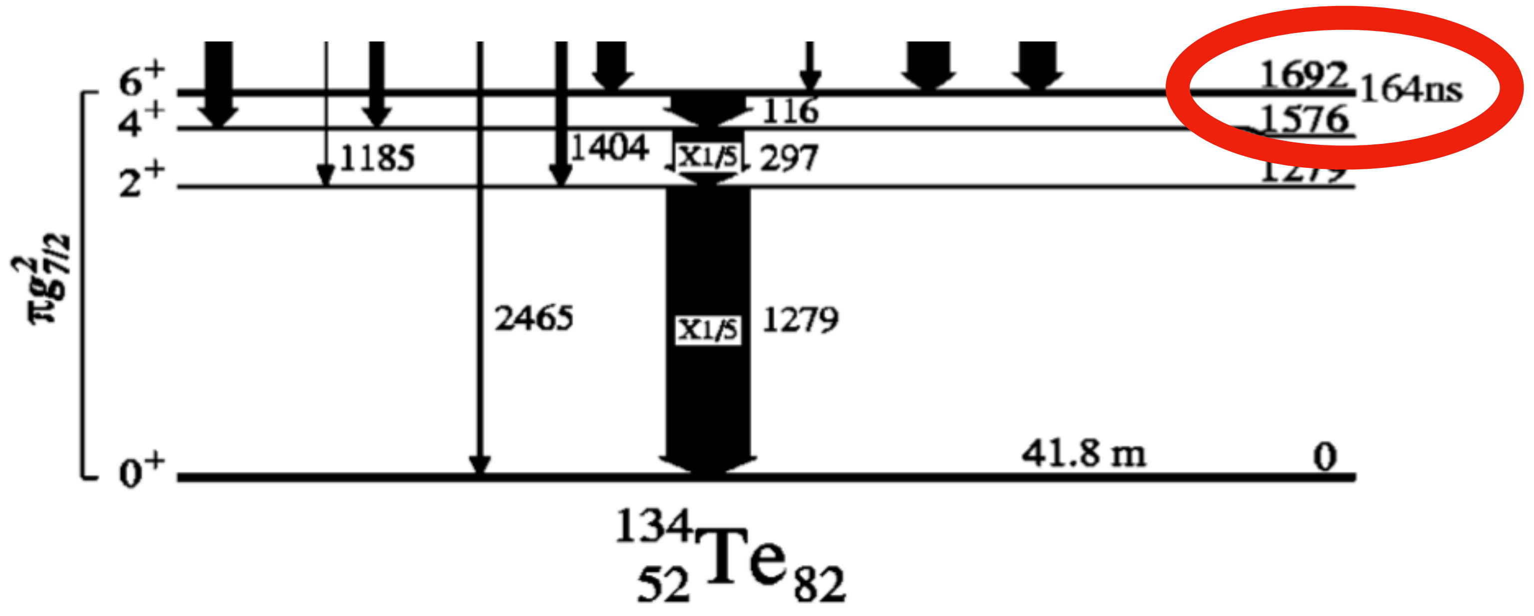
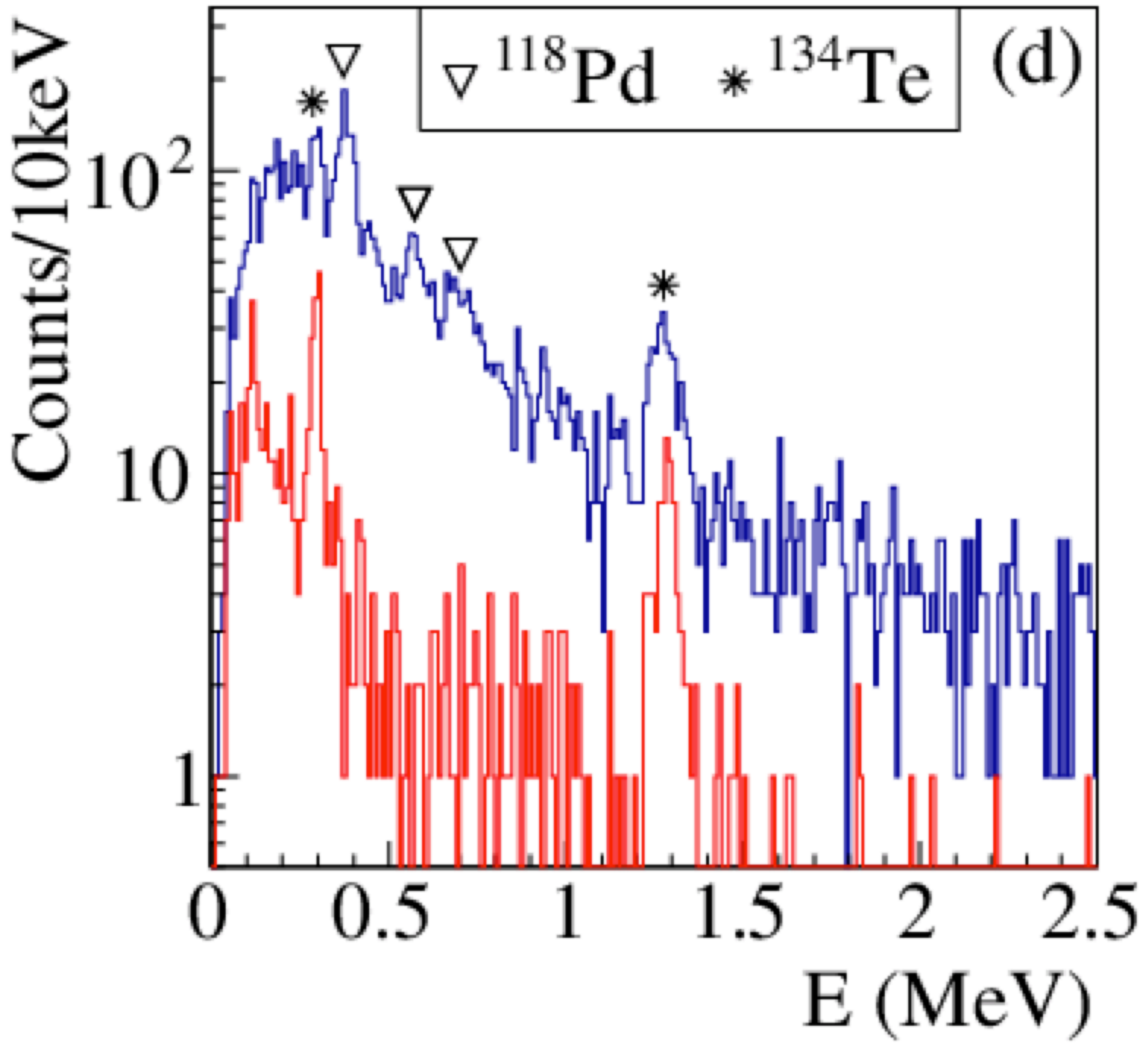
Where is the missing $2^+$ intensity?
⇒Similar to Cd/Sn? Large GS direct population?

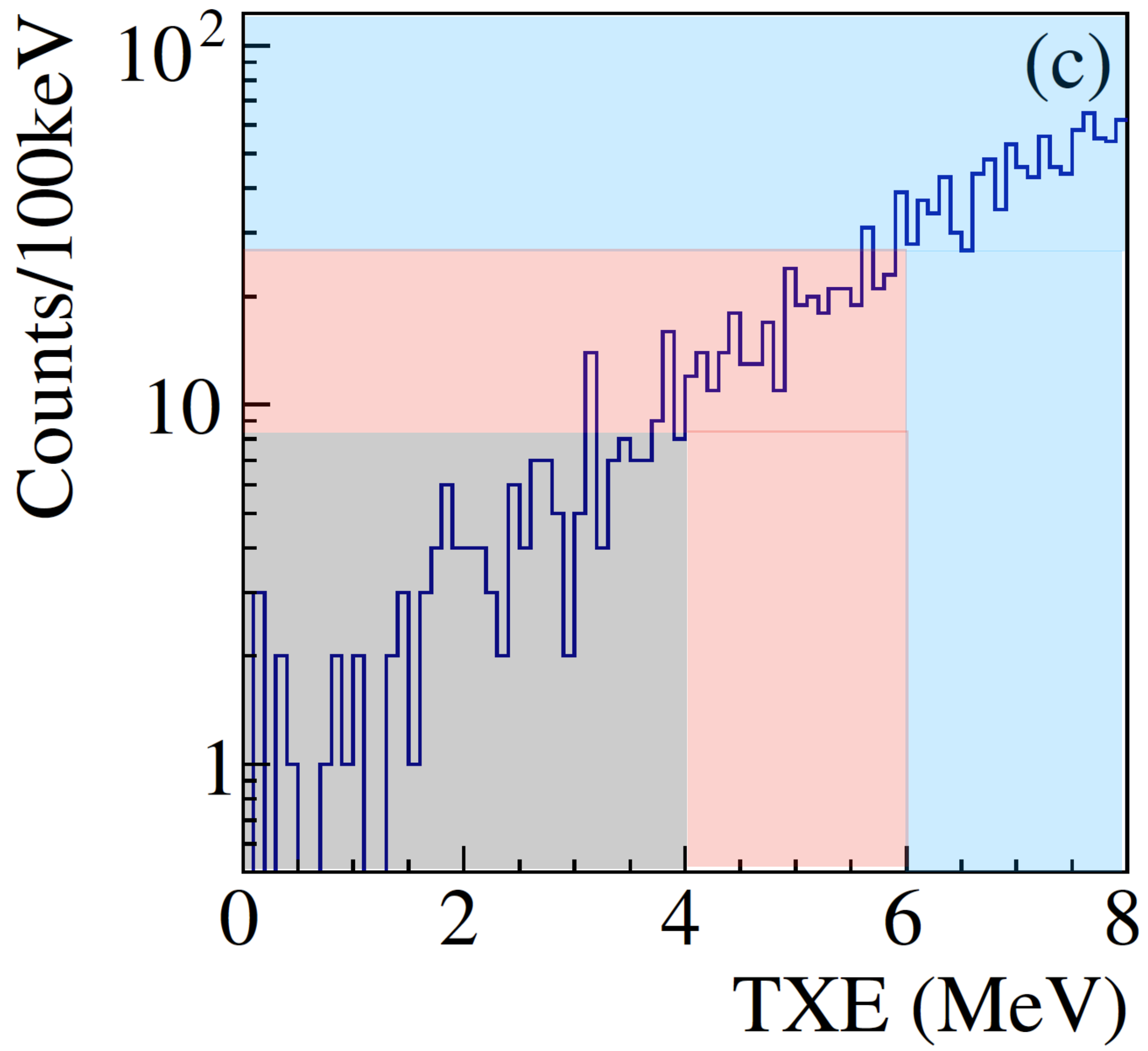


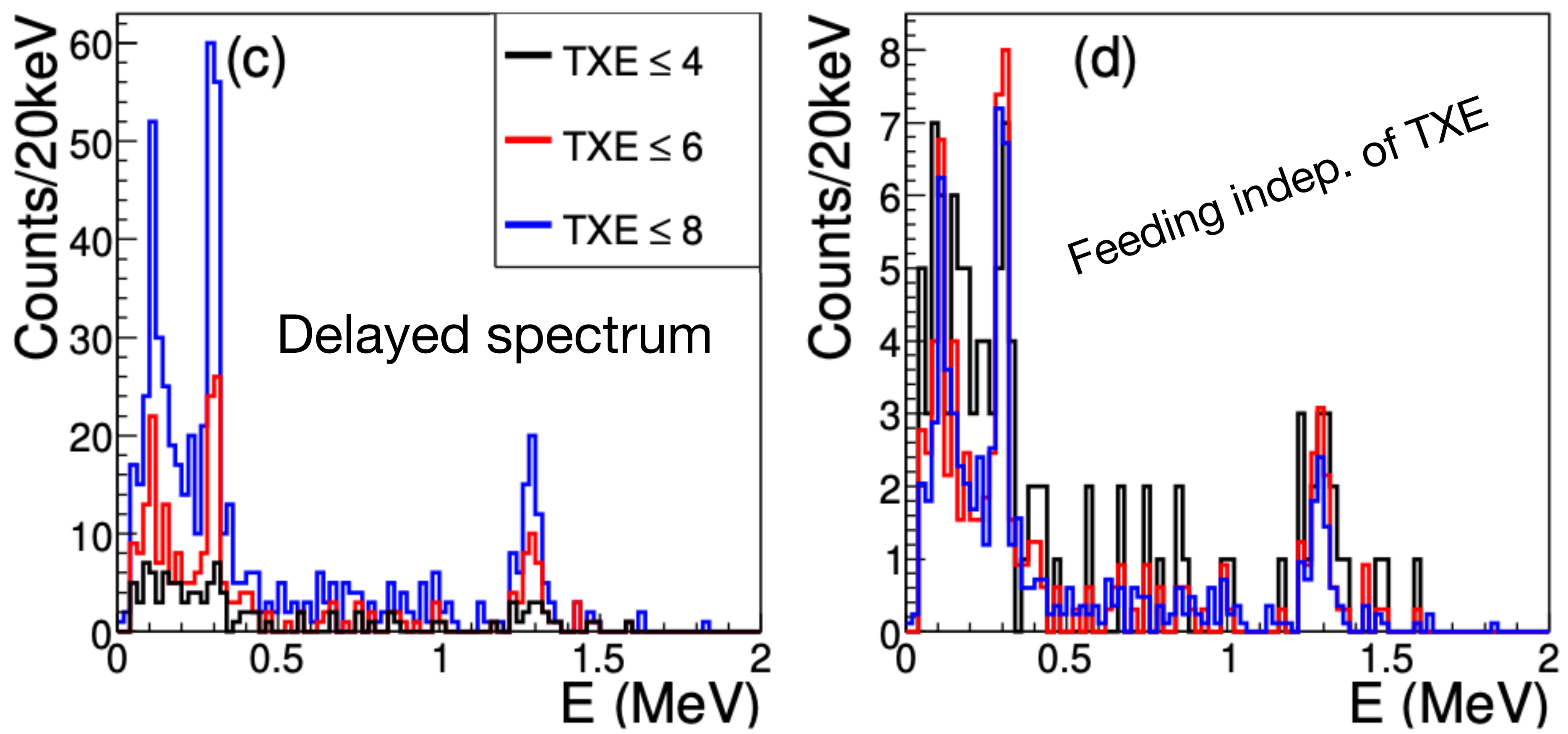

Which TXE sharing between the fragments and which AM distributions provide the best description of these properties?

# Measured properties to reproduce




TXE = Q-TKE



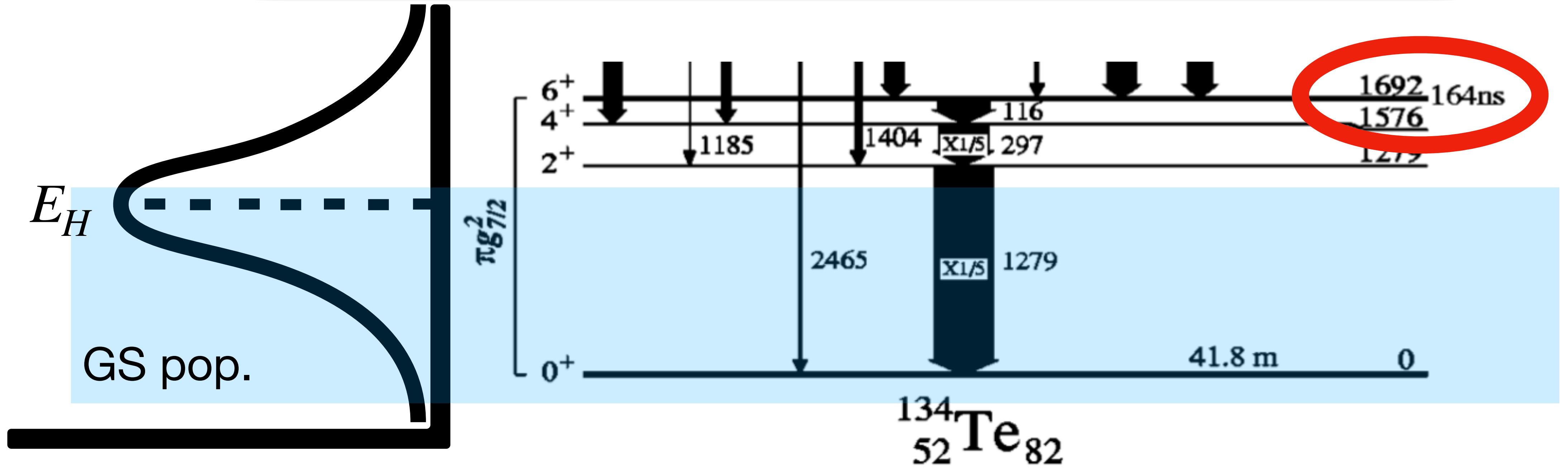




- TXE = $E_x^H + E_X^L$
- $^{118}Pd \Rightarrow$ I($2_1^+$) = 75(7)% and I($4_1^+$) = 22(8)%
- $^{134}Te \Rightarrow$ I($2_1^+$) = 46(8)%, I($4_1^+$) = 36(6)% and I($6_1^+$) = 14(2)%
- $^{134}Te \Rightarrow$ Feeding $6_1^+$ @ 1.7MeV independent of TXE gate

Which TXE sharing between the fragments and which AM distributions provide the best description of these properties?

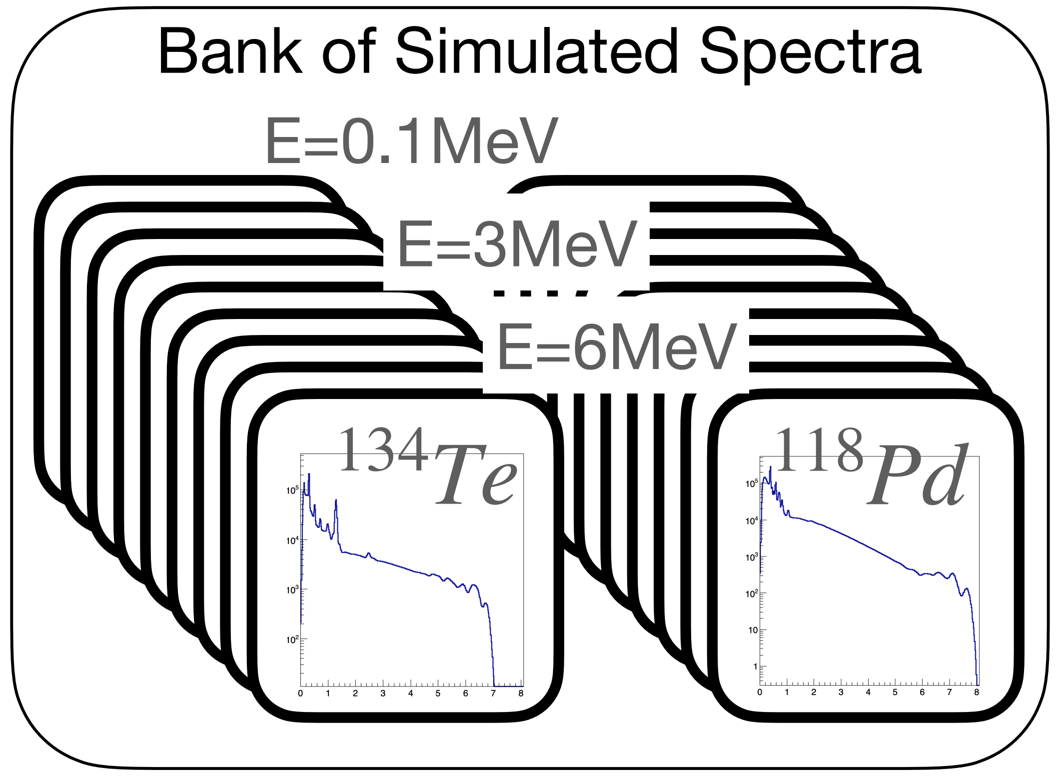
Assumption :

$E^*_{L,H} \propto e^{-\left(\frac{[x - E_{L,H}(TXE)]^2}{2\sigma^2}\right)}$ with $E_{L,H} = f(TXE)$ and $\sigma = cst$

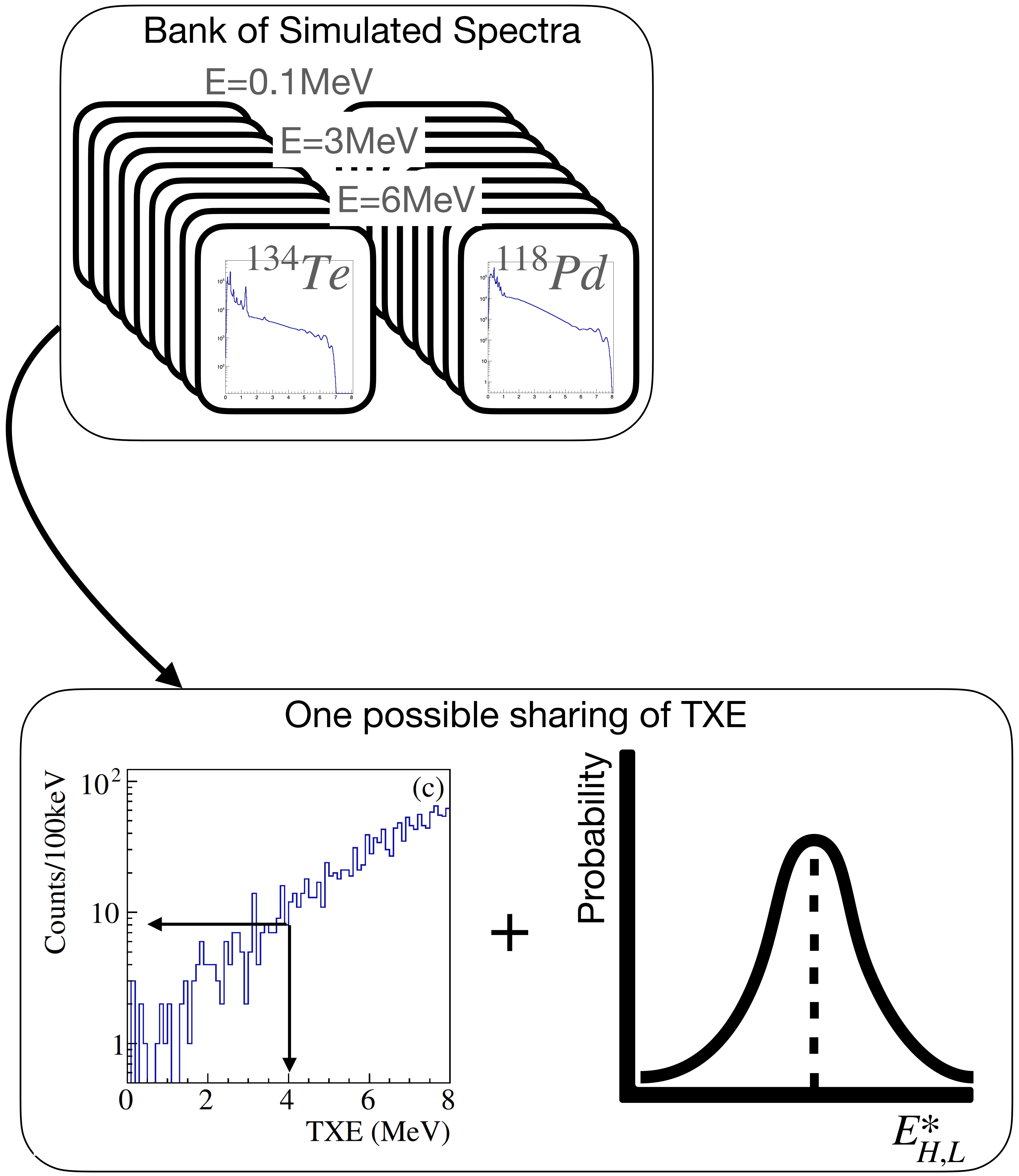



⇒ Natural explanation for experimental observations if $E_H \approx 0$ MeV and $\sigma \approx E(6_1^+)$

# Optimization Strategy

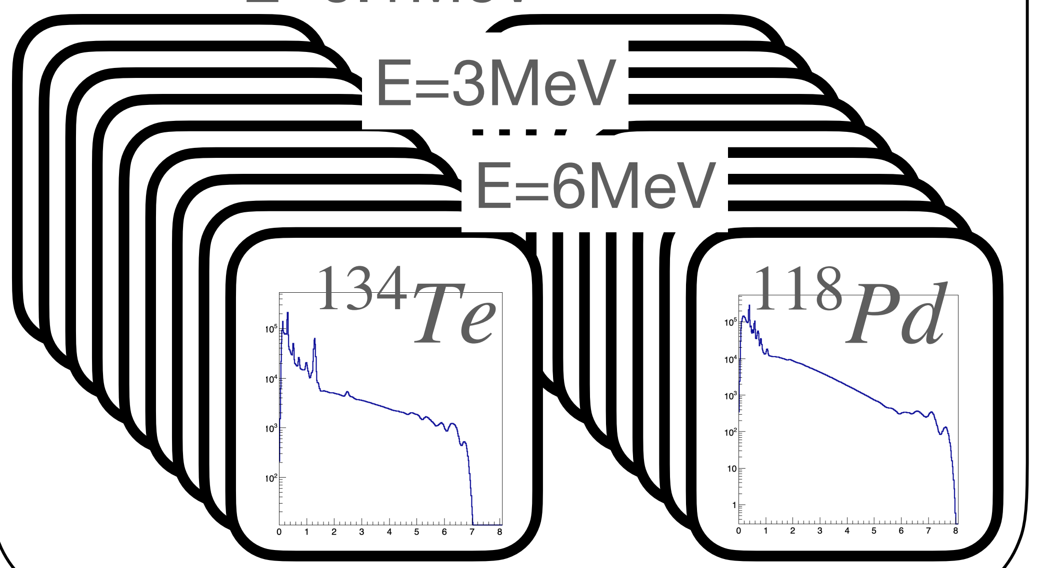


# Optimization Strategy



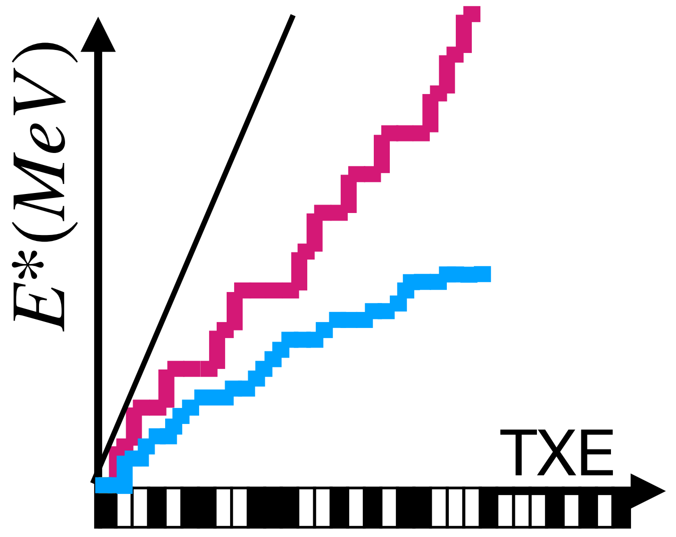
# Optimization Strategy

Bank of Simulated Spectra



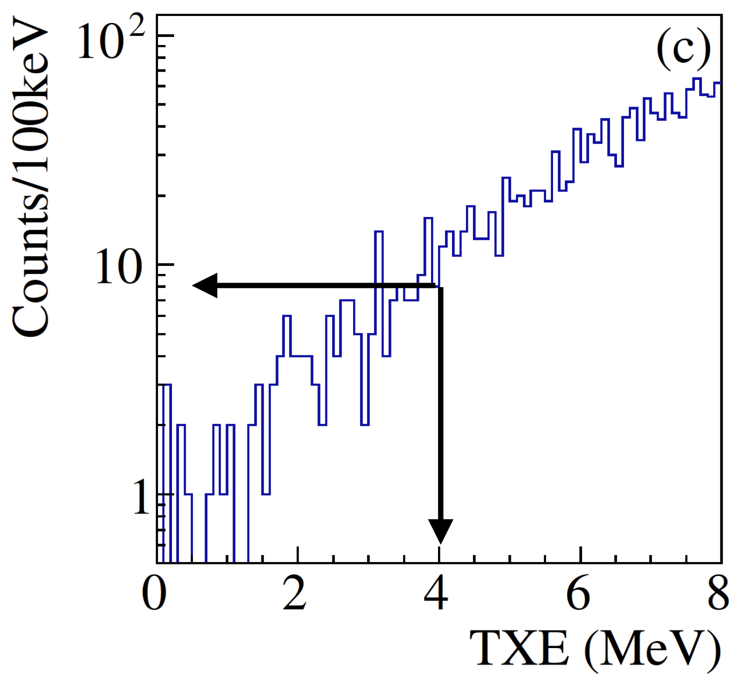

Genetic Evolution of Population of Solutions

Genetic Code :
TXE sharing




- Selection : Best candidate survive
- Crossover : Mix the code of two good candidates
- Mutation : random modification of the code.

One possible sharing of TXE

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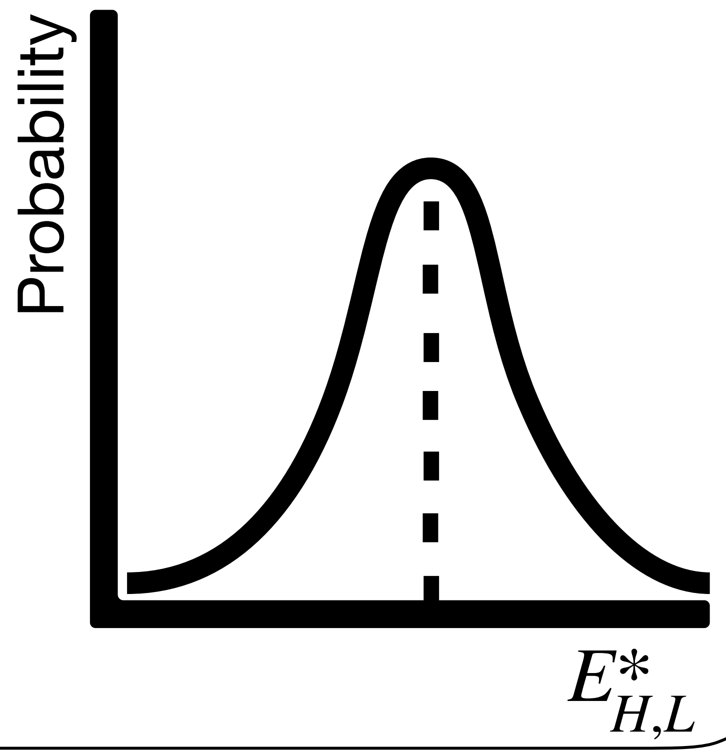
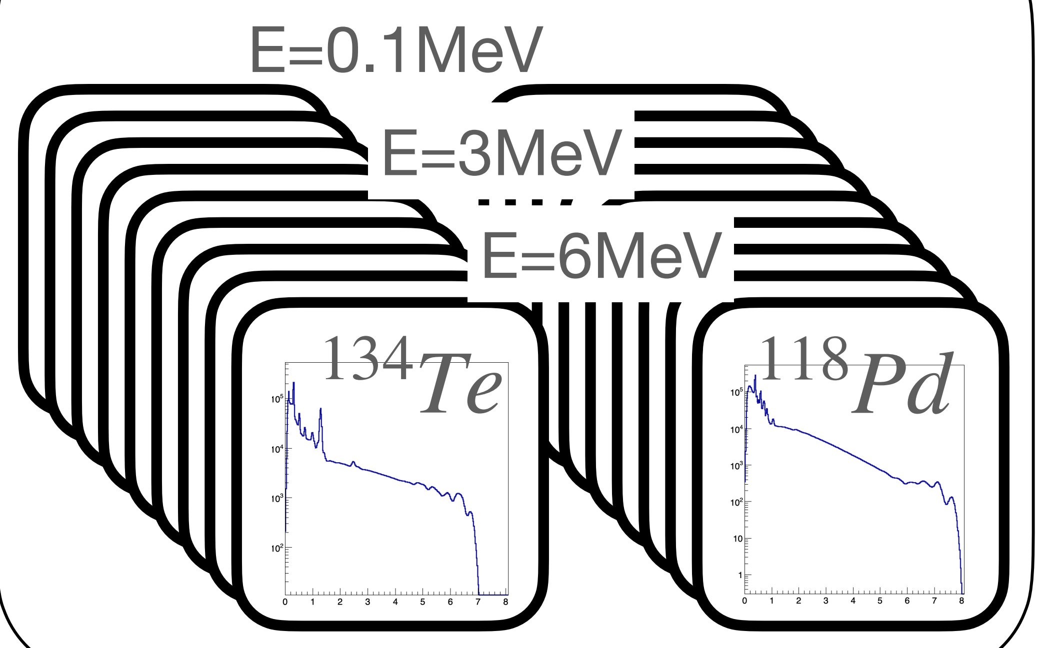


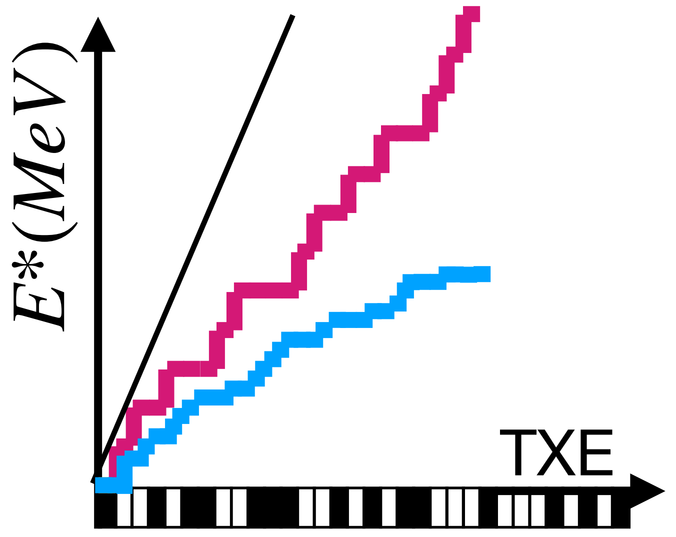
# Optimization Strategy

Bank of Simulated Spectra



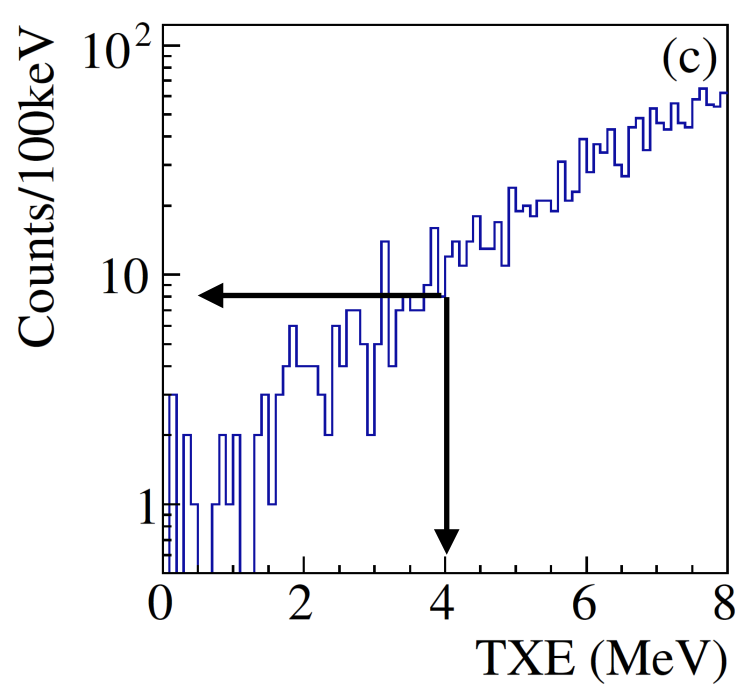

Genetic Evolution of Population of Solutions

Genetic Code : TXE sharing




- Selection : Best candidate survive
- Reproduction : Mix the code of two good candidates
- Mutation : random modification of the code.

One possible sharing of TXE

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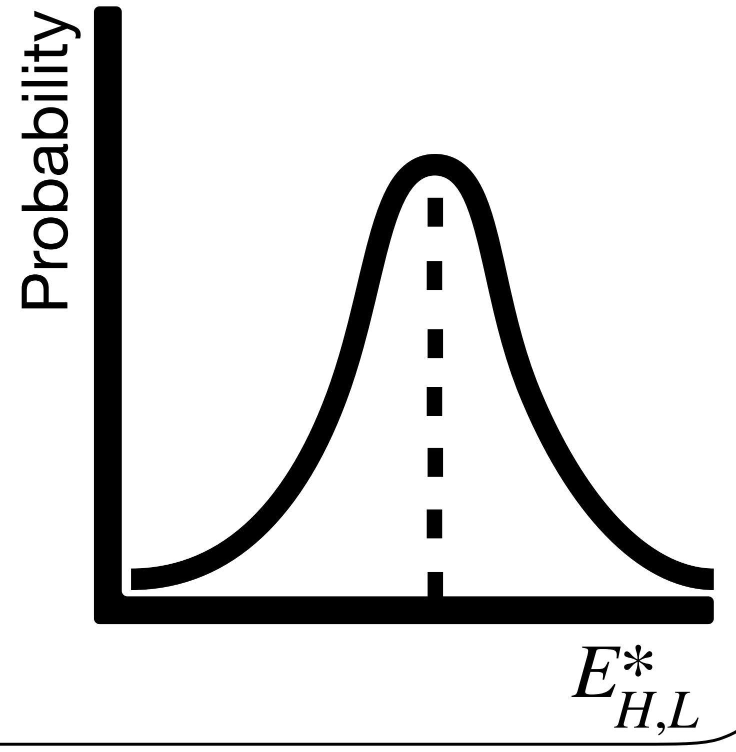
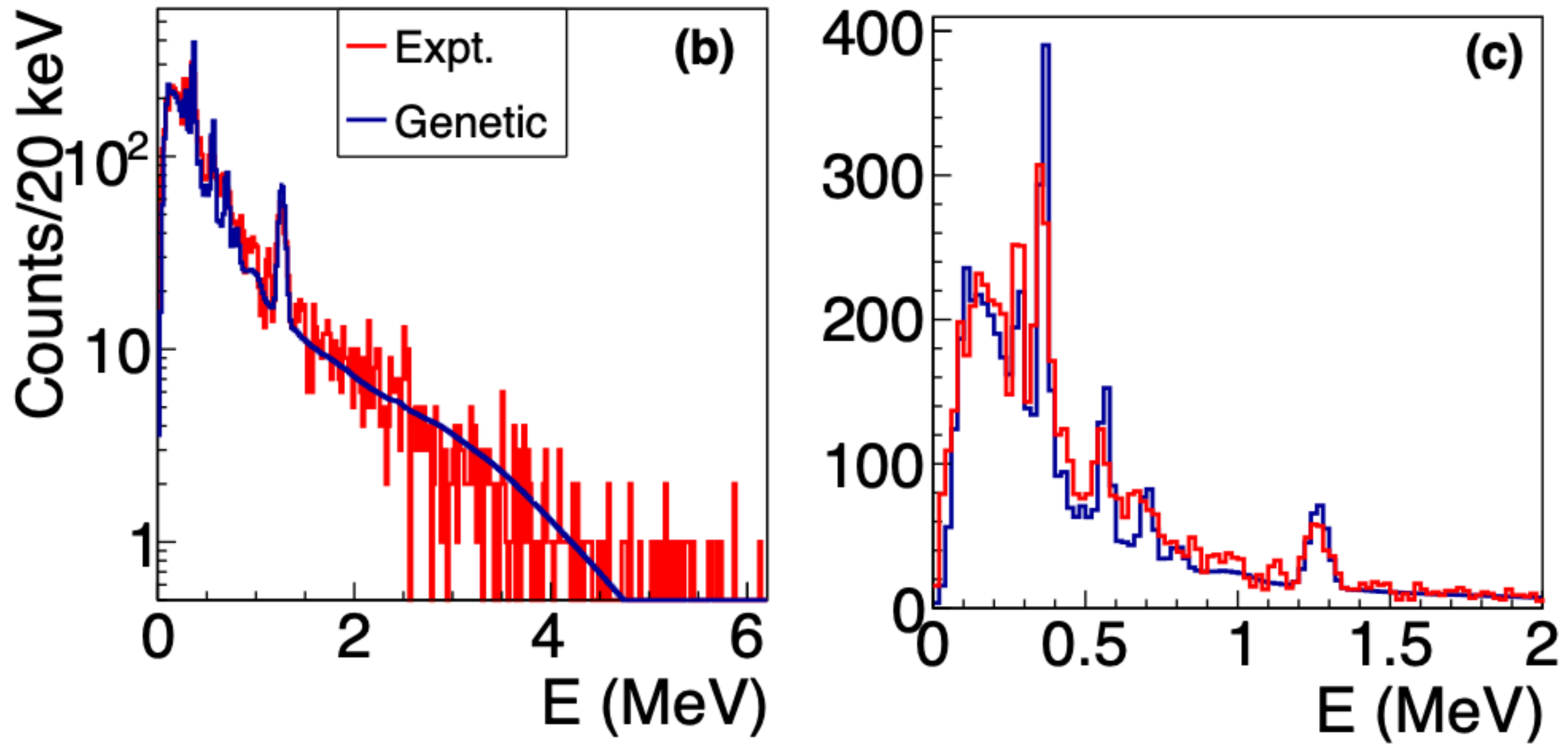
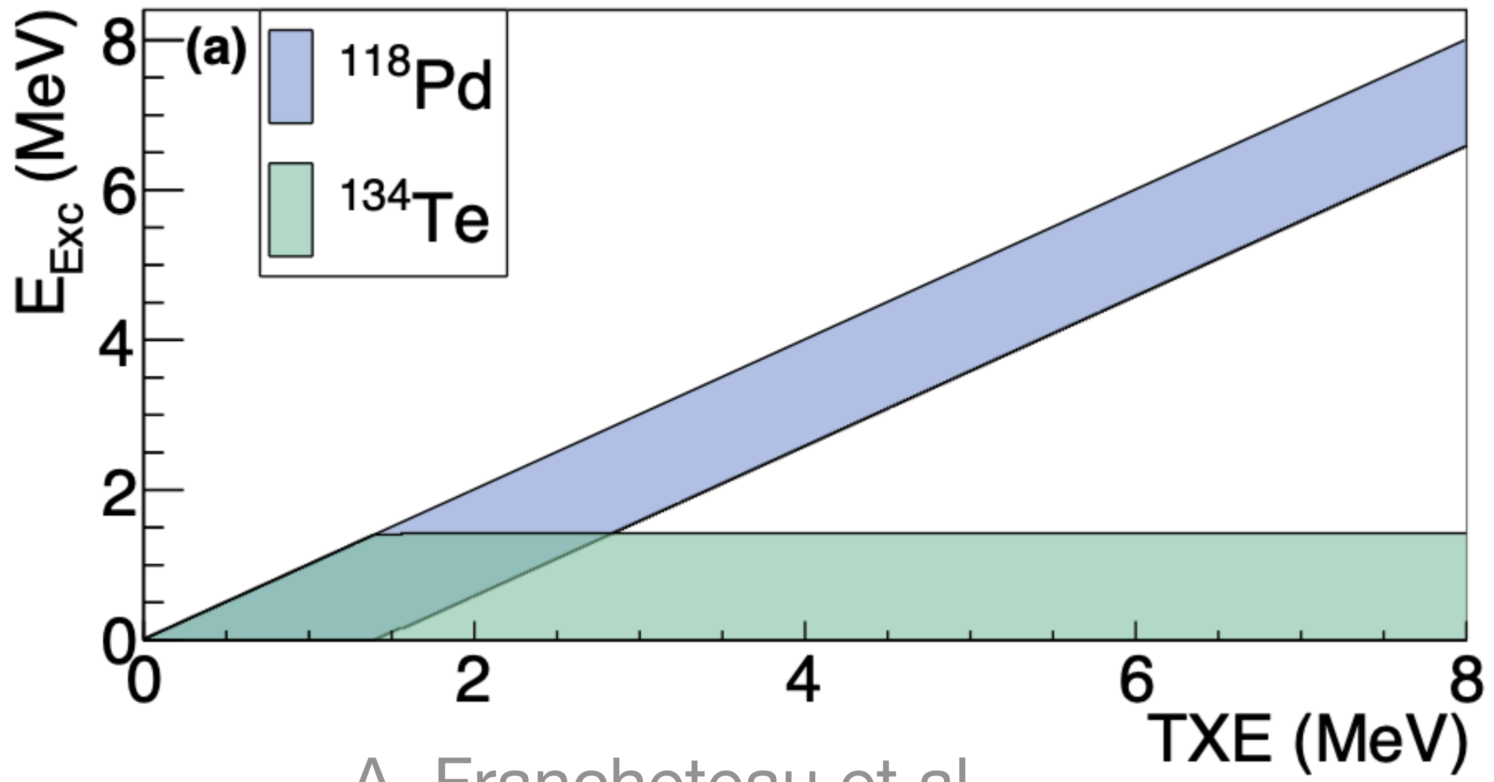



Optimized Results



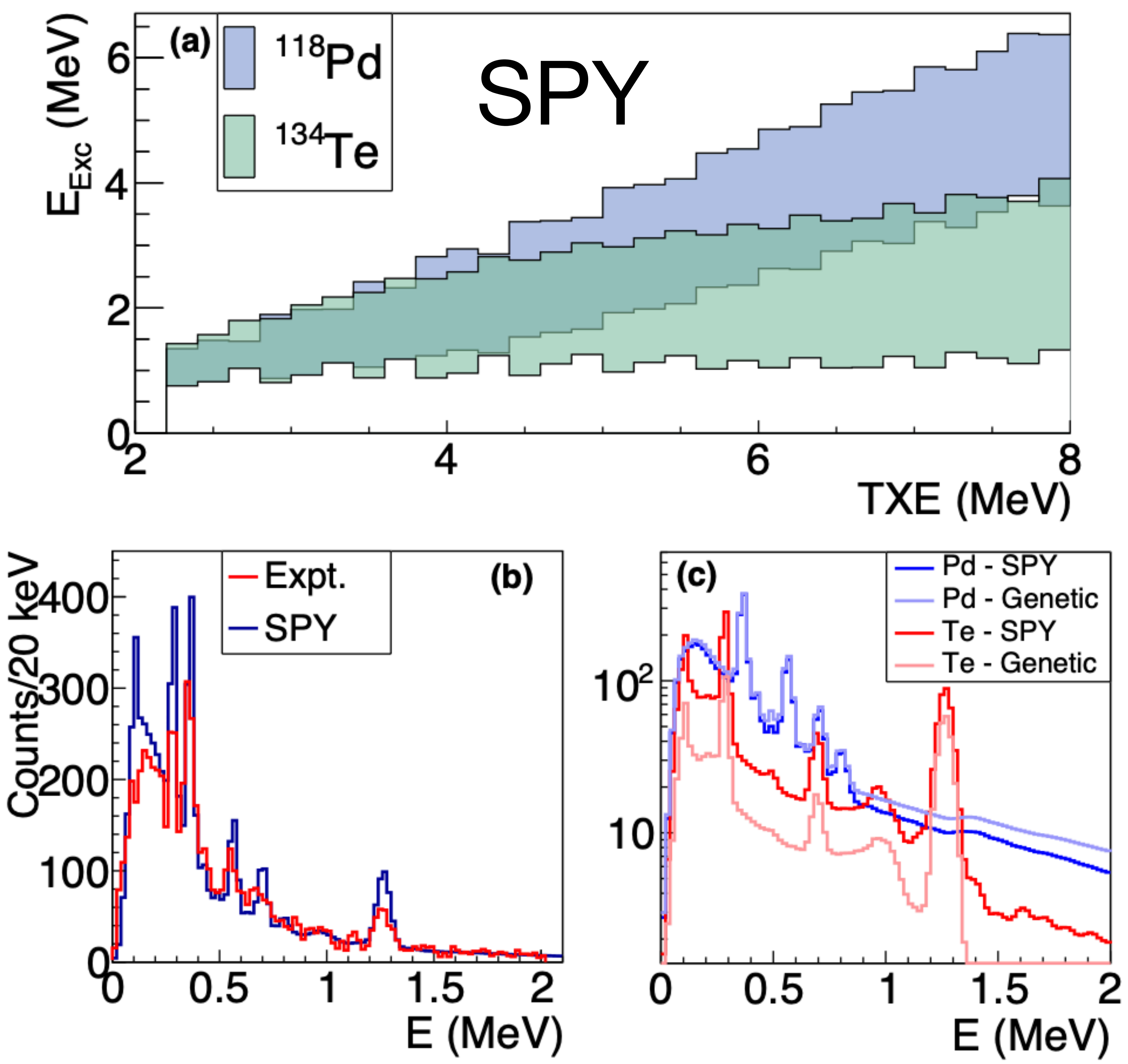

A. Francheteau et al.,
PRC 113, 034610 (2026)

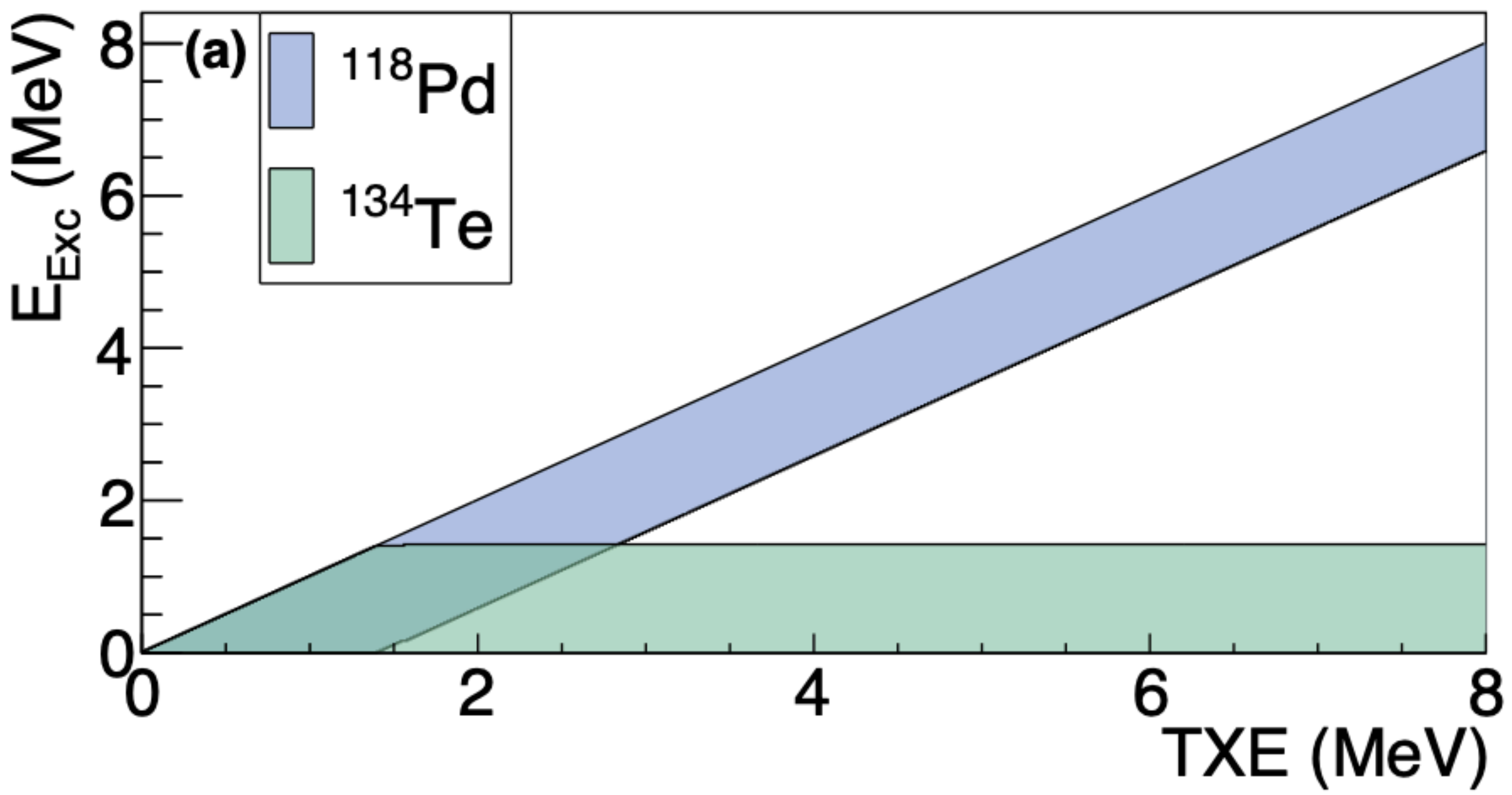
1. $^{134}Te$ weakly excited
   $\Rightarrow I(GS) \approx 50\,\%$
2. $\sigma \approx$ 1.3 MeV
   $\Rightarrow I(6_1^+) \approx 15\,\%$ + indep. TXE
3. Spin cutoff $B^{Te} \sim 3\hbar$ and $B^{Pd} \sim 4.5\hbar$
   $\Rightarrow$ Global normalisation + $I(2_1^+)$ and $I(4_1^+)$

# Comparison with 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 $^{134}Te$.

<u>$^{118}Pd$</u> :

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

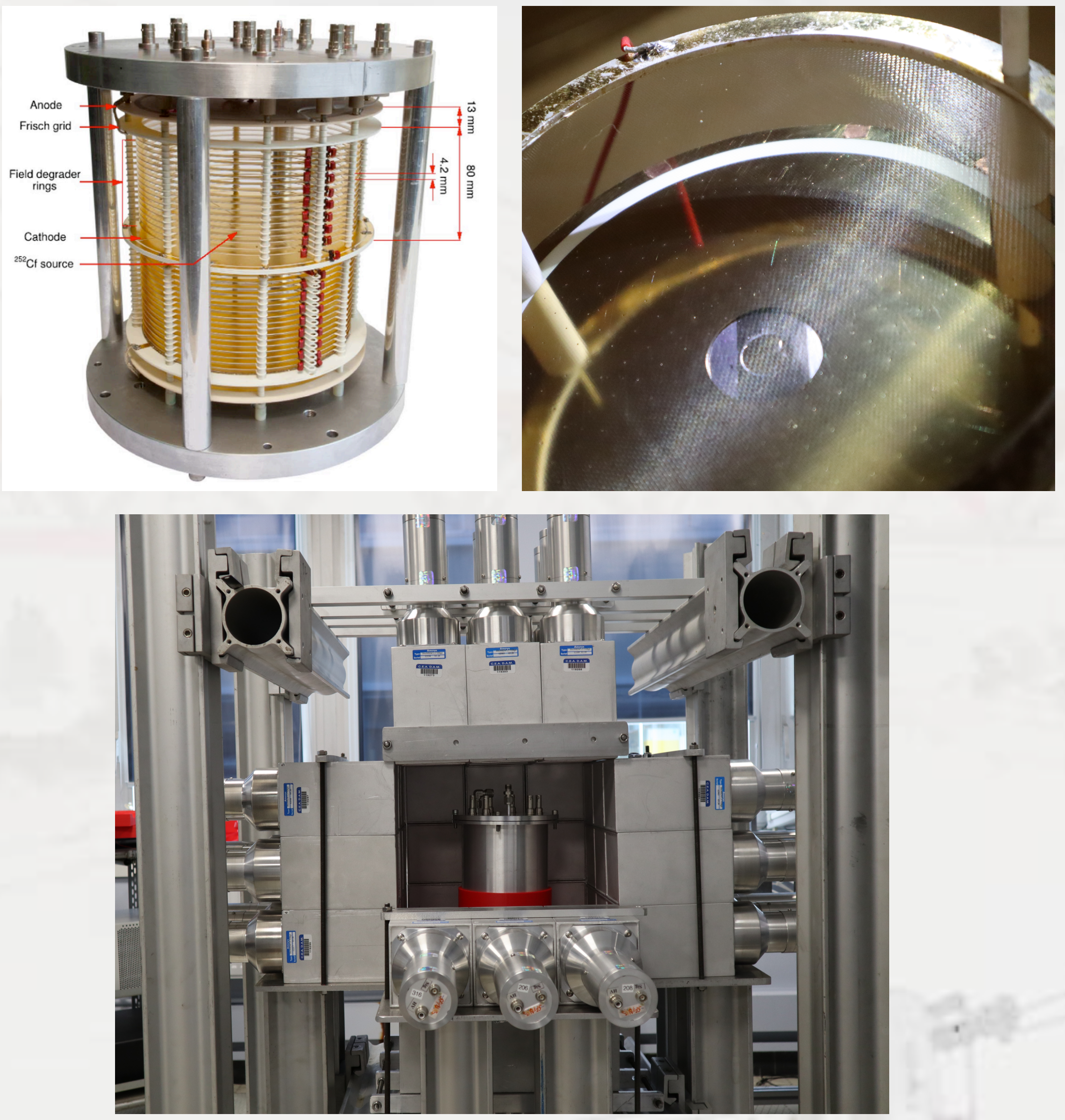
<u>**At fixed TXE**</u> :

- Lower $\beta_L \leftrightarrow$ lower $E^*_L$
- Lower $E^*_L \leftrightarrow$ higher $E^*_H$, since $(E^*_H = TXE - E^*_L)$

$\Rightarrow$SPY underestimates $\beta_{Pd}$.

$\Rightarrow$Indirect confirmation of the O-P mechanism.

## Fission Fragments' Properties from the Neutronless Channel in $^{252}Cf(sf)$



A relatively simple experimental setup
(challenge = spectroscopic source)

Simple TKE selection for efficient fragment ID.
Access to TXE distribution.
Coincident $\gamma$-ray spectrum.

Radiative decay of Neutronless fragmentation.
$^{120}Cd/^{132}Sn$ : doubly magic nucleus in its GS.
$^{118}Pd/^{134}Te$ : both fragments excited.

Reproducing the data :

Test the angular momentum distribution of the fragments.

Orientation/pumping mechanism provides satisfactory agreement with data.

⇒Indirect info on deformation of fragments.

Sharing of TXE between fragments.

⇒Distributed among fragments.
⇒Sizable width of the distribution.
⇒Test of models : SPY fails to reproduce our data - underestimation of deformation.

# Comparison with Standard fission

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

  $B^{Te} \sim 2.9\hbar$ similar to our $B^{Te} \sim 3\hbar$ ⇒Ratio ≈ 1.0
  $B^{Pd} \sim 6\hbar$ larger than our $B^{Pd} \sim 4.5\hbar$ ⇒Ratio ≈ 1.3

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

- Mean pre-neutron excitation energies

  Wilson et al. : $\bar{E}_x^{Te} \sim 12$ MeV and $\bar{E}_x^{Pd} \sim 21$ MeV (⇐ GEF)
  Our work : $\bar{E}_x^{Te} \sim 0$ MeV and $\bar{E}_x^{Pd} \sim 6$ MeV

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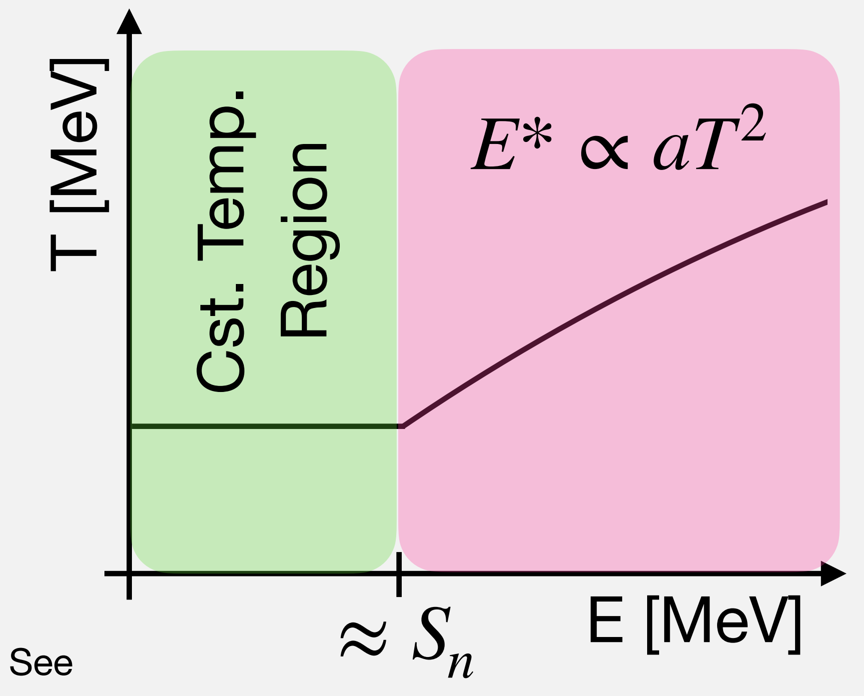
- Using Talys to estimate nuclear Temperatures

  $\bar{E}_x^{Te} \sim 12$ MeV ⇒ $T^{Te}$~0.99MeV
  $\bar{E}_x^{Te} \sim 0$ MeV ⇒ $T^{Te}$~0.78MeV
  ⇒Ratio ≈ 1.12

  $\bar{E}_x^{Pd} \sim 21$ MeV $T^{Pd}$~1.1MeV
  $\bar{E}_x^{Pd} \sim 6$ MeV $T^{Pd}$~0.58MeV
  ⇒Ratio ≈ 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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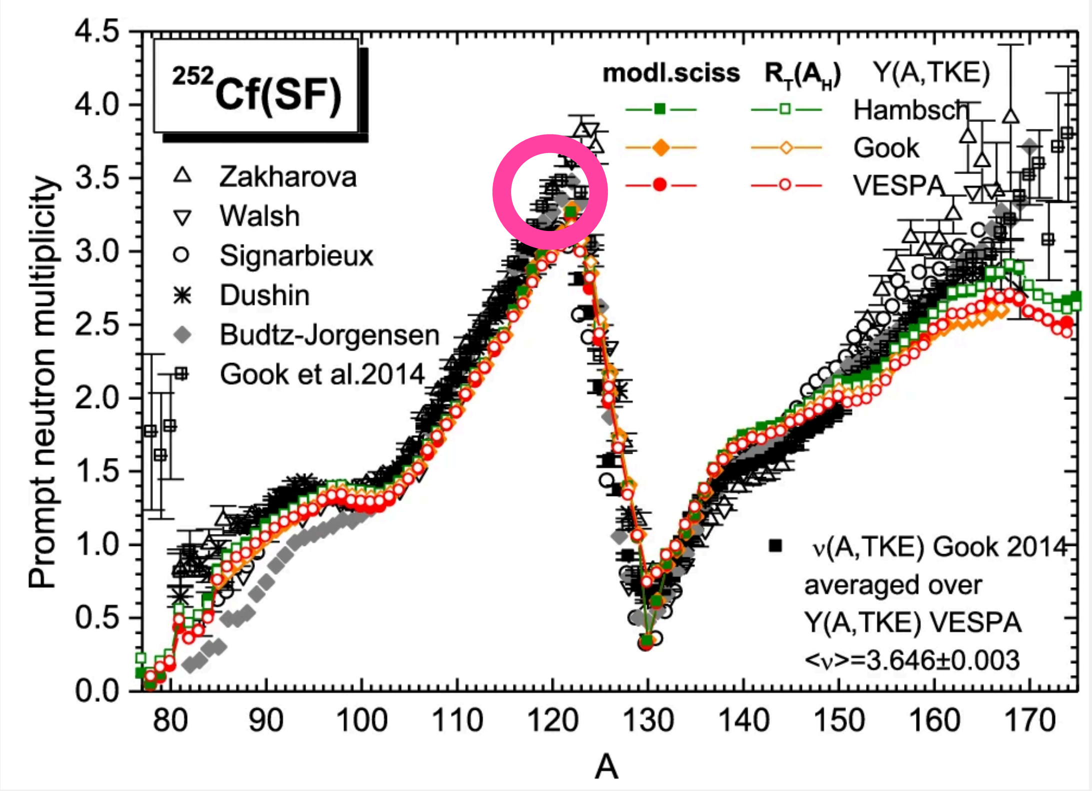
Spin distribution differences explained without a third-party effect.
⇒Neglect angular momentum removal by neutrons.
I. Stetcu et al., PRL **127**, 222502 (2021)




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