DE LA RECHERCHE À L'INDUSTRIE

Gamma-ray cascade study in the abundant fission fragments with the EXILL experiment and FIFRELIN simulation

MICHAŁ RĄPAŁA

Varenna, 12 June 2018

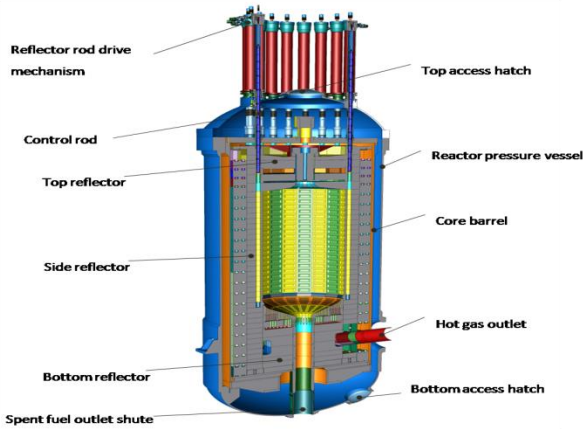
MOTIVATIONS

Generation III+ and IV reactors

- More accurate simulation
- Higher safety

Gamma heating process

- More precise simulation



HTMR Asia Development Limited, http://www.htmr-asia.com/en/product.php?id=27 (2014)

MOTIVATIONS

Generation III+ and IV reactors

- More accurate simulation
- Higher safety

Gamma heating process

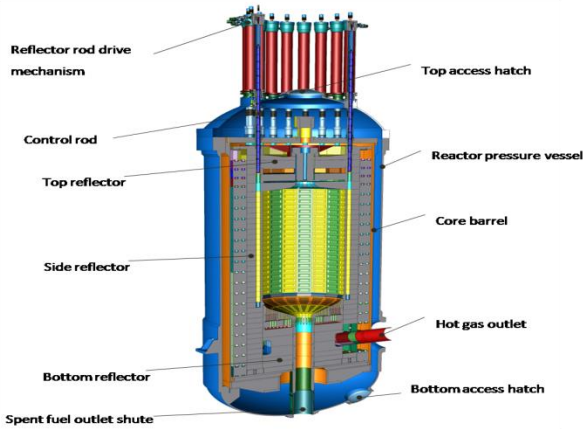
- More precise simulation

Fission fragment deexcitation simulation code

- Improvement of implemented models

Fission

- Prompt gamma-ray cascade



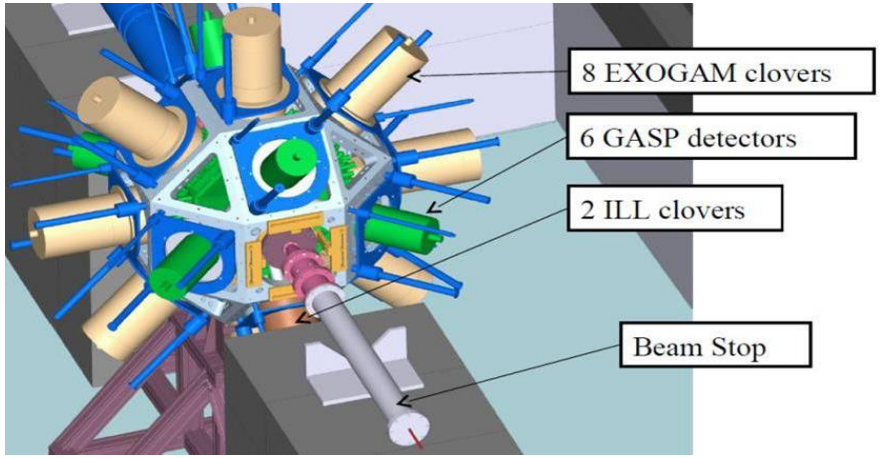
HTMR Asia Development Limited, http://www.htmr-asia.com/en/product.php?id=27 (2014)

Experimental data

EXOGAM EXPERIMENT AT ILL - EXILL

- Array of Ge-detectors around a fissile target in an intense cold neutron beam at ILL
  - 15 days with ^{235}U (575 mg/cm^2) + Sn/Zr
  - 5 days with ^{235}U (675 µg/cm2) + Be
  - 15 days with ^{241}Pu (300 µg/cm2) + Be

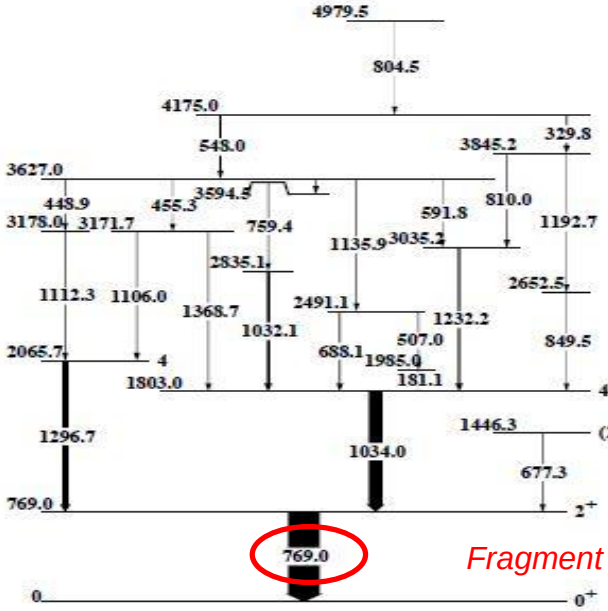
- Around 10^5 fissions per second
- Detection efficiency ~ 6% at 1MeV
- Fragments stopped in the target (no Doppler)
- Data analysis→ $\gamma\gamma\gamma$ coincidences



M. Jentschel et al, JINST 12, P11003 (2017)

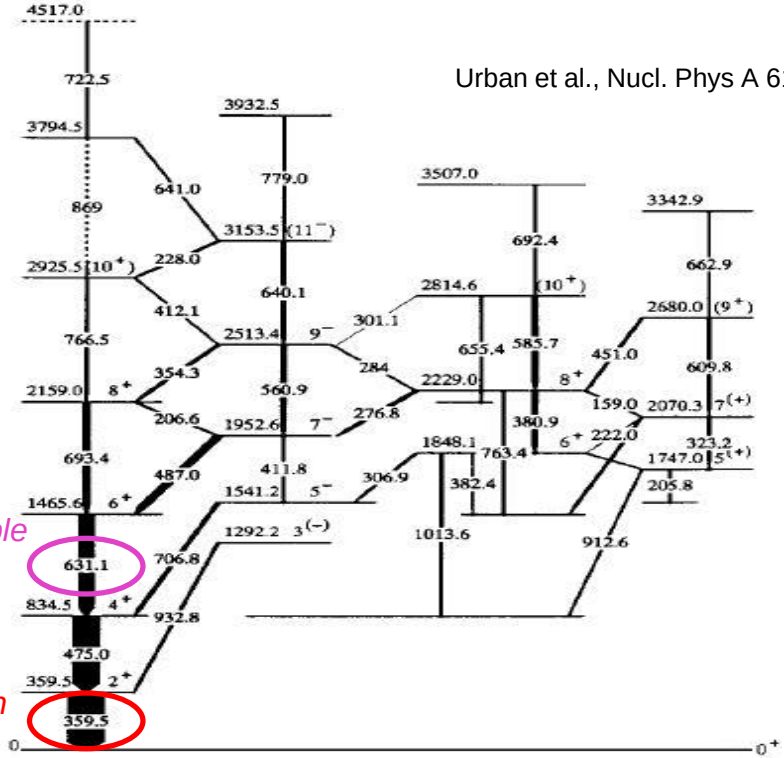
TRIPLE GAMMA COINCIDENCE IN PRACTICE (1/2)

Rząca-Urban et al., Eur. Phys. J. A 9 (2000) 165



92 ^{92}Kr

Urban et al., Nucl. Phys A 613 (1997) 107

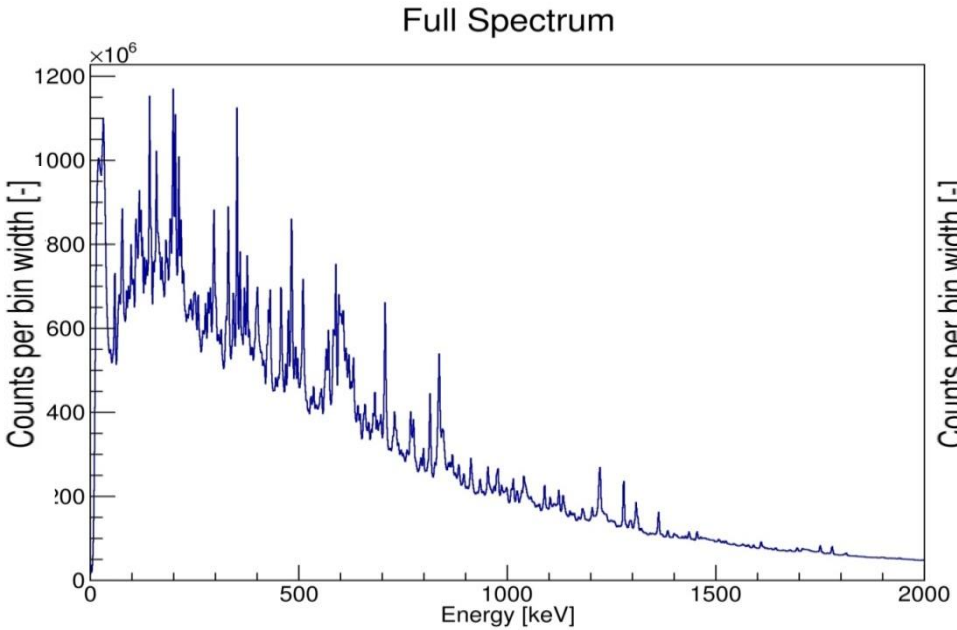


observable

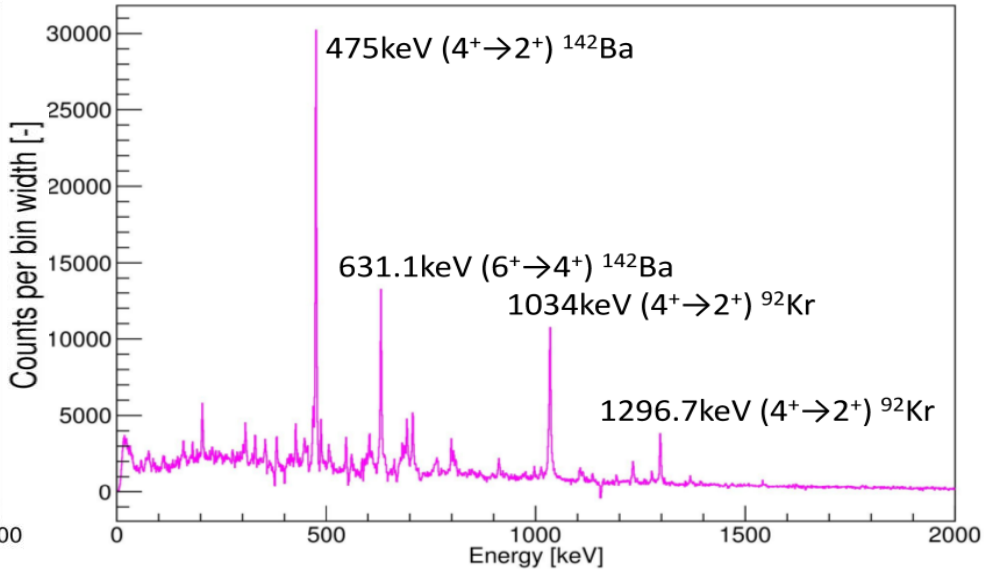
Fragment pair selection

^{142}Ba

TRIPLE GAMMA COINCIDENCE IN PRACTICE (2/2)



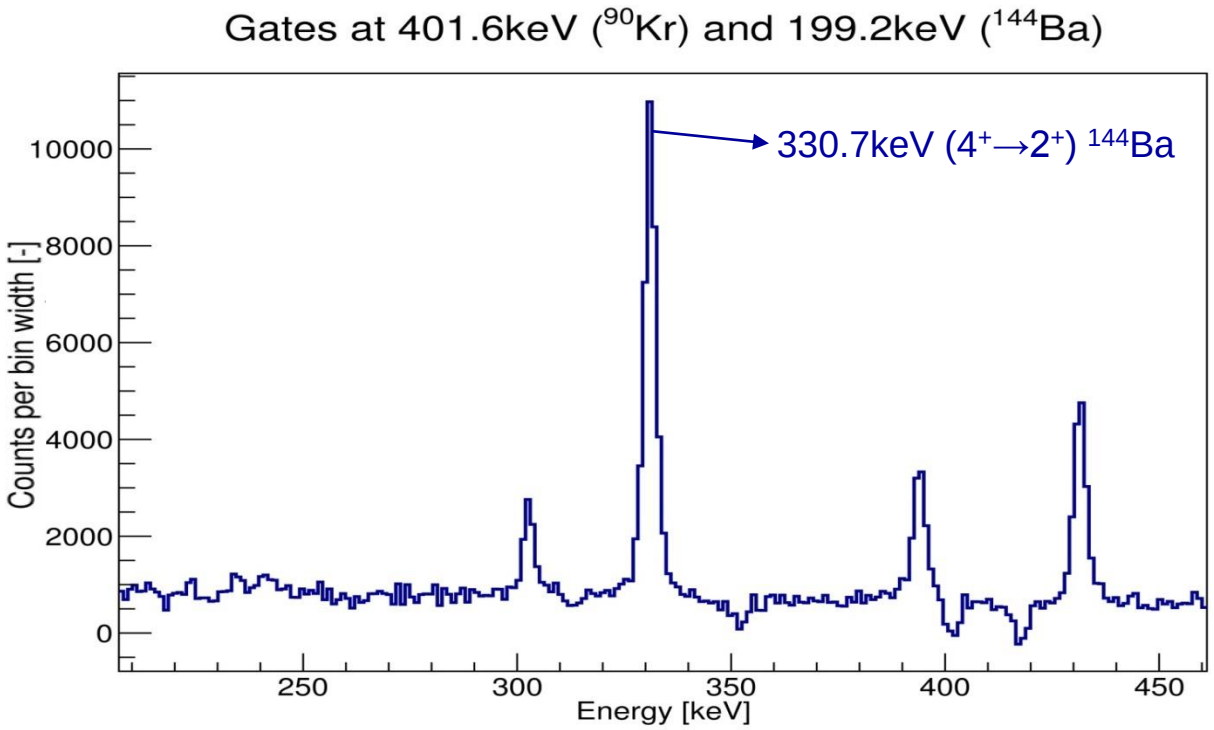
Coincidence spectrum with the 359.5 keV and 769.0 keV transitions



Problems with analysis and solutions

SPECTRA FITTING PROBLEMS - BACKGROUND

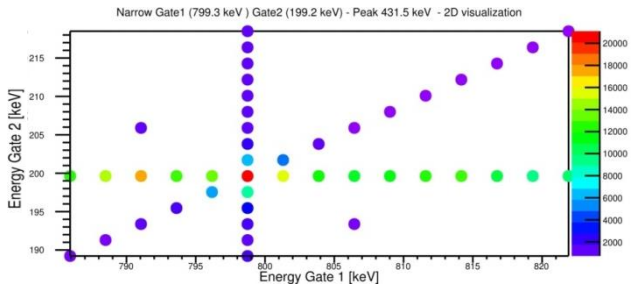
- Results depends on the gates and baseline selection

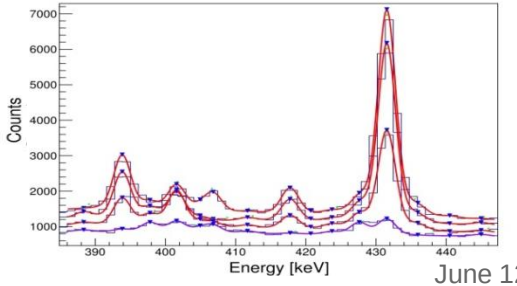


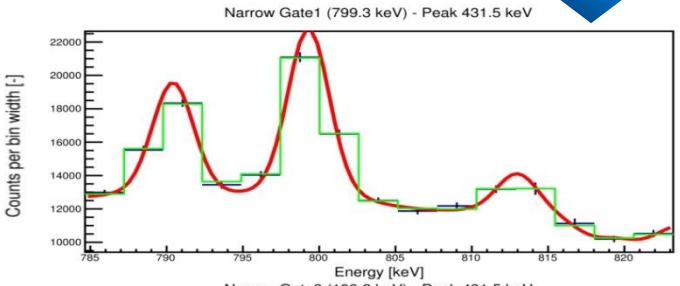
NEW ANALYSIS PROCEDURE

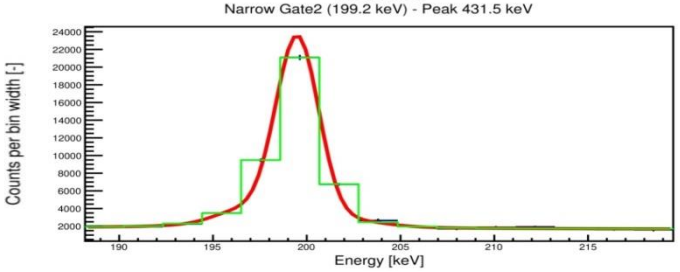
- Redefinition of background treatment
  - NO DIRECT BACKGROUND SUBTRACTION → GATE SCANNING

2D gate scan → Semi-automatic spectra fitting → Gate fitting









FIFRELIN simulations

FISSION FRAGMENT DEEXCITATION CODE FIFRELIN

FIFRELIN Ingredients

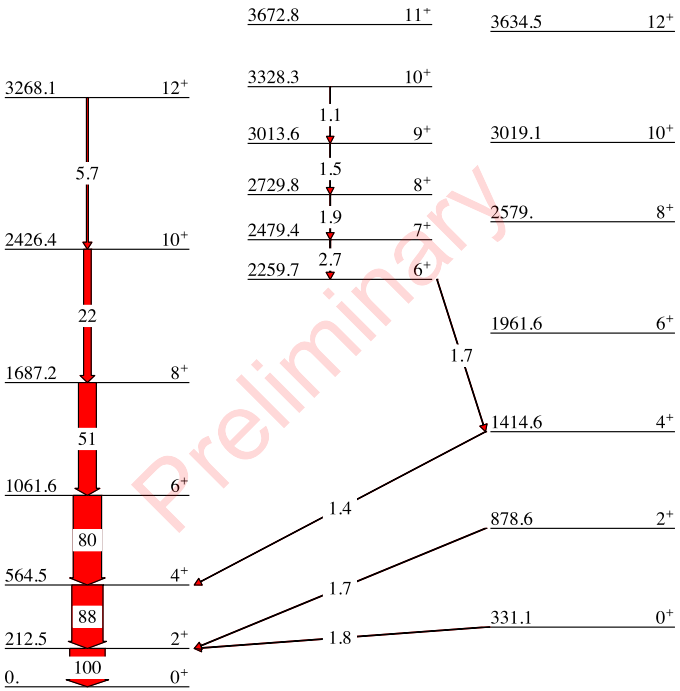
- Deexcitation with the Hauser-Feshbach treatment using
  - Experimental nuclear level scheme at low excitation energy,
  - Nuclear level density at high excitation energy,
  - Gamma strength functions,
  - Neutron transmission from optical potential

- (E*,J) distribution of the primary fragment

constant spin cut-off model (Constant)

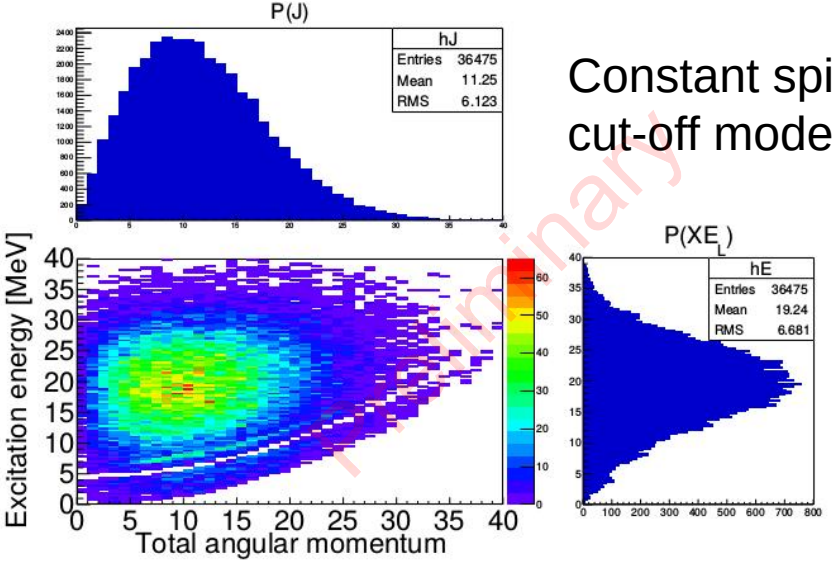
or

energy dependent spin cut-off model (BSFGM)



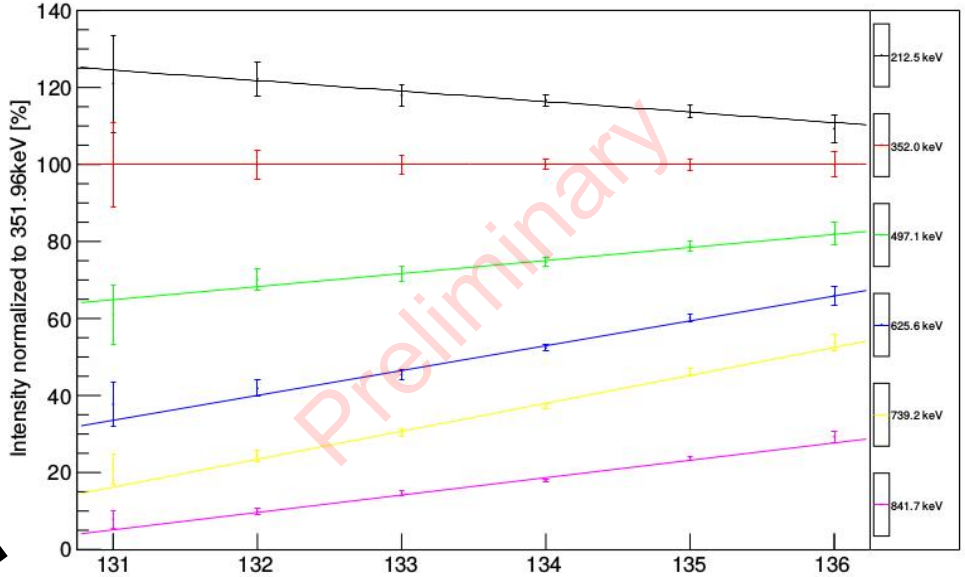
^{100}Zr gamma-ray cascade simulated with FIFRELIN

IMPACT OF THE (E,J) DISTRIBUTION ON THE EVOLUTION OF THE CASCADE WITH THE PARTNER (1)



Constant spin cut-off model

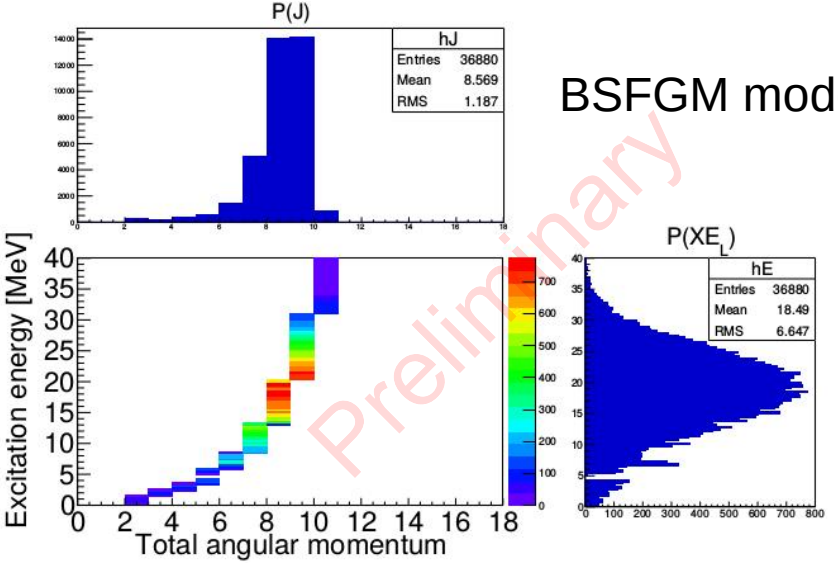
Evolution of the γ-ray intensities in ^{100}Zr



→ Te mass number
← Neutron evaporation
← Excitation energy

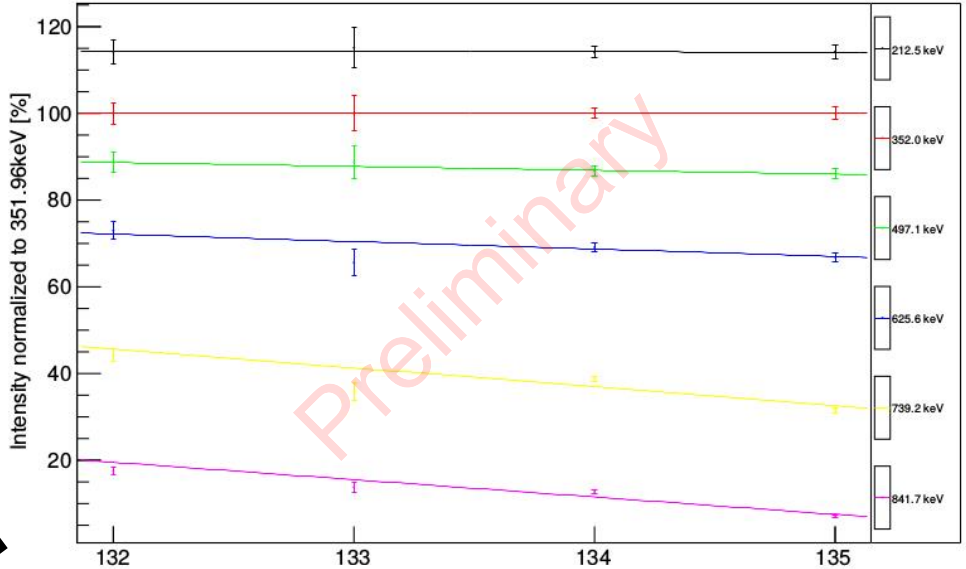
Strong dependence with the Fission partner

IMPACT OF THE (E,J) DISTRIBUTION ON THE EVOLUTION OF THE CASCADE WITH THE PARTNER (2)



BSFGM model

Evolution of the γ-ray intensities in ^{100}Zr

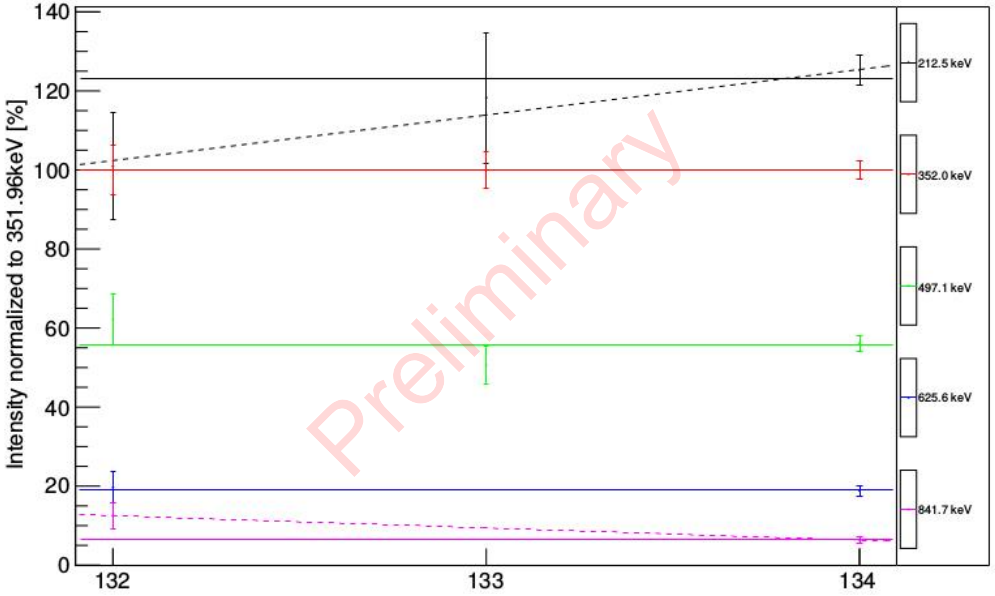


No dependence with the fission partner

→ Te mass number
← Neutron evaporation
← Excitation energy

RESULTS WITH EXILL DATA
EVOLUTION OF THE CASCADE WITH THE PARTNER

Evolution of the γ-ray intensities in ^{100}Zr

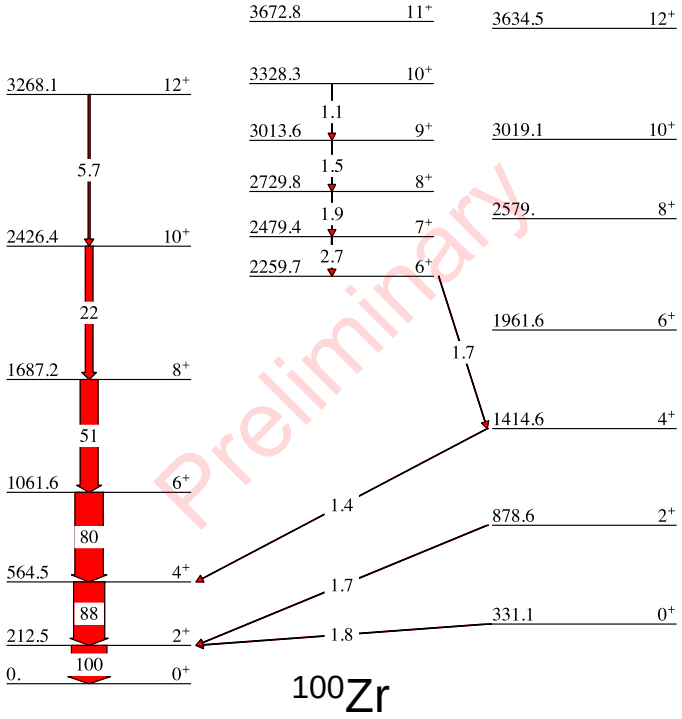


→ Te mass number
← Neutron evaporation
← Excitation energy

The intensities of the main transitions do not seem to depend on the fission partner (i.e. on the number of evaporated neutrons)

→ Rejection of the "Constant" model

MORE DETAILLED COMPARISON DATA-SIMULATION



E (keV)	J1→J2	I_γ	
		EXILL	FIFRELIN
212.5	$2^+\to0^+$	100	100
352.0	$4^+\to2^+$	78(3)	88(1)
497.1	$6^+\to4^+$	44(2)	80(1)
625.6	$8^+\to6^+$	15(1)	50.8(7)
739.2	$10^+\to8^+$	2.5(6)	21.8(4)
841.7	$12^+\to10^+$	1.2(5)	5.7(2)
219.8	$7^+\to6^+$	4.1(6)	2.7(1)
250.3	$8^+\to7^+$	1.8(4)	1.9(1)
267.3		0.8(4)	0.18(4)
301.3		1.2(6)	0.10(3)
536.0	$4^+\to2^+$	1.5(8)	0.91(8)
547.0	$6^+\to4^+$	2.0(4)	0.34(5)
845.2	$6^+\to4^+$	3.0(6)	1.7(1)
1695.2	$6^+\to4^+$	2.8(4)	0.88(8)
665.98	$2^+\to2^+$	1.9(7)	1.7(1)
850.1	$4^+\to4^+$	5.0(6)	1.4(1)

Preliminary

Feeding of the high spin states is overestimated in Fifrelin

MODEL PARAMETER ADJUSTMENT (1)

"BSFGM model"

Primary fragment distribution

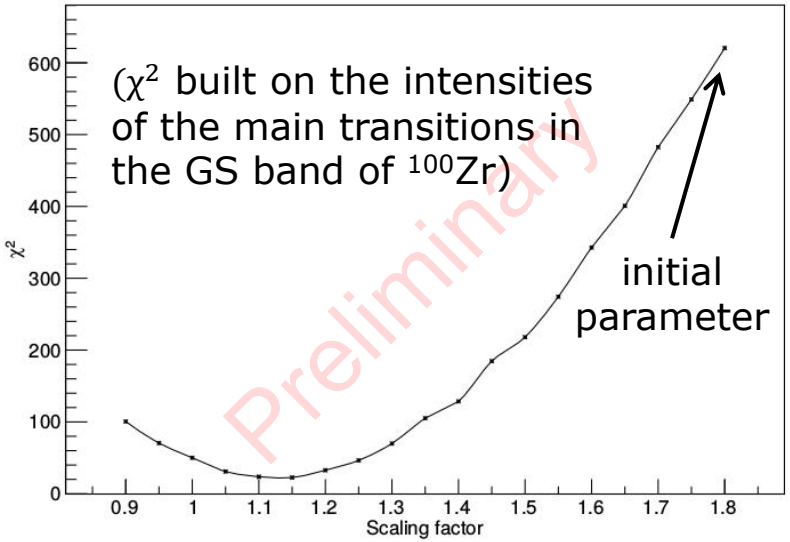
$$n(J) = f_\sigma \cdot \rho(J)$$

Where $\rho(J) = \frac{2J+1}{2\sigma^2} \exp(-\frac{\left(J+\frac{1}{2}\right)^2}{2\sigma^2})$

is the spin dependence of the nuclear level density

Idea : Scan of f_σ and comparison of simulations with data

χ^2 of simulations with different f_σ



The spin distribution of the fission fragments is close to the spin distribution of the nuclear level density

MODEL PARAMETER ADJUSTMENT (2)

Initial simulation

$\overline{\nu_L} = 1.42$
$\overline{\nu_H} = 1.01$
$\overline{\nu_T} = 2.43$

Simulation with modified f_σ

- Better intensities but :

$\overline{\nu_L} = 1.53$
$\overline{\nu_H} = 1.2$
$\overline{\nu_T} = 2.73$

Idea : Scan of the other free parameters

E (keV)	J1→J2	I_γ		
		EXILL	Initial simu,	Mod. simu.
212.5	$2^+ \to 0^+$	100	100	100
352.0	$4^+ \to 2^+$	78(3)	88(1)	84.8(9)
497.1	$6^+ \to 4^+$	44(2)	80(1)	54.9(7)
625.6	$8^+ \to 6^+$	15(1)	50.8(7)	14.9(3)
739.2	$10^+ \to 8^+$	2.5(6)	21.8(4)	1.9(1)
841.7	$12^+ \to 10^+$	1.2(5)	5.7(2)	0.14(3)
219.8	$7^+ \to 6^+$	4.1(6)	2.7(1)	2.1(1)
250.3	$8^+ \to 7^+$	1.8(4)	1.9(1)	1.14(8)
267.3		0.8(4)	0.18(4)	0.11(2)
301.3		1.2(6)	0.10(3)	0.05(1)
536.0	$4^+ \to 2^+$	1.5(8)	0.91(8)	2.2(1)
547.0	$6^+ \to 4^+$	2.0(4)	0.34(5)	0.95(7)
845.2	$6^+ \to 4^+$	3.0(6)	1.7(1)	1.7(1)
1695.2	$6^+ \to 4^+$	2.8(4)	0.88(8)	0.83(7)
665.98	$2^+ \to 2^+$	1.9(7)	1.7(1)	2.3(1)
850.1	$4^+ \to 4^+$	5.0(6)	1.4(1)	2.9(1)

Conclusions

CONCLUSIONS

- Experimental data (EXILL experiment)
  - Measurement of the prompt-gamma ray cascades coming from the deexcitation of the fission fragments
  - Semi-automatic analysis technique ($\gamma\gamma\gamma$ coincidences)
  - Determination of the prompt-gamma ray intensities

- Simulation data (FIFRELIN code)
  - Analysis of the spin cutoff models (rejection of the "Constant" model)
  - Optimization of spin (the nuclear level density spin distribution)
  - Prompt-neutron multiplicity optimization needed

COLLABORATION

T. Materna[1], A. Letourneau[1], A. Marchix[1], O. Litaize[2], O. Sérot[2], D. Regnier[2], W. Urban[3], A. Blanc[4], M. Jentschel[4], U. Köster[4], P. Mutti[4], T. Soldner[4], G. Simpson[5], Călin A. Ur[6], and G. de France[7]

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[6] INFN, Legnaro, Italy

[7] GANIL, Caen, France

DETECTION SYSTEM CALIBRATION

- Europium source data used for calibration

  $^{152}Eu \rightarrow {}^{152}Gd$ or ^{152}Sm

- Three types of detectors with different performance
- Total coincidence efficiency formula simplificatio

$$\varepsilon_{coinc}(E_1, E_2, E_3) = \sum_{i=1}^{N} \sum_{\substack{j \neq i \\ j=1}}^{N} \sum_{\substack{k \neq i \\ k \neq j \\ k=1}}^{N} \varepsilon_i(E_1)\varepsilon_j(E_2)\varepsilon_k(E_3)$$

$$\Downarrow$$

$$\varepsilon_{app}(E_1, E_2, E_3) = \frac{(N-1)(N-2)}{N^2} \varepsilon_T(E_1)\, \varepsilon_T(E_2)\varepsilon_T(E_3)$$

$$\varepsilon_T(E) = \sum_{i=1}^{N} \varepsilon_i(E) = N \cdot \varepsilon(E)$$

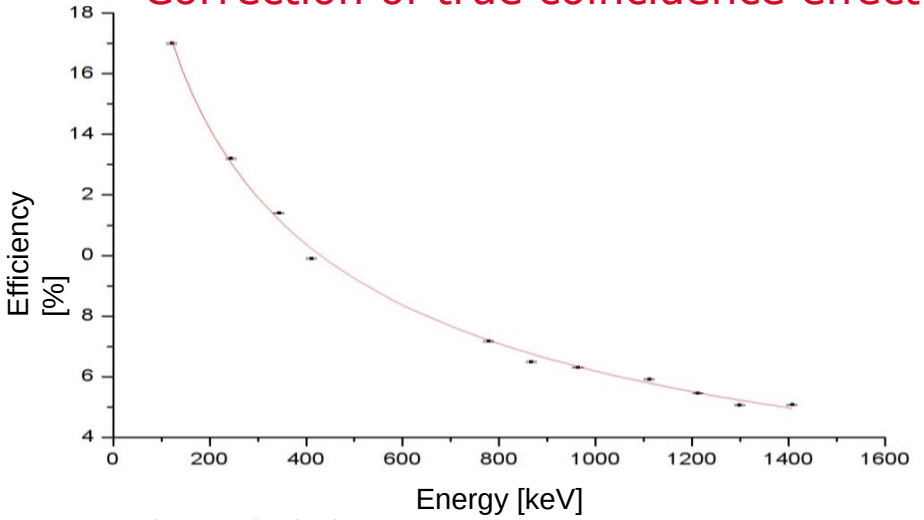
DIFFERENCE LOWER THAN 2% IN RANGE BETWEEN 100KEV TO 1.5MEV

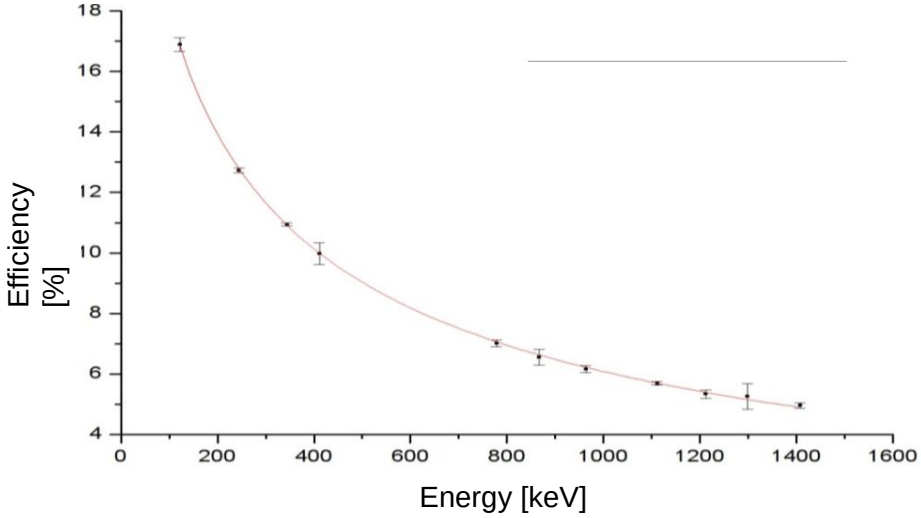
DETECTION SYSTEM CALIBRATION

- Europium source data used for calibration

  $^{152}Eu \rightarrow {}^{152}Gd$ or ^{152}Sm

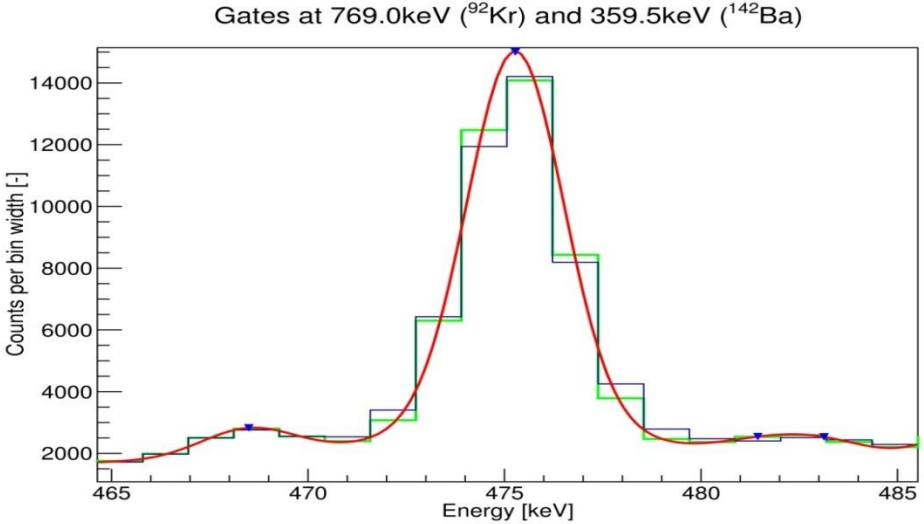
- Three types of detectors with different performance
- Total coincidence efficiency formula simplification
- Correction of true coincidence effect

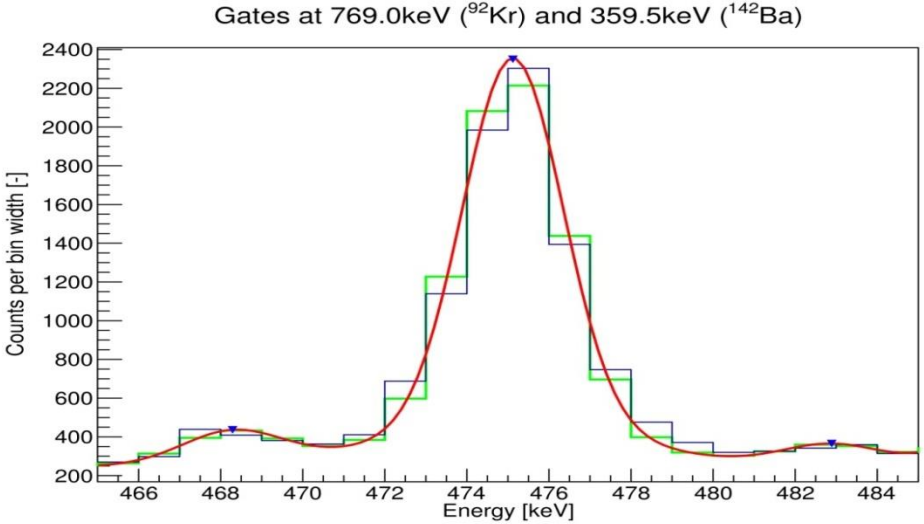




SPECTRA FITTING PROBLEMS - PEAK/BACKGROUND

- Better value of the peak/background ratio

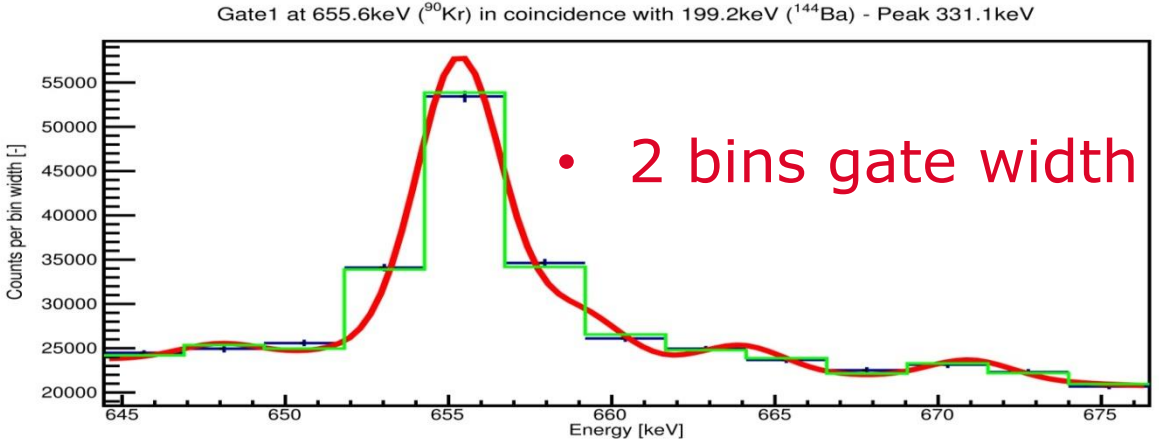




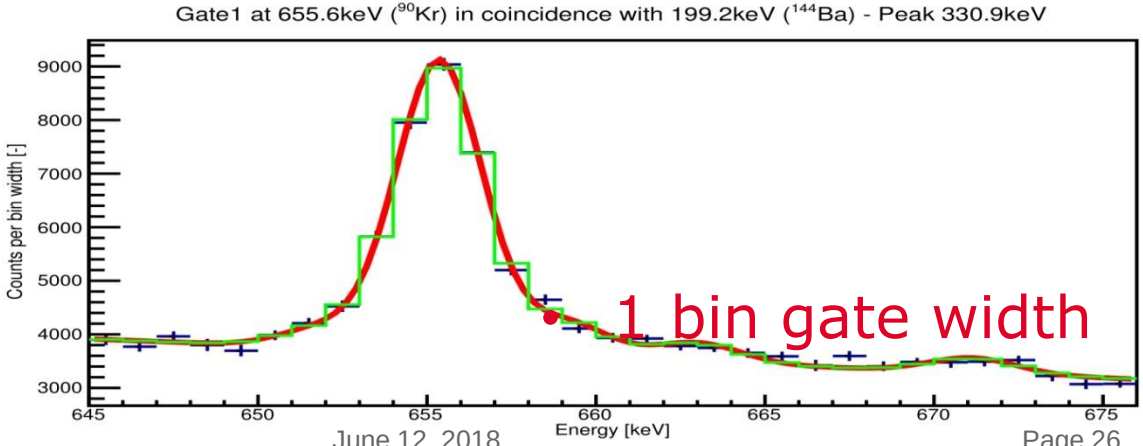
- 2 bins gate width
- 1 bin gate width

SPECTRA FITTING PROBLEMS - CONTAMINATION

- Better visibility of contaminants
- More precise contamination positioning
- More precise results
- Lower uncertainty

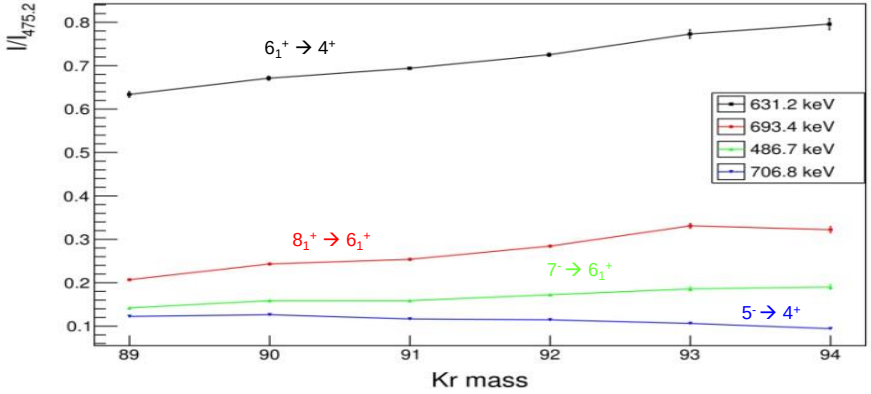


- 2 bins gate width



1 bin gate width

- Dependence on a complementary fragment (neutron evaporation)



FIFRELIN simulated transition intensities in ^{142}Ba

- EFFECT CAUSED BY DEPENDENCE BETWEEN EXCITATION ENERGY AND LEVEL DENSITY
- MORE EVAPORATED NEUTRONS

↓

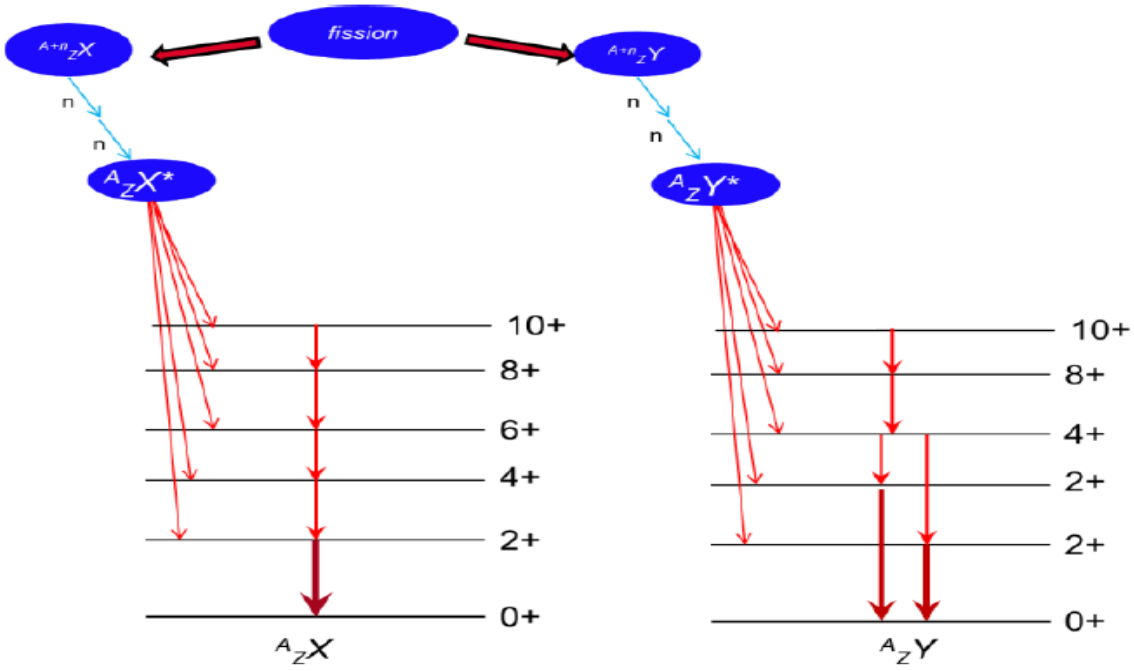
- LOWER EXCITATION ENERGY OF THE FISSION FRAGMENTS AFTER NEUTRON EVAPORATION

↓

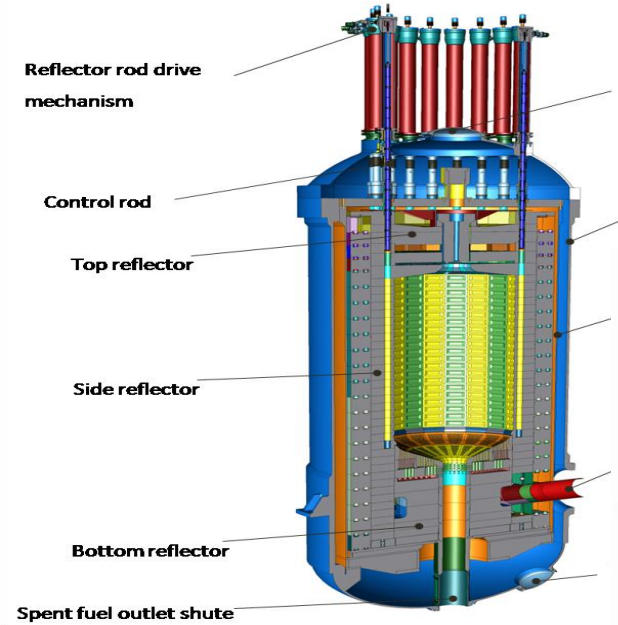
- LOWER PROBABILITY OF HIGH-SPIN TRANSITION PRODUCTION

TRIPLE-γ COINCIDENCE

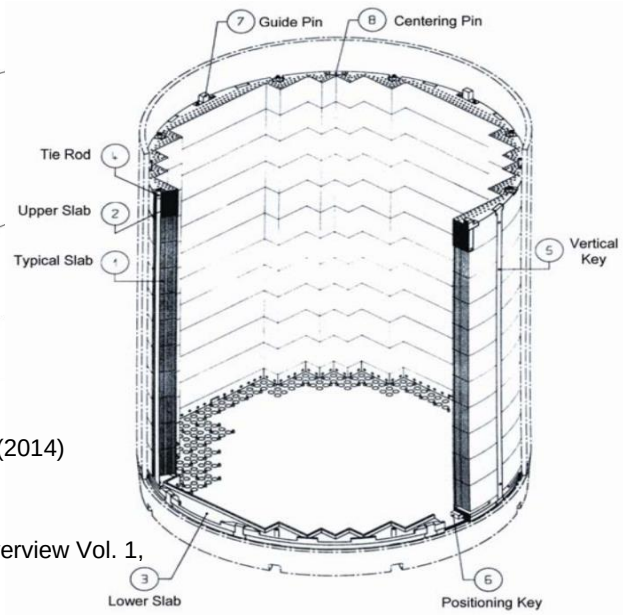
- Three-dimensional histogram → γγγ-cube
- Fixed time window
- Transitions coming within the time window limit are considered to be in coincidence



GAMMA HEATING PROCESS IN A NUCLEAR REACTOR

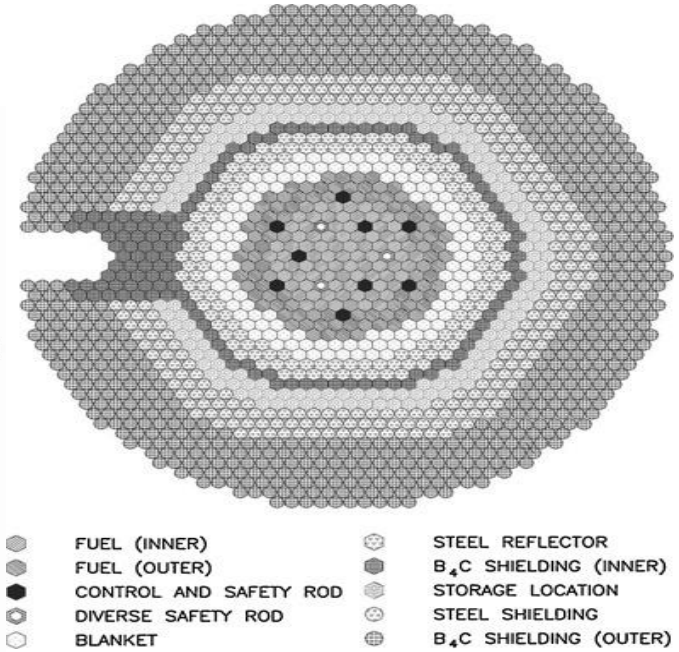


HTMR Asia Development Limited, http://www.htmr-asia.com/en/product.php?id=27 (2014)



Areva , UK-EPR, Fundamental safety overview Vol. 1, Chapter A, Page 63

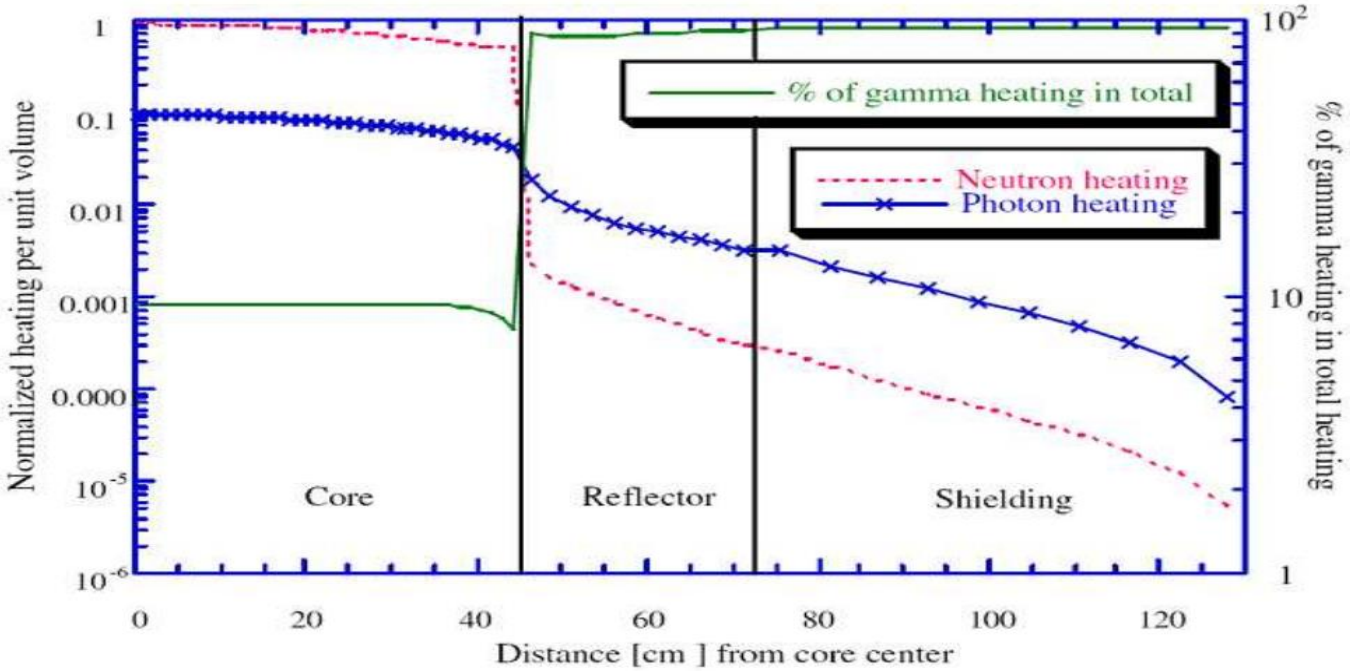
- Result of the gamma-ray energy deposition



S. Sen et al., Nuclear Engineering and Design Vol. 293, Pages 323-329 (2015)

GAMMA HEATING PROCESS IN A NUCLEAR REACTOR

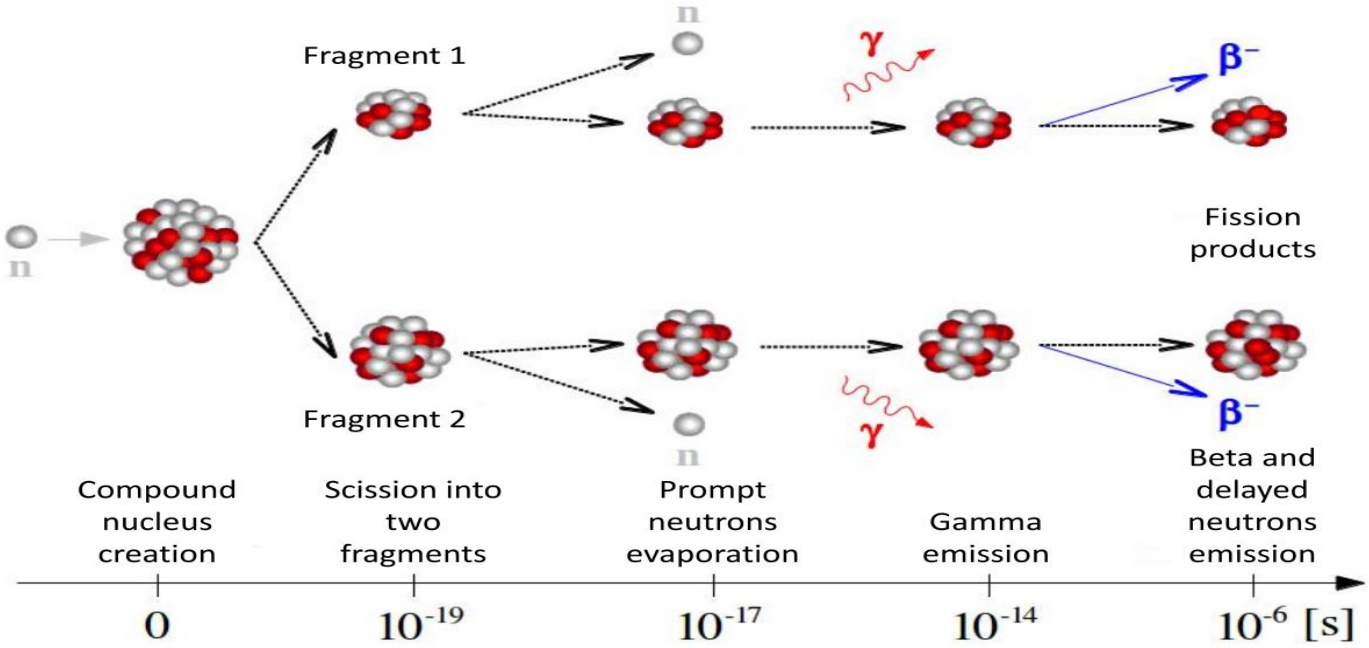
- Almost 100% of total heating in the reflector



A-C. Colombier et al., EPJ Web of Conferences 42, 04001 (2013)

What we want to study:

- FISSION PROCESS
-



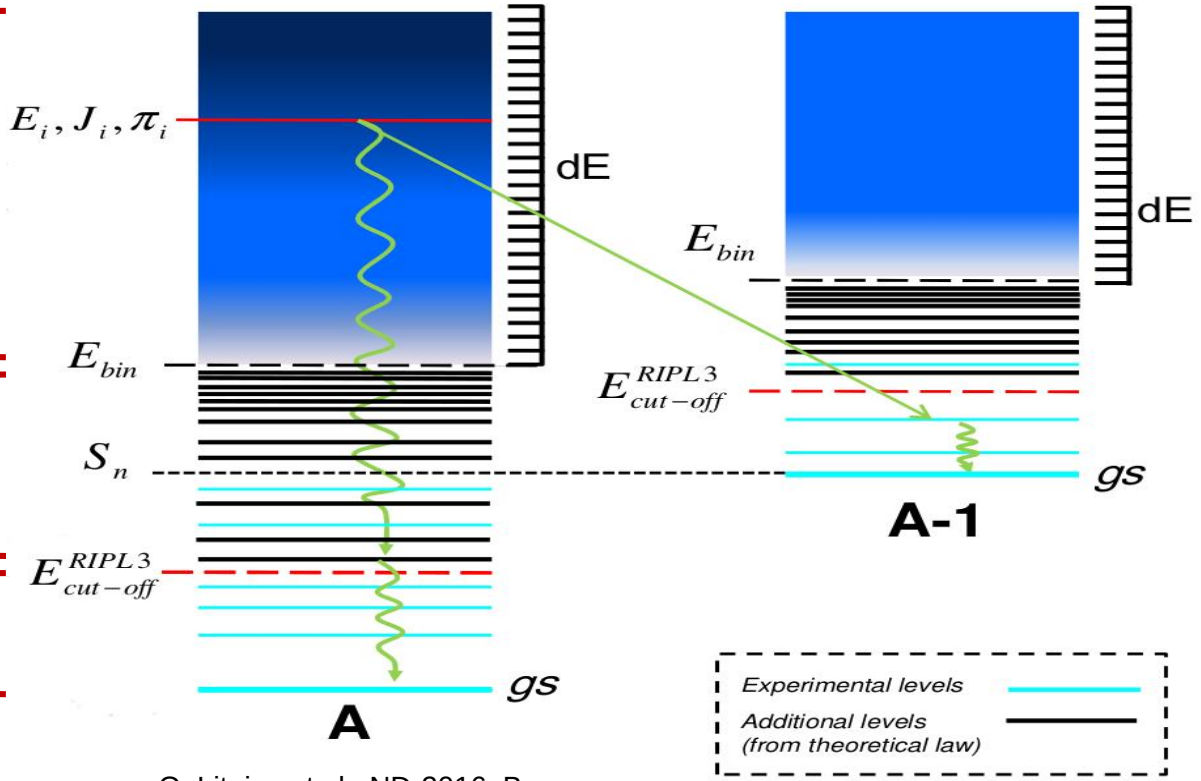
Courtesy of J.F. Lemaître, SPhN, IRFU, DRF, CEA Saclay

PROMPT GAMMA-RAY CASCADE

The continuum

The part partially completed from the models

The experimental nuclear levels



O. Litaize et al., ND-2016, Bruges

FISSION FRAGMENT DE-EXCITATION

Simulation code

FIFRELIN
- Fission Models
- Nuclear structure models
- De-excitation models
- Databases

Observables

Neutrons and prompt gamma-rays spectra and multiplicity

Post-neutron yields, released energy

Gamma-ray cascades in the fragments

Results useful for simulation of:
- Residual power
- Gamma-heating
- Radiation embrittlement of reactor vessel

Main questions concerning de-excitation process:

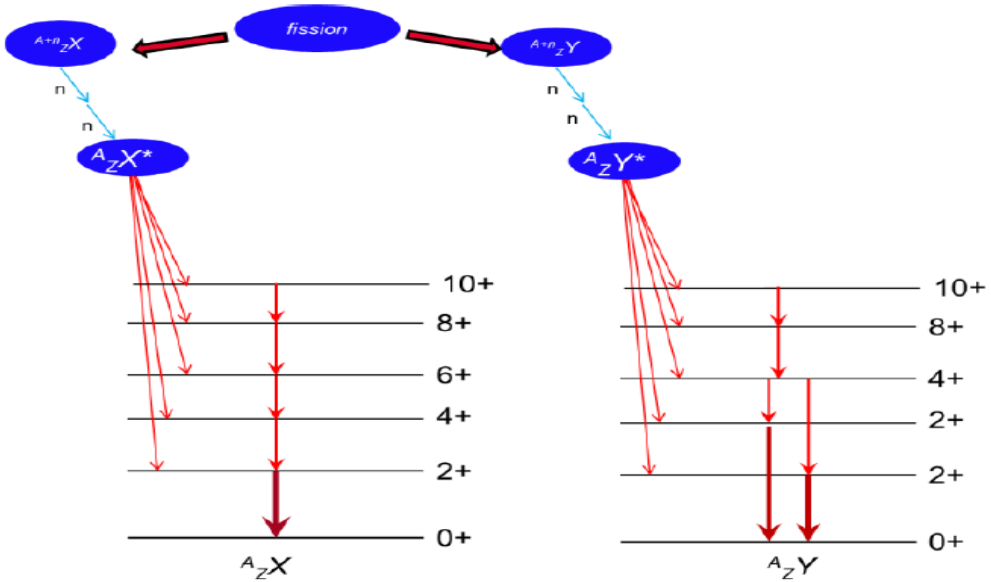
What happens after the scission point?

How is the excitation energy shared between the two fragments?

What are the initial spin distributions?

Are they correlated?

What is the process that generates high spin in the fragment?



Data preprocessing - Triple-γ coincidence

- Three-dimensional histogram → γγγ-cube

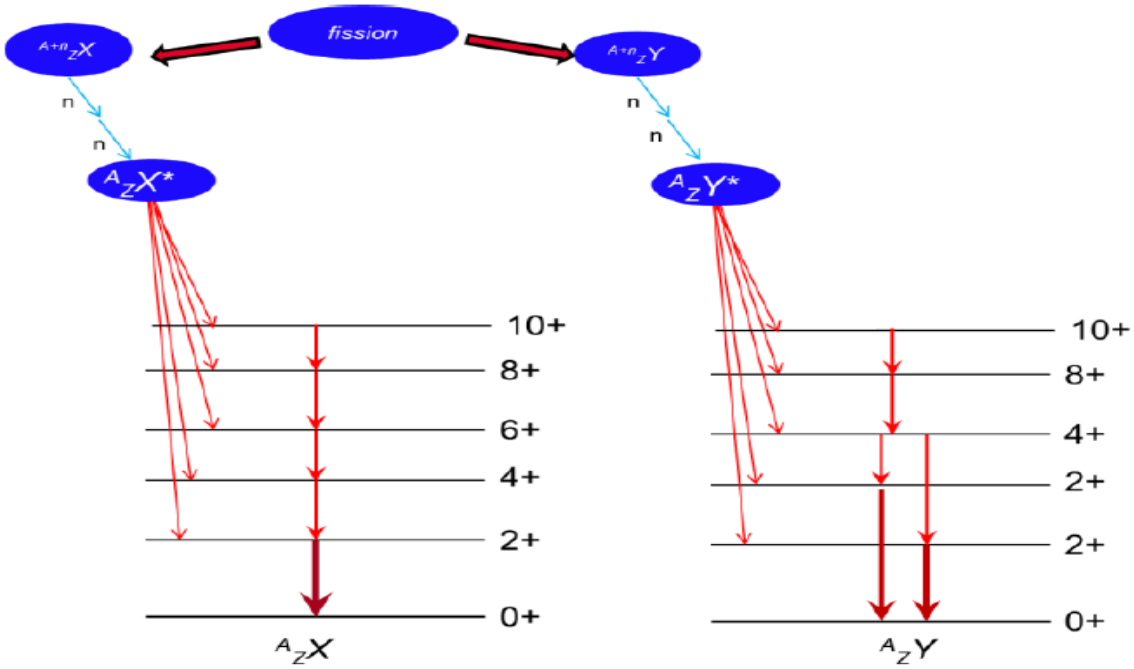
- Time shift correction for all Ge crystals
- Energy calibration of all Ge crystals (run after run)
- Coincidence time window
  - Fixed to 200ns

- Cube created in Poland at Warsaw University
  - Time needed: 6 to 12 months

- Gating process

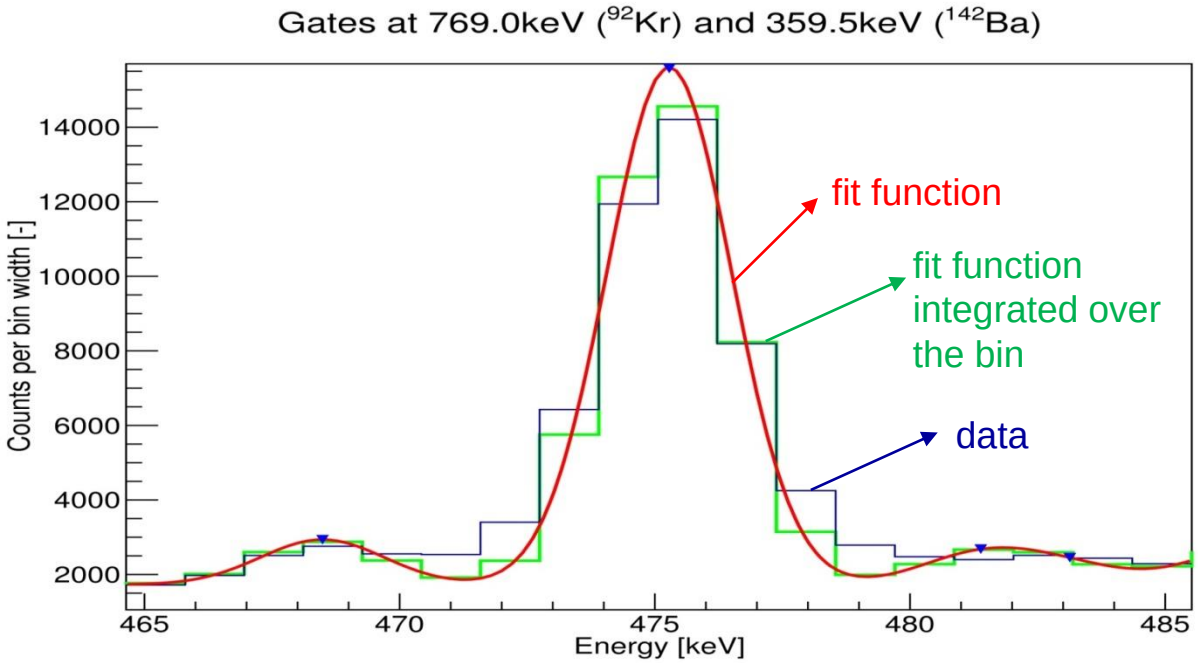
  - SELECTING TRANSITION OF A PARTICULAR ENERGY

  - SELECTING FISSION FRAGMENTS



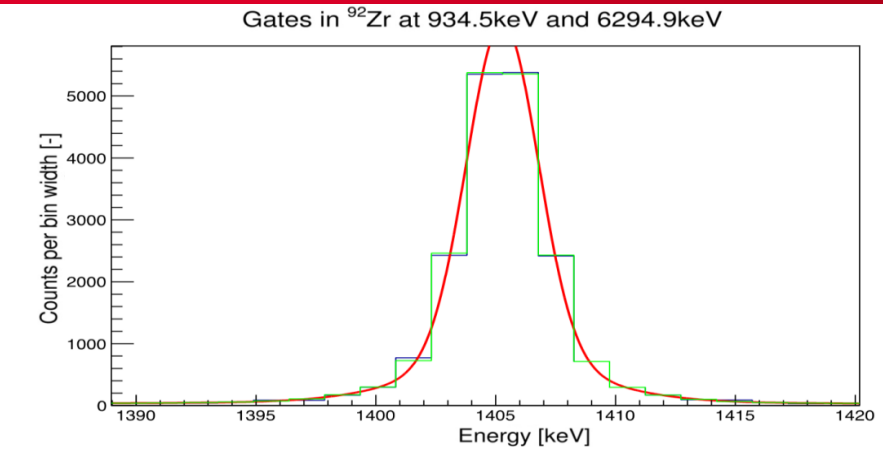
SPECTRA FITTING PROBLEMS - PEAK SHAPE

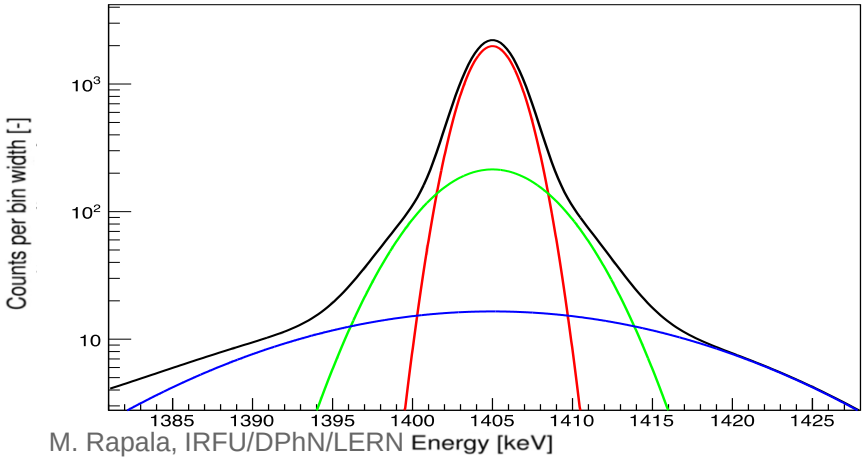
- Simple Gaussian



- Bad resolution
  - SUM OF ALL DETECTORS
  - SUM OF ALL RUNS
  - COMPTON – TAILS

EXILL RESOLUTION

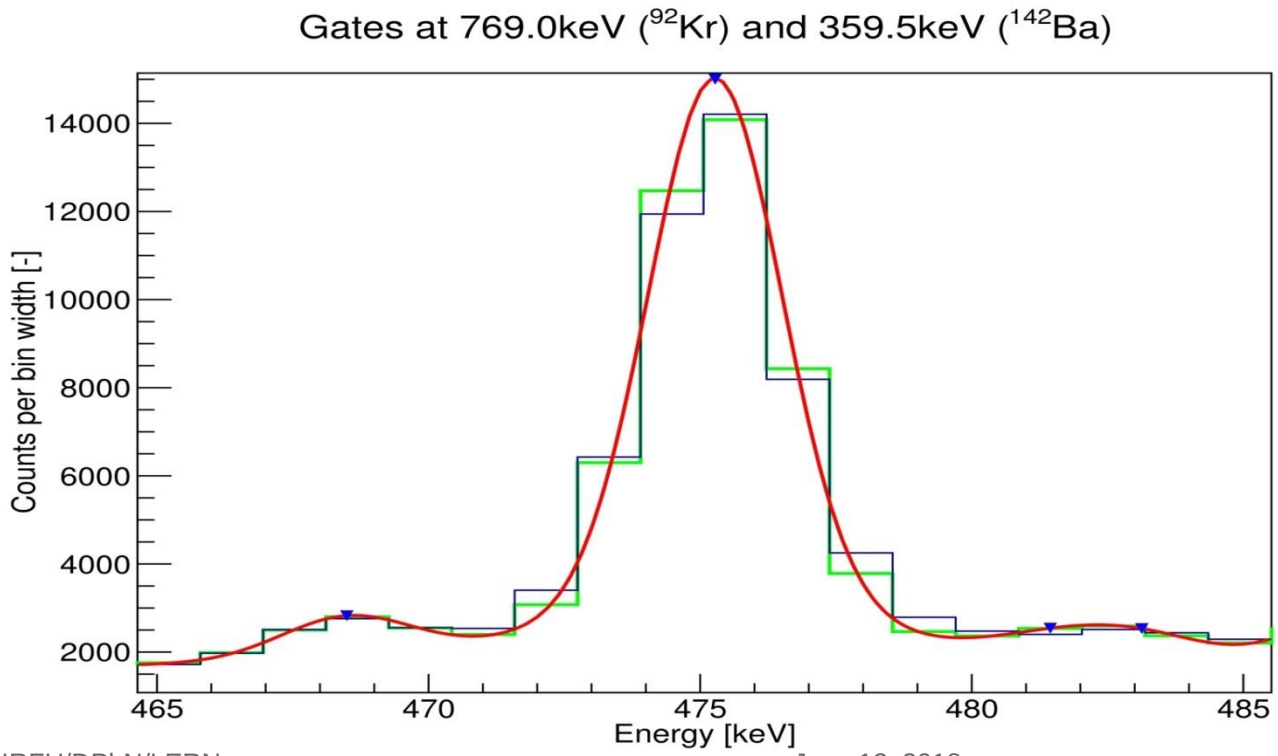




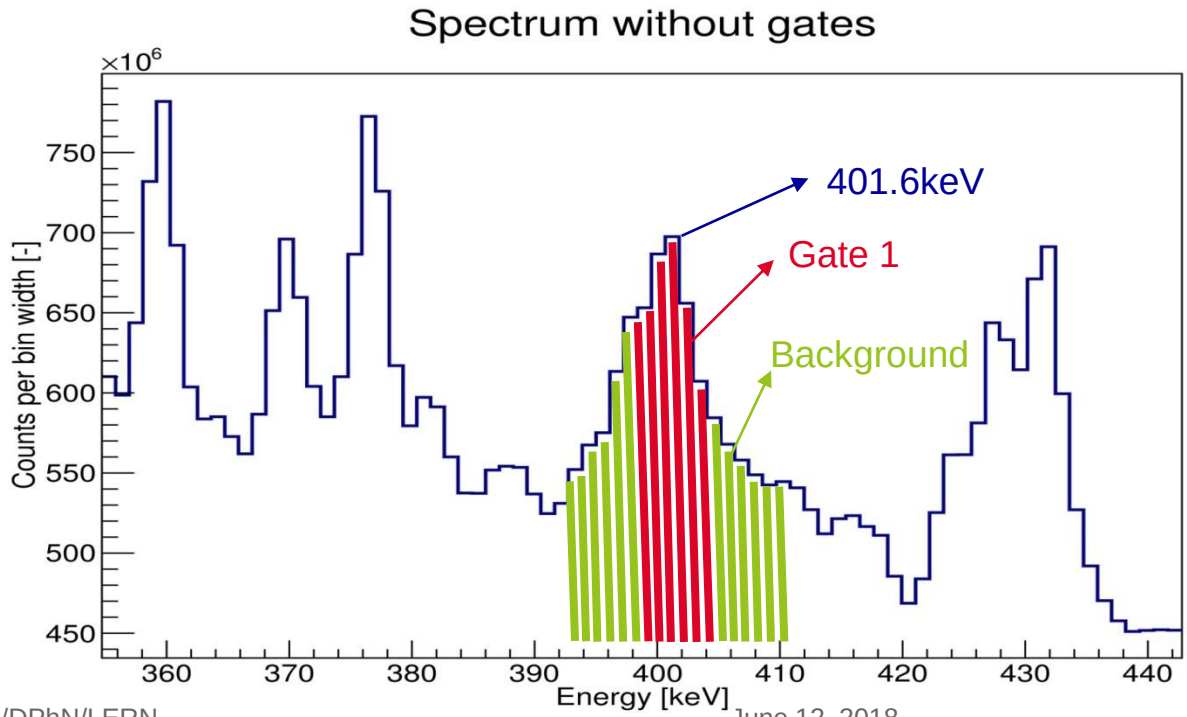
- ^{91}Zr(n,γ), ^{92}Zr(n,γ)
  - Adjusted on ^{92}Zr and ^{93}Zr clean peaks
- Fit function
  - Sum of 3 Gaussians
    - Same center
  - Compton – tails

SPECTRA FITTING PROBLEMS - PEAK SHAPE

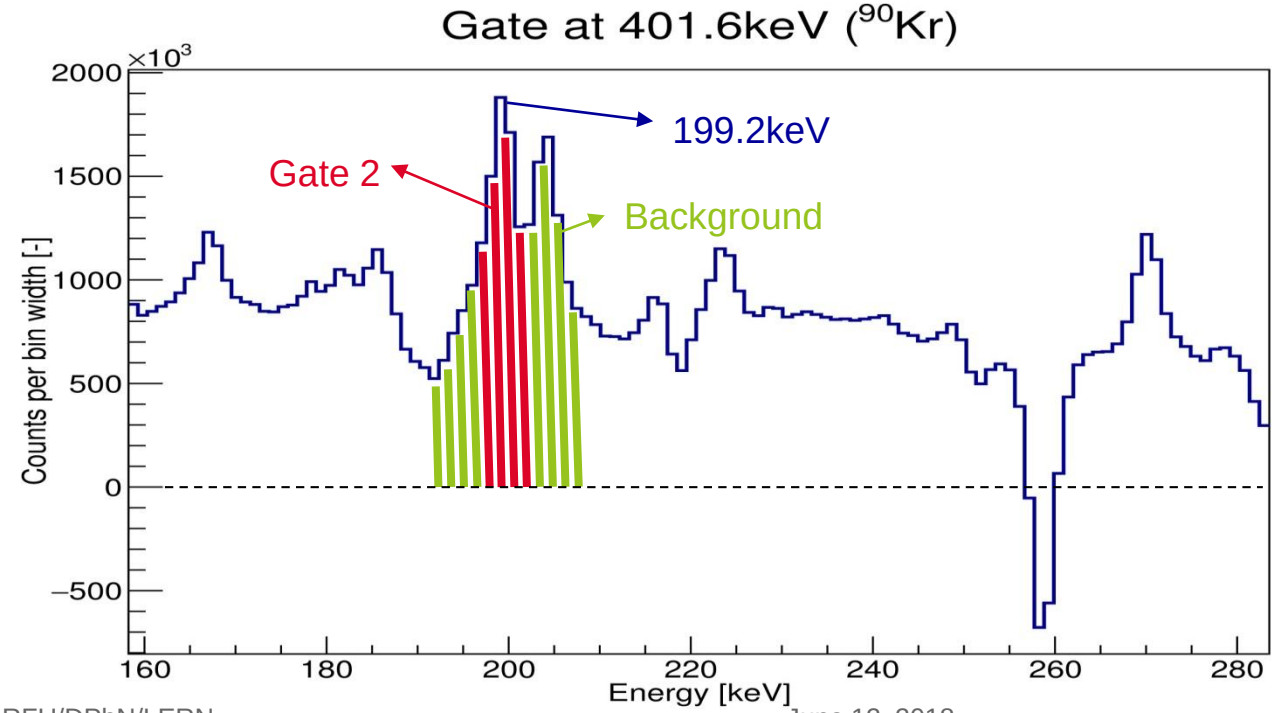
- Triple Gaussian + Compton tails



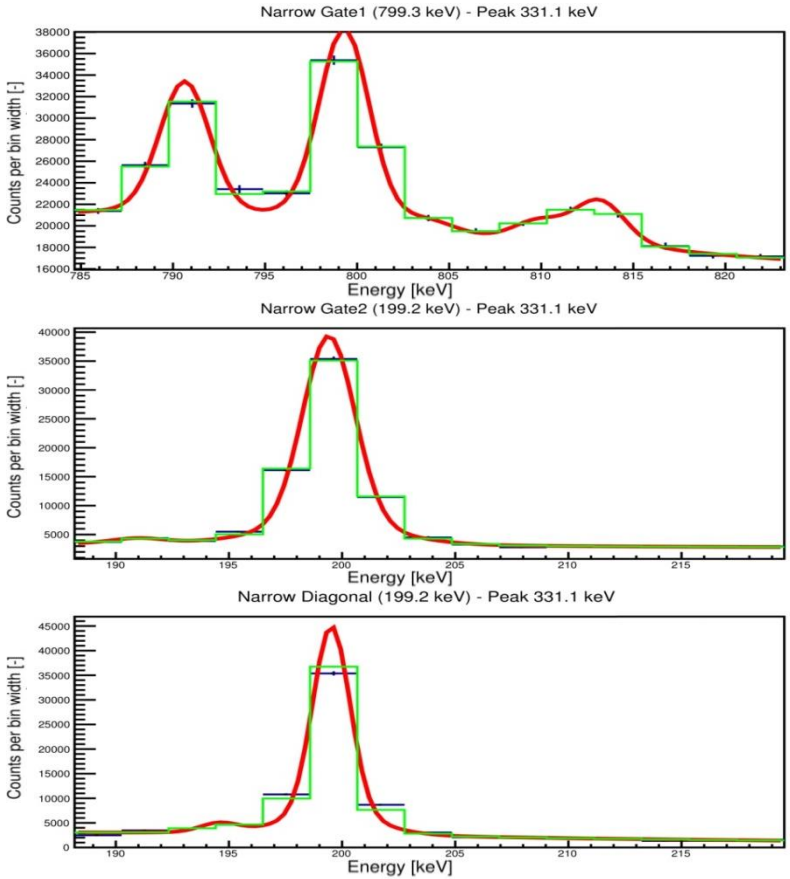
- Gating with subtracted background
  - GATE BACKGROUND CLOSE TO THE PEAK

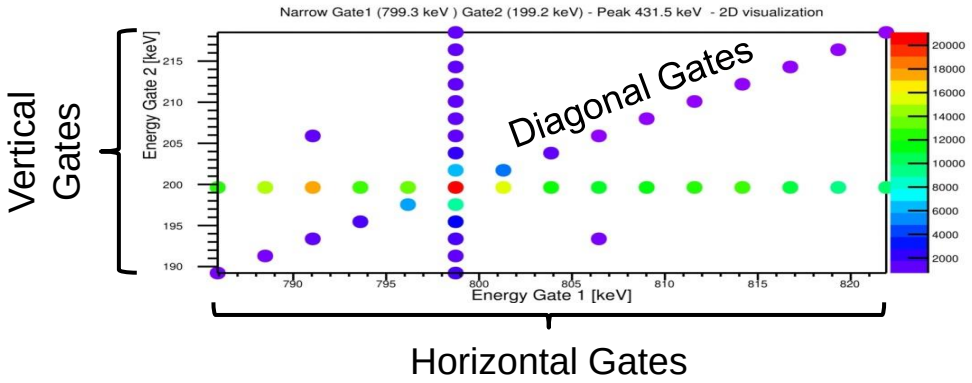


- Gating with subtracted background
  - GATE BACKGROUND CLOSE TO THE PEAK



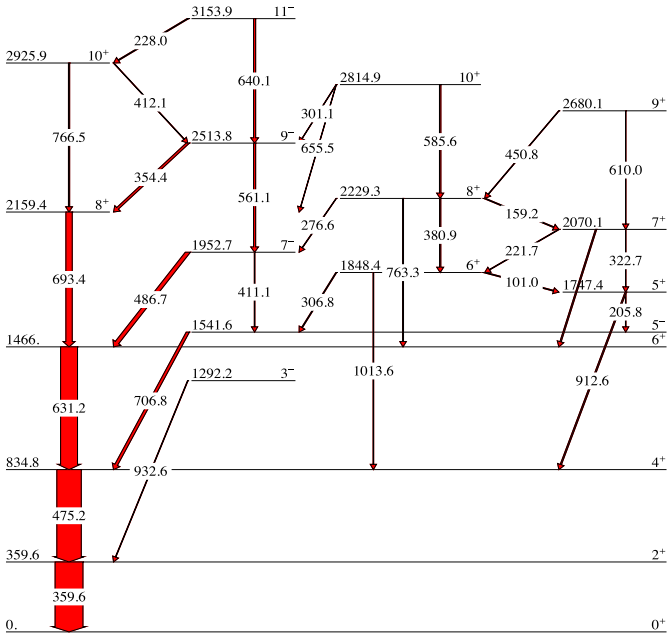
ANALYSIS PROCEDURE





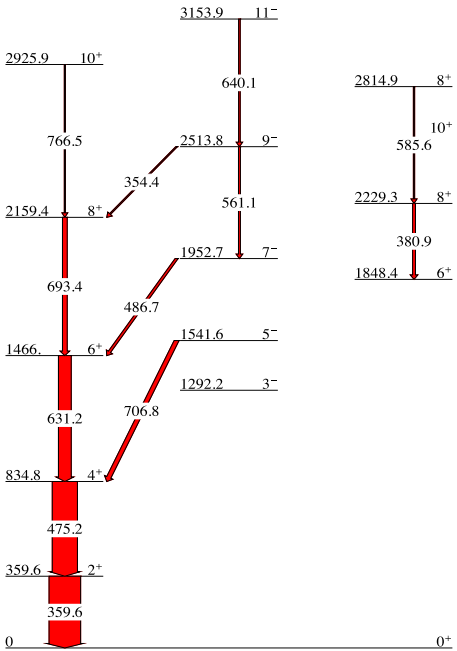
- Fitted background
- Precise contamination identification and removal
- Reproducible results

- Gamma-ray cascade



Gamma-ray cascade in ^{142}Ba according to FIFRELIN

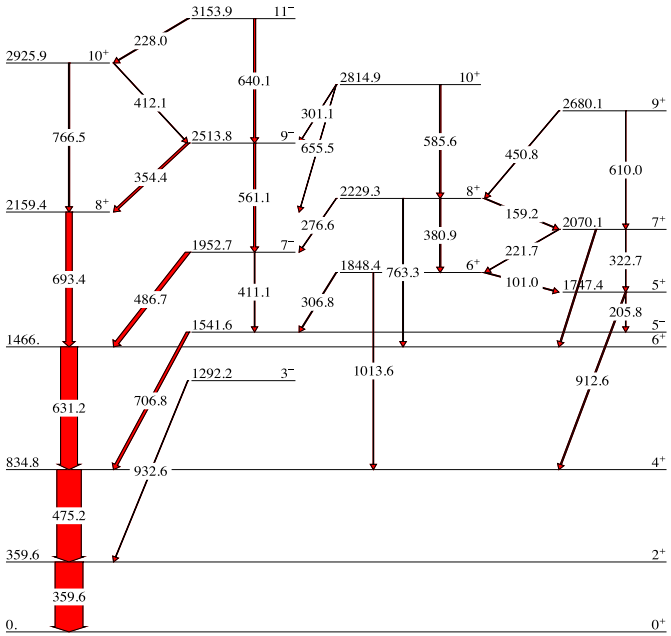
T. Materna et al., accepted for publ. In EPJ Web of Conferences (2017)



Gamma-ray cascade in ^{142}Ba according to EXILL data

T. Materna et al., accepted for publ. In EPJ Web of Conferences (2017)

- Gamma-ray cascade



Gamma-ray cascade in ^{142}Ba according to FIFRELIN

E (keV)	J1→J2	I_γ EXILL*	FIFR.**	Ratio(**/*)
359.6	$2^+\rightarrow0^+$	100 (3)	100.0 (1)	1.00 (3)
475.2	$4^+\rightarrow2^+$	80 (2)	91.4 (2)	1.14 (3)
631.2	$6^+\rightarrow4^+$	42 (2)	66.3 (1)	1.58 (8)
693.4	$8^+\rightarrow6^+$	12 (1)	26.0 (1)	2.2 (2)
766.5	$10^+\rightarrow8^+$	2.4 (7)	3.60 (3)	1.5 (4)
706.8	$5^-\rightarrow4^+$	10 (1)	10.17 (5)	1.0 (1)
486.7	$7^-\rightarrow6^+$	8 (1)	15.60 (6)	1.9 (2)
354.4	$9^-\rightarrow8^+$	4.4 (5)	8.40 (4)	1.9 (2)
561.1	$9^-\rightarrow7^-$	4.0 (5)	7.52 (4)	1.9 (2)
640.1	$11^-\rightarrow9^-$	2 (1)	6.22 (3)	3 (2)
380.9	$8^+\rightarrow6^+$	4.0 (6)	5.06 (3)	1.3 (2)
585.6	$10^+\rightarrow8^+$	4 (1)	5.66 (3)	1.4 (4)

T. Materna et al., accepted for publ. In EPJ Web of Conferences (2017)

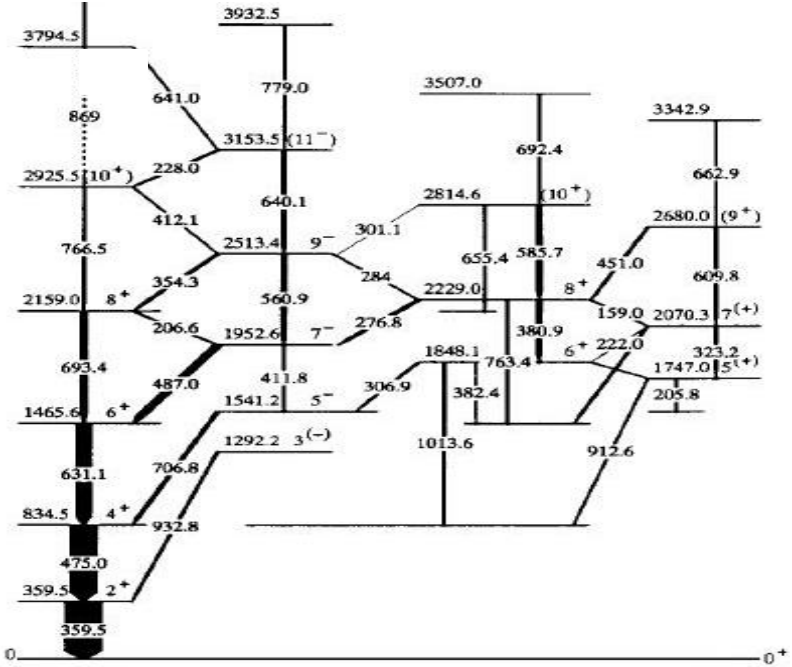
PRELIMINARY RESULTS

- Gamma-ray cascade
  - GOOD AGREEMENT FOR LOW SPIN TRANSITIONS
  - HIGH SPIN TRANSITIONS OVERESTIMATED BY FIFRELIN CODE
  - PROBABLY WRONG ESTIMATION OF A MEAN VALUE OF THE FISSION FRAGMENT SPIN DISTRIBUTION

E (keV)	J1→J2	I_γ		
		EXILL*	FIFR.**	Ratio(**/*)
359.6	$2^+ \rightarrow 0^+$	100 (3)	100.0 (1)	1.00 (3)
475.2	$4^+ \rightarrow 2^+$	80 (2)	91.4 (2)	1.14 (3)
631.2	$6^+ \rightarrow 4^+$	42 (2)	66.3 (1)	1.58 (8)
693.4	$8^+ \rightarrow 6^+$	12 (1)	26.0 (1)	2.2 (2)
766.5	$10^+ \rightarrow 8^+$	2.4 (7)	3.60 (3)	1.5 (4)
706.8	$5^- \rightarrow 4^+$	10 (1)	10.17 (5)	1.0 (1)
486.7	$7^- \rightarrow 6^+$	8 (1)	15.60 (6)	1.9 (2)
354.4	$9^- \rightarrow 8^+$	4.4 (5)	8.40 (4)	1.9 (2)
561.1	$9^- \rightarrow 7^-$	4.0 (5)	7.52 (4)	1.9 (2)
640.1	$11^- \rightarrow 9^-$	2 (1)	6.22 (3)	3 (2)
380.9	$8^+ \rightarrow 6^+$	4.0 (6)	5.06 (3)	1.3 (2)
585.6	$10^+ \rightarrow 8^+$	4 (1)	5.66 (3)	1.4 (4)

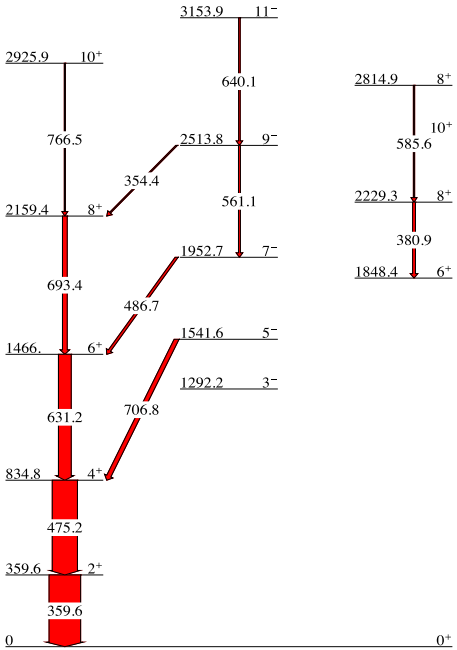
PRELIMINARY RESULTS

- Gamma-ray cascade



Gamma-ray cascade in ^{142}Ba according to ^{248}Cm data

Urban et al., Nucl. Phys A 613 (1997) 107



Gamma-ray cascade in ^{142}Ba according to EXILL data

T. Materna et al., accepted for publ. In EPJ Web of Conferences (2017)

- Gamma-ray cascade

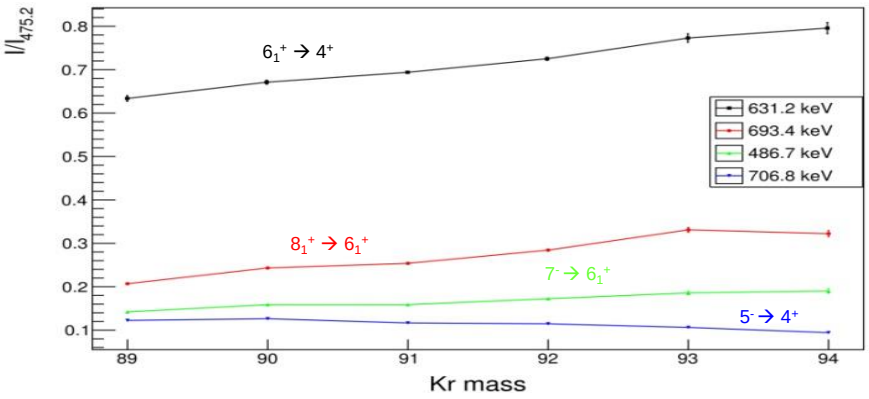
  - TRANSITION INTENSITY VALUES VERY CLOSE ESPECIALLY IN GROUND STATE BAND

  - PROBABLY INITIAL SPINS OF THE PRIMARY FISSION FRAGMENTS IN BOTH SYSTEMS ARE SIMILAR

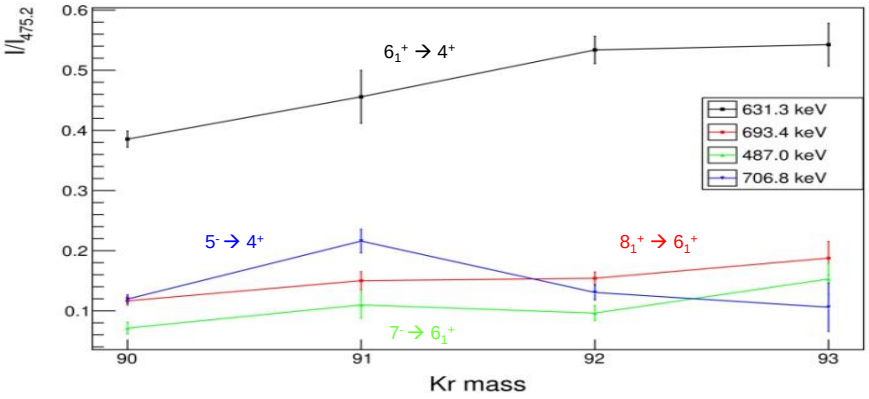
E (keV)	J1→J2	I_γ		
		EXILL*	^{248}Cm**	Ratio(**/*)
359.6	$2^+ \rightarrow 0^+$	100 (3)	100 (5)	1.00 (6)
475.2	$4^+ \rightarrow 2^+$	80 (2)	85 (5)	1.06 (7)
631.2	$6^+ \rightarrow 4^+$	42 (2)	40 (3)	0.95 (8)
693.4	$8^+ \rightarrow 6^+$	12 (1)	13 (2)	1.1 (2)
766.5	$10^+ \rightarrow 8^+$	2.4 (7)	2.3 (3)	0.9 (3)
706.8	$5^- \rightarrow 4^+$	10 (1)	6.0 (6)	0.60 (8)
486.7	$7^- \rightarrow 6^+$	8 (1)	18 (2)	2.2 (4)
354.4	$9^- \rightarrow 8^+$	4.4 (5)	5.1 (4)	1.2 (2)
561.1	$9^- \rightarrow 7^-$	4.0 (5)	4.5 (4)	1.1 (2)
640.1	$11^- \rightarrow 9^-$	2 (1)	5 (1)	2 (1)
380.9	$8^+ \rightarrow 6^+$	4.0 (6)	6.5 (8)	1.6 (3)
585.6	$10^+ \rightarrow 8^+$	4 (1)	5.5 (5)	1.4 (4)

PRELIMINARY RESULTS

- Dependence on a complementary fragment (neutron evaporation)

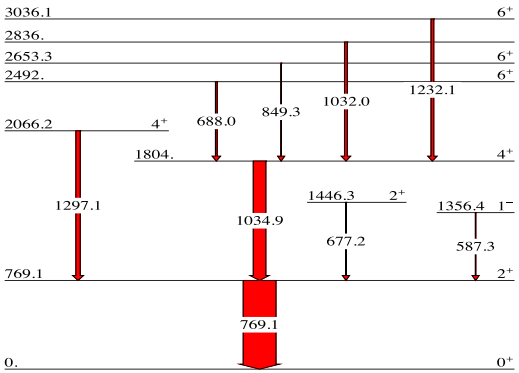


FIFRELIN simulated transition intensities in ^{142}Ba



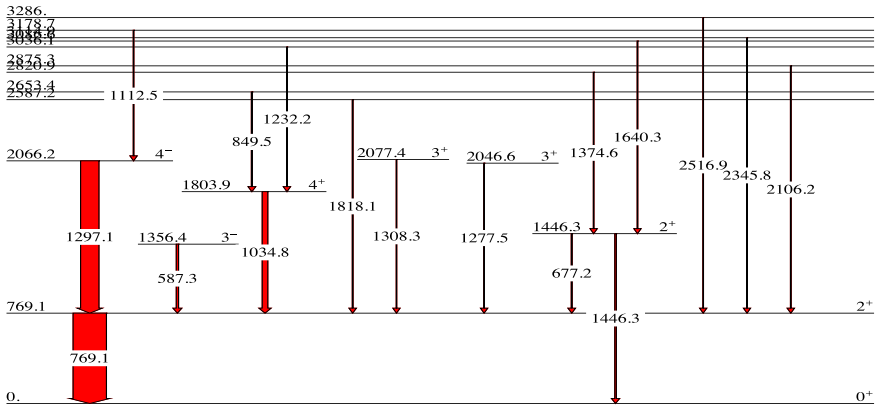
EXILL data transition intensities in ^{142}Ba

PRELIMINARY RESULTS



Gamma-ray cascade in ^{92}Kr according to EXILL data

(in coincidence with ^{142}Ba)
T. Materna et al., accepted for publ. In EPJ Web of Conferences (2017)

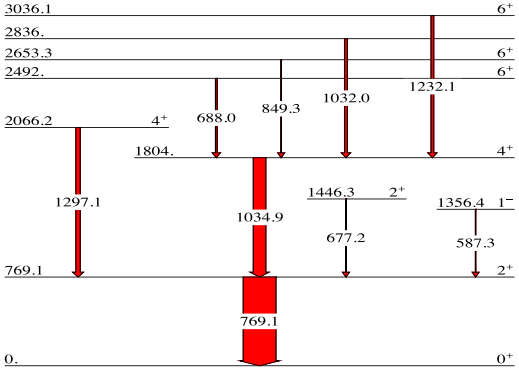


Gamma-ray cascade in ^{92}Kr according to FIFRELIN

(old RIPL-3 version, without low intensity transitions, in coincidence with ^{142}Ba)

PRELIMINARY RESULTS

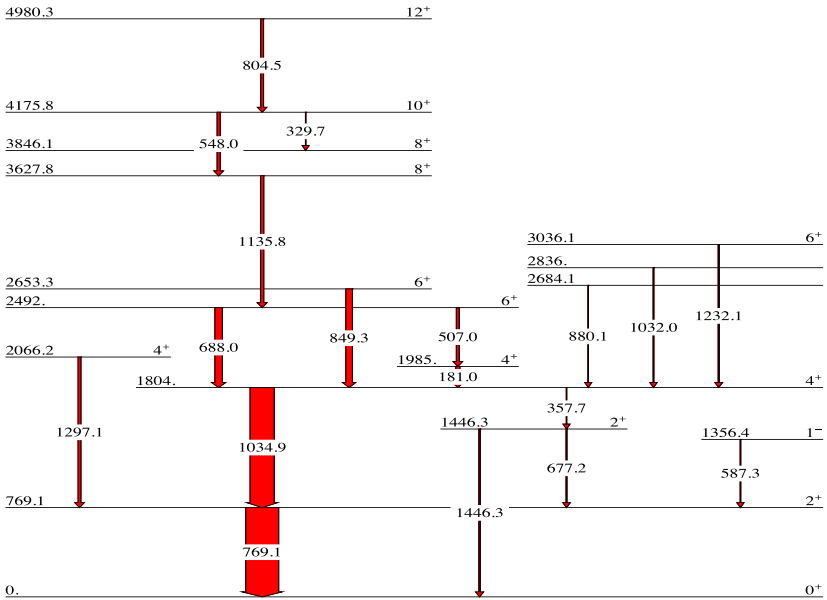
- RIPL-3 update
- Strong dependence of the FIFRELIN simulation output on spin values



Gamma-ray cascade in **^{92}Kr** according to **EXILL** data

(in coincidence with ^{142}Ba)

T. Materna et al., accepted for publ. In EPJ Web of Conferences (2017)



Gamma-ray cascade in **^{92}Kr** according to **FIFRELIN**

(new RIPL-3 version, without low intensity transitions,

in coincidence with ^{142}Ba)

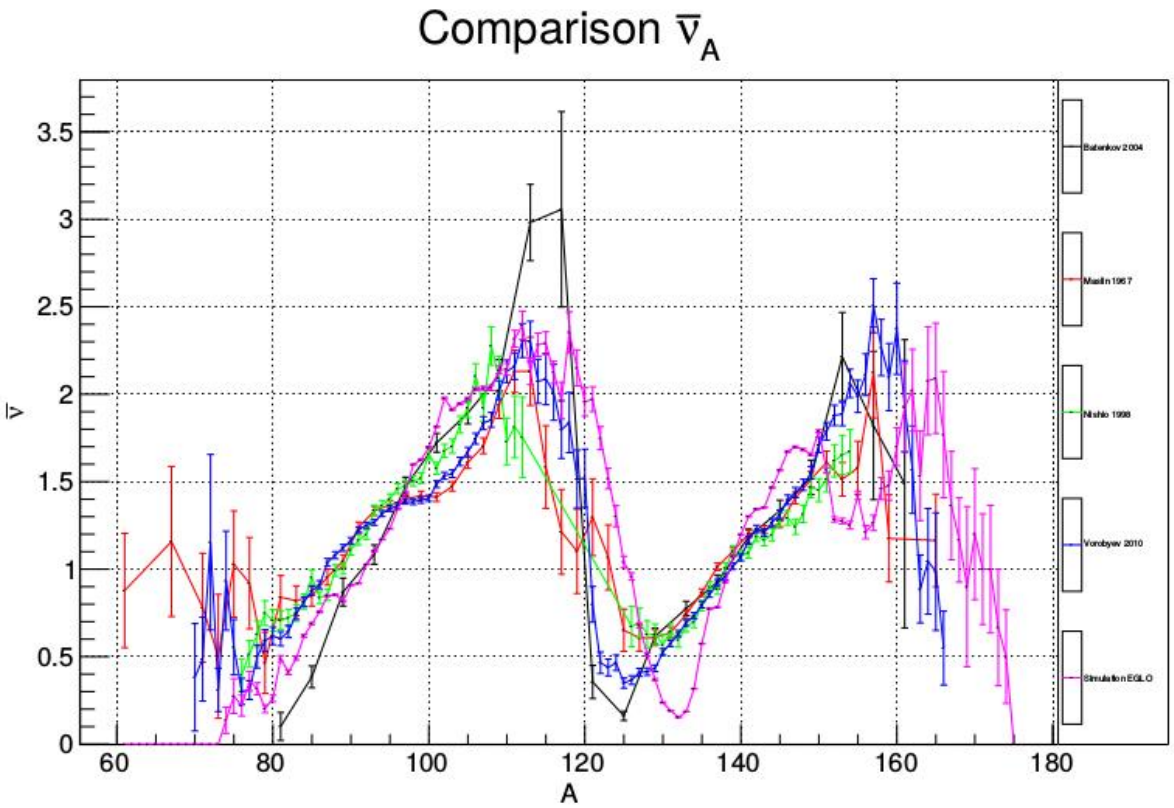
T. Materna et al., accepted for publ. In EPJ Web of Conferences (2017)

FIFRELIN SIMULATION - SPIN

- Simulations validity criterion:
  - AVERAGE PROMPT-NEUTRON MULTIPLICITY

$$\overline{\nu_L} = 1.41$$
$$\overline{\nu_H} = 1.01$$
$$\overline{\nu_T} = 2.42$$

- σ_L, σ_H (CONSTANT) or f_σ (BSFGM)

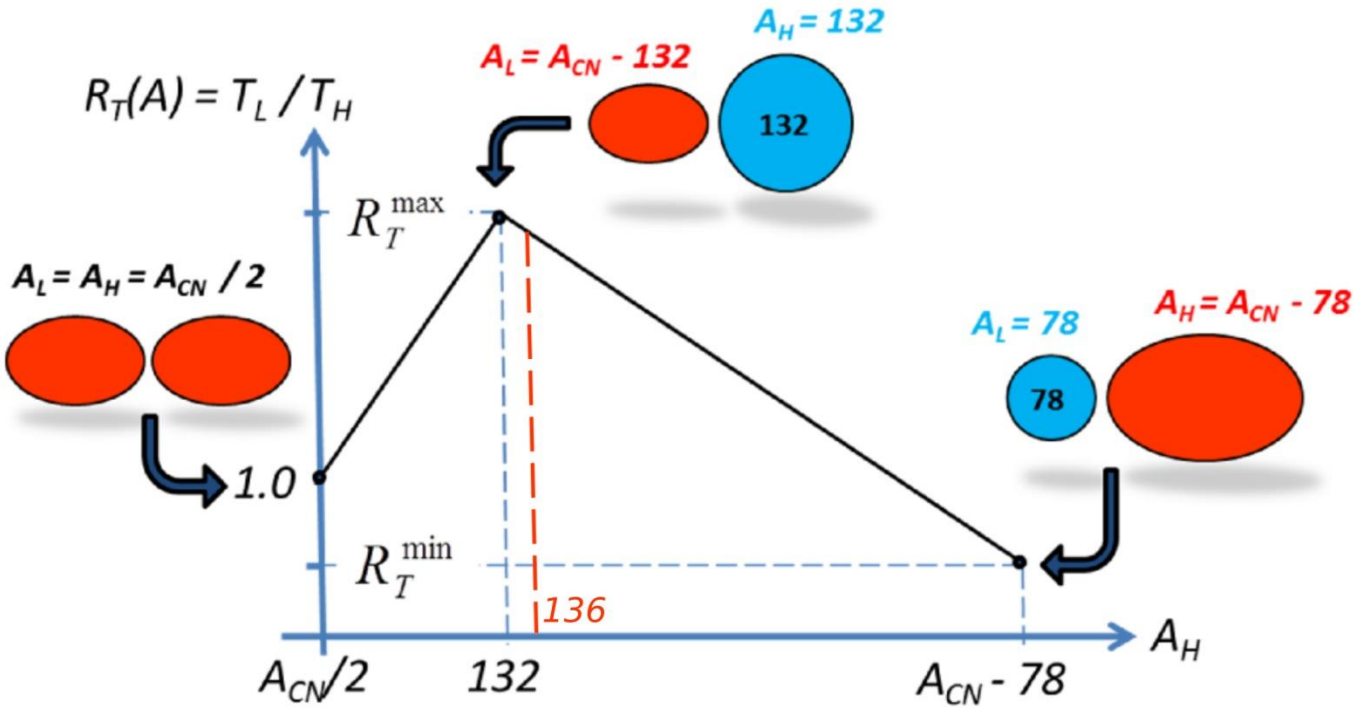


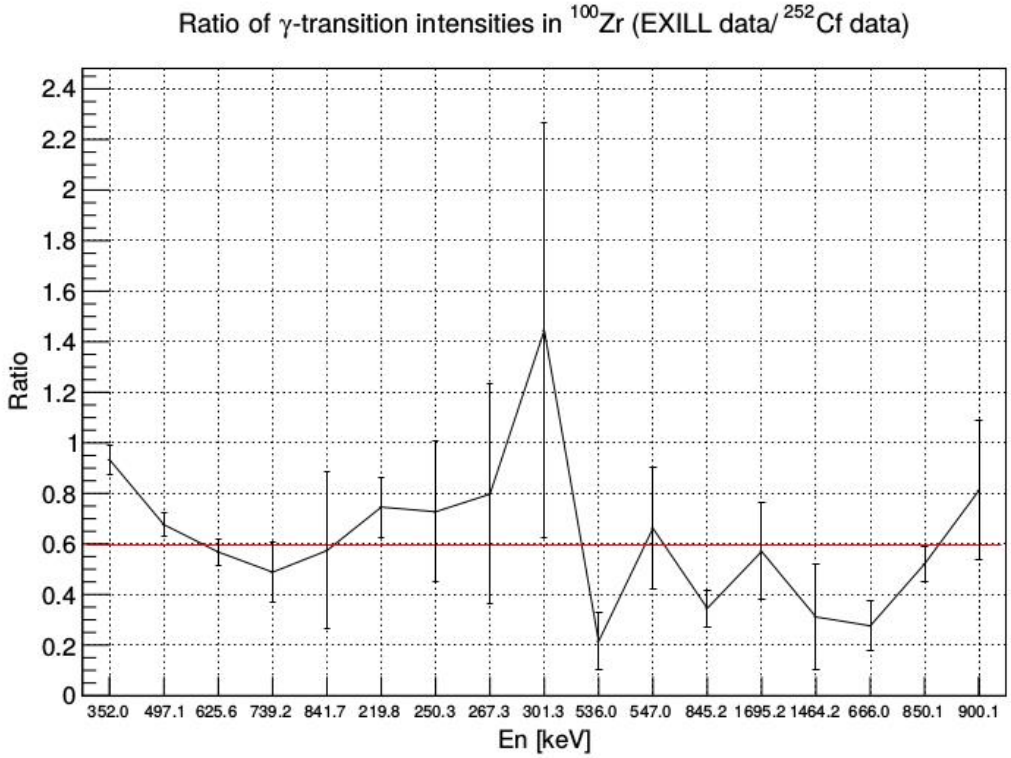
FIFRELIN SIMULATION – EXCITATION ENERGY

- Free parameters:
  - R_T^{min}
  - R_T^{max}

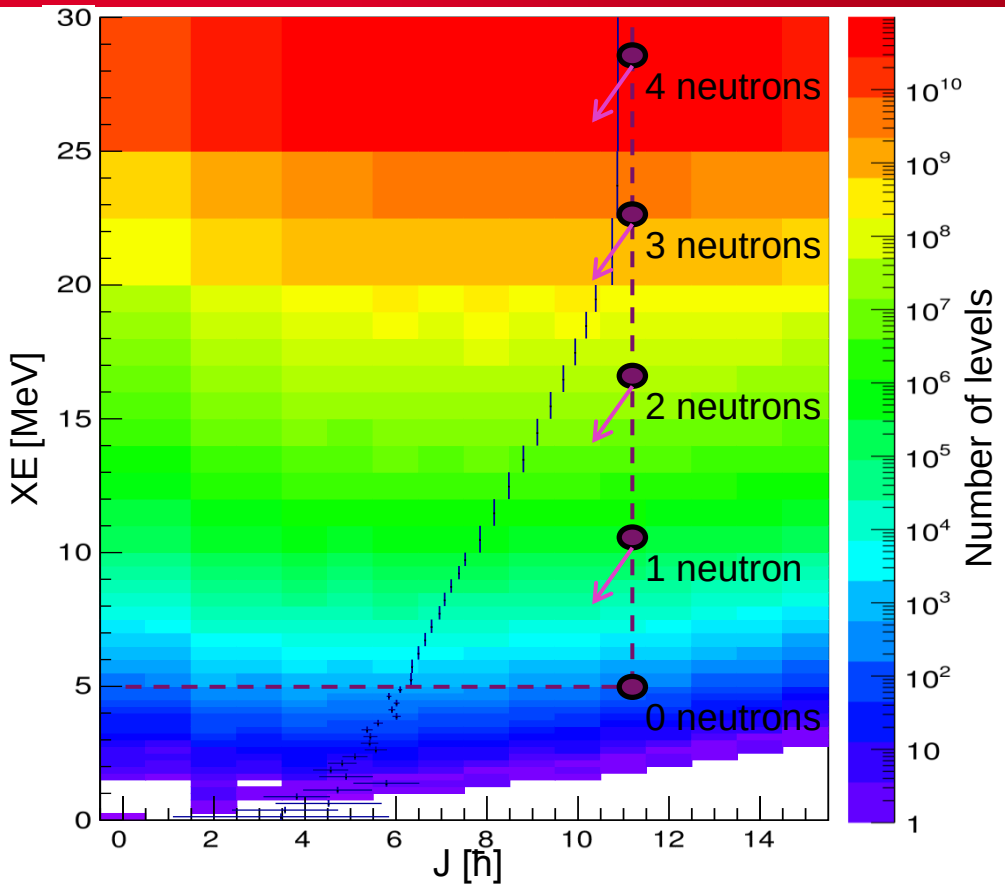
$$E^* = aT^2$$

$$XE_L = E_L^* + E_L^{rot}$$




Ratio of γ-transition intensities in 100Zr (EXILL data/ 252Cf data)
Ratio
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
352.0
497.1
625.6
739.2
841.7
219.8
250.3
267.3
301.3
536.0
547.0
845.2
1695.2
1464.2
666.0
850.1
900.1
En [keV]

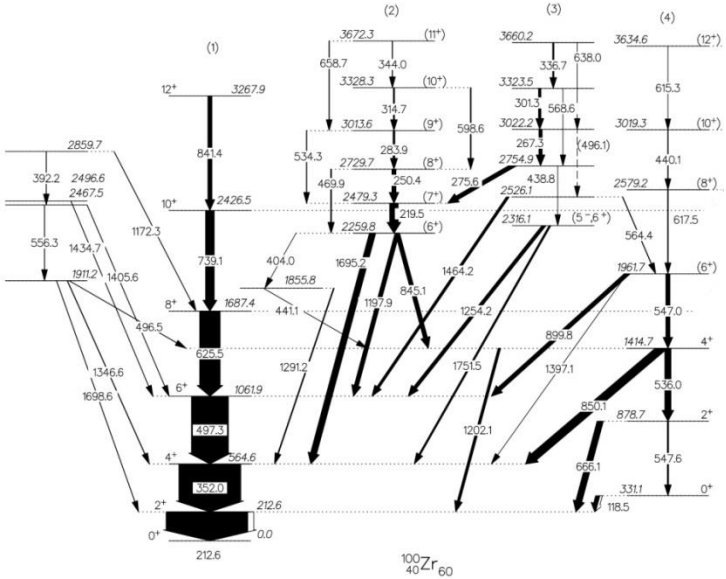
CONSTANT SPIN CUTOFF MODEL BEHAVIOR



- In CONSTANT model initial spin is unchanged
- Neutron evaporation follows the mean level density

RESULTS: COMPARISON WITH SPONTANEOUS FISSION

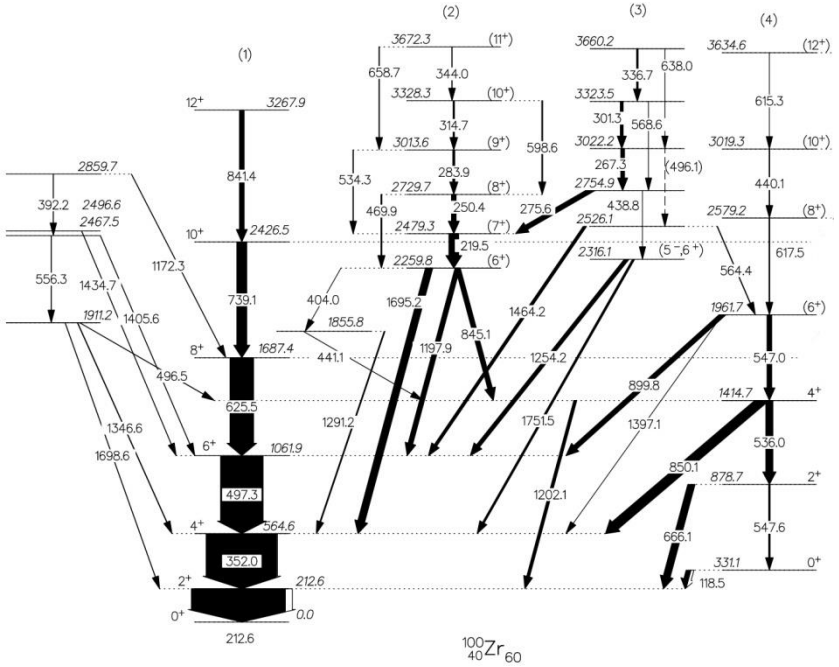
^{100}Zr



- ^{248}Cm – good agreement
- ^{252}Cf – discrepancy

E (keV)	J1→J2	I_γ		
		^{235}U(n_{th},f) (this work)	^{252}Cf	^{248}Cm
212.5	$2^+\to0^+$	100	100	100
352.0	$4^+\to2^+$	78(3)	84(4)	81(8)
497.1	$6^+\to4^+$	44(2)	65(3)	49(5)
625.6	$8^+\to6^+$	15(1)	26(1)	14(3)
739.2	$10^+\to8^+$	2.5(6)	5.2(3)	4(1)
841.7	$12^+\to10^+$	1.2(5)	2.1(6)	
219.8	$7^+\to6^+$	4.1(6)	5.5(3)	
250.3	$8^+\to7^+$	1.8(4)	2.4(7)	
267.3		0.8(4)	1.0(3)	
301.3		1.2(6)	0.8(2)	
536.0	$4^+\to2^+$	1.5(8)	6.8(3)	
547.0	$6^+\to4^+$	2.0(4)	3.0(9)	
845.2	$6^+\to4^+$	3.0(6)	8.8(4)	
1695.2	$6^+\to4^+$	2.8(4)	5(1)	
665.98	$2^+\to2^+$	1.9(7)	7.0(4)	
850.1	$4^+\to4^+$	5.0(6)	9.5(5)	

RESULTS - DIFFERENT SPIN CUTOFF MODELS



- The main band
  - TOO HIGH INTENSITIES

E (keV)	J1→J2	I_γ		
		EXILL	CONSTANT	BSFGM
212.5	$2^+\to0^+$	100	100	100
352.0	$4^+\to2^+$	78(3)	82(1)	88(1)
497.1	$6^+\to4^+$	44(2)	62.5(8)	80(1)
625.6	$8^+\to6^+$	15(1)	34.8(6)	50.8(7)
739.2	$10^+\to8^+$	2.5(6)	17.2(4)	21.8(4)
841.7	$12^+\to10^+$	1.2(5)	6.5(2)	5.7(2)
219.8	$7^+\to6^+$	4.1(6)	2.0(1)	2.7(1)
250.3	$8^+\to7^+$	1.8(4)	1.12(9)	1.9(1)
267.3		0.8(4)	0.27(4)	0.18(4)
301.3		1.2(6)	0.10(3)	0.10(3)
536.0	$4^+\to2^+$	1.5(8)	1.5(1)	0.91(8)
547.0	$6^+\to4^+$	2.0(4)	0.55(6)	0.34(5)
845.2	$6^+\to4^+$	3.0(6)	1.3(1)	1.7(1)
1695.2	$6^+\to4^+$	2.8(4)	0.85(8)	0.88(8)
665.98	$2^+\to2^+$	1.9(7)	2.6(1)	1.7(1)
850.1	$4^+\to4^+$	5.0(6)	1.9(1)	1.4(1)

PRELIMINARY RESULTS

- Scanning R_T^{min} and R_T^{max}
- Too high $\overline{\nu_T} \approx 2.7$

- Single element testing
  - PROMPT-NEUTRON MULTIPLICITY OF ^{100}ZR (1.4÷1.65)

- Valid $\overline{\nu_{Zr}}$
  - LOW $R_T^{max} = 1.00$

E (keV)	J1→J2	I_γ		
		EXILL	$\overline{\nu_{Zr}} = 1.78$	$\overline{\nu_{Zr}} = 1.49$
212.5	$2^+ \to 0^+$	100	100	100
352.0	$4^+ \to 2^+$	78(3)	84.8(9)	86.3(9)
497.1	$6^+ \to 4^+$	44(2)	54.9(7)	57.7(7)
625.6	$8^+ \to 6^+$	15(1)	14.9(3)	14.9(3)
739.2	$10^+ \to 8^+$	2.5(6)	1.9(1)	1.61(9)
841.7	$12^+ \to 10^+$	1.2(5)	0.14(3)	0.11(2)
219.8	$7^+ \to 6^+$	4.1(6)	2.1(1)	2.2(1)
250.3	$8^+ \to 7^+$	1.8(4)	1.14(8)	1.02(8)
267.3		0.8(4)	0.11(2)	0.15(3)
301.3		1.2(6)	0.05(1)	0.07(2)
536.0	$4^+ \to 2^+$	1.5(8)	2.2(1)	2.0(1)
547.0	$6^+ \to 4^+$	2.0(4)	0.95(7)	1.14(8)
845.2	$6^+ \to 4^+$	3.0(6)	1.7(1)	1.53(9)
1695.2	$6^+ \to 4^+$	2.8(4)	0.83(7)	1.01(7)
665.98	$2^+ \to 2^+$	1.9(7)	2.3(1)	2.1(1)
850.1	$4^+ \to 4^+$	5.0(6)	2.9(1)	3.0(1)

MEASURED FISSION FRAGMENTS

- Measurement of the prompt gamma-ray cascades of the fission fragment pairs
  - ZR-TE, KR-BA, SR-XE, MO-SN
  - COMPARISON TO OTHER EXPERIMENTAL DATA
  - ^{252}Cf, ^{248}Cm