Time and energy evolution of late radiative emissions in the ^{252}Cf spontaneous fission

An experimental study on gamma rays produced from isomeric states of fragments during the spontaneous fission of ^{252}Cf with the SFγNCS detection system

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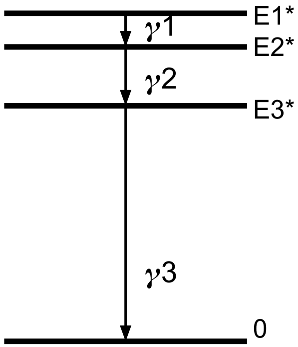
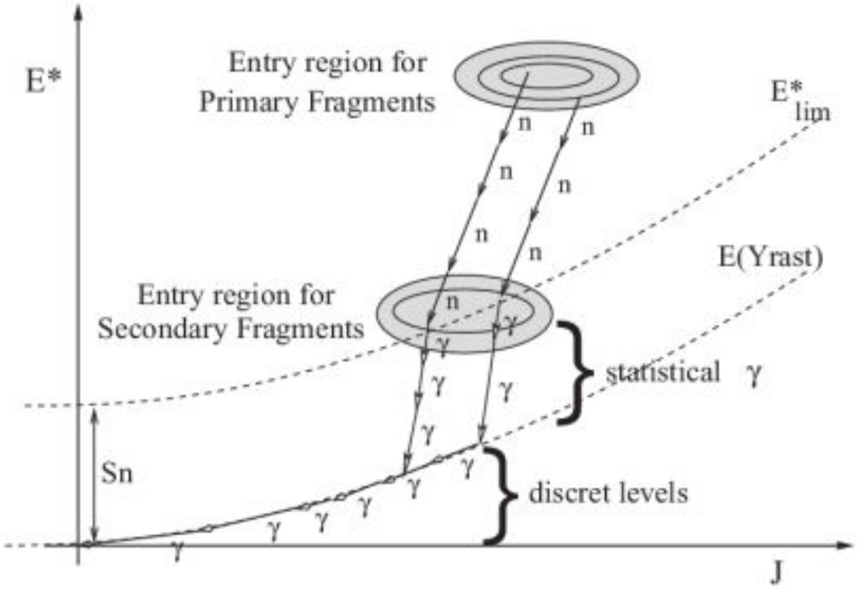
Context

During fission, the nucleus splits into two fragments.

The two fragments are produced in an excited state characterized by its excitation energy and angular momentum.

This energy and angular momentum excess is evacuated by the nuclei through neutron then photon emissions





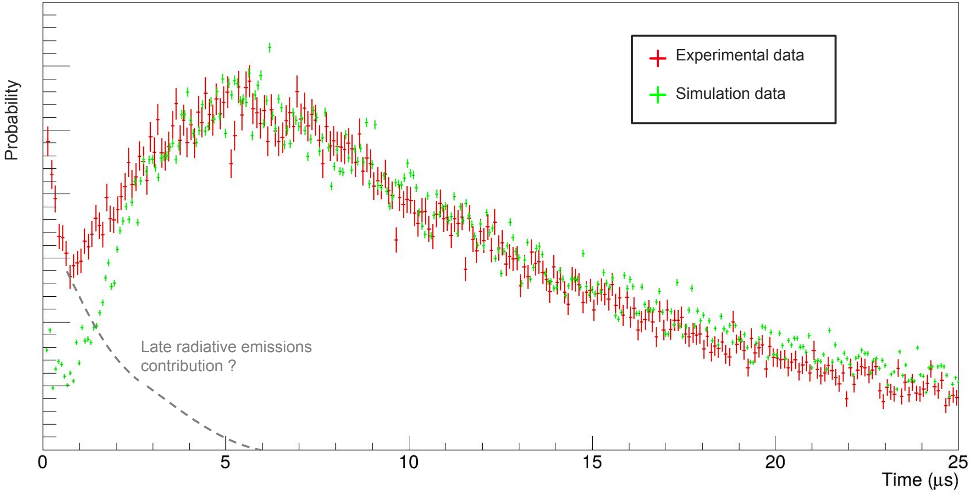
Evolution of excitation energy as a function of angular momentum

Context

^{252}Cf serves as a benchmark source for detection systems characterization and validation

Studying ^{252}Cf observables contributes to refining nuclear data evaluations and supports the design of industrial nuclear systems, particularly reactors

The average number of neutrons $\bar{\nu}$ emitted in the spontaneous fission of ^{252}Cf requires a more accurate evaluation



Neutron detection with compact devices, relying on long integration time, is strongly affected by late radiative emissions, due to neutron and photon time of flight discrimination

A precise characterization of these emissions is essential to reassess $\bar{\nu}$ value and its uncertainties

Figure 1 *: Neutron emission as a function of time since fission, measured with SCONE*

Context

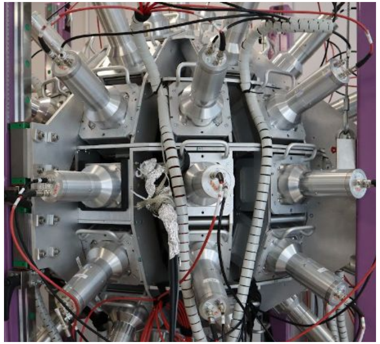


Figure 2 *: SFγNCS setup*

SFγNCS

Multi NaI scintillators spectrometer

Roig et al, NIMA 1073 (2025)

Time and energy evolution of the late radiative emissions are measured with SFγNCS, over an extended time interval

SCONE

Gd-loaded plastic scintillators
n-efficiency 78%
Bélier et al, NIMA 1072 (2025)

Late radiative emissions measurements performed with SFγNCS will be unfolded and will complement the data analysis carried out on SCONE

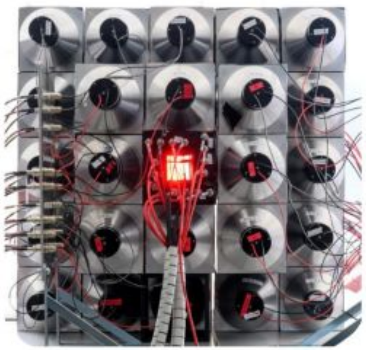


Figure 3 *: SCONE setup*

SFγNCS experimental setup

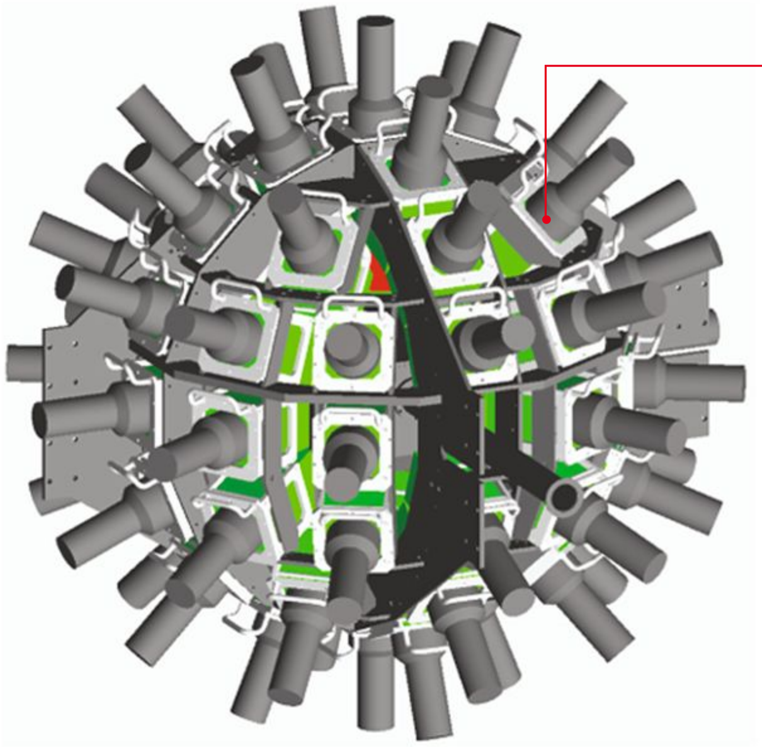


***Figure 4** : SFγNCS setup simulated using GEANT4 toolkits*

γ Strength Function for Neutron Capture Cross Sections

A multi-detector spectrometer to study the radiative de-excitation of nuclei

- 62 NaI(TI) scintillators
- Time resolution of 5 ns energy resolution of 9% (FWHM) at 662 keV
- Detectors are arranged spherically with a total solid angle of 61.27% of 4π and a radius of 28 cm

Roig et al, NIMA 1073 (2025)

Fission chamber

Two electrodes placed facing each other, surrounding a thin ^{252}Cf deposit

- Used as a trigger to start a measurement
- Discrimination between alpha and fission
- A pulser simulate a fake fission to perform background measurements

SFγNCS experimental setup

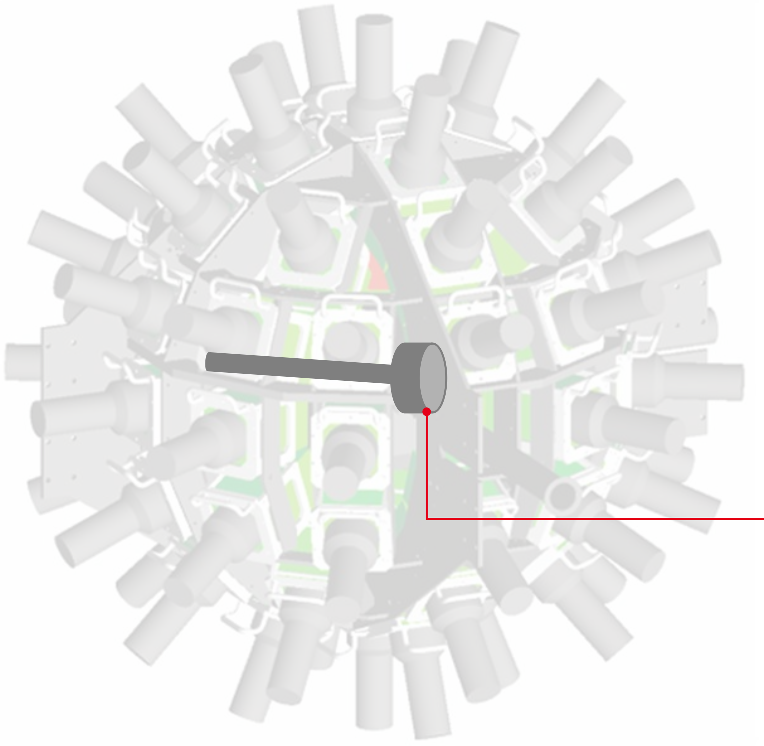


Figure 4 : *SFγNCS setup simulated using GEANT4 toolkits*

γ Strength Function for Neutron Capture Cross Sections

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Roig et al, NIMA 1073 (2025)

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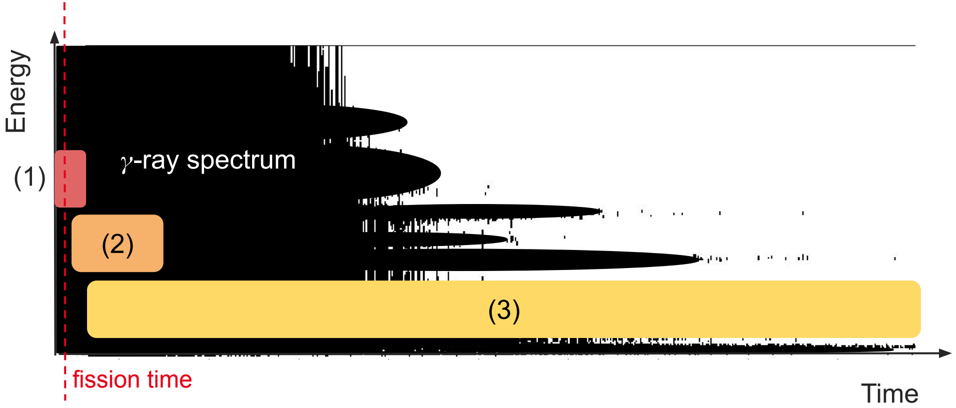
Measurement principle with SFγNCS



Time evolution of the energy spectrum is sliced in three intervals

1. **Prompt emissions and neutron activation** [-50 ns - 100 ns]
2. **Already investigated interval** [50 ns - 2 µs]
3. **Extended interval** [100 ns - 100 µs]

Analysis conditions :

Energy threshold : 100 keV

Time window : [-10µs ; 100µs]

100 000 000 fissions
(25% of data acquisition)

Prompt emission

- Neutron activation γ-rays

^{127}I (n, n'+γ)

202.92 keV	744.70 keV
417.95 keV	1044.21 keV
618.41 keV	1306.4 keV

Nucl. Data Sheets 112, 1647 (2011)

- Prompt emission

  Shows a time interval of 5 ns, corresponding to SFγNCS time resolution

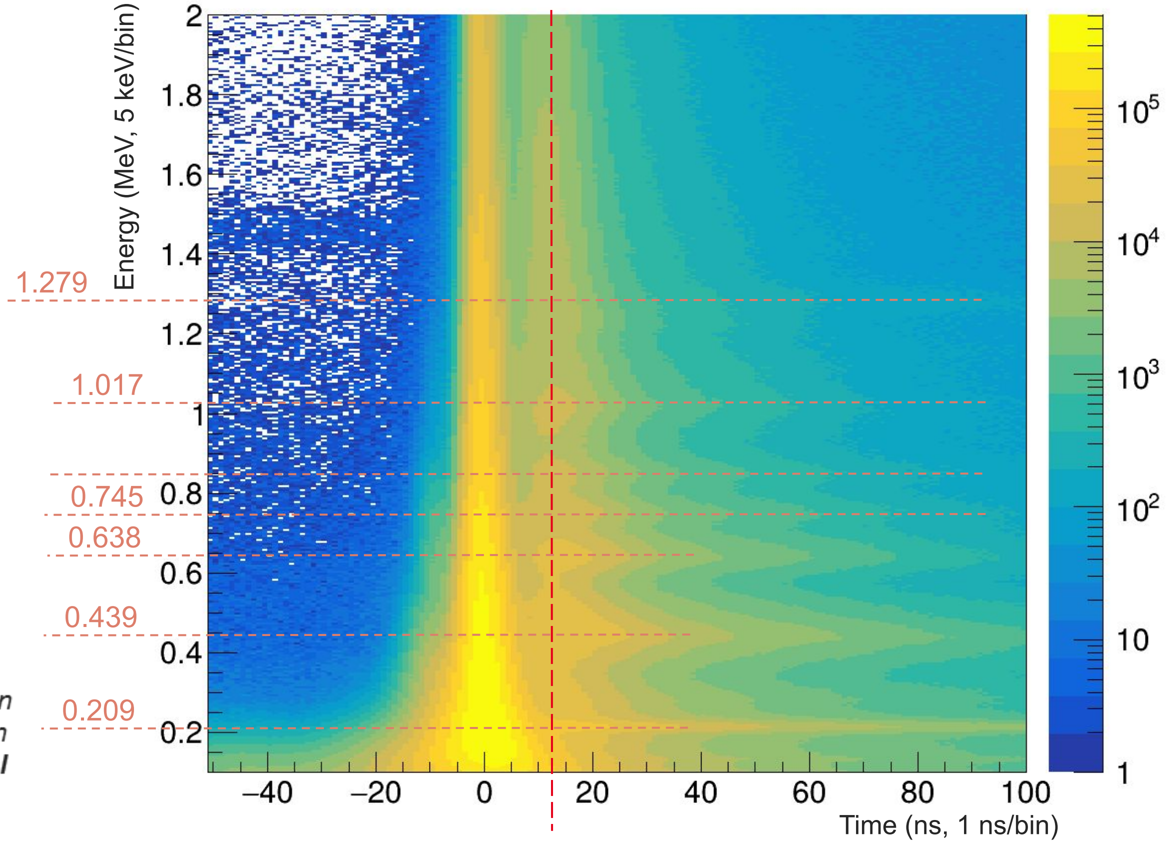


Figure 5** : γ-ray spectrum of ^{252}Cf (sf) as a function of time since fission, measured with SFγNCS, within **prompt emission and neutron activation interval

First time interval after fission (50 ns - 2 µs)

- Already measured γ-rays from ^{252}Cf spontaneous fission, identified in previous studies

Rusev et al, Physical Review 111 (2025)
Talou et al, Physical Review 112 (2025)

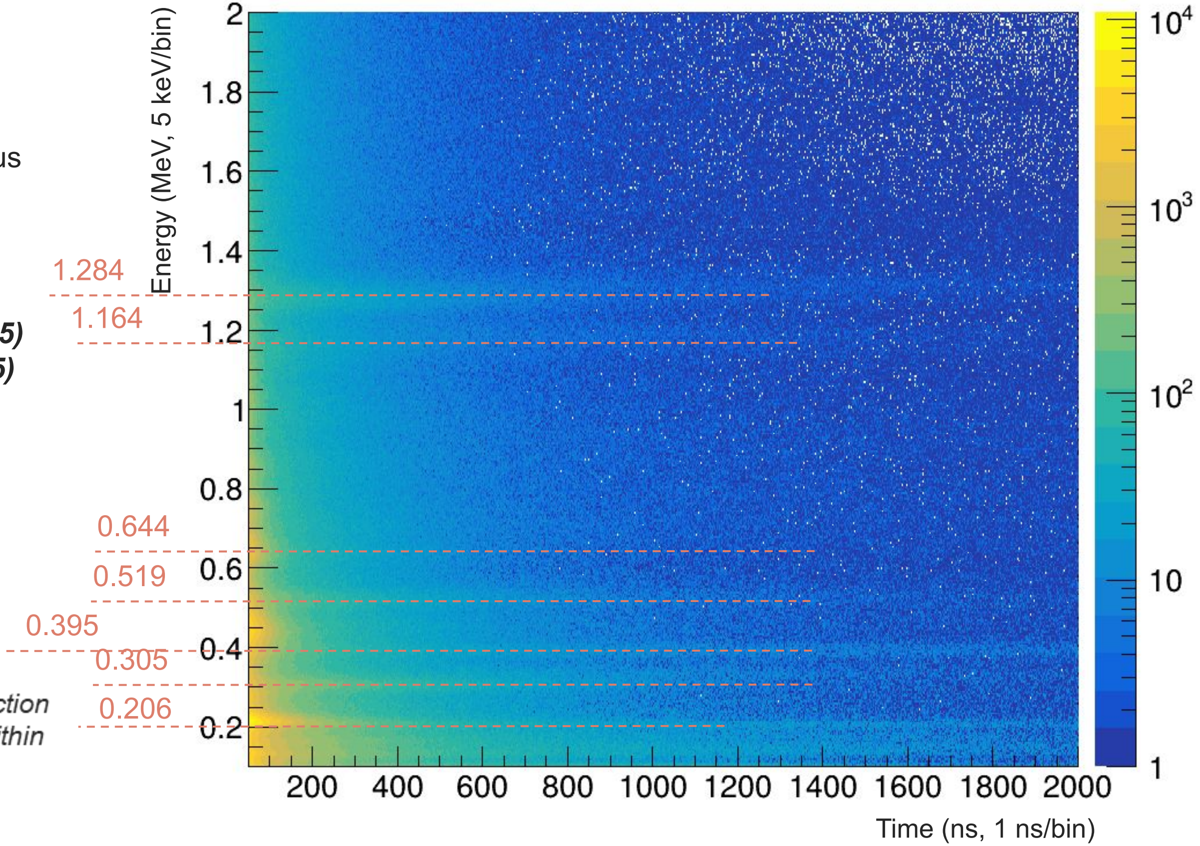


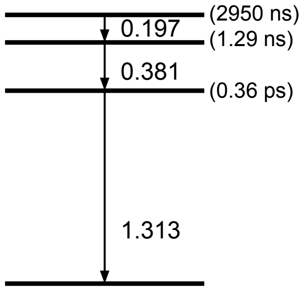
Figure 6** : γ-ray spectrum of ^{252}Cf (sf) as a function of time since fission, measured with SFγNCS, within the **already investigated interval

γ_1- γ_2 coincidence matrix

Event by event, γ_i energy is associated to other γ energies measured within ± 5 ns (SFγNCS time resolution)

Coincidence matrix is used to identify γ de-excitation cascade, starting from one isomeric state and decaying instantly through several states

136m Xe
(2950 ns)
8.16E-3



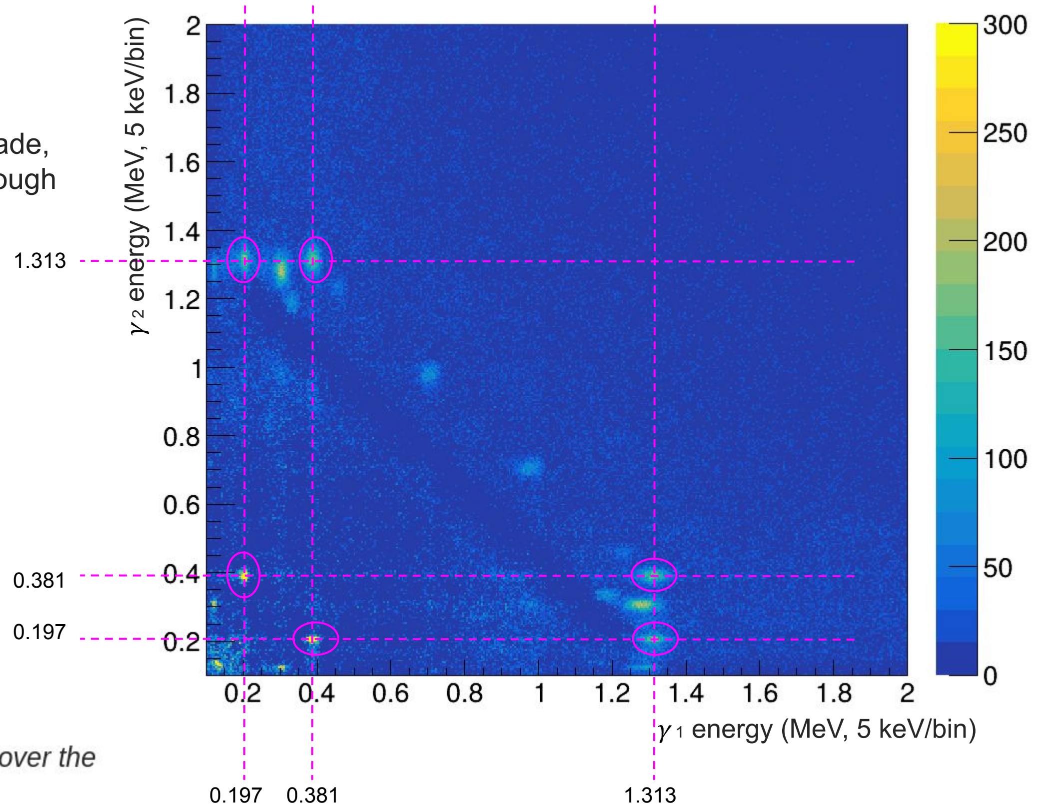
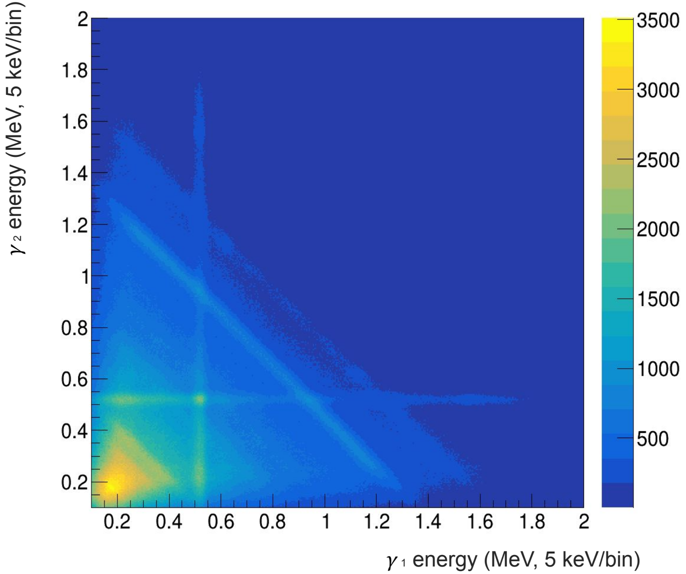
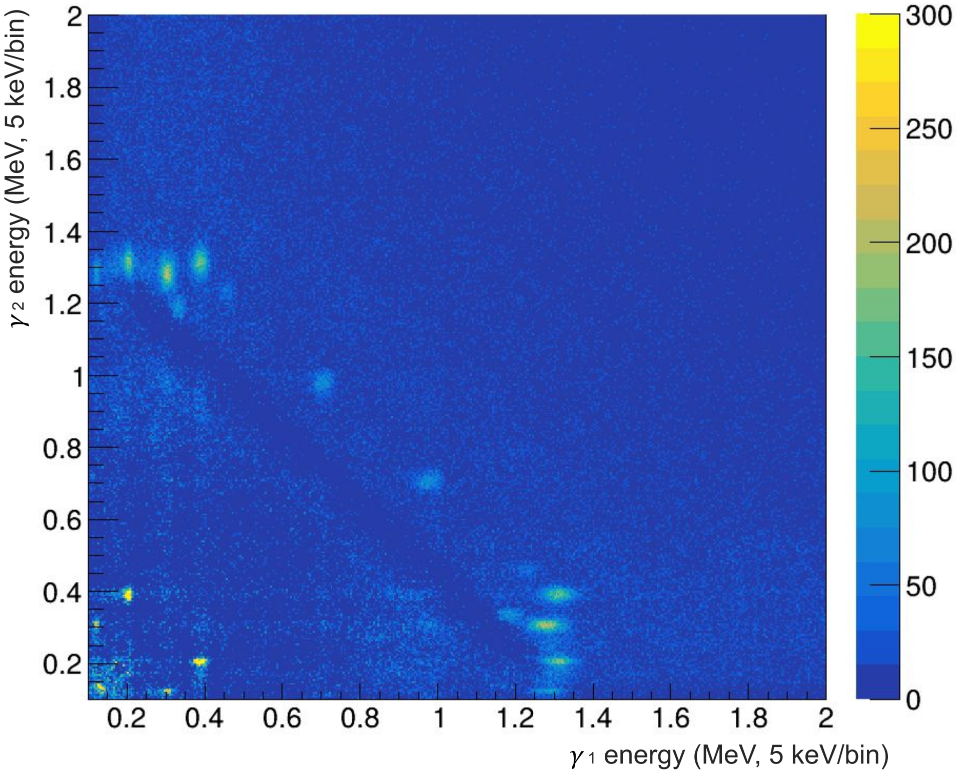


Figure 7** : γ1-γ2 coincidence matrix in energy, of* ^{252}Cf *(sf), over the **[100 ns, 100µs] interval

γ_1-γ_2 coincidence matrix



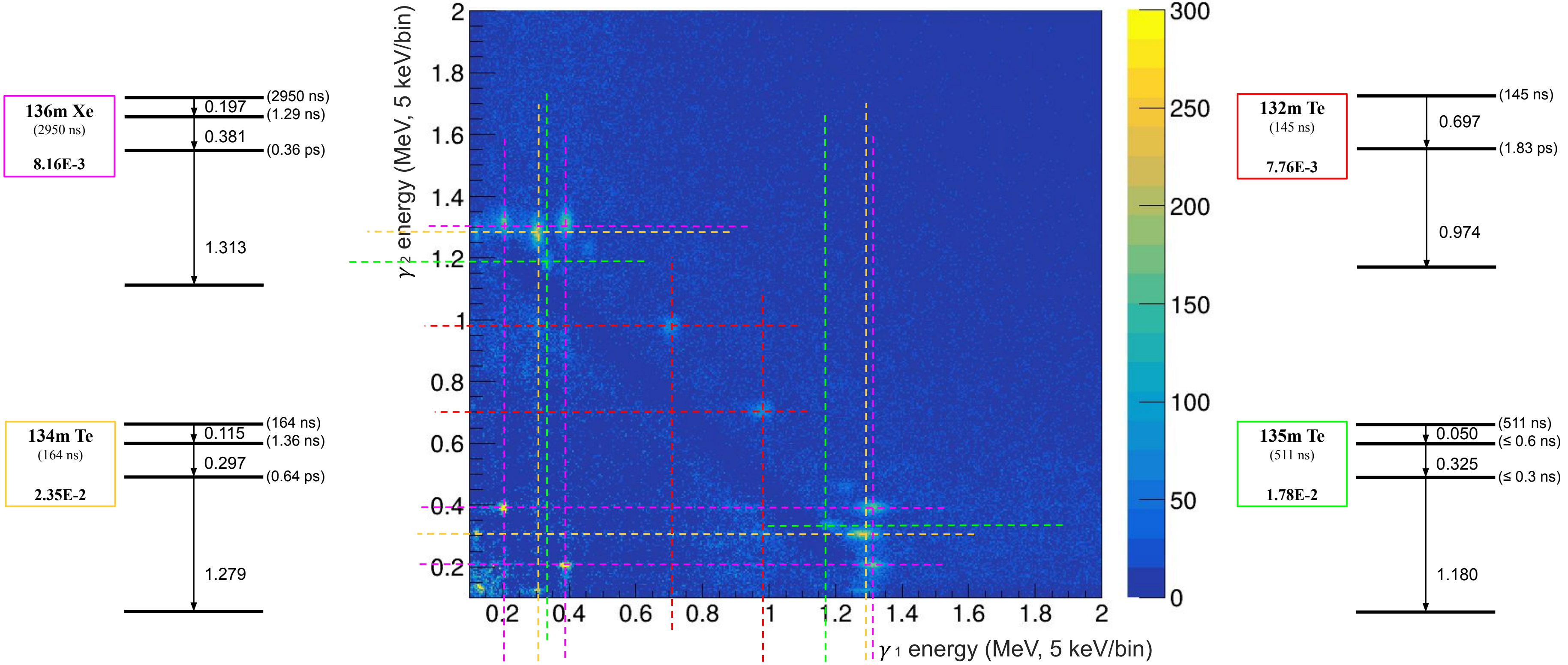
(a) Background spectrum



(b) Background removed spectrum

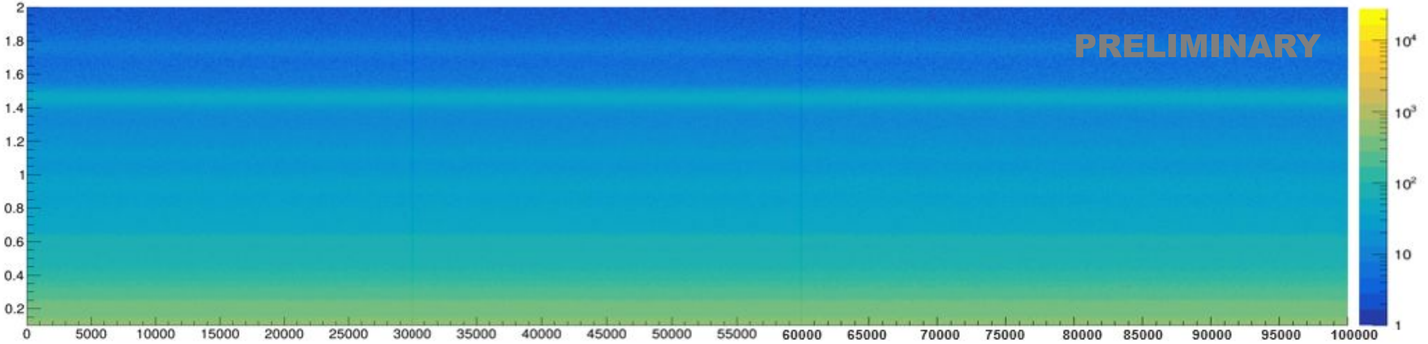
Figure 7** : γ1-γ2 coincidence matrix in energy, of ^{252}Cf (sf), over the* ***[100 ns, 100µs] interval

γ_1-γ_2 coincidence matrix



Nucl. Data Sheets* 152**, *331 (2018),* ***103*, 1 (2004),* ***104****, 497 (2005),* ***109****, 517 (2008)*

Extended interval (100 ns - 100 μs)



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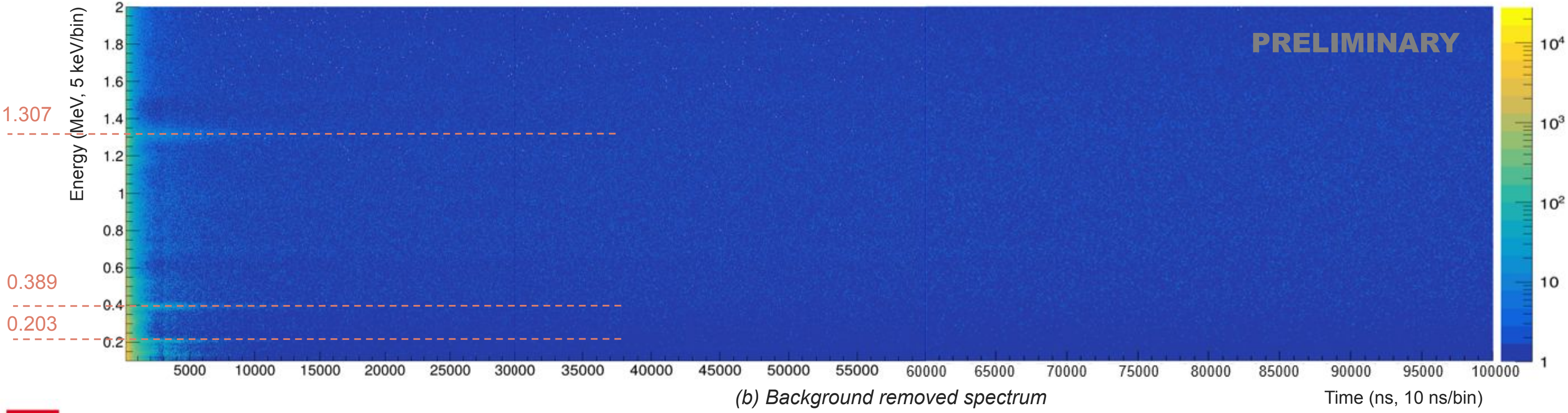
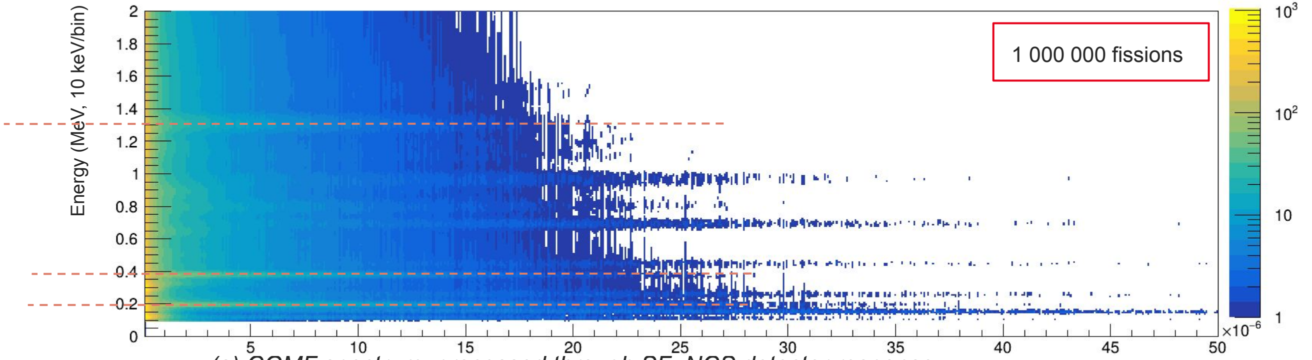


(b) Background removed spectrum

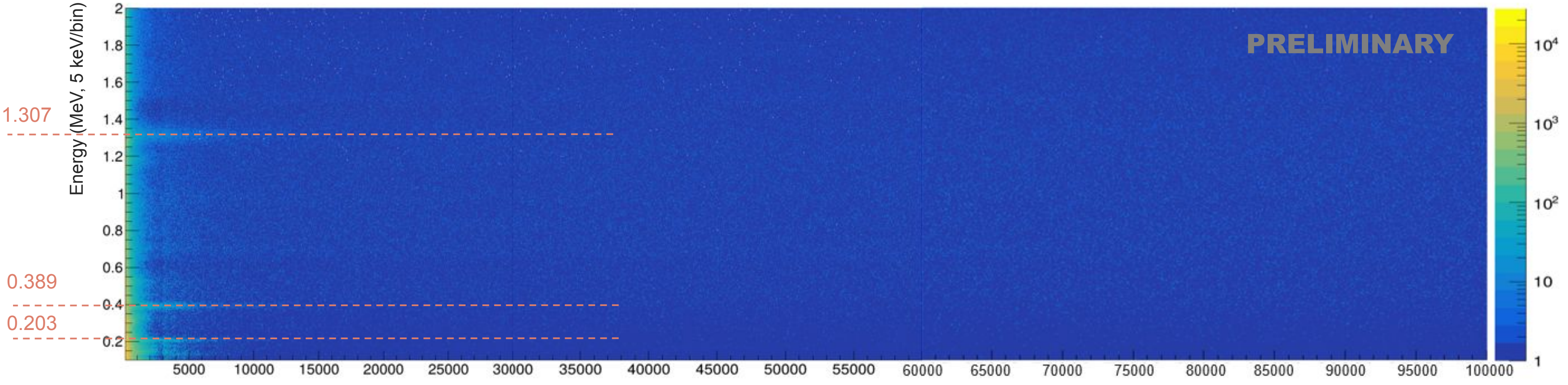
Extended interval (100 ns - 100 µs)

Data analysis is in progress for this time interval, with the following goals :

- Accumulate more fission events to observe low yields isomeric states γ-rays
- Identify clearly isomeric states and measure their lifetime



(a) CGMF spectrum, processed through SFγNCS detector response



(b) Background removed experimental spectrum

Perspectives

- Identify low-intensity isomers by accumulating the entire dataset
- Obtain the isomers distribution depending on time evolution
- Use the data produced with the aim of constraining fission-event simulation codes regarding delayed emissions
- Unfold the spectrum in time and energy in order to use it for the complement of several experiments, notably SCONE

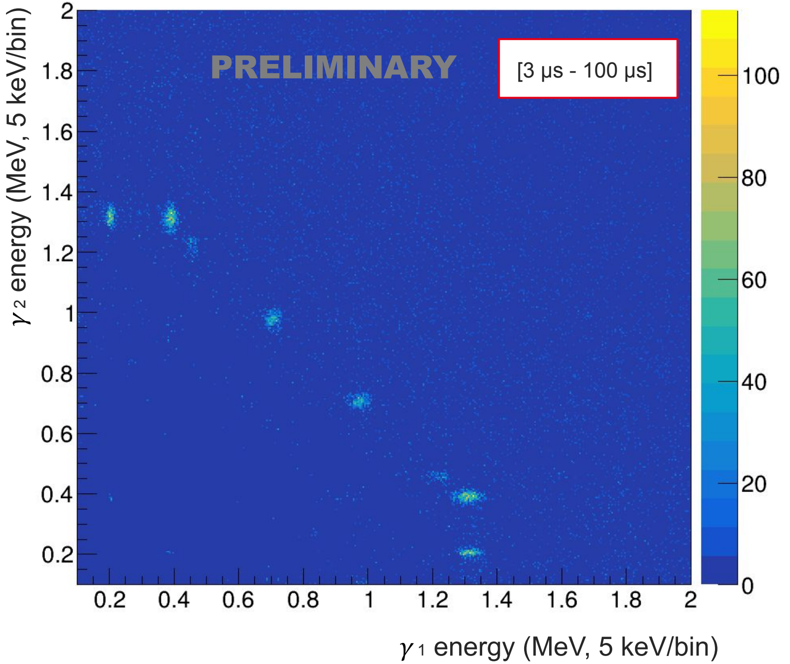


Figure 9** : γ1-γ2 coincidence matrix in energy, of ^{252}Cf(sf), over the **[3 μs, 100μs] interval