

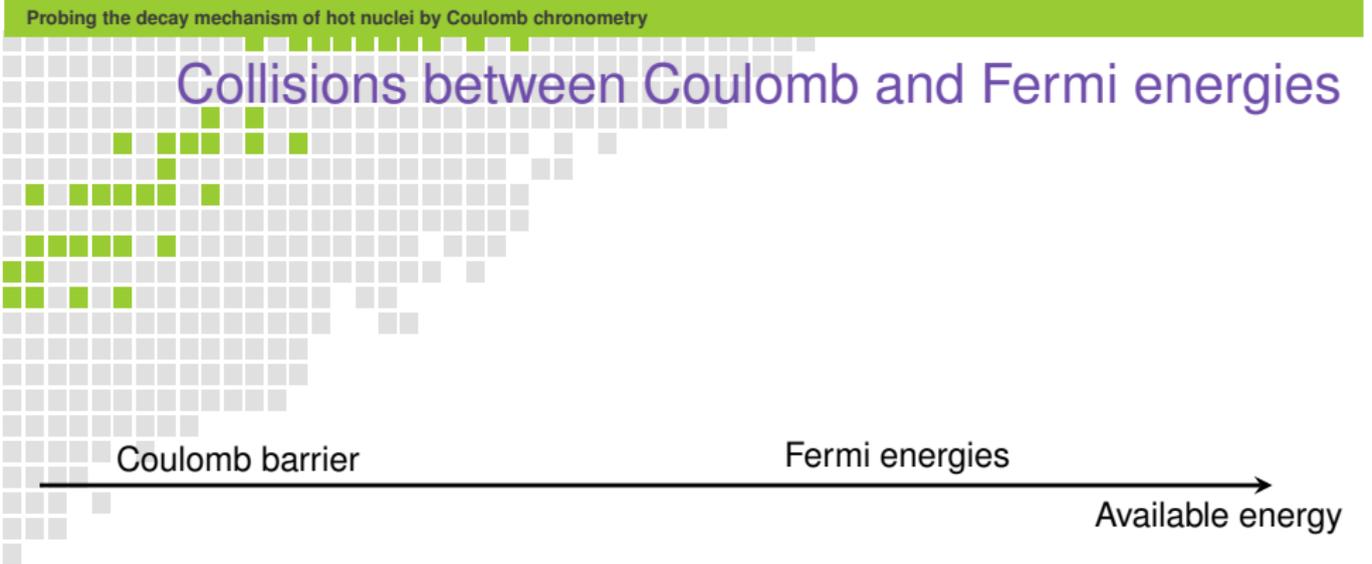
Probing the decay mechanism of hot nuclei by Coulomb chronometry

Diego Gruyer

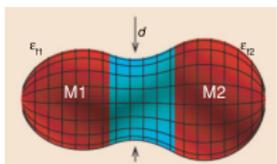
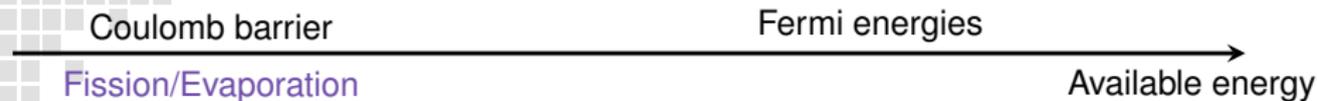
Grand Accélérateur National d'Ions Lourds, and
Université de Caen Basse-Normandie



Collisions between Coulomb and Fermi energies

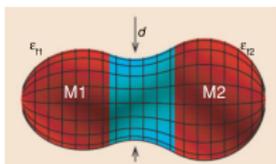
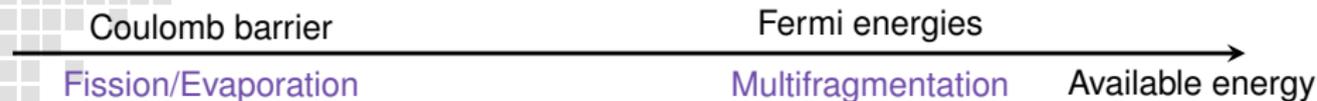


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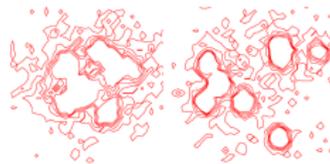


adapted from P. Möller et al.
 Phys. Rev. C **79**, 064304 (2008)

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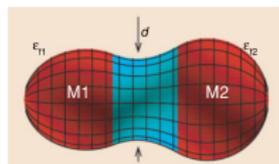
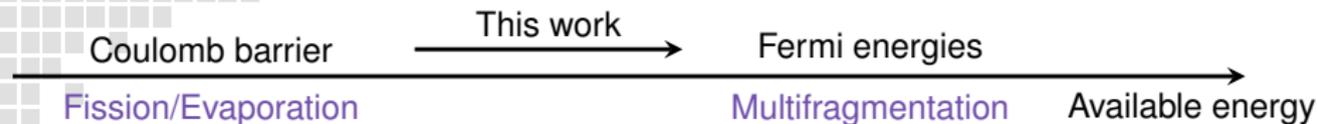


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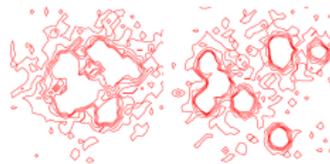


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Multifragment production in Xe+Sn central collisions

Studied reactions

- Xe+Sn at 8, 12, 15, 18, 20, 25 MeV/A
- Measured with INDRA at GANIL
- Fusion-like events

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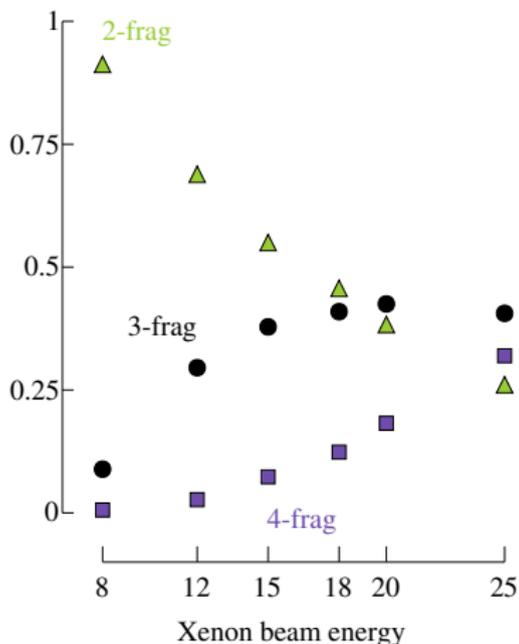
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- $E_b = 8$ MeV/A : mainly two fragments

Production rate



A.Chbihi et al. J.Phys. : Conf.Ser. **420**, 012099 (2012)

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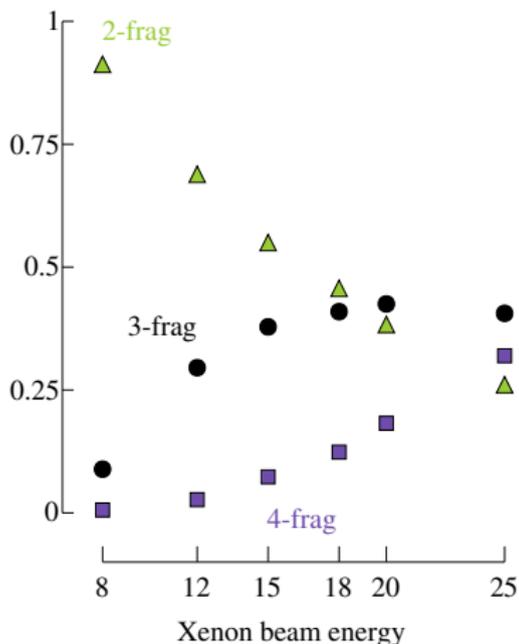
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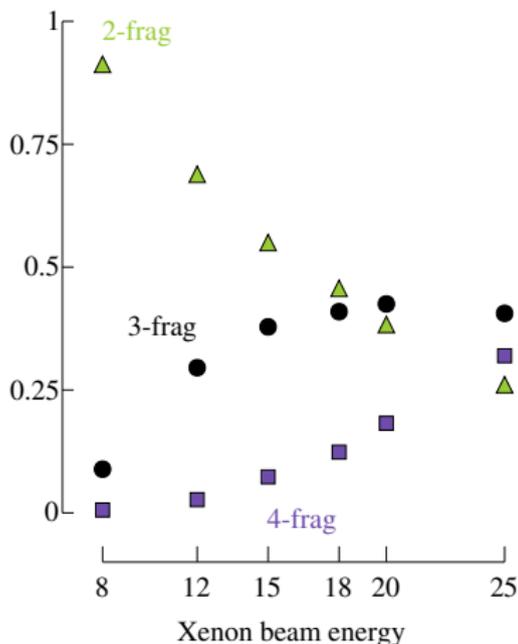
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Mechanism of 3-frag production

- Continuation of fission ?
- Precursor of multifragmentation ?

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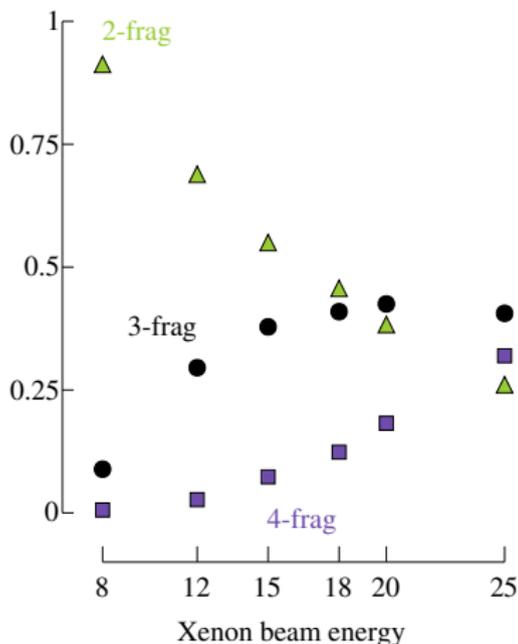
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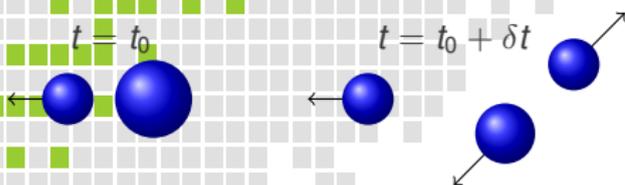
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- Estimation of the involved timescales

Production rate



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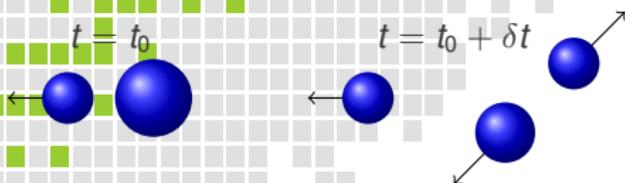
From hot sequential fission to multifragmentation



Experimental results

- Two successive binary splittings

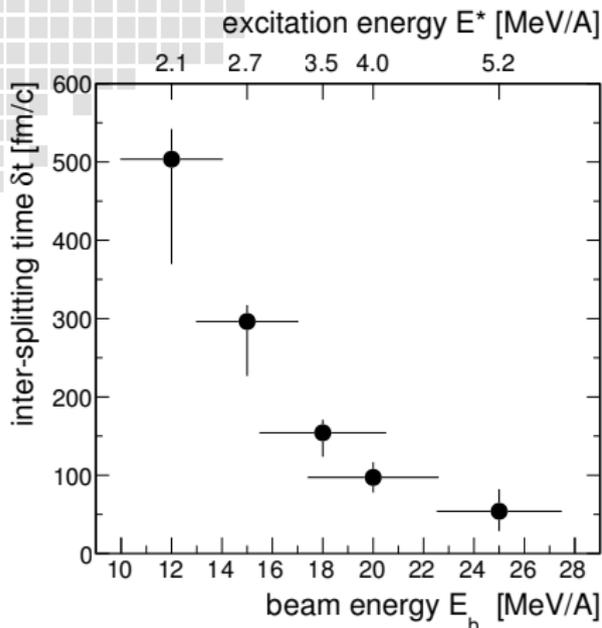
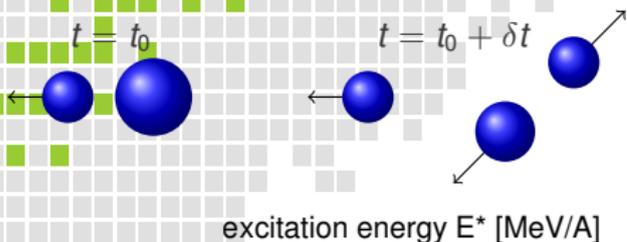
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- Two successive binary splittings
- Strong Coulomb proximity effects

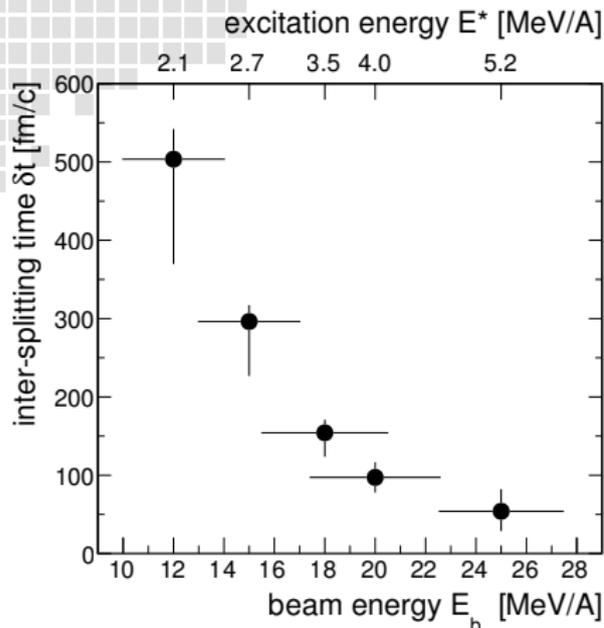
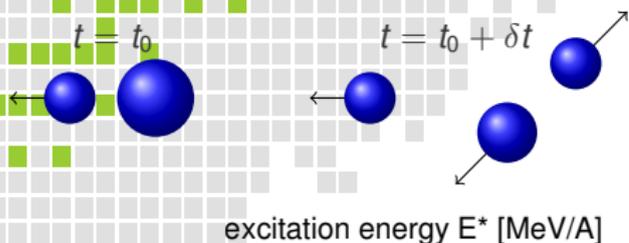
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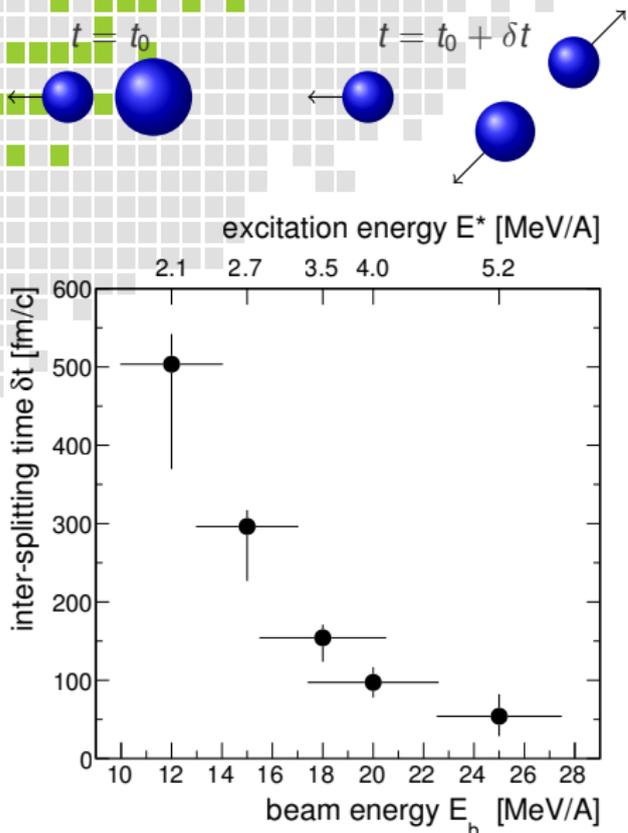
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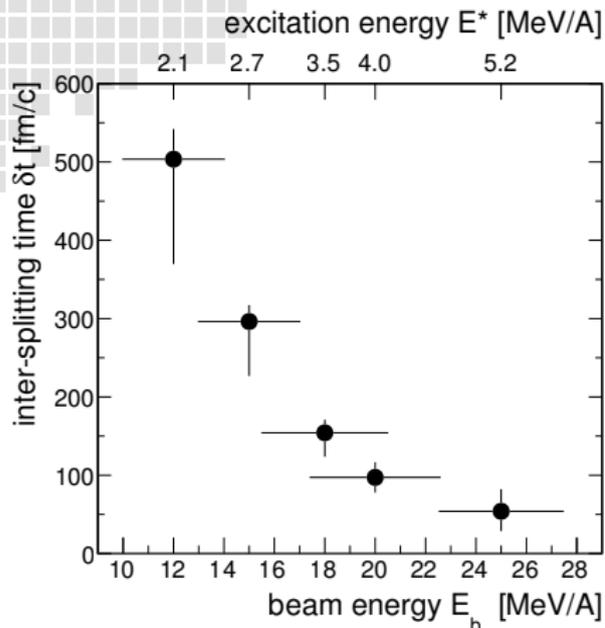
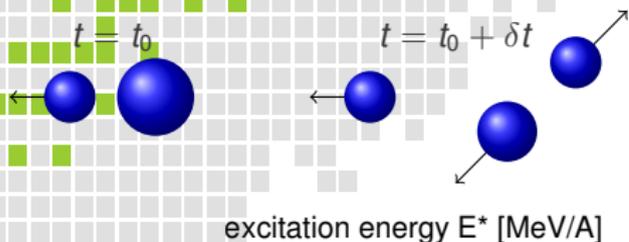


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Decay mechanism

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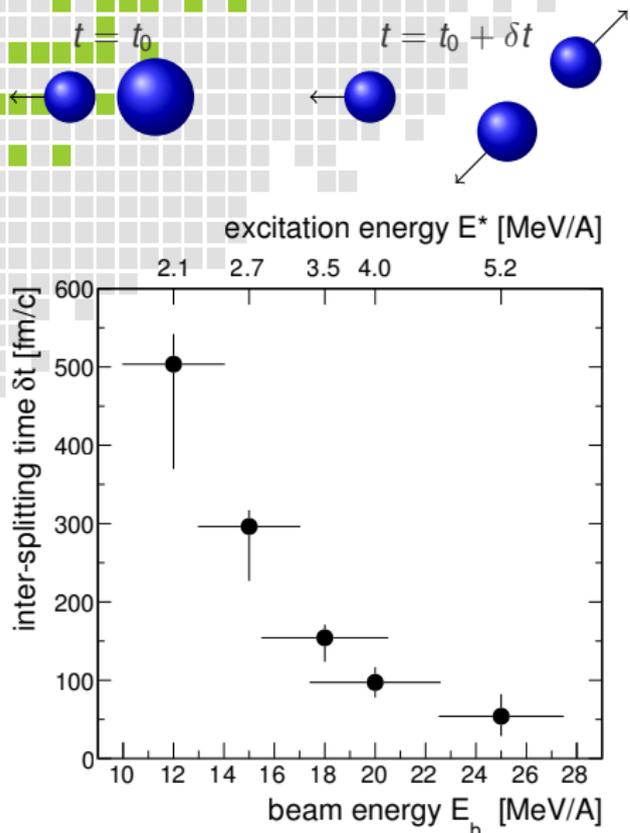
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Decay mechanism

- Successive splittings occurring on shorter and shorter time scale

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Decay mechanism

- Successive splittings occurring on shorter and shorter time scale
- Compatible with simultaneous break-up above $E_b = 20 \text{ MeV/A}$
- Onset of multifragmentation above $E^* = 4.0 \pm 0.5 \text{ MeV/A}$

Coulomb chronometry to probe the decay mechanism of hot nuclei

Diego Gruyer*, J.D. Frankland, A. Chbihi, and E. Bonnet
 GANIL, CEA-DSM/CHRS-IN2P3, Caen France
 *diego.gruyer@ganil.fr

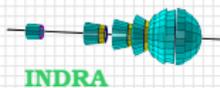
Reaction and decay mechanism

General scheme: In heavy-ion collisions of overlapping nuclei around 10-30 MeV/u, the production of 1, 2, 3 or more heavy fragments is observed. By detecting all of them in coincidence and correlating their mass, energy and momentum we can learn a lot about the underlying reaction mechanism.

Three-fragment break-up: In heavy-ion central collisions, the 3-fragment exit channel is observed above 12 MeV/u beam energy (Fig. 1). The decay mechanism responsible for these 3-fragment events is not understood: Is it the combination of the binary fission at the production of high energy simultaneous fragmentation?

Experimental approach: We investigate the 3-fragment exit channel in fusion-like events produced in ³⁶Ar+³⁶Ar central collisions at 12, 15, 18, 20, 25, and 30 MeV/u. Data were measured with INDRA at GANIL.

CORRELATIONS

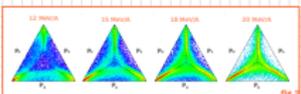


From sequential to simultaneous

Method: For each event we calculate P_1, P_2, P_3 , and we fit them in a 2D plot (Fig. 2). P_i measure the compatibility with the sequence $i \rightarrow (j, k) \rightarrow (l, m) \rightarrow \dots$

How to read it: Sequential events are located close to the edge, while simultaneous break-ups would be on the center of the triangle.

Interpretation: When increasing beam energy, the three heavy fragments production becomes more and more simultaneous.



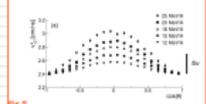
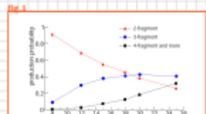
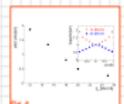
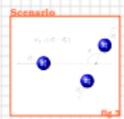
Coulomb

chronometer

Identification of the sequence: If two successive splittings occur, these possible sequences have to be considered: (12), (21), (23), (32). To identify the sequence, we compare the relative velocity between each pair of fragments with that expected for binary fission experiments. Proceeding during the second splitting, we can deduce that the remaining fragment was emitted first.

Inter-splitting angle: At the lowest beam energies, the detection of two coincident splittings at an arbitrary beam energy, the angular distribution pattern and the time delay is important to study. Each of this quantity is measured for an isolated fissioning system and suggests the presence of a Coulomb field close interaction.

Three-fragment correlations: To estimate the mean inter-splitting time, we used the Coulomb pattern to find the relative velocity of the nuclei splitting for long inter-splitting time. In the case of a sequential splitting for short inter-splitting time it is modified by the Coulomb field of the first emitted fragment and prevents a maximum for θ_{12} experimentally. This maximum is more pronounced as the beam energy increases (Fig. 3), we quantify this effect by the Coulomb distortion (Fig. 4).



D.Gruyer¹, J.D.Frankland¹,
 E.Bonnet¹, A.Chbihi¹, G.Ademard³,
 M.Boisjoli^{1,4}, B.Borderie³,
 R.Bougault⁵, E.Galichet^{3,10},
 E.Gauthier⁴, D.Guinet⁶, P.Lautesse⁶,
 L.Manduci⁷, N.Le Neindre⁵,
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 R.Roy⁴, E.Rosato⁹, G.Spadaccini⁹,
 G.Verde¹², E.Vient⁵, M.Vigilante⁹,
 and J.P.Wieleczko¹
 (INDRA Collaboration)

Time scale

Calibration: To translate the Coulomb distortion by in terms of inter-splitting time, we performed Coulomb chronometry calibration for different charges. We simulated sequential break-up for different values of Z_1 and Z_2 and we compared the results with the results of 2D with the beam energy and the excitation energy of the fissioning nuclei (around 10 MeV).

Time scale: We observe a clear decrease of the inter-splitting time with increasing beam (excitation) energy. It shows that the 3-frag event exit channel is compatible with successive binary splitting occurring in shorter and shorter time scales.

Order of magnitude: Below 10-20 MeV, the fast nuclei resulting from the first splitting do not have sufficient time to move apart beyond the range of the nuclear force, 3-fragment events can be treated independently. It is no longer meaningful to speak of a sequential process. The time scale becomes comparable with simultaneous break-up above 10-12 MeV, which can be interpreted as the excitation energy required for the onset of multifragmentation.

