Theoretical description of the hot nuclei de-excitation

K. Mazurek, M. Ciemała, M. Kmiecik, A. Maj, D. Lacroix, D. Gruyer, J. Frankland

The Niewodniczanski Institute of Nuclear Physics - PAN, Kraków, Poland
IPNO, CNRS/IN2P3, Université Paris-Sud, Université Paris-Saclay, F-91406 Orsay, France

January 23, 2018

Outline

- Entrance channel: Heavy-Ion Phase-Space Exploration (HIPSE)
- Exit channels
  - Thermal Shape Fluctuation Method (TSFM) for GDR
  - Dynamic description by solving Langevin transport equations for evaporation and fission
- Sequential fission

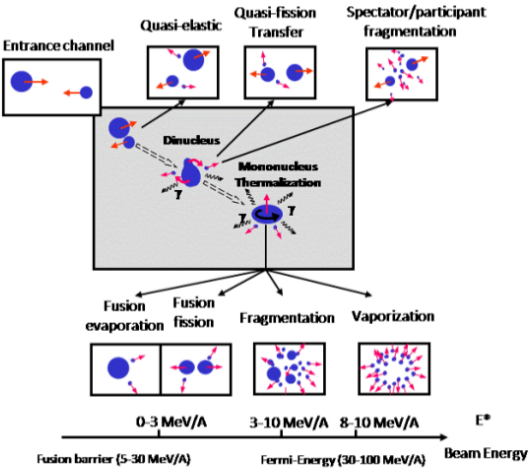


FIG. 33: *Illustration of the diversity of reaction mechanisms. Top: competing phenomena whe fossil quasi-target and quasi-projectile survive. Middle: competing phenomena where a compound nucleus is eventually formed at the intermediate reaction stage. The excitation energ and/or beam energy for which these mechanisms appear are given in the bottom part (Adapte from (Lacroix, 2002b)).*

Experimental Results - ^{48}Ti+^{40}Ca→ ^{88}Mo

M. Ciemała et al. Phys. Rev. C 91, 054313 (2015)

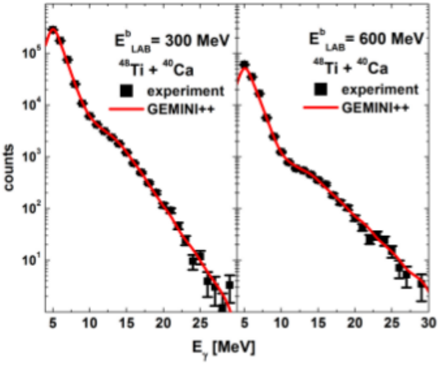
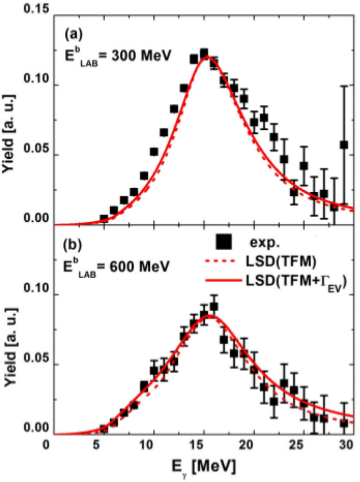
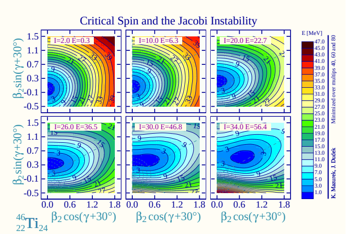


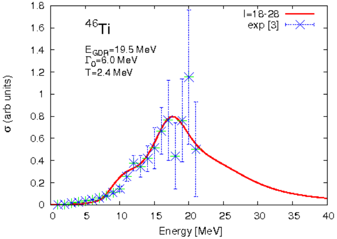
FIG. 9. (Color online) A comparison of the γ-ray spectra from the ^{48}Ti + ^{40}Ca reaction, at the beam energies of 300 MeV and 600 MeV, with the results of the *GEMINI++* fit (see text).

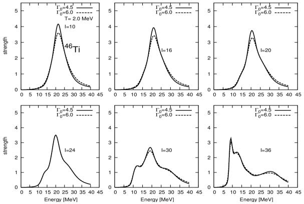


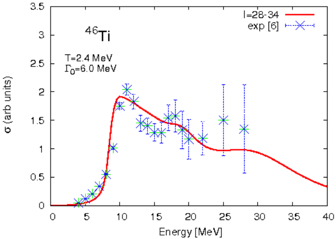
Geometrical Symmetry Breaking

Thermal Shape Fluctuation Model - GDR









Experiment: A. Maj et al., Nucl. Phys. A 731, 319 (2004).

Reaction scenarios - HIPSE

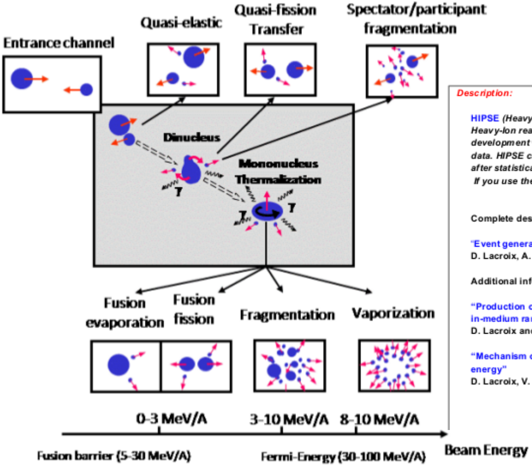


FIG. 33: *Illustration of the diversity of reaction mechanisms. Top: competing phenomena where fossil quasi-target and quasi-projectile survive. Middle: competing phenomena where a compound nucleus is eventually formed at the intermediate reaction stage. The excitation energy and/or beam energy for which these mechanisms appear are given in the bottom part (Adapted from (Lacroix, 2002b)).*

Description:

HIPSE *(Heavy-Ion Phase-Space Exploration) is a phenomenological model dedicated to Heavy-Ion reactions around Fermi energy. The main goal of our group during its development was to identify minimal physical hypothesis to reproduce experimental data. HIPSE can be used as an event generator and gives access to partitions before and after statistical decay.*
If you use the model or/and encounter problem, please contact us (Denis Lacroix).

Complete description of the model can be found in:

"Event generator for nuclear collisions at intermediate energies"
D. Lacroix, A. Van Lauwe, and D. Durand, *Physical Review C 69, 054604 (2004)*

Additional information and some applications can be found in:

"Production of light particles in low energy spallation and in fragmentation reaction by in-medium random clusterization"
D. Lacroix and D. Durand, *arXiv:nucl-th/0505053.*

"Mechanism of light cluster production in nucleon induced reactions at intermediate energy"
D. Lacroix, V. Blideanu, and D. Durand, Physical Review C 71, 024601 (2005)

HIPSE - Results

LACROIX, VAN LAUWE, AND DURAND PHYSICAL REVIEW C 69, 054604 (2004)

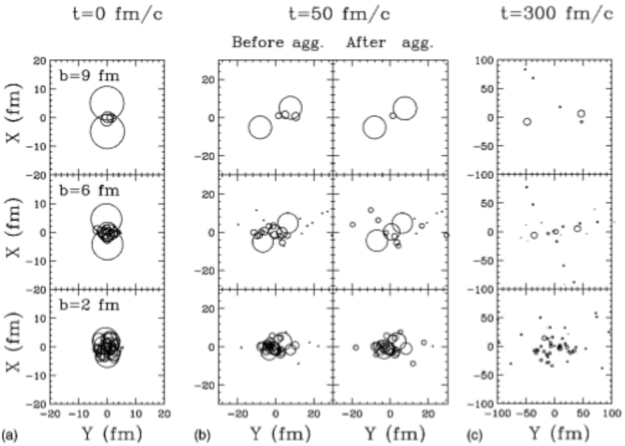
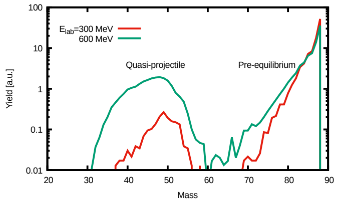
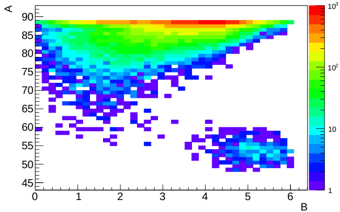


FIG. 2. Example of nuclear dynamics obtained for the reaction $^{129}Xe+^{120}Sn$ at $E = 50$ MeV/nucleon. From top to bottom, the initial impact parameters $b=9$ fm, $b=6$ fm, and $b=2$ fm are presented. In each case, from left to right figures correspond to the initial cluster configuration ($t=0$ fm/c), the configuration before and after the reaggregation ($t=50$ fm/c), and during the deexcitation ($t=300$ fm/c).

Entrance channel effect - ^{48}Ti+^{40}Ca→ ^{88}Mo

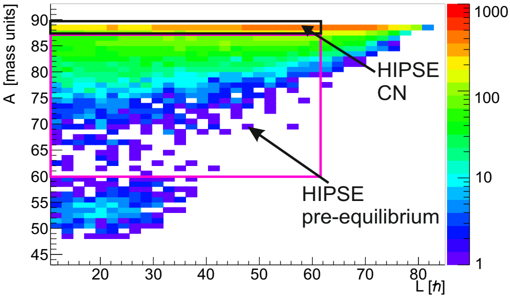
Mass distribution





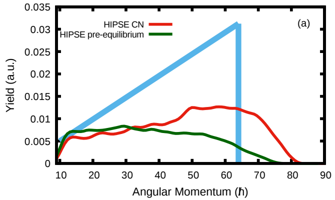
The correlation of the prefragment mass with the impact parameter in ^{48}Ti(600 MeV)+^{40}Ca.

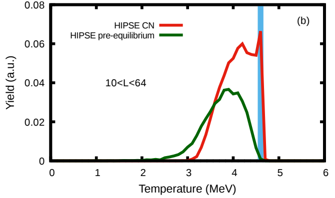
Outcome from the HIPSE code



Compound nuclei created by HIPSE code. The L_{cut}=64 $\hbar$ marks the spin at which the fission barrier vanishes.

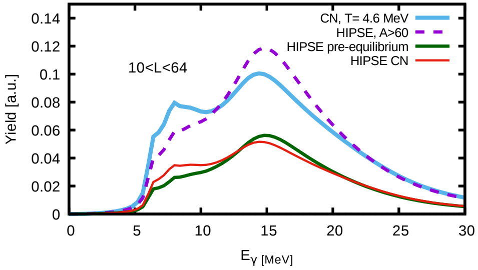
Angular momentum and temperature distribution





Blue line shows the values of the spin/ temperature taken usually for hot compound nucleus ^{88}Mo.

HIPSE + TSFM



The strength functions of the GDR built in compound nucleus ^{88}Mo (CN) and for ensemble of nuclei generated in the HIPSE code:
the compound nucleus (HIPSE CN), the nuclei produced with pre-equilibrium emission (HIPSE pre-equilibrium) and integrated over the prefragment mass distribution (HIPSE A$>$60). All calculations were done for 10-64 $\hbar$ range of angular momentum.

Stochastic Approach - Langevin transport equations

Dynamical effect

• path from equilibrium to scission slowed-down by the nuclear viscosity
• description of the time evolution of the collective variables like the evolution of Brownian particle that interacts stochastically with a "heat bath".
• excess of prescission particles
• all the parameters of the two dimensional fission fragment distribution and their dependence on various parameters of compound nucleus

Observables

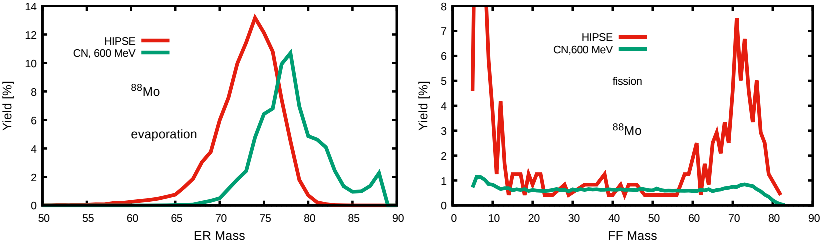
• Pre- and post-scission particle multiplicity and energy spectra
• Mass, charge, angular distributions of the fragments
• Total Kinetic Energy distribution
• Isotopic distribution, $\langle N/Z \rangle$....

Limitations

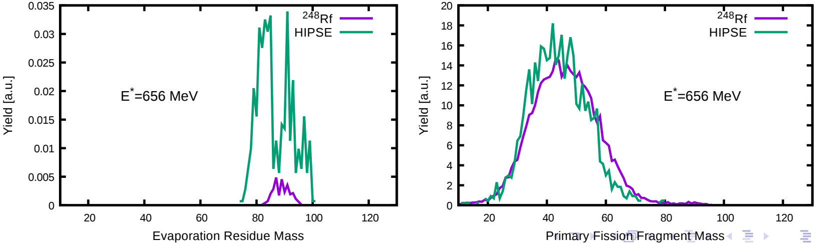
• Wide domain in compound nucleus mass (from 50 to 250)
• Excitation energy $E^{\star}$ (from 30 to 250MeV)
• Angular momentum L (from 0 to 100 $\hbar$)

Entrance channel effect - HIPSE + 4DLangevin

^{48}Ti (12 AMeV) +^{40}Ca→ ^{88}Mo (preliminary)

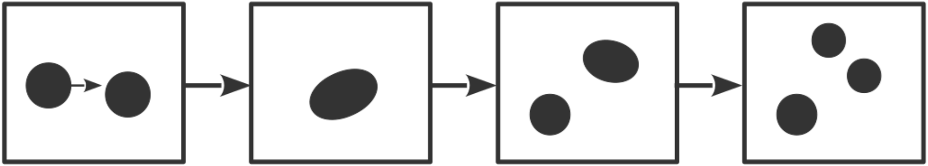


^{119}Xe (15 AMeV)+^{129}Sn→ ^{248}Rf (preliminary)



Sequential Fission Procedure

Dynamical evolution of compound nucleus and later each primary fission fragment.



Fusion → CN → I fission → II fission

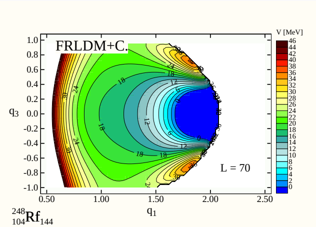
Xe+Sn central collision from 8 to 25 MeV/A measured with INDRA

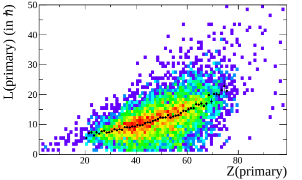
Sequential Fission Procedure

Four different cases can occur:

1. compound nucleus ending as an evaporation residue (M_{frag}=1);
2. primary fission of the CN with both fragments ending as a secondary evaporation residua (M_{frag}=2);
3. primary fission of the CN with one primary fragments undergoing secondary fission while the complementary ends as secondary ER (M_{frag}=3);
4. primary fission of the CN with both primary fragments undergoing secondary fission (M_{frag}=4).

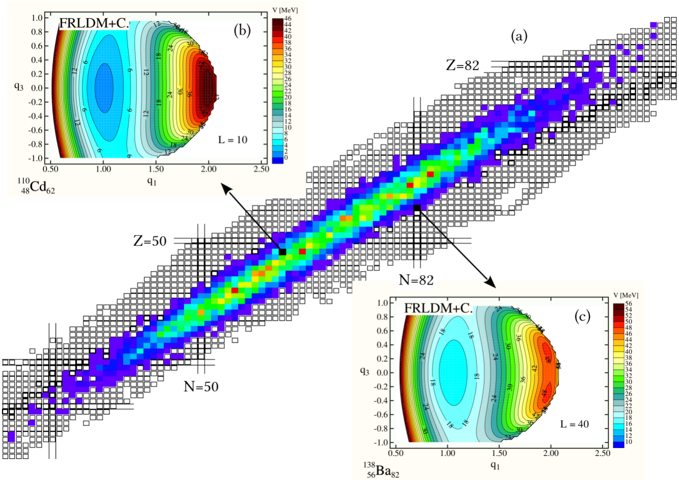
I. Dynamical evolution of compound nucleus ^{248}Rf at excitation energy 223 MeV.



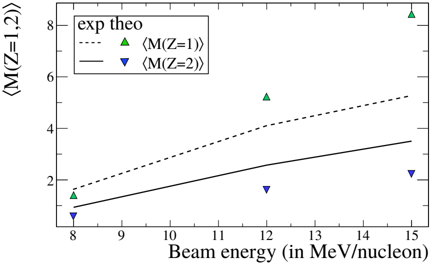


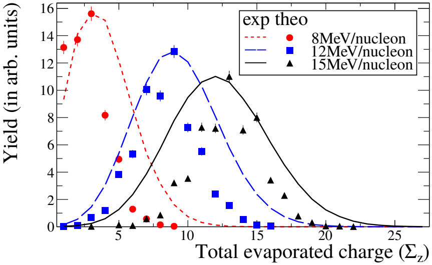
Sequential Fission Procedure: II step

II. Dynamical evolution of each primary fission fragment.



Particle Multiplicities

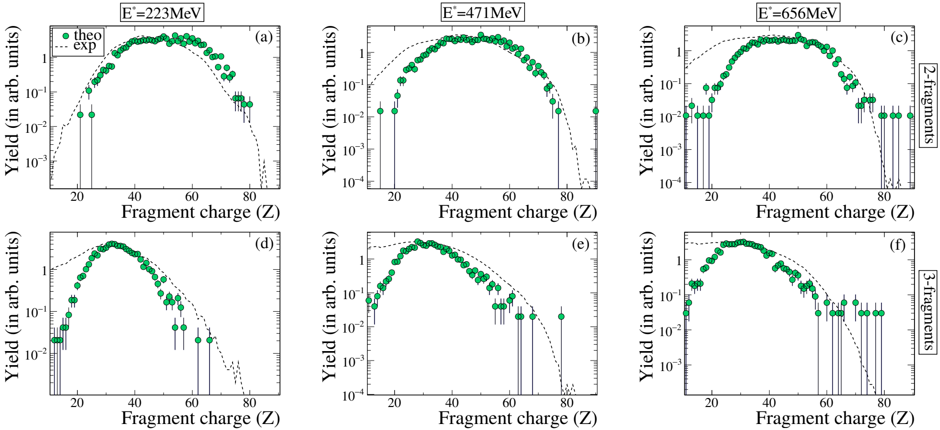




The particle multiplicity emitted during fission (pre) and from the evaporation residue (ER) coming from the primary and secondary FF of the ^{248}**Rf** compound nucleus. The particle multiplicity from Abdu Chbihi (priv. comm.)

E_{lab} [AMeV]	primary				secondary			
	$\langle p_{pre} \rangle$	$\langle p_{exp} \rangle$	$\langle \alpha_{pre} \rangle$	$\langle \alpha_{exp} \rangle$	$\langle p_{pre} \rangle$	$\langle p_{exp} \rangle$	$\langle \alpha_{pre} \rangle$	$\langle \alpha_{exp} \rangle$
8	0.8236	0.696	0.005	0.417	0.038	0.197	0.055	0.794
12	3.7837	1.838	0.079	1.321	0.153	0.475	0.146	2.418
15	6.648	2.367	0.183	1.876	0.188	0.567	0.181	3.367

Final fragment charge distribution – Xe + Sn →Rf



E_{lab}=8 AMeV E_{lab}=12 AMeV E_{lab}=15 AMeV

Summary

- The study of the pre-equilibrium particle emission is crucial for discussion of de-excitation of hot nuclei.
- The preliminary estimation of the influence of the pre-equilibrium emission on the shape of the GDR strength function has been done with the Thermal Shape Fluctuation Model.
- The difference between GDR emitted from HIPSE CN and standard CN is due to higher spin influence in the later.
- The pre-equilibrium emission lowers prefragments of spin and temperature thus the low-energy component in GDR spectrum is suppressed.
- The final charge distribution for two fragment and three fragment channels are estimated, sequential fission confirmed.

Wish list:

- FF isomeric distributions for various CN and excitation energies 50-300 MeV
- Correlation between fission fragments and GDR strength functions
- Looking for sequential fission at non-symmetric entrance channel