Photo-fission experiments at the γ-ray facility of Alba

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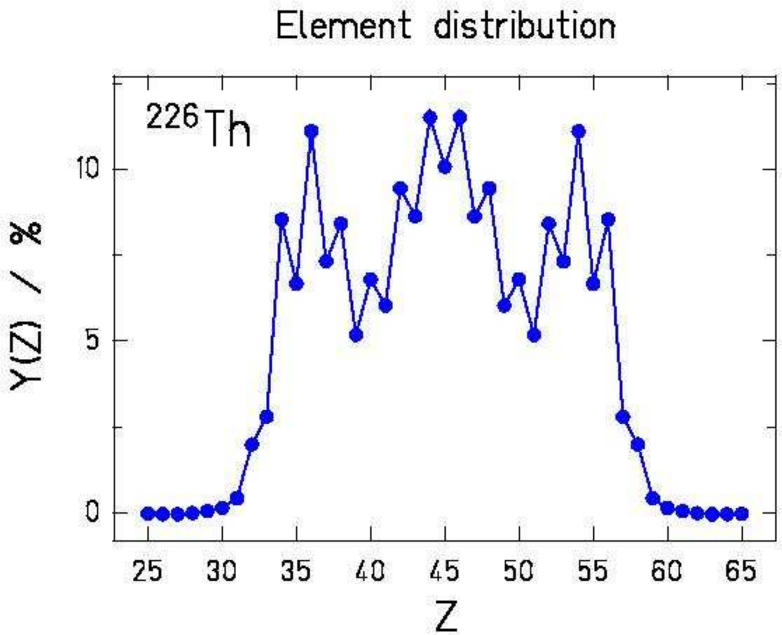
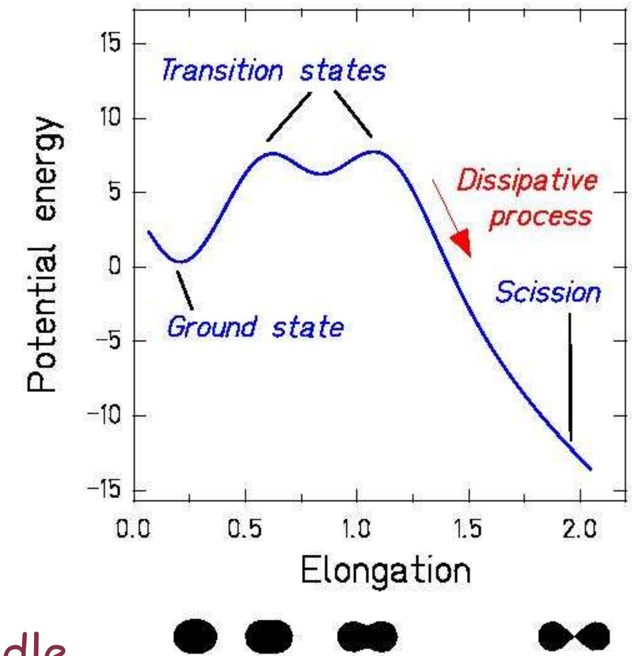
Photo-fission with monochromatic γ-rays

- Physics case:
  - Pairing through even-odd effects in the yields of fission fragments
  - Shell effects in fission
  - Multi-phonon excitations
  - Fission in stellar nucleosynthesis: r-process
  - Dynamics of fission at high-excitation energy (nuclear viscosity)
  - Applications of photo-fission
- Experimental technique

Pairing and viscosity in cold nuclear matter



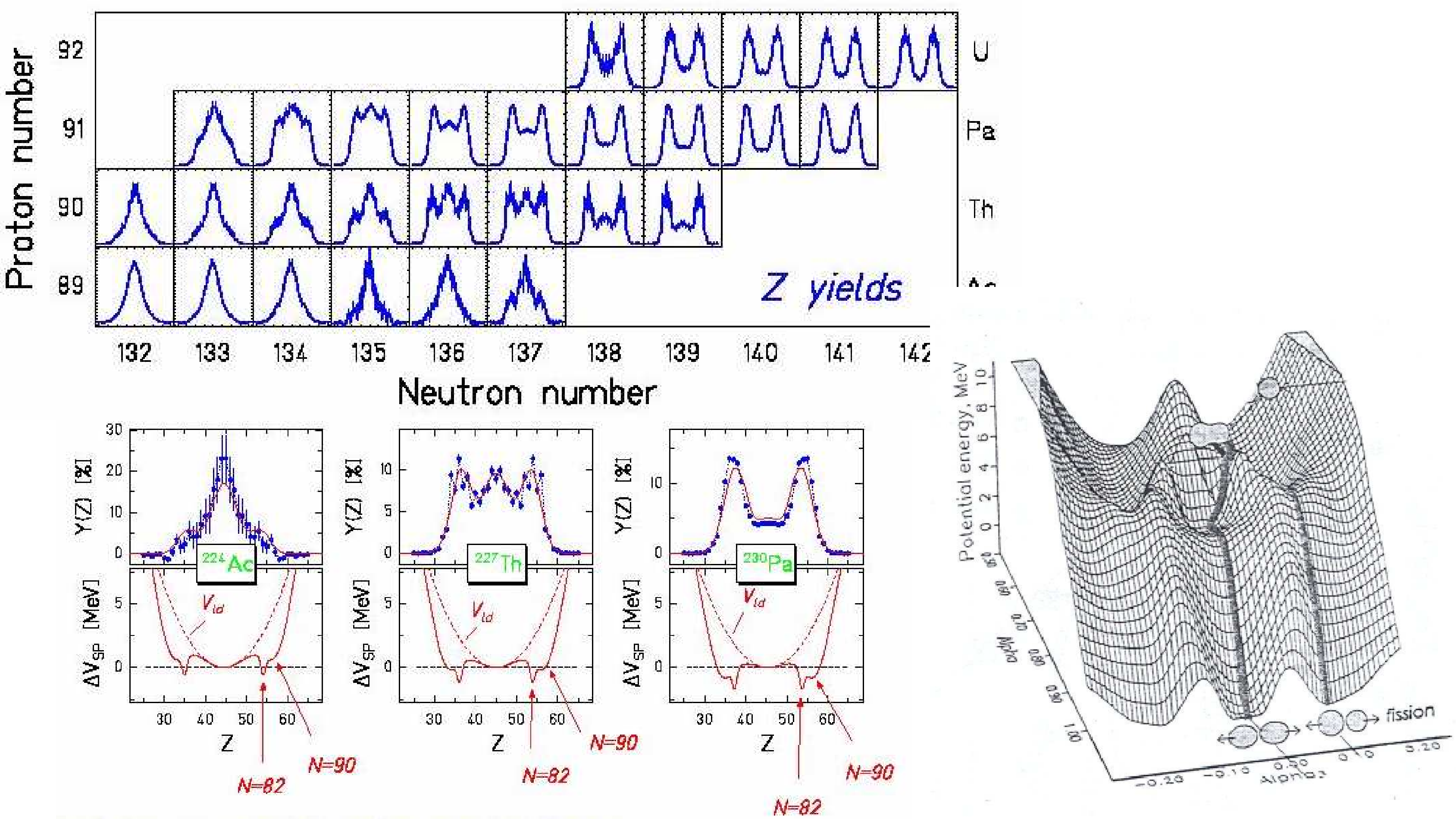


- Cold fission: superfluid phase at saddle
- Onset of dissipation from saddle to scission
- Phase transition from a superfluide phase to a Fermi liquid phase

Experimental requirements

- Accurate determination of the charge distribution of fission fragments

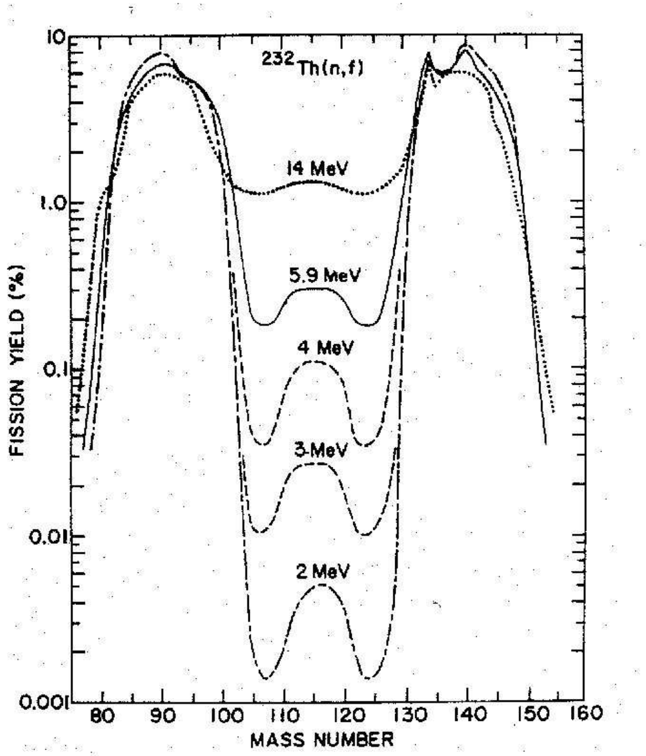
Shell effects in low-energy fission



➢ Shells effects are responsible of the asymmetric components in fission yields (N=82,86 Z=50)

Alba, BCN '04

Shell effects in low-energy fission

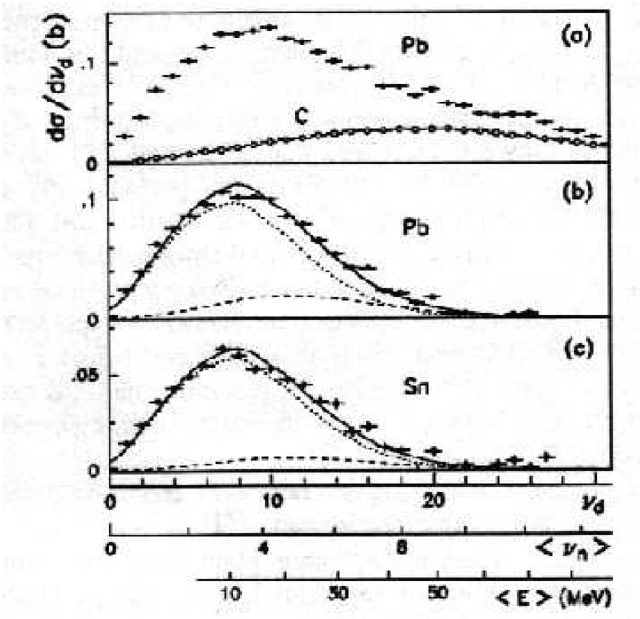


➢ Excitation-energy dependence of shell effects

Experimental requirements

➢ Mass and/or charge distribution of fission fragments (accuracy 1%)

Multi-phonon excitations



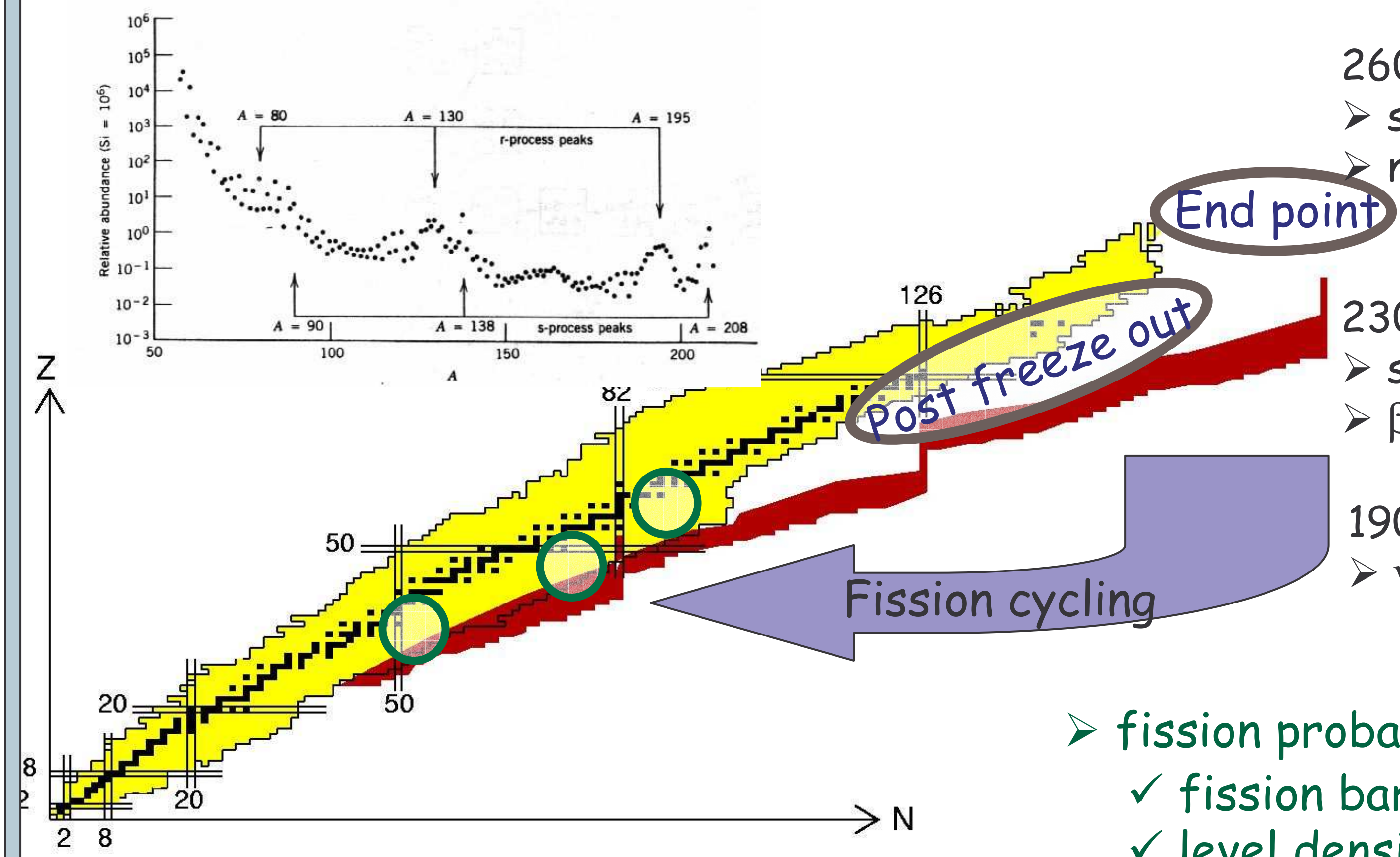
Indications for multi-phonon Giant Resonances have been obtained in electromagnetic fission of ^{238}U
Phys. Rev. Lett. 92 (2004) 112502-1

In this experiment the energy of the resonances is determine from the multiplicity of emitted neutrons

The gamma line of Alba would allow for more accurate experiments

Experimental requirements
- Excitation function of the total fission cross section

Fission in stellar nucleosynthesis: the r-process



260 < A < 320
- spontaneous fission
- n-induced fission

230 < A < 260
- spontaneous fission
- β-delayed fission

190 < A < 230
- ν-induced fission

- fission probabilities
  - ✓ fission barriers
  - ✓ level densities
  - ✓ masses
- fission fragment distributions

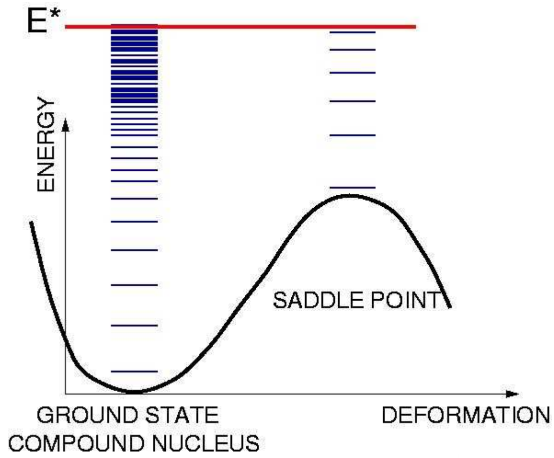
Alba, BCN '04

Dynamics of fission at high energy

Fission probability:

Statistical model: Available phase-space at the saddle point

Dynamical model: Time evolution of the probability flow across the saddle point: difussion process

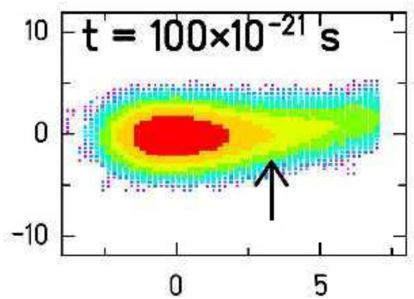


Coupling of collective deformation degree of freedom with internal degrees of freedom through dissipation

Langevin equation:

$$\frac{d^2Q}{dt^2} = -\frac{1}{M}\frac{d\tilde{V}(Q)}{dQ} - \beta\frac{dQ}{dt} + \sqrt{\frac{T}{M}\beta}\cdot F(t)$$

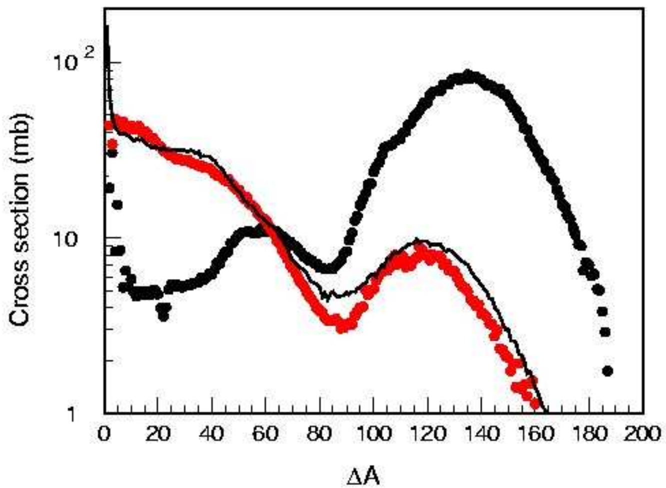
Drift force — Friction force — Diffussion (stochastic) force

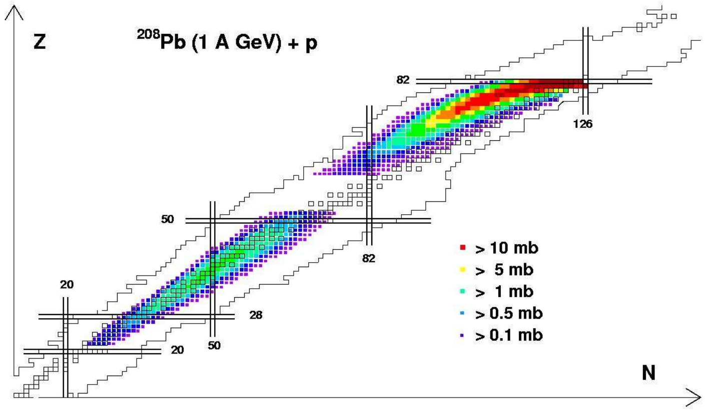


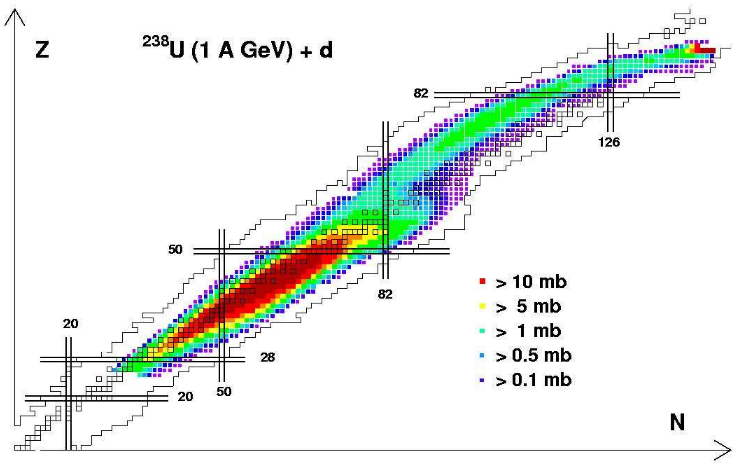
Fission: diffusion process governed by the Reduced Dissipation Coefficient β

Alba, BCN '04

Dynamics of fission at high energy







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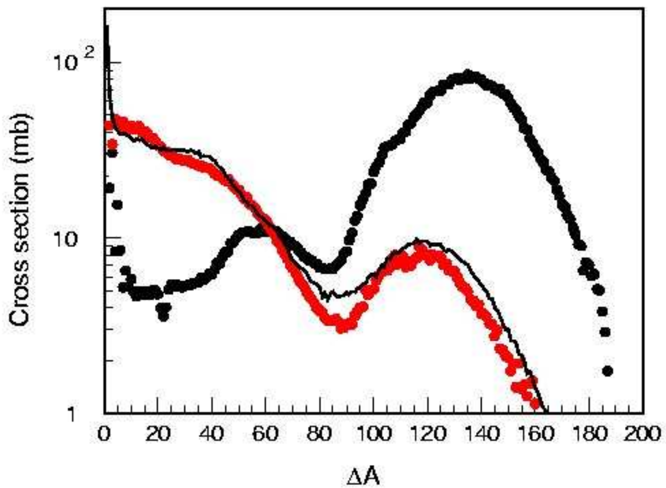
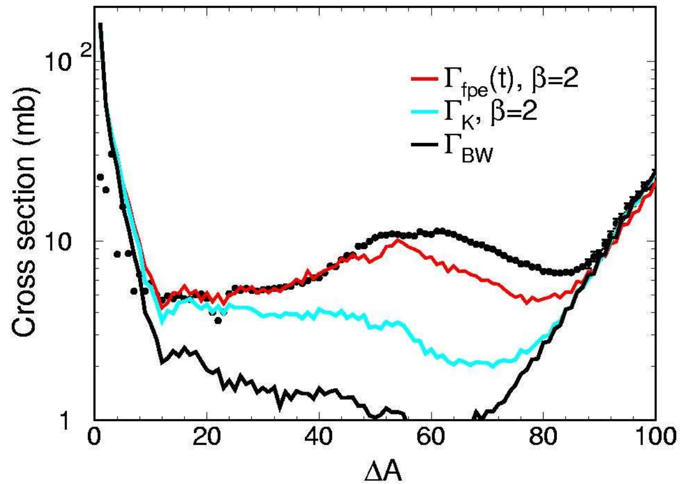
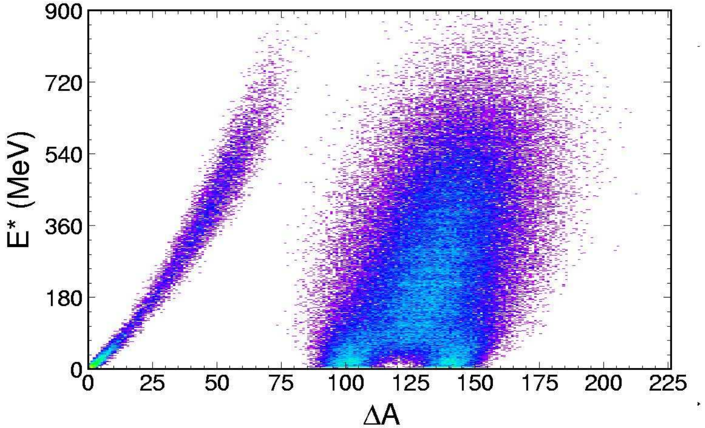
Dynamics of fission at high energy







- Excitation-energy dependence of the fission probability

Experimental requirements
- excitation function of total fission cross sections

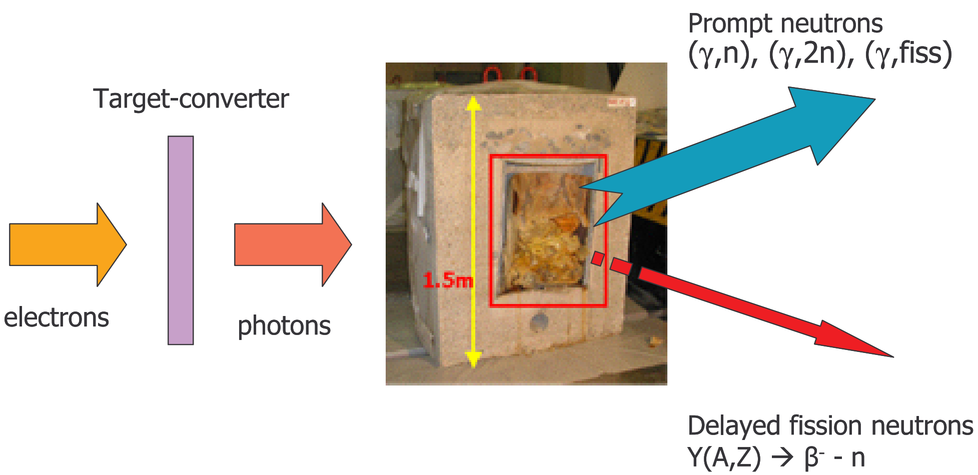
Applications

✓ Detection of radioactive fissile material via photo-fission

Non-destructive method to detect and control the presence of small quantities of radioactive fissile materials hiding in a huge mass/volume of other materials

- ➢ Transport security (airports,...)
- ➢ Non proliferation of radioactive materials
- ➢ Optimization and control of nuclear waste storage

Delayed neutron re-interrogation



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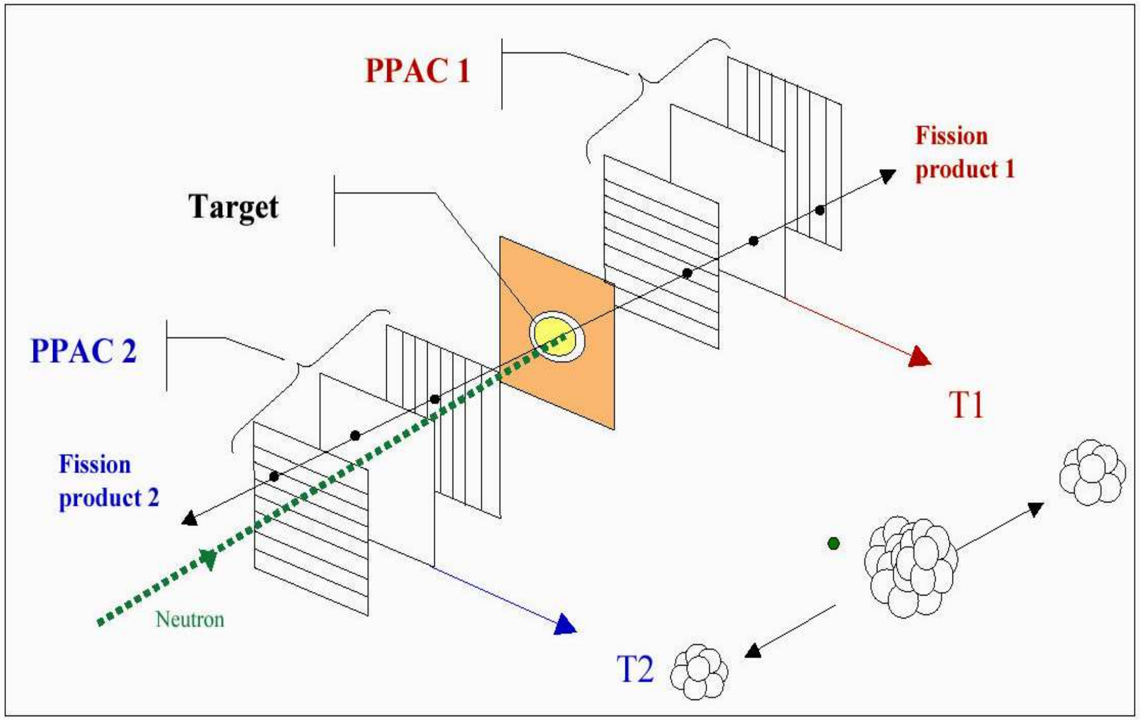
Experimental technique

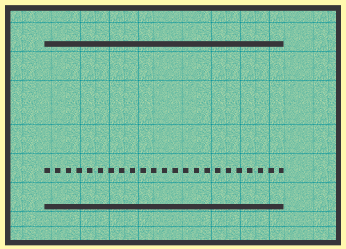
Total fission cross sections measured with parallel plate avalanche counters:



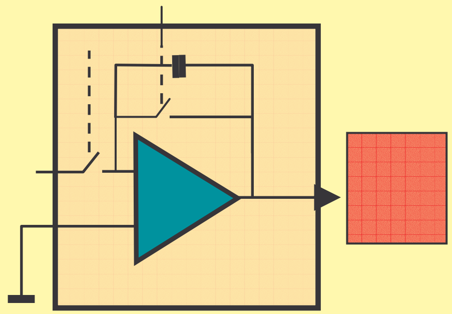
IPN-Orsay, USC at N_ToF

Experimental technique

Mass and charge distributions of fission residues with digitalized ionization chambers :



Twin ionization chamber



Fast digital acquisition

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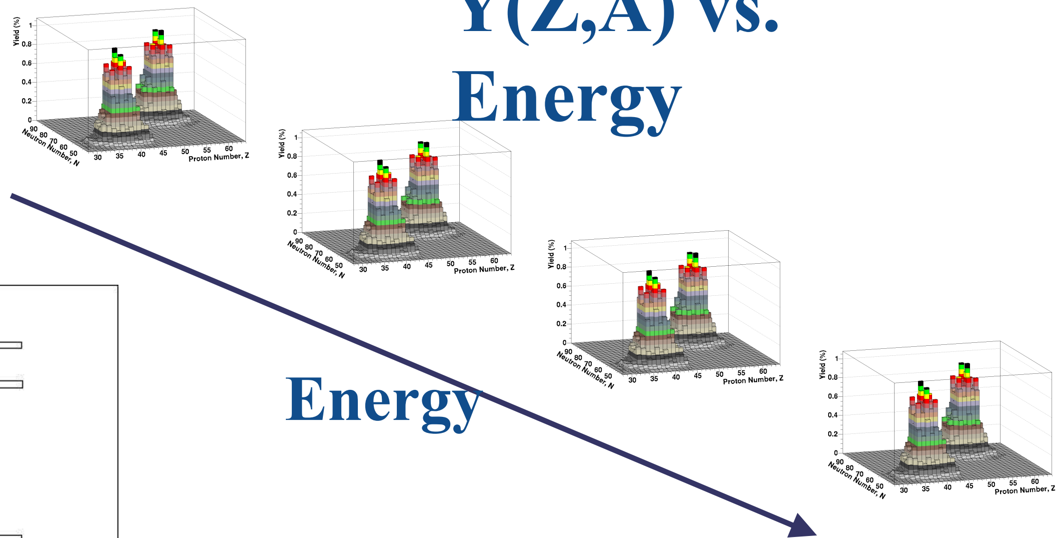
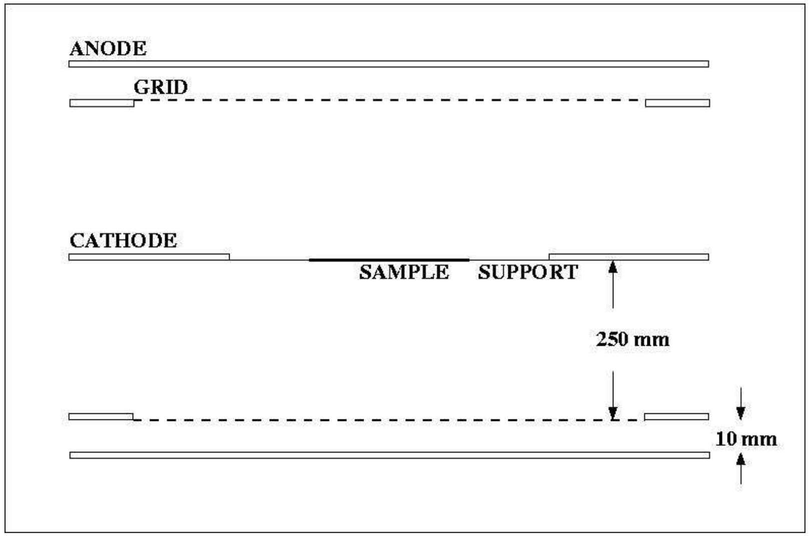
Experimental technique

Mass and charge distributions of fission residues with digitalized ionization chambers :

Y(Z,A) vs. Energy





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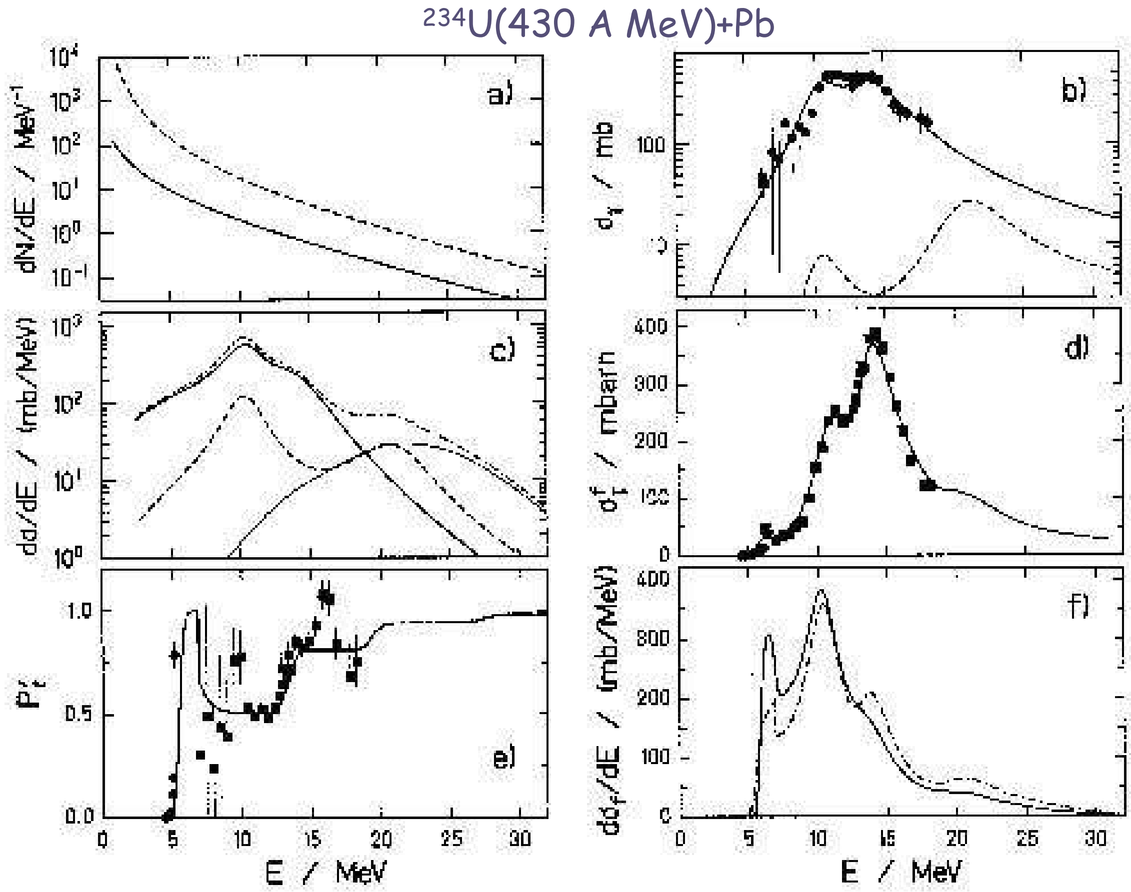
Physics cases

- Total photo-fission cross sections:
  - ✓ Excitations of the GDR and GQR
  - ✓ Precise mapping of fission barriers
  - ✓ Photo-absorption at high energies

- Mass and charge distribution of fission residues:
  - ✓ Pairing correlations in cold nuclear matter
  - ✓ Viscosity of cold nuclear matter
  - ✓ Washing out of shell effects with temperature
  - ✓ Collective excitations at high temperature
  - ✓ Viscosisty of highly excited matter

Photo-fission cross sections

- ✓ Coulomb excitation



- ✓ γ backscattering
  - ➢ Access to higher energies → photo-absorption
  - ➢ Role of γ polarization

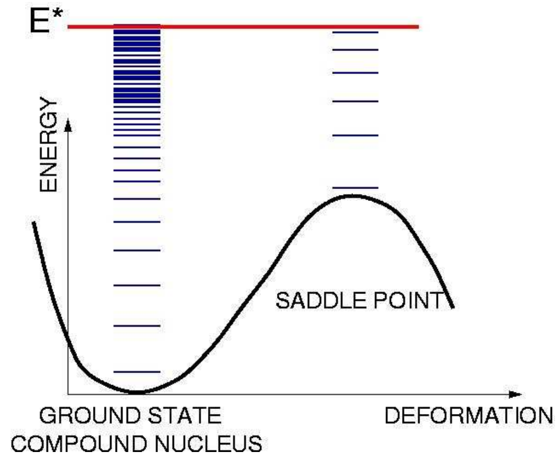
Dynamics of fission

Fission probability

Statistical model: Available phase-space at the saddle point

Dynamical model: Time evolution of the probability flow across the saddle point

Coupling of collective deformation degree of freedom Q with internal degrees of freedom through dissipation



•Dynamics of fission from the ground-state to the saddle-point:
evaporation residue productions

•Dynamics of fission beyond the saddle point:
kinematical properties and production cross sections of fission residues

Dynamics of fission

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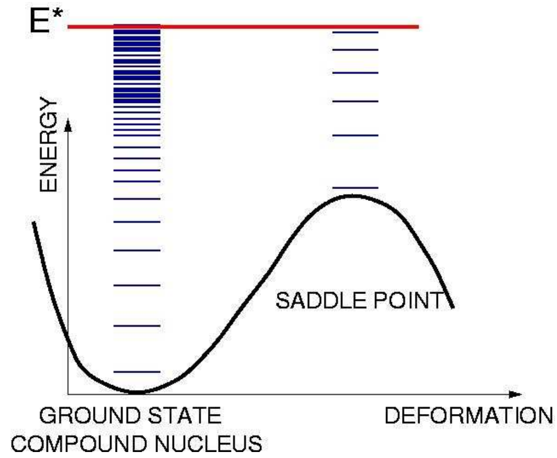
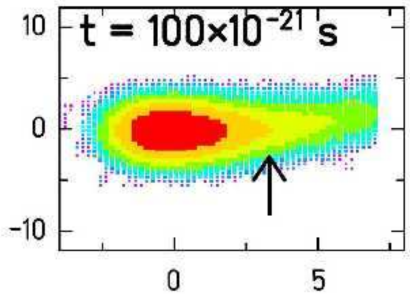


•Fission probability needs time to go up to the stationary value (transient effects)

•During this time the compound nucleus can evaporate nucleons

Transient effects increase evaporation residue productions with respect to fission (specially at high energies)



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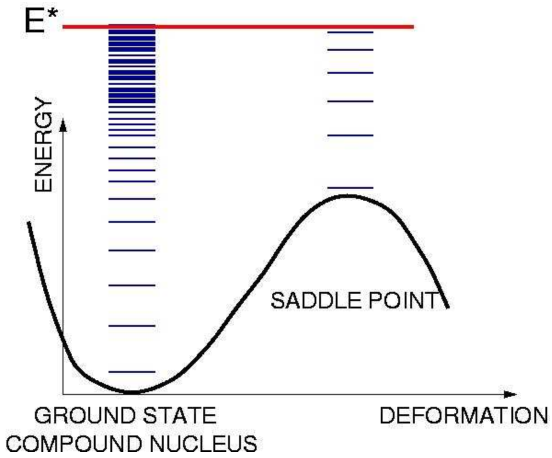


Langevin equation:

$$\frac{d^2Q}{dt^2} = -\frac{1}{M}\frac{d\tilde{V}(Q)}{dQ} - \beta\frac{dQ}{dt} + \sqrt{\frac{T}{M}\beta}\cdot F(t)$$

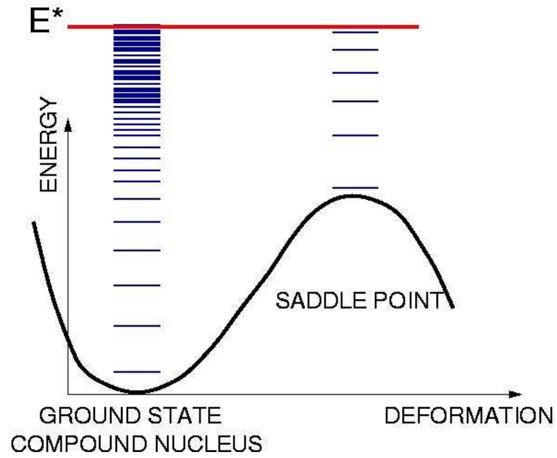
Drift force

Friction force

Diffussion (stochastic) force

Fission: diffusion process governed by the Reduced Dissipation Coefficient β

Dynamics of fission



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