# Fission by Intermediate Energy Nucleons

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Fission induced by intermediate energy nucleons (200 MeV - 2.5 GeV) is usually considered as a two-stage process:

- **Fast intranuclear cascade** described as a succession of binary collisions, leading to the emission of fast nucleons, light fragments, pions . . . and leaving an excited residual nucleus, which decays by:
- **De-excitation**: Evaporation, fission or other mechanism.

# Theoretical features for Cascade and De-excitation 1/2

Fast Cascade: **INCL++**

**(A. Boudard, J. Cugnon, J.-C. David, S. Leray and D. Mancusi, Phys. Rev. C 87 , 2013)**

**(A. Boubard, J. Cugnon, report INDC(NDS)-530, IAEA, Vienna, 2008, p. 29)**

De-excitation:

- **GEMINI++**

  **D. Mancusi, R.J. Charity and J. Cugnon, Phys. Rev. C 82 (2010) 044610**

- **ABLA07**

  **A. Kelic, M.V. Ricciardi and K.-H. Schmidt, report INDC(NDS)-530, IAEA, Vienna, 2008, p. 181**

# Theoretical features for Cascade and De-excitation 2/2

In **GEMINI++** an important parameter is the ratio between the level density parameter at the saddle point and the level density parameter at ground state configuration. The default value is:

$$\frac{\tilde{a}_f}{\tilde{a}_n} = 1.036$$

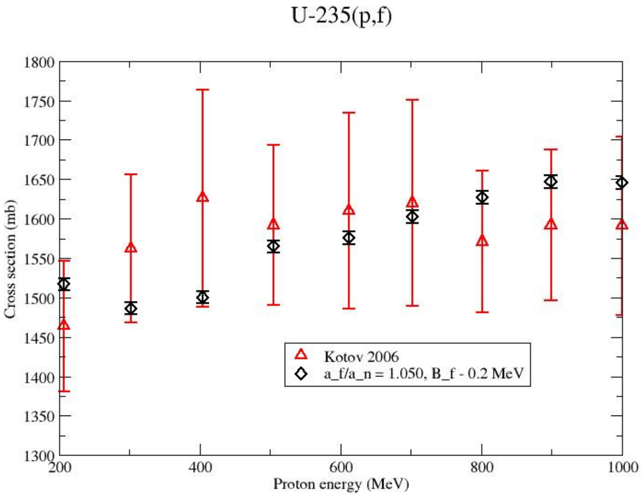
In **ABLA07** the level density parameter is defined as:

$$\tilde{a}_f = 0.073 \cdot A + 0.095 \cdot B_S \cdot A^{2/3}$$

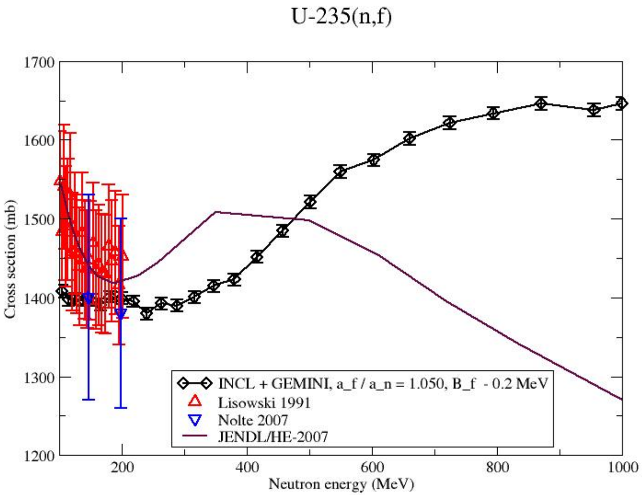
where $B_S$ is the ratio of the surface of the deformed nucleus and a spherical one with same A.

- **Parameters of fission models** (basically $\tilde{a}_f/\tilde{a}_n$ and the fission barrier $B_f$ in GEMINI and $\tilde{a}_f$ in ABLA) are calibrated on experimental **(p,f)** cross sections in the energy range 200 MeV - 1 GeV (Kotov et al., Phys. Rev. C 74 2006 034605) and are then applied to the calculation of **(n,f)** cross sections.
- **The theoretical ratios** to the $^{235}U(n,f)$ cross section are compared with the **n_TOF ratios** in the actinide region (C. Paradela et al., Phys. Rev. C 82 2010 034601) and in the Pb-Bi region (D. Tarrìo et al., Phys. Rev. C 83 2011 044620).

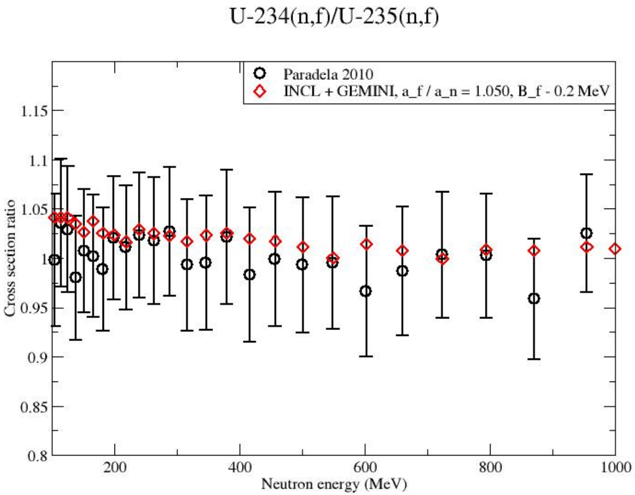
# Computational results (GEMINI): $^{235}U(p,f)$



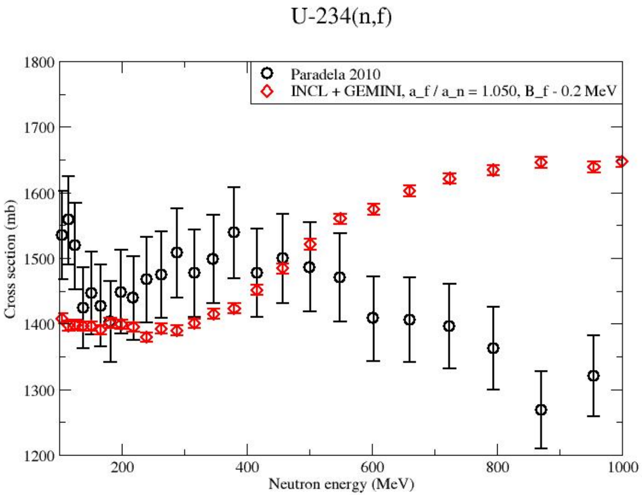
# Computational results (GEMINI): $^{235}U(n, f)$



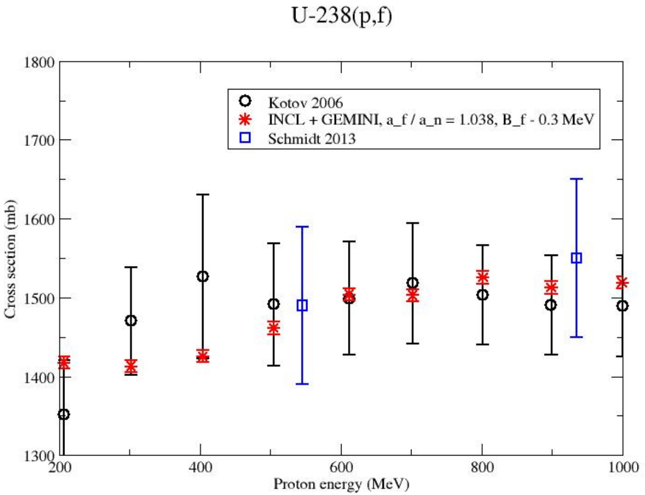
# Computational results (GEMINI): $\sigma_f(^{234}U)/\sigma_f(^{235}U)$



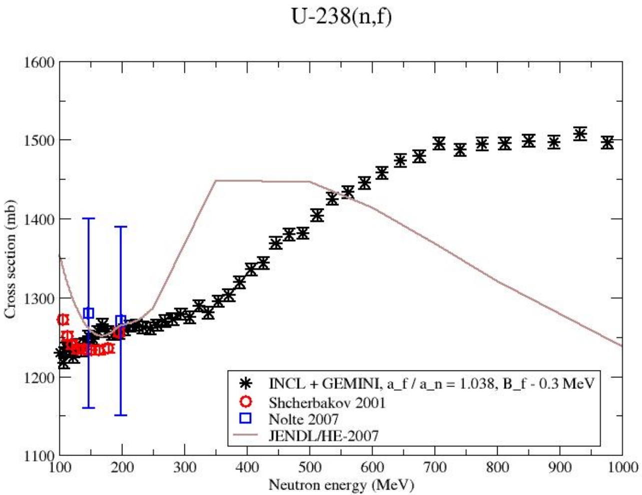
# Computational results (GEMINI): $^{234}U(n, f)$



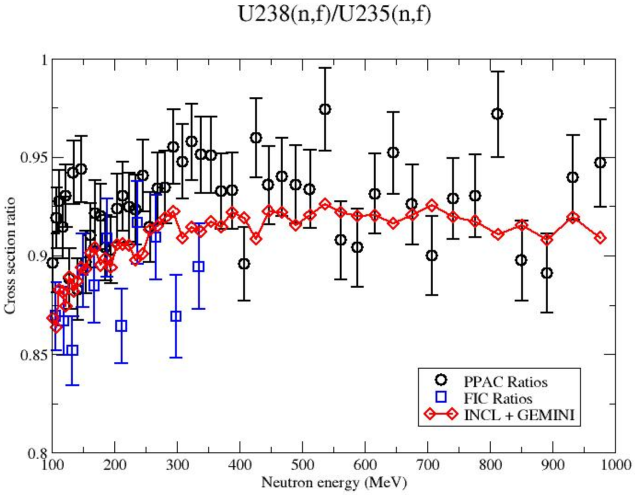
# Computational results (GEMINI): $^{238}U(p, f)$



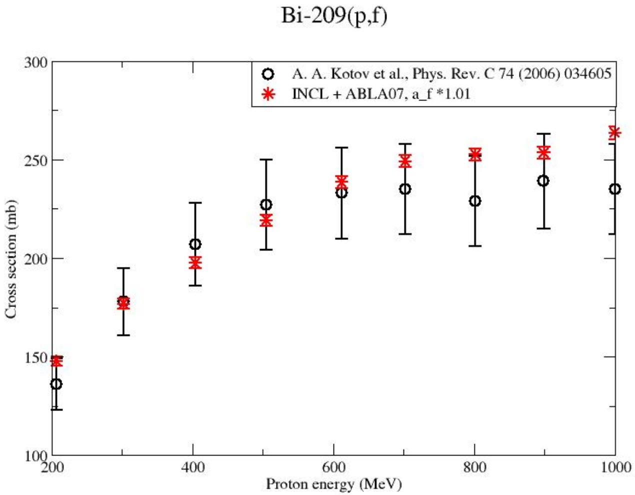
# Computational results (GEMINI): $^{238}U(n,f)$



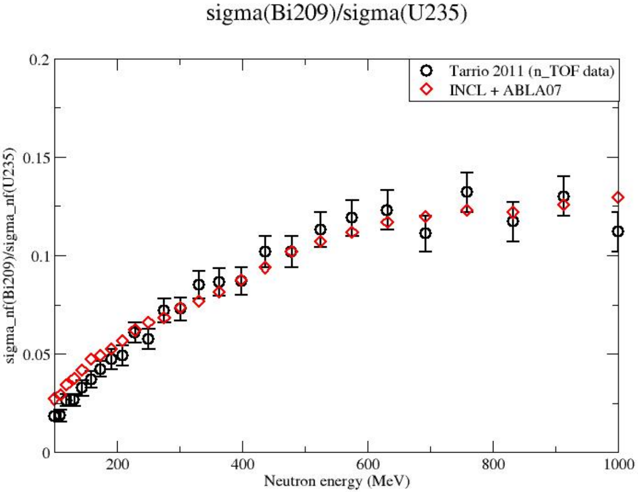
# Computational results (GEMINI): $\sigma_f(^{238}U)/\sigma_f(^{235}U)$



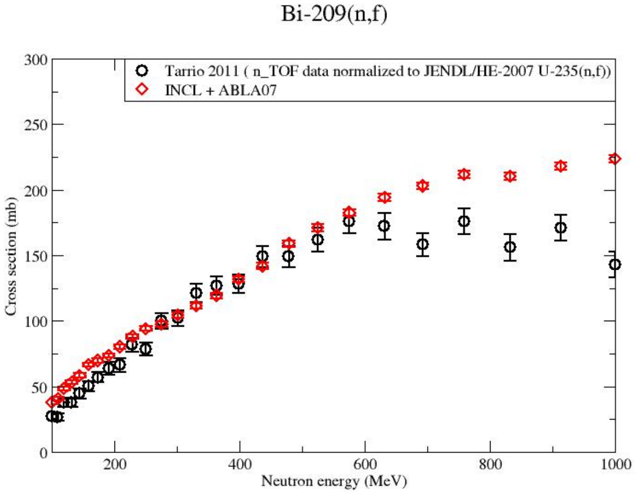
# Computational results (ABLA): $^{209}Bi(p, f)$



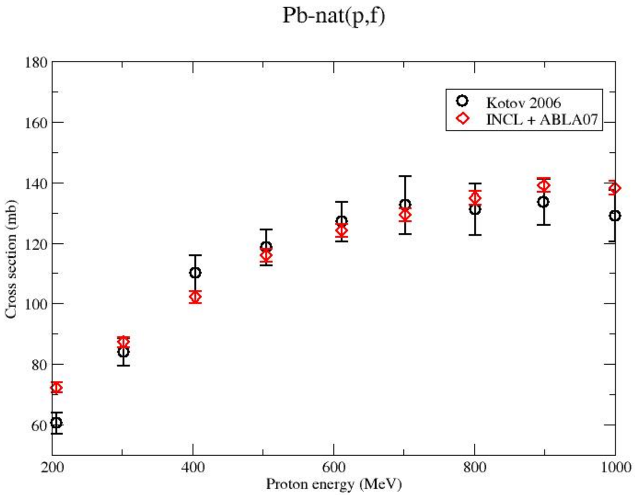
# Computational results (ABLA): $\sigma_f(^{209}Bi)/\sigma_f(^{235}U)$



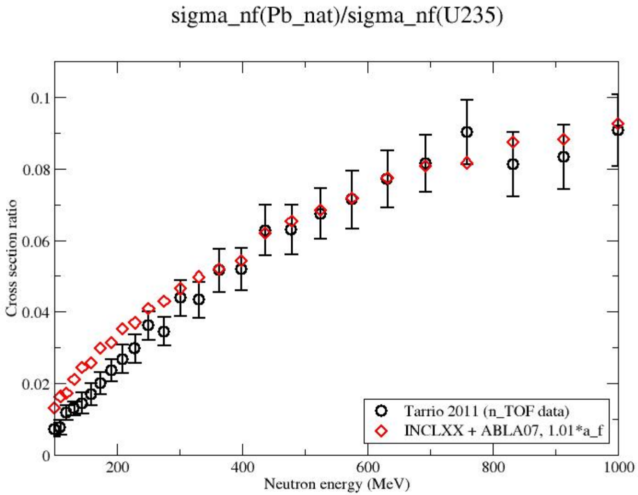
# Computational results (ABLA): $^{209}Bi(n,f)$



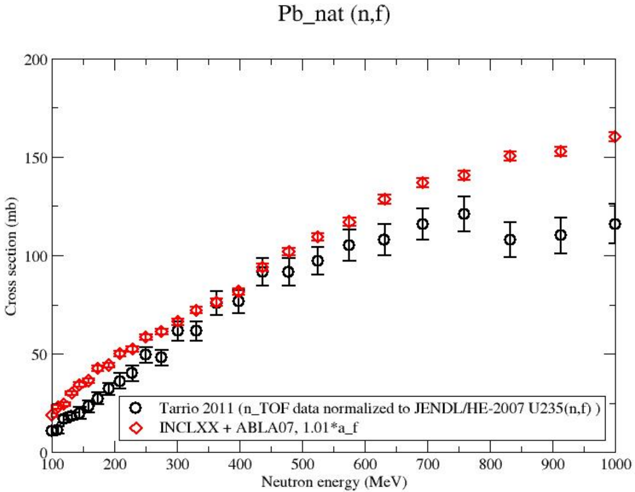
# Computational results (ABLA): $^{nat}Pb(p, f)$



# Computational results (ABLA): $\sigma_f(^{nat}Pb)/\sigma_f(^{235}U)$



# Computational results (ABLA): $^{nat}Pb(n, f)$



# Conclusion

- **INCL + GEMINI** and **INCL + ABLA07** are able to reproduce experimental (p,f) cross sections (Kotov 2006) and experimental ratios of (n,f) cross sections to $^{235}U(n,f)$ (n_TOF data) respectively in the actinide and Pb-Bi region.
- **Absolute (n,f) cross sections** are larger than those published by n_TOF in the energy region from 500 MeV to 1 GeV because of different normalization. The JENDL evaluation of the $^{235}U(n,f)$ cross section does not seem to be consistent with the experimental (p,f) cross section in the same energy range.

# Outlook

- **Systematic analysis** of (p,f) and (n,f) cross sections above 100 MeV for determination of crucial parameters as a function of the fissility parameter and other characteristics of target nuclei.
- **Prediction** of (n,f) cross sections to be measured by n_TOF.
- **Calculation** of angular distributions of fission fragments for the isotopes of interest to n_TOF.

**For further details:**

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# Thank you for your attention!