

Approches microscopiques de la dynamique nucléaire

Applications aux réactions autour de la barrière

1) Introduction

2) Définitions et concepts

- Interaction noyau-noyau et barrières de fusion
- Les étapes de la fusion
- Fonction d'excitation

3) Phénoménologie autour de la barrière

- Mécanismes en compétition
- Observables et techniques expérimentales
- Distributions de barrières
- Cas des noyaux exotiques

4) Les théories de champ moyen dynamique: une approche microscopique

- Introduction sur les théories microscopiques
- Rappels de mécanique quantique
- Hamiltonien microscopique
- Valeurs moyennes d'observables à un corps
- La théorie Hartree-Fock dépendant du temps (TDHF)
- Condition initiale du problème dynamique
- Evolution dynamique

5) Etude de réactions autour de la barrière avec TDHF

- Barrières de fusion et fonctions d'excitation
- Après la fusion: équilibration des degrés de liberté
- Transfert de nucléons sous la barrière
- Conclusions: succès et limitations de TDHF

6) Théories dynamiques au delà du champ moyen

Mécanismes en compétition autour de B

diffusion élastique



diffusion inélastique



fusion



sections efficaces bien comprises à $E \ll B$ et $E \gg B$
mais très sensible à la structure à $E \sim B$

transfert



peut dominer sous B
étonnamment grand pour des noyaux exotiques (${}^6\text{He}$)

cassure



cas particulier de la diffusion inélastique
= excitation vers un état du continuum

Distributions de barrières

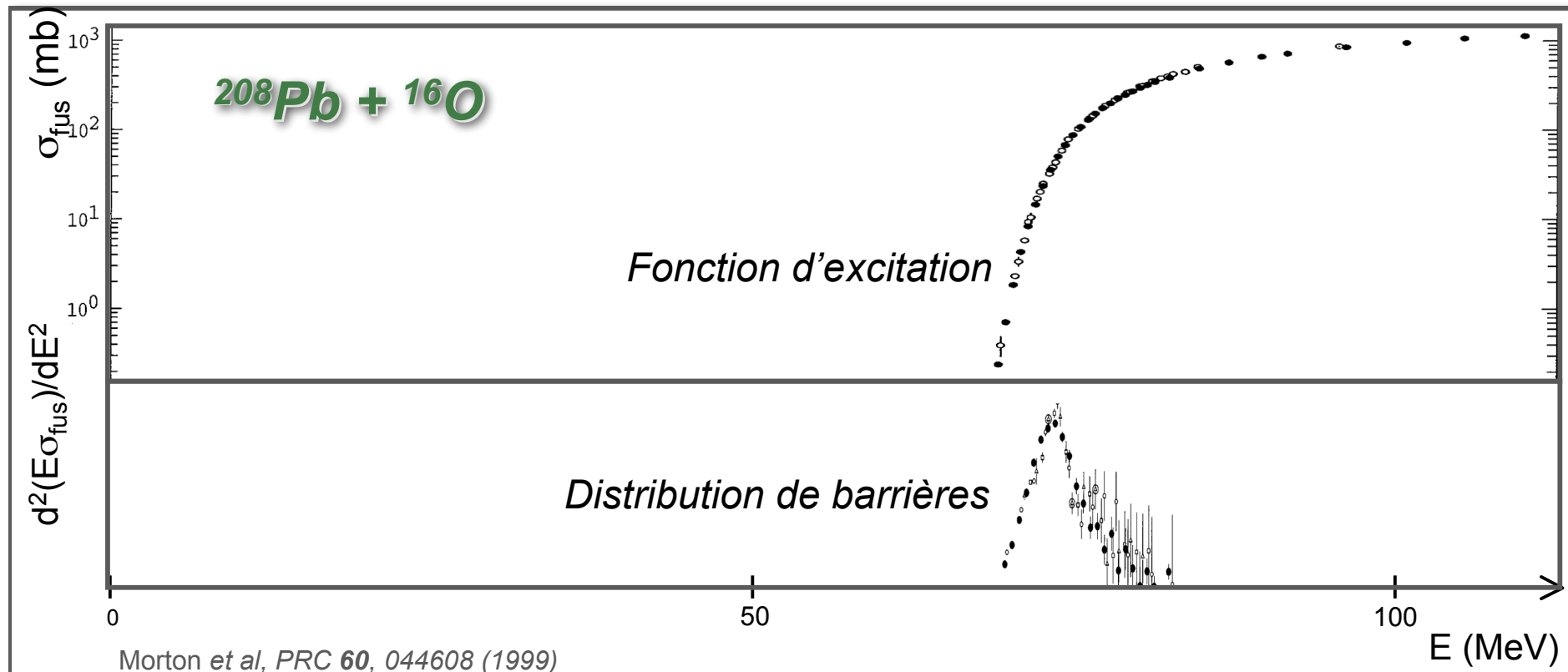
- **Fonction d'excitation:**

$$\sigma_{fus} = f(E_{cm})$$

- **Distribution de barrières:**

Rowley et al, PLB 254, 25 (1991)

$$D_B(E_{cm}) = \frac{d^2}{dE_{cm}^2} (\sigma_{fus} E_{cm})$$



Distributions de barrières

- **Fonction d'excitation:**

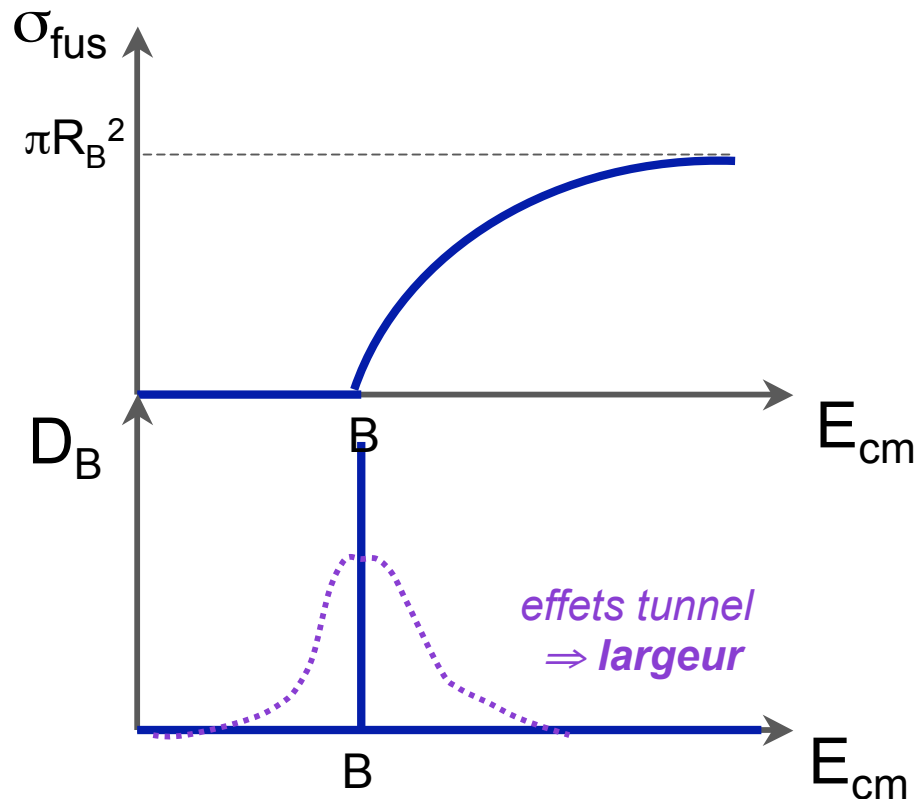
$$\sigma_{fus} = f(E_{cm})$$

- **Distribution de barrières:**

Rowley et al, PLB 254, 25 (1991)

$$D_B(E_{cm}) = \frac{d^2}{dE_{cm}^2} (\sigma_{fus} E_{cm})$$

Approche classique, cas à 1 barrière B:



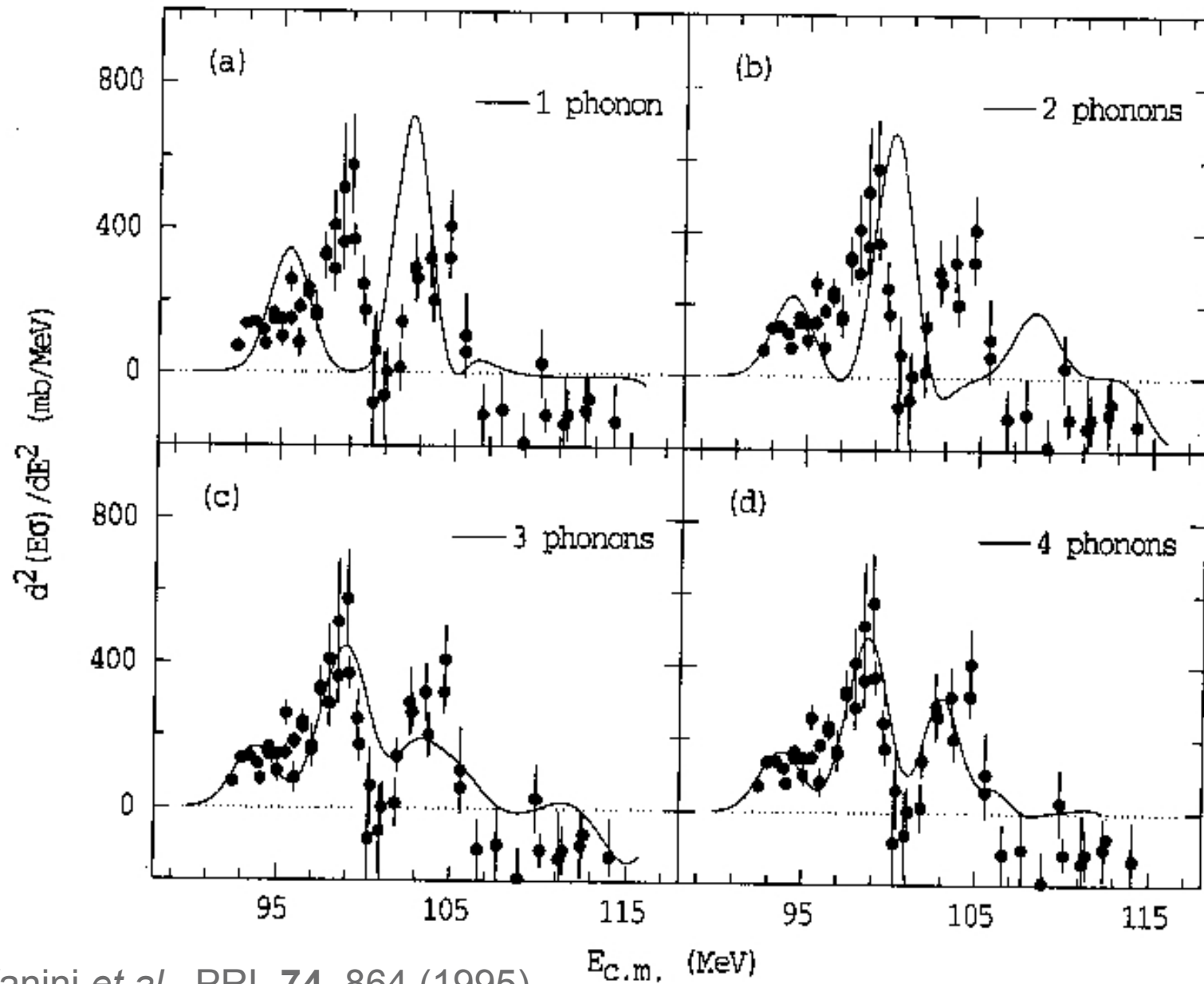
$$\begin{aligned} \sigma_{fus} &= 0 & E < B \\ &= \pi R_B^2 (1 - B/E) & E > B \end{aligned}$$

$$\begin{aligned} \frac{1}{\pi R_B^2} \frac{d(\sigma_{fus} E_{cm})}{dE_{cm}} &= 0 & E < B \\ &= 1 & E > B \\ &\equiv H(E - B) \end{aligned}$$

$$\frac{1}{\pi R_B^2} \frac{d^2(\sigma_{fus} E_{cm})}{dE_{cm}^2} = \delta(E - B)$$

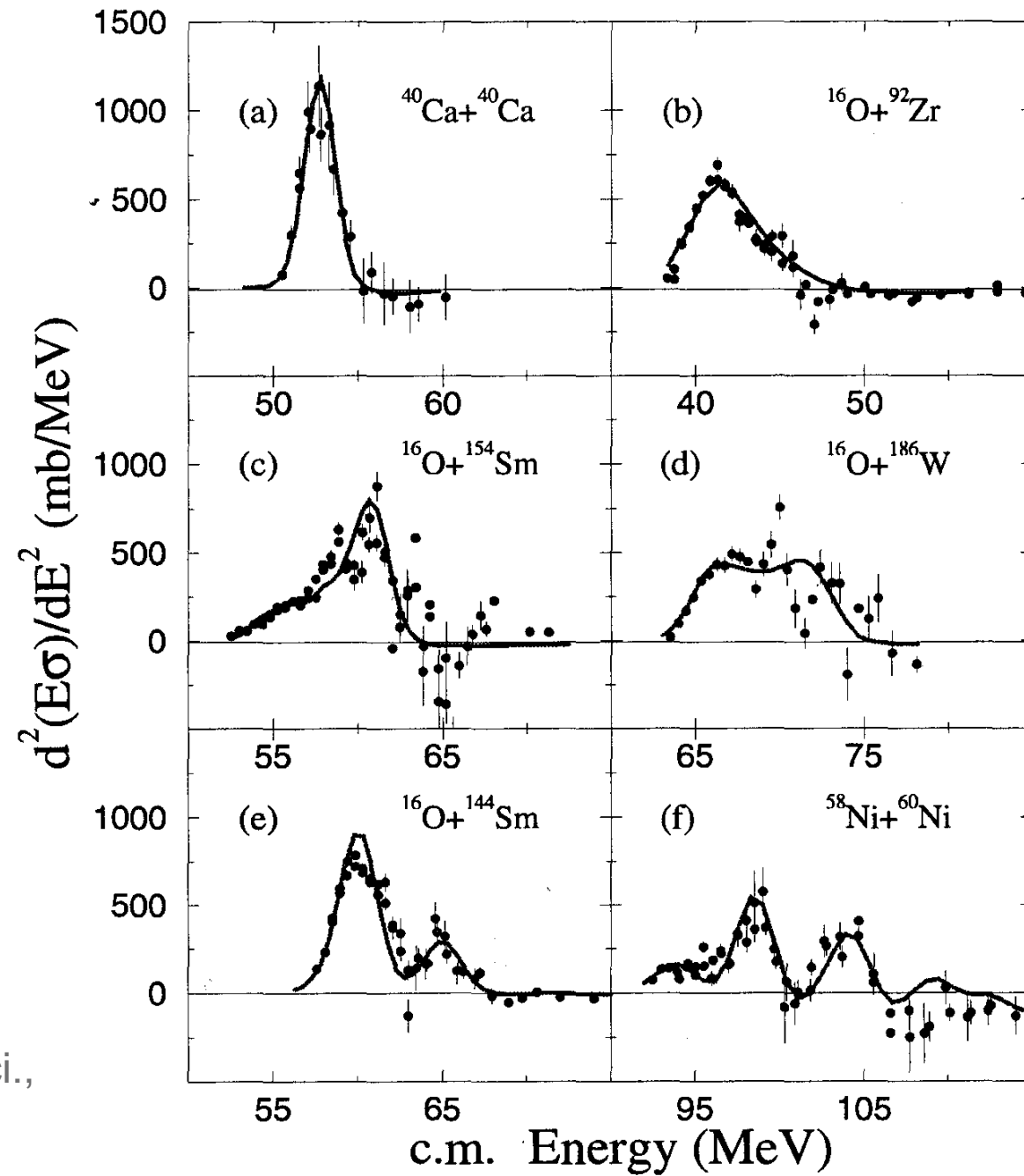
Distributions de barrières

$^{58}\text{Ni}+^{60}\text{Ni}$



A.M. Stefanini *et al.*, PRL 74, 864 (1995)

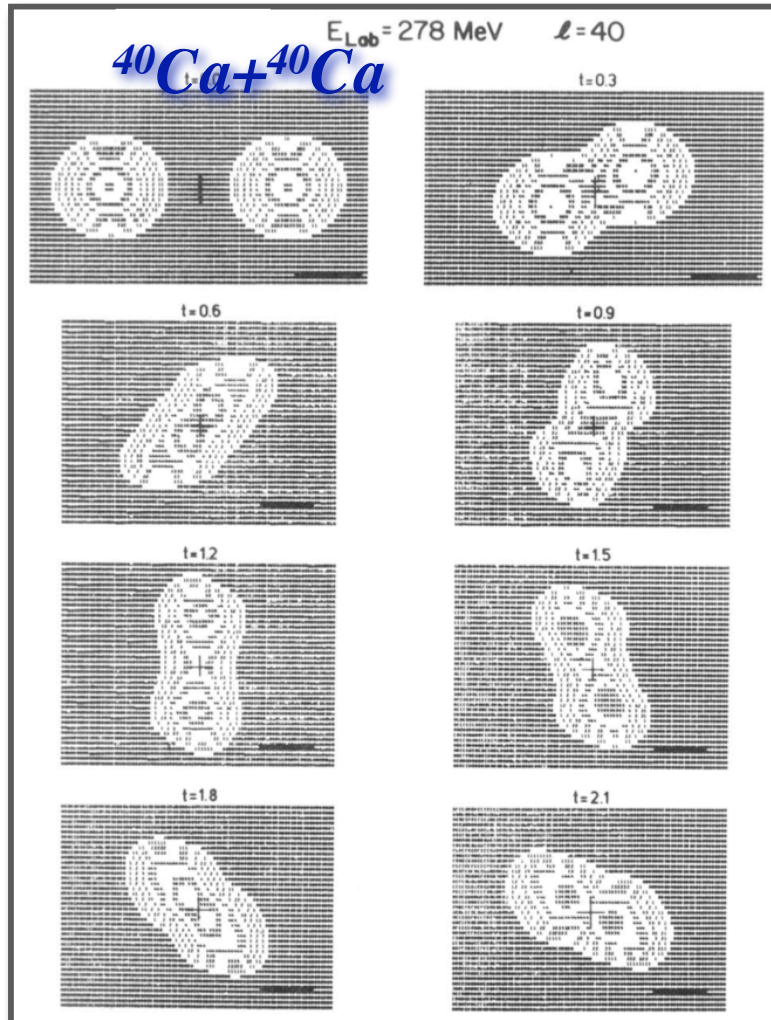
Distributions de barrières



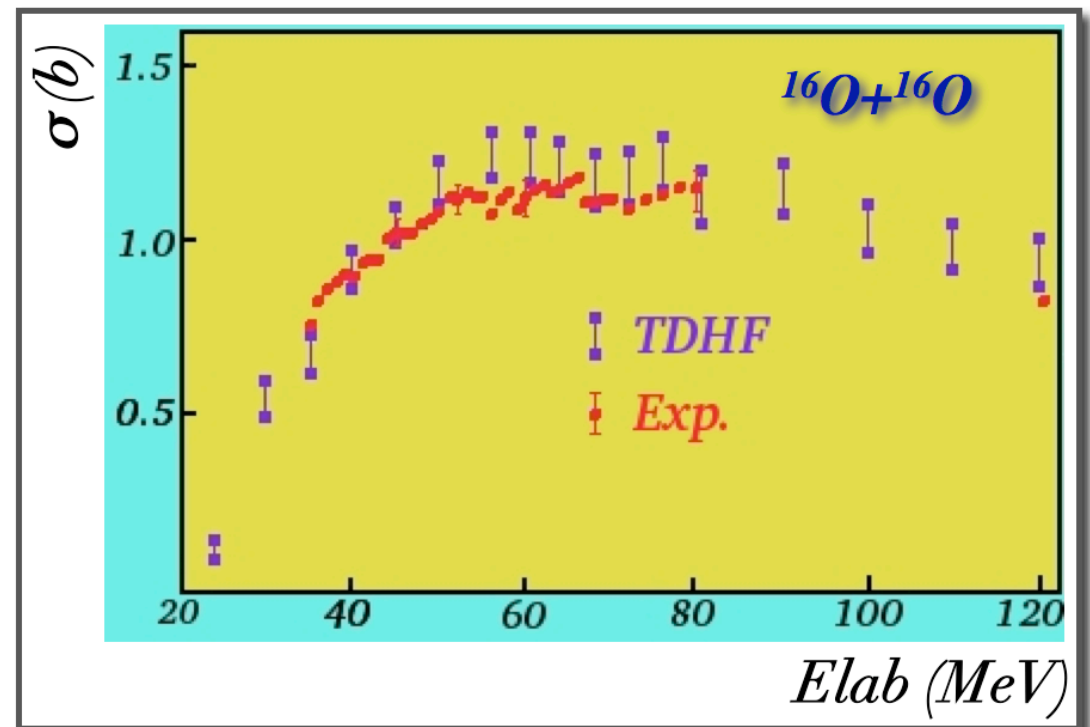
M.D Dasgupta *et al.*,
Annu. Rev. Nucl. Part. Sci.,
48, 401 (1998)

TDHF:

P.A.M. Dirac, Proc. Camb. Phil. Soc. **26**, 376 (1930)



P. Bonche, B. Grammaticos and S. Koonin
Phys. Rev. C 17, 1700 (1978)



État de N particules indépendantes = déterminant de Slater

Base de l'espace de Hilbert des états à N particules

$$\phi_{\nu_1 \dots \nu_N}(\xi_1 \dots \xi_N) = \frac{1}{\sqrt{N!}} \begin{vmatrix} \varphi_{\nu_1}(\xi_1) & \dots & \varphi_{\nu_1}(\xi_N) \\ \vdots & & \vdots \\ \varphi_{\nu_N}(\xi_1) & \dots & \varphi_{\nu_N}(\xi_N) \end{vmatrix}$$

Interaction effective de Skyrme

$$\begin{aligned}
 \hat{V}(1,2) = & t_0 \left(1 + x_0 \hat{P}_\sigma\right) \hat{\delta} \\
 & + \frac{1}{2} t_1 \left(1 + x_1 \hat{P}_\sigma\right) \left(\hat{\mathbf{k}}^2 \hat{\delta} - \hat{\delta} \hat{\mathbf{k}}^2\right) \\
 & + t_2 \left(1 + x_2 \hat{P}_\sigma\right) \left(\hat{\mathbf{k}} \cdot \hat{\delta} \hat{\mathbf{k}}\right) \\
 & + \frac{1}{6} t_3 \left(1 + x_3 \hat{P}_\sigma\right) \rho^\alpha(\hat{\mathbf{R}}) \hat{\delta} \\
 & + i W_0 \hat{\boldsymbol{\sigma}} \cdot \left(\hat{\mathbf{k}} \times \hat{\delta} \hat{\mathbf{k}}\right)
 \end{aligned} \tag{38}$$

avec $\hat{\delta} = \delta(\hat{\mathbf{r}}(1) - \hat{\mathbf{r}}(2))$, $\hat{\mathbf{k}} = (\hat{\mathbf{p}}(1) - \hat{\mathbf{p}}(2)) / \hbar$ (moment relatif), $\hat{\boldsymbol{\sigma}} = \hat{\boldsymbol{\sigma}}(1) + \hat{\boldsymbol{\sigma}}(2)$, $\hat{\mathbf{R}} = (\hat{\mathbf{r}}(1) + \hat{\mathbf{r}}(2)) / 2$, $\hat{\boldsymbol{\sigma}}(i) = \hat{\sigma}_x(i) \mathbf{e}_x + \hat{\sigma}_y(i) \mathbf{e}_y + \hat{\sigma}_z(i) \mathbf{e}_z$, $\hat{\sigma}_{xyz}(i)$ sont les opérateurs agissant sur le spin de la particule i et représentés par les matrices de Pauli dans l'espace de spin, et $\hat{P}_\sigma = (1 + \hat{\boldsymbol{\sigma}}(1) \cdot \hat{\boldsymbol{\sigma}}(2)) / 2$ est l'opérateur d'échange de spin. Les termes "t₁" et "t₂" sont non locaux et simulent une courte portée de l'interaction. Le terme "W₀" est le terme de spin-orbite.

Équation d'évolution de la matrice densité à un corps

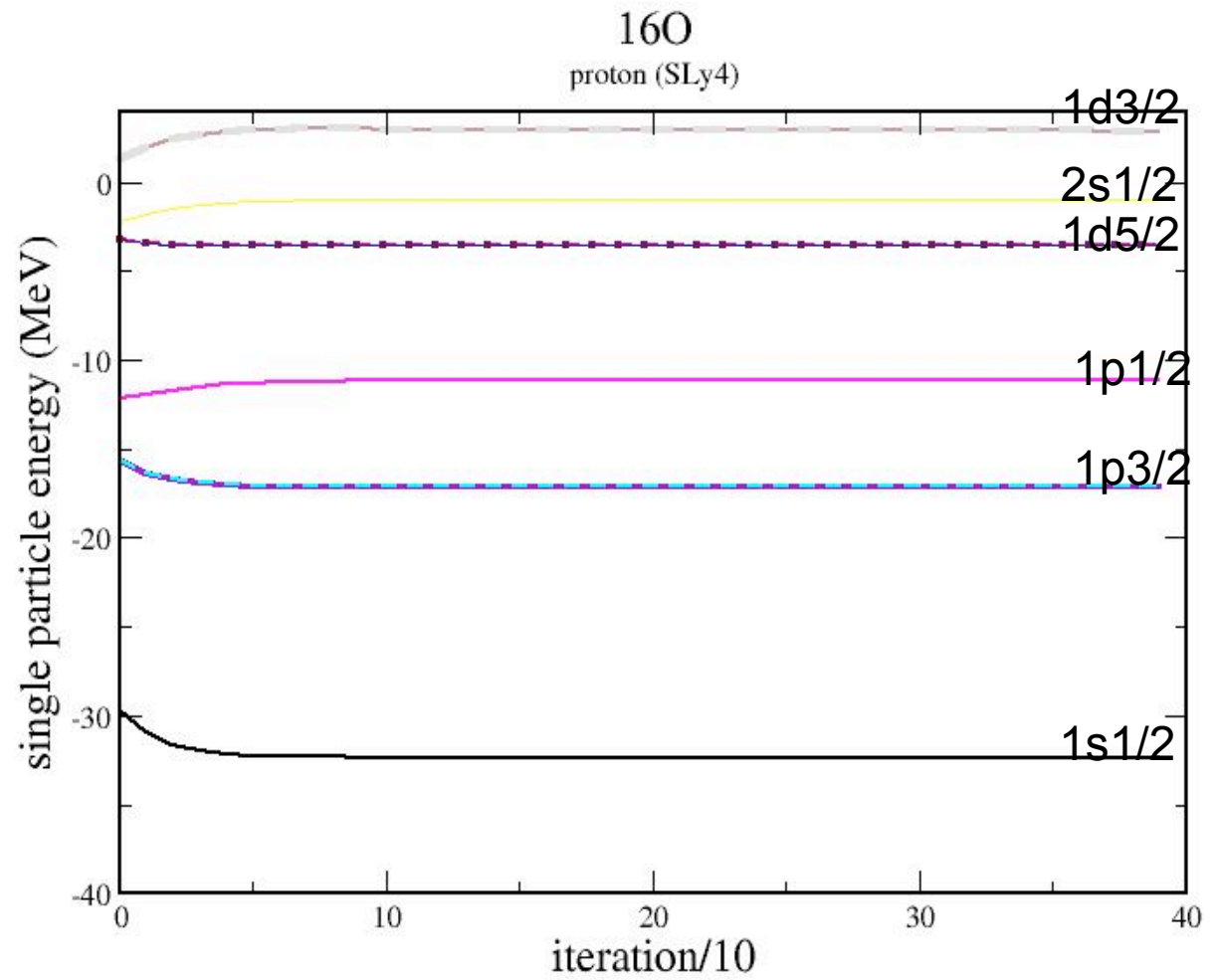
$$i \hbar \frac{\partial}{\partial t} \rho_{ji} = [h[\rho], \rho]_{ji} + \frac{1}{2} \text{Tr}_2 [\bar{v}(1, 2) , C(1, 2)]_{ji}$$

$$h[\rho] = t + U[\rho]$$

$$U[\rho]_{ij} = \sum_{kl} \bar{v}_{ikjl} \rho_{lk} = \text{Tr}_2 \{ \bar{v}(1, 2) \rho(2) \}_{ij}$$

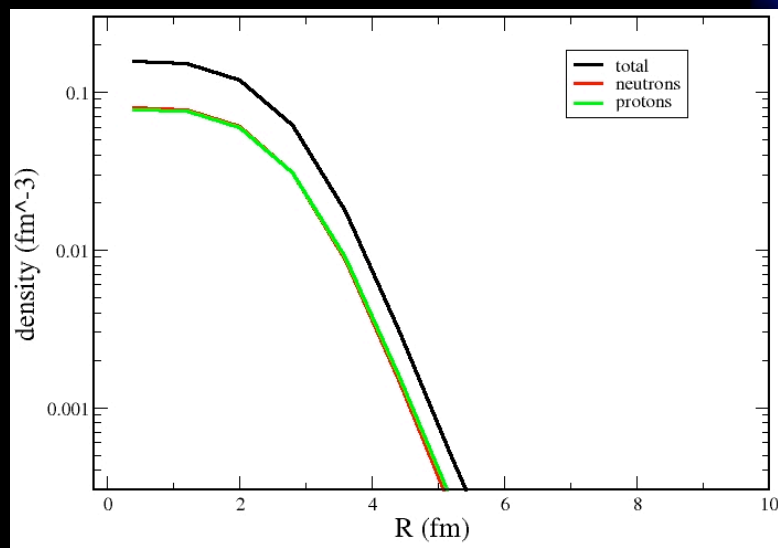
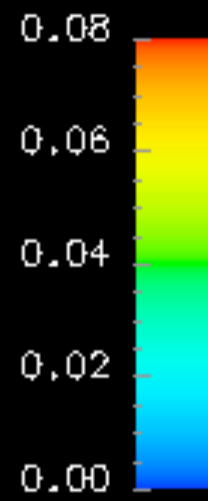
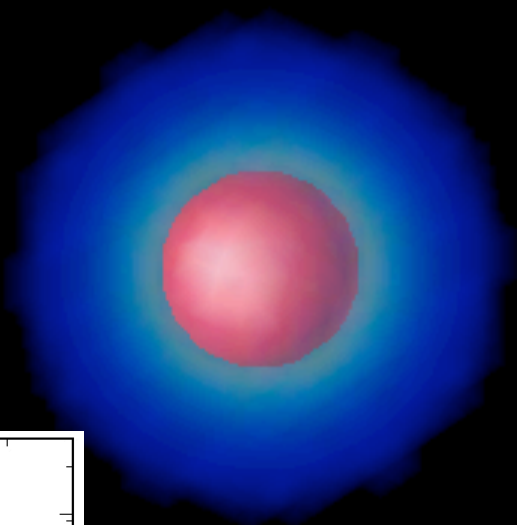
Etat fondamental HF

Calculs HF



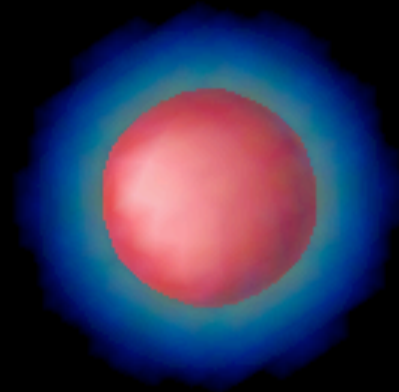
¹⁶O

density (fm⁻³)



1s_{1/2}

density (fm⁻³)



0.08

0.06

0.04

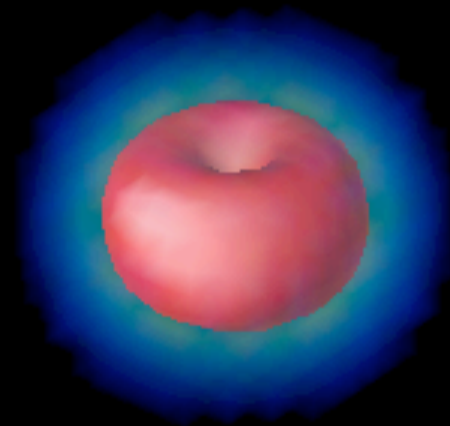
0.02

0.00



1p_{3/2}

density (fm⁻³)



0.08

0.06

0.04

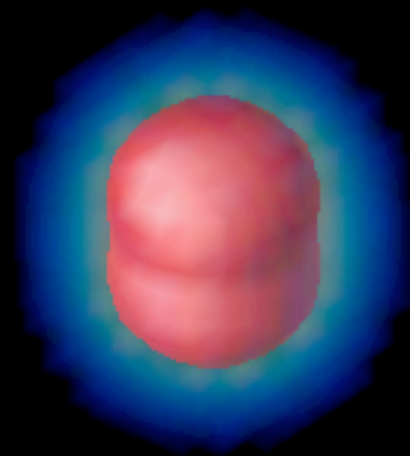
0.02

0.00



1p_{3/2}

density (fm⁻³)



0.08

0.06

0.04

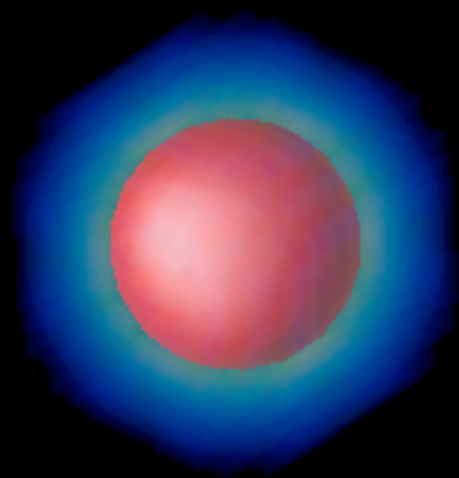
0.02

0.00



1p1/2

density (fm⁻³)



0.08

0.06

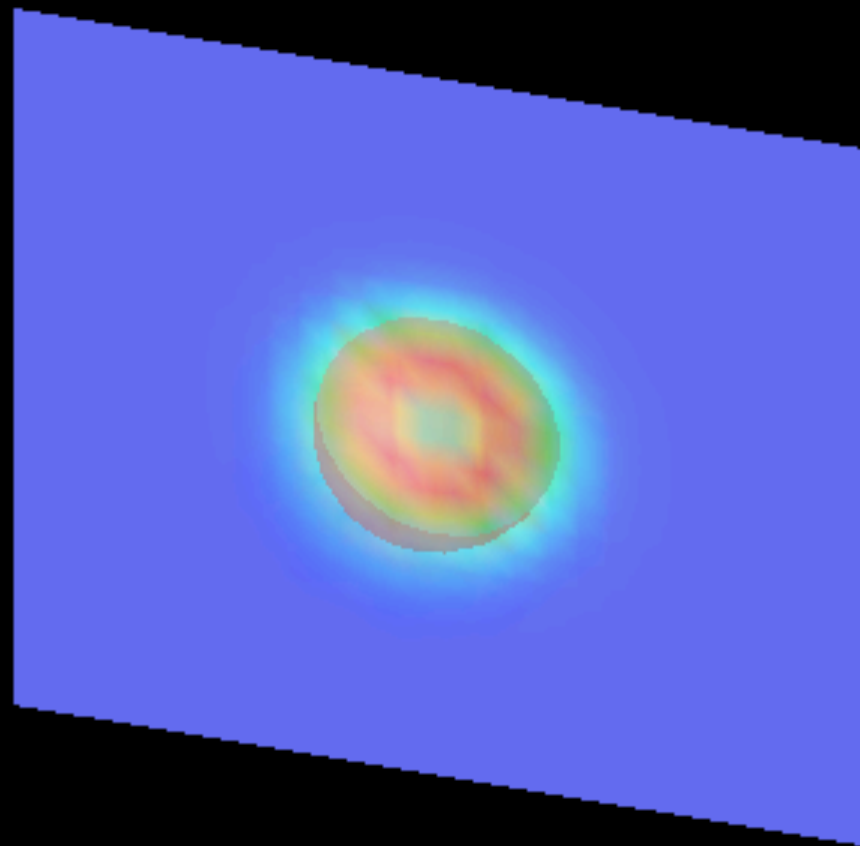
0.04

0.02

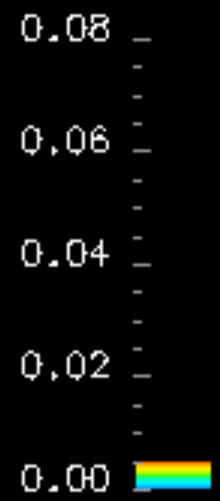
0.00



1p1/2

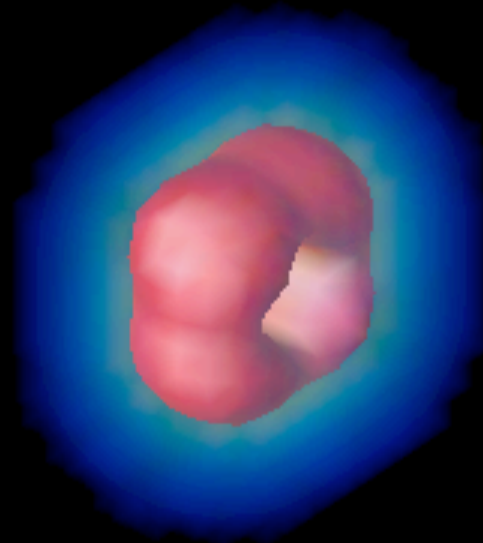


density (fm⁻³)



1d5/2

density (fm⁻³)



0.08

0.06

0.04

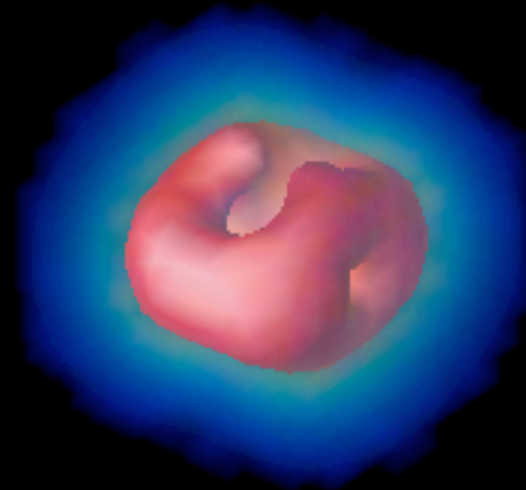
0.02

0.00



1d5/2

density (fm⁻³)



0.08

0.06

0.04

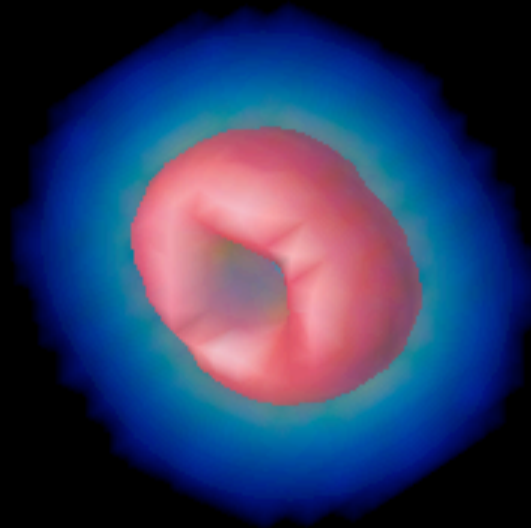
0.02

0.00



1d5/2

density (fm⁻³)



0.08

0.06

0.04

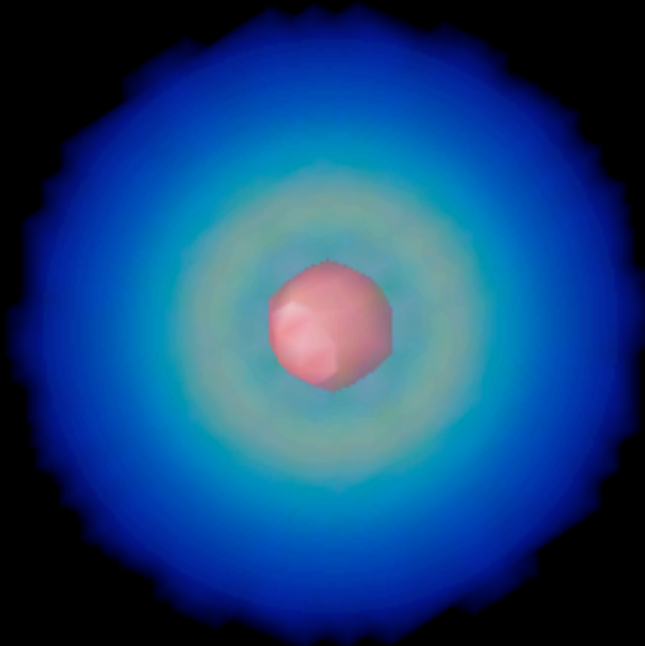
0.02

0.00



2s_{1/2}

density (fm⁻³)



0.08

0.06

0.04

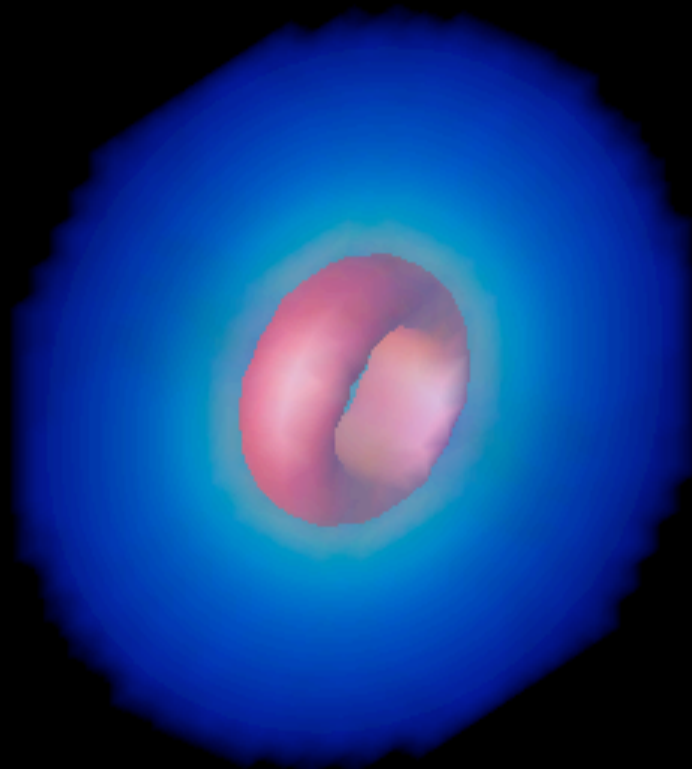
0.02

0.00



1d3/2

density (fm⁻³)



0.08

0.06

0.04

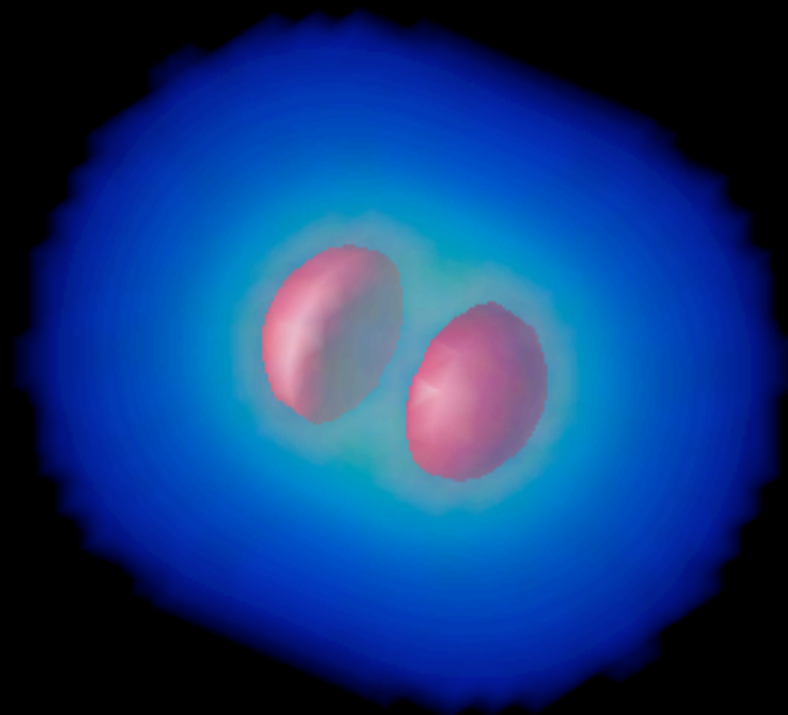
0.02

0.00



1d3/2

density (fm⁻³)



0.08

0.06

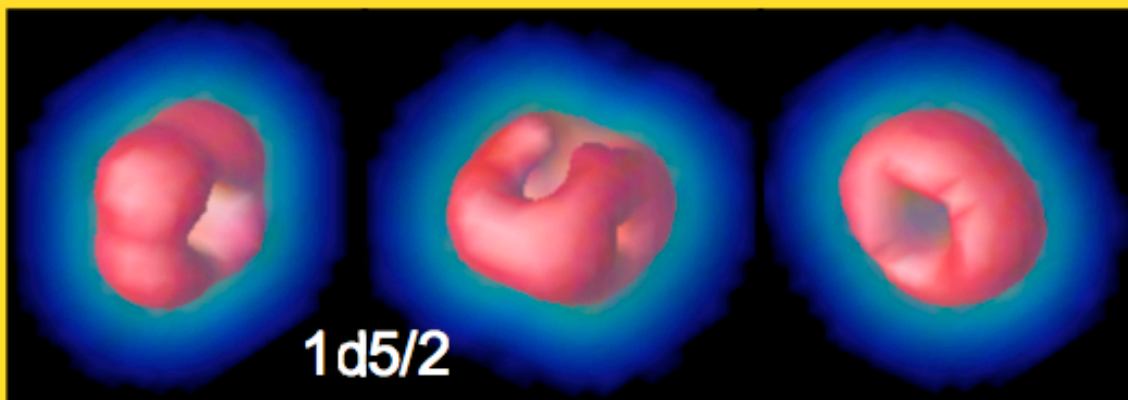
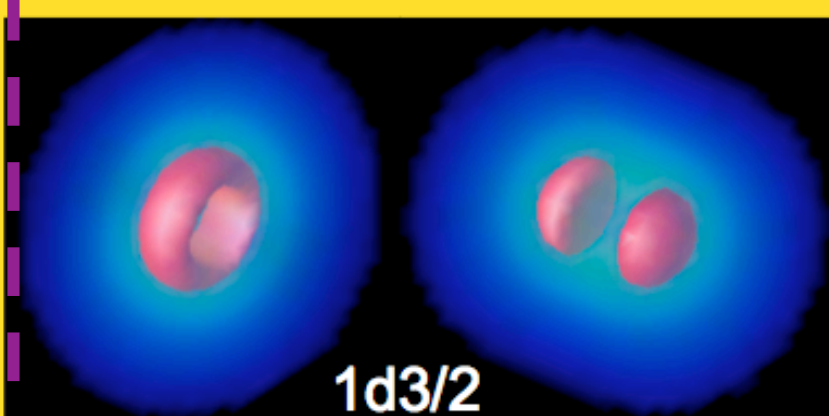
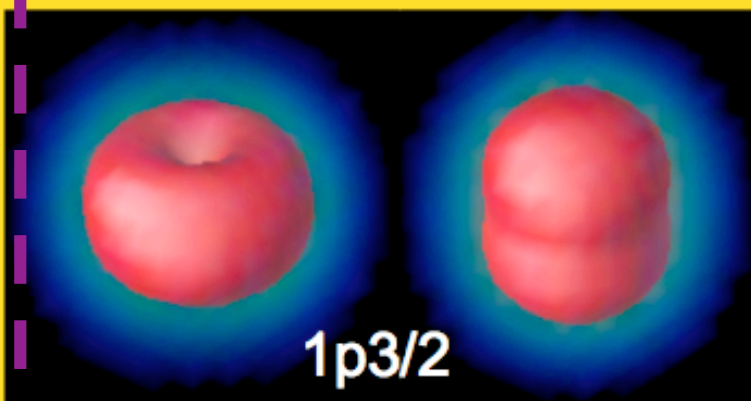
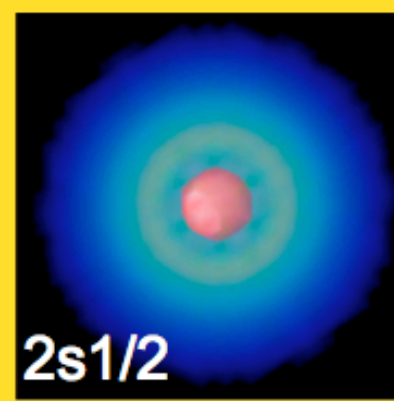
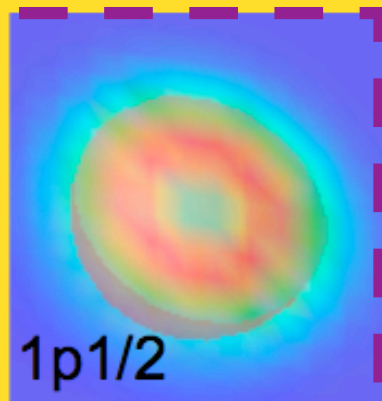
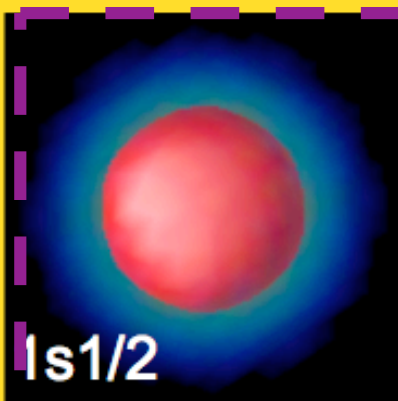
0.04

0.02

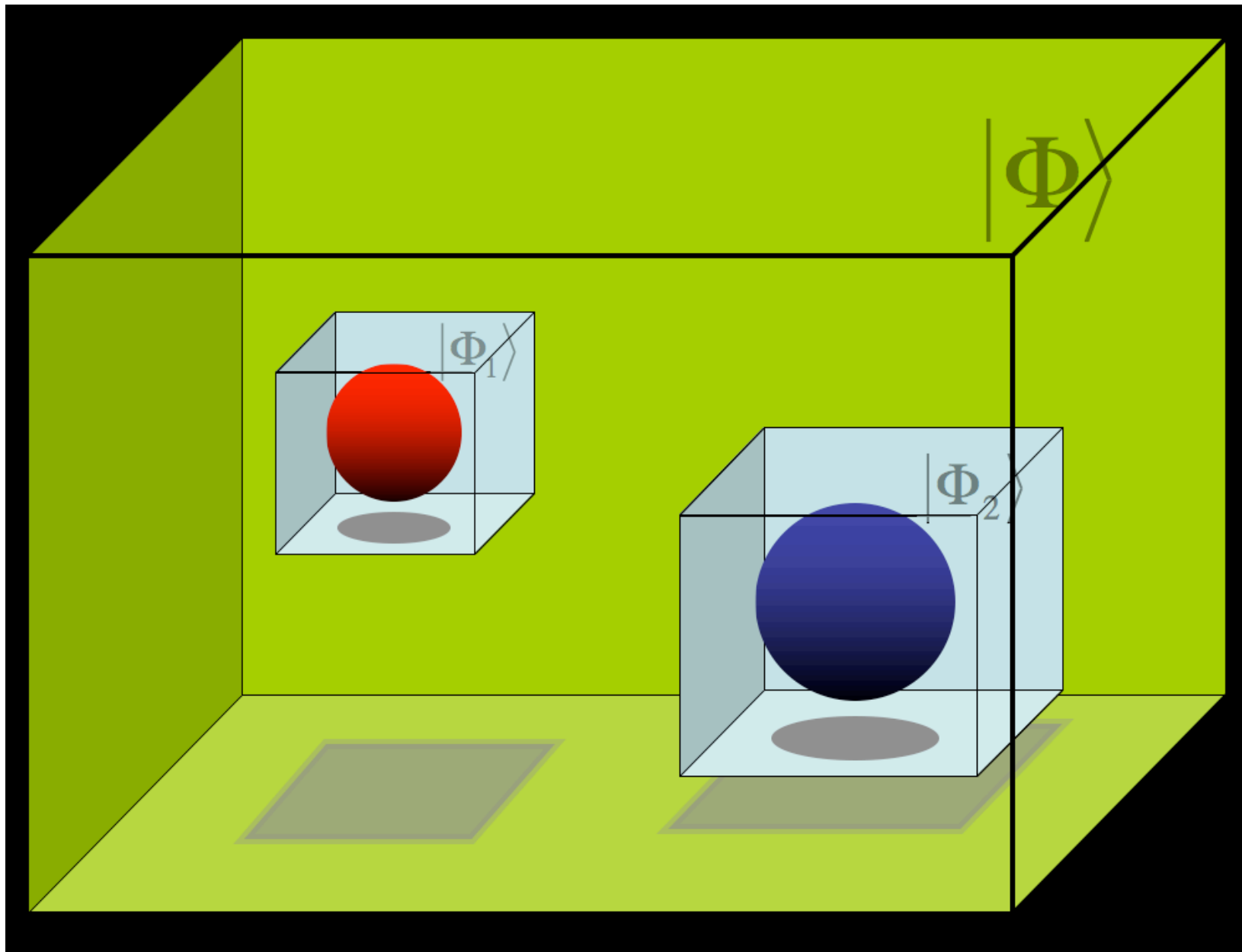
0.00



États occupés



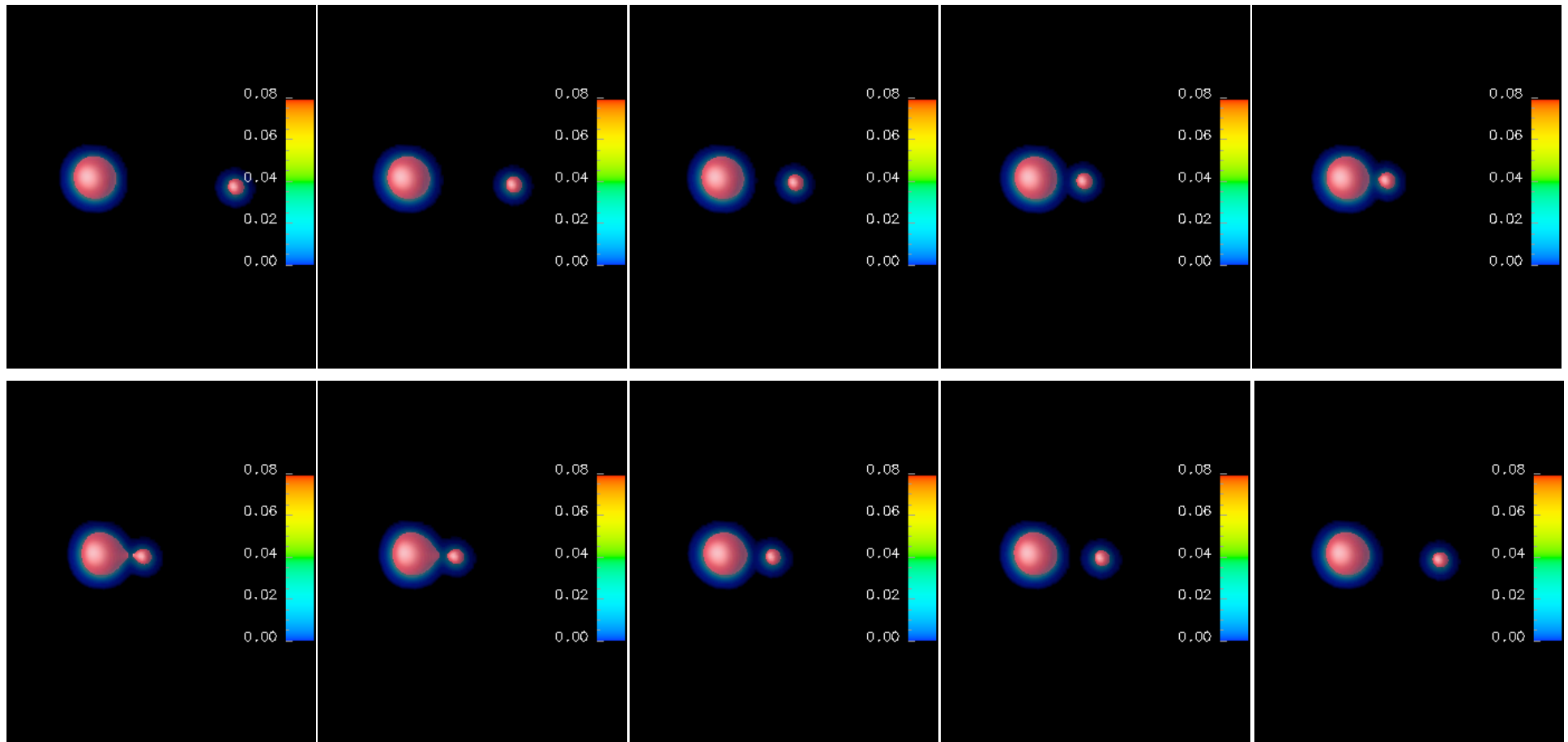
État initial à 2 noyaux



Barrières de fusion de noyaux sphériques



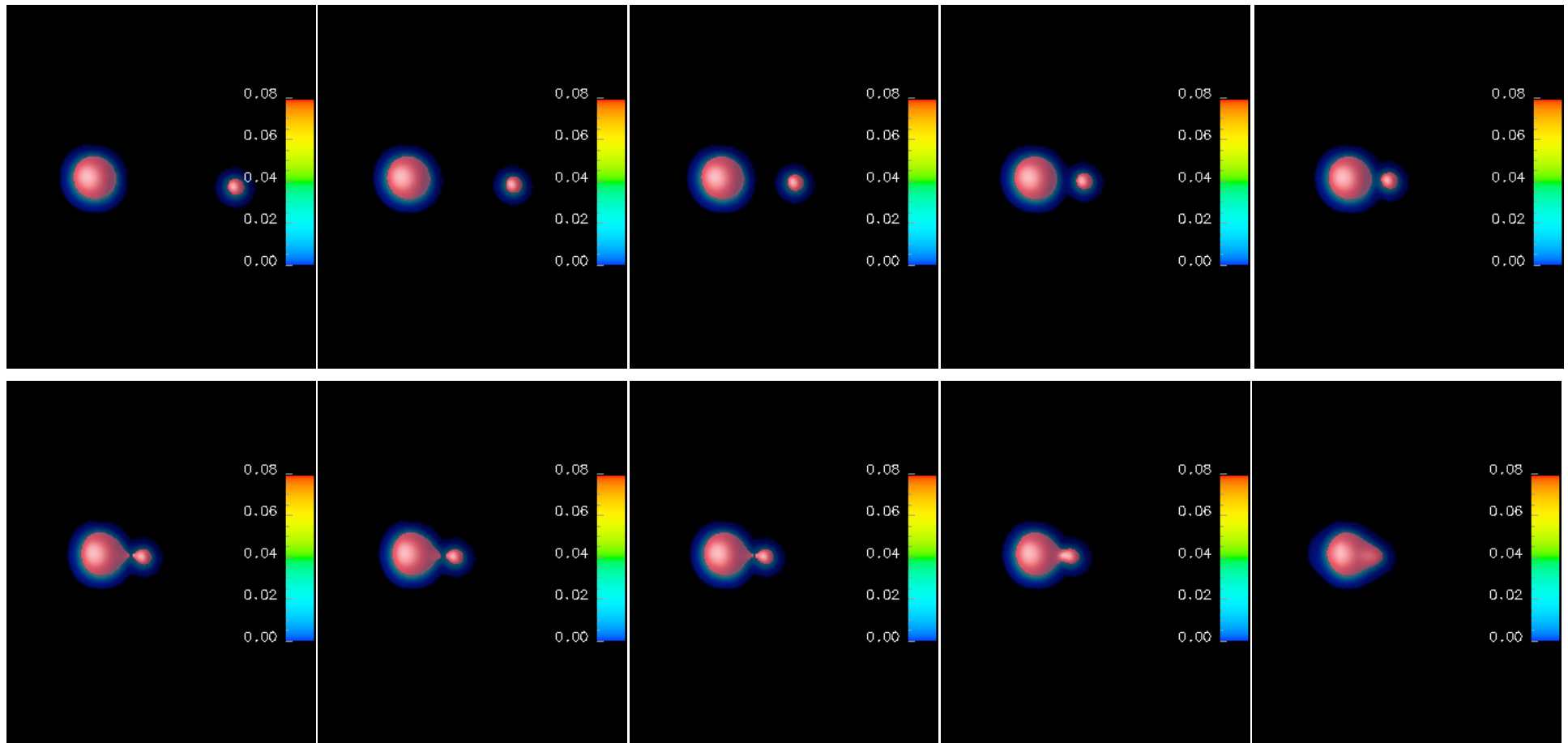
74.44 MeV



Barrières de fusion de noyaux sphériques

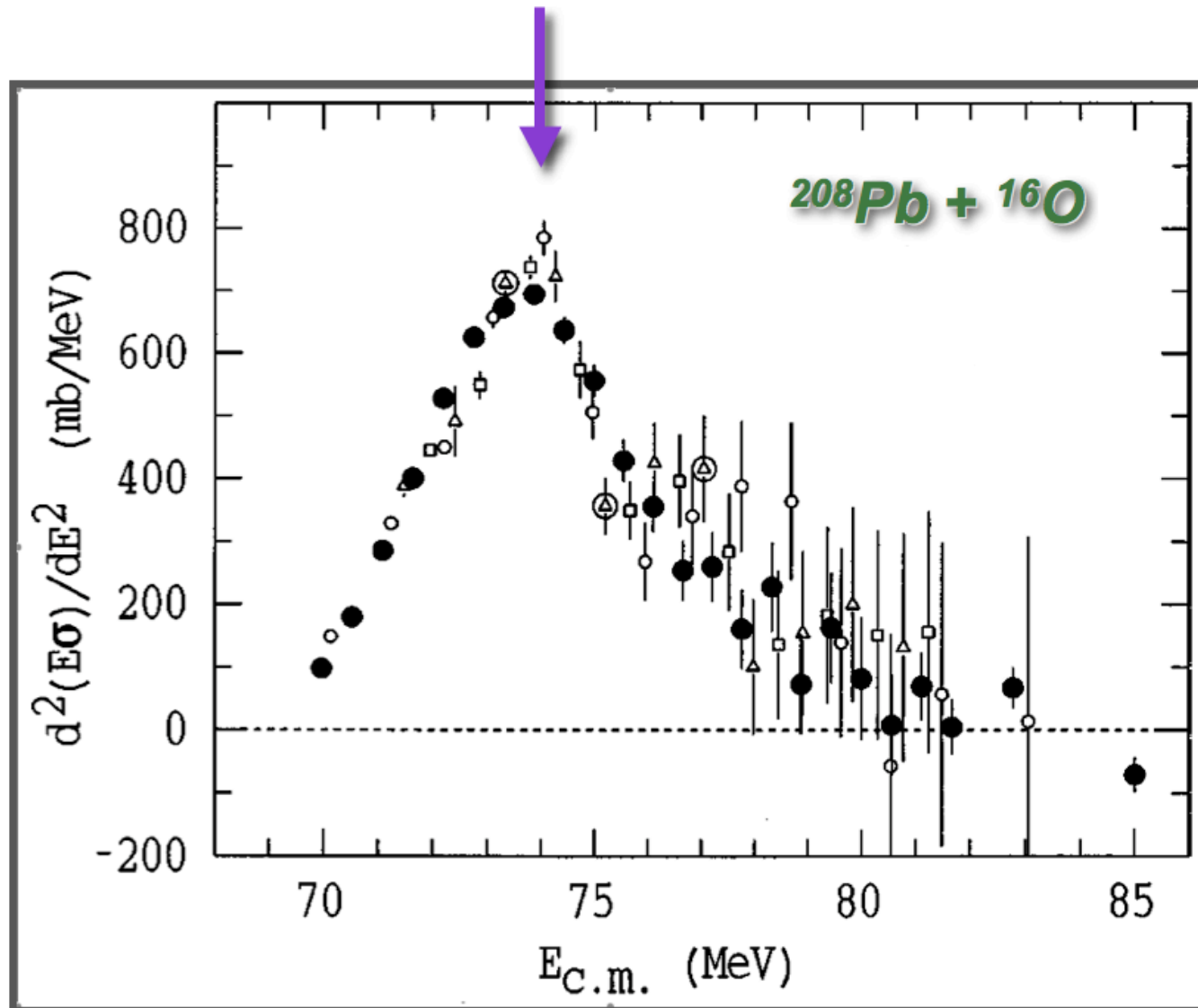
$^{208}\text{Pb} + ^{16}\text{O}$

74.45 MeV

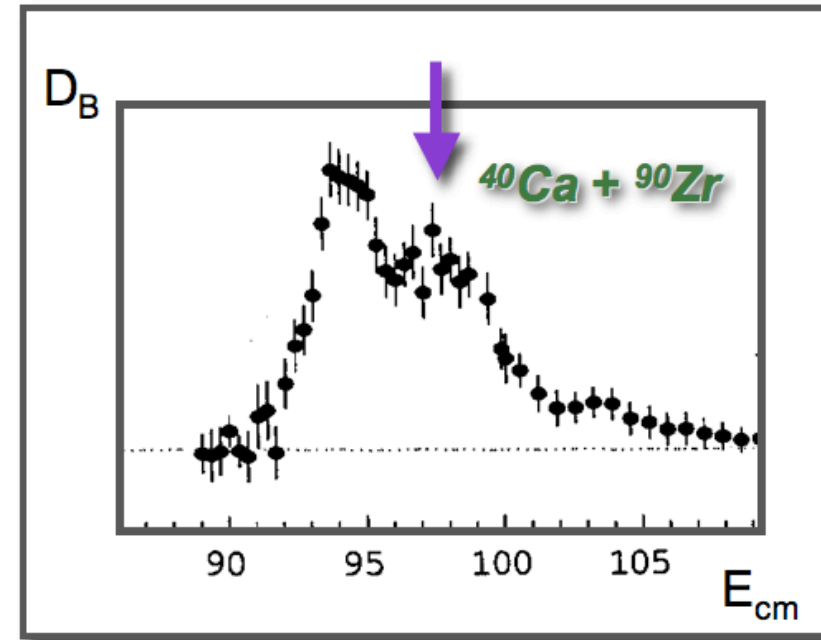
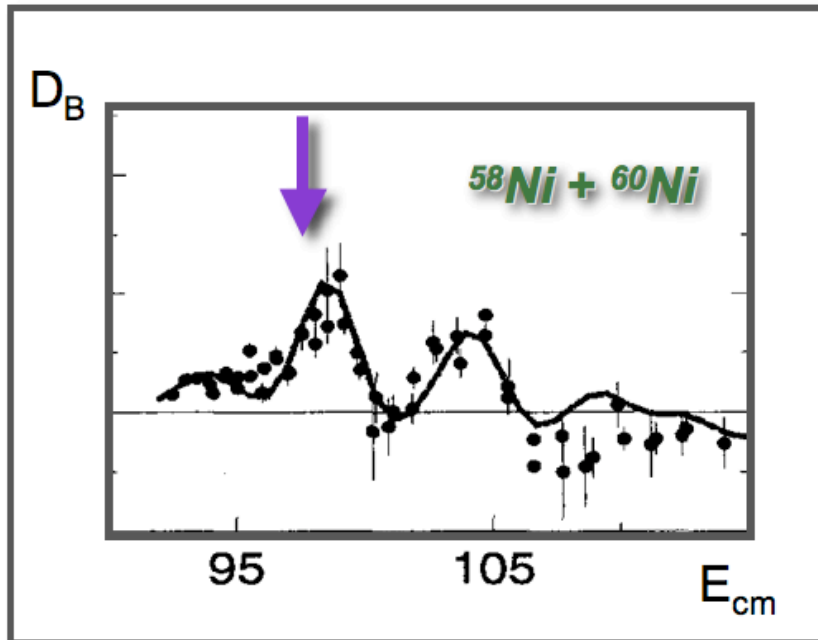
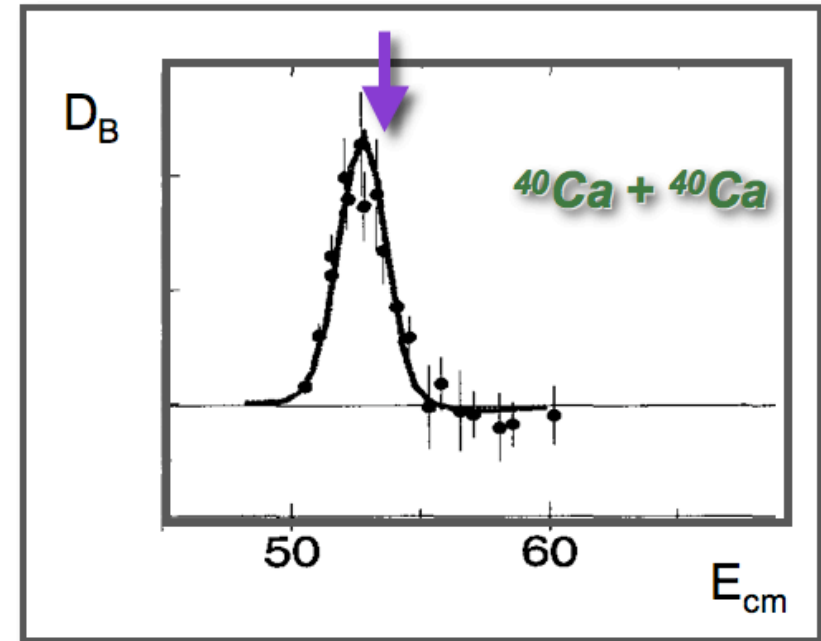
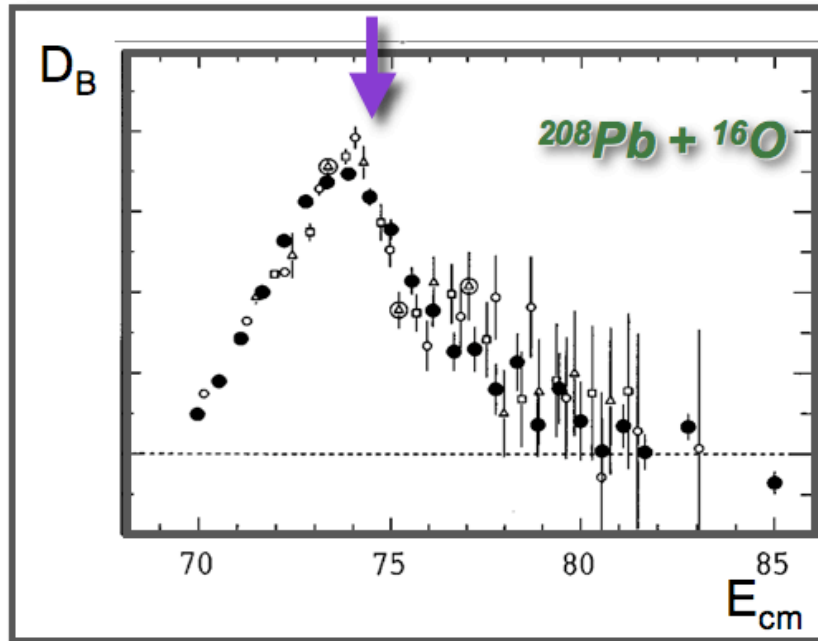


Barrières de fusion de noyaux sphériques

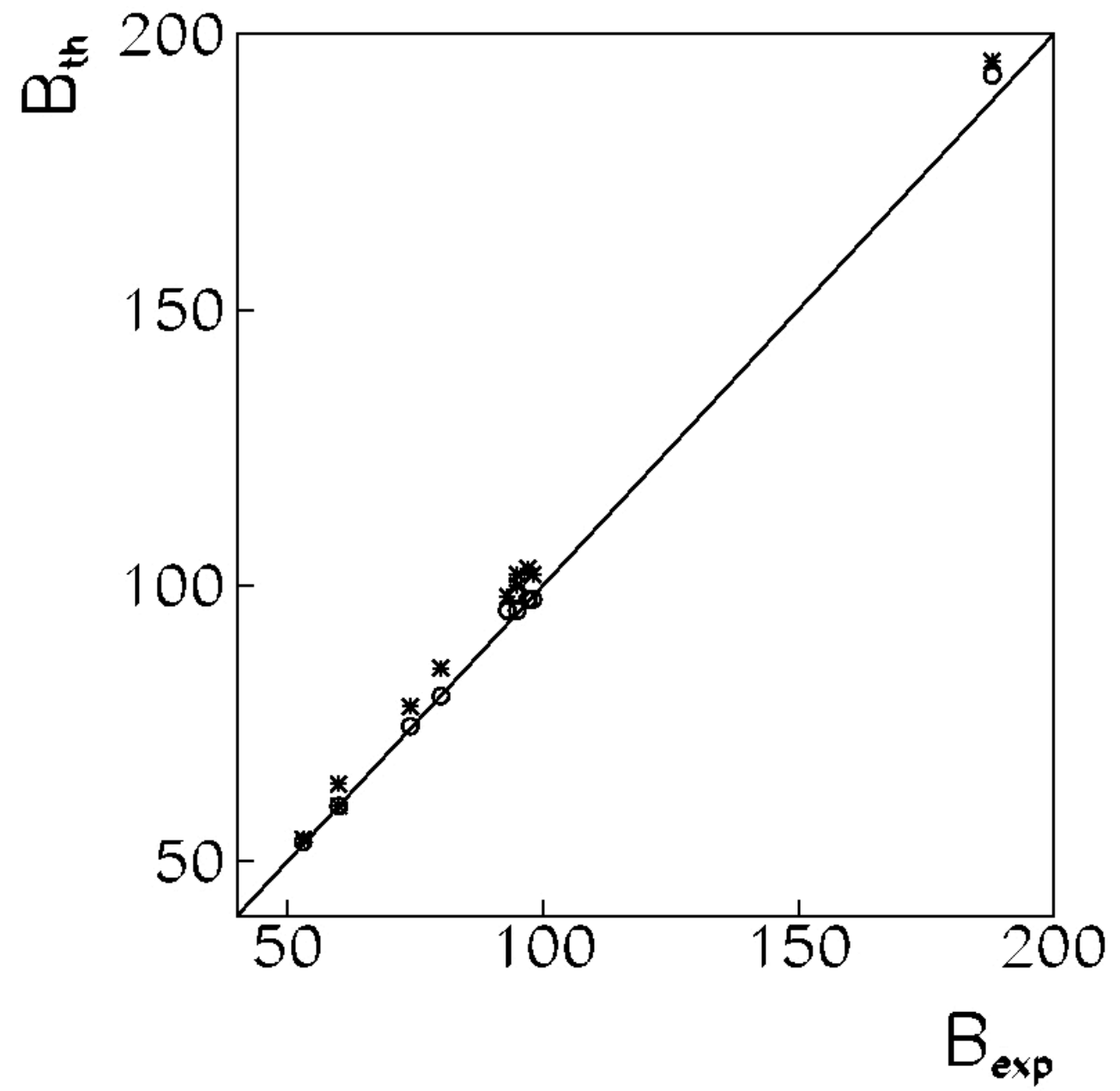
TDHF



Barrières de fusion de noyaux sphériques

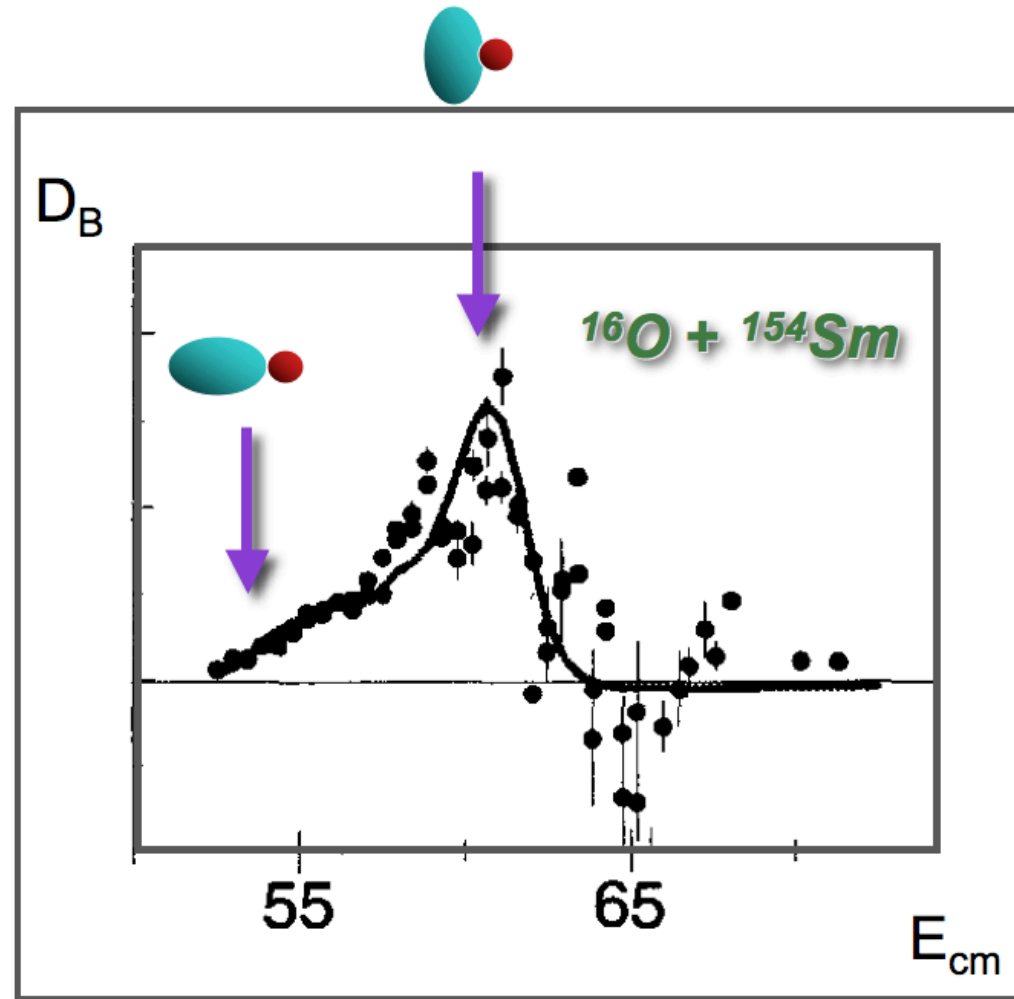


Barrières de fusion: systématiques

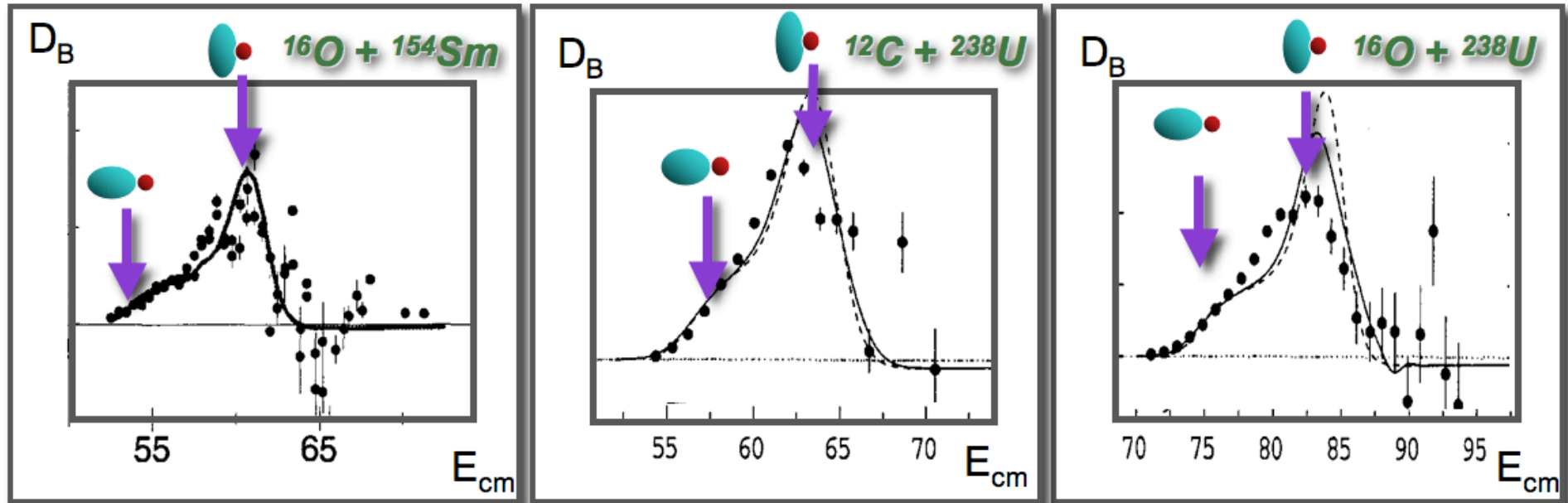


* Bass 73
o TDHF

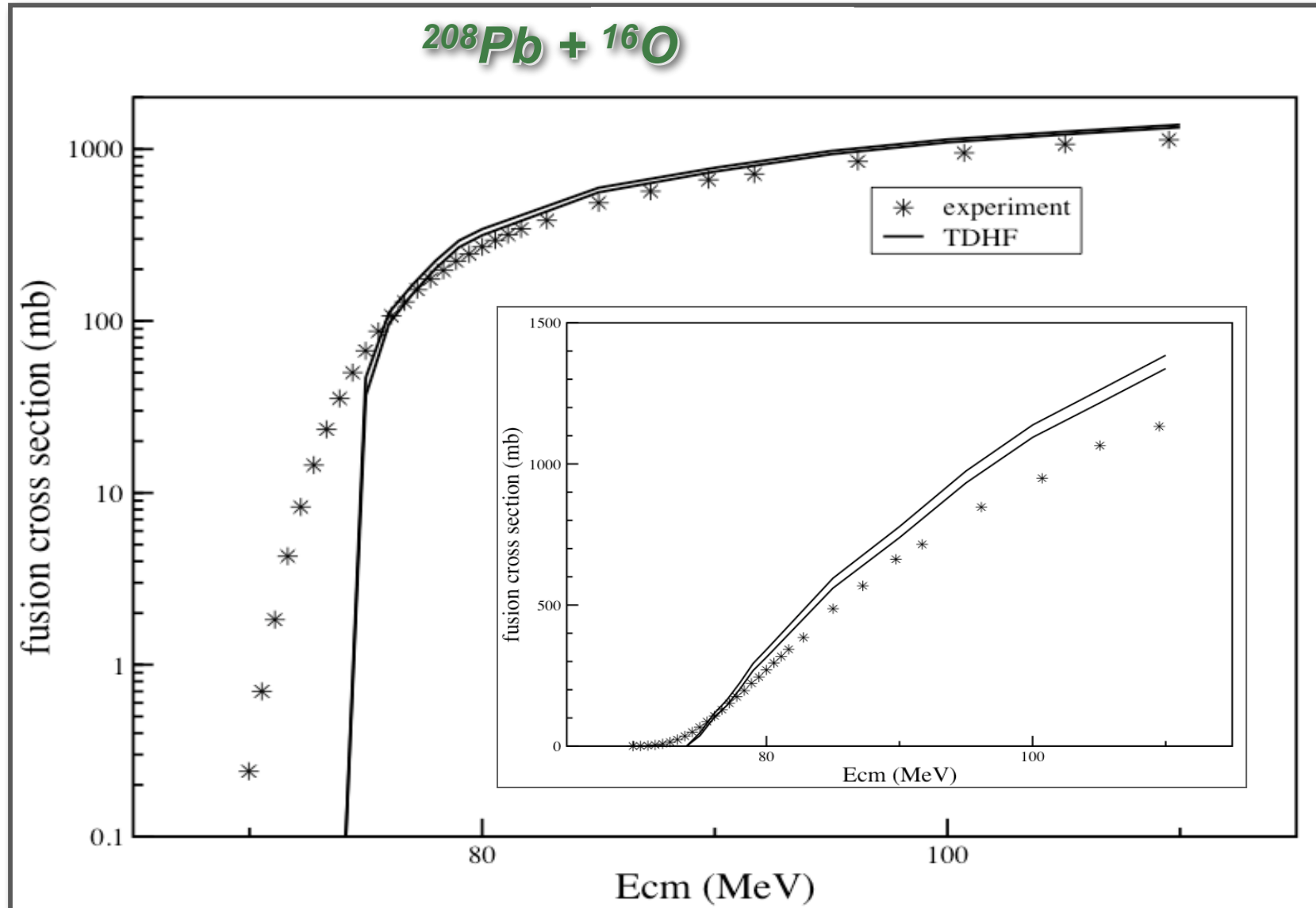
Barrières de fusion avec un noyau déformé



Barrières de fusion de noyaux sphériques



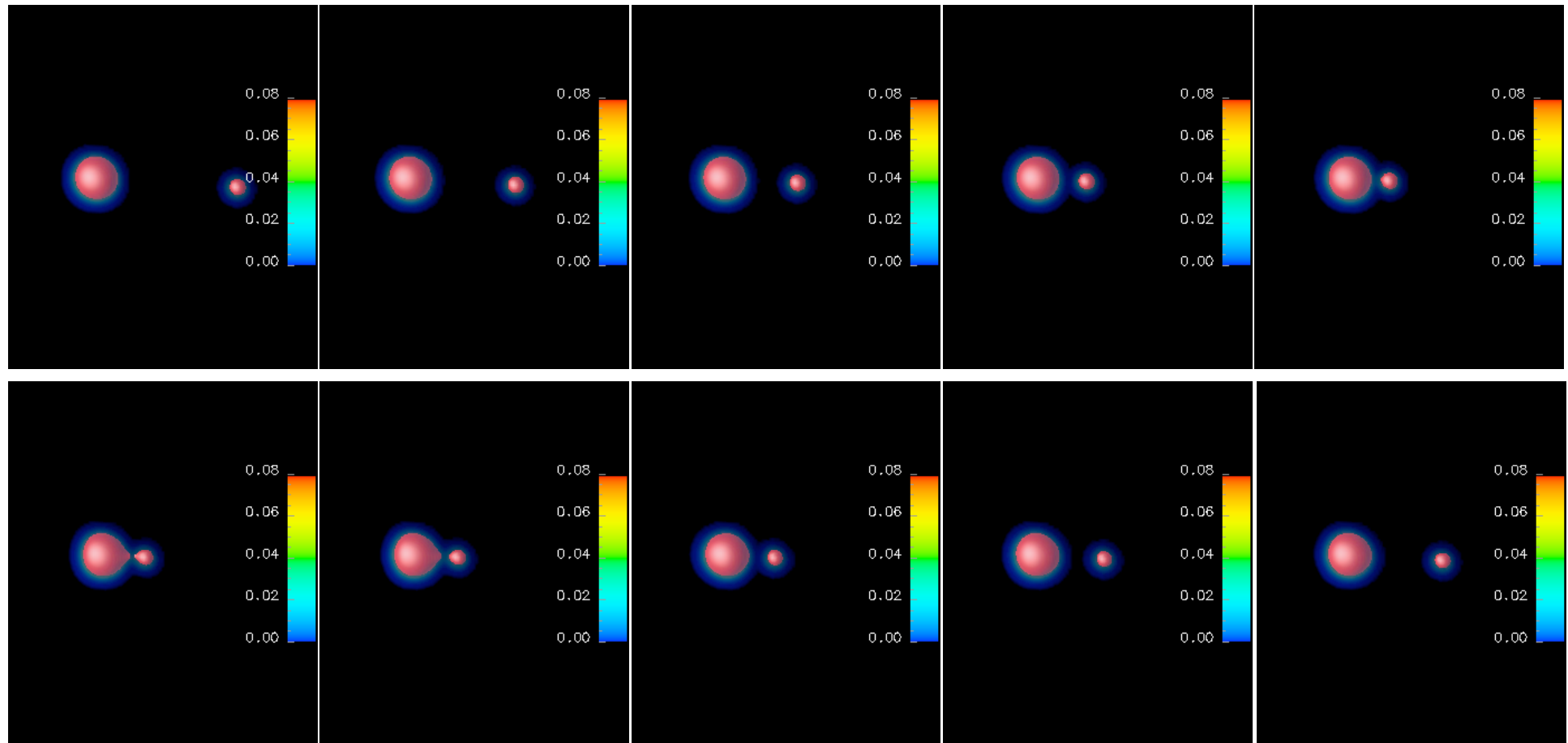
Fonction d'excitation



Transfert de nucléons sous B

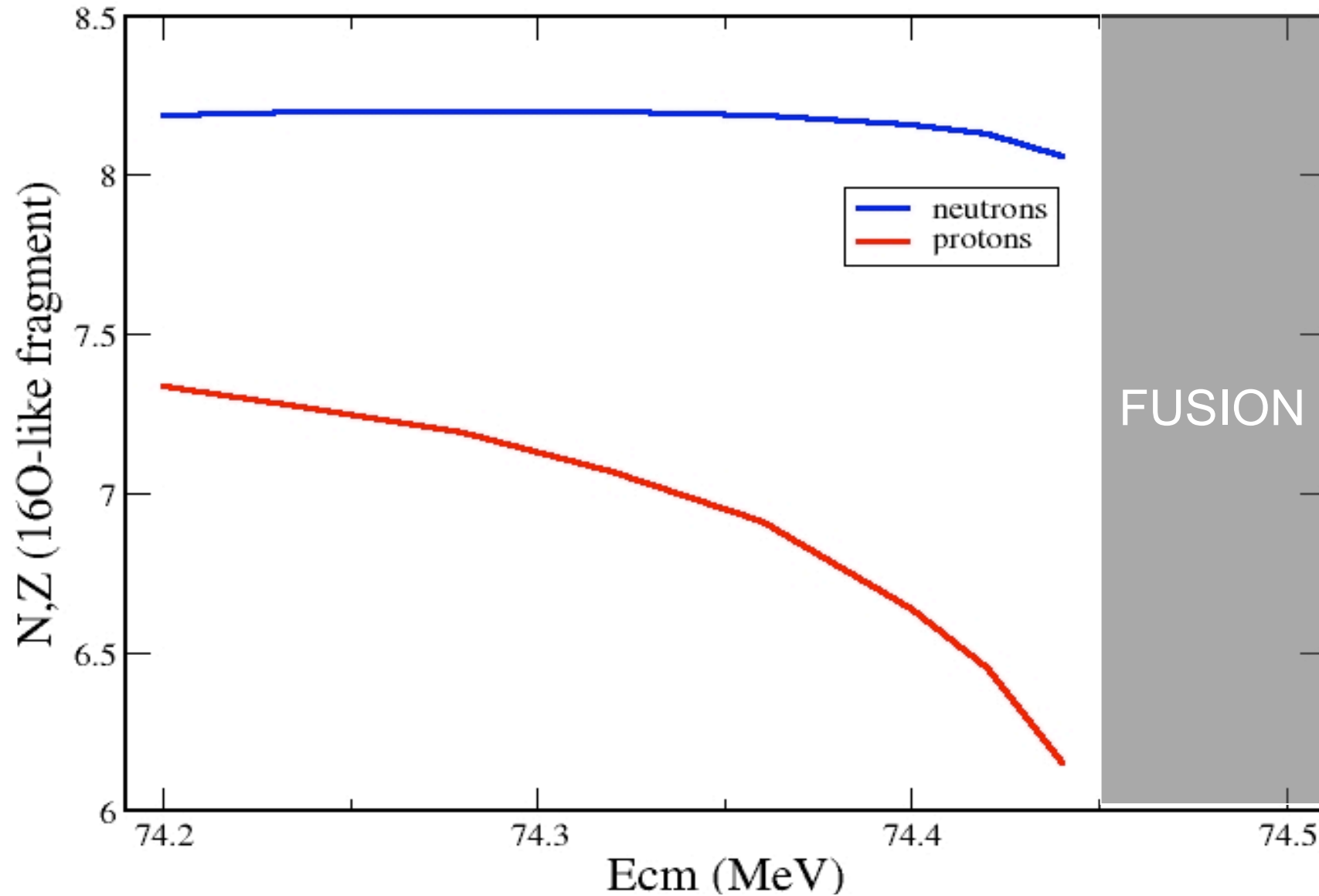


74.44 MeV

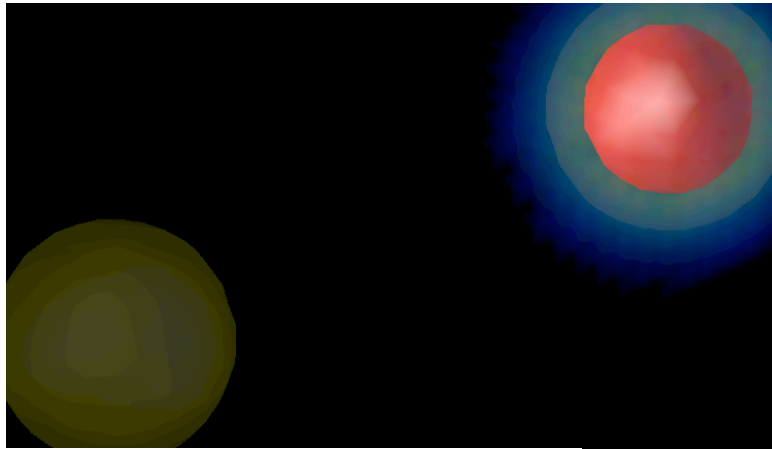


Transfert de nucléons sous B

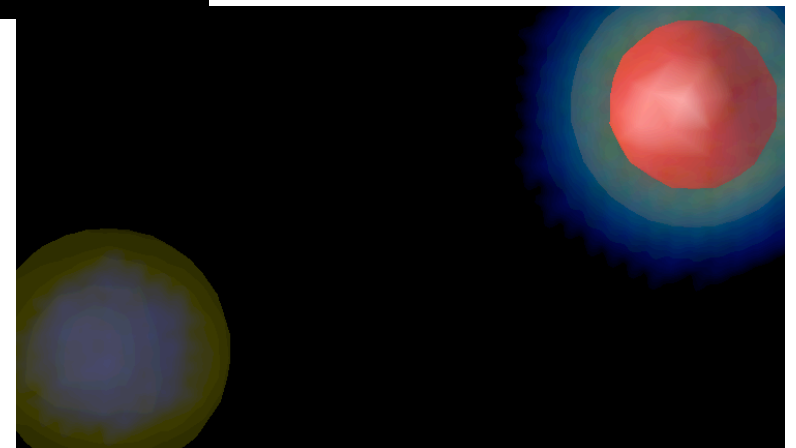
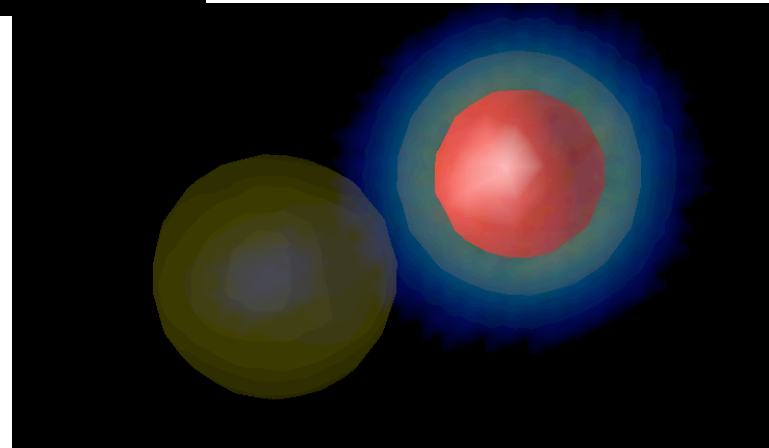
$^{208}\text{Pb} + ^{16}\text{O}$



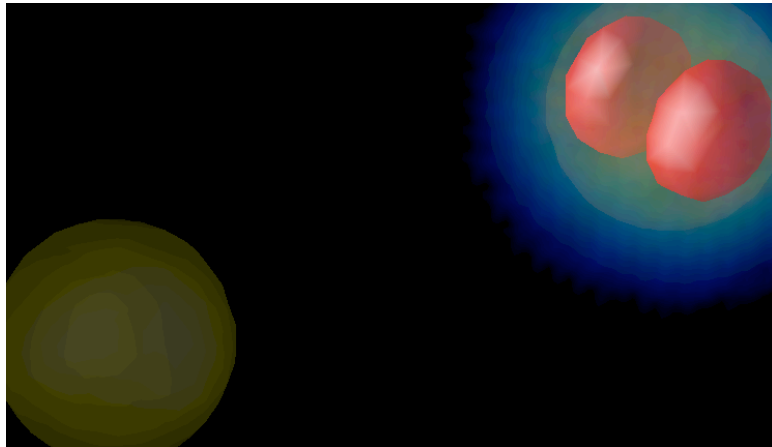
Transfert de nucléons sous B



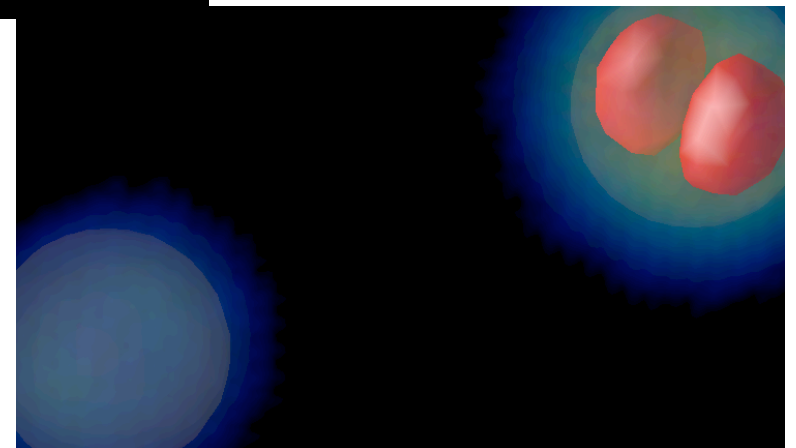
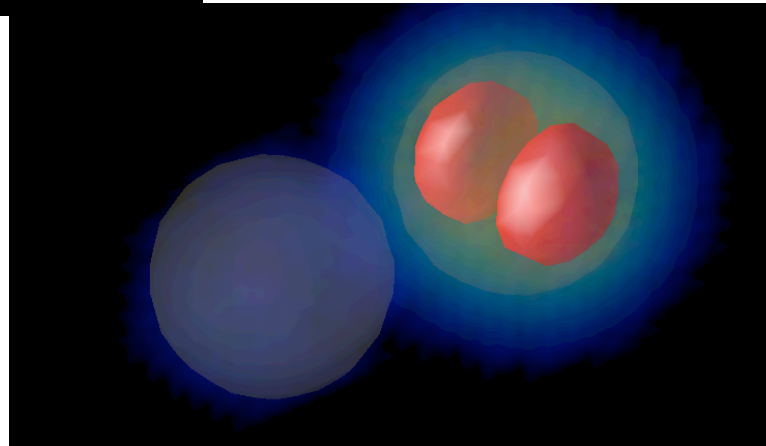
$^{16}\text{O}+^{16}\text{O}: 1s_{1/2}$



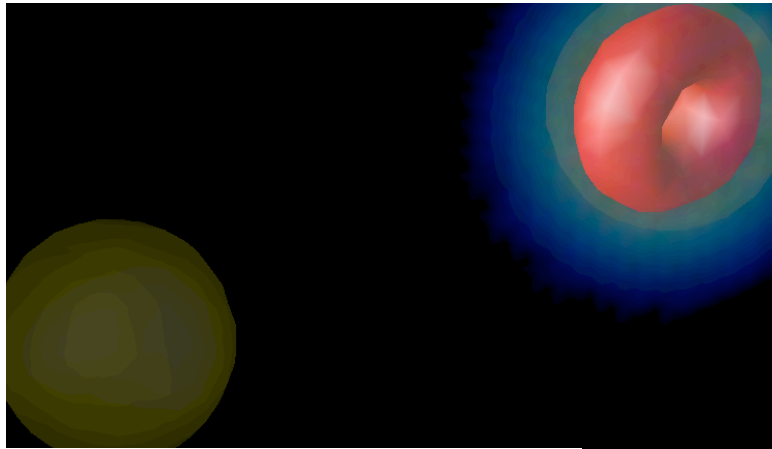
Transfert de nucléons sous B



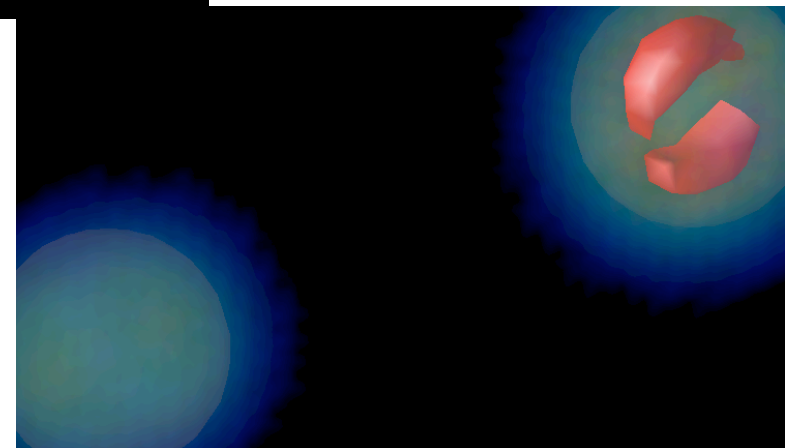
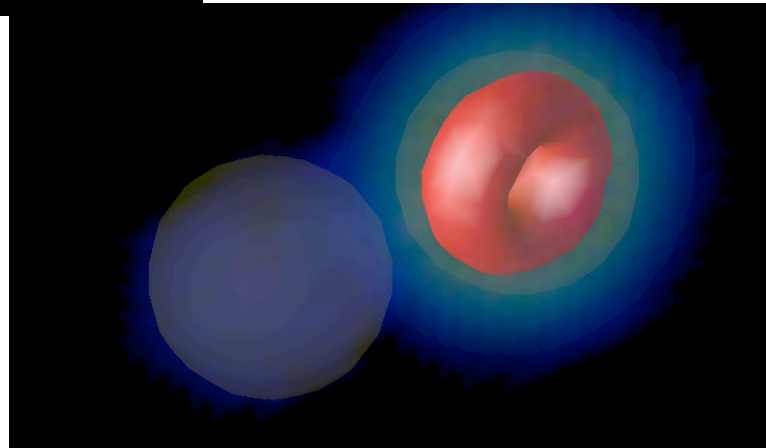
$^{16}\text{O} + ^{16}\text{O}: 1p_{3/2}$



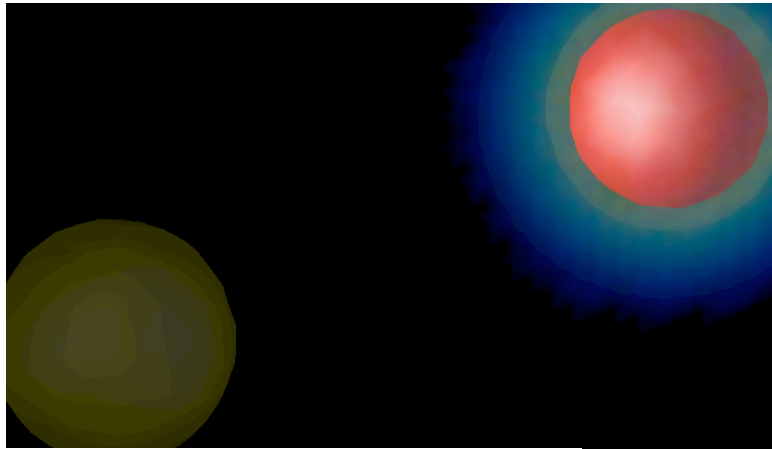
Transfert de nucléons sous B



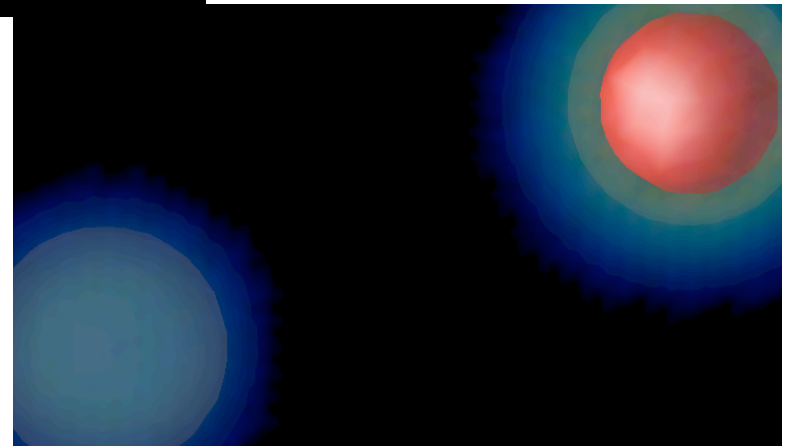
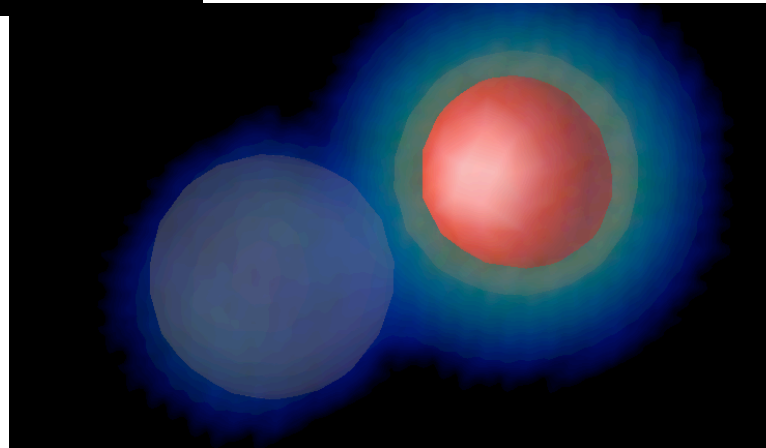
$^{16}\text{O} + ^{16}\text{O}: 1p_{3/2}$



Transfert de nucléons sous B



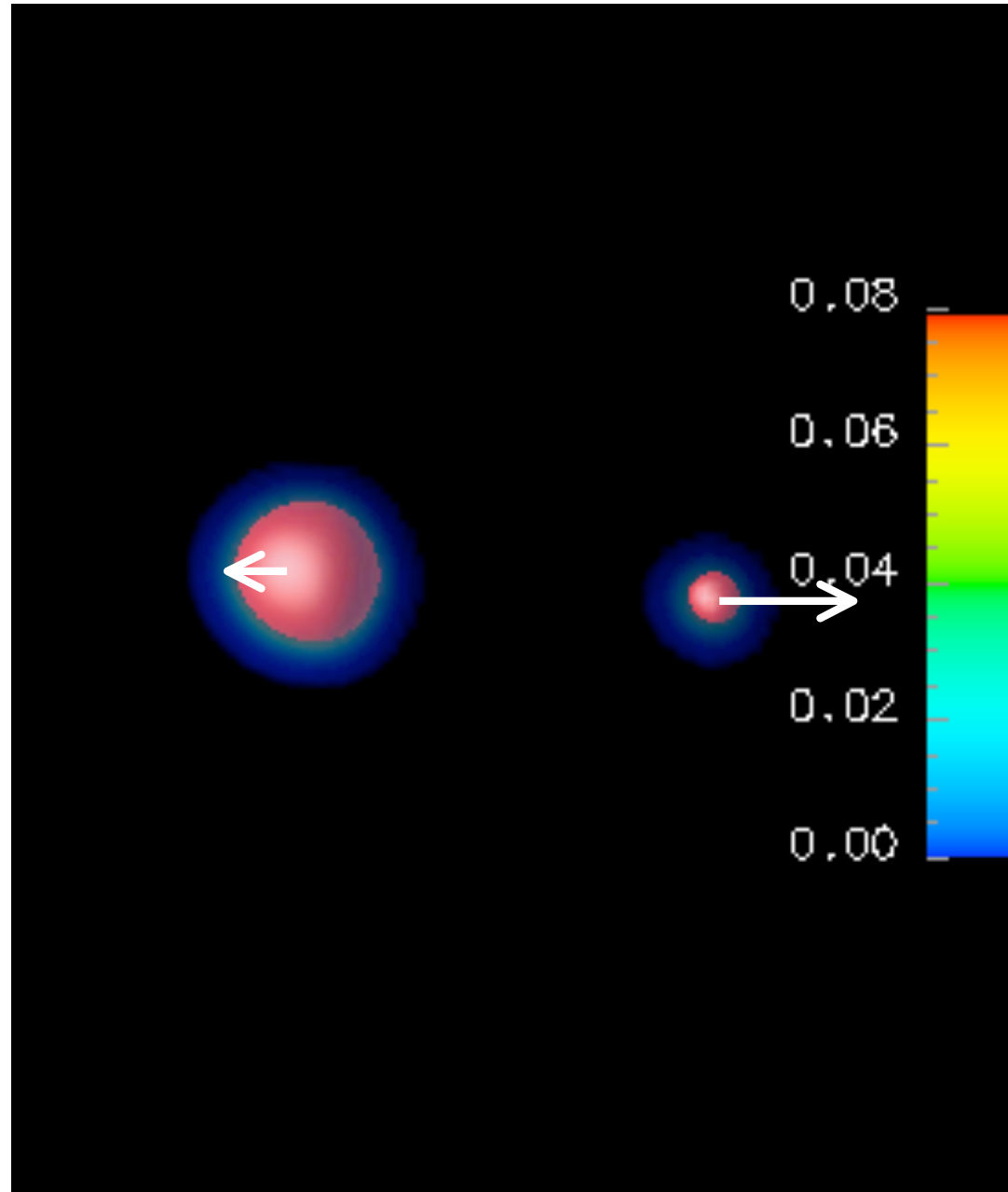
$^{16}\text{O}+^{16}\text{O}: 1p1/2$



Transfert de nucléons sous B



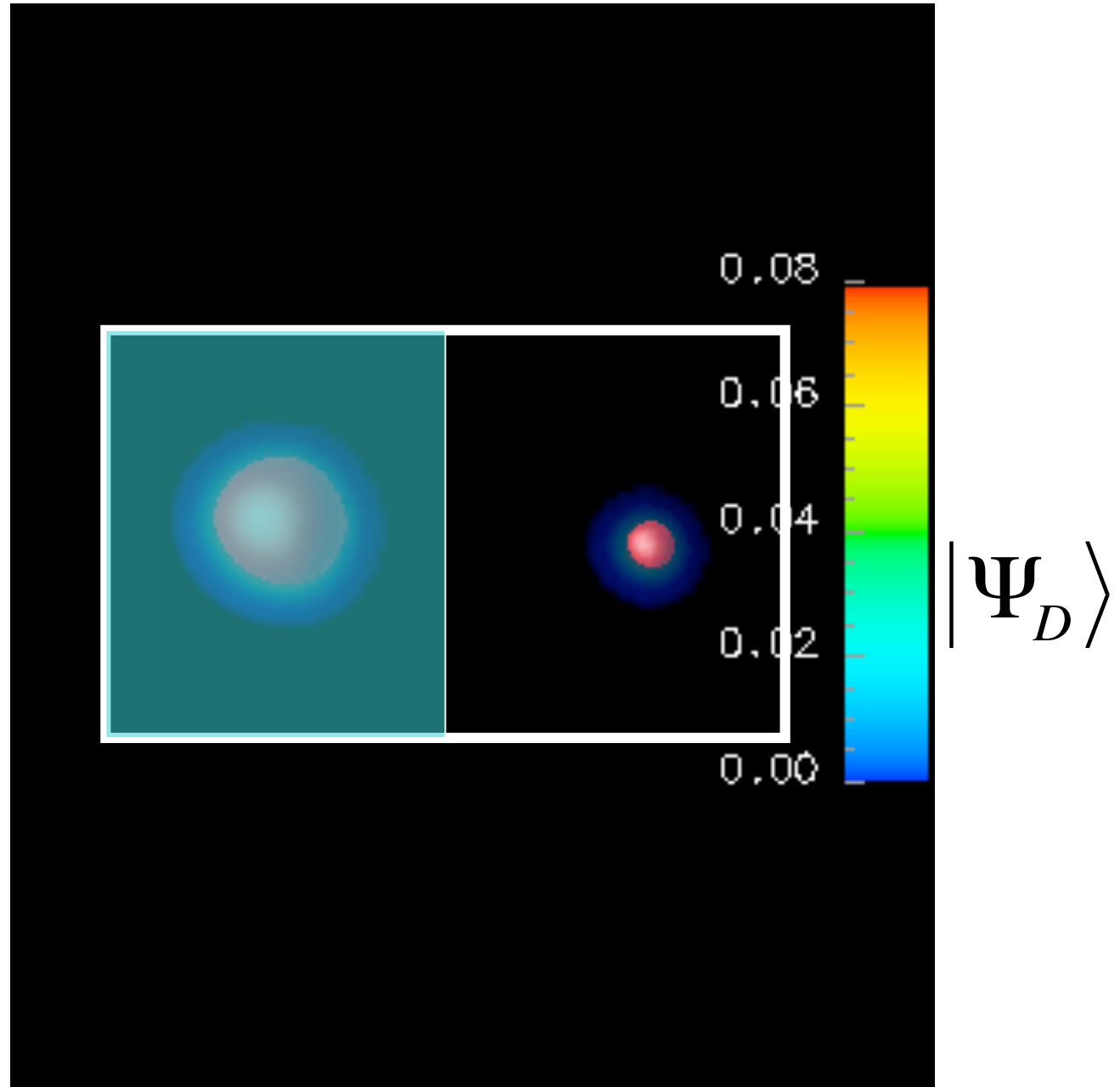
74.44 MeV



Transfert de nucléons sous B

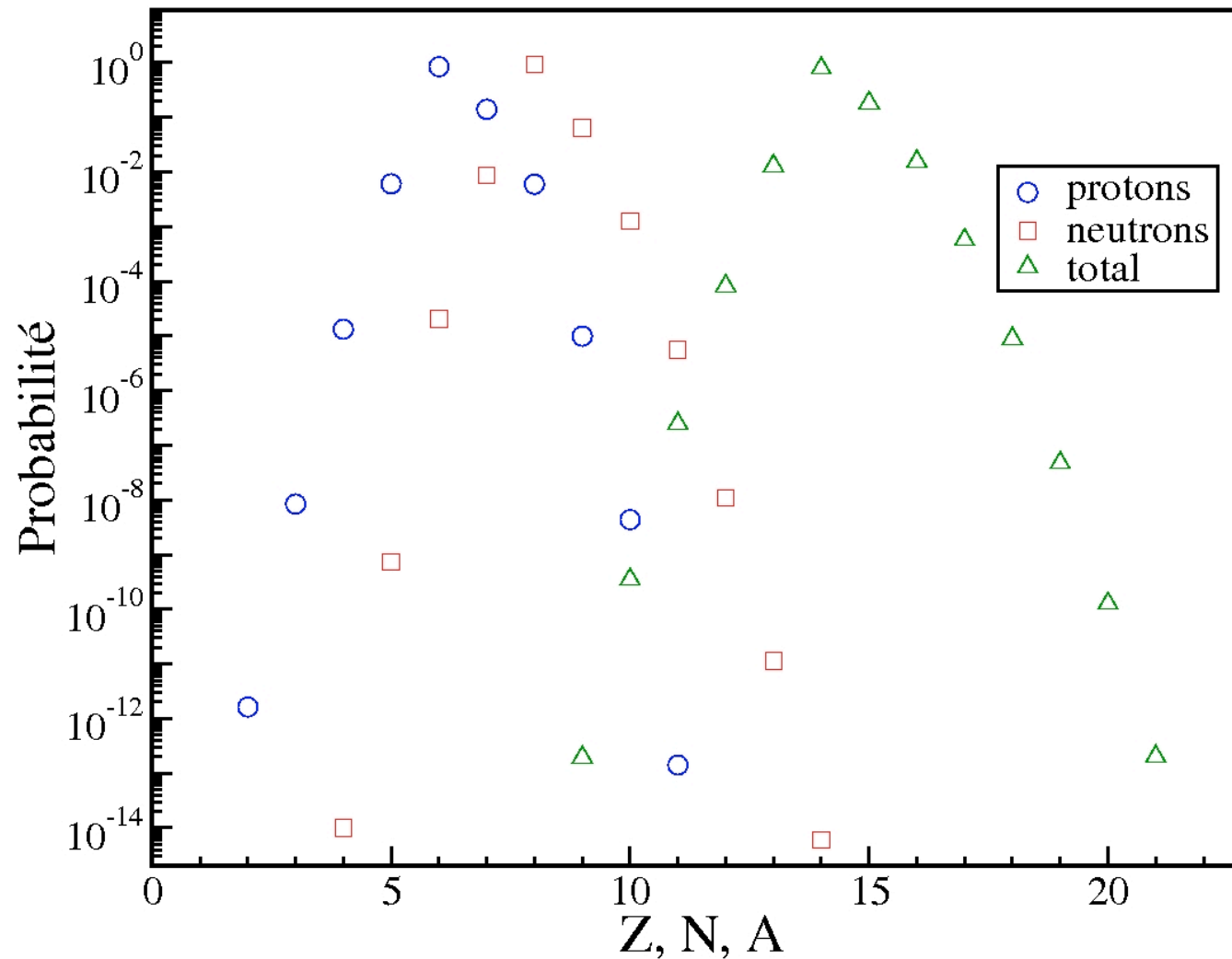
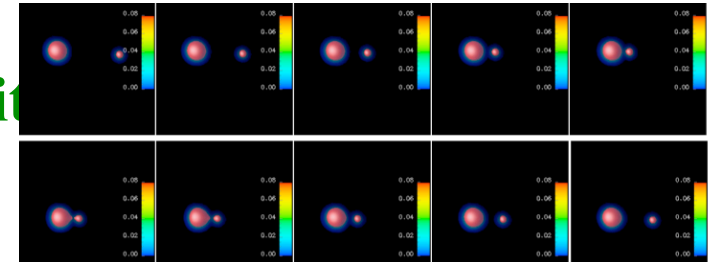


74.44 MeV



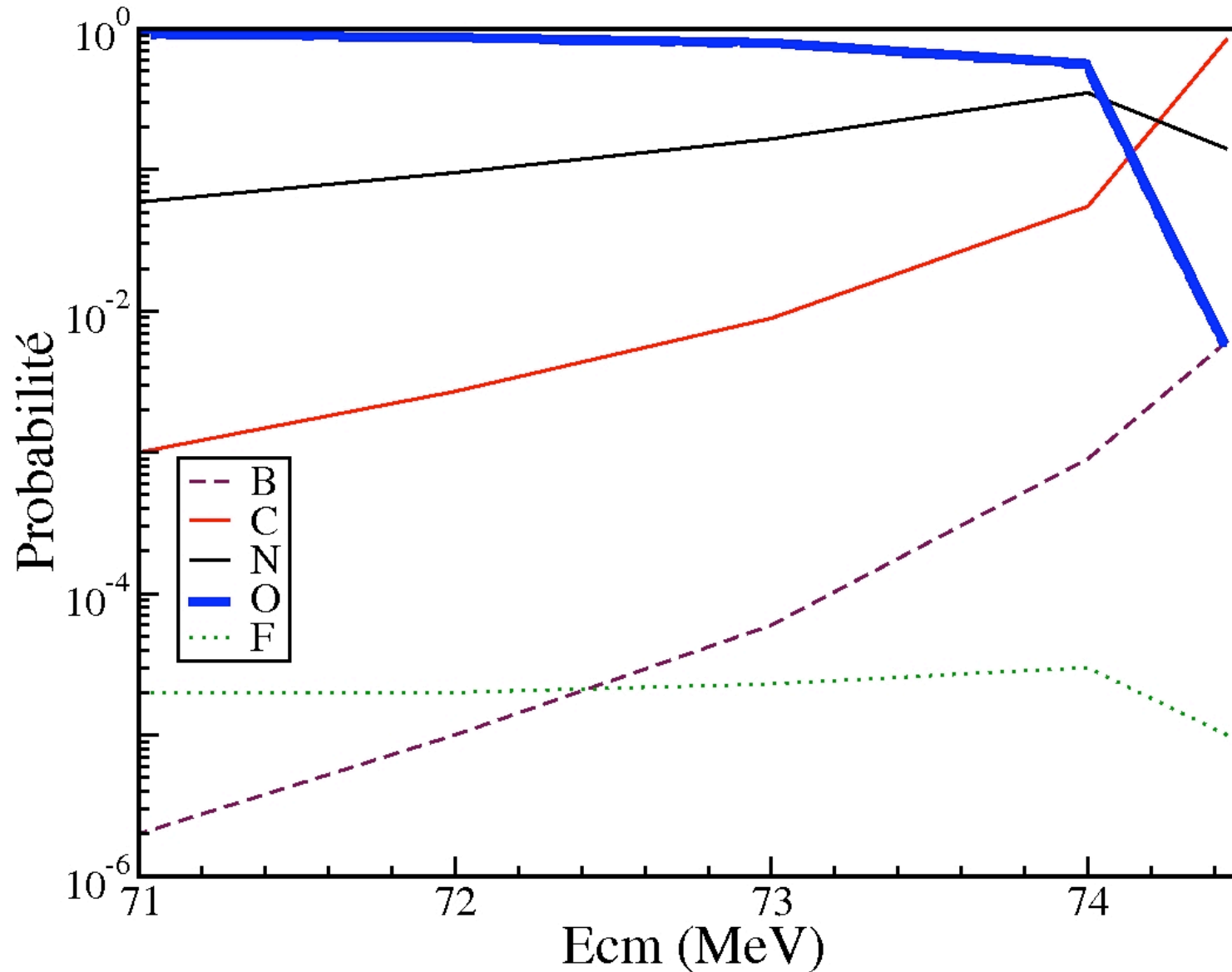
Transfert de nucléons sous B

Distribution de nucléons dans le petit
Fragment après une collision
 $^{16}\text{O} + ^{208}\text{Pb}$ à 74.44 MeV



Transfert de nucléons sous B

Petit fragment en voie de sortie de $^{16}\text{O}+^{208}\text{Pb}$



Transfert de nucléons sous B

Petit fragment en voie de sortie de $^{16}\text{O}+^{208}\text{Pb}$

