Accurate numerical implementation of nuclear and Coulomb breakup calculations

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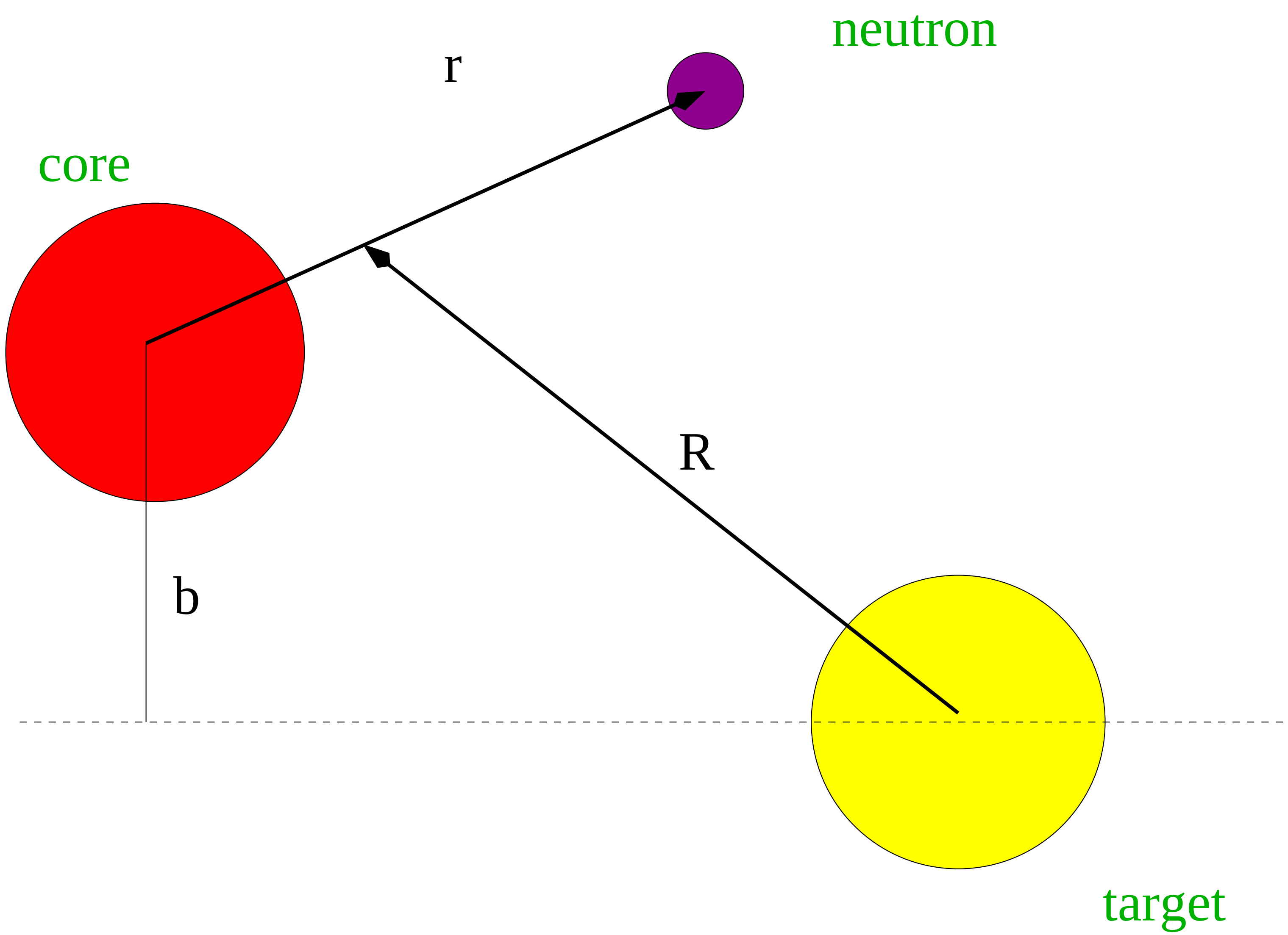
Outline

- Reactions
- Reaction model
- What's new
- Results


neutron
r
core
R
b
target

J. Margueron *et al*, **Nucl. Phys.** A 703, 105 (2002).

$$\frac{d\sigma}{d\epsilon} = \int d\vec{b}|S_{ct}(b)|^2 \frac{dP}{d\epsilon} \tag{1}$$

$$i\hbar \frac{\partial}{\partial t}\psi(\vec{r},\vec{b},t) = \left(H_r + V_{nt}(\beta_2\vec{r} + \vec{R}(t)) + V_{eff}(\vec{r},\vec{R}(t)\right)\psi(\vec{r},\vec{b},t) \tag{2}$$

$$V_{eff} = e^2 Z_c Z_t \frac{\beta_1 \vec{r}\cdot\vec{R}}{R^3} \tag{3}$$

Amplitude:

$$g = \frac{1}{i\hbar}\int_{-\infty}^{\infty} dt \langle \psi_f(t)|V_{nt}(t) + V_{eff}(t)|\psi_i(t)\rangle \tag{4}$$

$$\psi_f = \exp\left(i\vec{k}\cdot\vec{r} - i\epsilon_k t/\hbar\right)\exp\left(-\frac{1}{\hbar}\int_t^{\infty}(V_{nt}(\vec{r},\vec{R}(t')) + V_{eff}(\vec{r},\vec{R}(t')))dt'\right) \tag{5}$$

Initial state

- Single particle wave function in WS potential
- Spherical core

Final state: No neutron-core interactions

$$g = \frac{1}{i\hbar} \int d\vec{r} \int dt e^{-i\vec{k}\cdot\vec{r} + i\omega t} e^{\left(-\frac{1}{\hbar v} \int_t^{\infty} (V_{nt}(\vec{r},t') + V_{eff}(\vec{r},t'))dt'\right)}$$

$$\times \quad (V_{nt}(\vec{r},t) + V_{eff}(\vec{r},t))\phi(\vec{r}) \tag{6}$$

$$\omega = \frac{\epsilon - \epsilon_i}{\hbar} \tag{7}$$

Nuclear part

$$g^n(\vec{k},\vec{b}) = \int d\vec{r} e^{-i\vec{k}\cdot\vec{r}} \left(e^{-i\chi_{nt}(\vec{b}+\vec{r})} - 1 \right) \phi(\vec{r}) \tag{8}$$

$$\chi_{nt}(b) = \frac{1}{\hbar v} \int_{-\infty}^{\infty} V_{nt}(\sqrt{b^2 + z^2}) dz \tag{9}$$

Coulomb part

$$g^C(\vec{k},\vec{b}) = -i\int d\vec{r}e^{-i\vec{k}\cdot\vec{r}}\chi_{eff}(r,\vec{\omega})\phi_(\vec{r}) \tag{10}$$

$$\chi_{eff}(r,\vec{\omega}) = \frac{1}{\hbar}\int_{-\infty}^{\infty} dte^{i\omega t}V_{eff}(\vec{r},\vec{R}) \tag{11}$$

Interference

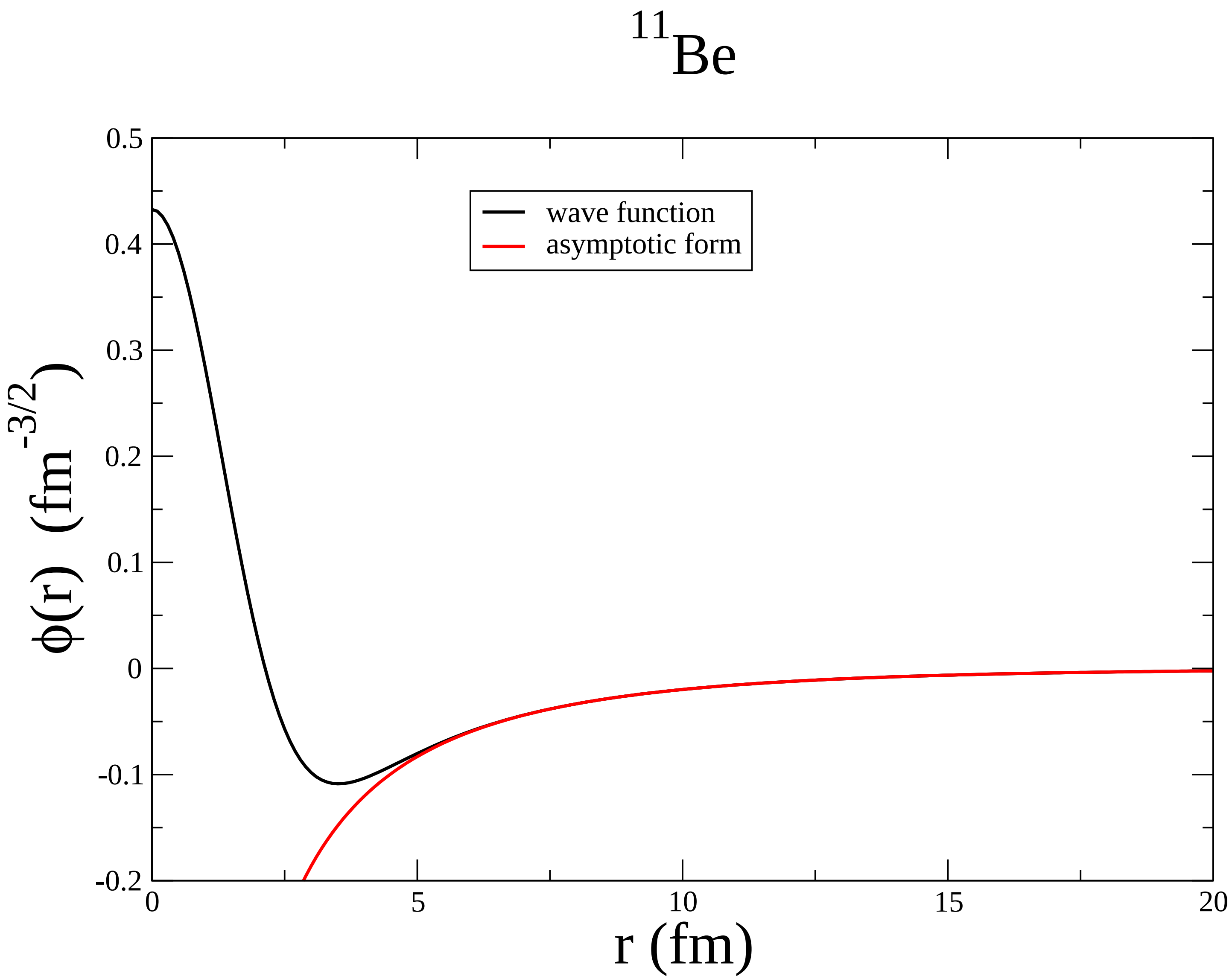
$$g^{nC}(\vec{k},\vec{b}) = \int d\vec{r}e^{-i\vec{k}\cdot\vec{r}}\left(1 - e^{i\chi_{nt}(\vec{b})}\right)B(\vec{b},\omega)\phi(\vec{r}) \tag{12}$$

$$B(\vec{b},\omega) = \frac{i}{\hbar}\left(\int_{-\infty}^{0} dte^{i\omega t}V_{eff}(\vec{r},t) + \int_{0}^{\infty} dtV_{eff}(\vec{r},t)\right) \tag{13}$$

Aims

- Aim I: validity of asymptotic forms
- Aim II: high order effects in V_{eff}

Aim I: validity of asymptotic forms



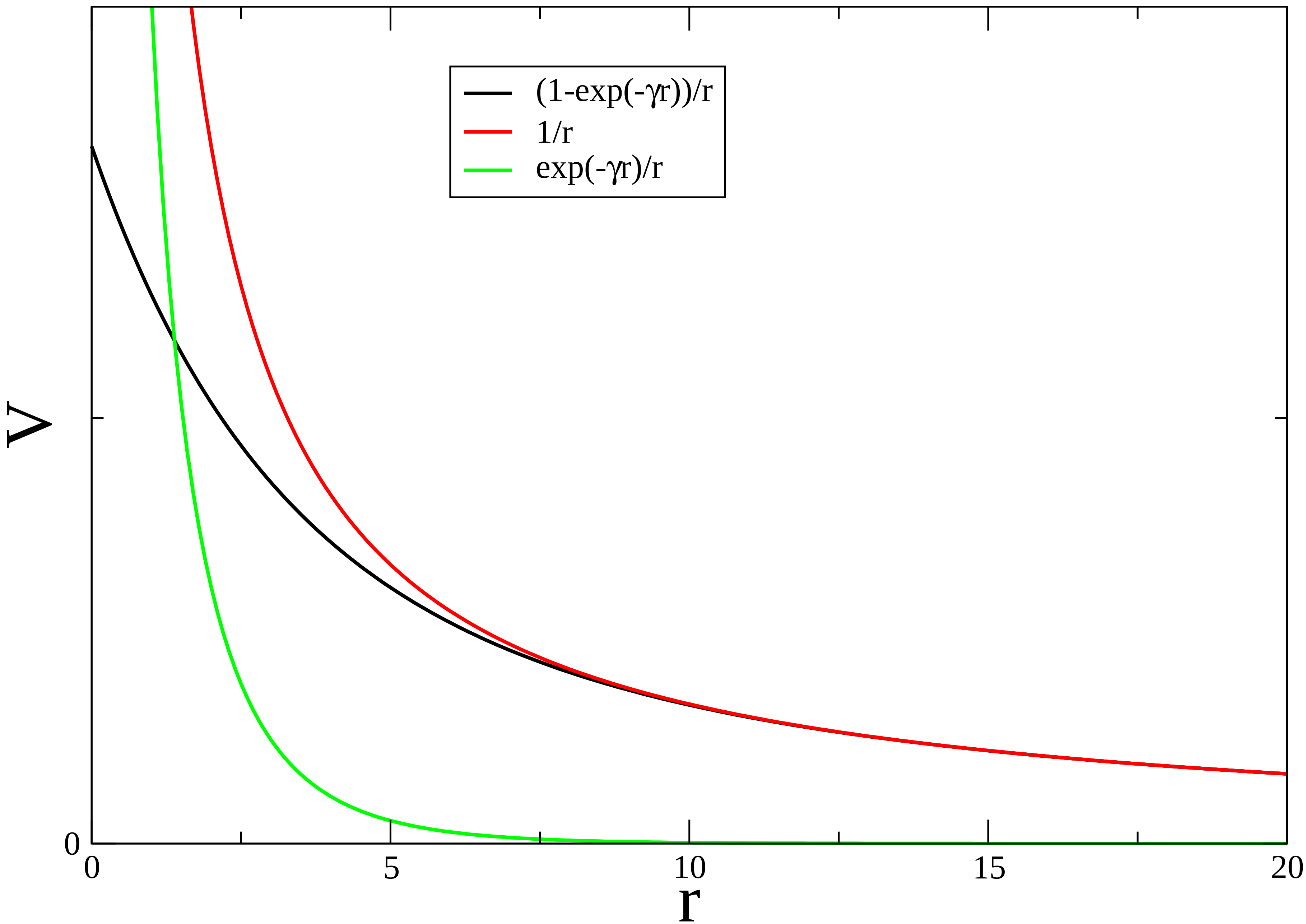
Aim II: dipole approximation

$$V_{eff} = e^2 Z_c Z_t \left(\frac{1}{|\vec{R} - \beta_1 \vec{r}|} - \frac{1}{R} \right) = e^2 Z_c Z_t \frac{\beta_1 \vec{r} \cdot \vec{R}}{R^3} + ... \tag{14}$$

Introducing screening-like parameter γ

$$V(r) = \frac{C}{r} = C \left(\frac{e^{-\gamma r}}{r} + \frac{1 - e^{-\gamma r}}{r} \right) \tag{15}$$

$$V(\vec{r}, \vec{R}) = V_0 \frac{e^{-\gamma |\vec{R} - \beta_1 \vec{r}|}}{|\vec{R} - \beta_1 \vec{r}|} - V_0 \frac{1 - e^{-\gamma |\vec{R} - \beta_1 \vec{r}|}}{|\vec{R} - \beta_1 \vec{r}|} - V_0 \frac{e^{-\gamma R}}{R} + V_0 \frac{1 - e^{-\gamma R}}{R} \tag{16}$$


(1-exp(-γr))/r
1/r
exp(-γr)/r
V
0
0
5
10
15
20
r

Coulomb short range phase

$$\chi_{Cou}(\vec{b},\vec{R}) = \frac{V_0}{\hbar v}\left(K_0(\gamma b) - K_0(\gamma R_\perp)\right) \tag{17}$$

Coulomb long range phase

$$\chi_{eff}(\bar{\omega}) = \frac{2V_0}{\hbar v} e^{i\beta_1 \bar{\omega} z/b}\left(K_0(\bar{\omega}) - K_0(\sqrt{\bar{\omega}^2 + (\gamma b)^2})\right)$$
$$- \quad \frac{2V_0}{\hbar v}\left(K_0(\bar{\omega}) - K_0(\sqrt{\bar{\omega}^2 + (\gamma R_\perp)^2})\right) \tag{18}$$

Interference

$$B = i\frac{V_0}{\hbar v}\Big(e^{i\omega\beta_1 z/v} F(\gamma b, \omega b/v) - F(\gamma R_\perp, \omega R_\perp/v)$$
$$- \quad \int_{-\beta_1 z/b}^{0} ds \ \left(e^{i\omega\beta_1 z/v} \ e^{i\omega b s/v} - 1\right) \frac{1 - e^{-\gamma b\sqrt{1+s^2}}}{\sqrt{1+s^2}}\Big)$$
$$- \quad i\frac{V_0}{\hbar v}\left(K_0(\gamma b) - K_0(\gamma R_\perp)\right) \tag{19}$$

with

$$F(x,y) = \int_{-\infty}^{0} ds e^{isy} \frac{1 - e^{-x\sqrt{1+s^2}}}{\sqrt{1+s^2}} = K_0(y) - K_0(\sqrt{x^2+y^2})$$

$$+ \quad i\frac{\pi}{2}\left(I_0(y) - I_0(\sqrt{x^2+y^2}) - L_0(y) + L_0(\sqrt{x^2+y^2})\right) \qquad (20)$$

limit $\gamma = \infty$

$$\chi_{Cou} = 0 \tag{21}$$

$$\chi_{eff} = \frac{2V_0}{\hbar v}\left(e^{i\beta_1 \omega z/v} K_0(\omega b/v) - K_0(\omega R_\perp/v)\right) \tag{22}$$

$$B = \frac{iV_0}{\hbar v}\left[e^{i\beta_1 \omega z/v} K_0(\omega b/v) - K_0(\omega R_\perp/v) - \int_{-\beta_1 z/b}^{0} \frac{e^{i\omega\beta_1 z/v} e^{i\omega b s/v} - 1}{\sqrt{1+s^2}}\right]$$

In first order, these are

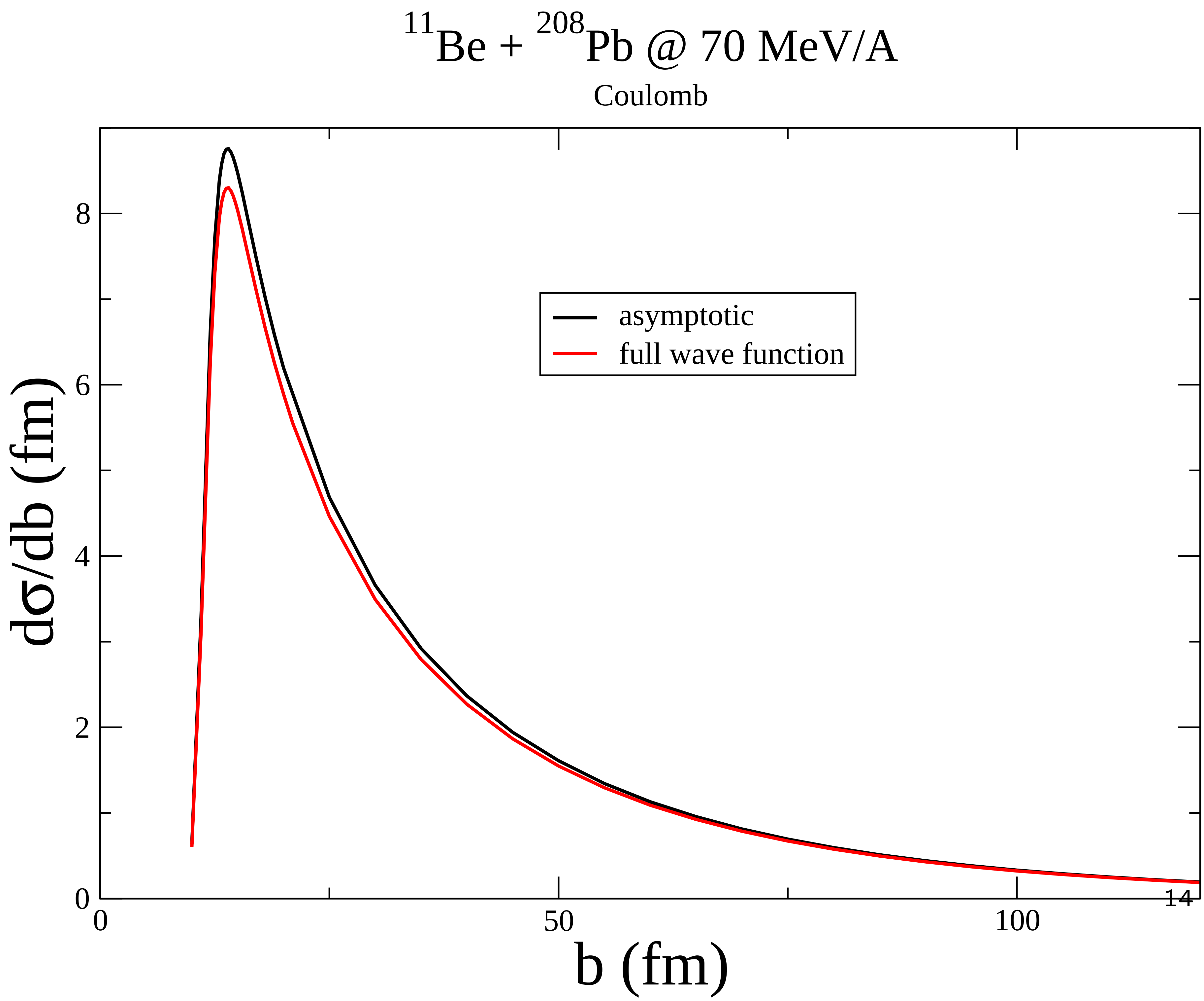
$$\chi_{eff} = \frac{2V_0}{\hbar v}\left(K_0(\omega R_\perp/v)\frac{i\omega z}{v}\beta_1 + K_1(\omega R_\perp/v)\frac{\vec{R}_\perp \cdot \vec{r}_\perp}{R_\perp}\frac{\omega}{v}\beta_1\right) \tag{23}$$

$$B = \frac{iV_0}{\hbar v}\left(\frac{i\beta_1 \omega z}{v} K_0(\omega R_\perp/v) + K_1(\omega R_\perp/v)\frac{\vec{R}_\perp \cdot \vec{r}_\perp}{R_\perp}\frac{\omega}{v}\beta_1\right) \tag{24}$$

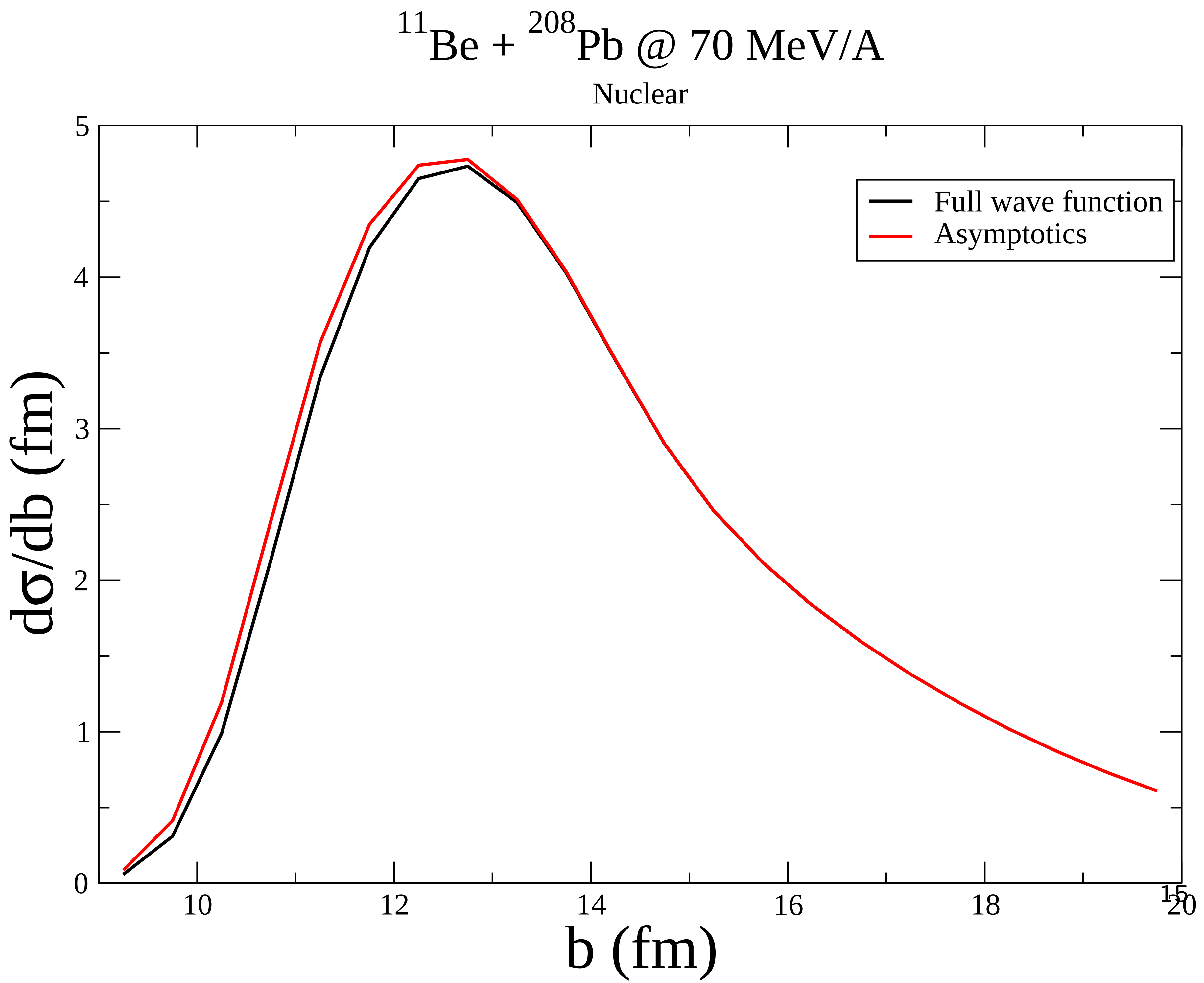
A word about 2-body interactions:

$V_{ct} \rightarrow$ Optical limit of Glauber theory (W. A. Richter and B. A. Brown, PRC **67**, 034317 (2003), S. Karataglidis *et al*, PRC **65**, 044306 (2002), A. Ozawa et al, NPA **693**, 32 (2001))

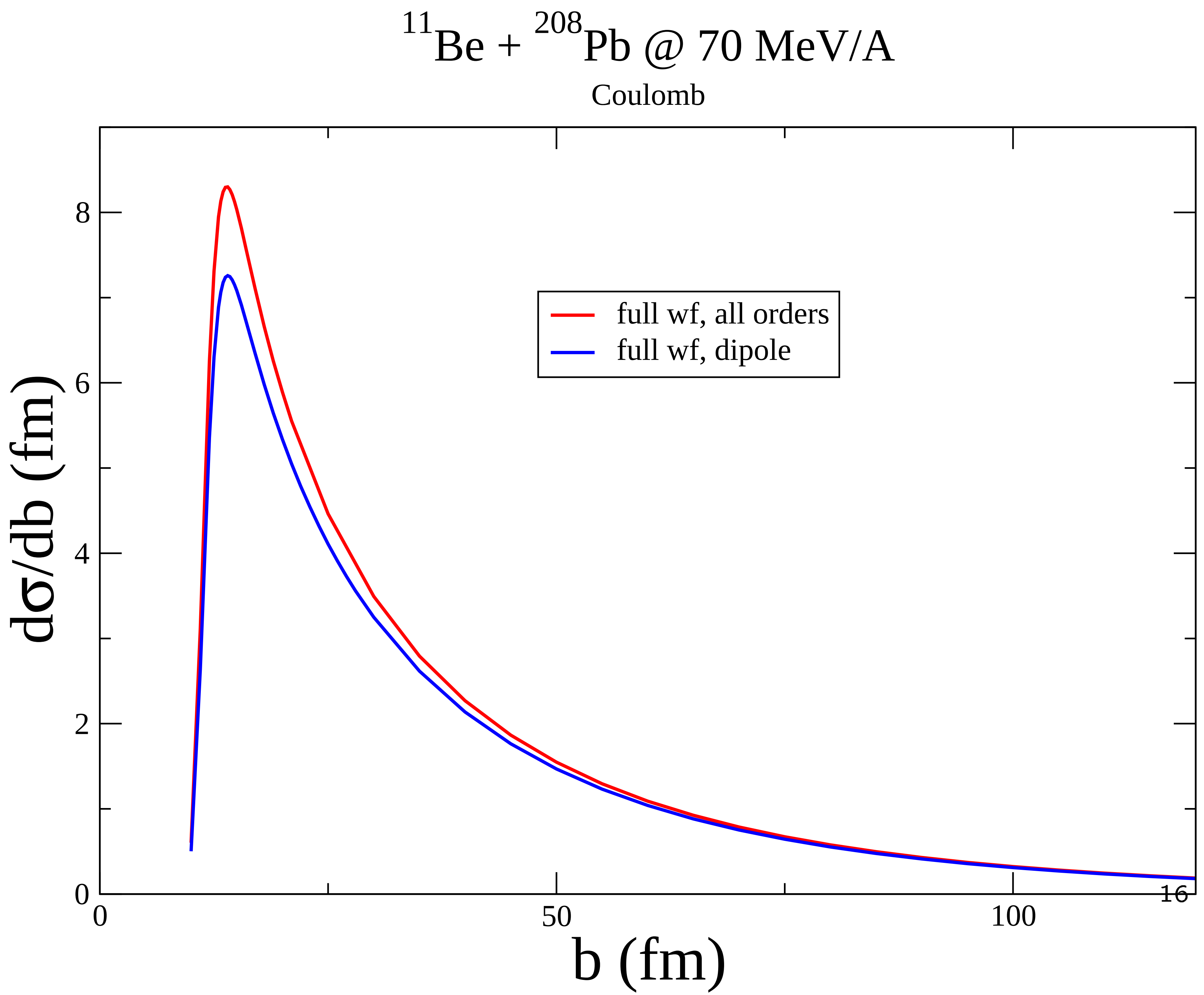
$V_{nt} \rightarrow$ Optical potential from C. Mahaux and R. Sartor, NP**A493**, 157 (1989).



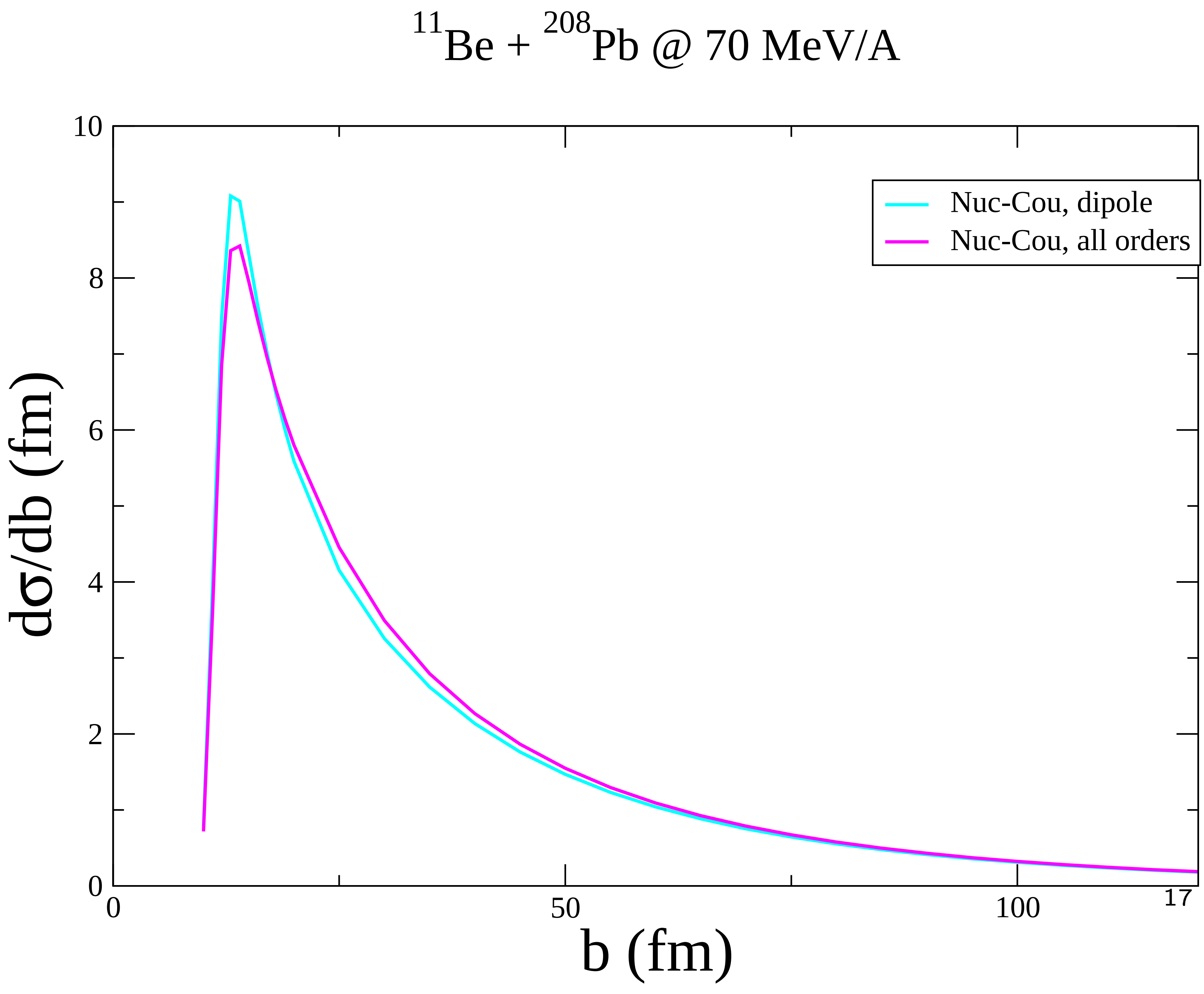
11Be + 208Pb @ 70 MeV/A
Coulomb
asymptotic
full wave function
dσ/db (fm)
b (fm)
0
2
4
6
8
0
50
100



^{11}Be + ^{208}Pb @ 70 MeV/A
Nuclear
Full wave function
Asymptotics
dσ/db (fm)
b (fm)
0
1
2
3
4
5
10
12
14
16
18
20
15



11Be + 208Pb @ 70 MeV/A
Coulomb
full wf, all orders
full wf, dipole
dσ/db (fm)
b (fm)
0
2
4
6
8
0
50
100



^{11}Be + ^{208}Pb @ 70 MeV/A
Nuc-Cou, dipole
Nuc-Cou, all orders
dσ/db (fm)
b (fm)
0
2
4
6
8
10
0
50
100
17