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NUCLEON DENSITY DISTRIBUTIONS AND DIABATIC POTENTIAL

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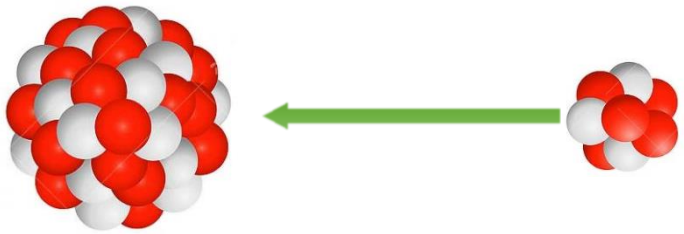
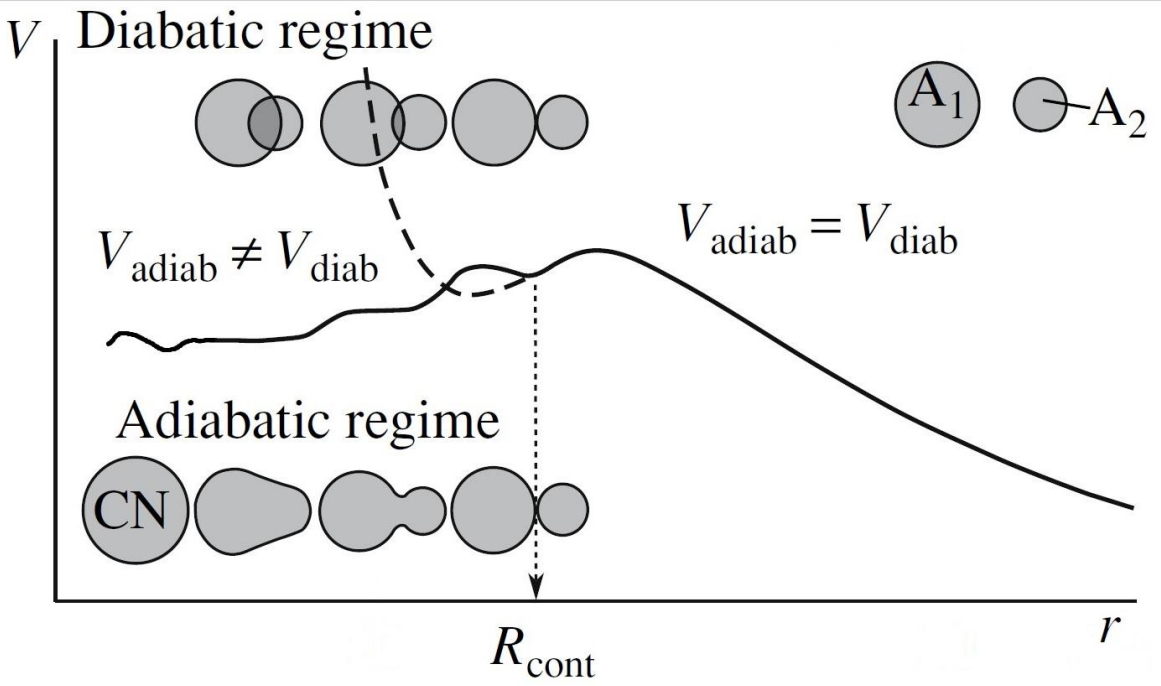
Introduction

Reactions with heavy ions:

1. Two collision regime: diabatic and adiabatic
2. Fast collisions: no dynamic deformations => double density and repulsion





Adopted from: **Zagrebaev V. et al.**// Phys. Part. Nucl., 2007. 38, 4, 469–491

Objectives:

1. Investigate how *nucleon density* parameters impact on profile of diabatic potential
2. Select density parameters and calculate *diabatic potential* for spherical nuclei

$$V_{diab}(r) = V_{NN}(r) + V_{coulomb}(r)$$

The model

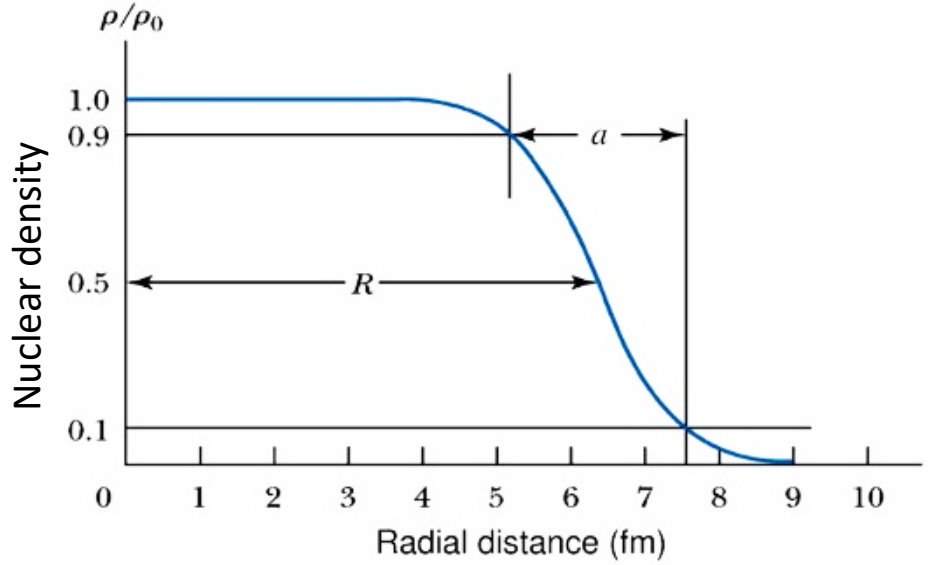
1. Folding potential: $$V_{NN}(r) = \int_{V_1} \rho_1(\boldsymbol{r}_1) \int_{V_2} \rho_2(\boldsymbol{r}_2)\, v_{NN}(\boldsymbol{r} + \boldsymbol{r}_2 - \boldsymbol{r}_1)\, \mathrm{d}^3 r_2\, \mathrm{d}^3 r_1$$

2. Effective Migdal forces: $$v_{NN}(\boldsymbol{r}_{12}) = \mathrm{C}\left[\mathrm{F_{ex}} + (\mathrm{F_{in}} - \mathrm{F_{ex}})\frac{\rho_1(\boldsymbol{r}_1) + \rho_2(\boldsymbol{r}_2)}{\rho_2(0) + \rho_2(0)}\right]\delta(\boldsymbol{r}_{12})$$

3. Total nucleonic density:

$$\rho_{1,2}(r) = \rho^{\mathrm{p}}_{1,2}(r) + \rho^{\mathrm{n}}_{1,2}(r),$$

$$\rho(r) = \frac{\rho_0}{1 + \exp\left(\frac{r - R}{a}\right)} \text{ for } p, n$$

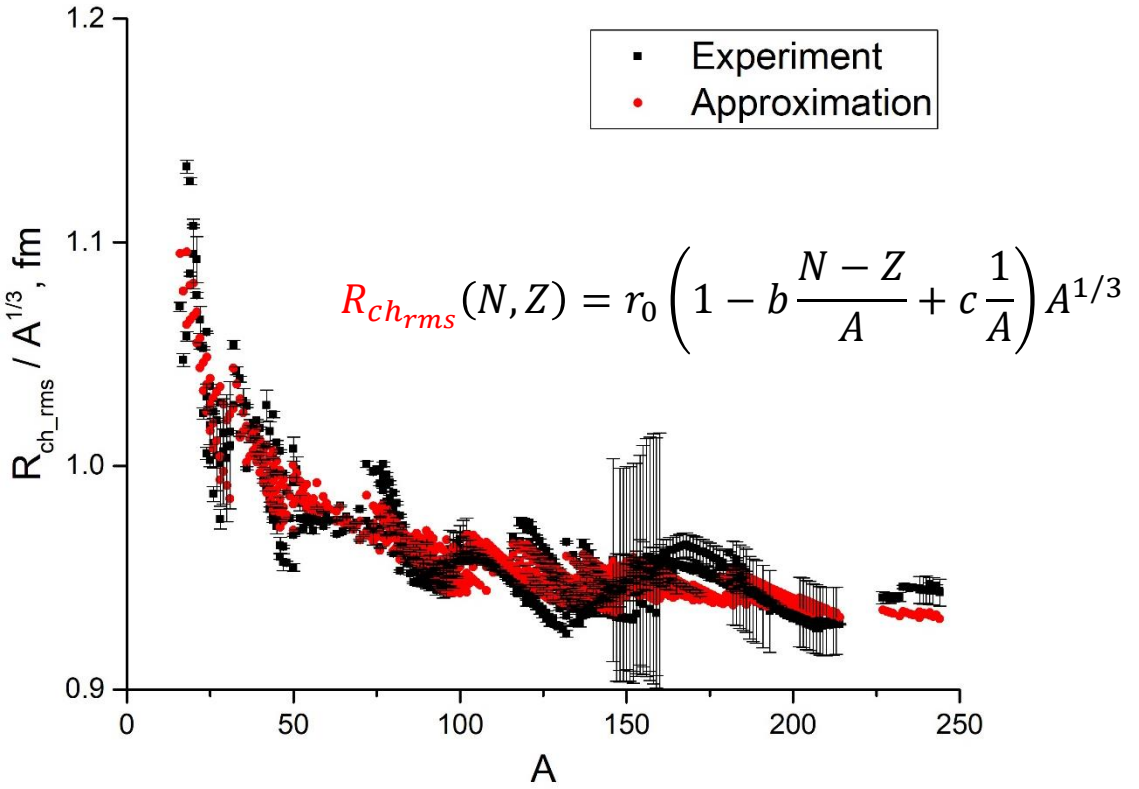


4. Spherical nuclei $Z \geq 8$, $N \geq 8$

Charge density

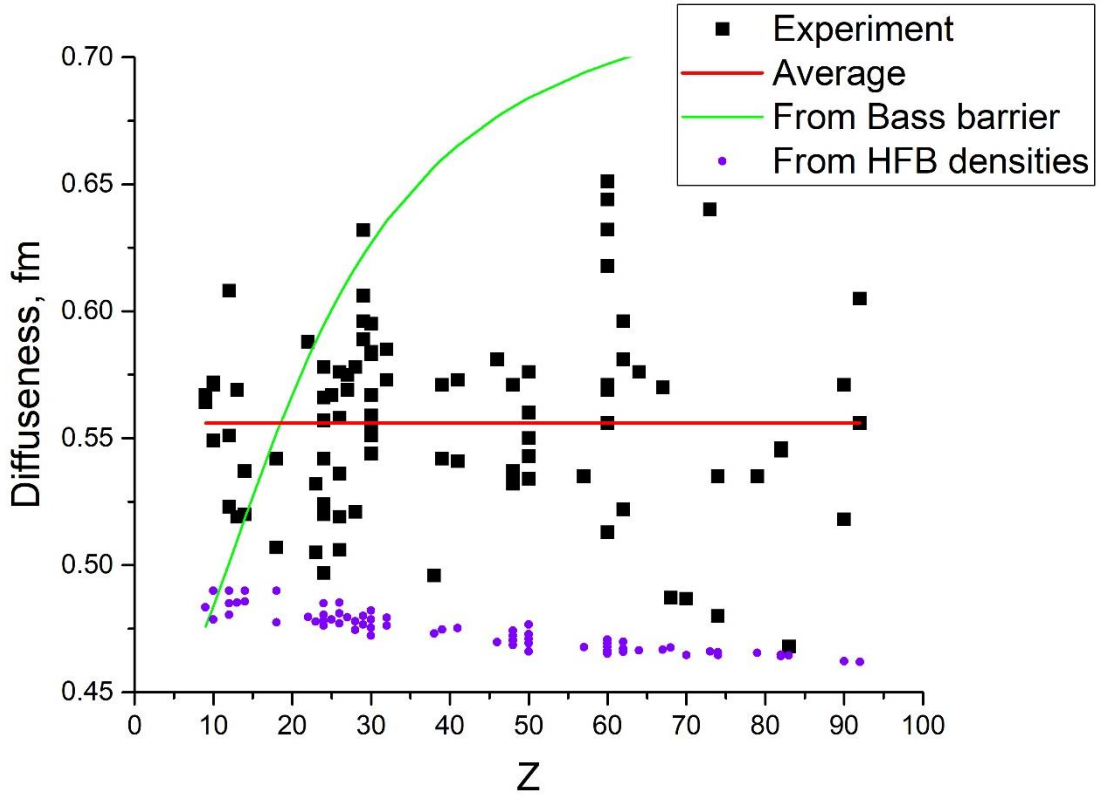
Charge density: $\rho_{ch}(r) = \frac{\rho_{0ch}}{1+\exp\left(\frac{r-R_{ch}}{a_{ch}}\right)} \approx \rho_p(r)$

$R_{ch_{rms}} \rightarrow R_{ch}$



Exp. data: I. Angeli et al. At. Data Nucl. Data Tables 99, 69 (2013).
Approx. formula: B. Nerlo-Pomorska et al. Zeitschrift für Phys. A Hadron. Nucl. 348 (1994).

$a_{ch} = 0.556(4)\ fm\ (const)$



Exp. data: H. de Vries et al. At. Data Nucl. Data Tables 36, 495–536 (1987).
Data from HFB calculations: G. G. Adamian et al. Phys. Rev. C 94, 1 (2016).
Data from Bass barrier: A. V. Karpov et al. AIP Conf. Proc., 912, 286 (2007).

Neutron density

Neutron density: $\rho_n(r) = \frac{\rho_{0n}}{1+\exp\left(\frac{r-R_n}{a_n}\right)}$

Neutron skin thickness:

$\Delta R_{np} = R_{n_{rms}} - R_{p_{\mathrm{rms}}}$

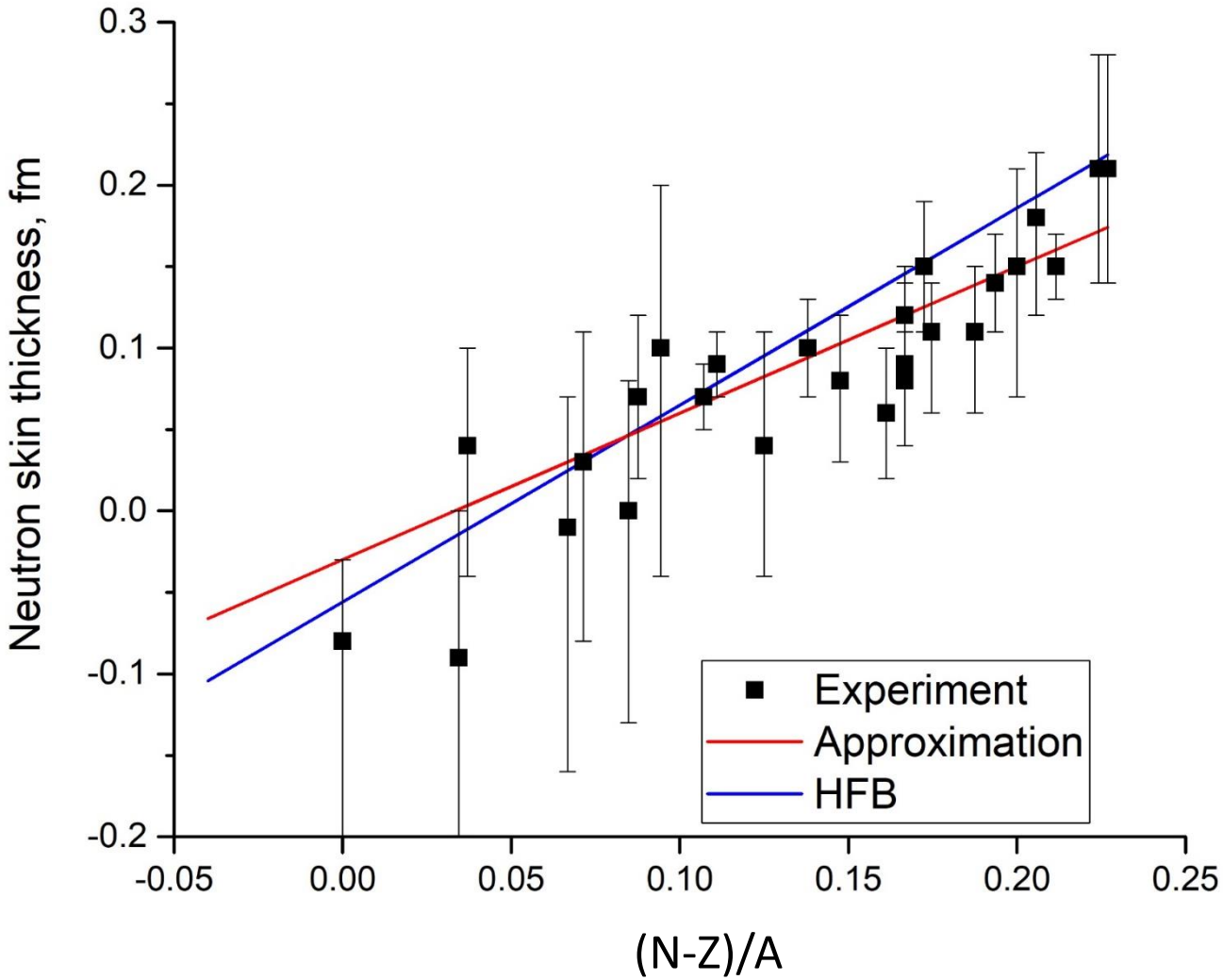
Antiprotons-nuclei scattering (approximation of experimental data):

$$\Delta R_{np} = a\frac{N-Z}{A} - b$$

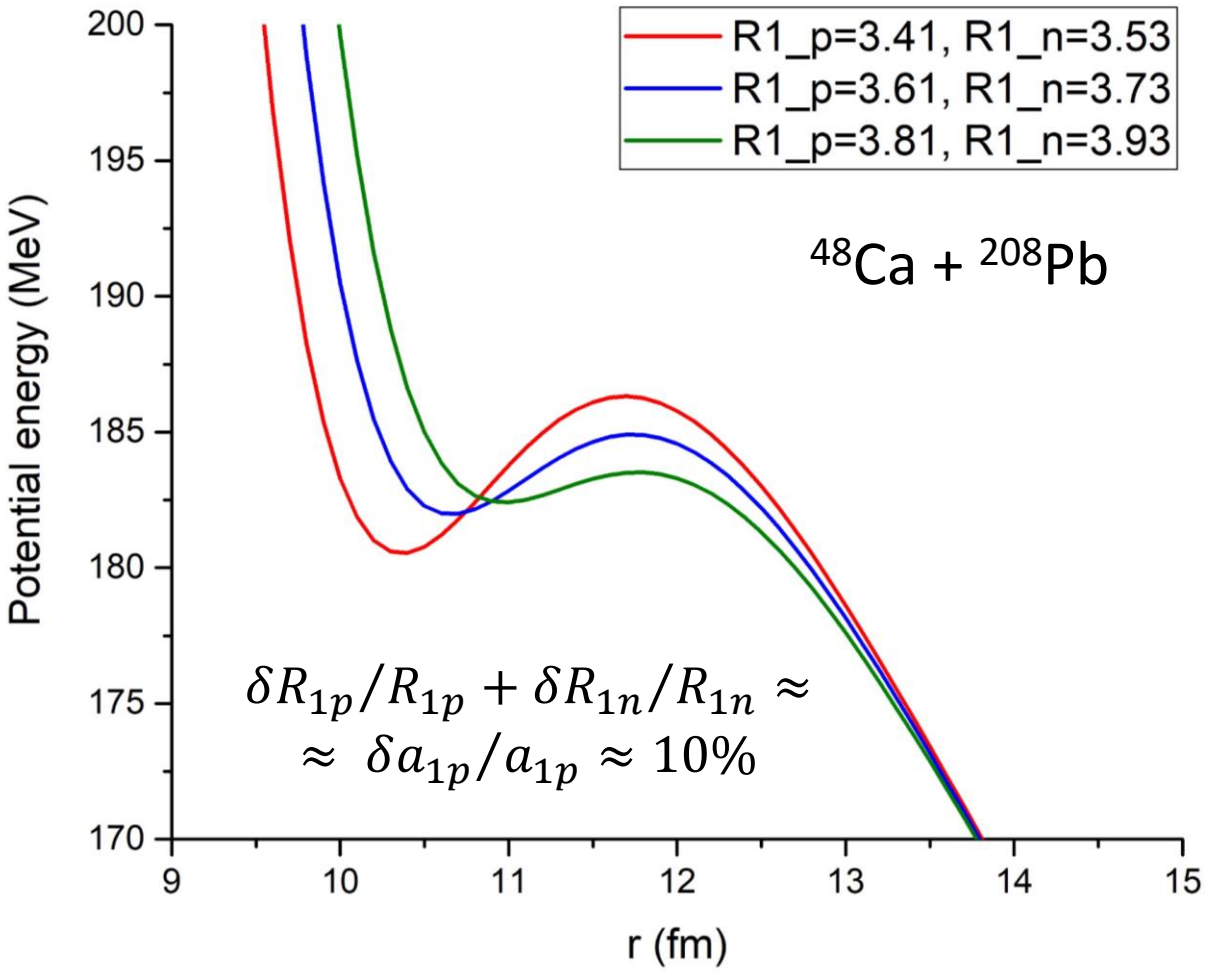
J. Jastrzebski et al. IJMP E, vol. 13. (2004)

$R_{ch_rms} \rightarrow R_{p_rms} \rightarrow \Delta R_{np} \rightarrow R_{n_rms} \rightarrow R_n$

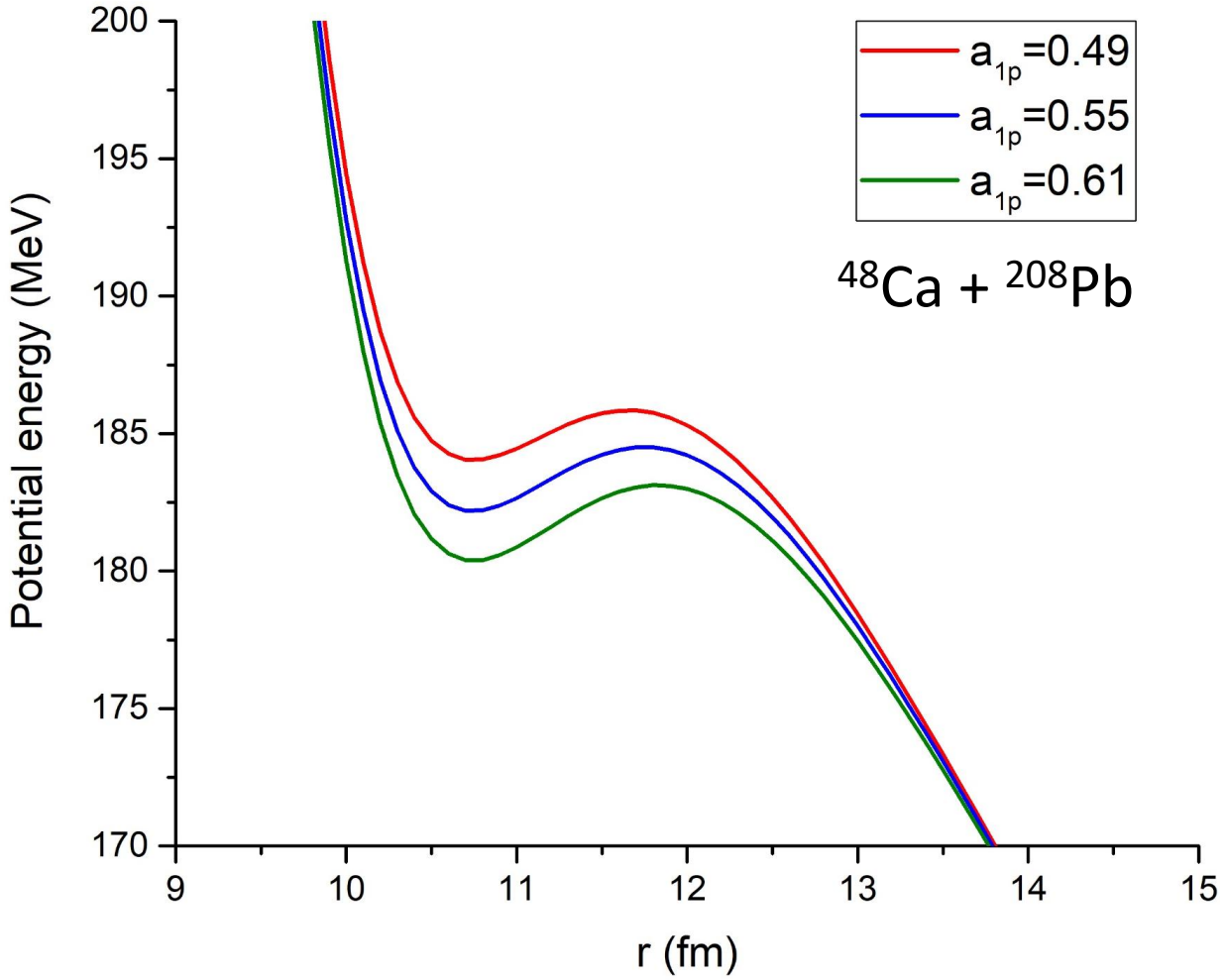
Assumption: $a_{ch} \approx a_n$



Variation of densities parameters

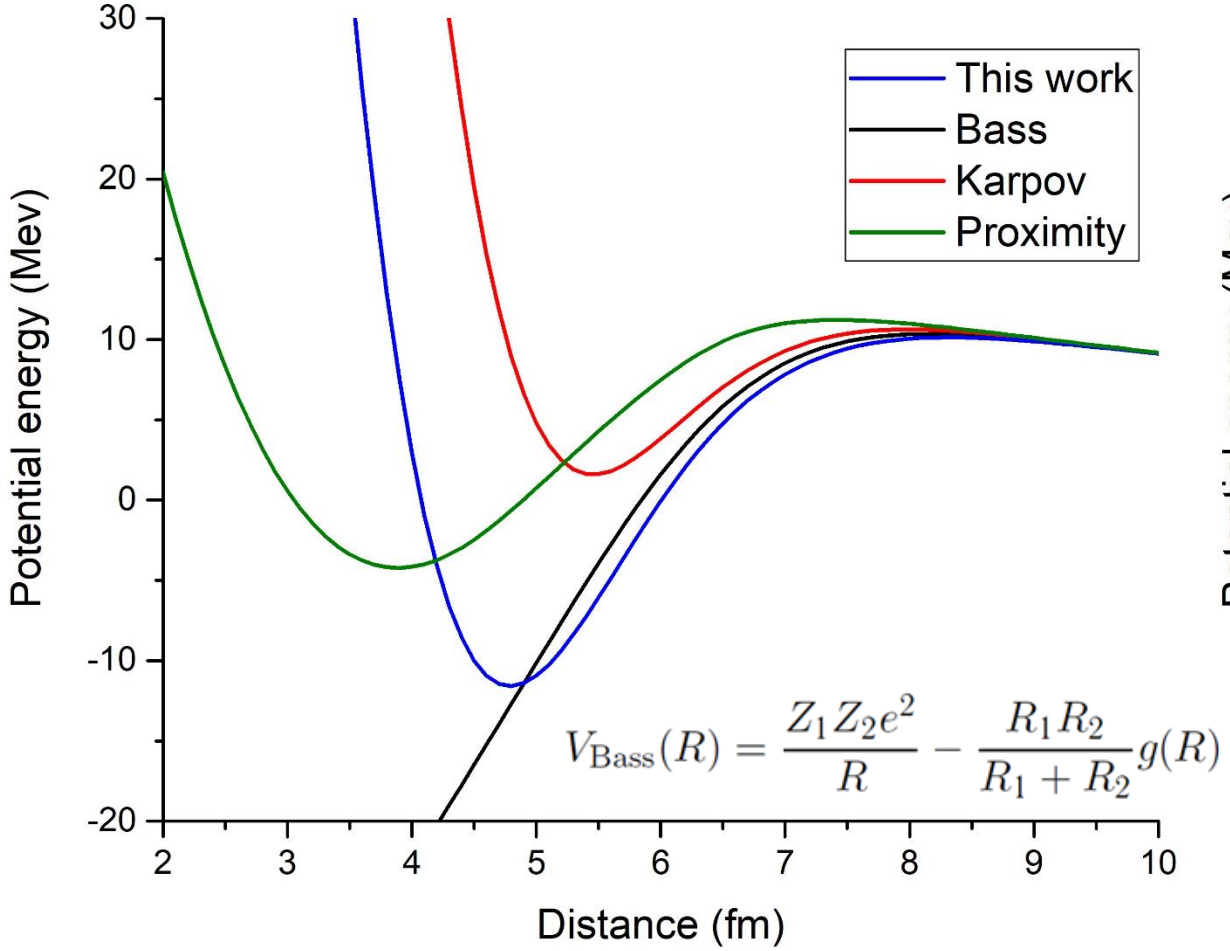


Half-density radii variation: $R_{1p} = (3.61 \pm 0.2)\ fm$

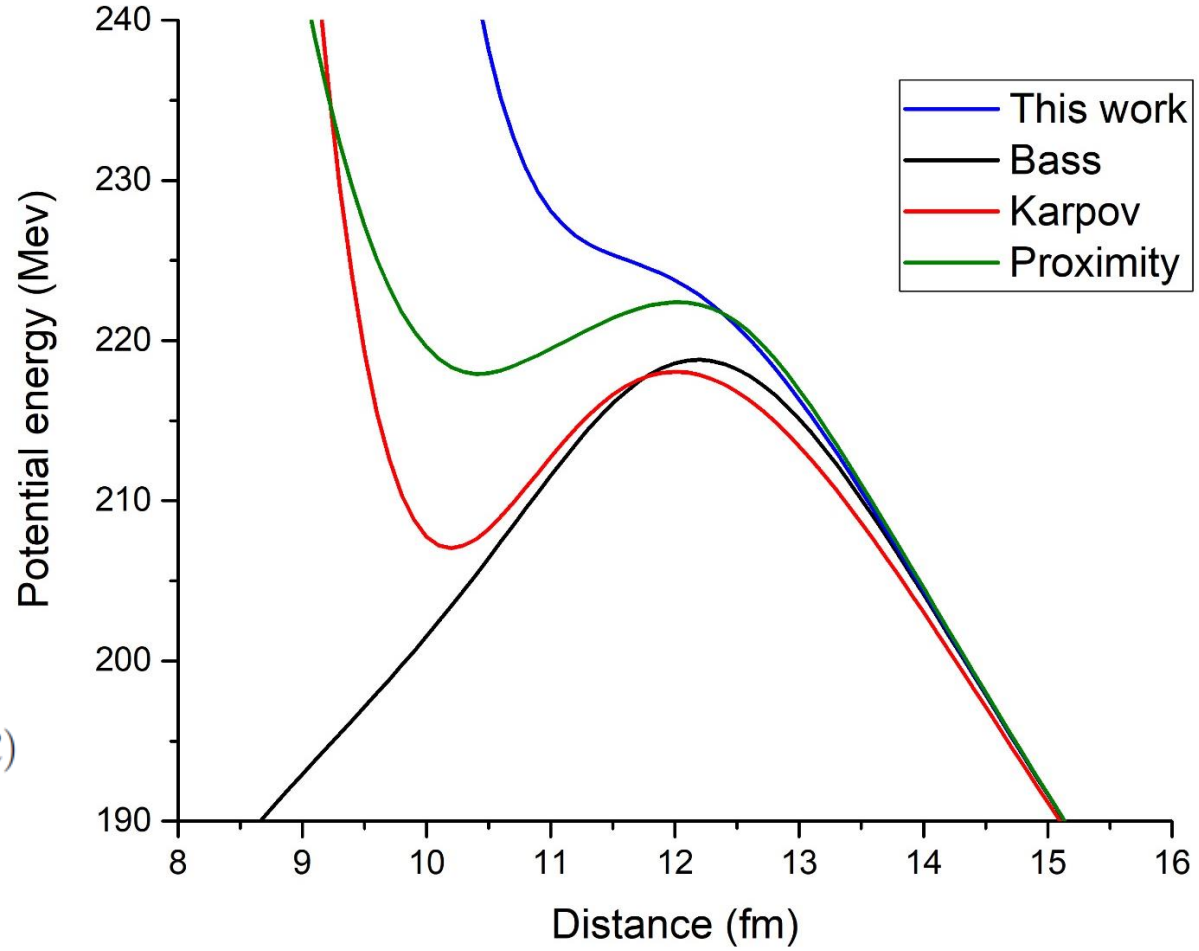


Diffuseness variation: $a_{1p} = (0.55 \pm 0.06)\ fm$

Results-1



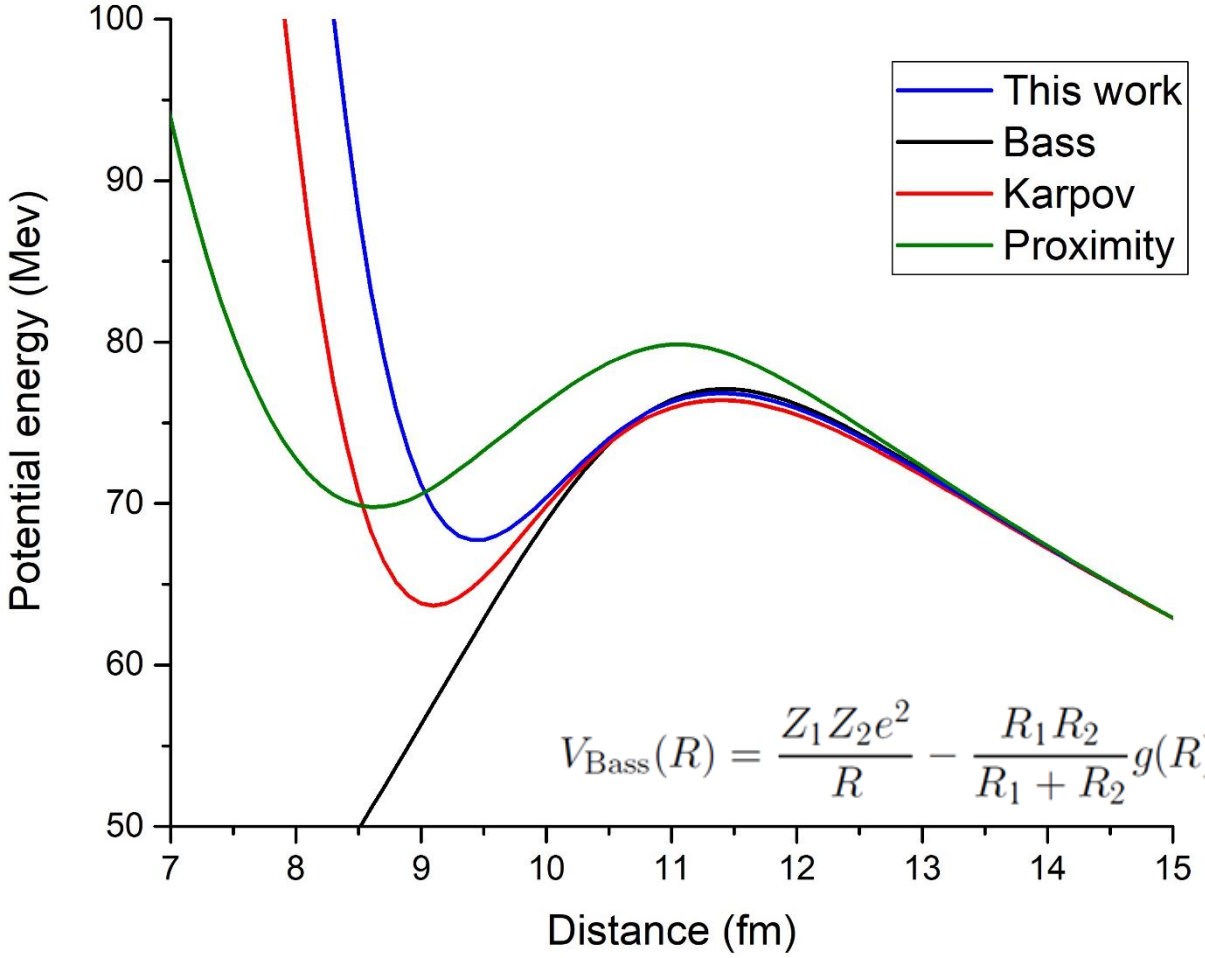
System of "light"+"light" nuclei: $^{16}O + ^{16}O$



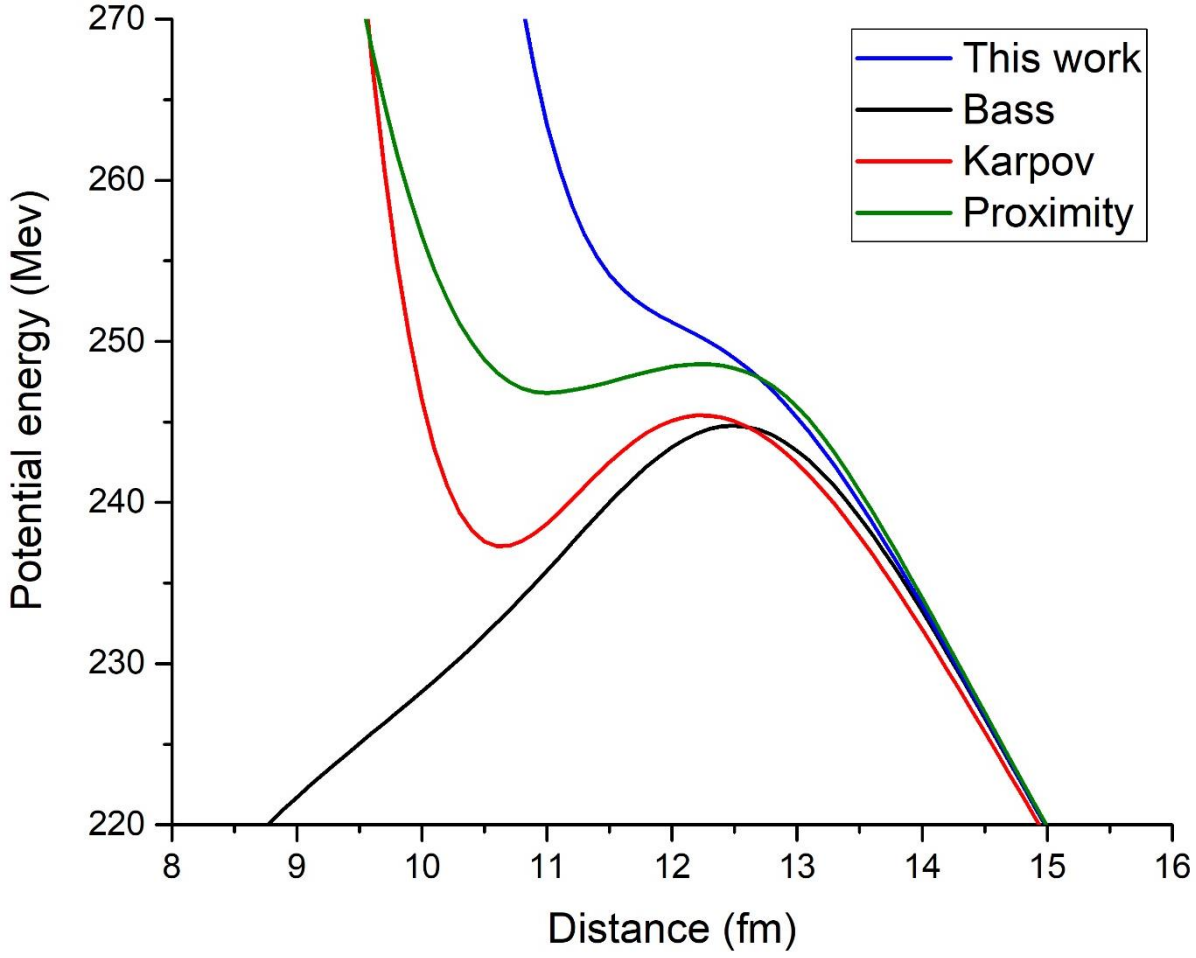
System of "middle"+"middle" nuclei: $^{90}Zr + ^{124}Sn$

__Bass potential__: R. Bass. Nuclear Reactions with Heavy Ions. Berlin: Springer, 1980.
Density parameters adjustment for Bass potential: __A. V. Karpov__ et al. AIP Conf. Proc., 912, 286 (2007).

Results-2



System of "light"+"heavy" nuclei: ^{16}O + ^{208}Pb

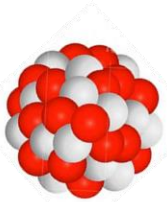


System of "middle"+"heavy" nuclei: ^{60}Ni + ^{208}Pb

Bass potential: *R. Bass. Nuclear Reactions with Heavy Ions. Berlin: Springer, 1980.*
Density parameters adjustment for Bass potential: ***A. V. Karpov*** *et al. AIP Conf. Proc., 912, 286 (2007).*

Conclusion

1. Approximation coefficients are obtained on the base of experimental data for:
   - **rms. charge radius**,
   - **diffuseness**.
2. Neutron radii are determined from **neutron skin thickness** and proton radii.
3. Sensitivity of diabatic potential to parameters of nucleonic densities is shown.
4. Nucleus-nucleus interaction potential is calculated for spherical nuclei with $Z \geq 8$, $N \geq 8$. For heavy systems it is found:
   - Due to the permanence of diffuseness' value (0.55 fm) the potential profiles are different to Bass barrier.
   - No minimum was found for diabatic potential.



Thank you for your attention!

Appendix: Used formulas

1. Radii data:
   - This work: charge rms. radius (exp)

$$R_{ch_{rms}} = 0.956\left(1 - 0.153\frac{N-Z}{A} + 2.326\frac{1}{A}\right)A^{1/3}$$

   - Rms. and half-density radius

$$R_i = R_{i_{rms}}\sqrt{\frac{5}{3} - \frac{7}{3}\left[\frac{\pi a_i}{R_{i_{rms}}}\right]^2}$$

   - Rms. neutron radius

$$R_{n_{rms}} = R_{p_{rms}} + \Delta R_{np}$$

   - Neutron skin thickness from antiprotons-nuclei scattering data (exp)

J. Jastrzebski et al. IJMP E, vol. 13. (2004)

$$\Delta R_{np} = (0.90 \pm 0.15)\frac{N-Z}{A} - (0.03 \pm 0.02)$$

   - *Proton rms. radius correction (not used)*

$$R_{p_{rms}} = \sqrt{R^2{}_{ch_{rms}} - r^2{}_{proton}}$$

2. Diffuseness data:
   - This work:

$$a_{ch} = 0.55\ fm$$

   - From HFB-densities

G. G. Adamian et al. Phys. Rev. C 94, 1 (2016).

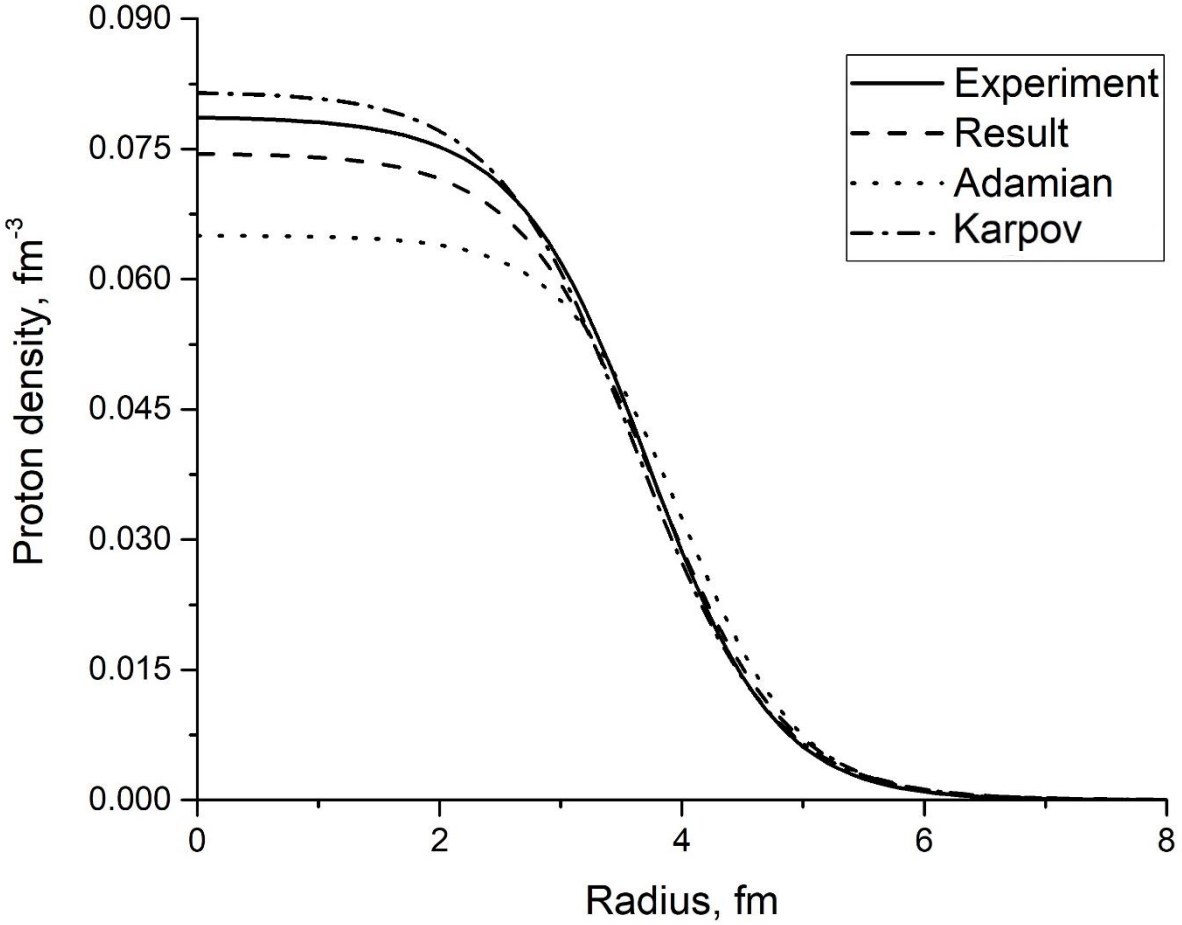
$$a(N,Z) = 0.4899 - 0.1236\frac{N-Z}{A}$$

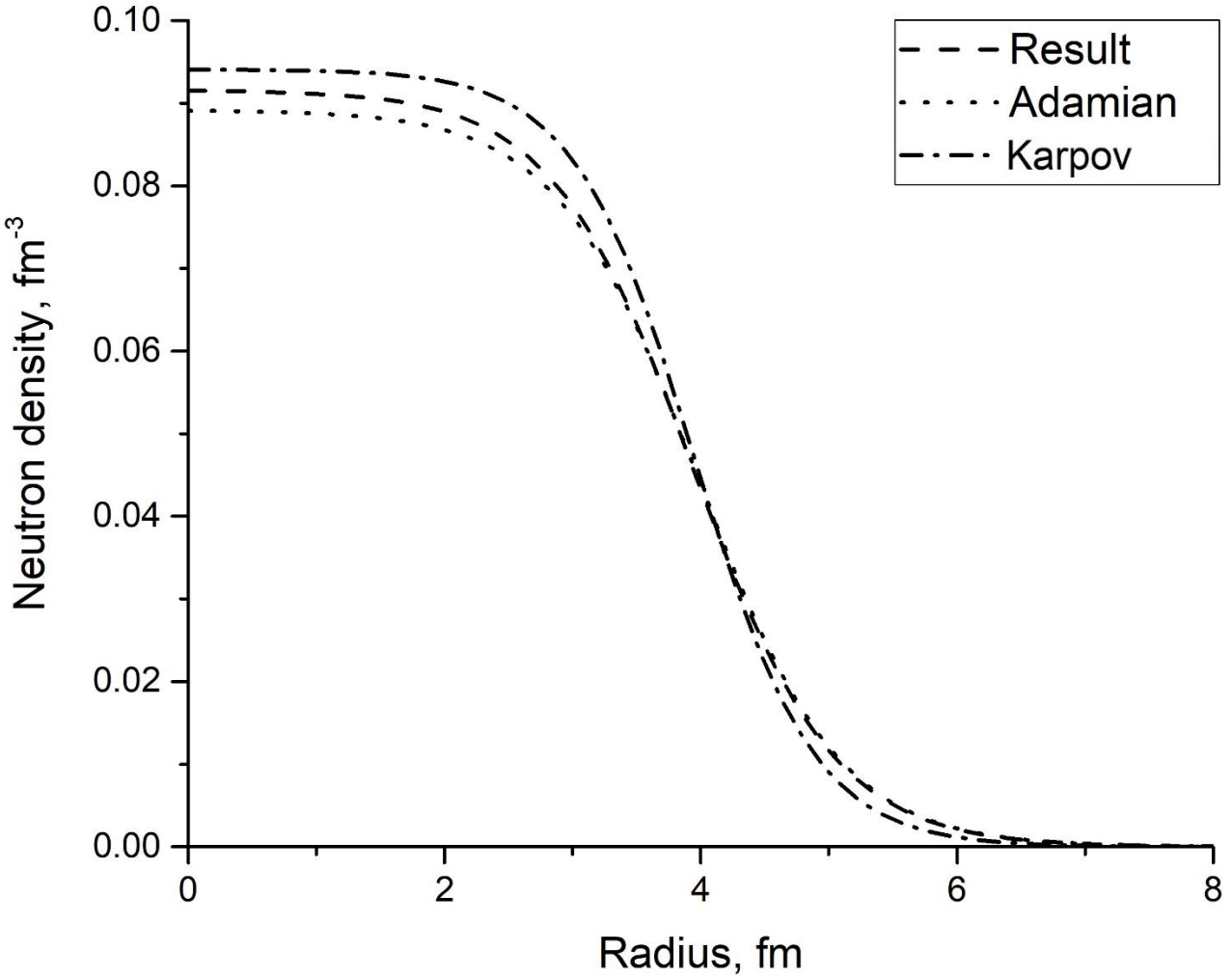
   - From comparison with Bass barrier

A. V. Karpov et al. AIP Conf. Proc., 912, 286 (2007).

$$a(Z) = 0.734 - \frac{150}{Z^2 + 500}$$

Appendix: Densities for ^{48}Ca





Experimental data:
J.B. Bellicard et al. Phys. Rev. Lett. 19, 527 (1967)

A. V. Karpov et al. AIP Conf. Proc. (EXON06), 912 (2007) 286.
G. G. Adamian et al. Phys. Rev. C 94, 1 (2016).

Appendix: Potential parameters

Effective nucleon-nucleon Migdal potential:

$$v_{NN}(\boldsymbol{r}_{12}) = \mathrm{C}\left[\mathrm{F_{ex}} + (\mathrm{F_{in}} - \mathrm{F_{ex}})\frac{\rho_1(\boldsymbol{r}_1) + \rho_2(\boldsymbol{r}_2)}{\rho_2(0) + \rho_2(0)}\right]\delta(\boldsymbol{r}_{12}), \qquad F_{\mathrm{ex(in)}} = f_{\mathrm{ex(in)}} \pm f'_{\mathrm{ex(in)}}$$

C, MeV·fm^{-3}	f_{in}	f_{ex}	f_{in}'	f_{ex}'
300	0.09	-2.59	0.42	0.54

A. B. Migdal. The Theory of Finite Fermi-Systems and Properties of Atomic Nuclei, 2-nd ed. (Nauka, Moscow, 1983) [in Russian].

Bass potential:

$$V_{\mathrm{Bass}}(R) = \frac{Z_1 Z_2 e^2}{R} - \frac{R_1 R_2}{R_1 + R_2} g(\xi)$$

$$g(\xi) = \left[A \exp\left(\frac{\xi}{d_1}\right) + B \exp\left(\frac{\xi}{d_2}\right)\right]^{-1}$$

$$\xi = R - (R_1 + R_2)$$

A, MeV^{-1}·fm	B, MeV^{-1}·fm	d_1, fm	d_2, fm
0.03	0.0061	3.3	0.65

R. Bass. Nuclear Reactions with Heavy Ions. Berlin: Springer, 1980.