Nucleon-Nucleon Correlations and Gribov Inelastic Shadowing in High Energy Collisions

C. Ciofi degli Atti

Department of Physics, University of Perugia and Istituto Nazionale di Fisica Nucleare, Sezione di Perugia, Via A. Pascoli, I-06123, Italy

Abstract. The effects of nucleon-nucleon (NN) short range correlations (SRC) and Gribov inelastic shadowing (IS) in high energy collisions are illustrated.

Keywords: short-range correlations, Gribov inelastic shadowing, high-energy collisions
PACS: 24.85.+p, 13.85.Lg, 13.85.Lg, 25.55.Ci

The nuclear quantity which enters most Glauber-like calculations is the modulus squared of the nuclear wave function ψ_0, whose exact expansion [1] is usually approximated by the lowest order, fully uncorrelated term, *viz*

$$|\,\psi_0(\mathbf{r}_1,...,\mathbf{r}_A)\,|^2 = \prod_{j=1}^{A}\rho_1(\mathbf{r}_j) + \sum_{i<j}\Delta(\mathbf{r}_i,\mathbf{r}_j)\prod_{k\neq i,j}\rho_1(\mathbf{r}_k) + ... \simeq \prod_{j=1}^{A}\rho_1(\mathbf{r}_j). \tag{1}$$

Here the *two-body contraction* $\Delta(\mathbf{r}_i,\mathbf{r}_j) = \rho_2(\mathbf{r}_i,\mathbf{r}_j) - \rho_1(\mathbf{r}_i)\rho_1(\mathbf{r}_j)$, contains the effect of SRC, represented by a hole in the two-body density ρ_2 at short inter-nucleon separations (see Fig. 1). SRC lead to an additional contribution to the nuclear thickness function as follows $(\mathbf{r}_i = \{\mathbf{s}_i, z_i\})$ [3]

$$\Delta T_A^h(b) = \frac{1}{\sigma_{tot}^{hN}}\int d^2\mathbf{s}_1\, d^2\mathbf{s}_2\, \Delta_A^{\perp}(\mathbf{s}_1,\mathbf{s}_2)\,\mathrm{Re}\,\Gamma^{pN}(\mathbf{b}-\mathbf{s}_1)\;\mathrm{Re}\,\Gamma^{pN}(\mathbf{b}-\mathbf{s}_2), \tag{2}$$

where $\Delta_A^{\perp}(\mathbf{s}_1,\mathbf{s}_2)$ is the transverse two-nucleon contraction and the total thickness function is $\widetilde{T}_A^h = T_A^h - \Delta T_A^h$. The thickness functions of ^{12}C and ^{208}Pb at HERA-B energies are shown in Fig. 2. SRC increase the thickness functions and, consequently, the total neutron-nucleus cross section at high energies, making the nucleus more opaque [3], unlike Gribov IS corrections which increase nuclear transparency. An exhaustive calculation [4] of the total, σ_{tot}^{hA}, elastic, σ_{el}^{hA}, quasi-elastic, σ_{qel}^{hA}, inelastic, σ_{in}^{hA}, and diffractive dissociation hadron-nucleus cross sections, which include both SRC and Gribov IS summed to all orders by the dipole approach [5, 6, 7], confirms the opposite roles played by SRC and IS, with the total contribution to the thickness function due to SRC and Gribov IS reading as follows

$$\Delta T_A^{dip}(b,\mathbf{r}_T,\alpha) = \\ = \frac{1}{\sigma_{dip}(r_T)}\int d^2\mathbf{s}_1\, d^2\mathbf{s}_2\, \Delta_A^{\perp}(\mathbf{s}_1,\mathbf{s}_2)\,\mathrm{Re}\,\Gamma^{\bar{q}q,N}(\mathbf{b}-\mathbf{s}_1,\mathbf{r}_T,\alpha)\,\mathrm{Re}\,\Gamma^{\bar{q}q,N}(\mathbf{b}-\mathbf{s}_2,\mathbf{r}_T,\alpha). \tag{3}$$

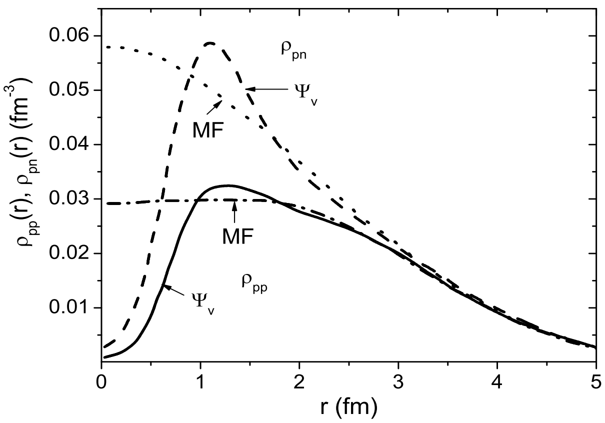

FIGURE 1. The proton-neutron (pn) and proton-proton (pp) two-body densities in ^{16}O calculated [2] within a mean field model (MF)and by solving the many-body problem with a realistic NN interaction (Ψ_v). The behavior of ρ_{NN} at relative distances $r \leq 1.5 \div 2\ fm$ is governed by the repulsive short-range core and by the attractive intermediate-range tensor force (after Ref. [2]).

TABLE 1. Various $p - {}^{208}Pb$ cross sections at LHC energies (after Ref. [4]).

^{208}Pb	Glauber	Glauber +SRC	q-2q model +SRC	3q model +SRC
σ^{NA}_{tot} $[mb]$	3850.63	3885.77	3833.26	3839.26
σ^{NA}_{el} $[mb]$	1664.76	1690.48	1655.70	1660.67
σ^{NA}_{sd} $[mb]$	-	-	2.62	0.59
$\sigma^{NA}_{sd+g}[mb]$	-	-	2.58	2.56
σ^{NA}_{qe} $[mb]$	120.92	112.65	113.37	113.88
σ^{NA}_{qsd} $[mb]$	-	-	-2.08	-2.62
σ^{NA}_{tsd} $[mb]$	-	-	17.55	17.63
σ^{NA}_{dd} $[mb]$	-	-	-2.08	-2.62

SRC and Gribov IS affect also the number of inelastic collisions $N^{hA}_{coll} = A\,\sigma^{hN}_{in}/\sigma^{hA}_{in}$ which is the normalization factor used to obtain the nucleus to nucleon ratio of the cross section of a hard reaction. The results of calculations of Refs. [4, 8], performed with realistic one- and two-body densities and correlation functions from Ref. [9], are shown in Tables 1 and 2. The behavior of N^{NA}_{coll} is entirely governed by the non-diffractive σ^{NA}_{in} which, as shown in Table 2, is decreased by SRC and increased by Gribov IS. The effects of both SRC and Gribov IS amount to few percent in agreement with the results of the calculation of deuteron-gold scattering [6]. Concerning the high energy collision of two nuclei, A and B, the correlation contribution to the thickness function can be written as

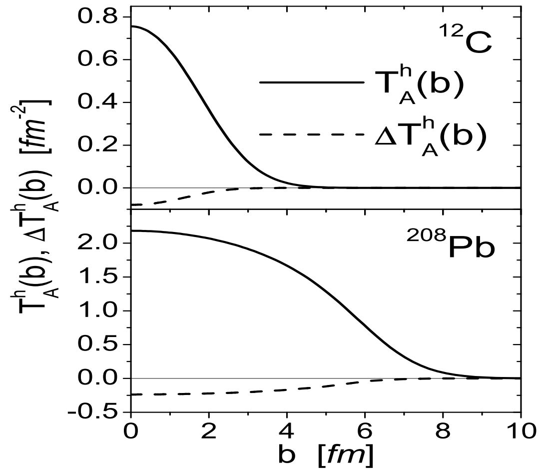

FIGURE 2. The thickness function $T_A^h(b)$ and the correlation contribution $(\Delta T_A^h(b))$ in $p-^{12}C$ and $p-^{208}Pb$ collisions at HERA-B energies. The total thickness function is given by $\widetilde{T}_A^h = T_A^h - \Delta T_A^h$ (after Ref. [4]).

TABLE 2. Number of inelastic collisions N_{coll} in $p-^{208}Pb$ scattering at RHIC and LHC energies (after Ref. [8]).

	GLAUBER					
	σ_{in}^{NN} $[mb]$	σ_{tot}^{NA} $[mb]$	σ_{el}^{NA} $[mb]$	σ_{qel}^{NA} $[mb]$	σ_{in}^{NA} $[mb]$	N_{coll}
RHIC	42.10	3297.56	1368.36	66.06	1863.14	4.70
LHC	68.30	3850.63	1664.76	120.92	2064.95	6.88

	GLAUBER+SRC					
	σ_{in}^{NN} $[mb]$	σ_{tot}^{NA} $[mb]$	σ_{el}^{NA} $[mb]$	σ_{qel}^{NA} $[mb]$	σ_{in}^{NA} $[mb]$	N_{coll}
RHIC	42.10	3337.57	1398.08	58.47	1881.02	4.65
LHC	68.30	3885.77	1690.48	112.65	2082.64	6.82

	GLAUBER+SRC+GRIBOV$(q-2q)$					
	σ_{in}^{NN} $[mb]$	σ_{tot}^{NA} $[mb]$	σ_{el}^{NA} $[mb]$	σ_{qel}^{NA} $[mb]$	σ_{in}^{NA} $[mb]$	N_{coll}
RHIC	42.10	3228.11	1314.04	71.99	1842.08	4.75
LHC	68.30	3833.26	1655.70	113.37	2064.19	6.88

follows

$$\Delta T_{AB}^h(b) = \frac{1}{\sigma_{tot}^{NN}} A_A A_B^2 \times$$
$$\times \int d^2 s_A \rho_A(\mathbf{s}_A) \int d^2 s_{B1} d^2 s_{B2} \Delta_B^{\perp}(\mathbf{s}_{B1}, \mathbf{s}_{B2}) \Gamma^{NN}(\mathbf{b} - \mathbf{s}_A + \mathbf{s}_{B1}) \Gamma^{NN}(\mathbf{b} - \mathbf{s}_A + \mathbf{s}_{B2}) +$$
$$+ \{A \longleftrightarrow B\} \tag{4}$$

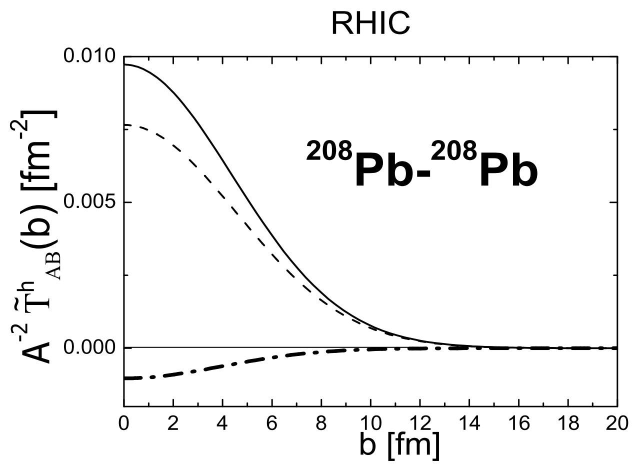

FIGURE 3. Uncorrelated thickness function $T^h_{AB}(b)/A^2$ (dash); correlation contribution $\Delta T^h_{AB}(b)/A^2$ (dot-dash); total thickness function $\widetilde{T}^h_{AB}/A^2 = [T^h_{AB}(b) - 2\Delta T^h_{AB}(b)]/A^2$ (full) in $^{208}Pb - ^{208}Pb$ collisions at RHIC energies (after Ref. [8]).

where the 1st term describes the interaction of a nucleon in A with two correlated nucleons in B and the 2nd term in figure brackets viceversa. The thickness function including the effects of SRC in $^{208}Pb - ^{208}Pb$ scattering at RHIC energies is shown in Fig. 3; it can be seen that SRC can appreciably affect the usual definition of the number of collisions $N^{AB}_{coll}(b)$.

ACKNOWLEDGMENT

A stimulating collaboration with Boris Kopeliovich, Irina Potashnikova and Ivan Schmidt, Departamento de Física, Universidad Federico Santa María, Valparaíso, Chile, is gratefully acknowledged.

REFERENCES

1. R. J. Glauber, in *Lectures in Theoretical Physics*, W. E. Brittin *et al* Editors, New York (1959).
2. S. C. Pieper, R. B. Wiringa, V. R. Pandharipande, *Phys. Rev.***C46** (1992) 1741.
3. M. Alvioli, C. Ciofi degli Atti, I. Marchino, V. Palli, H. Morita *Phys. Rev.***C78** (2008) 031601(R).
4. M. Alvioli, C. Ciofi degli Atti, B. Z. Kopeliovich, I. K. Potashnikova, I. Schmidt, *Phys. Rev.* **C81** (2010) 025204.
5. B. Z. Kopeliovich, L. I. Lapidus, A. B. Zamolodchikov, *JETP Lett. 33* (1981) 595. [Pisma Zh. Eksp. Teor. Fiz. **33** (1981) 595].
6. B. Z. Kopeliovich, *Phys. Rev.* **C68** (2003) 044906.
7. B. Z. Kopeliovich, I. K. Potashnikova and I. Schmidt *Phys. Rev.* **C73** (2006) 034901.
8. C. Ciofi degli Atti, C. B. Mezzetti, B. Z. Kopeliovich, I. K. Potashnikova, I. Schmidt, *to appear*.
9. M. Alvioli, C. Ciofi degli Atti, H. Morita, *Phys. Rev. Lett.* **100** (2008) 162503.