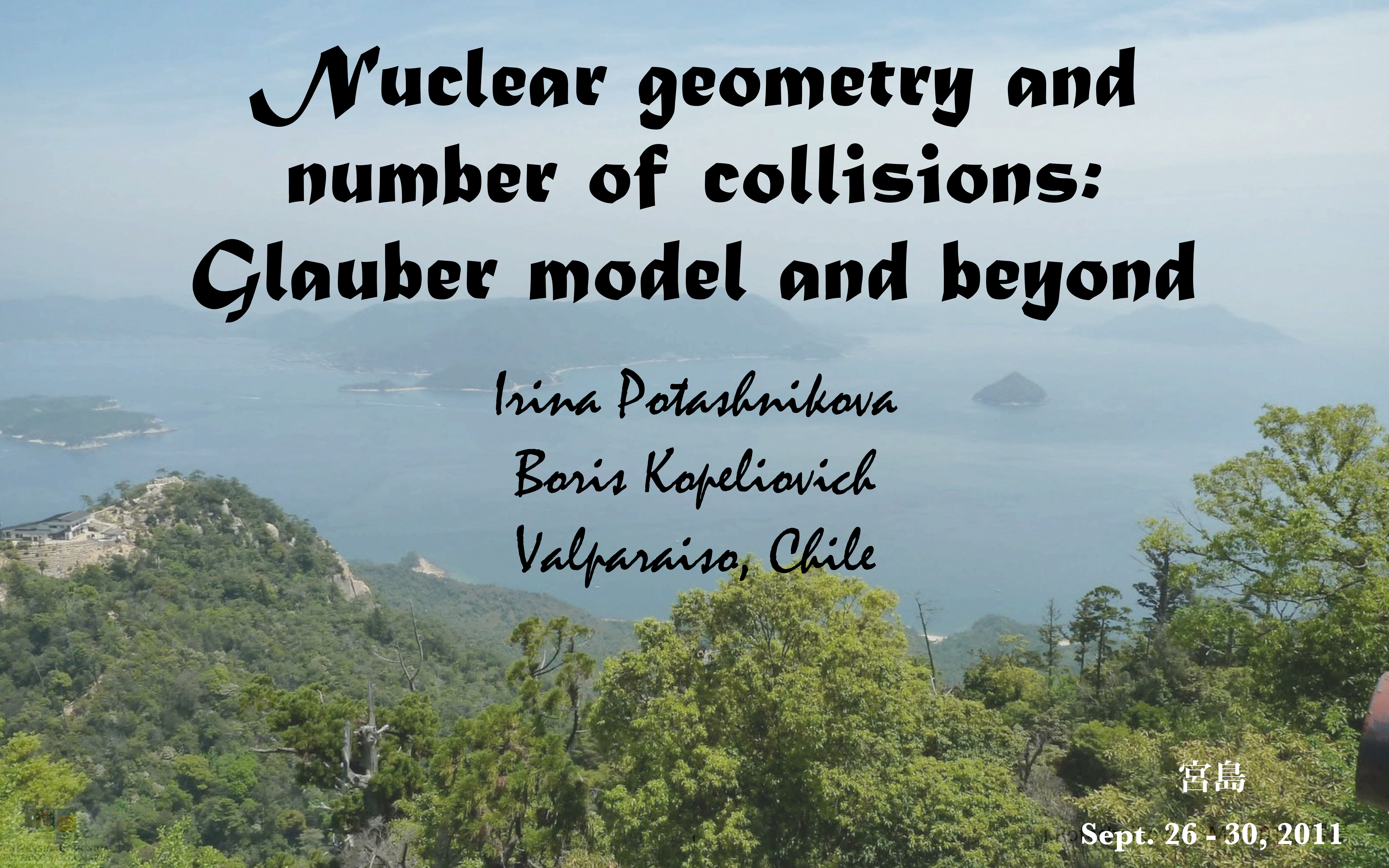

Nuclear geometry and number of collisions: Glauber model and beyond

Irina Potashnikova

Boris Kopeliovich

Valparaiso, Chile

宮島

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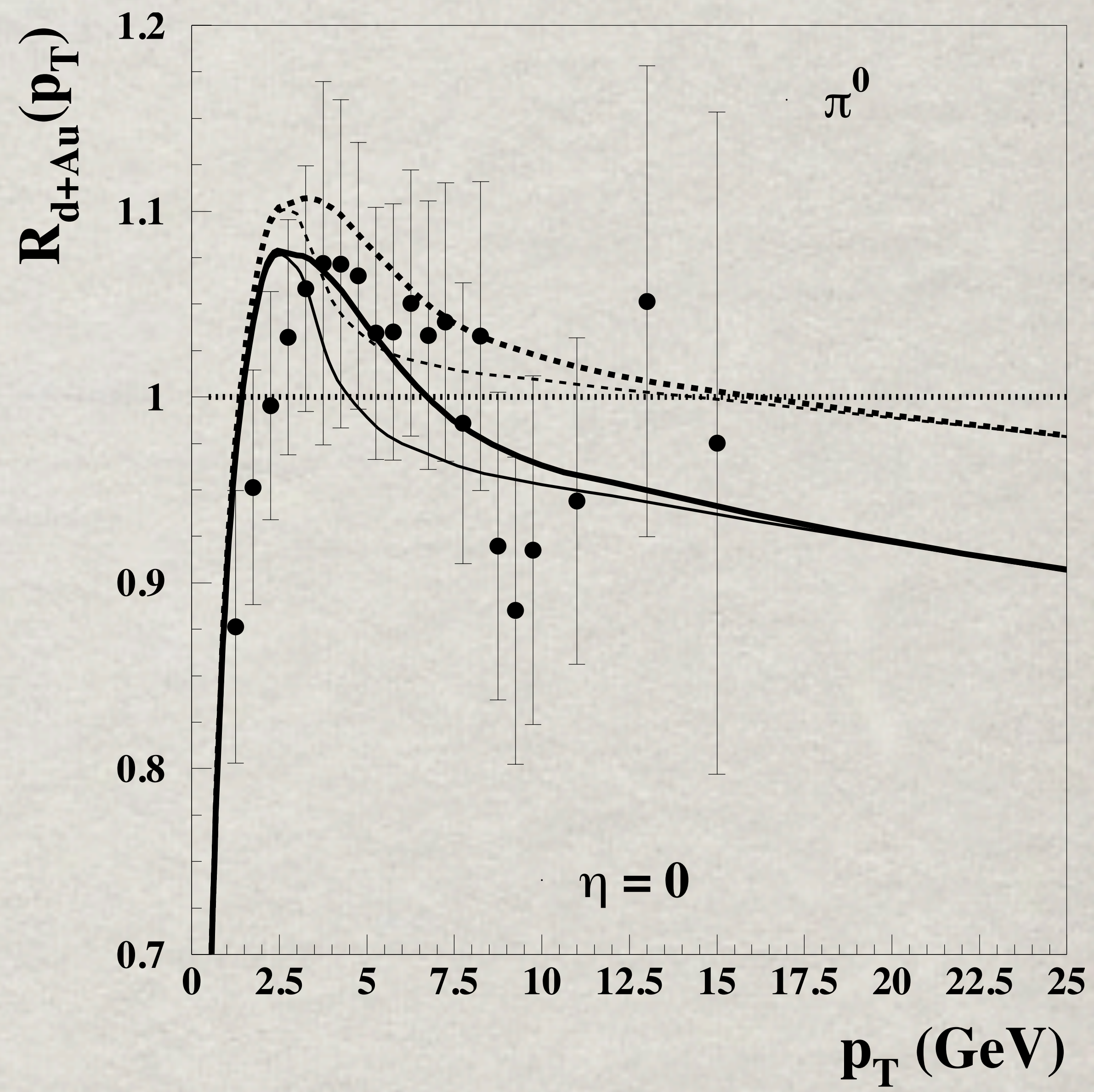
Normalization of hard processes

The measured pA to pp ratio of the numbers of events is to be normalized in order to get the ratio of hard cross sections



$$R^{hard}_{A/N}(b) \equiv \frac{d\sigma^{hA}_{hard}/d^2b}{T_A(b)\,\sigma^{hN}_{hard}} = \frac{N^{hA}_{hard}(b)}{n_{coll}(b)\,N^{hN}_{hard}}$$

$$n_{coll}(b) = \frac{\sigma^{hN}_{in}\,T_A(b)}{P_{in}(b)}; \quad P^{Gl}_{in}(b) \equiv \frac{d\sigma^{hA}_{in}}{d^2b} = 1 - e^{-\sigma^{hN}_{in}\,T^h_A(b)}$$

Nuclear effects in hard pA collisions usually are rather small ~10%, so the Glauber model for $n_{coll}(b)$ might be not sufficiently accurate.

- Gribov inelastic shadowing makes the nucleus more transparent
- $n_{coll}(b)$ should be redefined, if diffraction escapes detection
- Short-range NN correlations make the nucleus more opaque

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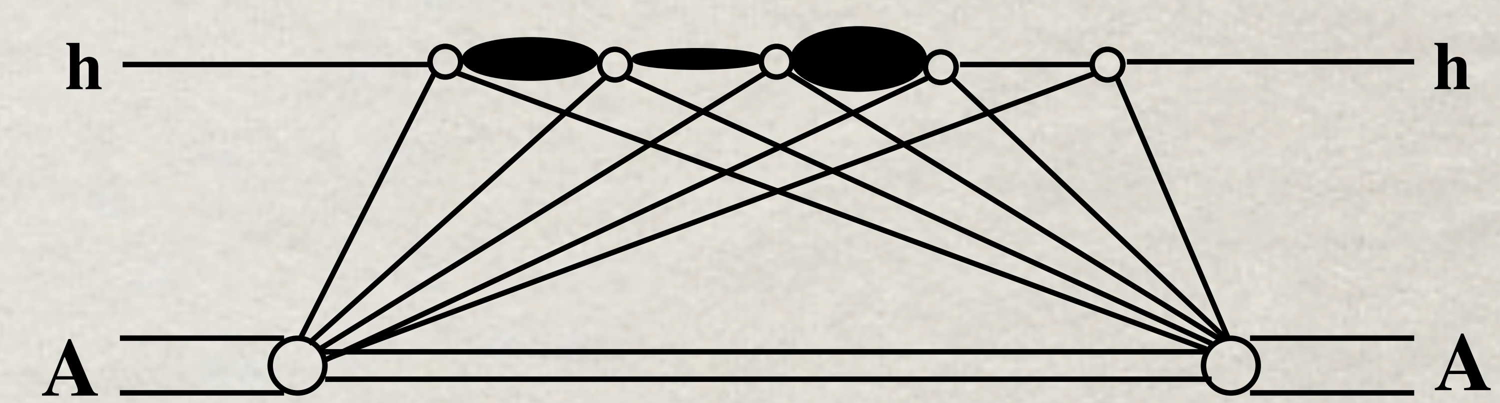
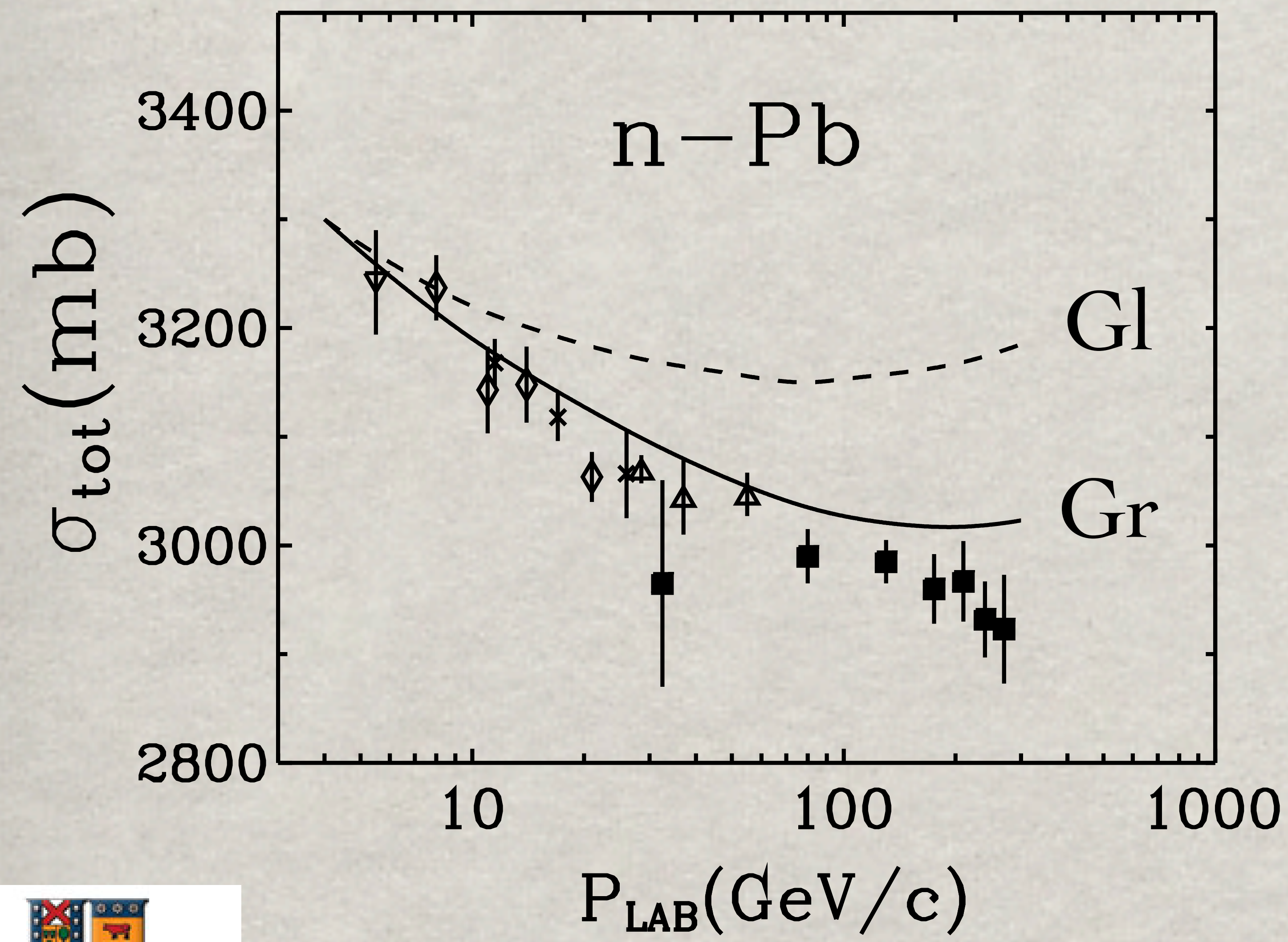
Gribov inelastic corrections

The Glauber model is a single-channel approximation. A multi-channel problem includes the off-diagonal diffractive transitions - Gribov inelastic corrections.



Only the lowest order correction is known.

$$\Delta\sigma^{hA}_{tot} = -4\pi \int d^2b\, e^{-\frac{1}{2}\,\sigma^{hN}_{tot}\,T_A(b)} \int\limits_{M^2_{min}} dM^2\, \frac{d\sigma^{hN}_{sd}}{dM^2\, dp_T^2} \int\limits_{-\infty}^{\infty} dz_1\, \rho_A(b,z_1) \int\limits_{z_1}^{\infty} dz_2\, \rho_A(b,z_1)\, e^{iq_L(z_2-z_1)}$$



At high energies one can sum up the inelastic corrections in all orders switching to the eigenstates of interaction.

$$\Delta\sigma^{hA}_{tot} = 2 \int d^2b \left[e^{-\frac{1}{2}\langle\sigma_i\rangle T_A(b)} - \left\langle e^{-\frac{1}{2}\,\sigma_i T_A(b)} \right\rangle \right]$$

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N_{coll} beyond the Glauber model

- Glauber single-channel model: $$n_{coll}^{Gl}(b) = \frac{\sigma_{in}^{hN} T_A(b)}{P_{in}^{Gl}(b)}$$

$$P_{in}^{Gl}(b) = \frac{d\sigma_{tot}^{hA}}{d^2b} - \frac{d\sigma_{el}^{hA}}{d^2b} - \frac{d\sigma_{qel}^{hA}}{d^2b} = 1 - e^{-\sigma_{in}^{hN} T_A^h(b)}$$

If diffractive excitation of the proton and/or the nucleus escape detection, their cross sections should be subtracted as well. However, diffraction cannot be treated self-consistently within the Glauber model.

- Gribov multi-channel approach: $$n_{coll}^{Gr}(b) = \frac{(\sigma_{in}^{hN} - \sigma_{diff}^{hN}) T_A(b)}{P_{in}^{Gr}(b)}$$

$$P_{in}^{Gr}(b) = \frac{d\sigma_{tot}^{hA}}{d^2b} - \frac{d\sigma_{el}^{hA}}{d^2b} - \frac{d\sigma_{qel}^{hA}}{d^2b} - \frac{d\sigma_{diff}^{hA}}{d^2b} - \frac{d\sigma_{qsd}^{hA}}{d^2b} - \frac{d\sigma_{tsd}^{hA}}{d^2b} - \frac{d\sigma_{dd}^{hA}}{d^2b}$$

All these cross sections haven't been measured, can be only calculated.

Eigenstates - color dipoles

At high energies color dipoles are the eigenstates of interactions:

$$\hat{f}\,|\mathbf{r_T}\rangle = f_{dip}(\mathbf{r_T})\,|\mathbf{r_T}\rangle$$

$$\frac{1}{2}\,\frac{d\sigma^{hA}_{tot}}{d^2b} = 1 - \left\langle e^{-\frac{1}{2}\sigma_{dip}T^h_A(b)}\right\rangle$$

L. Lapidus, A. Zamolodchikov, B.K.
JETP Lett 33(1981)595

B.K. PRC 68(2003)044906

$$\frac{d(\sigma^{hA}_{el}+\sigma^{hA}_{diff})}{d^2b} = \frac{d\sigma^{hA}_{tot}}{d^2b} - 1 + \left\langle e^{-\sigma_{dip}T^h_A(b)}\right\rangle$$

I. Schmidt, B.K. & I.P.
PRC 73(2006)034901

$$\frac{d(\sigma^{hA}_{qel}+\sigma^{hA}_{qsd})}{d^2b} = \left\langle e^{-\sigma_{dip}T^h_A(b)}\left[e^{\frac{\sigma^2_{dip}T^h_A(b)}{16\pi B_{el}}} - 1\right]\right\rangle$$

M. Avioli, C. Ciofi degli Atti,
I. Schmidt, B.K. & I.P.
PRC 81(2010)025204

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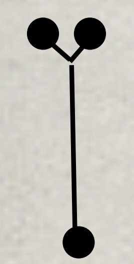
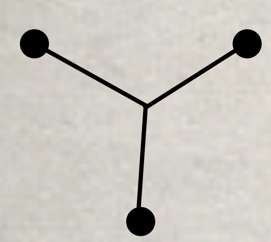
Gribov corrected cross sections

The cross sections in mb at $\sqrt{s} = 200\,\mathrm{GeV}$





Model	σ_{tot}^{pPb}	σ_{el}^{pPb}	$\left[\sigma_{sd}^{pPb}\right]_{I\!PI\!PI\!R}$	$\left[\sigma_{sd}^{pPb}\right]_{3I\!P}$	σ_{qel}^{pPb}	σ_{qsd}^{pPb}	σ_{tsd}^{pPb}	σ_{dd}^{pPb}
Glauber	3616.8	1446.8	-	5.1	98.6	-	42.3	-
q-2q	3457.5	1313.8	33.3	7.6	96.2	3.1	41.4	3.1
3q	3514.1	1362.3	8.9	6.3	98.9	0.6	42.53	0.6

$\sqrt{s} = 5.5\,\mathrm{TeV}$

Model	σ_{tot}^{pPb}	σ_{el}^{pPb}	$\left[\sigma_{sd}^{pPb}\right]_{I\!PI\!PI\!R}$	$\left[\sigma_{sd}^{pPb}\right]_{3I\!P}$	σ_{qel}^{pPb}	σ_{qsd}^{pPb}	σ_{tsd}^{pPb}	σ_{dd}^{pPb}
Glauber	4241.5	1794.9	-	28.8	141.43	-	22.9	-
q-2q	4194.2	1755.6	5.8	33.4	141.8	0.0	23.0	0.0
3q	4207.1	1767.3	0.9	31.2	142.5	0.0	23.1	0.0

Gribov corrections make the nucleus more transparent, i.e. $\mathrm{N_{coll}}$ increases by about 10%, nearly eliminating the Cronin enhancement

Short range NN correlations

Inclusion of SRC leads to an effective modification of the nuclear profile

- $$\mathbf{T^h_A(b) \Rightarrow \widetilde{T}^h_A(b) = T^h_A(b) - \Delta T^h_A(b)}$$

$$\mathbf{\Delta T^h_A(b) = \frac{1}{\sigma^{hN}_{tot}} \int d^2l_1\, d^2l_2\, \Delta^{\perp}_A(l_1, l_2)\, \mathrm{Re}\, \Gamma^{pN}(b - l_1)\, \mathrm{Re}\, \Gamma^{pN}(b - l_2)},$$

$$\mathbf{\Delta^{\perp}_A(l_1, l_2) = A^2 \int\limits_{-\infty}^{\infty} dz_1 \int\limits_{-\infty}^{\infty} dz_2\, \Delta_A(r_1, r_2)}$$

$$\mathbf{\Delta_A(r_1, r_2) = \rho^{(2)}_A(r_1, r_2) - \rho_A(r_1)\rho_A(r_2)}$$

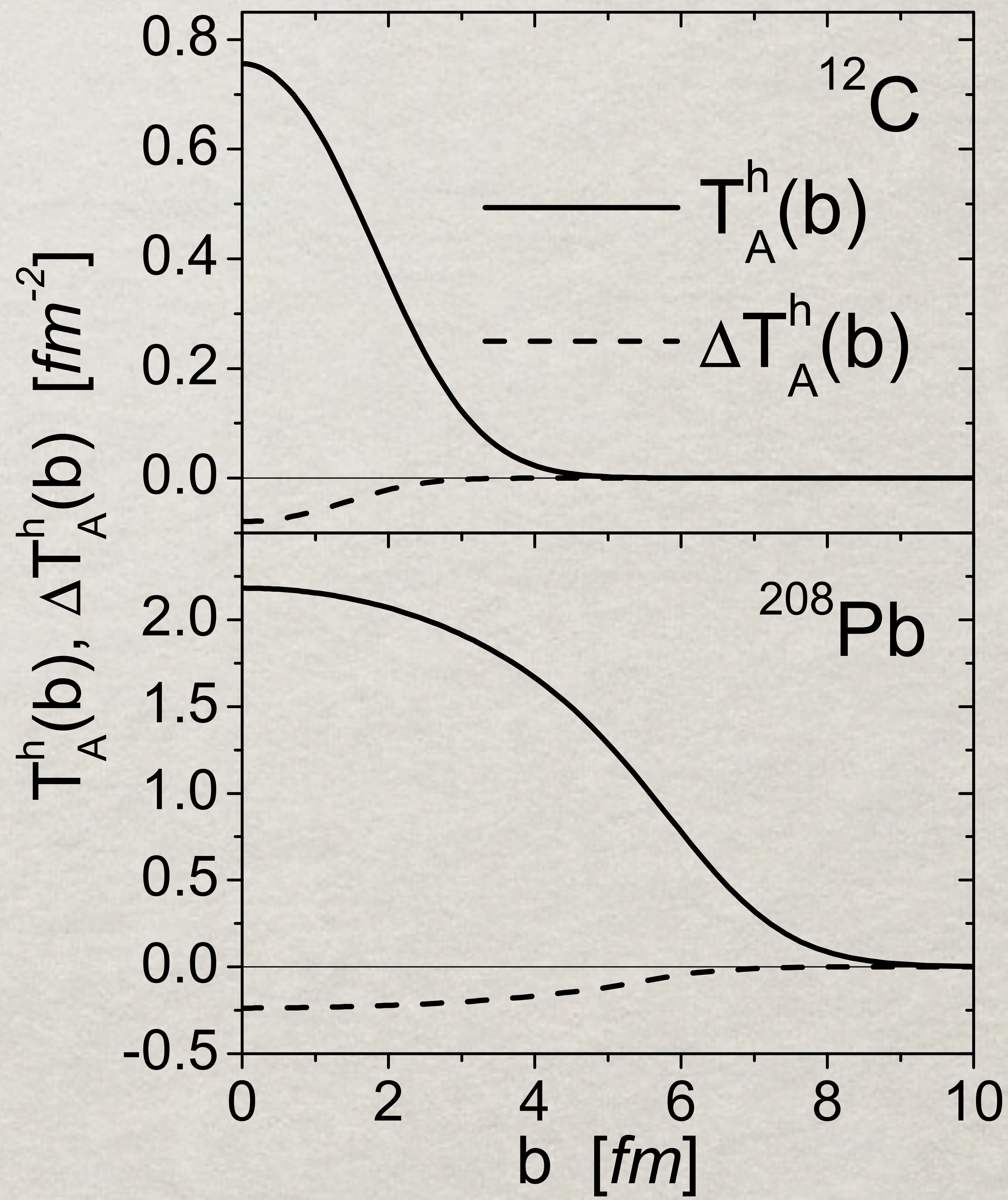
The usual single-nucleon density: $$\mathbf{\rho_A(r_1) = \int |\psi_o(r_1, r_2, ..., r_A)|^2 \prod_{i=2}^{A} d^3r_i}$$

The 2-body density matrix: $$\mathbf{\rho^{(2)}_A(r_1, r_2) = \int |\psi_o(r_1, r_2, ..., r_A)|^2 \prod_{i=3}^{A} d^3r_i}$$

Short range NN correlations

$\mathbf{\Delta_A(r_1, r_2)}$ **is calculated employing a realistic phenomenological NN potential including spin** $\tilde{\sigma}_\mathbf{i} \cdot \tilde{\sigma}_\mathbf{j}$ **,**
isospin $\tilde{\tau}_\mathbf{i} \cdot \tilde{\tau}_\mathbf{j}$ **,**
spin-isospin $(\tilde{\sigma}_\mathbf{i} \cdot \tilde{\sigma}_\mathbf{j})(\tilde{\tau}_\mathbf{i} \cdot \tilde{\tau}_\mathbf{j})$ **,**
etc. correlations.

M. Avioli, C. Ciofi degli Atti, H. Morita, PRL 100(2008)162503



SRC/Gribov corrected N_{coll}

Glauber

	σ_{in}^{pN} [mb]	σ_{tot}^{pA} [mb]	σ_{el}^{pA} [mb]	σ_{qel}^{pA} [mb]	σ_{in}^{pA} [mb]	N_{coll}
RHIC	42.1	3297.6	1368.4	66.0	1863.2	4.70
LHC	68.3	3850.6	1664.8	121.0	2064.8	6.88

Glauber+SRC

	σ_{in}^{pN} [mb]	σ_{tot}^{pA} [mb]	σ_{el}^{pA} [mb]	σ_{qel}^{pA} [mb]	σ_{in}^{pA} [mb]	N_{coll}
RHIC	42.1	3337.6	1398.1	58.5	1881.0	4.65
LHC	68.3	3885.8	1690.5	112.6	2082.7	6.82

Glauber+SRC+Gribov

	σ_{in}^{pN} $(\sigma_{in}^{pN} - \sigma_{diff}^{pN})$	σ_{tot}^{pA}	σ_{el}^{pA} $(\sigma_{el}^{pA} + \sigma_{diff}^{pA})$	σ_{qel}^{pA} $(\sigma_{qel}^{pA} + \sigma_{qsd}^{pA})$	σ_{in}^{pA}	N_{coll}
RHIC	42.1 (30.0)	3228.1	1314.0 (1331.0)	72.0 (74.4)	1842.1 (1823.0)	4.75(3.42)
LHC	68.3 (56.3)	3833.3	1655.7 (1658.0)	113.4 (111.3)	2064.2 (2064.0)	6.88(5.67)

Gribov corrections and SRC essentially compensate each other in N_{coll}
Missed diffractive events significantly affect N_{coll} (in parentheses)

C. Ciofi degli Atti, C. Mezzetti, I. Schmidt, B.K. & I.P. PRC 84(2011)025205

Summary

- Gribov inelastic shadowing corrections make the nucleus more transparent, increasing $\mathrm{N_{coll}}$. One can sum up the Gribov corrections in all orders employing the dipole representation. For heavy nuclei $\mathrm{N_{coll}}$ rises by about 10%.

- On the contrary, the short-range NN correlations make nuclei more opaque and reduce $\mathrm{N_{coll}}$. The two effects partially compensate each other.

- $\mathrm{N_{coll}}$ may be strongly affected by missed diffractive events, which contribute to $\sigma_{\mathrm{in}}^{\mathrm{hA}}$ and include diffractive excitation of the beam (coherent/incoherent) of the bound nucleons, or both. This correction might be significant.