Cross section fluctuations in hadronic and nuclear collisions

Maciej Rybczyński and Zbigniew Włodarczyk
Jan Kochanowski University, PL-25406 Kielce, Poland

Introduction

- The nucleon-nucleon collision profile, being the basic entity of the wounded nucleon model, is usually adopted in the form of hard sphere or the Gaussian shape.
- The cross section fluctuations, given by the gamma distribution, lead to the profile function which smoothly ranges between the both, above mentioned, limiting forms.
  M. Rybczynski and Z. Wlodarczyk, J. Phys. **G41** 015106
- Nucleon-nucleon cross section fluctuations have been evaluated from the elastic differential cross section, multiplicity fluctuations and attenuation of cosmic rays. Energy dependence of cross section fluctuations has been compared with model predictions and other existing estimates.
- Examples of some initial state characteristics (fluctuations of target participants, standard and participant eccentricity) for deuteron-nucleus and nucleus-nucleus collisions at wide range of center of mass energies demonstrating sensitivity on cross section fluctuations will be discussed.

The nucleon-nucleon collision profile

In the wounded nucleon model the basic entity is the nucleon-nucleon collision profile, $\mathbf{p(b)}$, defined by the probability density of inelastic nucleon-nucleon collision at the impact parameter $\mathbf{b}$. It is normalized to the total inelastic nucleon-nucleon cross section:

$$2\pi \int \mathbf{dbbp(b)} = \sigma_{\mathbf{NN}}.$$

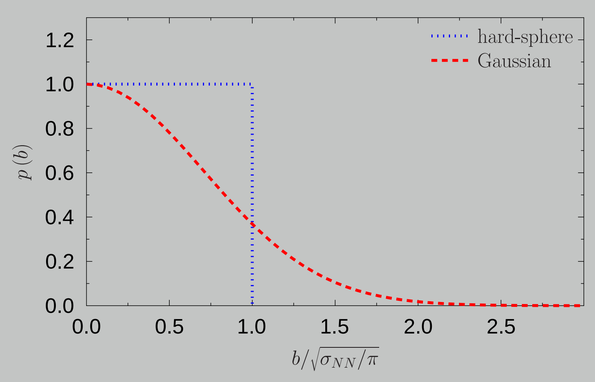
- Hard-sphere approximation:

  $$\mathbf{p_{HS}(b)} = \Theta\left(\sqrt{\sigma_{\mathbf{NN}}/\pi} - \mathbf{b}\right)$$

  is used, for simplicity, in most Glauber Monte Carlo codes.
- Gaussian approximation:

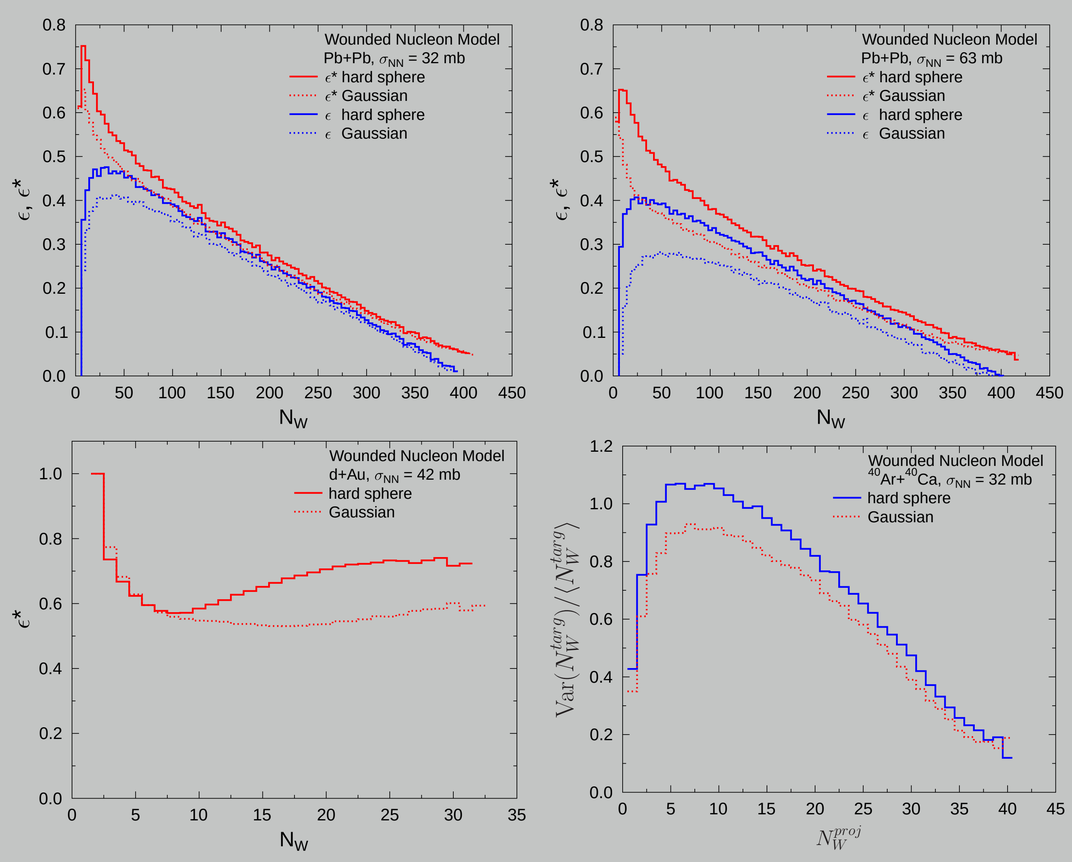
  $$\mathbf{p_G(b)} = \mathbf{A}\exp\left(-\frac{\pi \mathbf{A b^2}}{\sigma_{\mathbf{NN}}}\right)$$

  explains the nucleon-nucleon elastic differential cross section at ISR.
  A. Bialas and A. Bzdak, Acta Phys. Polon. **B38** 159



Shape of nucleon-nucleon collision profile affects various observables, e.g.:

$$\epsilon = \frac{\sigma_y^2 - \sigma_x^2}{\sigma_y^2 + \sigma_x^2} \qquad \epsilon^* = \frac{\sqrt{\left(\sigma_y^2 - \sigma_x^2\right)^2 + 4\sigma_{xy}^2}}{\sigma_y^2 + \sigma_x^2}$$



M. Rybczynski and W. Broniowski, Phys. Rev. **C84** 064913

Cross section fluctuations

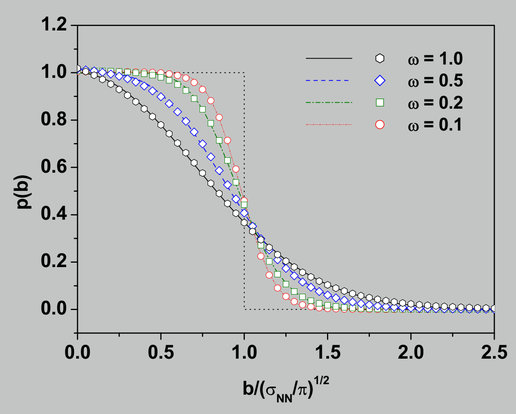
The origin of the cross section fluctuations can be traced down to the fact that hadrons have internal degrees of freedom (color-carrying quarks and gluons) and can therefore collide in different internal configurations resulting in different cross sections.
B. Blaettel et al., Phys. Rev. **D47** 2761
Cross section fluctuations given by gamma distribution

$$\mathbf{g(\sigma)} = \frac{\mathbf{1}}{\mathbf{\Gamma(1/\omega)}}\frac{\mathbf{1}}{\sigma_0\omega}\left(\frac{\mathbf{1}}{\omega}\frac{\sigma}{\sigma_0}\right)^{\frac{1}{\omega}-1}\exp\left(-\frac{\mathbf{1}}{\omega}\frac{\sigma}{\sigma_0}\right)$$

with relative variance $\omega = \mathrm{Var}(\sigma)/\langle\sigma^2\rangle$ leads to the profile function

$$\mathbf{p_\Gamma(b)} = \mathbf{\Gamma}\left(\frac{\mathbf{1}}{\omega}, \frac{\mathbf{b^2}}{\mathbf{R^2}\omega}\right)/\mathbf{\Gamma}\left(\frac{\mathbf{1}}{\omega}\right),$$

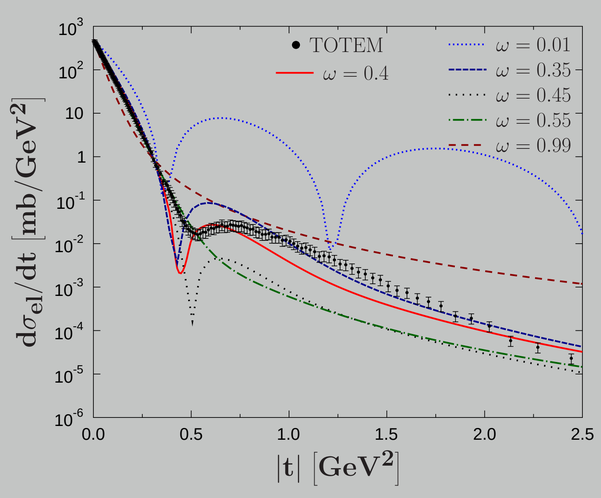
where $\mathbf{\Gamma(z)}$ is Euler gamma function, $\mathbf{\Gamma(\alpha, z)}$ is incomplete gamma function, and parameter $\omega \in \mathbf{(0,1)}$.



$\lim_{\omega\to 0} \mathbf{p_\Gamma(b)} = \mathbf{p_{HS}(b)}$
$\lim_{\omega\to 1} \mathbf{p_\Gamma(b)} = \mathbf{p_G(b)}$

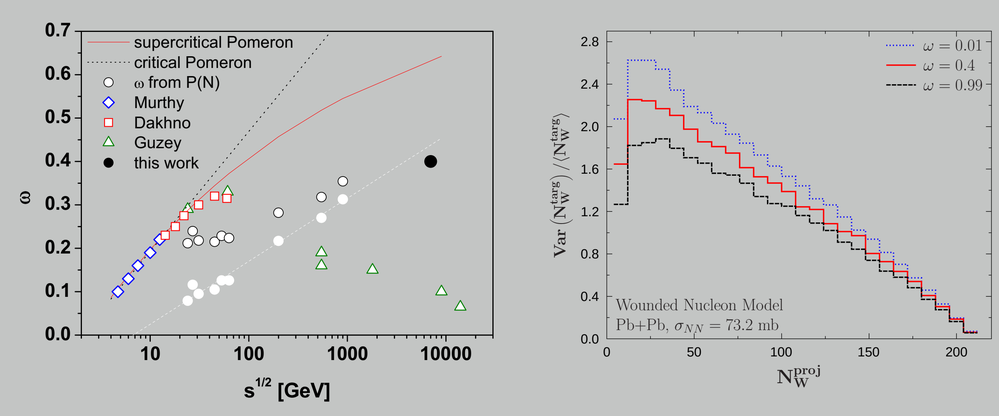
Information from elastic scattering

The profile function is determined by the different configuration of partons. The distribution of partons in momentum space, e.g. the number of *wee* partons in a hadron affects its cross section.



Data from:
G. Antchev et al. [TOTEM Collaboration], Europhys. Lett. **95**, 41001
G. Antchev et al. [TOTEM Collaboration], Europhys. Lett. **101**, 21002

Implication for nuclear collisions



Increasing ω results in decrease of fluctuations of target participants

Conclusions

- The fluctuations of cross-section are described by the gamma distribution with relative variance ω.
- The experimental data on elastic differential proton-proton cross-section at LHC energy indicate large fluctuations, $\omega = \mathbf{0.4}$.
- Cross section fluctuations can affect observables measured in nuclear collisions.

Maciej.Rybczynski@ujk.edu.pl Zbigniew.Wlodarczyk@ujk.edu.pl