Глауберовое моделирование столкновений адронов и ядер на партонном уровне

Владимир Коваленко (Санкт-Петербургский государственный университет)

Научная сессия секции ядерной физики Отделения физических наук Российской академии наук

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Introduction

Glauber approach is widely used for describing multiparticle production in the interactions involving hadrons and nuclei in a wide energy range. For the more detailed description of nuclear interaction features, this model is increasingly being used at the parton level, however, usually, the pp-interaction is given insufficient attention.

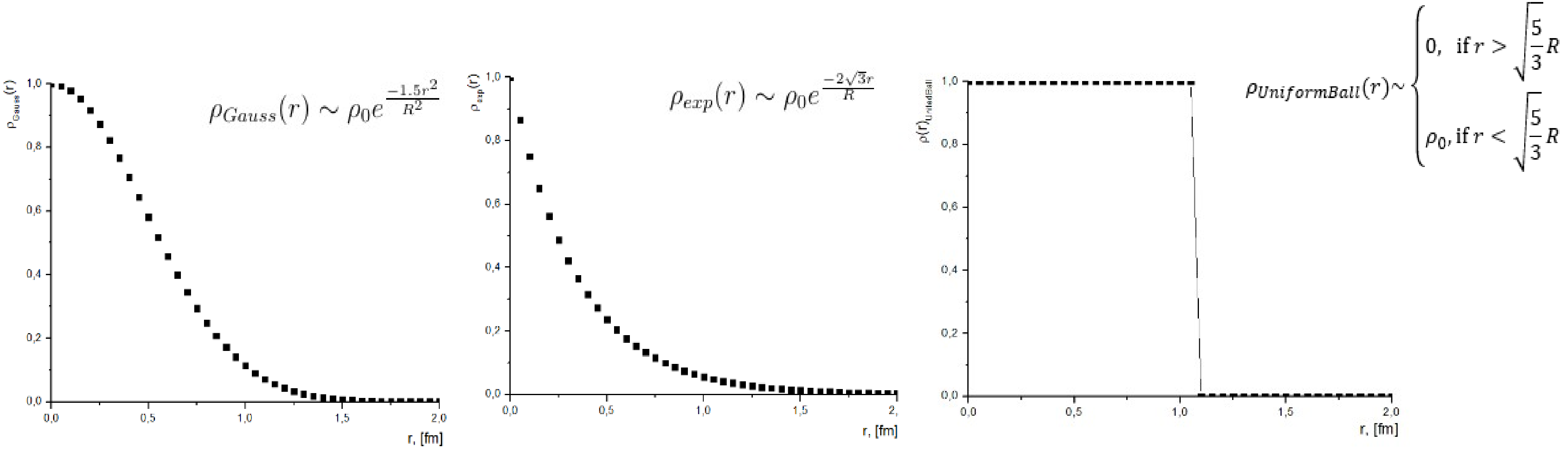
Before application of the model to nucleus-nucleus collisions, one has to ensure that the major features of the pp interaction are adequately described.

In this regard, in this work the parton-based Monte Carlo model is developed and generalized to proton-nucleus and nucleus-nucleus collisions. It is demonstrated that in pp-collisions the total, elastic, and inelastic cross sections, the slope of the diffraction cone in the energy range from SPS to LHC are satisfactorily described. Using the condition of self-consistency of the model under Lorentz transformations, an explicit form of the dependence of the number of initial partons on the beam energy is obtained, allowing minimization of the number of free parameters.

The model is applied to p-Pb and Pb-Pb collisions at LHC energy. The relation of this approach to other Monte Carlo models is discussed

Setup

- Analysis of proton collisions is performed using the Monte Carlo generator of the Glauber model. In this model, not nuclei are considered, but protons, instead of nucleons in nuclei, respectively, partons.
- It were considered three variants of the spatial distribution of partons in protons (see Fig.).
- The root-mean-square radius of the proton is chosen equal to R = 0.831fm [1], and the parton cross section is σ_{parton} = 3.3 mb [2].



[1] J.-P. Karr, D. Marchand, Nature 575, 61-62 (2019)
[2] N.S.Amelin, N. Armesto, C. Pajares and D. Sousa, Eur. Phys. J. C 22

Observables

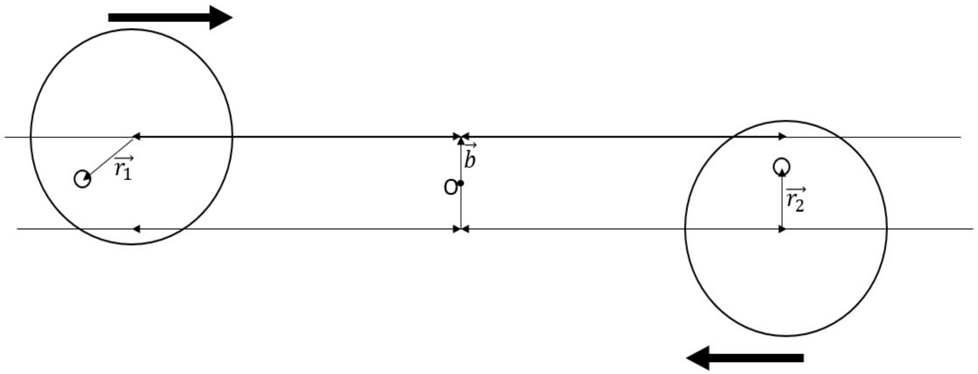
- The profile function σ (b) of pp collision is the probability of interaction of protons at a given impact parameter b
- The number of partons in protons and the average number of participating partons $\langle N_{part} \rangle$
- Elastic σ_{el}, inelastic σ_{inel} and total σ_{tot} scattering cross sections
- The slope of the diffraction cone B is a characteristic of elastic pp-interaction
- In the approximation of a purely imaginary amplitude of pp-interaction:

$$\sigma_{inel} = \int_0^\infty 2\pi b \sigma(b)\, db \qquad \sigma_{el} = \sigma_{total} - \sigma_{inel}$$

$$\sigma_{total} = \int_0^\infty 4\pi b (1 - \sqrt{1-\sigma(b)})\, db \qquad B = \frac{1}{2} \frac{\int_0^\infty b^3 (1 - \sqrt{1-\sigma(b)})\, db}{\int_0^\infty b (1 - \sqrt{1-\sigma(b)})\, db}$$

[3] V.N.Kovalenko, Dipole Description of pp-Interaction // ТМФ, 184:3 (2015), 465–474; Theoret. and Math. Phys., 184:3 (2015), 1295–1303

Monte Carlo algorithm



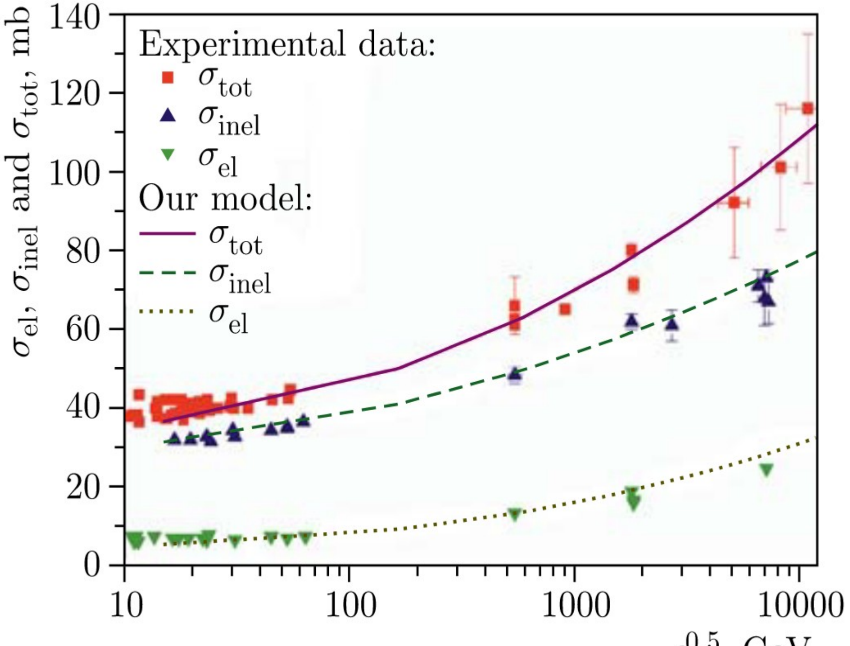
-The impact parameter b and the number of partons and in each proton are fixed to simulate a collision
-At the first stage, the spatial coordinates of the partons are generated according to the given distributions.
- At the second stage, the participating partons are determined, i.e. the partons of the projectile and target, which are at a distance of interaction from each other. If there is one pair of interacting partons, it is considered that there is an inelastic event.
- Next, the statistics of the probability of inelastic interaction are accumulated and then σ (b) is calculated.
-Next, the cross sections and the slope of the diffraction cone are calculated using σ (b)

Energy dependence of cross sections

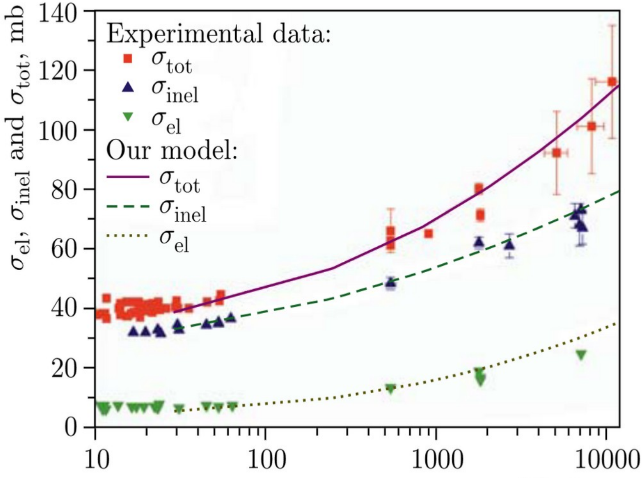
Let's show the energy dependence of the scattering cross sections for various distributions of partons in protons.

It can be seen that all distributions agree well with the experimental data, but the exponential distribution manifests itself best of all.

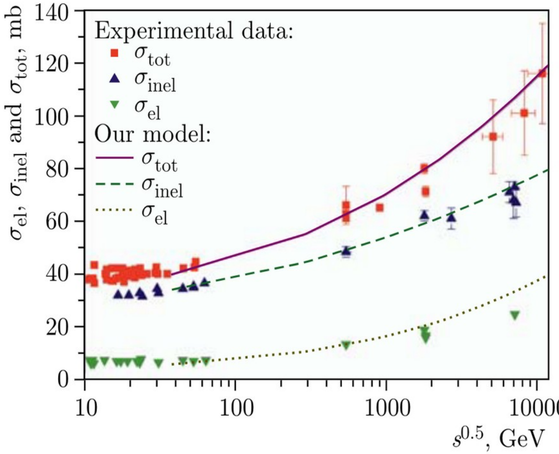
Calculated and experimental dependences of cross sections on energy inelastic, elastic and total:



Exponential distribution



Gaussian distribution



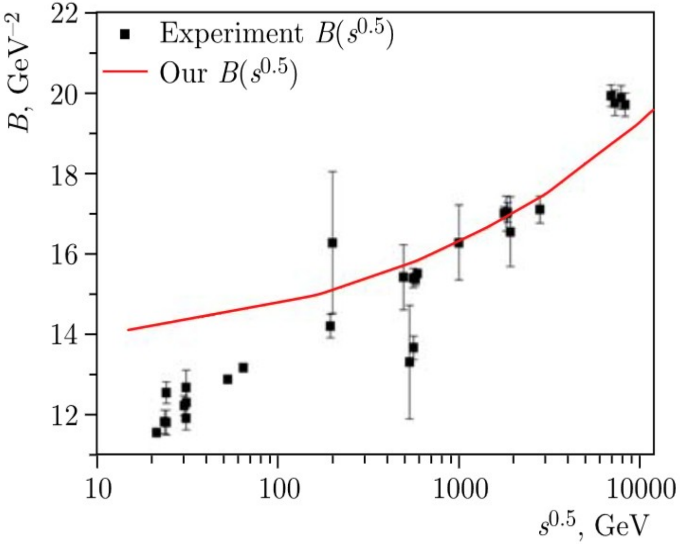
Distribution of a Uniform ball

Energy dependence of diffraction cone slope

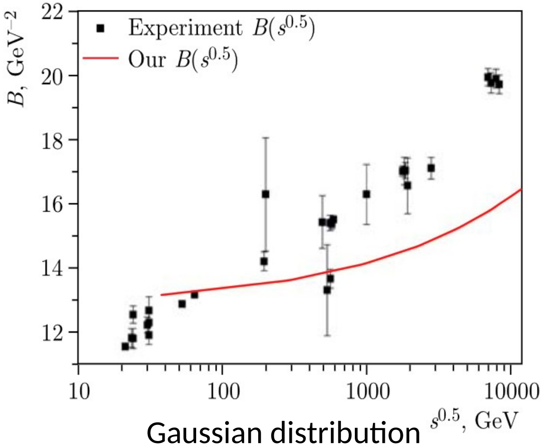
Calculated and experimental ([5],[6]) dependences of slope of the diffraction cone on energy:

For the slope of the diffraction cone, the situation is similar

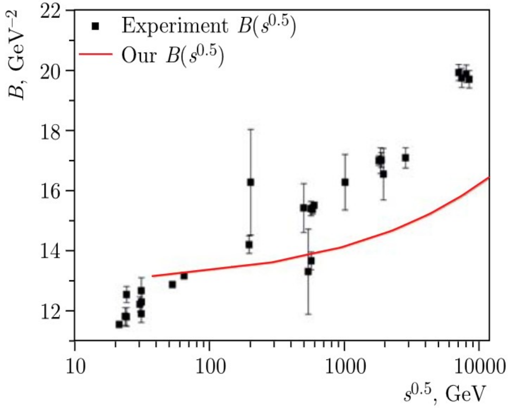
We tried to improve the distributions by varying the parton cross section σ_{parton}, but calculations have shown that the scattering cross sections are stable to such changes, and the slope of the diffraction cone slightly increases with an increase of the σ_{parton}.



Exponential distribution



Gaussian distribution

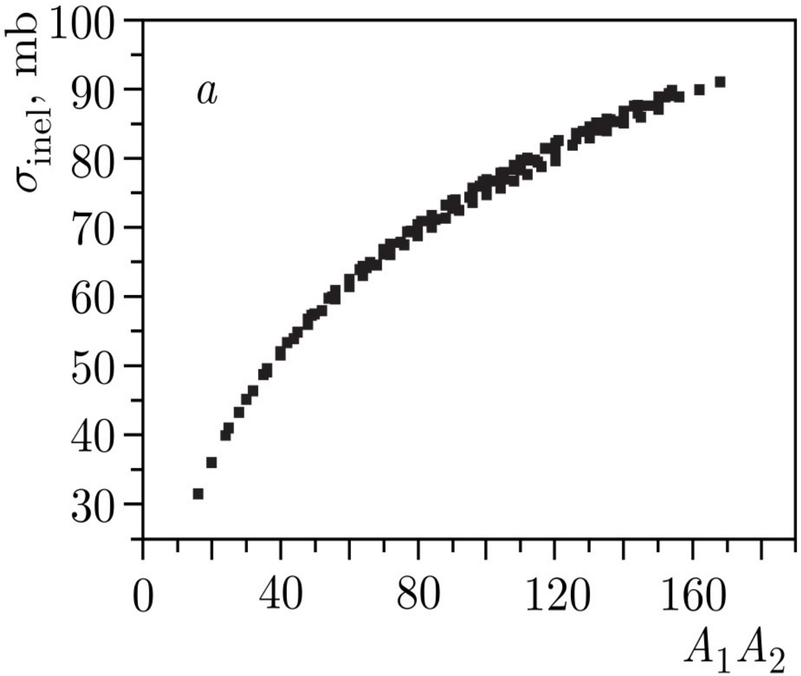


Distribution of a uniform ball

[5] V. A. Schegelsky, M. G. Ryskin// Phys. Rev. D, 85:9, 094024 (2013)7
[6] V.A. Khoze , M. Ryskin and M. Taševský (2020)

Explicit energy dependence of the mean number of partons

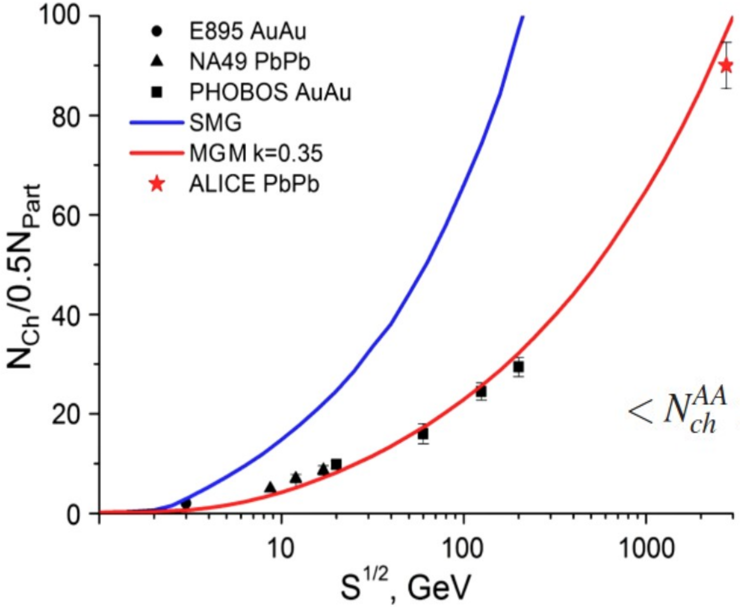
We derived a formula for the dependence of energy on the number of particles for the asymmetric case. Now, knowing the coefficients a and b for each specific distribution, it became possible to analytically calculate the energy from the number of particles without using a Monte Carlo generator:



$$\begin{cases} A_1 A_2 = a e^{bY}; \\ Y = 2\ln\left(\dfrac{\sqrt{s}}{m_p}\right); \end{cases} \Rightarrow \sqrt{S} = \left(\frac{A_1 A_2}{a}\right)^{\frac{1}{2b}} m_p;$$

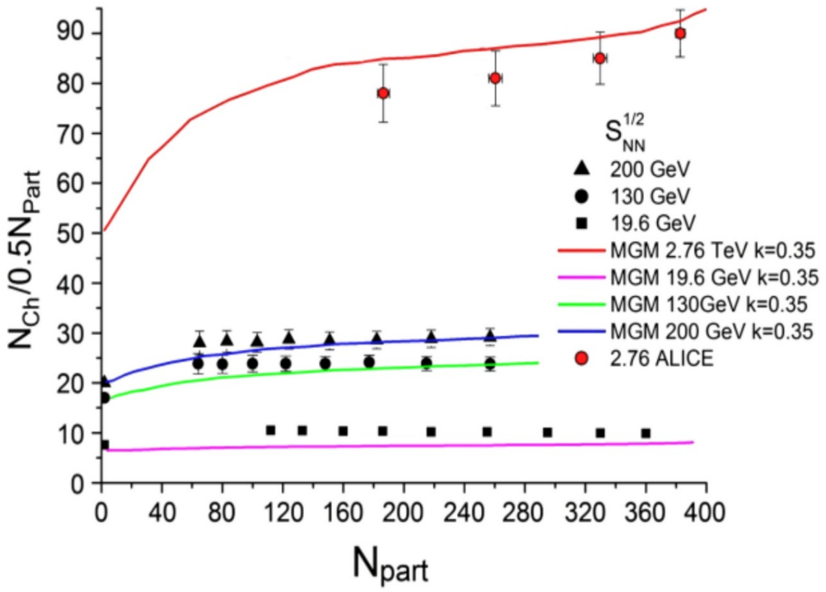
$$\begin{cases} a = 0{,}41 \pm 0{,}01, \quad b = 5{,}5 \pm 0{,}6 & \text{Exponential} \\ a = 0{,}17 \pm 0{,}01, \quad b = 5{,}7 \pm 1{,}1 & \text{Gaussian} \\ a = 0{,}18 \pm 0{,}02, \quad b = 4{,}3 \pm 1{,}2 & \text{Uniform} \end{cases}$$

Modified Glauber Model [1] for heavy ion collisions in wide energy range



$p' = k \cdot p$,
$k \simeq 0.21$

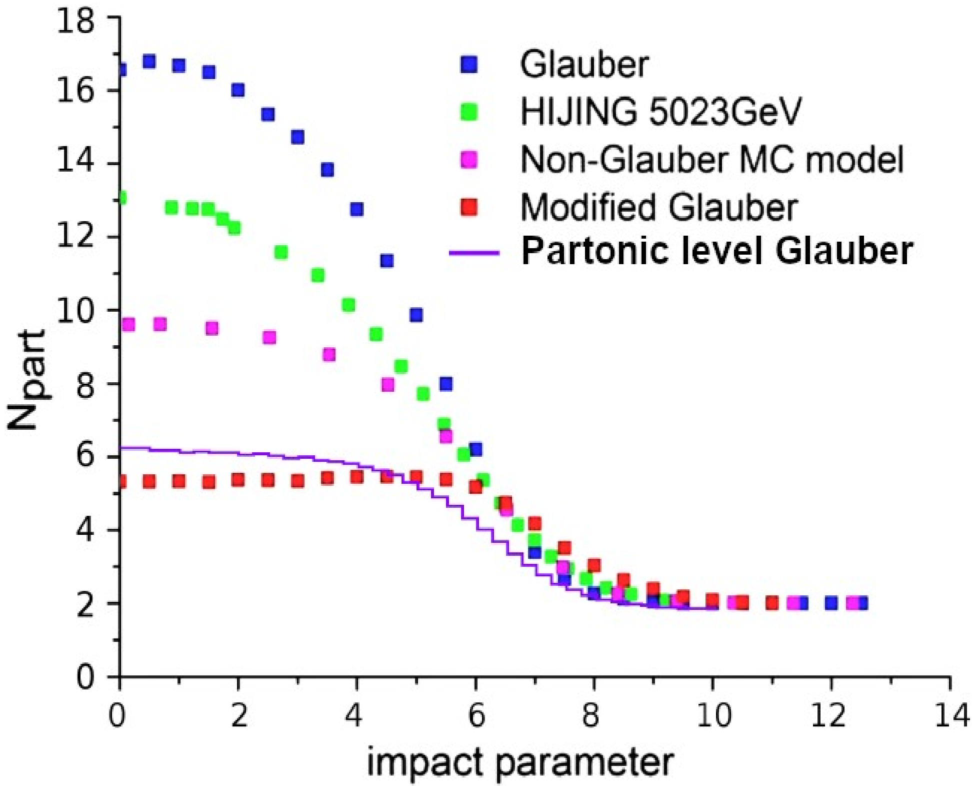
$$< N_{ch}^{AA} > = < N_{coll} > < N_{ch}^{pp} >$$



- The fixed portion (1-k) of momentum in the center of mass system[1] is lost by nucleon in each inelastic collision
- Losses are due to the production of charged and neutral particles
- Parameter k is defined by fitting the available experimental data on charged-particle multiplicity yields in AA collisions

[1] G. Feofilov, A. Ivanov, Journal of Physics CS, 5, (2005) 230-237,
[2] T.Drozhzhova, G. Feofilov, V. Kovalenko, A. Seryakov, PoS (QFTHEP 2013) 053

Impact parameter dependence of the mean number of participants in p-Pb collisions at 5.02 TeV

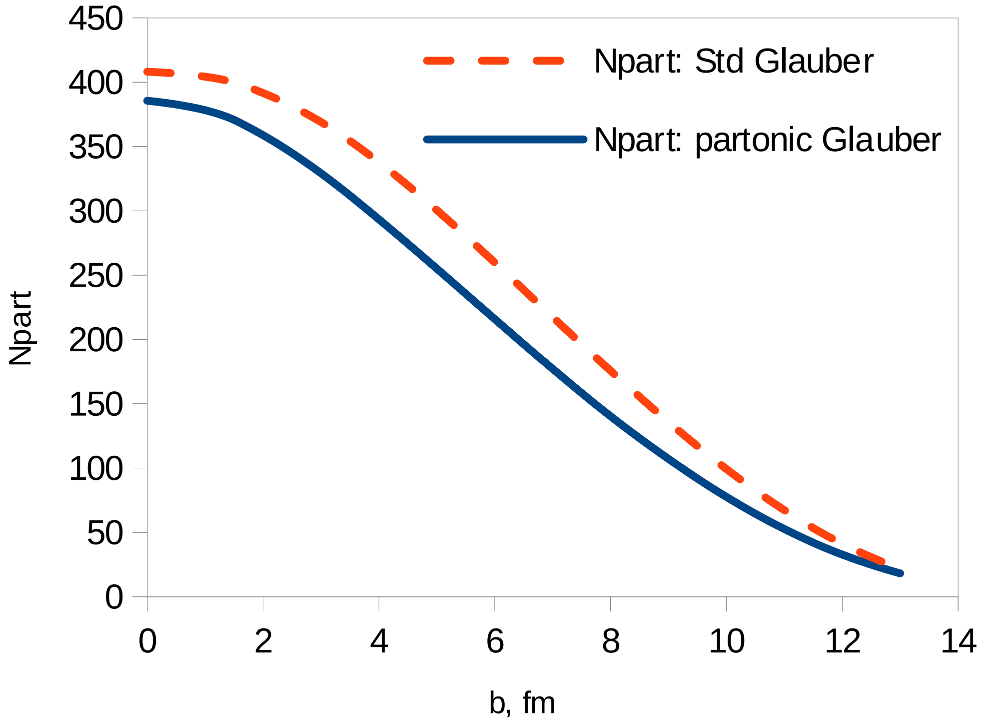


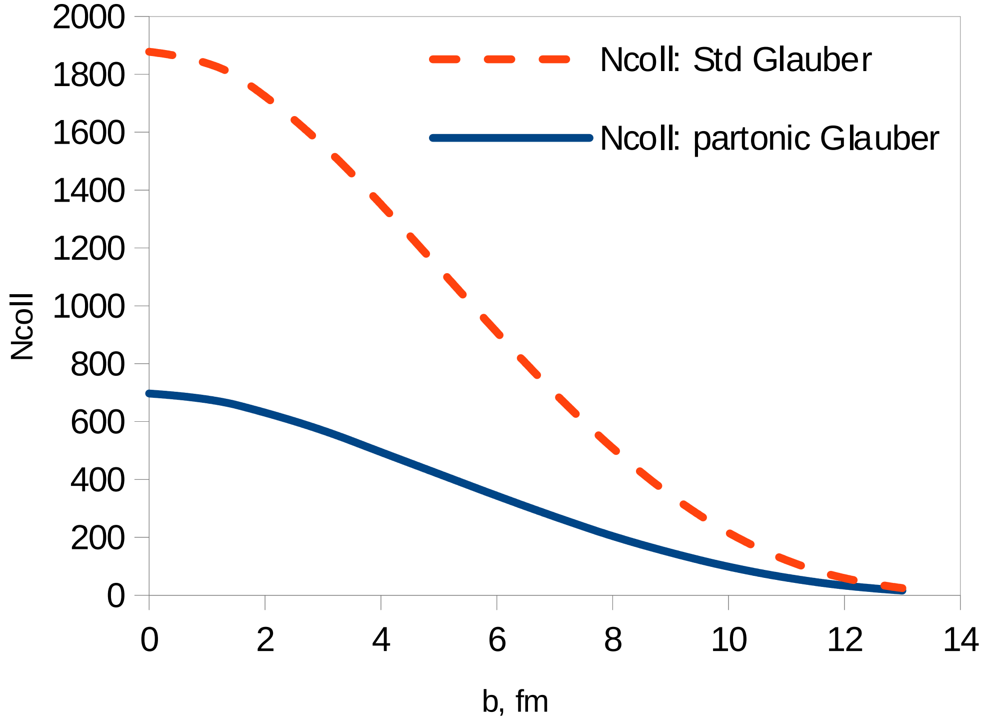
Important:
A parton can interact only once

Partonic-based MC Glauber results are close to the Modified Glauber

Plot adapted from T.Drozhzhova, G. Feofilov, V. Kovalenko, A. Seryakov, PoS (QFTHEP 2013) 053

Impact parameter dependence of the mean number of nucleons-participants and binary collisions in Pb-Pb collisions at 2.76 TeV

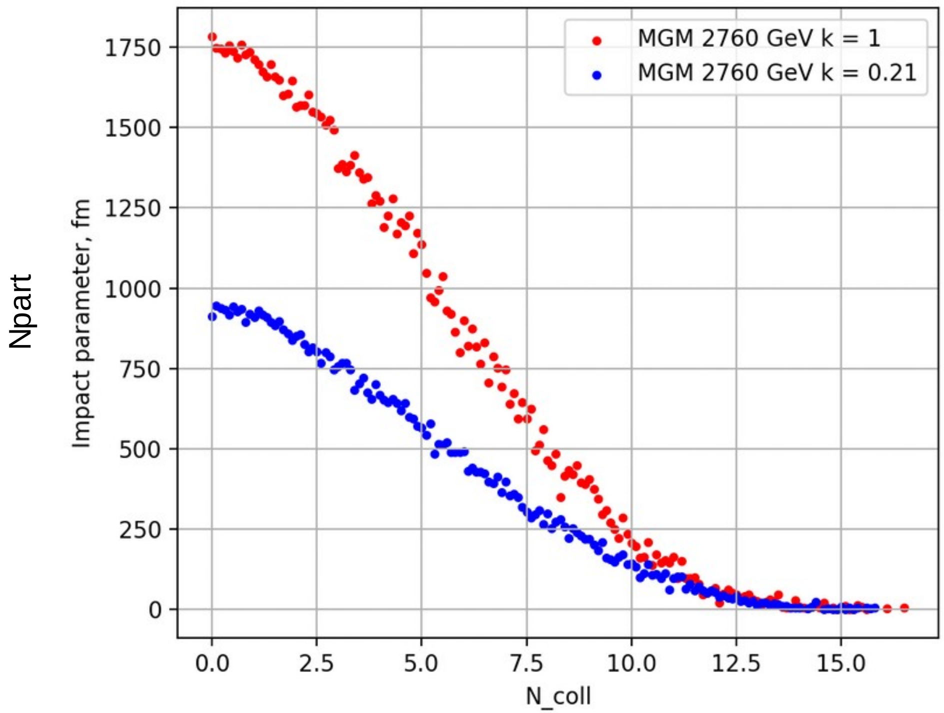


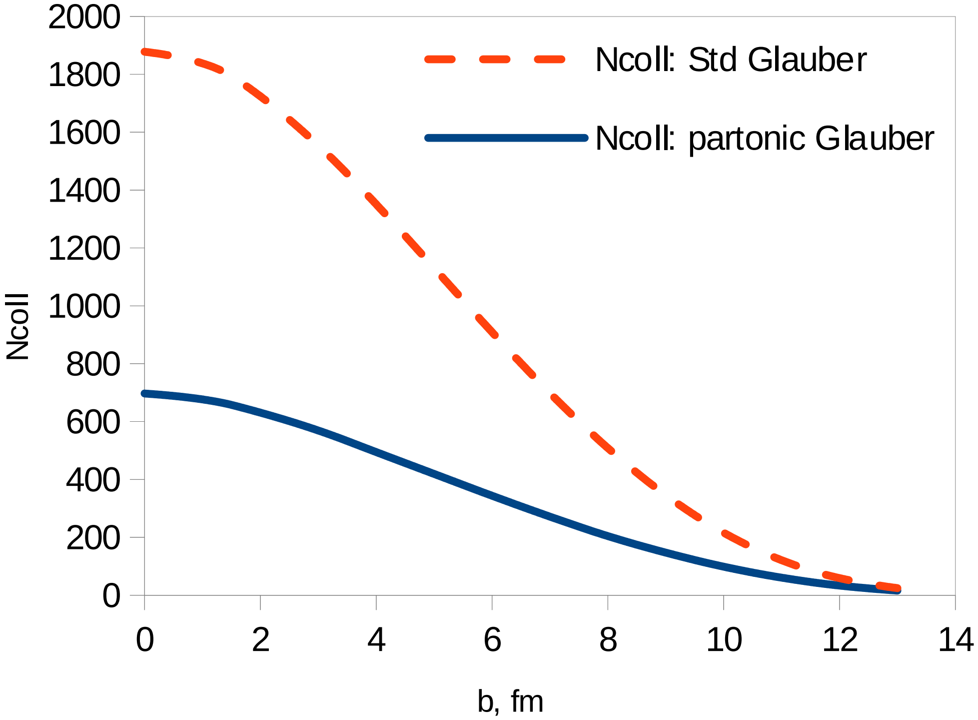


Partonic-based MC Glauber results are close to the Standatd Glauber for Npart and different for Ncoll

Impact parameter dependence of the mean number of nucleons-participants and binary collisions in Pb-Pb collisions at 2.76 TeV

Modified Glauber model

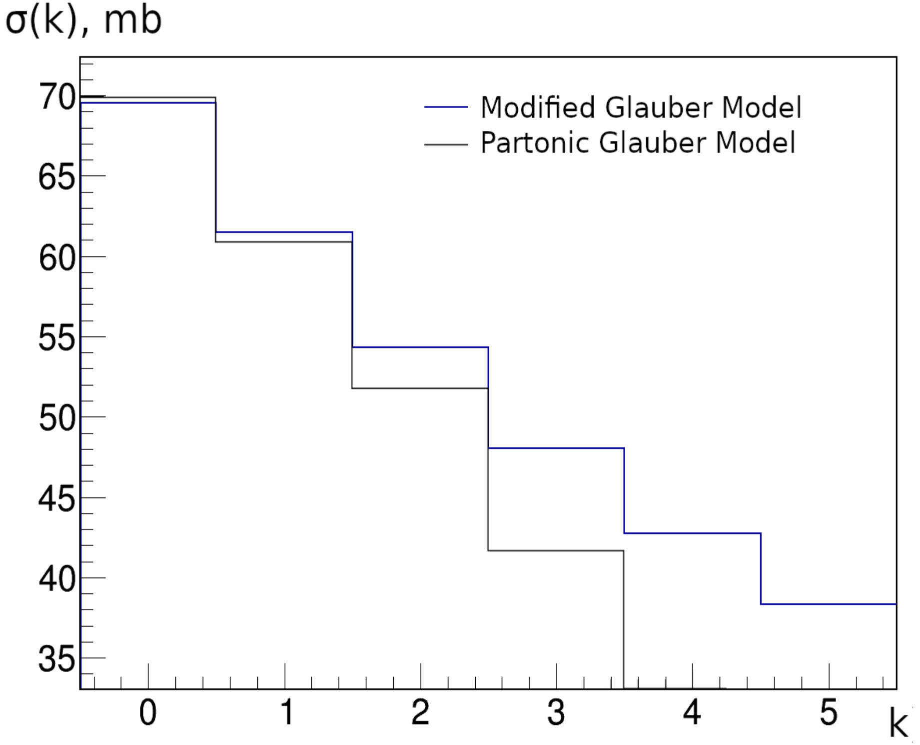




Partonic-based MC Glauber results are close to the Standatd Glauber for Npart and different for Ncoll

*Poster: Svetlana Simak, Grigory Feofilov, Accounting for energy losses within the framework of modified Glauber Monte Carlo model, Scientific session of the nuclear physics section of the Division of Physical Sciences of the Russian Academy of Sciences, JINR, 2024

Sequential cross-sections in the Partonic level Glauber and Modified Glauber model



Pb-Pb, 5.02 TeV,
MGM: k=0.21

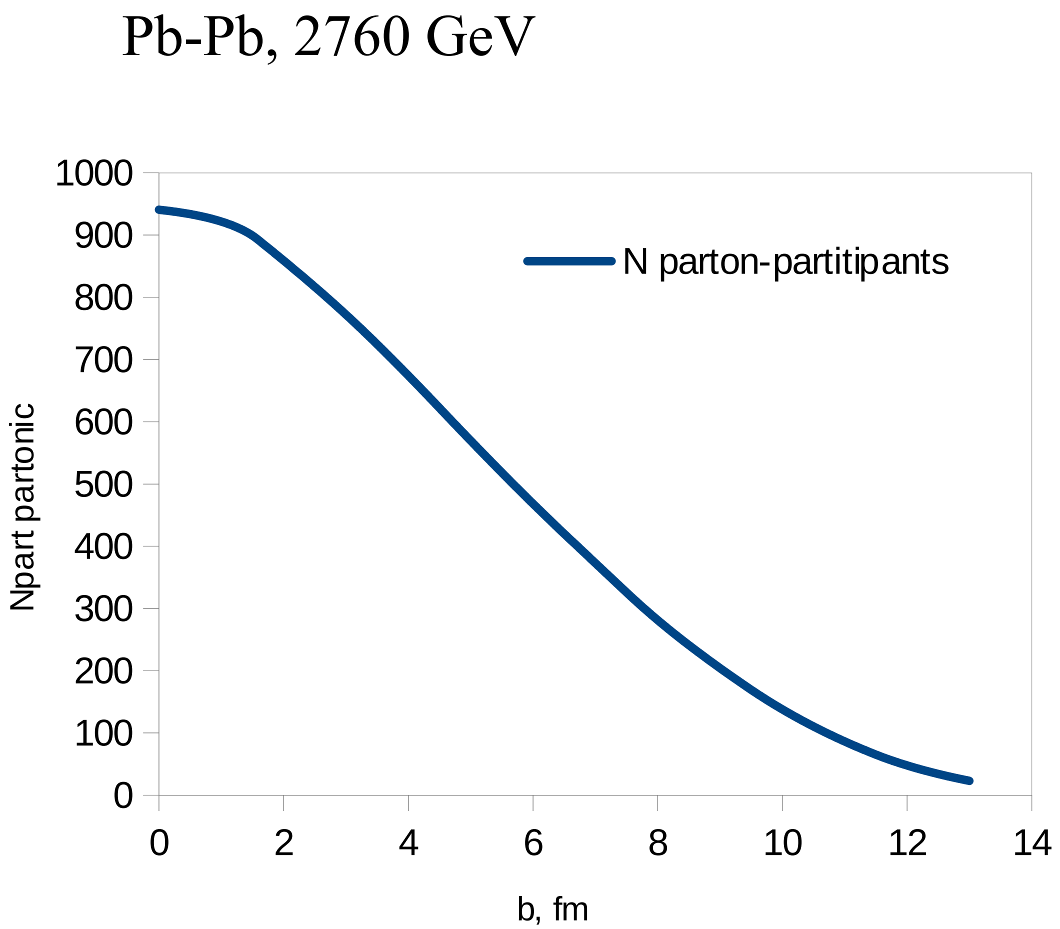
Partonic-based MC Glauber results are close to the Modified Glauber

Number of partons-partitipants in Pb-Pb collision

A parton can interact only once:

$N_{partA\ partonic}=$
$=N_{partB\ partonic}=$
$=N_{coll\ partonic}$

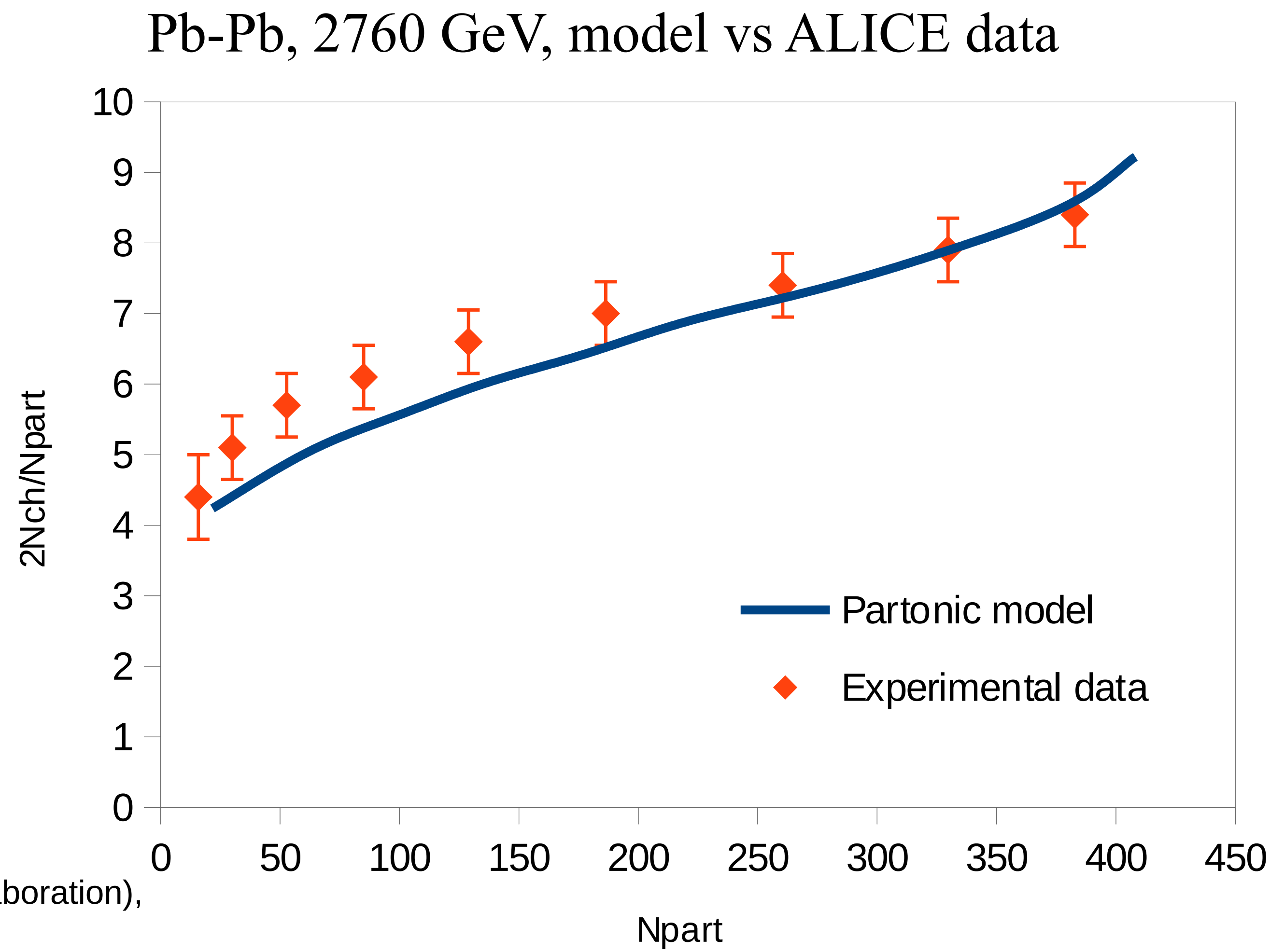
$N_{ch}=f(N_{part\ partonic})$



Charged multiplicity rapidity density at mid-rapidity

$N_{partA\ partonic} =$
$= N_{partB\ partonic} =$
$= N_{coll\ partonic}$

$N_{ch} = f(N_{part\ partonic}) \simeq$
$\simeq 2 \cdot N_{part\ partonic}$



ALICE data: K. Aamodt et al. (ALICE Collaboration), Phys. Rev. Lett. 106, 032301 (2011)

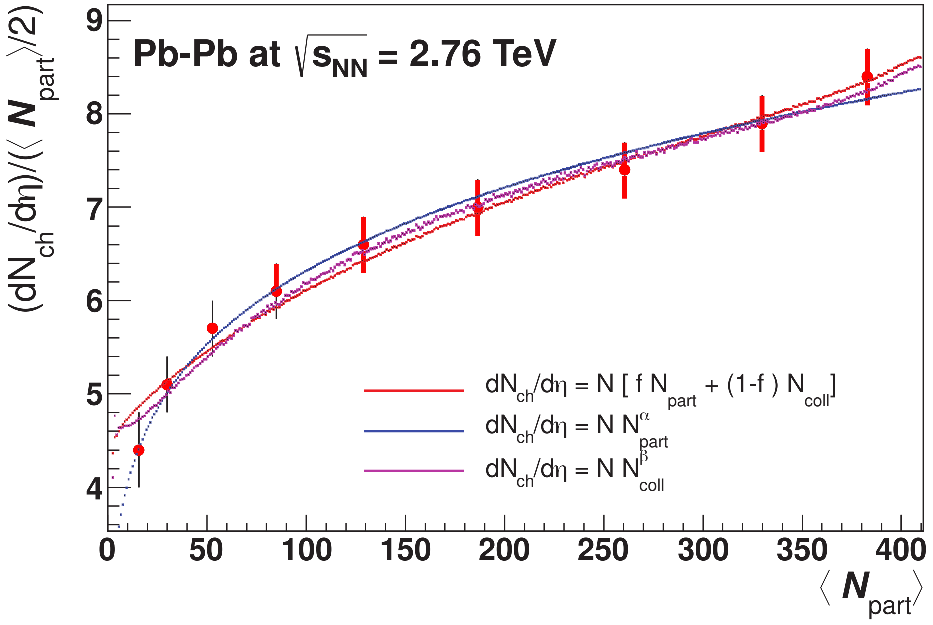
Conclusions

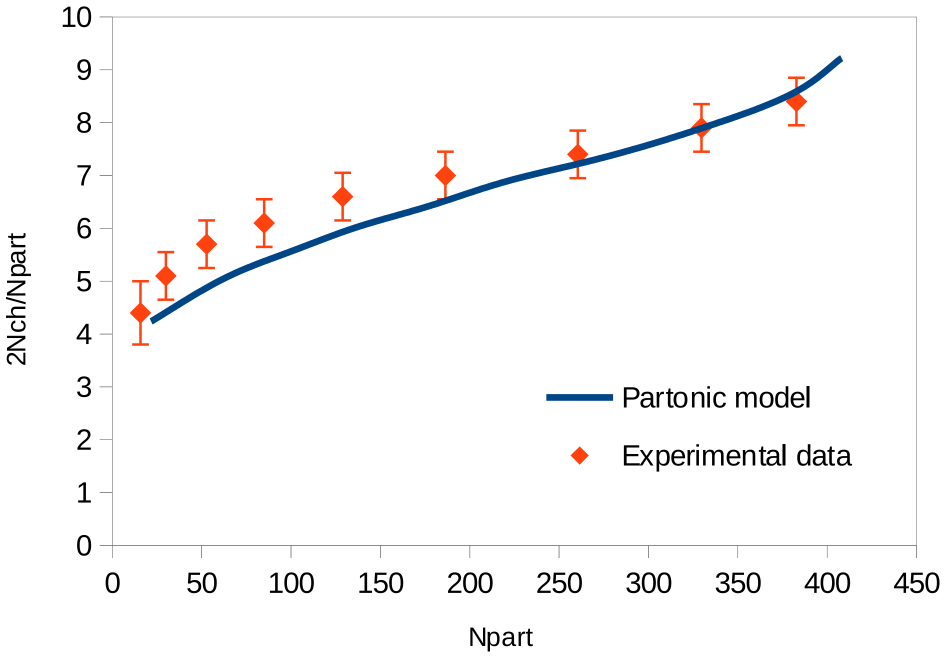
A parton-based Monte Carlo model is generalized to proton-nucleus and nucleus-nucleus collisions.
In pp-collisions the total, elastic, and inelastic cross sections, the slope of the diffraction cone in the energy range from SPS to LHC are satisfactorily described.
Explicit form of the dependence of the number of initial partons on the beam energy is obtained.
The model is applied to p-Pb and Pb-Pb collisions at LHC energy.
The energy conservation in the initial state modifies the N_{part} especially in the light colliding system.
The model behave similarly to the Modified Glauber model

Thank you

Charged multiplicity rapidity density at mid-rapidity

Pb-Pb, 2760 GeV, model vs ALICE data





ALICE: B. Abelev et al (ALICE Collaboration), Phys. Rev. C 88, 044909 (2013)