Correlations and fluctuations in pA and AA collisions

M. Alvioli

CNR

Consiglio Nazionale delle Ricerche

(IRPI - Perugia, Italy)

OUTLINE

1 Monte Carlo Glauber approach for pA and AA

1.a Glauber *vs.* Monte Carlo Glauber

1.b Nuclear configurations including NN correlations

1.c N_{part} and Geometry fluctuations in pA and AA collisions

1.d Recent updates on configurations

2. Beyond the Glauber approach

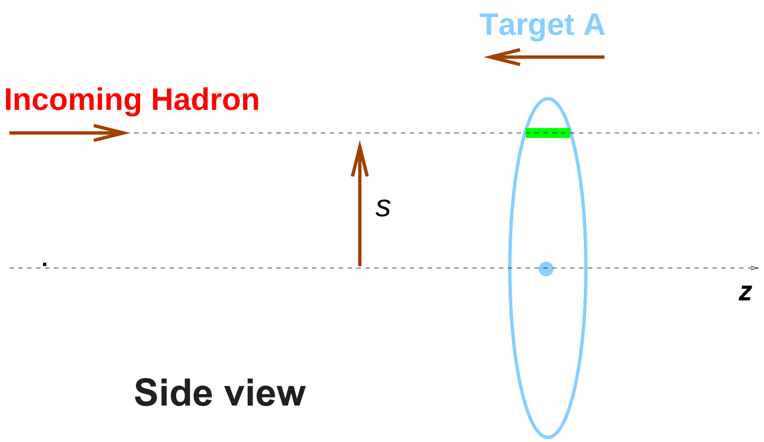
2.a NN interaction strenght fluctuations

2.b Inclusion of hard processes

2.c Perspectives

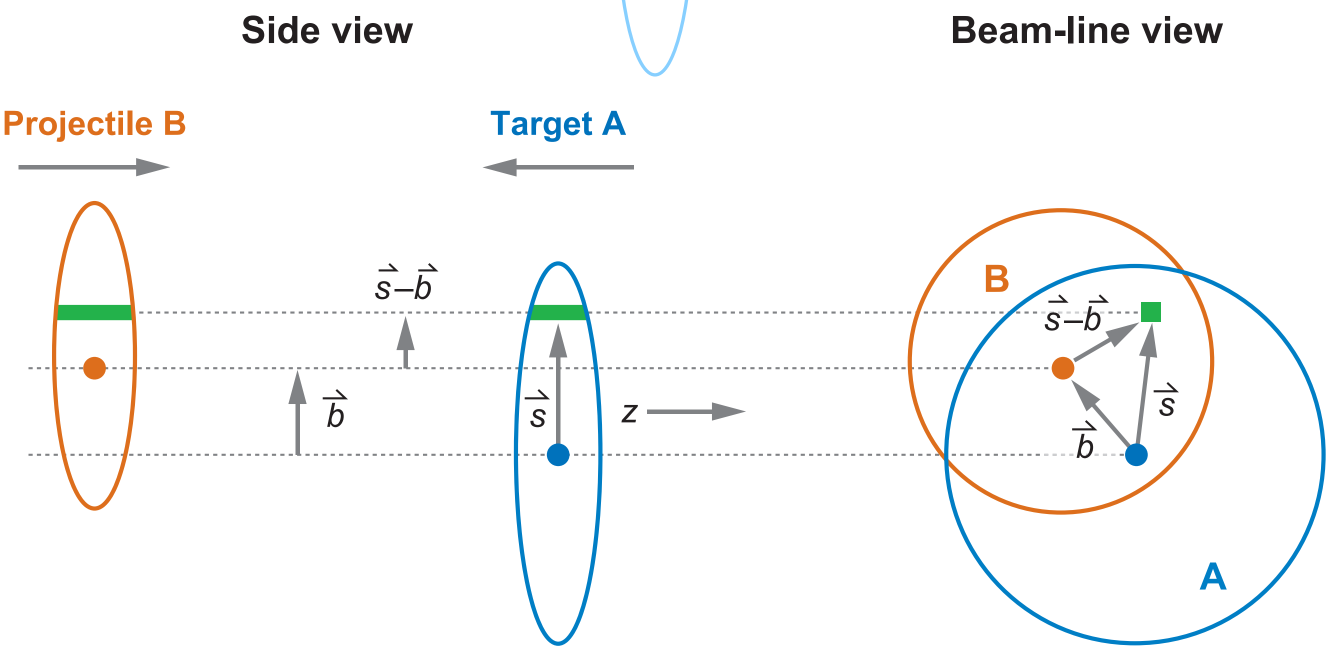
1.a - Glauber multiple scattering pA and AA scattering

Glauber approach: quantum mechanics of high-energy many-body scattering $\Longrightarrow$ frozen approximation; straight line trajectories, transverse momentum exchange negligible wrt longitudinal momentum.



Inputs:

- $\star$ (charge) densities of nuclei
- $\star$ energy-dependent Nucleon--Nucleon (NN) cross sections



for given energy and AA impact parameter $\boldsymbol{b}$:

$\longrightarrow$ *interacting*
$\longrightarrow$ *spectators*
$\longrightarrow$ *elastically scattered*

1.a - Glauber: semi-analytic description

- continuous density distributions of nuclei, $\rho(\boldsymbol{r})$; $\boldsymbol{r} = (\boldsymbol{b}, z)$
- probability of n binary collisions in AA using *binomial distribution* and thickness functions $T_A(\boldsymbol{b}) = \int dz \rho(\boldsymbol{b}, z)$, $T_{AA}(\boldsymbol{b}) = \int d\boldsymbol{s} T_A(\boldsymbol{s}) T_A(\boldsymbol{b} - \boldsymbol{s})$:

$$P_n(\boldsymbol{b}) = \binom{A^2}{n} \left[T_{AA}(\boldsymbol{b})\sigma_{NN}^{in}\right]^n \left[1 - T_{AA}(\boldsymbol{b})\sigma_{NN}^{in}\right]^{A^2-n}$$

- e.g., total AA inelastic cross section requires mutlidimensional integrations:

$$\sigma_{AA}^{in} = \int d\boldsymbol{b} \int \prod_i^{A\otimes A} d\boldsymbol{s}_i T_A(\boldsymbol{s}_i) \left\{1 - \prod_j^A \prod_k^A \sigma(\boldsymbol{b} - \boldsymbol{s}_j + \boldsymbol{s}_k)\right\}$$

- *optical limit*: assuming uncorrelated scattering centers, A⊗A integrations over transverse coordinates are reduced to one integration:

$$\sigma_{AA}^{in,opt} = \int d\boldsymbol{b} \left\{1 - \left[1 - \sigma_{NN}^{in} T_{AA}(\boldsymbol{b})\right]^{A^2}\right\}$$

• Mostly accurate. *Finite radius of NN interaction neglected.* Details of density are lost. Difficult to estimate event-by-event ***fluctuations***

1.a - Monte Carlo Glauber (MCG) description

- event-by-event simulation: details of density distributions by randomly generated ***nucleons positions***: in average give the nucleus density.
- MCG introduces of N_{part} and N_{coll}, not directly measurable, but contain a lot of information about the fluctuating ***collision geometry***.

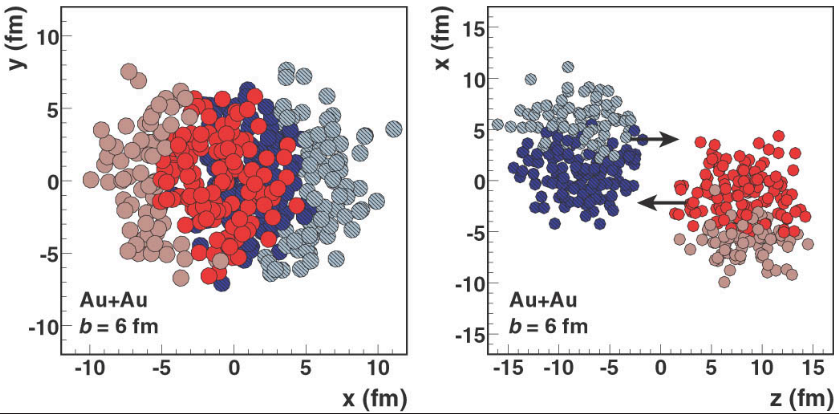
  In particular:

  $\rightarrow$ N_{part} experimentally related to energy in ZDCs $\Leftrightarrow$ *centrality*

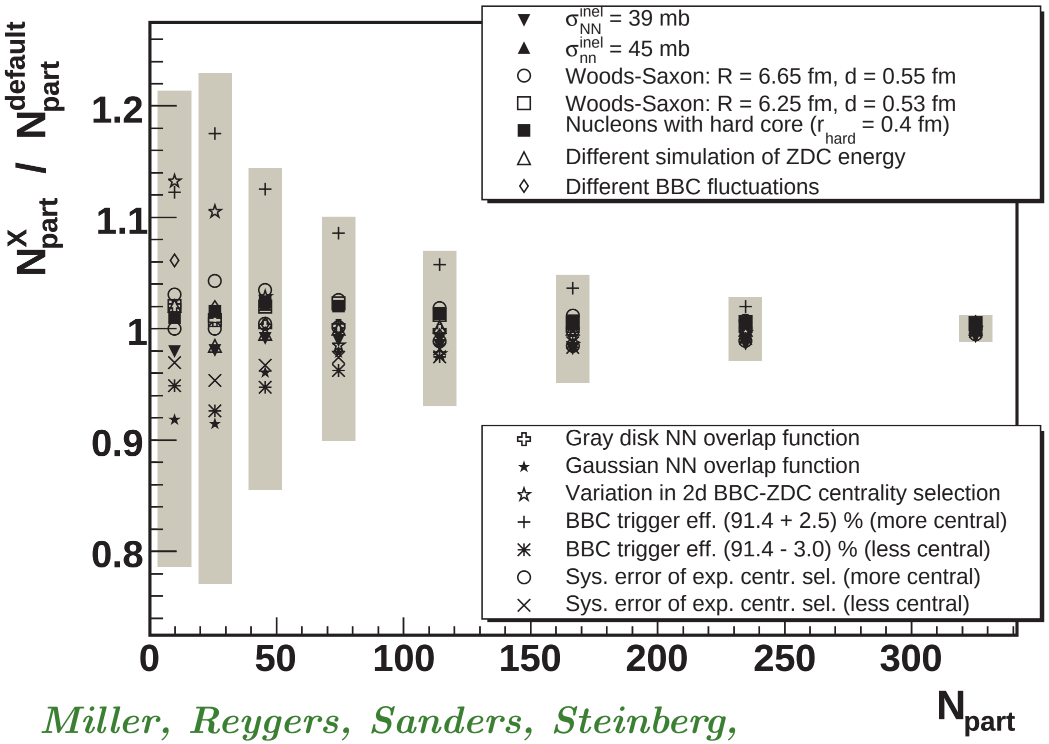
  $\rightarrow$ charged particle multiplicity scales with N_{part}, N_{coll} $\Leftrightarrow$ *centrality*

  $\rightarrow$ participant distribution *shape* determines *elliptic flow* of low p_T particles

- MCG is a starting point for models that require *production points* for individual subprocesses
- also used in experimental analyses



1.a - Monte Carlo Glauber (MCG) description: fluctuations



Miller, Reygers, Sanders, Steinberg, Ann. Rev. Nucl. Part. Sci. 57 (2007)

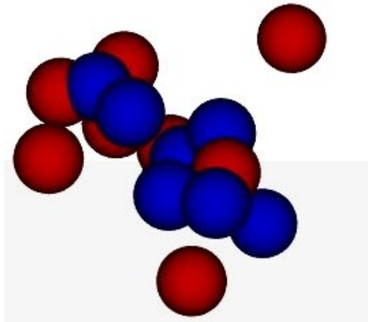
effects of different sources of fluctuations and parameter dependencies within MGC and detector simulation

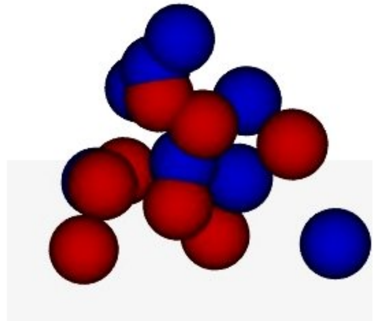
We focus on fluctuations due to:

- inclusion of NN correlations in preparing nuclear configurations
- no black-disk approximation for NN $\longrightarrow P(|\boldsymbol{b} - \boldsymbol{b}_j|)$
- initial nucleon positions $\longrightarrow$ initial geometry
- fluctuation of the NN cross section $\longrightarrow$ average number of participants $\longrightarrow$ different impact parameter dependence

1.b - A Monte Carlo generator for nucleon configurations

- Configurations generated according to the independent particle model contain *overlapping nucleons*

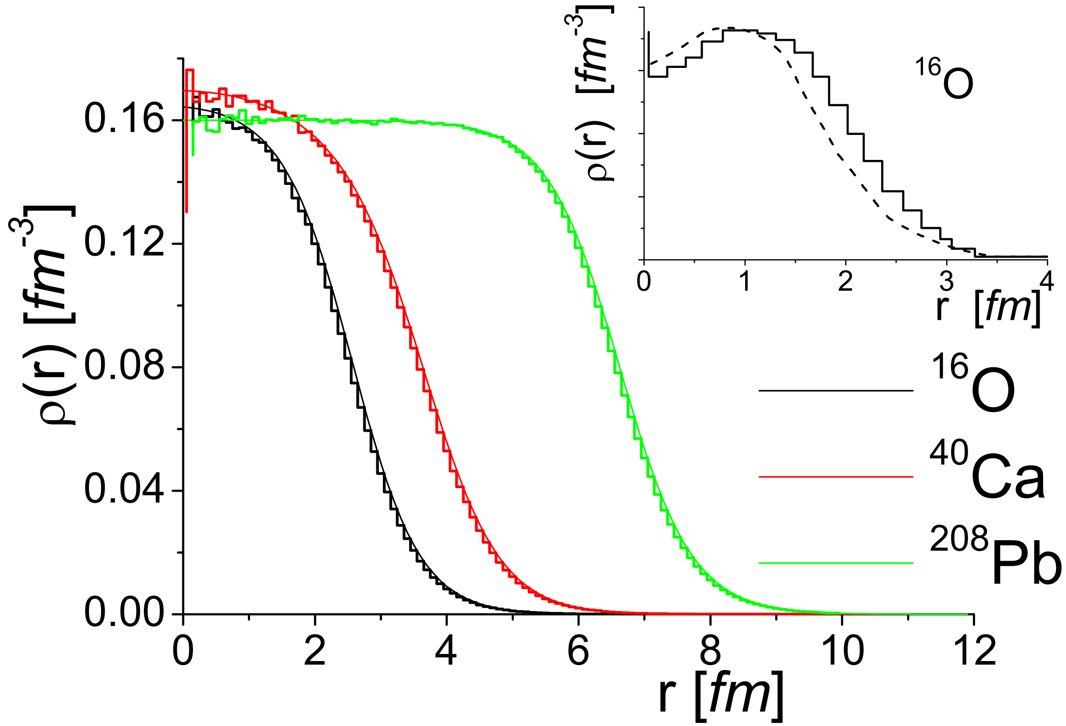




- Ad-hoc *hard-core* rejection methods avoids overlapping nucleons but is not linked to realistic correlations and do not reproduce two-body density

- We developed a Metropolis code which includes **realistic NN correlations functions** in a way which is consistent with the input one-body density

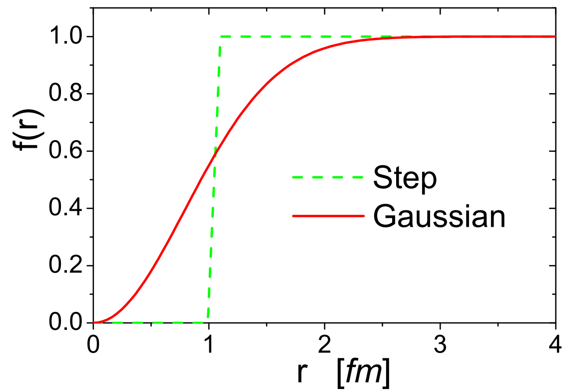
- We also have a two-body density close to the one obtained in microscopic calculations of w.f.



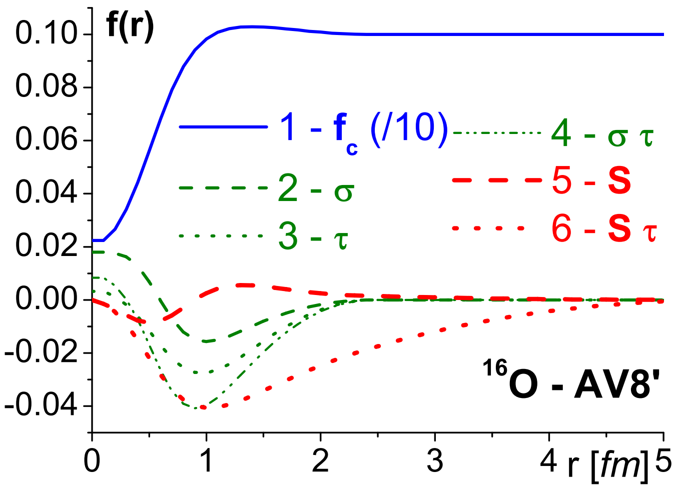
- We used $|\Psi|^2$ as a Metropolis weight function

$$\Psi(\boldsymbol{r}_1, ..., \boldsymbol{r}_A) = \prod_{i<j}^{A} \hat{f}(r_{ij})\, \Phi(\boldsymbol{r}_1, ..., \boldsymbol{r}_A)$$

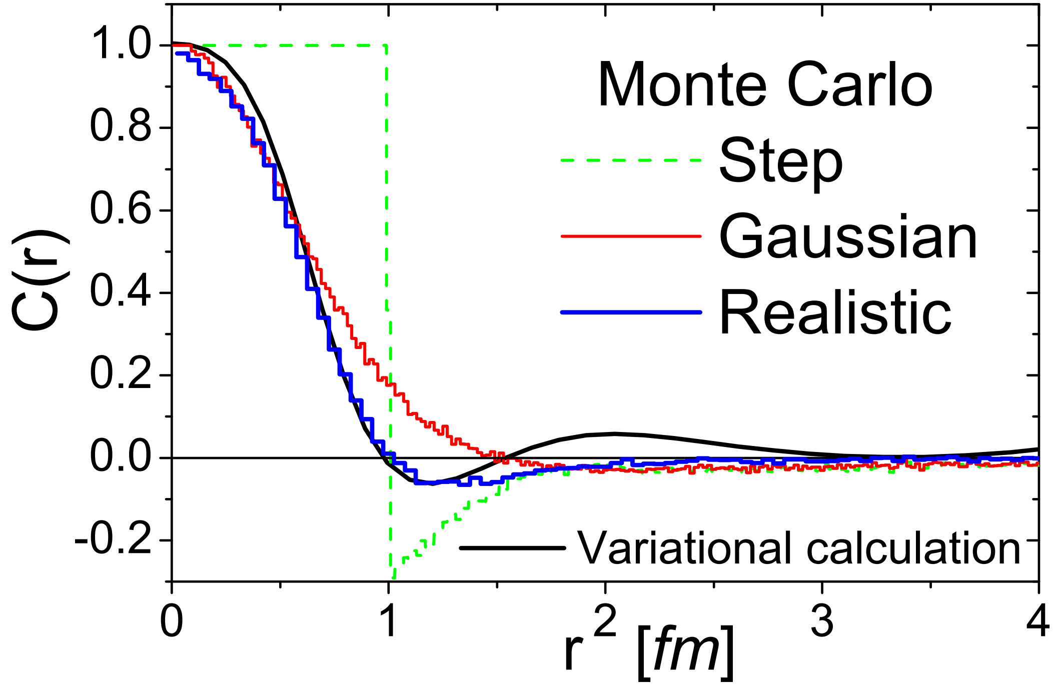
where Φ is given by the independent particle model.



$\Downarrow$



$\Longrightarrow$

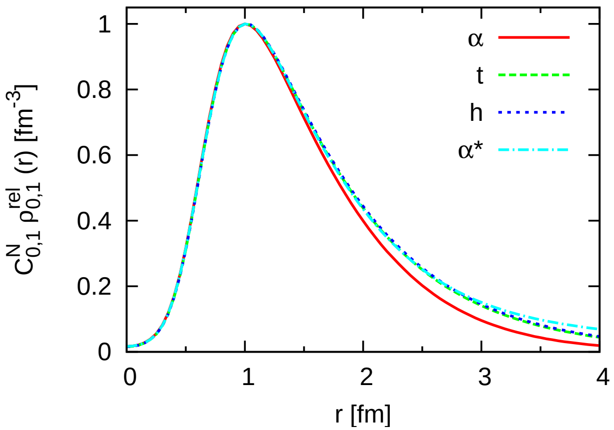


$\Uparrow$

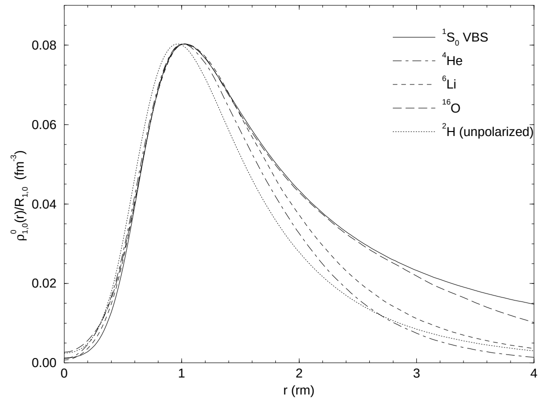
- We use **realistic correlation functions** from variational calculation

1.b - Correlations signatures in coordinate space densities

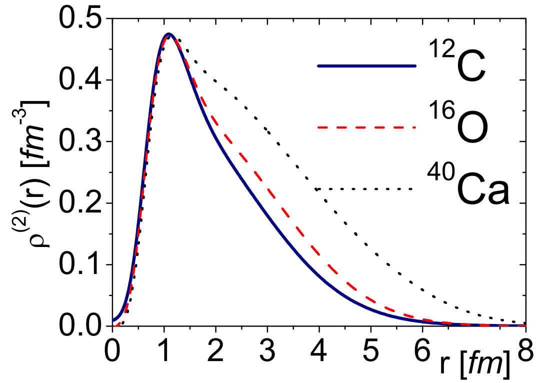
- ***realistic*** relative two-body density $\rho(r) = \int d\boldsymbol{R}\, \rho^{(2)}\Big(\boldsymbol{r} = \boldsymbol{r}_1 - \boldsymbol{r}_2, \boldsymbol{R} = (\boldsymbol{r}_1 + \boldsymbol{r}_2)/2\Big)$



Feldemeier *et al*,
Phys. Rev. **C84**, 054003 (2011)

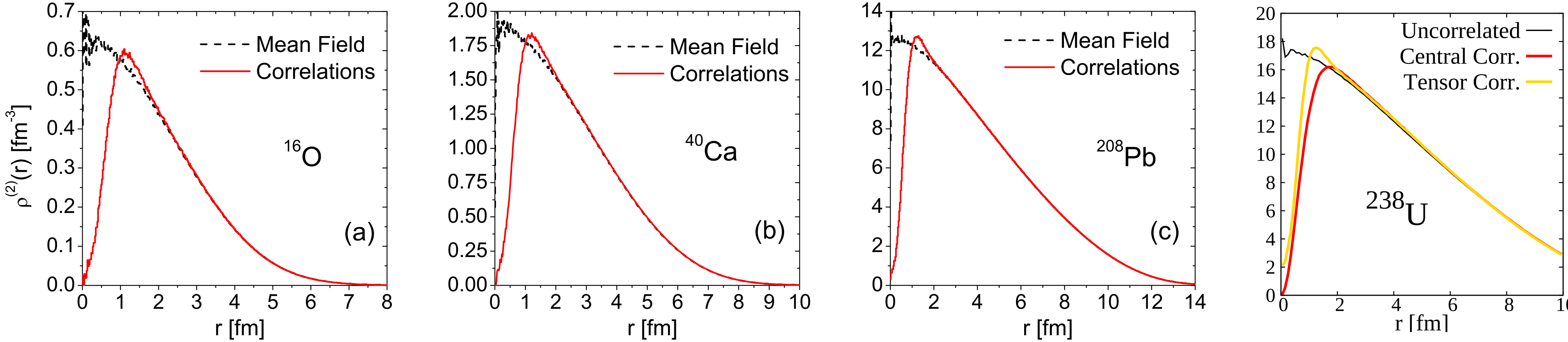


Forest *et al*,
Phys. Rev. **C54** (1996) 646-667



Alvioli *et al*, Phys. Rev. **C72**;
Phys. Rev. Lett. **100** (2008)

- ***MC algorithm*** to include correlations in heavy nuclei



M. Alvioli, H.-J. Drescher, M. Strikman, Phys. Lett. **B680** (2009) 225

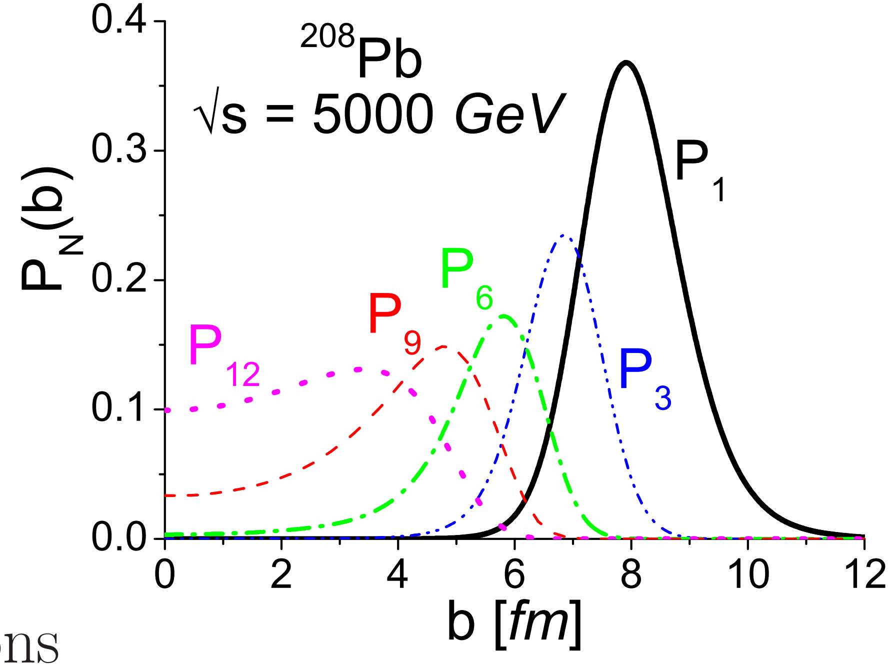
1.b - Probabiltity distribution functions $P_N(b)$ in pA collisions

- probability of interaction with nucleon i: $P(\boldsymbol{b}, \boldsymbol{b}_i) = 1 - [1 - \Gamma(\boldsymbol{b} - \boldsymbol{b}_i)]^2$
- black disk approximation replaced by the Glauber profile $\Gamma(\boldsymbol{b})$:

$$\Gamma(\boldsymbol{b}) = \frac{\sigma_{NN}^{tot}}{4\pi B} e^{-b^2/(2B)},$$

the Fourier transform of the NN elastic scattering amplitude A(t) for

$$d\sigma/dt \propto exp(Bt)$$



- probability of interaction with N nucleons

$$P_N(\boldsymbol{b}) = \sum_{i_1,\ldots,i_N}^{N} P(\boldsymbol{b}, \boldsymbol{b}_{i_1}) \cdot \cdots \cdot P(\boldsymbol{b}, \boldsymbol{b}_{i_N}) \prod_{j \neq i_1,\ldots,i_N}^{A-N} [1 - P(\boldsymbol{b}, \boldsymbol{b}_j)]$$

(*M. Alvioli, H.-J. Drescher, M. Strikman Phys. Lett.* ***B680*** *(2009)*)

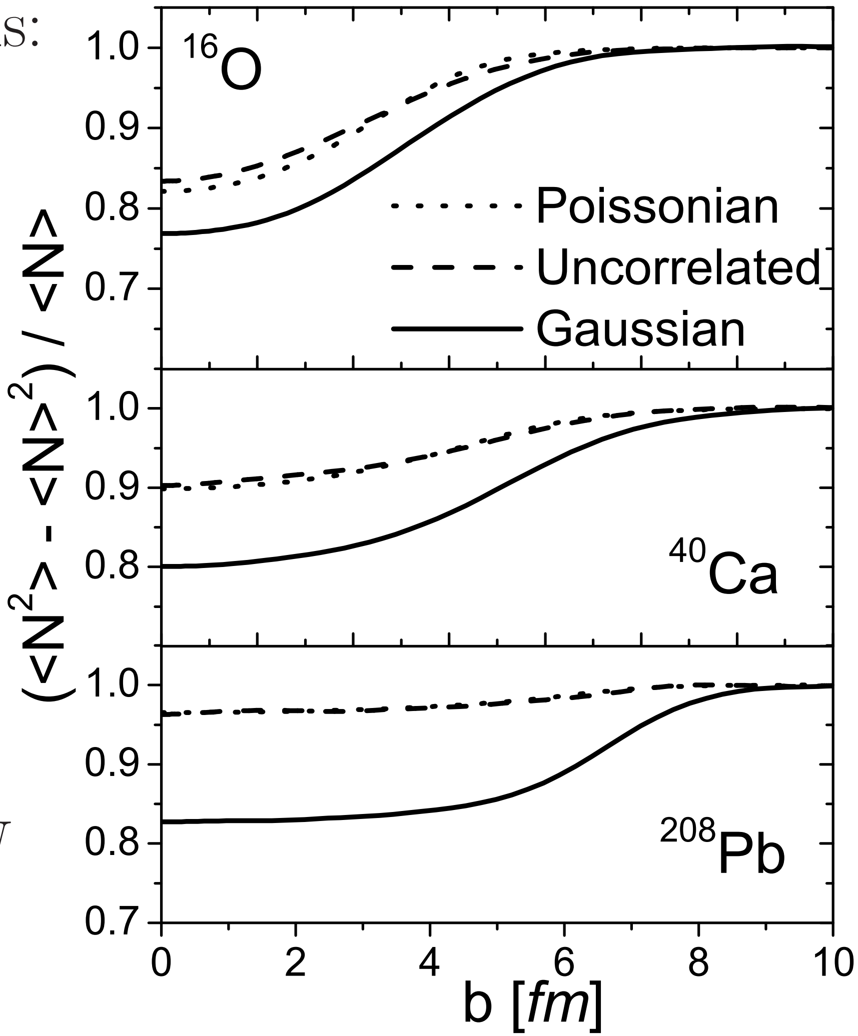
1.c - fluctuations in pA collisions

- average number of single and double collisions:

$$\langle N\rangle = \sum_N N\, P_N(b)$$

$$\langle N(N-1)\rangle = \sum_N \left(N^2 - N\right)\, P_N(b)$$

- dispersion: $D(b) = \dfrac{\langle N^2\rangle - [\langle N\rangle]^2}{\langle N\rangle} \longrightarrow$

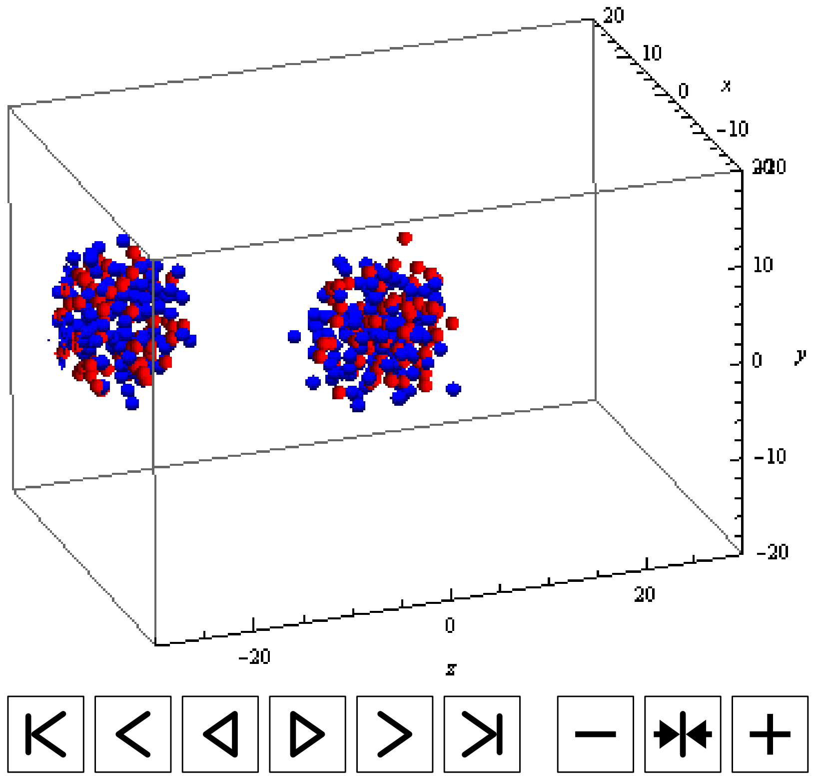


- *Poissonian* result is obtained using

$$P_N(b) = \binom{A}{N} \left(\sigma^{in}_{NN} T(b)\right)^N \left[1 - \sigma^{in}_{NN} T(b)\right]^{A-N}$$

(*M. Alvioli, H.-J. Drescher, M. Strikman Phys. Lett.* ***B680*** *(2009)*)

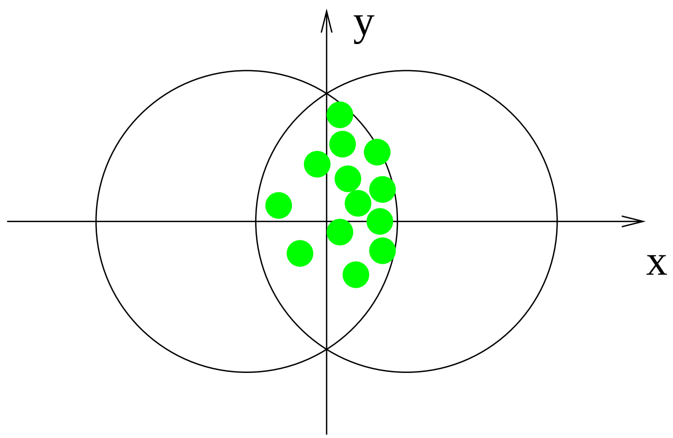
1.c - Fluctuations of the geometry of participant matter



- Fluctuations effects on geometry investigated through participant matter distribution moments and their dispersion

$$\epsilon_n = -\frac{\langle w(r)\, \cos n(\phi - \psi_n)\rangle}{\langle w(r)\rangle}$$

$$\Delta\epsilon_n = \sqrt{\frac{\sum(\epsilon_n^i - \langle\epsilon_i\rangle)^2}{N}}$$



$\longrightarrow$ participant nucleons • in transverse plane

PHYSICAL REVIEW C **85**, 034902 (2012)

Initial-state anisotropies and their uncertainties in ultrarelativistic heavy-ion collisions from the Monte Carlo Glauber model

M. Alvioli,[1,*] H. Holopainen,[2,3,4,†] K. J. Eskola,[2,3,‡] and M. Strikman[5,§]

[1]*ECT, European Centre for Theoretical Studies in Nuclear Physics and Related Areas, Strada delle Tabarelle 286, I-38123 Villazzano (TN) Italy*

[2]*Department of Physics, P.O. Box 35, FI-40014 University of Jyväskylä, Finland*

[3]*Helsinki Institute of Physics, P.O. Box 64, FI-00014 University of Helsinki, Finland*

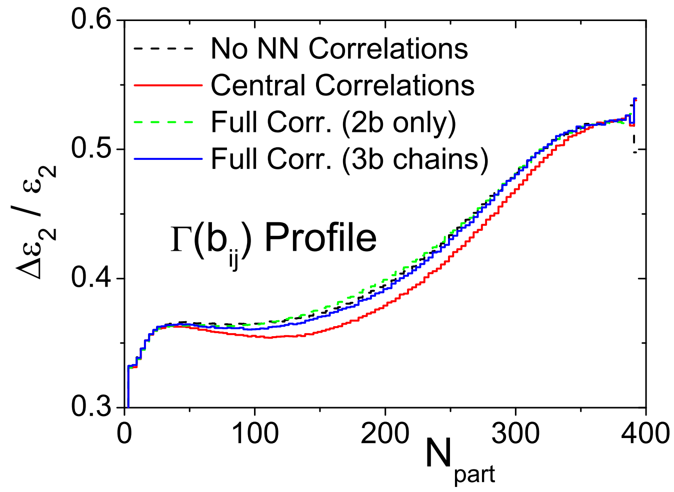
[4]*Frankfurt Institute for Advanced Studies, Ruth-Moufang-Strasse 1, D-60438 Frankfurt am Main, Germany*

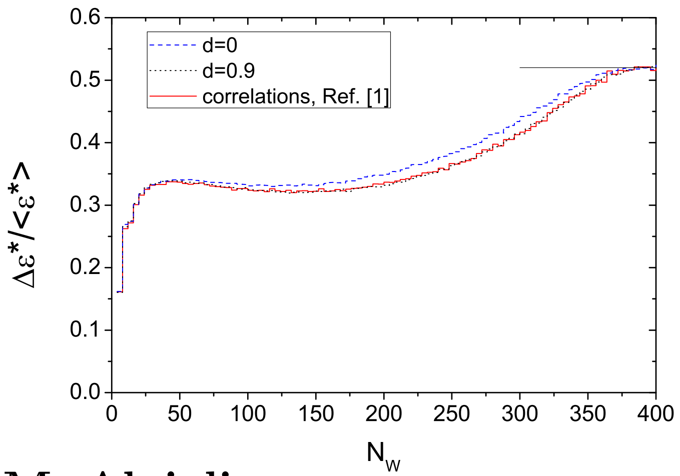
[5]*The Pennsylvania State University, 104 Davey Lab, University Park, Pennsylvania 16803, USA*

(Received 28 December 2011; published 7 March 2012)

In hydrodynamical modeling of heavy-ion collisions, the initial-state spatial anisotropies are translated into momentum anisotropies of the final-state particle distributions. Thus, understanding the origin of the initial-state anisotropies and their uncertainties is important before extracting specific QCD matter properties, such as viscosity, from the experimental data. In this work we review the wounded nucleon approach based on the Monte Carlo Glauber model, charting in particular the uncertainties arising from modeling of the nucleon-nucleon interactions between the colliding nucleon pairs and nucleon-nucleon correlations inside the colliding nuclei. We discuss the differences between the black disk model a
for the inelastic nucleon-nucleon interactions and investigate the i
state-of-the-art modeling of these.

DOI: 10.1103/PhysRevC.85.034902 PACS





PHYSICAL REVIEW C **81**, 064909 (2010)

Two-body nucleon-nucleon correlations in Glauber models of relativistic heavy-ion collisions

Wojciech Broniowski[1,2,*] and Maciej Rybczyński[2,†]

[1]*The H. Niewodniczański Institute of Nuclear Physics, Polish Academy of Sciences, PL-31342 Kraków, Poland*

[2]*Institute of Physics, Jan Kochanowski University, PL-25406 Kielce, Poland*

(Received 4 March 2010; revised manuscript received 6 June 2010; published 28 June 2010)

We investigate the influence of the central two-body nucleon-nucleon correlations on several quantities observed in relativistic heavy-ion collisions. It is demonstrated with explicit Monte Carlo simulations that the basic correlation measures observed in relativistic heavy-ion collisions, such as the fluctuations of participant eccentricity, initial size fluctuations, or the fluctuations of the number of sources producing particles, are all sensitive to the inclusion of the two-body correlations. The effect is at the level of about 10–20%. Moreover, the realistic (Gaussian) correlation function gives indistinguishable results from the hard-core repulsion, with the expulsion distance set to 0.9 fm. Thus, we verify that for investigations of the considered correlation measures, it is sufficient to use the Monte Carlo generators accounting for the hard-core repulsion.

DOI: 10.1103/PhysRevC.81.064909 PACS number(s): 25.75.Dw, 25.75.Ld

Computer Physics Communications 185 (2014) 1759–1772

Contents lists available at ScienceDirect

Computer Physics Communications

journal homepage: www.elsevier.com/locate/cpc

GLISSANDO 2: GLauber Initial-State Simulation AND mOre…, ver. 2[☆,☆☆]

Maciej Rybczyński[a,*], Grzegorz Stefanek[a], Wojciech Broniowski[a,b], Piotr Bożek[c,b]

[a] Institute of Physics, Jan Kochanowski University, 25-406 Kielce, Poland
[b] The H. Niewodniczański Institute of Nuclear Physics, Polish Academy of Sciences, 31-342 Cracow, Poland
[c] AGH University of Science and Technology, Faculty of Physics and Applied Computer Science, 30-059 Cracow, Poland

ARTICLE INFO

Article history:
Received 22 October 2013
Received in revised form
30 January 2014
Accepted 7 February 2014
Available online 15 February 2014

Keywords:
Glauber model
Wounded nucleons
Monte Carlo generator
Relativistic heavy-ion collisions
LHC
RHIC
SPS

ABSTRACT

We present an extended version of GLISSANDO, a Monte-Carlo generator for Glauber-like models of the initial stage of relativistic heavy-io… parametrization of shape of nucle… deformation, a possibility of using c… an option of overlaying distributio… inclusion of the core–corona effect… event hydrodynamics. Together wi… models, or the implementation of a… tical approach to describe the early… used in modeling the intermediate… with the ROOT platform. The suppl… such as the multiplicity distributio… correlations, forward–backward co… deuteron–nucleus collisions.

PHYSICAL REVIEW C 90, 034906 (2014)

Correlations in the Monte Carlo Glauber model

Jean-Paul Blaizot,[1,*] Wojciech Broniowski,[1,2,3,†] and Jean-Yves Ollitrault[1,‡]

[1] Institut de Physique Théorique, CNRS/URA 2306, F-91191 Gif-sur-Yvette, France
[2] The H. Niewodniczański Institute of Nuclear Physics, Polish Academy of Sciences, PL-31342 Kraków, Poland
[3] Institute of Physics, Jan Kochanowski University, PL-25406 Kielce, Poland

(Received 15 May 2014; revised manuscript received 22 August 2014; published 10 September 2014)

Event-by-event fluctuations of observables are often modeled using the Monte Carlo Glauber model, in which the energy is initially deposited in sources associated with wounded nucleons. In this paper, we analyze in detail the correlations between these sources in proton-nucleus and nucleus-nucleus collisions. There are correlations arising from nucleon-nucleon correlations within each nucleus, and correlations due to the collision mechanism, which we dub twin correlations. We investigate this new phenomenon in detail. At the Brookhaven Relativistic Heavy Ion Collider and CERN Large Hadron Collider energies, correlations are found to have modest effects on size and eccentricity fluctuations, such that the Glauber model produces to a good approximation a collection of independent sources.

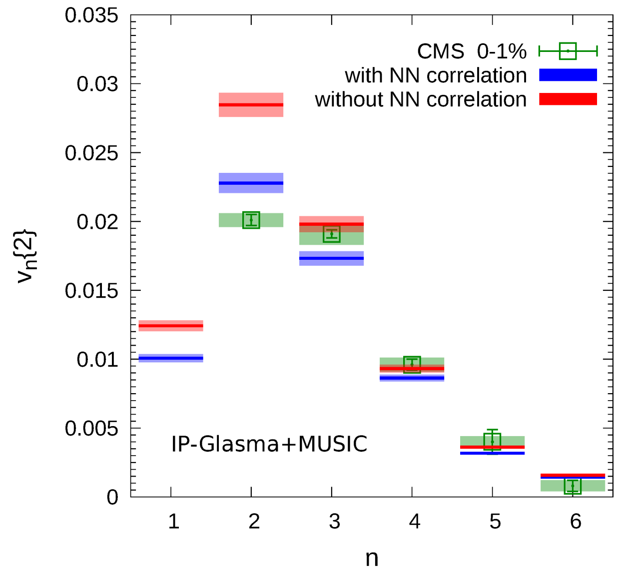
DOI: 10.1103/PhysRevC.90.034906 PACS number(s): 25.75.Gz, 25.75.Ld

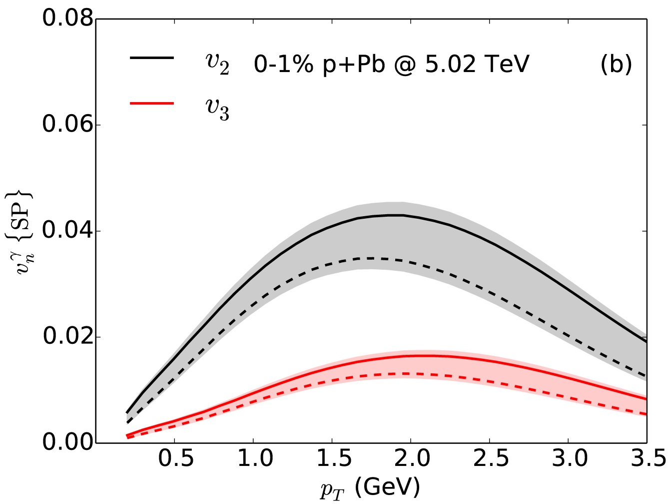
Effect of initial-state nucleon-nucleon correlations on collective flow in ultra-central heavy-ion collisions

G. S. Denicol[a], C. Gale[a,b], S. Jeon[a], J.-F. Paquet[a], and B. Schenke[c]
[a] *Department of Physics, McGill University, 3600 University Street, Montreal, Quebec, H3A 2T8, Canada*
[b] *Frankfurt Institute for Advanced Studies, Ruth-Moufang-Str. 1, D-60438 Frankfurt am Main, Germany and*
[c] *Physics Department, Bldg. 510A, Brookhaven National Laboratory, Upton, NY-11973, USA*

We investigate the effect of nucleon-nucleon correlations on the initial condition of ultra-central heavy ion collisions at LHC energies. We calculate the eccentricities of the MC-Glauber and IP-Glasma models in the 0–1% centrality class and show that they are considerably affected by the inclusion of such type of correlations. For an IP-Glasma initial condition, we further demonstrate that this effect survives the fluid-dynamical evolution of the system and can be observed in its final state azimuthal momentum anisotropy.

PACS numbers:





Thermal photon radiation in high multiplicity p+Pb collisions at the Large Hadron Collider

C. Shen, J.-F. Paquet, G. S. Denicol, S. Jeon, and C. Gale
Department of Physics, McGill University, 3600 University Street, Montreal, QC, H3A 2T8, Canada

The collective behaviour of hadronic particles has been observed in high multiplicity proton-lead collisions at the Large Hadron Collider (LHC), as well as in deuteron-gold collisions at the Relativistic Heavy-Ion Collider (RHIC). In this work we present the first calculation, in the hydrodynamic framework, of thermal photon radiation from such small collision systems. Owing to their compact size, these systems can reach temperatures comparable to those in central nucleus-nucleus collisions. The thermal photons can thus shine over the prompt background, and increase the low p_T direct photon spectrum by a factor of 2-3 in 0-1% p+Pb collisions at 5.02 TeV. This thermal photon enhancement can therefore serve as a clean signature of the existence of a hot quark-gluon plasma during the evolution of these small collision systems, as well as validate hydrodynamic behavior in small systems.

Shape and flow fluctuations in ultra-central Pb+Pb collisions at the LHC

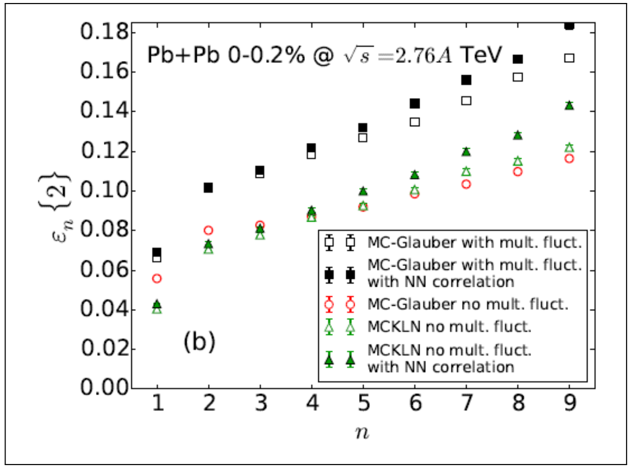
Chun Shen,[1,2,*] Zhi Qiu,[1] and Ulrich Heinz[1]

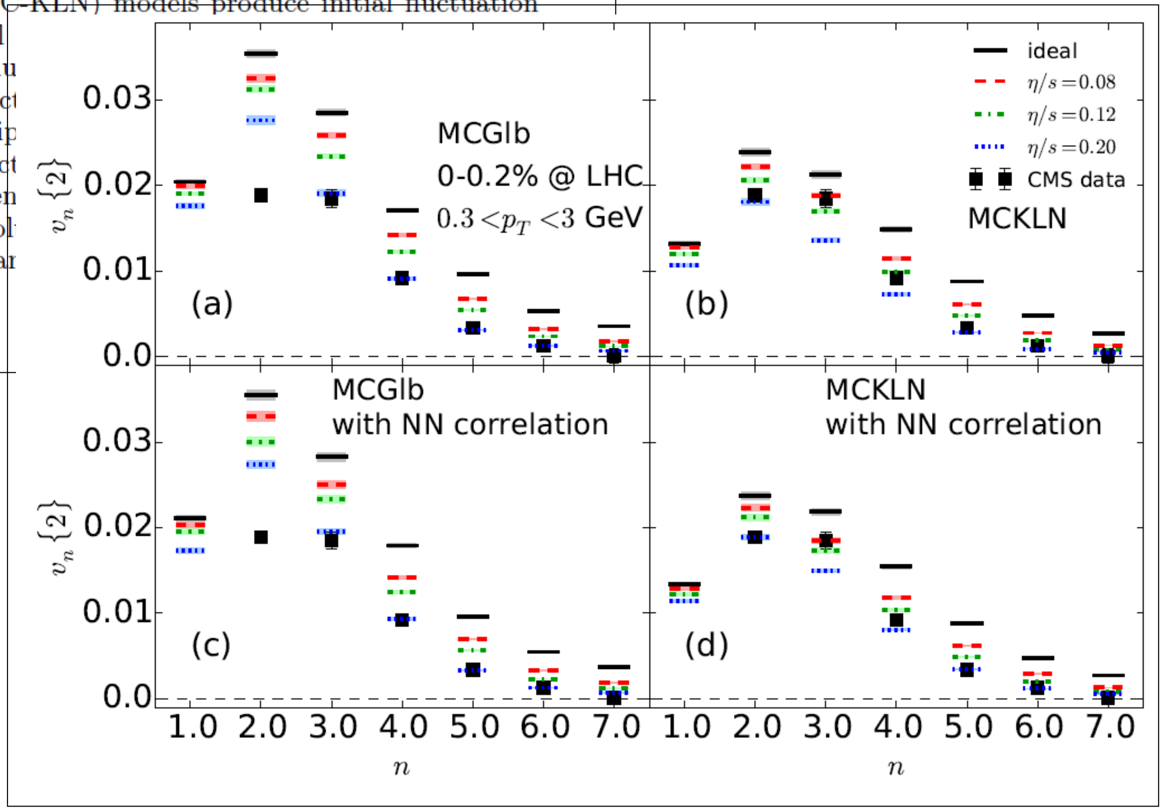
[1]*Department of Physics, The Ohio State University, Columbus, Ohio 43210-1117, USA*
[2]*Department of Physics, McGill University, 3600 University Street, Montreal, QC, H3A 2T8, Canada*

(Dated: June 18, 2015)

In ultra-central heavy-ion collisions, anisotropic hydrodynamic flow is generated by density fluctuations in the initial state rather than by geometric overlap effects. For a given centrality class, the initial fluctuation spectrum is sensitive to the method chosen for binning the events into centrality classes. We show that sorting events by total *initial* entropy or by total *final* multiplicity yields event classes with equivalent statistical fluctuation properties, in spite of viscous entropy production during the fireball evolution. With this initial entropy-based centrality definition we generate several classes of ultra-central Pb+Pb collisions at LHC energies and evolve the events using viscous hydrodynamics with non-zero shear but vanishing bulk viscosity. Comparing the predicted anisotropic flow coefficients for charged hadrons with CMS data we find that both the Monte Carlo Glauber (MC-Glb) and Monte Carlo Kharzeev-Levin-Nardi (MC-KLN) models produce initial fluctuation spectra that are incompatible with the measured final
choice of the specific shear viscosity. In spite of this failu
can qualitatively explain, in terms of event-by-event fluct
and flow angles, the breaking of flow factorization for ellip
sured by the CMS experiment. For elliptic flow, this fact
collisions. We conclude that the bulk of the experimen
effects are qualitatively explained by hydrodynamic evol
their quantitative description requires a better understan

PACS numbers: 25.75.-q, 12.38.Mh, 25.75.Ld, 24.10.Nz





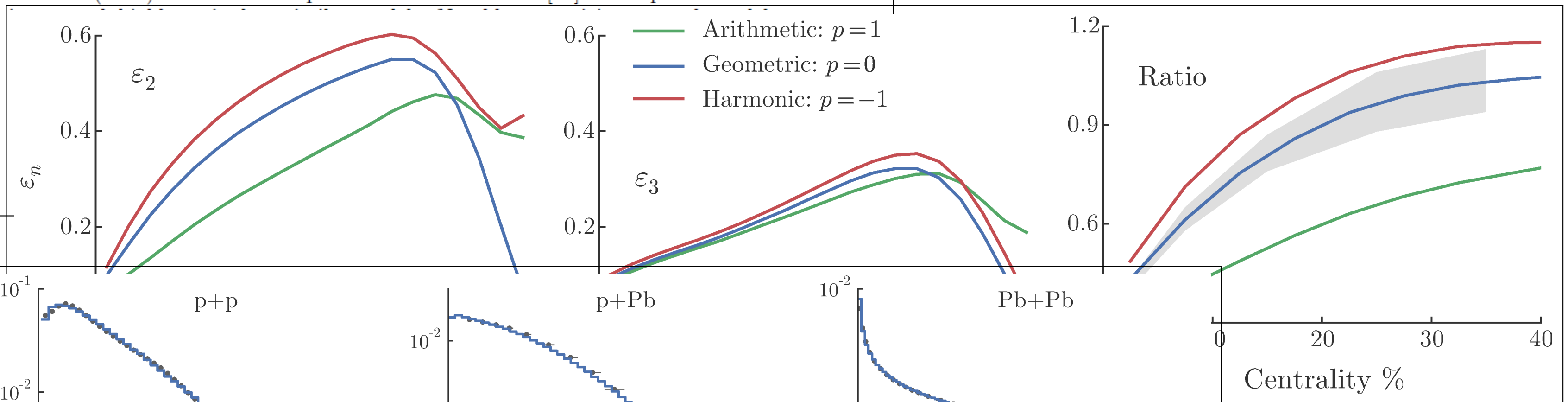
An effective model for entropy deposition in high-energy pp, pA, and AA collisions

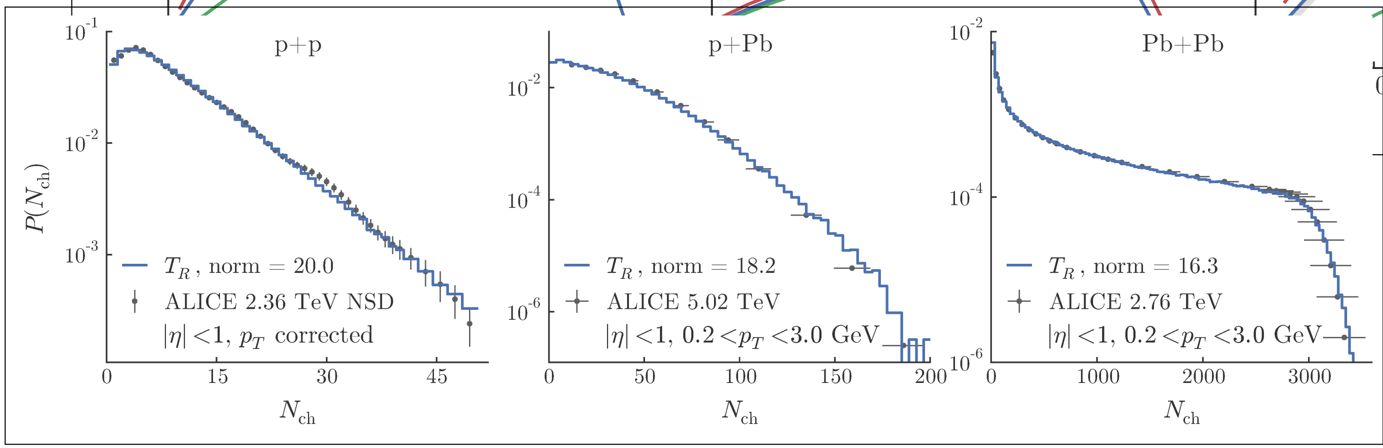
J. Scott Moreland, Jonah E. Bernhard, and Steffen A. Bass
Department of Physics, Duke University, Durham, NC 27708-0305
(Dated: December 16, 2014)

We introduce TRENTo, a new initial condition model for high-energy nuclear collisions based on eikonal entropy deposition via a "reduced thickness" function. The model simultaneously predicts the shapes of experimental proton-proton, proton-nucleus, and nucleus-nucleus multiplicity distributions, and generates nucleus-nucleus eccentricity harmonics consistent with experimental flow constraints. In addition, the model provides a possible resolution to the "knee" puzzle in ultra-central uranium-uranium collisions.

Over the last decade, the ultra-relativistic heavy-ion collision programs at the Relativistic Heavy Ion Collider (RHIC) and the Large Hadron Collider (LHC) have suc-

ticipant and binary nucleon-nucleon collision. Despite its simplicity, the Glauber model has qualitatively fit many experimental measurements [27] and inspired a number of





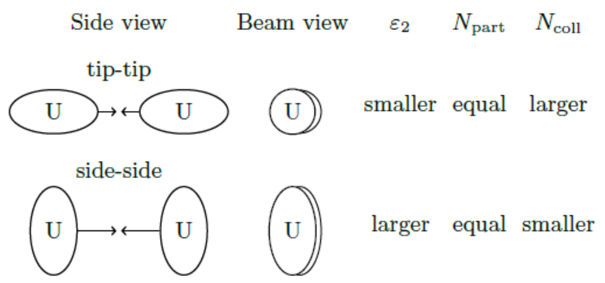
1.d - Latest updates of nuclear configurations - I

- ***Nucleus deformation*** – for ^{238}U we use a modified WS profile:

$$\rho(r) = \frac{\rho_0}{1 + e^{(r-R_0)/a}} \longrightarrow \rho(r,\theta) = \frac{\rho_0}{1 + e^{(r-R_0-R_0\beta_2 Y_{20}(\theta)-R_0\beta_4 Y_{40}(\theta))/a}}$$

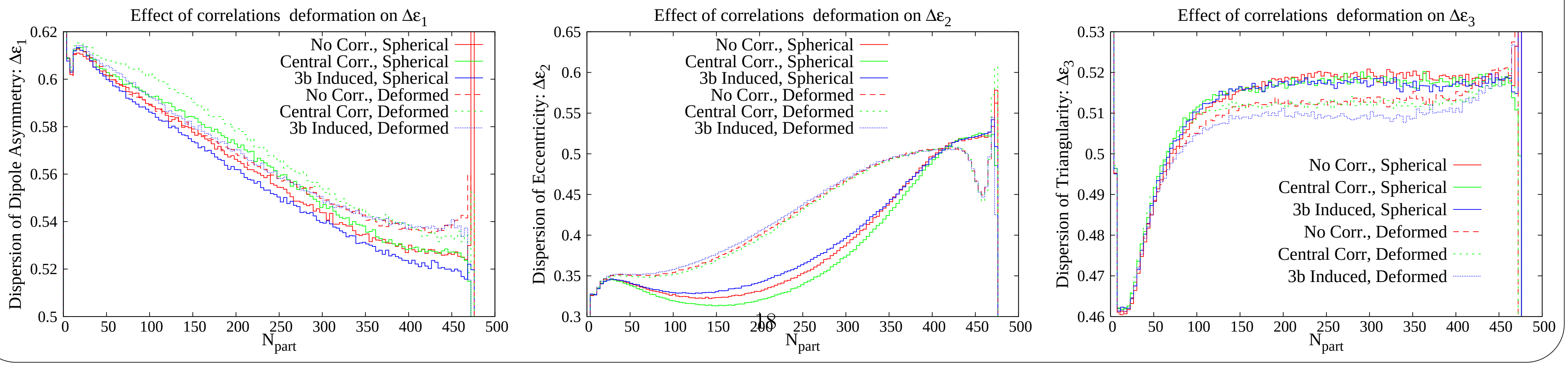
$$Y_{20}(\theta) = \frac{1}{4\,r^2}\sqrt{\frac{5}{\pi}}\left(2z^2 - x^2 - y^2\right)$$

$$Y_{40}(\theta) = \frac{1}{16\,r^4}\sqrt{\frac{9}{\pi}}\left(35z^4 - 30z^2r^2 + 3r^4\right)$$



(*P. Filip, R. Lednicky, H. Masui, N. Xu Phys. Lett.* ***C80*** *(2009)*)

- deformation effect on dispersion of moments:



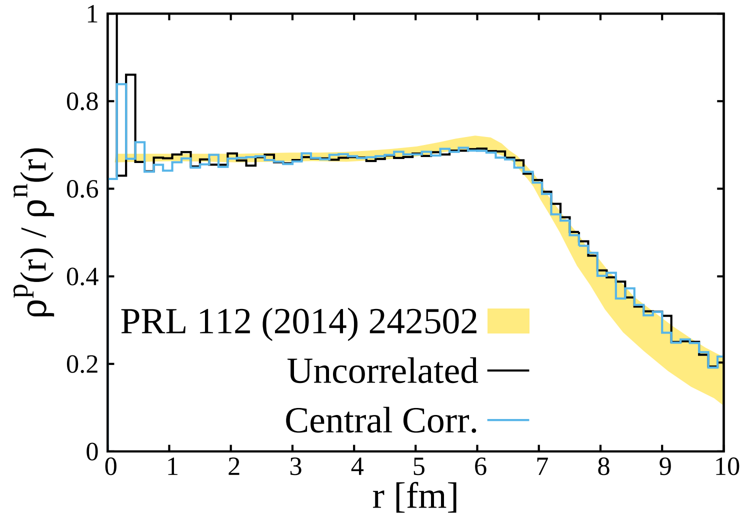
1.d - Latest updates of nuclear configurations - II

- ***Neutron skin*** – **p/n** profiles for ^{208}Pb:

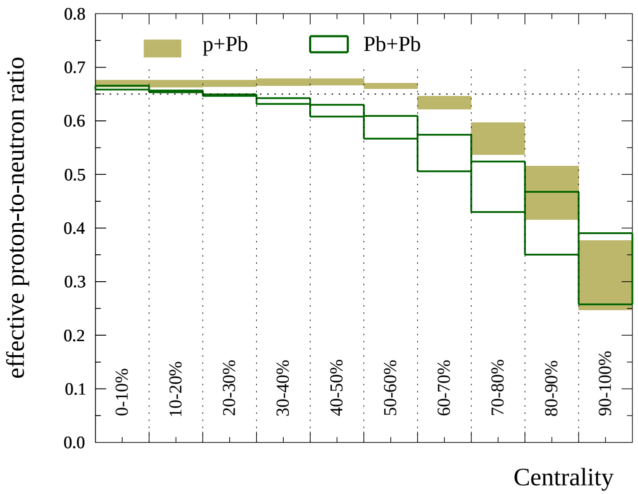
$$\rho(r) = \rho_0^{(p,n)} \; / \; \left(1 + e^{(r - R_0^{p,n})/a^{p,n}}\right)$$

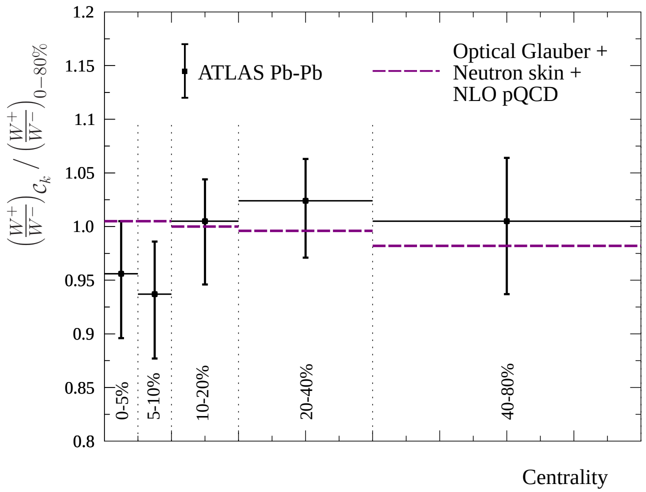
$$(\rho_0^p, R_0^p, a_0^p) \;=\; (\text{"}82\text{"}, 6.680 fm, 0.447 fm)$$
$$(\rho_0^n, R_0^n, a_0^n) \;=\; (\text{"}126\text{"}, 6.700 fm, 0.550 fm)$$

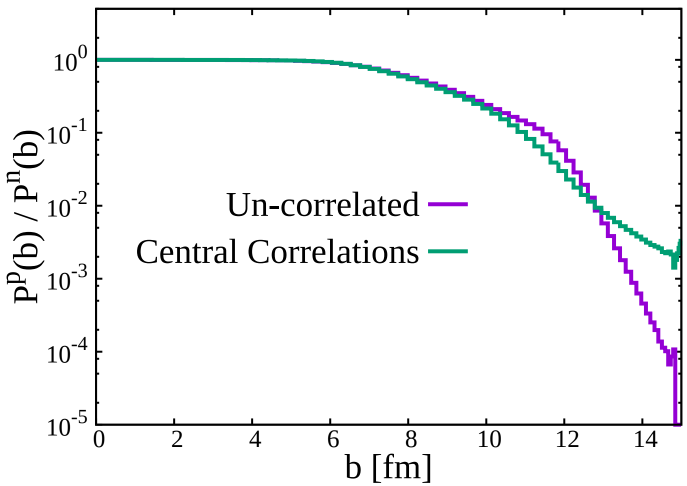
(*C.M. Tarbert et al., Phys. Rev. Lett.* ***112*** *(2014)*)



- additional tool for determination of centrality:



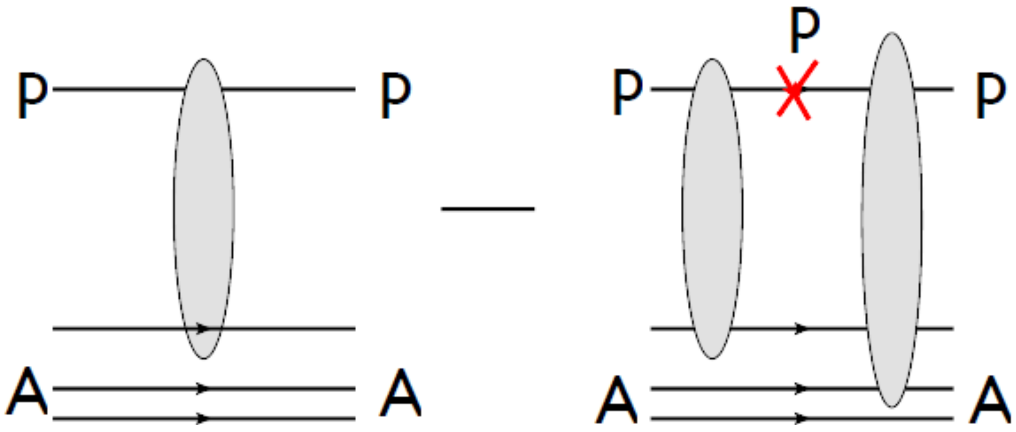




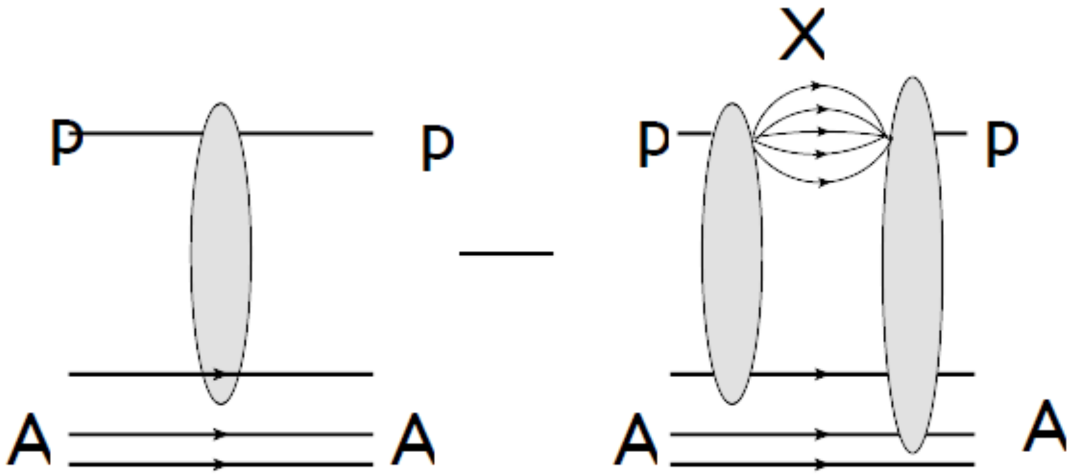
*H. Paukkunen, PL****B745*** *(2015)* — *Alvioli, Strikman*

- The smearing of impact parameter is expected to reduce the p/n difference

2 - Beyond Glauber approach (*also Mark's talk*)



⟶ Glauber model: in rescattering diagrams the proton cannot propagate in intermediate states



⟶ Gribov-Glauber model: the proton can access a set of intermediate state as in pN diffraction; relevant at high energies ($E_{inc} >> 10$ GeV)

X is a set of intermediate states that stay frozen during $\boldsymbol{pA}$ interaction

2.a - NN interaction with frozen configurations

- at sufficiently high energy, i.e. when the relation

$$2\,R\,<\,2\,p_{lab}/(M^2\,-\,m^2)$$

holds, intermediate states are frozen during the pA interaction

- the fluctuations into intermediate states, i.e. different internal configurations, is a manifestation of the structure of the proton

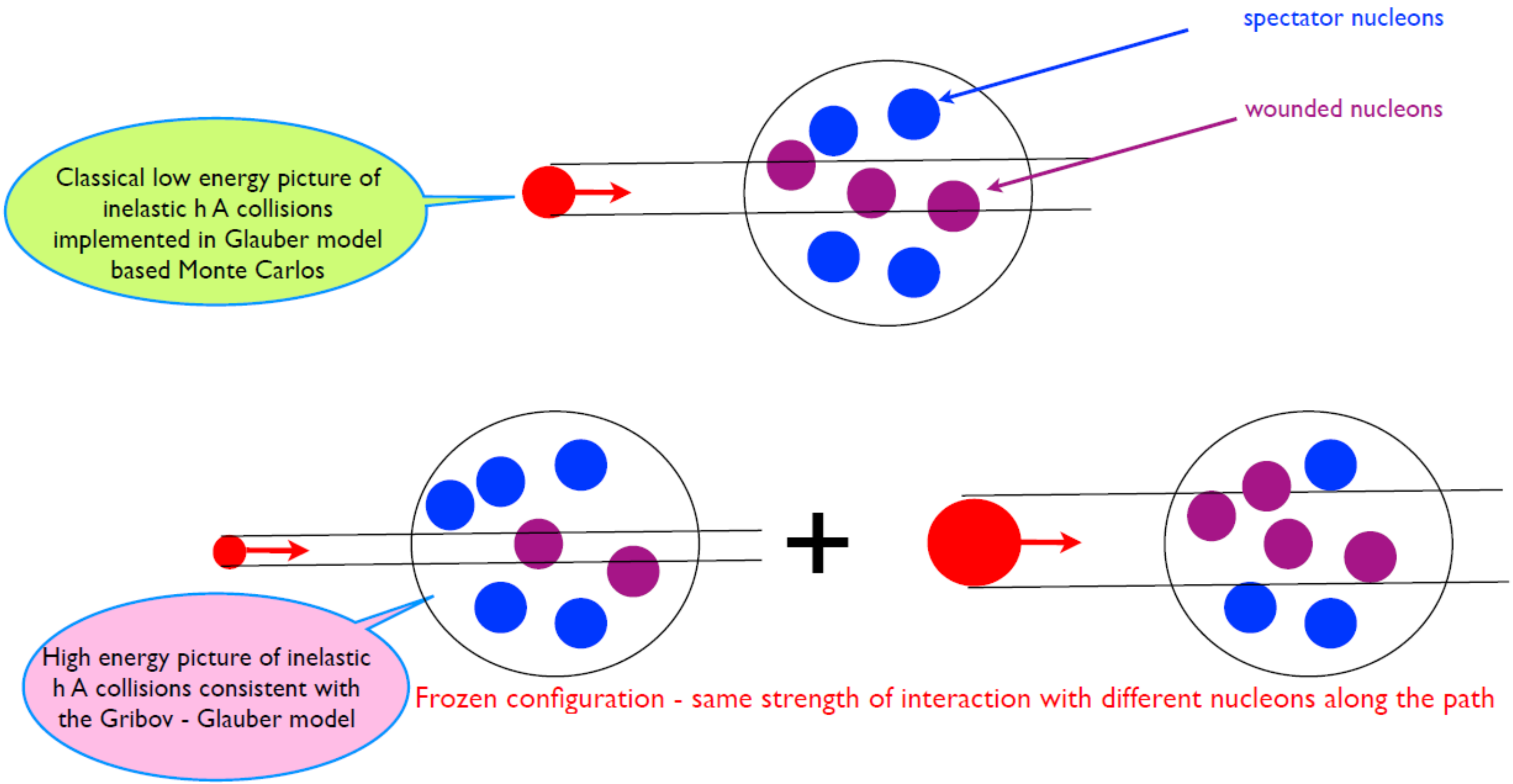
- the transverse spatial extent of the color field and of the momentum distribution in each particular configuration determines the $h_M - N$ interaction strengh

- different configurations $\longrightarrow$ different cross sections $\longrightarrow$ relation with color transparency/opacity phenomena

G. Baym, B. Blattel, L. Frankfurt, M. Strikman, Phys.Rev. ***D47*** *(1993)*

Heiselberg, Baym, Blattel, Frankfurt, Strikman, Phys.Rev.Lett. ***70*** *(1993)*

2.a - NN interaction Fluctuations in high-energy pA scattering



G. Baym, B. Blattel, L. Frankfurt, M. Strikman, Phys.Rev. ***D47*** *(1993)*

Heiselberg, Baym, Blattel, Frankfurt, Strikman, Phys.Rev.Lett. ***70*** *(1993)*

2.a - Color Fluctuations in high-energy pA scattering

- GMC: pA process calculated for different configurations with given σ, which do not interfere with each other, then averaged over all possible configurations with a ***weight*** given by the probability of the configuration, $P(\sigma)$

$$P(\sigma) = \gamma \frac{\sigma}{\sigma + \sigma_0} e^{-\frac{(\sigma/\sigma_0 - 1)^2}{\Omega^2}}$$

$$\int d\sigma \, P(\sigma) = 1 \,, \qquad \int d\sigma \, \sigma \, P(\sigma) = \sigma_{tot}$$

$$\frac{1}{\sigma_{tot}^2} \int d\sigma \, (\sigma - \sigma_{tot})^2 \, P(\sigma) = \omega_\sigma$$

proposed by

G. Baym, B. Blattel, L. Frankfurt, M. Strikman, Phys.Rev. ***D47*** *(1993)*

parametrized in *V. Guzey, M. Strikman, Phys. Lett.* ***B633*** *(2006)*

first used in MCG: *M. Alvioli, M. Strikman, Phys. Lett.* ***B722*** *(2013)*

2.a - Color Fluctuations in high-energy pA scattering

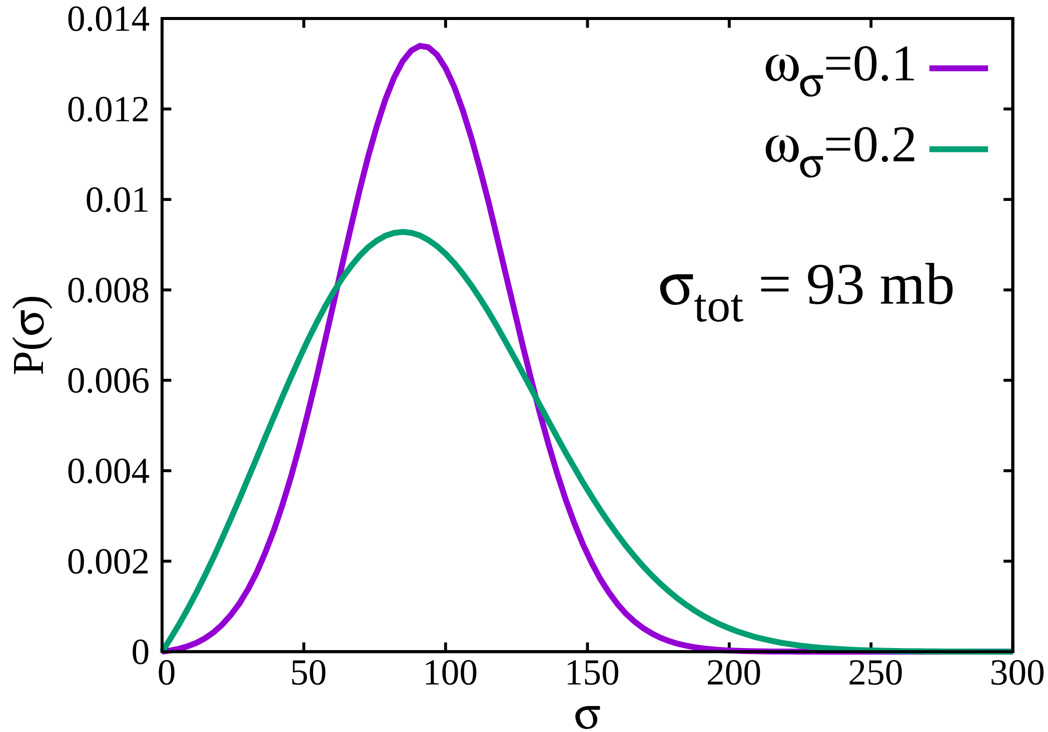
- Effects of fluctuations mainly determined by the dispersion ω_σ of $P(\sigma)$

$$P(\sigma) = \gamma \frac{\sigma}{\sigma + \sigma_0} e^{-\frac{(\sigma/\sigma_0 - 1)^2}{\Omega^2}}$$

$$\int d\sigma\, P(\sigma) = 1$$

$$\int d\sigma\, \sigma\, P(\sigma) = \sigma_{tot}$$

$$\frac{1}{\sigma_{tot}^2} \int d\sigma\, (\sigma - \sigma_{tot})^2\, P(\sigma) = \omega_\sigma$$



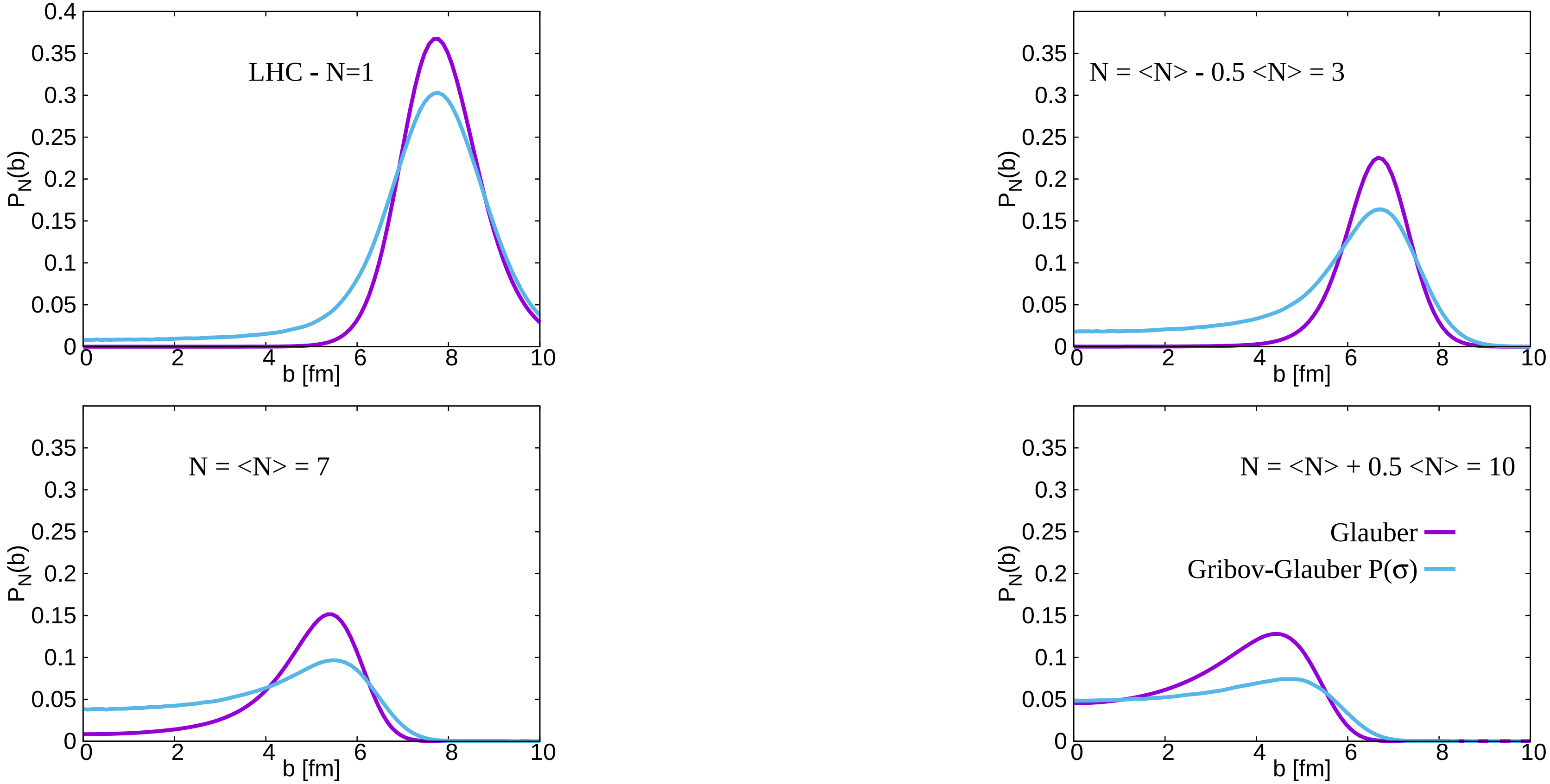
- A simple two-states model illustrates fluctuations effects: for $\omega_\sigma = 0.1$

$$\sigma_{1,2} = \sigma_{tot}\,(1 \pm \sqrt{\omega_\sigma}) \longrightarrow \begin{cases} \sigma_1 = \sigma_{tot}\,(1 + \sqrt{0.1}) \longrightarrow \sigma_1/\sigma_{tot} = 0.77 \\ \sigma_2 = \sigma_{tot}\,(1 - \sqrt{0.1}) \longrightarrow \sigma_2/\sigma_{tot} = 1.43 \end{cases}$$

Mark will discuss the parametrization of $P(\sigma)$

2.a - Color Fluctuations: probability of N interactions at b

- fluctuations of the number of wounded nucleons $\mathbf{N_{coll}}$ for given impact parameter $\mathbf{b} \Longrightarrow$ smearing of centrality

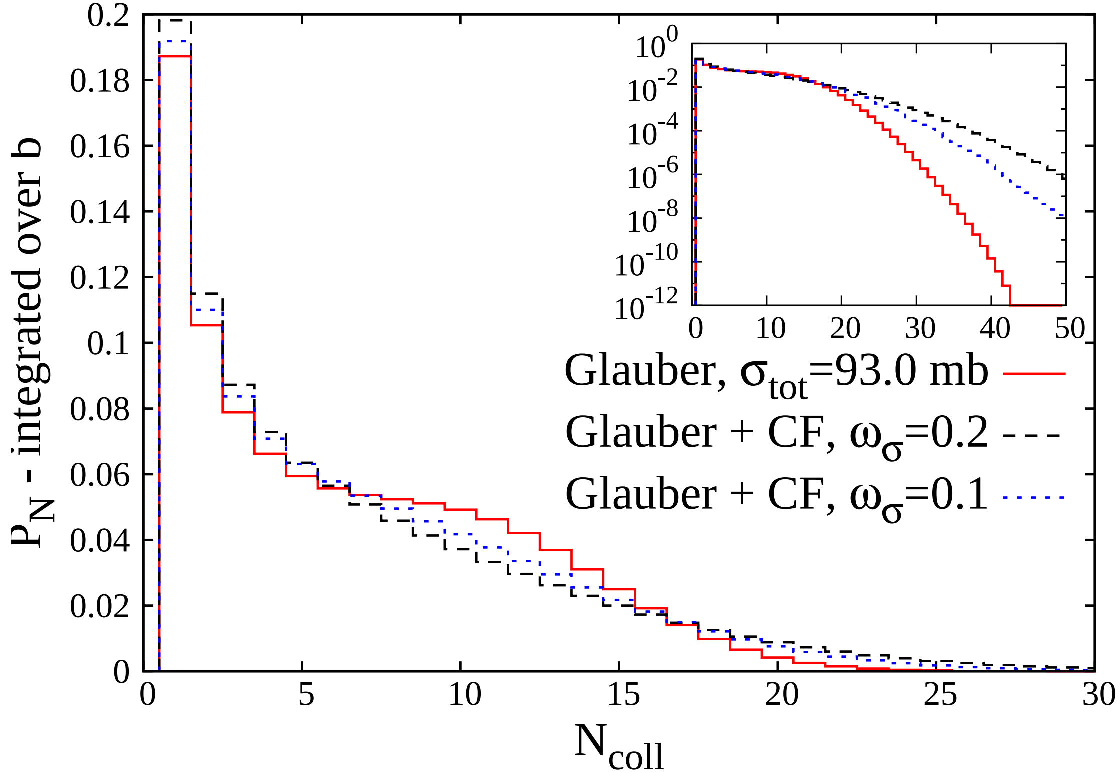


- we find enhancement of the probability of events with large $N = N_{coll}$

M. Alvioli, M. Strikman, Phys. Lett. ***B722*** *(2013)*

2.a - Color Fluctuations: probability of N interactions

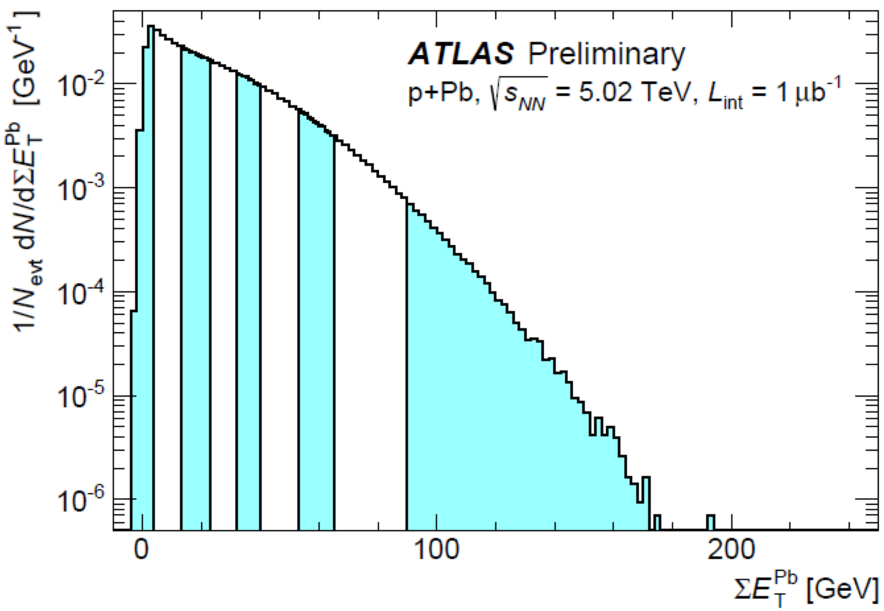
- fluctuations of the number of wounded nucleons $\mathbf{N_{coll}}$ for given impact parameter $\mathbf{b} \Longrightarrow$ smearing of centrality
- $P_N = \int d\boldsymbol{b}\, P_N(b);\; N = N_{coll}$



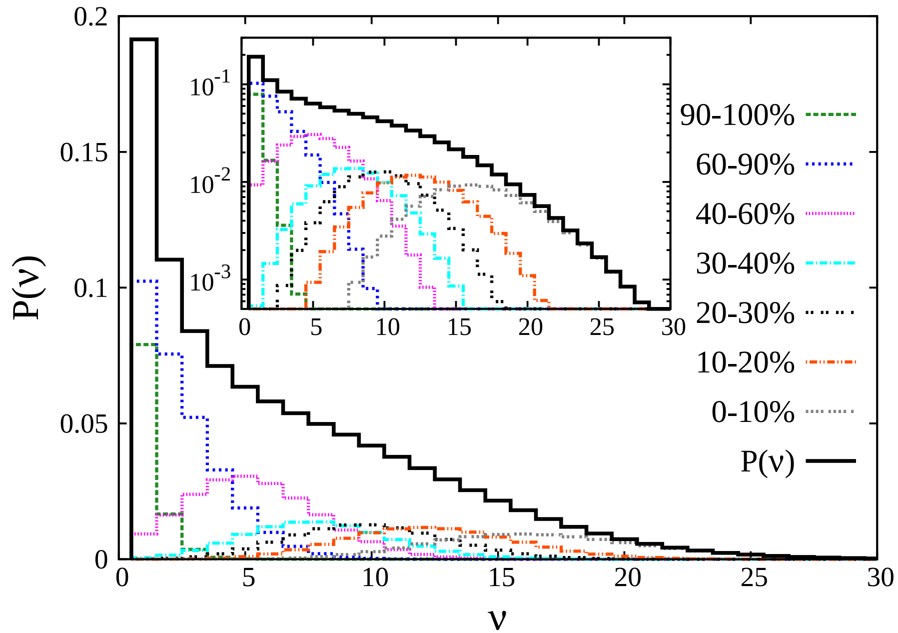
M. Alvioli, M. Strikman, Phys. Lett. ***B722*** *(2013)*
M. Alvioli, V. Guzey, L. Frankfurt, M. Strikman, Phys. Rev. ***C90*** *(2014)*

2.a - Color Fluctuations: N_{coll} and b dependence

- We use ATLAS (*ATLAS-CONF-2013-096*) model for ΔE_T in pp collisions with a convolution to obtain the pA model



$\Longrightarrow$

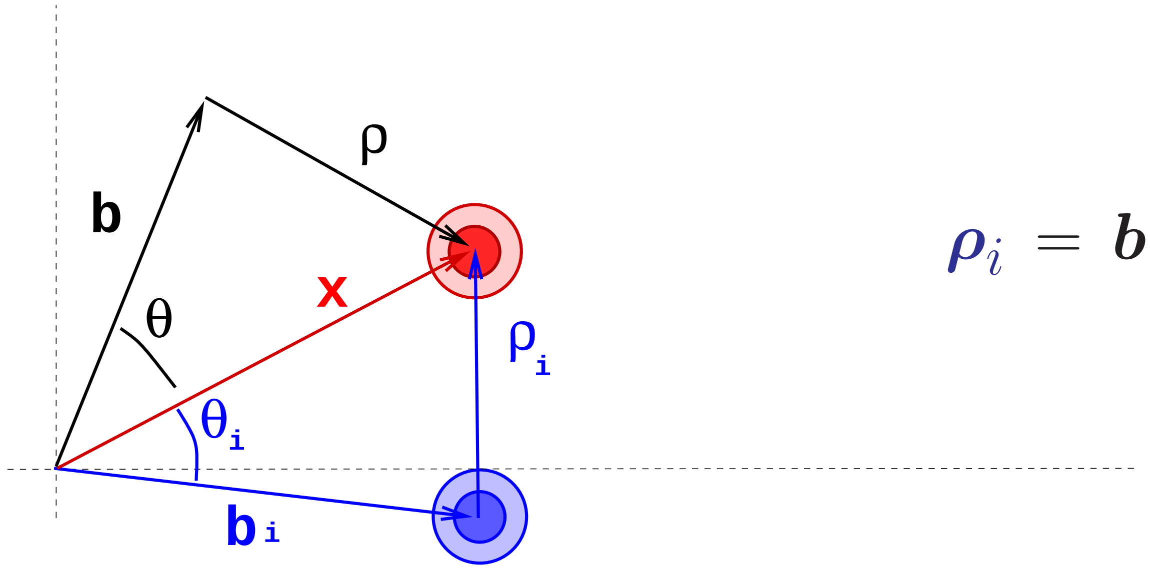


Alvioli, Cole, Frankfurt, Perepelitsa, Strikman, arXiv:1409.7381 [hep-ph]

- ATLAS and CMS found deviations from the Glauber model (N_{coll} tail)
- we derive a non-trivial relation between bins in ΔE_T and N_{coll} and thus determine $P(N_{coll})$ dependence on centrality ($\nu = N_{coll}$)

2.b - Geometry & hard trigger in pA processes (*Mark's talk*)

- We have developed a model to characterize events with one hard scattering and the remaining soft scatterings, as a function of $\nu = N_{coll}$
- The hard event (HT) is triggered in a probabilistic way, using the gluon distributions in the transverse plane $F_g(\rho) = exp(-\rho^2/B^2)/\pi B^2$
- We have coupled the MCG average (< ... >) for the N-1 soft interactions with 2-d integral over the position of the hard scattering



$$\boldsymbol{\rho}_i = \boldsymbol{b} + \boldsymbol{\rho} - \boldsymbol{b}_i$$

M. Alvioli, L. Frankfurt, V. Guzey, M. Strikman, Phys. Rev. ***C90*** *(2014)*

2.b - Geometry & hard trigger in pA processes (*Mark's talk*)

- The particular target nucleon j that undergoes hard scattering is selected in each event according to the probability

$$p_j = \frac{F_g(\boldsymbol{b} + \boldsymbol{\rho} - \boldsymbol{b}_j)}{\sum_{k=1}^{A} F_g(\boldsymbol{b} + \boldsymbol{\rho} - \boldsymbol{b}_k)}, \qquad \boldsymbol{\rho}_j = \boldsymbol{b} + \boldsymbol{\rho} - \boldsymbol{b}_j$$

$$Rate(N_{coll}) = < \sigma_{HT} \int d\boldsymbol{b} d\boldsymbol{\rho} \prod_{i=1}^{A} d\boldsymbol{\rho}_i F_g(\rho) \sum_{i=1}^{A} F_g(\rho_i)\, p_{hard}(N_{coll}) >$$

- where p_{hard} is the (MC-calculated) probability that the event contains

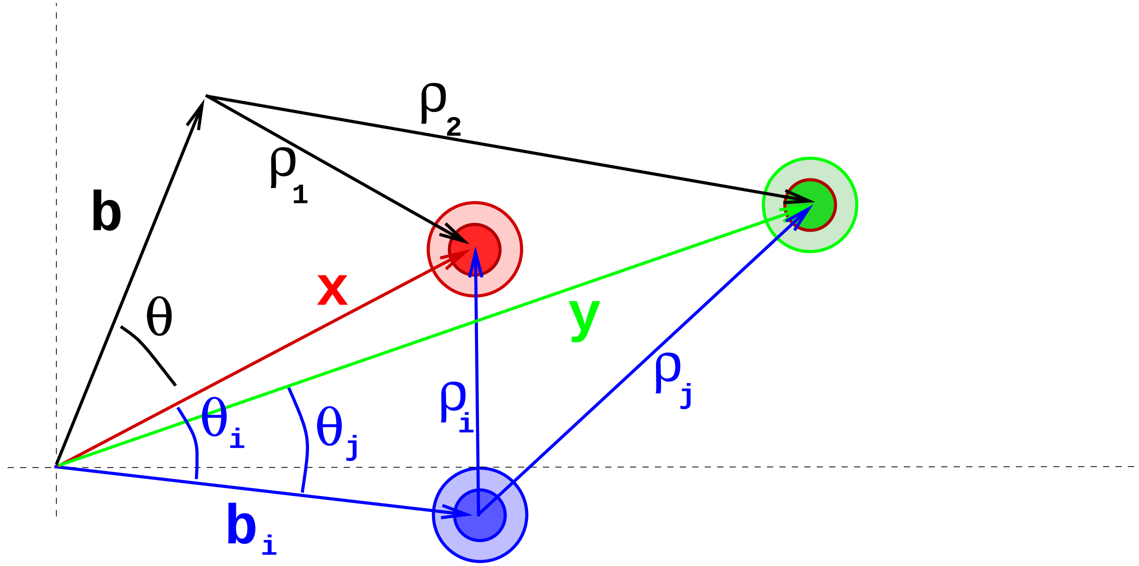
$$N_{coll} = N_{coll}(other) + 1\,,$$

with $N_{coll}(other)$ denoting all the inelastic interaction in the event, but the one with target nucleon j, which we selected as a hard trigger

M. Alvioli, L. Frankfurt, V. Guzey, M. Strikman, Phys. Rev. ***C90*** *(2014)*

2.c - Perspectives: modeling Double Partonic Interactions

- we can extend the formalism developed for one hard +(A-1) soft interactions to additional hard interactions



- we can easily describe events where two hard interactions are from one target nucleon or two different nucleons, useful to study MPI and partonic correlations, *i.e.* as in

M. Strikman, D. Treleani, Phys. Rev. Lett. ***88*** *(2002)*

2.c - Perspectives: calculation of AA processes

- the extension of the pA calculations to investigate color fluctuations effects is straightforward and the expression of the dispersion of $P(\sigma)$ in pA

$$\omega = \omega_0 + \omega_{def} + 1 - \alpha + \Big(N_{pA} - \alpha\Big)\,\omega_\sigma$$

becomes for AB collisions:

$$\omega = \omega_0 + \omega_{def} + 2 - \alpha - \beta + \Big(N_{pA} + N_{pB} - \alpha - \beta\Big)\,\omega_\sigma$$

- $\omega_0 \simeq 0.5$ depends from the individual pp process, ω_{def} is due to target deformations, α, β are due to NN correlations, and

$$N_{pA} = <\sigma> T(b) \qquad\qquad N_{pB} = <\sigma> \int d\boldsymbol{s}\, T_A(\boldsymbol{s})\, T(\boldsymbol{b}-\boldsymbol{s})$$

H. Heiselberg, G. Baym, B. Blattel, L.L. Frankfurt, M. Strikman
Phys. Rev. Lett. **67** (1991)

my final message:

use our MC-generated configurations available at:
`http://www.phys.psu.edu/~malvioli/eventgenerator`

described in:
M. Alvioli, H.-J. Drescher, M. Strikman, Phys. Lett. ***B 680*** *(2009)*