Manifestation of proton structure in ridge-like correlations in high-energy proton-proton collisions

Patryk Kubiczek[1], Stanisław D. Głazek[2]
patryk.kubiczek@student.uj.edu.pl
[1]*Faculty of Physics, Astronomy and Applied Computer Science, Jagiellonian University in Kraków, Poland*
[2]*Institute of Theoretical Physics, Faculty of Physics, University of Warsaw, Poland*

Ridge effect

Analysis of multi-particle angular correlations in p-p collisions provides detailed information on the properties of particle production and allows one to reconstruct events structure in phase space. Unpredicted by theoretical models long-range two-particle correlation in pseudorapidity in high-energy p-p collisions called "ridge effect" is still not fully understood (Fig. 1).

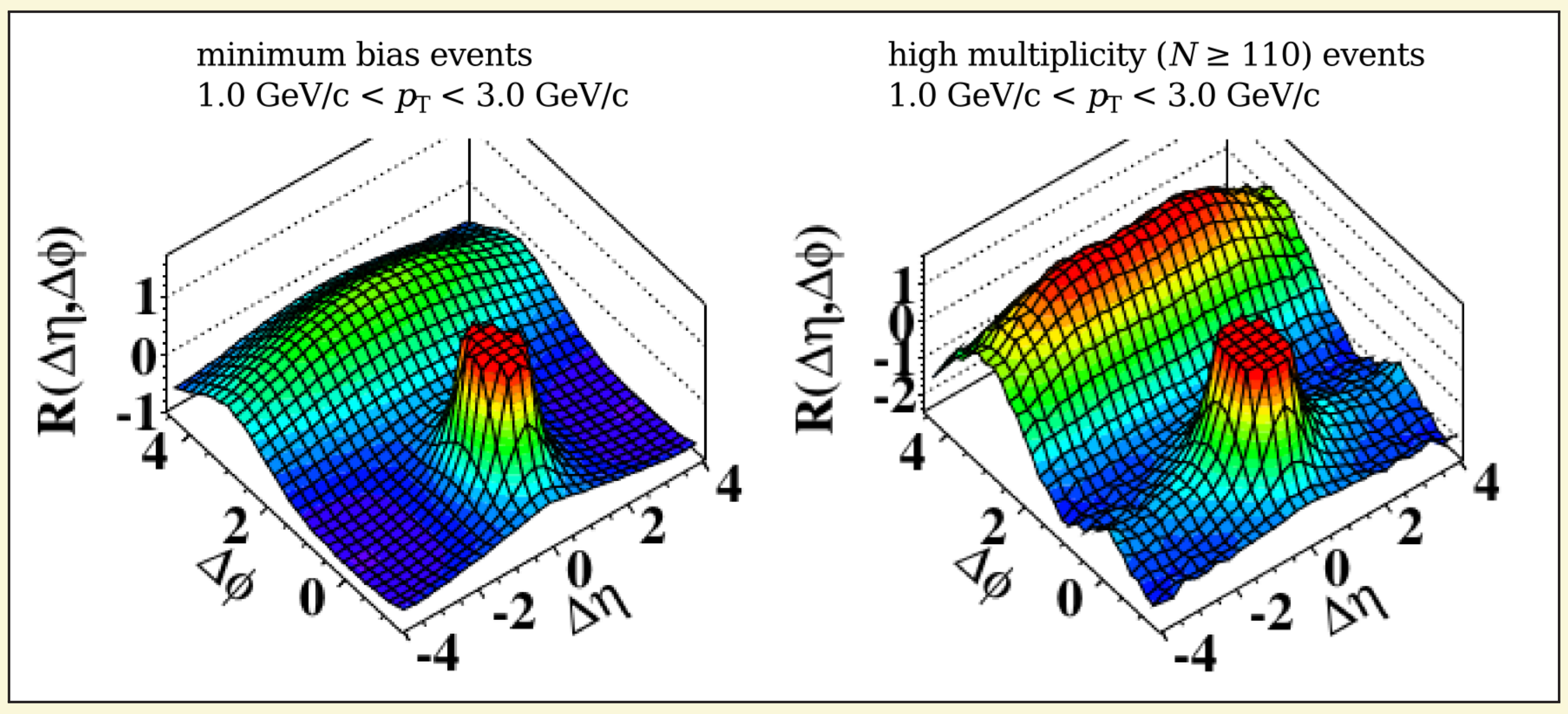

Figure 1: Two-particle charged hadron correlations measured by the CMS experiment for $\sqrt{s} = 7\,\mathrm{TeV}$ p-p collisions [1]. $\Delta\phi$ and $\Delta\eta$ are respectively azimuthal angle and pseudorapidity ($\eta = -\ln[\tan(\theta/2)]$) differences of produced hadrons.

Assumption of the hydrodynamic origin

Ridge effect has been previously observed in relativistic heavy-ion collision and was explained by a collective anisotropic flow of quark-gluon plasma created in collisions. It is possible that the ridge-like correlation in high-multiplicity p-p collisions has a similar hydrodynamic origin [2]. We assume that Fourier coefficients v_n of the anisotropic particle flow are proportional to the initial spatial anisotropies ϵ_n (Fig. 2) defined as [3]:

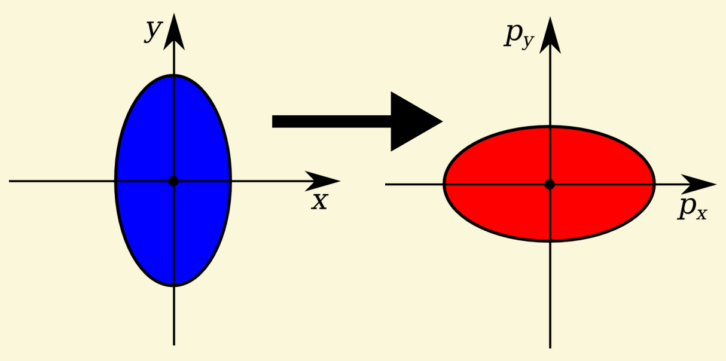

Figure 2: Spatial anisotropy ϵ_n leads to a collective anisotropic flow v_n

$$\epsilon_n = \frac{\sqrt{\langle r^n \cos(n\phi)\rangle^2 + \langle r^n \sin(n\phi)\rangle^2}}{\langle r^n \rangle}$$

The average $\langle \ldots \rangle$ is taken with respect to the impact plane (xy) collision density $n_{coll}(x, y)$ calculated within Glauber model formalism [4]:

$$n_{coll}(x, y; b) = \sigma_{gg} \int_{-\infty}^{\infty} dz\, \rho\left(x - \frac{b}{2}, y, z\right) \rho\left(x + \frac{b}{2}, y, z\right),$$

where $\rho(x, y, z)$ is a proton density, b is an impact parameter and σ_{gg} is an effective partonic cross-section.

Fixed proton structure models

According to [5] the ridge effect shall be the consequence of large eccentricities ϵ_2 in high-multiplicity collisions between aligned quark-diquark states (I) of protons. The probability of such a configuration is assumed to be 20%. We assume that the remaining 80% of proton states are fixed triangular configurations (Y). We modelled proton densities corresponding to these configurations by superpositions of isotropic and anisotropic gaussians (Fig. 3).

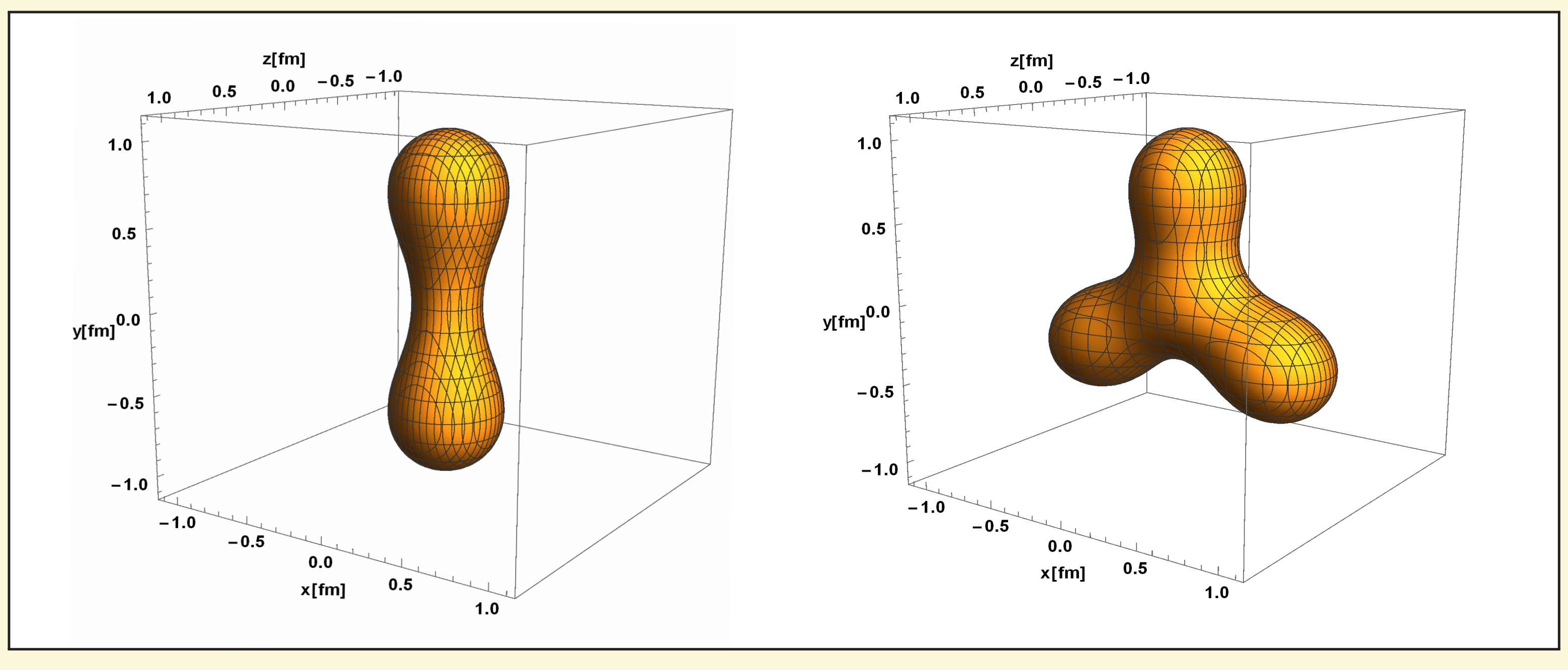

Figure 3: Constant proton density surfaces for I (left) and Y (right) configurations

Model of a Gaussian-fluctuating proton structure

We also consider fluctuating proton configuration. Renormalization group procedure for effective particles (RGPEP) suggests a description in terms of three effective quarks in a harmonic potential and a gluon body [6]. Again we model proton with use of Gaussians, though now positions of quarks in a particular collision are randomly selected from a Gaussian distribution.

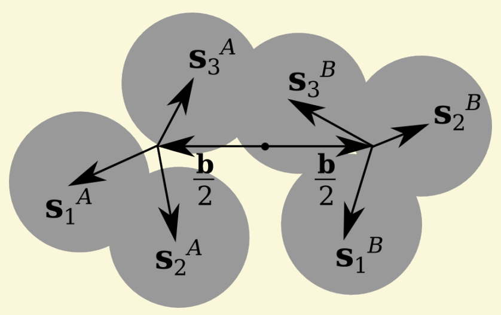

Figure 4: An event with impact parameter b and quarks positions $\mathbf{s}_i^{A,B}$

Results

Following the Glauber Monte Carlo method [4] we calculated the mean ϵ_2, ϵ_3 as a function of expected collision multiplicity N as well as the distributions of ϵ_2, ϵ_3 for 5 classes of collisions: II, YY, IY, mixed II/IY/YY and collisions of Gaussian-fluctuating protons (Fig. 5).

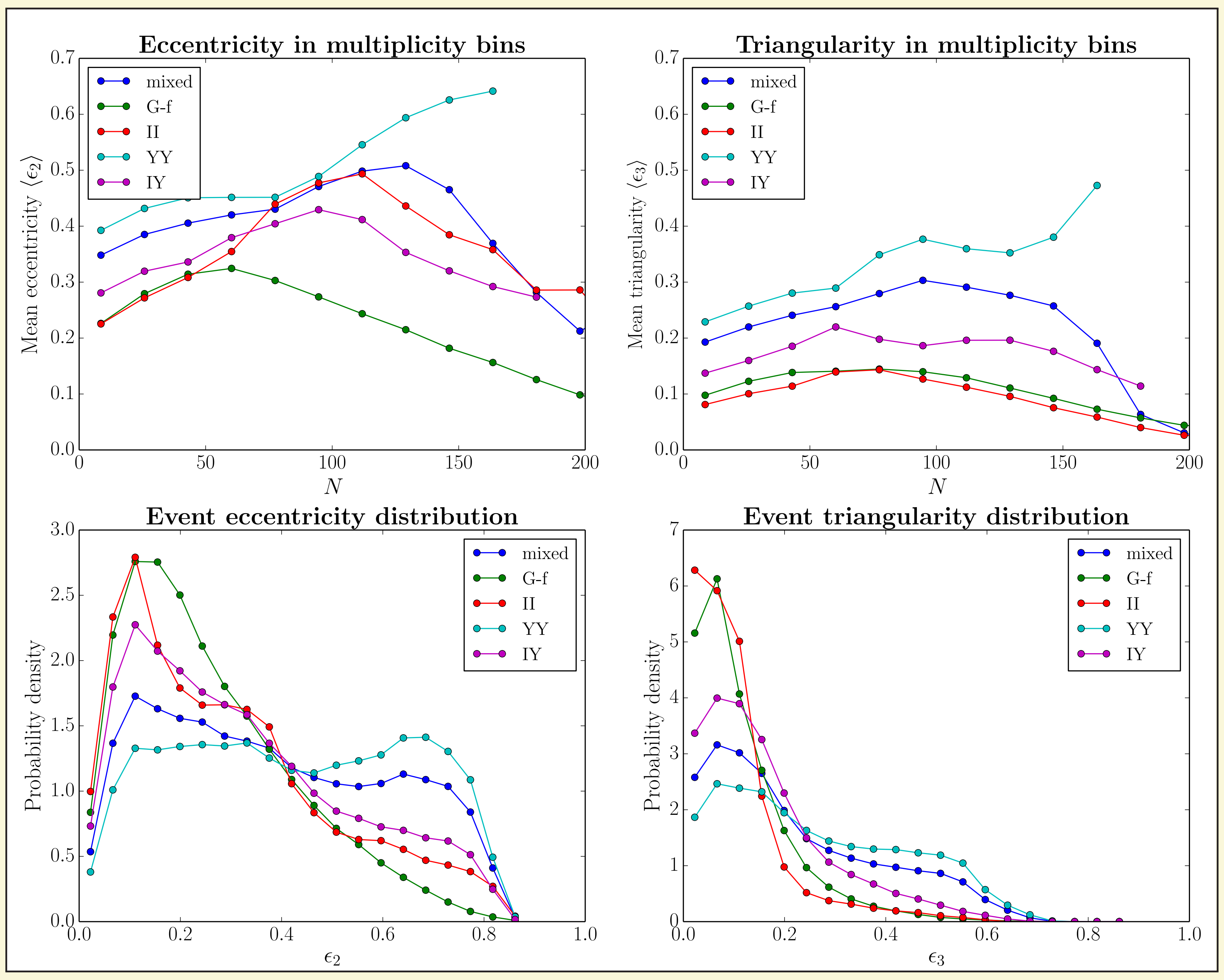

Figure 5: Results of the calculations of spatial anisotropies

Moreover, Glauber model constrained with the demand of reproducing the experimental mean multiplicity allows one to calculate the collision multiplicity distribution. We compared the results for a mixed (80%/20%) beam of Y and I protons and for Gaussian-fluctuating protons to the CMS data [7] (Fig. 6).

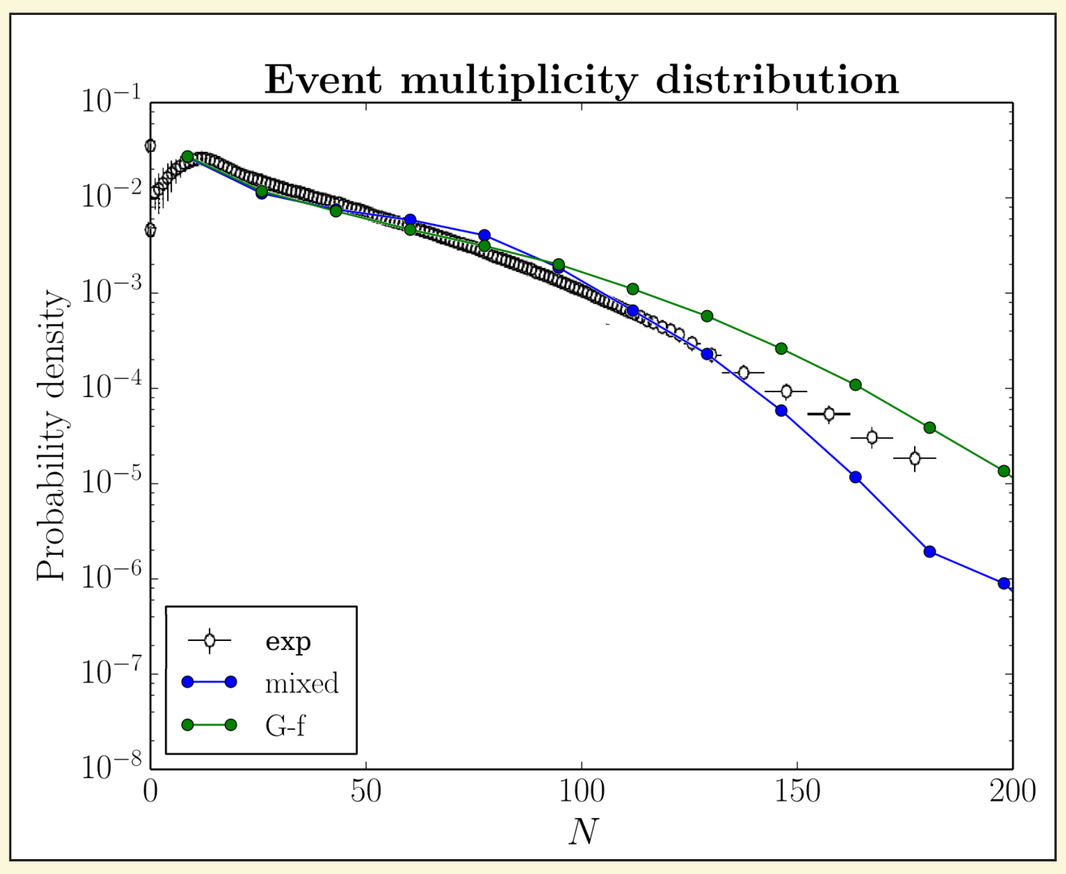

Figure 6: Results of the calculations of event multiplicity distribution and the experimental data

Conclusions

We point out that even simple model ideas concerning distribution of quarks and gluons in proton lead to potentially observable effects in the multi-particle correlations in high-energy proton-proton collisions.

We find that collisions of triangular protons, not quark-diquark ones, will exhibit strongly enhanced anisotropies for high N, while the anisotropies in collisions of Gaussian-fluctuating protons shall be relatively smaller. Thus we predict that one in principle would be able to distinguish quark-diquark, triangular and Gaussian-fluctuating proton configurations by extracting the collective flow coefficients v_2 and v_3 from ridge-like correlations.

It is remarkable that the multiplicity distributions resulting from our simple models agrees quite satisfactorily with the experiment. We also observe that fluctuations in proton configuration induce larger fraction of high-multiplicity events than we would expect to obtain in a fixed configuration model.

References

[1] V. Khachatryan *et al.* [CMS Collaboration]: Observation of Long-Range, Near-Side Angular Correlations in Proton-Proton Collisions at the LHC *J. High Energy Phys.* **1009**, 091 (2010)

[2] P. Bożek: Elliptic flow in proton-proton collisions at $\sqrt{s}$ = 7 TeV *Eur. Phys. J. C* **71**, 1530 (2011)

[3] J.-P. Blaizot, W. Broniowski, J.-Y. Ollitrault: Correlations in the Monte Carlo Glauber model *Phys. Rev.* **C 90**, 034906 (2014)

[4] M. L. Miller, K. Reygers, S. J. Sanders, P. Steinberg: Glauber Modeling in High Energy Nuclear Collisions *Ann. Rev. Nucl. Part. Sci.* **57**, 205 (2007)

[5] J. D. Bjorken, S. J. Brodsky, A. S. Goldhaber: Possible multiparticle ridge-like correlations in very high multiplicity proton-proton collisions *Phys. Lett.* **B 726**, 334

[6] S. D. Głazek: Hypothesis of Quark Binding by Condensation of Gluons in Hadrons *Few-Body Syst.* **52**, 367 (2012)

[7] V. Khachatryan *et al.* [CMS Collaboration]: Charged particle multiplicities in *pp* interactions at $\sqrt{s}$ = 0.9, 2.36 and 7 TeV *J. High Energy Phys.* **1101**, 079 (2011)