Talk at LC2015, Frascati, 21 Sept 2015

Proton structure in high-energy high-multiplicity p-p collisions

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Ridge-like correlations in high-energy high-multiplicity proton-proton collisions reported by the CMS and ATLAS collaborations suggest a collective flow that resembles the one considered in heavy-ion collisions. The observed effect may thus result from the initial anisotropy of the colliding matter, which depends on the distribution of matter in protons. We estimate the initial anisotropy using several models of protons and find the models potentially discernible using high-energy high-multiplicity proton-proton collision data.

P. Kubiczek, S. D. Głazek, *Manifestation of proton structure in ridge-like correlations in high-energy proton-proton collisions*, arXiv:1505.04155 [hep-ph].

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Outline:

Structure of protons may become discernible in

high-energy high-multiplicity proton-proton collisions

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Miguel Arratia for the ATLAS collaboration Ridge effect

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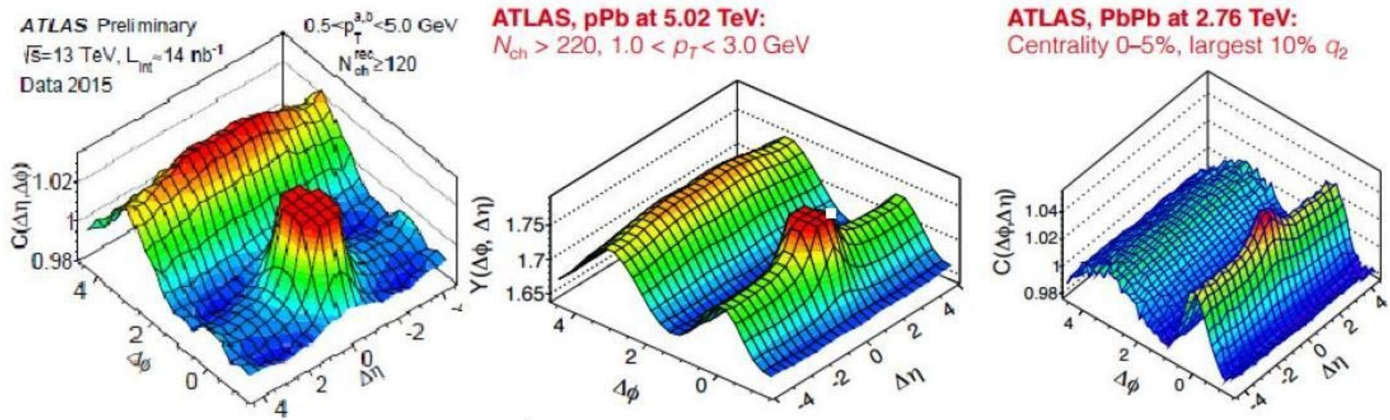
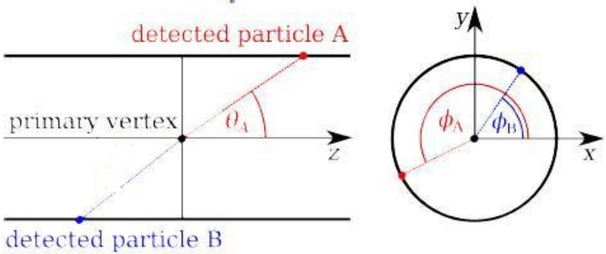
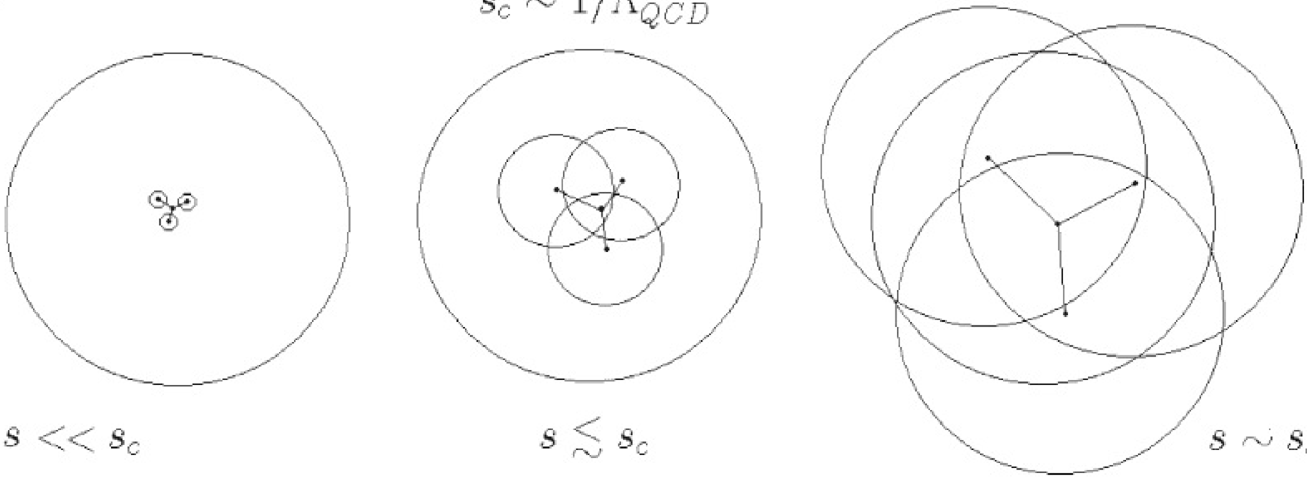




CMS: JHEP 1009 (2010), PLB 718 (2013), PLB 724 (2013)
ALICE: PLB 719 (2013)
ATLAS: PRL 110 (2013), PRC 90 (2014)

Pseudorapidity $\eta = -\ln\left[\tan\left(\theta/2\right)\right]$

proton in the RGPEP



SDG, Few-Body Systems 52, 367 (2012).

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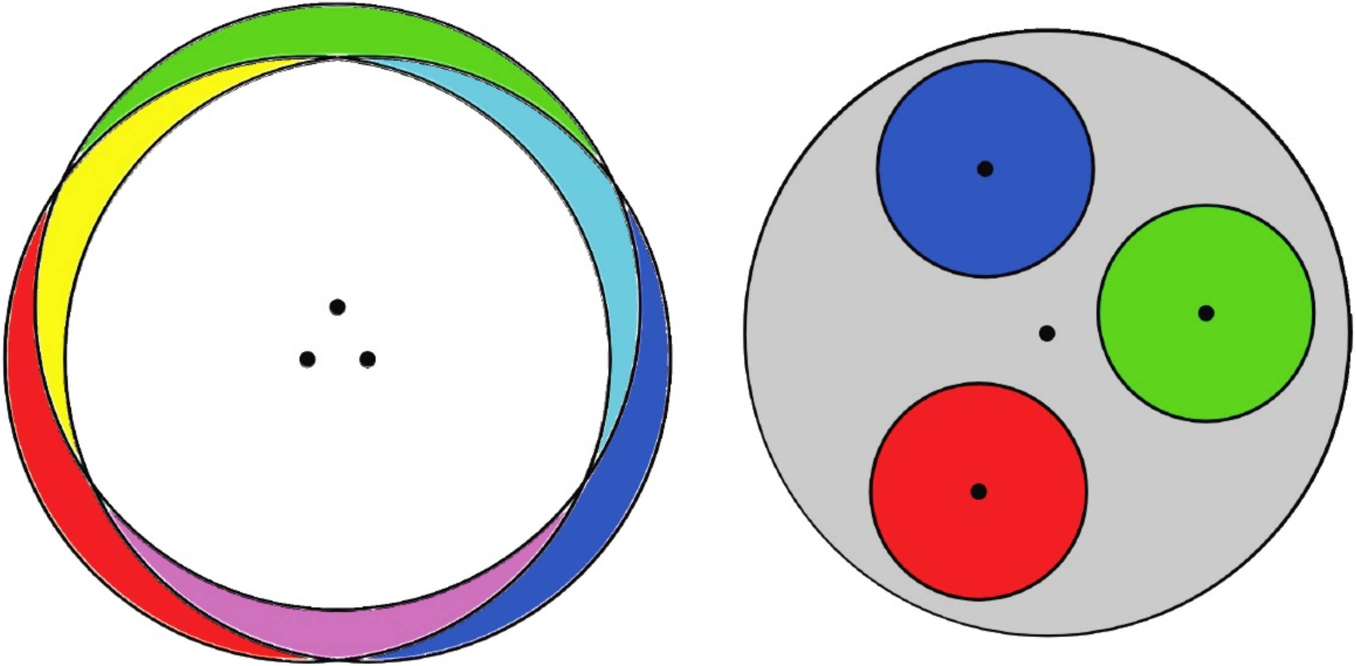
Color structure for two values of the RGPEP scale parameter



From: P. Kubiczek, *Geometrical model of azimuthal correlations in high-multiplicity proton-proton collisions*, Bachelor Thesis, University of Warsaw, September 2014; Fig. 5.1.

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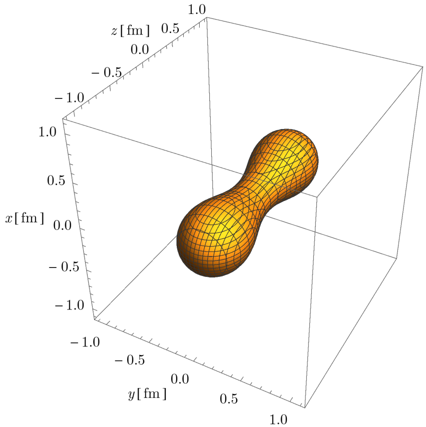
Proton quark-diquark configuration denoted by **I**

a few Gaussians for quark, diquark and gluons



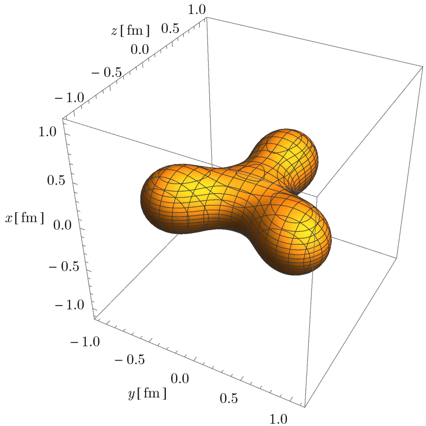
Analogous to:

J. Bjorken, S. Brodsky and A. Goldhaber, *Possible multiparticle ridge-like correlations in very high multiplicity proton-proton collisions*, Phys. Lett. B **726**, 344 (2013).

J. Bjorken, *Double diffraction at zero impact parameter*, Int. J. Mod. Phys. A **29**, 1446006 (2014).

Proton three-quark configuration denoted by **Y**

Gaussians for three quarks and gluons



rotations of **Y** with fixed shape parameters

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Gaussian fluctuating three-quark configuration

denoted by **G-f**

rotations of **Y** with shape parameters

generated with Gaussian probability distributions

(analogue of harmonic oscillator wave functions)

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Proton-proton scattering Glauber model

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

Collision state expectation values:

$$\{f(x,y)\} = \frac{\int dx\,dy\;f(x,y)\;n_{\rm coll}(x,y;b,\mathbf{\Sigma}_A,\mathbf{\Sigma}_B)}{\int dx\,dy\,n_{\rm coll}(x,y;b,\mathbf{\Sigma}_A,\mathbf{\Sigma}_B)}$$

Eccentricity ϵ_2 and triangularity ϵ_3

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

$x = s\cos\phi$ $\quad$ $y = s\sin\phi$ $\quad$ $s=\sqrt{x^2+y^2}$

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$$N_{\rm coll}(b, \mathbf{\Sigma}_A, \mathbf{\Sigma}_B) = \int dx\, dy\, n_{\rm coll}(x, y; b, \mathbf{\Sigma}_A, \mathbf{\Sigma}_B)$$

$$\sigma(b, \mathbf{\Sigma}_A, \mathbf{\Sigma}_B) = 1 - \left[1 - \frac{N_{\rm coll}(b, \mathbf{\Sigma}_A, \mathbf{\Sigma}_B)}{N_g^2}\right]^{N_g^2} \qquad 2\pi b\, db$$

$$\sigma_{pp} = \int_0^\infty 2\pi b\, db \int P(\mathbf{\Sigma}_A)\, d\mathbf{\Sigma}_A \int P(\mathbf{\Sigma}_B)\, d\mathbf{\Sigma}_B\ \sigma(b, \mathbf{\Sigma}_A, \mathbf{\Sigma}_B)$$

$P(\mathbf{\Sigma})$ = the probability density of proton configuration $\mathbf{\Sigma}$

$\sigma_{gg} \sim 4.3$ mb and $\sigma_{pp} \sim 60$ mb require $N_g \sim 10 \pm 2$.

$$\langle Q \rangle = \frac{1}{\sigma_{pp}} \int_0^\infty 2\pi b\, db \int P(\mathbf{\Sigma}_A)\, d\mathbf{\Sigma}_A \int P(\mathbf{\Sigma}_B)\, d\mathbf{\Sigma}_B \times \sigma(b, \mathbf{\Sigma}_A, \mathbf{\Sigma}_B)\, Q(b, \mathbf{\Sigma}_A, \mathbf{\Sigma}_B)$$

Multiplicity $\quad N = \alpha N_{\rm coll} \qquad \langle N \rangle = 30 \quad \to \alpha \sim 5 \pm 1$

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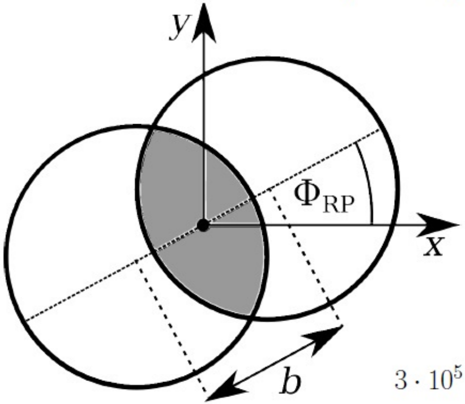
$$\frac{d^3N}{d^2p_T d\eta} = \frac{d^2N}{2\pi p_T dp_T d\eta}\left(1 + 2\sum_{n=1}^{\infty} v_n(p_T,\eta)\cos\left[n(\phi - \Phi_{RP})\right]\right)$$



$v_2 \sim 0.3\ \epsilon_2$

$v_2 \sim 0.11$ quark-diquark

$v_2 \sim 0.14$ triangular

$v_2 \sim 0.09$ Gaussian-fluctuating

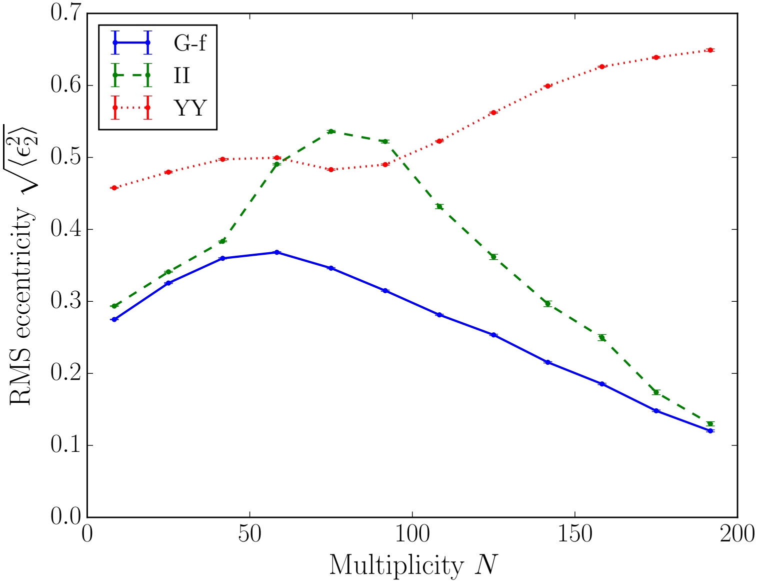
$3 \cdot 10^5$ Monte Carlo generated events for each proton model

H. J. Drescher, A. Dumitru, C. Gombeaud, J. Y. Ollitrault, The centrality dependence of elliptic flow, the hydrodynamic limit, and the viscosity of hot QCD, Phys. Rev. C **76**, 024905 (2007).

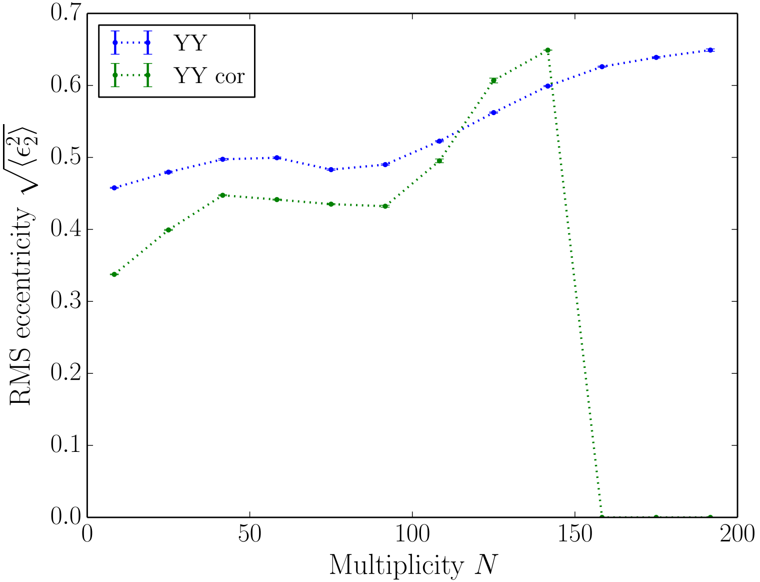
B. Alver, G. Roland, Collision geometry fluctuations and triangular flow in heavy-ion collisions, Phys. Rev. C **81**, 054905 (2010).

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

Eccentricity two Euler angles



Eccentricity two and three Euler angles



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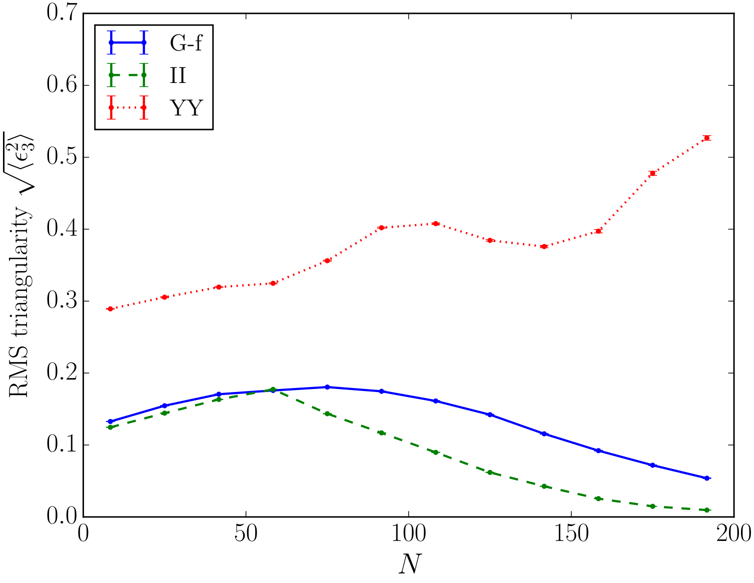
Triangularity



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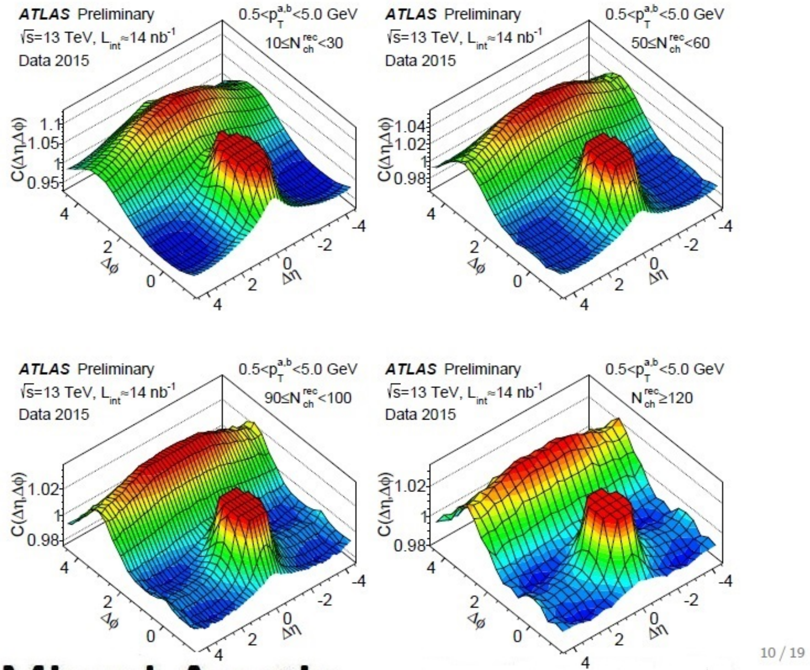
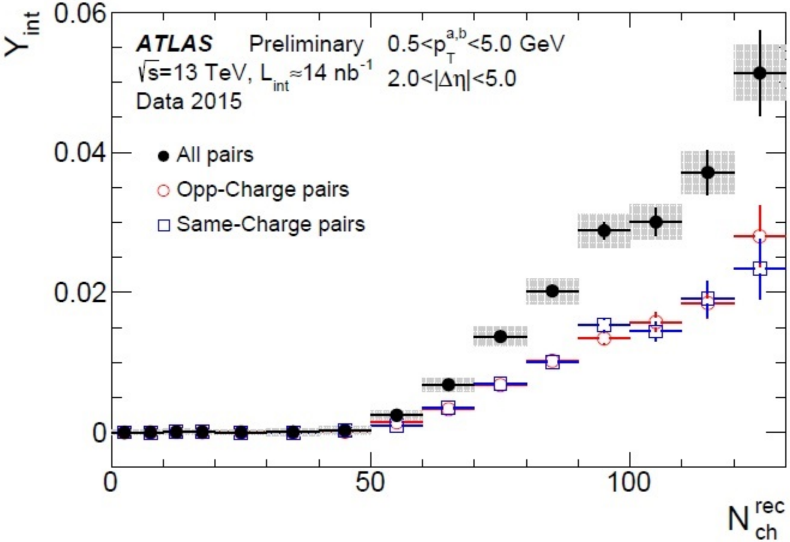


Miguel Arratia EPS HEP2015 talk in Vienna, 23 July 2015



Miguel Arratia for the ATLAS

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Parameters Examples

Input					
Quark radius r_q [fm]	0.25	0.30	0.35	0.40	0.45
Gluon body content κ	0.5	0.4	0.3	0.2	0.1
Effective partonic cross section σ_{gg} [mb]	4.3	4.3	4.3	4.3	4.3
Output					
Effective number of partons N_g	6.4	6.5	6.5	6.1	5.7
Mean number of parton collisions $\langle N_{\rm coll} \rangle$	2.5	2.7	2.7	2.3	1.9
Produced particles parton collision α	11.8	11.1	11.3	13.2	16.1
dN/dy per parton collision γ	2.3	2.1	2.2	2.6	3.1
Mean eccentricity $\langle \epsilon \rangle$	0.18	0.18	0.17	0.13	0.09
RMS eccentricity $\sqrt{\langle \epsilon^2 \rangle}$	0.22	0.21	0.20	0.16	0.10
Mean eccentricity in HM events $\langle \epsilon \rangle_{\rm HM}$	0.18	0.15	0.13	0.09	0.05
RMS eccentricity in HM events $\sqrt{\langle \epsilon^2 \rangle_{\rm HM}}$	0.20	0.17	0.14	0.10	0.05
Expected elliptic flow $\sqrt{\langle v_2^2 \rangle}$	0.04	0.04	0.03	0.03	0.02
Expected elliptic flow in HM events $\sqrt{\langle v_2^2 \rangle_{\rm HM}}$	0.05	0.04	0.03	0.02	0.01
Fraction of HM events	0.03	0.03	0.03	0.03	0.01

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Conclusion

Simple model estimates suggest that the correlations among final-state hadrons in high-energy high-multiplicity proton-proton collisions depend on the proton structure.

It is not excluded that sophisticated calculations will identify spatial features of protons through precise interpretation of experimental data on these correlations.

Is proton a tripod?

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