FEMTOSCOPY OF STOPPED PROTONS*

Andrzej Bialas

M. Smoluchowski Institute of Physics, Jagiellonian University
S. Łojasiewicza 11, 30-059 Kraków, Poland

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Short account of the results obtained in the paper by A. Bialas, A. Bzdak and V. Koch [*Phys. Rev. C* **99**, 034906 (2019), is presented.

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With the start of the BES program at RHIC, the studies of the phase structure of QCD at non-vanishing baryon density became of major interest. It is clear that any meaningful interpretation of data requires good knowledge of the net baryon density and thus both the net baryon number and the volume these baryons occupy in the configuration space. While the net baryon number in the central rapidity region, $y_{\mathrm{cm}} \approx 0$, is directly accessible in experiment, this is of course not the case for the volume. Moreover, as we have argued in our recent paper [1], the theoretical evaluation of this volume is by no means straightforward, as it depends on the adopted picture of the nucleus–nucleus and nucleon–nucleon collisions. Although for the central collisions the transverse dimension of the interaction volume is relatively well-determined, the longitudinal dimension is strongly model-dependent. Two limiting pictures may be considered:

(i) The colliding nucleons transfer most of their energy into produced particles very soon after collision and thus stop at a very short distance from the collision point. In this case, the resulting longitudinal (z) distance between them is of the order of nuclear radius reduced by Lorentz contraction, *i.e.* very small.

(ii) The colliding nucleons continue their motion for some time after collision, loosing gradually their energy at some (approximately constant) rate, σ, often called string tension. The best-known example of realization of the picture is the Lund model [2]. In this case, the right-moving

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and the left-moving nucleons are separated in the configuration space and thus the corresponding volume is larger. What is even more important, the baryon density at $z \approx 0$, where the plasma is expected to occur, may be much less than naively expected.

Even a very crude estimate shows that in the second scenario, the separation between left- and righ-movers may be rather significant. Taking the standard value $\sigma \approx 1$ GeV/fm, one sees that the nucleon of c.m. energy 10 GeV shall stop (*i.e.* loose all its energy) at the distance of about 10 fm from the collision point! In the case of central nucleus–nucleus collision, where one expects many nucleon–nucleon collisions and thus three wounded quarks in every nucleon, one may estimate the effective string tension growing to $\sigma \approx 3$ GeV/fm. However, even in this case, the distance between the two groups is expected to be still more than 6 fm.

The Lund picture, valid at high energies, may be substantially modified when extrapolated directly to energies relevant for the BES program. We thus feel that most likely the actual picture interpolates between these two limiting scenarios. Since, however, as already argued, the effected shift is indeed very large, one may hope that even serious corrections are not going to wash it out entirely.

To obtain a better insight, we evaluated in [1] the space-time distribution of the nucleons at $y_{\rm cm} \approx 0$ in a very simplified version of the second scenario, using the wounded quark model as the guiding principle. The result of our calculations for Pb–Pb collisions at $\sqrt{s} = 14$ GeV is shown in Fig. 1 where the distribution integrated over time is plotted *versus* the longitudinal distance. The calculation takes into account the spread of the collision points which induces spread in the distribution of the positions of the final nucleons. Also the consequences of Fermi motion, inducing spread in the initial energy (and thus also additional spreads in the position of the final nucleons), are included. One sees that these effects do not change the original expectation: One observes a clear separation between the left- and right-movers.

As already mentioned, this simplified model calculation represents only one of the two the extreme possibilities and thus one may expect that in reality the results are less dramatic. As there is no better theoretical argument, to obtain more reliable information of what really happens, one has to turn to experiment. It is well-known that the space-time distribution of particles can be tackled by studying the HBT correlations. We have thus evaluated the proton–proton correlation function following from the space-time distribution resulting from our model [3]. The results are shown in Fig. 2 where the p–p correlation function is plotted *versus* the difference of the *longitudinal* momenta of the two protons. One sees characteristic oscillations generated by the two-peak structure seen in Fig. 1.

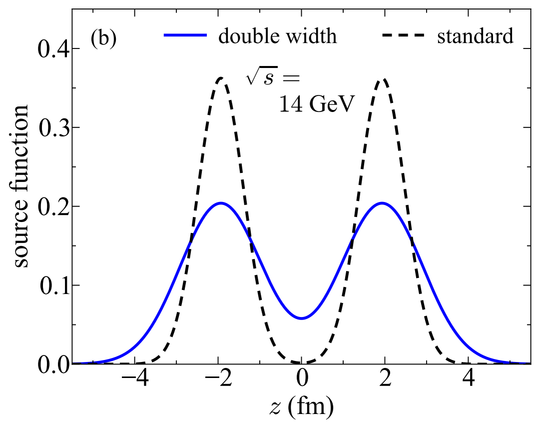

Fig. 1. Distribution along the beam direction of the protons stopped at $y_{\rm cm} \approx 0$ in Pb–Pb collisions at $\sqrt{s} = 14$ GeV. Dashed curve: the width of the peaks evaluated taking into account size of the nucleus (reduced by the Lorentz factor) and the Fermi motion. Full curve: the same for doubled width.

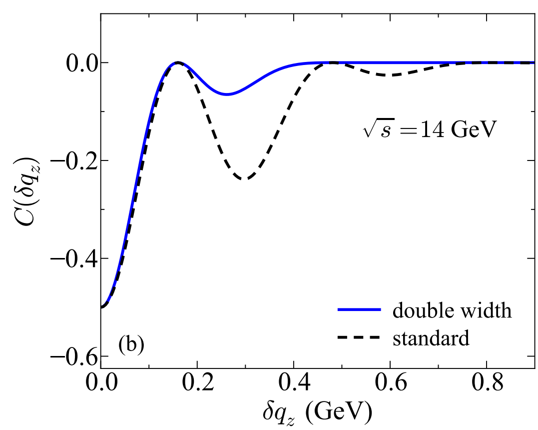

Fig. 2. The p–p HBT correlation function following from the z-distribution shown in Fig. 1, plotted *versus* the difference of the longitudinal momenta of protons. One sees the characteristic oscillations. The position of the first maximum is determined by the distance between the two peaks seen in Fig. 1. The depths of the minima depend on the width of these peaks.

A closer examination of the formulae leading to the results in Fig. 2 shows that the position of the first maximum is primarily determined by the magnitude of the distance between the two peaks shown in Fig. 1, whereas the depth of the first minimum is controlled by their width.

Observation of such oscillations would be a spectacular confirmation of the idea that the picture well-established in hadronic collisions at high energies can be successfully extrapolated to much lower energies, as those relevant for the BES project. Even if they are not seen, however, measurements of HBT correlations between protons stopped in the c.m. frame should give information on the size of the proton system in the longitudinal direction, information which is very important for the quantitative analysis of the QCD phase diagram at non-vanishing net baryon density.

One should add an important warning: the results presented in Fig. 2 do not include effects of the strong interaction between the two protons which may modify significantly the expected outcome of the experiment. They also do not include effects of fluctuations in the number of left- and right-movers which are expected to reduce the oscillations somewhat [4]. Both problems are now under study [5].

Note added in proof: The effects of strong interactions were estimated and are already included in Ref. [3]. It turns out that they do not change significantly the results presented in this paper.

REFERENCES

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[4] I owe this remark to P. Danielewicz.

[5] A. Bzdak, V. Koch, private communication.