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PREDICTIONS FOR TWO-PION CORRELATIONS FOR $\sqrt{s} = 14$ TeV PROTON–PROTON COLLISIONS[*] [**]

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A simple model based on relativistic geometry and final-state hadronic rescattering is used to predict pion source parameters extracted in two-pion correlation studies of proton–proton collisions at $\sqrt{s} = 14$ TeV. By comparing the results of these model studies with data, it might be possible to obtain information on the hadronization time in these collisions. As a test of this model, comparisons between existing two-pion correlation data at $\sqrt{s} = 1.8$ TeV and results from the model are made. It is found at this lower energy that using a short hadronization time in the model best describes the trends of the data.

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With first proton–proton collisions at $\sqrt{s} = 14$ TeV from the Large Hadron Collider (LHC) being only about a year (or so) away, it is tempting to use simple models to make baseline predictions of what we might expect for "bread and butter" observables at this unexplored energy. Comparisons between data and such models could give us a first impression of the presence of new physics which might cause significant disagreements between them. If significant disagreements are seen, the simple models might then be used to point in a direction as to the nature of the new physics.

The "bread and butter" observable studied in the present work is two-pion correlations. From this observable, information about the space-time geometry of the pion emissions produced in the proton–proton collisions can

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be, at least in principle, extracted using the interferometric technique pioneered by Hanbury Brown and Twiss (HBT) [1]. Many such experimental studies using this technique have been carried out over the past nearly 50 years [2,3], the highest energy study being carried out at the Tevatron with p–$\bar{p}$ collisions at $\sqrt{s} = 1.8$ TeV [4]. The strategy of the present study is to use a simple model based on relativistic geometry and final-state hadronic rescattering to predict pion source parameters extracted in two-pion correlation studies of proton–proton collisions at $\sqrt{s} = 14$ TeV. As a test of this model, comparisons with existing two-pion correlation data at $\sqrt{s} = 1.8$ TeV are made.

The model calculations are carried out in four main steps: (A) generate hadrons in p–p and p–$\bar{p}$ collisions from PYTHIA [5], (B) employ a simple space-time geometry picture for hadronization of the PYTHIA-generated hadrons, (C) calculate the effects of final-state rescattering among the hadrons, and (D) impose Bose–Einstein correlations pairwise on pions, calculate correlation functions, and fit the correlation functions with Gaussian or more general functions to extract pion source parameters. These steps are discussed in detail elsewhere [6].

The simple space-time geometry picture for hadronization consists of the emission of a PYTHIA particle from a thin uniform disk of radius 1 fm in the plane transverse (x–y) to the beam direction (z) followed by its hadronization which occurs in the proper time of the particle, τ. The space-time coordinates at hadronization in the lab frame $(x_{\rm h}, y_{\rm h}, z_{\rm h}, t_{\rm h})$ for a particle with momentum coordinates (p_x, p_y, p_z), energy E, rest mass m_0, and transverse disk coordinates (x_0, y_0) can then be written as

$$x_{\rm h} = x_0 + \tau \frac{p_x}{m_0}\,, \qquad y_{\rm h} = y_0 + \tau \frac{p_y}{m_0}\,, \qquad z_{\rm h} = \tau \frac{p_z}{m_0}\,, \qquad t_{\rm h} = \tau \frac{E}{m_0}\,. \quad (1)$$

The simplicity of this geometric picture is now clear: it is just an expression of causality with the assumption that all particles hadronize with the same proper time, τ. We do not *a priori* know the value of τ but for the present study it is set to 0.1 fm/c since it is found that this gives the best agreement with the Tevatron data (see below and Ref. [6]).

The final step in the calculation is extracting fit parameters by fitting a parameterization to the Monte Carlo-produced two-pion invariant correlation function, $C(Q_{\rm inv})$, where $Q_{\rm inv}$ is the invariant momentum difference defined as the magnitude of the difference between the four-momenta of the two pions, *i.e.* $Q_{\rm inv} = \mid p_1 - p_2 \mid$. The forms of the Gaussian and general fit functions are given, respectively, by

$$C(Q_{\rm inv}) = A\left[1 + \lambda \exp\left(-R^2 Q_{\rm inv}^2\right)\right]\,, \quad (2)$$

$$C(Q_{\rm inv}) = A\left[1 + \lambda \cos\left(B Q_{\rm inv}^2\right) \exp\left(-R^\alpha Q_{\rm inv}^\alpha\right)\right]\,, \quad (3)$$

where R is a radius parameter, λ is an empirical parameter normally employed to help fit the function to the correlation function (*i.e.* $\lambda = 1$ in the ideal case of pure Bose–Einstein correlations), B describes oscillations in the correlation function, α represents the degree to which the correlation function falls off with increasing $Q_{\rm inv}$, and A is a normalization factor.

Fig. 1 shows comparisons of Gaussian fit parameters (see Eq. (2)) for pions between Tevatron data (Experiment E735 [4]) and model predictions with and without rescattering at $\tau = 0.1$ fm/c *versus* $p_{\rm T}$ and charged particle multiplicity, $N_{\rm C}$. it is found that rescattering has a significant influence on the fit parameters. This suggests that final-state hadronic rescattering is already important at $\sqrt{s} = 1.8$ TeV, and hadronization times are short.

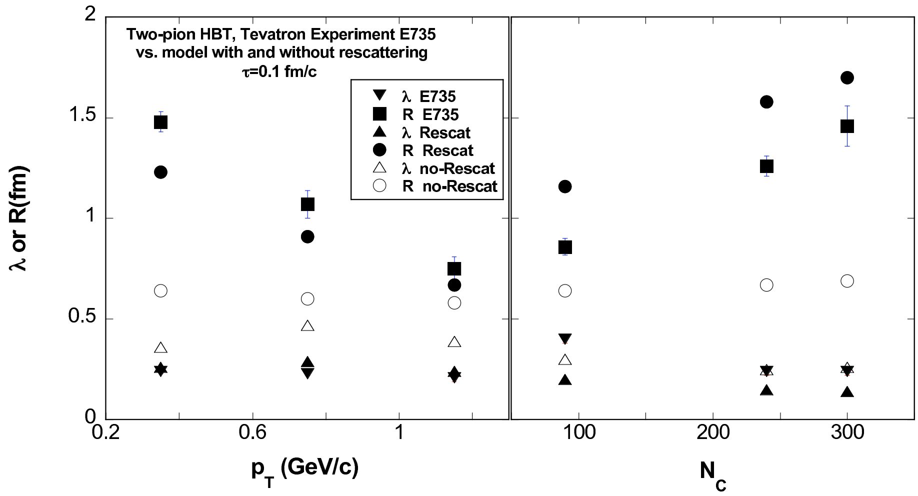

Fig. 1. Comparisons of Gaussian fit parameters for pions between Tevatron data (Experiment E735) and model predictions with and without rescattering at $\tau = 0.1$ fm/c *versus* $p_{\rm T}$ and $N_{\rm C}$.

Fig. 2 shows the predicted dependences of the general fit parameters (Eq. (3)) on $p_{\rm T}$ and total multiplicity, m, for $\tau = 0.1$ for $\sqrt{s} = 14$ TeV p–p collisions. Plots are made with low and high multiplicity cuts, *i.e.* $m < 100$ and $m > 300$, and low and high $p_{\rm T}$ cuts, *i.e.* $0.1 < p_{\rm T} < 0.3$ GeV/c and $0.9 < p_{\rm T} < 1.1$ GeVc. As is seen, there are significant differences in the magnitudes and dependences on kinematical variables for the general fit parameters predicted from the model calculations. Comparisons of these results with actual future data from the LHC will be able to establish (a) if this simple model describes the data in even a qualitative way and (b) if so, the scale of the hadronization time in these collisions since the results shown in Fig. 2 are sensitive to the value of τ [6].

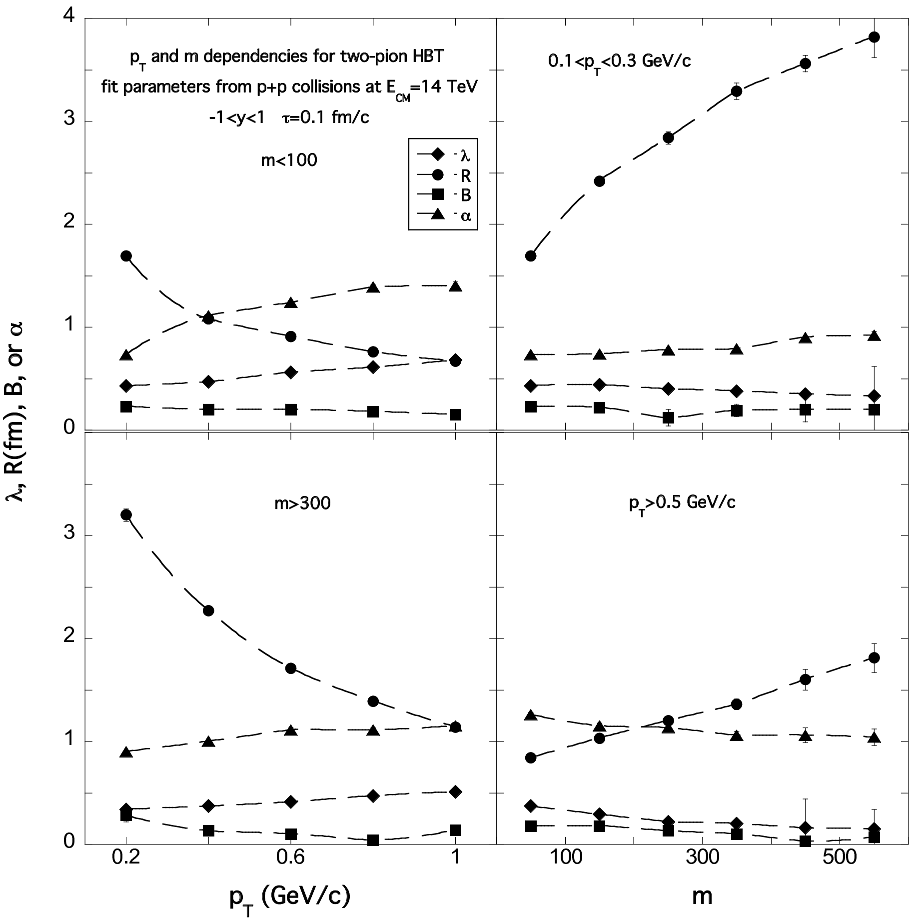

Fig. 2. General function fit parameters *versus* p_{T} and particle multiplicity from the rescattering model with $\tau = 0.1$ fm/c for several multiplicity and p_{T} cuts for p–p collisions at $\sqrt{s} = 14$ TeV. The dashed lines are drawn to guide the eye.

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