SPACE-TIME STRUCTURE AND RESCATTERING IN ULTRARELATIVISTIC NUCLEAR COLLISIONS

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We report on recent developments in the string model VENUS 3 concerning secondary interactions of primary string decay products. Participant-spectator as well as participant-participant interactions are considered. We provide a covariant method by defining the average local restframe at some space-time point to be the reference frame for interactions of two particles in the vicinity of this point. A space-time analysis reveals a longitudinal expansion like for a Bjorken-fluid with $y = \eta$ which allows a very simple and fast procedure. As an application we calculate some rapidity and m_t spectra for p -Ag, O-Au, and S-S collisions at 200 GeV.

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We report on recent developments in the string model VENUS 3 concerning secondary interactions of primary string decay products. Participant-spectator as well as participant-participant interactions are considered. We provide a covariant method by defining the average local restframe at some space-time point to be the reference frame for interactions of two particles in the vicinity of this point. A space-time analysis reveals a longitudinal expansion like for a Bjorken-fluid with $y = \eta$ which allows a very simple and fast procedure. As an application we calculate some rapidity and m_t spectra for p -Ag, O-Au, and S-S collisions at 200 GeV.

The initial stage of a heavy ion collision should be well described by “colour exchange” (or something similar) with the main effect of transforming incident nucleons into longitudinally excited objects (strings). The final stage — provided energy and mass number are large enough — is hopefully the expansion of a quark gluon plasma (QGP). So what happens in between?

Until recently string models only considered stage I, namely the formation of strings, the latter ones then decaying freely. Although many experimental data could be explained (negative particle rapidity spectra, tranverse energy distributions) there were clearly deficiencies, most strikingly in the target fragmentation region for reactions with light projectiles and heavy targets: there were considerably more protons seen than predicted. But also in the central region of symmetric collisions discrepancies were observed, for example concerning p_t (or m_t) spectra.

During the last year several attempts were made to include effects of secondary interactions of particles from string fragmentation ([1, 2, 3, 4, 5]). Whereas in refs. [1, 2] mainly the aspect of participant-spectator scattering was considered, to account for the observed baryon access at backward rapidities, in refs. [3, 4, 5] also participant-participant interactions were included.

We made in ref. [5] the very first attempt to include secondary interactions in the string model VENUS (version 3.00). Many improvements occurred since — in particular we do not consider a constant reference frame for all collisions any more.

First of all we sketch how VENUS handles string formation and fragmentation, neglecting secondary interactions for the beginning (for details see [6, 7]). Like in the Dual Parton Model [8] the mechanism to form strings is “colour exchange”. Let us consider two mesons $(\bar{q}_p - q_p)$ and $(\bar{q}_t - q_t)$ where we use the general notation of $(a-b)$ being a string with a and b at the endpoints. Colour exchange

$$(\bar{q}_p - q_p) + (\bar{q}_t - q_t) \rightarrow (\bar{q}_p - q_t) + (\bar{q}_t - q_p) \quad (1)$$

means that after the interaction the four endpoints of the strings are linked together differently: the new strings consist of (anti)quarks from different incident hadrons. Similarly colour exchange for two colliding nucleons can be written as

$$(q_p q_p - q_p) + (q_t q_t - q_t) \rightarrow (q_p q_p - q_t) + (q_t q_t - q_p) \quad (2)$$

(the dash “-” on the lhs of eq. (2) simply separates the “bare” quark to be involved in the colour exchange), providing two diquark-quark strings. We also consider multi-colour exchange which makes it then almost straightforward to generalize to collisions involving nuclei [6]. Since for nuclear collisions each nucleon-nucleon interaction provides at least one colour exchange, and each colour exchange in general two strings, we obtain already for intermediate nuclei many strings — making a treatment of secondary interactions inevitable.

We use a string fragmentation procedure [7] based on the Artru-Mennessier model [9]. The main characteristics of a string break are: the evolution in space and time for both string and string fragments occurs according to classical string theory and the breakpoint is fixed by the requirement that the break probability is proportional to an area on the string surface.

We are now going to explain how secondary interactions are included in VENUS 3. We first form and fragment strings as described above. In our string fragmentation treatment we have full information about all strings and string fragmentation products, so we may define “string tracks” which are straight line trajectories of the centres of mass of the strings (including hadrons being the final string segments). We also construct the tracks of spectator nucleons. We follow all tracks through space-time, and whenever two track $\vec{x}_A(t)$ and $\vec{x}_B(t)$ come close, i.e.

$$|\vec{x}_A(t) - \vec{x}_B(t)| < r_0, \quad (3)$$

then these two objects interact. The interaction radius r_0 is parametrized as $r_0 = r_1 + r_2$ with $r_i = r_{bar}$ for a baryon and $r_i = r_{mes}$ for a meson (we use $r_{bar} = 0.75 \text{ fm}$ and $r_{mes} = 0.35 \text{ fm}$). Interaction is always assumed to be fusion with subsequent isotropic decay (after a corresponding lifetime).

Since we are dealing with nonlocal interactions, the sequence of collisions according to eq. (3) is frame dependent, so in order to have a covariant procedure we are going to introduce a space-time dependence of the reference frame. We define the reference frame at a given space-time point to be the average local rest frame at this point (averaging over many events). Ignoring small transverse momenta we may characterize the local rest frame simply by a rapidity y_{LR} . We show in the following that y_{LR} depends (approximately) in a very simple fashion on time t and longitudinal coordinate z . In order to do so we present already some results of our model which is justified since these results are almost independent of the actual rescattering procedure. We consider a central cylinder for a central S-S collision. For a given t and z we determine the velocity $v_{LR}(t, z)$ of the cylinder piece between $z - \delta z$ and $z + \delta z$ considering a superposition of many events. The rapidity y_{LR} is then given as $0.5 \ln(1+v_{LR})/(1-v_{LR})$. In fig. 1 we show the results for $t=1 \text{ fm}/c$, $3 \text{ fm}/c$ and $5 \text{ fm}/c$ separately for “mesons” (baryon number zero) and “baryons” (baryon

number nonzero). The curves represent the space-time rapidity $\eta(t, z) = 0.5 \ln(t+z)/(t-z)$. We observe apart from the region $z > t$, to a very good approximation

$$y_{LR} = \eta \equiv \frac{1}{2} \ln \frac{t+z}{t-z} \quad (4)$$

which is the crucial assumption of Bjorken hydrodynamics. Eq. (4) is the promised simple space-time dependence of y_{LR} . Our procedure is now to simply consider interactions of particles at equal proper-time $\tau = (t^2 - z^2)^{1/2}$ and to consider an interaction earlier than some other if the corresponding proper-time is smaller.

After fixing parameters mainly in neutrino-neon scattering we are ready to apply the model to nuclear collisions. We demonstrate in fig. 2 that for both proton-nucleus and nucleus-nucleus collisions, rescattering affects baryon production substantially: there are much more slow protons produced due to activating target protons. The effect on pions is much smaller, nevertheless significant: we observe a backward shift in (pseudo)rapidity. In fig. 3 finally we demonstrate for central S-S collisions that rescattering makes transverse mass spectra flatter due to a transformation of longitudinal into transverse motion.

We conclude by remarking that although rescattering cures several deficiencies, we are still at a very preliminary stage and need in particular information from lepton-nucleus scattering which provides a reasonably simple scenario to study secondary interactions.

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Fig. 1. Longitudinal expansion of “mesons” (a,c,e) and “baryons” (b,d,f) for a central cylinder in a central S-S collision. The curves represent space-time rapidity ($\eta = 0.5 \ln(t+z)/(t-z)$) for fixed times t (1fm/c, 3fm/c, 5fm/c) versus the longitudinal coordinate z . The histograms represent VENUS results for average rapidities y_{LR} at space-time points (t,z) . Over a large range we see “Bjorken-behaviour”: $y_{LR} = \eta$.

Fig. 2. Rapidity distributions of π^- (a) and protons (b) in $p\text{-Ag}$ at 100 GeV and pseudorapidity distributions of charged particles (c) and protons (d) in O-Au collisions at 200 GeV. The dots represent data ([11, 12, 13]), the histograms are VENUS results with (solid lines) and without (dotted lines) secondary interactions. Whereas rescattering increases the proton number considerably (b,d), pions are only weakly affected: we observe a small backward shift.

Fig. 3. Transverse mass ($m_t = (m^2 + p_t^2)^{1/2}$) distributions of π^- (a), K_s (b), protons (c) and lambdas (d) in central S-S collisions at 200 GeV. The rapidity intervals cover central rapidity: $1.5 < y < 3.5$ (a), $1.4 < y < 2.7$ (b), $1.5 < y < 3.0$ (c), $0.8 < y < 2.0$ (d). The points are data ([14]), the histograms are VENU results with (solid lines) and without (dotted lines) secondary interactions. Rescattering makes the spectra flatter.