MODELS FOR THE STATISTICAL DECAY OF FIREBALLS

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Simple models for the statistical decay of fireballs are formulated in terms of integral equations for different physical quantities like single particle distributions, multiplicity distributions, etc. The integral equations are solved assuming the statistical bootstrap for fireball states and reciprocity between the fireball's composition and decay. The case of non-spherically symmetric fireballs is also considered. The resulting physical picture of the fireball is that of a strongly interacting, weakly correlated gas of hadrons.

I. Introduction and summary

The multiparticle production in high energy hadronic collisions is considered in many of the statistical models as a two-step process: the production of highly excited hadronic states (called "fireballs") and their subsequent statistical decay. The very existence of this two-step process is not yet proved experimentally hence all of the models contain a great deal of speculations. The experimental observation of the fireball structure is therefore of great theoretical interest. A direct consequence of the existence of fireballs would be the clustering of the produced particles in rapidity [1]. This effect is difficult to prove in the presently available rapidity range especially if the fireballs decay asymmetrically. There are, however, less direct evidences making the existence of fireballs experimentally plausible. For instance, there is a "locality" (with respect to velocity) in the conservation of baryon number, strangeness and charge [2, 3] or the diffraction dissociation region in phase space is characterized by the competition between final states of different multiplicities following the variation of the available phase space volumes [4].

The theoretical understanding of the two steps (fireball production and decay) is at present at different stages of perfection. We have only rough ideas concerning the number, mass and momentum of the produced fireballs (for a noncomplete list of models see [2, 5–8]) but rather detailed and elaborated (though not unique) picture of what we would consider as the statistical fireball decay. It is worth mentioning at this point that there is a process, namely $e^+e^-$ annihilation in the one-photon approximation, where the fireball production is presumably much simpler than in hadronic collisions. Considering the
timelike virtual photon "hadron like" is in this case equivalent to the assumption that only a single fireball is produced and hence the hadronic final state is entirely determined by the decay of the fireball. (For details and further references see the recent paper [9].)

The statistical decay results by definition in a phase-space distribution therefore it is unique provided the number of decay products is given (the only freedom is in that case to choose the true phase space resulting in spherically symmetric distributions in the fireball rest frame or to introduce a weight function in momentum space for each of the particles like in the uncorrelated jet model [10, 11] allowing in such a way non-spherical distributions, too). The weight of the different multiplicities, however, requires an additional physical consideration and therefore this is the point where different statistical models of the fireball decay give different answers. (That different multiplicities cannot be compared without further ado is simply shown by the different dimensions of the relativistic momentum space integrals.) Therefore, in Section II, we shall first consider the simplest case when the multiplicity of decay products is fixed, calculate the inclusive distributions and derive a new asymptotic form of the relativistic many-body phase space. The results of this Section will be used in Sections III—IV for the description of two large classes of models, namely the "independent emission" type of models and "statistical bootstrap" type of models, respectively.

The independent emission type of models will be considered here only briefly, mainly for comparison. In the statistical (or "thermodynamical") bootstrap [12, 13] the fireball decays in a cascade fashion into other fireballs or stable hadrons until the final hadron distribution is reached. For the description of this cascading process a very convenient mathematical tool is the set of integral equations for different kinds of hadron distributions like single particle distribution, multiplicity distribution etc. [14]. These equations are equivalent to the Chapman—Kolmogorov equations (see e.g. [15]) for the Markov-chain represented by the cascade. In the case of exact (or approximate) "reciprocity" between the fireball decay and composition these integral equations can be explicitly solved giving the relative weights of the different multiplicities in the final states.

The results of Section III and IV can be briefly summarized by saying that for a given fireball mass $M$ there is always (in both classes) a characteristic multiplicity $l_0$ where the multiplicity distribution is sharply peaked. In the statistical bootstrap model $l_0$ is proportional to the fireball mass $M$. In independent emission models $l_0$ grows slower than $M$. The main difference between the two classes of models is that independent emission implies that the characteristic temperature grows with $M$ infinitely, whereas in statistical bootstrap models the temperature is practically equal to HAGEDORN's limiting temperature [12] once the fireball mass is high enough.