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HIJET and Beyond (RHIC::EVENT, RHIC::PLASMA, RHIC::LANDAU, RHIC::SMOKE, RHIC::CHIRAL)

Ron S. Longacre
Brookhaven National Laboratory, Upton, NY 11973, USA

1 HIJET

We present a discussion of event generators which are based on a program called HIJET[1]. HIJET generator considers $p-A$ and $A-A$ collisions to be a sum of independent $N-N$ collisions, with the $N-N$ cross section and scattering dynamics not dependent on whether the nucleon has previously participated in an interaction. For each primary $N-N$ interaction, a call is made to the MINBIAS routine of the program ISAJET[2] - an event generator for high energy $N-N$ interactions. MINBIAS computes the energy loss of the colliding nucleons and the produced particles. MINBIAS is based on inclusive high energy $N-N$ interactions forming multi-pomeron chains, with each chain fragmenting according to the Field-Feynman algorithm[3]. At beam momentum below 50 GeV/c MINBIAS had to be modified in order to agree with $p-p$ data[4].

HIJET takes account of the geometry of the $A-A$ collision. HIJET populates nucleons in the target and the projectile systems according to a Woods-Saxon distribution. Each nucleon is given a fermi momentum which has a quassian distribution with a σ of 200 MeV/c. The nucleons are off the mass shell, with the average binding energy being 8 MeV. An interaction between a projectile and a target nucleon occurs when the distance of closest approach is less than $\sqrt{\frac{\sigma}{\pi}}$ with $\sigma = 33$ mb (this distance is 1.025 Fermi the approximate size of a proton).

2 RHIC::EVENT

HIJET was written from the prospective that a proton or a small A nucleus (projectile) collides with a large A nucleus(target). The collisions are carried out in the target rest frame. When one runs the HIJET code for equal A nuclei, symmetry is not achieved about center rapidity. This lack of symmetry was corrected for in the RHIC::EVENT program.

RHIC::EVENT chooses the $N-N$ center of mass frame and let nucleons from the projectile and the target move towards each other in a symmetric way.

In $A-A$ events the second and greater collision of a nucleon is not really a true $N-N$ collision. After a nucleon suffers a collision it becomes forward going di-quark system whose momentum is equal to the baryon it will form into. HIJET uses the leading baryon of a MINBIAS collision for the di-quark for the next collision. As a di-quark travels through the system it will maintain its flavor as long as it does not get broken up. On the other hand the HIJET algorithm can change flavors because sea quarks that are present in the leading baryon have an equal weight in the next collision. RHIC::EVENT corrects for this problem by not letting the leading baryon change flavors. Another problem with the leading baryon algorithm is the momentum of the di-quark is always as low as it can possibly be. However we know that the leading di-quark can form into a very heavy baryon resonance. If one also believes in clusters and that the forward going cluster is what the fragmentation region is, it is clear the di-quark must carry more momentum than given by the leading baryon. RHIC::EVENT sums up the momentum of the particles produced by MINBIAS that one wants to associate with the di-quark cluster. The larger the cluster size and momentum the more RHIC::EVENT creates nuclear transparency which implies less stopping. This algorithm generates a very nice flat central region plateau for RHIC energies (flat over 6 units of rapidity), while straight HIJET gives about 4 units.

3 RHIC::PLASMA

Plasma formation and decay is a very uncertain process and our first model of this phenomenon is based on work of L.Van Hove ten years ago[5]. Van Hove's model predicted that the deconfinement transition is described in terms of formation of QCD strings in the expanding plasma. These strings in the plasma are stopped from expanding because of string tension and because of string breaking droplets or bubbles are formed. These bubbles hadronize by deflagration at the phase transition through their outer surface by ejection of low pressure hadron gas with velocities associated with the critical temperature. This process creates a rapidity distribution dn/dy of hadrons with isolated maxima of width $\delta y \sim 1$ or high bumpy regions a few units of rapidity wide on an event-by-event basis.

The generator RHIC::PLASMA takes the regular RHIC::EVENT generation and Van Hove type[5] spherical plasma bubbles generated by a regional tagging scheme which takes particles from the intial RHIC::EVENT collisions and converts their energy and baryon number to a plasma bubble. The tagging region is defined as a circular cross sectional area within the overlapping nuclei with radius Rtag. Each region is then subdivided in phase space by a longitudinal momentum cuts (three bubbles can be defined in present code). The bubble has an intial energy and baryon number, where its rest frame is given by the total momentum energy four vector of the sum of the tagged particles that make up the bubble. The thermal dynamics of the bubble is generated in accord with the model of Koch, Muller and Rafelski[6]. Initially the tagged volume is used to define the chemical potential and thus the quark and gluon populations for a plasma sitting at its critical temperature. Reference 6 has worked out these equations up to a temperature of 170 MeV. We expand the volume until we get a self consistent condition that satisfies energy and baryon number between the tagged particles and the plasma bubble. This self consistent condition is equal to the number of quarks, anti-quarks and gluons ($N_q N_{\bar{q}} N_g$). N_s and $N_{\bar{s}}$ are the strange quark and anti-quark numbers where N_q and $N_{\bar{q}}$ are the light quarks(u, d). When hadronization takes place gluons fragment into quarks and anti-quarks leading to an effective number given by $\tilde{N}_q = N_q + f_q N_g$; $\tilde{N}_{\bar{q}} = N_{\bar{q}} + f_q N_g$; $\tilde{N}_s = N_s + f_s N_g$; $\tilde{N}_{\bar{s}} = N_{\bar{s}} + f_s N_g$, where f_q = gluon fragmentation function for u and d quarks and f_s = gluon fragmentation function for s quarks. The average number of particles produced each with a Boltzman distribution corresponding to the critical temperature is: $N_\pi = \alpha \tilde{N}_q \tilde{N}_{\bar{q}}$, $N_K = \alpha \tilde{N}_q \tilde{N}_{\bar{s}}$, $N_\phi = \alpha \tilde{N}_s \tilde{N}_{\bar{s}}$, $N_n = \frac{1}{3!}\beta \tilde{N}_q \tilde{N}_q \tilde{N}_q$, $N_{\bar{n}} = \frac{1}{3!}\beta \tilde{N}_{\bar{q}} \tilde{N}_{\bar{q}} \tilde{N}_{\bar{q}}$, $N_\Lambda = \frac{1}{2!}\beta \tilde{N}_q \tilde{N}_q \tilde{N}_s$, $N_{\bar{\Lambda}} = \frac{1}{2!}\beta \tilde{N}_{\bar{q}} \tilde{N}_{\bar{q}} \tilde{N}_{\bar{s}}$, $N_\Xi = \frac{1}{2!}\beta \tilde{N}_q \tilde{N}_s \tilde{N}_s$, $N_{\bar{\Xi}} = \frac{1}{2!}\beta \tilde{N}_{\bar{q}} \tilde{N}_{\bar{s}} \tilde{N}_{\bar{s}}$, $N_\Omega = \frac{1}{3!}\beta \tilde{N}_s \tilde{N}_s \tilde{N}_s$, $N_{\bar{\Omega}} = \frac{1}{3!}\beta \tilde{N}_{\bar{s}} \tilde{N}_{\bar{s}} \tilde{N}_{\bar{s}}$.

α and β are given by the equations:

$$\alpha = \frac{4Q_1}{(3Q_1^2 + Q_2^2)}; \quad (1)$$

$$\beta = \frac{8}{(3Q_1^2 + Q_2^2)}; \quad (2)$$

where $Q_1 = \tilde{N}_q + \tilde{N}_{\bar{q}} + \tilde{N}_s + \tilde{N}_{\bar{s}}$ and $Q_2 = \tilde{N}_q - \tilde{N}_{\bar{q}}$. These equations make sure baryon number is conserved and particles are formed randomly out of the particle densities. The above particles then are generated with a Boltzman distribution of a 170 Mev temperature spherically in phase space. The spherical distribution creates a bump in rapidity of the type that Van Hove[5] predicted. The geometry of the expansion of the plasma bubble or fireball is dependent on QCD.

4 RHIC::LANDAU

In particle and nuclear physics spherical fireballs have not been observed, but rather fireballs that have an additional one dimensional or longitudinal expansion left over from their production mechanism(Landau fireball[7]). The program RHIC::LANDAU takes the regular RHIC::PLASMA program and replaces the spherical expansion by a fireball expansion that is consistent with thermal fits done on SS collisions at 200 GeV/c per nucleon[8]. The width of the rapidity distribution changes from a two unit spread to a four unit spread, where 50% of the tagged energy goes into particle production and 50% goes into longitudinal expansion. In the language of Van Hove the string stopping due to breaking is not complete, so that longitudinal expansion is left in the individual strings or bubbles.

5 RHIC::SMOKE

The plasma bubbles that we have generated give structure to the rapidity or psuedo-rapidity spectrum of the produced particles. This structure is directly related to the geometry of the expansion. The geometry which has been observed in experiments is the elliptical expansion of the Landau fireball, however sharpe structure in psuedo-rapidity has been observed in cosmic ray experiments[9]. We can make our plasma bubbles with sharp structures by changing a elliptical or watermelon shape to a flat or pancake shape. We do this only as a phenomenological manipulation of our code. The end process is a ring of particles emitted at a fixed angle to the beam axis much like an expanding smoke ring. Since these particles have nearly a fixed angle they lead to sharpe psuedo-rapidity bumps of the intermittent type seen in cosmic ray data[9].

6 RHIC::CHIRAL

Another novel event structure seen in cosmic ray data[10] is the so-called "centauro-like" and "anti-centauro-like" fluctuations of charged and neutral particles. A popular explanation of these events relies on a chiral phase transition. Rajagopal and Wilczek[11] proposed a "quench" scenario in which the hadronic condensate after a phase transition is initially chirally symmetric, but its evolution is taken to follow classical equations of motion at zero temperature. This non-equilibrium dynamics of the chiral transition (using a linear σ model to describe the collective chiral behavior) in relativistic heavy ion collisions yield large disoriented chiral condensates. These disoriented chiral condensates lead to the non-Poisson distribution of the "centauro-like" and the "anti-centauro-like" events. The probability distribution of neutral pions $P(R_3)$[12], where $R_3 = N_{\pi^0}/(N_{\pi^+} + N_{\pi^0} + N_{\pi^-})$, is equal to $P(R_3) = 1/(2\sqrt{R_3})$. In contrast, typical hadronic collisions produce a binomial distribution of R_3 peaked at the isospin symmetric value of 1/3.

RHIC::CHIRAL generates the above like structures using the RHIC::PLASMA bubble code but making the bubble hadronize into a 70 MeV temperature pion gas with a R_3 distribution chosen to be that of the disoriented chiral condensate model. In a given Au-Au event each bubble has an independent R_3.

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