CHIPS based hadronization of quark-gluon strings.

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Abstract. Quark-gluon strings are usually fragmented on the light cone in hadrons (PITHIA, JETSET) or in small hadronic clusters which decay in hadrons (HERWIG). In both cases the transverse momentum distribution is parameterized as an unknown function. In CHIPS the colliding hadrons stretch Pomeron ladders to each other and, when the Pomeron ladders meet in the rapidity space, they create Quasmons (hadronic clusters bigger then Amati-Veneziano clusters of HERWIG). The Quasmon size and the corresponding transverse momentum distribution are tuned by the Drell-Yan $\mu^+\mu^-$ pairs. The final Quasmon fragmentation in CHIPS is tuned by the e^+e^- and proton-antiproton annihilation at rest.

The LHC measurements at super high energies demand approximation and extrapolation of the all existing high energy data to simulate electromagnetic and hadronic processes in the LHC detectors. The Chiral Invariant Phase Space (CHIPS) model included in the Geant4 simulation toolkit [1] considers hadrons as clusters (Quasmons) of asymptotically free massless partons. The excited chiral invariant phase space of partons is hadronized dissipating its excessive energy. There are two main mechanisms of hadronization: parton fusion in vacuum and quark exchange in nuclear matter. The main parameter of the model is a critical temperature ($T_c \approx 200\ MeV$) which determines the number of partons in the Quasmon with the mass M.

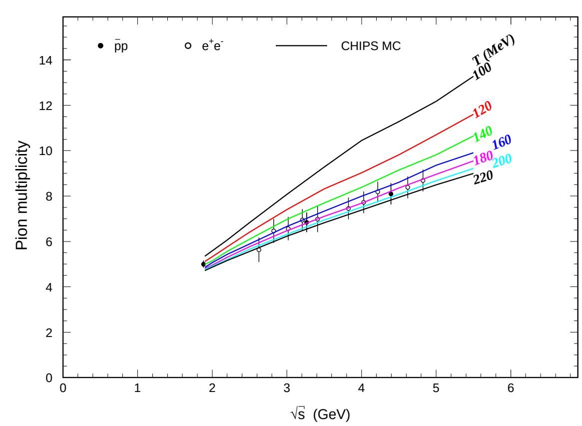

Fig. 1. Average meson multiplicities in proton-antiproton and in electron-positron annihilation, as a function of the CMS energy.

The first achievement of the CHIPS model is the fit of the light quark hadrons [2]. For the massless u and d quarks one can define the 2-quark and 3-quark masses as $M_2 = \frac{3\cdot m_\rho + m_\pi}{4}$ and $M_3 = \frac{m_N + m_\Delta}{2}$. For massless partons the Quasmon mass can be calculated as $M^2 = 4T_c^2 n(n-1)$. Using the M_2 and M_3 values one can find that $T_c \approx 200\ MeV$. In CHIPS the Quasmon mass can be calculated for $m_q \neq 0$ [2], but the interaction corrections for heavy quarks are too big. That is why only masses of the light quark hadrons (u, d, s) have been calculated. With the same number of parameters (temperature instead of pressure) CHIPS fits 23 hadronic masses better than the BAG-model.

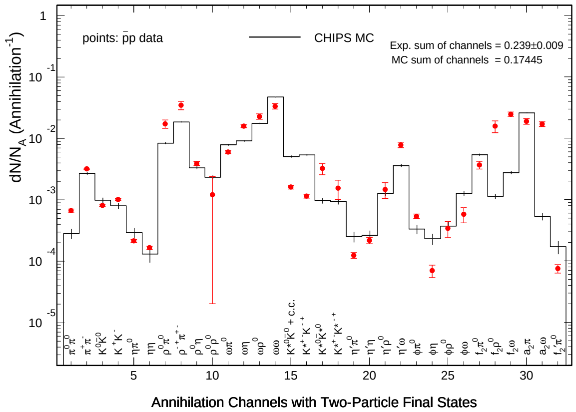

Fig. 2. Branching probabilities for different channels with two-particle final states in proton-antiproton annihilation at rest.

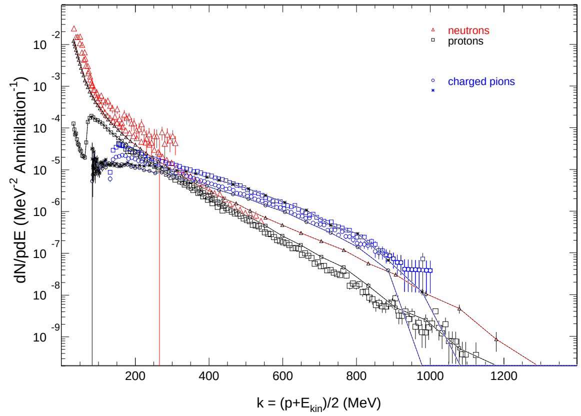

Fig. 3. Spectra of protons, neutrons, and pions in antiproton-uranium annihilation at rest. Preliminary.

The second achievement of the CHIPS model is a detailed simulation of the proton-antiproton annihilation at rest [3]. In the CHIPS model the proton-antiproton compound Quasmon is a prototype of the high energy jet which is considered as a decaying on flight Quasmon. The pion multiplicity in the proton-antiproton and e^+e^- reactions as a function of the total mass of the compound Quasmon is shown in Fig. 1. The simulation curves correspond to different values of the parameter T_c. The dynamic simulation confirms the $T_c \approx 200\ MeV$ value. The fragmentation of Quasmons in vacuum demands the strangeness suppression parameter which is used in almost all high energy event generators. The most difficult issue is simulation of the two particle decays of the Quasmons. The CHIPS simulation of the two particle branchings of the proton-antiproton annihilation at rest are shown in Fig. 2.

The third achievement of the CHIPS model is a detailed simulation of the Quasmon fragmentation in nuclear matter. The pion capture at rest and photonuclear reactions below the pion production threshold have been simulated and the results have been published in [4] and [5]. In Fig. 3 the preliminary results of the simulation of the antiproton capture by uranium nuclei are shown. Simulation of the heavy nuclear fragment yield demands the nuclear clusterization parameters.

The CHIPS algorithm supports the multiquasmon fragmentation in nuclear matter. When the multiquasmon algorithm was created the final hadronization part of the CHIPS model has been completed, and the main efforts were concentrated on the initial interaction of photons and hadrons with nuclei. Three data bases have been created: the photonuclear data base, the structure function data base, and the Drell-Yan data base. The detailed photo-nuclear approximation with extrapolation to infinite energies was made in [6]. For the first time the total electro-nuclear cross section was calculated (there are no measurements of this value) and used in the Geant4 simulation. The developed generalized equivalent photon method lets simulate most of the electro-nuclear, muon-nuclear, and tau-nuclear reactions, but at high Q^2 it loses applicability.

The detailed approximation of structure functions completed the simulation package for the lepto-nuclear interactions. The DIS data are simulated in CHIPS as a sum of two kinds of interactions: direct (one photon

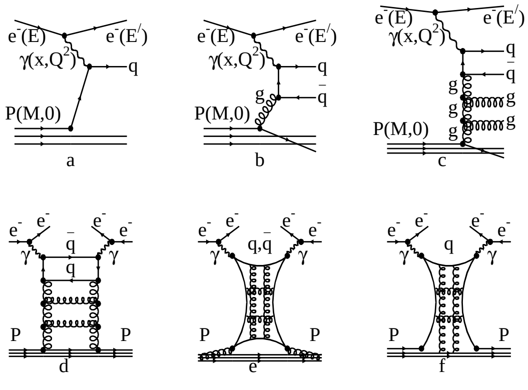

Fig. 4. Diagrams of different contributions to the structure functions of nucleons: (a) direct interactions with quark-partons, (b) a universal diagram for the photon structure function, the photo-gluon fusion, and the QCD radiation corrections, (c) multiperipheral interactions, (d) quark box Pomeron exchange, (e) photo-gluon fusion string, and (f) quark annihilation string.

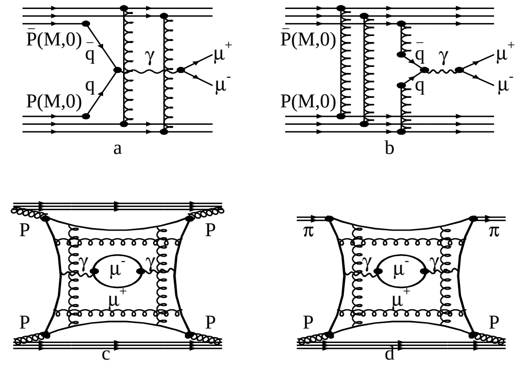

Fig. 5. Diagrams of different contributions to the Drell-Yan process: (a) direct interaction, (b) multiperipheral interaction, (c) gluon-gluon dual string, (d) pion-gluon dual string.

exchange) and multiperipheral. The approximation formula for structure functions [7] covers all Q^2 including $Q^2 = 0$ (photo-nuclear reactions) and has an explicit total momentum normalization for the parton distributions. The structure function diagrams are shown in Fig. 4. The multiperipheral contribution is calculated as a cut of the dual quark-gluon strings Fig. 4(e,f). The Q^2-dependence of the number of the additional qluons in the nonperturbative phase space of the nucleon was found to be $N_g(Q^2) \approx \frac{0.511}{\alpha_s(Q^2)}$. In the CHIPS approximation the freezed strong coupling $\alpha_s(Q^2) = \frac{4\pi}{9 \cdot ln(1+\frac{Q^2}{T_c^2})}$ was used ($\alpha_s^{-1}(0) = 0$). For the first time the number of partons in the nucleon at $Q^2 = 0$ was found to be equal to three valence quarks ($N(0) = 3 + N_g(0)$). The Pomeron intercept was approximated as $\alpha_P(Q^2) = 1.08 + g_{11}(Q^2)$, where $g_{11}(Q^2) = \frac{0.00811}{\alpha_s^2(Q^2)}$ is a universal one Pomeron to one Pomeron vertex. The published approximation includes only protons and deuterons. The same method, taking into account nuclear clusters, have been used for approximation of nuclear structure functions.

Similarly to the DIS spectra the Drell-Yan spectra have been approximated as a sum of the direct $q\bar{q} \to \mu^+\mu^-$ production (Fig. 5(a)) and the multiperipheral production (Fig. 5(b)). In the central region ($y = 0$) the Drell-Yan cross sections are functions of $\sqrt{\tau} = \frac{M}{\sqrt{s}}$. These spectra for $\bar{p}p$, pp, and $\pi^- p$ reactions (including nuclear target measurements) are shown in Fig. 6. The direct interaction can contribute only to the antiproton-proton and pion-proton interactions. It was found that the multiperipheral contribution is the same for $\bar{p}p$ and pp interactions. The difference of these spectra is determined by the direct contribution. The multiperipheral contribution was found to be determined by the cut gluon-gluon fusion dual string Fig. 5(c). The naive expectation for the πp Drell-Yan cross section is $DY_{\pi p} = \frac{DY_{\bar{p}p} + DY_{pp}}{3}$. It is shown in Fig. 6(c) by a dashed line.

The CHIPS approximation shows, that the multiperipheral part of the $\pi^- p$ interaction is four times bigger than expected. The only explanation for this effect is a big pion-gluon dual string contribution (Fig. 5(c)). The pion-gluon enhancement of the string production is confirmed by the J/ψ production measurements [8]: in πA reactions the J/ψ production

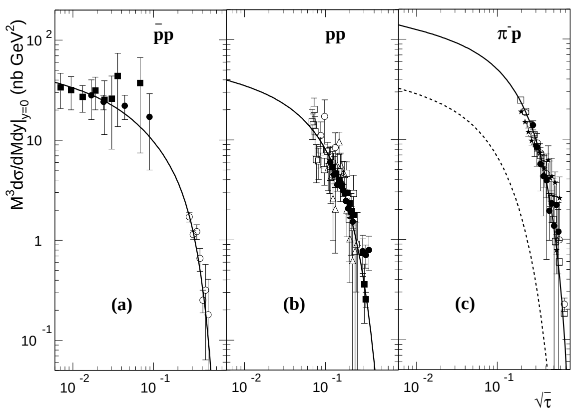

Fig. 6. Spectrum of masses of $\mu\mu$ pairs at $y=0$ for $\bar{p}p$, pp, and $\pi^- p$ reactions ($dx = (x_1+x_2)\cdot dy$). Preliminary.

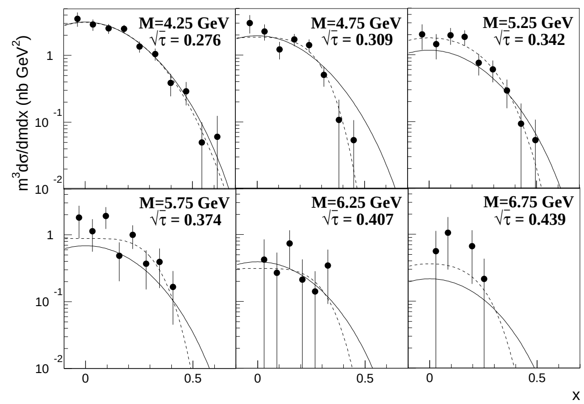

Fig. 7. Parallel momentum spectrum for different masses of the $\mu\mu$ pairs ($x = x_1 - x_2 = \frac{2p^{\mu\mu}_{||CM}}{\sqrt{s}}$). Preliminary.

($B\sigma_{\pi^- A}(J/\psi) = 88\pm12\frac{nb}{A}$,$B\sigma_{\pi^+ A}(J/\psi) = 82\pm12\frac{nb}{A}$) is bigger than for pA ($B\sigma_{pA}(J/\psi) = 53\pm 7\frac{nb}{A}$). It is as big as in $\bar{p}A$ reactions ($B\sigma_{\bar{p}A}(J/\psi) = 85\pm 40\frac{nb}{A}$), while the direct contribution to $\pi^- p$ reactions must be at least twice smaller than to the $\bar{p}p$ reactions ($\frac{8}{17}$ for the proton target and $\frac{4}{9}$ for nuclear targets). The enhanced multiperipheral fragmentation of the pion induced nuclear reactions in respect to the proton induced nuclear reactions can be very important for the hadronic showers simulation at LHC energies.

The Drell-Yan cross section can be calculated as $\frac{d\sigma^{DY}}{d\tau dy} = \frac{4\pi\alpha^2}{9M^2}\sum e_a^2(f_a^{(1)}(x_1)f_{\bar{a}}^{(2)}(x_2)+f_{\bar{a}}^{(1)}(x_1)f_a^{(2)}(x_2))$, where 1 corresponds to the projectile, 2 corresponds to the target, a is a flavor index ($a = u, d, s, c, d, t$), $f(x) = x\cdot q(x)$ is a part of the total momentum, carried by quarks, M is the mass of the $\mu^+\mu^-$ pair, $\tau = \frac{M^2}{s}$, $y = \frac{1}{2}ln\frac{x_1}{x_2} = \frac{1}{2}ln\frac{E^{\mu\mu}_{CM}+p^{\mu\mu}_{||CM}}{E^{\mu\mu}_{CM}+p^{\mu\mu}_{||CM}}$, $x_1 = \sqrt{\tau}e^y$, and $x_1 = \sqrt{\tau}e^{-y}$. The two dimensional approximation of the $\bar{p}p$ Drell-Yan cross section is shown in Fig. 7 by the solid lines. The dashed lines show a polynomial approximation of the $\frac{d\sigma^{DY}}{d\tau dy}$ values to $x=0$, which was used in Fig. 6. As soon as the $f_a(x)$ functions are found from the Drell-Yan reactions, one can get rid of e_a^2 and of the photon propagator factor $\frac{1}{M^2}$. Then, the Quasmon production cross section is $\frac{d\sigma^Q}{d\tau dy} = C\sum(f_a^{(1)}(x_1)f_{\bar{a}}^{(2)}(x_2) + f_{\bar{a}}^{(1)}(x_1)f_a^{(2)}(x_2))$. The Quasmons are produced by the multiperipheral part of the interaction, and the direct interactions of quarks are simulated following the Field-Feynman model [9]. The C parameter must be tuned by approximation of the inclusive spectra of the hadronic reactions. The diffractively excited nucleons in nuclei are fragmented by the multiquasmon algorithm.

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