Nucleus-Nucleus Collisions at Highest Energies

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The microscopic phasespace approach URQMD is used to investigate the stopping power and particle production in heavy systems at SPS and RHIC energies. We find no gap in the baryon rapidity distribution even at RHIC. For CERN energies URQMD shows a pile up of baryons and a supression of multi-nucleon clusters at midrapidity.

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1   Motivation

One of the main aims of relativistic heavy ion collisions at collider energies is to discover if the individual hadrons dissolve into a gas of free quarks and gluons (quark-gluon-plasma, QGP) in the extremely compressed and heated hadronic matter. This may happen in line with a transition into the chiral symmetric phase which modificates most hadron masses drastically. The achievable energy deposition depends on the amount of stopping of the colliding nuclei.

2   The URQMD Model

The Ultrarelativistic Quantum Molecular Dynamics (URQMD)[1], is used to analyze the physics of the excitation function of hadronic abundances, stopping and flow. This framework bridges with one model consistently the entire available range of energies from below SIS to CERN, even for the heaviest system Pb+Pb. URQMD is a hadronic transport model including strings. Its collision term contains 50 different baryon species (including nucleon, delta and hyperon resonances with masses up to 2 GeV) and 25 different meson species (including strange meson resonances), which are supplemented by their corresponding antiparticle and all isospin-projected states.
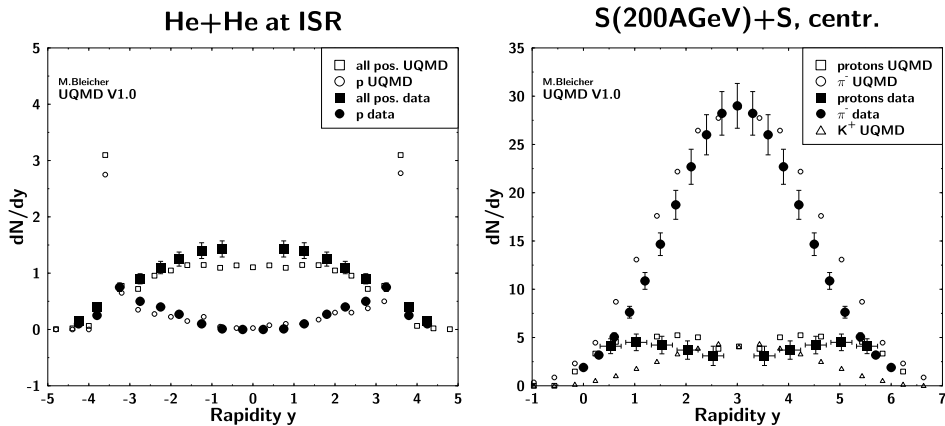
Figure 1: Left:Rapidity distribution of protons and positively charged particles for the reaction He+He at $\sqrt{s} = 31$ AGeV compared to the data [2]. Right: Rapidity distribution of protons and negatively charged pions for central S+S reactions at $E_{lab} = 200$ AGeV compared to the data [8].

3   He-He Collisions at ISR

In general it appears to be an intricate problem to describe stopping behaviour of baryons and pion production within one theoretical frame at very high energies. If one wants to do LHC calculations it may be necessary to include multi-string-excitation as it is done in dual parton approach. To demonstrate the ability of URQMD to model a nucleus-nucleus collision even at the today highest available bombarding energies for heavy particles, we compare the calculated He+He collision at ISR with data [2] as shown in Fig.1 (left).

It is not surprising, that such a light system as helium is totally transparent. A baryon free area of 3 units in rapidity is produced. URQMD and the data agree well, the calculated produced particle yield may increase by 15% if one also simulates gluon jet events [3], which is not included yet.

4   SPS Energy Regime

The dominant reaction mechanism in the early stage of a reaction is the excitation of collision partners to resonances or strings[1]. Then secondary interactions, i. e. the annihilation of produced mesons on baryons, lead also to the formation of s channel resonances or strings, which may explain the strangeness enrich-
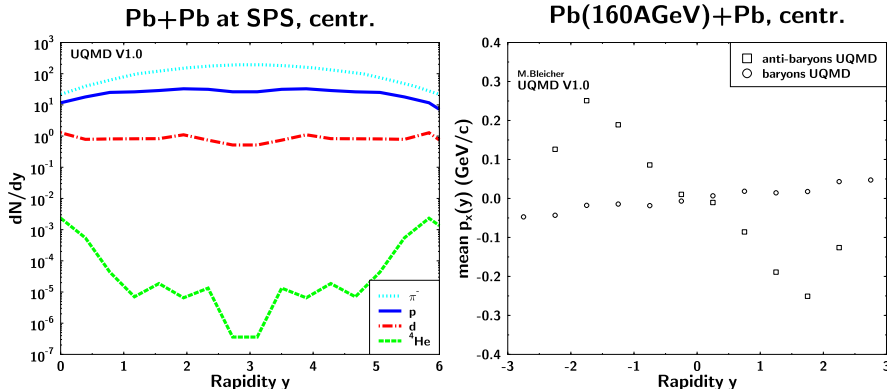
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Figure 2: Left: Rapidity distribution of π^-, protons, deuterons and ^{4}He in central Pb+Pb reactions at $E_{lab} = 160$ AGeV. Right: Directed flow of baryons and antibaryons for the same system.

ment [4] and (for masses larger than $3m_N$) allow for $\overline{N}N$ creation [5]. The escape probability for $\bar{p}$'s from the exploding nuclear matter enters via the free $N\overline{N}$ annihilation cross section. For central events of Pb+Pb at SPS approx. 85% of the produced anti-baryons are annihilated during the reaction.

These two counter–acting effects may be measured by the directed "anti-flow" of antimatter. The observable asymmetry for bouncing antimatter can be quantified by the mean p_x vs. rapidity (Fig.2, right). The anti–flow of antibaryons appears to be strongest for semicentral collisions, while for baryons the maximum p_x is at considerably smaller b–values. The latter is due to the pressure (i. e. the EOS) the former one due to absorption and geometry.

Comparisons of URQMD calculations to data from SIS to SPS is documented elsewhere [6]. Good agreement of baryon and meson production and dynamics has been achieved. An impression is given in Fig.1 (both) - protons as well as pions and kaons are shown.

Further insight into the collision geometry may be gained by looking at composite particle probes. Since URQMD does not include the production of light nuclei dynamically, cluster formation is added after strong freeze-out. (Freeze-out means after the last strong interaction of the particle.) We calculate the deuteron (helium) formation probability by projecting the nucleon pair phasespace on the deuteron wave function via the Wigner-function method as described in [7]. Especially for high bombarding energies or exotic clusters it is necessary to use this sophisticated method, since the complex phasespace
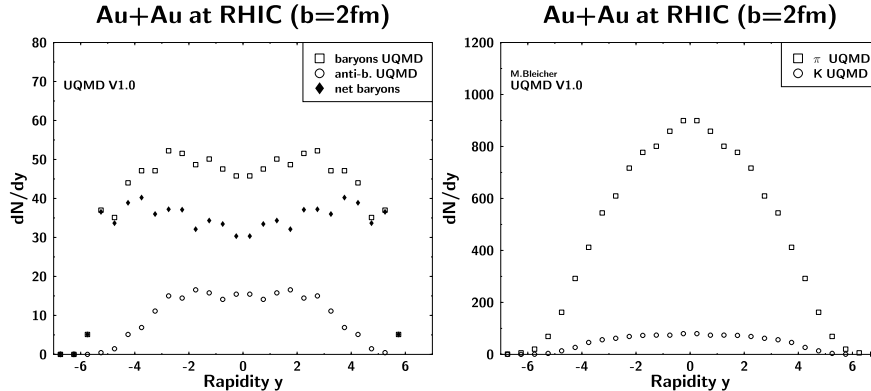
Au+Au at RHIC (b=2fm)   **Au+Au at RHIC (b=2fm)**

Figure 3: The system Au+Au at an energy of $\sqrt{s} = 200$ AGeV (RHIC), central collisions selected. Left:Rapidity distribution of baryons, antibaryons and net-baryons. Right: Rapidity distribution of pions and kaons

distribution of the cluster ingredients has to be taken into account [9]. The Hulthén parametrization is used to describe the relative part of the deuteron wavefunction. The yield of deuterons is given by

$$ \mathrm{d}N_d = \frac{1}{2}\frac{3}{4}\Big\langle \sum_{i,j} \rho_d^{\mathrm{w}}\big(\Delta\vec{R},\Delta\vec{P}\big)\Big\rangle \mathrm{d}^3(p_{i_p} + p_{j_n})\,. $$

The Wigner-transformed Hulthén wavefunction of the deuteron is denoted by ρ_d^{w}. The sum goes over all n and p pairs, whose relative distance $(\Delta\vec{R})$ and relative momentum $(\Delta\vec{P})$ are calculated in their rest frame at the earliest time after both nucleons have ceased to interact. The factors $\frac{1}{2}$ and $\frac{3}{4}$ account for the statistical spin and isospin projection on the deuteron state. The calculation of the high mass clusters is straight forward, e.g. by exchanging the Hulthén parametrization of the d wavefunction with a 4-body harmonic oscillator wavefunction[7] to describe the ^{4}He (See Fig. 2 (left), π^-, protons, as well as deuterons and ^{4}He are depicted). In contrast to the pile up of protons at midrapidity, cluster production is strongly supressed due to the high temperatures in the center of the collisions.

Calculations of H^0 ($\Lambda\Lambda$-clusters) for AGS and SPS energies have also be performed in this framework [10].

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5 RHIC Estimates

As shown above URQMD seems to be well suited for an estimate of stopping power in Au+Au collisions at RHIC. However, we are well aware of the fact that for certain observables (e.g. high p_t components of particle spectra) the current framework is not sufficient, since it does not incorporate hard partonic scattering explicitely. Figure 3 (left) shows the results of our calculation for gold-gold at $\sqrt{s} = 200$ AGeV (RHIC). The nuclei suffer a mean rapidity shift of more than 2 units of rapidity. The mid-rapidity region is apparently not baryon free, in contrast to some earlier expectations. Our results are similiar to RQMD calculations[3].

We finally put our interest on the produced mesons. In Fig.3 (right) we show the rapidity distribution of kaons and pions. As mentioned above at this high energies modifications of the string fragmentation may be necessary. The inclusion of gluon jets as a first step will increase the meson multiplicities by about 15%[3].

6 Conclusion

At first some remarks on the validity of our calculation: It is believed to be a fact that a quark-gluon-plasma is created at RHIC. While our calculation does not assume a QGP, it certainly goes beyond the purely hadronic scenario - strings are excited and quarks and diquarks are subject to further interaction. From our calculation we infer that the interaction of leading quarks and diquarks dictate the stopping behaviour of heavy ion collisions even at SPS energies.

Acknowledgments

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