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EXPERIMENTAL RESULTS FROM CERN ON REACTION MECHANISMS IN HIGH ENERGY HEAVY ION COLLISIONS

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Three main experimental results from CERN concerning reaction mechanisms in high energy heavy ion collisions are discussed: 1) the striking validity of the single particle picture, 2) the nuclear stopping power and 3) the attained energy densities.

1. INTRODUCTION

One of the primary goals of the initial phase of the CERN heavy ion program has been to study the reaction mechanisms of ultrarelativistic heavy ion collisions in order to establish a baseline against which any QGP signal will have to be evaluated. Three collaborations, NA34, NA35, and WA80, have to a significant extent incorporated detectors sensitive to global parameters in their setups. The most important recorded quantities have been: 1) charged particle multiplicity, 2) transverse energy and 3) forward energy. For 1) and 2) also pseudorapidity distributions have been measured. Due to the limited space available it is not possible here to present the raw experimental data. Please refer to refs. 1 and 2 for a more detailed review. Instead we will here focus on three of the more important results derived from the data.

2. VALIDITY OF THE SINGLE PARTICLE PICTURE

The most important parameter for understanding the features of minimum bias data has turned out to be the nuclear overlap volume or, with other words, the number of participating nucleons. This is best illustrated by the remarkable success of most of the heavy ion Monte Carlo models, like FRITIOF³, VENUS⁴ and HIJET⁵, especially at the forward hemisphere in the CMS, where the codes in general are within 10-15% of the data. These codes are all to first order based on a linear superposition of individual collisions between the participating nucleons. This simple picture gets, however, more complicated at smaller pseudorapidities, where rescattering effects in the target spectator matter can be expected to contribute. Only models like MCFM⁶, HIJET, VENUS, and RQMD⁷, which in various ways incorporate rescattering, are able to obtain reasonable fit to transverse energy data recorded in the target rapidity region. At the moment the detailed investigation of these rescattering effects seems to be the most promising tool for extracting information on the particle formation time τ_0 . Current estimates⁴⁻⁷ indicate a value of τ_0 around 1-2 fm/c. The systematic uncertainties are, however, large. Especially the transverse mass dependence of τ_0 seems to be uncertain.

Currently no generally accepted collective phenomena have been discovered. Flow analysis, that has been very successful at Bevalac energies, has given negative results. The shapes

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of pion transverse momentum distributions have been interpreted as evidence of collective transverse flow⁸, but that conclusion has not been generally accepted⁹.

3. NUCLEAR STOPPING POWER

Estimates of the nuclear stopping power in heavy ion collisions have been difficult to obtain due to a proliferation of definitions of the concept. Based on leading baryon spectra the momentum degradation length in p+A reactions has been determined to be 6 ± 2 fm¹⁰ corresponding to a rapidity shift of 2.4 in central p+Pb collisions. Based on the available E_T - and forward energy- spectra Wong determined¹¹ the effective momentum degradation length in ¹⁶O-induced reactions at 60 and 200 A GeV to be approximately 4 fm indicating a very large degree of stopping in nuclear collisions. Another approach¹² based on the Landau fireball model has estimated the total energy contained in the fireball to be around 90% of the available CM energy consistent with a momentum degradation length of 5 fm. It should be noted that an energy independent momentum degradation length, as would be expected by the constant nucleon-nucleon cross section at $\sqrt{s} > 3$ GeV, will result in a constant ratio between the fireball energy and the CM energy. This does, however, not necessarily indicate full stopping, which should be defined as the situation where the average final rapidities of the projectile and target participants are the same. The "mid-rapidity stopping", defined as $(dE_T/d\eta)_{max}/(E_{cm}/2)$, has been introduced by WA80¹³ as a simple and convenient experimental measure of stopping. Table 1 illustrates how this quantity increases with decreasing beamenergy and increasing target mass in central collisions.

4. ENERGY DENSITY

Most simple estimates of the attained energy densities have been based on two different approaches. In the first the global energy density has been defined as $\epsilon = (\text{some energy}) / (\text{some volume})$. Typically the energy has been chosen as the total transverse energy and the volume as the Lorentz-contracted target volume, but many other combinations have been used. The fundamental problem with this approach, which in general leads to $\epsilon = 3-8$ GeV/fm³, is that at the time during the reaction where the fireball volume is as small as the f. ex. the target nucleus, then only a fraction of the total fireball energy has come on the mass shell due to timelike formation times. In short, the energy and volume are not referring to the same time. A more realistic estimate of the on-shell energy at the point of

$\Downarrow$ Reaction \ Target $\Rightarrow$	C	Al	Cu	Ag	AU
60 A GeV ¹⁶ O	0.29		0.37	0.39	0.44
200 A GeV ¹⁶ O	0.22		0.27	0.31	0.34
200 A GeV ³² S		0.22	0.24	0.25	0.29

Table 1: Mid-rapidity stopping measure for extracted from WA80 data. Please see text for further information

time during the collision, where the fireball volume has a size close to the target participant volume, will therefore lead to considerable lower energy densities.

The other approach has been to use Bjorkens¹⁴ formula, which leads to values of ϵ around 3 GeV/fm³ for the most central O+Au collisions assuming $\tau_0 = 1$ fm/c. The basic problem in applying Bjorkens formula at 200 A GeV is not so much the lack of cylindrical boost-invariance, but more the ignorance of the nuclear transit time, which is close to 1 fm/c. The kinetic energy of the nuclei is therefore not instantaneously transformed into off-shell gluon field energy, but the energy release takes place gradually during the transit time. This will again lead to lower values of the maximum energy density.

Probably the most detailed study of different formation- and reaction-times and their influence on the attained energy density can be found in ref. 15. Here it is found, based on a space-time version of ATTILA, that the maximum energy density in central 200 A GeV O+Au collisions is only around 1.5 GeV/fm³.

5. CONCLUSIONS

At CERN SPS energies heavy ion Monte Carlo codes has reached a degree of maturity, where global parameters like transverse energy and charged particle multiplicities can be predicted to within 10-15%. The nuclear stopping power seems to be high as expressed in the low value of 4-5 fm for the momentum degradation length, but the attained maximum energy density in central collisions is probably not higher than 1.5 GeV/fm³, which might be just short of the energy density needed for the phase transition between the hadron and the quark-gluon phases.

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