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Production of $\rho+\omega$ and ϕ in $p-W$ and $S-U$ collisions at 200 GeV/nucleon

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Abstract

The transverse mass differential cross-sections for the $\rho+\omega$ and ϕ resonances is obtained, in the central rapidity region, in $p-W$ and $S-U$ interactions at 200 GeV/nucleon. The measured $\rho+\omega$ and ϕ temperatures are ~ 15 % higher in $S-U$ as compared to $p-W$ collisions. The ratio of cross-sections times branching ratios into the dimuon channel $\frac{B_\phi\sigma_\phi}{B_\rho\sigma_\rho+B_\omega\sigma_\omega}$ is studied as a function of the energy density reached in the collision and of the dimuon transverse momentum. The measured ratio is 2 to 3 times larger in $S-U$ than in $p-W$ collisions and an enhancement is observed in $S-U$ interactions with increasing energy density.

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1 INTRODUCTION

A. Shor suggested in 1985 that a strong enhancement of the ϕ/ω ratio in heavy ion collisions, as compared to the value measured in $p-p$, could be a clean signature of Quark-Gluon Plasma (QGP) formation [1]. In the plasma in chemical equilibrium it is expected, from chiral symmetry restoration, that strange quark pairs $s\bar{s}$ are abundantly produced with respect to light quark pairs $u\bar{u}, d\bar{d}$, for temperatures of the order of the strange quark mass. A first experimental indication has been reported by our collaboration in the high transverse dimuon momentum region [2]. Our analysis, extended afterwards to low transverse momentum, showed an enhancement of the cross-sections relative yield times braching ratio into the dimuon channel $\frac{B_\phi \sigma_\phi}{B_\rho \sigma_\rho + B_\omega \sigma_\omega}$ with increasing transverse neutral energy released in the interaction [3].

It has also been anticipated that the presence of a phase transition would be revealed by the evolution of the average transverse momentum $\langle P_T \rangle$ of hadrons as a function of the energy density ϵ [4]. Moreover, it has been predicted that a collective expansion of the system produced in the collision would change the thermal spectra of the hadrons [5]. Both informations could be provided by the inverse exponential slope of the final hadron transverse mass spectra ($M_T = \sqrt{M^2 + P_T^2}$), the so-called temperature (T).

The data presented in this letter were collected with 200 GeV/nucleon proton and sulphur beams impinging on tungsten and uranium targets respectively. Two dedicated configurations of the NA38 detector were used with special emphasis on muon pair mass resolution. A detailed description of the experimental setup and data analysis can be found in [6]. Differential cross-sections for the production of $\rho + \omega$ and ϕ resonances in the dimuon channel as a function of the transverse mass M_T and of the energy density ϵ are measured. From these, the cross-section ratio $\frac{B_\phi \sigma_\phi}{B_\rho \sigma_\rho + B_\omega \sigma_\omega}$ as a function of ϵ and P_T are obtained. Finally, we discuss hadron nuclear absorption effects.

2 $\rho + \omega$ AND ϕ TRANSVERSE MASS DIFFERENTIAL CROSS-SECTIONS

As pointed out by R. Hagedorn [7], a thermal radiation source in local equilibrium at fixed rapidity produces a transverse mass spectrum described by $i)\ \frac{1}{M_T} \cdot \frac{dN}{dM_T} = A \cdot M_T \cdot K_1(\frac{M_T}{T})$, where K_1 is the modified Bessel function and the inverse slope T is a temperature. In the limit where the mass of the resonance m_R is much greater than T, $m_R \gg T$, it follows that formula $i)$ becomes $ii)\ \frac{1}{{M_T}^{3/2}} \cdot \frac{dN}{dM_T} = A \cdot exp(-\frac{M_T}{T})$. The differences between the exact expression $i)$ and the approximation $ii)$ are substantial at very low P_T, but rather small for the P_T range covered by this analysis, i.e. for $P_T \geq$0.6 GeV/c. We also use the approximation $iii)\ \frac{1}{M_T} \cdot \frac{dN}{dM_T} = A \cdot exp(-\frac{M_T}{T})$, the so-called M_T scaling. The inverse slope fitted values obtained with the three different parametrizations are summarized in Table 1. No significant differences are observed between $i)$ and $ii)$. On the other hand, the inverse slopes given by $iii)$ are systematically higher by about 10 MeV than the corresponding ones obtained with $i)$ or $ii)$. Fig. 1 shows the resonance's differential cross-section $(1/M_T^{3/2})\ d\sigma/dM_T|_{\Delta Y}$ parametrized by expression $ii)$.

In general, if the system is thermalized, the temperatures given by the different parametrizations are of the order of 200 MeV. The temperatures $T_{\rho+\omega}$ and T_ϕ are 23 to 26 MeV higher in $S-U$ than in $p-W$ collisions, which could be interpreted as a possible evidence for higher energy densities in $S-U$ collisions or as an indication of a collective

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transverse expansion of the system [5]. As as a function of the energy density ϵ [1)] the vector meson temperatures, as shown in Fig. 2, exhibit a rise from proton to sulphur, followed by a plateau. This pattern is qualitatively in agreement with what is expected from a first order phase transition [4]. Finally, we observe that T_ϕ temperatures are slightly smaller then $T_{\rho+\omega}$.

3 CROSS-SECTION RATIO

The relative yield $R = \frac{B_\phi \sigma_\phi}{B_\rho \sigma_\rho + B_\omega \sigma_\omega}$ is studied for low ($0.6 \leq P_{T\mu\mu} \leq 1.15$ GeV/c) and high ($1.15 \leq P_{T\mu\mu} \leq 3.0$ GeV/c) dimuon transverse momentum regions. In addition, an extrapolation from $P_{T\mu\mu} \geq 0.6$ GeV/c to zero is done in order to obtain an integrated result, using the parametrization *ii)* mentioned above. The integrated value of this ratio does not depend on the parametrization, within a 1% uncertainty (the parametrizations *i)* and *iii)* give different values for $\rho+\omega$ and ϕ cross-sections but their ratio is the same for all parametrizations). The systematic error assigned to the ratio R, not quoted in figures, is estimated to be in the range 15 – 20 %. The different sources of uncertainty are discussed in detail in [6]; for the ratio, the systematic error due to the absolute normalization is cancelled and an additional error related to the extrapolation down to P_T=0 of 10% is considered.

As shown in Fig. 3, the measured ratio is 2 to 3 times larger in $S-U$ than in $p-W$ collisions, independently of P_T. A clear rise of the ratio with the energy density is seen for high P_T. Fig. 4 shows the dependence of the ratio R with ϵ for the whole P_T domain, after the extrapolation to zero as described above. A smooth increase with ϵ is observed in $S-U$ reactions and an enhancement of a factor of 2.5 is seen (Fig. 4) for the most central $S-U$ collisions with respect to $p-W$ interactions. The Helios/3 experiment finds similar results [10].

4 NUCLEAR ABSORPTION EFFECTS

The P_T and E_T^0 integrated results are particularly interesting when compared to other experiments. Moreover, they allow a common discussion of nuclear absorption effects in $p-N$ and $N-N$ collisions. The value of $\frac{B_\phi \sigma_\phi}{B_\rho \sigma_\rho + B_\omega \sigma_\omega}$ measured in $p-W$ is consistent with other $p-p$ and $p-N$ measurements [11]. Within experimental uncertainties, these combined results favour a similar $(A_{beam} \cdot A_{target})^\alpha$ dependence, i.e. alike nuclear effects, for the ϕ and $\rho+\omega$ resonances [12], since they lead to $\Delta\alpha_{\phi,\rho+\omega} = \alpha_\phi - \alpha_{\rho+\omega}$ =0.05±0.05. On the other hand, comparing the ratio R measured in $S-U$ collisions, with the value obtained in $p-W$ (in the domain $0. \leq P_T \leq 3.0$ GeV/c), we are led to $\Delta\alpha_{\phi,\rho+\omega} = 0.23 \pm 0.06 \pm 0.07$, a result which can hardly be explained by hadronic rescattering processes in nuclear matter as described in [13], given the p-induced experimental results.

Let us recall that in the previous paper [6] we have obtained directly $\alpha_{\rho+\omega} = 1.00 \pm 0.02 \pm 0.07$, $\alpha_\phi = 1.23 \pm 0.03 \pm 0.05$ from our $\rho+\omega$ and ϕ cross-section measurements for $P_{T\mu\mu} \geq 0.6$ GeV/c, leading to $\Delta\alpha_{\phi,\rho+\omega} = 0.23 \pm 0.04 \pm 0.09$ [2)]. The P_T integrated value quoted in the last paragraph is quite compatible with this previous one and reinforces

1) The energy density is estimated in the framework of the Bjorken model [8] and can be written as $\epsilon = 3 < E_t^0 > / A_T \Delta y \tau_0$, where A_T is the transverse area of the participant's region determined within a geometrical model [9], $< E_T^0 >$ the average transverse neutral energy corresponding to the rapidity interval Δy= 2.4 and τ_0= 1 fm/c the formation time.

2) All the alpha values quoted are calculated in the rapidity region $3 < y_{lab} < 4$. They may differ if determined for the hole rapidity domain as pointed out in the previous paper.

the enhancement observation of the ϕ meson production in ion collisions as compared to proton interactions.

5 CONCLUSIONS AND DISCUSSION

The higher $\rho + \omega$ and ϕ temperatures measured in $S - U$ collisions with respect to those measured in $p - W$ could be interpreted as an evidence of a collective transverse expansion of the system produced in heavy ion reactions. The study of the vector-meson temperatures as a function of the energy density in $S - U$ interactions shows a behaviour which qualitatively agrees to what is expected from a first order phase transition.

The observed strangeness enhancement of a factor of 2 to 3, in low and high P_T regions, in $S - U$ as compared to $p - W$ collisions is found to be compatible with a Quark Gluon Plasma scenario [14]. Interpretations based only on secondary scattering processes in the framework of Hadron Gas formation, including or not high P_T effects, [15, 13] seem to be ruled out since experimentally ϕ and $\rho + \omega$ resonances show similar absorptions rates and the observed ϕ enhancement exhibits no P_T dependence. Recent calculations considering string fusion models show the same trends as our results [16, 17]. In any case, the observed increase requires the presence of a dense and strongly interacting system evolving towards chemical equilibrium.

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2 Temperature T (MeV) of $\rho + \omega$ and ϕ resonances as a function of the energy density ϵ obtained in $S-U$ collisions (points) and in $p-W$ (shaded areas). The values presented were obtained by fitting the data with parametrization ii). *7*

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4 The ratio $B_\phi\sigma_\phi/(B_\rho\sigma_\rho + B_\omega\sigma_\omega)$ in the dimuon channel, integrated in P_T with extrapolation to zero (as explained in the text), as a function of ϵ in $S-U$ collisions. The shaded area represents the value measured in $p-W$. *9*

Parametrization of $\frac{1}{M_T} \cdot \frac{dN}{dM_T}$	Temperature (MeV)			
	$p-W$		$S-U$	
	$\rho+\omega$	ϕ	$\rho+\omega$	ϕ
$i) M_T\ K_1\,(M_T/T)$	180.3±2.0±5.6	173.6±2.5±2.3	203.4±3.0±7.4	197.4±9.4±13.
$ii) \sqrt{M_T}\ exp\,(-M_T/T)$	178.7±2.0±6.0	171.9±3.3±2.3	202.6±2.3±5.4	195.4±3.7±3.3
$iii) exp\,(-M_T/T)$	190.4±2.0±6.8	182.1±3.5±2.5	216.1±3.0±6.1	207.7±2.5±8.8

Table 1: $\rho+\omega$ and ϕ temperatures measured in $p-W$ and $S-U$ collisions.

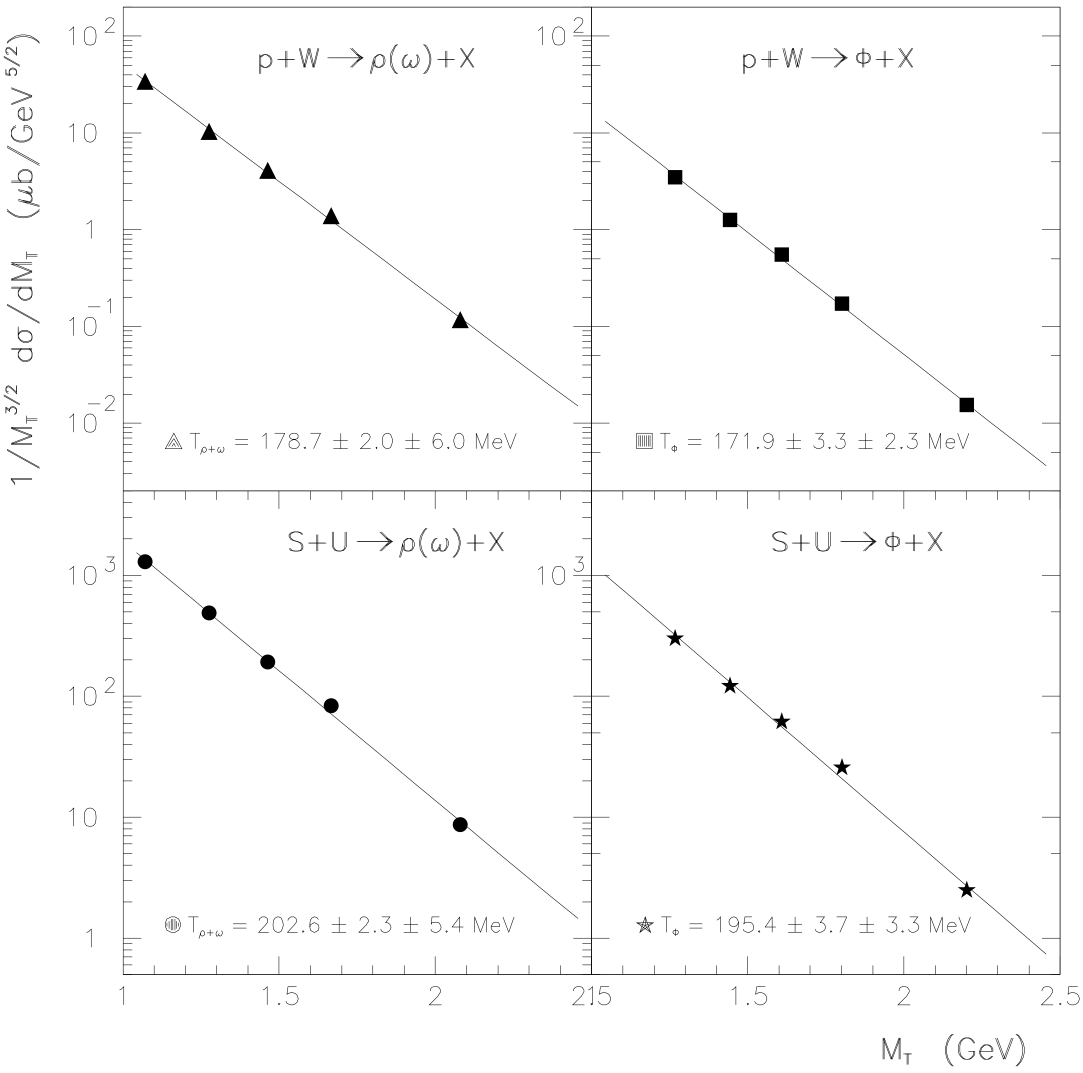

Figure 1: $(1/M_T^{3/2})\ d\sigma/dM_T|_{\Delta Y}\ (\mu\mathrm{b}/(\mathrm{GeV/c})^{5/2})$ for $\rho+\omega$ and ϕ measured in $p-W$ and $S-U$ collisions at 200 GeV/nucleon.

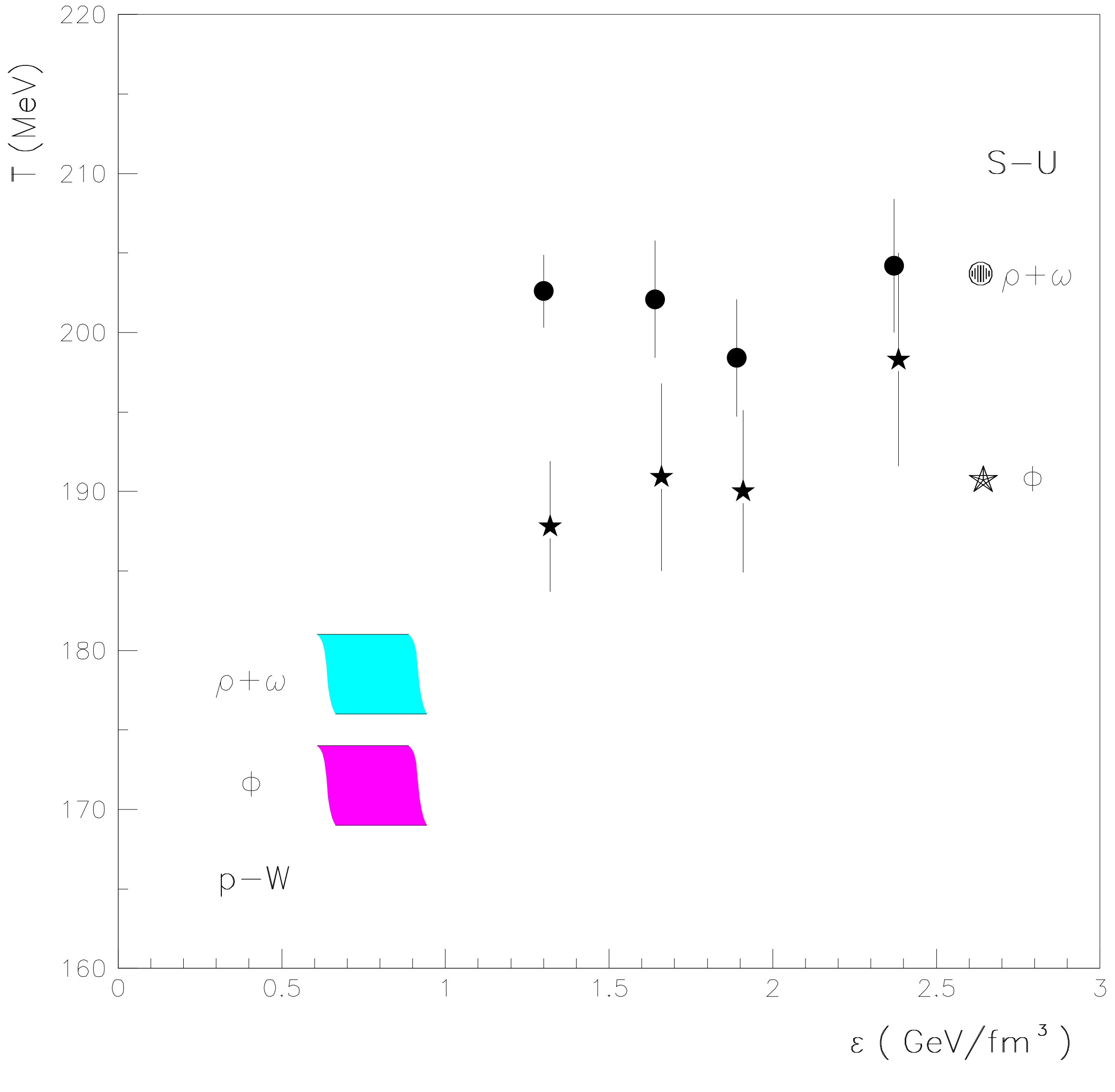

Figure 2: Temperature T (MeV) of $\rho + \omega$ and ϕ resonances as a function of the energy density ϵ obtained in $S - U$ collisions (points) and in $p - W$ (shaded areas). The values presented were obtained by fitting the data with parametrization ii).

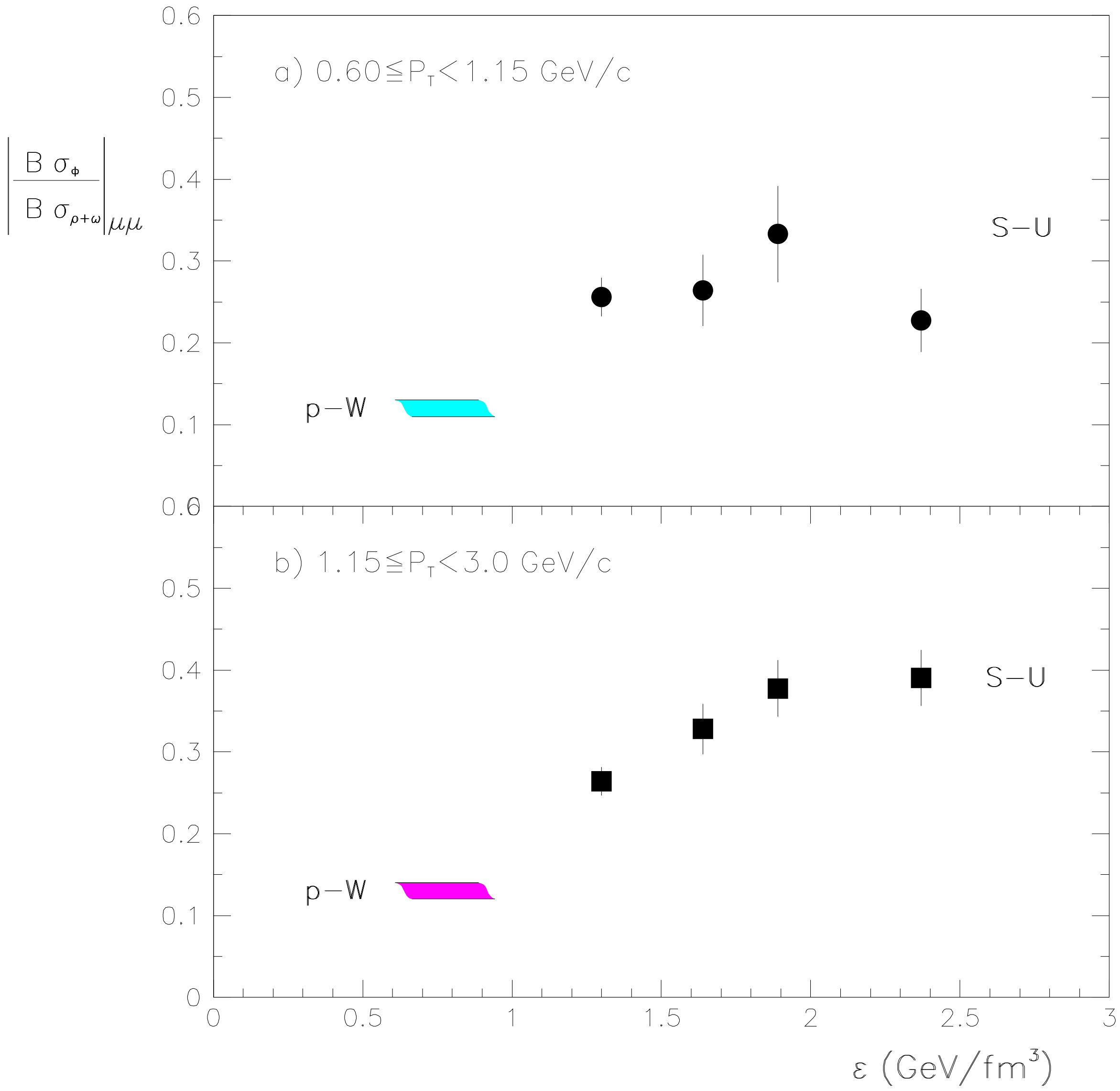

Figure 3: The ratio $B_\phi\sigma_\phi/(B_\rho\sigma_\rho + B_\omega\sigma_\omega)$ in the dimuon channel, as a function of the energy density ϵ in $S-U$ collisions: a) 0.6≤ P_T <1.15 GeV/c and b) 1.15≤ P_T <3.0 GeV/c. The shaded areas represent the value measured in $p-W$.

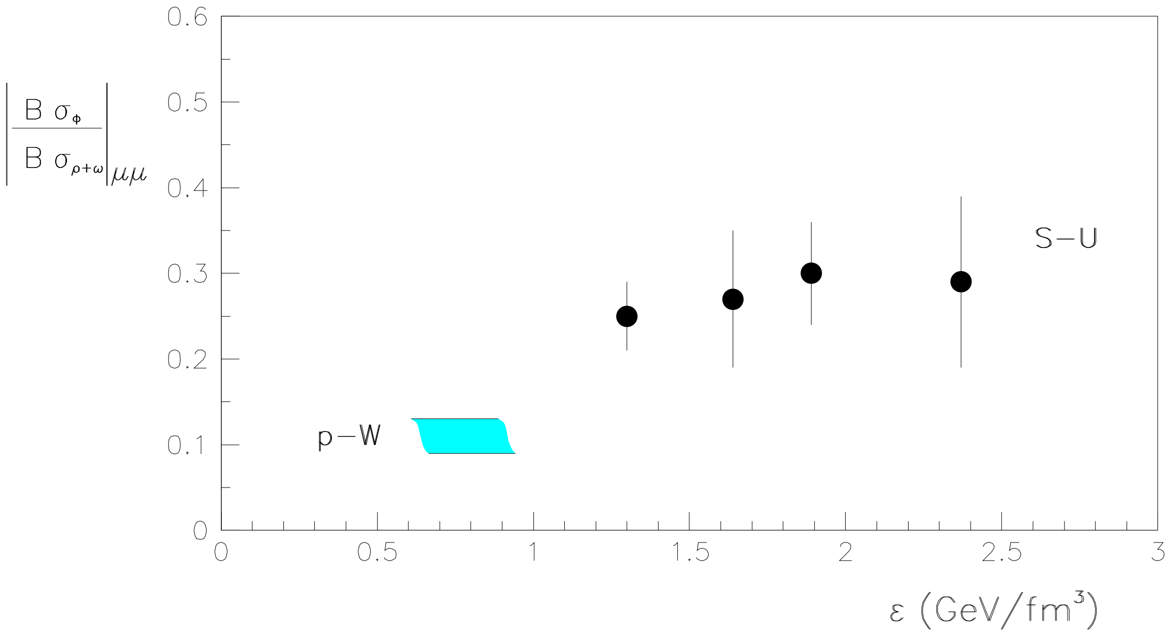

Figure 4: The ratio $B_\phi\sigma_\phi/(B_\rho\sigma_\rho + B_\omega\sigma_\omega)$ in the dimuon channel, integrated in P_T with extrapolation to zero (as explained in the text), as a function of ϵ in $S-U$ collisions. The shaded area represents the value measured in $p-W$.