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TRANSVERSE MOMENTUM PHYSICS: FROM SPS TO LHC ENERGIES, COMPARISON TO THE DATA ON π^{-12}C -INTERACTIONS AT P_{π^-}= 40 GeV/c

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The aim of the presented analysis is to review the transverse momentum physics in SPS CERN, RHIC BNL and LHC CERN energies and investigate inclusive hadron production in π^{-12}C interactions at P_{π^-}=40GeV/c. We focus on p_T dependence of the nuclear modification factor (R) for proton and charged π meson production. We demonstrate that the results are in agreement with the SPS and RHIC ones.

Keywords: Nucleus, Transverse momentum, Suppression, Enhancement, π^{-12}C, 40GeV/c, Proton, Meson, Heavy ion collision, SPS, RHIC, LHC

1 Introduction

The physics of the transverse momentum (p_T) is of a great interest. J.D Bjorken [1] has shown that the p_T is a constant variable. Then taking into account the Heisenberg's uncertainty principle, p_T x $A \sim h$, one can find the size of particle emission area (A), where h is the Plank constant. Using p_T one can talk about applicability region of different models (for example, recombination, fragmentation, etc). In a collision the p_T plays crucial role, when:

1. The nuclei barely graze each other ("peripheral" collision), a high-p_T parton (quark and gluon) quickly escapes the medium and it emerges after losing less energy;
2. The collision might be almost head-on ("central" collision), high-p_T partons have larger in-medium path-lengths and thus lose more energy (in average).

The transverse momentum of a particle being a Lorentz invariant quantity has been accepted as a useful parameter in the study of strong interaction dynamics. Experimental results and theoretical calculations suggest distinction of three p_T regions [2]: bulk (or low), intermediate and high-p_T. It is a rough distinction, because if in 90th years a start value of high-p_T was 2GeV/c, now it is around 6 GeV/c with the starting of first heavy-ion collisions (*HIC*) in Large Hadron Collider (*LHC*) of European Organization for Nuclear Research (*CERN*) experiment in 2010 year it is expected to be 13GeV/c. Thus, above mentioned p_T regions will be changed with increasing incident energy. Further we are giving figures which are correct only for today. The bulk region (p_T<2GeV/c) seems to be driven by the thermal properties of the matter created in heavy-ion collisions. Majority of the particles (about 99% of produced hadrons at the Relativistic Heavy Ion Collider (*RHIC*) of Brookhaven National Laboratory (BNL) have p_T of less than 1GeV) emitted in *HIC* appear in the low-p_T region. In the intermediate-p_T region ($2<p_T<6$GeV) one can investigate to the interaction between the hard probes and the bulk matter created in hadron+nucleus (*hA*), nucleus+nucleus (*AA*) interactions and *HIC*. In the high-p_T ($p_T > 6$ GeV/c) region measured particle spectra are well described by perturbative Quantum Chromo-Dynamics (*pQCD*) calculations. High-p_T particles suppression is one of the signatures of quark-gluon plasma (*QGP*), i.e. a thermalized phase in which partons are the relevant degrees of freedom.

The study of hadron production at high transverse momentum (high-p_T) is a sensitive tool to characterize the matter created in ultra-relativistic HIC, and in particular, to detect the possible formation of *QGP*. Particles at high-p_T result from parton scatterings with high momentum transfer (hard scattering) which can be described by *pQCD*. The scattered partons will traverse the created medium as they fragment into the

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observable hadrons. High-p_T particle production in proton+nucleus (*pA*) and *AA* interactions was predicted to be suppressed [3] as a consequence of the energy loss of the scattered projectile partons (or hadrons) in the hot and dense medium (a phenomenon known as “jet quenching") before the particle production process. Such suppression was observed by experiments at RHIC in central *Au+Au* and *Cu+Cu* collisions at a center-of-mass energy of upto $\sqrt{s_{NN}}$ =200GeV [4]. Particles are suppressed not equally. Another phenomenon, called “Cronin enhancement” [5] is presented in *d+Au* and peripheral *Au+Au* collisions. It is believed to be due to multiple nucleons scattering within the nucleus. Neither of these are clearly understood thus require further experimental and theoretical study.

The hard scatterings are still present in the heavy-ion data, but resulting distributions are found to be modified due to medium interactions. Thus, understanding modifications to the high-p_T particle distributions can lead to qualitative conclusions on the energy loss mechanisms within the medium.

The medium effects (suppression and enhancement) which mentioned above, is characterized by the R_{AA} quantity, a term used for the observation of an increased amount of particle production at high-p_T in *AA* (or *pA*), compared to the elementary *pp* reactions [6].

The R_{AA} quantity is called the nuclear modification factor (*NMF*) and defined by $R_{AA} = \frac{\sigma_{NN}^{inel}}{< N_{coll}^{AA} >} \frac{d^2N_{AA}/dp_T dy}{d^2\sigma_{pp}/dp_T dy}$, where $d^2N_{AA}/dp_T dy$ is the invariant yield, <N_{coll}> is the mean number of binary (nucleon+nucleon) collisions occurring in central *HIC*, σ_{NN}^{inel} is the inelastic *pp* cross section and y is the rapidity, i.e., the relativistic analog of velocity. For perfect binary scaling (in the absence of jet quenching), a value of R_{AA} = 1 would be expected. For R_{AA} < 1 the spectra is referred to as suppressed, whilst R_{AA} > 1 corresponds to an enhancement.

For a more sensitive search of the other nuclear effects the R_{CP} (central to peripheral) modification factor

$$R_{CP} = \frac{d^2N/(2\pi p_T dp_T dy)(central)/N_{coll}(central)}{d^2N/(2\pi p_T dp_T dy)(peripheral)/N_{coll}(peripheral)}$$

is used. If the multiple scattering interpretation of the Cronin enhancement effect is correct, its contribution to the R_{CP} ratio is expected to be reduced, as it should already be present in the peripheral base line.

It is believed that the emission of hadrons with transverse momentum upto about 6GeV/c in central relativistic *HIC* is dominated by recombination of partons, where three quarks or a quark/antiquark pair in a densely populated phase space can form a baryon or meson, respectively. High-p_T hadrons originate primarily from the fragmentation of hard scattered partons, in which the single parton with the probability for a parton *i* hadronize into a hadron *h*, that carries a fraction *z*<1 of the momentum of the parent parton. Such hard scatterings occur in the early phase of the reaction, and the transiting partons serve as probes of the strongly interacting matter produced in the collisions. Measurement of identified particles upto the highest possible p_T, establishing the magnitude, p_T and centrality dependence of the suppression pattern, is crucial to constrain the theoretical models and separate contributions of initial and final state effects from the energy loss mechanism [7].

In the presented paper, in conditions of 4π-geometry, we investigate proton and charged π-meson production, the π^-/π^+ ratio in π^{-12}C interactions at P_{π^-}=40GeV/c and compare these to Super Proton Synchrotron (SPS) and RHIC data on proton and heavy ion collision data, seeking similarities in the particle momentum probabilities transverse to the beam axis. A single nuclear modification factor, *R* is computed for this comparison. The goal is to use the *R* quantity to learn about the unseen collisions among the quarks and gluons created in this range of collisions.

2. Transverse Momentum Physics in SPS, RHIC and LHC Energies

In this section we have presented the recent development in the transverse momentum physics by measurements of identified hadrons in hadron-nucleus (*hA*) and nucleus-nucleus (*AA*) collisions at *SPS* and *RHIC* energies and some predictions of *LHC* experiment.

2.1 Transverse momentum physics in SPS energies

A long-standing puzzle concerns the magnitude of partonic energy loss in nuclear collisions at the *SPS*. *WA98* data [8] indicated a large enhancement of inclusive π^0 production at p_T ~ 3−4GeV/c in central *Pb+Pb* relative to *p+p* collisions when normalized per binary collision ($R_{AA}(p_T)$), although a suppression was observed in central relative to peripheral nuclear collisions ($R_{CP}(p_T)$, also normalized per binary collision) by the same experiment.

New measurements of high-p_T hadron suppression at the *SPS* were presented at the Quark Matter 2005 conference for K_s^0 R_{CP} (p_T) [9] and charged pions and protons [10] compared to radiative energy loss calculations. Introduction of energy loss in a medium, with charged hadron multiplicity scaling as $dN_{ch}/d\eta$ (the density of charged particles per unit of η, where η is the pseudorapidity, a variable which approaches rapidity for particles with mass less than p_T and which is a function only of polar angle), results in good agreement between calculation and data. These new data solve the high-p_T suppression puzzle at the *SPS*: the medium densities inferred from bulk multiplicity and high-p_T inclusive hadron measurements are consistent. However, significant theoretical uncertainties remain due to a potentially large Cronin effect at these lower energies.

The neutral pion spectra were measured [3] in minimum bias *p+C* and *p+Pb* collisions at $\sqrt{s_{NN}}$ =17.4GeV in the range 0.7≤p_T≤3.5GeV/c. Based on these spectra the *NMF* for *Pb+Pb* collisions at *CERN SPS* energies could be determined using a measured *p+A* reference. In very central *Pb+Pb* collisions (0 -1%) a significant suppression of high- p_T neutral pions was observed (≈ 0.5) that is reminiscent of the high-p_T hadron suppression observed in *Cu+Cu* and *Au+Au* collisions at *RHIC*. The pion suppression, together with the results at higher energies from *RHIC*, will allow constraining the energy dependence of hadron suppression as predicted by jet-quenching models.

Transverse momentum spectra upto 4.5GeV/c around mid rapidity of $\pi^{\pm}$, p, $\bar{p}$ and $K^{\pm}$ in *Pb+Pb* reactions were measured [11] at $\sqrt{s_{NN}}$ =17.3GeV by the *CERN-NA49* experiment. The extracted R_{AA} ratios scaled with the number of binary collisions show a rapid rise with transverse momentum in the covered p_T region. The R_{CP} ratio stay below one in the $\pi^{\pm}$ channel. Interestingly, the R_{CP} ratios stay rather close to the $\sqrt{s_{NN}}$ =200GeV *RHIC* results for $\pi^{\pm}$, $K^{\pm}$ and p in the available p_T region; however the 200GeV $\pi^{\pm}$ ratio shows a much larger suppression at p_T≥2GeV. The p ratio is almost identical to the 200GeV ratio. The modification factors, when scaled with the number of wounded nucleons, start from one, show a rapid rise with p_T, and the R_{pA} ratios stay below the R_{AA} data over the covered p_T region for both collision energies.

2.2 Transverse momentum physics in RHIC energies

In *HIC*, high-p_T hadrons, photons and heavy mesons, can be used to probe the soft matter generated in the collision. Initial state production of high-p_T partons is relatively unaffected by the presence of the soft medium, but the partons lose energy when traversing the medium, dominantly due to gluon radiation. The goal of high-p_T measurements is to study these interactions and to use them to measure the density and temperature of the soft matter.

In [12] in *p+p* collisions, charged pions and (anti-) protons are measured in the range 5.0≤p_T≤15.0GeV/c and the $\bar{p}/\pi^+$, p/π^-, $\bar{p}/p$ and π^-/π^+ ratios are discussed. The ρ^0 production at high-p_T (5.0≤p_T≤10.0GeV/c) measured in minimum bias (*MB*) *p+p, Au+Au* and central *Au+Au* collisions in the *STAR RHIC* detector are presented. The ρ°/π ratio measured in *p+p* is compared to *PYTHIA* calculations as a test of *pQCD* that describes reasonably well particle production from hard processes and also to the ρ°/π ratio measured in *Au+Au* collisions. The charged pions, ρ^0 and proton plus anti-proton *NMF* were also presented. The protons plus anti-protons and the charged pions R_{AA} seem to behave oppositely to what is naively expected from color charge dependence of energy loss. The ρ^0, charged pions and π^0 *NMF* are comparable indicating that the fragmentation of vector mesons and pseudo-scalars are similar in *p+p* and *Au+Au* collisions.

In paper [13] the π^0 yields for *Cu+Cu* collisions at $\sqrt{s_{NN}}$ =22.4, 62.4 and 200GeV are presented. Reference data for *p+p* collisions at $\sqrt{s_{NN}}$ =62.4 and 200GeV were taken with the same experiment [14]. At $\sqrt{s_{NN}}$ =22.4GeV a *p+p* reference was obtained from a parameterization of the world's data on pion production [15]. It is shown that, high-p_T π^0 yields in central *Cu+Cu* collisions at 62.4 and 200GeV are suppressed, suggesting that parton energy loss is significant, while at 22.4GeV the π^0 yields for p_T≥2GeV/c are not suppressed. The R_{AA} measured in central *Cu+Cu* at 22.4GeV is consistent with Cronin enhancement alone but does not rule out parton energy-loss effects. These measurements provide a unique constraint for jet-quenching models and demonstrate that parton energy loss starts to prevail over the Cronin enhancement between $\sqrt{s_{NN}}$ =22.4 and 62.4GeV.

In paper [16], the *J/Ψ* spectra at high-p_T (5<p_T<14GeV/c) in *p+p* and *Cu+Cu* collisions at $\sqrt{s_{NN}}$ =200GeV are reported. The high-p_T *J/Ψ* production was found to follow the x_T ($x_T = 2p_T/\sqrt{s}$) scaling with a beam energy dependent factor ~ $(\sqrt{s_{NN}})^{5.6\pm0.2}$. Within the errors the power was found to be the same for pion, proton and for *J/Ψ*, which indicates that the high-p_T *J/Ψ* production mechanism is closer to parton-parton scattering. The *J/Ψ NMF* R_{AA} in *Cu+Cu* increases from low to high-p_T which challenges some models. The average of R_{AA} at p_T>5GeV/c is 0.9±0.2, consistent with no *J/Ψ* suppression. It implies that high-p_T *J/Ψ* may be produced from virtual photon or formed outside of the hot interaction region.

The paper [17] exhibits the suppression for direct photons and various mesons (π^0, *η*, *φ*, *J/Ψ* and *ω*) in central *Au+Au* collisions at $\sqrt{s_{NN}}$ =200GeV, measured up to p_T≈20GeV/c. The comparison of the π^0 suppression in *Au+Au* and *Cu+Cu* collisions at $\sqrt{s_{NN}}$ unveils a simple scaling: the suppression only depends on the number of participating nucleons (N_{part}) for the same $\sqrt{s_{NN}}$. Such a scaling with N_{part} is consistent with a parton energy loss picture. More work is needed to understand the different suppression patterns of *φ* and *ω* mesons as compared to pions and *η*'s and the scaling of direct photons at high-p_T in central *Cu+Cu* and *Au+Au* collisions.

It has also been found at *RHIC* that at intermediate p_T≈2−6GeV/c, the baryon/meson ratio is much larger in *HIC* than in proton-proton collisions [18]. This could imply that soft production mechanisms, e.g. hadron formation by coalescence of quarks from thermal matter [19], have a significant contribution to baryon (and meson) production up to p_T~6GeV/c.

2.3. Transverse momentum physics in LHC energies

CERN confirmed that the *LHC* will restart in the autumn of 2009. The experimental study of jet quenching has reached a new level of detail and precision, and interpretation of the striking effects that have been observed is currently limited by theoretical uncertainties. *HIC* at the *LHC* will open up a huge new kinematic regime for jet quenching studies, with qualitatively new observables available. While the *LHC* regime may provide better grounds for quantitative theoretical predictions, a complete picture of jet interactions with dense *QCD* matter must describe all of the phenomena we observe, both at *RHIC* and at the *LHC*. One can only say that with respect to *LHC* energies we have some predictions underlying model calculations (e.g. the *KKT* model of gluon saturation) [20]. In this model, using the calculation and theoretical results, the dependence of the *NMF* on p_T of pion and open charm and beauty production at *RHIC* and *LHC* are presented. They teach us that at *LHC* at rapidities *y*≥0, the *NMF* is a very slow function of rapidity. This is an anticipated result.

3. Methods and Materials

The *NMF*, R of the $\pi^{\pm}$-mesons and protons (with momentum p_p<1GeV/c) as a function of the p_T of these particles in laboratory frame were analyzed by us using the experimental data on $\pi^{-12}C$-interactions at P_{π^-}=40GeV/c (in centre of mass energy it is $\sqrt{s_{NN}}$ =32GeV). The values of R as a ratio of the inclusive spectrum of $1/N_{ev}(dN/dp_T)$, obtained in the events with number of protons N_p≥2 (we call it multi-nucleon events and number of these events is N_{ev}=3571), to the similar ones in the events with N_p<2 (N_{ev}=5220) were determined for the first time, i.e.

$$R = \frac{[1/N_{ev}(dN/dp_T]_{N_p \geq 2}}{[1/N_{ev}(dN/dp_T]_{N_p < 2}}$$

In conditions of 4π -geometry, the new method is offered to separate the multi-nucleon events for central collisions and to extract more information on the enhancement and suppression phenomenon.

The experimental data were obtained using the 2m propane bubble chamber of the Laboratory of High Energies (*LHE*) of Joint Institute for Nuclear Research (*JINR*) (Dubna, Russia) exposed to a beam of relativistic π^- -mesons at the momentum of 40GeV/*c* at Serpukhov Accelerator. The statistics of the analyzed data consists of 16865 measured π^-+^{12}C inelastic events corresponding to the cross section 179±2mb [21]. The methodological issues connected with the processing of the stereo photos, selection and identification of types of interactions in propane (C_3H_8), reconstruction of the kinematical characteristics of the secondary particles, their identification, and inclusion of corrections due to the loss of particles emitted under large angle to the object plane of the camera are described in details in [22]. The separation of protons and π^+ -mesons was done visually based on their ionization in region p<700 MeV/*c* and protons were identified, since a momentum 140 MeV/c at which the track starts to be precisely visible (length >3cm). The analysis on δ -electrons showed that the admixture of protons among the fast positive singly charged particles identified as π^+-mesons was 12±5% of the measured mean multiplicity of protons [23]. It should be mentioned that π^- -mesons make up the main fraction (>95%) among the negatively charged particles [23].

4. Results and Discussion

The values of R for the $\pi^{\pm}$-mesons and protons (with momentum p_p<1GeV/c) as a function of the p_T of these particles in $\pi^{-12}C$ -interactions at P_{π^-} =40GeV/c are shown in Figure1.

The R values are normalized to unit in our spectra. We can see that for the π^- -mesons and protons, within the error bars R =1. But for π^+ -mesons, beginning from p_T~1.2GeV/c, one can observe anomaly behavior with maximum at p_T=1.2GeV/c. This result could be explained with admixture of protons among the fast π^+ -mesons. Another reason could be due to weak criterion in the selection of multi-nucleon events in our experiment. This result needs further analysis.

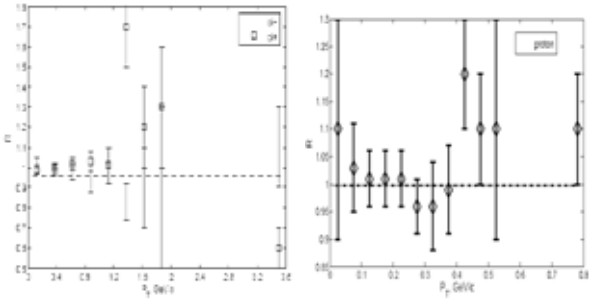

Figure 1. R (p_T) dependence for $\pi^{-12}C$ -interactions at P_{π^-} =40GeV/c. left –pions, right –proton.

Figure 2 shows the π^-/π^+ ratio in 0%–12%, MB *Au+Au*, and *d+Au* collisions [19]. We observe that the π^-/π^+ ratios are consistent with unity in *d+Au*, *MB*, and central *Au+Au* collisions. Predictions from a *pQCD* based model with and without partonic energy loss are consistent with the data. The behavior of our experimental curve (left graph) is the same that for above mentioned collisions in region p_T<3.5 GeV/c. Some discrepancy maybe is due to weak criterion in the selection of multi-nucleon events in our experiment.

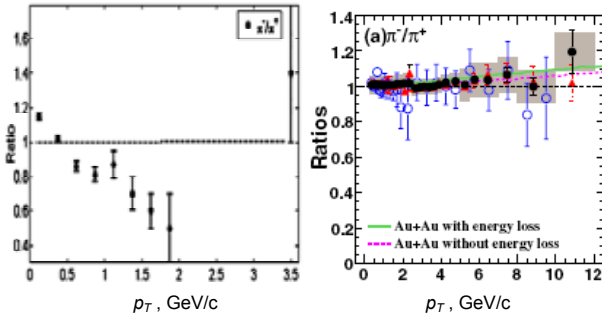

Figure 2. The π^-/π^+ ratios in: (left) π^-+^{12}C interactions at 40GeV/*c*; (right) 12% central (○), *MB Au+Au* (●) and *d+Au* (▲) [24] collisions at $\sqrt{s_{NN}}$ =200GeV. The shaded boxes represent the systematic uncertainties in the top 12% central *Au+Au* collisions. The systematic uncertainties for *MB Au+Au* collisions are similar. Curves are the corresponding predictions from a jet quenching model [25].

Figure 3 shows R (p_T) dependence of charged pions $((\pi^+ + \pi^-)/2)$ in different collisions [26]. For comparison our experimental data is given too(left). It is seen that our data approximately consistent with the *PHENIX RHIC* collisions ones (*Au + Au* at 200 GeV /nucleon). One can also see that strong suppression at $\pi^{-12}C$– interactions are observed, while only small suppression at *SPS* observed.

Table 1.

No	Experiment	Collision	Energy, $\sqrt{s_{NN}}$, GeV	Particle	Observation	Paper
1	*SPS*, *WA98*	*Pb+Pb*	17.4	π^0	A significant suppression (.5±.14) that is reminiscent of the high-p_T suppression observed in *Cu+Cu* and *Au+Au* at *RHIC*.	3
2	*SPS*, *WA98*	*Pb+Pb*	17.3	π^0	large enhancement at p_T ~ 3−4GeV/c in central *Pb+Pb* relative to *p+p* collisions; a suppression in central relative to peripheral nuclear collisions	8
3	*SPS*, *NA57*	*Pb+Pb*	17.3	K_s^0 K^-	R_{CP} is constant at 0.9 for p_T >1GeV/c and is significantly larger than *WA98* for π^0 (≈.6); At top *RHIC*, the kaon R_{CP} is larger than for π^0 for p_T ≤2GeV/c, while they are same for higher p_T	9
4	*SPS*, *NA49*	*Pb+Pb*	17.3	p/π K/π Λ/K K/π	enhancement of the baryon/meson ratio for p_T>2 GeV/c; R_{CP} ratio does not show Cronin enhancement for the mesons at larger p_T when using binary collision scaling; a saturation tendency at high p_T is observed.	10
5	*SPS*, *NA49*	*Pb+Pb*	17.3	$\pi^{\pm}$, p, $\bar{p}$, $K^{\pm}$	R_{AA} shows a rapid rise p_T upto 4.5GeV/c; R_{CP} ratio stays below 1 in the $\pi^{\pm}$ channel. R_{CP} ratios stay rat-her close to the 200GeV *RHIC* results,the 200GeV $\pi^{\pm}$ ratio shows a larger suppression at p_T≥2GeV; p ratio is almost identical to the 200GeV ratio.	11
6	*RHIC, STAR*	*Au+Au and p+p*	200	$\pi^{\pm}$, ρ^0, π^0, $\bar{p}$ p	$p+\bar{p}$ &$\pi^{\pm}$ R_{AA} seem to behave oppositely to what is naively expected from color charge dependence of energy loss; the ρ^0, $\pi^{\pm}$&π^0 *NMF* are comparable; fragmentation of mesons are similar,5≤p_T≤15GeV.	12
7	*RHIC, Phenix*	*Cu+Cu*	22.4, 62.4 and 200	π^0	high-p_T yields in central collisions at 62.4& 200 GeV are suppressed; at 22.4GeV, yields for p_T≥2GeV/c are not suppressed; R_{AA} at 22.4GeV is consistent with Cronin enhancement; the results demonstrate that suppression starts to prevail over enhancement between 22.4&62.4GeV.	13, 14,15
8	*RHIC, STAR*	*Cu+Cu and p+p*	200	*J/Ψ*	high-p_T production mechanism is closer to parton-parton scattering; R_{AA} in *Cu+Cu* increases from low to high-p_T ; the average of R_{AA} at p_T>5GeV/c is 0.9±0.2, consistent with no *J/Ψ* suppression.	16
9	*RHIC, Phenix*	*Au+Au, Cu+Cu*	200	π^0,γ *J/Ψ* ω η,φ	all high-p_T particles are suppressed (except for γ in *Cu+Cu*); not all mesons are suppressed by the same factor;π^0 suppression only depends on the N_{part} for the same $\sqrt{s_{NN}}$ which is consistent with a parton energy loss picture.	17
10	*RHIC, STAR*	*Au+Au*	200	$\pi^{\pm}$,p $\bar{p}$	p& $\bar{p}$ less suppressed than $\pi^{\pm}$, in 1.5≤p_T≤6GeV/c; π^- /π^+& $\bar{p}$ /p ratios show a weak p_T dependence.	18
11	*JINR*	$\pi^{-12}C$	32	$\pi^{\pm}$,p	for π^-&p, the R = 1; for π^+, the anomaly behavior with maximum at p_T = 1.2 GeV/c is observed; behavior of π^-/π^+ ratio& $(\pi^+ + \pi^-)/2$ R (p_T) in p_T < 3.5GeV/c is the same that for *Au+Au* 200GeV *RHIC PHENIX* data.	

5. Conclusion and Recommendations

Starting from a discussion on *SPS*, *RHIC* and *LHC* results, we have tried to motivate the necessity to move from them to $\pi^{-12}C$ –interaction to extract more information on the enhancement and suppression phenomenon. In conditions of 4π -geometry, the new method is offered to separate the multi-nucleon events for central collisions. We demonstrate that the results are in agreement with the *SPS CERN* and *RHIC BNL* ones. The π^-/π^+ ratio of $\pi^{-12}C$ data are consistent with results obtained for *Au+Au* and *d+Au* collisions. Table 1 presents the papers of the cases concerned, with a description of the experiment, collision, energy, type of particle and observation.

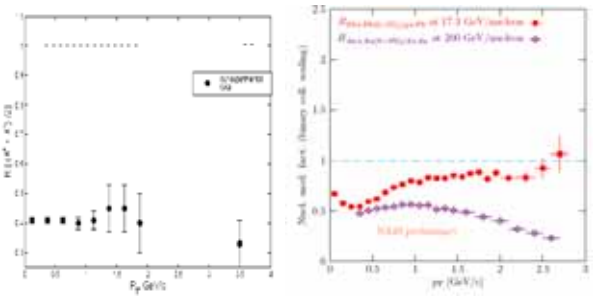

Figure 3. The $(\pi^+ + \pi^-)/2)\, R\,(p_T)$ dependence in different collisions.

Measurements of identified protons and pions from low- to high transverse momentum have proven to be a valuable tool in understanding the particle production and energy loss mechanisms in relativistic heavy ion collisions. The suppression of hadrons at high transverse momentum leads one to conclude that the partons undergo a large energy loss due to a hot, dense medium created during the collisions. By studying the multi-nucleon events in hadron - nucleus and nucleus - nucleus interactions one can get useful information about collective phenomena. Our results could be used in other hadron - nucleus and nucleus-nucleus interactions with different incident particles and energies, as well as in heavy ion collisions, especially in *SPS*, *RHIC* and *LHC* experiments.

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