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STUDY OF THE TRANSVERSE COMPONENT OF THE MOMENTUM VECTOR OF CHARGED PIONS AND PROTONS IN p^{12} +C INTERACTIONS AT MOMENTUM OF INCIDENT PROTONS WITH 4.2GeV/c

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***Abstract*:** To obtain information on collective phenomena, such as the formation of Δ^0-baryon resonances, the properties of negative π -mesons and protons are studied using comparisons of pC - and pp - interactions at 4.2 GeV/c. For comparison, the value of $R\ (p_T)$ as a function of the transverse momentum is used. The data were obtained from a 2-m propane bubble chamber of the Joint Institute for Nuclear Research (Dubna, Russia).

Keywords: proton-carbon interaction, 4.2GeV/c, transverse momentum, collective phenomena

1. Introduction

The transverse momentum of a particle, which is a Lorentz-invariant quantity, has been accepted as a useful parameter in the study of strong interaction dynamics [1].

From the study of proton-proton, proton-nucleus interactions at the energies of Relativistic Heavy-Ion Collisions (RHIC), it is clear that the production of baryons is enhanced and this is believed to be due to the multi-nucleon scatterings of initial partons [2]. The production of negative hadrons and protons has also been calculated, which shows that as the mass of the incident particle increases, the multiplicity (average number of negative particles) of negative particles also increases as a result of proton-proton and proton-nucleus interactions [3].

The particles with high transverse momentum at low energies, $\sqrt{s_{NN}}$ = 17.2GeV, show Cronin enhancement [4], which is related to the multiple nucleon scatterings of the partons inside the substance. At higher energies, $\sqrt{s_{NN}}$ =62.4GeV, in central collisions, there is no Cronin enhancement and high-p_T particles suppress at very high energy, i.e. $\sqrt{s_{NN}}$ =200GeV. The suppression of the particles varies with the particle mass at $\sqrt{s_{NN}}$ =200GeV, i.e. particle with higher mass suppresses less and vice versa. The nuclear modification factor, a term used for the observation of an increased amount of particle production at high p_T, decreases with increasing energy. One interpretation of no Cronin enhancement at forward rapidity is that coalescence decreases it.

At the QM2005 conference, calculations of high-p_T hadron suppression at the Super Proton Synchrotron (SPS) were presented for neutral short-lived K -mesons R_{CP} (p_T), positive and negative π^--mesons and protons [5] in comparison with radiative energy loss calculations. The 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 pseudo-rapidity) leads to good agreement between calculation and data. These data solve the high transverse momentum 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 the potentially high Cronin effect at lower energies.

The neutral pion spectra are measured [6] in pC and pPb collisions at the energy of $\sqrt{s_{NN}}$ = 17.4GeV in the range of $0.7 \leq p_T \leq 3.5$GeV/c. Based on these spectra, the nuclear modification factor for PbPb collisions at CERN SPS energies has been determined using a measured pA reference. In very central PbPb collisions (0 -1%), a significant suppression of high-p_T neutral pions is observed (≈ 0.5), which is reminiscent of the high-p_T hadron suppression observed in CuCu and AuAu collisions at RHIC. The pion suppression, together with the results at higher energies from RHIC, will allow constraining the energy dependence of hadron suppression.

A study of transverse momentum spectra for positive and negative pions, protons, and antiprotons from gold-gold and copper-copper data at the energies $\sqrt{s_{NN}}$ = 200 and 62.4GeV as a function of collision centrality and by comparing these measurements with pp and dAu data shows [7] that the suppression of the charged pions at high-p_T allows us to conclude that the partons undergo a large energy loss due to a hot, dense medium created during the collisions. Analysis of protons and pions indicates that the partonic energy loss is similar for both the gluons and quarks.

2. The Experimental method of pC –interactions

The experimental data were obtained using the 2m propane bubble chamber of the Laboratory of High Energies of Joint Institute for Nuclear Research (JINR) (Dubna, Russia) exposed to a beam of protons, helium, and carbon nuclei at the momentum 4.2AGeV/c per nucleon at Dubna Synchrophasotron [8]. In Table 1, specifications of pC and pp –interactions are given. In this experiment, the impurity of the charged strange particles does not exceed 1%. Therefore, all negative particles, except for identified electrons, were considered as negative pions. The impurity not identified electrons in studied collisions are practically absent. The average density of δ -electrons on tracks of protons with a length of a trace more than 5 mm made $0.021 \pm 0.001 cm^{-1}$.

Table 1

Features of the experiments

Type of interaction	**The momentum of the beam, GeV/c**	**Accelerator**	**year**	**No. of inelastic interactions**
pC	4.2	Synchrophazotron, LHE, JINR, Russia	1976	6736
pp	4.2	Synchrophazotron,	1976	4753

Positive particles contain positive pions, protons, and heavier single-charged fragments of nuclei (deuteron, tritium). The observed fragments with $Z \geq 2$ were fragments of a nucleus

projectile. Different procedures were used for the allocation of fragments from a set of all positively charged particles. Using them, it has been obtained, that a fraction of positive pions in the total number of positive particles in the momentum range of p_{π^+}= (0.5–2.0)GeV/c did not exceed 13.5 %.

Protons, deuterons, and heavier fragments in a propane bubble chamber can be possibly divided for the ionization density along the tracks only in a momentum range of (1.0–2.0)GeV/c. Experimentally certain value of the contribution of deuterons and heavier fragments in the total number of fragments was equal to ~2.2% in a considered momentum range. In our experiment, it allows us to assume that the positively charged particles (except for identified positive pions) are mainly protons. Protons used in the work were taken with p>0.15GeV/c and negative pions with p>0.08GeV/c, since 0.15GeV/*c* and 0.08GeV/*c* are the average lower momentum thresholds for proton and pion registrations, respectively, in propane chamber. Below these threshold values the efficiency of registration of these particles is very low. So-called stripping protons (spectator protons from projectile-nucleus) with p>3GeV/*c* and θ (emission angle) <4 degrees (in laboratory frame) for interactions at initial momentum of 4.2*A*GeV/*c* were excluded.

We have analyzed 4753 inelastic pp -interactions at energy 4.2GeV/c and 6736 inelastic pC -interactions at 4.2GeV/c. To obtain information on collective phenomena, such as the formation of Δ^0-baryon resonances, the properties of negative π -mesons and protons are studied using comparisons of pC - and pp -interactions at 4.2 GeV/c. Particle yield dN/dp_T is calculated and then nuclear modification factor R is established by comparing *pA* yield with *pp* yield.

Now let's present the experimental results from proton-carbon interactions taken from 2m propane bubble chamber. The Nuclear Modification Factor has been used to analyze the results. Its general formula is the following:

$$R = \frac{[1/N_{events}^{tot}(dN_{\pi^-,proton}/dp_t)]^{pC}}{[1/N_{events}^{tot}(dN_{\pi^-,proton}/dp_t)]^{pp}}$$

It should be noted that integration of the nominator (and denominator) gives us the mean multiplicity (it is the number of particles per event) of pC and pp -interactions. The mean multiplicity is one of the important features for obtaining important information from hadron-nuclear and nuclear-nuclear interactions.

2.1. The experimental results for protons

In Figure 1, the values of R for protons are given. The momentum of the incident protons is 4.2GeV/c. It is seen that:

1. In low p_t region (p_T<0.3GeV/c), a peak at p_T>0.15GeV/c is seen;
2. There is a weak enhancement in the high-p_t region (p_T>1.2GeV/c).

2.2. The Experimental results for negative pions

In Figure 2, the values of $R = \frac{[1/N_{events}^{tot}(dN_{\pi^-}/dp_t)]^{pC}}{[1/N_{events}^{tot}(dN_{\pi^-}/dp_t)]^{pp}}$ negative pions are given. The momentum of the incident protons is p_p= 4.2GeV/c. It is seen that:

1. There are two different regions for the emission of π^- -mesons: p_T<0.45GeV/c and p_T>0.45GeV/c. The value of R in both regions increases;
2. At p_T≈0.45GeV/c, one can observe a minimum that could be used in order to distinguish low and high-p_T regions for pions;

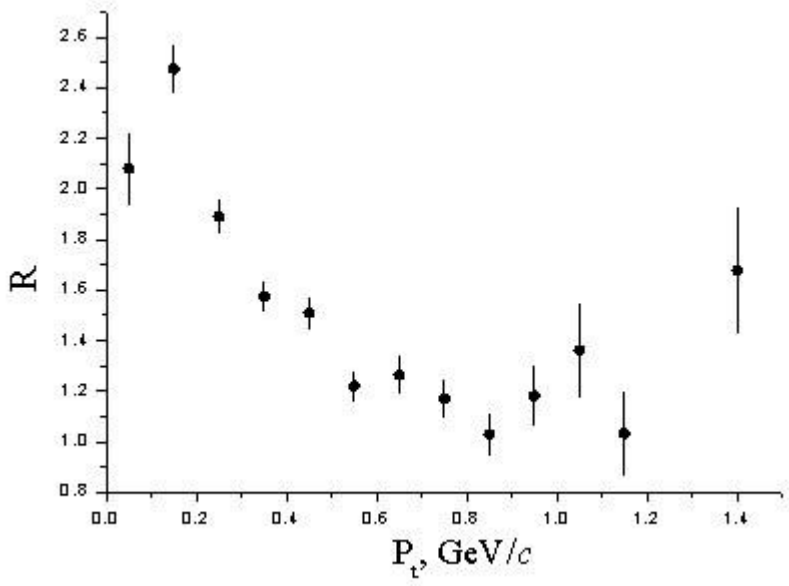

Fig. 1. The ratio R (protons) for pC -interactions at 4.2GeV/c

3. There is a tendency in the increase of the mean multiplicity of negative pions in the low-p_t region (p_T<0.45GeV/c) in pC -interactions compared to pp -interactions at the same incident energy (4.2GeV/c).

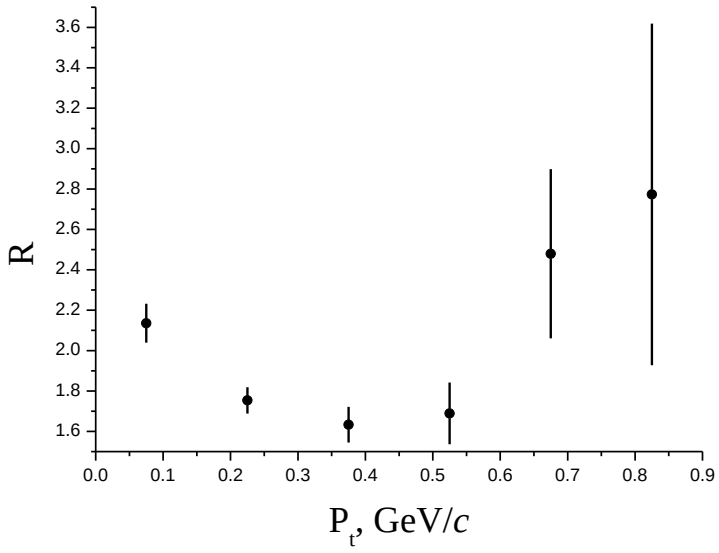

Fig. 2. The ratio of R (negative pions) for pC -interactions at 4.2GeV/c.

3. Conclusion

In $R(p_T)$ dependence, the mean multiplicity of negative pions increases in the high- p_T region (p_T>0.45GeV/c). These are not correlated with the slow protons (p_T<0.3GeV/c), which do not participate in the interaction. That's why these high-p_T pions and slow protons are direct particles. But in $R(p_T)$ dependence, in the high-p_t region (p_T>1.2GeV/c) for protons, the enhancement is observed. This enhancement is due to the collective phenomena, i.e. because of the contribution from central-central collisions, where the p_T enhancement can be explained to be due to the processes of hard scattering in central nucleus-nucleus collisions. High-p_T protons are correlated with the low-p_t negative pions (p_T<0.45GeV/c). The dominant mechanism for the emission of the low-p_T negative pions and high-p_T protons is the Δ^0 -baryon resonance decay.

By studying the multi-nucleon phenomenon in hadron-nucleus and nucleus-nucleus interactions one can get useful information about collective phenomena. Our results can 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 Large Hadron Collider (LHC) experiments.

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ИЗУЧЕНИЕ ПОПЕРЕЧНЕГО КОМПОНЕНТА ВЕКТОРА ИМПУЛЬСА ЗАРЯЖЕННЫХ ПИОНОВ И ПРОТОНОВ В p^{12} +C ВЗАИМОДЕЙСТВИЯХ ПРИ ИМПУЛЬСЕ ПАДАЮЩИХ ПРОТОНОВ С 4,2ГэВ/с

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Резюме: Чтобы получить информацию о коллективных явлениях, например, о рождении Δ^0 – барионных резонансов, свойства отрицательного π –мезонов и протонов изучены с использованием сравнений *pC* - и *pp* –взаимодействий при импульсе 4,2ГэВ/с. Для сравнения,

использована величина $R\ (p_T)$, как функция поперечного импульса. Данные получены из 2-х метровой пропановой пузырьковой камеры Объединённого Института Ядерных Исследований (Дубна, Россия).

Ключевые слова: протон-углеродное взаимодействие, 4.2ГэВ/с, поперечный компонент импульса, коллективные явления

4.2QeV/c İMPULSLU DÜŞƏN PROTONLARIN p^{12} +C QARŞILIQLI TƏSİRLƏRİNDƏ YÜKLÜ PİON VƏ PROTONLARIN İMPULS VEKTORUNUN ENİNƏ TOPLANANININ ÖYRƏNİLMƏSİ

Y.H. Hüseynəliyev

Xülasə: Kollektiv hadisələr, məsələn Δ^0 –baryon rezonansın əmələgəlməsi haqqında məlumat almaq üçün 4,2GeV/c impulslu *pC* və *pp* qarşılıqlı təsirlərində yaranan proton və mənfi yüklü π –mezonun xassələri öyrənilmişdir. Müqayisə üçün, impulsun eninə toplananının funksiyası kimi $R\ (p_T)$ kəmiyyətindən istifadə olunmuşdur. Verilənlər, Birləşmiş Nüvə Tədqiqatları İnstitutunda, propanla doldurulmuş 2 metrlik qabarcıqlı kameradan (Dubna, Rusiya) alınmışdır.

Açar sözlər: proton-karbon qarşılıqlı təsiri, 4.2QeV/c, impulsun eninə toplananı, kollektiv hadisələr