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A SEARCH FOR NONNUCLEONIC DEGREES OF FREEDOM BY MEANS OF πXe INTERACTIONS AT 2.34 AND 3.5 GeV/c

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Поиск ненуклонных степеней свободы при помощи реакции πXe
при импульсах 2,34 и 3,5 ГэВ/с

Анализируются ранее полученные экспериментальные данные, касающиеся периферических взаимодействий π-мезонов с ядрами ксенона при импульсах 2,34 и 3,5 ГэВ/с с точки зрения поиска ненуклонной внутриядерной мишени, которая могла бы проявить себя в этих взаимодействиях. Поскольку изучаемые взаимодействия являются, в основном, только однократными внутриядерными столкновениями (или, другими словами, так называемыми квазисвободными столкновениями), то возможные корреляции между измеренными углами эмиссии θ_π и полной энергией E_π π-мезонов, образованных в этих взаимодействиях, и, в частности, в квазидвухчастичных каналах, могут заключать в себе информацию о массе внутриядерной мишени. Данные, представленные в виде двумерных диаграмм рассеивания (θ_π; E_π), свидетельствуют о существовании четкой концентрации экспериментальных точек в области кинематической кривой, соответствующей внутриядерной мишени с массой π-мезона. Обсуждаются также фоновые эффекты, которые могут приводить к аналогичной корреляции.

Работа выполнена в Лаборатории высоких энергий ОИЯИ.

Сообщение Объединенного института ядерных исследований. Дубна, 1999

Slowiński B. E1-99-93
A Search for Nonnucleonic Degrees of Freedom by Means
of πXe Interactions at 2.34 and 3.5 GeV/c

The experimental data concerning the peripheral interactions of π mesons with xenon nuclei at 2.34 and 3.5 GeV/c [1] are reanalysed in order to search for a nonnucleonic intranuclear target, which may appear in these interactions. Since such interactions are predominantly one-step intranuclear collisions (or, otherwise, the so-called quasi-free collisions) only, therefore a possible correlation between the measured emission angles θ_π and total energies E_π of π mesons produced in these interactions, and, in particular, in quasi-two-body channels, may give information about the intranuclear target's mass [1]. Our results presented in the form of two-dimensional scatter plots (θ_π vs. E_π) show a clear concentration of experimental points around the kinetic curve corresponding to the intranuclear target of pion's rest mass [2]. Background effects, which may simulate the observed correlation, are also discussed.

The investigation has been performed at the Laboratory of High Energies, JINR.

Communication of the Joint Institute for Nuclear Research. Dubna, 1999

I. INTRODUCTION

The interest in searching for experimental signals of pionic degrees of freedom in nuclei has already a long story and is inspired by the basic role of pions in the nuclear many-body problem. The relevant results are also of principal importance for hadronuclear physics (for example, [2-4]). In this work we re-examine our experimental data concerning the interactions of π^+ mesons at 2.34 GeV/c and π^- mesons at 3.5 GeV/c with xenon nuclei [1]. These data have been obtained using two xenon bubble chambers (XeBC): the 24 l XeBC of the Laboratory of High Energies, JINR (Dubna) [5] and $1m^3$ XeBC of the ITEP (Moscow) [6]. The principal idea of our analysis consists in probing the nuclei with fast pions in such a way that only the simplest events, i.e. the so-called quasi-free two-body channels of the reaction could be selected. It has been showed that such channels may be considered as one step intranuclear collisions in which both secondary particles experience no more interactions in the target nucleus except small angle rescatterings being indistinguishable within experimental error [1]. Therefore they may be considered to be used in order to extract information about the mass of intranuclear effective target involved in these collisions.

I.1. The probability of quasi-free interactions

The quasi-free channels of interaction of fast projectile particles (for instance, protons or π mesons) with heavy enough nuclei may be defined [7] as such when a primary particle penetrating through the target nucleus with the radius R at the impact parameter r_o experiences only one inelastic collision with an intranuclear (quasi-free) hadron and the particles produced in this collision leave the nucleus without any inelastic scattering inside it, as schematically shown in Fig.1.

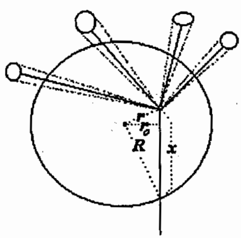

Fig.1. Schematic picture of a quasi-free intranuclear collision.

The probability density function for such event is [7]:

$$f(r_o) = \sigma_N \int_{-\sqrt{R^2-r_o^2}}^{\sqrt{R^2-r_o^2}} \rho(\sqrt{r_o^2+x^2})\exp\{-[\sigma_N \int_{-\sqrt{R^2-r_o^2}}^{x} \rho(\sqrt{r_o^2+x^2})dx + \sum_i f_i(r_{o_i})]\}dx. \quad (1)$$

Here σ_N is the total cross section for interaction of the primary particle with a nucleon, $\sigma_N^{(i)}$ is the total cross section for inelastic interactions of the i-th particle produced in the collision, $\rho(r)$ is the single nucleon density distribution (SNDD) in the target nucleus, and

$$f_i(r_{o_i}) = \sigma_N^{(i)} \int_{(\varphi_i,\vartheta_i)} \rho(\sqrt{r_{o_i}^2 + x_i^2})dx_i \quad (2)$$

where (φ_i, ϕ_i) are emission and azimuthal angles of the trajectory of the i-th produced particle.

In consequence of considerable similarity of a shape of SNDD of intermediate and heavy nuclei and relatively weak energy dependence of total inelastic cross sections for hadron-nucleon interactions at energy above ~1 GeV the behaviour of the function (1) does not change appreciably with energy and atomic number. Moreover, the effect of increasing multiplicity of secondary particles at higher energy is also efficiently compensated by the narrowing a cone (φ_i, ϕ_i) within which these particles are emitted. It is easy to see it when considering the fraction P of quasi-free interactions expressed by the function $f(r_o)$ (1) and the total cross section σ_{in}^{tot} for inelastic channels as:

$$P = \frac{2\pi}{\sigma_{in}^{tot}} \int_0^R f(r_o) r_o dr_o. \quad (3)$$

The calculated value of this quantity is 0.30±0.01 for π-Xe interactions in the interval of primary pions energy of ~2-9 GeV, which is in good agreement with the experimental value 0.30±0.03 for these interactions, and, in particular, for π-Em interactions at much higher energy, too [7]. Space localisation of quasi-free interactions is such that half of all them occur in the region of impact parameters $r_o \geq 0.8R$. As an example the function $f(r_o)$ for the probability of quasi-free interactions of π^+ mesons with xenon nuclei at 2.34 GeV/c [7] is displayed in Fig.2.

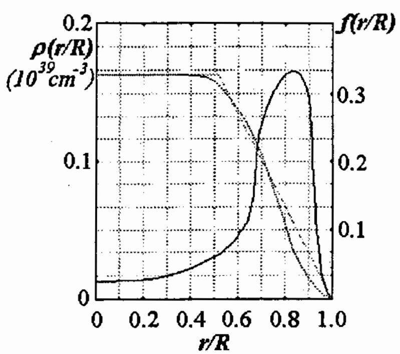

Fig.2. The probability of quasi-free interactions of π^+ mesons with xenon nuclei at 2.34 GeV/c [7].

In this figure there is also displayed the SNDD for the nucleus $_{54}Xe^{131}$ as a function of relative radius r/R and its trapezoidal approximation used for calculations. One can also note that the form of the probability density function $f(r_o)$ (1) does not depend remarkably on the specific channel of quasi-free hadron-nucleon interactions although the maximum of this function slightly shifts towards the larger values of impact parameter r_o with increasing the multiplicity of produced particles in the channel and at the same time the width of this maximum becomes narrower.

I.2. Kinematics of two-body collisions

Let us consider the following two-body collision of a primary particle **1** with a target particle **x** when particles **3** and **4** are secondary ones:

$$1 + x \to 3 + 4.$$

Then according to the momentum and energy conservation law we have:

$$\vec{P}_1 + \vec{P}_x = \vec{P}_3 + \vec{P}_4$$

$$E_1 + E_x = E_3 + E_4.$$

In the LAB system of reference, where the target particle **x** is at rest one can easily obtain a relation between the emission angle Θ_o and energy E_o of particle **3** (see Fig.3):

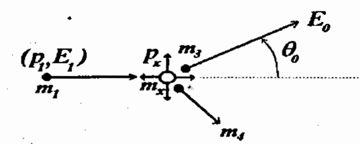

Fig.3. Kinematics of two-body collision with a target particle **x** 1) at rest and 2) oscillating.

$$\cos\Theta_0 = \frac{2E_0(E_1 + m_x c^2) - [(m_1c^2)^2 + (m_xc^2)^2 + (m_3c^2)^2 - (m_4c^2)^2 + 2E_1 m_x c^2]}{2\sqrt{(E_1^2 - m_1c^2)(E_0^2 - (m_3c^2)^2}} \quad (4)$$

In the case of oscillating target:

$$b_l \cos\Theta_0 + b_t \sin\Theta_0 =$$

$$\frac{E_0^2 - (m_3c^2)^2 - [(E_1 + E_x - E_0)^2 - (m_4c^2)^2)]^2 + (p_1c)^2 + 2p_1cp_x\cos\Theta_x + (p_xc)^2}{2c\sqrt{E_0^2 - (m_3c^2)^2}} \quad (5)$$

Here $p_x \in \exp(-\frac{p_x^2}{2p_0^2})$ with $p_0 \cong 200 MeV/c$ and $b_l \equiv p_1 + p_x\cos\Theta_x$, $b_t \equiv p_x \sin\Theta_x$.

So, in the scatter plot Θ_o/E_o experimental points concerning the particle **3** (fig.3) should be spread around the curve (4) of the form $\cos\Theta_o = f(E_o|m_x)$ within experimental errors, and, if in addition we take into account Fermi oscillations of the target m_x an area of experimental observations becomes much larger according to the formula (5). En example of such distribution is shown in Fig.4 where experimental points represent π^o mesons produced in the quasi two-body reaction π^++Xe->π^o+p+A at 2.34 GeV/c [1,3]. Solid curves in the figure correspond to kinematics of two-body reactions π^++n -> π^o+p and π^++ π^- -> π^o + π^o at the same primary momentum, respectively.

Within two dashed curves comprised are about 90% experimental points representing π^o mesons from the reaction π^++n-> π^o+p when target neutrons oscillate at the temperature of 20 MeV.

II. RESULTS AND DISCUSSION

In the following figures shown are scatter plots Θ_o / E_o for experimental points corresponding to π^o mesons from two reactions: π^++Xe at 2.34 GeV/c and π^-+Xe at 3.5 GeV/c, leading to quasi two-body channels pointed in these figures.

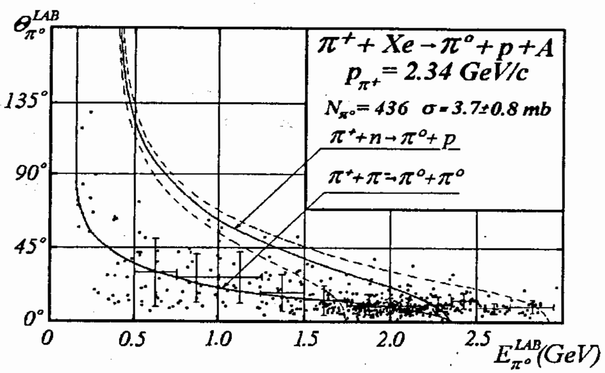

Fig.4. Scatter plot of experimental points for π^o mesons from the reaction π^++Xe->π^o+p+A at 2.34 GeV/c [1,8]. Two solid curves correspond to kinematics of two-particle reactions pointed in the Figure. Within the two dashed curves comprised should be about 90% experimental points representing π^o mesons from the reaction π^++n-> π^o+p when target neutrons oscillate at the temperature of 20 MeV. Crosses mark out the regression curve for experimental points.

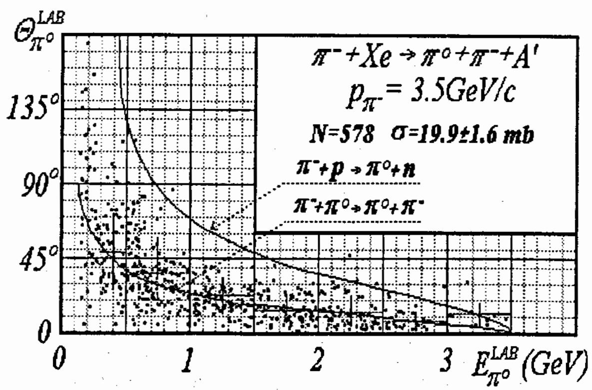

Fig.5. Same as in Fig.4 but for the reaction π^-+Xe at 3.5 GeV/c [1,8].

One can notice that experimental points are remarkably concentrated around the curve corresponding to the pionic effective mass target: experimental regression curves coincide with kinematics curves for ππ->ππ scattering within the limits of r.m.s. deviation of experimental points. But such a conclusion is not more valid if we consider the reaction π^++Xe->(η^o->2γ)+A' at 2.34 GeV/c where only one η^o meson has been produced, although in this case a number of analysed events is very low [8]. Moreover, we do not observe any collimation of experimental observations around the kinematics curves for ππ->ππ scattering in the case of interactions of π^+ mesons with free protons: π^++p->π^o+π^++p and π^++p->π^++π^++n at 2.34 GeV/c [9], even when a constraint following from the condition of applicability of one pion exchange mechanism of the interaction was taken into consideration [8].

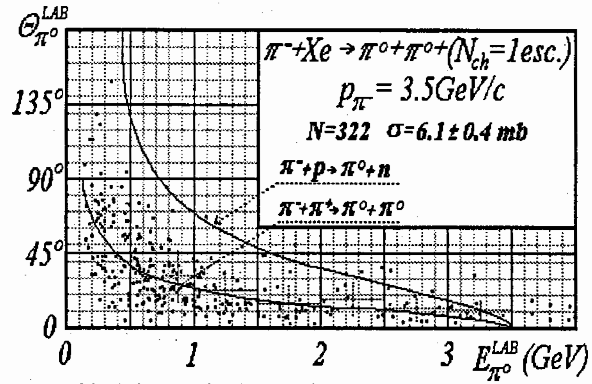

Fig.6. Same as in Fig.5 but for the reaction pointed in the figure.

III. CONCLUDING REMARKS

It is interesting to remark that some collimation in the vicinity of kinematics of ππ->ππ scattering at the same values of energy is also observed in the case of π^o mesons produced in all channels of quasi-free π^++Xe interactions at 2.34 GeV/c, π^++Xe->π^o+(N_{ch} ≤4) at 2.34 GeV/c, in which the number N_{ch} of secondary charged particles N_{ch} ≤4 and, therefore, more than 2 pions are produced (Fig.7)[8].

Finally it should be noted that in all examined cases the observed correlation may also be influenced, at least to some extent, by the effect of intranuclear quasi-elastic re-scattering of observed neutral pions since this effect reduces energy of emitted pions remaining them within a narrow enough cone of emission angles what may suggest the ππ->ππ kinematics of the reaction. Other probable effect consists in many-body intranuclear collisions leading to the emission of slow fragments and neutrons which are not registered in the experiment. The evaluation of such background effects is feasible only by means of computer modelling of intranuclear cascade-evaporation process but our preliminary results seemed to not confirm this suggestion.

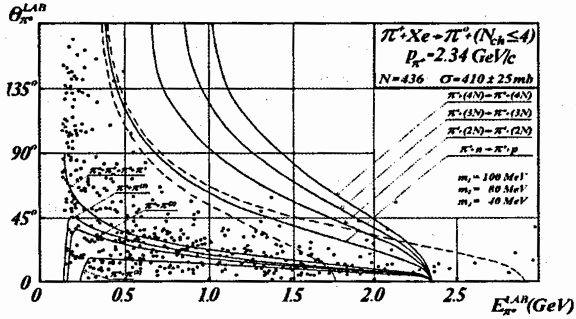

Fig.7. Same as in Fig.4 but for all channels of quasi-free π^++Xe interactions [1,8]. Showed are also different kinematics curved described in the figure.

Finally it should be noted that in all examined cases the observed correlation may also be influenced, at least to some extent, by the effect of intranuclear quasi-elastic re-scattering of observed neutral pions since this effect reduces energy of emitted pions remaining them within a narrow enough cone of emission angles what may suggest the $\pi\pi \to \pi\pi$ kinematics of the reaction. Other probable effect consists in many-body intranuclear collisions leading to the emission of slow fragments and neutrons which are not registered in the experiment. The evaluation of such background effects is feasible only by means of computer modelling of intranuclear cascade-evaporation process but our preliminary results seemed to not confirm this suggestion.

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