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STUDY OF NUCLEAR TRANSPARENCY.

Proposal for European Electron Facility

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STUDY OF NUCLEAR TRANSPARENCY: Preprint ITEP 93-23/

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The experimental program for studying the effect of nuclear transparency at high energy eA interaction is suggested. The studying of nuclear response as a criteria of nuclear transparency is suggested for the first time. The experimental conditions for these studying, which could be achieved at European Electron Facility using the 4π detector are discussed.

Fig. - 7, ref. - 23

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1 Introduction.

Using nuclei for the determination of resonances cross-sections is known long ago and rather good [1]. For the determination of cross-sections one should study A-dependence of resonance yield and compare it with some model. Up to now the cross-sections of interactions of resonances from ρ to ψ and D with nucleons are determined by this way.

This activity based on the hypothesis that resonances are produced on nucleons inside nucleus and further their interactions with individual nucleons take place, i.e. in the hypothesis that definite reaction mechanism exists.

The passage of particles produced just now through the nucleus also can be used for the studying of space-time structure of such process [2]. The idea is that the produced particle not at once collects its field or partons ladder, so the cross-section for this particle is less than cross-section for the free particle.

Field collection time should increase with increasing of energy of secondary particle due to the relativistic effects and this also should affects on A-dependence of cross-section.

This conception is not full and not always correct. For example there is definite distribution of hadrons formation lengths which depends on the x_F of hadron [3]. The ν dependence of nuclear transparency

$$T = \frac{d\sigma(eA \to aX)}{Ad\sigma(eN \to aX)} \tag{1}$$

will be varied for different ranges of x_F . For various values of parameter x_F transparency should not approach to 1 at $\nu \to \infty$. Moreover there are models in which mean formation length approach to zero at $x_F \to 1$ [4].

Brodsky [5] presented a good example of nuclear transparency and named this phenomenon color transparency. The idea is that the particle has been produced at high momentum transferred Q^2, i.e. in the small volume and therefore in the pressed state. It is clear that in this case one should expect that $T \to 1$ if energy transferred $\nu \to \infty$. Fig. 1 shows experimental data [6] which qualitatively support this idea. It is important to emphasize that predictions of different models [7] shown in Fig. 1 differ to each other in detail.

It was pointed in [8] that "compressed" hadron is not a free hadron, but a superposition of a number of hadron states. The authors of [9] develop this thesis and pointed out that in the process of the formation of this superposition the role of the nucleus is very important; so the nucleus is not only the "detector" for the measuring of the value of the transparency. To separate the function of the "generator" and the function of the "detector" it will be useful to have measurements both for light and for heavy nucleus.

The term "color transparency" means consideration on quark level. On this level color transparency is treated as mutual color screening of quarks like charge screening of ultrarelativistic electron and positron pair at short distances from the production vertex (Chudakov effect) [10].

If one not suggest the quark hadronization in nucleus at the collision point, the connection between nuclear transparency and quark hadronization in nuclear matter becomes obvious. The hadronization process can prove to be very complicated and depends on many parameters.

Recently the effect of color transparency for J/ψ and ψ' mesons has been considered [8]. Sufficiently complicated behavior of function $T(\nu)$ has been predicted. This functions differ for J/ψ and ψ', e.g. $T < 1$ for J/ψ for all ν, while T can be more than 1 for ψ' for the large ν due to the presence of zero in ψ' wave function.

Finally, these examples show that

1. Nuclear or color transparency gives various information about hadrons properties during their passage through the nucleus and hadronization processes of quarks in nuclei what is more fundamental.

2. Properties of function $T(Q^2, \nu)$ depend on the mechanism and consequently on type of nuclear reaction in which hadron produced and naturally on the range of variables characterized this reaction.

In this proposal we suggest to study nuclear transparency for deep inelastic nuclear reactions for the wide range of Q^2 and ν. In this case we pay attention to different cases of nuclear response as an additional criteria of nuclear transparency.

2 Scenario of high energy hA interactions and its modification for lepton-nucleus interaction.

As a result of the analyses of deep inelastic nuclear reactions we suggest some variants of scenarios of particle production in hadron-nucleus and lepton-nucleus collision [11].

Fig. 2a. (hA interaction). The incident hadron is considered as a quark-gluon jet which successively interacts in the nuclear matter both with separate quasi-free nucleons and with any kind of fluctons. These fluctons may be shot-range few-nucleon clusters or multi quark bags (MQB) [12]. We shall use term "center of interaction" as more general notion. The hadronization of high energy quark-gluon jet occurs

outside the nucleus. The products of fragmentation of excited center are hadronized in nuclear matter into different particles ($p, n, \pi, K, \Lambda, \bar{p}$...) .

A lot of experimental data support this scenario for hA interaction. The most direct confirmation of space-time picture of this process was obtained in correlation measurements for two hadrons at small relative momentum [13, 14]. See also proposal concerning the cumulative particles production [15].

The scenario of particle production process in the electron-nucleus interaction at small Q^2 is shown in Fig. 2b. In this case virtual photon dissociates into $q\bar{q}$ -pair for a period of time which is considerably longer than time necessary to pass through a nucleus [16]. Therefore the $q\bar{q}$ -pair is the object interacting with the nucleus. This scenario is very similar to the scenario of hadron-nucleus interactions (see Fig. 2a). The experimental evidences for this scenario [17] are not so numerous as for hA interaction, but this scenario could be verified experimentally using the existing machine and properties of this interaction should be similar to that of high energy hadron-nucleus interaction.

The modification of properties of particle production process with the transition from the region of low Q^2 ($Q^2 < 0.1 GeV^2$) to that of high Q^2 ($Q^2 > 1 GeV^2$) is worthy of especial investigation. The scenario of the process of particle production in eA-interaction with high Q^2 is shown in Fig. 2c,d. In this case a virtual photon is absorbed by a quark in the vicinity of the point of its emission by the electron.

The schemes shown in Fig. 2c,d correspond to the different hadron jet energy $\nu = E - E'$. In the case of low energy ν (Fig.2c) not only the primary e-center interaction may serves as a source of secondary particles. Additional secondary nuclear "stars" would be produced by recoil quark if its hadronization will occur in the nucleus [2, 7, 18].

Fig. 2d shows the case of quark emission at high Q^2 and ν interaction, (but for $\frac{Q^2}{2m\nu} \doteq x > 0.1$; in other case the coherent interaction of the soft quark in nucleus in possible) when the hadronization of knocked quark should occur outside of the nucleus [2, 7]. Therefore the products of its hadronization would not take part in the generation of secondary particles. In this case the particles should be produced only as a result of the hadronization of the spectator quarks of that center in which the virtual photon have been absorbed.

3 Nuclear transparency in deep inelastic nuclear reactions.

Scenarios of deep inelastic nuclear reactions, which have been discussed above, contain definite information and make some predictions concerning nuclear transparency. These predictions depend on Q^2 and ν. Kopeliovich and Nemchik suggested a model [7] which also predicts the dependence of transparency on Q^2 and ν. Fig. 3 shows this model predictions for the transparency value as ν function up to the photon

energy 30 GeV for different A and Q^2 as a parameters. Transparency value depends on A and Q^2 strongly, so experiments with light and heavy nuclear targets and with different Q^2 in the range 1 - 10 GeV^2 would be mostly crucial.

Scenarios show that nuclear responses also depend on the Q^2 and ν. Nuclear response allows to determin for what kinematical area these scenarios realised.

Namely:

1.Experimental points in Fig.4 shows the value of normalized invariant cross section or the probability of cumulative particles production ρ

$$\rho = \frac{E \cdot d^3\sigma}{\sigma_{in} \cdot d\vec{p}} \tag{2}$$

as a function of energy of incident hadron [19], where σ_{in} is the cross-sections for incident particle interactions with nucleus. For the scenario in Fig. 2b one should expect the same dependencies of ρ on ν. In this case the definition of ρ should be transformed into

$$\rho = \frac{\frac{E \cdot d^3\sigma}{d\nu dQ^2 d\vec{p}}}{\frac{d^2\sigma}{d\nu dQ^2}} \tag{3}$$

For $Q^2 > 1GeV^2$ and small ν (Fig. 2c) ρ should be about one half of the value ρ for hadron-nucleus interactions and ρ should be further decrease with increasing ν if scenario in Fig. 2d is true.

2.The ν dependence of ρ is different for different nuclei. For small Q^2 and large ν $\rho \sim A^{1/3}$, for large ν and large Q^2 $\rho \rightarrow const$.

3. Mean sizes of the region of secondary hadrons production differ from each other for Fig. 2b, 2c, 2d. The transverse sizes are constant $r_\perp \sim 1fm$ while longitudinal sizes l and its A-dependence vary, so the shape of interaction region varys.

Predictions (see Table 1) are not depend on the manner of measuring of the sizes of the interaction region (by the measuring of mesons Bose-Einstein correlations or the final state interaction of nucleons or coalescense coefficient for deutrons e.t.c.).

4. For the hadron nucleus deep inelastic reactions the connection between sizes r and azimuthal asymmetry β [20, 21]

$$\beta = 2\frac{\int_{\frac{\pi}{2}}^{\pi} \sigma\, d\phi - \int_0^{\frac{\pi}{2}} \sigma\, d\phi}{\int_{\frac{\pi}{2}}^{\pi} \sigma\, d\phi + \int_0^{\frac{\pi}{2}} \sigma\, d\phi} \tag{4}$$

has been found [22]. This result is shown in Fig. 5. This connection should be expected in according to scenarios in Fig.2. Predictions for the values β for different Q^2, ν and A are obvious and listed in Table 1. The bright prediction is sharp angle asymmetry for heavy nucleus for $Q^2 \gg 1(GeV/c)^2$ and $\nu > 10$ GeV which is the same for light nucleus.

All these facts one can summarize in the table 1:

$Q^2, (GeV/c)^2$	$\ll 1$	$\gg 1$	$\gg 1$
ν, GeV	~ 5	~ 5	$\gg 5$
ρ	$\rho_h \sim A^{1/3}$	$1/2\rho_h \sim A^{1/3}$	$\rho_e \neq \rho_e(A)$
$r_\perp$	$const \sim 1fm$	$const \sim 1fm$	$const \sim 1fm$
l	$r_0 \cdot A^{1/3}$	$1/2r_0 \cdot A^{1/3}$	$const \sim 1fm$
β	$\sim A^{-1/3}$	$\sim A^{-1/3}$	$\beta_e \neq \beta_e(A)$

4 Why EEF and MEMUS.

Electron accelerator is desirable machine because electron at $Q^2 > 1GeV^2$ interacts with single quark locally. It takes electron accelerator with the energy 20-30 GeV because in this case only one can realize measuring of upper limit of nuclear transparency. One should use beams having sufficiently large intensity for accumulation of necessary statistics at large Q^2 and ν including the correlation measurements. All measurements should be carried out in coincidence with scattered electron for the determination of Q^2 and ν. One should measure also time coincidence of secondary particles from the nucleus fragmentation region. To carry out the experiments where the coincidence between secondary particles and scattered electrons or between secondary particles for the correlation measurements the high duty cycle is needed. For the detecting both forward and backward particles 4π detector is needed.

For the experiments with 4π detector counting rate is determined by the ee' cross-section. Table 2 shows the number of events for the different values of Q^2 and ν (in GeV and $(GeV/c)^2; E_0 = 15GeV; L = 10^{36} sm^{-2} sec^{-1} nucleon^{-1}; t = 10hours$).

	$1 < Q^2$	$2 < Q^2$	$4 < Q^2$	$8 < Q^2$	$16 < Q^2$
$1 < \nu < 2$	$3.7 \cdot 10^7$	$7.0 \cdot 10^6$	$6.0 \cdot 10^2$		
$2 < \nu < 3$	$4.0 \cdot 10^8$	$5.0 \cdot 10^7$	$1.0 \cdot 10^5$		
$3 < \nu < 4$	$3.5 \cdot 10^8$	$8.2 \cdot 10^7$	$2.0 \cdot 10^6$	$2.0 \cdot 10^2$	
$4 < \nu < 5$	$3.1 \cdot 10^8$	$8.8 \cdot 10^7$	$8.0 \cdot 10^6$	$4.0 \cdot 10^3$	
$5 < \nu < 6$	$2.5 \cdot 10^8$	$8.0 \cdot 10^7$	$1.0 \cdot 10^7$	$4.0 \cdot 10^4$	
$6 < \nu < 7$	$2.1 \cdot 10^8$	$7.0 \cdot 10^7$	$1.0 \cdot 10^7$	$2.0 \cdot 10^5$	3
$7 < \nu < 8$	$1.7 \cdot 10^8$	$6.0 \cdot 10^7$	$1.1 \cdot 10^7$	$6.0 \cdot 10^5$	4
$8 < \nu < 9$	$1.5 \cdot 10^8$	$5.0 \cdot 10^7$	$1.1 \cdot 10^7$	$1.0 \cdot 10^6$	$2.0 \cdot 10^2$
$9 < \nu < 10$	$1.3 \cdot 10^8$	$4.9 \cdot 10^7$	$1.1 \cdot 10^7$	$1.0 \cdot 10^6$	$9.0 \cdot 10^2$
$10 < \nu < 11$	$1.2 \cdot 10^8$	$4.8 \cdot 10^7$	$1.2 \cdot 10^7$	$2.0 \cdot 10^6$	$3.0 \cdot 10^3$
$11 < \nu < 12$	$1.0 \cdot 10^8$	$4.7 \cdot 10^7$	$1.2 \cdot 10^7$	$2.0 \cdot 10^6$	$8.0 \cdot 10^3$
$12 < \nu < 13$	$1.0 \cdot 10^8$	$4.5 \cdot 10^7$	$1.2 \cdot 10^7$	$2.0 \cdot 10^6$	$2.0 \cdot 10^4$
$13 < \nu < 14$	$9.0 \cdot 10^7$	$4.3 \cdot 10^7$	$1.2 \cdot 10^7$	$2.0 \cdot 10^6$	$4.0 \cdot 10^4$
$14 < \nu < 15$	$8.0 \cdot 10^7$	$4.0 \cdot 10^7$	$1.2 \cdot 10^7$	$3.0 \cdot 10^6$	$7.0 \cdot 10^4$

Main measuring time should be spend on the statistics rising at high Q^2 and ν. For the accumulation of statistics at small Q^2 and small ν it takes about 10 percents of the total time. Fig. 6 shows Q^2 and ν ranges which can be achieved for various angles of scattered electron. Reliable rejection is needed for the fast hadrons at small angles where large amount of electrons at small Q^2 is available and for the electrons at large angles where large amount of π-mesons are available see Fig.7.

So MEMUS [23] is the 4π detector suitable for the registration and identification both fast forward particles and particles from the nucleus fragmentation region.

It is easy to see that suggested experiment coincide with respect its requirements with the experiment for studying of cumulative particles production (see proposal Degtyarenko et.al.[15]). Studing of the cumulative particles emitted by the single flucton is possible only in the case corresponding to Fig. 2d. One should verify that this effect really takes place.

So, we propose to measure using the MEMUS the correlations between e' at wide Q^2, ν region and

a) fast secondary hadrons in forward direction for measuring the value of transparency T

b) the values of ρ, r_{perp}, l, β for secondary hadrons in nuclear fragmentation region.

The targets set needed: H,Be(He,C),Cu(Ti),Pb(Ta,U)

We hope that selecting of widely discussed now problems of nuclear transparency helps to consolidate many physicists around the experiments on MEMUS spectrometer.

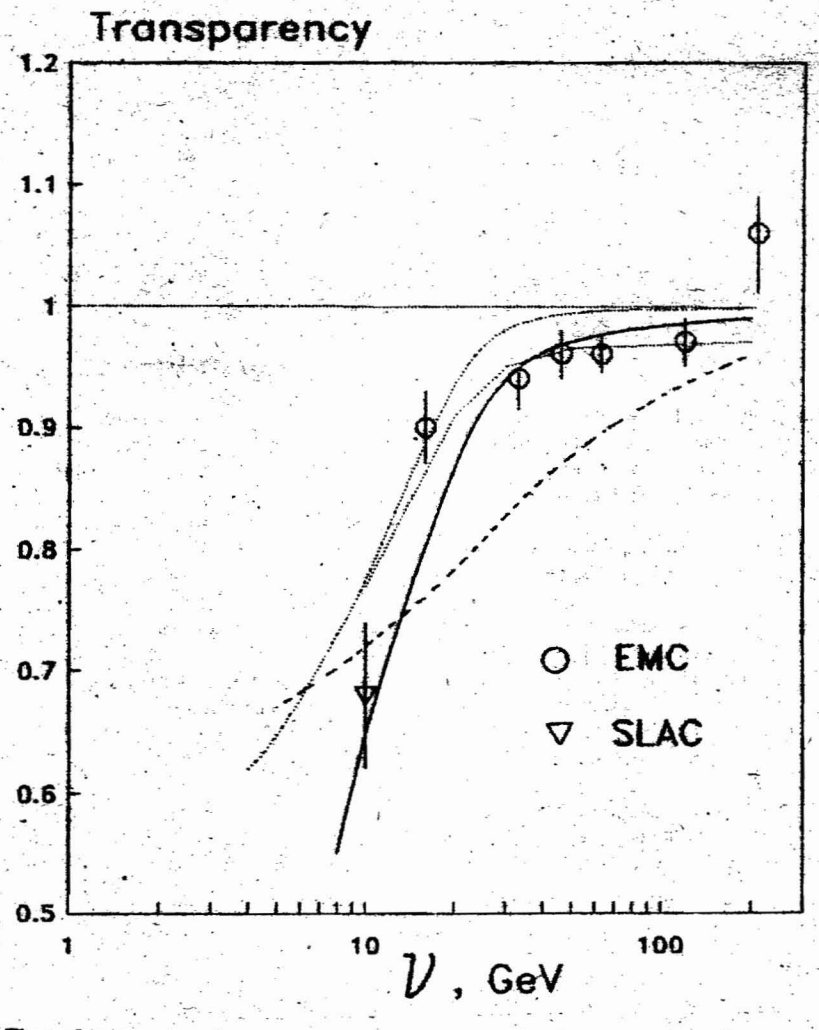


Figure 1.
Ratio of cross sections of inclusive hadron production in deep-inelastic scattering on Cu and nucleon integrated over Feynman x from x=0.2 to 1, v.s. photon energy.
Data points are taken from [6]. Curves correspond to models [7]

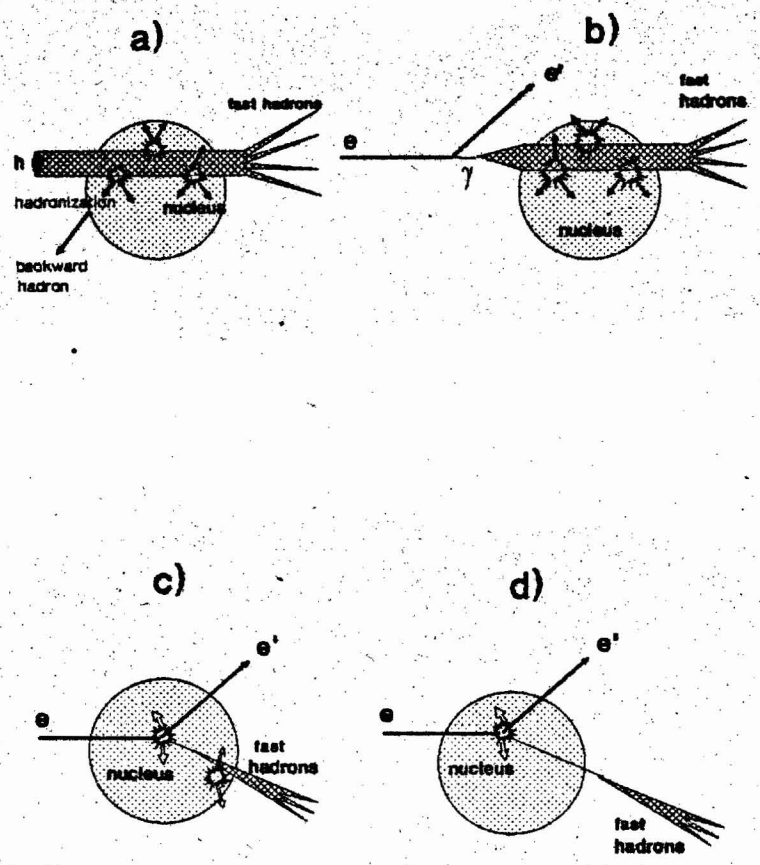
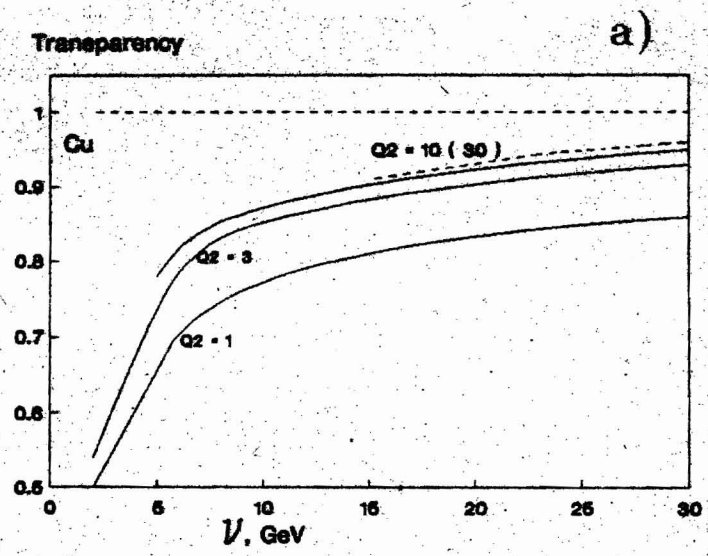


Figure 2.
The scenarios of particle production in a) hA interaction, b) eA interaction at small Q^2 region, c) eA interaction at high Q^2 and small ν , d) eA interaction at high Q^2 and high ν .



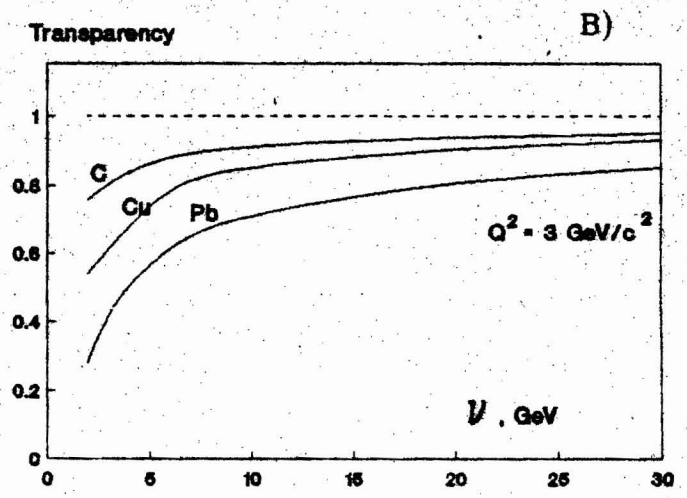


Figure 3.
The Kopeliovich et.al. model [7] predictions for the transparency as a function of ν for different A and Q^2.

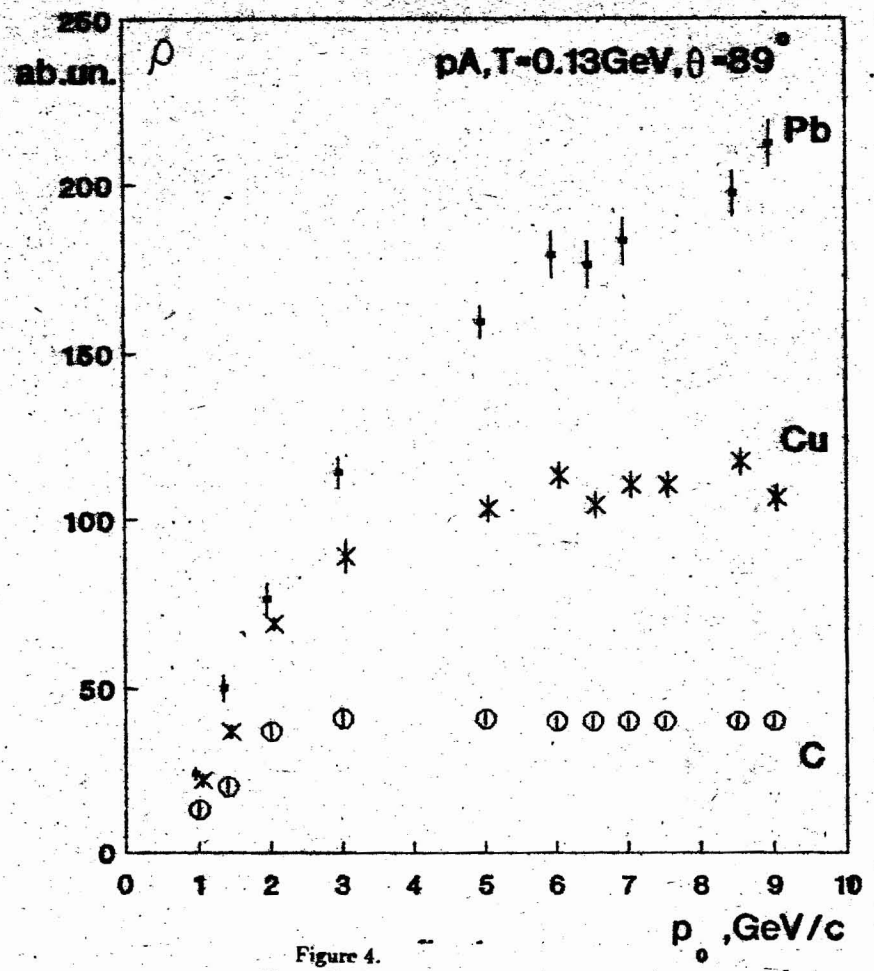


Figure 4.
Normalised invariant cross sections for hA reactions.

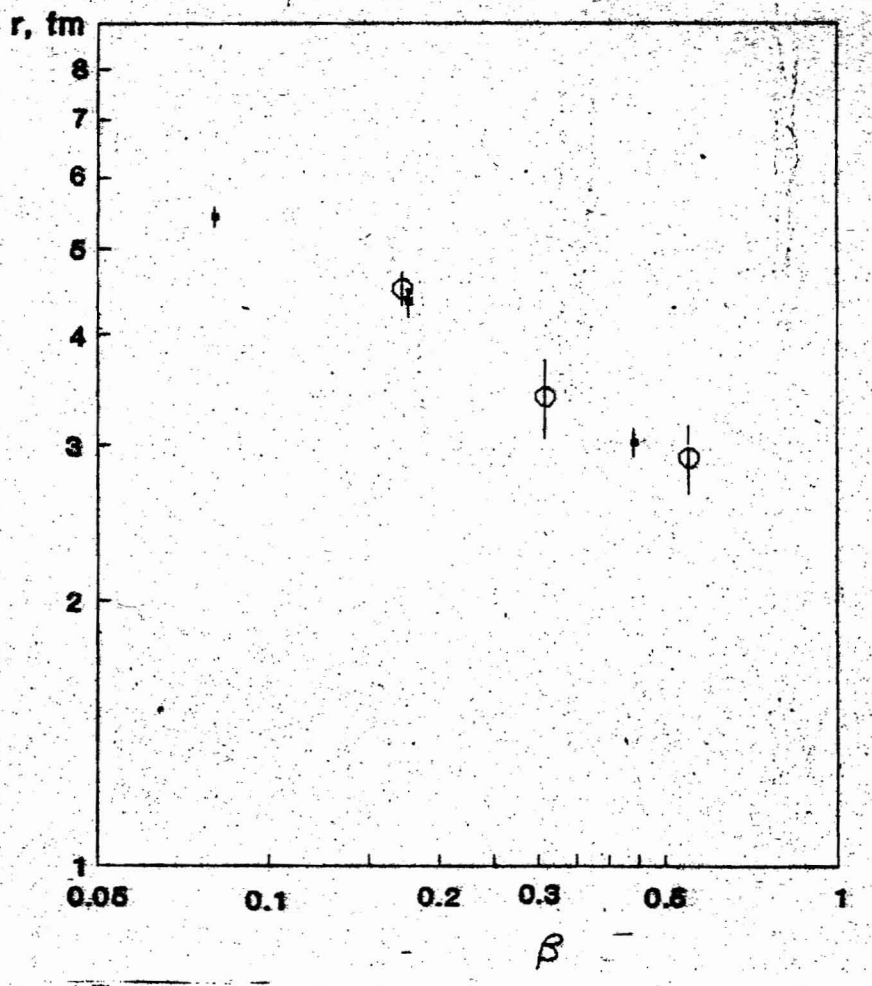


Figure 5.
The dependence of r on β in pA interactions. o - 3 GeV/c initial momentum; • - 7.5GeV/c.

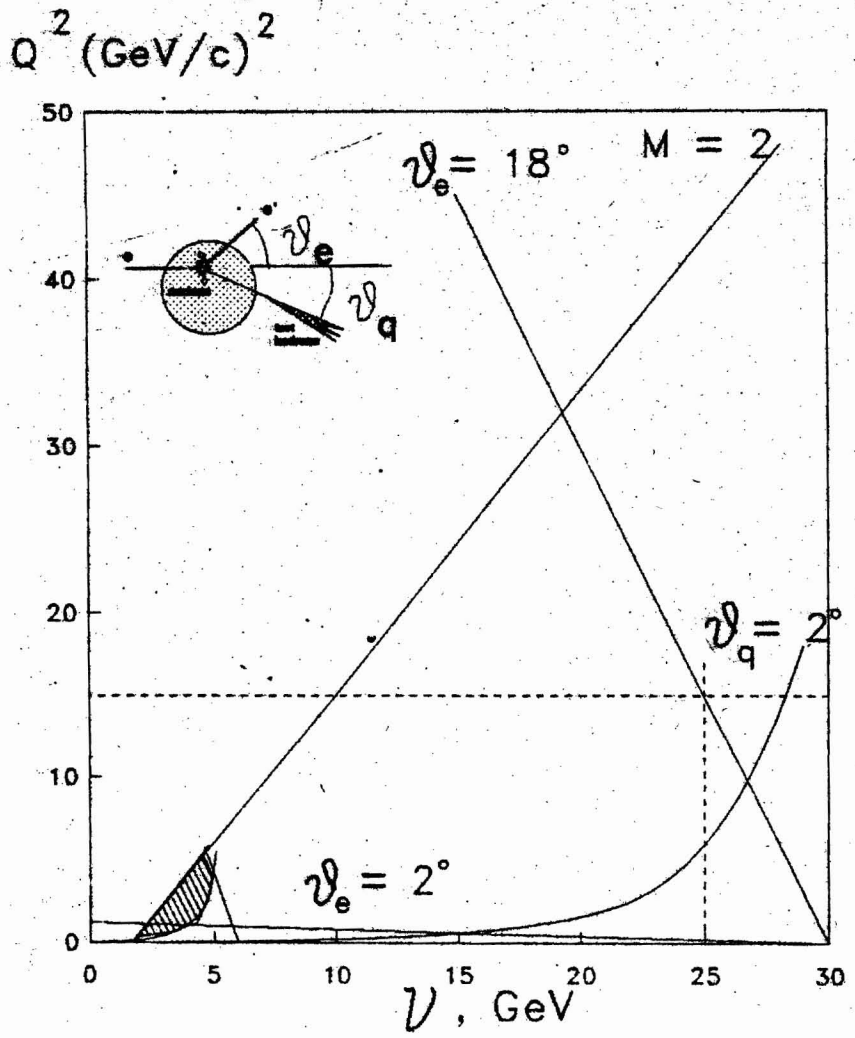


Figure 6.
ν-Q^2 plot of the region to be investigated at 30 GeV machine.

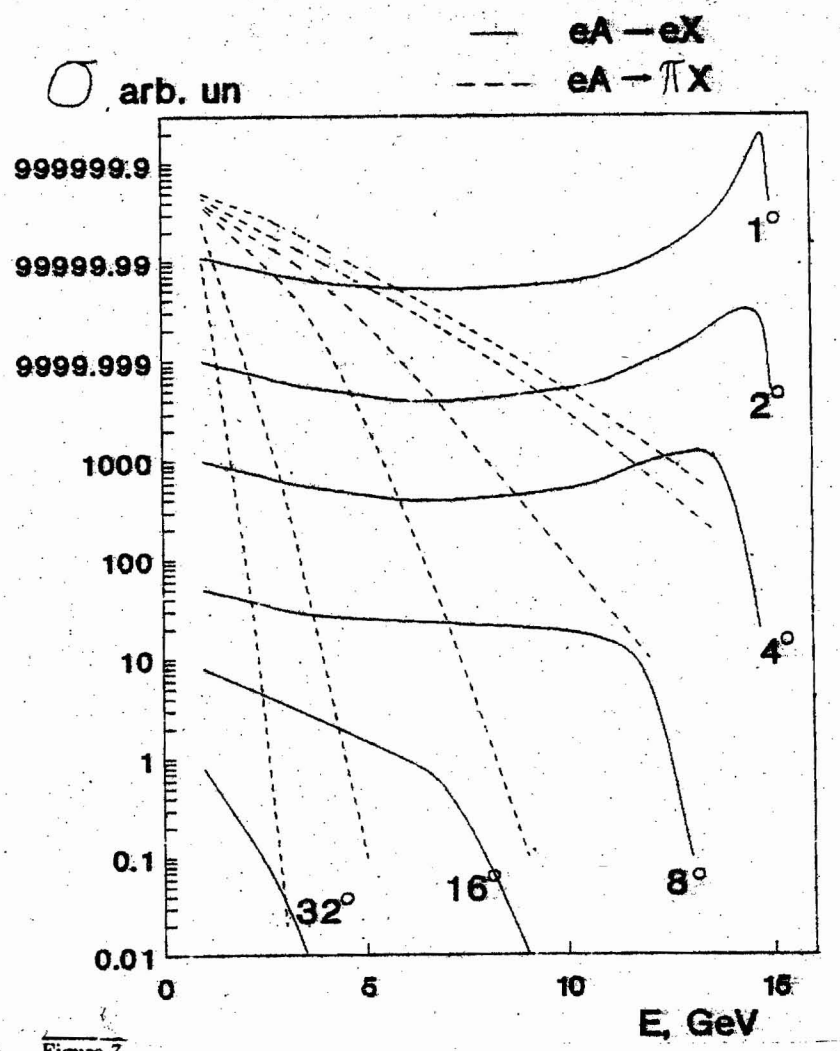


Figure 7.
The estimation of the cross sections for electrons and pions production at e(15GeV)A interactions for different emission angle as a function of the energy of secondaries.

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