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PHENOMENOLOGICAL STUDY OF INCLUSIVE SINGLE PARTICLE SPECTRA IN THE TRIPLE REGGE LIMIT

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1. Introduction

The first and up to now most complete description of single particle spectra in inclusive reactions

$$a + b \rightarrow X + anything \qquad (1)$$

was given by the thermodynamic model[1,2,3]. More recently the multi-Regge model was used successfully to describe inclusive single particle spectra[4,5]. Proposals to study the asymptotic behaviour of inclusive particle production in the form of scaling[6] and limiting fragmentation[7] triggered much interest in inclusive particle production during the last two years. One of the most important steps forward was the discovery of Mueller[8] that the inclusive spectra are related to discontinuities of multiparticle forward scattering amplitudes. This opened the way to apply Regge phenomenology and dual models to the study of inclusive reactions.

Here we are interested in inclusive single particle spectra of particles X in the fragmentation region (s large, s/M^{*2} large, see Fig. 1). In the Regge model this region is due to single peripheral Regge exchange graphs in Fig. 1.

Imposing the constancy of the high energy total cross section between the exchanged trajectory $\alpha(t)$ and the incoming particle b for the cross section as function of the missing mass M^*, Ceneschi and Rignotti [4] derived an expression which is equivalent to

$$\frac{d^2N}{dt\,dM^*} = \sum_{i,j} \beta_{i,j}(t)\; s^{2\alpha_i(t)-2}\; M^{*\,2(\tilde{\tilde{\alpha}}_j(0)-2\tilde{\tilde{\alpha}}_i(t)+1/2)} \tag{2}$$

in Lorentz invariant form. Using Mueller's generalized optical theorem [8] this form was pointed out [9] to correspond to the triple Regge limit (s large, s/M^{*2} large and M^{*2} large) which holds near the kinematic boundary, see Fig. 2.

Various aspects of the triple Regge graph have recently been studied and compared with experimental data [10-19]. These papers study the s, M^* and t dependence, the implications of duality etc. It was pointed out that the triple Pomeron contribution should be dual to the background underneath the resonances in the missing mass spectra and from the s variation of the background it was found that the triple Pomeron coupling is very small [17].

Chen et al. [17] used the data of Allaby et al. [20] at 19.2 GeV/c and of Anderson et al. [21] at 30 GeV/c to determine the Regge parameters entering formula (2).

We describe here an extension of this work using in addition data from Serpukhov [22] and the new data of Allaby et al. [23] at 14.25, 19.2 and 24 GeV/c. We are therefore able to study the behaviour of the data over a rather large region in s. The fit of the data is described in Section 2 and the results of the fit are described and discussed in Section 3.

2. Parametrization and Fitting

We use in the fit only one effective intercept $\alpha_j(0)$ and only one effective Regge trajectory $\alpha_i(t)$.

$$\frac{d^2N}{dt\ dM^*} = \beta(t)\ s^{2\alpha(t)-2} M^{*\ 2(\tilde{\tilde{\alpha}}(0)\ -\ 2\alpha(t)\ +\ 1/2)} \tag{3}$$

$\beta(t)$ stands for the residue function at the aX and triple Regge vertices of Fig. 2 and is parametrized for small t as

$$\beta(t) \approx \exp\ (bt). \tag{4}$$

The effective trajectory $\alpha(t)$ is parametrized as

$$\alpha(t) = \alpha_0 + \alpha'\cdot t. \tag{5}$$

The parameters b, α_0, α' and $\tilde{\tilde{\alpha}}(0)$ are determined by a least squares fit from the data [20,22,23] in the fragmentation region, that is for large values of the laboratory momentum p and small angles θ.

For single particle spectra of π^+, K^+ and p produced in $p-p$ collisions we perform two independent fits, the first using the data [20] at 19.2 GeV/c at only one s value, the second using the data [23] at three different primary momenta P_0 = 14.25, 19.2 and 24 GeV/c.

π^--spectra are only fitted using the data [20] at 19.2 GeV/c. For single particle spectra of K^- and $\bar{p}$ produced in $p-p$ collisions we perform again two different fits, the first one with the data [20] at 19.2 GeV/c and the second one using the data [22] at 70 GeV/c. Bushnin et al. [22] reported the ratios

$$R(p,\theta) = \frac{\frac{d^2N}{dp\,d\Omega}(pp \to \bar{X} + \dots)}{\frac{d^2N}{dp\,d\Omega}(pp \to \pi^- + \dots)} \quad . \tag{6}$$

In the fit we assume that the π^- spectra at 70 GeV/c are described by (3) with the same parameters as obtained in the 19.2 GeV/c fit and determine only new parameters for the K^- and $\bar{p}$ spectra. The parameters obtained in all fits are given in Table 1. The fits are good as can be seen from Figs 3 to 5.

It was tried to improve the fit further by fitting the data to a two term formula (2) with two different values of $\tilde{a}_j(0)$, but no improvement was obtained.

In the case of the K^- and the $\bar{p}$ spectra with exotic exchange at the pK^- and the $p\bar{p}$ vertices it was tried to obtain a better description of the data with a formula corresponding to (3) but with the exchange of a Regge cut instead of the trajectory $\alpha(t)$, but these fits turned out to be not better than with one single effective Regge trajectory.

3. Discussion of the Results

i) Formula (3) describes the inclusive single particle spectra in the fragmentation region remarkably well. The parameters obtained in the s independent fit at 19.2 GeV/c and in the s dependent fit with data at 14.25, 19.2, and 24 GeV/c agree with each other within the errors. In the case of the proton spectra the fit is however not as good and the two sets of parameters differ.

The K^- fits at 19.2 GeV/c and at 70 GeV/c lead to nearly identical parameters. This indicates that (3) describes the s dependence of the K^- spectra essentially correct and that the parameters change only slightly with s if they change at all. The corresponding parameters of the $\bar{p}$ spectra differ however at the two s values.

We conclude that the s, M^* and t dependence of the π^+, π^-, K^+ and K^- spectra is well described by (3) with s-parameters changing not significantly with s. The p and $\bar{p}$ spectra seem to behave differently and further study with more data is advisable before drawing conclusions.

ii) The parametrization (4) of the residue functions is too simple minded. Data from different experiments which are measured in somewhat different t regions lead to different parameters b /24,25/. This indicates that the t dependence is no simple exponential as is also known from other investigations.

iii) Asymptotic scaling or limiting fragmentation behaviour of the spectra is present if the Reggeon-particle total cross section is dominated by the Pomeron $\tilde{\alpha}(0)=1$. The fact that the parameters $\tilde{\alpha}(0)$ obtained in the fits are in most cases near to 1 indicates that scaling or limiting fragmentation is approximately present already at present accelerator energies but is not yet completely correct.

iv) From quasi two body reactions one expects the following leading Regge trajectories to be dominating the triple Regge graph in Fig. 2:

in $pp \to \pi^+ + M^*$ the N_α and the Δ_δ trajectories

$$\alpha_{N_\alpha}(t) = -0.4 + t, \qquad \alpha_{\Delta_\delta}(t) = -.15 + t$$

in $pp \to \pi^- + M^*$ the Δ_δ trajectory

in $pp \to K^+ + M^*$ the Λ trajectory

$$\alpha_\Lambda(t) = -.7 + t$$

in $pp \to p + M^*$ the Pomeron and also P' and ω.

The channels $pp \to K^- + M^*$ and $pp \to \bar{p} + M^*$ are exotic. The intercepts α_o found (Table 1) are, with the possible exceptions of the K^+ and p spectra, too low. If we use in the fits instead of (3) formula (2) with several trajectories instead of one effective trajectory only this situation cannot be improved.

Furthermore we find equally good Regge pole fits for the K^- and $\bar{p}$ spectra with exotic exchanges.

v) The good fits on one side but the unexpected Regge parameters on the other side as well as the success in fitting the K^- and $\bar{p}$ spectra establish that (3) is certainly a good empirical parametrization of the inclusive spectra in the fragmentation region, but it does not seem to be more. It does not necessarily mean that this success in fitting provides any physical insight into the underlying mechanism. At the energies where the data are measured s and M^{*2} are not high enough, therefore duality is necessary if (2) with one dominating Regge exchange mechanism is valid. It might be that this mechanism will dominate at much higher energy. The result of our study suggests however that at present energies other mechanisms probably dominate and that the success in fitting data to the triple Regge term is only by chance.

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Table 1

Regge parameters obtained in the fit

Particle	Data references	Primary momentum P_0(GeV/c)	b (GeV/c)	a_0	a' GeV/c	$\tilde{a}(0)$
π^+	/20/	19.2	1.19	-1.17	0.83	0.98
	/23/	14.25, 19.2, 24.0	2.81	-1.09	0.83	0.82
K^+	/20/	19.2	0.65	-0.98	0.40	1.00
	/23/	14.25, 19.2, 24.0	1.01	-0.97	0.55	1.00
p	/20/	19.2	1.54	-0.01	0.97	0.20
	/23/	14.25, 19.2, 24.0	1.79	0.35	0.47	0.94
π^-	/20/	19.2	1.23	-1.98	0.86	0.84
K^-	/20/	19.2	1.03	-4.30	0.90	1.00
K^-/π^- §)	/22/	70.0	1.09	-3.81	0.72	0.70
$\bar{p}$	/20/	19.2	0.47	-5.55	0.47	0.96
$\bar{p}/\pi^-$ §)	/22/	70.0	0.88	-4.98	0.00	0.75

§) π^- parameters unchanged.

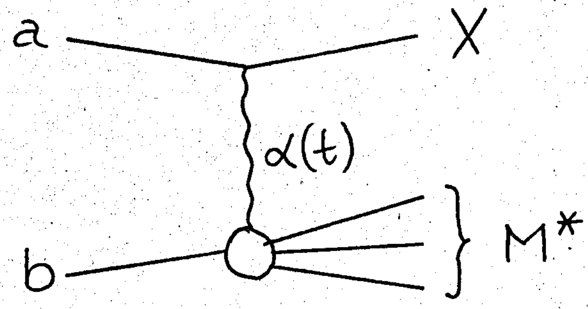


Fig. 1. The fragmentation graph.

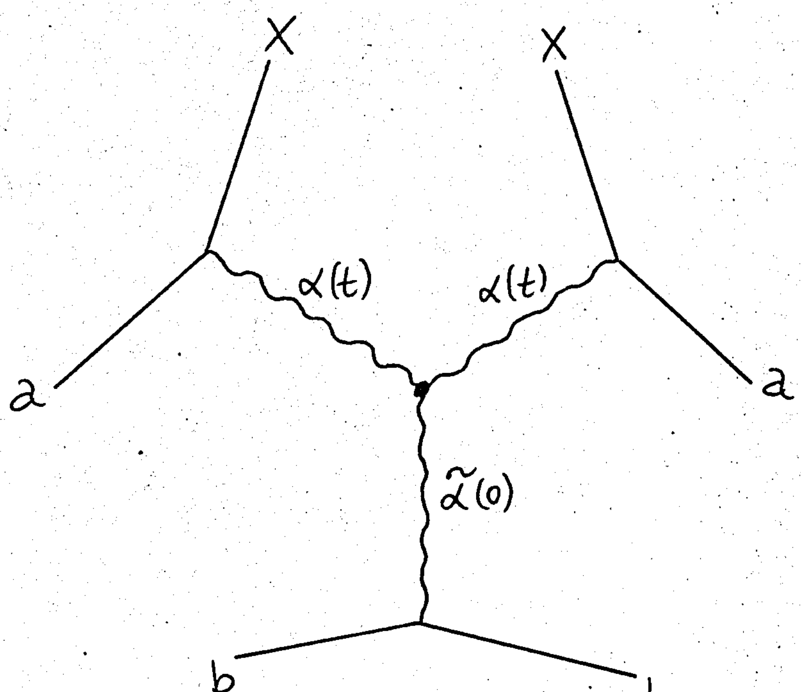


Fig. 2. The triple Regge graph for inclusive production of particle X via exchange of $\alpha_1(t)$ and $\tilde{\alpha}(0)$.

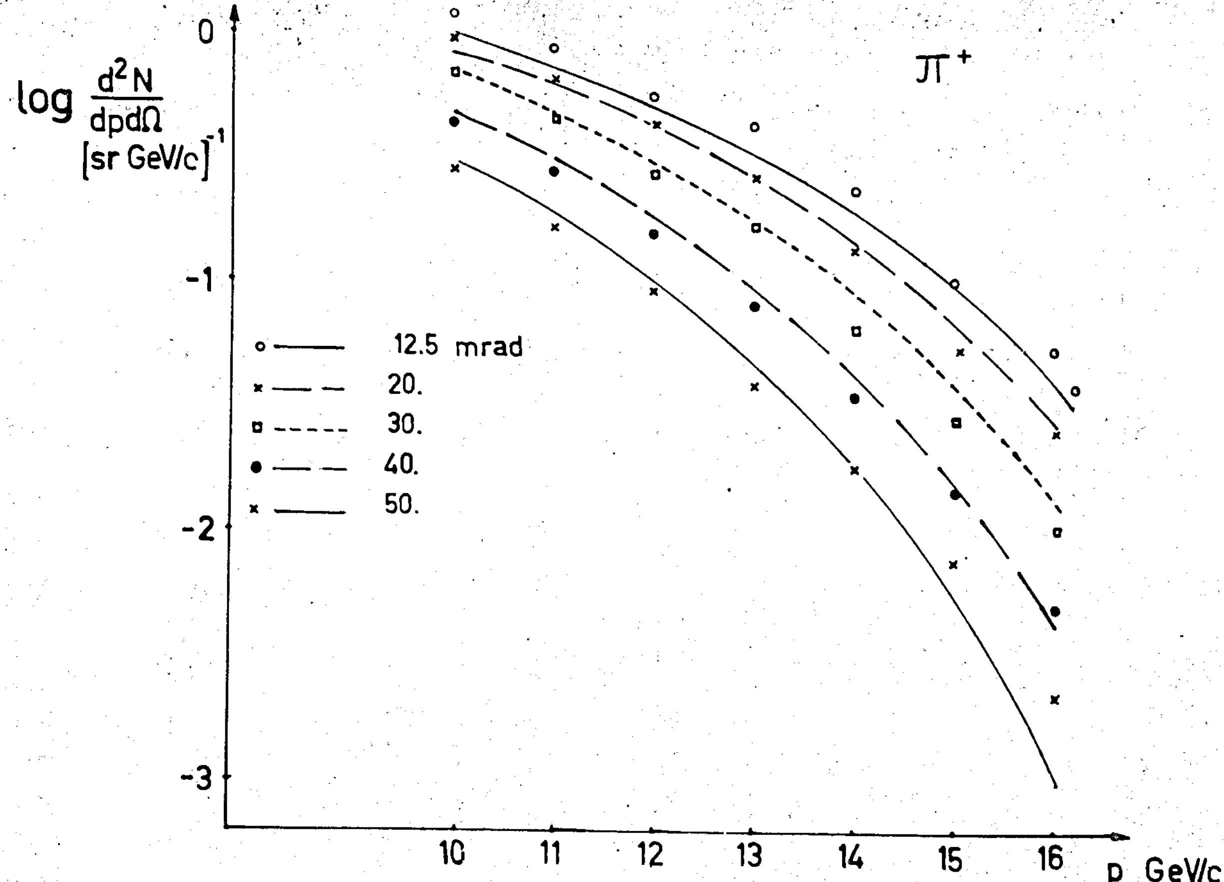
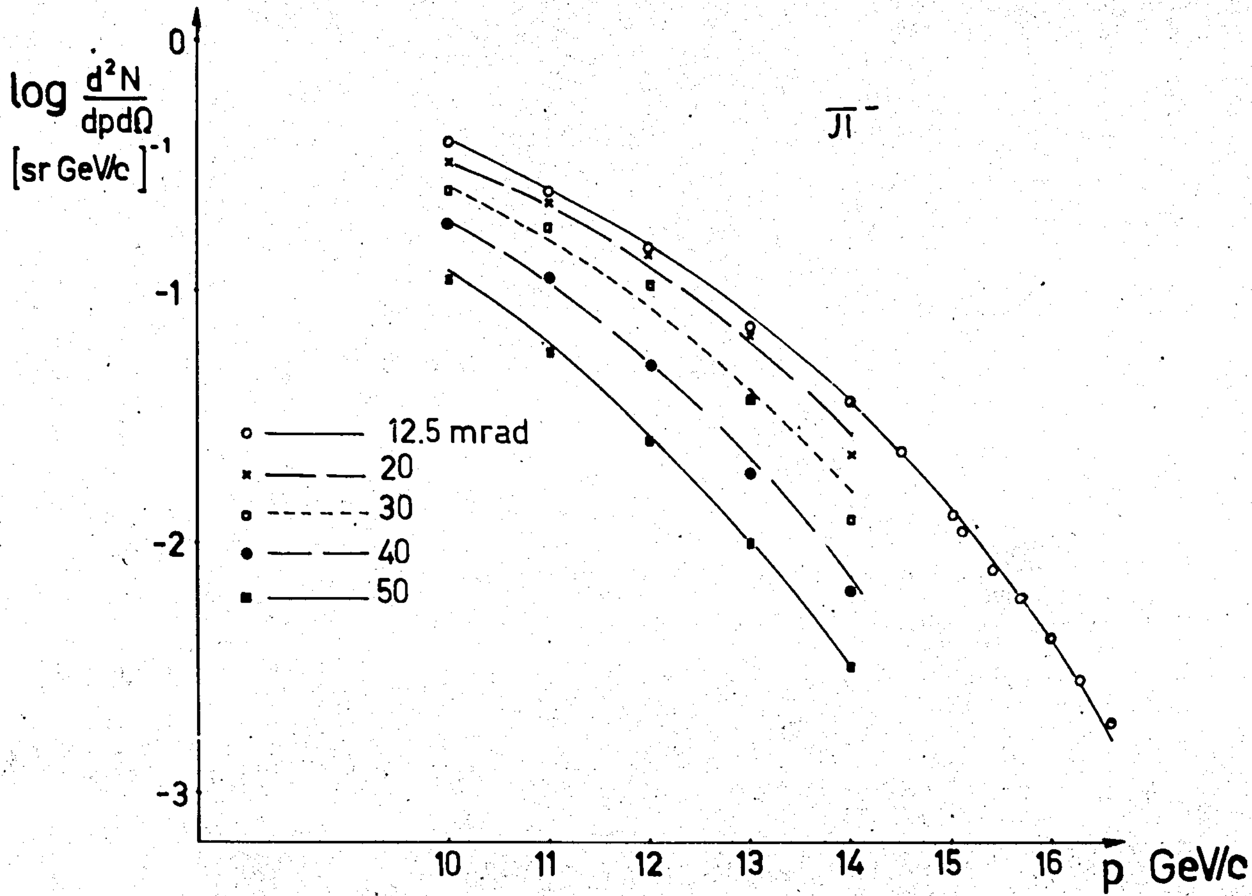
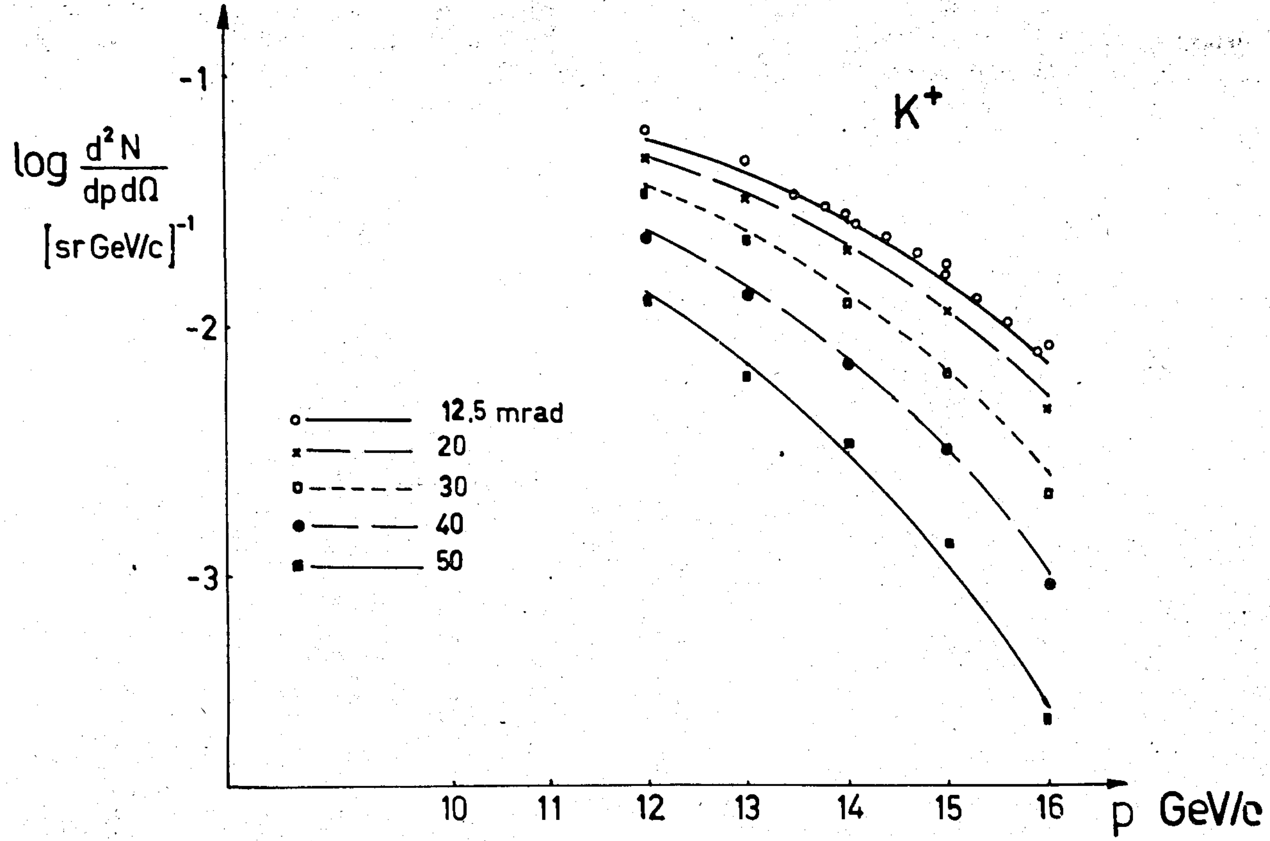


Fig. 3 a.Theoretical single particle spectra from the triple Regge expression (3) with the parameters in Table 1 and experimental data at 19.2 GeV/c and at various angles/20/ a) π^+, b) π^-, c) K^+, d) K^-, e) $\bar{p}$, f) p.



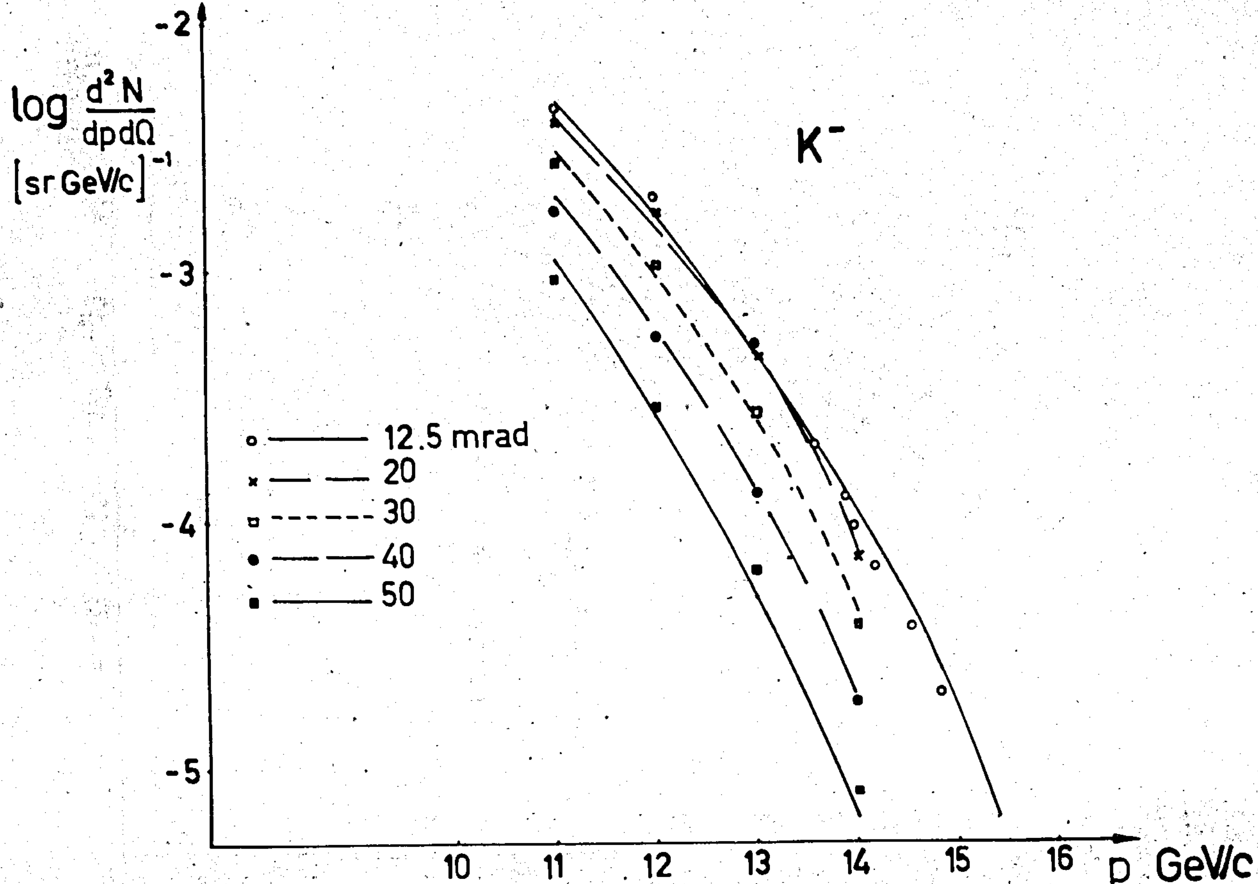
0
log $\frac{d^2N}{dp d\Omega}$
[sr GeV/c]$^{-1}$
π^-
-1
-2
-3
12.5 mrad
20
30
40
50
10
11
12
13
14
15
16
p GeV/c

Fig. 3b



K+
log d²N/dp dΩ
[sr GeV/c]⁻¹
-1
-2
-3
12,5 mrad
20
30
40
50
10
11
12
13
14
15
16
p GeV/c

Fig. 3c



log $\frac{d^2N}{dp\,d\Omega}$
[sr GeV/c]$^{-1}$
K$^-$
-2
-3
-4
-5
12.5 mrad
20
30
40
50
10
11
12
13
14
15
16
p GeV/c

Fig. 3d

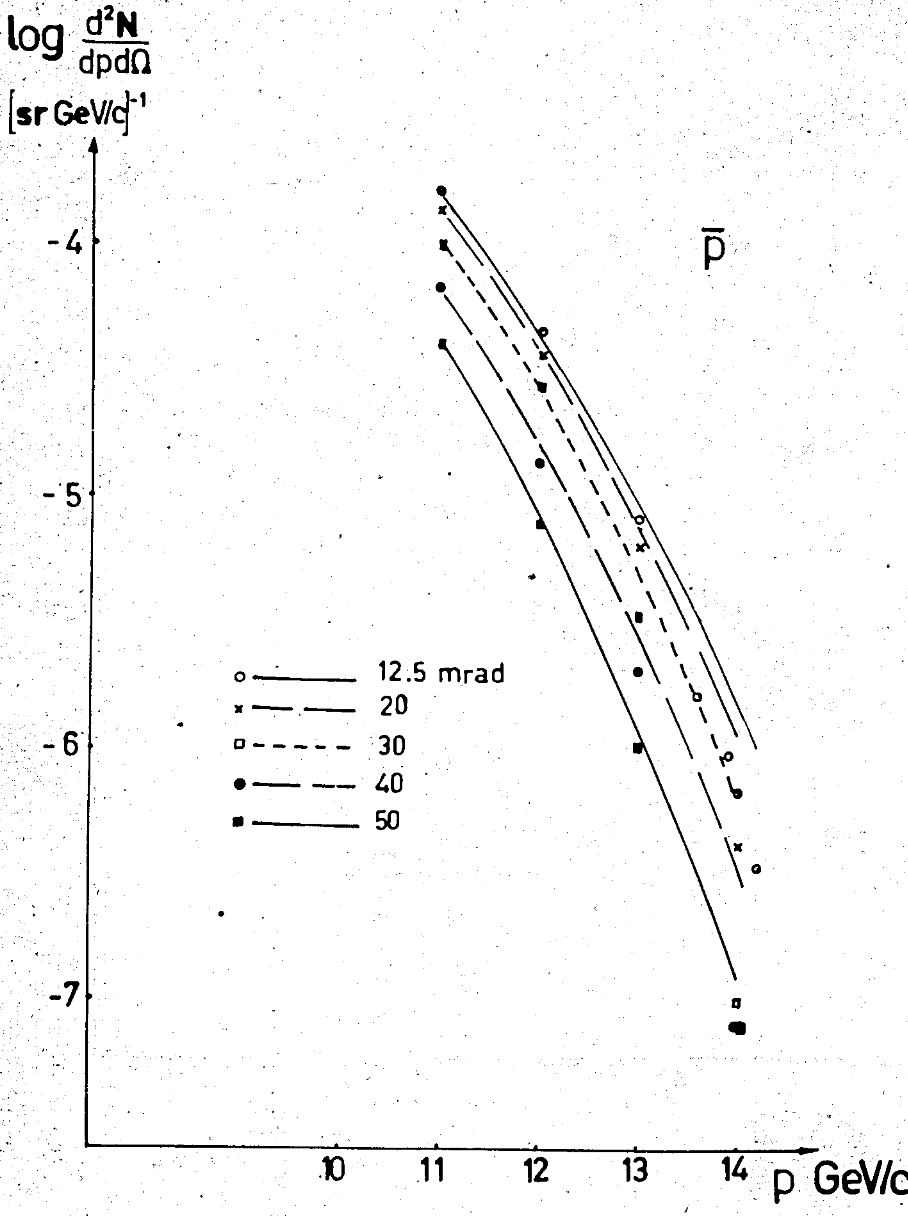
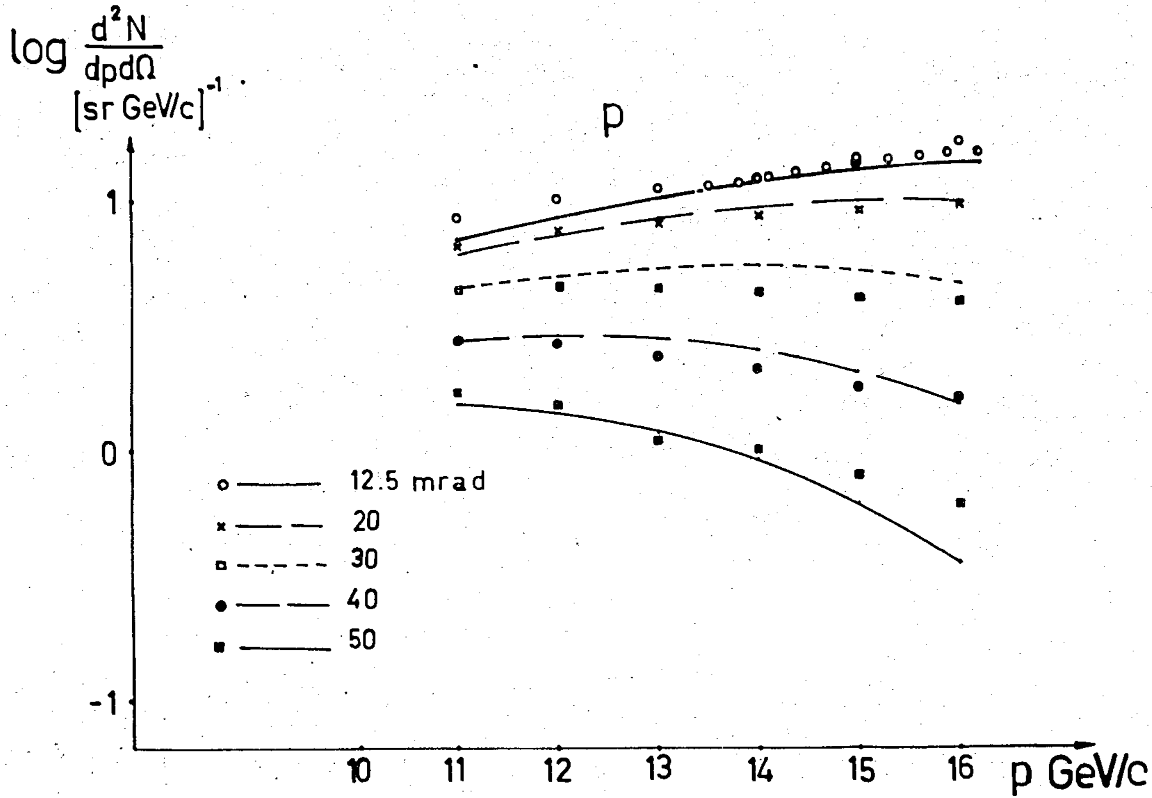

log $\frac{d^2N}{dp d\Omega}$
[sr GeV/c]$^{-1}$
-4
-5
-6
-7
$\bar{p}$
12.5 mrad
20
30
40
50
10
11
12
13
14
p GeV/c

Fig. 3e



log $\frac{d^2N}{dp\,d\Omega}$ [sr GeV/c]$^{-1}$
p
1
0
-1
12.5 mrad
20
30
40
50
10
11
12
13
14
15
16
p GeV/c

Fig. 3f

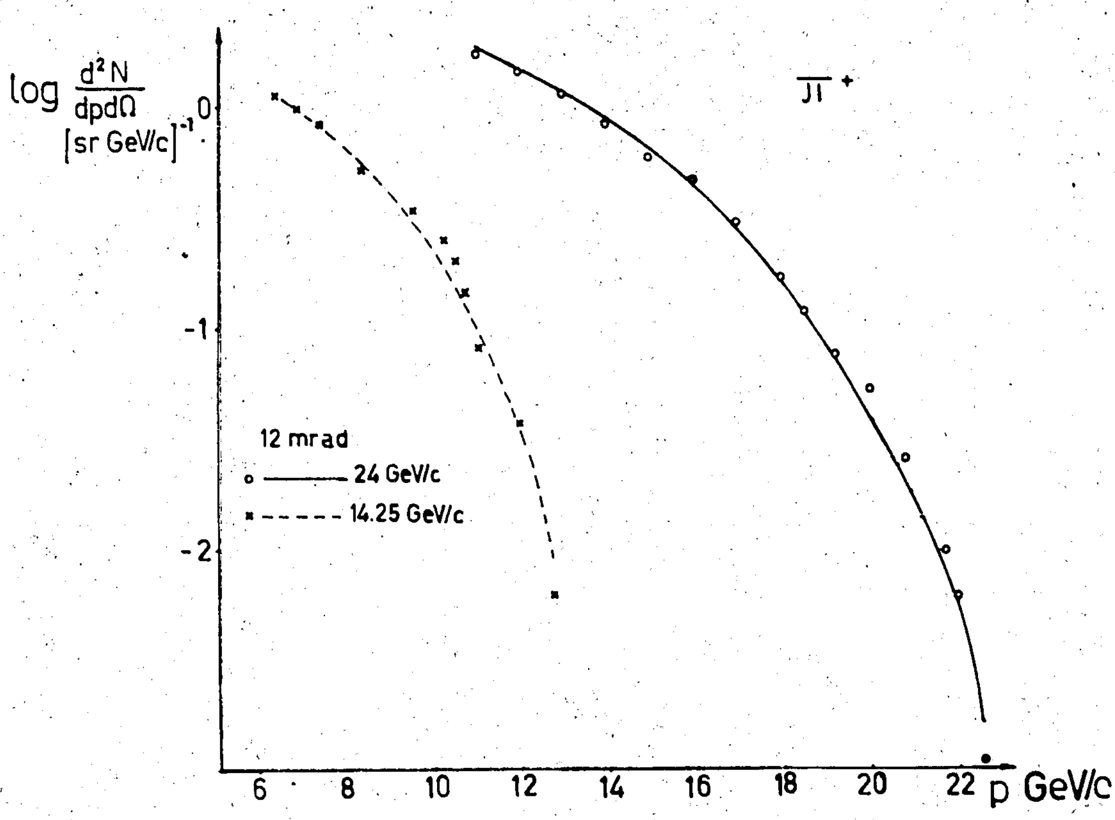
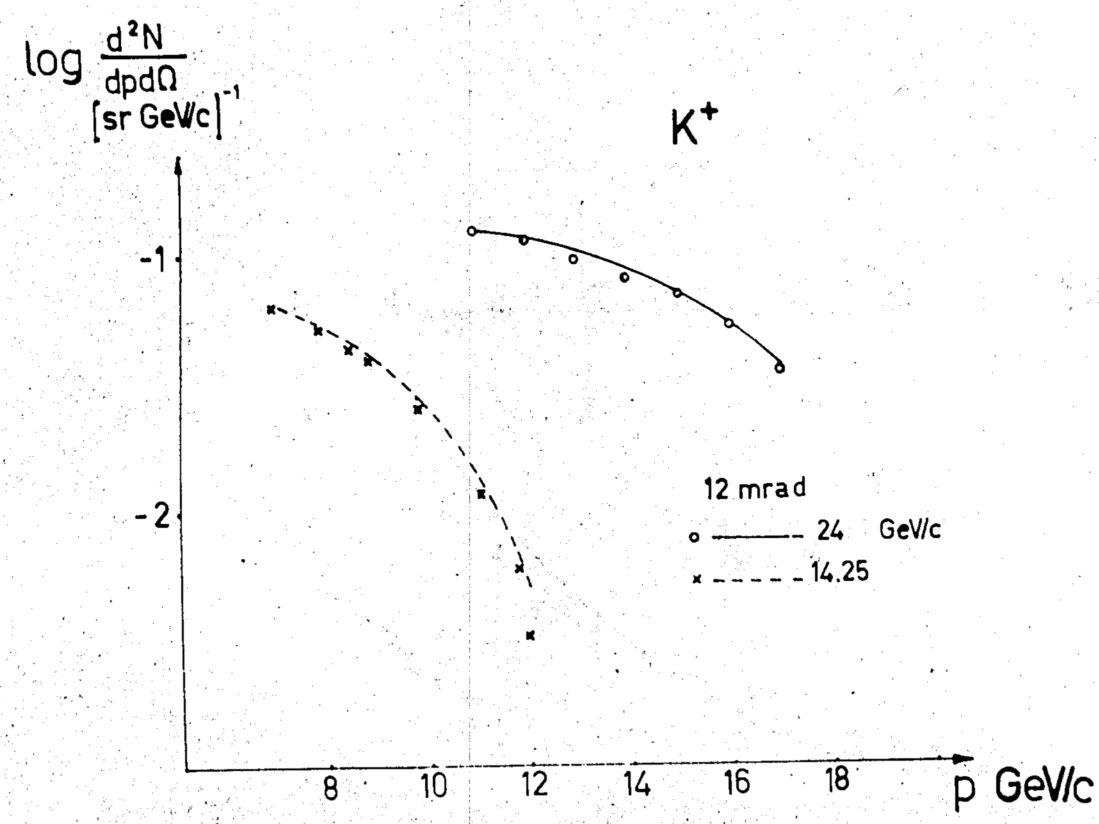


Fig. 4a.Energy dependent fit of the triple Regge expression (3) with the parameters in Table 1 at 12 mrad and experimental data/23/. Only spectra at primary energy 24 and 14.25 GeV/c are drawn. a) π^+, b) K^+, c) p .



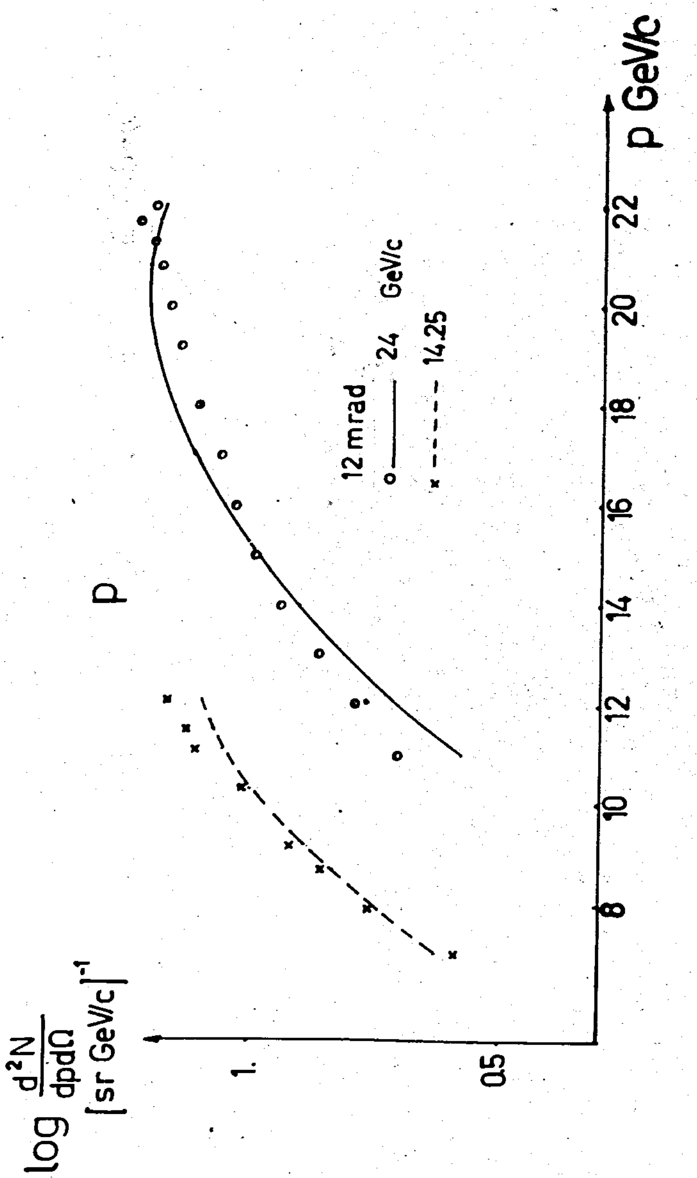


Fig. 4c

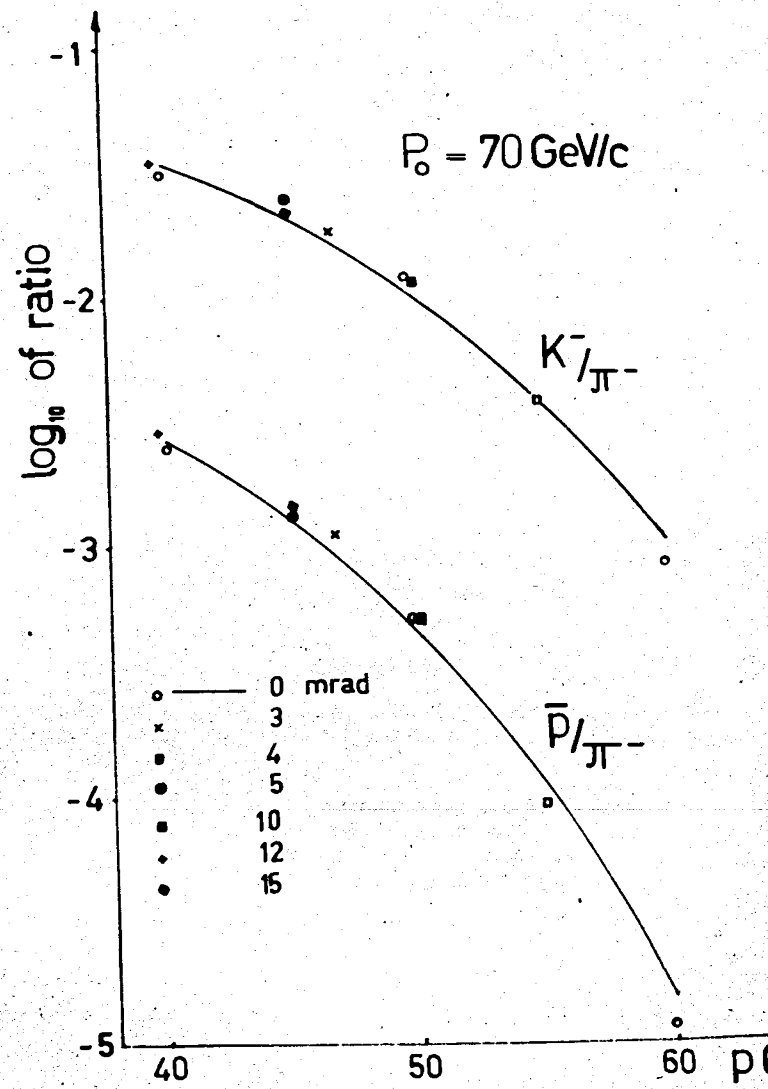


Fig. 5. Theoretical fit from the triple Regge expre
(3) and experimental data/22/ for the ratios (6) of
single particle spectra at 670 GeV/c and at various
les.