Multiparticle production in the Quark-Gluon strings model.

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HERA-LHC Workshop
21 march 2005

Contents:

Introduction

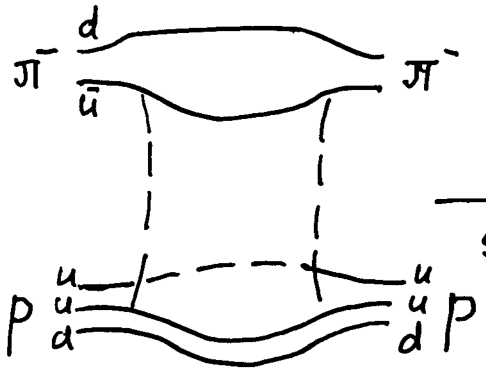
High-energy hadronic interact. and DIS at small x_B can be described in reggeon theory by exchange of the pomeron ($\mathbb{P}$).

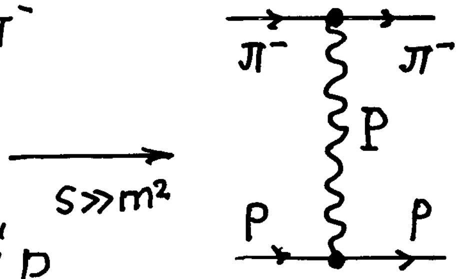
In QCD the pomeron is mostly gluonic object. In large N-expansion of QCD the pomeron corresponds to cylinder-type diagrams.

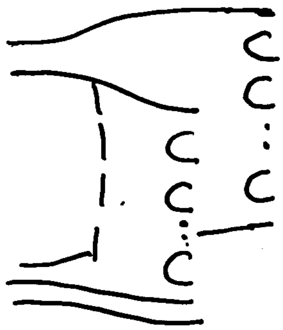
For pomeron with $\alpha_{\mathbb{P}}(0) > 1$ (supercritical $\mathbb{P}$) multipomeron exchanges in the t-channel are necessary.

Gribov's reggeon technique and AGK-cutting rules constitute a powerful method of investigation of high-energy interactions.

Pomeron in $1/N$-expansion







Cylinder type diagrams

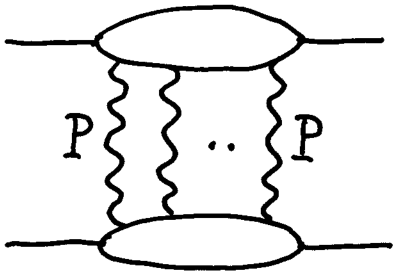
$T_P \sim \frac{1}{N^2}$

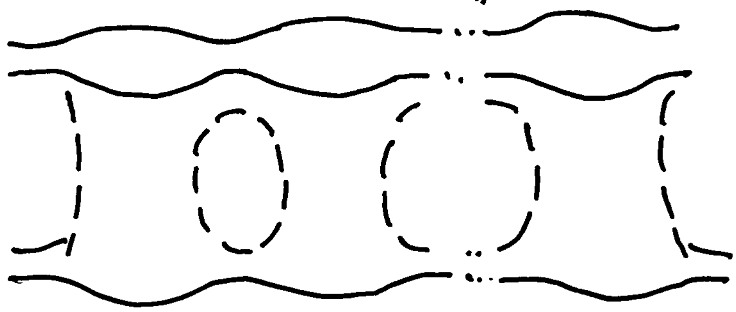
$\sigma_P \sim s^\Delta$

Muliparticle production 2-chains

Multipomeron contributions are important for restoration of unitarity at high energies

V. N. Gribov, I. Ya. Pomeranchuk, K. A. Ter-Martirosyan





$T_{nP} \sim \left(\frac{s^\Delta}{N^2}\right)^n$

multicylinder diagrams

Gribov reggeon diagrams technique and AGK-cutting rules are used in formulation of the QGSM.

A. K. P.L. 116B, 459 (1982)

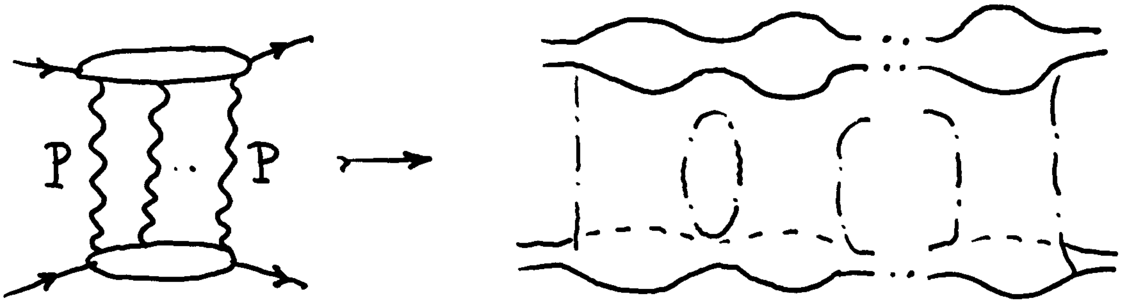
A. K., K. A. Ter-Martirosyan P.L. 117B, 247 (82)

— " — " — Yad. Fiz. 39, 1545 (84)

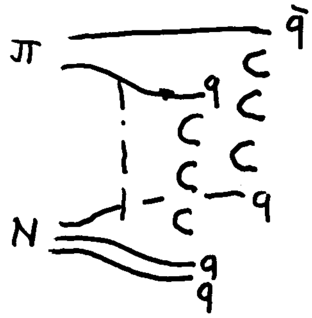
40, 211 (84)

Dual parton model. A. Capella, U. Sukhatme, C. I. Tan, J. Tran Thanh Van, Phys. Rep. 236, 225 (1994)

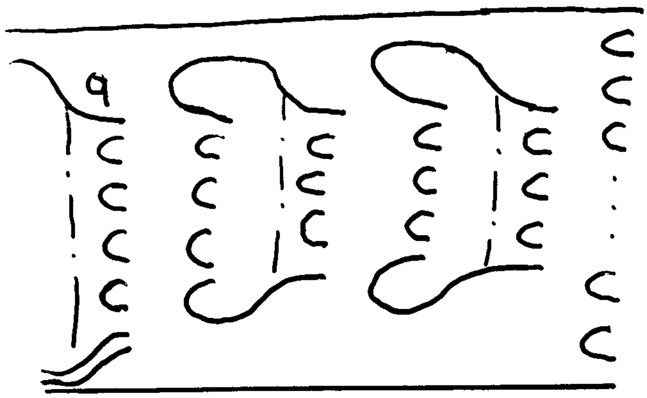
DPM



Multiparticle content



Production of 2 chains of hadrons. Based on valence quarks of hadrons



Production of 2n chains. Extra chains are due to sea quarks (or gluons).

AGK-cutting rules determine the weights of different configurations.

Rapidity and multiplicity distributions of final hadrons in the chains can be determined theoretically.

For review see A. Capella et. al Phys. Rep. 236 (1994) 225

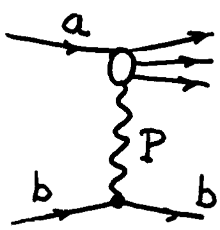
A. Kaidalov. Surveys in High Energy Phys. 13, 265 (99)

- AGK - cutting rules.

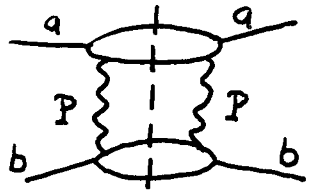
What is the s-channel content of Regge-cuts contributions

$$\mathrm{Im}\, T_{2P}(s,0) \equiv -A(s)$$

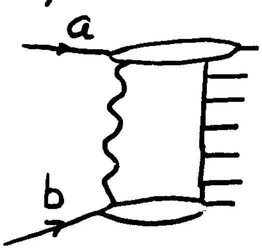
a) Diffractive cutting (between Pomerons)



$+A(s)$

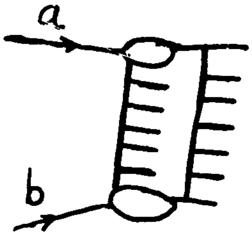


b) Absorption correction to multipart. content of a Pomeron (cutting of one of the Pomerons).

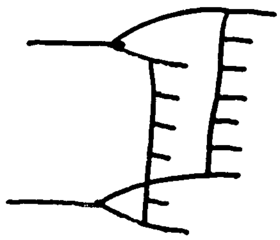


$-4A(s)$

c) Production of two multiperipheral chains (cutting through both Pomerons)



$+2A(s)$



+1 , −4 , +2 AGK coefficients. The sum is −1

- Theory based on $1/N$-expansion (DPM-model, QGSM-model) gives predictions for particle production. in the Pomeron case (cylinder) and for cuttings of many Pomerons

$$\frac{d\sigma^h}{dy} = \sum_{k=0}^{\infty} \sigma_k(s)\, \varphi_k^h(s,y)$$

$$\varphi_k^h(s,y) = \frac{1}{\sigma_k} \frac{d\sigma_k^h(s,y)}{dy}$$ - rapidity distributions for k-cut Pomerons

e.g. $\varphi_1^h(s,x) \approx \int_x^1 dx_1\, f_a^q(x_1)\, D_q^h\left(\frac{x}{x_1}\right) \cdot \frac{x}{x_1}$ + contrib of the second chain

in fragm. region of the hadron a

distribution of "quarks"

fragmentation functions

$f_a^q(x_1)$ is known for $x_1 \to 0$ and $x_1 \to 1$

e.g. $$f_p^q(x_1) = \begin{cases} c_1\, x_1^{-\alpha_R(0)} & x_1 \to 0 \\ c_2 (1-x)^{\alpha_R(0) - 2\alpha_N(0)} & ; \; x_1 \to 1 \end{cases}$$

Functions $D_q^h(z)$ can be determined in the limits $z \to 0$, $z \to 1$ (Regge counting rules).

For example:

$x D_u^{\pi^+}(x)$ $\quad x \to 0 \quad x D_i^h \to a^h \quad x \to 1 \quad \xrightarrow{u} \; [\Delta y \approx \ln \frac{1}{1-x} \gg 1$

$D_u^{\pi^+} \sim (1-x)^{-\alpha_R(0) + 2\alpha'_R \cdot p_\perp^2}$

Interpolation formula

$$x D_u^{\pi^+}(x) = a^\pi (1-x)^{-\alpha_R(0) + \lambda}$$

$$\lambda = 2\alpha'_R \cdot \overline{p}_\perp^2 \approx 0.5$$

Constraints due to energy-momentum, S, B, Q_i.. conservation allow one to determine constants a_i^h in many cases. No free parameters!

The model has correct double ($x \to 0$) and triple ($x \to 1$) Regge limits.

- ## Comparison with experiment

Quasieikonal approximation for multipomeron contributions.
K.A. Ter-Martirosyan (7:

The parameters of the model have been determined from the data on $\sigma^{(tot)}_{(s)}$ and elastic scattering

$\Delta = 0.12 \div 0.14 \qquad \alpha'_P \approx 0.2\ GeV^{-2}$

For supercritical $\mathcal{P}$ $(\Delta > 0)$ average number of chains increases with energy as s^{Δ}. So at very high energy colliding hadrons are complicated configurations of partons with large number of sea quarks and gluons.

The main parameter of the theory is Δ. From comparison with experiment

$$\Delta = 0.12 \div 0.2$$

← when "enhanced" diagrams are included

b) Predictions for high-energy hadronic collisions.

Models give a unified description of

$\sigma^{(tot)}_{hp}(s)$, $\frac{d\sigma^{(el)}(s,t)}{dt}$, $\frac{d\sigma^{(D)}(s,M^2,t)}{dM^2dt}$ $\qquad \sigma^t \underset{s\to\infty}{\sim} \ln^2 s$

$\frac{d\sigma^c}{dy}$ for $c = \pi^{\pm}, K^{\pm}, K^0(\bar{K}^0), p, \bar{p}, \Lambda, \bar{\Lambda}, \dots$ $\qquad \frac{d\sigma}{dy} \sim s^{\Delta}$

$\sigma_n(s)$, Correlations, ... $\qquad$ Figures.

Substantial deviations from predictions of the models at superhigh energies would indicate to new physics.

Qualitative predictions:

a) $\sigma^{(tot)}_{(s)} \sim \ln^2 \frac{s}{s_0}$ as $s \to \infty$

b) Diffractive slope $B(s) \sim \ln^2 \frac{s}{s_0}$

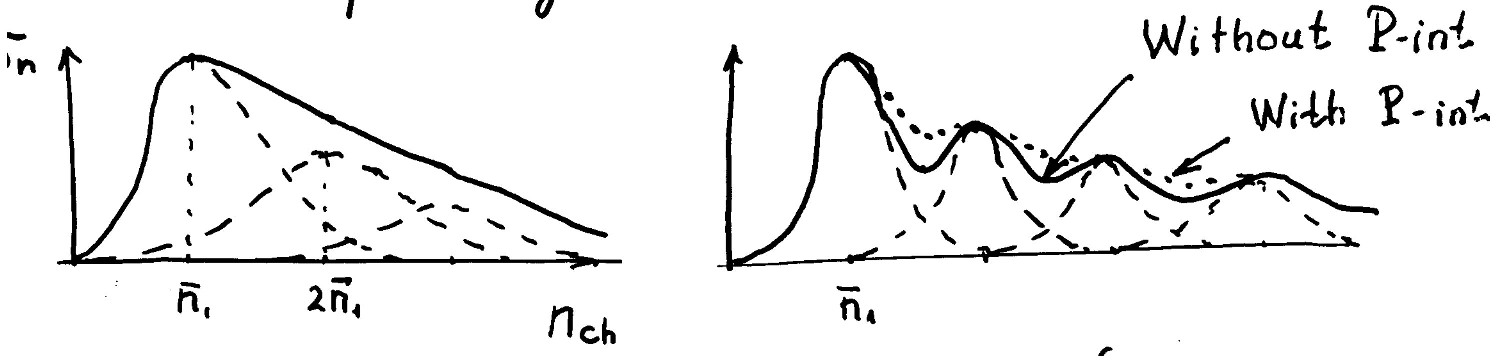
c) $\langle n(s) \rangle \sim s^{\Delta} / \ln \frac{s}{s_0}$ without Pomeron interactions

$\langle n(s) \rangle \sim \ln^3 \frac{s}{s_0}$ with account of P-interac.

d) $\left.\frac{d\sigma}{dy}\right|_{y=0} \sim s^{\Delta}$

$\ln^4 \frac{s}{s_0}$ (with P-interactions)

e) Multiplicity distributions



$\sqrt{s} \sim 10^2$ GeV $\qquad$ $\sqrt{s} \sim 10^6$ GeV

f) Important long range correlations.

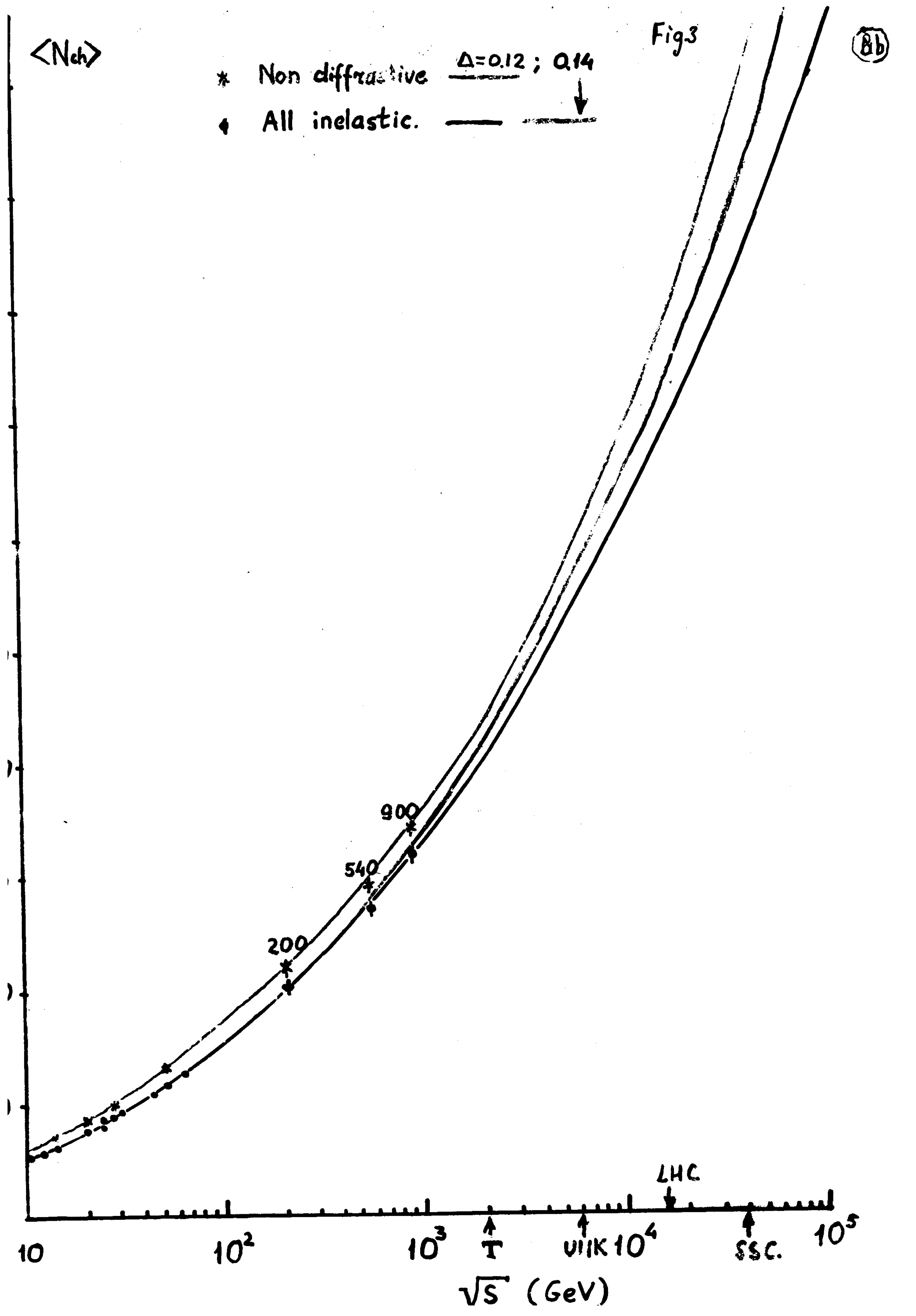
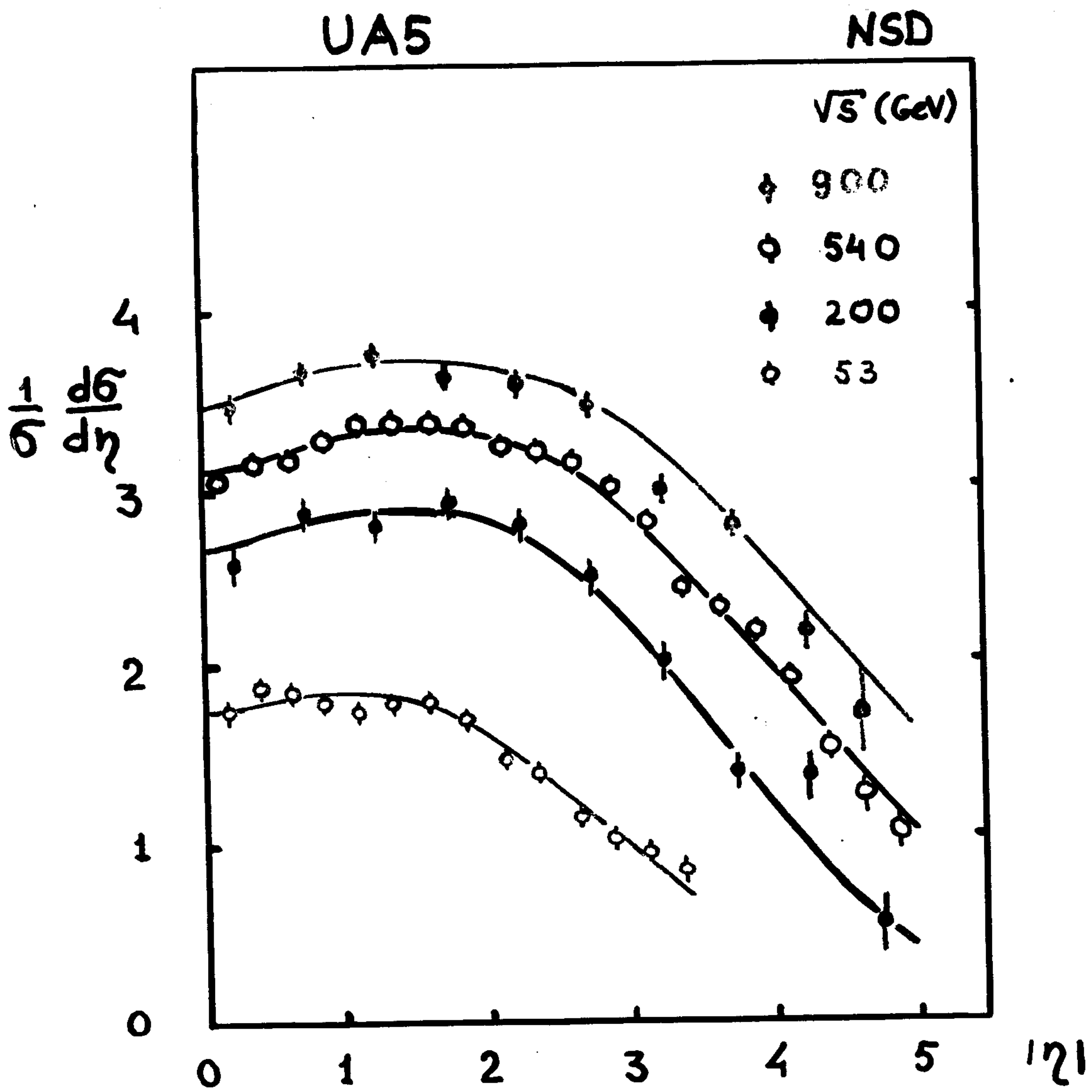
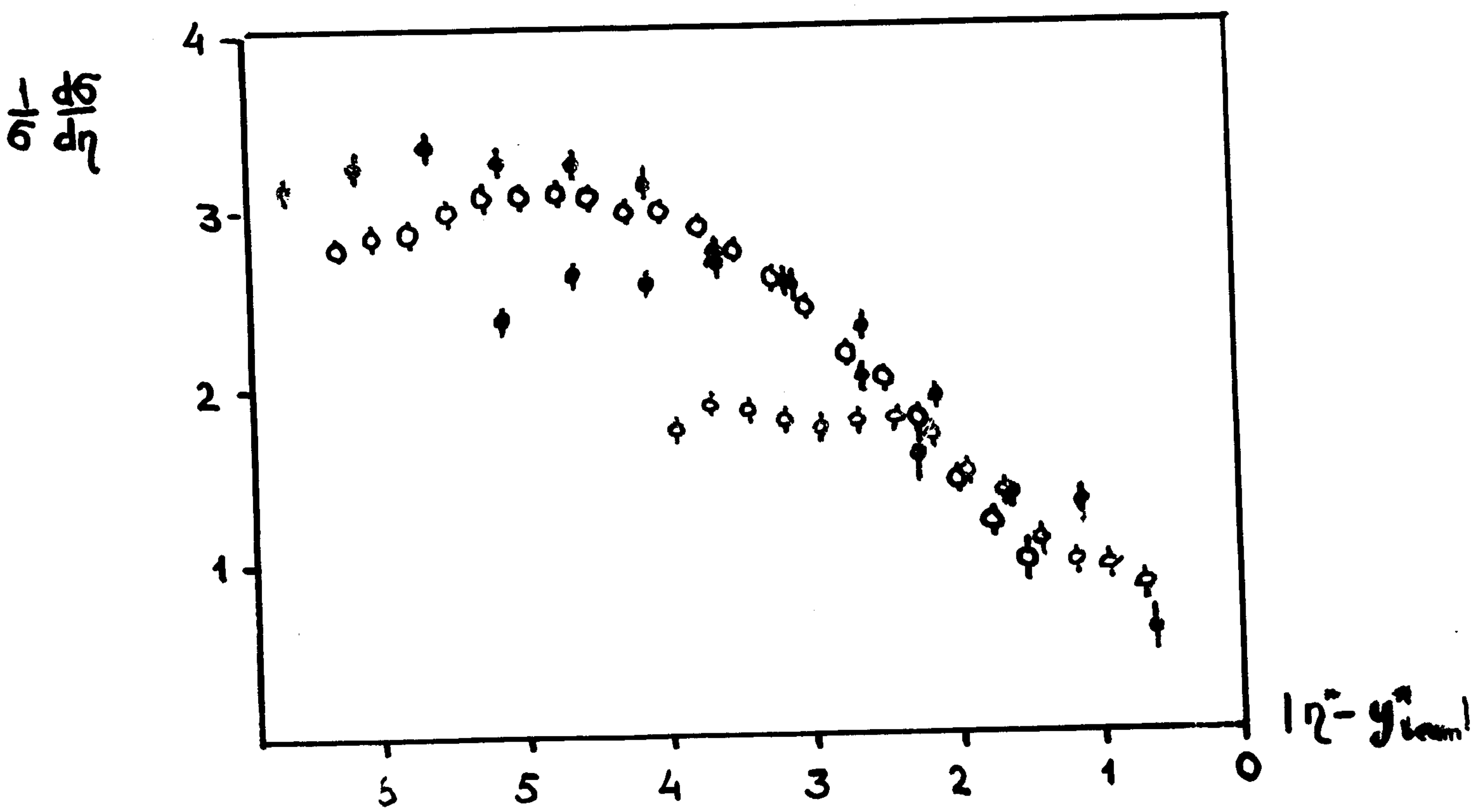


Fig 3
8b
<Nch>
* Non diffractive
• All inelastic.
Δ=0.12 ; 0.14
900
540
200
LHC
10
10^2
10^3
T
UNK
10^4
SSC.
10^5
√s (GeV)

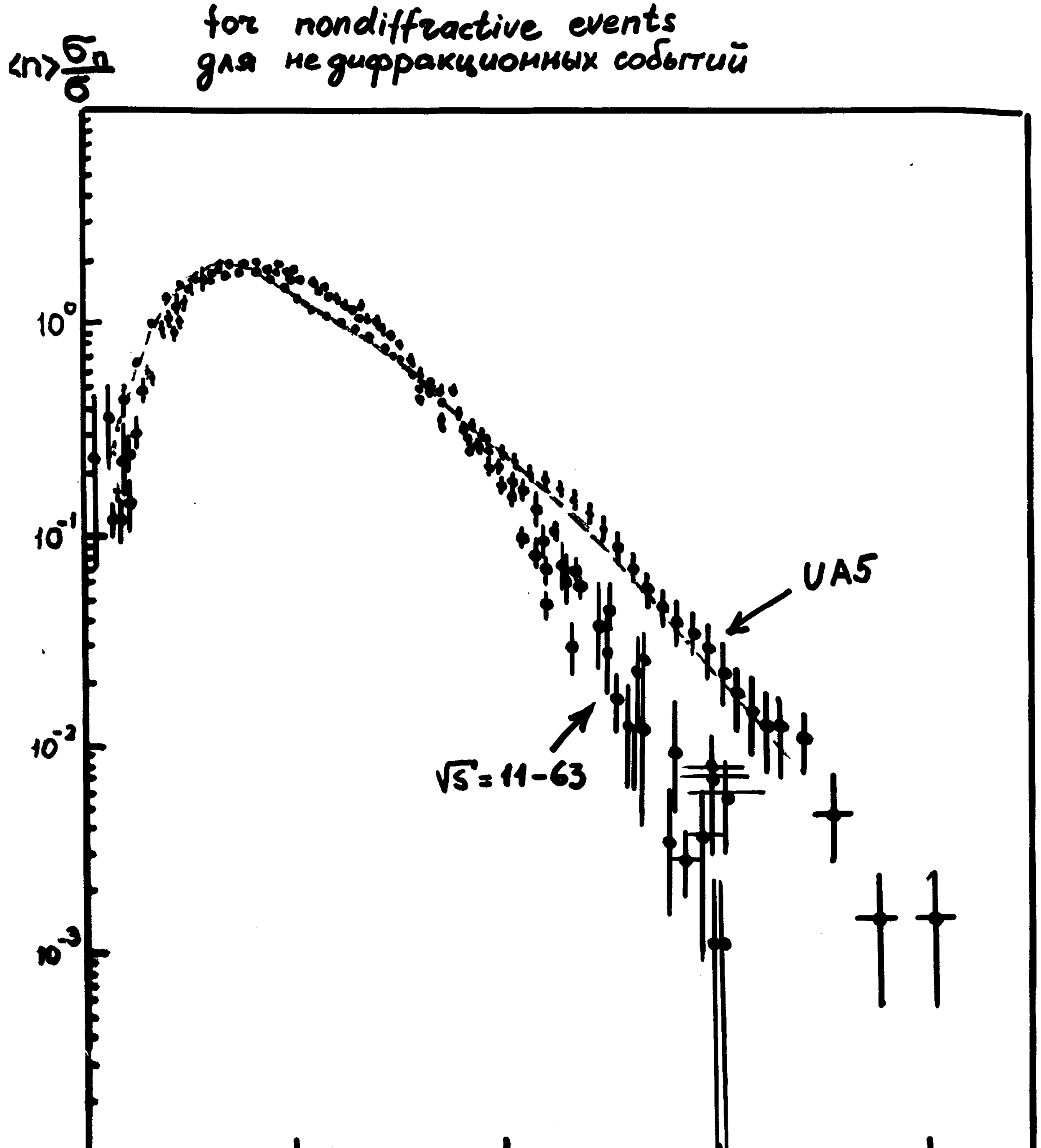
8c



UA5
NSD
√s (GeV)
900
540
200
53
$\frac{1}{\sigma}\frac{d\sigma}{d\eta}$
|η|

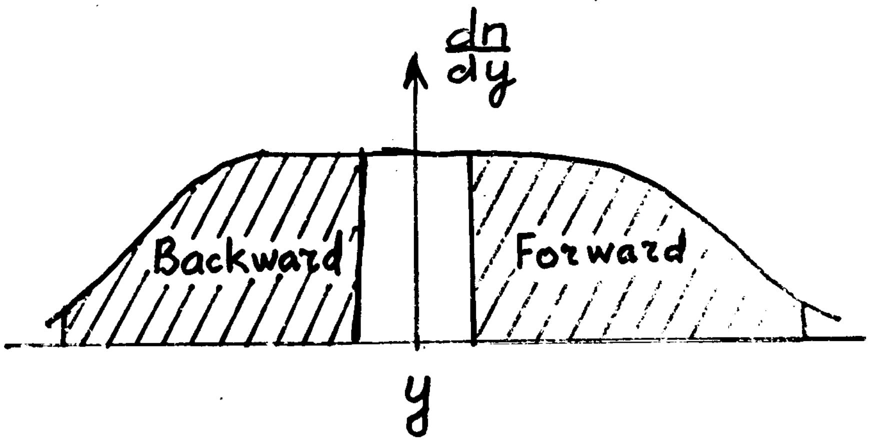


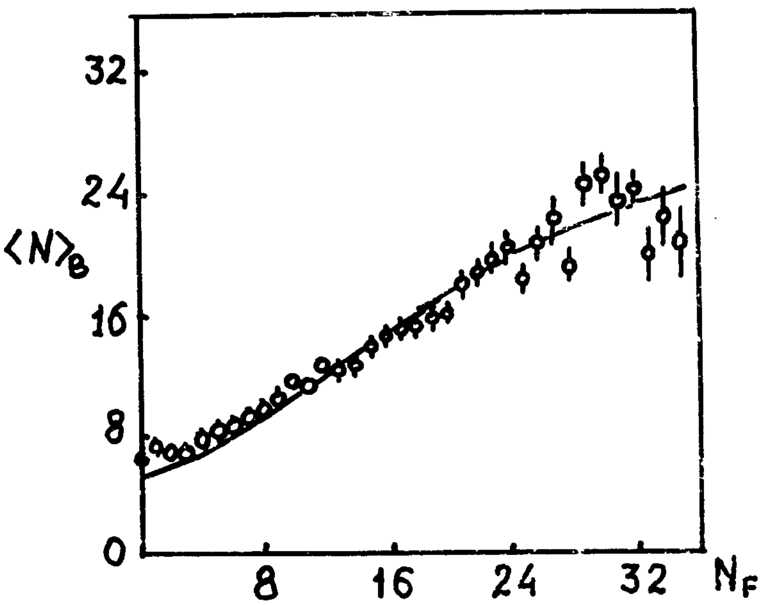
$\frac{1}{\sigma}\frac{d\sigma}{d\eta}$
$|\eta^* - y^*_{beam}|$



for nondiffractive events
для недифракционных событий
$\langle n \rangle \frac{\sigma_n}{\sigma}$
10^0
10^{-1}
10^{-2}
10^{-3}
UA5
$\sqrt{s} = 11-63$
1
2
3
4
$z = \frac{n}{\langle n \rangle}$

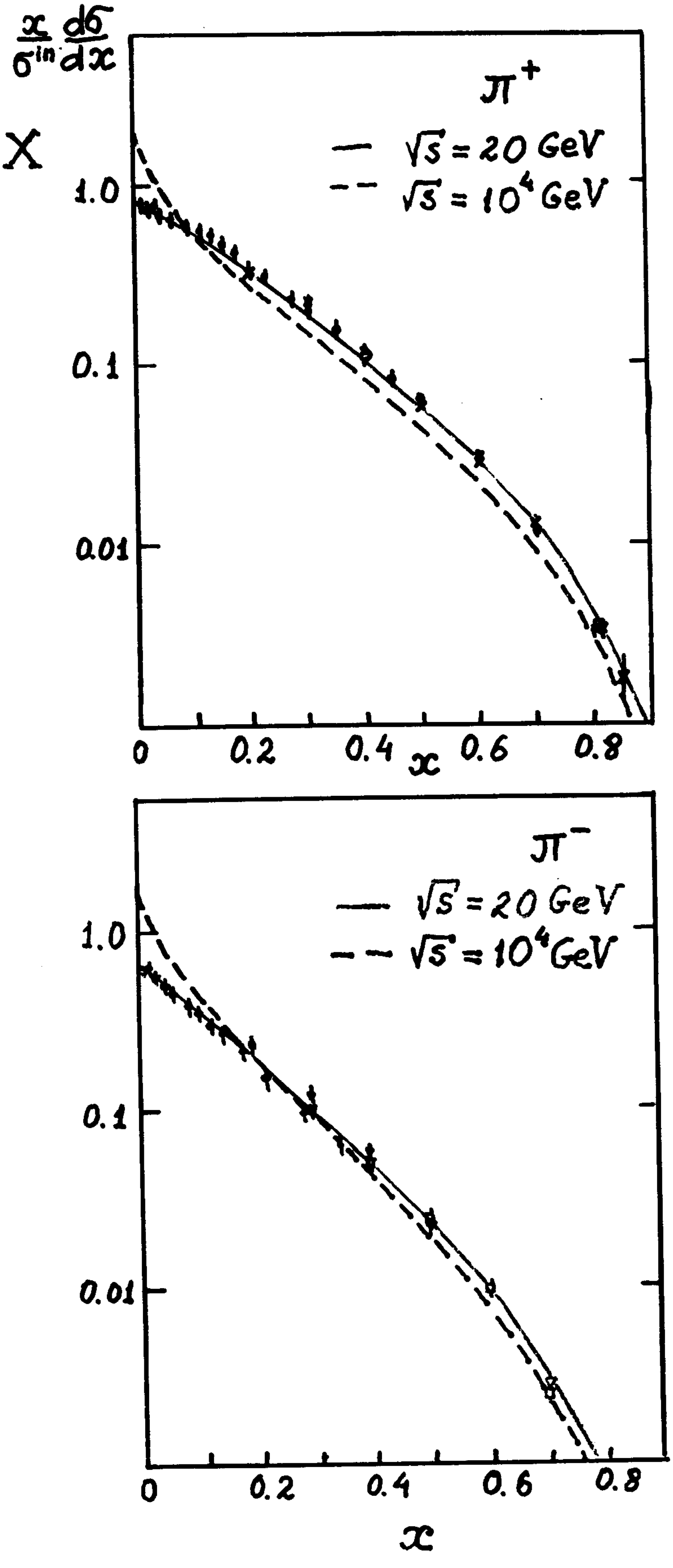
(C





(d)

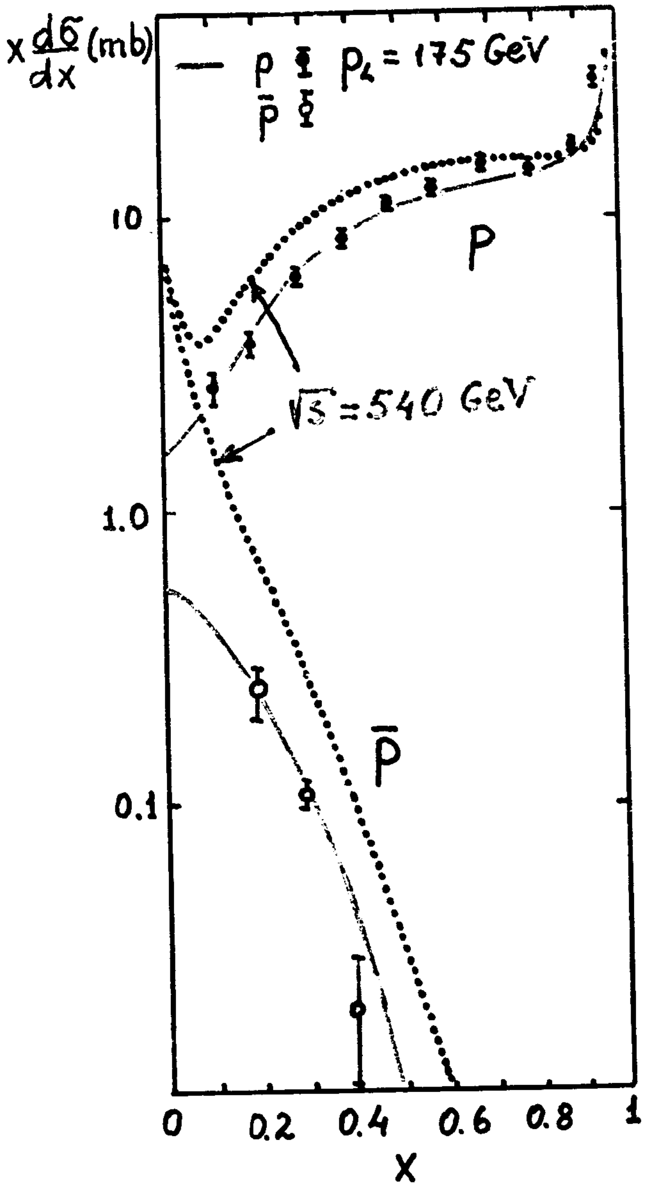
$pp \to \pi^+(\pi^-)X$



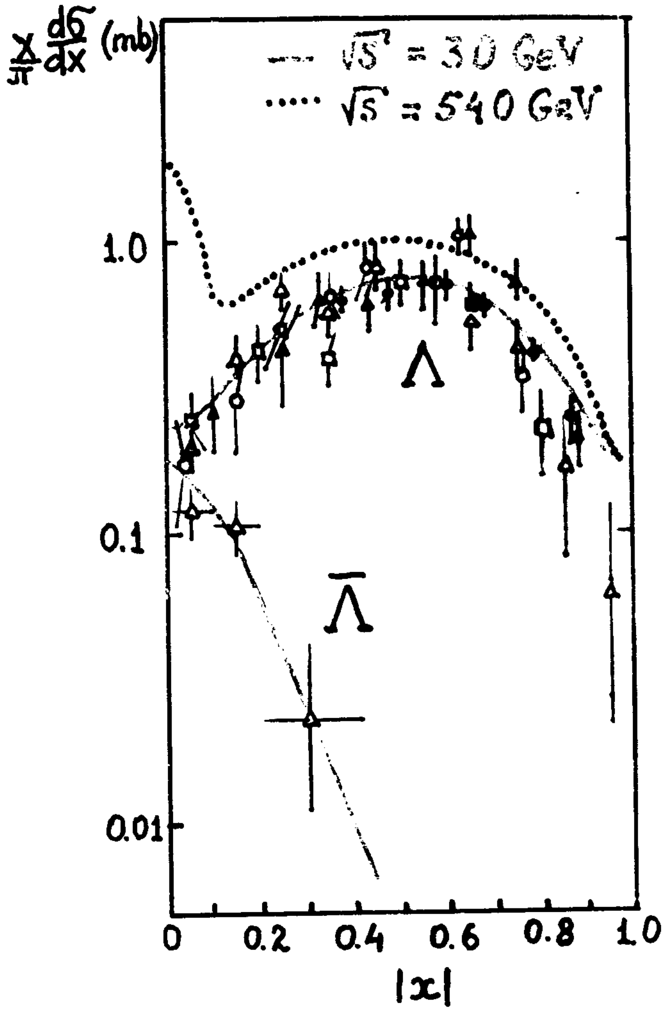
$\frac{x}{\sigma^{in}}\frac{d\sigma}{dx}$
π^+
$\sqrt{s} = 20$ GeV
$\sqrt{s} = 10^4$ GeV
1.0
0.1
0.01
0
0.2
0.4
0.6
0.8
x
π^-
$\sqrt{s} = 20$ GeV
$\sqrt{s} = 10^4$ GeV
1.0
0.1
0.01
0
0.2
0.4
0.6
0.8
x

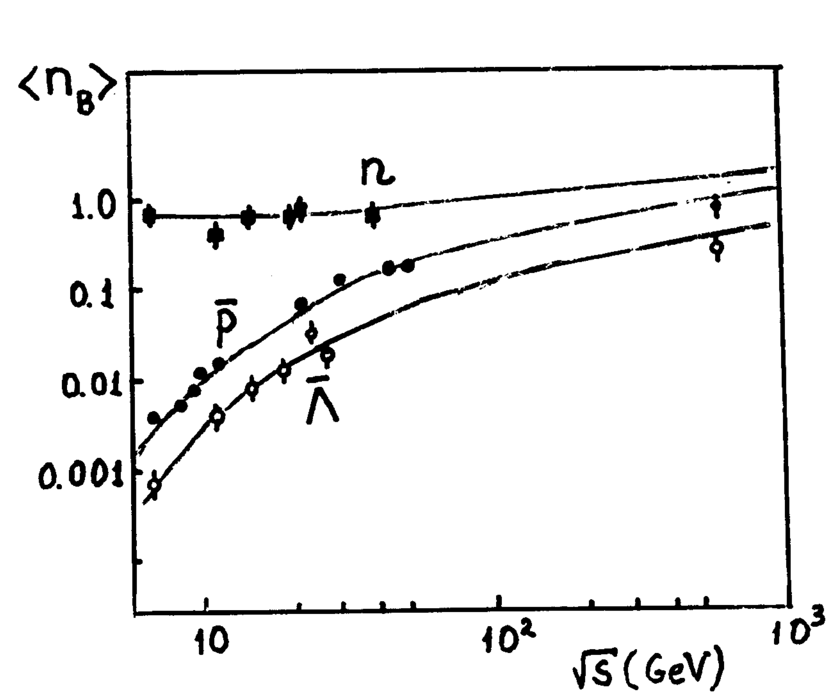
f

$pp \to p(\bar{p})X$



$pp \to \Lambda(\bar{\Lambda})X$





A unified approach to
$\sigma^{(tot)}(s)$, $\frac{d\sigma^{(el)}}{dt}$, $x\frac{d\sigma^{h}(s,x)}{dx}$, $\sigma_n(s)$, ...

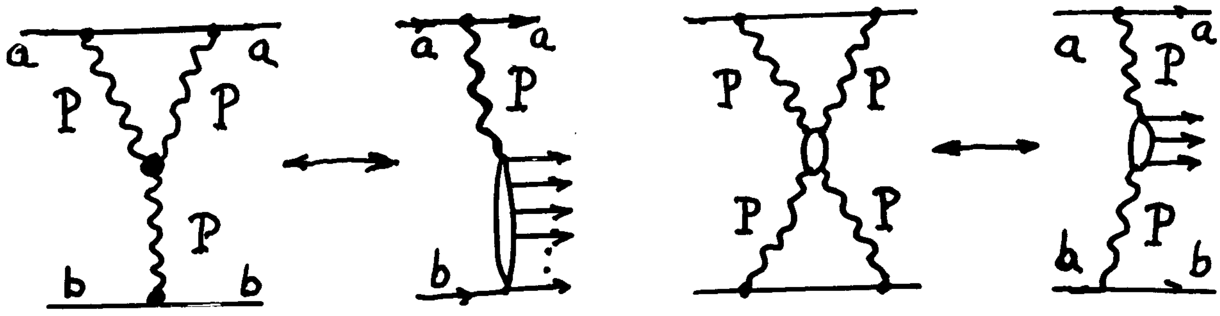
Theoretical description of multiparticle production (inclusive spectra of π^+, π^-, π^0, $K^+, K^-, K^0, \bar{K}^0$, $p, n, \Lambda, \ldots$, multiplicity distributions, correlations,..) is obtained without any free parameters. Figures

Strong violation of Feynman scaling in the central region.

Violation of KNO scaling $\left(\frac{\sigma_n}{\sigma^{in}}\langle n\rangle = \Psi\left(\frac{n}{\langle n\rangle}\right)\right)$ - confirmed by $Sp\bar{p}S$ data

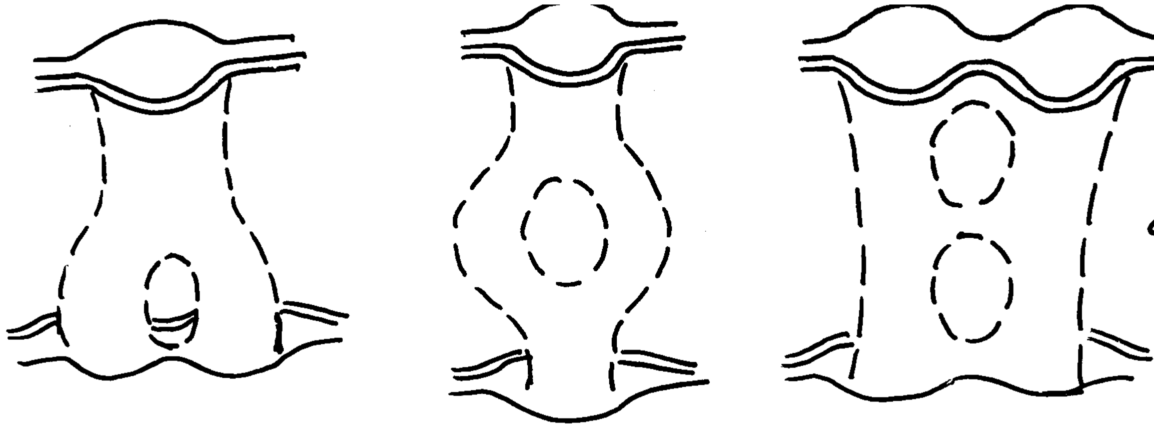
- Interactions between pomerons.

At very high energies interactions between pomerons are important



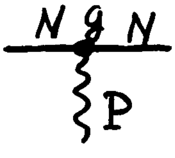
PPP inter. 4P inter

g_{PPP}, g_{4P} have been determined from exp. data and are relatively small

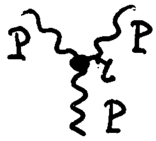


In $1/N$-approach

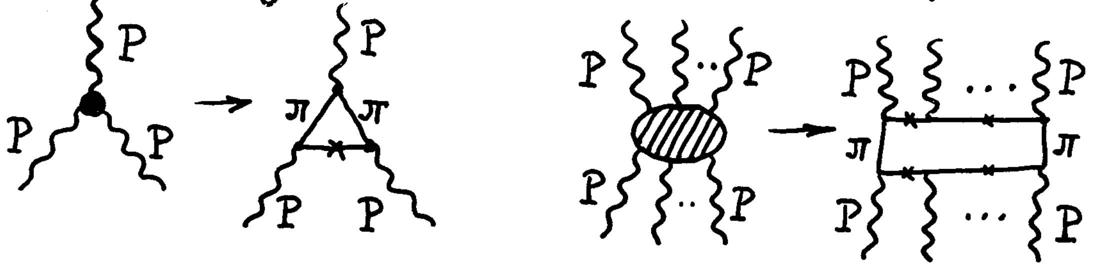
The vertices g_{mn} are small. This justifies dominating role of nonenhanced diagrams



$g^{P}_{NN} \sim (\sqrt{N_c})^0$ $\qquad r^{P}_{PP} \sim \left(\frac{1}{\sqrt{N_c}}\right)^2$



The g_{mn} vertices were calculated in the π-exchange model (L. Ponomarev, K.A. Ter-Martirosyan, A. Kaidalov) 1986



$$g_{mn} = g_{PPP}\,(g_\pi C_{\pi\pi}^{1/2})^{m+n-3}$$

The model is unitary at each rapidity interval and impact parameter.

An effective method of summation of all the diagrams is proposed

The value of r^{P}_{PP} was determined from the data on high mass diffractive production

$$r^{P}_{PP} = 0.15\,\mathrm{Gev}^{-1}$$

From analysis $\sigma^{(tot)}$, $\sigma^{(el)}$, $\sigma^{(diff)}$

$$\Delta = 0.21$$

Predictions for LHC

1. $\sigma^{(tot)}$ 103 mb $\left(\sigma^{(tot)}(s) \sim \ln^2 \frac{s}{s_0}\right)$

2. $\sigma^{(el)}$ 26 mb $\left(\sigma^{(el)}(s) \sim \ln^2 \frac{s}{s_0}\right)$

3. $B(0)$ 21.5 GeV^{-2} $\left(B(0) \sim \ln^2 \frac{s}{s_0}\right)$

4. $\rho = \frac{Re\,T(0)}{Im\,T(0)}$ 0.11

5. σ_{SD} $12 \div 13$ mb $\left(\sigma_{SD} \sim \sigma_{DD} \sim \ln \frac{s}{s_0}\right)$

6. σ_{DD} $11 \div 13$ mb

$$\sigma^{(el)} + \sigma_{SD} + \sigma_{DD} \approx 51\,mb \approx \frac{1}{2}\sigma^{(tot)}$$

7. $\langle n_{ch} \rangle$ $80 \div 100$

8. $\left.\frac{dn_{ch}}{dy}\right|_{y=0}$ $5.5 \div 6.0$

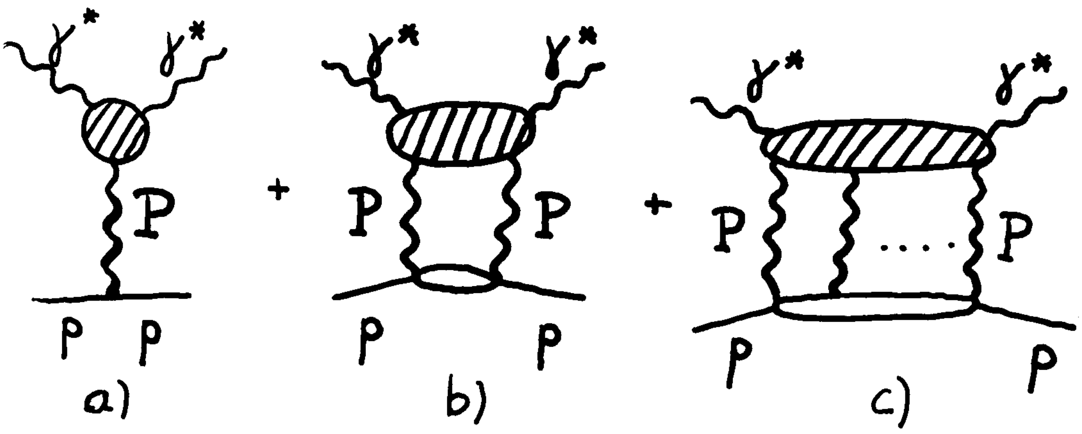
9. Structures in σ_n

10. Strong long-range (in y) correlations

11. Large amount of minijets.

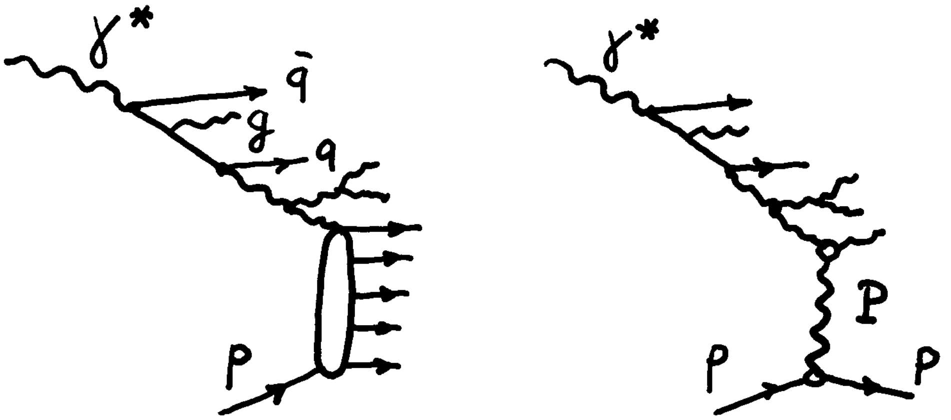
• Applications for HERA

Model for multiparticle production ($\gamma^* p$)



Physical picture

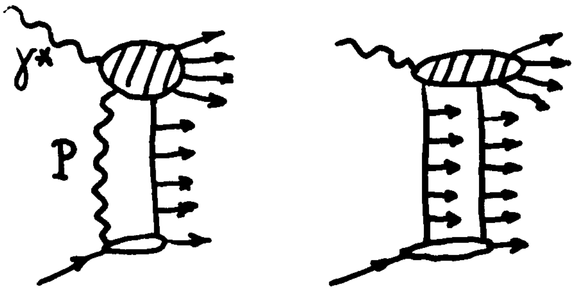
Generalization of the "aligned jet" model of Bjorken



inelastic events

diffractive production

Cuttings of PP-exchange diagram. AGK-cutting rules.

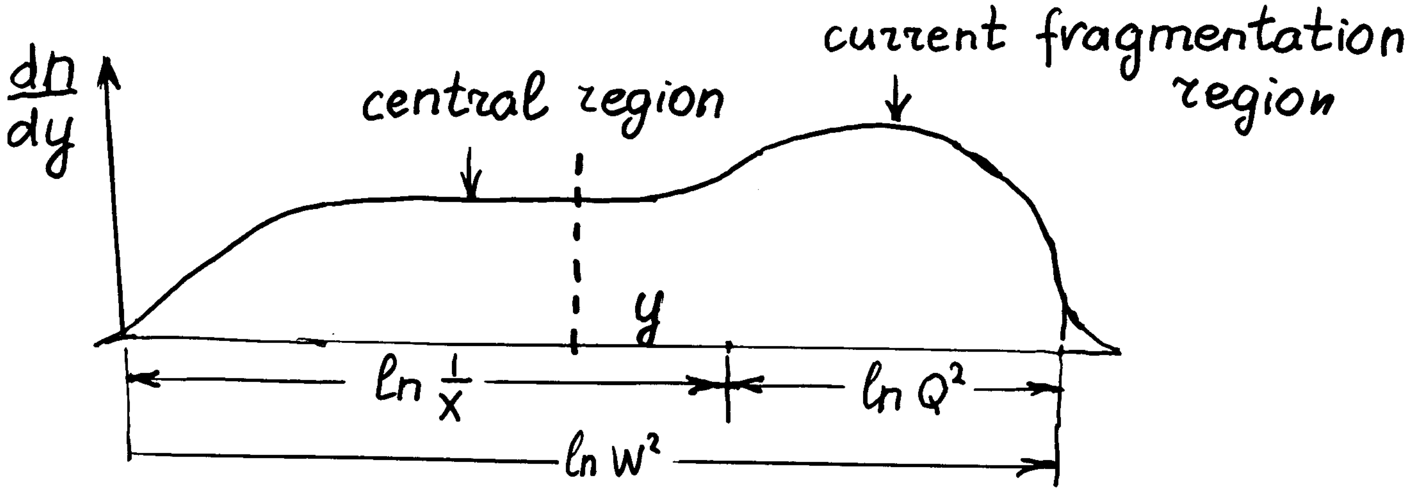


Amount of multichain diagrams depends on Q^2

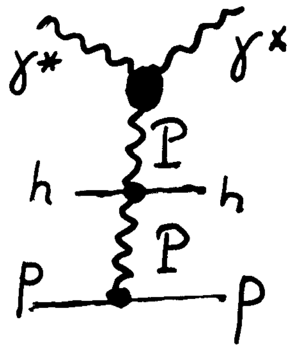
DPM and QGSM will be used to describe particle production for cut Pomerons.

• Structure of hadronic final states.

• Inclusive spectra and particle densities.



Due to AGK cancellation only pole term contributes to the inclusive cross section in the central region.



$$\frac{d\sigma^h}{dy} = a_h \sigma_{\gamma^* p}(x) \sim \left(\frac{1}{x}\right)^{\Delta}$$

density of particles

$$\frac{dn^h}{dy} = \frac{1}{\sigma_{\gamma^* p}} \frac{d\sigma^h}{dy} \approx a_h$$

independent on x, Q^2 (W^2)

if $\sigma_{\gamma^* p}$ is determined by pole term

In present kinematic range of DIS $x \gtrsim 10^{-4}$, $Q^2 > 2\ GeV^2$ contribution of the second rescattering is small $\sim 10\%$ (from diffractive data).

Quasieikonal model. It works well in hadr. inter.

$$\sigma^{(tot)}_{\gamma^* p}(W^2, Q^2) = \sum_{k=0}^{\infty} \sigma^{k}_{\gamma^* p}(W^2, Q^2) = \sigma_P(W^2, Q^2) f\left(\frac{z}{2}\right)$$

$$\sigma_P = f(Q^2)\exp(\Delta\xi) \quad ; \qquad \Delta \equiv \alpha_P(0) - 1, \quad \xi = \ln\frac{1}{x}$$

$$f(z) = \sum_{n=1}^{\infty} \frac{(-z)^{n-1}}{n \cdot n!}$$

$$z = \frac{C(Q^2)}{R^2 + \alpha'_P \xi} \exp(\Delta\xi)$$

it can be determined from the ratio

$$R^D \equiv \frac{\sigma^D_{\gamma^* p}}{\sigma^{(tot)}_{\gamma^* p}} = \frac{F_2^D(x, Q^2)}{F_2(x, Q^2)} = 1 - \frac{f(z)}{f\left(\frac{z}{2}\right)}$$

for small z $\quad R^D \simeq \frac{z}{8}$

for $x \to 0$ $\quad z \to \infty$ $\quad R^D \to \frac{1}{2}$

CKMPT model allows to determine $F_2^D(R^D)$

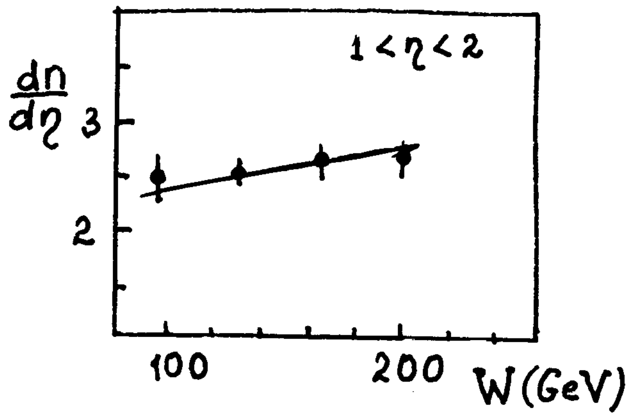
($R^2 = 2.2\ GeV^{-2}$, $\alpha'_P = 0.25\ GeV^{-2}$, $\Delta \simeq 0.2$)

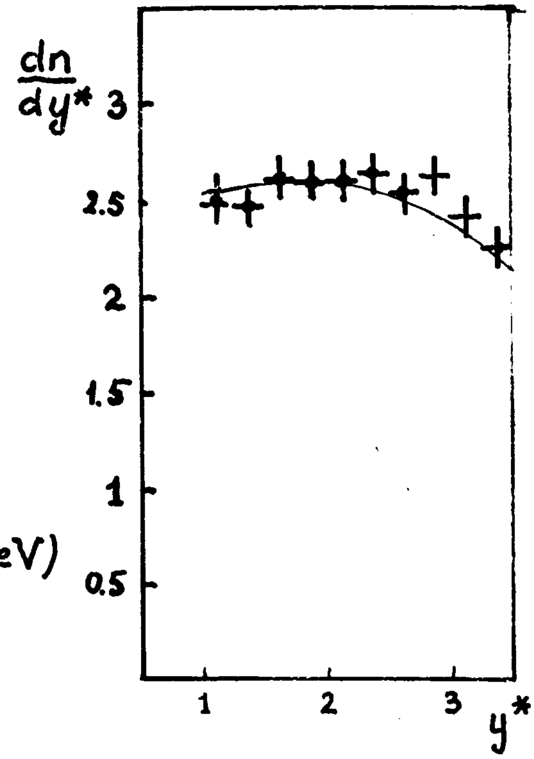
z increases as Q^2 decreases

$z \simeq 1.5 \quad Q^2 = 10\ GeV^2$

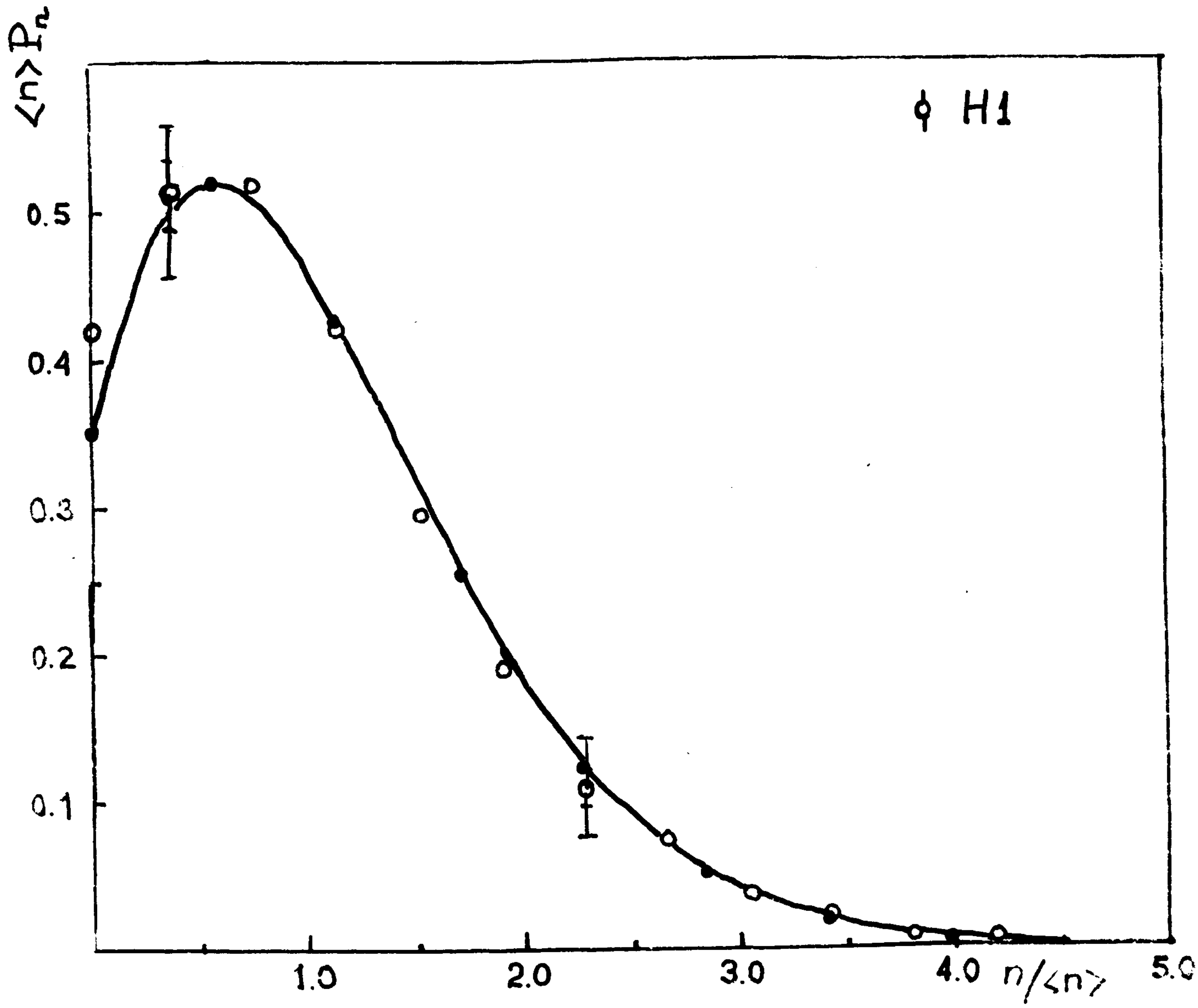
$z \simeq 6 \quad Q^2 = 0$

$W^2 \sim 10^4\ GeV^2$





A. Capella, A.K.,
V. Nechitailo, J. Tran Thanh Van.
LPTHE Orsay 97-58, Phys. Rev. D (98)



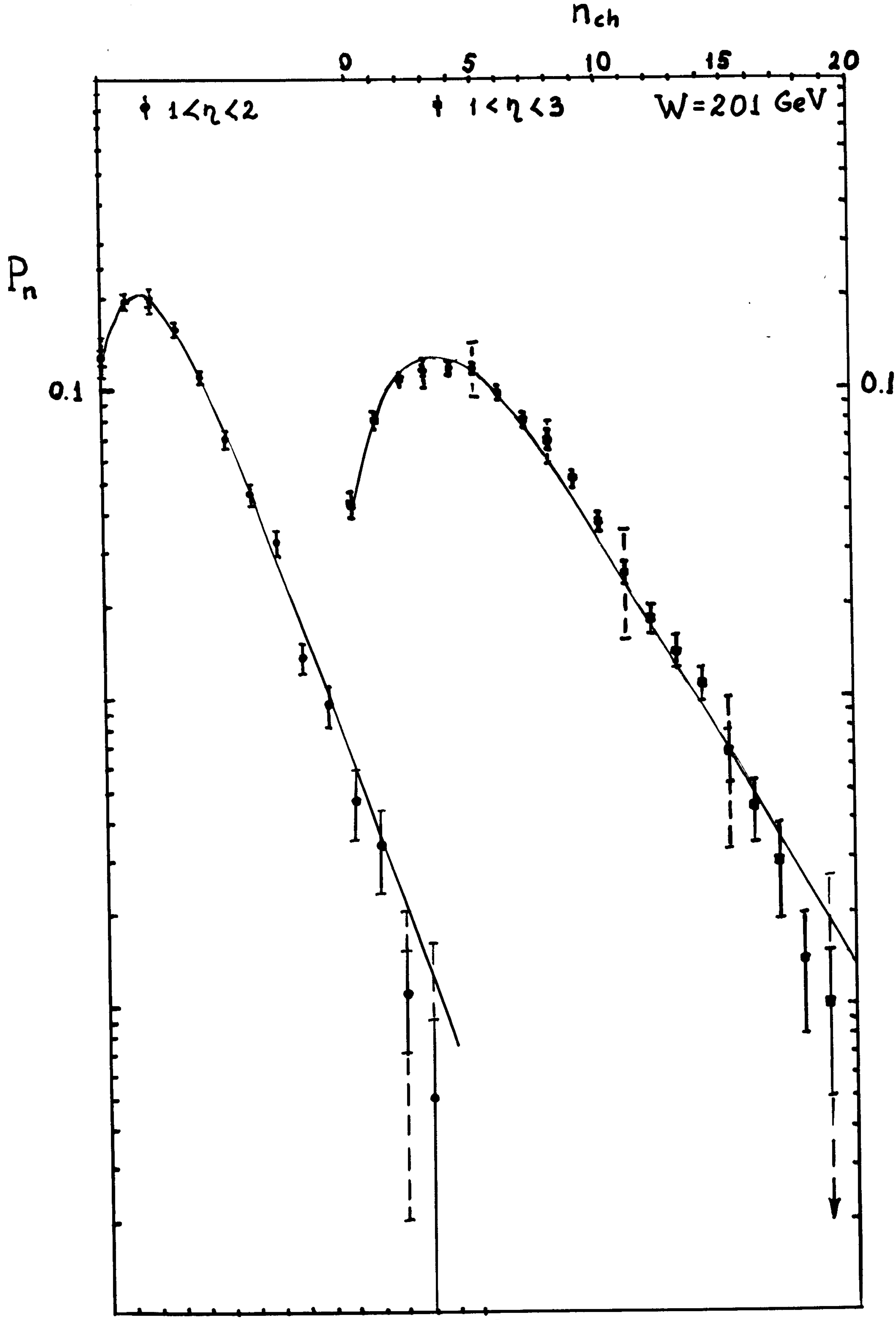
- Problems and new development.

Interactions between pomerons and the problem of "saturation"
Fast increase of minijet cross sections with energy.
Both problems are related.

Existing Monte Carlo:

DPMjet, Phojet, ..	J. Ranft, R. Engel ...
QGSM (with string fusion)	N. Amelin et.al
QGSM jet	S. Ostapchenko et.al
NEXSUS	K. Werner et.al.

Goal: to formulate Monte Carlo, which will include all essential diagrams and will give a selfconsistent descviption of $x \to 0$ region



n_{ch}
0
5
10
15
20
$1<\eta<2$
$1<\eta<3$
W=201 GeV
P_n
0.1
0.1
0
5
10
15
n_{ch}

Conclusions

- Reggeon theory and $1/N$-expansion in QCD allow to formulate dynamical models of multiparticle production, which give a good description of many features of experimental data.
- Same formalism can be applied to small-x physics in DIS. This in turn can stimulate description of semi-hard processes in hadronic interactions.