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DECAMERON DYNAMICS IN THE HIGH ENERGY ANTIPROTON INTERACTION

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1. It was proposed by Rossi and Veneziano[1] to describe the asymptotic contribution to the annihilation cross section in the dual topological expansion scheme by the three-sheet diagram resulting from annihilation of string junctions in the incident baryons. Unfortunately, this qualitative pattern is not supplied with any calculation scheme.

The wide spread opinion that the experimentally observed (up to 12 GeV) energy dependence $\sigma^{\bar{p}p}_{ann} \propto E^{-1/2}$ is connected with this asymptotic contribution is based on the estimations by Eilon and Harrari[2]. But they used the oversimplified Chew-Pignotti approach[3] to the multiperipheral model[4,5] which is also too crude.

We insist on the statement that measured energy dependence of annihilation cross section is connected with preasymptotic mechanisms, but asymptotic one is almost energy independent.

2. Let us consider a natural mechanism in the QCD perturbative theory (PT) leading to three-sheet configuration in the final state. It can be a result of exchange by two gluons which are in the decuplet colour state[6,7] as it is shown in fig.1.

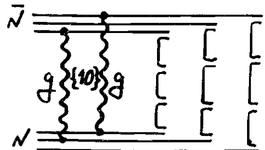

Fig.1. The lowest order perturbative graph with two-gluon decuplet exchange leading to three-sheet final state configuration.

The final state $(3q)_{\{10\}}(3\bar{q})_{\{\overline{10}\}}$ can be considered as three $q\bar{q}$ colourless states (strings) independently decaying into hadrons.

The cross section of this process is connected through unitarity with cut of the four-gluon graph shown in fig.2a. Let us call this graph decameron.

This contribution to the elastic scattering amplitude is energy independent and is forbidden in pp scattering (in eikonal approximation). Nevertheless the Pomeranchuk theorem is not violated because different cuts of the decameron graph through decuplet-antidecuplet (fig.2a) and octet-octet (fig.2b) intermediate states

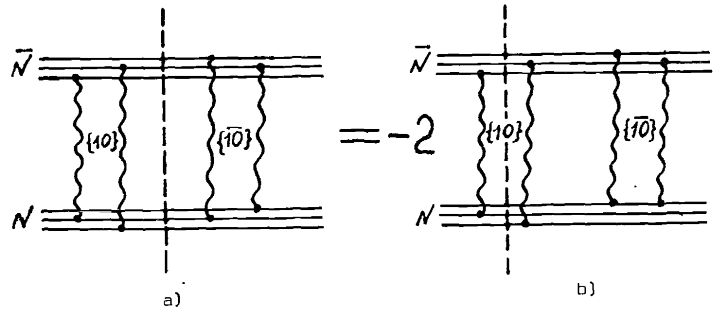

Fig.2.

Decuplet-antidecuplet (a) and octet-octet (b) cuts of the perturbative decameron.

cancell each other in the imaginary part of $\bar{p}p$ elastic amplitude.

This property differs the decameron from the odderon which makes a noticible contribution to the difference between $\bar{p}p$ and pp elastic scattering[6].

It is important to note that cancellation of decameron contribution does not occur in the inclusive $\bar{p}p$ cross section and multiplicity distribution due to different topology of these cuts. One can calculate the cross section of the process $\bar{B}B \to (3\bar{q})_{\{\overline{10}\}}(3q)_{10}$ in the PT. The result denoted by $\sigma_{\{10\}}$ is the cross section of three-sheet events. It is clear that in lowest order approximation $\sigma_{\{10\}}$ is energy independent.

The cross section corresponding to fig.1 has the following form[7]

$$\sigma_{\{10\}} = \frac{\alpha_s^4}{256\pi^2} \int \prod_{i=1}^{4} \frac{d^2 q_i}{q_i^2 + M_g^2} \, \delta^{(2)}\Big(\sum_{j=1}^{4} \vec{q}_j\Big) \times$$

$$\sum_{\alpha_1 \ldots \alpha_4 = 1}^{8} R^{\alpha_1 \ldots \alpha_4}(q_1 \ldots q_4)\, \bar{R}^{\alpha_1 \ldots \alpha_4}(q_1 \ldots q_4) \,, \tag{1}$$

where

$$R^{\alpha_1 \ldots \alpha_4}(q_1 \ldots q_4) = \sum_{\substack{i_1 \neq i_2 \\ i_3 \neq i_4}} \sum_{\{10\}} \left\langle \Psi^{+}_{STR} \Psi^{\{1\}}_{c} \right| \hat{\lambda}^{\alpha_1}_{i_1} \hat{\lambda}^{\alpha_2}_{i_2} \times$$

$$\exp(i\vec{q}_1 \vec{\tau}_{i_1} + i\vec{q}_2 \vec{\tau}_{i_2}) \left| \Psi^{-}_{STR} \Psi^{\{10\}}_{c} \right\rangle \left\langle \Psi^{-}_{STR} \Psi^{\{10\}}_{c} \right| \hat{\lambda}^{\alpha_3}_{i_3} \hat{\lambda}^{\alpha_4}_{i_4} \times$$

$$\exp(i\vec{q}_3 \vec{\tau}_{i_3} + i\vec{q}_4 \vec{\tau}_{i_4}) \left| \Psi^{+}_{STR} \Psi^{\{1\}}_{c} \right\rangle . \tag{2}$$

Here Mg is the effective gluon mass taking into account the confinement; $\hat{\lambda}^{\alpha}$ are the Gell-Mann colour matrices; α_s is the QCD coupling constant; Ψ^{+}_{STR} and Ψ^{-}_{STR} are the three quark wave functions(WF), depending on spin, isospin and spatial coordinates with the Young schemes ☐☐☐ and ☐ , respectively; $\Psi^{\{1\}}_{c}$ and $\Psi^{\{10\}}_{c}$ are the singlet and decuplet colour WF; $\vec{\tau}_i$ are the spatial coordinates of quarks in the c.m. of three quarks; $\vec{q}_i$ are the gluon transverse momenta; the indices $i_1, \ldots, i_4$ are the number of the quark in the three-quark WF; the sum over $\{10\}$ denotes the sum over all possible states of three quarks which are in the decuplet colour state. The expression for $\bar{R}^{\alpha_1 \ldots \alpha_4}(q_1 \ldots q_4)$ in formula(1) is obtained from (2) by substitution $\hat{\lambda}^{\alpha} \to (\hat{\lambda}^{\alpha})^{T}$.

After cumbersome calculations[7] one can reduce the expression (1) to the following one

$$\sigma_{\{10\}} = \frac{5\alpha_s^4}{2\pi^4} \int \prod_{i=1}^{4} \frac{d^2 q_i}{q_i^2 + M_g^2} \, \delta^{(2)}\Big(\sum_{j=1}^{4} \vec{q}_j\Big) R^2(q_1 \ldots q_4) . \tag{3}$$

Here

$$R(\vec{q}_1 \ldots \vec{q}_4) = F(\vec{q}_1 + \vec{q}_3, \vec{q}_2 + \vec{q}_4, 0) + F(\vec{q}_1 + \vec{q}_4, \vec{q}_2, \vec{q}_3) +$$

$$F(\vec{q}_1, \vec{q}_2 + \vec{q}_3, \vec{q}_4) - F(\vec{q}_1 + \vec{q}_3, \vec{q}_2, \vec{q}_4) - F(q_1 + q_4, q_2 + q_3, 0) - F(\vec{q}_1, \vec{q}_2 + \vec{q}_4, \vec{q}_3), \tag{4}$$

where

$$F(\vec{Q}_1, \vec{Q}_2, \vec{Q}_3) = \left\langle \Psi^{+}_{STR} \right| \exp\Big(i \sum_{i=1}^{3} \vec{Q}_i \vec{\tau}_i\Big) \left| \Psi^{+}_{STR} \right\rangle \tag{5}$$

is the three-particle formfactor of baryon.

We use two types of the nonrelativistic nucleon WF. In the first case (denoted by I) the symmetrical oscillatory spatial WF is used. In the second case(II) we take into account the possibility /9/ of existence in the nucleon WF of the dynamically enhanced ud-diquark with S=T=0.

The value of α_s in (3) is related by means of one-loop approximation formula to $\alpha_s^{\{8\}}$ which enters in the expression for the NN-total cross section, calculated in the double gluon approximation. The mean gluon momentum transferred in the present case is somewhat larger than in the case of total cross section.

The results of calculations are shown in fig.3.

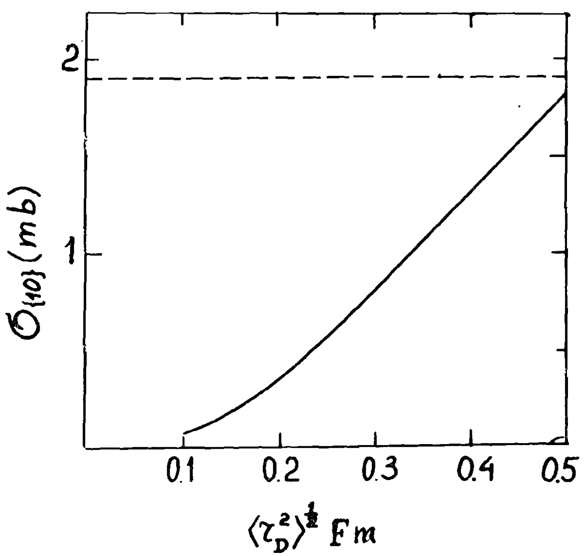

Fig.3.

Results of perturbative QCD calculations of $\sigma_{\{10\}}$. The dashed and solid curves correspond to variants I and II of nucleon WF respectively.

We can see that in case II the value of $\sigma_{\{10\}}$ tends to zero when the diquark mean square radius $\langle r_D^2\rangle$ turns into zero. This is the result of colour screening inside diquark. If the impurity of compact diquark in the nucleon WF is about 50% /9/ one can conclude that the value of $\sigma_{\{10\}}$ is approximately $1 \div 2$ mb.

3. In spite of the absence of high energy annihilation data one can attempt to utilize the fact of enlarged particle multiplicity corresponding to the three-sheet

graph in fig.1. Let us try to extract $\sigma_{\{10\}}$ from the data /10/ on charge particle multiplicity distribution difference $\Delta\sigma_n = \sigma_n^{\bar{p}p} - \sigma_n^{pp}$. First we smoothed over the energy dependence of the $\sigma_n^{\bar{p}p}$ and σ_n^{pp} data by polynomial fitting and than fitted $\Delta\sigma_n$ by sum of two Gaussian functions

$$\Delta\sigma_n = \sum_{i=1}^{2} \frac{\alpha_i}{\beta_i}\left(\frac{\gamma_i}{\pi}\right)^{1/2} \exp\left[-\gamma_i\left(\frac{n}{\beta_i}-1\right)^2\right], \qquad (6)$$

corresponding to contributions of graphs with different topology. We fixed $\gamma_2/\gamma_1 = \beta_2/\beta_1$ and parametrized the energy dependence of $\alpha_1(s)=\omega s^{\varphi}-\rho$ where the first term corresponds to contributions of ω-Reggeon, two-sheet annihilation graph, etc., but the second one corresponds to the negative contribution of two-sheet graph in fig.2b, which compensates decameron contribution to $\sigma_{tot}^{\bar{p}p}$. The fit of the data in the energy interval $10 \div 100$ GeV showed indeed that area under the first Gaussian curve, i.e. parameter α_1 decreases with the energy: φ=-0.56, ω=134 mb. In opposite, as is seen from table I the area of the second Gaussian, i.e. value of parameter α_2, displays no energy dependence and has the

Table 1

E(GeV)	10	20	30	40	50	60	70	80	90	100
α_2 (mb)	2.4	2.2	2.9	3.8	4.0	4.5	4.5	4.2	4.0	3.3
$\pm\Delta\alpha_2$ (mb)	0.4	0.4	0.5	0.5	0.7	0.8	0.9	0.9	1.0	0.9
β_1	5.35	6.4	6.8	6.5	6.3	6.1	6.0	6.0	6.1	6.7
$\pm\Delta\beta_1$	0.05	0.1	0.1	0.2	0.3	0.4	0.4	0.5	0.7	0.8
γ_1	5.26	4.3	3.8	4.3	3.6	3.3	2.7	2.4	2.3	3.2
$\pm\Delta\gamma_1$	0.24	0.3	0.5	0.8	1.1	1.3	1.3	1.3	1.3	1.6
β_2/β_1	1.40	1.25	1.22	1.45	1.5	1.5	1.6	1.6	1.6	1.7
$\pm\Delta\beta_2/\beta_1$	0.03	0.04	0.08	0.05	0.1	0.2	0.2	0.3	0.3	0.2

mean value $\alpha_2 = \rho$ =3± 0.2 mb. This difference in energy dependence of two contributions can be seen with the naked eye in pictures shown for example in fig.4.

So we indeed found the energy independent large multiplicity contribution which can be identified with annihilation cut of the decameron and has the cross section

$$\sigma_{\{10\}}^{exp} = 1.5 \pm 0.1 \text{ mb}. \qquad (7)$$

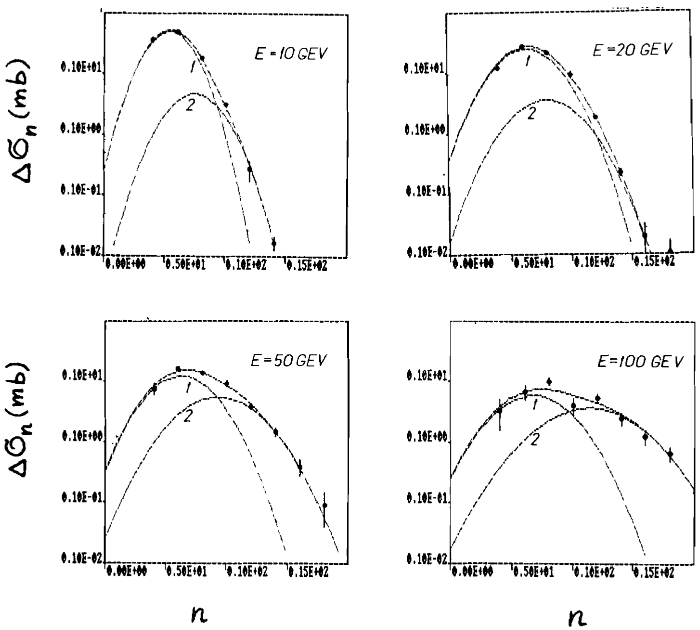

Fig.4.

Examples of multiplicity distribution difference $\Delta\sigma_n = \sigma_n^{\bar{p}p} - \sigma_n^{pp}$. Points and errors are obtained by polynomial interpolation over energy of experimental data/10/. The curves I and II correspond to the first and second terms of expression (6).

This value very well corresponds to the above estimations in PT of QCD.

Note that if the energy is large enough the value of $\alpha_1(s) = 134\, s^{-0.56} - 3$ becomes negative, i.e. $\Delta\sigma_n$ is negative at small n and is positive at large n. This is justified by the ISR data/11/ shown in fig.5 together with our prediction. All the parameters in (6) are fixed by mean values from table I, except the mean multiplicity β_1, which is found to be $\beta_1 = 8.9 \pm 0.6$.

As was mentioned above the different cuts of the decameron shown in fig.2 do not compensate each other in the inclusive cross section. Thus one can expect some difference between $\bar{p}p$ and pp inclusive cross sections in the central region,

$$\frac{\sigma_{in}^{pp}\, d\sigma^{\bar{p}p}/dy}{\sigma_{in}^{\bar{p}p}\, d\sigma^{pp}/dy} = \frac{\sigma_{in}^{pp}}{\sigma_{in}^{\bar{p}p}} + \frac{\sigma_{\{10\}}^{\bar{p}p}}{\sigma_{in}^{pp}}\left(\frac{\beta_2}{\beta_1} + \frac{\alpha_1}{\alpha_2}\right). \qquad (8)$$

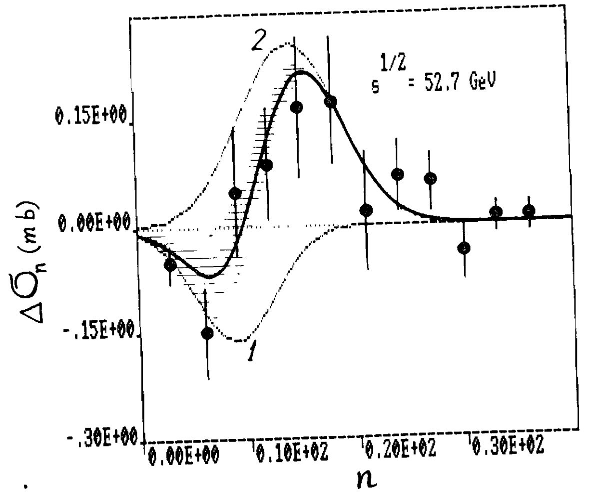

Fig.5.

The same as in fig.4 at $\sqrt{s}$ =52.7 GeV. The sick curve with error bar shows our predictions.

This value calculated with averaged parameters from table I is compared in fig.6 with ISR experimental data/11/.

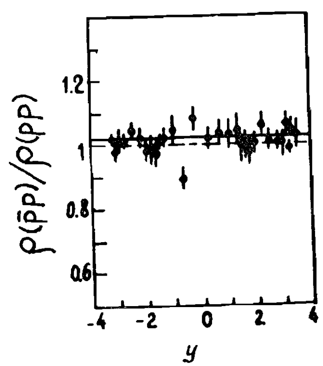

Fig.6. The ratio of the $\bar{p}p$ to pp inclusive cross sections in central region. The horizontal line shows our prediction.

4. We can conclude now that the perturbative decameron is a physical reality. Its three-sheet cut is desplayed indeed in high multiplicity events with cross section nearly energy independent up to ISR energies. The negative contribution of two-sheet cut of the decameron is developed in lower multiplicity region in the ISR data.

Decameron contribution to the annihilation cross section is too small to observe it in present annihilation data. Annihilation at intermediate energies is governed by another mechanism [7] connected with slowing down one of the valence quarks.

A few remarks in the conclusion. The effects of the higher orders of PT expansion should not influence significantly the energy dependence of decameron contribution. Comparison of the results of Bronzan and Shugar [12] for reggeization of singlet and decuplet two-gluon exchanges shows that negative bias of the intercept in the last case is small enough [6].

As for energy dependence of the annihilation cross section it is determined by factor $\exp(-3\langle n_\pi\rangle W_N/W_\pi)$, where $\langle n_\pi\rangle$ is mean multiplicity of charged pions, $W_N/W_\pi \approx 0.03$ is relative probability of $\bar{N}N$ pair production in central rapidity region. This factor is connected with prohibition of $\bar{N}N$ pair production in each of three $\bar{q}q$ strings in the final state. Unfortunately, there is no assurance that annihilation cross section will be measured at high energies some time.

In the future we need the high energy data with high statistics on the difference between $\bar{p}p$ and pp multiplicity distributions, inclusive $\bar{p}p$ and pp cross sections in central rapidity region, data on proton throw through large rapidity gap. The last process is effectively carried out by the decuplet gluonic exchange.

It is very interesting to search for exotic string junction-antijunction states which should lie on the decameron Regge trajectory. [1]

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Динамика декамерона во взаимодействии антипротонов высокой энергии

Декамерон - система из цветовых декуплета-антидекуплета, в низшем порядке теории возмущений КХД отвечает обмену четырьмя глюонами в перекрестном канале. Вклад декамерона в полное сечение $\bar{p}p$ взаимодействия исчезает из-за сокращения различных разрезаний, связанных унитарностью с двух- и трехлистными конечными конфигурациями. Сокращение однако не происходит в распределении по множественности. Анализ соответствующих данных вплоть до энергий ISR показал, что имеется независящий от энергии вклад декамерона с сечением (1,5+/-0,1) мбн, что хорошо соответствует оценкам в теории возмущений КХД.

Работа выполнена в Лаборатории ядерных проблем ОИЯИ.

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Decameron Dynamics in the High Energy Antiproton Interaction

Decameron which is a colour decuplet-antidecuplet state in crossing channel corresponds to the four-gluon exchange graph in the lowest order of the perturbative QCD. It does not contribute to imaginary part of the $p\bar{p}$ elastic scattering amplitude because of cancellation between different cuts of the decameron with three-sheet and two-sheet intermediate states. But this cancellation does not occur in the multiplicity distribution. Analysis of experimental data up to ISR energies reveals energy independent decameron contribution to three sheet events with cross section 1.5+0.1 mb in accordance with perturbative QCD estimations.

The investigation has been performed at the Laboratory of Nuclear Problems, JINR.

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