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Possible origin of observed at incident protons energy 50 GeV events $pp \rightarrow pp + n\pi$ with anomalous multiplicity

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It is argued here that detected in experiment [1] events $pp \rightarrow pp + n\pi$ with anomalously high multiplicity of mesons (up to n=36) may be explained as sequential emission of $n_\pi/2$ σ-mesons (pairs of π-mesons in $0^+(0^+)$ state) by incident proton in the time of formation and disappearance of repeated short-lived rotational states, which may arise in peripheral inelastic collision with impact parameter $b \approx 2R_0 \approx 1.0(\pm 0.01)\,f$. Proven in [2],[3] model of "black balls" for colliding nucleons is used, where nucleons are treated as probability distributions of internal events with sharp boundary $b \leq 2R_0$ of inelastic NN-interactions. With this mechanism of the reaction considered pairs $\pi\pi$ can be emitted from an area on the surface R_0 of incident proton, remote from center of proton target at a distance $b_\sigma > b$. Predictions follow from such assumptions $L_\sigma = 12\hbar$ for angular momentum $L_\sigma \approx b_\sigma P_\sigma$ of emitted $\pi\pi$ pair and $P_p \approx P_0 - 12\hbar n_\sigma/b$ for final longitudinal momentum P_p of incident proton after emission of n_σ pairs of π mesons. These predictions may be tested with obtained in experiment [1] data for events with large number of π mesons.

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1. Introduction

Detected in experiment [1] reactions $pp \rightarrow pp + n\pi$ with anomalously high multiplicity of mesons have no satisfactory explanation. In the events with maximum observed number $n_\pi = 36$ with mean energy $70\,MeV$ of π mesons in centre of mass system the more than $95\,\%$ of kinetic energy of collided protons $\sqrt{s} - 2m_p c^2 \approx 7,90\,GeV$ is spent on emission of these mesons. In existing hypothesis [1] such events are regarded as a possible result of formation of gluons cascade in central collisions of protons. But estimated probability of this is hundreds of times less than observed cross-sections.

In "black balls" model of NN interaction [2], [3] alternative mechanism of π-mesons multiplicity production is possible. Nucleons are treated here as probability distributions of constituent inner events. Non-equilibrium probability distribution of interacted nucleon differs from unobserved inner distribution of free nucleon and has a sharp boundary $R_0 \approx 0.50\,f$, as "black" ball. If impact parameter $b > 2R_0$ then only elastic scattering occurs, and if $b < 2R_0$ then inelastic interaction appears (with probability ~ 1 at energy $\sqrt{s} > 5\,GeV$). Some justifications of "black balls" model for NN interaction are given below.

In the case of peripheral collision rotational state forms of two-protons system with moment of inertia $I = 2mR_0^2$. With angular momentum $L = bP_0 \sim 2R_0P_0$ of incident proton rotational energy of (pp) system $E_{rot} = L^2/2I$ is much greater than energy of incident proton $E_0 = 50\,GeV$ and must be compensated by decrease of potential energy $\Delta U \sim -E_{rot}$. Shifted by energy $\Delta E \sim E_{rot}$ nonequilibrium state may exist only short time $\delta t_{rot} \approx \hbar/\Delta E$.

Transfer of longitudinal momentum $\delta P_{p'}$ to proton-target leads to the decrease of angular momentum $\delta L_p = b\delta P_{p'} \approx 2R_0\delta P_{p'}$. For conservation of total angular momentum (in laboratory coordinate system) simultaneously with momentum transfer $\delta P_{p'}$ incident proton has to emit a meson with such parameter $b_{mes} > 2R_0$ and longitudional momentum P_{mes}, that its contribution $L_{mes} = b_{mes}P_{mes}$ equals to decreasing of protons angular momentum: $\Delta L_p = 2R_0(\delta P_{p'} + P_{mes}) = L_{mes}$. During the time of inelastic interaction $\Delta t_{int} \sim \hbar/2cP_0$ such noneqilibrium rotational states can appear and disappear $\sim \Delta t_{int}/\delta t_{rot} \gg 1$ times. Emission of σ-meson, which carries even momentum $L_\sigma = b_\sigma P_\sigma$ (and further disintegrates into the observed π-mesons), can be repeated for each appearance of short-lived rotational state. In such events all observed π-mesons may appear in small volume outside nucleons at a distance $b_\pi \sim 2R_0$ from the point of contact of interacted protons.

Made below estimates for detected in [1] event with maximum number $n_{pi} = 36$ give the value $L_\sigma = 12\hbar$ and the determinate longitudinal momenta of final protons. Testing of these predictions can lead to some conclusions about possible mechanism of observed multiplicity production.

2. Ground of "black balls" model of interacted nucleons

Nucleon is extent particle and may be imagined as some distribution of probabilities of possible inner events, which is unobserved for free nucleon. Probability is abstract quantity, so probability distribution is not "distribution of matter" and can be changed simultaneously in whole volume without effects of lateness, if transfer of energy and momentum is absent. In the case of interacted nucleons their inner distributions are nonequilibrium and can differ very much from inner state of free nucleon.

Cross-section of inelastic NN scattering $\sigma_{inel} \approx 32\,mb$ is nearly independent from energy (in wide energy range $\sqrt{s} \sim 5 - 100\,GeV$), so it may be treated as geometric cross-section $4\pi R_0^2$ of "blac balls" scattering with radius $R_0 \approx 0.50\,f$. Present scattering theory describes a diffusion of plane wave $\psi = e^{-ikz}$ by some objects and is some kind of Fraunhofer's "theory difraction in parallel beams", which does not consider collisions of extent particles. Correct ratio for scattering of identical particles with "black balls" interaction

$$\sigma_{el} = \pi R_0^2 = \sigma_{inel}/4$$

has been obtained in [2]. Observed elastic NN cross-section $\sigma_{el} \approx 8\,mb$ is nearly independent from energy and equals to $1/4$ of inelastic. This confirms that nonequilibrium inner probability distributions of interacted nucleons in energy range $\sqrt{s} \sim 5 - 100\,GeV$ may be treated as similar to "black balls" with sharp boundary $b \approx 2R_0$ of inelastic interaction.

It may mean that intersection of inner distributions leads to such strong disturbance of collided nucleons, which is prohibited for instance by law of conservation of energy. Therefore non-equilibrium probability distributions of interacted nucleons may be "compressed" to size $R < b/2$ and stay safe in elastic events with $b > 2R_0$, while in inelastic events compressed to size $R < R_0$ these distributions become disturb and emission of secondary particles occurs with probability ~ 1. In this case NN interaction must be treated as interaction of whole probability distributions, rather than interaction of some inner events from these distributions.

The difference of angular momentum $\delta L = \hbar$ separates the neighbouring elastic and inelastic possible events with $\Delta b \approx \hbar c/\sqrt{s}$. The value Δb defines "time of interactions" $\Delta t_{int} = 2\Delta b/2c$, during which possible events may be determined (elastic with keeping of nucleons or inelastic with disturbation of compresed to R_0 nonequilibrium distributions).

"Black balls" model can explain empirical dependence of NN cross-section from energy

$$\sigma_{tot}(\sqrt{s}) \approx 40\,mb(\sqrt{s}/70GeV)^{1/5}, \quad \sqrt{s} > 70\,GeV,$$

where value $40\,mb$ is NN total cross-section at energy $\sqrt{s} < 70\,GeV$, and empirical parameter $70\,(\pm 10)GeV$ may be connected with a size $r_0 \approx c\hbar/140\,GeV$ of "free" inner events (or inner events in interacted nucleons at energy $\sqrt{s} < 70\,GeV$). Thickness of border $\Delta b/2 \approx \hbar c/2\sqrt{s}$ of inelastic interaction limits the size of possible events $r < \Delta b/2$ of nonequilibrium distributions. If $r < r_0$ then inner events with size $\sim r$ may be perturbed, so probability distributions of perturbed events can became excited even when $R > R_0$ and interaction can became inelastic in event with $b > 2R_0$. After increasing of protons energy $dE = d\sqrt{s}$ the part of coherent (indistinguishable) elastic events

$$d'\sigma_{el}^{(p,p)} = -\sigma_{el}^{(p,p)} dr/r = \sigma_{el}^{(p,p)} dE/E$$

transforms into "total" events (elastic or inelastic): $d\sigma_{tot}^{(p,p)} = d'\sigma_{el}^{(p,p)}$. This equality and "black-balls" expression $\sigma_{el}^{(p,p)} = \sigma_{tot}^{(p,p)}/5$ for coherent elastic cross-section give the equation

$$d\sigma_{tot}^{(p,p)} = 1/5 \cdot \sigma_{tot}^{(p,p)} dE/E.$$

Solution of this equation (with empirical parameter $E_0 \approx 70\,GeV$ and $\sigma_0 = 5\pi R_0^2$)

$$\sigma_{tot}^{(p,p)}(E) = (E/E_0)^{1/5}\sigma_0$$

describes observed increasing of total NN cross-section to energy $\sqrt{s} \sim 30\,TeV$. (During (pp) interaction at large energy "virtual" inner events may be turn into real free particles with mass $\sim 2E_0/c^2$. Detected in LHC boson with mass $\sim 126\,GeV/c^2$ may be possible observation of such particles.)

"Black balls" model was used in [3] for explanation of large cross-section $\sim 2\,mb$ of the events $n + p \to n + p + \pi^+\pi^-$ with "reflection" nucleons (where directions of longitudinal momenta in system of centrum mass are reversed) and 0^+ state of $\pi^+\pi^-$ pairs of mesons, observed in experiment [4] with incident neutrons momentum $p_n \approx 5.2\,GeV/c$, and for explanation of 8 narrow peaks in distribution on masses $M_{\pi\pi}$ of pairs $\pi^+\pi^-$ mesons, observed in such events. These peaks were treated as result of quantization of angular momentum $L_0 = bp_n$ of rotational state of two-nucleons system with initial spin $S_z = -1$ and its transition in state with $S_z = 1$ and $L = L_0 - 2$ with emission of difference ΔU_{LS} of potential energy of spin-orbit (np) interaction.

It is proposed, that on distance $\Delta r = 2R_0$ between nucleons their interaction becomes inelastic with probability ~ 1. Angular momentum of incident nucleon bP_0 is conserved and turns into orbital momentum $L_0 = bP_0$ of two-nucleons system with moment of inertia $I = 2m_p R_0^2$. Large rotational energy $E_{rot} = L_0^2/2I$ must be compensated by strong nonequilibrium interaction $\Delta U \sim -E_{rot}$ (which may exist the time $\sim \hbar/\Delta U$). Transfer of momentum δP to nucleon-target leads to decreasing of momentum of incident nucleon and to decreasing of orbital momentum of system, because nucleon-target with parameter $b_{tar} = 0$ gives zero contribution in angular momentum of system. In the case of initial spin $S_z = -1$, then rotational states with kept total angular momentum $J = L_0 - 1$ can exist because of decreasing of orbital momentum may be compensated by opposite change of spin $\Delta L + \Delta S = 0$. So keeping of total momentum $J = L + S$ (in laboratory system) can explain probability ~ 1 of transition from state $J = L_0 - 1$ into state $J = L + 1$ during short lifetime $\sim \hbar/E_{rot}$ of rotational two-nucleons system. Change of potential energy of spin-orbit interaction $\Delta U_{LS} = V_{LS}(2L_0 - 1)$ emits during of pair $\pi^+\pi^-$ production. Quantized values of emitted potential energy explain observed narrow peaks in masses $M_{\pi\pi}$ probability distribution.

After overturn of spin rotation becames impossible and (np) system disintegrates into "reflected" nucleons (in centrum mass system). Statistical weight $g_{(-1)} = 1/16$ of initial states with $S_z = -1$ of neutron-proton system in antisymmetric isospin state $\tau = 0$ (where charge exchange is absent) and probability ~ 1 of rotational state formation explain observed cross-section of such events with reflection of nucleons $\sigma_{refl} = g_{(-1)}\sigma_{inel} \approx 2\,mb$. These explanations of unusual data [4] confirm adequacy of "black balls" model.

Inaccuracy of some generally accepted ideas becomes apparent in analysis of these data. For instance in events with maximum mass $M_{\pi\pi} \approx 1,4\,GeV$ nucleons lose nearly all kinetic energy in centrum mass system, so in final state nucleons and $\pi^+\pi^-$ pair (in 0^+ state) nearly do not move. Angular momentum of such final state is nearly zero, so moved with centrum mass "observer" sees disappearance of initial angular momentum of collided nucleons instead of keeping of initial value. Angular momentum is kept in laboratory system, where it was created. (This leads to conclusion that law of keeping of angular momentum is not "relativistically invariant". But it is not contrary to the "principle of relativity of motion": impossibility to reveal "absolute" movement means that results of any identical experiments, which may be made in different inertial coordinate systems, must be identical. If different "observers" see one experiment, which is made in some one system, they can see a violation of the laws, that have been discovered by them during observations of their "own" experiments, made in "own" systems.)

In the case of experiment with colliding beams (with the same energy $\sqrt{s} \approx 3.42\,GeV$ as in [4]) initial angular momentum $L_0 = 2b_p P_p$ is created and kept in laboratory system, therefore in events with impact parameter $b \neq 0$ final states are impossible with $M_{\pi\pi} \approx 1.4\,GeV$ of $\pi^+\pi^-$ mesons pair (in 0^+ state) and slow nucleons. It demonstrates that completely different inelastic events may occur with the same impact parameter b in experiments with rested nucleon-target and with colliding beams, so these experiments are not identical.

3. Emission of $\pi\pi$ pairs in short-lived rotational states of (pp) system at 50 GeV

Observed in [1] multiplicity production of π mesons at incident proton energy $50\,GeV$ may also be result of emission of pairs $\pi\pi$ by rotating (pp) system, which forms in collisions with impact parameter of incident proton $b \leq 2R_0$. Large rotational energy $E_{rot} \sim 2700\,GeV$ of two-nucleons system with moment of inertia $2mR_0$ in possible state with maximum value of angular momentum $L_0 = 2R_0 P_0 \approx 253\hbar$ must be compensated by decreasing of potential energy $\Delta U \approx -E_{rot}$ during short lifetime of such state $\Delta t_{rot} \sim \hbar/E_{rot}$ with nonequilibrium interaction $\sim \Delta U$.

Transfer of longitudinal momentum δP_p to proton-target leads to decreasing of angular momentum of incident proton $\delta L_p = b\delta P_p$ and to the loss of angular momentum of (pp) system $\delta L = \delta L_p$, because proton-target with parameter $b_{p'} \approx 0$ gives zero contribution into total angular momentum. Law of keeping of total momentum may be fulfilled (then existence of rotational state will be permitted), if during transfer of momentum δP_p incident proton emits meson with such parameter b_{mes} and longitudinal momentum P_{mes} that its angular momentum $L_{mes} = b_{mes} P_{mes}$ is equal to decreasing of momentum of incident proton:

$$b_{mes} P_{mes} = \Delta L_p = b(\delta P_p + P_{mes}).$$

After disappearance of rotational state with short lifetime Δt_{rot} next initial state of incident proton (without nonequilibrium interaction ΔU) may be repeated with decreased angular momentum $L = L_0 - L_{mes}$ and new short-lived rotation state may be formed with decreasing angular momentum and emission of next meson. Parity of repeated two-protons state with reduced by L_{mes} momenta $L_0 - L_{mes}$, $L_0 - 2L_{mes}$, ..., $L_0 - n_{mes} L_{mes}$ remains if σ-mesons are emitted (pairs $\pi\pi$ mesons in $0^+(0^+)$ state) with even momentum L_{mes}.

Repetition of such states may be possible if any other inelastic events do not occur. This is more probable in inelastic peripherical collisions with maximum impact parameter $b \approx 2R_0$, where perturbation of inner states of protons may be minimum. In the events, where 36 π-mesons were detected [1] with mean energy 70 MeV in s.c.m., assumed here 18 σ mesons give contribution $E'_{18\sigma} \approx 7,56\,GeV$ to total energy $\sqrt{s} \approx 9,78\,GeV$. Only with the value $L_\sigma = 12\hbar$ of σ-meson angular momentum $b_\sigma P_\sigma$ such mechanism of observed mesons production would be consistent. Then a conservation of angular momentum $\Delta L_p = L_\sigma$ and supposition of peripherical collision $b_p \approx 2R_0$ define the decrease of momentum $\Delta P_p = L_\sigma/2R_0 \approx 2.36\,GeV/c$ of incident proton and its momentum $P_p = P_0 - n_\sigma \Delta P_p$ in final state after emission of n_σ mesons. For event with maximum number $n_\sigma = 18$ final value $P_p \approx 7,3\,GeV/c$ of this momentum may be predicted.

Even numbers of observed π-mesons $n_\pi = 2n_\sigma$ are followed from this mechanism. Simultaneous emission and disintegration of few σ-mesons may explain increasing of neutral pion number fluctuations, which were observed in events with large n_π [5].

System of protons experiences n_σ sudden accelerations in the case of such n_σ mesons emission. Addition of n_σ amplitudes of bremsstrahlung may explain detected probability of soft photon radiation (with $P_\gamma < 50\,MeV$), which is several times larger in observed events than expected one from other possible mechanisms of reaction with large n_π [5].

Momentum of meson $P_\sigma = L_\sigma/b_\sigma$ with $L_\sigma = 12\hbar$ and transfered to proton-target longitudinal momentum $\delta P_{p'} = \Delta P_p - P_\sigma$ are depend on parameter b_σ of emission of this meson. In the case of maximum value $b_\sigma^{(max)} = 3R_0 \approx 1.5\,f$ momentum of meson must be $P_\sigma \approx 12\hbar/b_\sigma^{(max)} \approx 1,58\,GeV/c$ and transfered to proton-target momentum must be $\delta P_{p'} \approx 0.78\,GeV/c$. Then after emission of 18 σ-mesons longitudinal momentum of proton-target $P_{p'} \approx 14.22\,GeV/c$.

Without taking into account small contributions of transverse momenta approximate estimation is $E_{18\sigma} \approx E_0 - E_p - E_{p'} \approx 29,30\,GeV$ for energy of these 18 mesons, so their mean velocity $v_\sigma \approx 0.97\,c$ must be less than velocity of centre mass $v_{s.c.m.} \approx 0.981\,c$, and velocity of final protons system $v_{p+p'} \approx 0.996\,c$ must be more than velocity of centrum mass.

In the case of experiment with colliding protons beams this mechanism of multiplicity production is impossible. Here transfer of longitudinal momentum occurs without tranfer of kinetic energy and leads to transformation of it into energy of perturbation of protons. Difference of possible mechanisms may result in different distributions of final particles, observed in experiments with rested proton-target and with colliding beams.

4. Conclusions

Obtained in [1] large probabilities of events $pp \to pp + n\pi$ with high multiplicity of π meson production may be treated in "black balls" model with $R_0 = 0,50\,f$ for NN interaction as possible result of nonrandom emission of $\pi\pi$ meson pairs in 0^+ states (or σ mesons) with quantized momentum $L_\sigma = b_\sigma P_\sigma = 12\hbar$ during repetitive appearance and disappearance of short-lived nonequilibrium rotational states of (pp) system, which presumably can be formed during peripherical collisions with impact parameter of incident proton $b \approx 2R_0$.

Such mechanism of large number n_π production defines final angular momentum of incident proton in events with n_σ $\pi\pi$ pairs $L_p = L_0 - n_\sigma 12\hbar$ and final momentum of incident proton $P_p \approx L_p/2R_0 \approx P_0 - n_\sigma L_\sigma/b \approx 50\,GeV/c - n_\sigma 2.4\,GeV/c$.

Momentum of $\pi\pi$ pair $P_\sigma \approx L_\sigma/b_\sigma$ and transfered to proton-target longitudinal momentum depend from parameter b_σ of σ mesons emission $P_{p'} \approx n_\sigma(2.4\,GeV/c - P_\sigma$. This parameter of emission b_σ must be larger than proposed impact parameter $b \approx 2R_0$, so these $\pi\pi$ pairs appear on large distance $b_\sigma > 2R_0$ from proton-target and from area of its contact with incident proton. In the case of maximum value $b_\sigma \approx 3R_0$ the value $P_{p'} \approx n_\sigma 0.78\,GeV/c$ of final longitudinal momentum of proton-target may be obtained. Then velocity $v_\sigma \approx P_\sigma c^2/E_\sigma \approx 0.97c$ of such $\pi\pi$ pairs must be less than velocity of centrum mass system $v_{s.c.m.} \approx 0.981c$, and velocity of final protons system $v_{(p+p')} \approx (P_p + P_{p'})c^2/(E_p + E_{p'}) \approx 0.996c$ must be more than velocity of centrum mass.

These estimates may be tested by obtained in [1] data about momenta of particles in events with large multiplicity. Interaction of particles in final states may disturb these predictions in individual events, but average values may be disturbed smaller. If such or similar difference of velocities in the events with large number of mesons will be detected, this may be explained by considered mechanism.

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