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S-Matrix unitarity and Pomeron shadowing corrections

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Regge theory is the only valid framework to describe soft scattering processes where the perturbative QCD is not applicable. In Regge theory, the particle diffraction is treated as an exchange of some 'object' called Pomeron (which in some way generalizes a particle — in particular, it is described by variable complex angular momentum which generalizes a spin). That approach was found surprisingly useful to phenomenologically calculating cross sections.

In 1960s, it was shown that multi-Pomeron shower production reactions $pp \to p + X_1 + X_2 + ... + p$, where showers (X_i) are separated by large rapidity gaps, are breaking the S-matrix unitarity because corresponding cross-sections σ_{tot} grow with the rapidity (ξ) faster than allowed by unitarity (the upper bound is $\sigma_{tot} \le \xi^2$). This issue is known as Finkelstein-Kajantie problem. In 1974, a possible solution was proposed [1] in multichannel Eikonal model. It considered the gap survival probability S^2 — the probability to observe the pure process where the gap is not populated by secondaries produced in the additional inelastic interaction. In the impact parameter representation the probability is given by $S^2(b) = |e^{-\Omega(b)}|$, where b is the impact parameter and Ω is the proton opacity. In the black disc limit $Re(\Omega) \to \infty$, so $S^2(b) \to 0$. So the additional rescatterings should close the rapidity gaps. The work [2] shows that decreasing of the survival probability should overcompensate the original cross-sesction growth so, as a result, the cross-sections should also vanish with energy: $\frac{d\sigma}{d\xi_1} \sim e^{-\Delta\xi_1} \to 0$, where ξ_1 is the shower width on the rapidity scale. If the result is correct then the unitarity is restored. Over the past decades, it has been considered a cure for the FK problem [3].

The work [4] had discovered that such an approach still fails to unitarize the Pomeron contribution to the single diffraction dissociation amplitude due to an error in the calculations. The suspicion had arised: is the cure really effective in terms of all the processes it is purposed for? Recent TOTEM soft scattering data renewed the interest to these questions.

In the work [5] we investigate the survival probability method for all the diffractive processes. The main processes are next. The first is single diffraction dissociation where one of the two incoming protons transforms into a shower: $pp \to X + p$. The second is double diffraction dissocastion where both protons transforms: $pp \to X_1 + X_2$. The third is central production: $pp \to p + X + p$. Integrated cross-sections of all these processes behave similar to each other, so only the simplest, the single dissociation, will be considered in this talk. Its cross-section contains a multiplier $e^{\Delta(\xi_1+2\xi_2-a\xi)}$, where $a \to 2\frac{\xi}{\xi+\xi_1}$ as $\xi \to \infty$. Here ξ_2 is the rapidity gap between the produced shower and the initial proton; $\xi_1 + \xi_2 = \xi$ — the overall rapidity difference between interacting protons. While investigating the high energy asymptotics ($\xi \to \infty$), the authors of [2] considered a as 2 and $e^{\Delta(\xi_1+2\xi_2-a\xi)}$ simply became $e^{-\Delta\xi_1}$. However, if the calculations are done in an explicit way, one can see that $a = 2(1 - \frac{\xi_1}{\xi} + O(\frac{\xi_1^2}{\xi^2}))$ and so $e^{\Delta(\xi_1+2\xi_2-a\xi)} = e^{\Delta(\xi_1+2\xi_2-2\xi(1-\frac{\xi_1}{\xi}))} = e^{+\Delta\xi_1}$, thus the fast cross-section growth is in fact maintained.

Thereby the existing survival probability methods are unable to keep the cross-section growth within the unitarity bound. We develop a different approach based on the Pomeron and triple-Pomeron vertex renormalization via Schwinger-Dyson equations. We take the Pomeron in it's maximal form providing the maximal strong interactions strength allowed by unitarity. The triple-Pomeron vertex is chosen to contain zeroes at some transferred momenta and complex angular momenta. The parameters of developing model can be chosen in such a way that the unitarity bounds are not violated.

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