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ОДДЕРОН: МИФЫ И РЕАЛЬНОСТЬ

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В рамках модели Редже полюсов исследовано поведение фазы рассеяния вперед протонов на протонах (ρ(13 TeV) = 0,1 ± 0,01), измеренной недавно на ускорителе LHC. Модель включает дипольный померон, оддерон и обмен вторичными реджеонами. Она описывает «излом» при малых $|t|$ (отклонение от экспоненциального поведения дифракционного конуса), ускоренный рост с энергией наклона конуса $B(s, t = 0)$, а также отсутствие дополнительных структур в дифференциальном сечении. В отличие от большинства моделей Редже полюсов наш подход основан на использовании двукратного померона. Он обладает рядом преимуществ по сравнению с моделью простого полюса. Двукратный померон генерирует растущие сечения даже при единичном интерсепте померона и, что еще важнее, рождает дифракционный минимум и максимум в дифференциальном сечении в соответствии с экспериментальными данными. В рамках модели вычислен относительный вклад в амплитуду рассеяния различных ее компонент.

Ключевые слова: модель Редже полюсов; померон; оддерон.

THE ODDERON: MYTHS AND REALITY

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In the framework of a Regge-pole model, we discussthe forward phase of the proton-proton elastic scattering amplitude (ρ(13 TeV) = 0.1 ± 0.01), recently measured at the LHC. Our model includesa dipole pomeron, odderon and secondary reggeon exchanges. It accommodetes forthe low-$|t|$ «break» (departure from the exponential behavior of the

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diffraction cone), the accelerating rise with energy of the forward slope $B(s, t = 0)$ and absence of secondary dips and bumps. Contrary to the majority of Regge-pole models, our approach is based on he use of a dipole (double pole) pomeron (DP). It has a number of advantages over the conventional simple pole pomeron: DP generates rising cross sections even at unit pomeron intercept and, what is even more important, it produces a single diffraction minimum and maximum in the differential cross section, in accord with the experimental data. Relative contributions from different components to the scattering amplitude are evaluated from the fitted model.

Keywords: Regge-pole model; pomeron; odderon.

During the past couple of years discussion on the so-called odderon was triggered by the TOTEM Collaboration, who produced a number of spectacular results on proton-proton elastic and total cross sections measured at the LHC in the range $2.76 \le \sqrt{\rho} \le 13$ TeV [1]. Most, but not all of them can be fitted within Regge-pole models with a simple pomeron pole as input.

A possible alternative to the simple Regge-pole model as input is a double pole (double pomeron pole, or simply dipole pomeron, DP) in the angular momentum (j) plane. It has a number of advantages over the simple pomeron Regge-pole. In particular, it produces logarithmically rising cross sections already at the «Born» level.

The pomeron amplitude may be rewritten in the following «geometrical» form (for details see [2] and references therein):

$$A_p(s, t) = i\frac{a_P s}{b_P s_{0p}}\left[r_{1P}^2(s)e^{r_{1P}^2(s)[\alpha_P - 1]} - \varepsilon_P r_{2P}^2(s)e^{r_{2P}^2(s)[\alpha_P - 1]}\right], \quad (1)$$

where $r_{1P}^2(s) = b_P + L_P - \frac{i\pi}{2}$; $r_{2P}^2(s) = L_P - \frac{i\pi}{2}$, $L_P \equiv \ln\left(\frac{s}{s_{0P}}\right)$. The pomeron trajectory, in its simplest version is linear:

$$a_P \equiv a_P(t) = 1 + \delta_P + a'_P t. \quad (2)$$

We assume that the odderon contribution is of the same form as one of the pomeron, implying the relation $A_O = -iA_P$ and different values of adjustable parameters (labeled by subscript «O»):

Secondary reggeons are parameterized in a standard way with linear Regge trajectories and exponential residua.

The complete scattering amplitude used in our fits is:

$$A(s, t)_{\mathrm{pp}}^{\bar{\mathrm{p}}\mathrm{p}} = A_P(s, t) + A_f(s, t) \pm \left[A_\omega(s, t) + A_O(s, t)\right]. \quad (3)$$

We use the norm where

$$\sigma_{\mathrm{tot}}(s) = \frac{4\pi}{s}\operatorname{Im} A(s, t = 0) \text{ and } \frac{d\sigma_{\mathrm{el}}}{dt}(s, t) = \frac{\pi}{s^2}\left|A(s, t)\right|^2. \quad (4)$$

The parameter $\rho(s)$, the ratio of the real and imaginary part of the forward scattering amplitude is

$$\rho(s) = \frac{\operatorname{Re} A(s, t = 0)}{\operatorname{Im} A(s, t = 0)}. \quad (5)$$

Next we show the main results. More details on the t and values of the fitted parameter scan be found in [3].

Recent measurement of the phase ρ(13 TeV) = 0.09 ± 0.01 (or ρ(13 TeV) = 0.1 ± 0.01) [4] is widely discussed in the literature. The above data point lies well below the expectations (extrapolations) from lower energies, although this should not be dramatized. The exibility of the odderon parameterization leaves room for perfect ts to this data point simultaneously with the total cross section. More critical is the inclusion of non-forward data, both for pp and $\bar{\mathrm{p}}\mathrm{p}$ especially around the dip region, to which the odderon is sensitive!

Figure 1 shows the results of our fits to pp and $\bar{\mathrm{p}}\mathrm{p}$ ρ-parameter data. The case without the odderon (shown as a dotted line) does not provide a description for the new 13 TeV data point. However, we found that neglect of the oddereon has no significant effect on the description of the new TOTEM total cross section measurements.

The forward slope, defined as

$$B(s, t \to 0) = \frac{d}{dt}\ln\left(\frac{d\sigma}{dt}\right)|t = 0, \quad (6)$$

where $A(s, t)$ is the elastic scattering amplitude, is shown in fig. 2 for pp and $\bar{\mathrm{p}}\mathrm{p}$ by using (6).

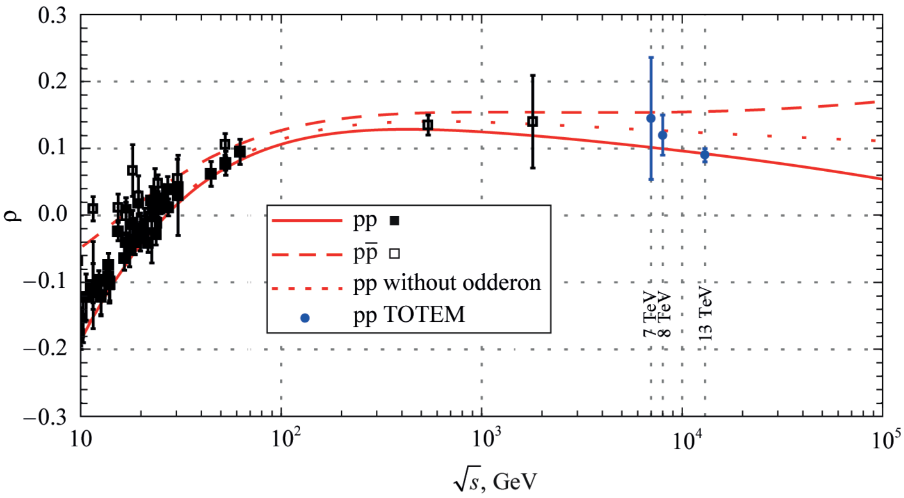

Fig. 1. Fits to pp and p̄p ratio ρ data using the model (1)–(3), (5)

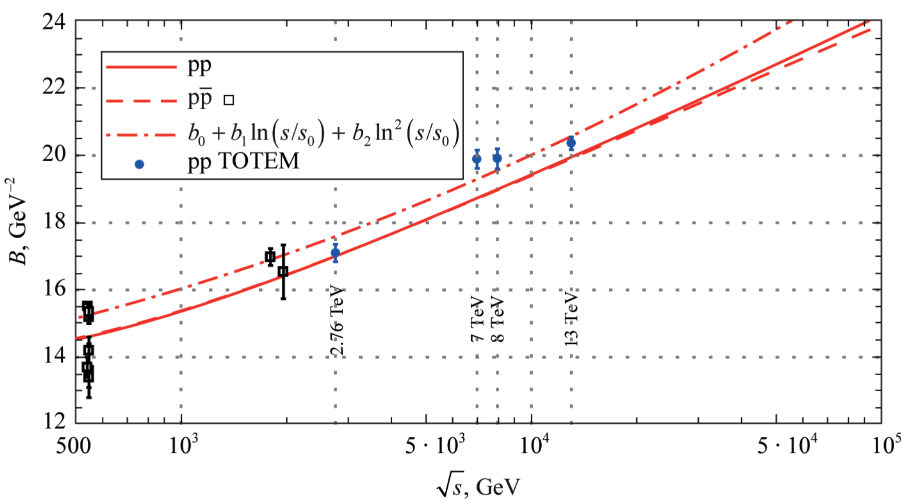

Fig. 2. pp and p̄p elastic slope $B(s)$ calculated from the fitted model (1)–(4)

In [3] we have shown that the odderon promotes a faster than ln$s$ rise of the elastic slope $B(s)$ beyond the LHC energy region.

The non-exponential behavior of the low-$|t|$ pp differential cross section, called «break» was confirmed by recent measurements by the TOTEM Collaboration at the CERN LHC, first at 8 TeV (with a significance greater than 7σ) [5] and subsequently at 13 TeV [4].

Recently in [6], by using a simple pole Regge model with two leading (pomeron and odderon) and two secondary reggeon (f and ω) exchanges we have mapped the «break» fitted at the ISR into the LHC TOTEM 8 and 13 TeV data. We found that the observed «break» can be identified with the two-pion exchange (loop) in the t-channel both at the ISR and the LHC.

The most sensitive (crucial) test for any model of elastic scattering is the well-known dip-bump structure in the differential cross section [7]. None of the existing models was able to predict the position and dynamics of the dip for (especially when both pp and p̄p data are included). The first LHC measurements (at 7 TeV) [8] clearly demonstrated their failure. The result of the fits for pp and p̄p differential cross sections, using (1)–(4) is shown in fig. 3.

Within the framework of the model (1–3), we calculated the relative contribution from the different components of the amplitude

$$R_i(s) = \frac{\operatorname{Im} A_i(s, t=0)}{\operatorname{Im} A(s, t=0)} \tag{7}$$

to the pp and p̄p total cross sections, where $i = f + \omega$ for the relative weight of the reggeons, $i = P$ for the relative weight of the pomeron and $i = 0$ for the relative weight of the odderon. The result is shown in fig. 4. One

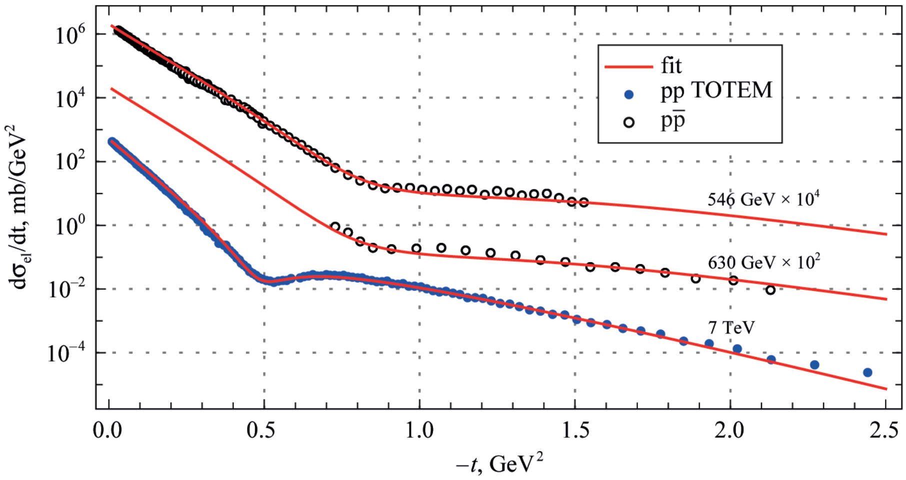

Fig. 3. Results of the fit for pp and $\bar{p}p$ differential cross section data using the model (1)–(4)

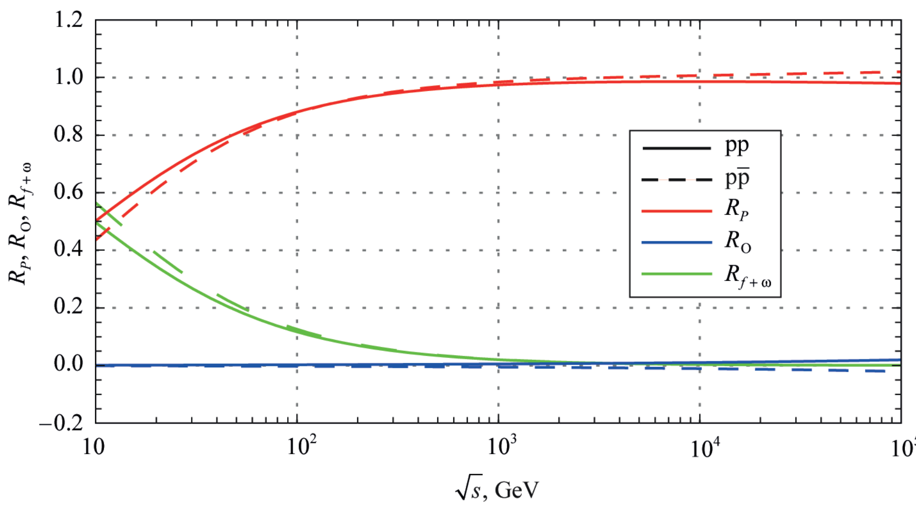

Fig. 4. Relative contribution from different components of the amplitude to pp and $\bar{p}p$ cross sections calculated from the model (1)–(3), (7)

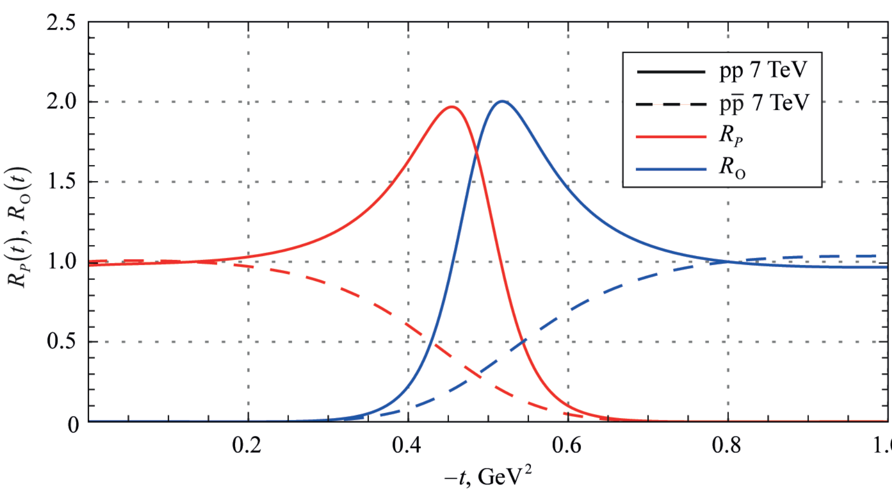

Fig. 5. Relative contribution from the pomeron and from the odderon to the pp and $\bar{p}p$ differential cross sections at 7 TeV calculated from the model (1)–(3), (8)

can see that at «low» energies (typically 10 GeV) the contribution from reggeons and the pomeron are nearly equal, but as the energy increases the pomeron takes over and at the same time the importance of the odderon is slightly growing.

We calculated the relative contributions of different components of the amplitude for non-forward scattering ($t \neq 0$):

$$R_i(s, t) = \frac{|A_i(s, t)|^2}{|A(s, t)|^2}. \tag{8}$$

The relative contribution in $-t$ from the pomeron R_P and of the odderon R_O at 7 TeV is shown in fig. 5. One can see that at low-$|t|$ values the pomeron completely dominates, then around the dip-bump region the pomeron-odderon importance is about 50 to 50 percent, and finally at higher $|t|$ values the odderon takes over. The role of the secondary reggeons is completely negligible in $-t$ at the LHC.

We conclude that the new data neither confirm, nor rule out the existence of the odderon.

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