PROCEEDINGS OF SCIENCE

Searching for odderon in exclusive reactions: $pp \to ppp\bar{p}$, $pp \to pp\phi\phi$ and $pp \to pp\phi$

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There seem to be recently an evidence for C = -1 exchanges in pp and $p\bar{p}$ elastic scattering at high energies. The analysis there is difficult as the two processes were not measured at the same (large) energies. Here we discuss three different exclusive processes given in the title as a possible source of information for odderon exchange. A sketch of the formalism is presented for each of the reactions. We consider low energy processes measured in the past by the WA102 collaboration and try to make predictions for the LHC. We discuss possible evidences at the low energies and try to make suggestions for the LHC.

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1. Introduction

The odderon exchange became recently topical again. So far there is no unambiguous evidence for the odderon – the $C = -1$ partner of the pomeron [1]. For a theoretical review of the odderon see e.g. [2]. Recent analysis of the elastic scattering by the TOTEM collaboration [3, 4] allow for the (soft) odderon exchange interpretation of the data [5].

In this talk we discussed three processes mentioned in the title [6, 7, 8]. We try te estimate upper limit of the size of odderon exchanges in these exclusive processes.

2. A sketch of formalism

We discuss shortly the three considered here reactions.

2.1 $pp \to pp\phi\phi$

In Fig.**??** we show conventional processes leading to the exclusive production of two ϕ mesons.

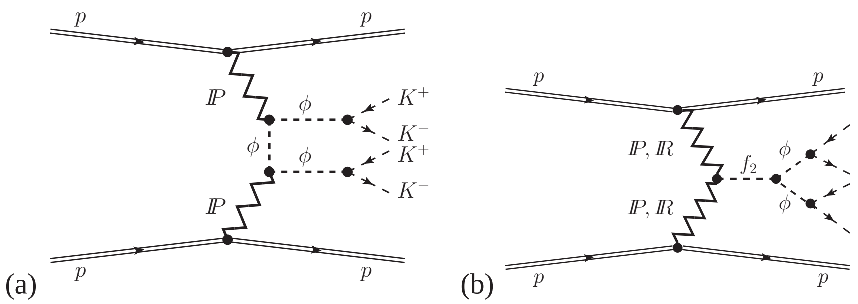

Figure 1: The "Born level" diagrams for double-pomeron/reggeon central exclusive $\phi\phi$ production and their subsequent decays into $K^+K^-K^+K^-$ in proton-proton collisions. In (a) we have the continuum $\phi\phi$ production, in (b) $\phi\phi$ production via an f_2 resonance. Other resonances, e.g. of f_0- and η-type, can also contribute here.

Let us sketch the formalism to descibe the conventional processes.

For the $f_2\phi\phi$ vertex we take the following ansatz, in analogy to the $f_2\gamma\gamma$ vertex:

$$i\Gamma^{(f_2\phi\phi)}_{\mu\nu\kappa\lambda}(p_3,p_4) = i\frac{2}{M_0^3}g'_{f_2\phi\phi}\,\Gamma^{(0)}_{\mu\nu\kappa\lambda}(p_3,p_4)\,F'^{(f_2\phi\phi)}(p_{34}^2) - i\frac{1}{M_0}g''_{f_2\phi\phi}\,\Gamma^{(2)}_{\mu\nu\kappa\lambda}(p_3,p_4)\,F''^{(f_2\phi\phi)}(p_{34}^2)\,, \tag{2.1}$$

with $M_0 = 1$ GeV and dimensionless coupling constants $g'_{f_2\phi\phi}$ and $g''_{f_2\phi\phi}$ being free parameters. Two free couplings are allowed in general.

The propagator for ϕ exchange in diagram (a) must be modified (compared to the corresponding one for meson exchange) at higher $\phi\phi$ subsytem energies. In [6] we proposed the following parametrization:

$$\Delta^{(\phi)}_{\rho_1\rho_2}(\hat{p}) \to \Delta^{(\phi)}_{\rho_1\rho_2}(\hat{p})\left(\exp(i\phi(s_{34}))\,\frac{s_{34}}{s_0}\right)^{\alpha_\phi(\hat{p}^2)-1}, \tag{2.2}$$

where we take $s_0 = 4m_\phi^2$ and $\alpha_\phi(\hat{p}^2) = \alpha_\phi(0) + \alpha'_\phi\,\hat{p}^2$ with $\alpha_\phi(0) = 0.1$ from [10] and $\alpha'_\phi = 0.9\ \mathrm{GeV}^{-2}$.

The different considered processes are added coherently and therefore interfere. In order to have a correct phase behaviour we introduced the function $\exp(i\phi(s_{34}))$ with

$$\phi(s_{34}) = \frac{\pi}{2}\exp\left(\frac{s_0 - s_{34}}{s_0}\right) - \frac{\pi}{2} \tag{2.3}$$

which role is to interpolate between meson physics close to the $\phi\phi$ threshold, $s_{34} = 4m_\phi^2$, and Regge physics at high energies. Another prescription was considered in [6] in addition.

In addition to the processes discussed above we considered processes shown in Fig.2. We think that the contribution of the diagram with two odderon exchanges is much smaller than that for the diagram with one odderon exchange. Therefore we include only contribution of the diagram with odderon exchange in the middle of the left diagram.

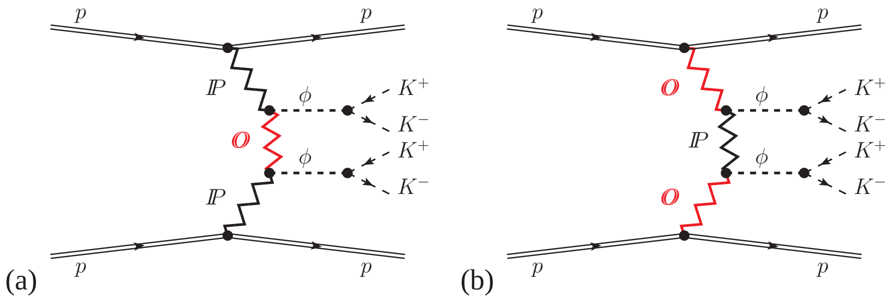

Figure 2: The Born level diagrams for diffractive production of a ϕ-meson pair with one and two odderon exchanges.

Our ansatz for the effective propagator of $C = -1$ odderon follows [9]

$$i\Delta^{(\mathbb{O})}_{\mu\nu}(s,t) = -ig_{\mu\nu}\frac{\eta_{\mathbb{O}}}{M_0^2}(s\alpha'_{\mathbb{O}})^{\alpha_{\mathbb{O}}(t)-1}, \tag{2.4}$$

$$\alpha_{\mathbb{O}}(t) = \alpha_{\mathbb{O}}(0) + \alpha'_{\mathbb{O}}\,t, \tag{2.5}$$

where we have $M_0^{-2} = 1\ (\mathrm{GeV})^{-2}$ for dimensional reasons. Furthermore, we shall assume representative values for the odderon parameters

$$\eta_{\mathbb{O}} = -1, \qquad \alpha_{\mathbb{O}}(0) = 1.05, \qquad \alpha'_{\mathbb{O}} = 0.25\ \mathrm{GeV}^{-2}. \tag{2.6}$$

For the $\mathbb{P}\mathbb{O}\phi$ vertex we use an ansatz analogous to the $\mathbb{P}\rho\rho$ vertex. We get then, orienting the momenta of the $\mathbb{O}$ and the ϕ outwards, the following formula:

$$i\Gamma^{(\mathbb{P}\mathbb{O}\phi)}_{\mu\nu\kappa\lambda}(k',k) = iF^{(\mathbb{P}\mathbb{O}\phi)}((k+k')^2,k'^2,k^2)\left[2a_{\mathbb{P}\mathbb{O}\phi}\,\Gamma^{(0)}_{\mu\nu\kappa\lambda}(k',k) - b_{\mathbb{P}\mathbb{O}\phi}\,\Gamma^{(2)}_{\mu\nu\kappa\lambda}(k',k)\right]. \tag{2.7}$$

2.2 $pp \to pp\phi$

For single ϕ production we include processes shown in Fig.3.

The Odderon exchange contributions (lower row) may modify the photon-exchange contribution (upper low). More processes will be considered in [6].

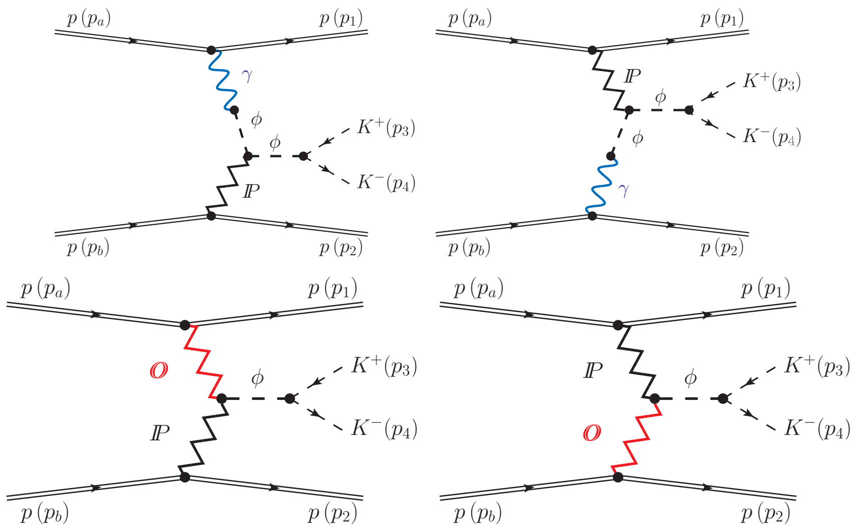

Figure 3: Some diagrams included in the analysis of single ϕ production.

2.3 $pp \to ppp\bar{p}$

Several mechanisms of central $p\bar{p}$ production were discussed in [7] and the formalism how to calculate relevant diffractive processes (continuum and resonances) was given there.

The exchange of $C =$ -1 objects leads to specific asymmetries discussed in [7]. In two dimensions (e.g. η_1, η_2) we can define the asymmetry:

$$\widetilde{A}^{(2)}(\eta,\eta') = \frac{\frac{d^2\sigma}{d\eta_3 d\eta_4}(\eta,\eta') - \frac{d^2\sigma}{d\eta_3 d\eta_4}(\eta',\eta)}{\frac{d^2\sigma}{d\eta_3 d\eta_4}(\eta,\eta') + \frac{d^2\sigma}{d\eta_3 d\eta_4}(\eta',\eta)}. \tag{2.8}$$

As discussed in [7] the $C =$-1 reggeon exchanges lead to such asymmetries. The odderon exchange also leads to asymmetries. How big are such asymmetries was discussed in detail in [7].

3. Results

It is very difficult to describe the WA102 data for $pp \to pp\phi\phi$ reaction including resonances and $\mathbb{PP}$ mechanism only [6]. Inclusion of the odderon exchange improves the description of the data. The result of our analysis is shown in Fig.4.

Having fixed the parameters of our quasi fit to the WA102 data we wish to show our predictions for the LHC. In Fig. 5 we show the results for the ATLAS experimental conditions ($|\eta_K| < 2.5$, $p_{t,K} > 0.2$ GeV). The distribution in four-kaon invariant mass is shown in the left panels and the difference in rapidity between the two ϕ mesons in the right panels.

In Fig. 6 we show more complete result including the odderon exchange with $\eta_{\mathbb{O}} = -1$ and various values of the odderon intercept $\alpha_{\mathbb{O}}(0)$.

The measurement of large $M_{\phi\phi}$ or Y_{diff} events at the LHC would therefore suggest presence of the odderon exchange.

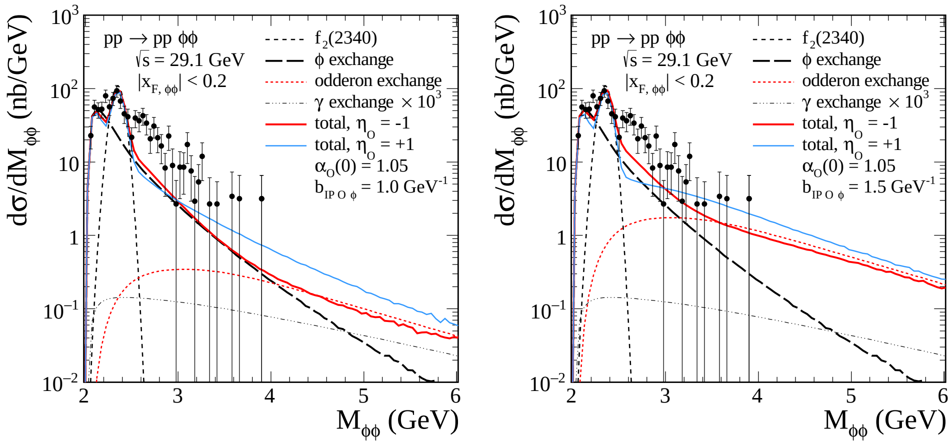

Figure 4: Invariant mass distributions for the central production of $\phi\phi$ at $\sqrt{s} = 29.1$ GeV and $|x_{F,\phi\phi}| \leqslant 0.2$ together with the WA102 data [11] are shown. The black long-dashed line corresponds to the ϕ-exchange contribution and the black dashed line corresponds to the $f_2(2340)$ contribution. The black dot-dashed line corresponds to the γ-exchange contribution enlarged by a factor 10^3. The red dotted line represents the odderon-exchange contribution for $a_{\mathbb{P}\mathbb{O}\phi} = 0$, $b_{\mathbb{P}\mathbb{O}\phi} = 1.0$ GeV^{-1} (the left panel) and for $a_{\mathbb{P}\mathbb{O}\phi} = 0$, $b_{\mathbb{P}\mathbb{O}\phi} = 1.5$ GeV^{-1} (the right panel). The coherent sum of all terms is shown by the red and blue solid lines for $\eta_{\mathbb{O}} = -1$ and $\eta_{\mathbb{O}} = +1$, respectively. Here we take $\alpha_{\mathbb{O}}(0) = 1.05$. The absorption effects are included in the calculations.

We will not present here (in the written version) preliminary results for the $pp \to pp\phi$ reaction. Some preliminary results were presented in the talk and details will be presented soon in [8]. We wish to mention only here that the inclusion of $\mathbb{P}\mathbb{O}$ fusion (see Fig.3) leads to a sizeable improvement of the description of the rather old WA102 data [12] for this reaction.

Now we go to the $pp \to ppp\bar{p}$ reaction. In Fig.7 we show estimated, allowed at present, asymmetry defined in detail in [7] for two different kinematical conditions specified in the figure description. Rather small asymmetries are allowed. A measurement of such asymmetries would require gigantic statistics for the $pp \to ppp\bar{p}$ reaction and may be difficult to reach in planned experiments.

4. Conclusions

Our results/presentation can be summarized in the following way:

- The Regge phenomenology was extended to $2 \to 3$, $2 \to 4$ and $2 \to 6$ exclusive processes.
- The tensor pomeron/reggeon model was applied in all these reactions.
- At lower energies tensor/vector reggeon exchanges must be included.
- Three reactions ($pp \to pp\phi\phi$, $pp \to pp\phi$ and $pp \to ppp\bar{p}$ have been studied in the context of identifying odderon exchange.
- $pp \to pp\phi\phi$ seems promising as here the odderon does not couple to protons. An upper limit for the odderon exchange has been etablished based on the WA102 data.

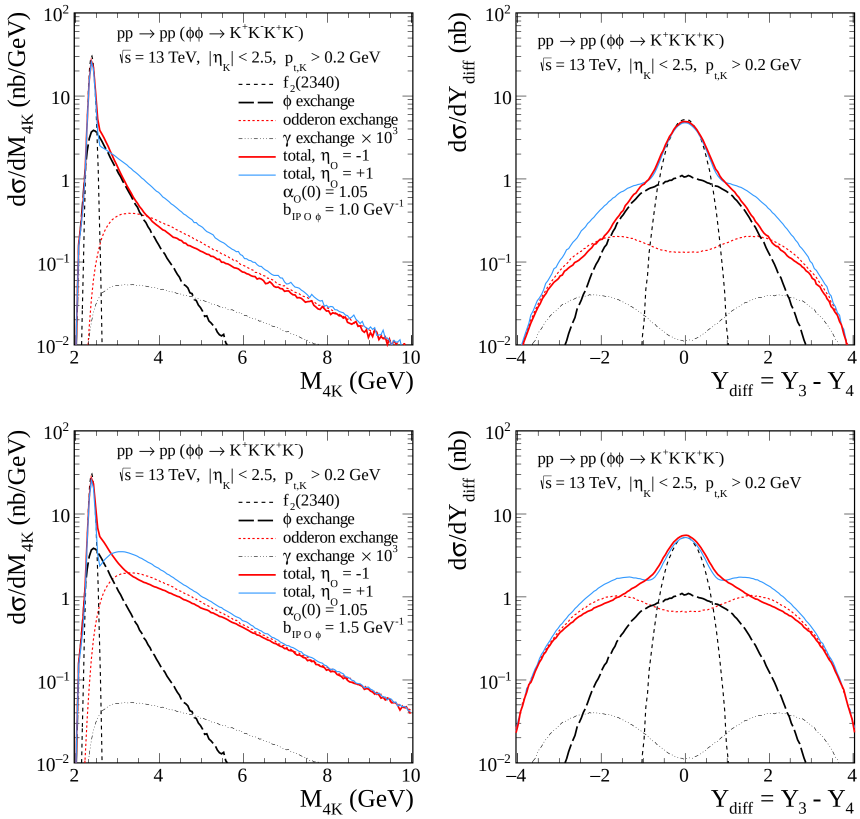

Figure 5: The distributions in M_{4K} (the left panels) and in $Y_{\rm diff}$ (the right panels) for the $pp \to pp(\phi\phi \to K^+K^-K^+K^-)$ reaction calculated for $\sqrt{s} = 13$ TeV and $|\eta_K| < 2.5$, $p_{t,K} > 0.2$ GeV. The red and blue solid lines correspond to the complete results with $\eta_{\mathbb{O}} = -1$ and $\eta_{\mathbb{O}} = +1$, respectively. The results for $b_{\mathbb{P}\mathbb{O}\phi} = 1.0$ GeV^{-1} (the top panels) and for $b_{\mathbb{P}\mathbb{O}\phi} = 1.5$ GeV^{-1} (the bottom panels) are presented. The absorption effects are included in the calculations.

- This upper limit for the $\mathbb{P}\mathbb{O} \to \phi$ coupling was used for the $pp \to pp\phi$ reaction, together with the TOTEM estimate. The WA102 data for single ϕ production support existence of odderon exchange (not shown in the written version).

- Special asymmetries for centrally produced $p\bar{p}$ system have been proposed to identify $C = -1$ exchanges. The asymmetry caused by subleading reggeon exchanges is probably considerably larger than that for the odderon exchange which makes this reaction difficult in searches for odderon exchanges.

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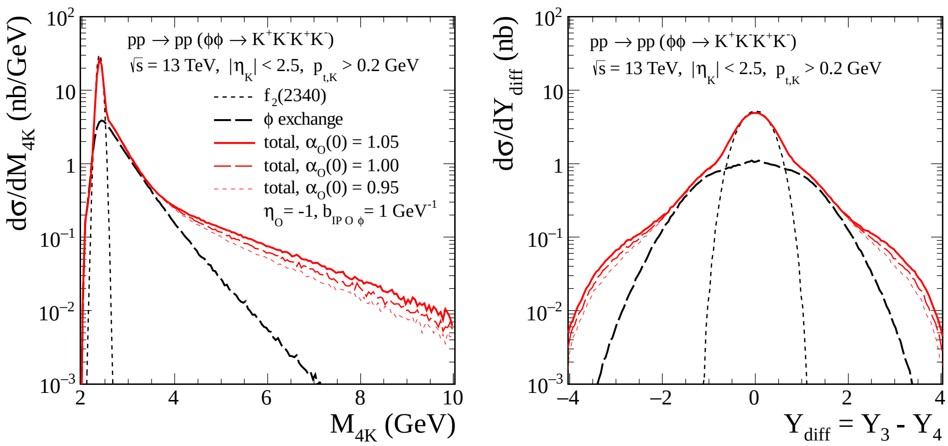

Figure 6: The complete results for $\sqrt{s} = 13$ TeV and $|\eta_K| < 2.5$, $p_{t,K} > 0.2$ GeV are shown. Here we show results for $\eta_{\mathbb{O}} = -1$ and for various values of the odderon intercept $\alpha_{\mathbb{O}}(0)$. Here we take $a_{\mathbb{P}\mathbb{O}\phi} = 0$ and $b_{\mathbb{P}\mathbb{O}\phi} = 1$ GeV^{-1}. Odderon could be visible for $M_{\phi\phi} > 6$ GeV and/or for $Y_{diff} > 3$.

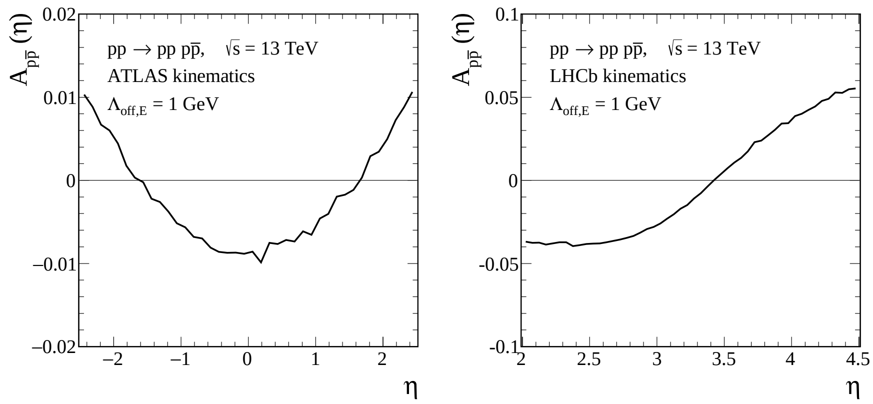

Figure 7: Allowed asymmetry for $p\bar{p}$ production due to odderon-pomeron exchange for ATLAS and LHCb kinematics.

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