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The search for new strong dynamics in exclusive diffraction

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Introduction

After recent discovery of the Higgs boson [1, 2] at the LHC and follow-up precision studies of its interactions with known matter [3], a rough picture of consistency with the Standard Model (SM) has began to emerge. This consistency, however, does not mean yet that the nature of the Higgs boson and electroweak symmetry breaking (EWSB) is completely understood. One of the immediate questions that challenge our current understanding of symmetries in Nature is what initiates the Higgs mechanism of electroweak symmetry breaking (EWSB) in the SM. Namely, whether it is actually SM-like or in fact an effective description appearing as a consequence of a new fundamental symmetry. The experimental precision should be noticeably increased to the level of precision tests achieved in other SM sectors in order to draw final conclusions. In particular, in the electroweak SM sector the agreement of theoretical predictions with experiment takes place at the level of relative error $\sim 10^{-3}$ which remains a rather big challenge for ongoing experimental investigations of the SM Higgs sector.

One of the major questions to be answered in the ongoing search for New Physics at the LHC is whether a fine structure of the Higgs-like signal exists in the low invariant mass interval $110 - 140$ GeV, predominantly in $\gamma\gamma$, $W\gamma$ and $Z\gamma$ channels, or not. As was indicated by CMS data [4] such a fine structure is not yet completely excluded and is being theoretically explored in various beyond the SM scenarios at the moment. It is thus reasonable to study this, or such a structure in $\gamma\gamma$ and $Z\gamma$ decay channels, both in QCD and VBF-initiated exclusive production mechanisms.

A new strongly-coupled dynamics at a TeV energy scale is often believed to be responsible for EWSB in the SM [5, 6]. Namely, it initiates the EW symmetry breaking dynamically by means of confined techniquark condensation at low energy scales. A straightforward analogy to this effect is the spontaneous chiral symmetry breaking in non-perturbative chiral QCD with only difference that the effective Higgs mechanism is initiated by a non-diagonal techniquark condensate. Such a new dynamics unavoidably predicts a plenty of new states, most importantly, composite Higgs-like particles [9, 10] and partners of SM fermions [11], whose properties depend on the group-theoretical structure of underlined theory and its ultraviolet (UV) completion. Besides the composite Higgs-like state, the latter predict a plenty of new relatively light pseudo-Goldstone composite states, like technipions (or T-pions), technisigma, techni-K, etc, whose search in low invariant mass regions is strongly limited by large SM backgrounds. The discovery of a family of new (pseudo)scalar states with invariant masses not exceeding 200 GeV in these channels is of high priority for strongly-coupled dynamics searches at the LHC. Hence, in order to verify the theoretically favorable scenarios for new strongly coupled scenarios at the LHC, one has to find a way to reduce the backgrounds in $\gamma\gamma$, $W\gamma$ and $Z\gamma$ channels.

A number of various realisations of such a new dynamics at a TeV scale, commonly dubbed as "Technicolor" (TC) or "compositeness" scenarios, have been proposed in the literature so far (for a review, see e.g. Refs. [7, 8]). Such a big variety, however, has got strongly reduced by severe electroweak (EW) precision tests [12] and recent SM Higgs-like particle observations. At present, among the most appealing scenarios of dynamical EWSB consistent with current constraints is a class of TC models with vector-like (Dirac) UV completion – the vector-like Technicolor (VLTC). The simplest realisation of VLTC scenario with two vector-like or Dirac techniflavors and a SM-like Higgs boson has been studied for the first time in Refs. [13–15] and very recently has emerged in composite Higgs scenarios with confined $SU(2)_{\rm TC}$ [16, 17].

The diffractive reactions such as central exclusive $pp \to p + X + p$ and single diffractive production $pp \to p + X$ processes, where X is a diffractive system separated from the one or two very forward protons by large rapidity gaps, have been in focus for many dedicated theoretical and phenomenological studies in last few decades (see Ref. [18, 19] for a review on the topic). In particular, these processes are considered to be very important in the search for New Physics at the LHC due to strongly reduced backgrounds. Here we suggests a possibility to explore the favorable Technicolor/compositeness scenarios of a new strongly coupled TeV-scale dynamics by means of the diffractive production reactions at the LHC [15].

Interactions of lightest composite states

Consider the simplest vector-like TC model with $SU(2)_{\rm W}$ doublet of Dirac T-quarks confined under a new strongly-coupled gauge symmetry $SU(N_{\rm TC})_{\rm TC}$ [13, 15]

$$\tilde{Q} = \begin{pmatrix} U \\ D \end{pmatrix} , \qquad Y_{\tilde{Q}} = \begin{cases} 0, & \text{if } N_{\rm TC} = 2\,, \\ 1/3, & \text{if } N_{\rm TC} = 3\,. \end{cases} \tag{0.1}$$

The interactions of the constituent T-quarks and the lightest T-hadrons, namely, the scalar SM-singlet T-sigma S field, and the $SU(2)_{\rm W}$-adjoint triplet of T-pion fields P_a, $a = 1, 2, 3$, can be decribed by (global) chiral $SU(2)_{\rm R} \otimes SU(2)_{\rm L}$ invariant effective Lagrangian in the linear σ-model (LσM)

$$\begin{aligned}
\mathcal{L}_{\rm L\sigma M} &= \frac{1}{2}\,\partial_\mu S\,\partial^\mu S + \frac{1}{2} D_\mu P_a\, D^\mu P_a + i\bar{\tilde{Q}}\hat{D}\tilde{Q} \\
&- g_{\rm TC}\bar{\tilde{Q}}(S + i\gamma_5\tau_a P_a)\tilde{Q} - g_{\rm TC}\, S\,\langle \bar{\tilde{Q}}\tilde{Q}\rangle \\
&- \lambda_{\rm H}\mathcal{H}^4 - \frac{1}{4}\lambda_{\rm TC}(S^2 + P^2)^2 + \lambda\mathcal{H}^2(S^2 + P^2) \\
&+ \frac{1}{2}\mu_{\rm S}^2(S^2 + P^2) + \mu_{\rm H}^2\mathcal{H}^2\,,
\end{aligned} \tag{0.2}$$

where $P^2 \equiv P_a P_a = \tilde{\pi}^0\tilde{\pi}^0 + 2\tilde{\pi}^+\tilde{\pi}^-$, and the EW-covariant derivatives are

$$\hat{D}\tilde{Q} = \gamma^\mu \left(\partial_\mu - \frac{iY_{\tilde{Q}}}{2}\, g' B_\mu - \frac{i}{2}\, g W_\mu^a \tau_a\right) \tilde{Q}\,,$$
$$D_\mu P_a = \partial_\mu P_a + g\epsilon_{abc} W_\mu^b P_c\,. \qquad (0.3)$$

The Higgs boson doublet $\mathcal{H}$ acquires an interpretation as a composite bound state of vector-like T-quarks in the model extended by an extra $SU(2)_{\rm W}$-singlet $\tilde{S}$ T-quark such that $\mathcal{H} = \tilde{Q}\bar{\tilde{S}}$. Note, the chiral symmetry implies the equality of constituent Dirac masses $M_U = M_D \equiv M_{\tilde{Q}}$ at tree level. In the limit of small current T-quark masses $m_{\tilde{Q}}$ compared to the constituent ones $M_{\tilde{Q}}$, i.e. $m_{\tilde{Q}} \ll M_{\tilde{Q}} \sim \Lambda_{\rm TC}$, in analogy to ordinary QCD the conformal symmetry is approximate such that the μ-terms can be suppressed $\mu_{S,H} \ll m_{\tilde{\pi}}$. Then the spontaneous EW and chiral symmetry breakings are initiated dynamically by the Higgs v and T-sigma u vevs

$$\mathcal{H} = \frac{1}{\sqrt{2}} \begin{pmatrix} \sqrt{2} i\phi^- \\ H + i\phi^0 \end{pmatrix}\,, \quad \langle H \rangle \equiv v \simeq 246\,{\rm GeV}\,, \quad \langle S \rangle \equiv u \gtrsim v\,,$$
$$H = v + hc_\theta - \sigma s_\theta\,, \qquad S = u + hs_\theta + \sigma c_\theta\,, \qquad (0.4)$$

respectively, by means of T-quark condensation, namely,

$$u = \left(\frac{g_{\rm TC}\lambda_{\rm H}}{\delta}\right)^{1/3} |\langle \bar{\tilde{Q}}\tilde{Q}\rangle|^{1/3}\,,$$
$$v = \left(\frac{|\lambda|}{\lambda_{\rm H}}\right)^{1/2} \left(\frac{g_{\rm TC}\lambda_{\rm H}}{\delta}\right)^{1/3} |\langle \bar{\tilde{Q}}\tilde{Q}\rangle|^{1/3}\,, \qquad (0.5)$$

where $s_\theta \equiv \sin\theta$, $c_\theta \equiv \cos\theta$, $\delta = \lambda_{\rm H}\lambda_{\rm TC} - \lambda^2$, $g_{\rm TC} > 0$ and $\lambda_H > 0$.

Therefore, in this model the SM-like Higgs mechanism has an effective nature and is initiated by the Dirac T-quark condensation due to a presence of $\lambda\mathcal{H}^2 S^2$ term in the potential (0.2). While the Peskin-Tacheuchi S and U parameters are strongly suppressed for all relevant model parameters $S,\, U \sim 0.01-0.001$, the T-sigma–Higgs mixing angle θ is bounded by the T-parameter and the SM Higgs decay constraints provided that $s_\theta \lesssim 0.2$ [13]. In general, such a phenomenologically consistent small $h\sigma$-mixing limit $s_\theta \to 0$ corresponds to a decoupling of the TC dynamics from the SM up to higher energy ~ 1 TeV scales, hence, to a suppressed ratio $v/u \ll 1$ as well as to weak T-scalar self-couplings $\lambda, \lambda_{\rm TC} \ll 1$. In this case, the deviations of the Higgs properties from those in the SM are small while the dynamical nature of the Higgs mechanism as a theoretically favorable possibility is realized. The physical Lagrangian of the VLTC model can be found in Refs. [13, 15].

In this situation of SM-like Higgs boson, what would be the basic phenomenological signature for dynamical EW symmetry breaking? Besides the light SM-like Higgs boson, in the VLTC model described above the T-pions are among the lightest physical T-hadron states which should be searched for in vector boson VV and photon $\gamma\gamma$ fusion channels, preferrably, in the low invariant mass region $m_{\tilde{\pi}} \sim 80 - 200$ GeV. The T-sigma state σ is supposed to be generally heavier since the no Higgs–T-sigma mixing limit $s_\theta \to 0$ corresponds to $M_\sigma \to \sqrt{3} m_{\tilde{\pi}}$. Besides, the T-sigma interactions with gauge bosons are strongly suppressed. So, the most straightforward way to search for the new strongly-coupled dynamics and dynamical EW symmetry breaking is to look for T-pion signatures in $\gamma\gamma$-fusion channels which is the main proposal of this letter.

T-pion production channels

The VBF is typically considered as one of the key production modes of the Higgs boson. The Higgs boson in the $h \to \gamma\gamma$ decay channel (other modes are usually more difficult to measure due to a huge inclusive background contamination) has been analyzed using full statistics. The signal is mostly due to gluon-gluon fusion mechanism while the VBF contributes less than 10 % to the total Higgs yield accounting for zero or one additional jet [20].

Since T-pions in the VLTC scenario do not couple directly to SM fermions and gluons, the only way to produce them is in the vector-boson ($\gamma\gamma$, γZ, ZZ) fusion. At Born level, the pseudoscalar T-pions can only be produced in pairs in $\gamma\gamma$ and VBF reactions. At one-loop level, T-pions are coupled to photon and vector bosons via T-quark triangle and box diagrams depending on number of T-colors. In a QCD-like scenario with $N_{\rm TC} = 3$ and degenerated T-quark doublet, the T-pion decays into two gauge bosons V_1 and V_2 as shown in Fig. 1 (left), while in the case of $N_{\rm TC} = 2$ T-pion can only decay into three gauge bosons via T-quark box diagram [13] (see Fig. 1 (right)). Thus, in the former case one expects single T-pion $\tilde{\pi}^0$ production, predominantly, in $\gamma\gamma$-fusion via T-quark triangle, whereas in the latter case a single T-pion can be produced in V_1V_2-fusion in association with an extra gauge boson V_3 only. Then, the produced T-pion should further decay either into two or three gauge bosons, depending on $N_{\rm TC}$, or into a pair of Higgs bosons $\tilde{\pi} \to hh$.

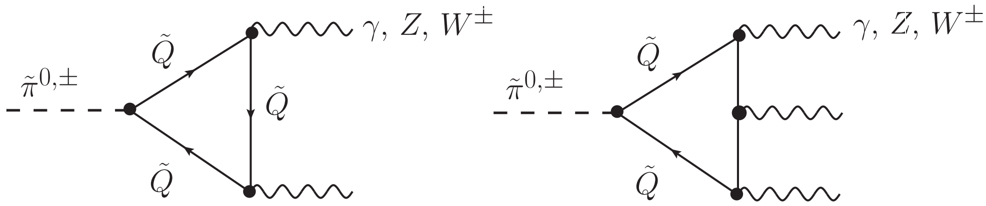

FIG. 1: The loop-induced light T-pion couplings to the gauge bosons through constituent T-quark loops. In the case of $Y_{\tilde{Q}} \neq 0$ (e.g. in $SU(3)_{\rm TC}$ theory), the T-pion is coupled to two gauge bosons to the lowest order $\tilde{\pi}V_1V_2$ via T-quark triangle diagrams (left), while for the $Y_{\tilde{Q}} = 0$ (e.g. in $SU(2)_{\rm TC}$ theory) case the T-pion is coupled only to three gauge bosons $\tilde{\pi}V_1V_2V_3$ via a box diagram (right). The latter case is much more involved and will not be considered here.

Such a qualitative picture shows that it may be difficult to verify the $SU(2)_{\rm TC}$ dynamics in the case of composite but SM-like Higgs boson and dynamical EW symmetry breaking since the unique T-pion signatures are rather complicated in this case. Namely, the T-pion production at the Born level leads to complex six gauge bosons final states where each very narrow T-pion resonance should be found in three-boson invariant mass distribution. For single T-pion production, one should deal with a loop-induced heavy T-quark box VBF process with four gauge bosons in the final state and very narrow T-pion resonance in the three-boson invariant mass distribution. A novel experimental technique for analysis of such multi-boson (e.g. multi-γ) signatures would be desirable. Instead, here we are focused on $SU(3)_{\rm TC}$ case where the single neutral T-pion appears to be produced in the $\gamma\gamma$-fusion reaction with subsequent dominating two-body decay mode (for more details, see Ref. [15]). Corresponding typical partonic $2 \to 3$ hard subprocesses of $\tilde{\pi}^0$ and competing Higgs production in high energy hadron-hadron collisions via intermediate VBF mechanism are shown in Fig. 2.

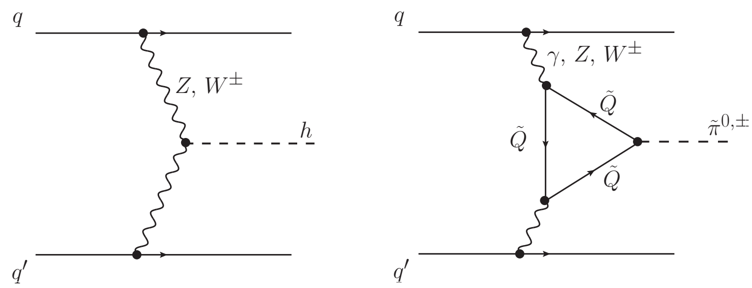

FIG. 2: Typical VBF production channels of the Higgs boson at tree level (left) and T-pion via a triangle T-quark loop (right) via a gauge boson fusion in the quark-(anti)quark scattering.

In Fig. 3 we show branching fractions for major real T-pion $\tilde{\pi}^0$ decay channels in the $SU(3)_{\rm TC}$ case. In a very broad range of T-pion and T-quark masses the two-photon decay channel seems to be the most optimal one. In addition, this is one of the golden channels for Higgs boson searches and the LHC detectors are well suited for such studies.

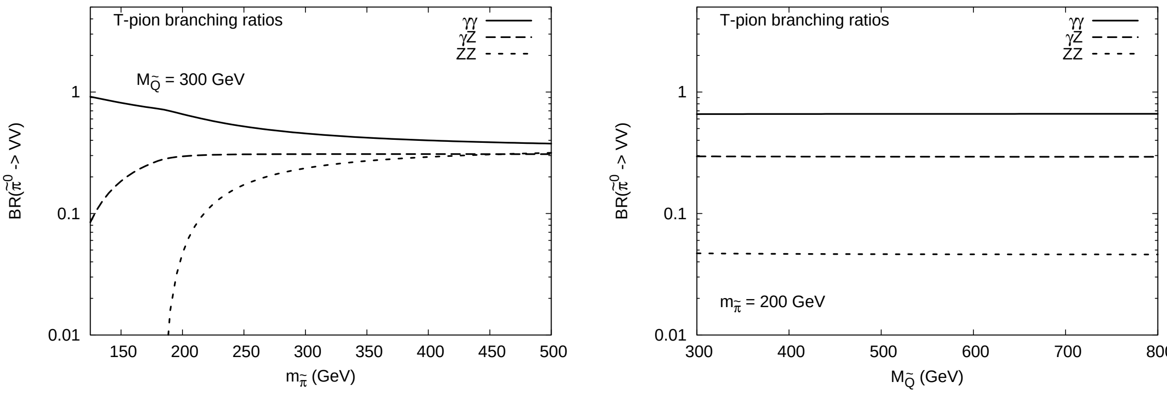

FIG. 3: Branching fractions of T-pion decays into $\gamma\gamma$, γZ and ZZ final states as a function of T-pion mass $m_{\tilde{\pi}^0}$ for a fixed value of T-quark mass (left) and as a function of T-quark mass $M_{\tilde{Q}}$ for a fixed value of T-pion mass (right).

In the case of T-pion production the gluon-gluon fusion channel is absent, only the loop-induced VBF is possible. There is a notable difference between the Higgs boson and T-pion in the VBF as well: the Higgs boson VBF is dominated by $WW \to h$ and $ZZ \to h$ fusion channels at tree-level whereas the T-pion VBF is given mostly by the $\gamma\gamma \to \tilde{\pi}$ production channel via a T-quark loop diagram (see Fig. 2).

The leading-order hard (parton level) VBF subprocess in the inclusive h (left) and $\tilde{\pi}$ (right) production in the high energy pp scattering is quark-initiated one

$$q_i q'_j \to q_i q'_j (\gamma^* \gamma^* \to h,\, \tilde{\pi}^0)\,, \tag{0.6}$$

where q_i and q_j can be either a quark or an antiquark of various flavors from each of the colliding protons, and the virtual $\gamma\gamma$ fusion is concerned. So, the both VBF processes, the h and $\tilde{\pi}^0$ production may "compete". In contrast to the Higgs boson production, one T-pion can be produced only via heavy T-quark triangle loop in the VBF mechanism. The loop-induced T-pion VBF cross section is suppressed by roughly a factor of $\sim 10^{-3}$ or so (depending on TC model parameters) compared to the tree-level Higgs boson VBF cross section in the same mass range. Having in mind that inclusive sample for the Higgs boson production contains only 7.3 % of VBF at $m_h = 125$ GeV, the net yield of the Higgs bosons dominates over T-pion yield by a factor of 10^4 in the same mass range. On the other hand, given very different branching ratios, $\mathrm{BR}(h \to \gamma\gamma) \sim 10^{-3}$ and $\mathrm{BR}(\tilde{\pi} \to \gamma\gamma) \sim 0.5 - 1$, one may argue that the $\gamma\gamma$ yield from pseudoscalar T-pions may be suppressed compared to that from the Higgs boson only by roughly an order of magnitude in the same mass range, or even larger for large T-pion masses, which introduces certain difficulties in the inclusive T-pion observation, at least, at the current level of statistics.

In Fig. 4 we show characteristic diagrams for the inclusive (left) and central exclusive (right) T-pion production processes in dominant $\gamma\gamma$ fusion and decay channel. Both, production and decay subprocesses are initiated by triangle loop of U, D T-quarks. We assume $M_U = M_D$ for simplicity. The calculation of the inclusive production cross sections in QCD

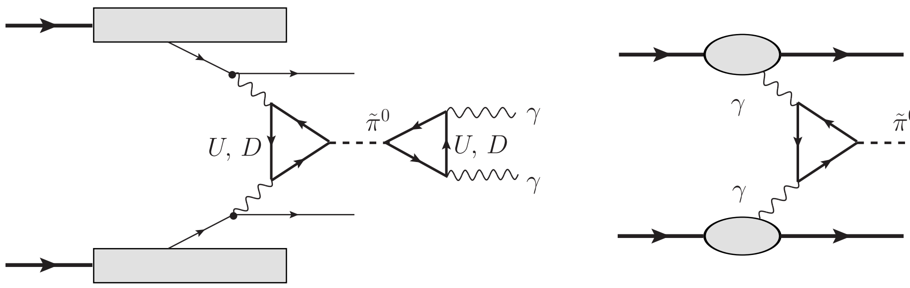

FIG. 4: Hadron-level T-pion production channels in VBF mechanism and the leading $\gamma\gamma$ decay channel: inclusive $\tilde{\pi}^{0,\pm}$ production in association with two quark jets (left) and the central exclusive $\tilde{\pi}^0$ production in the $\gamma\gamma$ fusion (right).

is rather straightforward and based upon standard collinear factorisation technique so we do not discuss it here. In numerical estimations of these cross sections which will be discussed later in the Results section, it is naturally assumed that the incoming quark q_i and (anti)quark q'_j loose only a small fraction of their initial energy taken away by intermediate vector bosons. In this kinematics, the final-state quarks are seen as forward-backward hard jets, and by measuring their momenta one accurately reconstructs the invariant mass of the produced state. As was advocated in Ref. [13], an overall inclusive one-T-pion production rate is suppressed compared to the Higgs boson production rate, which along with extremely narrow T-pion resonance makes it rather hard to study experimentally. So, even light T-pions down to W boson mass may not be excluded yet by LEP II and LHC studies e.g. due to a misidentification of $\tilde{\pi}^0$ and $\tilde{\pi}^\pm$ with longitudinally polarized Z and $W^\pm$ bosons production, respectively, and the latter point is an interesting subject for further investigations.

Alternatively to the inclusive production, it is worth to consider the exclusive diffractive T-pion production in the dominant $\gamma\gamma$ fusion and subsequent $\gamma\gamma$ decay channel as illustrated in Fig. 3 (right). As will be discussed below the latter has advantages compared to the inclusive T-pion production since the signal-to-background ratio is much larger. This advantage makes the central exclusive T-pion production favorable compared to the inclusive T-pion production.

Exclusive T-pion production: signal vs background

Consider the central exclusive $pp \to pp\tilde{\pi}^0$ process illustrated in Fig. 4 (right). Similarly to the inclusive case discussed above, this process is determined by the colorless VBF subprocess. We take into account only dominant $\gamma\gamma \to \tilde{\pi}^0$ fusion reaction and omit $\gamma Z \to \tilde{\pi}^0$, $Z\gamma \to \tilde{\pi}^0$ and $ZZ \to \tilde{\pi}^0$ subprocesses which turn out to be numerically very small being suppressed by large masses in propagators. The partonic and hadronic matrix elements for this three-body reaction are specified in Ref. [15].

In order to estimate the feasibility of exclusive T-pion measurement one should analyze carefully the exclusive $\gamma\gamma$ background. There are two basic non-resonant leading order box-induced contributions – the QCD (Durham) diffractive mechanism [21] via $gg \to \gamma\gamma$ shown in Fig. 5 (left) and the QED (light-by-light) scattering mechanism ($\gamma\gamma \to \gamma\gamma$) shown in Fig. 5 (right). These contributions are discussed in detail in Ref. [15] based upon the standard theoretical description of CEP processes developed by the Durham group for the exclusive production of Higgs boson in Ref. [21]. The details of the kinematics for the central exclusive production of one or two objects can be found e.g. in Ref. [18].

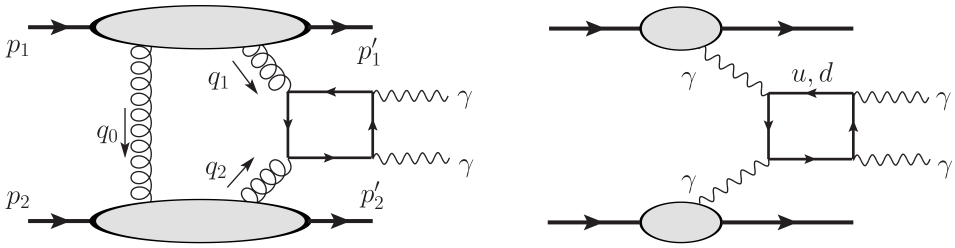

FIG. 5: Irreducible non-resonant background processes for the central exclusive T-pion $\tilde{\pi}^0 \to \gamma\gamma$ production in pp collisions at the LHC: the QCD diffractive $\gamma\gamma$ pair production (left) and the QED-initiated $\gamma\gamma$ pair production (right). In the latter case, only a part of contributions corresponding to quark boxes is shown here for illustration while in actual calculations the full set of SM contributions including quark, lepton and W boson loops is taken into account.

Typical contributions to the leading order $gg \to \gamma\gamma$ subprocess are shown in Fig. 6. The total number of topologically different loop diagrams in the Standard Model amounts to twelve boxes. So the $\gamma\gamma$ background does not exhibit resonant features which is good for probing New Physics $\gamma\gamma$-resonant contributions like the T-pion signal under consideration.

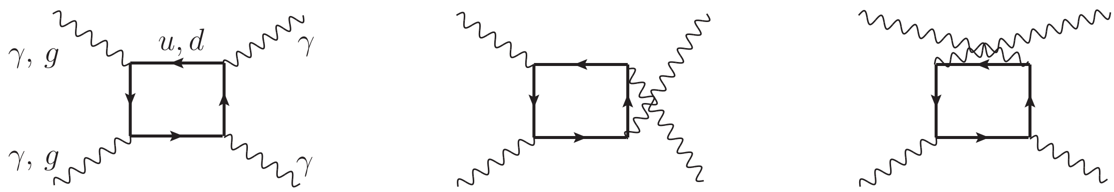

FIG. 6: Representative topologies of the hard subprocesses $gg \to \gamma\gamma$ and $\gamma\gamma \to \gamma\gamma$, which contribute to exclusive $\gamma\gamma$ pair production. These subprocesses constitute irreducible background for the exclusive $\tilde{\pi}^0 \to \gamma\gamma$ reaction at the LHC. In the $gg \to \gamma\gamma$ case only quarks propagate in boxes and the amplitude is dominated by light quarks. In the $\gamma\gamma \to \gamma\gamma$ case, all the charged fermions – quarks, leptons, as well as $W^\pm$ bosons participate in the corresponding box diagrams. In the latter case, only a part of contributions corresponding to quark boxes is shown here for illustration.

The box contributions to the $gg \to \gamma\gamma$ parton level subprocess amplitude in Fig. 6 for on-shell fusing gluons were calculated analytically by using the Mathematica-based `FormCalc` (FC) [22] package. For the evaluation of the scalar master tree- and four-point integrals in the gluon-gluon fusion subprocess we have used the `LoopTools` library [22]. The result is summed up over all possible quark flavors in loops and over distinct loop topologies. We have also checked that the sum of relevant diagrams is explicitly finite and obeys correct asymptotical properties and energy dependence. It is worth to mention that a large cancelation between separate box contributions in the total sum of diagrams takes place, which is expected from the general Standard Model principles.

Consider now exclusive production of two photons via hard light-by-light $\gamma\gamma \to \gamma\gamma$ scattering subprocess as illustrated in Fig. 5 (left). The relevant subprocess diagrams are similar in topology to those for $gg \to \gamma\gamma$ shown in Fig. 6 but contain extra contributions from leptonic and vector boson W loops. In this study we consider the leading-order approximation for the $\gamma\gamma \to \gamma\gamma$ subprocess. In a similar way as the QCD diffractive mechanism described above, the loop-induced helicity matrix elements for the $\gamma\gamma \to \gamma\gamma$ subprocess were calculated by using `LoopTools` library [22]. In numerical calculations we include box diagrams with leptons, quarks as well as with W bosons. At high diphoton invariant masses the inclusion of diagrams with W bosons is crucial. In principle, effects beyond the Standard Model possibly responsible for anomalous gauge-boson couplings could be important, so the exclusive non-resonant $\gamma\gamma$ background is very interesting by itself. In the present analysis we concentrate on the search for T-pion and ignore effects beyond the Standard Model as far as the background is considered.

Search for Technicolor signal in exclusive reactions

Consider first the inclusive $\tilde{\pi}^0$ production in association with two forward jets. In Fig. 7 we show the integrated inclusive cross section as a function of T-pion (left) and T-quark (right) masses, $m_{\tilde{\pi}}$ and $M_{\tilde{Q}}$, respectively. We notice that the photon-photon $\gamma\gamma$ fusion mechanism dominates, while $Z\gamma$ and ZZ fusion contributions are always small (suppressed by a large mass of Z boson in propagators).

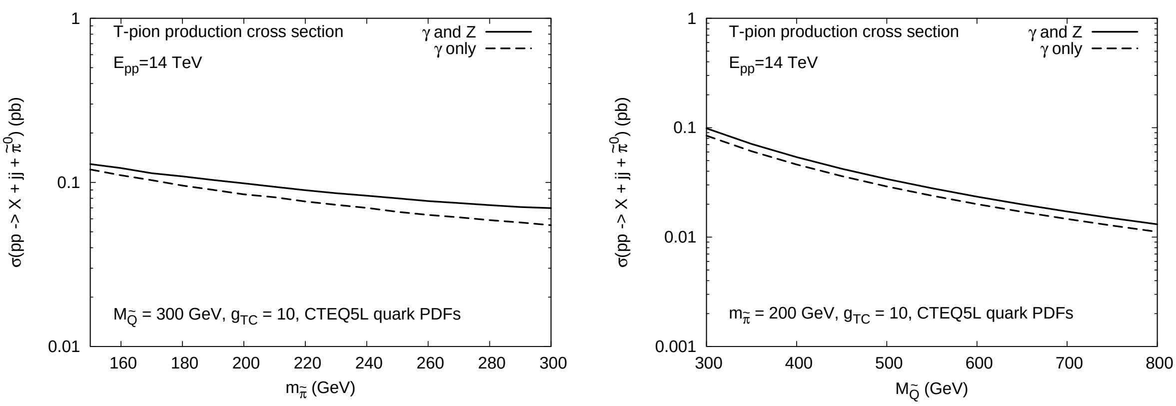

FIG. 7: Inclusive $\tilde{\pi}^0$ production cross section in association with two forward jets as a function of T-pion mass (left panel) and as a function of T-quark mass (right panel) for fixed values of the g_{TC} coupling constant at the nominal LHC energy $\sqrt{s} = 14$ TeV.

In order to demonstrate the advantage of the exclusive T-pion signature compared to the VBF inclusive production mechanism one should compare results for the $pp \to jj + \tilde{\pi} + X$ cross section in Fig. 7 ($\sim$ 0.1 pb) and T-pion CEP cross section shown in Fig. 8 ($\sim$ 1 fb) as a function of T-pion (left) and T-quark (right) masses. Even though the VBF and CEP $\tilde{\pi}$ cross sections differ by two orders of magnitude, the $\gamma\gamma$ background for the T-pion VBF is expected to be larger due to tree-level $WW \to \gamma\gamma$ contribution which is absent in the $\gamma\gamma$ CEP case. The latter point leads to a larger S/B ratio for the T-pion CEP than that for the inclusive T-pion VBF.

Now let us consider some important differential distributions of the T-pion CEP. In Fig. 9 we show a distribution in T-pion rapidity (left) and azimuthal angle between outgoing protons (right). The larger the T-pion mass the smaller the cross section. The T-pions are produced dominantly at midrapidities as expected. The fact that the signal dominates at $\phi_{12} = \pi/2$ can be further used to reduce QCD and QED background which is expected to dominate at $\phi_{12} \sim \pi$.

Let us discuss now the exclusive diphoton background to the exclusive T-pion production. In Fig. 10 we show the corresponding distribution in invariant mass of the two outgoing photons $M_{\gamma\gamma}$. We show contributions for the Durham QCD mechanism and for the QED $\gamma\gamma$ fusion mechanism. At relatively low masses, the Durham mechanism dominates. However, above $M_{\gamma\gamma} > 200$ GeV the photon-photon mechanism takes over. The latter is therefore the most important potential background for the T-pion signal if observed in the $\gamma\gamma$ channel. For the pQCD background we have also shown a result without Sudakov form factors.

As can be seen from the above figure, the Sudakov form factors strongly damp the cross section, especially at larger photon-photon invariant masses. Assuming the experimental resolution in invariant $\gamma\gamma$ mass of about 5 GeV or so, the background turns out to be by two orders of magnitude smaller than the corresponding T-pion signal for the whole range of vector-like TC model parameters considered here. To summarize, the signal-to-background ratio in exclusive T-pion production process is by far better than that in inclusive T-pion production [13]. The latter is clear from comparing the corresponding inclusive $\gamma\gamma$ background estimates which have been done in the Higgs boson $\gamma\gamma$ signal studies at the LHC [1, 2] and typical inclusive T-pion production cross sections shown e.g. in Fig. 7.

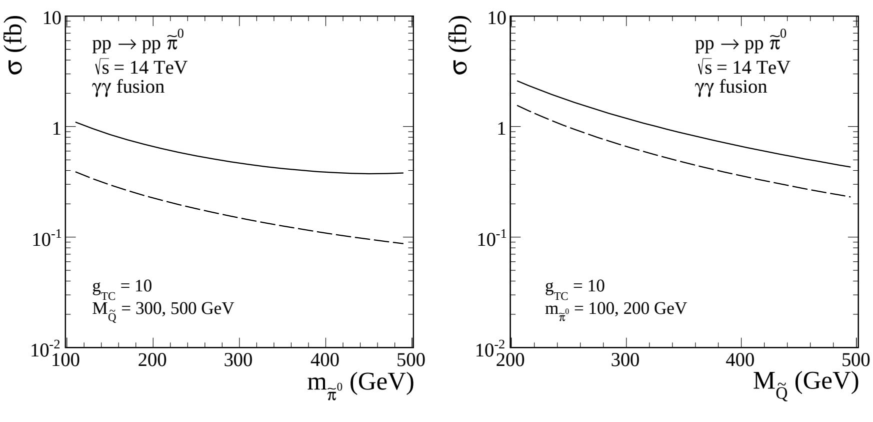

FIG. 8: Integrated exclusive cross section as a function of T-pion mass (left) and T-quark mass (right) for fixed remaining model parameters as specified in the figure.

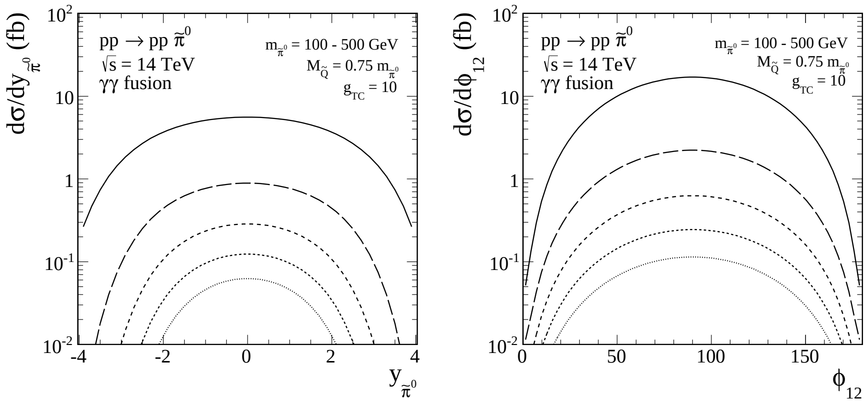

FIG. 9: Differential distributions in T-pion rapidity (left panel) and azimuthal angle between outgoing protons (right panel) for different masses of the T-pion ($m_{\tilde{\pi}^0} = 100, 200, 300, 400, 500$ GeV from top to bottom). Here the T-quark mass is fixed to be $M_{\tilde{Q}} = 0.75\, m_{\tilde{\pi}^0}$.

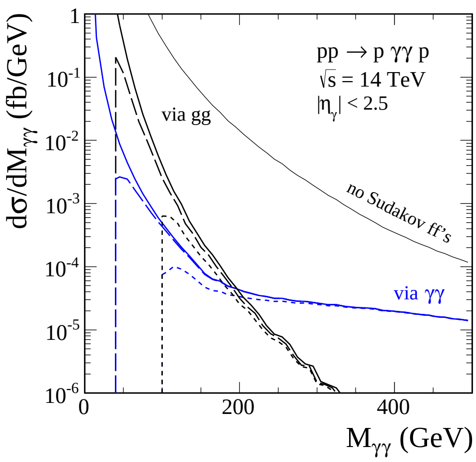

FIG. 10: Distribution in invariant mass of the two-photon system for the Durham QCD mechanism (black lines) and the QED $\gamma\gamma$ fusion mechanism (blue lines) at $\sqrt{s} = 14$ TeV. A realistic cut on both photon pseudorapidities $|\eta_\gamma| < 2.5$ is imposed. We present results without an extra cut (solid line) and with cuts on transverse momenta of both outgoing photons $p_{\perp,\gamma} > 20, 50$ GeV (long dashed, dashed lines, respectively).

Summary

There exists a possibility that yet unknown weaker resonances which decay into two photons could be very difficult to identify in the inclusive measurements. In contrast, an exclusive measurement has the advantage that $\gamma\gamma$-resonance signals could be “enhanced” relative to the two-photon background. The latter offers important advantages compared to searches of new $\gamma\gamma$-resonances in inclusive reactions. Here we consider an important case of light exotic resonances, the pseudo-Goldstone T-pions, commonly predicted by Technicolor extensions of the Standard Model.

In this Yellow report, we have made a first analysis of an interesting possibility to search for T-pions (mostly decaying into two photons) in exclusive $pp \to pp\gamma\gamma$ process at the LHC.

We have considered a particularly interesting case of light T-pions which do not directly interact with gluons and quarks to the leading order, but can interact only with SM gauge bosons. A single T-pion in this case can only be produced via a T-quark triangle loop in a vector boson fusion channel. The latter specific properties of physical T-pions are predicted, in particular, by recently suggested phenomenologically consistent vector-like Technicolor model [13]. We have calculated the dependence of the $pp \to pp(\widetilde{\pi^0 \to \gamma\gamma})$ cross section on the vector-like TC model parameters. With a natural choice of parameters obtained by a mere QCD rescaling the corresponding cross sections of the order of one to a few femtobarns could be expected. This means that the exclusive $\tilde{\pi}^0$ production cross section in the $\gamma\gamma$ channel can be of the same order or even exceeds the traditional Higgs boson CEP cross section making the considered proposal very interesting for the forward physics program at the LHC [18, 19].

In order to study the competiveness of the considered exclusive $\tilde{\pi}$ production we have considered irreducible $\gamma\gamma$ production via QCD $gg \to \gamma\gamma$ and QED $\gamma\gamma \to \gamma\gamma$ subprocesses. After inclusion of the ATLAS detector resolution, the S/B ratio for the T-pion CEP is significantly better than for the inclusive case as well as for the Higgs boson CEP seen in the $b\bar{b}$ channel. This makes the exclusive production of two photons attractive channel for New Physics searches at the LHC. To summarize, this analysis demonstartes that the exclusive reaction $pp \to pp\gamma\gamma$ is probably the best suited in searches for T-pions at the LHC. More details can be found in Ref. [15]

The current analysis, although focussed on T-pion production, discusses also important aspects of exclusive two-photon production in general. As shown in our paper, at high $M_{\gamma\gamma}$ the $\gamma\gamma \to \gamma\gamma$ process dominates over the $gg \to \gamma\gamma$ one. This is interesting by itself and rather unique. Any deviation from the Standard Model production may be a signal of New Physics contributions. It would be wise to use the opportunity at the LHC. We thus suggest to search for both continuum and resonance $\gamma\gamma$ signals of New Physics in the exclusive process. There is no clear alternative for such studies at present. This is also one of arguments for installation of forward tagging at ATLAS and CMS.

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