

Detection of mirror-meson decays at CERN

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Abstract. The existence of mirror partners (katoptrons) of Standard-Model fermions offers a viable alternative to a fundamental BEH mechanism, with the coupling corresponding to the mirror generation gauge symmetry becoming strong at around 1 TeV. The resulting non-perturbative processes produce dynamical katoptron masses and create mirror mesons with masses ranging approximately from 0.1 to 2.8 TeV. Since the corresponding phenomenology expected at the LHC is particularly rich, some relevant detection methods of mirror mesons are explored in order to obtain a deeper understanding of strongly-interacting mirror fermions.

1 Introduction

Several decades after the discovery of massive gauge bosons corresponding to the electroweak symmetry, the origin of their mass remains a mystery. The recent discovery of a 125-GeV particle at the LHC, considered to be the central actor of the BEH mechanism, is theoretically complicated by the well-known fact that the mass of an elementary scalar particle is unstable under quantum corrections, unless a new mechanism, like a natural low-energy cut-off, is introduced in the theory. Efforts to have a new strong interaction supply such a cut-off as a mass-stabilization mechanism [1], in which case the agents of the BEH mechanism would be several new composite bosons which should be observable at CERN, are confronted by experimental data since the early 1990s, which indicate via the smallness of the S parameter that the size of new fermion representations under possible new gauge symmetries, while in parallel also coupled to the electroweak symmetry, should be quite limited [2]. These data constrain severely QCD-like strongly-coupled gauge theories providing a dynamical BEH mechanism.

However, the introduction of new fermions in the theory, usually called mirror fermions [3] or katoptrons, having quantum-number assignments “mirroring” the ones of known Standard-Model (SM) fermions, i.e. the same after interchanging left- and right-handed components, in addition to transforming under an initially unbroken $SU(3)_K$ gauged generation symmetry, might offer a solution to this problem. At very high energies, the role of $SU(3)_K$ is to prevent the mixing of mirror fermions with SM ones, which would otherwise give them unacceptably heavy masses. Assuming that the strength α_K of the $SU(3)_K$ gauge coupling is equal to the strengths of the gauge couplings of all the SM gauge groups near the Planck energy scale [4], something that would suggest unification of all the gauge symmetries at that scale and was first attempted in [5] under a different symmetry group, the renormalization group equations governing the running of α_K suggest that $SU(3)_K$ becomes naturally strongly coupled near 1 TeV, i.e. near the electroweak-symmetry breaking scale [6]. Although this

fact renders it a serious candidate for an agent of dynamical electroweak-symmetry breaking, in which way might this new mirror sector couple to the SM fermions?

Attempting to answer this question leads one to the next crucial step involving the study of mirror-fermion-condensates of the form $\mathbf{3} \times \mathbf{3} \rightarrow \mathbf{3}$ due to non-perturbative $SU(3)_K$ dynamics around 1 TeV, which, apart from breaking dynamically the electroweak symmetry, lead to the self-breaking of $SU(3)_K$ down to $SU(2)_K$, which in its turn self-breaks at energies around six times lower via similar condensates. Their formation has several interesting consequences. On one hand, the breaking of the katoptron generation symmetry allows the mixing of mirror fermions with their SM counterparts. The operators mixing these two kinds of fermions are isospin singlets, which allows for the lifting of the mass degeneracy of SM-fermion isospin doublets without introducing too large contributions to the $\Delta\rho$ parameter. On the other hand, mirror fermions acquire dynamical masses due to $SU(3)_K$. Therefore, the diagonalization of mass matrices including both SM and mirror fermions not only provides mass to the SM fermions, which is consistent with their appearance in three generations, but also supplies a mechanism for the natural emergence of the CKM and neutrino-mixing matrices. In parallel, the smallness of neutrino masses can be explained by the standard see-saw mechanism [7]. The resulting mass matrices allow for the introduction of CP-violating phases possibly being at the root of the baryon asymmetry of the Universe, while their form has the potential to solve the strong CP problem. Moreover, their diagonalization after the self-breaking of the mirror generation symmetry $SU(3)_K$ leads to an explicit breaking of mirror-fermion chiral symmetry, providing thus masses to the relevant pseudo-Nambu-Goldstone bosons, i.e. mirror pions, as well as to other mirror mesons, on the order of at least 100 GeV.

Furthermore, the sequential breaking of $SU(3)_K$ offers additionally three considerable advantages. First, it leads to a correct order-of-magnitude mass hierarchy between the SM-fermion generations. In fact, an inductive analysis within the framework of dynamical symmetry breaking could lead one to argue in favour of a broken gauge symmetry of a new strongly-coupled theory based exactly on the large mass hierarchy between SM fermion generations. Second, it may produce contributions to the S parameter which are compatible with present experimental limits. The reason is that mirror-pion decay-constant constraints stemming from the first Weinberg sum rule can be largely fulfilled by the heaviest mirror fermion generation, leaving the decay constants pertaining to the two lightest mirror generations relatively unconstrained, possibly leading to near-zero or even negative contributions to the S parameter [8]. Third, it renders the existence of a low-lying 125 GeV composite Higgs boson, considered here to be a mirror meson, compatible with a dynamically-generated electroweak energy scale roughly estimated via the Pagels-Stokar formalism, since this boson is accompanied by several additional heavier mirror mesons. Last, note that problems related to flavor-changing neutral currents within this framework are expected to be minimal since mirror fermions are not contained within the same representation of a gauge group at low energies. Having listed the main advantages of strongly-interacting mirror fermions in the context briefly described above, we proceed by presenting the corresponding Lagrangian \mathcal{L}_K which is expected to reproduce the SM at lower energies.

2 The Lagrangian

As usual, \mathcal{L}_K is the sum of gauge kinetic and self-interaction terms \mathcal{L}_{YM} and of gauge-fermion interaction terms \mathcal{L}_{int} expressed respectively as [8]

$$\begin{aligned} \mathcal{L}_{YM} &= -\frac{1}{4}B_{\mu\nu}B^{\mu\nu} - \frac{1}{4}W_{\mu\nu}^a W^{a\mu\nu} - \frac{1}{4}G_{\mu\nu}^e G^{e\mu\nu} - \frac{1}{4}G_{\mu\nu}^K G^{K\mu\nu} \\ \mathcal{L}_{int} &= i \sum_{j,k} \left[(\bar{\psi}_u^{j|k}, \bar{\psi}_d^{j|k}) \gamma_\mu \mathcal{D}_k^\mu \begin{pmatrix} \psi_u^{j|k} \\ \psi_d^{j|k} \end{pmatrix} + (\bar{\psi}_u^{j|k}, \bar{\psi}_d^{j|k}) \gamma_\mu \hat{\mathcal{D}}_k^\mu \begin{pmatrix} \hat{\psi}_u^{j|k} \\ \hat{\psi}_d^{j|k} \end{pmatrix} \right] \end{aligned} \quad (1)$$

in flat space-time and at energies above electroweak-symmetry breaking, where γ_μ are Dirac matrices,

$$\begin{aligned} B_{\mu\nu} &= \partial_\mu B_\nu - \partial_\nu B_\mu, & W_{\mu\nu}^a &= \partial_\mu W_\nu^a - \partial_\nu W_\mu^a - g_2 f_2^{abc} W_\mu^b W_\nu^c, \\ G_{\mu\nu}^e &= \partial_\mu G_\nu^e - \partial_\nu G_\mu^e - g_3 f_3^{efg} G_\mu^f G_\nu^g, & G_{\mu\nu}^{K\,e} &= \partial_\mu G_\nu^{K\,e} - \partial_\nu G_\mu^{K\,e} - g_{3K} f_3^{efg} G_\mu^{K\,f} G_\nu^{K\,g} \end{aligned} \quad (2)$$

are the curvatures of the gauge symmetries $U(1)_Y$, $SU(2)_L$, $SU(3)_C$ and $SU(3)_K$ with coupling strengths $g_{1,2,3,3K}$ respectively, $\mu, \nu = 0, \dots, 3$ are space-time indices, f_2^{abc} are the structure functions of $SU(2)_L$ with $a, b, c = 1, 2, 3$, f_3^{efg} are the structure functions of $SU(3)$ and $SU(3)_K$ with $e, f, g = 1, \dots, 8$, the SM-fermion generations are denoted by $j = 1, 2, 3$ and the space-time dependence of the various fields is omitted for simplicity.

The index k introduced above, $k = 1, \dots, 4$ ($k = 1, 2$ for SM fermions and $k = 3, 4$ for mirror fermions), defines fermion fields consisting of two sets of Weyl fermions of opposite chirality:

$$\begin{aligned} \psi_u^{jk} &= (N_L^j, U_L^j, N_R^K \delta^{3j}, U_R^K \delta^{3j}), & \psi_d^{jk} &= (E_L^j, D_L^j, E_R^K \delta^{3j}, D_R^K \delta^{3j}), \\ \hat{\psi}_u^{jk} &= (N_R^j, U_R^j, N_L^K \delta^{3j}, U_L^K \delta^{3j}), & \hat{\psi}_d^{jk} &= (E_R^j, D_R^j, E_L^K \delta^{3j}, D_L^K \delta^{3j}) \end{aligned} \quad (3)$$

where neutrinos are denoted by N^j , charged leptons by E^j , up-type quarks by U^j and down-type quarks by D^j . The superscript "K" denotes mirror fermions, the subscripts "L" and "R" denote fermion chirality, Kronecker's δ^{3j} prevents multiple counting of mirror generations under summation, while the Weyl-spinor, color and mirror-generation indices carried by fermions are omitted for notational simplicity.

The correct assignment of quantum numbers to the fermions of the theory leads to the following definitions for the covariant derivatives:

$$\begin{aligned} \mathcal{D}_k^\mu &= \hat{\mathcal{D}}_k^\mu + \frac{ig_1 Y_k}{2} B^\mu + \frac{ig_2 \tau_a}{2} W_a^\mu \\ \hat{\mathcal{D}}_1^\mu &= \partial^\mu + \frac{ig_1 \hat{Y}_1}{2} B^\mu \\ \hat{\mathcal{D}}_2^\mu &= \partial^\mu + \frac{ig_1 \hat{Y}_2}{2} B^\mu + \frac{ig_3 \lambda_e}{2} G_e^\mu \\ \hat{\mathcal{D}}_3^\mu &= \hat{\mathcal{D}}_1^\mu + \frac{ig_{3K} \lambda_e}{2} G_e^{K\,\mu} \\ \hat{\mathcal{D}}_4^\mu &= \hat{\mathcal{D}}_2^\mu + \frac{ig_{3K} \lambda_e}{2} G_e^{K\,\mu} \\ \text{with } Y_k &= \begin{pmatrix} -1/2 & 0 \\ 0 & 1/2 \end{pmatrix}, \hat{Y}_1 = \begin{pmatrix} 0 & 0 \\ 0 & -1 \end{pmatrix}, \hat{Y}_2 = \begin{pmatrix} 2/3 & 0 \\ 0 & -1/3 \end{pmatrix}, \end{aligned} \quad (4)$$

where the 2×2 unit matrix in isospin space multiplying ∂^μ and the $SU(3)$, $SU(3)_K$ gauge fields is omitted. The $SU(2)$ and $SU(3)$, $SU(3)_K$ generators are denoted by τ_a and λ_e respectively. In the above, we omit for simplicity not only an extra $U(1)'$ interaction possibly felt only by katoptrons [6] but also neutrino Majorana mass terms responsible for a neutrino see-saw mechanism [7], as well as possible additional sterile-neutrino terms implied by the embedding of this model within larger gauge symmetries [6].

As already mentioned, the $SU(3)_K$ -coupling renormalization assuming unification renders mirror fermions strongly coupled around 1 TeV. Apart from breaking the fermion chiral and electroweak gauge symmetries, this is expected to lead to the formation of composite spin-0 and spin-1 bosons similarly to QCD. Leaving aside most parity-even and excited states of these bosons, estimates of the masses of the lowest-lying parity-odd bosons along with the analogue of the QCD σ resonance follow next. With regards to states similar to the ρ meson in QCD, one expects two groups of spin-1

mesons, the heavier one corresponding to the third mirror generation (denoted by B) and the lighter corresponding to the two lighter mirror generations (denoted by A) with the following mass ranges [8]:

$$M_{\rho_A^K} \approx 0.25 - 0.5 \text{ TeV}, \quad M_{\rho_B^K} \approx 1.4 - 2.8 \text{ TeV}. \quad (5)$$

With regards to QCD singlet spin-zero mirror mesons, one has the following rough order of magnitude estimates (σ^K denoting scalar and π^K pseudoscalar particles)[8]:

$$M_{\sigma_A^K, \pi_A^K} \approx 0.1 - 0.2 \text{ TeV}, \quad M_{\sigma_B^K, \pi_B^K} \approx 0.57 - 1.15 \text{ TeV}. \quad (6)$$

Last, with regards to QCD colored spin-zero mirror mesons, one has the following rough order of magnitude estimates (π_3^K denoting QCD triplets and π_8^K QCD octets)[8]:

$$\begin{aligned} M_{\pi_{3A}^K} &\sim 0.11 - 0.23 \text{ TeV}, & M_{\pi_{3B}^K} &\sim 0.64 - 1.3 \text{ TeV}, \\ M_{\pi_{8A}^K} &\sim 0.13 - 0.26 \text{ TeV}, & M_{\pi_{8B}^K} &\sim 0.72 - 1.45 \text{ TeV}. \end{aligned} \quad (7)$$

The order-of-magnitude mass ranges presented above may provide a rough guide for experiments in order to detect excesses of events in comparison to the SM at specific center-of-mass ranges. Note that one cannot exclude *a priori* the possibility of a doubling of the group-A mirror-meson spectrum [8]. We proceed below by presenting some approximate cross-sections involving production and decay of these mirror mesons at the LHC.

3 The Cross-sections

The processes presenting particular interest at the LHC most frequently involve mirror-meson production via gluon-gluon fusion. Taking this into account in the narrow-width approximation and neglecting proton quark distribution functions, an order-of-magnitude estimate of the cross-section of a mirror meson R of mass M and total width Γ_{tot} produced via proton collisions and decaying into a final state X is given by

$$\begin{aligned} \sigma(\bar{p}p \rightarrow R \rightarrow X) &= \mathcal{L}(M) \frac{c \Gamma^{gg} \Gamma^X}{M \Gamma_{tot}}, \\ \text{with } \mathcal{L}(M) &\approx 4(M/\text{TeV})^{-(6+1.6 \log_{10}(M/\text{TeV}))} \text{ nb} \end{aligned} \quad (8)$$

a luminosity function fitting in a very rough approximation the proton gluon distribution functions [9], c an appropriate QCD-color factor and $\Gamma^{gg, X}$ the relevant mirror-meson production and decay widths.

Given that mirror-meson decay widths to SM fermion pairs are expected to be proportional to the square of the final fermion masses, just the most interesting kinematically allowed processes are considered here, which include on one hand group-A mirror meson decays to $\bar{\tau}\tau$ and $\bar{b}b$ pairs and on the other hand group-B mirror meson decays to $\bar{\tau}\tau$ and $\bar{t}t$ pairs. In addition, mirror-meson decays to photon pairs are also studied since they are expected to produce clear signals free of QCD background. The relevant expressions using a specific assumption for the total mirror meson decay widths are given by [8]:

$$\begin{aligned} \sigma(\bar{p}p \rightarrow \sigma_A^K \rightarrow \bar{\tau}\tau) &= \mathcal{L}(M_{\sigma_A^K}) \frac{c_{\sigma g A}}{\pi} \left(\frac{\alpha_{sA}(M_{\sigma_A^K}) M_{\sigma_A^K} m_\tau}{36\pi v m_b} \right)^2 \\ \sigma(\bar{p}p \rightarrow \sigma_A^K \rightarrow \bar{b}b) &= \mathcal{L}(M_{\sigma_A^K}) \frac{3c_{\sigma g A}}{\pi} \left(\frac{\alpha_{sA}(M_{\sigma_A^K}) M_{\sigma_A^K}}{36\pi v} \right)^2 \\ \sigma(\bar{p}p \rightarrow \sigma_A^K \rightarrow \gamma\gamma) &= \mathcal{L}(M_{\sigma_A^K}) \frac{3c_{\sigma g A} c_{\sigma\gamma A}}{2\pi} \left(\frac{\alpha_{sA}(M_{\sigma_A^K}) \alpha(M_{\sigma_A^K}) M_{\sigma_A^K}^2}{486\pi^2 v m_b} \right)^2 \end{aligned}$$

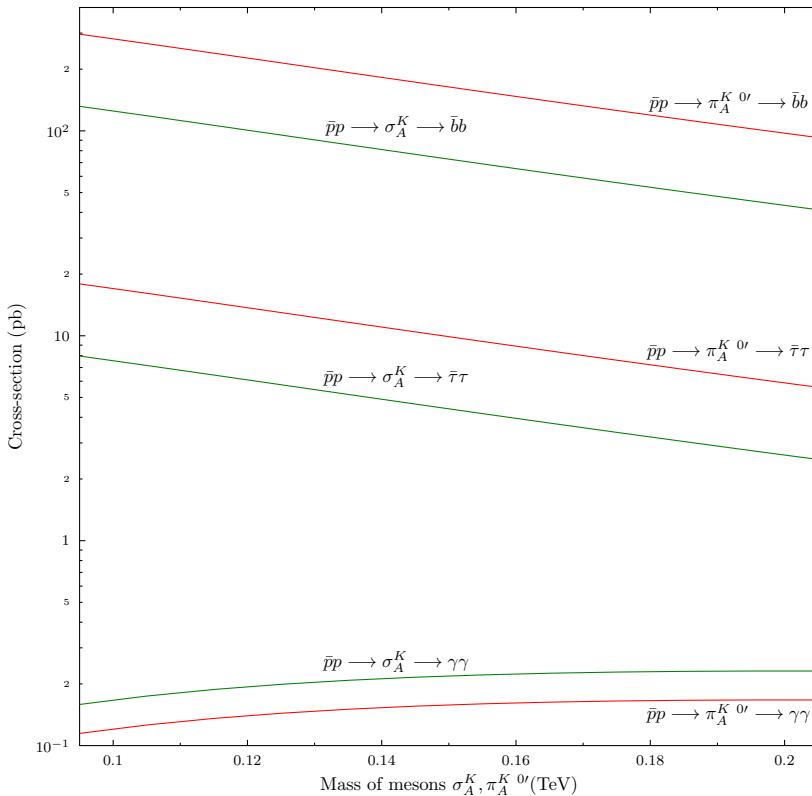


Figure 1. Cross sections of group-A spin-0 color-singlet mirror mesons versus their invariant mass. The Higgs particle discovered in 2012 should correspond to σ_A^K [8].

$$\begin{aligned}
 \sigma(\bar{p}p \rightarrow \pi_A^{K \ 0'} \rightarrow \bar{\tau}\tau) &= \mathcal{L}(M_{\pi_A^{K \ 0'}}) \frac{c_{\pi g \ A}}{\pi} \left(\frac{\alpha_{s \ A}(M_{\pi_A^{K \ 0'}}) M_{\pi_A^{K \ 0'}} m_\tau}{24\pi v m_b} \right)^2 \\
 \sigma(\bar{p}p \rightarrow \pi_A^{K \ 0'} \rightarrow \bar{b}b) &= \mathcal{L}(M_{\pi_A^{K \ 0'}}) \frac{3c_{\pi g \ A}}{\pi} \left(\frac{\alpha_{s \ A}(M_{\pi_A^{K \ 0'}}) M_{\pi_A^{K \ 0'}}}{24\pi v} \right)^2 \\
 \sigma(\bar{p}p \rightarrow \pi_A^{K \ 0'} \rightarrow \gamma\gamma) &= \mathcal{L}(M_{\pi_A^{K \ 0'}}) \frac{3c_{\pi g \ A} c_{\pi\gamma \ A}}{2\pi} \left(\frac{\alpha_{s \ A}(M_{\pi_A^{K \ 0'}}) \alpha(M_{\pi_A^{K \ 0'}}) M_{\pi_A^{K \ 0'}}^2}{216\pi^2 v m_b} \right)^2
 \end{aligned}$$

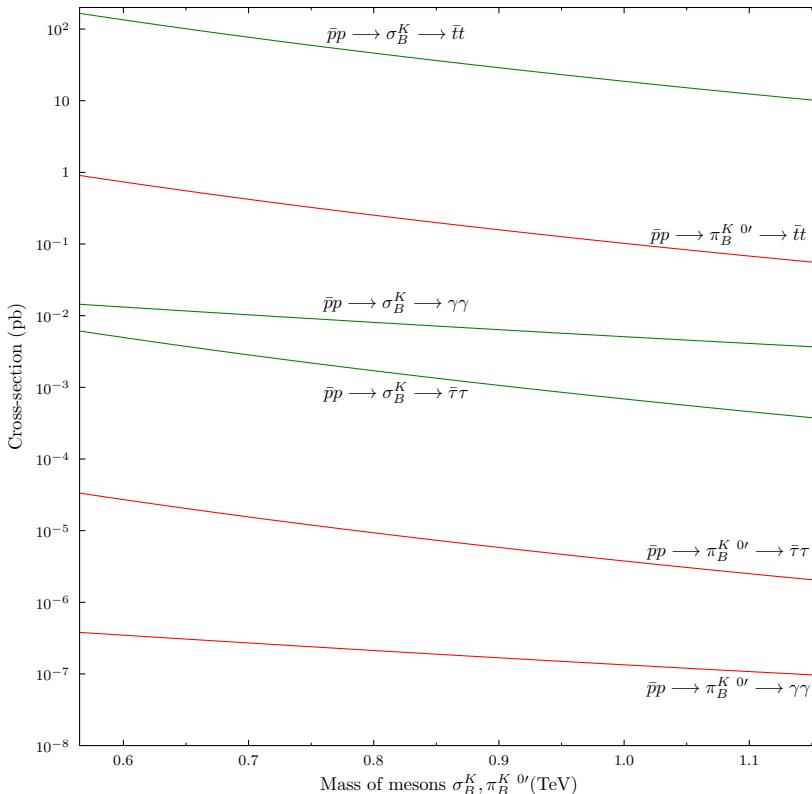


Figure 2. Cross sections of group-B spin-0 color-singlet mirror mesons versus their invariant mass [8]. The excess of diphoton events around 750 GeV reported in 2016 by LHC might be related to σ_B^K , but it should be followed by an excess of $t\bar{t}$ events over the QCD background at the same mass.

$$\begin{aligned}
 \sigma(\bar{p}p \rightarrow \sigma_B^K \rightarrow \tau\tau) &= \mathcal{L}(M_{\sigma_B^K}) \frac{c_{\sigma g B}}{\pi} \left(\frac{\alpha_s B(M_{\sigma_B^K}) M_{\sigma_B^K} m_\tau}{36\pi v m_t} \right)^2 \\
 \sigma(\bar{p}p \rightarrow \sigma_B^K \rightarrow t\bar{t}) &= \mathcal{L}(M_{\sigma_B^K}) \frac{3c_{\sigma g B}}{\pi} \left(\frac{\alpha_s B(M_{\sigma_B^K}) M_{\sigma_B^K}}{36\pi v} \right)^2 \\
 \sigma(\bar{p}p \rightarrow \sigma_B^K \rightarrow \gamma\gamma) &= \mathcal{L}(M_{\sigma_B^K}) \frac{3c_{\sigma g B} c_{\sigma\gamma B}}{2\pi} \left(\frac{\alpha_s B(M_{\sigma_B^K}) \alpha(M_{\sigma_B^K}) M_{\sigma_B^K}^2}{486\pi^2 v m_t} \right)^2
 \end{aligned}$$

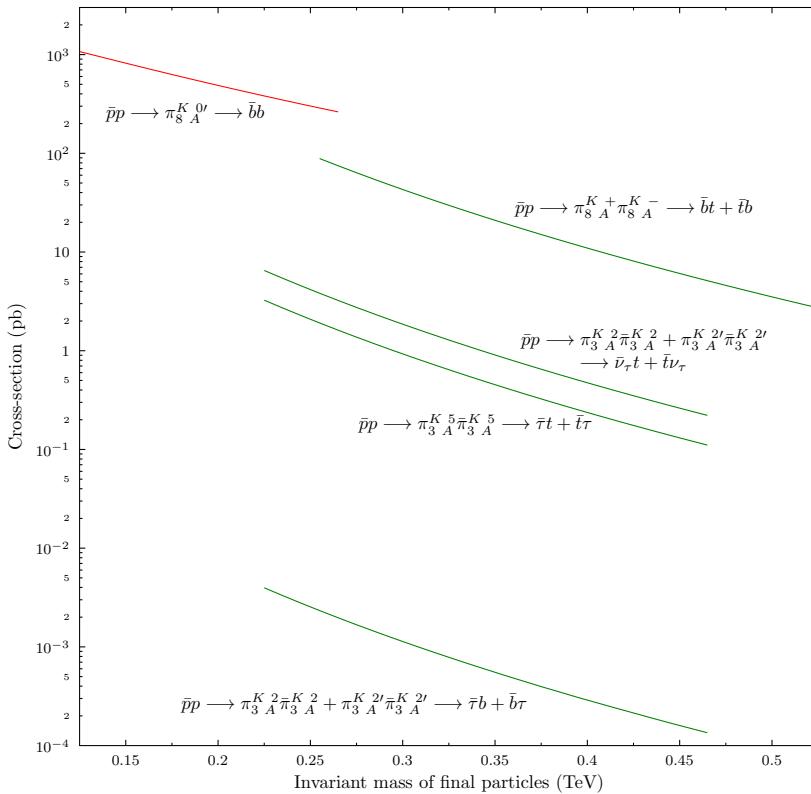


Figure 3. Cross sections involving single or pair production of group-A pseudoscalar spin-0 color-octet and color-triplet mirror mesons versus their total invariant mass [8].

$$\begin{aligned}
 \sigma(\bar{p}p \rightarrow \pi_B^{K0'} \rightarrow \bar{\tau}\tau) &= \mathcal{L}(M_{\pi_B^{K0'}}) \frac{c_{\pi g_B}}{\pi} \left(\frac{\alpha_s B(M_{\pi_B^{K0'}}) M_{\pi_B^{K0'}} m_\tau}{24\pi v m_t} \right)^2 \\
 \sigma(\bar{p}p \rightarrow \pi_B^{K0'} \rightarrow \bar{t}t) &= \mathcal{L}(M_{\pi_B^{K0'}}) \frac{3c_{\pi g_B}}{\pi} \left(\frac{\alpha_s B(M_{\pi_B^{K0'}}) M_{\pi_B^{K0'}}}{24\pi v} \right)^2 \\
 \sigma(\bar{p}p \rightarrow \pi_B^{K0'} \rightarrow \gamma\gamma) &= \mathcal{L}(M_{\pi_B^{K0'}}) \frac{3c_{\pi g_B} c_{\pi\gamma_B}}{2\pi} \left(\frac{\alpha_s B(M_{\pi_B^{K0'}}) \alpha(M_{\pi_B^{K0'}}) M_{\pi_B^{K0'}}^2}{216\pi^2 v m_t} \right)^2
 \end{aligned} \tag{9}$$

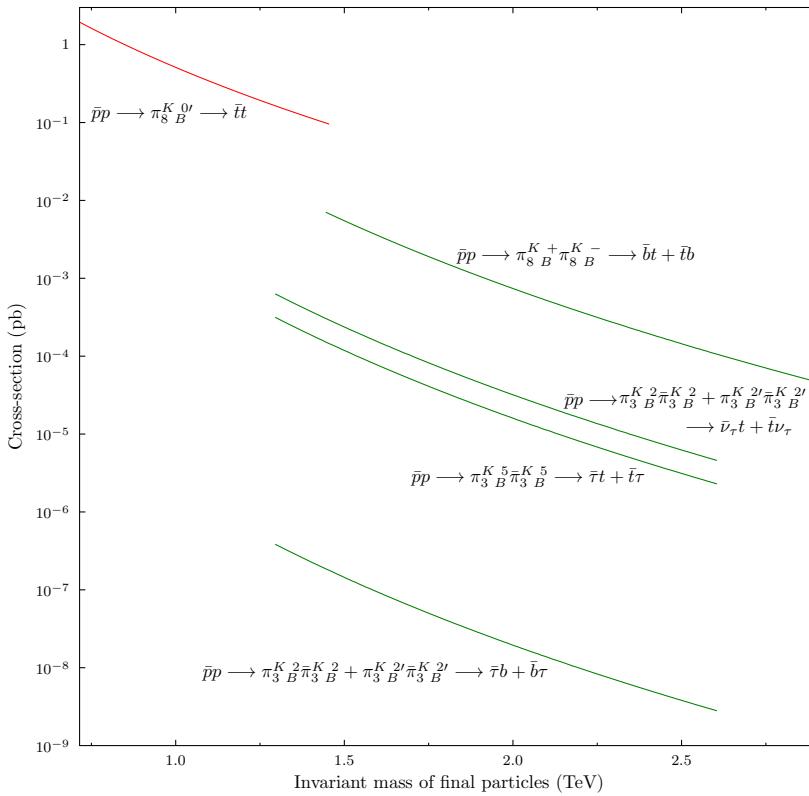


Figure 4. Cross sections involving single or pair production of group-B pseudoscalar spin-0 color-octet and color-triplet mirror mesons versus their total invariant mass [8].

$$\begin{aligned}
 \sigma(\bar{p}p \rightarrow \pi_{8A}^{K0'} \rightarrow \bar{b}b) &= \mathcal{L}(M_{\pi_{8A}^{K0'}}) \frac{15c_{\pi gA}}{\pi} \left(\frac{\alpha_{sA}(M_{\pi_{8A}^{K0'}}) M_{\pi_{8A}^{K0'}}}{24\pi v} \right)^2 \\
 \sigma(\bar{p}p \rightarrow \pi_{8B}^{K0'} \rightarrow \bar{t}t) &= \mathcal{L}(M_{\pi_{8B}^{K0'}}) \frac{15c_{\pi gB}}{\pi} \left(\frac{\alpha_{sB}(M_{\pi_{8B}^{K0'}}) M_{\pi_{8B}^{K0'}}}{24\pi v} \right)^2.
 \end{aligned} \tag{10}$$

In the above, v denotes the weak scale, $\alpha(M)$ corresponds to the electromagnetic coupling at energy M and $\alpha_{sA,B}(M)$ corresponds to the QCD coupling at energy M , with the A, B subscripts reminding the different gauge coupling renormalization according to the number of particles participating in the renormalization loops.

Similarly, expressions involving production of pairs of mirror color-octet mesons and mirror lept-quarks (differentiated from each-other by numerical superscripts) are given below, neglecting production enhancements stemming from color-octet vector mirror mesons and using a specific assumption for the total mirror meson decay widths [8]:

$$\begin{aligned}
 \sigma(\bar{p}p \rightarrow \pi_{8A,B}^{K+} \pi_{8A,B}^{K-} \rightarrow \bar{b}t + \bar{t}b) &\approx \mathcal{L}(2M_{\pi_{8A,B}^{K\pm}}) 27 c_w \pi \left(\frac{\alpha_s(2M_{\pi_{8A,B}^{K\pm}})}{32} \right)^2 \\
 \sigma(\bar{p}p \rightarrow \pi_{3A,B}^{K5} \bar{\pi}_{3A,B}^{K5} \rightarrow \bar{\tau}t + \bar{t}\tau) &= \mathcal{L}(2M_{\pi_{3A,B}^{K5}}) \frac{7c_w\pi}{12} \left(\frac{\alpha_s(2M_{\pi_{3A,B}^{K5}})}{32} \right)^2 \\
 \sigma(\bar{p}p \rightarrow \pi_{3A,B}^{K2} \bar{\pi}_{3A,B}^{K2} + \pi_{3A,B}^{K2'} \bar{\pi}_{3A,B}^{K2'}) &\rightarrow \bar{\nu}_\tau t + \bar{t}\nu_\tau = \\
 &= \mathcal{L}(2M_{\pi_{3A,B}^{K2}}) \frac{7c_w\pi}{6} \left(\frac{\alpha_s(2M_{\pi_{3A,B}^{K2}})}{32} \right)^2 \\
 \sigma(\bar{p}p \rightarrow \pi_{3A,B}^{K2} \bar{\pi}_{3A,B}^{K2} + \pi_{3A,B}^{K2'} \bar{\pi}_{3A,B}^{K2'}) &\rightarrow \bar{\tau}b + \bar{b}\tau) = \\
 &= \mathcal{L}(2M_{\pi_{3A,B}^{K2}}) \frac{7c_w\pi}{6} \left(\frac{\alpha_s(2M_{\pi_{3A,B}^{K2}})m_b}{32m_t} \right)^2. \quad (11)
 \end{aligned}$$

The prefactors c_σ or $c_{\gamma,g}$ or $c_{\gamma,A}$ or $c_{\gamma,B}$ above contain information on the content of quantum loops contributing to the corresponding processes and c_w quantifies the effect of a certain cut of the final-particle total invariant mass [8]. Using certain assumptions in order to approximate these prefactors, figures 1-4 present the relevant order-of-magnitude results corresponding to the mirror-meson mass ranges reported in Section 2. The results in figures 1 and 2 indicate that one should mostly expect excess production of $\bar{b}b$ and $\bar{t}t$ pairs over the relevant QCD background at specific invariant mass bins. This is also true for the results pertaining to single spin-zero color-octet mirror meson production, as can be clearly seen in figures 3 and 4. Moreover, the results of figures 3 and 4 regarding pair production of spin-zero color-octet and color-triplet mirror mesons underline the importance of detection of acollinear $\bar{b}b$ and $\bar{t}t$ jets exceeding relevant estimates from QCD.

Since most of the processes above are obscured by significant QCD backgrounds, these results may be mostly used in order to have just a rough order-of-magnitude indication of the strength of the relevant signals and an estimate of their relative importance under specific assumptions. Crucial for their phenomenological importance would be their comparison with the corresponding QCD backgrounds, obviously using the same gluon luminosity function \mathcal{L} . However, the relevant signal-to-background ratios can be largely enhanced by judicious rapidity and transverse momentum cuts that may be best studied by computer simulations and which are therefore left for future work. Regarding mirror-meson decays to photon pairs which are free from QCD background, their strength varies considerably according to the aforementioned prefactors depending on effective mirror-meson couplings of non-perturbative origin, which are therefore *a priori* unknown. Further experimental input is obviously crucial for determining their relative importance.

4 Conclusions

In general, efforts to interpret physical phenomena of persistently unclear origin lead inexorably to the introduction of new degrees of freedom based on novel assumptions. In the present case, the desire to obtain a natural explanation for the appearance of three massive chiral fermion generations interacting

according to gauge symmetries including a broken one in the SM leads often to radical proposals which are ultimately connected to the fundamental structure of spacetime and are usually based on the introduction of an extra-dimensional space of non-trivial topology. The theory presented in this study might be based on a discrete version of such a multi-dimensional space, where mirror fermions carrying the required quantum numbers are expected to emerge naturally [6]. Partially restoring the left-right symmetry of fermion representations in the way briefly described here, apart from solving several important theoretical puzzles, entails numerous phenomenological consequences, some of which are timely studied in the present work since they are in principle accessible at the LHC.

In such a framework, quantities possibly exhibiting non-negligible deviations from their SM expected values include the CKM-matrix element $|V_{tb}|$, third-generation SM-fermion weak couplings, the muon magnetic moment and B-meson branching ratios, not to mention the proton-decay prediction due to unification considerations [10]. In the present work however, our interest is focused on the production and decay of some of the lowest-lying bound states of mirror fermions formed due to their interacting with a strongly-coupled gauged mirror-generation symmetry. The results obtained indicate that experiments should place particular emphasis on detecting spin-0 and spin-1 mirror mesons which are either QCD-color singlets or triplets or octets, belonging in two groups separated from each-other by a mass hierarchy of around six. Their existence is expected to be inferred mainly by excesses of $\bar{b}b$ and $\bar{t}t$ production over the QCD background within specific invariant-mass ranges, noting that in cases of mirror-meson pair production these jets are generally acoplanar. Possible excesses of Z^0 , W^\pm production over the SM background within specific invariant-mass bins, in case they can be traced to decays of QCD-color singlet mirror mesons, depend on quark distribution functions and are left for future work. Moreover, lest large QCD backgrounds at the LHC do not permit a solid confirmation of the processes described here, the case for a leptonic - electron or muon - collider with center-of-mass energies of around 3-4 TeV would appear more compelling, since around such energies the $SU(3)_K$ interactions between mirror fermions are expected to weaken to an extent possibly allowing for a measurement of their inverted left-right asymmetry [10].

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References

- [1] S. Weinberg, *Phys. Rev.* **D13** 974 (1976); L. Susskind, *Phys. Rev.* **D20** 2619 (1979).
- [2] M. E. Peskin, T. Takeuchi, *Phys. Rev. Lett.* **65** 964 (1990).
- [3] T. D. Lee, C. N. Yang, *Phys. Rev.* **104** 254 (1956).
- [4] J. C. Pati, A. Salam, *Phys. Rev.* **D8** 1240 (1973); H. Georgi, S. L. Glashow, *Phys. Rev. Lett.* **32** 438 (1974).
- [5] F. Wilczek, A. Zee, *Phys. Rev.* **D25** 553 (1982).
- [6] G. Triantaphyllou, *El. J. Th. Phys.* **10** 135 (2013); *ibid.*, *Eur. Phys. J. Web Conf.* **70** 00051 (2014).
- [7] G. Triantaphyllou, *Eur. Phys. J.* **C10** 703 (1999).
- [8] G. Triantaphyllou, *El. J. Th. Phys.* **13** 115 (2016).
- [9] C. Quigg, Fermilab Preprint FERMILAB-FN-0839-T, August 2009.
- [10] G. Triantaphyllou, *Int. J. Mod. Phys.* **A15** 265 (2000).