Strongly-interacting mirror fermions at the LHC

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Abstract. The introduction of mirror fermions corresponding to an interchange of left- with right-handed fermion quantum numbers of the Standard Model can lead to a model according to which the BEH mechanism is just an effective manifestation of a more fundamental theory while the recently-discovered Higgs-like particle is composite. This is achieved by a non-abelian gauge symmetry encompassing three mirror-fermion families strongly coupled at energies near 1 TeV. The corresponding non-perturbative dynamics lead to dynamical mirror-fermion masses between 0.14 - 1.2 TeV. Furthermore, one expects the formation of composite states, i.e. "mirror mesons", with masses between 0.1 and 3 TeV. The number and properties of the resulting new degrees of freedom lead to a rich and interesting phenomenology, part of which is analyzed in the present work.

1 Introduction

The breaking of the electroweak symmetry is one of the most important problems of theoretical Physics still awaiting a satisfactory explanation. The Higgs-like particle recently discovered at CERN, if considered as fundamental, has a mass which cannot be easily stabilized due to quantum mechanics. Since introducing new particles associated with a 1-TeV ultraviolet cut-off might address the problem, one of the main tasks of the LHC is to determine the precise nature and properties of such hypothetical particles. However, completing the Standard-Model with a new strongly-interacting sector [1] manifesting itself via meson-like composite states has been facing serious phenomenological problems for almost three decades. In fact, the number of new chiral fermions introduced in a theory beyond the Standard Model is strictly bound by the so-called "oblique" quantum corrections expressed via the S-parameter [2].

Nevertheless, it has been argued that this problem can be solved by introducing mirror fermions [3] in the theory. In fact, it is assumed that, apart from them being endowed with left-right interchanged Standard-Model quantum-number assignments, they interact via a mirror-generation gauge symmetry which becomes strongly-coupled and self-breaks around 1 TeV. Above this energy scale, this generation symmetry supports the "survival hypothesis" since it forbids Standard-Model-fermion mixing quantum-mechanically with their mirror partners, something that would otherwise give all particles Planck-scale masses. The additional assumption of gauge-coupling unification around Planck-scale energies similarly to [4] but including a mirror-fermion generation gauge group as well, something frequently taken as an indication of gauge-symmetry unification under a larger gauge group, was

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first made in [5], within a framework however that led to an unacceptable phenomenology. On the contrary, renormalization of the gauge coupling α_K of the mirror-generation group taken here to be $SU(3)_K$ renders the theory naturally strongly-coupled near 1 TeV, i.e. close to the energy where electroweak symmetry breaks [6]. Obviously, strengthening the plausibility of the assumptions made above requires a precise elucidation of the way the new mirror-fermion sector couples to the Standard Model.

The first stage of this coupling mechanism involves the formation of non-zero vacuum expectation values (vevs) of composite operators consisting of two mirror fermions and transforming like $\mathbf{3}\times\mathbf{3} \rightarrow \mathbf{3}$ under $SU(3)_K$ around 1 TeV. These break dynamically not only the electroweak symmetry but $SU(3)_K$ as well. The mirror-generation symmetry self-breaks down to $SU(2)_K$, and the latter is also expected to self-break at energies approximately six times lower via similar vevs. After the mirror-generation symmetry breaks, mirror fermions can mix quantum-mechanically with Standard-Model fermions. This mixing can be realized in a way that can account for the large mass difference between the top and the bottom quarks while respecting existing limits on the $\Delta\rho$ parameter. In parallel, it might offer a solution to the strong-CP problem due to the structure of the fermion mass matrix.

Moreover, strong dynamics endow mirror fermions with dynamical masses on the order of the scales of mirror-generation symmetry breaking. Diagonalizing the resulting mass matrices including both Standard-Model and mirror fermions provides masses to Standard-Model fermions via a generalized see-saw mechanism being in parallel consistent with the number of fermion generations. Furthermore, it leads to an interesting interpretation of the CKM and neutrino-mixing matrices. In addition, this process can be easily incorporated within the usual see-saw mechanism usually employed to produce small neutrino masses [7]. The new degrees of freedom introduced allow in parallel the existence of several complex phases in the fermion mass matrices leading to CP violation possibly related to the observed baryon asymmetry of the Universe. Last, the process of mass-matrix diagonalization, after $SU(3)_K$ self-breaking, breaks the chiral symmetry of mirror fermions explicitly, which leads to non-zero masses for the relevant (pseudo)-Nambu-Goldstone bosons. These are therefore considered to be mirror pions with masses higher than around 100 GeV, as will be seen shortly.

It is important to note that the mirror-generation symmetry-group breaking in two stages serves several purposes. In particular, one of its most notable consequences is that it provides the basis for the reproduction of the hierarchy of fermion masses between different generations. Since Standard-Model fermion masses are "fed-down" via mixing with their mirror partners, such an hierarchy could most naturally be due to a sequentially-broken strongly-coupled gauge group. Another advantage is that it can lead to an S parameter which is within current experimental bounds, since the first Weinberg sum rule is saturated by spin-1 mirror mesons corresponding to the third mirror-fermion generation, leaving thus the spin-1 mirror-meson decay constants related to the two lighter mirror-fermion generations relatively unconstrained [8].

In addition, the sequential breaking of $SU(3)_K$ renders the low-lying mass of the Higgs-like particle recently discovered at CERN more natural, since the correct reproduction of the value of the weak scale requires the inclusion of several additional heavier mirror-fermion composite states. Last but not least, note that the coupling of the Standard-Model fermions with their mirror-fermion counterparts is performed in a way avoiding complications with flavor-changing neutral currents, in contrast to usual extended-technicolor models, since the two types of fermions are not parts of a common large fermion representation. The list of the advantages above providing sufficient motivation for the further study of the theory proposed, we present in what follows some rough estimates for the masses of the new degrees of freedom expected along with their most promising phenomenological signatures.

2 Masses and Cross-sections

2.1 Fermion mass estimates

The Lagrangian $\mathcal{L}_K$ given in [8] is chirally invariant at energies higher than around 1 TeV, since both Standard-Model and mirror fermions are initially massless. When the gauge coupling α_K becomes strong at energies close to 1 TeV, mirror fermions acquire dynamical masses $M_i(p^2)$ like the ordinary quarks of QCD. For a strongly-coupled $SU(N_i)$ gauge theory with fermions ψ, these masses are connected to vevs expressed, in the one-loop approximation, in Landau gauge and in Euclidean space, as

$$< \bar{\psi}\psi > \approx -\frac{N_i}{4\pi^2} \int dp^2 M_i(p^2). \quad (1)$$

These dynamical masses are non-trivial and break chiral symmetry dynamically only when the $SU(N_i)$ gauge coupling is larger than a critical value [9]. Except for breaking chiral symmetry, these vevs break also the electroweak symmetry, leading therefore to a dynamical BEH mechanism. After the self-breaking of $SU(N_i)$ taken here to be $SU(3)_K$, the mass submatrix m mixing Standard-Model fermions with their mirror partners becomes non-trivial as well due to gauge-invariant terms not allowed at higher energies due to $SU(3)_K$. Diagonalizing the mass matrix feeds down masses to SM-fermions, while giving rise to the CKM and to neutrino-mixing matrices [7],[10].

The mirror generation group $SU(3)_K$ is strongly coupled and self-breaks around $\Lambda_K \approx 0.5$ - 1 TeV down to $SU(2)_K$. Interactions stemming from $SU(2)_K$ become similarly strong at lower energies and lead in their turn to the self-breaking of $SU(2)_K$. Therefore, at energies lower than Λ_K where mirror fermions are not expected to propagate freely, new degrees of freedom are relevant which correspond to two distinct groups of mesons, denoted in the following by "A" for the lighter and "B" for the heavier group. Consequently, the process above leads to a doubling of the mass spectrum of mirror mesons, which is due to the hierarchy, denoted in the following by r, of the two energy scales where the strongly-coupled mirror-generation gauge group self-breaks. In fact, one could even contemplate a tripling of the mirror-meson mass spectrum in case the remaining $SU(2)_K$ mirror generation symmetry is severely broken.

The hierarchy r is roughly estimated to be equal to

$$r = \exp\Big(3(C_2(SU(3)_K) - C_2(SU(2)_K))\Big) \approx 5.75, \quad (2)$$

where $C_2(g)$ is the quadratic Casimir invariant of a Lie algebra g (there is a typographical mistake in this formula in the conference proceedings of [8]). Note the natural emergence of the r-hierarchy [11] which requires no fine-tuning of the relevant effective-potential parameters. An effective chiral Lagrangian $\mathcal{L}_{eff}$ may then be employed in order to study the new degrees of freedom which emerge, after mirror fermions and mirror-generation gauge fields are integrated out [8]. This Lagrangian contains the terms which are indispensable for the description of the mass spectrum and the interactions of mirror mesons, which are studied later.

We define next the mass matrix m_f containing the masses not only of Standard-Model but also of mirror fermions. Its form renders the mechanism behind fermion mass-generation transparent [7], [10]. At energies higher than around 1 TeV, m_f is obviously equal to zero. At lower energies however, where the mirror-fermion dynamical masses $M_{A,B}$ are not zero, one defines:

$$m_f = \begin{pmatrix} m_{SM} & m \\ m & M \end{pmatrix}, M \equiv \begin{pmatrix} M_A & 0 \\ 0 & M_B \end{pmatrix}, m \equiv \begin{pmatrix} m_{AA} & m_{AB} \\ m_{AB} & m_{BB} \end{pmatrix} \quad (3)$$

where M is the mirror-fermion dynamical-mass matrix and m is the Standard-Model-fermion/ mirror-fermion mixing matrix, assuming that

$$m_{AB} \sim m_{BB}/r. \quad (4)$$

and $m_{SM} = m_{AA} = 0$.

After diagonalizing m_f, which in parallel gives rise to the CKM and neutrino-mixing matrices, one finds approximately

$$m^D_{SM} = \begin{pmatrix} m_{f_A} & 0 \\ 0 & m_{f_B} \end{pmatrix} \approx \begin{pmatrix} (m^D_{AA})^2/M_A & 0 \\ 0 & m^2_{BB}/M_B \end{pmatrix} \tag{5}$$

where

$$m^D_{AA} \approx m_{BB}/r^2, \tag{6}$$

the superscript "D" above denoting matrix entries after diagonalization. This procedure yields roughly the mass hierarchy between the three generations of the Standard-Model fermions, with

$$\begin{aligned} m_{f_B} &= m^2_{BB}/M_B \\ m_{f_A} &= m_{f_B}/r^3. \end{aligned} \tag{7}$$

Assuming that $M_B = 1$ TeV and $m_{BB} = 0.418$ TeV yields $m_{f_B} \approx 0.175$ TeV $\approx m_t$, and $m_{f_A} \approx 0.92$ GeV $\approx m_c$, which give the correct order of magnitude for the masses of the two heavier Standard-Model fermion generations. The same mechanism is expected to yield the correct order of magnitude of masses for the lightest Standard-Model fermion generation, as shown explicitly in [7], [10].

2.2 Mirror-meson mass estimates

We now proceed with a more complete analysis of the structure of mirror mesons. Each mirror fermion generation consists of $N = 8$ fermions, i.e. $N_D = N/2 = 4$ isospin doublets, one color-singlet doublet and one color-triplet doublet. The corresponding chiral symmetry of the mirror-fermion Lagrangian is therefore equal to SU(N)$_L$⊗SU(N)$_R$, $N = 8$. The adjoint representations of this symmetry group may be expressed under their SU(2)×SU(3) subgroups as:

$$\begin{aligned} [\mathbf{8_L}] \otimes [\mathbf{8_R}] &= [\mathbf{2} \times (\mathbf{3} + \mathbf{1})] \otimes [\mathbf{2} \times (\bar{\mathbf{3}} + \mathbf{1})] \\ &= (\mathbf{3_2} + \mathbf{1}) \times (\mathbf{3} \otimes \bar{\mathbf{3}} + \mathbf{3} + \bar{\mathbf{3}} + \mathbf{1}) = (\mathbf{3_2} + \mathbf{1}) \times (\mathbf{8} + \mathbf{1} + \mathbf{3} + \bar{\mathbf{3}} + \mathbf{1}) \end{aligned} \tag{8}$$

where $\mathbf{2} \otimes \mathbf{2} = \mathbf{3_2} + \mathbf{1}$ corresponds to isospin ($\mathbf{3_2}$ standing for an isospin triplet) and $\mathbf{3} \otimes \bar{\mathbf{3}} = \mathbf{8} + \mathbf{1}$ to QCD.

After the gauge coupling of the mirror-fermion generation group becomes strong at about 1 TeV, chiral symmetry is broken down to its diagonal subgroup. This implies the emergence of $N^2 - 1$ Nambu-Goldstone (NG) bosons linked to the broken axial-vector symmetry. Except for these mesons, one expects the formation of spin-1 mesons analogous to the ρ meson in QCD. Following the previous formula, one may classify mirror mesons according to their isospin and QCD quantum numbers, the superscript "K" (from the word "katoptron"=mirror) denoting that they are mirror mesons.

On one hand we have three mirror mesons, $\pi^{K\ b\ 0}$ and $\pi^{K\ b\ \pm}$ which become the longitudinal components of $W^\pm$ and Z^0. In addition, we have five more spin-0 color-singlet mirror mesons which include η'^K associated to the broken $U(1)_A$ symmetry. Moreover, these are followed by their spin-1 partners:

$$\pi^{K\ a\ 0},\ \pi^{K\ a\ \pm},\ \pi^{K\ 0\prime}, \eta'^K\ \ (\text{spin} - 0)\ \ \text{and}\ \ \rho^{K\ a,b\ 0},\ \rho^{K\ a,b\ \pm},\ \rho^{K\ 0\prime}\ \text{and}\ \ \omega^K\ \ (\text{spin} - 1). \tag{9}$$

Furthermore, one has four color-triplets ("leptoquarks") followed their anti-particles, coming in spin-0 and spin-1 versions:

$$\pi_3^{K\ 1,2,2\prime,5},\ \bar{\pi}_3^{K\ 1,2,2\prime,5}\ (\text{spin} - 0)\ \ \text{and}\ \ \rho_3^{K\ 1,2,2\prime,5},\ \bar{\rho}_3^{K\ 1,2,2\prime,5}\ (\text{spin} - 1). \tag{10}$$

The leptoquarks above have fractional electromagnetic charges (either $-\frac{1}{3}$ for $\pi_3^{K\,1}$, $\rho_3^{K\,1}$, or $\frac{2}{3}$ for $\pi_3^{K\,2,2\prime}$, $\rho_3^{K\,2,2\prime}$, or $\frac{5}{3}$ for $\pi_3^{K\,5}$, $\rho_3^{K\,5}$). Last, one considers four spin-0 and spin-1 color-octet mirror mesons, denoted by

$$\pi_8^{K\,0},\, \pi_8^{K\,\pm},\, \pi_8^{K\,0\prime} \quad (\text{spin}-0) \;\text{ and }\; \rho_8^{K\,0},\, \rho_8^{K\,\pm},\, \rho_8^{K\,0\prime} \quad (\text{spin}-1). \tag{11}$$

Symbols of mirror mesons which are isospin-singlets (except for ω^K) are primed, the rest belonging to isospin triplets. Moreover, note that mirror mesons bearing the same electromagnetic and color charges can mix quantum-mechanically with each other, like $\pi^{K\,a\,0}$ with $\pi^{K\,0\prime}$, $\pi_3^{K\,2}$ with $\pi_3^{K\,2\prime}$ and $\pi_8^{K\,0}$ with $\pi_8^{K\,0\prime}$ for the spin-0 case, and similarly for the spin-1 case. This list of mirror mesons, expected to be the lightest composite mirror particles, might be completed not only by their parity partners (scalars and axial vectors) but also by their excited states, all of which are in principle expected to be heavier than the ones quoted above.

The analogue of the σ scalar QCD resonance in the mirror-fermion case, i.e. σ^K, might be the lightest mirror meson excluding the mirror "pions eaten" by $W^\pm$ and Z^0. In fact, the mirror meson σ^K should correspond in the present case to the "Higgs-type" particle with a 125 GeV mass recently discovered at the LHC. The fact that its mass is lower than double the masses of $W^\pm$, Z^0 and the top quark explains its relatively narrow width when compared to the σ-meson width in QCD. In principle, collective states consisting of more than a pair of mirror fermions (like mirror protons, mirror neutrons etc.) are conceivable as well, although their production and detection at hadronic colliders is expected to be particularly hard.

The mirror-meson spectrum described above is doubled or even tripled since the mirror-fermion generation symmetry is eventually broken. We denote the lighter mirror mesons by π_A^K and ρ_A^K, dropping numerical superscripts and color subscripts, corresponding to the two lighter mirror-fermion generations. The latter should acquire dynamical masses roughly estimated to be equal to

$$\Lambda_K/r \approx M_A \approx 0.1 - 0.2 \text{ TeV}, \tag{12}$$

noting that they might be further split into two mass subgroups. In a similar fashion, we denote the heavier mirror mesons as π_B^K and ρ_B^K, corresponding to mirror fermions having constituent masses roughly equal to

$$M_B = rM_A \sim 0.57 - 1.15 \text{ TeV}. \tag{13}$$

The range of these masses is dictated by the Pagels-Stokar formula [12] reproducing the right order of magnitude for the weak scale $v \approx 246$ GeV generated by three generations of $N_D = 4$ mirror-fermion doublets with dynamical masses M_i, $i = A, B$, for an $SU(N_i)$ theory with a strong gauge coupling and $\Lambda_{K\,i}$ an ultraviolet momentum cut-off:

$$v \approx \frac{1}{\pi}\sqrt{\sum_{i=A,B} n_i N_i M_i^2 \ln\left(\Lambda_{K\,i}^2/M_i^2\right)}, \tag{14}$$

with $n_A N_A = 2\cdot 2 = 4$ and $n_B N_B = 1\cdot 3$ (note that in [8] the factors $n_{A,B}$ in this formula were "absorbed" within $N_{A,B}$, which might be misleading since the strong groups are still $SU(3)_K$ and $SU(2)_K$). Since third-generation mirror mesons have masses on the order of M_B which is much larger than M_A, they are the principle determinants of the value of the weak scale in this scenario.

In analogy to QCD, an effort is now made to estimate the order of magnitude of spin-1 mirror-meson masses based on the value of the constituent mass of the up quark and the mass of the rho meson, a procedure yielding:

$$M_{\rho^K_{A,B}} \approx \frac{m_\rho}{m_u} M_{A,B}, \tag{15}$$

with $m_\rho \approx 770$ MeV the mass of the ρ meson and $m_u \approx 313$ MeV the constituent mass of the up quark. Plaguing-in the corresponding values gives:

$$\begin{aligned} M_{\rho^K_A} &\approx 0.25 - 0.5 \text{ TeV} \\ M_{\rho^K_B} &\approx 1.4 - 2.8 \text{ TeV}. \end{aligned} \tag{16}$$

We further assume that $\eta'^K_{A,B}$ and $\omega^K_{A,B}$ have masses on the same order of magnitude. The values above should be taken *cum grano salis* given the non-QCD-like and non-perturbative dynamics involved.

We proceed further by discussing briefly the S parameter [2], since the introduction of a large number of new fermions in the theory could in principle be difficult to accommodate it. The contributions to the S parameter can be separated into two groups: one related to group-"A" mirror spin-1 mesons and the other to group-"B" mirror spin-1 mesons. This leads us to the expression

$$S = S_A + S_B = 4\pi \sum_A \left(\frac{F^2_{\rho^K_A}}{M^2_{\rho^K_A}} - \frac{F^2_{a^K_A}}{M^2_{a^K_A}} \right) + 4\pi \sum_B \left(\frac{F^2_{\rho^K_B}}{M^2_{\rho^K_B}} - \frac{F^2_{a^K_B}}{M^2_{a^K_B}} \right) \tag{17}$$

where $F_{\rho^K_{A,B}, a^K_{A,B}}$ denote the mirror vector and axial-vector meson decay constants and summations are performed over group-"A" and group-"B" spin-1 mirror mesons. Since we expect that $F_B \sim 5.75 F_A$, the first Weinberg sum rule (WSR) is saturated by group-"B" mirror-meson contributions. In particular, one expects

$$\sum_B F^2_{\rho^K_B} - F^2_{a^K_B} \approx v^2. \tag{18}$$

Furthermore, taking vector and axial-vector mirror meson masses to be roughly equal, i.e. $M_{\rho^K_B} \approx M_{a^K_B}$, one finds approximately

$$S_B \approx 4\pi (v/M_{\rho^K_B})^2 \lesssim 0.122 \tag{19}$$

assuming that $M_{\rho^K_B} > 2.5$ TeV. Since the group-"A" spin-1 mirror-meson decay constants $F^2_{\rho^K_A, a^K_A}$ are not strictly constrained by WSR any more, S_A can be close to zero or even negative. Consequently, the sequential breaking of the mirror-fermion generation group offers a powerful solution to the S-parameter problem introducing non-QCD-like dynamics without needing to fine tune several parameters in unnatural or unlikely ways.

We now analyze the masses of spinless mirror mesons. Pseudoscalar mirror mesons are expected to be relatively light since they are pseudo-Nambu-Goldstone bosons corresponding to the mirror-fermion chiral symmetry which is broken around 1 TeV. We assume below that mirror-pion and σ^K masses are separated in two distinct groups, lying either around

$$100 - 200 \text{ GeV} \quad \text{for } (\sigma^K_A, \pi^K_A) \tag{20}$$

or around

$$0.57 - 1.15 \text{ TeV} \quad \text{for } (\sigma^K_B, \pi^K_B). \tag{21}$$

Mirror pions carrying color charges receive additional mass contributions due to QCD, which are roughly estimated to be equal to

$$\sqrt{\alpha_s} M_{\rho^K_{A,B}} \quad \text{for } \pi^K_{8\ A,B} \tag{22}$$

and

$$\frac{2}{3} \sqrt{\alpha_s} M_{\rho^K_{A,B}} \quad \text{for } \pi^K_{3\ A,B}, \tag{23}$$

with α_s the QCD coupling strength near the mirror-meson mass [13].

Taking the above into consideration, we list order-of-magnitude estimates for the colored spin-0 mirror-meson mass ranges:

$$\begin{aligned} M_{\pi^K_{3\ A}} &\sim 0.11 - 0.23 \text{ TeV} \\ M_{\pi^K_{3\ B}} &\sim 0.64 - 1.3 \text{ TeV} \\ M_{\pi^K_{8\ A}} &\sim 0.13 - 0.26 \text{ TeV} \\ M_{\pi^K_{8\ B}} &\sim 0.72 - 1.45 \text{ TeV} \end{aligned} \tag{24}$$

The rough estimates quoted above are also presented diagrammatically in figure 1. These should offer an approximate guide when analyzing collider data in an effort to detect excesses of events within specific invariant-mass bins. A brief discussion of expected cross-sections involving mirror mesons given their masses follows next.

2.3 The cross-sections

A particularly interesting subset of processes which might be studied at the LHC includes mirror-meson production via gluon fusion. Neglecting the contribution of proton quark distribution functions, a rough estimate of the cross-section of a mirror meson R of mass M and total width Γ_{tot} decaying into a final state X in the narrow-width approximation is given by

$$\sigma(\bar{p}p \longrightarrow R \longrightarrow X) = \mathcal{L}(M)\frac{c\Gamma^{gg}\Gamma^{X}}{M\Gamma_{tot}} \tag{25}$$

where $\mathcal{L}(M)$ is a luminosity function fitting approximately the proton gluon distribution functions [14], c is a QCD-color factor and $\Gamma^{gg,X}$ the corresponding mirror-meson production and decay widths given in [8].

The decay widths of mirror mesons to Standard-Model fermions are proportional to the square of the final fermion masses. Therefore, particular emphasis should be given to processes 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 worth analyzing since they produce clear signals not blurred by QCD background. The corresponding expressions and diagrams are presented in detail in [8].

Given that most of the processes discussed above are obscured by large QCD backgrounds, the results obtained can be studied in order to have just a rough impression of the strength of the corresponding signals and an estimate of their relative importance under certain assumptions. Obviously, it is very important to compare them with the relevant QCD backgrounds using the same gluon luminosity function $\mathcal{L}$. In any case, the relevant signal-to-background ratios can be significantly enhanced by proper rapidity and transverse momentum cuts which are best studied by simulations left for future investigations.

3 Conclusions

The apparent complexity of the structure of the various degrees of freedom needed to explain high-energy Physics phenomena within the framework of the Standard Model renders further theoretical extensions particularly compelling. However bold these might seem at first sight, they might offer novel conceptual viewpoints which clarify processes, complete the theory and unify its components in a more symmetric way. In particular, the introduction of mirror fermions interacting with a gauged

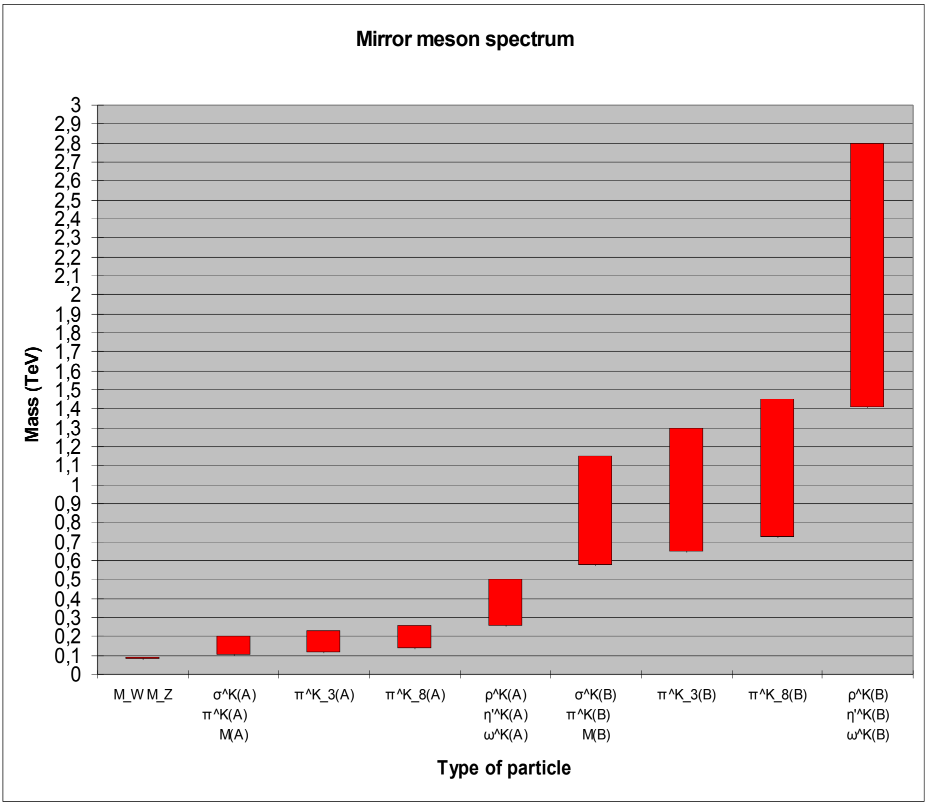

Figure 1. Approximate estimates of mirror-meson mass ranges, with
$M\_W, Z : M_{W,Z}$
$\sigma^\wedge K(A,B) : \sigma^K_{A,B}$
$\pi^\wedge K(A) : \pi_A^{K\ a\ 0}, \pi_A^{K\ a\ \pm}, \pi_A^{K\ 0\prime}$
$\pi^\wedge K(B) : \pi_B^{K\ a,b\ 0}, \pi_B^{K\ a,b\ \pm}, \pi_B^{K\ 0\prime}$
$M(A,B) : M_{A,B}$
$\pi^\wedge K\_3(A,B) : \pi^{K\ 1,2,2\prime,5}_{3\ A,B}, \bar{\pi}^{K\ 1,2,2\prime,5}_{3\ A,B}$
$\pi^\wedge K\_8(A,B) : \pi^{K\ 0}_{8\ A,B}, \pi^{K\ \pm}_{8\ A,B}, \pi^{K\ 0\prime}_{8\ A,B}$
$\rho^\wedge K(A,B)$: all kinds of $\rho^K_{A,B}$ mesons
$\eta'^\wedge K(A,B) : \eta'^K_{A,B}$
$\omega^\wedge K(A,B) : \omega^K_{A,B}$

generation symmetry, although it seems to burden the model with numerous additional fields, leads to the solution of several important, longstanding but still open, theoretical puzzles while in parallel completing particle Physics in a symmetric fashion.

Furthermore, it is conceivable that the advantages of such an extension are not limited to the ones regarding low-energy phenomenology which initially motivated this work, but might be linked to efforts based on the optimal connectivity principle, related to quantum gravity and to a possible discrete inner structure of space-time where elementary particles are considered as lattice defects and the solution to the Dark Matter problem lies in a different space-time topology [6], [8]. In any case, such a completion implies the emergence of several new phenomena which might be detectable at the LHC experiments.

In general, mirror-fermion experimental signatures can be divided in two categories. First come indirect signatures depending on quantum effects like deviations of the CKM-matrix element $|V_{tb}|$, of weak couplings of Standard-Model fermions of the heaviest generation, of the muon magnetic moment and of B-meson branching ratios from their Standard-Model expected values. One might add to these the proton-decay prediction due to the unification of the strong with the electroweak interaction at very high energies [15]. Second come direct experimental signatures which are analyzed in the present work. These are focused on the production and decay of mirror mesons expected to belong in two main groups separated by a mass hierarchy close to six, and which can be classified according to their QCD quantum numbers. Crucial for their detection will prove to be a very good resolution of the invariant mass and angular distribution of the bottom- and top-quark jets into which mirror mesons are expected to decay predominantly.

Moreover, excesses of Z^0 and $W^{\pm}$ production over the relevant Standard-Model background, possibly due to spin-1 color-singlet mirror mesons, might also prove particularly interesting. However, they depend on proton quark distribution functions and are left for future investigations. Last, note that significant QCD backgrounds render most of the processes mentioned here particularly hard to discern. Therefore, in case the LHC is not able to distinguish them from these backgrounds, one should seriously consider building leptonic - electron and/or muon - colliders with center-of-mass energies of approximately 3-4 TeV. At such energies the $SU(3)_K$ interactions should be weak enough in order to allow the measurement of the left-right asymmetry of mirror fermions within an environment free from QCD background [15]. The importance of such a prospect towards opening up new horizons in medium- and long-term high-energy Physics can hardly be over-emphasized.

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