Strongly-interacting mirror fermions at the LHC

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XIIth Quark Confinement and the Hadron Spectrum

August 2016 - Thessaloniki

Motivation

- Explore the inner works of mass generation
- Understand the Physics behind the M_{Planck}/M_{weak} hierarchy
- Results from the LHC might provide indirect clues for Planck-energy Physics

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Some natural solutions

- Large extra dimensions
  Stabilization via **size** of extra dimensions
- Known particles have spin-zero partners (SUSY)
  Stabilization via **space-time symmetry**
  Interaction: weak
- Known particles have mirror partners (Katoptrons)
  Stabilization via **gauge symmetry**
  Interaction: strong

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A field fertilized by great old ideas

- T.D. Lee and C.N. Yang (1956): mirror fermions
- J.C. Pati and A. Salam (1973): Coupling unification
- S. Weinberg (1976), L. Susskind (1979):
  Dynamical BEH mechanism
  Universe: a "superconductor", Composite Higgs $\sim < \bar{\Psi}\Psi >$
- F. Wilczek and A. Zee (1982):
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  Unification?

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2. Inductive approach
   - Hierarchy stabilization and extrapolation to M_{Planck}
   - Mirror fermions: a compelling completion of the SM
3. Mirror-meson phenomenology
   - A *déjà* – *vu* reminiscent of QCD
   - Mirror-meson decays at the LHC
4. Conclusions

An (almost) left-right symmetric Lagrangian

$$
\begin{aligned}
\mathscr{L} &= \mathscr{L}_{YM} + \mathscr{L}_{int} \\
\mathscr{L}_{YM} &= -\frac{1}{4} B_{\mu\nu} B^{\mu\nu} - \frac{1}{4} W^a_{\mu\nu} W^{a\,\mu\nu} - \frac{1}{4} G^e_{\mu\nu} G^{e\,\mu\nu} - \frac{1}{4} G^{K\,e}_{\mu\nu} G^{K\ e\,\mu\nu} \\
\mathscr{L}_{int} &= i \sum_{j,k} \left[(\bar{\psi}^{j|k}_u , \bar{\psi}^{j|k}_d) \gamma_\mu \mathscr{D}^\mu_k \begin{pmatrix} \psi^{j|k}_u \\ \psi^{j|k}_d \end{pmatrix} + (\bar{\hat{\psi}}^{j|k}_u , \bar{\hat{\psi}}^{j|k}_d) \gamma_\mu \hat{\mathscr{D}}^\mu_k \begin{pmatrix} \hat{\psi}^{j|k}_u \\ \hat{\psi}^{j|k}_d \end{pmatrix} \right]
\end{aligned}
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\psi^{j|k}_u &= (N^j_L, U^j_L, N^K_R \delta^{3j}, U^K_R \delta^{3j}) \\
\psi^{j|k}_d &= (E^j_L, D^j_L, E^K_R \delta^{3j}, D^K_R \delta^{3j}) \\
\hat{\psi}^{j|k}_u &= (N^j_R, U^j_R, N^K_L \delta^{3j}, U^K_L \delta^{3j}) \\
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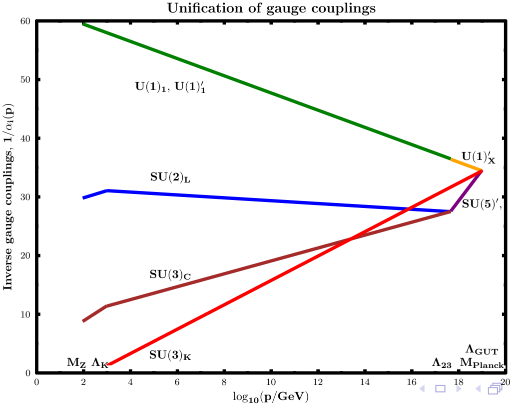
Gauged mirror generation symmetry: strong at 1 TeV $\sim M_{\mathrm{Planck}} \exp\left(-1/\alpha_{GUT}\right)$: G.T., *EJTP* **10** (2013) 135.

$$E_8 \times E_8'(M_{Planck}) \to SU(3)_C \times SU(2)_L \times U(1)_1 \times SU(3)_K(1\ \mathrm{TeV}) \to$$

$\to$ Standard Model



The (parity-odd) spectrum

- Color singlets:
  $\pi^{K\ 2\ 0}$ and $\pi^{K\ 2\ \pm}$, "eaten" by Z^0, $W^\pm$

  $$\pi^{K\ 1\ 0},\quad \pi^{K\ 1\ \pm},\quad \pi^{K\ 1\ 0\prime},\ \eta^K\quad \mathrm{(spin-0)}$$
  $$\rho^{K\ 1,2\ 0},\ \rho^{K\ 1,2\ \pm},\ \rho^{K\ 0\prime},\quad \omega^K\quad \mathrm{(spin-1)}$$

- Color triplets (leptoquarks):
  $$\pi_3^{K\ 1,2,2\prime,5},\ \bar{\pi}_3^{K\ 1,2,2\prime,5}\ \mathrm{(spin-0)}$$
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- SM-fermion mass generation:
  consecutive breaking of the
  $SU(3)_K$ katoptron-generation symmetry $\rightarrow$

  Doubling of the mirror-meson spectrum $\rightarrow$
  heavy (group "B") and light (group "A") mirror mesons:

$$r = M_B/M_A \sim \exp\Big(3(C_2(SU(3)_K) - C_2(SU(2)_K))\Big) \sim 5.75$$

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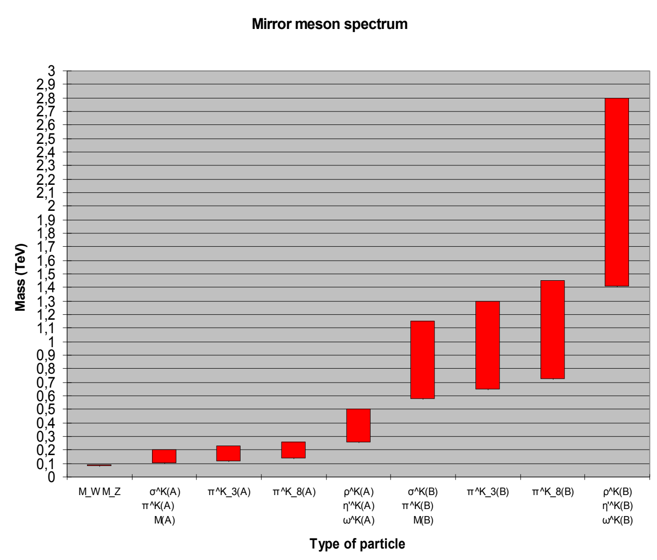
Group A &B mirror-meson mass spectra



Dynamical Masses and the S parameter

$$< \bar{\psi}^{3|3,4}_{u,d}\,\hat{\psi}^{3|3,4}_{u,d} + \text{h.c.} > \approx -\frac{N_i}{4\pi^2}\int dp^2 M_i(p^2)$$

$$m_f = \begin{pmatrix} m_{SM} & m \\ m & M \end{pmatrix}, \text{with } M \equiv \begin{pmatrix} M_A & 0 \\ 0 & M_B \end{pmatrix} \text{ and } m \equiv \begin{pmatrix} m_{AA} & m_{AB} \\ m_{AB} & m_{BB} \end{pmatrix}$$

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

$$S_B \approx 4\pi (v/M_{\rho^K_B})^2 \lesssim 0.122 \text{ for } M_{\rho^K_B} > 2.5 \text{ TeV}$$

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Deviations from SM due to radiative corrections

Importance of heavy fermions:

- top- and bottom-quark left-right asymmetries
- V_{tb} not assuming 3×3 CKM matrix unitarity
- lepton universality (B-meson decays?)

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Most promising processes

- $gg \longrightarrow \pi_{8\ (A)B}^{K\ 0\prime} \longrightarrow (\bar{b}b)\ \bar{t}t$
- $gg \longrightarrow \sigma_{(A)B}^{K\ 0} \longrightarrow (\bar{b}b)\ \bar{t}t,\ \gamma\gamma$
- Acollinear $\bar{f}f'$ jets:

$$gg \longrightarrow \text{direct},\ g,\ \rho_{8\ B}^{K\ 0\prime} \longrightarrow \pi_{8\ B}^{K\ +}\ \pi_{8\ B}^{K\ -} \longrightarrow \bar{b}t + \bar{t}b$$

$$gg \longrightarrow \text{direct},\ g,\ \rho_{8\ B}^{K\ 0\prime} \longrightarrow \pi_{3\ B}^{K\ 5}\ \bar{\pi}_{3\ B}^{K\ 5} \longrightarrow \bar{\tau}\ t + \bar{t}\ \tau$$

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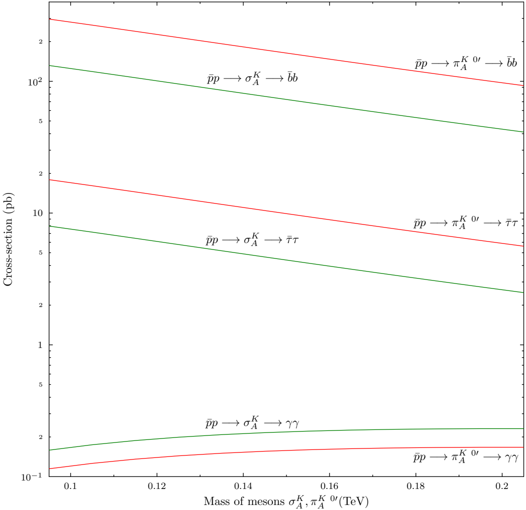
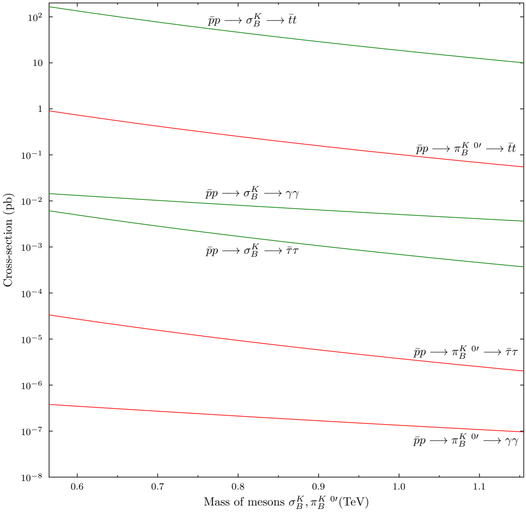
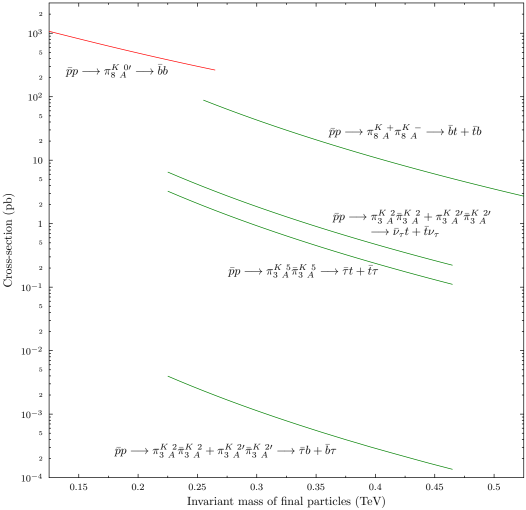
Color-singlet A-mirror-meson processes



Color-singlet B-mirror-meson processes



Color-octet & color-triplet A-mirror-meson decays



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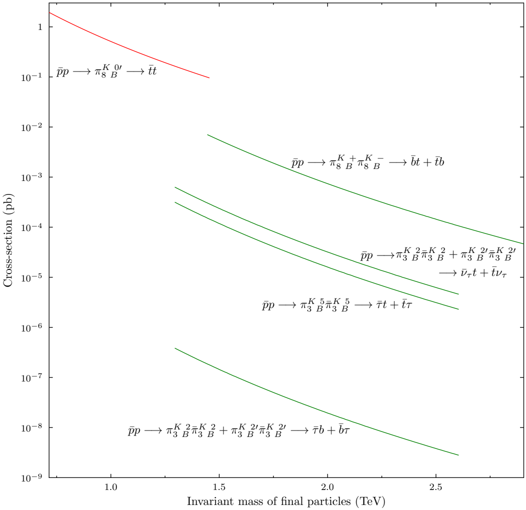

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  involving strongly-interacting mirror fermions (katoptrons)
- Rich mirror-meson phenomenology →
  Holistic approach enabling differentiation of competing models predicting similar signals
- Need for a 3-4 TeV leptonic collider
  due to the large QCD background at the LHC
- Quantum-gravity implications:
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  - Optimal Connectivity Principle→ emergence of $E_8 \times E_8'$

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