Phenomenology of Left-Right Symmetric Models

Luiz Vale Silva, in collaboration w/ S. Descotes-Genon (LPT) and V. Bernard (IPNO)

The Standard Model (SM) theory of particle physics successfully describes a wide variety of phenomena, up to energy scales below ~ 1 TeV. However, some aspects of the theory, though in good agreement with observations, are left unexplained, such as the violation of parity P and charge-conjugation C.

We investigate the possibility of nature being symmetric under parity transformations at high energy scales, what is formalized in a model called Left-Right Model (LRM). Then, as one goes down in energy, the vacuum state of the model assumes a configuration which breaks parity spontaneously.

- g_L, g_R, g' couplings
- $\kappa_R \gg$ EWSB ($\kappa_R \sim$ many TeV)
- $\kappa \equiv \sqrt{\kappa_1^2 + \kappa_2^2 + \kappa_L^2}$ sets EWSB
- Define $\epsilon_{SB} = \kappa/\kappa_R \ll 1$
- Known Gauge Bosons: $\xi, \zeta = \mathcal{O}(\epsilon_{SB}^2)$
  $W^\pm = W_L^\pm + \xi^* W_R^\pm$ and $Z = X + \zeta X'$
- New Gauge Bosons: $M = \mathcal{O}(\kappa_R)$
  $W'^\pm = W_R^\pm - \xi W_L^\pm$ and $Z' = X' - \zeta X$
- 1 light Higgs + $H^0_{1,2,3}$ and $A^0_{1,2}$, $H^\pm_{1,2}$

Spontaneous Symmetry Breaking (SSB) mechanism in the LRM

$$LRM = SU(3)_c \times SU(2)_L \times SU(2)_R \times U(1)'$$

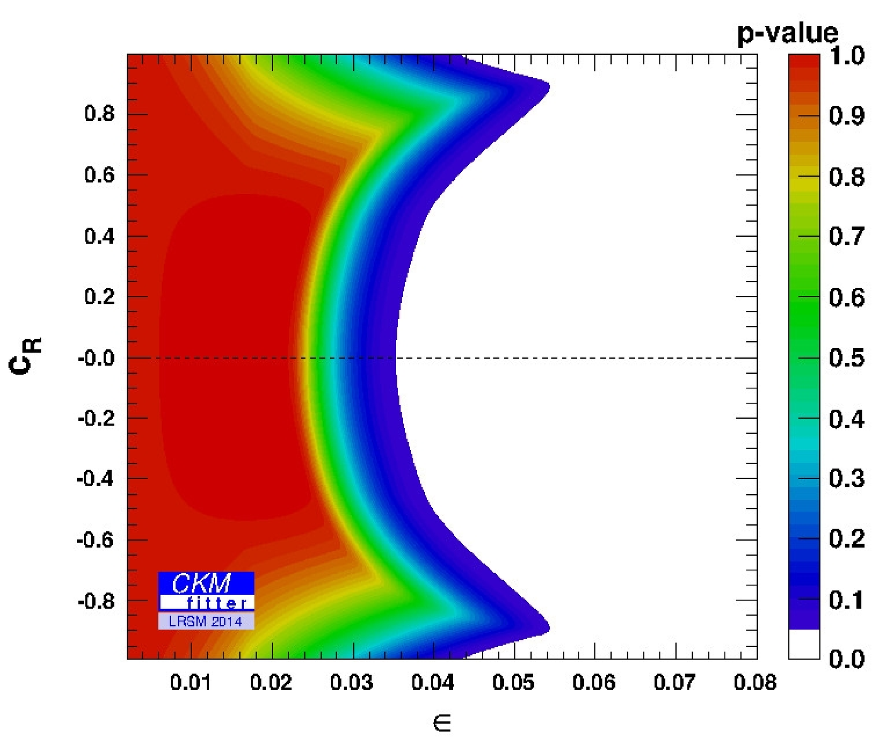
$$\downarrow \langle \chi_R \rangle \to \kappa_R$$

$$SM = SU(3)_c \times SU(2)_L \times U(1)_Y$$

$$\downarrow EWSB : \langle \phi \rangle, \langle \chi_L \rangle \to \kappa_{1,2,L}$$

$$SU(3)_c \times U(1)_{EM}$$

The viability of the model can be tested and its free parameters constrained by the study of different processes: Electro-Weak phenomena, mixing of quark generations, direct searches of new particles, etc.



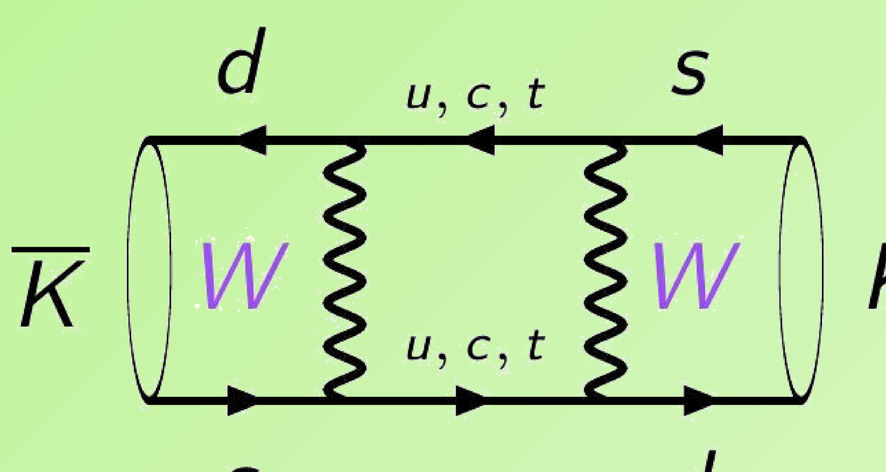
Resulting constraints: in order to reproduce the EWPO, one needs to push the scale of SSB of the LRM beyond ~ 1 TeV. Above, c_R is related to the Left and Right gauge couplings, and ϵ is the ratio of SSB scales

EWPO: We aim at probing the precise way in which the local symmetries in the Left-Right Model (LRM) are spontaneously broken. We employ Electro-Weak Precision Observables (EWPO), a powerful way to test the gauge sector of the Standard Model (SM) and its extensions, i.e. gauge couplings and gauge boson masses. In LRM, the main corrections to processes calculated in the SM come from the mixing of light and heavy gauge bosons.

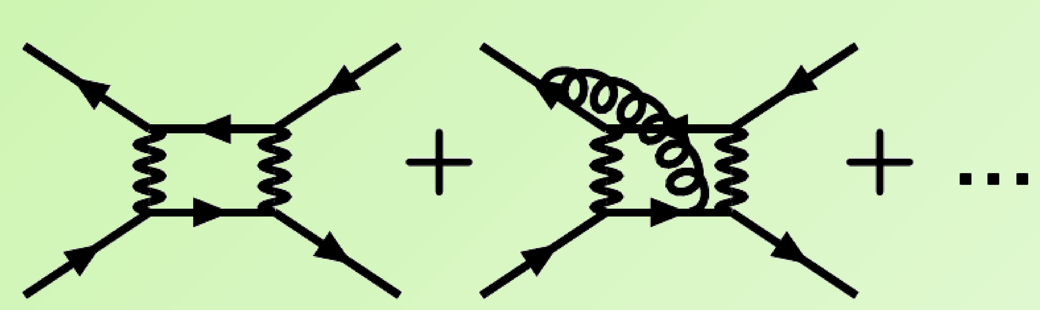
observable	reference	free in fit
m_{top}	[Tevatron, LHC]	yes
m_h	[CMS, ATLAS]	yes
α_s	[PDG] τ-decays, Lattice, DIS, e^+e^-, Z pole	yes
M_Z	[LEP, SLC]	yes
$\Delta\alpha^{(5)}_{had}$	–	yes
Γ_Z, σ^0_{had}, $R_{b,c}$, $R_{e,\mu,\tau}$, $\mathcal{A}_{b,c,\ell}$, $A_{FB}(b,c,\ell)$	[LEP, SLC]	–
$Q_{weak}(Cs)$	[Boulder and Paris groups]	–
$Q_{weak}(Tl)$	[Oxford and Seattle groups]	–
M_W	[Tevatron]	–
Γ_W	[LEP, SLC, Tevatron]	–
$M_{W'}$	[CMS, ATLAS]	c_R, ϵ_{SB}

Extensions of the SM generally introduce new particles. Direct searches for these new resonances imply strong constraints on the scales of a New Physics model.

Meson-mixing: A very different class of constraints comes from processes where the quantum number « flavour » changes, and we focus here on meson-mixing observables.



Main SM contributions



QCD corrections calculated perturbatively

In order to be predictive and match the experimental accuracy, one needs to correct the leading order process by considering corrections coming from gluon exchanges (which are in fact mandatory at low energies). Then, when shifting to LRM, new contributions appear, represented below. In order to precisely constrain new particle masses, similar QCD corrections need to be computed.

QCD corrections are collected into an effective Hamiltonian, following the formalism we now describe.

Factorization short/long distances @ μ

$$\mathcal{H}^{\rm SM} \overset{\rm OPE}{=} \sum_i C_i(\mu)\cdot Q_i(\mu), \quad \mathcal{H}^{\rm SM} \text{ independent of } \mu$$

$C_i(\mu)$, $Q_i(\mu)$ not calculated at the same scale:
$C_i(\mu_{\rm high})$ at high energies, $\langle K|Q_i|\bar{K}\rangle \equiv \langle Q_i(\mu_{\rm had})\rangle$ on the Lattice

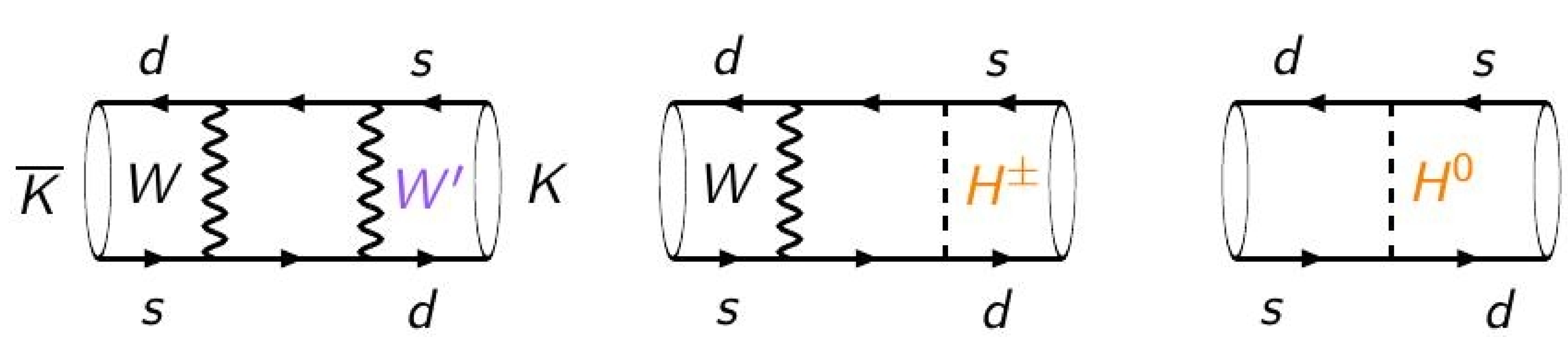
$$\frac{d}{d\log\mu}\begin{pmatrix} C_1 \\ C_2 \\ \vdots \end{pmatrix} \overset{\rm RGE}{=} \gamma^{\rm T}\cdot\begin{pmatrix} C_1 \\ C_2 \\ \vdots \end{pmatrix}$$

γ: anom. dim. matrix
(RGE = ren. group eqs.)

$$C(\mu_{\rm high})$$
$$\downarrow \text{running}$$
$$C(\mu_{\rm low}) \overset{\rm LL}{=} \left(\frac{\alpha_s(\mu_{\rm low})}{\alpha_s(\mu_{\rm high})}\right)^\gamma C(\mu_{\rm high})$$
$$(\mu_{\rm had} \equiv \mu_{\rm low})$$

- $\left(\frac{\alpha_s(\mu_{\rm low})}{\alpha_s(\mu_{\rm high})}\right)^\gamma \overset{\rm LL}{=} \left[\sum_{n=0}^\infty \left(\beta_0 \frac{\alpha_s(\mu_{\rm low})}{2\pi}\log\left(\frac{\mu_{\rm low}}{\mu_{\rm high}}\right)\right)^n\right]^\gamma$

  large $\alpha_s \cdot \log(\mu_{\rm low}/\mu_{\rm high})$ resummed to all orders in α_s by RGE



Future perspectives: A more solid and reliable picture of the possible LRM structure will come once we consider a global fit including EWPO, meson-mixing observables and other flavour processes altogether. They are combined efficiently using the CKMfitter package for the statistical analysis.

Contact :
luiz.vale@th.u-psud.fr

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