Strong electroweak symmetry breaking

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A.Falkowski, C.Grojean, AK, S.Pokorski, A.Weiler
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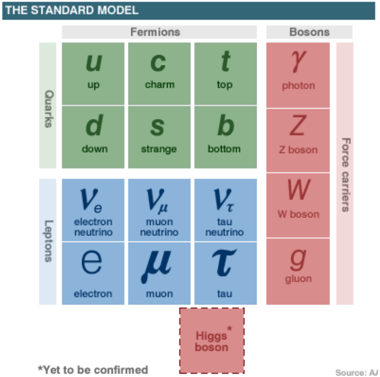
Rencontres de Moriond EW 2012

Standard Model



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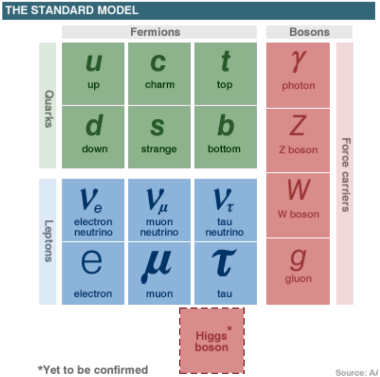

Electroweak symmetry breaking sector?

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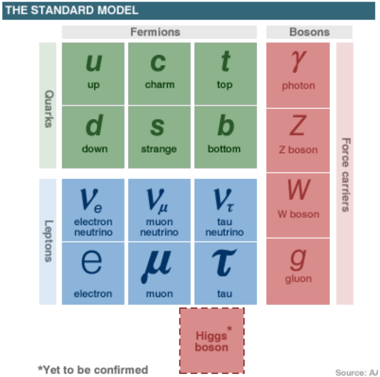

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- three Goldstone bosons $\to$ $W_L,\ Z_L$

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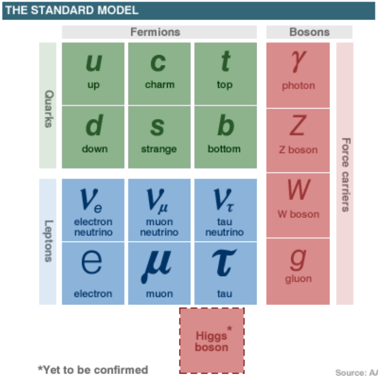

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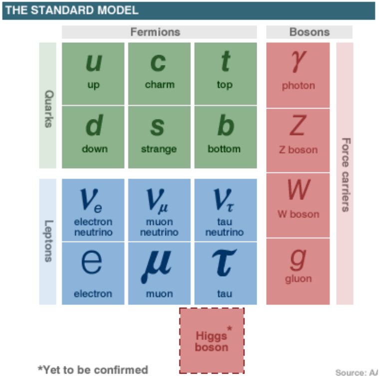

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- unitarization of WW scattering amplitudes

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EW symmetry breaking sector $\supset$ scalar doublet $H = \begin{pmatrix} H^+ \\ H^0 \end{pmatrix}$

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$$\phi \;\rightarrow\; g_L \phi g_R^\dagger$$

$$\phi = \begin{pmatrix} H^0 & H^+ \\ -H^- & H^0 \end{pmatrix} = e^{i\frac{\pi^a T^a}{v}} \begin{pmatrix} v+h & 0 \\ 0 & v+h \end{pmatrix}$$

$$\mathcal{L}_{SB} = \frac{1}{2} tr\left[D_\mu \phi^\dagger D_\mu \phi\right] - \frac{1}{2}\lambda \left(\frac{1}{2} Tr[\phi^\dagger \phi] - v^2\right)^2$$

WW scattering and perturbative unitarity

scattering amplitudes for longitudinally polarized W and Z (using the Goldstone boson equivalence theorem)

with the Scalar exchange

$$M(s,t,u) = \frac{s}{v^2} - \frac{s}{v^2}\frac{s}{s-m_h^2}$$

in the SM without the Scalar exchange

$$M(s,t,u) = \frac{s}{v^2}$$

perturbative unitarity lost $\sim 1.5\,TeV$

EW breaking by new strong interactions

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Can we provide an effective low-energy perturbative description?

- CHPT

(QCD: approximate $SU(2)_L \times SU(2)_R \to SU(2)_V \leftrightarrow$ pions)

What is the nature of the Goldstone bosons which provide $W_L^{\pm},\ Z_L$?

- π^a are composite fields

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spin-1 resonances - distinctive feature of strong electroweak symmetry breaking models

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$\rightarrow$ perfect laboratory for studying spin-1 resonances

Introducing spin-1 resonances

$$U \overset{SU(2)_L \times SU(2)_R}{\longrightarrow} g_L U g_R^\dagger, \qquad U = e^{i\sigma\cdot\pi(x)/v}$$

$$\mathcal{L}^{(2)}_{CHPT} = \frac{v^2}{4}\mathrm{Tr}\left\{D_\mu U^\dagger D^\mu U\right\}, \quad D_\mu U = \partial_\mu U - i\frac{g'}{2}B_\mu\sigma^3 U + i\frac{g}{2}U\sigma^a W^a_\mu$$

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spin-1 resonances $\leftrightarrow$ gauge bosons of a "hidden" local symmetry $SU(2)_h$

$$U = \xi_L \xi_R^\dagger, \qquad \xi_{L,R} \to g_{L,R}\xi_{L,R}h^\dagger$$

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Goldstone bosons

$$\xi_L = e^{\ i\pi^a\sigma^a/2}, \qquad \xi_R = e^{-i\pi^a\sigma^a/2}$$

Building the effective Lagrangian

building blocks

objects transforming as adjoints of $SU(2)_h$ with well defined $R \leftrightarrow L$ parity

$$V_\mu^\pm = -i\left(\xi_L^\dagger D_\mu \xi_L \pm \xi_R^\dagger D_\mu \xi_R\right)$$

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most general (parity preserving) Lagrangian
at the leading order in the derivative expansion

$$\mathcal{L} \supset -\frac{v^2}{4}\mathrm{Tr}\left\{\alpha V_\mu^+ V_\mu^+ + V_\mu^- V_\mu^-\right\} + \mathcal{L}_{kinetic}$$

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technicolor $\leftrightarrow$ $\alpha \approx 2$
deconstruction $\leftrightarrow$ $\alpha = 1$

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Study perturbative unitarity and check:

- up to which energy is this minimal setup self-consistent?
- what is the allowed resonance mass and its couplings?

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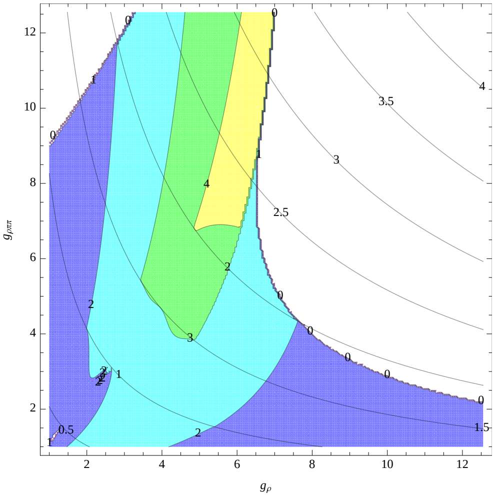
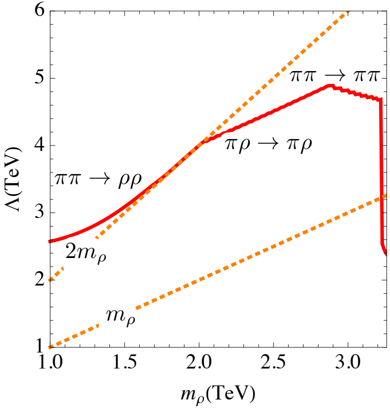
Collider phenomenology of such a minimal setup?

Perturbative unitarity region



$$g_{\rho\pi\pi} = \frac{\alpha}{2} g_\rho, \qquad m_\rho^2 = 2 g_{\rho\pi\pi} g_\rho v^2$$

Maximal cutoff



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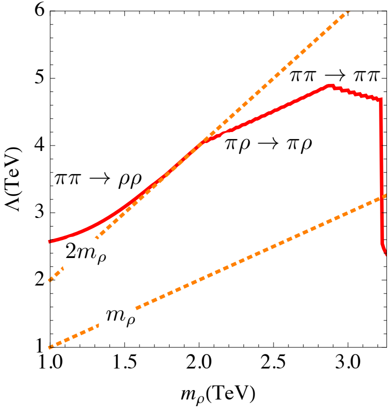

- the upper bound on the resonance mass ∼3 TeV
- light resonances not so efficient in unitarizing
- a crucial role played by $\pi\pi \to \rho\rho$

Phenomenology

Find couplings of resonances to matter fields
$\rightarrow$ assume that the SM quarks and leptons are fundamental, couplings to resonances only via mixing of the latter with the SM gauge bosons

$$\begin{aligned} W_\mu^\pm &\rightarrow W_\mu^\pm - \frac{g}{2g_\rho}\rho_\mu^\pm \\ Z_\mu &\rightarrow Z_\mu - \frac{g^2 - g'^2}{2g_\rho\sqrt{g^2 + g'^2}}\rho_\mu^0 \\ A_\mu &\rightarrow A_\mu - \frac{e}{2g_\rho}\rho_\mu^0 \end{aligned} \tag{1}$$

Phenomenology

Decays

- $\mathrm{Br}(\rho^{\pm} \to e^{\pm}\nu) \approx 2\mathrm{Br}(\rho^{0} \to e^{+}e^{-}) \approx \frac{16 m_W^4}{m_\rho^4}$ which is strongly suppressed in the interesting parameter space (for $m_\rho \gg 2m_W$)

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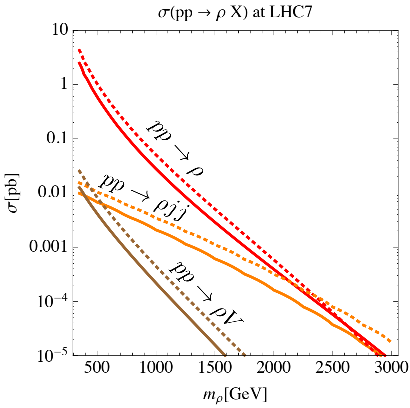
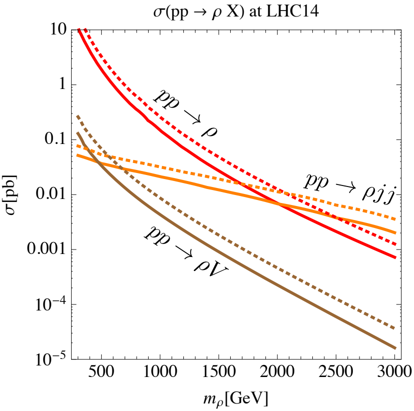
Production

- Drell-Yan ($q\bar{q} \to \rho$) $\rightsquigarrow$ $pp \to \rho$
- Vector boson fusion ($VV \to \rho$) $\rightsquigarrow$ $pp \to \rho jj$
- $\rho-$strahlung ($V \to \rho V$) $\rightsquigarrow$ $pp \to \rho V$

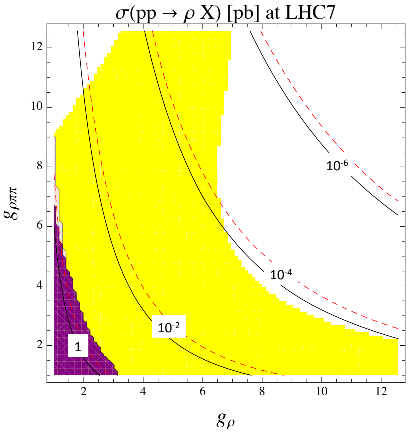
Collider phenomenology

Cross section for the production of a single neutral (solid) and charged (dashed) resonance at the LHC





Direct searches



Contours of the total cross section for the inclusive production of ρ^0, $\rho^\pm$ (solid, dashed) at the LHC; (purple) - CMS search for WZ resonant production exclusions.

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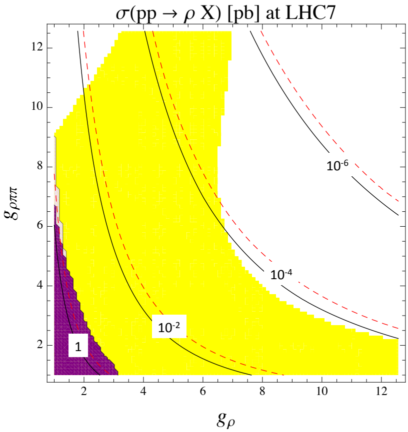

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- if the resonances are heavy and strongly coupled they might escape any direct detection at the the LHC

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- $SO(5)/SO(4) \;\rightarrow\; 4\pi \;\rightarrow\; H$

Agashe, Contino, Pomarol '04

- $SO(6)/SO(5) \;\rightarrow\; 5\pi \;\rightarrow\; H, a$
  $SU(4)/Sp(4,C) \;\rightarrow\; 5\pi \;\rightarrow\; H, s$

Gripaios, Pomarol, Riva, Serra '09
Chacko, Batra '08

- $SO(6)/SO(4)xSO(2) \;\rightarrow\; 8\pi \;\rightarrow\; H_1 + H_2$

Mrazek, Pomarol, Rattazzi, Serra, Wulzer '11

$$\mathcal{L} \supset \frac{v^2}{4}\left(1 + 2a\frac{h}{v} + b\frac{h^2}{v^2} + \ldots\right) \mathrm{Tr}\left(D_\mu U^\dagger D^\mu U\right)$$

Conclusions

- we have studied the physics of spin-1 resonances connected with strong EW symmetry breaking in a simple, general effective framework built using tools known from QCD (CHPT, ”hidden gauge”)
- considering perturbative unitarity in a simple, general setup with spin-1 resonances constrains the allowed resonance mass and couplings
- a crucial role is played by inelastic scattering effects - a heavy ρ meson (2.5-3) TeV is more efficient in prolonging perturbative unitarity than a light resonance ($\sim$2 TeV)
- if the resonances are heavy ($m_\rho \geq 2 TeV$) and strongly coupled they might escape any direct detection at the LHC
- it is interesting to use such effective frameworks to study strong EW symmetry breaking with a light composite scalar resonance