Improving LHC searches for strong EW symmetry breaking resonances

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Moriond EW, 18.03.15

Composite Higgs models

electroweak symmetry breaking by new strong dynamics

composite scalar - PNG boson

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

  Minimal Composite Higgs Model
  Agashe, Contino, Pomarol '04

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

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

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

  Minimal Composite Two Higgs Doublets
  Mrazek, Pomarol, Rattazzi, Serra, Wulzer '11

Minimal composite Higgs model

Agashe, Contino, Pomarol '04

$$SO(5) \to SO(4) \sim SU(2)_L \times SU(2)_R$$

GB transform as a **4** of $SO(4)$, $(2,2)$ of $SU(2)_L \times SU(2)_R$

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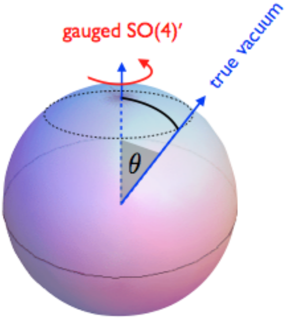

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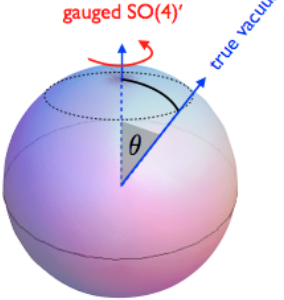

Higgs potential from $SO(5)$ breaking effects

- gauge interactions
- Yukawa interactions

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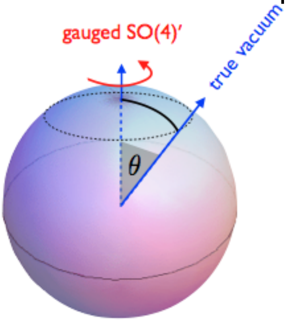

Higgs potential from $SO(5)$ breaking effects

- gauge interactions
- Yukawa interactions

$\to$ naturalness requires top partners $\lesssim 1\,\mathrm{TeV}$

Signatures of strong EW symmetry breaking

- modification of H couplings to W and Z bosons

  and to fermions

  $\rightarrow$ Higgs physics

  $\rightarrow$ electroweak precision data (S, T)

- vector resonances

- fermion resonances

- flavor physics

Effective description of spin-1 resonances

global symmetry breaking $\mathcal{G} \to \mathcal{H}$

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Spin-1 resonances

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$\to$ modify the symmetry breaking pattern

$$\mathcal{G} \times \mathcal{H}_{local} \to \mathcal{H}$$

ρ_μ gauge bosons of $\mathcal{H}_{local}$ $\to$ 'vector' resonances

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3 free parameters

$$m_\rho,\ g_\rho,\ \xi = \frac{v_{EW}^2}{f^2}$$

g_ρ - gauge coupling of $\mathcal{H}_{local}$

Production and decays of ρ_L

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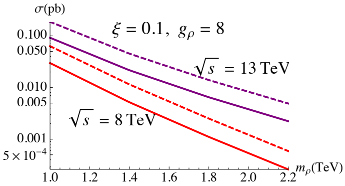
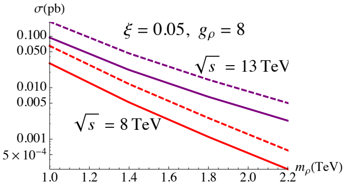
- production dominated by Drell-Yan $q\bar{q} \to \rho$





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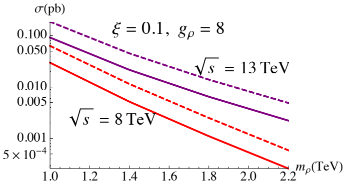
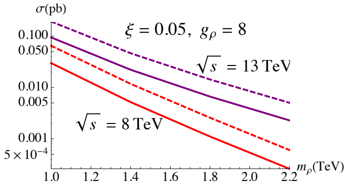
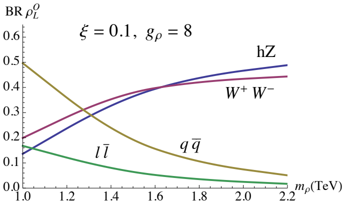
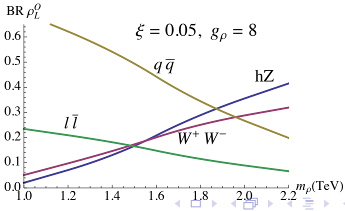




- decays mainly to hZ and WW, but ff non-negligible





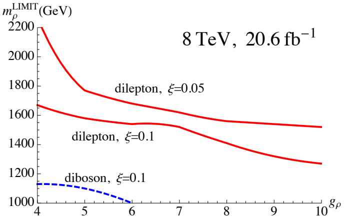
Direct searches

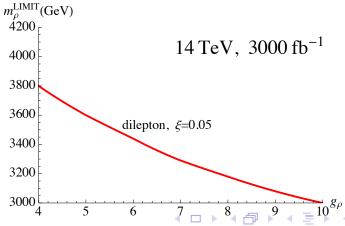
$$\Gamma\left(\rho^0 \to W^+W^-\right) \approx \Gamma\left(\rho^0 \to Zh\right) \approx \frac{m_\rho^5 \xi^2}{192\pi g_\rho^2 v^4}.$$

$$\Gamma\left(\rho^0 \to e^+e^-\right) \approx \Gamma\left(\rho^0 \to \mu^+\mu^-\right) \approx \frac{g^4 m_\rho \left(1+\sqrt{1-\xi}\right)^2}{96\ 4\pi g_\rho^2}$$

$$\Gamma\left(\rho^0 \to q_i \bar{q}_i\right) \approx \frac{g^4 m_\rho \left(1+\sqrt{1-\xi}\right)^2}{32\ 4\pi g_\rho^2}$$

present strongest exclusions - CMS search for ll resonances

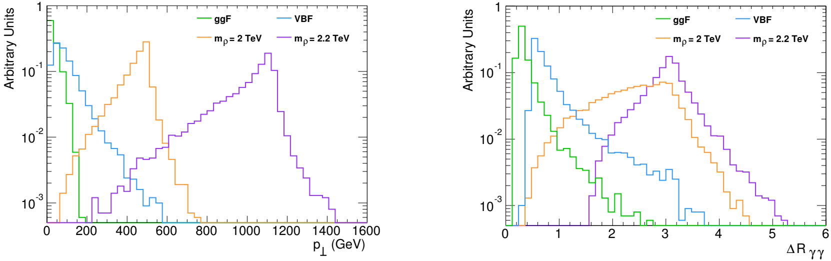




Searching for $\rho \to Vh$

M.Hoffmann, AK, R.Nikolaidou, S.Paganis
Eur.Phys.J. C74 (2014) 11, 3181 (arXiv:1407.8000)

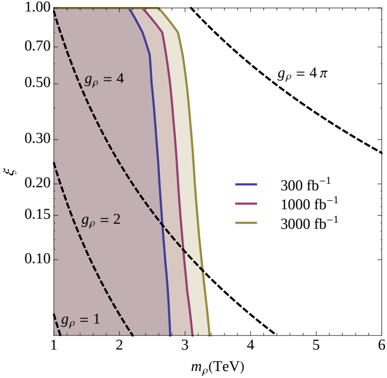
$h \to \gamma\gamma$, $h \to ZZ^{(*)} \to 4\ell$, where $\ell = e, \mu$, $V \to jj$



suppress the SM Higgs background by $p_\perp \geq 550$ GeV cut
$\to$ probing $m_\rho \sim 3\,\mathrm{TeV}$ in the next LHC run

Searching for $\rho \rightarrow Vh$

here assumed $m_\rho = g_\rho f = g_\rho v_{EW}/\sqrt{\xi}$



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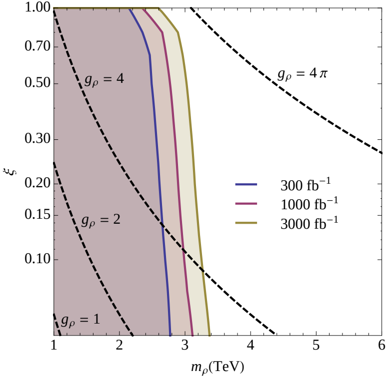

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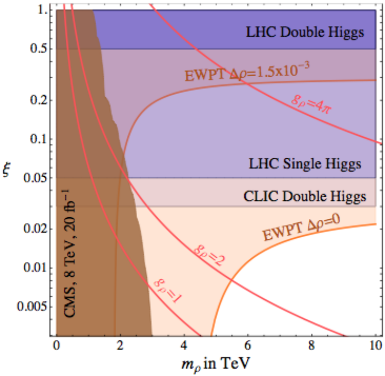

Contino, Grojean, Pappadopulo, Rattazzi, Thamm

Impact of composite fermions

spin-1 resonances may couple directly to fermion resonances

$$-i\bar{\psi}g_\rho\gamma^\mu T^a\rho^a_\mu\psi$$

partial compositeness $\rightarrow$ mass mixing with SM fermions

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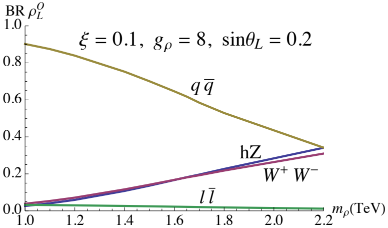
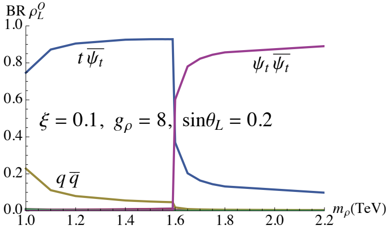
$$-i\bar{\psi} g_\rho \gamma^\mu T^a \rho^a_\mu \psi$$

partial compositeness → mass mixing with SM fermions → modified BR of spin-1 resonances

- 3 gen. resonances only,
  $m_T \gtrsim 2\,\mathrm{TeV}$ (left) and $m_T \sim 0.8\,\mathrm{TeV}$ (right)





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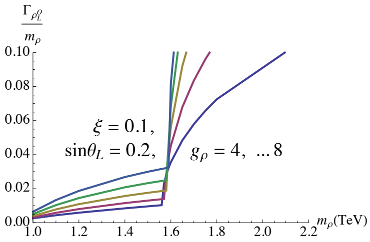

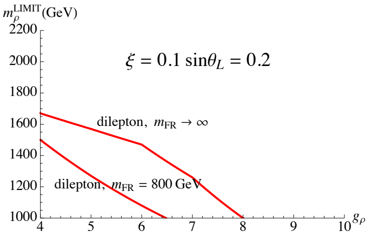

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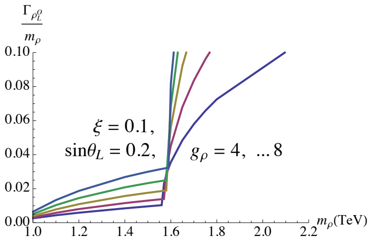
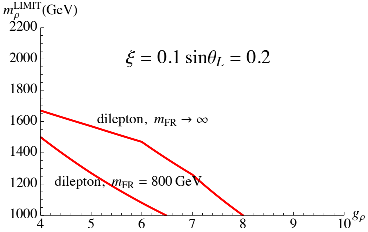
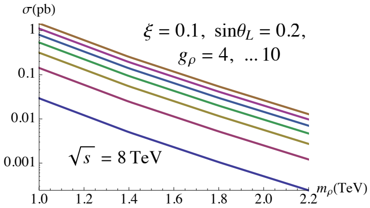
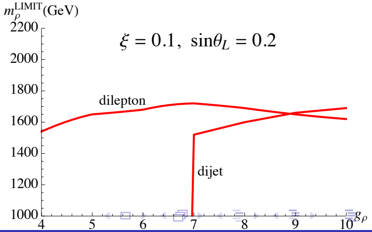




if we allow for significant partial compositeness of light quarks





Conclusions

- strong electroweak symmetry breaking can be tested at the LHC in many ways - Higgs properties, flavor constraints, direct searches for fermion and vector resonances
- LHC is already probing the parameter space of vector resonances allowed by electroweak precision data
- $\rho \to Vh$ (with boosted Higgs) is a promising channel for the search for heavy vector resonances
- in order to improve searches for resonances related to strong electroweak symmetry breaking a better understanding of possible interactions between vector and fermion resonances is needed

Backup - CCWZ description of spin-1 resonances

PNG bosons $\Pi(x) = \Pi^{\hat{a}}(x)\, T^{\hat{a}}$ of $\mathcal{G} \to \mathcal{H}$ can be described by $U(\Pi) = e^{i\Pi(x)/f}$ transforming as

$$U(\Pi) \to g\, U(\Pi)\;\; h^{\dagger}(\Pi, g)\,, \qquad g \in \mathcal{G},\;\; h \in \mathcal{H}.$$

leading order effective Lagrangian term describing pion self-interactions

$$\mathcal{L}^{\Pi} = \frac{f^2}{4} \mathrm{Tr}\{d_\mu d^\mu\}$$

where d_μ is defined by

$$-iU^\dagger D_\mu U = d_\mu^{\hat{a}} T^{\hat{a}} + E_\mu^a T^a = d^a + E^a$$

and $T^{\hat{a}}$, T^a are the broken and unbroken generators of $\mathcal{G}$. The vector meson

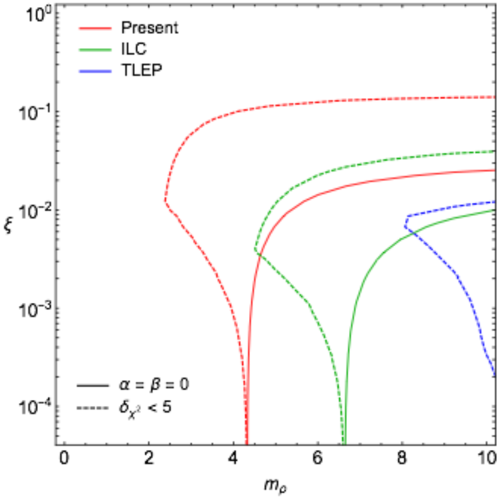
$$(T^a \rho_\mu^a) \;\to\; h\,(T^a \rho_\mu^a)\; h^\dagger - \frac{i}{g_\rho} h \partial_\mu h^\dagger\,, \quad h \in \mathcal{H},$$

(where in our case T^a are $SU(2)_L$ generators) has the general leading-order effective Lagrangian

$$\mathcal{L}^{\rho} = -\frac{1}{4g_\rho^2} \rho_{\mu\nu}^a \rho^{a\,\mu\nu} + \frac{m_\rho^2}{2g_\rho^2}\left(\rho_\mu^a - E_\mu^a\right)^2 .$$

The connection term E_μ^a introduces interactions of ρ mesons with PNG bosons and electroweak bosons.

Backup - electroweak precision constraints



from 1502.01701 by A.Thamm, R.Torre, A.Wulzer

Backup - $\rho \rightarrow Vh$ cut flow

- $h \rightarrow \gamma\gamma$ signal selected by requiring two hard photons with E_T of the leading (subleading) photon $\geq$ 40 (30) GeV
- events from $h \rightarrow ZZ^* \rightarrow 4l$ selected by requiring two pairs of oppositely charged, same-flavor leptons; the three leptons in the quadruplet with the largest transverse momentum must satisfy $p_\perp \geq 20, 15, 10$ GeV
- muons, electrons and photons must respectively satisfy $|\eta| < 2.7, 2.47, 2.37$
- the transverse momentum of the Higgs system $p_\perp \geq 550$ GeV