Composite or elementary?
Probing the nature of the Higgs

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with S.Pokorski, C.Grojean, A.Weiler

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Rencontres de Moriond, 14.03.13

QCD inspired

QCD Lagrangian in the limit $m_u,\ m_d \to 0$

$$SU(2)_L \times SU(2)_R \to SU(2)_V$$

$\sqrt{s} \ll \Lambda_{QCD}$ pions interact weakly $\to$ effective description

$$U \to g_L U g_R^\dagger, \quad U = e^{i\pi\sigma^a/f_\pi}, \quad \mathcal{L}^{(2)} = \frac{f_\pi^2}{4}\mathrm{Tr}\left\{D^\mu U^\dagger D_\mu U\right\}$$

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SM Higgs sector

$$\mathcal{G} = SU(2)_L \times SU(2)_R \quad \to \quad \mathcal{H} = SU(2)_C$$

$$\phi = \begin{pmatrix} H^0 & H^+ \\ -H^- & H^0 \end{pmatrix}, \quad \phi \to g_L \phi g_R^\dagger$$

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EW symmetry broken $\quad \phi = (v + h(x))\, e^{i\frac{\pi^a(x)\sigma^a}{v}} = (v + h(x))\, U$

$$\mathrm{Tr}\left\{D_\mu \phi^\dagger D_\mu \phi\right\} = \frac{1}{2}\partial^\mu h \partial_\mu h + \frac{(v+h)^2}{4}\mathrm{Tr}\left\{D^\mu U^\dagger D_\mu U\right\}$$

Strong electroweak symmetry breaking

electroweak symmetry broken by new strong interactions

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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

Signatures of composite Higgs

- modified Higgs couplings

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$$a = \sqrt{1-\xi}, \qquad b = 1 - 2\xi.$$

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$\to$ small values of ξ preferred, $\xi \lesssim 0.3$

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indirect (electroweak precision, flavor) and direct effects

- spin-1/2 resonances
- **spin-1 resonances**

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$\rightarrow$ analogue of ρ of QCD
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Guideline: QCD

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

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$\to$ modify the symmetry breaking pattern

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

- SM electroweak $SU(2)_L \times U(1)_Y$ group sits in $\mathcal{G}$
- gauge bosons of $\mathcal{H}_{local}$ $\to$ 'vector' resonances

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$$S \;\to\; g\, S\, h^\dagger, \qquad g \in \mathcal{G},\ h \in \mathcal{H}_{local}, \quad \langle S \rangle = \mathbf{1}.$$

$$\mathcal{L} \ni v_1^2 \mathrm{Tr}\left\{ D_\mu S D^\mu S^\dagger \right\}$$

- 'vector' resonances most relevant for phenomenology

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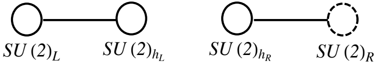

- 3 free parameters: $\xi,\ g_\rho,\ g_{\rho\pi\pi}$

$$g_{\rho\pi\pi}\epsilon^{abc}\pi^a\partial_\mu\pi^b\rho^c_\mu - g_\rho\epsilon^{abc}\partial_\mu\rho^a_\nu\rho^b_\mu\rho^c_\nu$$

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\begin{aligned}
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assumption: couplings of $\tilde{\rho}$ eigenstates with SM fermions arise only via their admixture in SM $W^\pm_\mu, Z_\mu$ and A_μ

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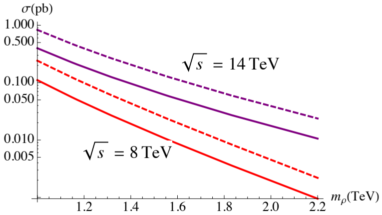
- coupling of ρ to two fermions enhanced for small ξ
- coupling of ρ to two SM gauge bosons suppressed

$$g_{\rho\pi\pi} = \xi\frac{m_\rho^2}{2g_\rho v^2} = \frac{m_\rho^2}{2g_\rho f_\pi^2}.$$

Production and decays

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

for a specific value of $\xi = 0.2$ and $g_\rho = 4$



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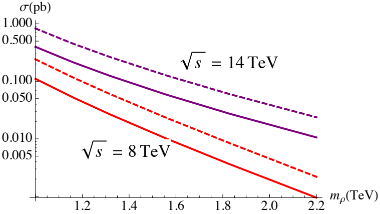

- decays mainly to hZ and WW, but ll non-negligible

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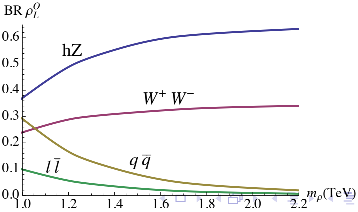
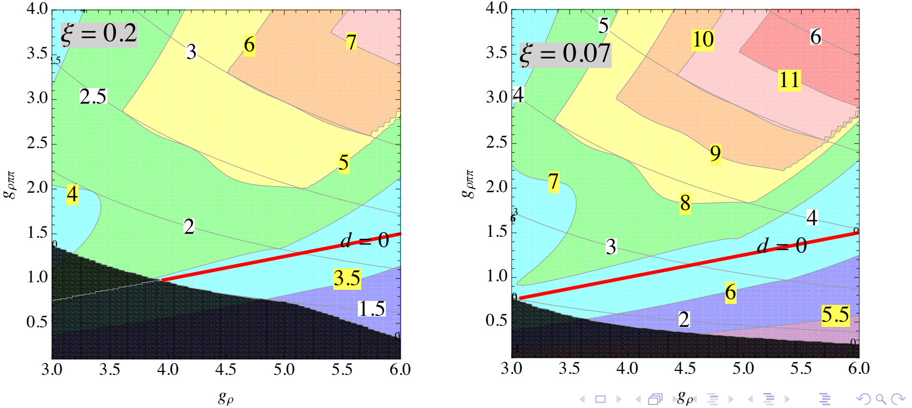
$\Gamma(\rho \rightarrow WW) \sim m_\rho g^2_{\rho\pi\pi}$



Direct searches

most sensitive: CMS search for dilepton resonances

$$m_\rho^2 \approx \frac{2 g_\rho g_{\rho\pi\pi} v^2}{\xi}$$



Conclusions

- signatures of composite Higgs - modified Higgs couplings, effects of resonances
- general effective framework for spin-1 resonances $\rightarrow$ phenomenology
- at small ξ - the spin-1 resonance coupling to two SM gauge bosons is suppressed, the coupling to two fermions is enhanced
- resonances mainly Drell-Yan produced
- exclusion limits from searches for dilepton resonances, diboson resonances, dijet mass spectra, ...
- the LHC is already probing the parameter space of spin-1 resonances allowed by electroweak precision tests

Perturbative unitarity constraints

without spin-1 resonances $\mathcal{M}^0_{WW\to WW}(s) \sim \frac{1}{16\pi}\frac{\xi s}{v^2} = \frac{1}{16\pi}\frac{s}{f_\pi^2}$

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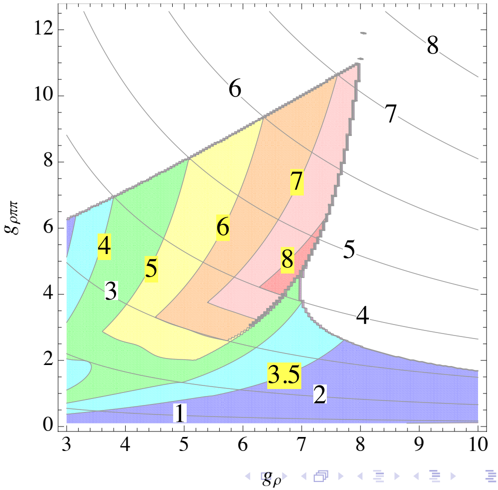
$\to$ perturbative unitarity violation at $\Lambda \sim 1.3\ \mathrm{TeV}/\sqrt{\xi}$

$\xi = 0.2$

add ρ_L and ρ_R resonances, inelastic channels included

$$m_\rho^2 \approx \frac{2 g_\rho g_{\rho\pi\pi} v^2}{\xi}$$



Comparison with indirect constraints

most constraining: prediction for $\hat{S} = \frac{g^2}{16\pi} S$
assume: saturation of Weinberg sum rules

$\xi = 0.2$ $\xi = 0.07$