Holography and DEWSB at the LHC

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+ work in progress

What we know:

- Strong interactions are difficult!
- Rescaled QCD models are ruled out:

$$\begin{aligned} f_\pi &\rightarrow v \\ \pi_a &\rightarrow W_L, Z_L \\ \rho, a_1 &\rightarrow \rho_T, a_T \end{aligned}$$

S parameter:

$$S > 0, \mathcal{O}(1)$$

Peskin-Takeuchi'90

- EW scale strong interactions must be very different from QCD -- But then how do we calculate?
- Many attempts have been made...

What's been done:

Very few collider studies!

- 4D:

  Walking Technicolor (Lane)
  Topcolor (Hill)
  Low-Scale TC (LSTC) (Lane)
  (D)BESS (Casalbuoni et al)
  Low-N TC (Sannino)
  Deconstructed Higgsless (Chivukula)
  ...

- 5D:

  Higgsless (Csaki et al)
  Composite Higgs (Pomarol et al)
  ...

Full Collider Study

Parton Level

Common feature: TeV scale spin-1 resonances (ρ_T, W_{KK})

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More Comprehensive Collider studies

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Moving beyond Models: Proposal

- Most general $\mathcal{L}(\mathrm{SM}\ +\ \mathrm{spin}-1)$ has $\mathcal{O}(100)$ parameters

  → way too many for practical pheno!

  Need an organizing principle

- Start by extending holographic techniques; Can we expose new + distinct features?

- NOT a new model, RATHER an organizing scheme

- Implement this scheme into matrix-element generator

  No models currently implemented!

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Short answer: Yes

- NOT a new model, RATHER an organizing scheme
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Higgsless Basics:

- AdS/CFT inspired 5D version of strong DEWSB

- 5D interval $z \in (\ell_0, \ell_1)$; containing
  $SU(2)_L \otimes SU(2)_R$ gauge fields.

- Bulk geometry usually: $\frac{\ell_0^2}{z^2}(\eta_{\mu\nu} dx^\mu dx^\nu - dz^2)$

- BC break EWS $\longrightarrow$ KK tower of states;
  zero modes are $\gamma, W^\pm, Z^0$
  +Vector, Axial resonances (not quite!): $W_n^\pm, Z_n$

- Resonance couplings: $g_{ABC} \propto \int_{\ell_0}^{\ell_1} dz \frac{\ell_0}{z} \phi_A(z) \phi_B(z) \phi_C(z)$

Higgsless cont.

- small $g_5 \longleftrightarrow$ large N_{TC}
- Spectrum: tower of narrow, weakly interacting resonances (large N_{TC})
  - → large coupling to W_L, Z_L comes from plugging in polarizations
  - → exchange of many resonances delays unitarity violation
- BUT, 5D+bifundamental leads to QCD-like spectrum

  $S > 0, \ \mathcal{O}(1)$; Small perturbations don't help

(Agashe et al '07)

Models can be made viable at the expense of $g_{ffV} \cong 0$ ⇒ Limited Phenomenology

Our scheme: Modifying Holography

- How can we extend the Holographic framework to incorporate new features?
- Effective warp factors:

$$\mathcal{L} = -\frac{1}{2g_5^2}\int dx\ \omega_V(z) F_{V,NM}F_V^{NM} + \omega_A(z) F_{A,MN}F_A^{MN}$$

$$\omega_{V,A}(z) = \frac{\ell_0}{z}\exp\left(o_4^{V,A}\left(\frac{z}{\ell_1}\right)^4\right) \qquad o_V, o_A < 0$$

(Hirn, Sanz '06,'07)

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(Hirn, Sanz '06,'07)

Positive definite

Deformed in IR - power of z unimportant

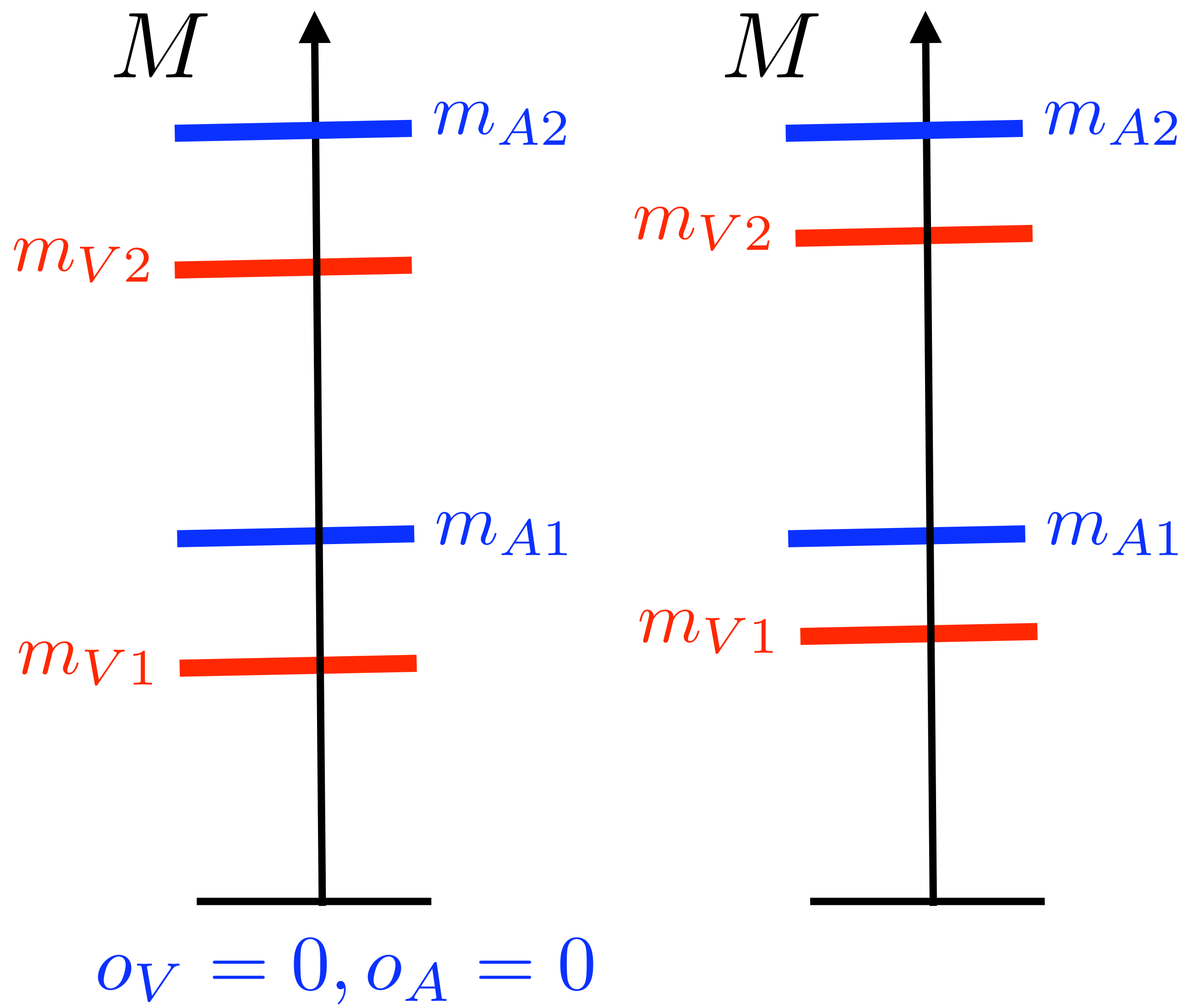
Acts like condensate

$$\Pi_{V,A} \sim \frac{o_{V,A}}{(Q\ell_1)^4}$$

Why this deformation?

$$\omega_{V,A} = \frac{\ell_0}{z} e^{o_{V,A} z^4/\ell_1^4}$$

- Allows us to vary the length of the dimension the vector feels relative to the axial



Dialing o_V for fixed o_A :

Remember:
Eigenstates $W^{\pm}_{1,2}, Z^0_{1,2}$ are a mixture of V, A

$$|\psi_X(z)\rangle = |V_X(z), A_X(z)\rangle$$

- Added only 2 new parameters, no new fields
- Couplings $g_{W_1 W Z}$, etc. will also vary with ℓ_1, o_V, o_A

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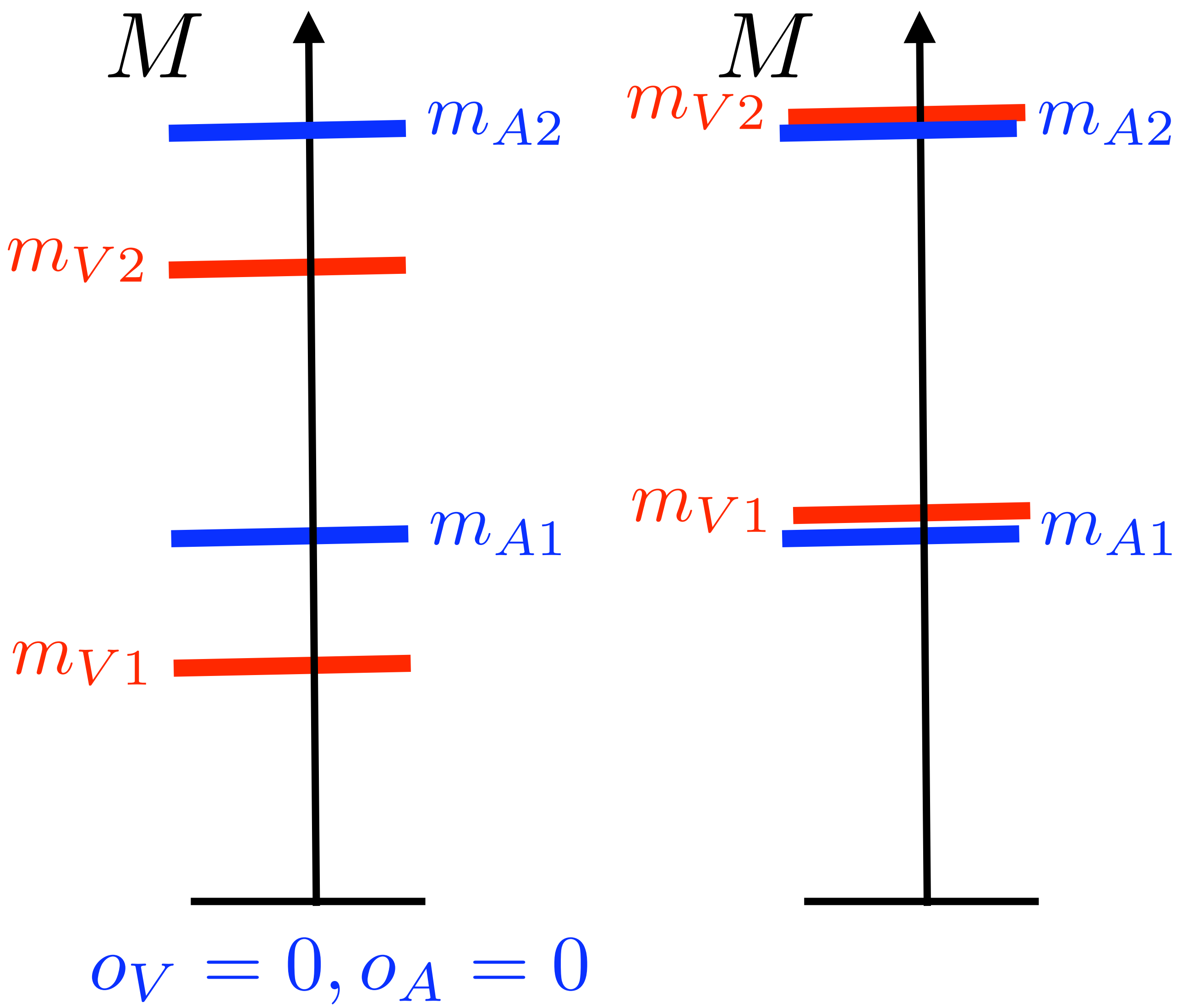

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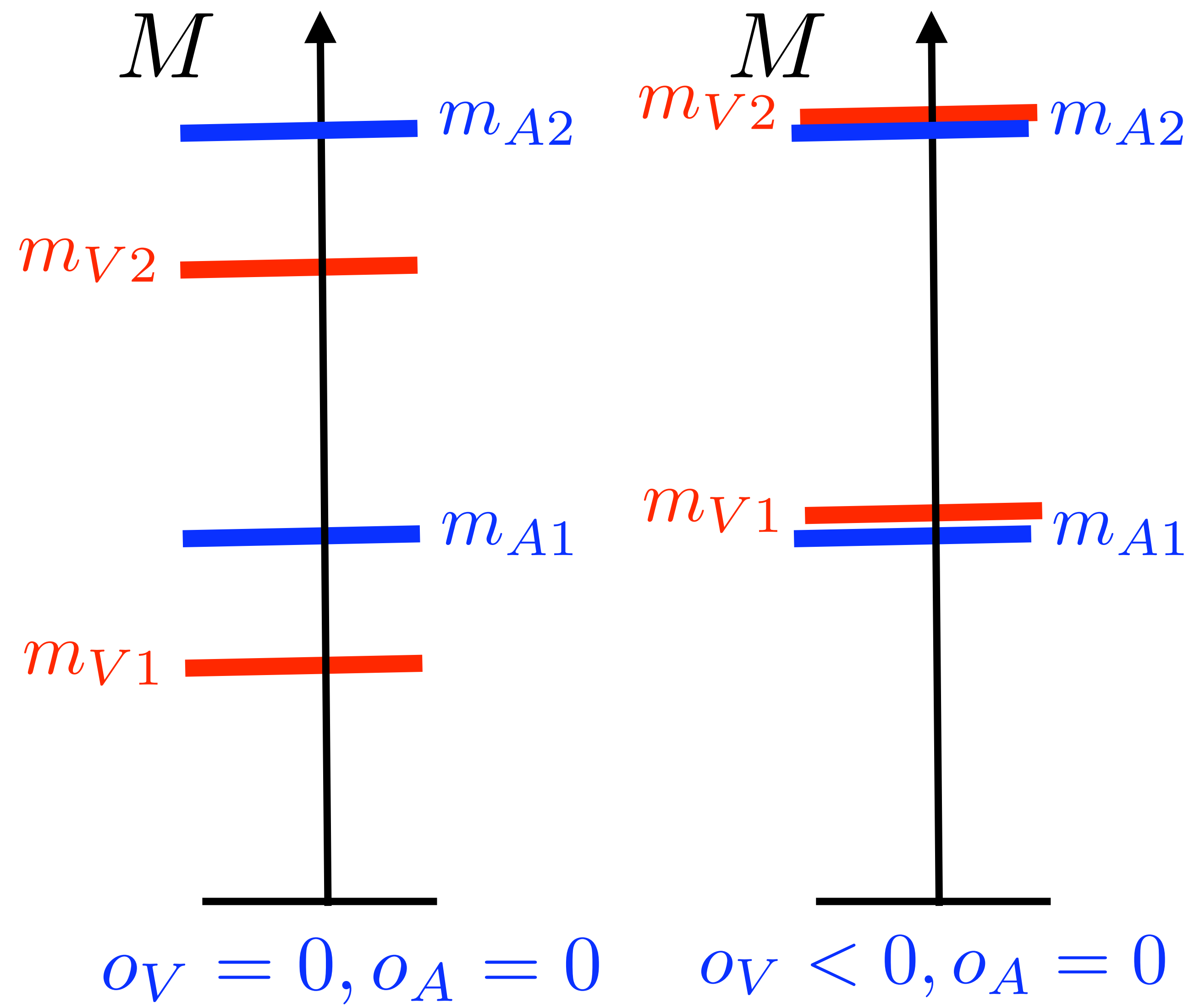

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Degenerate spectrum

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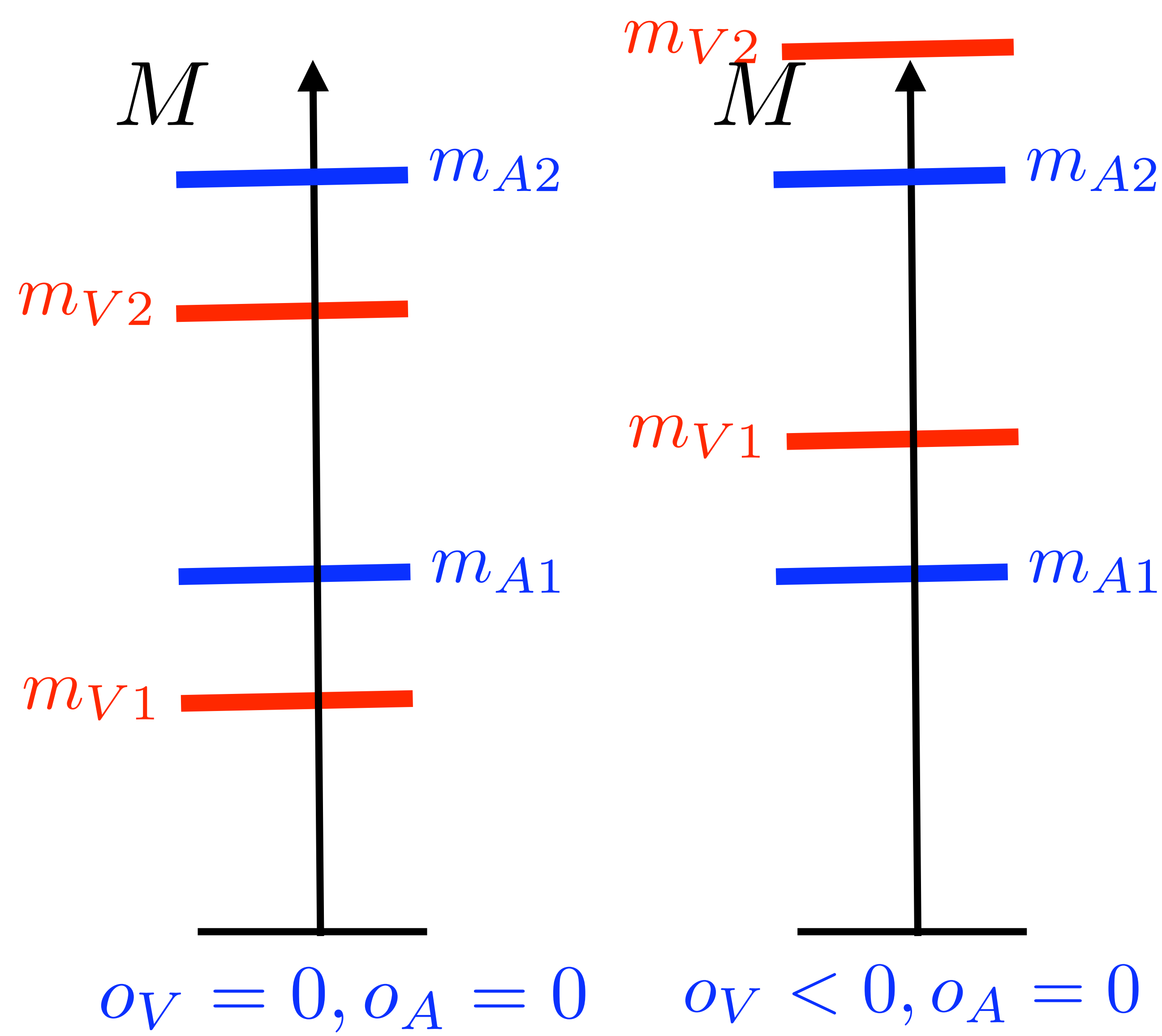

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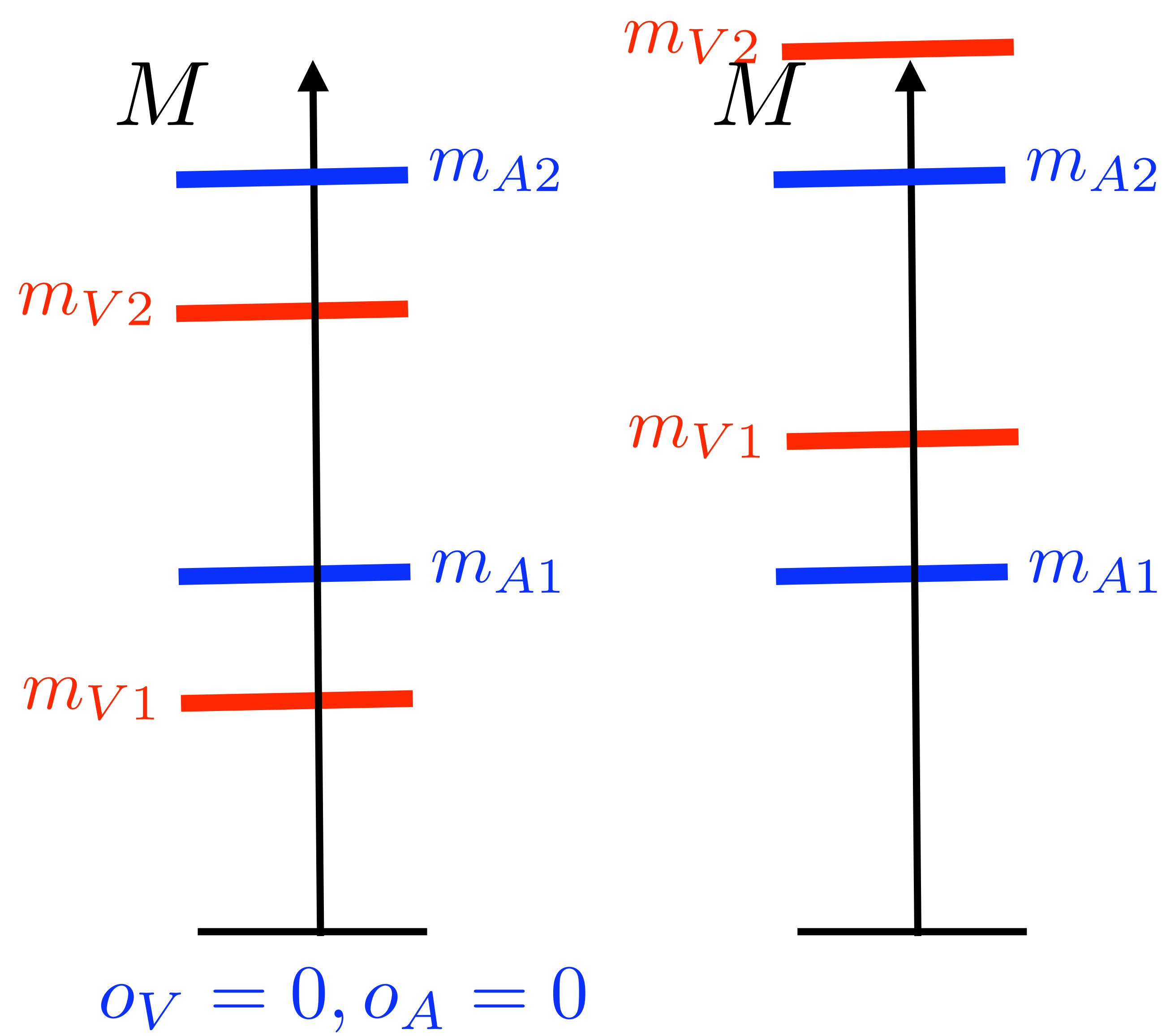

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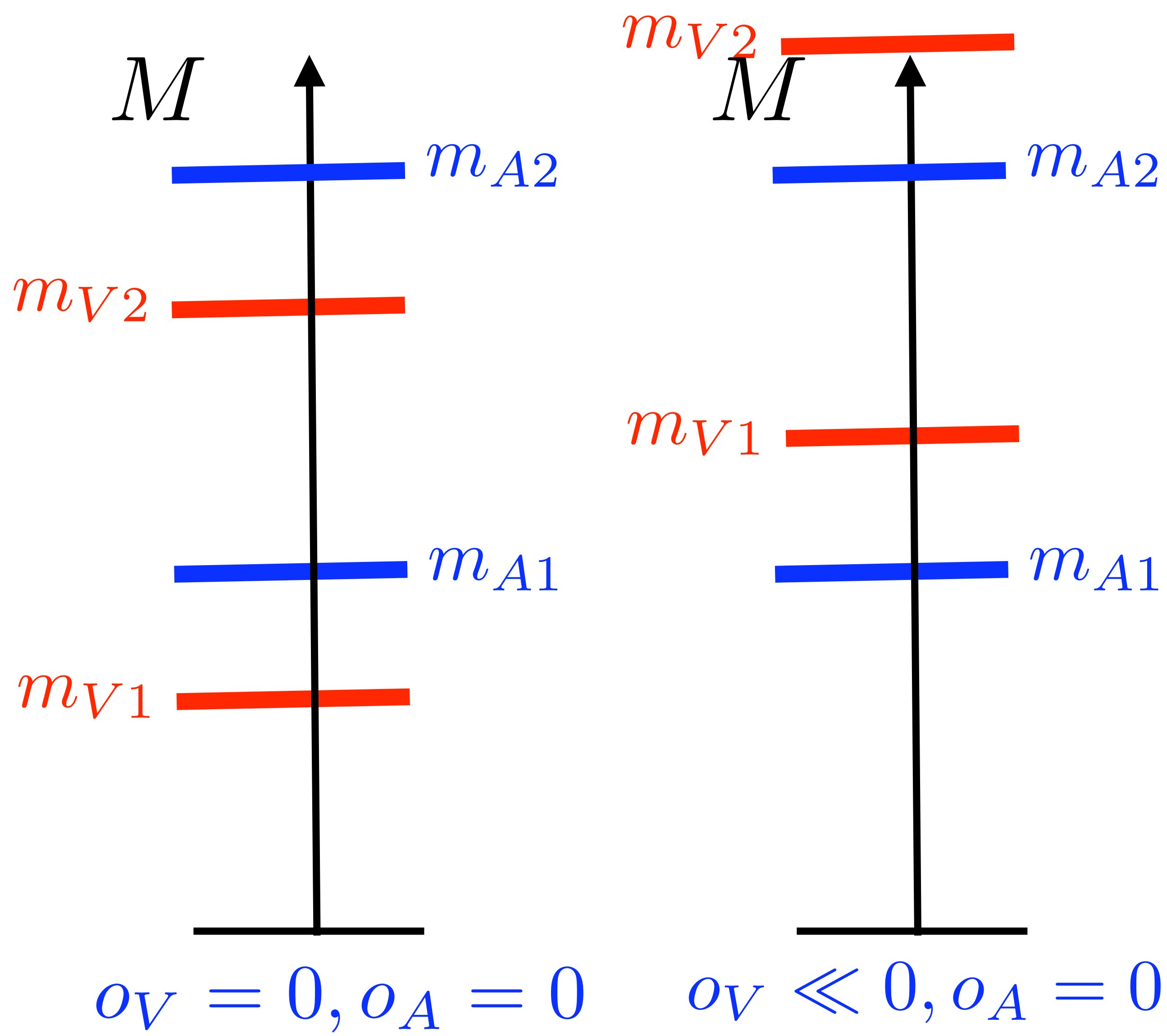

Dialing o_V for fixed o_A :

or Inverted spectrum

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What do we gain?

- Parameter space contains non-QCD like spectrum
- WSRs and simple resonance models S ameloriated when $M_{W_1} \cong M_{W_2}$

de Rafael-Knecht '97
Appelquist-Sannino '98

- Whenever $\omega_V \neq \omega_A$; unconventional triboson, 4-boson couplings

$$g_{W_1^- W Z} = g_1 \partial_{[\mu} W^-_{1\nu]} (W^+_{[\mu} Z^0_{\nu]}) + g_2 \partial_{[\mu} W^-_{\nu]} (Z^0_{[\mu} W^-_{1\nu]}) + g_3 \partial_{[\nu} Z^0_{\nu]} (W^-_{[1\nu} W^+_{\nu]})$$

$$g_1 \supset \int_{\ell_0}^{\ell_1} dz\, \omega_V (V_1 A_{W^+} A_Z) \cdots \neq g_3 \supset \int_{\ell_0}^{\ell_1} dz\, \omega_A (V_1 A_{W^+} A_Z) \cdots \neq g_2$$

Same region degenerate (non-QCD) mixed photon coupling

$$g_{W_1^- W^+ \gamma}$$

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New pheno. and a new twist on old pheno.

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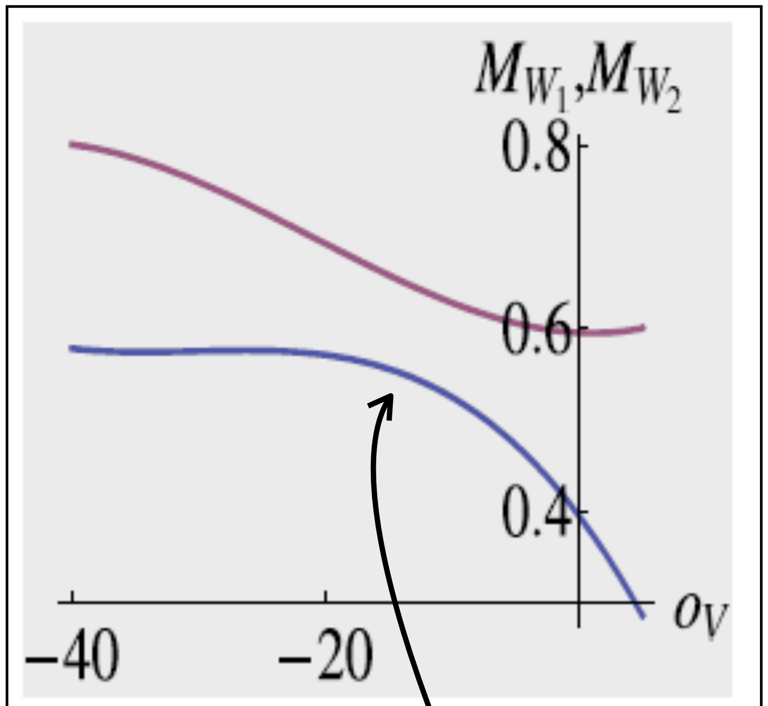
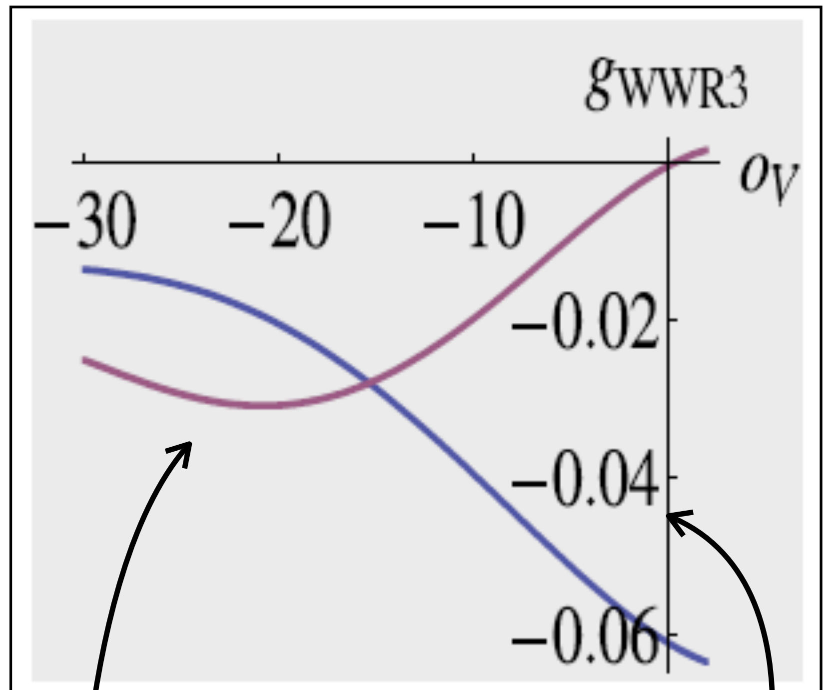
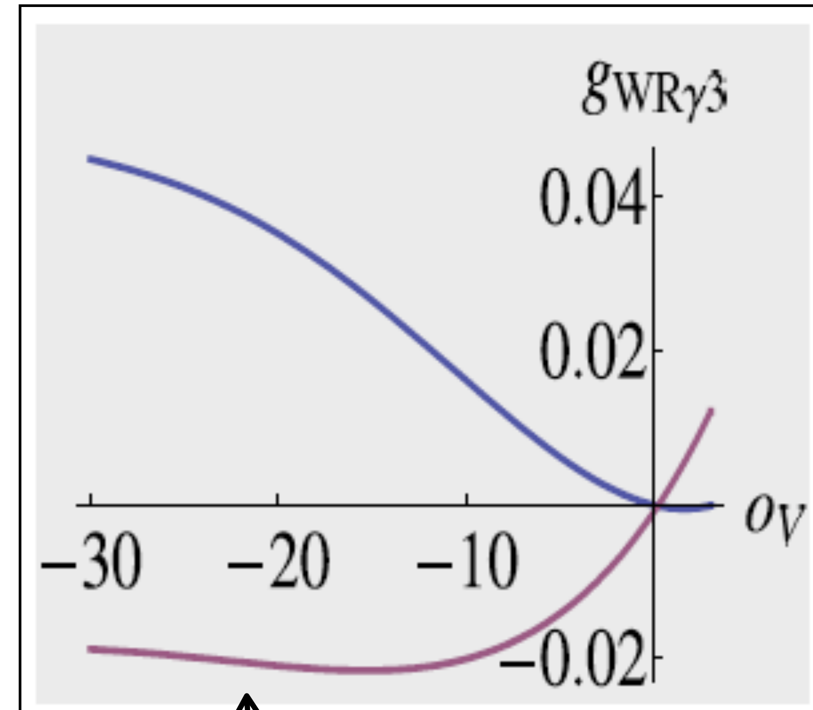
Exploring o_V and o_A :

Along $o_A = 0, o_V < 0$







Level repulsion

Both resonances in $W_L W_L \to W_L W_L$

Only vector unitarizes

Nonzero $g_{W_{1,2}W\gamma}$

What about SM fermions?

- Coupling of fermions to the new resonances will determine the best production methods at the LHC
- Full 5D treatment of fermions would re-introduce many parameters...

For starters: one more parameter g_{ffV}

$$g_{ffW} = g_{SM}$$

- We can study several models of fermion interactions

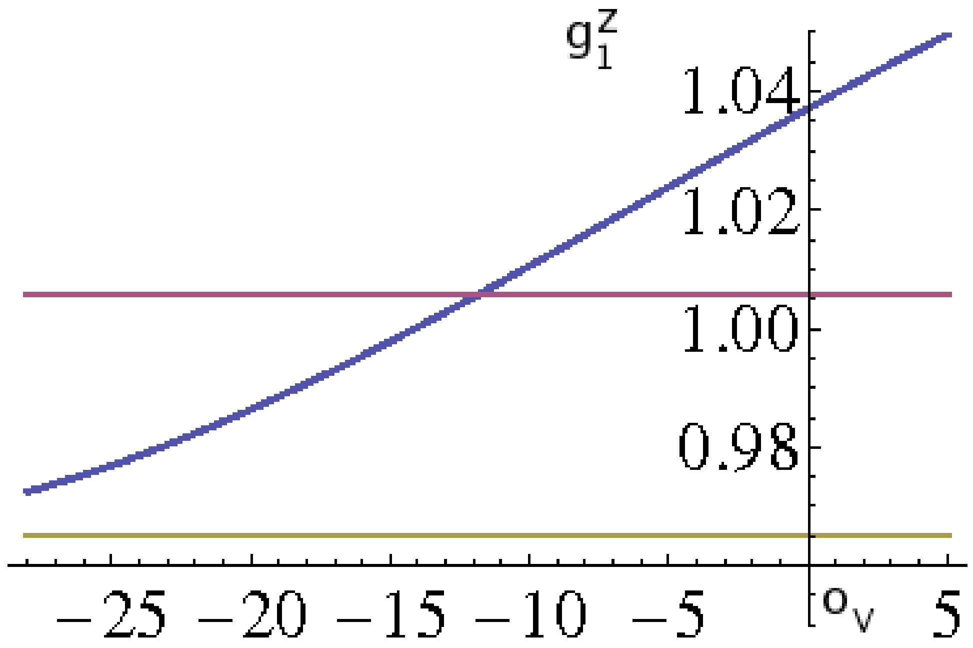
$$g_{ffV} = \kappa\, g_{ffW}$$

$g_{ffV} \cong 0$ ideally delocalized

$g_{t_R t_R V} \gg g_{ffV}$ mostly composite t_R

Constraints:

- Parameter count: $\ell_1, \ell_0, g_5, \tilde{g}_5, o_V, o_A, g_{ffV}$
- For a given ℓ_1: o_V, o_A constrained by anomalous $g_{WW\gamma}$, g_{WWZ} couplings (LEP).



- LEP, Tevatron constrain fermion-resonance coupling

contact interactions: $\frac{(\bar{f}f)(\bar{f}'f')}{\Lambda^2}$

direct bounds: $\sigma(p\bar{p} \to Z'(W') \to \ell^+\ell^-(\ell\nu))$
indirect bounds: # high p_T objects (Z^0, γ)

Constraints:

overall scale: $M_{res} \sim \frac{1}{\ell_1}$

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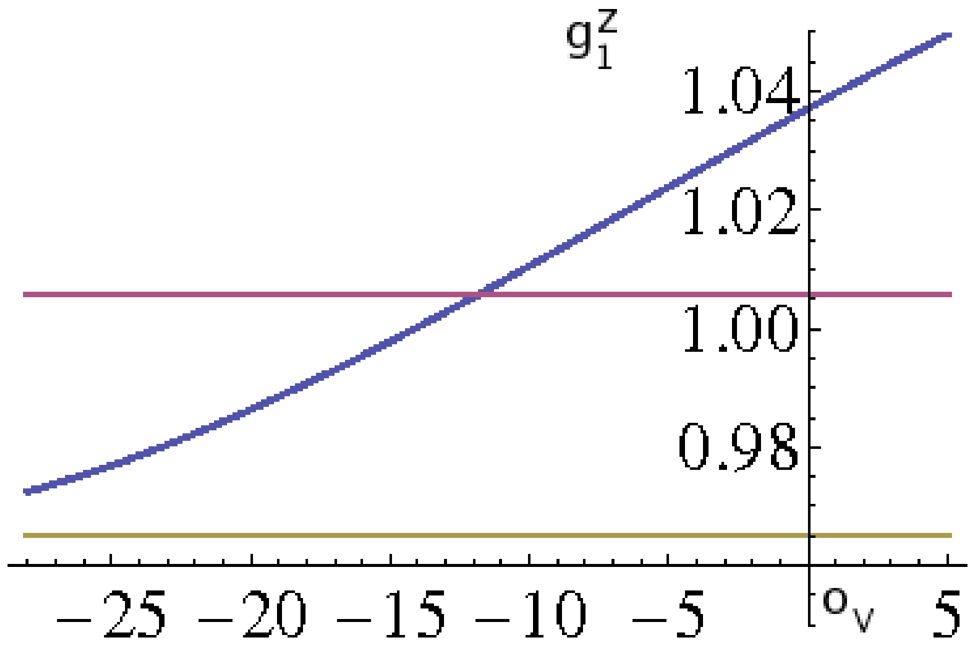

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Our Scheme: Review

$$\mathcal{L} \supset \mathcal{L}_{spin-1} + \mathcal{L}_{res+WZ\gamma} + g_{f_i f_j V} \bar{\psi}_i \gamma_\mu \psi_j V^\mu + g_{f_i f_j W} \bar{\psi}_i \gamma_\mu \psi_j W^\mu$$

Holography

$\omega_V \neq \omega_A$

- new spectrum + interactions
- anomalous couplings

$g_{WWZ} \neq (g\cos\theta_W)_{SM}$

Pheno. coupling

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SM values:

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SM values:

- We are NOT solving PEW problems here
- We ARE generating scenarios with new phenomenological features to be studied

For Collider Pheno, see Adam's talk in 15 mins!