$W_L W_L$ scattering at LHC: An approach to the Theoretical Background

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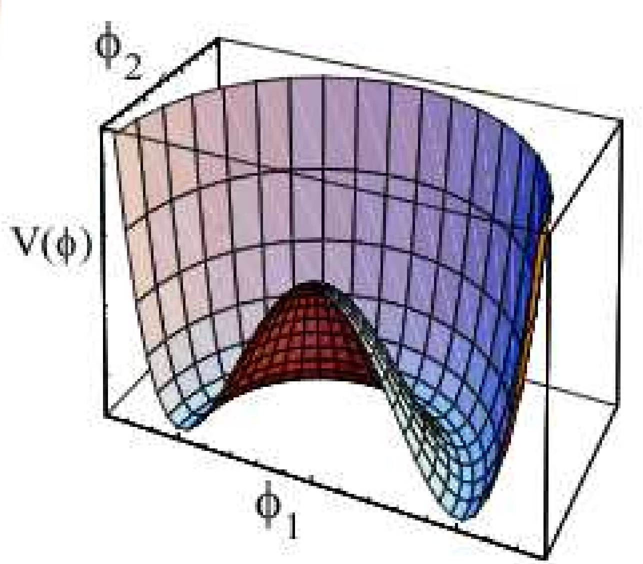
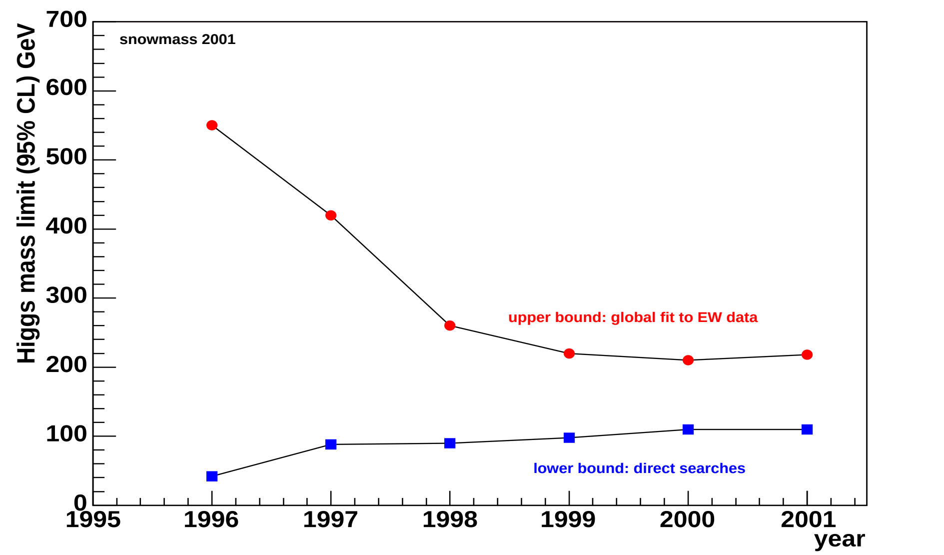
Introduction

- Standard Model: A very good model satisfying theorists and experimentalists.
- It explains the **Electroweak Symmetry Breaking-EWSB** by introducing the **Higgs** boson.





- However, any assumptions and any mass limits are **model dependent.**
- Alternative models to explain EWSB: SM with heavy higgs, technicolor, composite models etc etc
- Enchanced production of **longitudinal** vector boson pairs is one of the most characteristic signals of the new physics

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- Describes the low energy effects of different strongly interacting models of the Symmetry Breaking Sector.
- The differences among underlying theories appear through the values of the effective chiral couplings.
- It includes operators up to order of s^2 (E^4).
- At thel lowest order:

$$\mathcal{L}^{(2)} = \frac{u^2}{4} Tr\{D_\mu U D^\mu U^\dagger\} \tag{1}$$

where

$$D_\mu U = d_\mu U - W_\mu U + U B_\mu$$

$$W_\mu = -ig\frac{\sigma^\alpha W^\alpha_\mu}{2} \qquad B_\mu = ig\frac{\sigma^3 B_\mu}{2} \qquad U = \exp\left(\frac{i\omega^\alpha\sigma^\alpha}{u}\right)$$

where σ are the Pauli matrice, ω are the three Goldstone bosons and $u = 246$ GeV

- The next term includes the model-dependent effective couplings:

$$\mathcal{L}^{(4)} = \alpha_4 \left(Tr\{D_\mu U D^\mu U^\dagger\}\right)^2 + \alpha_5 \left(Tr\{D_\mu U D^\nu U^\dagger\}\right)^2 \tag{2}$$

- The α_4 and α_5 depend on the model but also on the renormalization scale μ. With $\mu = 1\,TeV$ we expect them to be in the range of [-0.01, 0.01]
- Additional terms of the order of s^2 contribute to anomalous trilinear couplings between vector bosons.

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- For the $W_L^a W_L^b \to W_L^c W_L^d$ in the weak isospin space:

$$\mathcal{M}(W_L^a W_L^b \to W_L^c W_L^d) \equiv A(s,t,u)\delta^{ab}\delta^{cd} + A(t,s,u)\delta^{ac}\delta^{bd} + A(u,t,s)\delta^{ad}\delta^{bc} \quad (3)$$

where the key amplitude $A(s,t,u)$ is:

$$\begin{aligned} A(s,t,u) &= \frac{s}{u^2} + \frac{1}{4\pi u^4}\left(2\alpha_5 s^2 + \alpha_4(t^2+u^2)\right) + \\ &+ \frac{1}{16\pi^2 u^4}\left(-\frac{t}{6}(s+2t)\log\left(-\frac{t}{\mu^2}\right) - \frac{u}{6}(s+2u)\log\left(-\frac{u}{\mu^2}\right) - \frac{s^2}{2}\log\left(-\frac{s}{\mu^2}\right)\right) \end{aligned} \quad (4)$$

(In the above: W_L denotes either $W_L^{\pm}$ or Z_L , $W_L^{\pm} = \frac{W_L^1 \mp i W_L^2}{\sqrt{2}}$, $Z_L = W_L^3$, $a,b,c,d = 1,2,3,4$ and s,t,u are the Mandelstam kinematical variables.)

- Precise measurement of the $W_L W_L \to W_L W_L$ scattering cross-section would allow the extraction of the α_4 and α_5 parameters.

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- The usuall EWChL approach doesn't respect **unitarityy**.
- Unitarity is restored by applying different **unitarization protocols**, for example:**Inverse Amplitude Method (Pade)**, N/D protocol etc.
- The **position** and the **nature** of the resonances **depend strongly** upon the unitarisation procedure.

  (see for example Phys.Rev.D **65** 096014 for comparison between the Pade and the N/D protocols)
- Using the Pade protocol, we obtain the following mass and the width of the resonances:

$$M_V^2 = \frac{u^2}{4(\alpha_4 - 2\alpha_5) + \frac{1}{144\pi^2}}, \qquad \Gamma_V = \frac{M_V^3}{96\pi u^2} \tag{5}$$

$$M_S^2 = \frac{12u^2}{16(11\alpha_5 + 7\alpha_4) + \frac{101}{48\pi^2}}, \qquad \Gamma_S = \frac{M_S^3}{16\pi u^2} \tag{6}$$

- For equal masses, scalar resonances would be **6 times wider** than vector resonances.

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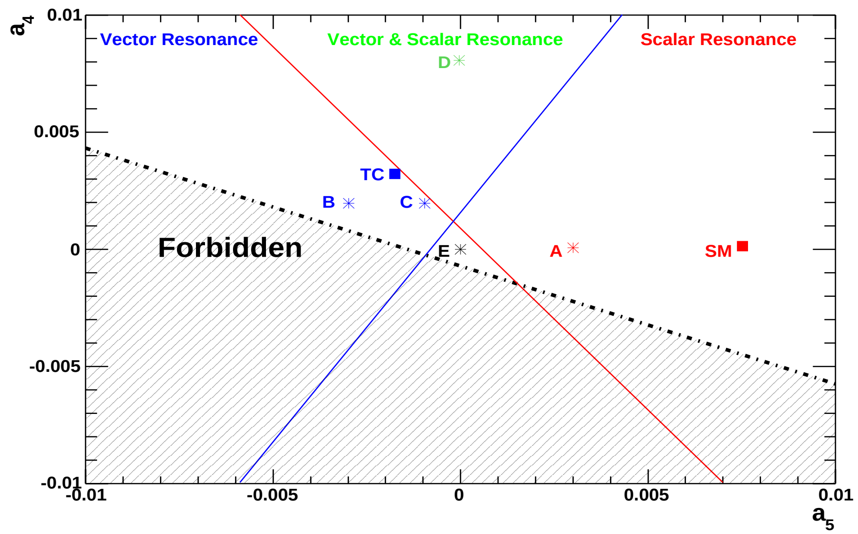
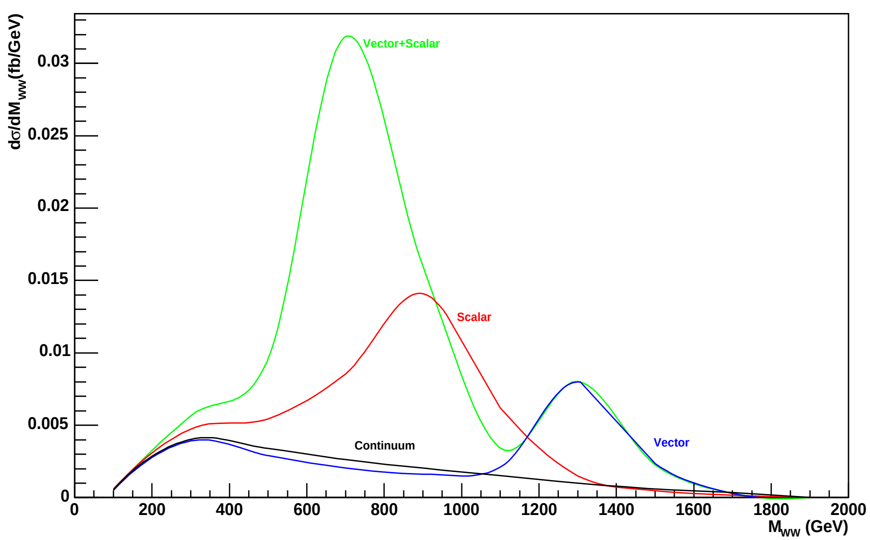
Parameter Space as determined by the Pade protocol





Scenario	α_4	α_5	Resonance Mass (GeV)
Scalar(A)	0.0	0.003	989.8
Vector(B)	0.002	-0.003	1360.3
Scalar + Vector (D)	0.008	0.0	809.6 + 1360.3
Continuum (E)	0.0	0.0	NA

- PYTHIA has been modified to include the EWChL and to produce the resonances for different parameters according to the Pade protocol.
- Forbidden region: Where causality is violated, i.e $\frac{32}{3}(\alpha_5 + 2\alpha_4) + \frac{273}{864\pi^2} < 0$

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