A "composite" scalar-vector system at the LHC

In (less than) ten minutes

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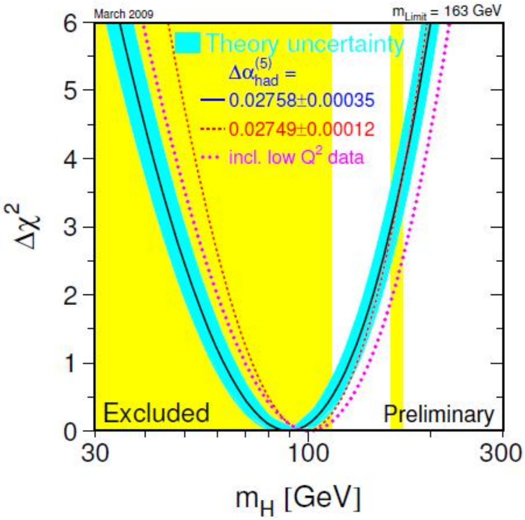
The most famous plot in High Energy Physics



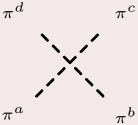
The "atheistic" Electro-Weak Symmetry Breaking (slogan revisited)

Why do we need the Higgs boson?

- To generate the mass for all the massive particles (weak gauge bosons and fermions)
- To keep S-matrix unitarity in longitudinal WW scattering

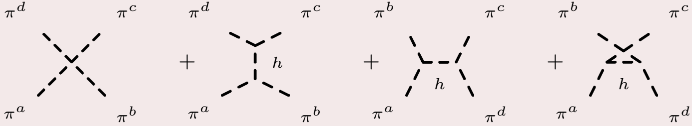
The $W_L W_L \to W_L W_L$ scattering without the Higgs boson

$$\mathcal{A}(\pi\pi \to \pi\pi) = \mathcal{A}(s,t,u)\,\delta^{ab}\delta^{cd} + \mathcal{A}(t,s,u)\,\delta^{ac}\delta^{bd} + \mathcal{A}(u,t,s)\,\delta^{ad}\delta^{bc} \quad (1)$$



$$\Rightarrow \quad \mathcal{A}(s,t,u) = \frac{s}{v^2} \quad (2)$$

The $W_L W_L \to W_L W_L$ scattering with the Higgs boson

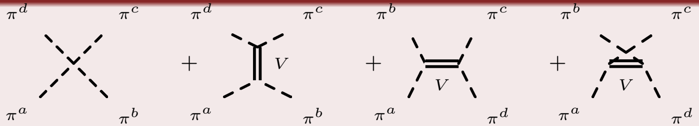


$$\mathcal{A}(s,t,u) = -\frac{m_h^2}{v^2}\,\frac{s}{s-m_h^2} \quad (3)$$

Make it without an Higgs boson: an example

- The masses can be generated by a non-linear Σ field $U = e^{i\frac{\pi^a \sigma^a}{v}}$ as A. Romanino showed before
- The exchange of a new massive particle, can turn the asymptotic amplitude for $W_L W_L \to W_L W_L$ to a constant
- An effective field theory based on the $SU(2)_L \times SU(2)_R / SU(2)_{L+R}$ global symmetry can be constructed in such a way to raise the cut-off Λ up to about $4\pi v \approx 3TeV$ being in accord with EWPT (R. Barbieri, G. Isidori, S. Rychkov, E. Trincherini, 2008)

An example: vector resonance exchange

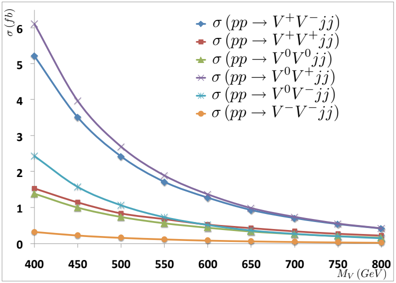


$$\mathcal{A}(s,t,u) = \left[\frac{s}{v^2} - \frac{G_V^2}{v^4}\left[3s + M_V^2\left(\frac{s-u}{t-M_V^2} + \frac{s-t}{u-M_V^2}\right)\right]\right] \quad (4)$$

- For $G_V = \frac{v}{\sqrt{3}}$ the asymptotic amplitude reduces to a constant
- However the unitarity is not formally restored up to all energies but only up to a cut-off $\Lambda \approx 3TeV$ (the coefficients of the partial wave expansion of the scattering amplitudes grow logarithmically with s even in the case $G_V = \frac{v}{\sqrt{3}}$)

Total cross sections for the pair production of heavy vector bosons

- The pair production of vector resonances is important since it is sensitive to different coupling with respect to the single production (in particular the trilinear coupling g_K)
- Exact numerical total cross sections at the LHC ($\sqrt{s} = 14$ TeV) as functions of the vector resonance mass obtained with the matrix element generator CalcHEP implementing our model with the model generator Mathematica package FeynRules.



Vector Boson Fusion ($p_T > 30$ *GeV*, $|\eta| < 5$)

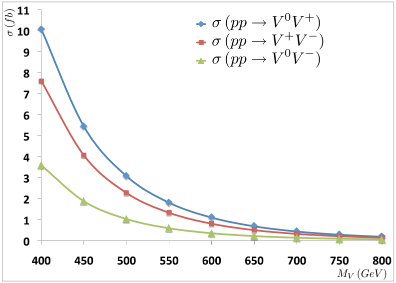


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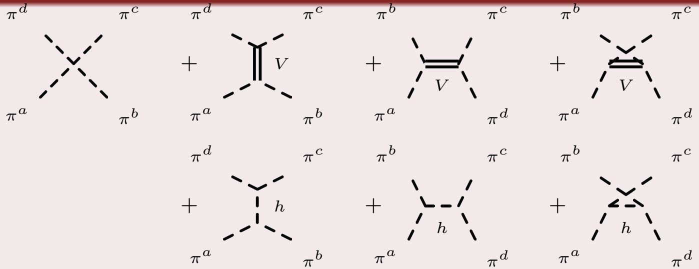
Figure: R. Barbieri, A. E. Carcamo, G. Corcella, R. T., E. Trincherini, 2009

A possible solution to the loss of unitarity

- The exchange of a both a scalar and a vector makes it possible to relax the bounds on the coupling of the two previous models

An example: vector resonance exchange



$$\mathcal{A}(s,t,u) = \frac{s}{v^2}\left(1 - \frac{a^2}{4} - \frac{3 g_V^2 M_V^2}{v^2}\right) + \frac{g_V^2 M_V^4}{v^4}\left[\left(\frac{(u-s)}{t} + \frac{(t-s)}{u}\right)\right] \quad (5)$$

- The unitarity conditions reduces to a simple relation between the coupling of the V to the Goldstones $g_V = G_V/M_V$ and the coupling of the Higgs to the Goldstones a

Asymptotic behavior of the relevant amplitudes

Asymptotic amplitudes

$$\mathcal{A}\left(s,t,u\right)^{\pi\pi\to\pi\pi} \approx \frac{s}{v^2}\left(1-\frac{a^2}{4}-\frac{3g_V^2M_V^2}{v^2}\right)+\frac{g_V^2M_V^4}{v^4}\left[\left(\frac{(u-s)}{t}+\frac{(t-s)}{u}\right)\right] \tag{6a}$$

$$\mathcal{A}\left(s,t,u\right)^{\pi\pi\to V_LV_L} \approx \left(\frac{ad}{4v^2}-\frac{1}{4v^2}\right)\left(s-2M_V^2\right) \tag{6b}$$

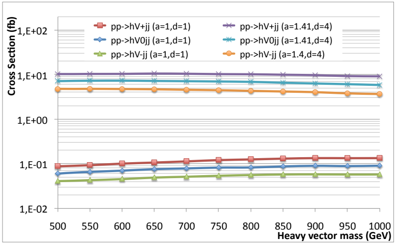
$$\mathcal{B}\left(s,t,u\right)^{\pi\pi\to V_LV_L} \approx \frac{u-t}{2v^2}\left[\frac{s}{2M_V^2}\left(c-1\right)-1+\frac{3c}{2}+\frac{3cM_V^2}{2s}\right]-\frac{g_V^2M_V^2u}{v^4}\left(1+\frac{4M_V^2}{s}+\frac{2M_V^2}{u}\right) \tag{6c}$$

$$\mathcal{A}\left(s,t,u\right)^{\pi\pi\to HH} \approx -\frac{1}{4v^2}\left(\left(b-a^2\right)s+am_H^2\left(3-2a\right)\right) \tag{6d}$$

$$\mathcal{A}\left(s,t,u\right)^{\pi\pi\to V_LH} \approx \frac{ig_VM_V\left(t-u\right)}{2v}\left[\frac{a}{v^2}-\frac{d}{4g_V^2M_V^2}\right] + \frac{ig_VM_V\left(t-u\right)}{2vs}\left[\frac{a}{v^2}\left(M_V^2-m_H^2\right)+\frac{d}{4g_V^2M_V^2}\left(m_H^2-2M_V^2\right)\right] \tag{6e}$$

Total cross sections for the associate production of an heavy vector bosons and a light scalar

- Preliminary results for the total cross section for the associate Higgs-Heavy vector production at the LHC at $14TeV$ for $M_h = 150GeV$ and different values of the couplings a and d



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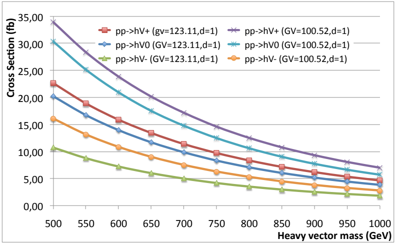

Drell-Yan

- The VBF associate total cross section is comparable to the heavy vectors pair production VBF total cross section
- The DY total cross sections can be some tens of fb
- A signal can be accessible to the LHC but...
- .. a careful study of the background is required to understand the visibility at the LHC

Summary

I'm probably late...

...see the previous 6 slides!

Thank you.

References

Ten references (not to be read in ten minutes)

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10. A. Carcamo, G. Corcella, R. T. and E. Trincherini on *A signature for the heavy vectors pair production at the LHC*, Work in progress