Research Statement

Axel Orgogozo

In the last decades, the Standard Model (SM) of Particle Physics passed successfully the experimental tests at colliders. Before 2012, one crucial piece was still missing though: The Higgs Boson. Since the discovery of the massive W and Z Electroweak gauge bosons, we knew that the Electroweak symmetry was spontaneously broken, but the discovery of the Higgs was a necessary step to check the validity of the Higgs mechanism of Electroweak Symmetry Breaking (EWSB). On the 4th of July 2012, the discovery of a new particle was announced by ATLAS and CMS at a mass of 126 GeV. Some of its properties still need to be checked, but it is very likely to be the Higgs scalar boson or something similar to it.

In spite of this great experimental success, the SM fails to explain Dark Matter, whose existence is unambiguously proven by astrophysical data. On the theory side, the hierarchies in the flavor sector are unexplained. A more direct threat for the Higgs mechanism of EWSB is the Hierarchy Problem. It arises from the fact that scalar masses are highly unstable through radiative corrections. Assuming the SM to be valid up to a very large scale, like the GUT or the Planck scale, would require an incredible amount of fine tuning between this scale and the bare mass of the Higgs in order to get a physical mass of 126 GeV. This asks for a mechanism to protect the Higgs mass and more generally the electroweak scale. All those facts require new physics Beyond the Standard Model (BSM). One of the main difficulty to build consistent BSM scenarios is that the indirect constraints from Electroweak Precision Tests (EWPT) are in really good agreement with the SM and a careful analysis is required for each given extension.

The suitable quantities to study the EWPT constraints are the S, T and U Peskin-Takeuchi parameters (Peskin, Takeuchi, 1992). They describe the deviations from the SM of the radiative corrections to the W boson mass, the forward/backward asymmetry of charged leptons and the Z boson width to charged leptons. T and U measure the size of the breaking of custodial symmetry (a global symmetry of the SM in the limit of vanishing hypercharge coupling and degenerate quark masses in doublets). The bounds on T and U from experiments do not allow large deviations and as a consequence, most of the BSM scenarios feature a custodial symmetry. in this case, U is in general negligible compared to T and one can study the consistency with data with T and S only.

During my Ph.D., I have been interested in the study of EWPT in Strongly coupled scenarios of EWSB. In this class of theories, the Hierarchy Problem is solved by a new strong sector. This makes the computation of S and T very challenging. They are generally evaluated by Naive Dimensional Analysis in the literature. Combining non perturbative techniques and Effective field theories approaches I focused on improving those estimates. This is a crucial step in order to use fully the LEP/Tevatron data and constrain those models. It can possibly lead to predict masses/couplings of new particles from the strong sector in simple set ups and provide a guideline for future collider experiments like the 14 TeV run of the LHC.

In the future, I would like to broaden my knowledge in strong realizations of EWSB. One of the interesting topic to study is flavor physics. Indeed, as most of the theories built to solve the hierarchy problem, they introduce new Flavor Changing Neutral Currents and as in the case of EWPT, strong interactions make the task of evaluating flavor observables really challenging. An other subject of interest to me is Dark Matter. In particular, the fact that composite Higgs scenarios featuring a discrete symmetry can accomodate for it (see (Frigerio, Pomarol, Riva, Urbano, 2012)) looks really promising. I would also be glad to learn more about warped 5 dimensional models which can be thought as explicit realizations of Composite Higgs models. More generally, I am enthusiastic about applying the different techniques I have used during my thesis to tackle various problems in high energy physics. The effective theory methods I have learned give me a framework to study completely different topics and as previously said, the EWPT are a strong constraint on any extension of the SM and the experience I acquired in this subject will be valuable in other BSM models.

Past Projects

EWPT in Higgsless[1] Technicolor. Minimal Technicolor corresponds to a massless scaled up QCD theory. The EWSB is triggered by techni-quark pair condensation at the scale where the theory gets strong: $\Lambda_{TC} \sim$ v = 246 GeV (Chiral Symmetry Breaking). Λ_{TC} is the analog of Λ_{QCD} and this scale is naturally small compared to the UV cut-off. This leads to a possible explanation for the Hierarchy between the electroweak scale and the Planck scale. Despite this appealing solution to the Hierarchy problem, this kind of scenarios suffers from large positive contributions to the S parameter, leading to a disagreement with EWPT. In [1], we revisited the EWPT analysis in these Higgsless models of EWSB and discussed the contribution of spin-1 resonances to the S and T Peskin-Takeuchi parameters. We restricted ourselves to a Vector Meson Dominance (VMD) scenario where only the first vector and axial resonances contribute. One of the main result we obtained was a full one loop estimation of the T parameter. We discussed also the S parameter, using the Peskin-Takeuchi dispersive relation (Peskin, Takeuchi,1992). The spectral densities entering the dispersive relation satisfy two sum rules (The Weinberg sum rules). We recovered, in this VMD framework, that minimal Technicolor produces a large S parameter. We remarked that in Conformal Technicolor scenarios (Luty, Okui, 2006), the second Weinberg sum rule is not satisfied, which leads to a possible cancellation between the vector resonance contribution to the S parameter and the axial one. Examining the correlation of S and T, we found that a good fit to EWPT can be obtained. Of course, now that the Higgs is almost certainly discovered, this kind of Higgsless scenarios is ruled out. But in other strongly coupled scenarios of EWSB featuring a light Higgs, one expects similar spin-1 resonances to play a role. Knowing a way to reduce their contribution to the S parameter and knowing that the contribution to S and T from the resonances can be made simultaneously small is still of relevance. A more general lesson we learned from this work is that large deviations from the Naive Dimensional Analysis estimates can be obtained for the S and T parameters.

A dispersive relation for the S parameter in Composite Higgs models. A promising solution to have a light (natural) Higgs is to introduce it as a Nambu-Goldstone of G/H where G is a symmetry group spontaneously broken by strong dynamics to a subgroup H. This is the path chosen in Composite Higgs models. The Higgs being a Nambu-Goldstone boson, a mass term is forbidden by shift-symmetry. But because of explicit breakings of G (electroweak gauge bosons couplings, yukawa couplings, ...), a Higgs potential is generated at one loop, and a naturally small mass is obtained. A common feature of Composite Higgs models is that the Higgs couplings are reduced compared to the SM. This produces an imperfect cancellation of the logarithmically divergent contributions to S and T from electroweak gauge boson loops and Higgs loops. This requires some attention, and one would like to understand how this UV sensitivity is cut off. In the Higgsless case and for the S parameter, one has the UV finite Peskin-

[1] this work was done before the 3σ hints for a Higgs boson was announced in December 2011

Takeuchi dispersive relation and using it in simple set up like in [1], one can see that the cut off can be replaced by the mass of a spin-1 resonance. In [2], we generalized this formula to the Composite Higgs case. Our main result is a UV finite formula for the S parameter in the case of the minimal Composite Higgs model $SO(5)/SO(4)$ (but easily generalizable to other symmetry breaking patterns). This formula connects the infrared contribution from Higgs loops, which we computed fully at one loop, to a dispersive relation receiving contributions from resonances of the strong sector via an appropriate matching. It allows to compute S with a really good accuracy of $O(\frac{m_h^2}{m_\rho^2})$, where m_ρ is the mass of the first spin-1 resonance in the spectrum.

Current Research Projects

T **in Composite Higgs models**. Having now some good understanding of the S parameter in Composite Higgs models, it makes sense to look for a more reliable way of computing the T parameter and in particular to control its UV behavior and understand how the logarithmic divergence, introduced by reduced Higgs couplings, is cut off. To do so, it would be interesting to have a dispersive relation like for the S parameter. Compared to the S parameter, the T parameter involves on top of two-point correlators, three and four-point ones (Peskin, Takeuchi, 1992). This makes the derivation of a dispersive relation challenging. Nevertheless, in Landau gauge, the T parameter is linked to the wave function renormalization of the goldstones, and in the QCD context, a dispersive relation was derived for the pion mass difference (Das,Guralnik, Mathur, Low, Young, 1967). Those quantities are conceptually close to each other and it might be possible to find a similar dispersive relation for T. Finding it would be a great achievement and would allow to use reliably the EWPT data in Composite Higgs models.

spin-1 resonances at future colliders. In spite of the lack of calculable models, in which the spectral densities are computable, I would like to investigate the correlation between S and T in some simple scenarios. The improvements in the understanding of S and possibly T can indeed change some estimates that were provided in the past. Furthermore, since the 4th of July 2012, we know the mass of the Higgs and its couplings are more and more constrained by LHC data. This, combined with the experimental constraints on S and T and theoretical constraints like elastic unitarity, sum rules etc. would lead to some tight bounds for the spin-1 resonances masses/couplings in some simple models. This is a valuable information to guide direct searches at colliders. The discovery of a spin-1 resonance combined with reduced Higgs couplings would be a striking signature for Composite Higgs models.

REFERENCES

[1] A. Orgogozo and S. Rychkov, "Exploring T and S parameters in Vector Meson Dominance Models of Strong Electroweak Symmetry Breaking," *JHEP* **1203** (2012) 046, arXiv:1111.3534 [hep-ph].

[2] A. Orgogozo and S. Rychkov, "The S parameter for a Light Composite Higgs: a Dispersion Relation Approach," arXiv:1211.5543 [hep-ph].