Lorenzo Rolla

First PhD year report

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Supervisors

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Research Activity

My research focused on Beyond Standard Model (BSM) phenomenology and aims at constraining the space of possible UV models that extend the Standard Model (SM). This is done by means of model-independent techniques. Indeed, at the core of my work lies the Standard Model Effective Field Theory (SMEFT): a low-energy theory that captures the deviations from the Standard Model due to New Physics (NP) living in the UV.

The SMEFT lagrangian is built upon the assumption of existence of an unknown fundamental energy scale Λ. This is the scale at which NP is expected to emerge, and it defines the energy range for which the effective theory is valid: predictions are reliable only for energy scales well below Λ. The SMEFT, then, is an Effective Field Theory (EFT) defined through an infinite expansion in inverse powers of this fundamental scale. This infinite sum is organized in terms of the canonical dimension D of the operators: for $D \leq 4$ the SM is recovered, for $D > 4$, all the Higher Dimensional Operators (HDOs) that do not break the gauge symmetry of the SM are added. The effects of NP are encoded in the Wilson coefficients of these operators: the goal of my work for this year was to constrain such coefficients for a class of $D = 6$ operators and to identify which BSM models are affected by such constraints.

The operators we analyzed are dipole operators, collectively denoted as $\mathcal{O}_{\psi^2 X \phi}$, and four-fermion operators built up with scalar and tensor spinor bilinears, denoted collectively as $\mathcal{O}_{\psi^4}$. The chiral structure of these operators drastically affects our analysis, as both the classes of operators couple spinors with opposite chirality. A first implication of this is that their contribution to observables is suppressed by a factor $1/\Lambda^4$. The angular distribution of lepton pairs in the Drell-Yan (DY) process allows for the definition of an observable for which the SM contribute vanishes up to $\mathcal{O}(\alpha_S)$, and for which the only $D = 6$ operators that contribute are $\mathcal{O}_{\psi^2 X \phi}$ and $\mathcal{O}_{\psi^4}$. This object then, known as the Lam-Tung observable, perfectly suits our purposes.

Bounds on the Wilson coefficients at the 95% confidence level were derived assuming a center-of-mass energy of $\sqrt{s} = 13$ TeV via a χ^2 minimization testing the SMEFT prediction against that of the SM. The analysis considered both the transverse momentum distribution, considering the di-lepton invariant mass $m_{\ell\ell}$ around the Z pole, used to constrain $\mathcal{O}_{\psi^2 X \phi}$, and the $m_{\ell\ell}$ distribution at high values, employed to constrain $\mathcal{O}_{\psi^4}$.

As a consequence of the chiral structure of the operators another important fact emerges: they explicitly break flavor symmetry. This highlights a feature of the models that can not be constrained by our analysis: our bounds are not strong enough to exclude regions in the parameter space of UV models built upon the assumption of minimal flavor violation. On the other hand, we found that other BSM scenarios such as those including multiple Higgs-doublets or extra $U(1)$ gauge symmetries are affected by our analysis.

Classes

Attended:

- Machine Learning methods for Physics (A. Coccaro, F. Di Bello, R. Torre, 6CFU),
- Non-abelian gauge theories (N. Maggiore, 6CFU),
- QCD and Collider physics (S. Marzani, 3 CFU),
- GGI Lectures On The Theory Of Fundamental Interactions 2025 (PhD school in Florence from 13 to 31 January 2025)
- BSM Odissey: twists and turns in particle theory (PhD school Cargese (Corsica), 21 July -2 August 2025)

Publications

- (in progress) Tests of chirality-breaking dimension-six interactions from Drell-Yan angular analysis

Conferences

- Digital Twins for Nuclear and Particle physics - NPTwins 2024 (conference in Genova, from 16 to 18 december 2024)