Samuele Grossi

First Year PhD Report

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Tutors

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Research Activity

My research activity is focused on the Effective Field Theory (EFT) framework applied to the Standard Model, the so called SMEFT. Effective Field Theory is a general tool which is useful in quantum field theory in order to describe phenomena at energies much lower than a given scale.
The approach of EFT is particularly useful in the context of high energy particle physics because it provides a model independent and indirect way to look for new physics (NP) heavy particles. This is something we need since no direct discovery of heavy particles has happened at the Large Hadron Collider (LHC) for years.
In particular I have analysed the impact of EFT on the so-called Drell-Yan processes:

$$\mathrm{q}\overline{\mathrm{q}} \to \ell^+\ell^- \,, \qquad \mathrm{u}\overline{\mathrm{d}} \longrightarrow \ell^+\nu_\ell \,, \qquad \mathrm{d}\overline{\mathrm{u}} \longrightarrow \ell^-\overline{\nu}_\ell \,,$$

which are observed and studied at LHC and are useful to target new physics whose effects grow with energy.
Including in the lagrangian of the Standard Model the seven dimension 6 operators which interfere with the Drell Yan processes one can extract information on the dimensionful coefficients that multiplies them, the so-called Wilson coefficients. Finding the bounds of these Wilson coefficients under different hypothesis was exactly what I have done during my first PhD year (expanding what I had done during my master thesis). In order to achieve such results I considered a likelihood which included the contribution of the EFT Wilson coefficients and of a set of nuisance parameters, which are needed to parameterize the theoretical and experimental uncertainties. The former appear in a Poisson distribution while the latter are included in both the Poisson distribution and in their prior distributions (which we considered as gaussians).
Exploiting the likelihood ratio test one can find the bounds on the Wilson coefficients at a desired confidence level (CL) imposing a specific value for the asymptotic χ^2 distribution. In my case I set the confidence level value at 95%.
During my master thesis I had manage to find the one dimensional single parameters constraints, at 95% CL and for luminosity values of $100\,\mathrm{fb}^{-1}$, $300\,\mathrm{fb}^{-1}$, $3000\,\mathrm{fb}^{-1}$, of all the seven Wilson coefficients considering all the sources of uncertainties and I evaluated the impact of each of them setting different subsets of nuisance parameters to 0 and extracting again the boundaries. I also managed to extract the one dimensional profiled constraints, but the method was not consistent and systematic. Finally the 2-dimensional bounds were not promising at all, given that plotting with a fast (and not precise) method a single couple of operators for a single value of luminosity needed around 5 hours (which could lead to even 50 hours with a precise method).
During the PhD year I focused on optimizing my code in order to get the 2D bounds in a feasible amount of time. The first idea was to Taylor expand the likelihood in order to obtain a polynomial

function who could be treated analytically. After some optimization work I managed to obtain the same results (not expanded) I got during my thesis in way less time and I managed to obtain a systematic way to extract the 1D profiled bounds. The Taylor expansion at second order instead worked pretty well in order to replicate the 1 dimensional constraints but had some limitation for the 2D bounds, given that it could give rise only to ellipses who did not represent well the expected plots (a part from rare exceptions). I then tried different expansions, but each of them lead to some problems related to the form of the expanded likelihood. In the end I tried again to run a not expanded 2D bounds with a fast method and I obtained the same plot of my very first try during the thesis but this time in just 20 minutes instead of 5 hours (the optimization lead to a factor 15 in speeding the code). Therefore I manage to plot all the sixty-three 2 dimensional bounds with a precise method with an average time of around three hours each.
I also performed a base change, meaning that I considered the seven linear combination of the Wilson coefficients which become relevant looking at specific regions of the phase space and I extracted the same bounds even for this new base. In this case it was a bit more complicated and I had to modify some parts of my code to make it work.
One last interesting idea was to Taylor expand just in the nuisance parameters while keeping untouched the Wilson coefficients. These would lead to the possibility of having an analytical solution to this problem while the ones I exposed until now are all numerical. Unluckily up to now I did not manage to obtain results in this way, given that the expanded likelihood seems to be too much complicated and does not manage to be treated by my code.

Courses

Attended:
- Machine Learning for particle physics (A. Coccaro, F. Di Bello, 3 CFU),
- Fisica Teorica (G. Ridolfi, 3 CFU),
- Non-Abelian Gauge Theory (N. Maggiore, 3CFU).
- GGI Lectures On The Theory Of Fundamental Interactions (3 CFU, PhD school in Florence from 9 to 27 January 2023)
- I will follow also QCD and Collider physics (S. Marzani, 3 CFU) starting on 18th September 2023

Exam given:
- Machine Learning for particle physics (A. Coccaro, F. Di Bello, 3 CFU),

Publication (in progress)

My code should be able to give interesting results once an updated analysis on the Drell-Yan will be performed, and it should be possible to public a paper where I expose my work. Up to now I have already wrote a draft with the backbone of a paper where I explain in technical details what I have done until now.

Conferences

I attended the following schools and conferences:
- “Milan Christmas meeting” in Milan, Italy 21-23 December 2022;
- “GGI Lectures On The Theory Of Fundamental Interactions”, PhD school in Florence, Italy, from 9 to 27 January 2023.
- Weekly seminars organized by INFN here in Genoa throught the whole year