Bachelor Thesis I – Priv.-Doz. Dr. Malgorzata Worek

Lorentz Invariant Phase-Space Integrals – Multichannel Weight Optimisation versus Deep Learning

An important numerical problem in particle physics is the computation of cross sections. Those are usually very complicated integrals over the square matrix element and the phase-space volume of momenta of the final state particles. Such cross sections exhibit strong peaks in many different regions of the phase space. Additionally, the presence of complicated kinematical cuts render an analytic treatment impossible. The Monte Carlo methods of integration are often used instead. In the Monte Carlo approach, a huge effort must be made to reduce the variance of the integrand. One of the popular approaches of variance reduction is the so-called stratified sampling technique, another approach is that of importance sampling. Recently, novel importance sampling techniques capable of overcoming typical deficiencies of existing approaches by incorporating neural networks have been proposed.

Main goals of the bachelor thesis:

- Implementation of a general algorithm for the n-particle phase space generation of final-state momenta.
- Calculation of the $d = 3n - 4$ phase-space integral via Monte Carlo methods.
- Application of results to the real-life calculations: $2 \to 4, 5, 6, \ldots$ massive and massless final states in QED $(e^+, e^-, \mu^+\mu^-, \tau^+\tau^-, \gamma)$.
- Comparison of standard Monte Carlo techniques to new deep learning approaches.

The student will learn:

- How to efficiently calculate dLips of momenta of the final state particles.
- How to reduce a variance of the integrand with e.g. stratified sampling technique, importance sampling techniques.
- How to use weight optimisation techniques in multichannel Monte Carlo.
- How to apply deep learning methods to optimise the numerical integration.
- How to use public Monte Carlo programs like RAMBO, MADGRAPH, VEGAS etc.

Requirements:

Basic understanding of particle physics is required. Can be obtained during the work on the thesis. Good programming skills are required e.g. in Fortran, C/C++.

Bachelor Thesis II – Priv.-Doz. Dr. Malgorzata Worek

The associated production of the SM Higgs boson with the $t\bar{t}$ pair at the LHC

The observation of the Higgs boson with a mass of 125 GeV at the Large Hadron Collider marked the starting point of a broad program to determine the properties of the newly discovered particle. To date, all measured properties, including couplings, spin, and parity are consistent with the Standard Model expectations within experimental uncertainties. Among many production processes the Higgs boson in association with a top-quark pair ($t\bar{t}H$) is very important. For the Higgs boson mass $m_H = 125$ GeV a wealth of different Higgs boson decay channels is available, among others the $b\bar{b}$ final state. However, the $pp \to t\bar{t}H \to t\bar{t}b\bar{b}$ production channel is very challenging. Since the top quark decays into $t \to W^+b$ and anti-top quarks into $\bar{t} \to \bar{b}W^-$, the final state that in reality has to be studied is $pp \to t\bar{t}H \to W^+W^-b\bar{b}H \to W^+W^-b\bar{b}b\bar{b}$. We have two main problems in this channel:

- The so called combinatorial problem with b-jets: the $b\bar{b}$ pair that builds the Higgs boson can be chosen incorrectly.
- The b-jet identification a.k.a. the b-jet tagging efficiency: At the LHC the b-tagging efficiency is not 100% so the b-jets for Higgs candidate can arise from mis-tagged QCD light jet.

As a consequence the Higgs boson has not yet been discover in this channel.

Main goals of the bachelor thesis:

- To understand the main phenomenological features of the $t\bar{t}H$ production process, with $H \to b\bar{b}$.
- To study Higgs production in this channel together with two main background processes, which are the top quark-pair production process with additional jets (b-jets or light jets), i.e. $pp \to t\bar{t}b\bar{b}$ and $pp \to t\bar{t}jj$ production.
- To use various techniques to reconstruct the Higgs boson and the $t\bar{t}$ pair and to understand how to identify b jets at parton level.
- To examine various observables and phase space cuts to suppress these two background production modes as compared to the signal process.

The student will learn:

- How to perform phenomenological analyses for the LHC.
- How to use publicly available Monte Carlo programs, e.g. HELAC-PHEGAS or MADEVENT.
- How to efficiently reduce background processes to enhance the signal process.

Requirements:

Basic understanding of particle physics is required and can be obtained during the work on the thesis. Programming skills in Fortran and/or C/C++ that can be easily learned during the time of the thesis.