CROSS SECTIONS AT NNLO

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In this talk we report on the state of the art on the calculation of cross section at next-to-next-to-leading (NNLO) accuracy.

1. Higher-order calculations

Next year, the LHC will start operating, ushering particle physics into a completely unchartered energy realm. The LHC is a proton-proton collider, thus in its use as a research tool it will be essential to have the best possible theoretical understanding of QCD, the theory of the strong interactions within the Standard Model. Because QCD is asymptotically free, at high Q^2 any cross section can be expressed as a series expansion in α_S. For most processes, it suffices to evaluate the series at next-to-leading (NLO) accuracy, which has several desirable features: *a*) the jet structure. At leading order it is trivial because each parton becomes a jet, at NLO the final-state collinear radiation allows up to two partons to enter a jet; *b*) a more refined p.d.f. evolution through the initial-state collinear radiation; *c*) the opening of new channels, through the inclusion of parton sub-processes which are not allowed at leading order; *d*) a reduced sensitivity to the renormalisation and factorisation scales, which are fictitious input scales, allows to predict the normalisation of physical observables, which is usually not accurate

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at leading order. That is the first step toward precision measurements in general, and in particular toward an accurate estimate of signal and background for Higgs and New Physics at the LHC; *e*) finally, the matching with a parton-shower MC generator, like MC@NLO, which allows for a reliable normalisation of the event, while generating a realistic event set up through showering and hadronisation.

2. The NNLO world

The NLO corrections, though, might be not accurate enough. For instance, *i*) in the extraction of α_S from the data, where in order to avoid that the main source of uncertainty be due to the NLO evaluation of some production rates, like the event shapes of jet production in e^+e^- collisions, only observables evaluated at NNLO accuracy are considered [1]; *ii*) in open b-quark production at the Tevatron, where the NLO uncertainty bands are too large to test the theory [2] *vs.* the data [3]; *iii*) in Higgs production from gluon fusion in hadron collisions, where it is known that the NLO corrections are large [4,5], while the NNLO corrections [6,7,8], which have been evaluated in the large-m_t limit, display a modest increase, of the order of less than 20%, with respect to the NLO evaluation; *iv*) in Drell-Yan productions of W and Z vector bosons at the LHC, which can be used as "standard candles" to measure the parton luminosity at the LHC [9,10,11,12].

In some cases, most notably in Higgs production from gluon fusion, the central value of a prediction may change when going from NLO to NNLO. However, the main benefit is in the reduction of the theory uncertainty band, due to the lesser sensitivity of the NNLO calculations to the μ_R, μ_F scales. In addition, up to three partons make up the jet structure. Thus, a lot of theoretical activity has been directed in the last years toward the calculation of cross sections at NNLO accuracy [a]. The total cross section [6,14], the rapidity distribution [15,16] and the differential cross section [17] for Drell-Yan W, Z production are known at NNLO accuracy. So are the total cross section [6,7,8], the rapidity and the differential distributions [18] for Higgs production via gluon-gluon fusion, in the large-m_t limit. However, only the calculations of Ref. [18], which has been extended to include the di-photon background [19], and Ref. [17] allow the use of arbitrary selection cuts.

There are essentially three ways of computing the NNLO corrections: *a*) Analytic integration, which is the first method to have been used [14], and

[a]For consistency, also the p.d.f. evolution has been computed to the same accuracy[13]

may include a limited class of acceptance cuts by modelling cuts as "propagators" [15,20]. Besides total cross sections, it has been used to produce the Drell-Yan rapidity distribution [15,16].
b) Sector decomposition, which is flexible enough to include any acceptance cuts [21,22,23,24], and has been used to produce the NNLO differential rates of Refs. [17,18,19] and of $e^+e^- \to 2$ jets [25]. The cancellation of the IR divergences is performed numerically.
c) Subtraction, for which the cancellation of the divergences is organised in a process-independent way by exploiting the universal structure of the IR divergences. However, the cancellation of the IR divergences at NNLO is very intricate [26,27,28,29,30,31,32,33,34], and except for test cases like $e^+e^- \to 2$ jets [29,34] and for parts of $e^+e^- \to 3$ jets [33], no NNLO numerical code has been devised yet. The standard approach of subtraction to NNLO relies on defining approximate cross sections which match the singular behaviour of the QCD cross sections in all the relevant unresolved limits. For processes without coloured partons in the initial state, in Ref. [32] we disentangled the various kinematical singularities of the squared matrix element in all singly- and doubly-unresolved parts of the phase space, which allows for the definition of subtraction terms for processes with any number of final-state coloured partons.

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