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Standard Model physics at the LHC

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Summary. — In this brief overview, we summarize theoretical advances and discuss selected topics of Standard Model physics at the Large Hadron Collider (LHC). In particular we show some illustrative recent results in the determination of parton densities and in the calculation of QCD radiative corrections.

PACS 12.38.-t – Quantum chromodynamics.
PACS 12.38.Bx – Perturbative calculations.
PACS 13.85.-t – Hadron-induced high- and super-high-energy interactions (energy > 10 GeV).

1. – Introduction

In the last decades the Standard Model (SM) emerged through an extraordinary theoretical and experimental effort as the theory describing the electromagnetic, weak, and strong interactions among the known elementary particles. The Standard Modelpredictions have passed all the experimental tests performed so far.

The recent discovery by the ATLAS and CMS experiments at the Large Hadron Collider (LHC) at CERN of a neutral boson resonance [1,2] represents the first important step towards the experimental exploration of the least known sector of the SM, the electroweak symmetry breaking mechanism [3, 4]. At present this particle has all the properties of the long sought Higgs boson, nonetheless the measurements still show large uncertainties which need to be further reduced with the help of more theoretical work. New and more stringent tests of the discovered particle — its couplings, mass and width — are in order to completely unveil the mechanism at the origin of the masses of the known elementary particles.

After a technical shutdown, the LHC is expected to start to operate in 2015 with nearly twice the energies it has managed so far. In order to fully exploit the information contained in the past and future LHC data, performing detailed studies of the known SM processes and, in case, to claim for new physics signals, it is fundamental to provide precise theoretical predictions for the SM cross sections and for the corresponding kinematical distributions.

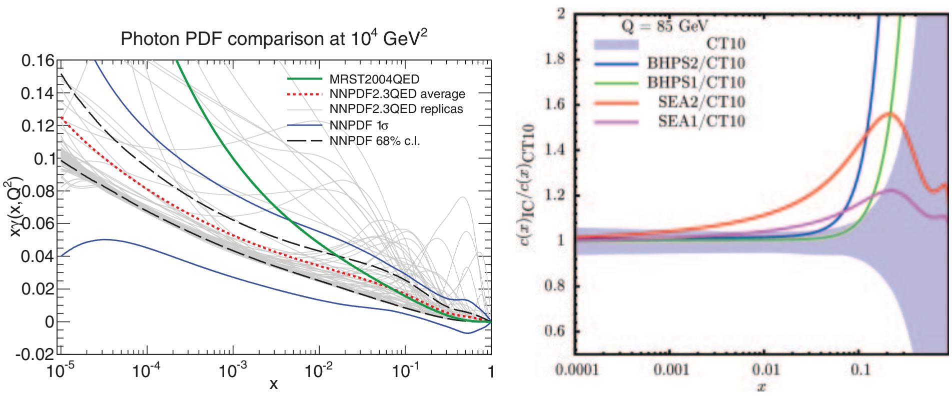

Fig. 1. – Left panel: photon distribution $x\gamma(x, Q^2)$ for $Q = 100\,\text{GeV}$, from ref. [11]. Right panel: ratio of charm quark distribution with and without intrinsic (non-perturbative) charm content $c(x, Q^2)_{IC}/c(x, Q^2)$ for $Q = 85\,\text{GeV}$, from ref. [12].

2. – Parton densities

A precise knowledge of the proton parton densities or parton distribution functions (PDF) is fundamental for physics studies at the LHC since PDF enter in the computation of any hadronic cross section. Moreover the PDF uncertainty is a large source of theoretical error and one of the limiting factors in the characterization of the Higgs boson at the LHC.

At present PDF are determined by fitting data from a wide variety of experiments and various collaborations have produced different sets of PDF, which differ in various aspects, such as the experimental input data, the perturbative order, the parameterization assumptions and the uncertainties [5-10].

The need for high precision theory predictions at the LHC require to consistently include in the PDF determination both the higher-order QCD corrections and the QED corrections together with the photon-initiated partonic contributions. Recently the NNPDF Collaboration presented a set of PDF which includes the photon PDF and the QED contributions to parton evolution [11] (see left panel of fig. 1). Substantial uncertainties related to electroweak corrections were observed in processes which are relevant for new physics searches at the LHC, such as high mass gauge boson production and double gauge boson production.

Another issue which may have an impact on LHC observables concern the possibility of an intrinsic (*i.e.* non-perturbative) charm component in the PDF. This effect was recently studied within the context of the CT10 next-to-next-to-leading order (NNLO) global analysis [12]. The intrinsic charm quark content at the matching scale $Q_c = m_c = 1.3\,\text{GeV}$ was parameterized with various models by a a valence-like (BHPS model) and sea-like (SEA model) parton distribution (see right panel of fig. 1). The correlation between the value of the charm quark mass and the intrinsic charm content was also discussed.

3. – Higher-order QCD calculations

In order to obtain accurate theoretical predictions for the LHC observables it is necessary to have a precise knowledge of both the *universal* parton densities and the

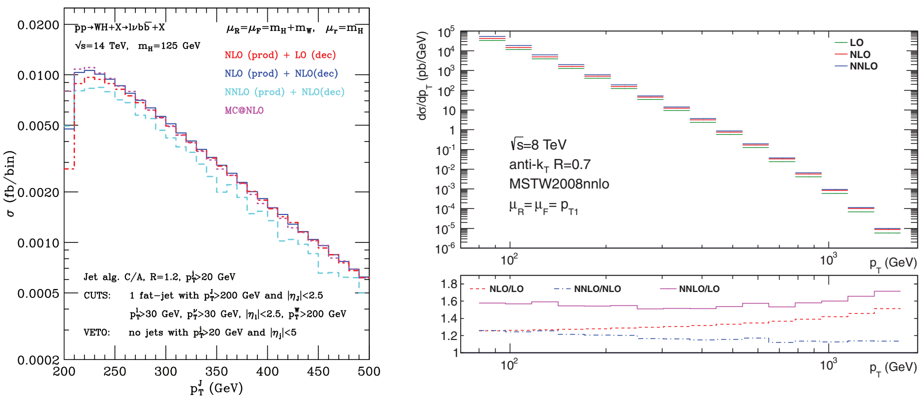

Fig. 2. – Left panel: $pp \to WH + X \to l\nu b\bar{b}$ production, transverse-momentum distribution of the fat $b\bar{b}$-jet at various perturbative orders compared with the parton-shower predictions, from ref. [28]. Right panel: Dijet production (gluonic channel), inclusive jet transverse-energy distribution in higher order QCD (lower panel shows the ratios), from ref. [31].

process dependent partonic cross sections. This task requires in particular the calculation of higher-order QCD perturbative corrections for a wide variety of processes.

It is well known that at hadron colliders, perturbative QCD calculations at the lowest order (the leading order, LO) give only a rough estimate of the corresponding cross sections. In order to obtain a reliable estimate it is necessary to calculate at least the next-to-leading order (NLO) corrections. A precise prediction with a trustable theoretical uncertainty can be obtained with the knowledge of the NNLO corrections.

The computation of the NLO and NNLO radiative corrections is not an easy task for the presence of singularities in the *real* and *virtual* quantum corrections. Moreover having experiments finite acceptances it is important to perform fully differential calculations which are particularly involved. Despite this, thanks to important advances in the field [13-21], in the past years various NLO [22-26] and NNLO [27-34] QCD calculations for processes of increasing complexity were obtained.

In ref. [28] it was considered the SM Higgs boson production in association with a W boson at the LHC. The fully exclusive computation of the NNLO QCD effects was supplemented with the computation of the Higgs boson decay into a $b\bar{b}$ pair in NLO QCD. By considering the selection cuts that are typically applied in the LHC experimental analysis, it was found that the NNLO corrections to the production process are important and typically decrease the cross section by an amount which depends on the detail of the applied cuts (see left panel of fig. 2).

In refs. [30, 31] it was presented the fully differential NNLO QCD calculation to dijet hadroproduction in the purely gluonic channel retaining the full dependence on the number of colours. The size of NNLO contributions are found to be approximately at 15–20% level. A strong reduction of the uncertainty due to variations of the factorization and renormalization scale was observed.

4. – Other results

There are many recent important results of SM physics at the LHC which could not be covered in this brief review. Some of them concern: automation in NLO calculations (see refs. [35-41]), all-order perturbative resummation (see refs. [42-50]), Monte Carlo parton showers (see refs. [51-57]), jets substructure (see refs. [58,59]), electroweak radiative effects (see refs. [60-64]) and Higgs physics (see refs. [65-68]).

5. – Conclusions

To fully exploit the information contained in the precise LHC data is fundamental to provide precise theoretical predictions for the Standard Model cross sections and for the corresponding distributions.

We reviewed some recent results on Standard Model physics at the LHC. In particular we showed some theoretical advances on parton densities and higher-order QCD calculations.

There are of course many important results that could not be covered in this brief overview, for some of them we have referred to the corresponding literature.

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