SM input parameters for Higgs physics

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This note summarises the Standard Model input parameters for Higgs cross section calculations. The same parameters can be used for other SM and BSM processes at the LHC.

1 Lepton masses

The lepton masses from the PDG are

$$m_e = 0.510998928 \pm 0.000000011 \text{ MeV} \tag{1}$$
$$m_\mu = 105.6583715 \pm 0.0000035 \text{ MeV} \tag{2}$$
$$m_\tau = 1776.82 \pm 0.16 \text{ MeV} \tag{3}$$

2 Electroweak parameters (to be completed)

The gauge boson masses and widths from the PDG are

$$m_W = 80.385 \pm 0.015 \text{ GeV} \qquad \Gamma_W = 2.085 \pm 0.042 \text{ GeV} \tag{4}$$
$$m_Z = 91.1876 \pm 0.0021 \text{ GeV} \qquad \Gamma_Z = 2.4952 \pm 0.0023 \text{ GeV} \tag{5}$$

Fermi constant

$$G_F = 1.1663787(6) \cdot 10^{-5} \text{ GeV}^{-2} \tag{6}$$

The gauge boson masses should the PDG ones. As for the gauge boson widths, values consistent with the perturbative order should be adopted. At NLO the W and Z widths are

$$\Gamma_W = 2.08872 \text{ GeV} \tag{7}$$
$$\Gamma_Z = 2.49595 \text{ GeV}\,. \tag{8}$$

The W width differs by 2.4% from the PDG value.

3 PDFs and the strong coupling constant α_S

The PDF uncertainty on a given cross section should be evaluated by using PDFs obtained with a common input value according to the PDF4LHC prescriptions. The α_S to be used should be the current PDF average

$$\alpha_S(m_Z) = 0.1185 \pm 0.0006 \tag{9}$$

but the uncertainty should be conservatively rescaled by a factor of 2 (?).[1]

$\alpha_S(m_Z)$ should be considered as the *overall input value* for the strong coupling. From this, ideally, one should compute the *specific input value* $\alpha_S(\mu_0)$ through RG running at the highest available perturbative order (currently 4-loop [6, 3]). However, this procedure introduces a mismatch with what is usually done at present, since the evolution from m_Z to the central renormalization scale of the process under consideration μ_0 is normally done through the RG evolution according to the order of the underlying calculation (i.e. at n-loop for a N^{n-1}LO calculation). In practice, when μ_0 is not too different from m_Z, the latter simplified procedure can be adopted.

Any further variation with the purpose of testing the perturbative stability (scale variation, $\overline{\text{MS}}$ /on-shell conversion) should be done at the appropriate order of the underlying calculation.

4 Quark masses

In Higgs physics, quark masses enter in two different ways. On the one hand, they occur as kinematical masses, associated with propagators, external lines, or phase space factors in the calculation of scattering and decay processes. On the other hand, in particular the masses of the three heaviest quark flavors enter as couplings: foremost in the Yukawa couplings of the quarks themselves, but also in other couplings related to those by symmetries (think of squark-Higgs couplings, for example). It is obvious that these Yukawa couplings are essential for Higgs physics, and that it is important to treat them to the best of our knowledge.

4.1 Overall input values

The first necessary condition for this is the precise knowledge of the numerical values for the quark masses. This values are process independent and will be referred to as *overall input values* (see the analogous discussion for α_S in Section 3). Since a direct measurement of their pole masses is impossible due to confinement, the quark mass determination typically involves some theoretical input.

Top-quark mass. The top quark is different from all other known quarks in the sense that it decays before it hadronizes. To a first approximation (i.e., neglecting soft QCD effects), the invariant mass of its decay products may be identified with the top quark pole mass. In fact, the agreement with the determination via the top quark pair production cross section justifies this with hindsight. We therefore recommend to use the current PDG value [2]

$$m_t^{\text{pole}} = 173.2 \pm 0.9 \text{ GeV} \tag{10}$$

as overall input value of the top quark mass.

Bottom-quark mass. The situation is much different for the bottom quark mass, because its mass can only be determined indirectly. We recommend to use the current PDG value for the $\overline{\text{MS}}$

[1]Note that this would lead us to $\Delta\alpha_S = 0.0012$ at 68% CL and $\Delta\alpha_S = 0.0020$ at 90% CL as recommended previously.

bottom mass [2]

$$m_b(m_b) = 4.18 \pm 0.03 \text{ GeV} \tag{11}$$

as overall input value.

Charm-quark mass. The charm quark mass is at the edge of the validity range of perturbation theory. Therefore, using $m_c(m_c)$ as overall input value in order to derive the charm quark mass at a different scale, or its perturbative pole mass, would force one to apply perturbation theory at these rather low energies. We therefore recommend to use [7]

$$m_c(3 \text{ GeV}) = 0.986 \pm 0.013 \text{ GeV} \tag{12}$$

as overall input value.

4.2 Specific input values

From the overall input values above, one should determine the *specific input value* that is suitable for the physical quantity under consideration. This could be m_b^{pole}, for example, or $m_b(m_H)$, if m_H is the characteristic scale of the process. The conversion from overall to specific input value should always be done at the highest available perturbative order (four-loop RGE evolution, three-loop $\overline{\text{MS}}$ - on-shell conversion).

Any further variation with the purpose of testing the perturbative stability (scale variation, $\overline{\text{MS}}$ /on-shell conversion) should be done at the appropriate order of the underlying calculation.

4.3 Consistency

Often, one has no access to a variation of the quark mass in certain parts of the calculation (e.g., most PDF sets are available only for one or a discrete set of quark mass values). In this case, one should still follow the procedure described above. The uncertainty due to a possible inconsistency introduced by using different quark mass values should be studied, for example by evaluating the observable with PDF sets corresponding to different values of the quark mass. The effect should be taken into account as a theoretical uncertainty.

4.4 Example

Consider the cross section $\sigma(pp \to Hb\bar{b})$ at NLO in the 4-flavor-scheme. The bottom quark plays two different roles here: as dynamical quantity in the propagators and the final state phase space, for which one may want to use the pole mass m_b^{pole}; and as a factor in the bottom Yukawa coupling, for which the $\overline{\text{MS}}$ value $m_b(\mu_0)$ may be more appropriate, with the central renormalization scale μ_0.

The recommendation is to evaluate both specific input values, m_b^{pole} and $m_b(\mu_0)$, from the central overall input value $m_b(m_b) = 4.18\,\text{GeV}$: m_b^{pole} by 4-loop conversion [1], and $m_b(\mu_0)$ by 4-loop RG running [5, 4] Analogously, $\alpha_{\text{S}}(\mu_0)$ should be evaluated through 4-loop RG running from $\alpha_{\text{S}}(m_Z)$ [6, 3].

In order to investigate the residual dependence of the cross section on the renormalization scale, $m_b(\mu)$ and $\alpha_S(\mu)$ should be evaluated from $m_b(\mu_0)$ and $\alpha_S(\mu_0)$ by 2-loop RG running, corresponding to the fact that the cross section (and thus its explicit μ dependence) is only available at NLO.

The parametric uncertainty due to the errors on the overall input parameters should be studied by simply varying $m_b(m_b)$ and $\alpha_S(m_z)$ within their error intervals.

The uncertainty induced by the m_b dependence of the PDF should be determined by convolving the partonic cross section with PDFs corresponding to different values of m_b, without altering the input values in the partonic process.

References

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