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Action to be taken | *Voting Procedure*

For endorsement	**SCIENTIFIC POLICY COMMITTEE** 273th Meeting **12-13 September 2011**	-
For information	**COUNCIL** 160th Session **15 September 2011**	-

Report on the question from Council to the SPC

The scientific significance of the possible exclusion of the SM Higgs boson in the mass range 114-600 GeV and how it should be best communicated

The scientific significance of the possible exclusion of the Standard Model Higgs boson in the mass range 114-600 GeV and how it should be best communicated

At its meeting in March 2011, the CERN Council asked for an assessment by the Scientific Policy Committee of the scientific significance of the possible exclusion of the Standard Model Higgs boson in the mass range 114-600 GeV and how it should be best communicated. At the SPC meeting in May 2011 a working group of the SPC consisting of M.Diemoz, K.Ellis, H.Murayama, K.Tokushuku and T.Wyatt (chair) was set up to carry out this assessment. The working group produced an oral interim report to the SPC at its June meeting, mostly focused on the scientific aspects of the question. Following the SPC discussion in June, which saw the active participation of several Council delegates, further work was made on the communication aspects. A written interim report was produced, incorporating suggestions from the CERN Communications group (C.Sutton), and was distributed to the Council president and scientific delegates before the major 2011 Summer conferences. The present document updates and completes this interim report. Preliminary results presented at the 2011 Summer conferences by the LHC and Tevatron experiments show that Higgs searches at the LHC are making very rapid progress, but the existence of the SM Higgs boson in its otherwise allowed mass range is still a very open experimental question. N.B. In preparing this document we have tried to distinguish material that uses language suitable for communication with the outside world (in standard font) from additional technical background for the Council scientific delegates as professional scientists *(in italic font).*

Answer to the Council Question

Summary of the main points

- The aim of the LHC is to explore particle physics phenomena at the TeV energy scale. In particular, one of the central goals is to discover the mechanism by which elementary particles acquire mass.

- Finding the Higgs boson, exactly as postulated in the Standard Model, would be a triumph. Ruling it out would be revolutionary, requiring textbooks to be rewritten.

- In both cases the same very stringent requirement on statistical significance should be applied. By the end of 2012, we expect the combination of data from LEP, the Tevatron and the LHC to meet this requirement.

- Either finding or ruling out the Standard Model Higgs boson will be just the start of a major programme of work to understand the origin of mass. This will require many years of operation of the LHC, accumulating the largest possible data set at the highest achievable energy.

Further Details

- Although in the popular imagination the goal of the LHC is to discover the Higgs boson, the scope of the LHC is really much broader: it is the scientific exploration of the TeV scale. A major part of this enterprise is to answer one of the most intriguing open questions in physics: "Why is it that the W and Z-bosons and the top quark have masses of around 100 times that of the proton, whereas the photon is massless?" *In technical terms this is "to discover the mechanism of electroweak symmetry breaking".* Discovering a light Higgs boson as predicted by the Standard Model is just one of the possible outcomes of this endeavour. However, other possibilities can be envisaged that would preserve the success of the Standard Model in describing the observed interactions of the elementary particles. What is finally discovered will depend ultimately on how Nature has chosen to resolve this intriguing puzzle. However, general arguments based on fundamental principles such as the conservation of total probability *(in technical terms: unitarity)* make us confident that by exploring the TeV scale the LHC will give us the answer one way or another. *Technical note: in this document we use the term "Standard Model Higgs" to refer to the simplest realisation of electroweak symmetry breaking with a single Higgs doublet.*

- Information on the existence or non-existence of the Higgs boson predicted by the Standard Model has so far been obtained in two ways. **Direct searches** for the production and decay of Higgs bosons at the LEP, LHC and Tevatron colliders indicate that the Standard Model Higgs boson is unlikely to have a mass of less than 114 GeV or to lie within the mass range from around 140 to 460 GeV. **Indirect evidence** for the existence of the Standard Model Higgs boson comes from taking into account the expected effect of processes involving "virtual Higgs" bosons on a large number of precisely measured physical processes at the LEP, SLC and Tevatron colliders. This analysis suggests that, if the Standard Model is the correct theory in the TeV region, the Higgs boson is unlikely to have a mass of more than 158 GeV. The above limits are quoted at 95% confidence level. *Technical note on the interpretation of a 95% confidence level interval: if the Standard Model Higgs boson were actually to exist and have a particular mass, there would be a less than 5% probability that statistical fluctuations in the experimental data (or "bad luck") would have led to that mass being nevertheless excluded at 95% confidence level.*

- Finding the Standard Model Higgs boson would be a very important discovery indeed, for which the commonly accepted "gold standard" of statistical significance is that there be much less than one in a million chance that any observed signal be the result of a statistical fluctuation rather than a genuine discovery. In technical terms this is referred to as "a significance of 5 standard deviations". However, ruling out the Standard Model Higgs boson in its otherwise allowed mass range, and with it the Standard Model in its simplest formulation, would be an even more important discovery, for which the same stringent requirement on statistical significance should be applied.

- With the amount of data expected at both the Tevatron and the LHC by the end of 2012 (*around 10 fb^{-1} of integrated luminosity per experiment for each of ATLAS, CMS, CDF and DØ)* a combined 5 standard deviation sensitivity for the Standard Model Higgs boson is expected for masses between 114 GeV and 600 GeV. *Technical note: a number of relatively modest possible extensions to the Standard Model could reconcile the indirect evidence from precision measurements with the discovery of a Higgs boson having a mass above 158 GeV. On the other hand, a Higgs mass greater than around 600 GeV would imply the replacement of the Standard Model with a more complete and strongly interacting theory already at the TeV scale, which would be accessible to the LHC.* Information from the Tevatron and the LHC is complementary in more than one respect. *Some technical detail: The most challenging region for* *the combined Tevatron and LHC Higgs boson search is the region just above 114 GeV, which happens also to be the one most favoured by the indirect evidence from electroweak data. In this region the dominant decay mode of the Standard Model Higgs is to a b quark-antiquark pair. At the LHC this decay mode is particularly difficult to observe, because of the backgrounds from other Standard Model processes containing b quarks. The most sensitive channel at the LHC in this mass region is provided by the decay of the Higgs boson to two photons. This decay provides a very clean experimental signature, but within the Standard Model it has a very low branching fraction. In contrast, at the Tevatron the dominant b quark decay of the Standard Model Higgs boson is visible above the background, in events in which the Higgs boson is produced in association with a W or Z vector boson. With 10 fb^{-1} per experiment, the Tevatron is expected to have 95% confidence level exclusion sensitivity down to 0.7 times the SM cross-section, the LHC down to 0.5 times the SM cross-section. Combining the Tevatron and LHC results will yield the required 5 standard deviation sensitivity.*

- At the time of the 2011 summer conferences the LHC experiments had analysed a data set *(about 1 fb^{-1} of integrated luminosity)* of around one tenth of that expected by the end of 2012. The combined Tevatron plus LHC sensitivity was therefore far from the required 5 standard deviation level over most of the range of possible Higgs boson mass. Summer 2011 therefore represents very much a "work in progress", with definitive answers much more likely to be available by summer 2012.

- Looking further into the future, if a light Standard Model Higgs boson were eventually excluded at the 5 standard deviation level, direct searches should continue, looking for Higgs particles or other signals foreseen in models alternative to the Standard Model. For example, many models with an extended Higgs sector and/or additional particles with respect to the Standard Model, such as supersymmetry or extra dimensions, predict the existence of one or more particles that would look like a Standard Model Higgs boson, but produce a lower rate of experimentally detectable signals at the Tevatron and LHC. This would call for extending the search to larger samples of LHC data, in which these more subtle signals could be detectable. In addition, it would be crucial to study the scattering of pairs of massive vector bosons (WW, WZ, ZZ) emitted by the colliding protons. *Of particular relevance are the "longitudinal" components of these vector bosons. These are the components that arise due to their non-zero mass and thus due to their coupling to the electroweak symmetry breaking sector.* Given sufficient collision energy and luminosity, the study of massive vector boson scattering can give information on what replaces the

Standard Model Higgs in ensuring that total probability is conserved *(more technically, in preventing the weak coupling amplitudes for WW, WZ and ZZ scattering from violating unitarity at a scale of around 1 TeV)*. Existing analyses of vector boson pair scattering, which should be updated, suggest that such a study would require many years of operation of the LHC, accumulating the largest possible data set at the highest achievable energy.

- Of course, all of this talk of exclusion limits should not make us forget that the discovery of a state consistent with the Standard Model Higgs boson would be a great triumph. Such a discovery would require extensive further experimental investigation at the LHC in at least two directions. First, it should be checked with the greatest achievable precision whether or not the observed state has indeed the properties expected of a Higgs boson in the Standard Model: in addition to its charge and mass, its spin, CP properties, coupling to the W, Z and fermions, and self couplings should be verified; in addition, the scattering of pairs of massive vector bosons should be shown to be consistent with expectations. Second, it should be checked whether such a Higgs boson is accompanied or not by additional new particles, not only additional resonances that might be evidence of an extended Higgs sector, but also other particles that may play a role in the global picture of electroweak symmetry breaking. Some simple possibilities have already been ruled out or strongly constrained by this initial phase of LHC operations, but others may have escaped detection in the searches that could be carried out with the so far available energy and integrated luminosity. Both of these programmes would require many years of operation of the LHC, accumulating the largest possible data set at the highest achievable energy. *For the first one, the detailed strategy would depend on the Higgs boson mass and thus the likely decay modes. From direct reconstruction of the final state particles the Higgs mass is expected to be determined to a precision of between around 1% (in the low mass region in which the observable decay mode is* $H\rightarrow\gamma\gamma$*) and around 3% (in the high mass region in which the dominant decay modes are to pairs of weak vector bosons). The determination of the Higgs couplings will require the measurement of the cross section times branching ratio into every observable final state. Information on the spin is readily available from either the gamma-gamma or fully reconstructed ZZ decay mode (depending on the Higgs mass). CP information can also be derived from the distributions of the tagging jets in vector boson fusion production.* Although some methods of measuring these parameters have been suggested, as usual having the data in hand will be a great spur to human ingenuity.