

Higgs boson production at the LHC

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Higgs boson is the only particle of SM model which was not observed yet.

From the fit of precise electroweak data ($\alpha_{e.m.}$, G_F , M_W , M_Z , ...) accounting for the radiative corrections – $M_H \sim 100\text{GeV}$.

(LEP2 $\rightarrow M_H > 114\text{ GeV}$; most probably Tevatron will reject the region of $M_H > 160\text{ GeV}$ soon)

If Higgs is light the dominant decay is $H \rightarrow b\bar{b}$.

A. Inclusive Higgs production goes mainly via the gluon-gluon fusion $gg \rightarrow H$. $\sigma_{incl}^H \sim 100$ pb but the QCD background in $b\bar{b}$ mode is huge. So the most promising channel to observe/discover Higgs boson are: $H \rightarrow \gamma\gamma$ ($Br \sim 10^{-3}$), $t\bar{t} + H (\rightarrow b\bar{b})$, $H \rightarrow \tau\tau$, may be $H \rightarrow \mu\mu$.

B. Another possibility, is to study the Higgs boson in exclusive process

$$pp \rightarrow p \oplus H \oplus p$$

Here Higgs is produced in the Pomeron-Pomeron fusion, where the Pomeron is represented by two t-channel gluons; the second gluon needed to compensate the colour flow across the Large Rapidity Gap (LRG).

The exclusive cross section is suppressed by a small probability not to fill LRG by the secondaries from soft rescattering (gap survival factor S^2) or by the QCD radiation in hard $gg \rightarrow H$ subprocess (Sudakov-like suppression T^2).

Therefore the expected cross section σ_{excl}^H is about factor 10^{-4} smaller than σ_{incl}^H but

a) no background from underlying high multiplicity event

b) QCD $b\bar{b}$ production is strongly suppressed ($\sim m_b^2/M_H^2$) by the $J_z = 0$ selection rule.

This opens the possibility to measure the $H \rightarrow b\bar{b}$ coupling.

The value of M_H can be measured precisely by the missing mass method detecting both forward protons.

$J_z = 0, P = \textit{even}$ selection rule suppresses the pseudoscalar boson production, non-relativistic 2^{++} heavy state production and simplifies the spin-parity analysis of the produced system.

The presence of Sudakov factor T selects a small size Pomeron components (to have a less probability of QCD radiation).

Thanks to this fact the 'bare' amplitude can be calculated perturbatively using the low x BFKL/DGLAP gluon distributions known from the global parton analysis.

Besides this we need the model for 'soft' rescattering to account for the screening S^2 .

The formalism to calculate the exclusive cross sections with Large Rapidity Gaps (LRG) and the corresponding backgrounds was developed.

To calculate the soft suppression factor S^2 the new model for soft interactions at high energies was built. The model accounts for the multi-Pomeron ($n \rightarrow m$) interactions and includes 3 component of different size to mimic the BFKL diffusion in $\ln(k_t)$ space. Thus the model has a possibility to embody a smooth matching of the perturbative QCD Pomeron and the 'soft' Pomeron.

The parameters were tuned to describe available high energy soft data in the CERN-ISR – Tevatron range. The model can be used to predict the cross sections expected at the LHC, the structure of the underlying events and the survival probabilities of the LRG, depending on the scale characteristic for one or another exclusive process.

In particular:

since the large-size Pomeron component is heavily screened by the effect of 'enhanced' multi-Pomeron diagrams we predict the saturation of the low p_t particle density (the multiplicity will grow due to the particles with a rather large p_t (of the order of 3 - 5 GeV)).

Due to a strong absorptive effects the model predicts a relatively low total cross section at the LHC – of about 90-95 mb.

Based on this results there was proposed to complement the CMS and ATLAS by the detectors of forward protons — Fp420-project.

The predicted exclusive cross sections are small. There is no hope to observe the exclusive Higgs production at the Tevatron. However this is not hopeless at the LHC since:

i) $\sigma_{excl}^H \sim 2fb$ is more than factor 10 larger

ii) LHC luminosity is much larger

For $L = 300$ 1/fb we expect 600 events

The calculated exclusive cross sections have uncertainties

(due to uncertainty in low x gluon distributions, NLO/NNLO corrections, phenomenological 'soft' model)

In order to check the formalism we considered other exclusive processes:

χ_c production

high $E_T > 5$ GeV $\gamma\gamma$ production

high E_T exclusive dijet production.

These processes were measured at the Tevatron. The results agree with our predictions.

The most important background cross sections were considered as well.

In particular, in 2008 the one loop corrections to the main irreducible background ($pp \rightarrow p + b\bar{b} + p$) were calculated. In comparison with the LO result the corrections reduce the background by a factor of 2 or more depending on the value of M_H .

Allowing for the dissociation of the incoming proton we get semi-exclusive cross sections which are more than 10 times larger than in a pure exclusive case.

Here we still have two LRG either side - so no background from the underlying event.

However then we lose the $J_z = 0$ selection rule, which suppresses the QCD background, and the possibility to use missing mass method to measure M_H precisely.

Going beyond the SM we expect a larger exclusive cross sections due to the presence of additional heavy particles which can mediate the $gg \rightarrow H$ interaction. In the case of Minimal Super Symmetric Model (MSSM) with a large $\tan \beta$ or in the case of "SM + 4th generation of fermions" the expected σ_{excl}^H will be an order of magnitude larger.

Moreover in exclusive events we may observe (and distinguish) both scalar bosons of the MSSM Higgs sector, while in semi-exclusive kinematics there will be a chance to observe the pseudoscalar boson of the MSSM Higgs sector.