Prospects for Top Mass Measurements at the LHC

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Summary. — The prospects for top mass measurements at the LHC are summarised. Some experimental techniques that have been exploited so far are outlined.

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1. – Introduction

The Large Hadron Collider LHC will start operation at the end of 2008. It will provide proton proton collisions at center-of-mass energies of 10 (14) TeV with a specific luminosity of $\approx 0.1\,(10)\,\mathrm{nb}^{-1}\mathrm{s}^{-1}$ (values in parenthesis for startup), which allow the inclusive production of top anti-top quark pairs at a rate of 10-100 Hz. The prospects of this enormous amount of statistics for precision measurements of the top quark mass with $\geq 1\,\mathrm{fb}^{-1}$ of data taken with the two experiments ATLAS and CMS will be discussed. The discussion will be divided into the different decay channels.

2. – Top mass measurement in the di-leptonic decay channel

In the di-leptonic decay channel a study for $1\mathrm{fb}^{-1}$ of data taken with the CMS detector is presented [1]. Main backgrounds are considered to be Z and di-boson production associated with additional hard jets and top events from other decay channels. All events were produced with the Pythia event generator in leading order and passed through the full simulation of the CMS detector including a simulation of the CMS L1 and High-Level-Trigger. Top events are selected by requiring two isolated leptons (e or μ) of opposite sign with transverse momentum $p_T > 20\,\mathrm{GeV}$, two jets with $p_T > 30\,\mathrm{GeV}$ and missing transverse momentum larger than 40 GeV, in addition to the trigger criteria. Leptons are considered isolated if the summed p_T of all reconstructed tracks within a cone of $\Delta R = \sqrt{\Delta\phi^2 + \Delta\eta^2} < 0.2$ in the vicinity of the lepton does not exceed 10% of the lepton's momentum. Electrons are identified using a likelihood method exploiting shower shape characteristics and the matching of tracks and calorimeter objects. For leptons of the same type an additional veto on the Z invariant mass is implied. The jets are required to fulfill a b-tag requirement based on the p_T and the invariant mass of the associated tracks and the result of a combined b-tag algorithm [2]. This selection is expected to provide a signal over background ratio of 12 : 1 for a top mass estimate between 100 and 300 GeV the remaining background mostly originating from other top decay channels. In fig. 1 (left) the most likely top mass determined from a parameter scan in the range of (100-300) GeV is shown. Unknowns are reduced imposing constraints on momentum conservation in the transverse plane, the W invariant mass and the equality of the top mass in both decay branches. Remaining ambiguities are taken into account by a weighting procedure based on the SM expectation of the neutrino momentum spectrum. The fit of a Gaussian function yields a top mass of $m_{\rm top}^{\rm rec} = 178.5 \pm 1.5\,({\rm stat.}) \pm 4\,({\rm syst.})$ GeV for an input mass of $m_{\rm top}^{\rm gen} = 175\,{\rm GeV}$. Systematic uncertainties are expected to be dominated by the uncertainty of the validity of the imposed constraints in the presence of initial and final state radiation, and the uncertainty of the jet energy scale (JES). For $10\,{\rm fb}^{-1}$ the uncertainties are expected to be reduced to $\Delta m_{\rm top} = 0.5\,({\rm stat.}) \pm 1\,({\rm syst.})$ GeV.

3. – Top mass measurement in the semi-leptonic decay channel

The semi-leptonic decay channel is considered to be the 'golden channel' for reconstruction of the top mass. The lepton in the event provides a well defined trigger and helps to reduce the expected large QCD background. We exemplify this channel by presenting a recent study performed by the ATLAS experiment which shows the expected performance using $1\,{\rm fb}^{-1}$ of integrated data. The study focuses on early data and makes use of as simple and robust methods as possible. The semi-leptonic events are selected requiring one high p_T lepton, transverse missing energy larger than 20 GeV, four jets with transverse energy E_T larger than 40 GeV, and two jets tagged as b-jets. To reconstruct the hadronically decaying W we select the two light jets which are closest in ΔR and which give the W mass peak within two sigma ($2*10.4$ GeV), this is referred to as the geometric method. Another method, that constrains the jet pair mass to the W boson mass and width from the Particle Data Group [3] by using a χ^2 minimization, has also been evaluated showing similar perfomance. The assignment of the b-jet associated with the hadronic top decay is made by choosing the hadronic W ($W_{\rm had}$) and corresponding b-jet that have the smallest distance in ΔR. The remaining b-jet (${\rm b_{lep}}$) and the leptonically decaying W ($W_{\rm lep}$) are assigned to the leptonic top quark. Four more cuts are applied in order to reduce background. The invariant mass of $W_{\rm had}$ and ${\rm b_{lep}}$ must be larger than 200 GeV, and the invariant mass of the lepton and ${\rm b_{lep}}$ must be smaller than 160 GeV. The W energy minus the b-jet energy in the top rest frame must be within one and a half sigma of the reconstructed distribution, and two times the b-jet energy in the top rest frame must be within two sigma. The top mass is reconstructed from the invariant mass of $W_{\rm had}$ and ${\rm b_{had}}$. To reduce the effect of the light JES we replace the observed invariant mass $M({\rm jjb})$ with $M({\rm jjb}) - M({\rm jj}) + M_W$, where M_W is the reconstructed W mass peak. The top mass is extracted using a fit to a Gaussian and a threshold function. The reconstructed top mass spectrum is shown in fig. 2. The estimated mass resolution is $\Delta m_{\rm top} = 0.3({\rm stat.}) \pm 0.7/(\%{\rm b_{JES}}) \pm 0.2/(\%{\rm JES}) \pm 0.4({\rm ISR/FSR})$, using $1\,{\rm fb}^{-1}$ of integrated data. The QCD initial and final state radiation is estimated by varying the QCD parameters in order to maximize the effect on the top quark mass. The top mass can also be used as commissioning tool to understand mass reconstruction calibration and performance. Even without b-tagging we expect this method to provide a mass accuracy of around 3.5 GeV assuming a JES uncertainty of 5%.

4. – Top mass measurement in the full hadronic decay channel

In the full hadronic decay channel the greatest difficulties arise from a large background of QCD multijet events and the large combinatorics originating from jet parton association for the event reconstruction. An estimate of the top quark mass is presented from a study for 1fb^{-1} of data taken with the CMS detector [4]. All events were produced with the Pythia event generator in leading order and passed through the full simulation of the CMS detector including a simulation of the CMS L1 and High-Level-Trigger. Top events are selected requiring between 6 and 8 jets with $p_T > 30\,\text{GeV}$ in the central detector in addition to the trigger requirements. The two leading jets are required to have $100\,\text{GeV} < p_T < 300\,\text{GeV}$. Further background discrimination is achieved with help of eventshape variables and by requiring two tags from a common b-tag algorithm. The signal to background ratio of this event selection is estimated to be 1 : 9. The jet parton association is performed with the help of a maximum likelihood method based on several kinematic variables. Only one of the top quarks of the reconstructed event is chosen for the mass measurement, the decision which one to take again being based on a maximum likelihood method. In fig. 1 (right) the resulting distribution of the reconstructed invariant top mass is shown. The fit of a Gaussian function in the region where the distribution exceeds 40% of the maximal value yields a top mass of $m_{\text{top}}^{\text{rec}} = 175 \pm 0.6\,(\text{stat.}) \pm 4\,(\text{syst.})$ GeV for an input mass of $m_{\text{top}}^{\text{gen}} = 175\,\text{GeV}$. Systematic uncertainties are expected to be dominated by the uncertainty of the amount and shape of QCD background. For $10\,\text{fb}^{-1}$ this uncertainty is expected to be understood to a level of $\Delta m_{\text{top}} = 2\,(\text{syst.})$ GeV, with negligible statistics uncertainties.

5. – Alternative methods of measuring the top mass

An alternative method of measuring the top quark mass indirectly via a correlation to related quantities has been exploited by a study of the CMS collaboration [5]. It makes use of the correlation between the invariant mass of the lepton originating from a leptonically decaying top quark and a reconstructed J/ψ in events with J/ψ's in subsequent decays of the b quark from the same top quark. This method is mostly independent of one of the major uncertainties of the direct measurements, which is JES The branching ratio of $t\bar{t} \to J/\psi\, X\, l\, \nu$ with $BR = 5.5 \cdot 10^{-4}$ is very small though, such that this method may only be accessible with more than $10\,\text{fb}^{-1}$ of integrated luminosity and a well understood tracking detector and lepton identification.

6. – Conclusions

The prospects for top mass reconstruction at LHC have been presented. We expect with current simulations that the top mass can be measured with high accuracy using 1 fb^{-1} of integrated data. Typically the uncertainty is around 1 GeV if the light jet energy uncertainty (JES) is around 1%. For data commissioning without b-tag we expect a mass accuracy of 3.5 GeV assuming an initial JES uncertainty of 5%.

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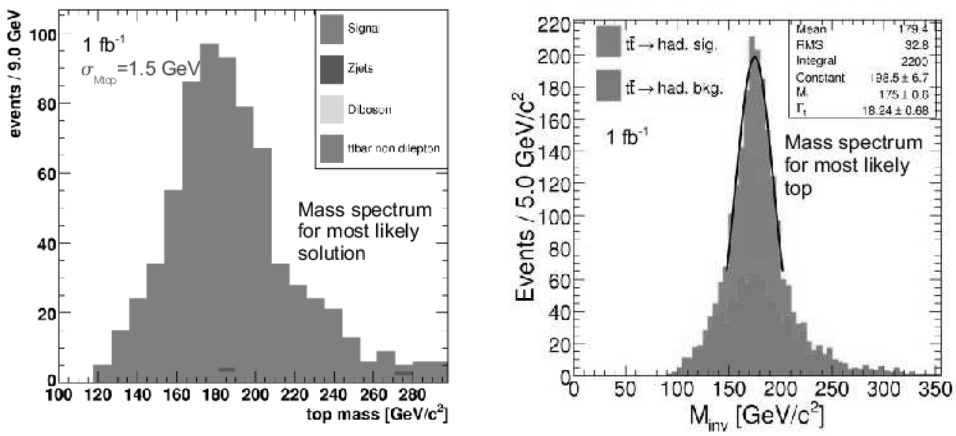

Fig. 1. – Top mass reconstructed from top anti-top quark pairs in the di-leptonic decay channel (left) and the full hadronic decay channel (right) as expected from full simulation with the CMS detector with $1\,\mathrm{fb}^{-1}$ of integrated luminosity [1] [4].

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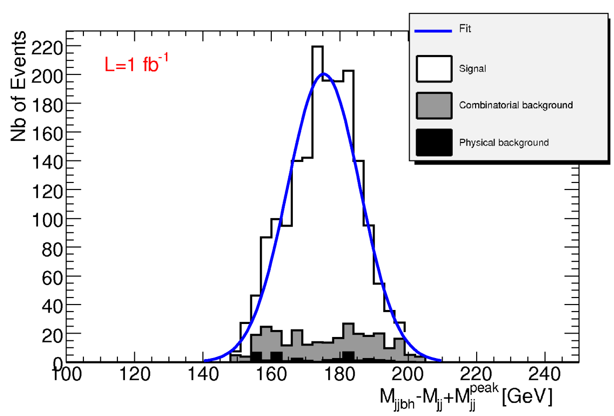

Fig. 2. – Expected top mass spectrum taken from full simulation of the ATLAS detector using reconstructed semi-leptonic events. The simulated events corresponds to 1 fb^{-1} of integrated luminosity. The statistical result from the fit is $m_{\mathrm{top}} = 175.3 \pm 0.3$ GeV, with a width of 10.6 ± 0.2 GeV.