Highlights from heavy-flavor measurements in ATLAS and CMS at LHC

G. Chiodini [a] , N. Orlando [a,b] and S. Spagnolo [a,b] and the ATLAS Collaboration

[a]Istituto Nazionale di Fisica Nucleare sez. di Lecce, Italy.

[b]Dipartimento di Matematica e Fisica ”Ennio De Giorgi”, Università del Salento, Italy.

The majority of the results on heavy flavor physics produced so far by the ATLAS[1] and CMS[2] experiments are based on the limited statistics of about 40 pb^{-1} per experiment collected in the 2010 LHC run at $\sqrt{\text{s}} = 7$ TeV. The relatively low luminosity and pileup allowed to select interesting events with inclusive low transverse momentum single or di-muon triggers, exploiting semileptonic decays of heavy flavors and $J/\psi \to \mu^+\mu^-$ decays. The measurements based on the 2011 data set, consisting of about 5 fb^{-1} per experiment, with an average number of interactions per crossing ranging from 6 to 12, have been performed thanks to dedicated J/ψ, Υ and $B \to \mu^+\mu^-$ triggers, with invariant mass selection and common vertex fit for the two muons. The main topics that have been investigated so far are inclusive and exclusive heavy flavor production, properties of well known and new hadrons with beauty, studies of the $c\bar{c}$ and $b\bar{b}$ bound states, precision measurements of the B_s system for CP violation studies and searches for rare decays. The results, summarized in this report, anticipate more and better contributions to the understanding of heavy flavor physics which will come with the analysis of the larger and still unexploited 2012 data set. This report was originally prepared for the proceedings of Les Rencontres de Moriond 2013, Electroweak Session. Here we concentrate on a few highlights only referring to [3] for a complete report of the results presented at the conference.

1. Onia properties

The charmonium system was one of the first physics topics widely studied with the LHC collisions at 7 TeV[4]. With increased statistics, the attention moved to the Υ system, triggered and reconstructed through the clean $\mu^+\mu^-$ signature. ATLAS observed a new state[5], interpreted as $\chi_b(3P)$, at M $= 10.530 \pm 0.005(\text{stat.}) \pm 0.009(\text{syst.})$ GeV in radiative transitions to $\Upsilon(1S)$ and $\Upsilon(2S)$. CMS measured the polarization of $\Upsilon(1S)$, $\Upsilon(2S)$ and $\Upsilon(3S)$ separating the data in two intervals of Υ rapidity and five transverse momentum bins[6]. The polarization parameters[7] $\lambda_\theta, \lambda_\phi$ and $\lambda_{\theta\phi}$ are extracted from the angular distributions of the polar and azimuthal angles of the μ^+ with respect to the z axis of the chosen polarization frame. Following a recently recommended strategy[7], the polarization parameters are measured in three different polarization frames along with the frame invariant combination $\lambda = (\lambda_\theta + 3\lambda_\phi)/(1 - \lambda_\phi)$. For all investigated Υ states no sign of significant transverse or longitudinal polarization is observed, in agreement with the findings of CDF, while the theory predictions are often predicting large and strongly model dependent polarization effects.

ATLAS has recently produced a measurement[8] of the differential production cross section of $\Upsilon(nS)$ in the approximation of null polarization. It can be seen that the dependence of the acceptance on the polarization can enhance or suppress the estimate of the production rate by up to about a factor of two. The variation affects mainly the contribution to the total cross section coming from the low $\text{p}_\text{T}(\Upsilon)$ region, while it induces a minor uncertainty at high p_T. The importance of the ATLAS measurements lies on the extension of the p_T range which reaches the unprecedented value of 70 GeV. The measurements are in agreement with earlier results, including an early CMS measurement. The comparison with theory is complicated by the contribution of radiative decays of higher mass charmonium states, which is generally not included in the calculations. The improved NLO non relativistic QCD prediction[9] is in rather good agreement with data in the intermediate p_T region, although it is affected by large uncertainties, arising from the incompete order of the calculation. The color evaporation model[10], which naturally accounts for phenomena like radiative feed-down, doesn't reproduce well the very low and high p_T regimes.

2. Studies of the B_s system

B_s can be observed through the fully reconstructed weak decay to $J/\psi\phi$ with $J/\psi \to \mu^+\mu^-$ and $\phi \to K^+K^-$. This channel is very important because, being open to both B_s^0 and $\bar{B}_s^0$, the interference between decay and oscillation amplitudes gives rise to CP violation via the phase ϕ_s. In the Standard Model ϕ_s has a small value, 0.0368 ± 0.0018[11], directly related to parameters of the CKM matrix but it is expected to receive extra contributions in several scenarios of new physics. ATLAS produced an

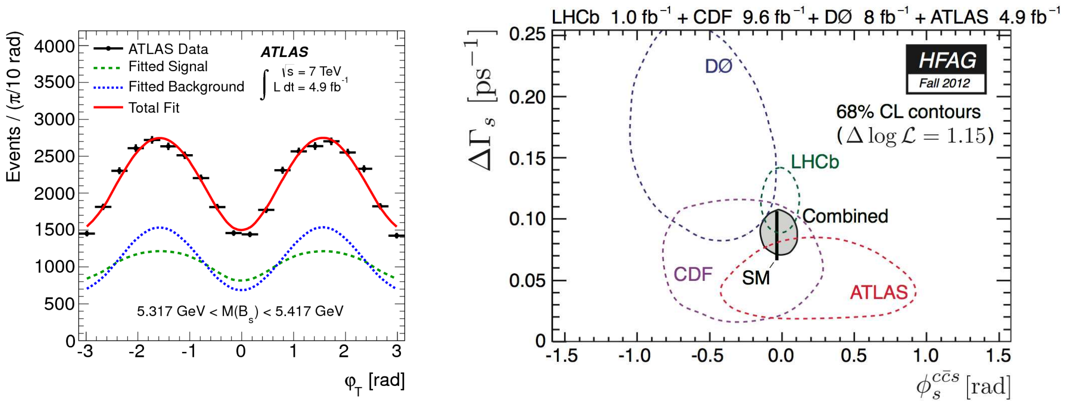

Figure 1. The ATLAS study[12] of the B_s^0 system: ϕ_T, one of the three angles in the transversity frame, (left) distributions for the selected candidates; the fit projection is overlaid to the data. The Fall 2012 HFAG combination[13], including the ATLAS results, of the constraints in the $\Delta\Gamma_s$ and ϕ_s plane at 68% CL (right).

analysis[12] of this decay based on the reconstructed mass, proper decay time and the three angles, θ_T, ϕ_T and ψ_T, defined in the so-called transversity frame, which uniquely define the full decay topology (with no attempt to tag the flavor of the B_s^0 meson). While the mass allows signal/background discrimination, the proper decay time distribution is sensitive to the lifetime difference between the two mass eigenstates and the angles are sensitive to the CP violating parameter ϕ_s. The power of this ATLAS measurement lies on the high statistics of the B_s sample extracted from the data. The results of the unbinned maximum likelihood fit, projected onto the ϕ_T distribution in Fig.1 (left), imply constraints on the $(\phi_s, \Delta\Gamma_s)$ plane which are consistent with those provided by CDF, D0 and LHCb and the precision is comparable with the Tevatron experiments. The Heavy Flavor Averaging Working Group produced a new combination[13], including the ATLAS constraints in Fall 2012, shown in Fig.1 (right) where the agreement between the measurements and the SM prediction is clearly established, although more precision is still needed on ϕ_s. A preliminary measurement of the lifetime difference was released by CMS[14]. The measured value, in agreement with the ATLAS results, is derived under the simplyfing assumption $\phi_s = 0$.

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