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Spectroscopy results from ATLAS and CMS (minireview at $\sqrt{s} = 7$ TeV)

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This paper reviews the preliminary results, collected at proton-proton collisions at $\sqrt{s} = 7$ TeV, on identification and reconstruction of strange, charm and beauty particles in the ATLAS and CMS experiments.

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1. ATLAS and CMS Detectors

In March 2010, the Large Hadron Collider (LHC) started to deliver pp-collisions at the centre of mass energy of 7 TeV. The luminosity delivered by the LHC was efficiently recorded by the two multipurpose detectors ATLAS [1] and CMS [2] and used for commissioning of the various detector components. For the spectroscopy measurements presented in this paper, it is important to notice the specifics of the two detectors in geometrical coverage and magnetic field. ATLAS and CMS can cover track reconstruction in pseudo-rapidity[1] $|\eta| < 2.5$, while the muon spectrometer can reach $|\eta| < 2.7$ for ATLAS and $|\eta| < 2.5$ for CMS. The CMS magnetic field of 3.8 T allows a p_T resolution of $\sigma_{p_T}/p_T = 0.015\% p_T \oplus 0.5\%$. The ATLAS detector can reach with its 2 T magnetic field a resolution of $\sigma_{p_T}/p_T = 0.05\% p_T \oplus 1\%$.

The various results presented here were obtained at different stages of collecting luminosity and they contain only statistical errors.

2. Reconstruction of Strange Particles

First particles that one can reconstruct in the commissioning phase of the two detectors are the strange particles K_S^0 and Λ^0. Due to their long life-time, the corresponding combinatorial background can be reduced to a level bellow one percent. In addition, they can be used as "candle resonances" allowing a direct check of the alignment and of the momentum resolution.

The K_S^0 resonance is reconstructed in the ATLAS [3] detector using two opposite charge tracks with the π mass hypothesis that can be merged to a secondary vertex (SV) which in the (x,y) plane is at least 0.4 cm far from Primary Vertex (PV). In Fig. 1 (left) one can see the resolution that can be achieved (5.6 MeV/c^2) when the π is required to fulfill $p_T > 0.1$ GeV and $|\eta| < 1.2$ criteria. The combinatorial background can be reduced by asking for $\cos\theta > 0.999$ which implies that the angle θ between the momentum and the direction of flight is close to zero.

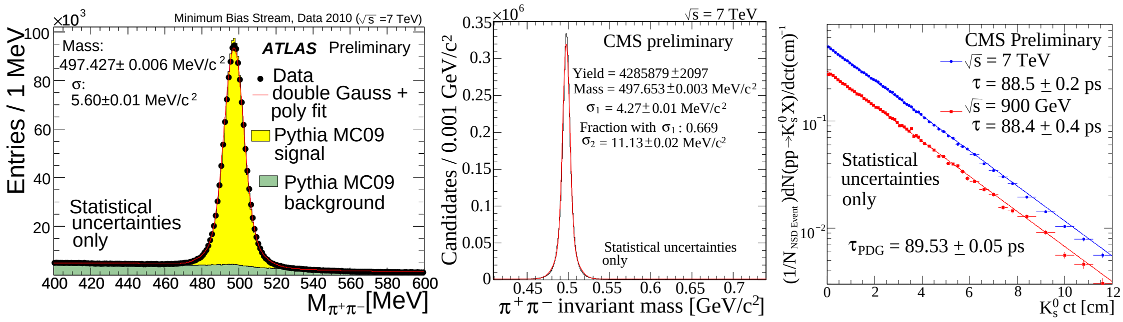

Figure 1: Invariant mass of the reconstructed K_S^0 using ATLAS (left) and CMS (middle) detector. The K_S^0 life-time measurement performed with the CMS detector (right).

A similar selection was applied also in CMS [4], requiring rapidity $|y| < 2.0$, for the results presented in Fig. 1 (middle) and (right) distributions. It is worth mentioning that the life-time obtained using the CMS detector in the first pp-collisions data has an accuracy on the per mille level.

[1] $\eta = -\ln[\tan(\theta/2)]$

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In addition to the K^0_S also strange mesons such as $K^*(890) \to K^0_S\pi^\pm$ [5] and $\phi(1020) \to K^+K^-$ were reconstructed. The $\phi(1020)$ resonance can be reconstructed cleanly in decays of higher resonances [6] (e.g. $D^\pm_s \to \phi(K^\pm K^\mp)\pi^\pm$) as one can see in Fig. 2 (right). The CMS results for $K^*(890)$ and $\phi(1020)$ at $\sqrt{s} = 900$ GeV and 2.36 TeV can be found at [7].

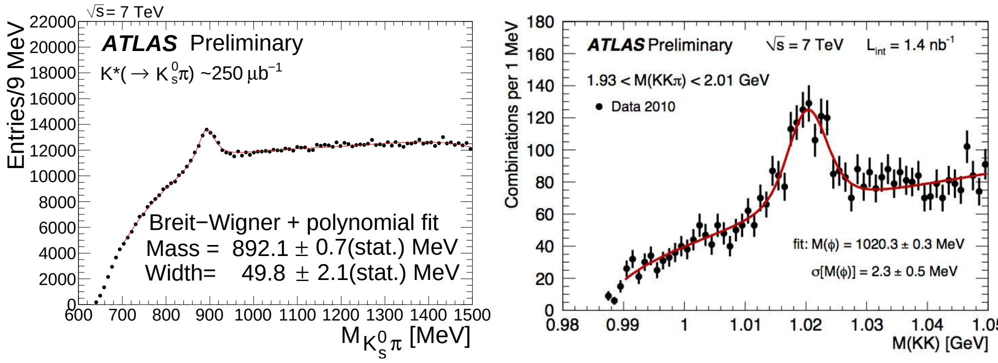

Figure 2: Invariant mass of the reconstructed $K^*(890) \to K^0_S\pi^\pm$ (left) and $\phi(1020) \to K^+K^-$ (right) using ATLAS detector.

The $\Lambda^0(uds) \to p\pi^-$ baryon and its corresponding anti-particle are reconstructed using a similar selection as for K^0_S. The background is reduced in ATLAS [3] analysis using a harder cut on $\cos\theta > 0.9998$, while in the analysis performed on data recorded with CMS [4] detector the π mass hypothesis was assigned to the lower momentum track.

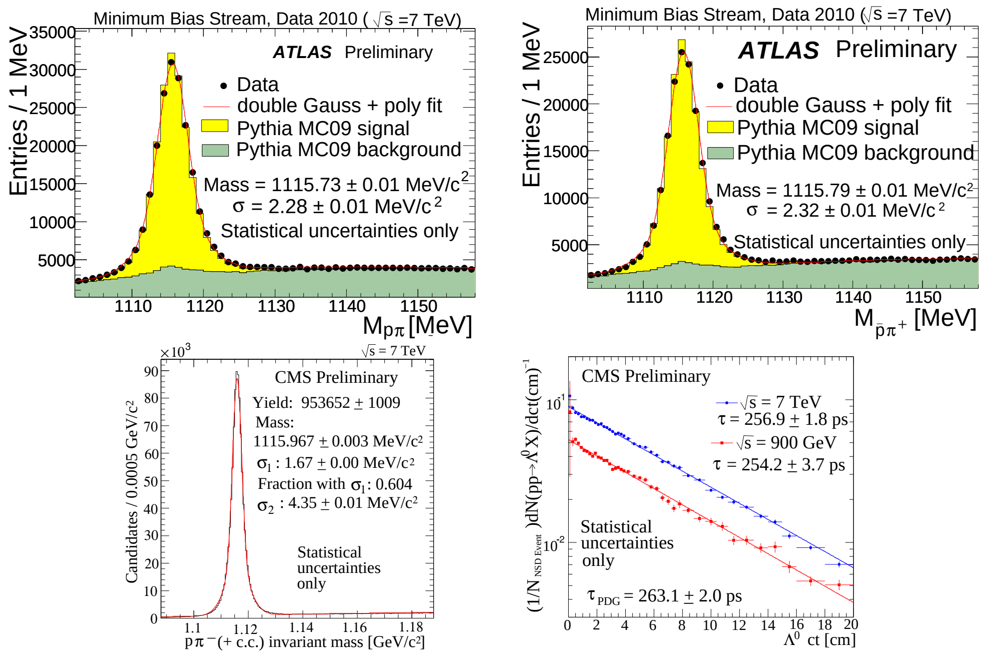

Figure 3: Invariant mass of the reconstructed Λ^0 and $\bar{\Lambda}^0$ using tracks selected within $|\eta| < 1.2$ in the ATLAS detector (top left and right). Invariant mass of $\Lambda^0 \to p\pi^-$ and charge conjugate combination (bottom left) and its lifetime (bottom right) using CMS data.

The results presented in Fig. 3 show a clear difference in reconstructing Λ^0 and $\bar{\Lambda}^0$ in the central part of the ATLAS detector, pointing back to differences in the production mechanism. This is also observed in CMS.

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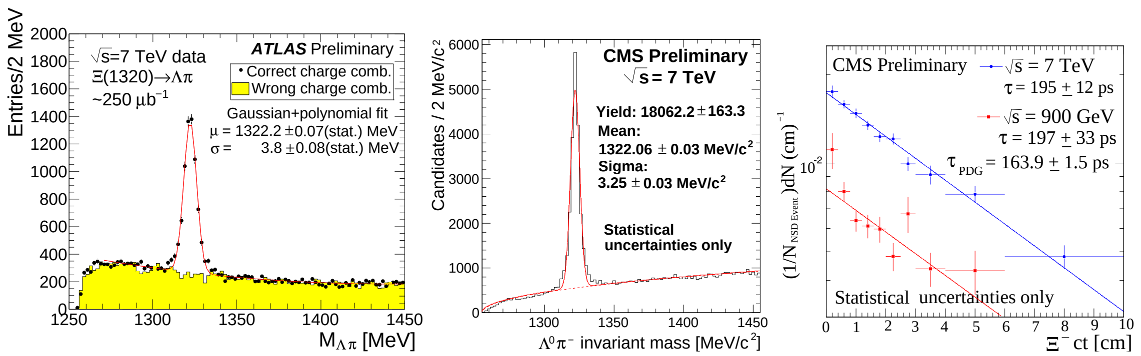

Figure 4: Invariant mass of the reconstructed $\Xi^{\pm}$ with ATLAS (left) and CMS (middle) recorded data. The first measurement of life-time of the $\Xi^{\pm}$ using CMS data (right).

Baryons with $S = 2$ have been reconstructed in the $\Lambda^0\pi^{\pm}$ decay mode, $\Xi^-(dss) \rightarrow \Lambda^0\pi^-$. The $\Xi^{\pm}$ is reconstructed in the ATLAS data [5], see Fig. 4 (left), selecting an additional charged track ($\pi^{\pm}$) having $p_T > 0.15$ GeV and the impact parameter in (x,y) plane $|d_0| > 0.5$ mm. The decay vertex of $\Xi^{\pm}$ is required to be 4 mm away from the PV. The CMS analysis [4] requires the flight distance of $\Xi^{\pm}$ larger than $4\sigma_d$ and asks for the trajectory to point back to the PV within 3σ. Results can be seen in Fig. 4 (middle). For the life-time of $\Xi^{\pm}$, Fig. 4 (right), more data need to be analysed in order to increase the precision of the measurement.

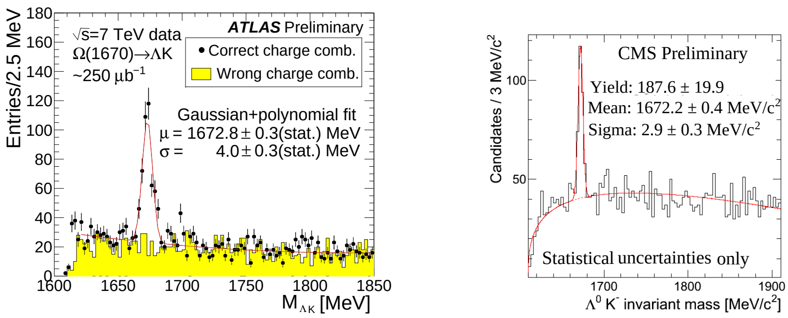

Figure 5: Invariant mass of the reconstructed $\Omega^- \rightarrow \Lambda^0 K^-$ with ATLAS (left) and CMS (right) detector.

The last strange baryon considered in this paper is the $\Omega^-(sss) \rightarrow \Lambda^0 K^-$. The invariant mass of ΛK system is shown in Fig. 5 for ATLAS (left) [5] and CMS data (right) [4]. The selection is similar to that for the Ξ^- baryon, additionally requiring $p_T > 1.5$ GeV for the reconstructed Ω^-.

The measurements of these very narrow strange resonances prove that both detectors have achieved a very good alignment and momentum resolution already in the commissioning phase.

3. Reconstruction of Charm Mesons

Another important chapter in spectroscopy that can be studied with the ATLAS and CMS detectors is represented by the charm mesons. In Fig. 6 one can observe the invariant mass difference used to identify the slow π from the golden decay channel $D^{*+} \rightarrow D^0\pi_s^+ \rightarrow K^-\pi^+\pi_s^+$ and its charge conjugate in case of ATLAS (left) [6] and CMS (middle) [8] recorded data. The invariant $K^-\pi^+$ mass accompanying the π_s is presented in Fig. 6 (right) for CMS detector. The selection criteria

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used in CMS analysis, very similar to those used in ATLAS analysis, are $p_{T\,K/\pi} > 0.6$ GeV and $p_{T\,\pi_s} > 0.25$ GeV, with the D^{*+} meson candidate fulfilling $p_{T\,D^*} > 5$ GeV and applying an invariant mass window around the D^0 mass $|M_{K\pi} - M_{D^0}^{PDG}| < 25$ MeV.

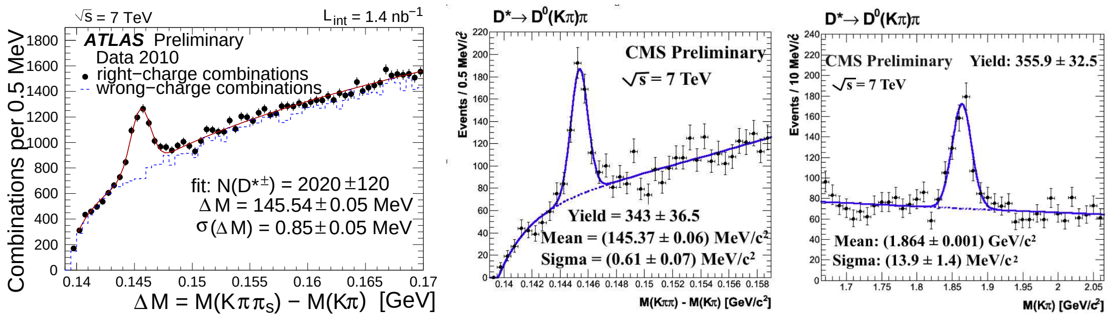

Figure 6: Invariant mass difference of the reconstructed slow π with ATLAS (left) and CMS (middle) recorded data. Invariant mass of D^0 messon candidates used in CMS analysis (right).

Two other important charm mesons that can be studied at ATLAS and CMS [8] are $D^{\pm} \to K^{\mp}\pi^{\pm}\pi^{\pm}$ and $D_s^{+}(c\bar{s}) \to \phi\pi^{\pm} \to K^{\mp}K^{\pm}\pi^{\pm}$. In Fig. 7 left (ATLAS) and middle (CMS) one can observe the reconstructed invariant mass of $D^{\pm}$ obtained with a simple and robust selection which requires a SV and certain amounts of p_T for K and π. The ATLAS analysis of D_s^{+} mesons requires a more elaborate selection, including criteria such as $\cos\theta^*(\pi) < 0.4$ where $\theta^*(\pi)$ is the angle between π in the $KK\pi$ rest frame and the $KK\pi$ line of flight in the laboratory frame. An additional angle selection used is $|\cos^3\theta'(K)| > 0.2$ where $\theta'(K)$ is the angle between one of the K's and π in the KK rest frame. As a supplementary result of the D_s^{+} mesons analysis one obtains the $\phi(1020) \to K^+K^-$

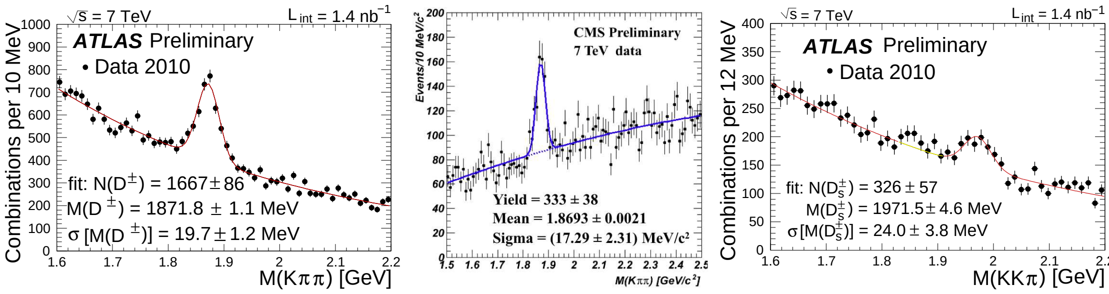

Figure 7: Invariant mass of the reconstructed $D^{\pm} \to K^{\mp}\pi^{\pm}\pi^{\pm}$ using ATLAS (left) and CMS (middle) detector. The $D_s^{+} \to \phi\pi^{\pm} \to K^{\mp}K^{\pm}\pi^{\pm}$ invariant mass obtained with ATLAS recorded data (right).

decay reconstruction, as shown in Fig. 2 (right).

The results on charmed mesons presented up to this point demonstrate the ability of the two detectors, ATLAS and CMS, to reconstruct low p_T tracks. The next step is to understand their performance regarding muon reconstruction. The best "candle resonances" for this purpose are the di-muon decays of the double charm ($J/\Psi(1S)$) and beauty ($\Upsilon(1S)$) mesons.

In the CMS analysis [9] the $J/\Psi(1S)$ di-muon candidates are reconstructed requiring a SV probability larger than 0.1% and transverse momentum of the reconstructed muons above certain thresholds depending on the η region of the detector where they have been reconstructed. In the ATLAS analysis [10] an asymmetric requirement on the p_T of the two muons was used (2 and 4 GeV respectively). In Fig. 8 one can observe that the invariant mass resolution that can be

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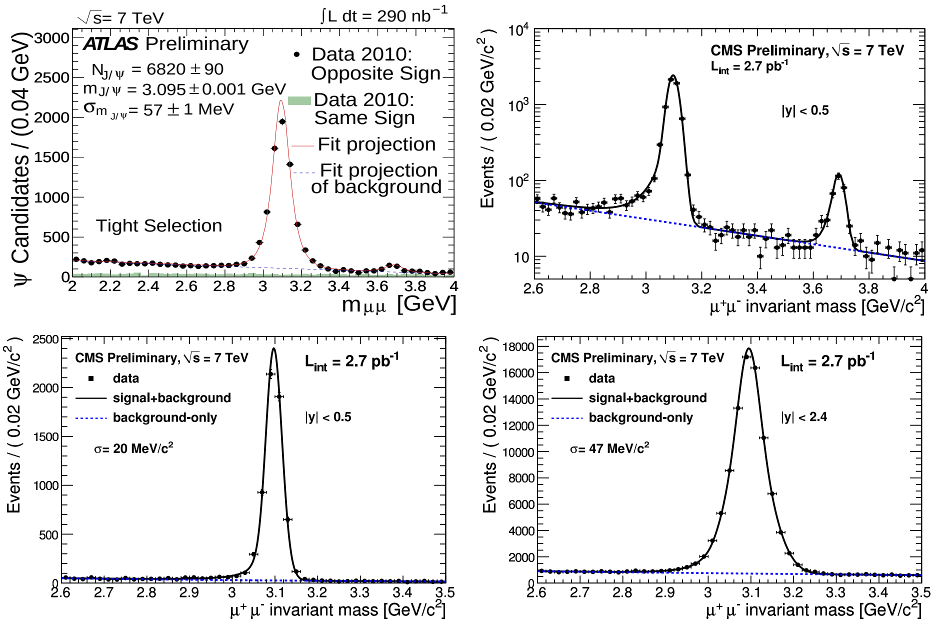

Figure 8: Invariant mass of $J/\Psi(1S)$ di-muon opposite charged pairs using the ATLAS (top left) and the CMS (bottom) detectors. The $\Psi(2S)$ resonance in CMS di-muon data (top right).

achieved with the ATLAS detector is about 1.8% and can reach even 0.6% for the central region of the CMS detector. This points back to a very good understanding of reconstruction issues, as for example the matching of the tracks from the tracker systems to those from the muon systems.

An additional indication of the very good muon reconstruction is the $\Psi(2S)$ di-muon resonance that can be observed already with an integrated luminosity of 2.7 pb^{-1} in the CMS data.

4. Reconstruction of Beauty Mesons

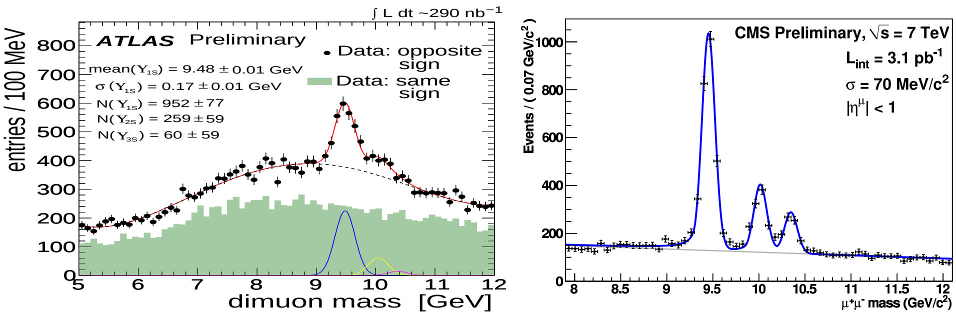

Figure 9: Invariant mass of Υ di-muon opposite charged pairs using the ATLAS (left) [10] and the CMS (right) detectors.

To complete the spectroscopy picture of the first pp-collisions data at $\sqrt{s} = 7$ TeV the $\Upsilon(b\bar{b})$ family (1S/2S/3S) reconstructed in the di-muon decay channel is presented in Fig. 9. The selection of the di-muon pairs is analogous to the one used for $J/\Psi(1S)$ reconstruction.

Using an integrated luminosity of 3.1 pb^{-1}, the three Υ resonances are observed in the CMS analysis [11], see Fig. 9 (right), with the fit resulting in $N(\Upsilon(1S)) = 2440 \pm 61$, $N(\Upsilon(2S)) = 757 \pm 40$ and $N(\Upsilon(3S)) = 464 \pm 34$ for the number of events in each of the three states.

In Fig. 10 (left) the results for the $B^- \rightarrow J/\Psi K^-$ analysis performed by CMS are presented. The B^- signal [12] was obtained after selecting events with a triggered muon of $p_T > 3$ GeV,

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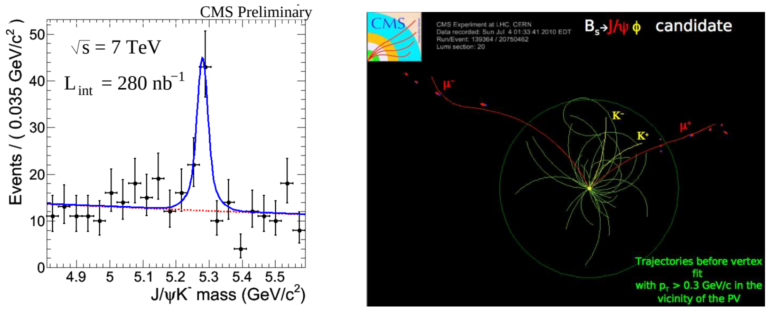

Figure 10: Invariant mass of B^- meson decaying into J/Ψ and K^- with the CMS detector (left). First $B_s^0 \to J/\Psi(\mu^+\mu^-)\phi(K^+K^-)$ candidate observed with CMS detector (right).

with the SV of both J/Ψ and B^- having a probability larger than 0.1% and requiring an additional charged track (the K) with $p_T > 0.9$ GeV. The fit performed on the invariant mass results in $m_{B^-} = 5280$ MeV/c^2 with a resolution of 32 MeV/c^2 and N_{B^-} of 48 ± 8. In addition to B^- mesons, also $B_s^0 \to J/\Psi(\mu^+\mu^-)\phi(K^+K^-)$ [13] can reconstructed as shown in Fig. 10 (right). For these a larger amount of data should still be analysed.

5. Conclusions

Measurements of the strange, charm and beauty hadrons collected with the ATLAS and the CMS detectors in the first pp-collisions at $\sqrt{s} = 7$ TeV were presented. In addition to these results, once more integrated luminosity becomes available, one can check for double K_S^0 resonances like $f_2(1270)/a_2^0(1320)$, higher $c\bar{c}$ states such as $X(3872)$ and of course analyse the B-meson sector looking for decay channels such as $B^0 \to J/\Psi K_s^0$ or $B_s^0 \to J/\Psi(\mu^+\mu^-)\phi(K^+K^-)$, and even studying baryons like $\Lambda_b^0 \to J/\Psi\Lambda^0$.

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