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Heavy Flavour Results from CMS

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The available statistics of heavy flavoured particles collected in pp collisions at the LHC provides an excellent opportunity to test the standard model and probe for new physics effects. A review of selected recent studies on heavy flavours, including the angular analysis in $B^0 \to K^{*0}\mu^+\mu^-$, the measurements of B^+ hadron production cross section, as well as the quarkonium production cross sections, by the CMS experiment based on datasets collected during LHC Run I and Run II is presented.

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1. Angular analysis of the decay $B^0 \to K^{*0}\mu^+\mu^-$

The decay $B^0 \to K^{*0}\mu^+\mu^-$ provides an excellent opportunity to look for new physics phenomena beyond the standard model (SM). The decay is a flavour-changing neutral current (FCNC) process and is particularly sensitive to the effect of new physics. Not just the decay branching fraction, other properties such as the forward-backward asymmetry of the dimuon (A_{FB}), and the longitudinal polarization fraction of the K^{*0} (F_L) can be also measured. In particular, these observables can be measured as a function of the q^2, which is the dimuon invariant mass squared. These observables can be well-predicted in the SM, while new physics may also contribute and modify them. Here we present the measurements of A_{FB}, F_L, and the differential branching fraction $d\mathscr{B}/dq^2$ from the $B^0 \to K^{*0}\mu^+\mu^-$ decays, using a dataset collected by the CMS experiment at a center-of-mass energy of 8 TeV, corresponding to an integrated luminosity of 20.5 fb^{-1}. A more detailed description of this analysis can be found in Ref. [1].

In the analysis, the K^{*0} candidate is reconstructed with its decay of $K^{*0} \to K^+\pi^-$, and the B^0 candidate is reconstructed by the two muon candidates and the two hadron tracks. These four tracks should form a common vertex, which should be displaced from the interaction point. The observables A_{FB} and F_L are measured by fitting the distribution of events as a function of two angular variables: the angle between the positively charged muon and the B^0 in the rest frame of dimuon pair (θ_l), and the angle between the K^+ and the B^0 in the rest frame of K^{*0} (θ_K). The following angular distribution is introduced:

$$\frac{1}{\Gamma}\frac{d^3\Gamma}{d\cos\theta_K d\cos\theta_l dq^2} = \frac{9}{16}\left\{\frac{2}{3}\left[F_S + A_S\cos\theta_K\right](1-\cos^2\theta_l) + (1-F_S)\left[2F_L\cos^2\theta_K(1-cos^2\theta_l) + \frac{1}{2}(1-F_L)(1-\cos^2\theta_K)(1+\cos^2\theta_l) + \frac{4}{3}A_{FB}(1-\cos^2\theta_K)\cos\theta_l\right]\right\} \quad (1.1)$$

where F_S and A_S are the fraction of S-wave contribution and the interference amplitude between S- and P-wave decays, respectively. These measurements are carried out for the events in bins of q^2, ranging from 1 to 19 GeV^2. Two q^2 regions ($8.68 < q^2 < 10.09$GeV^2 and $12.90 < q^2 < 14.18$GeV^2) which correspond to the decays of $B^0 \to J/\psi K^{*0}$ and $\psi' K^{*0}$, are used as control samples. In particular the $B^0 \to J/\psi K^{*0}$ channel is used to normalize the decay branching fraction of the target $B^0 \to K^{*0}\mu^+\mu^-$.

An angular analysis has been carried out with 1430 signal $B^0 \to K^{*0}\mu^+\mu^-$ candidates. The distributions of $K^+\pi^-\mu^+\mu^-$ invariant mass, and cosine of the two angles $\cos\theta_K$ and $\cos\theta_l$, for the events in a combined $1 < q^2 < 6$GeV^2 bin are shown in Fig. 1. The measured values of F_L, A_{FB}, and $d\mathscr{B}/dq^2$ as a function of q^2 are shown in Fig. 2. As a comparison, the shaded regions are from two SM predictions after averaging across the q^2 bins. Our measured results are consistent with the predictions as well as the previous experimental measurements.

2. Measurement of the B^+ production cross section

Measurements of b-hadron production cross sections can provide essential information to understand QCD. At the LHC, many measurements have been carried out during Run I period at center-of-mass energies of 7 or 8 TeV. Studies at a higher energies at the LHC Run II provide a

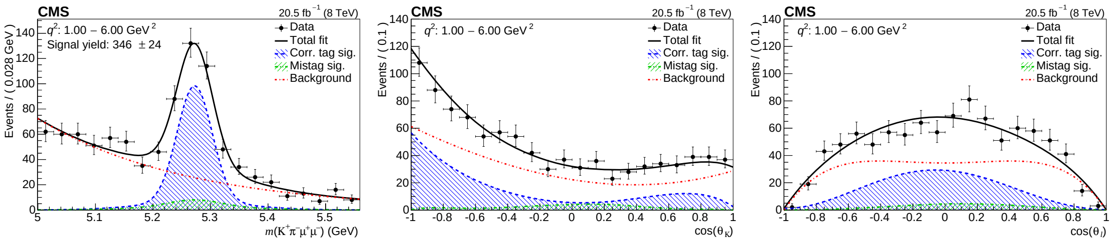

Figure 1: The $K^+\pi^-\mu^+\mu^-$ invariant mass (left) for the combined $1 < q^2 < 6\text{GeV}^2$ bin, and data and fit results projected onto the $\cos\theta_K$ (middle) and $\cos\theta_l$ (right) variables. The fit results show the total fit, as well as the three components: signal, K-π mistagged signal, and the background.

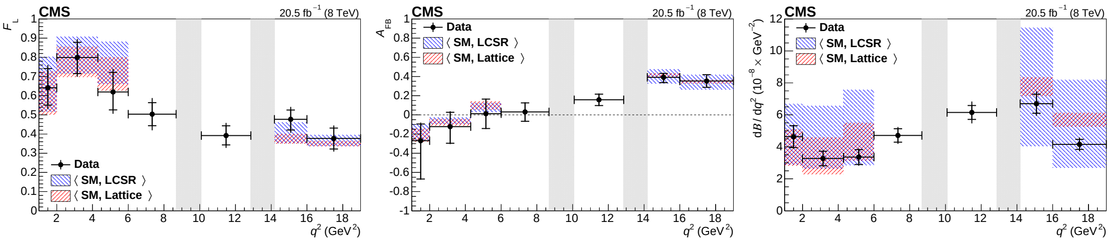

Figure 2: Measured values of F_L (left), A_{FB} (middle), and $d\mathscr{B}/dq^2$ (right) in bins of q^2. The statistical (total) uncertainty is shown by the inner (outer) vertical bars. The vertical shaded regions are excluded due to the J/ψ and ψ' resonances. The shaded regions are the SM predictions.

new test of theoretical calculations. A measurement of B^+ meson differential production cross section has been carried out in pp collisions at 13 TeV. The analysis, as described in Ref. [2] in detail, is carried out on a data sample corresponding to an integrated luminosity of 50.8 pb^{-1} collected by the CMS experiment.

The B^+ candidates are reconstructed in the decay chain $pp \to B^+X \to J/\psi K^+X$, with subsequent decay of $J/\psi \to \mu^+\mu^-$. The candidate muons are required to have $p_{\mathrm{T}} > 4$ GeV and $|\eta| < 2.4$, as well as a good track-fit quality. Candidate J/ψ mesons are reconstructed by combining pairs of oppositely charged muons, and have at least 8 GeV in p_{T}. Candidate B^+ mesons are formed by a J/ψ candidate with a charged kaon of $p_{\mathrm{T}} > 1$ GeV. Kinematic fits are performed to the μ-μ-K combinations, with a requirement of common vertex and constraining the dimuon mass to the nominal J/ψ mass. The transverse decay length significance is required to be greater than 3.5, and the B^+ candidate direction vector formed by the interaction point and the B^+ vertex should be in agreement with its momentum direction.

Differential production cross section of B^+ meson is reported a function of transverse momentum (p_{T}^B) and rapidity (y^B) of the B^+ candidate. Signal yields are extracted with extended unbinned maximum likelihood fits to the invariant mass distribution of the B^+ candidates. The differential cross sections are evaluated with

$$\frac{\mathrm{d}\sigma(pp \to B^+X)}{\mathrm{d}p_{\mathrm{T}}^B} = \frac{n_{\mathrm{sig}}(p_{\mathrm{T}}^B)}{2A \cdot \varepsilon(p_{\mathrm{T}}^B)\,\mathscr{B}\,\mathscr{L}\,\Delta p_{\mathrm{T}}^B}\,, \quad \frac{\mathrm{d}\sigma(pp \to B^+X)}{\mathrm{d}y^B} = \frac{n_{\mathrm{sig}}(|y^B|)}{2A \cdot \varepsilon(|y^B|)\,\mathscr{B}\,\mathscr{L}\,\Delta y^B}\,, \tag{2.1}$$

where $n_{\mathrm{sig}}(p_{\mathrm{T}}^{B})$ and $n_{\mathrm{sig}}(|y^{B}|)$ are the fitted signal yields in the p_{T}^{B} or $|y^{B}|$ bins; $\Delta p_{\mathrm{T}}^{B}$ and $\Delta y^{B} = 2\Delta|y^{B}|$ are the bin widths. The branching fraction $\mathscr{B}$ is the product of $\mathscr{B}(B^{+} \to J/\psi K^{+})$ and $\mathscr{B}(J/\psi \to \mu^{+}\mu^{-})$. The efficiency times acceptance $A \cdot \varepsilon(p_{\mathrm{T}}^{B})$ and $A \cdot \varepsilon(|y^{B}|)$ is calculated for each bin.

The differential cross sections as a function of p_{T}^{B}, integrated within $|y^{B}| < 2.4$, and as a function of y^{B}, integrated within $10 < p_{\mathrm{T}}^{B} < 100$ GeV, are shown in Fig. 3. The measured values show a reasonable agreement, both in terms of shape and of normalization, with the FONLL (shaded boxes) and PYTHIA (dashed lines) calculations.

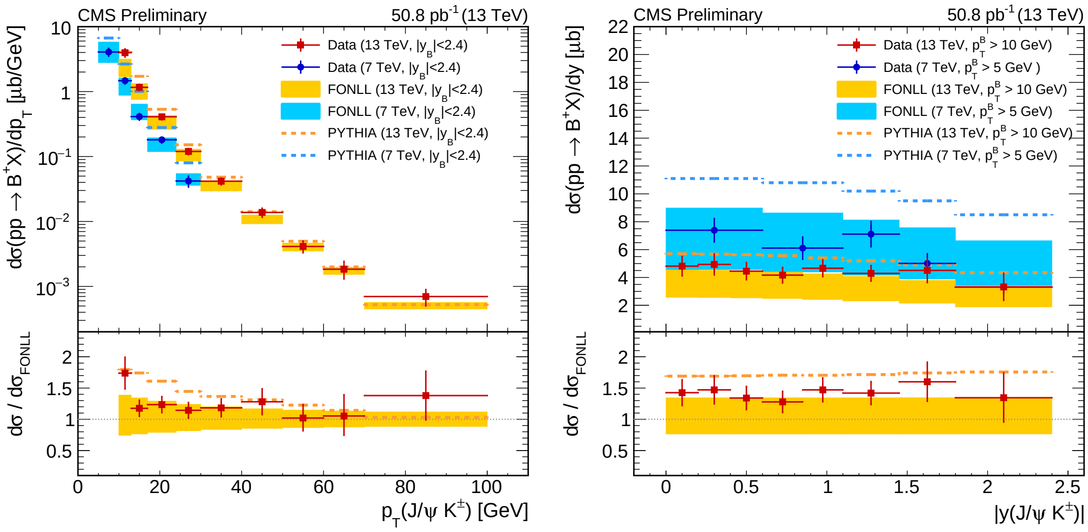

Figure 3: Differential $pp \to B^{+}X$ production cross sections $d\sigma/dp_{\mathrm{T}}^{B}$ for $|y^{B}| < 2.4$ (left) and $d\sigma/dy^{B}$ for $10 < p_{\mathrm{T}}^{B} < 100$ GeV (right).

3. Quarkonium production cross sections at $\sqrt{s} = 13$ TeV

Quarkonia is an ideal probe of hadron formation. The theoretical treatment is based on the Non-Relativistic QCD (NRQCD), which assumes factorization of the production process. The studies of quarkonium production in hadronic collisions have been carried out by colliders, including the LHC. In particular, comparison of the quarkonium production in pp collisions at 13 TeV and 7 TeV provides a good opportunity to test the factorization hypotheses of NRQCD. This analysis is documented in Ref. [3] in detail.

Events are triggered by requiring two muons. The two muons should have an invariant mass in the J/ψ, ψ', and Υ regions, and form a common decay vertex. Kinematical requirements, $p_{\mathrm{T}}(\mu) > 4.5$ GeV for $0.0 < |\eta(\mu)| < 0.3$, and $p_{\mathrm{T}}(\mu) > 4.0$ GeV for $0.3 < |\eta(\mu)| < 1.4$, are further applied to the muon candidates in order to perform the measurement in a region with high muon acceptance. Two oppositely charged muons are selected to form quarkonium candidates, and a minimum dimuon vertex-χ^2 probability of 1% is required. Cross sections of promptly produced quarkonium states are calculated in dimuon $p_{\rm T}$ and $|y|$ bins with

$$\mathscr{B}(q\overline{q} \to \mu^+\mu^-) \times \frac{d^2\sigma^{q\overline{q}}}{dp_{\rm T}dy} = \frac{N^{q\overline{q}}(p_{\rm T},y)}{\mathscr{L}\Delta y \Delta p_{\rm T}} \cdot \langle \frac{1}{\varepsilon(p_{\rm T},y)\mathscr{A}(p_{\rm T},y)} \rangle \,, \tag{3.1}$$

where $N^{q\overline{q}}(p_{\rm T},y)$ is the signal yield; Δy and $\Delta p_{\rm T}$ are the bin width in y and $p_{\rm T}$; $\langle \frac{1}{\varepsilon(p_{\rm T},y)\mathscr{A}(p_{\rm T},y)} \rangle$ accounts for the average of the acceptance times efficiency for all the events in the bin. The signal yields are measured using an extended unbinned maximum likelihood fit to the mass distribution for the Υ states, and a two-dimensional fit to the mass and the pseudo-proper decay length distributions is introduced for the J/ψ and ψ'.

The cross sections for the five quarkonium states are computed and presented in Fig. 4. A comparison of cross sections measured at 7 and 13 TeV are shown in Fig. 5. In summary, the double differential production cross sections for J/ψ, ψ', and $\Upsilon(nS)$ states have been measured by CMS in pp collisions at 13 TeV. Our results shall contribute to consolidate the NRQCD hypotheses and provide the inputs to constrain the theorical parameters.

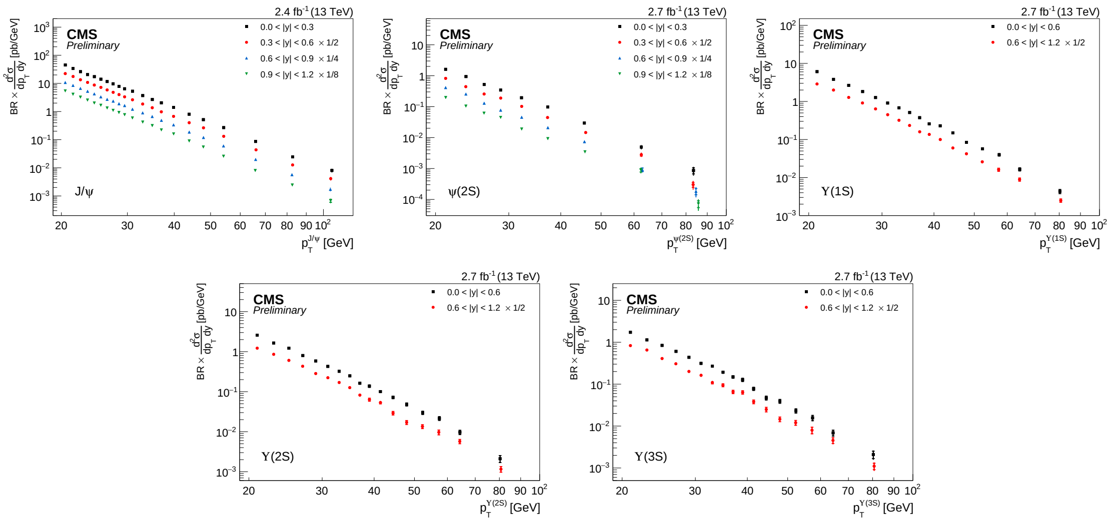

Figure 4: Double-differential cross sections times branching ratios for the five quarkonia states in several rapidity range. The inner (outer) error bars represent the statistical (total) uncertainty. The uncertainty on the luminosity is not included.

References

[1] V. Khachatryan *et al.* [CMS Collaboration], Phys. Lett. B **753**, 424 (2016) doi:10.1016/j.physletb.2015.12.020 [arXiv:1507.08126 [hep-ex]].

[2] CMS Collaboration, CMS Physics Analysis Summary BPH-15-004 (2015).

[3] CMS Collaboration, CMS Physics Analysis Summary BPH-15-005 (2015).

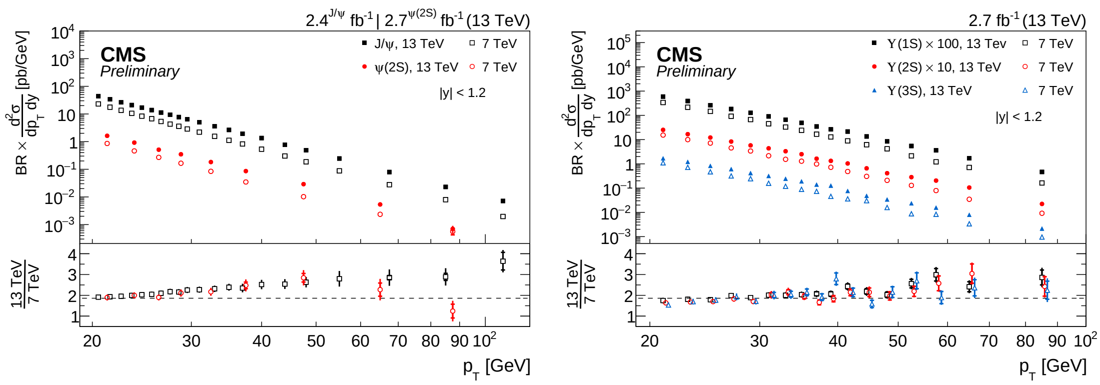

Figure 5: Differential cross sections times branching ratios for 7 and 13 TeV CMS data. The inner (outer) error bars represent the statistical (total) uncertainty. The uncertainty on the luminosity is not included.