Recent flavor physics results at CMS

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Thanks to the excellent tracking and muon identification performance, combined with a flexible trigger system, the CMS experiment at the Large Hadron Collider is conducting a rich and competitive program of measurements in the field of heavy flavor physics. In this talk we review our most recent results on heavy flavour physics, based on a data sample collected by the CMS detector.

1 Introduction

There are several motivations to study heavy flavour physics at LHC: advance beauty and charm spectroscopy, test QCD and effective theories, look for indirect evidence or constraints to new physics beyond the standard model, or simply try to have the best as possible description of the environment where direct new physics searches are conducted. In the following most recent results obtained by CMS will be shown.

All results are obtained with data collected at a center of mass energy $\sqrt{s} = 7$ TeV collected in 2011, with an integrated luminosity $\mathcal{L} \sim 5$ fb^{-1}, or $\sqrt{s} = 8$ TeV collected in 2012, with an integrated luminosity $\mathcal{L} \sim 20$ fb^{-1}. All measurements involve dimuons, most of the times originating from a resonance such as J/ψ or Υ. The presence of two muons in the final state allows maintaining a sustainable trigger rate at the high luminosities provided by LHC; the offline reconstruction of a vertex with the two muon candidates was also common for the involved analyses.

2 Mesons

The very rare exclusive decay $\mathcal{B}(B^0_{d,s} \to \mu^+\mu^-)$ was looked for since a very long time; the decay rate is highly suppressed and could be modified by new physics processes [1]. CMS measured its branching ratio by comparison with the decay $B^+ \to J/\psi K^+$, used for normalization:

$$\mathcal{B}(B^0_{d,s} \to \mu^+\mu^-) = \frac{N_{\rm sig}}{N_{\rm nrm}} \frac{\epsilon_{\rm nrm}}{\epsilon_{\rm sig}} \frac{f_u}{f_{d,s}} \mathcal{B}(B^\pm \to J/\psi K^\pm \to \mu^+\mu^- K^\pm) \qquad (1)$$

The B^0_s to B^+ production cross section ratio f_s/f_u has been assumed to be equal to LHCb measurement [2] $f_s/f_d = 0.256 \pm 0.020$, the corresponding ratio for B^0_d has been assumed to be 1. Signal and background have been discriminated by categorizing events by mean of a BDT variable

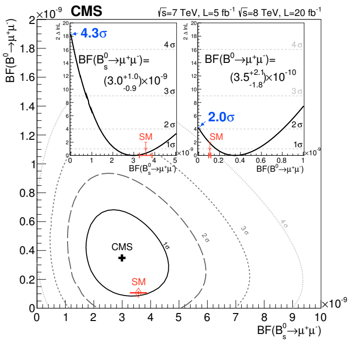

Figure 1: Comparison of CMS measurements with SM predictions in the $\mathcal{B}(B^0_s \to \mu^+\mu^-), \mathcal{B}(B^0_d \to \mu^+\mu^-)$ plane.

and fitting invariant mass distributions in each category to determine the signal yield and obtain the results [3]:

$$\mathcal{B}(B^0_s \to \mu^+\mu^-) = (3.0^{+1.0}_{-0.9}) \times 10^{-9}, \qquad \mathcal{S} = 4.3\sigma,$$
$$\mathcal{B}(B^0_d \to \mu^+\mu^-) = (3.5^{+2.1}_{-1.8}) \times 10^{-10}, \qquad \mathcal{S} = 2.0\sigma,$$
$$\mathcal{B}(B^0_d \to \mu^+\mu^-) < 1.1 \times 10^{-9} \ (95\% \text{ C.L.})$$

A comparison with the SM predictions [4] is shown in Fig. 1.

A preliminary combination of these results with the corresponding from LHCb has been performed [5]; LHCb had updated its measurement of f_s/f_d in the meanwhile [6] so the result has been rescaled before the combination:

$$\mathcal{B}(B^0_s \to \mu^+\mu^-) = (2.9 \pm 0.7) \times 10^{-9}, \ \ (f_s/f_u = 0.259 \pm 0.015),$$
$$\mathcal{B}(B^0_s \to \mu^+\mu^-) = (3.6^{+1.6}_{-1.4}) \times 10^{-10}.$$

In the decay $B^0_s \to J/\psi\phi$ the final state is unflavoured, so that it can be reached directly or after an oscillation $B^0_s \to \bar{B}^0_s \to J/\psi\phi$ leading to an interference between the two channels, and has no definite CP, so that an angular analysis is required to disentangle the odd and even components [7]. The differential decay rate

$$\frac{d^4\Gamma(B_s(t))}{d\Theta dt} = f(\Theta, t; \alpha) \propto \sum_{i=1}^{10} O_i(\alpha, ct) \cdot g_i(\Theta) \qquad (2)$$

can be expressed as a function of decay time t and angles $\Theta = \vartheta, \varphi, \psi$, as shown in Fig. 2, with a set of parameters α, including the amplitude and phases of S-wave and P-wave processes, the B^0_s lifetime τ_{B_s}, the width difference between the two CP states $\Delta\Gamma_s$ and the interference phase ϕ_s. When in the event we find a second b-hadron decaying semileptonically it can be used to determine the flavour, although with some dilution due to its own oscillation or cascade decays. The tagging information has been introduced in the differential decay rate and the events PDF has been fitted [8] by constraining the mass difference to the world average and assuming there's no direct CP violation:

$$\phi_s = (-0.03 \pm 0.11 \pm 0.03) \text{ rad},$$
$$\Delta\Gamma_s = (0.096 \pm 0.014 \pm 0.007) \text{ ps}^{-1}$$

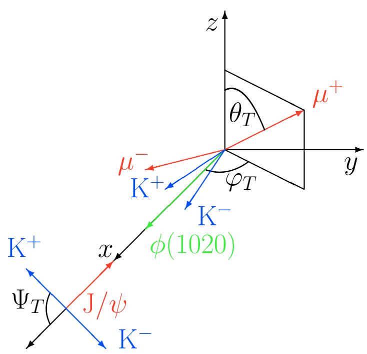

Figure 2: Angle definitions in $B^0_s \to J/\psi\phi$ decays.

Another important heavy-flavoured hadron to study is the $B^{\pm}_c$, which carries two heavy flavours, beauty and charm, that can be produced only in higher order processes and decay in a competition between the c and b quarks. A measurement of its cross section production and decay branching ratio can help in understanding the involved processes and is of course propaedeutic for more refined investigations. CMS has studied $B_c^\pm$ mesons in the decay channels to J/ψ and one or three pion(s); a fit to the invariant mass peaks for the two channels allows a determination of the ratios of cross section times branching fraction [9]:

$$\frac{\sigma(B_c^\pm)\times\mathcal{B}(B_c^\pm\to J/\psi\pi^\pm)}{\sigma(B^\pm)\times\mathcal{B}(B^\pm\to J/\psi K^\pm)} = \left(0.48\pm0.05\pm0.04^{+0.05}_{-0.03}(\tau_{B_c})\right)\times10^{-2},$$

$$\frac{\mathcal{B}(B_c^\pm\to J/\psi\pi^\pm\pi^+\pi^-)}{\mathcal{B}(B_c^\pm\to J/\psi\pi^\pm)} = 2.43\pm0.76^{+0.05}_{-0.03}.$$

The invariant mass of the $J/\psi\pi^\pm$ is shown in Fig. 3; the $B_c^\pm$ reconstruction efficiency has been determined assuming a lifetime $\tau_{B_c} = (0.452\pm0.032)$ ps and the effect of the corresponding uncertainty has been quoted explicitly in the systematic error.

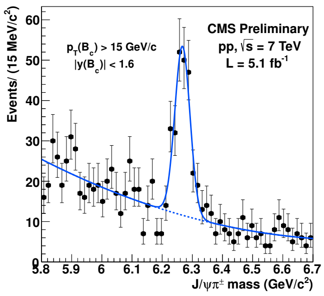

Figure 3: $J/\psi\pi^\pm$ invariant mass distribution.

3 Quarkonia

At CMS quarkonia are reconstructed by combining opposite charge muons and fitting a common vertex; this allowed the measurement of several properties of $\psi(n\text{S})$ and $\Upsilon(n\text{S})$, as production cross section and polarization. Recently the differential cross section for the production of prompt J/ψ and ψ' have been measured with 2011 data [10]; due to the integrated luminosity 100 times bigger than the one corresponding to 2010 data used for previous measurement the p_T acceptance was increased reaching 95 GeV in 4 rapidity bins. The event yield in the various p_T and rapidty bins was determined by mean of a simultaneous fit to invariant mass and flight distance to discriminate prompt and non prompt components while the acceptance was computed for several scenarios, corresponding to full longitudinal, transverse or null polarization. In Fig. 4 the differential cross section vs. p_T is shown, in the unpolarized production scenario.

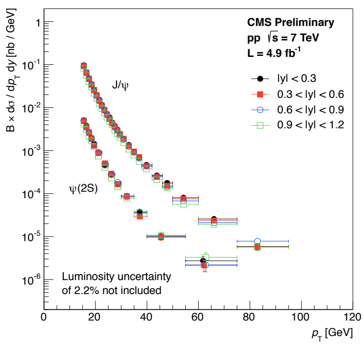

Figure 4: Differential cross section for prompt J/ψ and $\psi(2\text{S})$ production.

The measurement of the simultaneous production of two J/ψ mesons in the proton-proton collisions provides general insight into how particles are produced in the collision; J/ψ pairs produced in single-parton scattering are strongly correlated, while large values of rapidity difference $|\Delta y|$ are possible for production due to double-parton scattering [11]. The differential cross section for the production of charmonium pairs has been measured [12] in bins of rapidity difference $|\Delta y|$; acceptance has been determined by assuming unpolarized J/ψ production. The results are shown in Fig. 5; the cross section increase at $|\Delta y| > 2.6$ can be a hint of double parton scattering.

In addition to S-wave quarkonia at LHC also P-wave states are produced; they contribute with their decay to J/ψ and Υ production while the relative production of themselves is sensitive to singlet or octet states in the production mechanism.

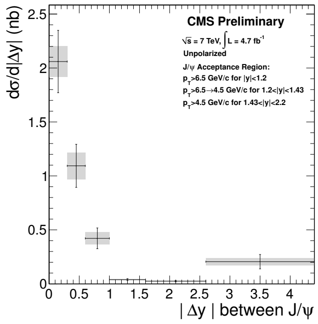

Figure 5: Double J/ψ production cross section vs. rapidity difference.

At CMS $\chi_b(1\text{P})$ states can be reconstructed in the decay channel to $\Upsilon(1\text{S})\gamma$, with the photon converting into an e^+e^- pair in the interaction with the detector material [13]; the conversion probability multiplied by the efficiency of reconstructing two low-p_T tracks is very small, but the mass resolution is high enough to distinguish the two states χ_{b1} and χ_{b2} having a very small mass difference $\Delta M = 19$ MeV. The ratio

$$R_b = \frac{\sigma(pp \to \chi_{b2}X)\mathcal{B}(\chi_{b2} \to \Upsilon(1\text{S})\gamma)}{\sigma(pp \to \chi_{b1}X)\mathcal{B}(\chi_{b1} \to \Upsilon(1\text{S})\gamma)} \tag{3}$$

has been measured in Υ transverse momentum bins and plotted in Fig. 6. No significant dependence on p_T was observed.

4 Conclusions

CMS has produced several results in heavy-flavour physics: B_s^0 decay to $\mu^+\mu^-$ has been observed, angular analysis in B_s^0 decays has been performed to measure width difference and mixing interference phase, single and double charmonium, as well as P-wave bottomonium cross sections have been measured to investigate production mechanisms.

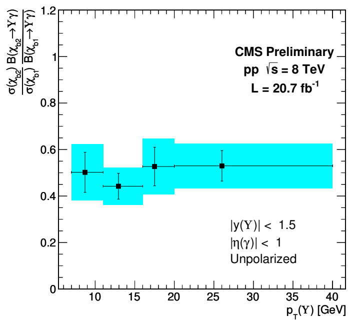

Figure 6: Cross section ratio $[\sigma(pp \to \chi_{b2}X)\mathcal{B}(\chi_{b2} \to \Upsilon(1\text{S})\gamma)]/[\sigma(pp \to \chi_{b1}X)\mathcal{B}(\chi_{b1} \to \Upsilon(1\text{S})\gamma)]$ vs. p_T^{Υ}, under the hypothesis of unpolarized production.

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