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FEASIBILITY STUDY FOR THE $\mathrm{B_C}$ MESON AT CMS

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FEASIBILITY STUDY FOR THE $\mathrm{B_C}$ MESON AT CMS

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Abstract

In this talk the prospects to measure the mass and lifetime of the B_c meson at CMS are discussed. Using the channel $B_c \to J/\psi\pi$ 120 B_c events are expected to be selected in the first 1 fb^{-1} of data. The expected accuracy of the mass measurement is 2.0(stat.)±14.9(syst.) MeV/c^2, and the accuracy on the lifetime is 0.044(stat.) ± 0.010(syst.) ps.

1 B-physics at CMS

The Compact Muon Solenoid (CMS) experiment is scheduled to start data taking in 2008 at the Large Hadron Collider (LHC) at CERN, where two 7 TeV proton beams will be collided head-on, resulting in collisions at a centre-of-mass energy of 14 TeV. The high luminosity data samples expected to be collected at CMS and the high energy reach will offer entirely new opportunities for B-physics studies. Measurements for B-physics in CMS will generally rely on

B-hadron decays into final states containing a J/ψ-meson, leading to two muons for which dedicated triggers exist. The most relevant subdetectors in CMS for many B-physics studies are the silicon tracker, providing momentum and vertex measurements, and the muon chambers, for muon identification and momentum measurements, both having a large acceptance ($|\eta| < 2.5$) and high precision.

2 The $\mathbf{B_c}$-meson

The B_c meson is the ground state of a charm and bottom quark-anti-quark pair: $B_c^+ = \bar{b}c$ or $B_c^- = b\bar{c}$ [1]. Unlike heavy-light quark systems as B_u, B_d or B_s, the dynamics of the B_c meson can be treated in a non-relativistic expansion just like the heavy quarkonia $c\bar{c}$ and $b\bar{b}$. At the same time, and contrary to the $c\bar{c}$ and $b\bar{b}$ ground states, the B_c meson carries flavour, leading to different heavy quark dynamics. Given the fact that no top-mesons exist, it is the only heavy-heavy quark system carrying flavour, making it a unique system.

2.1 Theory predictions

$\mathbf{B_c}$ production Many uncertainties exist in calculations for the B_c production cross section at the LHC [2, 3]. Just like production of $b\bar{b}$ and $c\bar{c}$, B_c production involves hard perturbative QCD (for the hard production of a $c\bar{c}$ and $b\bar{b}$ pair), and soft non-perturbative QCD (to describe the soft non-relativistic binding of the heavy quarks into a colour singlet bound state). Since the production involves the creation of both a $b\bar{b}$ and a $c\bar{c}$-pair, the production rate is predicted to be smaller ($\sim 10^{-1}$) than that for bottomonia and charmonia, where only one heavy quark pair is needed. The production cross section is also smaller ($\sim 10^{-3}$) than that of the lighter B-mesons like B_u, B_d and B_s because the creation of a $c\bar{c}$-pairs is suppressed in comparison with that of light quark pairs. The B_c production cross section at LHC is at least an order of magnitude larger than that at the Tevatron.

$\mathbf{B_c}$ mass Different theoretical predictions exist for the mass of the B_c meson. Traditionally non-relativistic potential models for heavy quark bound states were used to predict the mass of the B_c meson, giving values in the range 6.2–6.4 GeV [4] with large uncertainties. More recent NNLO calculations [5] predict the mass to be around 6.3 GeV with uncertainties of about 20 MeV. Even smaller uncertainties are obtained by calculations based on lattice QCD [6], with unquenched lattice calculations predicting a value of 6.304 ± 0.012 GeV.

$\mathbf{B_c}$ decay The B_c-meson being the ground state, it decays via weak interactions only. As a consequence it has a much longer lifetime than the $b\bar{b}$ and $c\bar{c}$ states. On the other hand, since either quarks can participate in the decay, the B_c meson has a shorter lifetime than the lighter B-mesons. There are three classes of B_c^+ decays:

1. the $\bar{b}$ quark decays weakly while the c-quark is spectator,
2. the c-quark decays weakly while the $\bar{b}$-quark is spectator,
3. the annihilation channel $B_c^+ \to \ell\nu_\ell/c\bar{s}/u\bar{s}$. with $\ell = e, \mu, \tau$

The first class leads to final states like $J/\psi\ell\nu_\ell$ or $J/\psi\pi$. Since the semi-leptonic mode is not fully reconstructable due to the missing neutrino, the hadronic mode is more suitable for a precise mass measurement, and is used in this analysis. The expected branching ratio for $B_c \to J/\psi\pi$ is 13–16% [8].

The second and third class both lead to final states which are experimentally much harder to detect.

The predicted branching ratios [7, 8] for the first class of decays are 19.6–25.0%, for the second class 64.3–72.0% and for the third 8.4–9.9%, all predictions agreeing within errors. For the B_c lifetime predictions range from 0.4–0.7, the most accurate prediction being $\tau[B_c^+] = 0.48 \pm 0.05$ ps [7].

3 Current experimental measurements

The first observation of the B_c meson was made by CDF in Run 1 [9] in the channel $B_c \to J/\psi\ell\nu_\ell$. Based on 20 signal events the B_c mass was measured to be $6.40 \pm 0.39 \pm 0.13$ GeV/c^2, and the lifetime $0.46^{+0.18}_{-0.16}$(stat) ± 0.03(syst) ps. The best mass measurement has been performed recently by CDF [11] in the $B_c \to J/\psi\pi$ channel; using 2.2 pb^{-1} of data the B_c mass was found to be 6274.1 ± 3.2(stat.)± 2.6(syst.)MeV/c^2, with 80 signal events. The best measurement for the B_c lifetime was recently reported by D0 [12], based on 1.4 fb^{-1} of data the lifetime was found to be $0.444^{+0.039}_{-0.036}$(stat)$^{+0.039}_{-0.034}$(syst) ps.

4 Event generation

Details of the analysis described below can be found elsewhere [13], and only a short summary is given here. The BCVEGPY generator [2] is used to generate B_c events, followed by hadronisation with PYTHIA. Fig.1(left) shows the differential cross section as function of the P_T of the B_c meson. At generator level the B_c meson is required to have $P_T > 10$ GeV and $|\eta < 2.0|$, the muons must have $P_T > 4$ GeV and $|\eta| < 2.2$, and the pion must have $P_T > 2$ GeV and $|\eta| < 2.4$. All J/ψ's were forced to decay into $\mu^+\mu^-$, the branching ratio of which is 5.93%. In total 5.2×10^4 events are generated corresponding to 29.2 fb^{-1}.

Generated backgrounds processes include events with light B-hadrons decays, prompt J/ψ's, $b\bar{b} \to \mu^+\mu^- X$, $c\bar{c} \to \mu^+\mu^- X$, W+jets, Z+jets and general QCD processes.

5 Event selection

Signal events are characterised by two muons from the J/ψ and a charged pion track, all coming from a displaced vertex due to the long-lived B_c. No trigger study has been performed, but the selection efficiency of the trigger requirements and offline reconstruction is expected to be similar. The offline selection is as follows. First J/ψ candidates are selected by requiring 2 muons with $P_T > 4$ GeV and $|\eta| < 2.2$ with opposite charge, from the same vertex, and

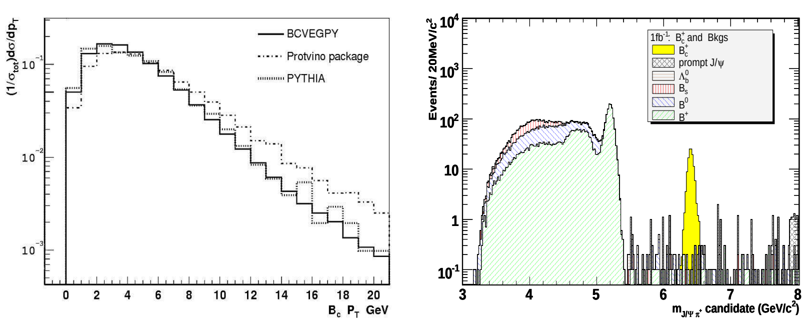

Figure 1: *Left: the differential cross section as function of P_T of the B_c meson for BCVEGPY, compared to spectra of the generators PYTHIA and Protvino. Right: the invariant mass distribution of the $J/\psi\pi$ from 3-7 GeV.*

having an invariant mass between 3.0 and 3.2 GeV. Secondly, pion candidates are selected by requiring a third track coming from the same vertex as the 2 muons with $P_T > 2$ GeV and $|\eta| < 2.4$, but not being a lepton. To reject prompt J/ψ background, the events are required to have a proper decay length $L_{xy}^{PDL} > 60\mu$m, a significance $L_{xy}/\sigma_{xy} > 2.5$ and a small opening angle θ between the vector from primary to secondary vertex and the momentum vector of the reconstructed B_c: $\cos\theta > 0.8$. The invariant mass distribution is given in Fig.1 (right). Finally the invariant mass of B_c candidates is required to be between 6.25 and 6.55 GeV. The selection efficiency for B_c events is 6.9%. In 1 fb^{-1} 120 ± 11 signal events are expected, and 2.6 ± 0.4 background events, dominated by light B-mesons and QCD background.

6 Kinematic fit

Using a kinematic fit the 2 muon tracks were constrained to have an invariant mass equal to that of the J/ψ (3.096 GeV), and the third track of the pion was imposed to come from the same same vertex as the two muon tracks. Fig. 2(left) shows the resulting invariant mass distribution. While the input mass in the Monte Carlo events was 6400 MeV, the fitted mass value is 6402 ± 2 MeV, and the width of the peak is 22 MeV. To extract the B_c lifetime a binned likelihood fit was performed, resulting in $c\tau = 148.8 \pm 13.1\mu$m while the input value was 150μm.

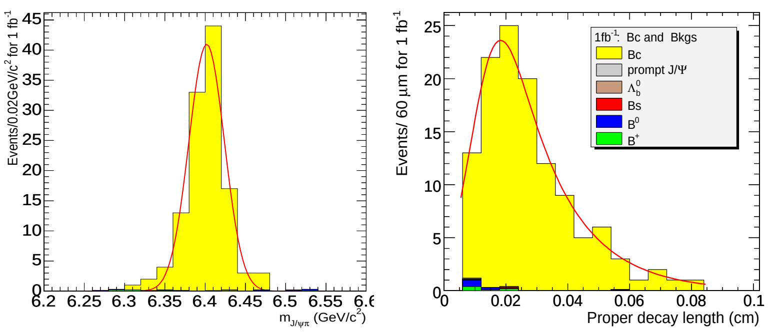

Figure 2: *Left: the invariant mass of the $J/\psi\pi$. Right: proper decay length distribution.*

7 Systematic errors

For the B_c mass the dominant systematic errors are the momentum scale uncertainty and the momentum resolution, resulting in a total systematic error of 14.9 MeV. Although these systematic sources also dominate in the CDF measurement [11], this is much larger than the 2.6 MeV quoted there. The reason is that the procedure to determine the error is very conservative, and it is based on a worst case scenario for a misaligned detector. Also, no control samples have been used so far. Only real data will allow for a realistic estimate of this kind of systematic errors, and with real data the $B^- \to J/\psi K^-$ control sample can be used as reference, expected to decrease the systematic errors significantly. For the lifetime the dominant contributions are the vertex uncertainty, theoretical uncertainties and the momentum resolution; the total systematic error being 3.0μm, representing again a highly conservative estimate.

8 Acknowledgements

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