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Searching for B_c mesons in ATLAS

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Abstract

We discuss the feasibility of the observation of B_c mesons at the ATLAS experiment. Theoretical interest is briefly addressed as well.

1 Introduction

There is a general consensus in the scientific community [1] that the scope of future high-luminosity, high-energy hadron colliders like LHC should not be restricted to the hunting of the standard model Higgs and its extensions, or the search for supersymmetry. Other topics requiring lower luminosities like top and beauty physics deserve in their own right a close attention. In this note we shall not dwell on general aspects of the latter, already treated in detail in references [2]. Rather we shall focus more specifically on the observation of B_c ($\bar{b}c$) mesons and to much less extent on baryons containing both b and c quarks (bcq).

From the theoretical point of view, B_c mesons exhibit some unique features making them especially suitable for the study of the strong interaction dynamics in hadrons. First, B_c states occupy an interpolating position in hadronic spectroscopy between charmonium and bottomonium resonances. QCD-inspired theories like potential models can be submitted to a close scrutiny in such intermediate mass region, besides with different constituent quark masses. Moreover, low-energy effective theories like non-relativistic QCD formulated on the lattice may be applied as well, providing an almost model-independent determination of the bottom and charm masses, fundamental parameters of the standard model.

Furthermore, in contrast to singly heavy hadrons (D, B, Λ_c, Λ_b, ...) both constituent quarks can undergo a weak decay, permitting a test of the "spectator" behaviour. (Let us note, nevertheless, that a simple-minded spectator model would not be valid since both heavy masses are involved in the hadron dynamics, even as an asymptotic limit).

2 B_c signal

At the center-of-mass energy $\sqrt{s} = 14$ TeV, the cross-section for beauty production is assumed to be 500 μb leading to 5×10^{12} $b\bar{b}$ pairs per year-run (10^7 s) at a luminosity of $\mathcal{L} = 10^{33}$ cm^{-2}s^{-1} (i.e. corresponding to an integrated luminosity of 10 fb^{-1}). The number of bottom pairs reduces, however, to 1.7×10^{10} [2] by requiring events with a triggering muon coming either from a b or a $\bar{b}$ under the kinematic cut $p_t > 6$ GeV/c (where p_t is measured with respect to the beamline) and the pseudorapidity constraint $|\eta| < 1.6$.

Supposing that the b-quark fragments into either a B_c or a B_c^* with probability $\simeq 10^{-3}$ [3], the number of produced B_c mesons (not yet triggered) per year would be roughly $\simeq 10^{10}$.

$B_c \to J/\psi\ \pi$ channel

This exclusive channel followed by the leptonic decay of the J/ψ resonance into a pair of oppositely charged muons offers several important advantages. First of all, it allows the mass reconstruction of the B_c meson. Observe also that anyone of the two muons can trigger the decay. Besides, it is very clean topologically with a common secondary vertex for all three charged particles, two of them (the muons) with the additional constraint of their invariant mass compatible with a J/ψ. Furthermore, the expected branching fraction is not too small, about 0.2% [4] [5], which combined with the branching fraction of the leptonic decay of the resonance $BR(J/\psi \to \mu^+\mu^-) \simeq 6\%$, yields an overall branching fraction for the signal of 10^{-4}. Thus, the number of such events turns out to be 10^6 per year.

$B_c \to J/\psi\ \mu^+\ \nu_\mu$ channel

In spite of the fact that this channel does not permit the measurement of the initial particle mass, its signature would be quite clean experimentally when the J/ψ decays into a pair of muons, providing a three muon vertex. The overall branching fraction is then $\simeq 10^{-3}$ [5]. Due to the foreseen accurate determination of the J/ψ momentum from the final muons, this channel might yield a precise extraction "à la Neubert" of $|V_{cb}|$ near zero recoil [6].

3 Detection efficiencies and background

A preliminary study has been performed in order to estimate the signal detection efficiency and background for the $B_c \to J/\psi(\to \mu^+\mu^-)\ \pi$ channel. The Monte Carlo employed for the signal simulation corresponds to a sample of $B_c \to J/\psi(\to \mu^+\mu^-)\ \pi$ decays while for the background we have used a sample of inclusive b muon decays generated in all cases with PYTHIA 5.7.

The signal and background analysis were performed imposing the following cuts on events:

- $p_{tmin}(trig.\mu) = 6$ GeV/c ; $| \eta_{max}(trig.\mu) |= 1.6$
- $p_{tmin}(\mu) = 3$ GeV/c ; $| \eta_{max}(\mu) |= 2.5$
- $p_{tmin}(\pi) = 1$ GeV/c ; $| \eta_{max}(\pi) |= 2.5$
- $M_{\mu^+\mu^-} = M_{J/\psi} \pm 50$ MeV

The two first cuts correspond to the requirement of the 1st level b physics trigger leading to an efficiency of $\sim 8\%$ in triggering one of the two muons from the J/ψ. Next we take into account the detection efficiency for the signal after applying the rest of p_t and η cuts which is $\sim 21\%$. Setting the efficiency for muon identification as 80% and the track reconstruction as 95% we get a combined detection efficiency of $\sim 1\%$ leading to an observable signal of order 10,000 events per year.

In reconstructing the signal the main source of background comes from pair combinations of oppositely charged muons together with another charged particle. The last of the cuts described above constrains the muons' invariant mass to be compatible with a J/ψ thus drastically reducing random combinations.

We get approximately one background event every 50,000 triggered events, with a reconstructed invariant mass inside the interval 6.3 ± 0.05 GeV, that is compatible with the expected mass of the B_c meson [7]. Taking into account the expected number of recorded $b\bar{b}$ events ($\simeq 1.7\times10^{10}$ per year), the above ratio amounts to about 330,000 background events per LHC year. Nevertheless, let us observe that the two muons coming from a J/ψ resonance produced at the primary interaction cannot contribute to the background once secondary vertex reconstruction is requested (since the decay vertex would occur at the same beams' interaction point). Moreover, those muons coming from leptonic or semileptonic decays of long-living particles such as pions or kaons should occur far enough from the interaction region.

4 Summary

We have found that the self-triggering weak decay $B_c \rightarrow J/\psi\ \pi$, followed by the leptonic decay of the J/ψ into two muons, can be observed in the ATLAS detector at LHC. Indeed, under rather conservative assumptions, a total number of 10,000 events could be fully reconstructed after one year run (corresponding to 10 fb^{-1} at the "low" luminosity of 10^{33} $\text{cm}^{-2}\text{s}^{-1}$). Although this represents a signal to background ratio of about 0.03, the significance of the signal amounts to 17 standard deviations above an almost flat nearby background. Furthermore, experience from the study of other channels shows that the background could be further suppressed by using vertex information.

We also consider as feasible the observation of the semi-leptonic decay $B_c \rightarrow J/\psi\ \mu^+\ \nu_\mu$, followed by the leptonic decay of the resonance into two muons. Generally speaking, semi-leptonic decays are easier to handle theoretically than hadronic ones. Despite that this exclusive channel does not allow the measurement of the B_c mass, it provides the life-time and semi-leptonic branching fraction, likely permitting as well an accurate determination of the mixing matrix element $|V_{cb}|$.

Finally let us mention, in particular, baryons (N_{bc}) containing b and c quarks. Decay channels leading to a final state J/ψ particle like $N_{bc} \rightarrow \Xi_c \; J/\psi$ would have a not small branching fraction, of order 1% [5]. Although their production rate in p-p collisions would be suppressed by one order of magnitude with respect to B_c baryons [8], the large statistics to be accumulated could make possible their observation at LHC.

References

[1] G. Carboni et al, Proceedings of the ECFA Large Hadron Collider Workshop, Aachen (1990).

[2] CERN preprint CERN/LHCC/93-53 (1993) ; ATLAS internal note PHYSICS-NO-041 (1994).

[3] E. Braaten, K. Cheung and T.C. Yuan, Phys. Rev. **D49** (1993) 5049; C-H Chang and Y-Q Chen, Phys. Rev. **D48** (1993) 4086; M. Lusignoli, M. Masetti and S. Petrarca, Phys. Lett. **B266** (1991) 142.

[4] M. Lusignoli and M. Masetti, Z. Phys. **C51** (1991) 549.

[5] M.A. Sanchis-Lozano, Valencia preprint IFIC/94-40.

[6] M. Galdón and M.A. Sanchis-Lozano, in preparation.

[7] E. Bagan et al, Z. Phys. **C64** (1994) 57.

[8] A.F. Falk et al, Phys. Rev. **D49** (1994) 555.