A Possible Measurement of CP-Violation in B^0 -decays by ATLAS on LHC

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Abstract

A possibility to measure CP-violation in B^0 -decays by ATLAS experiment was investigated. With one year of running at luminosity $10^{33}\ cm^{-2}s^{-1}$ with a muon p_t trigger threshold of 20 GeV and rapidity coverage $|\eta| < 2.5$ of the tracking detector the rate of 1490 events $B_d^0 \rightarrow J/\psi\ K^0 \rightarrow \mu^+\mu^-\ \pi^+\pi^-$ can be reached.

Introduction

The Standard model predicts sizable CP-violating effects from experimentally established constrains on Kobayashi-Maskawa matrix elements. The large observable asymmetries are expected in B^0 and $\overline{B}^0$ mesons decaying into CP eigenstates [1]. Experimentally the most accessible is a measurement of CP-violation in the decay $B_d^0 \rightarrow J/\psi\ K^0 \rightarrow \mu^+\mu^-\ \pi^+\pi^-$ which is convenient because of low combinatorial background of muons per event. At LHC the expected production cross section for b quarks is large, $\sigma(b\overline{b}) \approx 100\mu b \div 700\mu b$ [2]. In order to avoid multiple interactions per bunch crossing the luminosity will be taken $10^{33}\ cm^{-2}s^{-1}$.

The Method of Measurement

The method of measurement of CP-violation will consists in investigation of number of events N with final state $J/\psi\ K^0$ as a function of time-decay of B_d^0 meson. Because of mixing $B^0 — \overline{B}^0$ the tagging of associated b-particle has to be done by charge of muon in semileptonic decay μ^+X . The state $J/\psi\ K^0\ \mu^+X$ is produced by one of the combinations $B^+\ \overline{B}_d^0$, $B_s^0\ \overline{B}_d^0$, $B_d^0\ \overline{B}_s^0$, $\overline{N_b}\ \overline{B}_d^0$. The time-dependent rates for these cases are [3]:

$$\frac{dN}{dt} \sim \frac{|T_d|^2}{\Gamma_+ \Gamma_d} e^{-t}(1 - n\sin(x_d t))$$
$$\frac{dN}{dt} \sim \frac{|T_d|^2}{\Gamma_s \Gamma_d} e^{-t}(1 - \frac{n}{1+x_s^2}(x_s \cos(x_d t) + sin(x_d t))$$
$$\frac{dN}{dt} \sim \frac{|T_d|^2}{\Gamma_d^2} e^{-t}(1 - \frac{n}{1+x_d^2}(x_s \cos(x_d t) \pm sin(x_d t))$$
$$\frac{dN}{dt} \sim \frac{|T_d'|^2}{\Gamma_N \Gamma_d} e^{-t}(1 - n\sin(x_d t))$$

n ... parameter, describing CP-violation effect
t ... $\overline{\mathrm{B}}_{\mathrm{d}}^{0}$ decay time in lifetime units
$x_d = \frac{\Delta m_d}{\Gamma_d}$ ... mixing parameter of $\mathrm{B}_{\mathrm{d}}^{0}$ $\overline{\mathrm{B}}_{\mathrm{d}}^{0}$ mesons
$x_s = \frac{\Delta m_s}{\Gamma_s}$ ... mixing parameter of $\mathrm{B}_{\mathrm{s}}^{0}$ $\overline{\mathrm{B}}_{\mathrm{s}}^{0}$ mesons
$\Gamma_+ \Gamma_{d,s} \Gamma_N$ ... decay widths of B^+ , $\mathrm{B}_{\mathrm{d,s}}^{0}$, $\overline{\mathrm{N_b}}$ respectively

Assuming that the beauty hadron decays essentially due to the decay of $\mathrm{b}(\overline{\mathrm{b}})$ quark relations holds: $T_d = T_d'$; $\Gamma_+ = \Gamma_d = \Gamma_s = \Gamma_N$. The observed distribution will be obtained by adding these equations each of them weighted by it's production value.

The time-dependent measurement is possible only if the experimental precision of $\mathrm{B}_{\mathrm{d}}^{0}$ time-decay reaches the value $\approx \Delta m$, which means a precision of $400\mu m$ in decay length measurement. This question is under the study. Otherwise the time integrated formulae should be used involving dilutions.

The first estimate of the $\mathrm{B}_{\mathrm{d}}^{0}$ reconstruction efficiency was done using a fast detector simulation [4], which simulates the response of the detectors by smearing momenta, energies and particle identification according to the performance of each detector. Following cuts were used:

- all four final-state particles are within the tracking volume;
- the K^{0*} decay length in the transverse plane is between 1 cm and 30 cm;
- the angle between the K^{0*} and the $\mathrm{J}/\psi < 45^o$.

Muon identification efficiency was assumed to be 80% and track-finding efficiency to be 95%. The reconstruction efficiency for rapidity coverage $|\eta| < 2.5$ was $\epsilon = 0.13$. Expected rate of reconstructed events in one year of running at 10^{33} $cm^{-2}s^{-1}$ is 1490 . The muon trigger considered here is with $p_t > 20$ GeV. The dilution from wrong muon tags within this trigger threshold was found to be

$$D = \frac{N(correcttags) - N(mistags)}{N(correcttags) + N(mistags)} = 0.77.$$

Using the time dependent analysis the error of 0.14 on CP-violation parameter measurement could be reached within 2 years of running.

One of the ways of increasing statistics is to extract the CP- violation parameter from decay of $B^0_d \rightarrow J/\psi\ K^{0*}$, $K^{0*} \rightarrow K^0\ \pi^0$, $\pi^0 \rightarrow 2\gamma$. The branching ratio, following ARGUS and CLEO results [5] is around the same as for $J/\psi\ K^0$ channel. This possibility of measurement by ATLAS is under the study. In the case that $J/\psi\ K^{0*}$ states will not be recognized (by an extra γ -pair), they will be a source of background to the studied reaction (Figure). The amount of this background strongly depends on resolution.

More detailed simulation of the detector response should be done taking also into account background muons and π^+ , π^- from the same $b\overline{b}$ event.

FIGURE: Effective mass spectrum of ($J/\psi\ K^0$) system originated from reaction: $B^0_d \rightarrow J/\psi\ K^0$ (solid line), $B^0_d \rightarrow J/\psi\ K^{0*}$ (dashed line), $B^0_d \rightarrow J/\psi\ K^0\ \pi^0$ (dotted line).

The Extraction of the B^0 decay time from the event

The decay time of B^0 will be obtained by a two-step process. First step consists of the event reconstruction (the correct identification of all members of the B^0 decay chain) and the second one gives precise tracking of all particles, which ends in the τ_{B^0} value.

The procedure relays on the muon detectors, which enables reconstruction of all μ and thus also J/ψ . The moment of B^0 is obtainable in the first approximation by *Fox-Wollfram Moments.* Innermost silicon tracker (*SITV*) enables reconstructing of the second vertex and the distance of the first and second vertex gives proper decay time of B^0 . With mentioned geometrical and kinematical constrains, all other members of the decay-chain can be found, which further improves the reconstruction of the event and consequently the τ_{B^0} .

Conclusion

The preliminary results are encouraging and more detailed simulations are under way.

References

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