$B_s \to J/\psi\,\phi$ at LHCb

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The LHCb experiment will be at the forefront of precision beauty and charm physics.

Taking advantage of the large $b\bar{b}$ production cross-section at the Large Hadron Collider (LHC), LHCb will look for signs of physics beyond the Standard Model in CP violating processes and measure current SM parameters to world-leading precision.

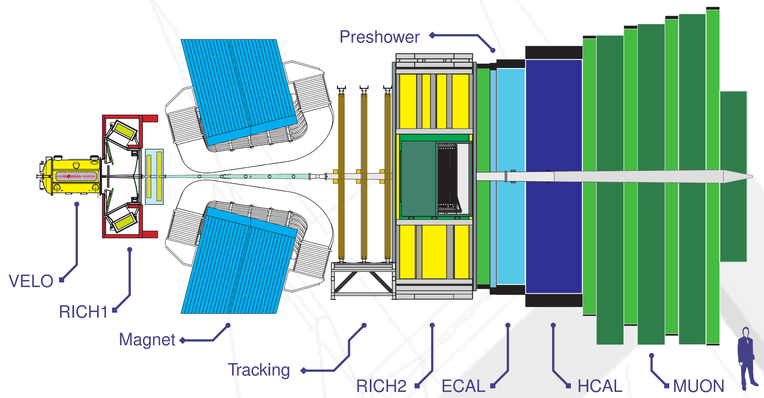

Fig. 1: The LHCb Experiment.

The LHCb Experiment

The Large Hadron Collider beauty (LHCb) experiment is a collaboration of over 50 universities and laboratories. It hopes to shed insight into the unsolved problem of the matter-antimatter asymmetry of the universe. Charge-Parity (CP) violation is a process through which the standard model permits such an asymmetry to arise, but at a level far too small to account for the abundance of matter we observe. The LHCb experiment (Fig. 1) will measure a number of CP violating processes, requiring precise vertexing, efficient particle Identification and a granular calorimetry system.

CP Violation in $B_s \to J/\psi\,\phi$

The CKM mechanism allows for the mixing of neutral mesons in the Standard Model as shown in fig. 2. This permits CP violation in mixing, and CP violation in the interference between mixing and decay to the same final state. The decay $B_s \to J/\psi\,\phi$ is susceptible to CP Violation of the latter form, $J/\psi\,\phi$ being an eigenstate accessible to both B_s and $\bar{B}_s$ mesons.

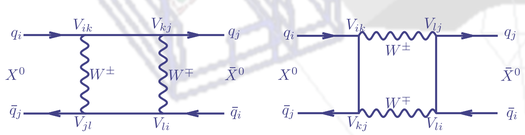

Fig.2: Neutral meson mixing via s and t-channel diagrams

Φ, the weak phase

$J/\psi\,\phi$ is accessible to B_s and $\bar{B}_s$ mesons at both tree and penguin level as shown in fig. 3. The tree level process is CKM favoured, and dominates the decay with amplitude $V_{cs}V_{cb}^*$. Neglecting penguin terms, and combining this with the mixing term $V_{ts}V_{tb}^*$ we obtain an expression for the weak phase:

$$\Phi^{\mathrm{SM}} \approx \arg(V_{ts}V_{tb}^*)^2 - 2\arg(V_{cs}V_{cb}^*) \equiv 2\arg\left[\frac{V_{ts}V_{tb}^*}{V_{cs}V_{cb}^*}\right] \equiv -2\beta_s$$

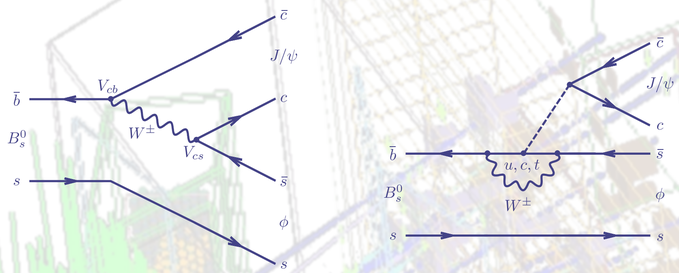

Fig. 3: $B_s \to J/\psi\,\phi$ at tree (left) and penguin (right) level.

New Physics in Φ

In the Standard Model, $2\beta_s$ is well predicted and is close to zero. Tree level decays are robust to the presence of new particles but these may enter into the box diagram. Deviations from the SM value of $\Phi^{\mathrm{SM}} = -2\beta_s \approx (-3.68 \pm 0.17) \times 10^{-2}$ can therefore signal new physics within the box. This may be thought of as an additional complex factor contributing to the mixing phase, resulting in a measurement of $\Phi = \Phi^{SM} + \Phi^{NP}$. Current Tevatron measurements indicate a 2.1σ deviation from the SM value.

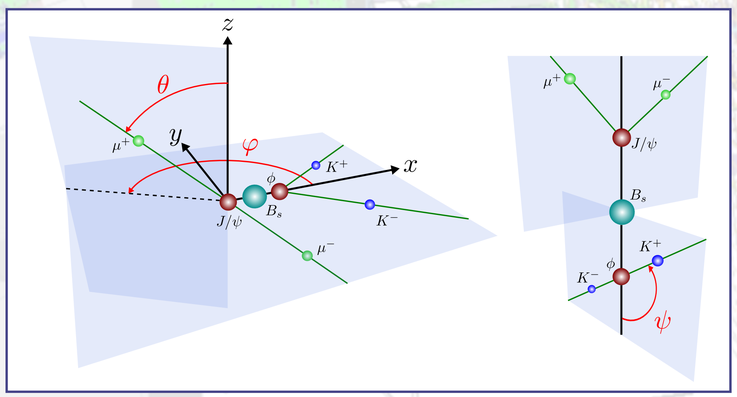

Fig. 4: Transversity angles θ, φ, ψ in the LHCb convention

Extraction of Φ by angular analysis

$B_s \to J/\psi\,\phi$ is a pseudoscalar to two vector decay; the final state is a mixture of CP eigenstates with orbital angular momentum $l = 0, 1, 2$ requiring an analysis that takes into account the angular distributions of the final states. The LHCb analysis uses the transversity basis as shown in fig. 4.

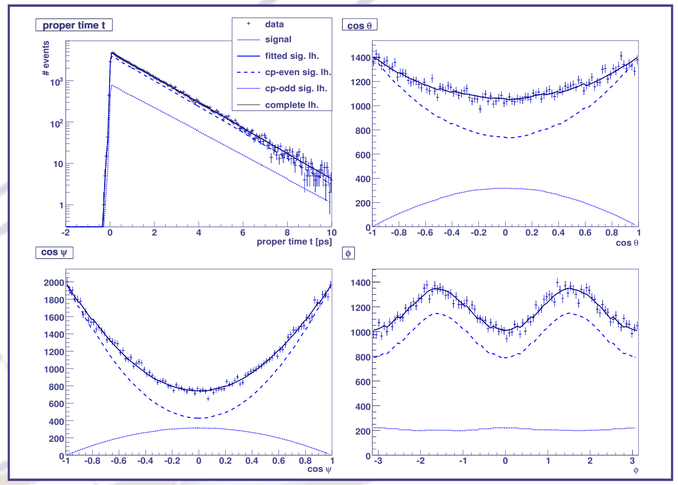

Fig. 5: Projections of simulated data and fitted signal PDF accounting for angular and propertime acceptance for $2fb^{-1}$ of data at the LHCb experiment

Signal yields and sensitivity to $\Phi = 2\beta_s$

The LHCb experiement expects to select 117k signal events after trigger in $2fb^{-1}$, the nominal integrated luminosity expected in 1 year of running of the LHC. Accounting for tagging efficiency, mistag rate, acceptance and resolution the 3-angle fit as shown in fig. 5 is expected to yield a measurement of $2\beta_s$ with an error of $\sigma(2\beta_s) = 0.030 \pm 0.002$, comparable to the error on the SM value. Considerably less data is required for a competitive measurement, as shown in Fig. 6.

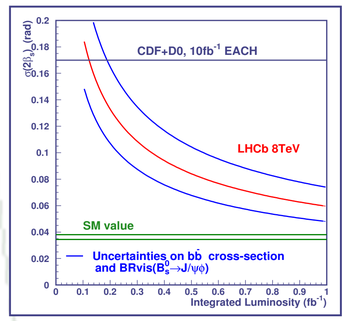

Fig. 6: Estimated sensitivity to $2\beta_s$ as a function of integrated luminosity

Summary

CP violation in the interference between mixing and decay of $B_s \to J/\psi\,\phi$ is characterised by the weak phase Φ which is predicted to be $-2\beta_s$ in the SM. A deviation in Φ from $-2\beta_s$ is an indicator of new physics entering into $B_s/\bar{B}_s$ mixing. LHCb will yield a competitive measurement of the phase Φ in less than one year of data taking.

Poster produced with the support of the following organisations