PROCEEDINGS OF SCIENCE

Sensitivity study of $B^0 \to K^{*0}\tau^+\tau^-$ at FCC-ee

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The aim of this work is to study the capabilities of experiments at the Future Circular Collider FCC-ee to unravel the quark transitions $b \to s\tau^+\tau^-$, unobserved to date. At meson scale the decay $B_d^0 \to K^{*0}\tau^+\tau^-$, with the transitions $K^{*0} \to K^+\pi^-$ and $\tau \to \pi\pi\pi\nu_\tau$, is studied with a method to reconstruct explicitly the two undetected neutrinos. The detector requirements to study this decay are evaluated, in particular the vertexing resolution performance are emulated and compared to IDEA, a detector concept used for FCC-ee simulations. Analysis of simulated signal events together with simulated dominant backgrounds has been done in order to draw the precision of the $B_d^0 \to K^*\tau^+\tau^-$ branching fraction measurement as function of the vertexing resolution performance and evaluate the feasibility of this measurement at FCC-ee.

20th International Conference on B-Physics at Frontier Machines (Beauty2023)
3-7 July, 2023
Clermont-Ferrand, France

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PoS(BEAUTY2023)060

1. Scientific context

The third generation couplings in quark transitions are the less-well known, and specific models addressing the Flavour problem(s) often provide $b \to \tau$ enhancements or modifications w.r.t. the Standard Model (SM). This is why $b \to s\tau\tau$ is a must do to sort out Beyond Standard Model (BSM) models [1, 2] if the remaining flavour anomalies are confirmed. Their study is interesting per se as unraveled quark transitions to date. The main difficulty is to reconstruct the ν's. In this work the unobserved decay $B^0 \to K^{*0}\tau^+\tau^-$ [3] (BR=$O(10^{-7})$ within SM) is studied through the specific 3-prongs $\tau \to \pi\pi\pi\nu$ channel for which the decay vertex can be reconstructed in order to fully solve the kinematics of the decay. There are 10 particles in the final state, including 2 undetected neutrinos, and 3 decay vertices.

The Future Circular Collider [4] (FCC) is a collider project at CERN thought of as successor of HL-LHC, with a target circumference of about 91 km. FCC-*ee* [5] is the first phase of the project with e^+e^- collisions. There are 4 interaction points foreseen along the ring and 4 data-taking years at the Z pole, in the current baseline, leading to 6×10^{12} Z bosons. FCC looks like the right place to study $B^0 \to K^{*0}\tau^+\tau^-$ because it combines a clear experimental environment (like B-factories but with higher statistics), and boosted b-hadrons (like the LHC).

The goal of this work is to study the sensitivity of the search for $B^0 \to K^{*0}\tau^+\tau^-$ at FCC-*ee* and to give the corresponding detector requirements, especially about the vertices measurement which is the key of this measurement.

2. Analysis

In order to fully reconstruct the kinematics of the decay, the neutrinos momenta must be resolved. Thanks to the decay topology, enough constraints are available to determine them. The energy momentum conservation is used at τ decay vertex to determine the neutrino momentum at the cost of a quadratic ambiguity :

$$\begin{cases} p^{\perp}_{\nu_\tau} = -p^{\perp}_{\pi_t} \\ p^{\parallel}_{\nu_\tau} = \dfrac{((m_\tau^2 - m_{\pi_t}^2) - 2p_{\pi_t}^{\perp,2})}{2(p_{\pi_t}^{\perp,2} + m_{\pi_t}^2)} . p^{\parallel}_{\pi_t} \pm \dfrac{\sqrt{(m_\tau^2 - m_{\pi_t}^2)^2 - 4m_\tau^2 p_{\pi_t}^{\perp,2}}}{2(p_{\pi_t}^{\perp,2} + m_{\pi_t}^2)} . E_{\pi_t} \end{cases},$$

where π_t denotes the 3π system, longitudinal and parallel axis are relative to the τ direction. The quadratic ambiguity that appears in equation 2 propagates to the B^0 reconstruction and leads to 4 possible solutions because of the two τ's. To solve the ambiguities, a selection rule has been built, from the energy momentum conservation at the B^0 decay-vertex and provides a condition between the τ's and the K^{*0}:

$$p_{\tau^\pm_\mp} = -\frac{\vec{p}^{\perp}_{K^{*0}} . \vec{e}_{\tau^\pm_\mp}}{1 - (\vec{e}_{\tau^\pm_\mp} . \vec{e}_B)^2} - p_{\tau^\mp_\pm} . \frac{\vec{e}_{\tau^\pm_\mp} . \vec{e}_{\tau^\mp_\pm} - (\vec{e}_{\tau^\pm_\mp} . \vec{e}_B)(\vec{e}_{\tau^\mp_\pm} . \vec{e}_B)}{1 - (\vec{e}_{\tau^\pm_\mp} . \vec{e}_B)^2},$$

where $\vec{e}_i$ denotes the i-particle normalised flight-vector and $\vec{p}^{\perp}_{K^{*0}}$ is the transverse momentum of the K^{*0} w.r.t. the B^0 direction. This reconstruction method has been validated at MC truth level on simulated signal samples.

Decay	BF (SM/meas.)	Intermediate decay	BF_had	Additional missing particles
Backgrounds $b \to c\bar{c}s$:				
$B^0 \to K^{*0}D_sD_s$	$5.47\times\ 10^{-5}$	$D_s \to \tau\nu$	$1.14\times\ 10^{-10}$	2ν
		$D_s \to \tau\nu, \pi\pi\pi\pi^0$	1.28×10^{-10}	ν , π^0
		$D_s \to \pi\pi\pi\pi^0$	1.45×10^{-10}	$2\pi^0$
		$D_s \to \tau\nu, \pi\pi\pi\pi^0\pi^0$	1.08×10^{-9}	ν , $2\pi^0$
		$D_s \to \pi\pi\pi 2\pi^0$	1.02×10^{-8}	$4\pi^0$
$B^0 \to K^{*0}D_sD_s^*$	1.73×10^{-4}	$D_s \to \tau\nu$	3.60×10^{-10}	2ν, γ/π^0
		$D_s \to \pi\pi\pi\pi^0\pi^0$	3.22×10^{-8}	$4\pi^0$, γ/π^0
Backgrounds $b \to c\tau\nu$:				
$B^0 \to K^{*0}D_s\tau\nu$	$9.17\times\ 10^{-6}$	$D_s \to \tau\nu$	$3.59\times\ 10^{-10}$	2ν
$B^0 \to K^{*0}D_s^*\tau\nu$	$2.03\times\ 10^{-5}$	$D_s \to \pi\pi\pi\pi^0\pi^0$	$7.51\times\ 10^{-9}$	ν, γ, $2\pi^0$

Table 1: List of the backgrounds considered in the analysis with their respective branching fractions and the additional missing particles w.r.t. the signal. BF_had denotes visible branching fractions including hadronisation fractions. Updated w.r.t. Beauty talk, new $BF(B^0 \to K^{*0}D_sD_s)$ guesstimate by starting from a recent LHCb measurement [6].

In order to evaluate the feasibility of the measurement, the signal and the main backgrounds, which are summarised in table 1, have been simulated and considered in the analysis.

Since we aim at providing detector requirements irrespective of a detector concept, vertexing resolutions are emulated via smearings that follow arbitrarily good expectations. To fix a point of comparison to an actual state-of-the-art vertex detector, IDEA [7] simulation has also been used. In order to discriminate the backgrounds that are overwhelming w.r.t. the signal, a selection based on a multivariate classifier, XGBoost [8], has been built. Figure 1 illustrates the performance of this selection.

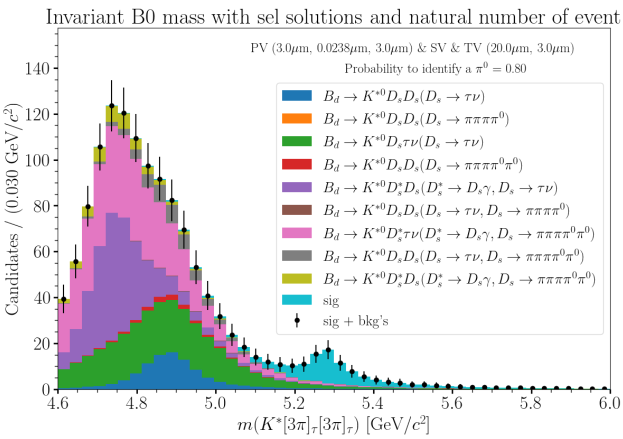

Figure 1: Reconstructed invariant-mass distribution after the selection for a reference vertexing configuration. Updated results w.r.t. Beauty talk.

3. Results

The precision on the branching fraction measurement is determined for each vertexing performance configuration from a MLL fit to the reconstructed B^0 invariant mass. Figure 2 displays the results. It can be observed that the actual state-of-the-art vertex detector used in this work does not allow to unravel the signal at SM value. Improvement of the track Impact Parameters measurement (IP) could allow, by contrast, to reach evidence or observation.

A comment is in order to conclude this proceeding: this work is focused on a 3-prongs τ decay; considering one leptonic τ decays would improve the intial statistics by about one order of magnitude; novel reconstruction methods would however have to be developed.

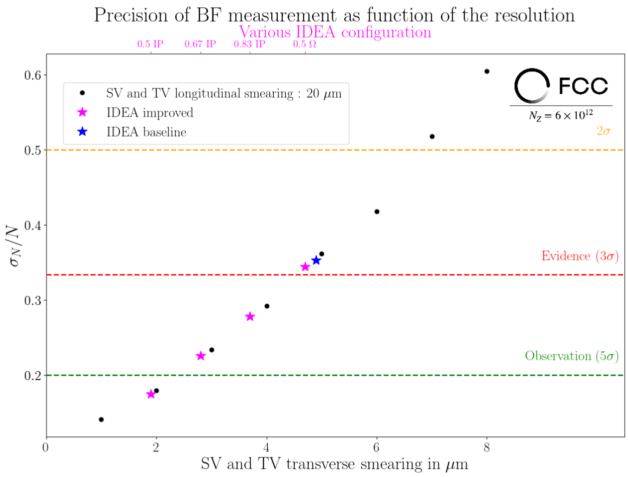

Figure 2: Precision of the $B^0 \to K^{*0}\tau^+\tau^-$ branching fraction measurement at FCC-*ee* as function of the vertexing performances. Updated results w.r.t. Beauty talk.

References

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