Effective lifetime analysis for $B_s^0 \rightarrow J/\psi K_s^0$ decay channel

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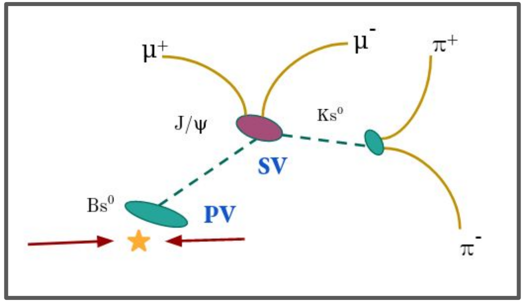
Introduction to lifetime

An unstable particle decays into several other particles. At time t, if we look at the collection and find the number N(t) of the original particles which have escaped decay, this number behaves as $N(t) = N0\, e(-t/\tau)$.

From the decay law, the decay probability of an unstable particle defined as,

$$P \propto e^{-t/\tau}$$

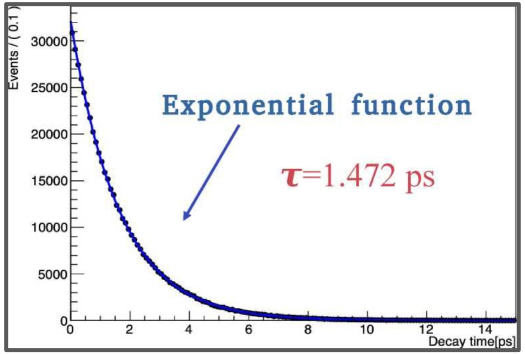


τ = lifetime of the particle, t = decay time of the particle.

Decay time is defined as,

$$t = \frac{L_{xy} M_{B_s^0}}{p_T}$$

Where M_B is the mass of the B candidate. (Reconstructed mass)
Lxy is the length difference between the PV (primary vertex) and SV (secondary vertex) in transverse plane.
p_T is the transverse momentum of the B candidate.



The lifetime can be obtained by fitting the decay time distribution.

Cont.

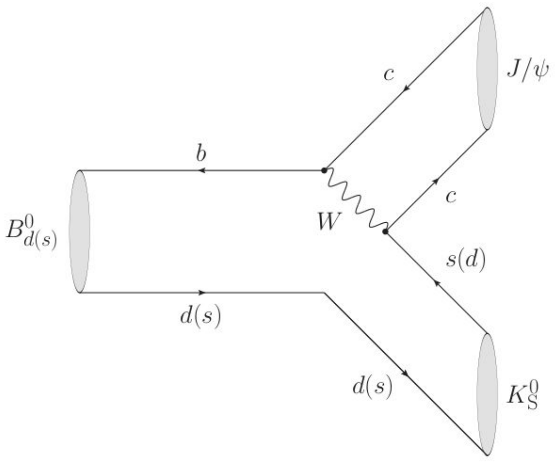
- Signal decay mode - $B_s^0 \rightarrow J/\Psi K_s^0$
- Control channel - $B^0 \rightarrow J/\Psi K_s^0$
- Related through interchanging all d quarks with s quarks.
- Effective lifetime is such an observable which offer interesting probe to measure CP asymmetry!

The $B_s^0 \rightarrow J/\Psi K s^0$ effective lifetime is defined as,

$$\tau_{J/\psi K_s^0} = \frac{\int_0^\infty t[\Gamma(B_s^0(t) \rightarrow J/\psi K_s^0) + \Gamma(\overline{B_s^0}(t) \rightarrow J/\psi K_s^0)]dt}{\int_0^\infty [\Gamma(B_s^0(t) \rightarrow J/\psi K_s^0) + \Gamma(\overline{B_s^0}(t) \rightarrow J/\psi K_s^0)]dt}$$

Can be rewritten as,

$$\tau_{J/\psi K_s^0} = \frac{\tau_{B_s^0}}{1 - {y_s}^2}\left(\frac{1 + 2A_{\Delta\Gamma}y_s + {y_s}^2}{1 + A_{\Delta\Gamma}.y_s}\right), \text{ Where } y_s = \tau_{B_s^0}\frac{\Delta\Gamma}{2}$$



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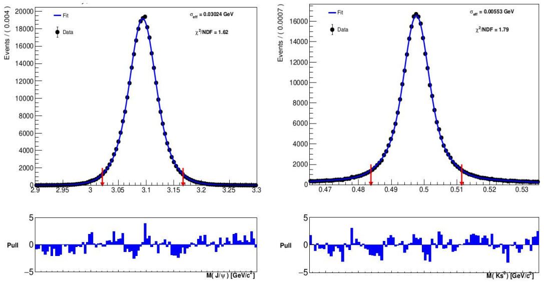
- The advantage of effective lifetime study is that it allows an efficient extraction of $A_{\Delta\Gamma}$.
- An effective lifetime for a B_s^0 decay channel is obtained in practice by fitting a single exponential function to its untagged rate.

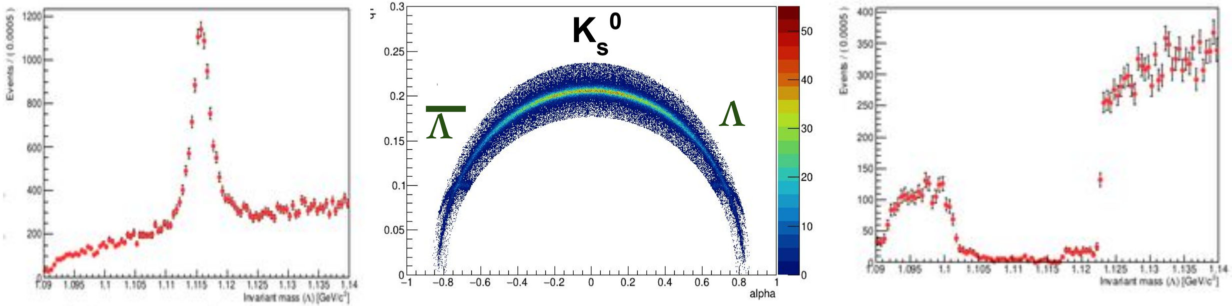
Selections

- Selection on J/ψ and K_s^0 invariant mass.
- J/ψ and K_s^0 mass distribution is fitted with double gaussian with common mean.
- $\pm$ 2.5σeff selection cut on J/ψ (1st column) and K_s^0 (2nd column) invariant mass.
- Effective sigmas for J/ψ and K_s^0 are ~ 0.03GeV and 0.005GeV.

Private work (CMS Data)



Private work (CMS Data)



Armenteros cuts removes almost all the Λ contributions.

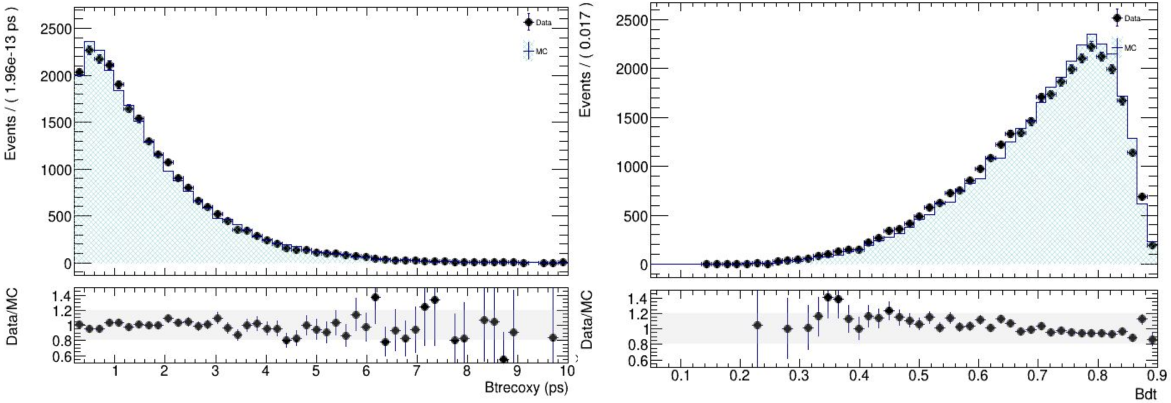
BDT is trained using 10 discriminating variables and it is optimised using best expected lifetime error where toy study is used. To arbitrate multi candidate per event highest BDT score has been considered.

Data-simulation comparison

➔ In order to understand whether the signal distributions in MC are modelled well or not, a comparison for different variables is verified with the control channel ($B^0 \rightarrow J/\Psi K_s^0$).

➔ The most important comparison among all, is the decay time comparison plot. There is a good match between MC and data for decay time.

Private work (CMS Data and Simulation)



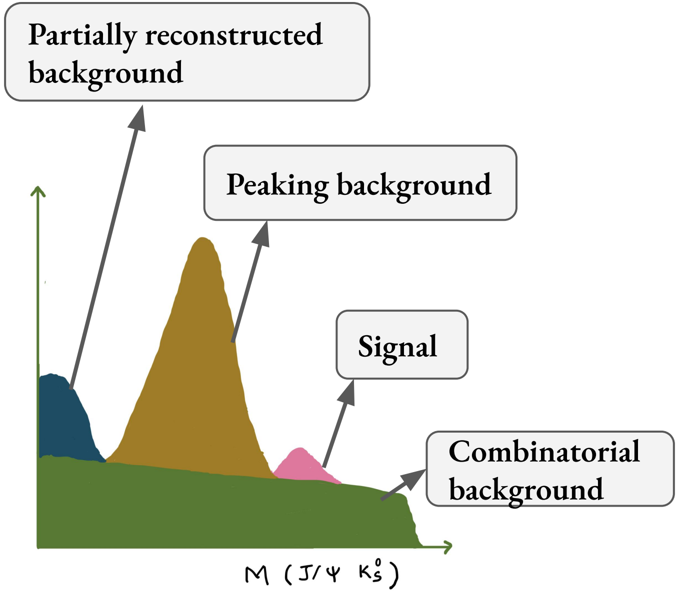
Lifetime validation

➔ 2D unbinned maximum likelihood method used.

➔ In this method, the data from three years are fitted simultaneously.

➔ To extract the effective lifetime for the signal decay, before performing the fit to the data samples, a study on the validity of the methods is tested on the signal MC.

➔ This study includes toy study as well as control channels from data. The validation is done excluding the signal region.



Efficiency

The generator level decay time for B mesons is a simple exponential function.

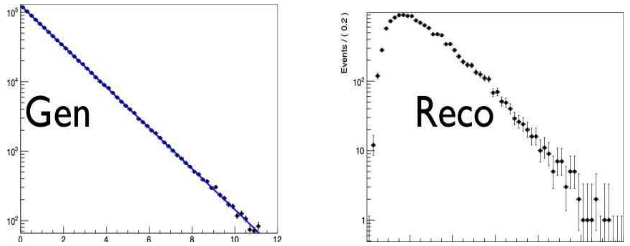
However, trigger and other selection cuts distort this exponential function. This distortion is measured by efficiency.

Efficiency as a function of decay time (from MC).

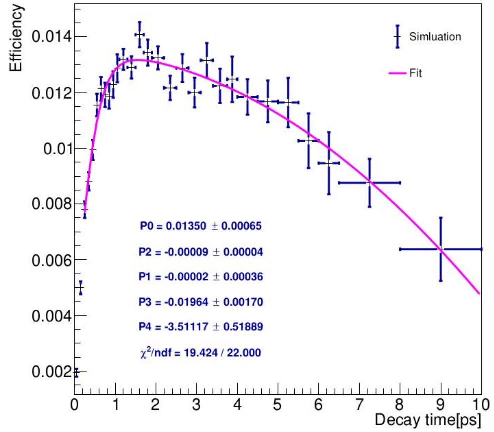
$$\text{Efficiency} = \frac{\text{Generated events at reconstruction level}}{\text{Events with generated distribution (1.472ps)}}$$

The function used to describe the efficiency distribution (0.2ps - 10 ps).

$$\epsilon(t; p_0, p_1, p_2, p_3, p_4) = p_0 + p_1 t + p_2 t^2 + \frac{p_3}{1 + exp(-p_4 t)}$$



Private work (CMS Simulation)



Signal MC validation

- Invariant mass : triple gaussian PDF with common mean and different widths where mean and widths are floated.

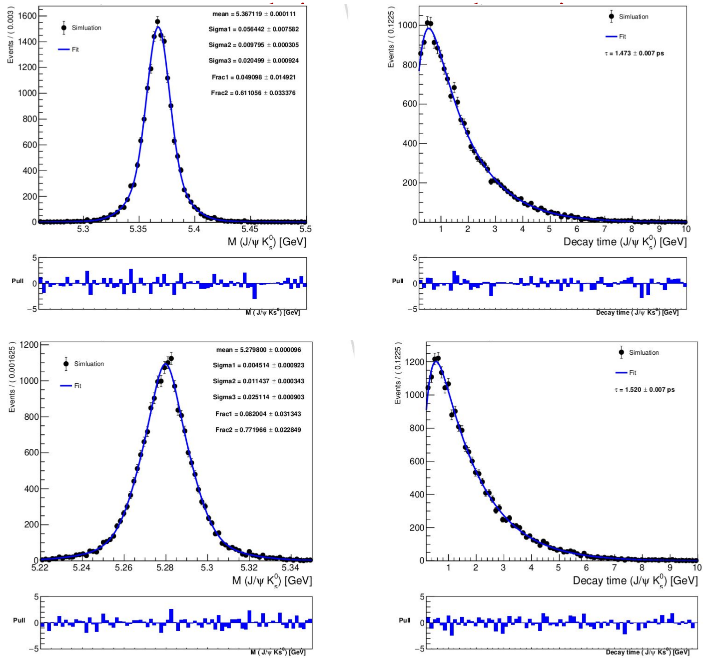
- Decay time : Fitted with Eff (t) × exp (-t/τ) , where parameters of efficiency function are fixed. τ is the lifetime of the signal sample we obtain from the fit.

- The lifetime obtained from simultaneous fit to the B_d signal MC samples is 1.520 ± 0.007ps (generated lifetime value is 1.525ps) and to the B_s signal MC samples is 1.473 ± 0.007ps (generated lifetime is 1.472ps).

- This validates the proper modeling of the efficiency functions.

Mass and decay time projection plots from MC :

Private work (CMS Simulation)



Decay time PDF for background

The high sideband region consists only of combinatorial background. It is fitted with double exponential.

$$k \times e^{(-t/\tau_{1,bkg})} + (1-k) \times e^{(-t/\tau_{2,bkg})}$$

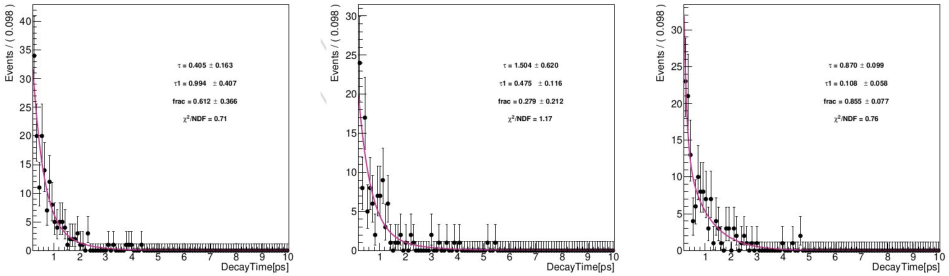
The low sideband region consists of both combinatorial background and partially reconstructed background.

Combinatorial PDF is fixed from high sideband, and the decay time pdf for partially reconstructed background is fit with eff*Exponential. Where all the parameters are floated.

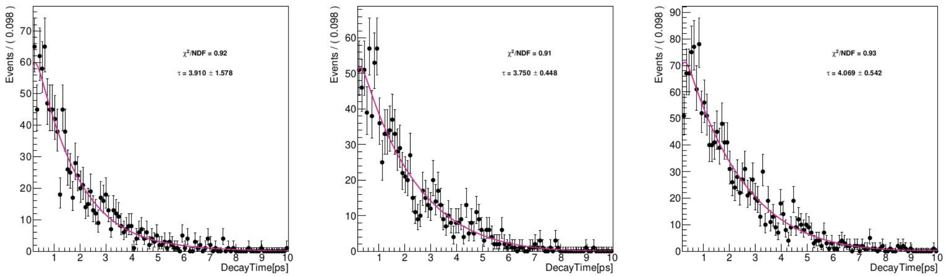
$$p_0 + p_1 t + p_2 t^2 + \frac{p_3}{1+exp(-p_4 t)} \times e^{(-t/\tau_{1,par})}$$

Private work (CMS Data)

Upper sideband 5.4-5.6 GeV (only Comb bkg)



Lower sideband 5.1 - 5.15 GeV (comb+partial bkg)

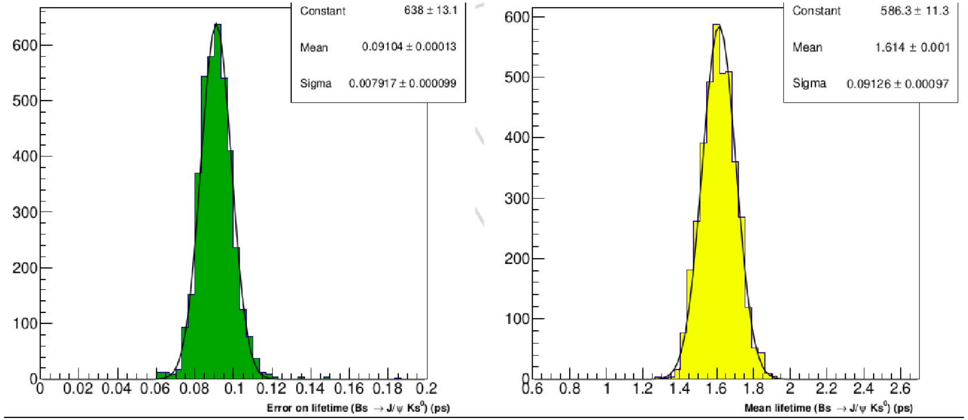


Toy results

- Simultaneous Fit to 3 years toy MC where each year is generated with data like events with similar signal and background yield (yield is varied Poissonian from toy to toy)
- The expected error on our lifetime measurement is ~ 0.09ps

Mean lifetime: 1.614ps (generated 1.619ps)

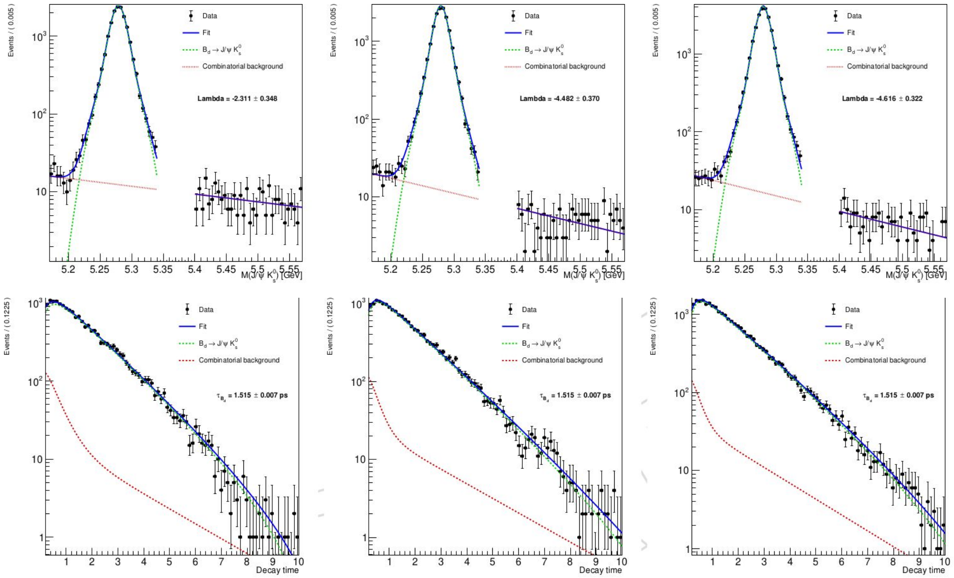
Private work (CMS Simulation)



Validation of control channel with data

- To validate the control channel, the blinded 2D UML fit has been done.
- The simultaneous fit results for $B^0 \rightarrow J/\Psi K_s^0$ is 1.515 ± 0.007ps.
- The PDG value for $B^0 \rightarrow J/\Psi K_s^0$ is 1.519 ± 0.004ps.
- Fit results are consistent with the PDG values.

Private work (CMS Data)

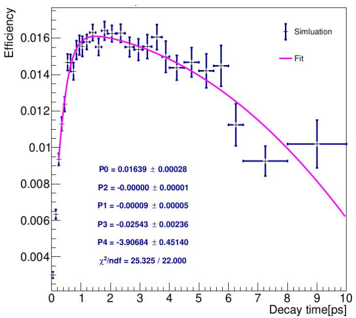


All the checks has been performed without the signal region using the 2D UML method. Systematic uncertainties are investigated for the following different sources.

I. Efficiency modeling

Two alternate functions are used to model the efficiency, to check if there is any difference with respect to the current model of the efficiency. Systematic uncertainty - 0.008ps

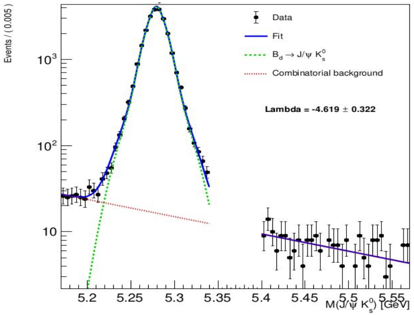
Private work (CMS Simulation)

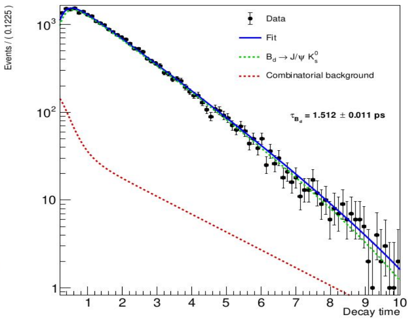


II. Era dependency

Fit to individual years . The maximum deviation between the years to PDG value is taken as systematic uncertainty. 2018 mass and decay time projection plots are shown. Systematic uncertainty - 0.031ps

Private work (CMS Data)





Summary

- Decay time comparisons agree well.
- Control sample study results are consistent with PDG.
- The expected lifetime statistical uncertainty is 0.09ps and the systematic uncertainty ~ 0.04ps.

Thank you

Backup

V^0 candidates and Armenteros variables

- The Armenteros-Podolanski plot (often abbreviated with "Armenteros plot") is the name of a special two-dimensional plot, in which the transverse momentum Q_T (in GeV/c) of the positive daughter particle with respect to the reconstructed mother particle's momentum is plotted against the longitudinal momentum asymmetry α, to illustrate the kinematic properties of the V^0 candidates. Q_T and α are defined by

$$Q_T = \frac{|\vec{p_d} \times \vec{p_m}|}{|\vec{p_m}|}$$

$$\alpha = \frac{p_L^+ - p_L^-}{p_L^+ + p_L^-}$$

- p_L^+ and p_L^- are the momenta of the daughter particles. The K_S^0 decays into two particles with the same mass. Their momenta are distributed symmetrically. In the decay of Λ^0 ($\overline{\Lambda^0}$) the p^+ (p^-) takes a larger part of the momentum than the π^- (π^+). The distribution is asymmetric.

Armenteros Plots :-

BOX cut :- qT - (0.065-0.11) and a - (0.65-0.85)