B mesons lifetime determination in fully hadronic decays

Text for the blessed web page – CDF note 7386

The CDF Collaboration

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Abstract

We present the lifetime measurements of B^+, B^0 and B_s mesons, performed using fully reconstructed hadronic decays collected by the SVT trigger. Due to the impact parameter cuts of the SVT trigger the proper decay time distributions of the B mesons no longer follow a simply exponential decay. The bias is corrected using a Monte Carlo based approach that have to take into account for bias coming form analysis cuts also. The lifetimes are extracted using the decay modes $B^+ \to \bar{D}^0\pi^+$, $B^0 \to \bar{D}^-\pi^+$, $B^0 \to \bar{D}^-\pi^+\pi^-\pi^+$, $B_s \to \bar{D}_s^-\pi^+$ and $B_s \to \bar{D}_s^-\pi^+\pi^-\pi^+$. We measure

$$c\tau(B^+) = 498 \pm 8(stat) \pm 4(syst)\ \mu m,$$
$$c\tau(B^0) = 453 \pm 7(stat) \pm 4(syst)\ \mu m,$$
$$c\tau(B_s) = 479 \pm 29(stat) \pm 5(syst)\ \mu m.$$

or

$$c\tau(B^+) = 1.66 \pm 0.03(stat) \pm 0.01(syst) ps,$$

$$c\tau(B^0) = 1.51 \pm 0.02(stat) \pm 0.01(syst) ps,$$

$$c\tau(B_s) = 1.60 \pm 0.10(stat) \pm 0.02(syst) ps.$$

The availability to measure lifetimes in hadronic decay modes is an important step for mixing analysis in these samples. Moreover the measurement itself is important to improve the B_s lifetime precision, and to test the Standard Model prediction that quote the ratio between B^0 and B_s to be no to much far from unity.

1 Description

The SVT trigger has already proved is effectiveness in the selection of fully hadronic B and D meson decays. The trigger selection, requiring the presence of displaced tracks to select the event, affects the proper decay time distribution of the reconstructed mesons. This effect have to be understood and correctly incorporated in the probability density functions used to build up the likelihood needed to extract the lifetime.
This analysis propose a Monte Carlo based method which makes full use of the realistic simulation of the CDF detector and trigger systems. The idea is to extract an efficiency distribution for each decay mode from the simulation and fit those distributions to obtain a functional form expressed as a function of reconstructed proper time.
The method is tested on Data using B^+ mesons decaying into $B^+ \to J/\psi K^+$. These decays have been collected using the J/ψ trigger, where there is no bias from the SVT trigger. We perform the full analysis both using the full dataset, and on the subset of the events obtained after having applied the SVT trigger requirements. Even if the statistic available after the trigger requirements is poor (400 events) the successful result of test gives us confidence on the method.
After that, we perform the lifetime measurements of B^+ and B^0 mesons, in the $B^+ \to \bar{D}^0\pi^+$, $B^0 \to D^-\pi^+$ and $B^0 \to D^-\pi^+\pi^-\pi^+$, decay modes respectively. The positive comparison with the PDG expectations of the lifetime measurements for these two high statistic modes, allowed us to apply the same technique for the $B_s \to D_s^-\pi^+$ and $B_s \to D_s^-\pi^+\pi^-\pi^+$, decay modes, with the D_s^- meson decaying in $\phi\pi^- \to K^+K^-\pi^-$.
All the measurements make use of the improved $L00$ tracking.
The measurements are extracted using a combined mass - lifetime unbinned maximum likelihood fit with per event σ_{ct}. A Mass-only fit is first performed on a wide mass window to fix the different contributions, then we moved to a narrower mass region to perform the combined fit.
The Large Window mass fit is intended to fix the relative contribution fractions and the combinatorial shape parameters. Then the proper time background contribution is modeled using the high mass side band. Finally in a narrower mass region, the combined mass-lifetime fit is performed.
Different sources of systematic errors are taken into account. The overall contribution is less then 5 μm.

2 Blessed Numbers

This section summarizes the numbers which have been blessed for this analysis.

2.1 Fit results

The following Table shows the results of the combined mass-lifetime fits for each decay mode. Then the weighted average is reported on the bottom for the neutral B mesons.

Single Decay Mode Results				
Decay mode	Mass Mean	Mass Width	$c\tau$	Number of B
$B^0 \to D^-\pi^+$	5279.6 ± 0.5	15.9 ± 0.4	457 ± 8	7957
$B^0 \to D^-\pi^+\pi^-\pi^+$	5278.4 ± 0.4	26.8 ± 0.7	442 ± 13	4173
$B^+ \to \bar{D}^0\pi^+$	5278.6 ± 0.2	18.0 ± 0.2	498 ± 8	8380
$B_s \to D_s^-\pi^+$	5365.2 ± 1.1	17.8 ± 1.1	479 ± 32	472
$B_s \to D_s^-\pi^+\pi^-\pi^+$	5368.6 ± 1.8	18.8 ± 3.4	480 ± 71	133
Unit	MeV/c^2	MeV/c^2	μm	

Combined Results		
Meson	$c\tau$	Unit
B^0	453 ± 7	μm
B_s	479 ± 29	μm
B^+	498 ± 8	μm

2.2 Systematic errors

The main systematic contributions are listed in the following table. Detailed informations on how the systematic errors are extracted can bee found in note 7386.

Effect	Variation(μm)	Variation(μm)
	B^0 $B^\pm$	B_s
MC input $c\tau$	negligible	negligible
p_T re-weight	1.9	1.9
Scale Factor	negligible	negligible
Kg ct description	1.1	1.1
Bkg fraction	2.0	2.0
I.P. correlation	1.0	1.0
Eff. parameterization	1.5	1.5
L_{xy} significance	negligible	2
$\Delta\Gamma_s$	-	1.0
Alignm. + others	2.4	2.4
Total	4.2	4.7

2.3 Final result

Then, combining the single decay mode measurements, we quote the following lifetimes:

$$c\tau(B^+) = 498 \pm 8(stat) \pm 4(syst)\ \mu m,$$

$$c\tau(B^0) = 453 \pm 7(stat) \pm 4(syst)\ \mu m,$$

$$c\tau(B_s) = 479 \pm 29(stat) \pm 5(syst)\ \mu m.$$

or

$$c\tau(B^+) = 1.66 \pm 0.03(stat) \pm 0.01(syst)ps,$$

$$c\tau(B^0) = 1.51 \pm 0.02(stat) \pm 0.01(syst)ps,$$

$$c\tau(B_s) = 1.60 \pm 0.10(stat) \pm 0.02(syst)ps.$$

The ratio of the lifetimes is found to be:

$$c\tau(B^+)/c\tau(B^0) = 1.10 \pm 0.02(stat) \pm 0.01(syst),$$

$$c\tau(B_s)/c\tau(B^0) = 1.06 \pm 0.07(stat) \pm 0.01(syst),$$

For comparison, the 2004 Particle Data Group results are:

$$c\tau(B^+) = 501 \pm 5\ \mu m,$$

$$c\tau(B^0) = 461 \pm 4\ \mu m,$$

$$c\tau(B_s) = 438 \pm 17\ \mu m.$$

3 Blessed Figures

The following figures have been blessed for the B lifetime measurements analysis. More detailed informations can be found in CDF note 7386.

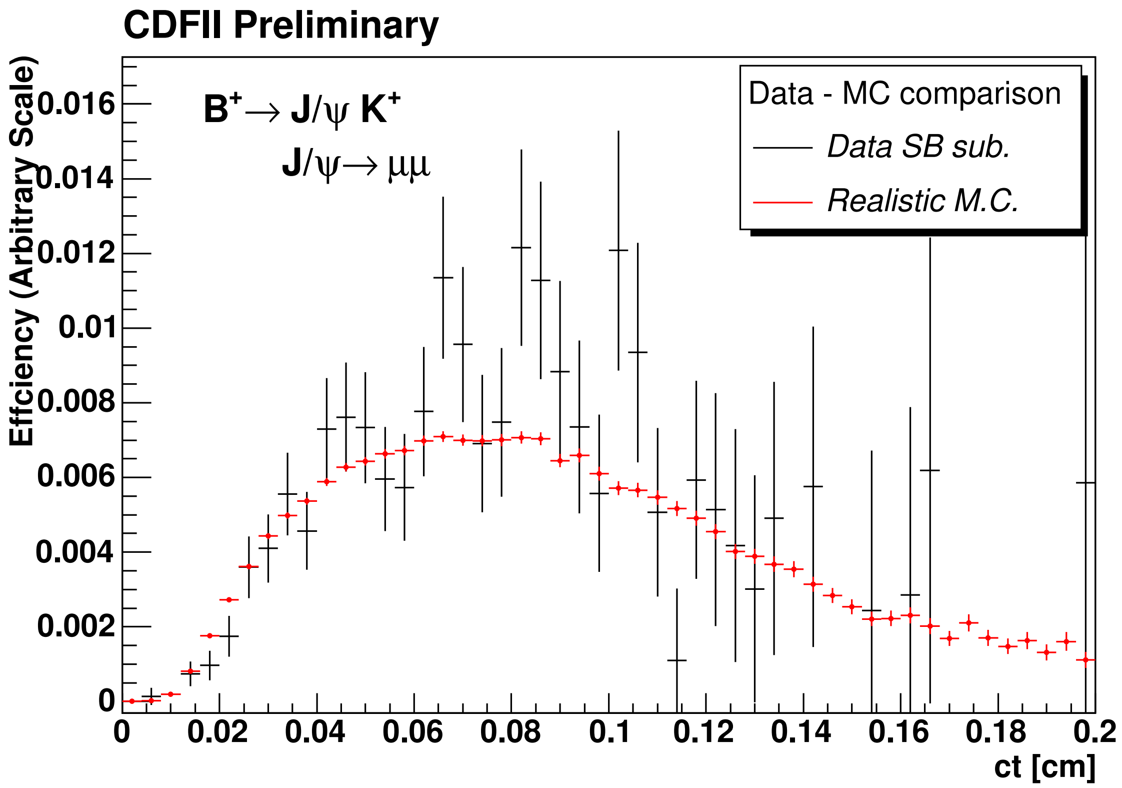

Figure 1: Efficiency distribution Comparison. For $B^+ \to J/\psi K^+$ decay mode is possible to extract the efficiency distribution directly from data. This plot shows the comparison between the efficiency distributions coming from Data (black) and Realistic Monte Carlo (red). A χ^2 test over the two distributions gives a probability of 52%.

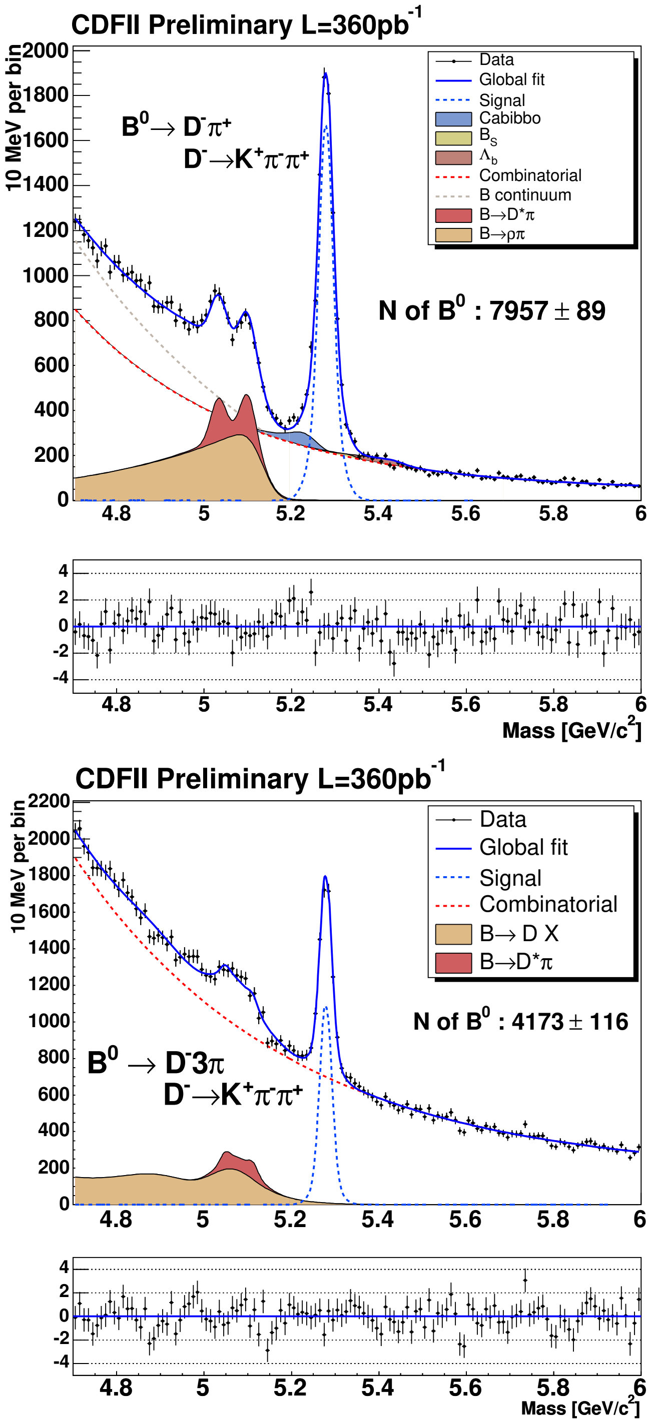

Figure 2: Wide Mass Region Fits: A Mass fit on a wide mass region is performed before to run the combined fit, in order to fix the mass shape of the combinatorial background and estimate the contamination coming from partially reconstructed background. These fits show the projection results for the B^0 decay modes.

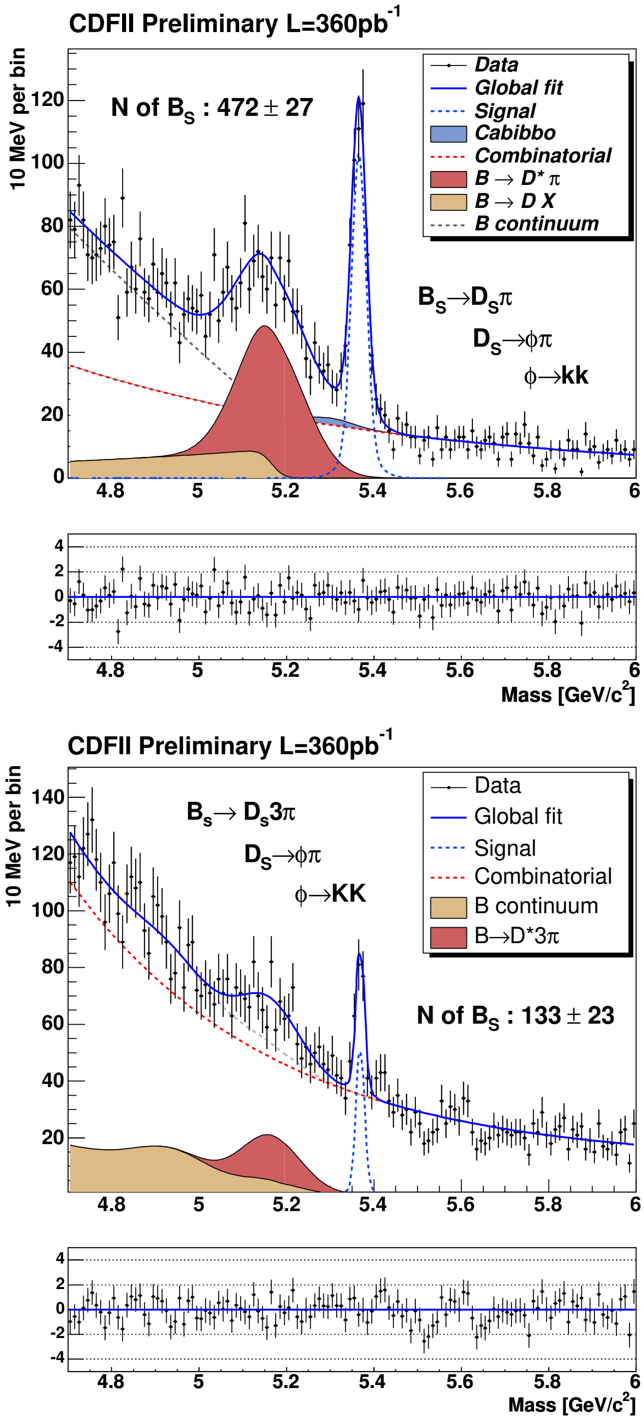

Figure 3: Wide Mass Region Fits: A Mass fit on a wide mass region is performed before to run the combined fit, in order to fix the mass shape of the combinatorial background and estimate the contamination coming from partially reconstructed background. These fits show the projection results for the B_s decay modes.

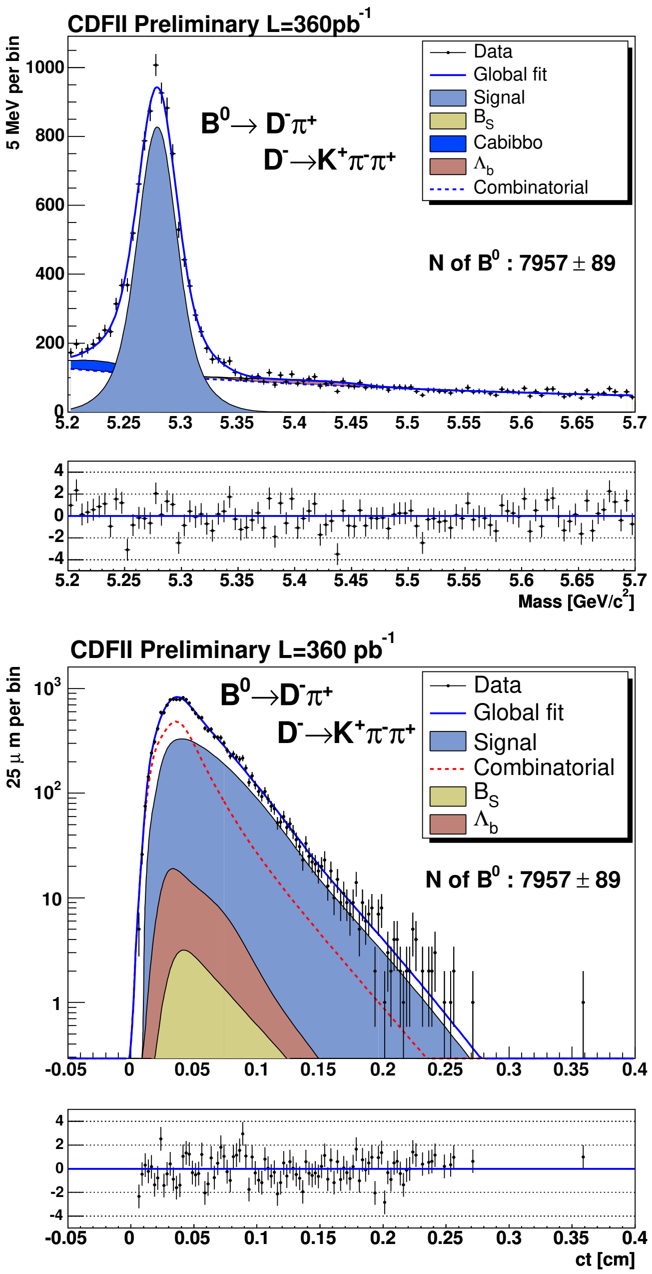

Figure 4: Projection plots for the combined Mass-Lifetime fit on $B^0 \to D^-\pi^+$ decay mode. B_s and Λ_b contributions are taken into account with *ad hoc* Monte Carlo templates. The partially reconstructed contribution is less then 1% and then can be neglected.

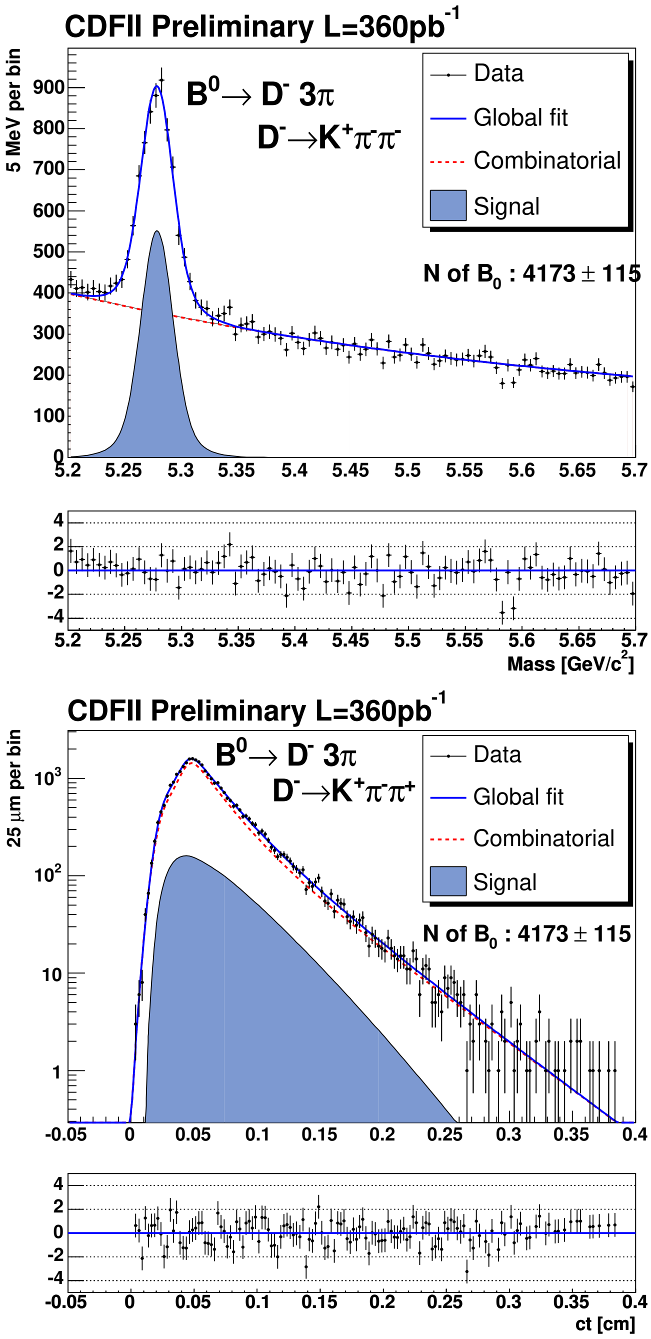

Figure 5: Projection plots for the combined Mass-Lifetime fit on $B^0 \to D^-\pi^+\pi^-\pi^+$ decay mode. The partially reconstructed contribution is less then 1% and then can be neglected.

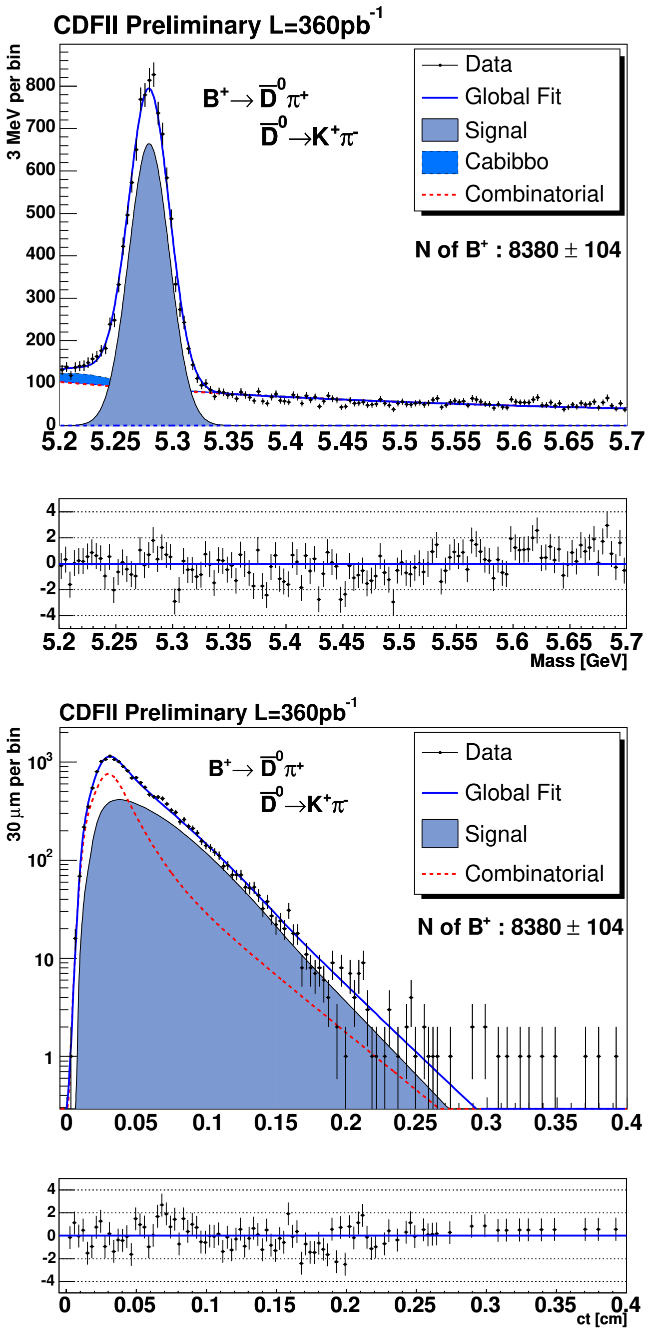

Figure 6: Projection plots for the combined Mass-Lifetime fit on $B^+ \to \bar{D}^0\pi^+$ decay mode. The partially reconstructed contribution is less then 1% and then can be neglected.

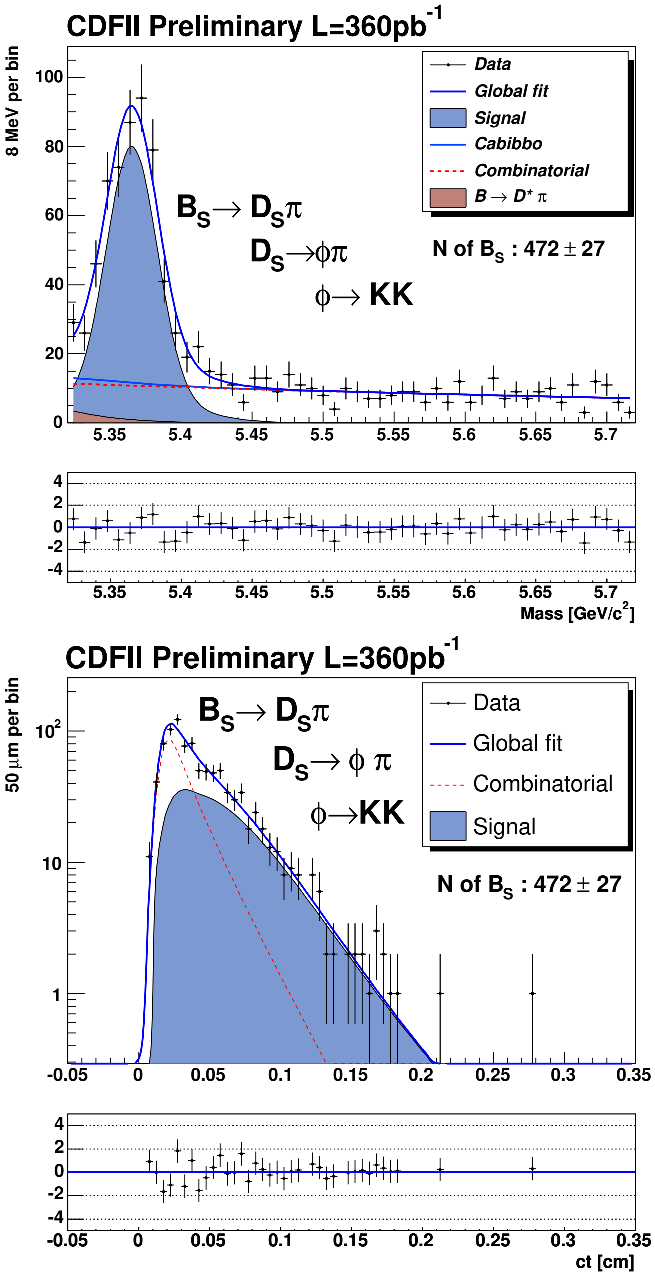

Figure 7: Projection plots for the combined Mass-Lifetime fit on $B_s \to D_s^- \pi^+$ decay mode. The partially reconstructed contribution is less then 1% and then can be neglected.

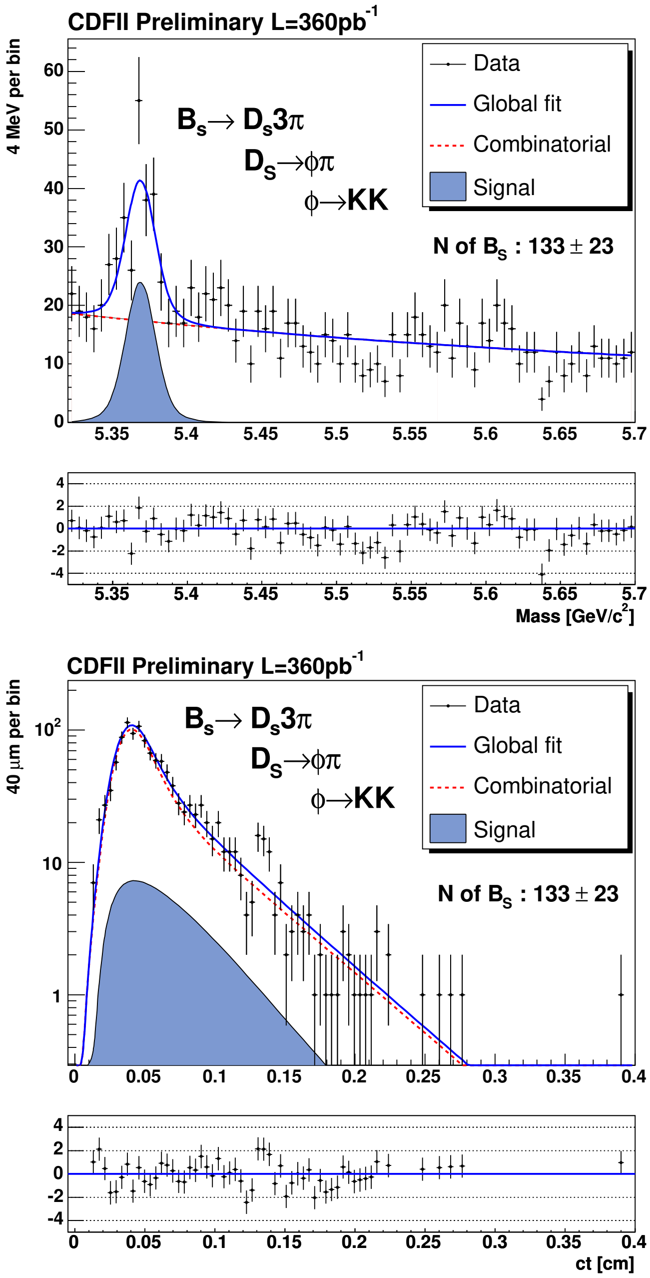

Figure 8: Projection plots for the combined Mass-Lifetime fit on $B_s \rightarrow D_s^- \pi^+ \pi^- \pi^+$ decay mode. The partially reconstructed contribution is less then 1% and then can be neglected.

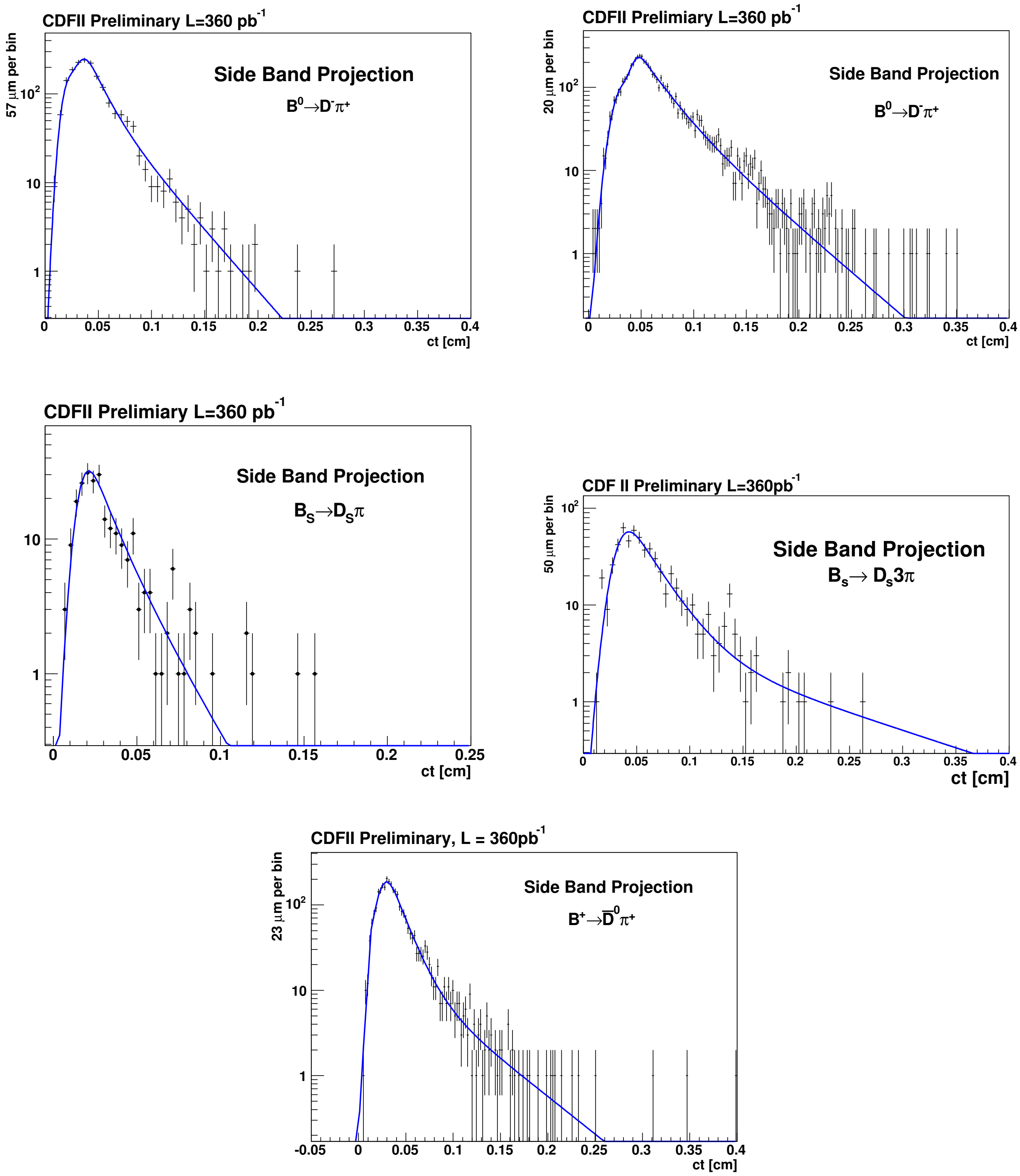

Figure 9: Projection Plots on ct Side Band. The fitting function is the sum of two exponentials convoluted with a Gaussian.