



Measurement of the D_s^\pm lifetime

(SELEX Collaboration)

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Abstract

We report a precise measurement of the D_s^\pm meson lifetime. The data were taken by the SELEX experiment (E781) spectrometer using 600 GeV/c Σ^- , π^- and p beams. The measurement has been done using 918 reconstructed D_s^\pm . The lifetime of the D_s^\pm is measured to be $472.5 \pm 17.2 \pm 6.6$ fs, using $K^*(892)^0 K^\pm$ and $\phi\pi^\pm$ decay modes. The lifetime ratio of D_s^\pm to D^0 is 1.145 ± 0.049 .

Key words:

1 Introduction

Precise measurements of the lifetimes of charm meson weak decays are important for understanding QCD in both perturbative and nonperturbative regimes. For mesons a joint expansion in Heavy Quark Effective Theory and perturbative QCD parameters treated through the third order in the heavy quark mass shows a term including non-spectator W-annihilation as well as Pauli interference. The resulting non-leptonic decay rate differences between W-exchange in D^0 and W-annihilation in D_s^\pm produce lifetime differences of order 10-20 % (1).

The D_s^\pm lifetime (2) was dominated by the measurements from E687 Collaboration ($0.475 \pm 0.020 \pm 0.007$ ps) (3). Recently new precision measurements of the D_s^\pm lifetime have been made by the E791 Collaboration ($0.518 \pm 0.014 \pm 0.007$ ps) (4) and the CLEO Collaboration ($486.3 \pm 15.0 \pm_{5.1}^{4.9}$ fs) (5). Both groups have taken advantage of improved precision in the D^0 lifetime measurement to report new results for the D_s^\pm to D^0 lifetime ratio of 1.254 ± 0.041 (4) and 1.190 ± 0.042 (5). Their average is 7.4σ from unity, emphasizing the large difference in W contributions to D_s^\pm and D^0 decays.

In this letter we report the results of a new measurement of the D_s^\pm lifetime based on data from the hadroproduction experiment SELEX (E781) at Fermilab. The measurement is based on about 1000 fully reconstructed decays into $KK\pi$ from a sample of 15.3×10^9 hadronic triggers.

The SELEX detector at Fermilab is a 3-stage magnetic spectrometer. The negatively charged 600 GeV/c beam contains nearly equal fractions of Σ and π . The positive beam contains 92% protons. Beam particles are identified by a Transition Radiation detector. The spectrometer was designed to study

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charm production in the forward hemisphere with good mass and decay vertex resolution for charm momenta in the range 100-500 GeV/ c . Five interaction targets (2 Cu and 3 C) had a total target thickness of 4.2% λ_{int} for protons. The targets are spaced by 1.5 cm. Downstream of the targets are 20 silicon planes with a strip pitch of 20-25 μm oriented in X, Y, U and V views. The scattered-particle spectrometers have momentum cutoffs of 2.5 GeV/ c and 15 GeV/ c respectively. A Ring-Imaging Cerenkov detector (RICH) (6), filled with Neon at room temperature and pressure, provides single track ring radius resolution of 1.4% and 2σ K/π separation up to about 165 GeV/ c . A layout of the spectrometer can be found elsewhere (7).

2 Data set and charm selection

The charm trigger is very loose. It requires a valid beam track, at least 4 charged secondaries in the forward 150 mrad cone, and two hodoscope hits after the second bending magnet from tracks of charge opposite to that of the beam. We triggered on about 1/3 of all inelastic interactions. A computational filter linked PWC tracks having momenta > 15 GeV/ c to hits in the vertex silicon and made a full reconstruction of primary and secondary vertices in the event. Events consistent with only a primary vertex are not saved. About 1/8 of all triggers are written to tape, for a final sample of about 10^9 events.

In the full analysis the vertex reconstruction was repeated with tracks of all momenta. Again, only events inconsistent with having a single primary vertex were considered. The RICH detector identified charged tracks above 25 GeV/ c . Results reported here come from a preliminary reconstruction through the data, using a production code optimized for speed, not ultimate efficiency. The simulated reconstruction efficiency of any charmed state is constant at about 40% for $x_F > 0.3$ where $> 60\%$ of SELEX events lie.

To separate the signal from the noncharm background we require that: (i) the spatial separation L between the reconstructed production and decay vertices exceeds 8 times the combined error σ_L , (ii) each decay track, extrapolated to the primary vertex z position, must miss by a transverse distance length $t \geq 2.5$ times its error σ_t , (iii) the secondary vertex must lie outside any target by at least 0.05 cm and (iv) decays must occur within a fiducial region.

There are 918 ± 53 events D_s^\pm candidates, each having two RICH-identified kaons and a pion, for which no particle identification is required. We divide them into three decay channels: $K^*(892)^0 K^\pm$, $\phi\pi^\pm$ and other $KK\pi$. The resonant mass window for the $K^*(892)^0$ (ϕ) was 892 ± 70 MeV/ c^2 (1020 ± 10 MeV/ c^2).

π/K misidentification causes a reflection of D^\pm under the D_s^\pm peak. We limit the maximum kaon momentum to 160 GeV/ c to reduce misidentification in the RICH. To evaluate the shape of this background we use the $D^\pm \rightarrow K^\mp \pi^\pm \pi^\pm$ sample that passes all the cuts listed above and lies within ± 15 MeV/ c^2 of the D^+ mass. We formed the invariant mass distribution of these events when one pion is interpreted as a kaon. At most one of the two possible reflections per event falls into the D_s^\pm mass window. The reflected mass distribution was fit by a polynomial function rising at 1925 MeV/ c^2 and decreasing to zero at large invariant mass. Dividing this distribution by the number of D^\pm events gives us the contribution per mass bin for each misidentified D^\pm in the D_s^\pm sample. We count the misidentified D^\pm in the D_s^\pm sample by fitting the D_s^\pm mass distribution within ± 20 MeV/ c^2 interval around the D_s^\pm mass with the sum of a Gaussian signal, a linear background shape estimated from the sidebands and the D^\pm shape with variable normalization. The resultant misidentified D^\pm contribution to the D_s^\pm mass distribution is shown as the hatched areas in Fig. 1(a), (b). The fit gives 52 ± 7 and 12 ± 3 misidentified D^\pm events in the K^*K and $\phi\pi$ decay mode, respectively (the error quoted is statistical only). The RICH kaon identification is a very powerful tool for rejecting D^\pm contamination; ϕ decay kinematics further reduces particle identification confusion in the $\phi\pi$ channel.

To estimate yields, we subtracted the sideband background and D^\pm contamination as evaluated above from the total number of events in the signal region. We find 430 ± 24 K^*K and 330 ± 19 $\phi\pi$ events. A Gaussian fit to the combined data shown in Fig. 1(a), (b) gives a mass of 1969 ± 9.7 MeV/ c^2 and $\sigma_{D_s^\pm} = 8.0$ MeV/ c^2 . Note that these fitted yields are not used as constraints in the lifetime fit, as discussed below.

3 Lifetime evaluation using a maximum likelihood fit

The average longitudinal error σ_z on the primary and secondary vertices is 270 μm and 500 μm , which gives a combined error of 570 μm . In the D_s^\pm sample, the average momentum is 215 GeV/ c , corresponding to a time resolution of 18 fs, about 4% of $\tau_{D_s^\pm}$. Because bin-smearing effects are small, we used a binned maximum likelihood fitting technique to determine the D_s^\pm lifetime. The fit was applied to a reduced proper time distribution, $t^* = M(L - L_{min})/pc$ where M is the known charm mass (2), p the reconstructed momentum, L the measured vertex separation and L_{min} the minimum L for each event to pass all the imposed selection cuts. L_{min} is determined event-by-event, along with the acceptance, by the procedure described below. We fitted all events with $t^* < 1600$ fs in the mass range $1.949 < M(KK\pi) < 1.989$ GeV/ c^2 , $\pm 2.5\sigma$ from the D_s^\pm central mass value.

To evaluate the mean lifetime we used a maximum likelihood method. The probability density was performed by the function :

$$f(\tau_{D_s}, \tau_{Bck}, \alpha, \beta; t^*) = (1 - \alpha)N_S \frac{e^{-t^*/\tau_{D_s^\pm}}}{\epsilon(t^*)\tau_{D_s^\pm}} + \alpha N_S B(t^*) + \frac{N_{D^\pm}}{\tau_{D^\pm}} e^{-t^*/\tau_{D^\pm}} \quad (1)$$

where

$$B(t^*) = \frac{\beta e^{-t^*/\tau_{Bck}}}{\tau_{Bck}} + \frac{1 - \beta}{t_{Max}^*} \quad (2)$$

The function is the sum of a term for the D_s^\pm exponential decay corrected by the acceptance function $\epsilon(t^*)$ plus a background function $B(t^*)$ consisting of a single exponential plus a constant to account for a flat background extending to large proper time. Its parameters were determined from the t^* distribution from the D_s^\pm sidebands. It also includes a term for the D^\pm exponential decay normalized to the number of misidentified events in the signal region. The τ_{D^\pm} lifetime used in the fit is 1051 ± 13 fs (2). The mass range of the sideband background windows, $1.890 < M(KK\pi) < 1.930$ GeV/ c^2 and $2.040 < M(KK\pi) < 2.080$ GeV/ c^2 was twice the signal mass window. We defined asymmetric sidebands to avoid the influence of $D^\pm \rightarrow K^+ K^- \pi^\pm$, and we excluded the $D^*(2010)$ mass region.

The four parameters are: $\tau_{D_s^\pm}$ (D_s^\pm lifetime), τ_{Bck} (background lifetime), α (background fraction in the signal region) and β (background splitting function). N_S is the total number of events in the signal region after D^\pm contamination subtraction.

The proper-time-dependent acceptance $\epsilon(t^*)$ is independent of spectrometer features after the first magnet, e.g., RICH efficiency and tracking efficiency. These efficiencies affect only the overall number of events detected. The proper time distribution of these events depends crucially on vertex reconstruction. To evaluate $\epsilon(t^*)$ we reanalyze each *observed* D_s^\pm event after moving it to a large set of different proper times t^* . Only the longitudinal position of the charm decay point and the axial orientation of the 3-body decay vectors are changed (8). A reanalyzed event is accepted if it passes the same cuts as those applied to the data. The minimum flight path after which an event is accepted defines L_{min} for this event. This method is independent of details of the true x_F or transverse momentum distributions (8).

Fig. 2 shows the overall fits to the data distributions as a function of reduced proper time for $K^*(892)^0 K^\pm$ and $\phi\pi^\pm$ decay modes. It also shows the acceptance $\epsilon(t^*)$, which differs significantly from unity only after 4 lifetimes where statistics are limited.

D_s^\pm	$\tau_{D_s^\pm}$ (fs)	Signal
$K^*(892)^0 K^\pm$	472.3 ± 23.0	430 ± 24
$\phi\pi^\pm$	473.0 ± 26.0	330 ± 19
Average	472.5 ± 17.2	760 ± 30

Table 1

Lifetime results and signal yields for the two D_s^\pm modes analyzed. The last row is the weighted average of the two resonant channels $K^*(892)^0 K^\pm$ and $\phi\pi^\pm$. The errors are statistical only.

Source of uncertainty	$K^*(892)^0 K^\pm$	$\phi\pi^\pm$
Vertex reconstruction	<1	<1
D^\pm contamination	2	–
Acceptance function	3	2
Fit procedure	5	0.3
Total systematic error	6.2	2.2

Table 2

Systematic error contributions in fs.

Table 1 summarizes the lifetime results for the two modes analyzed: $D_s^\pm \rightarrow K^*(892)^0 K^\pm$; and $D_s^\pm \rightarrow \phi\pi^\pm$. The uncertainties are statistical only, evaluated where $-\ln \mathcal{L}$ increases by 0.5. Combining these results for the two resonant modes, we measure an average lifetime $\tau_{D_s^\pm} = 472.5 \pm 17.2$ fs.

4 Systematic errors

The systematic uncertainties for the D_s^\pm lifetime analysis are listed in Table 2 and described below. We group them in the following categories:

4.1 Primary and secondary vertex reconstruction

Lifetime shifts due to reconstruction errors have been well studied in our D^0 and Λ_c work, with an order of magnitude higher statistics (8; 9). Because of the high redundancy and good precision of the silicon vertex detector, vertex mismeasurement effects are small at all momenta. Proper time assignment depends on correct momentum determination. The SELEX momentum error is less than 0.5% in all cases. We assign a maximum systematic error from proper time mismeasurement of 1 fs.

4.2 Misidentification

The effect of D^\pm contamination under the D_s^\pm peak was studied by changing the width of the exclusion window around the nominal D^\pm mass for the K/π interchange discussed above. Effects on the $\phi\pi$ mode are negligible. For the $K^*(892)^0 K^\pm$ mode this gives a systematic error of 2 fs.

4.3 Acceptance function

The technique to determine the acceptance correction dependence on proper time is discussed extensively in Ref. (8). It has been verified with much larger statistics there. The maximum systematic error here is dominated by the $K^*(892)^0 K^\pm$ correction, 3 fs. For the $\phi\pi^\pm$ mode it is less than 2 fs.

4.4 Fit procedure

The fit was performed by the maximum likelihood method using a background parametrized by an exponential function plus a constant. We varied the width of the sidebands and the t_{Max}^* independently. The systematic error due to the fit procedure is 5 fs and less than 0.5 fs for $K^*(892)^0 K^\pm$ and $\phi\pi^\pm$ decay modes respectively. That error is mainly dominated by the D_s^\pm background parametrization.

Combining in quadrature all the sources of systematic errors listed in Table 2 we obtain a total systematic error of 6.2 fs (2.2 fs) for the $K^*(892)^0 K^\pm$ ($\phi\pi^\pm$) mode.

5 CONCLUSIONS

We have made a new measurement of the D_s^\pm lifetime in two independent resonant decay channels, $K^*(892)^0 K^\pm$ and $\phi\pi^\pm$ using a maximum likelihood fit. SELEX measures the D_s^\pm lifetime to be $472.5 \pm 17.2 \pm 6.6$ fs. Using the result reported in the PDG (2) $\tau_{D^0} = 412.6 \pm 2.8$ fs we evaluate a ratio $\tau_{D_s^\pm}/\tau_{D^0} = 1.145 \pm 0.049$, 3σ from unity. The D_s lifetime reported in this Letter is comparable in precision with previous experiments (4; 5). Our result, combined with other world data, (2), lowers the overall D_s^\pm lifetime somewhat. Nevertheless, it is clear that the lifetime ratio $\tau_{D_s^\pm}/\tau_{D^0}$ is significantly larger than unity for all the precision measurements.

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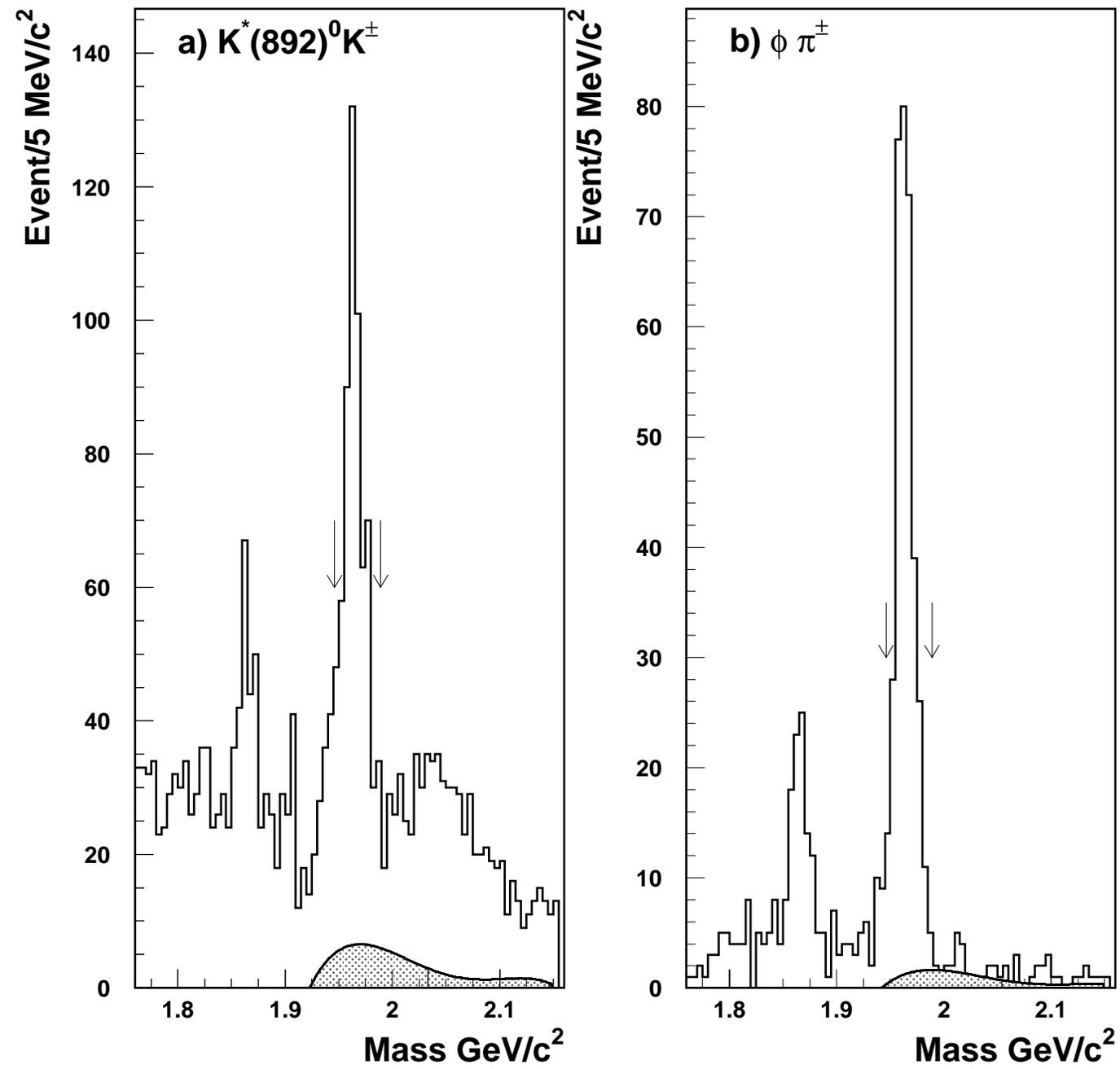


Fig. 1. Invariant mass distributions for a) $D_s^\pm \rightarrow K^*(892)^0 K^\pm$, b) $D_s^\pm \rightarrow \phi \pi^\pm$. Hatched regions show the $K^+K^- \pi^\pm$ background from misidentified D^\pm . The arrows show the D_s^\pm signal region.

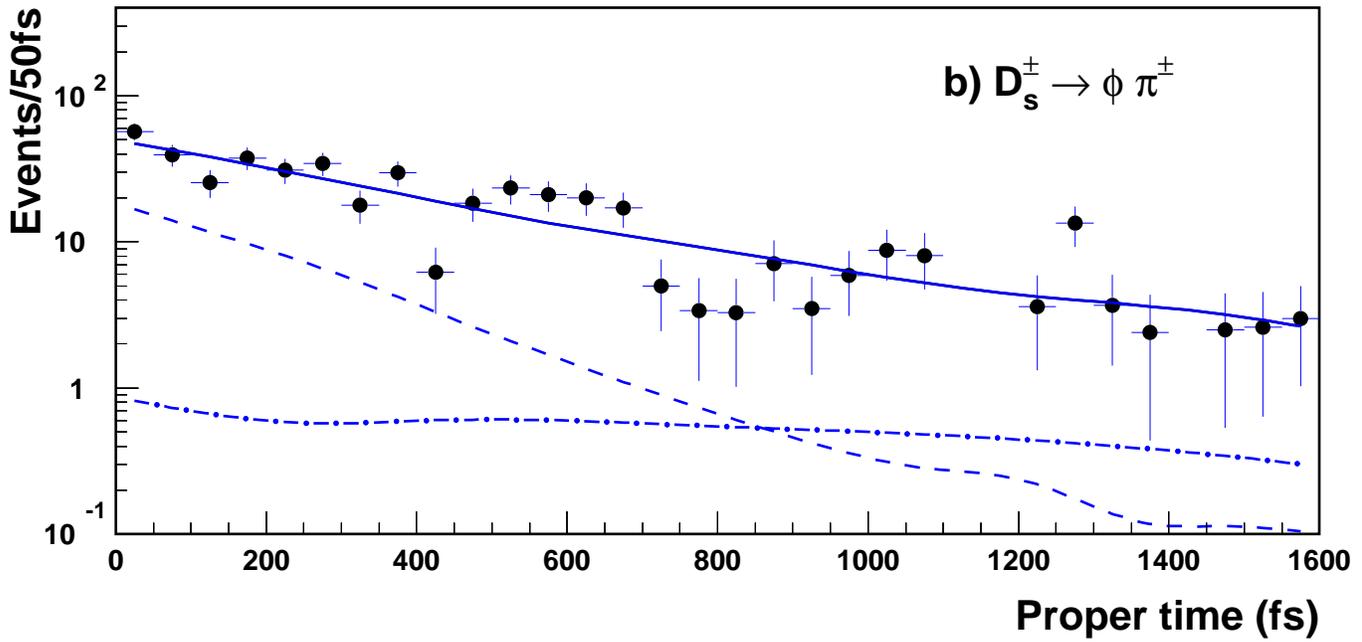
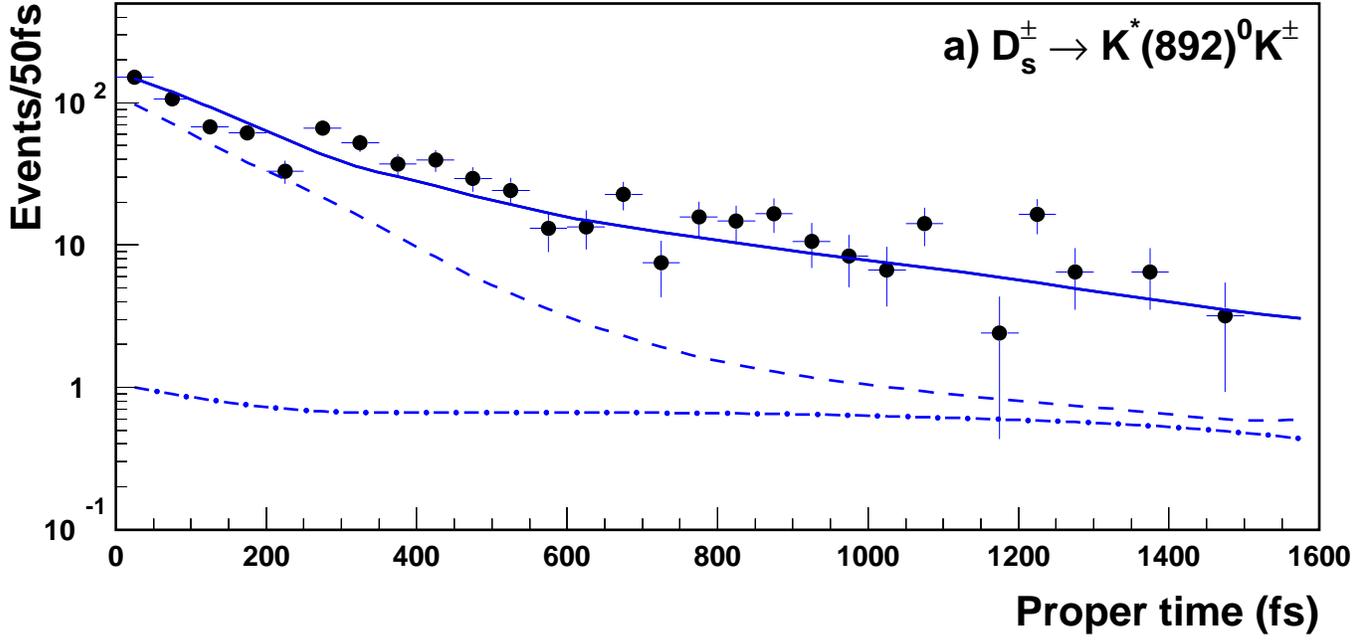


Fig. 2. Corrected reduced proper time distributions for events in the D_s^\pm window $1969 \pm 20 \text{ MeV}/c^2$ (full circles) and results from the maximum likelihood fit (solid curve) for: a) $D_s^\pm \rightarrow K^*(892)^0 K^\pm$; and b) $D_s^\pm \rightarrow \phi \pi^\pm$. The dashed curve shows the fitted background, including the D^\pm contribution. The dashed-dot curve describes the acceptance function, $\epsilon(t^*)$.