Measurement of the $\bar{B}_s^0$ meson Lifetime using Semileptonic Decay with Single Lepton Datasets in CDF Run II

(CDF 7683)

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Introduction

Why measuring the $\bar{B}_s^0$ lifetime is important?

- Provides a probe for weak interaction mechanics for heavy hadrons.
- Test HQE prediction (Heavy Quark Expansion, by I.I.Bigi)
  - $\tau(B^+)/\tau(\bar{B}^0) \sim 1 + 0.05(f_B/200 \text{ MeV})^2$
  - $\tau(B_s)/\tau(\bar{B}^0) \sim 1 \pm 0.01$
- Important for the $B_s^0 \bar{B}_s^{\,0}$ measurement.
- Past measurements are still statistically limited, good to measure with high statistics sample in CDF Run II.

$\bar{B}_s^0$ lifetime with 8 GeV lepton sample:

- Use $\bar{B}_s^0 \to \ell^- \bar{\nu} D_s^+ X$, $D_s^+ \to \phi\pi^+$, $\phi \to K^+K^-$.
- Large branching fraction
- Minimal trigger bias
- Charge correlation is useful to identify the B signal ($Q_\ell \neq Q_\pi$)

Analysis outline

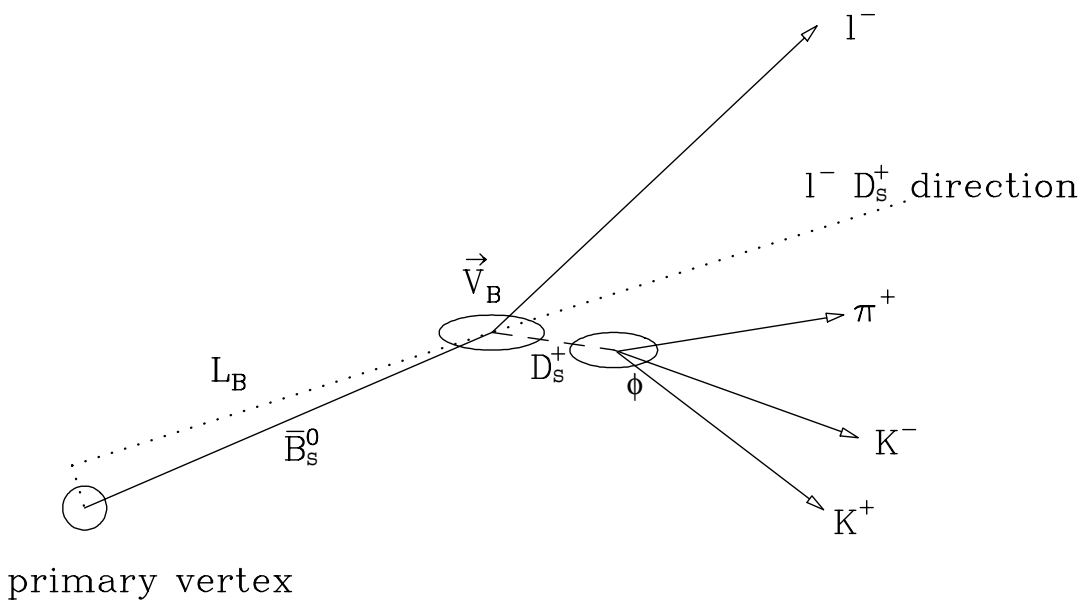
Basically the analysis strategy is same with the previous 8 GeV $B^-/\bar{B}^0$ lifetime analysis.

1. Select a lepton (e or μ) from 8 GeV lepton datasets
2. Reconstruct $D_s^+ \to \phi\pi^+, \phi \to K^+K^-$ signal around the lepton
3. Reconstruct $\bar{B}_s^0 \to \ell^-\bar{\nu}D_s^+X$ decay vertex in xy plane,
   and calculate $\bar{B}_s^0$ pseudo-proper decay time
4. Correct missing momentum (K factor)
   - $p_T(\bar{B}_s^0)$ can not be reconstructed due to some missing particles (neutrino, particles from $D_s^{+*(**)}$)
   - Correct it using MC
5. Model combinatorial background shape
   - use D_s^+ mass sideband
6. Determine resolution scale factor
7. Estimate physics backgrounds
   - Prompt charm background
   - Bottom background
8. Extract the lifetimes using unbinned likelihood fit
9. Estimate systematic uncertainties

Dataset & Reconstruction

- 8 GeV lepton trigger ..require μ,e with $p_T > 8$ GeV$/c$
- Minimal trigger bias
- 360 pb^{-1} of the data used for this analysis (electron trigger is dynamically prescaled)

Reconstruction of the $\bar{B}_s^0$ decay vertex in xy plane : (typical case)



pseudo decay length is calculated as

$$ct^*(\bar{B}_s^0) = \frac{L_{\bar{B}_s^0}}{p_T(\ell^- D_s^+)} M_{\bar{B}_s^0}$$

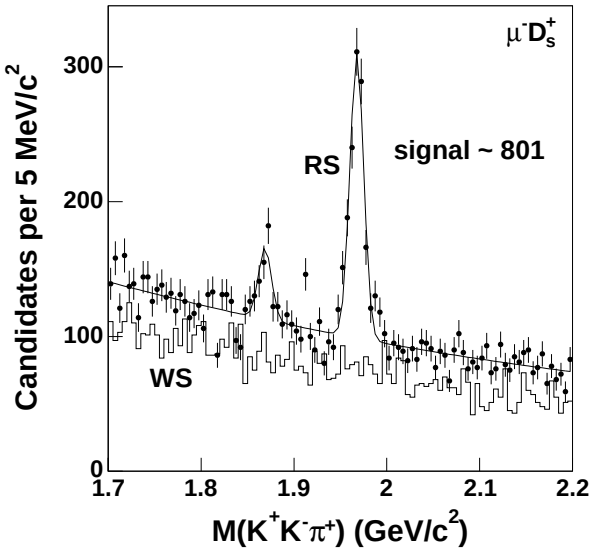
Event selection

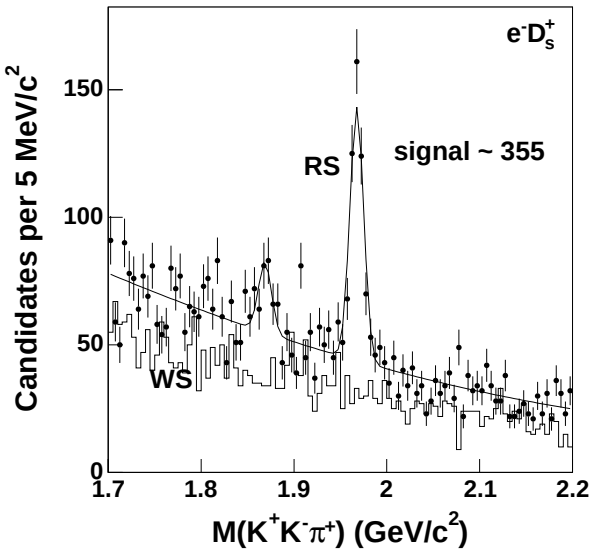
- **Muon selection:**
  - $p_T(\mu) >$ 8 GeV$/c$
  - χ^2_x(CMU, CMP) $<$ 7, χ^2_z(CMU) < 9
  - Iso(ΣE_T in $\Delta R <$ 0.4)$/p_T(D_s^+) <$ 2.5
- **Electron selection:**
  - $p_T >$ 8 GeV$/c$, $E_T >$ 8 GeV$/c^2$
  - Reconstructed in CEM fiducial region.
  - LSHR $<$ 0.2
  - CES $|\Delta x| <$ 1.4 cm
  - CES $|\Delta z \sin\theta| <$ 2 cm
  - CES $\chi^2_x, \chi^2_z <$ 15
  - $E_{\rm HAD}/E_{\rm EM} <$ 0.04 (if # of associated track $=$ 1)
  - $E_{\rm HAD}/E_{\rm EM} <$ 0.1 (if # of associated track $>$ 1)
  - 0.75 $< E/p <$ 1.4
  - Conversion Removal :
    - $|S| <$ 0.2 cm
    - $|\Delta \cot\theta| <$ 0.06

Event selection (cont'd)

- For $D_s^+ \to \phi\pi^+$, $\phi \to K^+K^-$ reconstruction:
  - Tracking algorithm is OI,OIZ, or OIS (for ℓ,K,π)
  - $p_T(K) > 1.2$ GeV/c, $p_T(\pi) > 0.9$ GeV/c
  - $\Delta R(\ell - K, \pi) < 0.8$
  - $|\Delta z_0(\ell - K, \pi)| < 1$ cm
  - $3 < M(\ell^- D_s^+) < 5.3$ GeV/c^2
  - $|\cos\psi| > 0.4$
    (ψ ... helicity angle between the K and D_s^+ in ϕ rest frame)
  - $L_{xy}(D_s^+ - P.V.) > 0$
  - $\log$(vertex fit prob.) > -10
  - $|ct(D_s^+)| < 0.1$ cm
  - $\sigma_{ct*}(\bar{B}_s^0)$, $\sigma_{ct}(D_s^+) < 0.02$ cm
  - $-0.15 < ct^*(\bar{B}_s^0) < 0.3$ cm

$\ell^- D_s^+$ signal





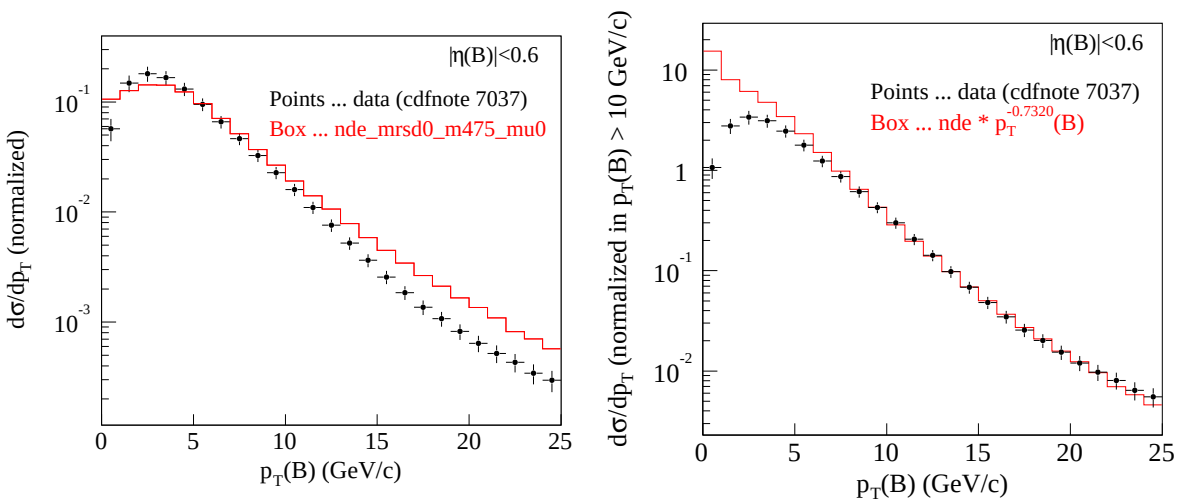
	$N_{D_s^+}$	Signal fraction
$\mu^- D_s^+$	1591	0.503 ± 0.014
$e^- D_s^+$	706	0.503 ± 0.021

$\bar{B}_s^0$ monte carlo samples

$\bar{B}_s^0$ semileptonic decay monte carlo sample is generated with Bgenerator + EvtGen.
Full detector simulation is applied with cdfsoft version 5.3.4.

Tuning on $p_T(\bar{B}_s^0)$ spectrum:

$p_T(\bar{B}_s^0)$ spectrum used in the Bgenerator have somewhat different shape from the real spectrum measured by J/ψ data (cdf7037). We correct the difference by weighting the MC events with a factor of $p_T(\bar{B}_s^0)^{-0.7320}$.



Tuning on f^{**}:

The f^{**} is defined as,

$$f^{**} = \frac{\mathcal{B}(\bar{B}_s^0 \to \ell^- \bar{\nu} D_s^{**+})}{\mathcal{B}(\bar{B}_s^0 \to \ell^- \bar{\nu} D_s^+ X)}.$$

EvtGen default is $f^{**} = 0.24$.
To use the consistent number with the previous 8 GeV $B^-/\bar{B}^0$ lifetime analysis, we re-weight the MC samples to tune the f^{**} to be 0.36 .

Missing momentum correction (K factor)

"Real" decay length of the $\bar{B}_s^0$ meson :

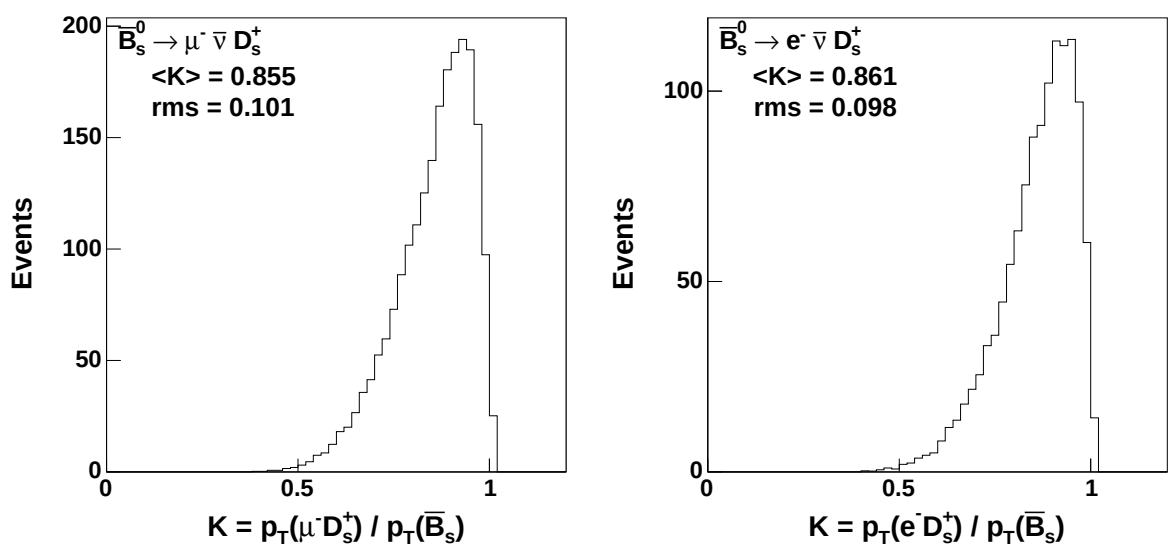
$$ct(\bar{B}_s^0) = \frac{L_{\bar{B}_s^0}}{p_T(\bar{B}_s^0)} M_{\bar{B}_s^0}$$

But since the $\bar{B}_s^0$ is not fully reconstructed, what we can measure is $P_T(\ell^- D_s^+)$ and "pseudo-proper" decay length ct^*.

$$ct^*(\bar{B}_s^0) = \frac{L_{\bar{B}_s^0}}{p_T(\ell^- D_s^+)} M_{\bar{B}_s^0} = ct \cdot K \quad \text{where } K \equiv \frac{p_T(\ell^- D_s^+)}{p_T(\bar{B}_s^0)}$$

From the distributions of both ct^*(data) and K factor, we can extract the lifetime of "true" decay length.

The K factor distributions are obtained from the $\bar{B}_s^0$ monte carlo samples.



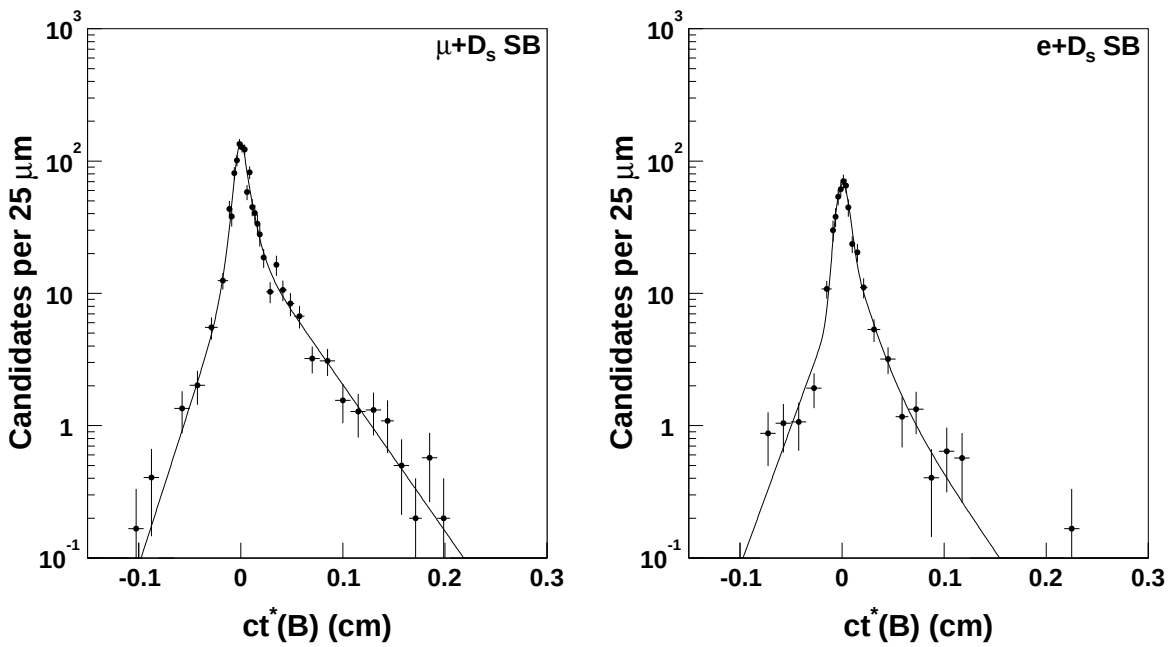
Combinatorial background modeling

The shape of the combinatorial background is taken from the $M(D_s^+)$ sideband events.
The sideband events are modeled with following background function:

$$\begin{aligned}\mathcal{F}_{BG}(ct^*) \;=\; & (1 - f_{1+} - f_{2+} - f_{1-} - f_{2-})\; G(ct^*;\sigma) \\ & + \{f_{1+}\mathsf{Exp}(-x;\lambda_{1+}) + f_{2+}\mathsf{Exp}(-x;\lambda_{2+})\}\,\theta(x) \otimes G(\sigma) \\ & + \{f_{1-}\mathsf{Exp}(+x;\lambda_{1-}) + f_{2-}\mathsf{Exp}(+x;\lambda_{2-})\}\,\theta(-x) \otimes G(\sigma)\end{aligned}$$

where $G(ct^*;\sigma)$ is a normalized Gaussian,
$\theta(x)$ is step function (0 for $x > 0$, 1 for $x < 0$).

Fit results:



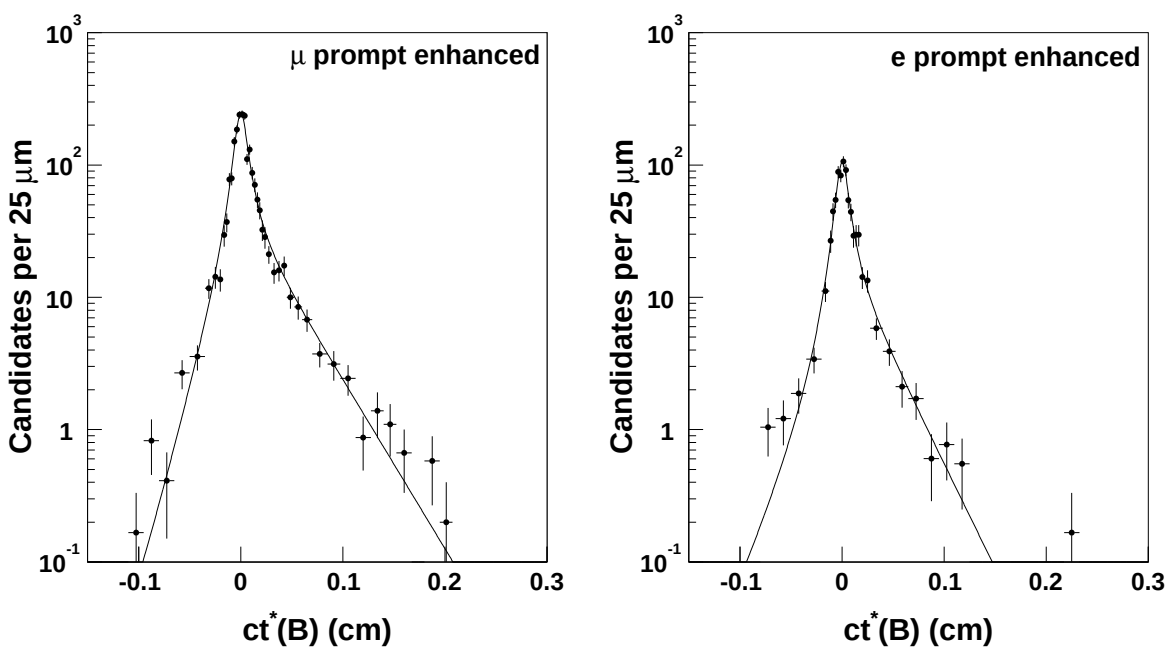
The background shapes under the signal peak are determined by these fits.

Resolution scale factor

The value of σ_{ct^*} provided by CTVMFT is known to be a wrong resolution. To correct it, we introduce a resolution scale factor s, and scale the σ_{ct^*} to $s\sigma_{ct^*}$.

To determine the scale factor, we use a "prompt enhanced sample" selected by loosening the lepton ID cuts. From this sample, we pick sideband events and fit the ct^* distribution with the following likelihood function

$$\begin{aligned}\mathcal{F}_{\text{prompt}} &= G(ct^*, s\sigma_{ct*}) \\ &\quad + f_+ \text{Exp}(-ct^*; \lambda_+)\theta(x) \otimes G(s\sigma_{ct^*}) \\ &\quad + f_- \text{Exp}(+ct^*; \lambda_-)\theta(-x) \otimes G(s\sigma_{ct^*})\end{aligned}$$



The scale factors are found to be

$$s = \begin{cases} 1.59 \pm 0.05 & \text{for muon} \\ 1.56 \pm 0.07 & \text{for electron} \end{cases}$$

Charm background

Following prompt charm events give the RS lepton+D_s^+ combinations
(the lepton may either real or fake).

1. $c \to D_s^+$ + prompt track
2. $c\bar{c}$, $c \to D_s^+$, $\bar{c} \to$ track + X

To estimate the prompt charm fraction from the data, we utilize a decay length information.

We define following variable:

$$ct_2 = \frac{L_{xy}(D_s^+ - P.V.)}{p_T(K^+K^-\pi^+)} M(K^+K^-\pi^+)$$

- If the D_s^+ is generated at P.V. (namely prompt charm), the mean lifetime of ct_2 should be same with $c\tau(D^0) = 147\ \mu$m.
- If the event is secondary charm from the $\bar{B}_s^0$ decays, the lifetime will be much longer. (Convolution of two exponentials)

Charm background (cont'd)

Idea : fit the ct_2 distribution with following templates, and measure the charm fraction f_c in each sample.

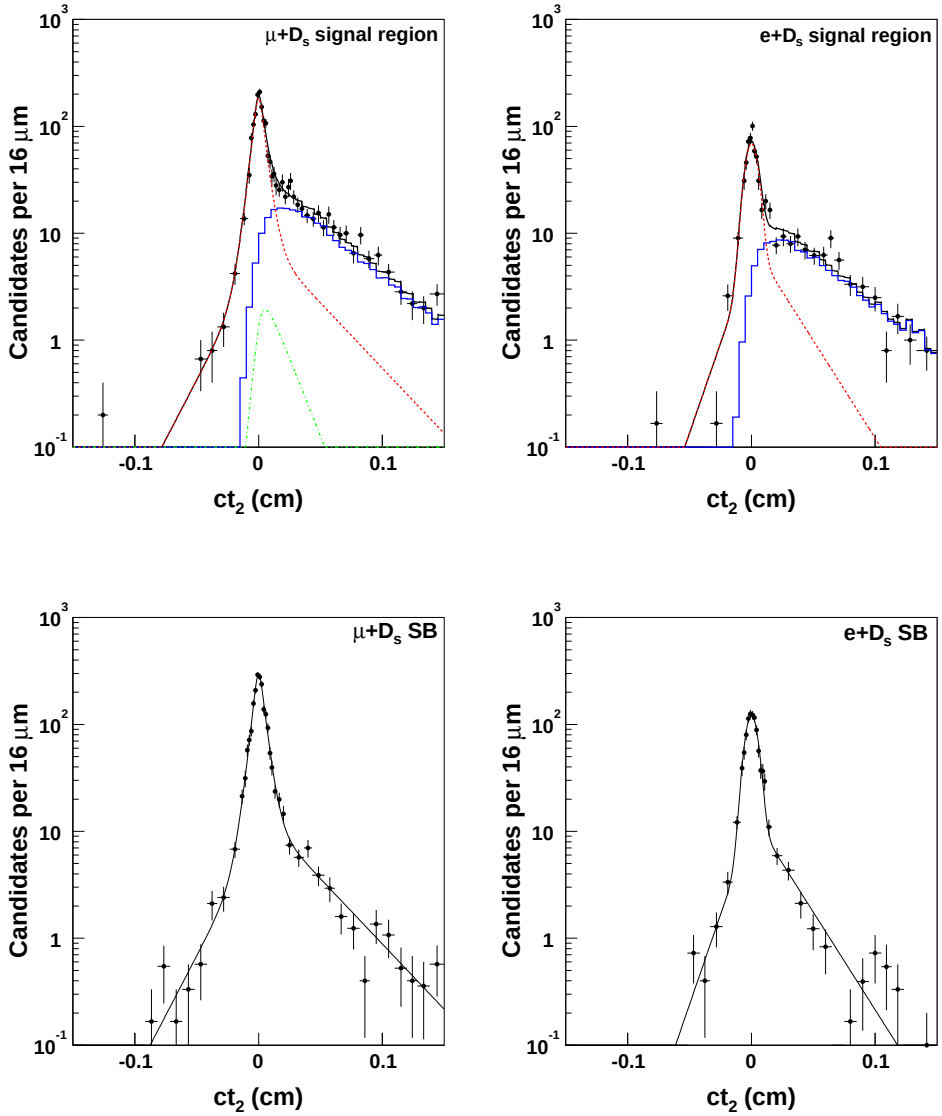
- Charm component (F_c) ... exponential with $c\tau =$ 147 μm, smeared by resolution
- $\bar{B}_s^0$ component ($F_{\bar{B}_s^0}$) ... shape obtained from $\bar{B}_s^0$ full simulation sample, smeared with proper resolution
- combinatorial BG ($F_{\rm BG}$) ... shape taken from the side-band events

Probability density function :

$$F = f_{\rm sig}(f_c F_c + (1 - f_c) F_{\bar{B}_s^0}) + (1 - f_{\rm sig}) F_{\rm BG}$$

The $L_{xy} > 0$ cut is disabled at the f_c fit.

Fit for prompt charm fraction



$$f_c = \frac{N_c}{N_{D^0}} = \begin{cases} 3.6 \pm 4.5\% & \text{for } \mu^- D_s^+ \text{ sample} \\ 0.0\ ^{+7.1}_{-0.0}\% & \text{for } e^- D_s^+ \text{ sample} \end{cases}$$

ct^* shape of the charm background

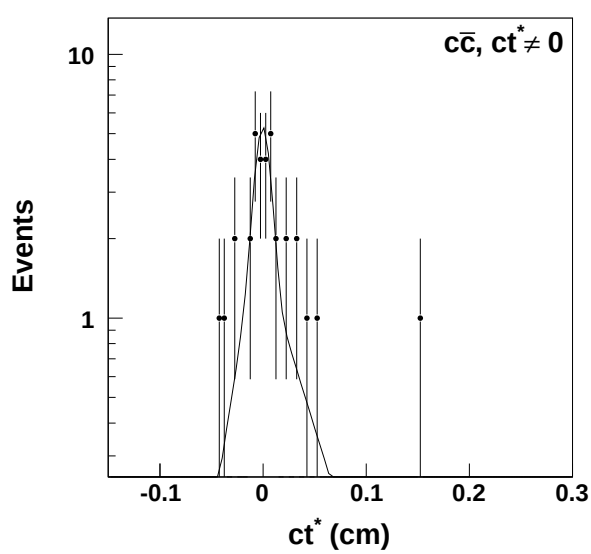
We can categorize prompt charm backgrounds into following two types:

1. $ct^* = 0$ events .. both the D_s^+ and track are from the P.V.
2. $ct^* \neq 0$ events ... $c\bar{c}$ event, track is from a pseudoscalar $\bar{D}$ hadron

For the $ct^* = 0$ events, the ct^* shape is given by Gaussian,

$$\mathcal{F}_c^{\text{zero}} = G(ct^*; s\sigma_{ct^*})$$

For the $ct^* \neq 0$, we use pythia $c\bar{c}$ MC to calculate the ct^* shape $\mathcal{F}_c^{\text{non-zero}}$.



In the final lifetime fit we use the $\mathcal{F}_c^{\text{zero}}$ as the charm background shape $\mathcal{F}_c$. The $\mathcal{F}_c^{\text{non-zero}}$ is used for evaluation of the systematic uncertainties.

Bottom background

Three dominant bottom background processes are generated as well as the signal events using Bgenerator + EvtGen + full detector simulation, and bottom background fraction is estimated with it.
($p_T(B)^{-0.732}$ weighting is applied on the counting).

process	N_{event} $\mu^- D_s^+$	$e^- D_s^+$
$\bar{B}_s^0 \to \ell^- \bar{\nu} D_s^+ X$	283.18 ± 2.90	264.40 ± 2.83
$B^-/\bar{B}^0 \to D_s^+ \bar{D} X$	12.77 ± 0.16	5.98 ± 0.11
$\bar{B}_s^0 \to D_s^+ D_s^- X$	2.92 ± 0.29	0.70 ± 0.14
$\bar{B}_s^0 \to \tau \bar{\nu} D_s^+ X$	4.18 ± 0.35	2.49 ± 0.28

From the table, we obtain the bottom BG fraction as,

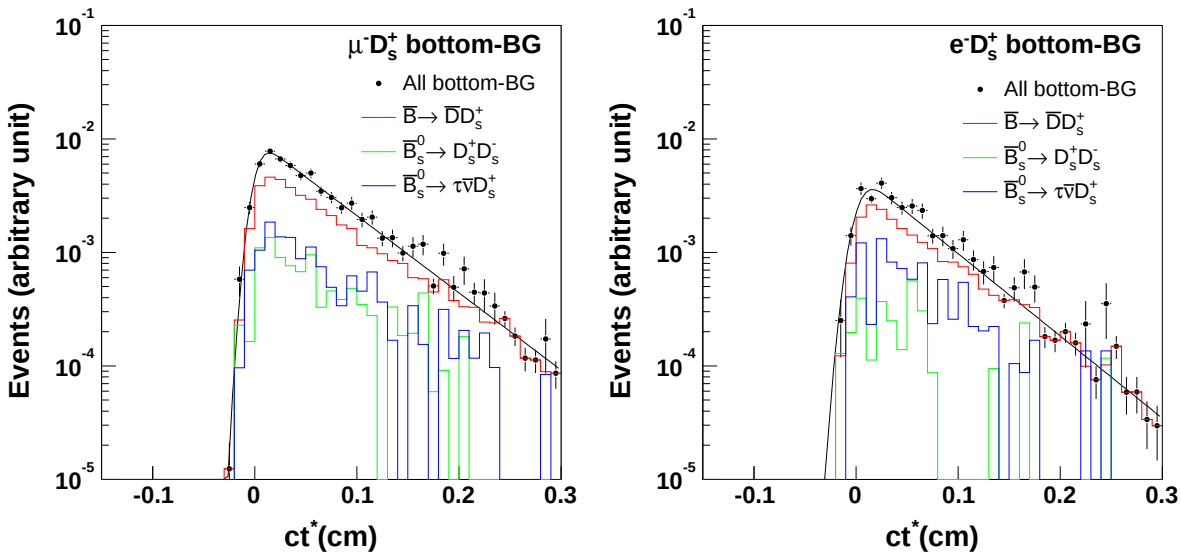
$$f_b = \frac{N_b}{N_{D_s^+}} = \begin{cases} 6.3 \pm 0.3\% & \text{for } \mu^- D_s^+ \text{ sample} \\ 3.4 \pm 0.3\% & \text{for } e^- D_s^+ \text{ sample} \end{cases}$$

Bottom background (cont'd)

The shape of the bottom background is obtained also from the monte carlo sample.

We fit these distributions with following function:

$$\mathcal{F}_b \;=\; \mathrm{Exp}(-ct^*;\lambda_+)\theta(x) \otimes G(\sigma)$$



	λ_+ (μm)	σ (μm)
Muon	638.8 ± 12.9	85.8 ± 3.8
Electron	599.5 ± 15.7	106.3 ± 12.7

The $\mathcal{F}_b$ is used as the bottom background shape in the final lifetime fit.

PDF for lifetime fit

Probability density function for the semileptonic $\bar{B}_s^0$ signal:

$$\mathcal{F}_{\bar{B}_s^0}(ct^*, \sigma_{ct^*}) = \exp\left(-\frac{ct}{c\tau}K\right) \otimes D(K) \otimes G(ct^*; s\sigma_{ct^*})$$

ct^*, σ_{ct^*}	...	$\bar{B}_s^0$ pseudo-proper decay length and its resolution, given event-by-event
$c\tau$	...	$\bar{B}_s^0$ meson lifetime
$D(K)$	...	K factor distribution
s	...	resolution scale factor

Event probability density function:

$$\begin{aligned} P_i(ct^*(i), \sigma_{ct^*}(i)) \;=\; & f_{\text{sig}}\left\{(1 - f_c - f_b)\mathcal{F}_{\bar{B}_s^0} + f_c\mathcal{F}_c + f_b\mathcal{F}_b\right\} \\ & +(1 - f_{\text{sig}})\mathcal{F}_{\text{BG}} \end{aligned}$$

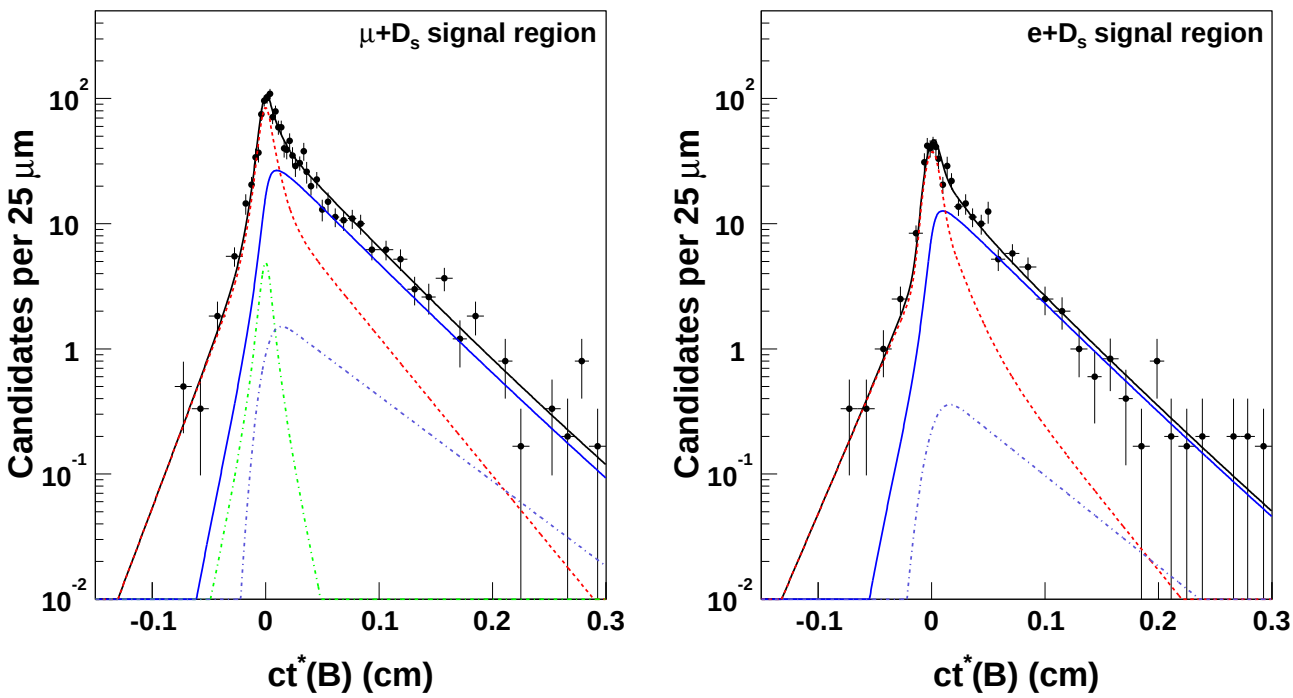
i	...	event ID
f_{sig}	...	fraction of D_s^+ events in signal region
$\mathcal{F}_{\text{BG}}(ct^*)$	...	combinatorial BG shape (gaus + 4 tails)
f_c, $\mathcal{F}_c(ct^*)$	...	fraction and shape of charm background
f_b, $\mathcal{F}_b(ct^*)$	...	fraction and shape of bottom background

Likelihood for each dataset:

$$L_X = \prod_i l_i \text{ (X = } \mu^- D_s^+, e^- D_s^+\text{)}$$

Results for the muon, electron separate fit

First we fit the muon and electron datasets separately. Only the $c\tau(\bar{B}_s^0)$ is floated at the fit.



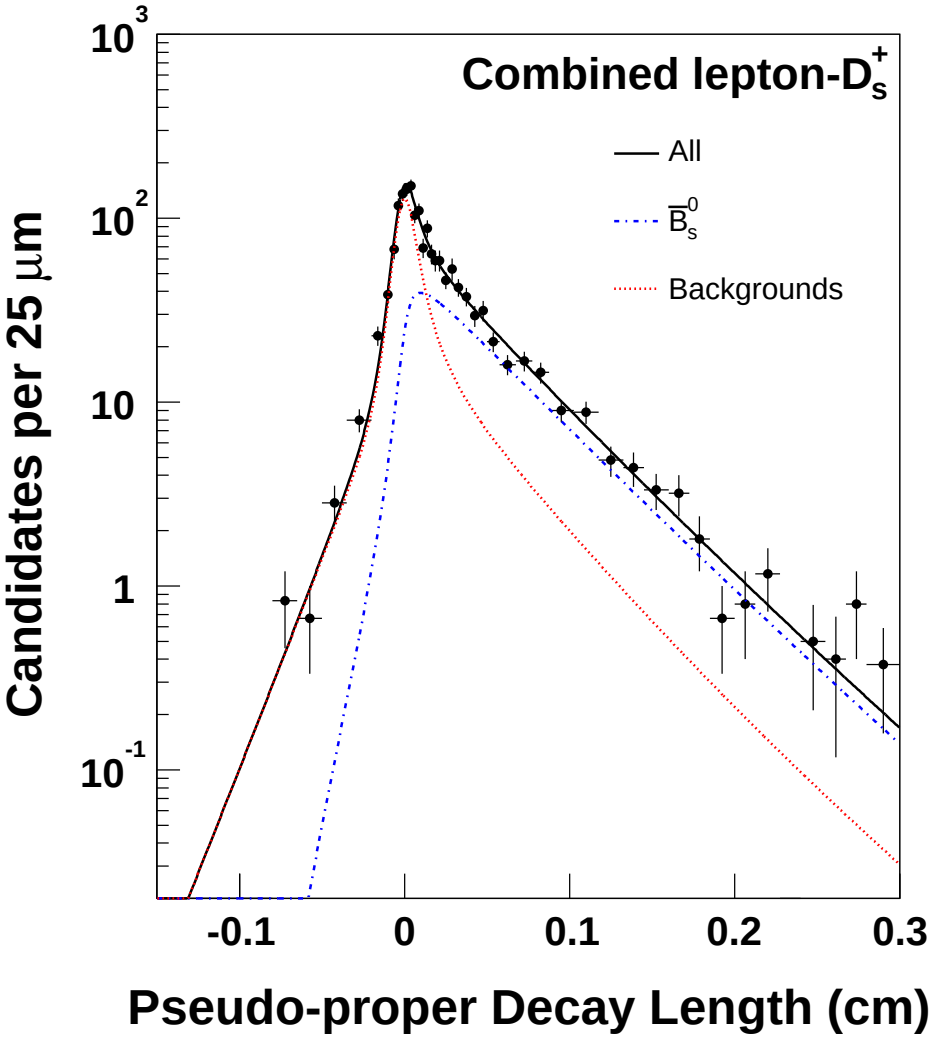
Points	...	data
Black	...	$\mathcal{F} = \mathcal{F}_B + \mathcal{F}_{BG} + \mathcal{F}_c + \mathcal{F}_b$
Blue	...	$\mathcal{F}_B$
Red	...	$\mathcal{F}_{BG}$
Dashed green	...	$\mathcal{F}_c$
Dashed blue	...	$\mathcal{F}_b$

Fit results for the both datasets:

$$c\tau(\bar{B}_s^0) = \begin{cases} 411.6 \pm 20.7\ \mu\text{m (muon)} \\ 418.4 \pm 27.8\ \mu\text{m (electron)} \end{cases}$$

Combined fit result

muon and electron combined fit results:



$$c\tau(\bar{B}_s^0) = 414.0 \pm 16.6\ \mu\text{m}$$

Systematic uncertainties

Source	Systematics on $c\tau(\bar{B}_s^0)$ (μm)
Prompt charm background	
prompt charm fraction (f_c)	$^{+14.4}_{-6.7}$
prompt charm shape ($\mathcal{F}_c$)	± 1.5
Bottom background	
Bottom background fraction (f_b)	± 3.6
Bottom background shape ($\mathcal{F}_b$)	± 5.1
Missing momentum correction	
$p_T(B)$ spectrum	± 4.9
B decay model	± 5.0
Electron cuts	± 1.1
D_s^{**+} fraction (f^{**})	± 1.8
Signal fraction ($f_{\rm sig}$)	± 6.5
Resolution scale factor	± 4.0
Decay length cut	$^{+0.0}_{-2.3}$
Combinatorial background shape	± 0.2
Detector alignment	± 2.0
Total	$^{+19.1}_{-14.4}$

$\tau(\bar{B}_s^0)/\tau(\bar{B}^0)$ ratio

The $\tau(\bar{B}^0)$ is from previous 8 GeV $B^-/\bar{B}^0$ lifetime analysis (CDF 7458).

$$c\tau(\bar{B}_s^0) = 414.0 \pm 16.6 \,^{+19.2}_{-14.4}\ \mu\text{m}$$
$$c\tau(\bar{B}^0) = 441.5 \pm 10.9 \pm 16.3\ \mu\text{m}$$

$$\Downarrow$$

$$\tau(\bar{B}_s^0)/\tau(\bar{B}^0) = 0.938 \pm 0.044 \,^{+0.050}_{-0.042}$$

Source	Systematics on $\tau(\bar{B}_s^0)/\tau(\bar{B}^0)$
Prompt charm background	
prompt charm fraction (f_c)	$^{+0.034}_{-0.019}$
prompt charm shape ($\mathcal{F}_c$)	± 0.012
Bottom background	
Bottom background fraction (f_b)	$^{+0.009}_{-0.008}$
Bottom background shape ($\mathcal{F}_b$)	± 0.012
Sample composition (affect only for $\tau(\bar{B}^0)$)	
D^{**} composition (P_V)	$^{+0.018}_{-0.023}$
π_s^+ reconstruction	$^{+0.000}_{-0.002}$
Missing momentum correction	
$p_T(B)$ spectrum	-
Electron cuts	-
B decay model	± 0.012
D^{**} fraction (f^{**})	$^{+0.017}_{-0.011}$
Signal fraction (f_{sig})	± 0.015
Resolution scale factor	± 0.004
Decay length cut	-
Combinatorial background shape	± 0.001
Detector alignment	-
Total	$^{+0.050}_{-0.042}$

Summary

We have measured the $\bar{B}_s^0$ meson lifetime using semileptonic decay with 8 GeV single lepton datasets.

The $\bar{B}_s^0$ lifetime is found to be

$$c\tau(\bar{B}_s^0) \;=\; 414.0 \pm 16.6\ ^{+19.1}_{-14.4}\ \mu\text{m}$$

or

$$\tau(\bar{B}_s^0) \;=\; 1.381 \pm 0.055\ ^{+0.064}_{-0.048}\ \text{ps}\ .$$

And the $\bar{B}_s^0$ and $\bar{B}^0$ lifetime ratio is found to be,

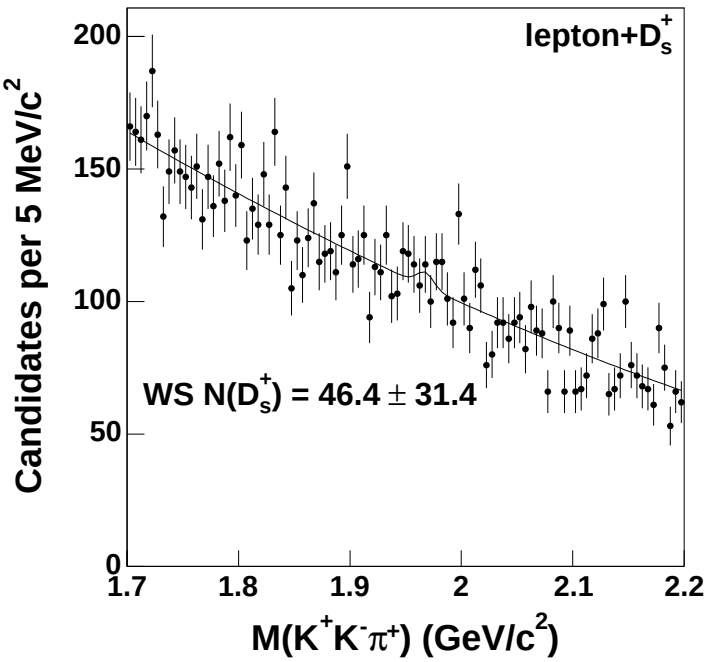
$$\tau(\bar{B}_s^0)/\tau(\bar{B}^0) \;=\; 0.938 \pm 0.044\ ^{+0.050}_{-0.042}$$

These results are consistent with the HQE prediction and current world average
($c\tau(\bar{B}_s^0) = 421.2\ ^{+12.9}_{-14.1}\mu$m).

Questions, comments and answers for this analysis will be summarized at,
http://hep-www.px.tsukuba.ac.jp/~satoru/cdf_Bslife/

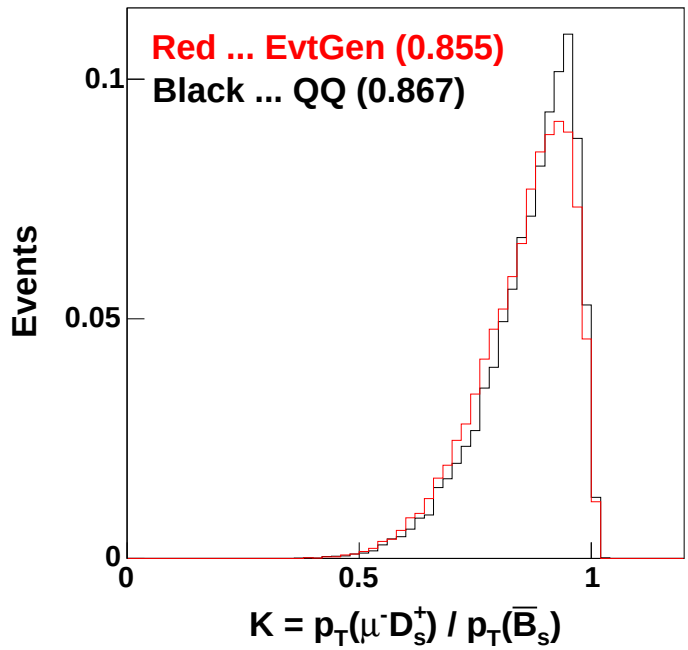
Backup slides

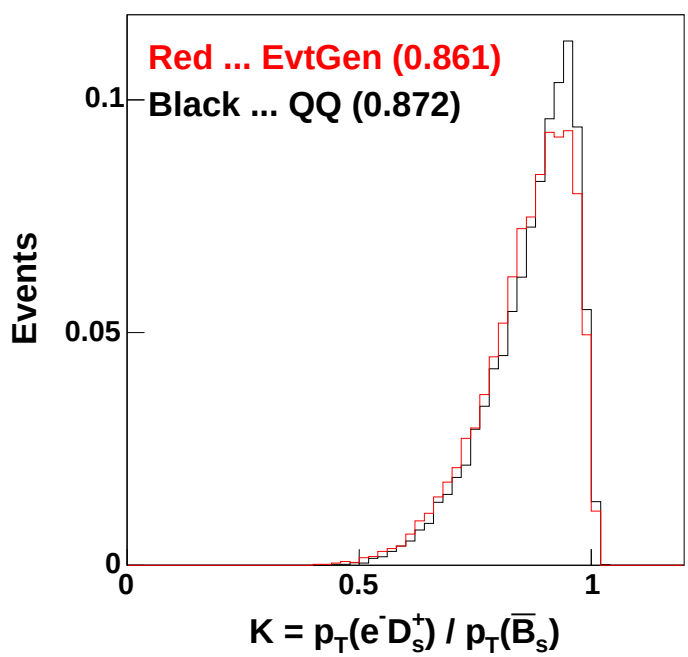
WS $\ell - D_s^+$ signal



$$\begin{aligned} \textsf{WS/RS} &= (1154.4 \pm 49.0)/(46.4 \pm 31.4) \\ &= 4.0 \pm 2.7\% \end{aligned}$$

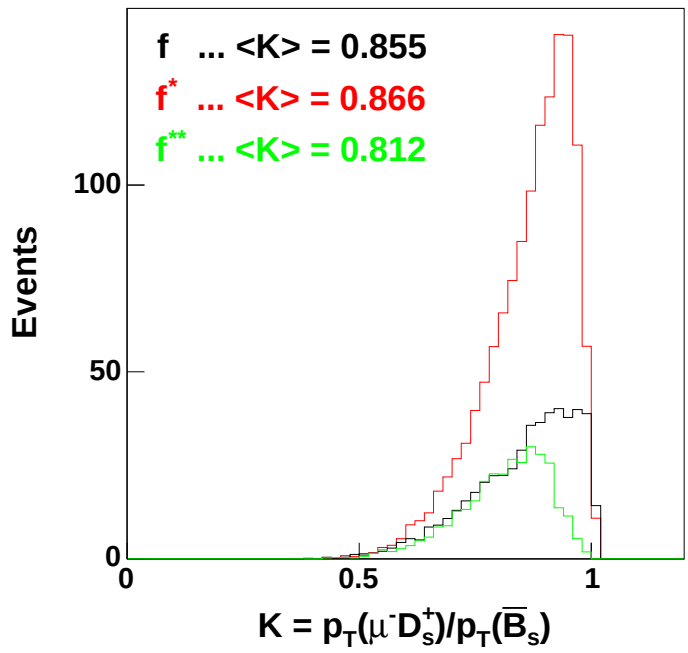
K factors ... QQ vs EvtGen





The shifts of mean values are about -1%.

Systematics from f^{**}



To evaluate the systematics from f^{**}, we change the value as $f^{**} = 0.36 \pm 0.12$).

Associate changes of the K factor mean values:

$$\langle K \rangle = \begin{cases} 0.858 \sim 0.851 & \text{for } \mu^- D_s^+ \text{ sample} \\ 0.864 \sim 0.858 & \text{for } e^- D_s^+ \text{ sample} \end{cases}$$

Corresponding systematics on $c\tau(\bar{B}_s^0)$ is found to be 1.8 μm.

EvtGen default decay table ($\bar{B}_s^0$ semileptonic part)

```
0.0210 D_s- e+ nu_e PHOTOS ISGW2;
0.0490 D_s*- e+ nu_e PHOTOS ISGW2;
0.0040 D_s1- e+ nu_e PHOTOS ISGW2;
0.0040 D_s0*- e+ nu_e PHOTOS ISGW2;
0.0070 D'_s1- e+ nu_e PHOTOS ISGW2;
0.0070 D_s2*- e+ nu_e PHOTOS ISGW2;
0.0030 D_s*- pi0 e+ nu_e PHOTOS GOITY_ROBERTS;
0.0090 D_s- pi0 e+ nu_e PHOTOS GOITY_ROBERTS;

0.0210 D_s- mu+ nu_mu PHOTOS ISGW2;
0.0490 D_s*- mu+ nu_mu PHOTOS ISGW2;
0.0040 D_s1- mu+ nu_mu PHOTOS ISGW2;
0.0040 D_s0*- mu+ nu_mu PHOTOS ISGW2;
0.0070 D'_s1- mu+ nu_mu PHOTOS ISGW2;
0.0070 D_s2*- mu+ nu_mu PHOTOS ISGW2;
0.0030 D_s*- pi0 mu+ nu_mu PHOTOS GOITY_ROBERTS;
0.0090 D_s- pi0 mu+ nu_mu PHOTOS GOITY_ROBERTS;

0.0070 D_s- tau+ nu_tau ISGW2;
0.0160 D_s*- tau+ nu_tau ISGW2;
0.0013 D_s1- tau+ nu_tau ISGW2;
0.0013 D_s0*- tau+ nu_tau ISGW2;
0.0018 D'_s1- tau+ nu_tau ISGW2;
0.0018 D_s2*- tau+ nu_tau ISGW2;
```

EvtGen default decay table ($\bar{B}_s^0 \to DsDs$ part)

```
0.0086 D_s- D_s+ PHSP;
0.0090 D_s*+ D_s- SVS;
0.0099 D_s*- D_s+ SVS;
0.0197 D_s*- D_s*+ SVV_HELAMP 1.0 0.0 1.0 0.0 1.0 0.0;

0.0096 D_s+ D- anti-K0 PHSP;
0.0096 D_s+ D0 K- PHSP;
0.0096 D_s*+ D- anti-K0 PHSP;
0.0096 D_s*+ anti-D0 K- PHSP;

0.0024 D_s+ D- pi0 anti-K0 PHSP;
0.0048 D_s+ anti-D0 pi- anti-K0 PHSP;
0.0048 D_s+ D- pi+ K- PHSP;
0.0024 D_s+ anti-D0 pi0 K- PHSP;

0.0024 D_s*+ D- pi0 anti-K0 PHSP;
0.0048 D_s*+ anti-D0 pi- anti-K0 PHSP;
0.0048 D_s*+ D- pi+ K- PHSP;
0.0024 D_s*+ anti-D0 pi0 K- PHSP;

0.0150 D_s*- D*0 K+ PHSP;
0.0150 D_s*- D*+ K0 PHSP;
0.0050 D_s*- D0 K+ PHSP;
0.0050 D_s*- D+ K0 PHSP;
0.0050 D_s- D*0 K+ PHSP;
0.0050 D_s- D*+ K0 PHSP;
```

```
0.0020 D_s- D0 K+ PHSP;
0.0020 D_s- D+ K0 PHSP;
0.0030 D_s*- D*0 K*+ PHSP;
0.0030 D_s*- D*+ K*0 PHSP;
0.0050 D_s*- D0 K*+ PHSP;
0.0050 D_s*- D+ K*0 PHSP;
0.0025 D_s- D*0 K*+ PHSP;
0.0025 D_s- D*+ K*0 PHSP;
0.0025 D_s- D0 K*+ PHSP;
0.0025 D_s- D+ K*0 PHSP;

# b --> c (d c=)
# Sum = 1.36%
0.0017 D_s+ D- PHSP;
0.0017 D*- D_s+ SVS;
0.0017 D_s*+ D- SVS;
0.0017 D_s*+ D*- SVV_HELAMP 1.0 0.0 1.0 0.0 1.0 0.0;

#
# first come the external W-emission decays:
#
0.0008 D_s1+ pi- SVS;
0.0021 D_s1+ rho- SVV_HELAMP 1.0 0.0 1.0 0.0 1.0 0.0;
0.0013 D_s2*+ pi- STS;

0.0027 D_s*+ pi- SVS;
0.0026 D_s+ pi- PHSP;
0.0073 rho- D_s+ SVS;
```

```
0.0070 D_s*+ rho- SVV_HELAMP 1.0 0.0 1.0 0.0 1.0 0.0;

0.0085 a_1- D_s+ SVS;
0.0009 D_s+ rho0 pi- PHSP;
0.0009 D_s+ rho- pi0 PHSP;
0.0009 D_s+ pi+ pi- pi- PHSP;
0.0009 D_s+ pi0 pi- pi0 PHSP;

0.0122 D_s*+ a_1- SVV_HELAMP 1.0 0.0 1.0 0.0 1.0 0.0;
0.0010 D_s*+ rho0 pi- PHSP;
0.0010 D_s*+ rho- pi0 PHSP;
0.0077 D_s*+ pi+ pi- pi- PHSP;
0.0010 D_s*+ pi0 pi- pi0 PHSP;
```

EvtGen default decay table ($\bar{B}^0 \to DDs$ part)

```
# b -> c (sc=) --> D Ds X Sum = 10%
#
0.0074 D- D_s+ PHSP;
0.0106 D*- D_s+ SVS;
0.0074 D_s*+ D- SVS;
0.0141 D_s*+ D*- SVV_HELAMP 0.48 0.0 0.734 0.0 0.48
0.0;
0.0010 D'_1- D_s+ SVS;
0.0020 D'_1- D_s*+ SVV_HELAMP 0.48 0.0 0.734 0.0 0.48
0.0;
0.0020 D_1- D_s+ SVS;
0.0040 D_1- D_s*+ SVV_HELAMP 0.48 0.0 0.734 0.0 0.48
0.0;
0.0070 D_2*- D_s+ STS;
0.0140 D_2*- D_s*+ PHSP;

0.0030 D_s+ D- pi0 PHSP;
0.0060 D_s+ anti-D0 pi- PHSP;
0.0030 D_s*+ D- pi0 PHSP;
0.0060 D_s*+ anti-D0 pi- PHSP;
0.0050 D_s+ D- pi- pi+ PHSP;
0.0037 D_s+ D- pi0 pi0 PHSP;
0.0037 D_s+ anti-D0 pi- pi0 PHSP;
0.0050 D_s*+ D- pi- pi+ PHSP;
0.0037 D_s*+ D- pi0 pi0 PHSP;
0.0037 D_s*+ anti-D0 pi- pi0 PHSP;
```

EvtGen default decay table ($B^- \to DDs$ part)

```
# b -> c (sc=) -> D Ds X Sum = 10%
0.0106 D0 D_s- PHSP;
0.0102 D*0 D_s- SVS;
0.0091 D_s*- D0 SVS;
0.0228 D_s*- D*0 SVV_HELAMP 0.48 0.0 0.734 0.0 0.48
0.0;
0.0010 D'_10 D_s- SVS;
0.0020 D'_10 D_s*- SVV_HELAMP 0.48 0.0 0.734 0.0 0.48
0.0;
0.0020 D_10 D_s- SVS;
0.0040 D_10 D_s*- SVV_HELAMP 0.48 0.0 0.734 0.0 0.48
0.0;
0.0070 D_2*0 D_s- STS;
0.0140 D_2*0 D_s*- PHSP;

0.0060 D_s- D+ pi- PHSP;
0.0030 D_s- D0 pi0 PHSP;
0.0060 D_s*- D+ pi- PHSP;
0.0030 D_s*- D0 pi0 PHSP;
0.0055 D_s- D+ pi- pi0 PHSP;
0.0055 D_s- D0 pi- pi+ PHSP;
0.0014 D_s- D0 pi0 pi0 PHSP;
0.0055 D_s*- D+ pi- pi0 PHSP;
0.0055 D_s*- D0 pi- pi+ PHSP;
0.0014 D_s*- D0 pi0 pi0 PHSP;
```