B_s lifetime measurement in the CP-odd decay channel $B^0_s \rightarrow J/\Psi\ f_0(980)$

(Submitted to PRD [1])

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[1] arXiv:1603.01302

Outline:

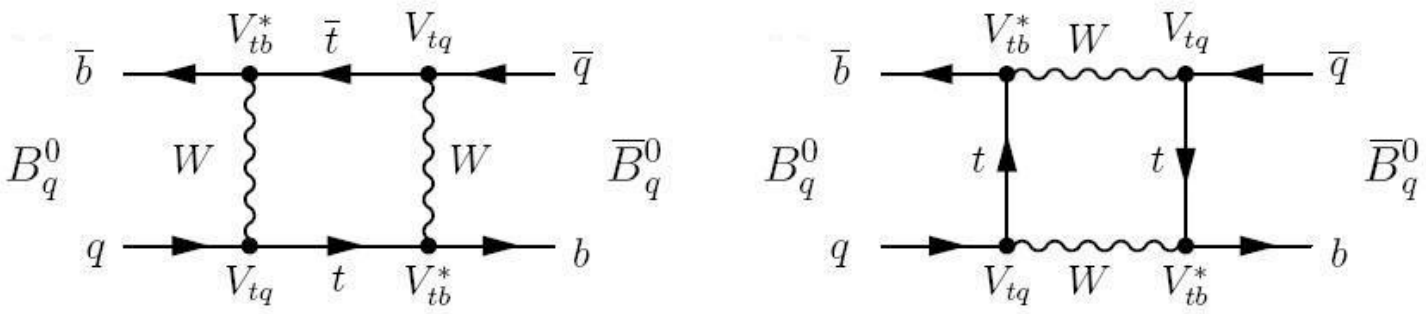
- The $B^0_s \rightarrow J/\Psi\ f_0(980)$ decay.
- DØ Data and Fitting
- Systematic uncertainties
- Conclusions

B_s Mixing

- B_s^0 and $\bar{B}_s^0$ mesons are produced as flavor eigenstates at colliders

$$|B_s^0\rangle = (\bar{b}s), \ |\bar{B}_s^0\rangle = (b\bar{s})$$

- Neither conservation law prevent B_s^0 and $\bar{B}_s^0$ from having transitions. ∴ they oscillate between themselves.



- They propagate as mass eigenstates

$$|B_L\rangle = p|B_s^0\rangle + q|\bar{B}_s^0\rangle \ ; \quad |B_H\rangle = p|B_s^0\rangle - q|\bar{B}_s^0\rangle$$

CP Eigenstates

- CP transformation interchanges B_s^0 and $\bar{B}_s^0$

$$CP|B_s^0\rangle = e^{i\phi_s}|\bar{B}_s^0\rangle; \;\; CP|\bar{B}_s^0\rangle = e^{-i\phi_s}|B_s^0\rangle$$

- We may define eigenstates of CP

$$|B^{\pm}\rangle = \frac{1}{\sqrt{2}}(|B_s^0\rangle \pm e^{i\phi_s}|\bar{B}_s^0\rangle),$$

- **Neglecting CP violation** (in mixing), it can be shown that[1]

$$q/p = \pm e^{i\phi_s}$$

so

$$CP|B_H\rangle = -|B_H\rangle; \;\; CP|B_L\rangle = |B_L\rangle$$

[1]Branco, Gustavo et. al. *CP Violation*. Oxford University Press, 1999.

The $B^0_s \to J/\Psi\ f_0(980)$ decay

- It's known that the $B^0_s \to J/\Psi\ f_0(980)$ channel is a pure CP-odd eigenstate decay.

$$J/\psi:\ J^{PC} = 1^{--} \quad ; \quad f_0(980):\ J^{PC} = 0^{++}$$

- Is a very good alternative of the "golden channel" $B^0_s \to J/\Psi\ \phi$ to study B_s mixing.
- Observed by **LHCb**[1] and confirmed by **Belle**[2], **CDF**[3], **D0**[4] and **CMS**[5] experiments.
- The final state can be produced only by the decay of the **heavy mass eigenstate.**

[1]Phys. Lett. B 698, 115 (2011)
[2]Phys. Rev. Lett. 106, 121802 (2011)
[3] Phys. Rev. D 84, 052012 (2011)
[4]Phys. Rev. D 85, 011103 (2012)
[5]Phys.Lett. B756 (2016) 84

The $B^0_s \rightarrow J/\Psi\ f_0(980)$ decay

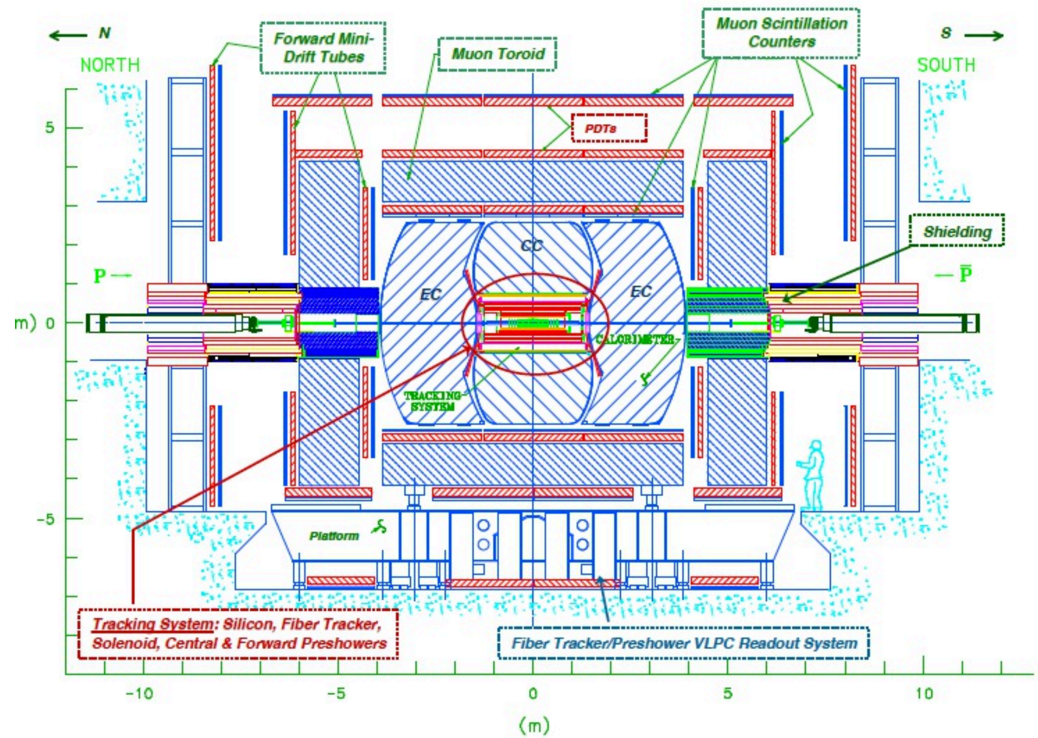
- The measurement of the lifetime can be translated into a measurement of $\mathbf{\Gamma_H}$, which is a parameter of interest in the search of new physics. [1]

- Previous measurements:
  - In 2011, the CDF collaboration reports a measure of **$c\tau$ = (510 ± 36 ± 9) μm**. [2]
  - LHCb gets **$c\tau$ = (510 ± 12 ± 8) μm**. [3]

[1] arXiv:1203:3545
[2] Phys. Rev. D 84, 052012 (2011)
[3] Phys. Rev. Lett. 109, 152002 (2012)

The DØ Detector

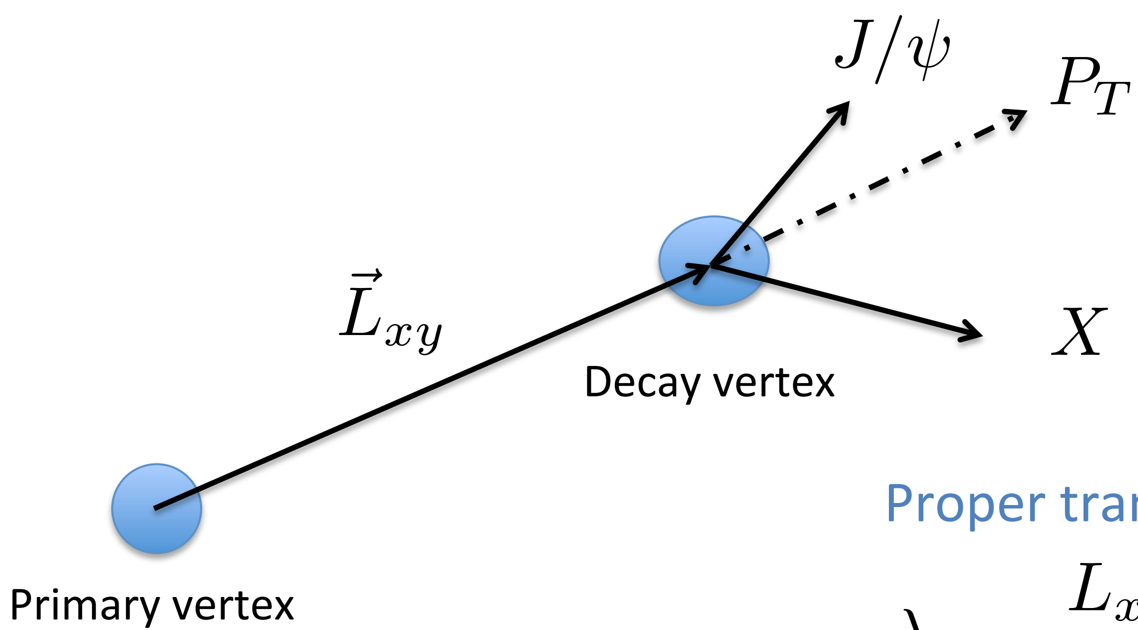
- Construction was completed in February 1992.
- Took data from 1992 – 1996.
- The experiment was upgraded from 1996 – 2001 and ran until the Tevatron ceased operations in 2011.
- **HEP Group@Cinvestav has contributed with several results.**



~500 papers

Proper Decay Length

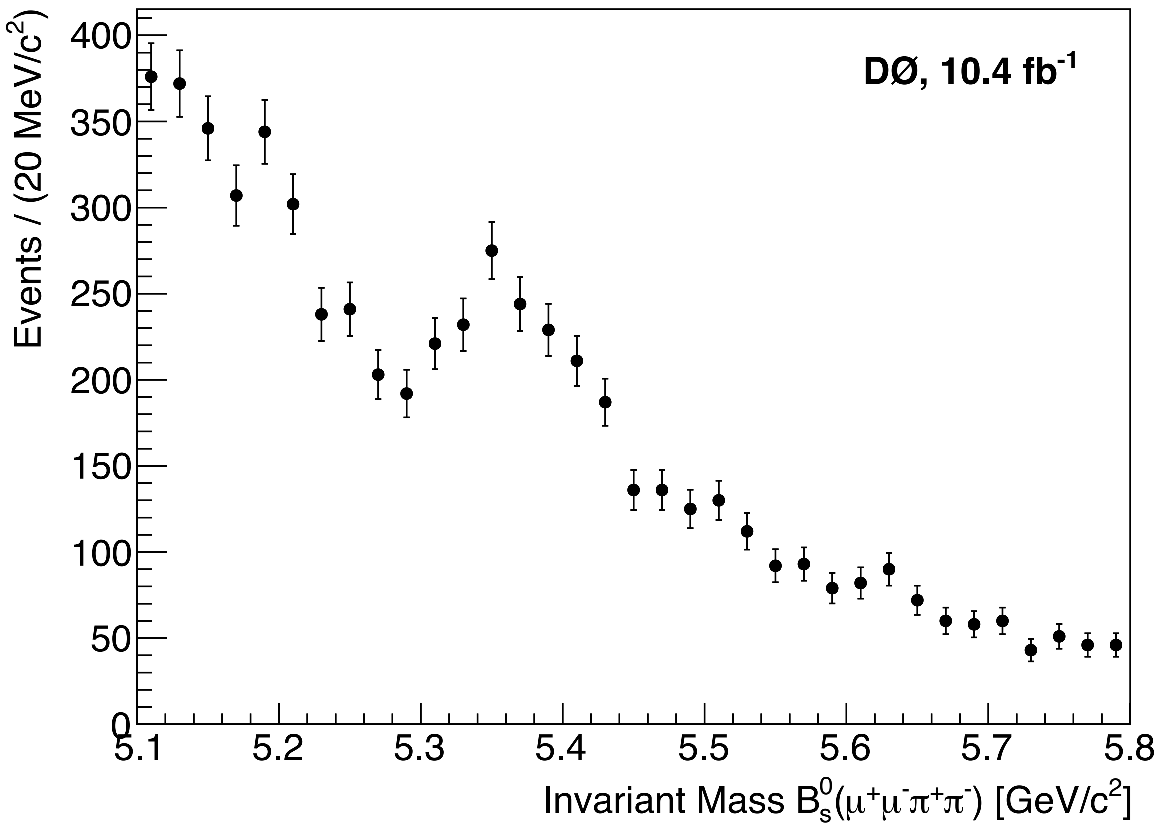
- The lifetime measurement is based on the transverse decay length method.



Proper transverse decay length:

$$\lambda = \frac{L_{xy}}{(\beta\gamma)_T} = L_{xy}\frac{M}{P_T}$$

Data Sample

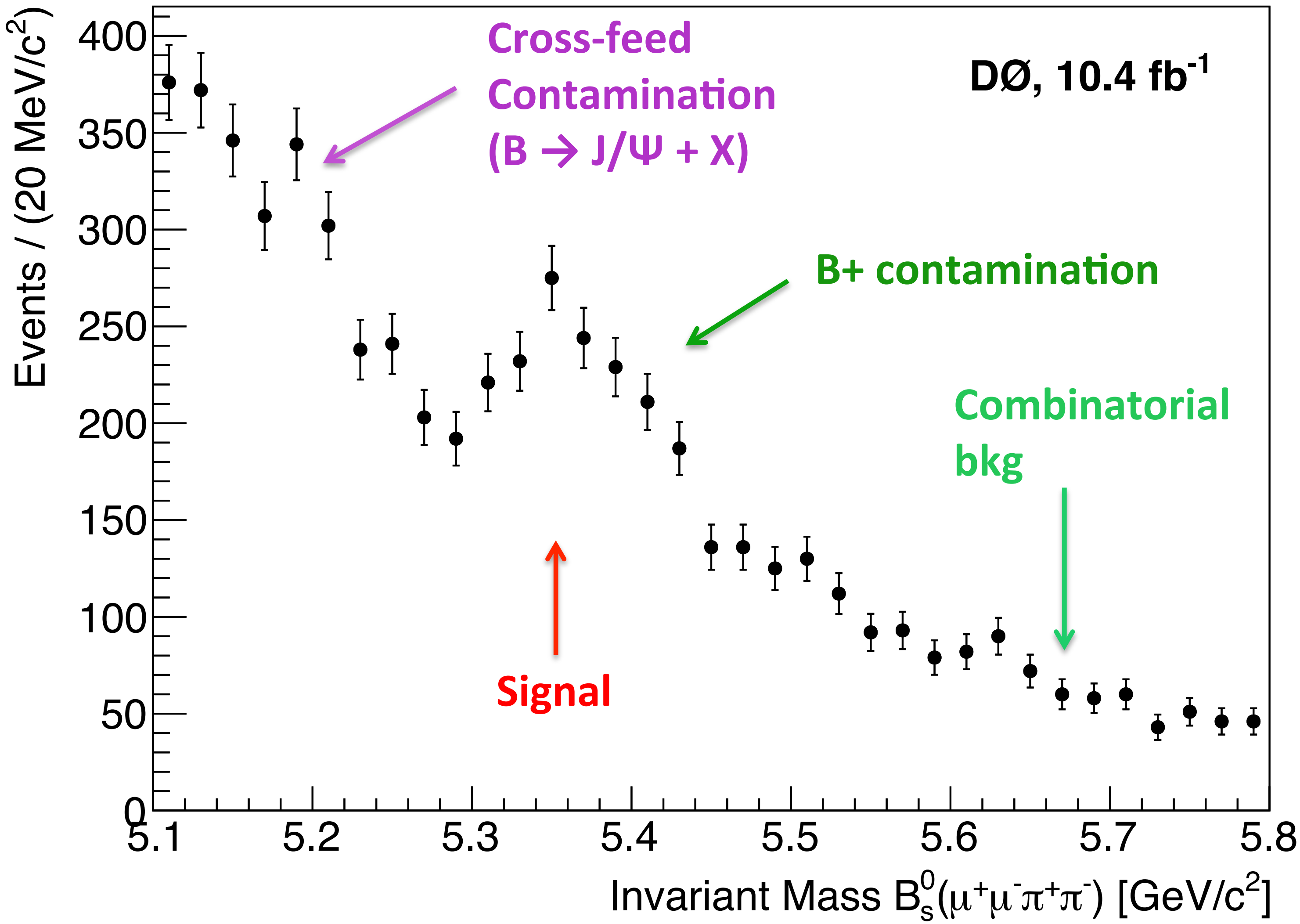


- Data collected during Run II.

(1.96 TeV, 10.4 fb^{-1}).

- Reconstruction by the dominant decays
  - **$J/\Psi \rightarrow \mu^+\mu^-$**
  - **$f0(980) \rightarrow \pi^+\pi^-$**

Data Sample



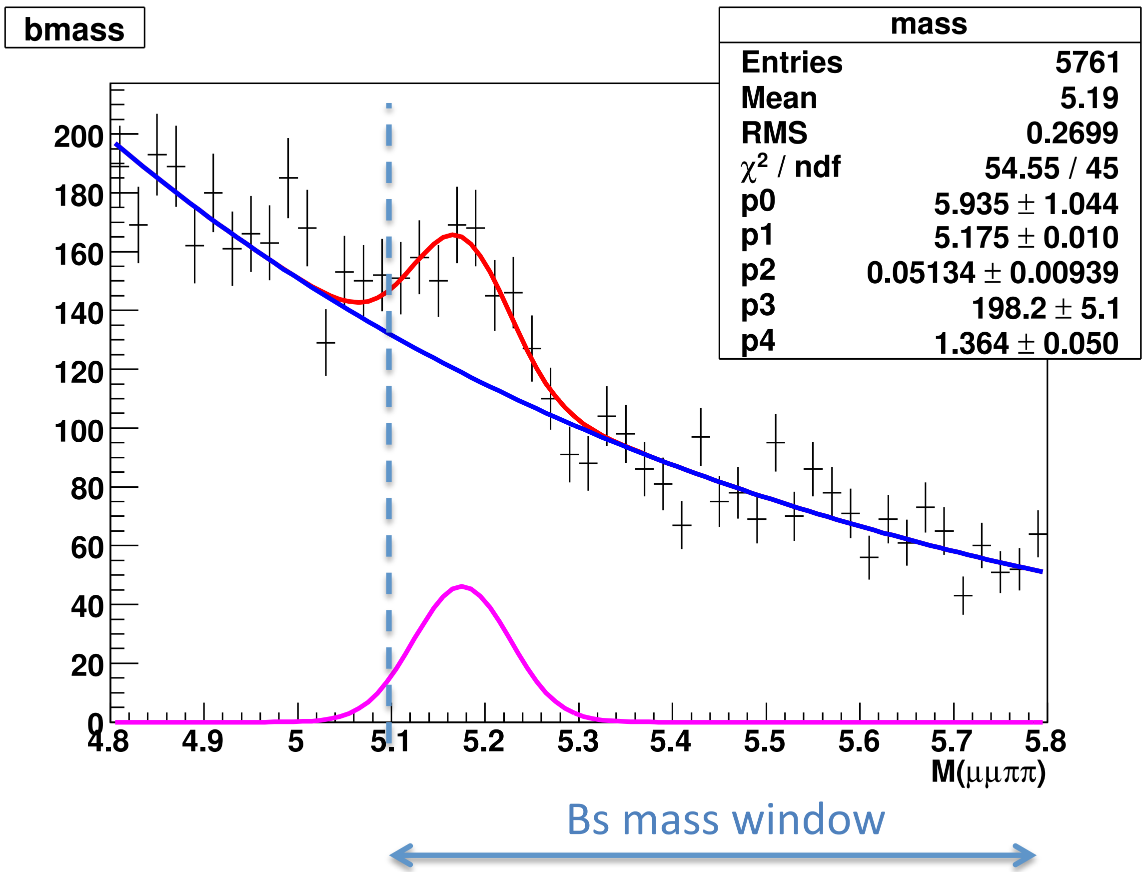
Events / (20 MeV/c²)
400
350
300
250
200
150
100
50
0
5.1
5.2
5.3
5.4
5.5
5.6
5.7
5.8
Invariant Mass $B_s^0(\mu^+\mu^-\pi^+\pi^-)$ [GeV/c²]
DØ, 10.4 fb⁻¹
Cross-feed
Contamination
(B → J/Ψ + X)
B+ contamination
Combinatorial
bkg
Signal

Cross-feed contamination

These decays can be modeled by a Gaussian function.

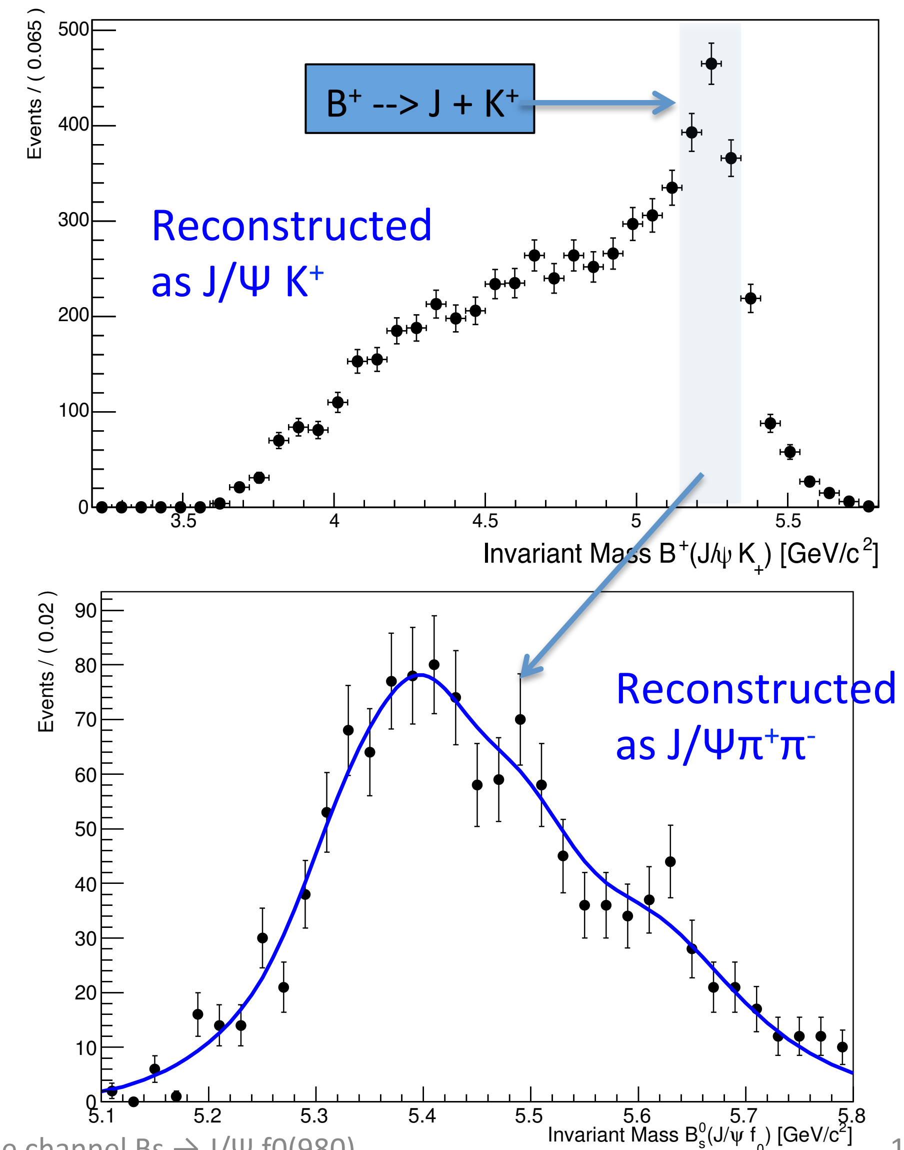
In the model, all the parameters of the Gaussian will be determined by the fit.

Simulation of $B^0 \rightarrow J/\Psi$ **+** X reconstructed as $B^0_s \rightarrow J/\Psi\ \pi^+\pi^-$:

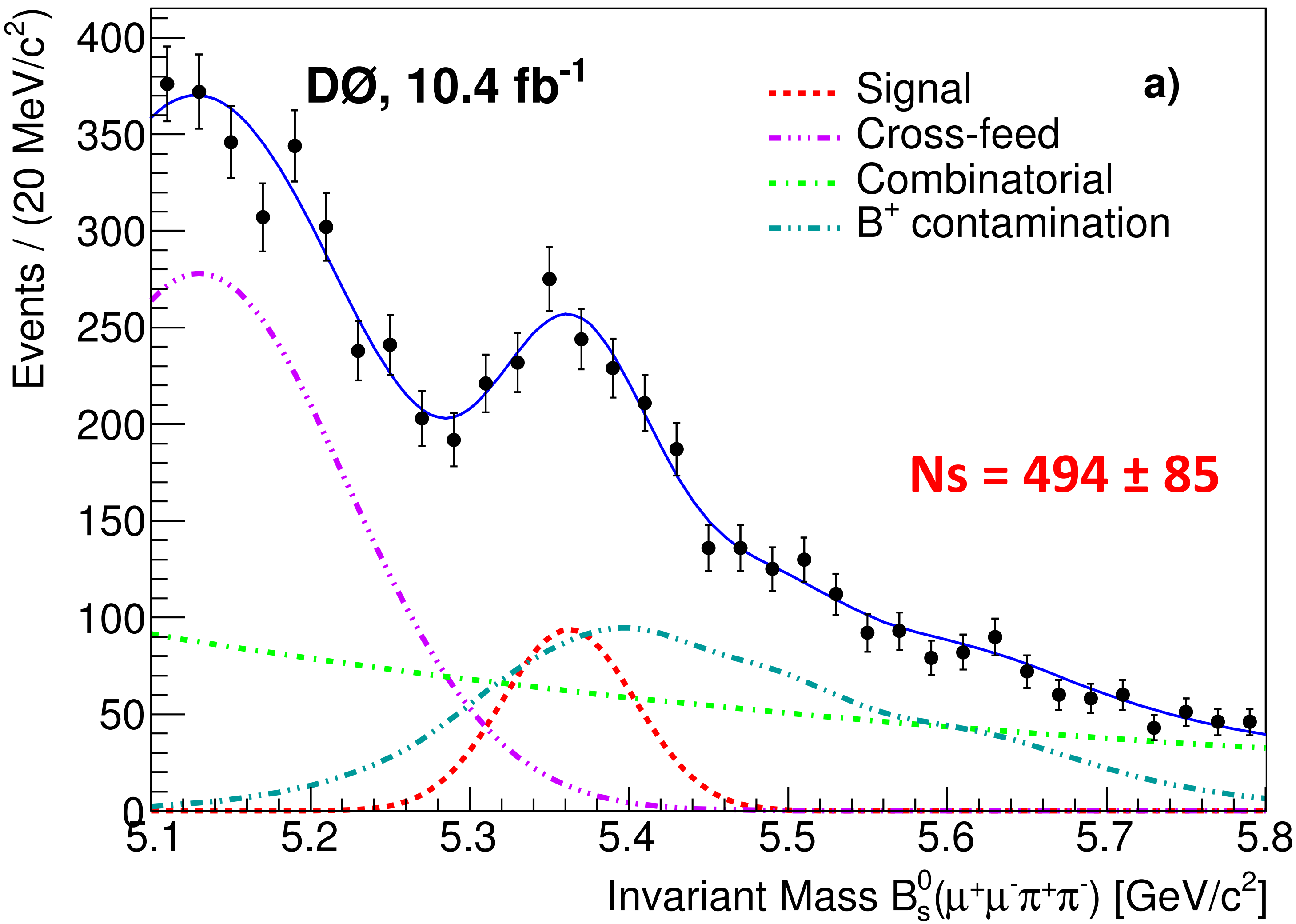


Misreconstructed B^+ decays

- If we reconstruct the data as $B^+ \to J/\Psi\ K^+$, is possible to see a peak related to these misreconstructed decays.
- We select 5.15 GeV < B^+ < 5.35 GeV to be reconstructed as $B^+ \to J/\Psi\ \pi^+\pi^-$.
- RooKeysPDF models the shape of the B^+ contamination.

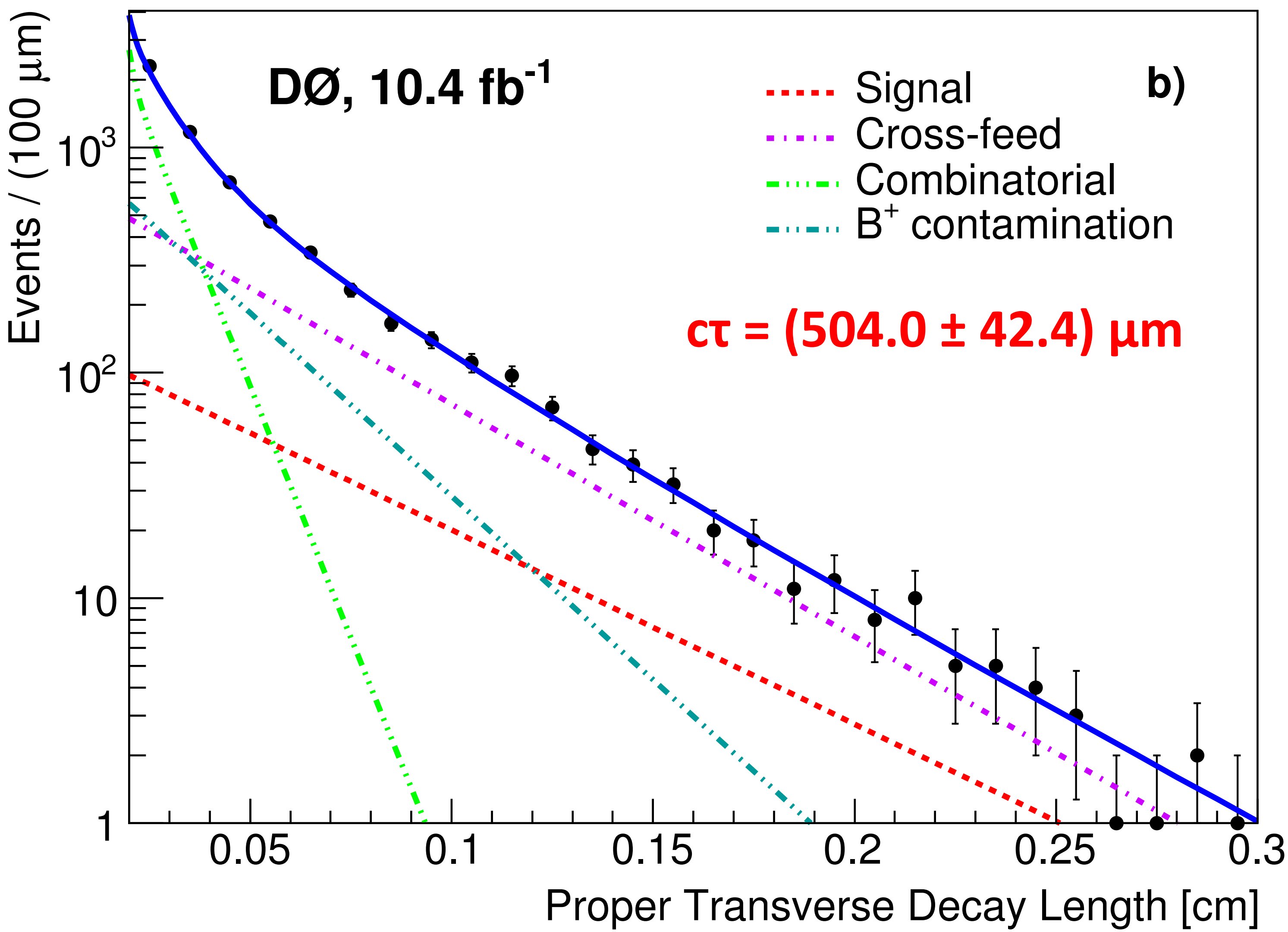


Mass Model



DØ, 10.4 fb^{-1}
a)
Signal
Cross-feed
Combinatorial
B^+ contamination
Ns = 494 ± 85
Events / (20 MeV/c^2)
0
50
100
150
200
250
300
350
400
5.1
5.2
5.3
5.4
5.5
5.6
5.7
5.8
Invariant Mass $B_s^0(\mu^+\mu^-\pi^+\pi^-)$ [GeV/c^2]

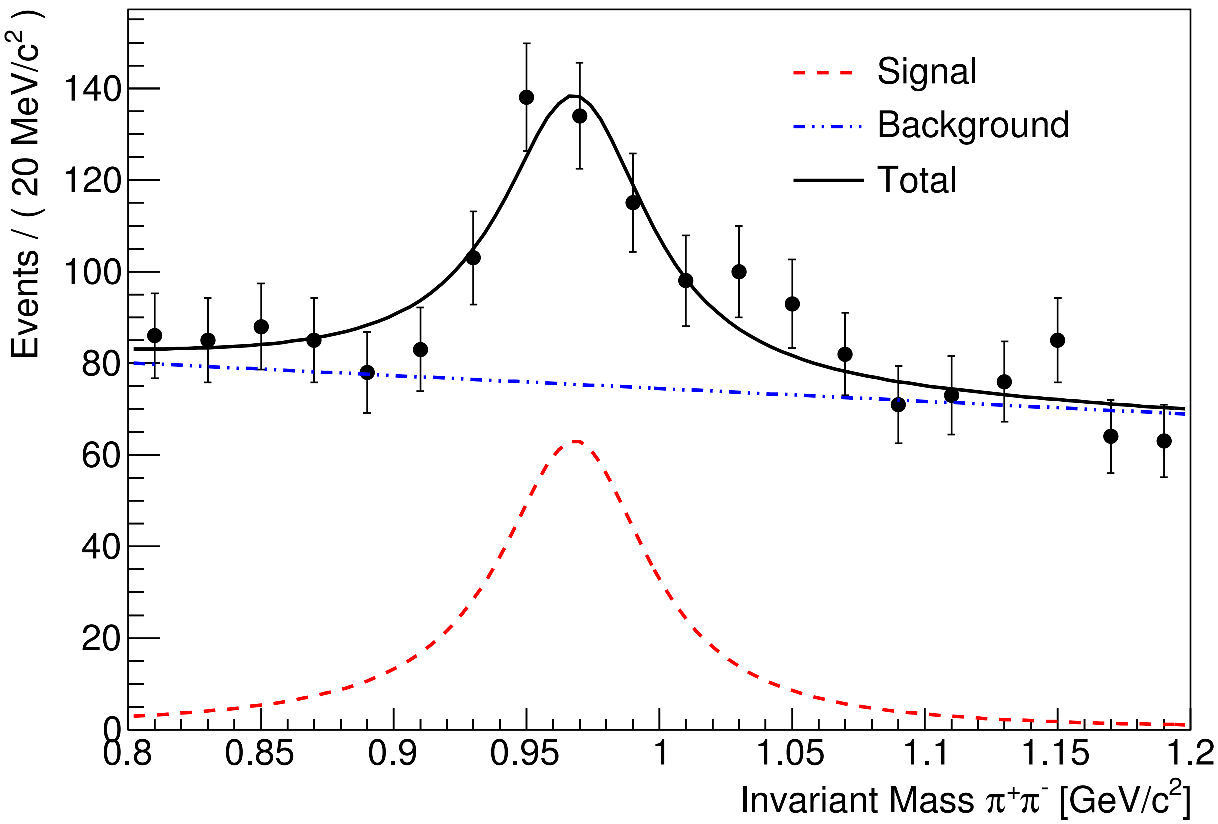
PDL Model



DØ, 10.4 fb-1
b)
Signal
Cross-feed
Combinatorial
B+ contamination
cτ = (504.0 ± 42.4) μm
Events / (100 μm)
1
10
10^2
10^3
0.05
0.1
0.15
0.2
0.25
0.3
Proper Transverse Decay Length [cm]

$\pi^+\pi^-$ invariant mass

$\pi^+\pi^-$ invariant mass distribution when a cut of ±1σ around the fitted B^0_s invariant mass mean is applied.



Summary of systematic uncertainties

Source	Error (μm)
Fit bias	± 4.4
Alignment [1]	± 5.4
$\pi^+\pi^-$ window mass	± 8.0
Distribution models	± 12.5
Total (combining in quadrature)	**± 16.4**

[1] Phys. Rev. Lett. **94**, 102001 (2005)

Conclusions

- The value obtained from the likelihood method is **$c\tau$ = (508 ± 42 ± 16) μm** [1].

- (Or τ = [1.70 ± 0.14 ± 0.05] ps).

- Neglecting CP violation in this decay

Γ_H = 0.59 ± 0.05 (stat) ± 0.02 (syst) ps^{-1}

- This result is in good agreement with previous measurements and provides and independent confirmation of the longer lifetime for the CP-odd eigenstate.

[1] **arXiv:1603.01302**

Thank you

Backup

Summary of parameters

Parameter	Min	Max	Initial Value	Final Value
Mass model:				
Mean of signal Gaussian (μ)	5.350 GeV	5.400 GeV	5.350 GeV	5.362$\pm$0.005 GeV
Width of signal Gaussian (σ)	0.000 GeV	0.150 GeV	0.004 GeV	0.042$\pm$0.004 GeV
Mean of cross-feed background Gaussian (μ_b)	5.000 GeV	5.500 GeV	5.000 GeV	5.130$\pm$0.012 GeV
Width of cross-feed background Gaussian (σ_b)	0.000 GeV	0.100 GeV	0.080 GeV	0.093$\pm$0.011 GeV
Number of signal events (Ns)	0	10,000	500	494$\pm$85 ←
Number of background events (Nb)	0	10,000	3,000	4,027$\pm$162
Number of misreconstructed B^+ events (Np)	0	10,000	1,000	1,511$\pm$178
Cross-feed background fraction (f_b)	0.000	1.000	0.500	0.494$\pm$0.040
Combinatorial bkg exponential coef (a_0)	-10.000	10.000	-1.000	-1.485$\pm$0.196
Proper transverse decay length model:				
Long-lived background decay constant (dlbl)	0.000	1.000	0.050	0.002$\pm$0.004
Short-lived background decay constant (dlbs)	0.000	1.000	0.050	0.0097$\pm$0.0024
Long-lived background fraction (fp)	0.000	1.000	0.500	0.0720$\pm$0.1568
B^+ background decay constant (dlblBpm)	0.000	1.000	0.050	0.0267$\pm$0.0014
Cross-feed background decay (dlblO)	0.000	1.000	0.040	0.0421$\pm$0.0015
Signal lifetime (cτ)	**10 μm**	**1,000 μm**	**500.0 μm**	**504.0$\pm$42.4 μm**

Likelihood function

The sum of four functions:

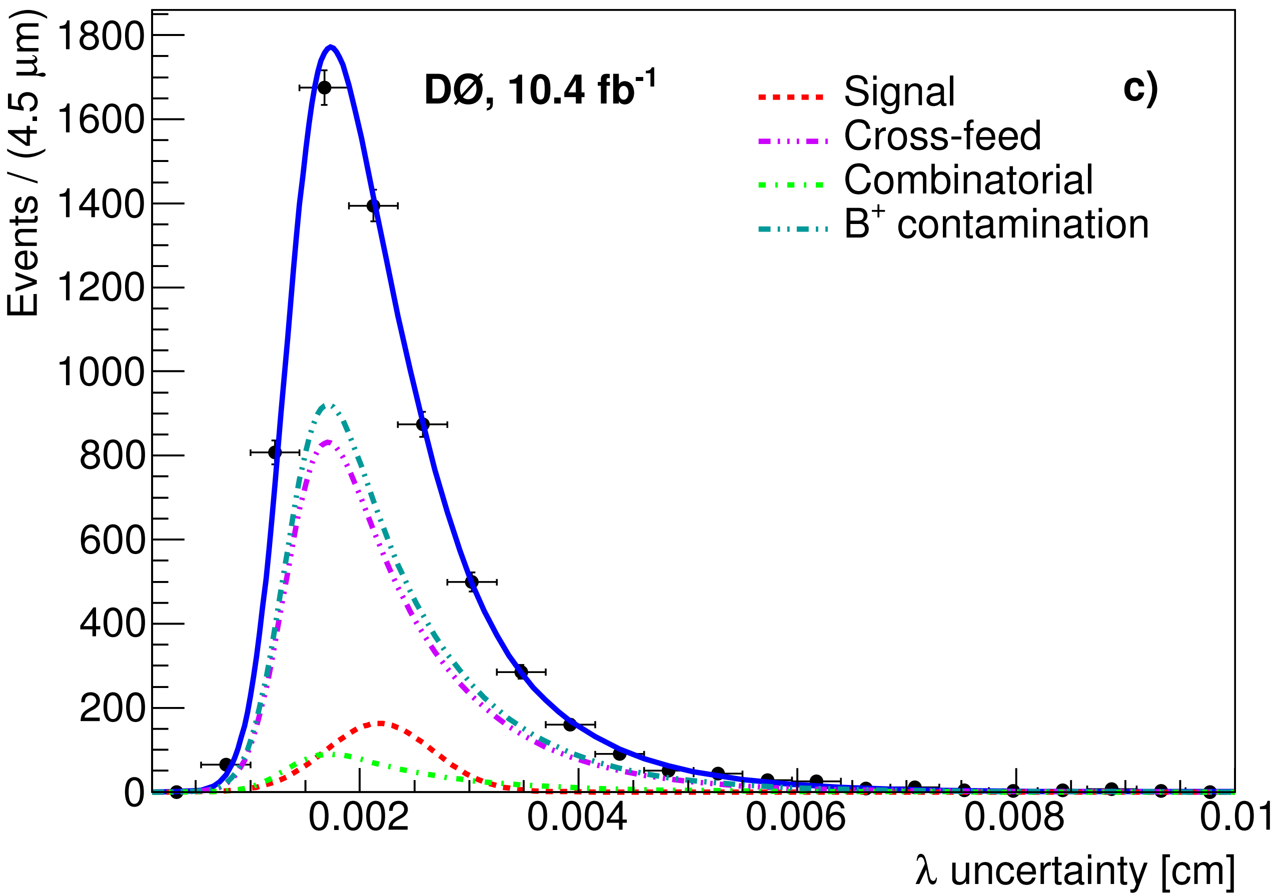
$$\mathcal{L} = \prod_{j=1}^{N} \left[N_{\rm sig}\mathcal{F}^{j}_{\rm sig} + N_{\rm comb}\mathcal{F}^{j}_{\rm comb} + N_{\rm xf}\mathcal{F}^{j}_{\rm xf} + N_{B^+}\mathcal{F}^{j}_{B^+} \right],$$

Each component is modeled by the product of three PDF: The **mass model** *M(m*$_j$*)*, the **proper transverse decay length model** *T(λ*$_j$*)* , and the **uncertainty model** *E(σ*$_{\lambda j}$*)*.

$$\mathcal{F}^{j}_{\alpha} = M_\alpha(m_j)T_\alpha(\lambda_j)E_\alpha(\sigma_{\lambda_j});$$

First, a fit determines and fix the parameters of *E*. After that, a second fit obtains the parameters of *M* and *T*, simultaneously.

Determination of E



An exponential convoluted with a Gaussian for the signal.

Two exponential functions convoluted with a Gaussian for the background.

$\pi^+\pi^-$ Mass Window

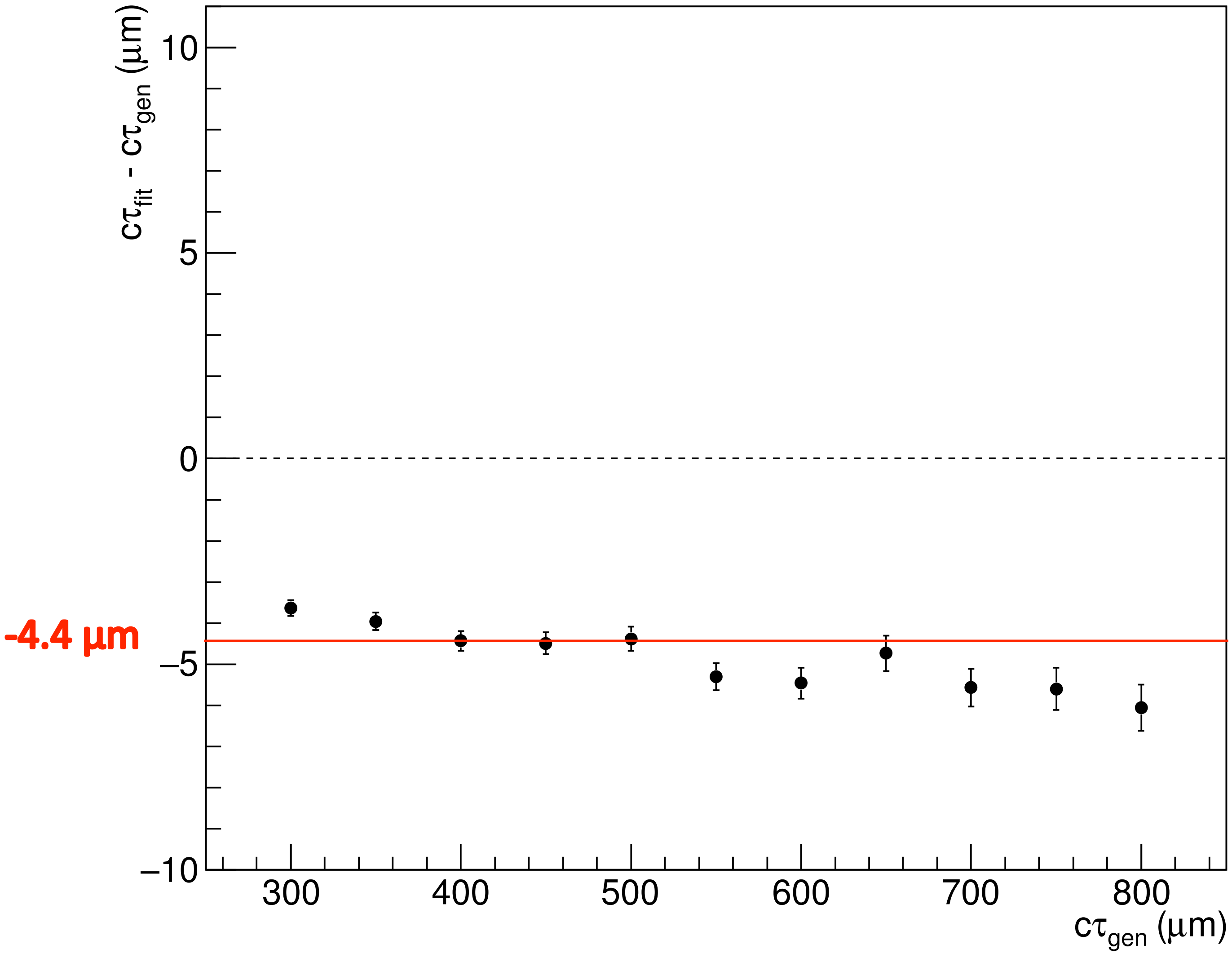
- We changed the size of the $\pi^+\pi^-$ mass window to vary any possible contamination inside.

Mass Window (MeV)	cτ (μm)	Variation w.r.t. nominal (μm)
980 ± 120	498.6	5.4
980 ± 110	499.6	4.4
980 ± 100 (nominal)	504.0	-
980 ± 90	502.4	1.6
980 ± 80	488.0	16.0

Half of the max variation is a systematic uncertainty due to the contamination in the reconstruction.

Fit bias

- We used fits to pseudo-experiments following the models as used for the measurement to explore any bias introduced by the fit method.
- The statistics of the pseudo-experiments was set to what is observed in data.
- From 10K pseudo-experiments with the lifetime input set to the value measured in data, we observed a bias in the lifetime fit estimate.

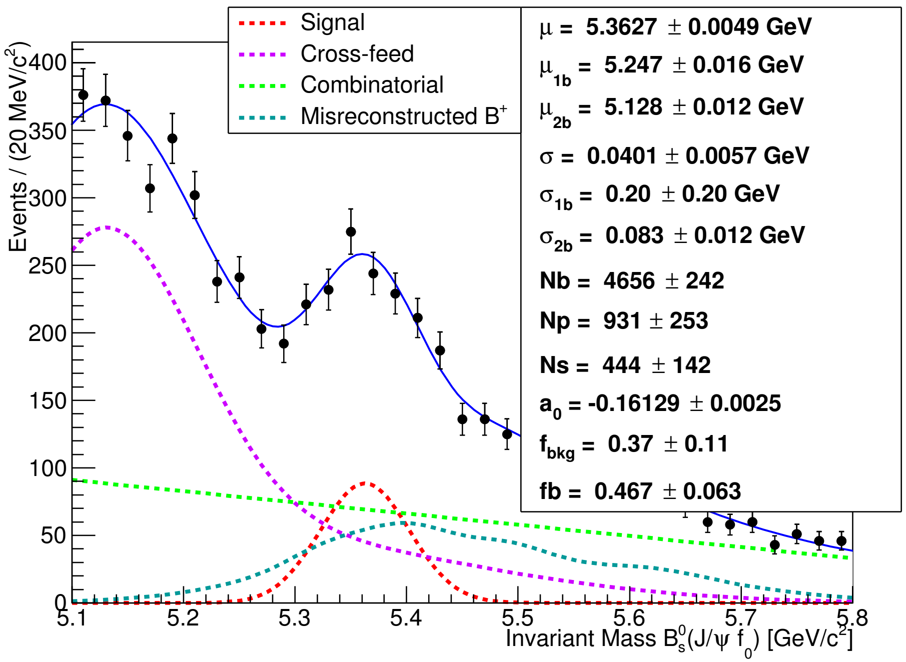


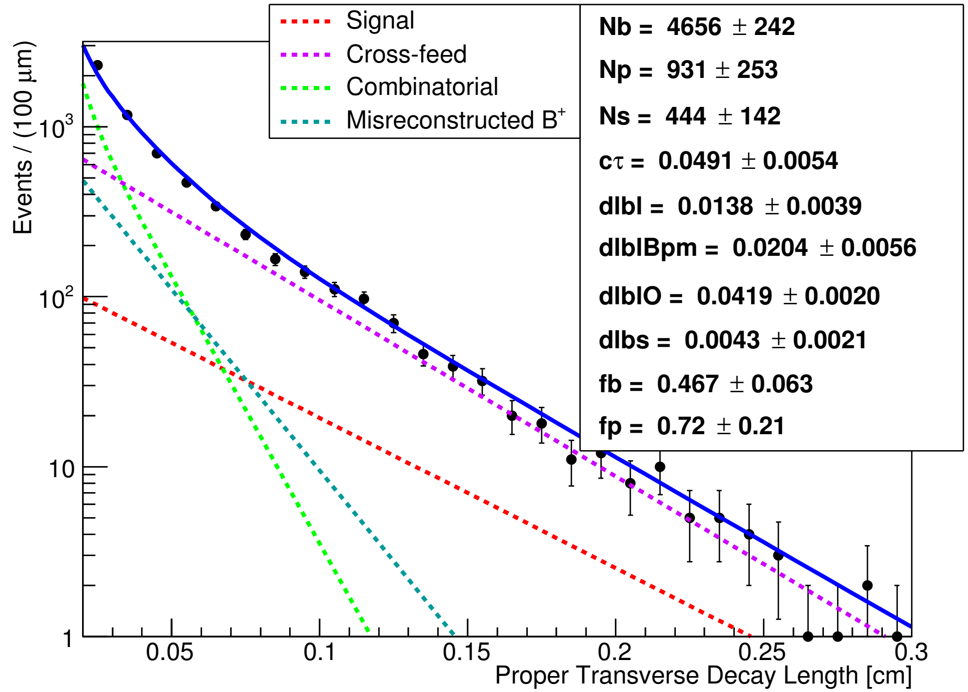
Each point represents 10,000 MC fits.

The average deviation from the input value is considered a systematic uncertainty.

Subtracted from the nominal measurement to correct the bias.

Uncertainty due to models

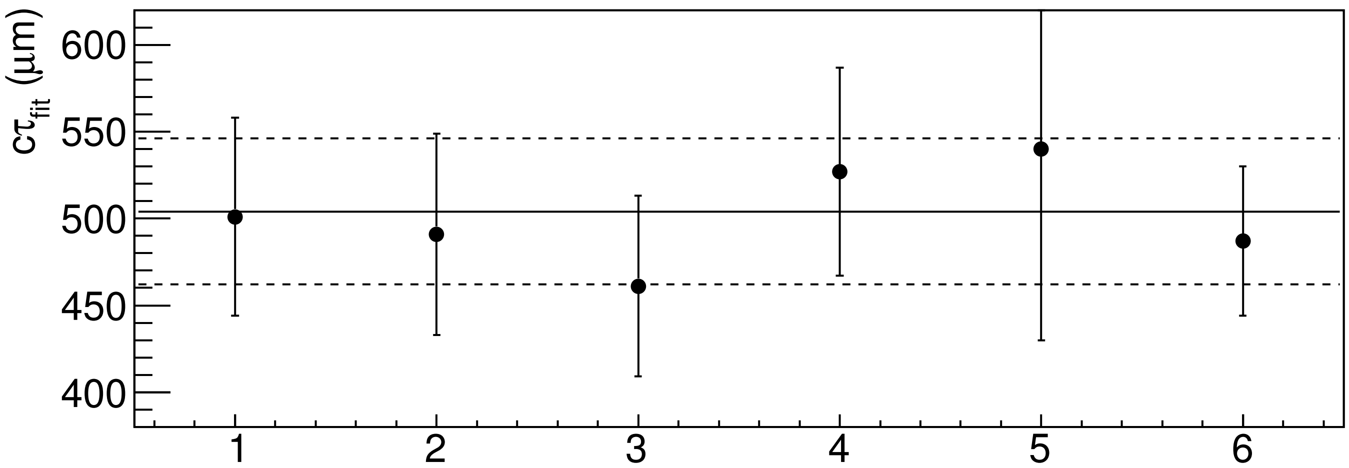




Fit result: 491 ± 54 μm.

The deviation of **12.5 μm** respect to the nominal value is considered a systematic uncertainty.

Cross Checks



Fitted lifetime values selecting B^0_s mesons with:
(1) $\eta > 0$, (2) $\eta < 0$, (3) $\phi > 0$, (4) $\phi < 0$, (5) Run IIa and
(6) Run IIb.

The horizonal lines represent the nominal value.