A novel, precise LHCb measurement of B^0_s and D^-_s lifetimes

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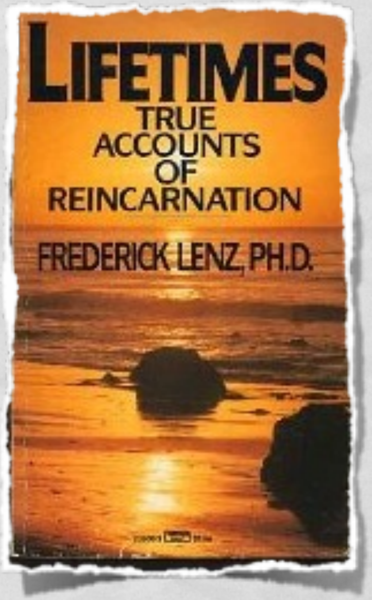
Heavy flavor lifetimes

Not just stamp collecting

Lifetimes test the heavy-quark expansion model: the best predictive tool for inclusive quantities in the dynamics of heavy mesons.

- $\tau(B^0_s)/\tau(B^0)$ has key discriminating power as corrections nearly vanish.
- Data value 0.99 ± 0.004 is 2.5σ off the 1.001 ± 0.002 prediction.
- ==> Improve the B^0_s lifetime.
- Look where most of the statistical power is: semileptonic decays



Reminder: with nonzero width-difference "B^0_s lifetime" is not uniquely defined. Here focus on flavor-specific lifetime

$$\tau_s^{\mathrm{fs}} = \frac{1}{\Gamma_s}\left[\frac{1+(\Delta\Gamma_s/2\Gamma_s)^2}{1-(\Delta\Gamma_s/2\Gamma_s)^2}\right]$$

Semileptonic got out of fashion

VALUE (10^{-12} s)	EVTS	DOCUMENT ID		TECN	COMMENT
1.520 ± 0.004	**OUR EVALUATION**				
1.534 ±0.019 ±0.021		[1] ABAZOV	2015A	D0	$p\bar{p}$ at 1.96 TeV
1.499 ±0.013 ±0.005		[2] AAIJ	2014E	LHCB	pp at 7 TeV
1.524 ±0.006 ±0.004		[3] AAIJ	2014E	LHCB	pp at 7 TeV
1.524 ±0.011 ±0.004		[4] AAIJ	2014R	LHCB	pp at 7 TeV
1.509 ±0.012 ±0.018		[5] AAD	2013U	ATLS	pp at 7 TeV
1.508 ±0.025 ±0.043		[2] ABAZOV	2012U	D0	$p\bar{p}$ at 1.96 TeV
1.507 ±0.010 ±0.008		[6] AALTONEN	2011	CDF	$p\bar{p}$ at 1.96 TeV
1.414 ±0.018 ±0.034		[7] ABAZOV	2009E	D0	$p\bar{p}$ at 1.96 TeV
1.504 ±0.013 $^{+0.018}_{-0.013}$		[8] AUBERT	2006G	BABR	$e^+e^- \to \Upsilon(4S)$
1.534 ±0.008 ±0.010		[9] ABE	2005B	BELL	$e^+e^- \to \Upsilon(4S)$
1.531 ±0.021 ±0.031		[10] ABDALLAH	2004E	DLPH	$e^+e^- \to Z$
1.523 $^{+0.024}_{-0.023}$ ±0.022		[11] AUBERT	2003C	BABR	$e^+e^- \to \Upsilon(4S)$
1.533 ±0.034 ±0.038		[12] AUBERT	2003H	BABR	$e^+e^- \to \Upsilon(4S)$
1.497 ±0.073 ±0.032		[13] ACOSTA	2002C	CDF	$p\bar{p}$ at 1.8 TeV
1.529 ±0.012 ±0.029		[14] AUBERT	2002H	BABR	$e^+e^- \to \Upsilon(4S)$
1.546 ±0.032 ±0.022		[15] AUBERT	2001F	BABR	$e^+e^- \to \Upsilon(4S)$
1.541 ±0.028 ±0.023		[14] ABBIENDI,G	2000B	OPAL	$e^+e^- \to Z$
1.518 ±0.053 ±0.034		[16] BARATE	2000R	ALEP	$e^+e^- \to Z$
1.523 ±0.057 ±0.053		[17] ABBIENDI	1999J	OPAL	$e^+e^- \to Z$
1.474 ±0.039 $^{+0.052}_{-0.051}$		[16] ABE	1998Q	CDF	$p\bar{p}$ at 1.8 TeV
1.52 ±0.06 ±0.04		[17] ACCIARRI	1998S	L3	$e^+e^- \to Z$
1.64 ±0.08 ±0.08		[17] ABE	1997J	SLD	$e^+e^- \to Z$
1.532 ±0.041 ±0.040		[18] ABREU	1997F	DLPH	$e^+e^- \to Z$
1.25 $^{+0.15}_{-0.13}$ ±0.05	121	[13] BUSKULIC	1996J	ALEP	$e^+e^- \to Z$
1.49 $^{+0.17}_{-0.15}$ $^{+0.08}_{-0.06}$		[19] BUSKULIC	1996J	ALEP	$e^+e^- \to Z$
1.61 $^{+0.14}_{-0.13}$ ±0.08		[16, 20] ABREU	1995Q	DLPH	$e^+e^- \to Z$
1.63 ±0.14 ±0.13		[21] ADAM	1995	DLPH	$e^+e^- \to Z$
1.53 ±0.12 ±0.08		[16, 22] AKERS	1995T	OPAL	$e^+e^- \to Z$

Mostly abandoned in the last decade, when large samples of fully reconstructed decays became available.

for a reason

Yield advantage typically offset by complications from unreconstructed neutrino momentum:

- Broadens B mass, spoiling separation from bckg and between the various signals within the inclusive final state
- Biases the decay-time determination from the observed decay length.

Pioneering attempts at the Tevatron, e.g.,

http://inspirehep.net/record/741160/files/fermilab-thesis-2006-78.PDF

http://inspirehep.net/record/1508436/files/fermilab-thesis-2010-76.pdf

some made it to paper, https://journals.aps.org/prl/abstract/10.1103/PhysRevLett.114.062001 although limited by large systematic uncertainties.

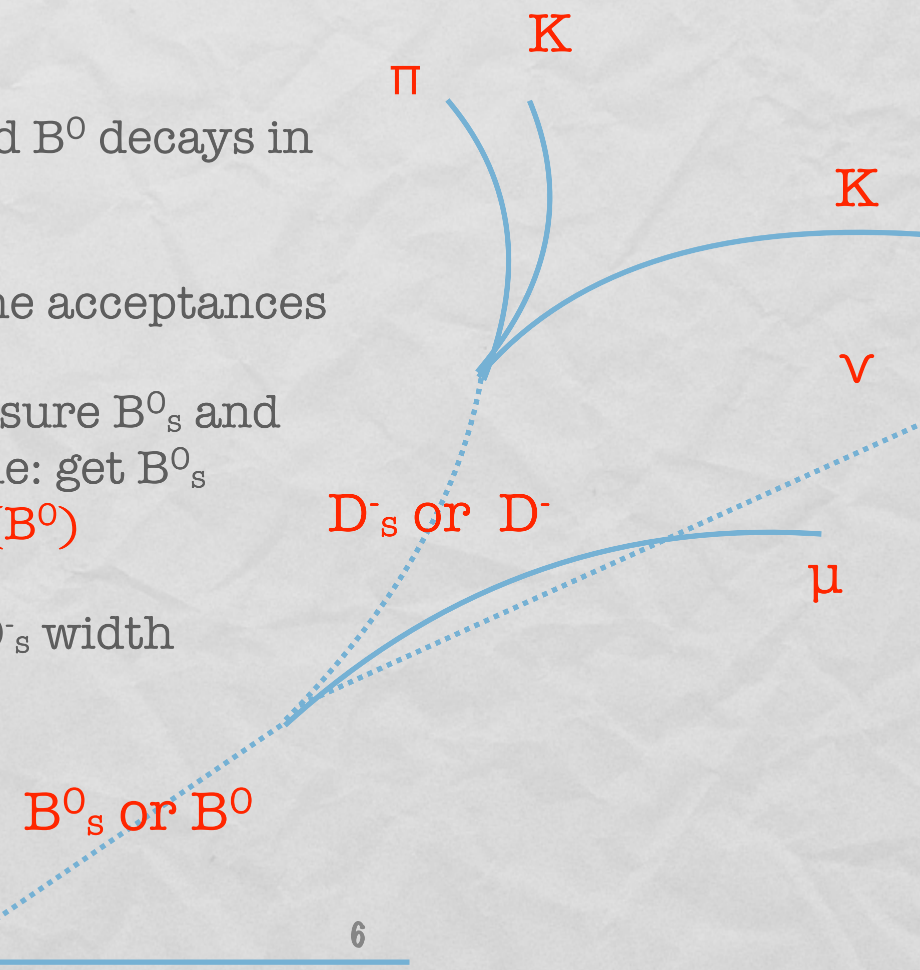
We report competitive B^0_s lifetimes from semileptonic decays thanks to a novel approach. Got D^-_s for free too..

How

$\tau(B^0_s)$ and $\tau(D^-_s)$ from change in B^0_s yield vs decay time, relative to the yield of B^0 decays reconstructed in the same final state.

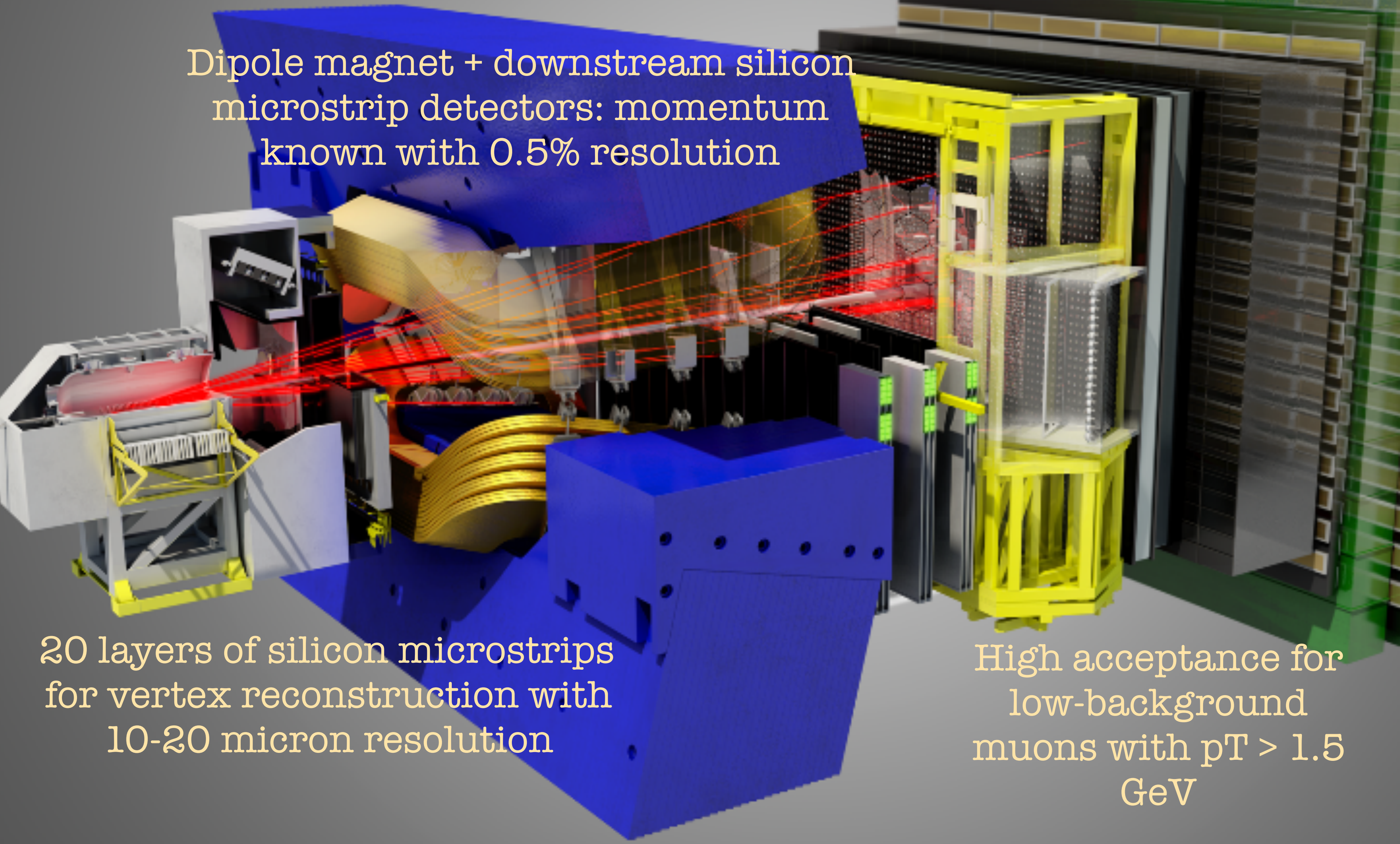
Name of the game: minimize B^0_s -to-B^0 differences in decay-time acceptance

- Reconstruct many low-bckg B^0_s and B^0 decays in the common $(KK\pi)_D\,\mu$ final state
- Enforce equal B^0_s and B^0 decay-time acceptances
- Fit (a proxy to) the B mass to measure B^0_s and B^0 yields vs (a proxy of) decay time: get B^0_s width relative to B^0 ==> $(1/\tau_{fs}) - \Gamma(B^0)$
- Repeat vs D^-_s decay time: get the D^-_s width relative to D^- ==> $\Gamma(D^-_s) - \Gamma(D^-)$



The LHCb detector

Sees 10—50k reconstructable B mesons per second



Dipole magnet + downstream silicon microstrip detectors: momentum known with 0.5% resolution

20 layers of silicon microstrips for vertex reconstruction with 10-20 micron resolution

High acceptance for low-background muons with pT > 1.5 GeV

JINST 3 (2008) S08005

Event selection

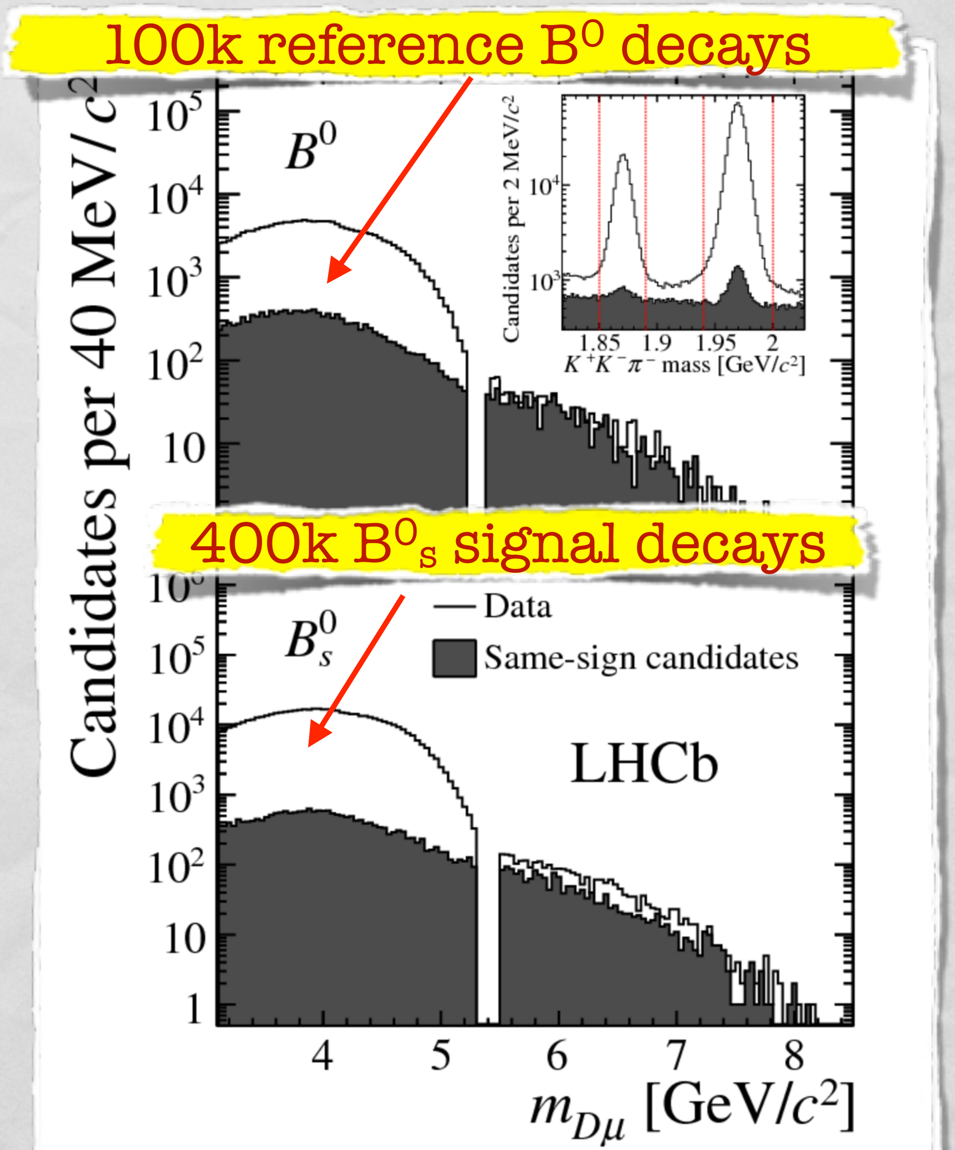
LHCb 2010-12 sample, restricted to single muon trigger

Combine single muon with opposite-sign $D^-_s/D^- \to KK\pi$

- Signal
- $b \to X$ (physics bckg)
- Combinatorial bckg

Tune PID, p_T and track/vertex quality to make $D\mu$-mass of same-sign and signal candidate decays similar at $m_{D\mu} > 5$ GeV

Use same-sign to model combinatorics



arXiv:1705.03475

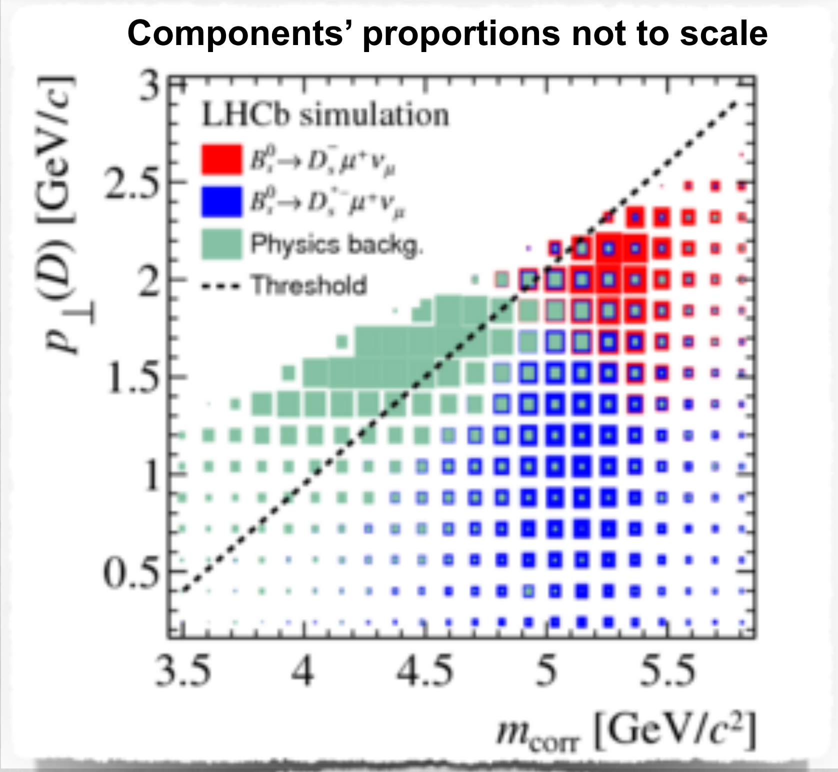
Suppressing b-> X bckg

Mass vetoes suppress

- $B_s^0 \to \psi^{(\prime)}(\to \mu^+\mu^-)\phi(\to K^+K^-)$ $[\mu \to \pi]$
- $\Lambda_b^0 \to \Lambda_c^+(\to pK^-\pi^+)\mu^-\bar{\nu}_\mu X$ $[p \to K$ or $\pi]$
- $B_{(s)}^0 \to D_{(s)}^-\pi^+$ $[\pi \to \mu]$

Correlation between mass and D-momentum component transverse to the B flight reduce to about 5% of the signal the following backgrounds

- $B_{(s)}^0 \to D_{(s)}^{(*)-}D_{(s)}^+$
- $B^+ \to \overline{D}^{(*)0}D^{(*)+}$
- $B^+ \to D^-\mu^+\nu_\mu X$
- $B^+ \to D_s^{(*)-}K^+\mu^+\nu_\mu X$
- $B^0 \to D_s^{(*)-}K^0\mu^+\nu_\mu X$
- $B_s^0 \to D^0D_s^-K^+$
- $B_s^0 \to D^-D_s^+K^0$
- $\Lambda_b^0 \to \Lambda_c^+D_s^{(*)-}X$
- $\Lambda_b^0 \to D_s^+\Lambda\mu^-\bar{\nu}_\mu X$



Sample composition

Fit corrected mass

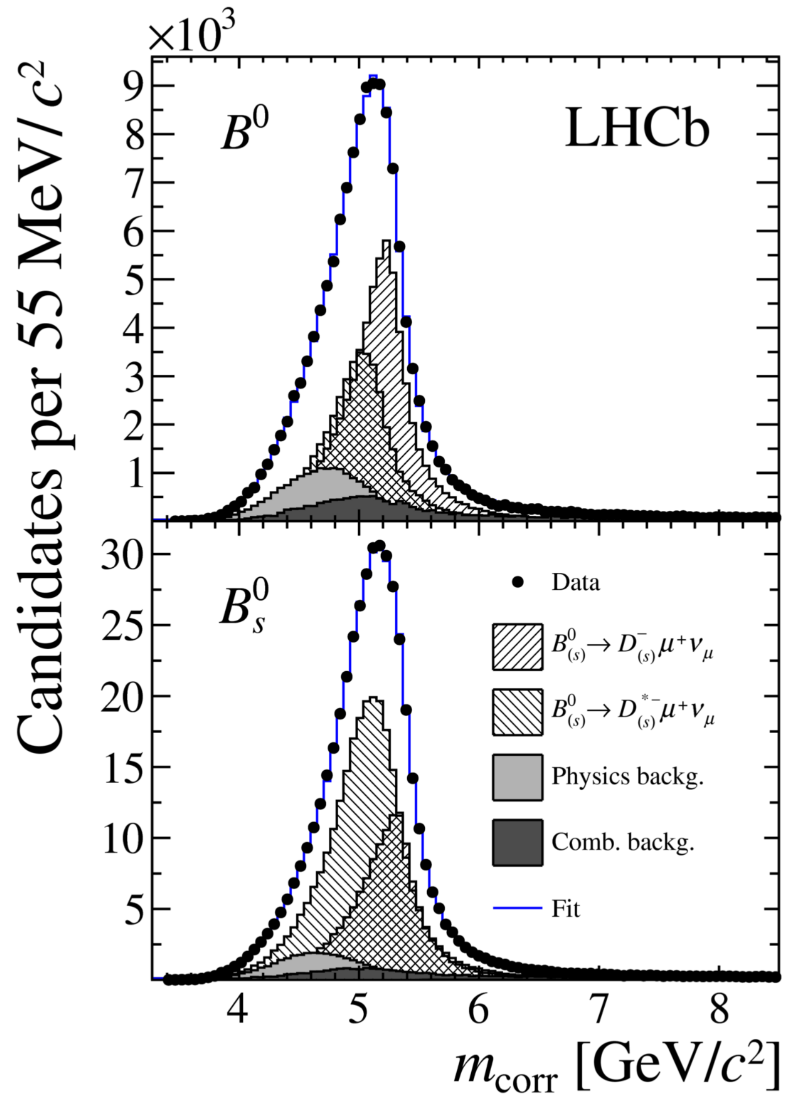
$$m_{\rm corr} = \sqrt{m^2(D\mu) + p_\perp^2(D\mu)} + p_\perp(D\mu)$$

PRL 66 1819 (1991)

Shapes: from MC, grouping together components with similar distributions.

Yields: from the fit, including shape and normalization uncertainties.

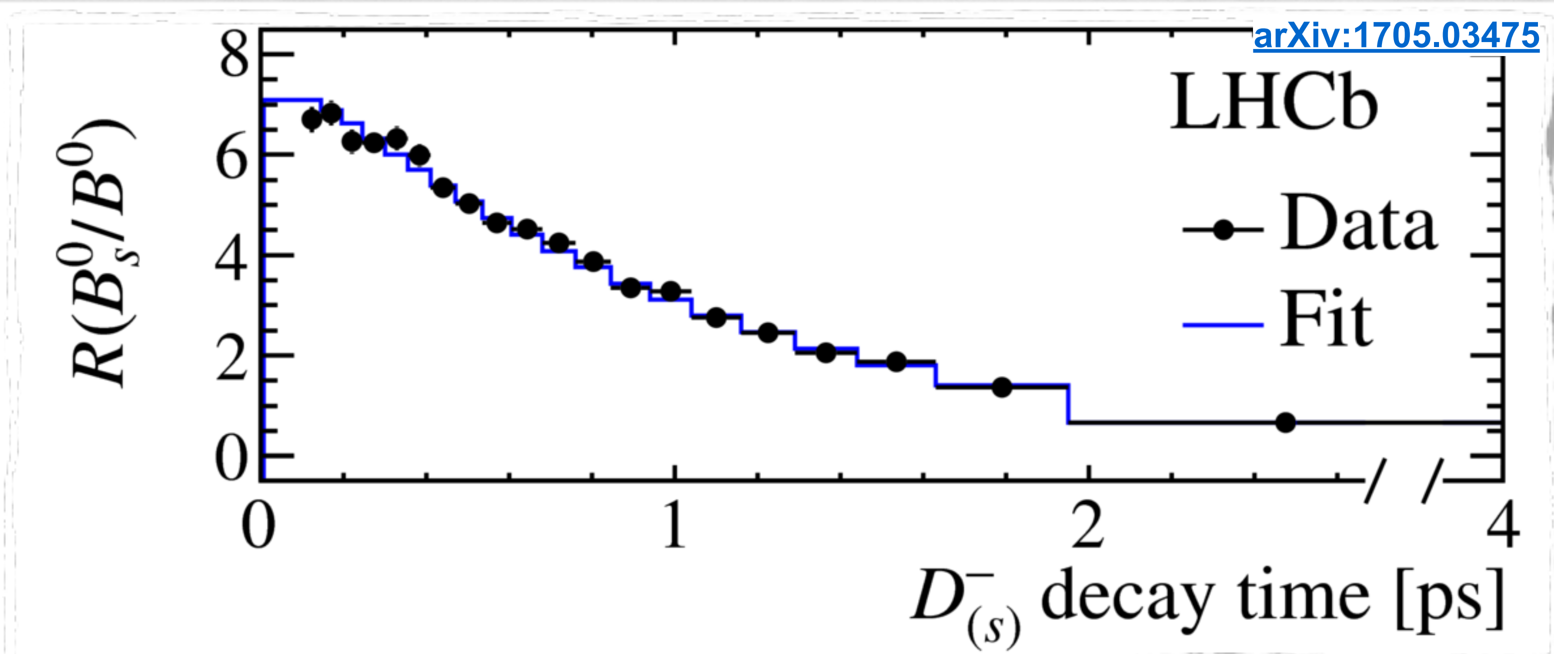
Validate fit on the B^0 sample, whose composition is precisely known from B-factories



arXiv:1705.03475

D^-_s lifetime result

Repeat composition fit in each D decay time bin and then fit the resulting signal-to-reference yield ratio, including a 4% relative acceptance correction and 110 fs decay-time resolution.



$\Delta(D) = 1.0131 \pm 0.0117 \pm 0.0065$ 1/ps which yields

$\tau(D^-_s) = 0.5064 \pm 0.0030 \pm 0.0017 \pm 0.0017$ ps

2x more precise than FOCUS's world's best, PRL 95 052003 (2005)

That was a bonus — now to the B^0_s

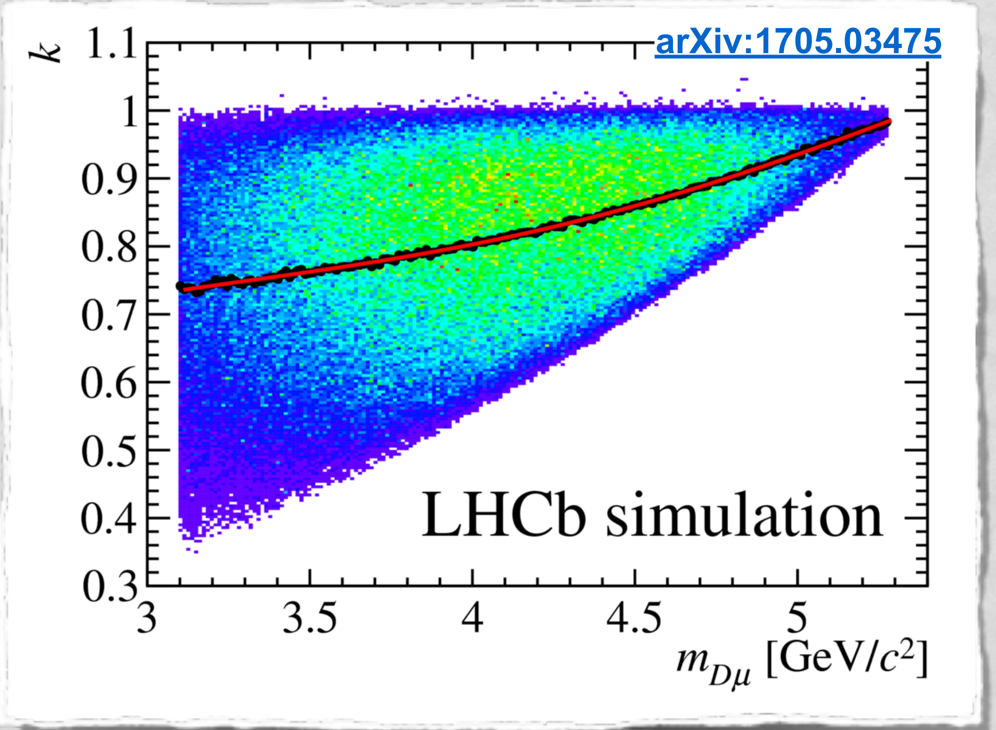
Correcting for the neutrino

Unreconstructed ν momentum biases the decay-time determination from the observed decay length.

Correct observed momentum for average missing momentum as determined in simulation:

$k = p(D\mu)/p(B)$

http://lss.fnal.gov/archive/thesis/2000/fermilab-thesis-2006-18.pdf



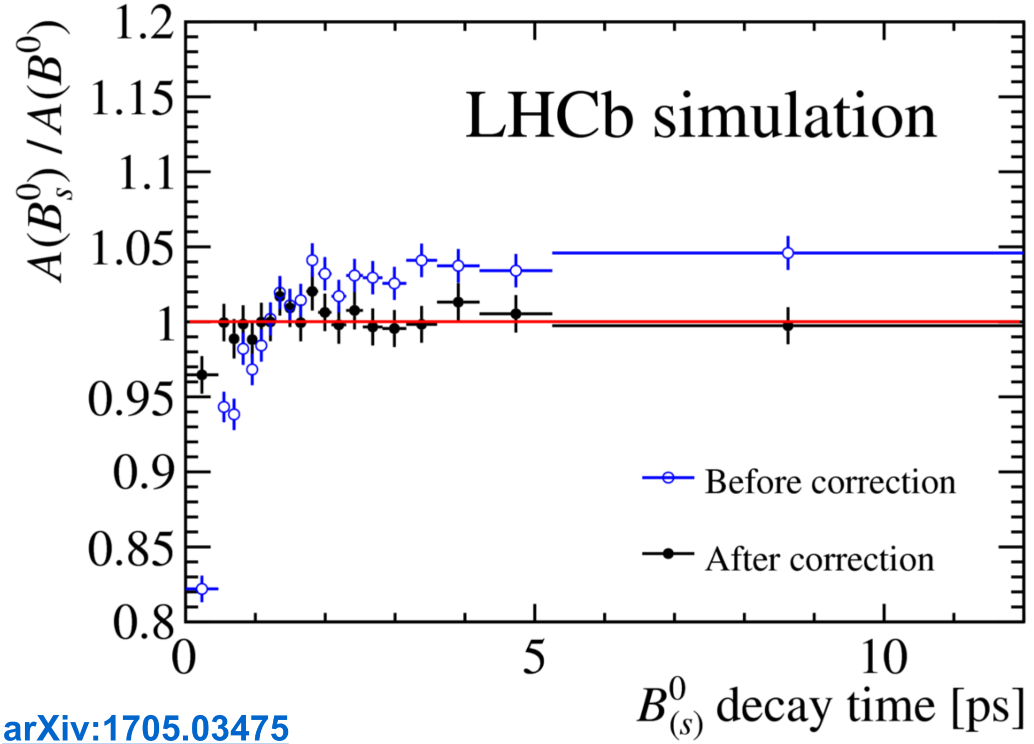
Spread of the correction dominates the final decay-time resolution and is included in the final fit for the width-difference.

Making acceptances equal

Need uniform signal-to-reference acceptance ratio as a function of decay time.

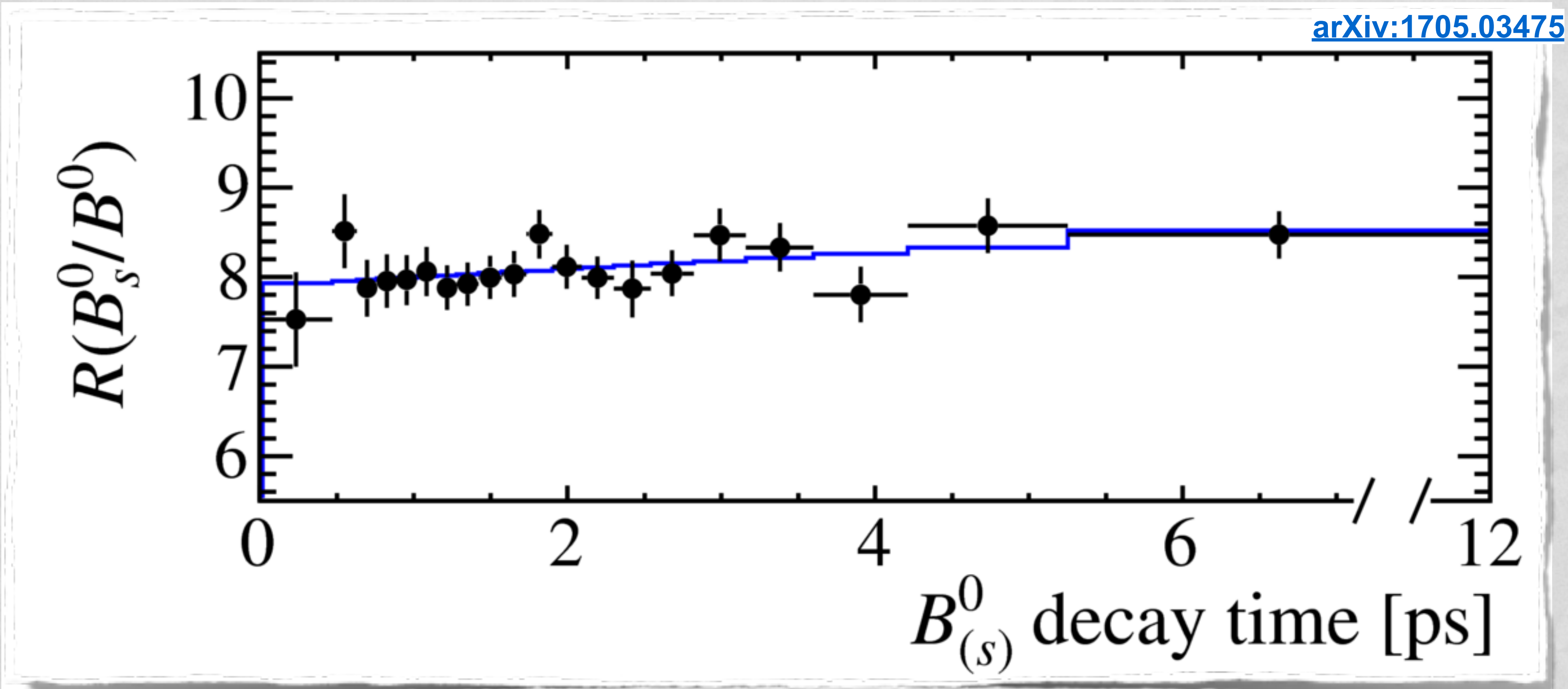
Known 2x difference between D^-_s and D^- lifetime introduces ± 20% nonuniformities.

Reweighting each signal candidate with exp[Δ(D)*t(D^-_s)] reduces them to within 5%.



arXiv:1705.03475

Flavor specific B^0_s lifetime



$\Delta(B) = -0.0115 \pm 0.0053 \pm 0.0041$ /ps

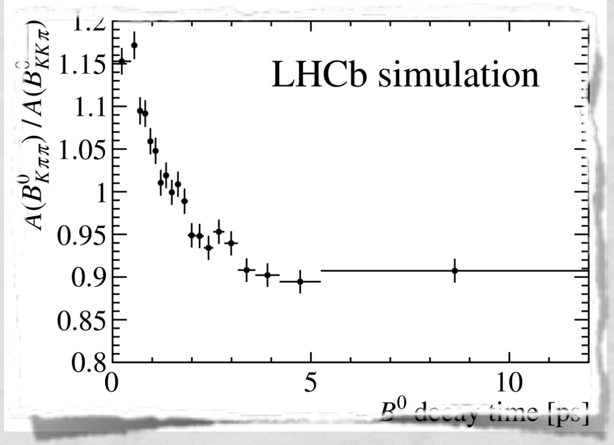
$\tau(B^0_s) = 1.547 \pm 0.013 \pm 0.010 \pm 0.004$ ps

15% more precise than LHCb's world's best, PRL 113 172001 (2014)

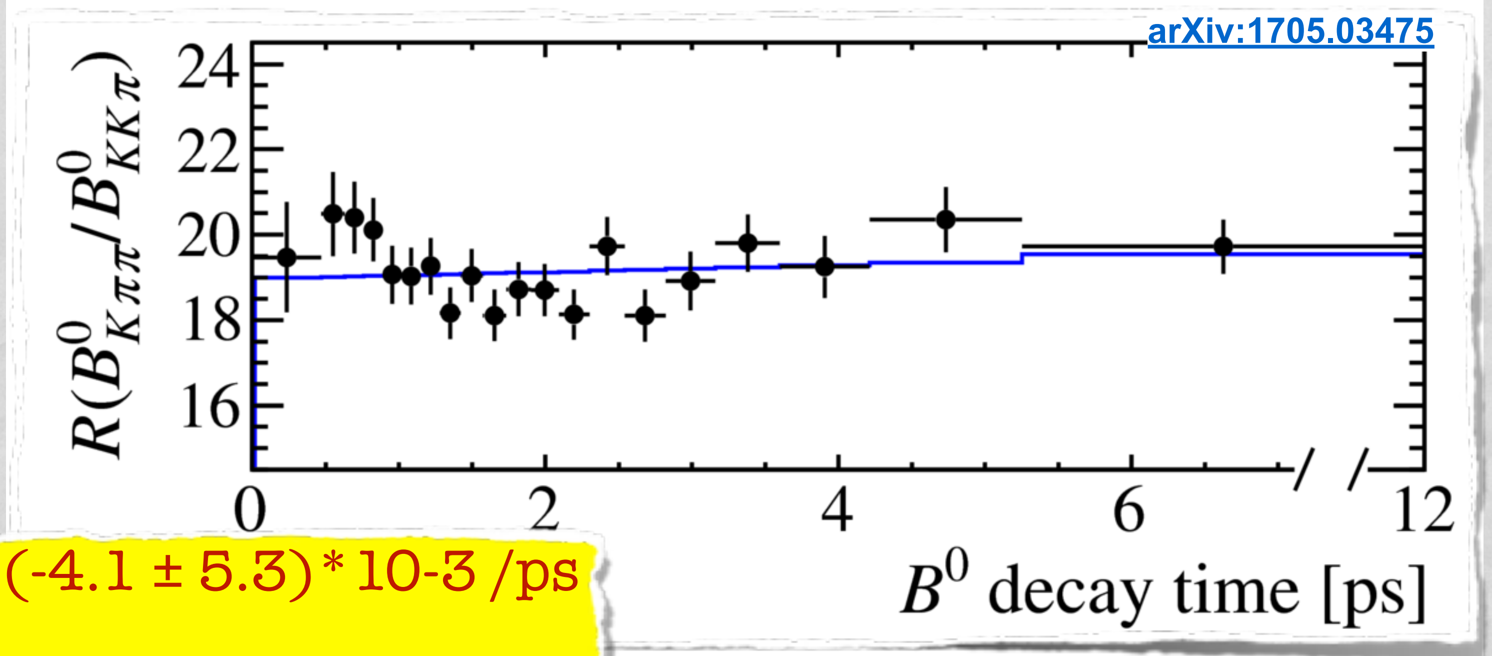
Closure test of acceptance

Width difference between B^0 decays reconstructed in KKπ μ and Kππ μ.

Same B meson, different final state!



Limiting case: 4x larger acceptance correction than in the signal sample



Δ(B) = (-4.1 ± 5.3) * 10-3 /ps

Δ(D) = (-19 ±10) * 10-3 /ps

Systematic uncertainties

	$\sigma[\Delta(D)]$ [ps^{-1}]	$\sigma[\Delta(B)]$ [ps^{-1}]
Fit bias	0.0004	0.0009
Decay model of $B_s^0 \to D_s^{*-}\mu^+\nu$	0.0005	0.0025
Sample composition	0.0007	0.0005
$f_s/f_d(p_T)$	0.0018	0.0028
Decay-time acceptance	0.0049	0.0004
Decay-time resolution	0.0039	0.0004
Feed-down from B_c^+ decays	–	0.0010
Total systematic	0.0065	0.0041
Statistical	0.0117	0.0053

Precision limited by the size of the reference sample

Summary

LHCb reports a novel data-driven method for competitive B-lifetime measurements using semileptonic decays

15% improvement in B^0_s lifetime and 2x in D^-_s lifetime. Accepted by PRL. arXiv:1705.03475

Results limited by reference sample size. Ample chances for improvement: extend to additional triggers (+20%), extend to Run II (3x), use alternative reference channels.

Method potential extends well beyond lifetimes: semileptonic BFs, form factors, etc.

Method is suitable for other experiments too.

(Occasionally stamp-collecting too can be quite rewarding)

Backup

Sweden Three Skilling Banco, Yellow Color Error, 1855

$2.3 million

Sweden Three Skilling Banco, Yellow Color Error, 1855 $2.3 million In 1855, Sweden issued its first series of stamps featuring the Swedish coat of arms. The stamps were available in a number of denominations ranging from 3 to 24 Swedish skillings. Each denomination was associated with a different color, which sometimes created confusion in the printing houses. Due to a printing error, one of the three skilling stamps appeared on yellowish orange paper meant for the eight skilling stamp of the same set instead of the usual blue-green color used for this denomination. One copy of the yellow error variety was discovered in 1885 by a young Swedish boy in his grandfather's collection.

The exact number of mistakenly printed stamps remains unknown. It is considered to be a one-of-a-kind rarity, as no other copies have been discovered to date. In 1996, the stamp was auctioned to an anonymous collector for $2.3 million.