B_s lifetime measurement at LHCb

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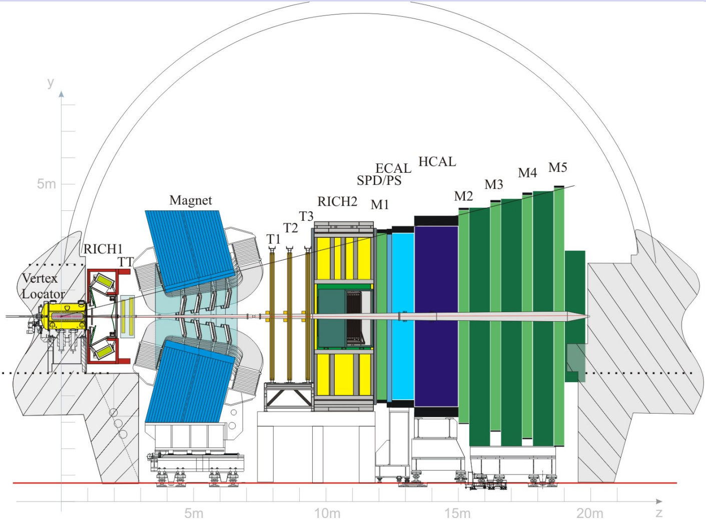
IOP meeting 30th March 2010

Overview

- Aim: measure B_s lifetimes using early LHCb data.
- Many decay channels available to do this:
  - Flavour specific: $B_s \to D_s\pi$, $B_s \to D_s\mu\nu$
  - Admixture of CP eigenstates: $B_s \to J/\psi\phi$
  - CP eigenstates: $B_s \to D_s D_s$
- This talk:
  - Introduce the LHCb experiment.
  - Motivate method for combining multiple channels in a lifetime fit.
    - Leading to higher precision measurement and reduced correlation.
  - Fits based on fully simulated Monte Carlo selected events.

The LHCb Experiment



- Single arm spectrometer with advanced Vertex detector and excellent tracking and Particle Identification.

Some theory about B_s lifetimes

- B_H, B_L mass eigenstates have two lifetimes: τ_H and τ_L.

$$\begin{array}{ll} \Gamma_H = 1/\tau_H & \bar{\Gamma}_s = (\Gamma_L + \Gamma_H)/2 \\ \Gamma_L = 1/\tau_L & \Delta\Gamma_s = \Gamma_L - \Gamma_H \end{array}$$

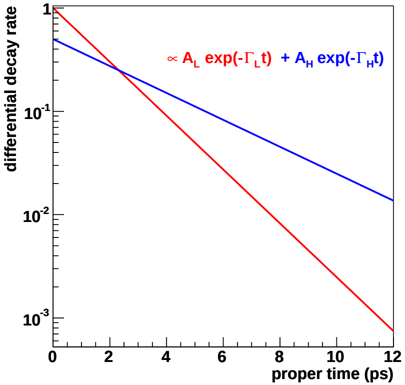
- New physics gives rise to new phases (ϕ_{NP}).

$$\Rightarrow \quad \Delta\Gamma_s \sim \Delta\Gamma_s^{SM} \cos(\phi_{NP})$$

- Theory prediction [Lenz, Nierste]: $\Delta\Gamma_s^{SM} = (8.8 \pm 1.7) \times 10^{-2} ps^{-1}$

	$\bar{\Gamma}_s$	$\Delta\Gamma_s$
current precision (HFAG)	$1.2 \times 10^{-2} ps^{-1}$	$3.4 \times 10^{-2} ps^{-1}$

Lifetimes from $B_s \to D_s\pi$

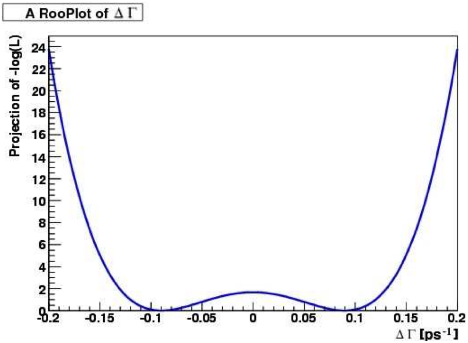


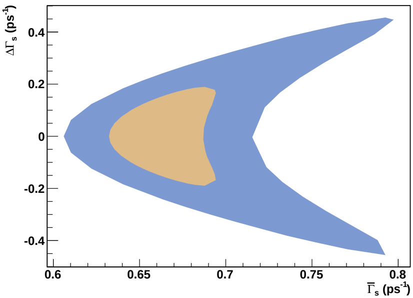
- $\bar{\Gamma}_s = \frac{\Gamma_L + \Gamma_H}{2}$, $\Delta\Gamma_s = \Gamma_L - \Gamma_H$
- A standard approach is to fit a single exponential to this distribution:

$$\boxed{\Gamma_{single} \approx \bar{\Gamma}_s + \mathcal{O}((\Delta\Gamma_s/\bar{\Gamma}_s)^2)}$$

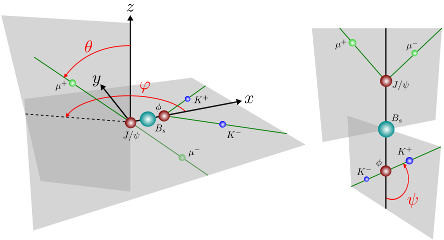
- BUT...
  - Poor constraint on $\Delta\Gamma_s$, particularly for small values of $\Delta\Gamma_s$.
  - Fitting for $\Delta\Gamma_s$ and $\bar{\Gamma}_s$ leads to large correlation.

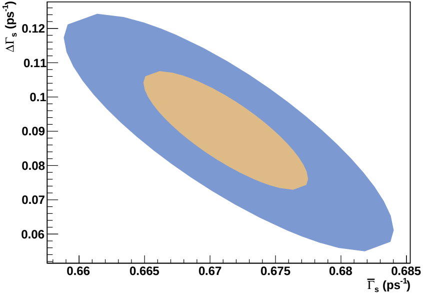
Why is the $\Delta\Gamma_s$ constraint bad in $B_s \to D_s\pi$?





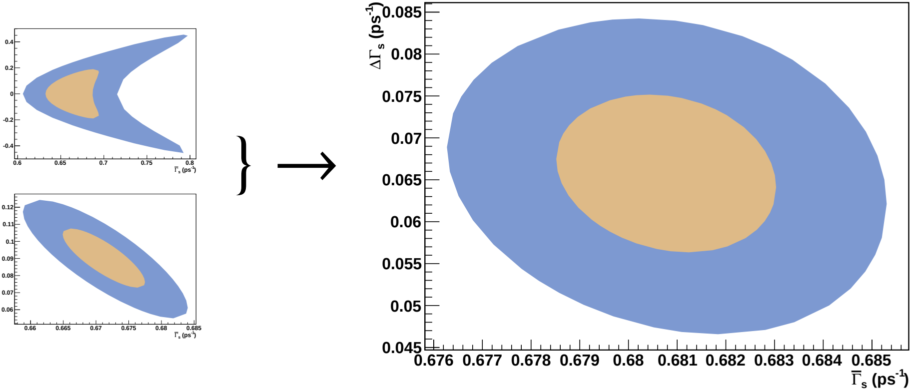
- Log-likelihood is non-parabolic for small $\Delta\Gamma_s$.
  - $\propto \exp(\bar{\Gamma}_s t)\cosh(\Delta\Gamma_s t/2)$.
- $\Rightarrow$ it's not possible to measure $\Delta\Gamma_s$ from $B_s \to D_s\pi$ with a small data set.





- Angular analysis of decay products separates CP+, CP- components.
- If separation was complete then this channel would measure Γ_L and Γ_H independently.
- The separation is not 100% $\Rightarrow$ large correlation ~ -0.8.

Simultaneous fit to $B_s \to D_s\pi$ and $B_s \to J/\psi\phi$



- Precision on $\bar{\Gamma}_S$ has greatly improved due to additional information.
- Correlation between $\Delta\Gamma_s$ and $\bar{\Gamma}_S$ reduced to ~ -0.1.

Fitting to Monte Carlo data

- Now lets do some fits to the fully simulated MC **signal** data.
  1. $B_s \to J/\psi\phi$ alone
  2. $B_s \to D_s\pi$ alone
  3. Simultaneous fit

$B_s \rightarrow J/\psi\phi$: Fit to $0.2 fb^{-1}$ fully simulated data

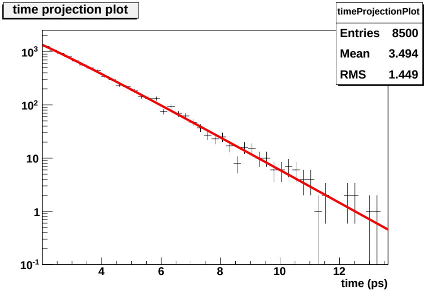
- Fit to ~ 6000 $B_s \rightarrow J/\psi\phi$ events after selection.
- Fit model contains:
  - Correct B_s mass distribution.
  - Time resolution.
  - Flat propertime acceptance.
  - Angular acceptance

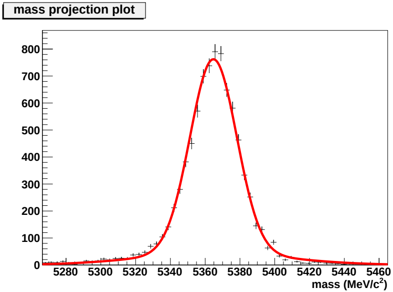
Parameter	Fit result and error, ps^{-1}	σ from input
$\bar{\Gamma}_s$	0.707 ± 0.019	1.4
$\Delta\Gamma_s$	0.015 ± 0.051	-0.88

$B_s \rightarrow D_s\pi$: Fit to $0.2fb^{-1}$ fully simulated data

- Fit to ~ 8500 $B_s \rightarrow D_s\pi$ events after selection.
- Fit model contains:
  - Correct B_s mass distribution.
  - Time resolution.
  - Ignores low proper times; fit $2 \rightarrow 15ps$

Parameter	Fit result and error, ps^{-1}	σ from input
Γ_s	0.686 ± 0.009	0.097
$\Delta\Gamma_s$	0.06 ± 0	fixed

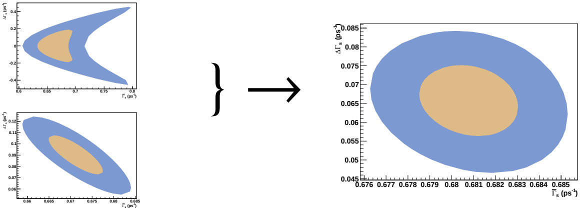




Simultaneous Fit

- Simultaneous fit to $B_s \to J/\psi\phi$ and $B_s \to D_s\pi$
- Fit model contains:
  - Correct B_s mass distribution.
  - Time resolution.
  - Angular acceptance for $B_s \to J/\psi\phi$.
  - Ignores low proper times; fit $2 \to 15ps$

Parameter	Fit result and error, ps^{-1}	σ from input
Γ_s	0.690 ± 0.0059	1.7
$\Delta\Gamma_s$	0.060 ± 0.022	-0.013



- Increased precison on both $\bar{\Gamma}_s$ and $\Delta\Gamma_s$.
- Correlation reduced to -0.04.

Summary

- So what are the precisions we can get on $\bar{\Gamma}_s$ and $\Delta\Gamma_s$ from these fits?

Fit type	$\bar{\Gamma}_s$ precision, ps^{-1}	$\Delta\Gamma_s$ precision, ps^{-1}	$\bar{\Gamma}_s - \Delta\Gamma_s$ correlation
$B_s \to J/\psi\phi$	1.9×10^{-2}	5.1×10^{-2}	-0.84
$B_s \to D_s\pi$	9×10^{-3}	-	-
$B_s \to J/\psi\phi + B_s \to D_s\pi$	5.8×10^{-3}	2.2×10^{-2}	-0.04

	$\bar{\Gamma}_s$ precision, ps^{-1}	$\Delta\Gamma_s$ precision, ps^{-1}
current precision (HFAG)	1.2×10^{-2}	3.4×10^{-2}

- Improved B_s lifetime measurement can be made at LHCb with early data ($0.2 fb^{-1}$).
- Highest precision reached by combining information from multiple channels, reducing $\bar{\Gamma}_s - \Delta\Gamma_s$ correlation.

Backup Slides

Propertime acceptance parametrisation

- $B_s \rightarrow J/\psi\phi$ is lifetime unbiased as it's triggered by the μs
- In $B_s \rightarrow D_s\pi$ small times not reconstructed as the HLT cuts on IP significance as this channel is triggered on the D_s displaced vertices.

$$acc(\tau) = \frac{(\tau \times b)^c}{1 + (\tau \times b)^c}(1+a\times\tau)$$