$\Delta\Gamma/\Gamma$ results review and future perspectives

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- Theoretical introduction $\Rightarrow$ see theoretical talks
- How did we measure it ?
- The current limit
- Reaches at Tevatron and LHC
- Is $\Delta\Gamma_d/\Gamma_d$ measurable soon?

How did we measure $\Delta\Gamma/\Gamma$?

Definitions:

$$1/\tau_{B_s} = \Gamma = (\Gamma_{long} + \Gamma_{short})/2 \qquad \Delta\Gamma = \Gamma_{long} - \Gamma_{short}$$

L3 Inclusive B_s lifetime

$$\tau_{B_s}^{incl} = \frac{1}{\Gamma} \frac{1}{1-\left(\frac{\Delta\Gamma}{2\Gamma}\right)^2} \qquad \frac{1}{\Gamma} = 1.49 \pm 0.06 \text{ ps}$$

$\Delta\Gamma/\Gamma < 0.67$ @ 95% C.L.

CDF $B_s \to J/\psi\ \phi$ (almost CP even $\Rightarrow f_{short} \sim 1$)

$$P_{J/\psi\phi}(t) = f_{short}\Gamma^{short}\exp(-\Gamma^{short}t) + (1-f_{short})\Gamma^{short}\exp(-\Gamma^{long}t)$$

Build likelihood, $\mathcal{L}$, by using $P_{J/\psi\phi}(t)$

$f_{short} = 0.84 \pm 0.16$ $\qquad \frac{1}{\Gamma}$ constrained to τ_{B_d}

Measurement $\tau_{B_s} = 1.34^{+0.23}_{-0.19} \pm 0.05$ $\qquad \Delta\Gamma/\Gamma = 0.36^{+0.50}_{-0.42}$

Delphi $B_s \to D_s l \nu X$

$P_{semi}(t) = (\Gamma_{long}\Gamma_{short} / (\Gamma_{long}+\Gamma_{short}))(\exp(-\Gamma^{short}t)+\exp(-\Gamma^{long}t))$

$\mathscr{L}$ scan as function $\frac{1}{\Gamma}$ constrained to τ_{Bd}, and $\Delta\Gamma/\Gamma$

$\Delta\Gamma/\Gamma < 0.47$ @ 95% C.L.

World average semi−leptonic lifetime

$$\tau^{l}_{Bs} = \frac{1}{\Gamma}\,\frac{1+(\Delta\Gamma/2\Gamma)^2}{1-(\Delta\Gamma/2\Gamma)^2}$$ $\tau^{l}_{Bs} = 1.46 \pm 0.07$ ps $\Delta\Gamma/\Gamma < 0.31$ @ 95% C.L.

Delphi $B_s \to D_s^-$ −hadron (π,k)

$D_s^- \to \phi\pi^-$ $D_s^- \to k^{*0}k^-$ $f_{DsDs} = 22 \pm 7\%$ (fraction of $D_s^{(*)+} D_s^{(*)-}$)

$P_{Ds-h}(t) = f_{DsDs}\Gamma_{short}\exp(-\Gamma_{short}t) + (1-f_{DsDs})P_{semi}(t)$

Scan $\mathscr{L}(1/\Gamma, \Delta\Gamma/\Gamma)$ $1/\Gamma$ const. τ_{Bd} $\Delta\Gamma/\Gamma < 0.70$ @ 95% C.L.

Aleph $B_s \to D_s^{(*)+} D_s^{(*)-} \to \phi\phi X$ (almost CP even)

Branching Ratio method

$$Br(B_s^{short} \to D_s^{(*)+} D_s^{(*)-}) = \frac{1}{\Gamma} \frac{\Delta\Gamma}{1+\frac{\Delta\Gamma}{2\Gamma}}$$

Small Velocity limit or Shifman−Voloshin limit

The measurement: $Br = 23 \pm 10\,(stat)\,^{+19}_{-9}\,(sys.)\%$

$\frac{1}{\Gamma} = \tau_{Bd}$ $\quad \Delta\Gamma/\Gamma = 0.26^{+0.30}_{-0.15}$

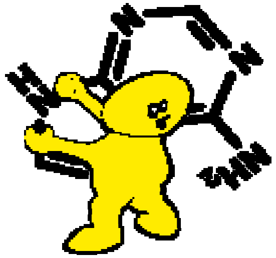
Lifetime method

$$P_{short}(t) = \Gamma_{short} \exp(-\Gamma^{short} t) \qquad \frac{\Delta\Gamma}{\Gamma} = 2\left(\frac{1}{\Gamma}\frac{1}{\tau_{Bs}^{short}} - 1\right)$$

The analysis: $\tau_{Bs}^{short} = 1.27 \pm 0.33 \pm 0.07$ ps

$\frac{1}{\Gamma} = \tau_{Bd}$ $\quad \Delta\Gamma/\Gamma = 0.43^{+0.81}_{-0.48}$

The combined limit

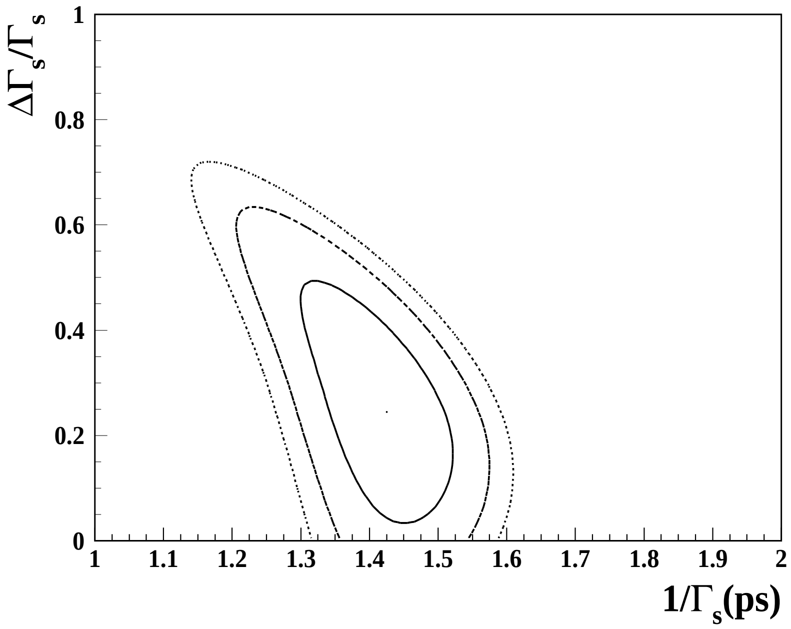


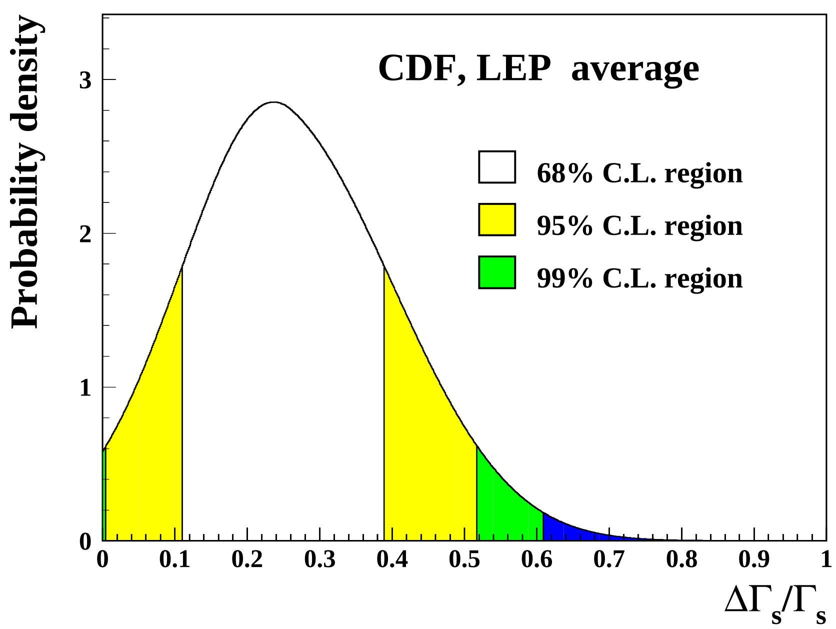
log−$\mathscr{L}$ in (1/Γ, ΔΓ/Γ) plane for each measurement

L3 not included, missing $\mathscr{L}$

∑log−$\mathscr{L}$, normalize respect to the minimum

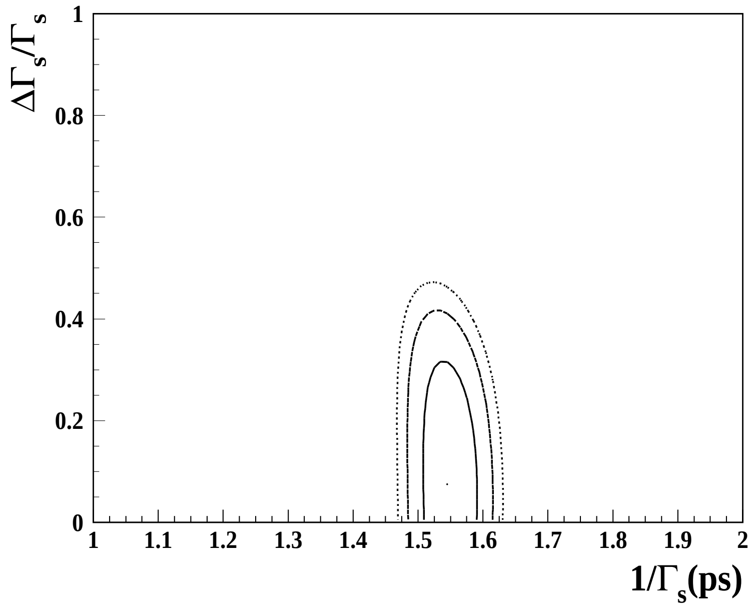
$\Delta\Gamma/\Gamma = 0.24^{+0.15}_{-0.48}$ $\Delta\Gamma/\Gamma < 0.52$ @ 95% C.L.

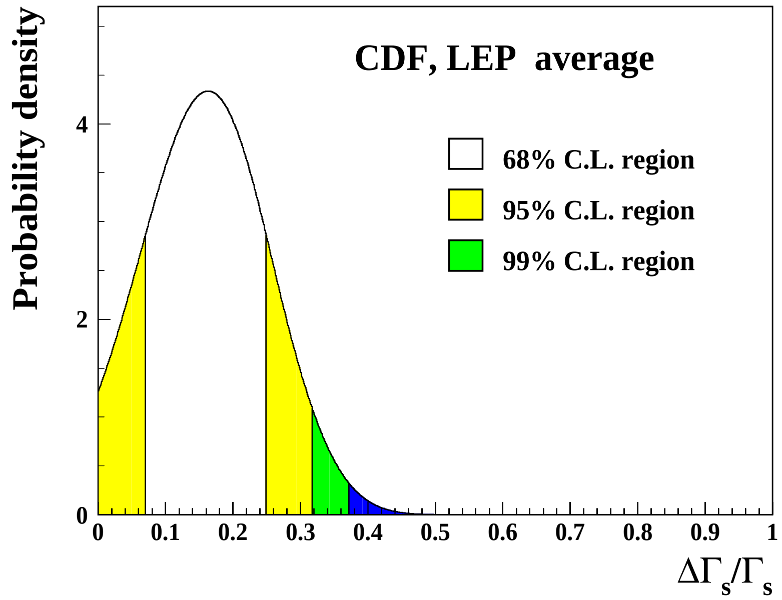




With constraint $\frac{1}{\Gamma} = \tau_{Bd} = 1.540 \pm 0.024$ ps

$\Delta\Gamma/\Gamma = 0.16^{+0.09}_{-0.09}$ $\Delta\Gamma/\Gamma < 0.32$ @ 95% C.L.





Add 2% syst. uncertainty for constraint $1/\Gamma = \tau_{Bd}$

$\Delta\Gamma/\Gamma = 0.17^{+0.10}_{-0.09}$ $\Delta\Gamma/\Gamma < 0.34$ @ 95% C.L

The future of $\Delta\Gamma/\Gamma$

CDF: $(2fb^{-1})$ 4,000 events

$B_s \to J/\psi(\mu\mu)\phi$: lifetime & transversity angle analysis together

S/N & mass resolution = Run I, $\sigma(c\tau)$=18 μm

CP_{even} = 0.77±0.19 $\sigma(\Delta\Gamma/\Gamma)$= 0.05

CP_{even}= 0.5 (1) $\sigma(\Delta\Gamma/\Gamma)$ = 0.08 (0.035)

$B_s \to D_s^- \pi^+$ ~75,000 events ⇒ measure $1/\Gamma$

$B_s \to D_s^+ D_s^-$ lifetime: (CP even) ~2,500 events

S:N=1:1.5 $\sigma(\tau_{Bs})$=0.044 ps $\sigma(\Delta\Gamma/\Gamma)$= 0.06

$B_s \to D_s^{(*)+} D_s^{(*)-}$ Branching Ratio: challenging, missing γ & π^0

~13,000 events S:N=1:1(2) $\sigma(\Delta\Gamma/\Gamma)$= 0.012(0.015)

Lifetime methods combined $\sigma(\Delta\Gamma/\Gamma)$= 0.04, with BR 0.01

BTEV 2 fb^{-1}

Strategy: measure $\tau_{CP}+$ and $\tau_{FS} = 1/\Gamma$

$\tau_{CP}+$: $B_s \to J/\psi(\mu\mu)\ \phi$ (~41,000 events)

$B_s \to J/\psi(\mu\mu)\ \eta^{(')}$ (~8,000 events)

τ_{FS} : $B_s \to D_s^- \pi^+$ (~91,000 events)

$$\sigma_{\frac{\Delta\Gamma_{CP}}{\Gamma}} = 2\frac{\tau_{FS}}{\tau_{CP+}}\sqrt{\left(\frac{\sigma_{\tau_{CP+}}}{\tau_{CP+}}\right)^2 + \left(\frac{\sigma_{\tau_{FS}}}{\tau_{FS}}\right)^2}$$

← Add other Gaussian terms if not only 1 component in $\tau_{CP}+$

Results:

Decay Modes Used	Error on $\Delta\Gamma_{CP}/\Gamma$		
	2 fb^{-1}	10 fb^{-1}	20 fb^{-1}
$J/\psi\eta^{(\prime)}$, $D_s^-\pi^+$	0.0273	0.0135	0.0081
$J/\psi\,\phi$, $D_s^-\pi^+$	0.0349	0.0158	0.0082
$J/\psi\eta^{(\prime)}$, $J/\psi\,\phi$, $D_s^-\pi^+$	0.0216	0.0095	0.0067
with $\Delta\Gamma_{CP}/\Gamma = 0.03$	0.0198	0.0088	0.0062
with $f = 0.13$	0.0171	0.0077	0.0054
with $f = 0.33$	0.0258	0.0112	0.0078

} f=0.229 (odd fraction)
$\Delta\Gamma/\Gamma = 0.15$

LHC

$B_s \to J/\psi(\mu\mu)\ \phi$: The  channel

Thanks to Maria Smizanska

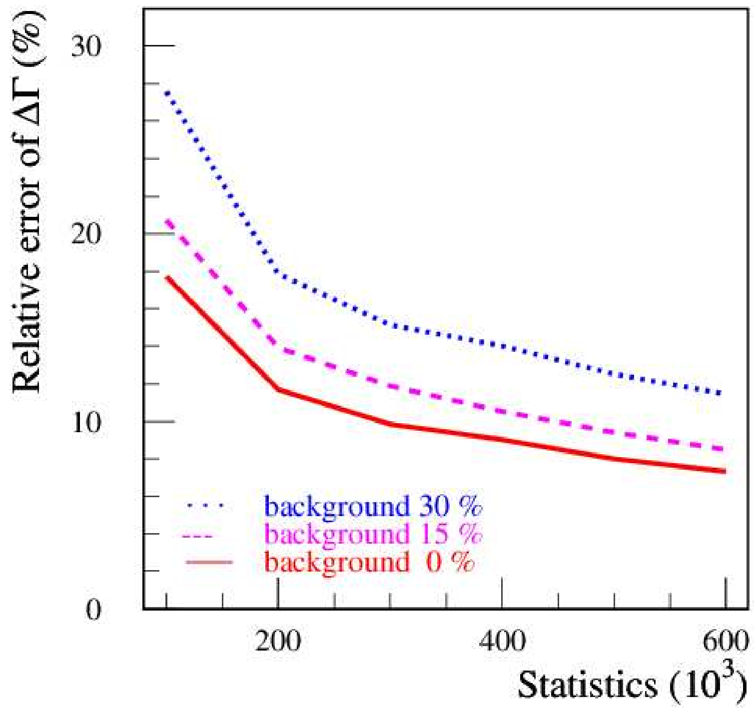
	ATLAS(3Y)	CMS(3Y)	LHCb(5Y)
Events	300,000	600,000	370,000
Bckg	~15%	~10%	~3%
$\sigma(\tau)$	0.063 ps	0.063 ps	0.031 ps

Input values: $\Delta\Gamma = 0.15 \times \Gamma$

$1/\Gamma = 1.54$ ps

Lifetime & angular analysis together

	ATLAS	CMS	LHCb
$\sigma(\Delta\Gamma)$	12%	8%	9%
$\sigma(\Gamma)$	0.7%	0.5%	0.6%



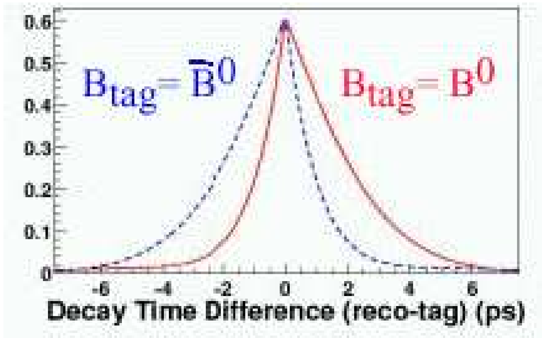
$J/\psi \to ee$ under evaluation

A method to measure $\Delta\Gamma_d$ using untagged CP events

S. Petrak, BCP4

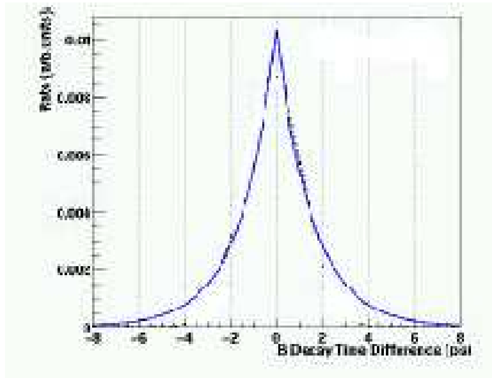
Usual Δt distributions for tagged CP events in BaBar sin(2β) measurement (perfect Δt resolution and tagging): $\Delta t = t_{CP} - t_{Tag}$ → $J/\psi K^0_s$

$$f_{\pm}(\Delta t;\tau_B,\Delta m,\hat{a}) = \frac{1}{4\tau_B}\exp\left(-\frac{|\Delta t|}{\tau_B}\right)\bullet\left[1\,\mathrm{m}\eta_{CP}\sin 2\hat{a}\,\sin\Delta m\Delta t\right]$$



If we do not use tagging information we simply get:

$$f(\Delta t;\tau_B) = \frac{1}{2\tau_B}\exp\left(-\frac{|\Delta t|}{\tau_B}\right)$$



Keep in mind: these equations contain the assumption $\Delta\Gamma = 0$.

Without this assumption the latter equation becomes (good to order $\Delta\Gamma$):

$$f(\Delta t;\tau_B,\hat{a},\Delta\Gamma) = \frac{1}{2\tau_B}\exp\left(-\frac{|\Delta t|}{\tau_B}\right)\bullet\left[1+\eta_{CP}\cos 2\hat{a}\cdot\frac{1}{2}\Delta\Gamma\Delta t\right] \Rightarrow \boxed{\langle\Delta t\rangle = \eta_{CP}\cos 2\hat{a}\,\tau_{B^0}\cdot\frac{\Delta\Gamma}{\Gamma}}$$

Jan Stark CKM workshop, CERN 10

Sensitivity estimate

$$\langle \Delta t \rangle = \eta_{CP} \cos 2\hat{a}\, \tau_{B^0} \cdot \frac{\Delta\Gamma}{\Gamma}$$

Knowing τ_{B0} and cos2β, we can turn
a measurement of <Δt> into a measurement of $\Delta\Gamma_d/\Gamma_d$

$$\sigma\left(\langle \Delta t \rangle\right) = \frac{\mathrm{RMS}(\Delta t)}{\sqrt{N}}$$

Width of Δt distribution: RMS(Δt) = 2.4 ps
(takes into account lifetime contrinution and detector resolution).

Number of "golden" CP events in 30 fb^{-1} : N = 700
(BaBar, hep−ex/0201020)

With τ_{B0} = 1.55 ps and sin2β = 0.6, this gives:

Remarks: The additional uncertainty due to the error on sin 2β is small compared to the uncertainty due to σ(<Δt>).

The contribution to <Δt> from experimental Δt reconstruction can be determined using the much larger flavour samples used in the lifetime analysis.

Extrapolation to 300 fb^{-1}: $\sigma\left(\frac{\Delta\Gamma}{\Gamma}\right) = 0.023$

to 500 fb^{-1}: $\sigma\left(\frac{\Delta\Gamma}{\Gamma}\right) = 0.018$

Theory: $\Delta\Gamma_d/\Gamma_d \sim 3\mathrm{x}10^{-3}$
see talk of Tobias Hurt

Summary

- The current limits are:
  1) $\Delta\Gamma/\Gamma < 0.52$ @ 95% C.L. no constraint
  2) $\Delta\Gamma/\Gamma < 0.34$ @ 95% C.L. with constraint $1/\Gamma = \tau_{Bd}$

- Near future: CDF $\sigma(\Delta\Gamma/\Gamma) = 0.04$ (lifetime method)
  $\sigma(\Delta\Gamma/\Gamma) = 0.01$ (lifetime+BR methods)

- Far future BTEV and LHC $\sigma(\Delta\Gamma/\Gamma) < 0.01$

- $\Delta\Gamma_d/\Gamma_d$ measurable with an error of 0.023 in 300 fb^{-1} of data at Babar