CP violation in $B_s \to J/\psi\phi$

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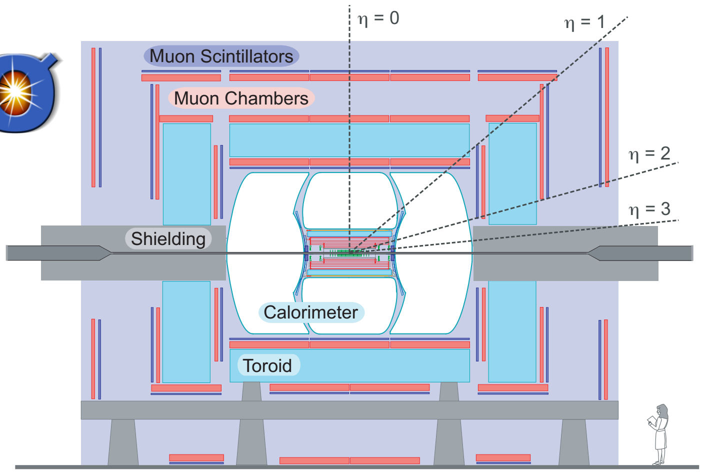
Flavour Physics and CP Violation

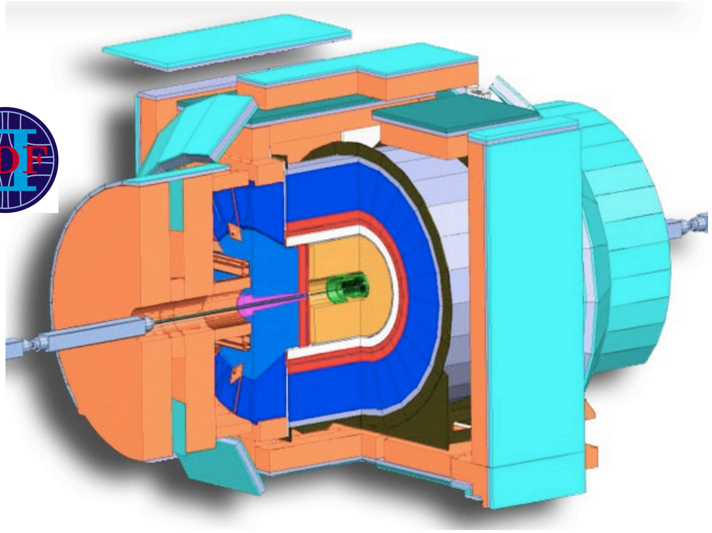
Hefei, China, May 2012

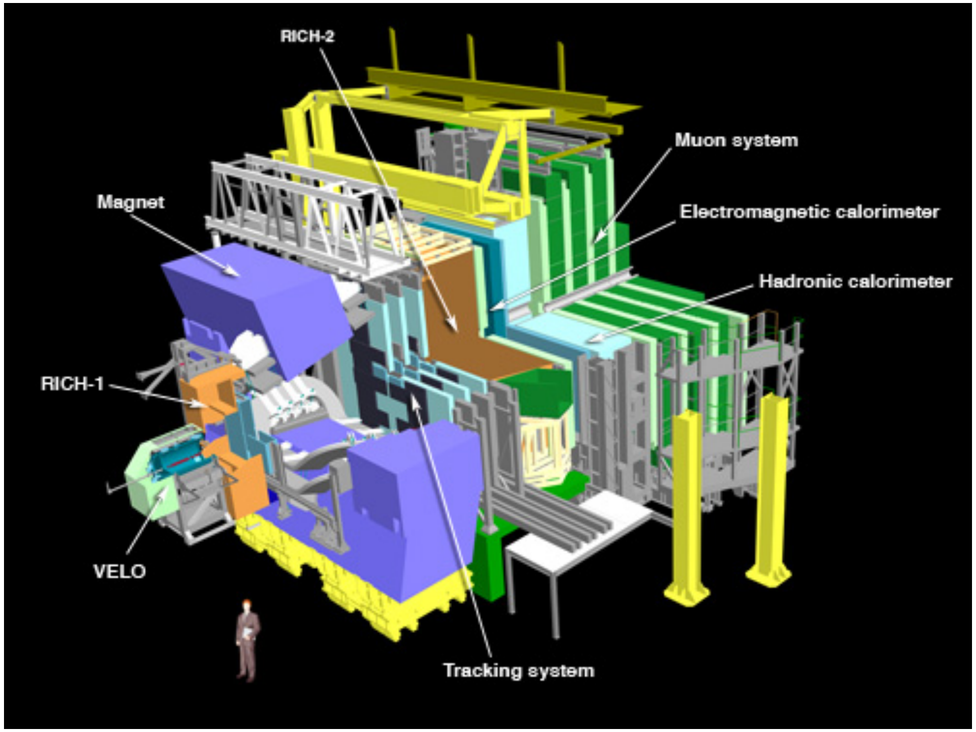
Outline

- $B_s \to J/\psi\phi$ as a probe for new physics
- History, progress and new results
- Implications
- Conclusions and outlook

This presentation will concern





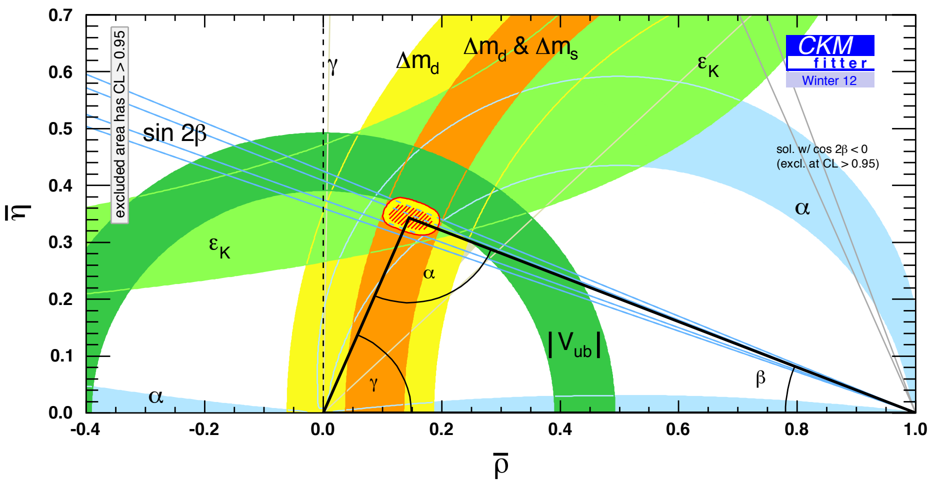


LHCb: forward spectrometer at LHC designed for flavour physics

CDF and D0: general purpose detectors at Tevatron

Look for ~~CP~~ in B_s system

- Flavour violation and CP violation (CPV) in K and B_d systems well described by CKM mechanism

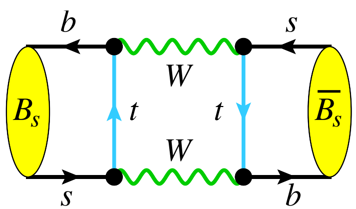


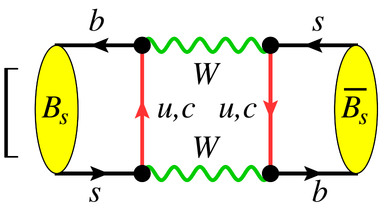
- CPV arising from a single phase in CKM matrix is too small to explain baryon asymmetry in the Universe
- B_s decays provide an excellent lab to look for new sources of CP violation

Neutral B_s-$\bar{B}_s$ system

- Schrödinger's equation describes time evolution

$$i\frac{d}{dt}\begin{pmatrix}|B_s(t)\rangle \\ |\bar{B}_s(t)\rangle\end{pmatrix} = \left(\begin{bmatrix} M_{11} & M_{12} \\ M_{12}^{*} & M_{11}\end{bmatrix} - \frac{i}{2}\begin{bmatrix}\Gamma_{11} & \Gamma_{12} \\ \Gamma_{12}^{*} & \Gamma_{11}\end{bmatrix}\right)\begin{pmatrix}|B_s(t)\rangle \\ |\bar{B}_s(t)\rangle\end{pmatrix}$$

$M_{12} = \Big[$  $\Big] + \mathrm{NP}$

$\Gamma_{12} = \mathrm{Im}\Big[$  $\Big]$

New physics (NP) naturally affects M_{12}. Possibility of new physics in Γ_{12} not excluded.

- Diagonalizing Hamiltonian leads to two mass eigenstates with masses $M_{H(L)}$ and decay width $\Gamma_{H(L)}$

$$B_{s,H} = pB_s + q\bar{B}_s, \qquad B_{s,L} = pB_s - q\bar{B}_s$$

B_s mesons change flavour during their lifetime

Probes for NP in B_s mixing

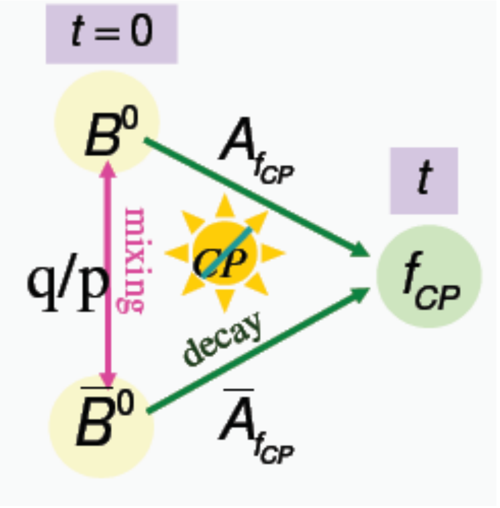
Comparing these direct measurements with their indirect determinations in the Standard Model (SM)

1) CPV in B_s mixing: $a^s_{fs} = 1-|q/p|^2 \approx |\Gamma_{12}/M_{12}|\sin\varphi$, $\varphi = \arg(-M_{12}/\Gamma_{12})$
   - SM: $a^s_{fs} = (0.29 \pm 0.09)\times 10^{-4}$ [Lenz, Nierste, arXiv1102.4274]
   - D0: $a^s_{fs} = \left(-17 \pm 91^{+14}_{-15}\right)\times 10^{-4}$ [PRD82 (2010) 012003]
2) mass difference $\Delta M_s = M_H - M_L \approx 2M_{12}$
   - SM: $\Delta M_s = 17.3 \pm 2.6\ \text{ps}^{-1}$ [Lenz, Nierste, arXiv1102.4274]
   - LHCb preliminary: $\Delta M_s = 17.725 \pm 0.041 \pm 0.026\ \text{ps}^{-1}$ [LHCb-CONF-2011-050]
3) decay width difference: $\Delta\Gamma_s = \Gamma_L - \Gamma_H \approx 2\Gamma_{12}\cos\varphi$
   - SM: $\Delta\Gamma_s = 0.087 \pm 0.021\ \text{ps}^{-1}$ [Lenz, Nierste, arXiv1102.4274]
   - Measured in $B_s \to J/\psi\phi$
4) mixing induced CPV in B_s decay to CP eigenstates (e.g. $B_s \to J/\psi\phi$)

Mixing-induced CPV in b→c$\bar{c}$s

- $B_s \rightarrow f_{CP}$ (eigenvalue η_{CP})

$$\lambda = \frac{q}{p}\frac{\overline{A}_{f_{CP}}}{A_{f_{CP}}} \qquad S = \frac{2\,\mathrm{Im}\,\lambda}{1+|\lambda|^2} \qquad C = \frac{1-|\lambda|^2}{1+|\lambda|^2}$$



Imλ≠0 ➔ mixing-induced CPV

$$A(t) \equiv \frac{\Gamma\left(B(t)\rightarrow f\right)-\Gamma\left(\bar{B}(t)\rightarrow f\right)}{\Gamma\left(B(t)\rightarrow f\right)+\Gamma\left(\bar{B}(t)\rightarrow f\right)} \propto S\cdot\sin\left(\Delta M_s t\right)+C\cdot\cos\left(\Delta M_s t\right)$$

- b→c$\bar{c}$s decays of B_s (ignore tiny CPV in mixing and penguin pollution)

$$S = -\eta_{CP}\sin\phi_s \qquad C = 0$$

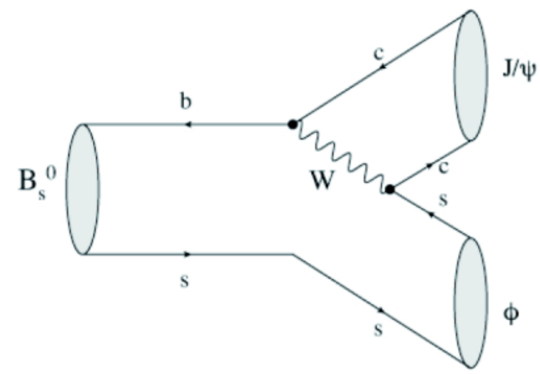
$$\phi_s^{SM} = -2\beta_s = -0.036 \pm 0.003$$ [Lenz, Nierste, arXiv1102.4274]

phase ϕ_s probes NP in M_{12}

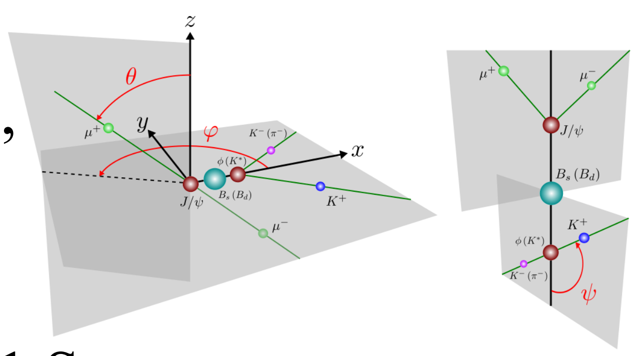
$$\phi_s = \phi_s^{SM} + \Delta\phi^{NP}, \quad \Delta\phi^{NP} = \arg\left(\frac{M_{12}}{M_{12}^{SM}}\right)$$

Golden channel $B_s \to J/\psi\phi$

- Theoretically and experimentally clean
  - $b \to c\bar{c}s$ tree dominance leads to precise prediction of ϕ_s in SM
  - Relatively large branching ratio
  - Easy to trigger on muons from $J/\psi \to \mu^+\mu^-$



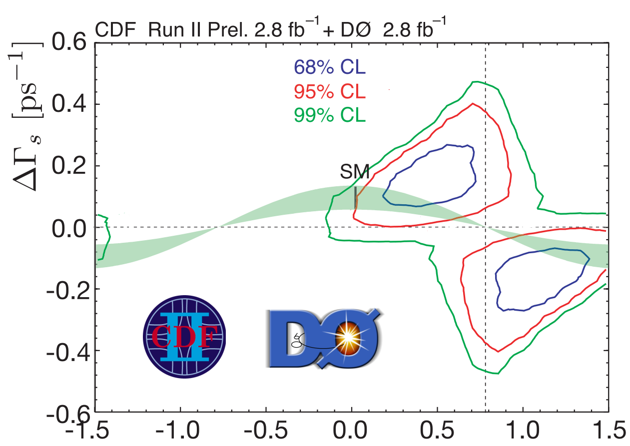
- Multivariate analysis
  - 10 physics parameters: ϕ_s, $\Delta\Gamma_s$, Γ_s, ΔM_s, 3 amplitudes and 3 strong phases
  - 2 initial B_s flavours
  - 4 CP eigenstates: 3 K^+K^- P-waves and 1 S-wave
  - 4D space: 3 angles (θ, ϕ, ψ) and decay time t



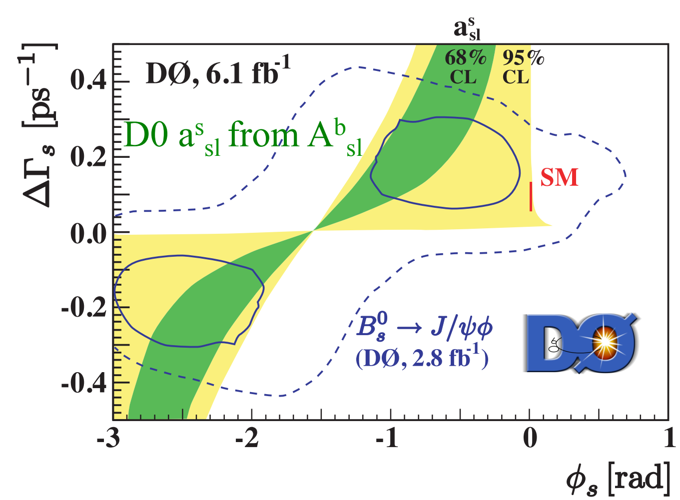
Need flavour-tagged, time-dependent angular analysis.

A bit of history

- 2007: first tagged analysis by CDF, followed by D0
- 2009: 2.1σ deviation from SM in CDF+D0 combination [DØ Note 5928-CONF]
- 2010: D0 same-sign dimuon asymmetry A^b_{sl} in 6.1fb^{-1} showed 3.2σ from SM, implying large ϕ_s (assuming NP in B_s M_{12} only) [PRD82 (2010) 032001]
- 2011: D0 update of A^b_{sl} with 9 fb^{-1} showed 3.9σ deviation from SM [PRD84 (2011) 052007]
- 2011: first LHCb tagged analysis result



$-\phi_s/2 =$



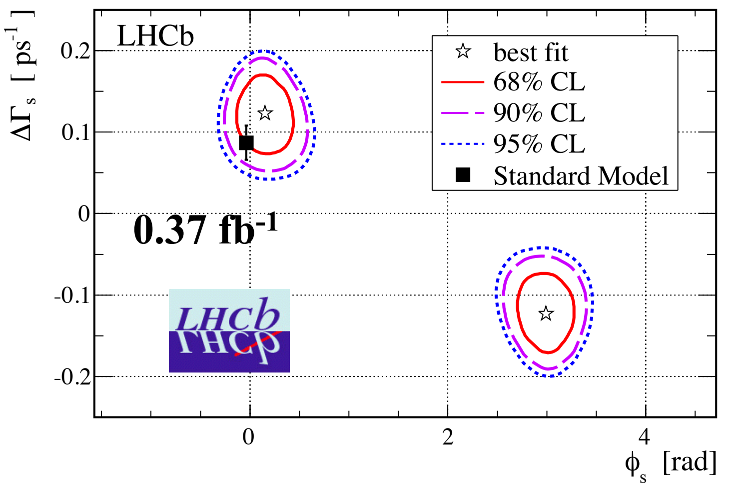
Latest publications

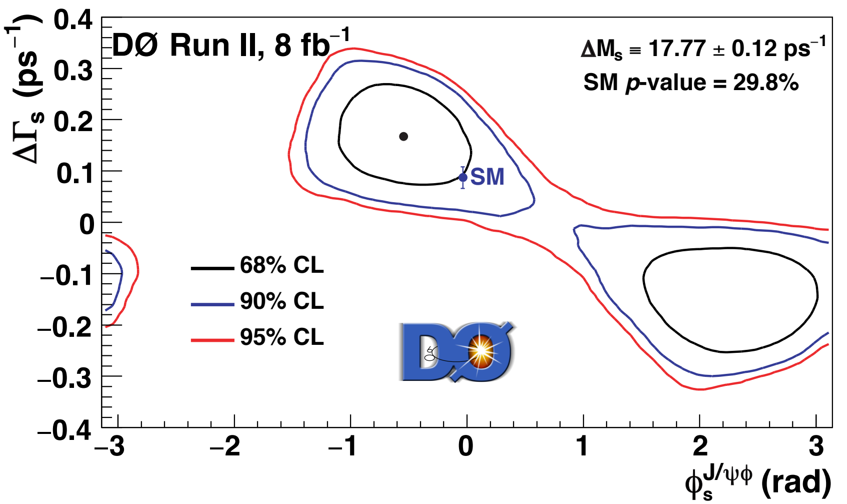
LHCb: PRL108 (2012) 101803

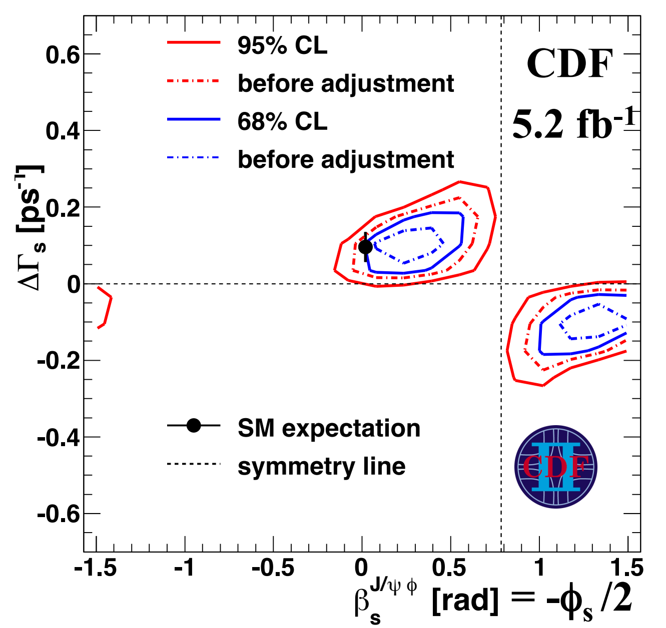
CDF: PRD85 (2012) 072002

D0: PRD85 (2012) 032006

SM: Lenz, Nierste, arXiv1102.4274







Method to resolve the ambiguity

[Y. Xie et al., JHEP 09 (2009) 074]

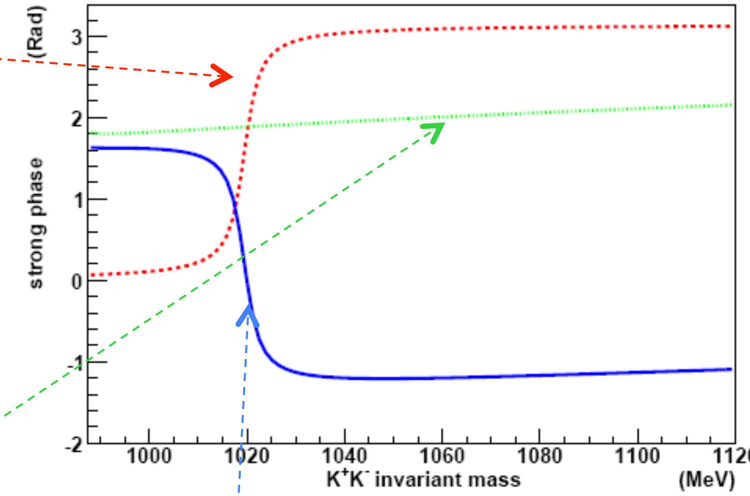
Two-fold ambiguity

$$(\phi_s, \Delta\Gamma_s, \delta_\parallel - \delta_0, \delta_\perp - \delta_0, \delta_s - \delta_0) \longleftrightarrow (\pi - \phi_s, -\Delta\Gamma_s, \delta_0 - \delta_\parallel, \pi + \delta_0 - \delta_\perp, \delta_0 - \delta_s)$$

K^+K^- P-wave:

Phase of Breit-Wigner amplitude increases rapidly across $\phi(1020)$ mass region

$$BW(m_{KK}) = \frac{F_r F_D}{m_\phi^2 - m_{KK}^2 - i m_\phi \Gamma(m_{KK})}$$



K^+K^- S-wave:

Phase of Flatté amplitude for $f_0(980)$ relatively flat (similar for non-resonance)

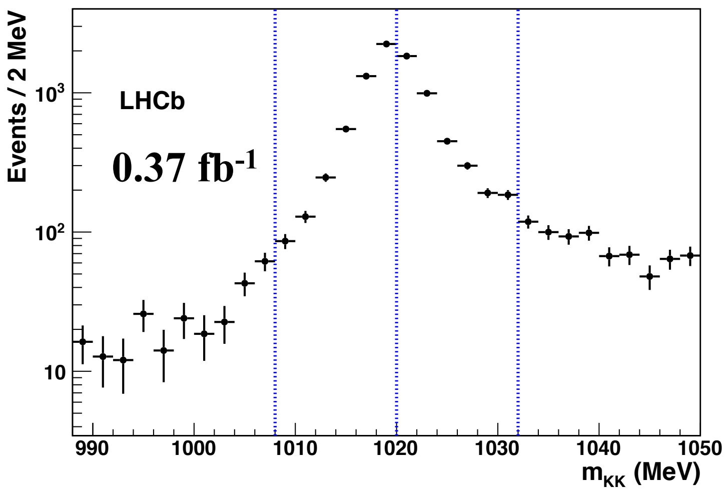
Phase difference between S- and P-wave amplitudes

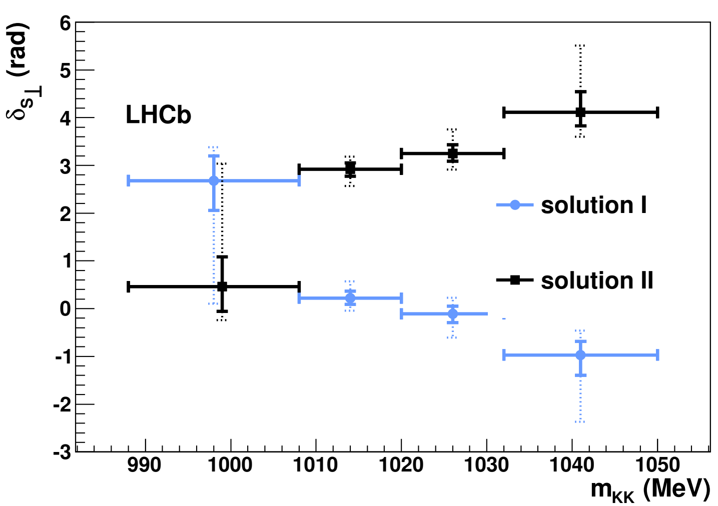
Decreases rapidly across $\phi(1020)$ mass region

Resolution method: choose the solution with decreasing trend of $\delta_S - \delta_P$ vs m_{KK} in the $\phi(1020)$ mass region

Ambiguity resolved, $\Delta\Gamma_s > 0$

LHCb-PAPER-2011-028,
arXiv:1202.4717, accepted by PRL





CERN COURIER

Mar 27, 2012

The heavier B_s meson state lives longer

The LHCb collaboration has determined the sign of the width difference in the B_s system, $\Delta\Gamma_s$, through the influence of quantum-mechanical interference. This shows for the first time that the heavier of the two B_s meson states has the longer lifetime, a result that is in agreement with the Standard Model expectation and similar to the situation in the kaon system.

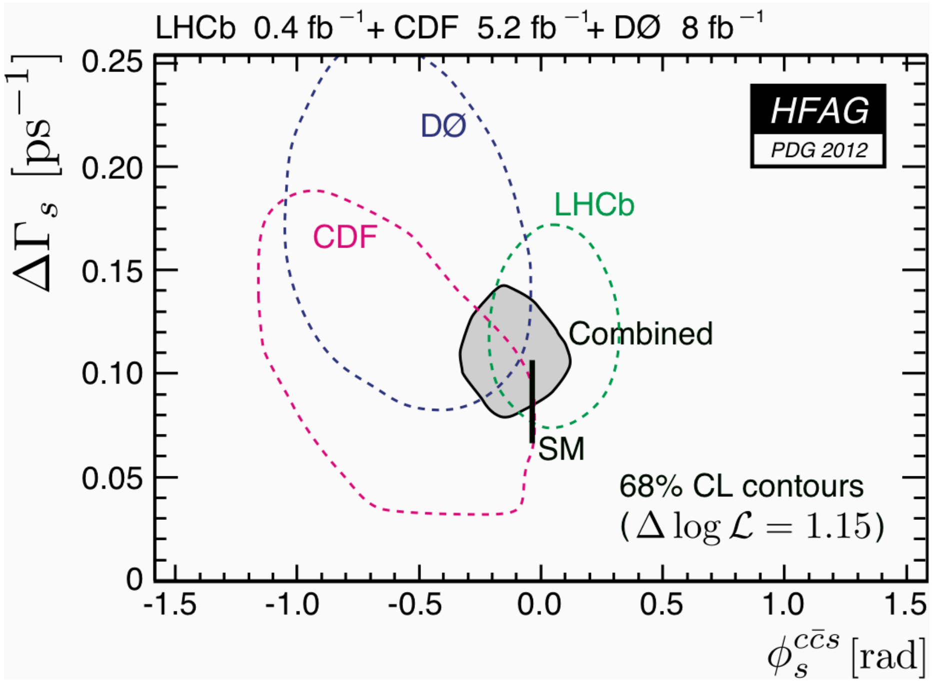
Also top news at LHCb public page
http://lhcb-public.web.cern.ch/lhcb-public/Welcome.html#phis-2

$\Delta\Gamma_s < 0$ and $\phi_s \sim \pi$ excluded at 4.7σ CL

True solution: $\Delta\Gamma_s > 0$ and $\phi_s \sim 0$.

SM wins so far.

One solution left

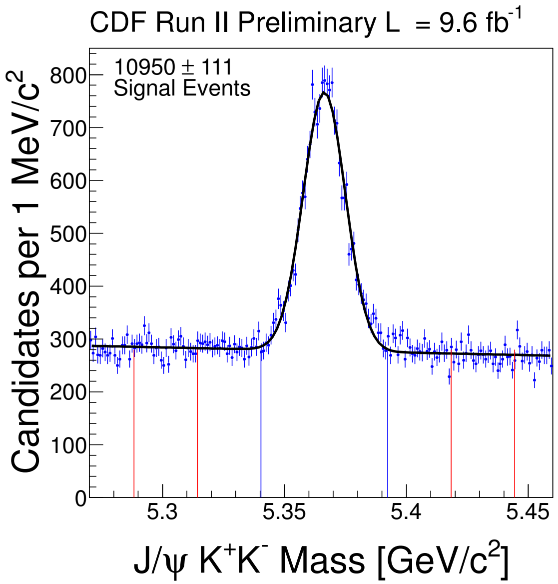


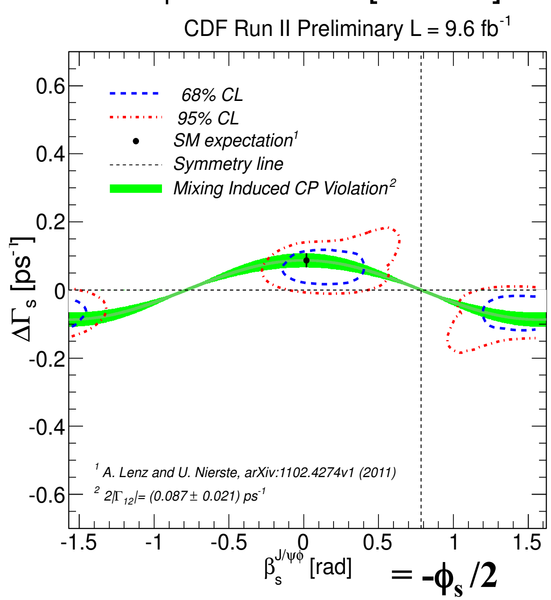
LHCb has the best precision

Consistent with SM, but still sizeable room for new physics in B_s mixing.
Higher precision (particularly for ϕ_s) required.

CDF update with 9.6 fb^{-1} and LHCb new result with 1 fb^{-1} not included.

CDF preliminary update





CDF Note 10778

9.6 fb^{-1}, 1.96 TeV $p\bar{p}$ collision

11000 signals

Opposite side tagging and same side tagging (first half of Run II data)

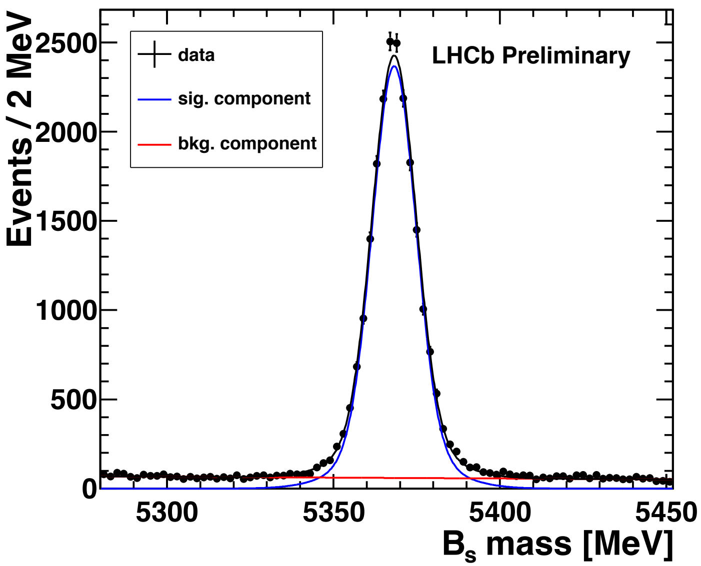
$$\tau(B_s^0) = 1.528 \pm 0.019\ (\text{stat}) \pm 0.009\ (\text{syst})\ \text{ps},$$
$$\Delta\Gamma_s = 0.068 \pm 0.026\ (\text{stat}) \pm 0.007\ (\text{syst})\ \text{ps}^{-1},$$
$$|A_0(0)|^2 = 0.512 \pm 0.012\ (\text{stat}) \pm 0.014\ (\text{syst}),$$
$$|A_{\parallel}(0)|^2 = 0.229 \pm 0.010\ (\text{stat}) \pm 0.017\ (\text{syst}),$$
$$\delta_{\perp} = 2.79 \pm 0.53\ (\text{stat}) \pm 0.15\ (\text{syst})\ \text{rad}.$$

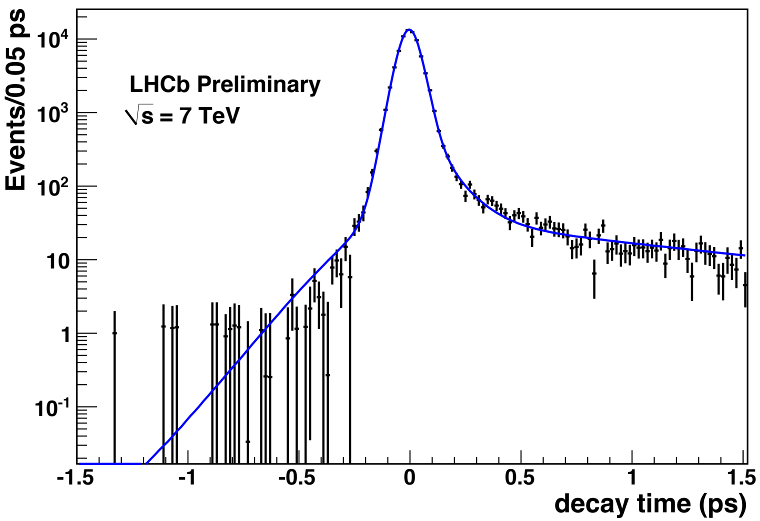
$$\beta_s^{J/\psi\phi} \in [-\pi/2, -1.51] \bigcup [-0.06, 0.30] \bigcup [1.26, \pi/2]$$

LHCb new analysis

1 fb^{-1} @ 7 TeV in 2011

LHCb-CONF-2012-002





very clean with 21200 signals

(t>0.3 ps required)

Effective time resolution 45 fs from prompt events

c.f. oscillation period ~350 fs

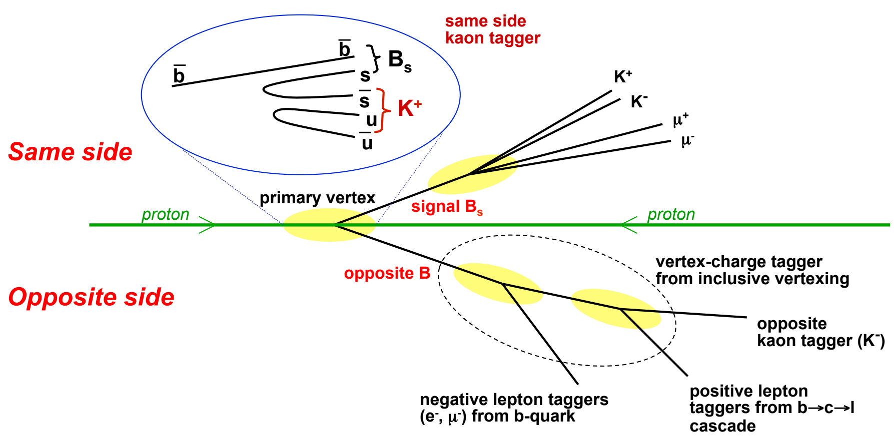
Flavour tagging

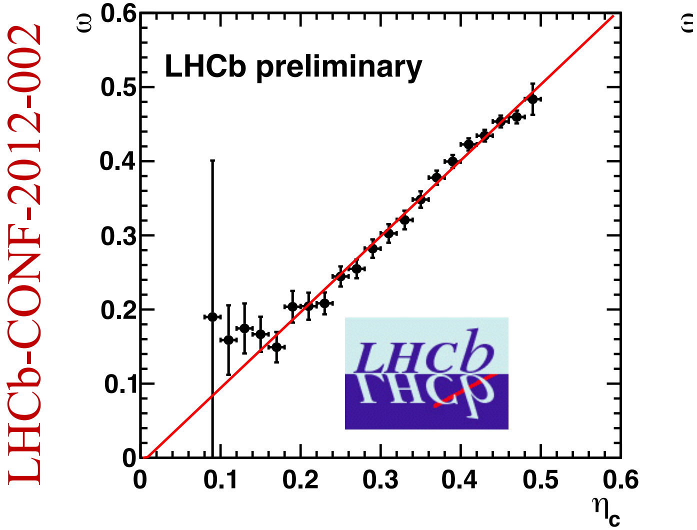
ϕ_s is obtained from time distributions of B_s ($\overline{B}_s$) to CP eigenstates

$$|A_0|^2(t) = |A_0|^2 e^{-\Gamma_s t}[\cosh\left(\frac{\Delta\Gamma}{2}t\right) - \cos\phi_s \sinh\left(\frac{\Delta\Gamma}{2}t\right) \pm \sin\phi_s \sin(\Delta m t)]$$

+ for B_s - for $\overline{B}_s$

- Currently use OS, fully optimized and calibrated on data





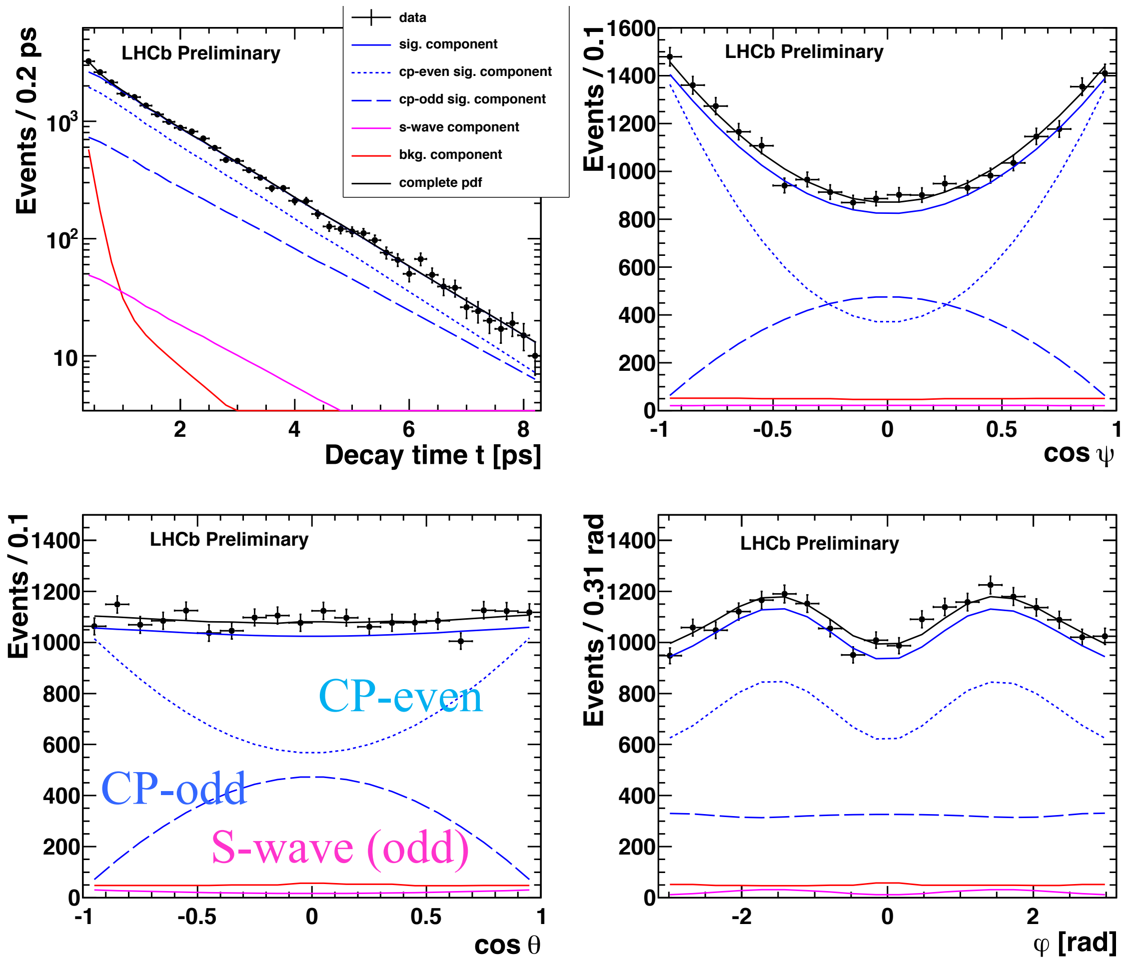
Effective tagging efficiency
(2.29 ±0.07 ±0.26)%

mistag probability calibration
with $B^+ \rightarrow J/\psi K^+$

Fit projection

Different CP eigenstates are statistically separated in maximum likelihood fit using angular information

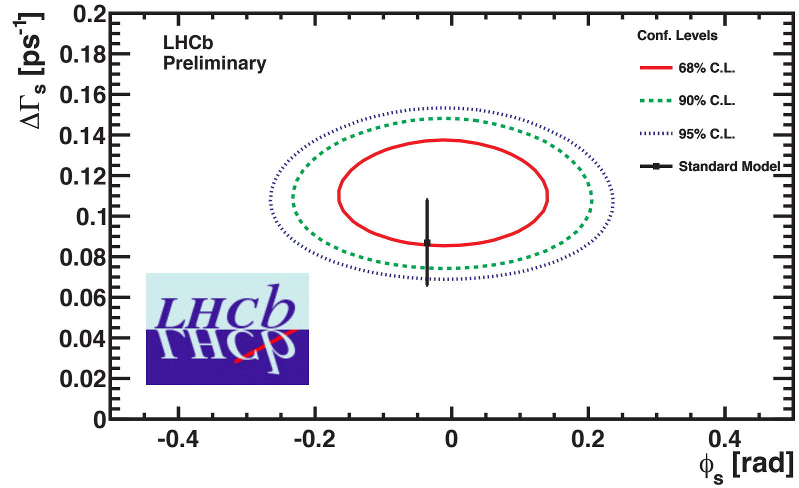
LHCb-CONF-2012-002

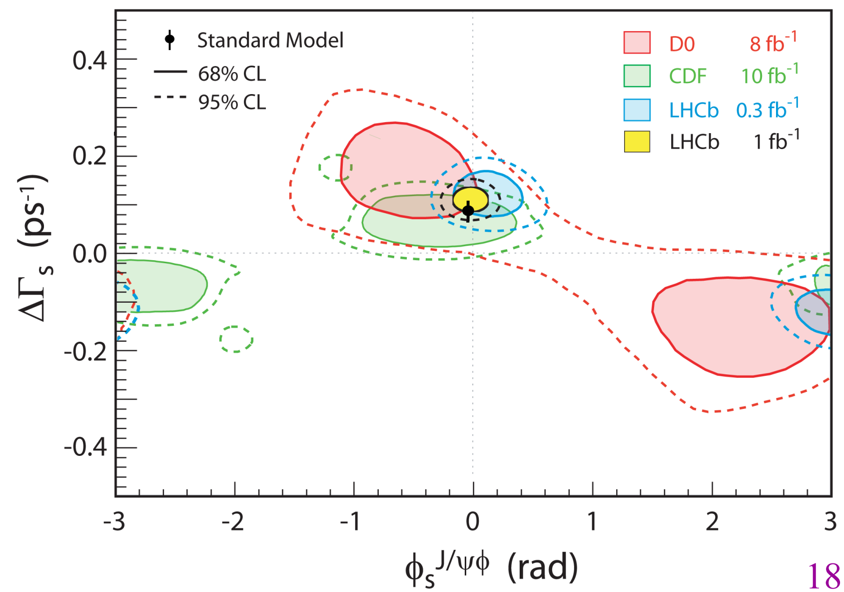


LHCb preliminary result

Parameter	Value	Stat.	Syst.
Γ_s [ps^{-1}]	0.6580	0.0054	0.0066
$\Delta\Gamma_s$ [ps^{-1}]	0.116	0.018	0.006
$\lvert A_\perp(0)\rvert^2$	0.246	0.010	0.013
$\lvert A_0(0)\rvert^2$	0.523	0.007	0.024
F_S	0.022	0.012	0.007
$\delta_\perp$ [rad]	2.90	0.36	0.07
$\delta_\parallel$ [rad]	[2.81, 3.47]		0.13
δ_s [rad]	2.90	0.36	0.08
ϕ_s [rad]	-0.001	0.101	0.027

LHCb-CONF-2012-002





Source of systematics on ϕ_s:

- direct CPV ignored in fit
- angular efficiency model
- background model

Improvement under investigation

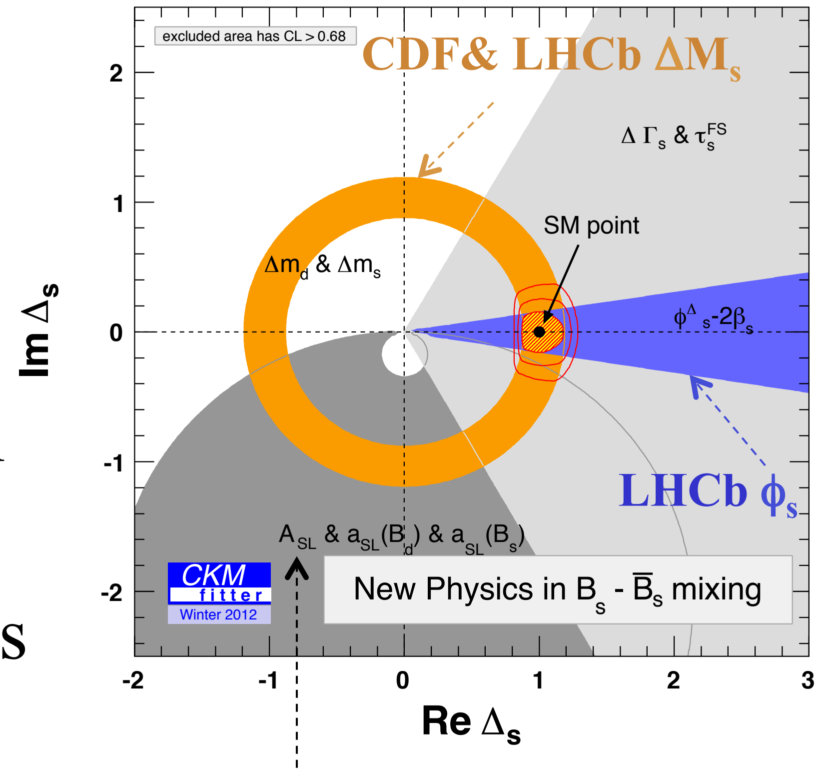
Implications [Lenz et al., arXiv:1203.0238]

- Model independent analysis of NP in B_s mixing

$$M_{12}^{s} = \left|M_{12}^{SM,s}\right| \Delta_s$$

Major constraints on NP in M_{12} come from ΔM_s and ϕ_s

- B_s mixing is SM-like
- ~30% new physics contribution in B_s mixing still allowed at 3σ
- Probing NP at this level requires
  - improving precision of ϕ_s
  - reducing theory uncertainty in SM prediction of ΔM_s
  - new measurement of a^s_{fs}



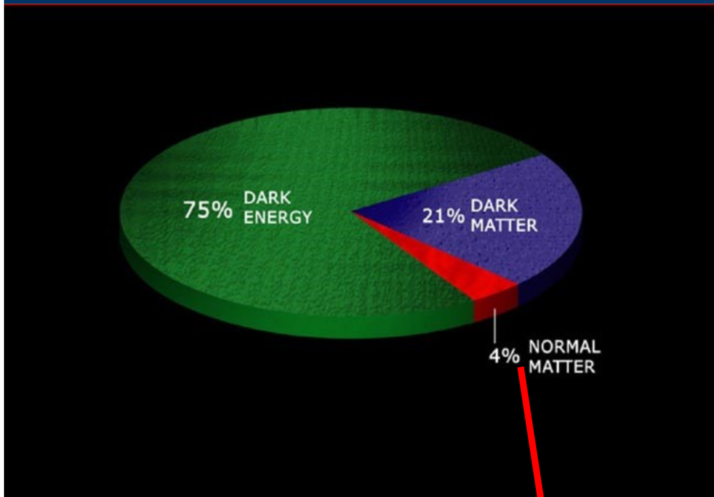
Anomaly with D0 dimuon asymmetry

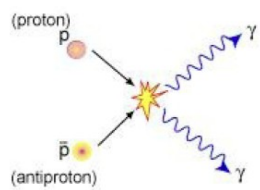
Conclusions and outlook

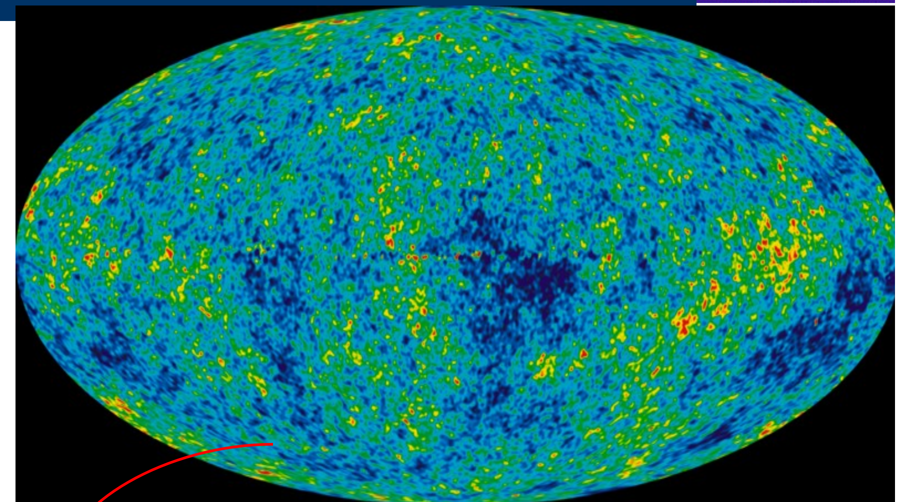
- Study of CPV in $B_s \to J/\psi\phi$ advanced greatly
- LHCb new preliminary result consistent with the SM
  - ϕ_s = -0.001 ± 0.101 ± 0.027 rad
  - $\Delta\Gamma_s$ = 0.116 ± 0.018 ± 0.006 ps-1
- Constraint on NP in B_s mixing significantly improved
- Quest for subleading level NP in B_s mixing requires higher precision and complementary measurements
- LHCb prospects
  - $5fb^{-1}$ before 2018: $\sigma(\phi_s) \sim 0.025$ rad in $B_s \to J/\psi\phi$
  - LHCb upgrade: $\sigma(\phi_s) \sim 0.008$ rad in $B_s \to J/\psi\phi$
  - More $b \to c\bar{c}s$ modes (see L. Zhang's talk) and a_{fs}^s

Backup slides

CPV and Baryogenesis







$$\frac{\Delta n_{\text{baryon}}}{n_\gamma} = \frac{n_{\text{baryon}} - n_{\overline{\text{baryon}}}}{n_\gamma} \sim O\left(10^{-10}\right)$$

The source of current matter domination over antimatter is unknown.
CPV is one of the three necessary conditions (Sacharow 1967)

The unique source of CPV in Standard Model is a single phase in the CKM matrix

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix} = \hat{V}_{CKM} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

CPV predicted in SM gives $\Delta n_{baryon}/n_\gamma \sim O(10^{-20})$. It is 10^{10} too small.
There must be come other CPV beyond SM

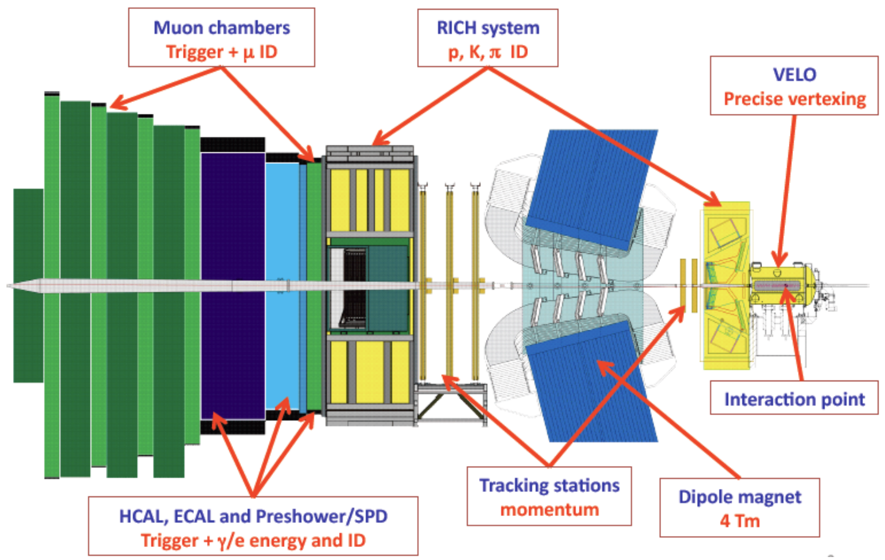
LHCb detector

LHCb is a single arm forward spectrometer: $1.9 < \eta < 4.9$
Dedicated for study of CP violation and rare B decays:
all B species; large B cross section; efficient, flexible trigger

Features:

Precise and robust vertexing and tracking

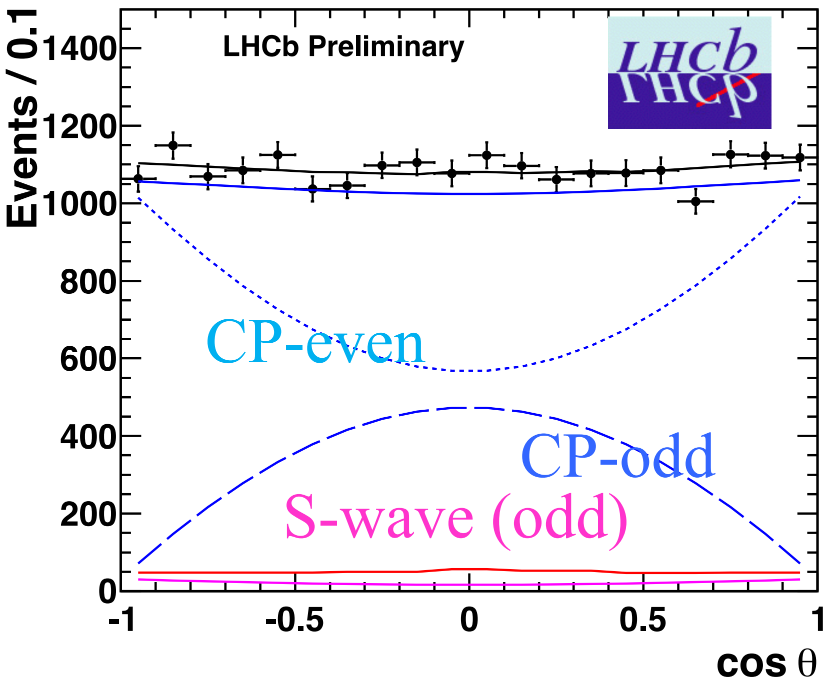
Good particle identification (hadron, muon, electron, photon)



About 1 fb^{-1} collected at 7 TeV in 2011 run

Separating CP eigenstates

Different CP eigenstates are statistically separated in maximum likelihood fit using angular information



k	$h_k(t)$	$f_k(\theta,\psi,\varphi)$
1	$\|A_0\|^2(t)$	$2\cos^2\psi\,(1-\sin^2\theta\cos^2\phi)$
2	$\|A_\parallel(t)\|^2$	$\sin^2\psi\,(1-\sin^2\theta\sin^2\phi)$
3	$\|A_\perp(t)\|^2$	$\sin^2\psi\sin^2\theta$
4	$\Im(A_\parallel(t)\,A_\perp(t))$	$-\sin^2\psi\sin 2\theta\sin\phi$
5	$\Re(A_0(t)\,A_\parallel(t))$	$\frac{1}{2}\sqrt{2}\,\sin 2\psi\sin^2\theta\sin 2\phi$
6	$\Im(A_0(t)\,A_\perp(t))$	$\frac{1}{2}\sqrt{2}\,\sin 2\psi\sin 2\theta\cos\phi$
7	$\|A_s(t)\|^2$	$\frac{2}{3}(1-\sin^2\theta\cos^2\phi)$
8	$\Re(A_s^*(t)A_\parallel(t))$	$\frac{1}{3}\sqrt{6}\sin\psi\sin^2\theta\sin 2\phi$
9	$\Im(A_s^*(t)A_\perp(t))$	$\frac{1}{3}\sqrt{6}\sin\psi\sin 2\theta\cos\phi$
10	$\Re(A_s^*(t)A_0(t))$	$\frac{4}{3}\sqrt{3}\cos\psi(1-\sin^2\theta\cos^2\phi)$

Angular efficiency accounted for in fit according to full Monte Carlo simulation

Time evolution for refernece

$$
\begin{aligned}
|A_0|^2(t) &= |A_0|^2 e^{-\Gamma_s t}\left[\cosh\left(\frac{\Delta\Gamma}{2}t\right) - \cos\phi_s \sinh\left(\frac{\Delta\Gamma}{2}t\right) + \sin\phi_s \sin(\Delta m t)\right], \\
|A_\parallel(t)|^2 &= |A_\parallel|^2 e^{-\Gamma_s t}\left[\cosh\left(\frac{\Delta\Gamma}{2}t\right) - \cos\phi_s \sinh\left(\frac{\Delta\Gamma}{2}t\right) + \sin\phi_s \sin(\Delta m t)\right], \\
|A_\perp(t)|^2 &= |A_\perp|^2 e^{-\Gamma_s t}\left[\cosh\left(\frac{\Delta\Gamma}{2}t\right) + \cos\phi_s \sinh\left(\frac{\Delta\Gamma}{2}t\right) - \sin\phi_s \sin(\Delta m t)\right], \\
\Im(A_\parallel(t)\, A_\perp(t)) &= |A_\parallel||A_\perp| e^{-\Gamma_s t}\left[-\cos(\delta_\perp - \delta_\parallel)\sin\phi_s \sinh\left(\frac{\Delta\Gamma}{2}t\right)\right. \\
&\quad \left. -\cos(\delta_\perp - \delta\_\|)\cos\phi_s \sin(\Delta m t) + \sin(\delta_\perp - \delta_\parallel)\cos(\Delta m t)\right], \\
\Re(A_0(t)\, A_\parallel(t)) &= |A_0||A_\parallel| e^{-\Gamma_s t}\cos(\delta_\parallel - \delta_0)\left[\cosh\left(\frac{\Delta\Gamma}{2}t\right) - \cos\phi_s \sinh\left(\frac{\Delta\Gamma}{2}t\right)\right. \\
&\quad \left. + \sin\phi_s \sin(\Delta m t)\right], \\
\Im(A_0(t)\, A_\perp(t)) &= |A_0||A_\perp| e^{-\Gamma_s t}\left[-\cos(\delta_\perp - \delta_0)\sin\phi_s \sinh\left(\frac{\Delta\Gamma}{2}t\right)\right. \\
&\quad \left. -\cos(\delta_\perp - \delta_0)\cos\phi_s \sin(\Delta m t) + \sin(\delta_\perp - \delta_0)\cos(\Delta m t)\right], \\
|A_s(t)|^2 &= |A_s|^2 e^{-\Gamma_s t}\left[\cosh\left(\frac{\Delta\Gamma}{2}t\right) + \cos\phi_s \sinh\left(\frac{\Delta\Gamma}{2}t\right) - \sin\phi_s \sin(\Delta m t\right], \\
\Re(A_s^*(t) A_\parallel(t)) &= |A_s||A_\parallel| e^{-\Gamma_s t}\left[-\sin(\delta_\parallel - \delta_s)\sin\phi_s \sinh\left(\frac{\Delta\Gamma}{2}t\right) - \sin(\delta_\parallel - \delta_s)\ \cos\phi_s \sin(\Delta m t)\right. \\
&\quad \left. + \cos(\delta_\parallel - \delta_s)\cos(\Delta m t)\right], \\
\Im(A_s^*(t) A_\perp(t)) &= |A_s||A_\perp| e^{-\Gamma_s t}\sin(\delta_\perp - \delta_s)\left[\cosh\left(\frac{\Delta\Gamma}{2}t\right) + \cos\phi_s \sinh\left(\frac{\Delta\Gamma}{2}t\right)\right. \\
&\quad \left. - \sin\phi_s \sin(\Delta m t)\right], \\
\Re(A_s^*(t) A_0(t)) &= |A_s||A_0| e^{-\Gamma_s t}\left[-\sin(\delta_0 - \delta_s)\sin\phi_s \sinh\left(\frac{\Delta\Gamma}{2}t\right)\right. \\
&\quad \left. -\sin(\delta_0 - \delta_s)\cos\phi_s \sin(\Delta m t) + \cos(\delta_0 - \delta_s)\cos(\Delta m t)\right].
\end{aligned}
$$

Major source of sensitivity to ϕ_s

Systematic uncertainties

LHCb-CONF-2012-002

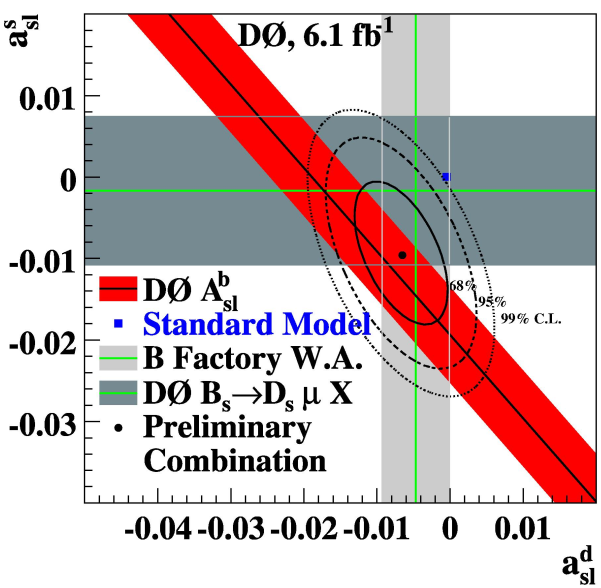
Source	Γ_s [ps^{-1}]	$\Delta\Gamma_s$ [ps^{-1}]	$A_\perp^2$	A_0^2	F_S	$\delta_\parallel$ [rad]	$\delta_\perp$ [rad]	δ_s [rad]	ϕ_s [rad]
Description of background	0.0010	0.004	-	0.002	0.005	0.04	0.04	0.06	0.011
Angular acceptances	0.0018	0.002	0.012	0.024	0.005	0.12	0.06	0.05	0.012
t acceptance model	0.0062	0.002	0.001	0.001	-	-	-	-	-
z and momentum scale	0.0009	-	-	-	-	-	-	-	-
Production asymmetry ($\pm$ 10%)	0.0002	0.002	-	-	-	-	-	-	0.008
CPV mixing & decay ($\pm$ 5%)	0.0003	0.002	-	-	-	-	-	-	0.020
Fit bias	-	0.001	0.003	-	0.001	0.02	0.02	0.01	0.005
Quadratic sum	0.0066	0.006	0.013	0.024	0.007	0.13	0.07	0.08	0.027

Systematics under control.
Improvement under way: better treatment of background and nuisance asymmetries.

a^s_{fs}: awaiting LHCb to clarify

- If $a^s_{fs} = |\Gamma_{12}/M_{12}|\sin\varphi \neq 0$: B_s mass eigenstate ≠ CP eigenstate
- SM: $\varphi = 0.22\pm0.06°$, $a^s_{fs} = (0.29 \pm 0.09)\times 10^{-4}$ [Lenz, Nierste, arXiv1102.4274]
- Mainly affected by NP in M_{12} (go away)

$$\varphi = \varphi^{SM} + \arg(M_{12}/M_{12}^{SM}) - \arg(\Gamma_{12}/\Gamma_{12}^{SM})$$



- A^s_{fs} measured in $B_s \to D_s^- \mu^+ X$

$$a^s_{fs} = \left(-17 \pm 91^{+14}_{-15}\right)\times 10^{-4}$$ [D0, PRD82 (2010) 012003]

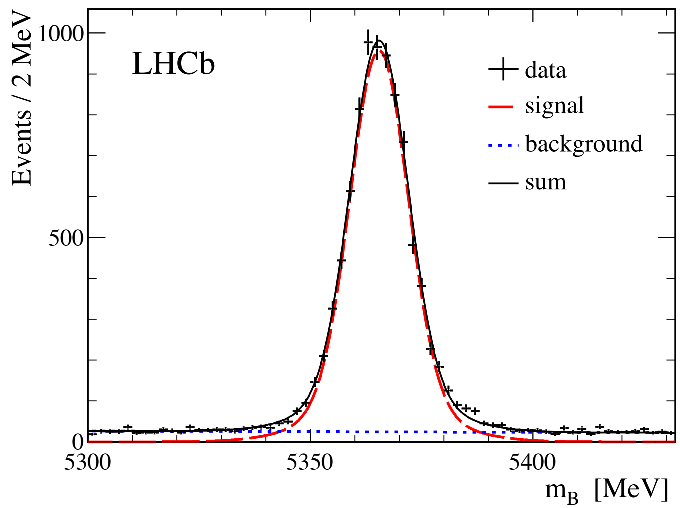
- Anomalous same-sign dimuon asymmetry [D0, PRD84 (2011) 052007]

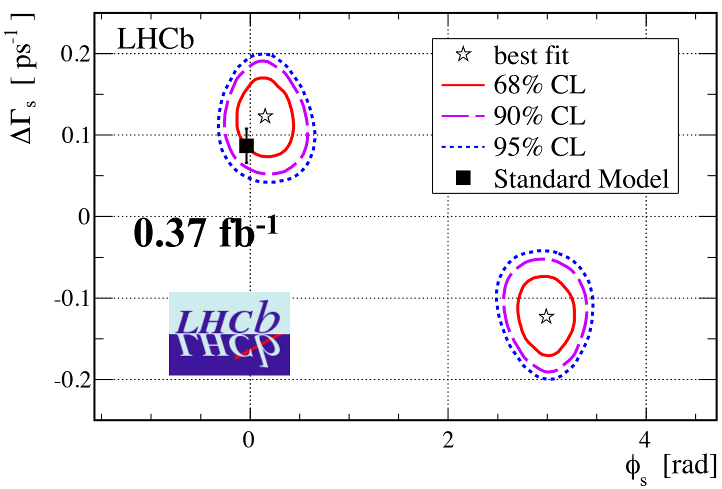
$$A^b_{SL} \approx 0.6 a^d_{fs} + 0.4 a^s_{fs} = (-78.7 \pm 17.1 \pm 9.3) \times 10^{-4}$$

c.f. SM: $A^b_{SL} = (-2.3\pm0.3)\times 10^{-4}$

- LHCb measurement of a^s_{fs} in untagged $B_s \to D_s^- \mu^+ X$ in progress

LHCb publication





PRL108 (2012) 101803

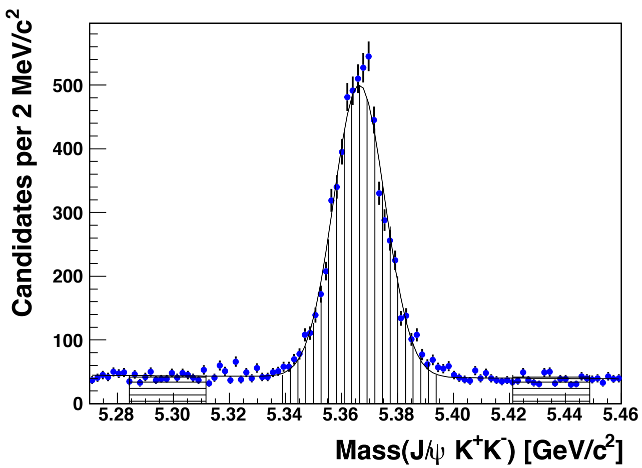
$0.37\ \mathrm{fb}^{-1}$, 7 TeV pp collision

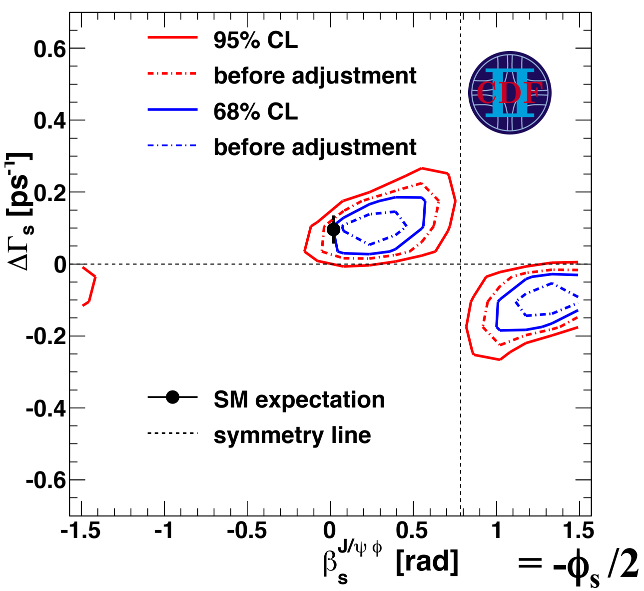
8500 signals

Effective tagging efficiency
$(2.29 \pm 0.07 \pm 0.26)\%$

Effective time resolution 50 fs

CDF publication





PRD85 (2012) 072002

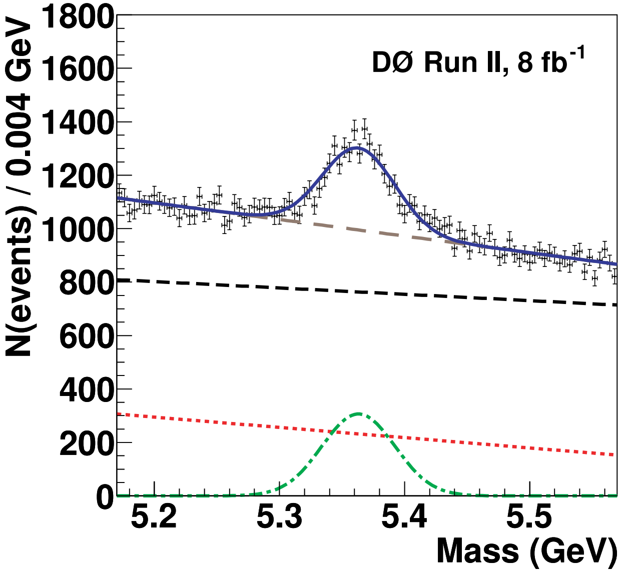
$5.2 fb^{-1}$, 1.96 TeV $p\bar{p}$ collision

6500 signals

Effective tagging efficiency:
same side kaon (3.5 ±1.4)%
opposite side (1.2 ±0.2)%

Effective time resolution 100 fs

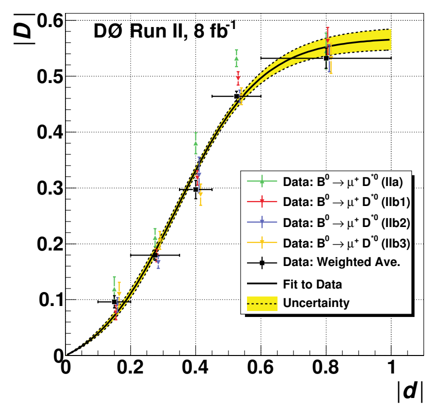
D0 publication

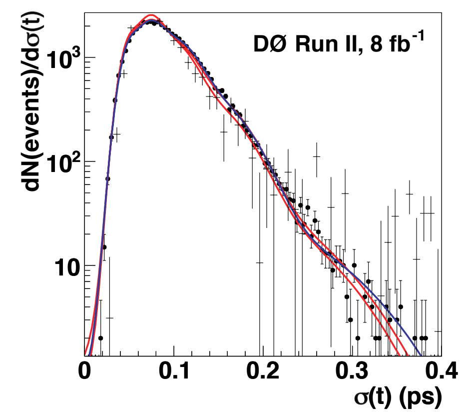


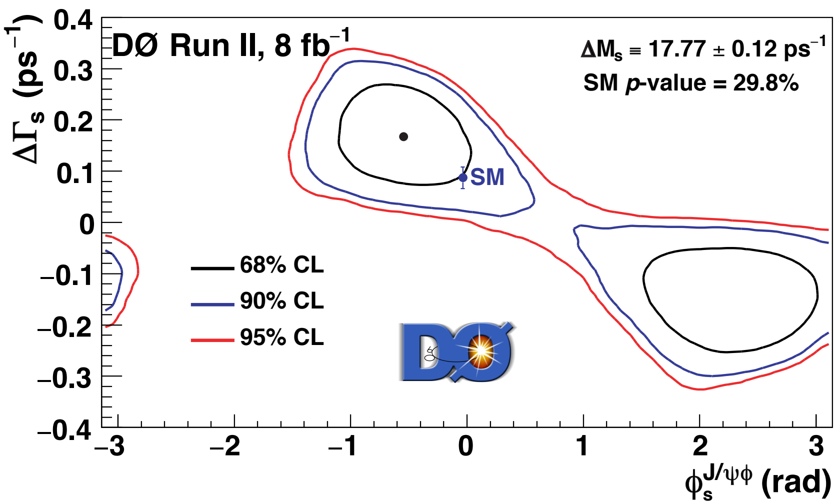
PRD85 (2012) 032006

8fb^{-1}, 1.96 TeV p$\bar{p}$ collision

6500 signals







Parameter	Default	$\sigma_A(t)$	$\sigma_B(t)$	$\Gamma_\phi = 8.52$ MeV
$\lvert A_0\rvert^2$	0.553 ± 0.016	0.553 ± 0.016	0.552 ± 0.016	0.553 ± 0.016
$\lvert A_\parallel\rvert^2/(1-\lvert A_0\rvert^2)$	0.487 ± 0.043	0.483 ± 0.043	0.485 ± 0.043	0.487 ± 0.043
$\overline{\tau}_s$ (ps)	1.417 ± 0.038	1.420 ± 0.037	1.417 ± 0.037	1.408 ± 0.434
$\Delta\Gamma_s$ (ps^{-1})	0.151 ± 0.058	0.136 ± 0.056	0.145 ± 0.057	0.170 ± 0.067
F_S	0.147 ± 0.035	0.149 ± 0.034	0.147 ± 0.035	0.147 ± 0.035