Measurements of CP violation in B-meson decays at DZero

The DØ Collaboration

presented by
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Outline

1. Introduction:
   Status of New Physics in $(B_s, \bar{B}_s)$ mixing and decay.

2. Time-dependent 3-angle fits to tagged decays $B_s \to J/\psi\phi$.

3. Search for direct CP violation in $B^+ \to J/\psi K^+$ and $B^+ \to J/\psi\pi^+$ decays.

4. Conclusions.

1. Introduction:

Status of New Physics in $(B_s, \bar{B}_s)$ mixing and decay.

- CP symmetry: particle $\leftrightarrow$ antiparticle, and $(x, y, z) \leftrightarrow (-x, -y, -z)$.

- To explain the baryon asymmetry of the universe we apparently need new sources of CP-violation beyond the Standard Model.

- It is promising to search for CP-violation in processes where the Standard Model predicts a small asymmetry, and extensions of the Standard Model predict large asymmetries.

- For these reasons we study CP-violation in $B_s \rightarrow J/\psi\phi$ and $B^+ \rightarrow J/\psi K^+$ decays.

Extensions of the Standard Model with new sources of CP violation:

- Multi-Higgs Doublet models with no "Natural Flavor Conservation"
- Supersymmetric models with "Effective SUSY"
- Supersymmetric models with "R-Parity Violation"
- Left-Right Symmetric models with $V_L \neq V_R$
- 4th generation models, and
- Z-mediated Flavor Changing Neutral Currents.

JoAnne L. Hewett, hep-ph/9803370 (1998)

If CPT is a symmetry,

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

The eigenvalues are

$$M_s + \frac{1}{2}\Delta M_s - \frac{i}{4}(\Gamma_s - \Delta\Gamma_s),$$
$$M_s - \frac{1}{2}\Delta M_s - \frac{i}{4}(\Gamma_s + \Delta\Gamma_s),$$

where $\Delta M_s > 0$ by definition.

The CP-violating phase is

$$\phi_s \equiv \arg\left(\frac{\Gamma_{12}^s}{M_{12}^s}\right).$$

The observables are M_s, Γ_s, ϕ_s,

$$\Delta M_s = 2\left|M_{12}^s\right|, \qquad \Delta\Gamma_s = 2\left|\Gamma_{12}^s\right|\cos\phi_s,$$

$$a_{sl}^s = \frac{\left|\Gamma_{12}^s\right|}{\left|M_{12}^s\right|}\sin\phi_s = \frac{\Delta\Gamma_s}{\Delta M_s}\tan\phi_s.$$

The semileptonic charge asymmetry is

$$a_{sl}^s \equiv \frac{N(\bar{B}_s \to f) - N(B_s \to \bar{f})}{N(\bar{B}_s \to f) + N(B_s \to \bar{f})},$$

where f is a flavor specific final state to which only B_s can decay.

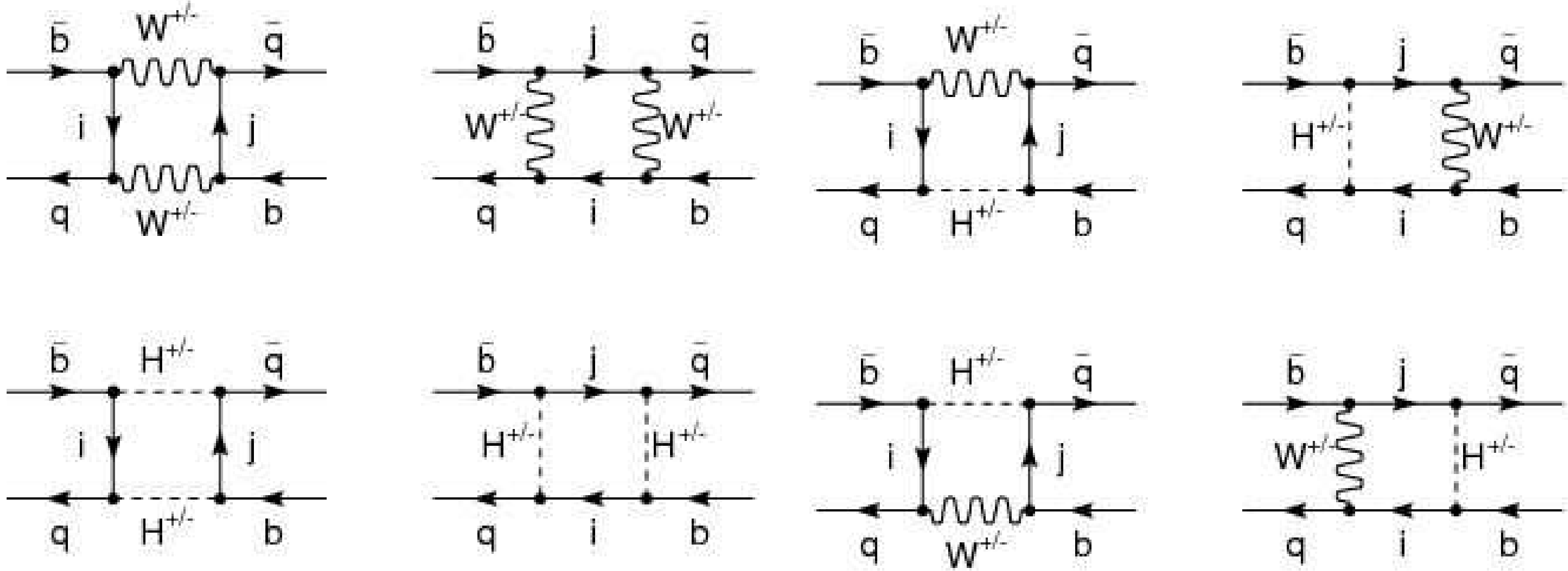
Notation:

$\Gamma_s \equiv \bar{\Gamma} \equiv 1/\bar{\tau}$,

$\Gamma_s - \Delta\Gamma_s \equiv \Gamma_H$,

$\Gamma_s + \Delta\Gamma_s \equiv \Gamma_L$.

$B^0 \leftrightarrow \bar{B}^0$ mixing in the 2 Higgs Doublet Model of type II. M_{12}. hep-ph/0210167



New Physics may alter M_{12}:

$$M_{12}^s \equiv M_{12}^{SM,s} \cdot \Delta_s = M_{12}^{SM,s} \cdot |\Delta_s|\, e^{i\phi_s^\Delta}.$$

$$\phi_s = \phi_s^{SM} + \phi_s^\Delta = 0.0042 \pm 0.0014 + \phi_s^\Delta,$$

$$\Delta M_s = \Delta M_s^{SM} \cdot |\Delta_s| = (19.30 \pm 6.74)\ \text{ps}^{-1} \cdot |\Delta_s|\,,$$

$$\Delta\Gamma_s = 2\,|\Gamma_{12}^s| \cos\phi_s = (0.096 \pm 0.039)\ \text{ps}^{-1} \cdot \cos\phi_s,$$

$$\frac{\Delta\Gamma_s}{\Delta M_s} = \frac{|\Gamma_{12}^s|}{\left|M_{12}^{SM,s}\right|} \cdot \frac{\cos\phi_s}{|\Delta_s|} = (4.97 \pm 0.94) \cdot 10^{-3} \cdot \frac{\cos\phi_s}{|\Delta_s|},$$

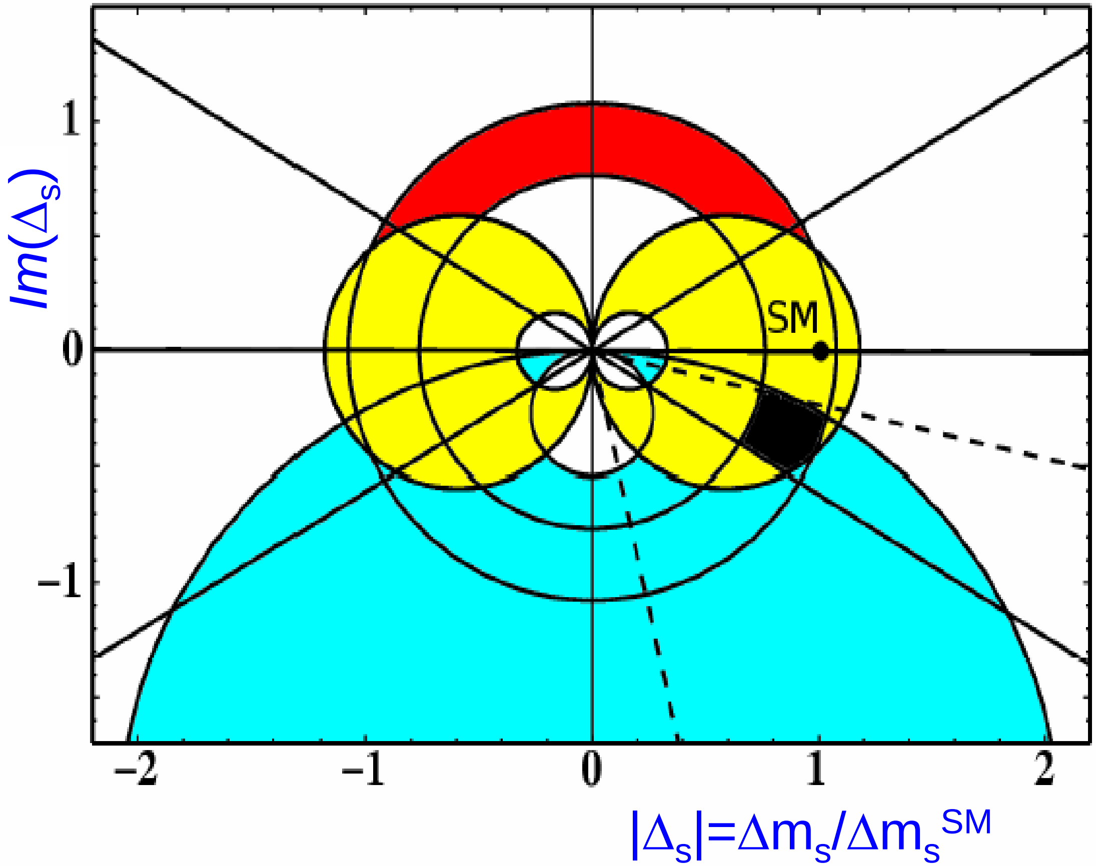
$$a_{sl}^s = \frac{|\Gamma_{12}^s|}{\left|M_{12}^{SM,s}\right|} \cdot \frac{\sin\phi_s}{|\Delta_s|} = (4.97 \pm 0.94) \cdot 10^{-3} \cdot \frac{\sin\phi_s}{|\Delta_s|}.$$

From Alexander Lenz and Ulrich Nierste, hep-ph/0612167, November 2007.

The ϕ_s obtained from fits to $B_s \to J/\psi\phi$ is slightly different:

$$\phi_s = -2\beta_s + \phi_s^{\Delta} = -0.04 \pm 0.01 + \phi_s^{\Delta}.$$

From Alexander Lenz and Ulrich Nierste, hep-ph/0612167, November 2007.



Constraints on New Physics in the Δ_s complex plane (at a confidence level of 1 standard deviation).

Footnotes:

$\Delta_s = 1$ in the Standard Model.

Red: from $\Delta M_s = 17.77 \pm 0.12$ ps^{-1} from CDF.

Yellow: from $\Delta\Gamma_s/\Delta M_s$, with $\Delta\Gamma_s = 0.17 \pm 0.1$ ps^{-1} from DØ.

Blue: from $a_{sl}^s = (-8.8 \pm 7.3) \cdot 10^{-3}$ from a combination of DØ experiments (for the case $a_{sl}^d =$ SM value).

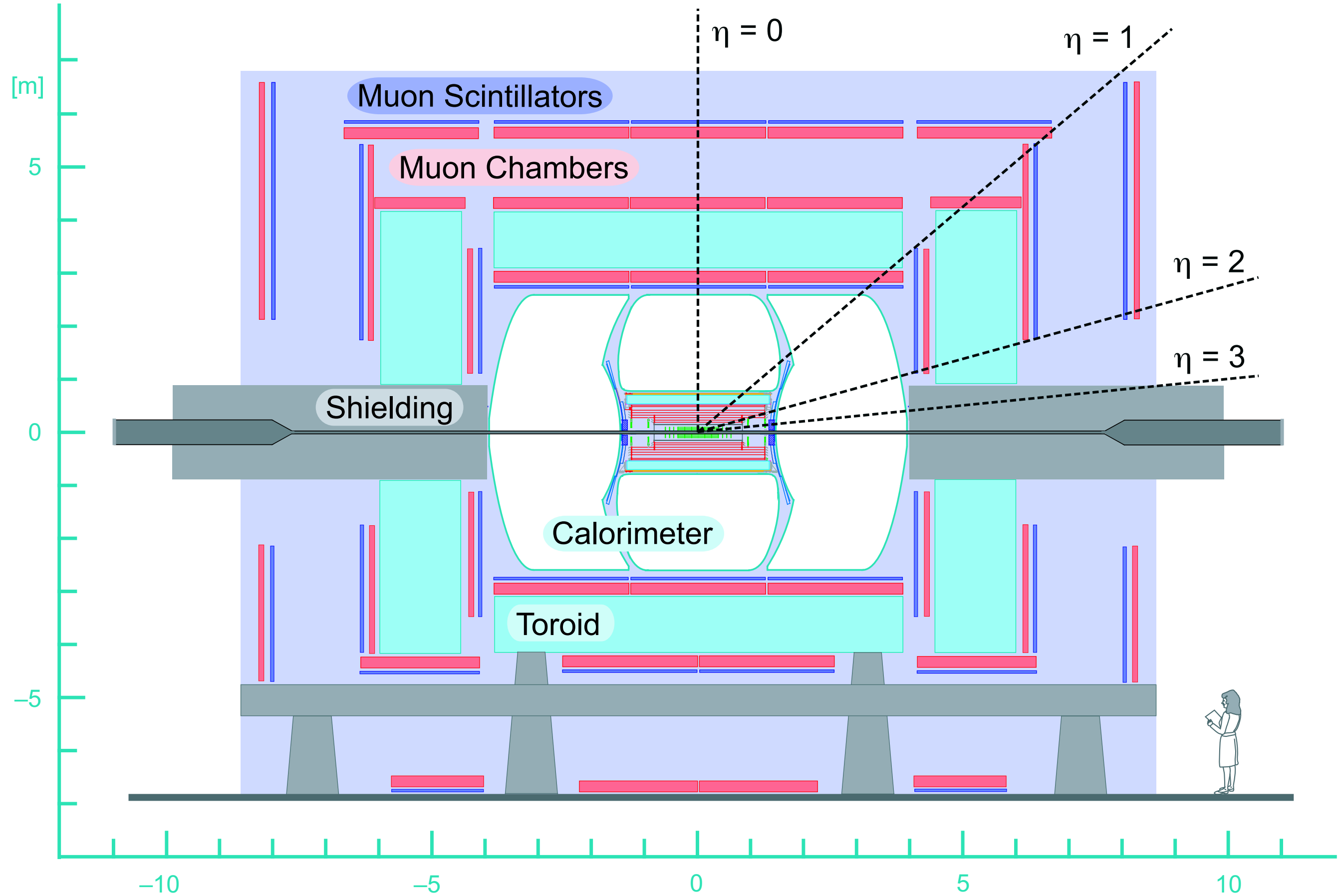
Forward and backward solid wedges from $\Delta\Gamma_s = +$ or -0.17 ± 0.10 ps^{-1} from DØ.

Dashed wedge from $\phi_s = -0.79 \pm 0.56$ from DØ.

The current experimental situation is 2σ deviation from the SM.

From Alexander Lenz and Ulrich Nierste, hep-ph/0612167, November 2007.

2. Time-dependent 3-angle fits to tagged decays $B_s \to J/\psi\phi$.



The DØ detector

$B_s \to J/\psi\phi$
$B_d \to J/\psi K^*(892)^0$
$(J=0) \to (J=1) \otimes (J=1)$
These decays are linked by an approximate SU(2) symmetry (U-spin symmetry).

Amplitudes:
$A_0(0)$: both V's longitudinal, CP $= +$,
$A_{||}(0)$: V's with transverse linear polarizations parallel to each other, CP $= +$,
$A_{\perp}(0)$: V's with transverse linear polarizations perpendicular to each other, CP $= -$.

$$|A_{||}(0)|^2 + |A_{\perp}(0)|^2 + |A_0(0)|^2 = 1.$$

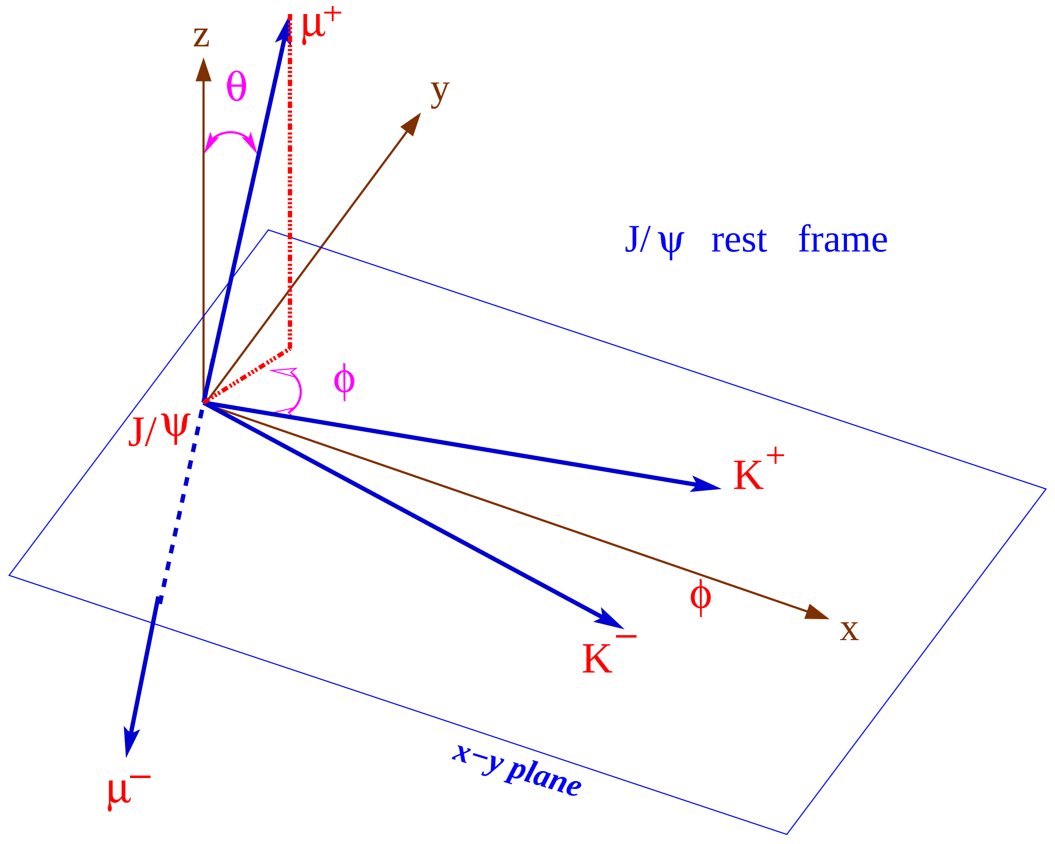
Observables:

$|A_\perp(0)|$, $|A_0(0)|^2 - |A_{||}(0)|^2$,

$$\delta_1 \equiv \arg\left\{A_{||}^*(0) A_\perp(0)\right\} \equiv -\delta_{||} + \delta_\perp,$$

$$\delta_2 \equiv \arg\left\{A_0^*(0) A_\perp(0)\right\} \equiv -\delta_0 + \delta_\perp.$$

δ_1 and δ_2 are CP-conserving strong phases.



Angles θ (transversity), φ and ψ. ψ is the angle between $\vec{p'}_{K+}$ and the x-axis in the rest frame of ϕ.

Differential decay probability

$$
\frac{d^4\Gamma\left[B_s^0(t) \to J/\psi(\to \mu^+\mu^-)\phi(\to K^+K^-)\right]}{d\cos\theta \quad d\varphi \quad d\cos\psi \quad dt} \propto
$$

$$
\begin{aligned}
2\cos^2\psi(1-\sin^2\theta\cos^2\varphi)\cdot|A_0(t)|^2 \\
+\sin^2\psi(1-\sin^2\theta\sin^2\varphi)\cdot|A_\parallel(t)|^2 \\
+\sin^2\psi\sin^2\theta\cdot|A_\perp(t)|^2 \\
+(1/\sqrt{2})\sin 2\psi\sin^2\theta\sin 2\varphi\cdot\Re(A_0^*(t)A_\parallel(t)) \\
+(1/\sqrt{2})\sin 2\psi\sin 2\theta\cos\varphi\cdot\Im(A_0^*(t)A_\perp(t)) \\
-\sin^2\psi\sin 2\theta\sin\varphi\cdot\Im(A_\parallel^*(t)A_\perp(t)).
\end{aligned}
$$

Polarization amplitudes for $B_s^0(0)$ (upper signs) and $\overline{B}_s^0(0)$ (lower signs):

$$|A_0(t)|^2 = |A_0(0)|^2 \left[\mathcal{T}_+ \pm e^{-\overline{\Gamma}t} \sin\phi_s \sin(\Delta M_s t)\right],$$
$$|A_\parallel(t)|^2 = |A_\parallel(0)|^2 \left[\mathcal{T}_+ \pm e^{-\overline{\Gamma}t} \sin\phi_s \sin(\Delta M_s t)\right],$$
$$|A_\perp(t)|^2 = |A_\perp(0)|^2 \left[\mathcal{T}_- \mp e^{-\overline{\Gamma}t} \sin\phi_s \sin(\Delta M_s t)\right],$$

where

$$\mathcal{T}_\pm = (1/2)\left[(1 \pm \cos\phi_s)e^{-\Gamma_L t} + (1 \mp \cos\phi_s)e^{-\Gamma_H t}\right].$$

$$\Re(A_0^*(t)A_{\|}(t)) = |A_0(0)||A_{\|}(0)|\cos(\delta_2 - \delta_1)[\mathcal{T}_+ \pm e^{-\overline{\Gamma} t}\sin\phi_s \sin(\Delta M_s t)],$$

$$\Im(A_0^*(t)A_{\perp}(t)) = |A_0(0)||A_{\perp}(0)|[e^{-\overline{\Gamma} t}(\pm\sin\delta_2\cos(\Delta M_s t) \mp \cos\delta_2\sin(\Delta M_s t)\cos\phi_s) - (1/2)\left(e^{-\Gamma_H t} - e^{-\Gamma_L t}\right)\sin\phi_s \cos\delta_2],$$

$$\Im(A_{\|}^*(t)A_{\perp}(t)) = |A_{\|}(0)||A_{\perp}(0)|[e^{-\overline{\Gamma} t}(\pm\sin\delta_1\cos(\Delta M_s t) \mp \cos\delta_1\sin(\Delta M_s t)\cos\phi_s) - (1/2)\left(e^{-\Gamma_H t} - e^{-\Gamma_L t}\right)\sin\phi_s \cos\delta_1],$$

Tagging

For a given event, the B_s or $\overline{B}_s$ decay rate is multiplied by the factor p^{B_s} or $(1 - p^{B_s})$, obtained from tagging.

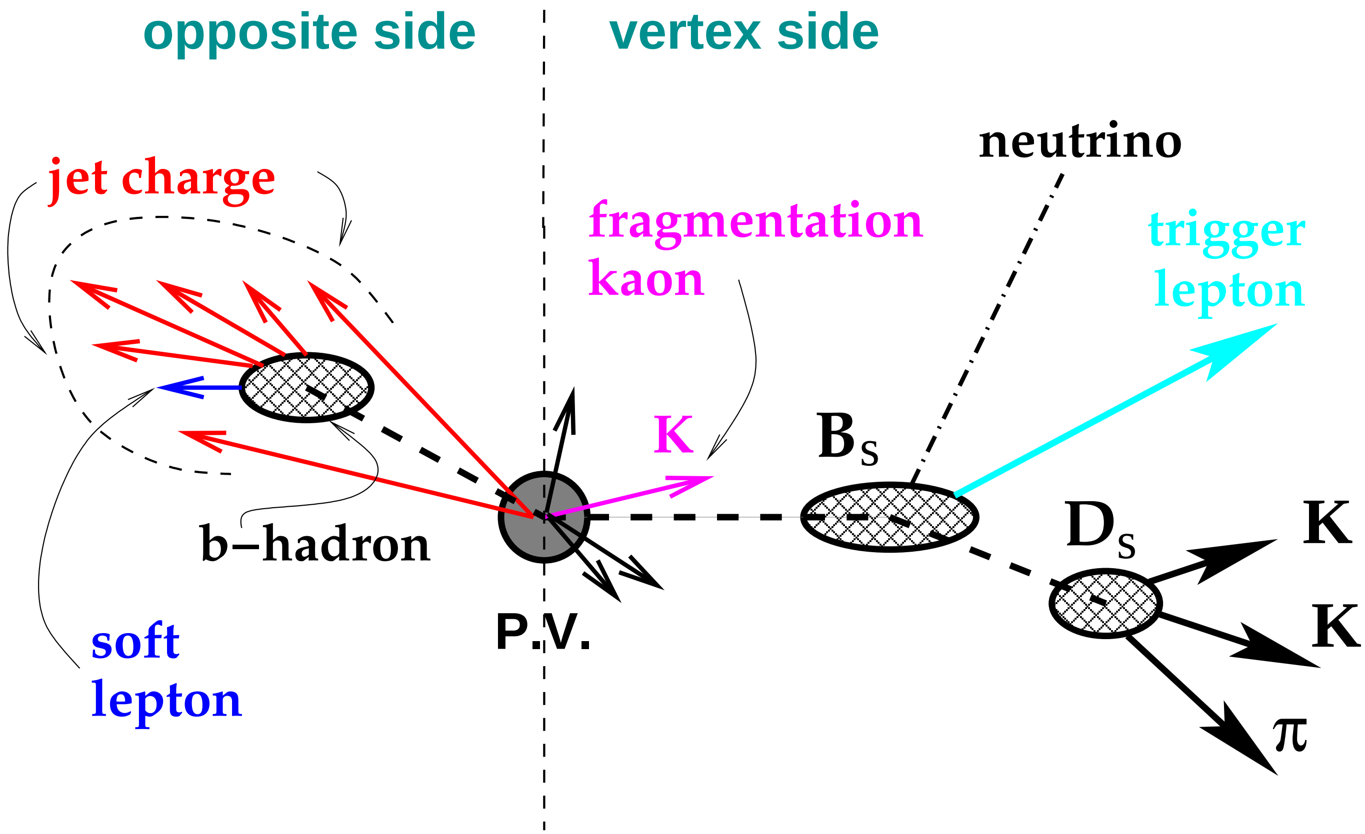
Tagging: Measurement of the B_s or $\overline{B}_s$ flavor of the meson at $t = 0$.

Definition of tagging "dilution", "efficiency", and "power":

$$\mathcal{D} \equiv \frac{N_{\text{cor}} - N_{\text{wr}}}{N_{\text{cor}} + N_{\text{wr}}},$$
$$\varepsilon \equiv \frac{N_{\text{cor}} + N_{\text{wr}}}{N_{\text{tot}}},$$
$$\mathcal{P} \equiv \varepsilon\mathcal{D}^2.$$

The tagging power for $B_s \to J/\psi\phi$ is $4.68 \pm 0.54\%$.

It was callibrated with $B^\pm \to J/\psi K^\pm$.



Tagging methods

Simultaneous unbinned maximum likelihood fit to the proper decay time, 3 decay angles, and mass. There are up to 33 free parameters in the fit.

The likelihood function is

$$\mathcal{L} = \prod_{i=1}^{N} [f_{\mathsf{sig}} \mathcal{F}^i_{\mathsf{sig}} + (1 - f_{\mathsf{sig}}) \mathcal{F}^i_{\mathsf{bck}}],$$

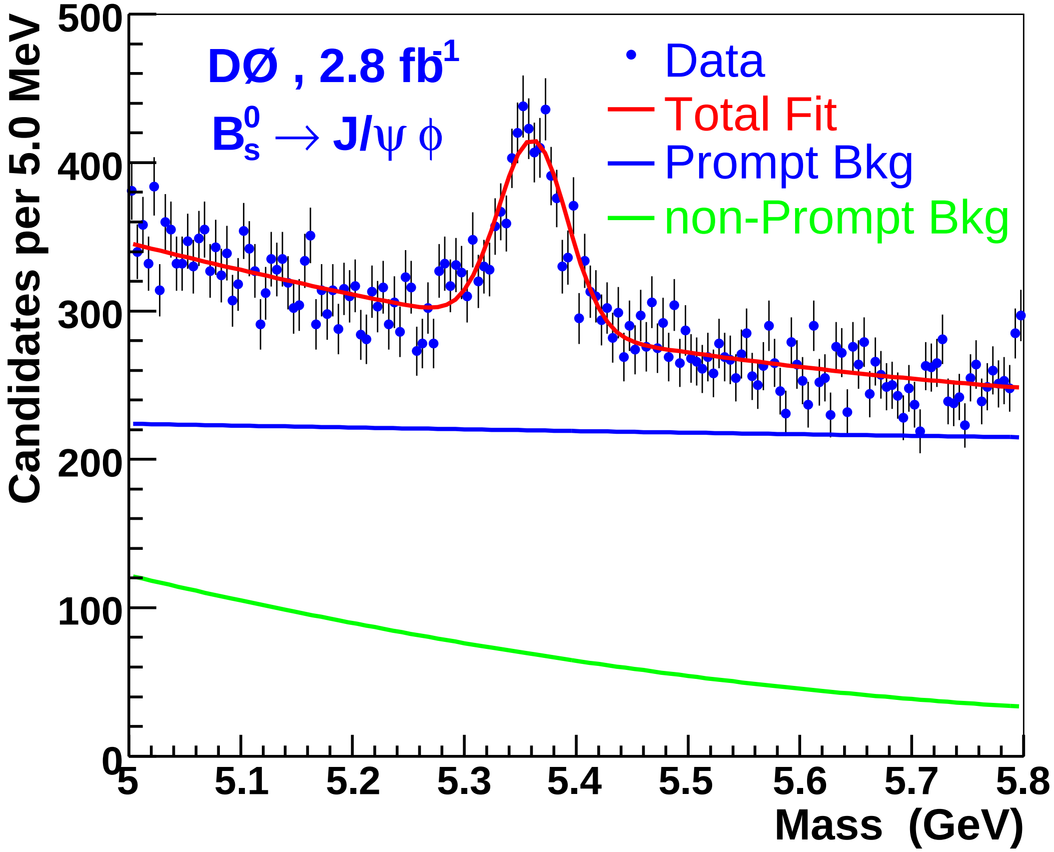
where N is the total number of events,
f_{sig} is the fraction of signal in the sample, and
$\mathcal{F}^i_{\mathsf{sig}}$ ($\mathcal{F}^i_{\mathsf{bck}}$) describes the distribution of the signal (background) in mass, proper decay time, and the 3 decay angles.

Constraints

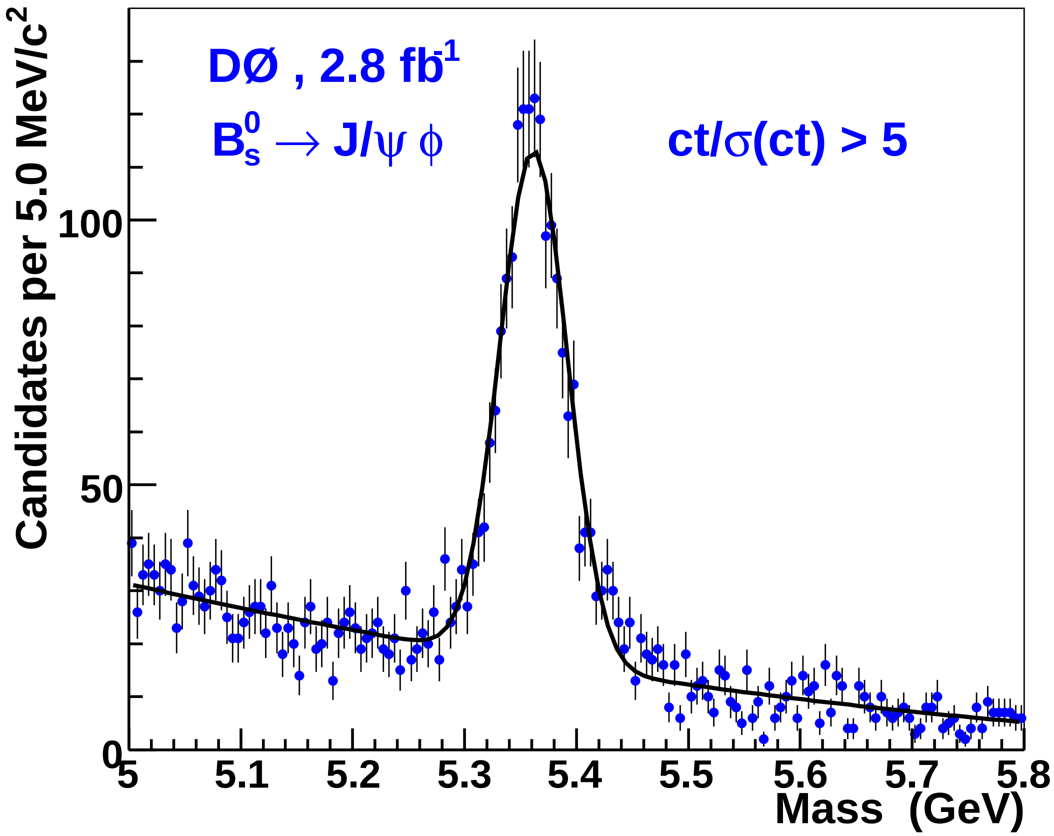
- We constrain $\Delta M_s = 17.77 \pm 0.12$ ps^{-1} from CDF.
- The fit to tagged $B_s \to J/\psi\phi$ data has a two-fold ambiguity:
  1. $\Delta\Gamma > 0$, $\cos\phi_s > 0$, $\cos\delta_1 > 0$, $\cos\delta_2 < 0$.
  2. $\Delta\Gamma < 0$, $\cos\phi_s < 0$, $\cos\delta_1 < 0$, $\cos\delta_2 > 0$.

  For $B_d \to J/\psi K^*$, the solution $\delta_1 = -0.46$ and $\delta_2 = 2.92$ is prefered over the solution $\delta_1 = 3.60$ and $\delta_2 = 0.22$. E. Barberio *et al.*, hep-ex/0704.3575, page 153. M. Suzuki, Phys. Rev. D 64, 117503, (2001). BaBar Collaboration. B. Aubert *et al.*, hep-ex/0704.0522.

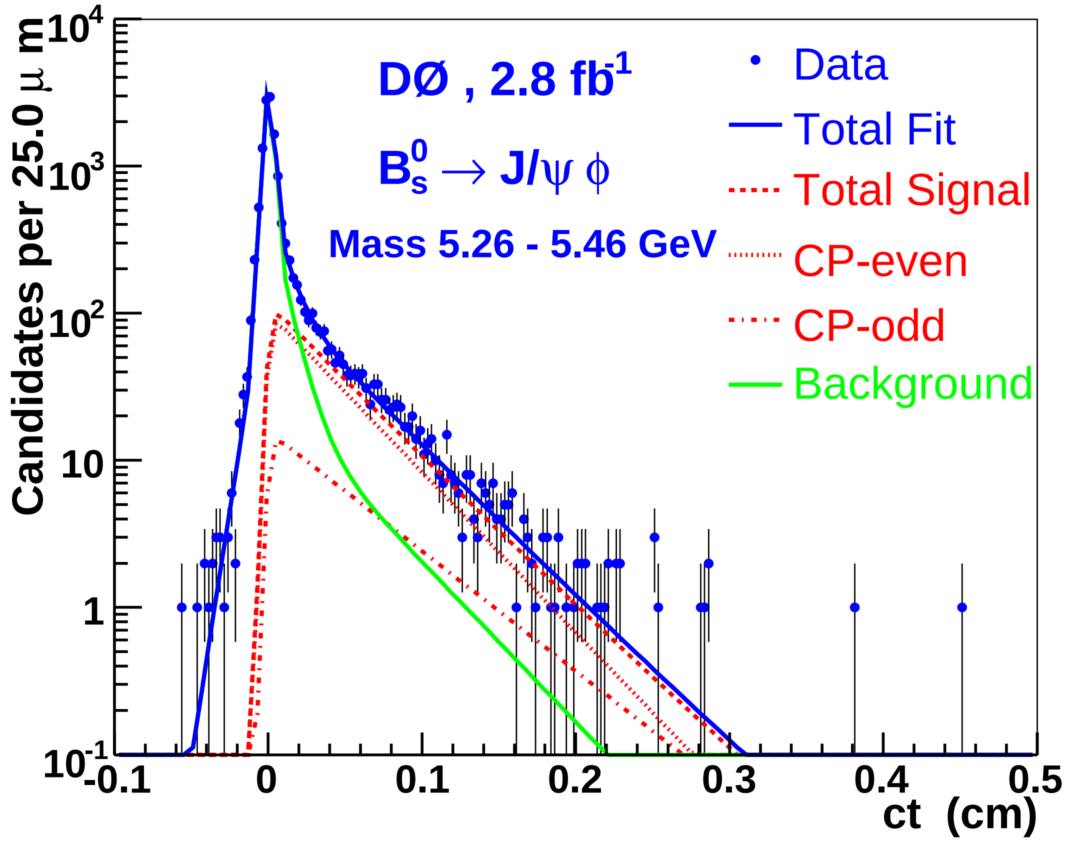
  We constrain $\delta_1 = -0.46$ and $\delta_2 = 2.92$ with gaussians of widths $\pi/5$, to allow for SU(2) flavor symmetry breaking.



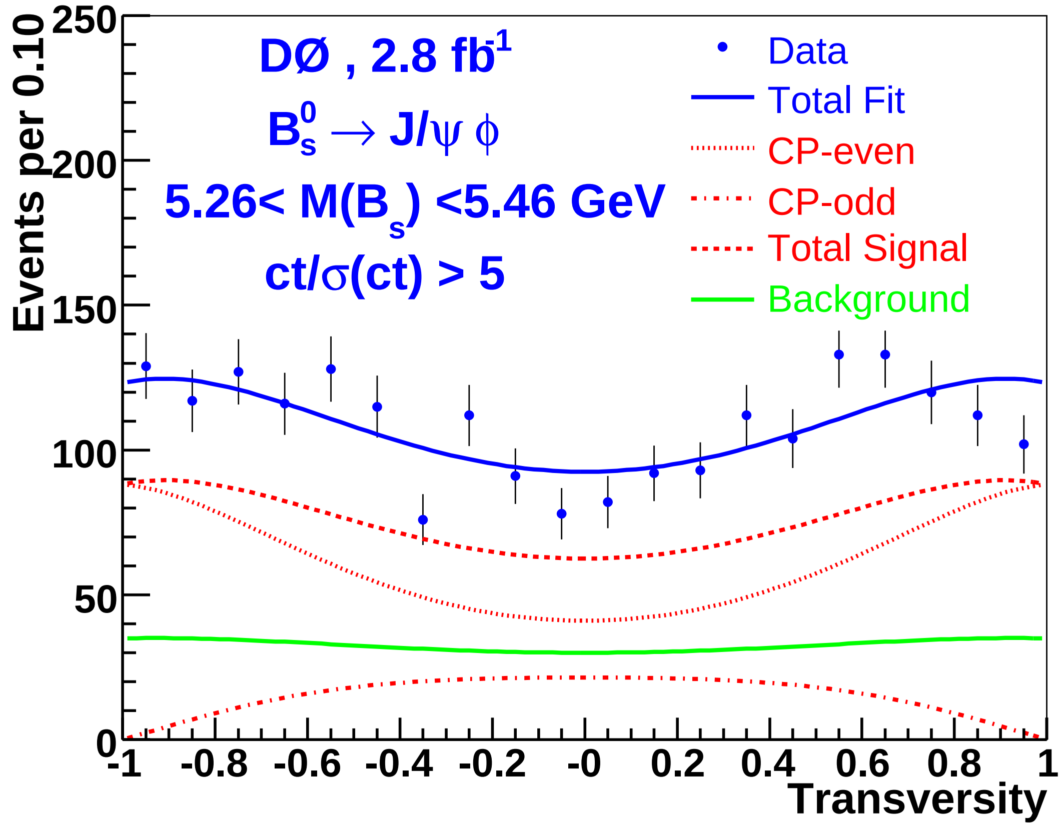
Invariant mass distribution of the $J/\psi + \phi$ candidates. The curves are projections of the unbinned maximum likelihood fit.



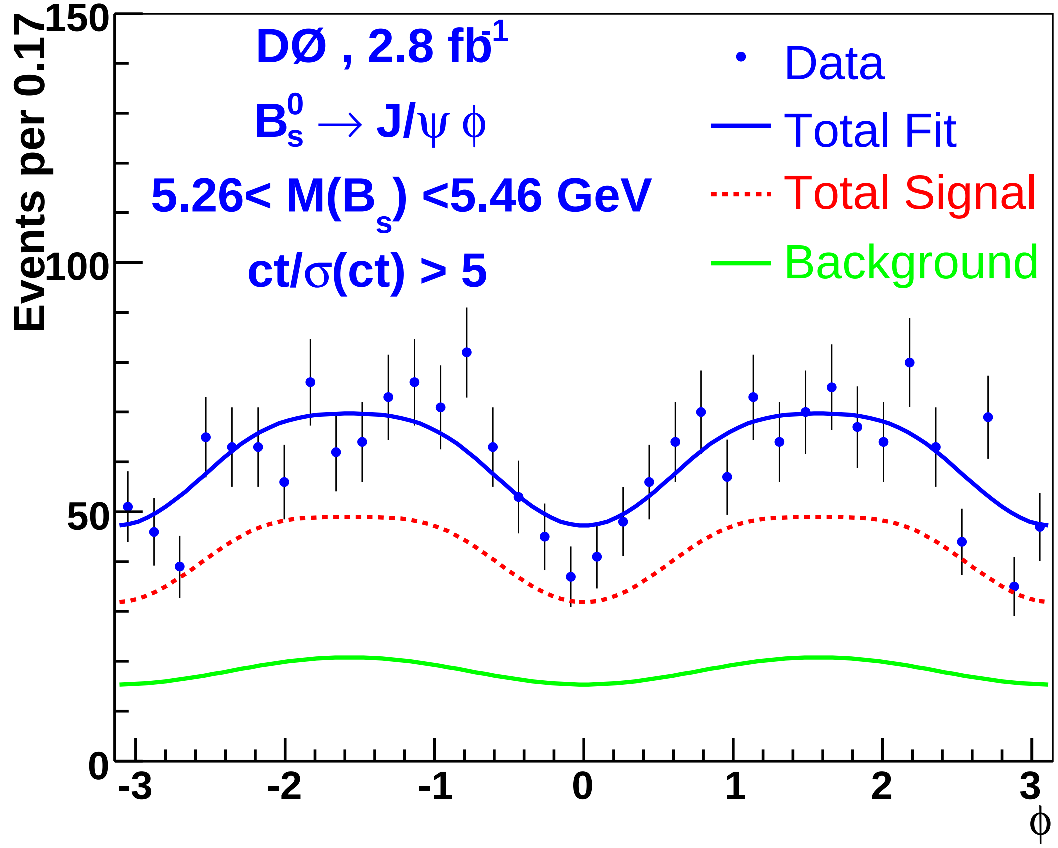
Invariant mass distribution of the $J/\psi + \phi$ candidates with the prompt background suppressed.



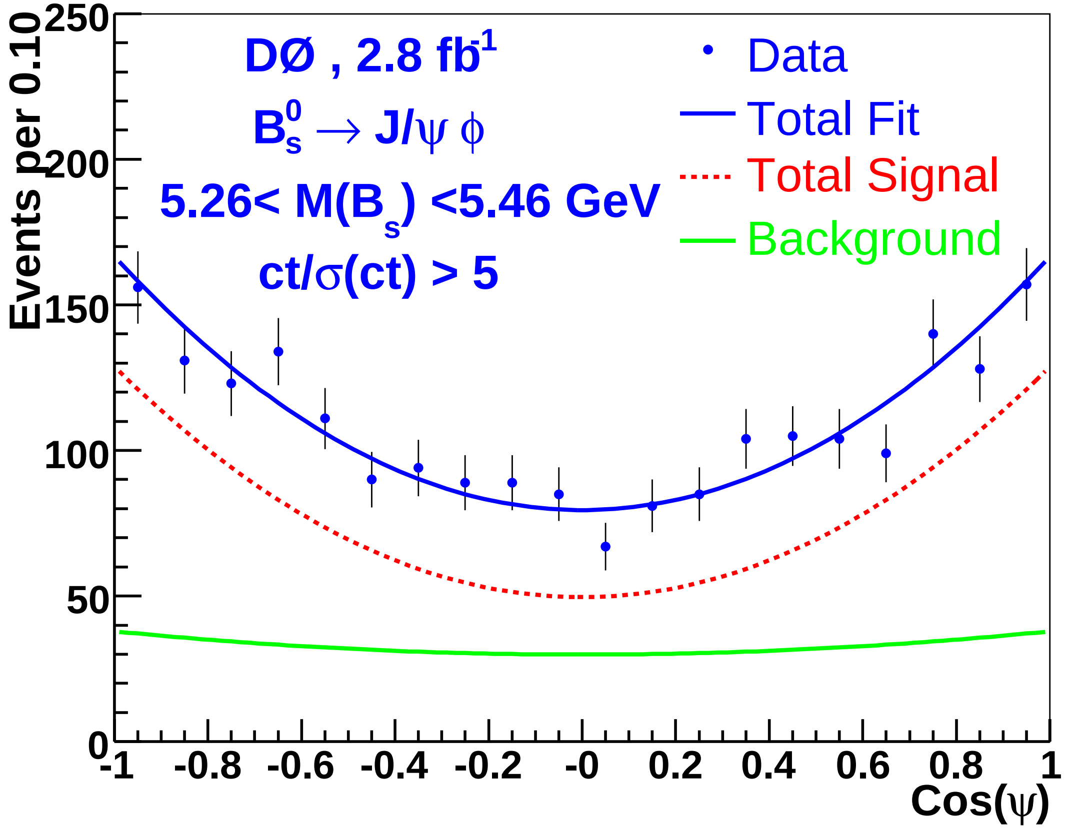
Histogram of the proper lifetime of $J/\psi + \phi$ candidates. The curves are projections of the maximum likelihood fit.



Histogram of $\cos\theta$ of $J/\psi + \phi$ candidates. The curves are projections of the maximum likelihood fit.



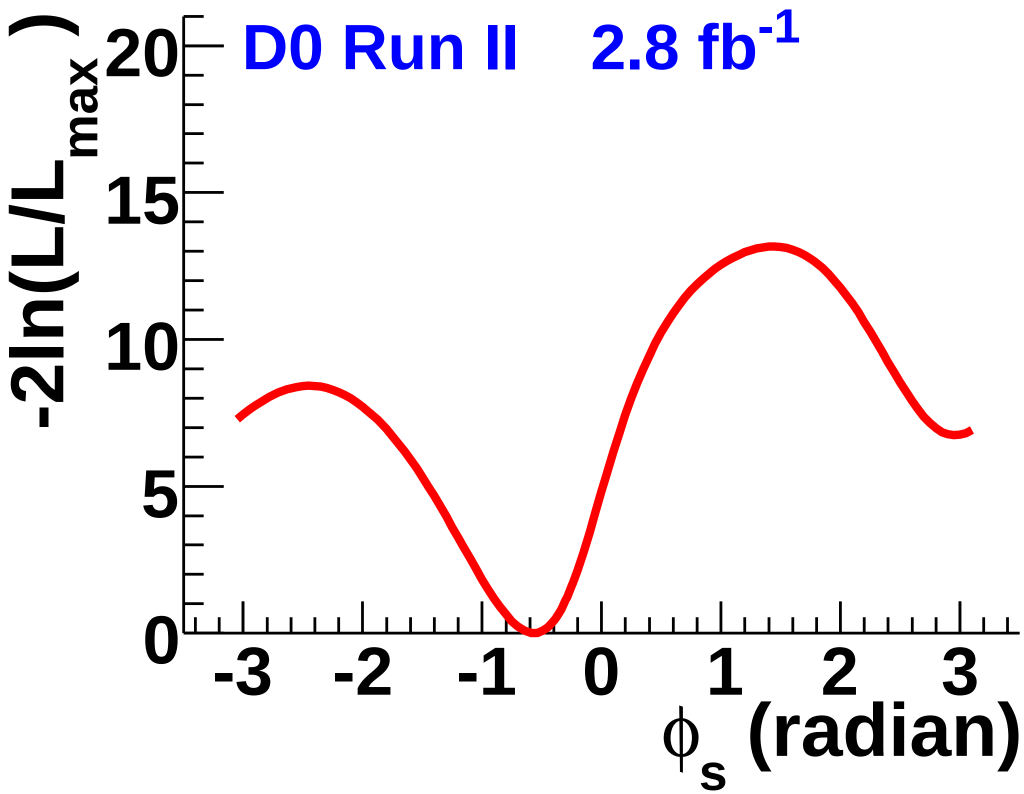
Histogram of the angle φ of $J/\psi + \phi$ candidates. The curves are projections of the maximum likelihood fit.



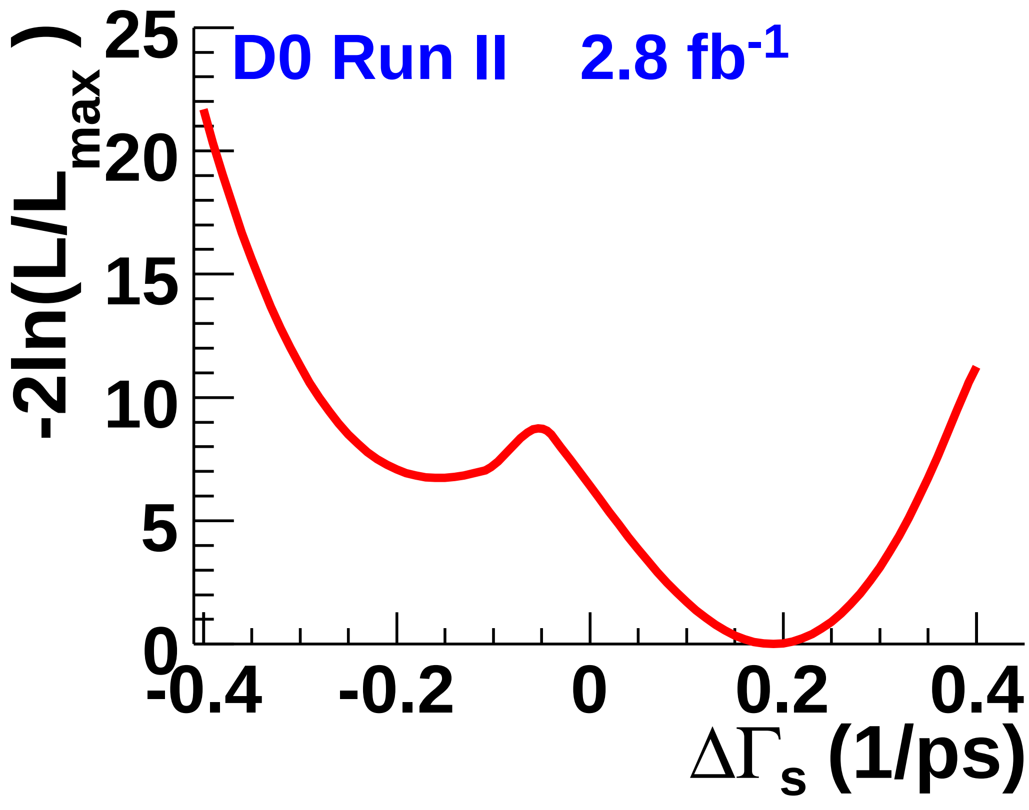
Histogram of $\cos\psi$ of $J/\psi + \phi$ candidates. The curves are projections of the maximum likelihood fit.

	free ϕ_s	$\phi_s \equiv \phi_s^{SM}$	$\Delta\Gamma_s^{th}$
$\overline{\tau}_s$ (ps)	1.52±0.06	1.53±0.06	1.49 ± 0.05
$\Delta\Gamma_s$ (ps^{-1})	0.19±0.07	0.14±0.07	0.083 ± 0.018
$\|A_\perp(0)\|$	0.41±0.04	0.44±0.04	0.45 ± 0.03
$\|A_0\|^2 - \|A_{\|\|}\|^2$	0.34±0.05	0.35±0.04	0.33 ± 0.04
δ_1	−0.52±0.42	−0.48±0.45	-0.47 ± 0.42
δ_2	3.17±0.39	3.19±0.43	3.21 ± 0.40
ϕ_s	$-0.57^{+0.24}_{-0.30}$	$\equiv -0.04$	-0.46 ± 0.28
ΔM_s (ps^{-1})	$\equiv 17.77$	$\equiv 17.77$	$\equiv 17.77$

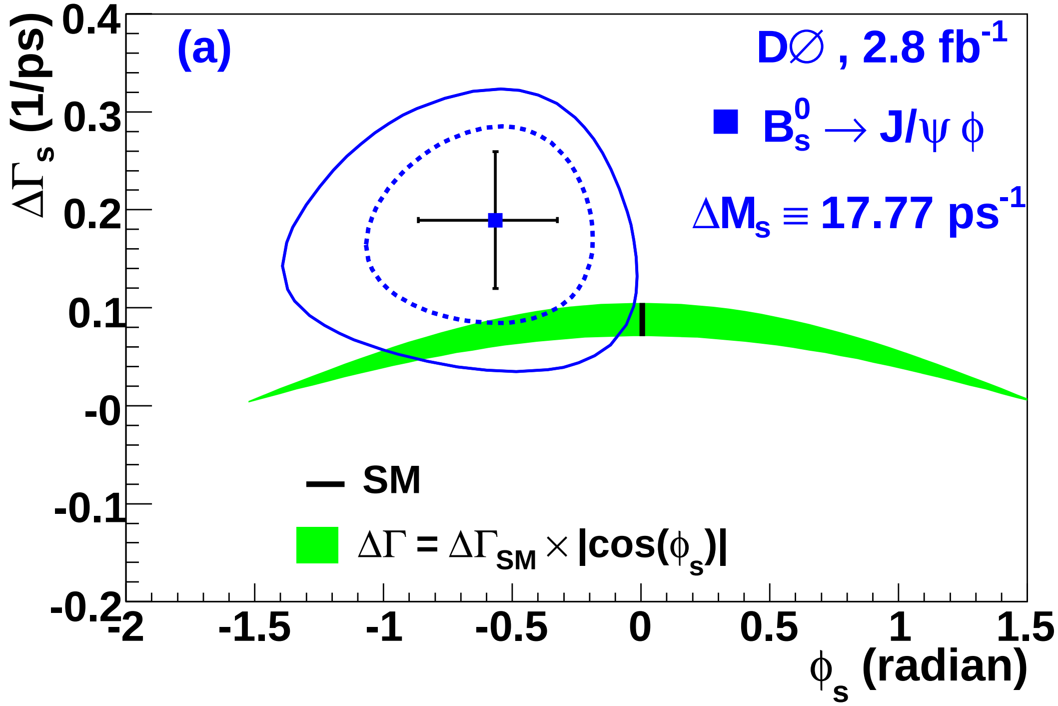
Summary of the likelihood fit results for the case of free ϕ_s, for the case $\phi_s \equiv -0.04$ as predicted by the Standard Model, and for $\Delta\Gamma_s^{th} = \Delta\Gamma_s^{SM} \cdot |\cos\phi_s|$.



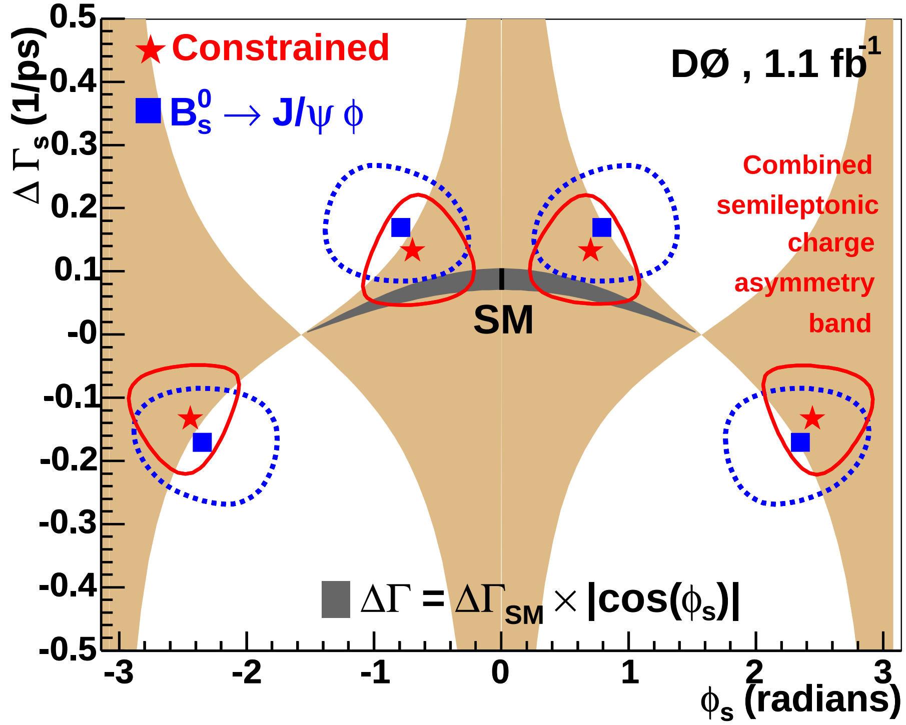
Likelihood profile of ϕ_s.



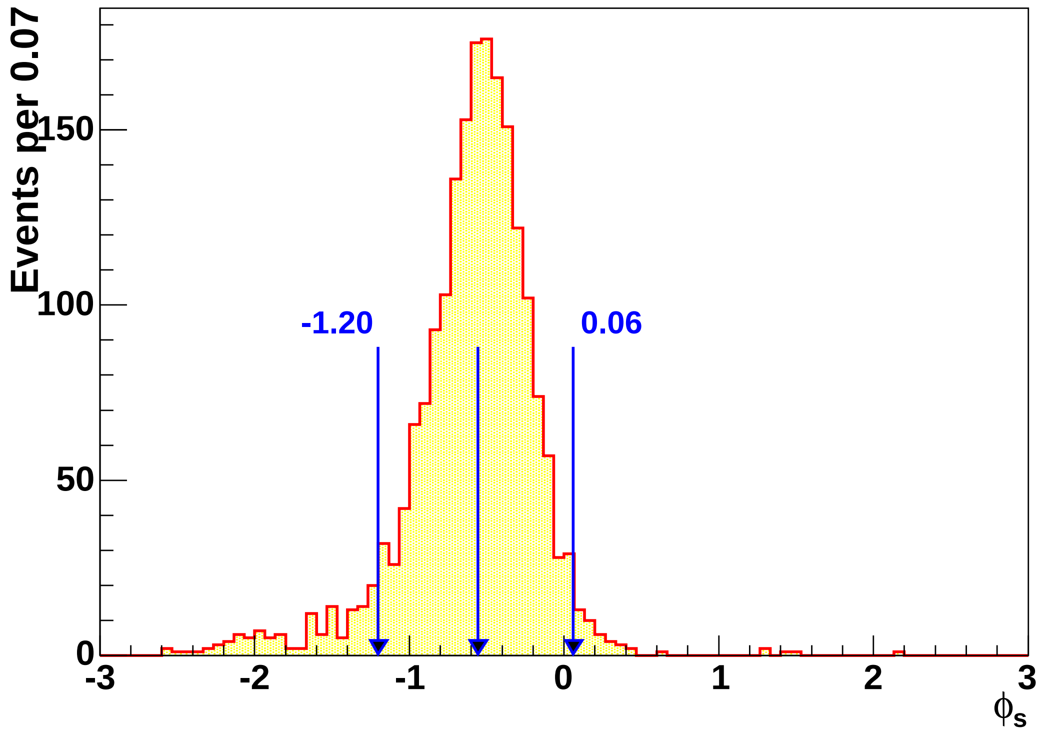
Likelihood profile of $\Delta\Gamma_s$.



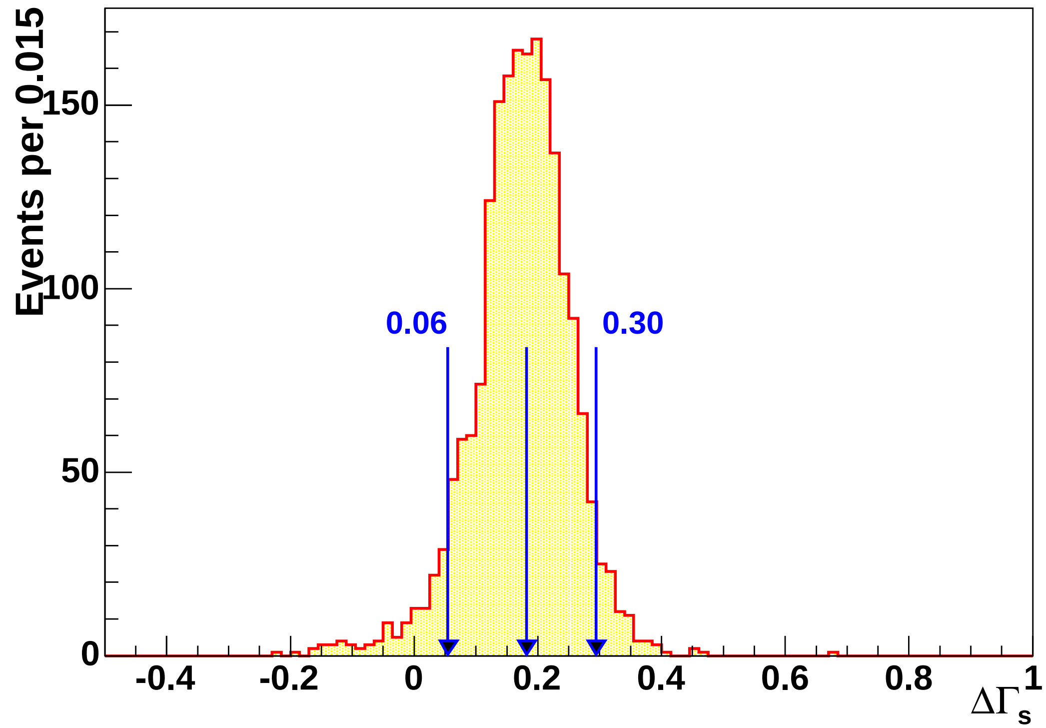
Confidence level contours, at $\delta(-2\ln L) = 2.30$ (CL $= 0.683$) and 4.61 (CL $= 0.90$), in the ϕ_s, $\Delta\Gamma_s$ plane. The cross has $\delta(-2\ln L) = 1.0$.



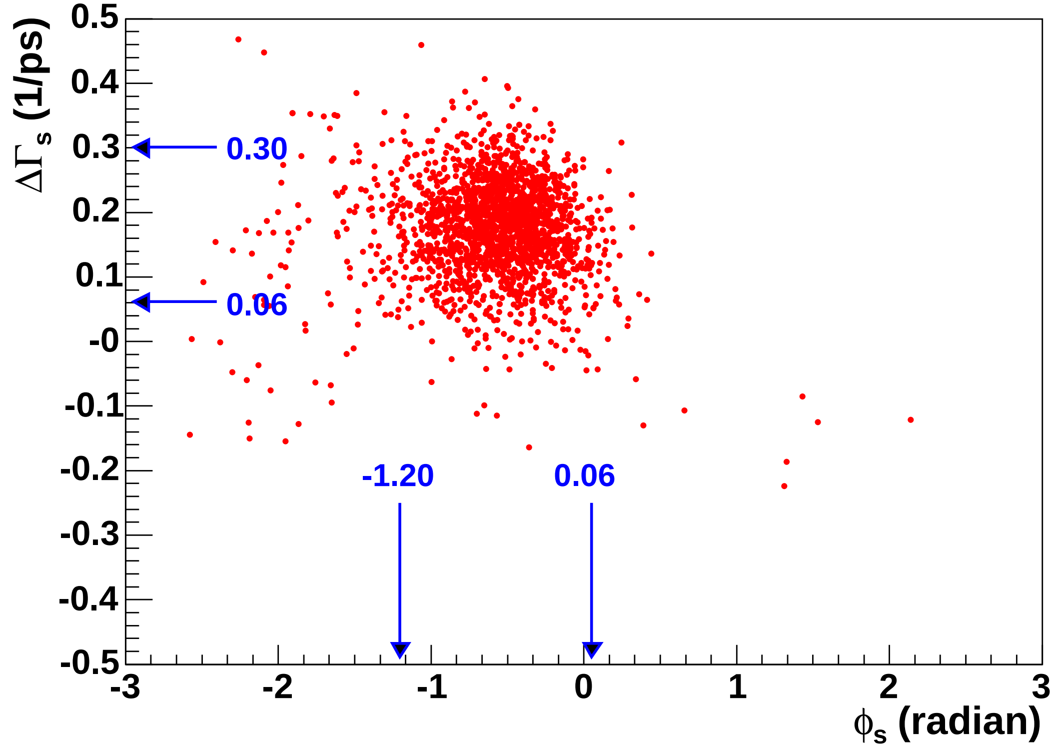
For comparison: fit to untagged $B_s \to J/\psi\phi$ with 1.1 fb^{-1} (dashed blue line), and same with a_{sl}^q constraints (solid red line). $\delta(-2\ln L) = 1.0$. DØ Collaboration, hep-ex/0702030 (2007).



Distribution of ϕ_s returned by fits to pseudo-experiments. The left and right arrows delimit the 90% exclusion region.



Distribution of $\Delta\Gamma_s$ returned by fits to pseudo-experiments. The left and right arrows delimit the 90% exclusion region.



The scatter plot of the fitted values of the $\Delta\Gamma_s$ and ϕ_s for an ensemble of simulated experiments.

Sources of systematic uncertainties

Source	$\bar{\tau}_s$ (ps)	$\Delta\Gamma_s$ (ps^{-1})
Acceptance	± 0.003	± 0.003
Signal mass model	-0.01	$+0.006$
Flavor purity estimate	± 0.001	± 0.001
Background model	$+0.003$	$+0.02$
ΔM_s input	± 0.01	± 0.001
Total	± 0.01	$+0.02, -0.01$

Source	$\lvert A_\perp(0)\rvert$	$\lvert A_0(0)\rvert^2 - \lvert A_{\parallel}(0)\rvert^2$	ϕ_s
Acceptance	± 0.005	± 0.03	± 0.005
Signal mass model	-0.003	-0.001	-0.006
Flavor purity estimate	± 0.001	± 0.001	± 0.01
Background model	-0.02	-0.01	$+0.02$
ΔM_s input	± 0.001	± 0.001	$+0.06, -0.01$
Total	$+0.01, -0.02$	± 0.03	$+0.07, -0.02$

Results:

- We measure:
  $\phi_s = -0.57^{+0.24}_{-0.30}(\text{stat})^{+0.07}_{-0.02}(\text{syst})$,
  $\Delta\Gamma_s = 0.19 \pm 0.07(\text{stat})^{+0.02}_{-0.01}(\text{syst})\ \text{ps}^{-1}$,
  $\overline{\tau}(B_s^0) = 1.52 \pm 0.05 \pm 0.01$ ps.

  At 90% C.L., $-1.20 < \phi_s < 0.06$, and $0.06 < \Delta\Gamma_s < 0.30\ \text{ps}^{-1}$.
  The SM hypothesis for ϕ_s has a P-value of 6.6%.

- For the SM case $\phi_s \equiv -2\beta_s = -0.04$, we obtain
  $\Delta\Gamma_s = 0.14 \pm 0.07(\text{stat})^{+0.02}_{-0.01}(\text{syst})\ \text{ps}^{-1}$,
  $\overline{\tau}(B_s^0) = 1.53 \pm 0.06 \pm 0.01$ ps.

- For the case $\Delta\Gamma_s^{th} = \Delta\Gamma_s^{SM} \cdot |\cos\phi_s|$ we obtain
  $\phi_s = -0.46 \pm 0.28(\text{stat})^{+0.07}_{-0.02}(\text{syst})$,
  $\overline{\tau}(B_s^0) = 1.53 \pm 0.06 \pm 0.01$ ps.

hep-ex/0802.2255. Submitted to Phys. Rev. Lett.

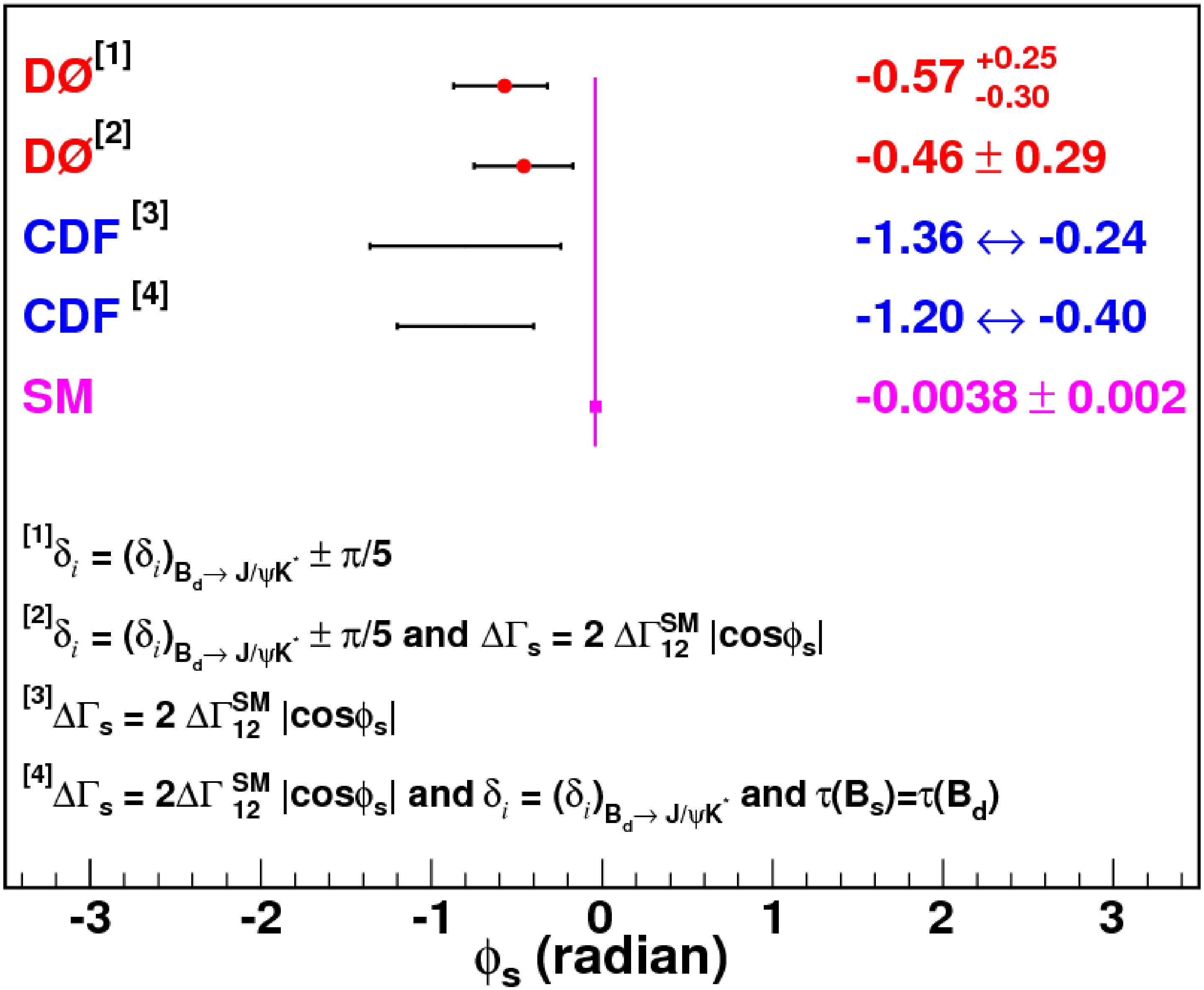
Comparison with other experiments:

- From the CDF analysis of 1.7 fb^{-1} of tagged $B_s \to J/\psi\phi$ with external constrains: $-1.20 < \phi_s < -0.40$ at 68% CL.

  Shown is the DØ ϕ_s sign convention, which is opposite to the CDF 2β. FERMILAB-PUB-07-663-E, arXiv:0712.2397. Submitted to Phys. Rev. Lett. December 14, 2007.

- A combination of previous DØ measurements obtains $\phi_s = -0.70^{+0.47}_{-0.39}$ with a 4-fold ambiguity.

  Phys. Rev. D 76, 057101 (2007).


DØ[1]
-0.57 +0.25 -0.30
DØ[2]
-0.46 ± 0.29
CDF [3]
-1.36 ↔ -0.24
CDF [4]
-1.20 ↔ -0.40
SM
-0.0038 ± 0.002
[1] $\delta_i = (\delta_i)_{B_d \to J/\psi K^*} \pm \pi/5$
[2] $\delta_i = (\delta_i)_{B_d \to J/\psi K^*} \pm \pi/5$ and $\Delta\Gamma_s = 2\,\Delta\Gamma_{12}^{SM}\,|\cos\phi_s|$
[3] $\Delta\Gamma_s = 2\,\Delta\Gamma_{12}^{SM}\,|\cos\phi_s|$
[4] $\Delta\Gamma_s = 2\Delta\Gamma_{12}^{SM}\,|\cos\phi_s|$ and $\delta_i = (\delta_i)_{B_d \to J/\psi K^*}$ and $\tau(B_s)=\tau(B_d)$
-3
-2
-1
0
1
2
3
ϕ_s (radian)

3. Search for direct CP violation in $B^+ \to J/\psi K^+$ and $B^+ \to J/\psi \pi^+$ decays.

We measure

$$A_{CP} \equiv \frac{\Gamma(B^- \to J/\psi K^-) - \Gamma(B^+ \to J/\psi K^+)}{\Gamma(B^- \to J/\psi K^-) + \Gamma(B^+ \to J/\psi K^+)}.$$

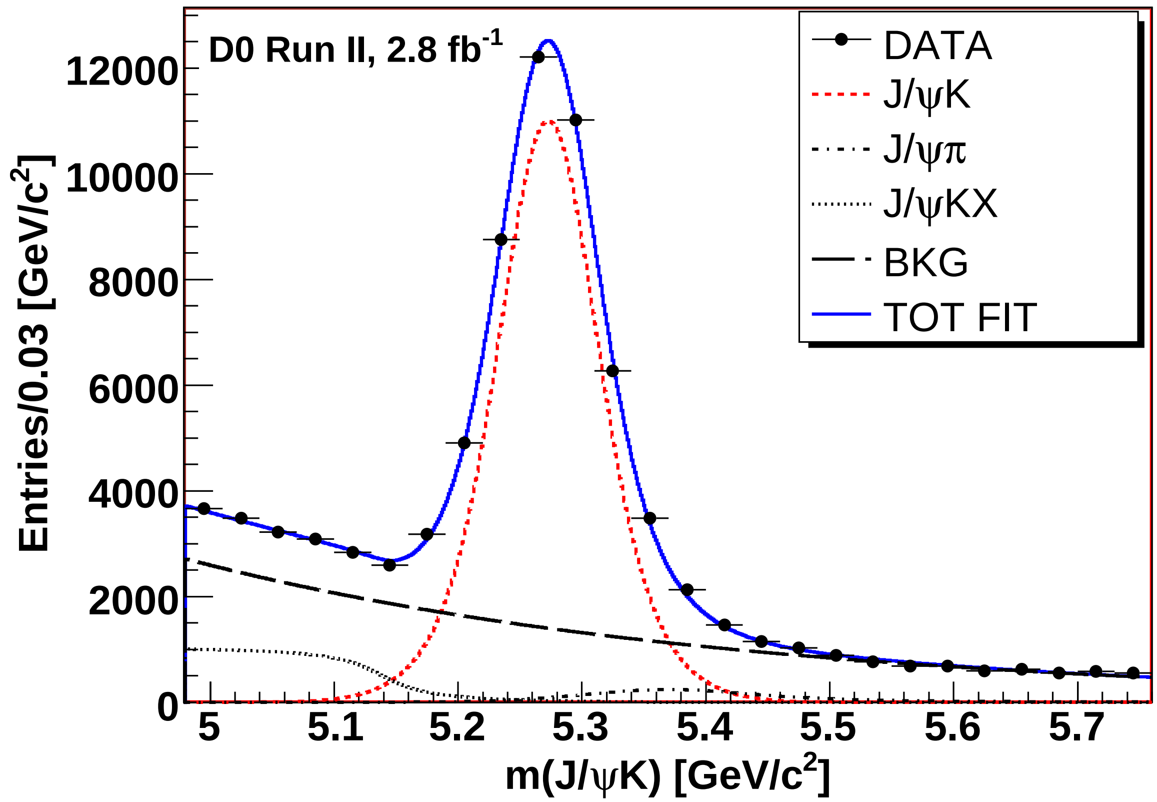
with 2.8 fb^{-1} of data.

The decay $B^\pm \to J/\psi K^\pm(\pi^\pm)$ proceeds via the tree level diagram $b \to c\bar{c}s$, and the penguin diagram $b \to s\gamma$. Their interference produces an asymmetry, predicted by the Standard Model (with input from experiment), to be of order $A_{CP} \approx 0.003$. *

Extensions of the Standard Model, such as an extra $U(1)'$ gauge boson or the Two-Higgs Doublet Model, can enhance this asymmetry.

* W.-S. Hou, M. Nagashima and A. Soddu, hep-ph/0605080 (2006).

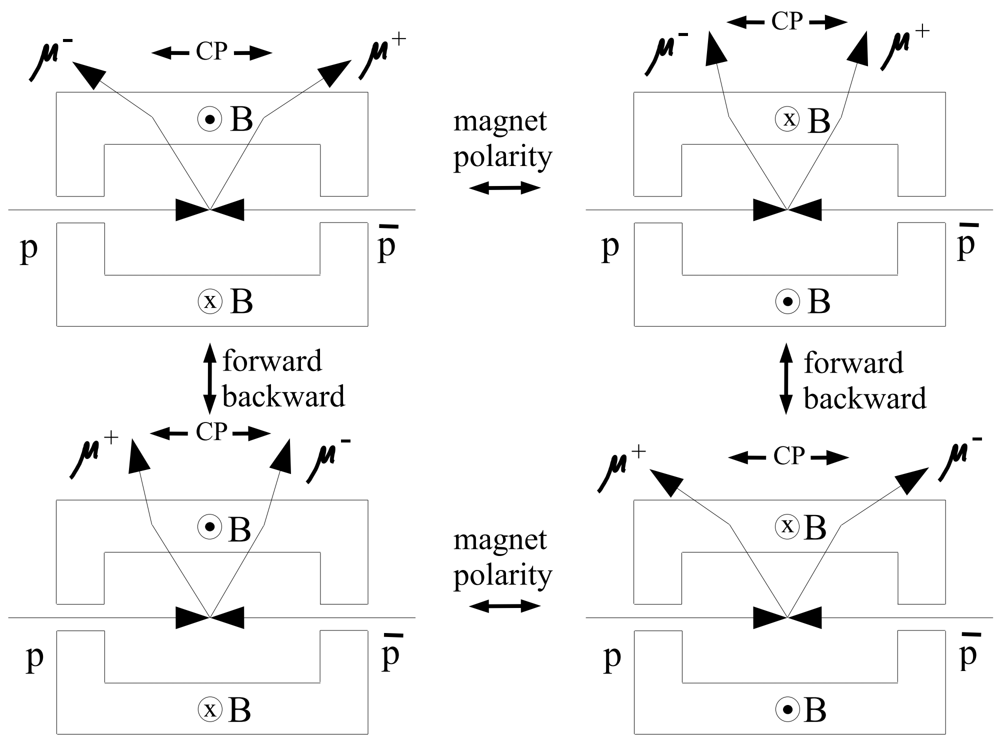
Unbinned fit of the invariant mass distribution of the $\mu\mu K$ system.



Channel	#events
$J/\psi K$	40,222 $\pm$ 242
$J/\psi\pi$	1,578 $\pm$ 119
$J/\psi K^*$	5,429 $\pm$ 217
Background	33,192 $\pm$ 425
Total # of events in the signal region	80,422

Begin digression

Precision charge asymmetry measurements



D0 detector toroid.

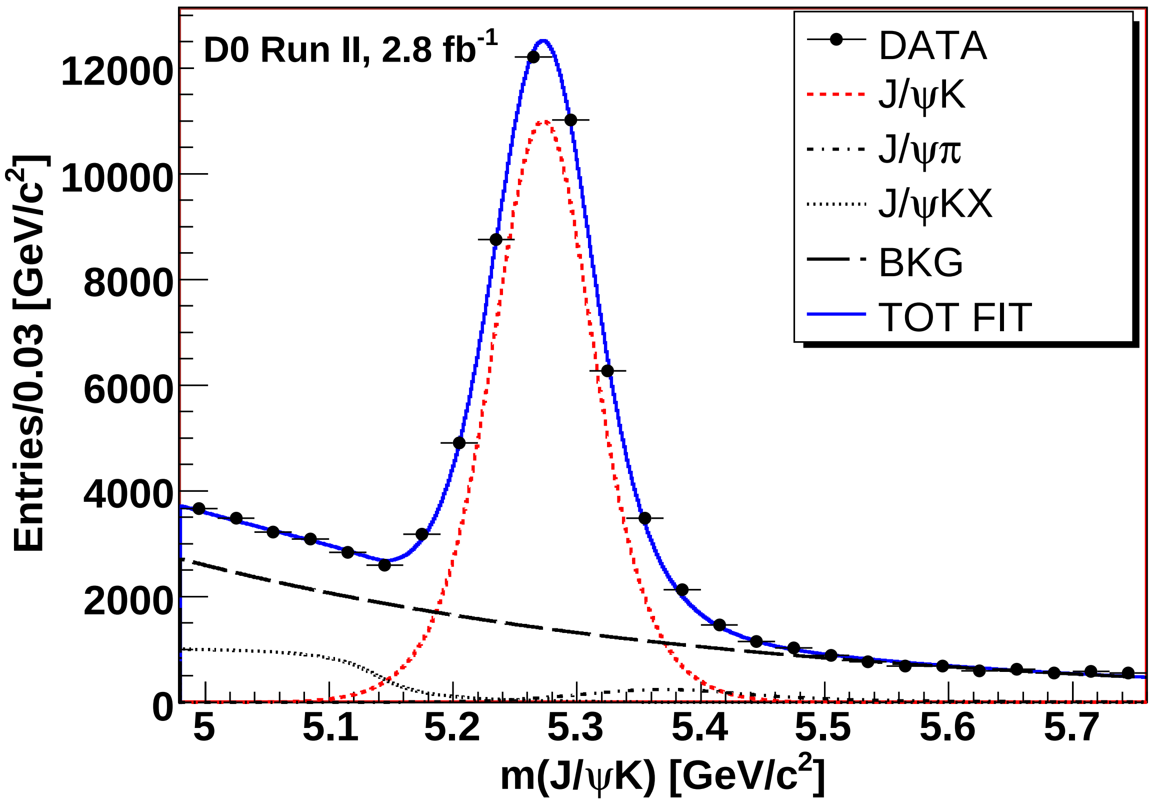
Reversal of solenoid and toroid magnet polarities allows cancelations of systematic uncertainties of the charge asymmetry.

Obtain number of events in 8 $\beta\gamma q$ bins. β is the solenoid polarity, γ is the sign of the pseudorapidity, and q is the charge.

$$\begin{aligned} n_q^{\beta\gamma} &= \frac{1}{4} N \epsilon^{\beta} (1 + qA)(1 + q\gamma A_{fb})(1 + \gamma A_{det}) \\ &\times (1 + q\beta\gamma A_{q\beta\gamma})(1 + q\beta A_{q\beta})(1 + \beta\gamma A_{\beta\gamma}). \end{aligned}$$

End of digression

Unbinned fit of the invariant mass distribution of the $\mu\mu K$ system.



Physics asymmetry A and detector asymmetries for different channels.

	$J/\psi K$	$J/\psi\pi$
N	$40,217 \pm 243$	$1,577 \pm 118$
ϵ^+	0.5060 ± 0.0030	0.5060 ± 0.0030
A	-0.0070 ± 0.0060	-0.0887 ± 0.0807
A_{fb}	0.0013 ± 0.0060	0.0453 ± 0.0890
A_{det}	-0.0033 ± 0.0060	0.2061 ± 0.0826
$A_{q\beta\gamma}$	-0.0050 ± 0.0060	-0.0207 ± 0.0873
$A_{q\beta}$	0.0001 ± 0.0060	-0.1896 ± 0.0823
$A_{\beta\gamma}$	-0.0030 ± 0.0060	0.0499 ± 0.0801

There is a kaon asymmetry because $\sigma(K^- d_{inelastic}) > \sigma(K^+ d_{inelastic})$.

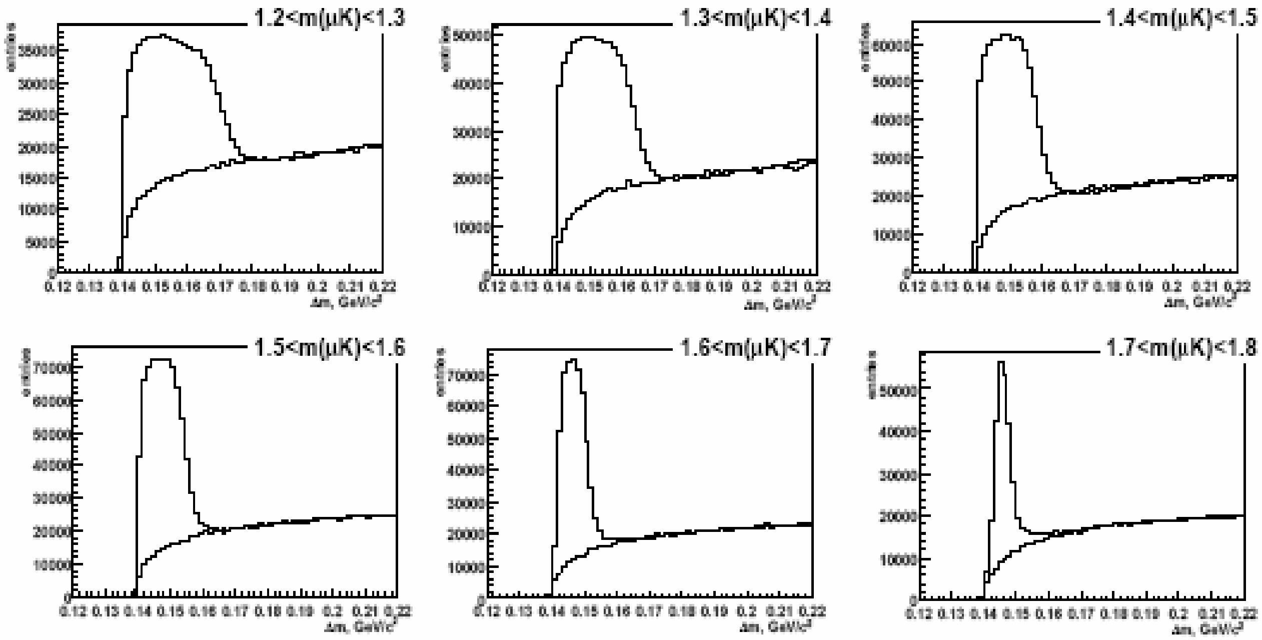
The difference is due to the existence of Y hyperons: reactions $K^- N \to Y\pi$ have no $K^+ N$ analog. Therefore

$$A_K = \frac{N(K^-) - N(K^+)}{N(K^-) + N(K^+)} < 0.$$

We measure the kaon asymmetry at DØ with 2.8 fb^{-1} of data in the channel

$$c \to D^{*+} \to D^0 \pi^+, \quad D^0 \to \mu^+ \nu K^-.$$

D0 Run II 2.8 fb^{-1}



The $\Delta m = m(\mu K\pi) - m(\mu K)$ distributions of D^{*+} events in different $m(\mu K)$ bins for the samples of "right" (solid line) and "wrong" (dashed line) charge correlation events. The background distribution is rescaled to fit the tail of the signal.

For each bin of p_K, the 8 numbers $n_q^{\beta\gamma}$ are obtained for the signal and sideband regions, and for "right" ($q_\mu \cdot q_K < 0$ and $q_\mu \cdot q_\pi > 0$), and "wrong" ($q_\mu \cdot q_K > 0$ and $q_\mu \cdot q_\pi > 0$) correlations of charges.

The signal region is selected for each $m(\mu K)$ bin to maximize $S/\sqrt{S+B}$. The sideband region is $\Delta m = 0.19$ to 0.22 GeV.

$$B = N_{wrong}^{sig} \cdot \frac{N_{right}^{side}}{N_{wrong}^{side}},$$

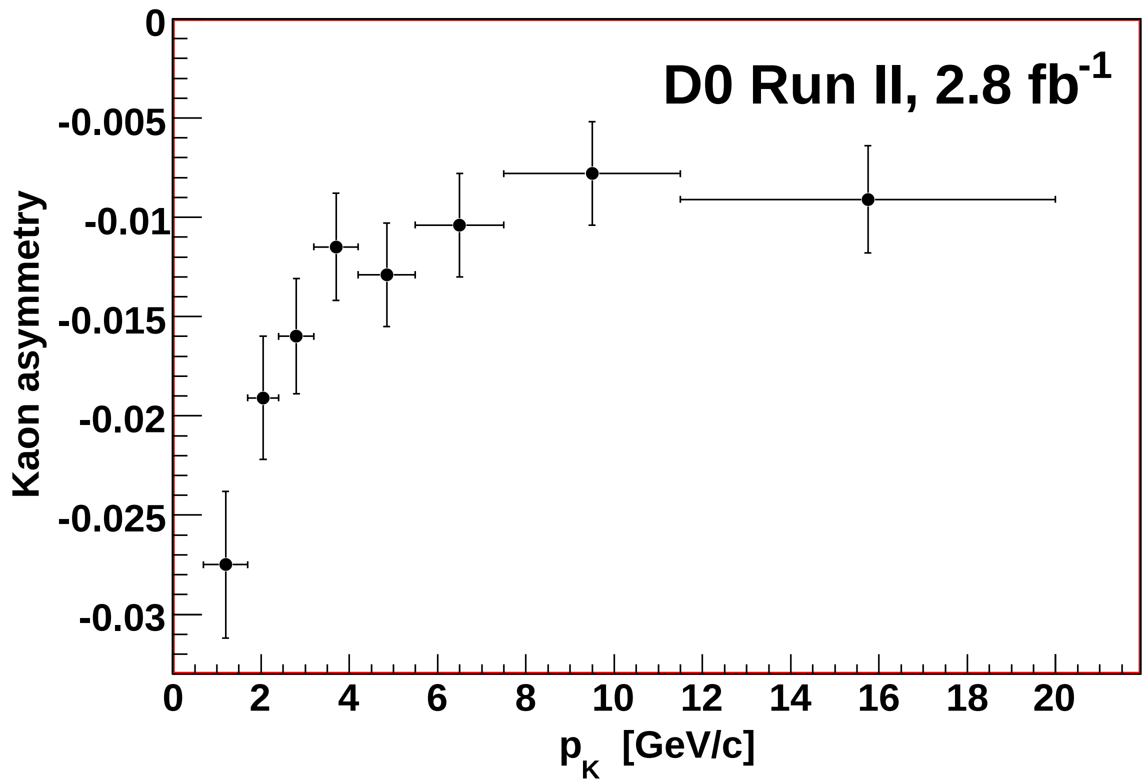
$$S = N_{right}^{sig} - B.$$

The result is corrected for sample composition of the D^0 decay:

No	Mode	Br, %
1	$\mu^+ K^- \nu$	3.51 ± 0.11
2	$\mu^+ K^{*-} \nu$	2.17 ± 0.16
a.	$K^{*-} \to K^- \pi^0$	$1/3 \cdot \mathrm{Br}(K^*)$
b.	$K^{*-} \to K^0 \pi^-$	$2/3 \cdot \mathrm{Br}(K^*)$
3.	$\mu^+ \pi^- \nu$	0.28 ± 0.02
4.	$\mu^+ \rho^- \nu,\ \rho^- \to \pi^- \pi^0$	0.19 ± 0.04

Corrected kaon asymmetry: $A_K(D^*) = A(D^*)/f_K$.

$f_K = 0.91 \pm 0.04$.



Dependence of kaon asymmetry $A_{K,i}(D^*)$ on p_K.

The kaon asymmetry in our $J/\psi K$ sample was measured to be

$$A_K = \sum_{i=1}^{N_{p_K bins}} A_{K,i}(D^*) \frac{N_i(J/\psi K)}{N(J/\psi K)} = -0.0145 \pm 0.0010 \text{ (stat)}.$$

Then

$$\begin{aligned} A_{CP} = A - A_K &= (-0.0070 \pm 0.0060) \\ &\quad -(-0.0145 \pm 0.0010) \\ &= 0.0075 \pm 0.0061 \text{ (stat)}. \end{aligned}$$

Systematic uncertainties of $A_{CP}(B^+ \to J/\psi K^+)$ and $A_{CP}(B^+ \to J/\psi \pi^+)$.

Source	$J/\psi K^+$	$J/\psi \pi^+$
$\pm 1\sigma$ variation of the parameters fixed during the fit	0.0002	0.0004
Fitting range variation	0.0004	0.0129
Likelihood parametrization of the $J/\psi\pi$ and $J/\psi K^*$ signals	0.0025	0.0252
Background definition	0.0008	–
Unknown reconstruction efficiency of some decay modes contributing to D^* sample	0.0005	–
Asymmetry of π reconstruction	–	0.0002
Total	0.0027	0.0283

Results: arXiv:0802.3299, submitted to PRL

$$A_{CP}(B^+ \to J/\psi K^+) = +0.0075 \pm 0.0061 \text{ (stat)} \pm 0.0027 \text{ (syst)}.$$

This is consistent with zero, but is measured with a precision that is of the order of the SM prediction (≈ 0.003). Our measurement is consistent with the PDG-2007 world average, $A_{CP}(B^+ \to J/\psi K^+) = +0.015 \pm 0.017$, but has a factor of three better precision.

$$A_{CP}(B^+ \to J/\psi \pi^+) = -0.089 \pm 0.081 \text{ (stat)} \pm 0.028 \text{ (syst)}.$$

4. Conclusions

- We have placed the most stringent bounds on new models predicting large values of $A_{CP}(B^+ \to J/\psi K^+)$.

- We measure
  $\phi_s = -0.57^{+0.24}_{-0.30}(\text{stat})^{+0.07}_{-0.02}(\text{syst})$.
  The SM hypothesis for ϕ_s has a P-value of 6.6%.

- For the case $\Delta\Gamma_s^{th} = \Delta\Gamma_s^{SM} \cdot |\cos\phi_s|$ we obtain
  $\phi_s = -0.46 \pm 0.28(\text{stat})^{+0.07}_{-0.02}(\text{syst})$.

CP violation measurements have an exciting future at the Tevatron!

Backup slides

1	f_{sig} (N_{sig})	0.0409±0.0013 (1967±65)
2, 3	M , σ (in MeV)	5361.4±1.0 , 30.1±1.0
4	$\overline{\tau}$ (in μm)	456±17
5	$\Delta\Gamma$ (in ps^{-1})	0.19±0.07
6	$\vert A_{\perp}(0)\vert$	0.41±0.04
7	$\vert A_0(0)\vert^2 - \vert A_{\vert\vert}(0)\vert^2$	0.34±0.05
8, 9	δ_1 , δ_2	-0.52±0.42 , 3.17±0.39
10	ϕ_s	$-0.57^{+0.24}_{-0.30}$
11	ΔM_s (in ps^{-1})	$\equiv$ 17.77
12	S	1.24±0.01
13, 14	a_{1p} , a_{1l}	-0.06±0.03 , -1.45±0.08
15	a_{2l}	0.68±0.11
16, 17	f_- , f_+	0.049±0.004 , 0.155±0.004
18	f_{++}	0.035±0.003
19, 20	b_- , b_+ (in μm)	65±3 , 88±3
21	b_{++} (in μm)	399±21
22, 23	X_{2p} , X_{4p}	0.85±0.09 , -0.60±0.09
24, 25	X_{2l} , X_{4l}	0.39±0.17 , -0.23±0.19
26, 27	Y_{1p} , Y_{2p}	-0.23±0.01 , -0.10±0.02
28, 29	Y_{1l} , Y_{2l}	-0.15±0.02 , -0.00±0.04
30, 31	Z_{2p} , Z_{2l}	0.05±0.02 , 0.27±0.06
32, 33	Int_p , Int_l	-0.011±0.003 , -0.018±0.001

Summary of the fit results for all free parameters (with non-linear Minos errors).

a_x are coefficients of the mass polynomial for the background. f_x and b_x are normalizations and slopes of time exponentials for the background at $ct > 0$ or $ct < 0$. X_x, Y_x and Z_x are coefficients of polynomials of $\cos^2\theta$, $\cos 2\varphi$ and $\cos^2\psi$ for the background. Int_x allow for interference-like terms in the background.

Definition of tagging "dilution", "power" and "efficiency":

$$\mathcal{D} \equiv \frac{N_{\text{cor}} - N_{\text{wr}}}{N_{\text{cor}} + N_{\text{wr}}}, \qquad \mathcal{P} \equiv \varepsilon \mathcal{D}^2, \qquad \varepsilon \equiv \frac{N_{\text{cor}} + N_{\text{wr}}}{N_{\text{tot}}}.$$

"d" is the output of the tagger.

$\lvert d \rvert$	$\mathcal{D}(B^\pm \to J/\psi K^\pm)$ (%) (MC)	$\mathcal{D}(B^\pm \to J/\psi K^\pm)$ (%) (data)
$0.00 < \lvert d \rvert < 0.10$	0.029 ± 0.014	0.024 ± 0.017
$0.10 < \lvert d \rvert < 0.20$	0.127 ± 0.015	0.154 ± 0.019
$0.20 < \lvert d \rvert < 0.35$	0.261 ± 0.015	0.275 ± 0.018
$0.35 < \lvert d \rvert < 0.45$	0.302 ± 0.028	0.397 ± 0.032
$0.45 < \lvert d \rvert < 0.60$	0.483 ± 0.038	0.545 ± 0.049
$0.60 < \lvert d \rvert < 1.00$	0.544 ± 0.045	0.573 ± 0.055

Dilution of combined flavor tagging in simulated and real $B^\pm \to J/\psi K^\pm$ events for different values of the $\lvert d \rvert$ variable. All uncertainties are statistical.

$\lvert d \rvert$	$\mathcal{D}$ (%)	$\mathcal{P}$ (%)
$0.00 < \lvert d \rvert < 0.10$	0.056 ± 0.024	0.10 ± 0.08
$0.10 < \lvert d \rvert < 0.20$	0.127 ± 0.025	0.45 ± 0.18
$0.20 < \lvert d \rvert < 0.35$	0.254 ± 0.026	1.60 ± 0.33
$0.35 < \lvert d \rvert < 0.45$	0.323 ± 0.045	0.83 ± 0.23
$0.45 < \lvert d \rvert < 0.60$	0.571 ± 0.059	1.15 ± 0.25
$0.60 < \lvert d \rvert < 1.00$	0.556 ± 0.084	0.55 ± 0.17
Total	-	4.68 ± 0.54

Dilution and tagging power of combined flavor tagging in simulated $B_s^0 \to J/\psi\phi$ events for different values of the $|d|$ variable. All uncertainties are statistical.

Reversal of solenoid and toroid magnet polarities allows cancelations of systematic uncertainties of the charge asymmetry.

$$n_q^{\beta\gamma} = \frac{1}{4} N \epsilon^{\beta} (1 + qA)(1 + q\gamma A_{fb})(1 + \gamma A_{det}) \times (1 + q\beta\gamma A_{q\beta\gamma})(1 + q\beta A_{q\beta})(1 + \beta\gamma A_{\beta\gamma}).$$

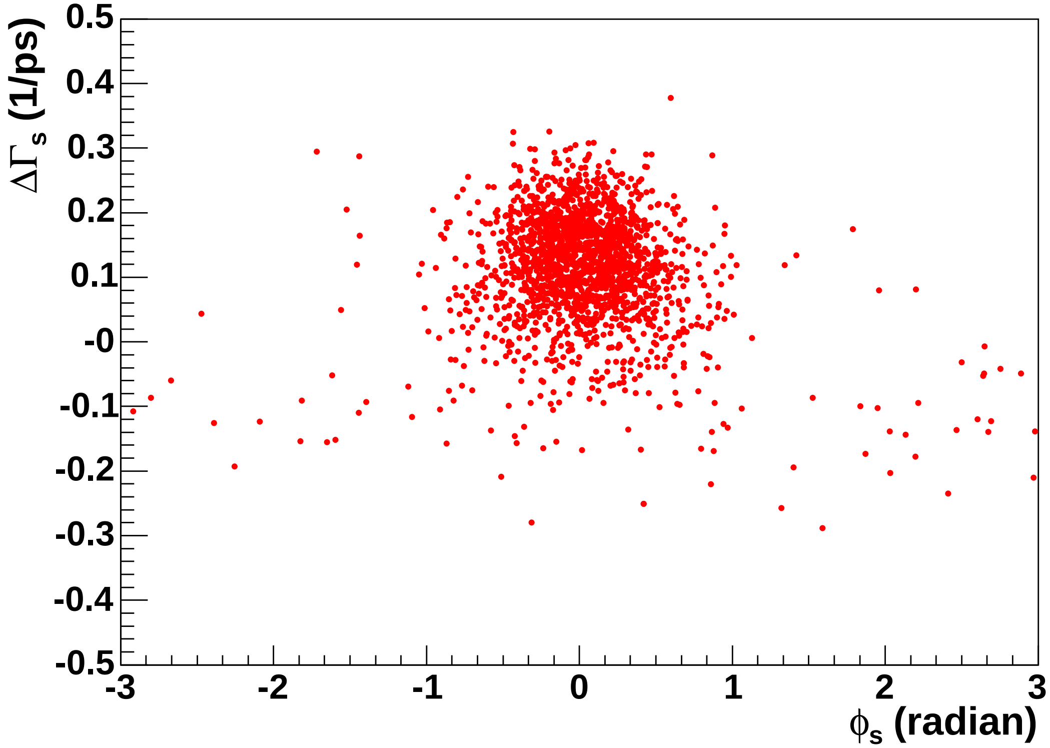
$\beta\gamma q$	$J/\psi K$	$J/\psi\pi$	$J/\psi K^*$	background
$+++$	$5,104 \pm 87$	337 ± 44	692 ± 77	$4,079 \pm 151$
$+-+$	$5,131 \pm 87$	222 ± 42	689 ± 78	$4,170 \pm 151$
$++-$	$4,999 \pm 85$	212 ± 40	767 ± 76	$3,978 \pm 149$
$+--$	$5,098 \pm 86$	144 ± 38	523 ± 77	$4,395 \pm 150$
$-++$	$4,973 \pm 86$	158 ± 41	578 ± 78	$4,397 \pm 151$
$--+$	$5,039 \pm 86$	127 ± 39	663 ± 78	$4,281 \pm 150$
$-+-$	$4,965 \pm 85$	242 ± 41	794 ± 76	$3,880 \pm 148$
$---$	$4,906 \pm 84$	138 ± 39	724 ± 75	$4,006 \pm 147$
#tot	$40,222 \pm 242$	$1,578 \pm 119$	$5,429 \pm 217$	$33,192 \pm 425$

Number of events in the $J/\psi K$, $J/\psi\pi$, $J/\psi K^*$, and background channels in different $\beta\gamma q$ subsamples. β is the solenoid polarity, γ is the sign of the pseudorapidity, and q is the charge.

	$J/\psi K$	$J/\psi\pi$	background
N	$40,217 \pm 243$	$1,577 \pm 118$	$33,189 \pm 424$
ϵ^+	0.5060 ± 0.0030	0.5060 ± 0.0030	0.5010 ± 0.0064
A	-0.0070 ± 0.0060	-0.0887 ± 0.0807	-0.0205 ± 0.0128
A_{fb}	0.0013 ± 0.0060	0.0453 ± 0.0890	-0.0170 ± 0.0128
A_{det}	-0.0033 ± 0.0060	0.2061 ± 0.0826	-0.0158 ± 0.0128
$A_{q\beta\gamma}$	-0.0050 ± 0.0060	-0.0207 ± 0.0873	-0.0024 ± 0.0128
$A_{q\beta}$	0.0001 ± 0.0060	-0.1896 ± 0.0823	0.0274 ± 0.0128
$A_{\beta\gamma}$	-0.0030 ± 0.0060	0.0499 ± 0.0801	-0.0145 ± 0.0128

Physics asymmetry A and detector asymmetries for different channels.

Pseudo-experiments generated with $\Delta\Gamma = 0.14$ ps^{-1} and $\phi_s = -0.04$.



Pseudo-experiments generated with $\Delta\Gamma = 0.0$ and $\phi_s = 0.0$.