Sin2β Measurement Backup

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Sin2β LHCb

Systematics

Table 1
Summary of systematic uncertainties on the *CP* parameters.

Origin	$\sigma(S_{J/\psi K^0_S})$	$\sigma(C_{J/\psi K^0_S})$
Tagging calibration	0.034	0.001
Tagging efficiency difference	0.002	0.002
Decay time resolution	0.001	0.002
Decay time acceptance	0.002	0.006
Background model	0.012	0.009
Fit bias	0.004	0.005
Total	0.036	0.012

Sin2β LHCb

Flavour Tagging – Calibration

Eur. Phys. J. C 72 (2012) 2022
LHCb-CONF-2012-026

- Calibrate the mistag probability prediction with self-tagging channels
  - linear calibration function

η=per event mistag probability prediction

$$\omega(\eta) = p_0 + p_1(\eta_c - \langle\eta_c\rangle)$$

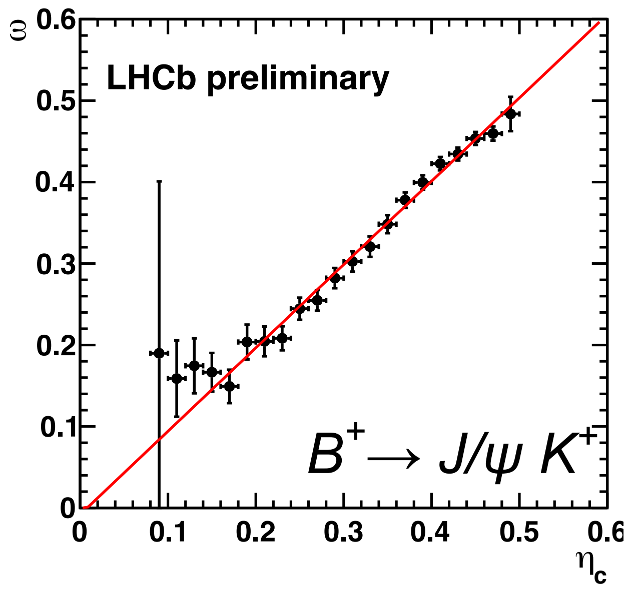
- perfect calibration if

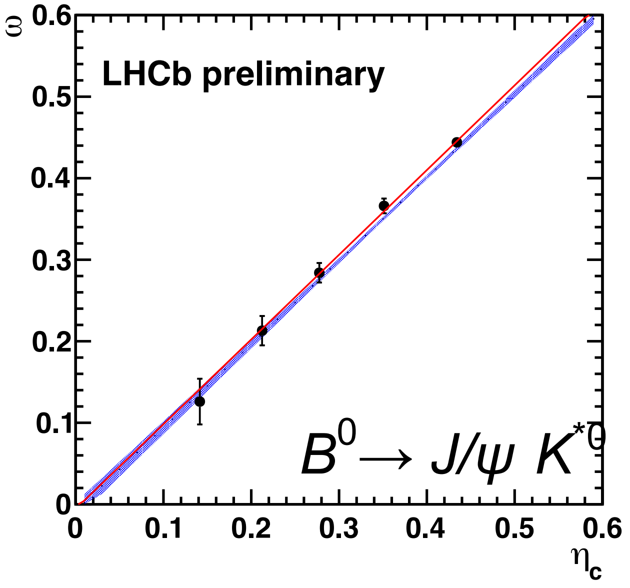
$$p_1 = 1$$
$$p_0 = \langle\eta_c\rangle$$

- for OS combination on $B^+ \rightarrow J/\psi\, K^+$
- validation on other control channels

- Mistag probability asymmetry

$$\Delta\omega = p_0(B^0) - p_0(\overline{B}^0) = 0.011 \pm 0.003$$





Sin2β Belle

CP parameters for individual modes

TABLE II. *CP* violation parameters for each $B^0 \to f_{CP}$ mode and from the simultaneous fit for all modes together. The first and second errors are statistical and systematic uncertainties, respectively.

Decay mode	$\sin 2\phi_1 \equiv -\xi_f \mathcal{S}_f$	$\mathcal{A}_f$
$J/\psi K_S^0$	$+0.670 \pm 0.029 \pm 0.013$	$-0.015 \pm 0.021^{+0.045}_{-0.023}$
$\psi(2S)K_S^0$	$+0.738 \pm 0.079 \pm 0.036$	$+0.104 \pm 0.055^{+0.047}_{-0.027}$
$\chi_{c1}K_S^0$	$+0.640 \pm 0.117 \pm 0.040$	$-0.017 \pm 0.083^{+0.046}_{-0.026}$
$J/\psi K_L^0$	$+0.642 \pm 0.047 \pm 0.021$	$+0.019 \pm 0.026^{+0.017}_{-0.041}$
All modes	$+0.667 \pm 0.023 \pm 0.012$	$+0.006 \pm 0.016 \pm 0.012$

Systematic Uncertainties

TABLE III. Systematic errors in $\mathcal{S}_f$ and $\mathcal{A}_f$ in each f_{CP} mode and for the sum of all modes.

		$J/\psi K_S^0$	$\psi(2S)K_S^0$	$\chi_{c1}K_S^0$	$J/\psi K_L^0$	All
Vertexing	$\mathcal{S}_f$	±0.008	±0.031	±0.025	±0.011	±0.007
	$\mathcal{A}_f$	±0.022	±0.026	±0.021	±0.015	±0.007
Δt resolution	$\mathcal{S}_f$	±0.007	±0.007	±0.005	±0.007	±0.007
	$\mathcal{A}_f$	±0.004	±0.003	±0.004	±0.003	±0.001
Tag-side interference	$\mathcal{S}_f$	±0.002	±0.002	±0.002	±0.001	±0.001
	$\mathcal{A}_f$	$^{+0.038}_{-0.000}$	$^{+0.038}_{-0.000}$	$^{+0.038}_{-0.000}$	$^{+0.000}_{-0.037}$	±0.008
Flavor tagging	$\mathcal{S}_f$	±0.003	±0.003	±0.004	±0.003	±0.004
	$\mathcal{A}_f$	±0.003	±0.003	±0.003	±0.003	±0.003
Possible fit bias	$\mathcal{S}_f$	±0.004	±0.004	±0.004	±0.004	±0.004
	$\mathcal{A}_f$	±0.005	±0.005	±0.005	±0.005	±0.005
Signal fraction	$\mathcal{S}_f$	±0.004	±0.016	<0.001	±0.016	±0.004
	$\mathcal{A}_f$	±0.002	±0.006	<0.001	±0.006	±0.002
Background Δt PDFs	$\mathcal{S}_f$	<0.001	±0.002	±0.030	±0.002	±0.001
	$\mathcal{A}_f$	<0.001	<0.001	±0.014	<0.001	<0.001
Physics parameters	$\mathcal{S}_f$	±0.001	±0.001	±0.001	±0.001	±0.001
	$\mathcal{A}_f$	<0.001	<0.001	±0.001	<0.001	<0.001
Total	$\mathcal{S}_f$	±0.013	±0.036	±0.040	±0.021	±0.012
	$\mathcal{A}_f$	$^{+0.045}_{-0.023}$	$^{+0.047}_{-0.027}$	$^{+0.046}_{-0.026}$	$^{+0.017}_{-0.041}$	±0.012

[PRL 108 171801 (2012)]

Belle Sin2β at the Y(5S)

- Belle has measured sin2β at the Y(5S) using the technique of “B-π” tagging

$$\Upsilon(5S)\ \text{to}\ \bar{B}^{(*)0}B^{(*)+}\pi^-$$

Tag with the charge of the π

Fully reconstructed to CP eigenstate

Not reconstructed

$$A_{BB\pi} \equiv \frac{N_{BB\pi^-} - N_{BB\pi^+}}{N_{BB\pi^-} + N_{BB\pi^+}} = \frac{\mathcal{S}x + \mathcal{A}}{1 + x^2},$$

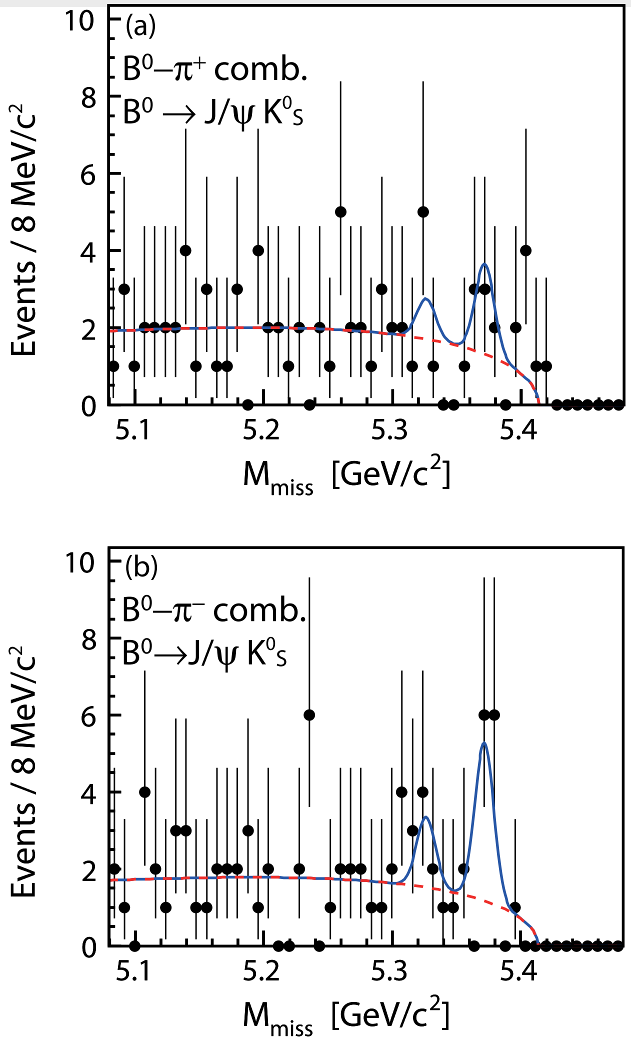
Time Integrated! Could be used for, e.g., $B^0 \to \pi^0\pi^0$ at Super B factory

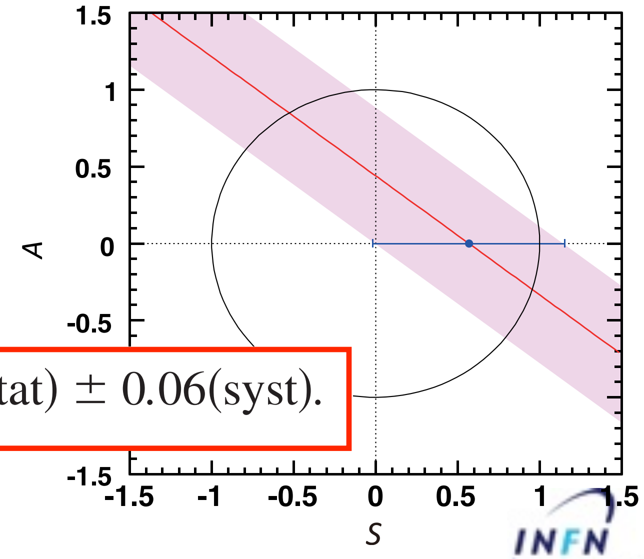
where $N_{BB\pi^+}$ and $N_{BB\pi^-}$ are the observed number of $B^{(*)0}B^{(*)-}\pi^+$ and $\bar{B}^{(*)0}B^{(*)+}\pi^-$ events in which the neutral B decays to a CP eigenstate, respectively, and $\mathcal{S}$ and $\mathcal{A}$ are the mixing-induced and direct CP-violating parameters,

$$x = (m_H - m_L)/\Gamma, \quad \Gamma = (\Gamma_H + \Gamma_L)/2,$$

$$y = (\Gamma_L - \Gamma_H)/2\Gamma$$

assuming y = 0 ⇒ $\sin 2\phi_1 = -\eta_{CP}\left(\frac{1 + x^2}{x}\right)A_{BB\pi}.$

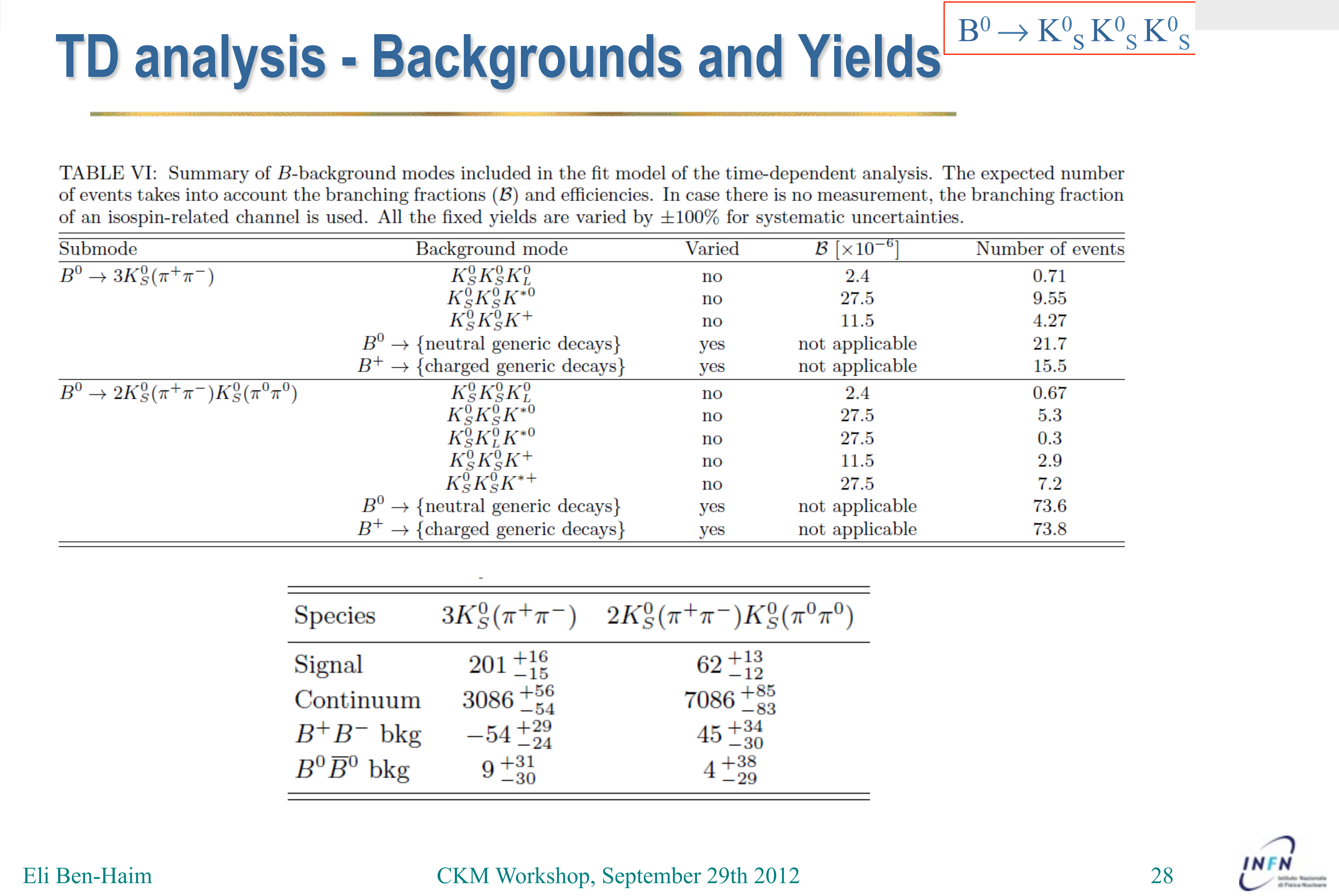




$$\boxed{\sin 2\phi_1 = 0.57 \pm 0.58(\text{stat}) \pm 0.06(\text{syst}).}$$

BaBar $B^0 \rightarrow K_S K_S K_S$

$B^0 \rightarrow K^0_S K^0_S K^0_S$



TD analysis - Backgrounds and Yields

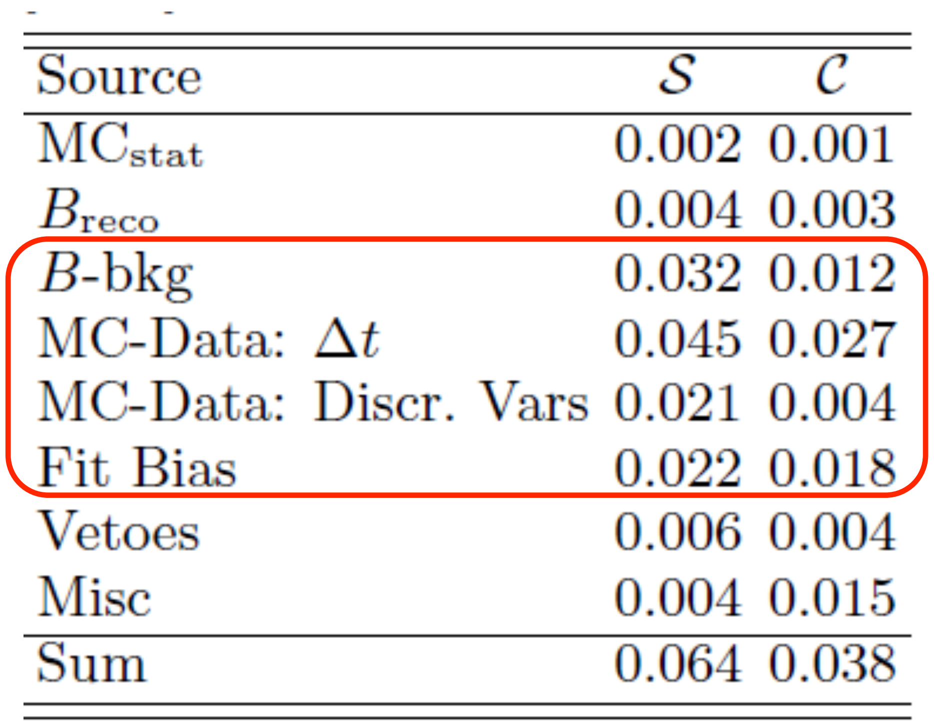
TABLE VI: Summary of B-background modes included in the fit model of the time-dependent analysis. The expected number of events takes into account the branching fractions ($\mathcal{B}$) and efficiencies. In case there is no measurement, the branching fraction of an isospin-related channel is used. All the fixed yields are varied by ±100% for systematic uncertainties.

Submode	Background mode	Varied	$\mathcal{B}$ [$\times 10^{-6}$]	Number of events
$B^0 \rightarrow 3K^0_S(\pi^+\pi^-)$	$K^0_S K^0_S K^0_L$	no	2.4	0.71
	$K^0_S K^0_S K^{*0}$	no	27.5	9.55
	$K^0_S K^0_S K^+$	no	11.5	4.27
	$B^0 \rightarrow$ {neutral generic decays}	yes	not applicable	21.7
	$B^+ \rightarrow$ {charged generic decays}	yes	not applicable	15.5
$B^0 \rightarrow 2K^0_S(\pi^+\pi^-)K^0_S(\pi^0\pi^0)$	$K^0_S K^0_S K^0_L$	no	2.4	0.67
	$K^0_S K^0_S K^{*0}$	no	27.5	5.3
	$K^0_S K^0_L K^{*0}$	no	27.5	0.3
	$K^0_S K^0_S K^+$	no	11.5	2.9
	$K^0_S K^0_S K^{*+}$	no	27.5	7.2
	$B^0 \rightarrow$ {neutral generic decays}	yes	not applicable	73.6
	$B^+ \rightarrow$ {charged generic decays}	yes	not applicable	73.8

Species	$3K^0_S(\pi^+\pi^-)$	$2K^0_S(\pi^+\pi^-)K^0_S(\pi^0\pi^0)$
Signal	201^{+16}_{-15}	62^{+13}_{-12}
Continuum	3086^{+56}_{-54}	7086^{+85}_{-83}
B^+B^- bkg	-54^{+29}_{-24}	45^{+34}_{-30}
$B^0\overline{B}^0$ bkg	9^{+31}_{-30}	4^{+38}_{-29}

BaBar $B^0 \rightarrow K_s K_s K_s$

TD analysis: systematic uncertainties



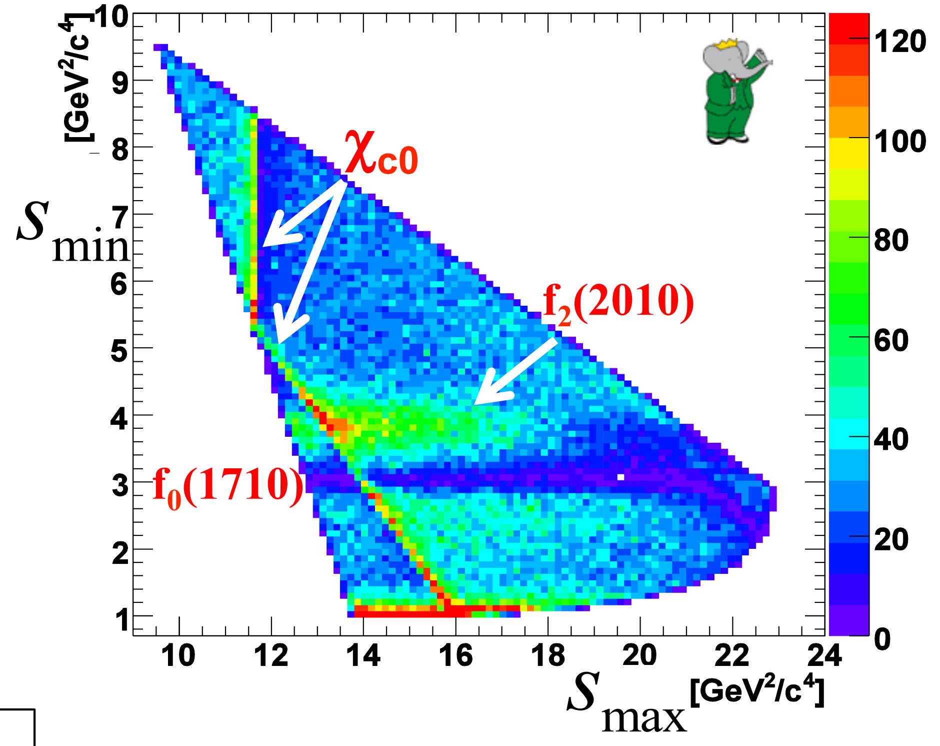
Source	$\mathcal{S}$	$\mathcal{C}$
MC_{stat}	0.002	0.001
B_{reco}	0.004	0.003
B-bkg	0.032	0.012
MC-Data: Δt	0.045	0.027
MC-Data: Discr. Vars	0.021	0.004
Fit Bias	0.022	0.018
Vetoes	0.006	0.004
Misc	0.004	0.015
Sum	0.064	0.038

BaBar $B^0 \rightarrow K_S K_S K_S$

$B^0 \rightarrow K_S K_S K_S$

Results of the amplitude analysis

$f_0(980)K_S^0$	**Fit Fraction (FF)**	$0.44\,^{+0.20}_{-0.19}$
	Significance $[\sigma]$	3.0
$f_0(1710)K_S^0$	FF	$0.07\,^{+0.07}_{-0.03}$
	Significance $[\sigma]$	3.3
$f_2(2010)K_S^0$	FF	$0.09\,^{+0.03}_{-0.03}$
	Significance $[\sigma]$	3.3
NR	FF	$2.16\,^{+0.36}_{-0.37}$
	Significance $[\sigma]$	8.0
$\chi_{c0}K_S^0$	FF	$0.07\,^{+0.04}_{-0.02}$
	Significance $[\sigma]$	3.9
	Total FF	$2.84\,^{+0.71}_{-0.66}$



5 (+inclusive) Branching fractions (*B*)

Mode	$\mathcal{B}\ [\times 10^{-6}]$
Inclusive $B^0 \rightarrow K_S^0 K_S^0 K_S^0$	$6.19 \pm 0.48 \pm 0.15 \pm 0.12$
$f_0(980)K_S^0,\quad f_0(980) \rightarrow K_S^0 K_S^0$	$2.7\,^{+1.3}_{-1.2} \pm 0.4 \pm 1.2$
$f_0(1710)K_S^0,\quad f_0(1710) \rightarrow K_S^0 K_S^0$	$0.50\,^{+0.46}_{-0.24} \pm 0.04 \pm 0.10$
$f_2(2010)K_S^0,\quad f_2(2010) \rightarrow K_S^0 K_S^0$	$0.54\,^{+0.21}_{-0.20} \pm 0.03 \pm 0.52$
NR, $\quad K_S^0 K_S^0 K_S^0$	$13.3\,^{+2.2}_{-2.3} \pm 0.6 \pm 2.1$
$\chi_{c0}K_S^0,\quad \chi_{c0} \rightarrow K_S^0 K_S^0$	$0.46\,^{+0.25}_{-0.17} \pm 0.02 \pm 0.21$

PDG:
$6.2 \pm ^{1.2}_{1.1}$

Consistent with other measurements

BaBar $B^0 \rightarrow K^+K^-K_s$

Main sources of backgrounds and yields

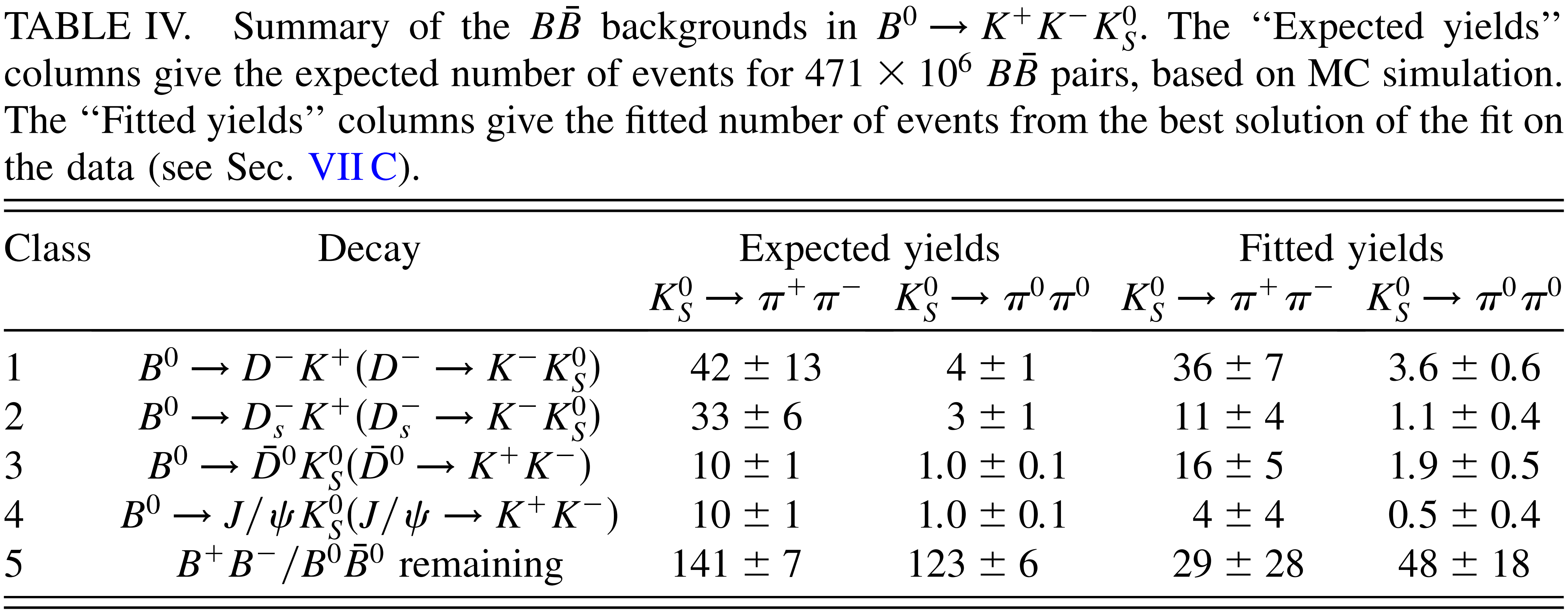


TABLE IV. Summary of the $B\bar{B}$ backgrounds in $B^0 \to K^+K^-K^0_S$. The “Expected yields” columns give the expected number of events for 471×10^6 $B\bar{B}$ pairs, based on MC simulation. The “Fitted yields” columns give the fitted number of events from the best solution of the fit on the data (see Sec. VII C).

Class	Decay	Expected yields		Fitted yields	
		$K^0_S \to \pi^+\pi^-$	$K^0_S \to \pi^0\pi^0$	$K^0_S \to \pi^+\pi^-$	$K^0_S \to \pi^0\pi^0$
1	$B^0 \to D^-K^+(D^- \to K^-K^0_S)$	42 ± 13	4 ± 1	36 ± 7	3.6 ± 0.6
2	$B^0 \to D^-_sK^+(D^-_s \to K^-K^0_S)$	33 ± 6	3 ± 1	11 ± 4	1.1 ± 0.4
3	$B^0 \to \bar{D}^0K^0_S(\bar{D}^0 \to K^+K^-)$	10 ± 1	1.0 ± 0.1	16 ± 5	1.9 ± 0.5
4	$B^0 \to J/\psi K^0_S(J/\psi \to K^+K^-)$	10 ± 1	1.0 ± 0.1	4 ± 4	0.5 ± 0.4
5	$B^+B^-/B^0\bar{B}^0$ remaining	141 ± 7	123 ± 6	29 ± 28	48 ± 18

BaBar $B^0 \rightarrow K^+K^-K_s$

Main sources of systematic uncertainties

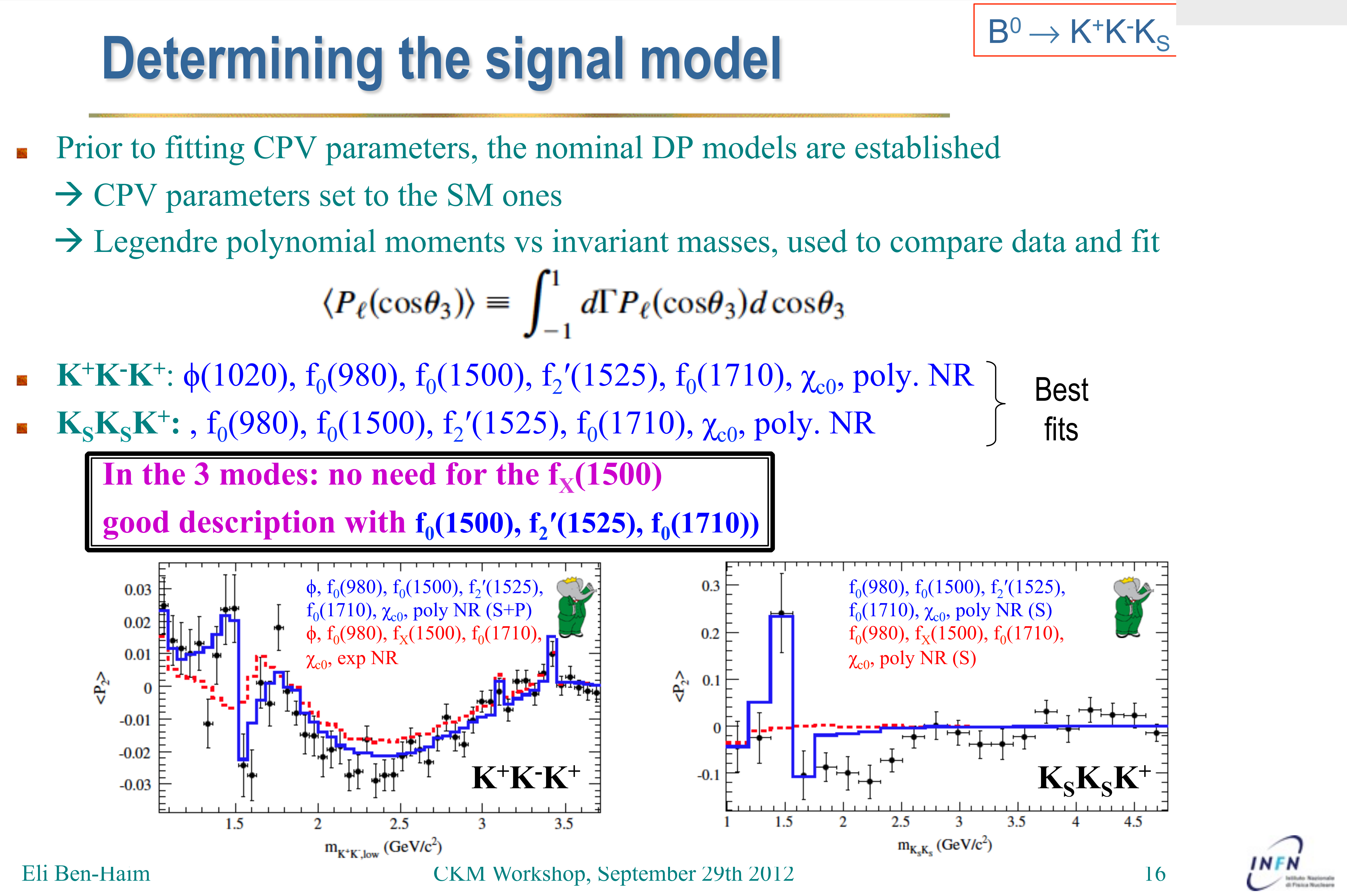
TABLE XVII. Summary of systematic uncertainties for $B^0 \to K^+K^-K_S^0$ parameters. Errors on angles, A_{CP}'s, and branching fractions are given in degrees, percent, and units of 10^{-6}, respectively.

Parameter	Line shape	Fixed PDF params	Other	Add resonances	Fit bias	Total
$\beta_{\mathrm{eff}}(\phi(1020))$	2	1	0	2	0	2
$\beta_{\mathrm{eff}}(f_0(980))$	1	1	0	4	0	4
β_{eff} (other)	0.7	0.4	0.2	0.8	0.4	1.2
$A_{CP}(\phi(1020))$	2	2	2	2	3	5
$A_{CP}(f_0(980))$	6	3	2	5	2	9
A_{CP} (other)	1	1	1	2	1	3
$\mathcal{B}(\phi(1020))$	0.13	0.05	0.08	0.05	0.03	0.18
$\mathcal{B}(f_0(980))$	1.3	0.3	0.1	2.0	0.1	2.4
$\mathcal{B}(f_0(1500))$	0.04	0.02	0.02	0.10	0.03	0.12
$\mathcal{B}(f_2'(1525))$	0.02	0.01	0.00	0.15	0.02	0.16
$\mathcal{B}(f_0(1710))$	0.3	0.1	0.1	0.4	0.1	0.5
$\mathcal{B}(\chi_{c0})$	0.02	0.02	0.02	0.01	0.04	0.06
$\mathcal{B}$ (NR(total))	2	1	1	8	1	9
$\mathcal{B}$ (NR (S wave))	2	1	1	8	1	8
$\mathcal{B}$ (NR (P wave))	0.1	0.2	0.1	0.3	0.1	0.4
$\mathcal{B}$ (total)	0.0	0.4	0.7	0.0	0.1	0.8
$\mathcal{B}$ (charmless)	0.1	0.4	0.6	0.0	0.2	0.8

Additional resonances:

We test for the $f_0(1370)$, $a_0^0(1450)$, $f_2(1270)$, $f_2(2010)$, and $f_2(2300)$ in each mode. We also test for the $\phi(1680)$ in $B^+ \to K^+K^-K^+$ and $B^0 \to K^+K^-K_S^0$, and the $a_0^\pm(980)$ and $a_0^\pm(1450)$ in $B^+ \to K_S^0K_S^0K^+$ and $B^0 \to K^+K^-K_S^0$.

BaBar $B^0 \to K^+K^-K_S$



$B^0 \to K^+K^-K_S$

Determining the signal model

- Prior to fitting CPV parameters, the nominal DP models are established

  → CPV parameters set to the SM ones

  → Legendre polynomial moments vs invariant masses, used to compare data and fit

$$\langle P_\ell(\cos\theta_3)\rangle \equiv \int_{-1}^{1} d\Gamma P_\ell(\cos\theta_3) d\cos\theta_3$$

- **$K^+K^-K^+$**: $\phi(1020)$, $f_0(980)$, $f_0(1500)$, $f_2'(1525)$, $f_0(1710)$, χ_{c0}, poly. NR
- **$K_SK_SK^+$**: , $f_0(980)$, $f_0(1500)$, $f_2'(1525)$, $f_0(1710)$, χ_{c0}, poly. NR

} Best fits

In the 3 modes: no need for the $f_X(1500)$

good description with $f_0(1500)$, $f_2'(1525)$, $f_0(1710)$)

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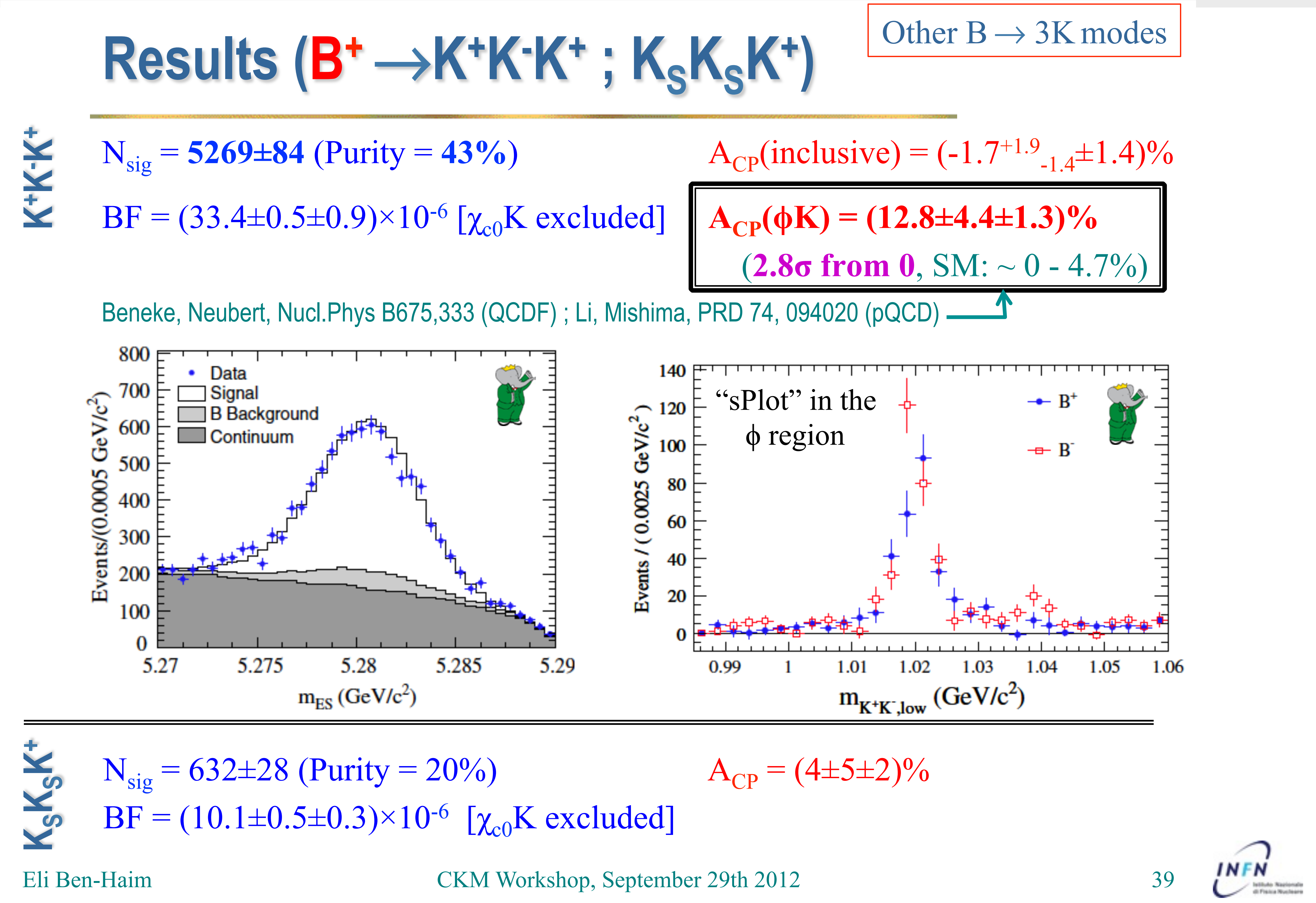
BaBar B±→K$^+$K$^-$K± and K$_S$K$_S$K±

Other B → 3K modes



Results ($B^+ \to K^+K^-K^+$; $K_SK_SK^+$)

$K^+K^-K^+$

N_{sig} = **5269±84** (Purity = **43%**)

BF = $(33.4\pm0.5\pm0.9)\times10^{-6}$ [χ_{c0}K excluded]

A_{CP}(inclusive) = $(-1.7^{+1.9}_{-1.4}\pm1.4)\%$

$A_{CP}(\phi K) = (12.8\pm4.4\pm1.3)\%$

(**2.8σ from 0**, SM: ~ 0 - 4.7%)

Beneke, Neubert, Nucl.Phys B675,333 (QCDF) ; Li, Mishima, PRD 74, 094020 (pQCD)

$K_SK_SK^+$

N_{sig} = 632±28 (Purity = 20%)

BF = $(10.1\pm0.5\pm0.3)\times10^{-6}$ [χ_{c0}K excluded]

A_{CP} = (4±5±2)%

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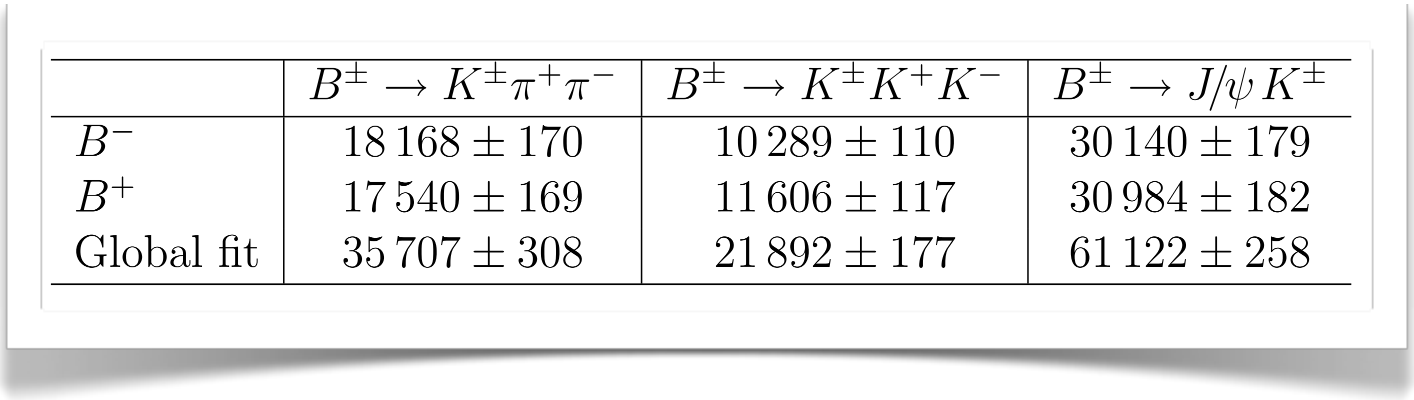
[LHCb-CONF-2012-018]

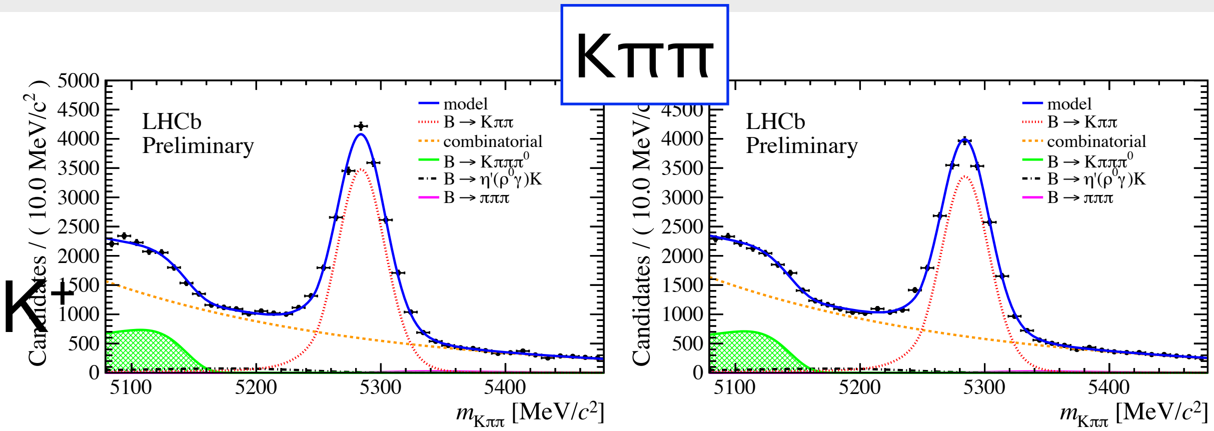
LHCb $B^\pm \rightarrow K^+K^-K^\pm$

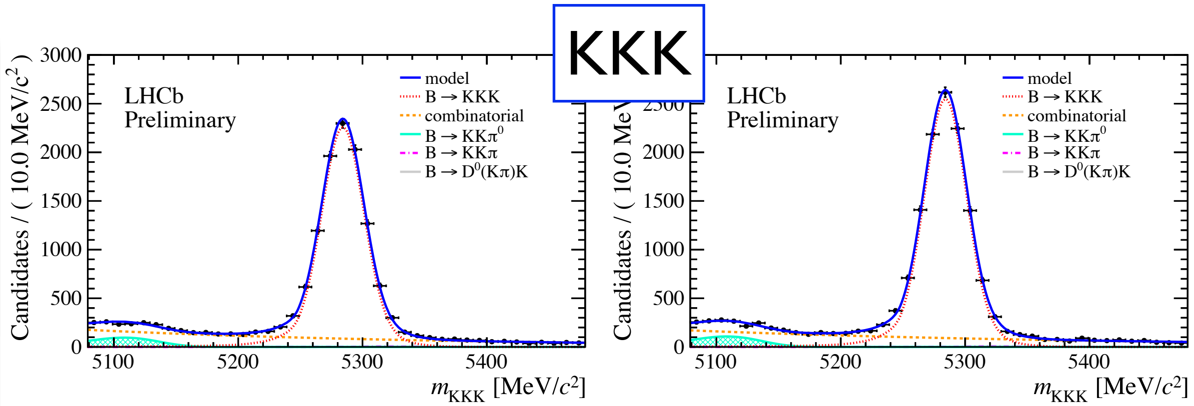
- Data sample: $L=1\ \mathrm{fb}^{-1}$
- Effect of production and detection asymmetries taken into account using $J/\psi K^+$ control sample

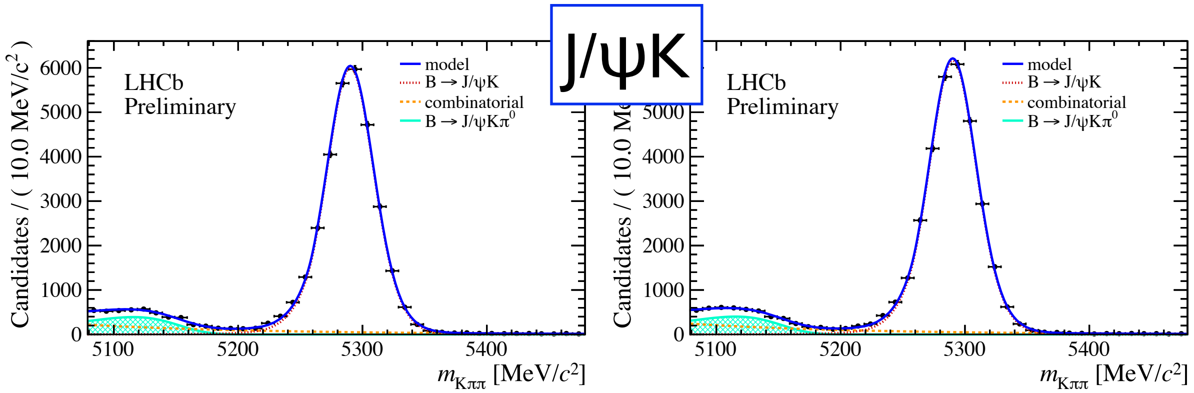


	$B^\pm \to K^\pm\pi^+\pi^-$	$B^\pm \to K^\pm K^+K^-$	$B^\pm \to J/\psi\, K^\pm$
B^-	$18\,168 \pm 170$	$10\,289 \pm 110$	$30\,140 \pm 179$
B^+	$17\,540 \pm 169$	$11\,606 \pm 117$	$30\,984 \pm 182$
Global fit	$35\,707 \pm 308$	$21\,892 \pm 177$	$61\,122 \pm 258$

$$A_{CP}^{\mathrm{RAW}} = \frac{N_{B^-} - N_{B^+}}{N_{B^-} + N_{B^+}}\,.$$







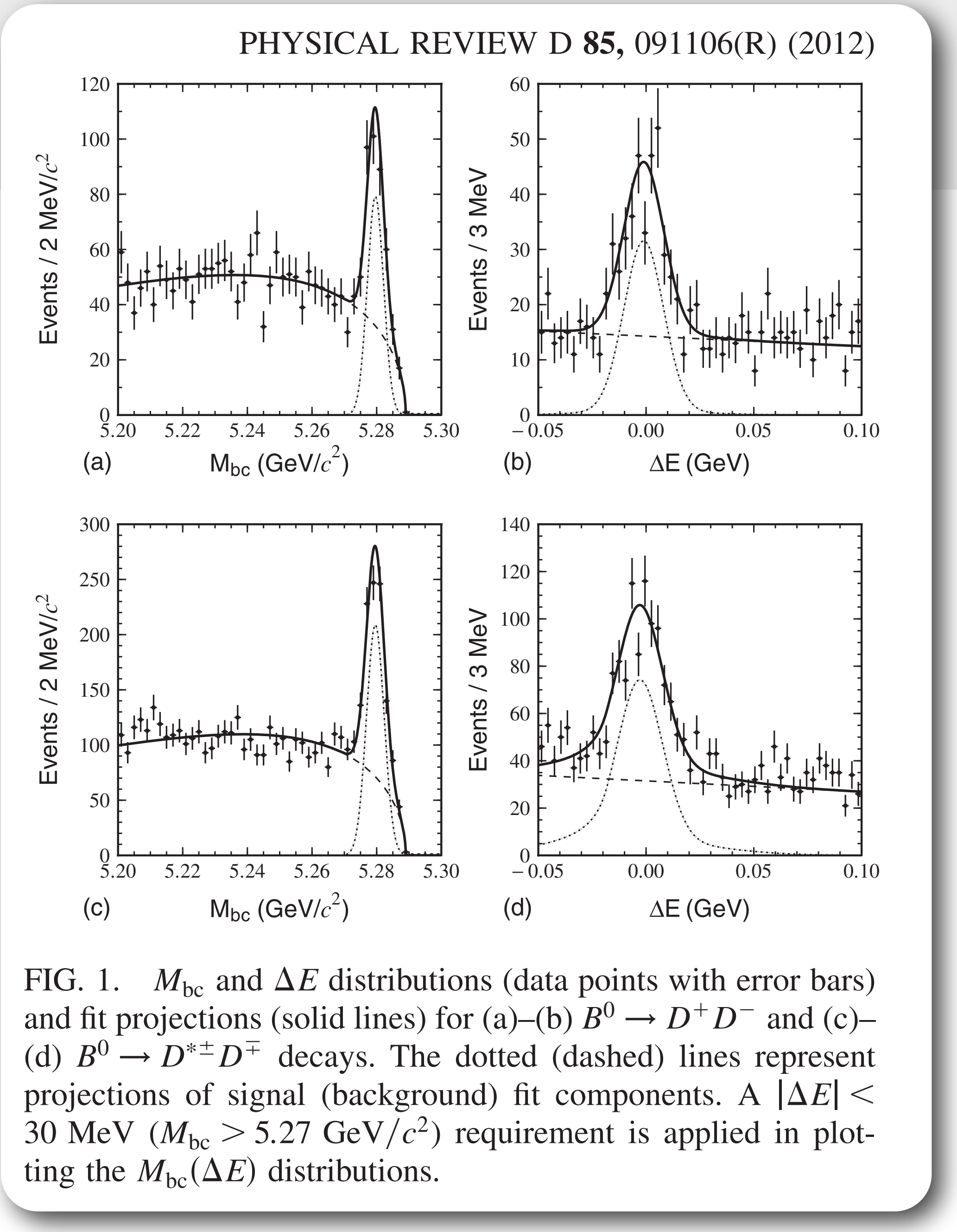
$$A_{CP}(K^\pm h^+ h^-) = A_{CP}^{\mathrm{RAW}}(K^\pm h^+ h^-) - A_{CP}^{\mathrm{RAW}}(J/\psi\, K^\pm) + A_{CP}(J/\psi\, K^\pm)\,,$$

FIRST EVIDENCE!

$$A_{CP}(B^\pm \to K^\pm\pi^+\pi^-) = +0.034 \pm 0.009(\mathrm{stat}) \pm 0.004(\mathrm{syst}) \pm 0.007(J/\psi K^\pm)\,,$$

$$\boxed{A_{CP}(B^\pm \to K^\pm K^+ K^-) = -0.046 \pm 0.009(\mathrm{stat}) \pm 0.005(\mathrm{syst}) \pm 0.007(J/\psi K^\pm)\,,}$$

Belle $B^0 \to D(^*)^+D^-$



PHYSICAL REVIEW D **85,** 091106(R) (2012)

FIG. 1. M_{bc} and ΔE distributions (data points with error bars) and fit projections (solid lines) for (a)–(b) $B^0 \to D^+D^-$ and (c)–(d) $B^0 \to D^{*\pm}D^{\mp}$ decays. The dotted (dashed) lines represent projections of signal (background) fit components. A $|\Delta E| < 30$ MeV ($M_{bc} > 5.27$ GeV$/c^2$) requirement is applied in plotting the $M_{bc}(\Delta E)$ distributions.

D^*D

$$\mathcal{A}_{D^*D} = +0.06 \pm 0.05 \pm 0.02,$$
$$\mathcal{S}_{D^*D} = -0.78 \pm 0.15 \pm 0.05,$$
$$\mathcal{C}_{D^*D} = -0.01 \pm 0.11 \pm 0.04,$$
$$\Delta\mathcal{S}_{D^*D} = -0.13 \pm 0.15 \pm 0.04,$$
$$\Delta\mathcal{C}_{D^*D} = +0.12 \pm 0.11 \pm 0.03,$$

D^+D^-

$$\mathcal{S}_{D^+D^-} = -1.06^{+0.21}_{-0.14} \pm 0.08,$$
$$\mathcal{C}_{D^+D^-} = -0.43 \pm 0.16 \pm 0.05,$$

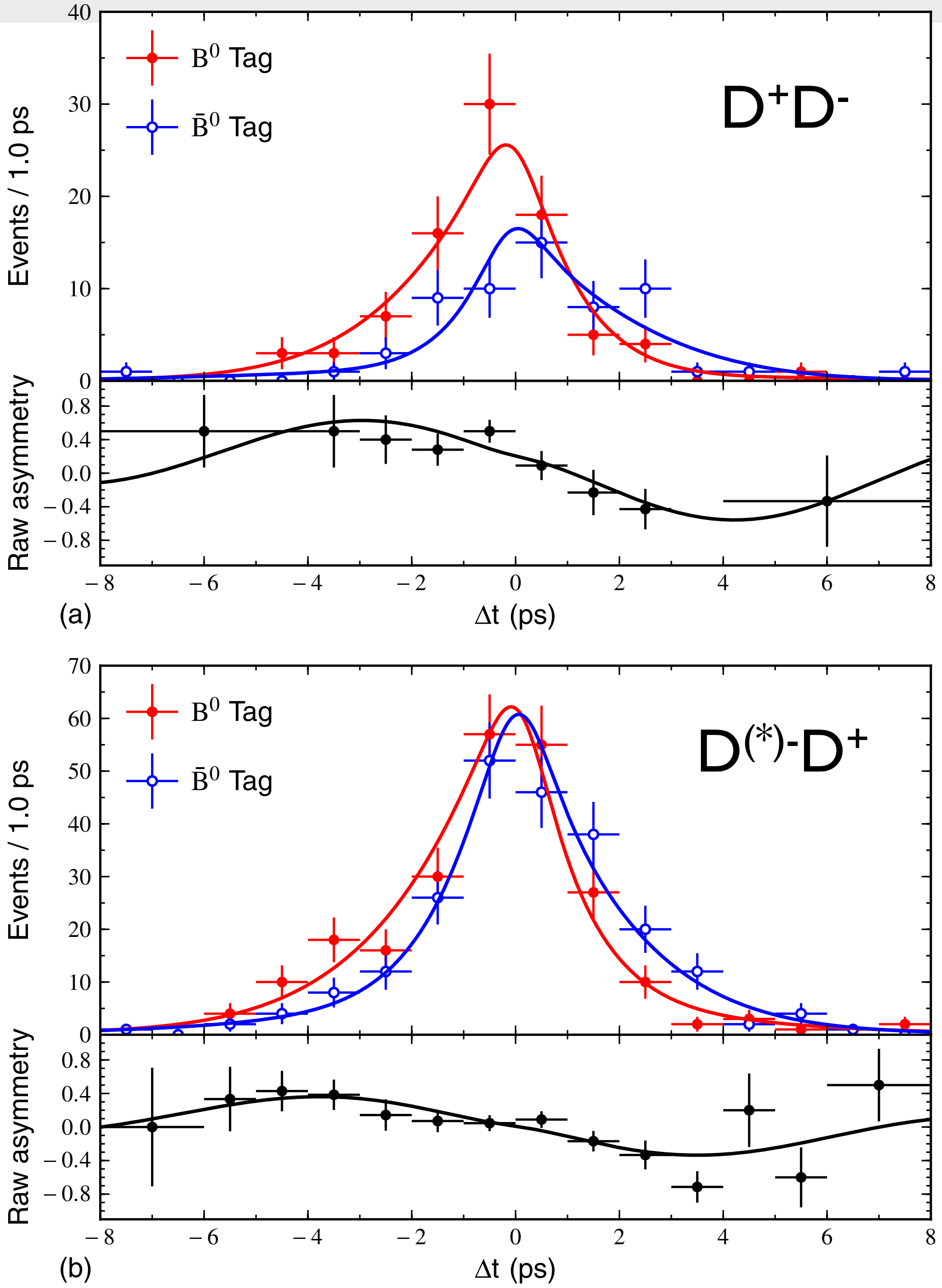


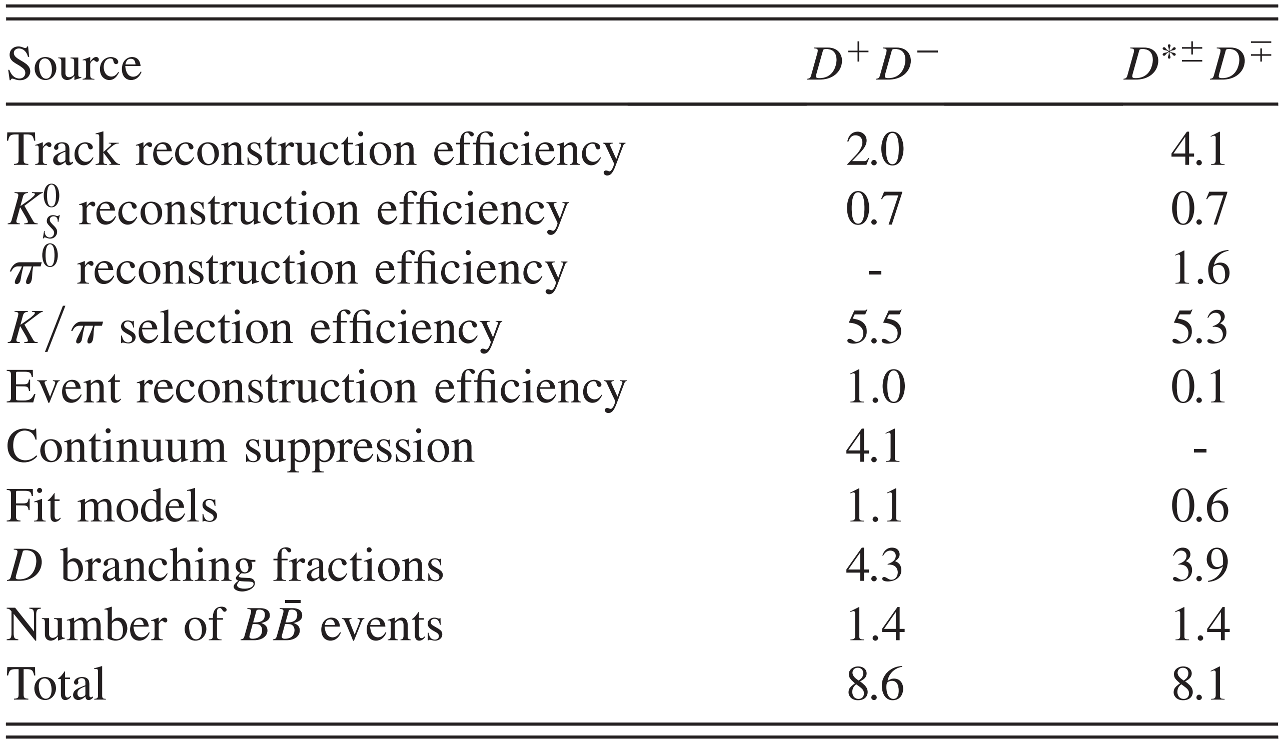
FIG. 2 (color online). Top: Δt distributions (data points with error bars) of (a) $B^0 \to D^+D^-$ and (b) $B^0 \to D^{*+}D^- + B^0 \to D^{*-}D^+$ candidates associated with high quality flavor tags ($r > 0.5$). The lines show projections of the sum of signal and background components in the fit. The signal purity for $r > 0.5$ is 69% (66%) for $B^0 \to D^+D^-(B^0 \to D^{*\pm}D^{\mp})$. Bottom: The *CP* asymmetry obtained from the above distributions and projections.

Belle $B^0 \rightarrow D(*)^+D^-$

Systematic uncertainties

on BR's

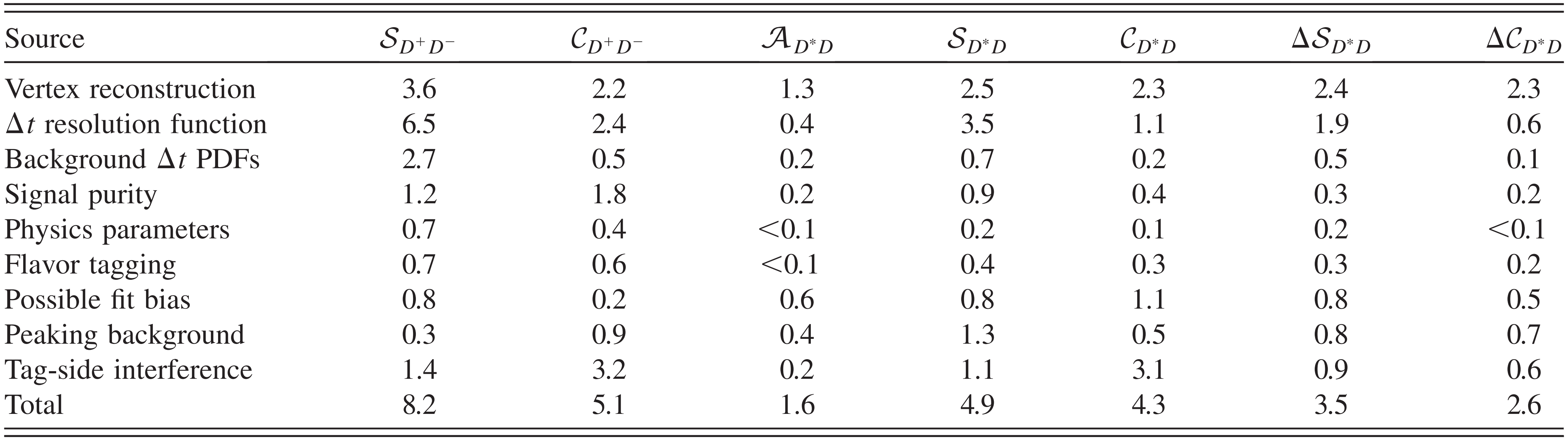
TABLE I. Summary of systematic uncertainties of the $B^0 \to D^+D^-$ and $B^0 \to D^{*\pm}D^{\mp}$ branching fractions (in %).



Source	D^+D^-	$D^{*\pm}D^{\mp}$
Track reconstruction efficiency	2.0	4.1
K_S^0 reconstruction efficiency	0.7	0.7
π^0 reconstruction efficiency	-	1.6
K/π selection efficiency	5.5	5.3
Event reconstruction efficiency	1.0	0.1
Continuum suppression	4.1	-
Fit models	1.1	0.6
D branching fractions	4.3	3.9
Number of $B\bar{B}$ events	1.4	1.4
Total	8.6	8.1

on CP asymmetries

TABLE II. Summary of systematic uncertainties in the time-dependent CP asymmetry parameters for $B^0 \to D^+D^-$ and $B^0 \to D^{*\pm}D^{\mp}$ decays (in units of 10^{-2}).



Source	$\mathcal{S}_{D^+D^-}$	$\mathcal{C}_{D^+D^-}$	$\mathcal{A}_{D^*D}$	$\mathcal{S}_{D^*D}$	$\mathcal{C}_{D^*D}$	$\Delta\mathcal{S}_{D^*D}$	$\Delta\mathcal{C}_{D^*D}$
Vertex reconstruction	3.6	2.2	1.3	2.5	2.3	2.4	2.3
Δt resolution function	6.5	2.4	0.4	3.5	1.1	1.9	0.6
Background Δt PDFs	2.7	0.5	0.2	0.7	0.2	0.5	0.1
Signal purity	1.2	1.8	0.2	0.9	0.4	0.3	0.2
Physics parameters	0.7	0.4	<0.1	0.2	0.1	0.2	<0.1
Flavor tagging	0.7	0.6	<0.1	0.4	0.3	0.3	0.2
Possible fit bias	0.8	0.2	0.6	0.8	1.1	0.8	0.5
Peaking background	0.3	0.9	0.4	1.3	0.5	0.8	0.7
Tag-side interference	1.4	3.2	0.2	1.1	3.1	0.9	0.6
Total	8.2	5.1	1.6	4.9	4.3	3.5	2.6

Belle $B^0 \to D^{*+}D^{*-}$

Systematic uncertainties

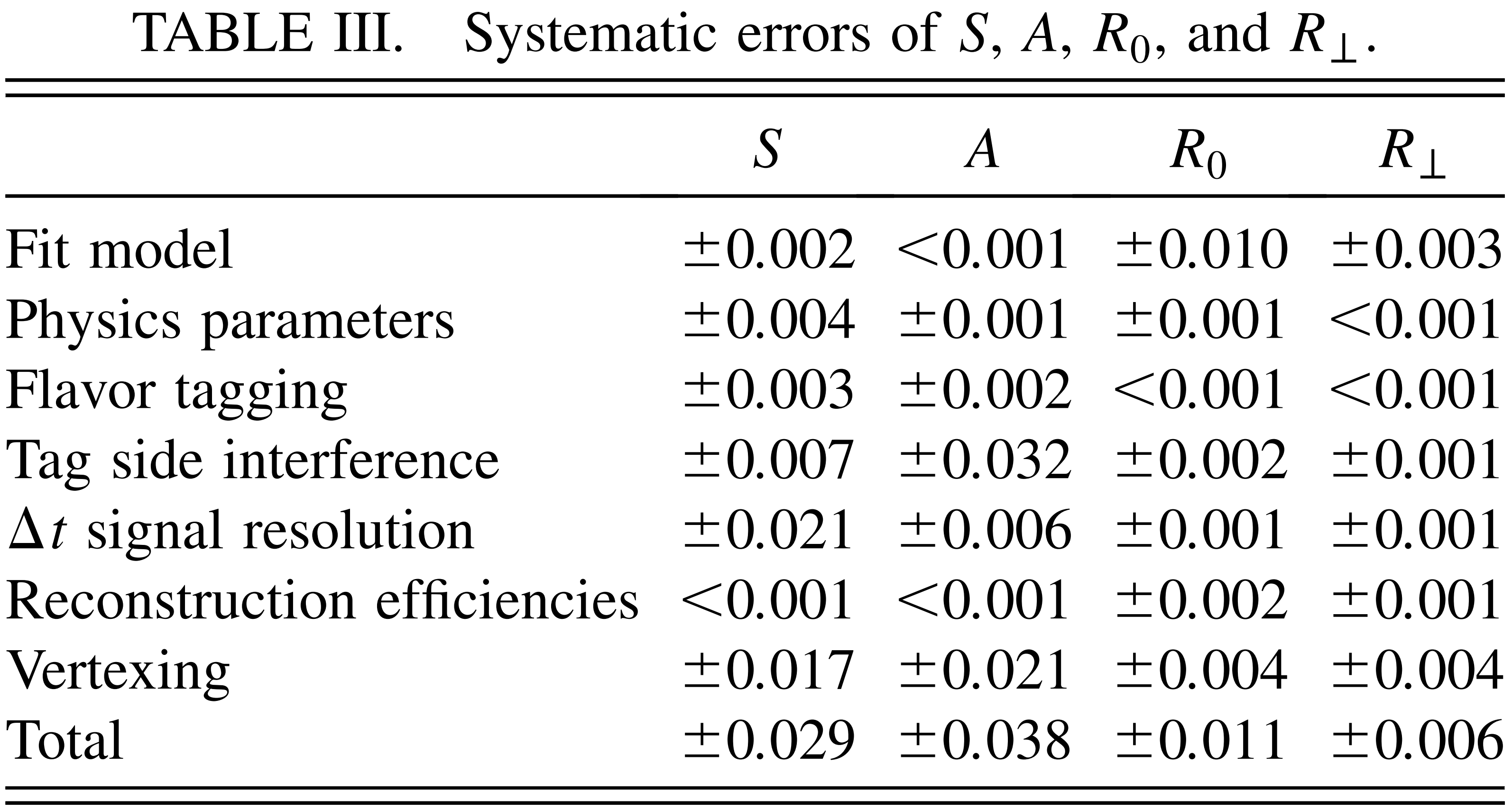
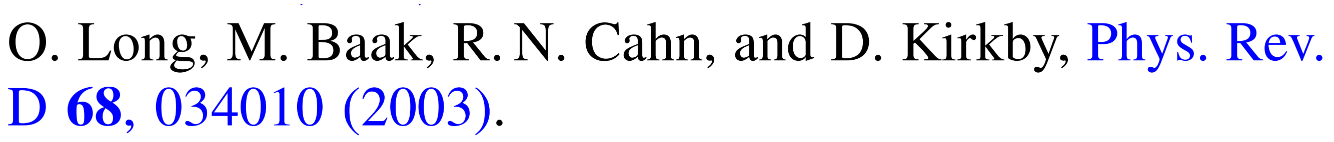


TABLE III. Systematic errors of S, A, R_0, and $R_\perp$.

	S	A	R_0	$R_\perp$
Fit model	± 0.002	< 0.001	± 0.010	± 0.003
Physics parameters	± 0.004	± 0.001	± 0.001	< 0.001
Flavor tagging	± 0.003	± 0.002	< 0.001	< 0.001
Tag side interference	± 0.007	± 0.032	± 0.002	± 0.001
Δt signal resolution	± 0.021	± 0.006	± 0.001	± 0.001
Reconstruction efficiencies	< 0.001	< 0.001	± 0.002	± 0.001
Vertexing	± 0.017	± 0.021	± 0.004	± 0.004
Total	± 0.029	± 0.038	± 0.011	± 0.006

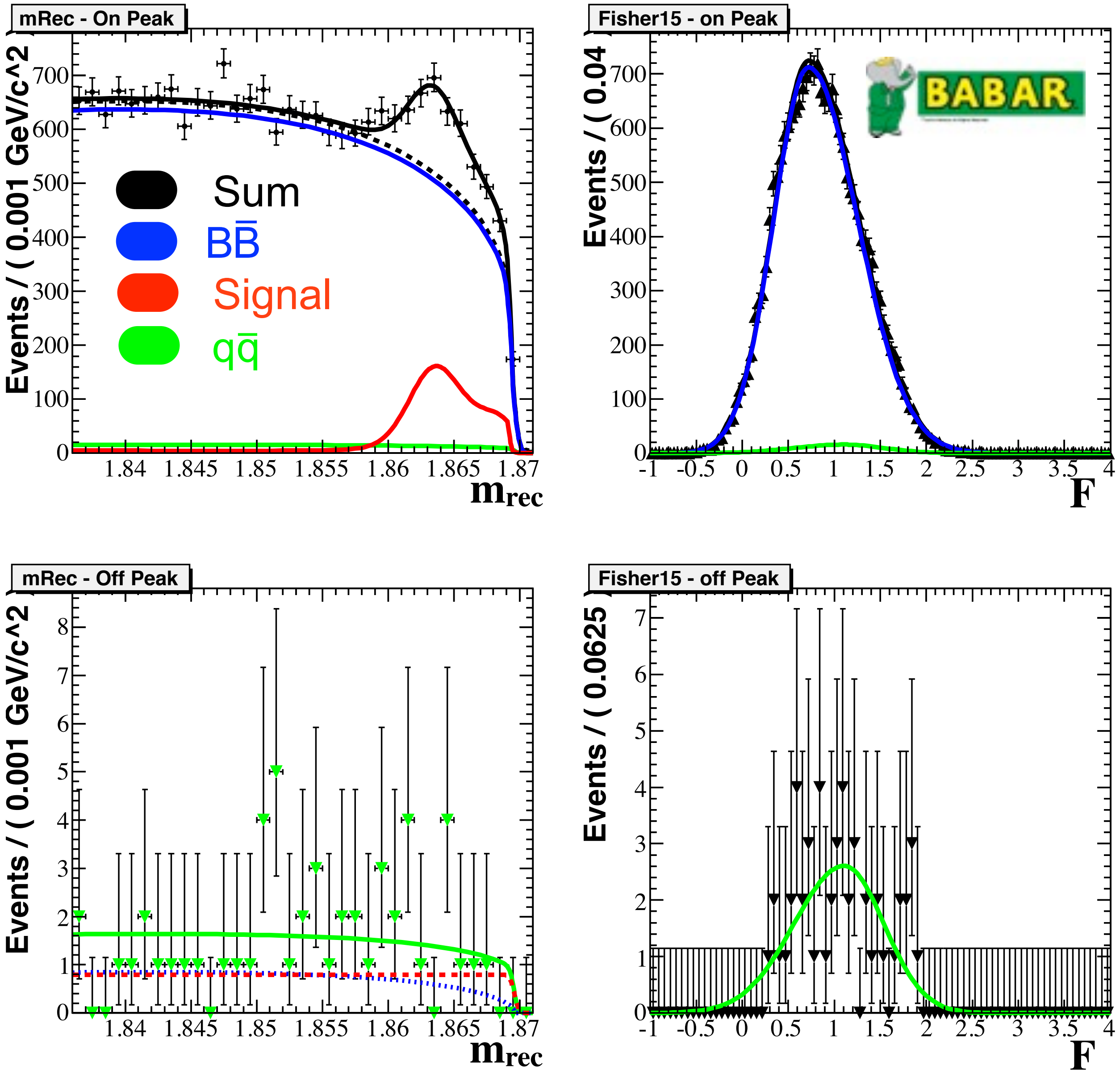
- Tag-side interference: interference between Cabibbo-favoured $b \to c\bar{u}d$ and doubly-Cabibbo suppressed $b \to \bar{c}u\bar{d}$ decays of the tag B



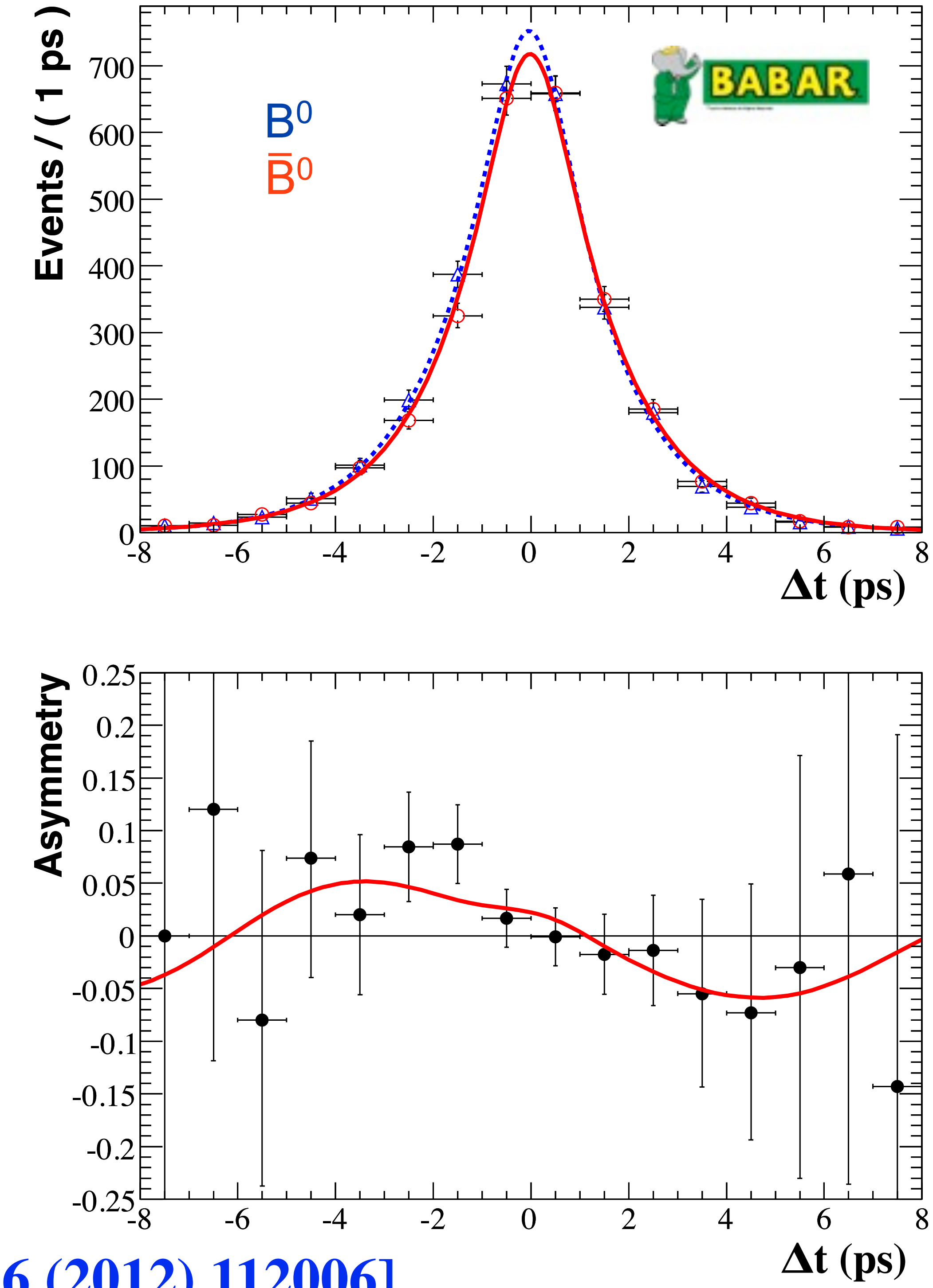
O. Long, M. Baak, R. N. Cahn, and D. Kirkby, Phys. Rev. D **68**, 034010 (2003).

BaBar $B^0 \rightarrow D^{*+}D^{*-}$ Partial Reconstruction

Kin Fit Result - DATA



Δt Fit Result and Raw Asymmetry

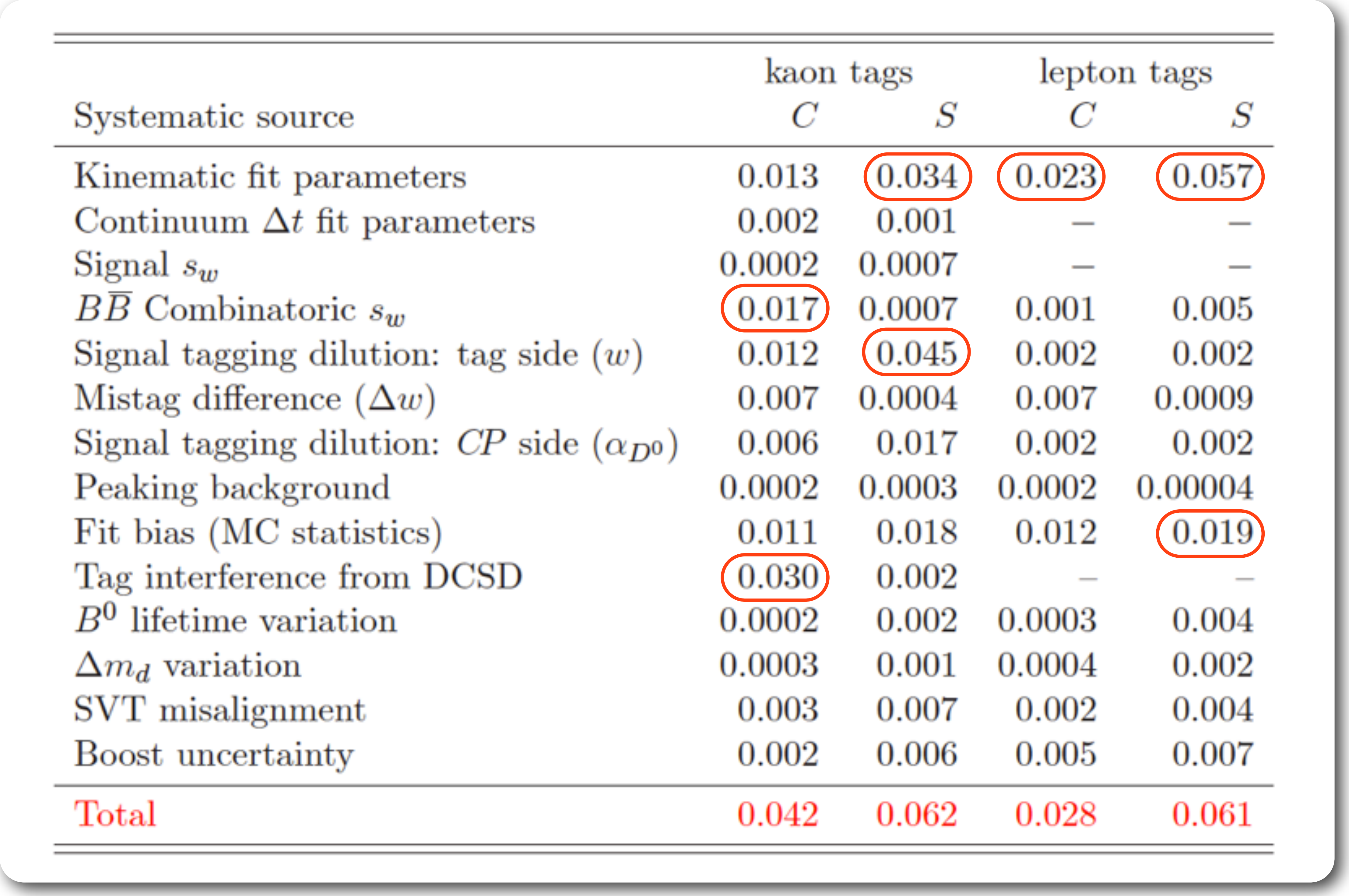


Lepton Tags

$$C = +0.20 \pm 0.15$$
$$S = -0.21 \pm 0.20$$

[PRD 86 (2012) 112006]

Evaluation of Systematic Errors $B^0 \rightarrow D^{*+}D^{*-}$



Systematic source	kaon tags C	kaon tags S	lepton tags C	lepton tags S
Kinematic fit parameters	0.013	0.034	0.023	0.057
Continuum Δt fit parameters	0.002	0.001	–	–
Signal s_w	0.0002	0.0007	–	–
$B\overline{B}$ Combinatoric s_w	0.017	0.0007	0.001	0.005
Signal tagging dilution: tag side (w)	0.012	0.045	0.002	0.002
Mistag difference (Δw)	0.007	0.0004	0.007	0.0009
Signal tagging dilution: CP side (α_{D^0})	0.006	0.017	0.002	0.002
Peaking background	0.0002	0.0003	0.0002	0.00004
Fit bias (MC statistics)	0.011	0.018	0.012	0.019
Tag interference from DCSD	0.030	0.002	–	–
B^0 lifetime variation	0.0002	0.002	0.0003	0.004
Δm_d variation	0.0003	0.001	0.0004	0.002
SVT misalignment	0.003	0.007	0.002	0.004
Boost uncertainty	0.002	0.006	0.005	0.007
Total	0.042	0.062	0.028	0.061

⬭ = top contributions

Probability Density Functions $B^0 \to D^{*+}D^{*-}$

- Overall PDF for the on-Peak sample is the sum of three components

$$P_{\rm on} = f_{B\bar{B}}\underbrace{[\overbrace{f_{\rm sig}P_{\rm sig}}^{\text{signal}} + \overbrace{(1-f_{\rm sig})P_{\rm comb}}^{\text{B}\bar{\text{B}}\text{ combinatoric}}]}_{\text{B}\bar{\text{B}}} + \underbrace{(1-f_{B\bar{B}})P_{q\bar{q}}}_{\text{continuum}} \qquad P_{\rm off} = P_{q\bar{q}}$$

- Each component is the product of a kinematical and a Δt part

$$P_i(m_{\rm rec}, F, \Delta t, \sigma_{\Delta t}, S_{\rm tag}) =$$
$$\underbrace{\mathcal{M}_i(m_{\rm rec})\,\mathcal{F}_i(F)}_{\text{“KIN”}}\,\underbrace{T'_i(\Delta t, \sigma_{\Delta t}, S_{\rm tag})}_{\text{“}\Delta\text{t”}}$$

- Δt PDF: $T'_i(\Delta t, \sigma_{\Delta t}, S_{\rm tag}) = \int d\Delta t_{\rm true}\, T_i(\Delta t_{\rm true}, S_{\rm tag})\,\mathcal{R}_i(\Delta t - \Delta t_{\rm true}, \sigma_{\Delta t})$

- Signal Δt:

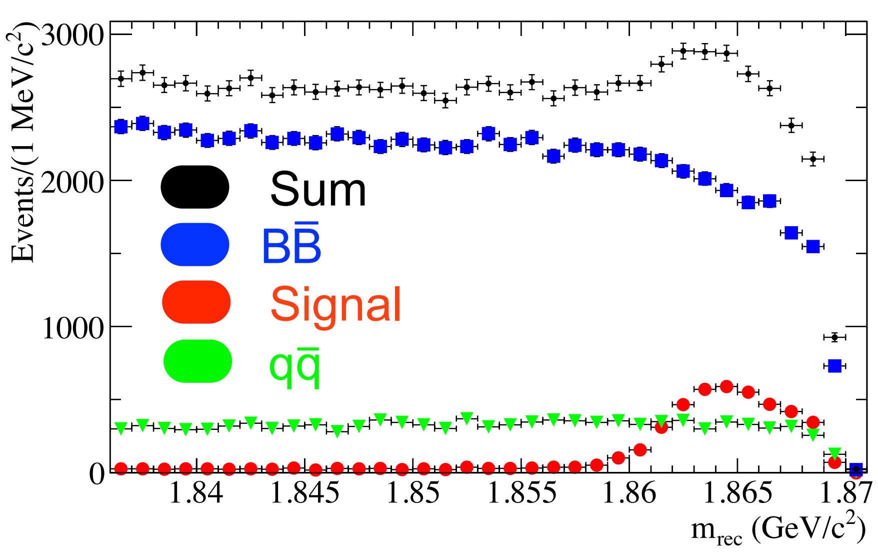
$$\begin{aligned} T_{\rm sig} &= \frac{1}{4\tau_b}\, e^{-|\Delta t_{\rm true}|/\tau_b} \cdot \Big\{(1 - S_{\rm tag}\,\Delta\omega(1-\alpha)) + \\ &\quad + S_{\rm tag}\,(1-2\omega)\,(1-\alpha) \\ &\quad \cdot[C\cos(\Delta m_d \Delta t_{\rm true}) + S\,\sin(\Delta m_d \Delta t_{\rm true})]\Big\} \end{aligned}$$

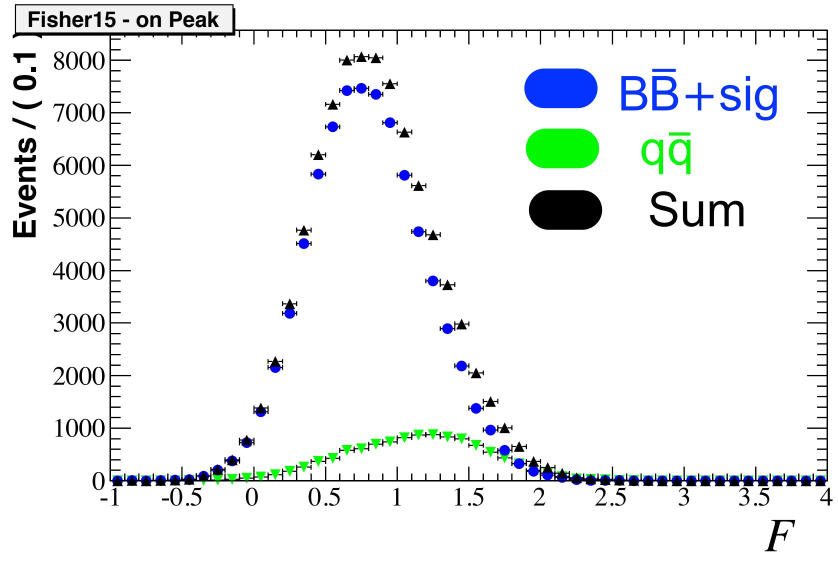
$$S = -\frac{2\Im m(\lambda)}{1+|\lambda|^2} \qquad C = \frac{1-|\lambda|^2}{1+|\lambda|^2} \qquad \lambda = \frac{q}{p}\frac{\overline{A}}{A}$$

Analysis Variables $B^0 \rightarrow D^{*+}D^{*-}$

- Recoil mass, m_{rec}
  - Signal peaks at D^0 mass
  - Backgrounds from $B\bar{B}$ combinatorial and continuum $q\bar{q}$ doesn't
  - Separate PDFs for different sample components: Signal, $B\bar{B}$ combinatorial, $q\bar{q}$ continuum
  - Require $m_{rec} \geqq 1.835$ GeV/c^2
- Fisher Discriminant based on event shape variables
  - Help discriminate between spherical $B\bar{B}$ and jet-like continuum $q\bar{q}$ events
    - No cut: PDF used in fit
  - Separate PDFs for $B\bar{B}$ and continuum
- Time difference Δt
  - Separate PDFs for all sample components
- Tagging based on single track (K or Lepton)
  - Additional dilution in partial reconstruction analysis due to tagging tracks from missing D^0
    - $(1-\alpha)$, where α is the fraction of tags from the unreconstructed D^0

MC distributions

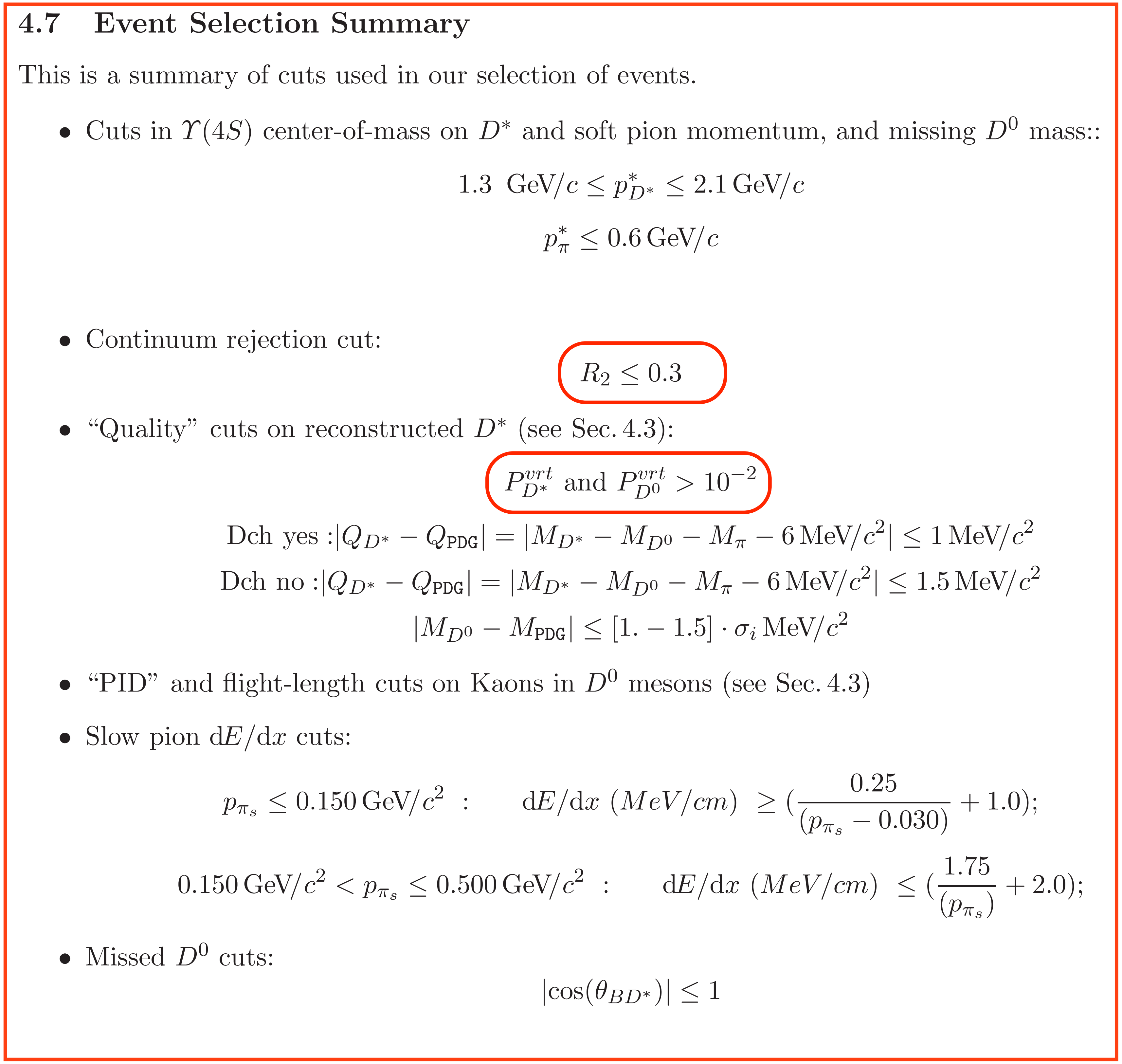




$$\Delta t = \Delta z / \gamma\beta c$$

$$\Delta z = z_{\rm rec} - z_{\rm tag}$$

Event Selection $B^0 \rightarrow D^{*+}D^{*-}$



4.7 Event Selection Summary

This is a summary of cuts used in our selection of events.

- Cuts in $\Upsilon(4S)$ center-of-mass on D^* and soft pion momentum, and missing D^0 mass::

$$1.3\ \mathrm{GeV}/c \leq p^*_{D^*} \leq 2.1\,\mathrm{GeV}/c$$

$$p^*_\pi \leq 0.6\,\mathrm{GeV}/c$$

- Continuum rejection cut:

$$\boxed{R_2 \leq 0.3}$$

- "Quality" cuts on reconstructed D^* (see Sec. 4.3):

$$\boxed{P^{vrt}_{D^*}\ \text{and}\ P^{vrt}_{D^0} > 10^{-2}}$$

$$\text{Dch yes}: |Q_{D^*} - Q_{\mathtt{PDG}}| = |M_{D^*} - M_{D^0} - M_\pi - 6\,\mathrm{MeV}/c^2| \leq 1\,\mathrm{MeV}/c^2$$

$$\text{Dch no}: |Q_{D^*} - Q_{\mathtt{PDG}}| = |M_{D^*} - M_{D^0} - M_\pi - 6\,\mathrm{MeV}/c^2| \leq 1.5\,\mathrm{MeV}/c^2$$

$$|M_{D^0} - M_{\mathtt{PDG}}| \leq [1. - 1.5] \cdot \sigma_i\,\mathrm{MeV}/c^2$$

- "PID" and flight-length cuts on Kaons in D^0 mesons (see Sec. 4.3)
- Slow pion dE/dx cuts:

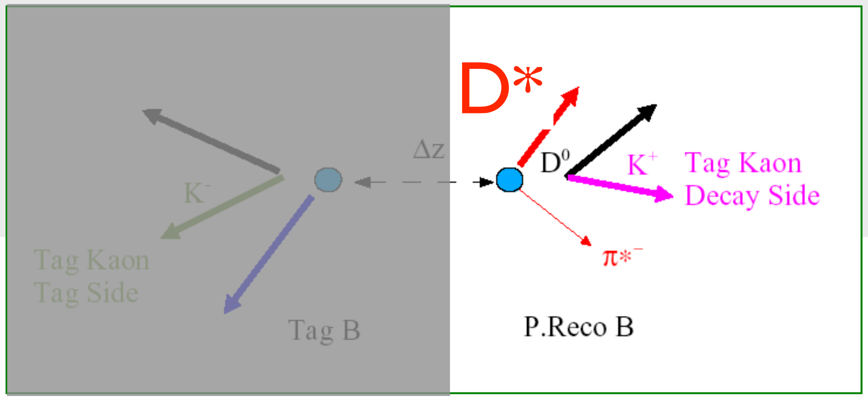
$$p_{\pi_s} \leq 0.150\,\mathrm{GeV}/c^2 \quad : \quad \mathrm{d}E/\mathrm{d}x\ (MeV/cm)\ \geq (\frac{0.25}{(p_{\pi_s} - 0.030)} + 1.0);$$

$$0.150\,\mathrm{GeV}/c^2 < p_{\pi_s} \leq 0.500\,\mathrm{GeV}/c^2 \quad : \quad \mathrm{d}E/\mathrm{d}x\ (MeV/cm)\ \leq (\frac{1.75}{(p_{\pi_s})} + 2.0);$$

- Missed D^0 cuts:

$$|\cos(\theta_{BD^*})| \leq 1$$

Tagging $B^0 \to D^{*+}D^{*-}$



- Mis-tag due to unreconstructed D^0 tracks
  - This introduces an additional dilution D=(1-α), where α is the fraction of tags coming from the missing D^0
  - This fraction can be obtained from data with some input from signal MC
  - Can be reduced with a cut on the cosine of the opening angle between the tagging track and the missing D^0 direction θ_{tag}

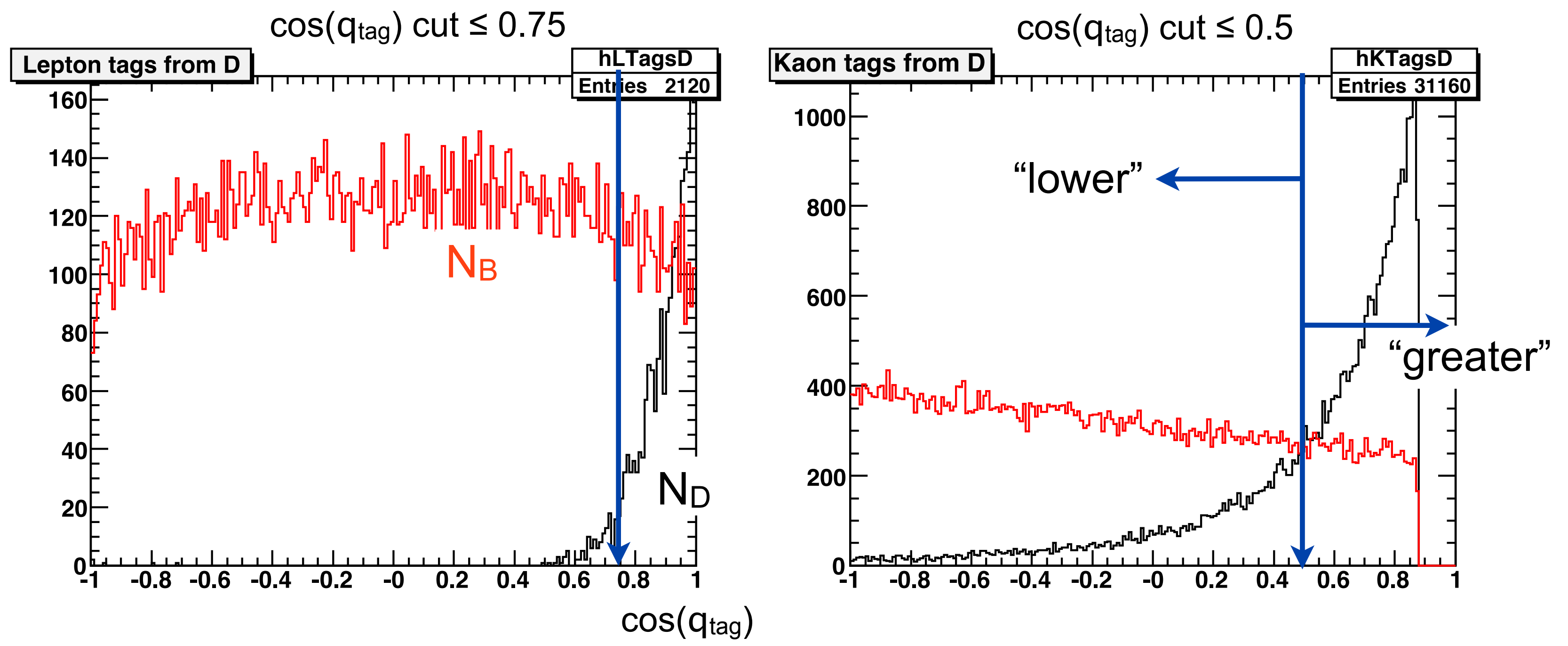
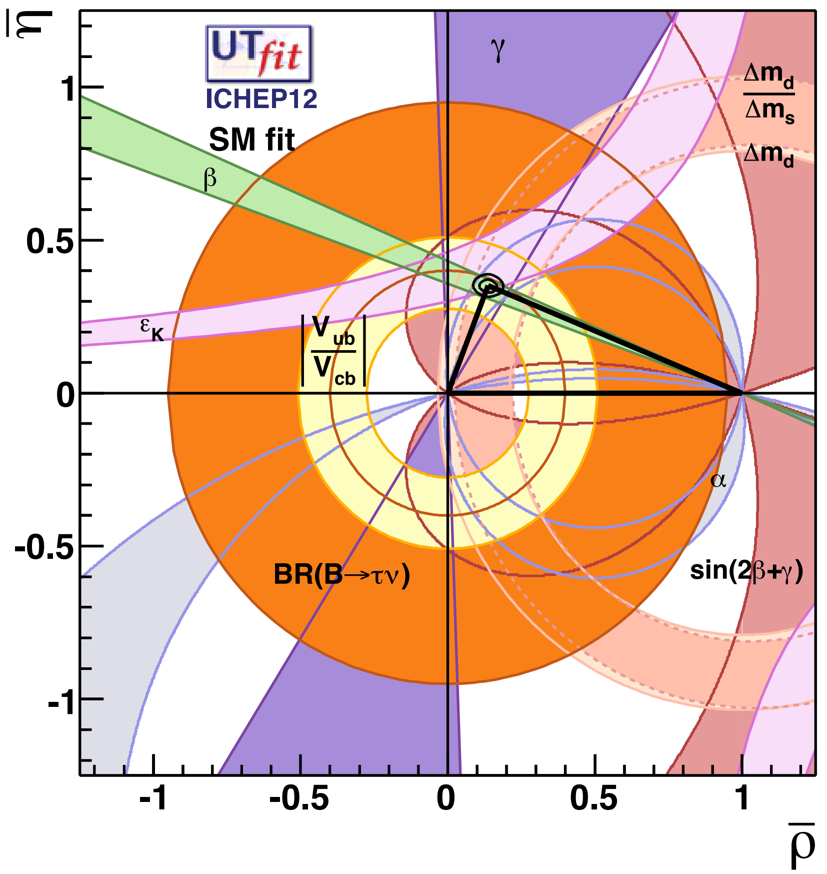


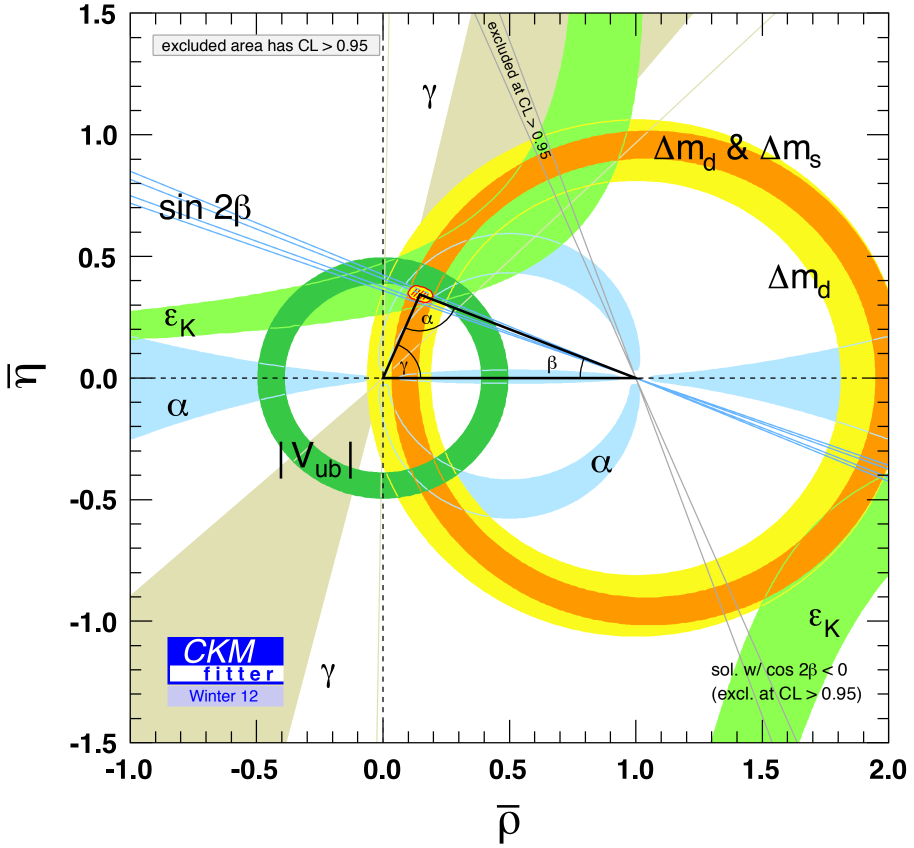
Figure 2.1: Signal Monte Carlo distributions of $\cos(\vartheta_{\rm tag})$ for tracks from the missed D^0 (black) and from the other B^0 (red); lepton tags on the left, kaon tags on the right.

$\sin(2\beta) = 0.679 \pm 0.020$

(HFAG average)

Unitarity Triangle Fit





"Tension" <~3σ between the SM fit sin2β prediction and the measured value

Parameter	UTfit			CKMfitter		
	prediction	measurement	pull	prediction	measurement	pull
$\alpha\,(^\circ)$	87.5 ± 3.8	91.4 ± 6.1	$+0.5\,\sigma$	$95.9\,^{+2.2}_{-5.6}$	$88.7\,^{+2.2}_{-5.9}$	$-1.0\,\sigma$
$\sin 2\beta$	0.809 ± 0.046	0.667 ± 0.024	$-2.7\,\sigma$	$0.820\,^{+0.024}_{-0.028}$	0.679 ± 0.020	$-2.6\,\sigma$
$\gamma\,(^\circ)$	67.8 ± 3.2	75.5 ± 10.5	$+0.7\,\sigma$	$67.2\,^{+4.4}_{-4.6}$	$66\,^{+12}_{-12}$	$-0.1\,\sigma$
$V_{ub}\,(10^{-3})$	3.62 ± 0.14	3.82 ± 0.56	$+0.3\,\sigma$	$3.55\,^{+0.15}_{-0.14}$	$3.92 \pm 0.09 \pm 0.45$	$0.0\,\sigma$
$V_{cb}\,(10^{-3})$	42.26 ± 0.89	41 ± 1	$-0.9\,\sigma$	$41.3\,^{+0.28}_{-0.11}$	$40.89 \pm 0.38 \pm 0.59$	$0.0\,\sigma$
$\varepsilon_k\,(10^{-3})$	1.96 ± 0.20	2.229 ± 0.010	$+1.3\,\sigma$	$2.02\,^{+0.53}_{-0.52}$	2.229 ± 0.010	$0.0\,\sigma$
$\Delta m_s\,(\mathrm{ps}^{-1})$	18.0 ± 1.3	17.69 ± 0.08	$-0.2\,\sigma$	$17.0\,^{+2.1}_{-1.5}$	17.731 ± 0.045	$0.0\,\sigma$
$\mathcal{B}(B \to \tau\nu)\,(10^{-4})$	0.821 ± 0.0077	1.67 ± 0.34	$+2.5\,\sigma$	$0.733\,^{+0.121}_{-0.073}$	1.68 ± 0.31	$+2.8\,\sigma$
β_s rad (*)	0.01876 ± 0.0008			$0.01822\,^{+0.00082}_{-0.00080}$		
$\mathcal{B}(B_s^0 \to \mu\mu)\,(10^{-9})$ (*)	3.47 ± 0.27			$3.64\,^{+0.21}_{-0.32}$		

LHCb arXiv 1208.3355v3, May 2013