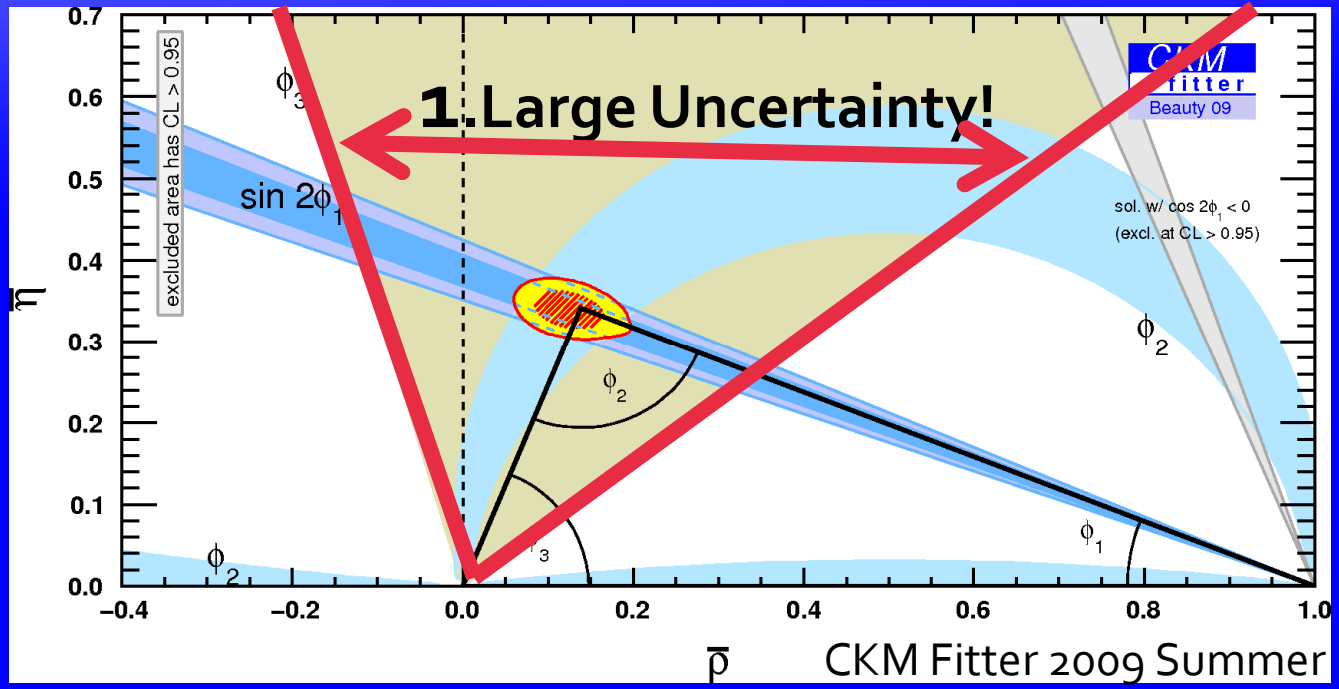
Recent results on ϕ_3 at Belle

Katsumi Senyo for Belle Collaboration

The uncertainty in direct ϕ_3 measurements is still large.



Dir. meas. results

$\phi_1 = 21.15^{+0.90^\circ}_{-0.88^\circ}$

$\phi_2 = 89.0^{+4.4^\circ}_{-4.2^\circ}$

$\phi_3 = 73^{+22^\circ}_{-25^\circ}$

2.triangle close?

$\phi_3 = 67.9 \pm 4.3^\circ\,(fit)$

3. Consistency among major direct measurements of ϕ_3?

A lot of things to be done in DIRECT ϕ_3 measurement .

ϕ_3 in three major approaches

- **$B \to D^{(*)+-}\pi^{-+}$ etc.** ($R_{D^*\pi} \sin(2\phi_1+\phi_3)$) where $R_{D^*\pi}$ ~0.02
  - Need precise mea. of $R_{D^*\pi}$ suppr. from **$B \to D_S^{+-}\pi^{-+}$ / K^{-+} etc.**
- **$B \to D^{+-} K_S \pi^{-+}$ etc.** ($r \sin(2\phi_1+\phi_3)$) where r ~0.4
  - Large stat. uncertainty in measurement.
- **$B \to D^{(*)}K^{(*)-+}$ etc.**(GLW/ADS/Dalitz approach)
  - lots of effort and better accuracy on ϕ_3 measurement
  - Systematic/decay model uncertainties will ultimately limit.

Today's topic!

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Larger data sample with a help of results from charm factories will solve difficulties in statistic/systematic/model uncertainties.

$B \to D_s^{*+-} \pi^{-+} / K^{-+}$

- to explore ratio of $R_{D^*\pi} = |A(B^0 \to D^{*+}\pi^-)/A(B^0 \to D^{*-}\pi^+)|$ amplitudes,

605 fb^{-1} of 657 x 10^6 BB pairs

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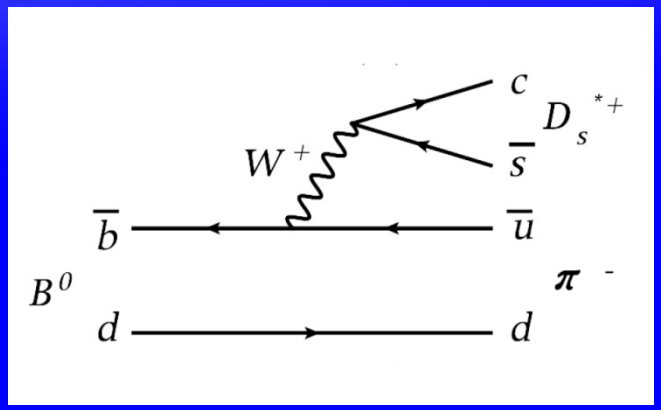
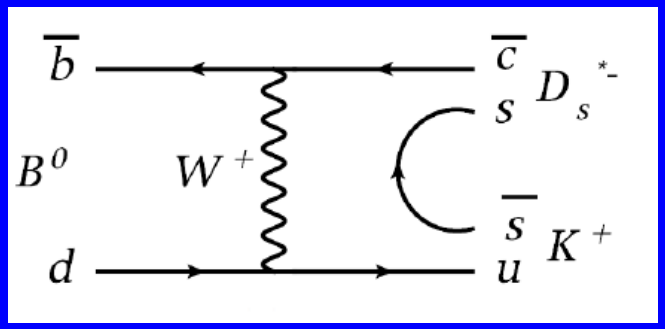
Motivation on $B \to D_s^{*+-}\pi^{-+}$ / K^{-+}

$R_{D^*\pi}$ provided by $B \to D_S^{*+}\pi^-$ self-tagging decay(no B^0bar contribution) using SU(3).

$$R_{D^*\pi} = \tan\theta_C \left(\frac{f_{D^*}}{f_{D_s^*}}\right) \sqrt{\frac{\mathcal{B}(B^0 \to D_s^{*+}\pi^-)}{\mathcal{B}(B^0 \to D^{*-}\pi^+)}}$$

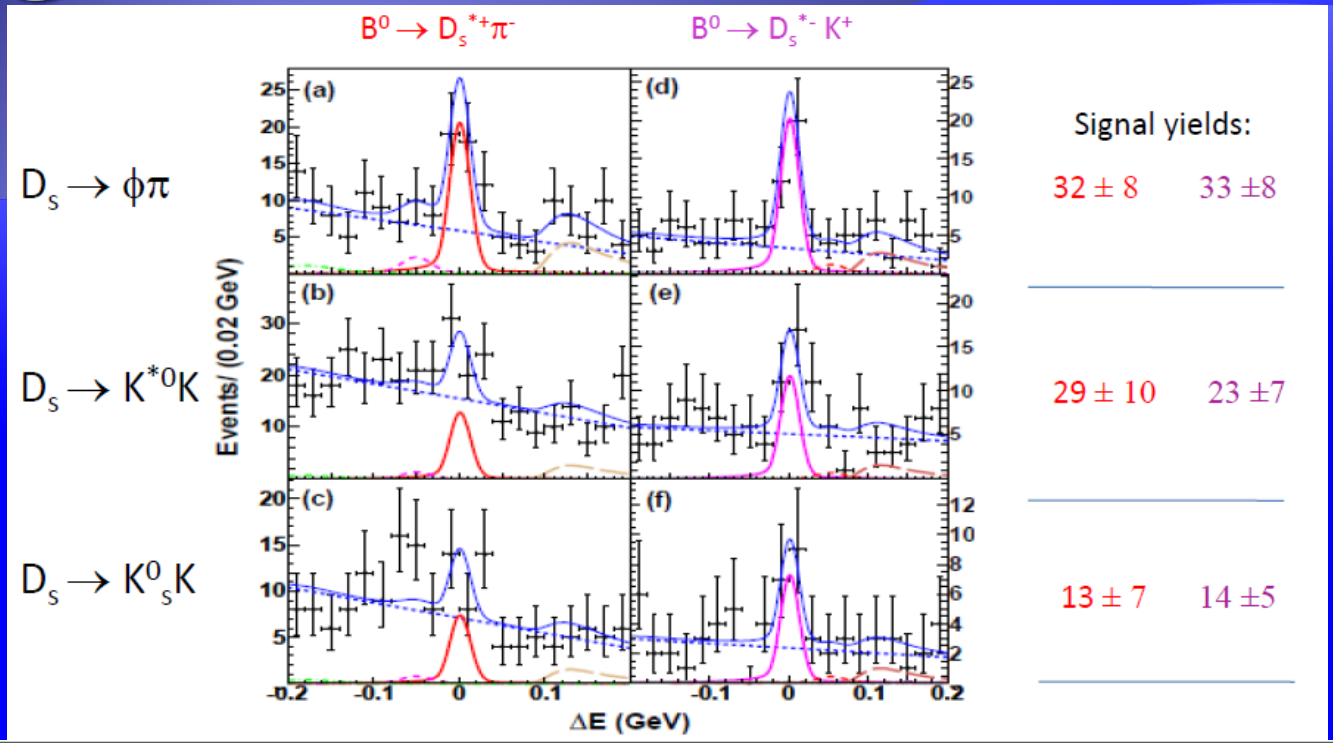


$Br(B \to D_S^{*+}\pi^-)$ provides the size of W-exchange diagram contribution.



Technically, after applying Belle standard selection criteria, both processes determined by simultaneous fit on ΔE distribution with K/π ID.

Signal fit results



B^0 mode	D_s^+ mode	ϵ (%)	N_{sig}	$\mathcal{B}(10^{-5})$	$\mathcal{S}(\sigma)$
$B^0 \to D_s^{*+}\pi^-$	$\phi(K^+K^-)\pi^+$	15.2	32 ± 8	$1.58 \pm 0.40 \pm 0.24$	3.2
	$\bar{K}^*(892)^0(K^-\pi^+)K^+$	7.9	29 ± 10	$2.30 \pm 0.76 \pm 0.35$	2.6
	$K^0_S K^+$	8.0	13 ± 7	$1.78 \pm 0.92 \pm 0.11$	2.2
	Simultaneous	...	...	$1.75 \pm 0.34 \pm 0.11$	6.6
$B^0 \to D_s^{*-}K^+$	$\phi(K^+K^-)\pi^+$	13.4	33 ± 8	$1.81 \pm 0.41 \pm 0.27$	3.2
	$\bar{K}^*(892)^0(K^-\pi^+)K^+$	6.4	23 ± 7	$2.22 \pm 0.66 \pm 0.34$	2.8
	$K^0_S K^+$	6.9	14 ± 5	$2.14 \pm 0.80 \pm 0.13$	3.1
	Simultaneous	...	...	$2.02 \pm 0.33 \pm 0.13$	8.6

Contribution to the syst. uncertainty

- Branching fraction of Ds decays ($D_s\pi$-5.9/ D_sK-6.2%)
- Tracking efficiency (4.0/4.0%)
- PID efficiency(2.4/2.4%)
- γ detection efficiency(7.0/7.0%)
- Signal PDF shape(3.4/1.5%)
- /Ks detection efficiency(2.4/2.1%)
- Peaking background in the fit(1.5/1.9%)

9.4% for $B\to D_S^{*+-}\pi^{-+}$, 8.8% for $B\to D_S^{*+-} K^{-+}$

Results for $B \to D_S^{*+-}\pi^{-+}$ / K^{-+}

$\mathcal{B}(B \to D_S^{*+-}\pi^{-+}) = (1.75 \pm 0.37(\text{stat.}) \pm 0.17(\text{syst.}) \pm 0.13(\mathcal{B}r)) \times 10^{-5}$

$$R_{D^*\pi} = \tan\theta_C \left(\frac{f_{D^*}}{f_{D_s^*}}\right) \sqrt{\frac{\mathcal{B}(B^0 \to D_s^{*+}\pi^-)}{\mathcal{B}(B^0 \to D^{*-}\pi^+)}} = (1.58 \pm 0.15(\text{stat.}) \pm 0.10(\text{syst.}) \pm 0.03(th))\%$$

0.2314 ± 0.0021

$1.164 \pm 0.006(\text{stat.}) \pm 0.020(\text{syst.})$

$(2.76 \pm 0.13) \times 10^{-3}$

$\mathcal{B}(B \to D_S^{*+-}K^{-+}) = (2.02 \pm 0.33(\text{stat.}) \pm 0.18(\text{syst.}) \pm 0.13(\mathcal{B}r)) \times 10^{-5}$

Two orders of magnitude lower than CFD $\mathcal{B}(B \to D^{*+-}\pi^{-+})$
→No W-exchange process enhancement by rescattering.

$B^- \to D^{(*)} K^-$ Dalitz plot analysis

- Direct measurement of the angle ϕ_3

605 fb^{-1} of 657 x 10^6 BB pairs

$B^- \to D^* K^{*-}$ ($D^* \to D\gamma$) analysis is first from Belle

arXiv:0803.3375

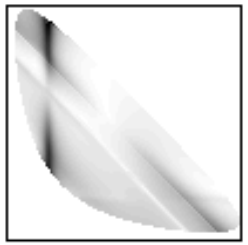
Idea of Dalitz plot analysis

Using $B^{\pm} \to D^{(*)} K^{(*)\pm}$ modes with 3- body decay $D \to K_S \pi^+ \pi^-$

- Dalitz plot density: $d\sigma_{\pm}(m_+^2, m_-^2) \sim |M_{\pm}|^2 d\, m_+^2 dm_-^2$

$$|M_{\pm}(m_+^2, m_-^2)|^2 = |f_D(m_+^2, m_-^2) + re^{i\delta_B \pm i\phi_3} f_D(m_-^2, m_+^2)|^2$$

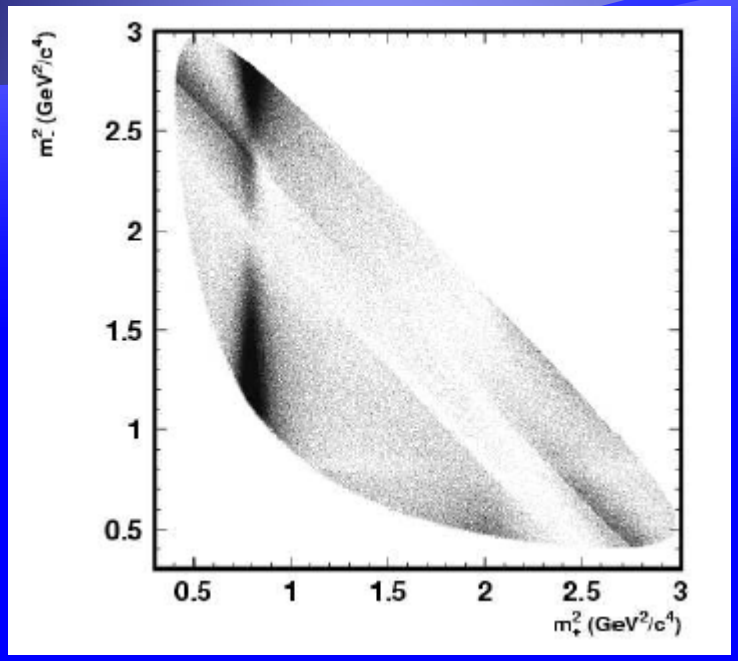
$$= \left| \quad + re^{i\delta_B \pm i\phi_3} \quad \right|^2$$



$D \to K_S \pi^+ \pi^-$ amplitude f_D is extracted from continuum($D^{*\pm} \to D\pi^{\pm}$), parametrized as a set of two amplitudes.

Fit variables: $x_{\pm} = r \cos(\delta_B \pm \phi_3)$, $y_{\pm} = r \sin(\delta_B \pm \phi_3)$

$D \to K_S\pi^+\pi^-$ Dalitz amplitude



plot from e+e-→cc high statistics data(290k evts)

$D^{*\pm} \to D\pi^{\pm}$ (flavor-tagged)

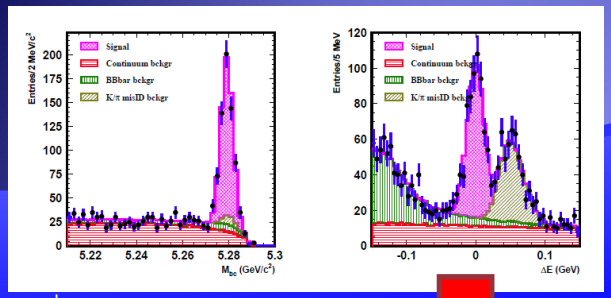
$\bar{D} \to K_S\pi^+\pi^-$

Fit results of $D \to K_S\pi^+\pi^-$

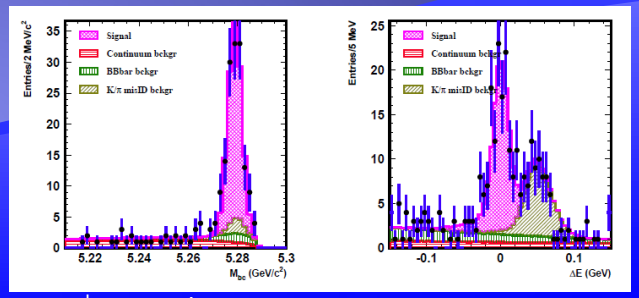
Intermediate state	Amplitude	Phase (°)	Fit fraction, %
$K_S\sigma_1$	1.56 ± 0.06	214 ± 3	11.0 ± 0.7
$K_S\rho^0$	1.0 (fixed)	0 (fixed)	21.2 ± 0.5
$K_S\omega$	0.0343 ± 0.0008	112.0 ± 1.3	0.526 ± 0.014
$K_S f_0(980)$	0.385 ± 0.006	207.3 ± 2.3	4.72 ± 0.05
$K_S\sigma_2$	0.20 ± 0.02	212 ± 12	0.54 ± 0.10
$K_S f_2(1270)$	1.44 ± 0.04	342.9 ± 1.7	1.82 ± 0.05
$K_S f_0(1370)$	1.56 ± 0.12	110 ± 4	1.9 ± 0.3
$K_S\rho^0(1450)$	0.49 ± 0.08	64 ± 11	0.11 ± 0.04
$K^*(892)^+\pi^-$	1.638 ± 0.010	133.2 ± 0.4	62.9 ± 0.8
$K^*(892)^-\pi^+$	0.149 ± 0.004	325.4 ± 1.3	0.526 ± 0.016
$K^*(1410)^+\pi^-$	0.65 ± 0.05	120 ± 4	0.49 ± 0.07
$K^*(1410)^-\pi^+$	0.42 ± 0.04	253 ± 5	0.21 ± 0.03
$K_0^*(1430)^+\pi^-$	2.21 ± 0.04	358.9 ± 1.1	7.93 ± 0.09
$K_0^*(1430)^-\pi^+$	0.36 ± 0.03	87 ± 4	0.22 ± 0.04
$K_2^*(1430)^+\pi^-$	0.89 ± 0.03	314.8 ± 1.1	1.40 ± 0.06
$K_2^*(1430)^-\pi^+$	0.23 ± 0.02	275 ± 6	0.093 ± 0.014
$K^*(1680)^+\pi^-$	0.88 ± 0.27	82 ± 17	0.06 ± 0.04
$K^*(1680)^-\pi^+$	2.1 ± 0.2	130 ± 6	0.30 ± 0.07
non-resonant	2.7 ± 0.3	160 ± 5	5.0 ± 1.0

preliminary results

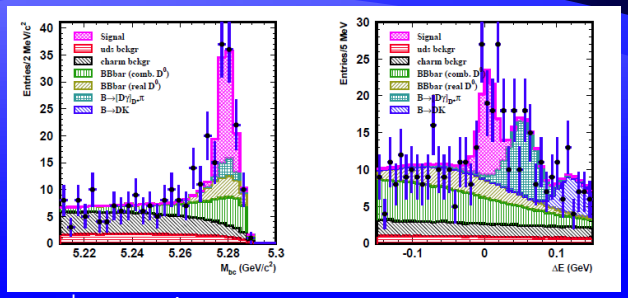
Dalitz plot after signal selection



$B^{\pm} \to DK$ (756events)

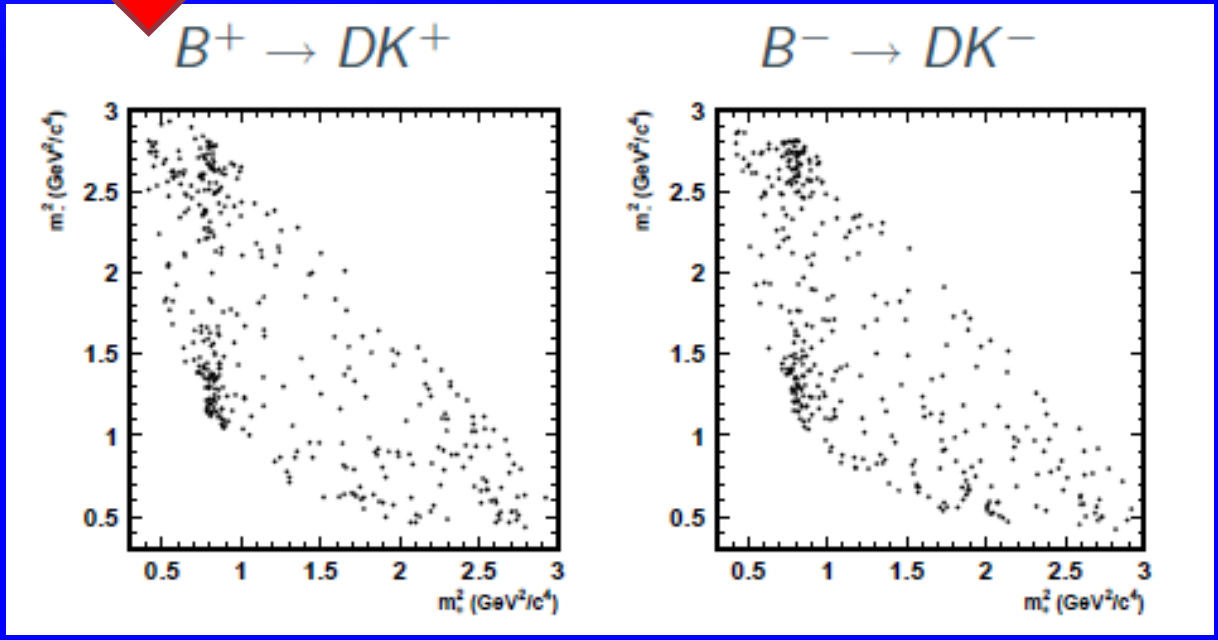


$B^{\pm} \to D^*K(D\pi^0)$ (149events)



$B^{\pm} \to D^*K(D\gamma)$ (141events)

First from Belle

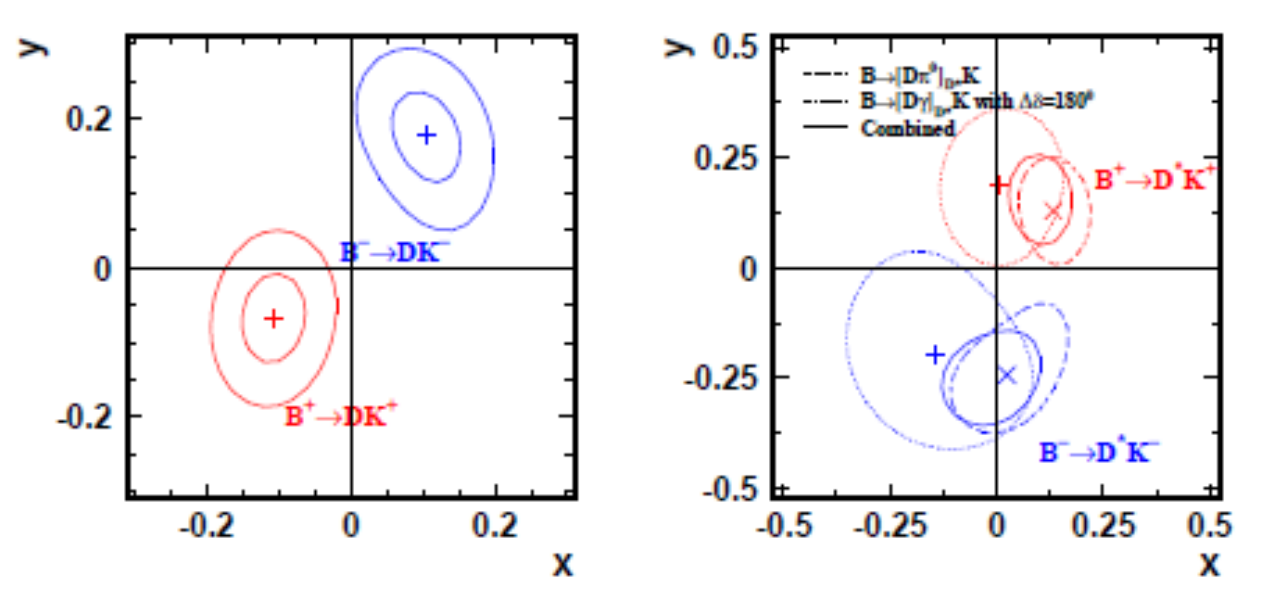


Separate fits to B^+ and B^- samples as a function of M_{bc}, ΔE, event thrust angle, virtual calorimeter.

Dalitz plot fits

preliminary results

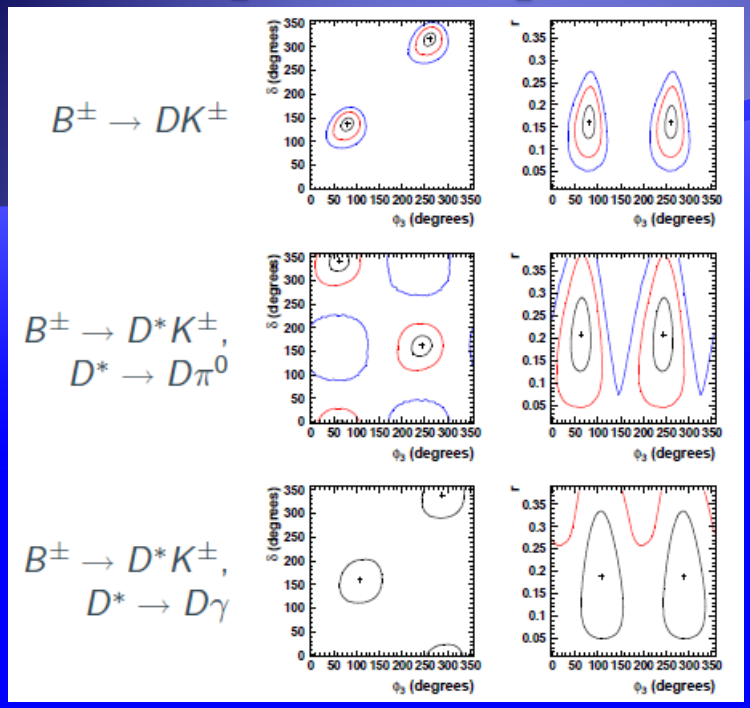
Fit variables: $x_\pm = r \cos(\delta_B \pm \phi_3)$, $y_\pm = r \sin(\delta_B \pm \phi_3)$



Parameter	$B^+ \to DK^+$	$B^+ \to D^*K^+,\ D^* \to D\pi^0$	$B^+ \to D^*K^+,\ D^* \to D\gamma$
x_-	$+0.105 \pm 0.047 \pm 0.011$	$+0.024 \pm 0.140 \pm 0.018$	$+0.144 \pm 0.208 \pm 0.025$
y_-	$+0.177 \pm 0.060 \pm 0.018$	$-0.243 \pm 0.137 \pm 0.022$	$+0.196 \pm 0.215 \pm 0.037$
x_+	$-0.107 \pm 0.043 \pm 0.011$	$+0.133 \pm 0.083 \pm 0.018$	$-0.006 \pm 0.147 \pm 0.025$
y_+	$-0.067 \pm 0.059 \pm 0.018$	$+0.130 \pm 0.120 \pm 0.022$	$-0.190 \pm 0.177 \pm 0.037$

preliminary results

Physics parameter fits



Separate fits to DK, D*(Dπ⁰)K and D*(Dγ)K processes are consistent .

Combined results of physics parameters

Parameter	1σ interval	2σ interval	Systematic error	Model uncertainty
ϕ_3	$78.4^\circ {}^{+10.8^\circ}_{-11.6^\circ}$	$54.2^\circ < \phi_3 < 100.5^\circ$	3.6°	8.9°
r_{DK}	$0.160^{+0.040}_{-0.038}$	$0.084 < r_{DK} < 0.239$	0.011	$^{+0.050}_{-0.010}$
r_{D^*K}	$0.196^{+0.072}_{-0.069}$	$0.061 < r_{D^*K} < 0.271$	0.012	$^{+0.062}_{-0.012}$
δ_{DK}	$136.7^\circ {}^{+13.0^\circ}_{-15.8^\circ}$	$102.2^\circ < \delta_{DK} < 162.3$	4.0°	22.9°
δ_{D^*K}	$341.9^\circ {}^{+18.0^\circ}_{-19.6^\circ}$	$296.5^\circ < \delta_{D^*K} < 382.7$	3.0°	22.9°

Conclusion

- Presented ϕ_3-related latest efforts at Belle
  - Branching fraction and DCSD/CFD ratio in $B \rightarrow Ds\pi^{\pm}/K^{\pm}$.
  - Precise measurement of ϕ_3 with Dalitz plot analysis.
- KEKB/Belle has accumulated even more data sample on $\Upsilon(4S)$. Stay tuned!
- Even more sensitivity to ϕ_3 physics at the next generation B factory.

Backup Slides

B→Dsh event selection

$D_s^+ \to \phi(K^+K^-)\pi^+$
$D_s^+ \to \bar{K}^*(892)^0(K^-\pi^+)K^-$
$D_s^+ \to K_S K^+$

- π(K)ID:85%(92%) eff. and 8%(15%) fake rate.
  - loose PID for K's from ϕ decay, tight for K from K* decay
- $|M_{KK} - M_\phi| < 14\text{MeV}/c^2$, $|M_{K\pi} - M_{K^*}| < 75\text{MeV}/c^2$ $|M_{\pi\pi} - M_{Ks}| < 10\text{MeV}/c^2$(3 sigma)
- Ds mass window: $<\pm 13\text{MeV}/c^2$, $<\pm 15\text{MeV}/c^2$, $<\pm 17\text{MeV}/c^2$(3 sigma)
- Ds* mass window $128 < M_{Ds\gamma} - M_{Ds+} < 162\text{MeV}/c^2$
- constraint on angle between g and B flight direction in Ds* rest frame

Dalitz plot analysis (selection)

$|M_{K_S\pi\pi} - M_D| < 11\text{MeV}/c^2$

$144.9 < M_{D^*} - M_D < 145.9\text{MeV}/c^2$ for $B^\pm \to D^*(D\pi^0)K^\pm$

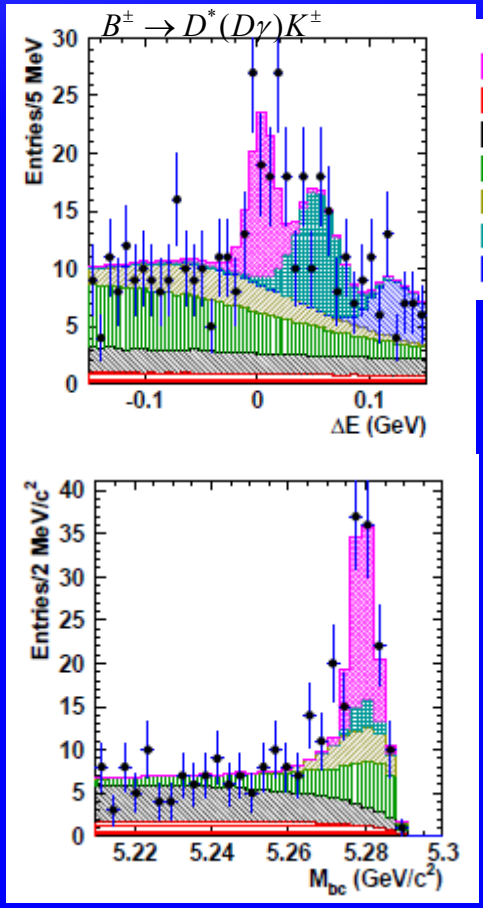
$M_{D^*} - M_D < 152\text{MeV}/c^2$ for $B^\pm \to D^*(D\gamma)K^\pm$

$E_\gamma > 100\text{MeV}$

$|\Delta E| < 30\text{MeV}$

$M_{bc} > 5.27\text{MeV}/c^2$

B→DK: 756 events, 29% background
B→D*(Dπ⁰)K: 149 events, 20% background
B→D*(Dγ)K: 141 events, 58% background



Dalitz plot D*(Dγ)K mode