Measurements of ϕ_3 at 3 fb^{-1}

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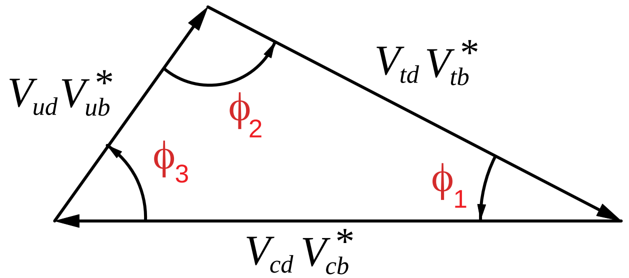
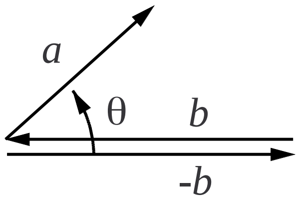
1. $D^{*+}\pi^-$ partial reconstruction
2. $D_{CP}K^-$ GLW method
3. DK^- ADS method
4. DK^- Dalitz analysis
5. Things to be done

V_{CKM} is unitary: e.g. orthogonality of d- and b-column:

$$V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0\,,$$





$$\theta = \arg\frac{a}{-b}$$

$$\phi_1 \equiv \arg\left(\frac{V_{cd}V_{cb}^*}{-V_{td}V_{tb}^*}\right),\ \phi_2 \equiv \arg\left(\frac{V_{td}V_{tb}^*}{-V_{ud}V_{ub}^*}\right),\ \phi_3 \equiv \arg\left(\frac{V_{ud}V_{ub}^*}{-V_{cd}V_{cb}^*}\right)$$

$\phi_1 + \phi_2 + \phi_3 = \pi \quad (\mathrm{mod} 2\pi)$ regardless of unitarity

$D^{*+}\pi^-$ Partial Reconstruction (Tim Gershon)

$$B \longrightarrow D^{*+}\pi_f^-,\ D^{*+} \longrightarrow (D^0)\pi_s$$

Flavor tag by high momentum lepton

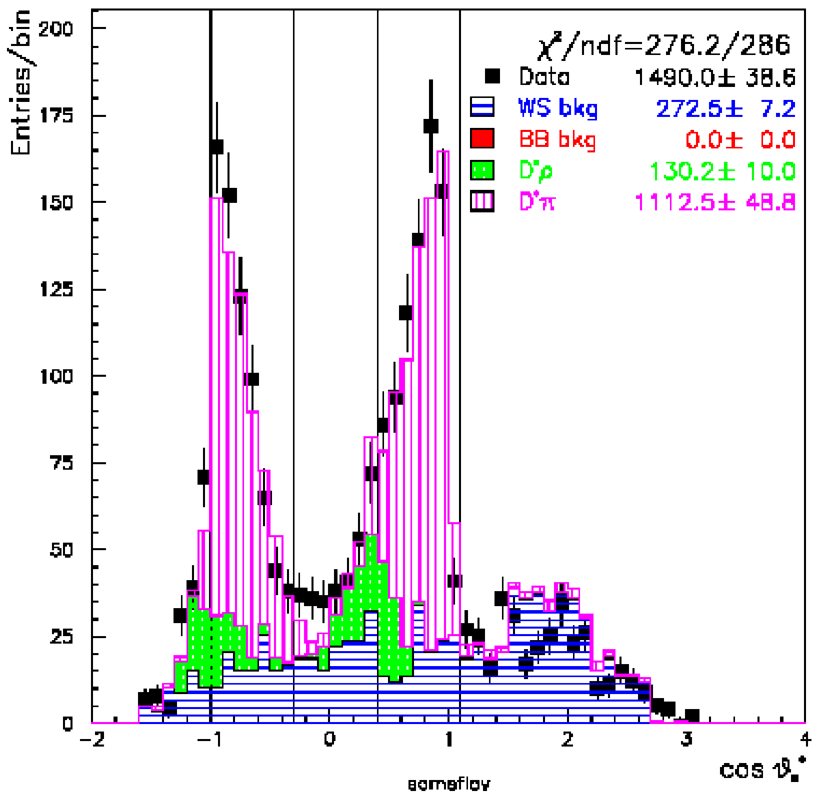
Usable kinematic parameters:

- p_{π_f}
- $\cos\theta_{fs}$ (π_f-π_s angle)
- $\cos\theta_s$ (π_s helicity angle)

$D^{*+}\pi^-$ Partial Reconstruction (78 fb^{-1})

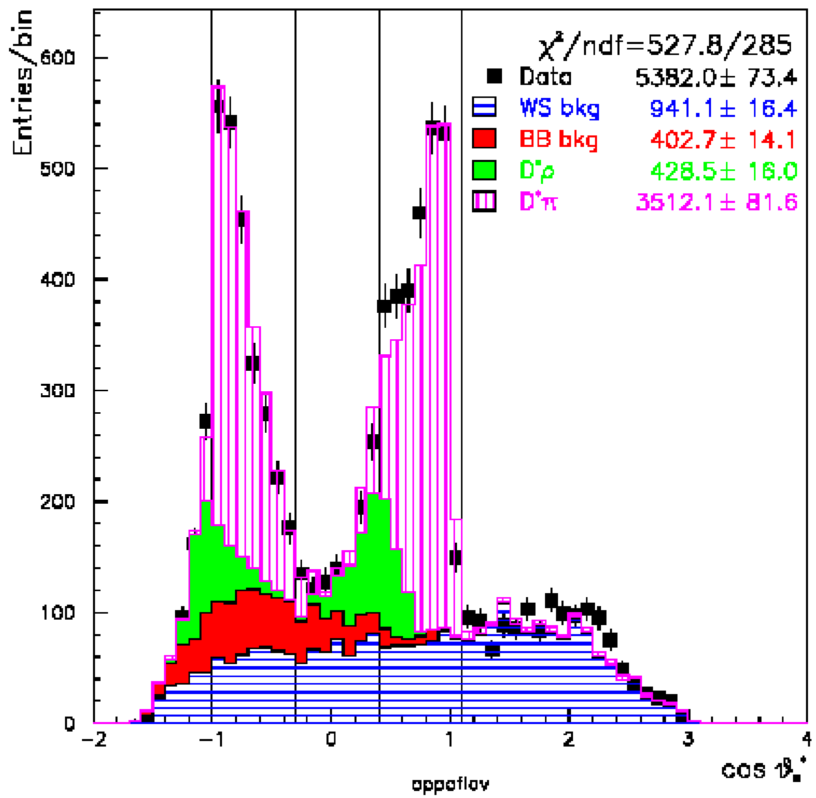
SAME FLAVOUR EVENTS

1490 candidates / 1110 $\pm$ 50 signal

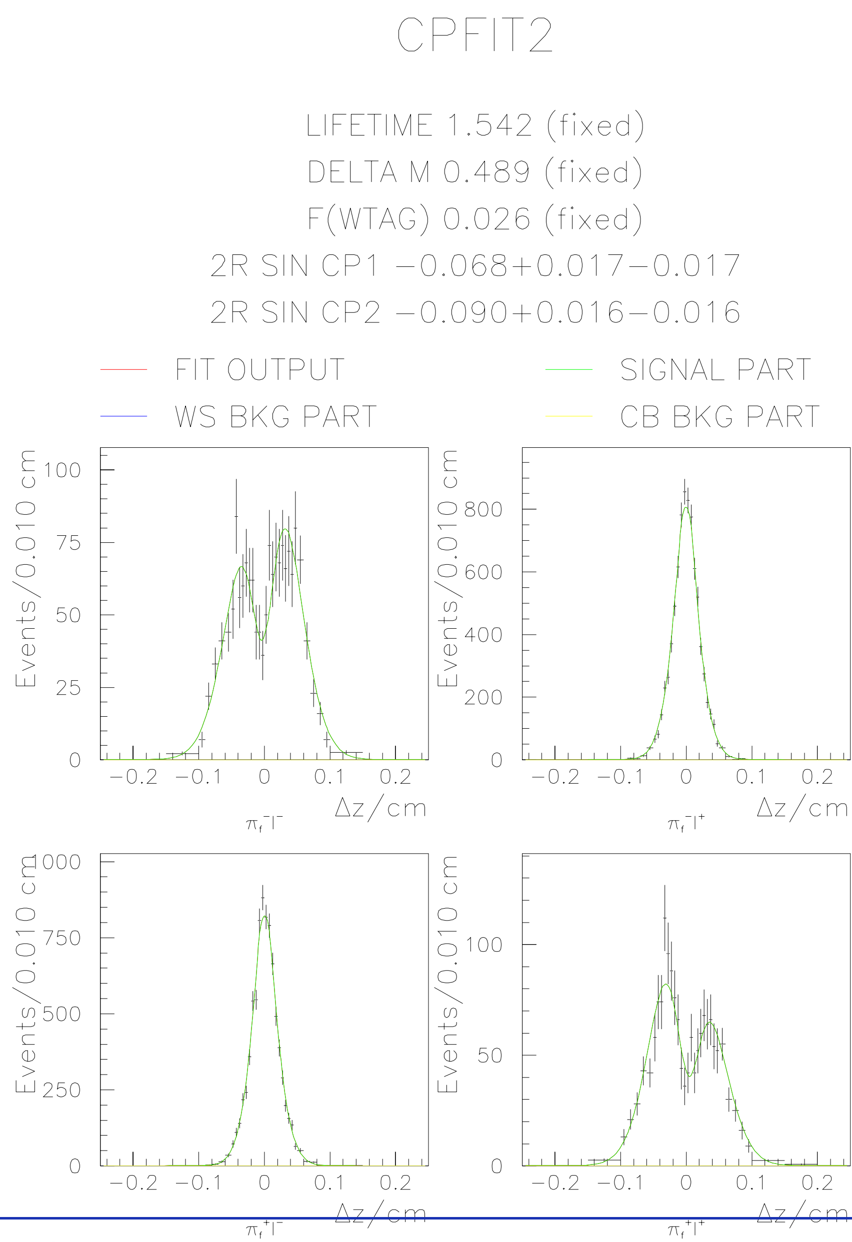


OPPOSITE FLAVOUR EVENTS

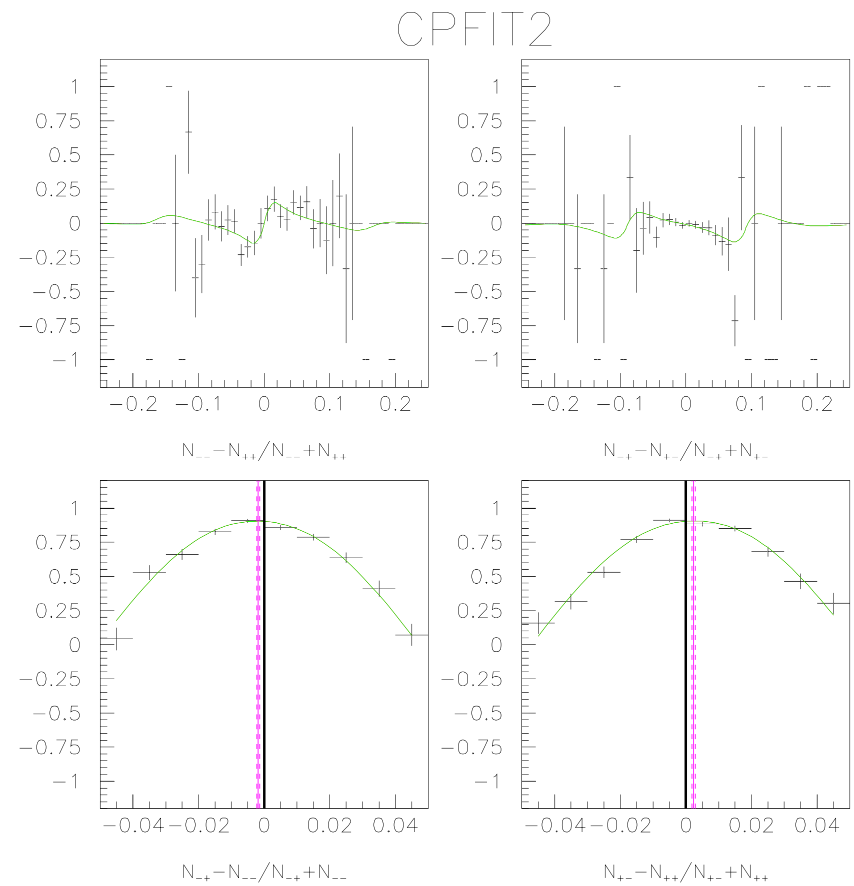
5382 candidates / 3510 $\pm$ 80 signal



Check with `EvtGen` Signal Monte Carlo



	INPUT	MEASURED
$2R_{D^*\pi}\sin(2\phi_1+\phi_3+\delta_{D^*\pi})$	-0.068	-0.068 ± 0.017
$2R_{D^*\pi}\sin(2\phi_1+\phi_3-\delta_{D^*\pi})$	-0.085	-0.090 ± 0.016



Expected sensitivities

- **78 fb^{-1}:** $\sigma(2R\sin(2\phi_1+\phi_3\pm\delta)) \sim 0.029$
- **300 fb^{-1}:** $\sigma(2R\sin(2\phi_1+\phi_3\pm\delta)) \sim 0.015$
- **3 ab^{-1}:** $\sigma(2R\sin(2\phi_1+\phi_3\pm\delta)) \sim 0.005$

$$R^2 \sim \frac{Br(D_s^{*+}\pi^-)}{Br(D^{*+}\pi^-)}\left(\frac{f_{D^*}}{f_{D_s^*}}\right)^2 \tan^2\theta_c$$

$$R = 0.022 \pm 0.007 \text{ (now)}$$

How much does this improve ?
(theoretically and experimentally)

Systematics

- CP components in the background
  $\longrightarrow$ more statistics will help (probably OK)

- Resolution functions
  $\longrightarrow$ more study (probably OK)

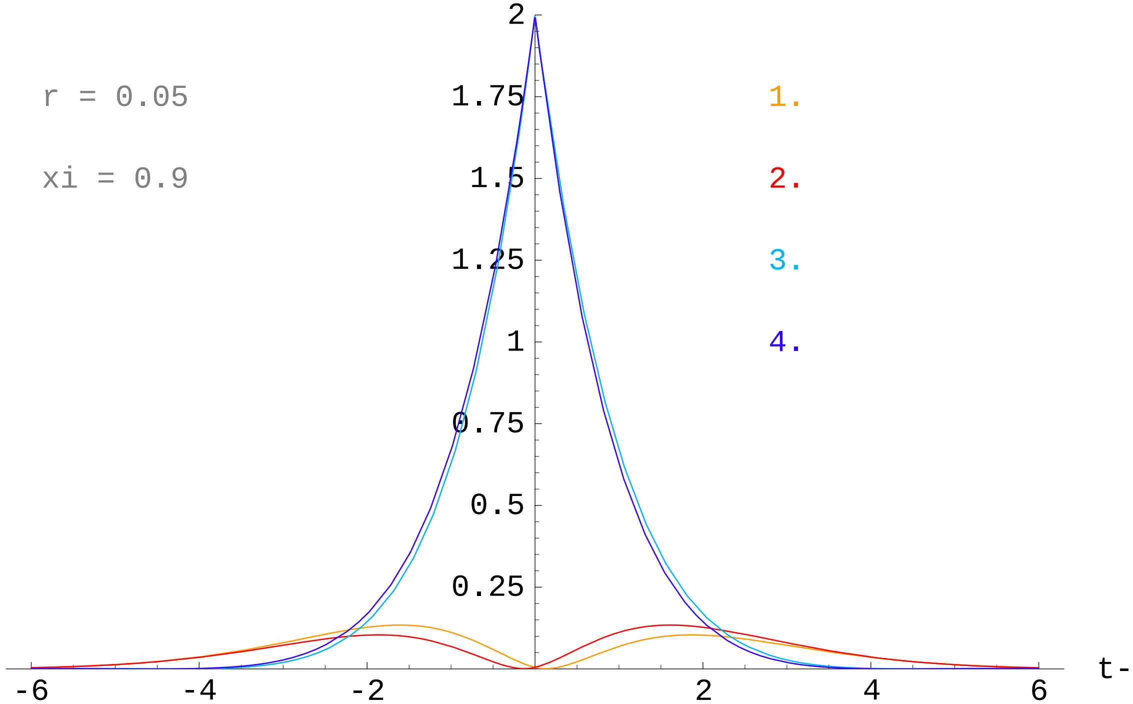
- Vertexing biases (tag-dependent)

  Tough systematics.

  $\longrightarrow$ If not simulatable, float Δt offsets.
  (preliminary study by Handa: $\sim$20% worse error on $\sin(2\phi_1 + \phi_3 \pm \delta)$.

$D^*\pi$ Δt distributions (unit $= \tau_B$)
($\delta = 0$ for simplicity)

blue: favored modes, red: suppressed modes



Most of the sensitivity is in the suppressed modes.

CPV information:
height asymmetry of two bumps (not affected by Δt bias)
location of the dip (affected by Δt bias)

$D_{CP}K$ modes (Sanjay Swain)

$$D_1 : K^+K^-, \pi^+\pi^-$$

$$D_2 : K_S\pi^0, K_S\phi, K_S\omega, K_S\eta, K_S\eta'$$

$$A_i \equiv \frac{(D_iK^-) - (D_iK^+)}{(D_iK^-) - (D_iK^+)} = \frac{\pm 2r \sin\delta \sin\phi_3}{1 + r^2 \pm 2r \cos\delta \cos\phi_3}$$

$$R_i \equiv \frac{(D_iK^- + c.c)/(D_i\pi^- + c.c)}{(D^0K^- + c.c)/(D^0\pi^- + c.c)} = 1 + r^2 \pm 2r \cos\delta \cos\phi_3 \quad (\text{order } r^2)$$

$$(\text{order } r^2) \quad A_1R_1 = -A_2R_2, \quad \frac{A_1 - A_2}{2} = 2r \sin\delta \sin\phi_3$$

$r \sim 0.1$ (or larger?)

With 78 fb^{-1}

$$A_1 = 0.06 \pm 0.19 \pm 0.04 \quad A_2 = -0.19 \pm 0.17 \pm 0.05$$

$$R_1 = 1.21 \pm 0.025 \pm 0.14 \quad R_2 = 1.41 \pm 0.24 \pm 0.15$$

- $\sigma_{A_{1,2}} \sim 0.10$ at 300 fb^{-1}, $\sigma_{R_{1,2}} \sim 0.03$ at 3 ab^{-1}
  Expected up to 0.3 $\longrightarrow$ asymmetry is likely to be seen.

- $\sigma_{R_{1,2}} \sim 0.15$ at 300 fb^{-1}, $\sigma_{R_{1,2}} \sim 0.05$ at 3 ab^{-1}
  This, however, cannot give r.

$$\frac{R_1 + R_2}{2} - 1 = r^2 \quad (\text{order } r^2 : \text{not usable})$$

- The value of r needs to be input.

$DK^{(*)}$ ADS method (Manabu Saigo)

ADS (Atwood, Dunietz, Soni) method:

$$d_i : \Gamma(B^- -> D(f_i)K^-)$$

$$\bar{d}_i : \Gamma(B^+ -> D(\bar{f}_i)K^+)$$

$$a \equiv \Gamma(B^+ \longrightarrow \bar{D}^0(\bar{f}_i)K^+)$$

$$b \equiv \Gamma(B^+ \longrightarrow D^0(\bar{f}_i)K^+)$$

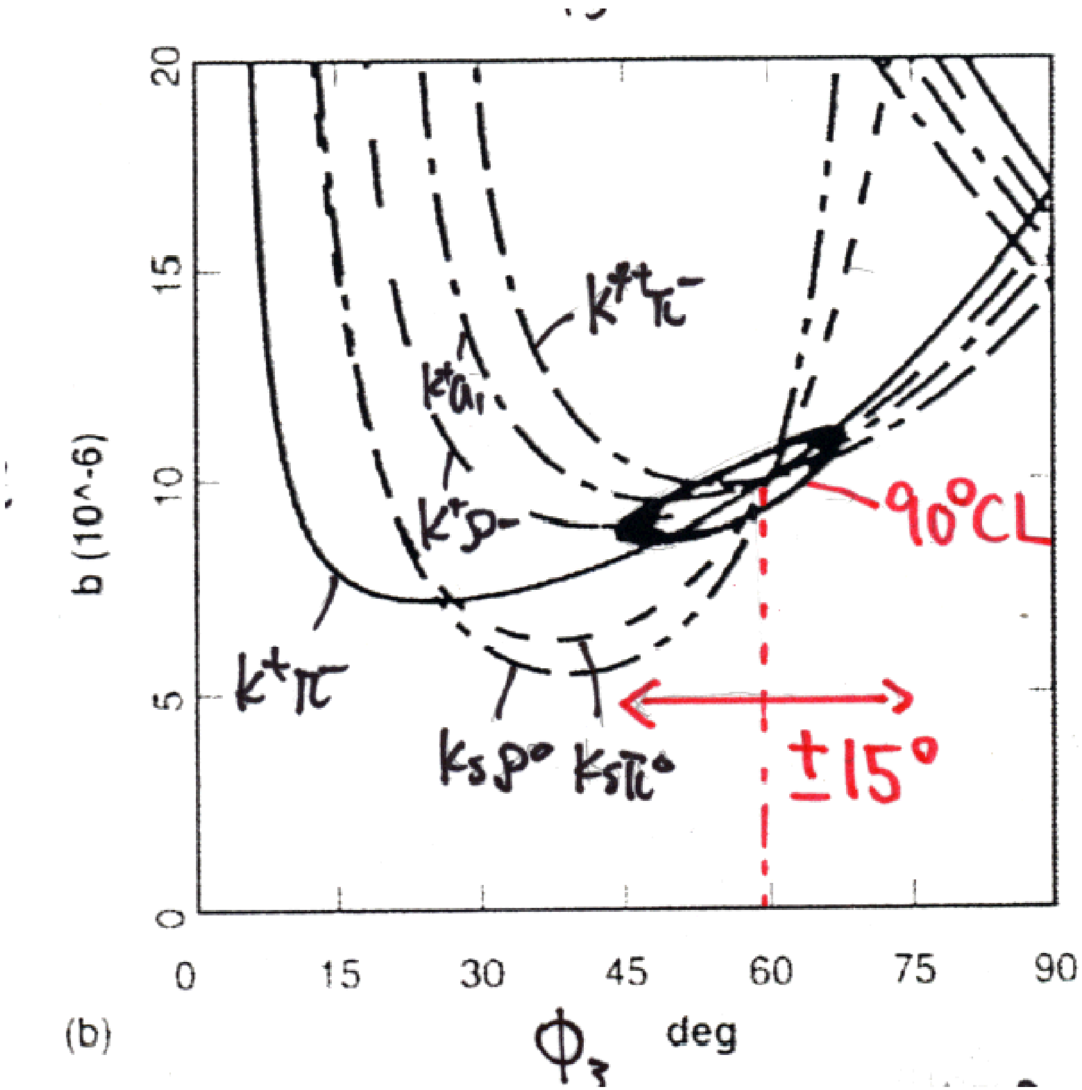
$$r \equiv \frac{b}{a}$$

$$d_i(\text{meas}) = d_i(\phi_3, \delta_i, b)$$

$$\bar{d}_i(\text{meas}) = \bar{d}_i(\phi_3, \delta_i, b)$$

Eliminate δ_i (strong phase) $\longrightarrow$
$F(\phi_3, b) = 0$: a line in $\phi_3 - b$ plane
2 modes $\longrightarrow$ soluction

ADS paper result: with 10^8 B^+B^- pairs



DK^{*+} modes

Use

$K^+\pi^-, K_S\pi^0, K^+\rho^-, K\ \ +a_1^-, K_S\rho^0, K^{*+}\pi^-$

The theoretical paper assumed

100% efficiency for all modes.
No backgrounds

$\sigma_{\phi_3} \sim 10^\circ$ at $10^8 B^+B^-$

$\longrightarrow \sigma_{\phi_3} \sim 6^\circ$ at 300 fb^{-1}

But . . .

DK^{*+} modes

Efficiency and S/N corrections

$\epsilon(K^+\pi^-) = 0.35$ (Belle K^+K^-)

Assume $\epsilon_{\rm trk} = \frac{2}{3}$, $\epsilon_{\pi^0} = \frac{1}{2}$.

$K^{*+} \longrightarrow K_S\pi^+, K^+\pi^0$, $K_S \longrightarrow \pi^+\pi^-$

S/N = 1/1

Total number of DK^* events with $10^8 B^+B^-$ reduces by $1/70$:

$\sigma_{\phi_3} \sim 50^\circ$ at 300 fb^{-1}

$\sigma_{\phi_3} \sim 16^\circ$ at 3 ab^{-1}

Efficiency corrections factor relative to $K^+\pi^-$

mode	N_i	$\epsilon_{\rm corr}$	$N_i\epsilon_{\rm corr}$
$K^+\pi^-$	83	1	83
$K_S\pi^0$	791	1/4	198
$K^+\rho^-$	224	1/3	112
$K^+a_1^-$	146	2/9	32
$K_S\rho^0$	362	2/9	80
$(K^+\pi^0)\pi^-$	$65 \times 1/3$	1/2	11
$(K_S\pi^+)\pi^-$	$65 \times 2/3$	2/9	10
total	1671		526

$$526/1671 = 0.31$$

DK^+ modes

Efficiency and S/N corrections

$\epsilon(K^+\pi^-) = 0.35$ (Belle $K^+K\ -$)

Assume $\epsilon_{\rm trk} = \frac{2}{3}$, $\epsilon_{\pi^0} = \frac{1}{2}$.

$K^{*+} \longrightarrow K_S\pi^+, K^+\pi^0$, $K_S \longrightarrow \pi^+\pi^-$

S/N = 1/1

$$\frac{Br(DK^+)}{Br(DK^{*+})} = 0.4$$

Total number of DK^* events with $10^8 B^+B^-$ reduces by $1/45$:

$\sigma_{\phi_3} \sim 40^\circ$ at 300 fb^{-1}

$\sigma_{\phi_3} \sim 13^\circ$ at 3 ab^{-1}

DK^+ Dalitz plot analysis (Anton Poluektov)

$$B^+ \to DK^+, \quad D = \bar{D}^0 + re^{i(\delta+\phi_3)}D^0$$

$$B^- \to D'K^-, \quad D' = D^0 + re^{i(\delta-\phi_3)}\bar{D}^0$$

$$A(s,t) = Amp(D^0 \to K_S\pi^+\pi^-)(s,t)$$

$$\bar{A}(s,t) = Amp(\bar{D}^0 \to K_S\pi^+\pi^-)(s,t) = A(t,s)$$

$$s \equiv M^2(K_S\pi^+), \quad t \equiv M^2(K_S\pi^-)$$

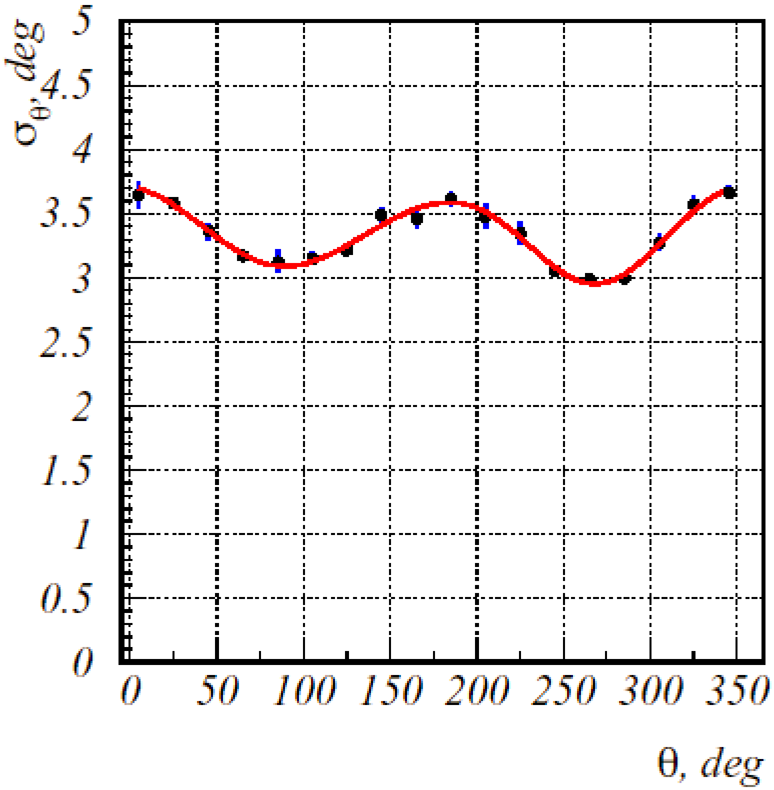
$$(B^+) \quad p^+(s,t) = |A(s,t) + re^{i(\delta+\phi_3)}A(t,s)|^2$$

$$(B^-) \quad p^-(s,t) = |A(t,s) + re^{i(\delta-\phi_3)}A(s,t)|^2$$

Fit $p^+(s,t)$ and $p^-(s,t)$ *to* extract $\delta + \phi_3$ and $\delta - \phi_3$.
(Use known Dalitz amplitudes, or measure)

DK Dalitz analysis - sensitivity

Sensitivity with 10^4 detected events



$\theta = \delta - \phi_3$

$\sigma_{\phi_3} \sim \sigma_\theta$

σ_{ϕ_3} is roughly constant
for any values of ϕ_3 and δ

DK Dalitz analysis summary

- No discrete ambiguities for ϕ_3.
- Dalitz model uncertainty $\sim 10^\circ$ now.
  (can be improved by measurements)
- $\sigma_{\phi_3} = 22\text{-}32^\circ$ at 300 fb^{-1}
- $\sigma_{\phi_3} = 7\text{-}10^\circ$ at 3 ab^{-1}

Conclusions

- ϕ_3 can be measured in varieties of modes. (important cross check)
- Sensitivities are reasonable at 3 ab^{-1} but marginal at 300 fb^{-1}.
- Super KEKB is needed.

Things to do

- $D^{(*)+}\pi^{(*)-}$ full reconstruction sensitivity estimation
- Errors on r for each $D^{(*)+}\pi^{(*)-}$ mode
- $D^{(*)+}\rho^{-}$ angular analysis sensitivity estimation
- More studies on S/N and efficiencies
  (Suppressed DK in particular)
- More theoretical studies on $K\pi$ and $\pi\pi$ modes