



Time-dependent CP Violation at Belle

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representing the
Belle Collaboration

XXXIX Rencontres de Moriond:
Electroweak Interactions and Unified Theories

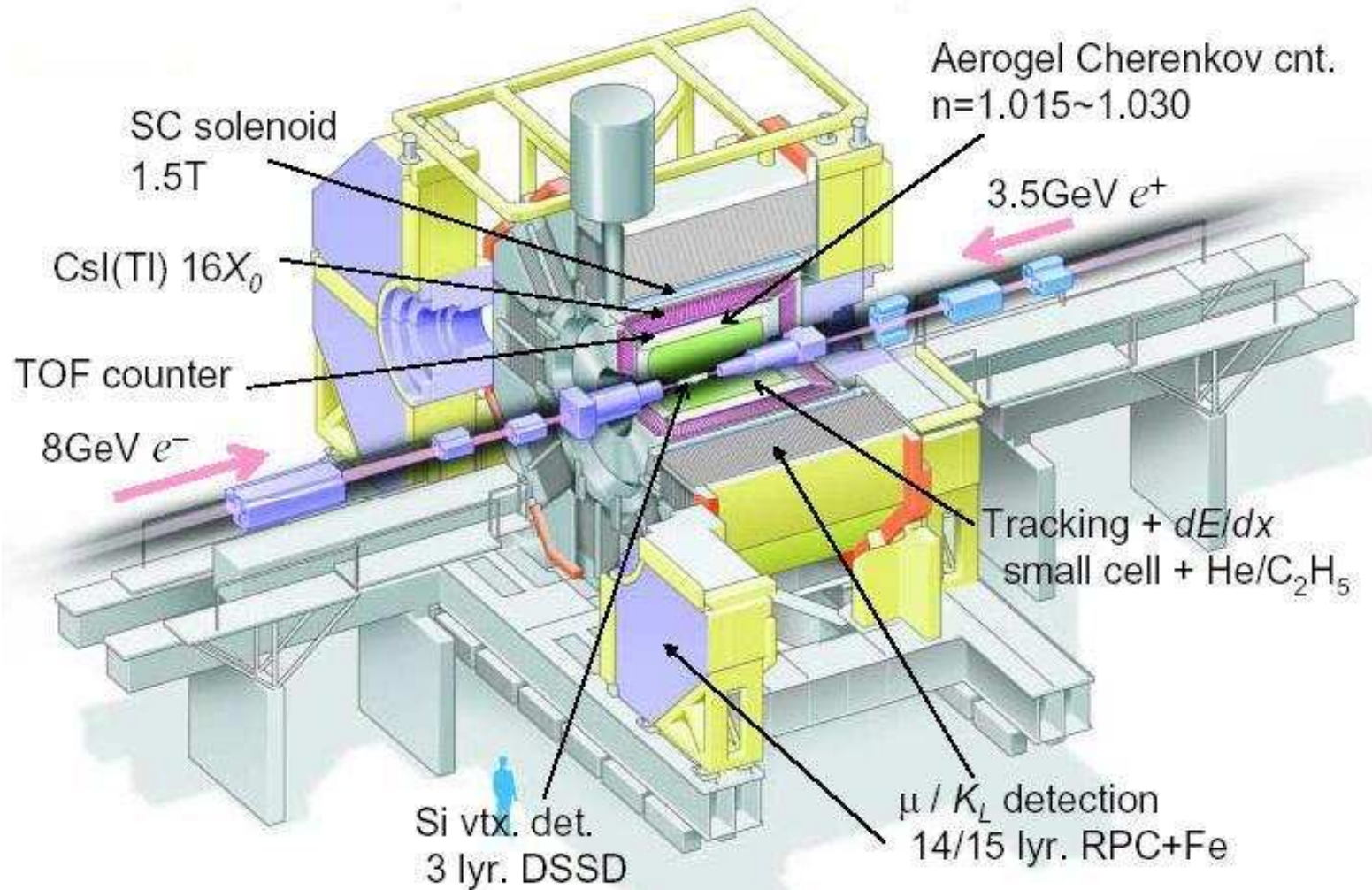
**XXXIX Rencontres de Moriond:
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Content



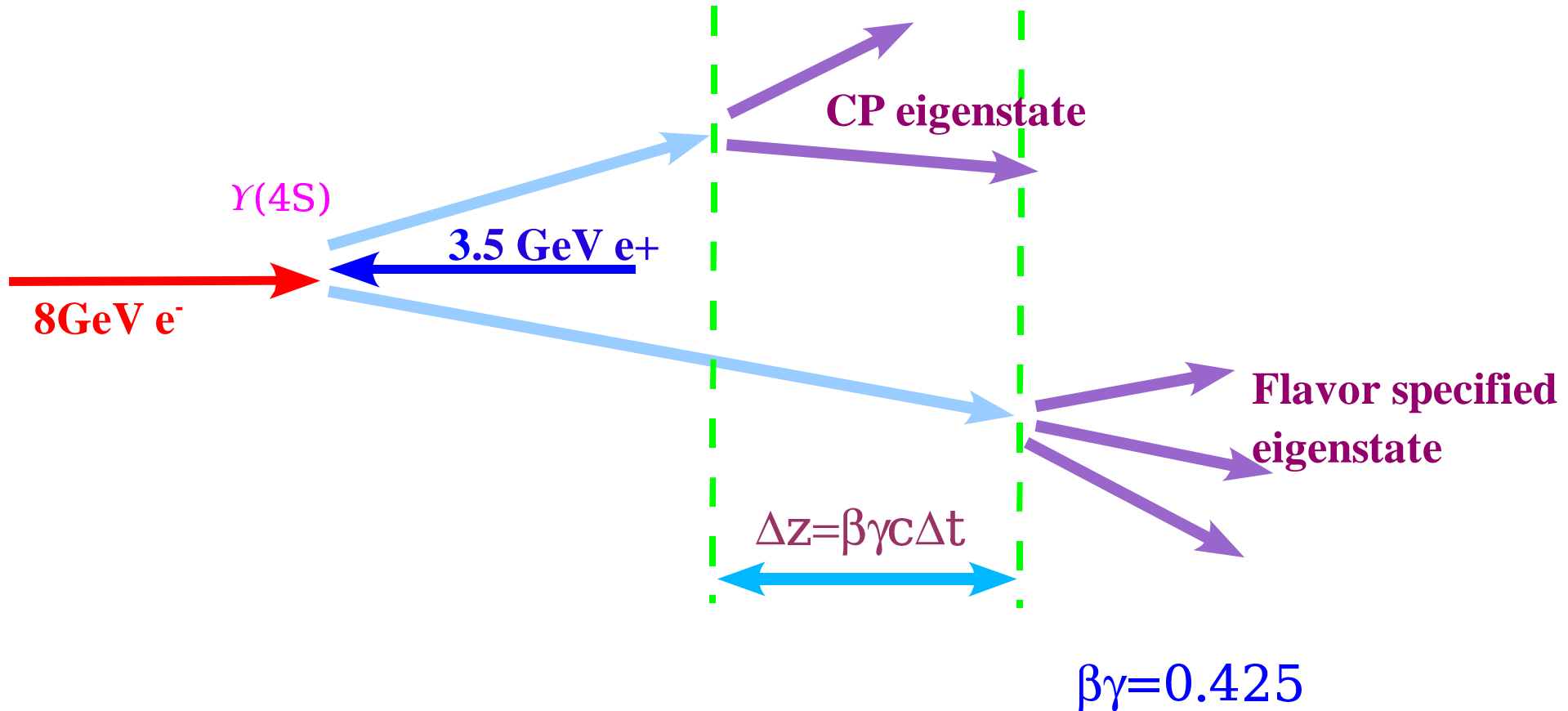
- Introduction
- How to extract CP violation parameters
- ϕ_2 related decay
 - $B^0 \rightarrow \pi^+ \pi^-$
- ϕ_1 related decay
 - $\phi K_s, B \rightarrow K^+ K^- K_s, B \rightarrow \eta' K_s$
- Summary



Vertex resolution: $\sigma(z_{cp}) = 75\mu\text{m}$, $\sigma(z_{tag}) = 140\mu\text{m}$



How to Measure Time Dependent CP Violation



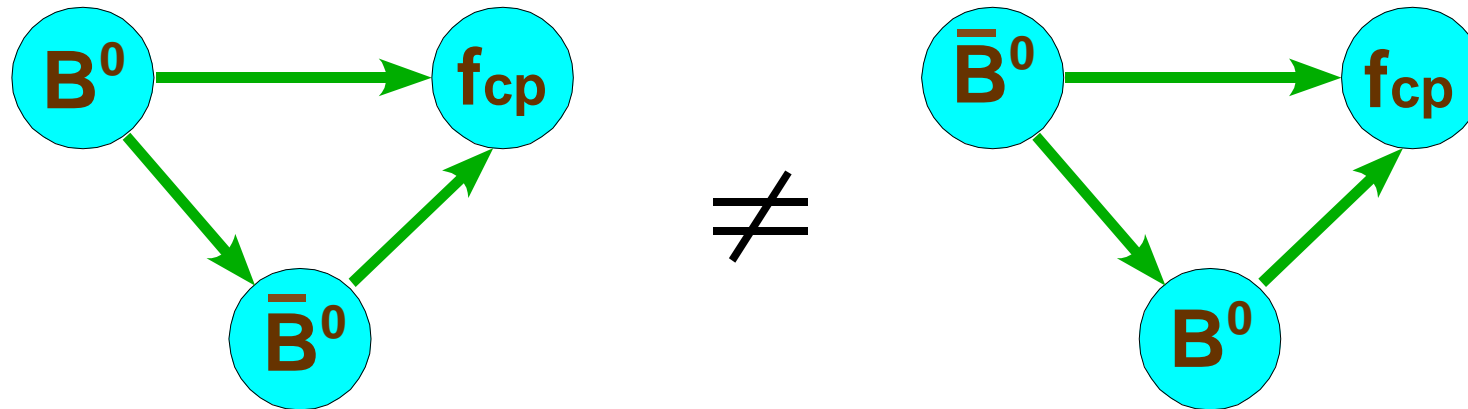


How to Measure Time Dependent CP Violation

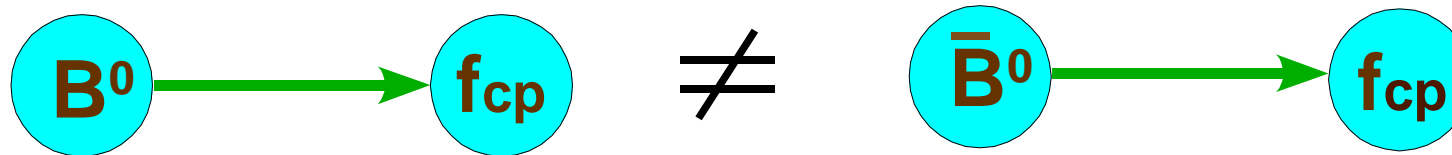


- Extract candidate event from large B sample
 - Event selection
 - qq continuum background suppression
- Tag the flavor of the other B
 - Use flavor specific, inclusive property to tag the flavor of B
 - Use the multi-dimensional likelihood to calculate the wrong tag fraction
- Extract Δt from $\Delta z = z_{CP} - z_{Tag} \approx \beta\gamma c\Delta t$
 - From SVD to obtain the precise vertex
- Performing the time-dependent fit
 - Event-by-event signal probability, Δt resolution function
 - Use maximum likelihood fit on selected sample

(1) Mixing-induced CP violation



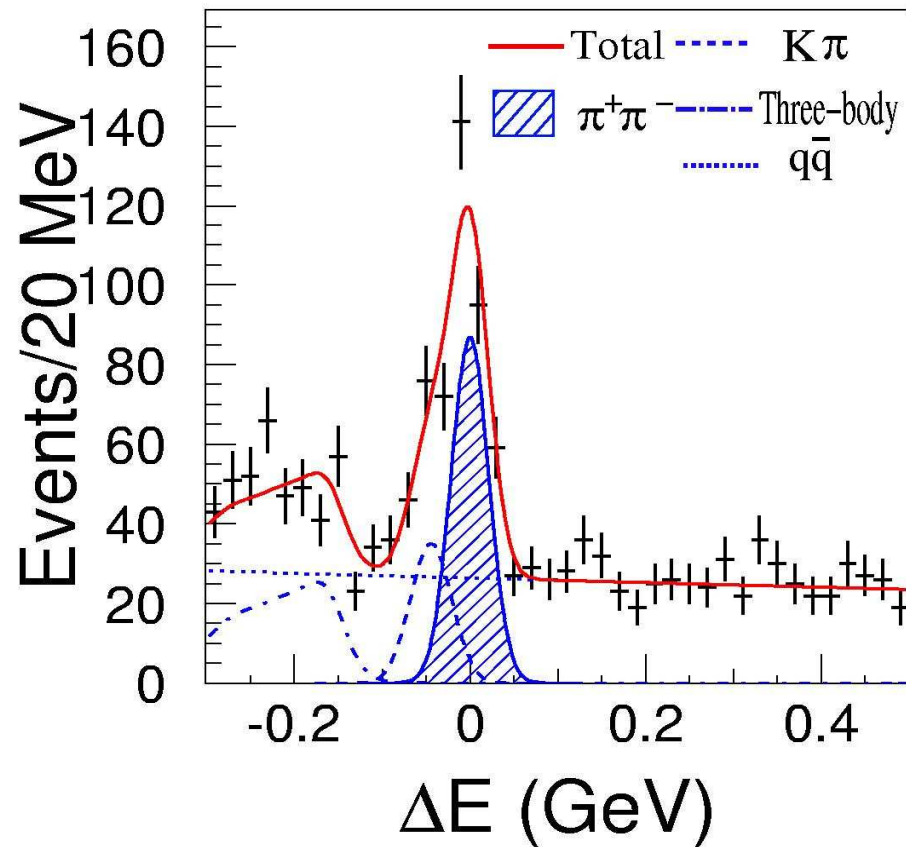
(2) Direct CP violation



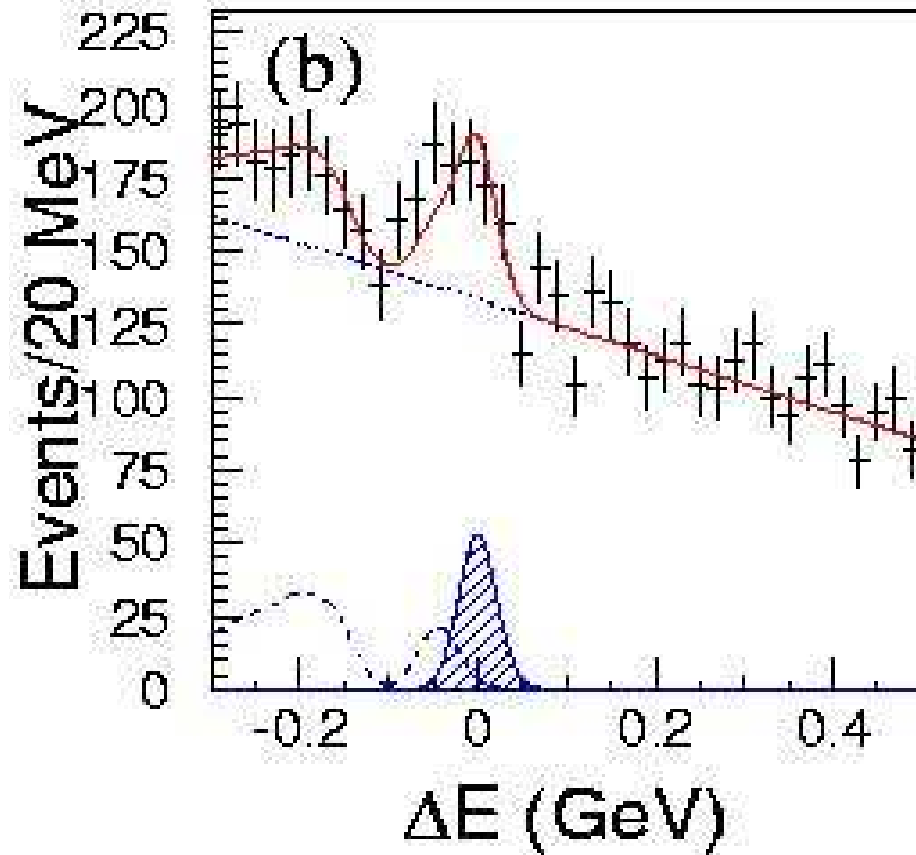
- Tree only: we can measure $\sin 2\phi_2$ from (1)
- Penguin contribution : pollute (1), but we can see (2)

note: $\phi_2 = \alpha$

High Quality Event



Low Quality Event



$$P_f^{q_{\text{flv}}}(\Delta t) = \frac{e^{-|\Delta t|/\tau_{B^0}}}{4\tau_{B^0}} [1 + (q_{\text{flv}})(S_{\pi\pi} \sin(\Delta m \Delta t) + A_{\pi\pi} \cos(\Delta m \Delta t))]$$

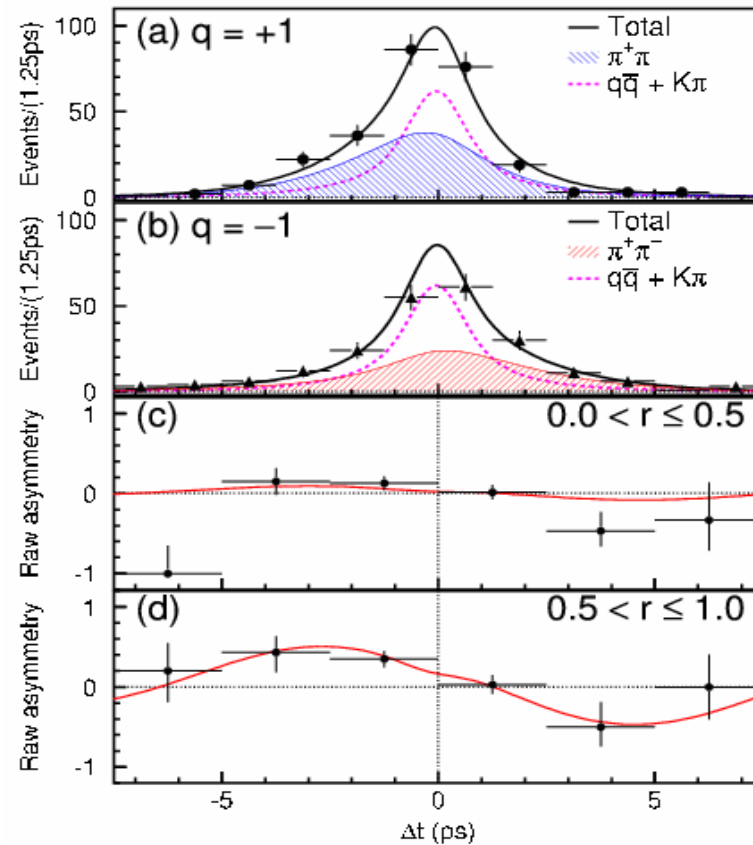
140 fb⁻¹

- 1529 candidates
- 372 ± 32 $\pi^+ \pi^-$ signal events

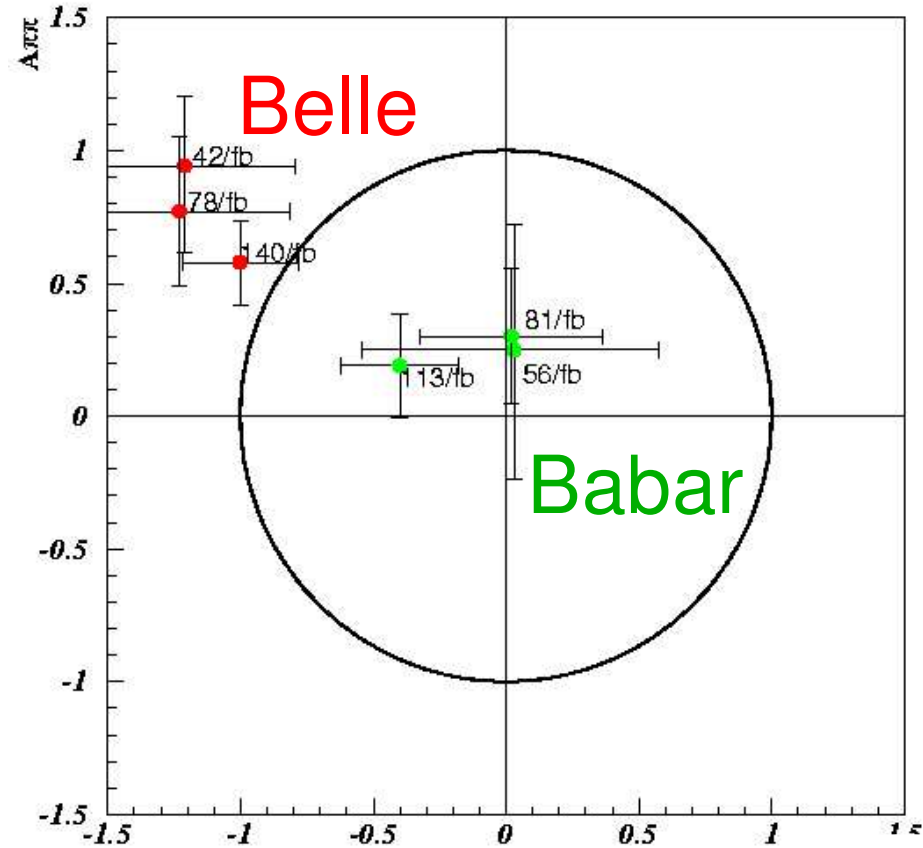
$$S_{\pi\pi} = -1.00 \pm 0.21 \pm 0.07$$

$$A_{\pi\pi} = 0.58 \pm 0.15 \pm 0.07$$

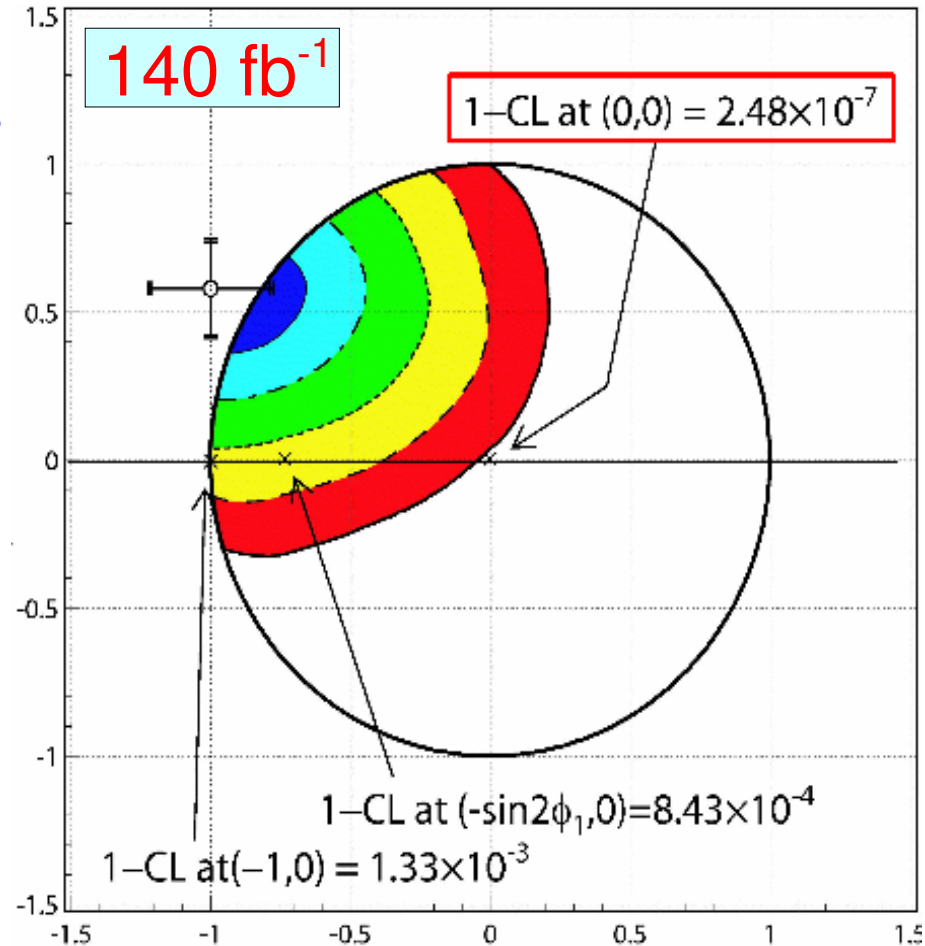
submitted to PRL
(hep-ex/0401029)



- Belle
- Babar



- Feldman-Cousins Analysis
- 5.2σ for CP violation
- 3.2σ for direct CP violation
- 3.3σ for superweak



$S_{\pi\pi}$, $A_{\pi\pi}$ can be expressed as a function of ϕ_1 , ϕ_2 , $|P/T|$, and δ
 (M.Gronau & J.L.Rosner, PRD 65, 0903012 (2002))

$$A(B^0 \rightarrow \pi^+ \pi^-) = -(|T|e^{i\delta_T} e^{i\phi_3} + |P|e^{i\delta_P})$$

$$A(\bar{B}^0 \rightarrow \pi^+ \pi^-) = -(|T|e^{i\delta_T} e^{-i\phi_3} + |P|e^{i\delta_P})$$

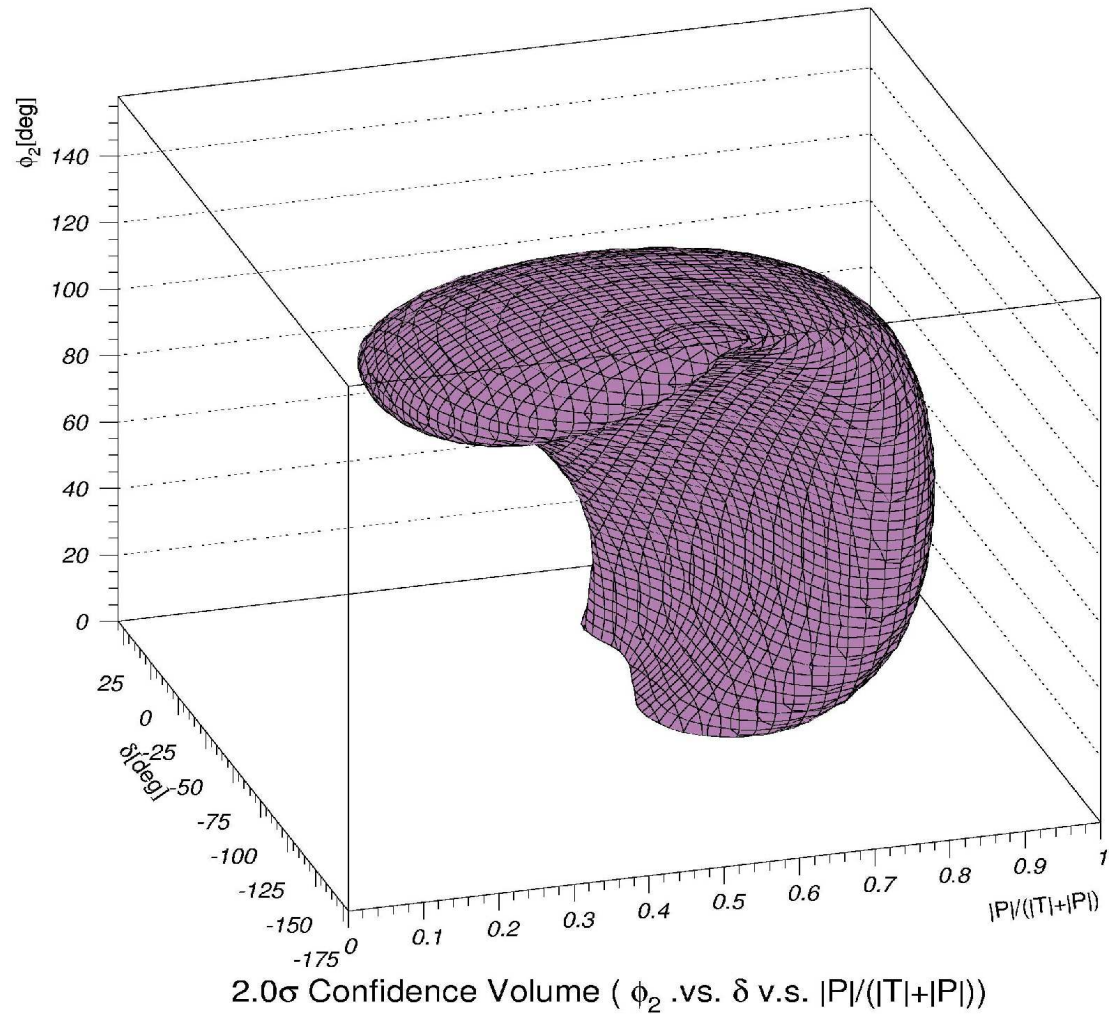
$$\lambda_{\pi\pi} = e^{2i\phi_2} \frac{1 + |P/T|e^{i\delta + \phi_3}}{1 + |P/T|e^{i\delta - \phi_3}}$$

$$S_{\pi\pi} = [\sin 2\phi_2 + 2|P/T|\sin(\phi_1 - \phi_2)\cos\delta - |P/T|^2 \sin 2\phi_1] / R_{\pi\pi}$$

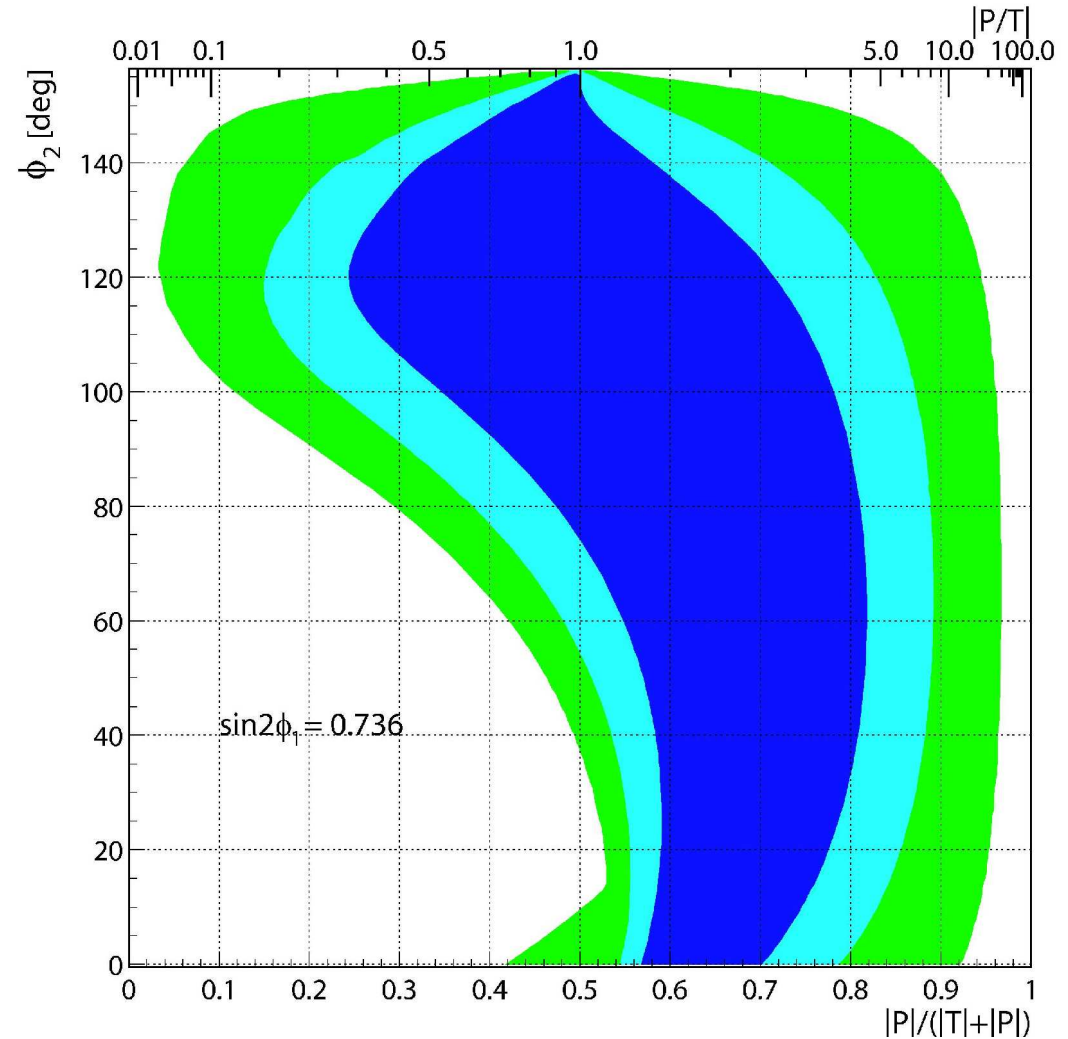
$$A_{\pi\pi} = -[2|P/T|\sin(\phi_2 + \phi_1)\sin\delta] / R_{\pi\pi}$$

$$R_{\pi\pi} = 1 - 2|P/T|\cos\delta\cos(\phi_2 + \phi_1) + |P/T|^2$$

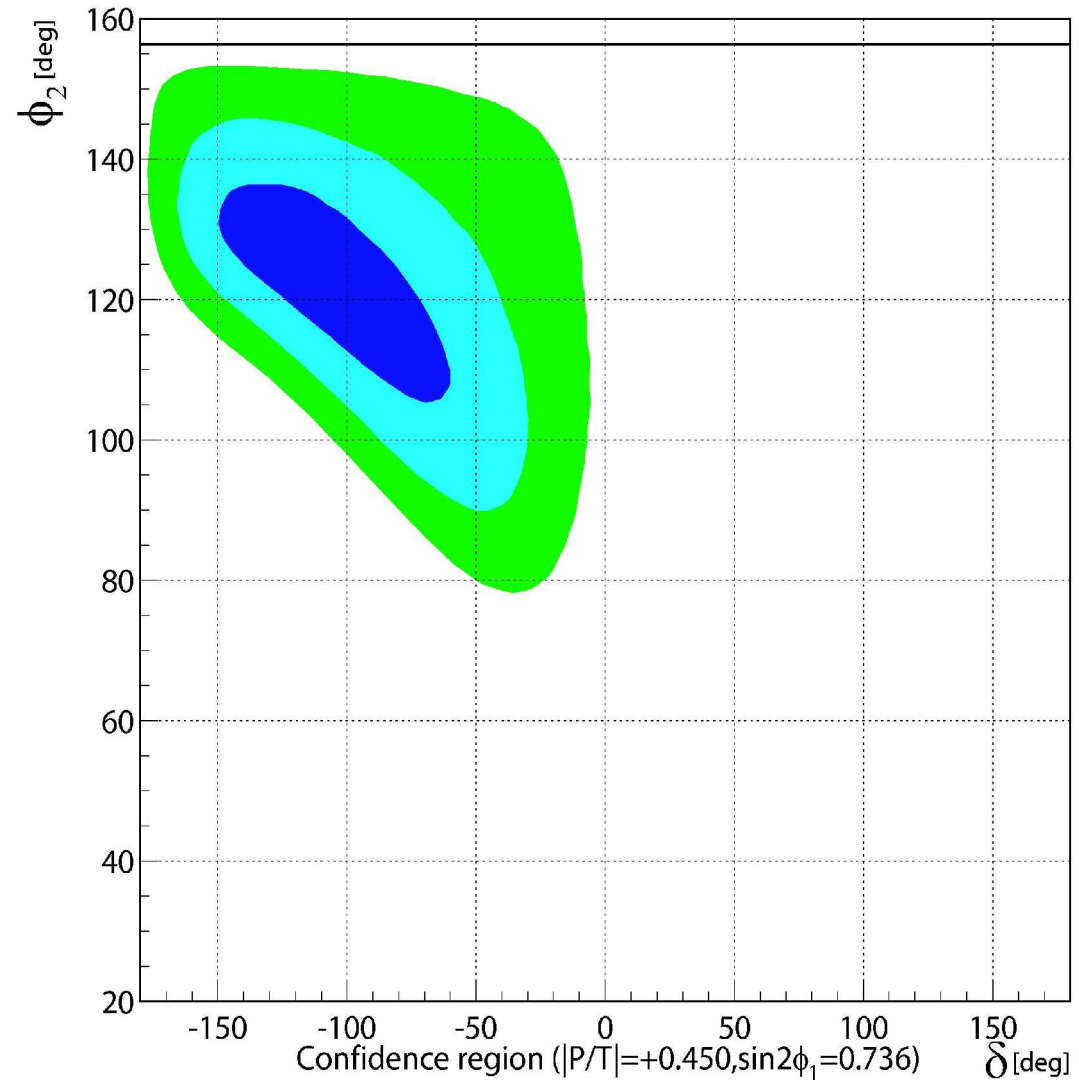
- Model independent constraint on ϕ_2 , $|P/T|$, and δ
- $\sin 2\phi_1 = 0.736$
- 95.5% confidence level

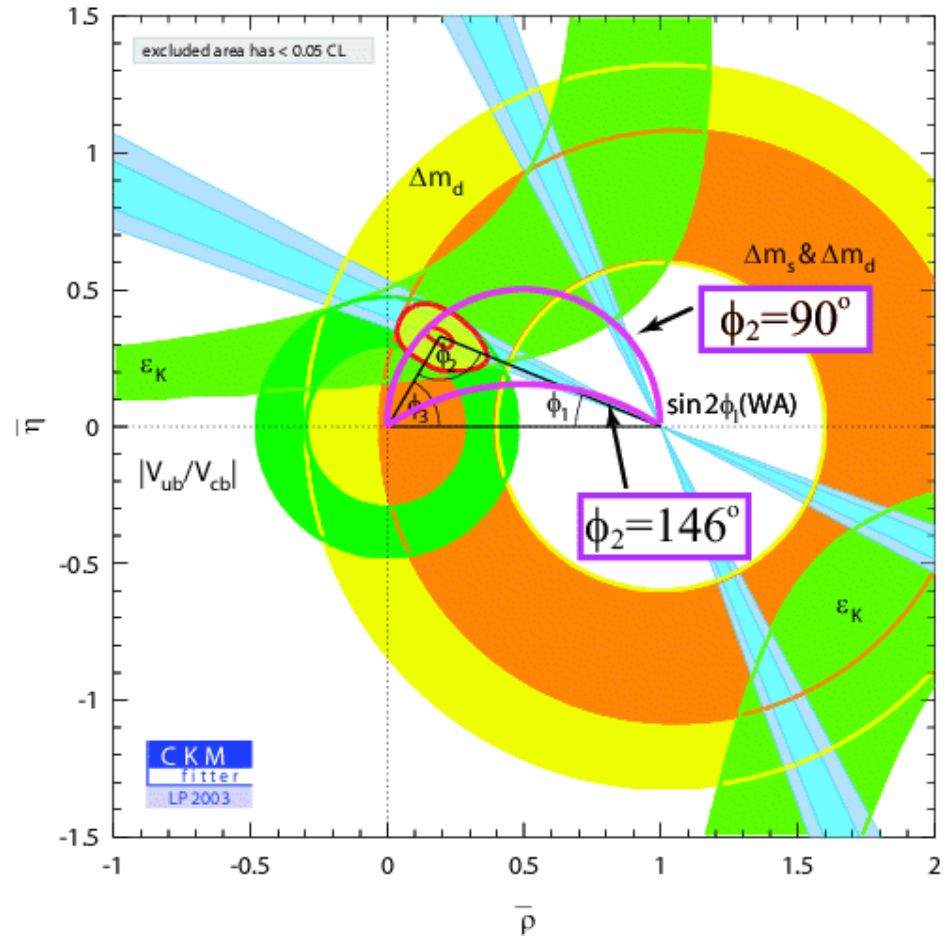


- $\sin 2\phi_1 = 0.736$
- With any ϕ_2, δ
- $P/T > 0.17$ with 95.5% confidence level



- $\sin 2\phi_1 = 0.736$
- $P/T \leq 0.45$
- With any δ
- $90^\circ \leq \phi_2 \leq 146^\circ$ with 95.5% confidence level







$b \rightarrow sq\bar{q}$

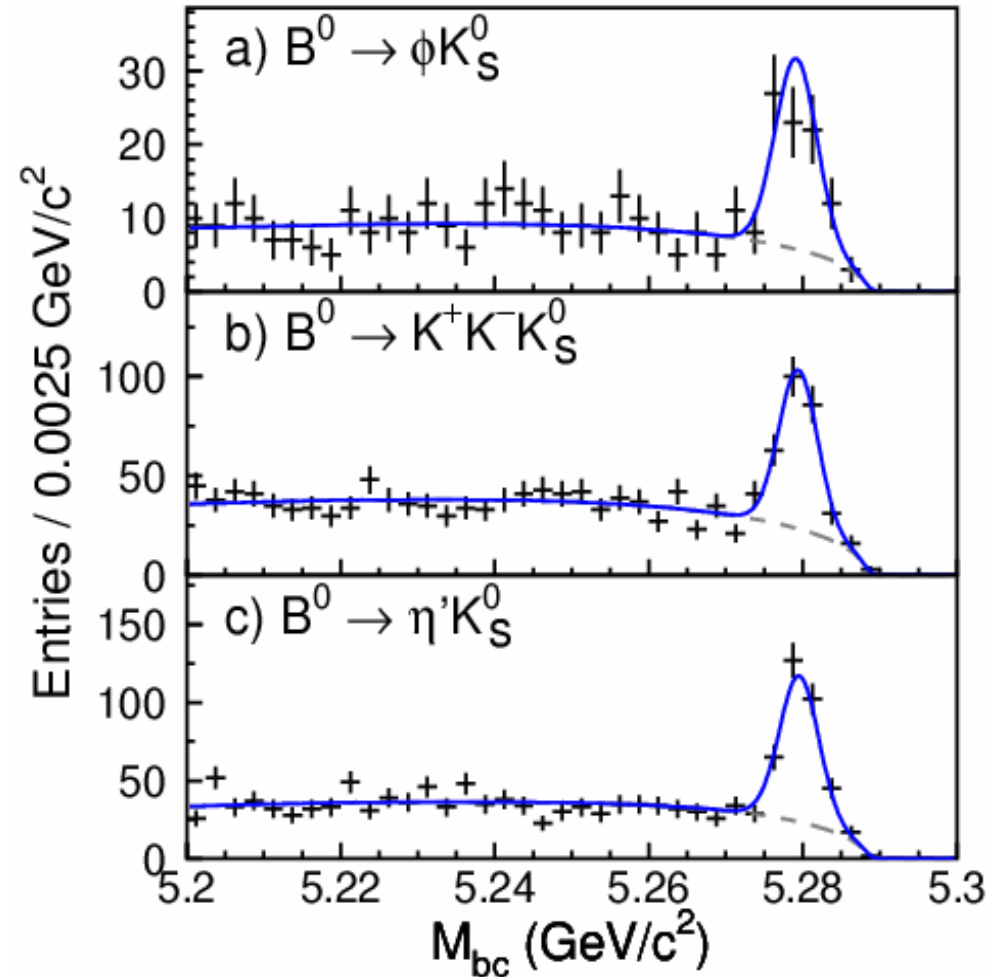


$$P_f^{q_{flv}}(\Delta t) = \frac{e^{-|\Delta t|/\tau_{B^0}}}{4\tau_{B^0}} [1 + (q_{flv})(S_{sq\bar{q}} \sin(\Delta m \Delta t) + A_{sq\bar{q}} \cos(\Delta m \Delta t))]$$

- $b \rightarrow sq\bar{q}$ contains same weak phase as $b \rightarrow c\bar{c}s$.
- Under SM $-\xi_{sq\bar{q}} S_{sq\bar{q}}$ should also measure $\sin 2\phi_1$, and
 $-\xi_{sq\bar{q}} S_{sq\bar{q}} = -\xi_{ccs} S_{ccs}$
- If we find $-\xi_{sq\bar{q}} S_{sq\bar{q}} \neq -\xi_{ccs} S_{ccs}$, it may be due to **new physics !!**

140 fb⁻¹

- $B \rightarrow \phi K_S$: 106 candidates
- $B \rightarrow K^+ K^- K_S$: 361 candidates
- $B \rightarrow \eta' K_S$: 421 candidates



$$B \rightarrow \phi K_s$$

$$S_{\phi K_s} = -0.96 \pm 0.50^{+0.09}_{-0.11}$$

$$A_{\phi K_s} = -0.15 \pm 0.29 \pm 0.07$$

$$B \rightarrow \eta' K_s$$

$$S_{\eta' K_s} = +0.43 \pm 0.27 \pm 0.05$$

$$A_{\eta' K_s} = -0.01 \pm 0.16 \pm 0.04$$

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

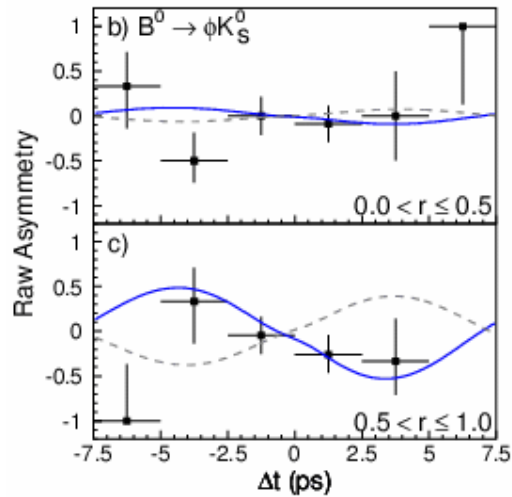
$$S_{K^+ K^- K_s} = -0.51 \pm 0.26 \pm 0.05^{+0.18}_{-0.00}$$

$$A_{K^+ K^- K_s} = -0.17 \pm 0.16 \pm 0.04$$

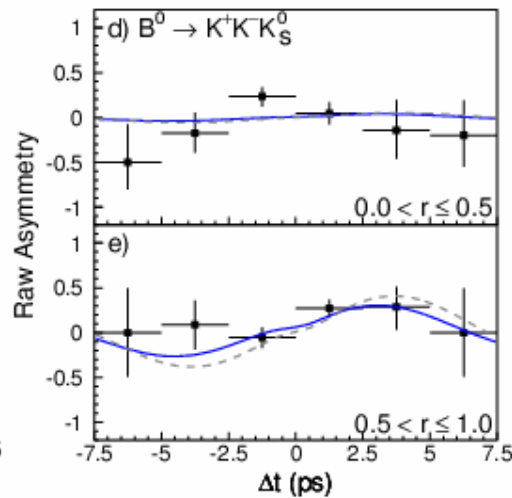
3.5



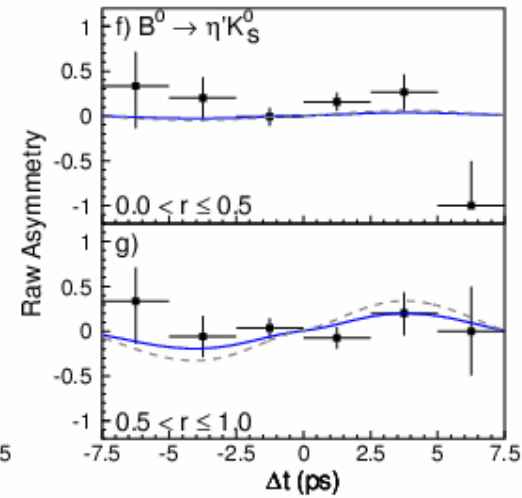
$B \rightarrow \phi K_S$



$B \rightarrow K^+ K^- K_S$



$B \rightarrow \eta' K_S$



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Summary

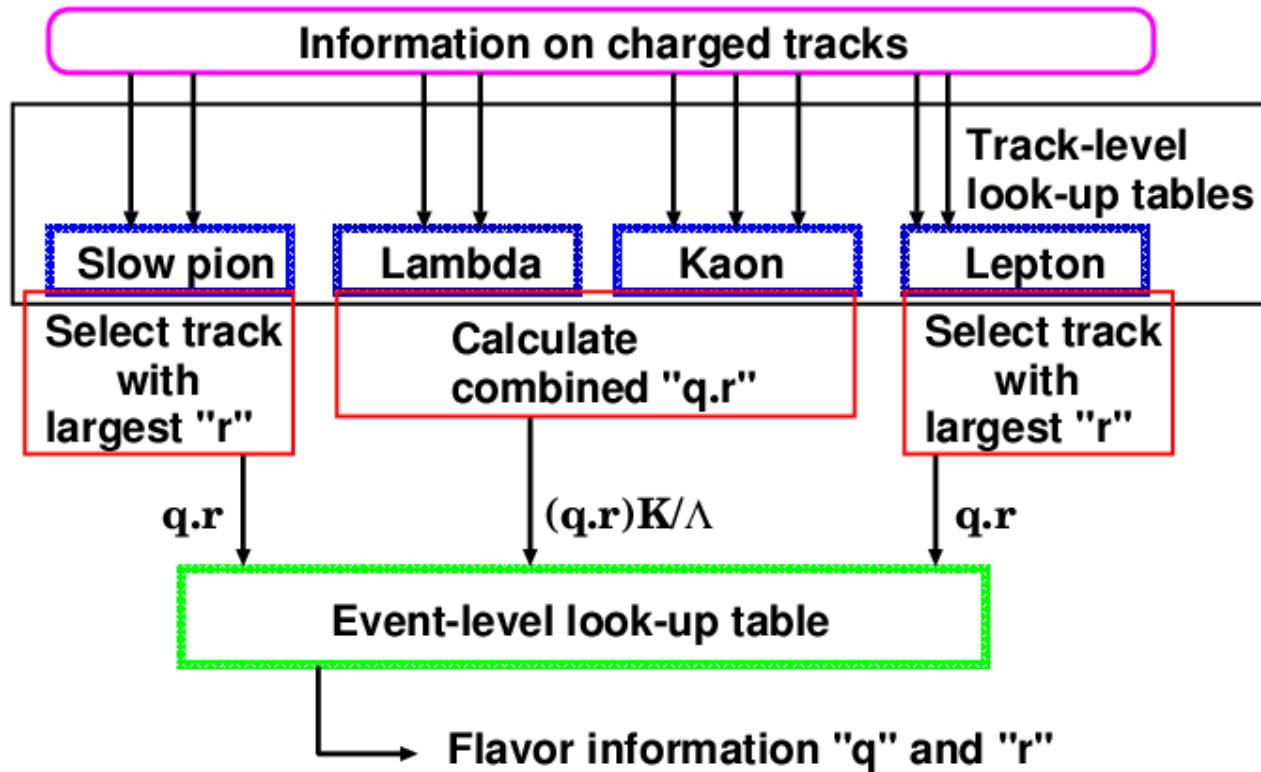


- CP violation in $B \rightarrow \pi^+ \pi^-$ is observed and has evidence of direct CP violation.
- $B \rightarrow \phi K_s$ has evidence for new physics.
- With increasing integrated luminosity, new and interesting impact for physics is coming soon.



Backup Slides

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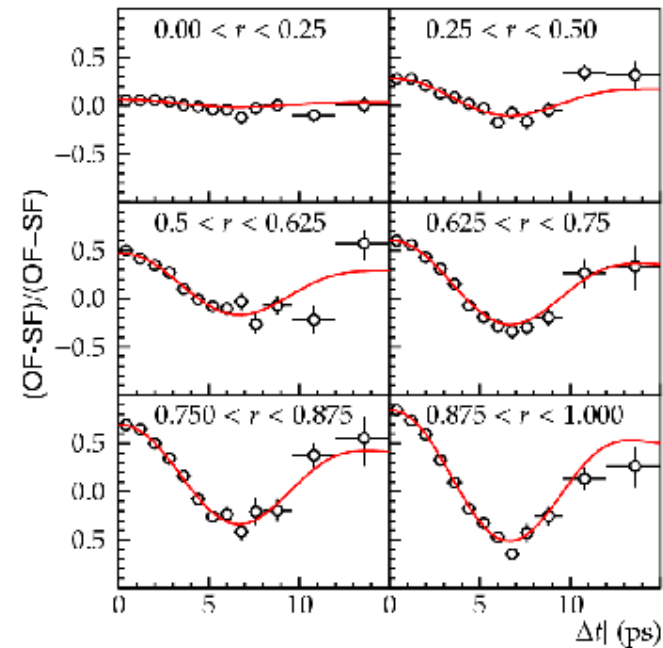
Mixing asymmetry:

$$\frac{OF - SF}{OF + SF} \propto (1 - 2w) \cos(\Delta M \Delta t)$$

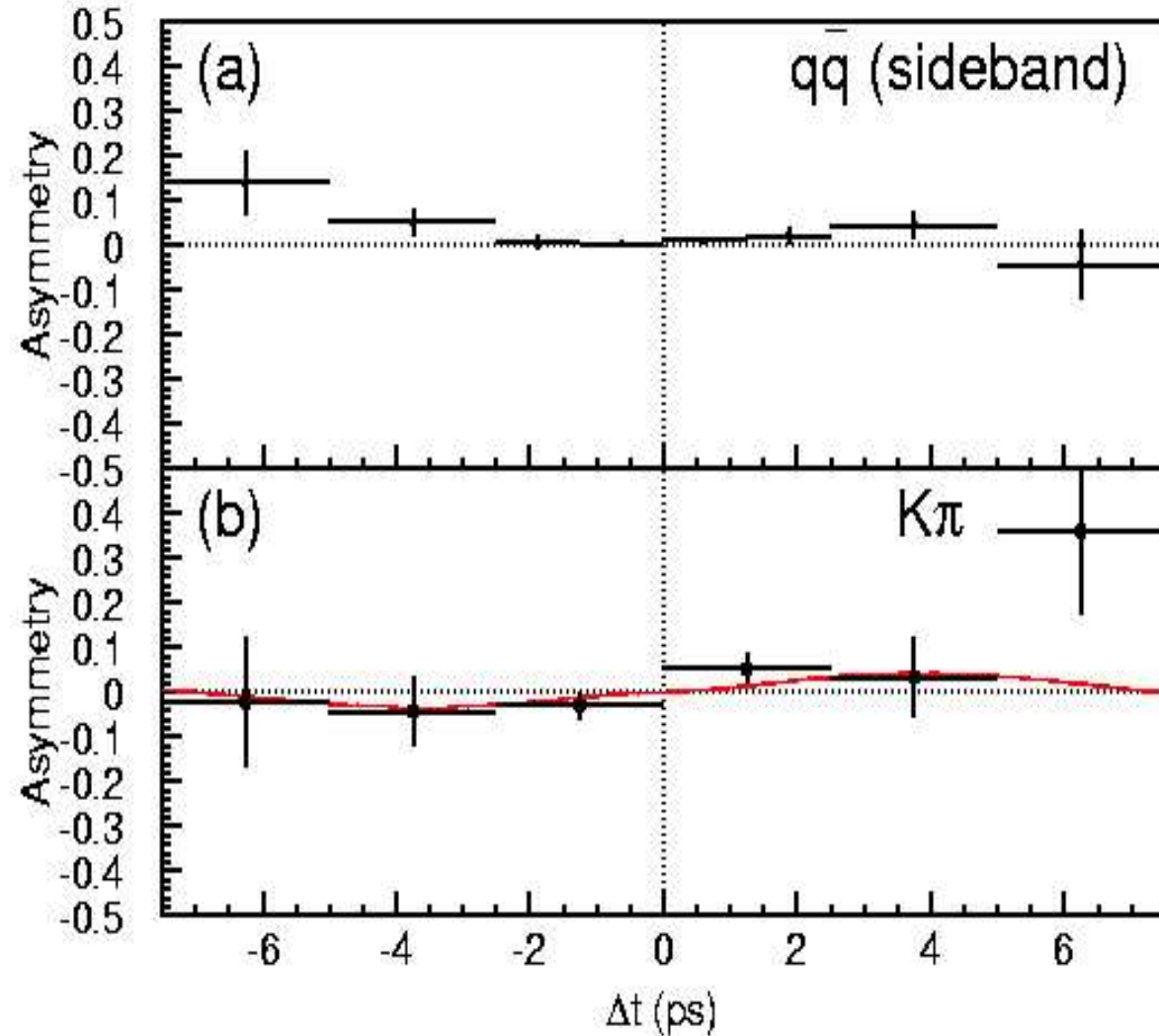
TABLE I: The event fractions q , wrong-tag fractions w , wrong-tag fraction differences Δw , and average effective tagging efficiencies $\epsilon_{\text{eff}}^1 = q(1 - 2w)^2$ for each r interval. The errors include both statistical and systematic uncertainties. The event fractions are obtained from the $J/\psi K_S^0$ simulation.

l	r interval	q	w	Δw	ϵ_{eff}^1
1	0.000 - 0.250	0.398	0.464 ± 0.006	0.011 ± 0.006	0.002 ± 0.001
2	0.250 - 0.500	0.143	0.331 ± 0.008	$+0.004 \pm 0.010$	0.017 ± 0.002
3	0.500 - 0.625	0.104	0.231 ± 0.009	-0.011 ± 0.010	0.030 ± 0.002
4	0.625 - 0.750	0.122	0.163 ± 0.008	0.007 ± 0.009	0.055 ± 0.003
5	0.750 - 0.875	0.391	0.109 ± 0.007	$+0.016 \pm 0.009$	0.057 ± 0.002
6	0.875 - 1.000	0.133	0.320 ± 0.005	$+0.003 \pm 0.006$	0.126 ± 0.003

Effective tagging efficiency $\approx 28.7\%$

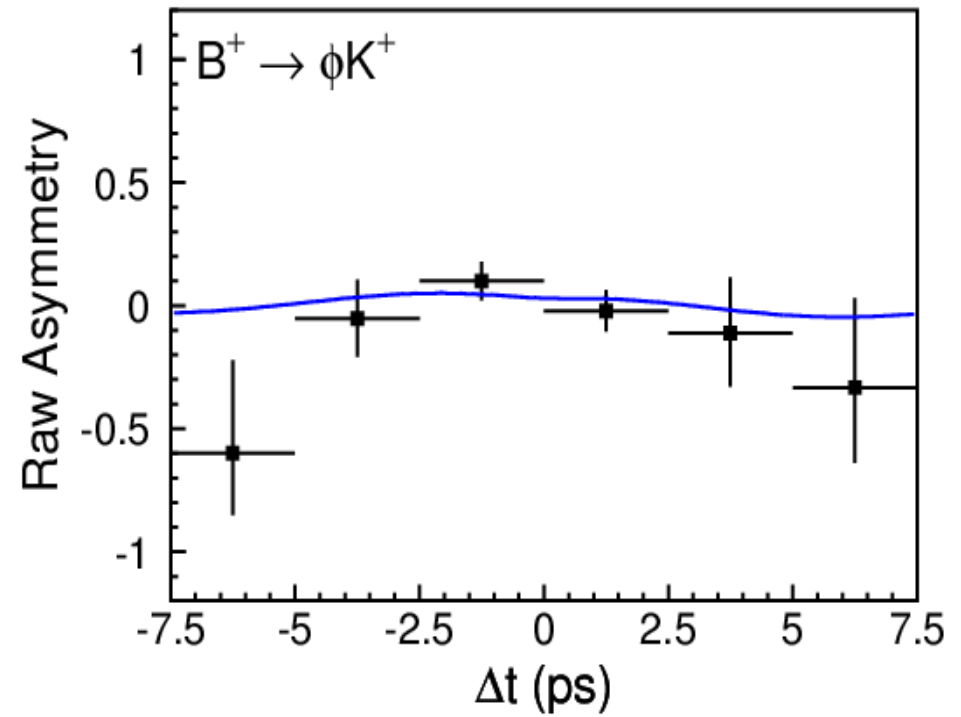
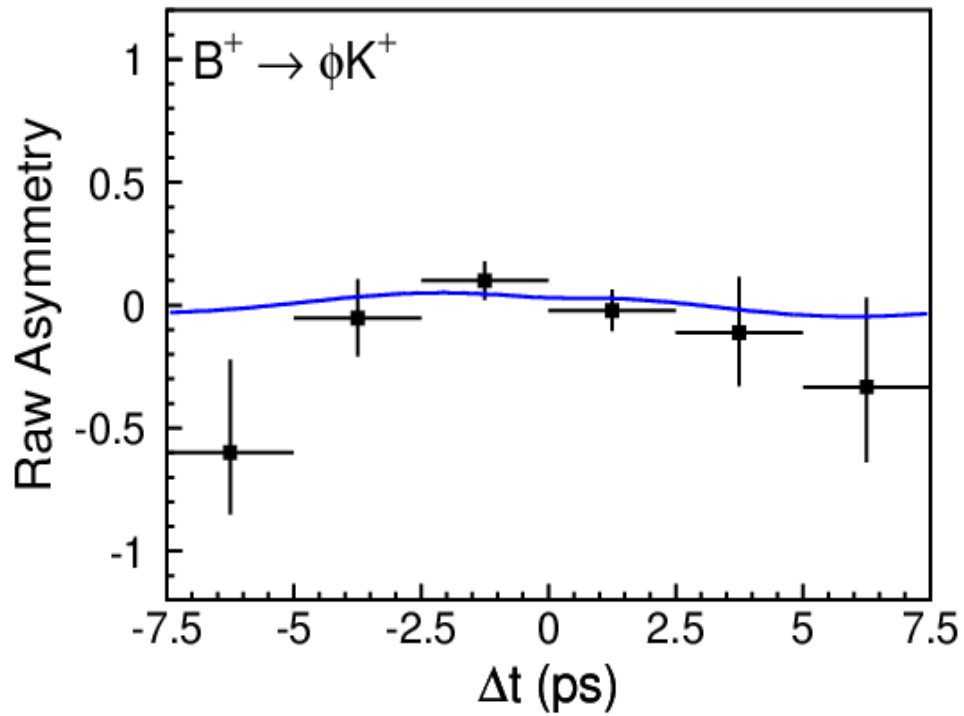


- Null asymmetry check on continuum sideband and $K\pi$ sample.
- $K\pi$ sample
 - $S_{K\pi} := +0.14 \pm 0.11$
 - $A_{K\pi} := -0.02 \pm 0.08$



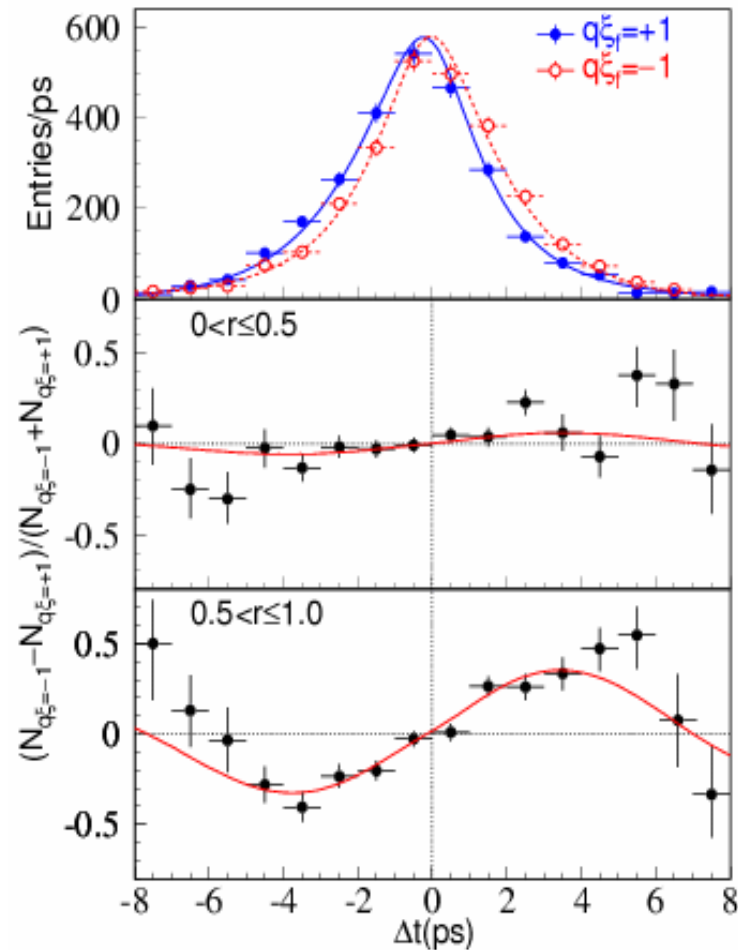
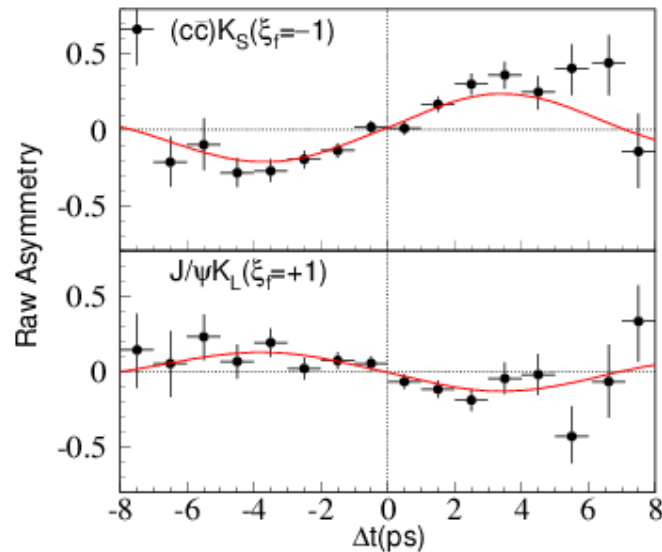


Control Sample for $B \rightarrow \phi K_s$



preliminary

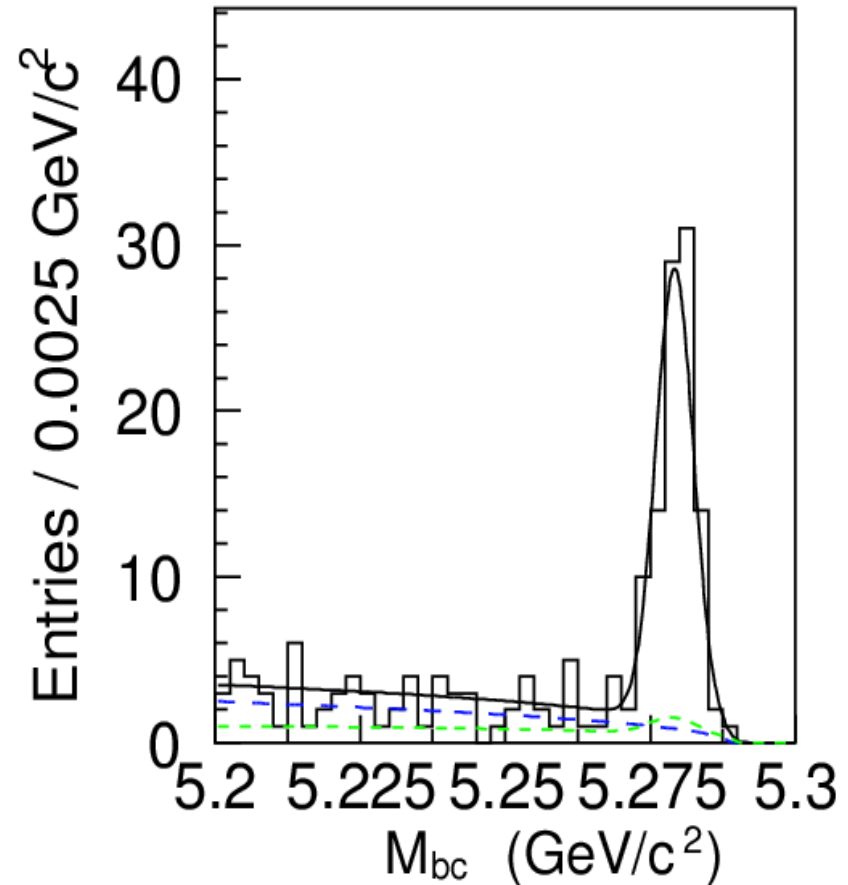
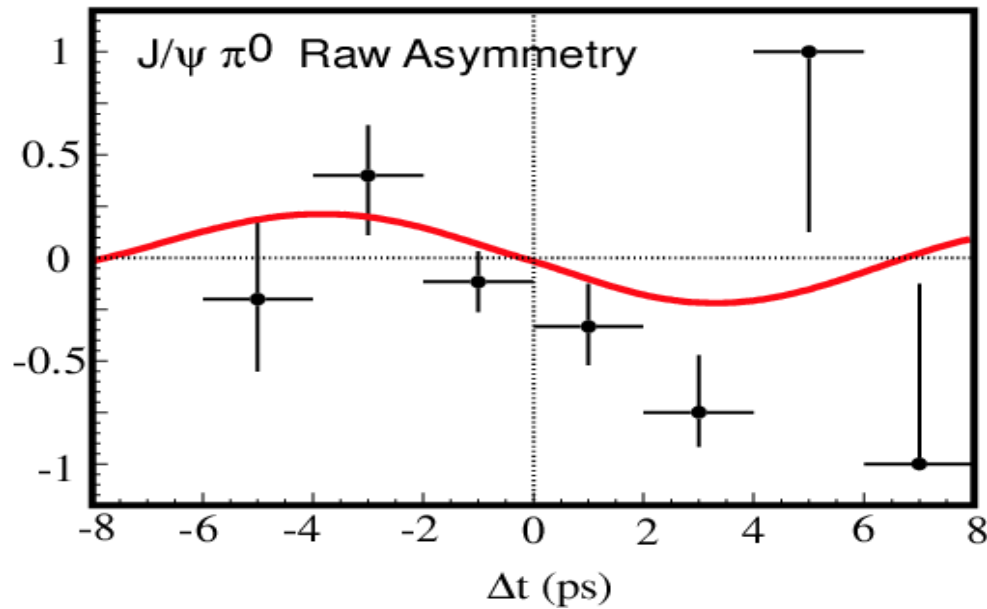
$$\sin 2 \phi_1 = 0.733 \pm 0.057 \pm 0.028$$



$$S_{J/\psi \pi^0} = -0.72 \pm 0.42 \pm 0.08$$

$$A_{J/\psi \pi^0} = -0.01 \pm 0.29 \pm 0.07$$

103 candidate events



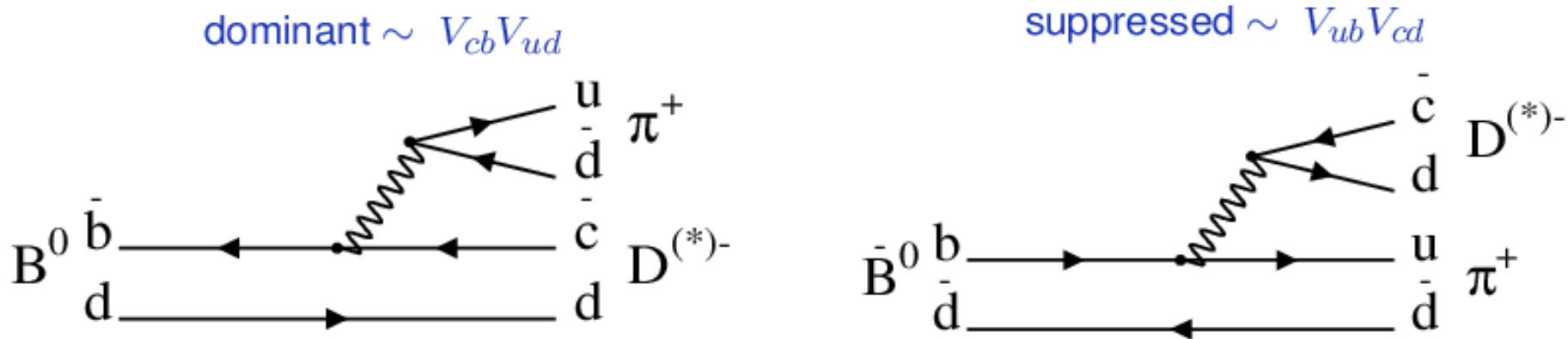
$$\rho = \frac{q}{p} \frac{\bar{A}_s}{A_d}, \bar{\rho} = \frac{p}{q} \frac{A_{\bar{s}}}{A_{\bar{d}}}$$

$$P_f^{\text{flv}}(\Delta t) = \frac{e^{-|\Delta t|/\tau_{B^0}}}{2 \tau_{B^0}} [1 - (q_{\text{flv}})(\cos(\Delta m \Delta t) + 2 S(\rho) \sin(\Delta m \Delta t))]$$

$$P_{\bar{f}}^{\text{flv}}(\Delta t) = \frac{e^{-|\Delta t|/\tau_{B^0}}}{4 \tau_{B^0}} [1 + (q_{\text{flv}})(\cos(\Delta m \Delta t) + 2 S(\bar{\rho}) \sin(\Delta m \Delta t))]$$

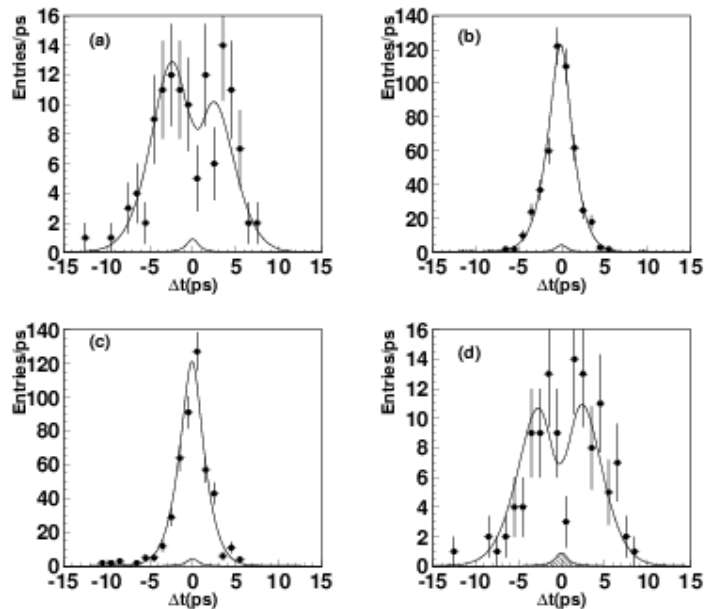
$$S(\rho) = -(-1)^L R \sin(2\phi_1 + \phi_3 - \delta)$$

$$S(\bar{\rho}) = (-1)^L R \sin(2\phi_1 + \phi_3 + \delta)$$



- $2R_{D^*\pi} \sin(2\phi_1 + \phi_3 + \delta_{D^*\pi}) = 0.109 \pm 0.057 \pm 0.019$
- $2R_{D^*\pi} \sin(2\phi_1 + \phi_3 - \delta_{D^*\pi}) = 0.011 \pm 0.057 \pm 0.019$
- $2R_{D\pi} \sin(2\phi_1 + \phi_3 + \delta_{D\pi}) = 0.087 \pm 0.054 \pm 0.018$
- $2R_{D\pi} \sin(2\phi_1 + \phi_3 - \delta_{D\pi}) = 0.037 \pm 0.052 \pm 0.018$

$D\pi$ - 12,027 candidates



$D^*\pi$ - 10,622 candidates

