LATEST RESULTS FROM BELLE
AND PLANS FOR A SUPER B FACTORY

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March 30, 2006

Contents

- KEK-B and Belle
- Summer 2005 highlights
  (`http://belle.kek.jp/conferences/CONF2005/`)
  - direct CP violation
  - measurements of UT angles
  - penguin dominated processes
- Super B Factory

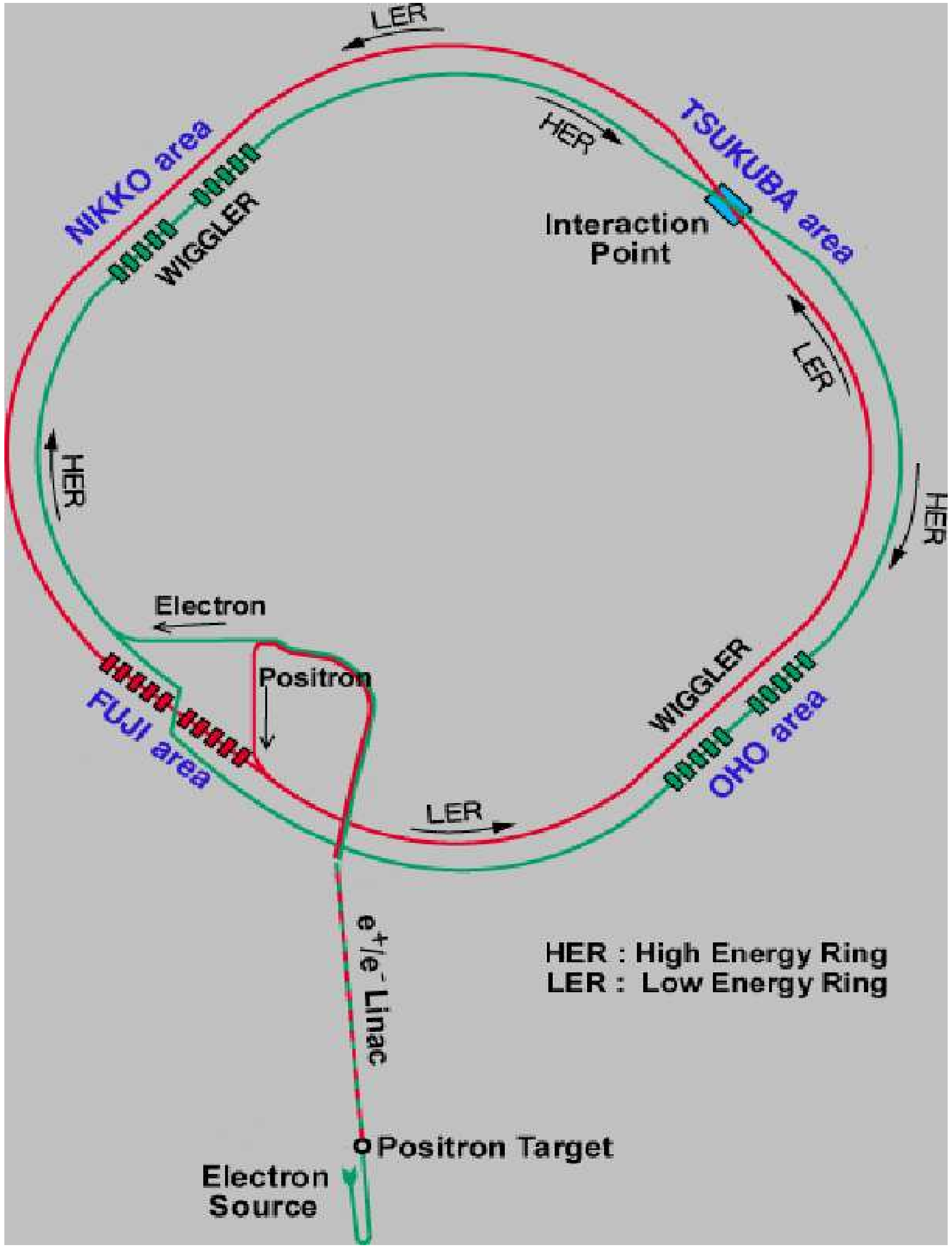
Belle Collaboration

International Collaboration: Belle

Aomori U.
BINP
Chiba U.
Chonnam Nat'l U.
U. of Cincinnati
Ewha Womans U.
Frankfurt U.
Gyeongsang Nat'l U.
U. of Hawaii
Hiroshima Tech.
IHEP, Beijing
IHEP, Moscow
IHEP, Vienna
ITEP
Kanagawa U.
KEK
Korea U.
Krakow Inst. of Nucl. Phys.
Kyoto U.
Kyungpook Nat'l U.
EPF Lausanne
Jozef Stefan Inst. / U. of Ljubljana / U. of Maribor
U. of Melbourne
Nagoya U.
Nara Women's U.
National Central U.
National Taiwan U.
National United U.
Nihon Dental College
Niigata U.
Osaka U.
Osaka City U.
Panjab U.
Peking U.
U. of Pittsburgh
Princeton U.
Riken
Saga U.
USTC
Seoul National U.
Shinshu U.
Sungkyunkwan U.
U. of Sydney
Tata Institute
Toho U.
Tohoku U.
Tohuku Gakuin U.
U. of Tokyo
Tokyo Inst. of Tech.
Tokyo Metropolitan U.
Tokyo U. of Agri. and Tech.
Toyama Nat'l College
U. of Tsukuba
VPI
Yonsei U.

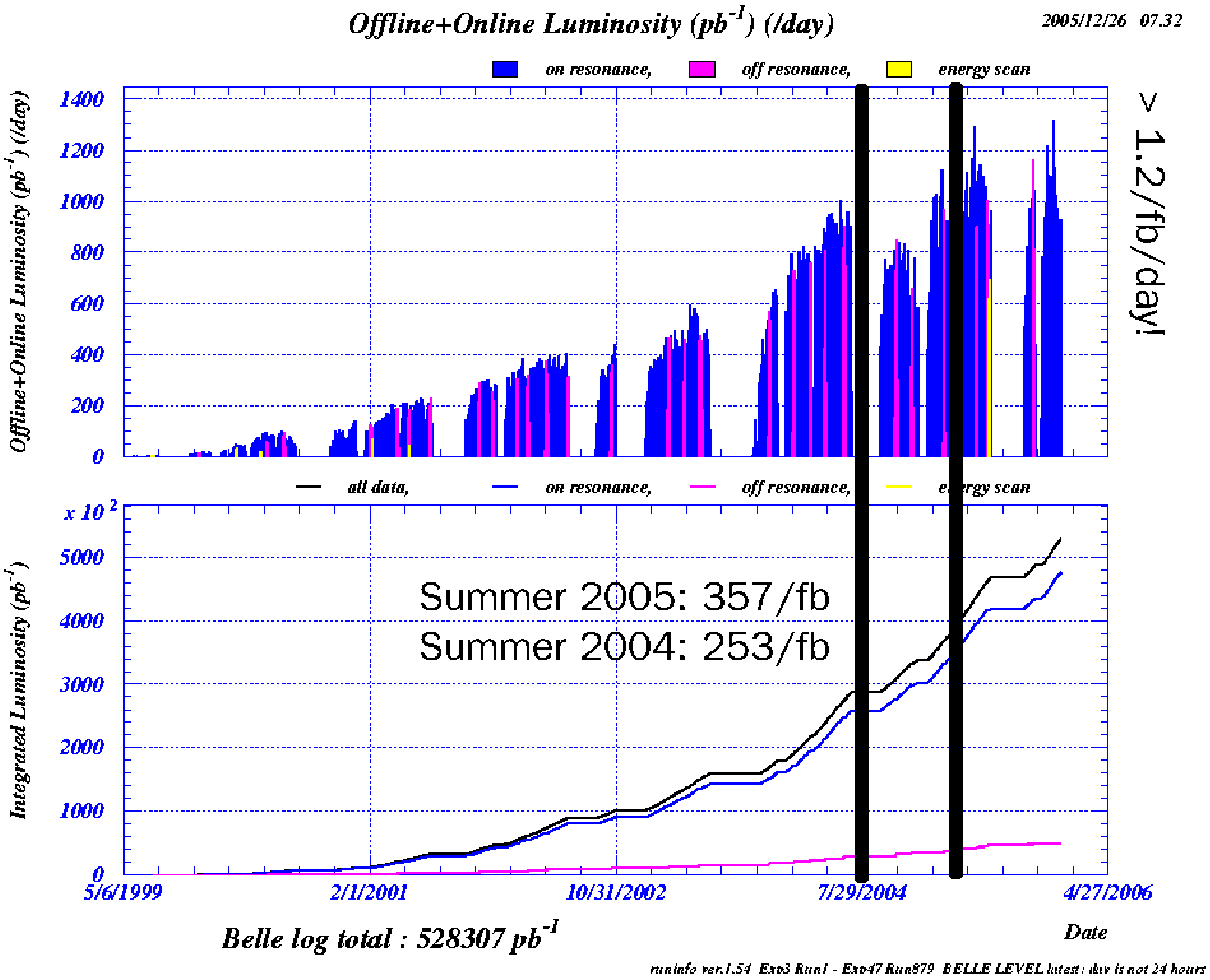
13 countries, 55 institutes, ~400 collaborators

KEK



HER : High Energy Ring
LER : Low Energy Ring

Integrated Luminosity

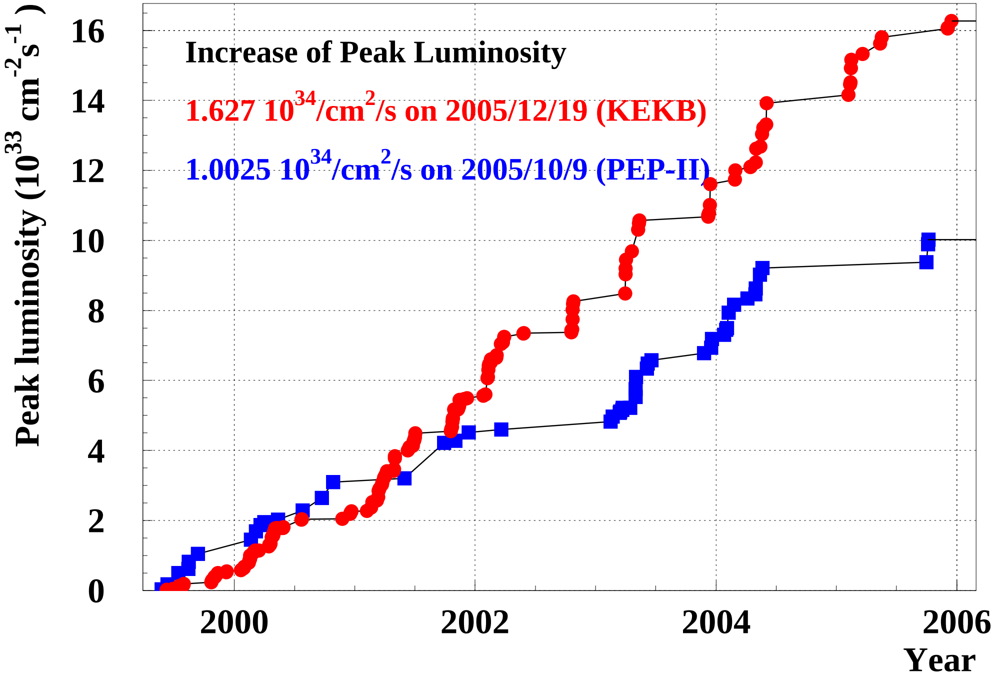


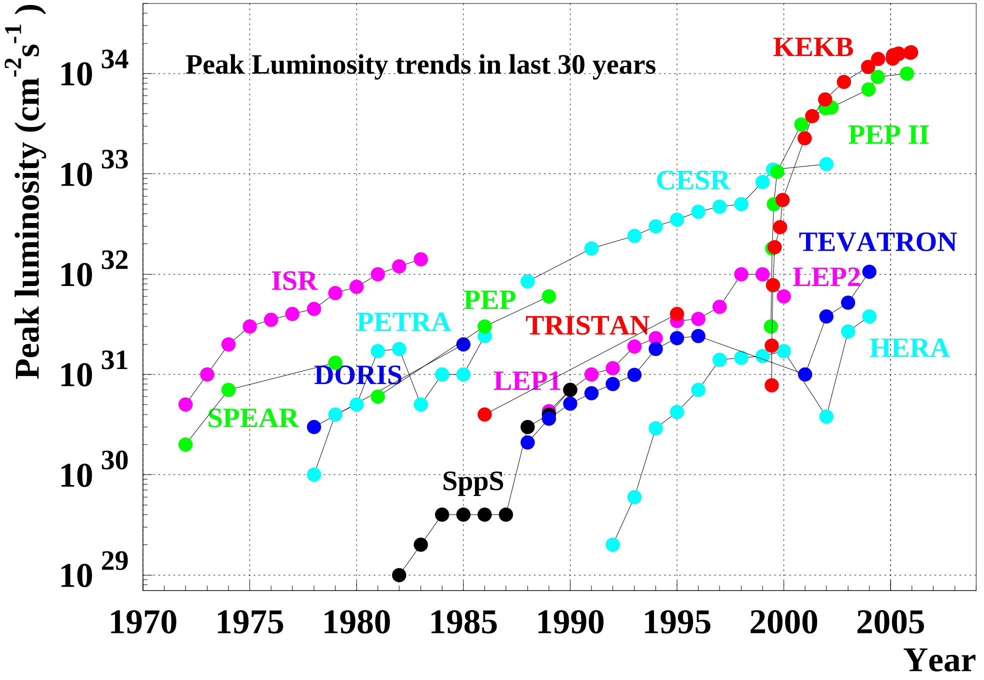
> 1.2/fb/day!

Summer 2005: 357/fb

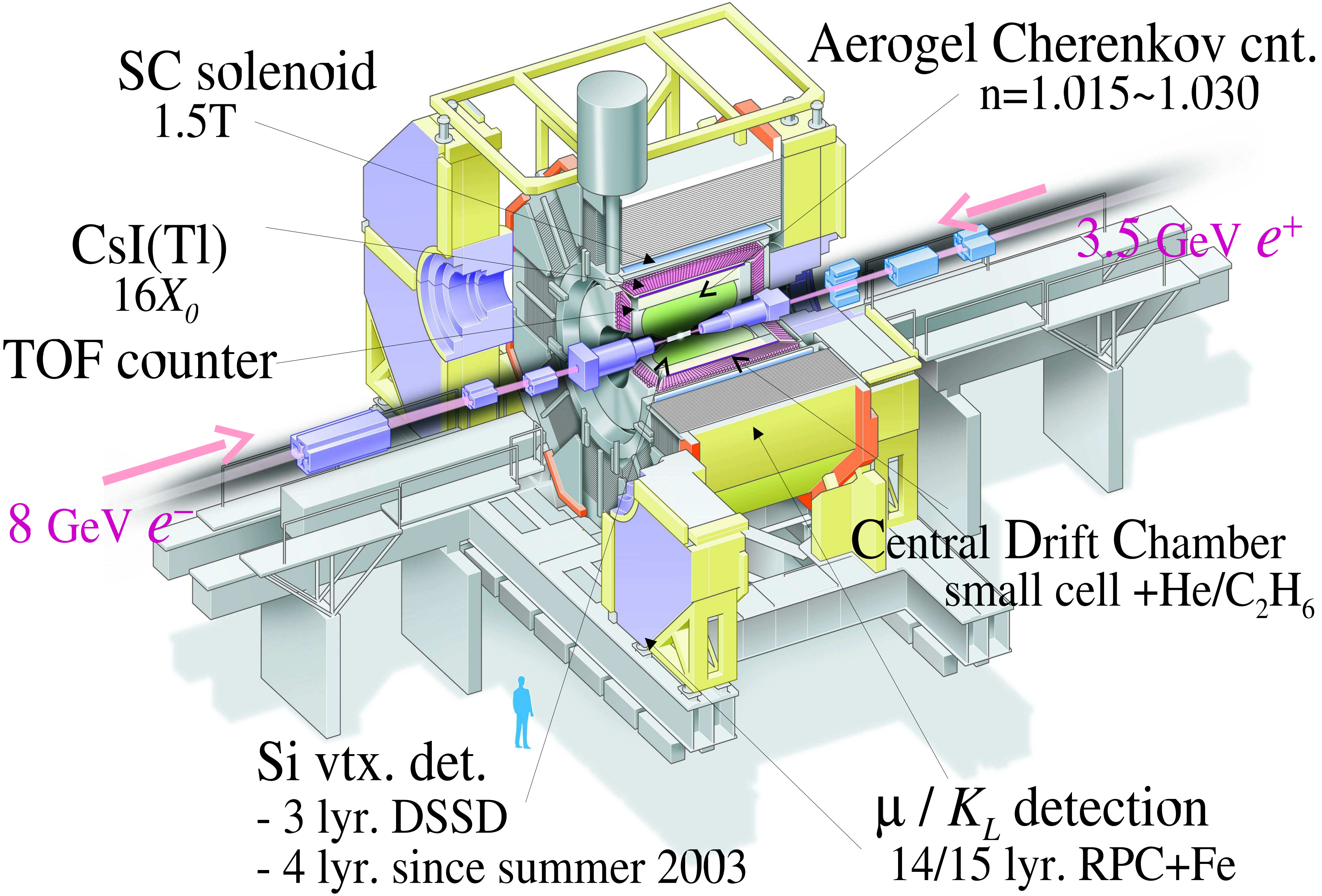
Summer 2004: 253/fb

Luminosity Trends





Belle Detector



SC solenoid 1.5T

CsI(Tl) $16X_0$

TOF counter

8 GeV e^-

Aerogel Cherenkov cnt. n=1.015~1.030

3.5 GeV e^+

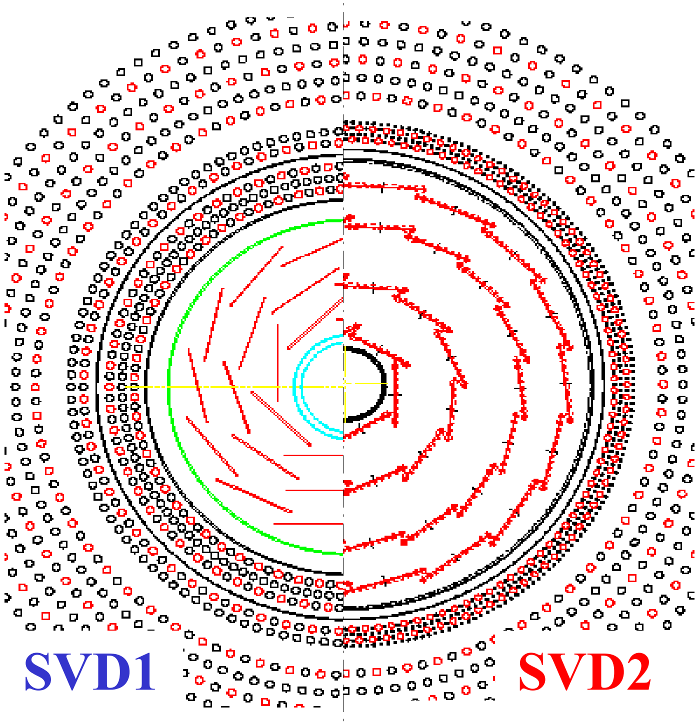
Central Drift Chamber small cell +He/C_2H_6

Si vtx. det.

- 3 lyr. DSSD
- 4 lyr. since summer 2003

μ / K_L detection 14/15 lyr. RPC+Fe

Inner Detector Upgrade - Summer 2003



Number of silicon DSSDs

3 layers → 4 layers

Radius of beam pipe

$r = 2.0$ cm → $r = 1.5$ cm

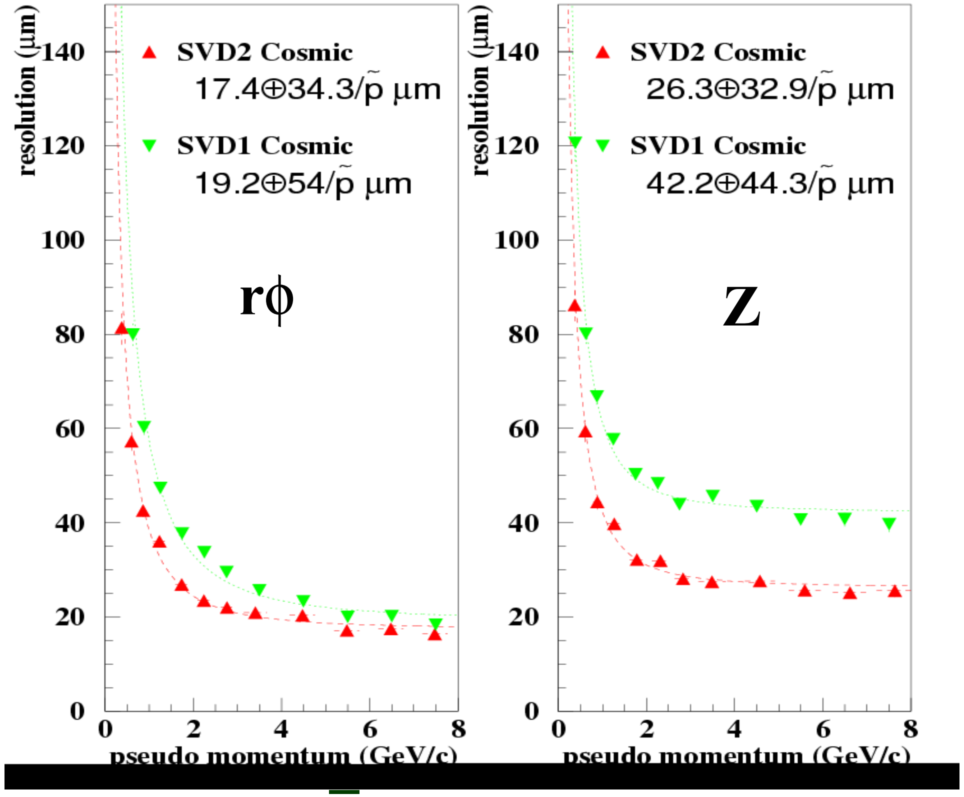
Radiation hardness

1 MRad → $>$ 20 MRad

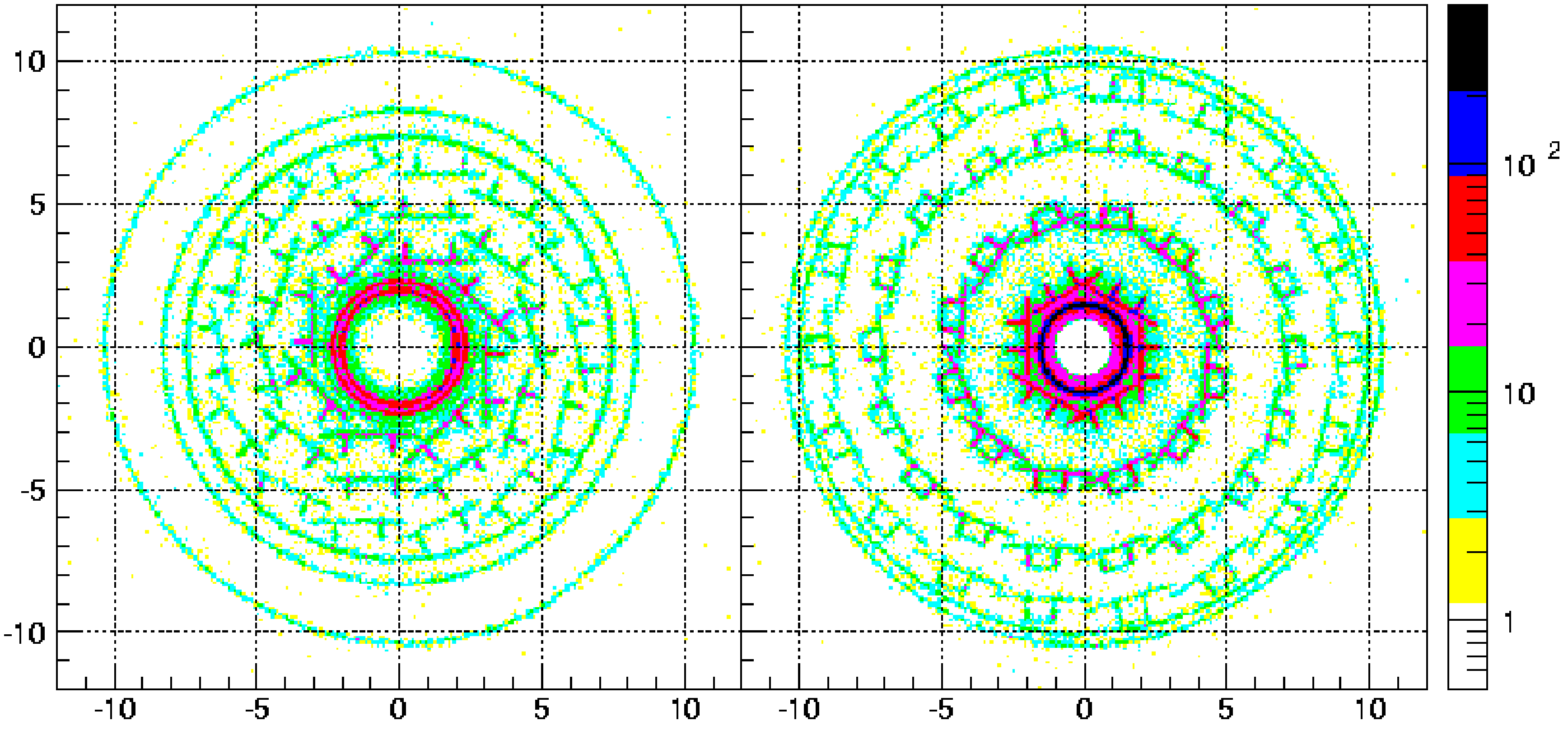
Laboratory polar angle coverage

$23^\circ < \theta < 139^\circ \rightarrow 17^\circ < \theta < 150^\circ$

IMPROVED RESOLUTION!



Search for $\Theta(1540)^+$ Using Kaon Interactions



397 fb^{-1} PLB 632, 173 (2006)

. . . no pentaquarks found

CKM Phenomenology

$$V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \sim \begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix}$$

where A, λ, ρ, η are Wolfenstein parameters

From unitarity ($V^*_{CKM}V_{CKM} = 1$):

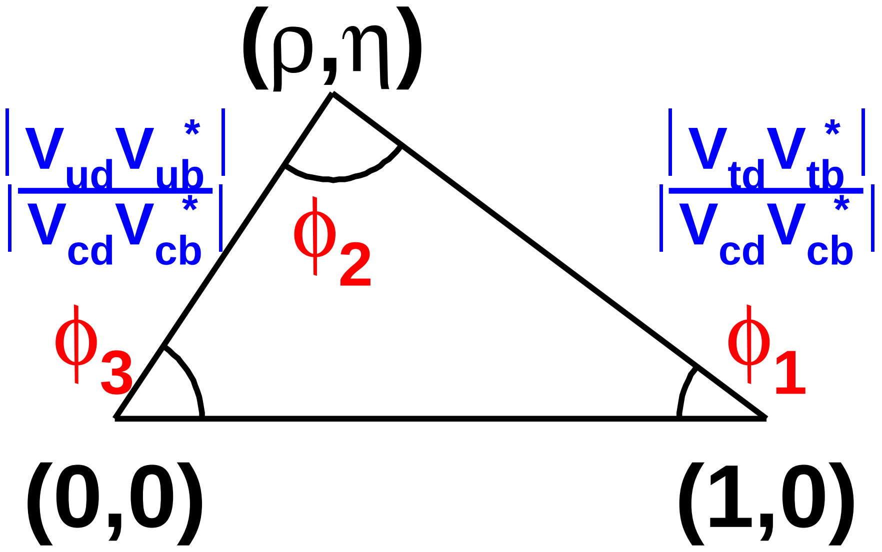
$$V_{ud}V^*_{ub} + V_{cd}V^*_{cb} + V_{td}V^*_{tb} = 0$$

The Unitarity Triangle

$\phi_1 \leftrightarrow \beta$

$\phi_2 \leftrightarrow \alpha$

$\phi_3 \leftrightarrow \gamma$



The Purpose of the B Factory

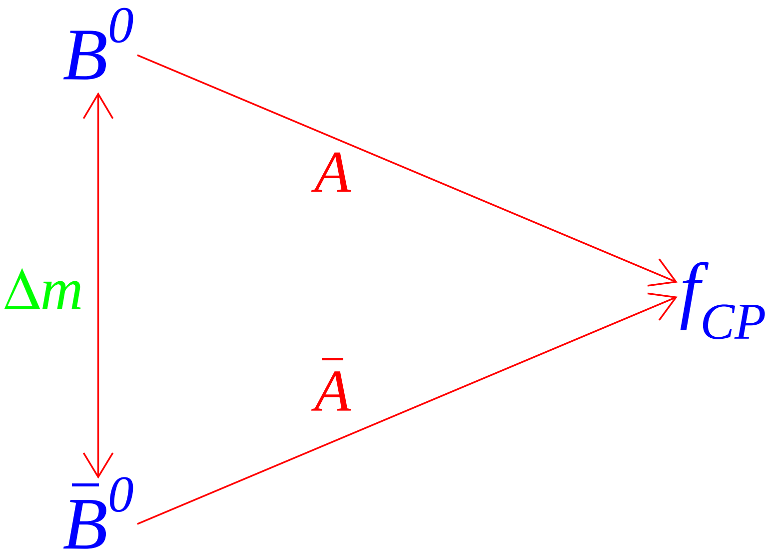
- Within the Standard Model, only B system has large CP violation
- Hadronic parameters (τ_B, Δm_d) $\Rightarrow$ CP effects accessible
- e^+e^- collisions at high luminosity
  - large data sample
  - clean environment

  $\rightsquigarrow$ reconstruct almost any decay mode (even with neutrinos)
- Precise test of quark mixing & CP violation within SM
- Search for new physics
- Copious samples of τ pairs, D mesons and other particles also produced
  $\Rightarrow$ broad physics program

Categories of CP Violation

- Usually discussed in the context of neutral B decays
- Consider $B^0/\bar{B}^0$ decaying to a CP eigenstate
- Define $\lambda_{CP} = \frac{q}{p}\frac{\bar{A}}{A}$
  - p, q from $B^0 - \bar{B}^0$ mixing
  - Standard Model : $\frac{q}{p} \sim e^{-2\phi_1}$

(usual phase convention)



- Three categories of CP violation

1	$\lvert q/p\rvert \neq 1$	CPV in mixing
2	$\lvert \bar{A}/A\rvert \neq 1$	CPV in decay (direct CPV)
3	$\mathrm{Im}(\lambda_{CP}) \neq 0$	CPV in mixing—decay interference

- With *amplitude analysis* can also consider

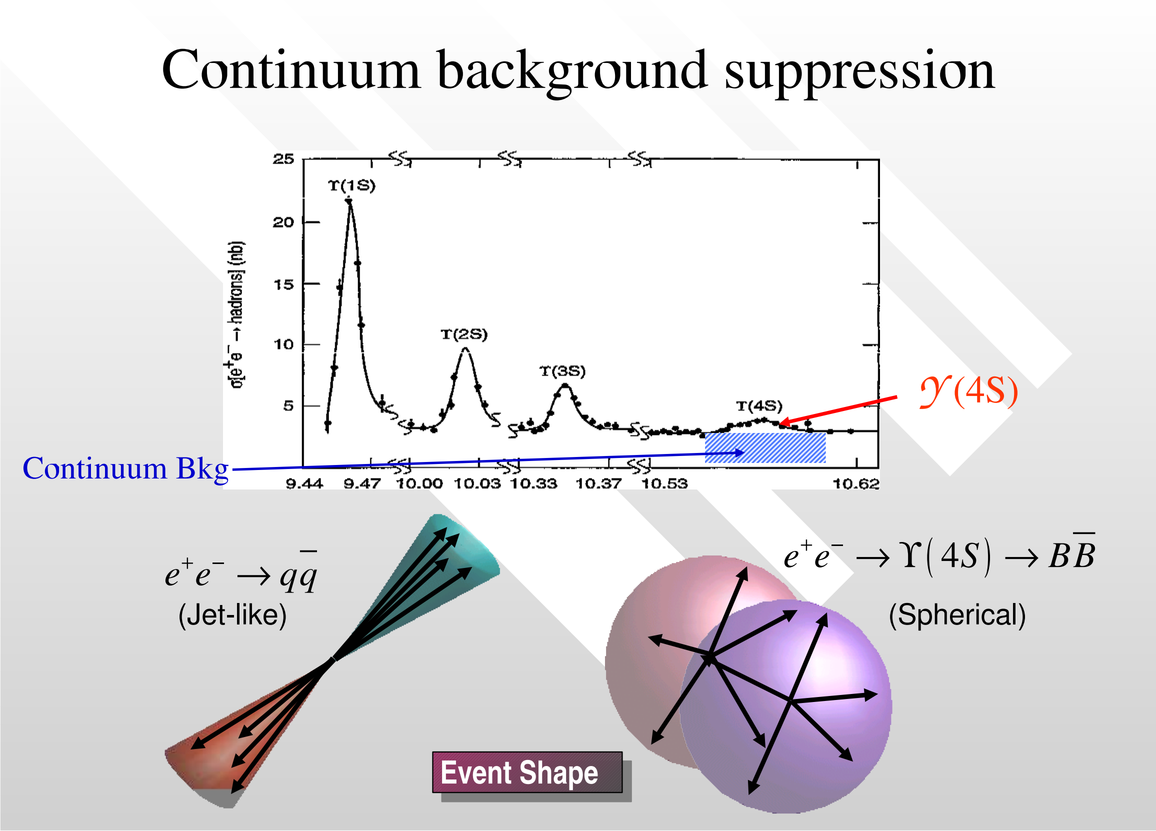
$2'$	$\mathrm{Im}(\bar{A}/A) \neq 0$	CPV in decay amplitude to Q2B state

Experimental Technique

- For most modes, use two kinematic variables to identify signal

$$\Delta E = E_B - E_{\text{beam}} \qquad M_{\text{bc}} = \sqrt{E^2_{\text{beam}} - p^2_B}$$

- Put event-shape variables into *likelihood ratio* to reject background

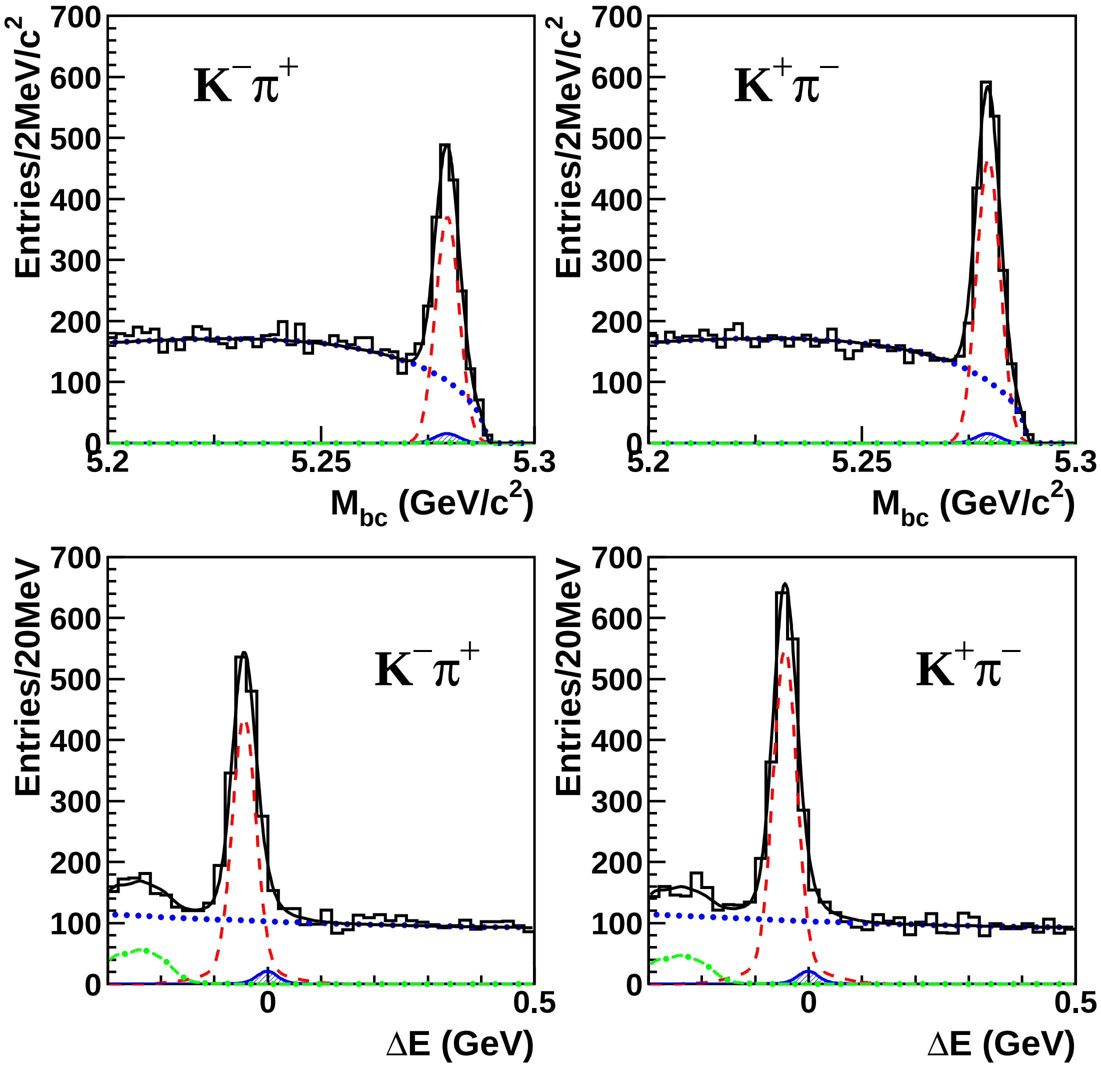


Continuum background suppression

- Particle ID from ACC, TOF & CDC used to separate K/π

Direct CP Violation

Direct CPV in $B^0 \to K^+\pi^-$



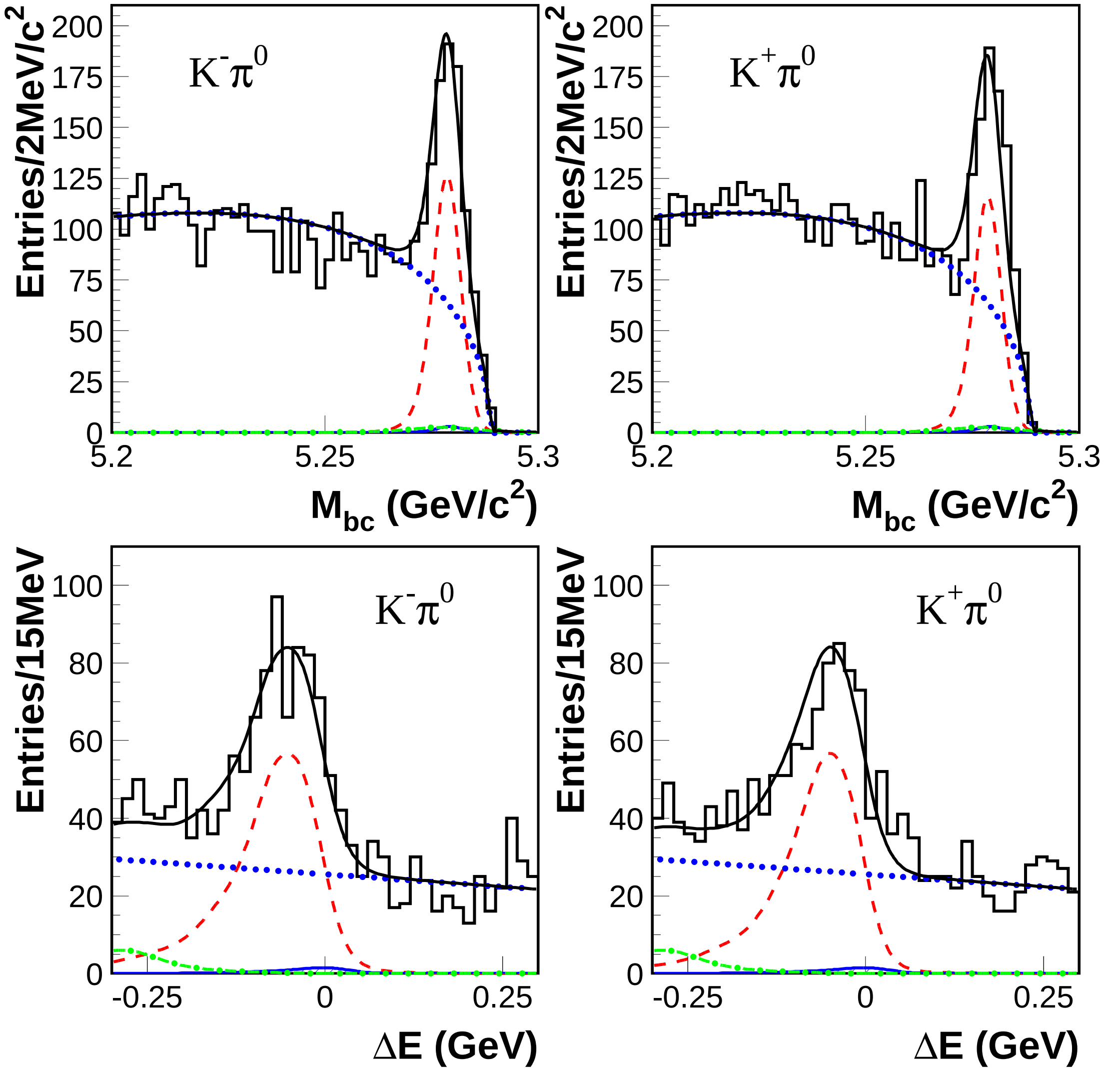
357 fb^{-1} BELLE-CONF-0523

Significance: 4.97σ

$$\mathcal{A}_{CP}\left(K^+\pi^-\right) = -0.113 \pm 0.022(\text{stat}) \pm 0.008(\text{syst})$$

Direct CPV in $B^+ \to K^+\pi^0$

357 fb^{-1} BELLE-CONF-0523



$\mathcal{A}_{CP}\left(K^+\pi^0\right) - \mathcal{A}_{CP}\left(K^+\pi^-\right)$

3.1σ from zero

$$\boxed{\mathcal{A}_{CP}\left(K^+\pi^0\right) = 0.04 \pm 0.04(\text{stat}) \pm 0.02(\text{syst})}$$

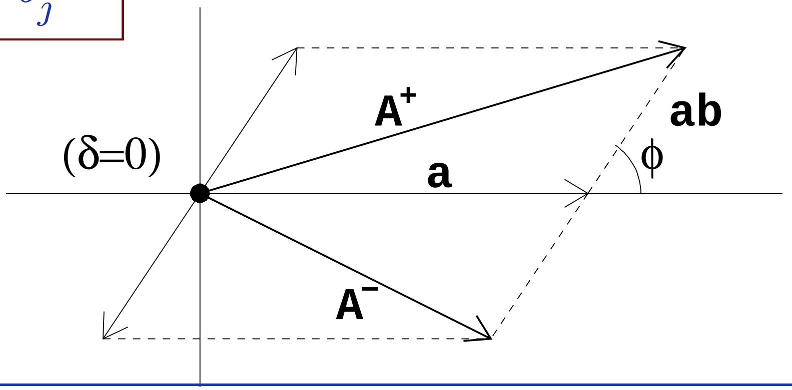
Direct CPV in $B^+ \to K^+\pi^+\pi^-$

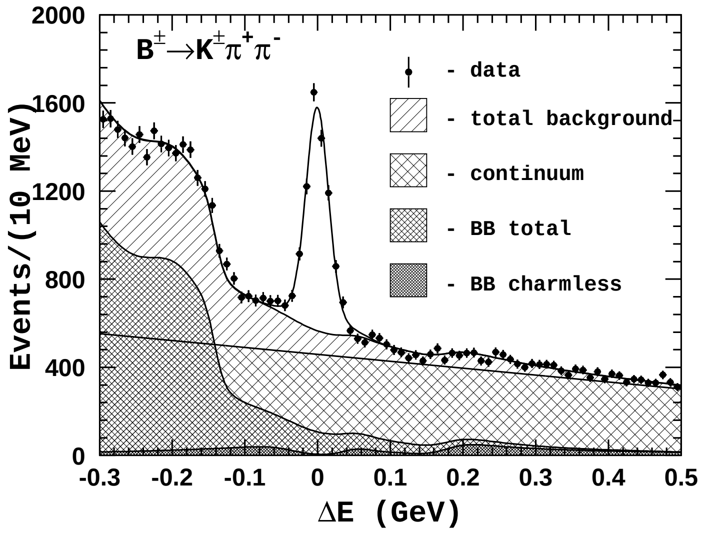
- Veto major charm(onium) contributions to $K^+\pi^+\pi^-$ final state
- 4286 ± 99 signal events
- Parametrize each contributing resonant term as

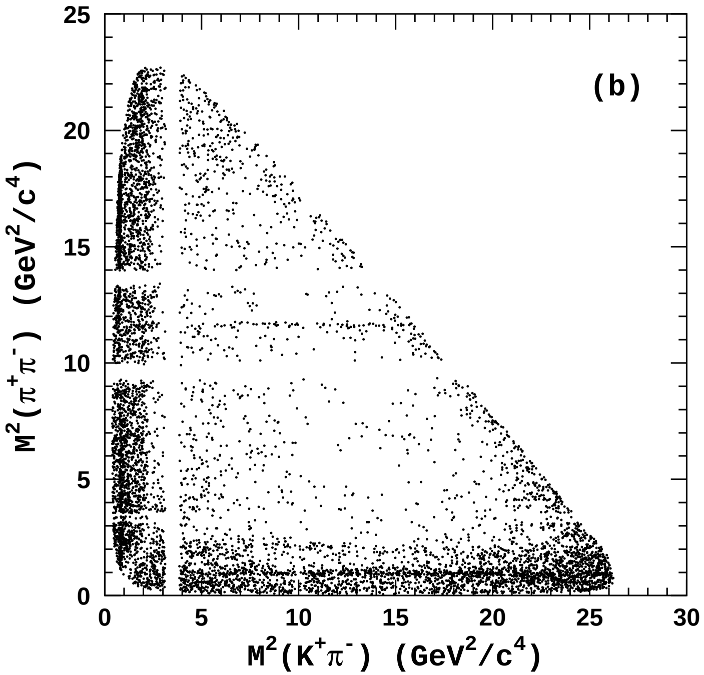
$$a_j e^{i\delta_j}\left(1+\eta b_j e^{i\phi_j}\right)\mathcal{A}_j$$

  - $a_j e^{i\delta_j}$ = CP conserving complex amplitude
  - $b_j e^{i\phi_j}$ = CP violating part
  - $\eta = +1(-1)$ for B^+ (B^-)
  - $\mathcal{A}_j$ = Breit-Wigner (*etc.*) dependence
- Can translate to usual CP asymmetry

$$\boxed{A_j^{CP} = -\frac{2b_j \cos\phi_j}{1+b_j^2}}$$







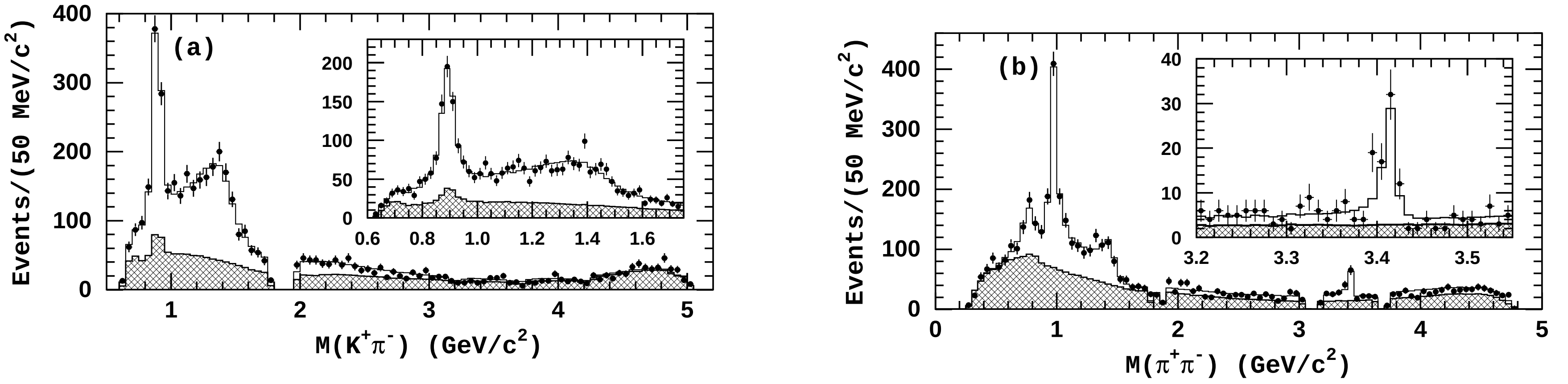
$357\ \text{fb}^{-1}$

Belle-Preprint-2005-36

Direct CPV in $B^+ \to K^+\pi^+\pi^-$

$357\ \text{fb}^{-1}$ Belle-Preprint-2005-36

Fit first without CP terms to establish model ($b_j = 0$)



Contributions from $K^*(892)^0\pi^+$, $K_0^*(1430)^0\pi^+$, ρ^0K^+, ωK^+, f_0K^+, $f_2(1275)K^+$, $f_X(1300)K^+$, $\chi_{c0}K^+$ & non-resonant terms

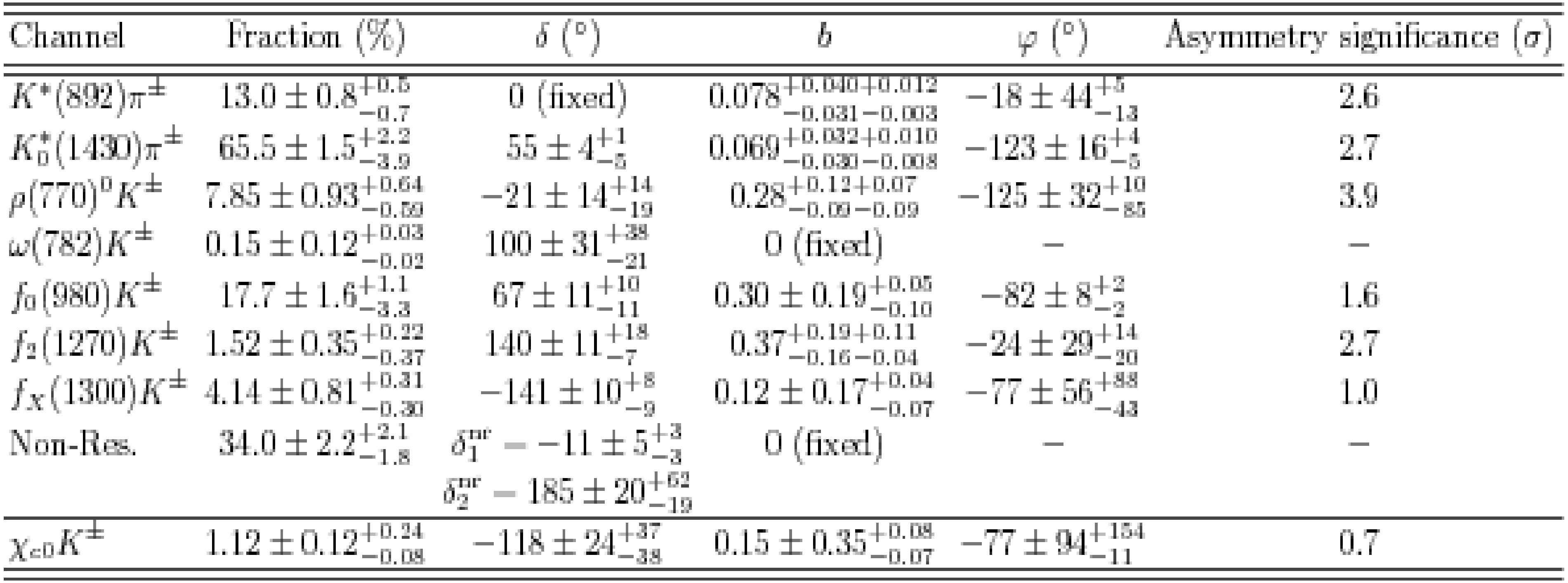
$f_0(980)$ parametrized by Flatté lineshape, $f_X(1300)$ assumed scalar ($f_0(1370)$?)

Direct CPV in $B^+ \to K^+\pi^+\pi^-$

$357\ \text{fb}^{-1}$

Belle-Preprint-2005-36

First evidence for direct CPV in charged B decays



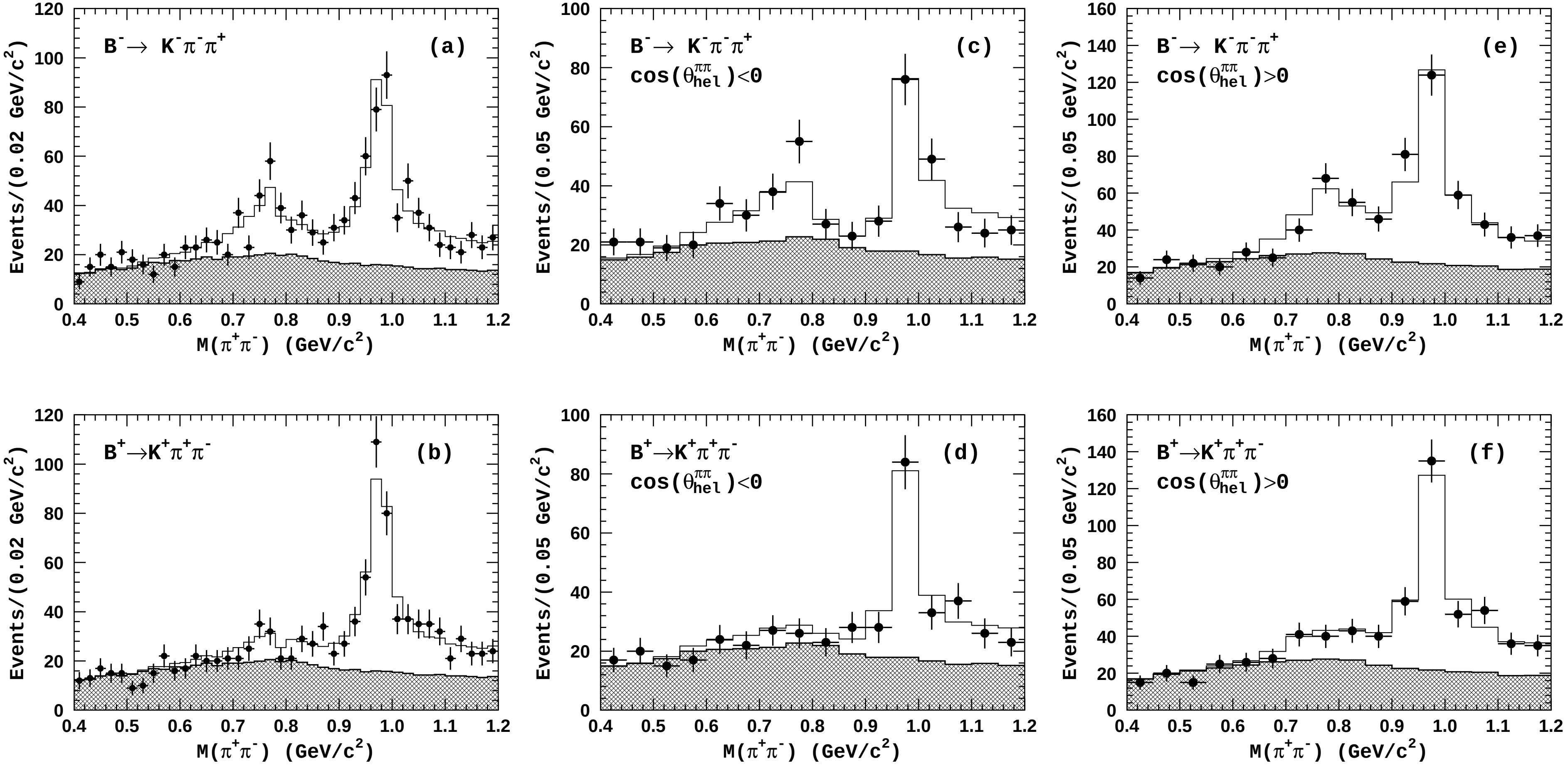
Channel	Fraction (%)	δ (°)	b	φ (°)	Asymmetry significance (σ)
$K^*(892)\pi^\pm$	$13.0 \pm 0.8^{+0.5}_{-0.7}$	0 (fixed)	$0.078^{+0.040+0.012}_{-0.031-0.003}$	$-18 \pm 44^{+5}_{-13}$	2.6
$K_0^*(1430)\pi^\pm$	$65.5 \pm 1.5^{+2.2}_{-3.9}$	$55 \pm 4^{+1}_{-5}$	$0.069^{+0.032+0.010}_{-0.030-0.008}$	$-123 \pm 16^{+4}_{-5}$	2.7
$\rho(770)^0K^\pm$	$7.85 \pm 0.93^{+0.64}_{-0.59}$	$-21 \pm 14^{+14}_{-19}$	$0.28^{+0.12+0.07}_{-0.09-0.09}$	$-125 \pm 32^{+10}_{-85}$	3.9
$\omega(782)K^\pm$	$0.15 \pm 0.12^{+0.03}_{-0.02}$	$100 \pm 31^{+38}_{-21}$	0 (fixed)	–	–
$f_0(980)K^\pm$	$17.7 \pm 1.6^{+1.1}_{-3.3}$	$67 \pm 11^{+10}_{-11}$	$0.30 \pm 0.19^{+0.05}_{-0.10}$	$-82 \pm 8^{+2}_{-2}$	1.6
$f_2(1270)K^\pm$	$1.52 \pm 0.35^{+0.22}_{-0.37}$	$140 \pm 11^{+18}_{-7}$	$0.37^{+0.19+0.11}_{-0.16-0.04}$	$-24 \pm 29^{+14}_{-20}$	2.7
$f_X(1300)K^\pm$	$4.14 \pm 0.81^{+0.31}_{-0.30}$	$-141 \pm 10^{+8}_{-9}$	$0.12 \pm 0.17^{+0.04}_{-0.07}$	$-77 \pm 56^{+88}_{-43}$	1.0
Non-Res.	$34.0 \pm 2.2^{+2.1}_{-1.8}$	$\delta_1^{nr} = -11 \pm 5^{+3}_{-3}$ $\delta_2^{nr} = 185 \pm 20^{+62}_{-19}$	0 (fixed)	–	–
$\chi_{c0}K^\pm$	$1.12 \pm 0.12^{+0.24}_{-0.08}$	$-118 \pm 24^{+37}_{-38}$	$0.15 \pm 0.35^{+0.08}_{-0.07}$	$-77 \pm 94^{+154}_{-11}$	0.7

- Statistical significance calculated as $\sqrt{-2\ln(L_0/L_{\text{max}})}$
- Largest systematics from model uncertainty

Direct CPV in $B^+ \to K^+\pi^+\pi^-$

357 fb^{-1} Belle-Preprint-2005-36

Asymmetry in the ρ region clearly visible in the data



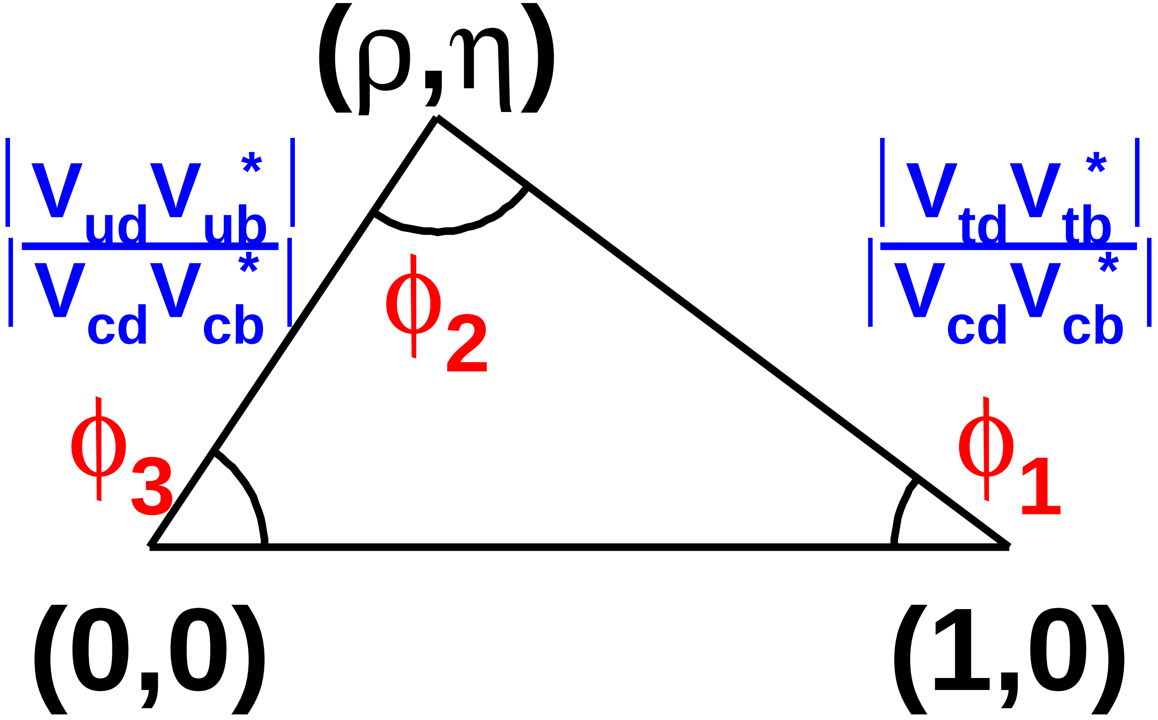
Direct CP Violation — Summary

Direct CP violation seen by Belle:

- $B^0 \to K^+\pi^-$ ($\sim$ 10% $\sim 5\sigma$)
- $B^0 \to \pi^+\pi^-$ ($\sim$ 50% $\sim 4\sigma$)
- $B^+ \to \rho^0 K^+$ ($\sim$ 30% $\sim 4\sigma$)

Measurements of UT Angles

Key: Redundancy



ϕ_1

$b \longrightarrow c\bar{c}s\ (J/\psi K_S)$

$b \longrightarrow c\bar{u}d\ (D\pi^0)$

$b \longrightarrow c\bar{c}d\ (J/\psi\pi^0, D^+D^-)$

$b \longrightarrow s\bar{q}q\ (\phi K_S)$

ϕ_2

$b \longrightarrow u\bar{u}d\ (\pi^+\pi^-, \rho^+\rho^-)$

ϕ_3

$b \longrightarrow c\bar{u}s/u\bar{c}s\ (DK^-)$

$b \longrightarrow u\bar{u}s$ vs. $b \longrightarrow u\bar{u}d\ (K\pi$ vs. $\pi\pi)$

$2\phi_1 + \phi_3$

$b \longrightarrow c\bar{u}d/u\bar{c}d\ (D^+\pi^-)$

. . . and many others!

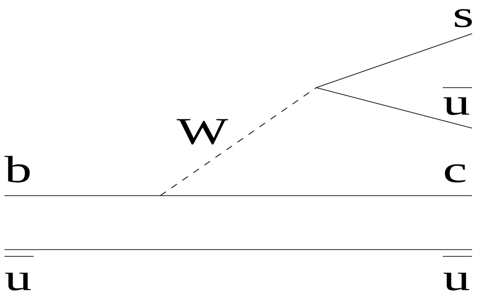
ϕ_3 from $B \to DK$

- Can access ϕ_3 via interference between $B^- \to D^0 K^-$ & $B^- \to \bar{D}^0 K^-$

  Bigi & Sanda; Gronau, London & Wyler

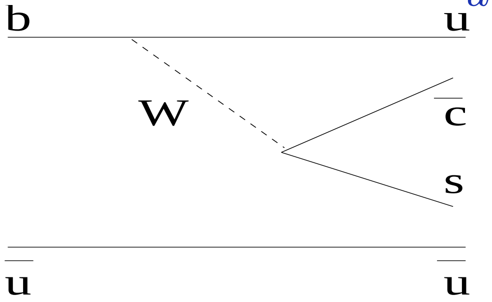
- Reconstruct D in final states accessible to both D^0 and $\bar{D}^0$

$B^- \to D^0 K^- \sim V_{us} V_{cb}^*$



COLOUR ALLOWED

$B^- \to \bar{D}^0 K^- \sim V_{cs} V_{ub}^*$



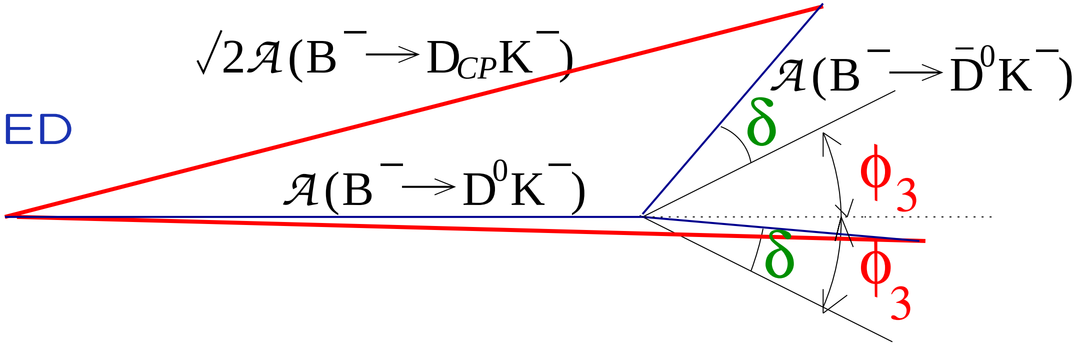
COLOUR SUPPRESSED

$\mathcal{A}$ — amplitude

$r_B = \mathcal{A}_{\text{SUPPRESSED}} / \mathcal{A}_{\text{FAVOURED}}$

$\sim 0.1 - 0.2$

δ_B — strong phase difference



ϕ_3 from $B \to DK$: Final States

- Ultimately aim to use many states and combine results

- Inclusive analyses can be performed but sensitivity is diluted
  - $\rightsquigarrow$ Reconstruct modes exclusively, where possible
  - $\rightsquigarrow$ Use amplitude analysis (not, *eg.*, Q2B analysis) where possible

- To extract ϕ_3, need D decay "model"
  - $\rightsquigarrow$ crucial rôle of charm factory

- Modes used so far
  1. CP even (mainly K^+K^-)
  2. CP odd (mainly $K_S\pi^0$)
  3. Doubly Cabibbo suppressed states ($K\pi$)
  4. Multibody final states ($K_S\pi\pi$)

- Modes that may be used in future
  - $*$ $K_SK^+K^-$, $\pi^+\pi^-\pi^0$, $K_S\pi^\pm K^\mp$, $K^\pm\pi^\mp\pi^0$, $K_S\pi^+\pi^-\pi^0$, $\ldots$

Parameters

- CP violation effects depend on

  ϕ_3 : weak phase difference between B decay amplitudes
  δ_B : strong phase difference between B decay amplitudes
  r_B : relative magnitude of B decay amplitudes
  δ_D : (strong phase difference of D decay amplitudes)
  r_D : (relative magnitude of D decay amplitudes)

- For multibody D decays, last two described by decay model

- D decay model also includes assumptions of
  - no mixing
  - no CP violation

  . . . well motivated and tested (effects can be included)

Principle of the Multi-Body Analysis

A. Giri, Y. Grossman, A. Soffer & J. Zupan, PRD 68, 054018 (2003)

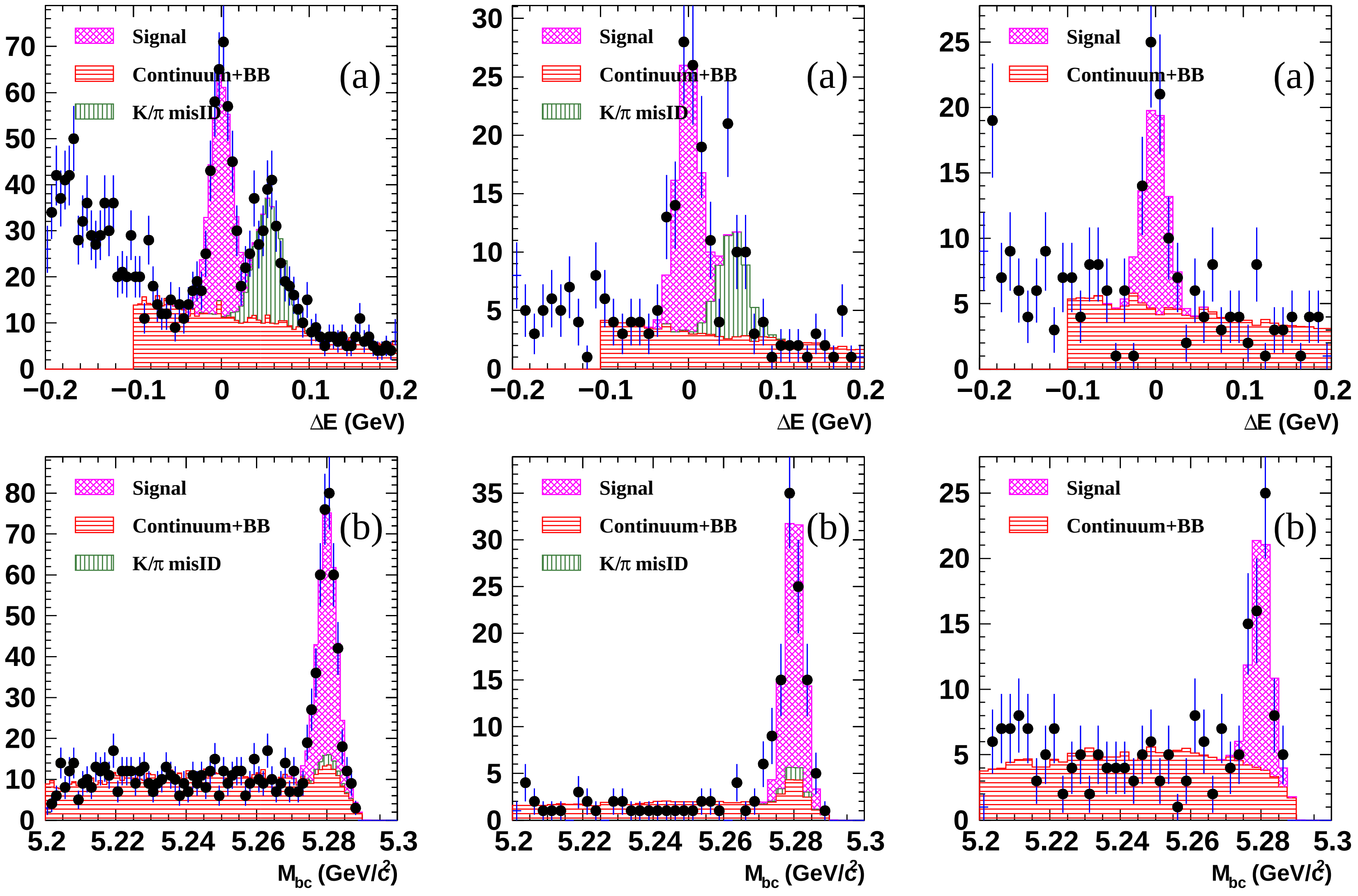
A. Poluektov *et al.* (Belle Collaboration), PRD 70, 072003 (2004)

- Consider $\bar{D}^0 \to K_S\pi^+\pi^-$
  $\to$ define amplitude at each Dalitz plot point as $f(m_+^2, m_-^2)$
  where $m_+ = m_{K_S\pi^+}$, $m_- = m_{K_S\pi^-}$
- Consider $D^0 \to K_S\pi^+\pi^-$
  $\to$ amplitude at each Dalitz plot point is $f(m_-^2, m_+^2)$
- $\left|f(m_+^2, m_-^2)\right|$ can be measured using flavour tagged D mesons

- Consider $B^+ \to \left(K_S\pi^+\pi^-\right)_D K^+$
  $\to$ amplitude is $f(m_+^2, m_-^2) + r_B e^{i(\delta_B+\phi_3)} f(m_-^2, m_+^2)$
- Consider $B^- \to \left(K_S\pi^+\pi^-\right)_D K^-$
  $\to$ amplitude is $f(m_-^2, m_+^2) + r_B e^{i(\delta_B-\phi_3)} f(m_+^2, m_-^2)$
- Can extract (r_B, δ_B, ϕ_3) from B^+ & B^- data

$B^{\pm} \to D^{(*)} K^{(*)\pm}$ Selection

$B^{\pm} \to D K^{\pm}$ $B^{\pm} \to D^{*} K^{\pm}$ $B^{\pm} \to D K^{*\pm}$



357 fb^{-1}

IN PREPARATION

470 candidate events
(331 ± 17 signal)

111 candidate events
(81 ± 8 signal)

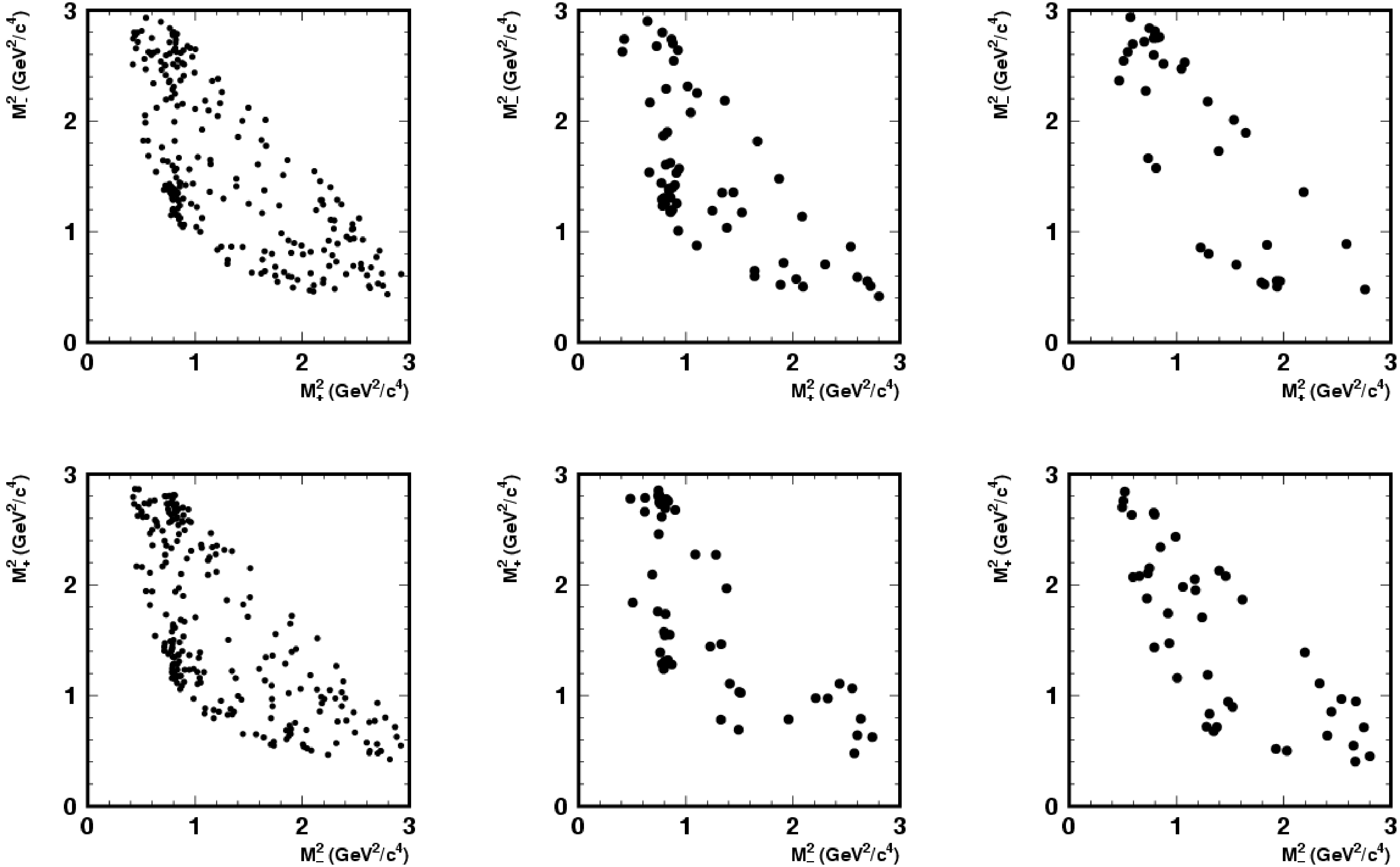
78 candidate events
(54 ± 8 signal)

$B^\pm \to DK^{(*)\pm}$, $D \to K_S\pi^+\pi^-$ Dalitz Plot Distributions

$B^\pm \to DK^\pm$ $B^\pm \to D^*K^\pm$ $B^\pm \to DK^{*\pm}$

$f(m_+^2, m_-^2) + r_B e^{i(\delta_B+\phi_3)} f(m_-^2, m_+^2)$

$f(m_-^2, m_+^2) + r_B e^{i(\delta_B-\phi_3)} f(m_+^2, m_-^2)$



357 fb^{-1}

IN PREPARATION

Extraction of $f(m_+^2, m_-^2)$

- Fit Dalitz plot distribution of tagged D mesons from e^+e^- continuum
- Tag using charge of π_s in $D^{*+} \to D^0 \pi_s^+$
- Used *model* defines phase variation of $f(m_+^2, m_-^2)$

357 fb^{-1}

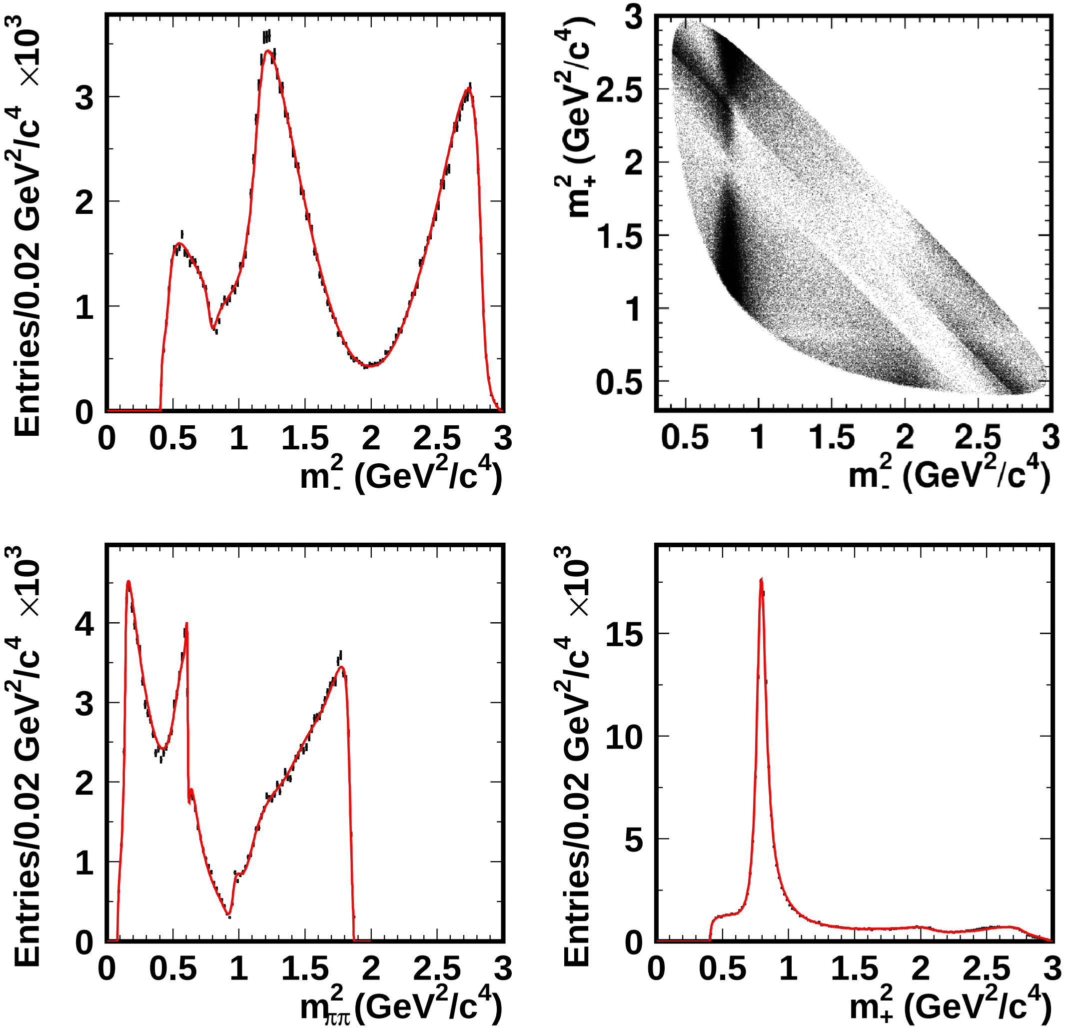
IN PREPARATION

$$\boxed{\chi^2/ndf = 2.72}$$

$(ndf = 1081)$

Fine tuning of model

$\rightsquigarrow$ little effect on ϕ_3



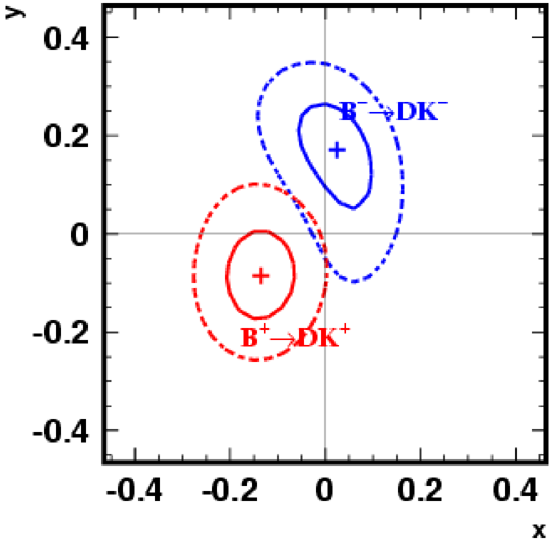
Dalitz Plot Fits

$357\ \text{fb}^{-1}$

IN PREPARATION

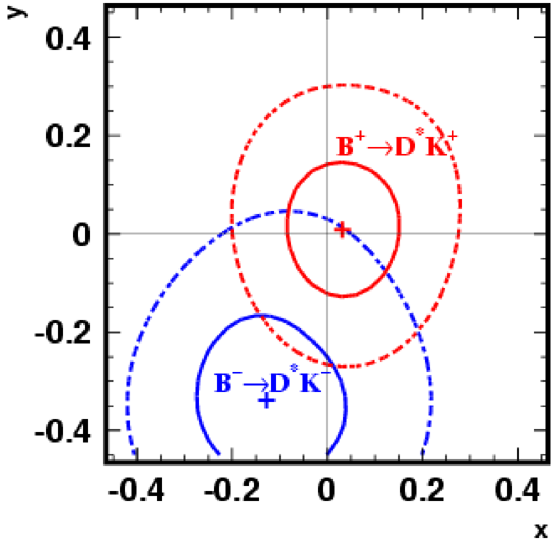
Fit $B^{\pm}$ samples separately, float $(x_{\pm}, y_{\pm}) = (r_B \cos(\delta_B \pm \phi_3), r_B \sin(\delta_B \pm \phi_3))$

$B^{\pm} \to DK^{\pm}$



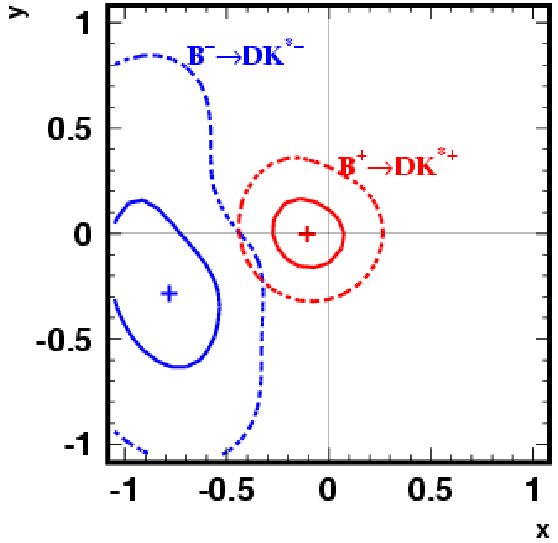
470 candidate events
(331 ± 17 signal)

$B^{\pm} \to D^{*}K^{\pm}$



111 candidate events
(81 ± 8 signal)

$B^{\pm} \to DK^{*\pm}$



78 candidate events
(54 ± 8 signal)

$x_+ = -0.135^{+0.069}_{-0.070}$	$x_+ = 0.032^{+0.120}_{-0.116}$	$x_+ = -0.105^{+0.177}_{-0.167}$
$y_+ = -0.085^{+0.090}_{-0.086}$	$y_+ = 0.008^{+0.137}_{-0.136}$	$y_+ = -0.004^{+0.164}_{-0.156}$
$x_- = 0.025^{+0.072}_{-0.080}$	$x_- = -0.128^{+0.167}_{-0.146}$	$x_- = -0.784^{+0.249}_{-0.295}$
$y_- = 0.170^{+0.093}_{-0.117}$	$y_- = -0.339^{+0.172}_{-0.158}$	$y_- = -0.281^{+0.440}_{-0.335}$

Extraction of ϕ_3

$357\ \mathrm{fb}^{-1}$ IN PREPARATION

Use frequentist approach to obtain confidence regions

(recall r_B and δ_B different for each mode)

STATISTICAL ERRORS ONLY

Parameter	$B^+ \to DK^+$ mode		$B^+ \to D^*K^+$ mode		$B^+ \to DK^{*+}$ mode	
	1σ interval	2σ interval	1σ interval	2σ interval	1σ interval	2σ interval
ϕ_3	$65.5^\circ\ {}^{+19.1^\circ}_{-19.9^\circ}$	$20.8^\circ < \phi_3 < 108.4^\circ$	$86.1^\circ\ {}^{+37.1^\circ}_{-93.1^\circ}$	-	$10.8^\circ\ {}^{+22.7^\circ}_{-57.1^\circ}$	-
r	$0.165^{+0.056}_{-0.059}$	$0.048 < r < 0.281$	$0.207^{+0.127}_{-0.131}$	$r < 0.510$	$0.549^{+0.231}_{-0.163}$	$0.242 < r < 1.120$
δ	$147.5^\circ\ {}^{+18.7^\circ}_{-20.3^\circ}$	$100.3^\circ < \delta < 187.7^\circ$	$334.7^\circ\ {}^{+36.8^\circ}_{-93.6^\circ}$	-	$210.2^\circ\ {}^{+24.2^\circ}_{-57.3^\circ}$	-

Combine $B^\pm \to DK^\pm$, $B^\pm \to D^*K^\pm$ & $B^\pm \to DK^{*\pm}$

Parameter	1σ statistical interval	2σ statistical interval	Systematic error	Model uncertainty
ϕ_3	$53.3^\circ\ {}^{+14.8^\circ}_{-17.7^\circ}$	$11.7^\circ < \phi_3 < 107.7^\circ$	2.5°	8.7°
r_{DK}	$0.159^{+0.054}_{-0.050}$	$0.048 < r_{DK} < 0.271$	0.012	0.049
δ_{DK}	$145.7^\circ\ {}^{+19.0^\circ}_{-19.7^\circ}$	$100.6^\circ < \delta_{DK} < 185.9^\circ$	3.0°	22.9°
r_{D^*K}	$0.175^{+0.108}_{-0.099}$	$0 < r_{D^*K} < 0.407$	0.013	0.049
δ_{D^*K}	$302.0^\circ\ {}^{+33.8^\circ}_{-35.1^\circ}$	-	6.1°	22.9°
r_{DK^*}	$0.564^{+0.216}_{-0.155}$	$0.231 < r_{DK^*} < 1.106$	0.041	0.084
δ_{DK^*}	$242.6^\circ\ {}^{+20.2^\circ}_{-23.2^\circ}$	$186.0^\circ < \delta_{DK^*} < 300.2^\circ$	2.5°	49.3°

$$\left\| \ \phi_3 = 53^\circ\ {}^{+15^\circ}_{-18^\circ}(\mathrm{stat}) \pm 3^\circ(\mathrm{syst}) \pm 9^\circ(\mathrm{model}) \ \right\|$$

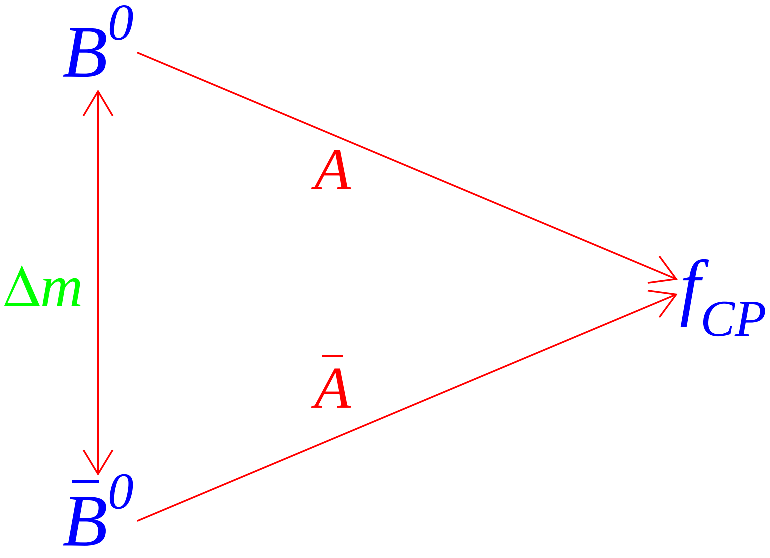
Time-Dependent CP Violation Phenomenology

- Interference between different paths to a final state ⇒ time-dependent CP violation

- Consider $B^0/\bar{B}^0$ decaying to a CP eigenstate

- Define $\lambda_{CP} = \frac{q}{p}\frac{\bar{A}}{A}$
  - p, q from $B^0 - \bar{B}^0$ mixing
  - Standard Model : $\frac{q}{p} \sim e^{-2\phi_1}$

- Simplest scenario:
  - $\left|\frac{q}{p}\right| = 1, \left|\frac{\bar{A}}{A}\right| = 1 \Rightarrow S_{CP} = \mathrm{Im}(\lambda_{CP})$



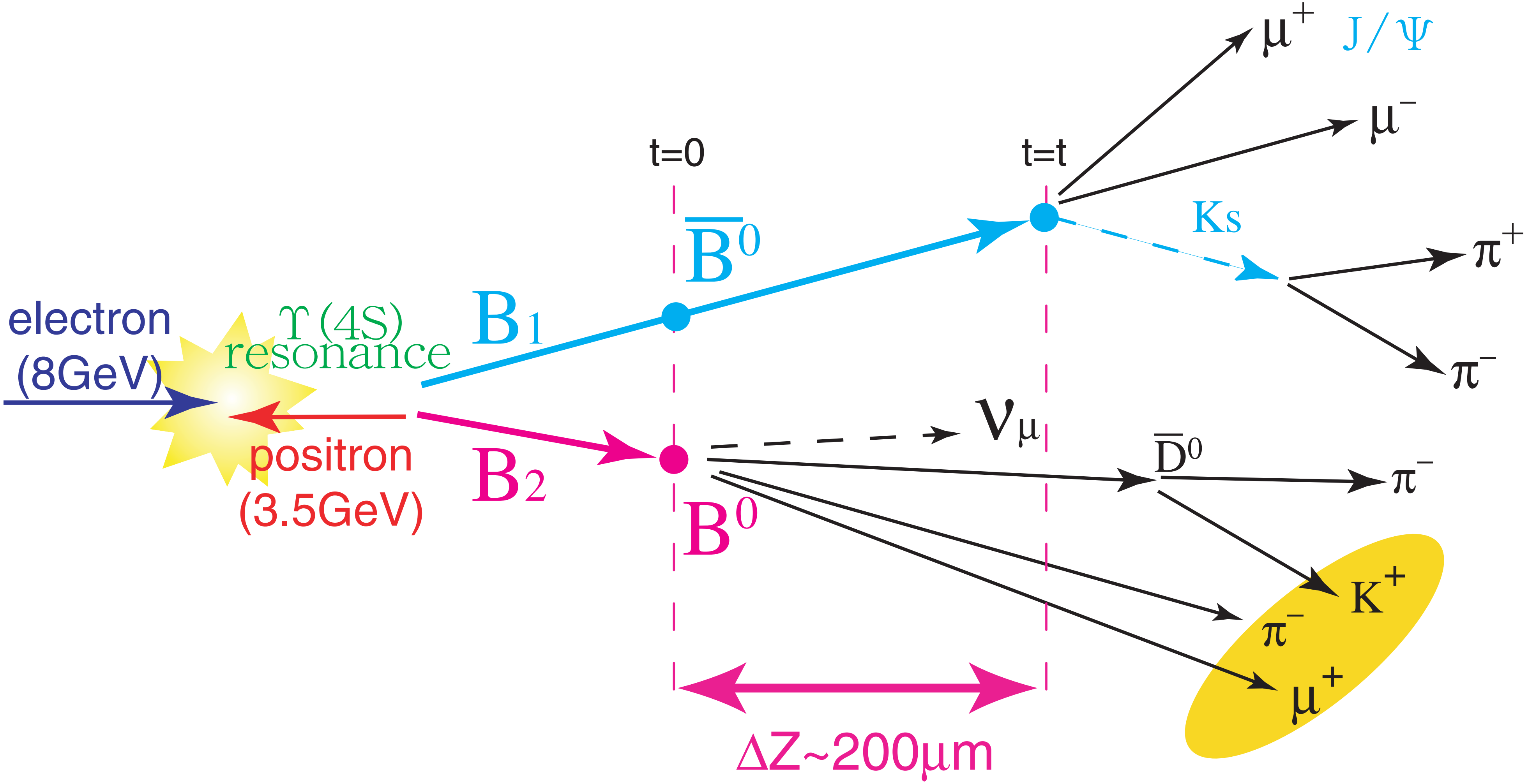
- At B factories, measure Δt from decay time of other B

(tagged as B^0 ($q = +1$) or $\bar{B}^0$ ($q = -1$))

$$\boxed{P^q_{CP}(\Delta t) = \frac{e^{-|\Delta t|/\tau_{B^0}}}{4\tau_{B^0}}\left[1 + q\left\{S_{CP}\sin(\Delta m \Delta t)\right\}\right]}$$

How To Measure Time-Dependent CP Violation

Illustrated using $\bar{B}^0 \to J/\psi K_S$, $B^0 \to D^{*-}\mu^+\nu_\mu$



$B^0 \to J/\psi K^0$ Selection

357 fb^{-1}

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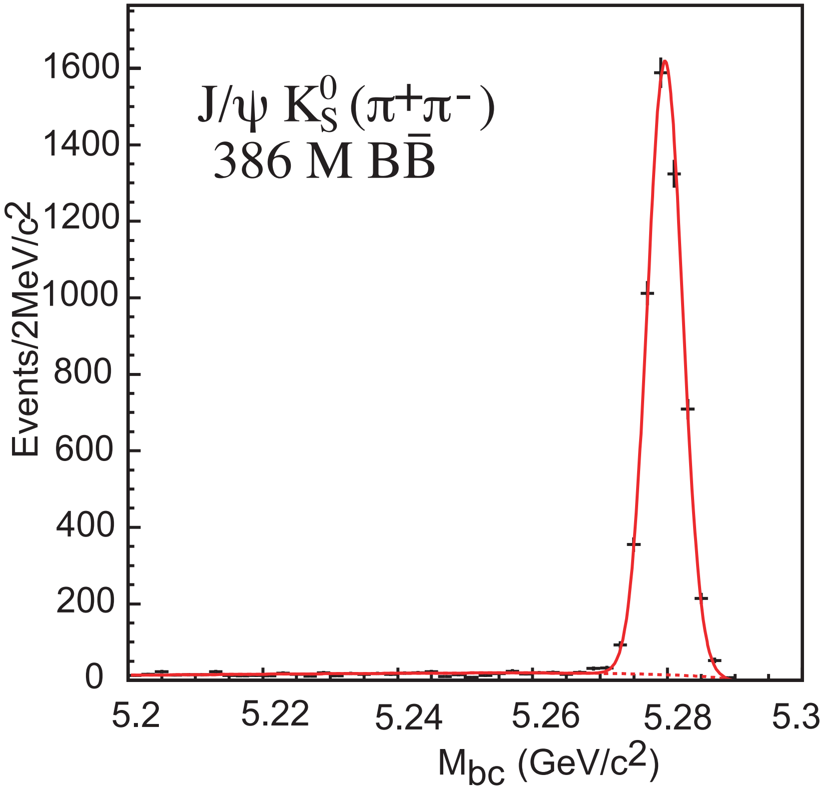
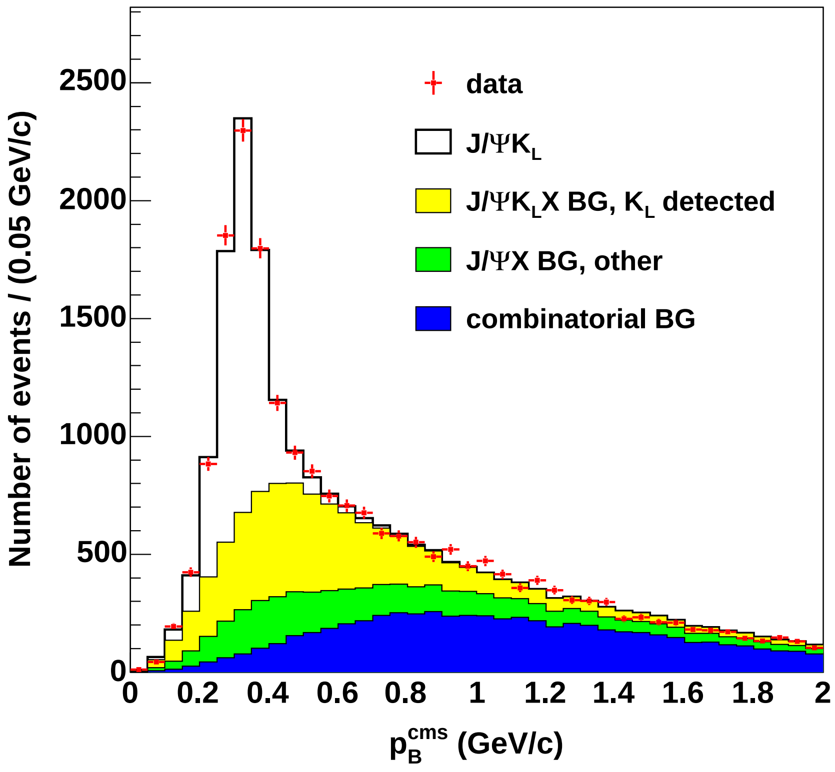
$B^0 \to J/\psi K_S$



5264 ± 73 signal events

$B^0 \to J/\psi K_L$



4792 ± 105 signal events

$B^0 \to J/\psi K^0$ — Δt Dependence

$357\ \mathrm{fb}^{-1}$

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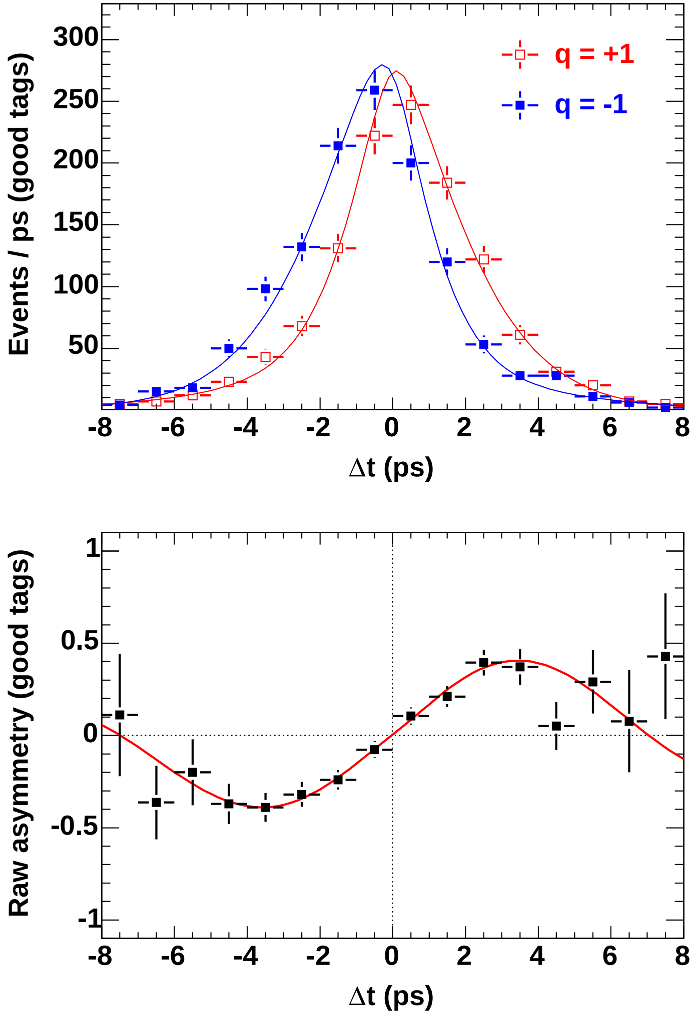
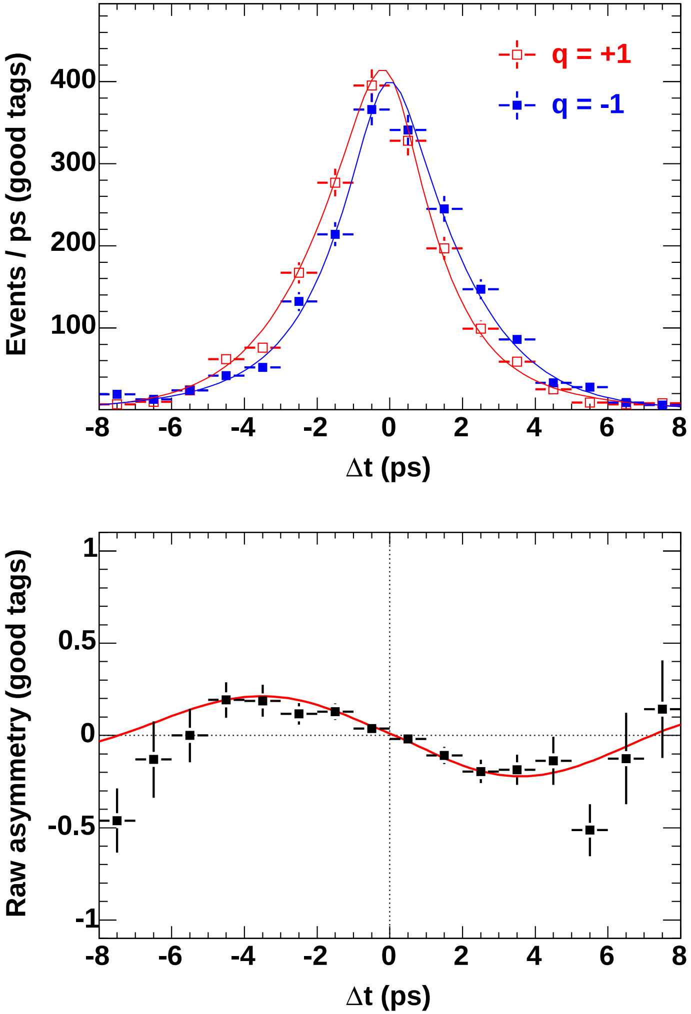
$B^0 \to J/\psi K_S$



$S = +0.668 \pm 0.047(\text{stat})$

$A = -0.021 \pm 0.034(\text{stat})$

$B^0 \to J/\psi K_L$



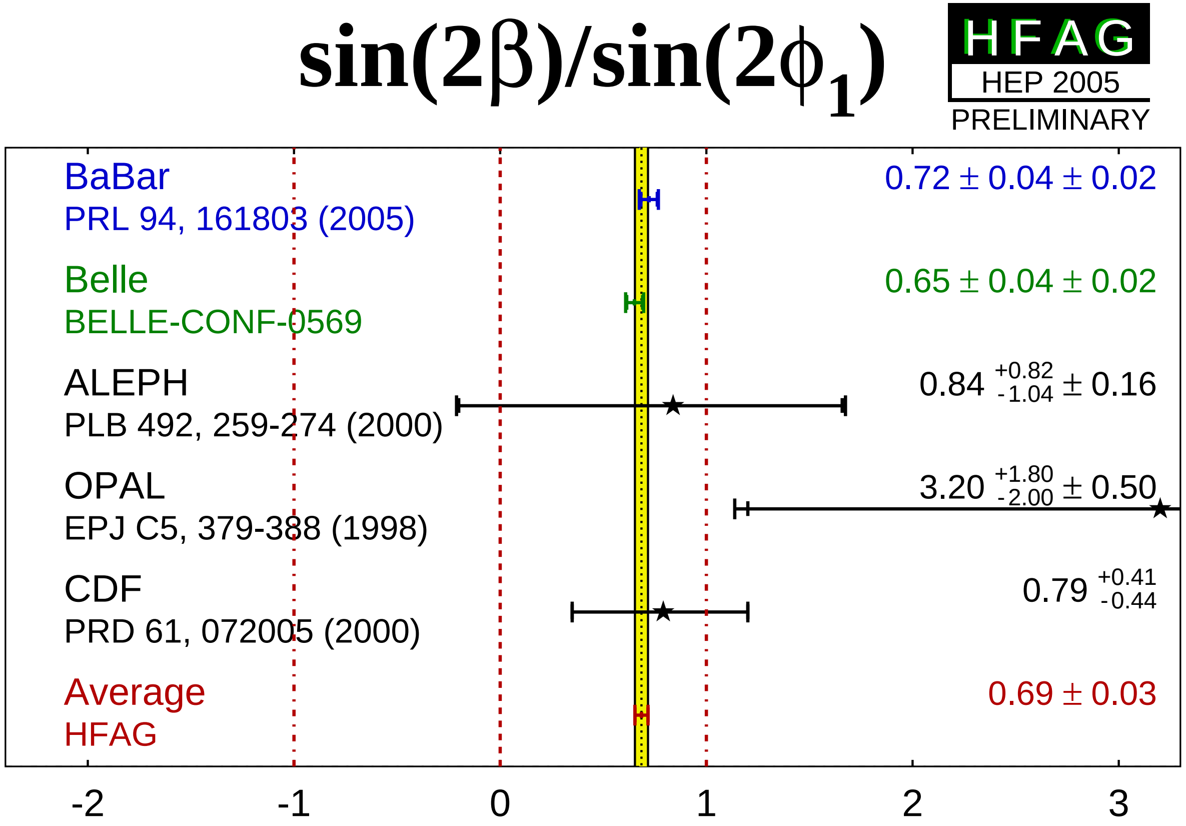
$S = -0.619 \pm 0.069(\text{stat})$

$A = +0.049 \pm 0.039(\text{stat})$

$B^0 \to J/\psi K^0$ — World Average

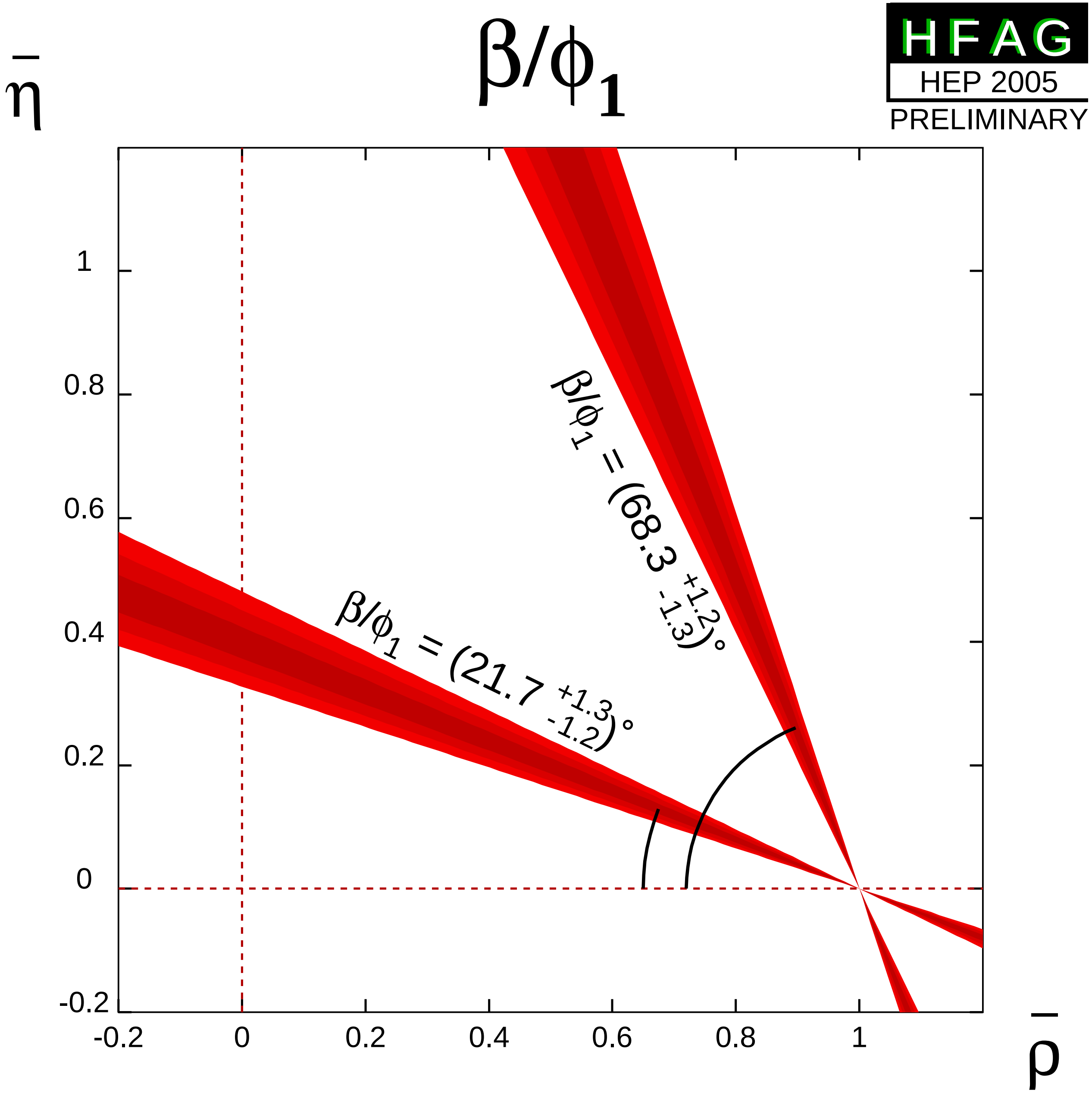
357 fb^{-1} BELLE-CONF-0569

Belle: $\sin(2\phi_1) = +0.652 \pm 0.039 \pm 0.020$

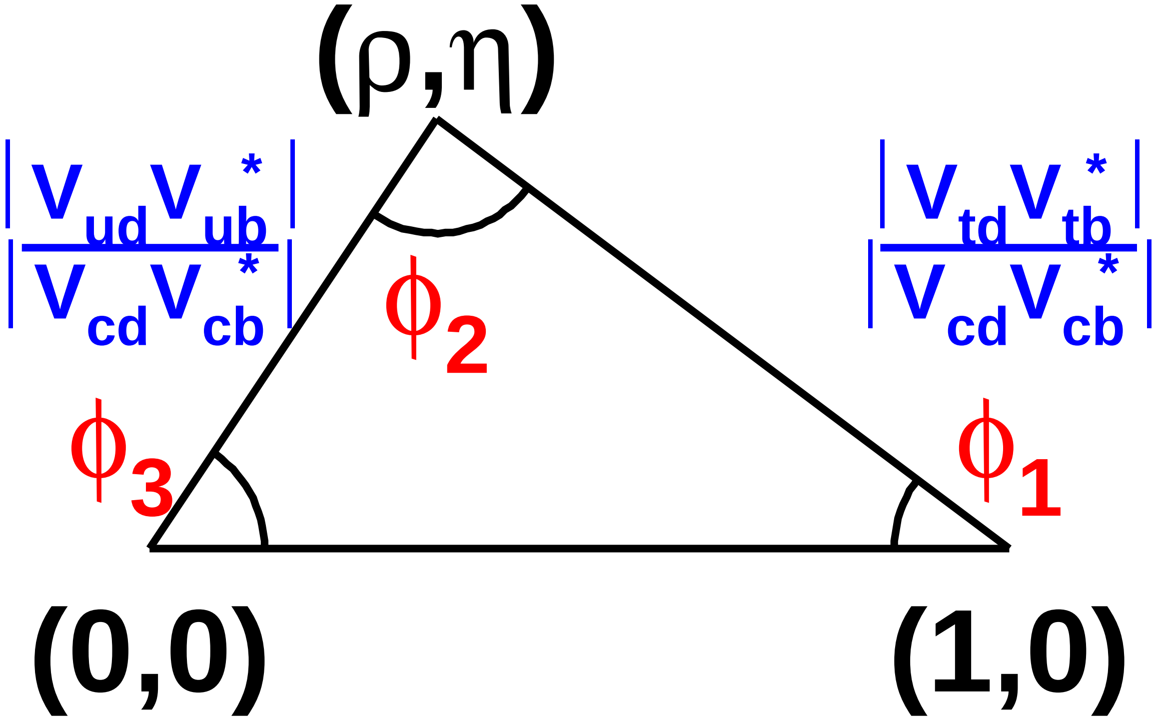


World Average: $\sin(2\phi_1) = +0.687 \pm 0.032$

$\sin(2\phi_1)$ — Constraint



UT angles — Summary



ϕ_1 $B^0 \to J/\psi K^0$

ϕ_2 $B^0 \to \pi^+\pi^-$ & $\rho^+\rho^-$

ϕ_3 $B^\pm \to DK^\pm$

$\sin(2\phi_1) = +0.652 \pm 0.039 \pm 0.020$

$\phi_2 = 93^{+12}_{-11}{}^\circ$

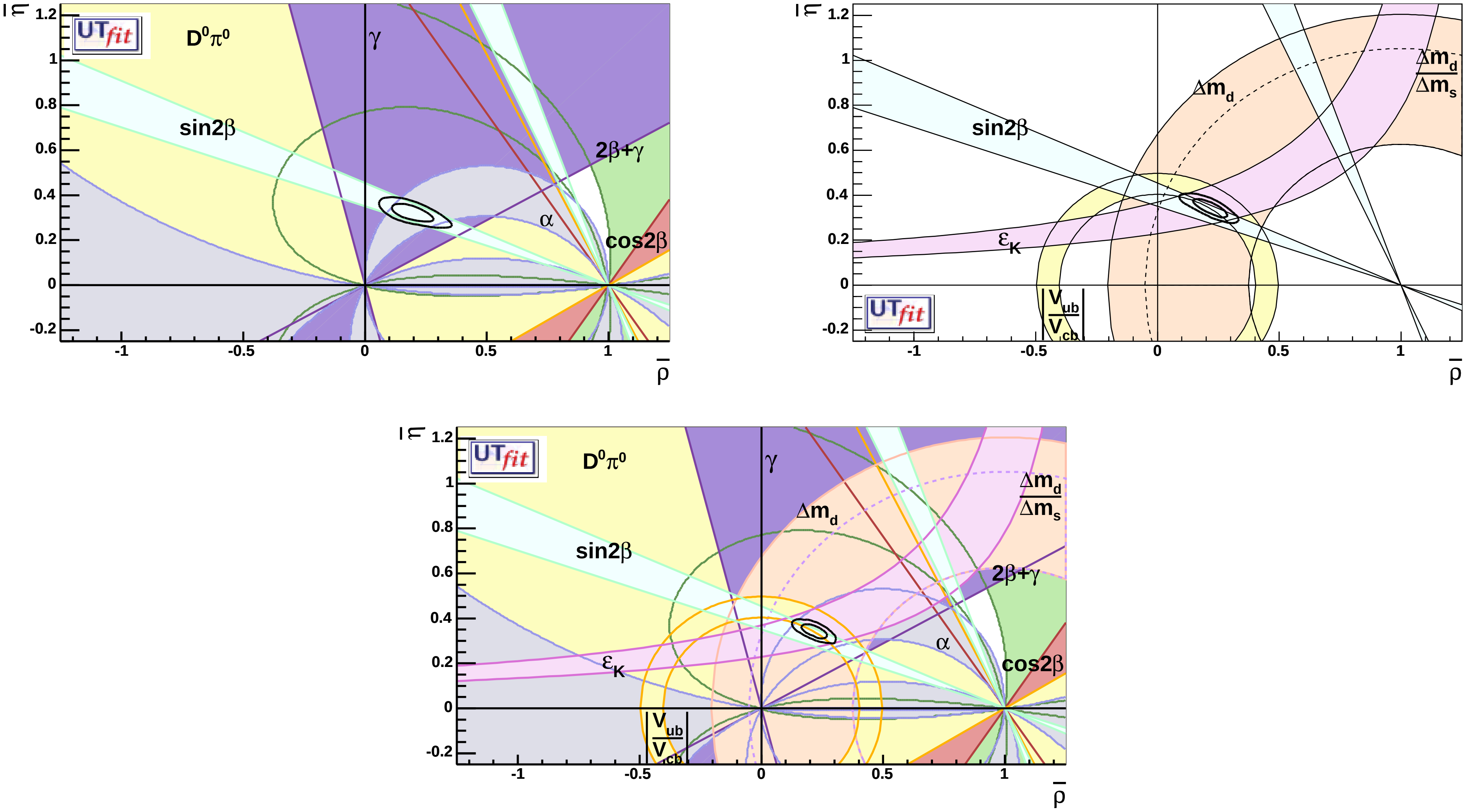
$\phi_3 = 53^\circ\,{}^{+15^\circ}_{-18^\circ}(\text{stat}) \pm 3^\circ(\text{syst}) \pm 9^\circ(\text{model})$

Ambiguities reduced by

$J/\psi K^*$ & $D^{(*)}h^0$ $\pi^+\pi^-\pi^0$ D.P. (BaBar) $D \to K_S\pi^+\pi^-$ D.P.

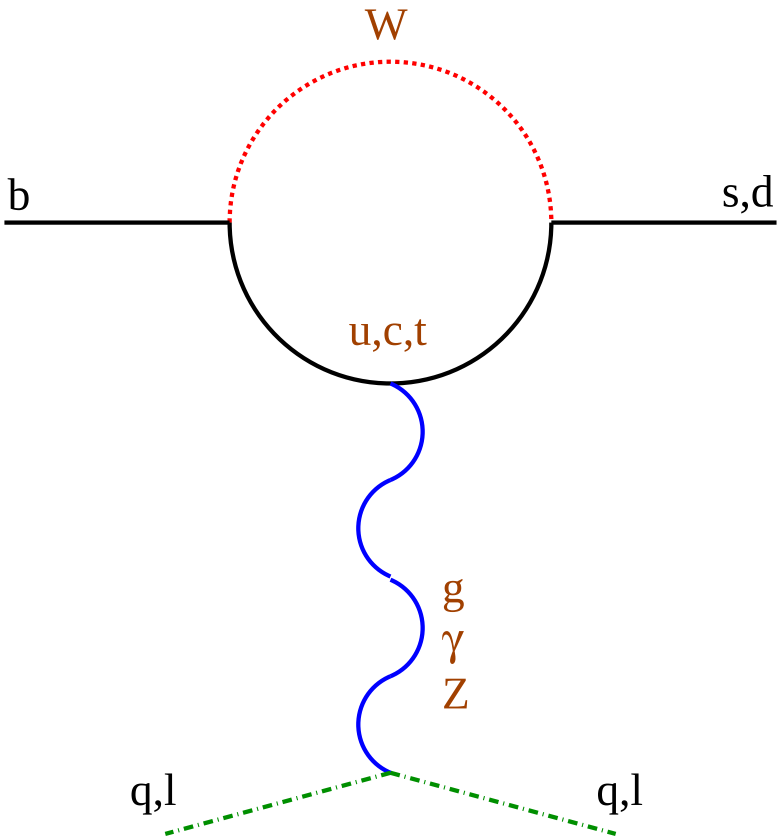
UT angles — Summary

Plots from UTFit Collaboration



Penguins

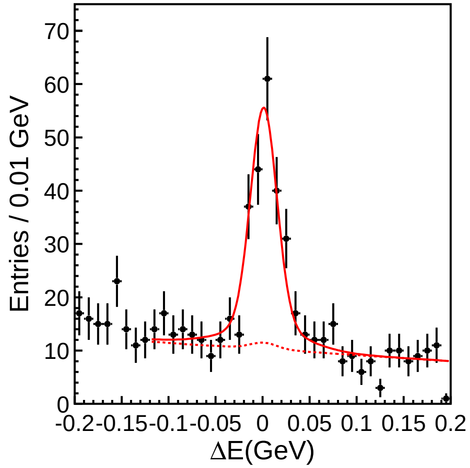
Why Hunt Penguins?



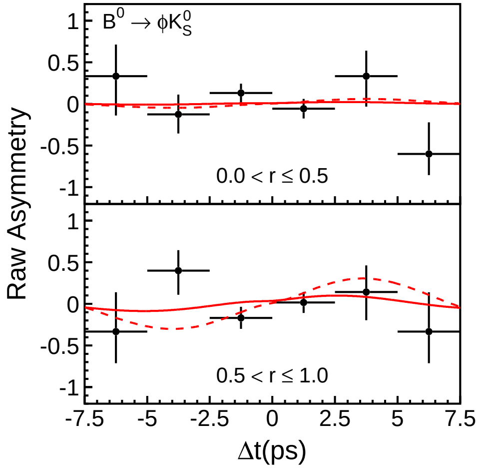
- loop diagrams ⇒ virtual particles ⇒ high masses
- expect new physics at TeV scale
- NP particles should appear in loops
- no reason for NP phases to be aligned
- many possible manifestations of NP
  - $b \rightarrow s$ *vs.* $b \rightarrow d$
  - gluonic *vs.* radiative *vs.* electroweak
  - $\Delta B = 2$ (mixing) processes

$B^0 \to \phi K^0$

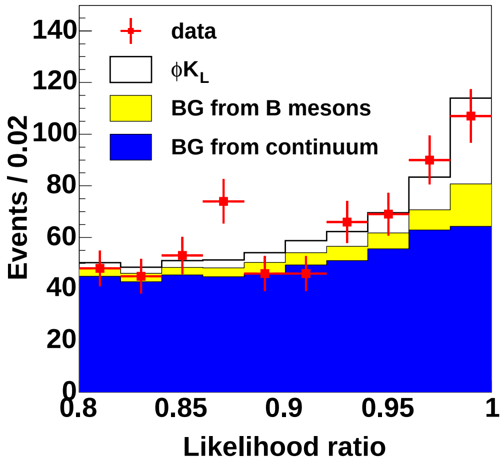
ϕK_S



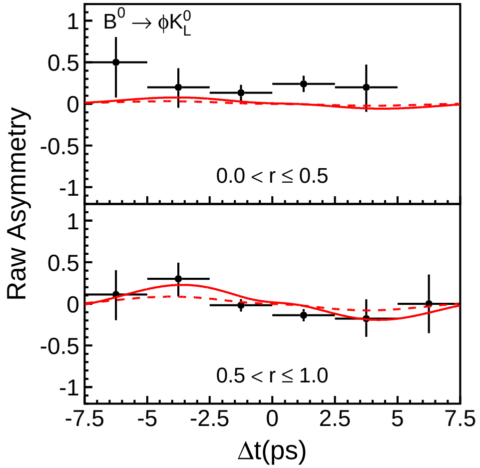
180 ± 16



ϕK_L



78 ± 13



$\sin(2\phi_1{}^{\rm eff}) = +0.44 \pm 0.27 \pm 0.05$ $\mathcal{A} = +0.14 \pm 0.17 \pm 0.07$

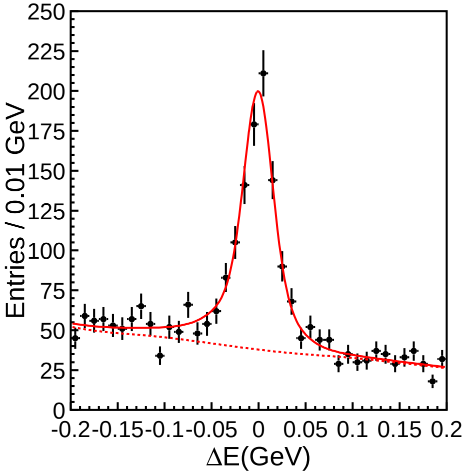
357 fb^{-1}

BELLE-CONF-0569

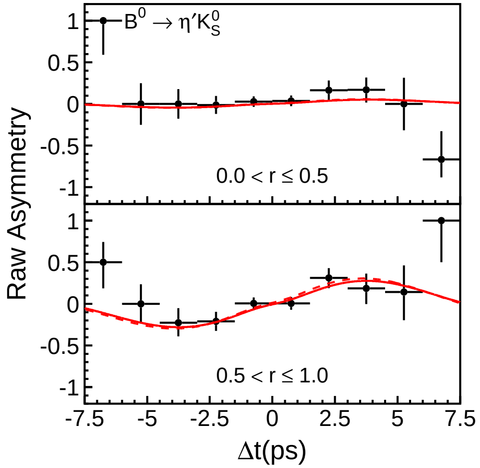
$B^0 \to \eta' K^0$

$357\ \mathrm{fb}^{-1}$ BELLE-CONF-0569

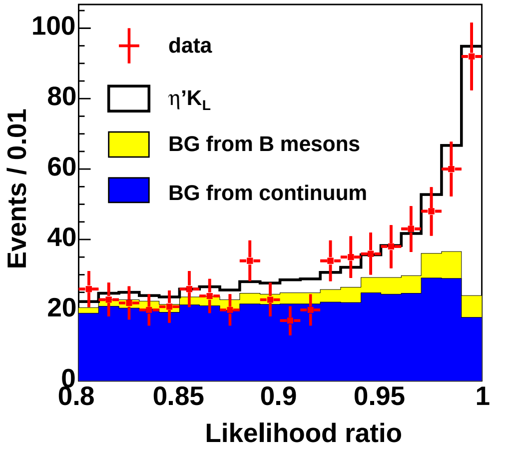
$\eta' K_S$



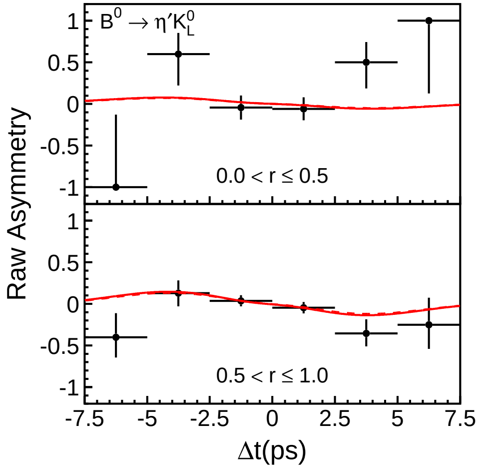
830 ± 35



$\eta' K_L$



187 ± 18



$\sin(2\phi_1^{\mathrm{eff}}) = +0.62 \pm 0.12 \pm 0.04 \qquad A = -0.04 \pm 0.08 \pm 0.06$

$b \longrightarrow q\bar{q}s$

$357\ \mathrm{fb}^{-1}$

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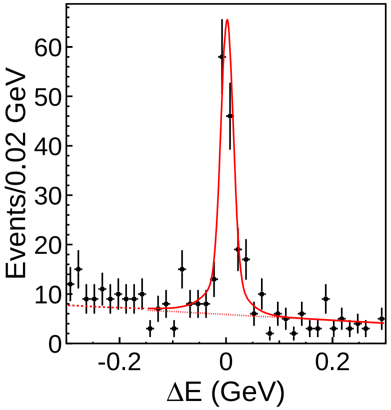
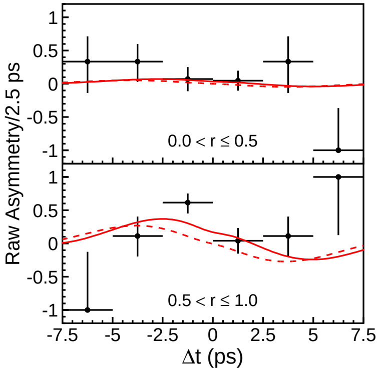
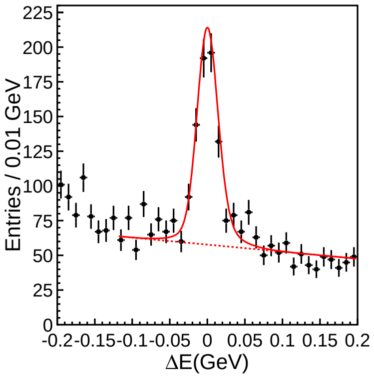
$K_S K_S K_S$



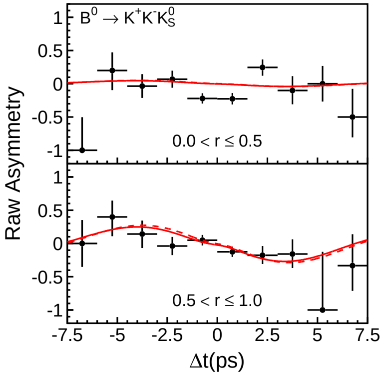
105 ± 12



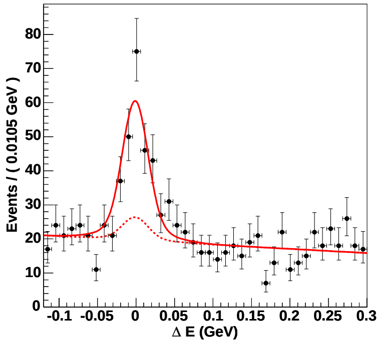
$K^+K^-K_S$



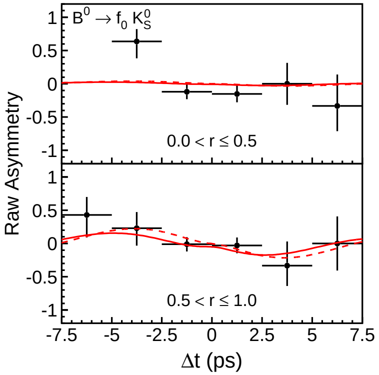
536 ± 29



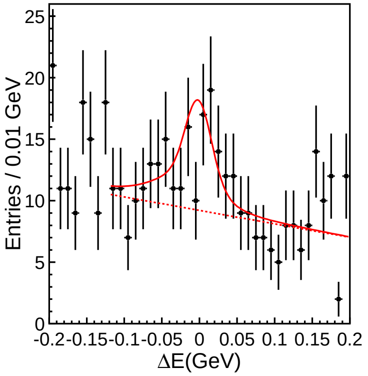
$f_0 K_S$



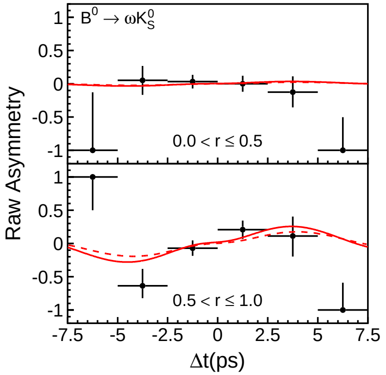
145 ± 16



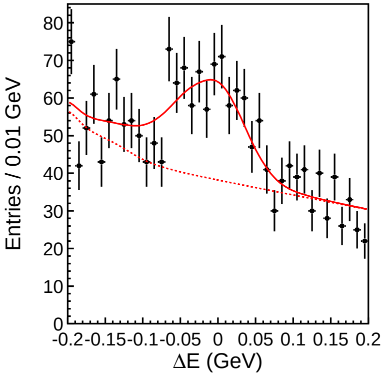
ωK_S



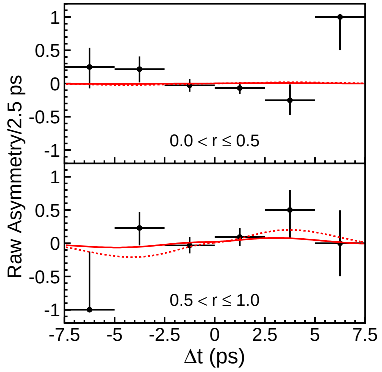
68 ± 13



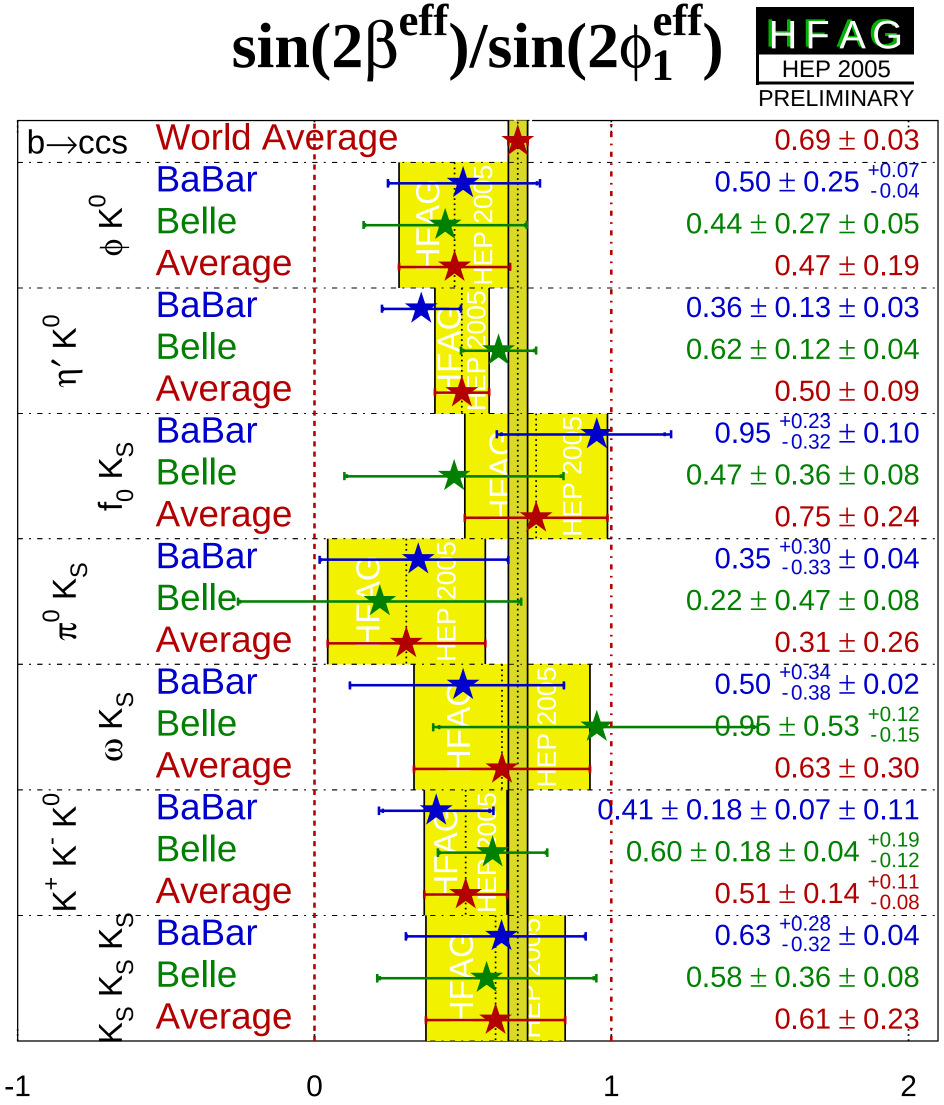
$K_S\pi^0$

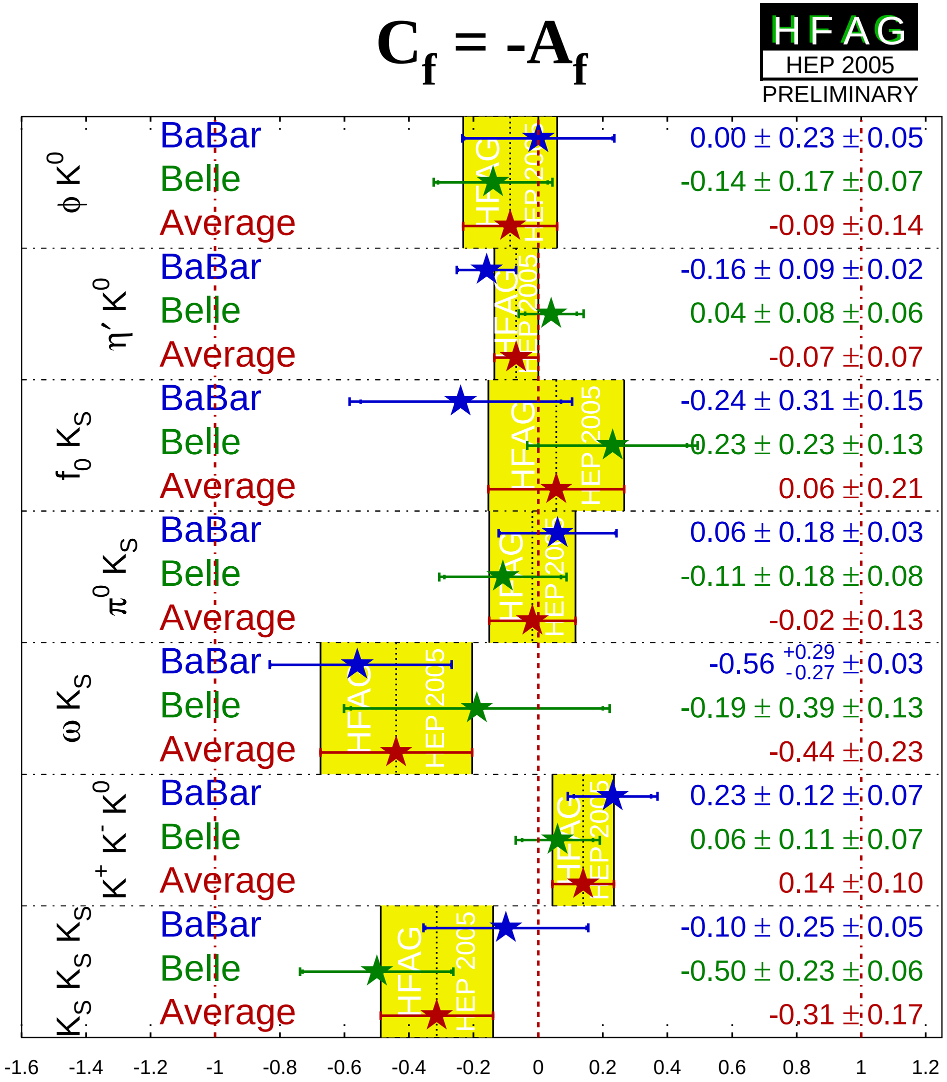


344 ± 30



$b \longrightarrow q\bar{q}s$





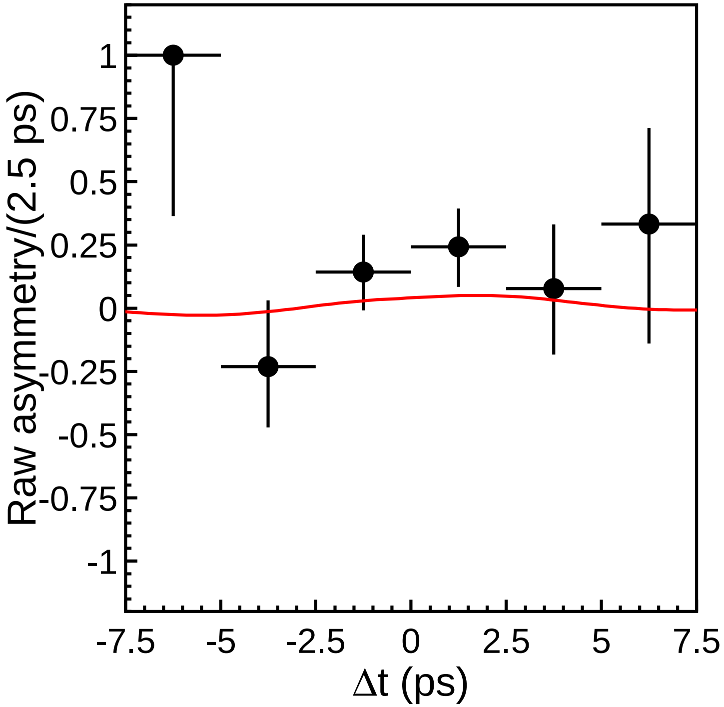
$357\ \mathrm{fb}^{-1}$

BELLE-CONF-0569

$B^0 \to K_S\pi^0\gamma$ — Time-Dependent CP Violation

386 fb^{-1} BELLE-CONF-0570

Time-dependence probes γ polarization



Invariant mass region: $0.8\ \text{GeV}/c^2 < m_{K_S\pi^0} < 1.8\ \text{GeV}/c^2$

70 ± 11 signal events

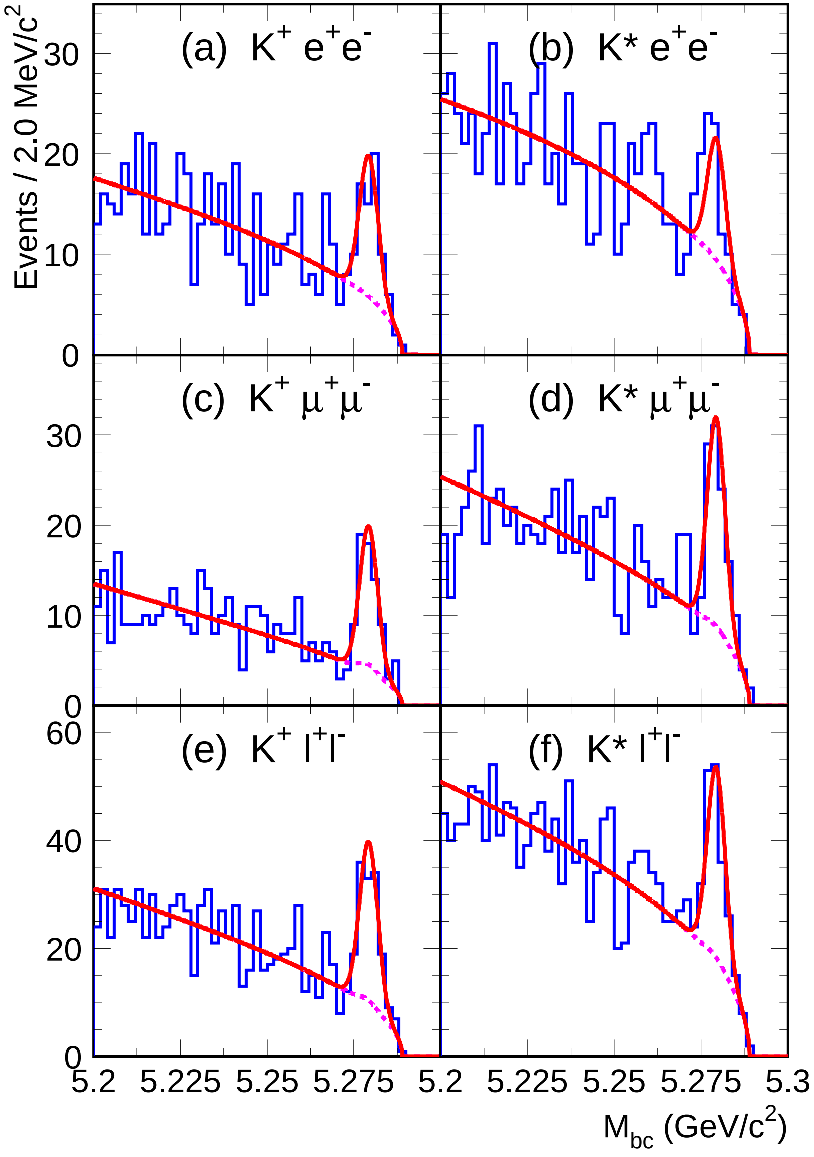
$$S_{K_S\pi^0\gamma} = +0.08 \pm 0.41(\text{stat}) \pm 0.10(\text{stat})$$
$$C_{K_S\pi^0\gamma} = -0.12 \pm 0.27(\text{stat}) \pm 0.10(\text{stat})$$

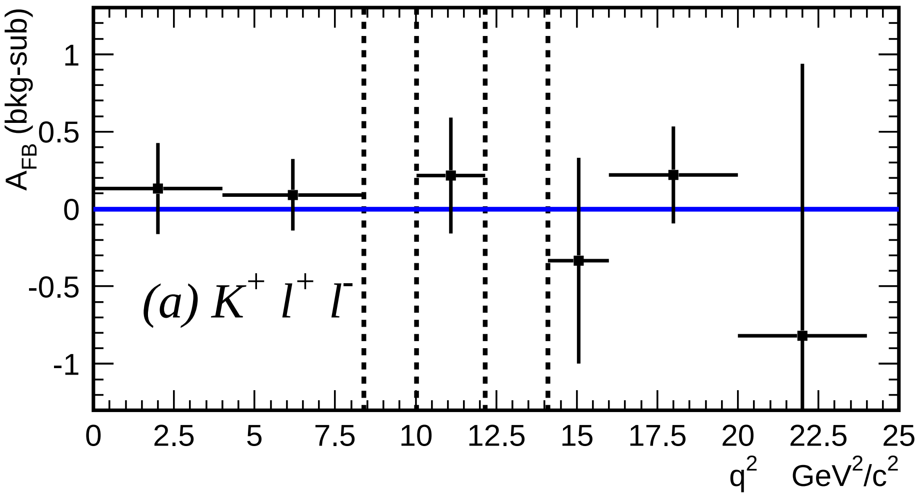
Belle: $B \to K^* l^+ l^-$ — F-B asymmetry

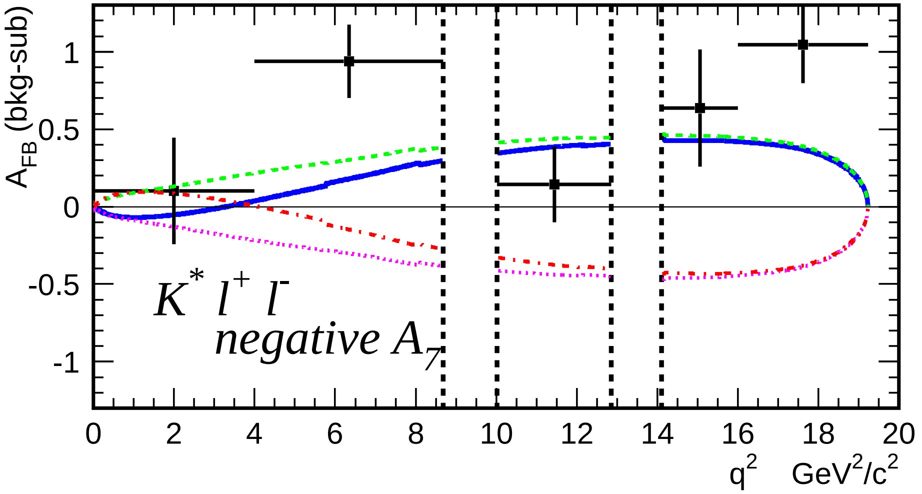
Measure Wilson coefficients (A_7, A_9, A_{10}); find $A_{FB} = 0$ point

357 fb^{-1}

Belle-Preprint-2006-9

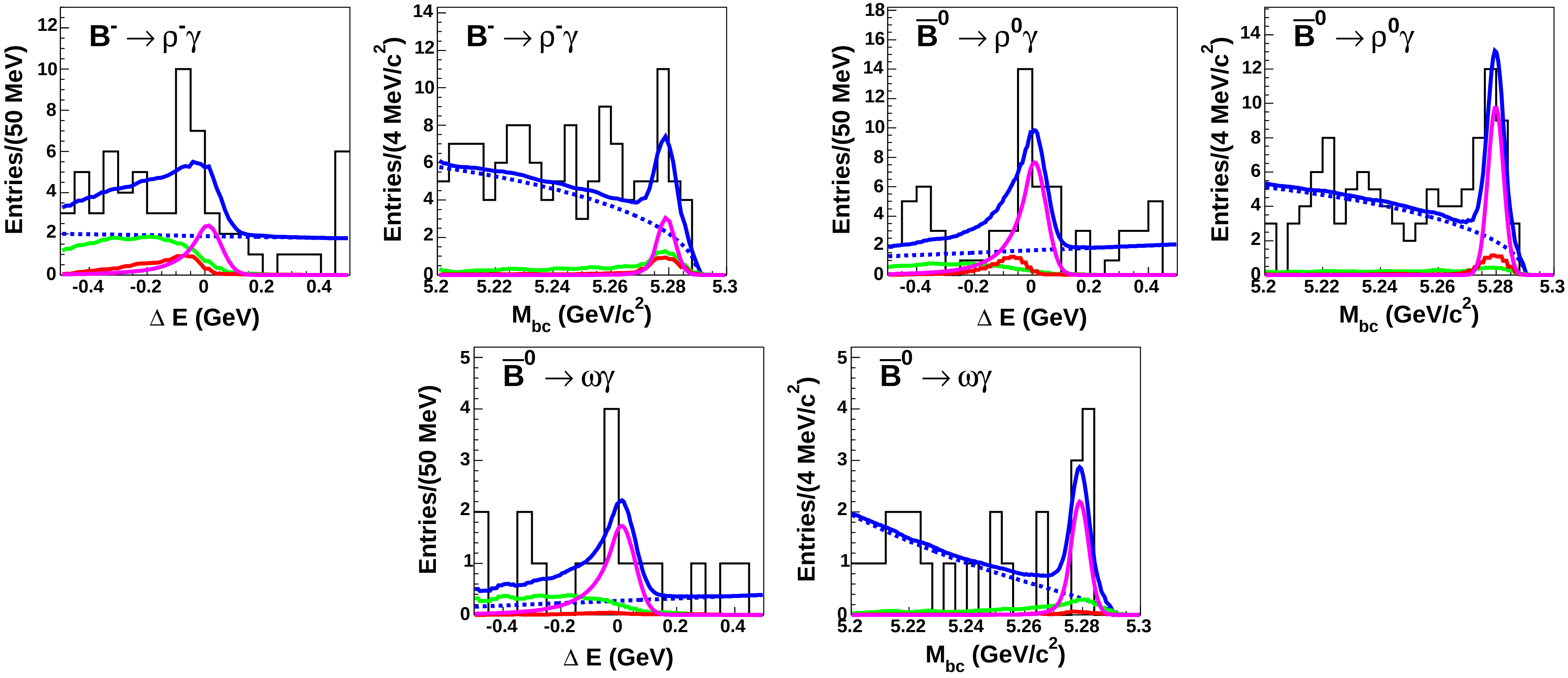






$A_9 A_{10} > 0$ excluded at 95% CL

$b \to d\gamma$



357 fb^{-1}

Belle-Preprint-2006-5

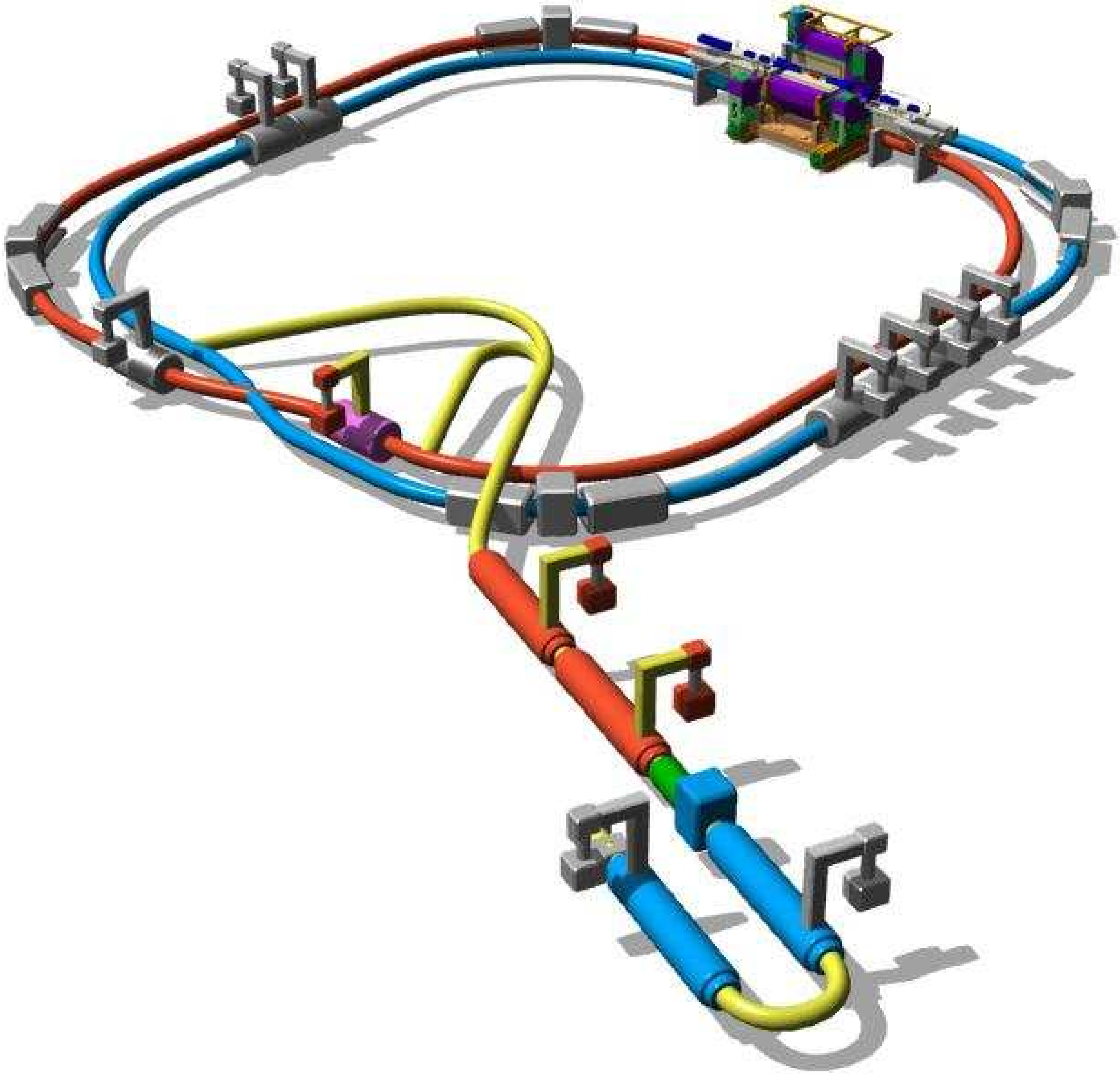
Assuming isospin relation:

$$\boxed{\mathcal{B}\left(B \to (\rho,\omega)\gamma\right) = \left(1.32\,^{+0.34}_{-0.31}\,^{+0.10}_{-0.09}\right) \times 10^{-6}}$$

Significance: 5.1σ

$$|V_{td}/V_{ts}| = 0.199\,^{+0.026}_{-0.025}(\text{exp})^{+0.018}_{-0.015}(\text{theo})$$

Super B Factory



Super B Factory

- Luminosity frontier probes new physics . . . complementary to energy frontier
- *eg.* When LHC discovers SUSY, Super B can help identify SUSY breaking mechanism
- Argument for B physics (& flavour physics) well established
  . . . important relation to baryon asymmetry of the Universe
- Complementarity between LHCb and Super B becoming clearer
  - Super B only: modes with neutrals, neutrinos, difficult topologies
  - LHCb only: modes with B_s, other heavy B hadrons
  - Overlap: *eg.* $B_d \to \pi^+\pi^-$, DK^{*0} to keep us honest
  - ATLAS/CMS: very rare modes (*eg.* $B_{d,s} \to \mu^+\mu^-$)

Fundamental Questions

- What: Origin of flavour mixing and CP violation
- Why: Matter dominated universe
- How: Flavour structure in and beyond Standard Model

- Are there new CP violating phases?
  $b \to s$ TDCPV; UT from tree *vs* loops; $\Delta B = 2$ & $\Delta B = 1$
- Are there new right-handed currents?
  $b \to s\gamma$ TDCPV *etc.*; $B \to VV$ polarization
- Are there new operators enhanced by new physics?
  $B \to K^* l^+ l^-$ A_{FB}; $B \to K\pi, \pi\pi$ rates & asymmetries
- Are there new FCNCs? (b,c or τ)
  $b \to s\nu\bar{\nu}$; $\tau \to \mu\gamma$ *etc.*; $D\bar{D}$ mixing, CPV, *etc.*

Data sample of $\sim$ 50 ab^{-1} @ $\Upsilon(4S)$ needed to address these questions

Super B Factory Parameters

Three factors to determine luminosity:

Stored current:

1.34 / 1.8 A (KEKB)

→ 4.1 / 9.4 A (SuperKEKB)

Beam-beam parameter:

0.057 (KEKB)

→ 0.19 (SuperKEKB)

Lorentz factor

$$L = \frac{\gamma_\pm}{2er_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\frac{I_\pm \xi_{\pm y}}{\beta_y^*}\left(\frac{R_L}{R_y}\right)$$

Classical electron radius

Beam size ratio

Geometrical reduction factors due to crossing angle and hour-glass effect

Luminosity:

0.15×10^{35} cm^{-2}s^{-1} (KEKB)

4×10^{35} cm^{-2}s^{-1} (SuperKEKB)

Vertical β at the IP:

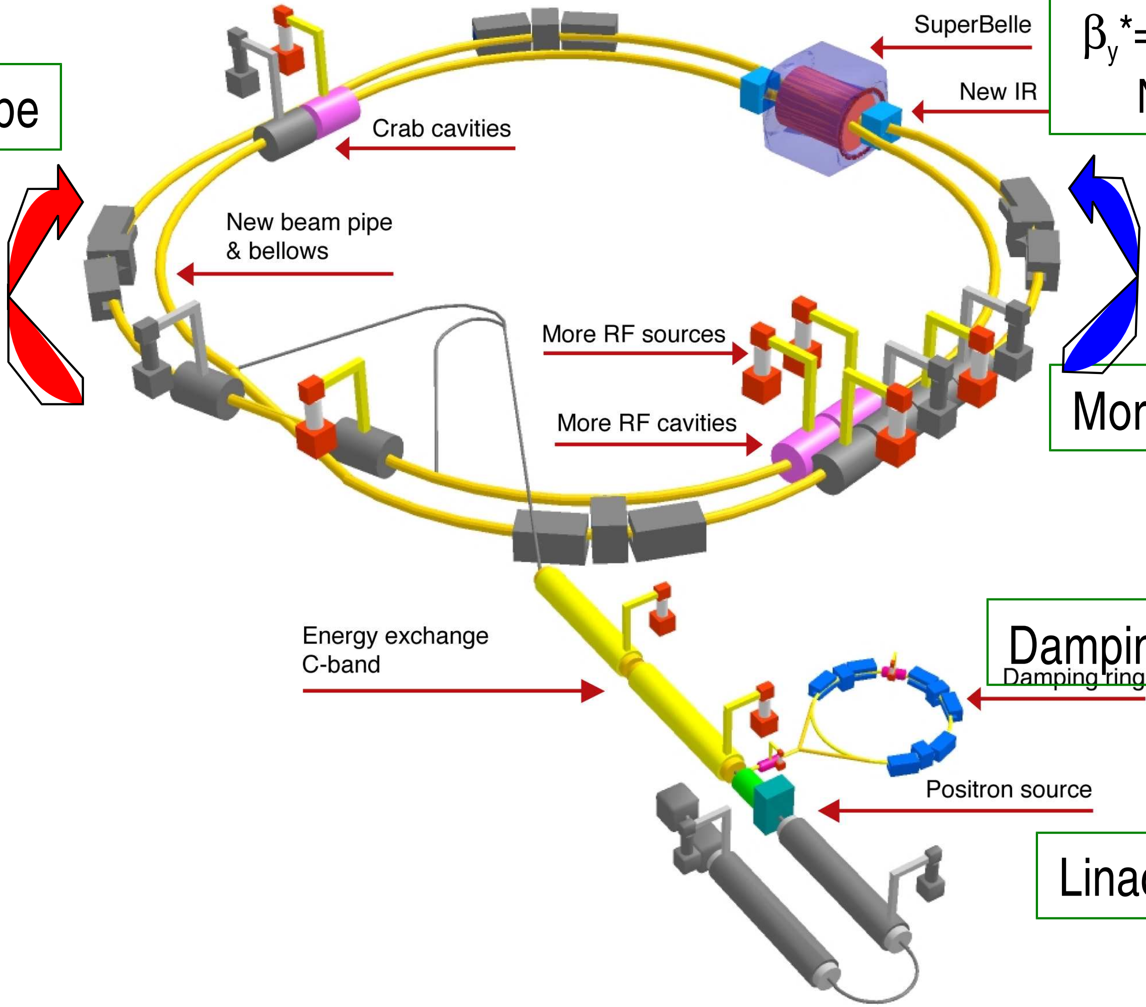
5.2/6.5 mm (KEKB)

→ 3.0/3.0 mm (SuperKEKB)

Bunch length (σ_s)

7 ~ 9 mm -> 3 mm

Super B Factory Upgrade



Interaction Region

Crab crossing

θ=30mrad.

β_y^*=3mm

New QCS

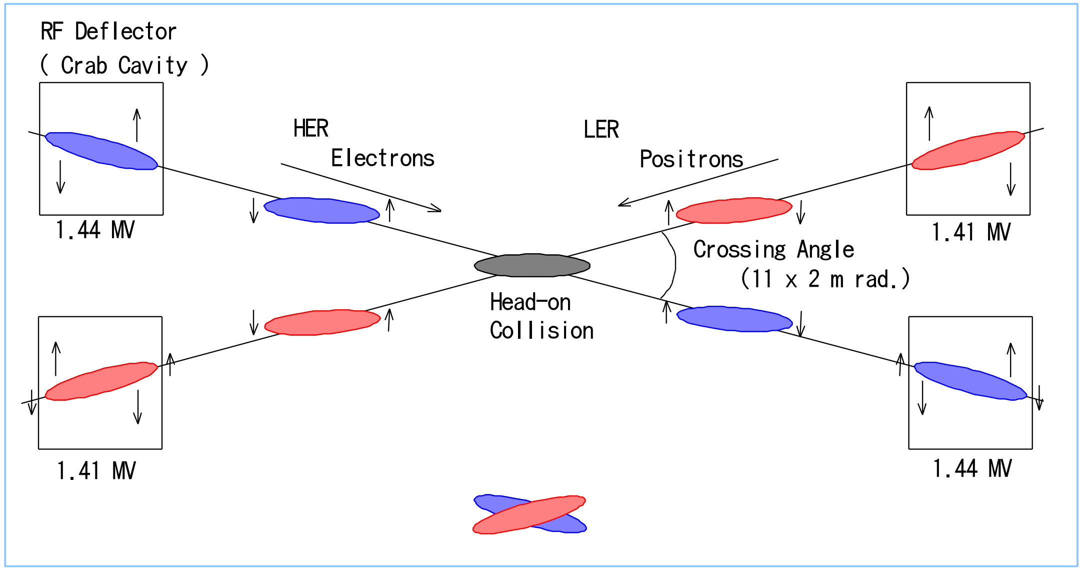
New Beam pipe

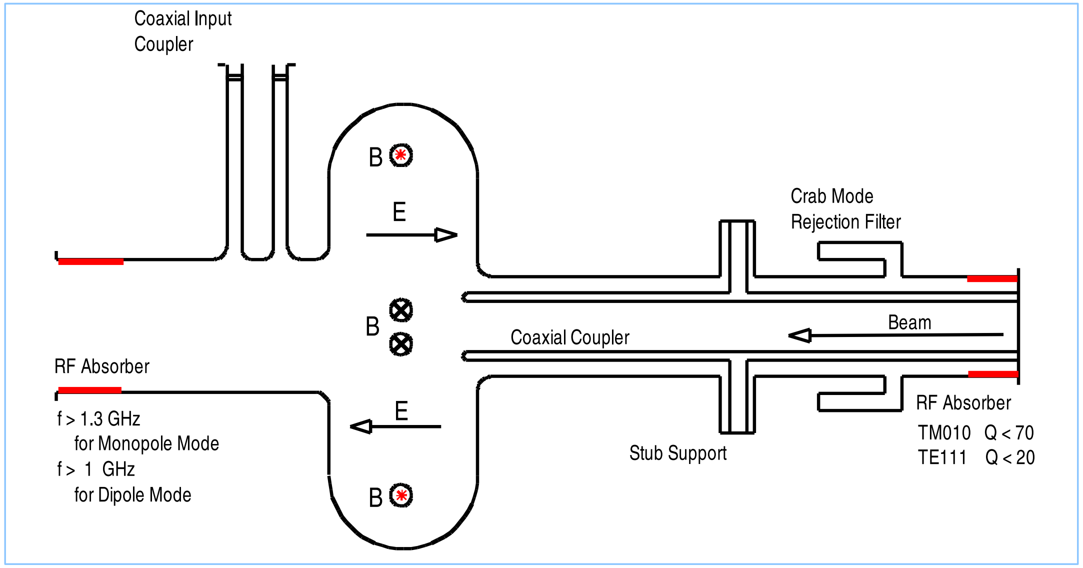
More RF power

Damping ring

Linac upgrade

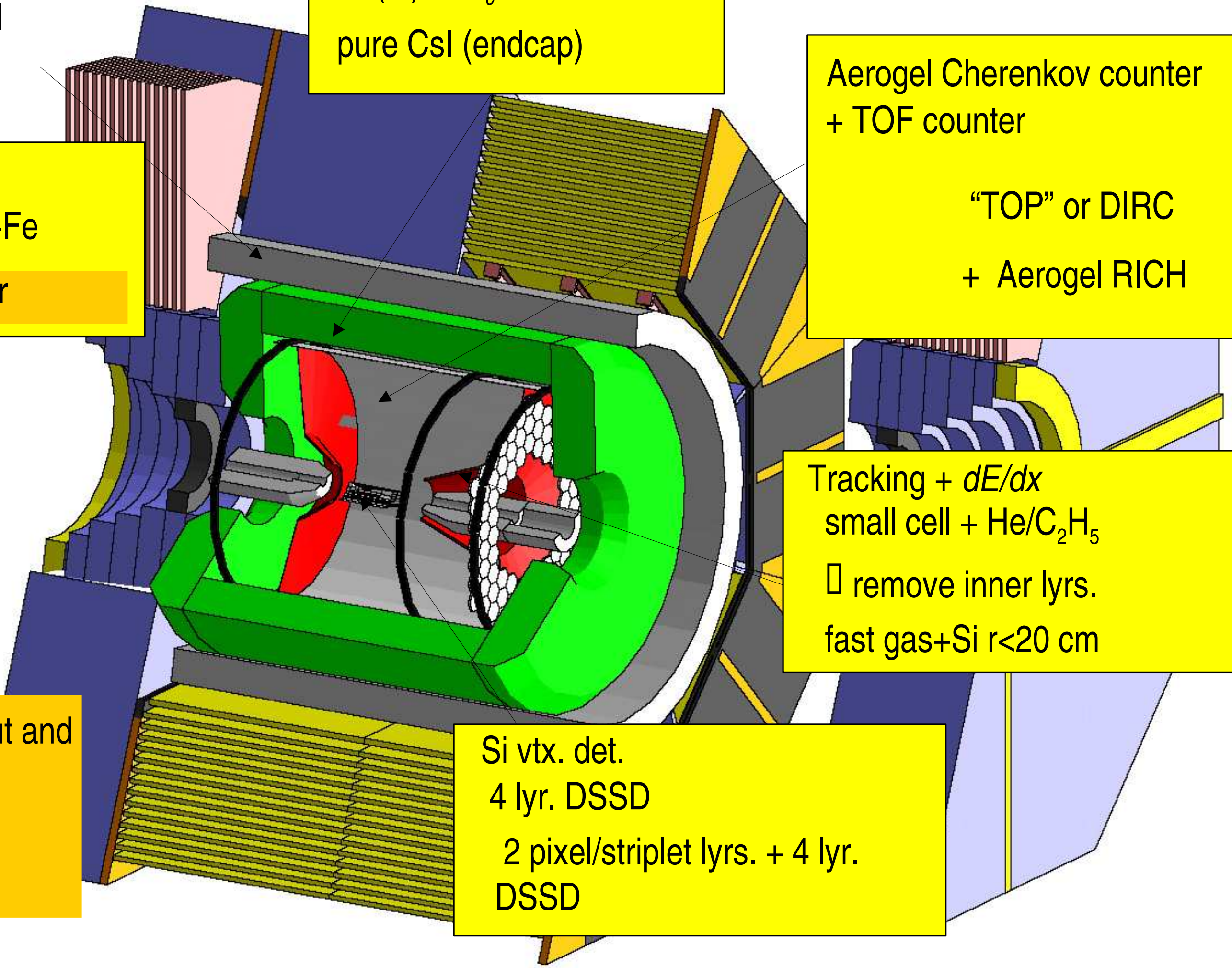
Crab Cavities





- Head-on collision with finite crossing angle
- Superconducting crab cavities under development
- Will be tested in early 2006

Belle Upgrade for Super-B



SC solenoid
1.5T

CsI(Tl) $16X_0$
pure CsI (endcap)

Aerogel Cherenkov counter
+ TOF counter

"TOP" or DIRC
+ Aerogel RICH

μ / K_L detection
14/15 lyr. RPC+Fe
tile scintillator

Tracking + *dE/dx*
small cell + He/C_2H_5
 remove inner lyrs.
fast gas+Si r<20 cm

New readout and computing systems

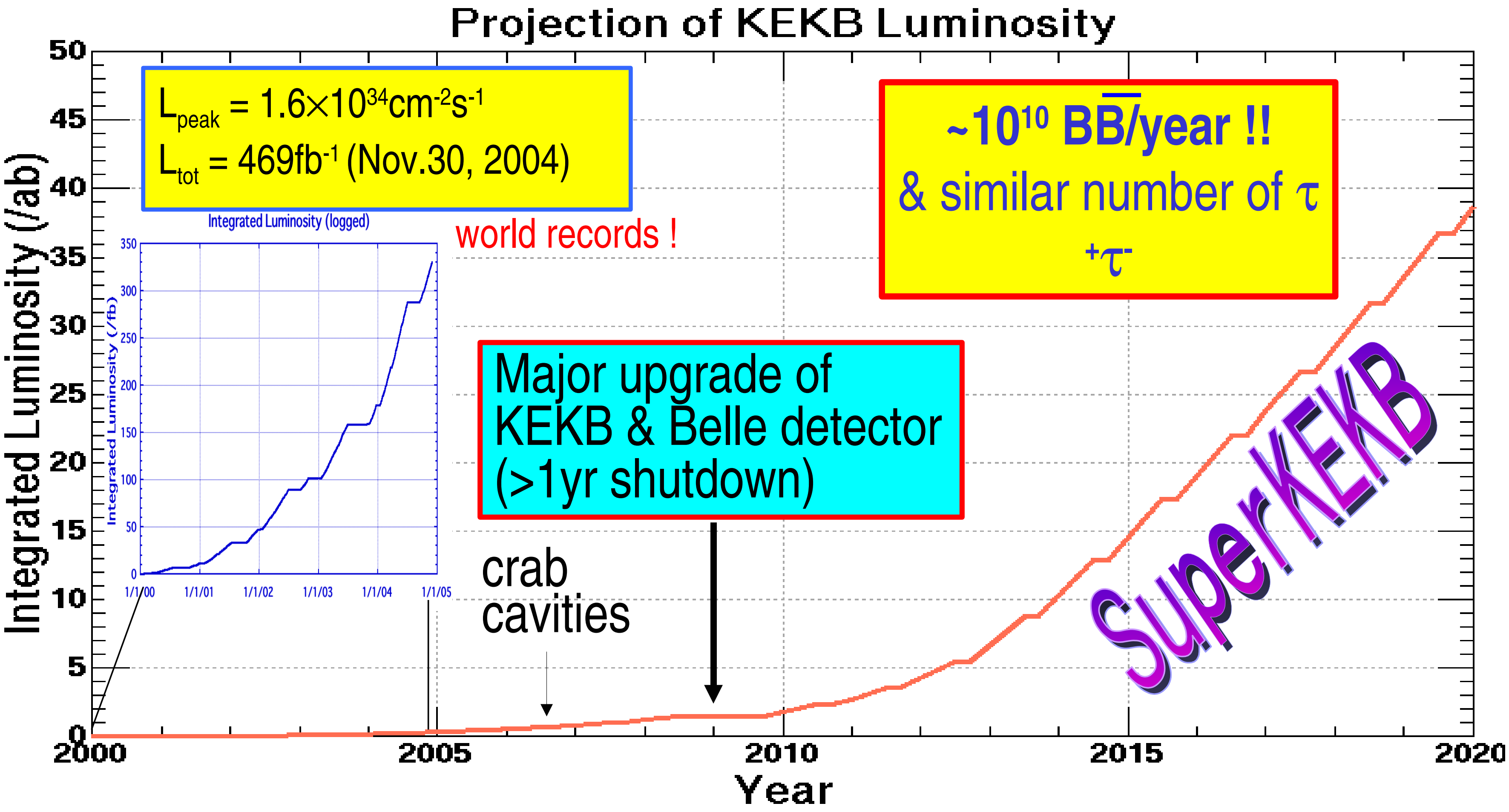
Si vtx. det.
4 lyr. DSSD
2 pixel/striplet lyrs. + 4 lyr. DSSD

Super B Factory Detector

- Issues
  - Higher background
  - Higher event rate
  - Special features:
    low p μ-ID; hermiticity $\Rightarrow$ ν reconstruction; K_S vertexing

- Possible solutions (nothing is fixed)
  - Inner SVD $\Rightarrow$ striplets
  - Inner tracker $\Rightarrow$ silicon
  - Outer tracker $\Rightarrow$ fast gas
  - PID $\Rightarrow$ “TOP”; RICH; FDIRC . . .
  - Endcap calorimeter $\Rightarrow$ pure CsI
  - KLM $\Rightarrow$ tile scintillator
  - Fast trigger & read out; improved DAQ & computing

Super B Factory Luminosity



$L_{peak} = 1.6\times10^{34}$cm^{-2}s^{-1}
L_{tot} = 469fb^{-1} (Nov.30, 2004)

world records !

~10^{10} $B\overline{B}$/year !!
& similar number of $\tau^{+}\tau^{-}$

Major upgrade of KEKB & Belle detector (>1yr shutdown)

crab cavities

Summary

- KEKB is running well, Belle has more and more data to analyze
- Many new and improved results, and more coming soon . . .
- Significant CPV effects appearing in many modes
- Amplitude analyses opening new vistas for B physics
- What I have shown is only a fraction

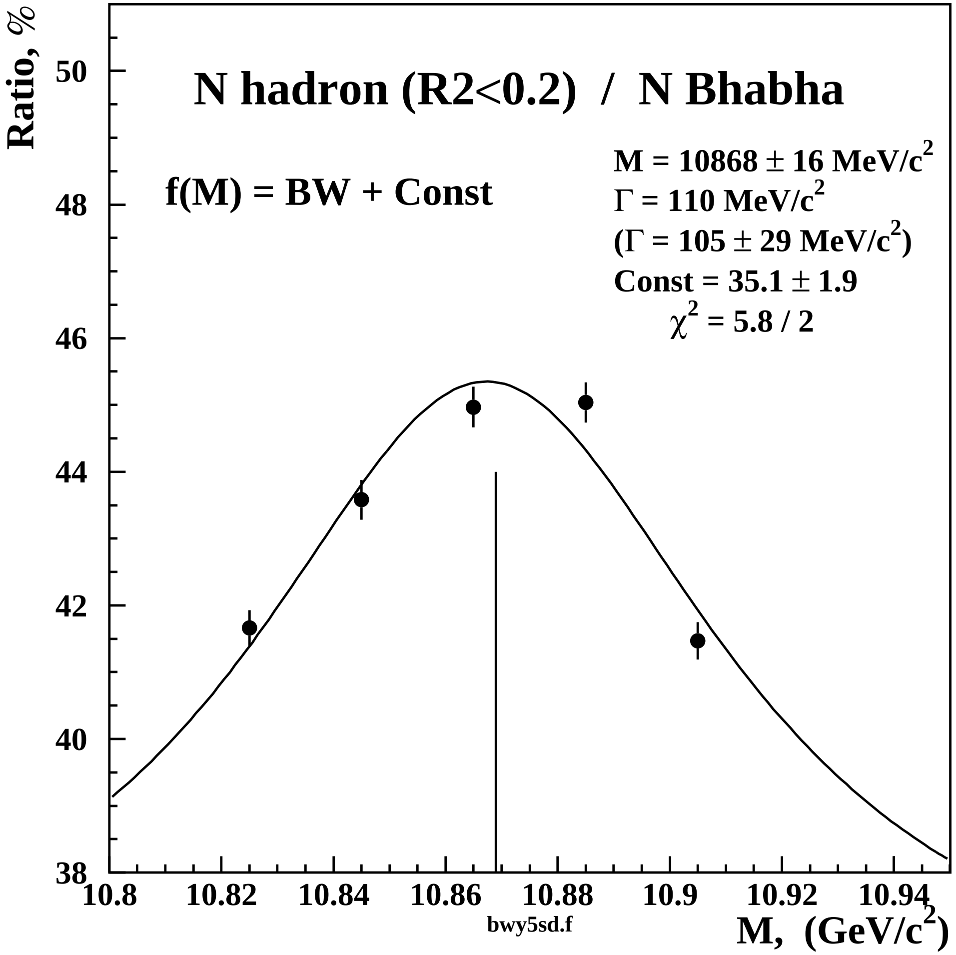
`http://belle.kek.jp/conferences/CONF2005/`

- All results shown here are preliminary

Back Up

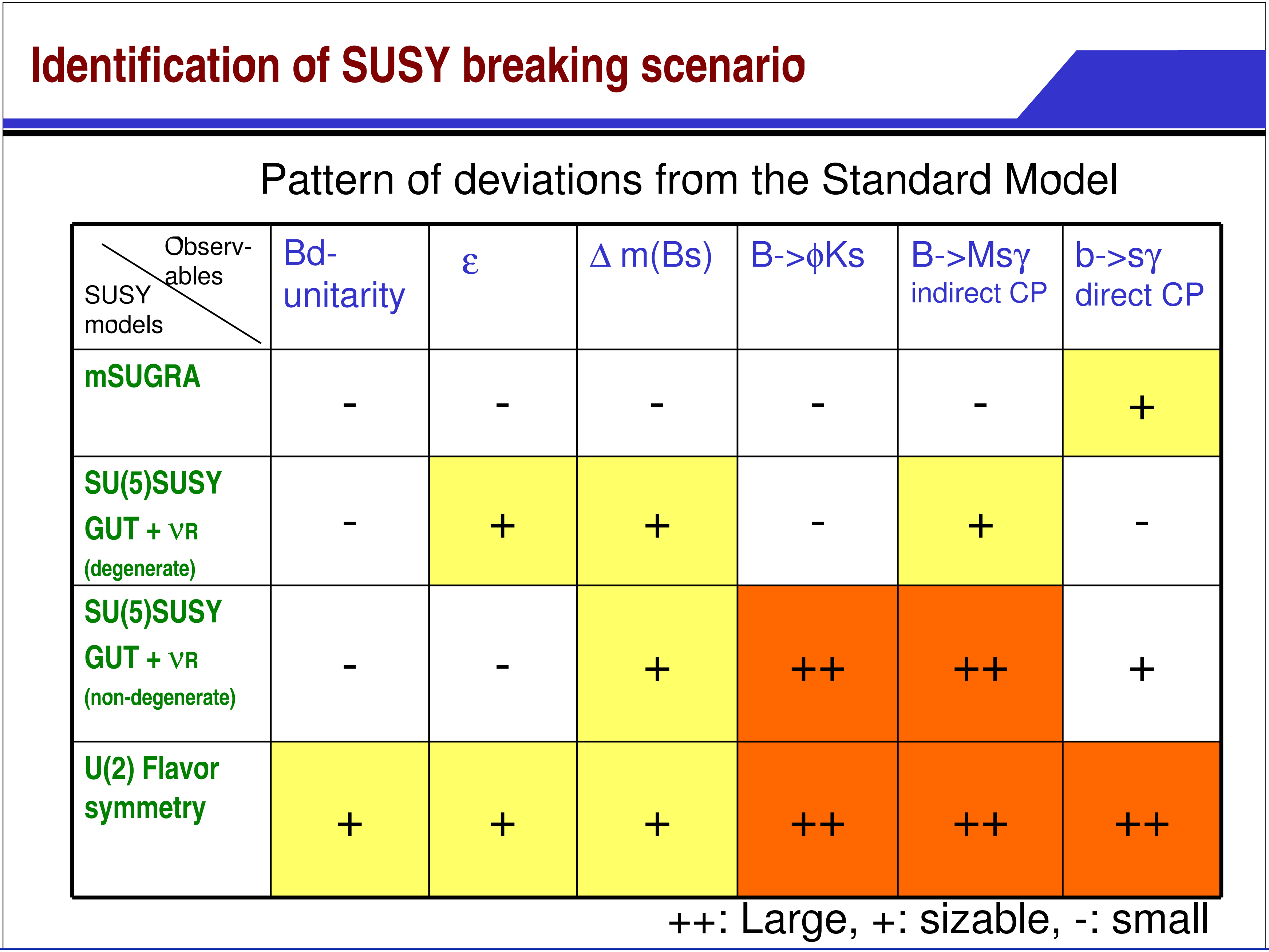
$\Upsilon(5S)$ Data Taking

Short engineering run has been performed ($\sim 2\,\mathrm{fb}^{-1}$ on $\Upsilon(5S)$)



$\Upsilon(5S)$ data taking at high luminosity is possible

Identifying SUSY Breaking



Identification of SUSY breaking scenario

Pattern of deviations from the Standard Model

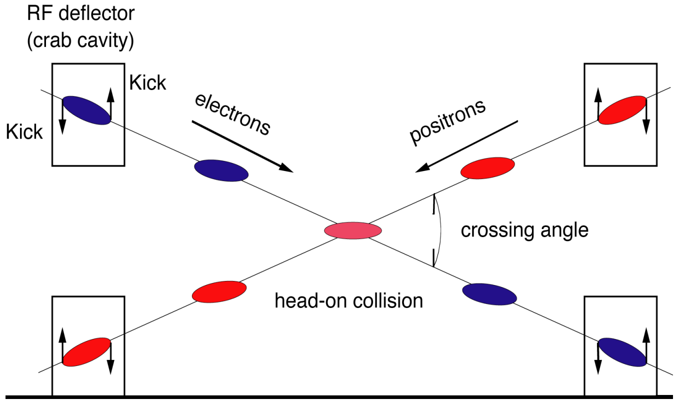
Observ-ables / SUSY models	Bd-unitarity	ε	Δ m(Bs)	B->ϕKs	B->Msγ indirect CP	b->sγ direct CP
mSUGRA	-	-	-	-	-	+
SU(5)SUSY GUT + ν_R (degenerate)	-	+	+	-	+	-
SU(5)SUSY GUT + ν_R (non-degenerate)	-	-	+	++	++	+
U(2) Flavor symmetry	+	+	+	++	++	++

++: Large, +: sizable, -: small

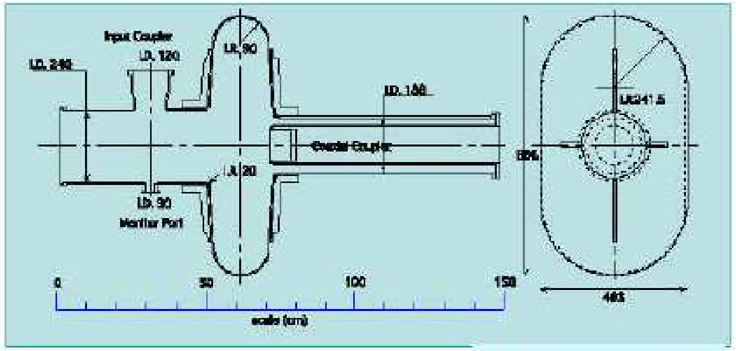
Crab Cavities

Crab cavity and ante-chamber

- Head-on collision w/ Crab cavity

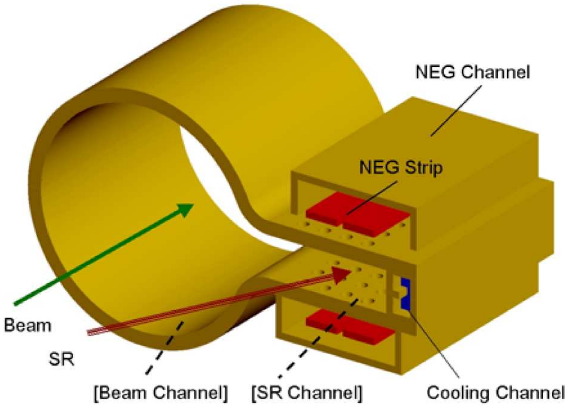


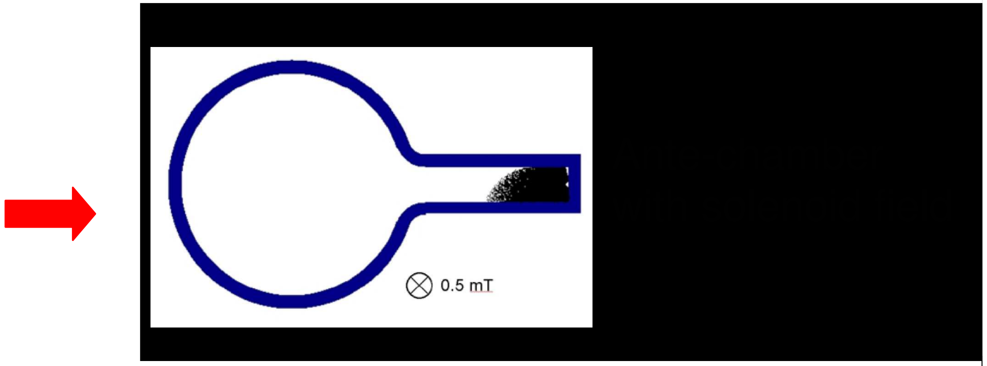
●Superconducting crab cavities are under development, will be installed in KEKB in early 2006.



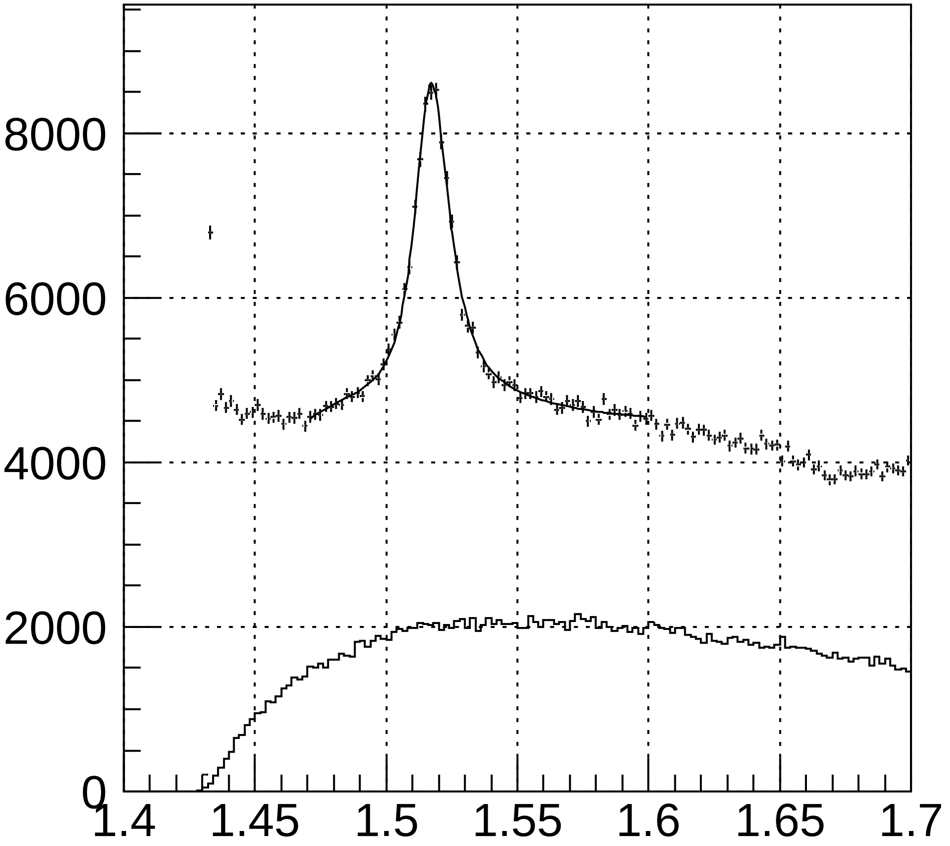
K. Hosoyama, et al

- Ante-chamber /solenoid for reduction of electron clouds





Search for $\Theta(1540)^+$ Using Kaon Interactions



397 fb^{-1} BELLE-CONF-0518

$\Lambda(1520)$ clearly seen in pK^-

No signal for $\Theta(1540)^+$ in pK_S

Not covered

- D physics
- τ physics
- ISR physics
- $\gamma\gamma$ physics
- spectroscopy & exotics
- Rare (& not-so-rare) $b \to c$ decays
- Many other rare decays
- $b \to ul\nu$
- $b \to cl\nu$
- $\ldots$

CP Violation — Summary

Direct CP violation seen by Belle:

- $B^0 \to K^+\pi^-$ ($\sim$ 10% $\sim 5\sigma$)
- $B^0 \to \pi^+\pi^-$ ($\sim$ 50% $\sim 4\sigma$)
- $B^+ \to \rho^0 K^+$ ($\sim$ 30% $\sim 4\sigma$)

Time-dependent CP violation seen by Belle:

- $B^0 \to J/\psi K^0$ ($\sim$ 65% $>> 5\sigma$)
- $B^0 \to \pi^+\pi^-$ ($\sim$ 65% $> 5\sigma$)
- $B^0 \to \eta' K^0$ ($\sim$ 60% $\sim 5\sigma$)

$B^+ \to D^{(*)}K^+$ DP Analysis History

- First results shown at Lepton-Photon 2003
    - $B^- \to DK^-$ & $B^- \to D^*K^-, D^* \to D\pi^0$
    - 140 fb^{-1}
    - Published in PRD 70, 072003 (2004)
- Update with 250 fb^{-1} at FPCP 2004
    - `hep-ex/0411049`
- First results with $B^- \to DK^{*-}$ at Moriond QCD 2005 / CKM2005
    - Not included in combined average yet
    - `hep-ex/0504013`
- Only $D \to K_S\pi^+\pi^-$ used so far

Measurement of $f(m_+^2, m_-^2)$ - Results

Resonance	Amplitude	Phase (°)	Fraction
$K_S\sigma_1$	1.57 ± 0.10	214 ± 4	9.8%
$K_S\rho^0$	1.0 (fixed)	0 (fixed)	21.6%
$K_S\omega$	0.0310 ± 0.0010	113.4 ± 1.9	0.4%
$K_Sf_0(980)$	0.394 ± 0.006	207 ± 3	4.9%
$K_S\sigma_2$	0.23 ± 0.03	210 ± 13	0.6%
$K_Sf_2(1270)$	1.32 ± 0.04	348 ± 2	1.5%
$K_Sf_0(1370)$	1.25 ± 0.10	69 ± 8	1.1%
$K_S\rho^0(1450)$	0.89 ± 0.07	1 ± 6	0.4%
$K^*(892)^+\pi^-$	1.621 ± 0.010	131.7 ± 0.5	61.2%
$K^*(892)^-\pi^+$	0.154 ± 0.005	317.7 ± 1.6	0.55%
$K^*(1410)^+\pi^-$	0.22 ± 0.04	120 ± 14	0.05%
$K^*(1410)^-\pi^+$	0.35 ± 0.04	253 ± 6	0.14%
$K_0^*(1430)^+\pi^-$	2.15 ± 0.04	348.7 ± 1.1	7.4%
$K_0^*(1430)^-\pi^+$	0.52 ± 0.04	89 ± 4	0.43%
$K_2^*(1430)^+\pi^-$	1.11 ± 0.03	320.5 ± 1.8	2.2%
$K_2^*(1430)^-\pi^+$	0.23 ± 0.02	263 ± 7	0.09%
$K^*(1680)^+\pi^-$	2.34 ± 0.26	110 ± 5	0.36%
$K^*(1680)^-\pi^+$	1.3 ± 0.2	87 ± 11	0.11%
nonresonant	3.8 ± 0.3	157 ± 4	9.7%

Systematic Errors

Source	$B^\pm \to DK^\pm$			$B^\pm \to D^*K^\pm$		
	Δr_B	$\Delta\phi_3$	$\Delta\delta_B$	Δr_B	$\Delta\phi_3$	$\Delta\delta_B$
Background shape	0.027	5.7°	4.1°	0.014	3.1°	5.3°
Background fraction	0.006	0.2°	1.0°	0.005	0.7°	1.4°
Efficiency shape	0.012	4.9°	2.4°	0.002	3.5°	1.0°
Momentum resolution	0.002	0.3°	0.3°	0.002	1.7°	1.4°
Control sample bias	0.004	10.2°	10.2°	0.004	9.9°	9.9°
Total	0.030	12.7°	11.3°	0.016	11.1°	11.4°

Model Uncertainty

$$f(m_+^2, m_-^2) = \left| f(m_+^2, m_-^2) \right| e^{i\phi(m_+^2, m_-^2)}$$

- Fit to flavour tagged D sample measures $\left| f(m_+^2, m_-^2) \right|$

  BUT $\phi(m_+^2, m_-^2)$ model-dependent

- Estimate model uncertainty by varying model

Fit model	$(\Delta r_B)_{\text{max}}$	$(\Delta \phi_3)_{\text{max}}$	$(\Delta \delta_B)_{\text{max}}$
Meson formfactors $F_r = F_D = 1$	0.01	3.1°	3.3°
Constant BW width $\Gamma(q^2)$	0.02	4.7°	9.0°
Only K^*, ρ, ω, f_0 non-resonant	0.03	9.9°	18.2°
Total	0.04	11°	21°

- Consider CP-tagged D mesons decaying to $K_S\pi^+\pi^-$

  $\longrightarrow$ amplitude is $f(m_+^2, m_-^2) \pm f(m_-^2, m_+^2)$

- FUTURE: use CP tagged D mesons from $c\tau$ factory ($\psi'' \rightarrow D\bar{D}$)

  $\hookrightarrow$ measure $\phi(m_+^2, m_-^2) \Rightarrow$ remove model uncertainty

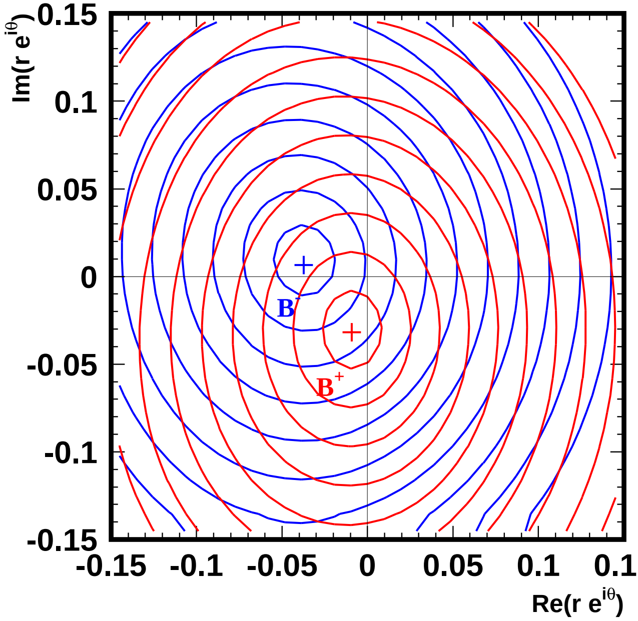
Test Samples

$357\ \mathrm{fb}^{-1}$

IN PREPARATION

Fit B, $\bar{B}$ samples separately, float $r_{B\pm}e^{i\theta_\pm}$, where $\theta_\pm = \delta_B \pm \phi_3$

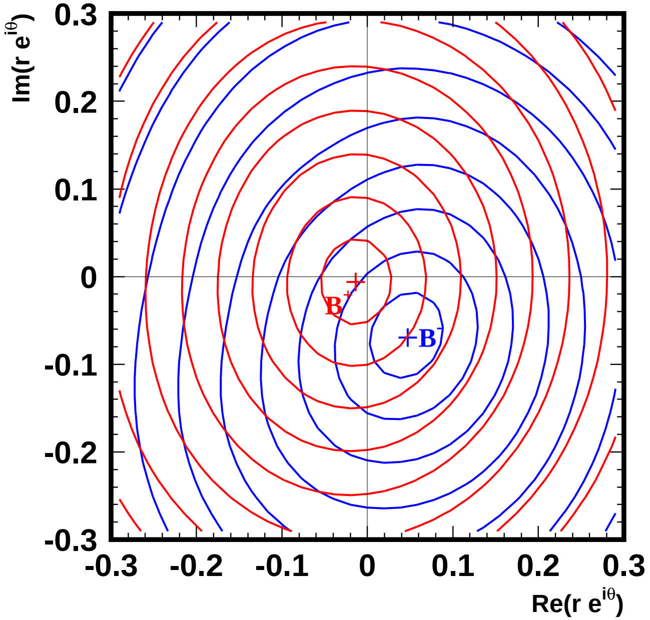
$B^\pm \to (K_S\pi^+\pi^-)_D\,\pi^\pm$
$(r \sim 0.01)$



3425 events

$r_{B-} = 0.047 \pm 0.018$
$\theta_- = 193^\circ \pm 24^\circ$
$r_{B+} = 0.039 \pm 0.021$
$\theta_- = 240^\circ \pm 28^\circ$

$B^\pm \to ((K_S\pi^+\pi^-)_D\,\pi^0)_{D^*}\,\pi^\pm$
$(r_B \sim 0.01)$



641 events

$r_{B-} = 0.086 \pm 0.049$
$\theta_- = 280^\circ \pm 30^\circ$
$r_{B+} = 0.015 \pm 0.042$
$\theta_- = 170^\circ \pm 186^\circ$

$B^- \to D_{CP}^{(*)} K^-$ — Observables

- Reconstruct $D^{(*)}$ mesons in CP even ($D_1^{(*)}$), CP odd ($D_2^{(*)}$) and flavour-specific favoured ($D_{\text{fav}}^{(*)}$) decay modes

- CP asymmetries

$$A_{D_{1,2}^{(*)}K^-} = \frac{\Gamma\left(B^- \to D_{1,2}^{(*)}K^-\right) - \Gamma\left(B^+ \to D_{1,2}^{(*)}K^+\right)}{\Gamma\left(B^- \to D_{1,2}^{(*)}K^-\right) + \Gamma\left(B^+ \to D_{1,2}^{(*)}K^+\right)}$$

$$\boxed{A_{D_1^{(*)}K^-} = \frac{2r_B \sin(\delta_B)\sin(\phi_3)}{1+{r_B}^2+2r_B\cos(\delta_B)\cos(\phi_3)} \quad A_{D_2^{(*)}K^-} = \frac{-2r_B \sin(\delta_B)\sin(\phi_3)}{1+{r_B}^2-2r_B\cos(\delta_B)\cos(\phi_3)}}$$

- Charge averaged rates, normalized to $B^- \to D\pi^-$

$$\mathcal{R}_{1,2} = \left(\frac{\Gamma\left(B^- \to D_{1,2}^{(*)}K^-\right) + \Gamma\left(B^+ \to D_{1,2}^{(*)}K^+\right)}{\Gamma\left(B^- \to D_{\text{fav}}^{(*)}K^-\right) + \Gamma\left(B^+ \to D_{\text{fav}}^{(*)}K^+\right)}\right) \Big/ \left(\frac{\Gamma\left(B^- \to D_{1,2}^{(*)}\pi^-\right) + \Gamma\left(B^+ \to D_{1,2}^{(*)}\pi^+\right)}{\Gamma\left(B^- \to D_{\text{fav}}^{(*)}\pi^-\right) + \Gamma\left(B^+ \to D_{\text{fav}}^{(*)}\pi^+\right)}\right)$$

$$\boxed{\mathcal{R}_1 = 1 + {r_B}^2 + 2r_B\cos(\delta_B)\cos(\phi_3) \quad \mathcal{R}_2 = 1 + {r_B}^2 - 2r_B\cos(\delta_B)\cos(\phi_3)}$$

- Four observables, three unknowns . . .

  (r_B, δ_B) different for $B^\mp \to DK^\mp$, $B^\mp \to D^*K^\mp$

$B^- \to D_{CP}^{(*)}K^-$ — Summary

253 fb^{-1} BELLE-CONF-0443

- Extract CP asymmetries by fitting B^- and B^+ yields separately

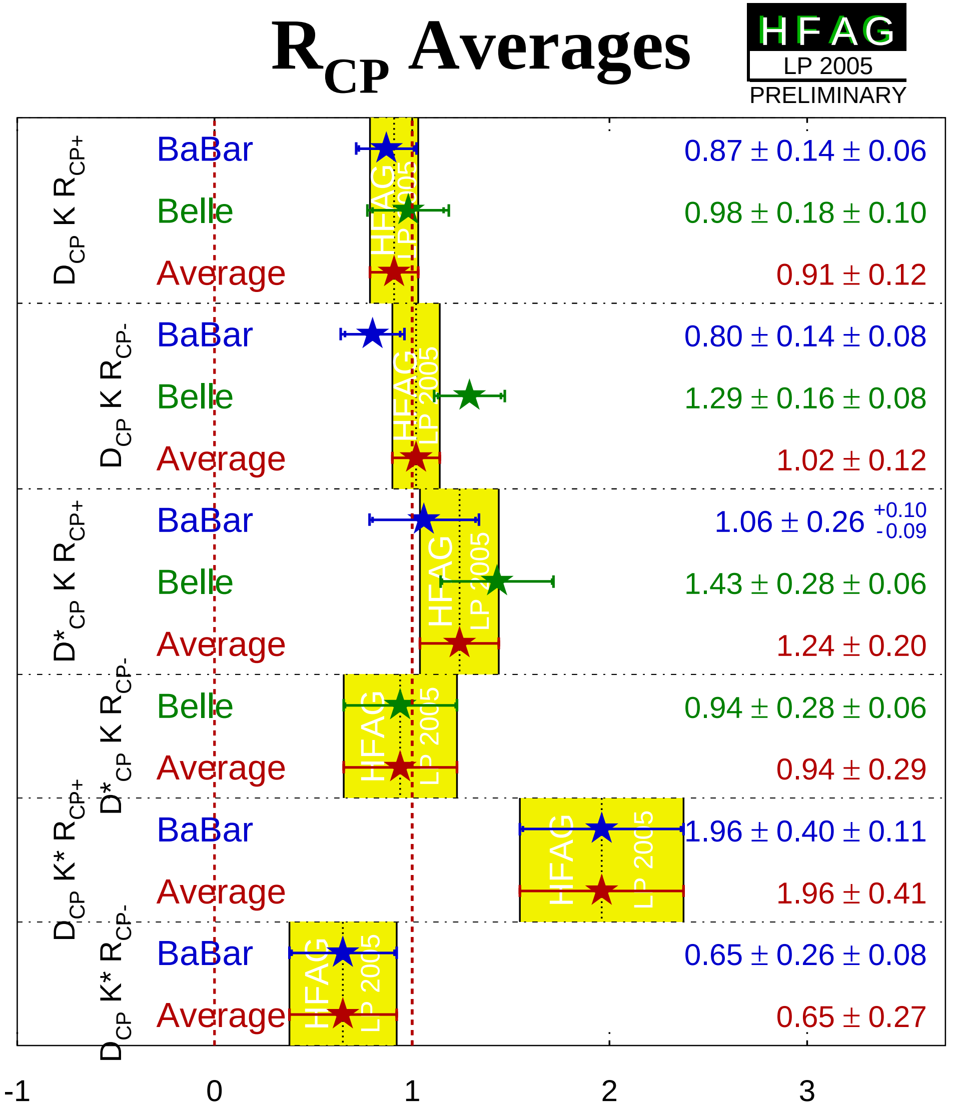
PRELIMINARY

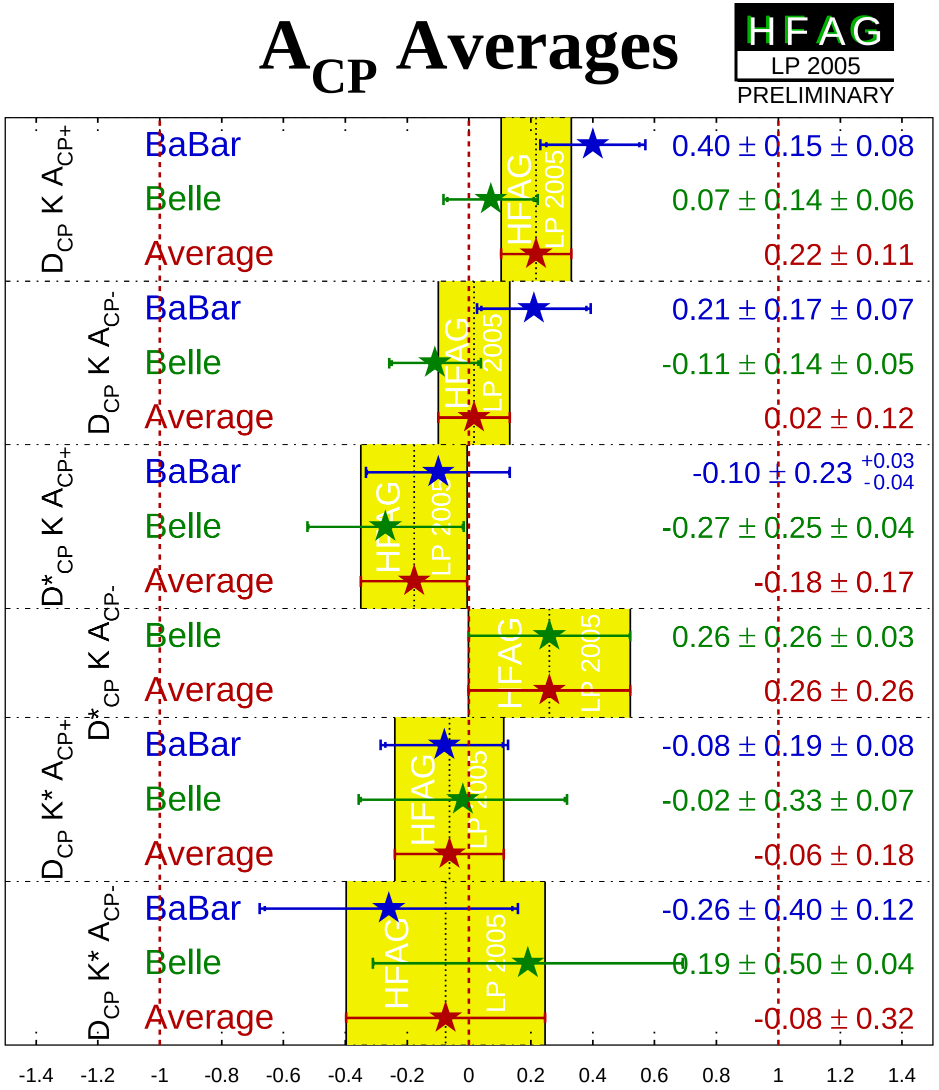
	$B^\mp \to DK^\mp$	$B^\mp \to D^*K^\mp$
A_1	$0.07 \pm 0.14(\text{stat}) \pm 0.06(\text{syst})$	$-0.27 \pm 0.25(\text{stat}) \pm 0.04(\text{syst})$
A_2	$-0.11 \pm 0.14(\text{stat}) \pm 0.05(\text{syst})$	$0.26 \pm 0.26(\text{stat}) \pm 0.03(\text{syst})$
$\mathcal{R}_1$	$0.98 \pm 0.18(\text{stat}) \pm 0.10(\text{syst})$	$1.43 \pm 0.28(\text{stat}) \pm 0.06(\text{syst})$
$\mathcal{R}_2$	$1.29 \pm 0.16(\text{stat}) \pm 0.08(\text{syst})$	$0.94 \pm 0.28(\text{stat}) \pm 0.06(\text{syst})$

- First observations of $B^\mp \to D^*_{1,2}K^\mp$ . . .

  and first measurements of $A_{1,2}$ in $D^*_{CP}K^\mp$ system

World Averages





New $B^- \to \left[K^+\pi^-\right]_D K^-$ Analysis

PRELIMINARY

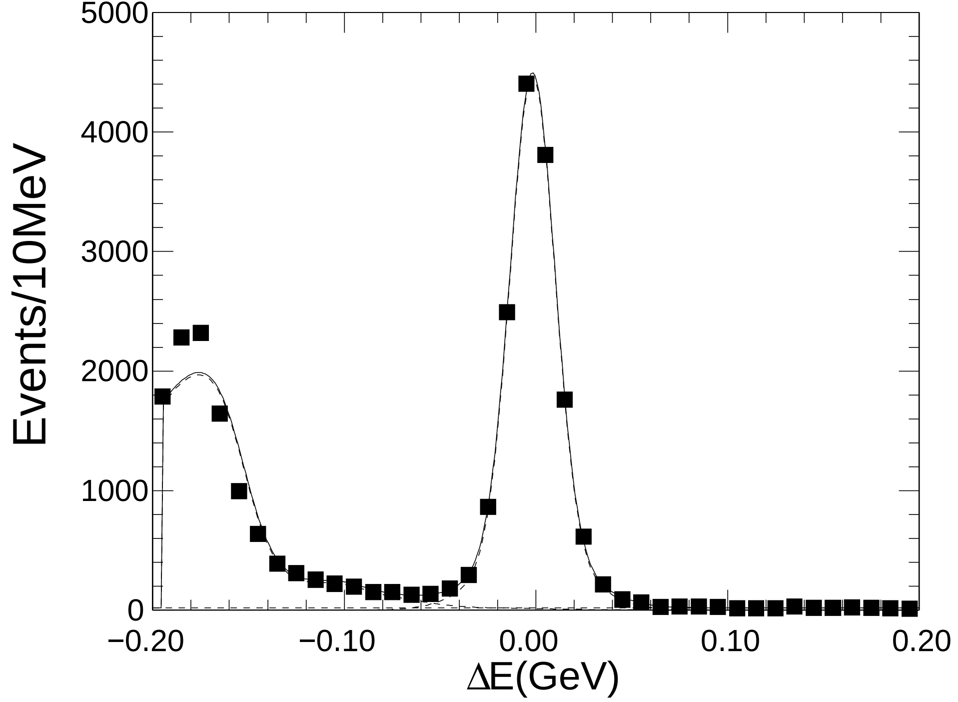
- Use 386 million $B\bar{B}$ pairs
- Use improved continuum suppression
- Other minor changes from PRL 94, 091601 (2005)

New ADS Analysis — $B^{\mp} \to D\pi^{\mp}$

357 fb^{-1}

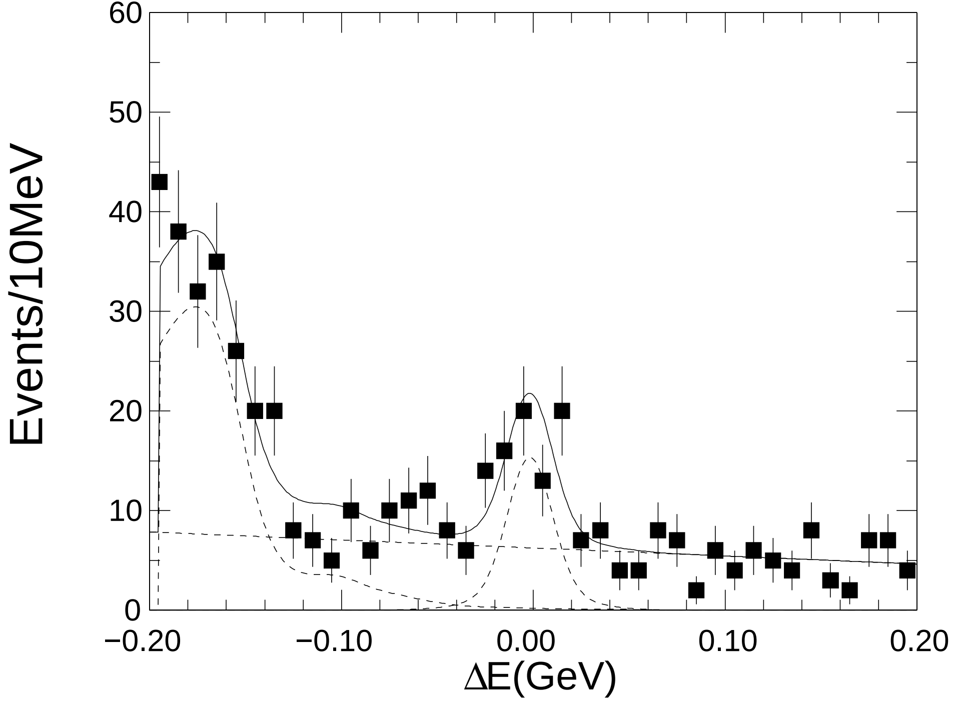
BELLE-CONF-0552

$$B^{\mp} \to \left[K^{\mp}\pi^{\pm}\right]_D \pi^{\mp}$$



14518 ± 125 signal events

$$B^{\mp} \to \left[K^{\pm}\pi^{\mp}\right]_D \pi^{\mp}$$

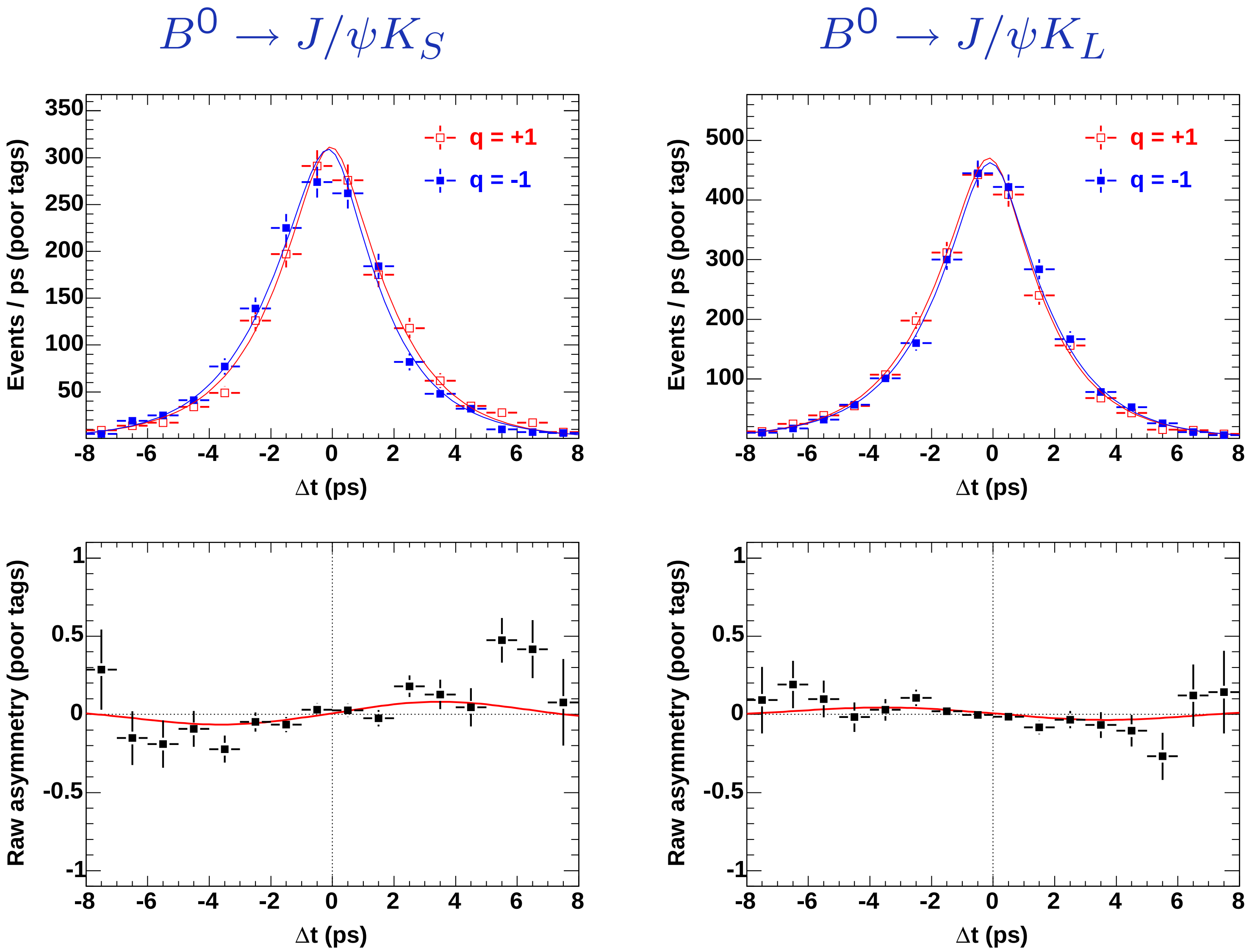


50^{+11}_{-10} signal events

$$\mathcal{R}_{D\pi} = (3.5\,^{+0.8}_{-0.7}\,(\text{stat}) \pm 0.3\,(\text{syst})) \times 10^{-3}$$

Consistent with previous Belle result

$B^0 \to J/\psi K^0$ — Δt Dependence (Poor quality tags)



$B^0 \to J/\psi K_S$

$B^0 \to J/\psi K_L$

357 fb^{-1}

BELLE-CONF-0569

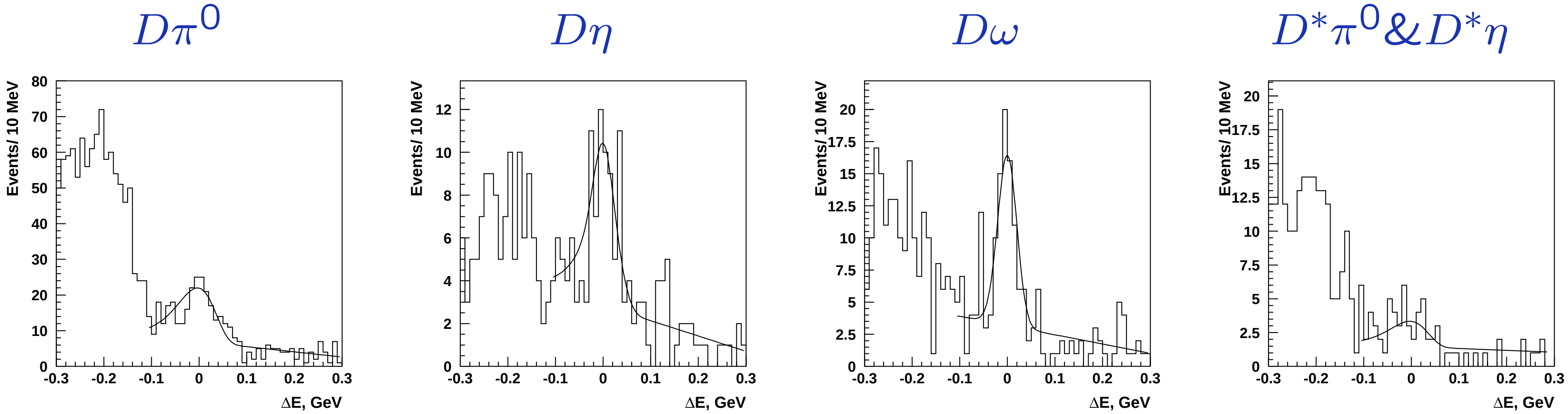
$S = +0.668 \pm 0.047(\mathrm{stat})$
$A = -0.021 \pm 0.034(\mathrm{stat})$

$S = -0.619 \pm 0.069(\mathrm{stat})$
$A = +0.049 \pm 0.039(\mathrm{stat})$

Resolving the $\sin(2\phi_1)$ Ambiguity

$357\ \mathrm{fb}^{-1}$ BELLE-CONF-0546

- Utilize *interference* between CP-even & CP-odd final states *eg.* $B^0 \to J/\psi K^{*0} \to J/\psi K_S\pi^0$ angular analysis
- New method uses analysis of (*eg.*) $D \to K_S\pi^+\pi^-$ Dalitz plot in $B^0 \to Dh^0$ decays ($h^0 = \pi^0, \eta, \ldots$)
- Similar to $B^+ \to DK^+$ analysis for ϕ_3
- Test SM prediction: $S_{b\to c\bar{c}s} \simeq S_{b\to c\bar{u}d}$

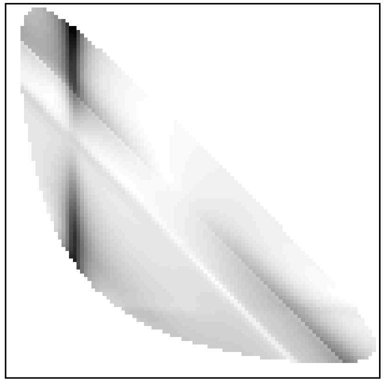


Description of the Method (Pictures)

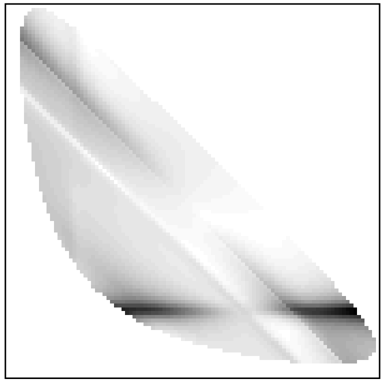
A. Bondar, T.G., P. Krokovny, PLB 624, 1 (2005)

(Terms of $e^{-|\Delta t|/\tau_{B^0}}$ have been dropped)

$\Gamma_{\bar{B}^0}(\Delta t) \propto \Bigg|$

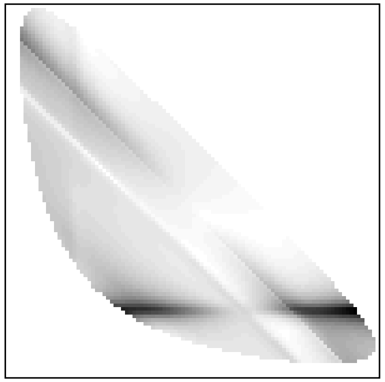


$\cos\left(\frac{\Delta m \Delta t}{2}\right) - i\Phi^*$

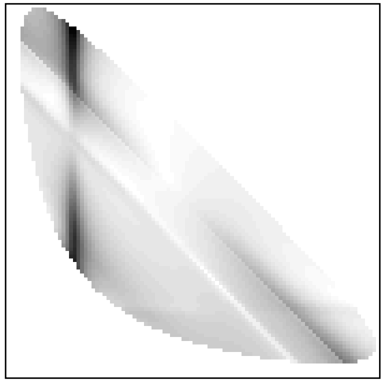


$\sin\left(\frac{\Delta m \Delta t}{2}\right)\Bigg|^2$

$\Gamma_{B^0}(\Delta t) \propto \Bigg|$



$\cos\left(\frac{\Delta m \Delta t}{2}\right) - i\Phi$



$\sin\left(\frac{\Delta m \Delta t}{2}\right)\Bigg|^2$

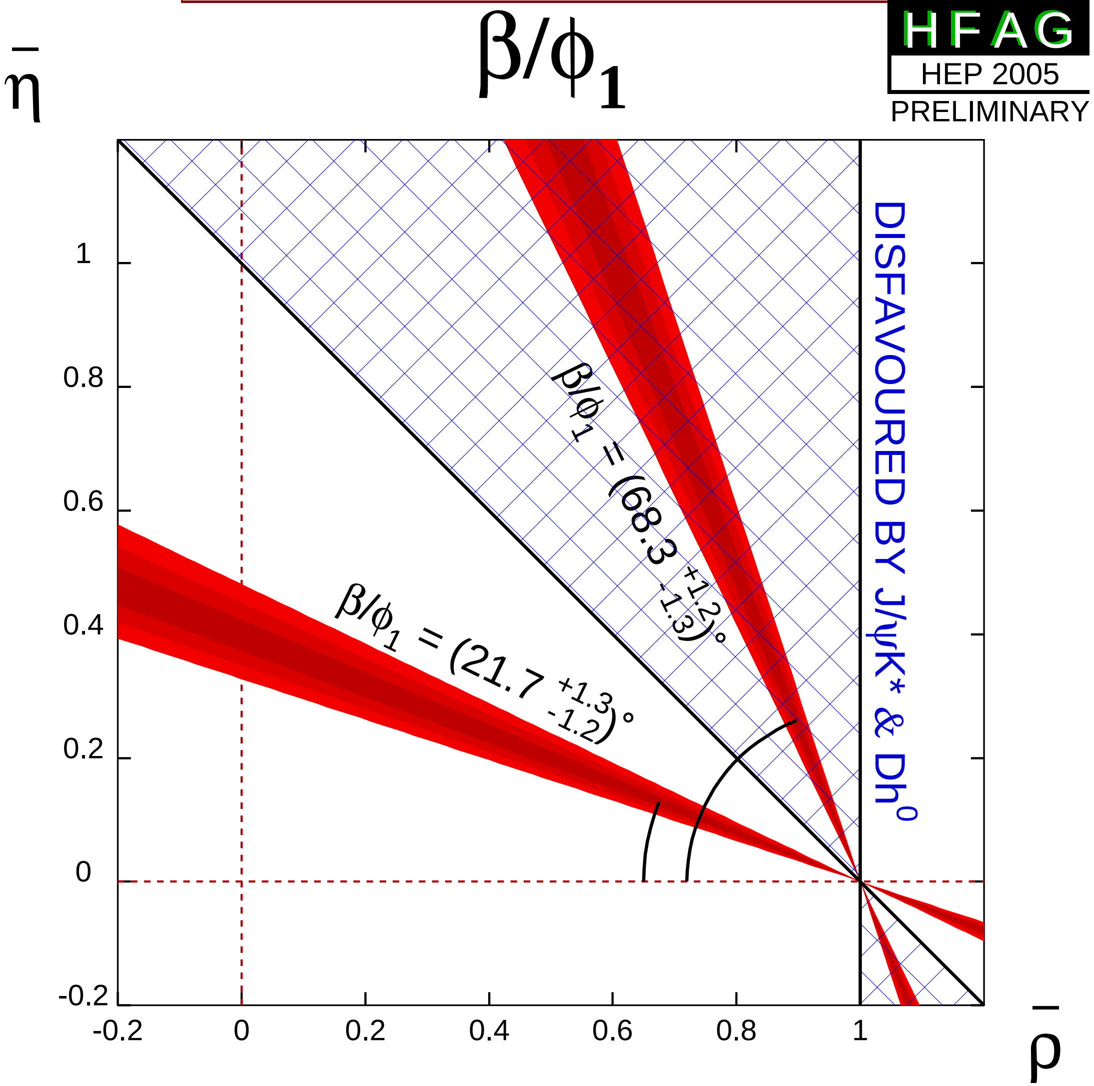
$$\Phi^* = e^{-i2\phi_1}\eta_{h^0}(-1)^l \qquad \Phi = e^{+i2\phi_1}\eta_{h^0}(-1)^l$$

$\sin(2\phi_1)$ — Constraint

357 fb^{-1}

BELLE-CONF-0546

$$\phi_1 = (16 \pm 21 \pm 11)^\circ$$



$B^0 \to \rho^+\rho^-$

$253\ \text{fb}^{-1}$ BELLE-CONF-0545

Initial attempts to extract ϕ_2 have focussed on $B^0 \to \pi^+\pi^-$.

However,

- penguin pollution found to be large
- $\mathcal{B}\left(B^0 \to \pi^0\pi^0\right) \approx 1.5 \times 10^{-6}$ (HFAG2005)
- large direct CP violation:
  $A\left(B^0 \to \pi^+\pi^-\right) = 0.56 \pm 0.12 \pm 0.06$ (Belle; PRL 95, 101801 (2005))

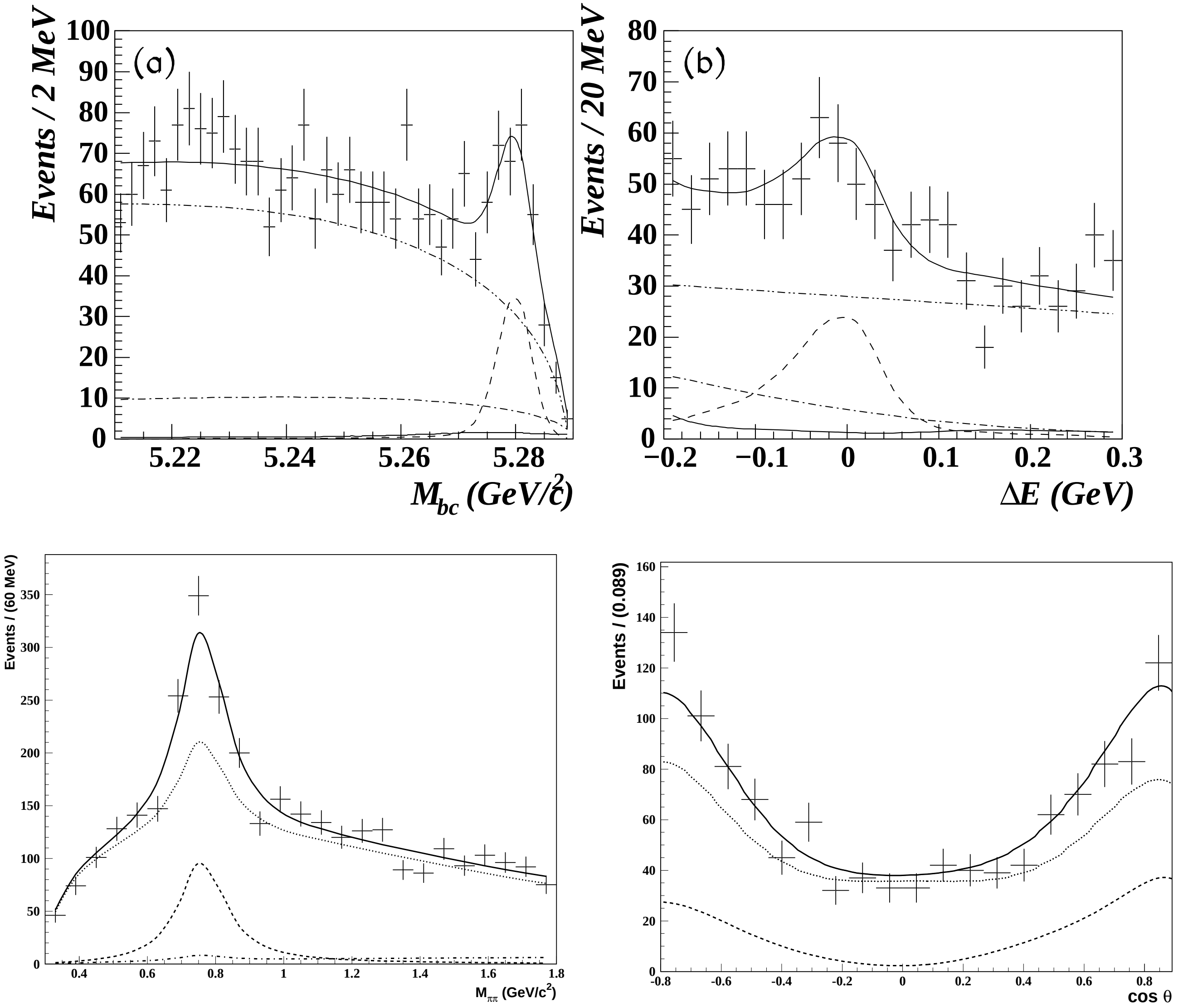
Isospin analysis possible; large statistical error & ambiguities

Recently, $B^0 \to \rho^+\rho^-$ found to be powerful for measurement of ϕ_2 because

- small penguin pollution ($\mathcal{B}\left(B^0 \to \rho^0\rho^0\right) < 1.1 \times 10^{-6}$ (BaBar))
- surprisingly (?) little nonresonant contribution
- $B^0 \to \rho^+\rho^-$ almost 100% longitudinally polarized
  (almost pure CP state . . . downside is cannot access interference)

$B^0 \to \rho^+\rho^-$

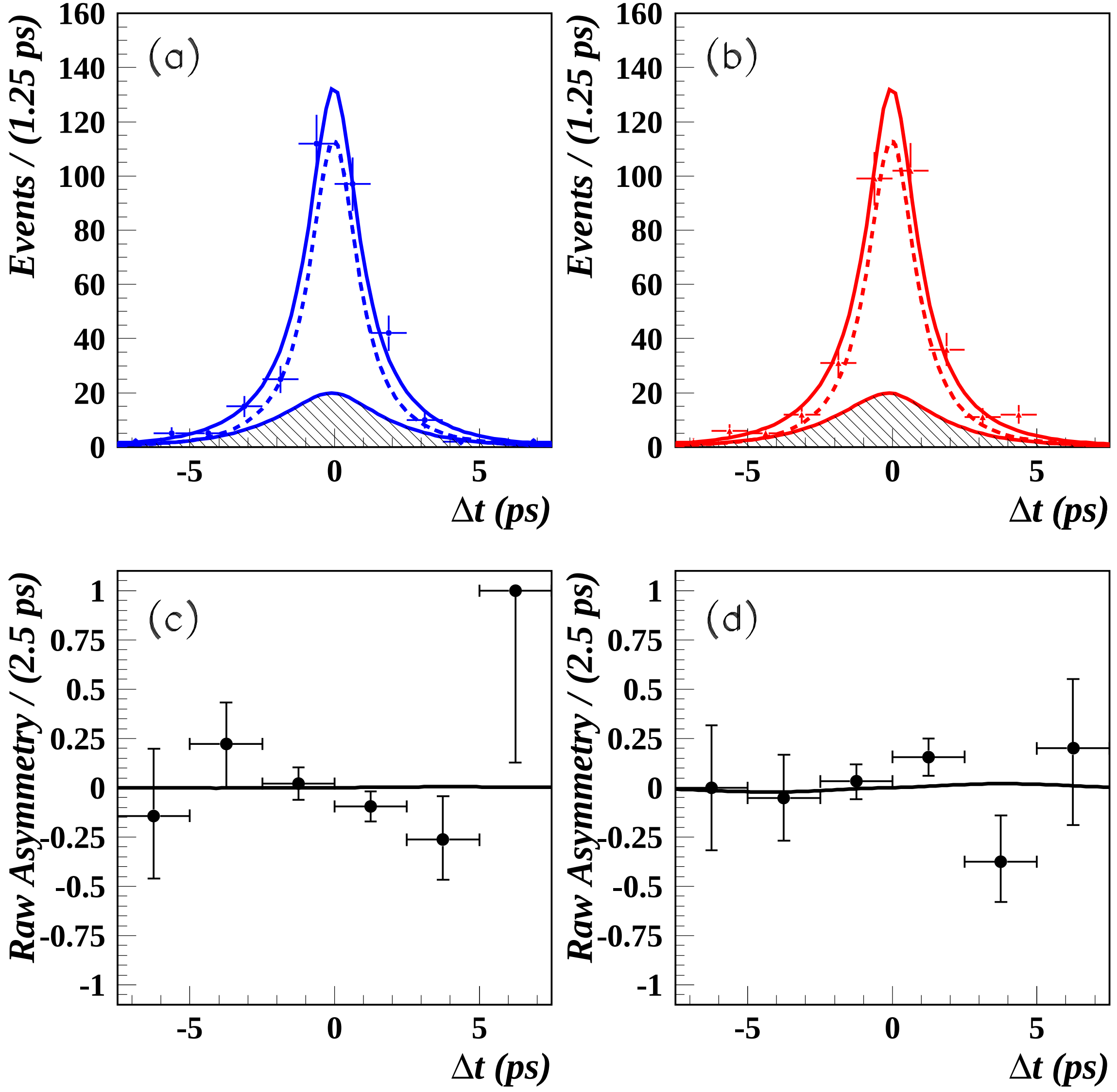
253 fb^{-1} BELLE-CONF-0545



142 ± 13 signal events $\quad f_{\text{long}} = 0.951^{+0.033}_{-0.039}{}^{+0.029}_{-0.031}$

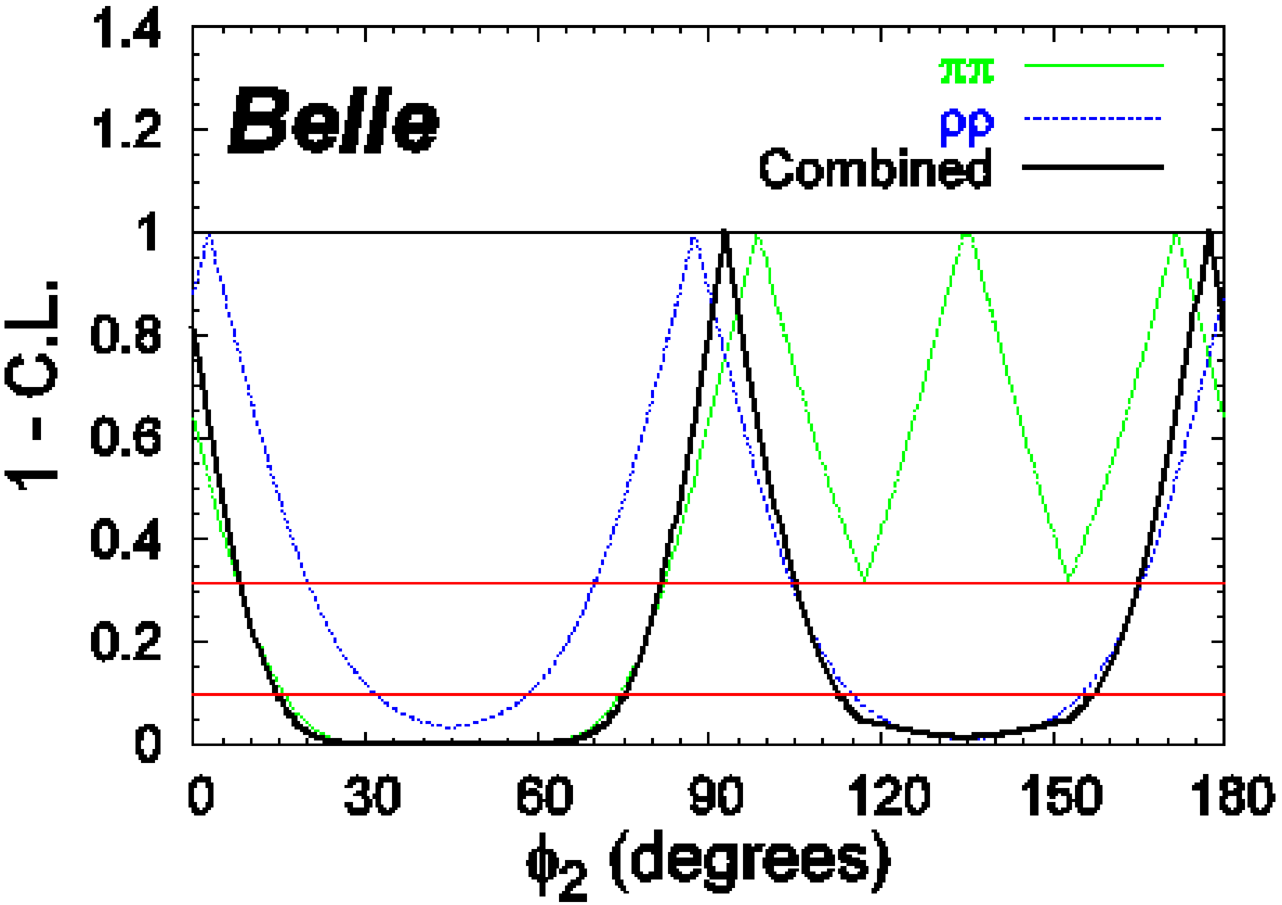
$B^0 \to \rho^+\rho^-$ — CP Fit

253 fb^{-1} BELLE-CONF-0545



$$S = 0.09 \pm 0.41 \pm 0.08 \qquad A = 0.00 \pm 0.039^{+0.10}_{-0.09}$$

Constraint on ϕ_2



253 fb^{-1}

BELLE-CONF-0501, BELLE-CONF-0545

$\rho\rho$ only

$\phi_2 = 87 \pm 17^\circ$

$\pi\pi$ & $\rho\rho$

$\phi_2 = 93^{+12}_{-11}{}^\circ$

(*cf.* $\phi_2 = 87 \pm 12^\circ$ from naïve $S = -\sin(2\phi_2)$ neglecting penguins)

Description of the Method (Equations)

A. Bondar *et al.*, hep-ph/0503174, to appear PLB

- Assume CPT, take $\Delta\Gamma = 0$, $|q/p| = 1$, $\arg(q/p) = 2\phi_1$
- Neglect Cabibbo-suppressed contribution (for now)
- Ignore mixing, CP violation in D system
- Amplitude description (terms of $e^{-|\Delta t|/2\tau_{B0}}$ dropped)

$$\left|\bar{B}^0(\Delta t)\right\rangle = \left|\bar{B}^0\right\rangle \cos(\Delta m \Delta t/2) - ie^{-i2\phi_1}\left|B^0\right\rangle \sin(\Delta m \Delta t/2)$$

$$\left|\tilde{D}_{\bar{B}^0}(\Delta t)\right\rangle = \left|D^0\right\rangle \cos(\Delta m \Delta t/2) - ie^{-i2\phi_1}\eta_{h^0}(-1)^l\left|\bar{D}^0\right\rangle \sin(\Delta m \Delta t/2)$$

$$M_{\bar{B}^0}(\Delta t) = f(m_-^2, m_+^2)\cos(\Delta m \Delta t/2) - ie^{-i2\phi_1}\eta_{h^0}(-1)^l f(m_+^2, m_-^2)\sin(\Delta m \Delta t/2)$$

$$\left|B^0(\Delta t)\right\rangle = \left|B^0\right\rangle \cos(\Delta m \Delta t/2) - ie^{+i2\phi_1}\left|\bar{B}^0\right\rangle \sin(\Delta m \Delta t/2)$$

$$\left|\tilde{D}_{B^0}(\Delta t)\right\rangle = \left|\bar{D}^0\right\rangle \cos(\Delta m \Delta t/2) - ie^{+i2\phi_1}\eta_{h^0}(-1)^l\left|D^0\right\rangle \sin(\Delta m \Delta t/2)$$

$$M_{B^0}(\Delta t) = f(m_+^2, m_-^2)\cos(\Delta m \Delta t/2) - ie^{+i2\phi_1}\eta_{h^0}(-1)^l f(m_-^2, m_+^2)\sin(\Delta m \Delta t/2)$$

$\eta_{h0} = CP$ eigenvalue of h^0 $\qquad$ $l =$ angular momentum

$B^0 \to D^{(*)} h^0$ Analysis

$357\ \mathrm{fb}^{-1}$

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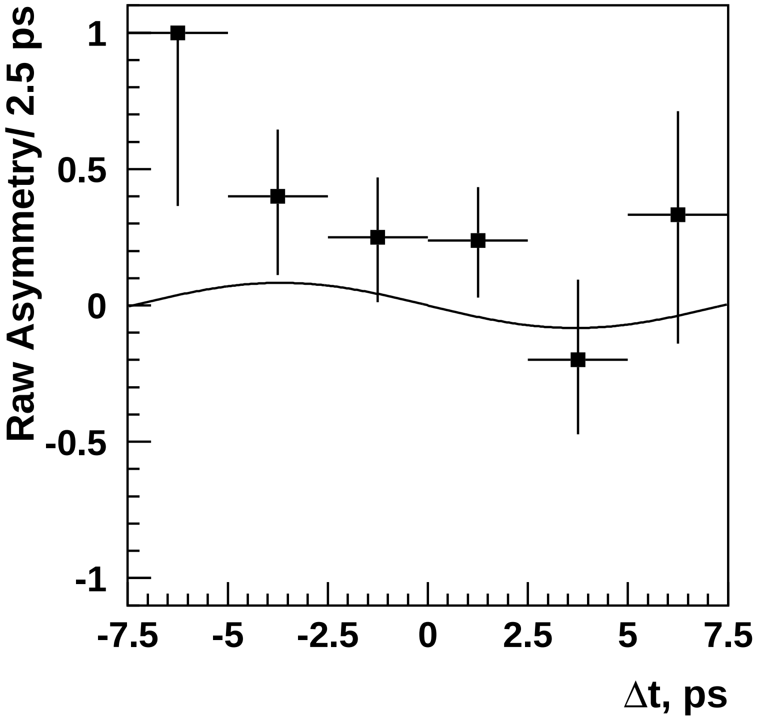
Process	N_{tot}	Efficiency (%)	N_{sig}	Purity
$D\pi^0$	265	8.7	157 ± 24	59%
$D\omega$	78	4.1	67 ± 10	86%
$D\eta$	97	3.9	58 ± 13	60%
$D^*\pi^0$,$D^*\eta$	52		27 ± 11	52%
Sum	492		309 ± 31	63%

Data fit results. Statistical errors from toy MC.

Final state	ϕ_1 fit result, °
$D\pi^0$	11 ± 26
$D\omega$, $D\eta$	28 ± 32
$D^*\pi^0$,$D^*\eta$	25 ± 35
Simultaneous fit	16 ± 21

Raw asymmetry.

$\left[K_S\rho^0\right]_D h^0$ candidates.



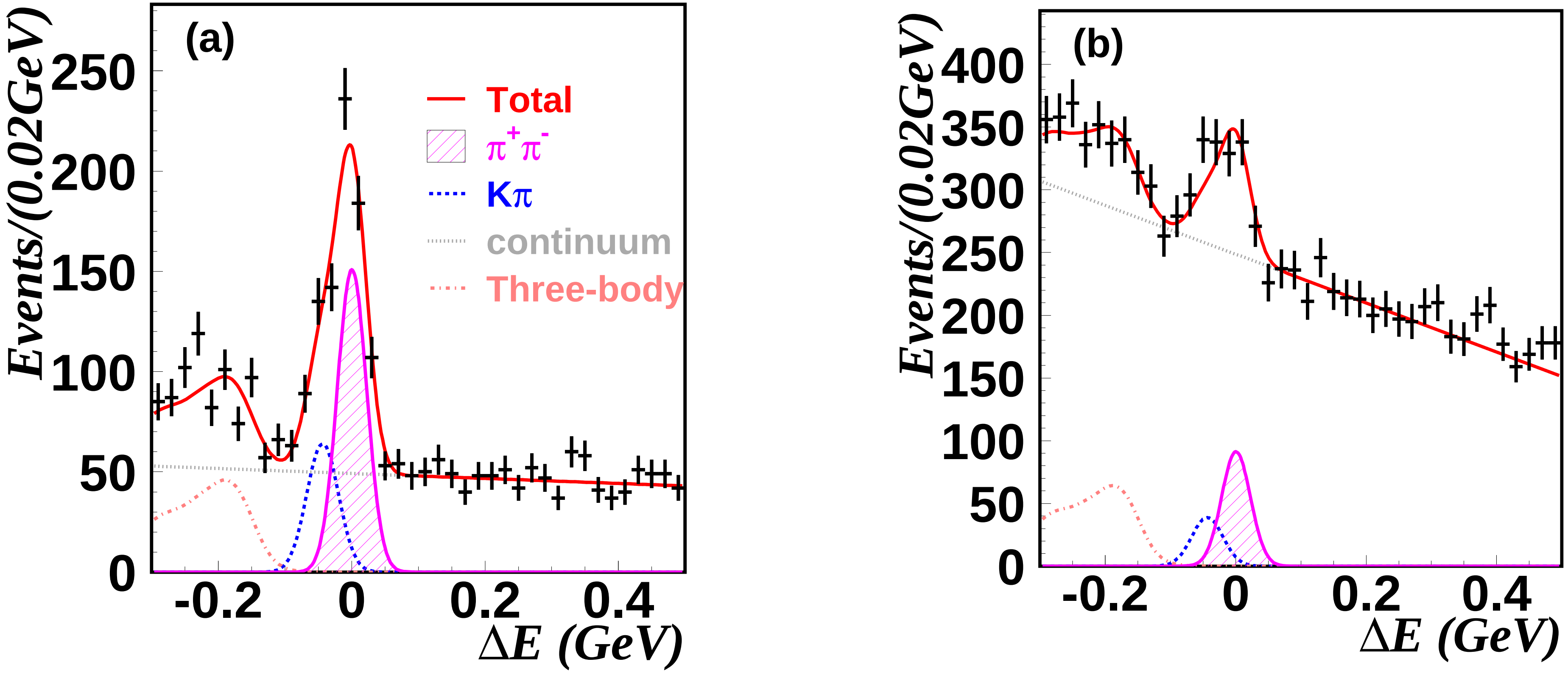
$B \to \pi^+\pi^-$ Candidates

$253\ \text{fb}^{-1}$ BELLE-CONF-0501

Categorize candidates based on level of $q\bar{q}$ background

High quality

Low quality



$B \to \pi^+\pi^-$ Analysis

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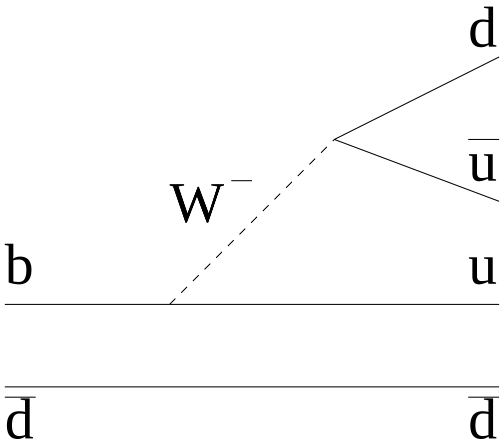
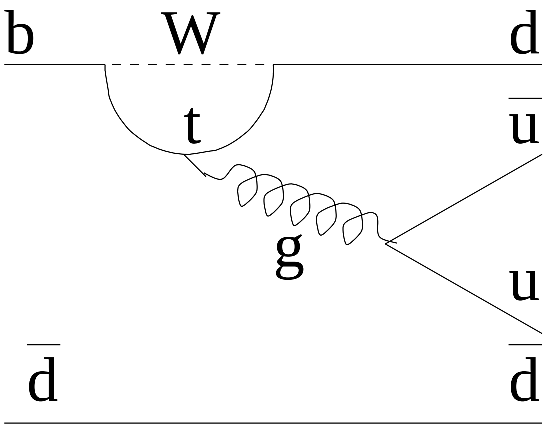
Contributions from tree and penguin amplitudes

tree contains V_{ub}



penguin contains V_{td}



- Small branching fraction ($\sim 4 \times 10^{-6}$)
- Large background from $e^+e^- \to q\bar{q} \quad (q = u, d, s, c)$
- Background from $B \to K^+\pi^-$

$B \to \pi^+\pi^-$ Fit Result

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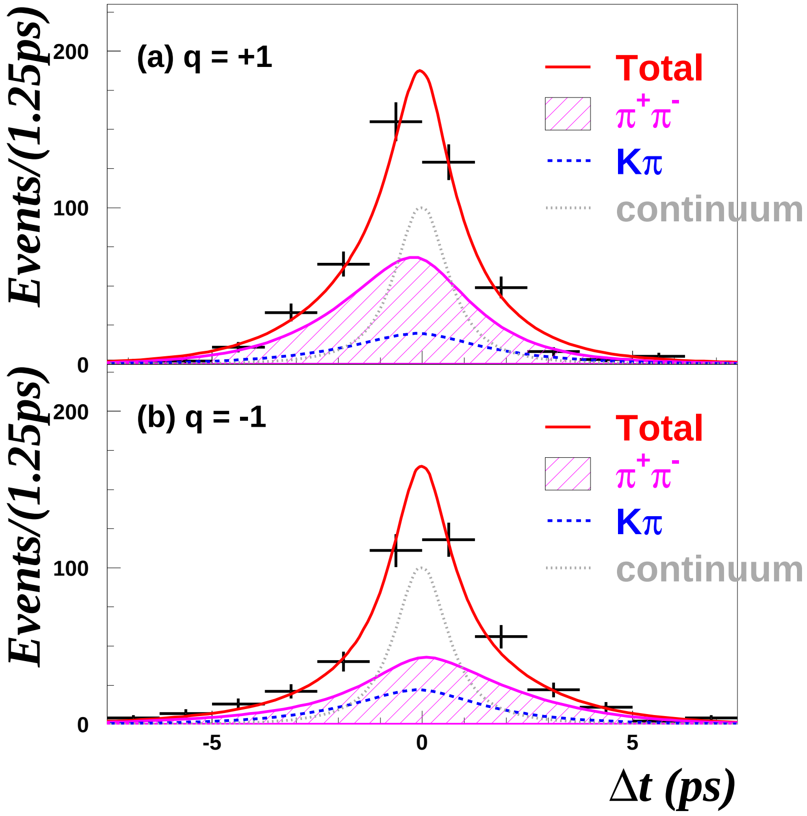
$\ast$ 2820 candidates $\ast$

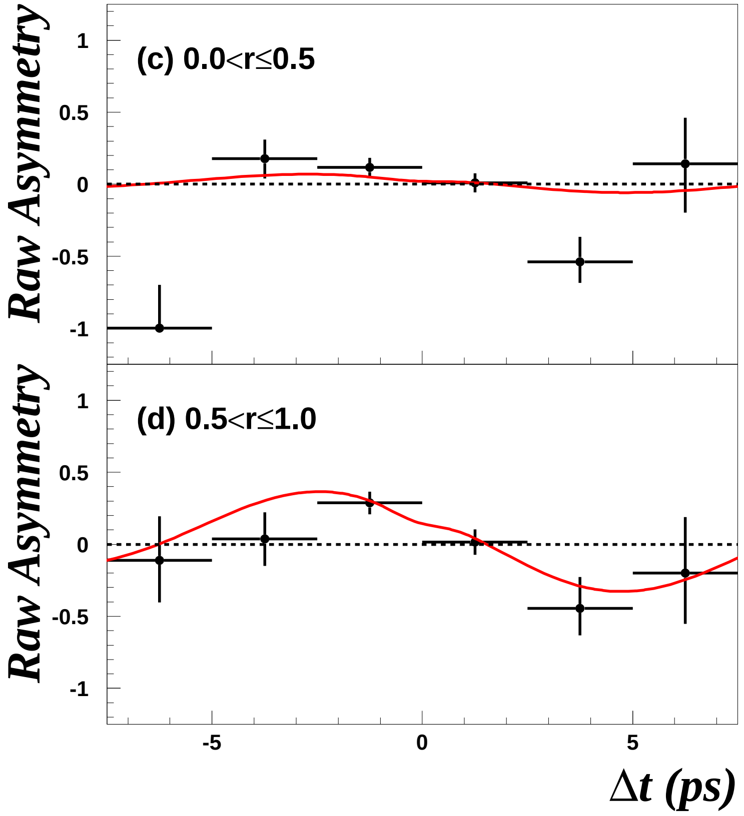
$\ast$ 666 ± 43 $\pi^+\pi^-$ signal events $\ast$

$$\boxed{S_{\pi^+\pi^-} = -0.67 \pm 0.16 \pm 0.06}$$

$$\boxed{A_{\pi^+\pi^-} = +0.56 \pm 0.12 \pm 0.06}$$

Plots for high quality events only





$B \to \pi^+\pi^-$

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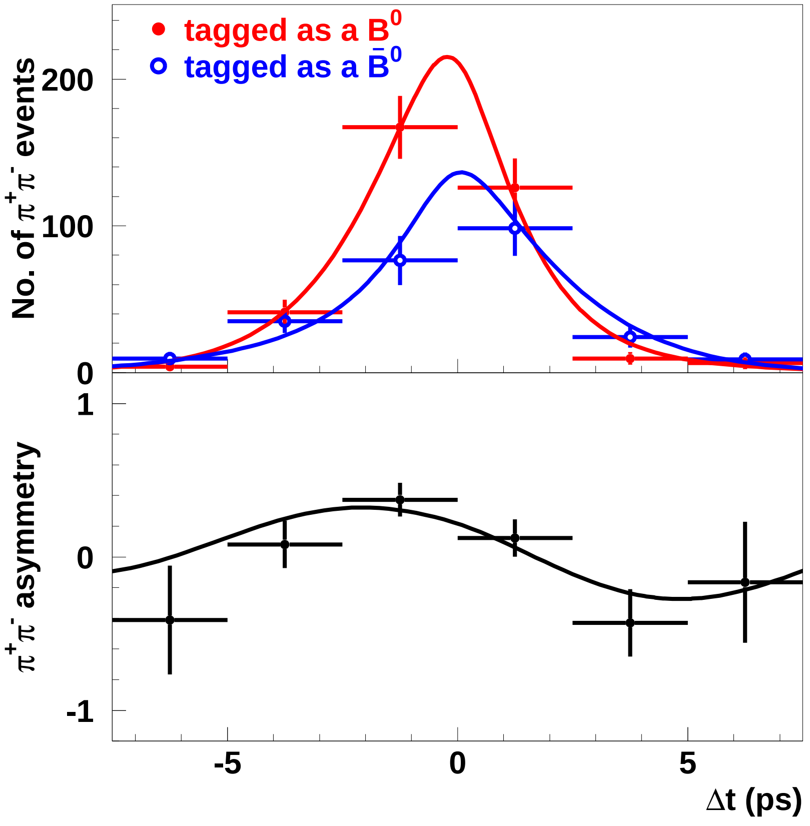
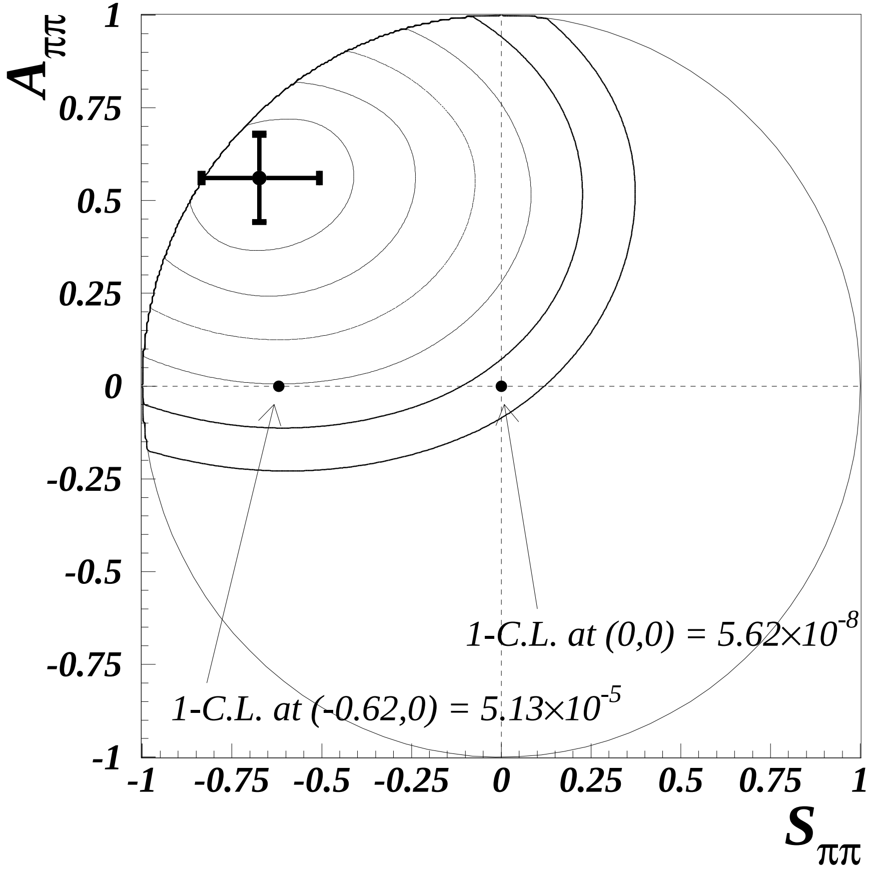
Yields from $M_{\rm bc}$—ΔE fits in bins of $(q, \Delta t)$





- CP violation significance $> 5\sigma$ (still)
- DIRECT CPV significance : 4σ

$B \to \pi^+\pi^-$: Extraction of ϕ_2

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- Due to large penguin contribution need isospin analysis to extract ϕ_2
- Such analyses are underway . . .
- Current limitation from knowledge of $B^0 \to \pi^0\pi^0$
  - branching fraction
  - direct CP asymmetry
- Other avenues for ϕ_2 ($\rho^\pm\pi^\mp$, $\rho^\pm\rho^\mp$, *etc.*) being explored

$B^0 \to \rho^0 \pi^0$

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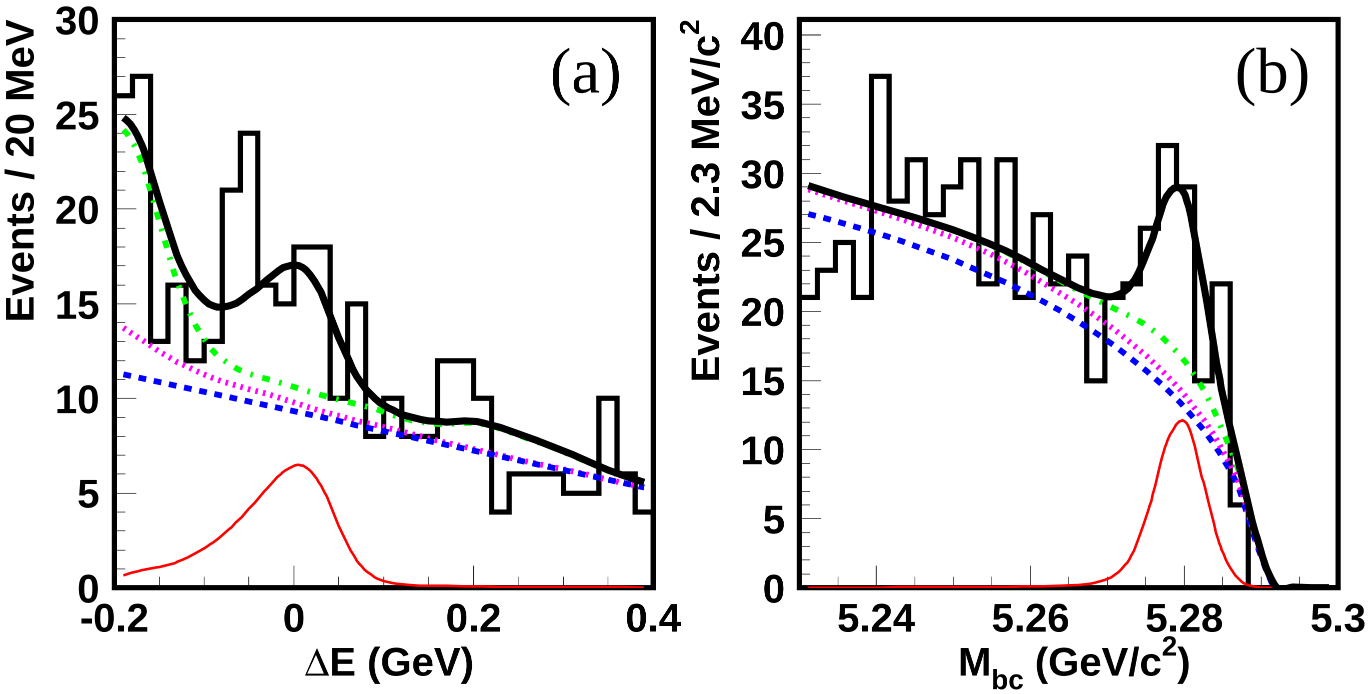
- Dalitz plot analysis of $B^0 \to \pi^+\pi^-\pi^0$ can measure ϕ_2 & resolve ambiguities
- Main contributions from $\rho^\pm\pi^\mp$, other contributions complicate the analysis



Significance: 4.2σ

$$\mathcal{B}\left(B^0 \to \rho^0\pi^0\right) = \left(3.12^{+0.88}_{-0.82}{}^{+0.60}_{-0.76}\right) \times 10^{-6}$$

$B^0 \to \rho^0\pi^0$

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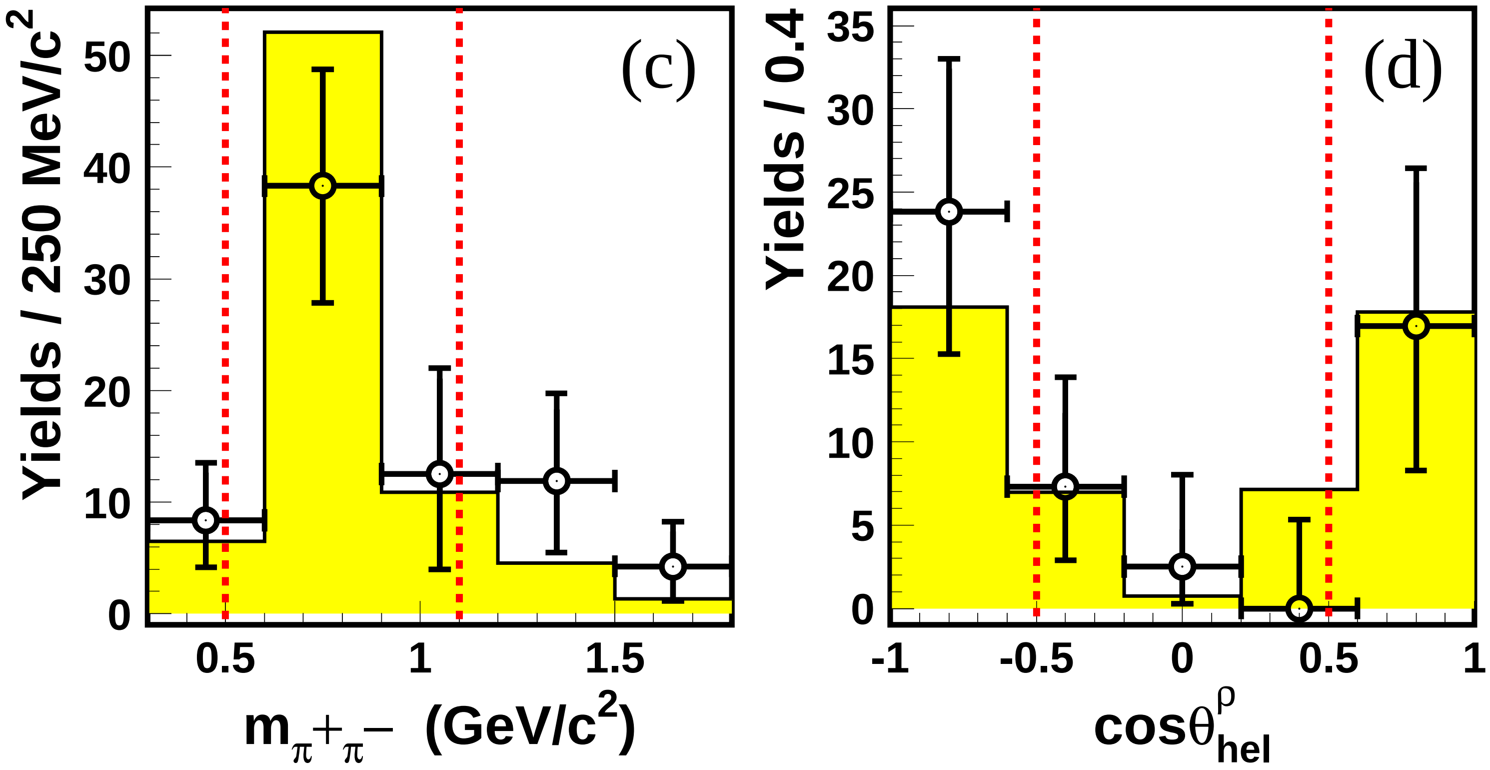
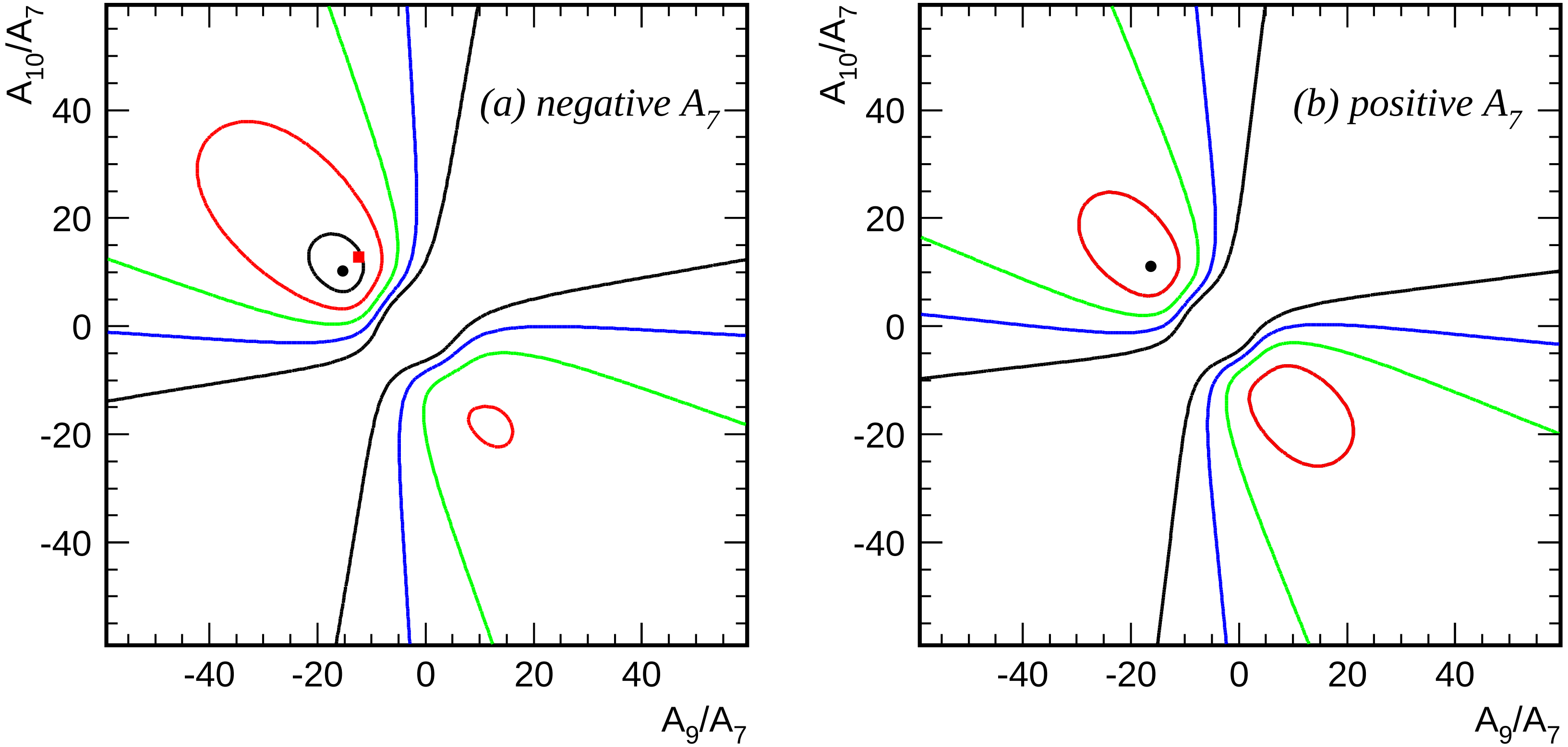


Belle: $B \rightarrow K^* l^+ l^-$ — F-B asymmetry



386 fb^{-1}

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$$A_9/A_7 = -15.3\,^{+3.4}_{-4.8} \pm 1.1$$

$$A_{10}/A_7 = 10.3\,^{+5.2}_{-3.8} \pm 1.8$$

$$A_9/A_7 = -16.3\,^{+3.7}_{-5.7} \pm 1.4$$

$$A_{10}/A_7 = 11.1\,^{+6.0}_{-3.9} \pm 2.4$$