Latest Results from Belle and Plans for a Super B Factory

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January 24, 2006

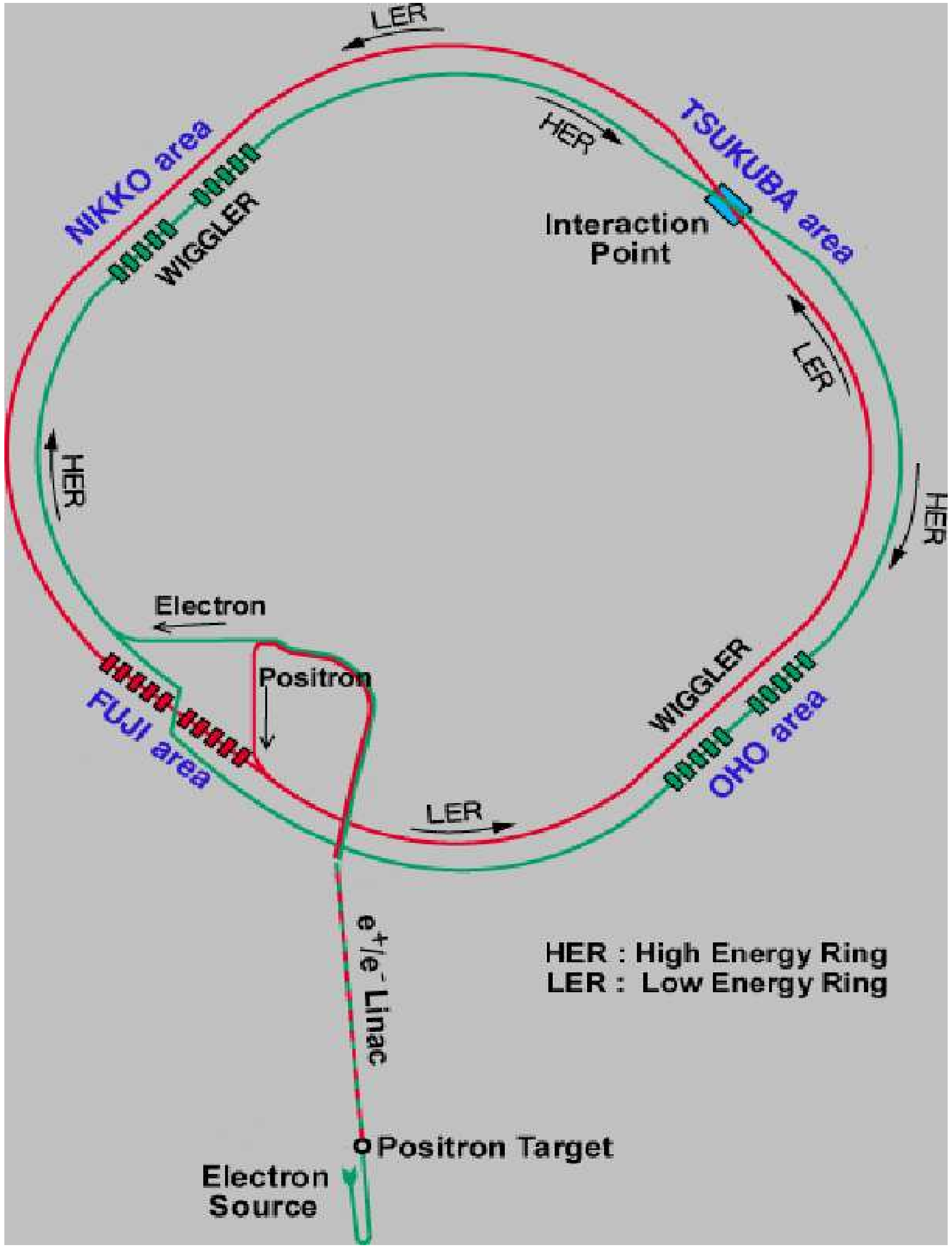
- KEK-B and Belle
- Summer 2005 highlights
  (`http://belle.kek.jp/conferences/CONF2005/`)
  - direct CP violation
  - measurements of UT angles
  - penguin dominated processes
- Super B Factory

International Collaboration: Belle

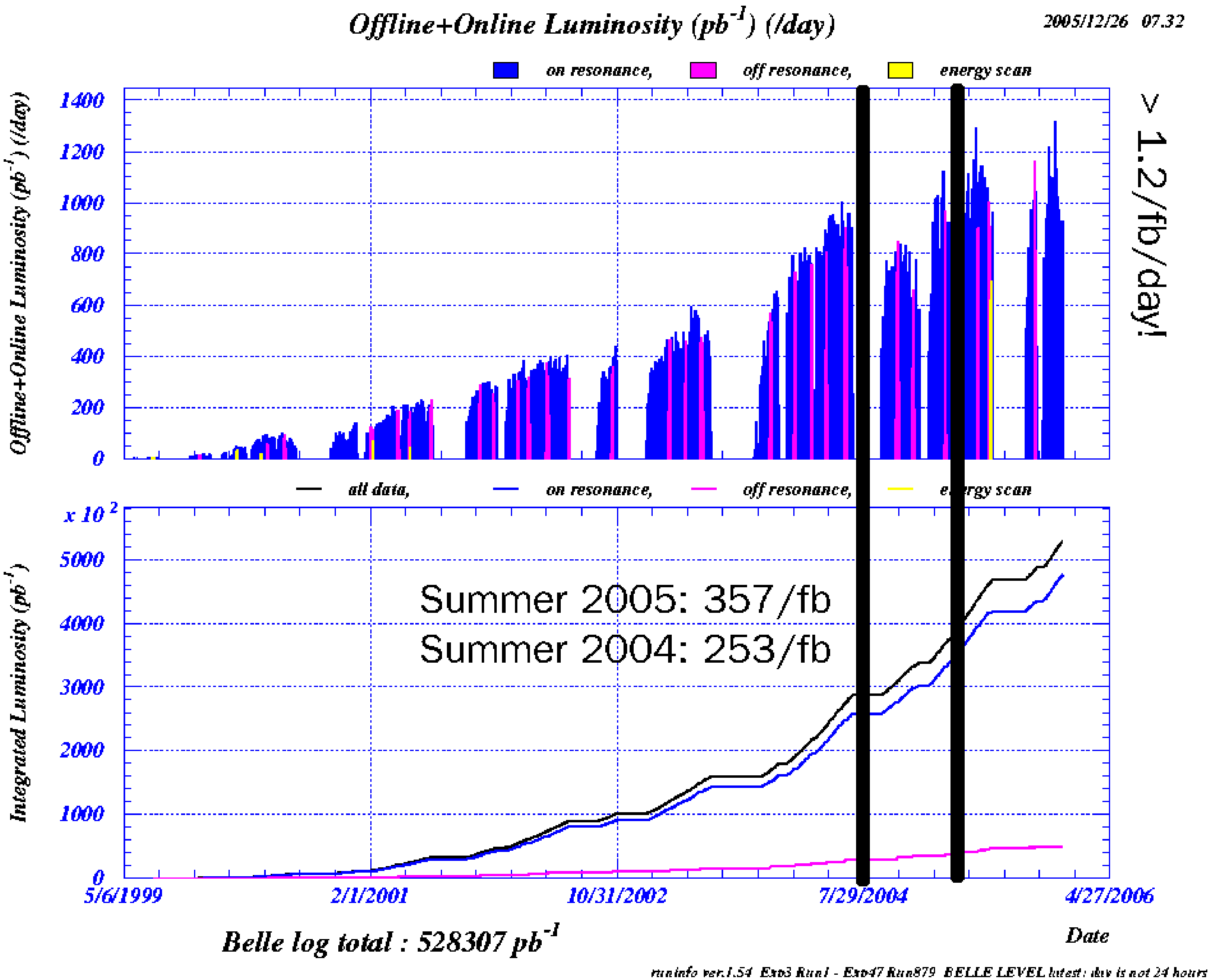
- Aomori U.
- BINP
- Chiba U.
- Chonnam Nat'l U.
- U. of Cincinnati
- Ewha Womans U.
- Frankfurt U.
- Gyeongsang Nat'l U.
- U. of Hawaii
- Hiroshima Tech.
- IHEP, Beijing
- IHEP, Moscow
- IHEP, Vienna
- ITEP
- Kanagawa U.
- KEK
- Korea U.
- Krakow Inst. of Nucl. Phys.
- Kyoto U.
- Kyungpook Nat'l U.
- 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

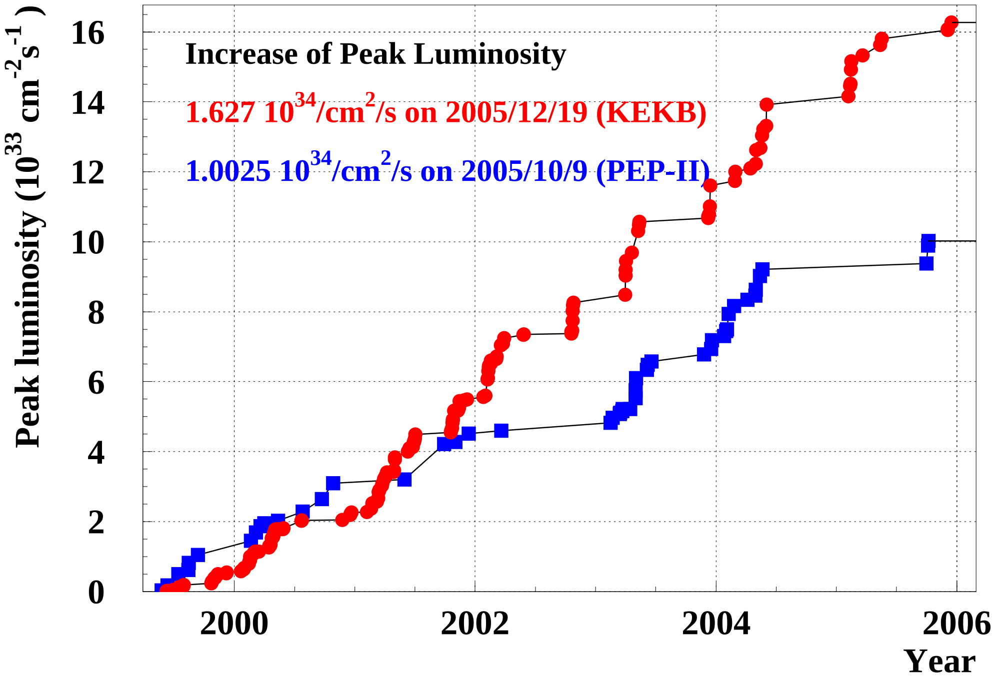
KEK

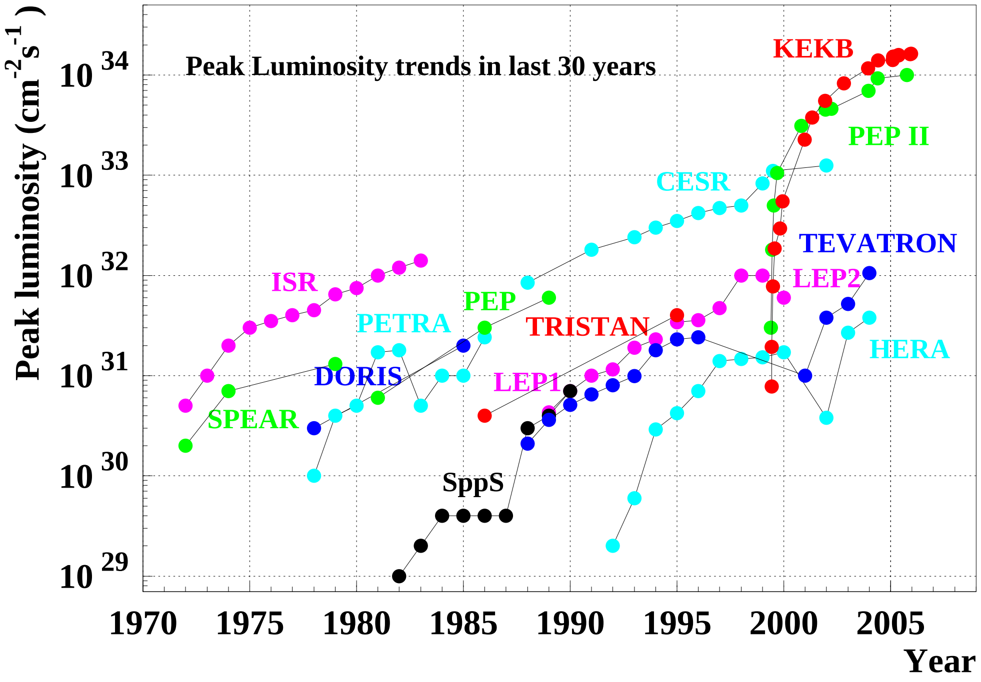

LER
HER
TSUKUBA area
NIKKO area
WIGGLER
Interaction Point
LER
HER
HER
Electron
Positron
WIGGLER
FUJI area
OHO area
LER
e+/e- Linac
HER : High Energy Ring
LER : Low Energy Ring
Positron Target
Electron Source

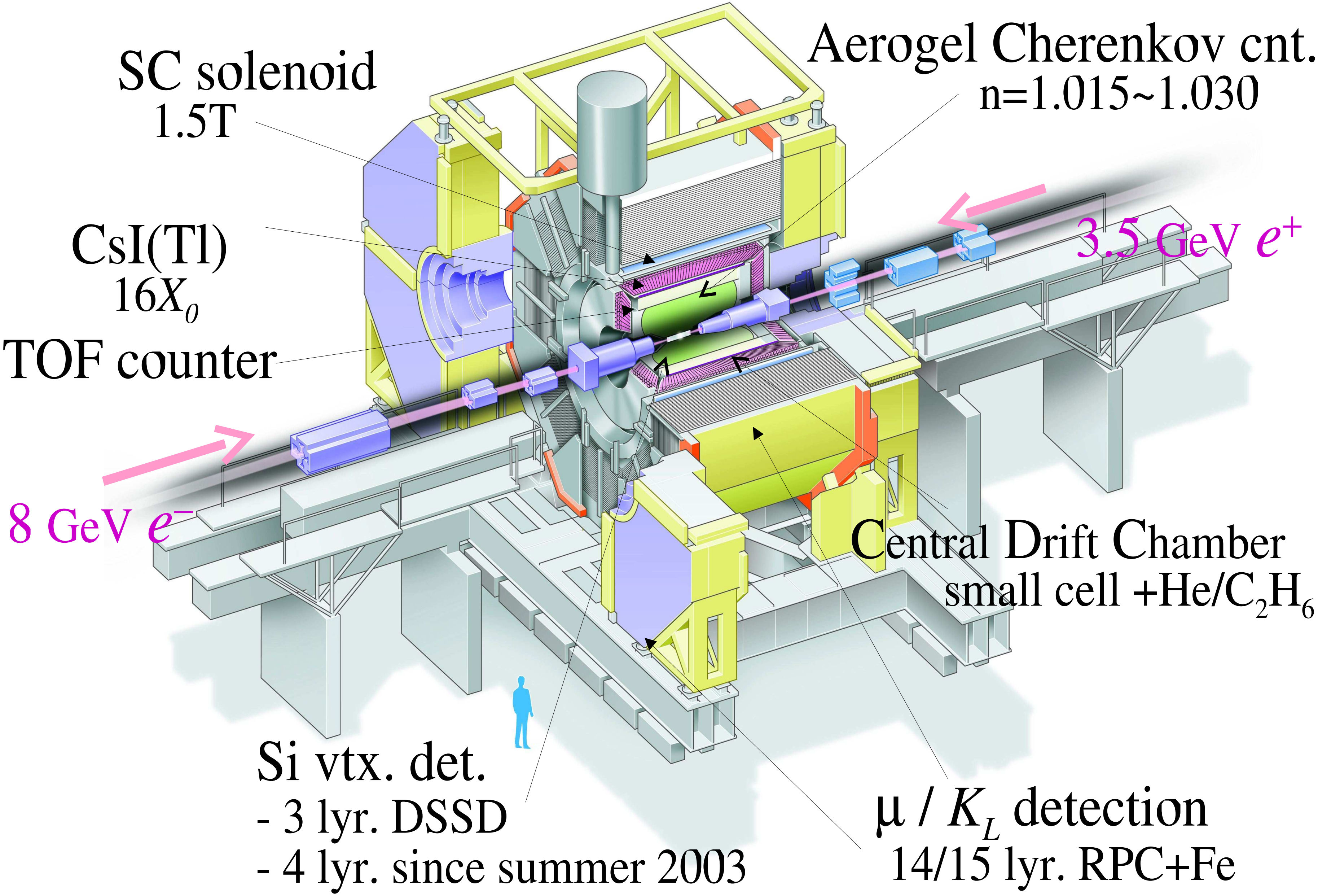
Integrated Luminosity

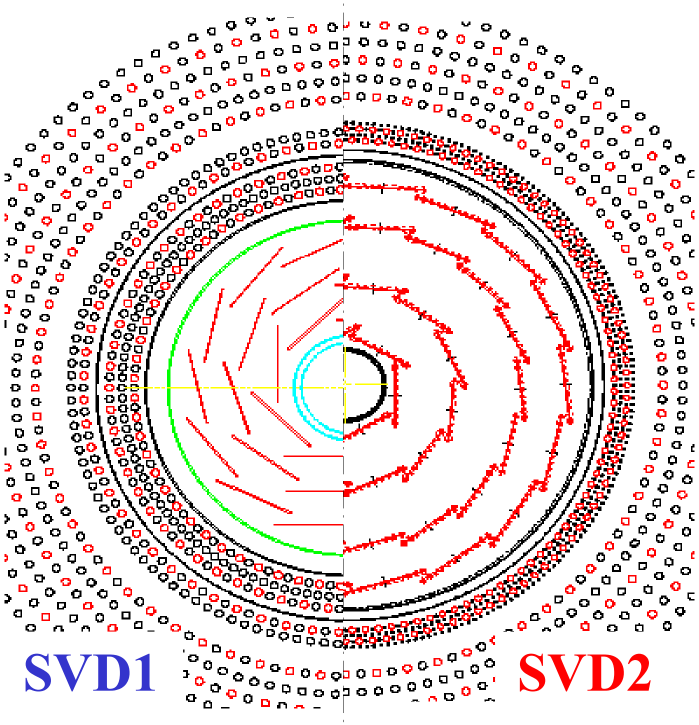


Luminosity Trends






SC solenoid
1.5T
Aerogel Cherenkov cnt.
n=1.015~1.030
CsI(Tl)
$16X_0$
TOF counter
3.5 GeV e^+
8 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



Number of silicon DSSDs

3 layers → 4 layers

Radius of beam pipe

$r = 2.0$ cm → $r = 1.5$ cm

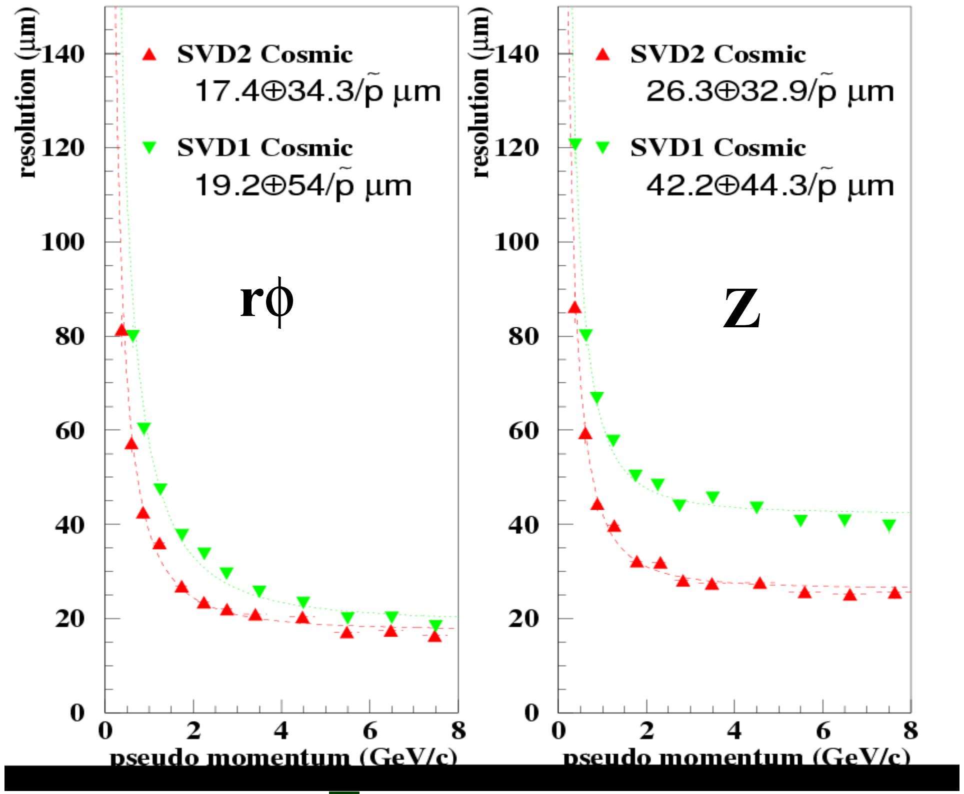
Radiation hardness

1 MRad → $>$ 20 MRad

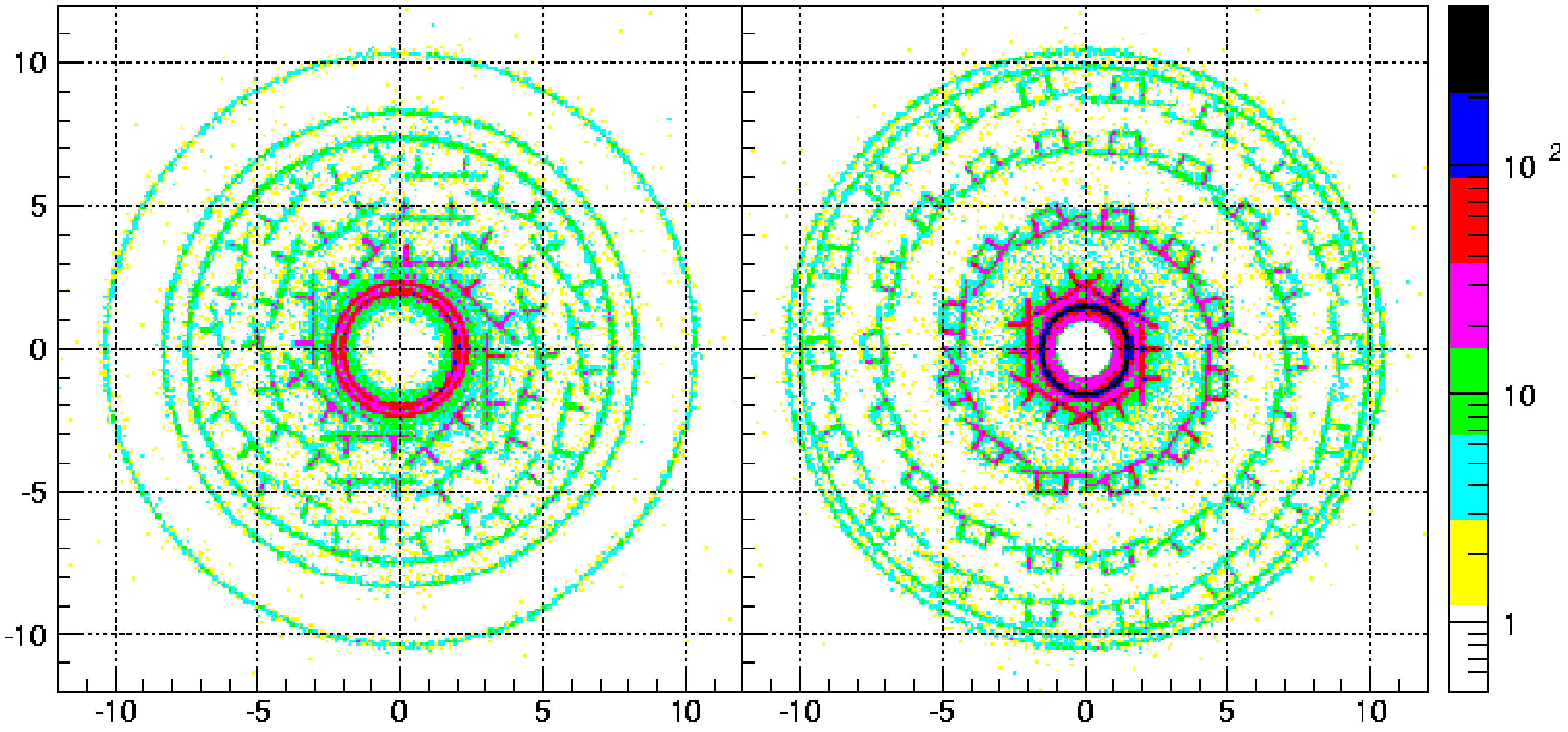
Laboratory polar angle coverage

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

IMPROVED RESOLUTION!



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



397 fb^{-1}

PLB 632, 173 (2006)

...no pentaquarks found

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

where A, λ, ρ, η are Wolfenstein parameters

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

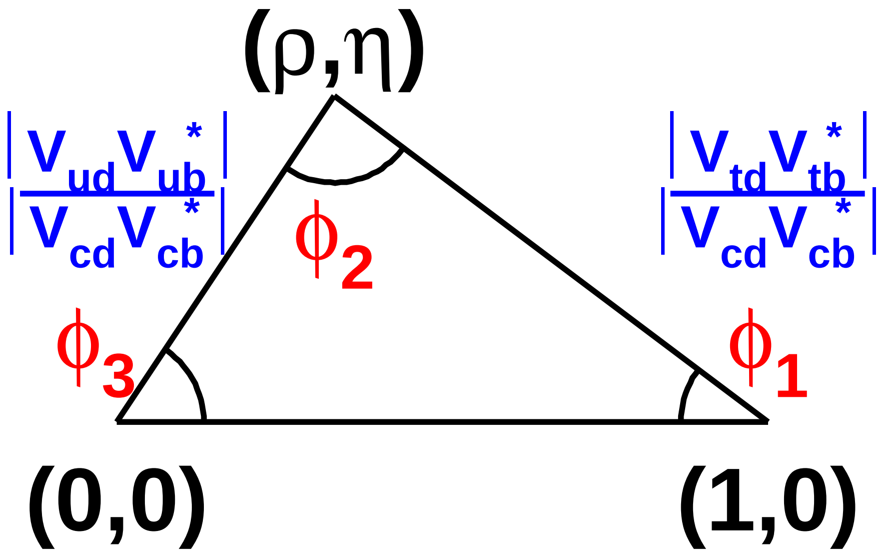
$$V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0$$

The Unitarity Triangle

$\phi_1 \leftrightarrow \beta$

$\phi_2 \leftrightarrow \alpha$

$\phi_3 \leftrightarrow \gamma$



The Purpose of the B Factory

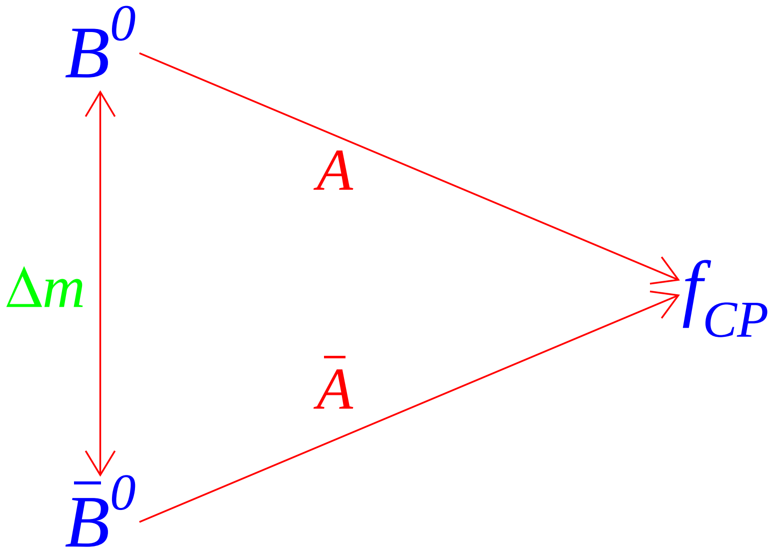
- Within the Standard Model, only B system has large CP violation
- Hadronic parameters (τ_B, Δm_d) $\Rightarrow$ CP effects accessible
- e^+e^- collisions at high luminosity
  - large data sample
  - clean environment

  $\rightsquigarrow$ 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

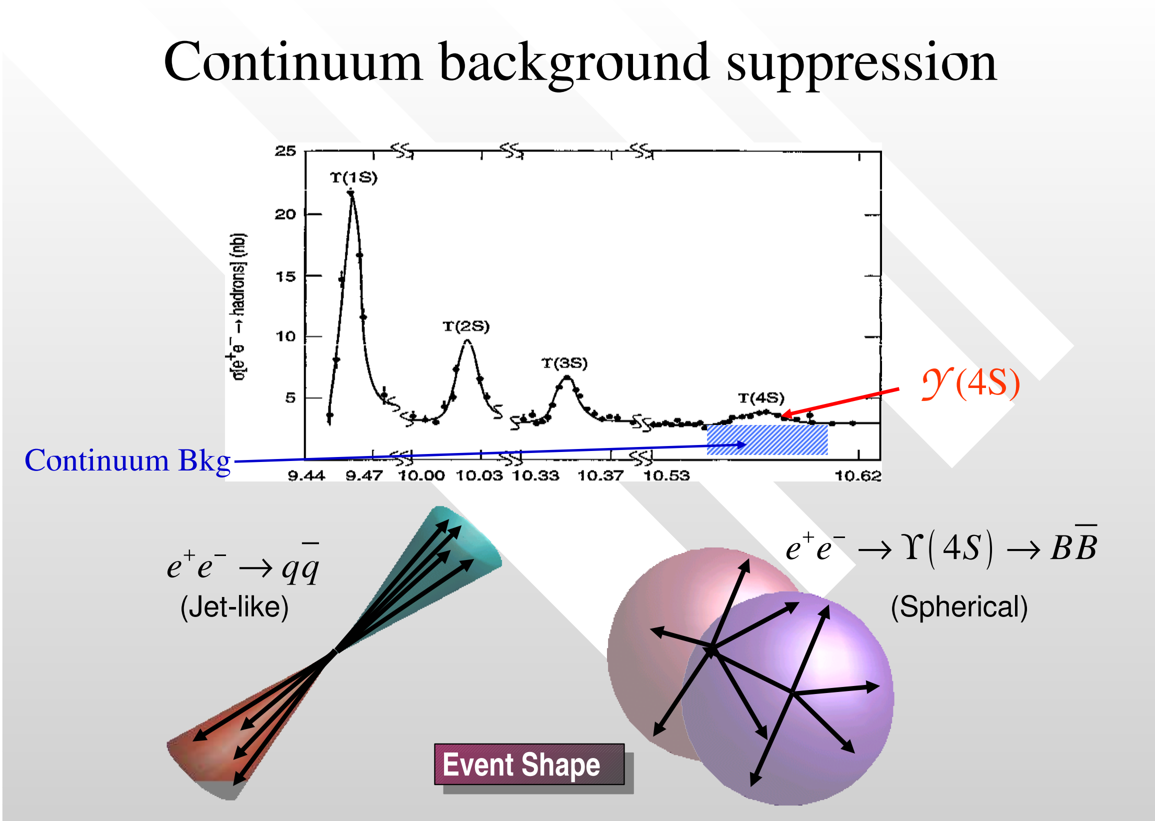
- With *amplitude analysis* can also consider

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

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

$$\Delta E = E_B - E_{\mathrm{beam}} \qquad M_{\mathrm{bc}} = \sqrt{E_{\mathrm{beam}}^2 - p_B^2}$$

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



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

Direct CP Violation

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

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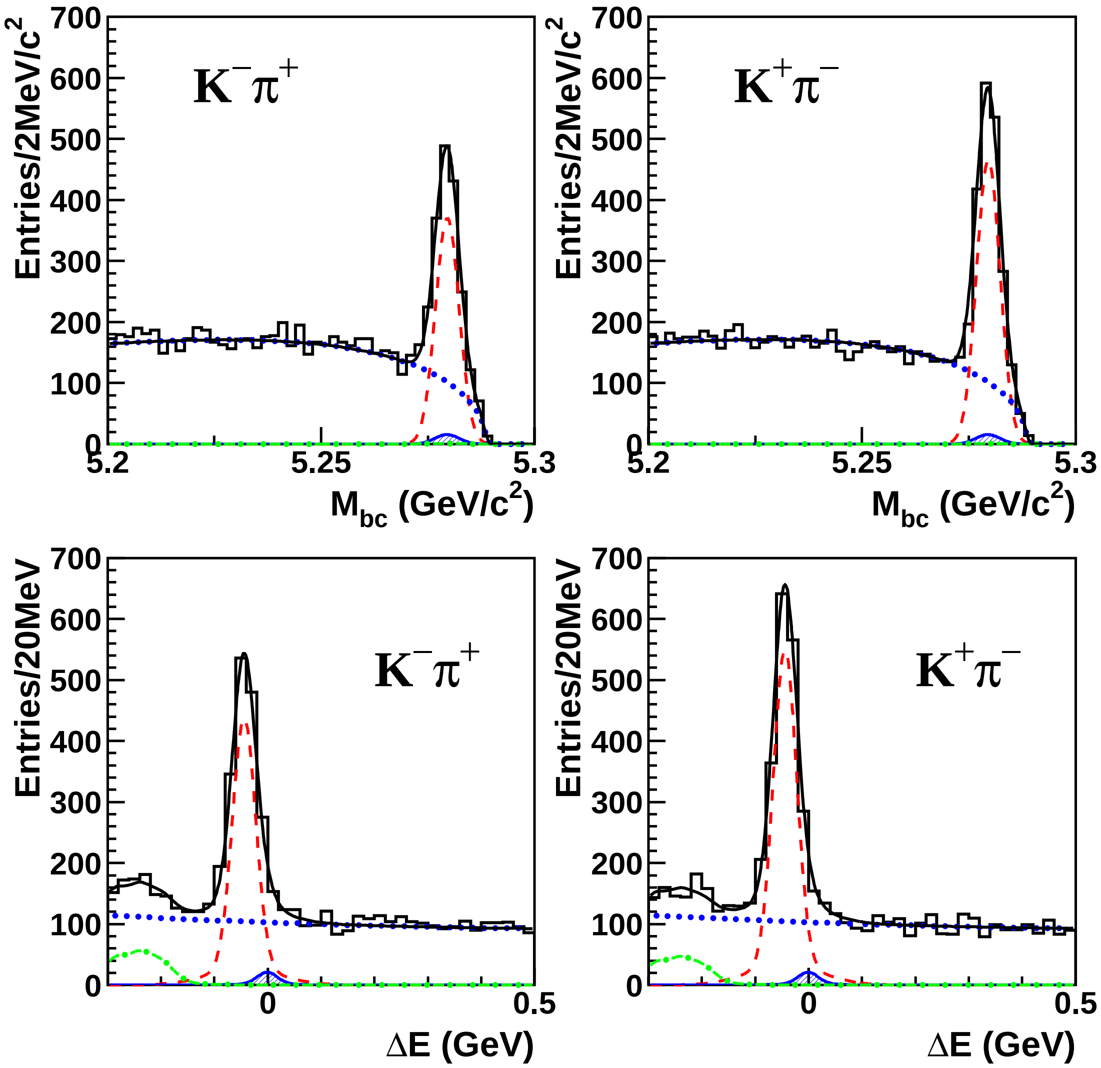
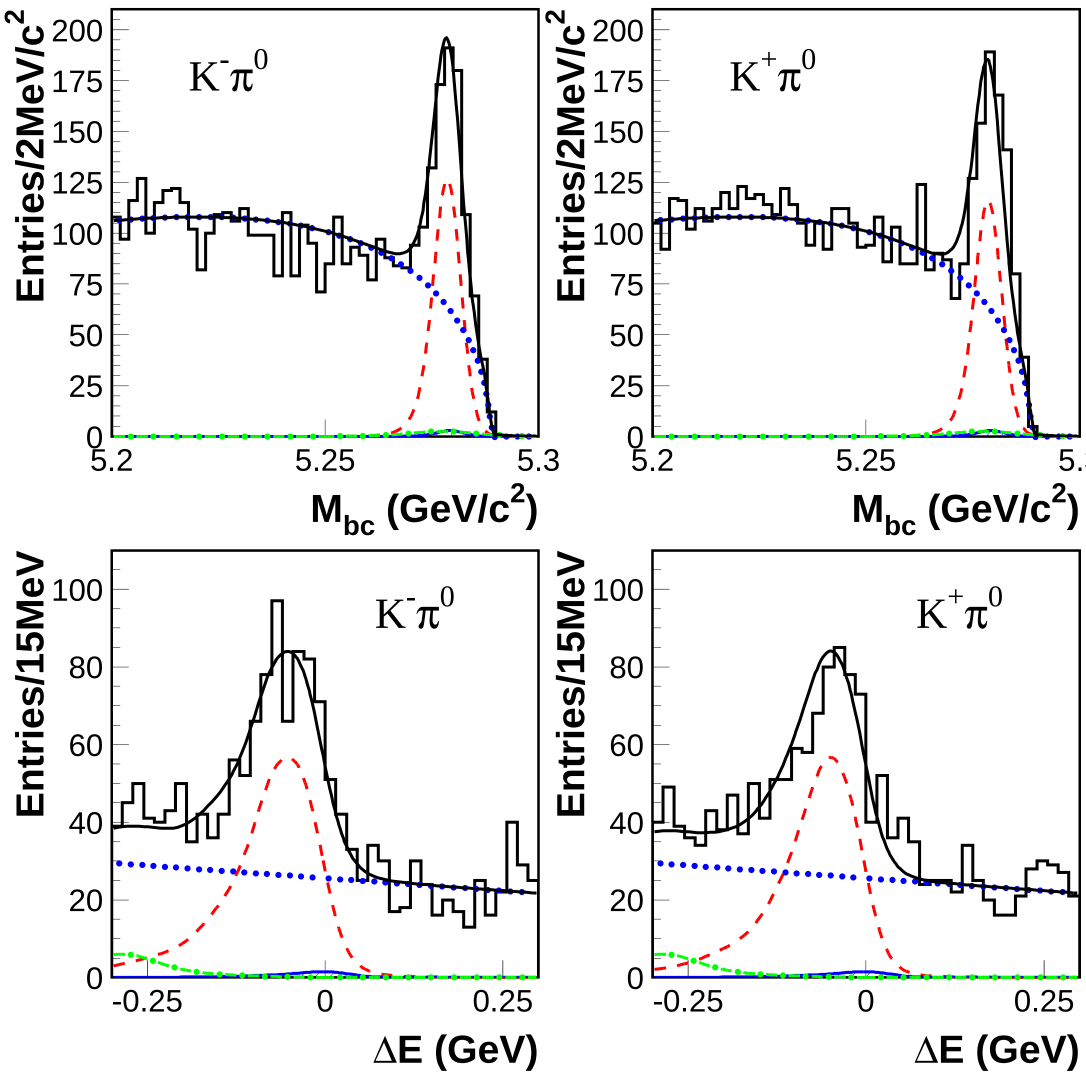


Significance: 4.97σ

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



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

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

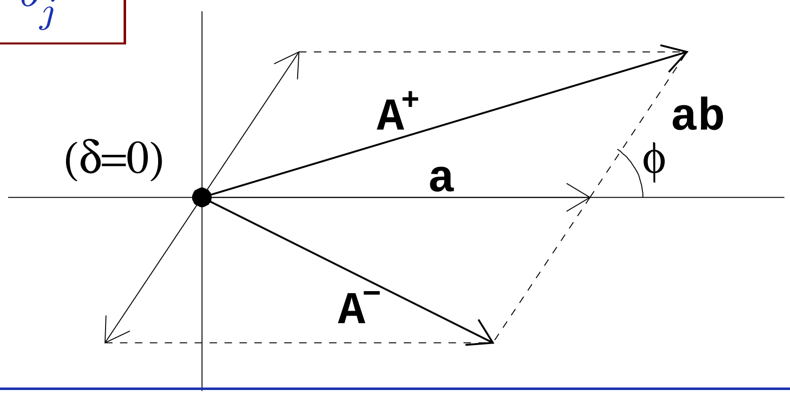
Direct CPV in $B^+ \to K^+\pi^+\pi^-$

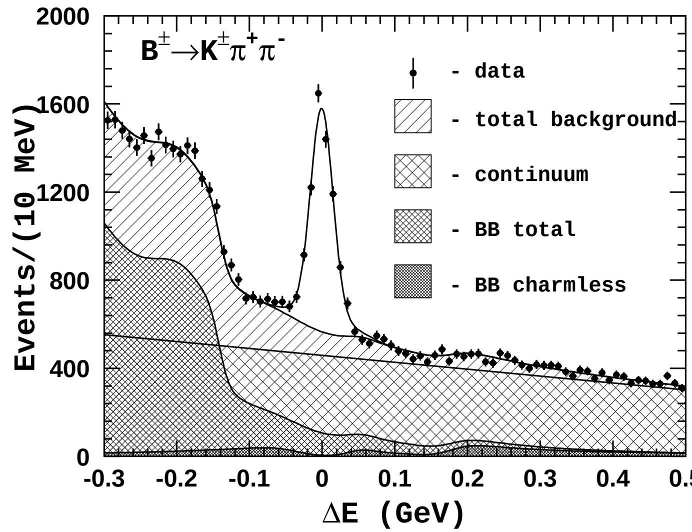
- Veto major charm(onium) contributions to $K^+\pi^+\pi^-$ final state
- 4286 ± 99 signal events
- Parametrize each contributing resonant term as

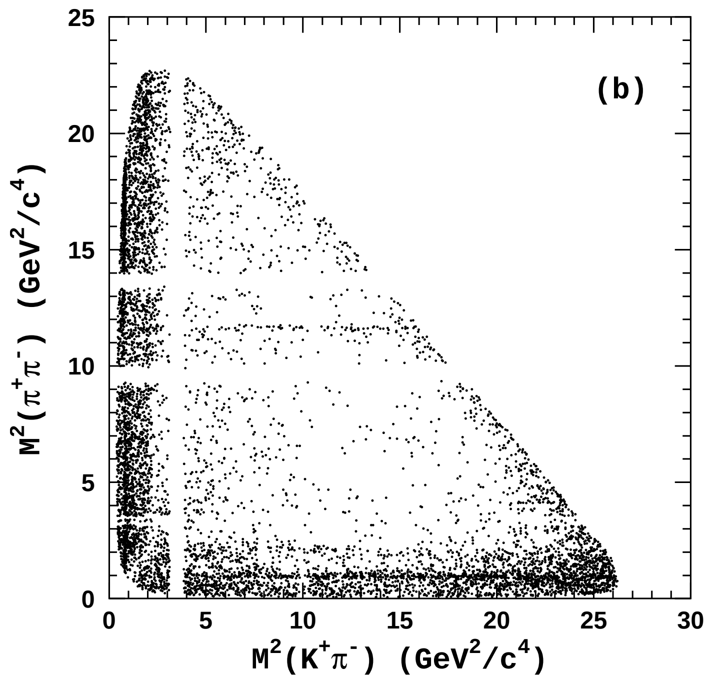
$$a_j e^{i\delta_j}\left(1 + \eta b_j e^{i\phi_j}\right)\mathcal{A}_j$$

  - $a_j e^{i\delta_j}$ = 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

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







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

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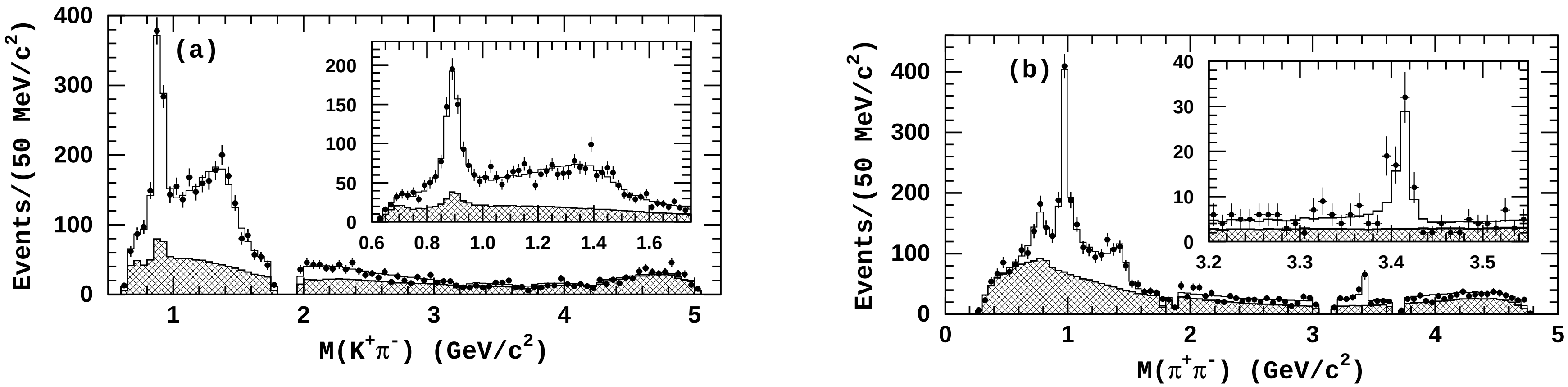
Fit first without CP terms to establish model ($b_j = 0$)



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

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First evidence for direct CPV in charged B decays

Channel	Fraction (%)	δ (°)	b	φ (°)	A_{CP} significance (σ)
$K^*(892)\pi^\pm$	$13.0 \pm 0.8^{+0.5}_{-0.7}$	0 (fixed)	$0.078 \pm 0.033^{+0.012}_{-0.003}$	$-18 \pm 44^{+5}_{-13}$	2.6
$K_0^*(1430)\pi^\pm$	$65.5 \pm 1.5^{+2.2}_{-3.9}$	$55 \pm 4^{+1}_{-5}$	$0.069 \pm 0.031^{+0.010}_{-0.008}$	$-123 \pm 16^{+4}_{-5}$	2.7
$\rho(770)^0 K^\pm$	$7.85 \pm 0.93^{+0.64}_{-0.59}$	$-21 \pm 14^{+14}_{-19}$	$0.28 \pm 0.11^{+0.07}_{-0.09}$	$-125 \pm 32^{+10}_{-85}$	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
$f_2(1270) K^\pm$	$1.52 \pm 0.35^{+0.22}_{-0.37}$	$140 \pm 11^{+18}_{-7}$	$0.37 \pm 0.17^{+0.11}_{-0.04}$	$-24 \pm 29^{+14}_{-20}$	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 $\sqrt{-2\ln(L_0/L_{max})}$
- Largest systematics from model uncertainty

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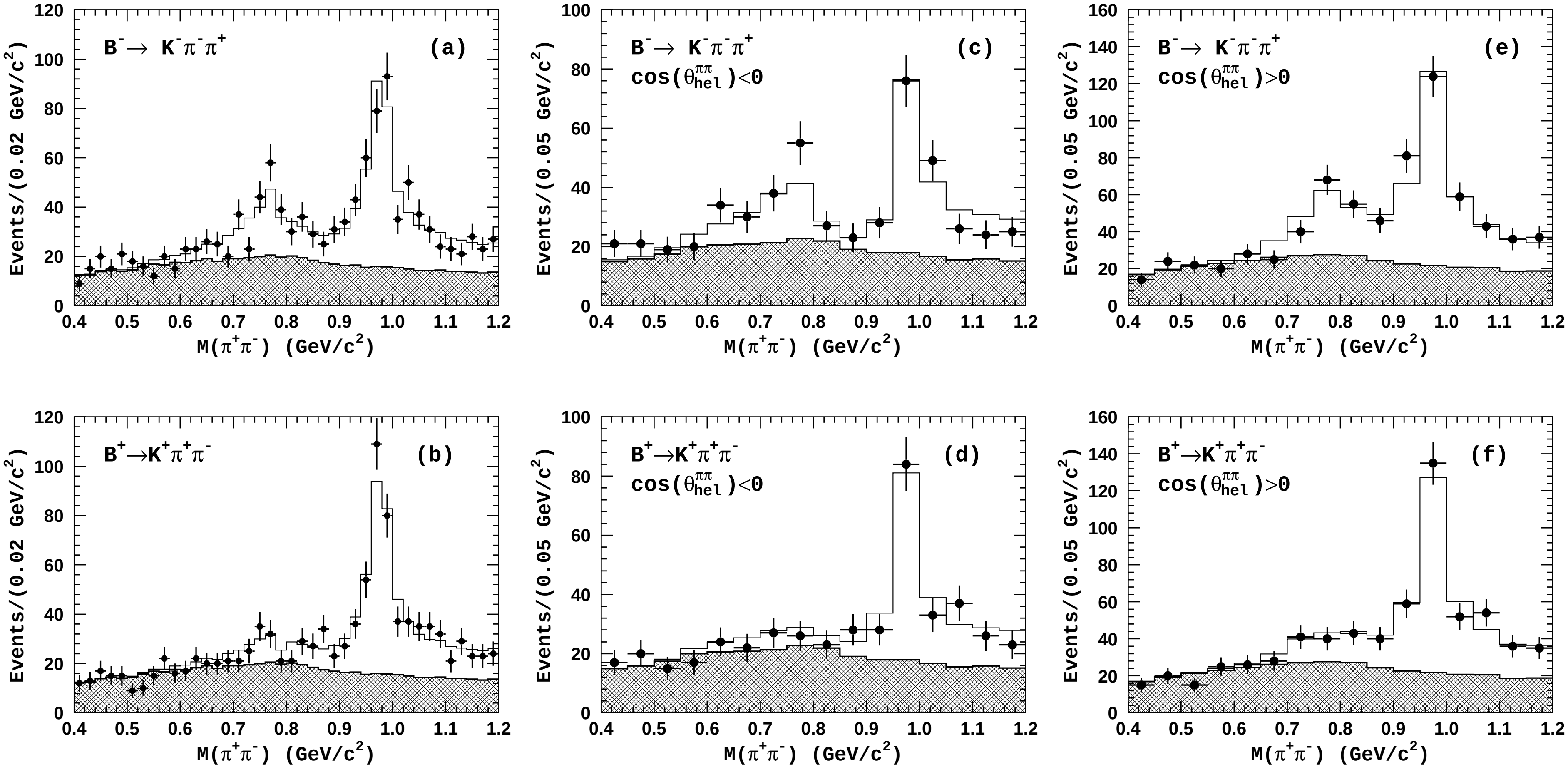
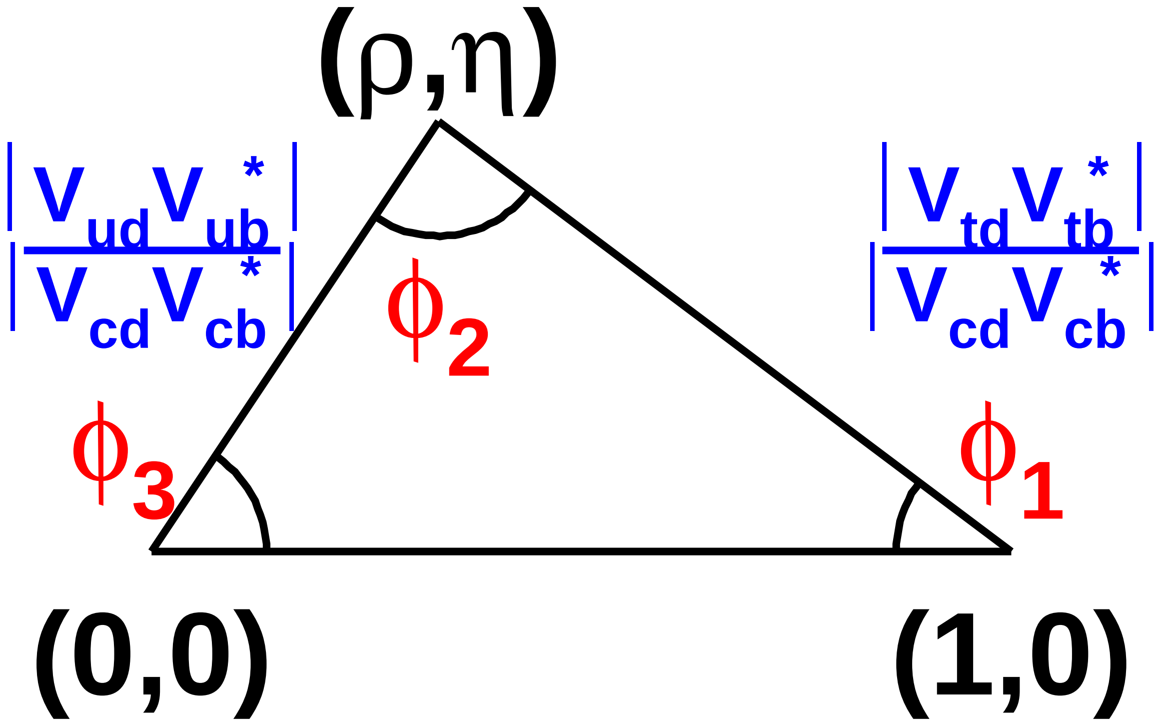
Asymmetry in the ρ region clearly visible in the data



Direct CP violation seen by Belle:

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

Measurements of UT Angles



ϕ_1	ϕ_2	ϕ_3
$b \to c\bar{c}s$ $(J/\psi K_S)$	$b \to u\bar{u}d$ $(\pi^+\pi^-, \rho^+\rho^-)$	$b \to c\bar{u}s/u\bar{c}s$ (DK^-)
$b \to c\bar{u}d$ $(D\pi^0)$		$b \to u\bar{u}s$ vs. $b \to u\bar{u}d$ ($K\pi$ vs. $\pi\pi$)
$b \to c\bar{c}d$ $(J/\psi\pi^0, D^+D^-)$		$2\phi_1 + \phi_3$
$b \to s\bar{q}q$ (ϕK_S)		$b \to c\bar{u}d/u\bar{c}d$ $(D^+\pi^-)$

…and many others!

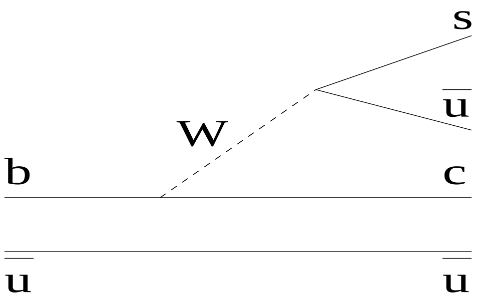
ϕ_3 from $B \to DK$

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

  Bigi & Sanda; Gronau, London & Wyler

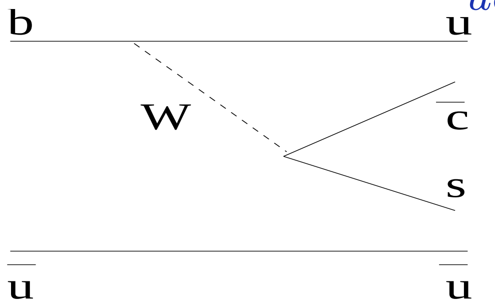
- Reconstruct D in final states accessible to both D^0 and $\bar{D}^0$

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



COLOUR ALLOWED

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



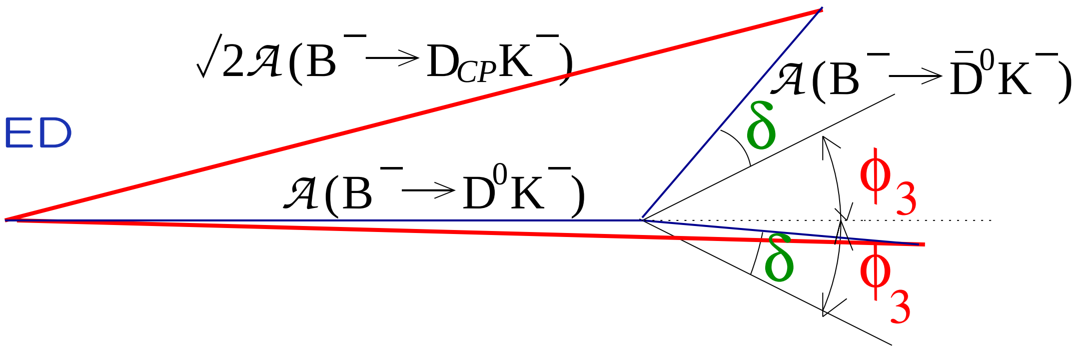
COLOUR SUPPRESSED

$\mathcal{A}$ — amplitude

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

$\sim 0.1 - 0.2$

δ_B — strong phase difference



- Ultimately aim to use many states and combine results
- Inclusive analyses can be performed but sensitivity is diluted
  - ⇝ Reconstruct modes exclusively, where possible
  - ⇝ Use amplitude analysis (not, *eg.*, Q2B analysis) where possible
- To extract ϕ_3, need D decay "model"
  - ⇝ 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
  - $K_SK^+K^-$, $\pi^+\pi^-\pi^0$, $K_S\pi^\pm K^\mp$, $K^\pm\pi^\mp\pi^0$, $K_S\pi^+\pi^-\pi^0$, ...

- 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)

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

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

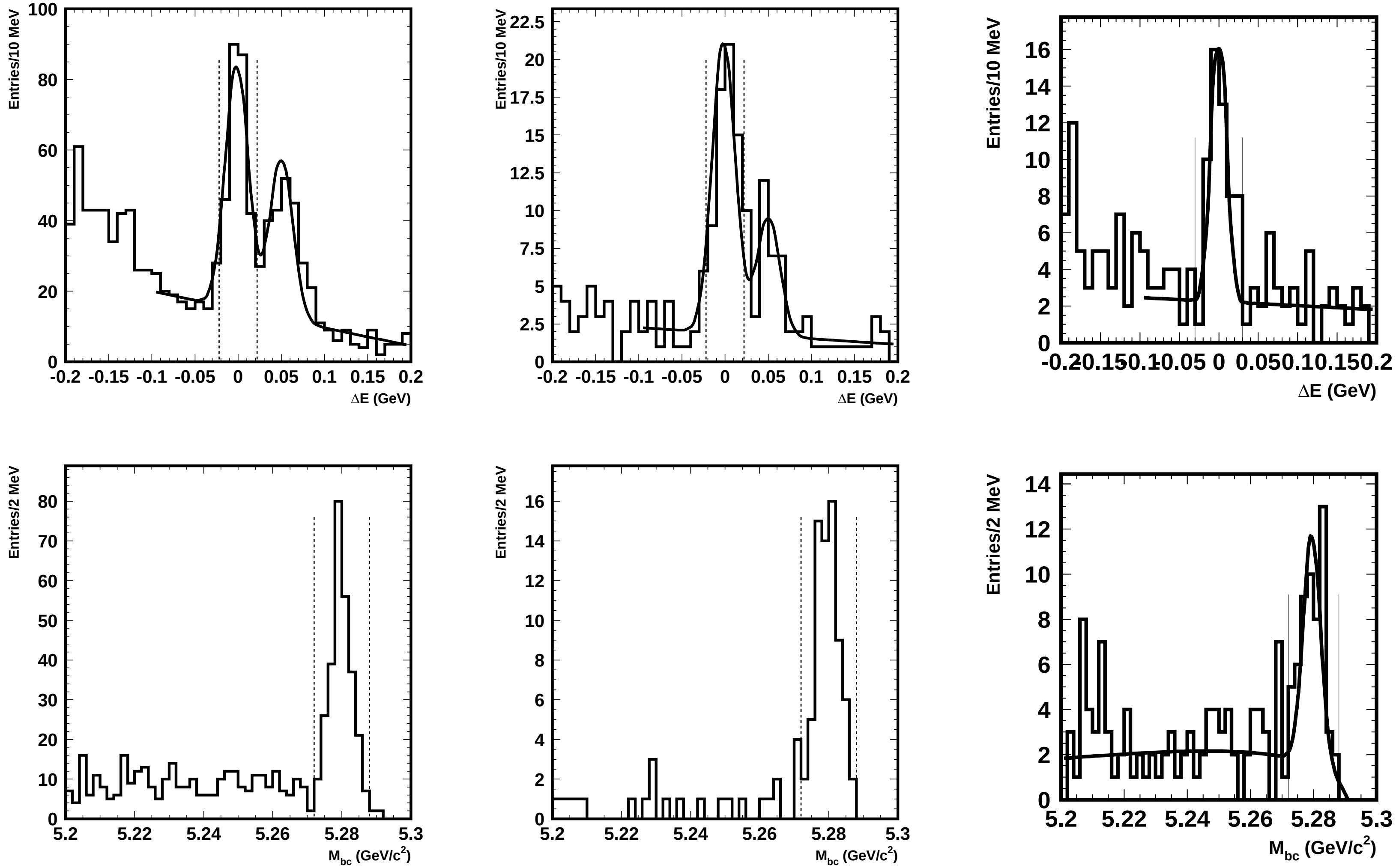
- Consider $\bar{D}^0 \to K_S \pi^+ \pi^-$
  $\to$ define amplitude at each Dalitz plot point as $f(m_+^2, m_-^2)$
  where $m_+ = m_{K_S\pi^+}$, $m_- = m_{K_S\pi^-}$
- Consider $D^0 \to K_S \pi^+ \pi^-$
  $\to$ amplitude at each Dalitz plot point is $f(m_-^2, m_+^2)$
- $\left| f(m_+^2, m_-^2) \right|$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

253 fb^{-1} BELLE-CONF-0476, BELLE-CONF-0502

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

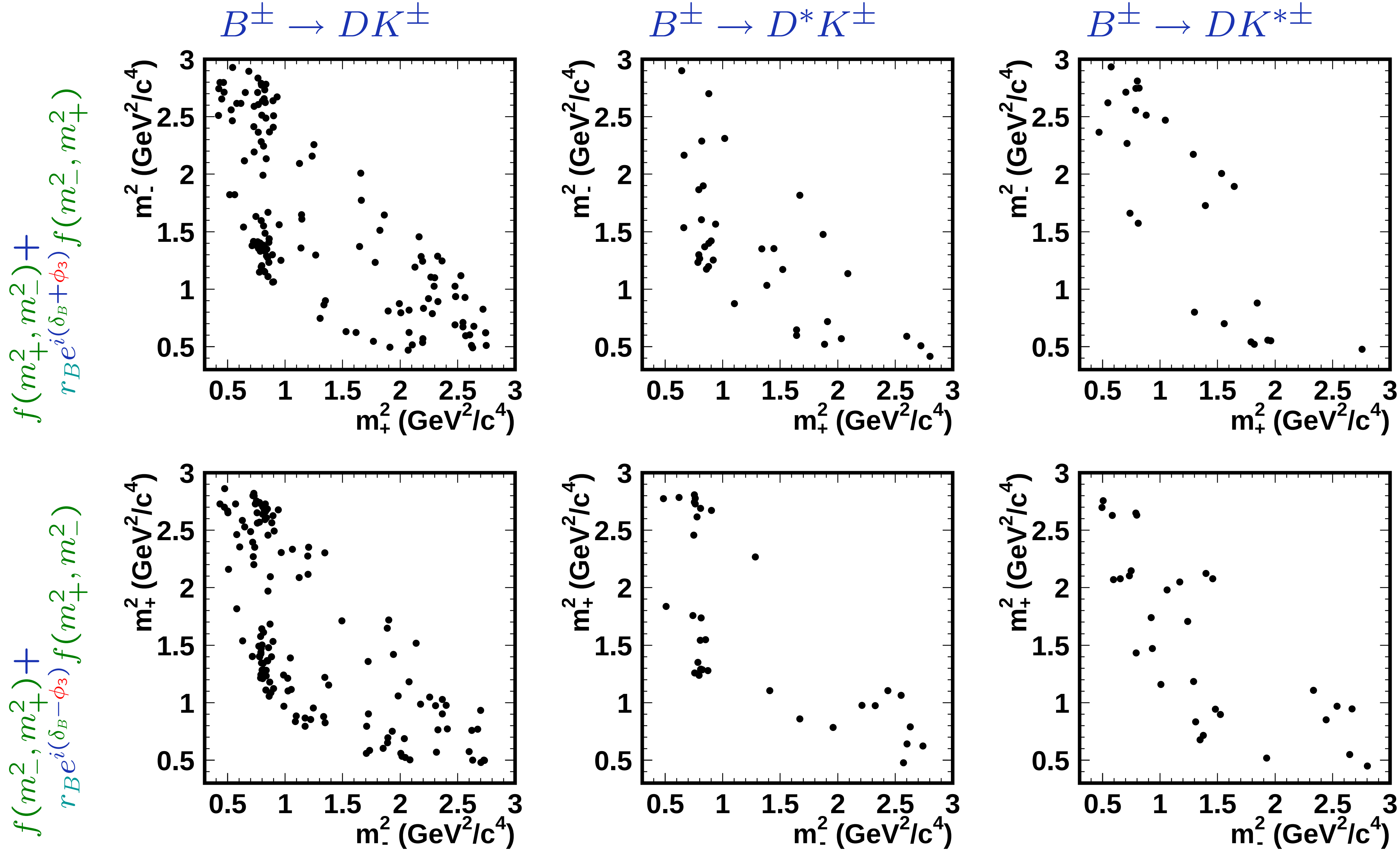


276 candidate events
(209 ± 16 signal)

69 candidate events
(58 ± 8 signal)

56 candidate events
(36 ± 7 signal)

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



253 fb^{-1}

BELLE-CONF-0476, BELLE-CONF-0502

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

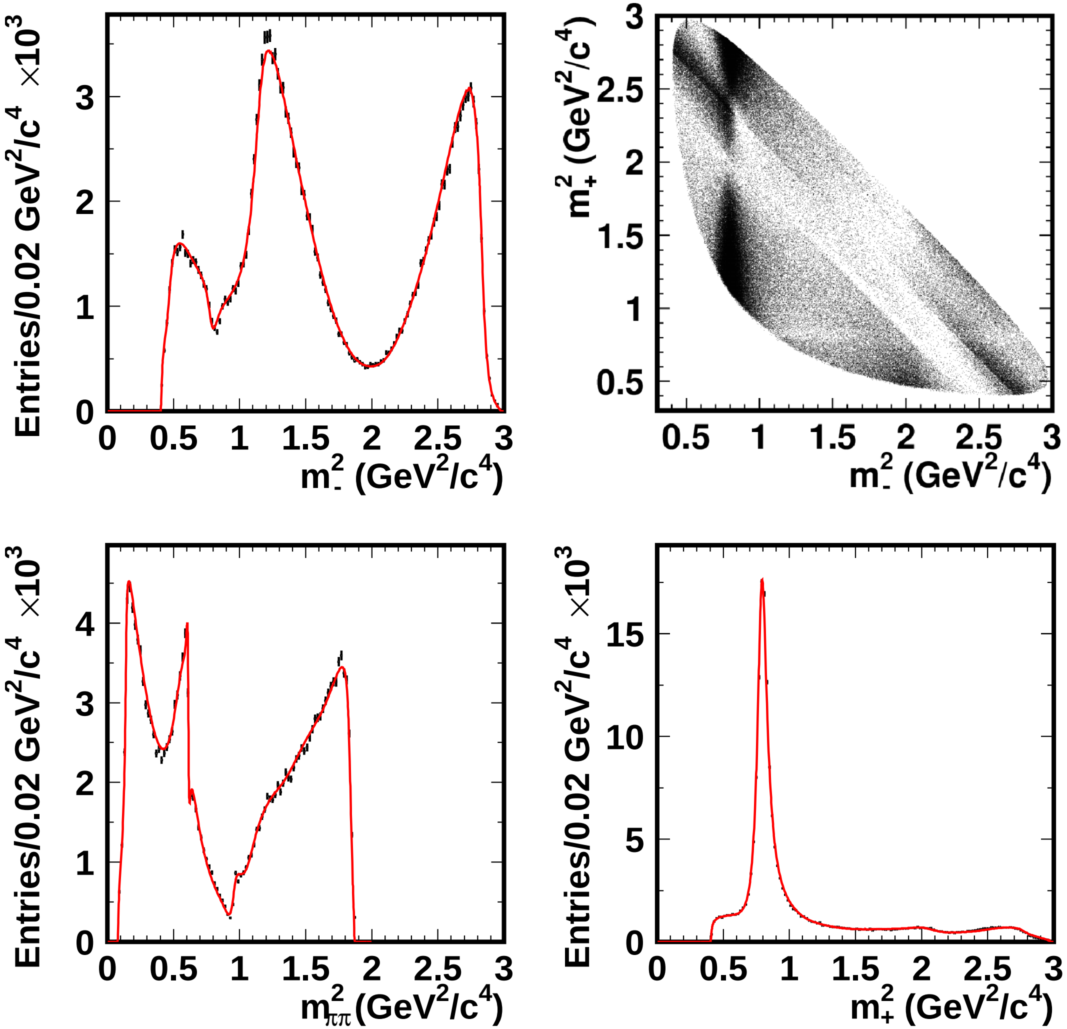
253 fb^{-1}

$\chi^2/ndf = 2.30$

$(ndf = 1106)$

Fine tuning of model

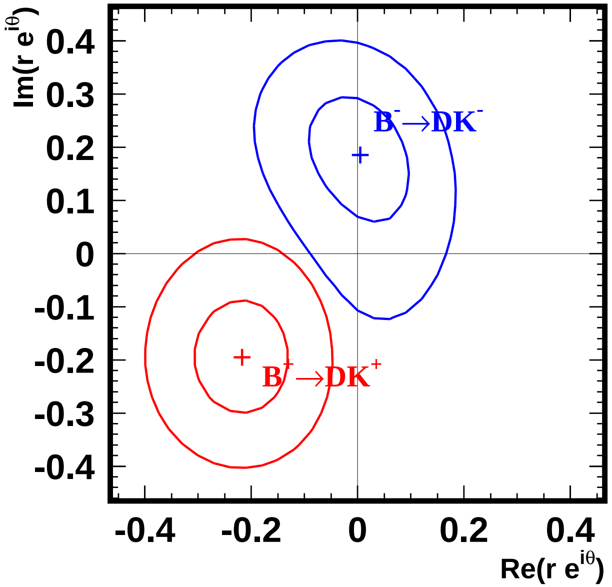
$\rightsquigarrow$ little effect on ϕ_3



BELLE-CONF-0476, BELLE-CONF-0502

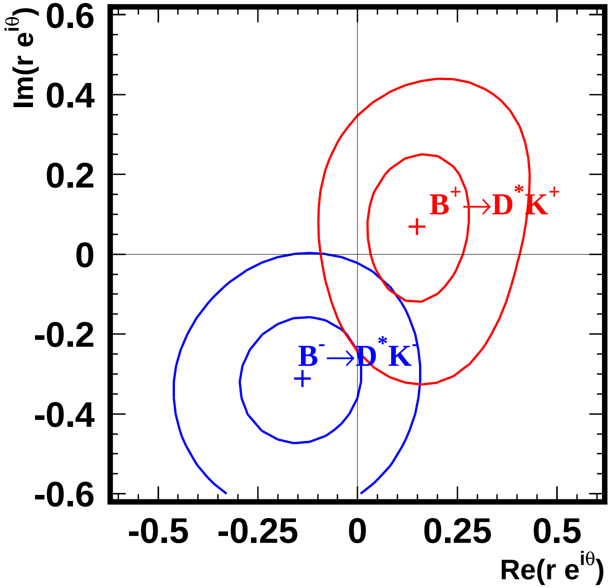
Fit $B^{\pm}$ samples separately, float $r_B e^{i(\delta_B \pm \phi_3)}$

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



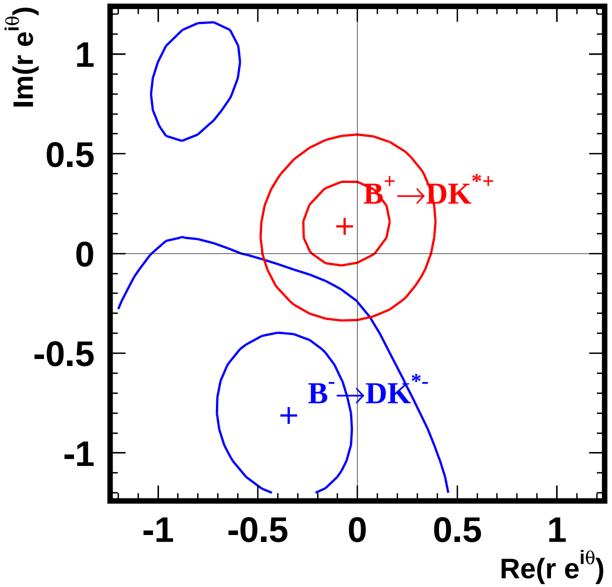
276 candidate events
(209 ± 16 signal)

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



69 candidate events
(58 ± 8 signal)

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



56 candidate events
(36 ± 7 signal)

$253\ \mathrm{fb}^{-1}$ BELLE-CONF-0476, BELLE-CONF-0502

Extraction of ϕ_3

253 fb^{-1} BELLE-CONF-0476, BELLE-CONF-0502

Avoid fit likelihood errors → use frequentist approach to obtain confidence regions

(recall r_B and δ_B different for each mode)

$B^\pm \to DK^\pm$

$$\phi_3 = 64^\circ \pm 19^\circ(\text{stat}) \pm 13^\circ(\text{syst}) \pm 11^\circ(\text{model})$$
$$r_B = 0.21 \pm 0.08(\text{stat}) \pm 0.03(\text{syst}) \pm 0.04(\text{model})$$
$$\delta_B = 157^\circ \pm 19^\circ(\text{stat}) \pm 11^\circ(\text{syst}) \pm 21^\circ(\text{model})$$

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

$$\phi_3 = 75^\circ \pm 57^\circ(\text{stat}) \pm 11^\circ(\text{syst}) \pm 11^\circ(\text{model})$$
$$r_B = 0.12\,^{+0.16}_{-0.11}(\text{stat}) \pm 0.02(\text{syst}) \pm 0.04(\text{model})$$
$$\delta_B = 321^\circ \pm 57^\circ(\text{stat}) \pm 11^\circ(\text{syst}) \pm 21^\circ(\text{model})$$

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

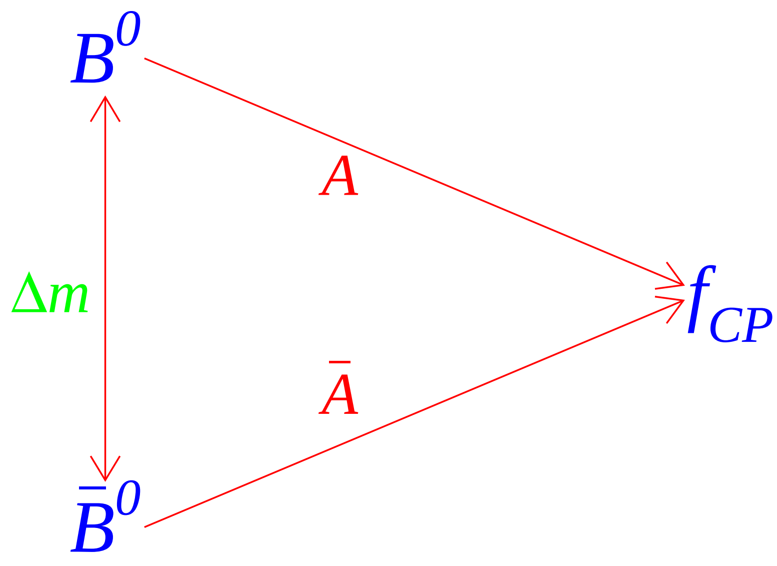
$$\phi_3 = 112^\circ \pm 35^\circ(\text{stat}) \pm 9^\circ(\text{syst}) \pm 14^\circ(\text{model})$$
$$r_B = 0.25 \pm 0.18(\text{stat}) \pm 0.09(\text{syst}) \pm 0.09(\text{model})$$
$$\delta_B = 353^\circ \pm 35^\circ(\text{stat}) \pm 8^\circ(\text{syst}) \pm 54^\circ(\text{model})$$

$B^\pm \to DK^\pm$ & $B^\pm \to D^*K^\pm$ combined

$$\phi_3 = 68^\circ\,^{+14^\circ}_{-15^\circ}(\text{stat}) \pm 13^\circ(\text{syst}) \pm 11^\circ(\text{model})$$

Time-Dependent CP Violation Phenomenology

- Interference between different paths to a final state $\Rightarrow$ 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:
  - $\left|\frac{q}{p}\right| = 1$, $\left|\frac{\bar{A}}{A}\right| = 1 \Rightarrow S_{CP} = \mathrm{Im}(\lambda_{CP})$

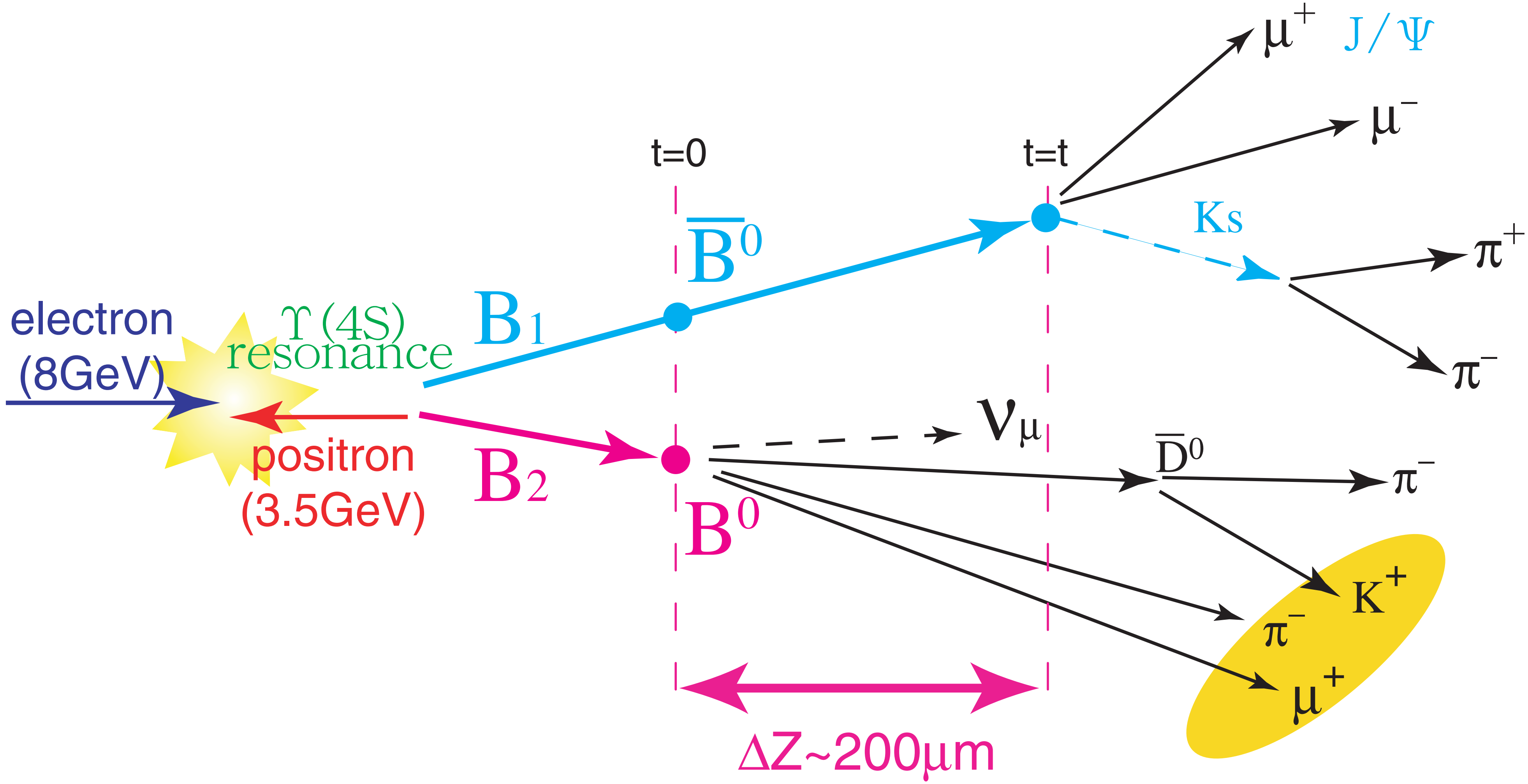


- At B factories, measure Δt from decay time of other B

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

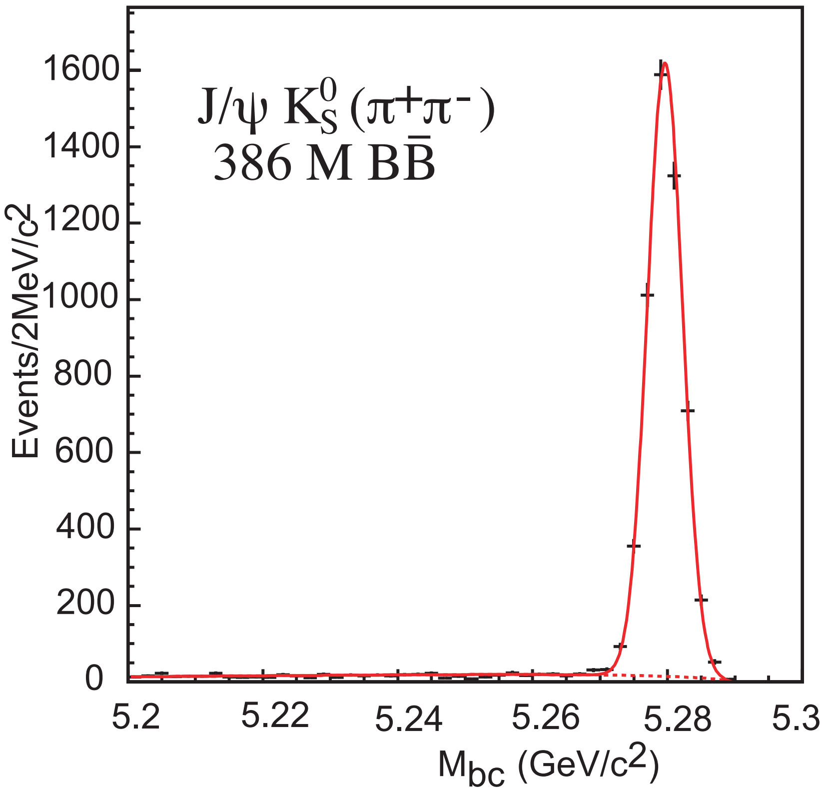
$$P^q_{CP}(\Delta t) = \frac{e^{-|\Delta t|/\tau_{B^0}}}{4\tau_{B^0}}\left[1 + q\left\{S_{CP}\sin(\Delta m \Delta t)\right\}\right]$$

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



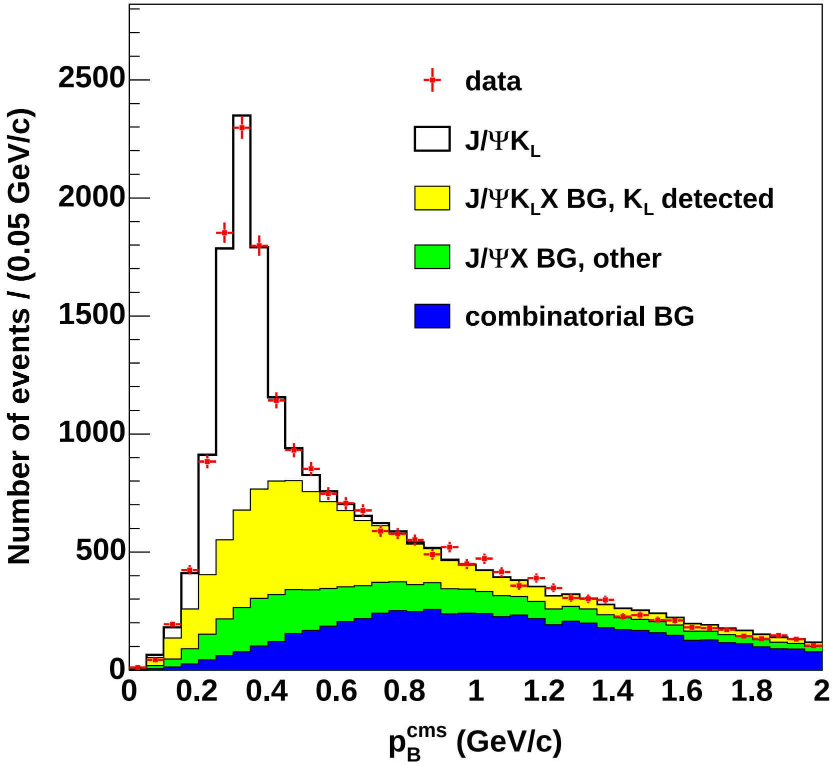
357 fb^{-1} BELLE-CONF-0569

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



5264 ± 73 signal events

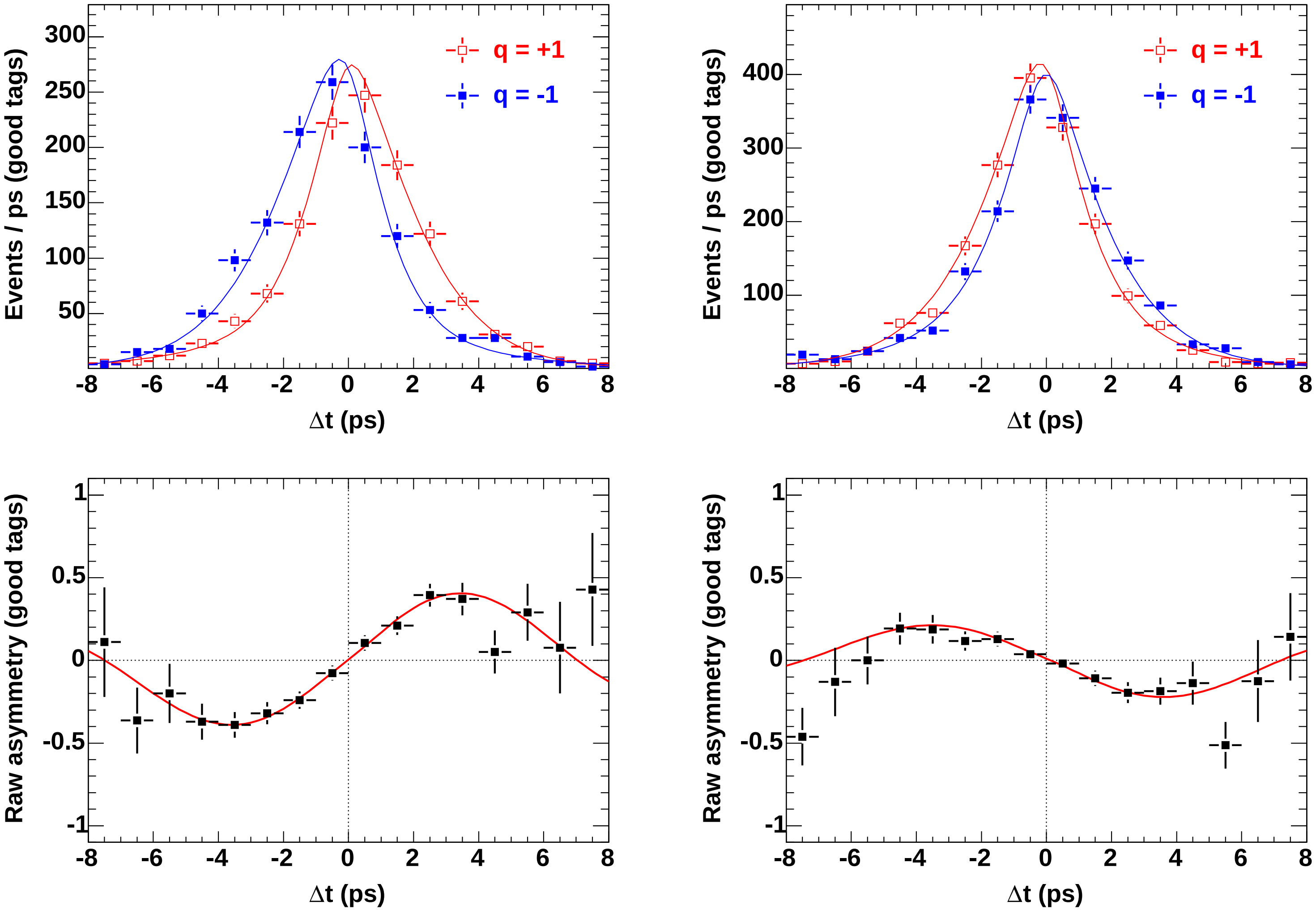
$B^0 \rightarrow J/\psi K_L$



4792 ± 105 signal events

$B^0 \to J/\psi K^0$ — Δt Dependence

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



$S = +0.668 \pm 0.047(\text{stat})$ | $S = -0.619 \pm 0.069(\text{stat})$

$A = -0.021 \pm 0.034(\text{stat})$ | $A = +0.049 \pm 0.039(\text{stat})$

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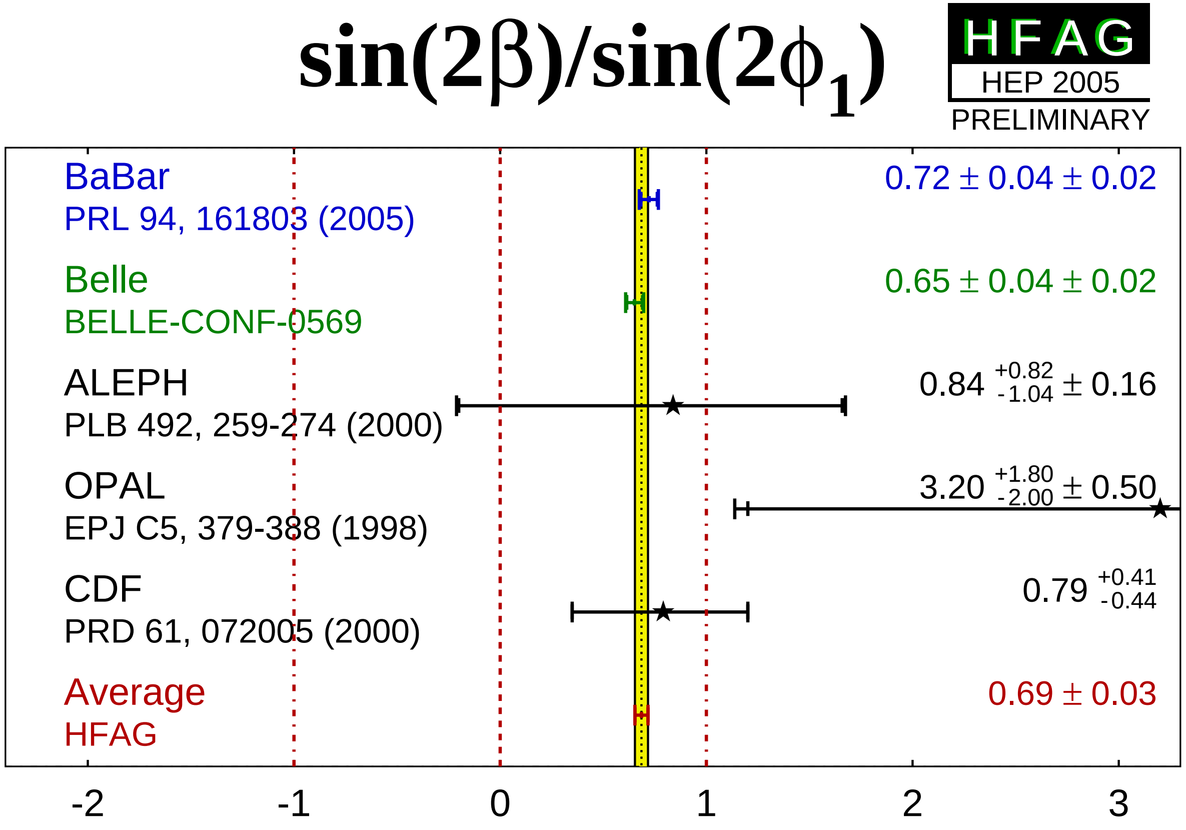
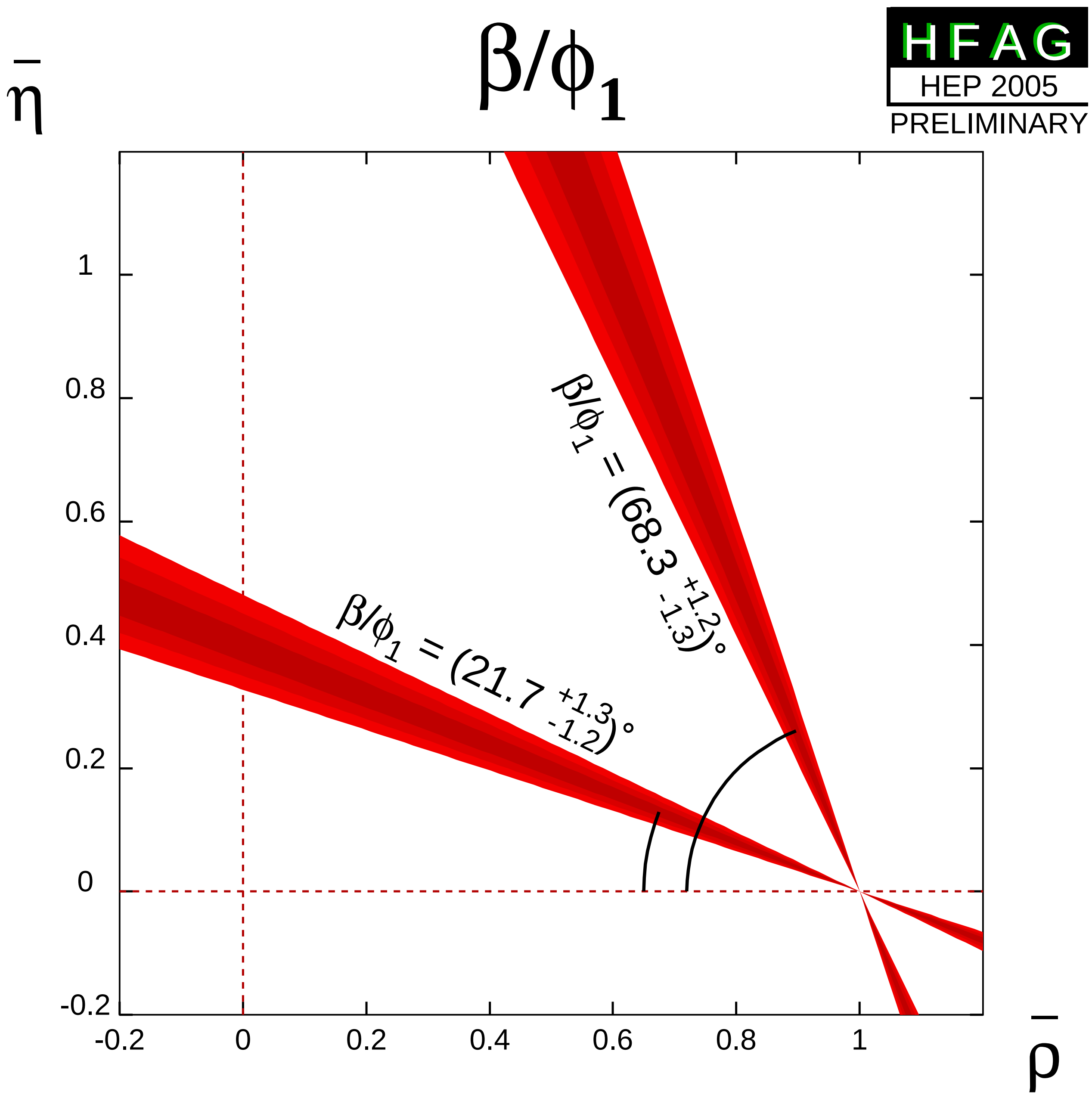
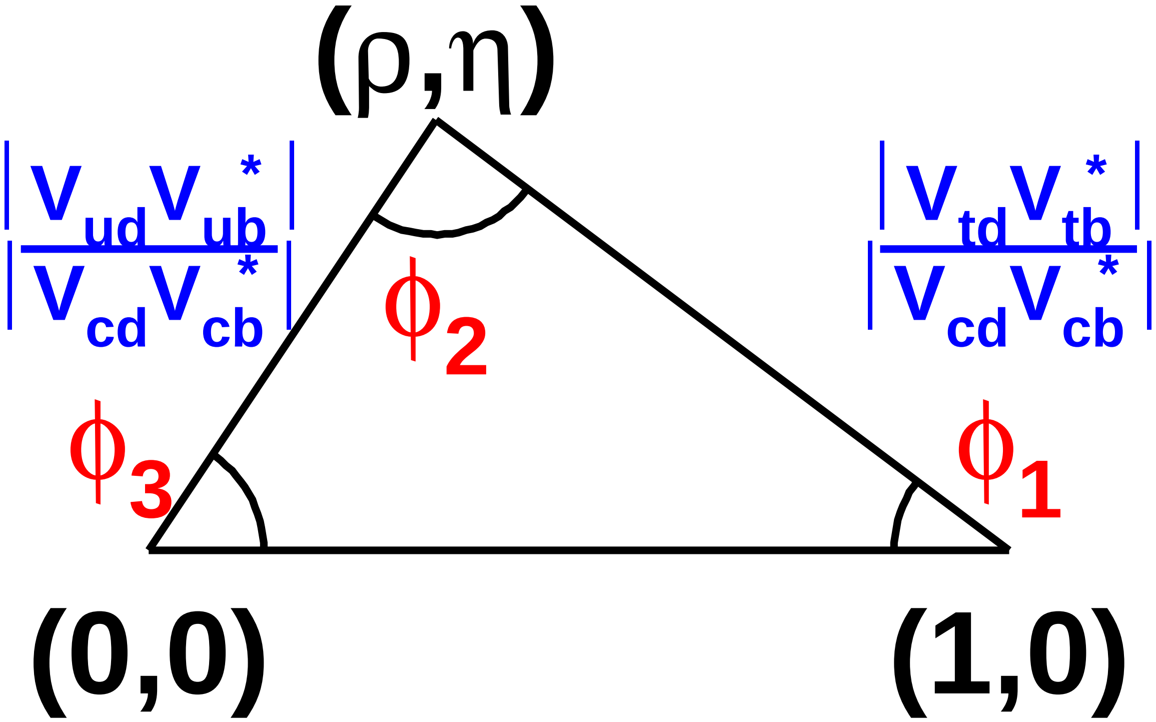
Belle: $\sin(2\phi_1) = +0.652 \pm 0.039 \pm 0.020$



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


β/φ1
HFAG
HEP 2005
PRELIMINARY
η̄
ρ̄
β/φ1 = (68.3 +1.2 -1.3)°
β/φ1 = (21.7 +1.3 -1.2)°
1
0.8
0.6
0.4
0.2
0
-0.2
-0.2
0
0.2
0.4
0.6
0.8
1

UT angles — Summary



ϕ_1	ϕ_2	ϕ_3
$B^0 \to J/\psi K^0$	$B^0 \to \pi^+\pi^-$ & $\rho^+\rho^-$	$B^\pm \to DK^\pm$

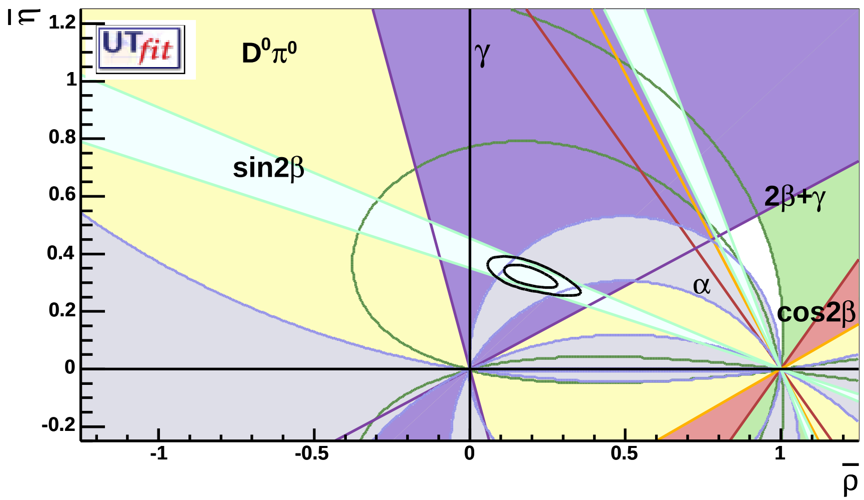
$\sin(2\phi_1) = +0.652 \pm 0.039 \pm 0.020$ $\quad \phi_2 = 93^{+12}_{-11}{}^\circ$

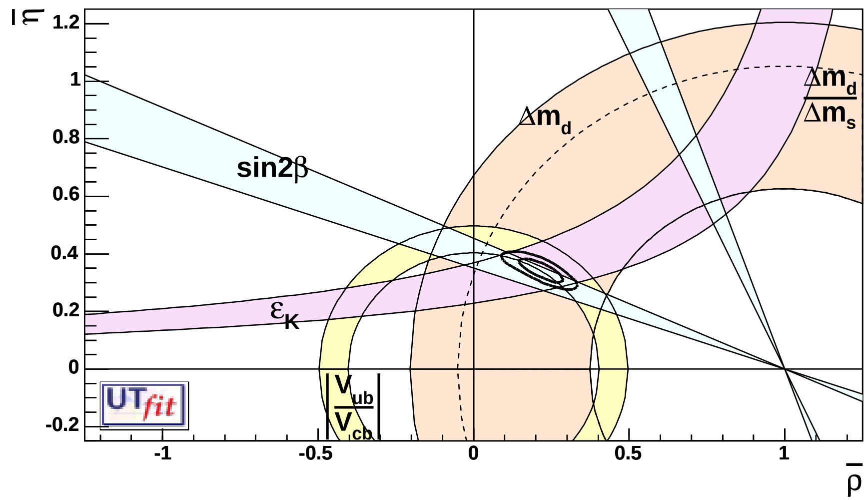
$\phi_3 = 68^\circ\,{}^{+14^\circ}_{-15^\circ}(\text{stat}) \pm 13^\circ(\text{syst}) \pm 11^\circ(\text{model})$

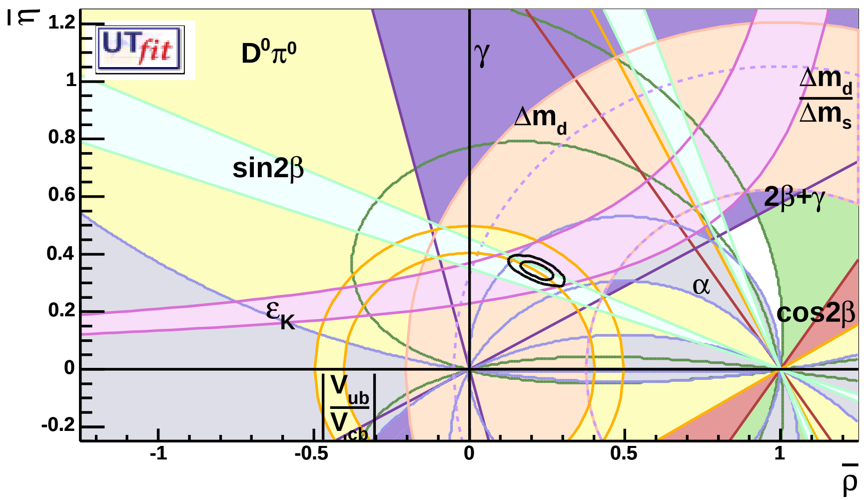
Ambiguities reduced by

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

Plots from UTFit Collaboration

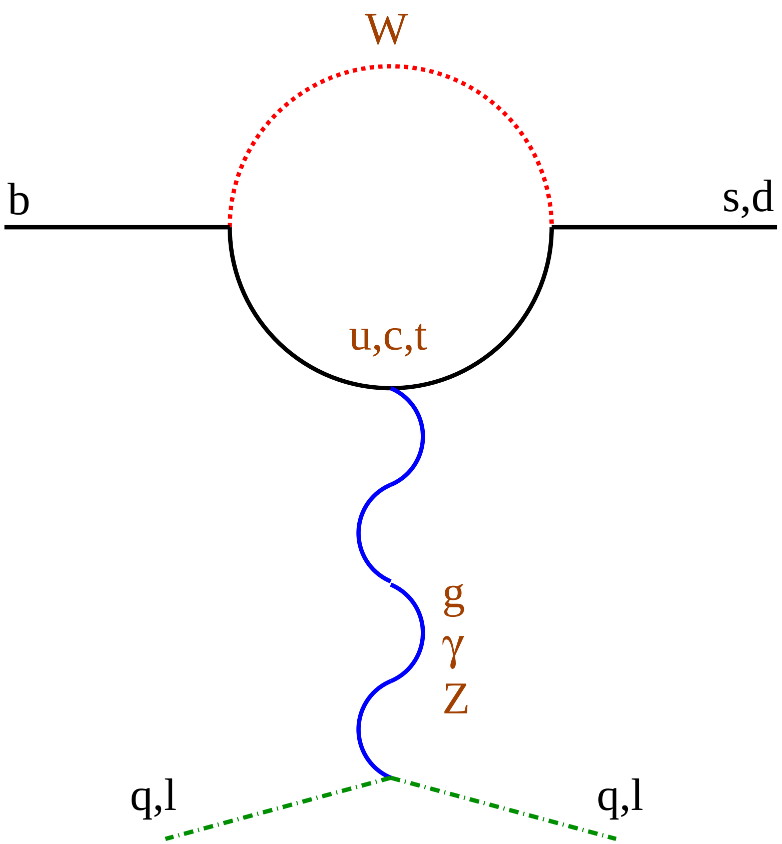






Penguins

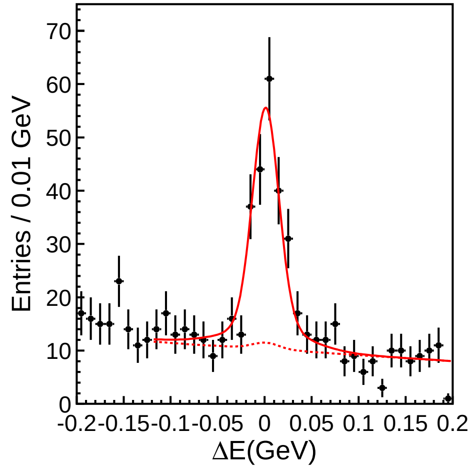
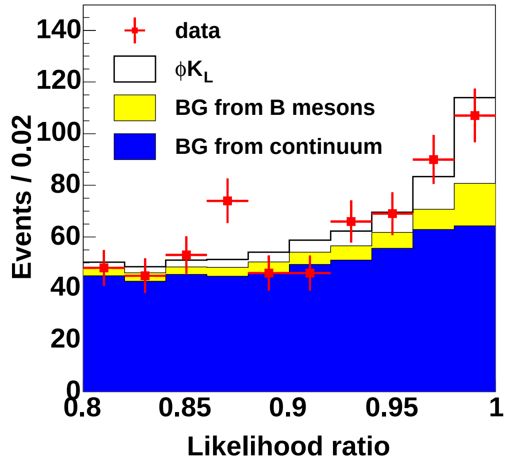
Why Hunt Penguins?

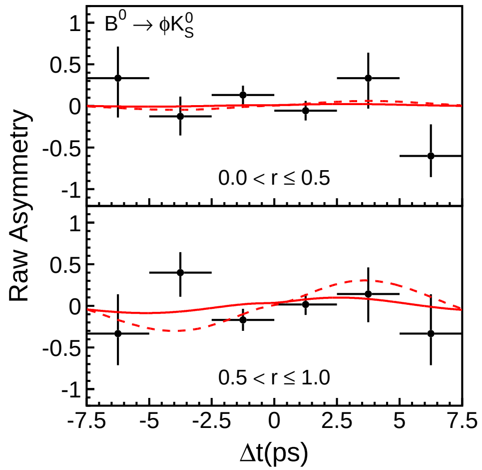


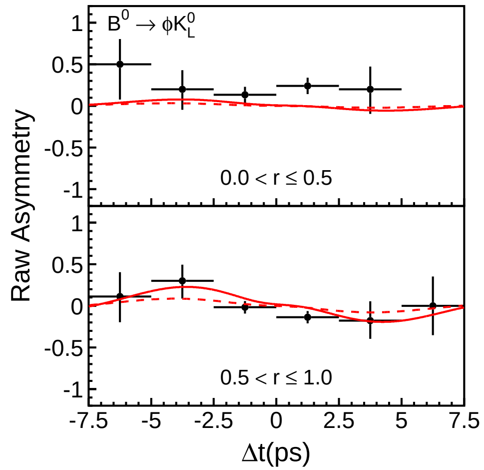
- loop diagrams ⇒ virtual particles ⇒ high masses
- expect new physics at TeV scale
- NP particles should appear in loops
- no reason for NP phases to be aligned
- many possible manifestations of NP
  - $b \to s$ *vs.* $b \to d$
  - gluonic *vs.* radiative *vs.* electroweak
  - $\Delta B = 2$ (mixing)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

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

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

ϕK_S	ϕK_L
	
180 ± 16	78 ± 13



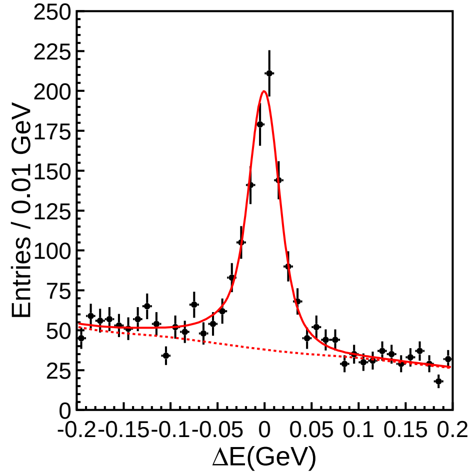


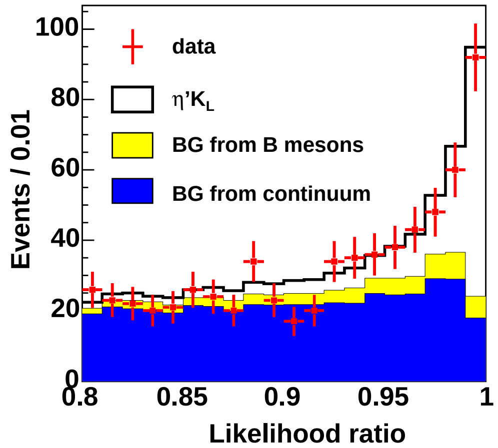
$\sin(2\phi_1{}^{\text{eff}}) = +0.44 \pm 0.27 \pm 0.05 \qquad \mathcal{A} = +0.14 \pm 0.17 \pm 0.07$

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

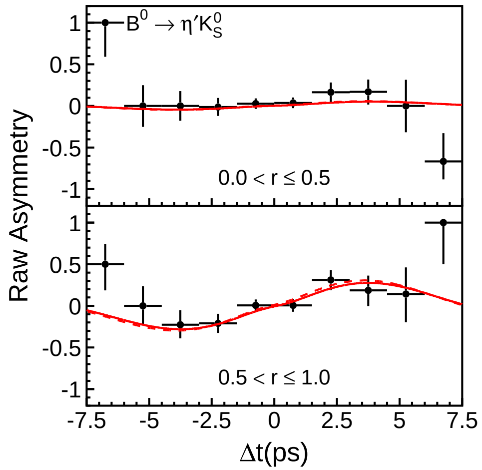
$357\ \text{fb}^{-1}$ BELLE-CONF-0569

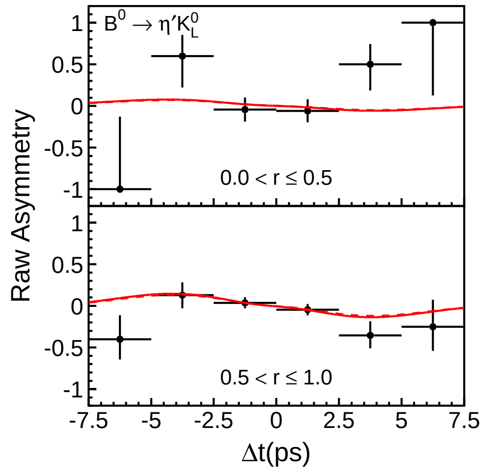
$\eta' K_S$	$\eta' K_L$





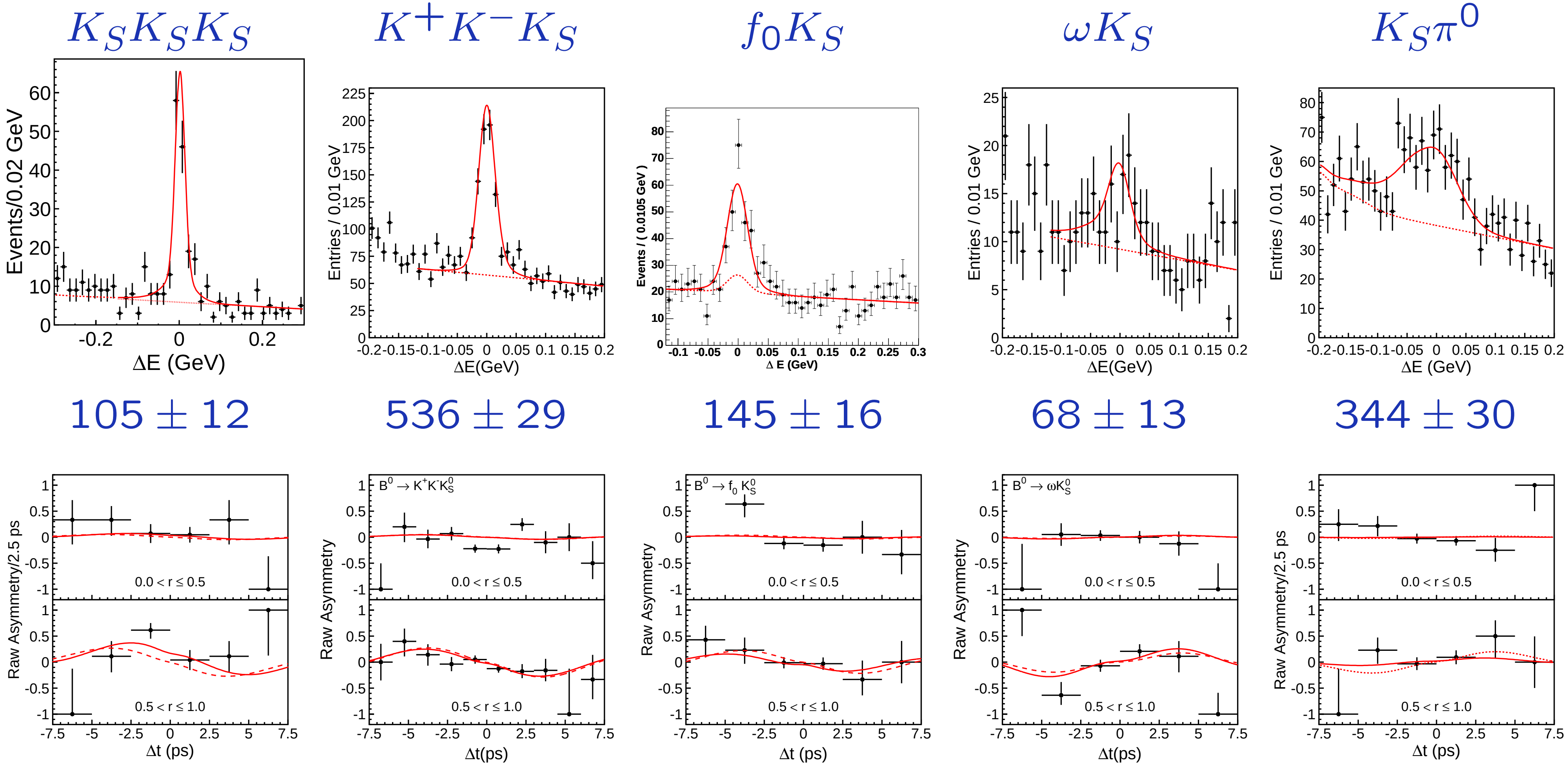
830 ± 35 $\qquad$ 187 ± 18





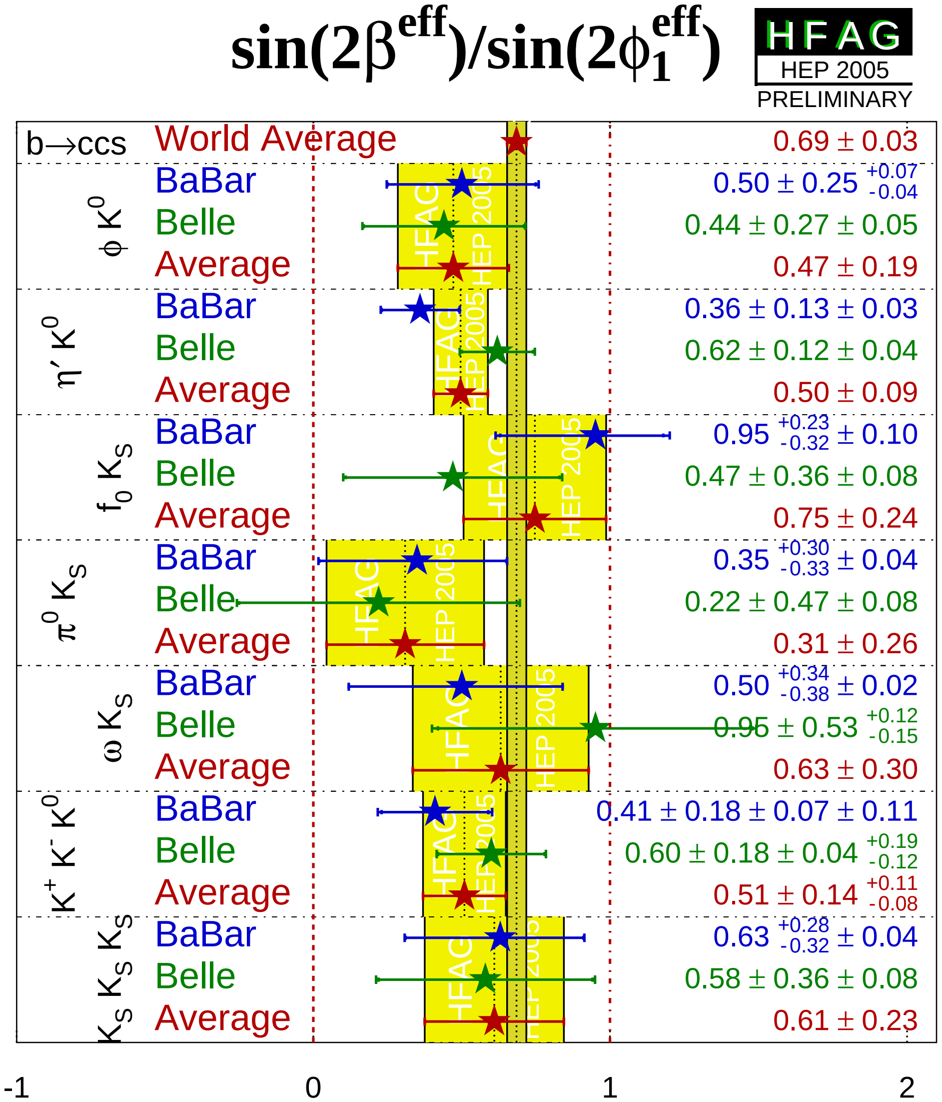
$\sin(2\phi_1^{\rm eff}) = +0.62 \pm 0.12 \pm 0.04 \qquad A = -0.04 \pm 0.08 \pm 0.06$

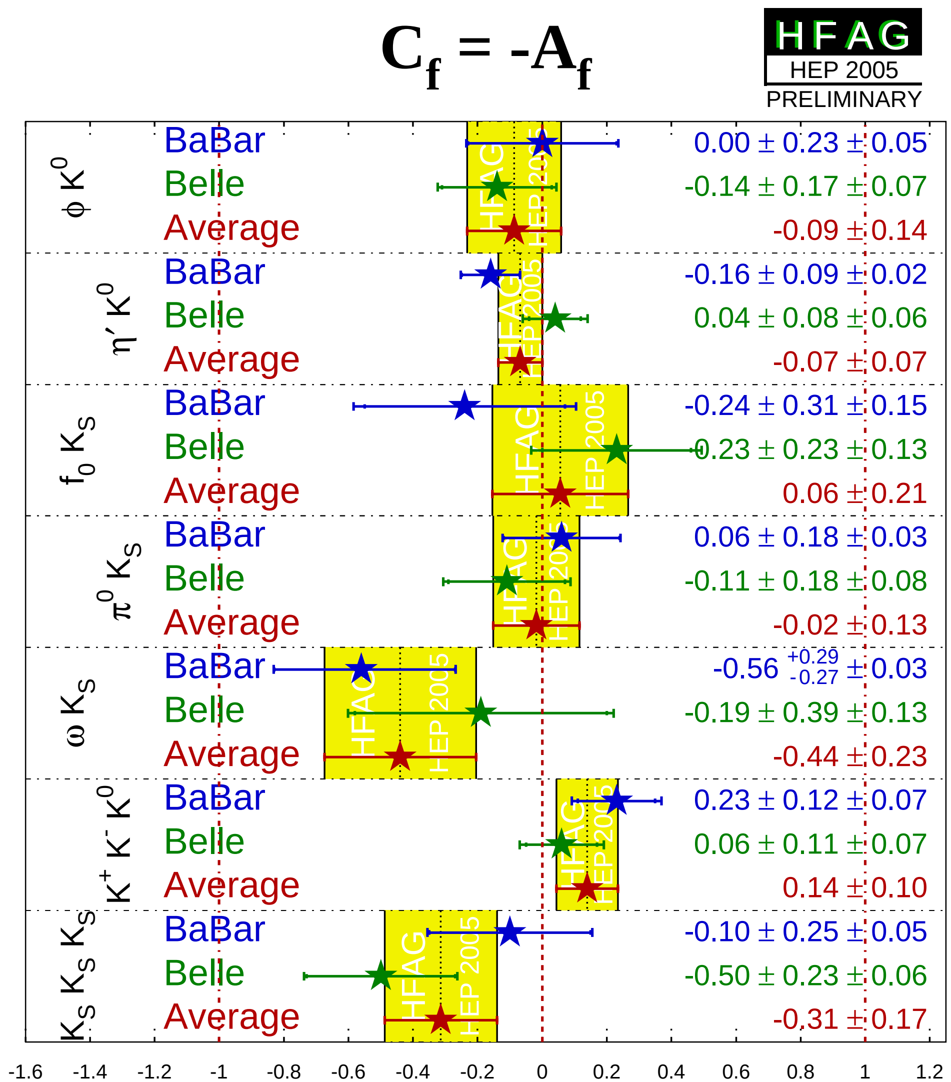
357 fb^{-1} BELLE-CONF-0569



$K_S K_S K_S$	$K^+ K^- K_S$	$f_0 K_S$	ωK_S	$K_S \pi^0$
105 ± 12	536 ± 29	145 ± 16	68 ± 13	344 ± 30

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

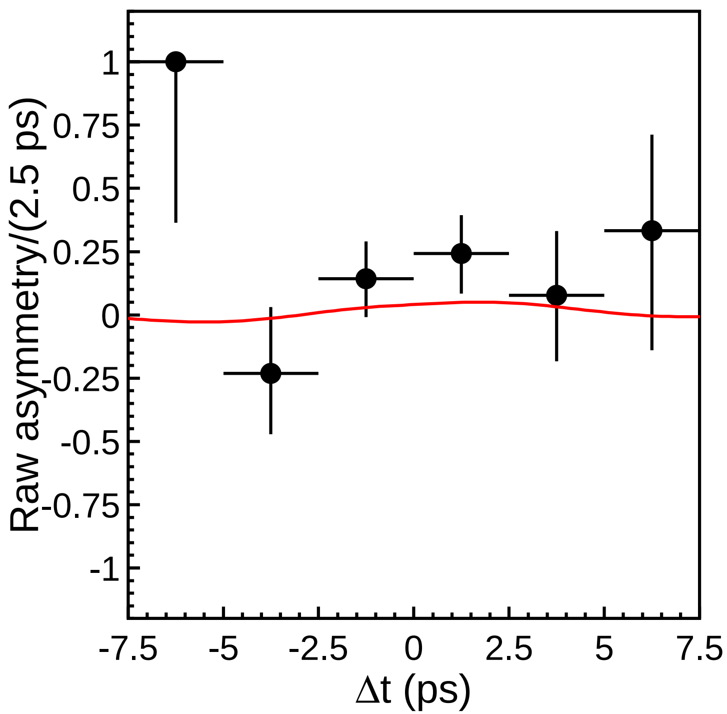




$357\ fb^{-1}$ BELLE-CONF-0569

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

Time-dependence probes γ polarization



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

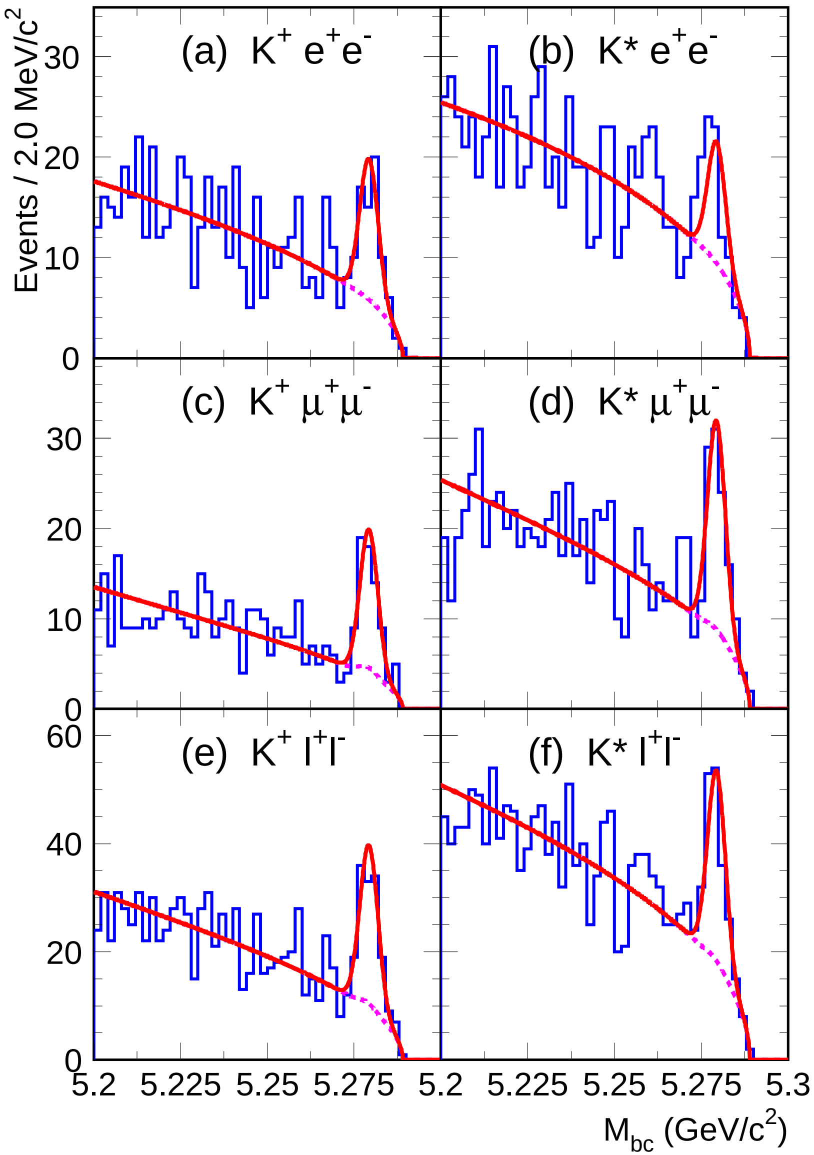
70 ± 11 signal events

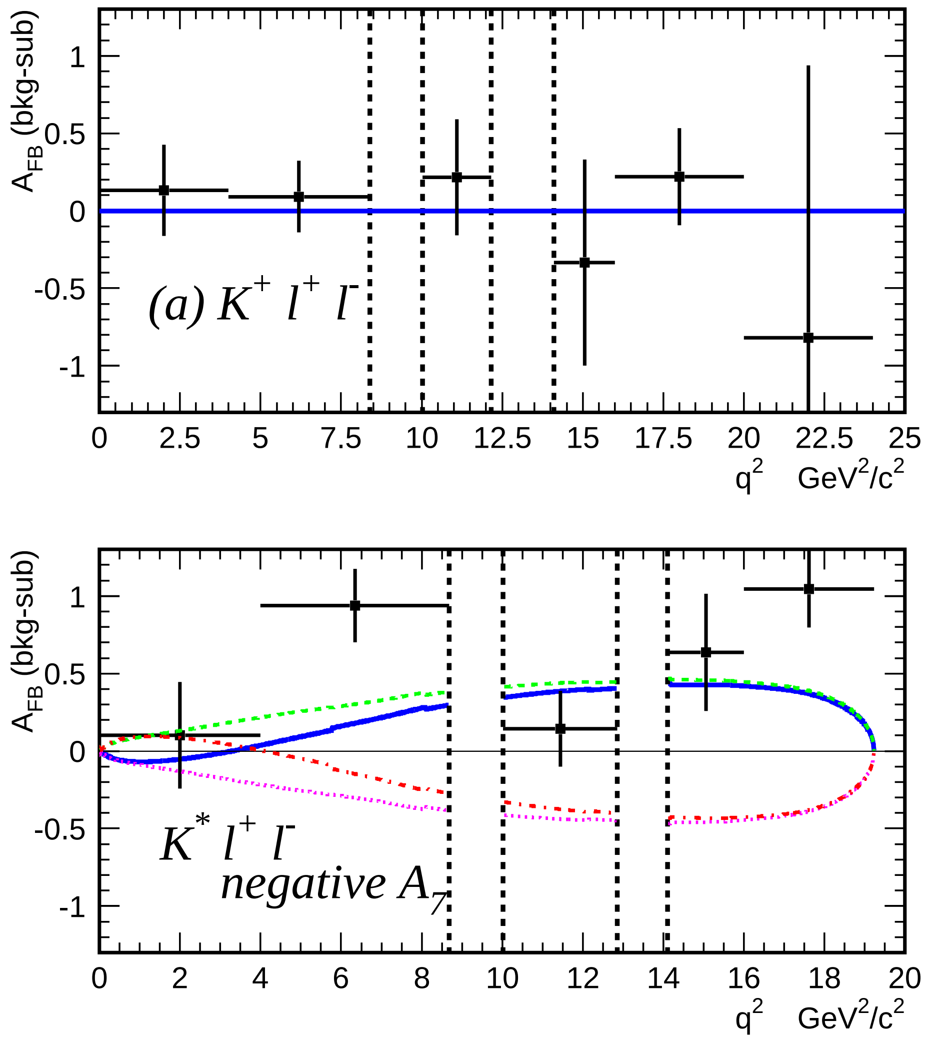
$$S_{K_S\pi^0\gamma} = +0.08 \pm 0.41(\text{stat}) \pm 0.10(\text{stat})$$
$$C_{K_S\pi^0\gamma} = -0.12 \pm 0.27(\text{stat}) \pm 0.10(\text{stat})$$

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

386 fb^{-1}

BELLE-CONF-0521

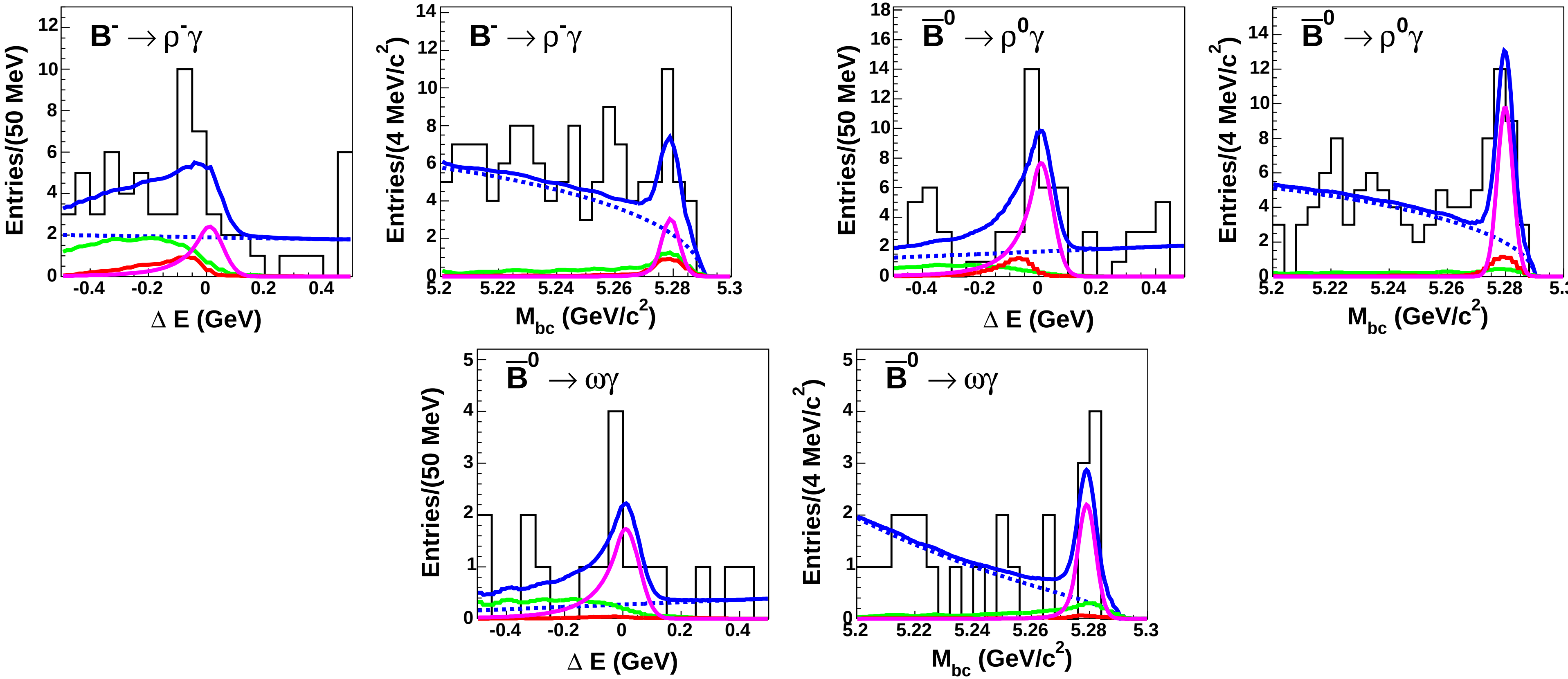




$A_9 A_{10} > 0$ excluded at 95% CL

$b \to d\gamma$

357 fb^{-1} BELLE-CONF-0520

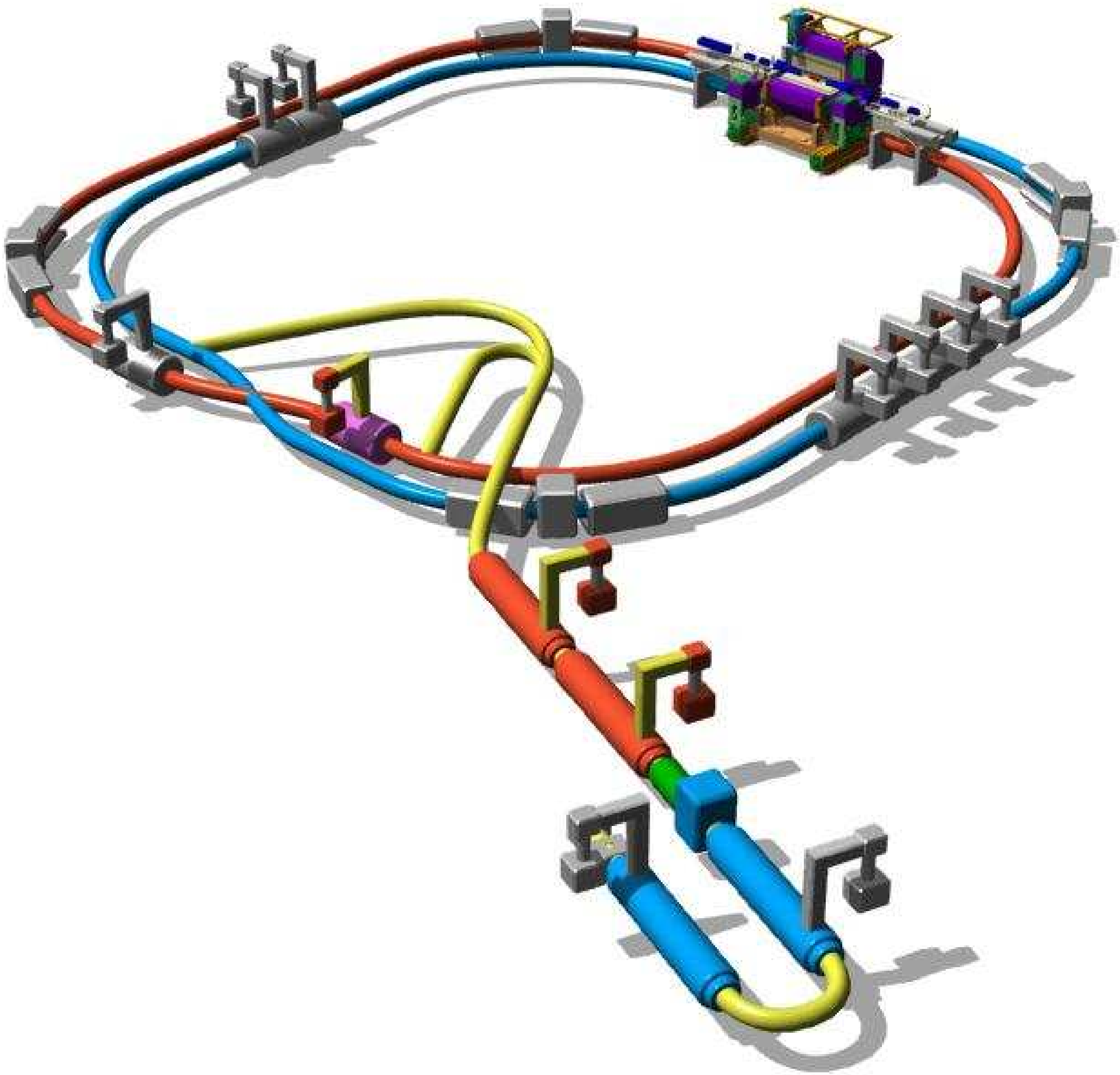


Assuming isospin relation:

$$\mathcal{B}(B \to (\rho, \omega)\gamma) = \left(1.34^{+0.34}_{-0.31}{}^{+0.14}_{-0.10}\right) \times 10^{-6}$$

Significance: 5.5σ

$$|V_{td}/V_{ts}| = 0.200^{+0.026}_{-0.025}(\text{exp})^{+0.038}_{-0.029}(\text{theo})$$



- 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.* $B_{d,s} \to \mu^+\mu^-$)

- 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

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

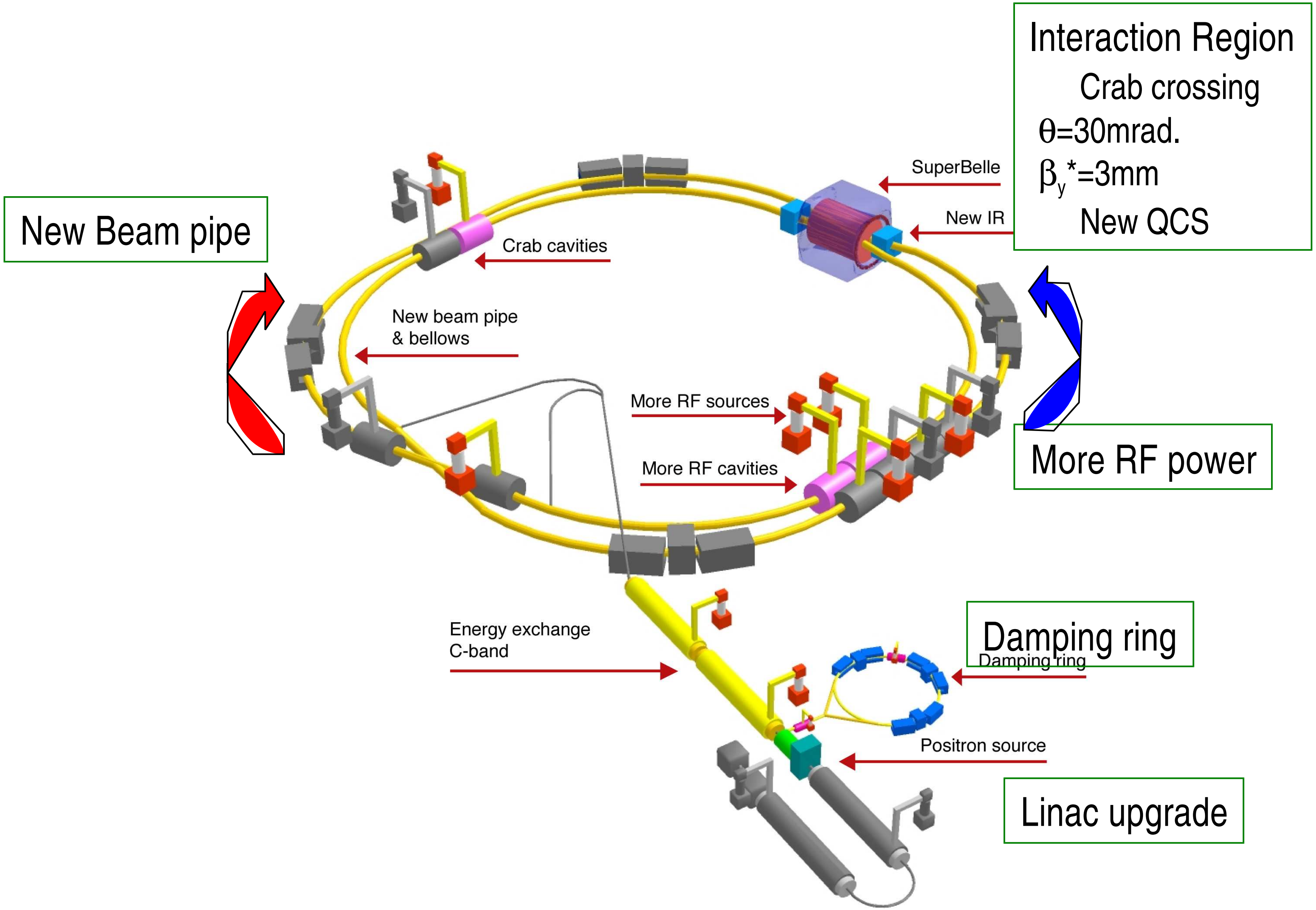
Beam size ratio

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)

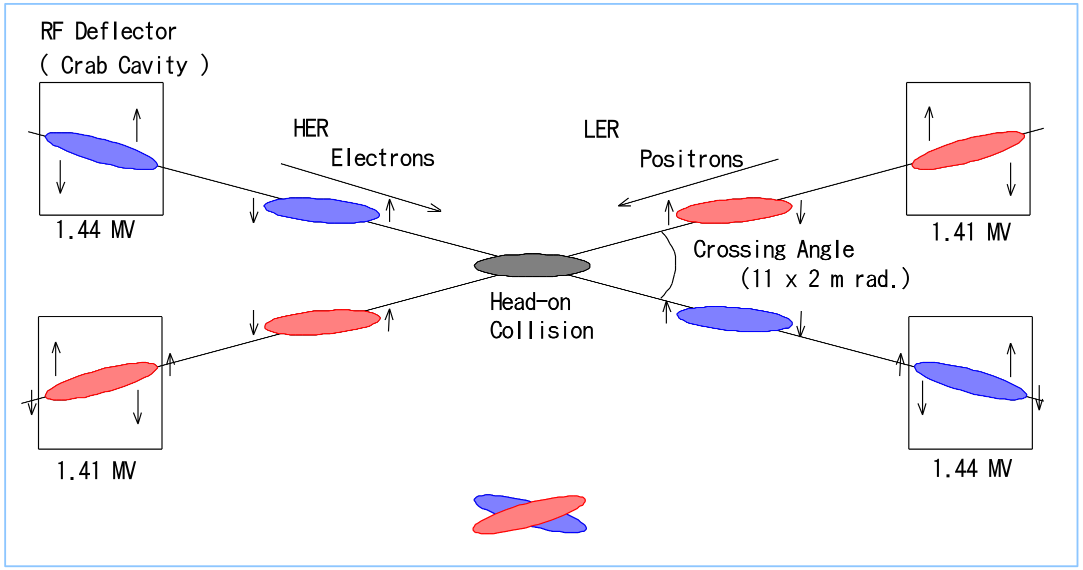
Vertical β at the IP:
5.2/6.5 mm (KEKB)
→ 3.0/3.0 mm (SuperKEKB)

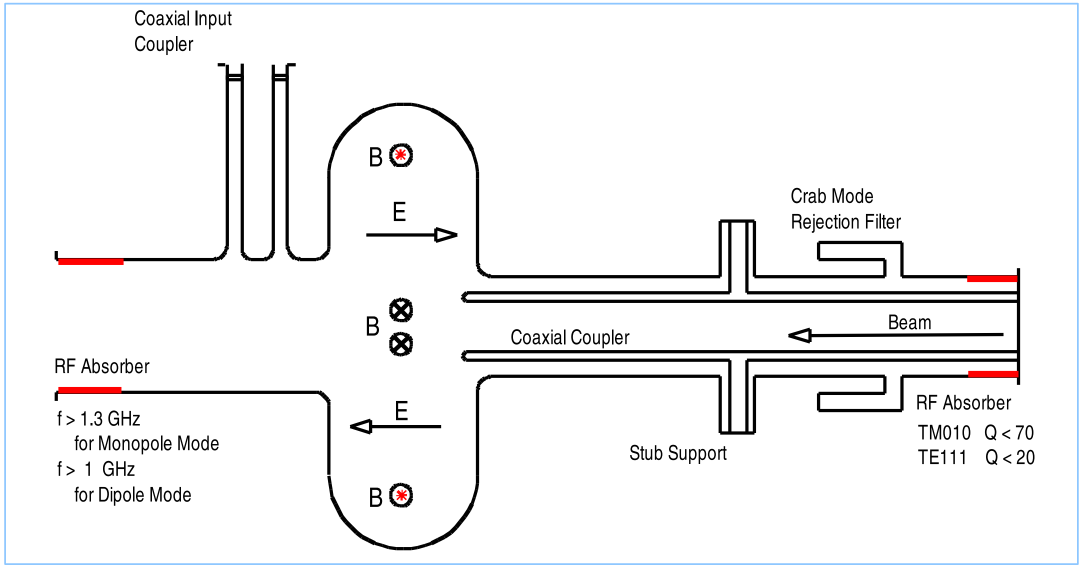
Bunch length (σ_s)
7 ~ 9 mm -> 3 mm



New Beam pipe
Crab cavities
New beam pipe
& bellows
SuperBelle
New IR
Interaction Region
Crab crossing
θ=30mrad.
β_y^*=3mm
New QCS
More RF sources
More RF cavities
More RF power
Energy exchange
C-band
Damping ring
Damping ring
Positron source
Linac upgrade

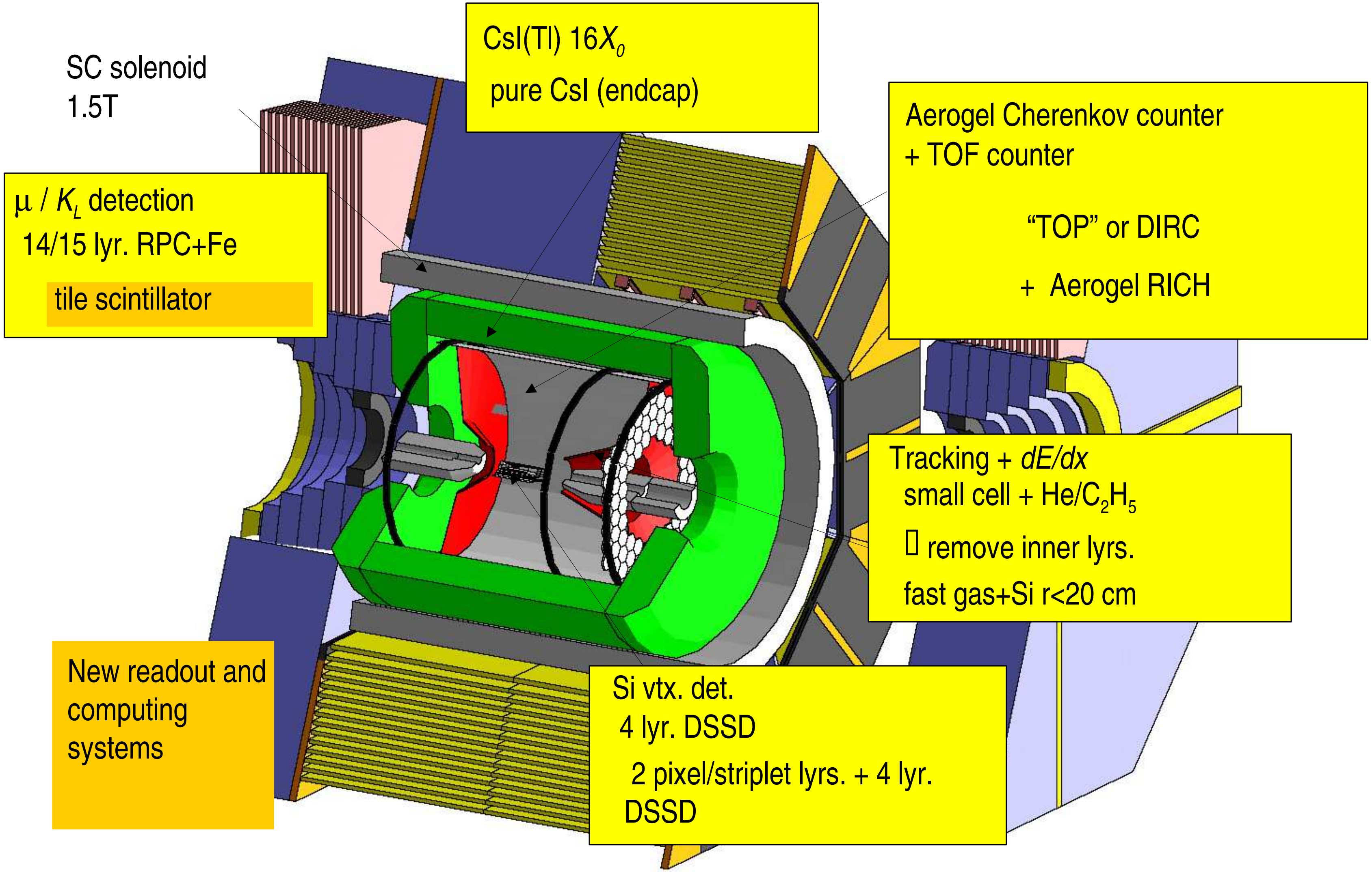
Crab Cavities





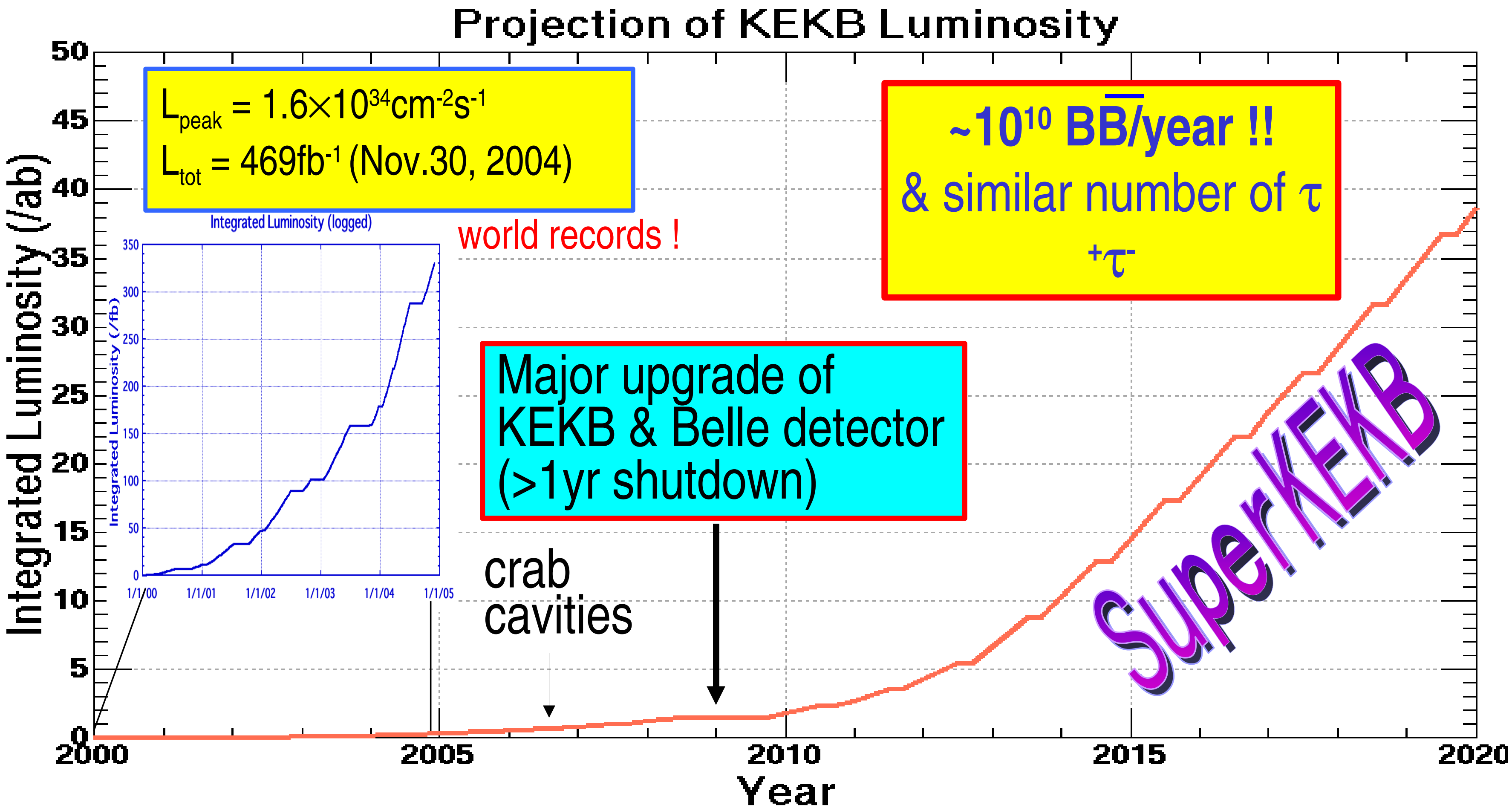
- Head-on collision with finite crossing angle
- Superconducting crab cavities under development
- Will be tested in early 2006

Belle Upgrade for Super-B



- 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



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

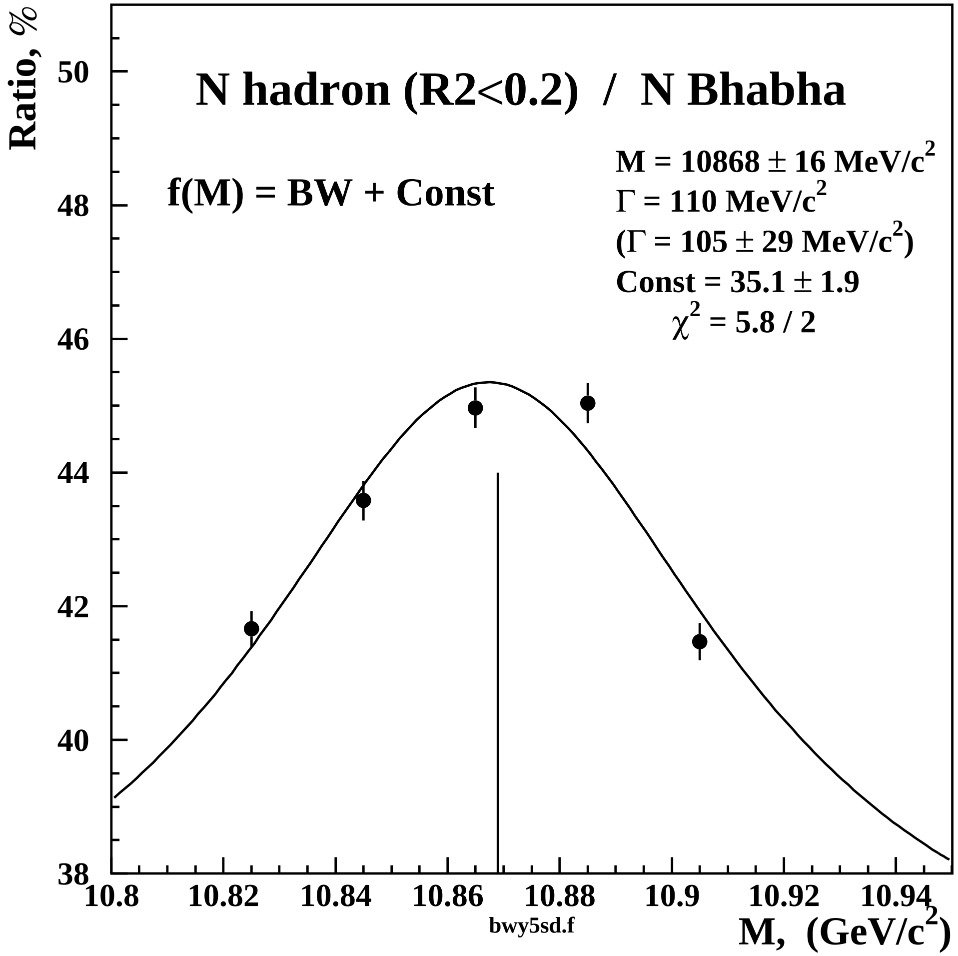
  `http://belle.kek.jp/conferences/CONF2005/`

- 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

Identification of SUSY breaking scenario

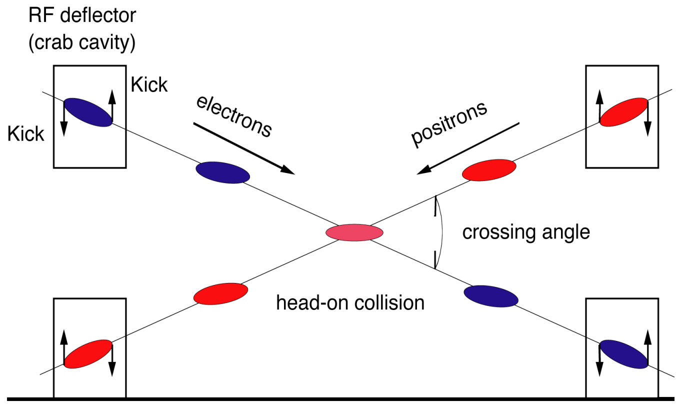
Pattern of deviations from the Standard Model

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 + νR (degenerate)	-	+	+	-	+	-
SU(5)SUSY GUT + νR (non-degenerate)	-	-	+	++	++	+
U(2) Flavor symmetry	+	+	+	++	++	++

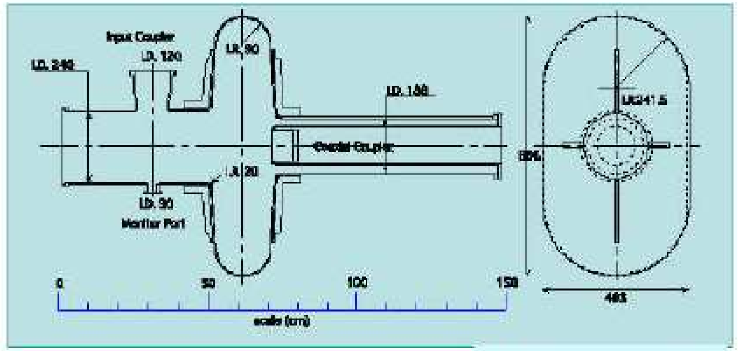
++: Large, +: sizable, -: small

Crab cavity and ante-chamber

- Head-on collision w/ Crab cavity

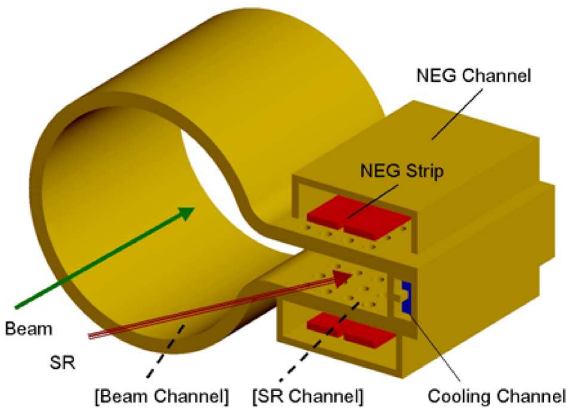


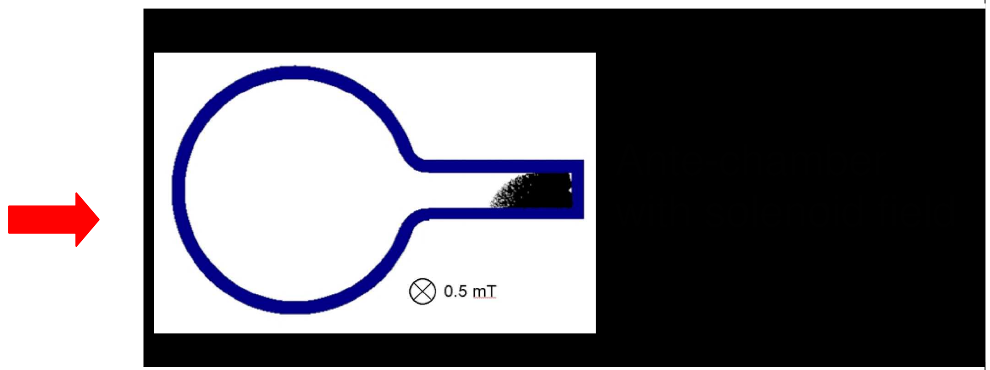
●Superconducting crab cavities are under development, will be installed in KEKB in early 2006.



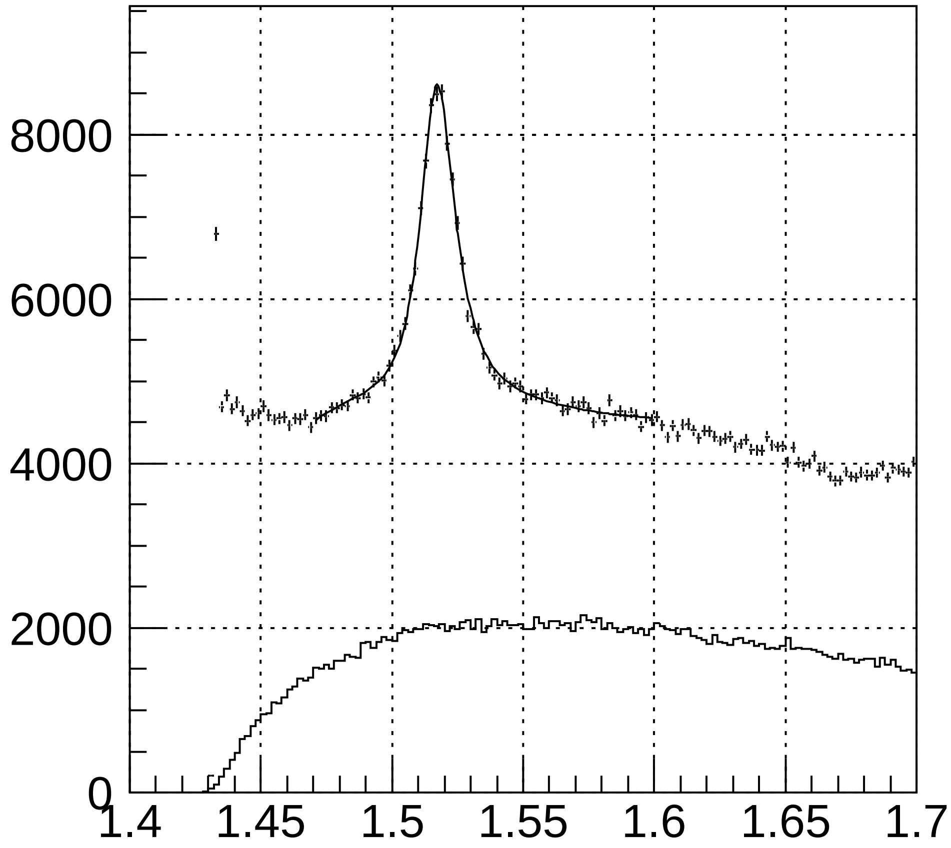
K. Hosoyama, et al

- Ante-chamber /solenoid for reduction of electron clouds





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



$397\ \mathrm{fb}^{-1}$ 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
- $b \to u l \nu$
- $b \to c l \nu$
- $\ldots$

Direct CP violation seen by Belle:

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

Time-dependent CP violation seen by Belle:

- $B^0 \rightarrow J/\psi K^0$ ($\sim$ 65% $>> 5\sigma$)
- $B^0 \rightarrow \pi^+\pi^-$ ($\sim$ 65% $> 5\sigma$)
- $B^0 \rightarrow \eta' K^0$ ($\sim$ 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%
$K_S f_0(980)$	0.394 ± 0.006	207 ± 3	4.9%
$K_S\sigma_2$	0.23 ± 0.03	210 ± 13	0.6%
$K_S f_2(1270)$	1.32 ± 0.04	348 ± 2	1.5%
$K_S f_0(1370)$	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°

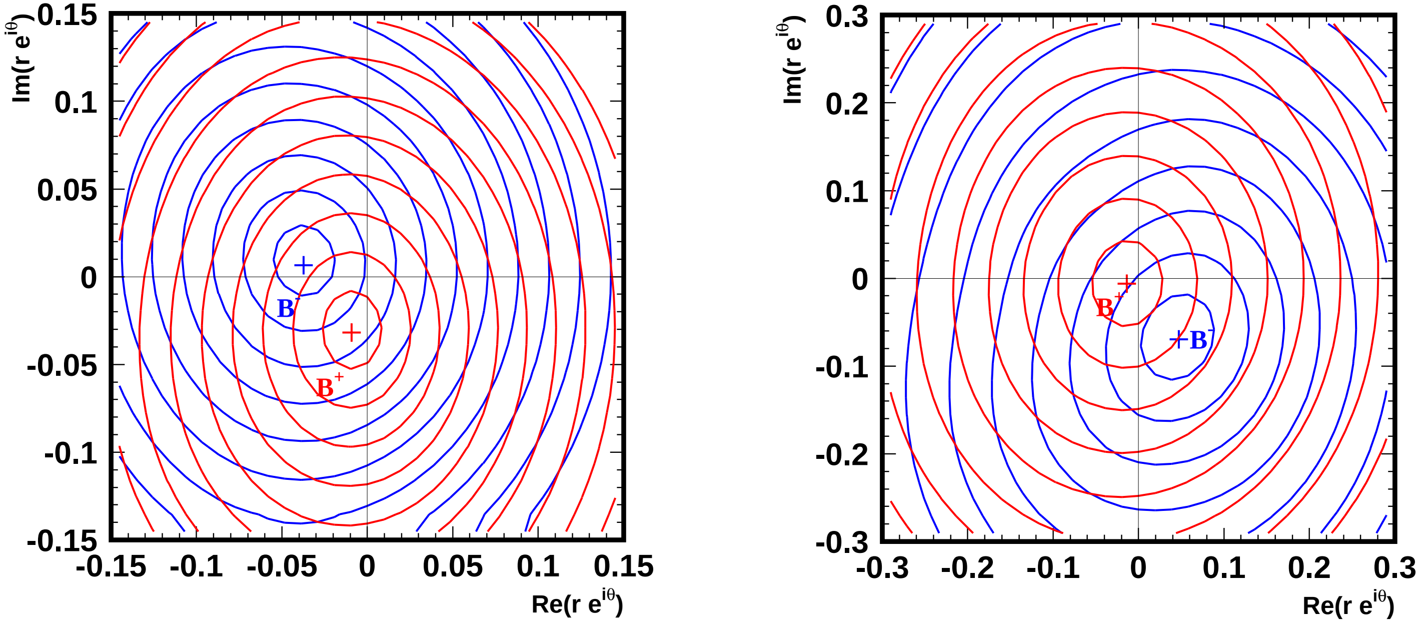
- Consider CP-tagged D mesons decaying to $K_S\pi^+\pi^-$
  $\rightarrow$ amplitude is $f(m_+^2, m_-^2) \pm f(m_-^2, m_+^2)$
- FUTURE: use CP tagged D mesons from $c\tau$ factory ($\psi'' \rightarrow D\bar{D}$)
  $\hookrightarrow$ measure $\phi(m_+^2, m_-^2) \Rightarrow$ remove model uncertainty

Test Samples

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

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

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



3425 events

$r_{B-} = 0.047 \pm 0.018$

$\theta_- = 193^\circ \pm 24^\circ$

$r_{B+} = 0.039 \pm 0.021$

$\theta_- = 240^\circ \pm 28^\circ$

641 events

$r_{B-} = 0.086 \pm 0.049$

$\theta_- = 280^\circ \pm 30^\circ$

$r_{B+} = 0.015 \pm 0.042$

$\theta_- = 170^\circ \pm 186^\circ$

253 fb^{-1} BELLE-CONF-0476, BELLE-CONF-0502

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

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

- CP asymmetries

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

$$A_{D^{(*)}_{1}K^-} = \frac{2r_B \sin(\delta_B)\sin(\phi_3)}{1+{r_B}^2+2r_B\cos(\delta_B)\cos(\phi_3)} \qquad A_{D^{(*)}_{2}K^-} = \frac{-2r_B \sin(\delta_B)\sin(\phi_3)}{1+{r_B}^2-2r_B\cos(\delta_B)\cos(\phi_3)}$$

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

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

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

- 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

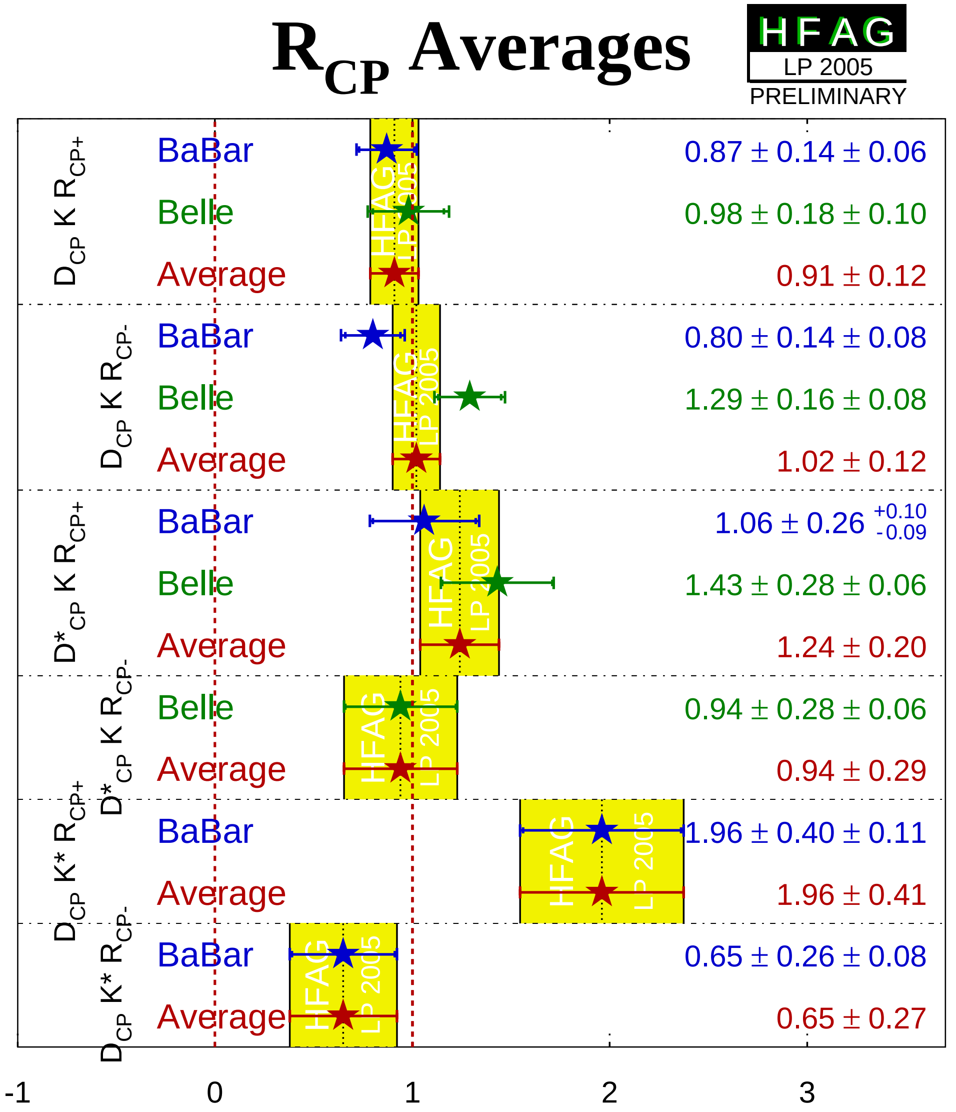
PRELIMINARY

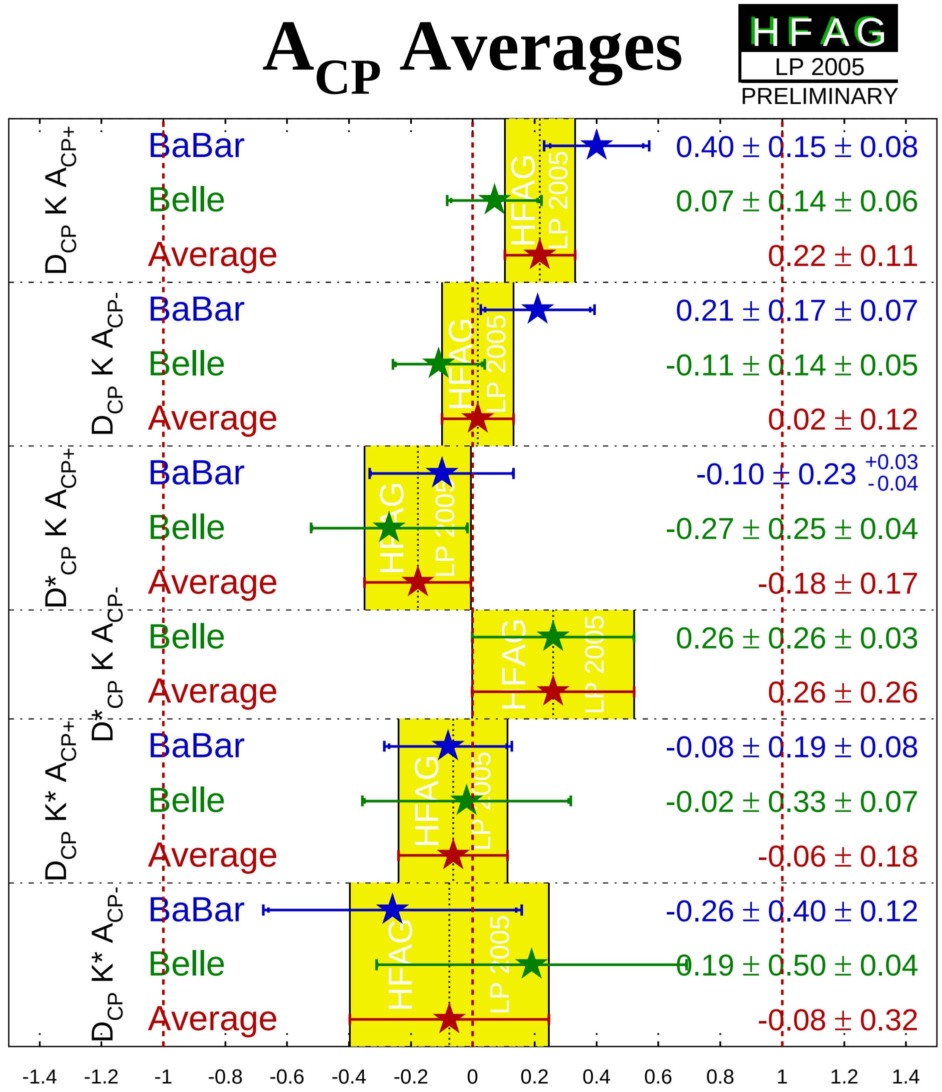
	$B^\mp \to DK^\mp$	$B^\mp \to D^* K^\mp$
$\mathcal{A}_1$	$0.07 \pm 0.14(\text{stat}) \pm 0.06(\text{syst})$	$-0.27 \pm 0.25(\text{stat}) \pm 0.04(\text{syst})$
$\mathcal{A}_2$	$-0.11 \pm 0.14(\text{stat}) \pm 0.05(\text{syst})$	$0.26 \pm 0.26(\text{stat}) \pm 0.03(\text{syst})$
$\mathcal{R}_1$	$0.98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

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

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

World Averages



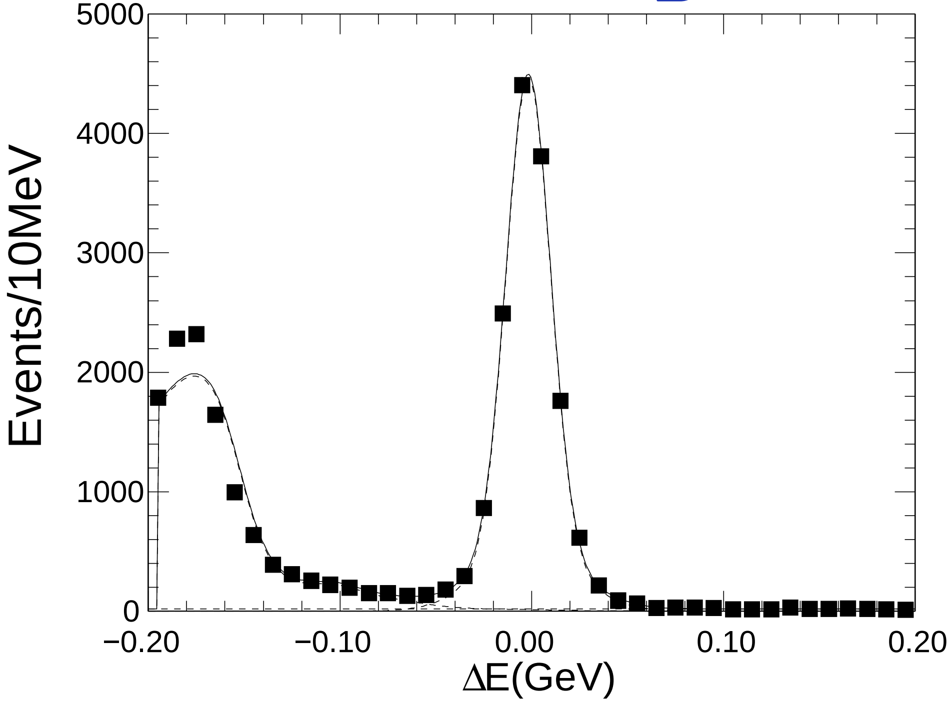


PRELIMINARY

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

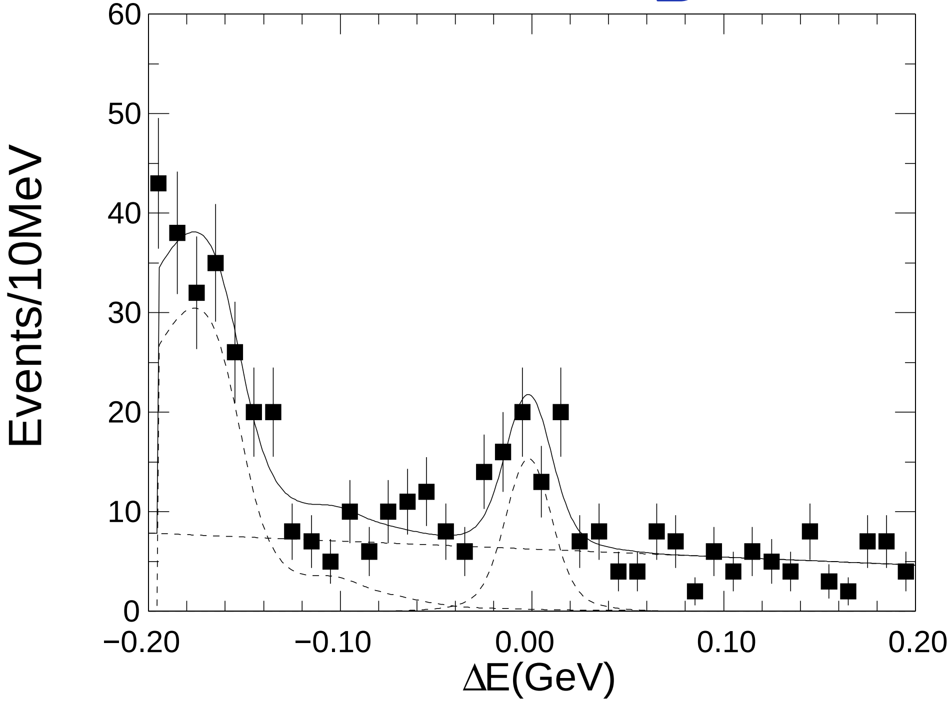
357 fb^{-1} BELLE-CONF-0552

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



14518 ± 125 signal events

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



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

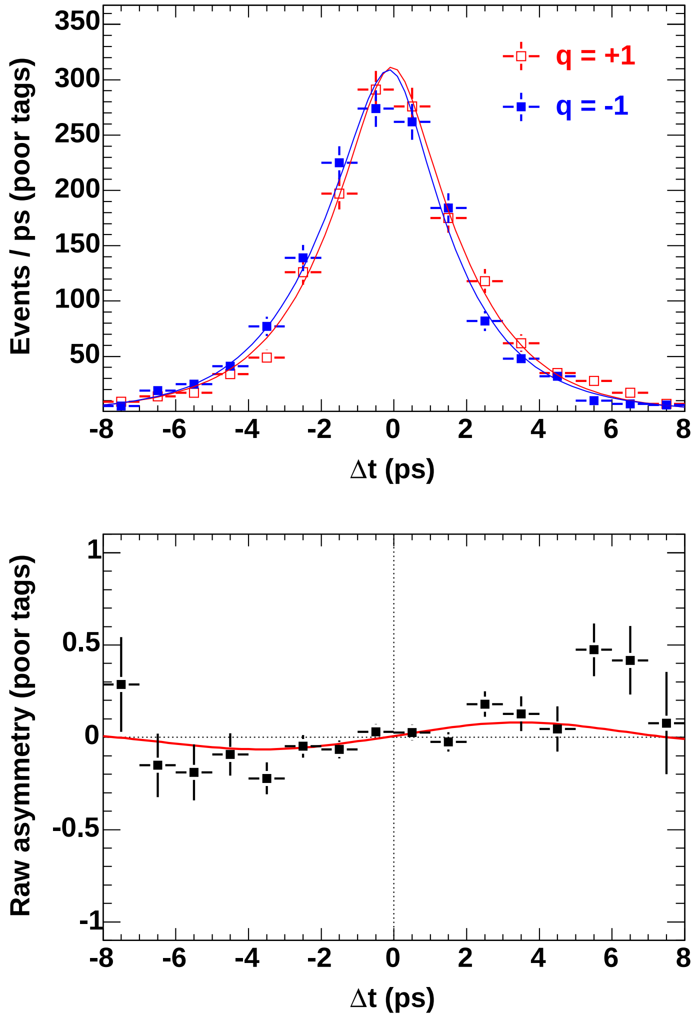
$$\mathcal{R}_{D\pi} = (3.5\,^{+0.8}_{-0.7}\,(\text{stat}) \pm 0.3\,(\text{syst})) \times 10^{-3}$$

Consistent with previous Belle result

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

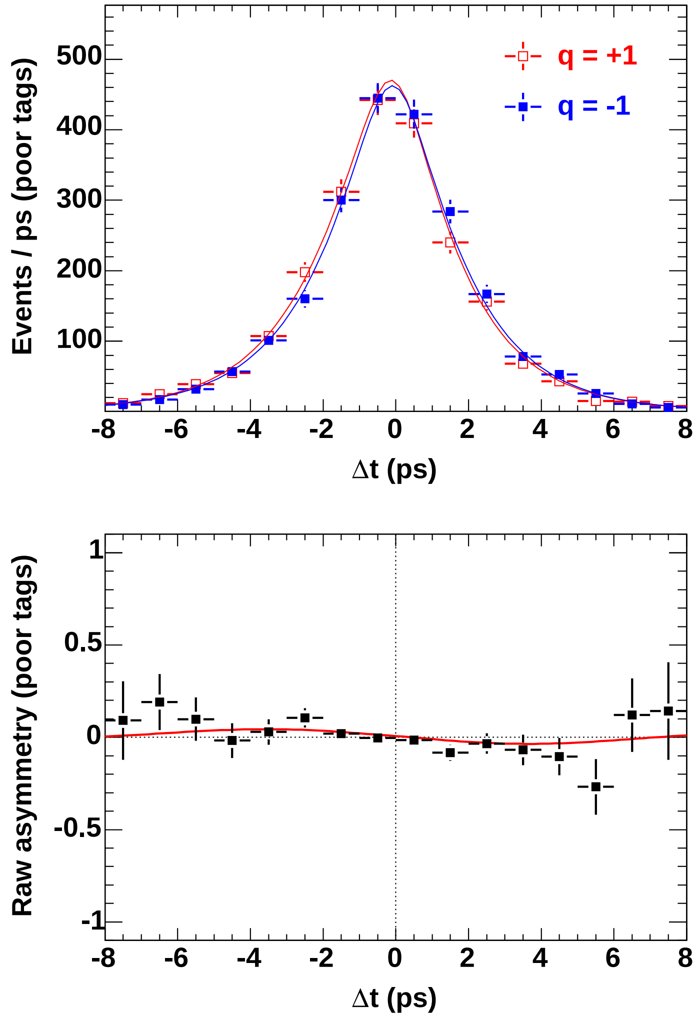
$357\ \text{fb}^{-1}$ BELLE-CONF-0569

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



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

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



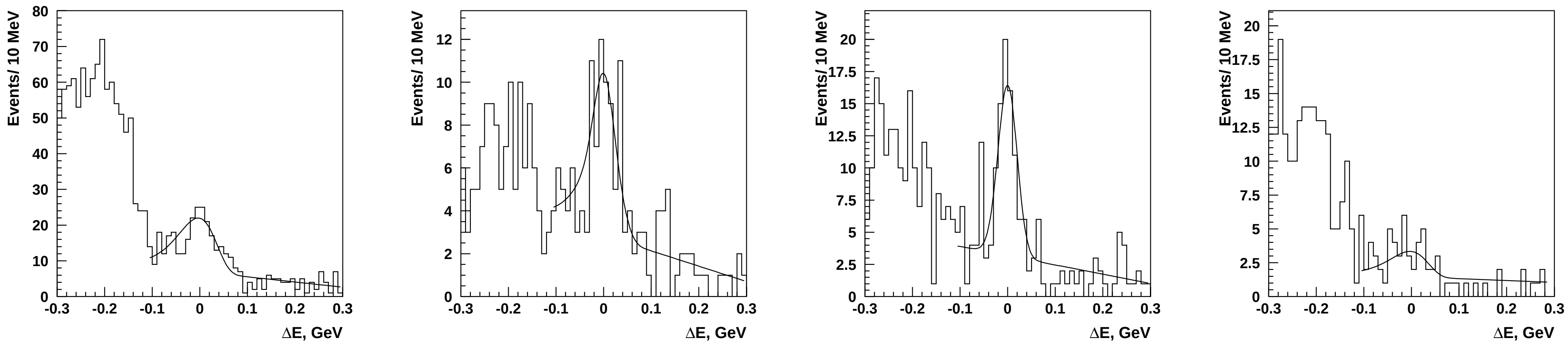
$$S = -0.619 \pm 0.069(\text{stat})$$
$$A = +0.049 \pm 0.039(\text{stat})$$

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

357 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 $B^0 \to D h^0$ decays ($h^0 = \pi^0, \eta, \ldots$)
- Similar to $B^+ \to D K^+$ analysis for ϕ_3
- Test SM prediction: $S_{b \to c\bar{c}s} \simeq S_{b \to c\bar{u}d}$

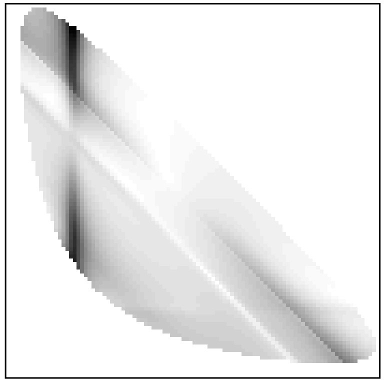
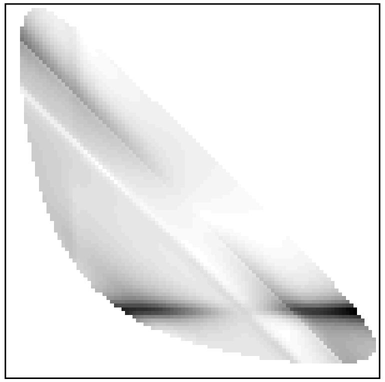
$D\pi^0$ $D\eta$ $D\omega$ $D^*\pi^0 \& D^*\eta$

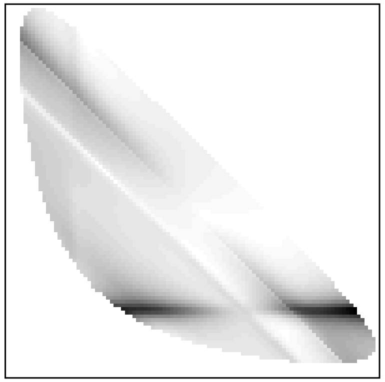
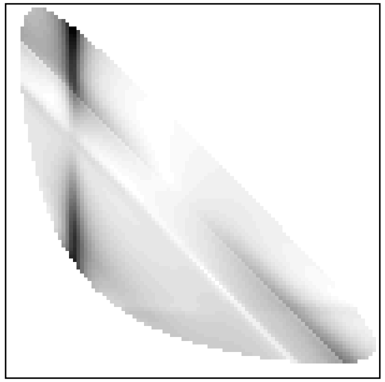


Description of the Method (Pictures)

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

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

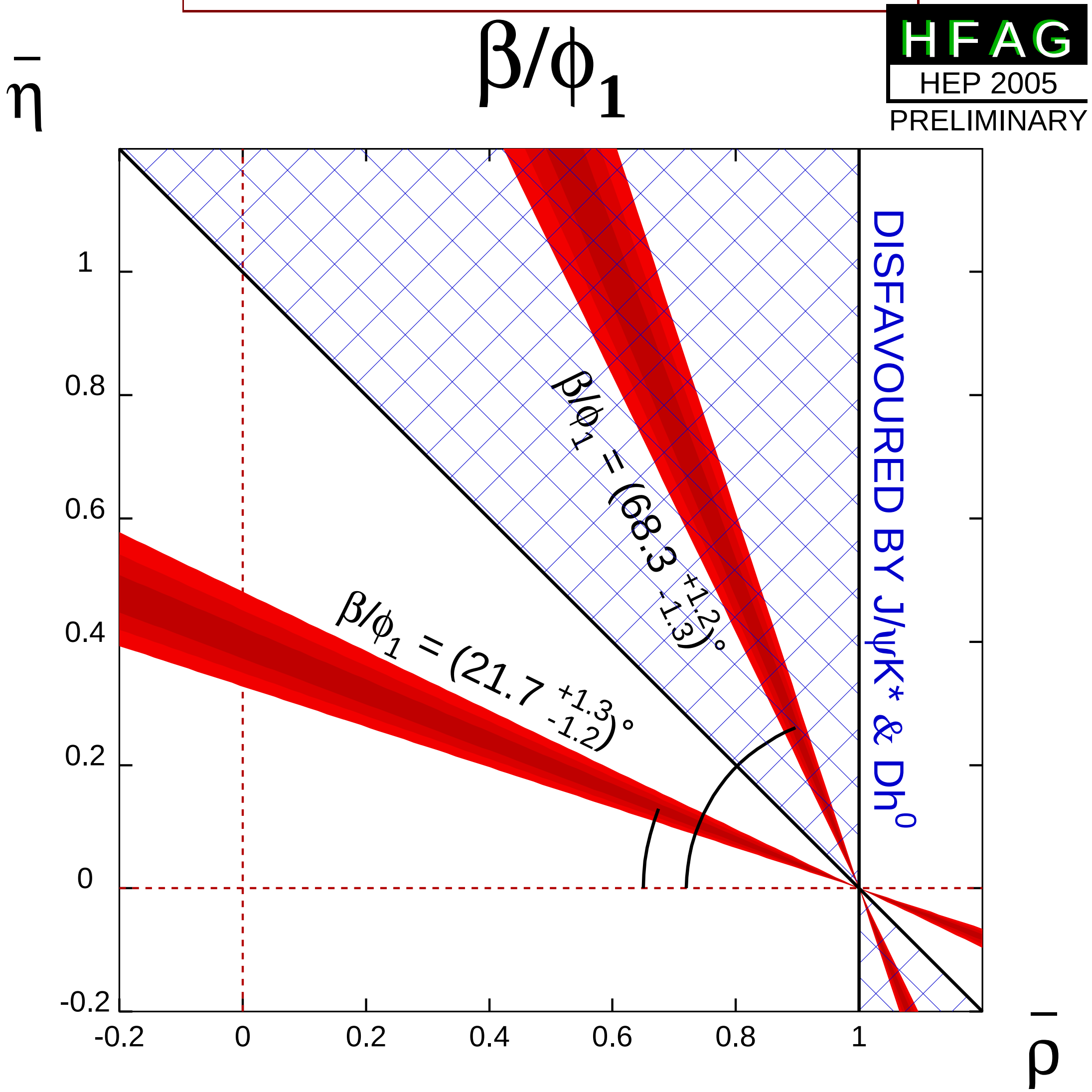
$\Gamma_{\bar{B}^0}(\Delta t) \propto \Big|$  $\cos\left(\frac{\Delta m \Delta t}{2}\right) - i\Phi^*$  $\sin\left(\frac{\Delta m \Delta t}{2}\right)\Big|^2$

$\Gamma_{B^0}(\Delta t) \propto \Big|$  $\cos\left(\frac{\Delta m \Delta t}{2}\right) - i\Phi$  $\sin\left(\frac{\Delta m \Delta t}{2}\right)\Big|^2$

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

$\sin(2\phi_1)$ — Constraint

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



357 fb^{-1}

BELLE-CONF-0546

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

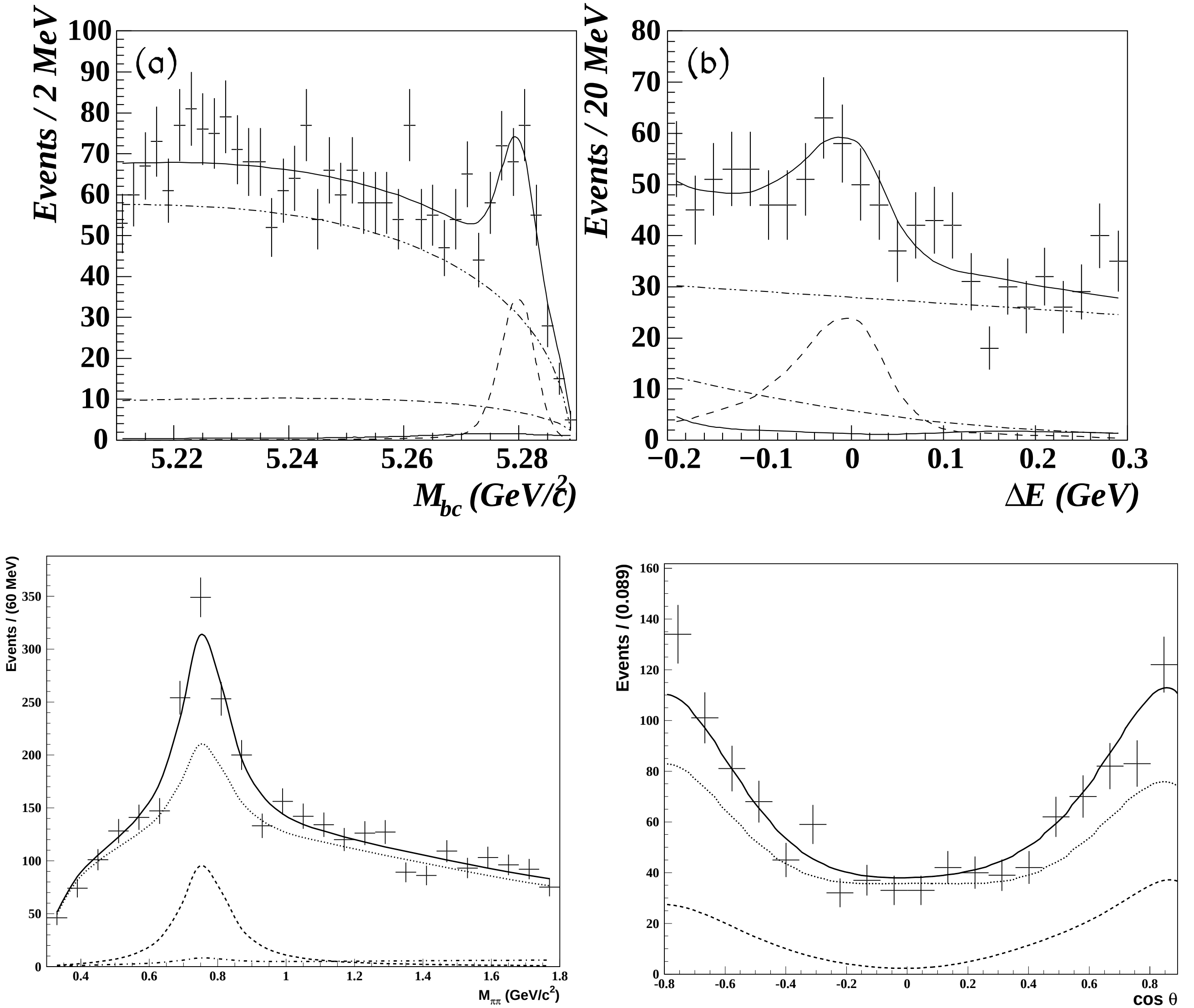
Initial attempts to extract ϕ_2 have focussed on $B^0 \to \pi^+\pi^-$.
However,

- 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)

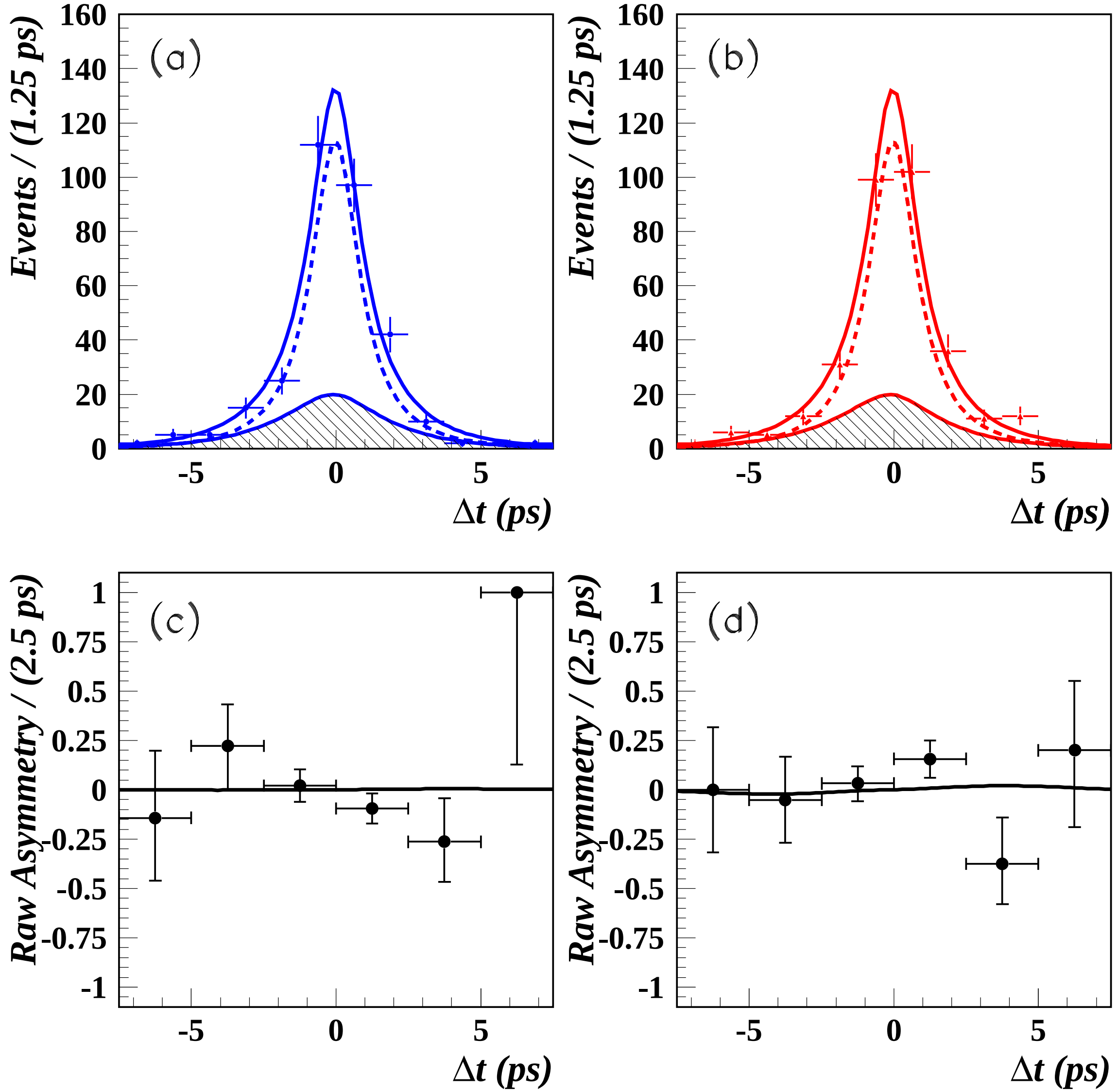


253 fb^{-1} BELLE-CONF-0545

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

$B^0 \to \rho^+\rho^-$ — CP Fit

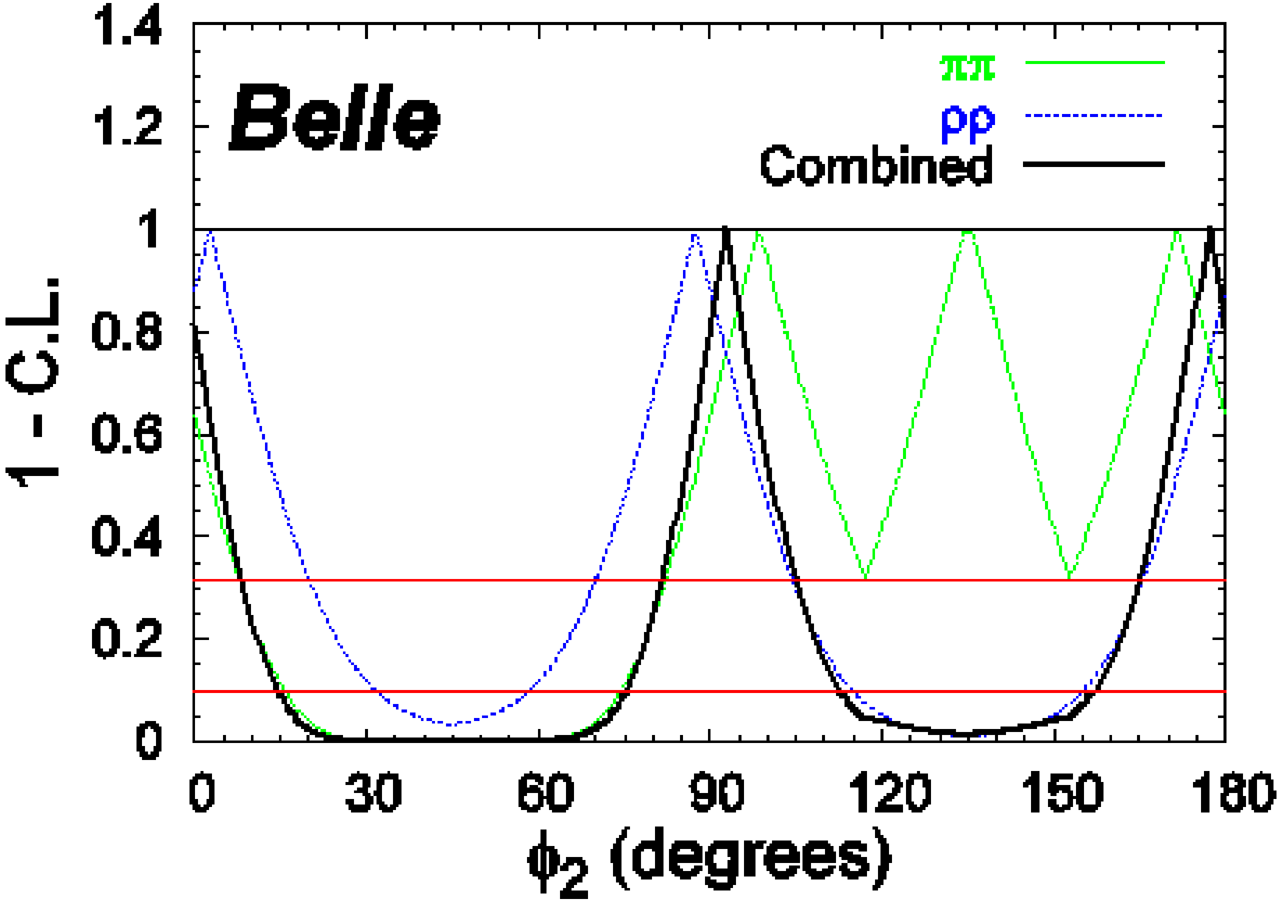
253 fb^{-1} BELLE-CONF-0545



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

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 $e^{-|\Delta t|/2\tau_{B^0}}$ dropped)

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

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

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

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

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

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

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

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

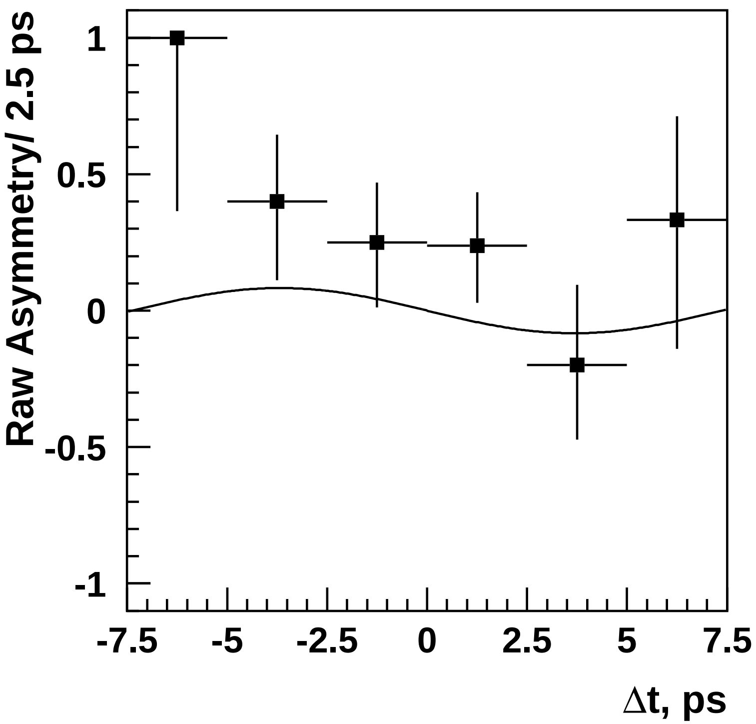
357 fb^{-1} BELLE-CONF-0546

Process	$N_{\rm tot}$	Efficiency (%)	$N_{\rm sig}$	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, $^\circ$
$D\pi^0$	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.

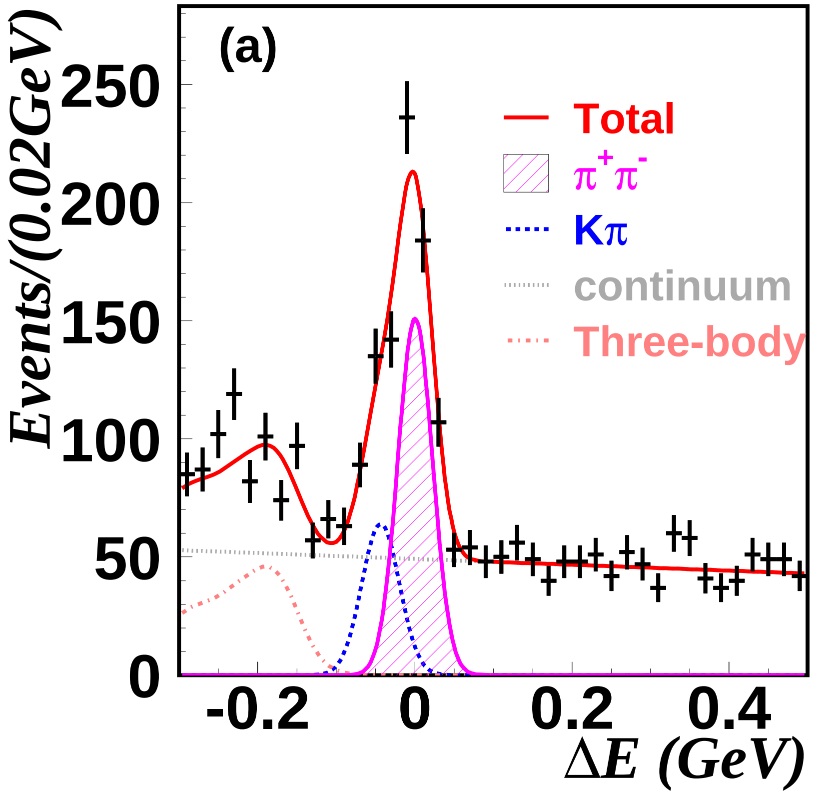


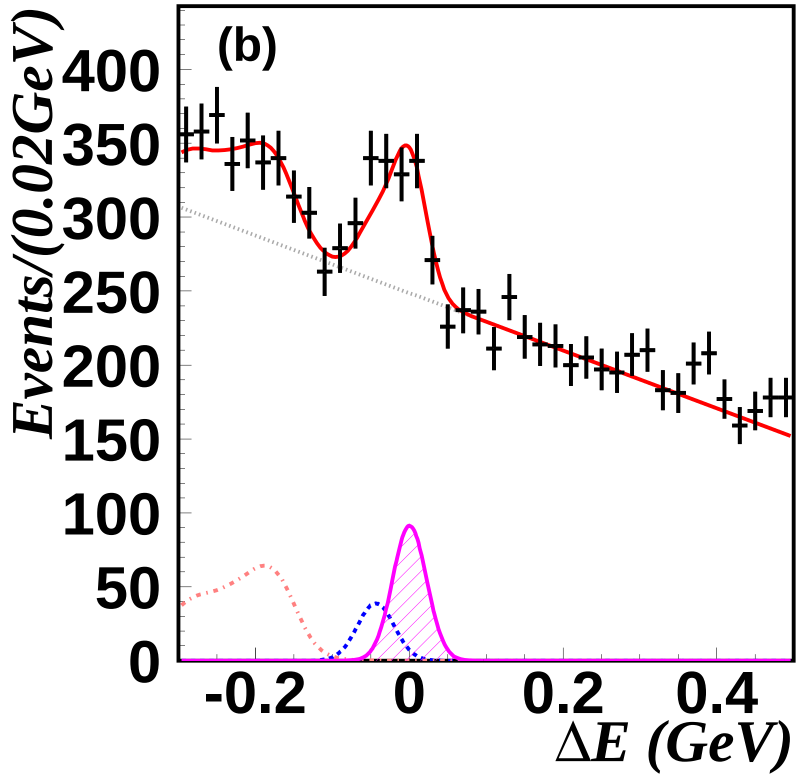
253 fb^{-1} BELLE-CONF-0501

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

High quality

Low quality

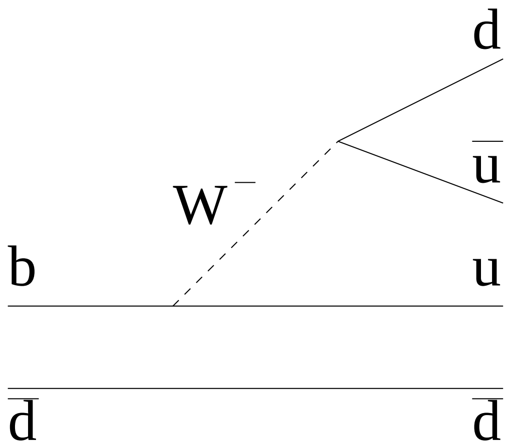




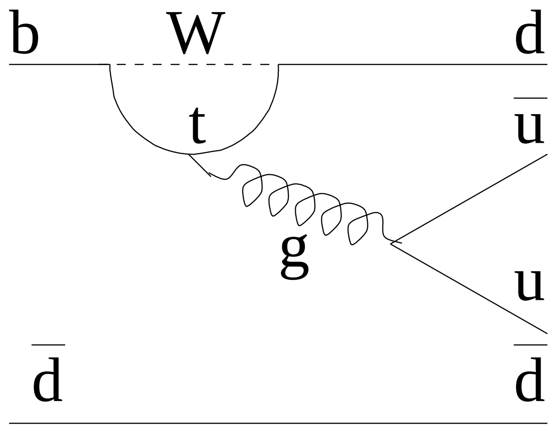
253 fb^{-1} BELLE-CONF-0501

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

253 fb^{-1} BELLE-CONF-0501

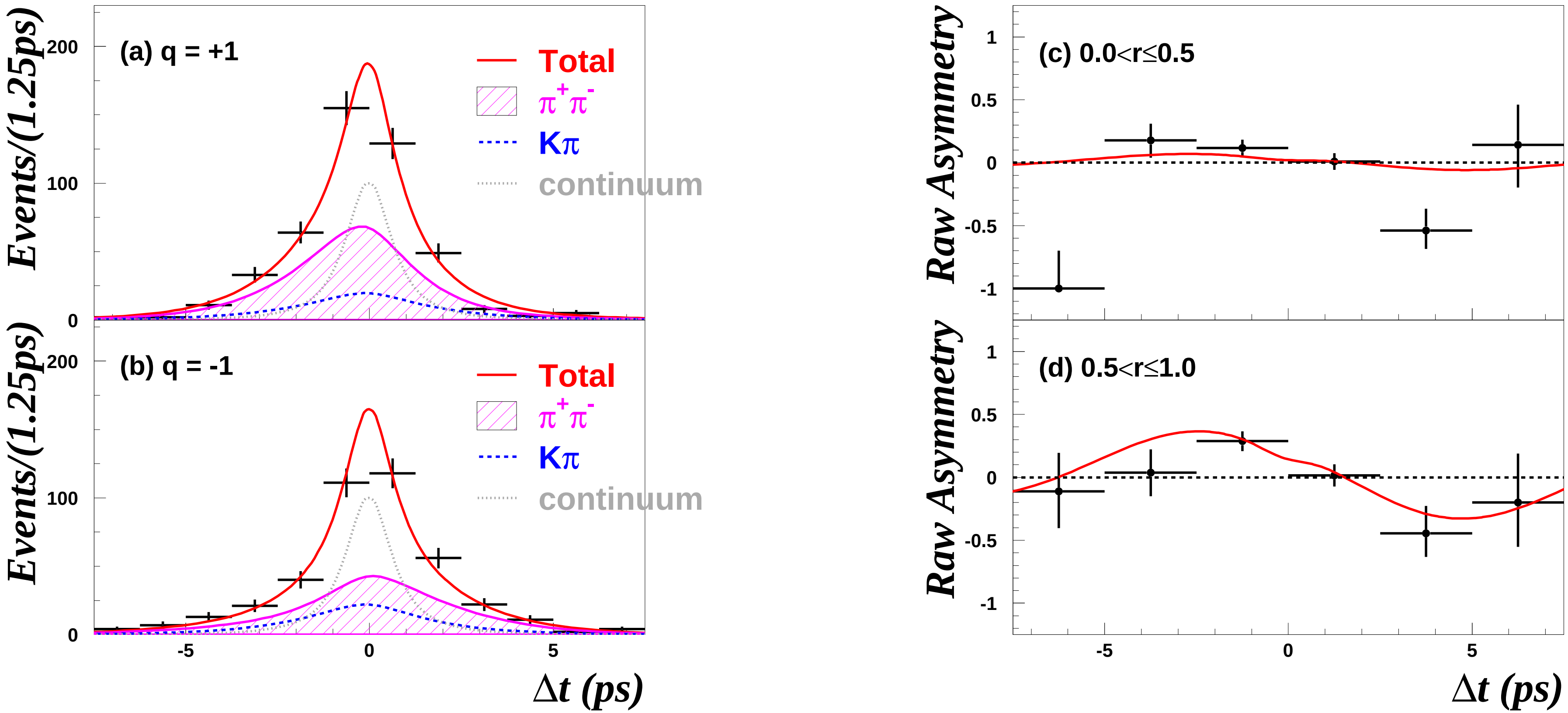
$*$ 2820 candidates $*$

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

$*$ 666 $\pm$ 43 $\pi^+\pi^-$ signal events $*$

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

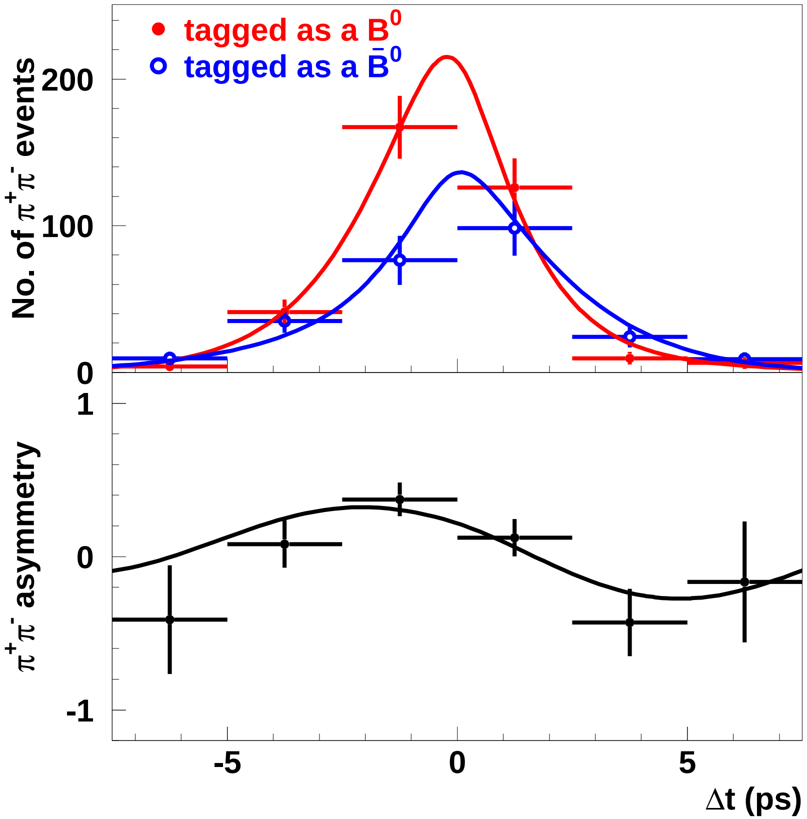
Plots for high quality events only

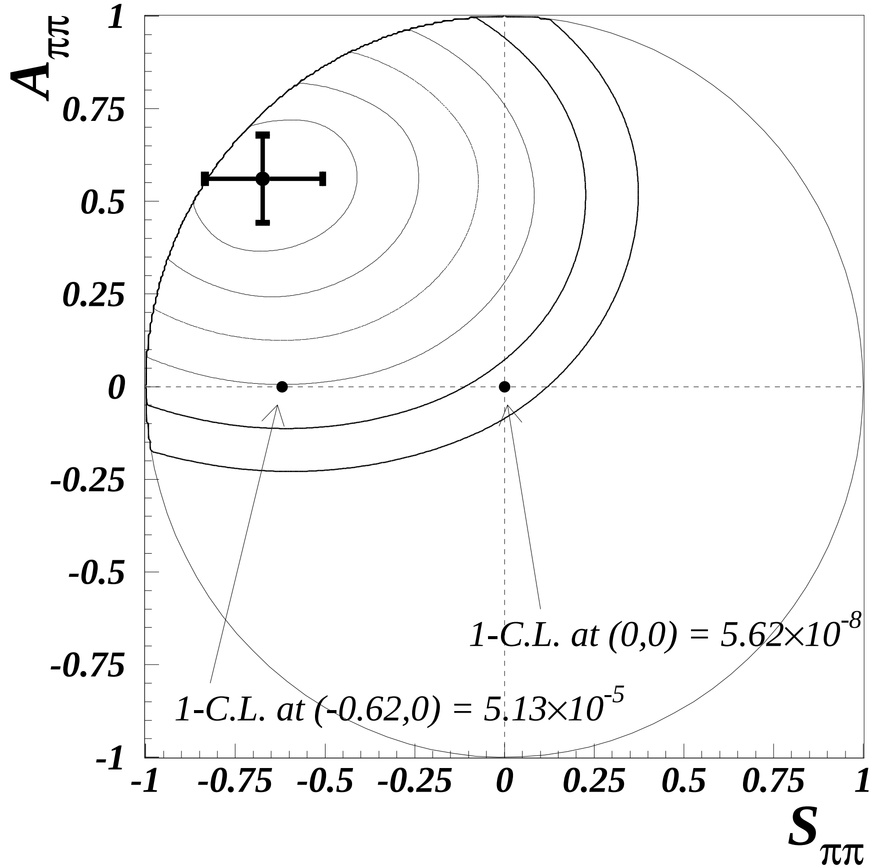


$253\ \text{fb}^{-1}$

BELLE-CONF-0501

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





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

253 fb^{-1} BELLE-CONF-0501

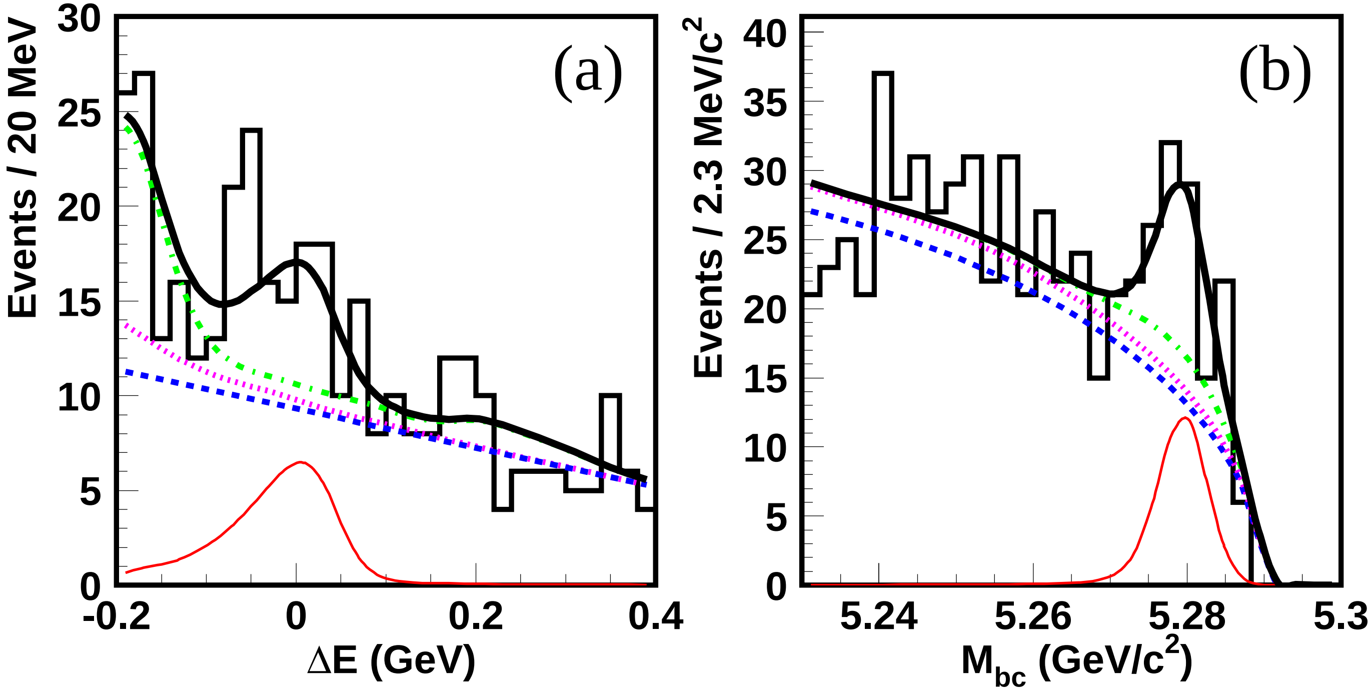
- Due to large penguin contribution need isospin analysis to extract ϕ_2
- Such analyses are underway . . .
- Current limitation from knowledge of $B^0 \to \pi^0\pi^0$
  - branching fraction
  - direct CP asymmetry
- Other avenues for ϕ_2 ($\rho^\pm\pi^\mp$, $\rho^\pm\rho^\mp$, *etc.*) being explored

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

- 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

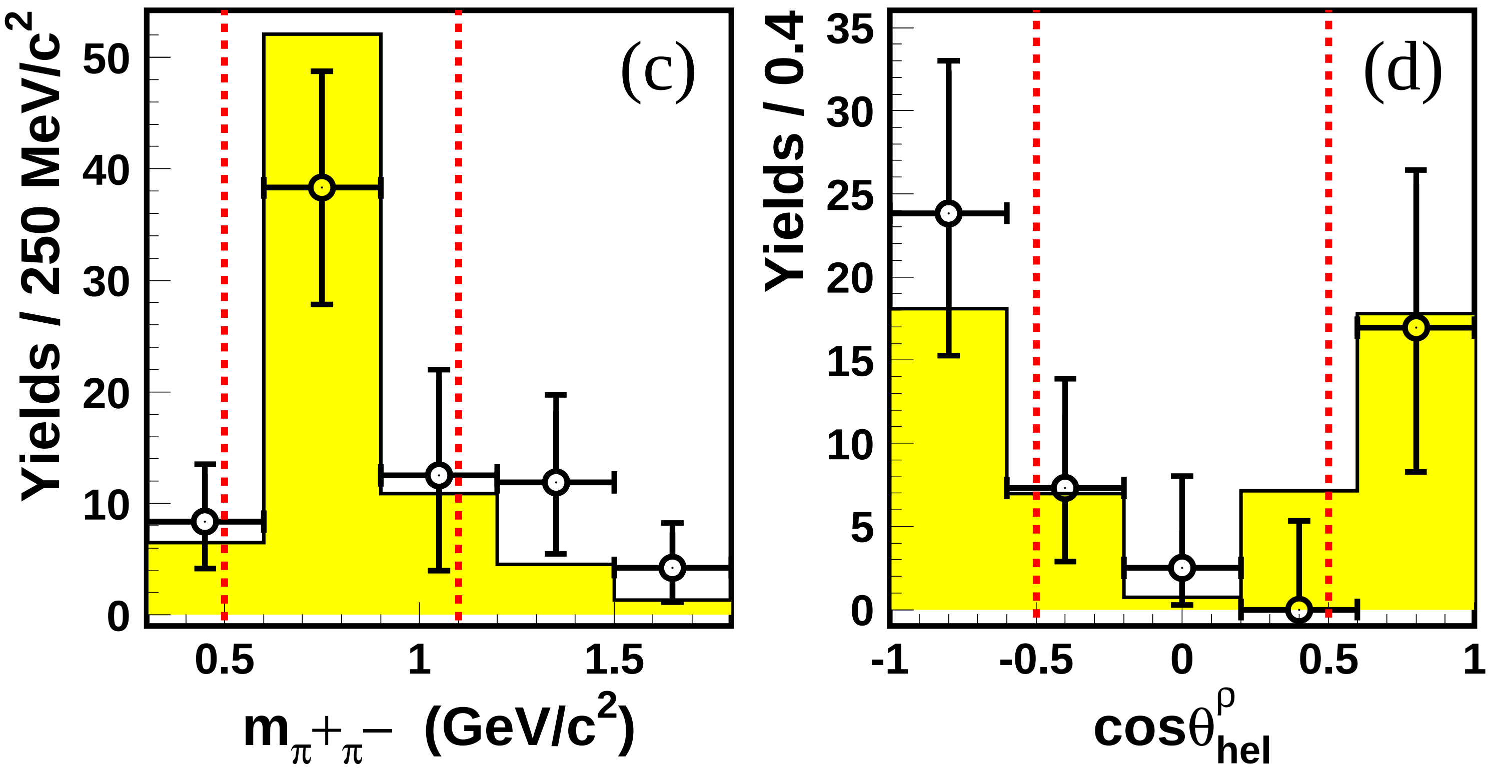
357 fb^{-1} BELLE-CONF-05



Significance: 4.2σ

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

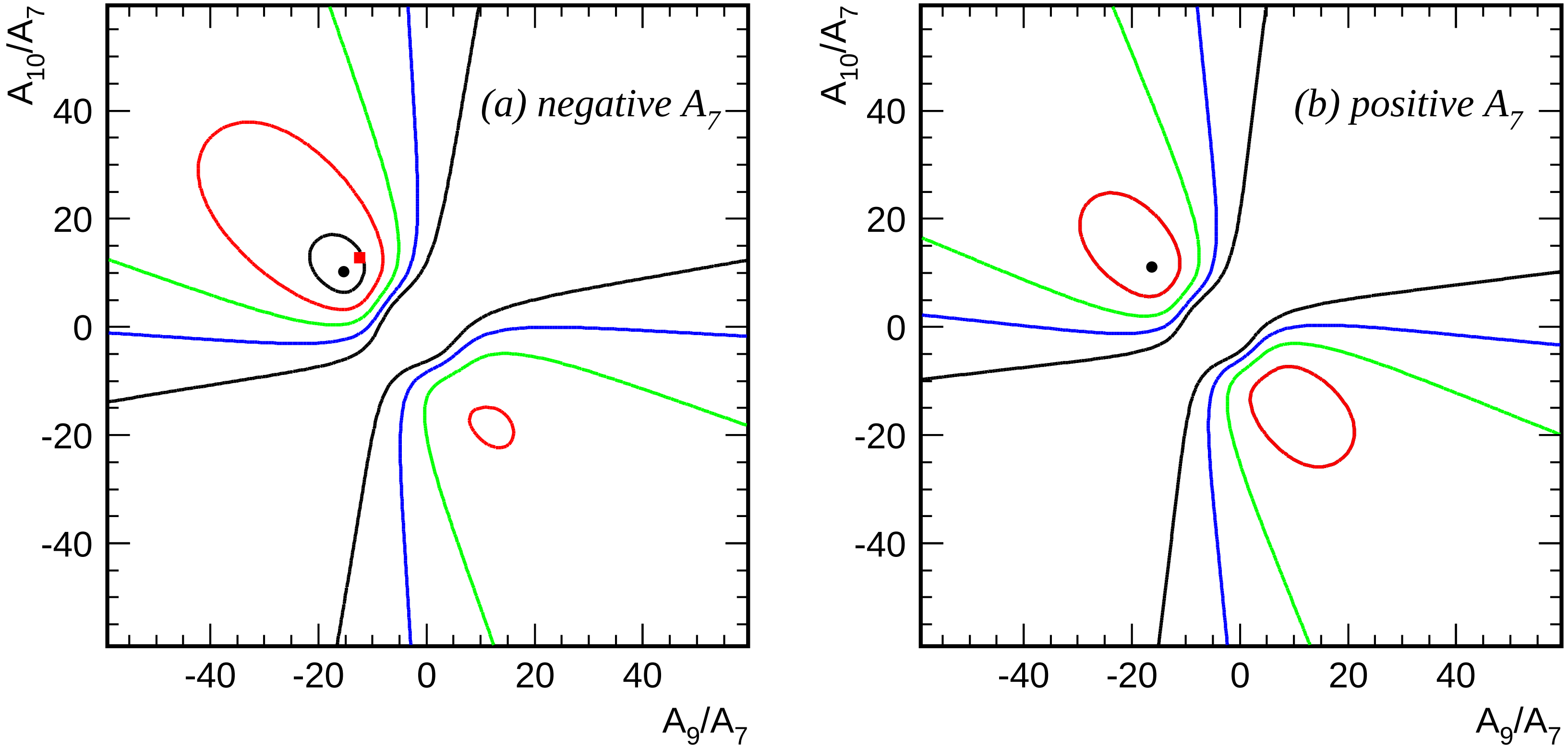
357 fb^{-1} BELLE-CONF-05



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

386 fb^{-1}

BELLE-CONF-0521



$$A_9/A_7 = -15.3\,^{+3.4}_{-4.8} \pm 1.1 \qquad A_9/A_7 = -16.3\,^{+3.7}_{-5.7} \pm 1.4$$

$$A_{10}/A_7 = 10.3\,^{+5.2}_{-3.8} \pm 1.8 \qquad A_{10}/A_7 = 11.1\,^{+6.0}_{-3.9} \pm 2.4$$