Unitarity Triangle Angles from Belle

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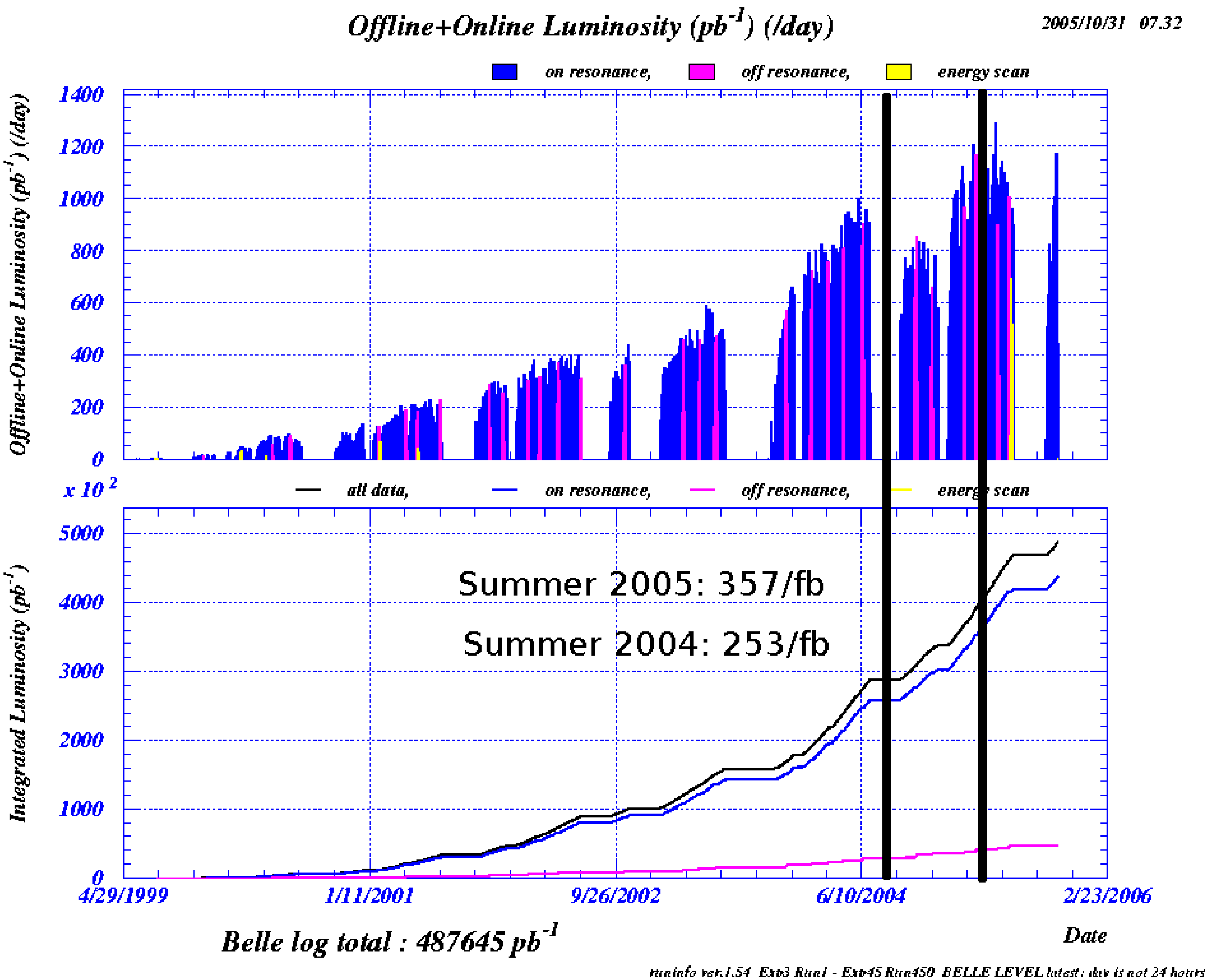
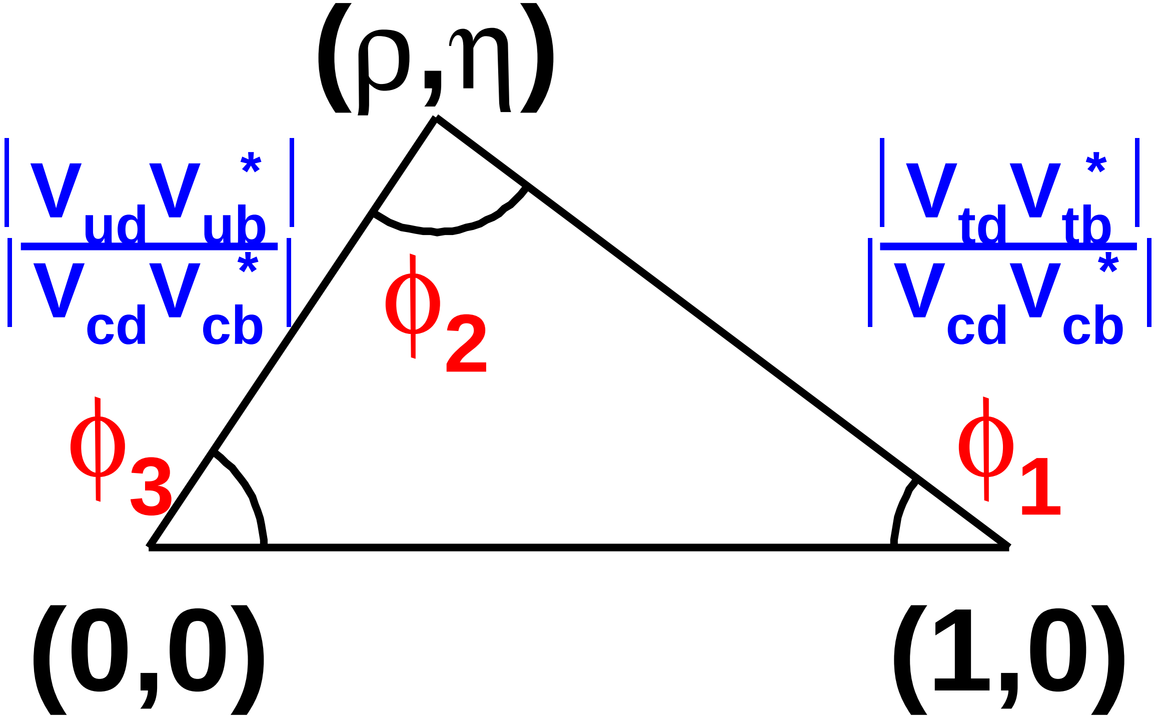
8 November, 2005

Integrated Luminosity





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^-)
$b \to c\bar{u}d$ ($D\pi^0$)		$b \to u\bar{u}s$ & $b \to u\bar{u}d$ ($K\pi$ & $\pi\pi$)
$b \to c\bar{c}d$ ($J/\psi\pi^0$, D^+D^-)		$2\phi_1 + \phi_3$
$b \to s\bar{q}q$ (ϕK_S, etc.)		$b \to c\bar{u}d/u\bar{c}d$ ($D^+\pi^-$)

. . . and others

Can use unitarity to select measured phase . . . consistency invariant

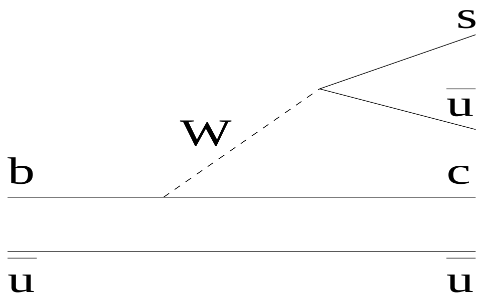
ϕ_3 from $B \to DK$

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

  Bigi & Sanda; Gronau, London & Wyler; Atwood, Dunietz & Soni

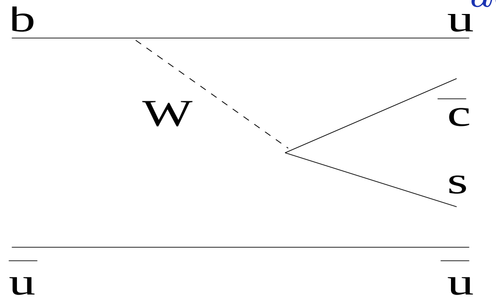
- Reconstruct D in any final state accessible to both D^0 and $\bar{D}^0$

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



COLOUR ALLOWED

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



COLOUR SUPPRESSED

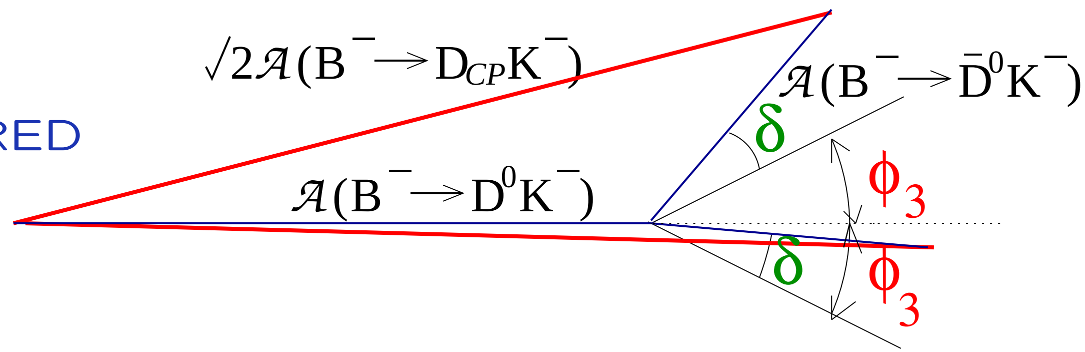
- Tree diagrams only — super clean

$\mathcal{A}$ — amplitude

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

$\sim 0.1 - 0.2$

δ_B — strong phase difference

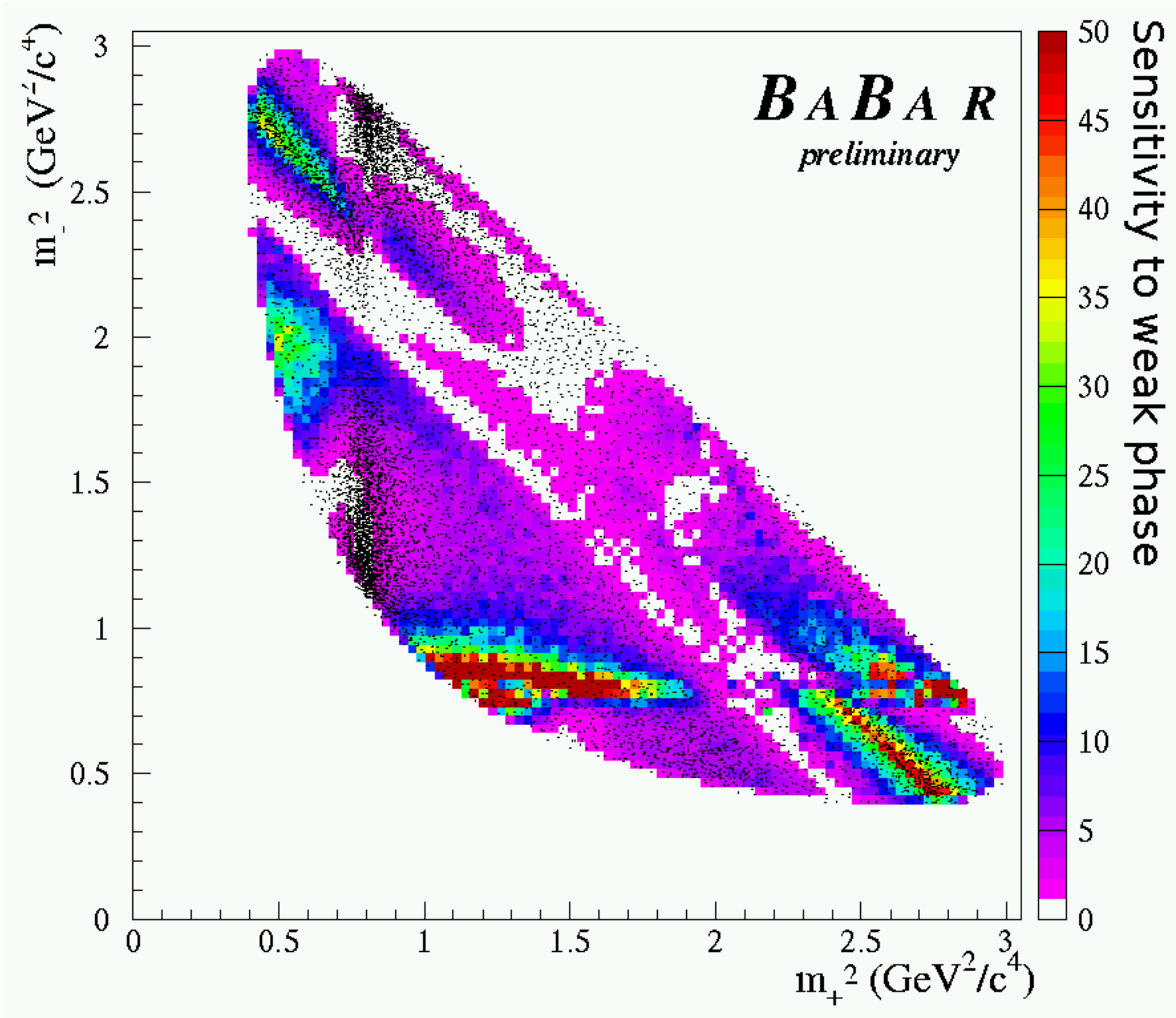


ϕ_3 from $B \to DK$: Final States

- 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
  - $K_SK^+K^-$, $\pi^+\pi^-\pi^0$, $K_S\pi^\pm K^\mp$, $K^\pm\pi^\mp\pi^0$, $K_S\pi^+\pi^-\pi^0$, ...

Why is $D \to K_S\pi^+\pi^-$ so good?

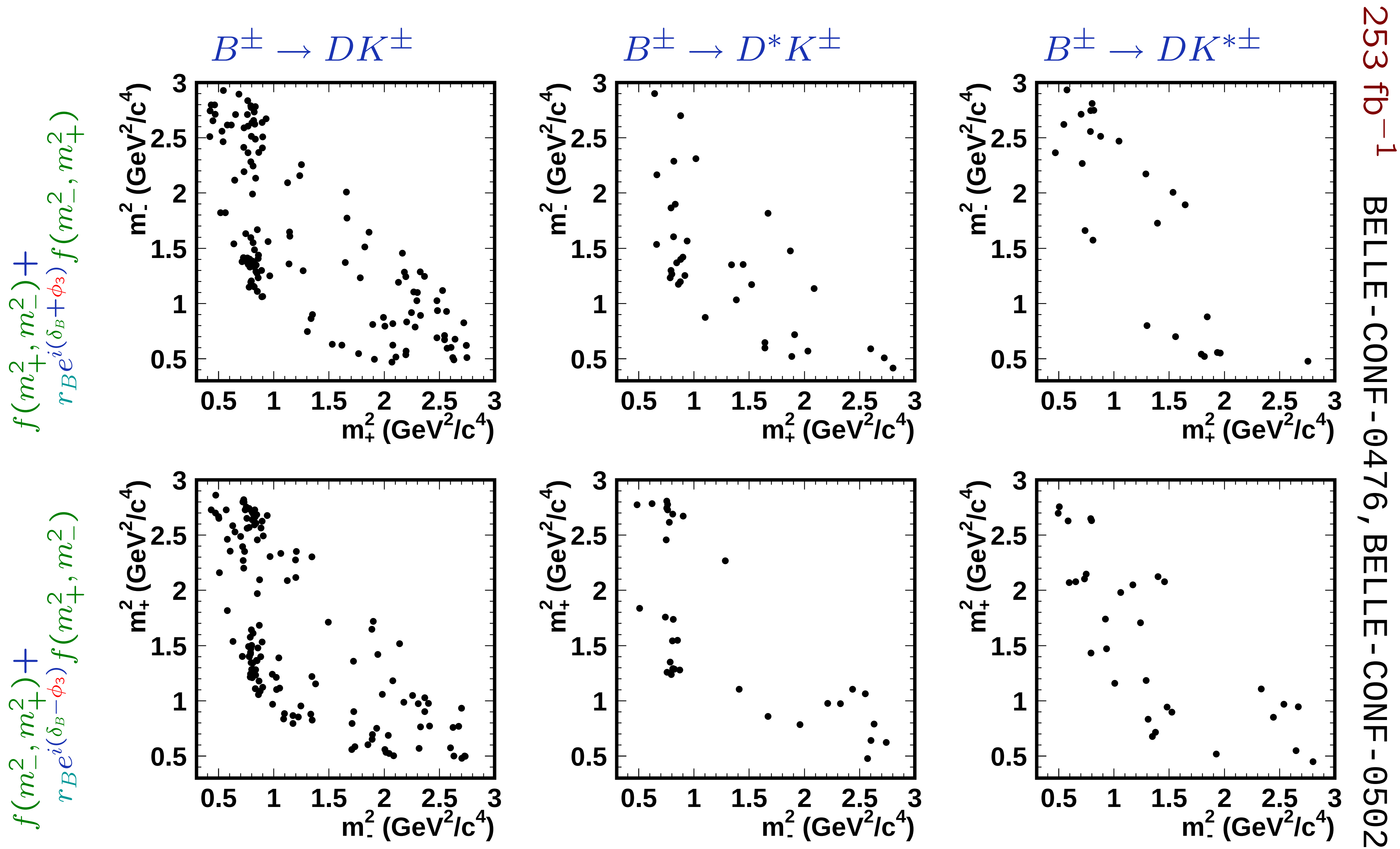
- $\mathcal{B}(D^0 \to \bar{K}^0\pi^+\pi^-) \sim 6\%$
- Fairly clean signal
- Rich Dalitz plot structure
- Large interference effects
  esp. $K^{*+}\pi^-$ with $K^{*-}\pi^+$
  ($\exists\,(m_+^2, m_-^2)$ s.t. $r_D(m_+^2, m_-^2) \sim r_B$)



However

- large $\pi\pi$ S wave
  $\rightsquigarrow$ model uncertainty
  $\rightsquigarrow$ crucial rôle of charm factory

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



Extraction of ϕ_3

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

(recall r_B and δ_B different for each mode)

253 fb^{-1}

BELLE-CONF-0476, BELLE-CONF-0502

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

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

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

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

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

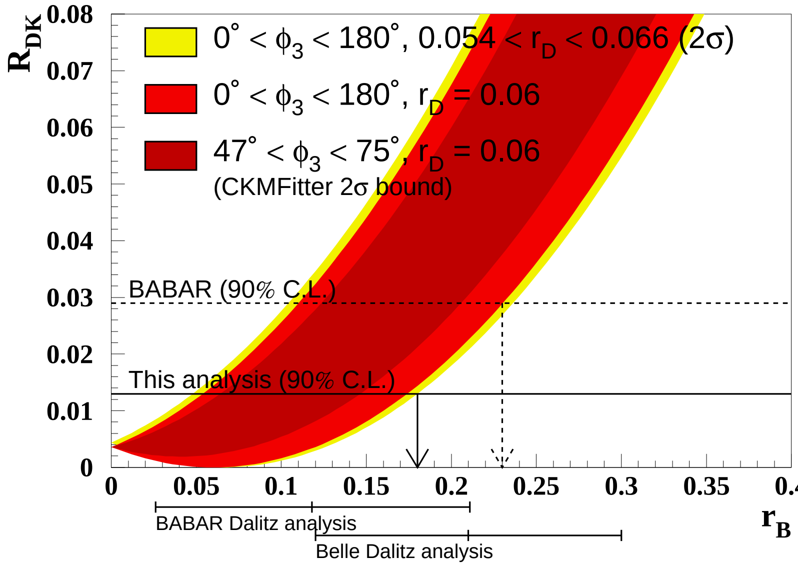
$$\phi_3 = 112^\circ \pm 35^\circ(\text{stat}) \pm 9^\circ(\text{syst}) \pm 14^\circ(\text{model})$$
$$r_B = 0.25 \pm 0.18(\text{stat}) \pm 0.09(\text{syst}) \pm 0.09(\text{model})$$
$$\delta_B = 353^\circ \pm 35^\circ(\text{stat}) \pm 8^\circ(\text{syst}) \pm 54^\circ(\text{model})$$

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

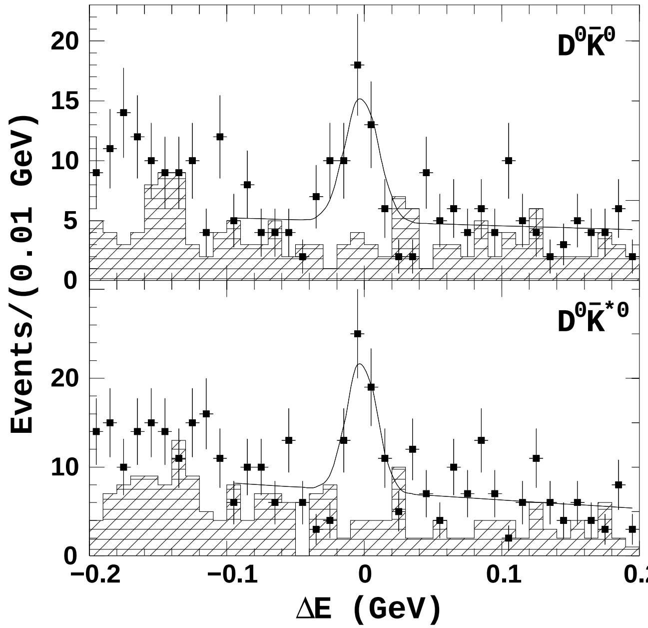
$$\phi_3 = 68^\circ\,^{+14^\circ}_{-15^\circ}(\text{stat}) \pm 13^\circ(\text{syst}) \pm 11^\circ(\text{model})$$

ϕ_3 from $B \to DK$: The Future

- Sensitivity to ϕ_3 has $r_B{}^{-1}$ dependence
- Result from $B^\pm \to \left[K^\mp\pi^\pm\right]_D K^\pm$ analysis
  $r_B(B^\pm \to DK^\pm) < 0.18$ @ 90% C.L.
  (no DCS signal seen)
  357 fb^{-1}; BELLE-CONF-0552
- Error on ϕ_3 may go worse than $1/\sqrt{N}$



- Neutral B decays become useful for ϕ_3
- $r_B(\bar{B}^0 \to D\bar{K}^0) \sim N_c \times r_B(B^+ \to DK^+)$
- In 600 fb^{-1} expect (roughly)
  - ∗ 300 favoured D decays
  - ∗ 10 $D \to K^+K^-$ & 10 $D \to K_S\pi^0$
  - ∗ 30 $D \to K_S\pi^+\pi^-$



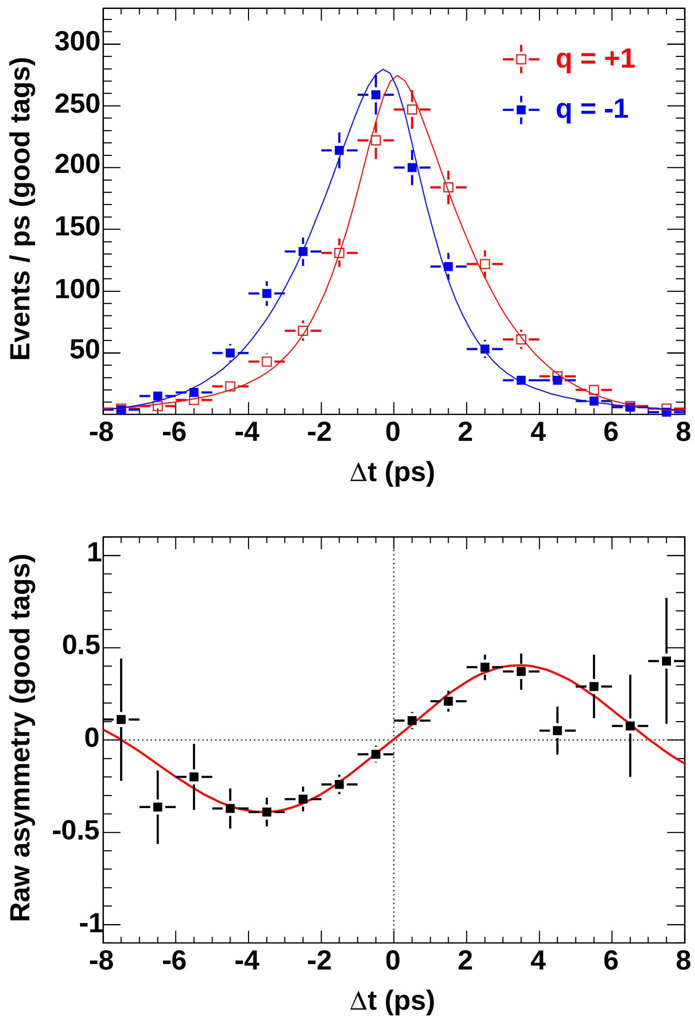
78/fb; PRL90, 141802 (2003)

Need optimal combination of multiple DK results

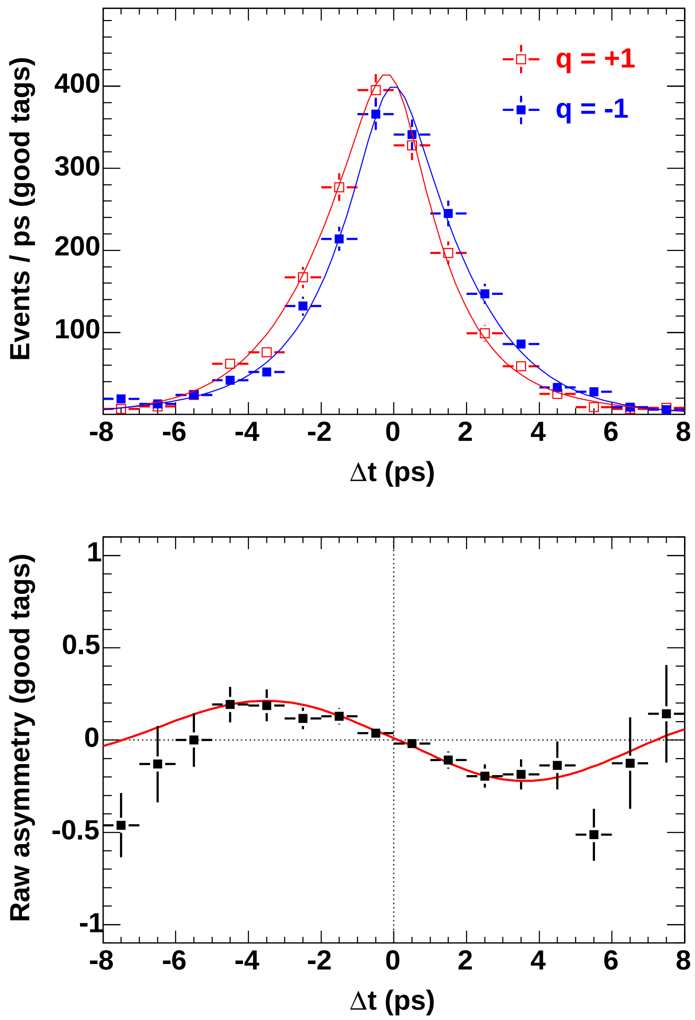
ϕ_1: $B^0 \to J/\psi K^0$ — Δt Dependence

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

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



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

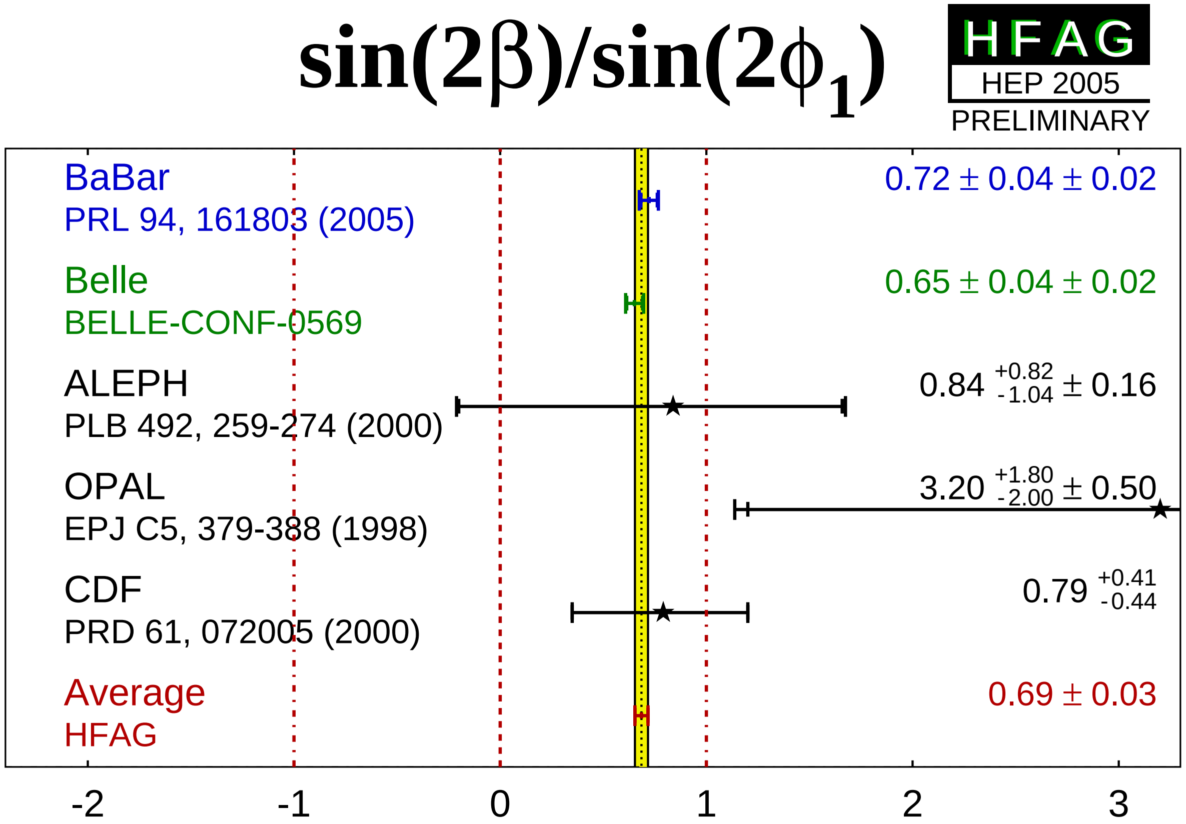


$S = +0.668 \pm 0.047(\text{stat})$
$A = -0.021 \pm 0.034(\text{stat})$

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

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

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



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

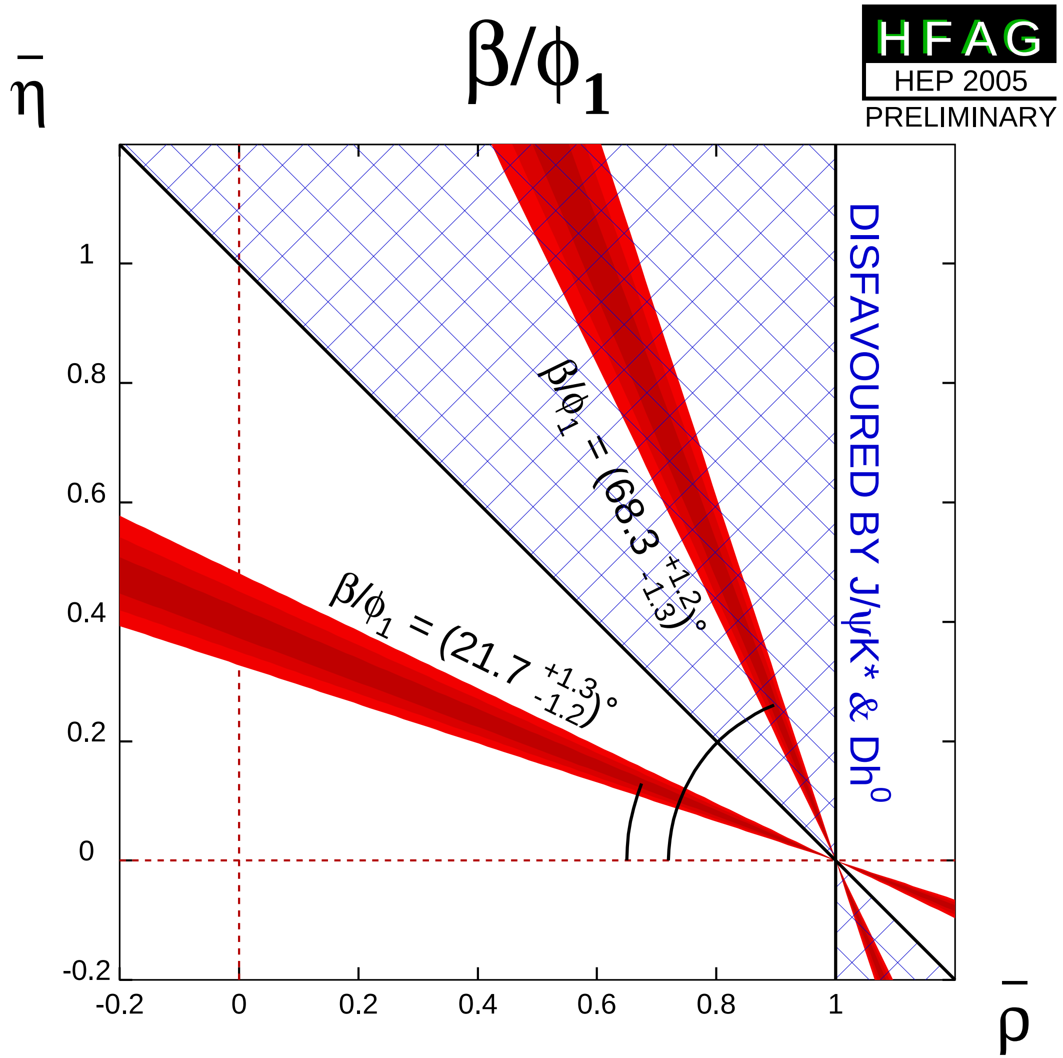
Theory error at or below experimental systematics

$\sin(2\phi_1)$ — Constraint

Use interference between CP-even and CP-odd to resolve ambiguity

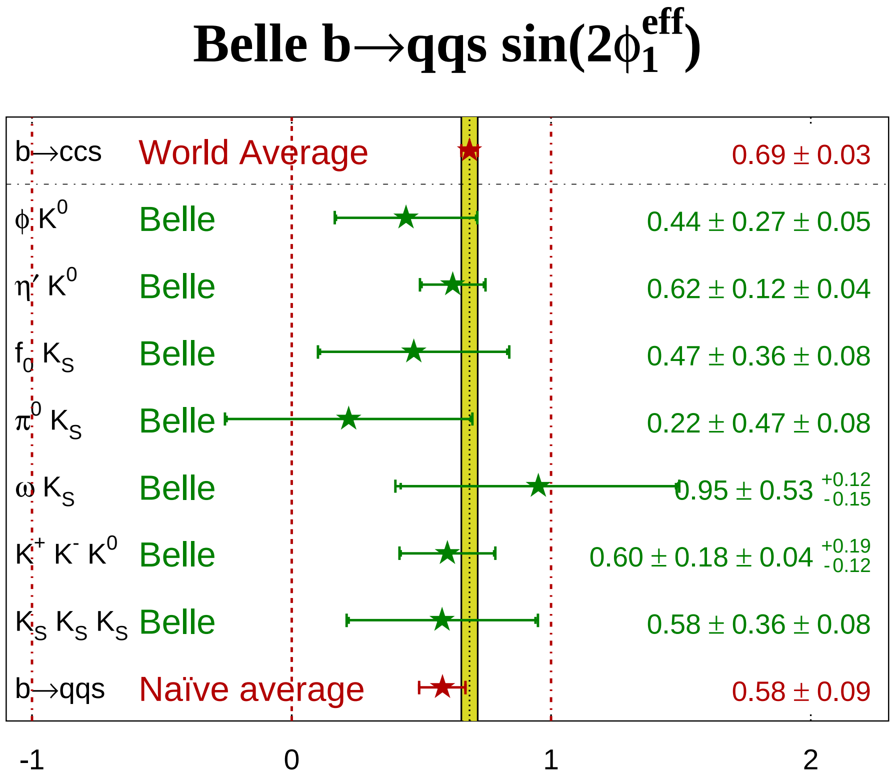
Some model assumption (strong phase variation) necessary

$J/\psi K^* \; VV$ analysis $D\pi^0$ with $D \to K_S\pi^+\pi^-$, *etc.* other possibilities



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

- Many modes sensitive to ϕ_1
- Theoretical uncertainties
  - $b \to c\bar{c}s$: $\sim \mathcal{O}(1\%)$
  - $b \to c\bar{u}d$: $< \mathcal{O}(1\%)$
  - $b \to s\bar{q}q$: $\gtrsim$ few %
  - $b \to c\bar{c}d$: $\sim \mathcal{O}(10\%)$ (?)
- Experimental systematics controllable
- Future allows
  - better precision
  - more involved analyses



- Initial attempts for ϕ_2 used $B \to \pi\pi$

$$S_{\pi^+\pi^-} = -0.67 \pm 0.16 \pm 0.06$$
$$A_{\pi^+\pi^-} = +0.56 \pm 0.12 \pm 0.06$$

- Significant (4σ) direct CP violation

  also $\mathcal{B}(B^0 \to \pi^0\pi^0) \approx 1.5 \times 10^{-6}$

  $\hookrightarrow$ penguin pollution

- Isospin analysis ongoing

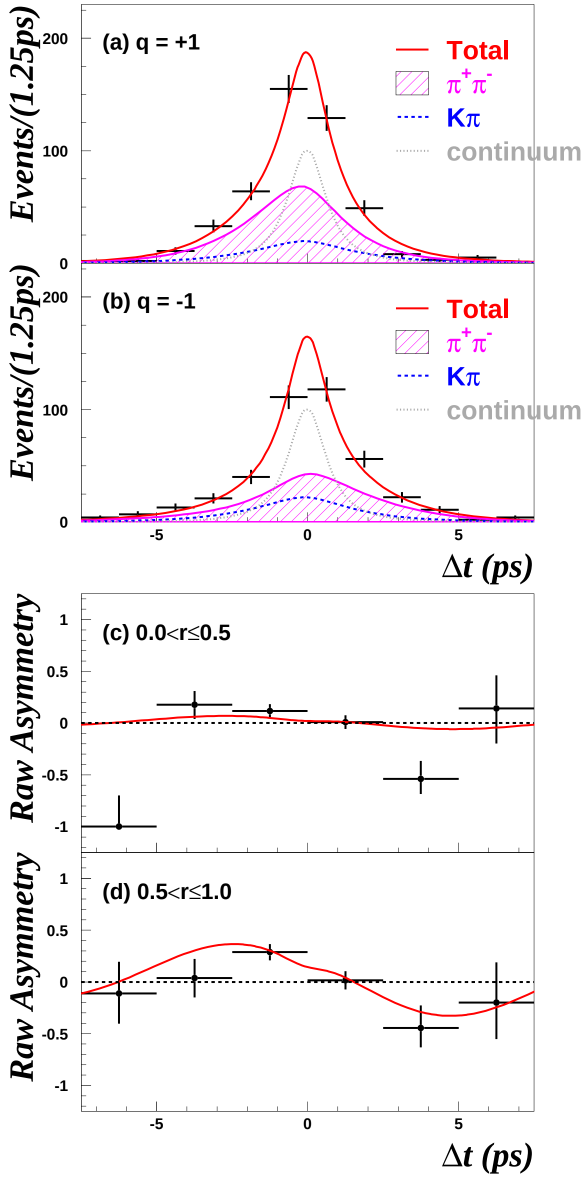
- $B \to \rho\pi$ requires Dalitz plot analysis

  $\mathcal{B}(B^0 \to \rho^0\pi^0) \neq 0 \rightsquigarrow$ complication

- $B \to \rho\rho$ appears surprisingly good
  - ∗ small penguin pollution

    $(\mathcal{B}\left(B^0 \to \rho^0\rho^0\right) < 1.1 \times 10^{-6})$
  - ∗ little nonresonant contribution
  - ∗ almost 100% longitudinally polarized

Plots for high quality events only



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

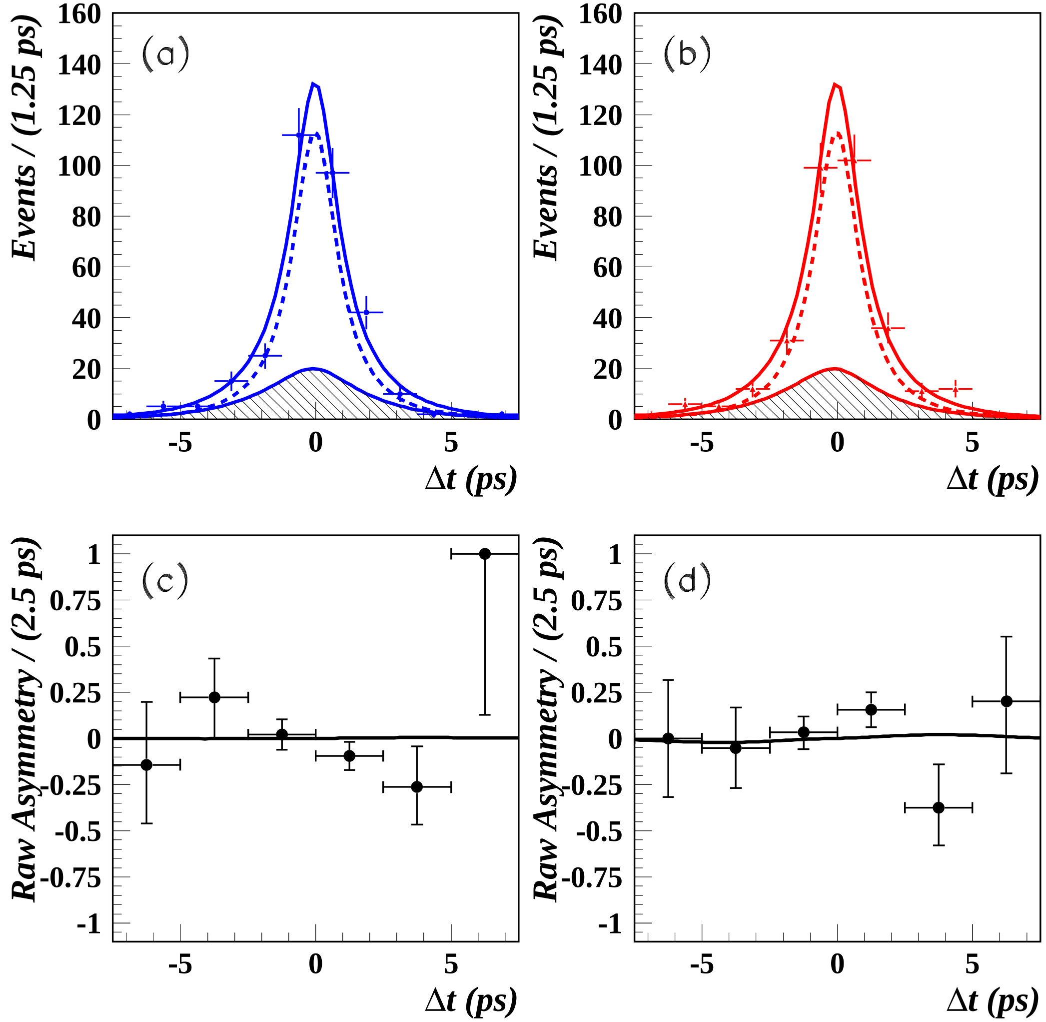
$$S_{\rho^+\rho^-} = 0.09 \pm 0.41 \pm 0.08$$
$$A_{\rho^+\rho^-} = 0.00 \pm 0.30^{+0.10}_{-0.09}$$

From naïve $S_{\rho^+\rho^-} = -\sin(2\phi_2)$:

$$\phi_2 = (87 \pm 12)^\circ$$

Neglects possible penguins

$\Rightarrow$ isospin analysis



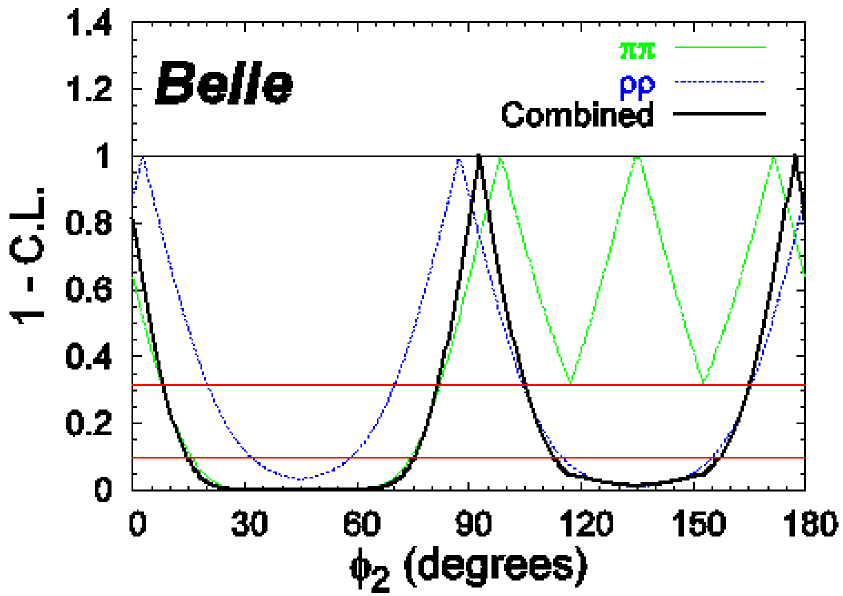
253 fb^{-1} BELLE-CONF-0545

$\rho\rho$ only

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

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

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

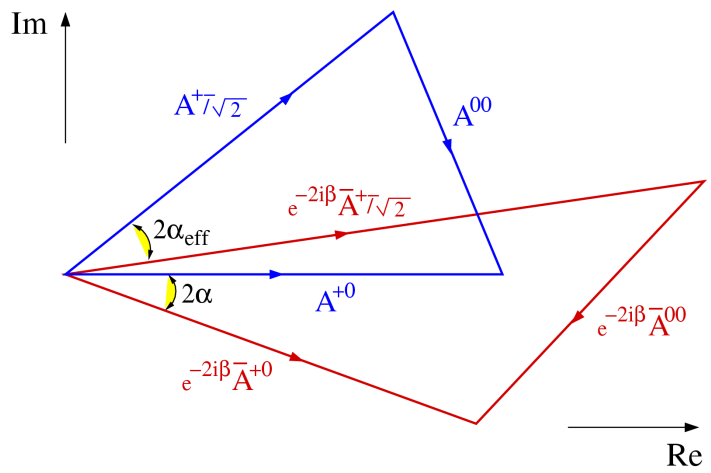


- $\rho\rho$ seems too good to be true?
- Isospin triangle does not close

  $\mathcal{B}(B^0 \to \rho^+\rho^-) = (26.2\,^{+3.6}_{-3.7}) \times 10^{-6}$

  $\mathcal{B}(B^+ \to \rho^+\rho^0) = (26.4\,^{+6.1}_{-6.4}) \times 10^{-6}$

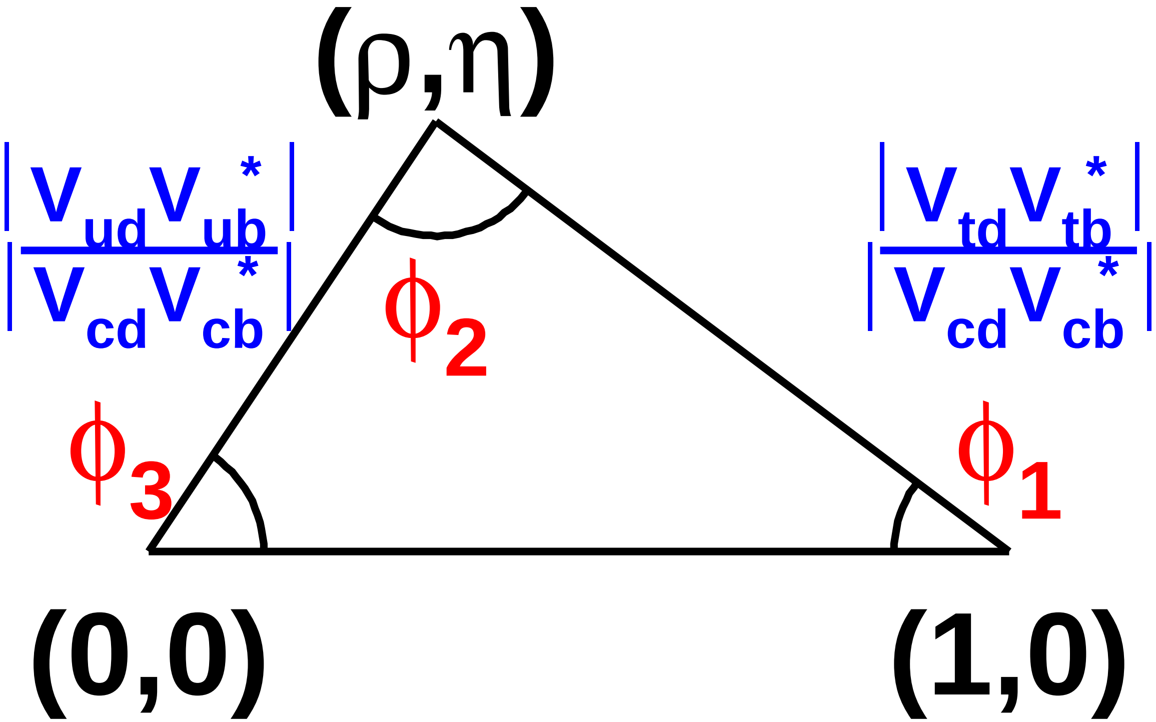
  $\mathcal{B}(B^0 \to \rho^0\rho^0) < 1.1 \times 10^{-6})$
- $I = 1$ term due to ρ width



253 fb^{-1} BELLE-CONF-0501, BELLE-CONF-0545

Is $\rho\rho$ a golden mode, or is it pyrite?

UT angles — Summary



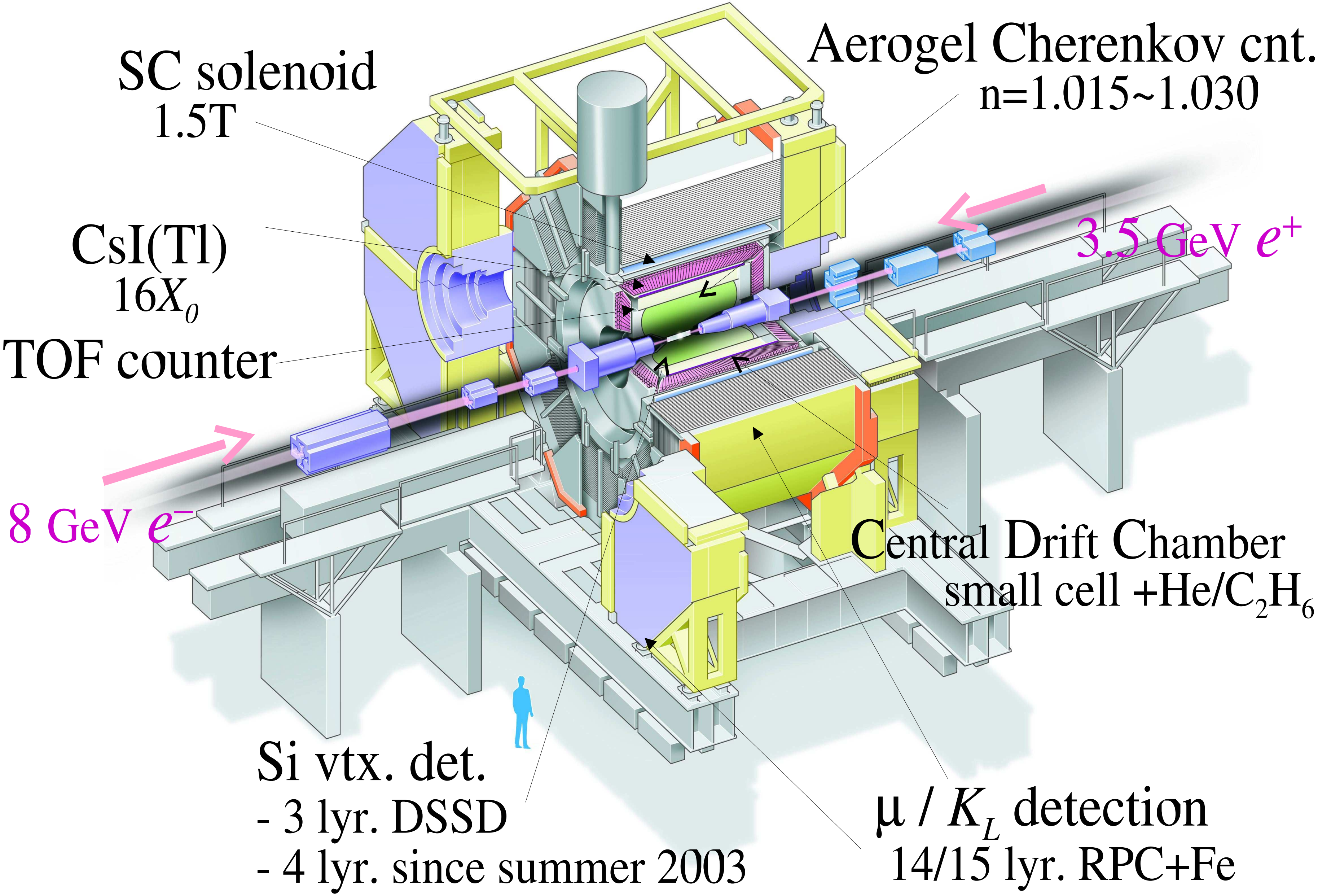
ϕ_1	ϕ_2	ϕ_3
$B^0 \to J/\psi K^0$	$B^0 \to \pi^+\pi^-$ & $\rho^+\rho^-$	$B^\pm \to DK^\pm$
$\sin(2\phi_1) = +0.652 \pm 0.039 \pm 0.020$	$\phi_2 = 93^{+12}_{-11}{}^\circ$	

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

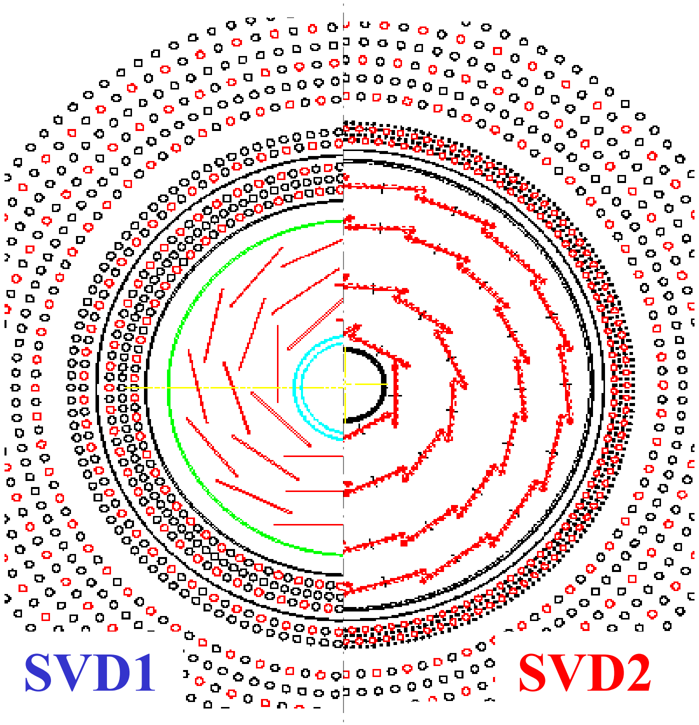
Ambiguities reduced by

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

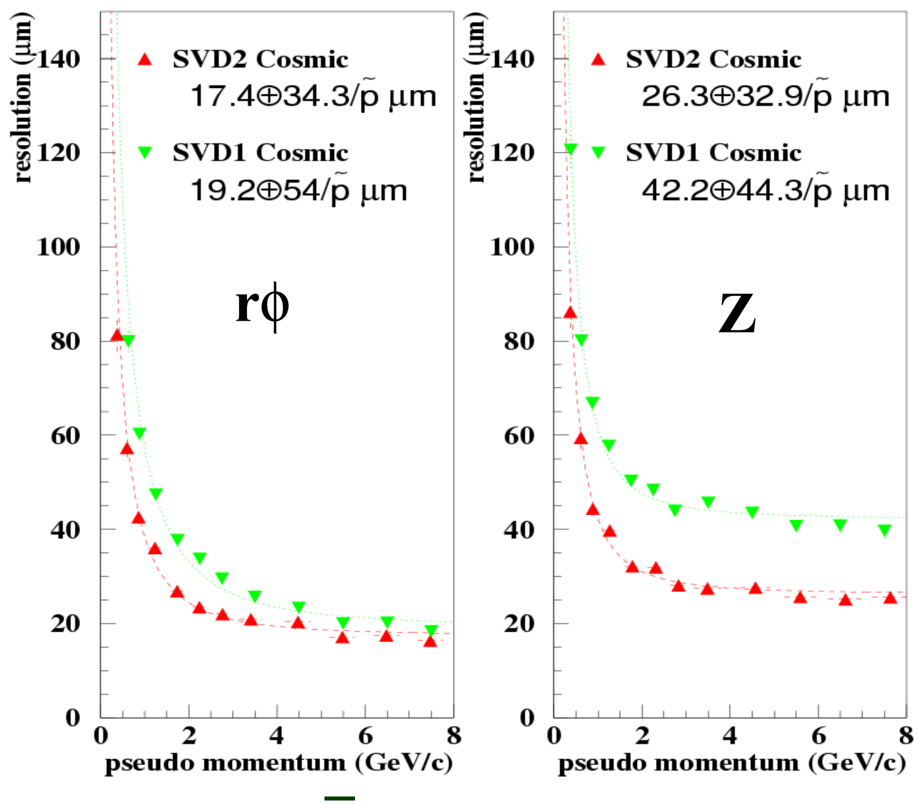
Back Up



SC solenoid
1.5T
CsI(Tl)
$16X_0$
TOF counter
Aerogel Cherenkov cnt.
n=1.015~1.030
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



IMPROVED RESOLUTION!



Number of silicon DSSDs

3 layers $\rightarrow$ 4 layers

Radius of beam pipe

$r = 2.0$ cm $\rightarrow$ $r = 1.5$ cm

Radiation hardness

1 MRad $\rightarrow$ > 20 MRad

Laboratory polar angle coverage

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

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

where A, λ, ρ, η are Wolfenstein parameters

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

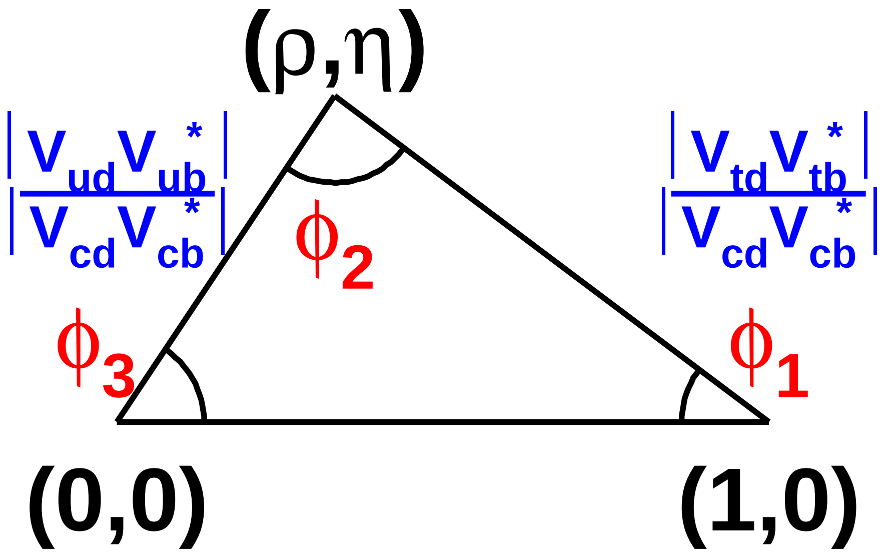
$$V_{ud}V^*_{ub} + V_{cd}V^*_{cb} + V_{td}V^*_{tb} = 0$$

The Unitarity Triangle

$\phi_1 \leftrightarrow \beta$

$\phi_2 \leftrightarrow \alpha$

$\phi_3 \leftrightarrow \gamma$

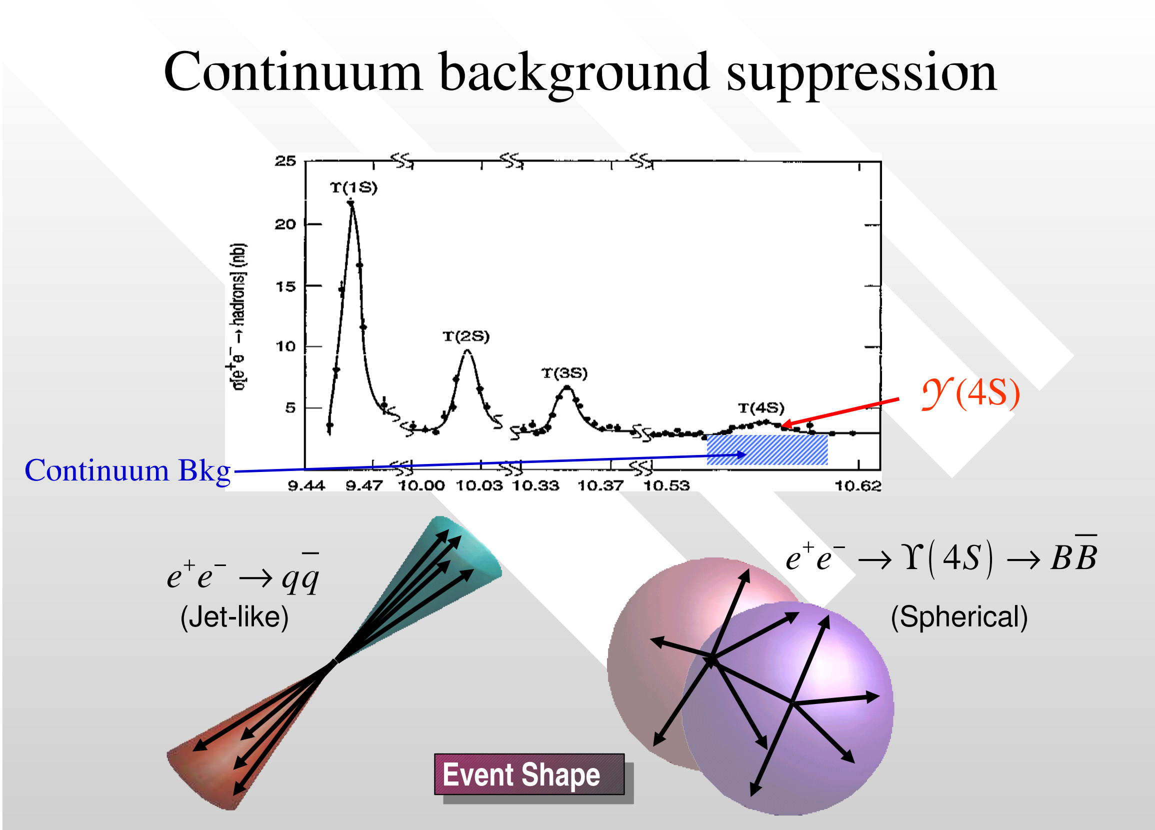


Experimental Technique

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

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

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



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

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

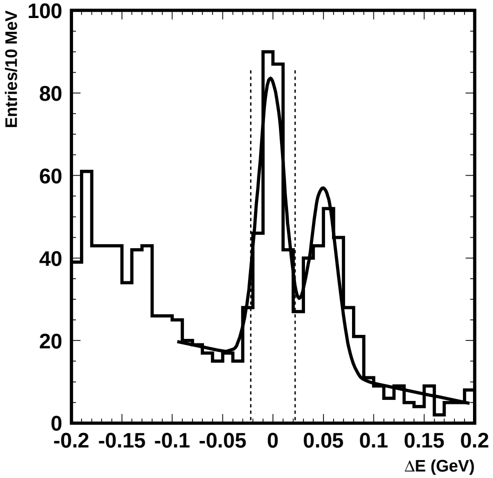
- Consider $B^+ \to \left(K_S\pi^+\pi^-\right)_D K^+$
  $\to$ amplitude is $f(m_+^2, m_-^2) + r_B e^{i(\delta_B+\phi_3)} f(m_-^2, m_+^2)$
- Consider $B^- \to \left(K_S\pi^+\pi^-\right)_D K^-$
  $\to$ amplitude is $f(m_-^2, m_+^2) + r_B e^{i(\delta_B-\phi_3)} f(m_+^2, m_-^2)$
- Can extract (r_B, δ_B,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

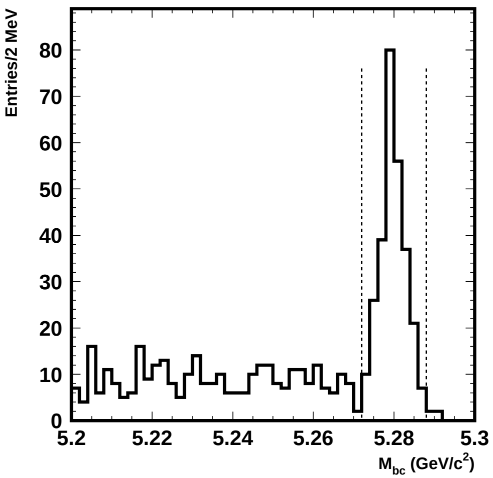
$B^+ \to D^{(*)}K^+$ DP Analysis History

- 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

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

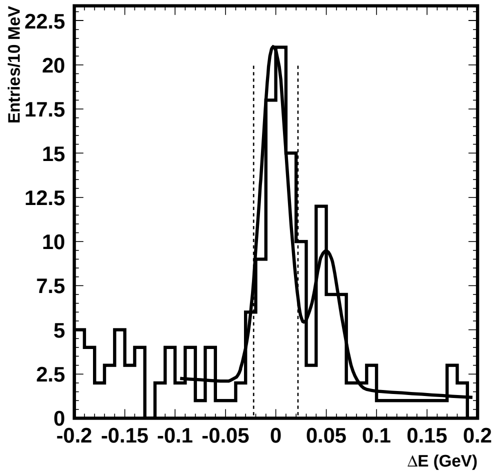
$B^\pm \to D K^\pm$

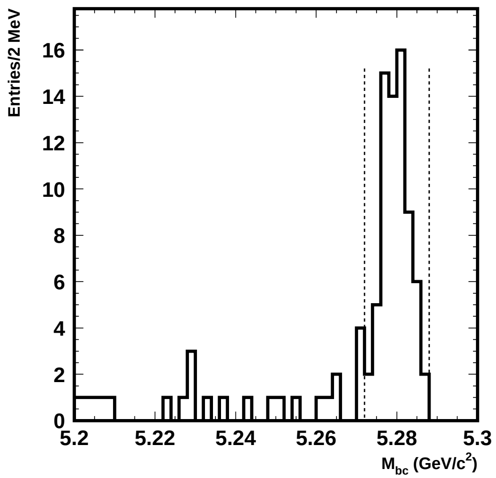




276 candidate events
(209 ± 16 signal)

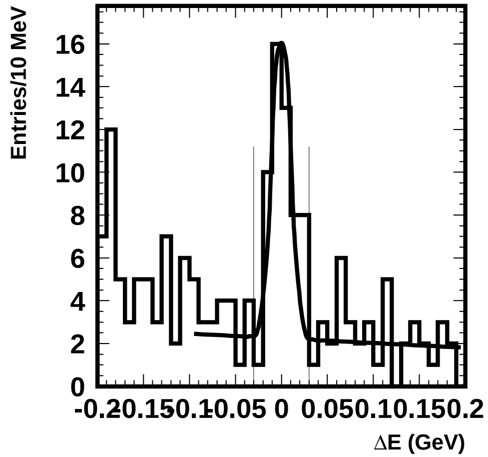
$B^\pm \to D^* K^\pm$

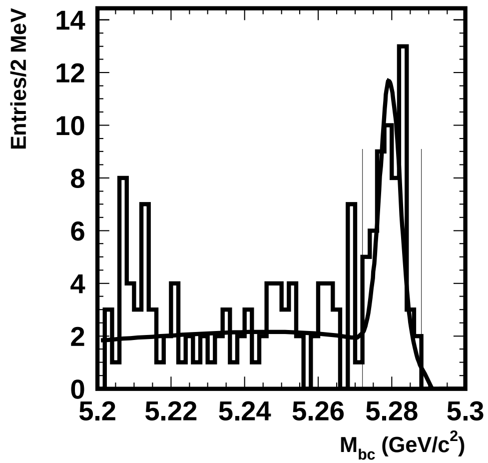




69 candidate events
(58 ± 8 signal)

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





56 candidate events
(36 ± 7 signal)

253 fb^{-1}

BELLE-CONF-0476, BELLE-CONF-0502

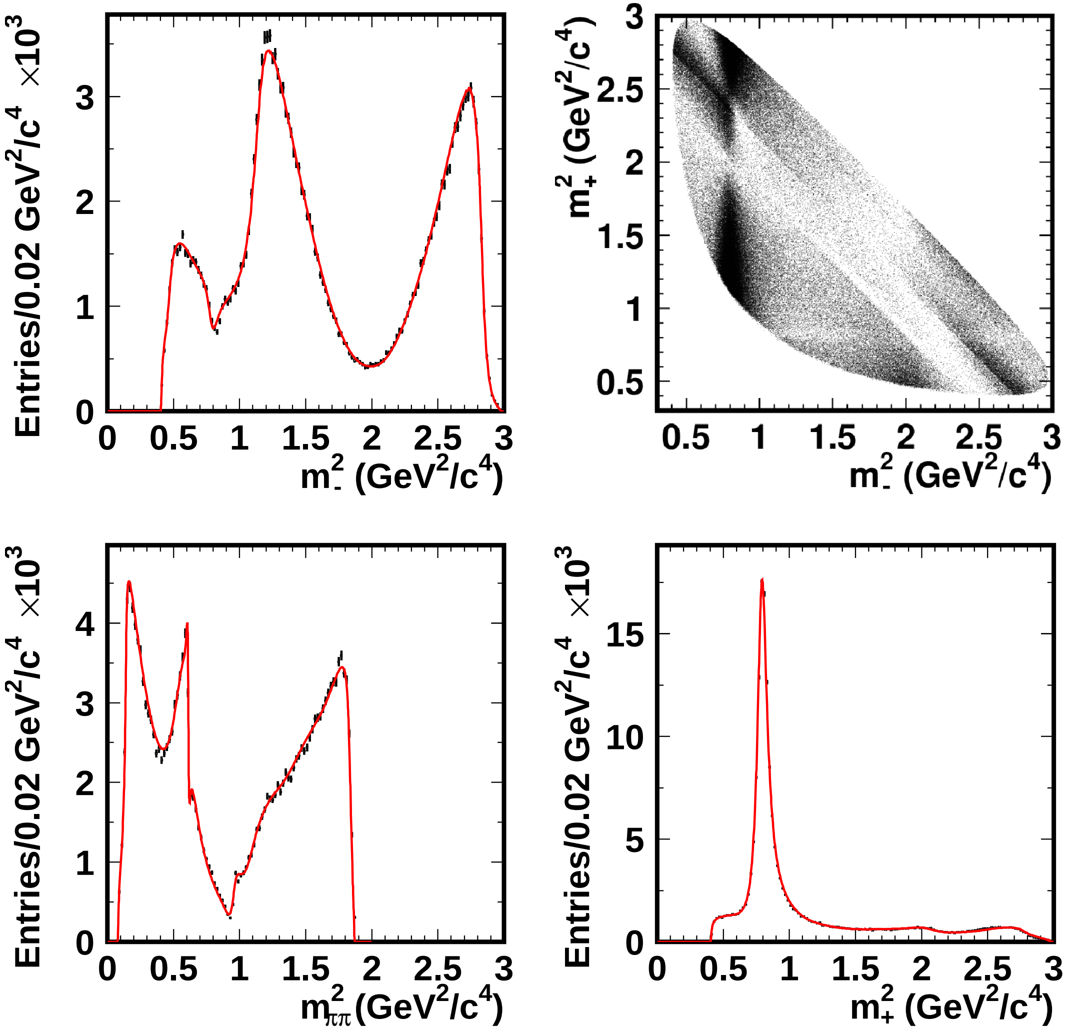
Extraction of $f(m_+^2, m_-^2)$

- 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}

$\chi^2/ndf = 2.30$

$(ndf = 1106)$



BELLE-CONF-0476, BELLE-CONF-0502

Fine tuning of model

$\rightsquigarrow$ little effect on ϕ_3

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%

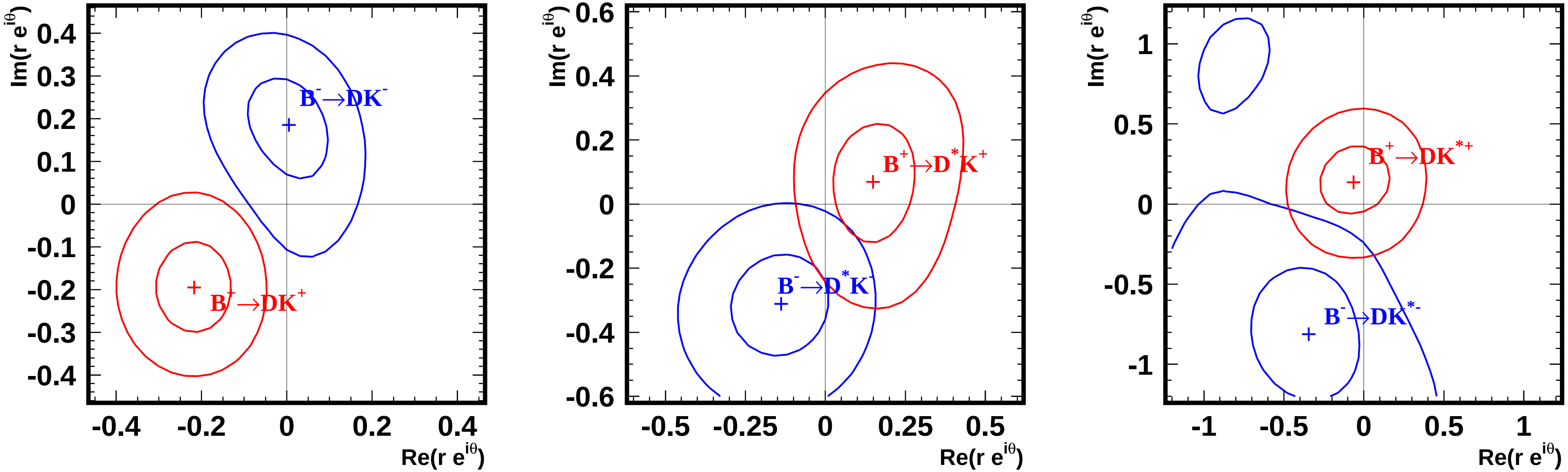
Dalitz Plot Fits

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

BELLE-CONF-0476, BELLE-CONF-0502

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

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



276 candidate events
(209 ± 16 signal)

69 candidate events
(58 ± 8 signal)

56 candidate events
(36 ± 7 signal)

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	$(\Delta r_B)_{\mathrm{max}}$	$(\Delta \phi_3)_{\mathrm{max}}$	$(\Delta \delta_B)_{\mathrm{max}}$
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 $f(m_+^2, m_-^2) \pm f(m_-^2, m_+^2)$

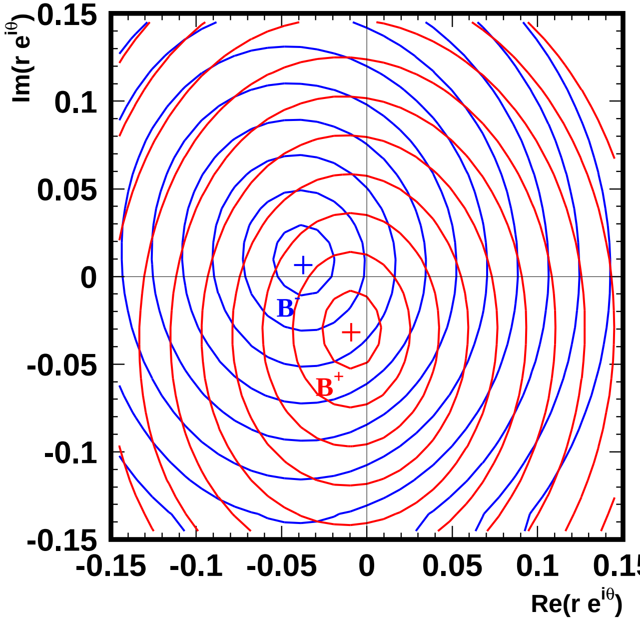
- FUTURE: use CP tagged D mesons from $c\tau$ factory ($\psi'' \to D\bar{D}$)

  $\hookrightarrow$ 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 $\theta_\pm = \delta_B \pm \phi_3$

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



3425 events

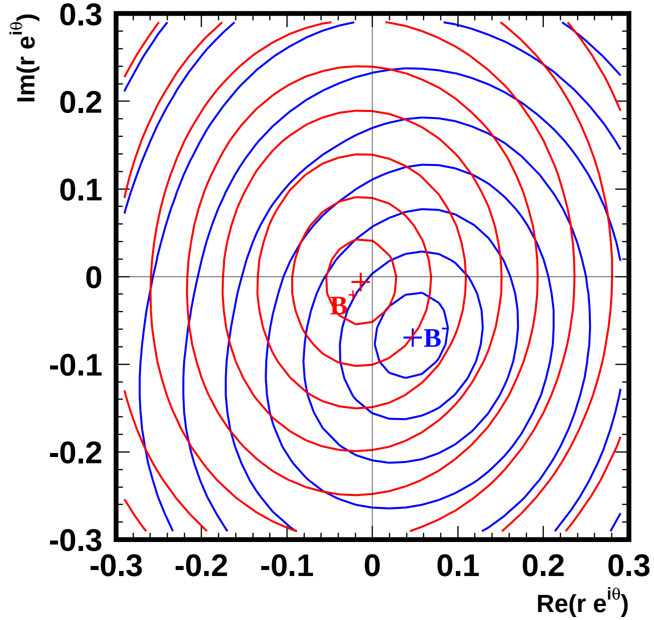
$r_{B-} = 0.047 \pm 0.018$

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

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

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

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



641 events

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

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

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

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

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 ($D_{\rm fav}^{(*)}$) 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 $B^- \to D\pi^-$

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

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

- Four observables, three unknowns . . .

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

253 fb^{-1}

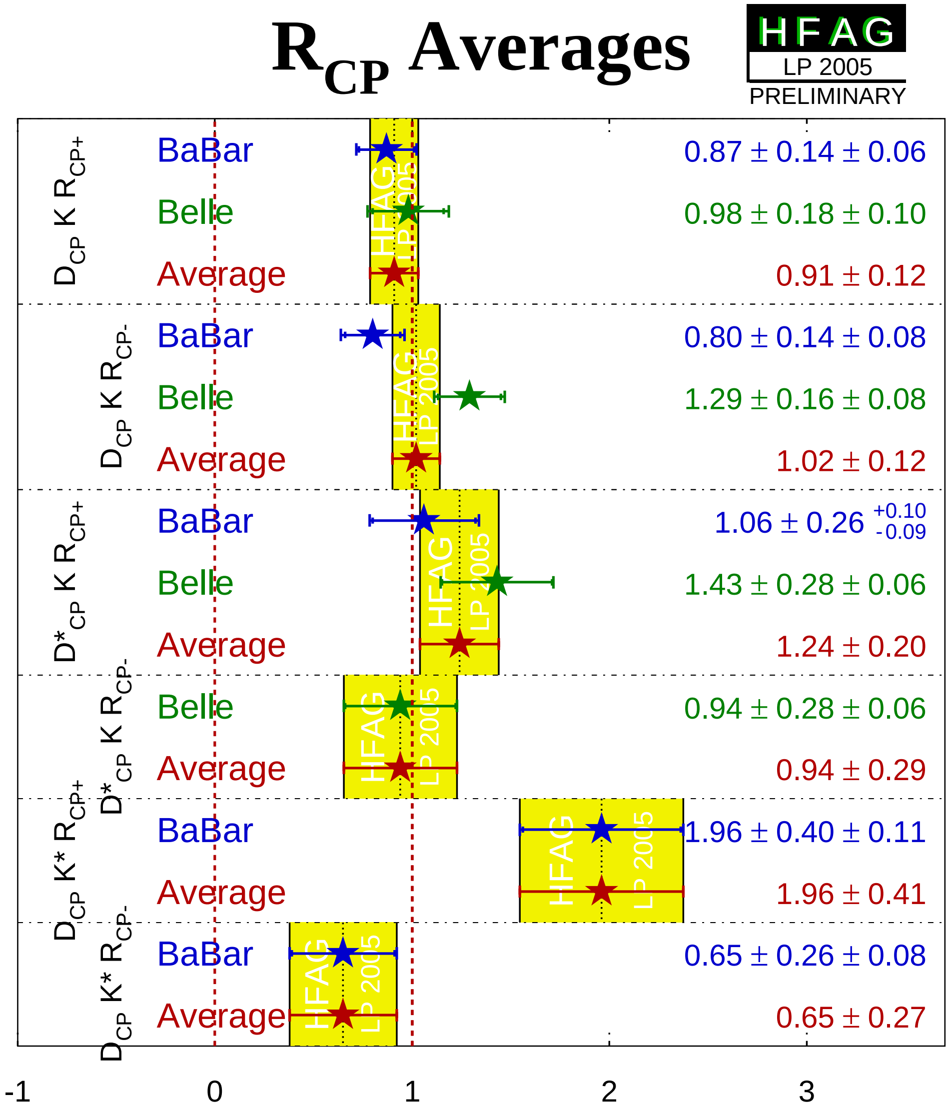
BELLE-CONF-0443

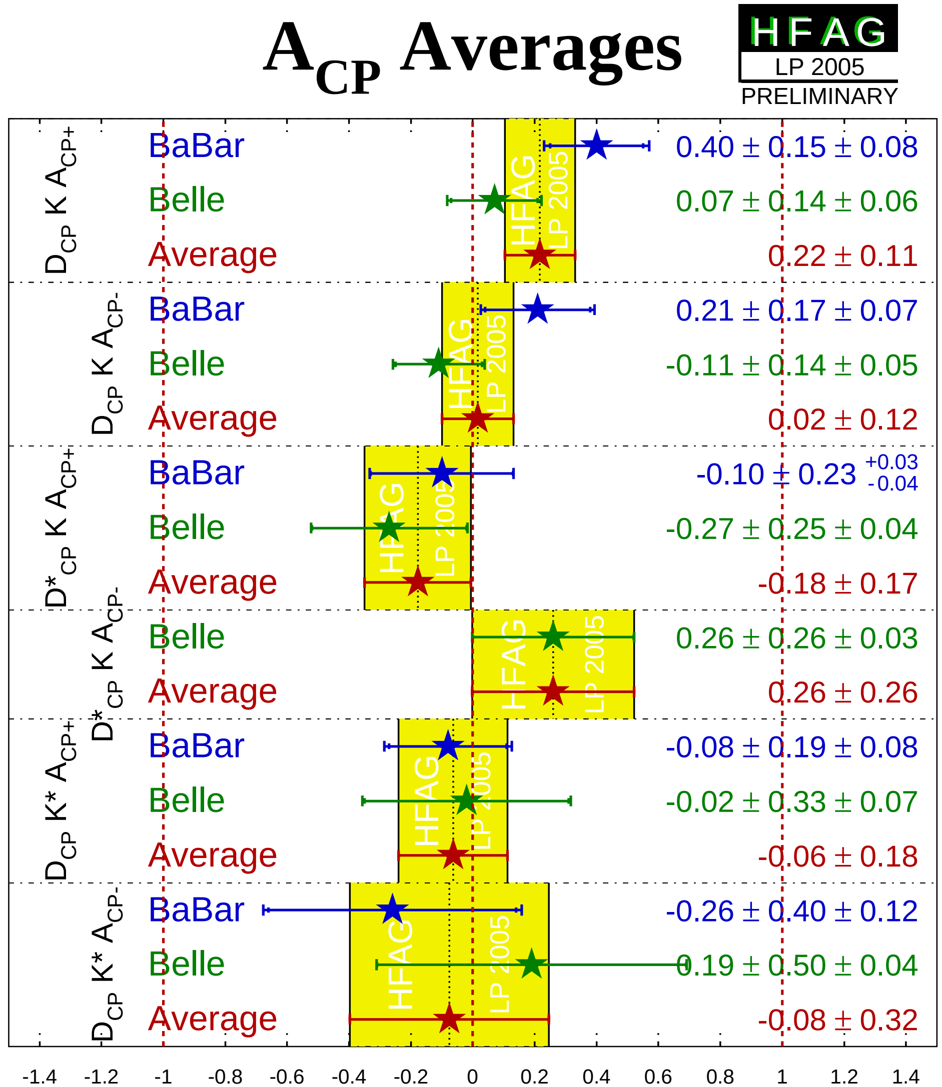
- Extract CP asymmetries by fitting B^- and B^+ yields separately

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

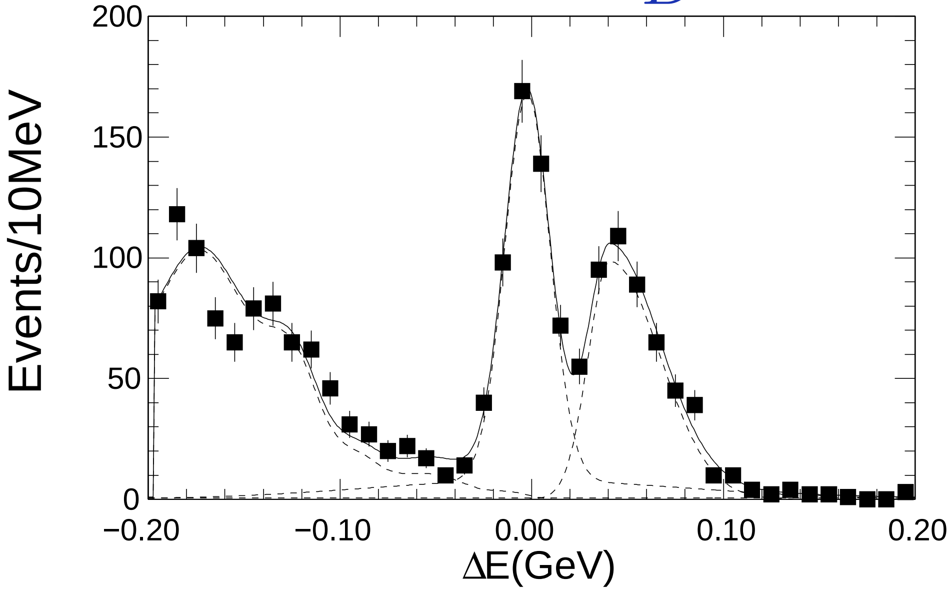

RCP Averages
HFAG
LP 2005
PRELIMINARY
DCP K RCP+
BaBar 0.87 ± 0.14 ± 0.06
Belle 0.98 ± 0.18 ± 0.10
Average 0.91 ± 0.12
DCP K RCP-
BaBar 0.80 ± 0.14 ± 0.08
Belle 1.29 ± 0.16 ± 0.08
Average 1.02 ± 0.12
D*CP K RCP+
BaBar 1.06 ± 0.26 +0.10 -0.09
Belle 1.43 ± 0.28 ± 0.06
Average 1.24 ± 0.20
D*CP K RCP-
Belle 0.94 ± 0.28 ± 0.06
Average 0.94 ± 0.29
DCP K* RCP+
BaBar 1.96 ± 0.40 ± 0.11
Average 1.96 ± 0.41
DCP K* RCP-
BaBar 0.65 ± 0.26 ± 0.08
Average 0.65 ± 0.27
-1
0
1
2
3


ACP Averages
HFAG
LP 2005
PRELIMINARY
DCP K ACP+
BaBar 0.40 ± 0.15 ± 0.08
Belle 0.07 ± 0.14 ± 0.06
Average 0.22 ± 0.11
DCP K ACP-
BaBar 0.21 ± 0.17 ± 0.07
Belle -0.11 ± 0.14 ± 0.05
Average 0.02 ± 0.12
D*CP K ACP+
BaBar -0.10 ± 0.23 +0.03 -0.04
Belle -0.27 ± 0.25 ± 0.04
Average -0.18 ± 0.17
D*CP K ACP-
Belle 0.26 ± 0.26 ± 0.03
Average 0.26 ± 0.26
DCP K* ACP+
BaBar -0.08 ± 0.19 ± 0.08
Belle -0.02 ± 0.33 ± 0.07
Average -0.06 ± 0.18
DCP K* ACP-
BaBar -0.26 ± 0.40 ± 0.12
Belle 0.19 ± 0.50 ± 0.04
Average -0.08 ± 0.32
-1.4
-1.2
-1
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1
1.2
1.4

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

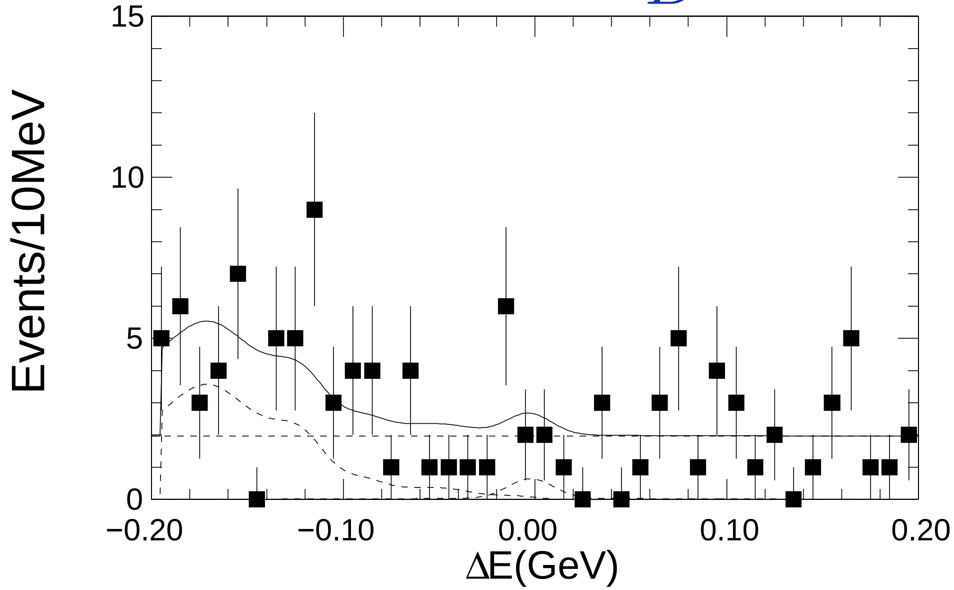
357 fb^{-1} BELLE-CONF-0552

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



634^{+59}_{-99} signal events

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



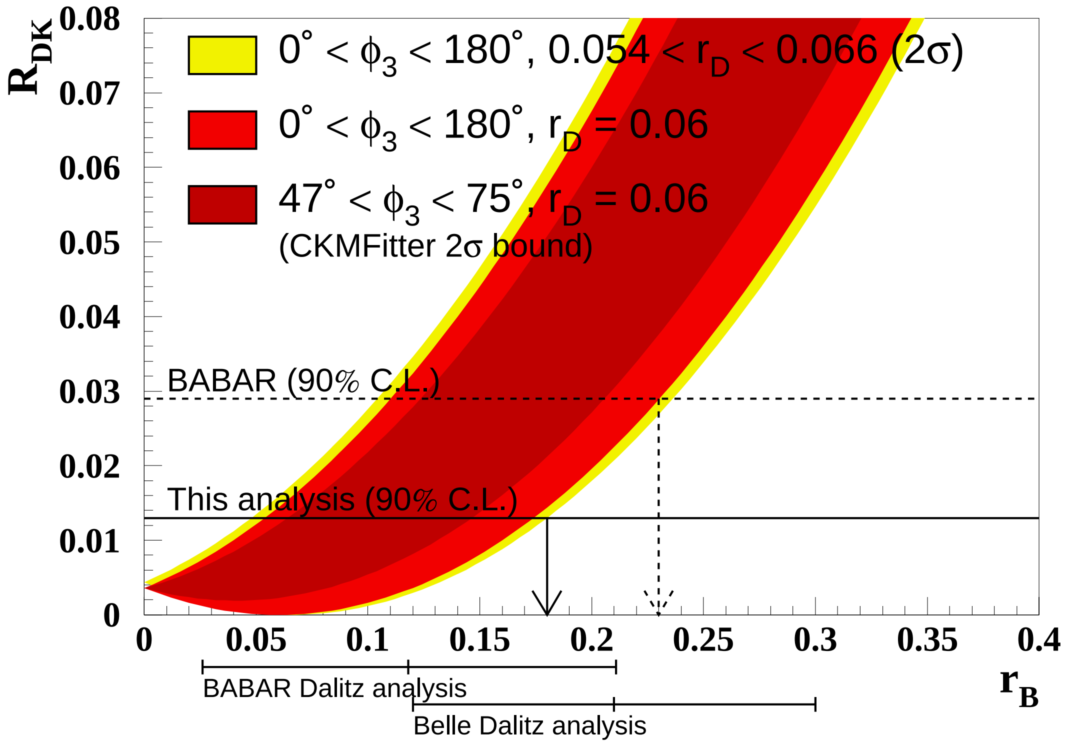
$2.4^{+4.9}_{-4.4}$ signal events

$B^{\mp} \to \left[K^{\mp}\pi^{\pm}\right]_D K^{\mp}$ yield consistent with expected peaking background ($2.4^{+2.3}_{-2.0}$)

$$\mathcal{R}_{DK}(B^{\pm} \to D K^{\pm}) = (0.0\,^{+8.4}_{-7.9}\,(\text{stat}) \pm 1.0\,(\text{syst})) \times 10^{-3}$$

Limit on r_B

$$\mathcal{R}_{DK} = {r_B}^2 + {r_D}^2 + 2 r_B r_D \cos(\delta_B + \delta_D) \cos(\phi_3)$$



$$\mathcal{R}_{DK} = (0.0\,^{+8.4}_{-7.9}\,(\text{stat}) \pm 1.0\,(\text{syst})) \times 10^{-3} < 13.9 \times 10^{-3} \text{ @ } 90\% \text{ C.L.}$$

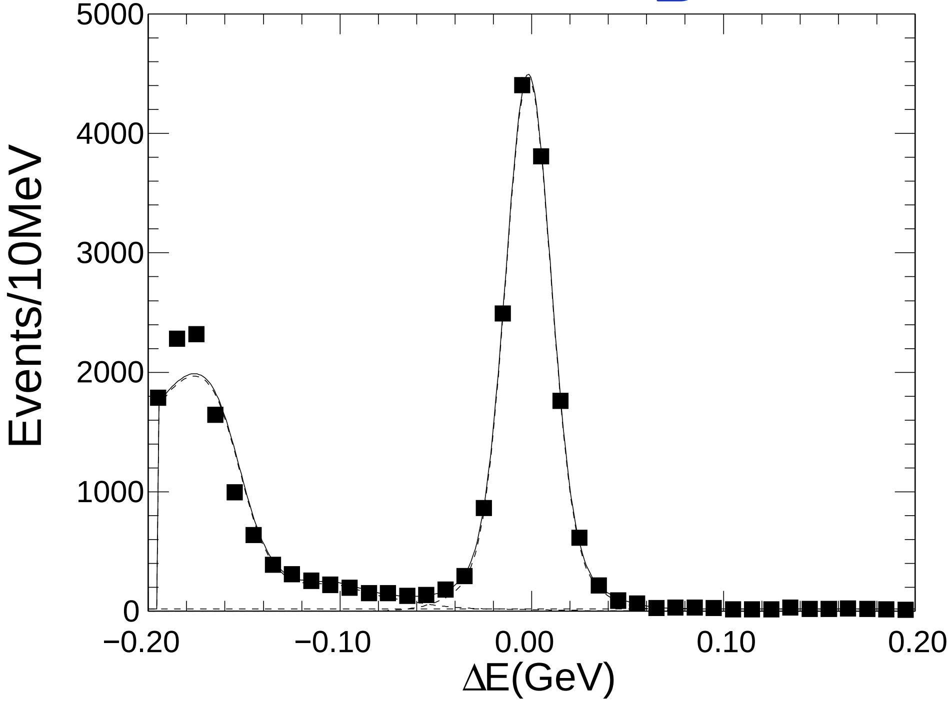
$$r_D = 0.060 \pm 0.003 \text{ (PDG)}$$

$$r_B(B^\pm \to DK^\pm) < 0.18 \text{ @ } 90\% \text{ C.L.}$$

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

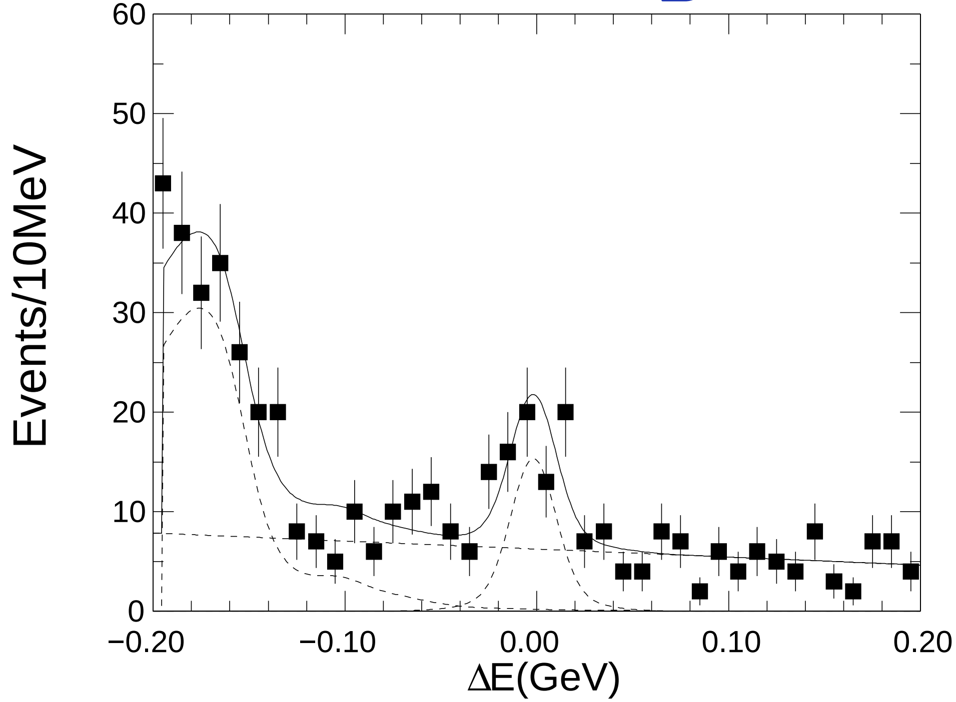
357 fb^{-1} BELLE-CONF-0552

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



14518 ± 125 signal events

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



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

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

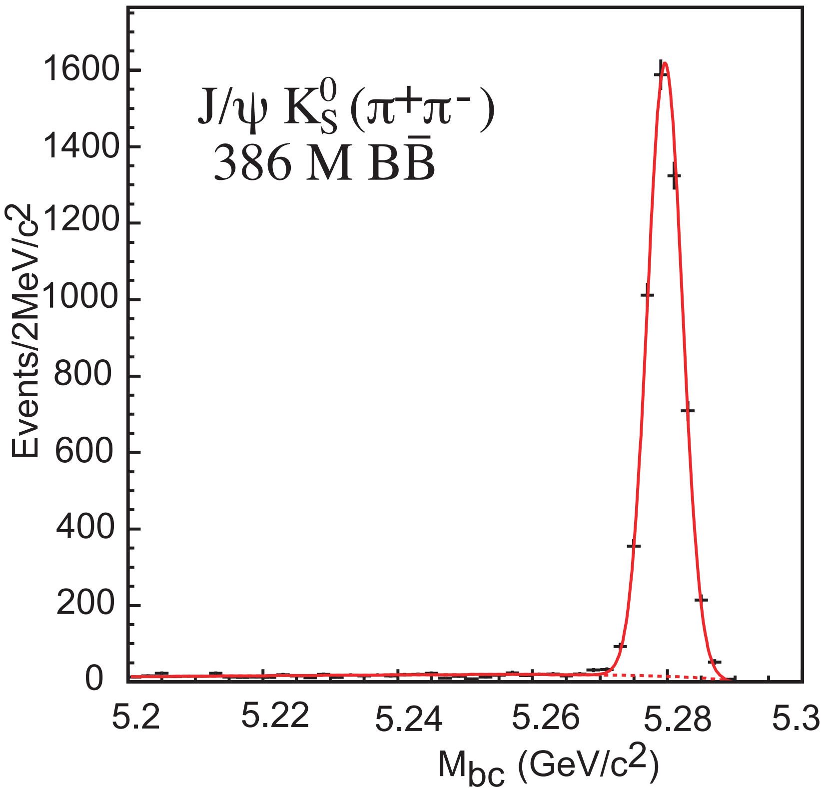
Consistent with previous Belle result

ϕ_1: $B^0 \to J/\psi K^0$ Selection

$357\ fb^{-1}$

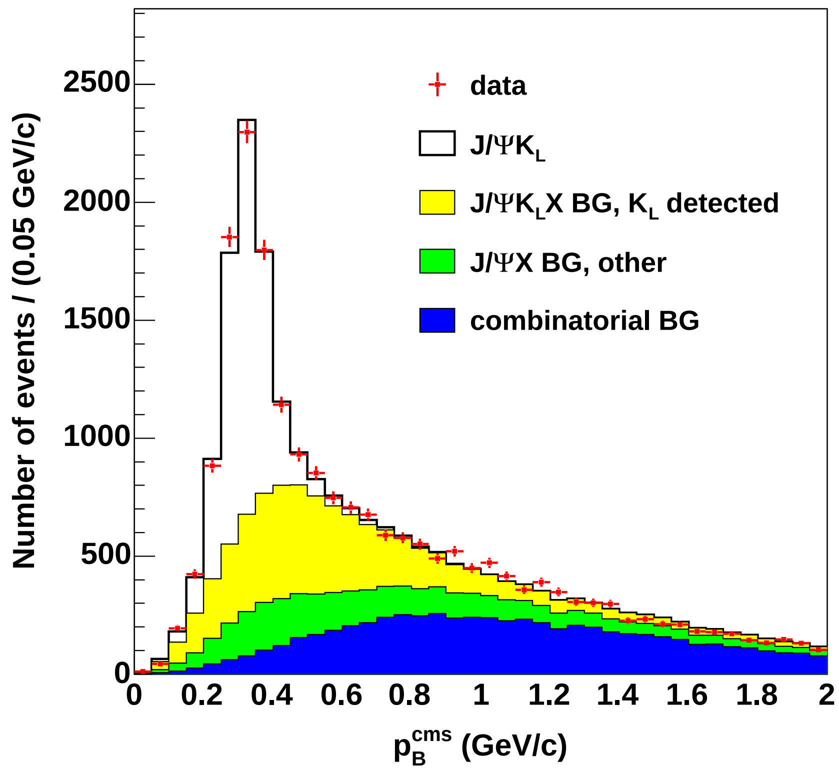
BELLE-CONF-0569

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



5264 ± 73 signal events

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

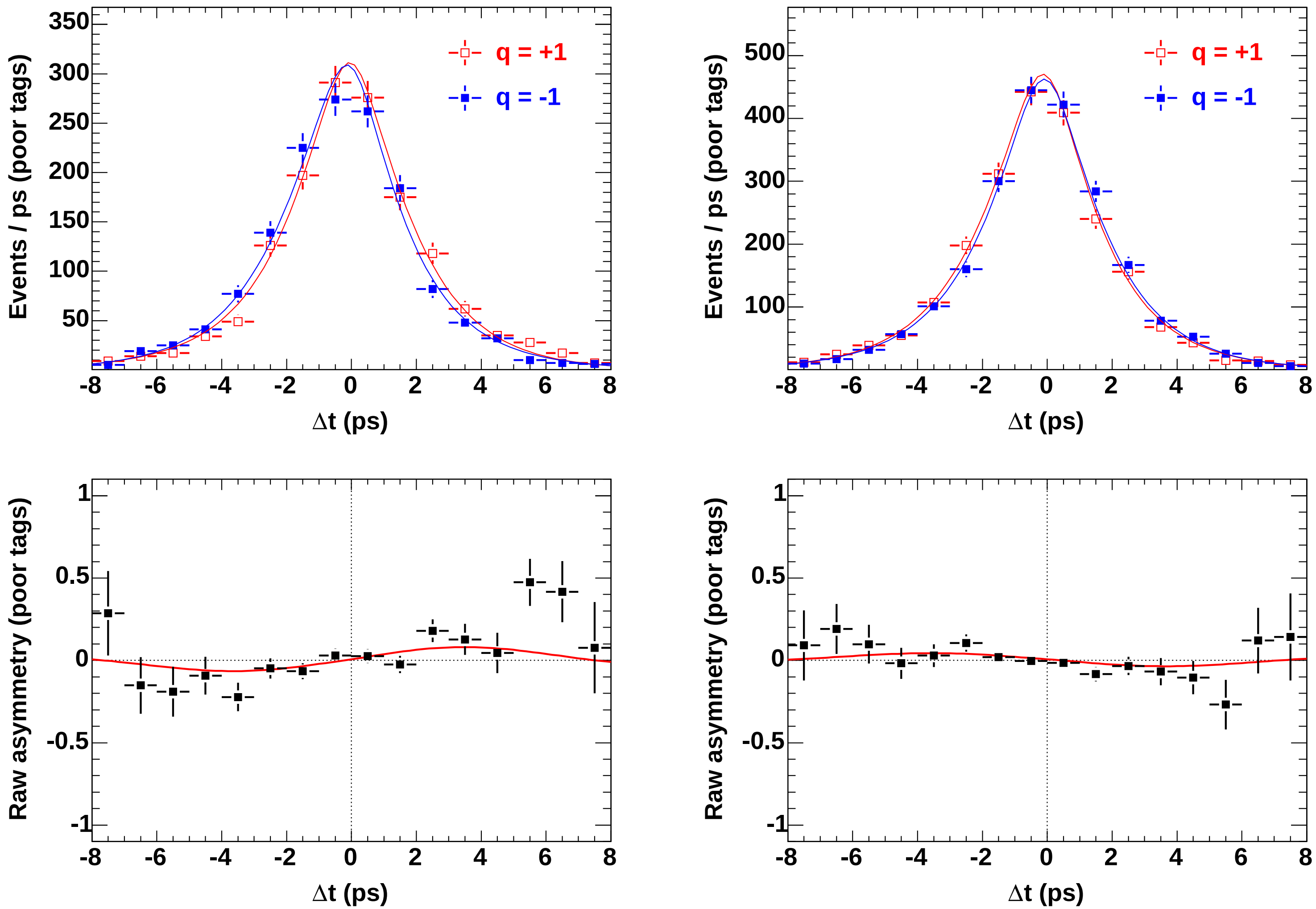


4792 ± 105 signal events

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

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

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



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

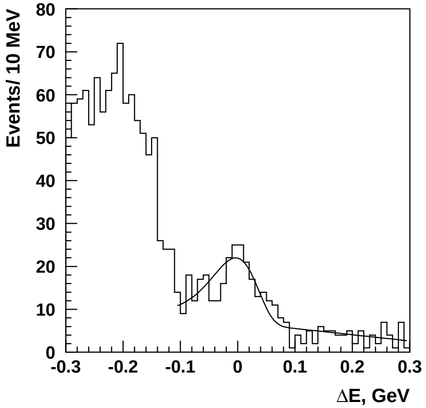
$A = -0.021 \pm 0.034(\text{stat})$ $\qquad$ $A = +0.049 \pm 0.039(\text{stat})$

357 fb^{-1}

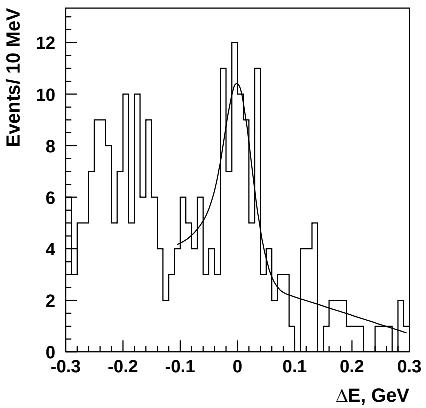
BELLE-CONF-0546

- 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: $S_{b \to c\bar{c}s} \simeq S_{b \to c\bar{u}d}$

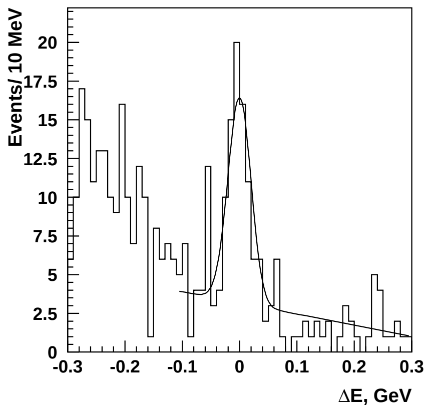
$D\pi^0$



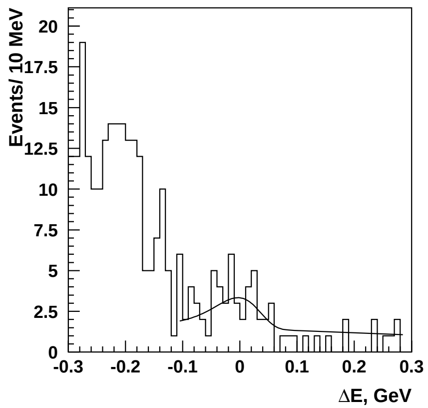
$D\eta$



$D\omega$



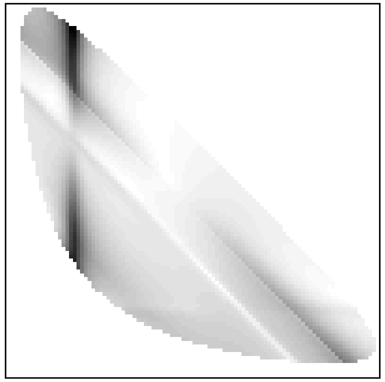
$D^*\pi^0 \& D^*\eta$



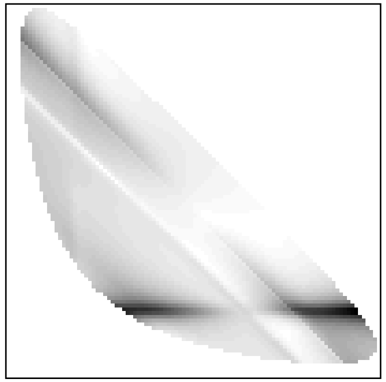
A. Bondar, T.G., P. Krokovny, PLB 624, 1 (2005)

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

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

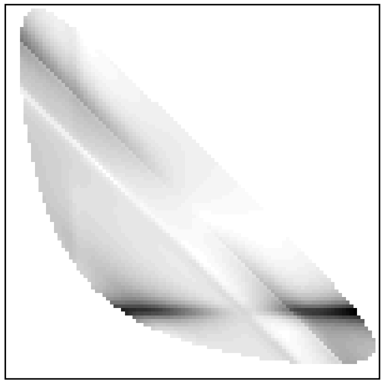


$\cos\left(\frac{\Delta m \Delta t}{2}\right) - i\Phi^*$

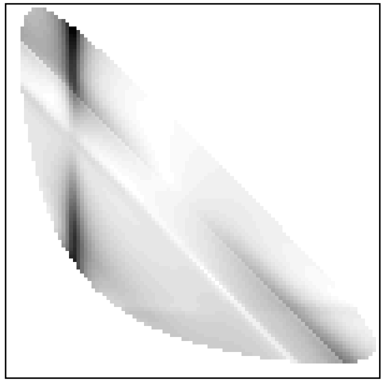


$\sin\left(\frac{\Delta m \Delta t}{2}\right)\Bigg|^2$

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



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



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

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

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

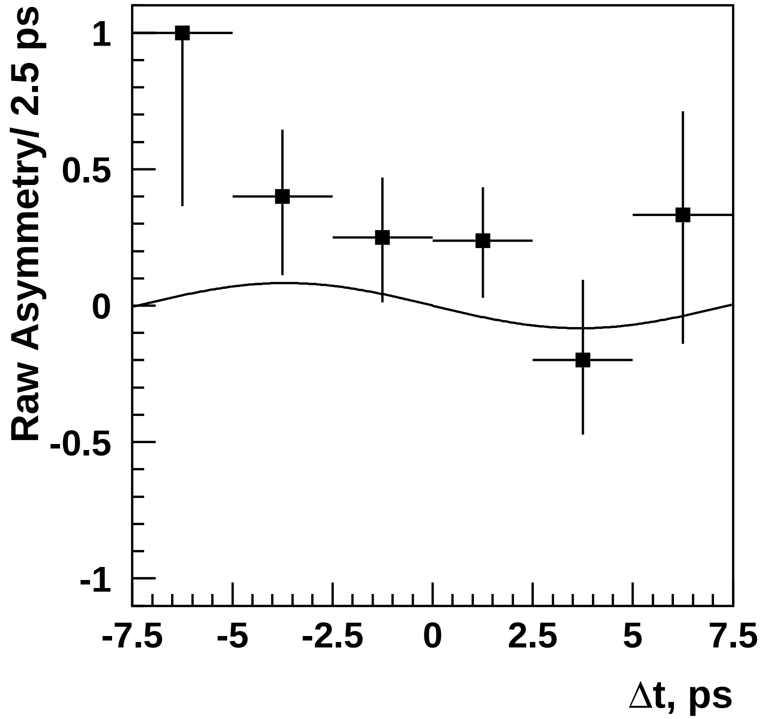
357 fb^{-1} BELLE-CONF-0546

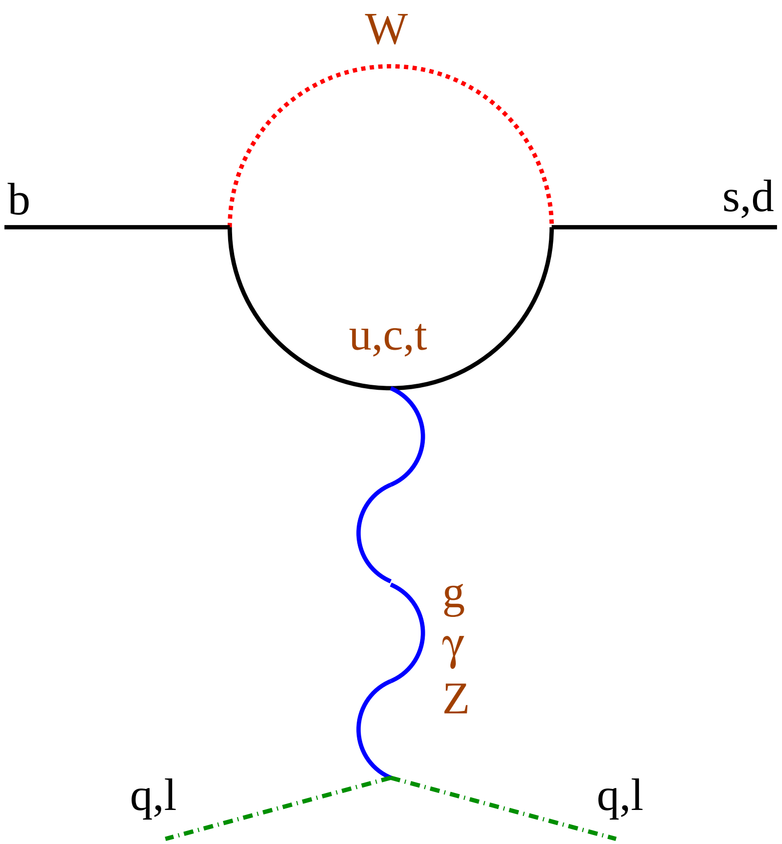
Process	N_{tot}	Efficiency (%)	N_{sig}	Purity
$D\pi^0$	265	8.7	157 ± 24	59%
$D\omega$	78	4.1	67 ± 10	86%
$D\eta$	97	3.9	58 ± 13	60%
$D^*\pi^0$,$D^*\eta$	52		27 ± 11	52%
Sum	492		309 ± 31	63%

Data fit results. Statistical errors from toy MC.

Final state	ϕ_1 fit result, $^\circ$
$D\pi^0$	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.

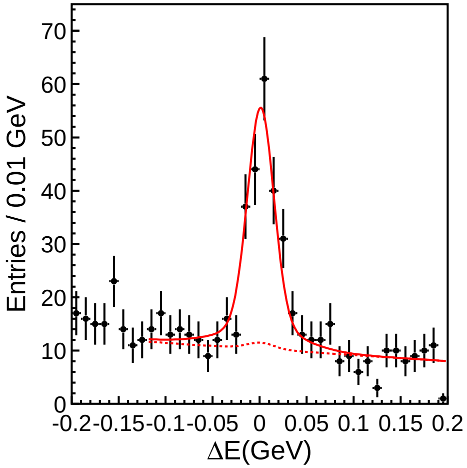


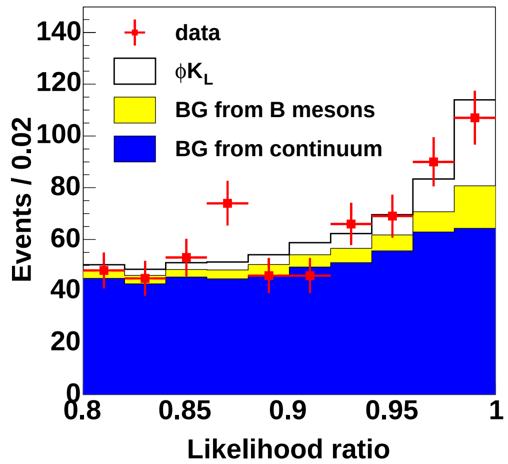


- loop diagrams ⇒ virtual particles ⇒ high masses
- expect new physics at TeV scale
- NP particles should appear in loops
- no reason for NP phases to be aligned
- many possible manifestations of NP
  - $b \to s$ *vs.* $b \to d$
  - gluonic *vs.* radiative *vs.* electroweak
  - $\Delta B = 2$ (mixing)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

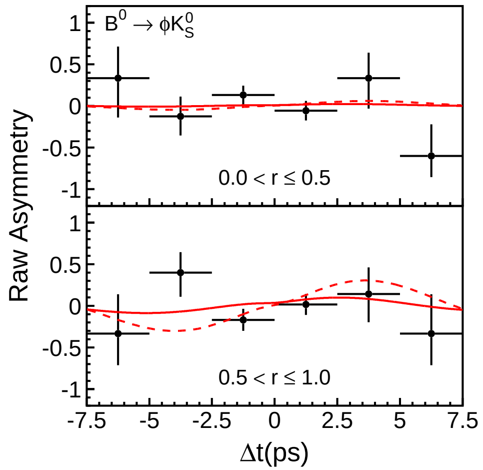
$B^0 \to \phi K^0$

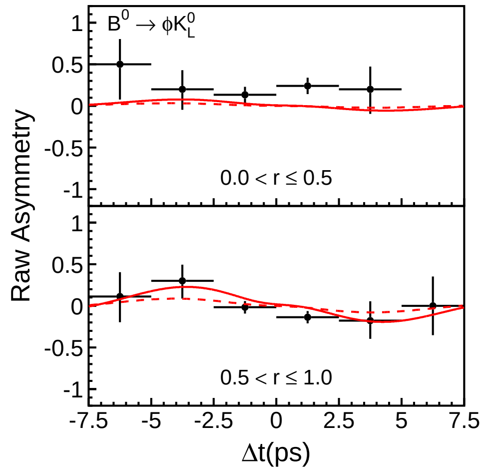
ϕK_S ϕK_L





180 ± 16 78 ± 13





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

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

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

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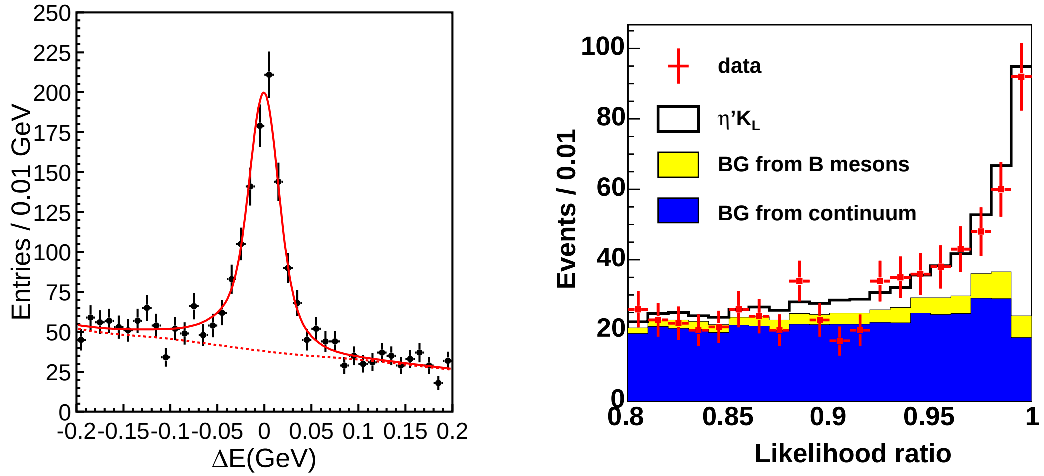
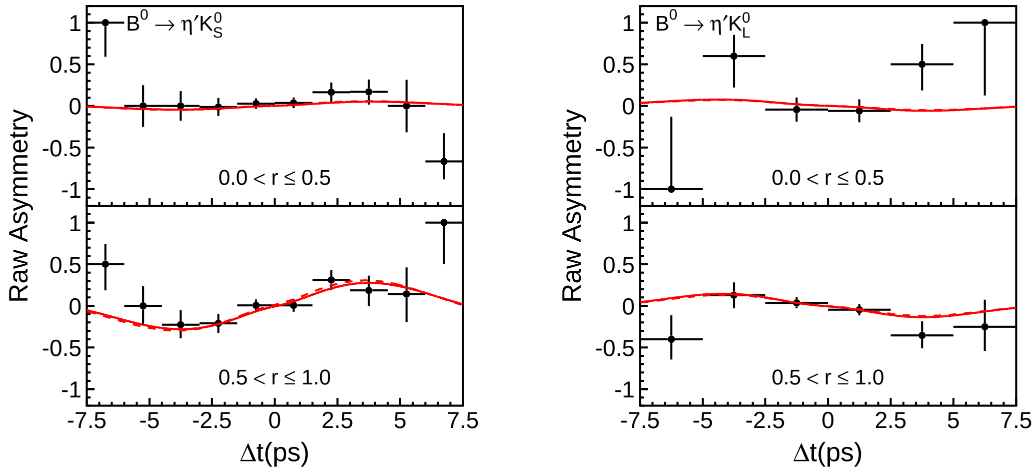
$\eta' K_S$	$\eta' K_L$



830 ± 35	187 ± 18



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

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

357 fb^{-1}

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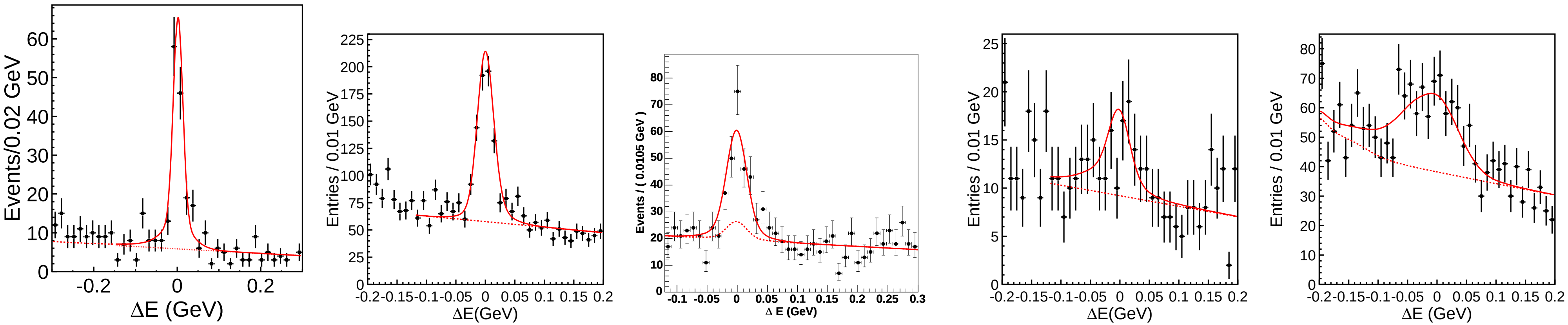
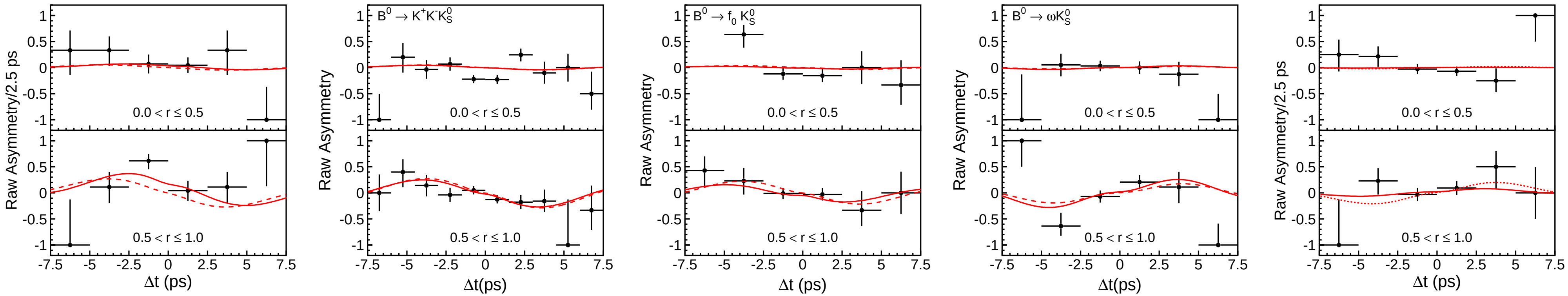
$K_S K_S K_S$	$K^+K^-K_S$	$f_0 K_S$	ωK_S	$K_S \pi^0$
105 ± 12	536 ± 29	145 ± 16	68 ± 13	344 ± 30





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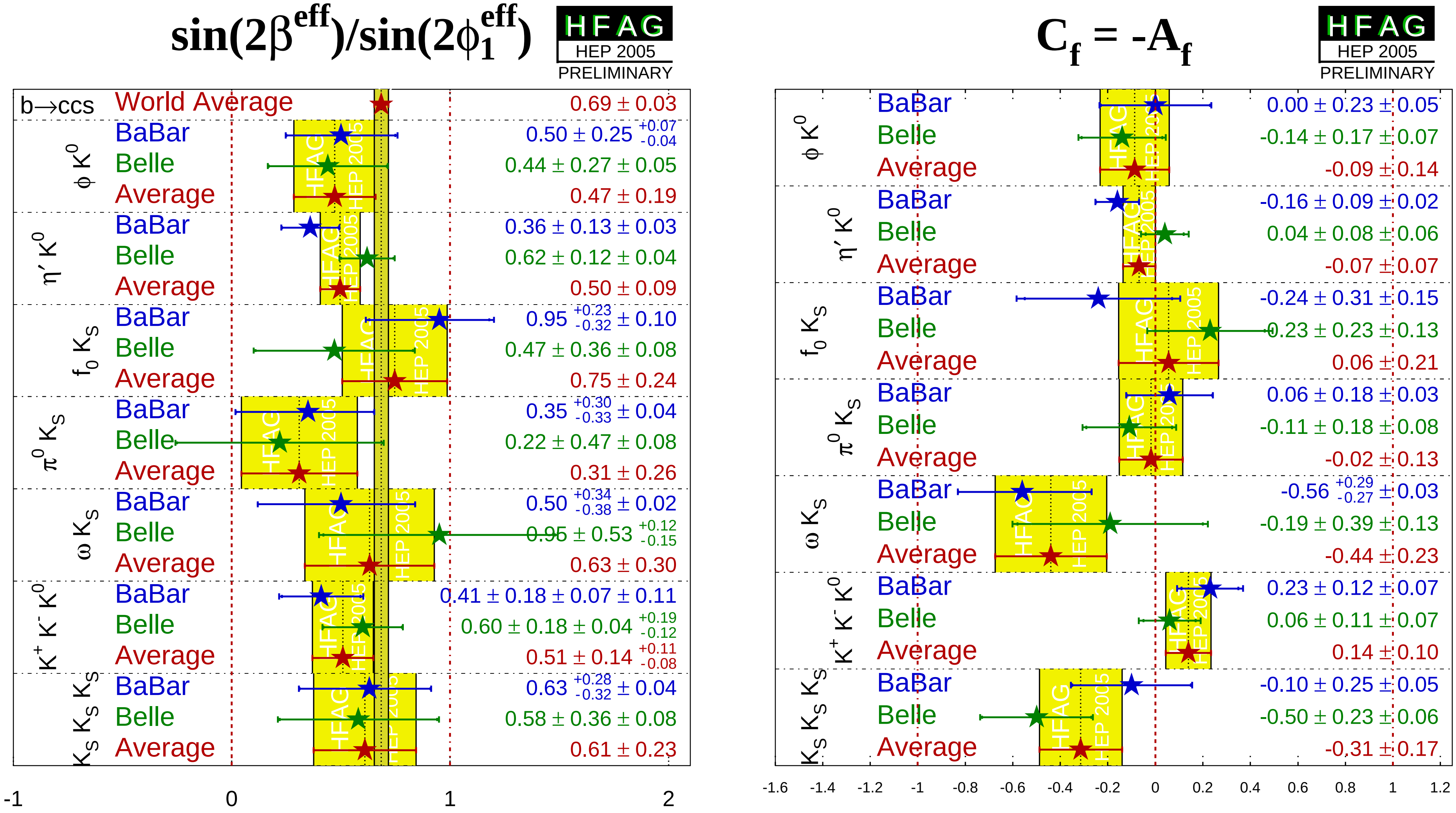

$B \to \pi^+\pi^-$ Candidates

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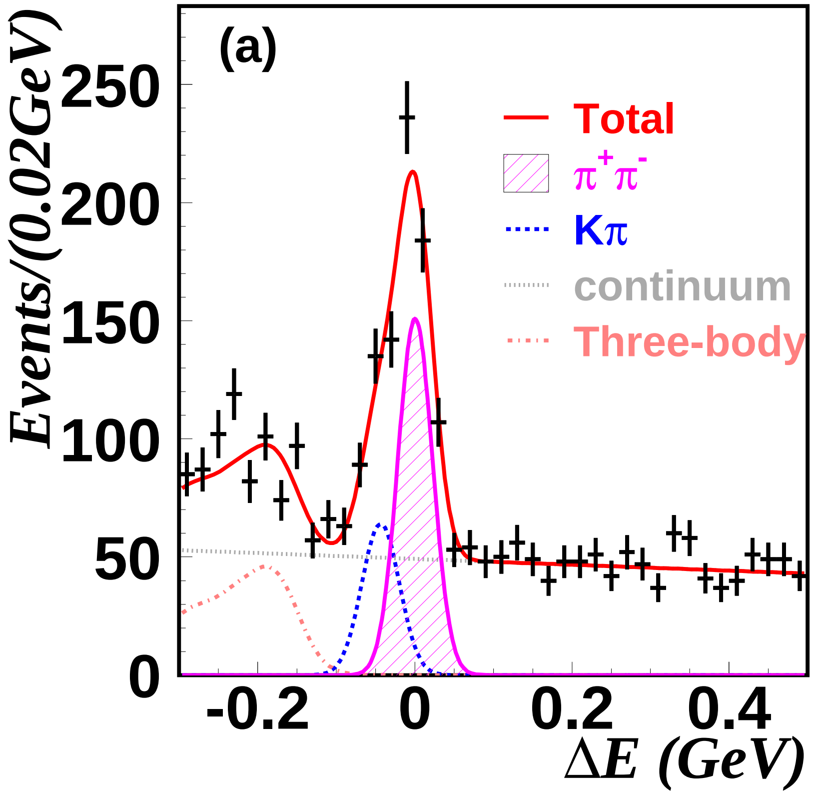
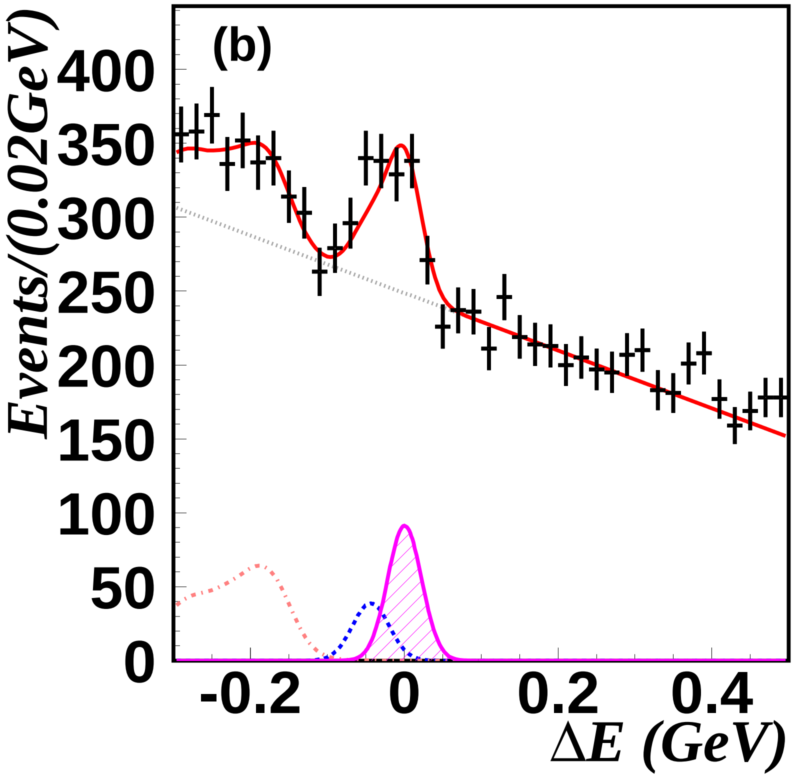
Categorize candidates based on level of $q\bar{q}$ background

High quality

Low quality





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

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

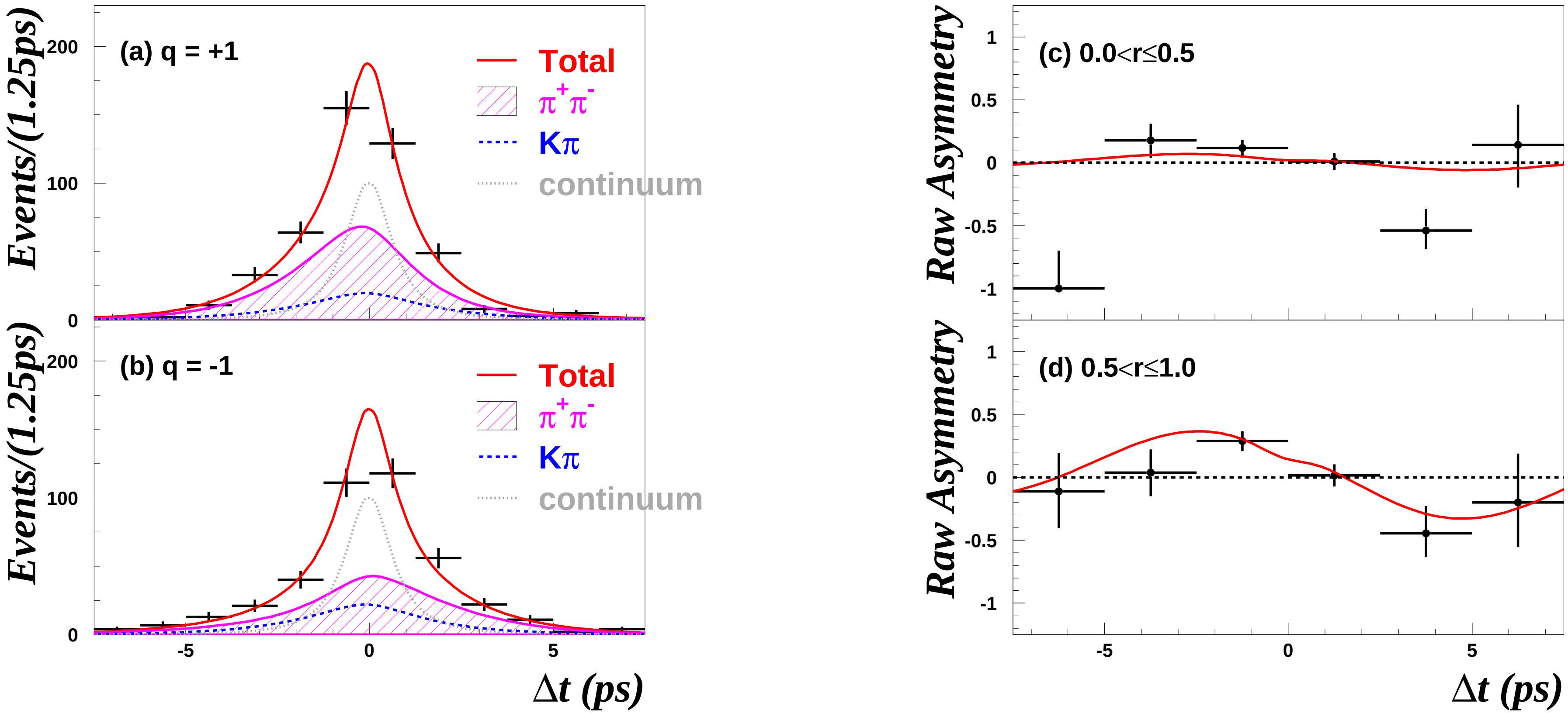
$*$ 2820 candidates $*$

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

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

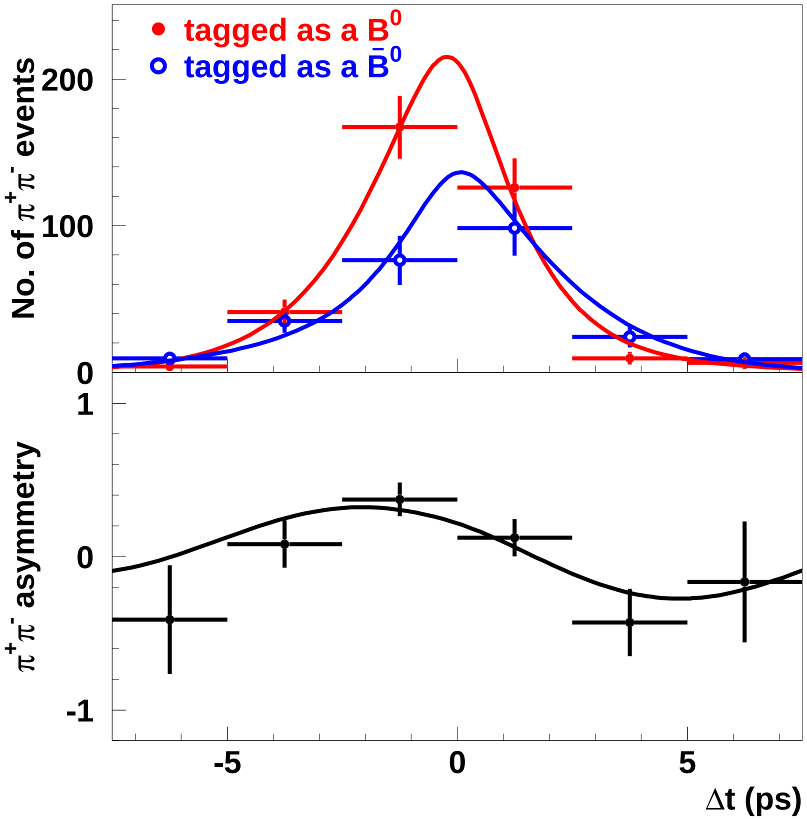
$A_{\pi^+\pi^-} = +0.56 \pm 0.12 \pm 0.06$

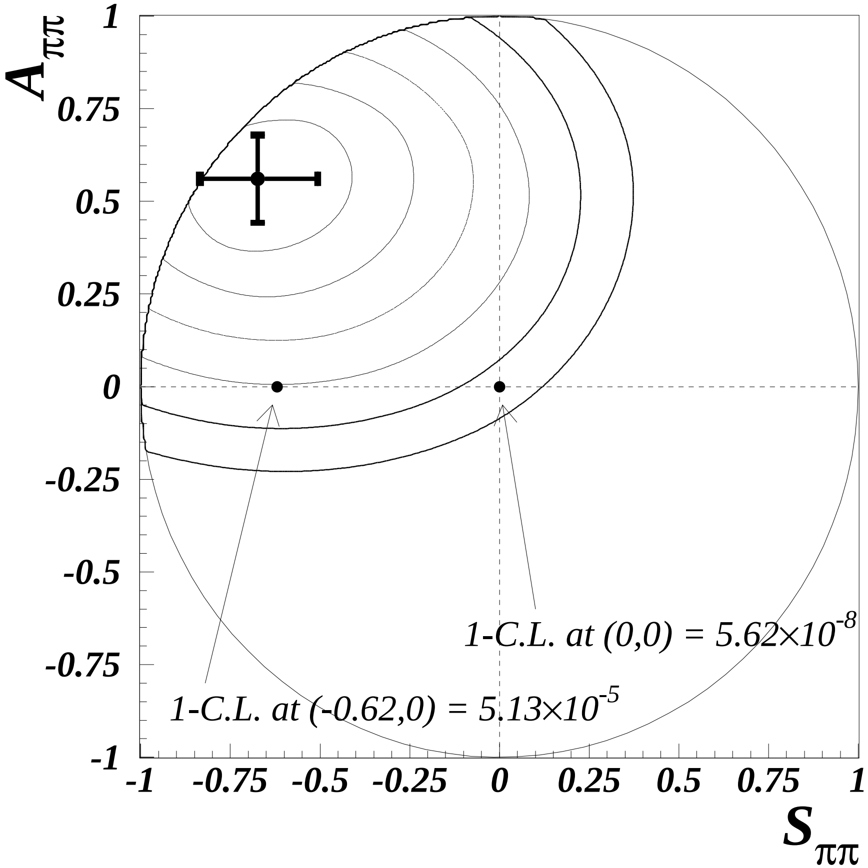
Plots for high quality events only



253 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

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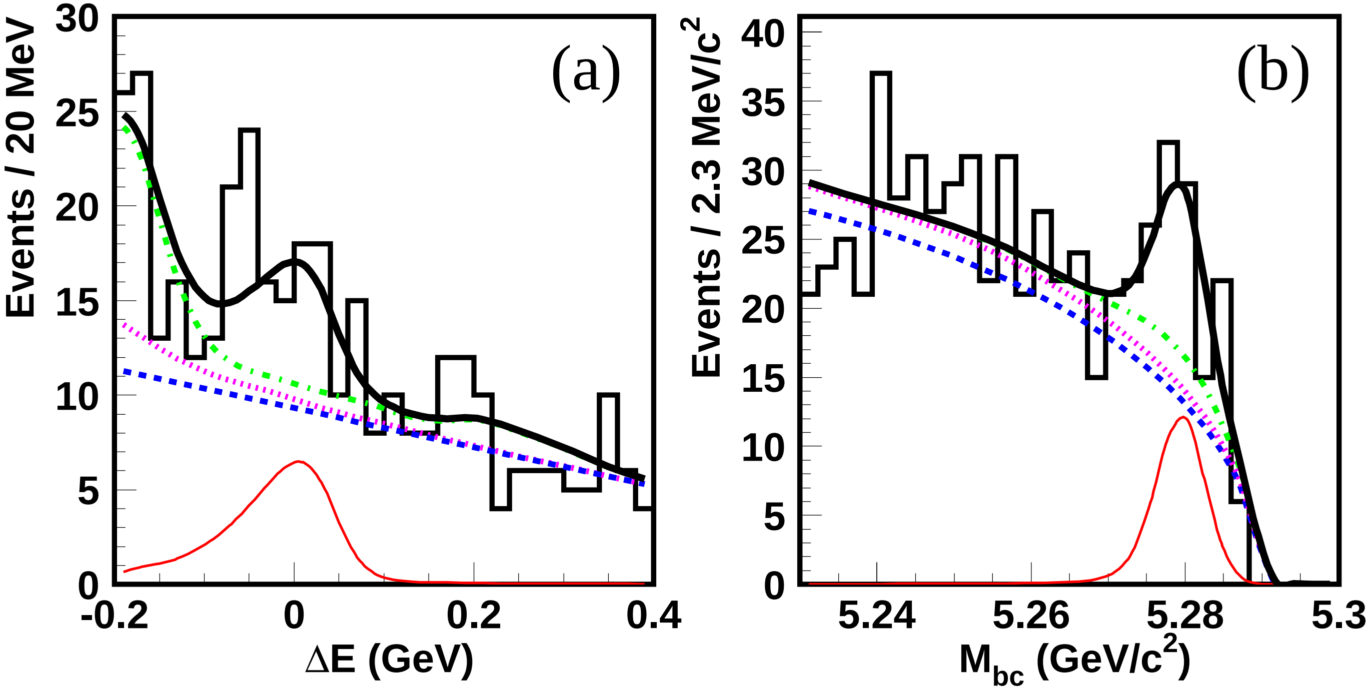
- Dalitz plot analysis of $B^0 \to \pi^+\pi^-\pi^0$ can measure ϕ_2 & resolve ambiguities
- Main contributions from $\rho^\pm\pi^\mp$, other contributions complicate the analysis



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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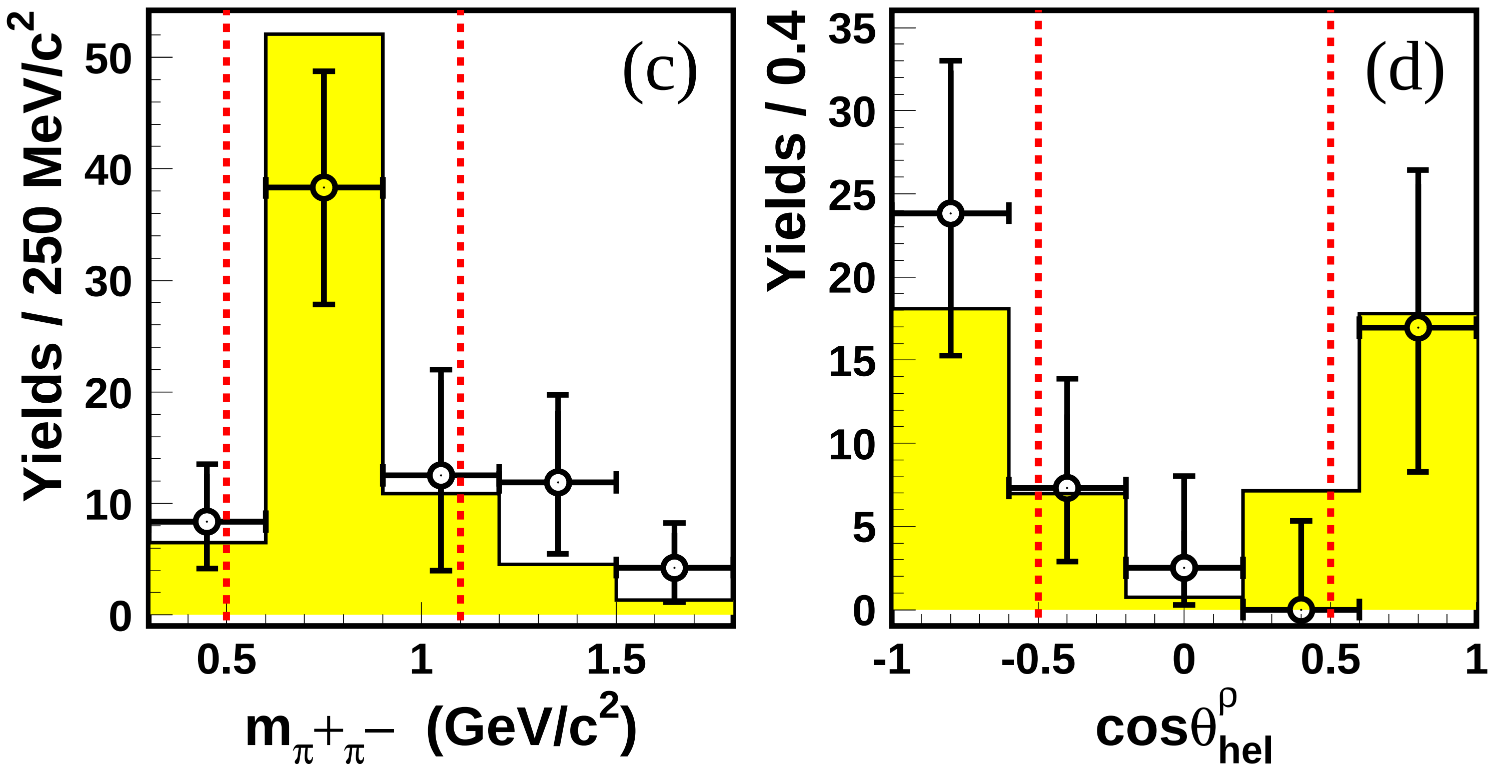

$B^0 \to \rho^+\rho^-$

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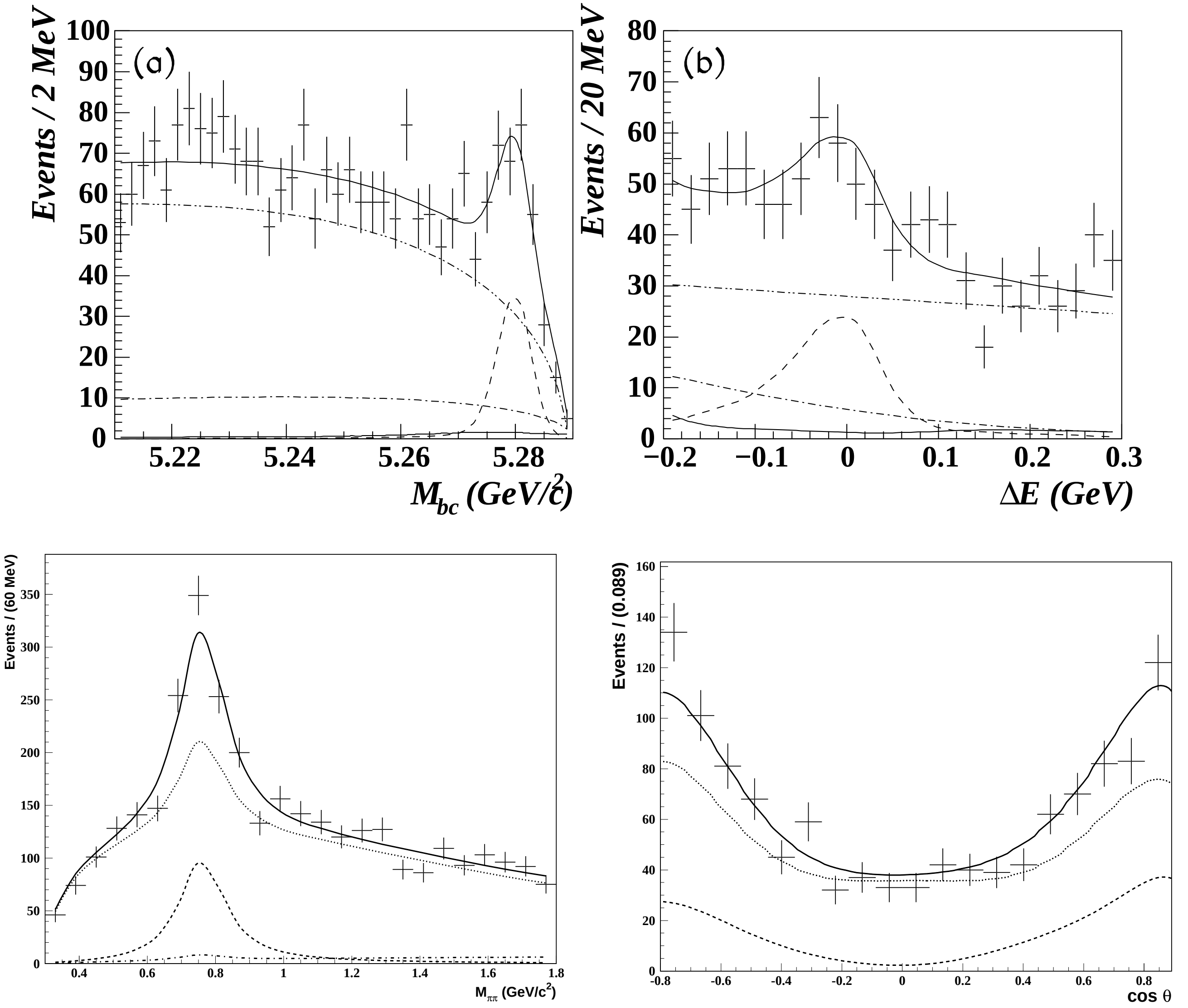

142 ± 13 signal events $\quad f_{\text{long}} = 0.951^{+0.033}_{-0.039}{}^{+0.029}_{-0.031}$