Measurement of ϕ_3 using $B^\pm \to DK^\pm$ with $D \to K_S\pi^+\pi^-$

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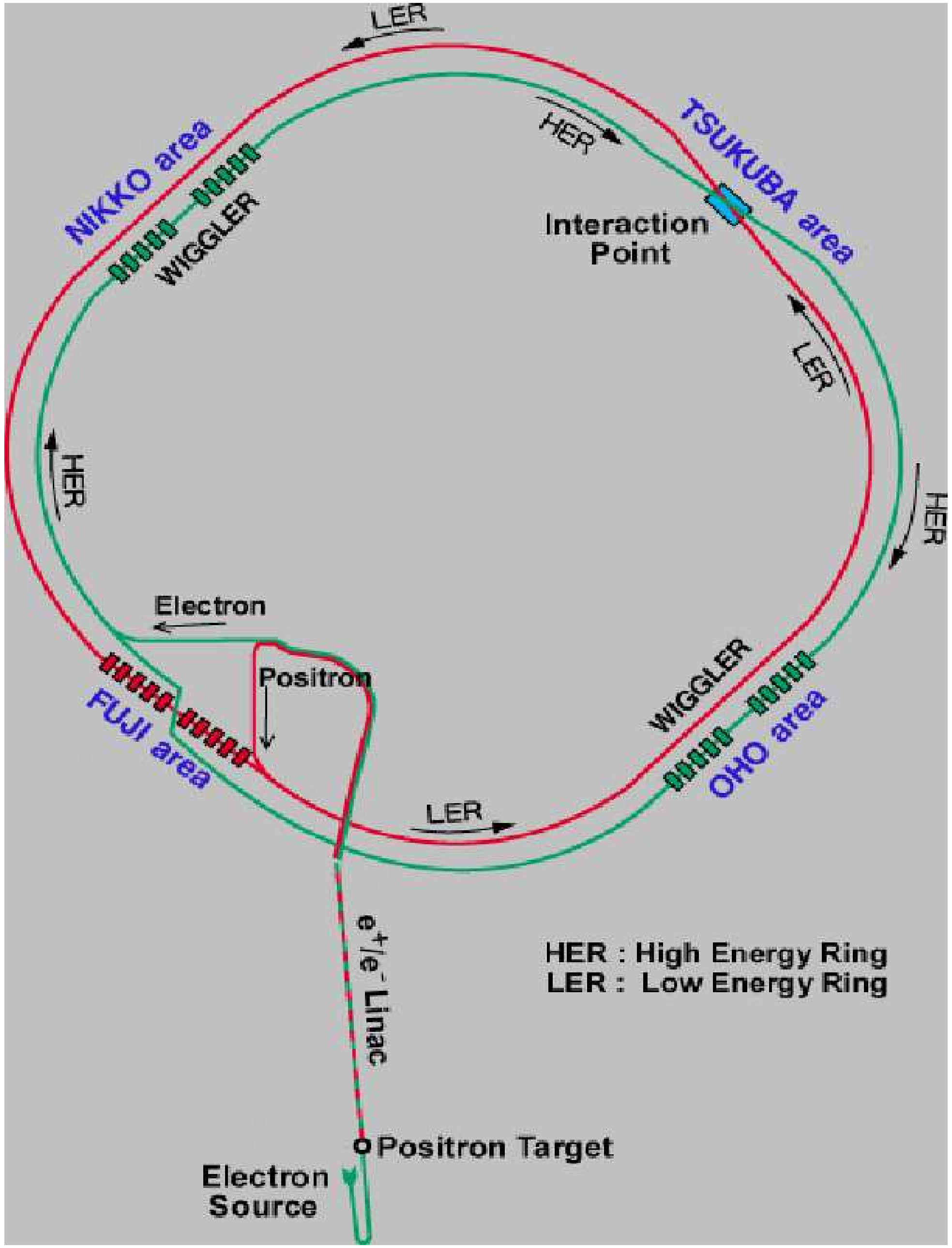
June 7, 2004

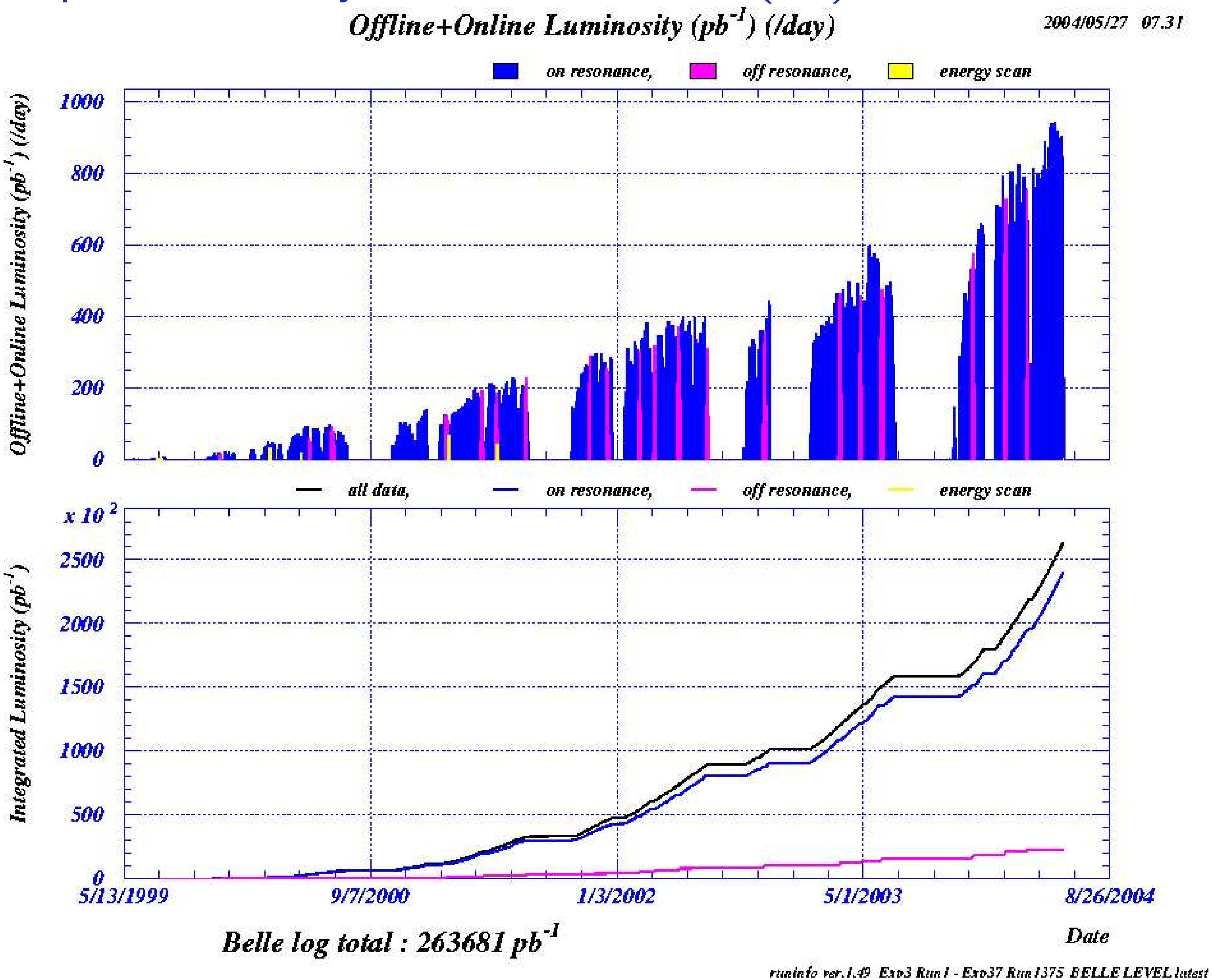
KEK



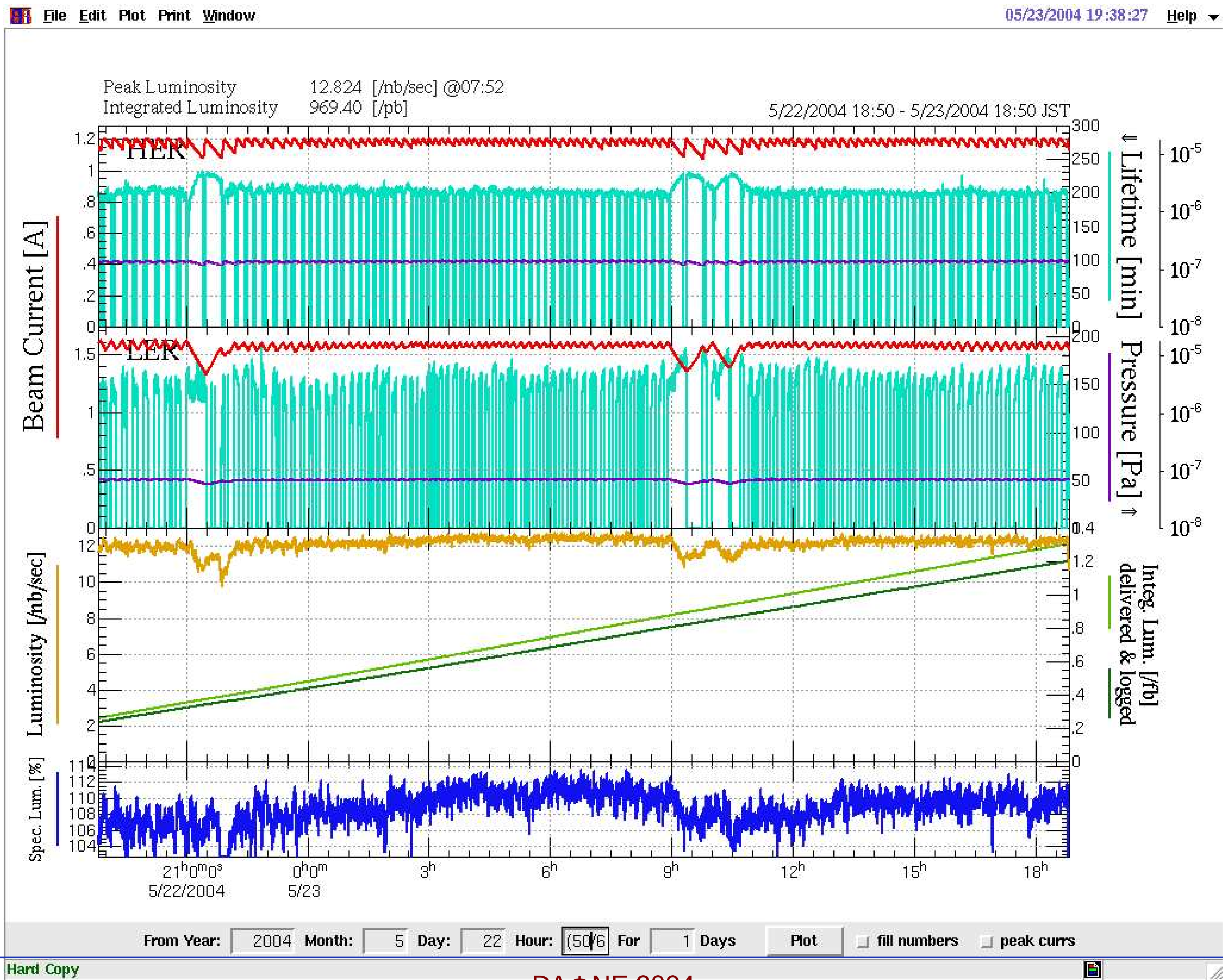
LER
HER
NIKKO area
WIGGLER
TSUKUBA area
Interaction Point
LER
HER
HER
Electron
Positron
FUJI area
LER
WIGGLER
OHO area
e^+/e^- Linac
HER : High Energy Ring
LER : Low Energy Ring
Positron Target
Electron Source

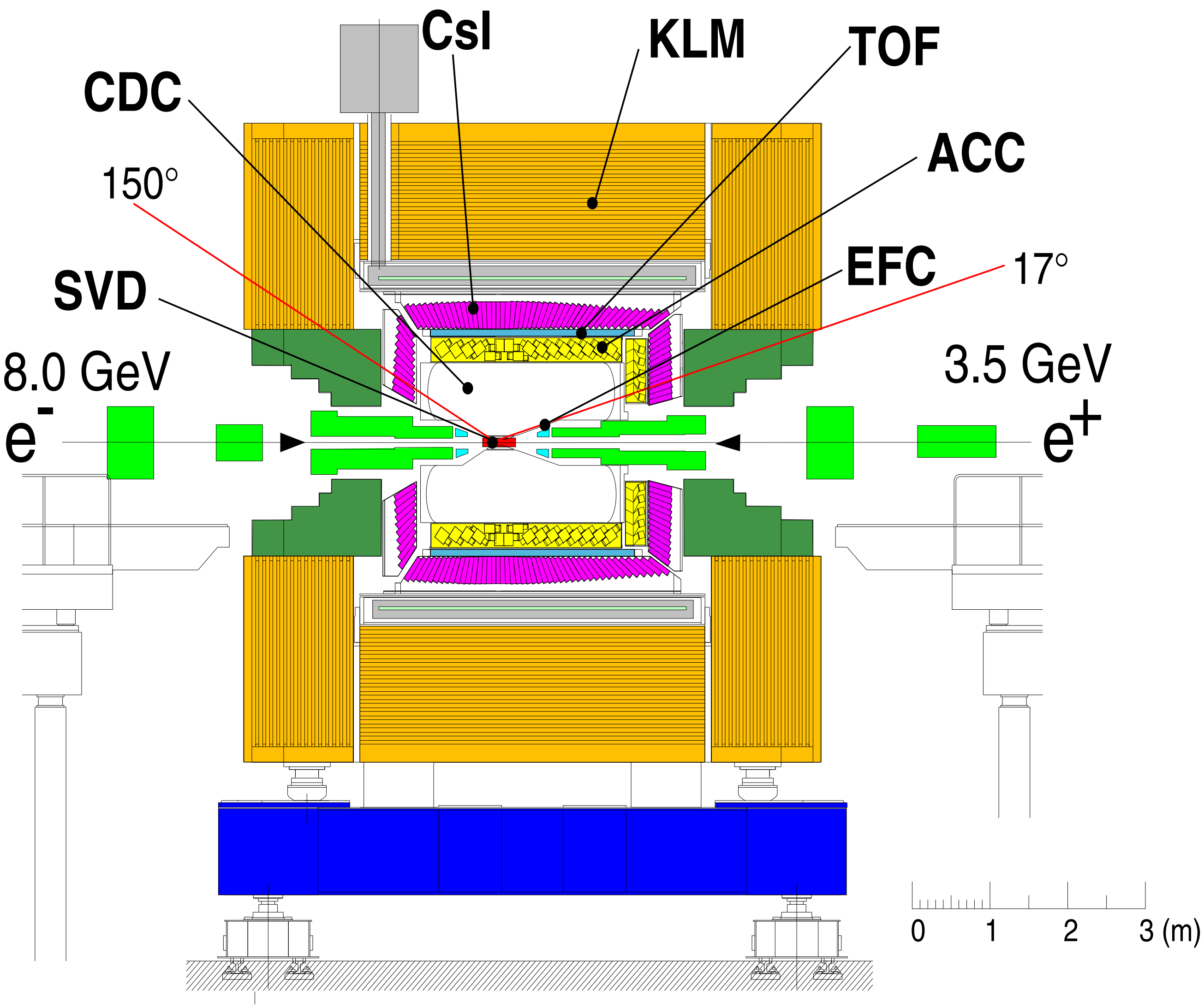
Integrated Luminosity

Results presented today use 140 fb^{-1} on $\Upsilon(4S) \cong 150 \times 10^6\, B\bar{B}$ pairs



The Best 24 Hours





- SVD 3 DSSD layers

  $\sigma \sim 55\ \mu$m for 1 GeV/c @ 90°
- CDC 50 layers

  $\sigma_p/p \sim 0.35\%$ @ 1 GeV/c

  $\sigma_\pi(dE/dx) \sim 7\%$
- TOF $\sigma_t \sim 95$ ps
- ACC ($n = 1.01 \rightarrow 1.03$)

  K/π separation up to 3.5 GeV/c
- CsI $\sigma_E/E_\gamma \sim 1.8\%$ @ 1 GeV
- KLM 14 RPC layers
- 1.5 T magnetic field

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

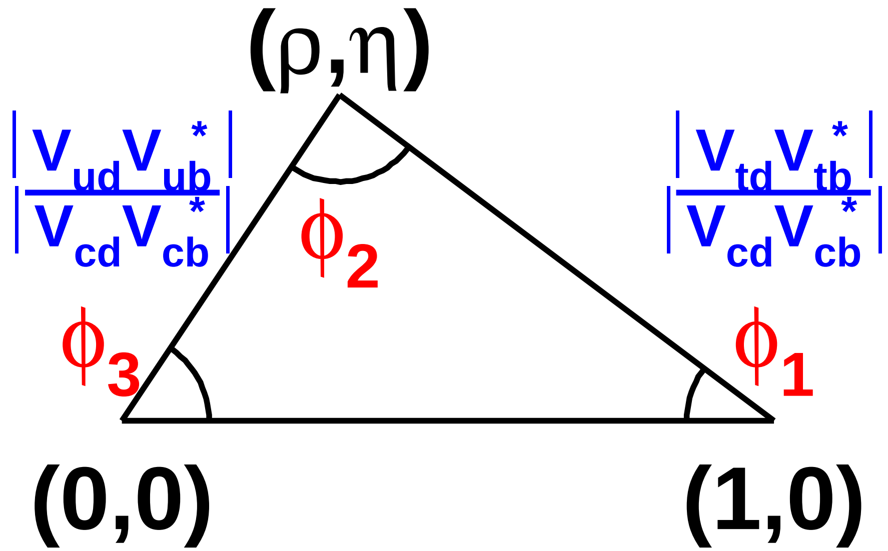
$$V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0$$

The Unitarity Triangle

$\phi_1 \leftrightarrow \beta$

$\phi_2 \leftrightarrow \alpha$

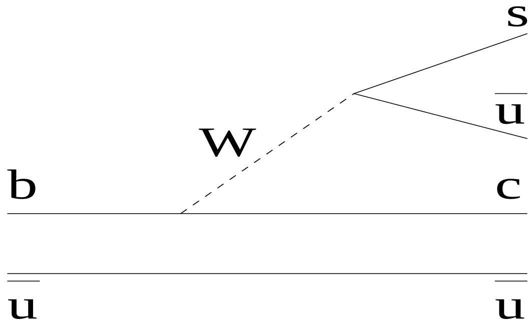
$\phi_3 \leftrightarrow \gamma$



- Can access ϕ_3 via interference between $B^- \to D^0 K^-$ & $B^- \to \bar{D}^0 K^-$
- Reconstruct D in final states accessible to both D^0 and $\bar{D}^0$

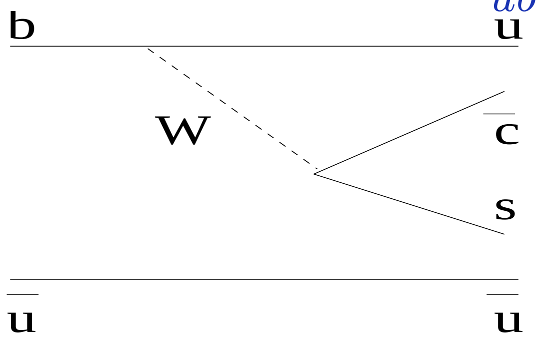
  eg. $D_{CP}K^-$ (Gronau, London, Wyler method)
- Can use multibody final states, *eg.* $K_S\pi^+\pi^-$ (first noted by Atwood, Dunietz, Soni)

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



COLOUR ALLOWED

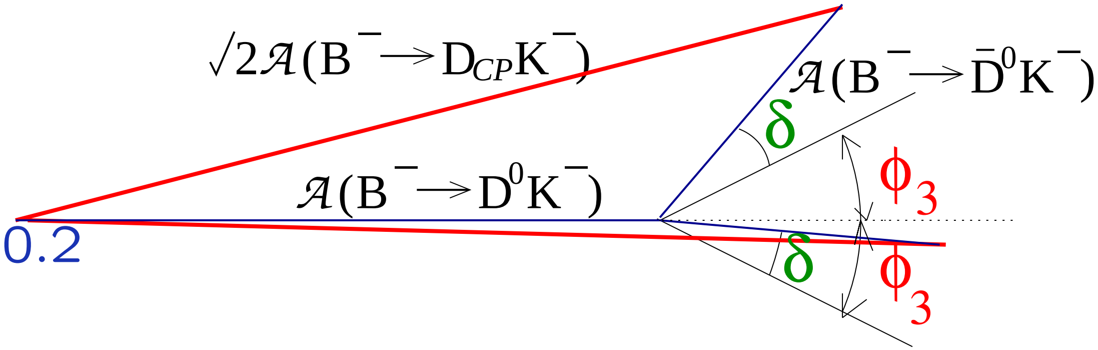
$B^- \to \bar{D}^0 K^- \sim V_{cs}V_{ub}^*$



COLOUR SUPPRESSED

$\mathcal{A}$ — amplitude

$r = \mathcal{A}_{\text{SUPPRESSED}}/\mathcal{A}_{\text{FAVOURED}} \sim 0.1 - 0.2$



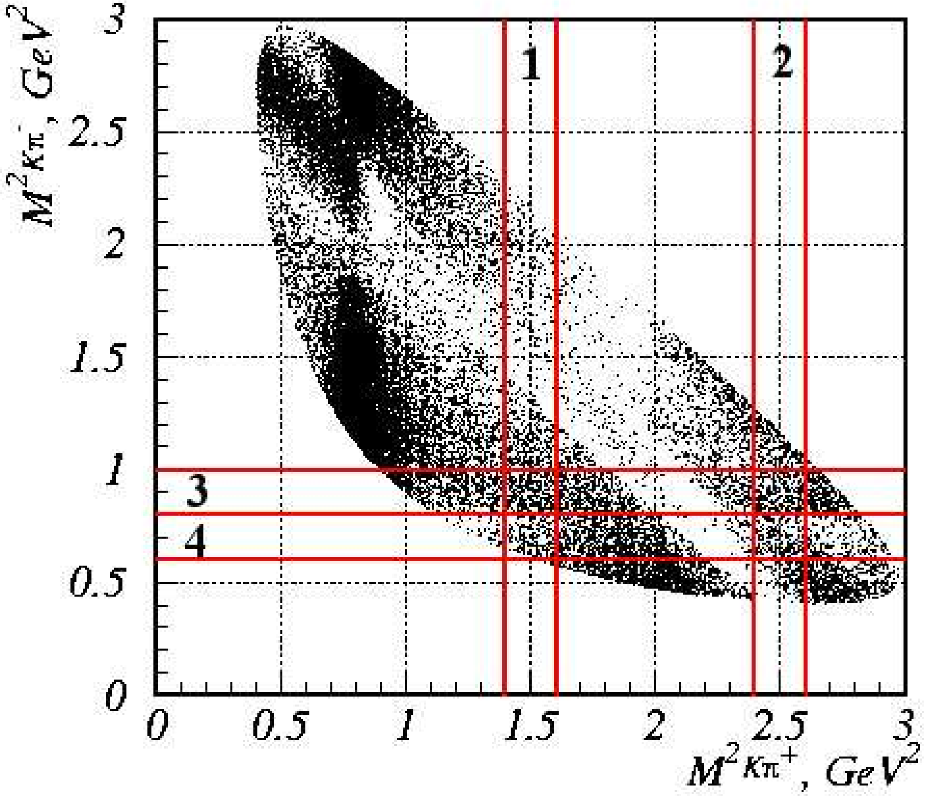
Principle of the Multi-Body Analysis

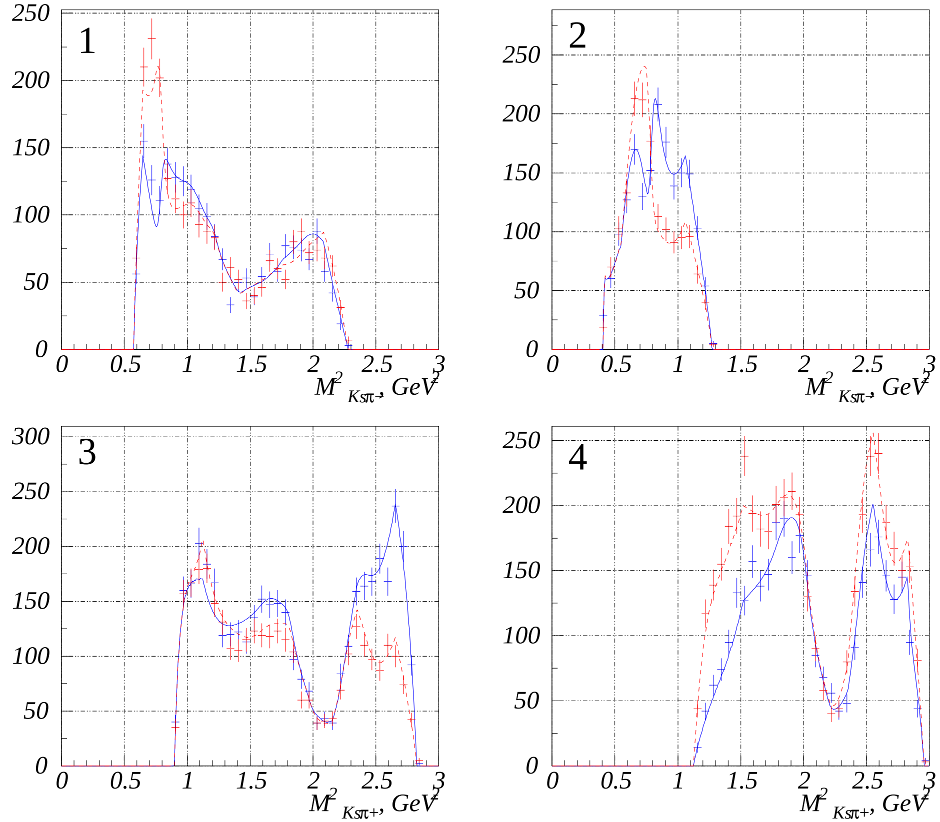
- Consider $\bar{D}^0 \to K_S\pi^+\pi^-$
  $\to$ define amplitude at each Dalitz plot point as $f(m_+^2, m_-^2)$
  where $m_+ = m_{K_S\pi^+}$, $m_- = m_{K_S\pi^-}$
- Consider $D^0 \to K_S\pi^+\pi^-$
  $\to$ amplitude at each Dalitz plot point is $f(m_-^2, m_+^2)$
- $\left|f(m_+^2, m_-^2)\right|$ can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

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

Illustration Using Monte Carlo

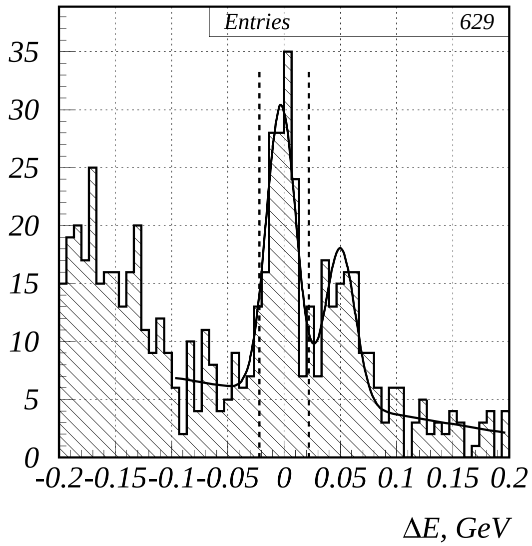
Generated 50,000 decays with $r = 0.125$, $\delta = 0$, $\phi_3 = 70°$

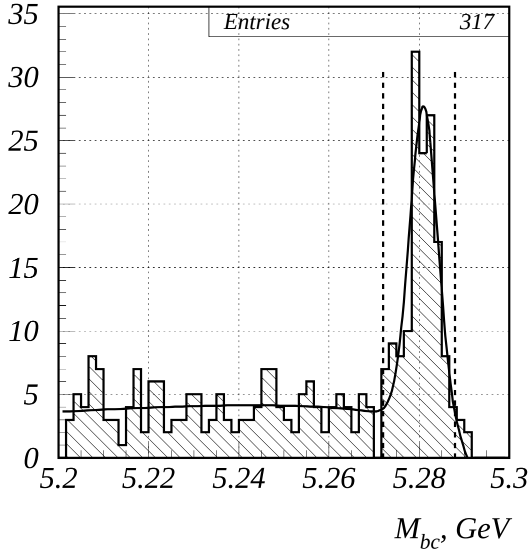




$B^\pm \to (K_S\pi^+\pi^-)_D K^\pm$ Selection

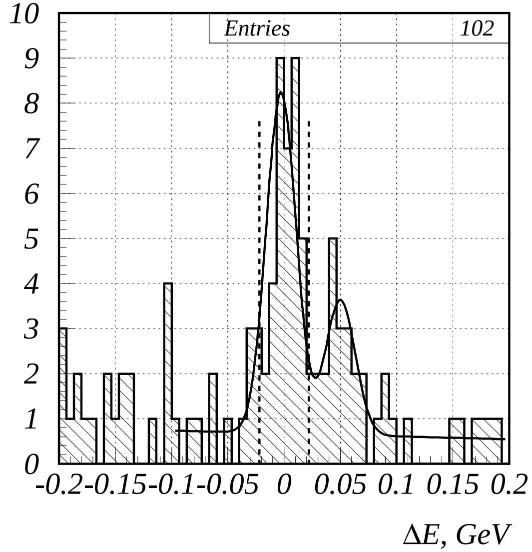
$B^\pm \to DK^\pm$

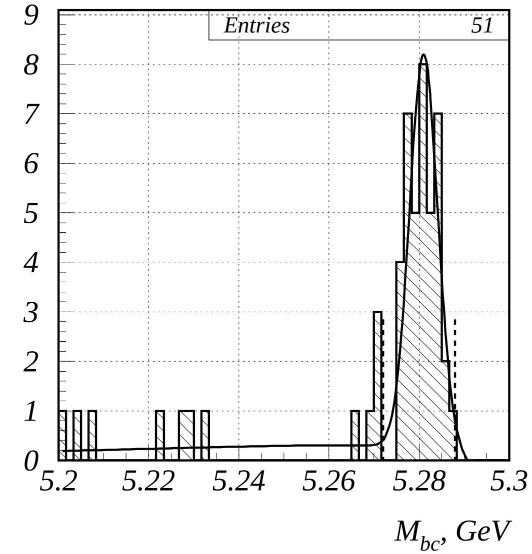




146 candidate events (112 $\pm$ 12 signal)

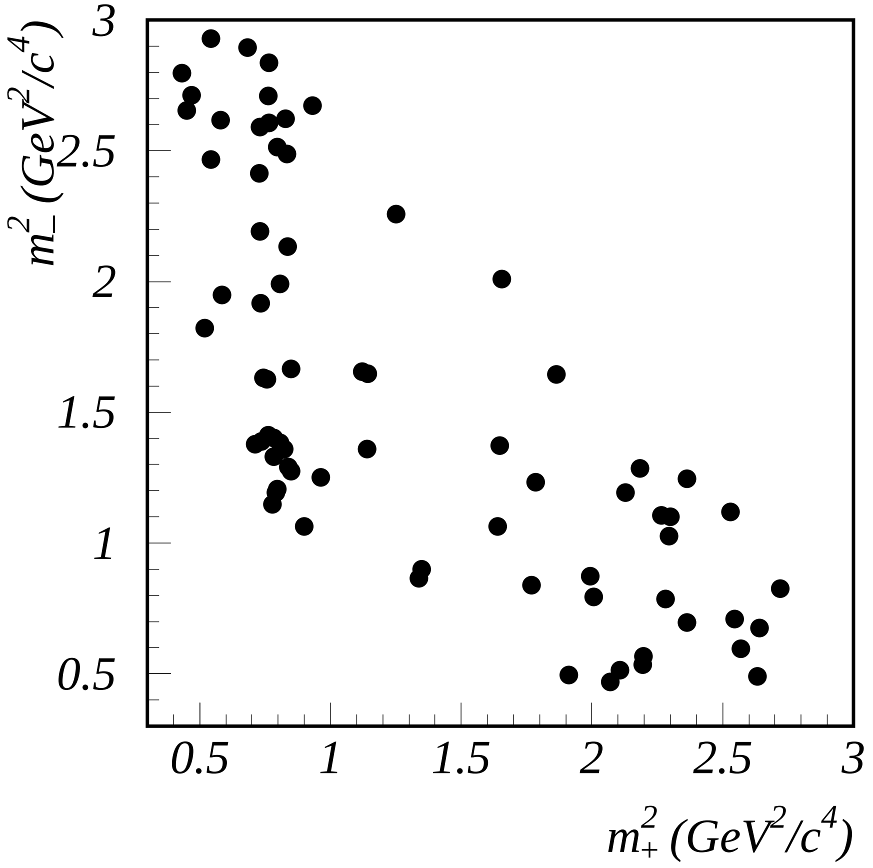
$B^\pm \to D^*K^\pm$

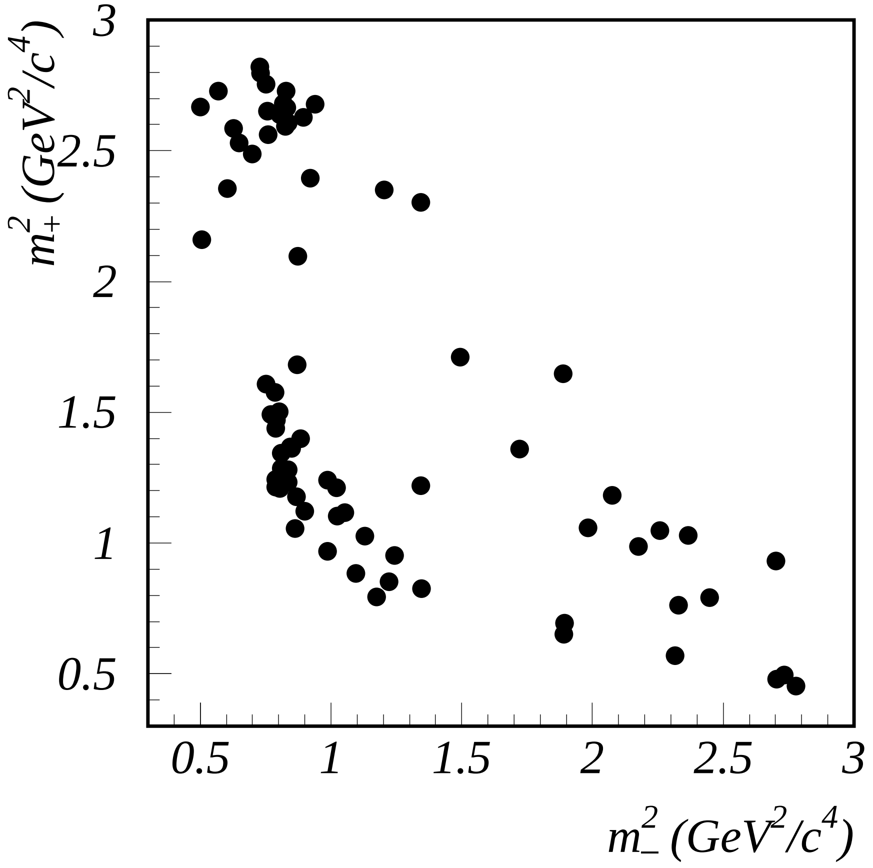




39 candidate events (34 $\pm$ 6 signal)

$$M_+ = f(m_+^2, m_-^2) + re^{i(\delta+\phi_3)} f(m_-^2, m_+^2) \qquad M_- = f(m_-^2, m_+^2) + re^{i(\delta-\phi_3)} f(m_+^2, m_-^2)$$

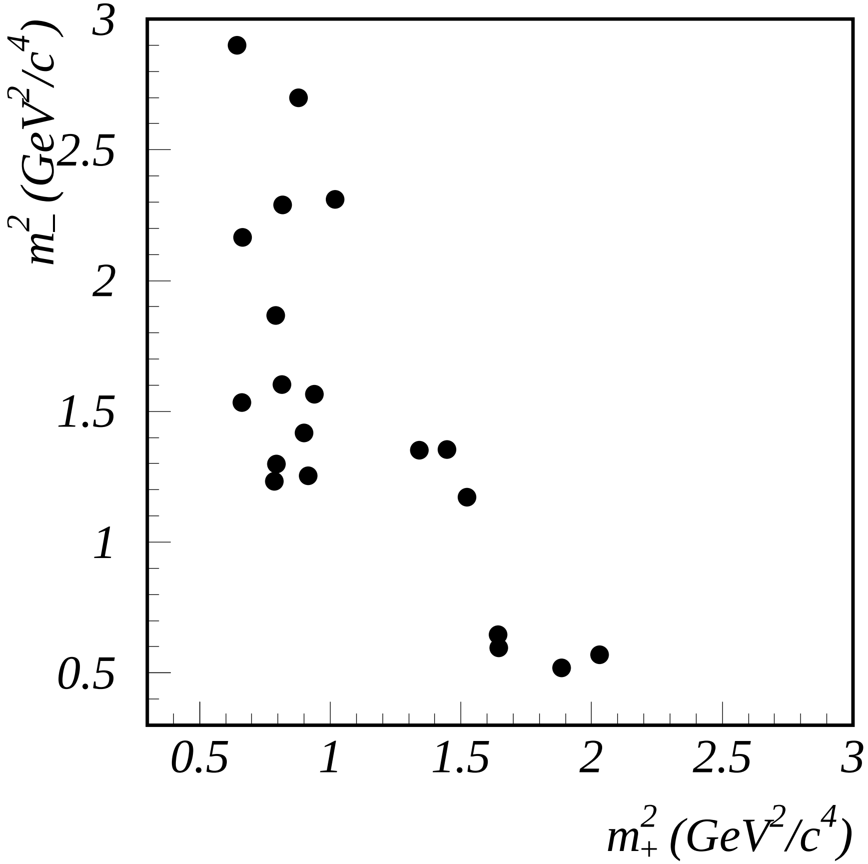


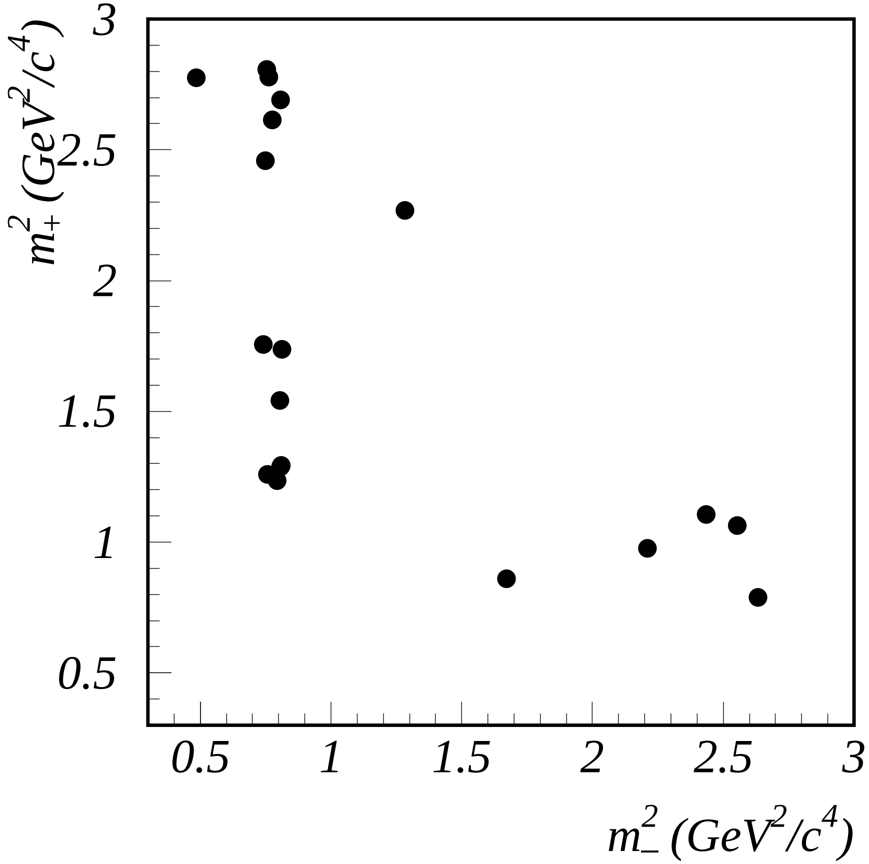


$B^{\pm} \to \left(\left(K_S\pi^+\pi^-\right)_D \pi^0\right)_{D^{*0}} K^{\pm}$ Dalitz Plot Distributions

$$M_+ = f(m_+^2, m_-^2) + re^{i(\delta+\phi_3)} f(m_-^2, m_+^2)$$

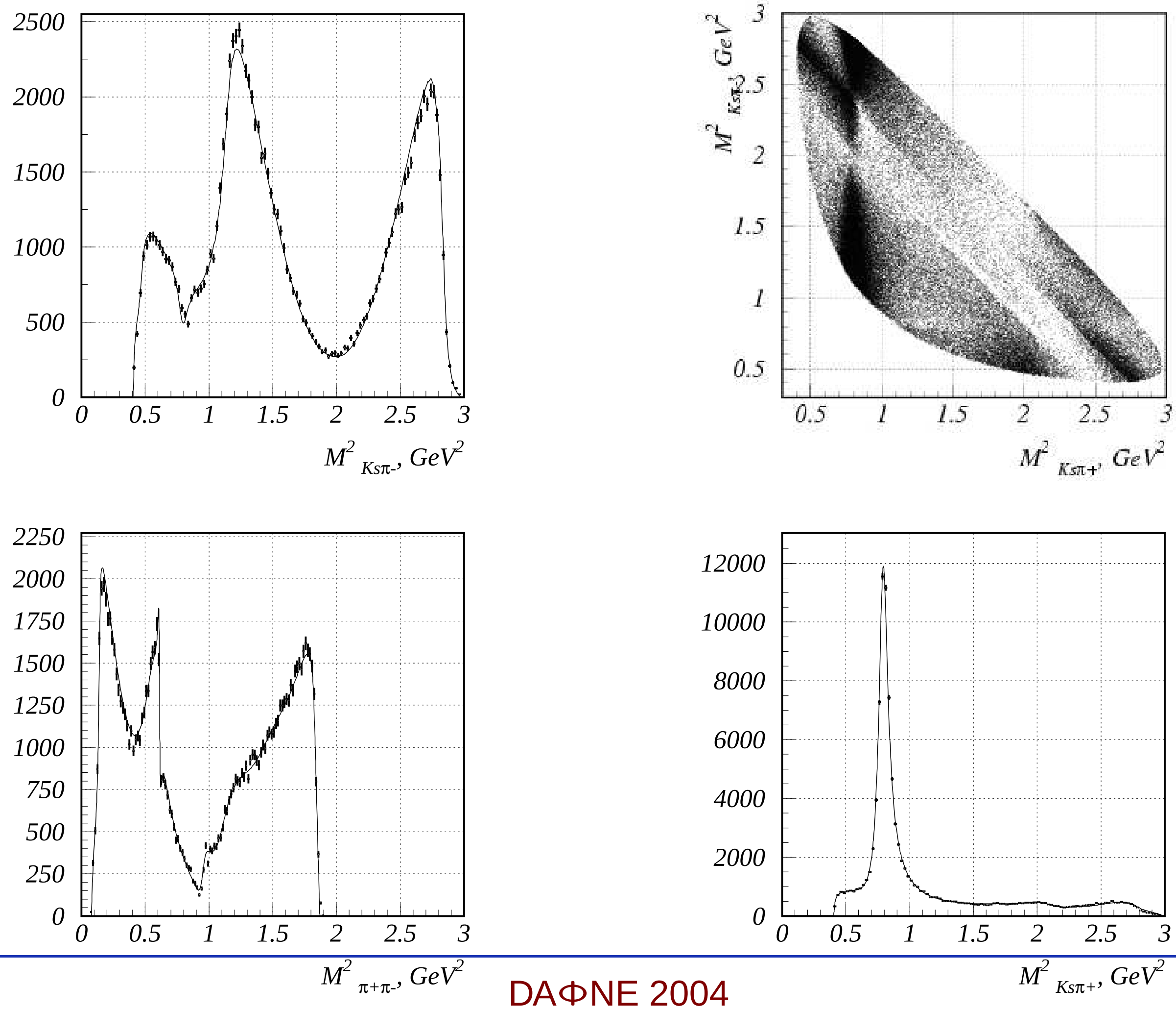
$$M_- = f(m_-^2, m_+^2) + re^{i(\delta-\phi_3)} f(m_+^2, m_-^2)$$





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

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



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

Resonance	Amplitude	Phase (°)
$K^*(892)^-\pi^+$	1.656 ± 0.012	137.6 ± 0.6
$K^*(892)^+\pi^-$	$(14.9 \pm 0.7) \times 10^{-2}$	325.2 ± 2.2
$K_0^*(1430)^-\pi^+$	1.96 ± 0.04	357.3 ± 1.5
$K_0^*(1430)^+\pi^-$	0.30 ± 0.05	128 ± 8
$K_2^*(1430)^-\pi^+$	1.32 ± 0.03	313.5 ± 1.8
$K_2^*(1430)^+\pi^-$	0.21 ± 0.03	281 ± 9
$K^*(1680)^-\pi^+$	2.56 ± 0.22	70 ± 6
$K^*(1680)^+\pi^-$	1.02 ± 0.2	103 ± 11
$K_s\rho^0$	1.0(fixed)	0(fixed)
$K_s\omega$	$(33.0 \pm 1.3) \times 10^{-3}$	114.3 ± 2.3
$K_s f_0(980)$	0.405 ± 0.008	212.9 ± 2.3
$K_s f_0(1370)$	0.82 ± 0.10	308 ± 8
$K_s f_2(1270)$	1.35 ± 0.06	352 ± 3
$K_s\sigma_1$	1.66 ± 0.11	218 ± 4
$K_s\sigma_2$	0.31 ± 0.05	236 ± 11
non-resonant	6.1 ± 0.3	146 ± 3

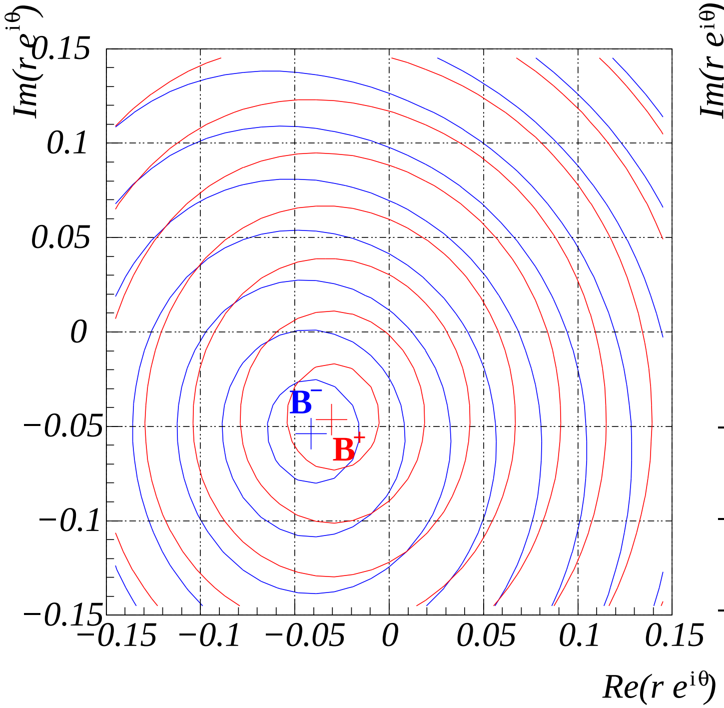
$M_{\sigma_1} = 539 \pm 9$ MeV, $\Gamma_{\sigma_1} = 453 \pm 16$ MeV $M_{\sigma_2} = 1048 \pm 7$ MeV, $\Gamma_{\sigma_2} = 109 \pm 11$ MeV

Test Samples

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

$B^{\pm} \to \left(K_S\pi^+\pi^-\right)_D \pi^{\pm}$

$(r \sim 0.02)$

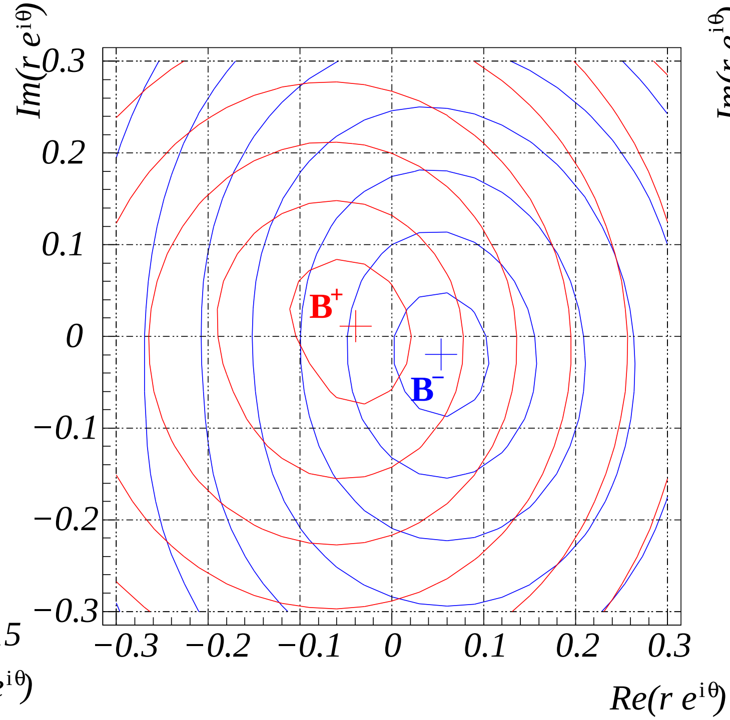


1850 events

2.5σ away from 0

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

$(r \sim 0.02)$

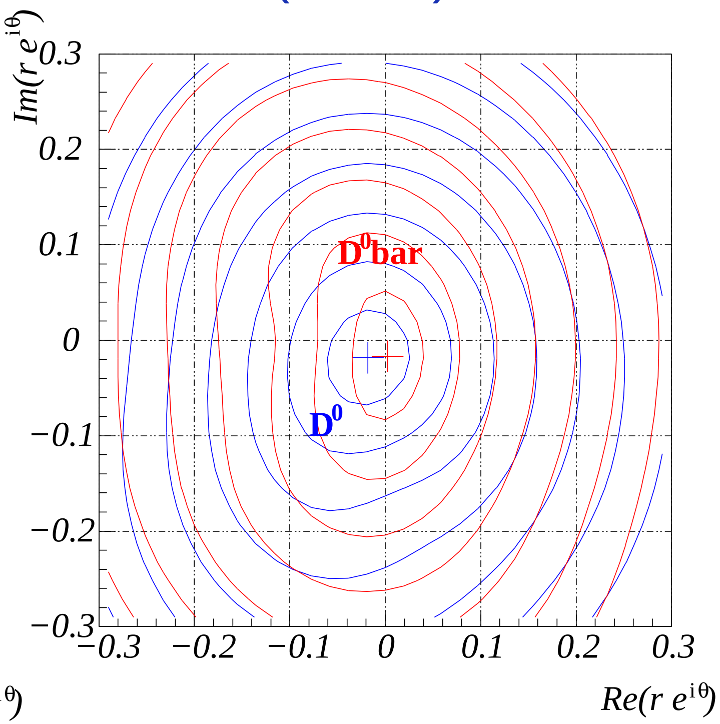


351 events

consistent with 0

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

$(r = 0)$



517 events

consistent with 0

Fits to Extract ϕ_3

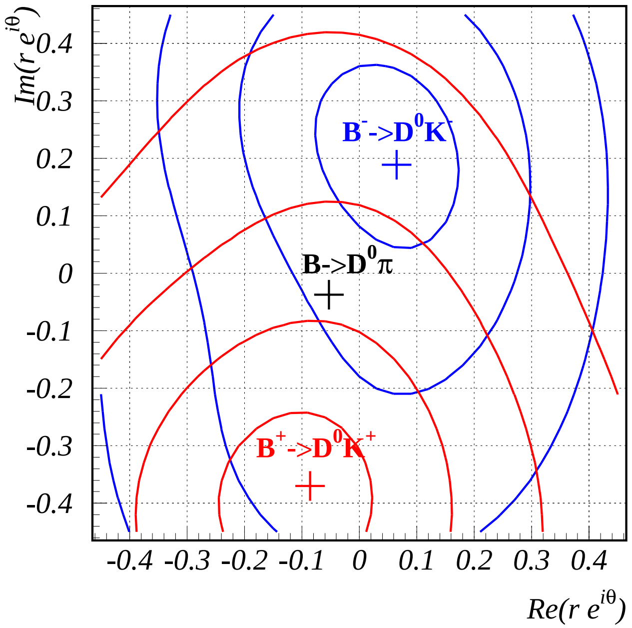
Fit $B^{\pm}$ samples separately, float $re^{i(\delta\pm\phi_3)}$

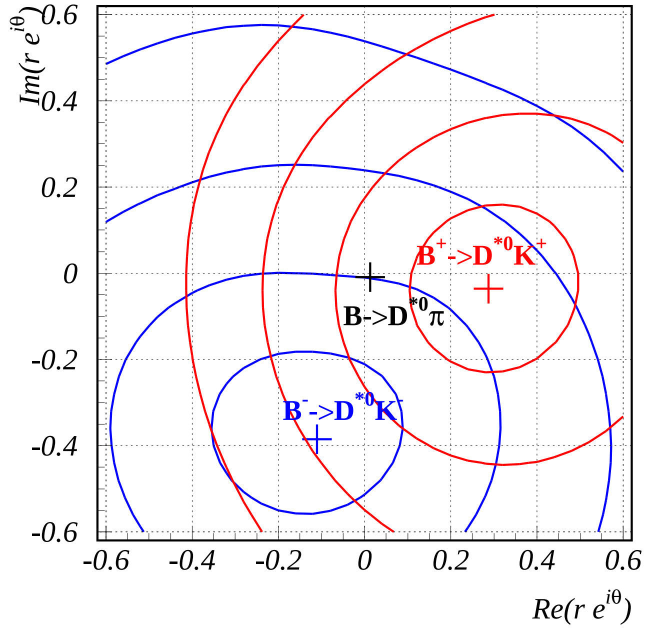
$$B^{\pm} \to \left(K_S\pi^+\pi^-\right)_D K^{\pm}$$

146 candidate events (112 ± 12 signal)

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

39 candidate events (34 ± 6 signal)





PRELIMINARY Results from simultaneous fits (B^+ & B^-) (Errors from likelihood curves)

- $\star\ r = 0.31 \pm 0.11$
- $\star\ \phi_3 = 86^\circ \pm 17^\circ$
- $\star\ \delta = 168^\circ \pm 17^\circ$

- $\star\ r = 0.34 \pm 0.14$
- $\star\ \phi_3 = 51^\circ \pm 25^\circ$
- $\star\ \delta = 302^\circ \pm 25^\circ$

Systematic Errors

	$B^{\pm} \to DK^{\pm}$	$B^{\pm} \to D^{*}K^{\pm}$
Background shape	4.6°	1.3°
Background fraction	0.1°	0.6°
Efficiency shape	3.5°	0.8°
Momentum resolution	2.5°	2.5°
$B^{\pm} \to D\pi^{\pm}$ test sample bias	11°	11°
Total	13°	11°

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	$(\Delta\phi_3)_{\text{max}}$
Only K^*, ρ, ω, f_0 non-resonant	9.9°
Meson formfactors $F_r = F_D = 1$	3.1°
Constant BW width $\Gamma(q^2)$	4.7°
No non-resonant amplitude $a_{NR} = 0$	0.4°
No $\sigma(500)$	0.7°
Total	11°

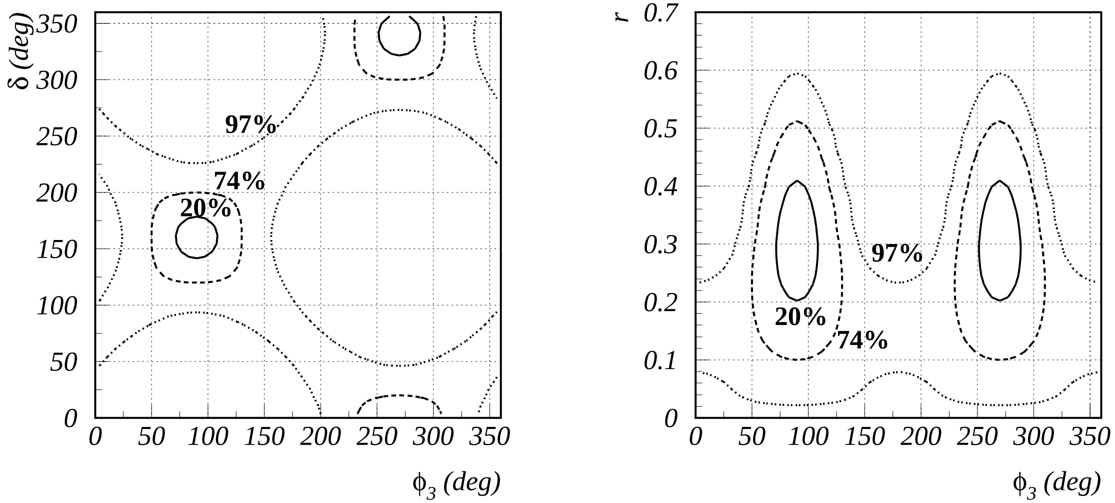
- Consider CP-tagged D mesons decaying to $K_S\pi^+\pi^-$
  $\rightarrow$ amplitude is $f(m_+^2, m_-^2) \pm f(m_-^2, m_+^2)$
- FUTURE: use CP tagged D mesons from $c\tau$ factory ($\psi'' \rightarrow D\bar{D}$)
  $\hookrightarrow$ measure $\phi(m_+^2, m_-^2) \Rightarrow$ remove model uncertainty

Extraction of ϕ_3

Avoid using fit likelihood errors $\rightarrow$ construct PDF for $(r, \phi_3, \delta)_{\text{true}}$ using Toy MC

$B^\pm \rightarrow \left(K_S\pi^+\pi^-\right)_D K^\pm$

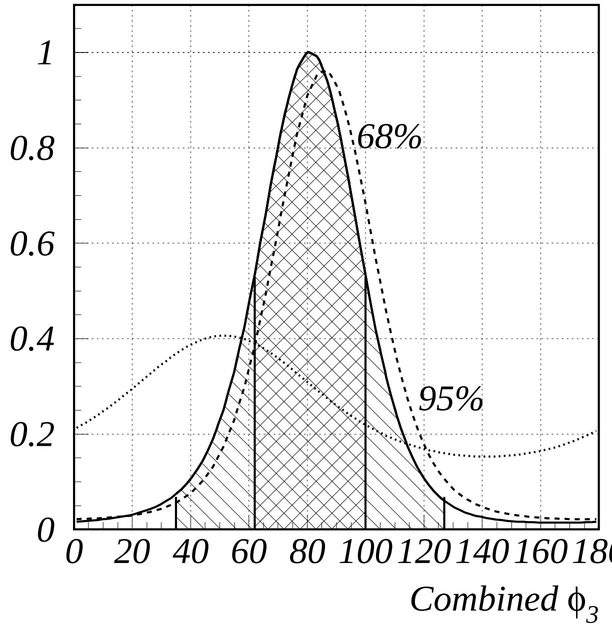
$\phi_3 > 0$ with $> 94\%$ probability



PRELIMINARY

$B^\pm \rightarrow \left(K_S\pi^+\pi^-\right)_D K^\pm$: $\phi_3 = 86^\circ \pm 20^\circ (49^\circ)$

$B^\pm \rightarrow \left(\left(K_S\pi^+\pi^-\right)_D \pi^0\right)_{D^*} K^\pm$: $\phi_3 = 51^\circ \pm 47^\circ (82^\circ)$



Combined:

$$\phi_3 = 81^\circ \pm 19^\circ (46^\circ)_{\text{stat}} \pm 13^\circ_{\text{sys}} \pm 11^\circ_{\text{model}}$$

Errors are 68% (95%) confidence limits

Summary

- Novel technique to extract ϕ_3 applied to $140\ \text{fb}^{-1}$ of Belle data
- First PRELIMINARY direct measurement of ϕ_3

$$\phi_3 = 81^\circ \pm 19^\circ (46^\circ)_{\text{stat}} \pm 13^\circ_{\text{sys}} \pm 11^\circ_{\text{model}}$$

- Model-independent approach exists using $c\tau$ factory data