EPS HEP 2011

ϕ_2 and ϕ_3 Measurements at Belle

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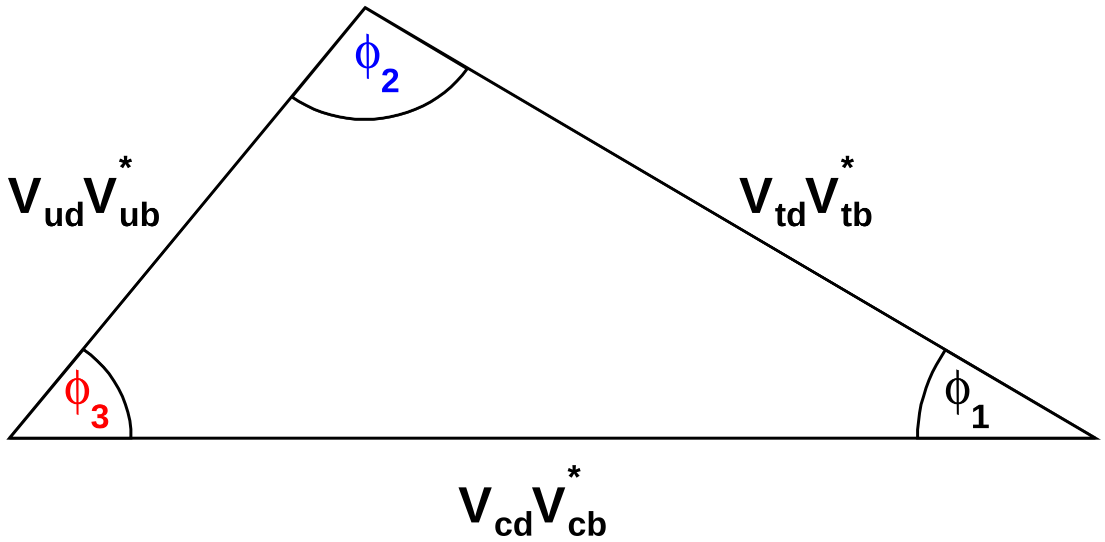
Outline

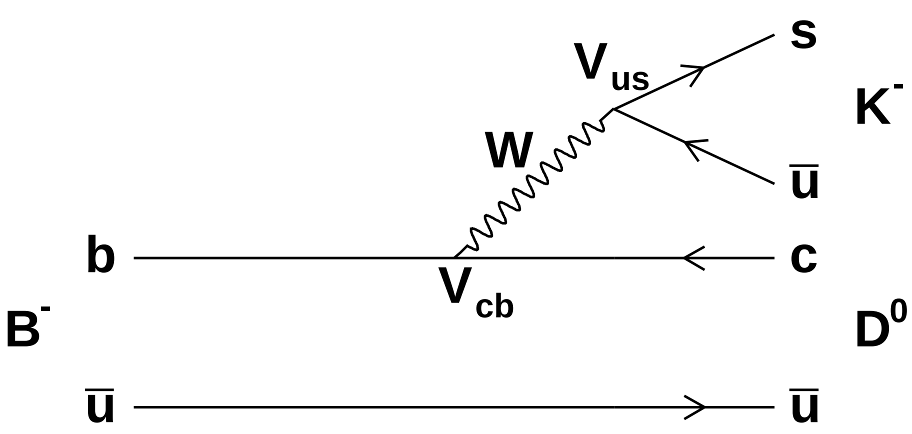
1. $B^- \to DK^-, D \to K^+\pi^-$
2. $B^- \to DK^-, D \to K_S^0\pi^+\pi^-$
3. $B^0 \to \pi^+\pi^-$
4. $B^0 \to \rho^0\rho^0$
5. $B^0 \to a_1(1260)^{\pm}\pi^{\mp}$

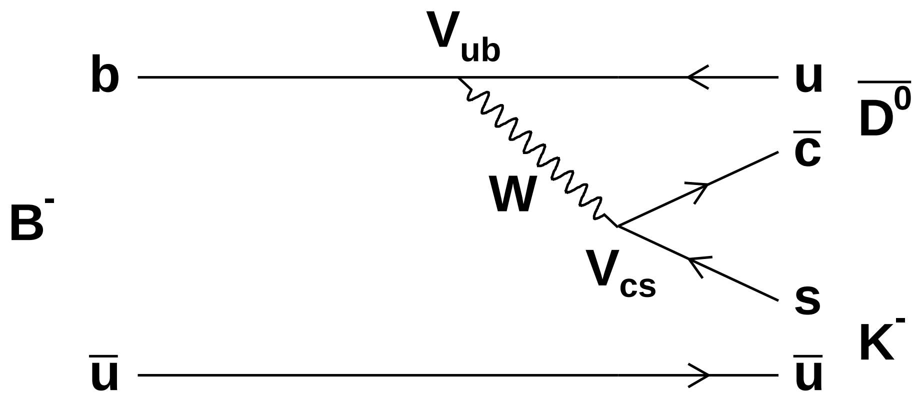


ϕ_3 from B decays

Measure ϕ_3 from interference between 2 diagrams

$A \propto \lambda^3$ $\quad\quad$ $A \propto \lambda^3(\rho - i\eta)$





where $D \equiv D^0$ or $\bar{D}^0$ decays to the same final state, $|D\rangle = |D^0\rangle + r_B e^{i\theta}|\bar{D}^0\rangle$

Phase difference, $\theta = \delta_B \pm \phi_3$ for $B^\pm$

Amplitude ratio, $r_B = \frac{A(B^- \to \bar{D}^0 K^-)}{A(B^- \to D^0 K^-)}$

Same order in λ but receives $\mathcal{O}(0.1)$ from colour suppression

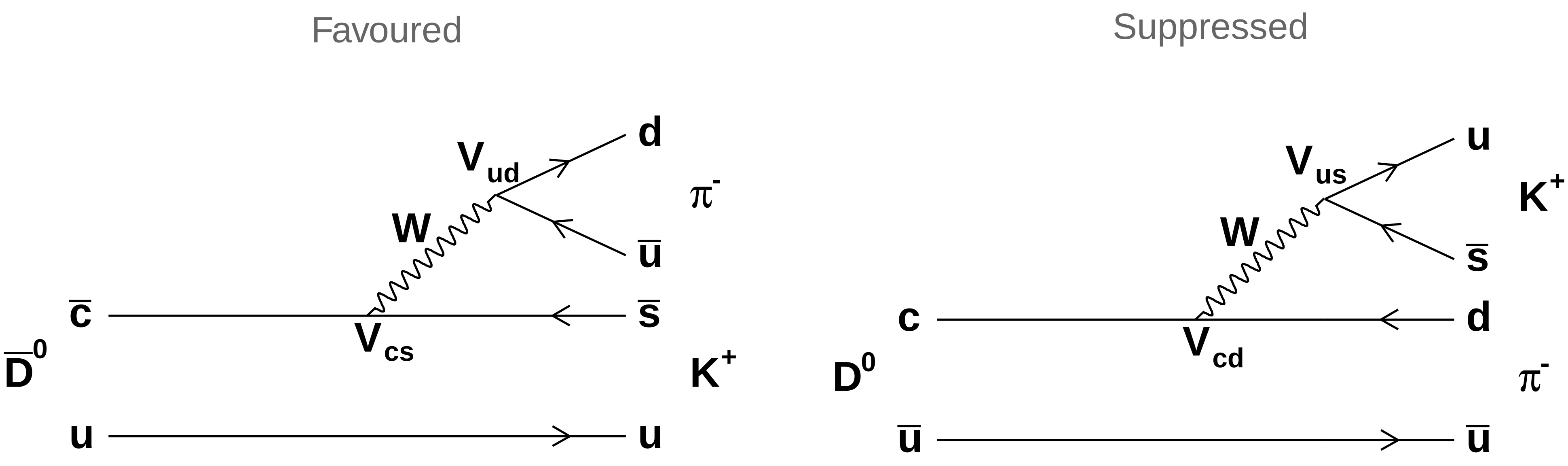
$B^- \to D_{\rm Sup}[K^+\pi^-]K^-$

ADS method

D. Atwood, I. Dunietz, and A. Soni, Phys. Rev. Lett. **78**, 3257 (1997); Phys. Rev. D **63**, 036005 (2001)

D decays to Cabibbo-favoured and doubly Cabibbo-suppressed same final state

Most promising channel is $D \to K^+\pi^-$



$B^- \to D_{\mathrm{Sup}}[K^+\pi^-]K^-$

Compare rates of $B^- \to D_{\mathrm{Fav}}[K^-\pi^+]K^-$ with $B^- \to D_{\mathrm{Sup}}[K^+\pi^-]K^-$

Measure

$$\mathcal{R}_{DK} \equiv \frac{\mathcal{B}([K^+\pi^-]K^-) + \mathcal{B}([K^-\pi^+]K^+)}{\mathcal{B}([K^-\pi^+]K^-) + \mathcal{B}([K^+\pi^-]K^+)}$$

$$\mathcal{A}_{DK} \equiv \frac{\mathcal{B}([K^+\pi^-]K^-) - \mathcal{B}([K^-\pi^+]K^+)}{\mathcal{B}([K^+\pi^-]K^-) + \mathcal{B}([K^-\pi^+]K^+)}$$

Related to ϕ_3 as

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

$$\mathcal{A}_{DK} = \frac{2r_B r_D \sin(\delta_B + \delta_D)\sin\phi_3}{\mathcal{R}_{DK}}$$

Amplitude ratio: $r_D = \frac{A(D^0 \to K^+\pi^-)}{A(\bar{D}^0 \to K^+\pi^-)}$

Strong phase difference, δ_D

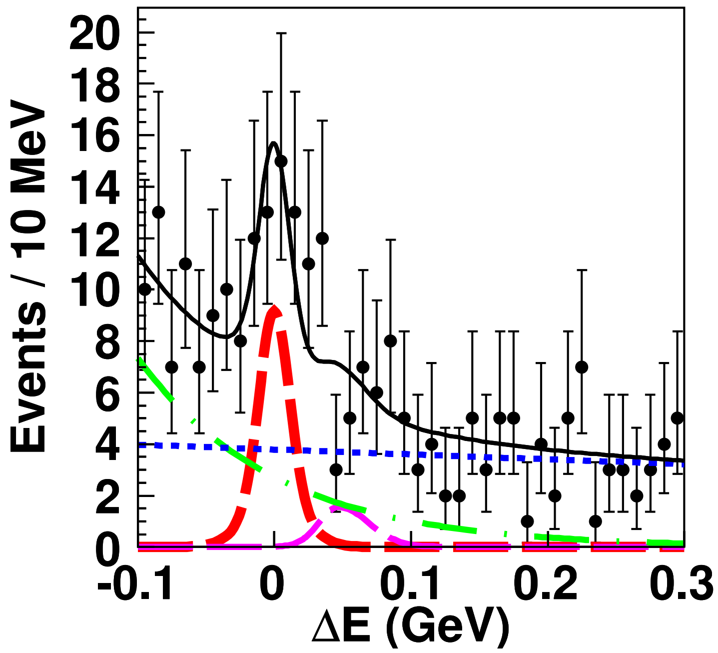
$B^- \to D_{\mathrm{Sup}}[K^+\pi^-]K^-$ Yield

Final data set from Belle, 772 million $B\bar{B}$ pairs

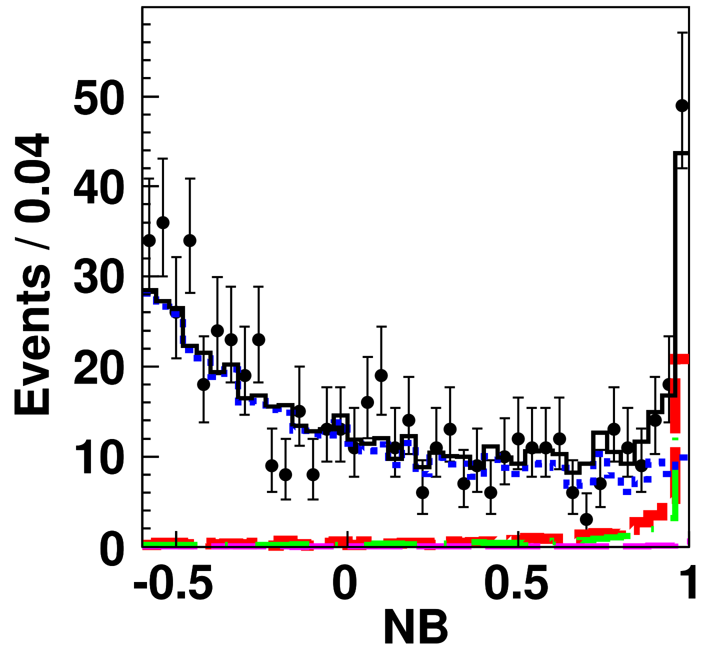
Difficulty in separating small signal from dominant continuum background

Fit ΔE and neural network output (NB) based on event shape

$NB > 0.9$



$|\Delta E| < 0.03$ GeV



First evidence: 4.1σ significance for suppressed $B^- \to D_{\mathrm{Sup}}[K^+\pi^-]K^-$

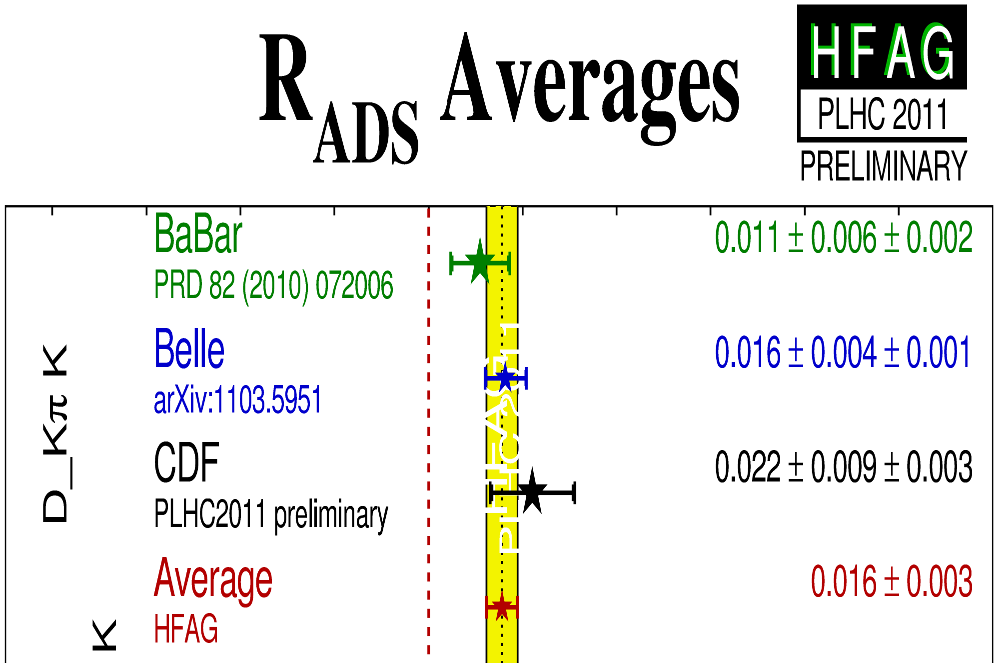
$B^- \to D_{\rm Sup}[K^+\pi^-]K^-$ Results

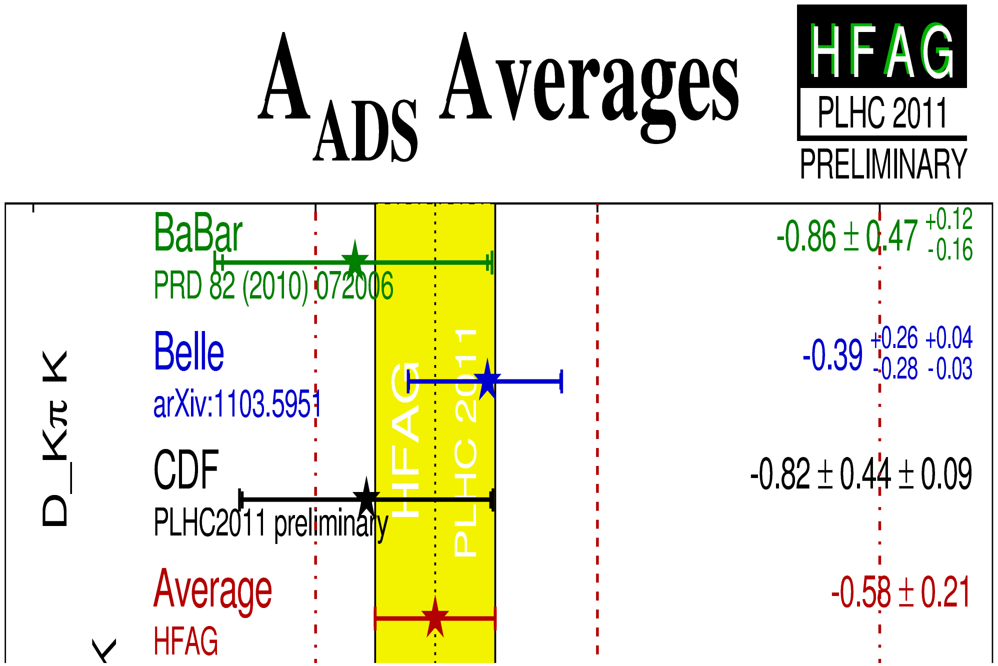
$$\mathcal{R}_{DK} = [1.63^{+0.44}_{-0.41}\,(\text{stat})^{+0.07}_{-0.13}\,(\text{syst})] \times 10^{-2}$$

$$\mathcal{A}_{DK} = -0.39^{+0.26}_{-0.28}\,(\text{stat})^{+0.04}_{-0.03}\,(\text{syst})$$

Most precise measurement to date

First evidence for $B^- \to D_{\rm Sup}[K^+\pi^-]K^-$





$B^- \to DK^-, D \to K^0_S\pi^+\pi^-$

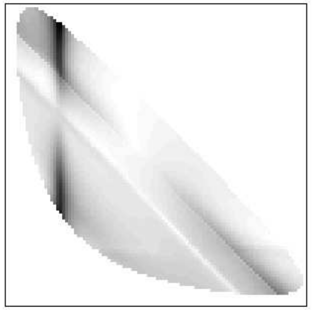
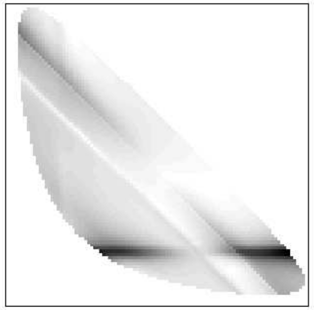
GGSZ method

A. Giri, Yu. Grossman, A. Soffer, J. Zupan, Phys. Rev. D **68**, 054018 (2003)

A. Bondar, Proceedings of BINP Special Analysis Meeting on Dalitz Analysis, 24-26 Sep. 2002, unpublished.

Fit $D \to K^0_S\pi^+\pi^-$ Dalitz plot and directly determine ϕ_3

$$|\mathcal{M}_\pm(m_+^2, m_-^2)|^2 = |f_D(m_+^2, m_-^2) + r_B e^{i(\delta_B \pm \phi_3)} f_D(m_-^2, m_+^2)|^2$$

$= \Big|$  $+ re^{i\delta \pm i\phi_3}$  $\Big|^2$

Parametrise amplitude as coherent sum of 2-body decays via intermediate resonances

Measure $|f_D|^2$

$B^- \to D^{(*)}K^-, D \to K_S^0\pi^+\pi^-$

Previous Belle measurement

657 million $B\bar{B}$ pairs

Combined results of $B^- \to DK^-$ and D^*K^-, $D^* \to D\pi^0$, $D\gamma$

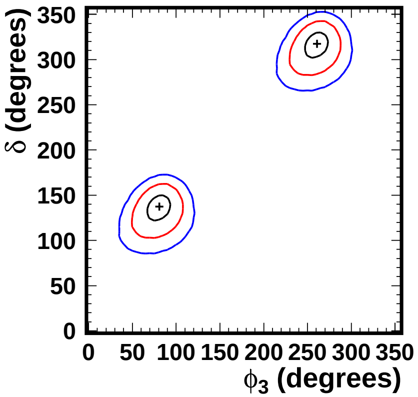
A. Poluektov *et al.* (Belle Collab.), Phys. Rev. D **81**, 112002 (2010)

$\phi_3 = (78^{+11}_{-12}\ (\mathrm{stat}) \pm 4\ (\mathrm{syst}) \pm 9\ (\mathrm{model}))^\circ$

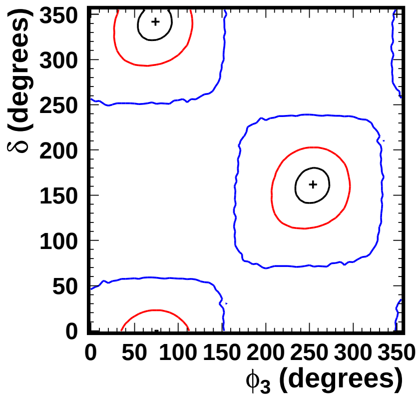
Parametrisation of amplitude $f_D \rightsquigarrow$ model dependence as dominant systematic uncertainty

Would dominate the total uncertainty at LHCb and the next generation B factories

$B^- \to DK^-$



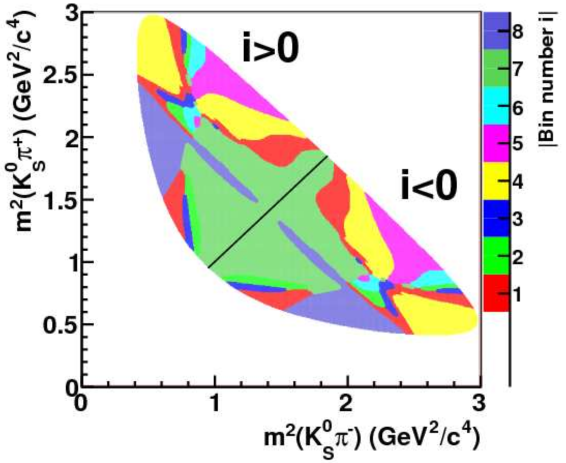
$B^- \to D^*K^-$



Binned Dalitz Plot Method

Use binned Dalitz plot and work with numbers of events in each bin

A. Bondar and A. Poluektov, Eur. Phys. J. C **47**, 347 (2006); Eur. Phys. J. C **55**, 51 (2008).



And compare in a χ^2 fit with

$$N_i^{\pm} = h_B[K_i + r_B^2 K_{-i} + 2\sqrt{K_i K_{-i}}(x_\pm c_i + y_\pm s_i)]$$

$$x_\pm = r_B \cos(\delta_B \pm \phi_3),\ y_\pm = r_B \sin(\delta_B \pm \phi_3)$$

$N_i^{\pm}$: Expected number of $B^{\pm} \to DK^{\pm}$ events in bin i

K_i: Number of events in bin i determined from a flavour-tagged sample ($D^{*\pm} \to D\pi^{\pm}$)

c_i, s_i: related to average strong phase difference in bin i

$$c_i = \langle \cos \Delta\delta_D \rangle_i,\ s_i = \langle \sin \Delta\delta_D \rangle_i$$

Measured by CLEO, can also be measured at BES-III

Optimal Binning and CLEO Input

Binned analysis reduces statistical precision of ϕ_3 compared to measuring $|f_D|^2$

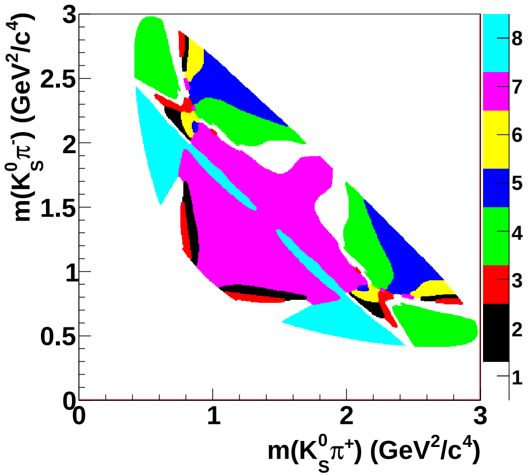
Precision also depends strongly on amplitude behaviour across the bins

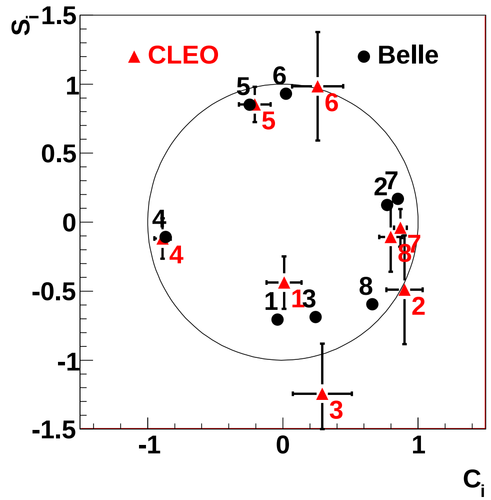
Phase difference between D^0 and $\bar{D}^0$ amplitudes varying as little as possible $\Rightarrow$ better precision

Optimal binning depends on model, ϕ_3 does not

Optimised binning using BaBar 2008 amplitude

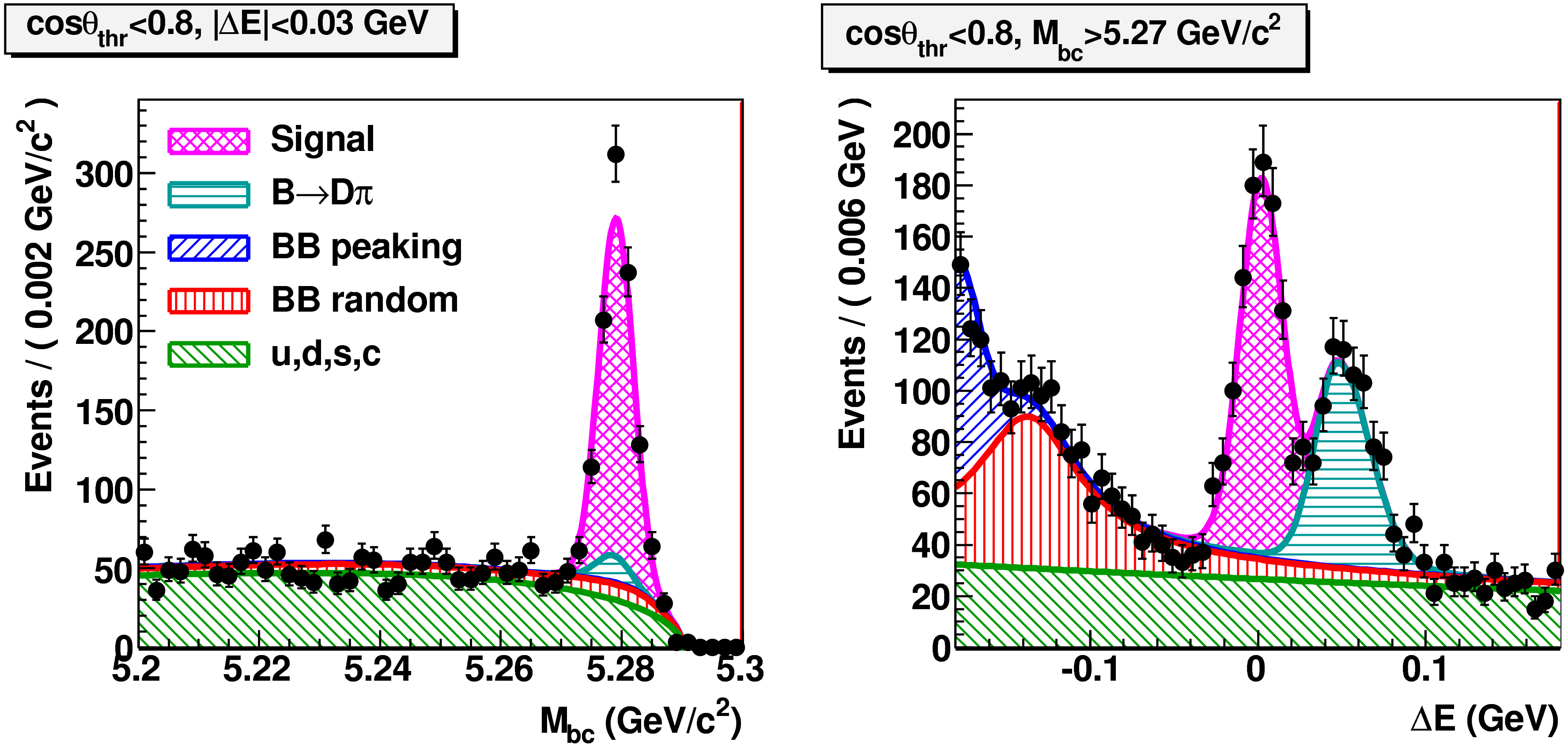
J. Libby *et al*. (CLEO Collab.), Phys. Rev. D **82**, 112006 (2010)





$B^- \to D[K_S^0\pi^+\pi^-]K^-$ Signal Yield

Final data set from Belle, 772 million $B\bar{B}$ pairs

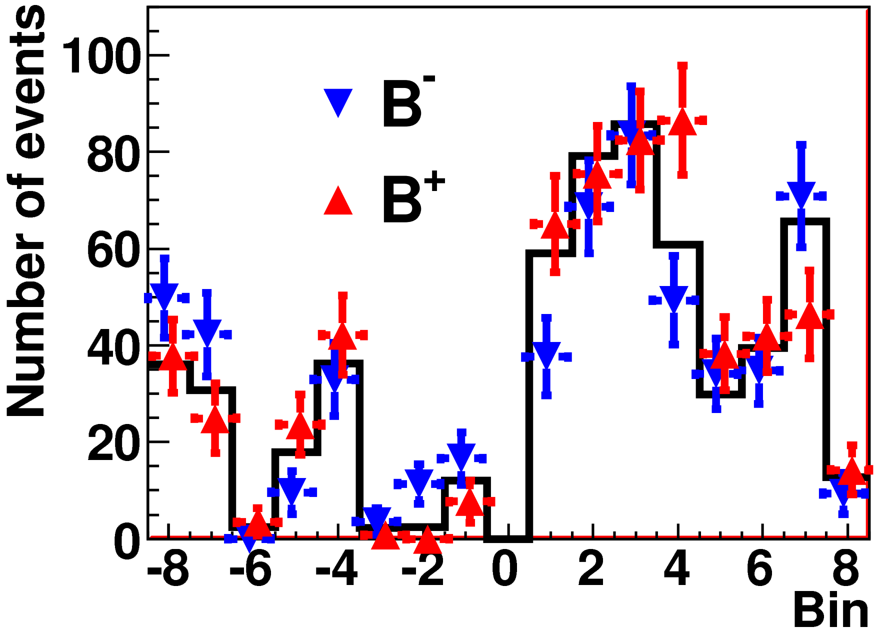


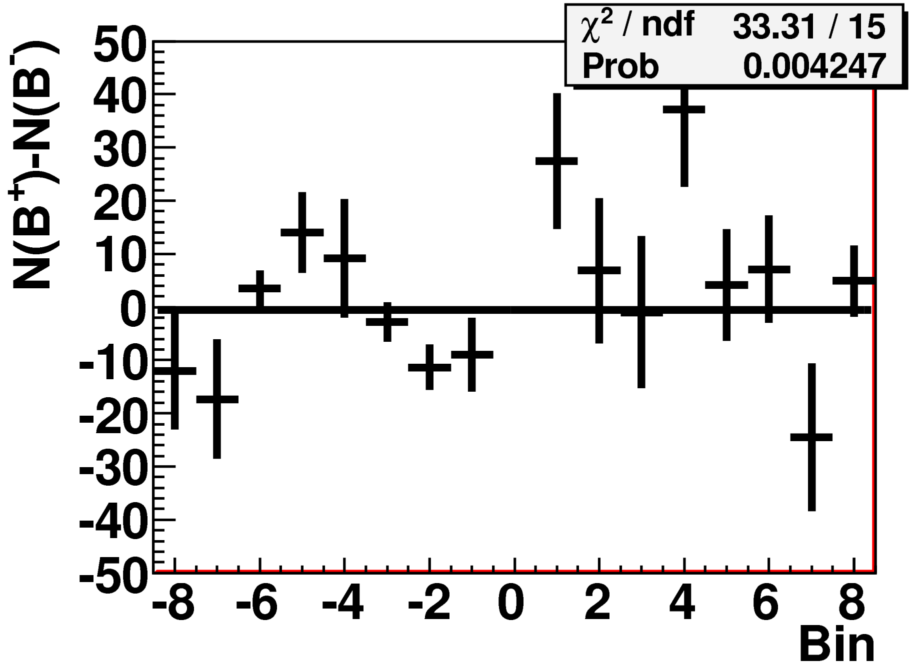
Signal yield: 1176 ± 43 events

$B^- \to D[K^0_S\pi^+\pi^-]K^-$ Asymmetry

Now determine signal yield in optimised Dalitz plot bins

Perform χ^2 fit to compare with expected signal yield determined from
$N_i^{\pm} = h_B[K_i + r_B^2 K_{-i} + 2\sqrt{K_i K_{-i}}(x_\pm c_i + y_\pm s_i)]$



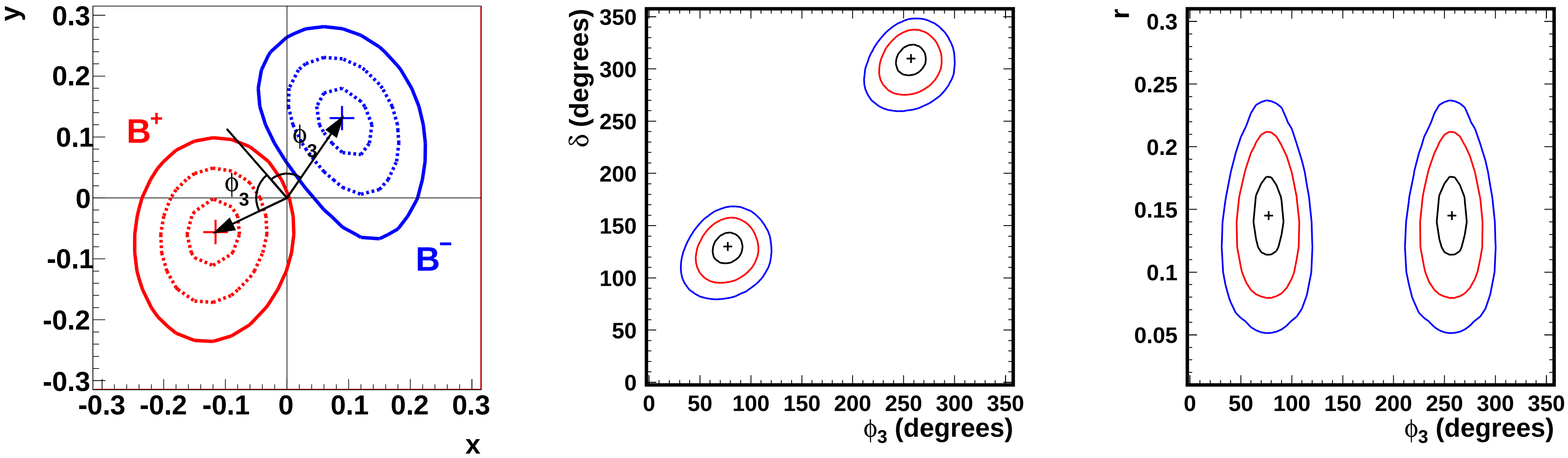


Significant CP asymmetry can be seen

0.4% probability of statistical fluctuation

$B^- \to D[K_S^0\pi^+\pi^-]K^-$ ϕ_3 Constrain

$x_\pm$ and $y_\pm$ determined in the fit, constrain ϕ_3, r_B and δ_B



$\phi_3 = (77.3^{+15.1}_{-14.9} \pm 4.2 \pm 4.3)^\circ$ cf. $\phi_3 = (78^{+11}_{-12}\ (\mathrm{stat}) \pm 4\ (\mathrm{syst}) \pm 9\ (\mathrm{model}))^\circ$

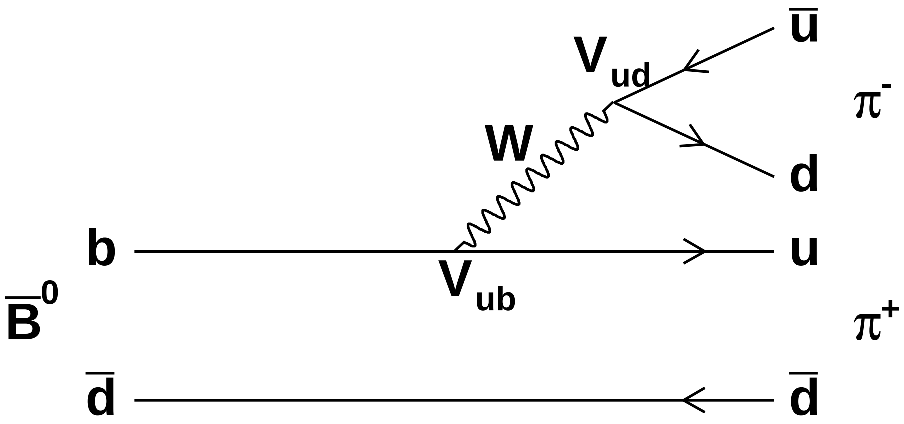
$r_B = 0.145 \pm 0.030 \pm 0.011 \pm 0.011$

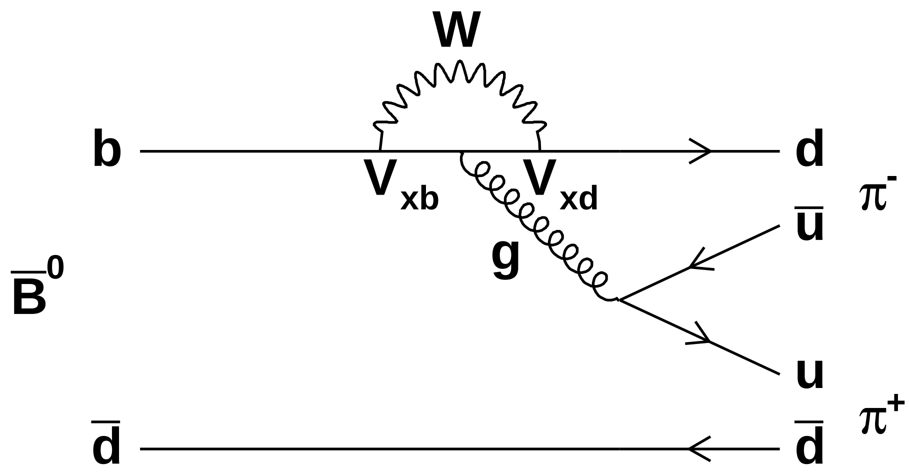
$\delta_B = (129.9 \pm 15.0 \pm 3.9 \pm 4.7)^\circ$

1st error - statistical, 2nd - systematic, 3rd - c_i, s_i precision

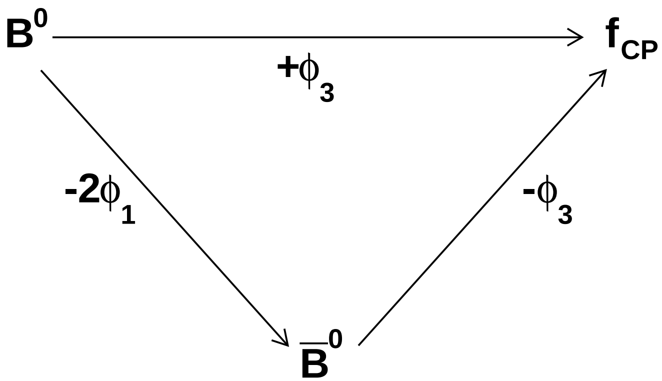
Precision comparable to previous measurement with $B^- \to DK^-$ only

$b \to u\bar{u}d$





V_{ub} carries the phase $e^{-i\phi_3}$



For tree amplitude,

The phase difference is $-2\phi_1 - \phi_3 - \phi_3$

Assuming a closed triangle, $2\phi_1 + 2\phi_3 = 2\pi - 2\phi_2$

Expect $\mathcal{A}_{CP} = 0$, $\mathcal{S}_{CP} = \sin 2\phi_2$

Departure from these in presence of penguin contribution

ϕ_2 Status

$B^0 \to \pi^+\pi^-$, $B^0 \to \rho^0\rho^0$ and $B^0 \to a_1(1260)^{\pm}\pi^{\mp}$ are ongoing analyses

Based on final data set from Belle, 772 million $B\bar{B}$ pairs

Data reprocessing with new tracking algorithm to improve detection efficiency

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

Parameter	Expected statistical uncertainty (772M)	Previous statistical uncertainty (535M)
$\mathcal{A}_{CP}$	0.06	0.08
$\mathcal{S}_{CP}$	0.08	0.10

Also expected to be the most precise measurement

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

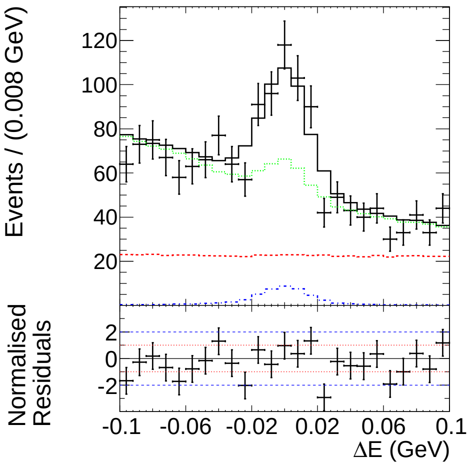
Parameter	Expected statistical uncertainty	World Average statistical uncertainty
$\mathcal{B}$	46%	38%
f_L	0.24	0.15

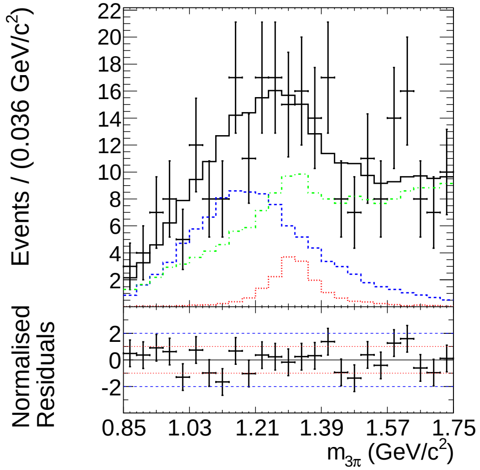
Halved statistical uncertainty over previous measurement $\Rightarrow$ Improved upper limit at least

ϕ_2 Status

$B^0 \to a_1(1260)^{\pm}\pi^{\mp}$

Statistical uncertainty on branching fraction $\sim 7\%$ cf. world average $\sim 11\%$





Based on yield of 1445 ± 101 events, expected statistical uncertainties

Parameter	Expected statistical uncertainty	World Average statistical uncertainty
$\mathcal{A}_{CP}$	0.05	0.07
$\mathcal{C}_{CP}$	0.10	0.15
$\mathcal{S}_{CP}$	0.12	0.21

Expected to be the most precise measurement

Summary

- First evidence for $B^- \to D_{\rm Sup}[K^+\pi^-]K^-$
  - Most precise measurement of ADS observables $\mathcal{R}_{DK}$ and $\mathcal{A}_{DK}$
- First ϕ_3 measurement with binned Dalitz plot analysis
  - $\phi_3 = (77.3^{+15.1}_{-14.9} \pm 4.2 \pm 4.3)^\circ$
  - Model-dependent result dominates the world average
  - Precision comparable to model-dependent analysis with $B^- \to DK^-$ only
- Final results on ϕ_2 related modes expected soon
  - $B^0 \to \pi^+\pi^-$ and $B^0 \to a_1(1260)^\pm\pi^\mp$ should dominate the world averages
  - If no signal found, $B^0 \to \rho^0\rho^0$ upper limit expected improve at least, should impact on ϕ_2

Backup

Measuring c_i, s_i

Can be obtained in $\psi(3770) \to D^0 \bar{D}^0$ decays

Coherent D^0 and $\bar{D}^0$ pairs produced

If both D^0 and $\bar{D}^0$ decay to $K_S^0 \pi^+ \pi^-$,

$$N_{ij} = K_i K_{-j} + K_{-i} K_j - 2\sqrt{K_i K_{-i} K_j K_{-j}} (c_i c_j + s_i s_j)$$

N_{ij}: Number of events in bin i (j) for $D_{1(2)} \to K_S^0 \pi^+ \pi^-$

Constrain c_i, s_i

If one D decays to a CP eigenstate while the other decays to $K_S^0 \pi^+ \pi^-$,

$$N_i = K_i + K_{-i} - 2\sqrt{K_i K_{-i}} c_i$$

N_i: Number of events in bin i for $D \to K_S^0 \pi^+ \pi^-$

Constrain c_i only