Dalitz-plot analysis of $B^0 \to \overline{D}^0 \pi^+ \pi^-$

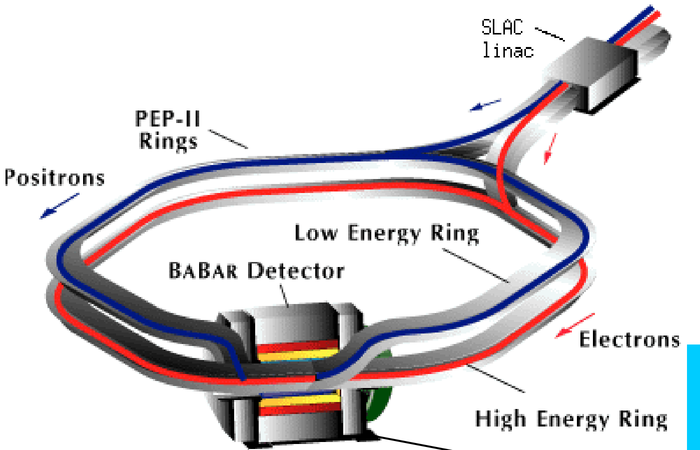
Thomas Latham
on behalf of the BaBar Collaboration

THE UNIVERSITY OF WARWICK

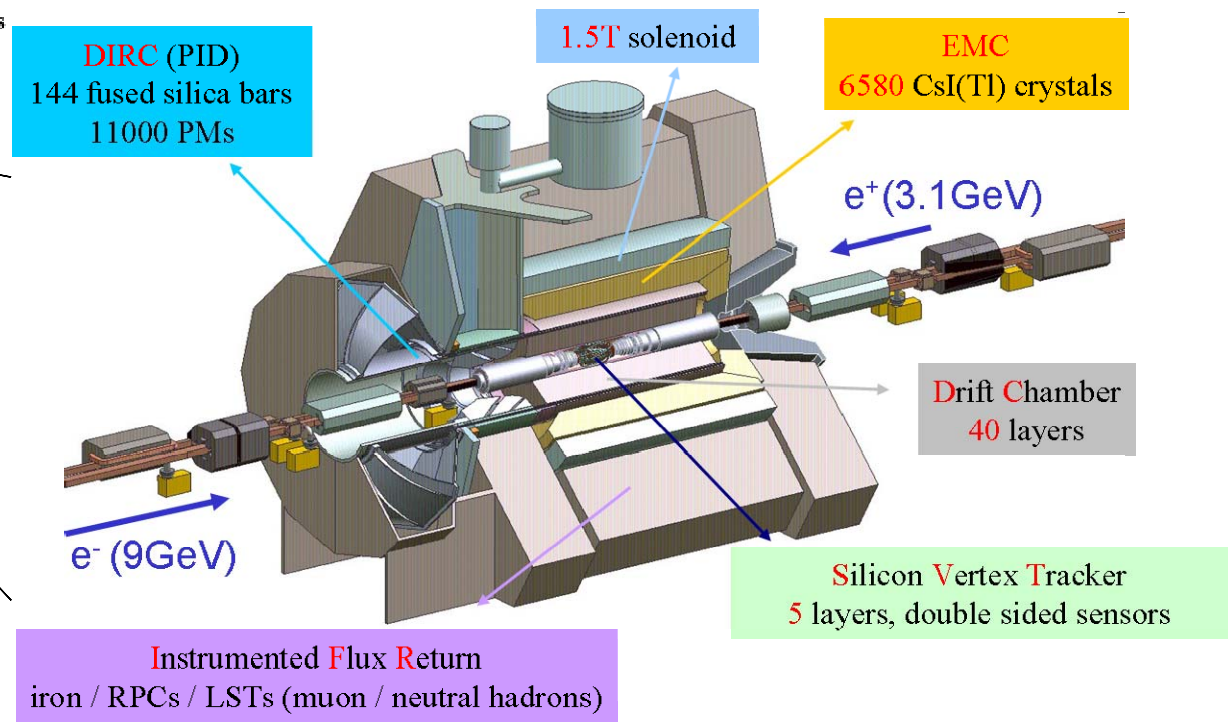
Motivation

- The $D^0\pi^+\pi^-$ Dalitz plot contains many interesting decays:
  - Colour-suppressed Dh^0 decays
  - D^{**} contributions
- Knowledge of both helps to test theoretical models, e.g. quark models and QCD sum rules
- BFs of $B \to D^{**}$ transitions of interest to help address discrepancy between theory and experiment in $B \to D^{**}l\nu$ decays
- BFs of $B \to D\rho$ decays related by isospin can give insight into strong interaction phases
- Can perform a time-dependent analysis to measure $\sin(2\beta)$ and $\cos(2\beta)$ if D is reconstructed in CP eigenstate
  - Requires knowledge of DP structure

PEP-II and BaBar



- PEP II/BaBar *B*-Factory located at SLAC National Accelerator Laboratory
- Collided beams of electrons and positrons with asymmetric energies

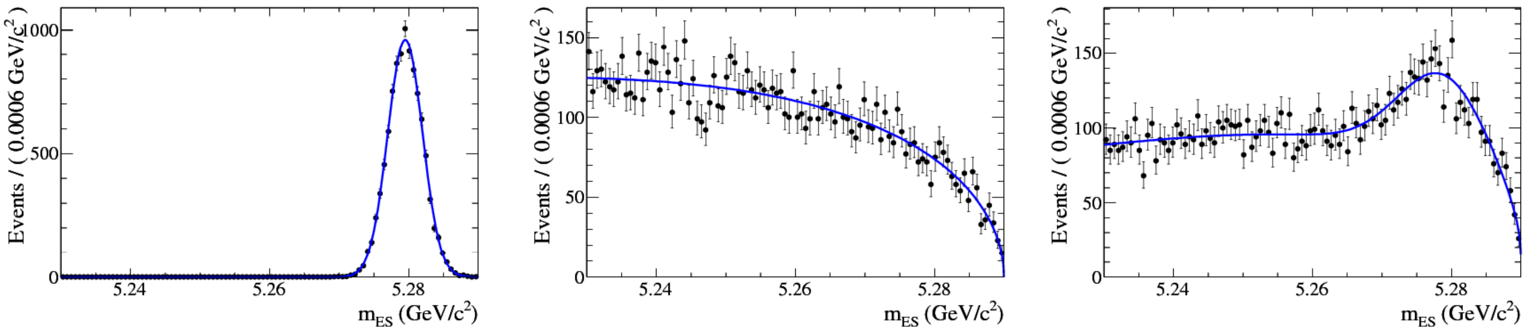


- Analysis presented here uses the full $\Upsilon(4S)$ dataset
- Corresponds to 471×10^6 BB pairs

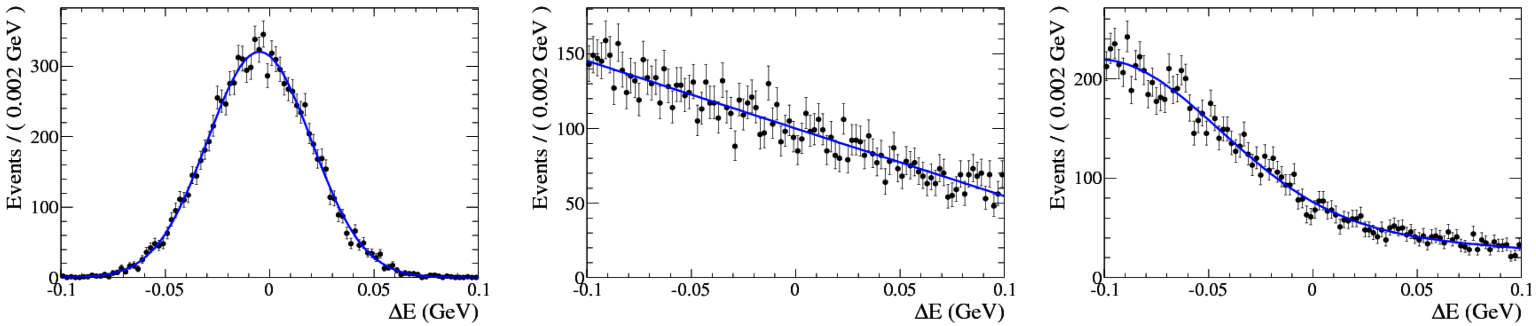
Analysis Variables – Kinematic

Make use of precision kinematic information from the beams.

$$m_{ES} = \sqrt{E^{*2}_{beam} - p^{*2}_{B}}$$



$$\Delta E = E^{*}_{B} - E^{*}_{beam}$$



Plots show MC events

Characteristic Signal Distributions

Characteristic Continuum Distributions

Characteristic B-background Distributions

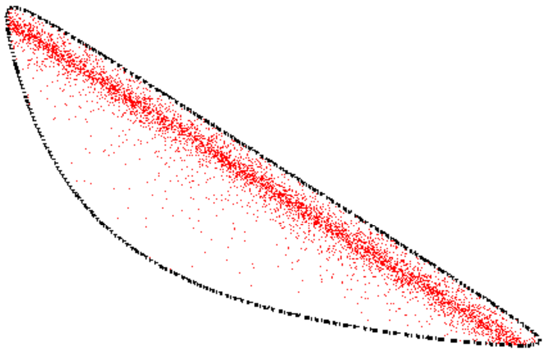
Dalitz-plot Analysis

- Dalitz plot is a representation of e.g. the $B \to PPP$ phase space:

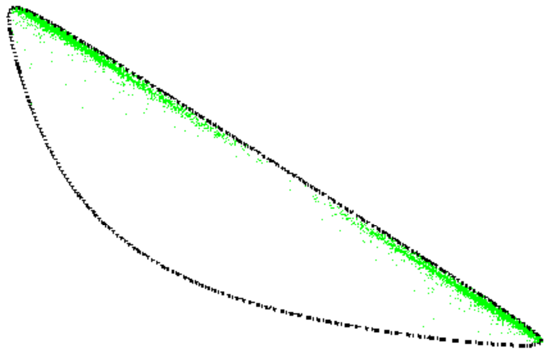
$$m_B^2 + m_i^2 + m_j^2 + m_k^2 = m_{ij}^2 + m_{ik}^2 + m_{jk}^2$$

P = pseudoscalar

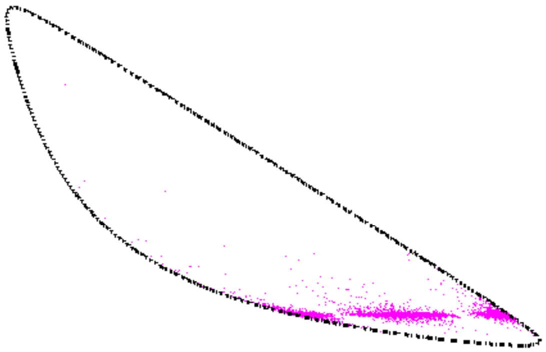
- A 2D scatter plot in ${m_{ik}}^2$ and ${m_{jk}}^2$
- Structure in the DP gives information on resonance masses, widths and spins, relative phases, interference etc.
- Model each contribution to the DP as a separate amplitude with a complex coefficient (isobar model)



Red points show a spin 0 $\pi\pi$ resonance



Green points show spin 1 $\pi\pi$ resonance



Purple points show spin 2 $D\pi$ resonance

Analysis Overview

- Reconstruct D^0 candidates in decay to $K^-\pi^+$
- Apply particle ID to pions and *D* daughters
- Suppress continuum background with a Neural Network of event-shape variables
- Veto $D^*(2010)^-\pi^+$ from the DP (require $m_{D\pi} > 2.02\ \text{GeV}/c^2$)
- Simultaneous fit to m_{ES}, ΔE and DP variables
- Determines signal and background yields plus Dalitz-plot complex coefficients
- Also account for effects of Dalitz-plot dependence of
  - signal reconstruction efficiency
  - fraction and migration of mis-reconstructed signal events
  - background event yields

Backgrounds

- Expect background from continuum light-quark production and from B-decays to a different final state
- Dominated by real $B \to D$ decays
- B-backgrounds separated into 6 categories depending on m_{ES} and ΔE shapes

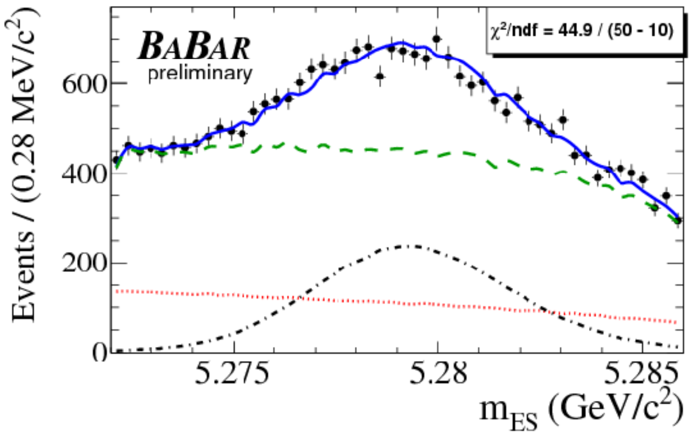
Category	Dominant contribution	Total # Expected
$B\overline{B}$ 1	$J/\psi K^+\pi^-$	444 ± 24
$B\overline{B}$ 2	$a_1^\pm \pi^\mp$	32 ± 7
$B\overline{B}$ 3	$D^0 K^+\pi^-$	240 ± 18
$B\overline{B}$ 4	$\overline{D}^0 \rho^+$	7415 ± 101
$B\overline{B}$ 5	$\overline{D}^{*0} \pi^+$	1475 ± 44
$B\overline{B}$ 6	Combinatoric	7336 ± 99
$q\overline{q}$		5352 ± 226

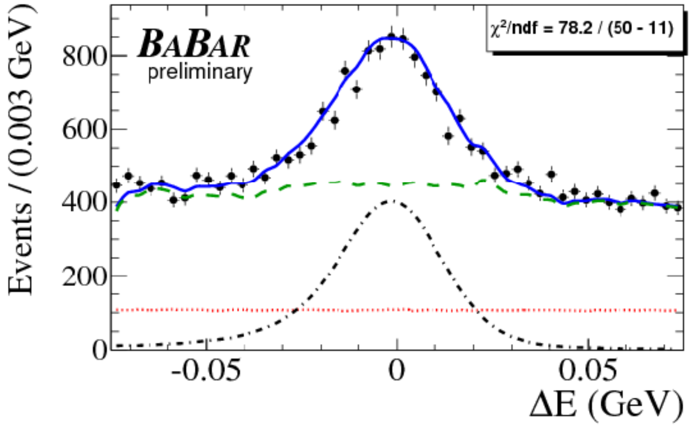
Signal Dalitz-plot Model

- For the following resonances we use a relativistic Breit-Wigner (RBW) lineshape with a mass-dependent width and Blatt-Weisskopf barrier factors:
  - $D^*_0(2400)^-$, $D^*_2(2460)^-$, $\rho(770)^0$, $f_2(1270)$
- Angular distribution described by Zemach tensor formalism
- We also include (as the tail of an RBW) a virtual $D^*_v(2010)^-$ amplitude – although the narrow $D^*(2010)^-$ pole is vetoed, off-shell production can contribute
- Nonresonant $D\pi$ S wave – exponential form
- $\pi\pi$ S wave is described using the K-matrix formalism

Fit Results – Yields

- Fit yields 5098 ± 102 signal events
- Yields of background categories in line with expectation
- Projections onto m_{ES} and ΔE shown on right
  - Points are data
  - Solid line is fit result
  - Dotted line is continuum background
  - Dashed line is total background
  - Dash/dotted line is signal

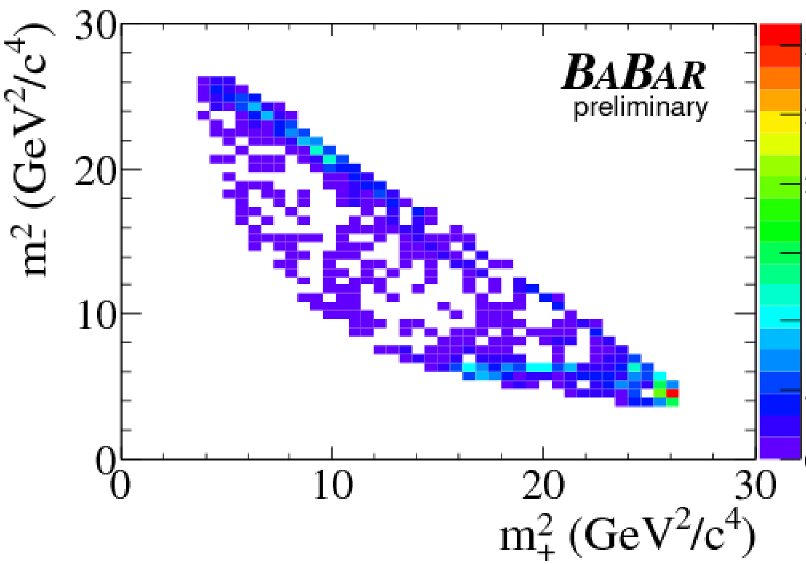


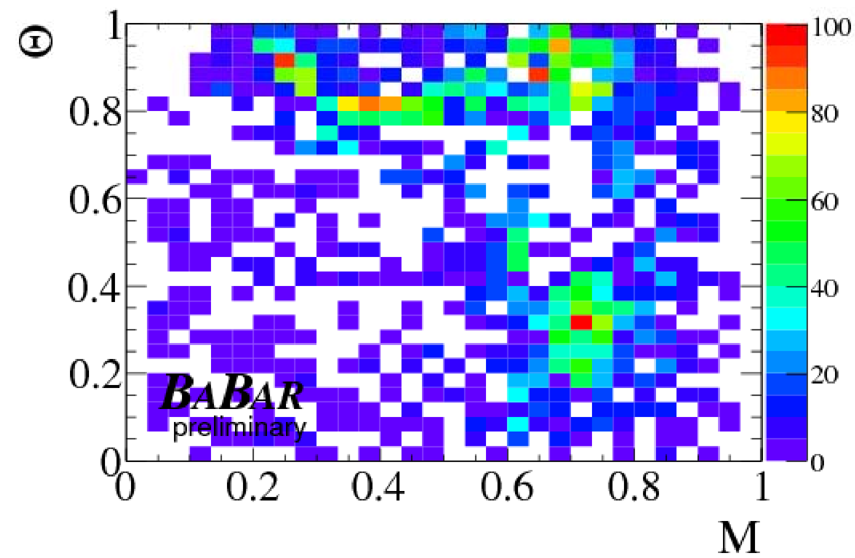


Fit Results – Signal Dalitz Plots

- The signal $_s$Plots for the conventional and square Dalitz plot shown below
- Structures due to $D^*_2(2460)^-$, $\rho(770)^0$ and $f_2(1270)$ are clearly visible
- Square Dalitz plot defined by:

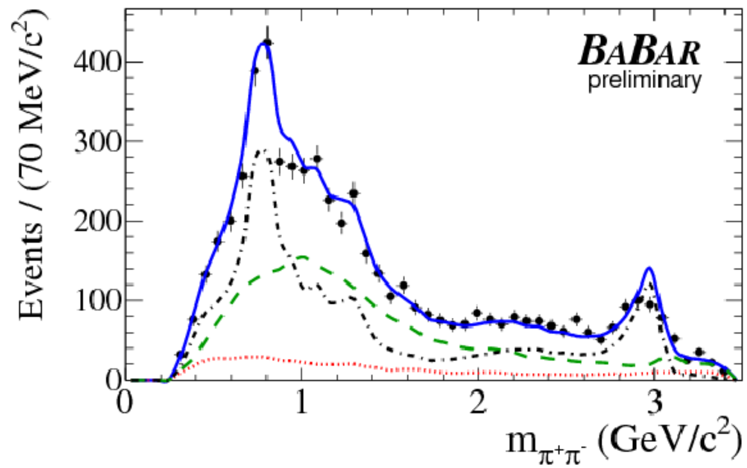
$$M \equiv \frac{1}{\pi} \arccos\left(2\frac{m_{\pi^+\pi^-} - m_{\pi^+\pi^-}^{\min}}{m_{\pi^+\pi^-}^{\max} - m_{\pi^+\pi^-}^{\min}} - 1\right) \quad \text{and} \quad \Theta \equiv \frac{1}{\pi}\theta_{\pi^+\pi^-}$$

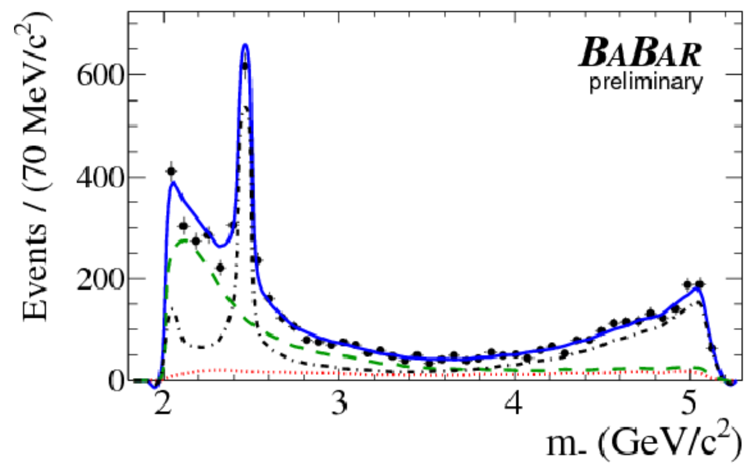




Fit Results – DP Projections

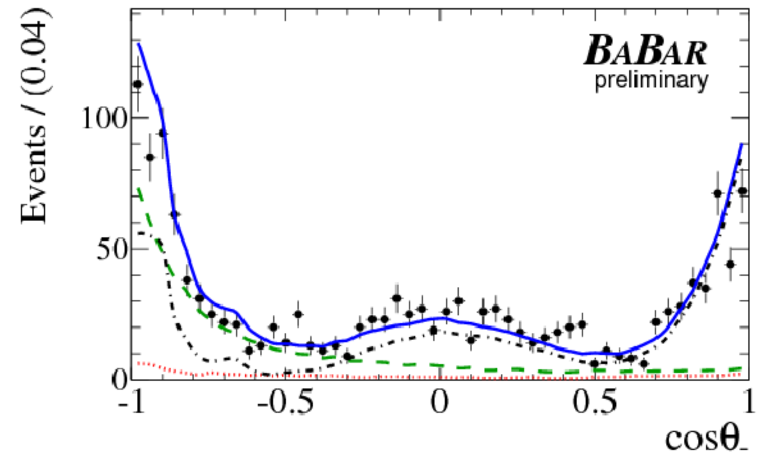
- Projections onto the $\pi^+\pi^-$ and $D\pi^-$ invariant mass combinations shown on right
- Plots have tighter m_{ES} and ΔE cuts applied to remove background
- Agreement between data and fit is good although some small discrepancies are present

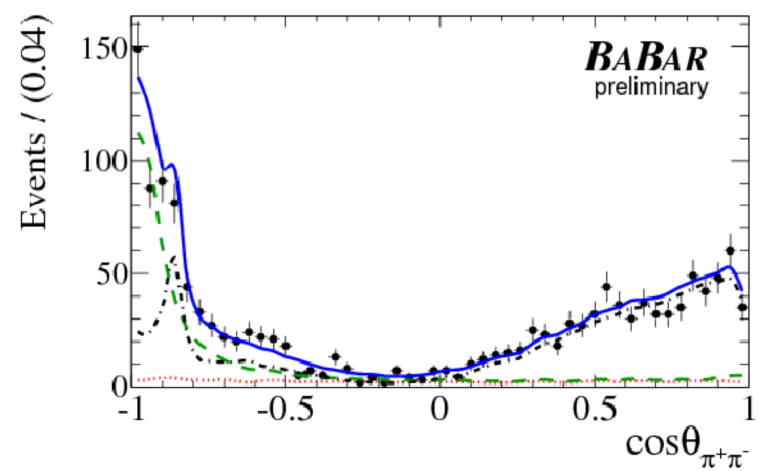




Fit Results – DP Projections

- Projections of the fit onto the helicity angles are shown on the right
- The top [bottom] plot shows the $D\pi^-$ [$\pi^+\pi^-$] helicity in the region of the $D^*_2(2460)^-$ [$\rho(770)^0$]
- The distributions show the expected shapes for a tensor [vector] resonance
- Regions towards -1 are affected by interference





Systematic Uncertainties

- Systematic uncertainties that affect the signal yield and fit fractions:
  - Fixed shapes of the efficiency and background DP histograms
  - Fixed m_{ES} and ΔE PDF parameters/histograms
  - Fixed fraction of misreconstructed signal events
  - Fit bias
- Other systematic uncertainties from data/MC differences in selection requirement efficiency, including NN cut and particle ID

Model Uncertainties

- Uncertainties in signal DP model:
  - Masses and widths of resonances described with RBW shapes
  - Fixed shape parameter of $D\pi$ nonresonant
  - Blatt-Weisskopf barrier radius
- Variations in the model that are considered:
- Gounaris-Sakurai lineshape for $\rho(770)^0$
- Replacement of $D\pi$ nonresonant with "dabba"
- Replace $\pi\pi$ S wave K matrix with sum of scalar RBW resonances
- Add other possible resonances, e.g. $\omega(782)$, D(2600)

D. Bugg,
J. Phys. G 36, 075003

See talk by Jose Benitez in spectroscopy session

Preliminary Branching Fraction Results

Resonance	Fit Fraction (%)	$\mathcal{B}(B^0 \to \text{Mode}) \times\mathcal{B}(R \to hh)$ (10^{-4})	$\mathcal{B}(B^0 \to \text{Mode})$ (10^{-4})
Inclusive $B^0 \to \overline{D}^0\pi^+\pi^-$	$\cdots$	$\cdots$	8.81±0.18±0.76±0.78±0.11
$D_2^*(2460)^-\pi^+$	20.5±0.9±1.3±3.7	1.80±0.09±0.19±0.37±0.02	$\cdots$
$D_0^*(2400)^-\pi^+$	24.8±2.5±3.0±12.9	2.18±0.23±0.33±1.15±0.03	$\cdots$
$\rho(770)^0\overline{D}^0$	33.4±2.0±5.2±10.0	2.94±0.19±0.53±0.92±0.04	2.98±0.19±0.53±0.93±0.04
$f_2(1270)\overline{D}^0$	9.8±1.1±1.6±3.4	0.86±0.10±0.16±0.31±0.01	1.02±0.12±0.18±0.36±0.03
$D_v^*(2010)^-\pi^+$	15.8±0.9±1.2±3.7	1.39±0.08±0.16±0.35±0.02	$\cdots$
$D\pi$ nonresonant	18.4±2.3±4.3±13.6	1.62±0.21±0.41±1.21±0.02	$\cdots$
K matrix total	25.6±2.5±3.2±6.1	2.26±0.22±0.34±0.58±0.03	$\cdots$

- Uncertainties are statistical, systematic, model and, where present, secondary branching fractions

Comparison with Belle

Branching Fraction	Our value (10^{-4})	Belle value (10^{-4})
Inclusive $B^0 \to \overline{D}^0\pi^+\pi^-$	$8.81 \pm 0.18 \pm 0.76 \pm 0.78 \pm 0.11$	$8.4 \pm 0.4 \pm 0.8$
$B^0 \to D_2^*(2460)^-\pi^+ \times D_2^*(2460)^- \to \overline{D}^0\pi^-$	$1.80 \pm 0.09 \pm 0.19 \pm 0.37 \pm 0.02$	$2.15 \pm 0.17 \pm 0.29 \pm 0.12$
$B^0 \to D_0^*(2460)^-\pi^+ \times D_0^*(2460)^- \to \overline{D}^0\pi^-$	$2.18 \pm 0.23 \pm 0.33 \pm 1.15 \pm 0.03$	$0.60 \pm 0.13 \pm 0.15 \pm 0.22$
$B^0 \to \rho(770)^0\overline{D}^0$	$2.98 \pm 0.19 \pm 0.53 \pm 0.93 \pm 0.04$	$3.19 \pm 0.20 \pm 0.24 \pm 0.38$
$B^0 \to f_2(1270)\overline{D}^0$	$1.02 \pm 0.12 \pm 0.18 \pm 0.36 \pm 0.03$	$1.20 \pm 0.18 \pm 0.21 \pm 0.32$
$B^0 \to D_v^*(2460)^-\pi^+ \times D_v^*(2460)^- \to \overline{D}^0\pi^-$	$1.39 \pm 0.08 \pm 0.16 \pm 0.35 \pm 0.02$	0.88 ± 0.13
$D\pi$ nonresonant	$1.62 \pm 0.21 \pm 0.41 \pm 1.21 \pm 0.02$	$\cdots$
K matrix total	$2.26 \pm 0.22 \pm 0.34 \pm 0.58 \pm 0.03$	$\cdots$

- Mode has been previously studied by Belle: Phys. Rev. D 76, 012006 (2007)
- Inclusive BF in very good agreement with Belle
- Sub-mode BFs also in good agreement except for $D^*_v{}^-\pi^+$ and $D^*_0(2400)^-\pi^+$, where we see larger values
- Direct comparison with S wave components not possible due to different parameterisations

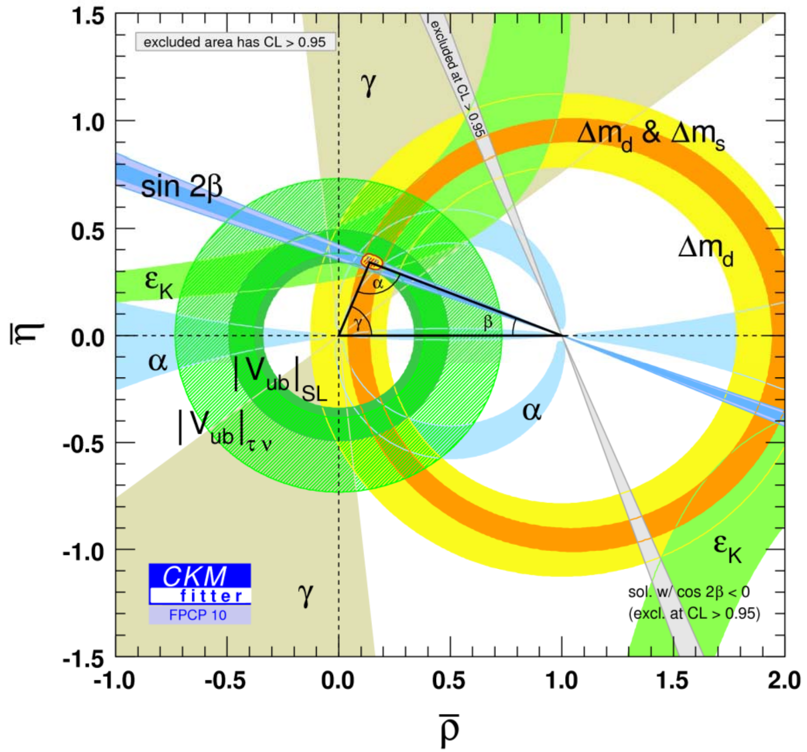
Conclusions

- Performed a Dalitz-plot analysis of $\boldsymbol{B^0 \to \overline{D}^0 \pi^+ \pi^-}$
- Presented preliminary branching fraction measurements for 7 contributions to the DP
- Inclusive BF and most sub-mode BFs in good agreement with Belle
- BF of $D^*_0(2400)^- \pi^+$, however, is much larger than Belle result and comparable with $D^*_2(2400)^- \pi^+$
- Isospin analysis of $B \to D\rho$ modes indicates presence of non-factorisable final state interaction effects
- Analysis documented in BABAR-CONF-10/004

BACKUP SLIDES

Motivation

- Need precise measurements of CKM matrix elements using *different quark level transitions* to test the Standard Model
- To maximise precision and remove ambiguities measure cos(2β) as well as sin(2β)

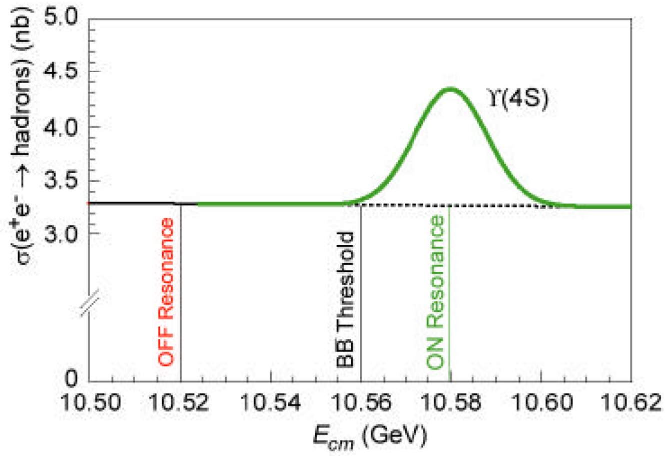


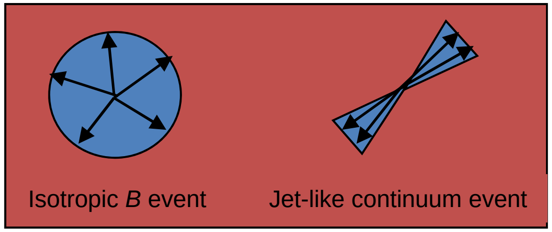
Motivation

- Idea to measure sin(2β) and cos(2β) in time-dependent Dalitz-plot analysis of $B^0 \to D_{CP}\pi^+\pi^-$ discussed in outline in
  - J. Charles et al. Phys. Lett. B 425, 375 (1998) [Erratum-ibid. B 433, 441 (1998)]
- Idea developed and feasibility study presented in
  - T. Latham and T. Gershon, J. Phys. G 36, 025006 (2009)
- Requires knowledge of contributions to the Dalitz plot
- Best way to determine Dalitz-plot model?
- Look at higher-statistics $D \to K\pi$ mode
- Can be treated as flavour-specific $\Rightarrow$ no time-dependence

Analysis Variables – Topological

- Light quark continuum cross section ~3x
- *B* mesons produced almost at rest since just above threshold
- Use event topology to discriminate
- Combine variables in a Neural Network (NN)





Systematic Uncertainties

	Efficiency	$q\overline{q}$ DP PDF	$B\overline{B}$ DP PDFs	CR $m_{\rm ES}$ & ΔE PDF parameters	SCF $m_{\rm ES}$ & ΔE PDF parameters	$B\overline{B}$ $m_{\rm ES}$ & ΔE PDFs	SCF fraction	$q\overline{q}$ $m_{\rm ES}$ PDF parameters	Fit bias	Total
Signal yield	6.3	19	24	35	0.7	22	302	2.1	46	310
$D_2^*(2460)^-\pi^+$ FF	0.0018	0.0036	0.0051	0.00072	0.00005	0.0033	0.010	0.00009	0.0037	0.013
$D_0^*(2400)^-\pi^+$ FF	0.003	0.016	0.024	0.00063	0.00013	0.0065	0.00096	0.00011	0.0023	0.030
$\rho(770)^0\overline{D}^0$ FF	0.016	0.028	0.031	0.00069	0.00010	0.025	0.0078	0.00023	0.0014	0.052
$f_2(1270)\overline{D}^0$ FF	0.0054	0.0091	0.0077	0.00040	0.00005	0.0078	0.0029	0.00006	0.0011	0.016
$D_v^*(2010)^-\pi^+$ FF	0.00097	0.0028	0.0045	0.00034	0.00004	0.0027	0.0091	0.00007	0.0052	0.012
$D\pi$ NR FF	0.015	0.023	0.022	0.00052	0.00010	0.020	0.015	0.00008	0.0036	0.043
K matrix total FF	0.0057	0.014	0.015	0.00075	0.00017	0.012	0.018	0.00008	0.010	0.032

Model Uncertainties

	Mass & width	$D\pi$ NR α	BW barrier radius	$\rho(770)^0$ GS lineshape	$D\pi$ S-wave "dabba"	$\pi^+\pi^-$ S-wave	
Signal yield	44	6.4	11	1.1	14	67	
$D_2^*(2460)^-\pi^+$ FF	0.028	0.0027	0.020	0.00007	0.0019	0.0052	
$D_0^*(2400)^-\pi^+$ FF	0.061	0.031	0.0098	0.00066	0.099	0.043	
$\rho(770)^0\overline{D}^0$ FF	0.045	0.0056	0.042	0.0010	0.00012	0.034	
$f_2(1270)\overline{D}^0$ FF	0.018	0.00061	0.0060	0.00058	0.0040	0.014	
$D_v^*(2010)^-\pi^+$ FF	0.018	0.0028	0.015	0.00076	0.025	0.0097	
$D\pi$ NR FF	0.10	0.024	0.021	0.0060	···	0.026	
K matrix total FF	0.023	0.0075	0.010	0.0034	0.038	···	
	Add $\omega(782)$	Add $\rho(1450)$	Add $D(2600)$ (scalar)	Add $D(2600)$ (vector)	Add $D(2760)$ (vector)	7 $B\overline{B}$ Cat.	Total
Signal yield	11	53	0.62	13	1.5	8.4	100
$D_2^*(2460)^-\pi^+$ FF	0.00019	0.0060	0.00026	0.011	0.00063	0.00088	0.037
$D_0^*(2400)^-\pi^+$ FF	0.0019	0.00091	0.0085	0.011	0.0090	0.00034	0.129
$\rho(770)^0\overline{D}^0$ FF	0.015	0.047	0.00075	0.050	0.0096	0.0015	0.100
$f_2(1270)\overline{D}^0$ FF	0.00048	0.010	0.00004	0.021	0.0021	0.00050	0.034
$D_v^*(2010)^-\pi^+$ FF	0.0015	0.0095	0.00012	0.0040	0.0016	0.00088	0.037
$D\pi$ NR FF	0.0053	0.045	0.0025	0.065	0.0036	0.0012	0.136
K matrix total FF	0.0070	0.034	0.0019	0.018	0.011	0.00073	0.061

Isospin Analysis

- Isospin symmetry relates $D\rho$ decay amplitudes

$$A\left(\overline{D}^0\rho^+\right) = \sqrt{3}A_{3/2},$$
$$A\left(D^-\rho^+\right) = \sqrt{1/3}A_{3/2} + \sqrt{2/3}A_{1/2},$$
$$\sqrt{2}A\left(\overline{D}^0\rho^0\right) = \sqrt{4/3}A_{3/2} - \sqrt{2/3}A_{1/2}$$

- which gives triangle relation

$$A\left(\overline{D}^0\rho^+\right) = A\left(D^-\rho^+\right) + \sqrt{2}A\left(\overline{D}^0\rho^0\right)$$

- Can be used to determine phase $\delta_{D\rho}$ between $A_{3/2}$ and $A_{1/2}$ amplitudes and the ratio

$$R_{D\rho} = A_{1/2} \Big/ \sqrt{2}A_{3/2}$$

- Using our result and the world average results for the other two modes we find

$$\cos\delta_{D\rho} = 0.998^{+0.133}_{-0.062}$$
$$R_{D\rho} = 0.68^{+0.15}_{-0.16}$$