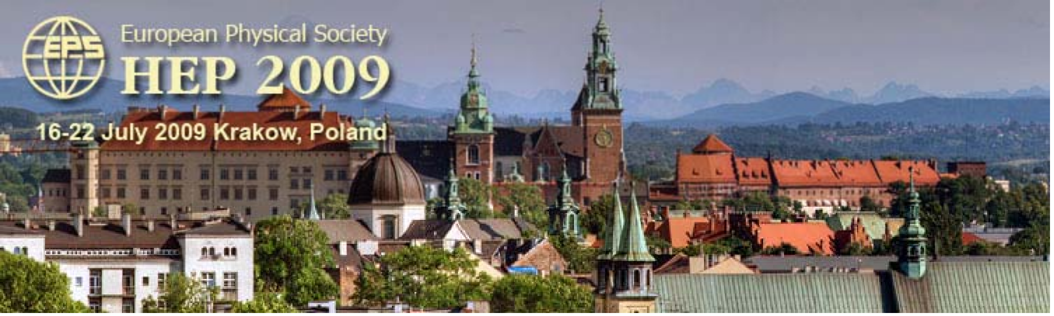
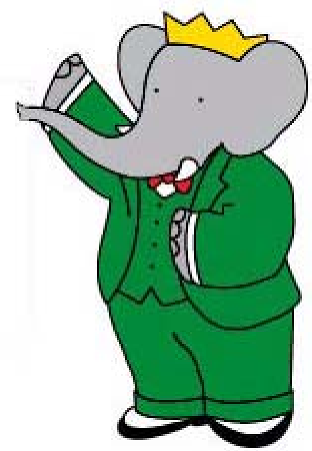


Three-body charmless hadronic *B* decays at BaBar

Thomas Latham
on behalf of the BaBar Collaboration

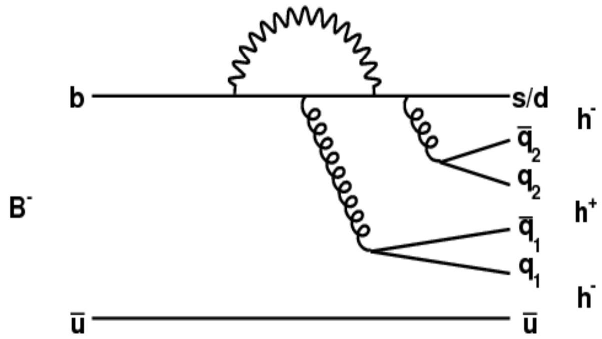
THE UNIVERSITY OF
WARWICK

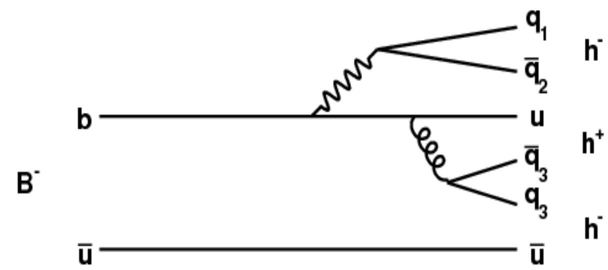


Overview

- Motivation and Introduction
- Analysis Techniques
- Search for $B^+ \rightarrow K_S K_S \pi^+$
- Search for $B^0 \rightarrow \pi^0 K_S K_S$, $\eta K_S K_S$, $\eta' K_S K_S$
- Dalitz-plot Analysis of $B^+ \rightarrow \pi^+\pi^+\pi^-$
- Conclusion

Why charmless 3-body decays?

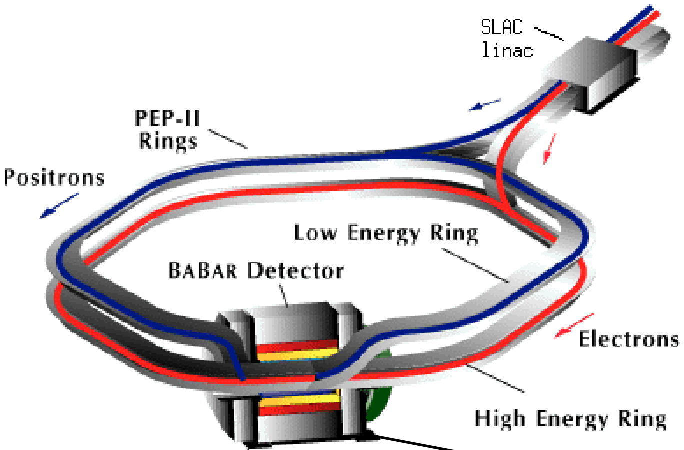


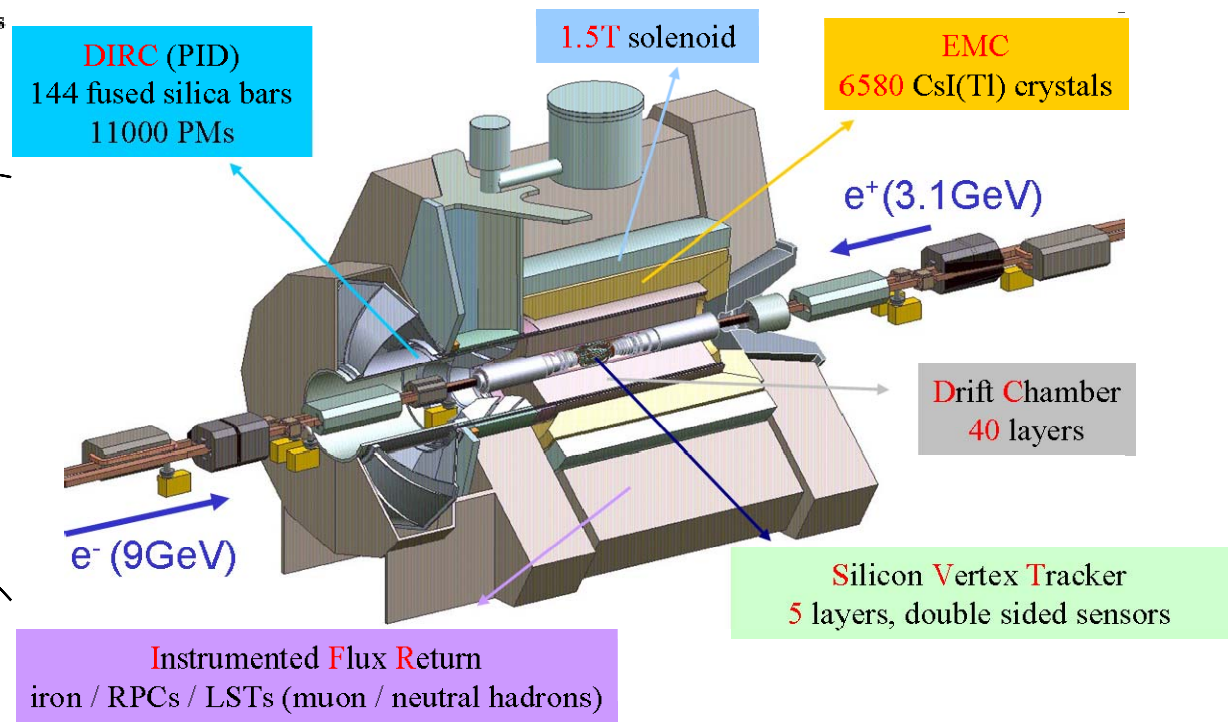


- Contributions from both penguin and tree diagrams can give rise to direct CP violation
- Time-dependent measurements and interferences between intermediate states can allow measurement of all three CKM angles
- Can search for signs of new physics such as enhanced branching fractions or CP asymmetries – new physics particles can enter in the loop diagrams
- Can help improve understanding of the nature of some intermediate resonances

PEP-II and BaBar

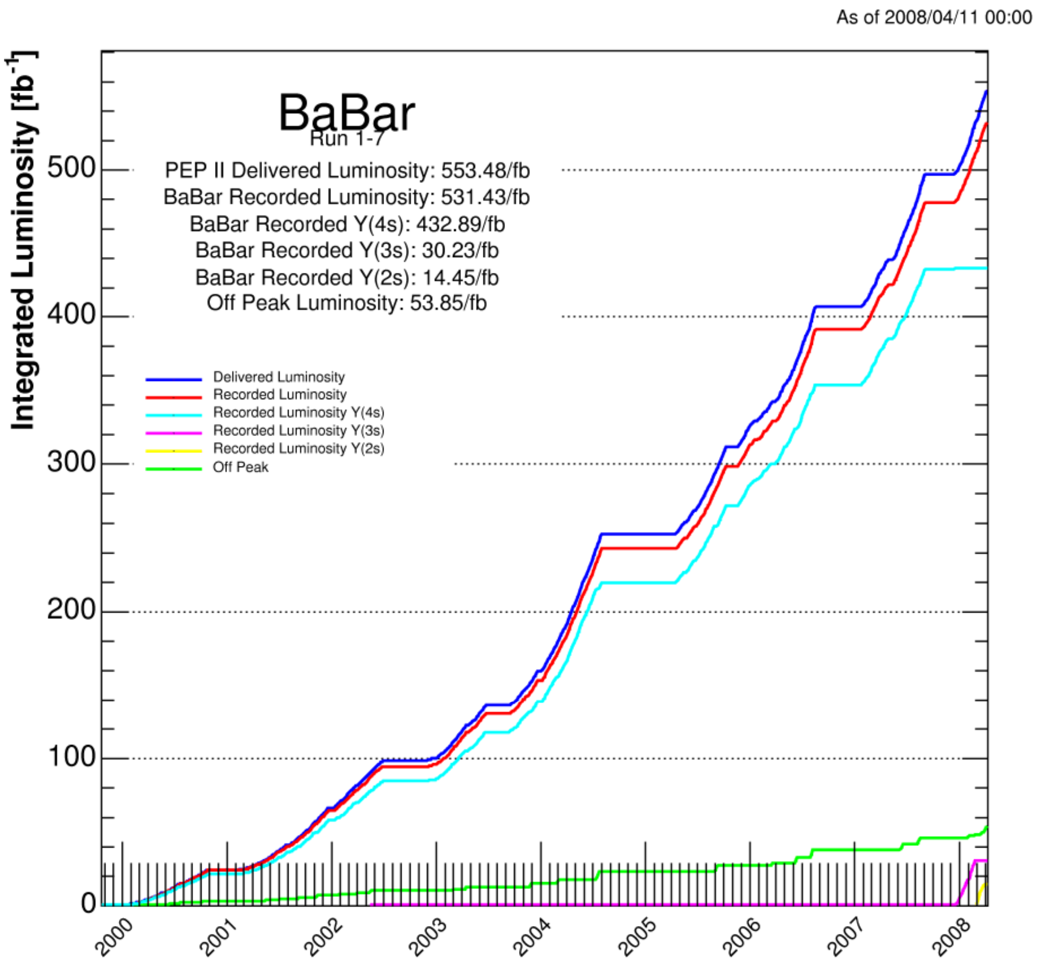
- PEP II/BaBar *B*-Factory located at Stanford Linear Accelerator Center
- Collided beams of electrons and positrons with asymmetric energies





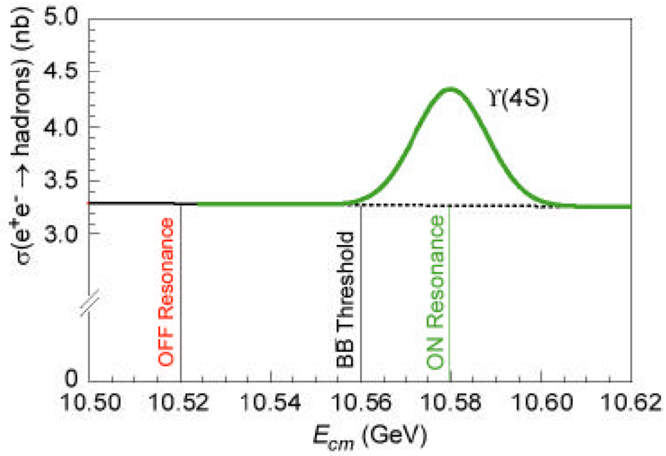
Dataset

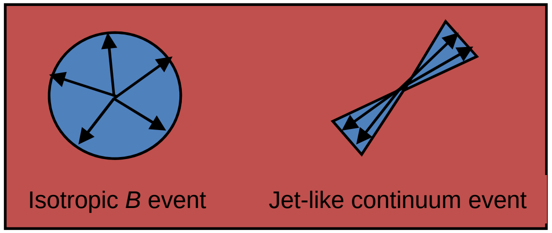
- BaBar data-taking ended on 7th April 2008
- Total of ~531 fb^{-1} recorded, ~432 fb^{-1} at the Υ(4S) (~ 467 million BB pairs)
- Analyses presented here use the full Υ(4S) dataset



Analysis Variables – Topological

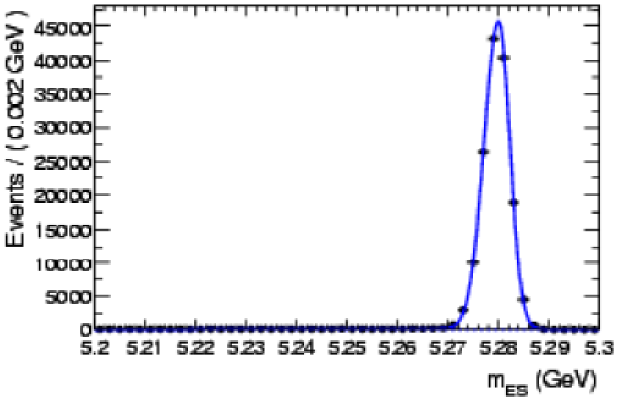
- Light quark continuum cross section ~3x $b\bar{b}$
- *B* mesons produced almost at rest since just above threshold
- Use event topology to discriminate
- Combine variables in an MVA, e.g. Fisher, Neural Network or Decision Tree



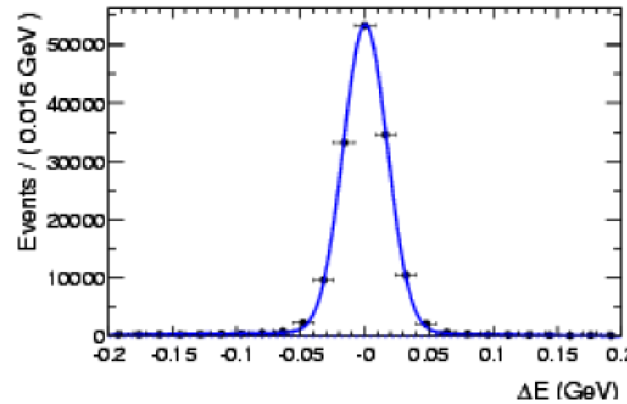


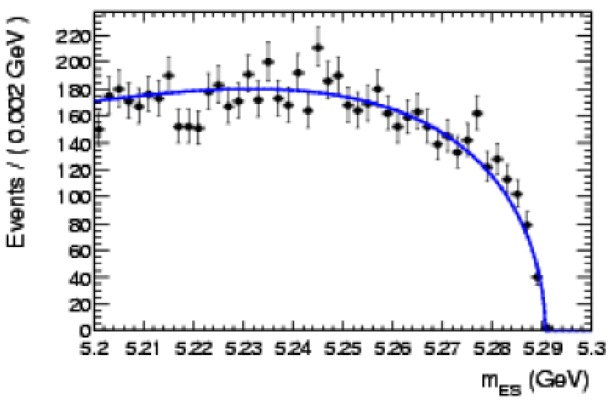
Analysis Variables – Kinematic

Make use of precision kinematic information from the beams.

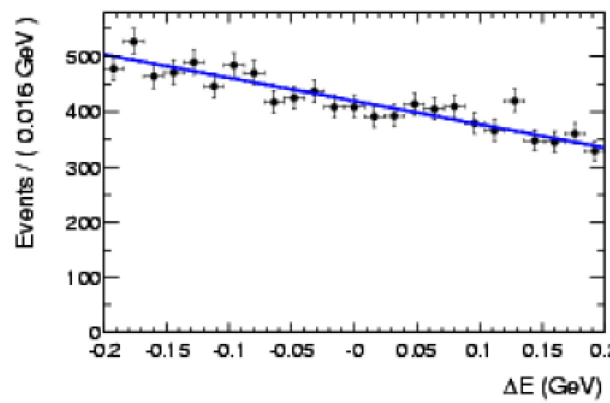


Characteristic Signal Distributions





Characteristic Continuum Distributions



$$m_{ES} = \sqrt{E_{beam}^{*2} - p_B^{*2}}$$

Plots show MC data

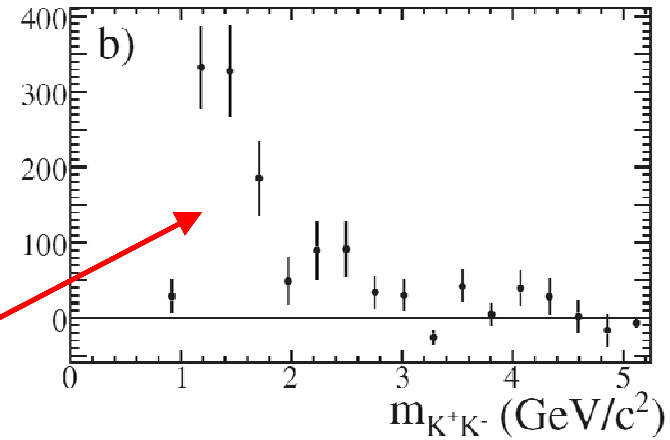
$$\Delta E = E_B^* - E_{beam}^*$$

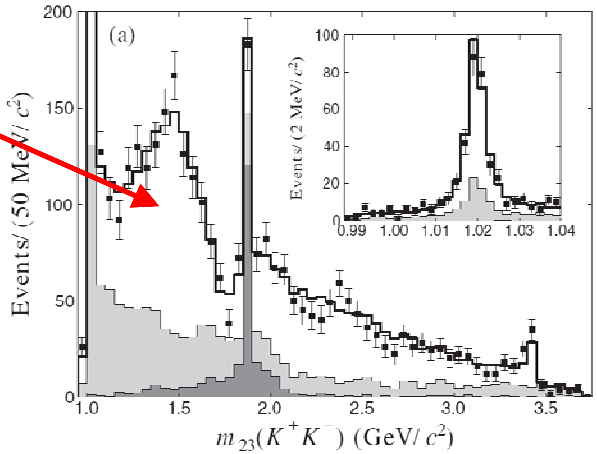
Phys. Rev. D 79, 051101(R)

Search for $B^+ \rightarrow K_S K_S \pi^+$

- Proceeds mainly via $b \rightarrow d$ penguin transition – suppresses the BF
  - Previous upper limit < 3.2×10^{-6}
  - Predictions of order 10^{-6}
- Recent observation by BaBar of $B^+ \rightarrow K^+K^-\pi^+$ with BF of 5×10^{-6}
  - Unexpected enhancement in K^+K^- invariant mass around 1.5 GeV
- Similar structures also seen in $B \rightarrow KKK$ decays, dubbed $f_X(1500)$
  - If decay follows isospin symmetry expect equal rates to K^+K^- and K^0K^0
  - If even spin, would be 50% K_SK_S, 50% K_LK_L, odd spin gives only K_SK_L
- Observation in $B^+ \rightarrow K_SK_S\pi^+$ could provide information on spin and/or quark content

Phys. Rev. Lett. 99, 221801



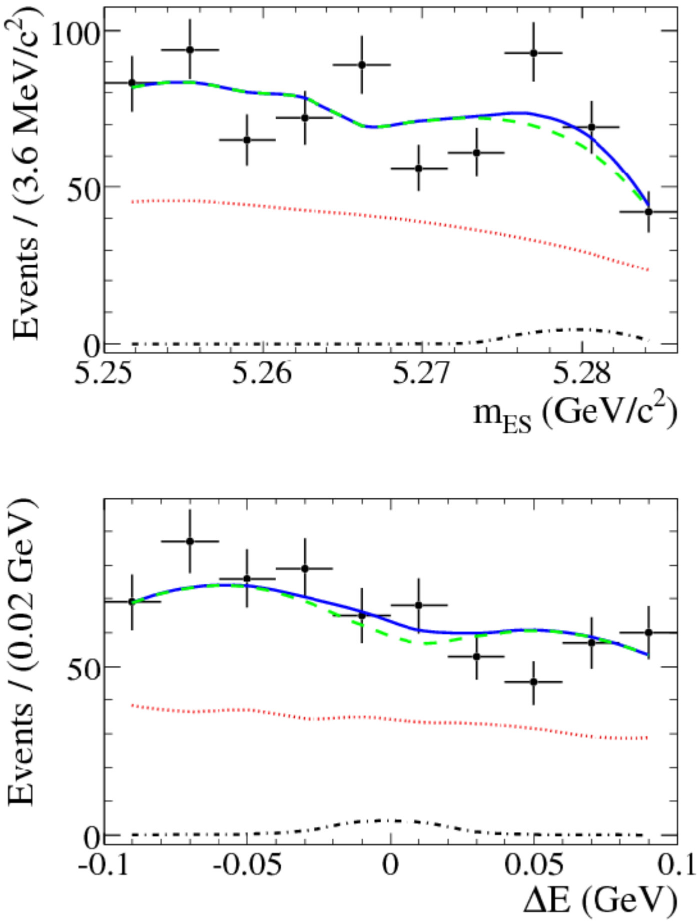


Phys. Rev. D 74, 032003

Phys. Rev. D 79, 051101(R)

Search for $B^+ \to K_S K_S \pi^+$

- Analysis is inclusive i.e. incorporates all possible resonant and nonresonant decay modes
- K_S reconstructed in decay to $\pi^+\pi^-$
- Unbinned maximum likelihood fit in 3 variables: m_{ES}, ΔE and a boosted decision tree combining topological variables
- Find no evidence of signal: 15 ± 15 signal events (statistical uncertainty only)



Phys. Rev. D 79, 051101(R)

Search for $B^+ \to K_S K_S \pi^+$

- Central value of BF is $(2.5 \pm 2.4 \pm 0.9) \times 10^{-7}$ (statistical and systematic uncertainties)
- Calculate Bayesian 90% CL upper limit $< 5.1 \times 10^{-7}$
- Largest source of systematic uncertainty due to variation in reconstruction efficiency over the Dalitz plot
- Lack of signal for $f_X(1500)$ disfavours models where the f_X has even spin and decays with isospin symmetry
- More data required to clarify this situation

arXiv:0905.0868, Accepted by Phys. Rev. D

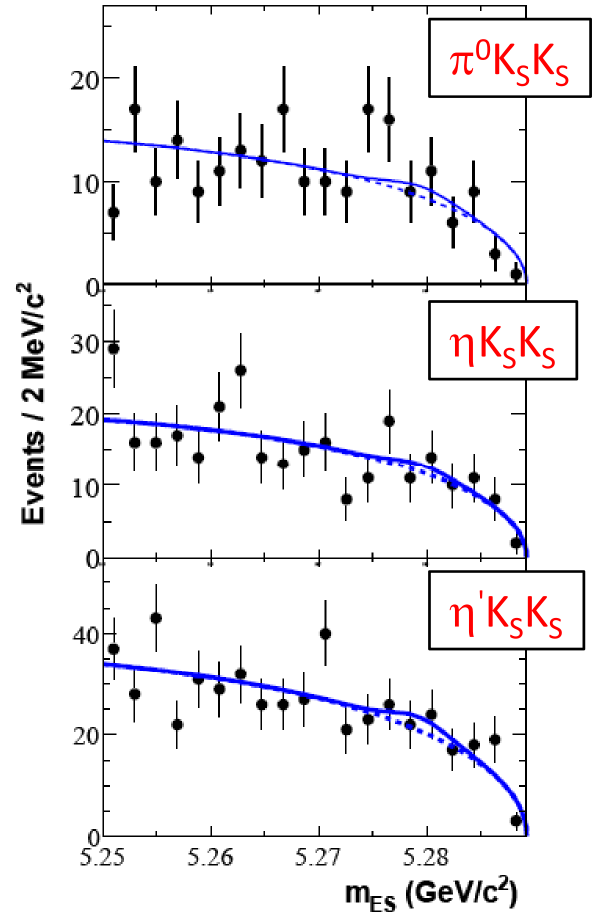
Search for $B^0 \to \pi^0 K_S K_S$, $\eta K_S K_S$, $\eta' K_S K_S$

- Searches mainly motivated by possibility for time-dependent CP asymmetry measurements
  - Final state is a CP eigenstate since it consists of 3 CP eigenstate particles, 2 of which are identical
  - No need for isospin or Dalitz-plot analysis in order to separate the different contributions
  - The decays $B^0 \to K_S K_S K_S$ and $B^0 \to K_S \pi^0 \pi^0$ are examples where such inclusive time-dependent analyses have already been performed → Phys. Rev. D 76, 091101; Phys. Rev. D 76, 071101(R)
- Also motivated by $f_X(1500)$ mystery

arXiv:0905.0868, Accepted by Phys. Rev. D

Search for $B^0 \rightarrow \pi^0 K_S K_S$, $\eta K_S K_S$, $\eta' K_S K_S$

- η candidates reconstructed in decays to $\gamma\gamma$ and 3π
- η' candidates reconstructed in decays to $\eta\pi\pi$ and $\rho\gamma$
- Analysis uses unbinned maximum likelihood fit to m_{ES}, ΔE and a Fisher discriminant of topological variables
- No evidence of signal found



arXiv:0905.0868, Accepted by Phys. Rev. D

Search for $B^0 \to \pi^0 K_S K_S$, $\eta K_S K_S$, $\eta' K_S K_S$

- Bayesian 90% CL upper limits are calculated including systematic uncertainties
- Dominant systematic again from variation of efficiency over the Dalitz plot
- Signal yields are unfortunately too small to permit a time-dependent analysis

Decay Mode	Branching Fraction (10^{-7})	90% CL UL (10^{-7})
$B^0 \to \pi^0 K_S K_S$	$2.7 \pm^{4.2}_{3.7} \pm 0.6$	9
$B^0 \to \eta K_S K_S$	$2.1 \pm^{4.7}_{3.8} \pm 1.2$	10
$B^0 \to \eta' K_S K_S$	$5.7 \pm^{8.0}_{6.5} \pm 3.4$	20

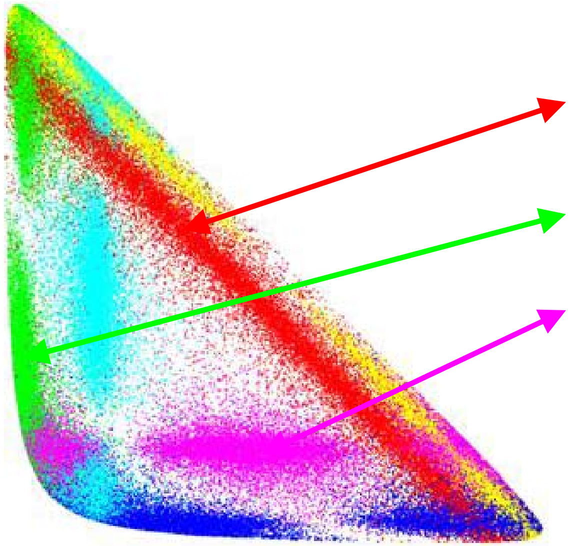
Dalitz-plot Analysis

- 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 resonance

Green points show spin 1 resonance

Purple points show spin 2 resonance

Each of these three has a different mass, width and composition.

Phys. Rev. D 79, 072006

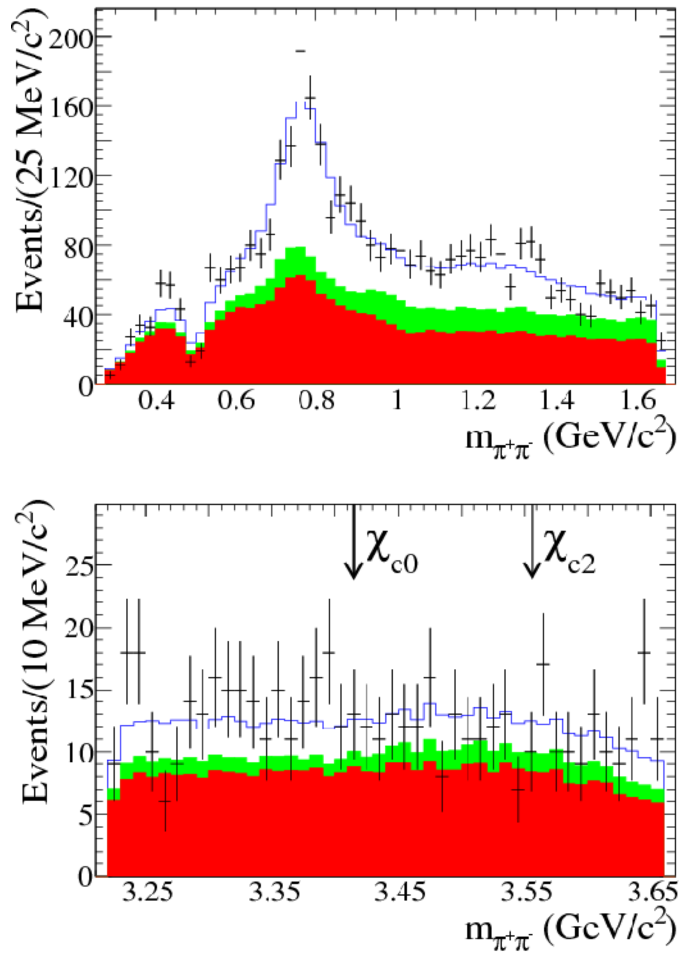
Dalitz-plot Analysis of $B^+ \to \pi^+\pi^+\pi^-$

- In principle can extract the CKM angle γ from the interference between $B^+ \to \chi_{c0}\pi^+$ and other modes such as $B^+ \to \rho^0\pi^+$
- This mode also provides important information to improve the DP model in $B^0 \to \pi^+\pi^-\pi^0$, which is used to measure the CKM angle α
- BF and A_{CP} measurements used to test factorisation and other effective theories
- Light meson spectroscopy aided by information from as many different final states as possible

Phys. Rev. D 79, 072006

Dalitz-plot Analysis of $B^+ \rightarrow \pi^+\pi^+\pi^-$

- Simultaneous maximum likelihood fit to m_{ES}, ΔE and the DP co-ordinates
- Determines both the event yields and Dalitz amplitudes
- Signal DP model contains contributions from $\rho^0(770)$, $\rho^0(1450)$, $f_2(1270)$, $f_0(1370)$ and a nonresonant component
- χ_{c0} and χ_{c2} components not found to be significant



Phys. Rev. D 79, 072006

Dalitz-plot Analysis of $B^+ \to \pi^+\pi^+\pi^-$

Mode	Fit fraction (%)	$\mathcal{B}(B^\pm \to \text{Mode})(10^{-6})$	$\mathcal{A}_{CP}$ (%)
$\pi^\pm\pi^\pm\pi^\mp$ total		$15.2 \pm 0.6 \pm 1.2^{+0.4}_{-0.3}$	$+3.2 \pm 4.4 \pm 3.1^{+2.5}_{-2.0}$
$\rho^0(770)\pi^\pm$; $\rho^0(770) \to \pi^+\pi^-$	$53.2 \pm 3.7 \pm 2.5^{+1.5}_{-7.4}$	$8.1 \pm 0.7 \pm 1.2^{+0.4}_{-1.1}$	$+18 \pm 7 \pm 5^{+2}_{-14}$
$\rho^0(1450)\pi^\pm$; $\rho^0(1450) \to \pi^+\pi^-$	$9.1 \pm 2.3 \pm 2.4^{+1.9}_{-4.5}$	$1.4 \pm 0.4 \pm 0.4^{+0.3}_{-0.7}$	$-6 \pm 28 \pm 20^{+12}_{-35}$
$f_2(1270)\pi^\pm$; $f_2(1270) \to \pi^+\pi^-$	$5.9 \pm 1.6 \pm 0.4^{+2.0}_{-0.7}$	$0.9 \pm 0.2 \pm 0.1^{+0.3}_{-0.1}$	$+41 \pm 25 \pm 13^{+12}_{-8}$
$f_0(1370)\pi^\pm$; $f_0(1370) \to \pi^+\pi^-$	$18.9 \pm 3.3 \pm 2.6^{+4.3}_{-3.5}$	$2.9 \pm 0.5 \pm 0.5^{+0.7}_{-0.5}(<4.0)$	$+72 \pm 15 \pm 14^{+7}_{-8}$
$\pi^\pm\pi^\pm\pi^\mp$ nonresonant	$34.9 \pm 4.2 \pm 2.9^{+7.5}_{-3.4}$	$5.3 \pm 0.7 \pm 0.6^{+1.1}_{-0.5}$	$-14 \pm 14 \pm 7^{+17}_{-3}$
$f_0(980)\pi^\pm$; $f_0(980) \to \pi^+\pi^-$	-	<1.5	-
$\chi_{c0}\pi^\pm$; $\chi_{c0} \to \pi^+\pi^-$	-	<0.1	-
$\chi_{c2}\pi^\pm$; $\chi_{c2} \to \pi^+\pi^-$	-	<0.1	-

- Fit has two solutions – best solution results shown above
- Dalitz plot is dominated by $\rho^0(770)$
  - BF consistent with theoretical predictions
- Also a large nonresonant component
- All CP asymmetries are consistent with zero
- Lack of signal in χ_c modes precludes measurement of CKM angle γ in this decay mode with present statistics

Conclusions

- Previous measurements of 3-body charmless hadronic B decays have helped constrain theoretical models such as factorisation, SU(3), etc.
- With full B-factory statistics can now probe more suppressed modes, such as the $b \rightarrow d$ penguin dominated modes $B \rightarrow K_S K_S h$ presented here
- At the same time more sophisticated analysis techniques can be applied to other modes, such as Dalitz plot analysis
- Several modes still to be updated to the full dataset, so watch this space…

BACKUP SLIDES

Phys. Rev. D 79, 072006

Two Solutions in $B^+ \rightarrow \pi^+\pi^+\pi^-$

TABLE VI. Comparison of results for the favored and second solutions. The uncertainties are statistical only.

	Favored solution	Second solution
Inclusive signal yield	1219 ± 50	1195 ± 45
Inclusive signal $\mathcal{A}_{CP}$	$+0.032 \pm 0.044$	$+0.015 \pm 0.043$
$q\bar{q}$ background yield	2337 ± 62	2358 ± 64
$q\bar{q}$ background $\mathcal{A}_{CP}$	$+0.002 \pm 0.027$	$+0.011 \pm 0.027$

	Favored solution		Second solution	
Resonance	Fit fraction	$\mathcal{A}_{CP}$	Fit fraction	$\mathcal{A}_{CP}$
$\rho^0(770)\pi^\pm$	0.532 ± 0.037	$+0.18 \pm 0.07$	0.458 ± 0.033	$+0.03 \pm 0.08$
$\rho^0(1450)\pi^\pm$	0.091 ± 0.023	-0.06 ± 0.28	0.064 ± 0.016	-0.54 ± 0.24
$f_2(1270)\pi^\pm$	0.059 ± 0.016	$+0.41 \pm 0.25$	0.079 ± 0.016	$+0.55 \pm 0.20$
$f_0(1370)\pi^\pm$	0.189 ± 0.033	$+0.72 \pm 0.15$	0.030 ± 0.019	$-1.00^{+0.58}_{-0.00}$
Nonresonant	0.349 ± 0.042	-0.14 ± 0.14	0.365 ± 0.042	-0.11 ± 0.14

arXiv:0905.0868, Accepted by Phys. Rev. D

ΔE plots and details for $B^0 \to XK_SK_S$

Mode	Yield (ev)	Fit bias (ev)	ϵ (%)	$\prod \mathcal{B}_i$ (%)	$\mathcal{S}(\sigma)$	$\mathcal{B}(10^{-7})$
$\boldsymbol{\pi^0 K_S^0 K_S^0}$	$11.7^{+16.2}_{-14.5}$	$+1.0 \pm 0.7$	17.5	47.9	**0.7**	$\mathbf{2.7^{+4.2}_{-3.7} \pm 0.6}$ **(< 9)**
$\eta_{\gamma\gamma} K_S^0 K_S^0$	$3.2^{+9.0}_{-7.2}$	$+1.1 \pm 0.7$	17.5	18.8	0.3	$1.4^{+5.9}_{-4.7}$
$\eta_{3\pi} K_S^0 K_S^0$	$2.2^{+5.5}_{-3.6}$	$+0.2 \pm 0.6$	12.0	10.9	0.5	$3.3^{+9.0}_{-5.9}$
$\boldsymbol{\eta K_S^0 K_S^0}$					**0.5**	$\mathbf{2.1^{+4.7}_{-3.8} \pm 1.2}$ **(< 10)**
$\eta'_{\eta\pi\pi} K_S^0 K_S^0$	$2.4^{+4.7}_{-3.4}$	$+0.1 \pm 0.4$	12.6	8.4	0.6	$4.6^{+9.5}_{-6.9}$
$\eta'_{\rho\gamma} K_S^0 K_S^0$	$13.4^{+16.1}_{-14.1}$	$+4.7 \pm 1.1$	15.9	14.1	0.6	$8.3^{+15.4}_{-13.5}$
$\boldsymbol{\eta' K_S^0 K_S^0}$					**0.8**	$\mathbf{5.7^{+8.0}_{-6.5} \pm 3.4}$ **(< 20)**