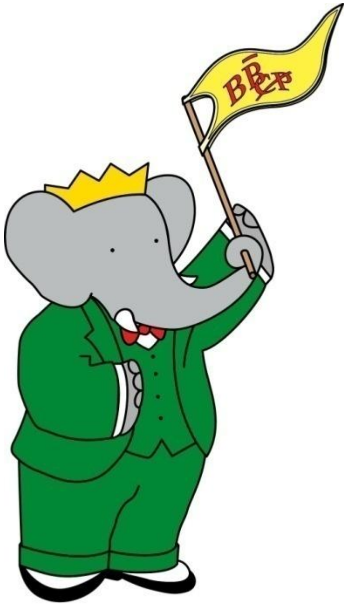
CP Asymmetries, Decay Rates, and Dalitz-Plot Analysis of $B \to KKK$ at BaBar



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On Behalf of the BaBar Collaboration

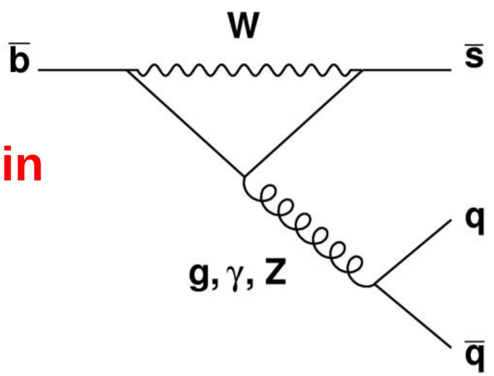
Les Rencontres de Physique de la Vallée d'Aoste

February 29, 2012

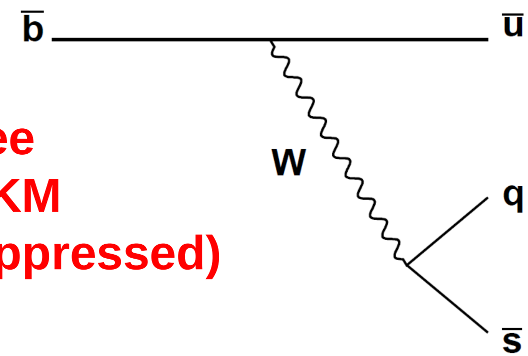
B→KKK Decays

- Decays are dominated by b→s loop (“penguin”) diagrams:

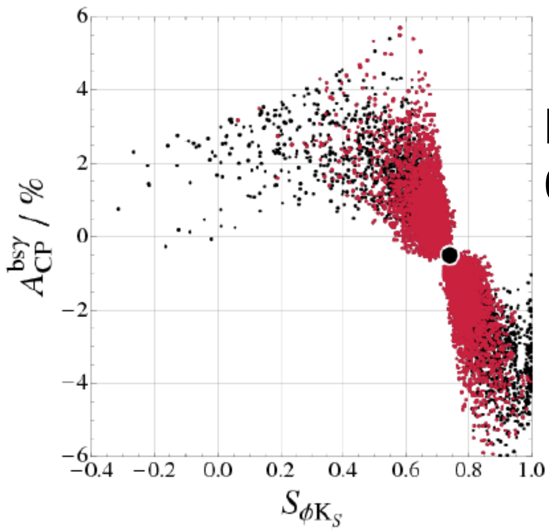
Penguin



Tree (CKM suppressed)



- Tree amplitudes subdominant in SM
- New Physics can appear in loops – altering CP violation from SM expectation!



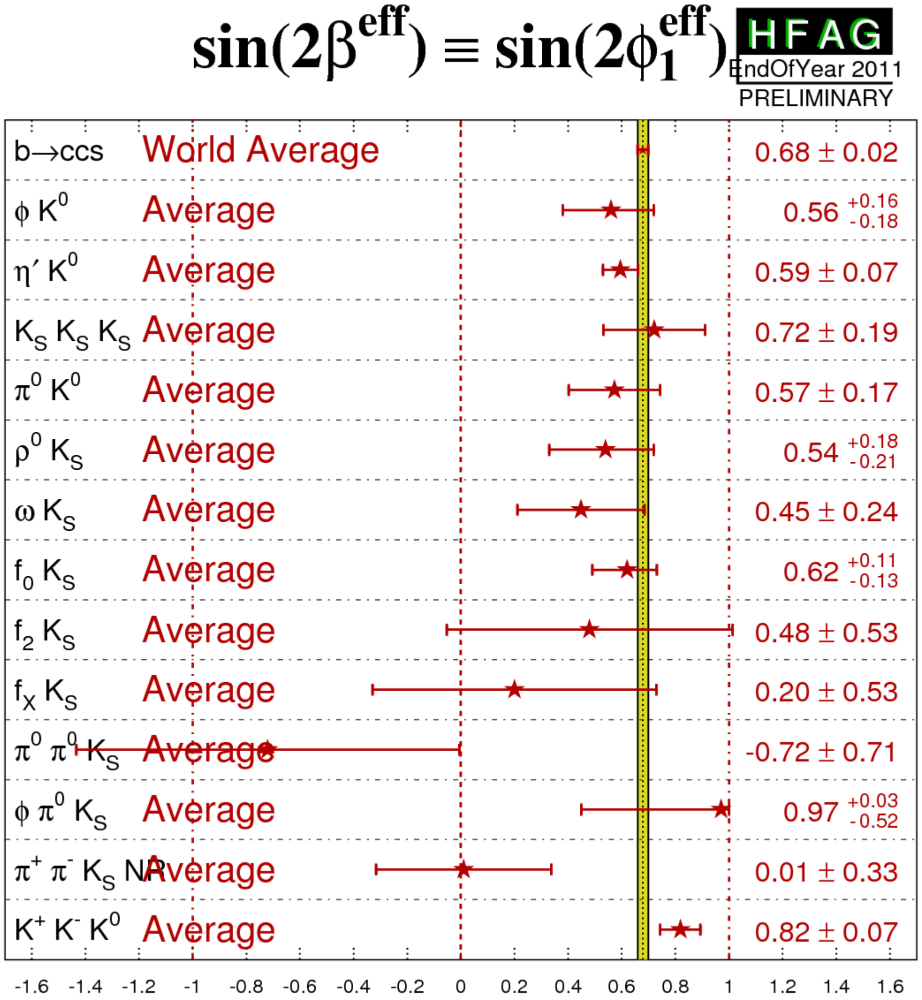
hep-ph: 0909.1333

CP Violation in b→s Penguins

- Time-dependent CP-violation:

$$A_{CP}(\Delta t) \sim \eta_{CP} \sin(2\beta_{eff}) \sin(\Delta m_d \Delta t)$$

- Measured in many B decays!
- This analysis includes ϕK_S
  - Especially clean theoretically
- Also measure direct CP asymmetry A_{CP}
  - $\phi K+$ particularly clean theoretically



Analysis Overview

Submitted to PRD
arXiv:1201.5897

- $B^0 \rightarrow K^+K^-K_S$:

  Measure time-dependent CP asymmetry

$$A_{CP}(\Delta t) \sim \eta_{CP} \sin(2\beta_{eff}) \sin(\Delta m_d \Delta t)$$

  Complication -- $K^+K^-K_S$ not CP eigenstate: $\eta_{CP} \sim (-1)^L$

  CP content depends on Dalitz plot/spin structure of decay

- $B^+ \rightarrow K^+K^-K^+$ and $B^+ \rightarrow K_SK_SK^+$

  Study Dalitz structure – help understand CP content in $K^+K^-K_S$

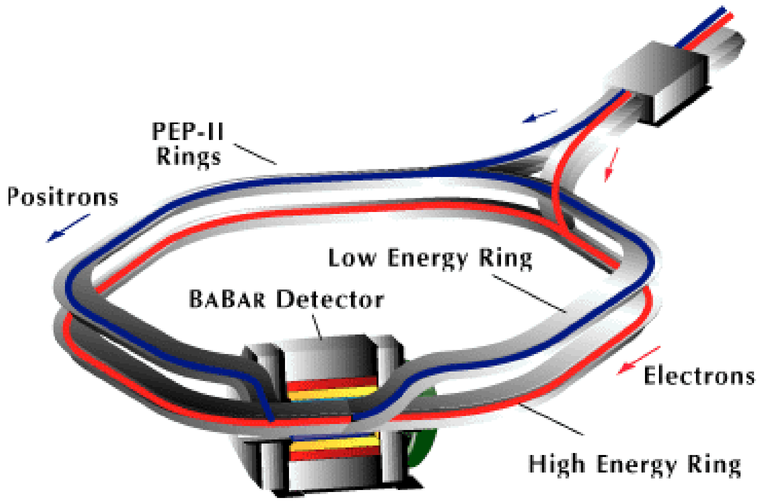
  $f_X(1500)$ – poorly understood resonance, seen in $B \rightarrow KKK$, taken to be a scalar

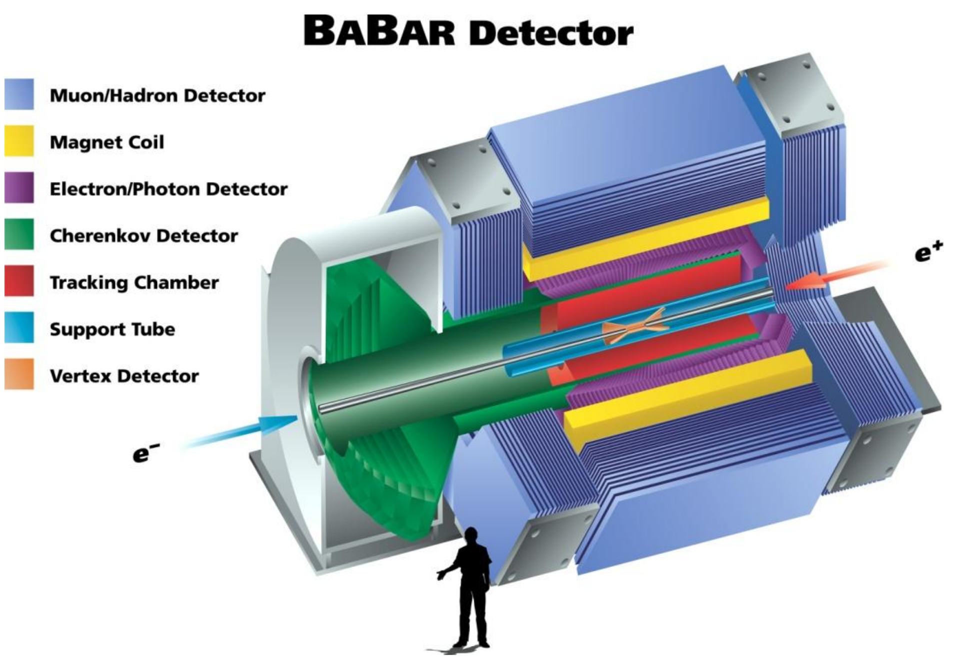
  Large “nonresonant” contribution needs further study

  Search for direct CP violation

The BaBar Experiment

- PEP-II asymmetric e^+e^- collider at SLAC
- 9.0 GeV e^- on 3.1 GeV e^+
- Operating at Upsilon(4S) resonance



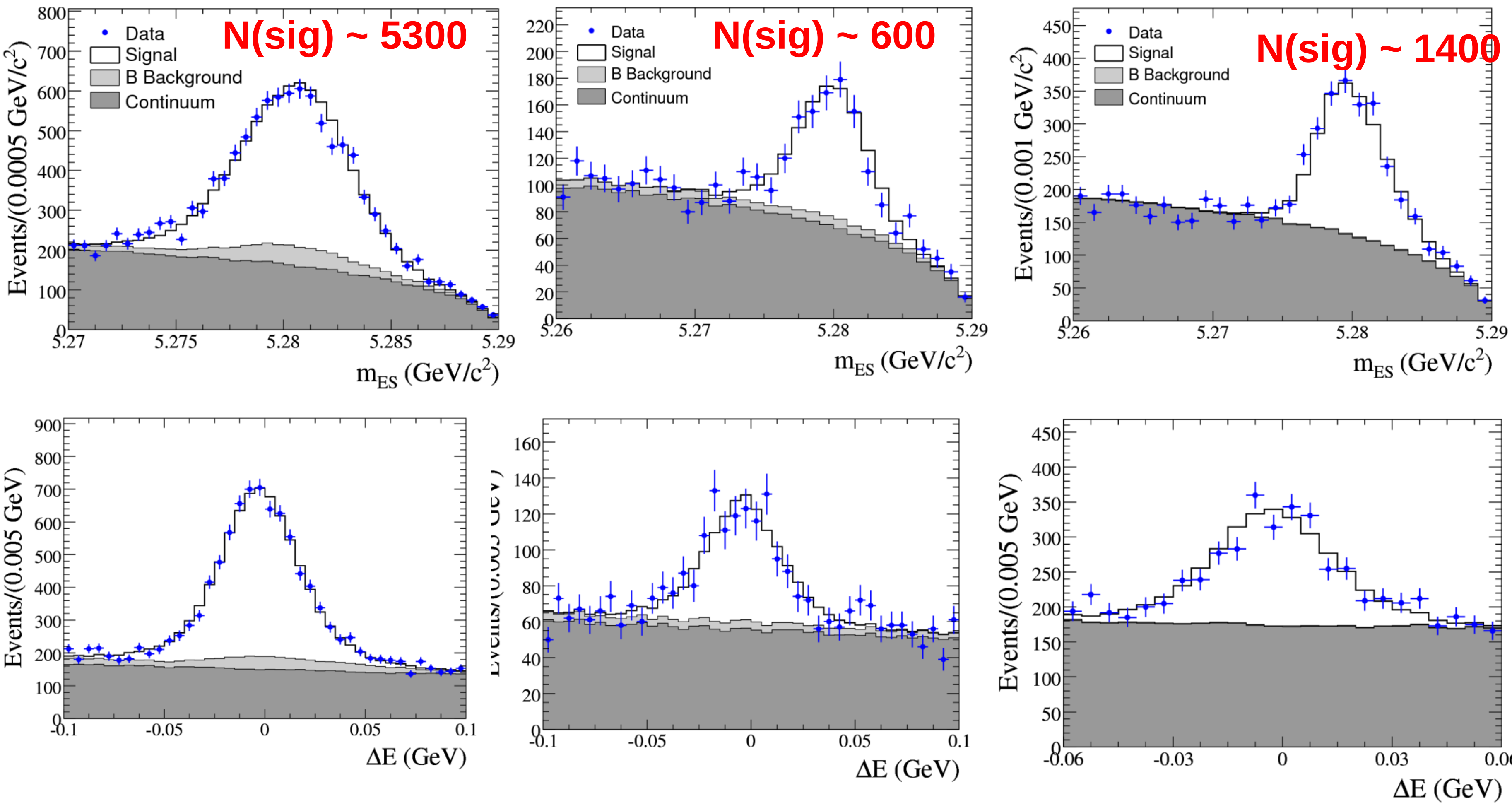


- BaBar took data from 1999-2008
- Analyses based on final dataset:
  - ~470M $B\bar{B}$ pairs

Data Fit Projections

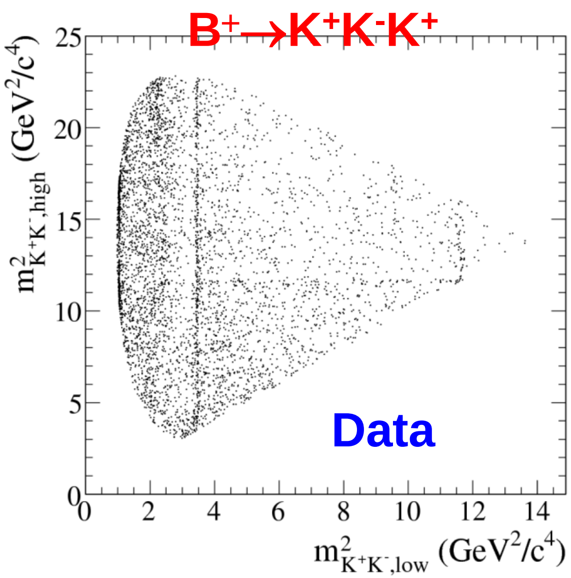
Preliminary

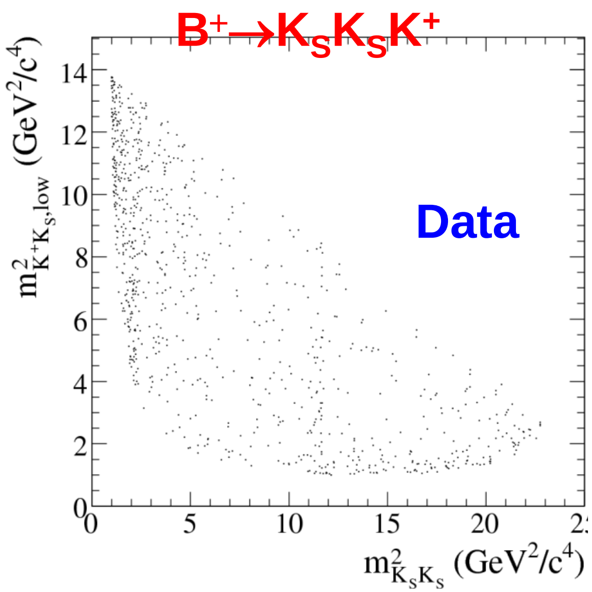
$B^+ \rightarrow K^+K^-K^+$ | **$B^+ \rightarrow K_SK_SK^+$** | **$B^0 \rightarrow K^+K^-K_S$**

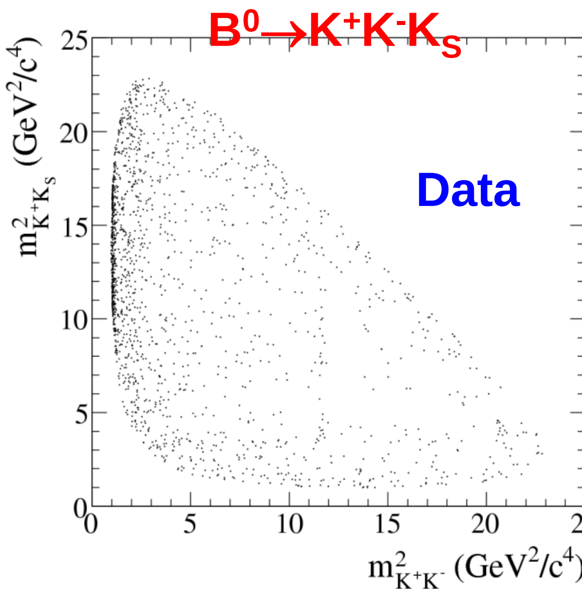


The Dalitz Plot

Preliminary







$$\mathcal{A} \equiv \mathcal{A}(B \to KKK; m_{12}, m_{23}) = \sum_j a_j F_j(m_{12}, m_{23})$$

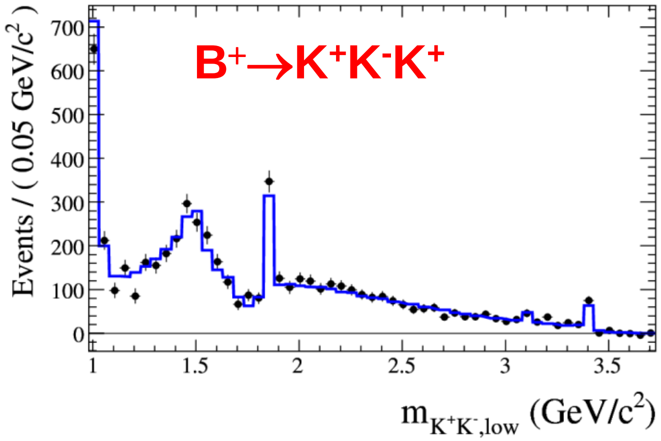
$$\begin{aligned} a_j &= c_j(1+b_j)e^{i(\phi_j+\delta_j)} \\ \bar{a}_j &= c_j(1-b_j)e^{i(\phi_j-\delta_j)} \end{aligned}$$

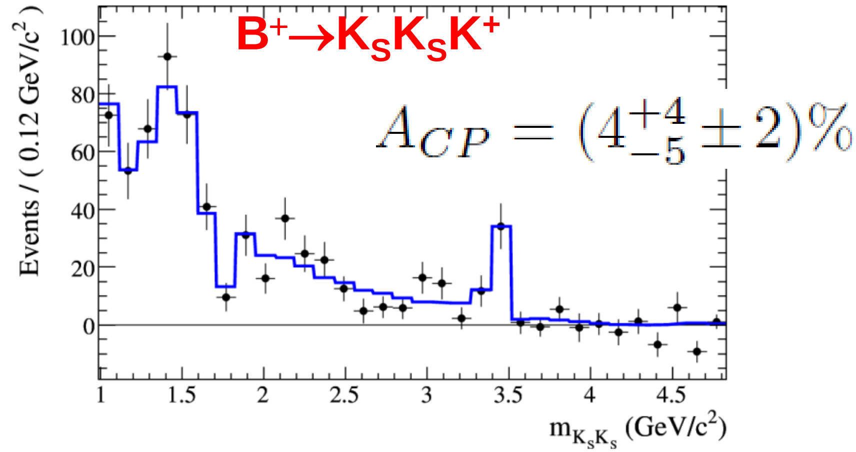
F_j are resonant or nonresonant lineshapes: relativistic Breit-Wigner, spin-factors, etc.

From isobar coefficients can derive: partial branching fractions, A_{CP} (= $-2b/(1+b^2)$), β_{eff} (= $\beta + \delta$), etc.

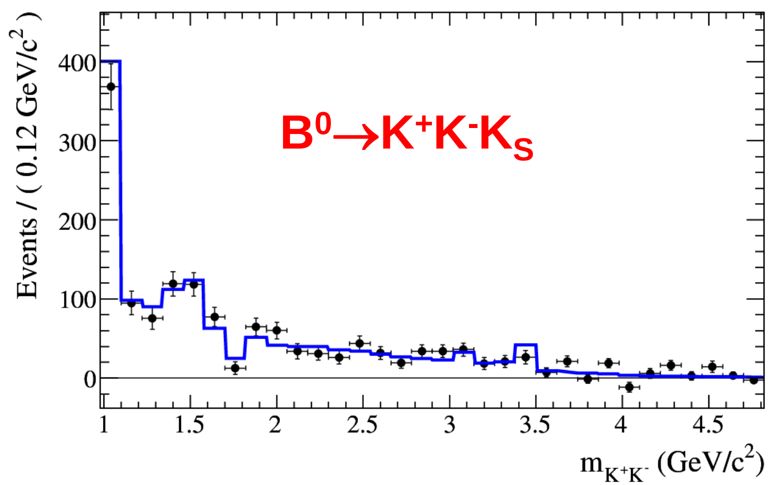
Dalitz Plot Projections

Preliminary





Signal-weighted data ("sPlot")



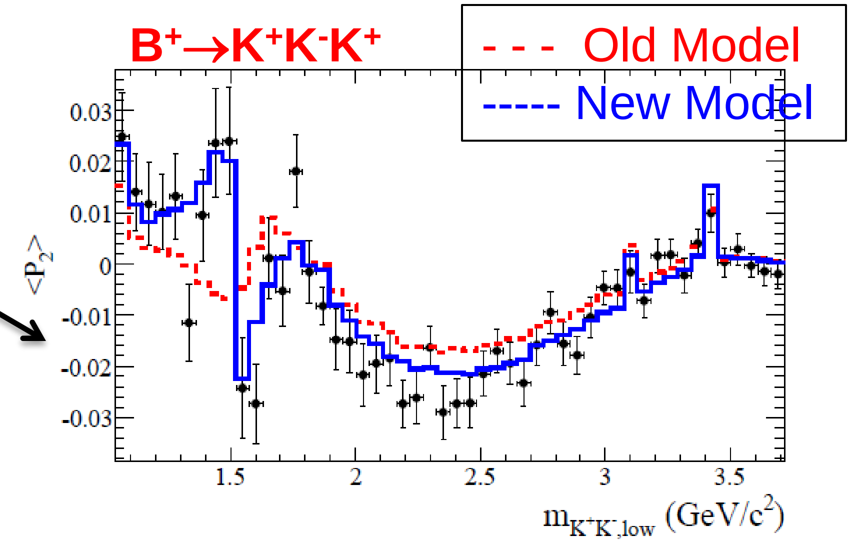
Dalitz Model

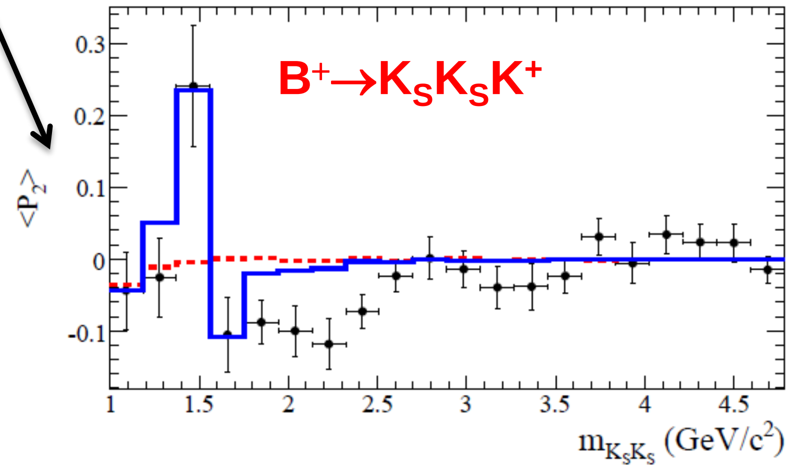
Preliminary

data weighted by P_L

$$\langle P_\ell \rangle \equiv \int_{-1}^{1} d\Gamma \, P_\ell(\cos\theta) d\cos\theta$$

- Include $\phi(1020)$, $f_0(980)$, χ_{c0}
- Previous analyses had $f_X(1500)$ and exponential NR model.
- $f_X(1500)$ and exponential NR inadequate to describe data





New Model

- $f_X(1500) \rightarrow f_0(1500) + f_2'(1525) + f_0(1710)$
- Polynomial NR model, with S-wave and P-wave terms

$B^+ \to K^+K^-K^+$ Results

Preliminary

Decay mode	A_{CP} (%)
$\phi(1020)K^+$	$12.8 \pm 4.4 \pm 1.3$
$f_0(980)K^+$	$-8 \pm 8 \pm 4$
$\left[f_0(1500), f_2'(1525), f_0(1710)\right]K^+$	$14 \pm 10 \pm 4$
NR	$6.0 \pm 4.4 \pm 1.9$

- $A_{CP}(\phi K^+)$ larger than SM expectation:

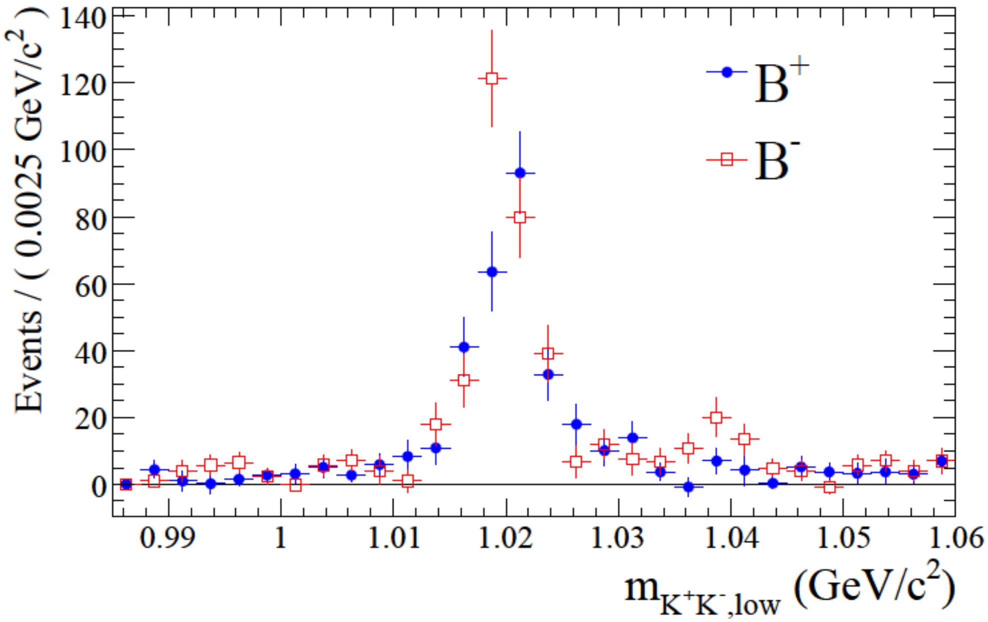
$$A_{CP} = (1.6^{+3.1}_{-1.4})\%$$ (QCDF) Beneke, Neubert, Nucl Phys B675, 333

$$A_{CP} = (1^{+0}_{-1})\%$$ (PQCD) Li, Mishima, PRD 74, 094020

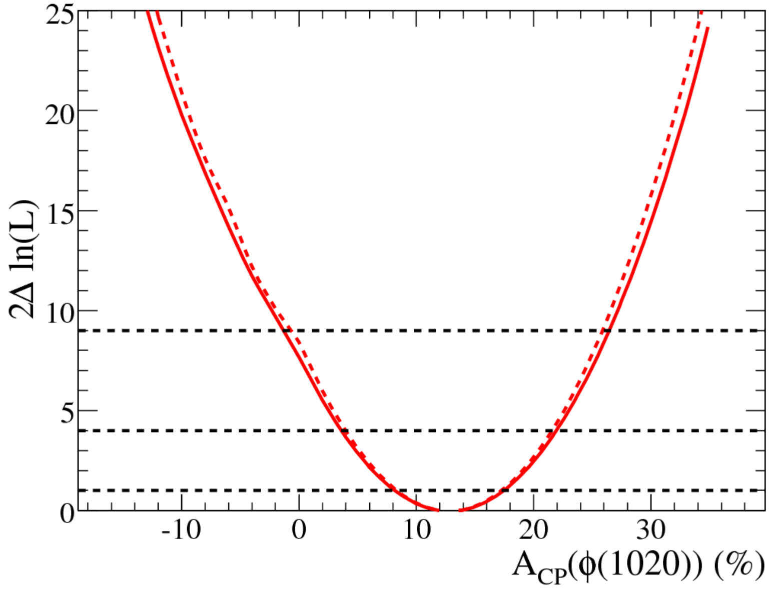
$B^+ \to \phi K^+$ Results

Preliminary

A_{CP}=(12.8 ± 4.4 ± 1.3)%



Signal-weighted data in ϕ(1020) region ("sPlot")



Likelihood scan in $A_{CP}(\phi(1020))$

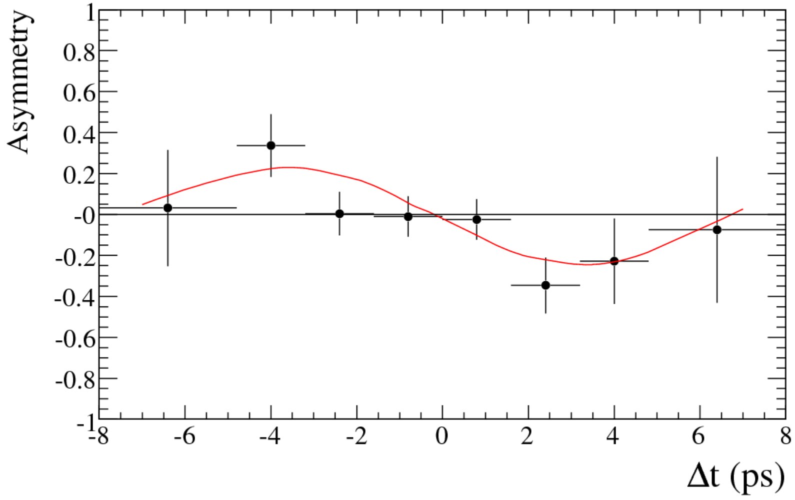
A_{CP}=0 excluded at 2.8 sigma

$B^0 \to K^+K^-K_S$ Results

Preliminary

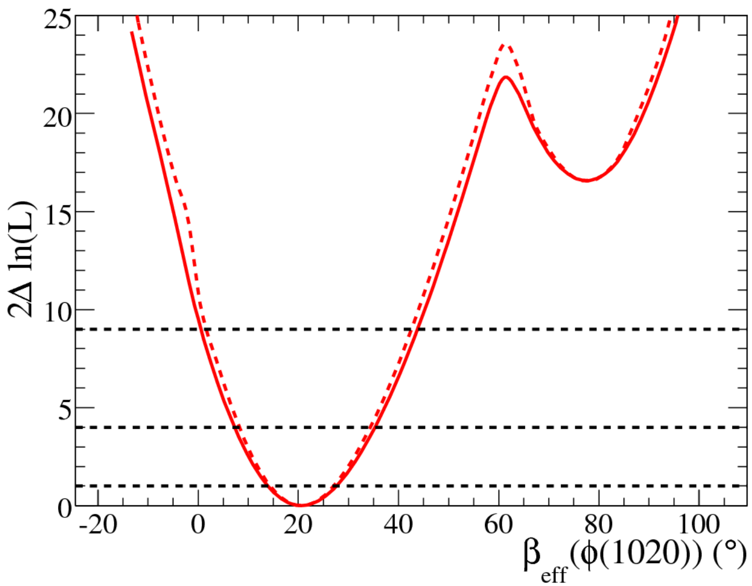
CP-violating parameters

Component	$\beta_{\rm eff}$ (deg)	$A_{CP}(=-C)(\%)$
$\phi(1020)K_S^0$	$21 \pm 6 \pm 2$	$-5 \pm 18 \pm 5$
$f_0(980)K_S^0$	$18 \pm 6 \pm 4$	$-28 \pm 24 \pm 9$
Other	$20.3 \pm 4.3 \pm 1.2$	$-2 \pm 9 \pm 3$



Good agreement with SM

Charmonium:
β = 21.4 ± 0.8 deg



Summary

Submitted to PRD
arXiv:1201.5897

- Indication of direct CP violation in $B^+ \to \phi K^+$ at 2.8σ.
  - $A_{CP} = (12.8 \pm 4.4 \pm 1.3)\%$
  - SM: $(0 - 4.7)\%$
- Most precise measurement of $\beta_{eff}(\phi K_S)$:
  - $\beta_{eff} = (21 \pm 6 \pm 2)$ degrees

- $f_X(1500)$ not a single resonance – well described by $f_0(1500)$ + $f_2'(1525)$ + $f_0(1710)$

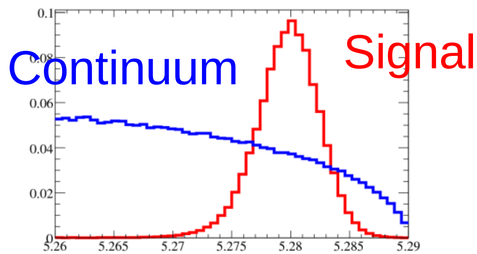
- We await results from Belle and LHCb!

Backup

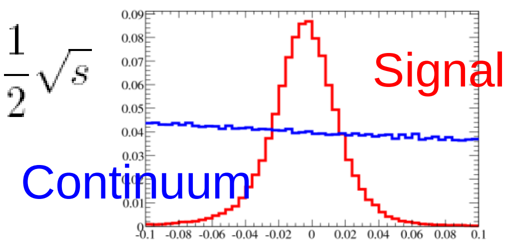
Common Analysis Techniques

- Suppress dominant "continuum" background: $e^+e^- \to q\bar{q}$ (q=u,d,s,c)

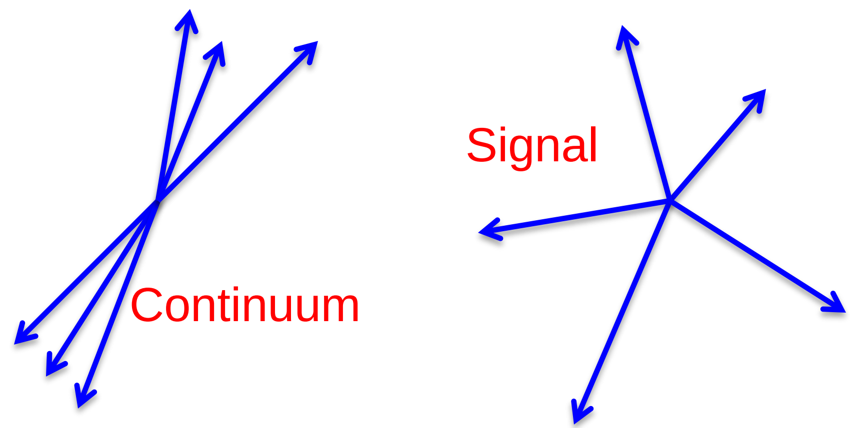
$$m_{ES} = \sqrt{\frac{s}{4} - p_B^2}$$



$$\Delta E = E_B - \frac{1}{2}\sqrt{s}$$



- Multivariate neural network (NN) to distinguish event shape:



- $B\bar{B}$ backgrounds: generally small, but some can look similar to signal – dangerous!
- Measurements extracted using multivariate maximum-likelihood (ML) fits

$B^+ \to K^+K^-K^+$ BF's

Decay mode	$\mathcal{B}(B^+ \to K^+K^-K^+) \times FF_j$ (10^{-6})
$\phi(1020)K^+$	$4.48 \pm 0.22^{+0.33}_{-0.24}$
$f_0(980)K^+$	$9.4 \pm 1.6 \pm 2.8$
$f_0(1500)K^+$	$0.74 \pm 0.18 \pm 0.52$
$f_2'(1525)K^+$	$0.69 \pm 0.16 \pm 0.13$
$f_0(1710)K^+$	$1.12 \pm 0.25 \pm 0.50$
$\chi_{c0}K^+$	$1.12 \pm 0.15 \pm 0.06$
NR	$22.8 \pm 2.7 \pm 7.6$
NR (S-wave)	$52^{+23}_{-14} \pm 27$
NR (P-wave)	$24^{+22}_{-12} \pm 27$

$B^+ \to K_S K_S K^+$ BF's

Decay mode	$\mathcal{B}(B^+ \to K^0_S K^0_S K^+) \times FF_j\ (10^{-6})$
$f_0(980)K^+$	$14.7 \pm 2.8 \pm 1.8$
$f_0(1500)K^+$	$0.42 \pm 0.22 \pm 0.58$
$f_2'(1525)K^+$	$0.61 \pm 0.21^{+0.12}_{-0.09}$
$f_0(1710)K^+$	$0.48^{+0.40}_{-0.24} \pm 0.11$
$\chi_{c0}K^+$	$0.53 \pm 0.10 \pm 0.04$
NR (S-wave)	$19.8 \pm 3.7 \pm 2.5$

$B^0 \rightarrow K^+K^-K_S$ BF's

Decay mode	$\mathcal{B}(B^0 \to K^+K^-K^0) \times FF_j \; (10^{-6})$
$\phi(1020)K^0$	$3.48 \pm 0.28^{+0.21}_{-0.14}$
$f_0(980)K^0$	$7.0^{+2.6}_{-1.8} \pm 2.4$
$f_0(1500)K^0$	$0.57^{+0.25}_{-0.19} \pm 0.12$
$f_2'(1525)K^0$	$0.13^{+0.12}_{-0.08} \pm 0.16$
$f_0(1710)K^0$	$4.4 \pm 0.7 \pm 0.5$
$\chi_{c0}K^0$	$0.90 \pm 0.18 \pm 0.06$
NR	$33 \pm 5 \pm 9$
NR (S-wave)	$30 \pm 5 \pm 8$
NR (P-wave)	$3.1 \pm 0.7 \pm 0.4$