New Results in Charmless B Meson Decays at BaBar

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Overview: 2 (of *Many*) New BaBar Results

1) **Evidence** for $B^0 \to \omega\omega$, and improved limit for $B^0 \to \omega\phi$.

Brand new! To be submitted to PRL

2) **Measurement of *CP* violation** in *B* decays to three charged kaons.

arXiv:1201.5897, PRD **85**:112010 (2012);
Also arXiv:1305.4218, SLAC-PUB-15451

1) **Evidence** for $B^0 \to \omega\omega$, and improved limit for $B^0 \to \omega\phi$

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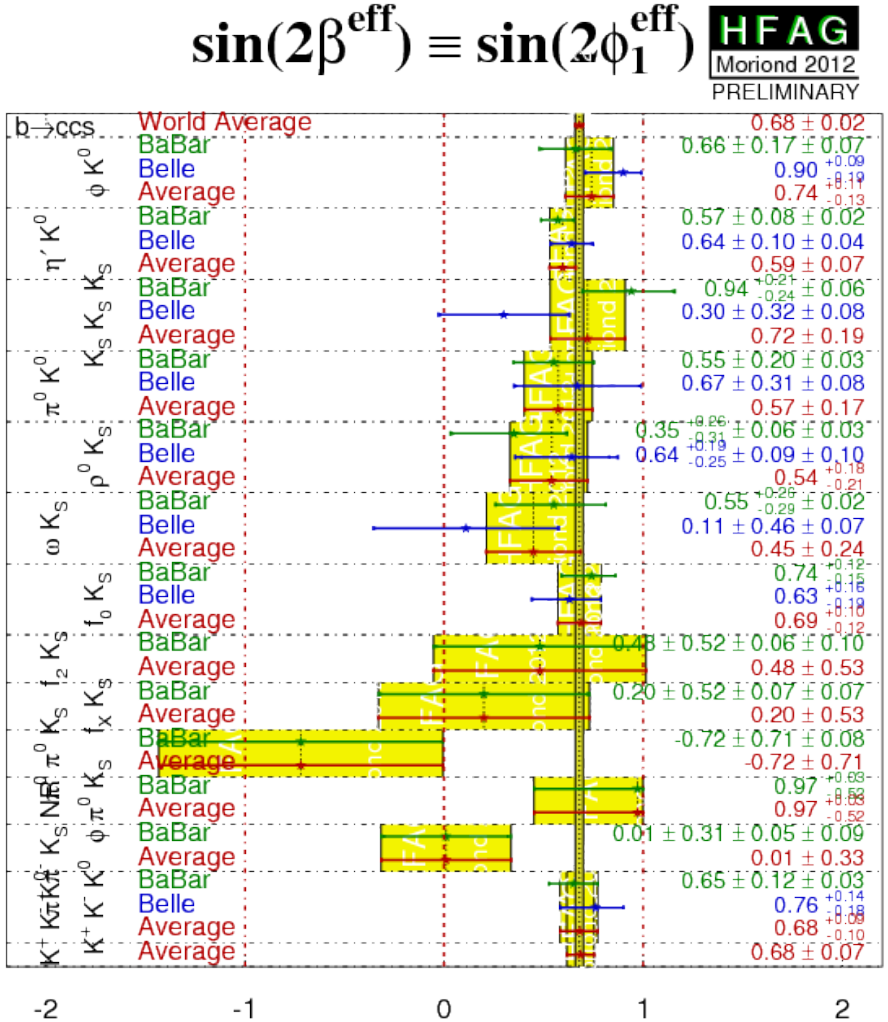
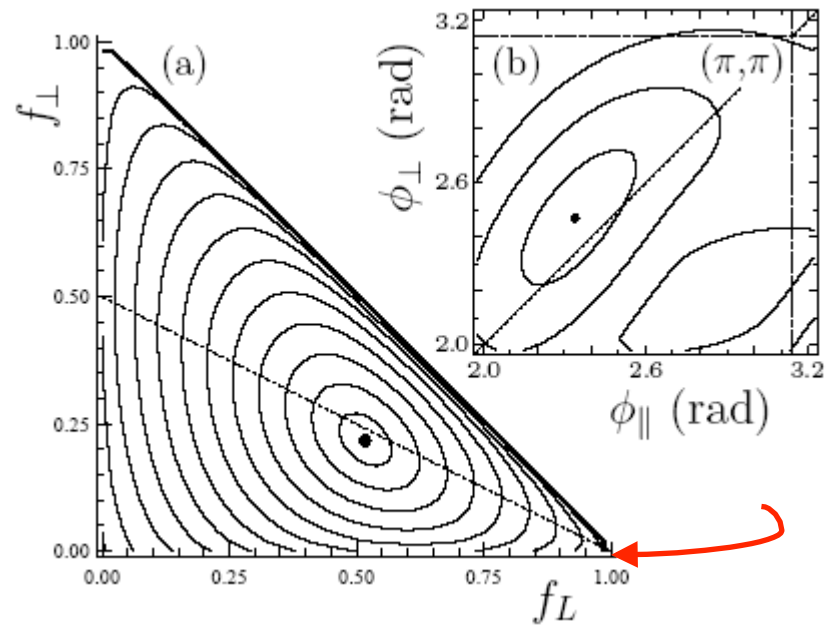
$B^0 \to \omega\omega$ and $B^0 \to \omega\phi$: Motivation

- ***Anomalies in charmless decays with loops:***





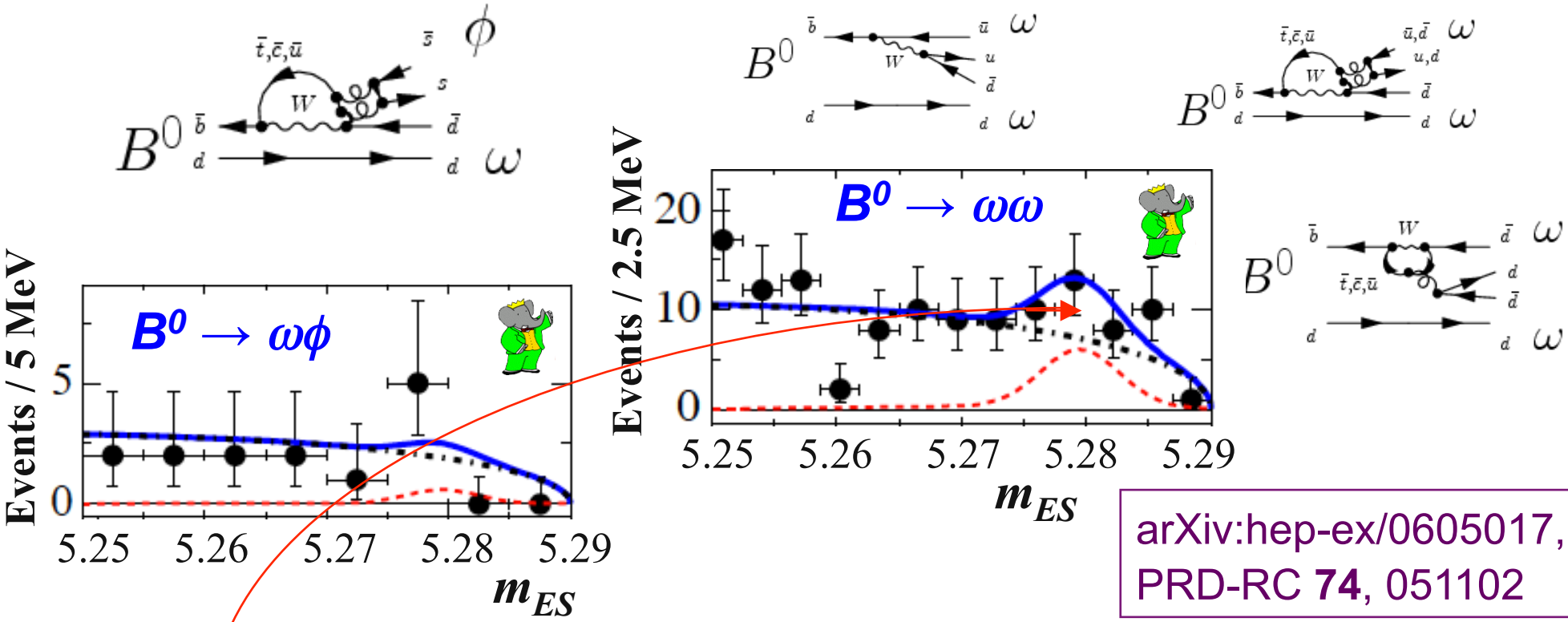
- ***Quite low value of longitudinally-polarized fraction in φK*.***
- ***Potential signs of new physics in loops…?***

- ***(Somewhat) low values of CP asymmetries.***

SM expected BFs:
$B^0 \to \omega\omega$: O(1 x 10^{-6})
$B^0 \to \omega\phi$: O(1 x 10^{-7})

$B^0 \to \omega\omega$ and $B^0 \to \omega\phi$: Previous Measurement at BaBar (2006)

233 x 10^6 $B\bar{B}$ decays



arXiv:hep-ex/0605017, PRD-RC **74**, 051102

- $\mathcal{B}(\phi\omega)$ **< 1.2 x 10^{-6}** *(90% CL)*, $\mathcal{B}(\omega\omega) = (1.8^{+1.3}_{-0.9} \pm 0.4) \times 10^{-6}$ (**< 4.0 x 10^{-6}** @ *90% CL*)
- 2σ excess for $B^0 \to \omega\omega$ in 2006 measurement, however both results were limits.
- At leading order, $\phi\omega$ is pure penguin and $\omega\omega$ is a penguin-tree combination.
- Limits on BFs can provide a constraint on amplitudes of ϕK^*. Neither helicity amplitude measurements, nor even significant signal peaks, are required.

$B^0 \to \omega\omega$ and $B^0 \to \omega\phi$: Reconstruction

- Full reconstruction of B^0 candidates, with $\omega \to \pi^+\pi^-\pi^0$ and $\phi \to K^+K^-$.

State	Inv. mass (MeV)
ω	$740 < m_{\pi\pi\pi} < 820$
ϕ	$1009 < m_{KK} < 1029$
π^0	$120 < m_{\gamma\gamma} < 150$

- Resulting B^0 signal candidates are characterized by the standard variables:

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

$$m_{ES} = \sqrt{(\tfrac{1}{2}s + \mathbf{p}_0 \cdot \mathbf{p}_B)^2 / E_0^{*2} - \mathbf{p}_B^2}$$

- For a candidate to be selected, it must satisfy $|\Delta E| < 200$ MeV and $5.24 < m_{ES} < 5.29$ GeV, and have a vertex probability > 0.

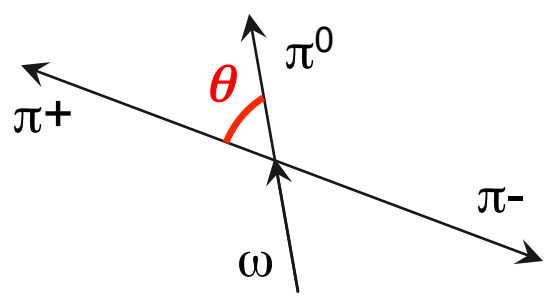
- Event shape variables are additionally used to help reject continuum background.

$B^0 \to \omega\omega$ and $B^0 \to \omega\phi$: Maximum Likelihood Fit

471 x 10^6 $B\bar{B}$ decays

- We use an unbinned maximum likelihood in the 8 (ωϕ) or 9 (ωω) variables:
  - m_{ES}
  - ΔE
  - the resonance masses (2)
  - the resonance helicities (2)
  - an event shape Fisher discriminant
  - + the ω "internal" helicity angle(s) (i.e. angle of the π^0 in the dipion rest frame) = 2 extra variables for $\omega\omega$, but just 1 extra variable for $\omega\phi$:

Di-pion (π+π-) rest frame:



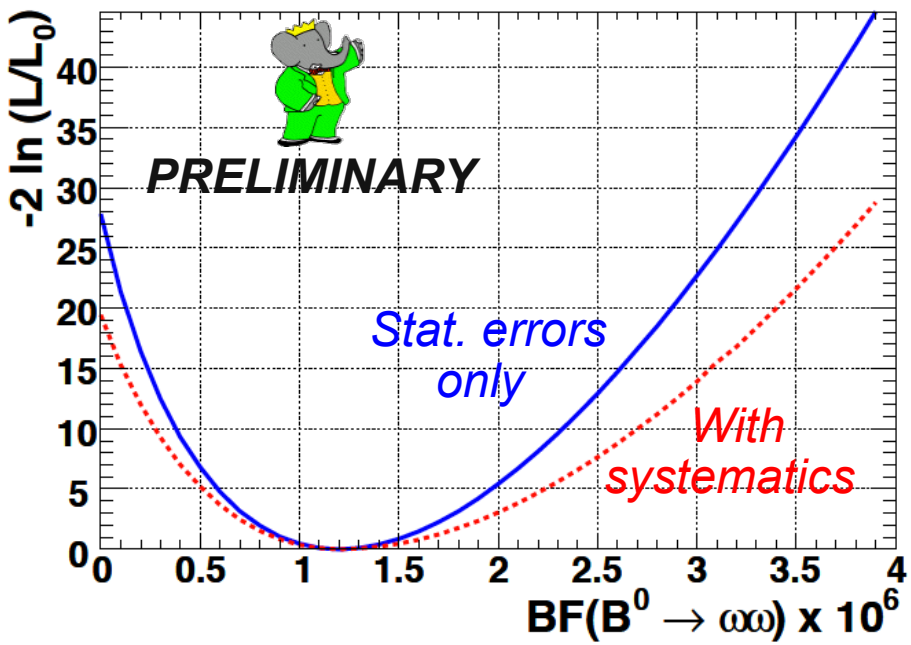
- The likelihood is defined as:

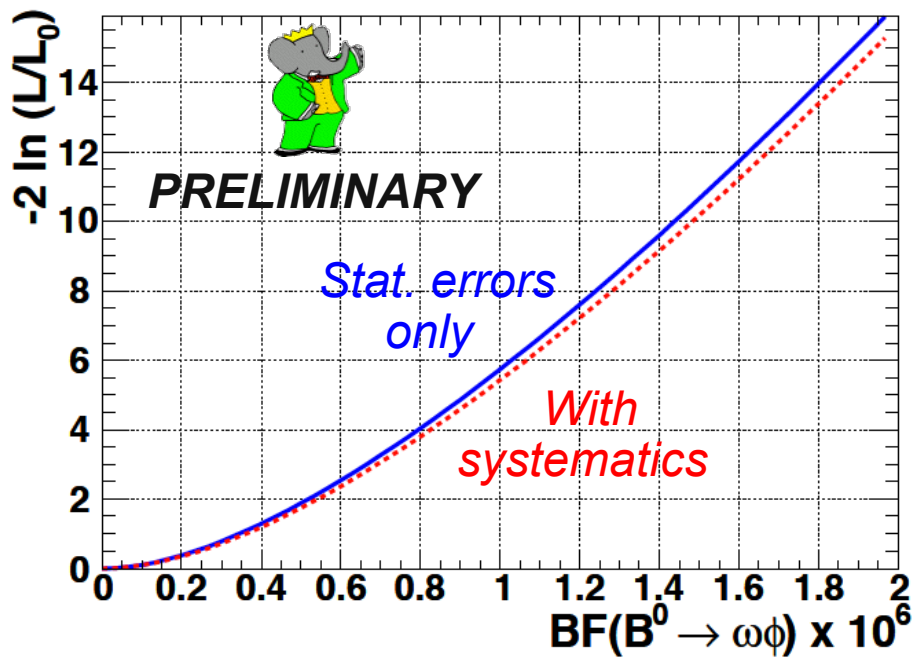
$$\mathcal{L} = \frac{e^{-(\sum Y_j)}}{N!} \prod_{i=1}^{N} \sum_j Y_j \mathcal{P}_j^i$$

where Y_j are the free parameters of the fit, i.e. the number of events for each hypothesis (signal, combinatoric background, and peaking background), and $P_j(x_i)$ are the probabilities for each hypothesis evaluated from the vector of 7 observables x_i, for each of the N total events.

471 x 10^6 $B\bar{B}$ decays

$B^0 \to \omega\omega$ and $B^0 \to \omega\phi$: Fit Result





- $\mathcal{B}(\omega\omega) = (1.2 \pm 0.3^{+0.3}_{-0.2}) \times 10^{-6}$ (4.4σ significance)
- $\mathcal{B}(\phi\omega) < 0.7 \times 10^{-6}$ (90% CL)
- Largest systematic contributions from fit yield bias estimation (O(5 events) ≲ 10% for $\omega\omega$) and marginalizing over longitudinal vs transverse fraction (f_L = 0.88 is used as the nominal central value).

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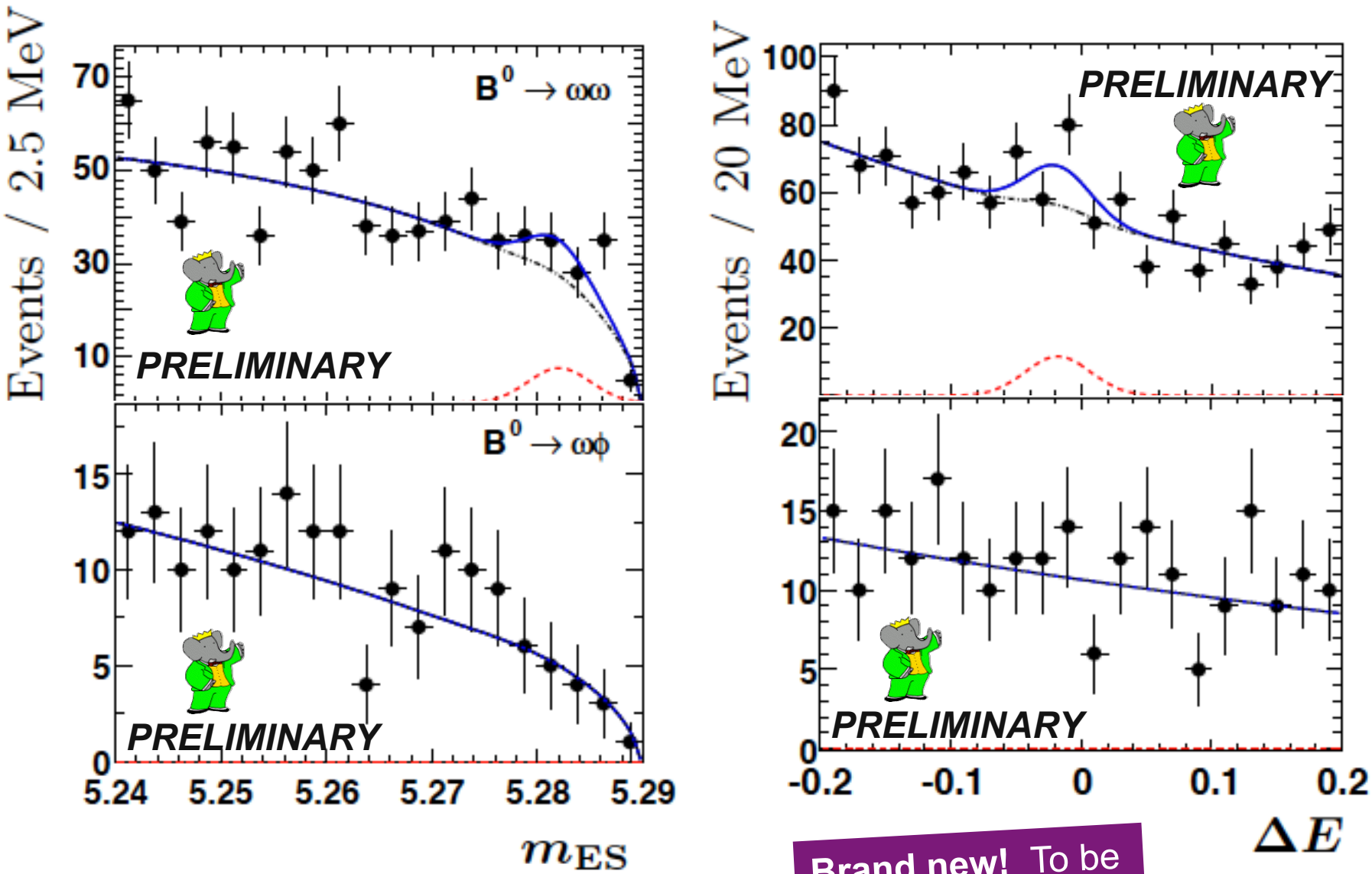
471 x 10^6 $B\bar{B}$ decays

$B^0 \to \omega\omega$ and $B^0 \to \omega\phi$: Projection Plots



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2) **Measurement of *CP* violation** in ***B*** decays to three charged kaons

arXiv:1201.5897,
PRD 85:112010 (2012)

$B \to 3K$ CPV

arXiv:1201.5897, PRD 85:112010 (2012)
471 x 10^6 *BB* decays

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

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

  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

  CP content depends on Dalitz plot/spin structure of intermediate state

- $B^+ \to K^+K^-K^+$ and $B^+ \to K_S K_S K^+$

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

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

  Large "nonresonant" contribution needs further study

  Search for direct CP violation

$B \to 3K$ CPV: Dalitz

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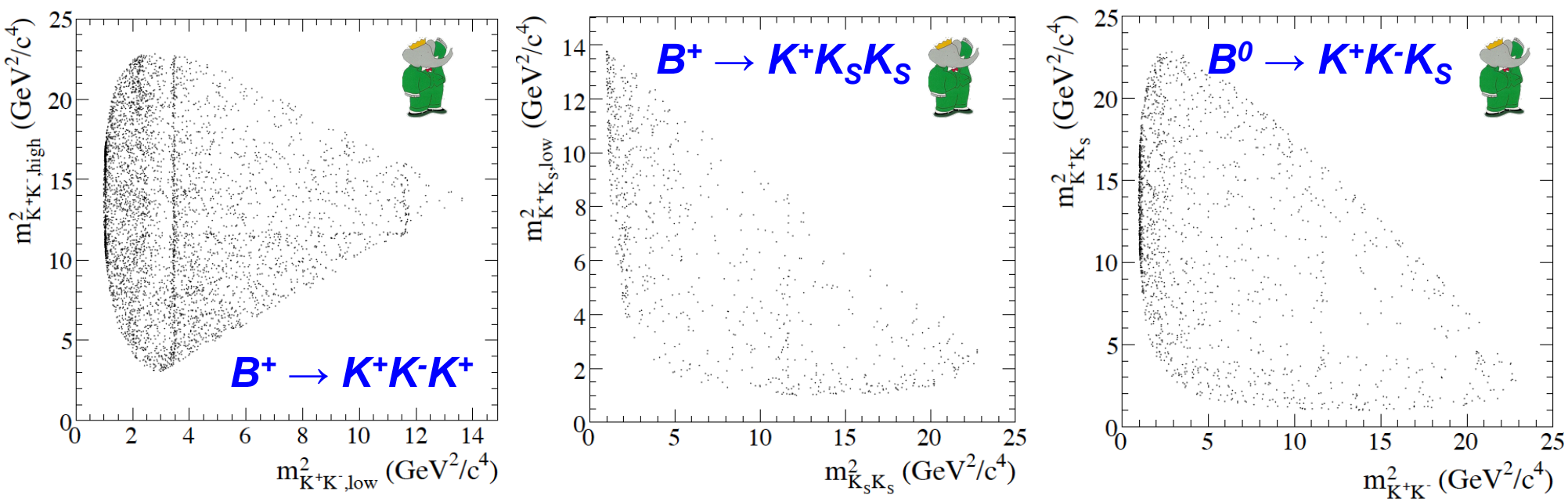
$$\mathcal{A} \equiv \mathcal{A}(B \to KKK; m_{12}, m_{23}) = \sum_j a_j F_j(m_{12}, m_{23})$$

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

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

We measure the isobar coefficients c_j.

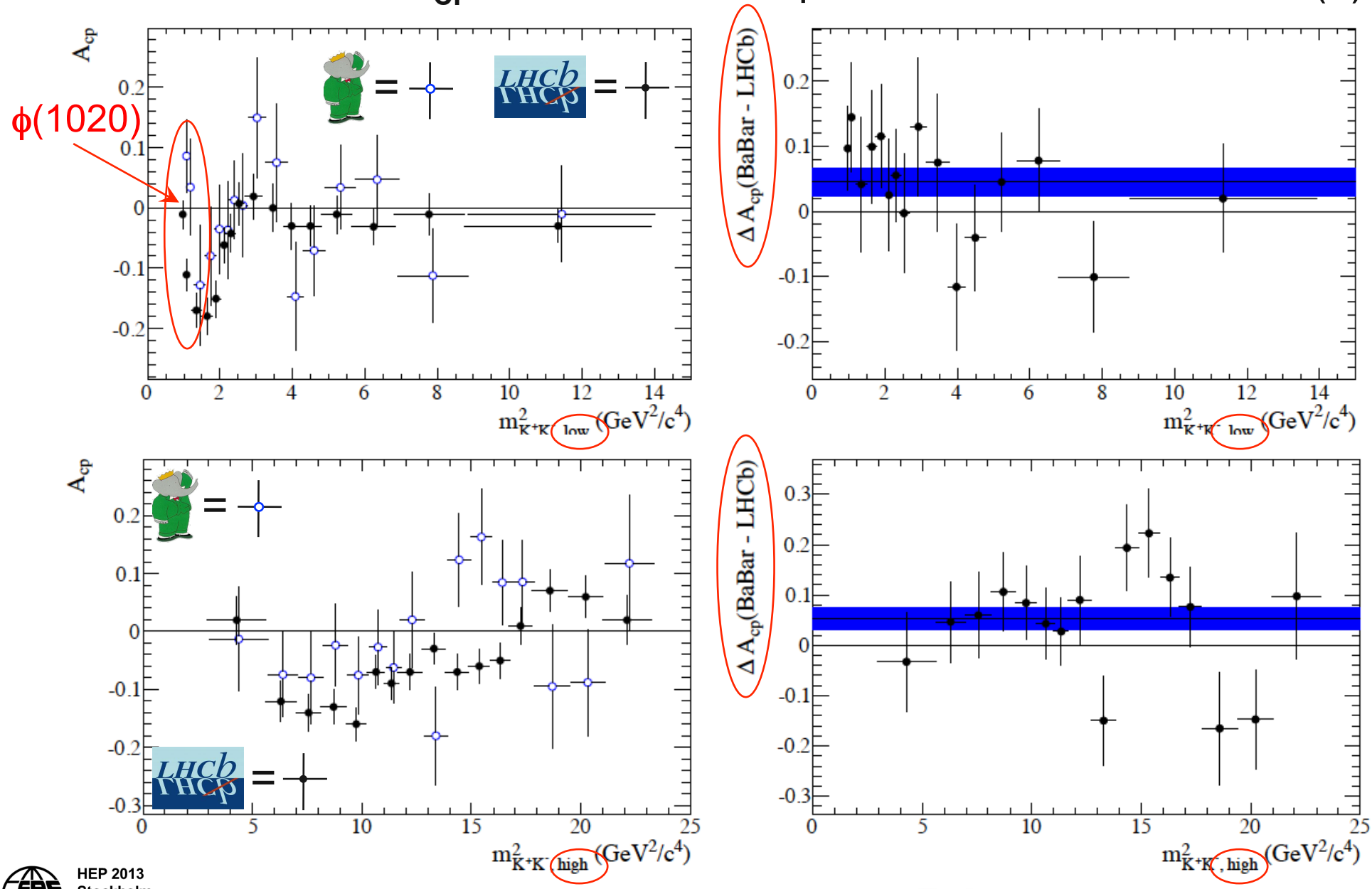
From isobar coefficients can derive: partial branching fractions, A_{CP} (= $-2b/(1+b^2)$), β_{eff} (= $\beta + \delta$), etc.



$B \rightarrow 3K$ CPV: CPV(Dalitz)

arXiv:1305.4218, SLAC-PUB-15451

Babar vs. LHC*b* A_{CP} results – similar patterns but constant offset (?):



$B \to 3K$ CPV: Summary

- Indication of direct CP violation in $B^+ \to \phi K^+$ at 2.8σ.
  - $A_{CP} = (12.8 \pm 4.4 \pm 1.3)\%$
  - SM: $(0 - 4.7)\%$

$A_{CP}(\phi K^+)$ 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

- World's most precise measurement of $\beta_{eff}(\phi K_S)$:
  - $\beta_{eff} = (21 \pm 6 \pm 2)$ degrees

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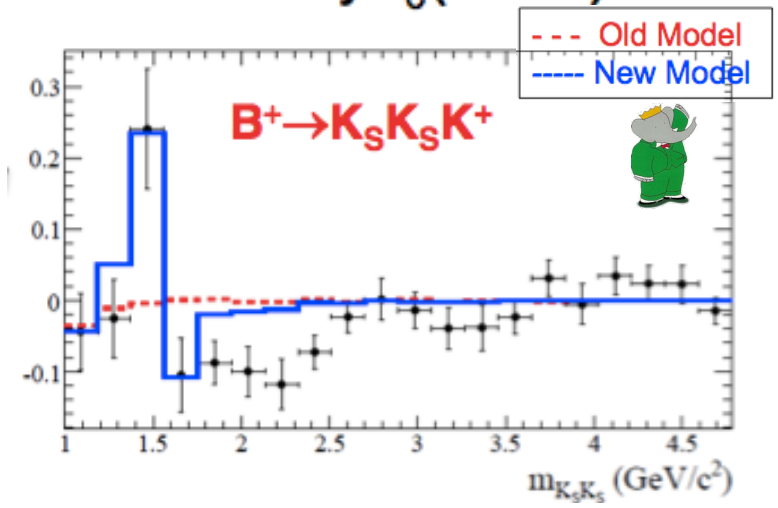
arXiv:1305.4218 (2013), SLAC-PUB-15451
471 x 10^6 *BB* decays

Good agreement with SM

Charmonium:
$\beta = 21.4 \pm 0.8$ deg

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



- Tension in A_{CP} measurements between Babar and LHC*b*; is there a nonzero offset?

Summary

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