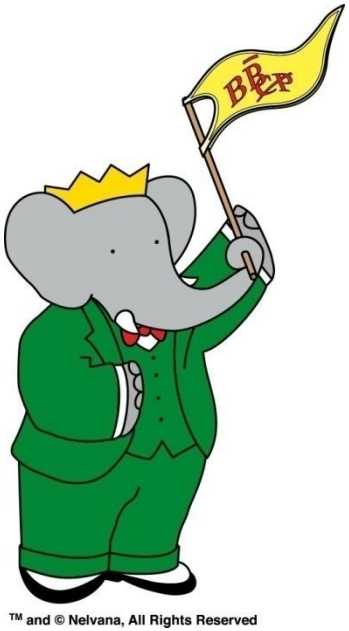
Charmless Hadronic B Decays with BaBar



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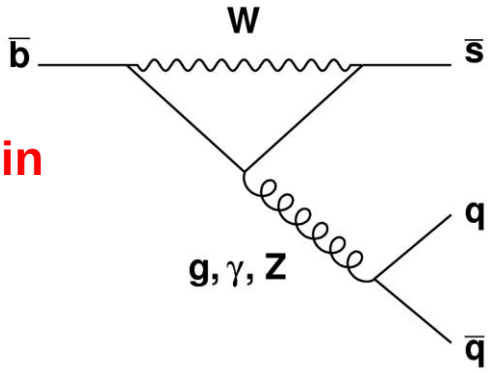
On Behalf of the BaBar Collaboration

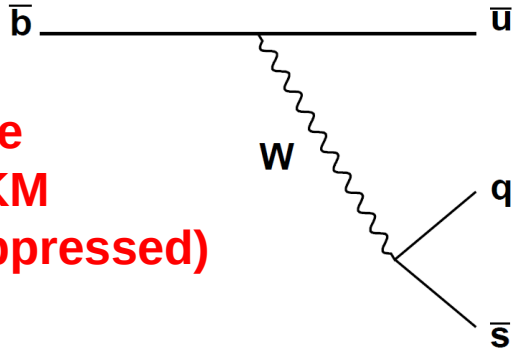
DPF 2011

Charmless B Decays

- Many such decays are dominated by b→s penguins



Penguin

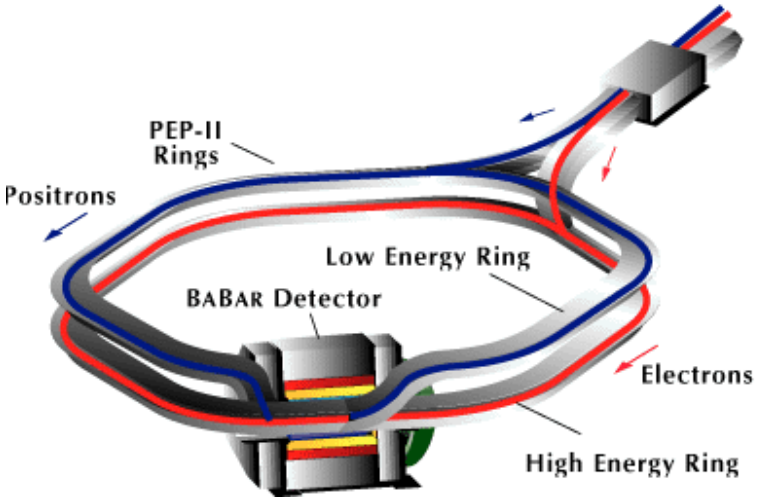


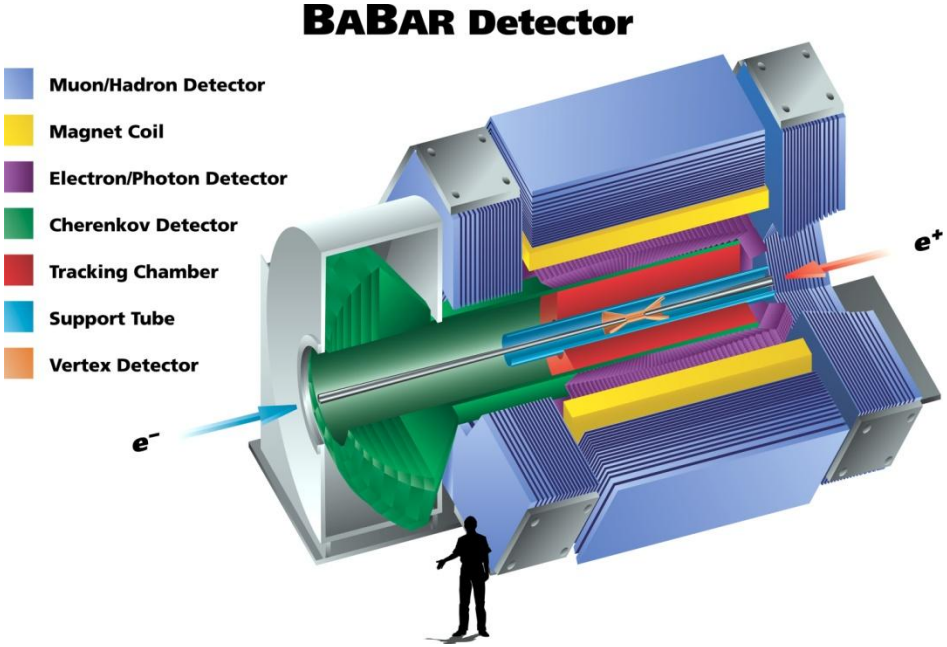
Tree (CKM suppressed)

- Tree amplitudes subdominant in SM
- New Physics can appear in loops – affecting:
  - CP-violating asymmetries (A_{CP}) in decays
  - Altered polarizations in B→VV decays (angular analysis)
  - Altered branching fractions

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



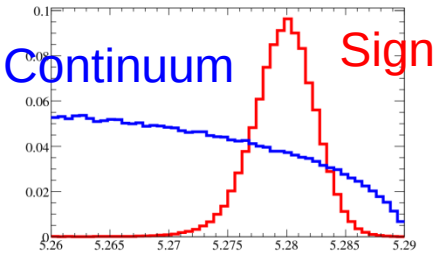


- BaBar took data from 1999-2008
- Analyses based on final dataset:
  - ~470M $B\bar{B}$ pairs

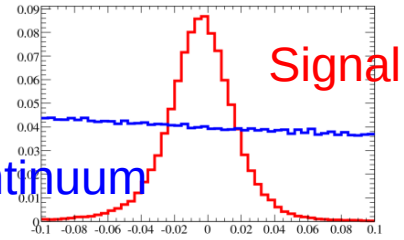
Common Analysis Techniques

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

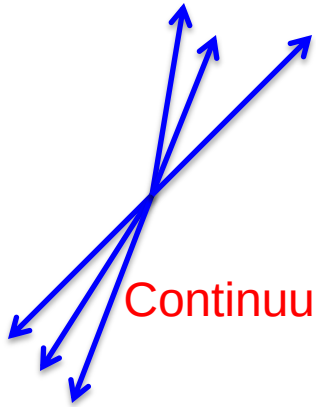
$$m_{\rm ES} = \sqrt{\frac{s}{4} - p_B^2}$$

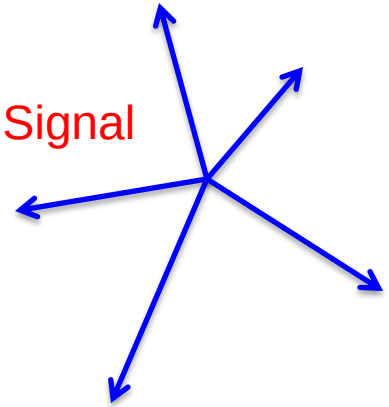


$$\Delta E = E_B - \frac{1}{2}\sqrt{s}$$



- Multivariate Fisher discriminant or 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

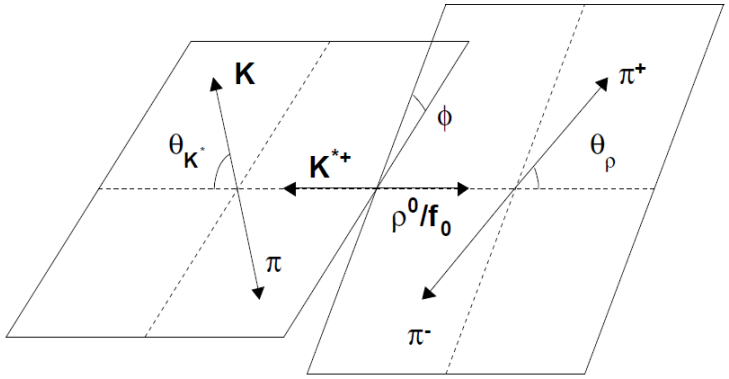
$B^+ \to \rho^0 K^{*+}$ and $B^+ \to f_0 K^{*+}$: Motivation

- Measure BF, A_{CP}, polarization
- $B^+ \to \rho^0 K^{*+}$ not yet observed

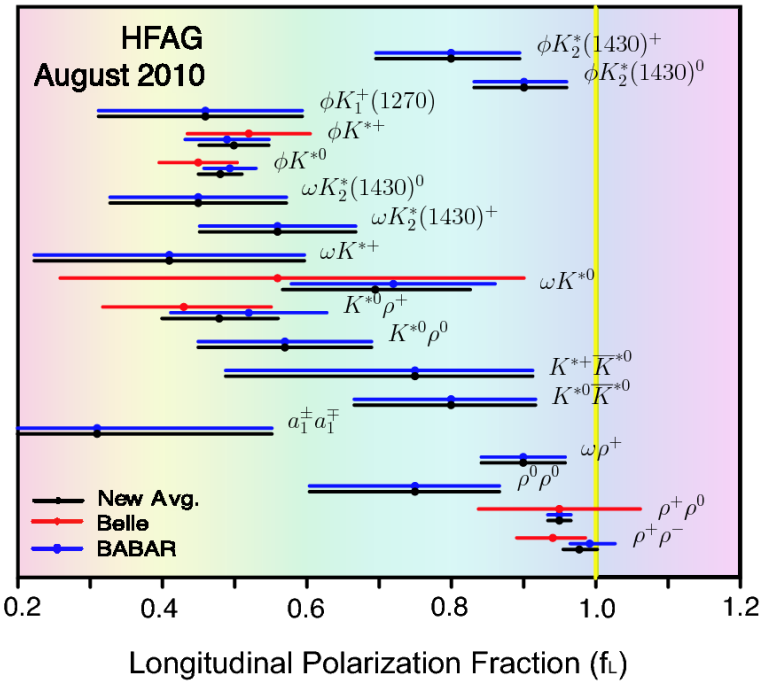
- $B^+ \to \rho^0 K^{*+}$ is VV decay, angular distribution given by

$$\frac{1 - f_L}{4} \sin^2\theta_{K^*} \sin^2\theta_\rho + f_L \cos^2\theta_{K^*} \cos^2\theta_\rho$$

- f_L: longitudinal polarization fraction
- Naïve factorization:
  - $f_L = (1 - m_V^2/m_B^2) \sim 0.9$
  - Works for $B \to \rho\rho$, not for other $B \to VV$ decays
  - "polarization puzzle" – recent work in QCDF to resolve issue



Polarizations of Charmless Decays

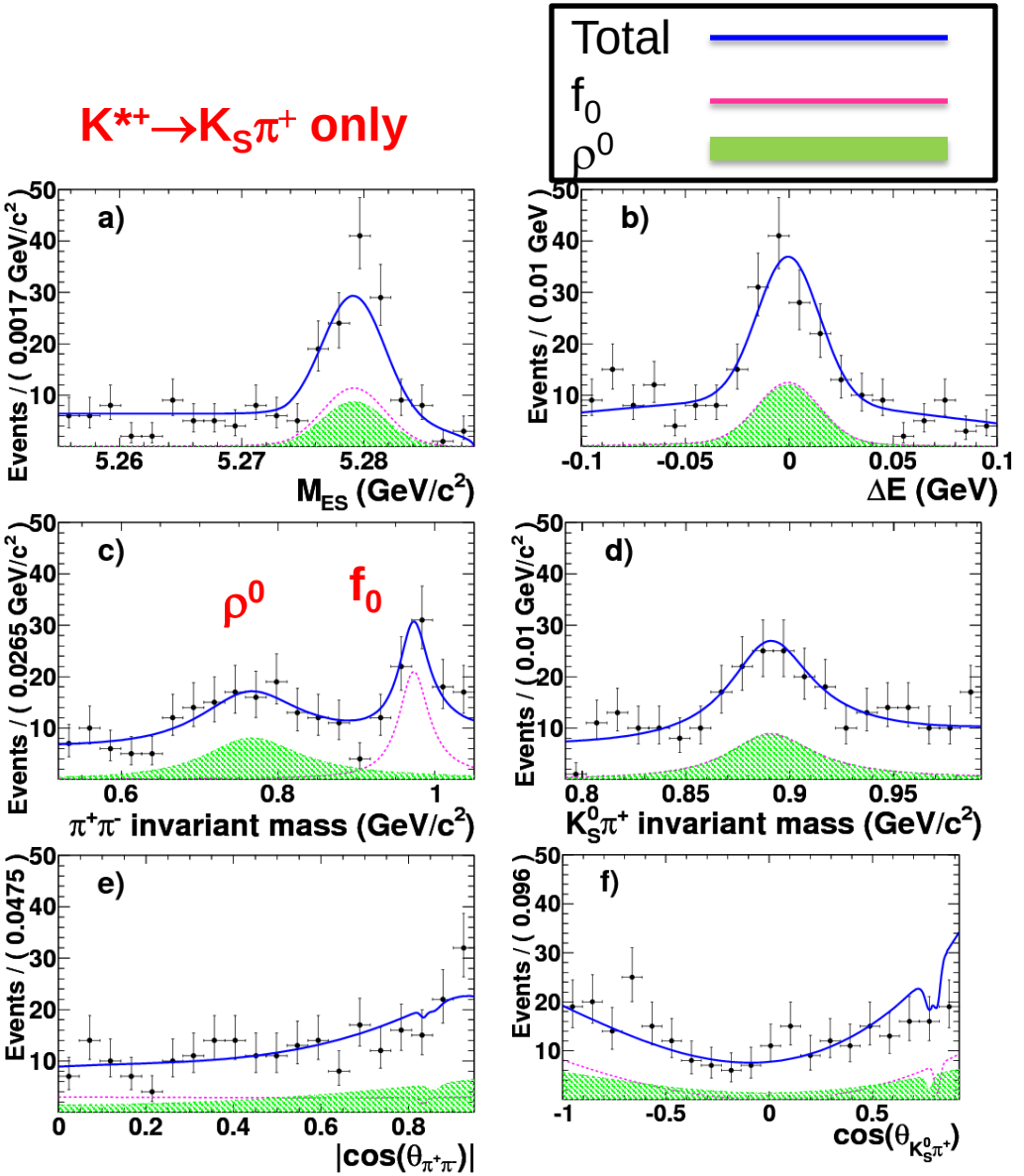


$B^+ \to \rho^0 K^{*+}$ and $B^+ \to f_0 K^{*+}$: Analysis

PRD 83 051101 (2011)

- Reconstruct $\rho/f_0 \to \pi^+\pi^-$, $K^{*+} \to K_S\pi^+$ and $K^+\pi^0$
- ML fit to 7 variables: m_{ES}, ΔE, NN, invariant masses, and cos(θ)
- Background: continuum + 9 BB categories.
- Fit simultaneously for BF's, A_{CP}'s, and f_L

$$A_{CP} = \frac{N^- - N^+}{N^- + N^+}$$



$B^+ \to \rho^0 K^{*+}$ and $B^+ \to f_0 K^{*+}$: Results

PRD 83 051101 (2011)

$B^+ \to \rho^0 K^{*+}$:

- N(Sig) = 85 ± 24 ($K_S\pi^+$) , 67 ± 31 ($K^+\pi^0$)
- BF = $(4.6 \pm 1.0 \pm 0.4) \times 10^{-6}$ consistent with prediction
  - 5.3 σ significance (incl. syst.) – first observation
- $A_{CP} = 0.31 \pm 0.13 \pm 0.03$
- $f_L = 0.78 \pm 0.12 \pm 0.03$ larger than other ρK^* modes

$B^+ \to f_0 K^{*+}$:

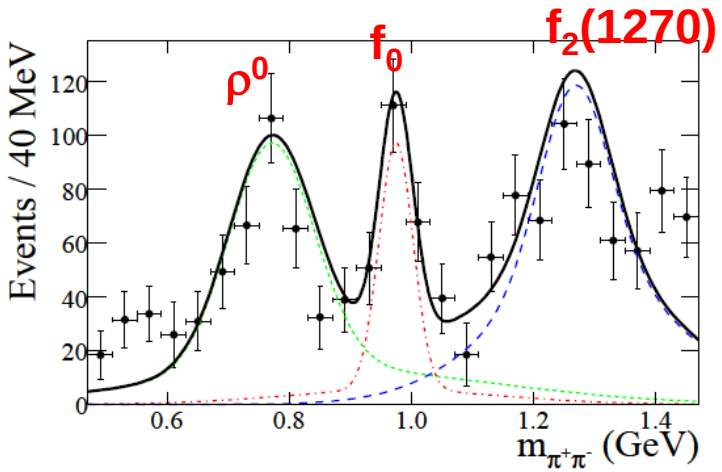
- N(Sig) = 69 ± 14 ($K_S\pi^+$) , 91 ± 20 ($K^+\pi^0$)
- BF x BF($f_0 \to \pi^+\pi^-$) = $(4.2 \pm 0.6 \pm 0.3) \times 10^{-6}$
- $A_{CP} = -0.15 \pm 0.12 \pm 0.03$

$B^0 \to (\rho^0/f_0)K^{*0}$ and $B^0 \to \rho^- K^{*+}$

Preliminary Result

New for DPF!

- Reconstruct $\rho/f_0 \to \pi\pi$, $K^{*0} \to K^+\pi^-$, $K^{*+} \to K^+\pi^0$
- ML fit to 7 variables: m_{ES}, ΔE, Fisher, invariant masses, and $\cos(\theta)$
- $f_2(1270)K^{*0}$ events extrapolated from $m_{\pi\pi}$ sideband
- Also measure scalar and tensor K* states in a "high-mass" region (not in this talk)



$B^0 \to (\rho^0/f_0)K^{*0}$ and $B^0 \to \rho^- K^{*+}$: Results

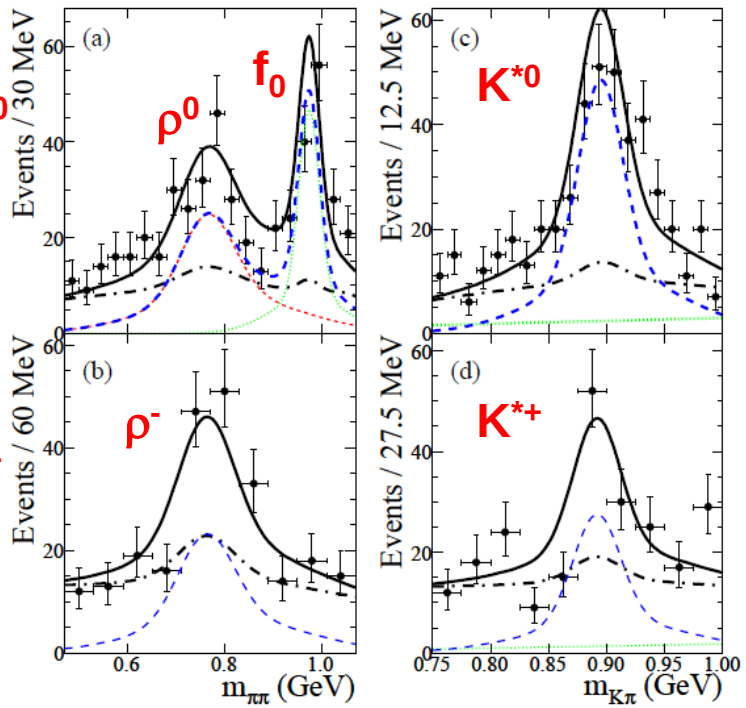
Preliminary Result

- First 5 σ observations of $B^0 \to \rho^- K^{*+}$ and $B^0 \to f_0 K^{*0}$!

$$\mathcal{B}(B^0 \to \rho^- K^{*+}) = (10.3 \pm 2.3 \pm 1.3) \times 10^{-6}$$
$$f_L(\rho^- K^{*+}) = 0.38 \pm 0.13 \pm 0.03$$
$$\mathcal{A}_{ch}(\rho^- K^{*+}) = +0.21 \pm 0.15 \pm 0.02$$

$$\mathcal{B}(B^0 \to \rho^0 K^{*0}) = (5.1 \pm 0.6^{+0.6}_{-0.8}) \times 10^{-6}$$
$$f_L(\rho^0 K^{*0}) = 0.40 \pm 0.08 \pm 0.11$$
$$\mathcal{A}_{ch}(\rho^0 K^{*0}) = -0.06 \pm 0.09 \pm 0.02$$

$$\mathcal{B}(B^0 \to f_0 K^{*0}) \times \mathcal{B}(f_0 \to \pi\pi) = (5.7 \pm 0.6 \pm 0.3) \times 10^{-6}$$
$$\mathcal{A}_{ch}(f_0 K^{*0}) = +0.07 \pm 0.10 \pm 0.02 \ .$$



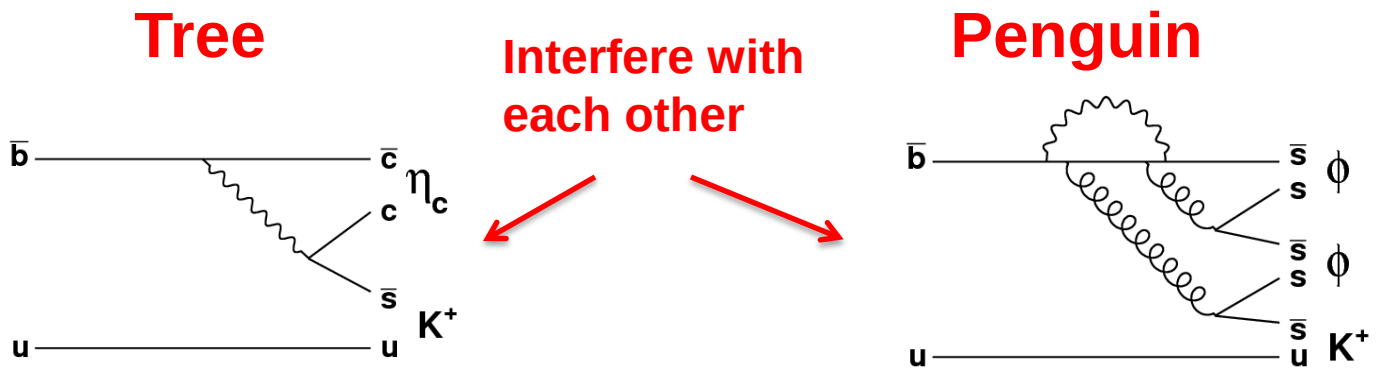
- Experiment: $f_L(\rho^- K^{*+}) \lesssim f_L(\rho^0 K^{*0}) \lesssim f_L(\rho^+ K^{*0}) < f_L(\rho^0 K^{*+})$
- QCDF: $f_L(\rho^0 K^{*0}) < f_L(\rho^+ K^{*0}) < f_L(\rho^- K^{*+}) < f_L(\rho^0 K^{*+})$

New for DPF!

More precision needed to really test Exp/Theory

$B \to \phi\phi K$: Motivation

- $B \to \phi\phi K$ and $B \to \eta_c(\to \phi\phi)K$ can interfere at $m_{\phi\phi} \sim m(\eta_c)$:



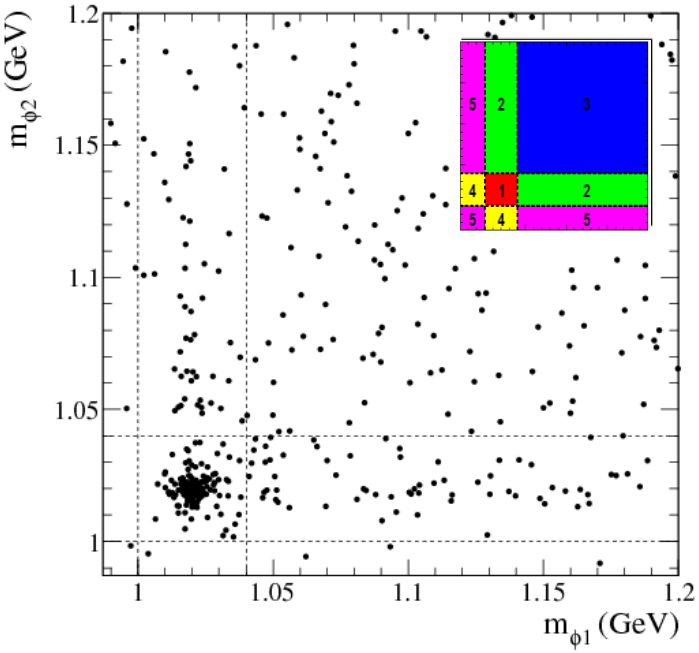
- In SM, tree and penguin carry (approx.) the same weak phase
  - No significant CP-violation in SM

- New physics in loop of penguin diagram could have different CP-violating phase
  - Large direct CP-violation possible!
    - (Hazumi, Phys. Lett. B 583, 285 (2004)).

B→ϕϕK: Backgrounds

PRD 84, 012001 (2011)

- Peaking backgrounds from B→ϕKKK, f_0KKK, and 5K
- Measured in sidebands in $m_{\phi 1}$–$m_{\phi 2}$ plane.
- Extrapolated into signal region based on MC $m_{\phi 1}$–$m_{\phi 2}$ distributions



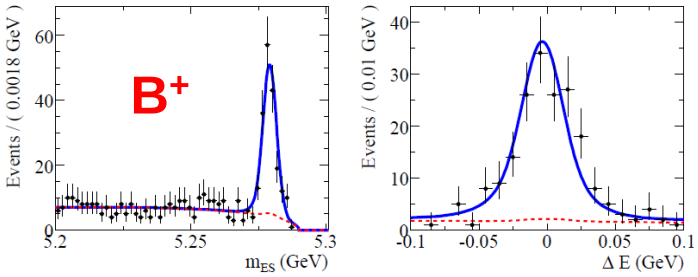
B→ϕϕK (signal)
B→ϕKKK
B→KKKKK
B→f_0ϕK
B→f_0KKK

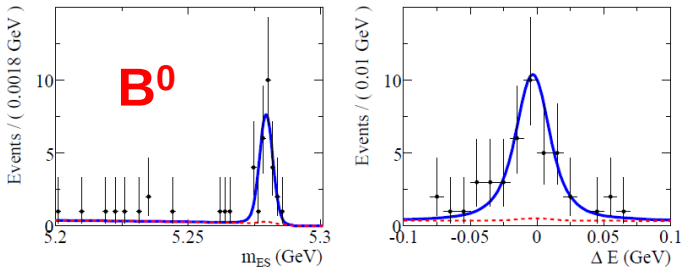
$B \to \phi\phi K$: Results

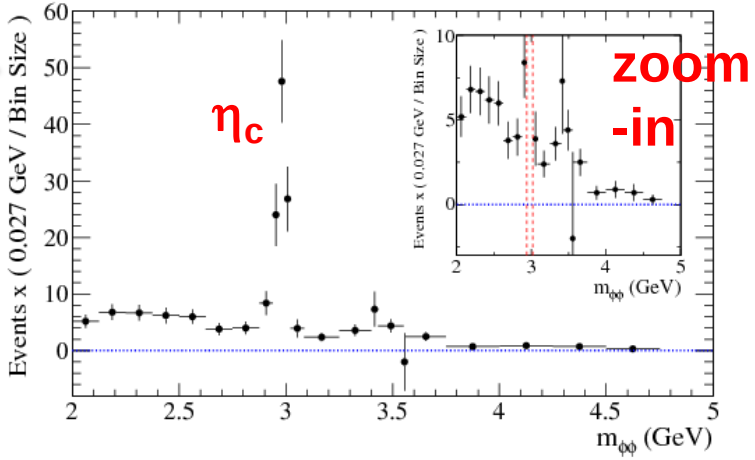
PRD 84, 012001 (2011)

- ML fit in m_{ES}, ΔE, Fisher, $m_{\phi 1}$, $m_{\phi 2}$
- For $m_{\phi\phi}$<2.85 GeV:
  - $BF(B^+ \to \phi\phi K^+) = (5.6 \pm 0.5 \pm 0.3) \times 10^{-6}$
  - $BF(B^0 \to \phi\phi K^0) = (4.5 \pm 0.8 \pm 0.3) \times 10^{-6}$
  - $A_{CP}(B^+ \to \phi\phi K^+) = -0.10 \pm 0.08 \pm 0.02$
- ML fit in bins of $m_{\phi\phi}$
- A_{CP} in η_c region ($2.94 < m_{\phi\phi} < 3.02$):
  - $A_{CP} = -0.09 \pm 0.10 \pm 0.02$

Consistent with SM







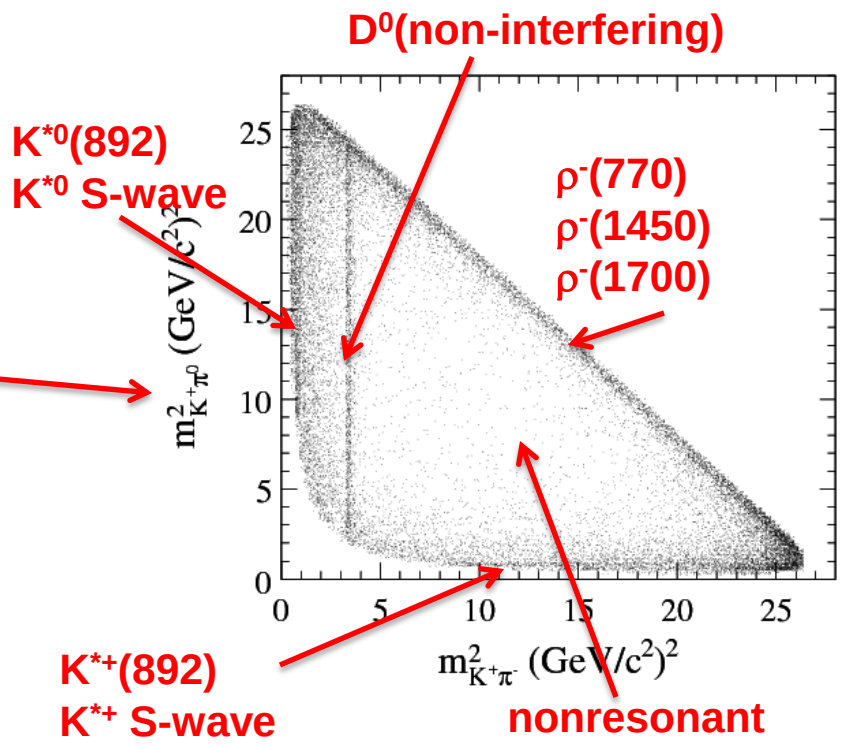
$B^0 \to K^+\pi^-\pi^0$: Motivation

- "K π puzzle"
- Naively, we expect:
  - $A_{CP}(B^0 \to K^+\pi^-) = A_{CP}(B^+ \to K^+\pi^0)$
- Experimentally, we find:
  - $A_{CP}(B^+ \to K^+\pi^0) = 0.050 \pm 0.025$
  - $A_{CP}(B^0 \to K^+\pi^-) = -0.098 \pm 0.012$

5.3 σ difference!

Color-suppressed tree, EW penguin – SM or NP?

- Is there a similar "K^* π" puzzle?
- Measure $B^0 \to K^{*+}\pi^-$
- Many resonances interfere
- Full amplitude analysis accounts for interference between resonances



$B^0 \to K^+\pi^-\pi^0$: Analysis

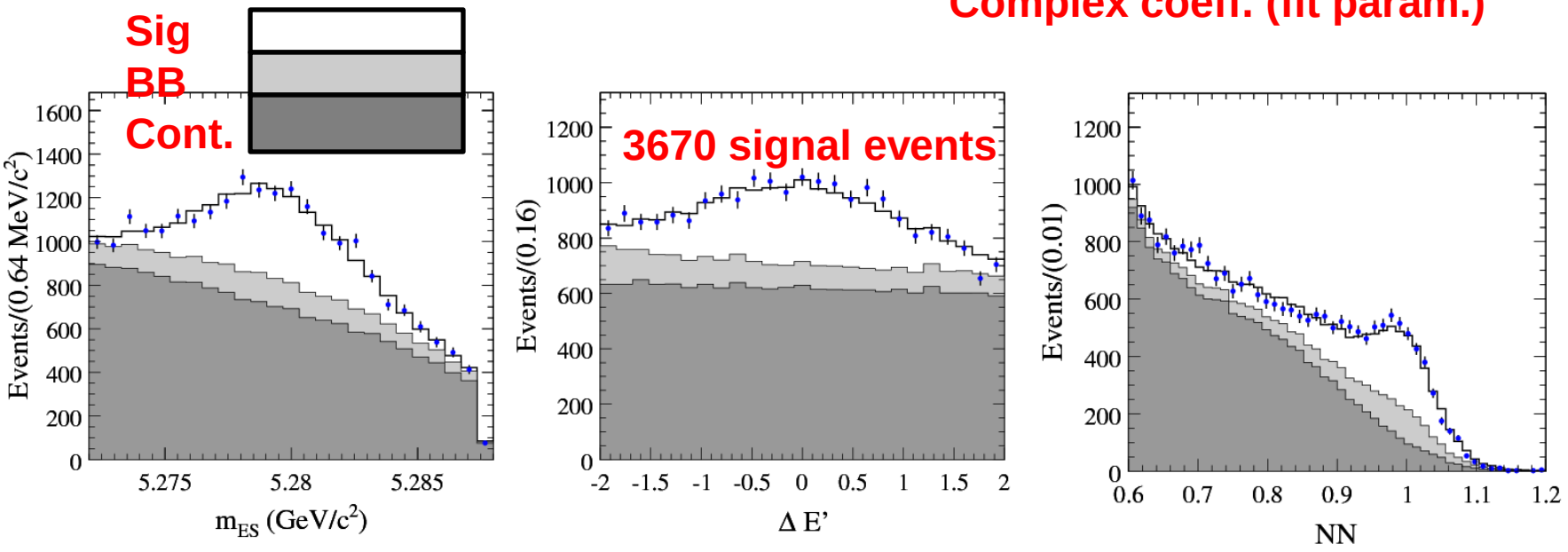
PRD 83, 112010 (2011)

- Large backgrounds: continuum + 19 BB background categories
- ~10% of signal events misreconstructed – explicitly modeled in fit
- Amplitude model with interference:

$$A(m_{K^+\pi^-}, m_{K^+\pi^0}) = \sum_{i=1}^{N} c_i F_i(m_{K^+\pi^-}, m_{K^+\pi^0})$$

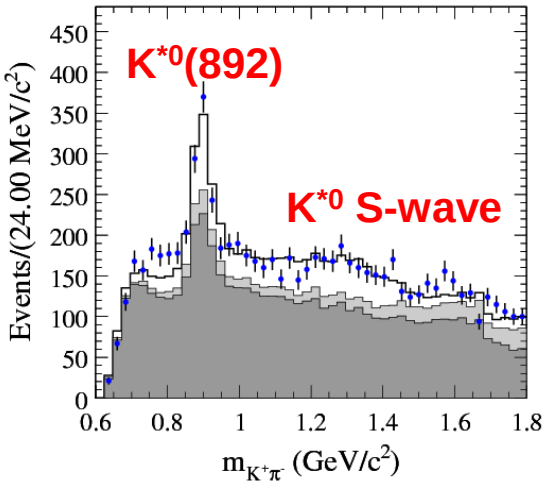
e.g. relativistic Breit-Wigner

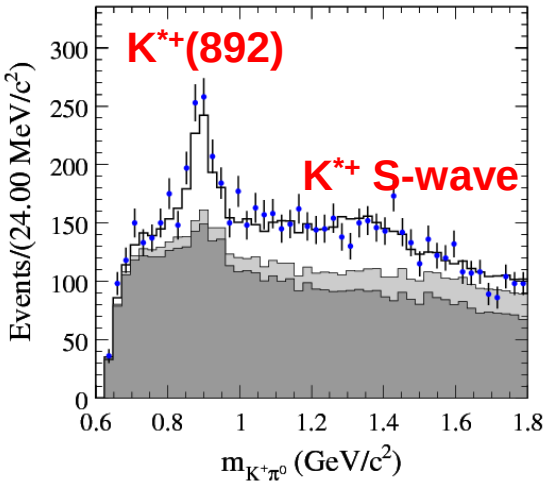
Complex coeff. (fit param.)

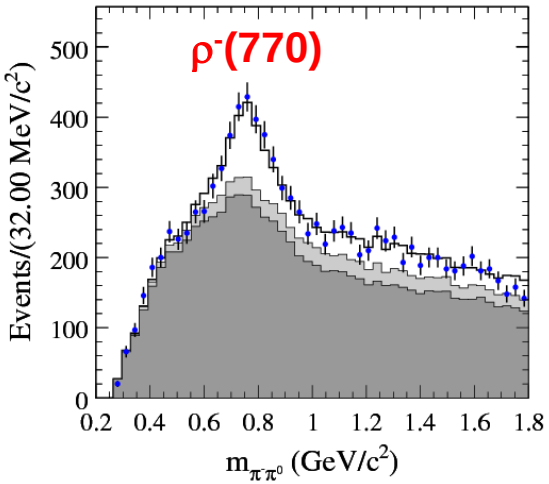


$B^0 \to K^+\pi^-\pi^0$: Results

PRD 83, 112010 (2011)

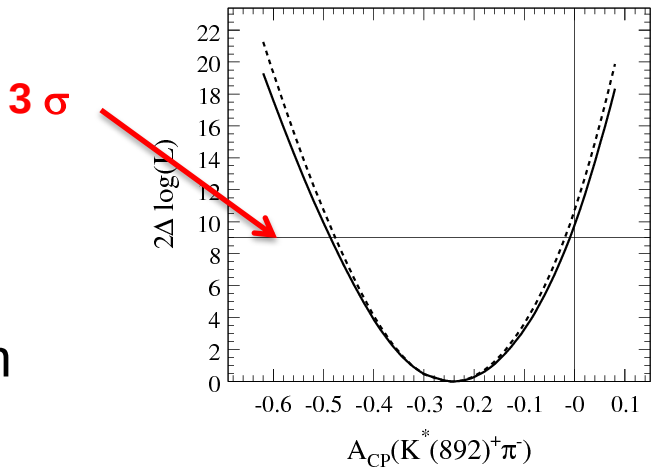






- BF($B^0 \to K^+\pi^-\pi^0$) = (38.5 ± 1.0 ± 3.9) x 10^{-6}

- $A_{CP}(K^{*+}\pi^-)$ = -0.29 ± 0.11 ± 0.02
- When combined with $B^0 \to K_S\pi^+\pi^-$:
  - $A_{CP}(K^{*+}\pi^-)$ = -0.24 ± 0.07 ± 0.02
  - 3.1 σ evidence of direct CP-violation



$B^+ \to K^+\pi^0\pi^0$: Introduction

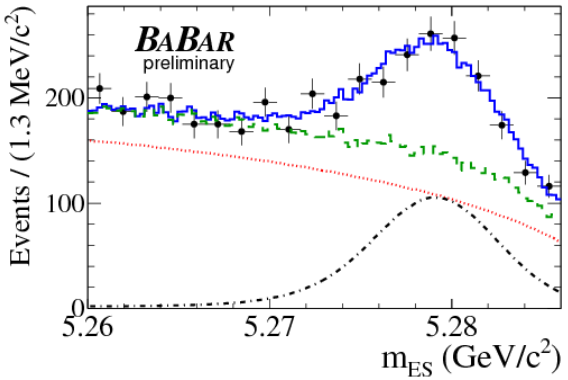
Preliminary Result

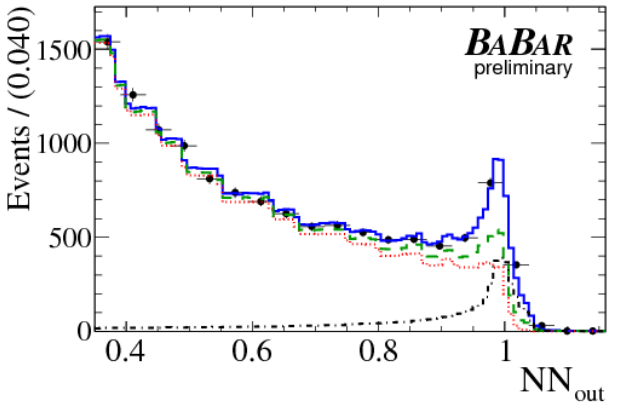
- $B^+ \to K^{*+}\pi^0$ can provide another piece to $K^*\pi$ set of measurements
- Is $A_{CP}(B^+ \to K^{*+}\pi^0) = A_{CP}(B^0 \to K^{*+}\pi^-)$?

- World's first inclusive $B^+ \to K^+\pi^0\pi^0$ measurement:
  - BF = $(16.2 \pm 1.2 \pm 1.5) \times 10^{-6}$
  - $A_{CP} = -0.06 \pm 0.06 \pm 0.04$

- Two π^0's lead to large fraction of misreconstructed events – full Dalitz plot amplitude analysis difficult
- Measure resonances in a two-body fashion

N(sig) = 1220 ± 85

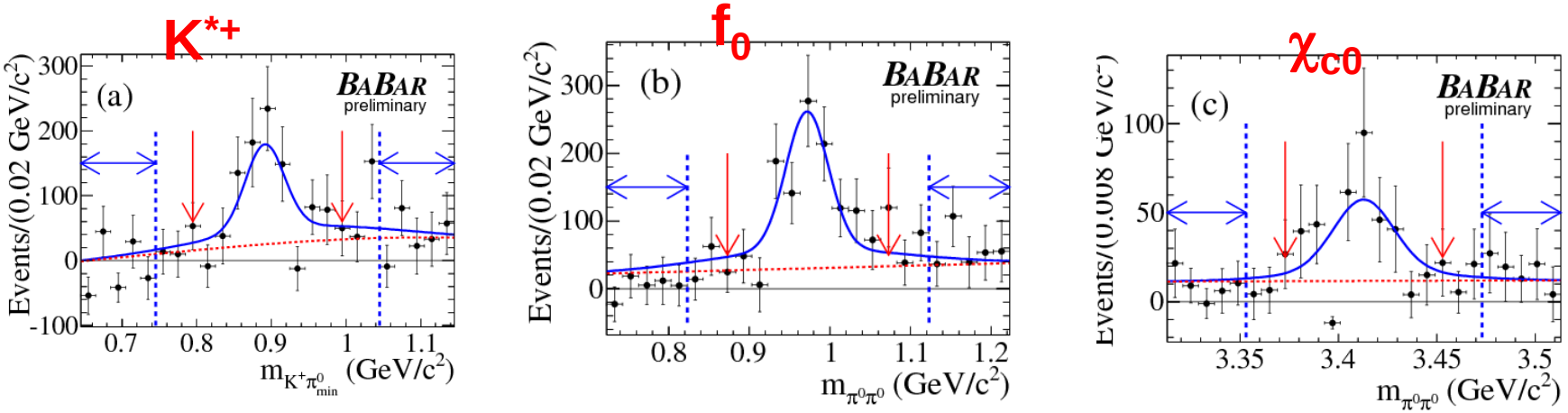




$B^+ \to K^+\pi^0\pi^0$: Resonances

Preliminary Result

Plots signal-weighted using "sPlots" method



- Measure $K^{*+}\pi^0$, f_0K^+, and $\chi_{c0}K^+$
- Contributions from nonresonant $K^+\pi^0\pi^0$ and other resonances extrapolated from $m_{\pi\pi}$ and $m_{K\pi}$ sidebands

	BF	A_{CP}
$B^+ \to K^{*+}\pi^0$	$(8.2 \pm 1.5 \pm 1.1) \times 10^{-6}$	$-0.06 \pm 0.24 \pm 0.04$
$B^+ \to f_0(\to \pi^0\pi^0)\ K^+$	$(2.79 \pm 0.57 \pm 0.51) \times 10^{-6}$	$0.18 \pm 0.18 \pm 0.04$
$B^+ \to \chi_{c0}K^+$	$(182 \pm 78 \pm 32) \times 10^{-6}$	$-0.96 \pm 0.37 \pm 0.04$

Summary

- Charmless hadronic B decays provide a wealth of measurements (A_{CP}, polarization, etc.) that are probes of new physics
- We measure:
  - Polarization f_L in $\rho^0 K^{*+}$, $\rho^- K^{*+}$, and $\rho^0 K^{*0}$
  - $A_{CP} = -0.09 \pm 0.10 \pm 0.02$ in η_c region of $\phi\phi K^+$
  - 3.1 σ evidence for direct CP-violation in $B^0 \to K^{*+}\pi^-$
  - BF's and A_{CP}'s for resonances in $B^+ \to K^+\pi^0\pi^0$
- No clear evidence for new physics, but "polarization puzzle" and "$K\pi$" puzzle need better understanding
- Many measurements remain statistically limited
- The future lies with LHCb, Belle-II, and SuperB!
  - Belle II/Super B expect ~100x statistics of present B factories