Charmless Hadronic B Decays

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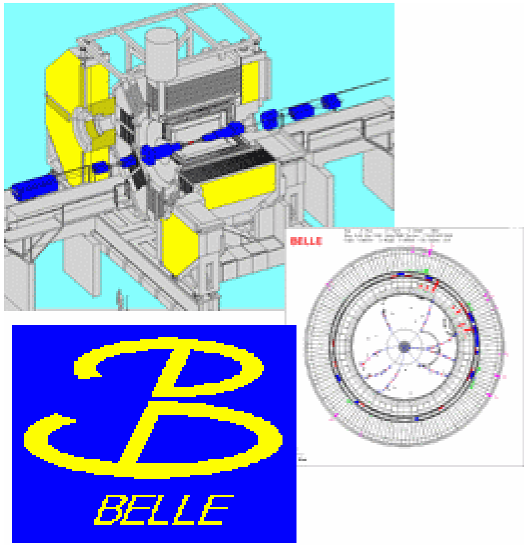
BaBar Collaboration



CKM 2010 – September 9, 2010 – Warwick, U.K.

Charmless Hadronic B Decays

- At B factories:
  - $e^+e^- \to \Upsilon(4S) \to B\bar{B}$

- Study $B \to M_1M_2$ or $M_1M_2M_3$ light mesons
  - Pseudoscalar ($J^P = 0^-$): π, η, η', K
  - Scalar ($J^P = 0^+$): $f_0, K_0^*(1430), \ldots$
  - Vector ($J^P = 1^-$): $\rho, \omega, \phi, \mathrm{K}^*(892)$
  - Axial Vector ($J^P = 1^+$): $a_1(1260), \ldots$
  - Tensor ($J^P = 2^+$): $K_2^*(1430), \ldots$
  - etc.

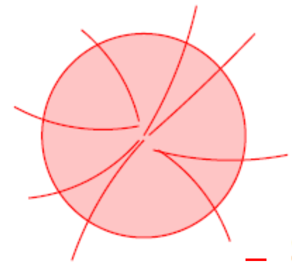
Charmless B Decays Overview

- ~ 100 charmless B decays have been measured with $> 4\sigma$ significance.
- Provides a strong test of theory, requiring calculations to accommodate $\mathcal{B}$, A_{CP}, f_L, . . . measurements.
- Theoretical description complicated due to the interplay of short- & long-distance QCD effects.
  - Quarks ≠ Hadrons.
- The heavy mass of the b quark allows SD contributions to be factored out.
  - See earlier talks (ie. G. Bell, S. Jager)
- Predictions from:
  - QCD Factorization (QCDF)
  - Perturbative QCD (pQCD)
  - Soft-Collinear Effective Theory (SCET)
  - Naïve Factorization (NF)
- Power corrections often have end-point divergences requiring model-dependent solutions & leading to large uncertainties.
- Comparing to many experimental measurements helps refine theoretical methods and may exhibit hints of physics beyond the Standard Model.

Experimental Techniques in Charmless B Decays

- Data sets $\sim 500 fb^{-1}$ $\sim 500 \times 10^6$ $B\bar{B}$ pairs
- Access branching fractions: $\mathcal{B} \sim 10^{-5} - 10^{-7}$

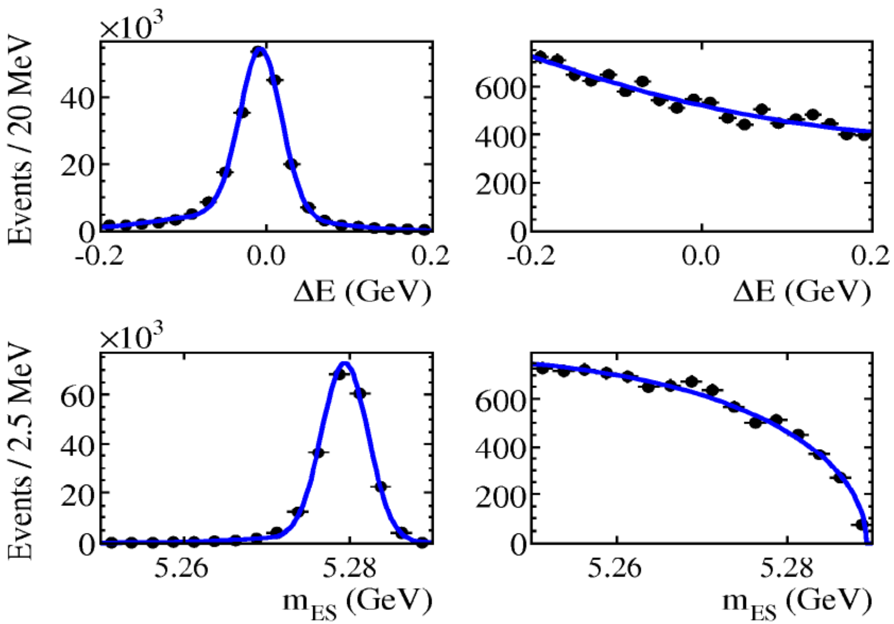
- Dominant backgrounds from $e^+e^- \to q\bar{q}$ where $q = u, d, s, c$
  - Discriminate against with event shape (Fisher, Neural Net, etc.)



- Extract signals using Maximum Likelihood (ML) Fit using several variables:
  - $\Delta E = E_{meas} - E_{beam}$ ~ 0
  - $m_{ES} = \sqrt{E_{beam}^2 - p_{meas}^2}$ $\sim m_B$
  - Event shape
  - Resonance masses & helicities

signal

- $M_{bc} = m_{ES}$ used by Belle



Experimental Results from 2010

BABAR

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- $B \to \eta'\rho, \eta' f_0$, and $\eta' K^*$, where $K^* = K^*(892)$, $K_2^*(1430)$, and $K_0^*(1430) + (K\pi)$ S−wave
- $B^+ \to a_1^+(1260)K^{*0}(892)$
- Inclusive $B^0 \to K_S^0 K^{\pm}\pi^{\mp}$
- Inclusive $B^+ \to K^+\pi^0\pi^0$

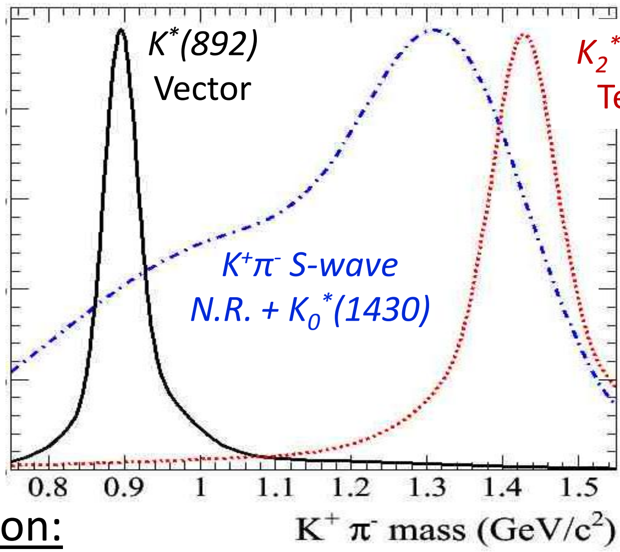
BELLE

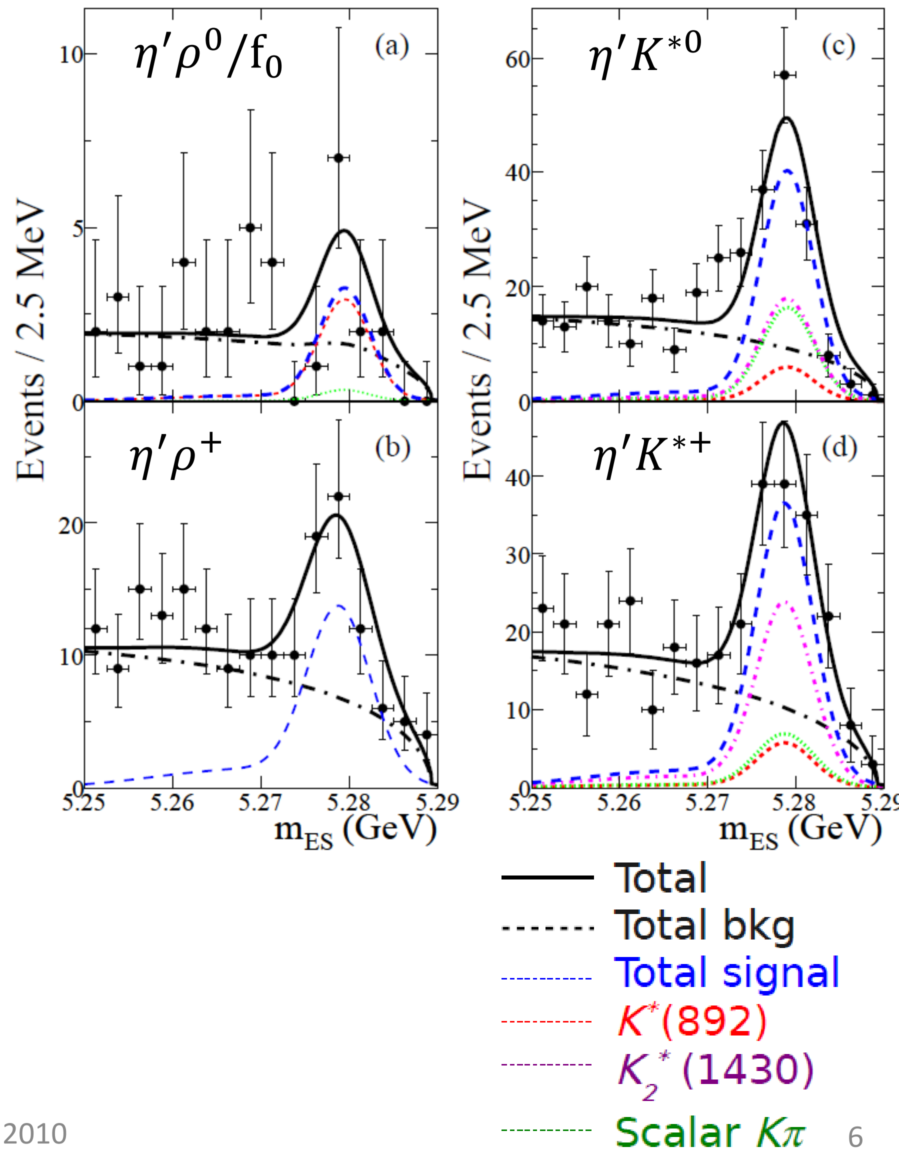
- $B^0 \to K^{*0}\overline{K^{*0}}, K^{*0}K^{*0}, K^+\pi^-K^{\mp}\pi^{\pm}$
- $B_S^0 \to hh$ $(h = K^+, K^0, \pi^+)$

B decays to $\eta'\rho$, $\eta' f_0$, and $\eta' K^*$

Data used: $424\ fb^{-1}$

arXiv:1004.0240 [hep-ex]
Phys. Rev. D82, 011502 (2010)





Motivation:

- Confirm predicted η/η' mixing
- Poor agreement between previous BaBar & Belle measurements (see next slide)
- Theoretical predictions from pQCD, QCDF, SCET, and SU(3) flavor symmetry
- Few predictions with K_0^* or K_2^*

Results:

- ML fit of 6 variables
- Simultaneously fit 3 K^* resonances and ρ^0/f_0
- Observe $> 5\sigma$ signals in 4 channels

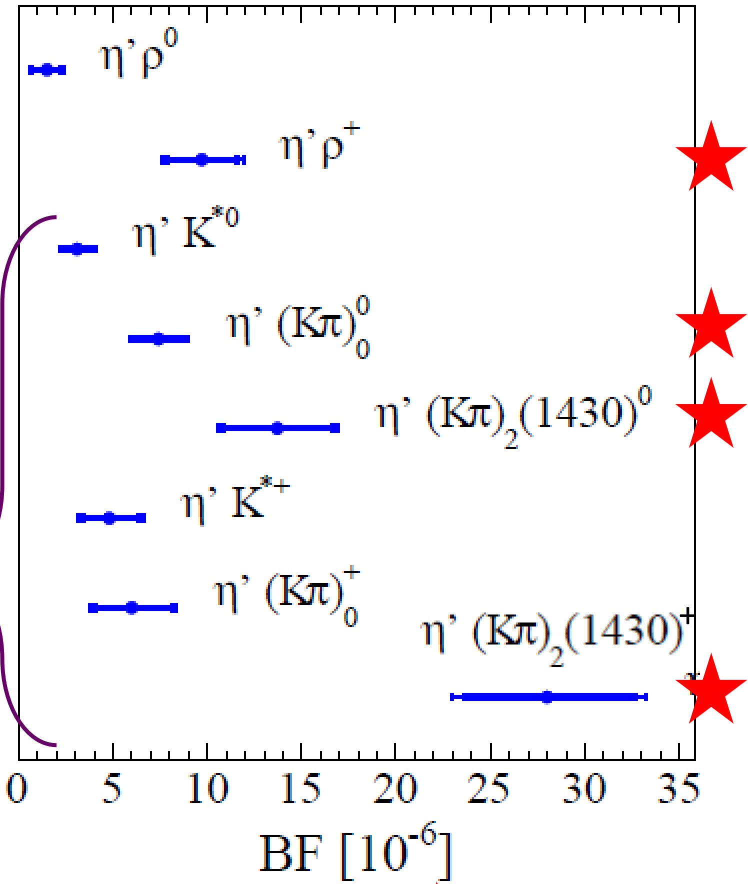
B decays to $\eta'\rho$, $\eta' f_0$, and $\eta' K^*$

Phys. Rev. D82, 011502 (2010)

Theoretical Expectations:

- $\mathfrak{B}[\eta'\rho^0] \sim 10^{-8} - 10^{-7}$
- $\mathfrak{B}[\eta'\rho^+] \sim 0.4 \times 10^{-6}$ (SCET)
  $\sim (6-9) \times 10^{-6}$ (pQCD, QCDF)
- $\mathfrak{B}[\eta' K^*] \sim \text{few} \times 10^{-6}$

Dominance of $\eta' K_2^*$ over $\eta' K^*$ not anticipated by theory. (Pattern seen in ωK^* but not ηK^*)



★ = 1st observation

Mode	BaBar			Belle*
	σ	BF(10^{-6})	UL(10^{-6})	Belle(10^{-6})
$\eta'\rho^0$	2.0	1.5 ± 0.9	< 2.8	< 1.3
★ $\eta'\rho^+$	5.8	9.7 ± 2.2	---	< 5.8
$\eta' K^*(892)^0$	4.0	3.1 ± 0.9	< 4.4	< 2.6
$\eta' K^*(892)^+$	3.8	4.8 ± 1.7	< 7.2	< 2.9

BaBar-Belle agreement remains poor
BaBar favors pQCD/QCDF over SCET

BaBar-Belle agreement shaky, but need more data

*Phys. Rev. D75, 092002 (2007); 535M $B\bar{B}$

$B^0 \to K^{*0}\overline{K^{*0}}, K^{*0}K^{*0}, K^+\pi^-K^\mp\pi^\pm$

Data used: $657\ fb^{-1}$

arXiv:1001.4595 [hep-ex]
Phys. Rev. D81, 071101 (2010)

Motivation:

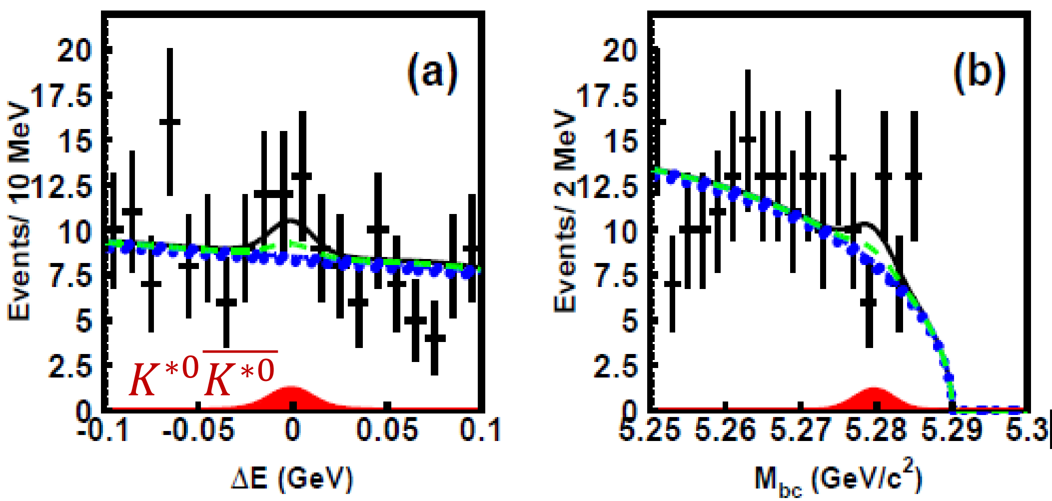
- decay dominated by $b \to d$ penguin
  - Expect $\mathrm{BF}(B^0 \to K^{*0}\overline{K^{*0}}) \sim 10^{-7} - 10^{-6}$
- If observe SM-suppressed $K^{*0}K^{*0} \to$ NP
  - Expect $\mathrm{BF}(B^0 \to K^{*0}K^{*0}) \sim 10^{-15}$
- Want to measure $K^{*0}\overline{K^{*0}}$ polarization to help understand the $B \to VV$ polarization puzzle

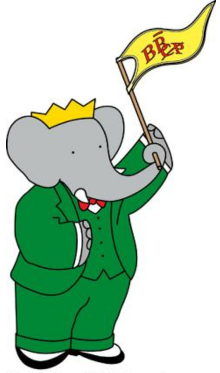
Results:

- K^{*0} is either $K^*(892)^0$ or $K_0^*(1430)^0$
- No signal observed
- Set 90% CL UL $< (0.2 - 72) \times 10^{-6}$

Mode	BaBar* BF(10^{-6})	Belle BF(10^{-6})
$K^{*0}\overline{K^{*0}}$	1.28 ± 0.34	< 0.8
$K^{*0}K^{*0}$	< 0.41	< 0.2

* Phys. Rev. Lett. 100, 081801 (2008)





Search for $B^+ \to a_1^+(1260)K^{*0}(892)$

arXiv:1007.2732v1 [hep-ex]

Data used: $424\ fb^{-1}$

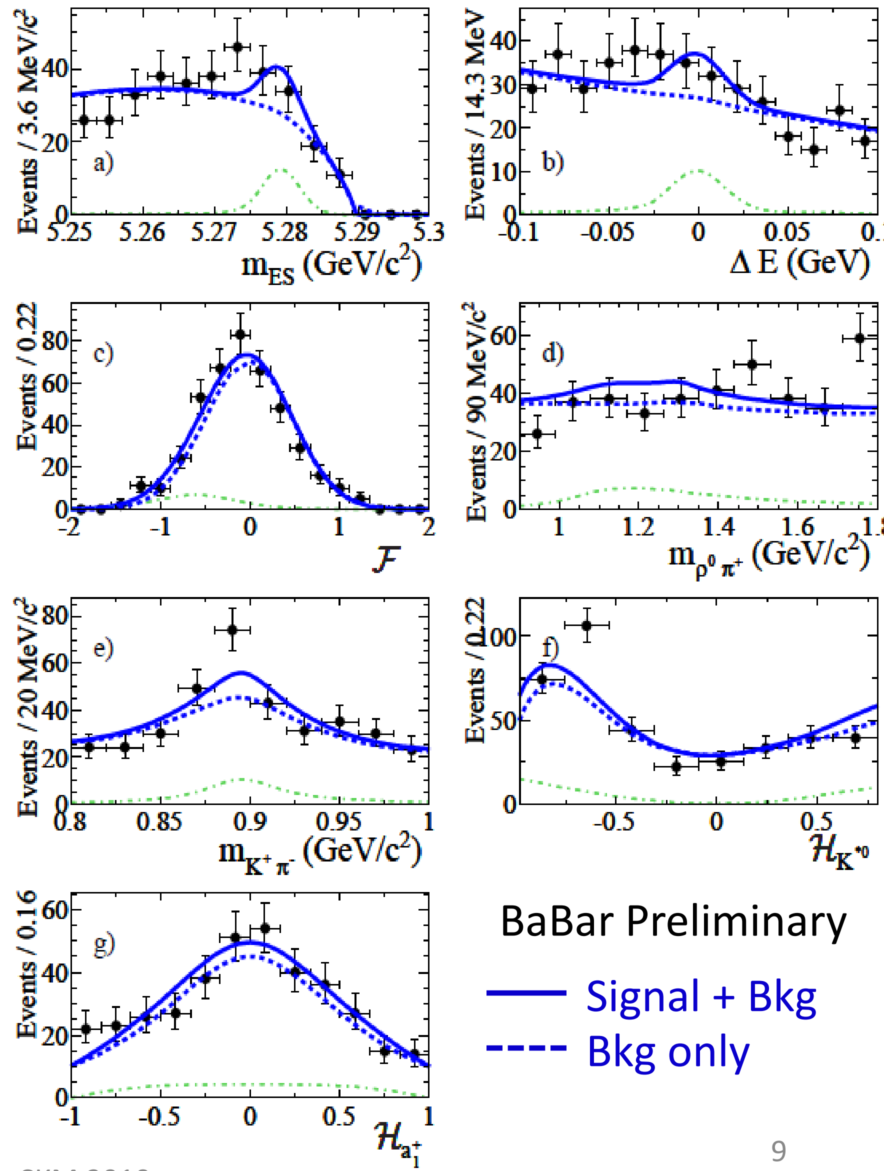
Motivation:

- Axial vector ($J^P = 1^+$) meson $a_1(1260)$
- measuring $B \to AV$ or AP will help better understand contributing amplitudes & helicity structure of charmless modes
- Predict $\mathcal{B}[B^+ \to a_1^+(1260)K^{*0}]$
  - QCDF: $(11^{+6}_{-4}\ {}^{+32}_{-9}) \times 10^{-6}$
  - NF: $\sim 0.5 \times 10^{-6}$

Results:

- ML fit with 7 variables
- No significant signal observed (0.5σ)
- Set 90% CL UL

  $\mathcal{B}[B^+ \to a_1^+ K^{*0}] < 3.6 \times 10^{-6}$
- Assumes $\mathcal{B}[a_1^+ \to \pi^+\pi^-\pi^+]$ = 50%
- Favors NF; still consistent with QCDF



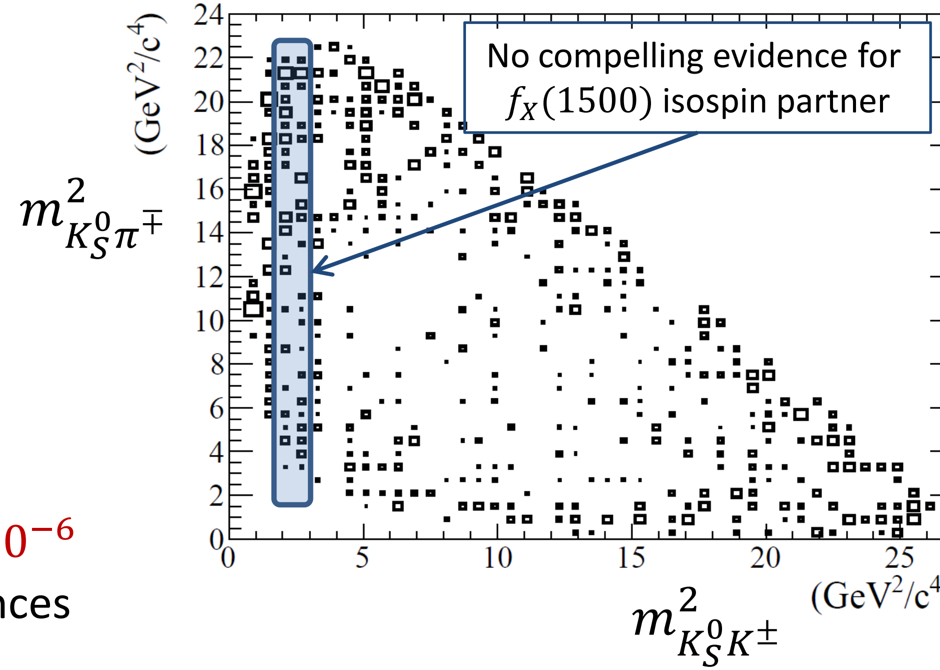
Observation of $B^0 \to K_S^0 K^\pm \pi^\mp$

arXiv:1003.0640 [hep-ex]
Phys. Rev. D 82, 031101 (2010)

Data used: $424\ fb^{-1}$

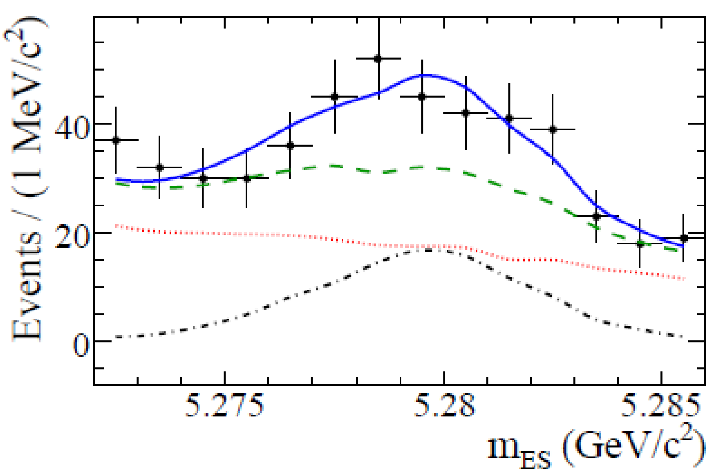
Motivation:

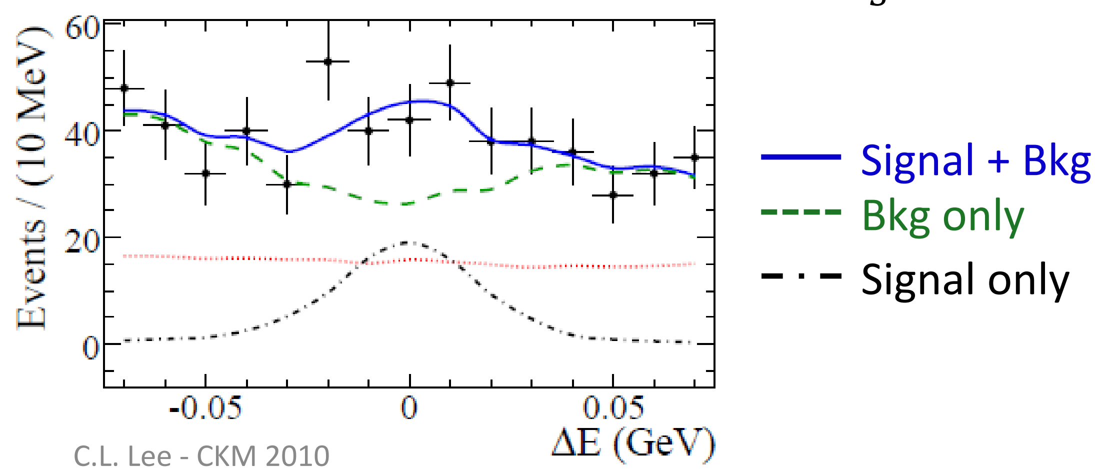
- $b \to d$ penguin (NP?) & $b \to u$ tree
- Isospin partner to $f_X(1500)$?
  - Peak in K^+K^- spectrum of $B^+ \to K^+K^-\pi^+$
  - Not observed in $B^+ \to K_S^0 K_S^0 \pi^+$



Results:

- ML fit of m_{ES}, ΔE, Fisher
- 5.2σ observation
  $\mathcal{B}[B^0 \to K_S^0 K^\pm \pi^\mp] = (3.2 \pm 0.5 \pm 0.3) \times 10^{-6}$
- $_s$Plot of DP to qualitatively look for resonances

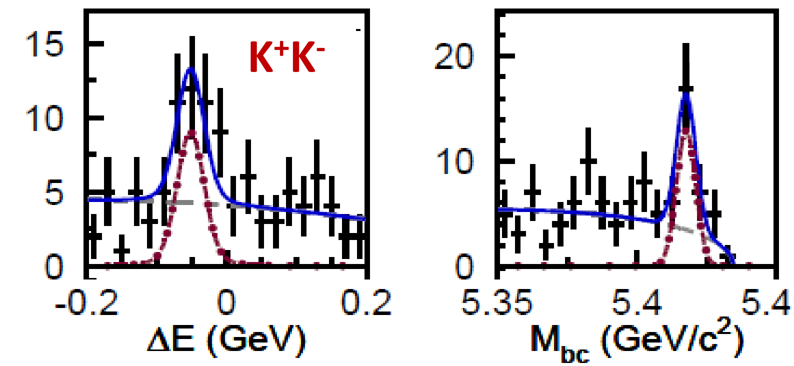




$B_S^0 \to hh\ (h = K^+, K^0, \pi^+)$

arXiv:1006.5115 [hep-ex]

Data used: 1.25M $B_S^{(*)}\bar{B}_S^{(*)}$ pairs at $Y(5S)$, 23.6 fb^{-1}



Motivation:

- Help understand the $K\pi$ Puzzle in B_d decays
- NP comparing A_{CP} in B_s and B_d decays?

Results:

- ML fit with m_{ES} & ΔE
- 5.8σ measurement of $B_S^0 \to K^+K^-$
- Compatible with CDF measurements
  - See Tuesday talk by M. Dorigo

Mode	Belle BF (10^{-6})	CDF* BF (10^{-6})
K^+K^-	38 ± 12	24 ± 5
$K^+\pi^-$	< 26	5.0 ± 1.1
$\pi^+\pi^-$	< 12	< 1.2
$K^0\,\overline{K^0}$	< 66	---

* arXiv:hep-ex/0612018 and Phys. Rev. Lett. 103, 031801 (2009)

Theory/Future Experimental Effort:

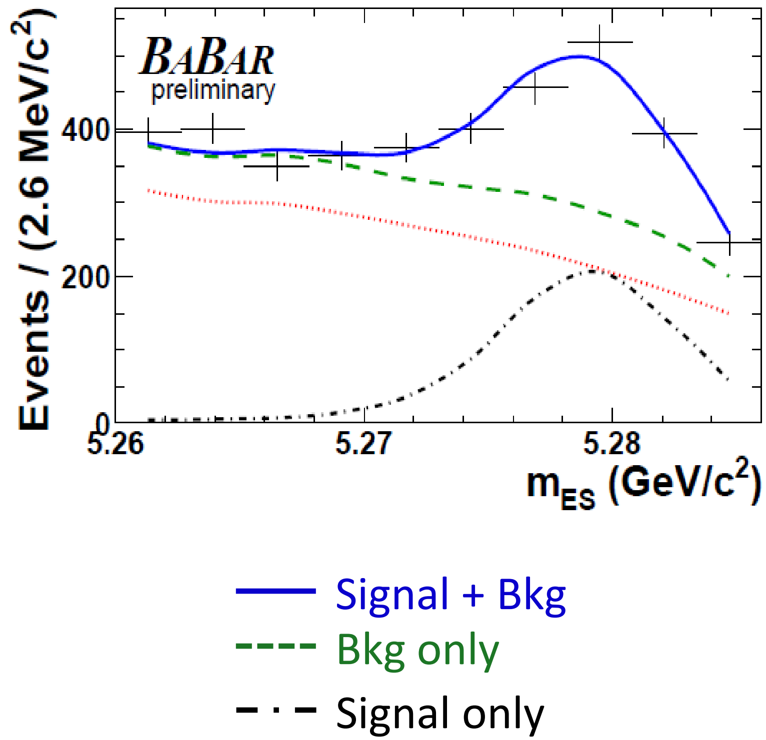
arXiv:1002.4518 [hep-ph], G. Zhu

- In QCDF, “tree” amplitude can be well estimated, but result gives too low a BF for $B_S^0 \to K^+\pi^-$.
- Could solve with larger $B_S \to K$ form factor, or if charming penguins are not small.
- To differentiate, investigate ratio: $\frac{\mathcal{B}[B_S\to\rho^+K^-]}{\mathcal{B}[B_S\to\pi^+K^-]} = 2.5 \pm 0.2$ (in QCDF)

Search for Inclusive $B^+ \to K^+\pi^0\pi^0$

Data used: $429\ fb^{-1}$

arXiv:1005.3717 [hep-ex]



Motivation:

- Understanding $K^*\pi$ may shed light on the $K\pi$ puzzle
- $B^+ \to K^{*+}\pi^0$ poorly measured; 3 body state previously not investigated
- DP studies of $K\pi\pi$ show presence of $f_X(1300)$ in $\pi^+\pi^-$. Finding it in $\pi^0\pi^0$ would suggest spin-even.
- May help interpret TD CP results in $K_S^0\pi^0\pi^0$ ($b \to s$ penguin measures β/ϕ_1)

Results:

- 2D ML fit with m_{ES} & Event Shape (NN)
  - Cut on ΔE (correlated with DP resolution)
- Observe with significance $> 10\sigma$

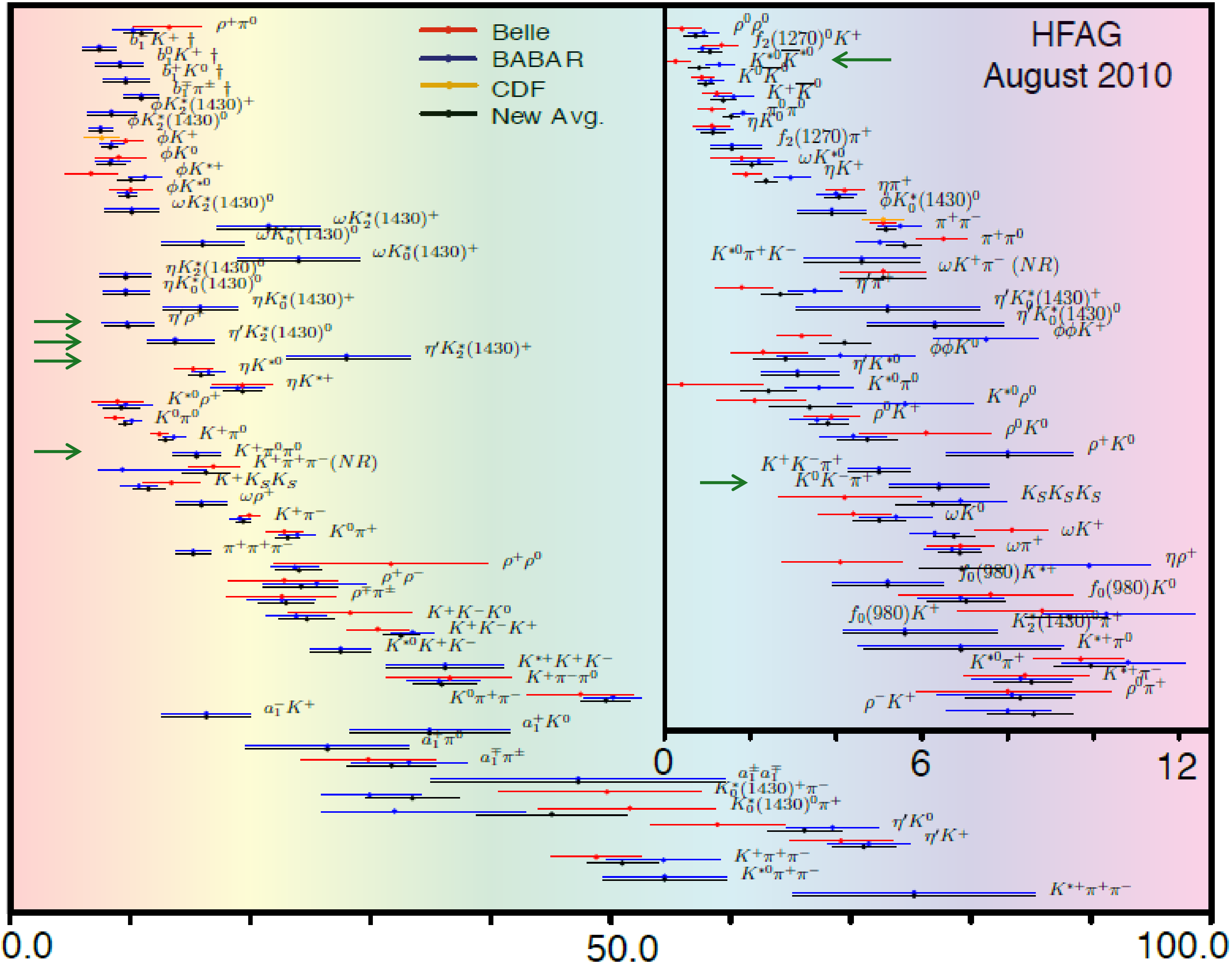
$\mathcal{B}[B^+ \to K^+\pi^0\pi^0] = (15.5 \pm 1.1 \pm 1.6) \times 10^{-6}$

Summary & Outlook

- BaBar & Belle continue to make interesting measurements of charmless hadronic B decays.
- $\mathcal{B}$, A_{CP}, and f_L measurements challenge & test theoretical methods.
- Super B factories will…
  - access SM-suppressed processes,
  - allow for more precise measurements of $\mathcal{B}$, A_{CP}, and f_L to further challenge theoretical calculations,
  - enable measurements impossible with current data sets (ie. TD analyses & full angular analyses) that give further insight into decay dynamics.

- Current measurements already map out an impressive landscape of charmless B decays…

Charmless Mesonic B Branching Fractions



→ = Result presented in this talk

Backup Slides

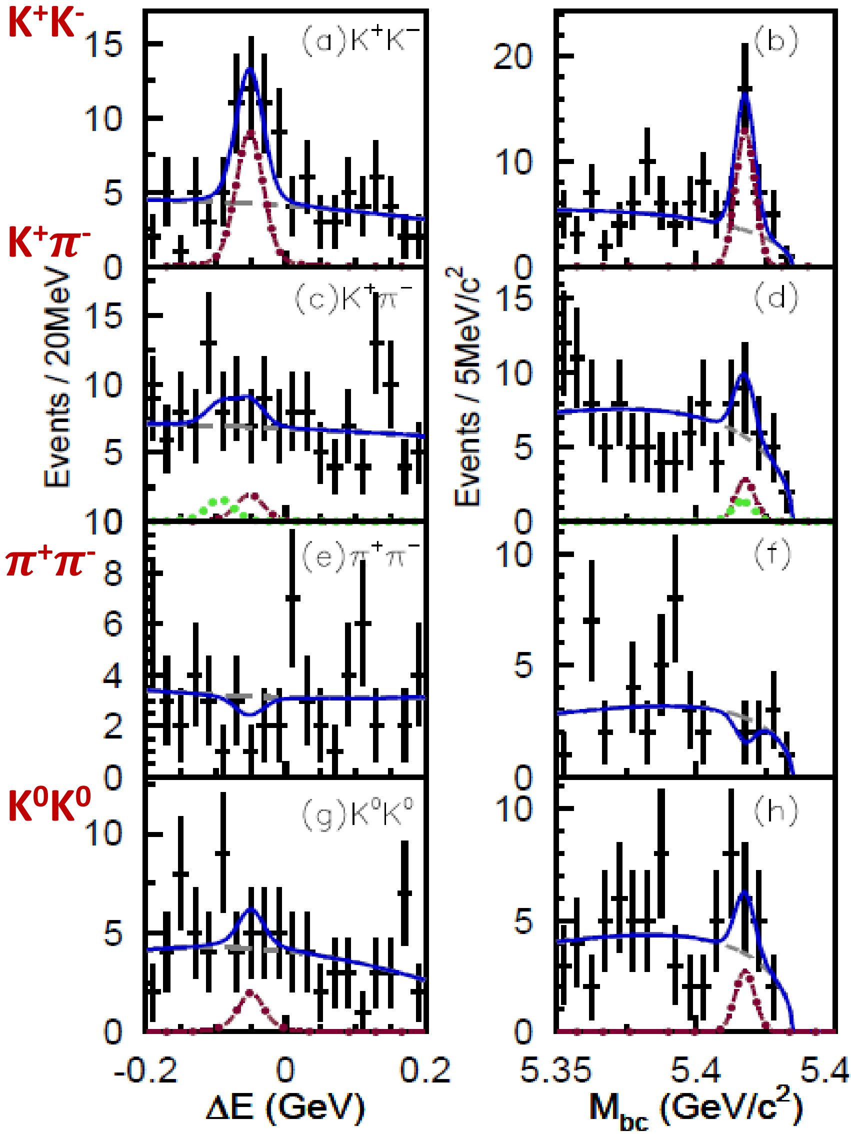
Puzzles in Charmless B Decays

- Theory & experiment are generally in good agreement.
- Some puzzles remain.
  - many were discussed in dedicated sessions at CKM 2010.
- $K\pi$ CP puzzle:
  - Naively expect A_{CP} to be equal for $B^+ \to K^+\pi^0$ and $B^0 \to K^+\pi^-$. They differ by $\sim 5\sigma$.
- Large rates for $B \to \eta' K$ but not $B \to \eta K$
  - Qualitatively understood, but predictions still not great.
- Predicted B for $B \to \pi^0\pi^0, \rho^0\pi^0$ are too small.
- Polarization puzzle:
  - Longitudinal polarization fraction (f_L) of penguin-dominated $B \to VV$ decays is smaller than naively anticipated.

$B_S^0 \to hh\ (h = K^+, K^0, \pi^+)$

arXiv:1006.5115 [hep-ex]

Data used: 1.25M $B_S^{(*)}\bar{B}_S^{(*)}$ pairs at $Y(5S)$, 23.6 fb^{-1}

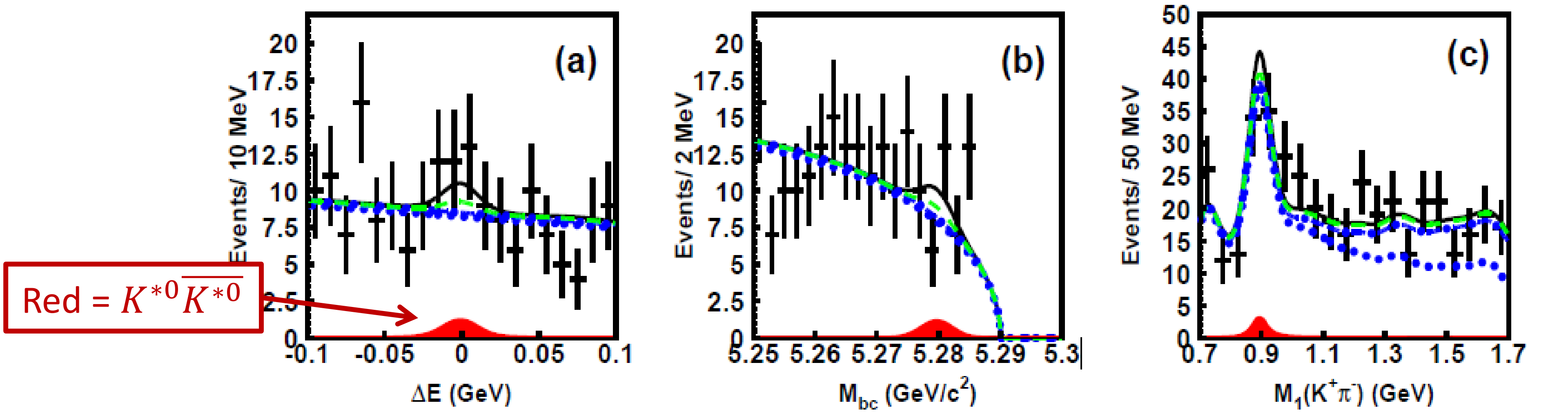


$B^0 \to K^{*0}\overline{K^{*0}}, K^{*0}K^{*0}, K^+\pi^-K^\mp\pi^\pm$

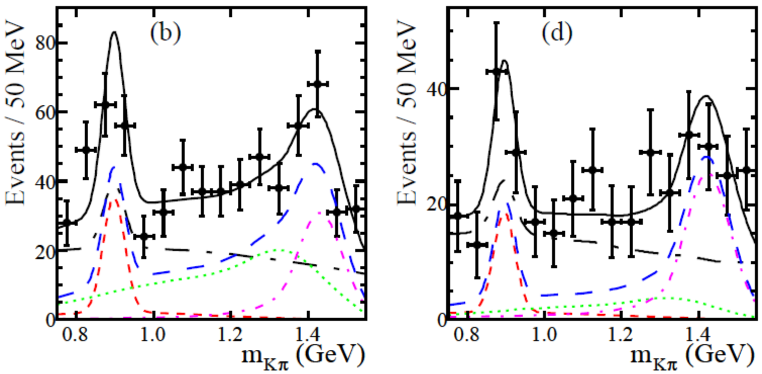
arXiv:1001.4595 [hep-ex]

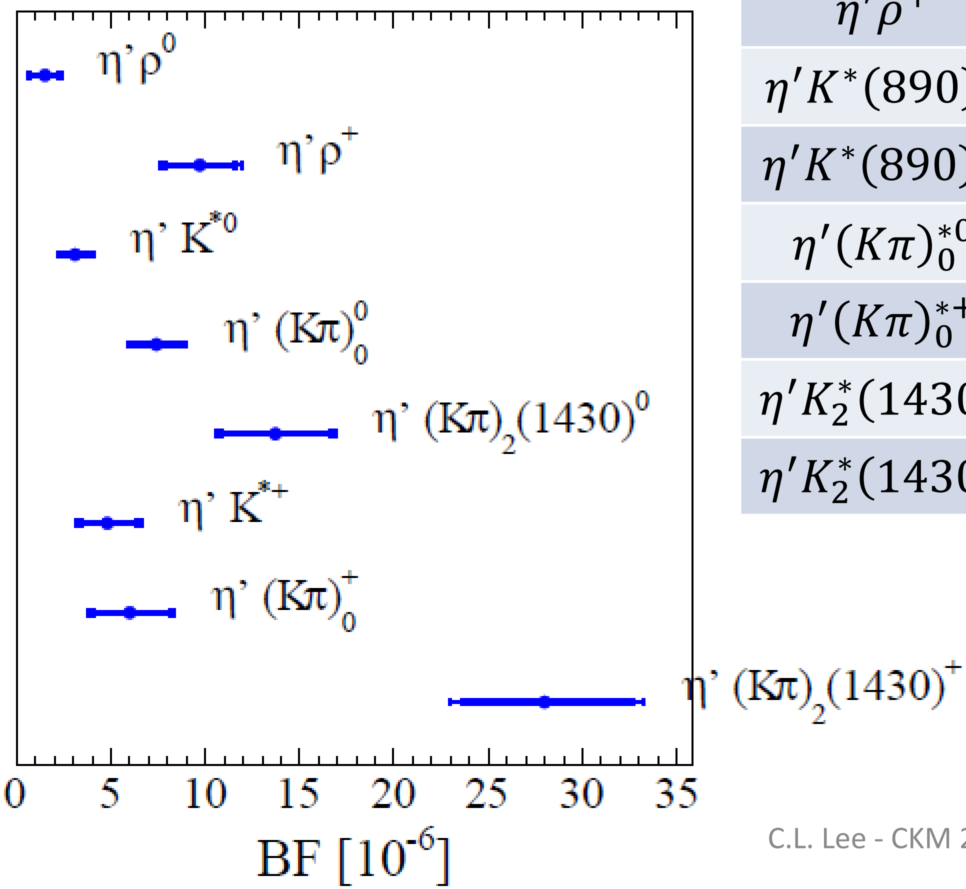
Mode	UL $\times 10^6$
$B^0 \to K^{*0}\overline{K}^{*0}$	< 0.8
$B^0 \to K^{*0}K^-\pi^+$	< 13.9
$B^0 \to K_0^*(1430)\overline{K}_0^*(1430)$	< 8.4
$B^0 \to K_0^*(1430)\overline{K}^{*0}$	< 3.3
$B^0 \to K_0^*(1430)K^-\pi^+$	< 31.8
Nonresonant $B^0 \to K^+\pi^-K^-\pi^+$	< 71.7
$B^0 \to K^{*0}K^{*0}$	< 0.2
$B^0 \to K^{*0}K^+\pi^-$	< 7.6
$B^0 \to K_0^*(1430)K_0^*(1430)$	< 4.7
$B^0 \to K_0^*(1430)K^{*0}$	< 1.7
Nonresonant $B^0 \to K^+\pi^-K^+\pi^-$	< 6.0

E_{56}^5



B decays to $\eta'\rho$, $\eta' f_0$, and $\eta' K^*$





Mode	σ	BF(10^{-6})	UL(10^{-6})	Belle(10^{-6})
$\eta'\rho^0$	2.0	1.5 ± 0.9	< 2.8	< 1.3
$\eta' f_0$	0.5	0.2 ± 0.4	< 0.9	---
$\eta'\rho^+$	5.8	9.7 ± 2.2	---	< 5.8
$\eta' K^*(890)^0$	4.0	3.1 ± 0.9	< 4.4	< 2.6
$\eta' K^*(890)^+$	3.8	4.8 ± 1.7	< 7.2	< 2.9
$\eta'(K\pi)_0^{*0}$	5.6	7.4 ± 1.6	---	---
$\eta'(K\pi)_0^{*+}$	2.9	6.0 ± 2.3	< 9.3	---
$\eta' K_2^*(1430)^0$	5.3	13.7 ± 3.2	---	---
$\eta' K_2^*(1430)^+$	7.2	28.0 ± 5.2	---	---

B decays to $\eta'\rho$, $\eta' f_0$, and $\eta' K^*$

Mode	σ	BF(10^{-6})	UL(10^{-6})
$\eta' f_0$	0.5	0.2 ± 0.4	< 0.9
★ $\eta'(K\pi)_0^{*0}$	5.6	7.4 ± 1.6	---
$\eta'(K\pi)_0^{*+}$	2.9	6.0 ± 2.3	< 9.3
★ $\eta' K_2^*(1430)^0$	5.3	13.7 ± 3.2	---
★ $\eta' K_2^*(1430)^+$	7.2	28.0 ± 5.2	---

★ = 1st observation

Dominance of $\eta' K_2^*$ over $\eta' K^*$ not anticipated by theory. (Pattern seen in ωK^* but not ηK^*)