B decays from Belle & BaBar

Youngjoon Kwon
Yonsei Univ./Belle

Outline

- *B* decays, general
- charmless hadronic decays
  - Inclusive $B \to X_s \eta$ and exclusive $B \to X \eta'$ decays
  - $B \to$ V V polarization puzzle
- Baryonic decays
  - multi-body hierarchy & near-threshold enhancement
  - $B^+ \to p\bar{\Lambda}\pi^+\pi^-$ and $B^0 \to p\bar{\Lambda}\pi^-$

What can we do with B?

- CP violation — T. Hara (4/22)
  - KM mechanism explains CP violation w/in SM

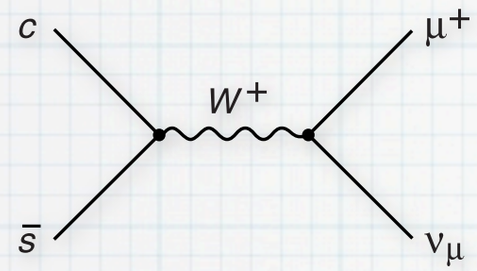
  --> *Test the internal consistency of the KM mechanism in the CKM U.T.*

- Search for rare/forbidden decays
  - for a precision test of the SM; and
  - *indirect search for PBSM*

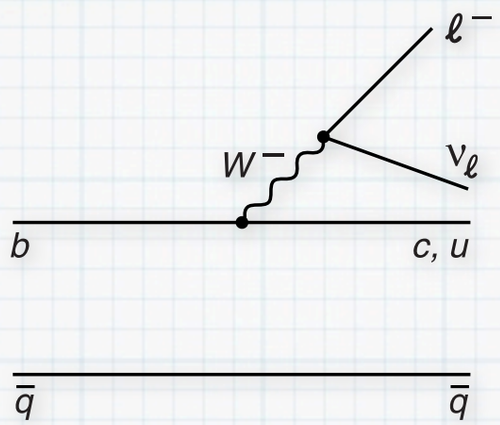
  } in this talk, partly

- study heavy-flavor dynamics
- look for exotic particles — A. Kuzmin (4/20)

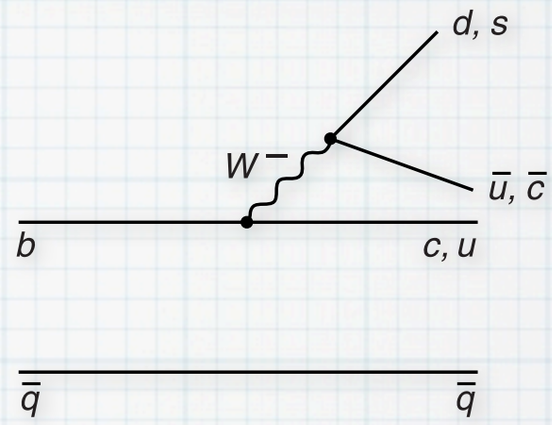
B decays in the SM



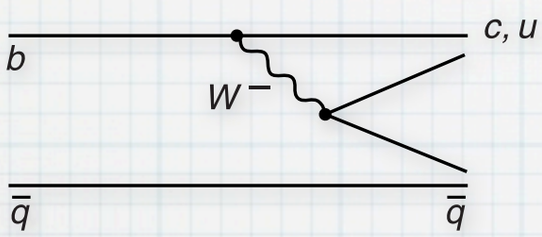
(a) Leptonic



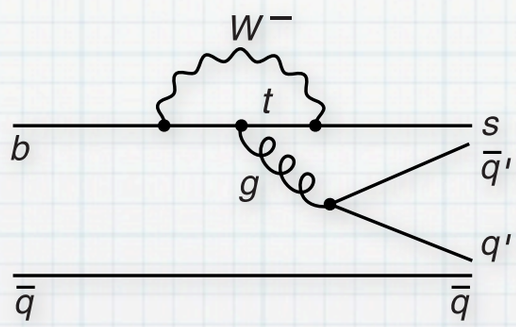
(b) Semileptonic



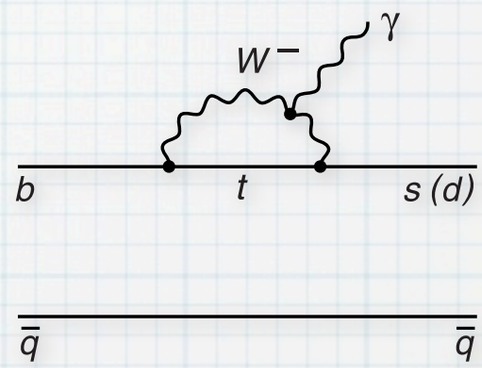
(c) Hadronic



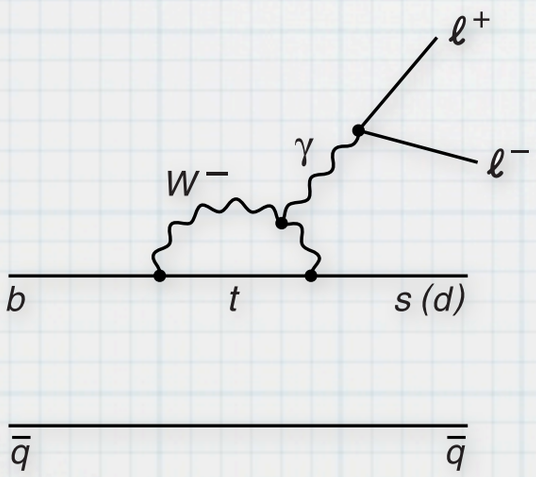
(d) Hadronic



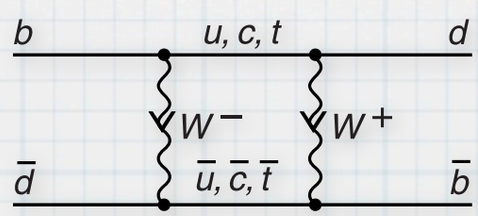
(e) Gluonic penguin

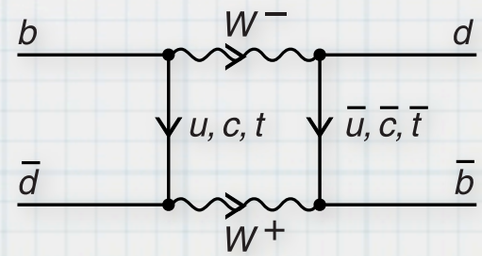


(f) EM penguin



(g) EM penguin



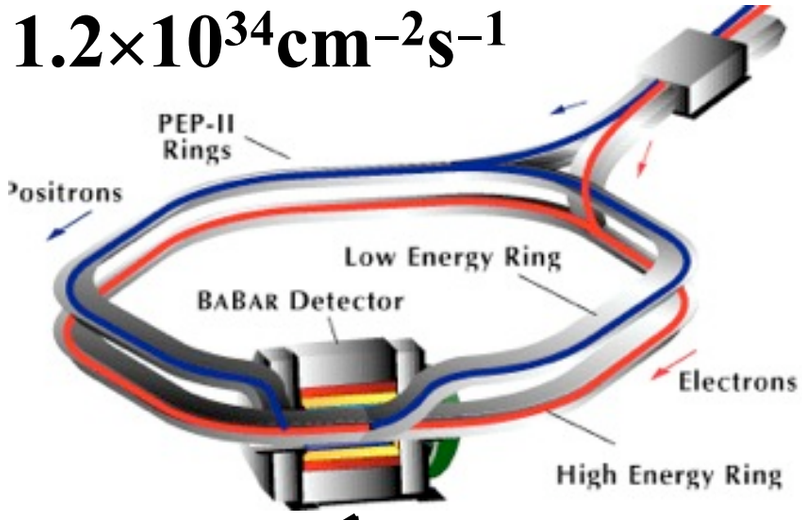


(h) Oscillation

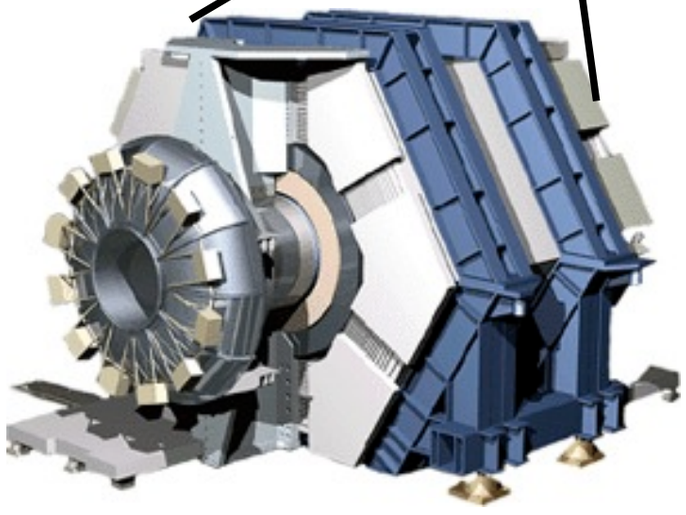
Two asymmetric B-factories

PEP-II at SLAC

9GeV (e^-) × 3.1GeV (e^+)
peak luminosity:
$1.2\times10^{34}cm^{-2}s^{-1}$

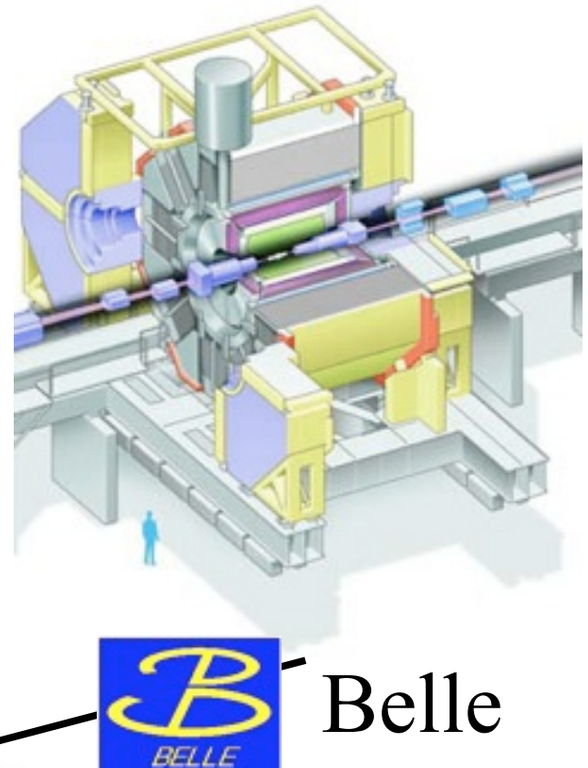


BaBar

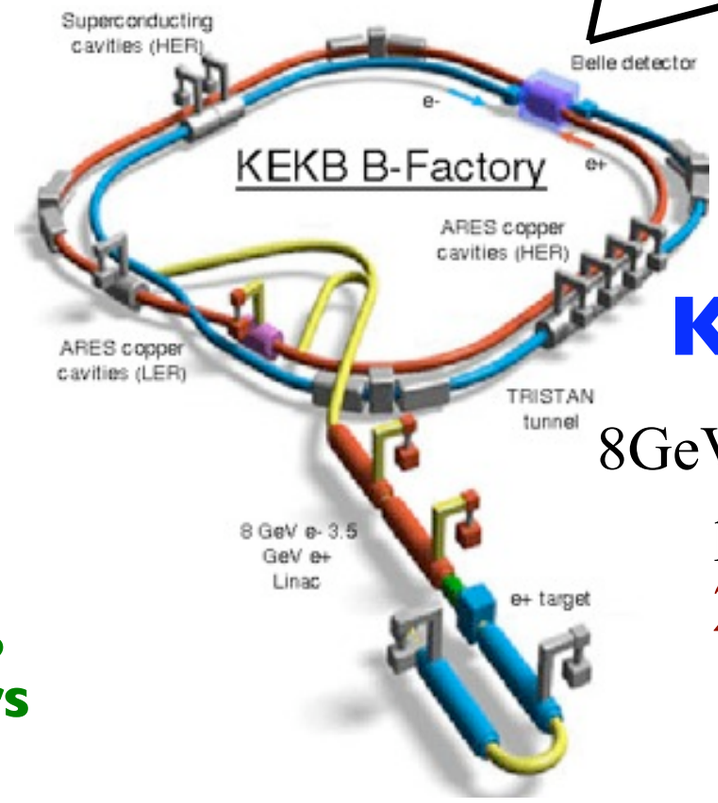


**11 nations,
80 institutes,
~600 members**

**13 countries,
57 institutes,
~400 members**



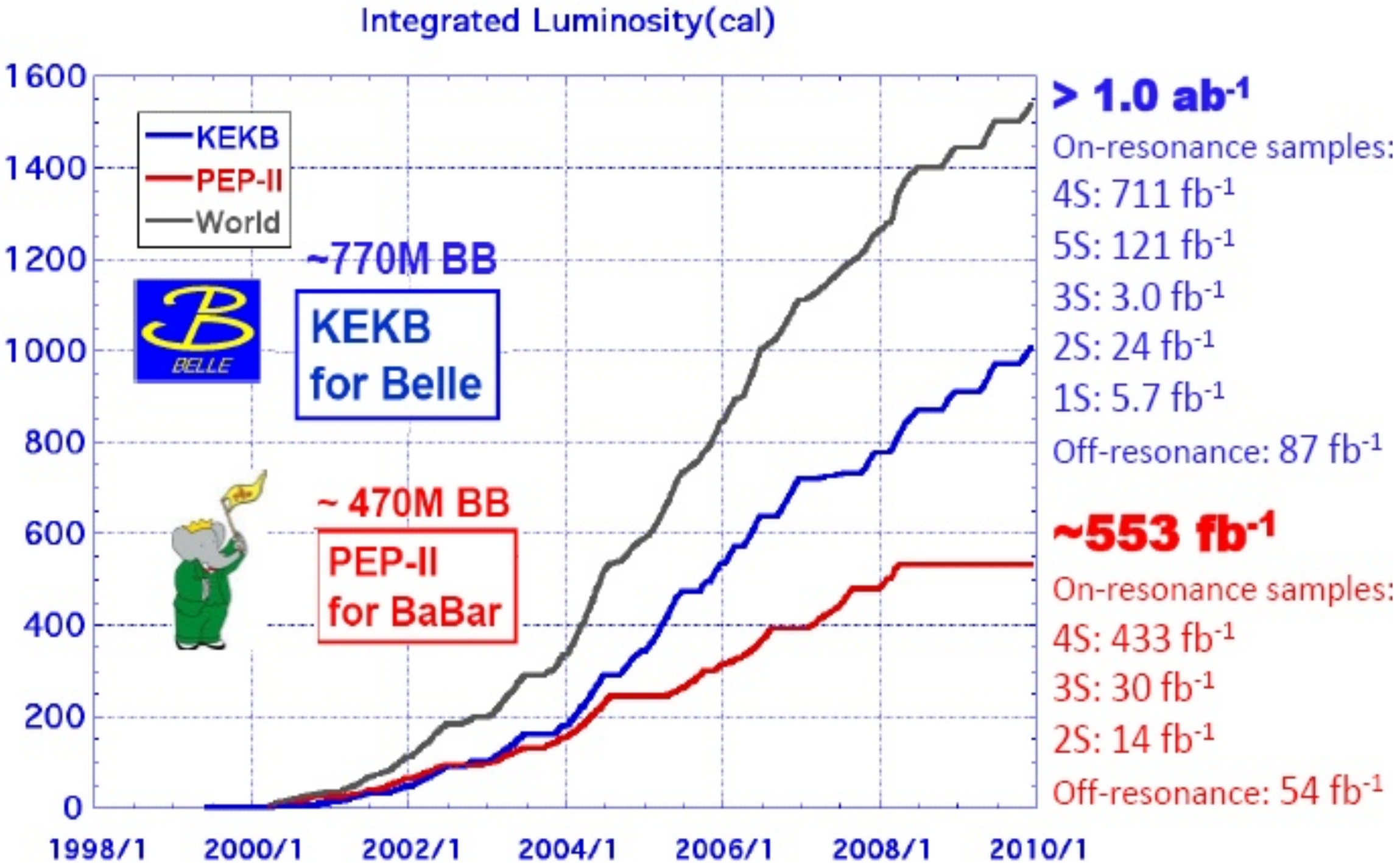
Belle



KEKB at KEK

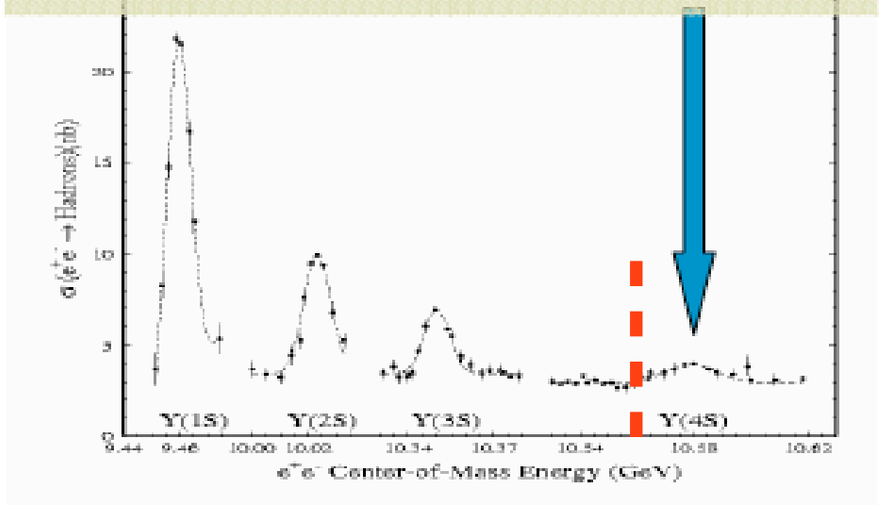
8GeV (e^-) × 3.5GeV (e^+)
peak luminosity:
$2.1\times10^{34}cm^{-2}s^{-1}$
world record

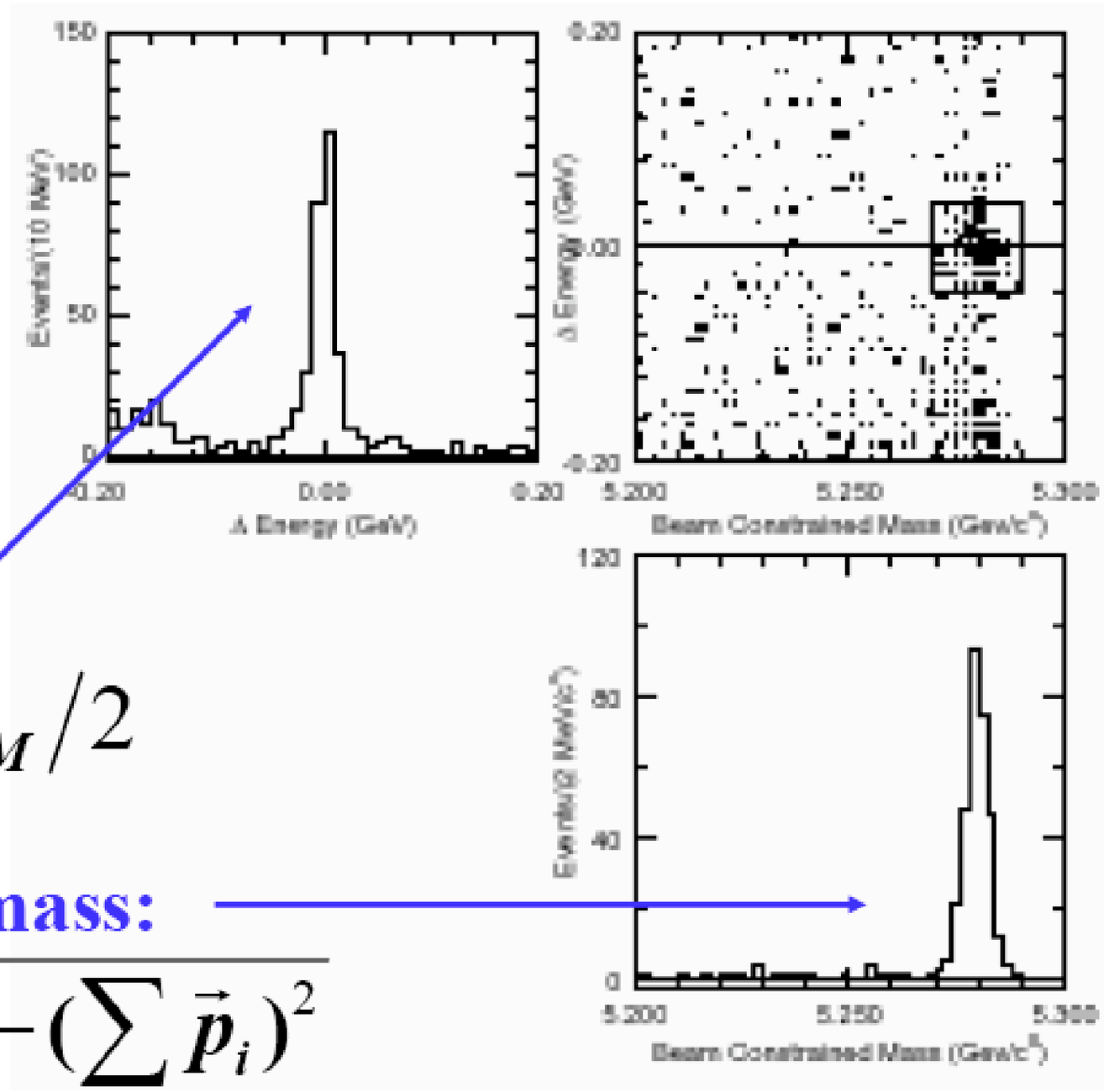
Belle/BaBar Luminosities



Two main variables for Belle/BaBar

$$e^+e^- \rightarrow \Upsilon(4S) \rightarrow B\overline{B}$$





Energy difference:

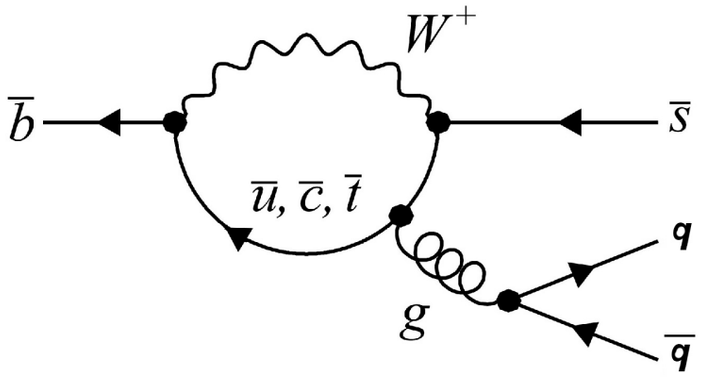
$$\Delta E \equiv \sum E_i - E_{CM}/2$$

Beam-constrained mass:

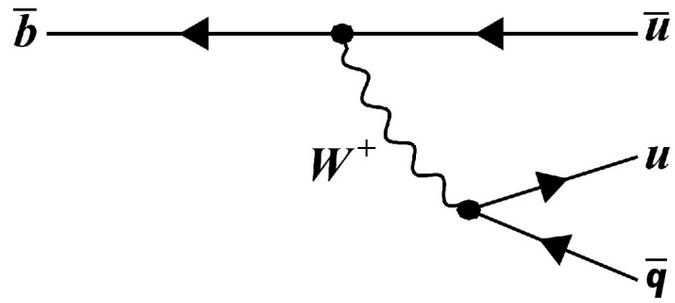
$$M_{bc} = \sqrt{(E_{CM}/2)^2 - (\sum \vec{p}_i)^2}$$

"$m_{\rm ES}$" for BaBar

charmless hadronic B decays



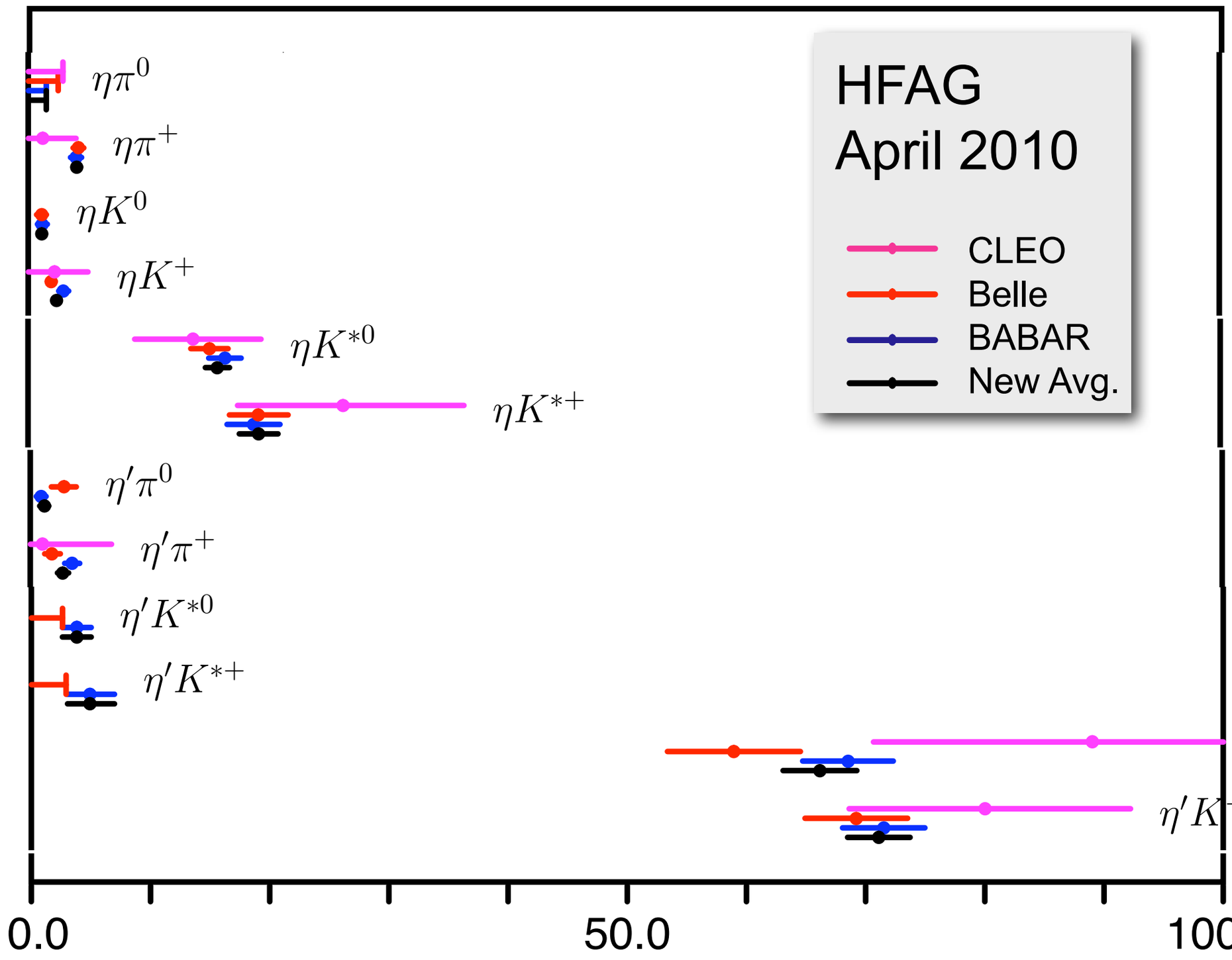
(i) $b \to s$ penguin diagram



(ii) $b \to u$ tree diagram

- $B \to X\,\eta^{(\prime)}$ decays (i)
- $V\,V$ polarization puzzle (i), (ii)

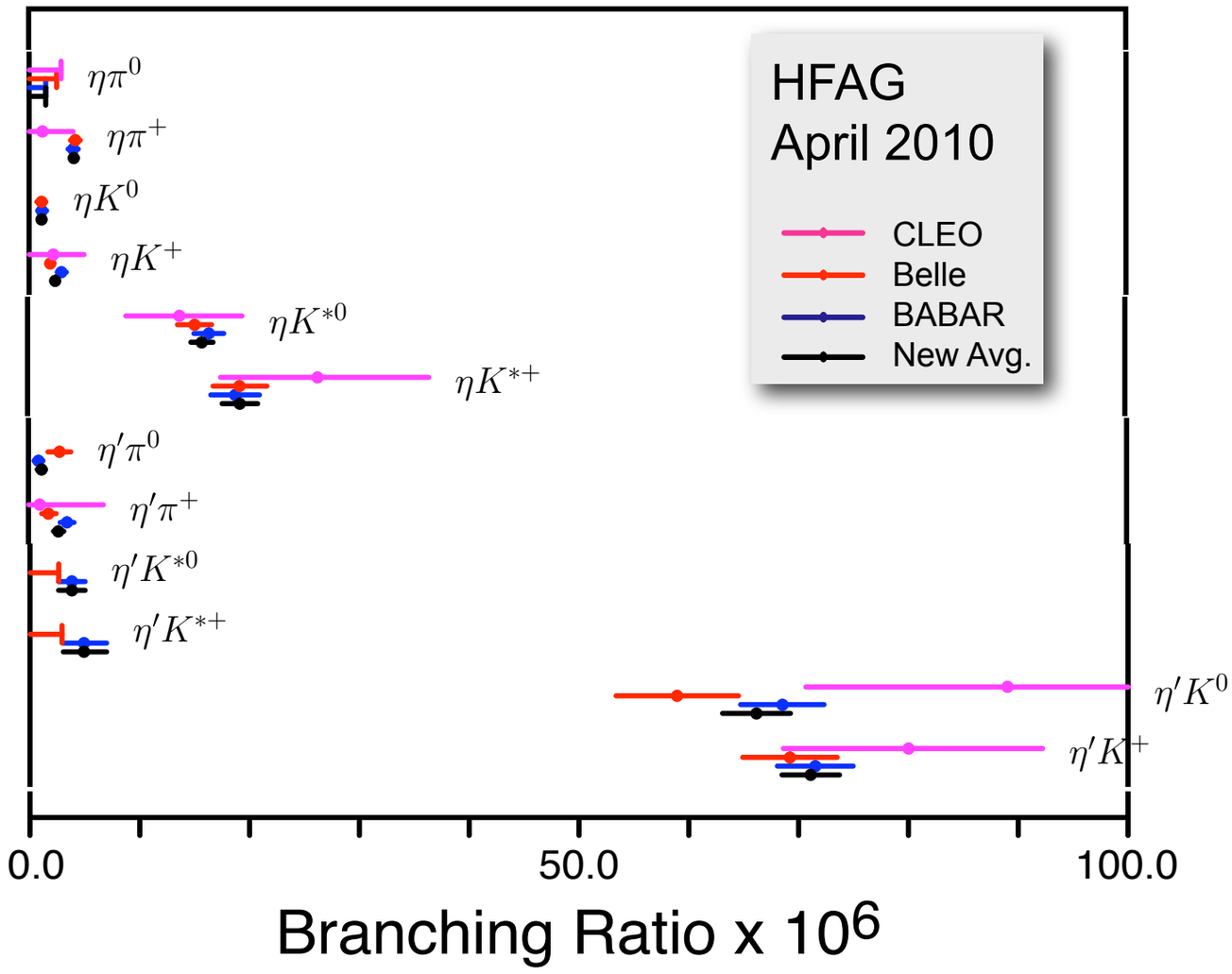
$B \to \eta^{(\prime)} K^{(*)},\ \eta^{(\prime)} \pi$



$B \to X\,\eta^{(\prime)}$ decays

- points of interest
  - unexpectedly large BF for some modes and unexpected patterns of BF's for others
  - sensitive to interference b.w. flavor singlet & octet components
  - many studies using pQCD, QCDF, SCET, etc.
- It will be valuable to have results in more related decay modes, for QCD studies

$B \to \eta^{(\prime)} K^{(*)},\ \eta^{(\prime)}\pi$



$B \to X\eta'$ exclusive

- Analysis brief
  - $N_{B\bar{B}} = 467$ M
  - measure BF & $A_{\rm ch}$ for $B \to \eta' h$ ($h = \rho, f_0, K^*$)
  - use $\eta' \to \eta\pi^+\pi^-$ and $\eta' \to \rho\gamma$ for $\eta' K^*$;
    only $\eta' \to \eta\pi^+\pi^-$ for the other modes
  - background comes dominantly from $q\bar{q}$ continuum events
    $\Longrightarrow$ use event-shape variables
  - measure the signal yields by EML fit to six variables:
    $\Delta E, m_{\rm ES}, \mathcal{F}, m_{\eta'}, m_h, \cos\theta_{\mathcal{H}}$ (for $h = \rho$ or K^*)
- other comments
  - LASS model is used for scalar $K\pi$ component
  - $\Delta E, m_{\rm ES}$ shapes are calibrated by control samples
  - Fitting bias is estimated with toy-MC ensembles, by which the signal yield is corrected

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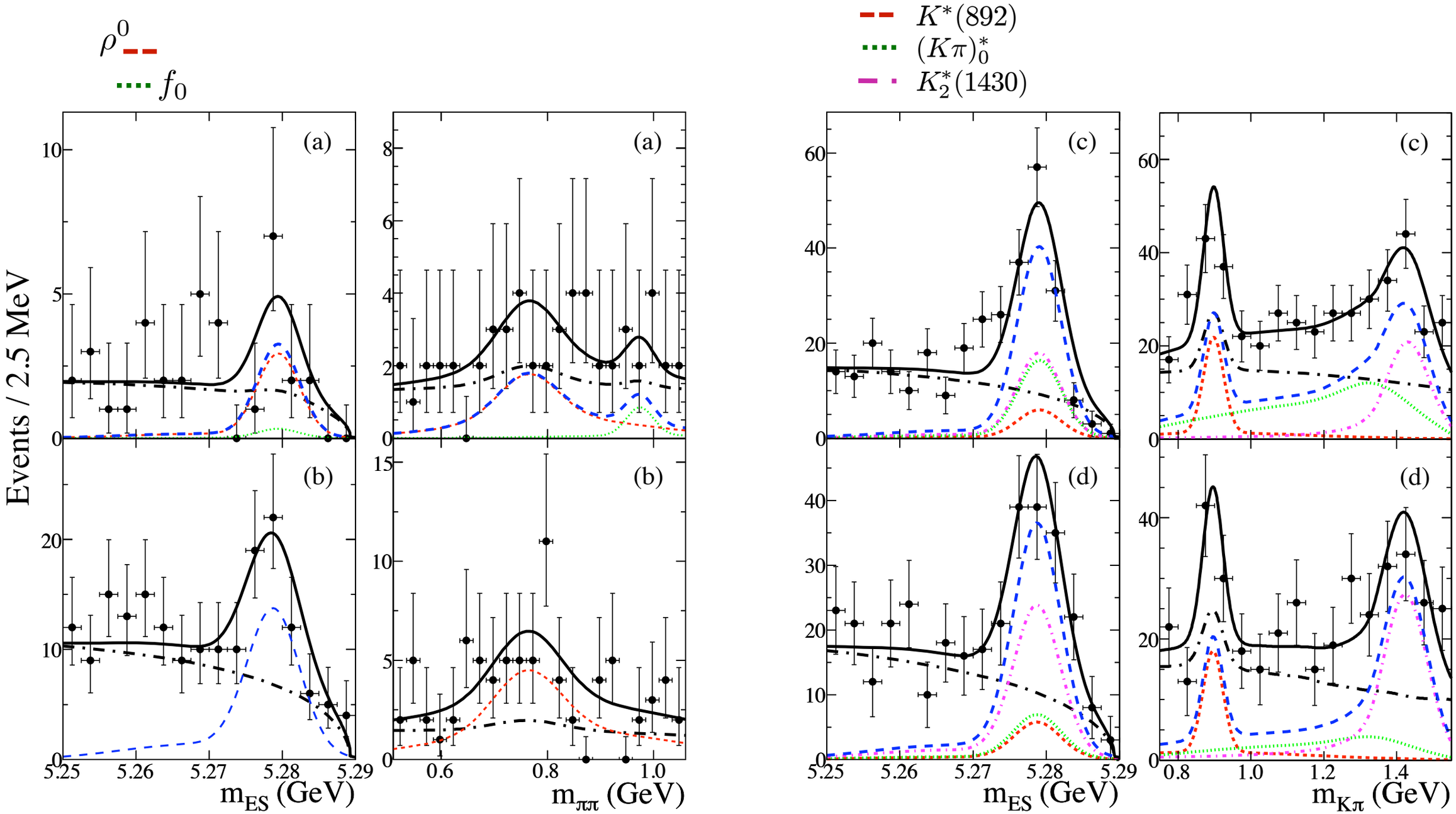
$B \to X \eta'$ exclusive



Observation of $\eta'\rho^+, \eta' K_2^*(1430)^{(0,+)}$ **!** **Evidence for** $\eta' K^{*(0,+)}$ **!**

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$B \to X\eta'$ exclusive

Mode	Y (events)	Y_0 (events)	ϵ (%)	$\prod \mathcal{B}_i$ (%)	S (σ)	$\mathcal{B}$ (10^{-6})	$\mathcal{B}$ U.L. (10^{-6})	$\mathcal{A}_{\rm ch}$
$\eta'\rho^0$	37±15	9±5	23.4	17.5	2.0	$1.5 \pm 0.8 \pm 0.3$	2.8	–
$\eta' f_0$	8±8	4±2	25.9	17.5	0.5	$0.2^{+0.4}_{-0.3} \pm 0.1$	0.9	–
$\eta'\rho^+$	128±22	15±8	14.3	17.5	5.8	$9.7^{+1.9}_{-1.8} \pm 1.1$	–	$0.26 \pm 0.17 \pm 0.02$
$\eta' K^{*0}$					4.0	$3.1^{+0.9}_{-0.8} \pm 0.3$	4.4	$0.02 \pm 0.23 \pm 0.02$
$\eta' K^{*+}$					3.8	$4.8^{+1.6}_{-1.4} \pm 0.8$	7.2	$-0.26 \pm 0.27 \pm 0.02$
$\eta'(K\pi)_0^{*0}$					5.6	$7.4^{+1.5}_{-1.4} \pm 0.6$	–	$-0.19 \pm 0.17 \pm 0.02$
$\eta'(K\pi)_0^{*+}$					2.9	$6.0^{+2.2}_{-2.0} \pm 0.9$	9.3	$0.06 \pm 0.20 \pm 0.02$
$\eta' K_2^*(1430)^0$					5.3	$13.7^{+3.0}_{-2.9} \pm 1.2$	–	$0.14 \pm 0.18 \pm 0.02$
$\eta' K_2^*(1430)^+$					7.2	$28.0^{+4.6}_{-4.3} \pm 2.6$	–	$0.15 \pm 0.13 \pm 0.02$

- no significant $A_{\rm ch}$ in any modes
- results for $\eta'\rho^+$ generally in favor of pQCD and QCDF over SCET
- unexpected $\mathcal{B}(B \to \eta' K_2^*(1430)) \gg \mathcal{B}(B \to \eta' K^*(892))$

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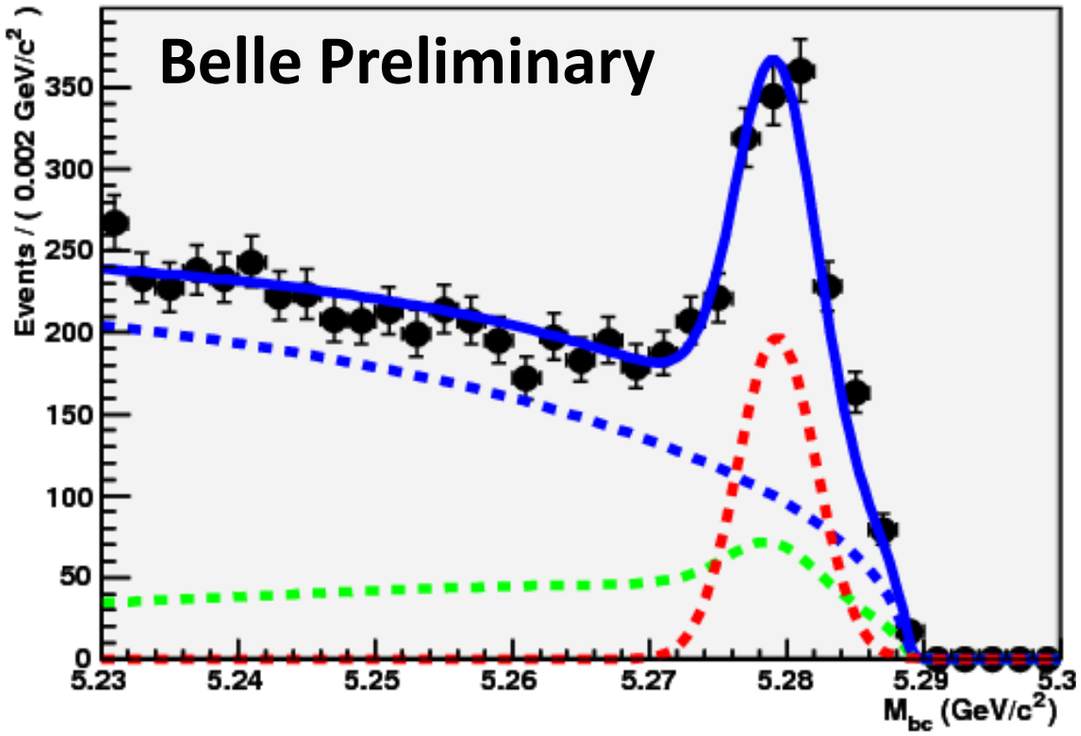
$B \to X_s\eta$ inclusive



----- : signal

----- : BB background

----- : combinatorial background

- $N_{B\bar{B}} = 657$ M
- pseudo-inclusive
  - sum of exclusive modes
    - $B \to X_s\eta$ ($p^*_\eta > 2.0$ GeV/c)
      $\eta \to \gamma\gamma$
      $X_s \to Kn\pi$ ($n \leq 4$, $n_{\pi^0} \leq 1$)
- signal yield

  $N_{\rm sig} = 749 \pm 48 \pm 7$
  for $1.0 < M_{X_s} < 2.6$ GeV/c^2

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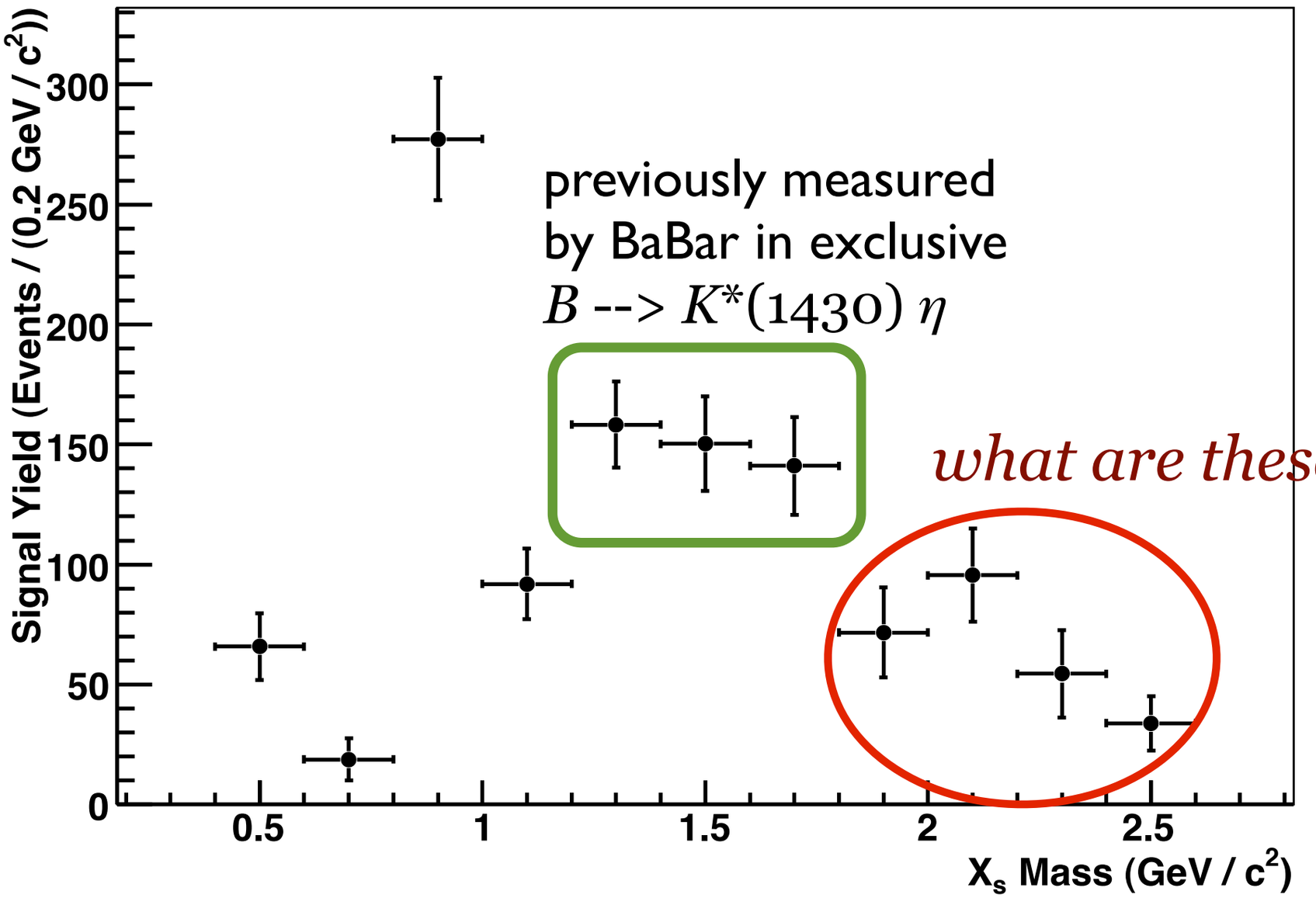
$B \to X_s \eta$ inclusive



- signal yields are obtained by fitting $M_{\rm bc}$ in bins of $M(X_s)$

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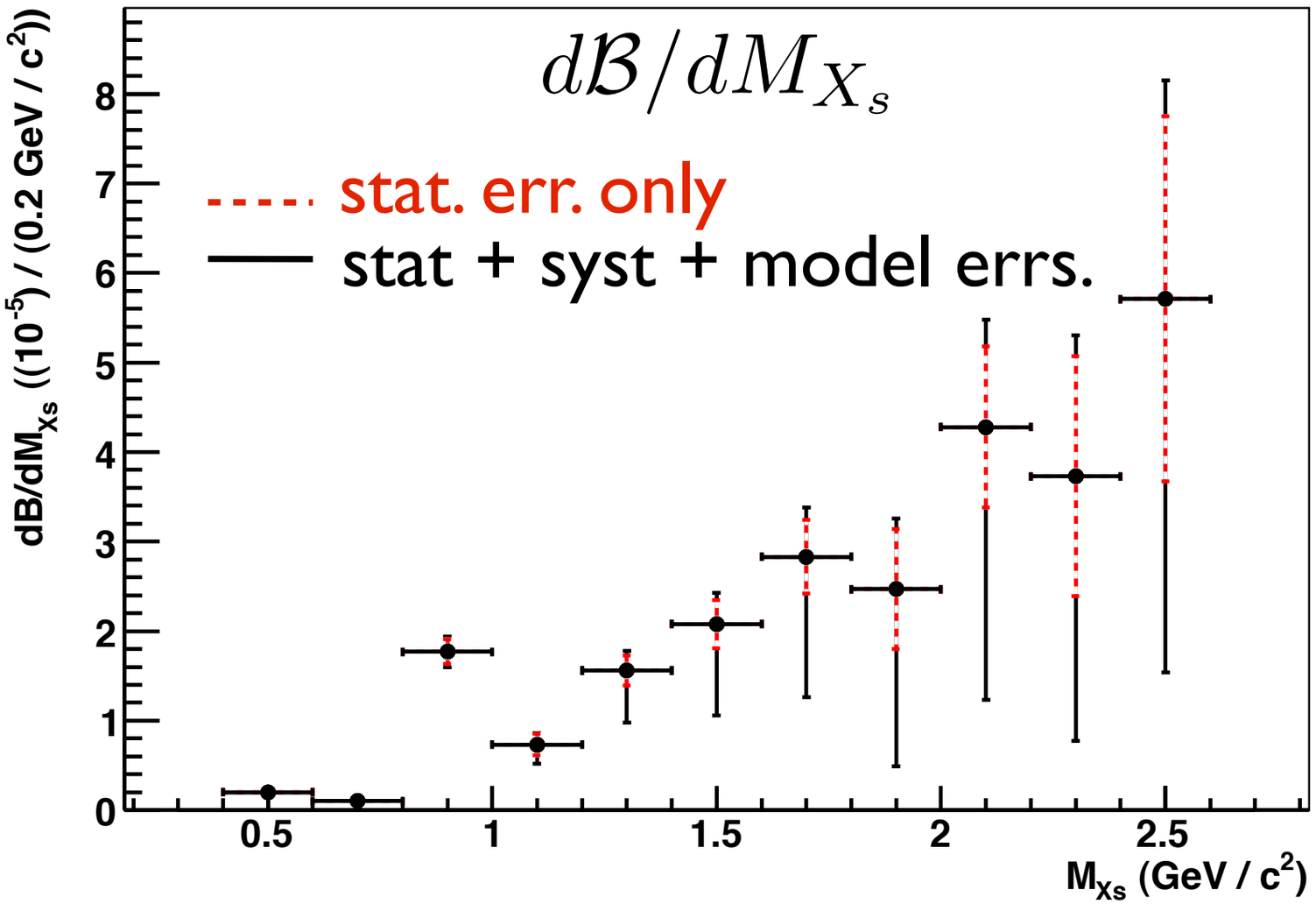
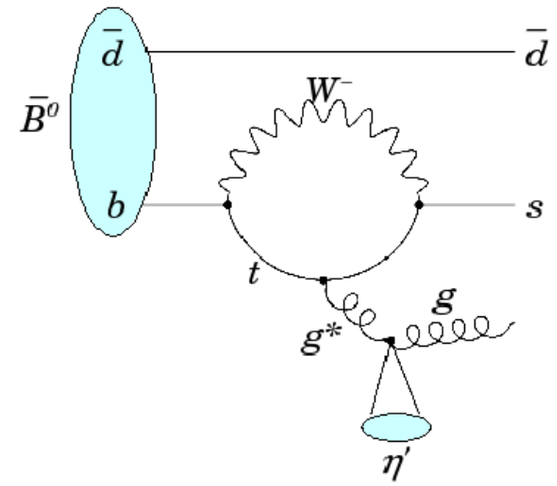
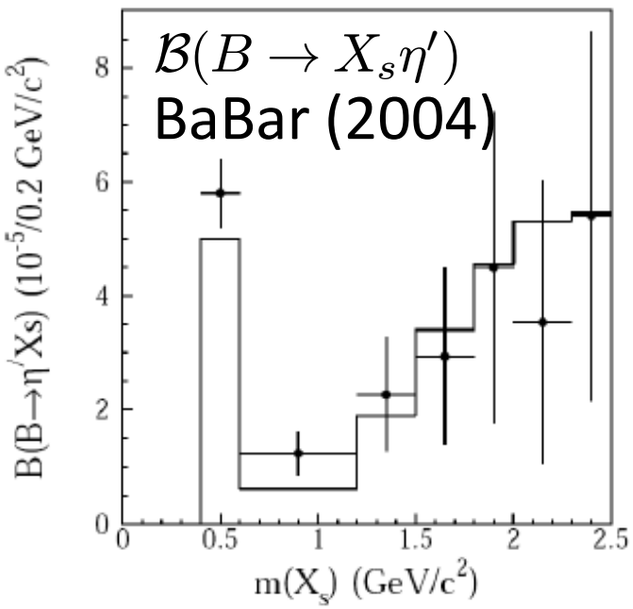
$B \to X_s\eta$ inclusive



$B \to X_s\eta'$, QCD anomaly?





- partial BF in $0.4 < M(X_s) < 2.6$ GeV/c^2
  $\mathcal{B}(B \to X_s\eta) = (25.5 \pm 2.7 \pm 1.6^{+3.8}_{-14.1}) \times 10^{-5}$ (JETSET for hadronization)
- large signals for $M_{X_s} > 2$ GeV/c^2 in both $X_s\eta$ and $X_s\eta'$ modes, disfavoring "large $\eta' gg$ coupling" hypothesis

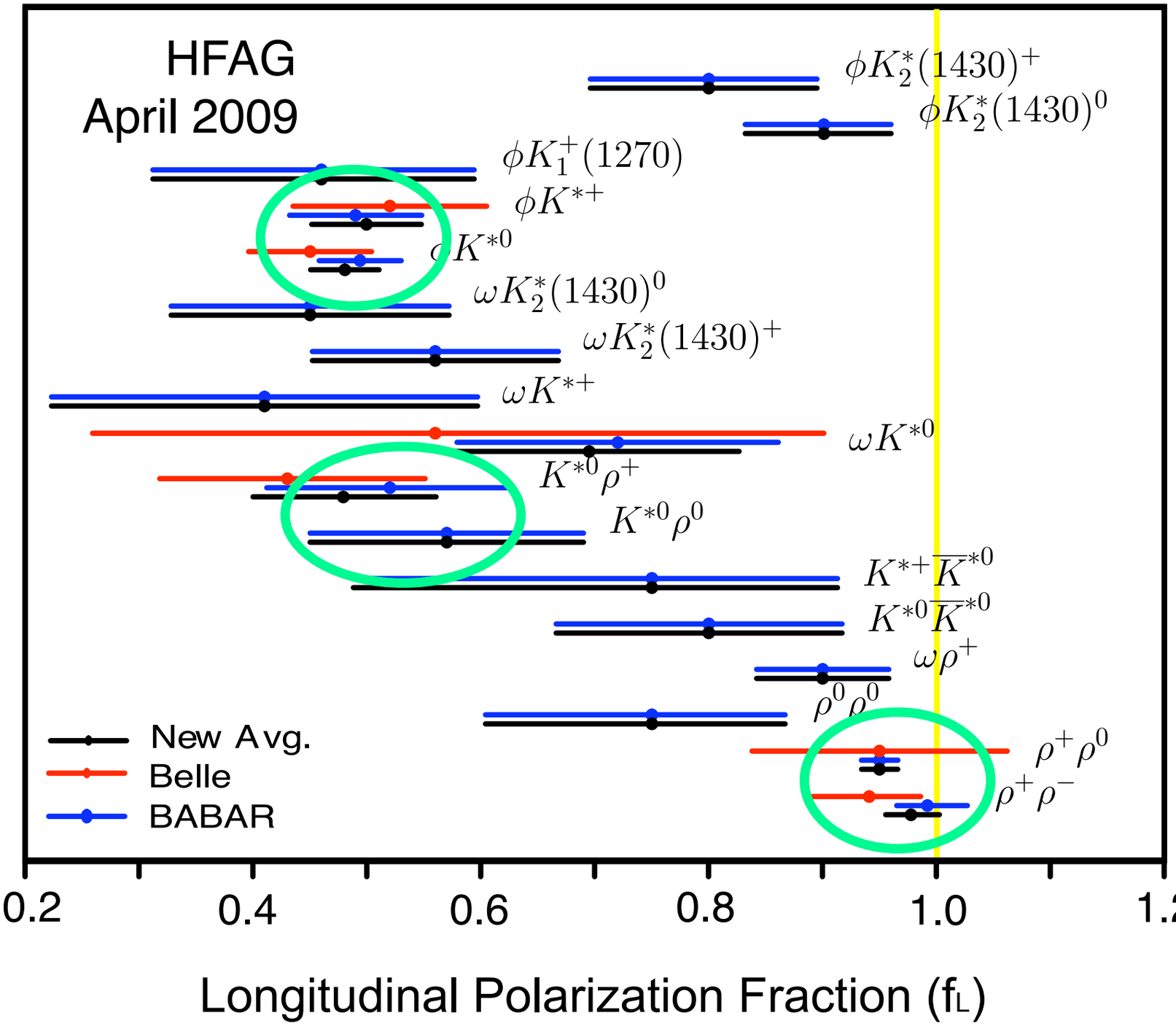
VV puzzle?

- B decays to vector + vector final states are actually three separate decays, corresponding to the polarization of the final-state vector mesons
- Naive SM expectation predicts dominance of longitudinal polarizations
  - by helicity conserving arguments

    $f_{\rm L} \sim 1 - m_V^2/m_B^2$
- But, a puzzling pattern of $f_{\rm L}$ is measured in $B \to VV$ decays

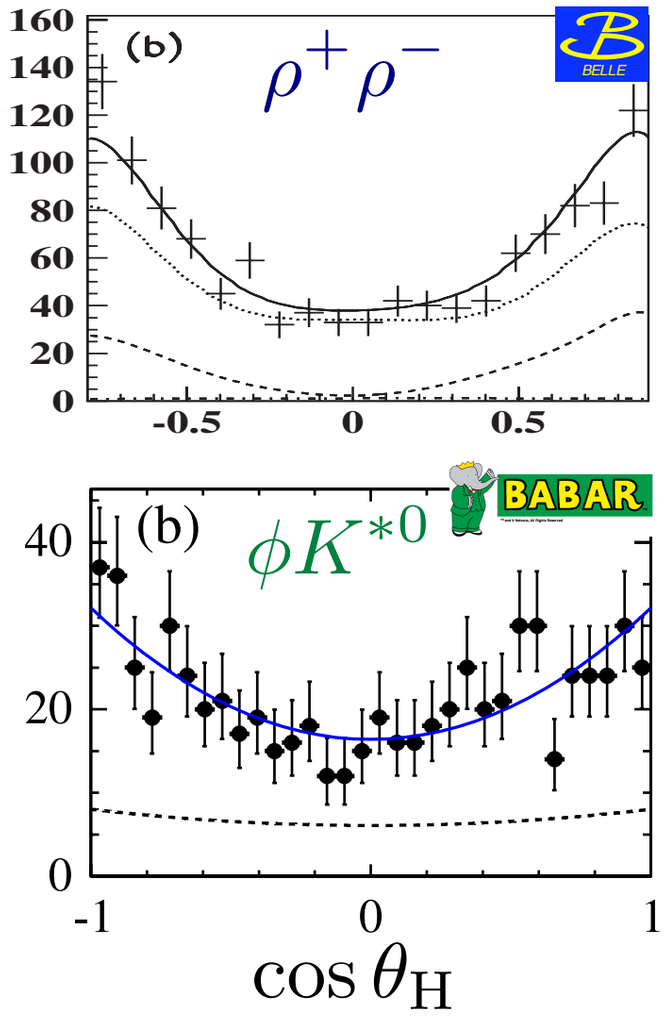
VV puzzle?

Polarizations of Charmless Decays



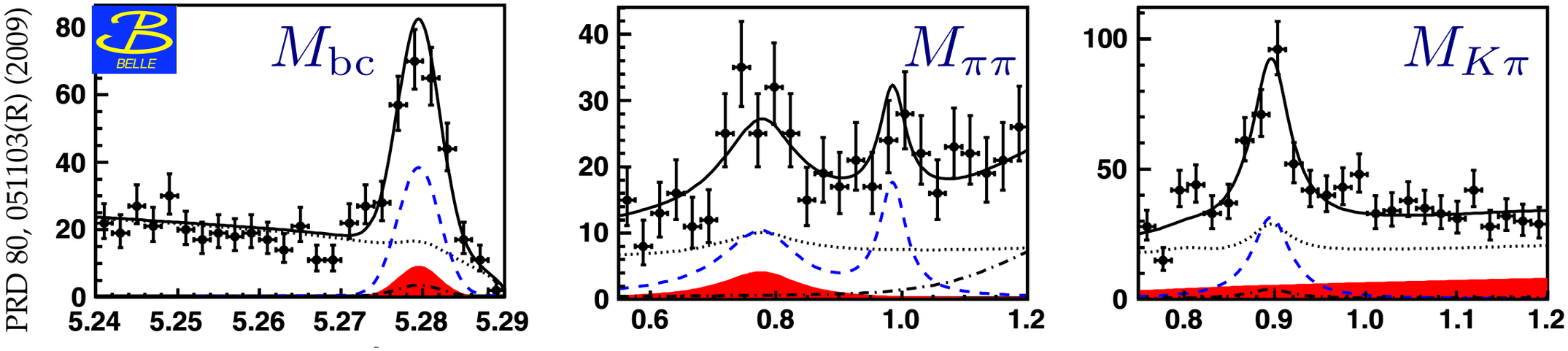
Ploarization patterns in $B \to VV$

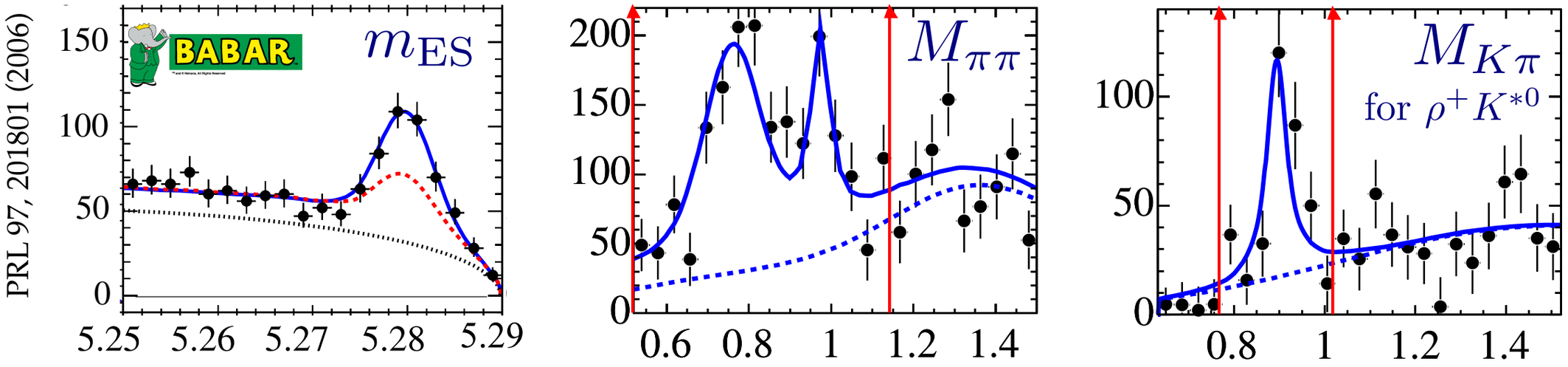
- $f_L \sim 1$ for $\rho\rho$, $\rho\omega$
  - tree-dominated decays
  - the naive picture works!
- $f_L \sim 0.5$ for ϕK^*
  - beginning of the puzzle, *c.* 2003
  - penguin-dominated decays
  - $\delta f_L \sim 0.05$
- What about other $B \to V\ V$ modes?



$$\frac{d^2\Gamma}{\Gamma d\cos\theta_1 d\cos\theta_2} = \frac{9}{4}\left[f_L \cos^2\theta_1 \cos^2\theta_2 \ + \frac{1}{4}(1 - f_L)\sin^2\theta_1 \sin^2\theta_2 \right]$$

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





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$N_{B\bar{B}}$		Y (events)	ϵ (%)	$S(\sigma)$	$\mathcal{B}(10^{-6})$	$f_{\rm L}$
232 M	BaBar	185 ± 30	22.9	5.3	$5.6 \pm 0.9 \pm 1.3$	~ 0.57
657 M	Belle	78 ± 20	5.7	2.7	< 3.4	–

$B \to K^{*0}\bar{K}^{*0}$

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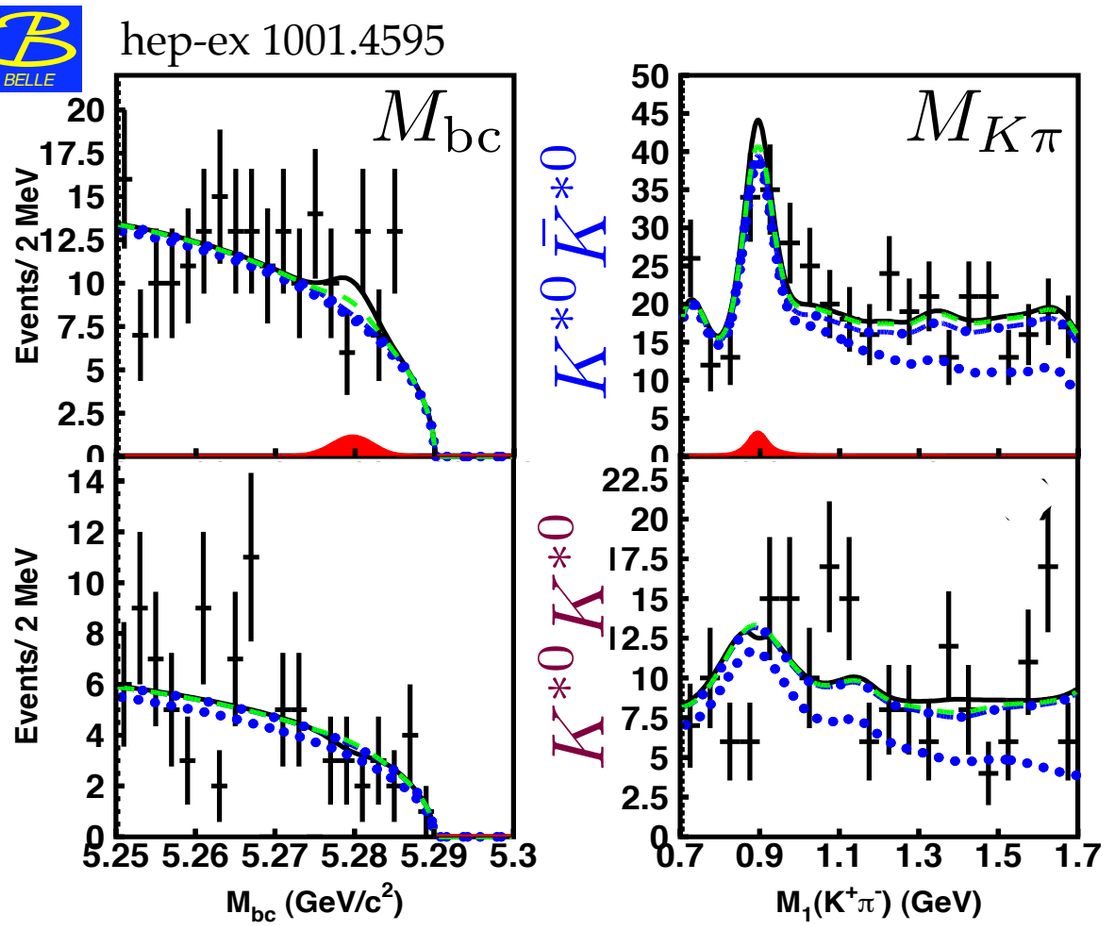
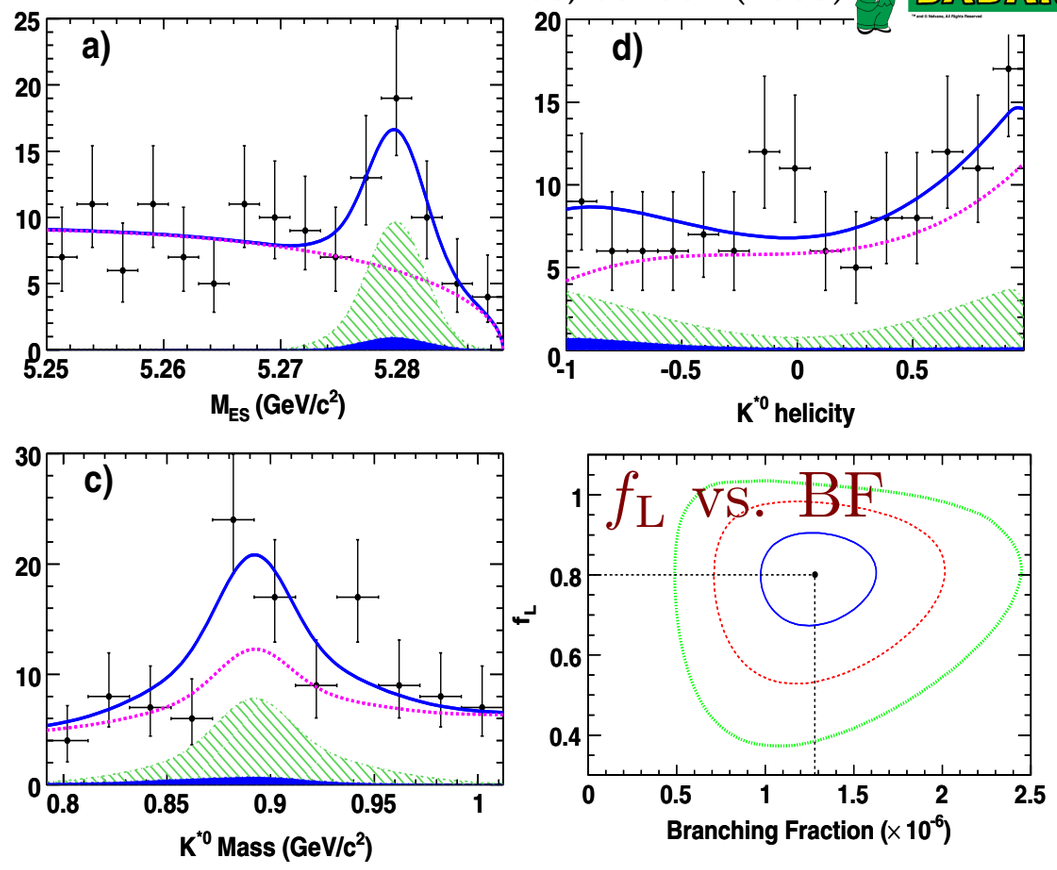


- $N_{B\bar{B}} = 657$ M
- no significant signal in either $K^{*0}\bar{K}^{*0}$ or $K^{*0}K^{*0}$

PRL 100, 081801 (2008)



- $N_{B\bar{B}} = 383$ M
- $K^{*0}\bar{K}^{*0}$ is observed by 6σ
  $f_{\rm L} = 0.80^{+0.10}_{-0.12} \pm 0.06$

$B \to K^{*0}\bar{K}^{*0}$

- $K^{*0}\bar{K}^{*0}$

??

	Y (events)	ϵ (%)	$S(\sigma)$	$\mathcal{B}(10^{-6})$	$f_{\rm L}$
BaBar	$33.5^{+9.1}_{-8.1}$	6.8	6.0	$1.28^{+0.35}_{-0.30} \pm 0.11$	~ 0.80
Belle	$7.7^{+9.7+2.8}_{-8.5-2.2}$	4.4	0.9	< 0.8	–

- $K^{*0}K^{*0}$

	Y (events)	ϵ (%)	$S(\sigma)$	$\mathcal{B}(10^{-6})$	$f_{\rm L}$
BaBar	2.7 ± 3.3	6.4	0.9	< 0.41	–
Belle	$-3.7 \pm 3.3^{+2.5}_{-2.7}$	5.7	–	< 0.2	–

Belle efficiencies assume $f_{\rm L} = 1.0$

VV puzzle?

Not completely understood, but improving

- Enhanced annihilation and non-factorizable contributions
  - Beneke, Rohrer, D.-S. Yang, NPB 774, 64 (2007)
  - Cheng, K.-C. Yang, PRD 78, 094001 (2008)
- Final-state interactions
- New physics?
- What about other spins?

Cheng&Yang, PRD 78, 094001 (2008).

Decay	$\mathcal{B}$		f_L		$f_\perp$	
	Theory	Expt	Theory	Expt	Theory	Expt
$B^- \to \rho^-\rho^0$	$20.0^{+4.0+2.0}_{-1.9-0.9}$	24.0±2.0	$0.96^{+0.02}_{-0.02}$	0.950±0.016	0.02 ± 0.01	
$\overline{B}^0 \to \rho^+\rho^-$	$25.5^{+1.5+2.4}_{-2.6-1.5}$	$24.2^{+3.1}_{-3.2}$	$0.92^{+0.01}_{-0.02}$	$0.978^{+0.025}_{-0.022}$	$0.04^{+0.01}_{-0.00}$	
$\overline{B}^0 \to \rho^0\rho^0$	$0.9^{+1.5+1.1}_{-0.4-0.2}$	0.68 ± 0.27	$0.92^{+0.06}_{-0.36}$	0.70 ± 0.15	$0.04^{+0.14}_{-0.03}$	
$B^- \to \rho^-\omega$	$19.2^{+3.3+1.7}_{-1.6-1.0}$	15.9±2.1	$0.96^{+0.02}_{-0.02}$	0.90±0.06	0.02 ± 0.01	
$\overline{B}^0 \to \rho^0\omega$	$0.1^{+0.1+0.4}_{-0.1-0.0}$	< 1.5	$0.55^{+0.47}_{-0.29}$		$0.22^{+0.16}_{-0.23}$	
$B^- \to \bar{K}^{*0}\rho^-$ [a]	$9.2^{+1.2+3.6}_{-1.1-5.4}$	9.2 ± 1.5	$0.48^{+0.52}_{-0.40}$	0.48 ± 0.08	$0.26^{+0.20}_{-0.26}$	
$B^- \to K^{*-}\rho^0$	$5.5^{+0.6+1.3}_{-0.5-2.5}$	< 6.1	$0.67^{+0.31}_{-0.48}$	$0.96^{+0.06}_{-0.16}$ [b]	$0.16^{+0.24}_{-0.15}$	
$\overline{B}^0 \to K^{*-}\rho^+$	$8.9^{+1.1+4.8}_{-1.0-5.5}$	< 12	$0.53^{+0.45}_{-0.32}$		$0.24^{+0.16}_{-0.22}$	
$\overline{B}^0 \to \bar{K}^{*0}\rho^0$	$4.6^{+0.6+3.5}_{-0.5-3.5}$	3.4±1.0	$0.39^{+0.60}_{-0.31}$	0.57 ± 0.12	$0.30^{+0.15}_{-0.30}$	
$B^- \to K^{*-}\phi$ [c]	$10.0^{+1.4+12.3}_{-1.3-\ 6.1}$	10.0 ± 1.1	$0.49^{+0.51}_{-0.42}$	0.50 ± 0.05	$0.25^{+0.21}_{-0.25}$	0.20 ± 0.05
$\overline{B}^0 \to \bar{K}^{*0}\phi$	$9.5^{+1.3+11.9}_{-1.2-\ 5.9}$	9.5 ± 0.8	$0.50^{+0.50}_{-0.42}$	0.484 ± 0.034	$0.25^{+0.21}_{-0.25}$	0.256 ± 0.032
$B^- \to K^{*-}\omega$	$3.5^{+0.4+3.0}_{-0.4-1.7}$	<7.4	$0.66^{+0.32}_{-0.38}$		$0.17^{+0.20}_{-0.17}$	
$\overline{B}^0 \to \bar{K}^{*0}\omega$	$3.0^{+0.5+2.9}_{-0.4-1.8}$	2.0±0.5	$0.57^{+0.44}_{-0.46}$	0.70±0.13	$0.21^{+0.25}_{-0.22}$	
$B^- \to K^{*0}K^{*-}$	$0.6^{+0.1+0.3}_{-0.1-0.3}$	1.2±0.5	$0.45^{+0.55}_{-0.38}$	$0.75^{+0.16}_{-0.26}$	$0.27^{+0.19}_{-0.27}$	
$\overline{B}^0 \to K^{*-}K^{*+}$	$0.1^{+0.0+0.1}_{-0.0-0.1}$	<2.0	1		0	
$\overline{B}^0 \to K^{*0}\bar{K}^{*0}$	$0.6^{+0.1+0.2}_{-0.1-0.3}$	$1.28^{+0.37}_{-0.32}$	$0.52^{+0.48}_{-0.48}$	$0.80^{+0.12}_{-0.13}$	$0.24^{+0.24}_{-0.24}$	

Free parameters in the models taken from experiment

Excellent agreement

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from J. Smith @ FPCP 2009

Baryonic *B* decays

- multi-body hierarchy, seen in *B* to charm-baryon decays
  - $Br(B^0 \to p\overline{\Lambda}_c^- \pi^+ \pi^-) > Br(B^+ \to p\overline{\Lambda}_c^- \pi^+) > Br(B^0 \to p\overline{\Lambda}_c^-)$
  - would this pattern repeat in charmless baryonic *B* decays?
- near-threshold enhancement is seen in all *B* baryonic decays
- first observation of 4-body charmless baryonic B decays (Belle, 2009)
  - what about multi-body hierarchy and near-threshold enhancement?

Near-threshold enhancement

observed in all baryonic decays

- $B \to \Lambda\bar{\Lambda}h,\ \ h = K^{\pm}, K^{*}, \bar{D}^{0}$

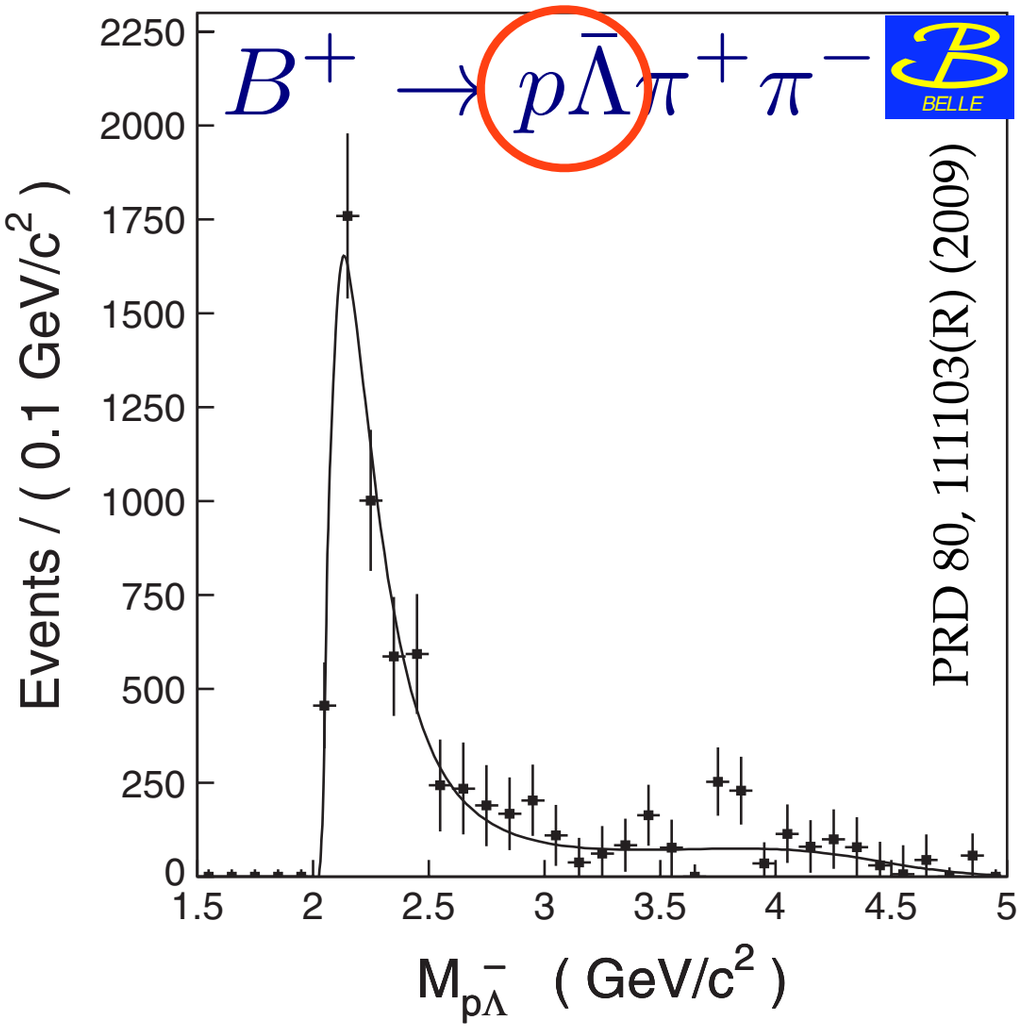
  PRD 79, 052006 (2009) BELLE

- $B \to p\bar{\Lambda}h,\ \ h = \pi^{\pm}, K^{\pm}, K^{*}$

  PRD 76, 052004 (2007) BELLE

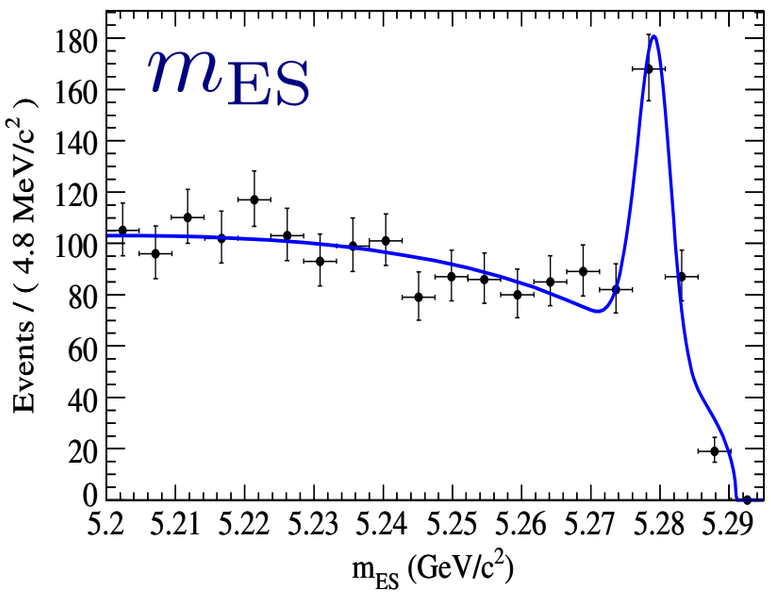
- $B \to p\bar{p}h,\ \ h = \pi^{\pm}, K^{\pm}, K^{*}$

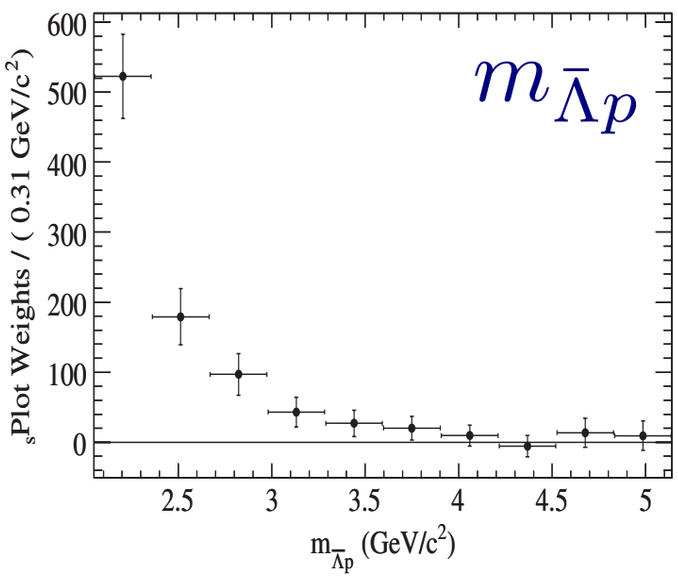
  PRL 100, 251801 (2008) BELLE

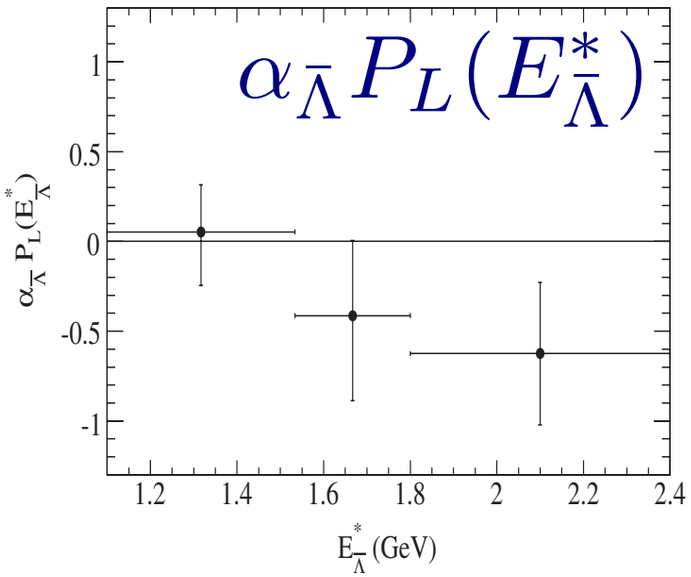


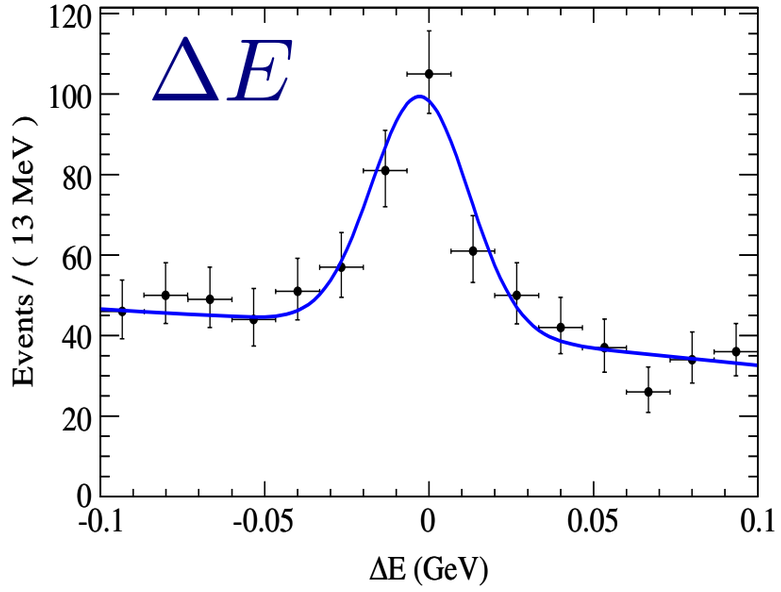
$B^0 \to p\bar{\Lambda}\pi^-$

PRD 79, 112009 (2009)









- $N_{B\bar{B}} = 467$ M
- near-threshold enhancement is seen as in all other baryonic B decays
- $\mathcal{B}(B^0 \to p\bar{\Lambda}\pi^-) = (3.07 \pm 0.31 \pm 0.23) \times 10^{-6}$
  $A_{\rm ch} = (-0.10 \pm 0.10 \pm 0.02) \times 10^{-6}$
- polarization is measured
  $\Rightarrow$ consistent with full longitudinal pol. at large $E^*_{\bar{\Lambda}}$

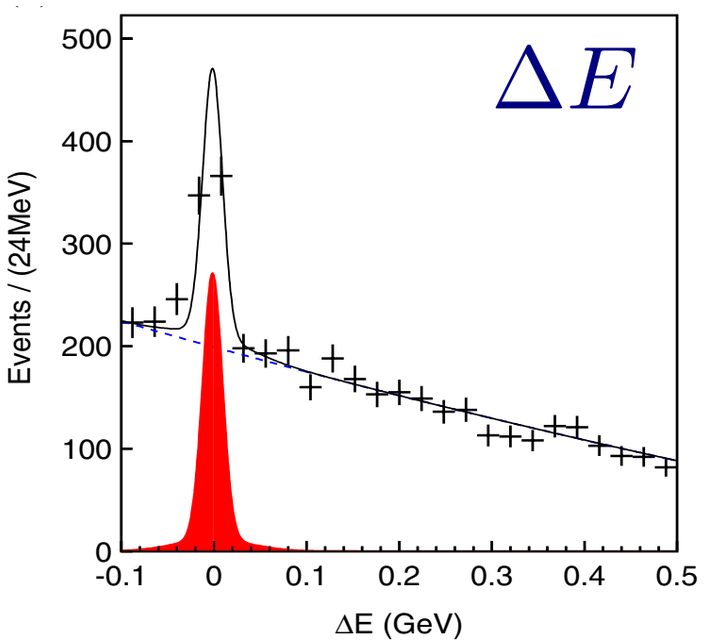
Note: Belle, PRD 76, 052004 (2007)

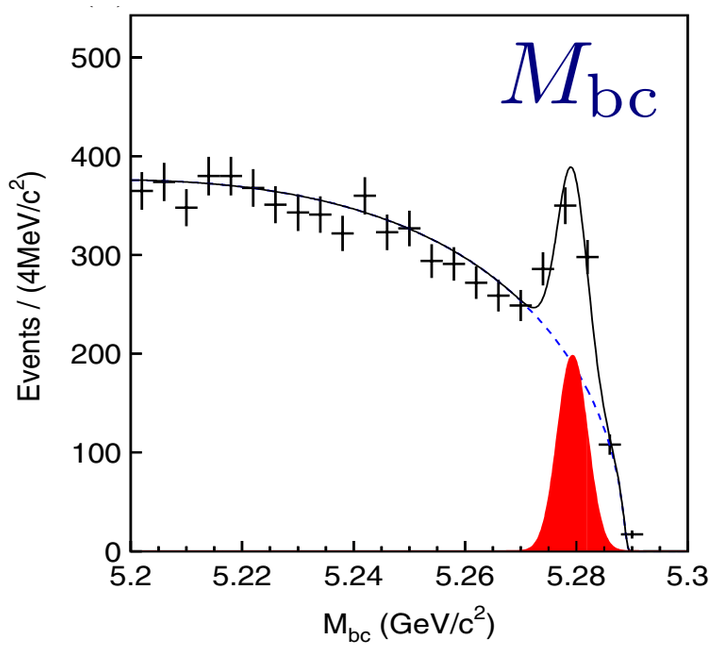
$$\mathcal{B}(B^0 \to p\bar{\Lambda}\pi^-) = (3.23^{+0.33}_{-0.29} \pm 0.29) \times 10^{-6}$$

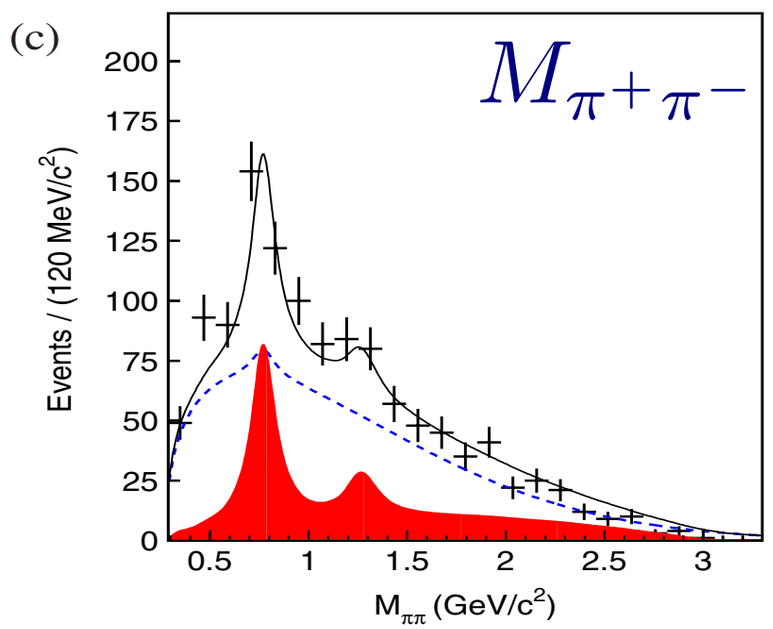
$$A_{\rm ch} = -0.02 \pm 0.10 \pm 0.03 \qquad A_\theta = -0.41 \pm 0.11 \pm 0.03$$

$B^+ \to p\bar{\Lambda}\pi^+\pi^-$

PRD 80, 111103(R) (2009)







$N_{B\bar{B}} = 657$ M

Mode	Yield	Efficiency (%)	$\mathcal{B}(10^{-6})$	Significance
$p\bar{\Lambda}\pi^+\pi^-$	$167.8^{+25.0}_{-23.7}$	4.32	$5.92^{+0.88}_{-0.84} \pm 0.69$	9.1
$p\bar{\Lambda}\rho^0$	$131.2^{+18.3}_{-17.5}$	4.17	$4.78^{+0.67}_{-0.64} \pm 0.60$	9.5
$p\bar{\Lambda}f_2(1270)$	$39.1^{+14.9}_{-14.0}$	2.94	$2.03^{+0.77}_{-0.72} \pm 0.27$	3.0

- first observation of 4-body charmless baryonic B decays
- multi-body hierarchy still holds for charmless baryonic B decays
- near-threshold enhancement is also seen

Summary

- Several new results in charmless hadronic and baryonic B decays, from Belle & BaBar
- New measurements in $B \to X_{(s)}\eta^{(\prime)}$ decays

BABAR unexpected $\mathcal{B}(B \to \eta' K_2^*(1430)) \gg \mathcal{B}(B \to \eta' K^*(892))$

BELLE $\mathcal{B}(B \to X_s\eta) = (25.5 \pm 2.7 \pm 1.6^{+3.8}_{-14.1}) \times 10^{-5}$
with large signals in $M_{X_s} > 2$ GeV/c^2

- $B \to VV$ polarization saga continues, with theory calculations improving
  - conflicting results (b/w Belle & BaBar) in $B^0 \to \rho^0 K^{*0}$ and in $B^0 \to K^{*0}\bar{K}^{*0}$ BABAR BELLE
- New results in charmless baryonic B decays

BELLE first observation of 4-body charmless baryonic B decays
  - both multi-body hierarychy and near-threshold enhancement shows up in 3-, 4-body charmless baryonic decays, too BELLE BABAR

backup

Cheng&Yang, PRD 78, 094001 (2008).

Decay	$\mathcal{B}$		f_L		$f_\perp$	
	Theory	Expt	Theory	Expt	Theory	Expt
$B^- \to \rho^-\rho^0$	$20.0^{+4.0+2.0}_{-1.9-0.9}$	18.2 ± 3.0	$0.96^{+0.02}_{-0.02}$	$0.912^{+0.044}_{-0.045}$	0.02 ± 0.01	
$\overline{B}^0 \to \rho^+\rho^-$	$25.5^{+1.5+2.4}_{-2.6-1.5}$	$24.2^{+3.1}_{-3.2}$	$0.92^{+0.01}_{-0.02}$	$0.978^{+0.025}_{-0.022}$	$0.04^{+0.01}_{-0.00}$	
$\overline{B}^0 \to \rho^0\rho^0$	$0.9^{+1.5+1.1}_{-0.4-0.2}$	0.68 ± 0.27	$0.92^{+0.06}_{-0.36}$	0.70 ± 0.15	$0.04^{+0.14}_{-0.03}$	
$B^- \to \rho^-\omega$	$19.2^{+3.3+1.7}_{-1.6-1.0}$	$10.6^{+2.6}_{-2.3}$	$0.96^{+0.02}_{-0.02}$	0.82 ± 0.11	0.02 ± 0.01	
$\overline{B}^0 \to \rho^0\omega$	$0.1^{+0.1+0.4}_{-0.1-0.0}$	< 1.5	$0.55^{+0.47}_{-0.29}$		$0.22^{+0.16}_{-0.23}$	
$B^- \to \bar{K}^{*0}\rho^-$ [a]	$9.2^{+1.2+3.6}_{-1.1-5.4}$	9.2 ± 1.5	$0.48^{+0.52}_{-0.40}$	0.48 ± 0.08	$0.26^{+0.20}_{-0.26}$	
$B^- \to K^{*-}\rho^0$	$5.5^{+0.6+1.3}_{-0.5-2.5}$	< 6.1	$0.67^{+0.31}_{-0.48}$	$0.96^{+0.06}_{-0.16}$ [b]	$0.16^{+0.24}_{-0.15}$	
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$\overline{B}^0 \to \bar{K}^{*0}\rho^0$	$4.6^{+0.6+3.5}_{-0.5-3.5}$	5.6 ± 1.6	$0.39^{+0.60}_{-0.31}$	0.57 ± 0.12	$0.30^{+0.15}_{-0.30}$	
$B^- \to K^{*-}\phi$ [c]	$10.0^{+1.4+12.3}_{-1.3-\ 6.1}$	10.0 ± 1.1	$0.49^{+0.51}_{-0.42}$	0.50 ± 0.05	$0.25^{+0.21}_{-0.25}$	0.20 ± 0.05
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$\overline{B}^0 \to \bar{K}^{*0}\omega$	$3.0^{+0.5+2.9}_{-0.4-1.8}$	< 2.7	$0.57^{+0.44}_{-0.46}$		$0.21^{+0.25}_{-0.22}$	
$B^- \to K^{*0}K^{*-}$	$0.6^{+0.1+0.3}_{-0.1-0.3}$	< 71	$0.45^{+0.55}_{-0.38}$		$0.27^{+0.19}_{-0.27}$	
$\overline{B}^0 \to K^{*-}K^{*+}$	$0.1^{+0.0+0.1}_{-0.0-0.1}$	< 141	1		0	
$\overline{B}^0 \to K^{*0}\bar{K}^{*0}$	$0.6^{+0.1+0.2}_{-0.1-0.3}$	$1.28^{+0.37}_{-0.32}$	$0.52^{+0.48}_{-0.48}$	$0.80^{+0.12}_{-0.13}$	$0.24^{+0.24}_{-0.24}$	

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