Hadronic B Decays at Belle

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Outline

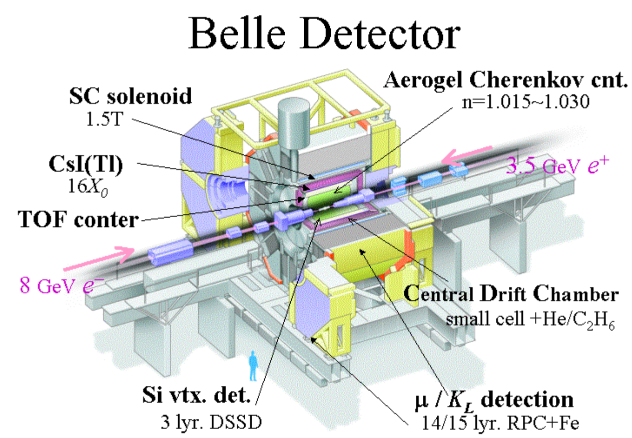
- $B \to \varphi \pi$
  - arXiv:1206.4760v1
  - New upper limit
- $B \to K\pi$, KK, $\pi\pi$
  - $K^+\pi^-$, $K^+\pi^0$, $K^0\pi^+$, $\pi^+\pi^-$, K^+K^0, K^0K^0 branching fraction and A_{CP} using final Belle dataset
  - New $K^0\pi^0$ branching fraction using final Belle dataset
  - New $\pi^+\pi^-$ branching fraction using final Belle dataset
- $B \to K K$
  - New K^+K^- upper limit using final Belle dataset

Hadronic B Decays

- Charmless B decays provide an excellent probe in to the accuracy of the Standard Model
- Measurement of Branching Fractions and A_{CP} can be used to measure CKM parameters
- Measurements can confirm theoretical predictions, or indicate the presence of New Physics.

Dataset

- Using Υ(4S) data collected using the Belle detector at the KEKB asymmetric e^+e^- collider



- B → φπ is measured using 657 x 10^6 BB pairs after processing

- All other analyses are performed on the full Belle Υ(4S) dataset of 772 x 10^6 BB pairs

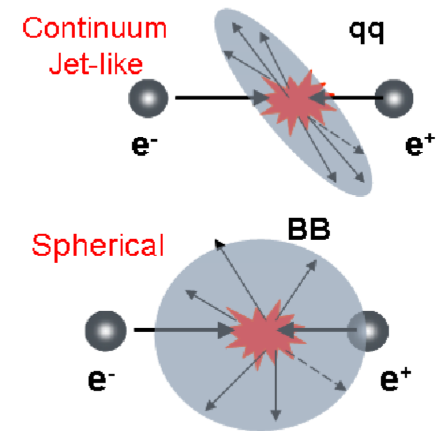
Event selection and analysis

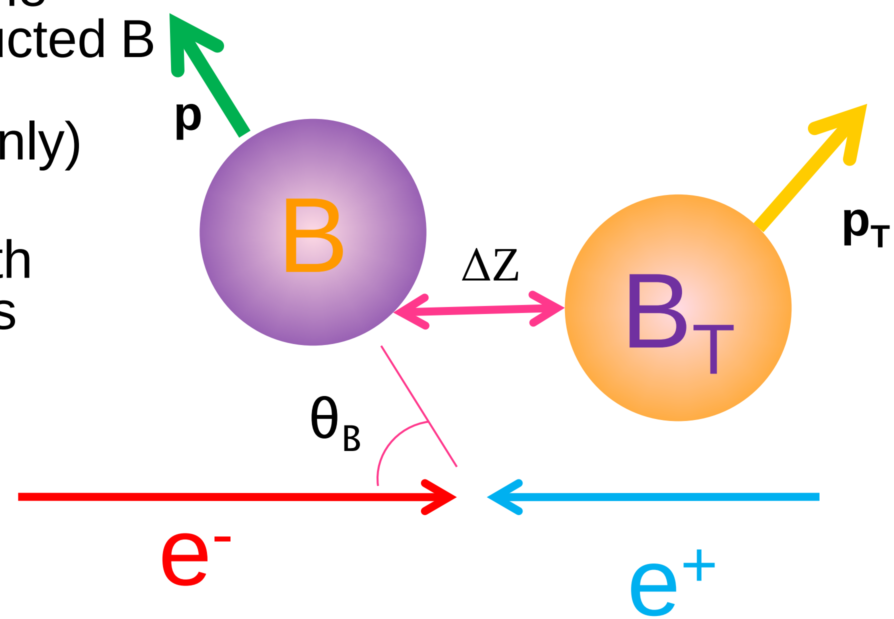
- B meson candidates are identified using two kinematic variables
  - $M_{BC} = \sqrt{E_{Beam}^2 - |\sum_i p_i|^2}$
  - $\Delta E = \sum_i E_i - E_{Beam}$

- These analyses all make use of a continuum suppression variable made up of a combination of event properties combined in to a likelihood ratio (LR)

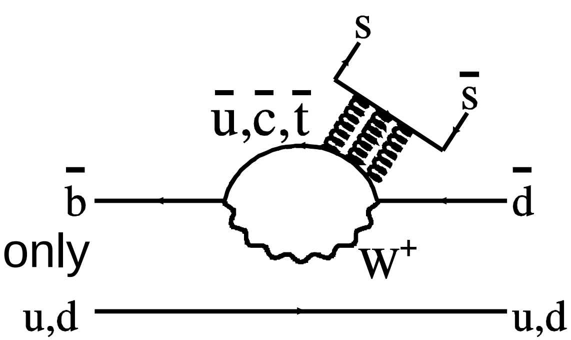
Continuum Suppression

- Typical continuum suppression variables include the
  - Modified Super Fox Wolfram moments combined using a Fisher discriminant
  - The distance between the vertices of the reconstructed B and the tag-side B (ΔZ) (charged track modes only)
  - The B flight direction with respect to the beam axis (Cos(B))



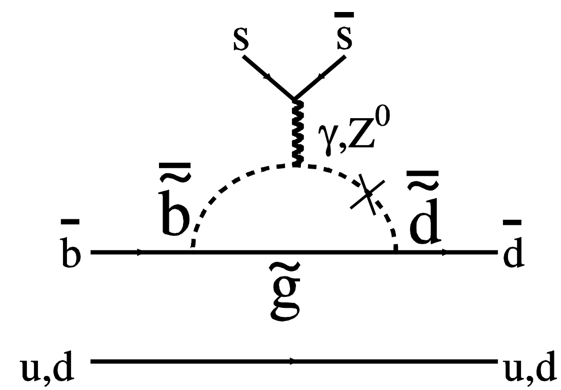


$B \rightarrow \phi\pi$



- $B \rightarrow \phi\pi$ is forbidden at tree level and can only proceed through penguin processes

- Expected SM branching fraction:
  - $B^0 \rightarrow \phi\pi^0 \sim 6.8 \times 10^{-9}$
  - $B^+ \rightarrow \phi\pi^+ \sim 3.2 \times 10^{-8}$ (Y. Li et al. Phys. Rev. D **80**, 014024 (2009))



- Upper limits from BaBar:
  - $B^0 \rightarrow \phi\pi^0 < 2.8 \times 10^{-7}$
  - $B^+ \rightarrow \phi\pi^+ < 2.4 \times 10^{-7}$

- A precise measurement provides a means to study SM from suppressed diagrams in other modes including non-perturbative effects

- An enhanced branching fraction could indicate CMSSM, or the presence of a Z′ boson.

Analysis

- Φ candidates are created from a pair of charged kaons with an invariant mass within 2.5σ of the Φ full width
- The K^+K^-, is then combined with either a π^+ or a π^0 candidate
- $M_{BC} > 5.2$GeV, and $|\Delta E| < 0.1$ for $B^+ \to \varphi\pi^+$ and $|\Delta E| < 0.4$ for $B^0 \to \varphi\pi^0$
- The M_{BC}-ΔE fit cannot distinguish signal from $B \to K^+K^-\pi$
- Additional background suppression is achieved through the use of B tagging algorithm

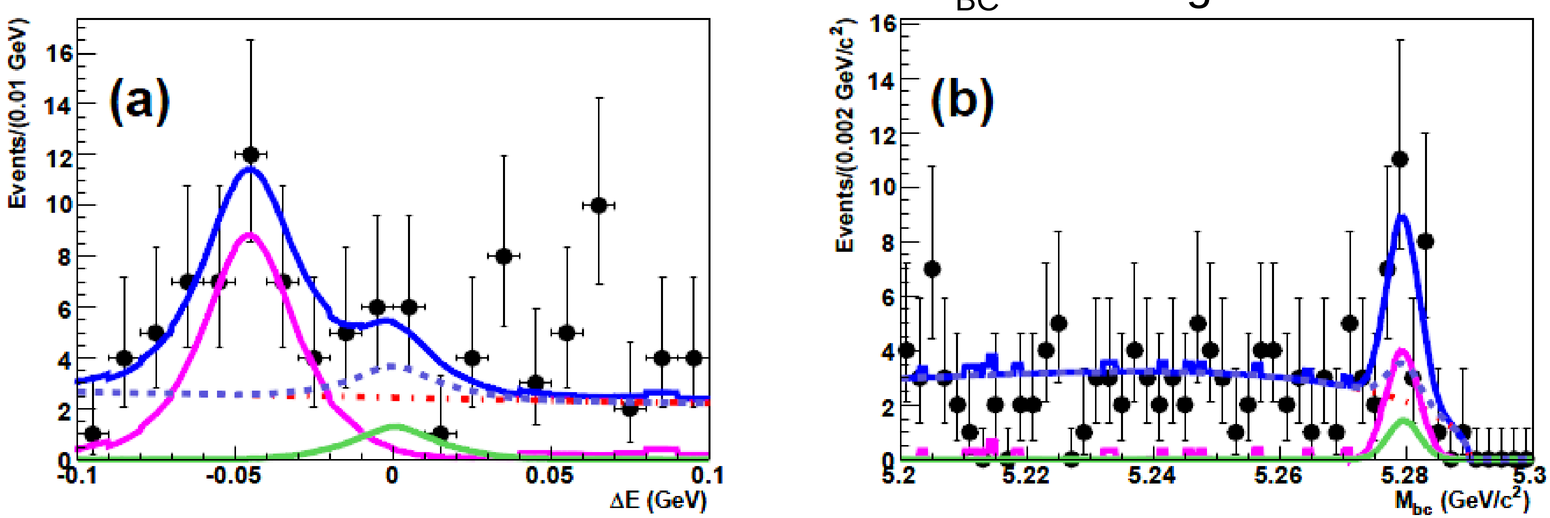
Source of systematic uncertainty	B > $\varphi\pi^+$ (%)	B > $\varphi\pi^0$ (%)
MC Statistics	0.6	0.8
PID	2.0	1.3
Tracking	3.1	2.0
π^0 eff	-	3.0
Continuum Likelihood	2.4	4.1
N_{BB}	1.4	1.4

Results $B \to \varphi\pi^+$

Signal + Continuum (dotted)
Continuum (dashed)
Non-resonant $B \to K^+K^-\pi$
Other Background
Total

		Statistic	Systematic
Yield	4.5	+5.1, -4.3	+3.1, -6.9
ϵ(data)	8.4%	-	-
B x 10^{-7}	0.8	+0.9, -0.8	+0.6, -1.3
B_{UL} x 10^{-7}	3.3	-	-

Projection of fits in the fit region with ΔE on the left and M_{BC} on the right.

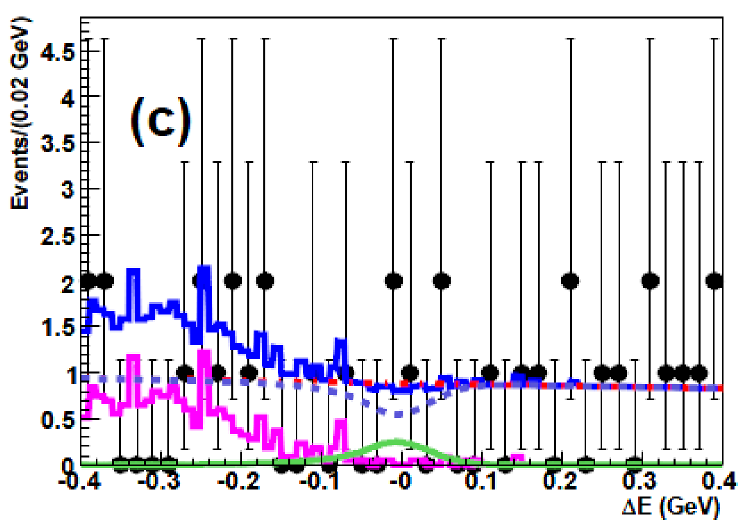


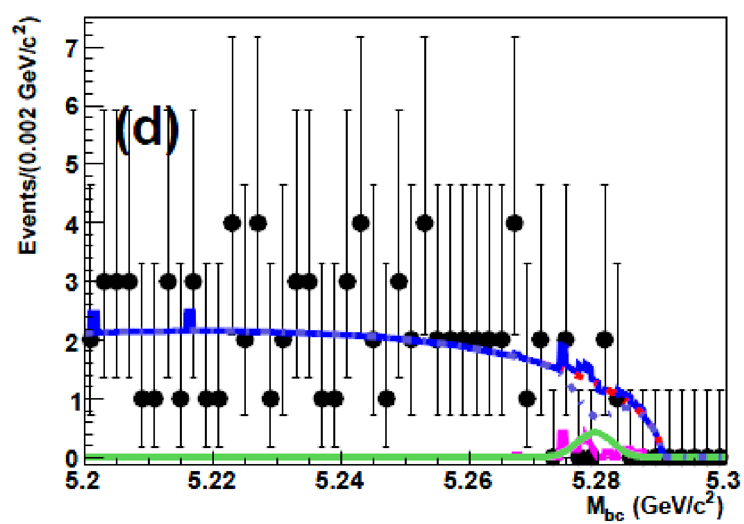
Results $B \to \varphi\pi^0$

		Statistic	Systematic
Yield	-2.2	+2.1, -1.2	+1.3, -2.4
ϵ(data)	4.9%	-	-
$B \times 10^{-7}$	-0.7	+0.6, -0.4	+0.64 -0.8
$B_{UL} \times 10^{-7}$	1.5	-	-

Signal + Continuum (dotted)
Continuum (dashed)
Non-resonant $B \to K^+K^-\pi$
Other Background
Total

Projection of fits in the fit region with ΔE on the left and M_{BC} on the right.





$B \to \pi\pi$, $K\pi$, and KK

- Theoretical calculations for these BF have large uncertainties
- These errors will cancel out in ratios of measurements
- The A_{CP} measurements will help observe SM quantities
- Improved experimental uncertainties can help our understanding of the standard model and help identify New Physics

Analysis

- K^0 candidates are created from a pair of charged pions with an invariant mass within 5.2σ of the K^0 full width

$$\vec{p}_B = \vec{p}_h + \frac{\vec{p}_{\pi^0}}{|p_{\pi^0}|}\sqrt{(E_{Beam} - E_h)^2 - m_{\pi^0}^2}$$

- Decays with a π^0 in the final state use an M_{BC} that accounts for the shower leakage in the ECL

- In the case of modes similar to each other ($B^0 \to K^+\pi^-$ and $B^0 \to \pi^+\pi^-$, $B^+ \to K^+\pi^0$ and $B^+ \to \pi^+\pi^0$, and $B^+ \to K^0\pi^+$ and $B^+ \to K^0K^+$) a simultaneous fit was performed on both modes at once

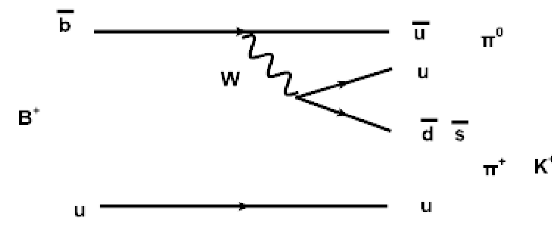
- Other modes were fitted separately

- Shapes were fitted in 3 dimensions - M_{BC}, ΔE and the continuum suppression variable

$\Delta A_{K\pi} = A_{CP}(K\pi^0) - A_{CP}(K\pi)$

- As $B \rightarrow K^+\pi^0$ and $B^0 \rightarrow K^+\pi^-$ have very similar leading order Feynman diagrams, we would expect them to have similar A_{CP}

- A difference could indicate the enhancement of the colour suppressed tree diagram

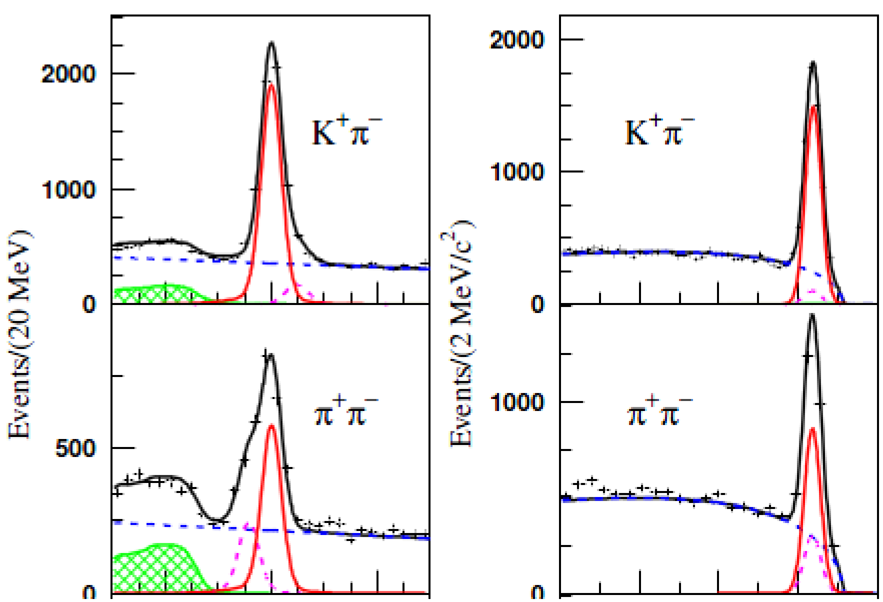


- However, the previous Belle result found the sign and magnitude of these asymmetries to be different

- The difference in these could indicate new Physics, such as a difference between direct CP in neutral and charged B decays

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

Mode	Yield	Branching Fraction x 10^{-6}	A_{CP}
$B \to K^{+/-}\pi^{+/-}$	7525 ± 127	20.00 ±0.34 ±0.63	-0.069±0.014 ±0.007
$B \to \pi^+\pi^-$	2111 ± 89	5.04 ±0.21 ±0.19	*Update coming soon*



Previous Belle Result A_{CP} $B \to K\pi$:

-0.094±0.018 ±0.008

Using 535 x 10^6 BB pairs

Nature **452**, 332 (2008)

Current Results:

BaBar: -0.107 ±0.016

arXiv:0807.4226

CDF: -0.086 ±0.023 ±0.009

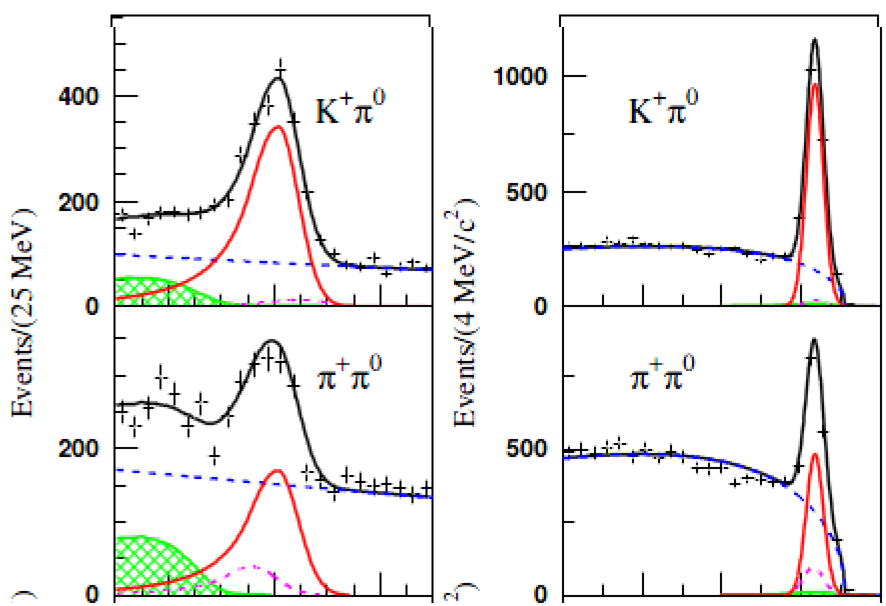
PRL **106**, 181802 (2011)

LHCb: -0.088 ±0.011 ±0.008

PRL **108**, 201601 (2012)

$B \to K^+\pi^0$ and $B \to \pi^+\pi^0$

Mode	Yield	Branching Fraction x 10^{-6}	A_{CP}
$B \to K^+\pi^0$	3731 ± 92	12.62 ±0.31 ±0.56	+0.043±0.024±0.002
$B \to \pi^+\pi^0$	1846 ± 82	5.86 ±0.26 ±0.38	+0.025±0.043±0.007



Previous Belle Result

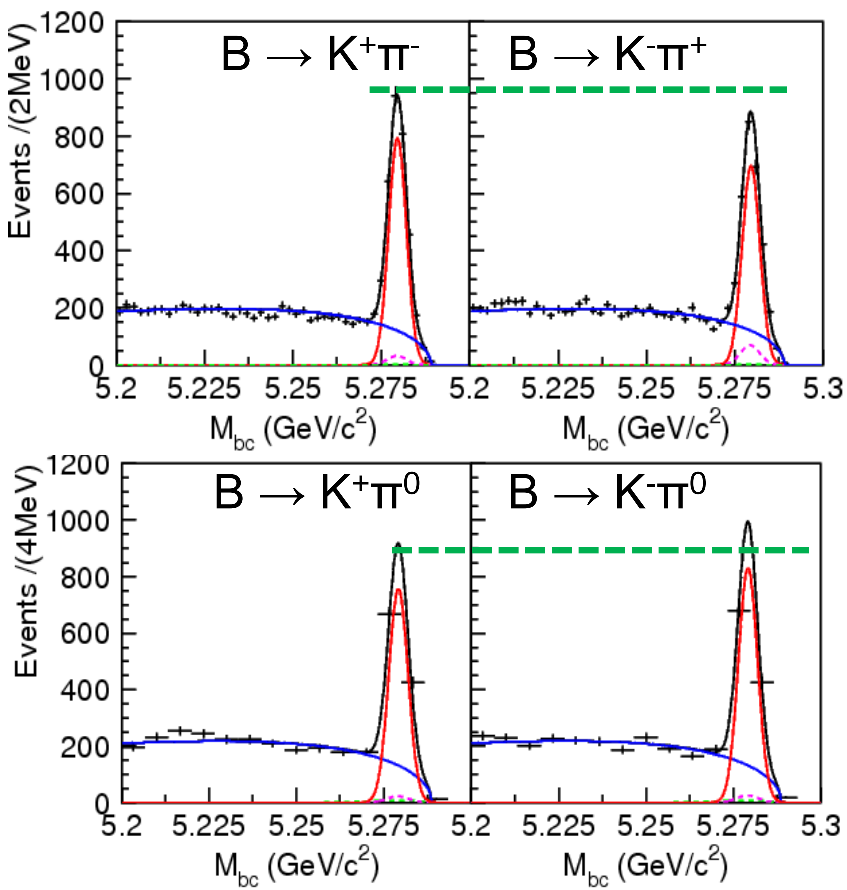
A_{CP} $B \to K\pi^0$:

0.07±0.03 ±0.01
Using 535 x 10^6 BB pairs
Nature **452**, 332 (2008)

A_{CP} $B \to \pi\pi^0$:

0.07±0.06 ±0.01
Using 535 x 10^6 BB pairs
Nature **452**, 332 (2008)

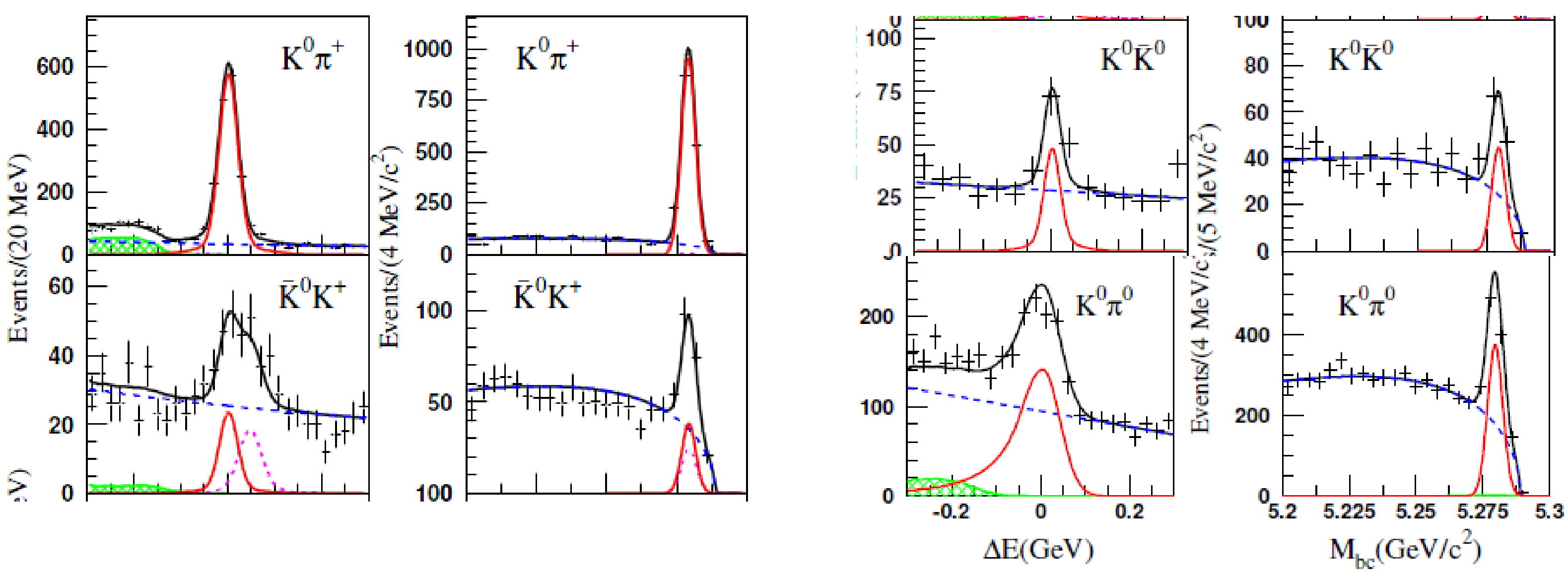
$\Delta A_{K\pi} = A_{CP}(K\pi^0) - A_{CP}(K\pi)$



- Previous Belle Result: $\Delta A_{K\pi} = +0.164 \pm 0.037$ 4.4σ
- New Result: $\Delta A_{K\pi} = +0.112 \pm 0.028$ 4σ

$B \to K^0\pi^{+/0}$ and $B \to K^0K^{+/0}$

Mode	Yield	Branching Fraction x 10^{-6}	A_{CP}
$B \to K^0\pi^+$	3229 ± 71	$23.97^{+0.53}_{-0.52} \pm 0.69$	-0.014±0.021 ±0.006
$B \to K^0K^+$	134 ± 23	$1.11^{+0.19}_{-0.18} \pm 0.05$	+0.017±0.168±0.002
$B \to K^0K^0$	103 ± 15	$1.26^{+0.19}_{-0.18} \pm 0.06$	-
$B \to K^0\pi^0$	961 ± 45	9.68 ±0.46 ±0.50	-



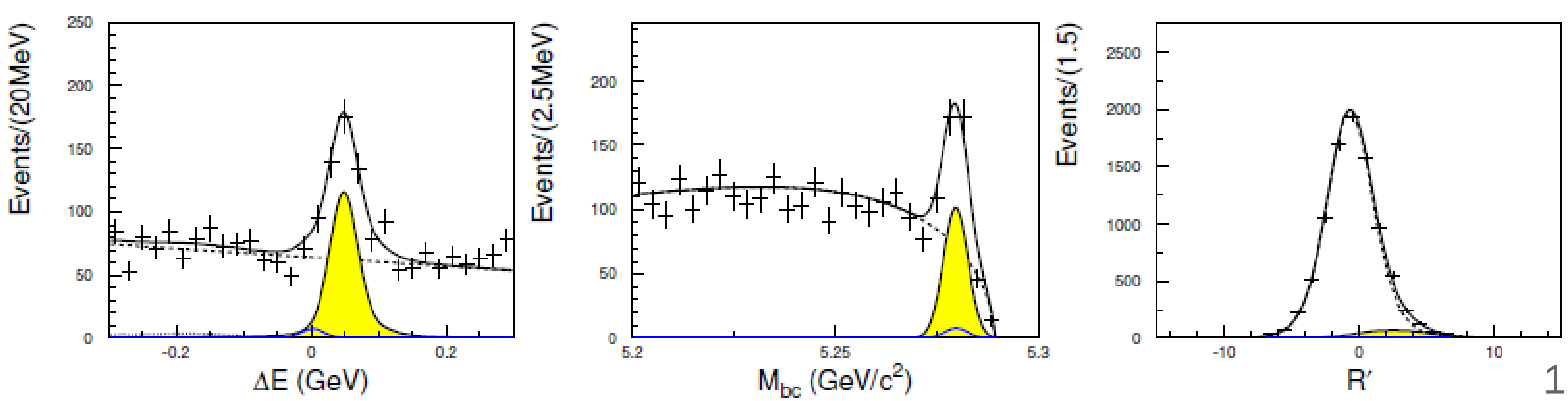
$B \to K^+K^-$

- The branching fraction of $B \to K^+K^-$ is expected to be 2 orders of magnitude smaller than $B \to K^+\pi^-$
- $B \to K^+\pi^-$ is a large background for this mode
- $B \to \pi^+\pi^-$ also makes a contribution

$B \to K^+K^-$

Mode	Yield	Branching Fraction x 10^{-6}
$B \to K^+K^-$	35 ± 29	0.10±0.08±0.04 (< 0.20) to 1.2σ

Experiment	BF x 10^{-6}	
Belle 2007	$0.09^{+0.18}_{-0.13} \pm 0.01$	(< 0.41)
Babar 2007	$0.04 \pm 0.15 \pm 0.08$	(< 0.5)
PDG 2010	$0.15^{+0.11}_{-0.10}$	(< 0.41)
LHCb 2012 (Preliminary)	$0.11^{+0.05}_{-0.04} \pm 0.06$	(< 0.18)



The A_{CP} Sum rule

- While $A_{K\pi}$ asymmetry can be explained by colour suppressed tree diagrams, the A_{CP} sum rule is a model independent, and should hold *(Gronau et al. hep-ph/0608040)*

- The A_{CP} sum rule is found to be non-zero to 2σ

$$A_{CP}(K^+\pi^-) + A_{CP}(K^0\pi^+)\frac{B(K^0\pi^+)}{B(K^+\pi^-)}\frac{\tau_0}{\tau_+} = A_{CP}(K^+\pi^0)\frac{2B(K^+\pi^0)}{B(K^+\pi^-)}\frac{\tau_0}{\tau_+} + A_{CP}(K^0\pi^0)\frac{2B(K^0\pi^0)}{B(K^+\pi^-)}$$

$$A_{CP}(K^+\pi^-) + A_{CP}(K^0\pi^+)\frac{\Gamma(K^0\pi^+)}{\Gamma(K^+\pi^-)} = A_{CP}(K^+\pi^0)\frac{2\Gamma(K^+\pi^0)}{\Gamma(K^+\pi^-)} + A_{CP}(K^0\pi^0)\frac{2\Gamma(K^0\pi^0)}{\Gamma(K^+\pi^-)}$$

Left side - right side = -0.270 ± 0.142

Using Acp($K^0\pi^0$=+0.14+-0.13+-0.06
*PRD **81**, 011101, (2010) Belle.*

Conclusion

- New branching fractions and direct A^{CP} are available for B→hh the final Belle dataset with improved analyses
  (Publication coming soon!!)

- A new, improved upper limit is available for B→ϕπ from Belle

- The ratios present in B → hh are consistent with the expected theoretical values, and have errors that are comparable with theoretical errors

- K^+K^- upper limits were improved by a factor of 2