Charmless Hadronic B decays from Belle

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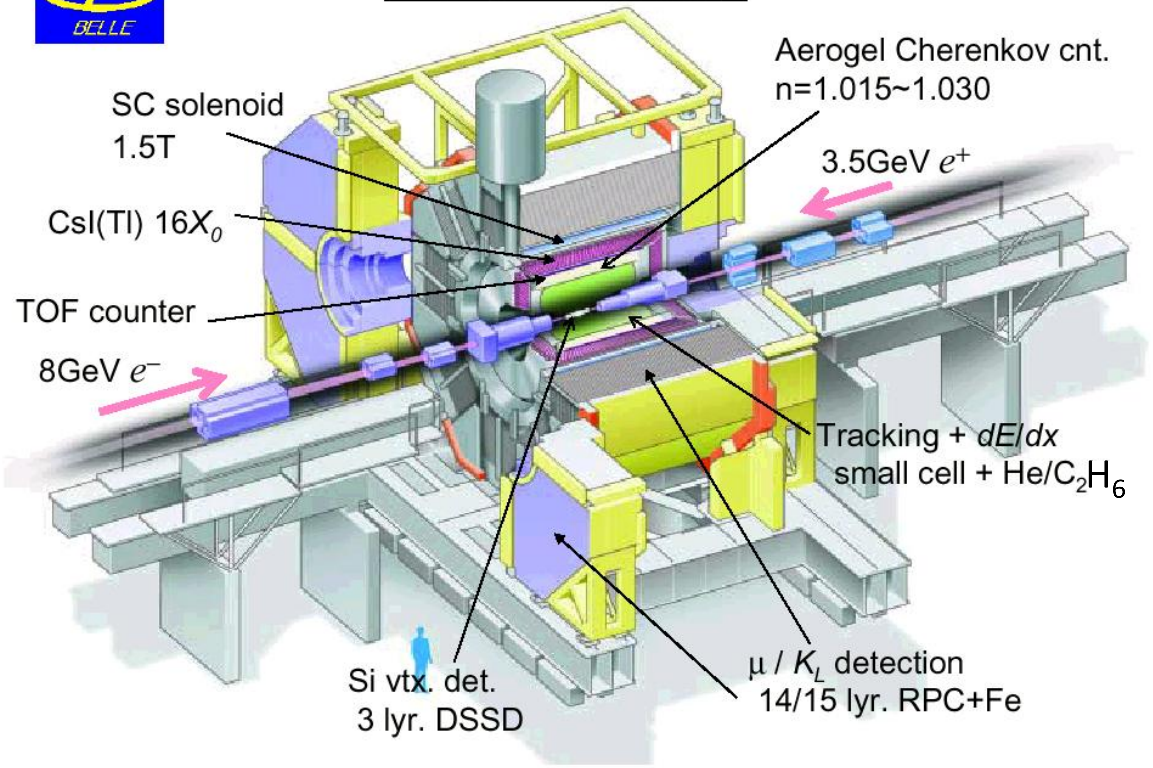
Outline

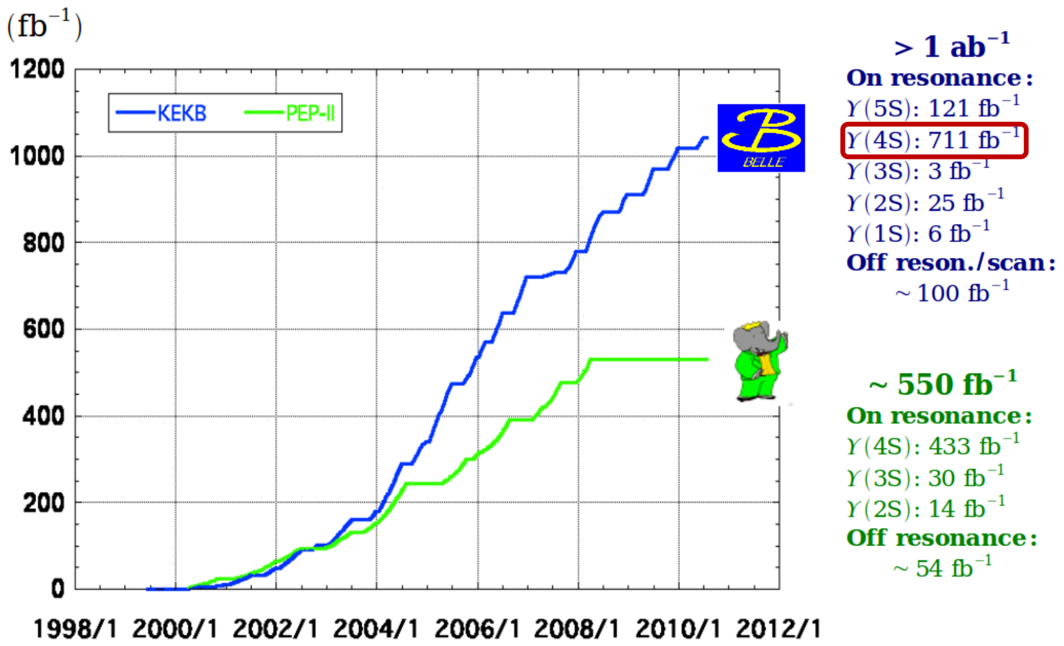
- Introduction
- Study of
  - $B^{\pm} \rightarrow K^{+} K^{-} \pi^{\pm}$ — PRD **96**, 031101 (2017)
  - $B^{0} \rightarrow \pi^{0} \pi^{0}$ — PRD **96**, 032007 (2017)
- Summary

Belle Detector



- Operated at the KEKB collider in Tsukuba, Japan (1999 – 2010)
- Asymmetric beam energy at the ϒ(4S) resonance (8 GeV e^- on 3.5 GeV e^+)

Integrated luminosity of B factories



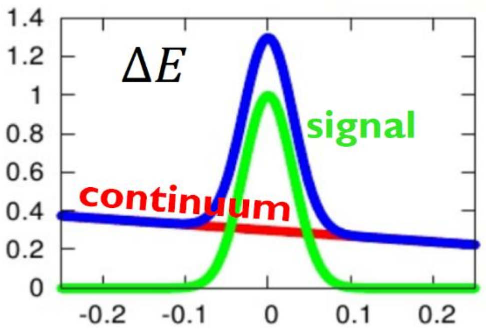
- Recorded 772 million $B\overline{B}$ pairs
- All analyses presented here are based on the full Belle data sample

Analysis Technique

- To identify *B* decays, two kinematic variables are used: $\Delta\mathrm{E}$ and $\mathrm{M_{bc}}$

Energy difference

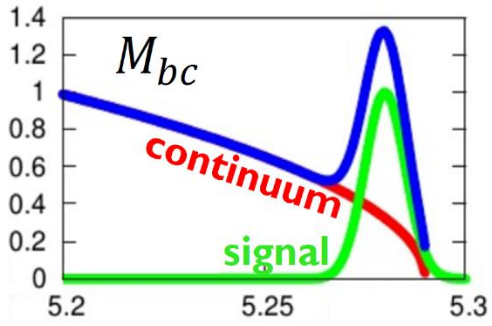
$$\Delta E = \sum_i E_i - E_{beam}$$



GeV

Beam-constrained mass

$$M_{bc} = \sqrt{E_{beam}^2 - |\sum_i \vec{p}_i|^2}$$



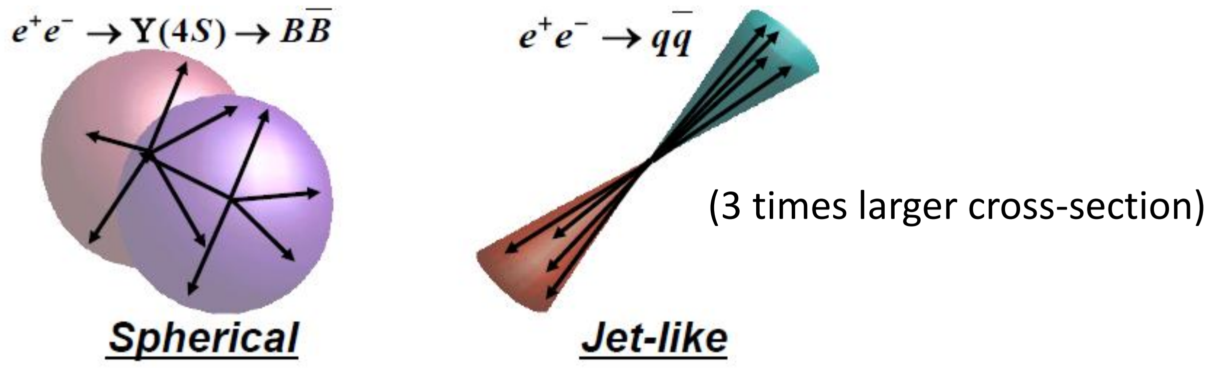
GeV/c²

p_i and E_i are the momentum and energy of i^{th} daughter of the reconstructed *B* meson in the CM frame

Analysis Technique (contd.)

- Continuum events are the primary source of background: $e^+e^- \rightarrow q\bar{q}$ (q = u, d, s and c) → fragmentation → hadrons as two back-to-back jets

- To suppress this background, variables describing the event shape topology are combined in a multivariate analyzer, such as a neural network (NN) or a Fisher discriminant



- Use an unbinned extended maximum likelihood (ML) fit based on different discriminating variables

- The fit usually includes signal, continuum, charm and charmless B background components

$B^{\pm} \to K^{+}K^{-}\pi^{\pm}$

- Mainly proceeds via $b \to u$ tree and $b \to d$ penguin diagrams

- No intermediate state observed yet

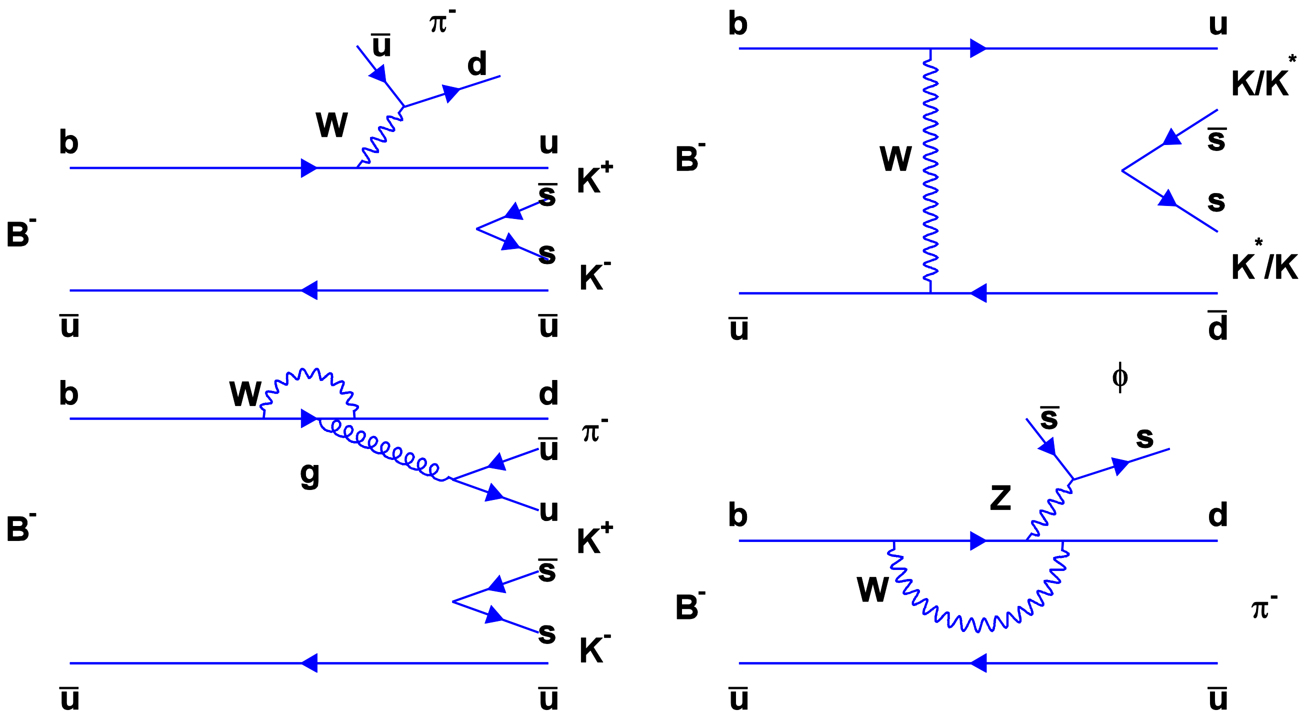
- Previous measurements:

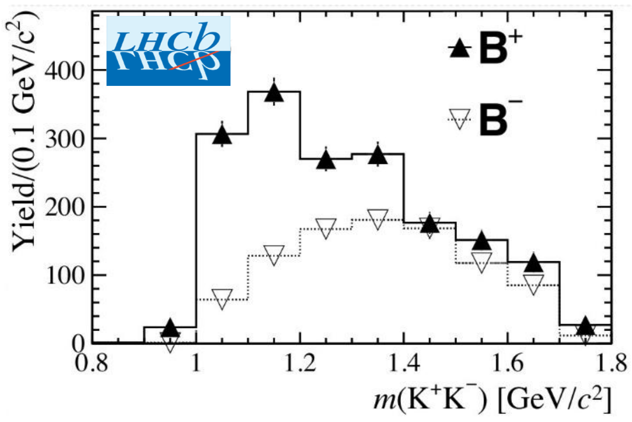
$$BF(B^{\pm} \to K^{+}K^{-}\pi^{\pm}) = (5.0 \pm 0.5 \pm 0.5) \text{ x } 10^{-6}$$

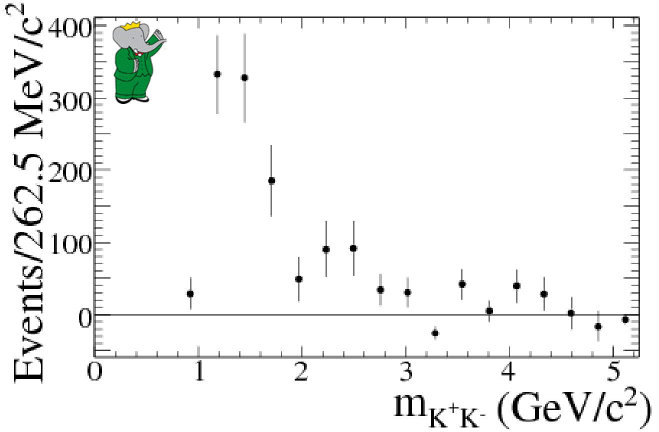
PRL **99**, 221801 (2007)

$$A_{CP} = -0.123 \pm 0.017 \pm 0.012 \pm 0.007$$

PRD **90**, 112004 (2014)







- A structure is seen by BaBar and LHCb in $K^{+}K^{-}$ low invariant mass spectrum of $B^{+} \to K^{+}K^{-}\pi^{+}$ and a large local CP asymmetry in the same mass region

- Final state interactions may contribute to CP violation

PRD **89**, 094013 (2014)

$B^{\pm} \to K^{+}K^{-}\pi^{\pm}$: Backgrounds

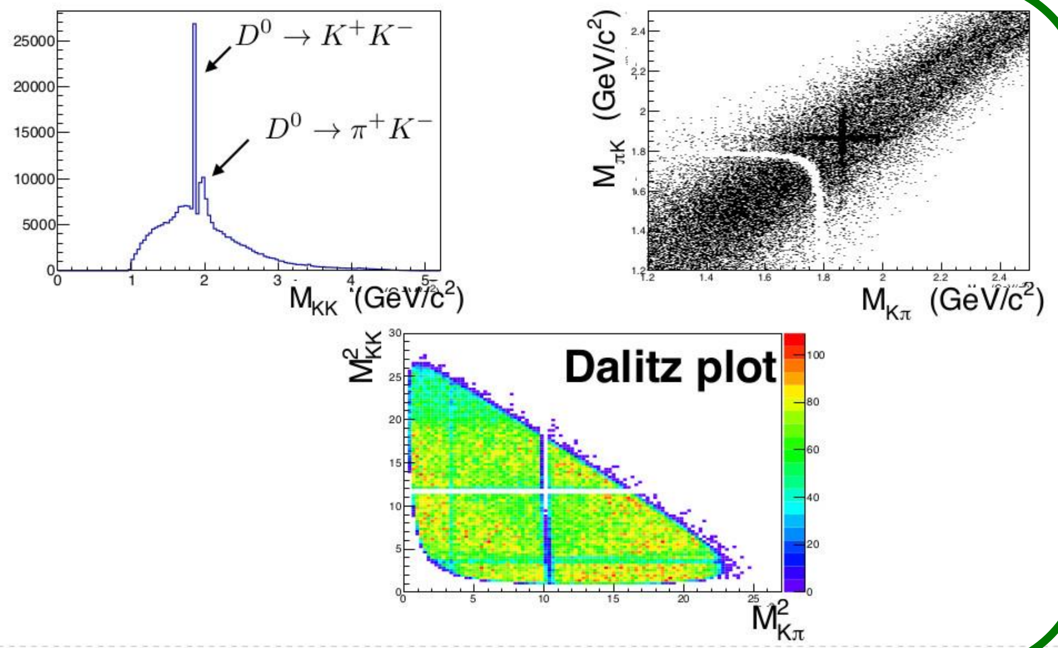
- Continuum background
- Continuum background suppression: Implement a NN based on 5 event-shape variables
- A tight requirement on NN removes 99% of the continuum events while retaining 48% of the signal

NN selection requirement is optimized by maximizing a figure of merit

$$F.O.M = \frac{N_S}{\sqrt{N_S + N_B}}$$

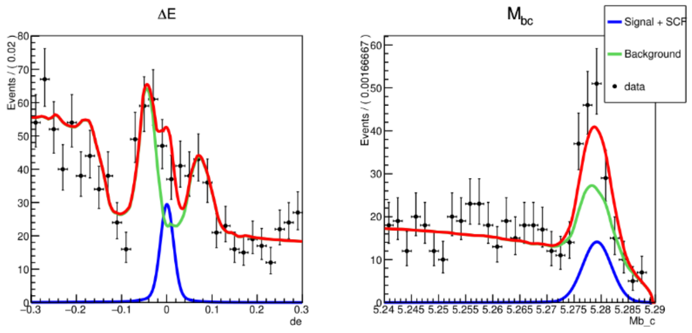
- Generic B background
- Arises due to B decays via the dominant $b \to c$ transition
- Charm veto to reject $b \to c$ backgrounds after investigating the $K^{+}K^{-}$ and $K^{+}\pi^{-}$

- Rare B background
- Arises due to B decays in which one of the B decays via $b \to u, d, s$

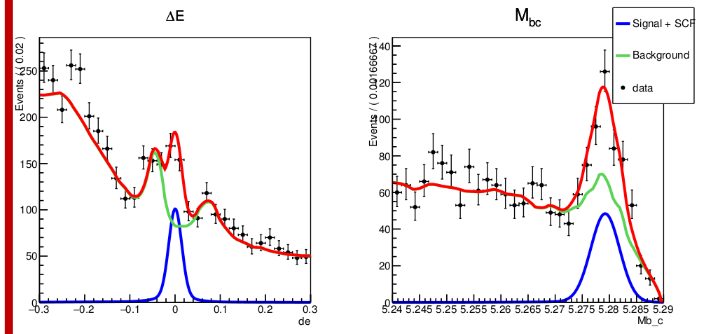


$B^{\pm} \to K^{+}K^{-}\pi^{\pm}$

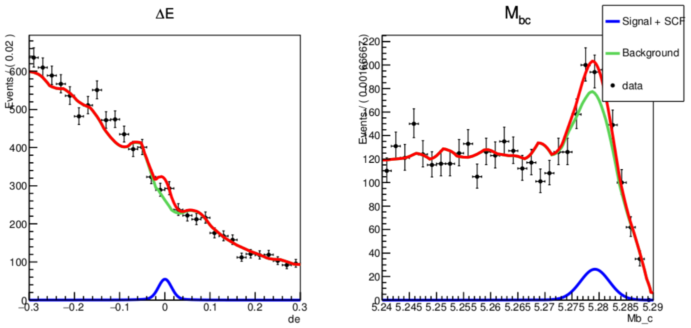
Signal enhanced projection plots



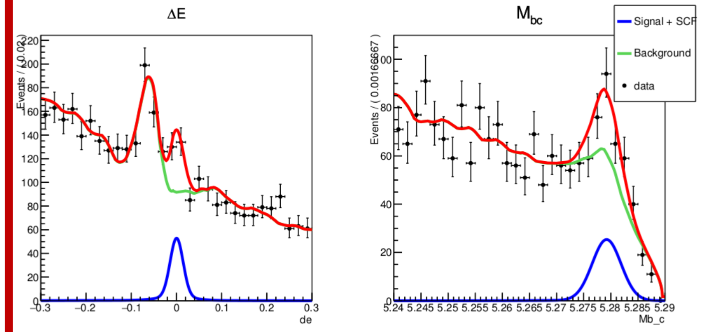
Bin0



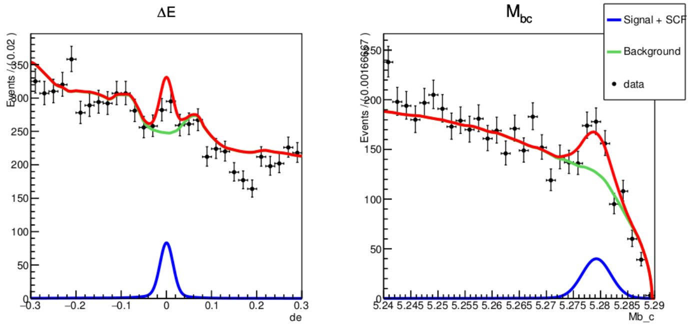
Bin1



Bin2



Bin3



Bin4

Signal
Background components

- Fit components:

Signal, continuum background, generic B background and rare B background

- Signal and A_{CP} are fitted in M_{KK} bins

- The overall results are obtained by integrating over the whole M_{KK} region

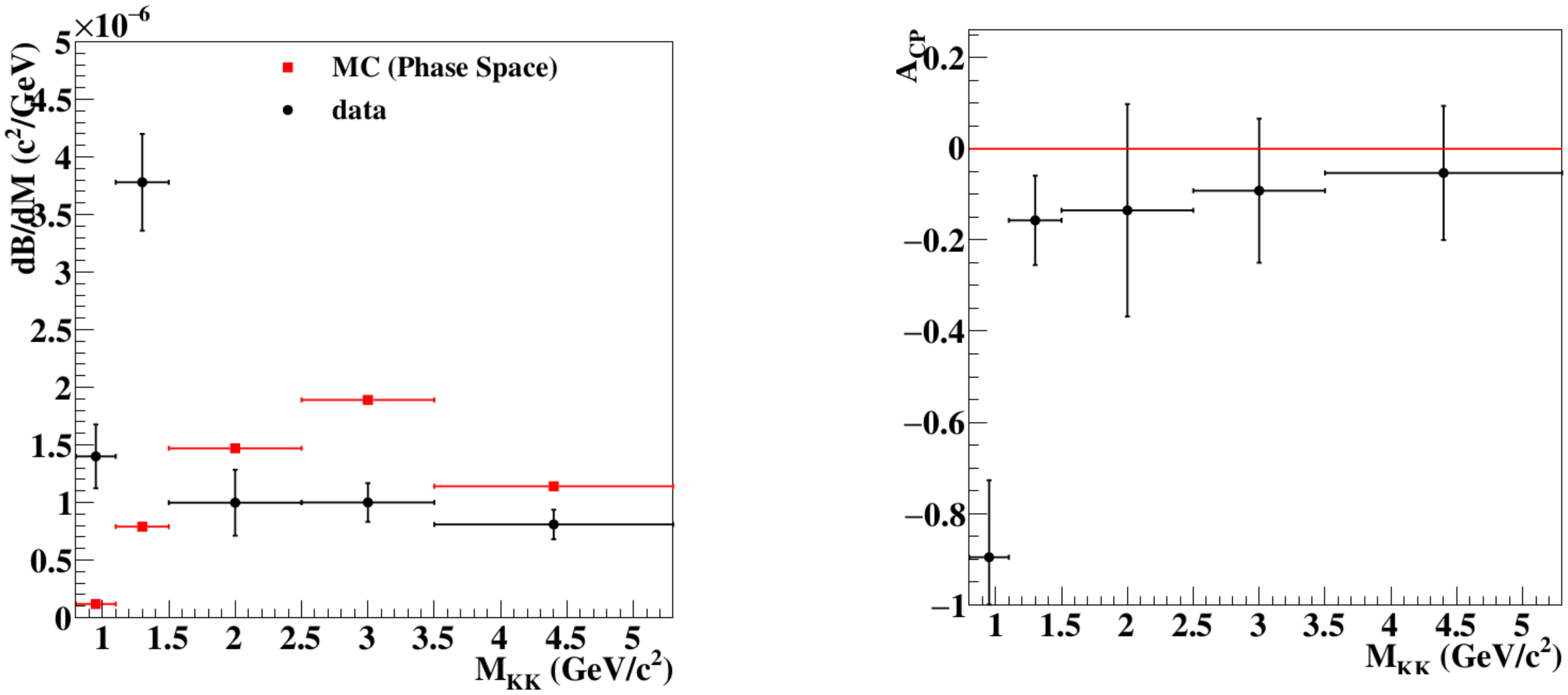
- We obtain

Signal yield = $\mathbf{715 \pm 48}$

$B^{\pm} \rightarrow K^{+}K^{-}\pi^{\pm}$

- An excess and a large CP asymmetry are seen in $M_{K^{+}K^{-}} < 1.5\ \mathrm{GeV/c^2}$, confirming the observations by BaBar and LHCb

- We find a strong evidence of a large CP asymmetry of $-0.90 \pm 0.17 \pm 0.03$ with 4.8σ significance for $M_{K^{+}K^{-}} < 1.1\ \mathrm{GeV/c^2}$



$B^{\pm} \to K^{+}K^{-}\pi^{\pm}$

$M_{K^+K^-}$ (GeV/c^2)	N_{sig}	Efficiency (%)	dBF/dM ($x10^{-7}$)	A_{CP}
0.8-1.1	59.8±11.4±2.6	19.7	14.0±2.7±0.8	-0.90±0.17±0.04
1.1-1.5	212.4±21.3±6.7	19.3	37.8±3.8±1.9	-0.16±0.10±0.01
1.5-2.5	113.5±26.7±18.6	15.6	10.0±2.3±1.7	-0.15±0.23±0.03
2.5-3.5	110.1±17.6±4.9	15.1	10.0±1.6±0.6	-0.09±0.16±0.01
3.5-5.3	172.6±25.7±7.4	16.3	8.1±1.2±0.5	-0.05±0.15±0.01

- Overall BF and A_{CP}

$$BF\ (B^{+} \to K^{+}K^{-}\pi^{+}) = (5.38 \pm 0.40 \pm 0.35)\ x\ 10^{-6}$$

$$A_{CP} = -0.182 \pm 0.071 \pm 0.016$$

$B^0 \rightarrow \pi^0\,\pi^0$

- Proceeds via $b \rightarrow u$ tree and $b \rightarrow d$ penguin diagrams
- Time dependent measurements of $B \rightarrow \pi\pi$ are sensitive to the UT angle ϕ_2/α
- Among the $B \rightarrow \pi\pi$ decays, BF and A_{CP} for $B^0 \rightarrow \pi^0\pi^0$ are the least well determined
- Previous measurements:

$$BF = \left(2.3 \ {}^{+0.4}_{-0.5} \ {}^{+0.2}_{-0.3}\right) \times 10^{-6}$$ (Belle) $(275 \times 10^6\ B\bar{B})$

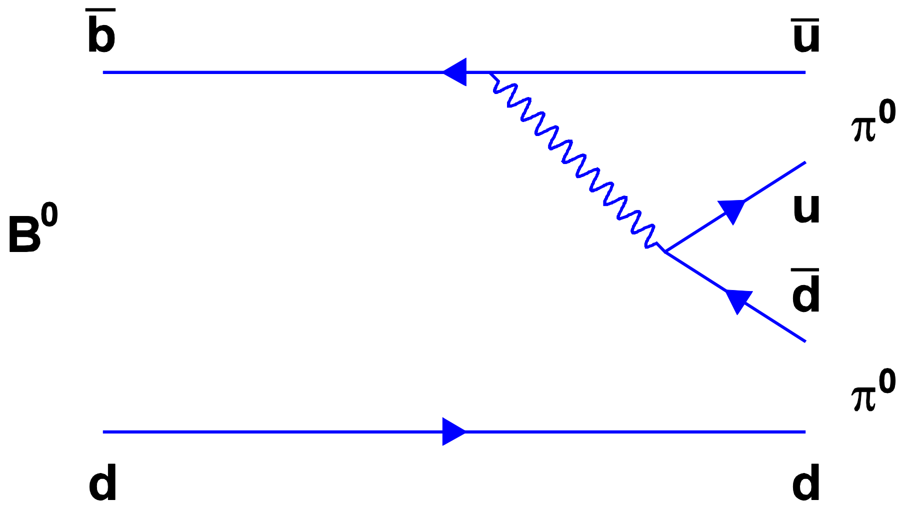
PRL **94**, 181803 (2005)

$$BF = (1.83 \pm 0.21 \pm 0.13) \times 10^{-6}$$ (BaBar) $(467 \times 10^6\ B\bar{B})$

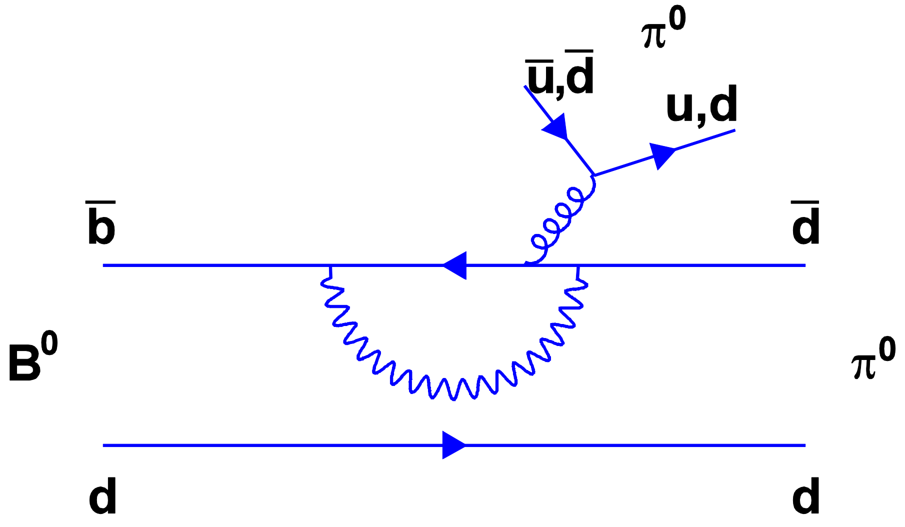
PRD **87**, 052009 (2013)

- Theory: quantum chromodynamics based factorization predicts BF below 1×10^{-6}

PRD **73**, 114014 (2006) PRD **83**, 034023 (2011)



$b \rightarrow u$ tree diagram



$b \rightarrow d$ penguin

$B^0 \to \pi^0 \pi^0$

- 3D fit to ΔE, M_{bc} and T_c (continuum suppression variable) with four components:
  - Signal
  - Continuum background
  - $B^+ \to \rho^+\pi^0$
  - Other rare charmless

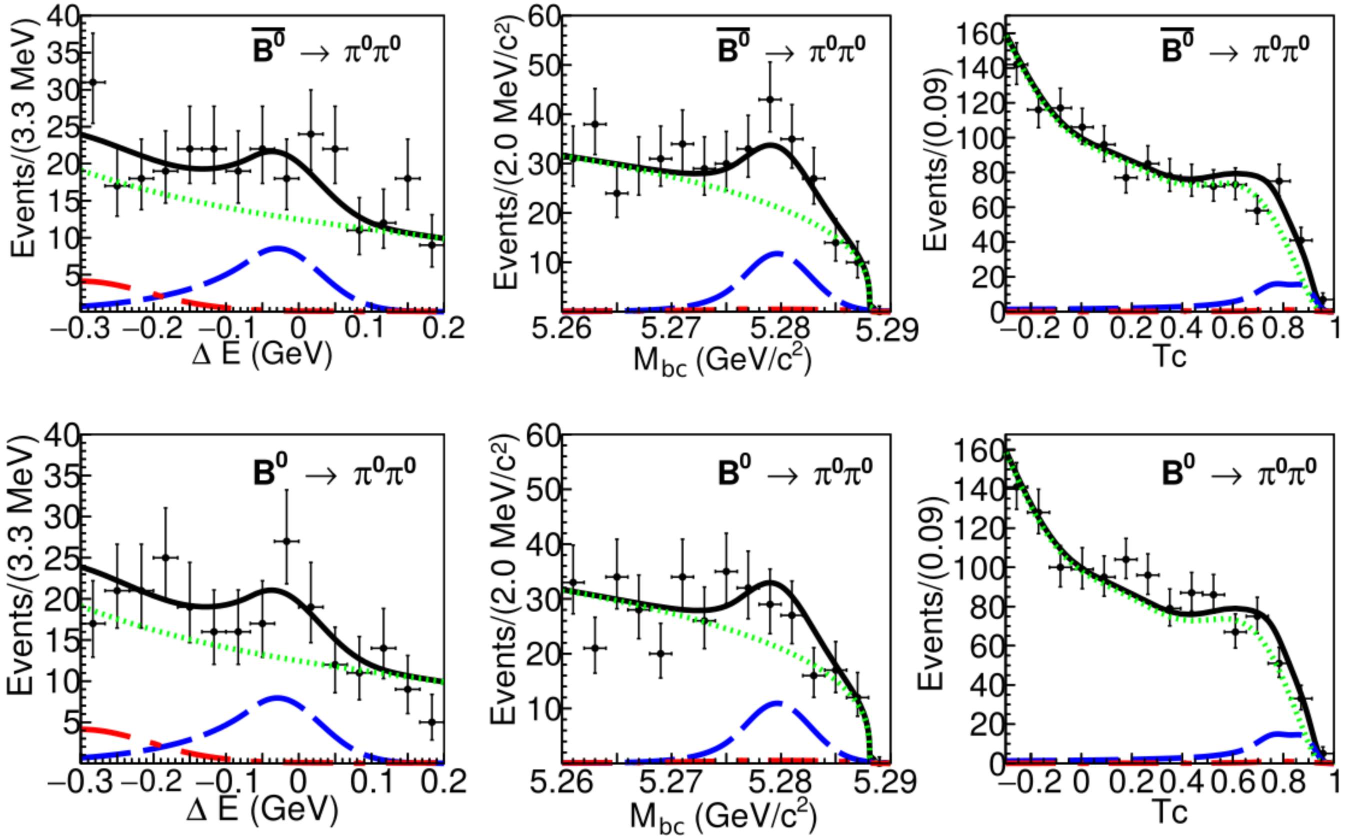
- b −flavor charge q: $[+1(-1)$ tagging a $B^0(\bar{B}^0)]$
- r: purity

- Simultaneous fit to 14 bins in the flavor tagging variable $(q \bullet r)$ for SVD1 (2)

- T_c: Fisher discriminant of likelihood (Fox-Wolfram moments), cosine of the polar angle of the B candidate with respect to the z axis and cosine of the angle between the thrust axis of the B candidate and rest of the event in the CM frame

$B^0 \to \pi^0\,\pi^0$

Signal enhanced projection plots



- **Data are points with error bars**

- **Full fit results**
- **Signal**
- **Continuum background**
- **$B^+ \to \rho^+\pi^0$**
- **Other rare charmless**

Signal yield = $\mathbf{217 \pm 32}$

$BF(B^0 \to \pi^0\pi^0) = (1.31 \pm 0.19 \pm 0.18) \text{ x } 10^{-6}$

$A_{CP} = +0.14 \pm 0.36 \pm 0.12$

$B^0 \to \pi^0 \pi^0$

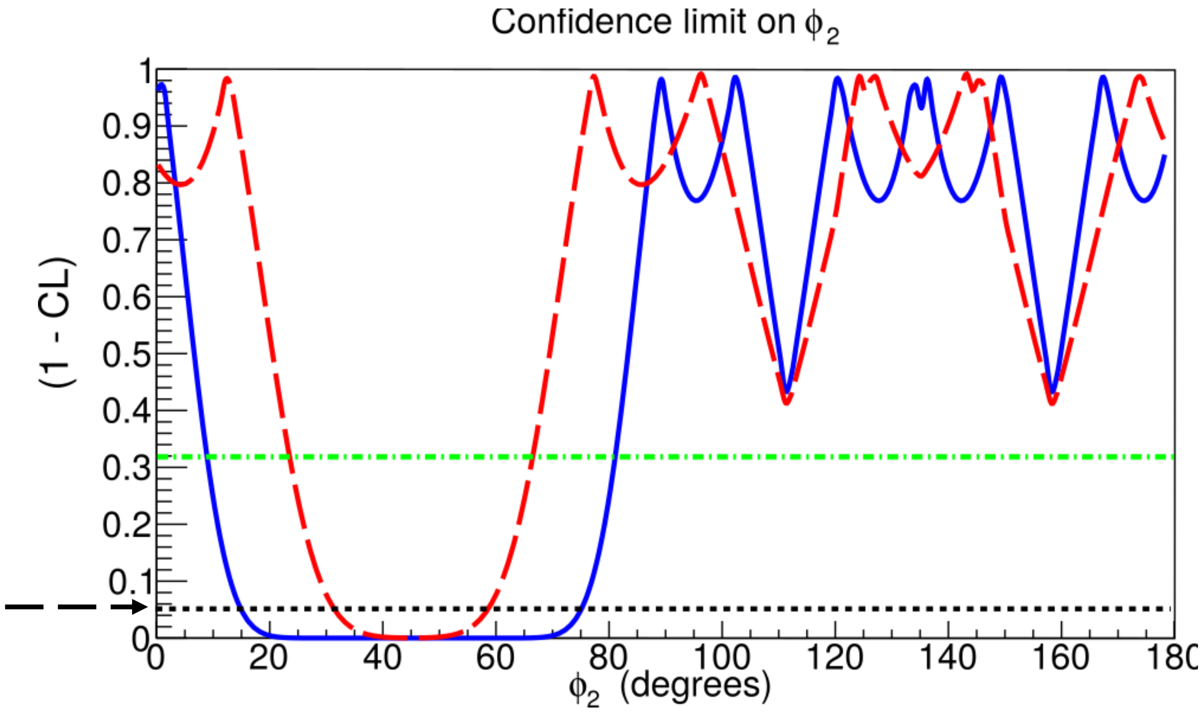
PRD **87**, 031103 (2012)

- BF and A_{CP} results for $B^0 \to \pi^0\pi^0$ are combined with previous Belle results on $B^0 \to \pi^+\pi^-$ and $B^+ \to \pi^+\pi^0$ to constrain ϕ_2 employing isospin relations

PRD **88**, 092003 (2013)

PRL **65**, 3381 (1990)

- We exclude the CP violating parameter ϕ_2 from the range 15.5° < ϕ_2 < 75° at 95% confidence level



------ Previous constraint from Belle

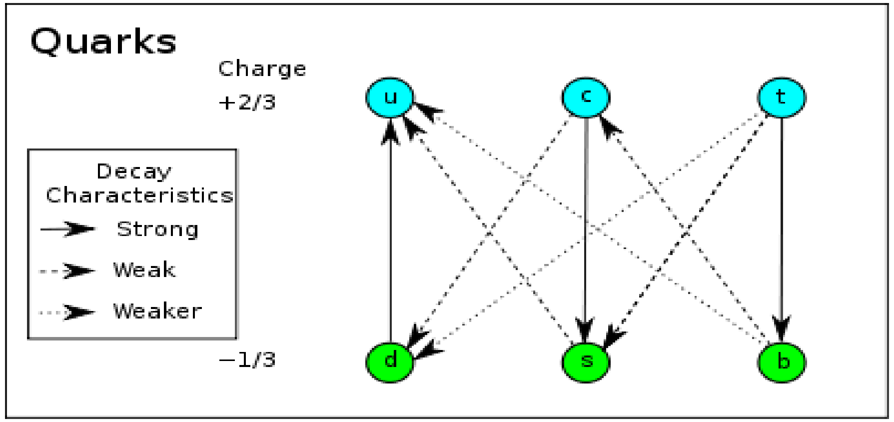
------ Including our new results

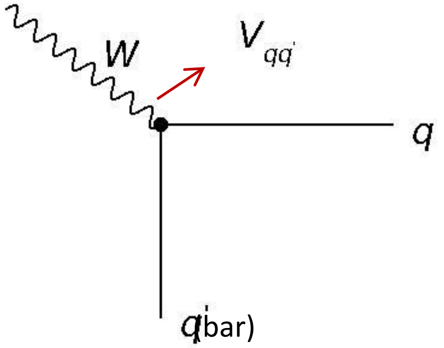
Summary

- Measured BF $(B^+ \rightarrow K^+K^-\pi^+)$ is $(5.38 \pm 0.40 \pm 0.35) \times 10^{-6}$
- $A_{CP} = -0.182 \pm 0.071 \pm 0.016$
- An excess and a large CP asymmetry are seen in $M_{K^+K^-} < 1.5\ GeV/c^2$, confirming the observations by BaBar and LHCb
- We find a strong evidence of a large CP asymmetry of $-0.90 \pm 0.17 \pm 0.03$ with 4.8σ significance for $M_{K^+K^-} < 1.1\ GeV/c^2$

- Measured BF $(B^0 \rightarrow \pi^0\pi^0)$ is $(1.31 \pm 0.19 \pm 0.18) \times 10^{-6}$ (6.4σ)
- $A_{CP} = +0.14 \pm 0.36 \pm 0.12$
- We exclude the CP violating parameter ϕ_2 from the range $15.5^o < \phi_2 < 75^o$ at 95% confidence

Introduction to CKM matrix





❖ CKM matrix describes the probability of a transition from one quark i to another quark j. These transitions are proportional to $|V_{ij}|^2$

❖ 3×3 Unitarity matrix ⇒ 4 independent parameters (1 irreducible phase)

$$V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

Wolfenstein parameterization

$$V_{CKM} = \begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix}$$

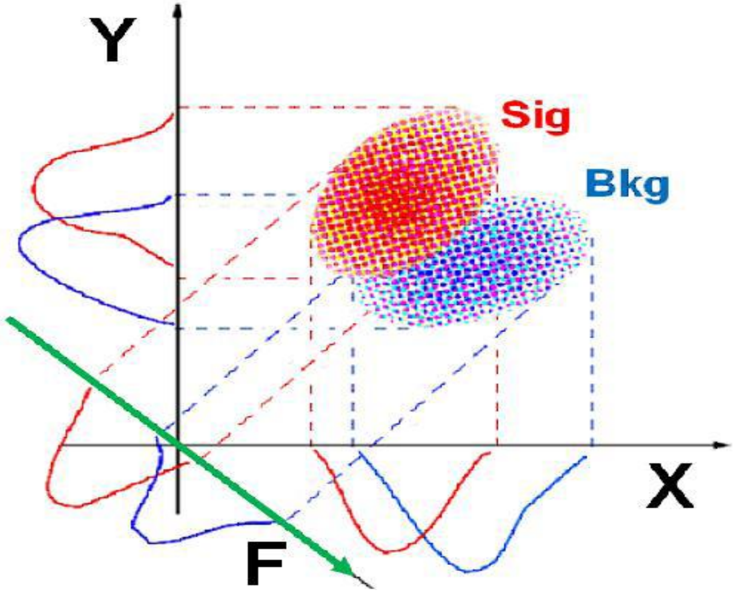
Unitarity $V^{\dagger}V=1$

$\lambda = 0.22$, $A = 0.81$, $\rho = 0.14$ and $\eta = 0.35$

Fisher Discriminant

The variable: $F = \sum_{i=1}^{N} \alpha_i x_i$

1. The discriminant F is a linear combination of the input variables x_i (such as FW moments)
2. Multi variables can be combined into a single variable
3. Project multi dimensional data onto one dimension (axis)
4. Find the axis (best set of α_i) to separate signal and background maximally



Fox Wolfram moments

$$H_l = \sum_{ij} |p_i||p_j| P_l(\cos\theta_{ij})$$

i,j= particles

Momentum of particle i and j

Legendre polynomial

Angle between particle i and j