Difference in direct charge-parity violation between charged and neutral *B* meson decays

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Motivation

– Equal amounts of matter and antimatter are predicted to have been produced in the Big Bang.

> It is thought that the first basic particles emerged when a large concentration of energy coagulated into matter and antimatter.

– Sakharov conditions for matter dominance

- Baryon number violation
- *C*-symmetry and *CP*-symmetry violation
- Interactions out of thermal equilibrium

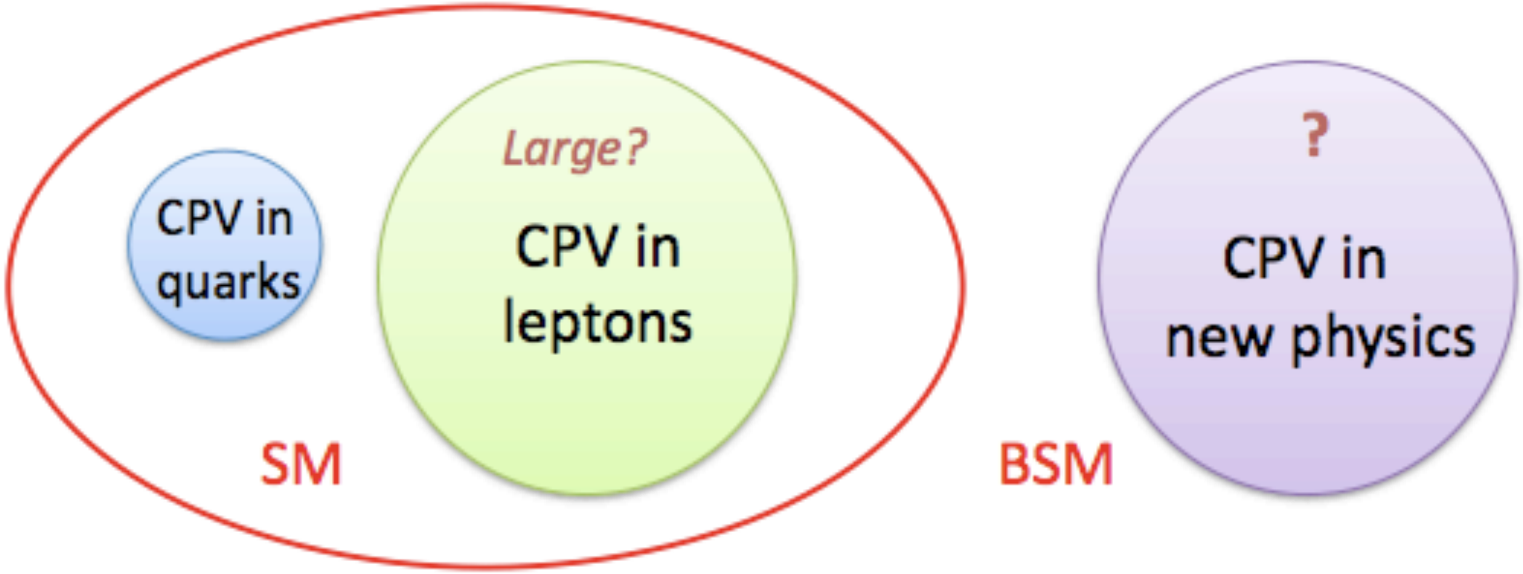
First Observations

1964: Indirect CPV
1999: Direct CPV
(for neutral kaons)

– CPV in quark sector can be explained using Kobayashi-Maskawa mechanism.

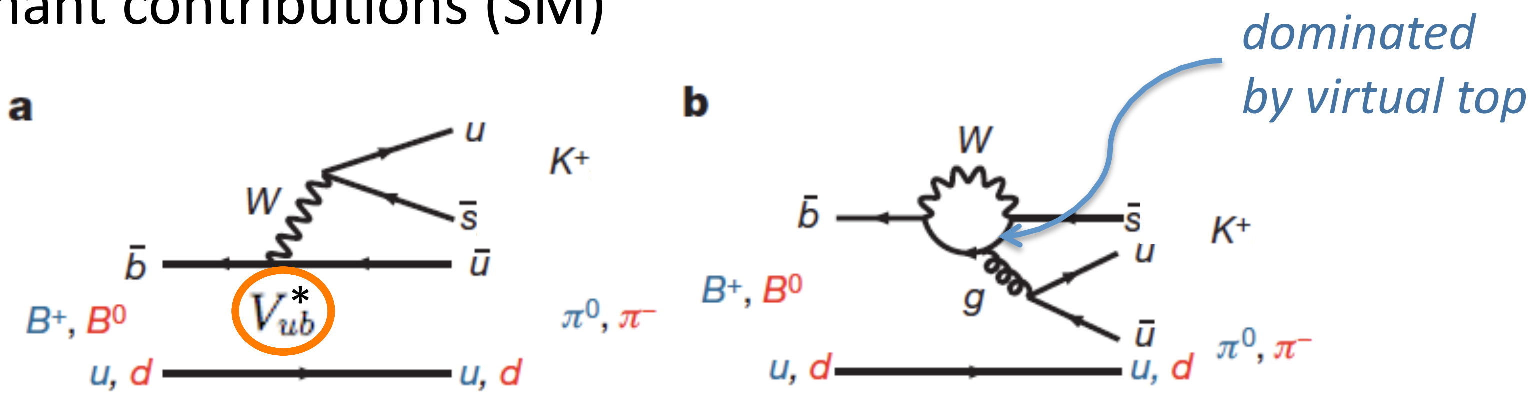
– CPV in quark sector are too small to account for the large matter-antimatter asymmetry in the Universe.

– Other sources of CPV needed.
  - CPV in lepton sector (SM)
  - CPV in new physics beyond the standard model



Decays $B \rightarrow K\pi$

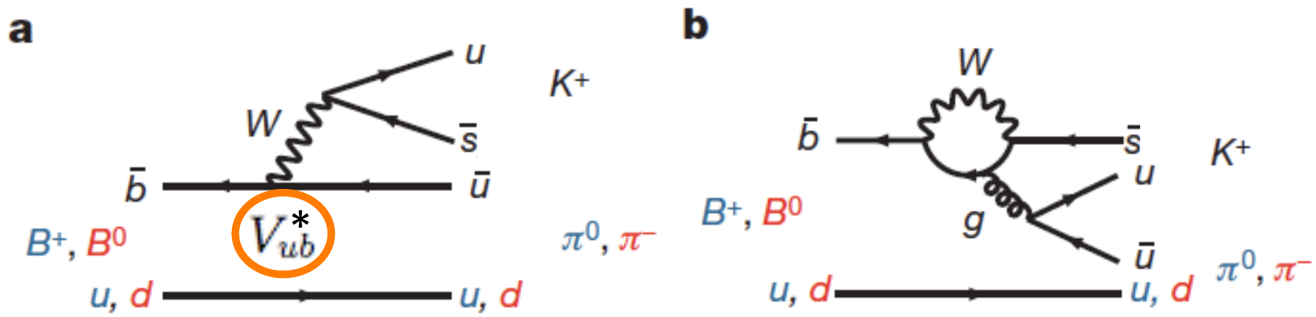
- Dominant contributions (SM)



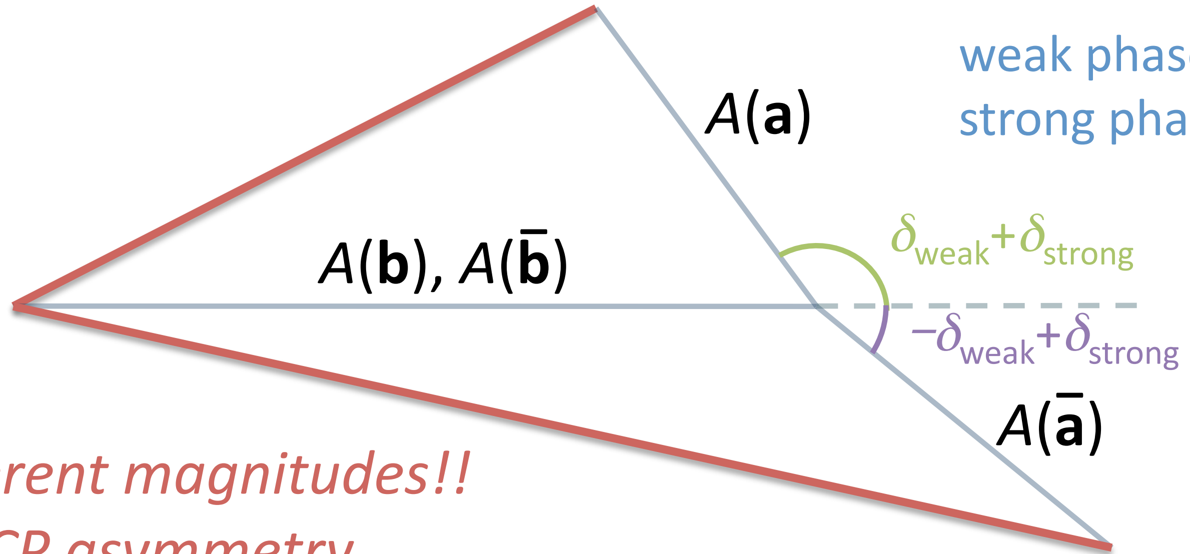
- *CP* violation via so-called V_{ub} → *CP* asymmetries: We observe.

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

We can choose the quark phases so that large complex phases appears only in V_{ub} and V_{td}.



- Relative amplitudes and the *CP* asymmetry



weak phase: δ_{weak}=arg(V_{ub}^*)
strong phase: δ_{strong}

Different magnitudes!!
= CP asymmetry

- Phase δ_{strong} can be different for the charged and neutral *B* decays.
- Similar values of δ_{strong} make the two asymmetries close to each other.

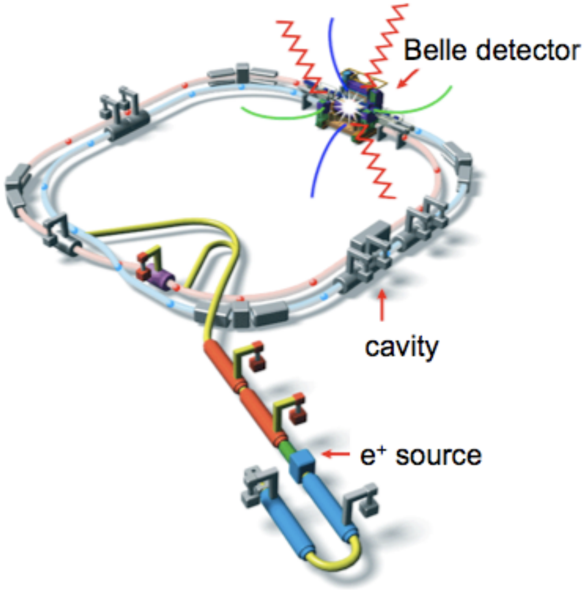
Belle Experiment

- Since the decays $B \rightarrow K\pi$ are strongly suppressed, we must produce many B mesons and detect them with high efficiency.

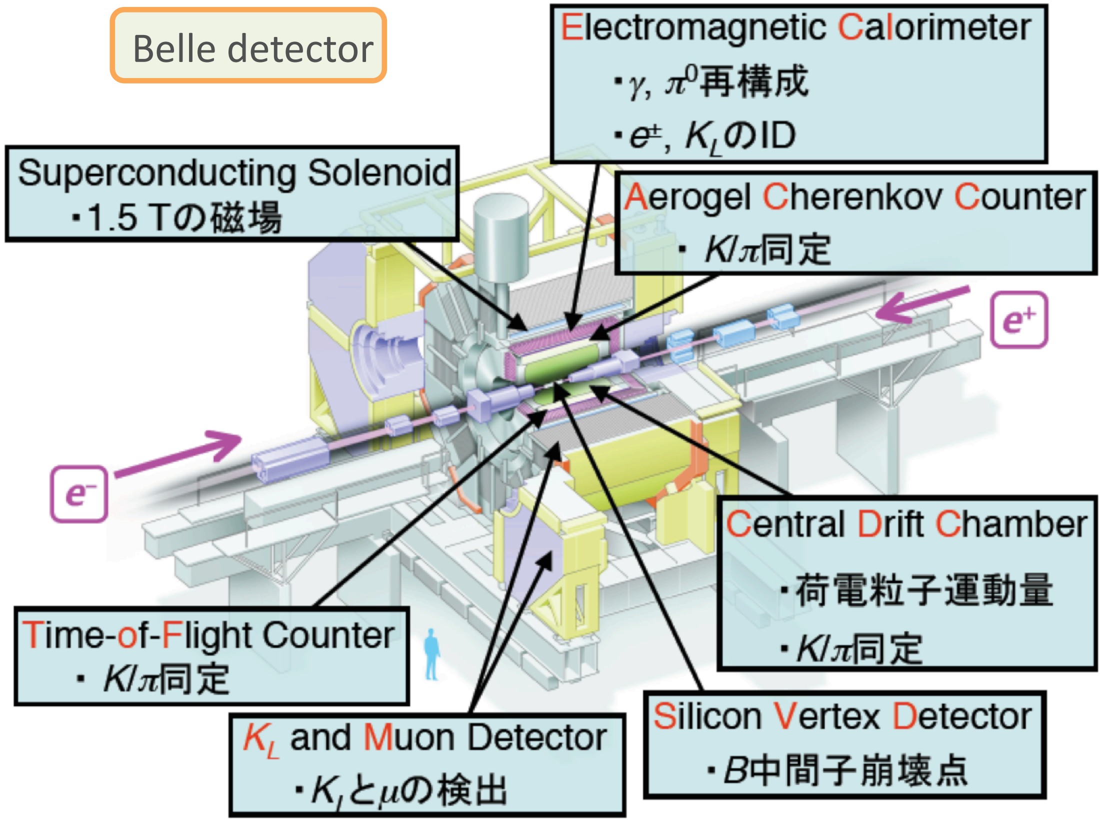
  → ***KEKB accelerator*** *and* ***Belle detector*** *are designed for such a purpose.*

KEKB accelerator

・周長：3 km
・重心系：10.58 GeV
（$\Upsilon(4S)$レゾナンス）

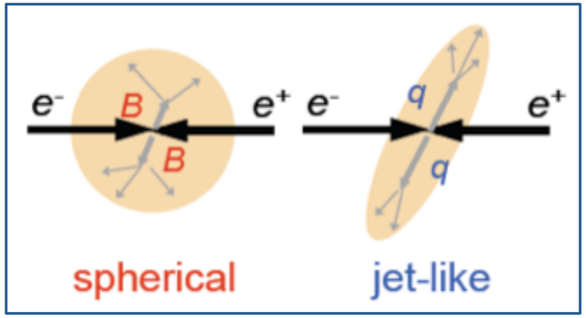


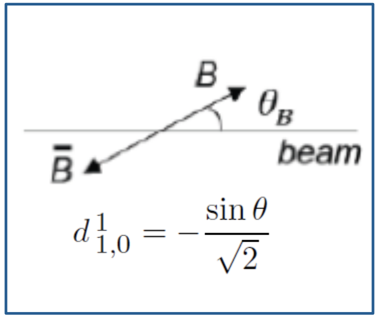
Belle detector



Methods

- $K^{\pm}$, $\pi^{\pm}$, and π^0 are reconstructed using the information provided by the Belle detector.
  - π^0: reconstructed from two photons.
- The dominant $e^+e^- \rightarrow q\bar{q}$ background is suppressed by employing
  - event shape variables and





  - B flavor tagging information.
    - » Unambiguous flavor assignment → Likely to be a BB event.
- *CP* asymmetries are extracted by fitting M_{bc}-ΔE distribution.

$$\mathcal{L} = e^{-\sum_j N_j} \times \prod_i \left(\sum_j N_j \wp^i_j \right)$$

$$\wp^i_j = \frac{1}{2}\left[1 - q^i \mathcal{A}_j\right] P_j\left(M^i_{\rm bc}, \Delta E^i\right)$$

$$M_{\rm bc} = \sqrt{E^2_{\rm beam} - P^2_B}$$

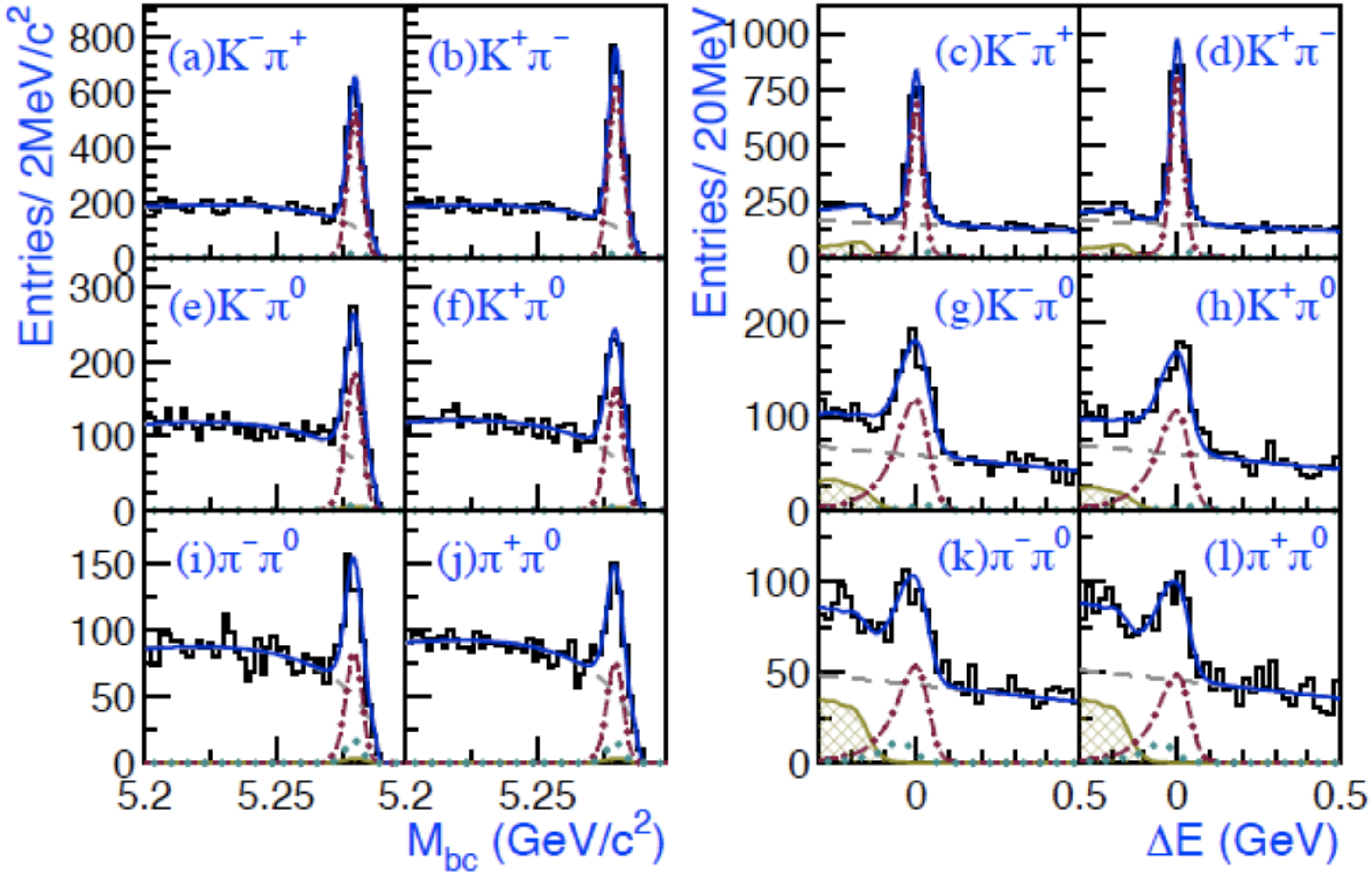
$$\Delta E = E_B - E_{\rm beam}$$

Fit Result

535 Million *BB* pairs

M_{bc} Projection
$|\Delta E|$<0.06 GeV for $K\pi$
-0.14<ΔE<0.06 GeV for others

ΔE Projection
M_{bc}>5.27 GeV/c^2



CP Asymmetries

$$\mathcal{A}_{K^\pm\pi^\mp} \equiv \frac{N(\bar{B}^0 \to K^-\pi^+) - N(B^0 - K^+\pi^-)}{N(\bar{B}^0 \to K^-\pi^+) + N(B^0 \to K^+\pi^-)} = -0.094 \pm 0.018 \pm 0.008$$

4.8σ

$$\mathcal{A}_{K^\pm\pi^0} = +0.07 \pm 0.03 \pm 0.01$$

$$\mathcal{A}_{\pi^\pm\pi^0} = +0.07 \pm 0.06 \pm 0.01$$

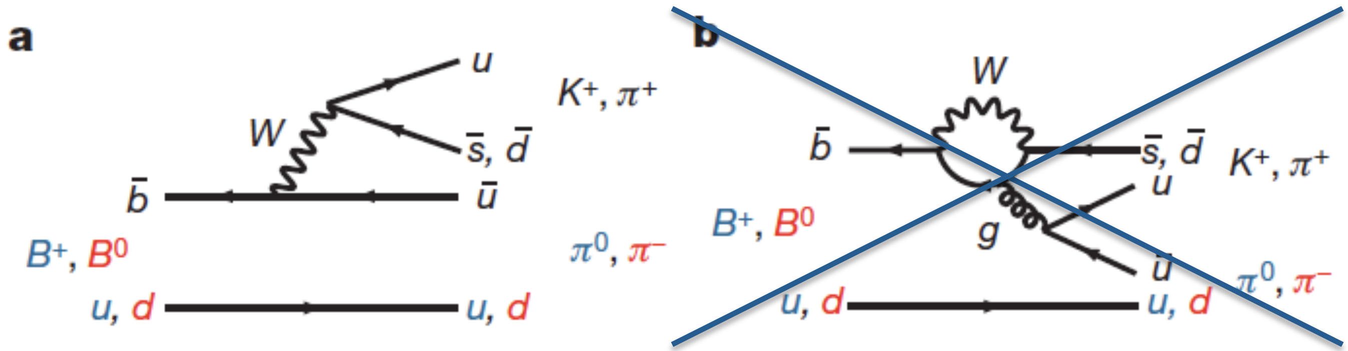
- Systematic error comes from
  - fitting and
    →Estimate by fitting after varying each parameters.
  - bias due to detector response.
    (*Detector is made from matter.*)
    →$K^\pm\pi^\mp$: Use decays whose asymmetry is negligible.
    →$h^\pm\pi^0$: Use BG asymmetries.

	$K^\pm\pi^\mp$	$K^\pm\pi^0$	$\pi^\pm\pi^0$
Signal PDF	$^{+0.0003}_{-0.0002}$	± 0.0004	± 0.0018
Charmless B fraction	± 0.0001	$^{+0.0006}_{-0.0004}$	$^{+0.0003}_{-0.0004}$
$\pi^+\pi^-$ amount	$^{+0.0003}_{-0.0001}$	–	–
Fake rate of $\pi^+\pi^-$ to $K^+\pi^-$	± 0.0013	–	–
Detector bias	± 0.0081	± 0.0056	± 0.0064
Total	± 0.0082	± 0.0056	± 0.0067

CP Asymmetry for B→$\pi^{\pm}\pi^{0}$

$$\mathcal{A}_{\pi^{\pm}\pi^{0}} = +0.07 \pm 0.06 \pm 0.01$$

- For the decay $B \to \pi^{\pm}\pi^{0}$, the contribution from the penguin diagram vanishes by isospin symmetry.



- CP asymmetry is expected to be very small.

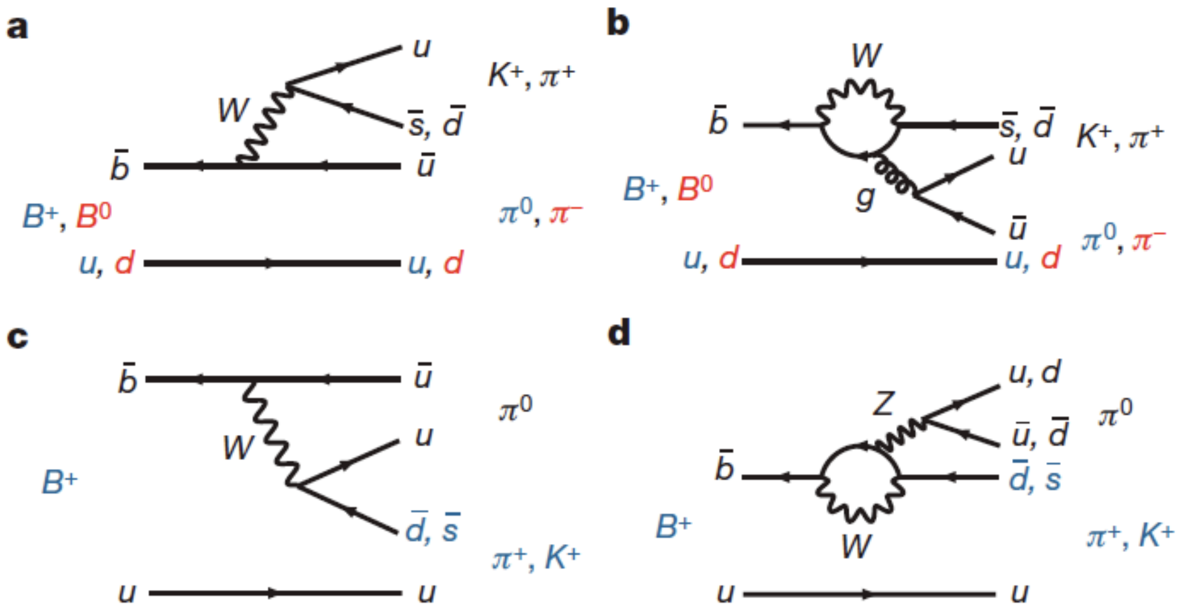
→Obtained result is consistent with this expectation.

Difference of CP Asymmetries for B→Kπ Decays

$$\Delta\mathcal{A} \equiv \mathcal{A}_{K^\pm\pi^0} - \mathcal{A}_{K^\pm\pi^\mp} = +0.164 \pm 0.037$$

<u>4.4σ</u>

- Contributions from **a** and **b** → $\Delta\mathcal{A} \doteqdot 0$.
- Enhancement of the color-suppressed tree **c**?
  - (Could exacerbate another puzzle: ΔS puzzle.)
- Enhancement of the electroweak penguin **d**?
  - Can pick up a CP-violating phase from new physics as a loop amplitude.



ΔS Puzzle

- The rate for B^0 decays to charmless states which is expected to be dominated by penguin diagrams, such as $B^0 \rightarrow K^0\pi^0$, are too small compared to the expectation: ΔS Puzzle.

- If color-suppressed tree diagram is enhanced, ΔS puzzle can be exacerbated.

- More data are needed to confirm ΔS problem.
  - One can measure direct *CP* asymmetry of $B^0 \rightarrow K^0\pi^0$, and compare it with the asymmetries for $B^\pm \rightarrow K^\pm\pi^0$ and $B \rightarrow K^\pm\pi^\mp$.

Conclusion

- *CP* asymmetries for $B \rightarrow K^{\pm}\pi^{\mp}$, $K^{\pm}\pi^{0}$, and $\pi^{\pm}\pi^{0}$ are measured using 535 million *BB* pairs.

- Direct *CP* violation in $B^{\pm} \rightarrow K^{\pm}\pi^{\mp}$ and large deviation between $\mathcal{A}_{K^{\pm}\pi^{\mp}}$ and $\mathcal{A}_{K^{\pm}\pi^{0}}$ are observed.

- The deviation could be an indication of new sources of *CP* violation beyond the SM.