Direct CP Violation in the K^0 Decays

HAICHUAN CAO
PURDUE UNIVERSITY
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OUTLINE

Overview of the Theory of K^0 Decays

The 2π Decay of the K_2 meson

Direct CP Violation Parameter Re$(\varepsilon'/\varepsilon)$ in the Neutral Kaon System

Overview of the Theory of K^0 Decays

Simple Introduction of K^0 and $\overline{K^0}$

2π Decay and 3π Decay of Kaon Meson

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Summary

Simple introduction of K^0 and $\overline{K^0}$

$K^0 : d\bar{s}$ $\overline{K^0} : \bar{d}s$

$\hat{C}\hat{P}\,|K^0>\ = |\overline{K^0}>$, $\hat{C}\hat{P}\,|K^0>\ = |\overline{K^0}>$

Neither $|K^0>$ nor $|\overline{K^0}>$ are the eigenstates of CP transformation

So we just make $|K_1> = \frac{1}{\sqrt{2}}[|K^0> + |\overline{K^0}>]$, $|K_2> = \frac{1}{\sqrt{2}}[|K^0> - |\overline{K^0}>]$

$\hat{C}\hat{P}\,|K_1>\ = |K_1>$, $\hat{C}\hat{P}\,|K_2>\ = -\,|K_2>$

$\eta_{CP}(K_1) = 1$， $\eta_{CP}(K_2) = -1$

2π decay and 3π decay of Kaon meson

$\eta_{CP}(\pi^0\pi^0)$ = $\eta_{CP}(\pi^+\pi^-)$ = 1

$\eta_{CP}(\pi^+\pi^-\pi^0)$ = $(-1)^{l'+1}$

$\eta_{CP}(\pi^0\pi^0\pi^0)$ = $(-1)^{l'+1}$

(Here, l' is the orbital angular momentum quantum number of the 3rd π^0)

For neutral K mesons with 2π decay $\tau_1 = 0.893 * 10^{-10}\, s$, $c\tau_1$= 2.68 cm(0.0879 ft)

For neutral K mesons with 3π decay $\tau_2 = 5.17 * 10^{-8}\, s$, $c\tau_1$= 15.51 m(50.89 ft)

If CP is conserved, K_1 has both 2π decay and 3π dacay, while K_2 only has 3π decay.

2π decay can only be from K_1

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The 2π Decay of the K_2 meson

- Experiment Principle
- Detector and Data Analysis
- Results and Conclusion

Direct CP Violation Parameter Re(ε'/ε) in the Neutral Kaon System

Summary

Experiment Principle

If there is no CP violation

$K_S = K_1$, $K_L = K_2$

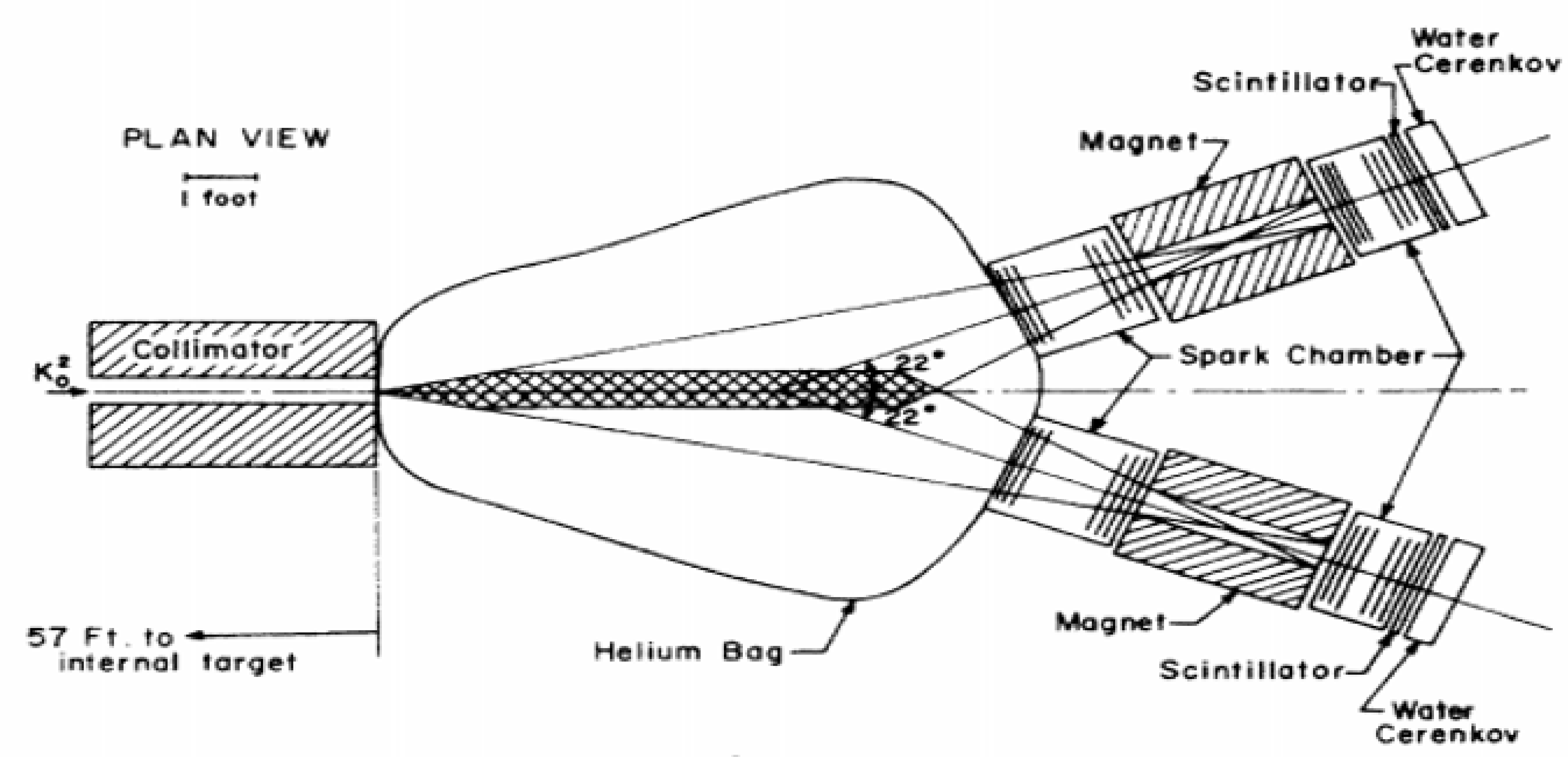
If there is CP violation

$K_S = (1\text{-}\varepsilon)K_1 + \varepsilon K_2$, $K_L = \varepsilon K_1 + (1\text{-}\varepsilon)K_2$,

ε is a mixing parameter.

The objective ⟶ Finding the long-lived 2π decay

Detector and Data Analysis



The experimental layout for 2π decay of the K_2^0 meson

- Invariant Mass

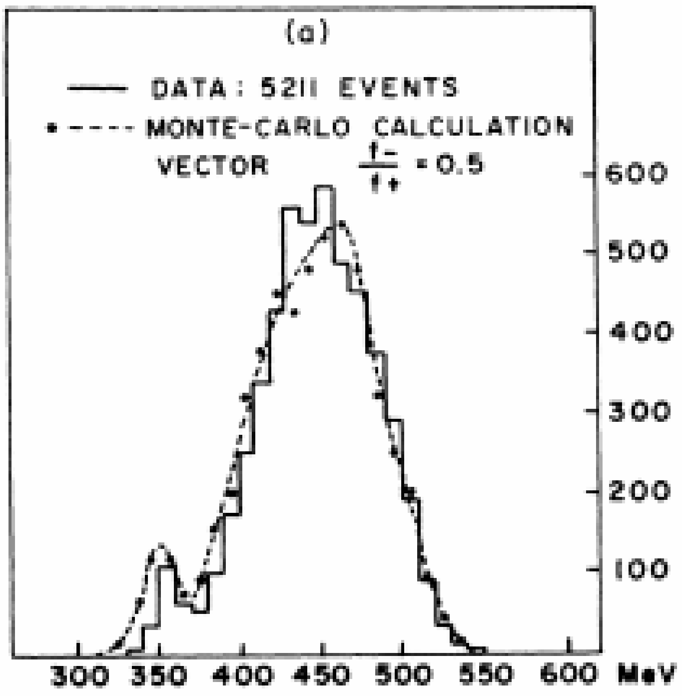
Ke3 decay 280——536 MeV
Kμ3 decay 280 ——516MeV
Kπ3 decay 280 ——363 MeV

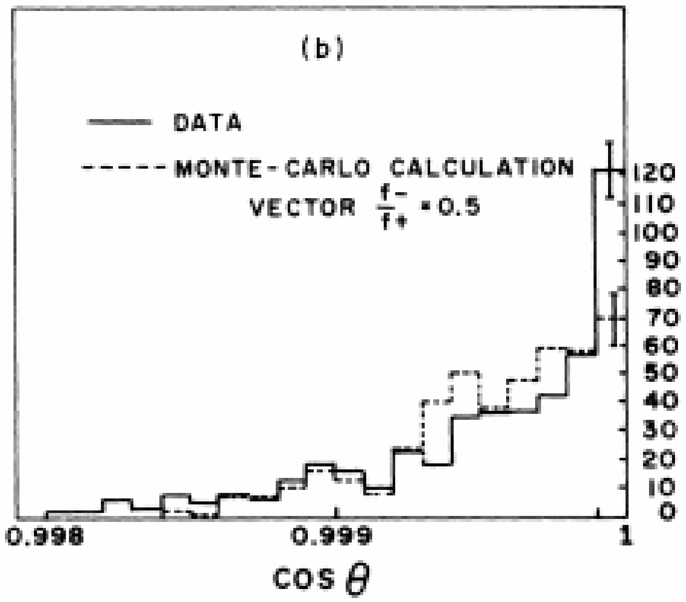
Kπ2 decay 498.1 $\pm$ 0.4 MeV, standard deviation 3.6 $\pm$ 0.2 MeV

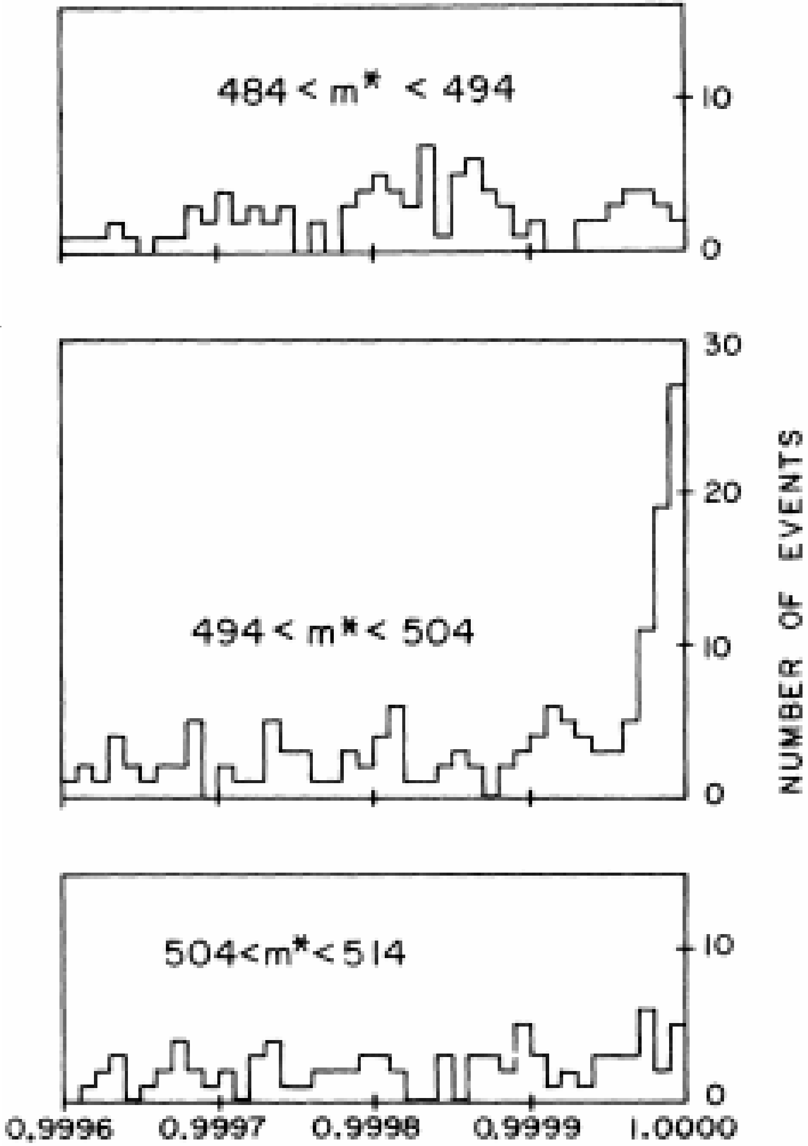
- The vector sum of the two momenta and the angle, θ , between it and the direction of the K should be zero for two-body decay.

  In general, θ is different from zero for three-body decays.

Results and Conclusion







$|\varepsilon| \cong 2.3 \ * 10^{-3}$

The presence of a 2π decay mode implies that the K_2 meson is not a pure eigenstate CP

Reason: a small difference between K^0 -> $\overline{K^0}$ and $\overline{K^0}$ -> K^0 transition rates

indirect CP violation

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Experiment Principle

Direct CP violation by KTeV experiment at Fermilab.

K $\rightarrow \pi^+\pi^-$ and K $\rightarrow \pi^0\pi^0$ decay amplitudes can be compared:

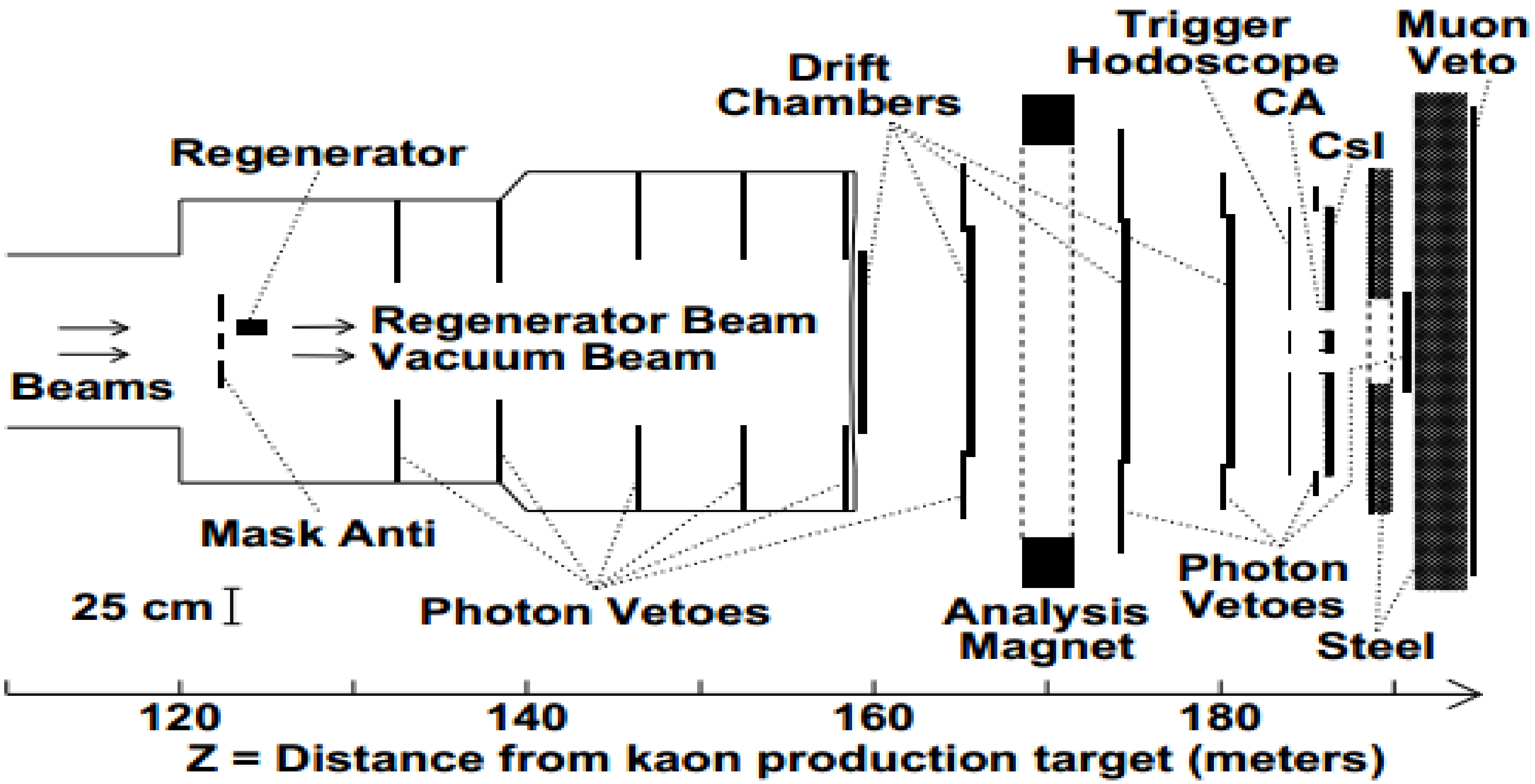
$$\varepsilon' = \frac{1}{\sqrt{2}} \frac{A(K_S \rightarrow (\pi\pi)_{I=2})}{A(K_S \rightarrow (\pi\pi)_{I=0})} * \left(\frac{A(K_L \rightarrow (\pi\pi)_{I=2})}{A(K_L \rightarrow (\pi\pi)_{I=0})} - \frac{A(K_S \rightarrow (\pi\pi)_{I=2})}{A(K_S \rightarrow (\pi\pi)_{I=0})}\right)$$

$$\varepsilon = \frac{A(K_L \rightarrow (\pi\pi)_{I=0})}{A(K_S \rightarrow (\pi\pi)_{I=0})}$$

Re($\frac{\varepsilon'}{\varepsilon}$) is a measure of direct CP violation while Im ($\frac{\varepsilon'}{\varepsilon}$) is a measure of CPT violation

$$\frac{A(K_L \rightarrow \pi^+\pi^-)/A(K_S \rightarrow \pi^+\pi^-)}{A(K_L \rightarrow \pi^0\pi^0)/A(K_S \rightarrow \pi^0\pi^0)} \approx 1 + 6Re\left(\frac{\varepsilon'}{\varepsilon}\right)$$

Detector and Data Analysis



Schematic view of the KTeV detector

$$\frac{A(K_L \to \pi^+\pi^-)/A(K_s \to \pi^+\pi^-)}{A(K_L \to \pi^0\pi^0)/A(K_s \to \pi^0\pi^0)} \approx 1 + 6Re(\frac{\varepsilon'}{\varepsilon})$$

1 The reconstruction of K $\to\pi^+\pi^-$:

selecting events with two track measured in the spectrometer.

2 The reconstruction of K $\to\pi^0\pi^0$

reconstructing π0 → γγ decays

Decays four photon clusters of energy are detected in the CsI calorimeter.

3 The distiguishment of K_L and K_S

Reconstructing the Z coordinate of the decay point.

For π0 → γγ, $Z_{12} = r_{12}\sqrt{E_1E_2}/m_{\pi_0}$ Where $E_{1,2}$ are photo energies, r_{12} is the distance between the photos.

m_{π_0} is the nominal π^0 mass.

Results and Conclusion

$Re(\frac{\varepsilon'}{\varepsilon})$ = [19.2 $\pm$ 1.1_{stat} $\pm$ 1.8_{syst}]*10^4 = [19.2 $\pm$ 2.1] *10^4

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Summary

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From the two experiment, we found the evidence that this is a CP violation in weak interaction

Reference

[1]Christenson J H. Cronin J W, Fitch VL,et al. Evidence for the $2\pi\ Decay$ of the K_2^0 Meson[J]. Phys. Rev. Lett., 1964,13: 138.

[2] A GLAZOV, MEASUREMENT OF DIRECT CP VIOLATION PARAMETER Re (ę′/ę) IN THE NEUTRAL KAON SYSTEM, KTeV Collaboration

[3]Konrad Kleinknecht 1 and Heinrich Wahl , First observation of direct CP violation,EPN06203

Thank you!