Contribution ID: **20** Type: **Plenary Talk**

Direct CP violation in charmed meson decays

Monday, 22 June 2026 15:50 (30 minutes)

In November of 2011 LHCb announced the first evidence of CP violation in the charm sector. A nonzero value for the difference of CP asymmetries in the decays $D^0 \to K^+K^-$ and $D^0 \to \pi^+\pi^-$,
$\Delta A_{CP} = (-0.82 \pm 0.21 \pm 0.11)\%$
was reported. This had triggered a flurry of studies exploring whether this CP violation in the charm sector implies new physics. Direct CP violation (DCPV) requires nontrivial strong and weak phase differences in two different subprocesses. The topological diagrammatic approach (TDA) is suitable for this purpose. DCPV in $D_s^+ \to K^+\eta$ induced from tree diagrams is estimated in TDA to be at the per mille level.
For CPV in the difference between $D^0 \to K^+K^-$ and $D^0 \to \pi^+\pi^-$, it is necessary to take penguin contributions into account and consider the interference between tree and penguin amplitudes.
Cheng-Wei Chiang and I found in 2012 that the short-distance penguin effect is too small. We conjectured that the long-distance (LD) penguin through the final-state rescattering is of the same order as the W-exchange topology. Since W-exchange can be extracted from the global fit to the data, we found two solutions: $\Delta A_{CP} = (-0.139 \pm 0.004)\%$ and $(-0.151 \pm 0.004)\%$. In the meantime, the original evidence of CP asymmetry difference was gone in 2013 and 2014 when LHCb started to use the muon tag to identify the D^0. In 2019, LHCb finally reported the first observation of
CP asymmetry in the charm system with the result
$\Delta A_{CP} = (-1.54 \pm 0.29) \times 10^{-3}$. Our predictions in 2012 are amazingly in excellent agreement with the LHCb observation of CP violation in 2019. Many mechanisms proposed in the literature for the penguin failed to give enough penguin enhancement. In this talk, we will also comment on the new measurement of CPV in $D^0 \to K^+K^-$ which leads to U-spin symmetry breaking and my indicate a signal of new physics.

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Session Classification: Session IV