CP violation in D-meson decays

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ITEP

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based on A.N.Rozanov, M.V.
Pisma v ZhETF 95 (2012) 443;
S.I.Godunov, A.D.Dolgov, A.N.Rozanov, M.V. in preparation.

Experimental data

November 2011:

$$\Delta A_{CP}^{LHCb} \equiv A_{CP}(K^+K^-) - A_{CP}(\pi^+\pi^-)$$

$$= [-0.82 \pm 0.21(\text{stat.}) \pm 0.11(\text{syst.})]\% \quad ,$$

where

$$A_{CP}(\pi^+\pi^-) = \frac{\Gamma(D^0 \to \pi^+\pi^-) - \Gamma(\bar{D}^0 \to \pi^+\pi^-)}{\Gamma(D^0 \to \pi^+\pi^-) + \Gamma(\bar{D}^0 \to \pi^+\pi^-)}$$

and $A_{CP}(K^+K^-)$ is defined analogously.
Winter 2012:

$$\Delta A_{CP}^{CDF} = [-0.62 \pm 0.21(\text{stat.}) \pm 0.10(\text{syst.})]\% \quad .$$

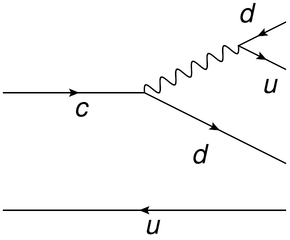
Main Questions

1. Is it possible to have $|\Delta A_{CP}| \approx 1\%$ in SM?
NO

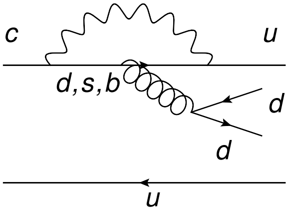
2. Is really $|\Delta A_{CP}| > 0.5\%$?
this Summer - much larger statistics (LHCb)

3. Is there any New Physics that allows big CPV in D decays?
Yes, the 4'th quark-lepton generation

Diagrams



a)



b)

T and P

It is convenient to present the penguin diagram contribution to $D \to \pi^+\pi^-$ decay amplitude in the following form:

$$V_{cd}V_{ud}^*[f(m_d) - f(m_s)] + V_{cb}V_{ub}^*[f(m_b) - f(m_s)] \ ,$$

$$\begin{aligned} A_{\pi^+\pi^-} &= T\left[1 + \frac{P}{T}e^{i(\delta-\gamma)}\right] \ , \\ \bar{A}_{\pi^+\pi^-} &= T\left[1 + \frac{P}{T}e^{i(\delta+\gamma)}\right] \ , \end{aligned}$$

$$A_{CP}(\pi^+\pi^-) = 2\frac{P}{T}\sin\delta\sin\gamma$$

$$\sin\delta\sin\gamma \approx 1$$

P/T

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

$$\Delta A_{CP} = 4\frac{P}{T}$$

and let us try to understand if in the Standard Model we can obtain

$$\frac{P}{T} = 1.8 \cdot 10^{-3}$$

The estimate:

$$\frac{P}{T} \sim \frac{V_{cb}V_{ub}}{V_{cd}}\frac{\alpha_s(m_c)}{\pi} \approx 10^{-4}$$

factorization

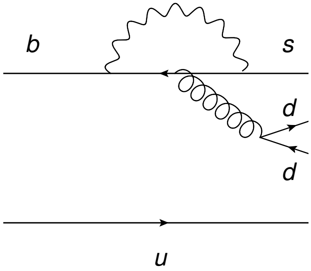
$$T = \frac{G_F}{\sqrt{2}} V_{cd} < \pi^+ | \bar{u}\gamma_\alpha (1+\gamma_5) d | 0 >< \pi^- | \bar{d}\gamma_\alpha (1+\gamma_5) c | D^0 >=$$
$$= \frac{G_F}{\sqrt{2}} V_{cd} f_\pi f_+(0) m_D^2 \ ,$$

The factorization overestimates T amplitude by the factor $\sqrt{6.2/3.4} \approx 1.4$

$$P = \frac{G_F}{\sqrt{2}} |V_{cb} V_{ub}^*| \frac{\alpha_s(m_c)}{12\pi} \ln\left(\frac{m_b}{m_c}\right)^2 \frac{8}{9} f_\pi f_+(0) m_D^2 \left[1 + \frac{2m_\pi^2}{m_c(m_u+m_d)}\right] ,$$

$$P/T \approx 9 \cdot 10^{-5} \ .$$

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



$$P/P_{\text{fact}} = \sqrt{14/4.1} = 1.8$$

$K \to \pi\pi$

$s \to d$ penguin transition changes the isospin by 1/2 in this way explaining the famous $\Delta I = 1/2$ rule in $K \to \pi\pi$ decays.
Calculation of $K_S \to \pi^+\pi^-$ decay amplitude generated by a penguin transition using the factorization underestimates the amplitude by factor 2-3.

In view of the results for B and K decays we can cautiously suppose that for $D \to \pi^+\pi^-$ decay factorization calculation underestimates the penguin amplitude by factor 5 at most leading to:

$$\left(\Delta A_{CP}^{\text{theor}}\right)_{SM} \leq 0.2\% \quad .$$

fourth generation

$$\Delta P = V_{cb'} V_{ub'} [f(m_{b'}) - f(m_s)] \ ,$$

$m_{b'} \gtrsim 600$ GeV.

$$\frac{P_4}{P_{SM}} = \frac{\ln(m_W/m_c)}{\ln(m_b/m_c)} \frac{|V_{cb'} V^*_{ub'}|}{|V_{cb} V_{ub}|} \frac{\sin(\arg V_{cb'} V^*_{ub'})}{\sin\gamma} \approx$$

$$\approx 3.3 \frac{3 \cdot 10^{-4}}{1.5 \cdot 10^{-4}} \approx 6 \ ,$$

$$\left(\Delta A_{CP}^{\text{theor}}\right)_{4G} \approx \Delta A_{CP}^{\text{exper}}$$

is possible.

Saving baryon number by the long-lived fourth generation neutrino

As it was noted in
H. Murayama, V. Rentala, J. Shu, T. Yanagida, Phys. Lett. B **705** (2011) 208
the long-lived fourth generation particles save baryon asymmetry generated at the Early Universe from erasure by the sphaleron transitions.
The sphaleron transitions conserve $B - L$, that is why if at the Early Universe $B_0 = L_0 \neq 0$ are generated, then the final baryon and lepton asymmetries proportional to $B - L$ are completely erased.
If the fourth generation particles weakly mix with three quark-lepton generations of the Standard Model, then two additional quantities are conserved: $B_4 - L_4$ and $L - 3L_4$, where B_4 and L_4 are the densities of baryons and leptons of the fourth generation, while B and L are the densities of baryons and leptons of three light generations.

Choosing the initial asymmetries $B_0 = L_0 = 3\Delta$, $B_4^0 = L_4^0 = 0$ and since $L - 3L_4 = 3\Delta \neq 0$ then the $B + B_4$ number density at the sphaleron freeze-out temperature proportional to linear superposition of conserved quantities is nonzero. After sphaleron freeze-out $B' \equiv B + B_4$ is conserved and equals the modern baryon density of the Universe.

For such a scenario to occur the lifetimes of the fourth generation quarks and leptons should be larger than the lifetime of the Universe at the sphaleron freeze-out: $\tau_4 > M_{\rm Pl}/T_{\rm sph}^2 \sim 10^{-10}$ sec. For the mixing angles in case of $b' \to (c,u)W$ decay it gives $\theta < 10^{-8}$, much smaller than what we need to explain large CPV in D-decays -
SO WE SUPPOSE THAT ONLY 4 GENERATION LEPTONS WEAKLY MIX WITH OURS.

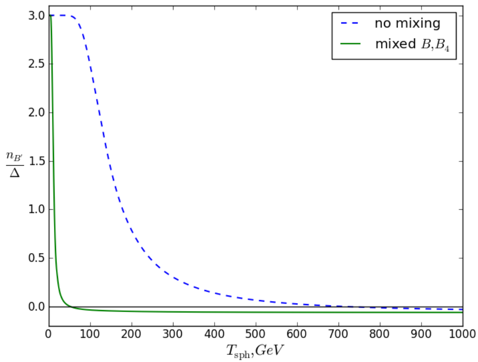


Figure: The final baryon asymmetry versus the initial asymmetry $n_{B'}/\Delta$ as a function of sphaleron freeze-out temperature T_{sph} (GeV) for the unmixed fourth generation is shown by a dashed blue line. It is analogous to the figure from H Murayama et al., but for $m_N = 57.8$ GeV, $m_E = 107.6$ GeV, $m_{t'} = 634$ GeV, $m_{b'} = 600$ GeV. The final baryon asymmetry for the case of the mixed fourth generation quarks and the unmixed fourth generation leptons is shown by a solid green line.

Conclusions

- ΔA_{CP} of the order of 1% is not possible in the SM;
- New Physics (in particular, 4th generation) can produce $\Delta A_{CP} \sim 1\%$;
- if the 4th generation leptons weakly mix with the leptons of three light generations then $B_0 = L_0$ generated in the Early Universe will not be erased by sphalerons.