

# CP Violation in D-Meson Decays and the Fourth Generation

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based on A.N.Rozanov, M.V.

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S.I.Godunov, A.D.Dolgov, A.N.Rozanov, M.V. in preparation.

# Experimental data

November 2011:

$$\begin{aligned}\Delta A_{CP}^{LHCb} &\equiv A_{CP}(K^+K^-) - A_{CP}(\pi^+\pi^-) \\ &= [-0.82 \pm 0.21(\text{stat.}) \pm 0.11(\text{syst.})]\% ,\end{aligned}$$

where

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

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

Winter 2012:

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

# Main Questions

1. Is it possible to have  $|\Delta A_{CP}| \approx 1\%$  in SM?

NO

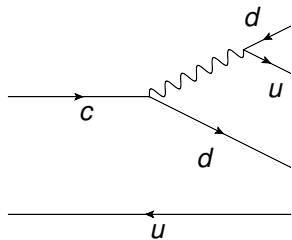
2. Is really  $|\Delta A_{CP}| > 0.5\%$  ?

this Summer - much larger statistics (LHCb)

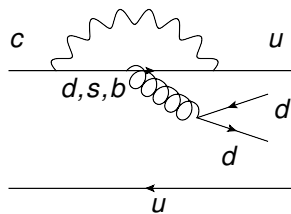
3. Is there any New Physics that allow big CPV in  $D$  decays?

Yes, 4'th quark-lepton generation

# Diagrams



a)



b)

# $T$ and $P$

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

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

$$A_{\pi^+\pi^-} = T \left[ 1 + \frac{P}{T} e^{i(\delta-\gamma)} \right] ,$$

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

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

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

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

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

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

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

An estimate:

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

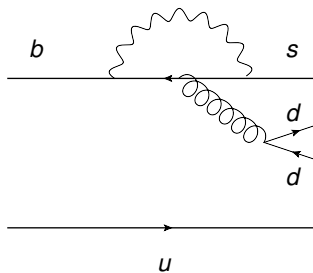
$$\begin{aligned}
 T &= \frac{G_F}{\sqrt{2}} V_{cd} \langle \pi^+ | \bar{u} \gamma_\alpha (1 + \gamma_5) d | 0 \rangle \langle \pi^- | \bar{d} \gamma_\alpha (1 + \gamma_5) c | D^0 \rangle = \\
 &= \frac{G_F}{\sqrt{2}} V_{cd} f_\pi f_+(0) m_D^2 ,
 \end{aligned}$$

Factorization overestimate  $T$  amplitude by the factor  $\sqrt{6.2/3.4} \approx 1.4$

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

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

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



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



# $K \rightarrow \pi\pi$

$s \rightarrow d$  penguin transition changes isospin by 1/2 in this way explaining famous  $\Delta I = 1/2$  rule in  $K \rightarrow \pi\pi$  decays.

Calculation of  $K_S \rightarrow \pi^+\pi^-$  decay amplitude generated by a penguin transition using a factorization underestimate the amplitude by the factor 2-3.

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

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

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

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

$$\begin{aligned} \frac{P_4}{P_{SM}} &= \frac{\ln(m_W/m_c)}{\ln(m_b/m_c)} \frac{|V_{cb'} V_{ub'}^*|}{|V_{cb} V_{ub}|} \frac{\sin(\arg V_{cb'} V_{ub}^*)}{\sin \gamma} \approx \\ &\approx 3.3 \frac{3 \cdot 10^{-4}}{1.5 \cdot 10^{-4}} \approx 6 , \end{aligned}$$

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

is possible.

# Saving baryon number by a long-lived fourth generation neutrino

As it was noted in

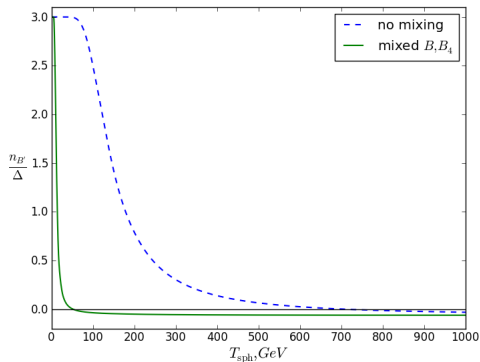
H. Murayama, V. Rentala, J. Shu, T. Yanagida, Phys. Lett. B **705** (2011) 208

long-lived fourth generation particles save baryon asymmetry generated at the Early Universe from erasure by sphaleron transitions. Sphaleron transitions conserve  $B - L$ , that is why if at early universe  $B_0 = L_0 \neq 0$  is generated, then final baryon and lepton asymmetries being proportional to  $B - L$  are completely erased.

If the fourth generation particles weakly mix with three quark-lepton generations of Standard Model, then two additional quantities are conserved:  $B_4 - L_4$  and  $L - 3L_4$ , where  $B_4$  and  $L_4$  are densities of baryons and leptons of the fourth generation, while  $B$  and  $L$  are densities of baryons and leptons of three light generations.

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

For such a scenario to occur life times of the fourth generation quarks and leptons should be larger than life time of the Universe at the sphaleron freeze-out:  $\tau_4 > M_{\text{Pl}}/T_{\text{sph}}^2 \sim 10^{-10}$  sec. For mixing angles in case of  $b' \rightarrow (c, u)W$  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  $T_{\text{sph}}$  (GeV) for 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 mixed fourth generation quarks and unmixed fourth generation leptons is shown by a solid green line.