

# Charmed penguin versus BAU

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based on A.N.Rozanov, M.V.  
JETP Letters 95 (2012) 397

S.I.Godunov, A.D.Dolgov, A.N.Rozanov, M.V.  
JETP Letters 96 (2012) 290

# 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

Summer 2012:

$$\Delta A_{CP}^{Belle} = [-0.87 \pm 0.41(\text{stat.}) \pm 0.06(\text{syst.})]\%$$

$$\Delta A_{CP}^{average} = [-0.74 \pm 0.15]\%.$$

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

NO

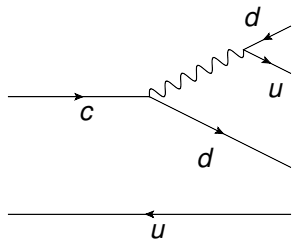
2. Is really  $|\Delta A_{CP}| > 0.5\%$  ?

Soon - much larger statistics (LHCb)

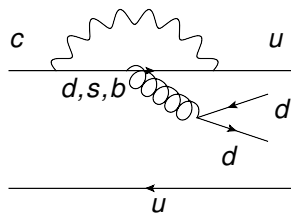
3. Is there any New Physics that allows big CPV in  $D$  decays?

Yes, the 4'th quark-lepton generation

# Diagrams



a)



b)

# $T$ and $P$

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

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

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

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

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

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

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

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

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

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

The estimate:

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

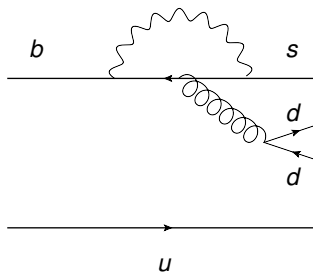
$$\begin{aligned}
 T &= \frac{G_F}{\sqrt{2}} V_{cd} \langle \pi^+ | \bar{u} \gamma_\alpha (1 + \gamma_5) d | 0 \rangle \langle \pi^- | \bar{d} \gamma_\alpha (1 + \gamma_5) c | D^0 \rangle = \\
 &= \frac{G_F}{\sqrt{2}} V_{cd} f_\pi f_+(0) m_D^2 ,
 \end{aligned}$$

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

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

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

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



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



# $K \rightarrow \pi\pi$

$s \rightarrow d$  penguin transition changes the isospin by 1/2 in this way explaining the 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 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  $D \rightarrow \pi^+\pi^-$  decay factorization calculation underestimates the penguin amplitude by factor 5 at most leading to:

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

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

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

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

CKM 4 from S.Nandi, A.Soni (2011)

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

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

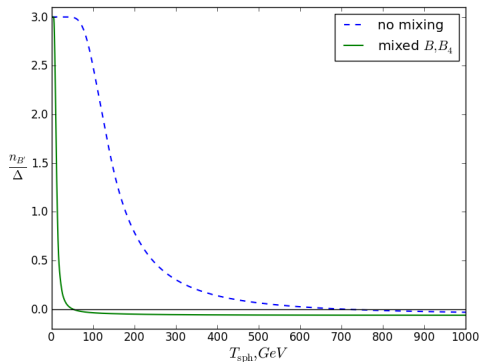
the long-lived fourth generation particles save baryon asymmetry generated at the Early Universe from erasure by the sphaleron transitions.

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:  $\tau_4 > M_{\text{Pl}}/T_{\text{sph}}^2 \sim 10^{-10}$  sec. For the 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 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.

# Higgs versus 4th generation

$$\sigma(gg \rightarrow H)_{4G} \approx 9\sigma_{SM} \implies$$

$\sigma * Br(H \rightarrow VV^*)$  too large.

Way out:  $M_Z/2 < M_N < M_H/2$  (allowed by EW precision data!).

But:  $Br(H \rightarrow \gamma\gamma)$  heavily suppressed:

$$(7 - 16/9 - 16/9(1 + 1/4 + 3/4))^2 / (7 - 16/9)^2 \approx 0.1$$

Way out: 2HDM with Fourth Family (Chen, He, 2012; Geller, Bar-Shalom, Eilam, Soni, 2012)

# Conclusions

- $\Delta A_{CP}$  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.
- LHC higgs data: 2HDM?