CP VIOLATION, NEW PHYSICS AND PHENOMENOLOGY

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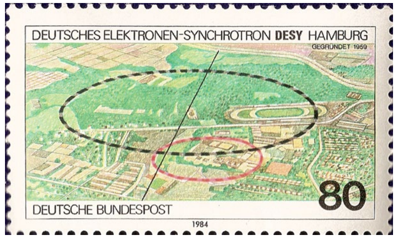
COLLABORATIONS WITH GABRIEL:

- CP violation in semileptonic tau lepton decays, D. Delepine(Guanajuato U.), G. Lopez Castro,L.-T. Lopez Lozano(CINVESTAV, IPN) (Mar, 2005), *Phys.Rev.D* 72 (2005) 033009.
- Supersymmetry and CP violation in |Delta S| = 1 tau-decays, D. Delepine (Guanajuato U.), G. Faisel (Ain Shams U., Cairo), S. Khalil (British U. in Egypt), G. Lopez Castro (Cinvestav, IPN), (Aug. 2006), *Phys.Rev.D* 74 (2006) 056004.
- Is there a paradox in CP asymmetries of tau+- ---> K(L,S)pi+- nu decays?, G. Calderon (Coahuila Autónoma U.), D. Delepine (Guanajuato U.), Gabriel Lopez Castro (CINVESTAV, IPN), (Feb.2007), *Phys.Rev.D* 75 (2007) 076001.
- QFT results for neutrino oscillations and New Physics, David Delepine(Guanajuato U., FIMEE), Vannia Gonzalez Macias(Guanajuato U.), Shaaban Khalil(British U. in Egypt),Gabriel Lopez Castro(CINVESTAV, IPN) (Jan, 2009), *Phys.Rev.D* 79 (2009) 093003.
- Lepton number violation in top quark and neutral B meson decays, N. Quintero, Gabriel Lopez Castro (CINVESTAV, IPN),D. Delepine (Guanajuato U.)
  (Ago,2011), *Phys.Rev.D* 84 (2011) 096011, *Phys.Rev.D* 86 (2012) 079905 (erratum)

- Ph.D . In Universidad de Lovaina, Belgica (1992-1997)
  Ph.D. supervisor: Dr. Jean Marc Gerard
  Main Thesis: Aspects de la Baryogenesis electrofailbe
  Second thesis: Equivalence of the sine gordon and thirring models at finite temperature.

Postdoc:

- DESY (Hamburg) in the theoretical group (Dr. Wilfried Buchmueller) (1998-2000)
- LNGS (Gran Sasso, Italy): in the theoretical group collaborating with Dr. Francesco Vissani on neutrinos physics
- CFIF (Centro de Fisica de las interacciones fundamentas, Instituto Superior Tecnico, Lisboa) in the Group of Prof. Gustavo Branco.



Desde 2003, IFUG (Universidad de Guanajuato)

WHY CP VIOLATION IS INTERESTING?

A DOOR TO NEW PHYSICS

- CP violation is well known in mesons formed by down quarks as Kaons and B mesons.
- CP violaton has been confirmed in 2019 in D mesons but still poor data on other channel decays. D mesons is not a very good oscillator compared to K or B mesons.
- CP violation is needed to produce the Baryon Asymmetry of the Universe. A door to AstroParticles Physics.
- New experiments (LHCB, BELLE 2,...) will strongly improved experimental data on B, D and tau decays.
- Indices of CP violation needed in PMNS Lepton mixing matrix.
- Still many theoretical questions unanswered on how to compute correctly SM contributions to CP asymmetries.

NECESSARY AND SUFICIENTE CONDITION TO OBSERVE A CP ASYMMETRY:

At least two amplitudes (ϕ/δ: weak/strong phases):

$$
\begin{aligned}
A_f &= |a_1|e^{i(\phi_1+\delta_1)} + |a_2|e^{i(\phi_2+\delta_2)} \\
\bar{A}_{\bar{f}} &= |a_1|e^{i(-\phi_1+\delta_1)} + |a_2|e^{i(-\phi_2+\delta_2)}
\end{aligned}
$$

$$
A_{CP} = \frac{\Gamma(B\to f) - \Gamma(\bar{B}\to\bar{f})}{\Gamma(B\to f) + \Gamma(\bar{B}\to\bar{f})} = \frac{2r\sin(\delta)\sin(\phi)}{1+r^2+2r\cos(\delta)\cos(\phi)}
$$

where $\phi = \phi_1 - \phi_2$, $\delta = \delta_1 - \delta_2$ and $r = |a_1/a_2|$

CP VIOLATION IN SM (I): YUKAWA COUPLINGS AND CKM MIXING MATRIX

$$L_{cc} = \frac{g}{\sqrt{2}}\left(\bar{u}_L V \gamma^{\mu} d_L W^{+}{}_{\mu} + \bar{d}_L V^{\dagger} \gamma^{\mu} u_L W^{-}{}_{\mu}\right)$$

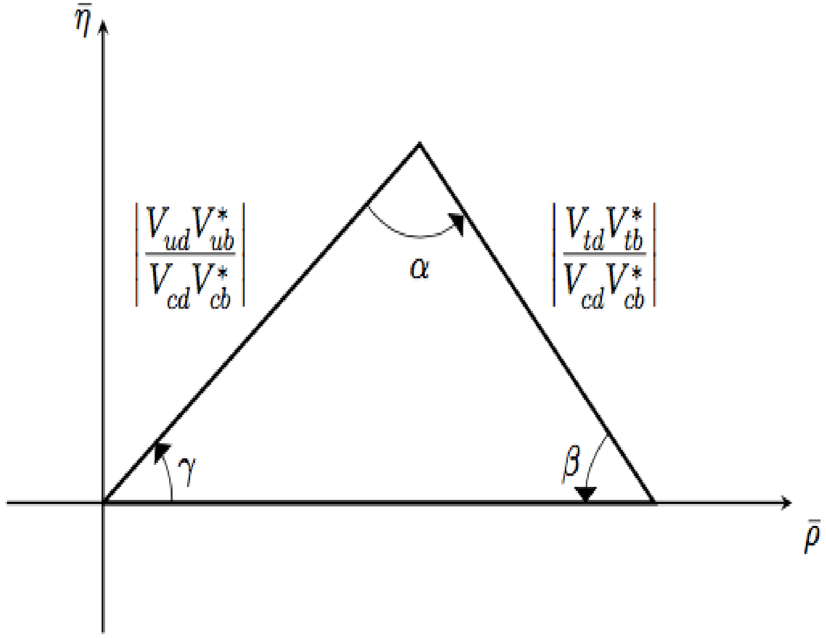
Condition to have CP violation in SM:

a) $m_{u_i} \neq m_{u_j}, m_{d_i} \neq m_{d_j} (i \neq j)$

b) $J \equiv \mathrm{Im}\left(V_{11}V_{21}^{*}V_{22}V_{12}^{*}\right) \neq 0$

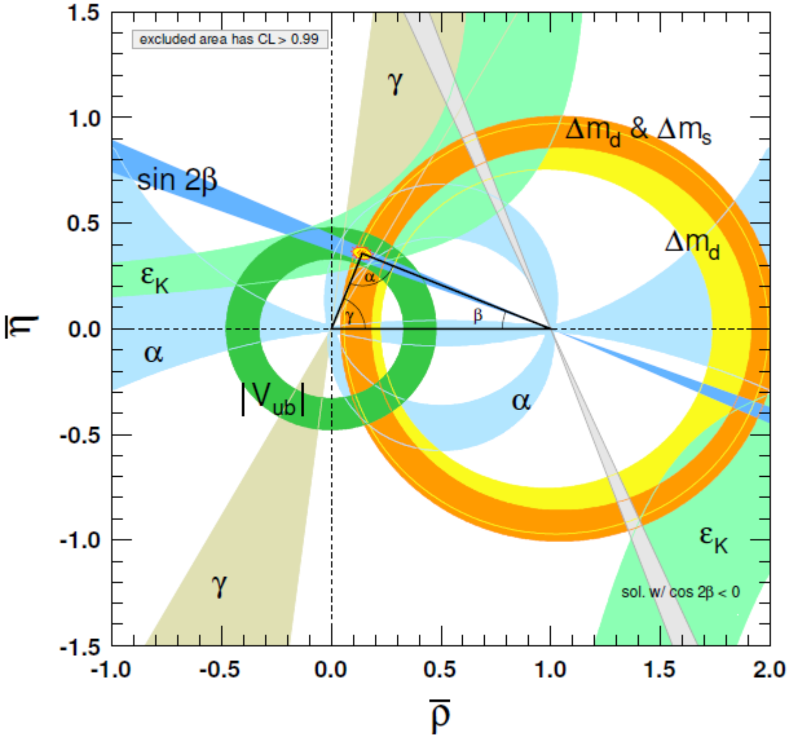
Unitarity of the V matrix

$$V_{ud}V_{ub}^{*} + V_{cd}V_{cb}^{*} + V_{td}V_{tb}^{*} = 0$$



CP VIOLATION IN SM (II): CABIBBO KOBAYASHI MASKAWA MATRIX

$$
\begin{aligned}
V_{\rm CKM} &= \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \\
&= \begin{pmatrix} c_{12}c_{13} & s_{12}c_{13} & s_{13}e^{-i\delta} \\ -s_{12}c_{23} - c_{12}s_{23}s_{13}e^{i\delta} & c_{12}c_{23} - s_{12}s_{23}s_{13}e^{i\delta} & s_{23}c_{13} \\ s_{12}s_{23} - c_{12}c_{23}s_{13}e^{i\delta} & -s_{23}c_{12} - s_{12}c_{23}s_{13}e^{i\delta} & c_{23}c_{13} \end{pmatrix} \\
&\simeq \begin{pmatrix} 1 - \frac{\lambda^2}{2} & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda - A^2\lambda^5(\rho + i\eta) & 1 - \frac{\lambda^2}{2} - A^2\lambda^6(\rho + i\eta) & A\lambda^2 \\ A\lambda^3(1 - \rho - i\eta) & -A\lambda^2 - A\lambda^4(\rho + i\eta) & 1 \end{pmatrix} + \\
s_{12} &= \lambda = \frac{|V_{us}|}{\sqrt{|V_{ud}| + |V_{us}|}}, \quad s_{23} = A\lambda^2 = \lambda\left|\frac{V_{cb}}{V_{us}}\right| \\
& s_{13}e^{i\delta} = V_{ub}^* = A\lambda^3(\rho + i\eta) \\
\sin 2\beta &= \sin 2\phi_1 = 0.682(19), \ \gamma = \delta = \phi_3 = 68.0^{+8.0}_{-8.5}, \ \alpha = \phi_2 = 85.4^{+3.9}_{-3.8}
\end{aligned}
$$

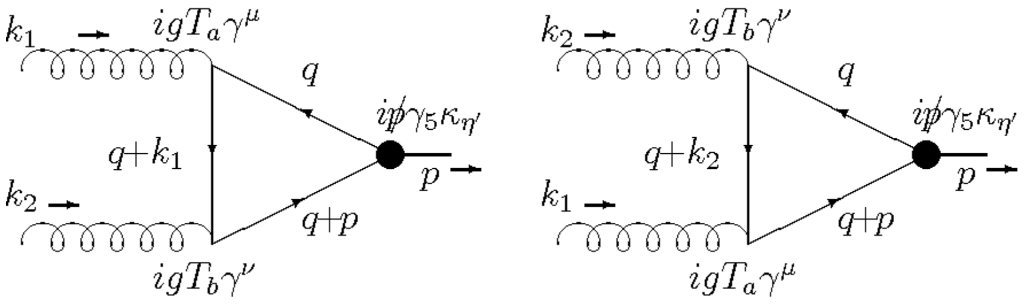


$$
\lambda = 0.22650 \pm 0.00048\,, \qquad A = 0.790^{+0.017}_{-0.012}\,,
$$

$$
\bar\rho = 0.141^{+0.016}_{-0.017}\,, \qquad \bar\eta = 0.357 \pm 0.011\,.
$$

$$
V_{\rm CKM} = \begin{pmatrix} 0.97401 \pm 0.00011 & 0.22650 \pm 0.00048 & 0.00361^{+0.00011}_{-0.00009} \\ 0.22636 \pm 0.00048 & 0.97320 \pm 0.00011 & 0.04053^{+0.00083}_{-0.00061} \\ 0.00854^{+0.00023}_{-0.00016} & 0.03978^{+0.00082}_{-0.00060} & 0.999172^{+0.000024}_{-0.000035} \end{pmatrix},
$$

QCD ANOMALY AND STRONG CP PROBLEM



Axial current is not conserved in QCD.

General Yukawa coupling

+

QCD Axial Anomaly

$$\theta = \theta_0 + \arg\det(M_u M_d)$$

Electric Dipole Moment of neutron

$$\theta < 10^{-10}$$

CP VIOLATION IN LEPTONIC SECTOR

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} \text{PMNS} \\ \text{matrix} \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

PMNS matrix

$$U_{\alpha i} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{bmatrix} \begin{bmatrix} c_{13} & 0 & s_{13}e^{-i\delta} \\ 0 & 1 & 0 \\ -s_{13}e^{i\delta} & 0 & c_{13} \end{bmatrix} \begin{bmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 \\ 0 & e^{i\alpha/2} & 0 \\ 0 & 0 & e^{i\beta/2} \end{bmatrix}$$

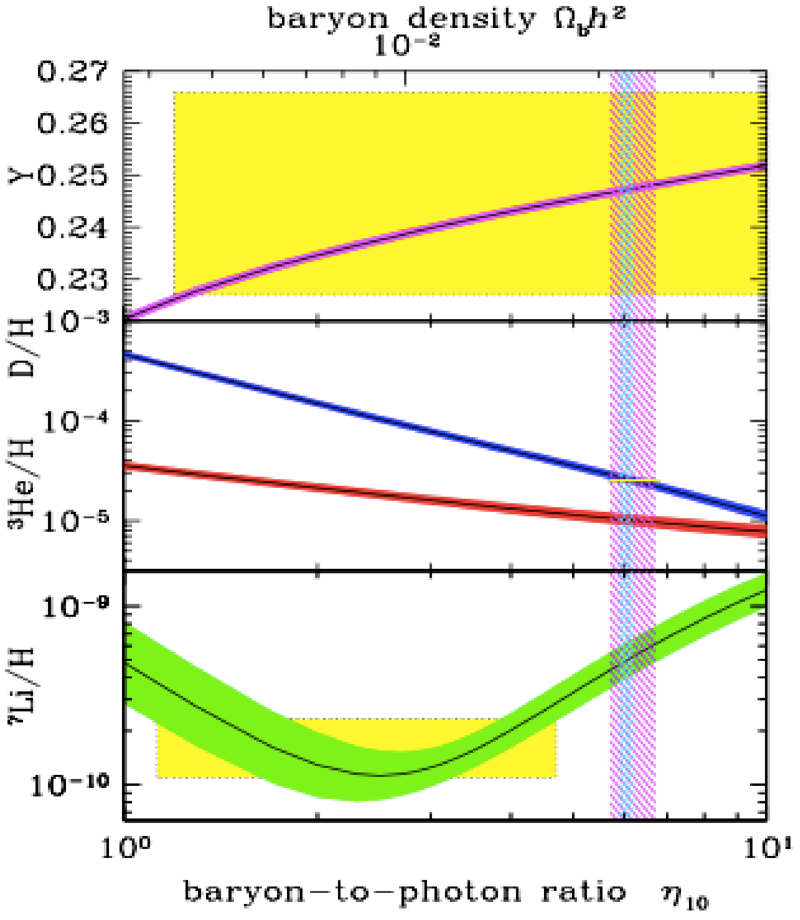
[only if Majorana]

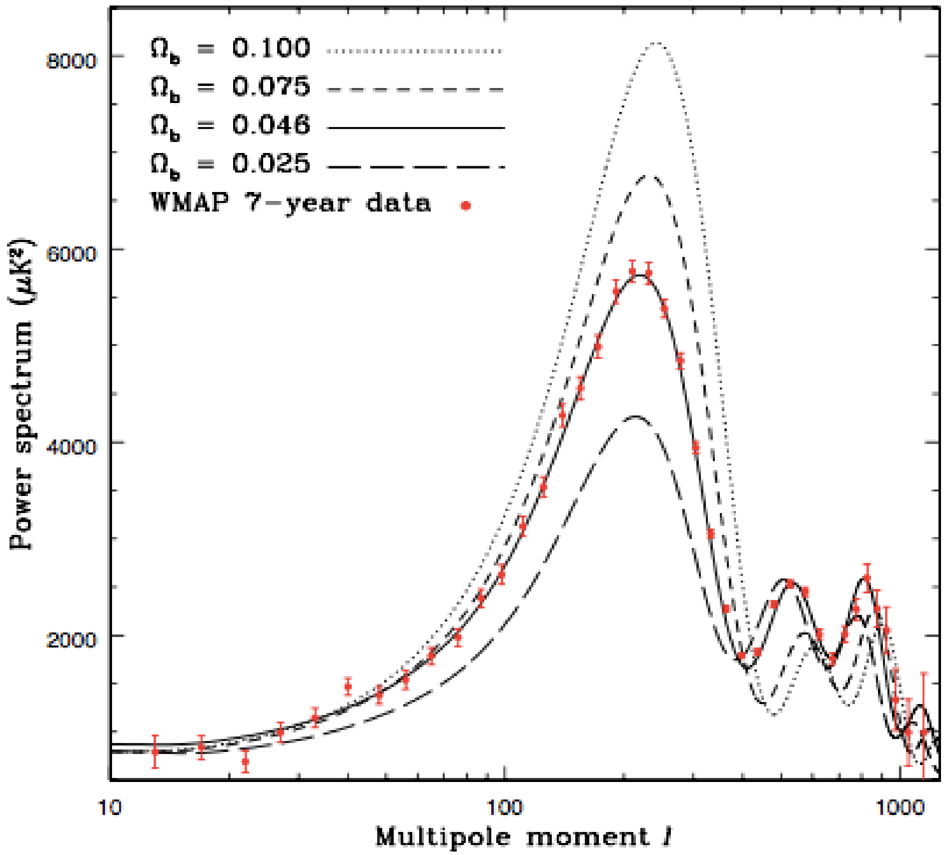
- Some hints for a no-zero CP violation phases
- Majorana phases could only appear in process violating the lepton number por 2 units.

Observables sensitive to Majorana Phases ⟷ $\Delta L = 2$

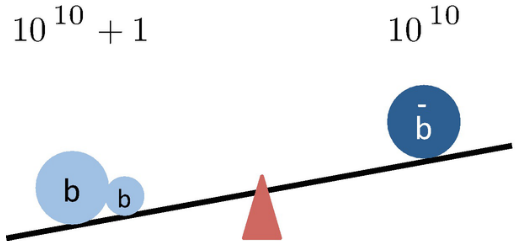
BARYOGENESIS AND SAKHAROV CONDITIONS (I).

$$\Omega_b = 0.0490 \pm 0.0007.$$





$$\eta = \frac{n_b - n_{\bar{b}}}{n_\gamma}.$$



$$0.046 \leq \Omega_b \leq 0.056 \quad (95\% \text{ CL}),$$

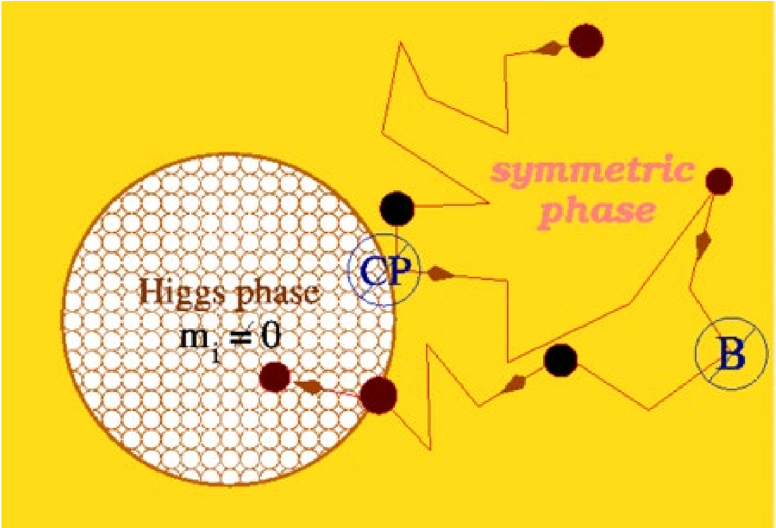
$$5.7\times10^{-10} \leq \eta \leq 6.7\times10^{-10}$$

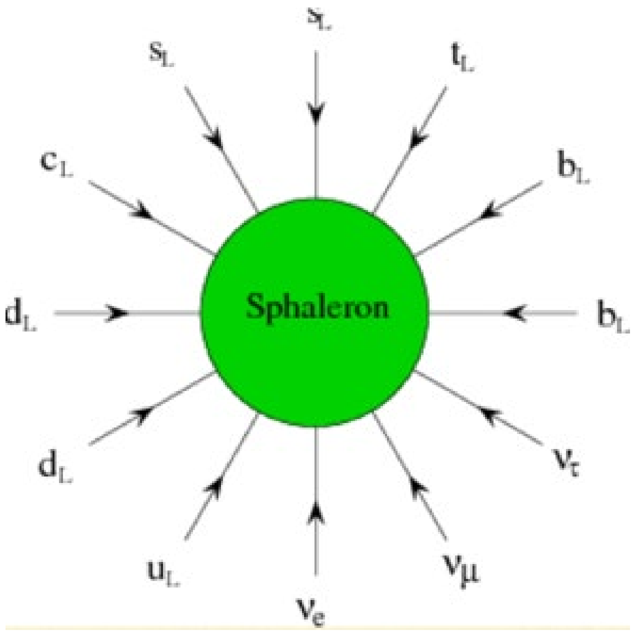
BARYOGENESIS AND SAKHAROV CONDITIONS (II).

Sakharov's conditions (1967):

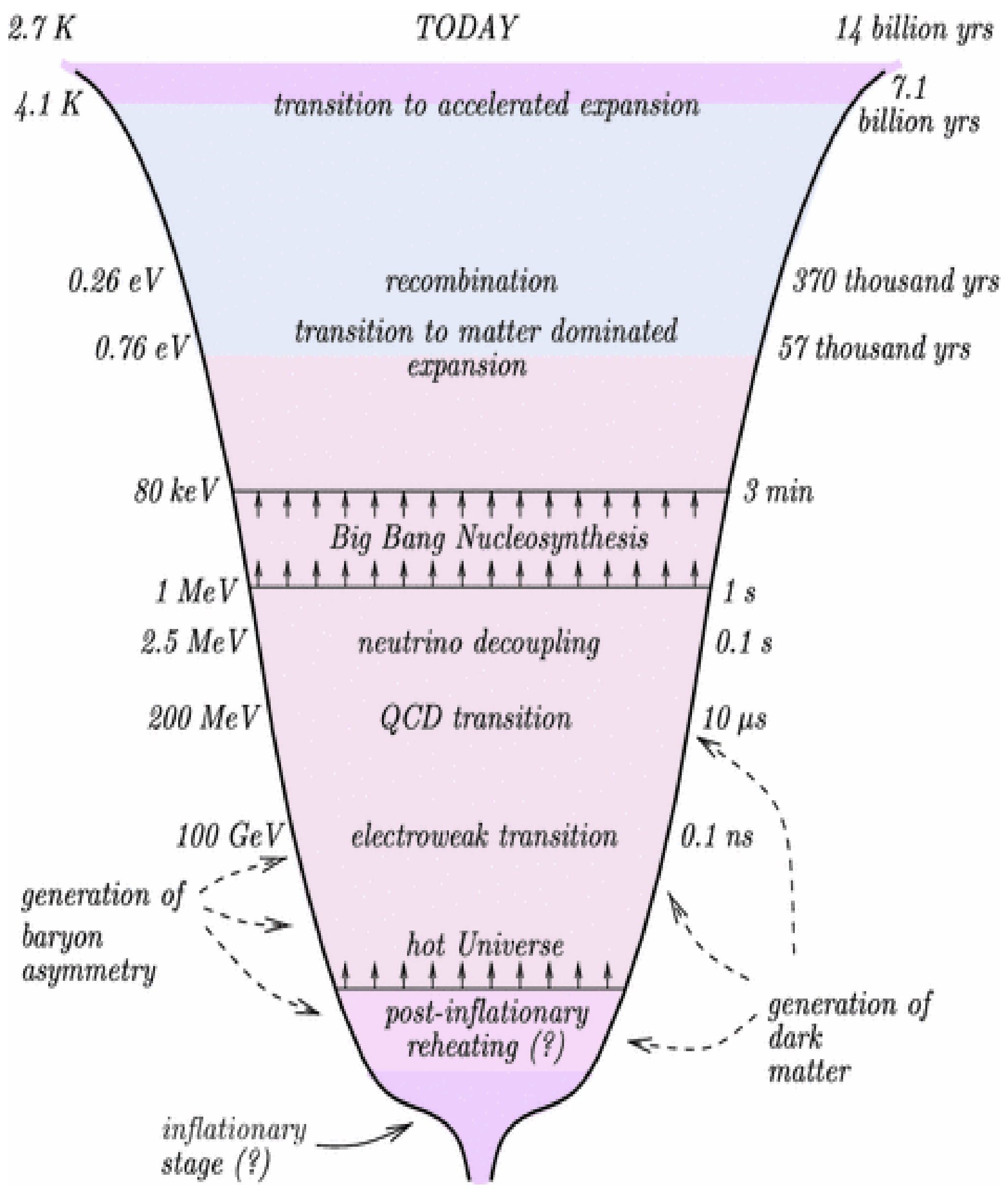
- to be out of thermal equilibrium
- to have C and CP violation
- to violate Baryon number

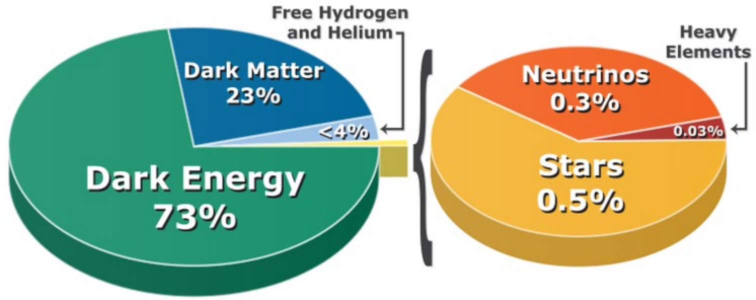
SM has B+L violations through sphalerons, has CP violation but Higgs mass too high to have a strong enough first order electroweak phase transition.

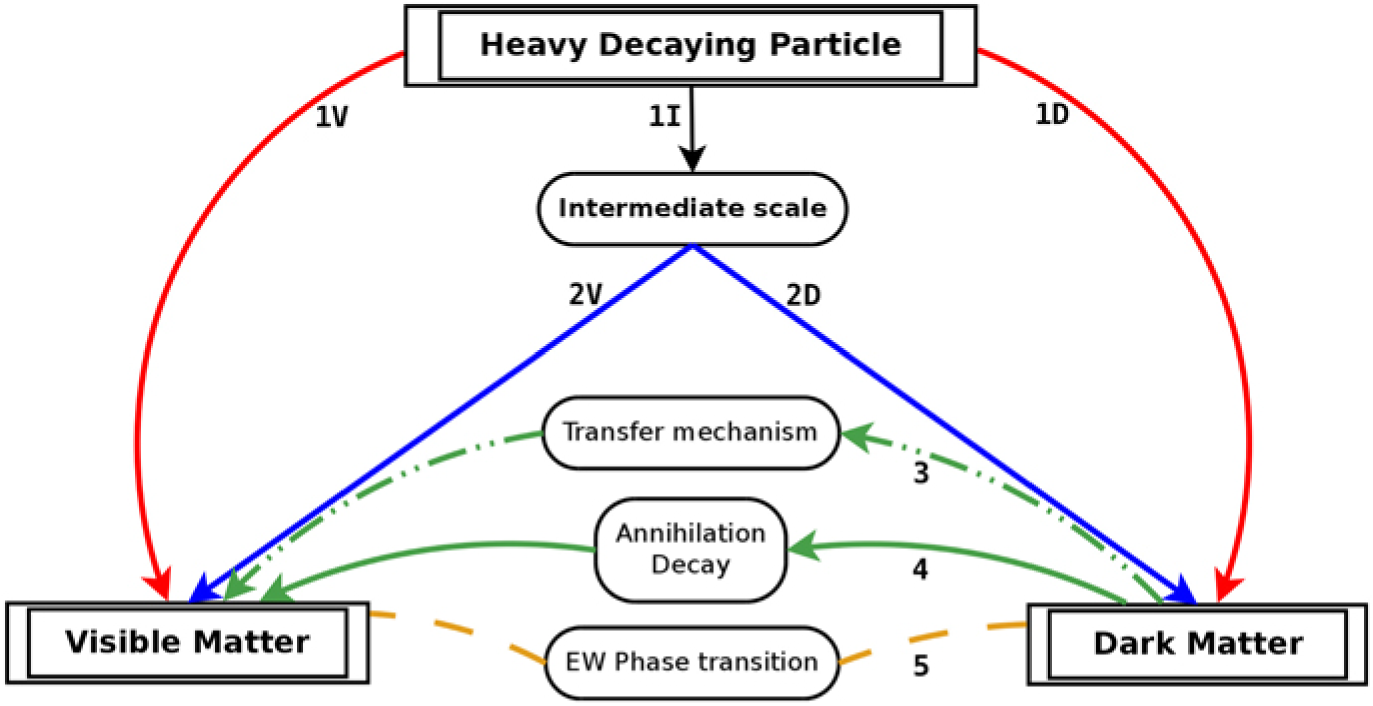




BARYON ASYMMETRY OF THE UNIVERSE AND DARK MATTER







TWO BODY NON LEPTONIC D DECAYS:

Two body non-leptonic D decays can be sorted according to the suppression factor $\lambda \simeq |V_{us}| \simeq |V_{cd}|$into:

1. Cabibbo. Favored (CF):
   - The effective hamiltonian is proportional to $V_{cs}^{*}V_{ud}$, for instance: $D^{+} \rightarrow K^{-}\pi^{+}\pi^{+}$, $D^{0} \rightarrow K^{-}\pi^{+}$
   - The CP asymmetry in SM is very suppressed.

D. Delepine, G. Faisel, C .A. Ramirez, 87(7), 075017 (2013). https://doi.org/10.1103/PhysRevD.87.075017. arXiv:1212.6281 [hep-ph]

Delepine, D., Faisel, G. & Ramirez, C.A. Direct CP violation in $D^{+} \rightarrow K^{0}(\bar{K}^{0})\pi^{+}$ decays as a probe for new physics. Eur. Phys. J. C 80, 596 (2020)

2. Singly Cabibbo-suppressed (SCS)
   - SCS decay amplitudes involve the CKM elements $\lambda_{q} = V_{cq}^{*}V_{uq}$ with q=d, s or b. Examples: $D^{0} \rightarrow K_{S}K_{0}^{*}, K_{s}K_{s}$
   - CP asymmetry can be as large as 3×10^{-3}

B. Bhattacharya, M. Gronau and J.L. Rosner, Phys. Rev. D 85, 054014 (2012) (Phys. Rev. D 85(7), 079901, 2012). https://doi.org/10.1103/PhysRevD.85.079901, https://doi.org/10.1103/PhysRevD.85.054014. arXiv:1201.2351 [hep-ph]

U. Nierste, S. Schacht, arXiv:1708.03572 [hep-ph]

U. Nierste, S. Schacht, Phys. Rev. D 92(5), 054036 (2015). https://doi.org/10.1103/PhysRevD.92.054036. arXiv:1508.00074 [hep-ph]

3. Double Cabibbo suppressed (DCS)
   - The effective hamiltonian is proportional to $V_{cd}^{*}V_{us}$, for instance:, $D^{0} \rightarrow K^{+}\pi^{-}$
   - The CP asymmetry in SM is very suppressed

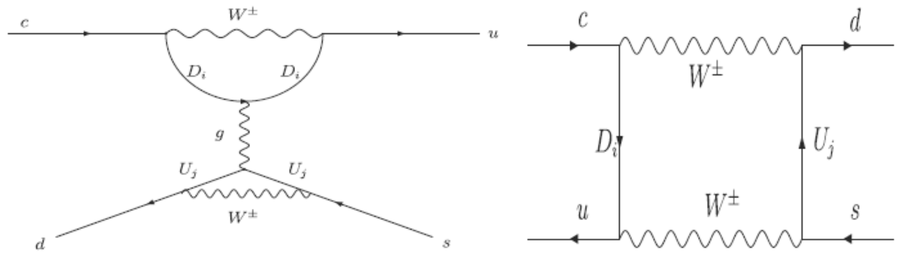


Fig. 1 Feynman diagrams for DCS processes: left (right) di-penguins contribution (box) contribution. For CF processes we make the replacements $d \leftrightarrow s$ in each diagram

D. Delepine, G. Faisel, C .A. Ramirez, Phys. Rev. D 96(11), 115005 (2017). https://doi.org/10.1103/PhysRevD.96.115005. arXiv:1710.00413 [hep-ph]

DIRECT CP VIOLATION IN D MESONS AND NEW PHYSICS :

$$\mathcal{H}^{SM}_{\text{eff.}} = \frac{G_F}{\sqrt{2}} V^*_{cq} V_{uq'} \Big[c_1 \big(\bar{q}\gamma_\mu c_L \big)\big(\bar{u}\gamma^\mu q'_L \big) + c_2 \big(\bar{u}\gamma_\mu c_L \big)\big(\bar{q}\gamma^\mu q'_L \big) \Big] + \text{h.c.} = \frac{G_F}{\sqrt{2}} V^*_{cq} V_{uq'} \left(c_1 Q_1 + c_2 Q_2 \right) + \text{h.c.}$$

For CF decays q=s and q'=d while for DCS decay q=d and q'=s

$$a_1 = c_1 + c_2/N_C$$
$$a_2 = -(c_2 + c_1/N_C)$$

$$A^{SM}_{D^+\to\bar{K}^0\pi^+} = -i\frac{G_F}{\sqrt{2}} V^*_{cs} V_{ud} \Big[(a_1 + \Delta a_1^{sd}) X^{\pi^+}_{D^+\bar{K}^0} + (a_2 + \Delta a_2^{sd} + \Delta a_2^{sdK^0}) X^{\bar{K}^0}_{D^+\pi^+} \Big],$$

$$A^{SM}_{D^+\to K^0\pi^+} = i\frac{G_F}{\sqrt{2}} V^*_{cd} V_{us} \Big[(a_1 + \Delta a_1^{ds}) X^{D^+}_{K^0\pi^+} + (a_2 + \Delta a_2^{ds} - \Delta a_2^{dsK^0}) X^{K^0}_{D^+\pi^+} \Big]$$

Very small strong phases

What about strong phases?

$$X^{P_1}_{P_2P_3} = i f_{P_1} \Delta^2_{P_2P_3} F_0^{P_2P_3}(m^2_{P_1}), \quad \Delta^2_{P_2P_3} = m^2_{P_2} - m^2_{P_3}$$

$$A_{D^+\to\bar{K}^0\pi^+} = V^*_{cs} V_{ud} (T + C)$$
$$A_{D^+\to K^0\pi^+} = V^*_{cd} V_{us} (C'' + A'')$$

where the amplitudes T, $C\,(C'')$ and A'' represent the tree level color-allowed external W-emission quark diagram, the color-suppressed internal W-emission diagram and the W-annihilation diagram respectively. Their expressions in Naive Factorization Approximation (NFA) can be approximated as

$$T \simeq \frac{G_F}{\sqrt{2}} (a_1 + \Delta a_1^{sd}) f_\pi m_D^2 F_0^{DK}(m_\pi^2)$$
$$C = \frac{G_F}{\sqrt{2}} (a_2 + \Delta a_2^{sd} + \Delta a_2^{sdK^0}) f_K m_D^2 F_0^{D\pi}(m_K^2)$$
$$C'' \simeq \frac{G_F}{\sqrt{2}} (a_1 + \Delta a_1^{ds}) f_D m_K^2 F_0^{K\pi}(m_D^2)$$
$$A'' \simeq \frac{G_F}{\sqrt{2}} (a_2 + \Delta a_2^{ds} - \Delta a_2^{dsK^0}) f_K m_D^2 F_0^{D\pi}(m_K^2)$$

CP VIOLATION IN CHARM DECAYS:

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

Measurement of the *CP* violation parameter A_Γ in $D^0 \to K^+K^-$ and $D^0 \to \pi^+\pi^-$ decays

Abstract

Asymmetries in the time-dependent rates of $D^0 \to K^+K^-$ and $D^0 \to \pi^+\pi^-$ decays are measured in a pp collision data sample collected with the LHCb detector during LHC Run 1, corresponding to an integrated luminosity of 3 fb^{-1}. The asymmetries in effective decay widths between D^0 and $\overline{D}^0$ decays, sensitive to indirect *CP* violation, are measured to be $A_\Gamma(K^+K^-) = (-0.30 \pm 0.32 \pm 0.10) \times 10^{-3}$ and $A_\Gamma(\pi^+\pi^-) = (0.46 \pm 0.58 \pm 0.12) \times 10^{-3}$, where the first uncertainty is statistical and the second systematic. These measurements show no evidence for *CP* violation and improve on the precision of the previous best measurements by nearly a factor of two.

Published in Phys. Rev. Lett. 118, 261803 (2017)

$$A_\Gamma(K^-K^+) = (-0.30 \pm 0.32 \pm 0.10) \times 10^{-3}$$

$$A_\Gamma(\pi^-\pi^+) = (0.46 \pm 0.58 \pm 0.12) \times 10^{-3}$$

$$A_\Gamma(K^-\pi^+) = (0.16 \pm 0.10) \times 10^{-3}$$

Delepine, D., Faisel, G. & Ramirez, C.A. New physics signature in D0(D¯0)⟶f effective width asymmetries. Eur. Phys. J. C 79, 597 (2019).

Observation of *CP* violation in charm decays

LHCb collaboration†

Abstract

A search for charge-parity (*CP*) violation in $D^0 \to K^-K^+$ and $D^0 \to \pi^-\pi^+$ decays is reported, using pp collision data corresponding to an integrated luminosity of 5.9 fb^{-1} collected at a center-of-mass energy of 13 TeV with the LHCb detector. The flavor of the charm meson is inferred from the charge of the pion in $D^*(2010)^+ \to D^0\pi^+$ decays or from the charge of the muon in $\overline{B} \to D^0\mu^-\overline{\nu}_\mu X$ decays. The difference between the *CP* asymmetries in $D^0 \to K^-K^+$ and $D^0 \to \pi^-\pi^+$ decays is measured to be $\Delta A_{CP} = [-18.2 \pm 3.2\,(\text{stat.}) \pm 0.9\,(\text{syst.})] \times 10^{-4}$ for π-tagged and $\Delta A_{CP} = [-9 \pm 8\,(\text{stat.}) \pm 5\,(\text{syst.})] \times 10^{-4}$ for μ-tagged D^0 mesons. Combining these with previous LHCb results leads to

$$\Delta A_{CP} = (-15.4 \pm 2.9) \times 10^{-4},$$

where the uncertainty includes both statistical and systematic contributions. The measured value differs from zero by more than five standard deviations. This is the first observation of *CP* violation in the decay of charm hadrons.

Published in Phys. Rev. Lett. **122** (2019) 211803

New Physics and tau decays (I):

Delepine, D., Faisel, G. & Ramirez, C.A. Exploring new physics contributions to CP violation in τ−→K−π0ντ. Eur. Phys. J. C 81, 368 (2021).

$$A_{\mathrm{CP}}^{\mathrm{exp.}} = \frac{\Gamma(\tau^+ \to K_S\pi^+\bar{\nu}_\tau) - \Gamma(\tau^- \to K_S\pi^-\nu_\tau)}{\Gamma(\tau^+ \to K_S\pi^+\bar{\nu}_\tau) + \Gamma(\tau^- \to K_S\pi^-\nu_\tau)} = -(0.36 \pm 0.23 \pm 0.11)\%$$

⟷

$$A_{\mathrm{CP}}^{\mathrm{theo.}} \simeq 2\mathrm{Re}\,\epsilon_K = 2\cdot(0.166(2))\% = 0.332(2)\%$$

There is a 2.8 sigma discrepancy that may indicate the presence of direct CPV, absent in the SM. However experimental details as the efficiency in the *KS* detection has to betaken into account properly as was pointed out by Grossman and Nir and G. Calderon et al. Any real discrepancy is direct CPV and therefore is new physics (NP) and it should be present in related channels:

$$\tau^- \to K^-\pi^0\nu_\tau$$

$$\mathcal{H}_{eff} = -\frac{G_F}{\sqrt{2}}V_{us}^{\star}\sum_{i=V,A,S,P,T} C_i(\mu)\,Q_i(\mu),$$

$$Q_V = \big(\bar{\nu}_\tau\gamma_\mu\tau\big)\big(\bar{s}\gamma^\mu u\big),$$
$$Q_A = \big(\bar{\nu}_\tau\gamma_\mu\gamma_5\tau\big)\big(\bar{s}\gamma^\mu u\big),$$
$$Q_S = \big(\bar{\nu}_\tau\tau\big)\big(\bar{s}u\big),$$
$$Q_P = \big(\bar{\nu}_\tau\gamma_5\tau\big)\big(\bar{s}u\big),$$
$$Q_T = \big(\bar{\nu}_\tau\sigma_{\mu\nu}(1+\gamma_5)\tau\big)\big(\bar{s}\sigma^{\mu\nu}u\big),$$

$$\langle K^-\pi^0|\bar{s}\gamma^\mu u|0\rangle = \frac{1}{\sqrt{2}}\Big((p_K - p_\pi)^\mu f_+(s) + (p_K + p_\pi)^\mu f_-(s)\Big),$$

$$f_-(s) = \frac{\Delta^2_{K\pi}}{s}\big(f_0(s) - f_+(s)\big),$$

$$\langle K^-\pi^0|\bar{s}u|0\rangle = \frac{(M_K^2 - M_\pi^2)}{\sqrt{2}(m_s - m_u)}f_0(s) = \frac{\Delta^2_{K\pi}}{\sqrt{2}(m_s - m_u)}f_0(s),$$

$$\langle K^-\pi^0|\bar{s}\sigma^{\mu\nu}u|0\rangle = \frac{i(p_K^\mu p_\pi^\nu - p_K^\nu p_\pi^\mu)}{\sqrt{2}M_K}B_T(s).$$

New Physics and tau decays (II):

$$A_{CP} = \frac{\Gamma(\tau^- \to K^-\pi^0\nu_\tau) - \Gamma(\tau^+ \to K^+\pi^0\nu_\tau)}{\Gamma(\tau^- \to K^-\pi^0\nu_\tau) + \Gamma(\tau^+ \to K^+\pi^0\nu_\tau)}.$$

$$A_{\mathrm{CP}}(s,\ x) = \frac{\mathrm{d}^2\Gamma^+/\mathrm{d}s\mathrm{d}x - \mathrm{d}^2\Gamma^-/\mathrm{d}s\mathrm{d}x}{\mathrm{d}^2\Gamma^+/\mathrm{d}s\mathrm{d}x + \mathrm{d}^2\Gamma^-/\mathrm{d}s\mathrm{d}x}$$
$$= \frac{4m_\tau^2\Delta_{K\pi}^2\sqrt{s}\,|\mathbf{p}_K|x\ \mathrm{Im}[C_V C_S^*]\ \mathrm{Im}(f_+(s)f_0^*(s))}{4s\left(s+2m_\tau|\mathbf{q}|x^2\right)|\mathbf{p}_K C_V f_+(s)|^2 + m_\tau^2\Delta_{K\pi}^4\,|C_S f_0(s)|^2 + 4m_\tau^2\Delta_{K\pi}^2\sqrt{s}\,|\mathbf{p}_K|x\ \mathrm{Re}(C_V C_S^*)\ \mathrm{Re}(f_+(s)f_0^*(s))},$$

$$A_{CP}^{NP} = -\frac{G_F^2|V_{us}|^2 S_{\mathrm{EW}}\, Im\, C_T^{NP}}{512\pi^3 m_\tau^2 M_K \Gamma_\tau \mathrm{BR}(\tau \to K\pi\nu_\tau)}$$
$$\times \int_{(M_\pi+M_K)^2}^{m_\tau^2} \mathrm{d}s\, \frac{\lambda^{3/2}(s, M_\pi^2, M_K^2)(m_\tau^2 - s)^2}{s^2}$$
$$\times |f_+(s)||B_T(s)|\sin\left(\delta_+(s) - \delta_T(s)\right),$$

To evaluate the tensorial form factor we used the following ref.:

V. Cirigliano, A. Crivellin, M. Hoferichter, A no-go theorem for non-standard explanations of the $\tau \to K_S\pi\nu_\tau$ CP asymmetry. Phys. Rev. Lett. **120**(14), 141803 (2018). arXiv:1712.06595 [hepph]

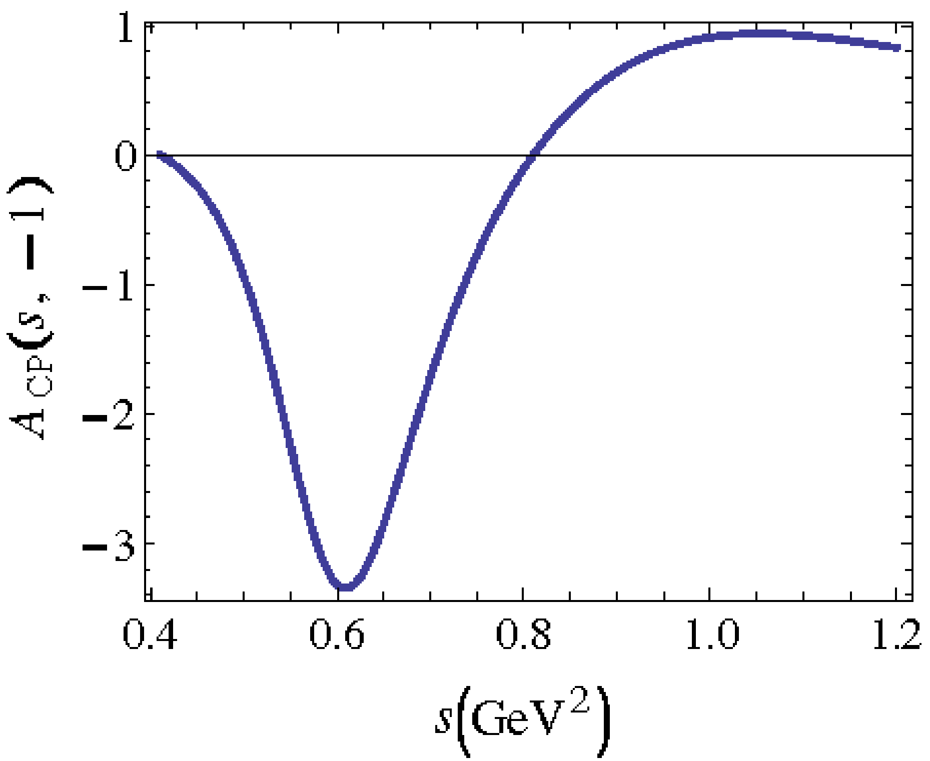
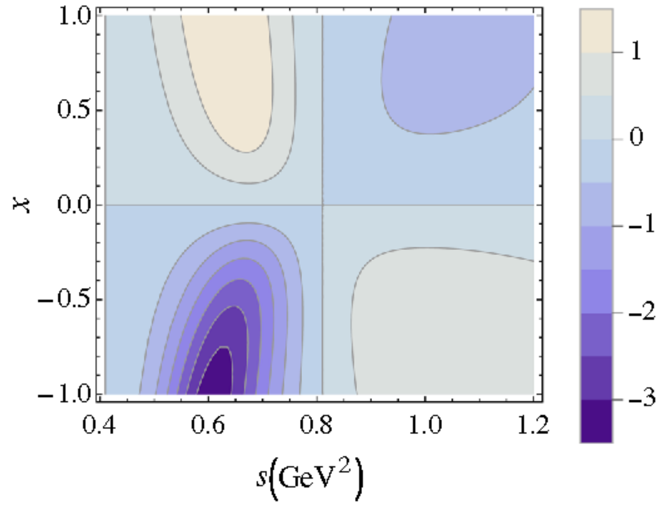


Fig. 2 Local CPV, in units of 10^{-3} as a function of s and $x = \cos\theta$ and the same but for $x = -1$



NEW PHYSICS AND TAU DECAYS (III):

LAST BUT NOT LEAST: CP VIOLATION AND NEUTRINOS?

Distinguishing Dirac and Majorana neutrinos with astrophysical fluxes, J Barranco *et al* 2020 *J. Phys. G: Nucl. Part. Phys.* **47** 035201

- Dirac vs Majorana neutrinos

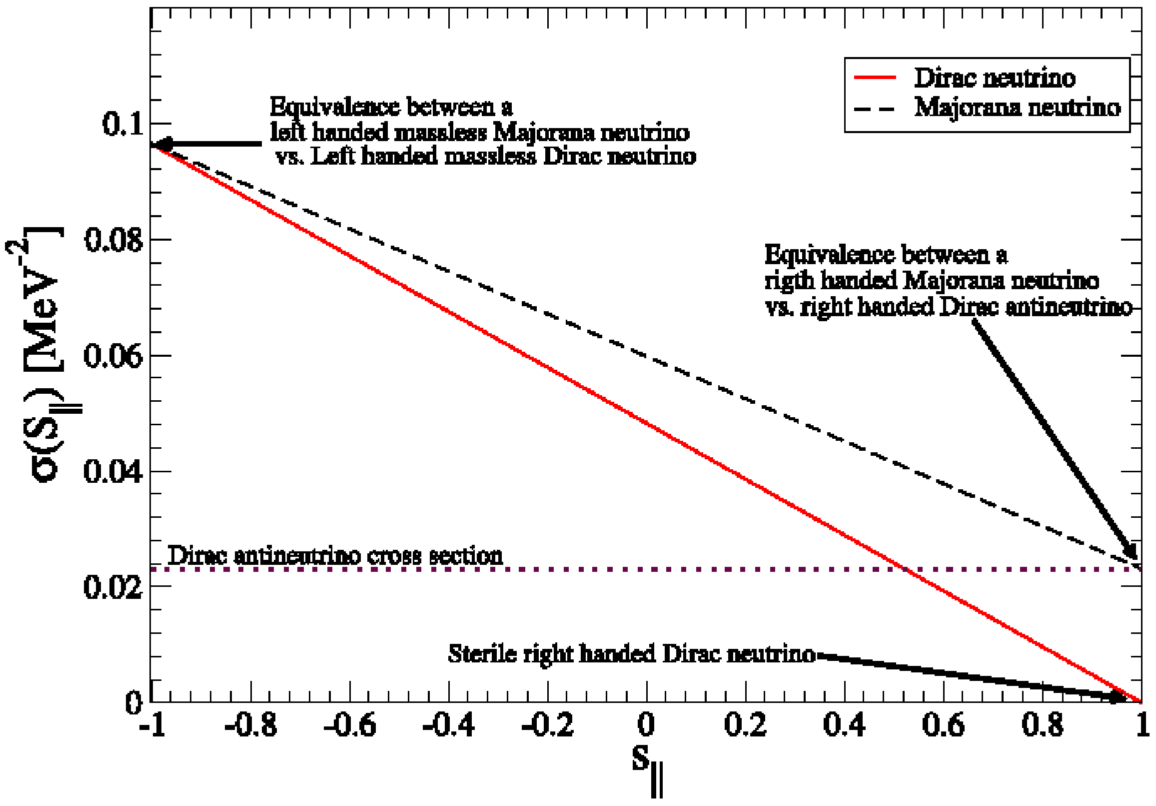
$$\mathcal{L} = \frac{G_F}{\sqrt{2}} \left[\bar{u}^f_{\nu_\ell} \gamma^\mu \left(1-\gamma^5\right) u^i_{\nu_\ell}\right] \left[\bar{u}^f_e \gamma_\mu \left(g^\ell_V - g^\ell_A\right) u^i_e\right],$$

$$\mathcal{M}_D = -i\frac{G_F}{\sqrt{2}} \left[\bar{u}^f_{\nu_\ell} \gamma^\mu \left(1-\gamma^5\right) u^i_{\nu_\ell}\right] \left[\bar{u}^f_e \gamma_\mu \left(g^\ell_V - g^\ell_A \gamma^5\right) u\right.$$

$$\mathcal{M}_M = i\frac{2G_F}{\sqrt{2}} \left[\bar{u}^f_e \gamma^\mu \left(g^\ell_V - g^\ell_A \gamma^5\right) u^i_e\right] \left[\bar{u}^f_{\nu_\ell} \gamma_\mu \gamma^5 u^i_{\nu_\ell}\right],$$

Experiment	Limit
$\text{GEMMA}_{\text{Reactor}\bar{\nu}_e - e^-}$	$\mu_{\nu_e} < 2.9 \times 10^{-11} \mu_B$
$\text{LSND}_{\text{Accelerator}(\nu_\mu,\bar{\nu}_\mu) - e^-}$	$\mu_{\nu_\mu} < 6.8 \times 10^{-10} \mu_B$
$\text{Borexino}_{\text{Solar}\nu_e - e^-}$	$\mu_{\nu_e} < 5.4 \times 10^{-11} \mu_B$
$\text{SN 1987A}_{\text{Supernova}}$	$\mu_{\nu_e} < (2.-8.) \times 10^{-12} \mu_B$

$$\frac{ds_{||}}{dr} = -2\mu_\nu B_\perp s_{||},$$



Used neutrino astrophysical fluxes to look for difference in cross sections.

OPEN QUESTIONS

- How to determine the strong phases in Mesons decays and form factors in tau decays. To answer to it, Theoretical physicists need to be closer to experiments.
- D mesons: a windows to New Physics reachable at next generation of experiments (Belle 2, LHCB,....)
- Majorana vs Dirac neutrinos: what about CP violation?
- Where to look for indirect access to leptonic CP violating phases?
- Is it possible to relate the CP violation needed for Baryogenesis to low physics experiment.
- Dark matter vs CP violation, related through Baryogenesis?
- And many more..