All Quiet on CP-violating front?*

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(*) “All quiet on the Western front” written by Erich Maria Remarque

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Plan

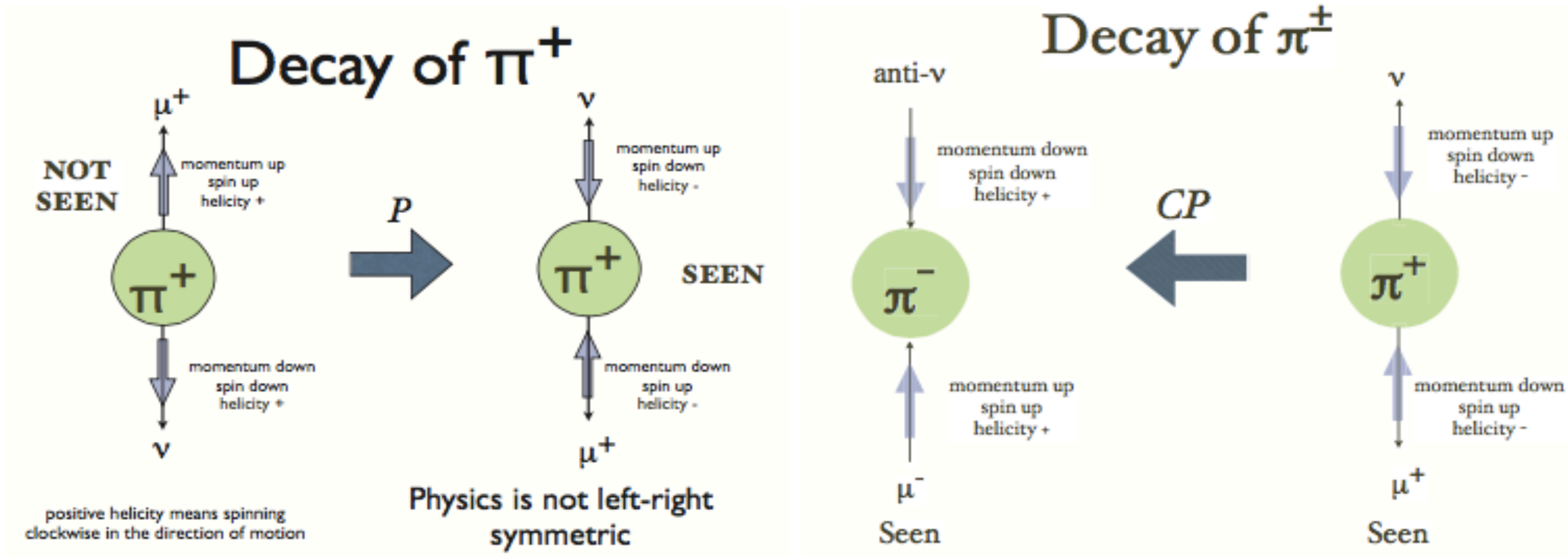
- Generalities on CP Violation (CPV)

- CP violation in Standard Model:
  - Strong-T violation
  - CKM mixing matrix
  - PNMS mixing matrix : Maximal CP violation in neutrinos?

- CP violation in Intensity frontier: D mesons case

- CP violation in Cosmos Frontier: Baryogenesis as an example

- Conclusion



B. McKellar,AIP Conf. Proc. **1657**, 030001 (2015); doi: 10.1063/1.4915151

- In 1956, T.D. Lee and C.N.Yang proposed that weak interactions are not invariant under parity symmetry (Nobel Prize 1957)
- In 1957 C.S.Wu proved it in the beta decay of polarized ^{60}Co
- In 1964, Cronin, Fitch found evidence of CP violation in neutral K meson decay. (Nobel Prize 1980)

Classification of CPV (I)

$$|P_H\rangle = p|P_0\rangle + q|\overline{P}_0\rangle$$
$$|P_L\rangle = p|P_0\rangle - q|\overline{P}_0\rangle$$

If CP is converved →

$$CP|P_H\rangle = \pm|P_H\rangle$$
$$CP|P_L\rangle = \mp|P_L\rangle$$

$$i\frac{\mathrm{d}}{\mathrm{dt}}\begin{pmatrix}|P^0(t)\rangle \\ |\overline{P}^0(t)\rangle\end{pmatrix} = \left(M - \frac{i}{2}\Gamma\right)\begin{pmatrix}|P^0(t)\rangle \\ |\overline{P}^0(t)\rangle\end{pmatrix}$$

$$\Rightarrow \quad |P_{L,H}(t)\rangle = e^{-(im_{L,H}+\Gamma_{L,H}/2)t}\,|P_{L,H}\rangle$$

$$\mathrm{Im}\,\frac{\Gamma_{12}}{M_{12}} = \frac{1-|q/p|^4}{1+|q/p|^4}$$

$$A_f \equiv \langle f|T|P_0\rangle$$
$$\overline{A}_f \equiv \langle f|T|\overline{P}_0\rangle$$

Direct CPV → $\left|\frac{\bar{A}_{\bar{f}}}{A_f}\right|$,

Indirect CPV → $\left|\frac{q}{p}\right|$,

Interference CPV → $\lambda_f = \frac{q}{p}\frac{\bar{A}_f}{A_f}$,

CP violation in mixing (Indirect CPV)

$$\left|\frac{q}{p}\right| \neq 1$$

$$|A_f| = |\overline{A}_{\overline{f}}|$$
$$|A_{\overline{f}}| = |\overline{A}_f|$$

- Similar to **semileptonic decays** $f = l^{\pm}X, \quad \overline{f} = l^{\mp}X$
- if $\quad A_{\overline{f}} = \overline{A}_f = 0$ which means $\quad l^{\pm} tag\ P_0\ or\ \overline{P}_0$

$$A_{CP} = \frac{\Gamma(\overline{P}_0 \to l^{\pm}X) - \Gamma(P_0 \to l^{\mp}X)}{\Gamma(\overline{P}_0 \to l^{\pm}X) + \Gamma(P_0 \to l^{\mp}X)} = \frac{1 - \left|\frac{q}{p}\right|^4}{1 + \left|\frac{q}{p}\right|^4}$$

CP violation in Decays (direct CPV)

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 $r = |a_1/a_2|$

CPV in interference between decays with and without mixing.

$$\lambda_f = \frac{q}{p}\frac{\bar{A}_f}{A_f}$$

$$\mathrm{Im}\,\lambda_f \neq 0$$

$$M,\ \bar{M} \to f.$$

$$A_f(t) = \frac{\Gamma(\bar{M}^0(t) \to f) - \Gamma(M^0(t) \to f)}{\Gamma(\bar{M}^0(t) \to f) + \Gamma(M^0(t) \to f)} = -C_f \cos(\Delta m t) + S_f \sin(\Delta m t)$$

$$C_f = \frac{1 - |\lambda_f|^2}{1 + |\lambda_f|^2} \qquad S_f = \frac{2\,\mathrm{Im}(\lambda_f)}{1 + |\lambda_f|^2},$$

CPV in Standard Model (I)

◆ **Strong T-violation:**

General Yukawa coupling + QCD Axial Anomaly

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

Electric Dipole Moment of neutron → $\theta < 10^{-10}$

CPV in Standard Model (II)

- **Yukawa couplings and CKM mixing matrix:**

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

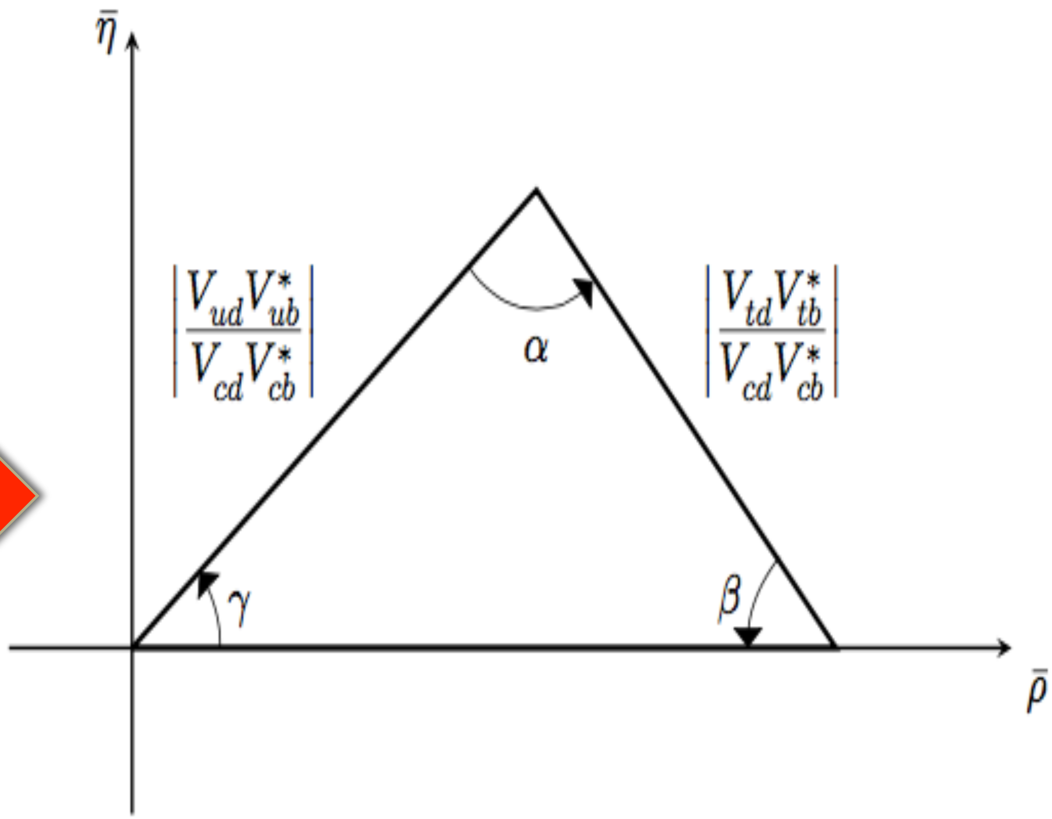
Condition to have CP violation in SM:

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

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

Unitarity of the V matrix

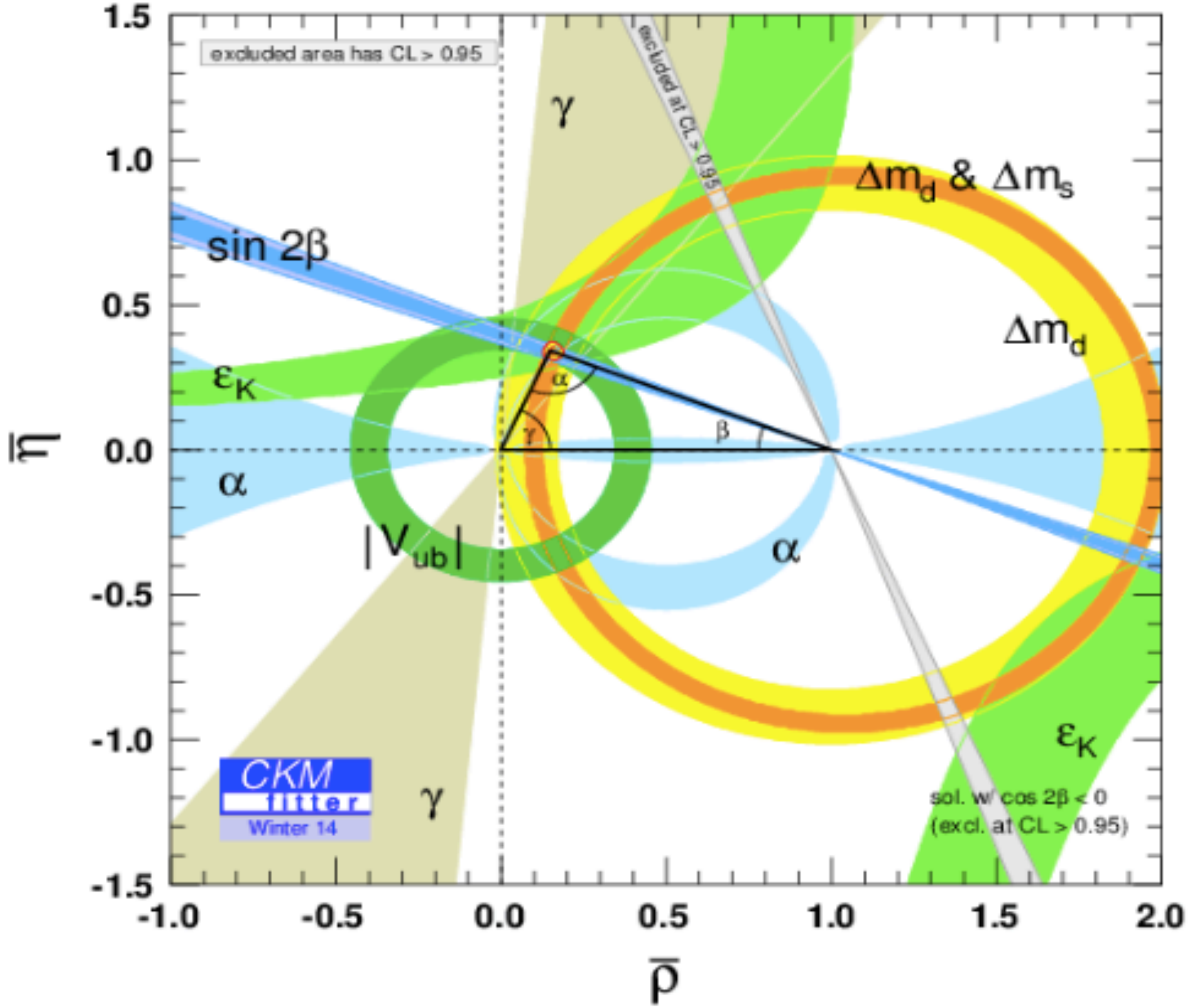
$$V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0$$



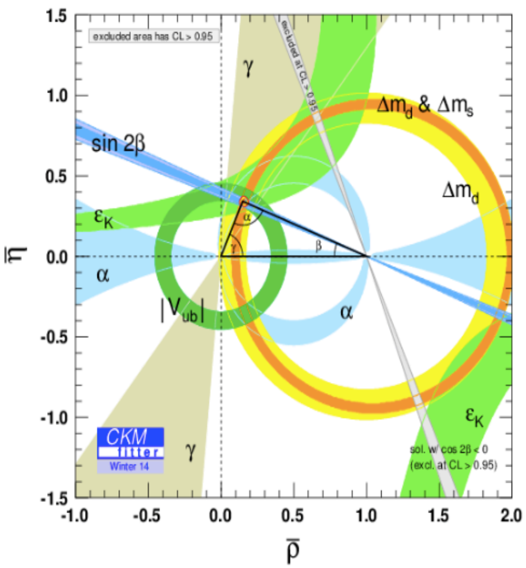
Cabibbo Kobayashi Maskawa (I)

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

Cabibbo Kobayashi Maskawa (II)



Future: Cabibbo Kobayashi Maskawa (I)



J. Charles et al., Phys. Rev D 89, 033016 (2014)

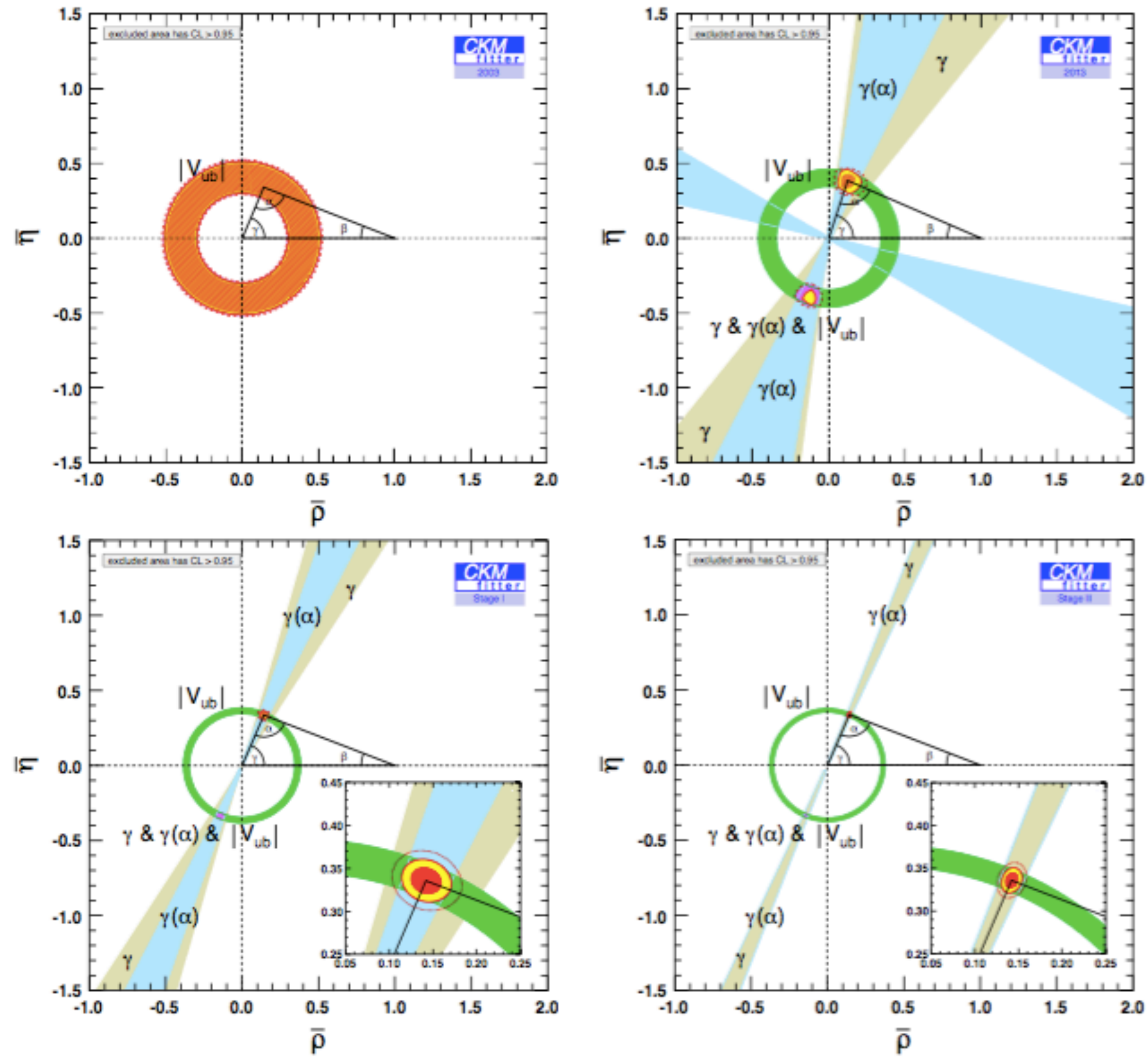


FIG. 1. The past (2003, top left) and present (top right) status of the unitarity triangle in the presence of NP in neutral-meson mixing. The lower plots show future sensitivities for Stage I and Stage II described in the text, assuming data consistent with the SM. The combination of all constraints in Table I yields the red-hatched regions, yellow regions, and dashed red contours at 68.3% CL, 95.5% CL, and 99.7% CL, respectively.

Future: Cabibbo Kobayashi Maskawa (II)

	2003	2013	Stage I		Stage II	
$\lvert V_{ud}\rvert$	0.9738 ± 0.0004	$0.97425 \pm 0 \pm 0.00022$	id		id	
$\lvert V_{us}\rvert$ ($K_{\ell 3}$)	$0.2228 \pm 0.0039 \pm 0.0018$	$0.2258 \pm 0.0008 \pm 0.0012$	0.22494 ± 0.0006		id	
$\lvert \epsilon_K\rvert$	$(2.282 \pm 0.017) \times 10^{-3}$	$(2.228 \pm 0.011) \times 10^{-3}$	id		id	
Δm_d [ps^{-1}]	0.502 ± 0.006	0.507 ± 0.004	id		id	
Δm_s [ps^{-1}]	> 14.5 [95% CL]	17.768 ± 0.024	id		id	
$\lvert V_{cb}\rvert \times 10^3$ ($b \to c\ell\bar{\nu}$)	$41.6 \pm 0.58 \pm 0.8$	$41.15 \pm 0.33 \pm 0.59$	42.3 ± 0.4	[17]	42.3 ± 0.3	[17]
$\lvert V_{ub}\rvert \times 10^3$ ($b \to u\ell\bar{\nu}$)	$3.90 \pm 0.08 \pm 0.68$	$3.75 \pm 0.14 \pm 0.26$	3.56 ± 0.10	[17]	3.56 ± 0.08	[17]
$\sin 2\beta$	0.726 ± 0.037	0.679 ± 0.020	0.679 ± 0.016	[17]	0.679 ± 0.008	[17]
α (mod π)	—	$(85.4^{+4.0}_{-3.8})^\circ$	$(91.5 \pm 2)^\circ$	[17]	$(91.5 \pm 1)^\circ$	[17]
γ (mod π)	—	$(68.0^{+8.0}_{-8.5})^\circ$	$(67.1 \pm 4)^\circ$	[17, 18]	$(67.1 \pm 1)^\circ$	[17, 18]
β_s	—	$0.0065^{+0.0450}_{-0.0415}$	0.0178 ± 0.012	[18]	0.0178 ± 0.004	[18]
$\mathcal{B}(B \to \tau\nu) \times 10^4$	—	1.15 ± 0.23	0.83 ± 0.10	[17]	0.83 ± 0.05	[17]
$\mathcal{B}(B \to \mu\nu) \times 10^7$	—	—	3.7 ± 0.9	[17]	3.7 ± 0.2	[17]
$A^d_{SL} \times 10^4$	10 ± 140	23 ± 26	-7 ± 15	[17]	-7 ± 10	[17]
$A^s_{SL} \times 10^4$	—	-22 ± 52	0.3 ± 6.0	[18]	0.3 ± 2.0	[18]
$\bar{m}_c$	$1.2 \pm 0 \pm 0.2$	$1.286 \pm 0.013 \pm 0.040$	1.286 ± 0.020		1.286 ± 0.010	
$\bar{m}_t$	167.0 ± 5.0	$165.8 \pm 0.54 \pm 0.72$	id		id	
$\alpha_s(m_Z)$	$0.1172 \pm 0 \pm 0.0020$	$0.1184 \pm 0 \pm 0.0007$	id		id	
B_K	$0.86 \pm 0.06 \pm 0.14$	$0.7615 \pm 0.0026 \pm 0.0137$	0.774 ± 0.007	[19, 20]	0.774 ± 0.004	[19, 20]
f_{B_s} [GeV]	$0.217 \pm 0.012 \pm 0.011$	$0.2256 \pm 0.0012 \pm 0.0054$	0.232 ± 0.002	[19, 20]	0.232 ± 0.001	[19, 20]
B_{B_s}	1.37 ± 0.14	$1.326 \pm 0.016 \pm 0.040$	1.214 ± 0.060	[19, 20]	1.214 ± 0.010	[19, 20]
f_{B_s}/f_{B_d}	$1.21 \pm 0.05 \pm 0.01$	$1.198 \pm 0.008 \pm 0.025$	1.205 ± 0.010	[19, 20]	1.205 ± 0.005	[19, 20]
B_{B_s}/B_{B_d}	1.00 ± 0.02	$1.036 \pm 0.013 \pm 0.023$	1.055 ± 0.010	[19, 20]	1.055 ± 0.005	[19, 20]
$\tilde{B}_{B_s}/\tilde{B}_{B_d}$	—	$1.01 \pm 0 \pm 0.03$	1.03 ± 0.02		id	
$\tilde{B}_{B_s}$	—	$0.91 \pm 0.03 \pm 0.12$	0.87 ± 0.06		id	

PNMS mixing matrix (I):

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]

Maximum CP violation seems to be favoured by T2K and Daya Bay results.

$$\sin\delta \sim -1$$

$$\Delta m^2_{31} \equiv m^2_3 - m^2_1$$

$$\Delta m^2_{32} \equiv m^2_3 - m^2_2$$

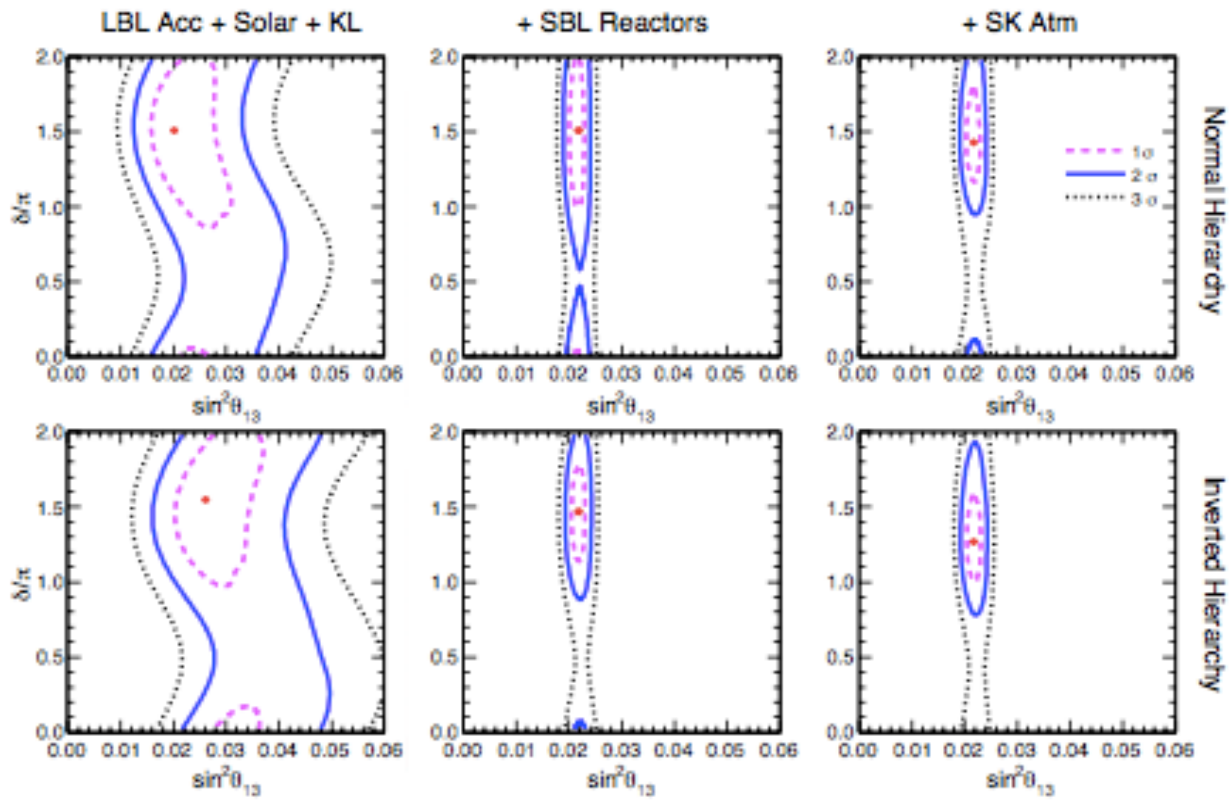
$$\Delta m^2_{31} \sim \Delta m^2_{32}$$

$$\Delta m^2_{31} = 2.32 \times 10^{-3} eV^2$$

P. Adamson et al. (MINOS Collaboration), Phys. Rev. Lett. 106, 181801(2011).

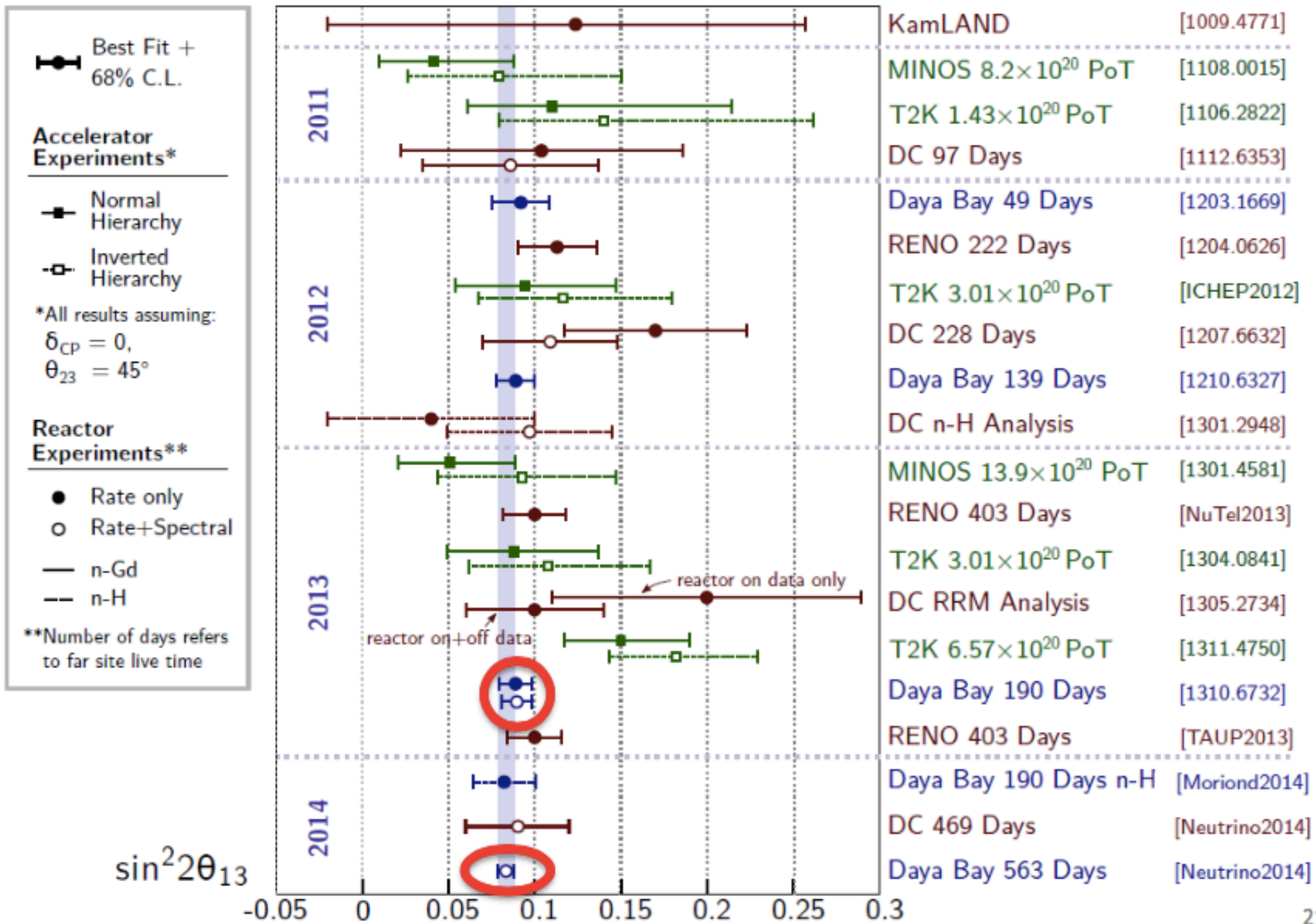
$$\Delta m^2_{21} \equiv m^2_2 - m^2_1 = 7.59 \times 10^{-5} eV^2$$

$$\sin^2 2\theta_{12} = 0.861^{+0.026}_{-0.022}$$



E. Lisi, talk given at Moriond 2015 (March 2015)

List of Recent θ_{13} Measurements



Bei-Zhen Hu, talk given at Moriond 2015

Measurements of θ_{13} via $\nu_\mu \to \nu_e$ and $\bar{\nu}_\mu \to \bar{\nu}_e$ oscillations are dependent on δ_{CP}.

Other observables:

β decay, sensitive to the "effective electron neutrino mass":

$$m_\beta = \left[c_{13}^2 c_{12}^2 m_1^2 + c_{13}^2 s_{12}^2 m_2^2 + s_{13}^2 m_3^2\right]^{\frac{1}{2}}$$

0νββ decay: only if Majorana. "Effective Majorana mass":

$$m_{\beta\beta} = \left|c_{13}^2 c_{12}^2 m_1 + c_{13}^2 s_{12}^2 m_2 e^{i\phi_2} + s_{13}^2 m_3 e^{i\phi_3}\right|$$

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

CPV in D mesons (I):

- D mesons decays can be classified as :
  - Cabibbo Favour Decays (CF):
    $$D^0 \to K^-\pi^+, D^+ \to K^-\pi^+\pi^+$$
    - no CPV within SM o extremely suppressed
  - Simple Cabibbo Suppressed (SCS):
    $$D^0 \to K^+K^-, \pi^+\pi^-$$
    - CPV within SM of order 10^{-4}
  - Doube Suppressed Cabibbo (DSC):
    $$D^0 \to K^+\pi^-, D^0 \to K^+\pi^-\pi^0$$
    - no CPV within SM o extremely suppressed

CPV in D mesons (II):

Mode	BR[%]	A_{CP} [%]	Mode	BR[%]	A_{CP} [%]
$D^0 \to K^-\pi^+$ CF	3.95(5)	-	$D^0 \to \bar{K}^0\pi^0$ CF	2.4(1)	-
$D^0 \to \bar{K}^0\eta$ CF	0.96(6)	-	$D^0 \to \bar{K}^0\eta'$ CF	1.90(11)	-
$D^+ \to \bar{K}^0\pi^+$ CF	3.07(10)	-	$D_s^+ \to K^+\bar{K}^0$ CF	2.98(8)	-
$D_s^+ \to \pi^+\eta$ CF	1.84(15)	-	$D_s^+ \to \pi^+\eta'$ CF	3.95(34)	-
$D^0 \to K^+\pi^-$ DCS	$1.48(7) \cdot 10^{-4}$	-	$D^0 \to K^0\pi^0$ DCS	-	-
$D^0 \to K^0\eta$ DCS	-	-	$D^0 \to K^0\eta'$ DCS	-	-
$D^+ \to K^0\pi^+$ DCS	-	-	$D^+ \to K^+\pi^0$ DCS	$1.72(19) \cdot 10^{-2}$	-
$D^+ \to K^+\eta$ DCS	$1.08(17) \cdot 10^{-2}$	-	$D^+ \to K^+\eta'$ DCS	$1.76(22) \cdot 10^{-2}$	-
$D_s^+ \to K^+K^0$ DCS	-	-			
$D^0 \to \pi^-\pi^+$	0.143(3)	0.22(24)(11)			
$D^0 \to K^-K^+$	0.398(7)	-0.24(22)(9)	$A_{CP}(K^+K^-) - A_{CP}(\pi^+\pi^-)$	–	-0.65(18)
$D^+ \to K_S^0\pi^+$	1.47(7)	-0.71(19)(20)	$D^\pm \to \pi^+\pi^-\pi^\pm$	0.327(22)	1.7(42)
$D^\pm \to K^\mp\pi^\pm\pi^\pm$	9.51(34)	-0.5(4)(9)	$D^\pm \to K_s^0\pi^\pm\pi^0$	6.90(32)	0.3(9)(3)
$D^\pm \to K^+K^-\pi^\pm$	0.98(4)	0.39(61)			

TABLE I. Direct CP in D non-leptonic decays, from Heavy Flavor Averaging Group HAFG [1, 51]

CPV in Simple Cabibbo Suppressed (I)

$$D^0 \to K^+K^-, \pi^+\pi^-$$

slow mixing rate of charm mesons

$$A_{CP}(h^+h^-,t) = \frac{N(D^0 \to h^+h^-;t) - N(\overline{D}^0 \to h^+h^-;t)}{N(D^0 \to h^+h^-;t) + N(\overline{D}^0 \to h^+h^-;t)}$$

$$\Rightarrow A_{CP}(h^+h^-;t) \approx A_{CP}^{\rm dir}(h^+h^-) + \frac{t}{\tau} A_{CP}^{\rm ind}(h^+h^-)$$

$$A_{CP}^{\rm dir}(h^+h^-) \equiv A_{CP}(t=0) = \frac{|\mathcal{A}(D^0 \to h^+h^-)|^2 - |\mathcal{A}(\overline{D}^0 \to h^+h^-)|^2}{|\mathcal{A}(D^0 \to h^+h^-)|^2 + |\mathcal{A}(\overline{D}^0 \to h^+h^-)|^2},$$

$$A_{CP}^{\rm ind}(h^+h^-) = \frac{\eta_{CP}}{2}\left[y\left(\left|\frac{q}{p}\right| - \left|\frac{p}{q}\right|\right)\cos\varphi - x\left(\left|\frac{q}{p}\right| + \left|\frac{p}{q}\right|\right)\sin\varphi\right],$$

$$A_\Gamma(KK) = (-0.35 \pm 0.62 \pm 0.12) \times 10^{-3},$$

$$A_\Gamma(\pi\pi) = (0.33 \pm 1.06 \pm 0.14) \times 10^{-3}$$

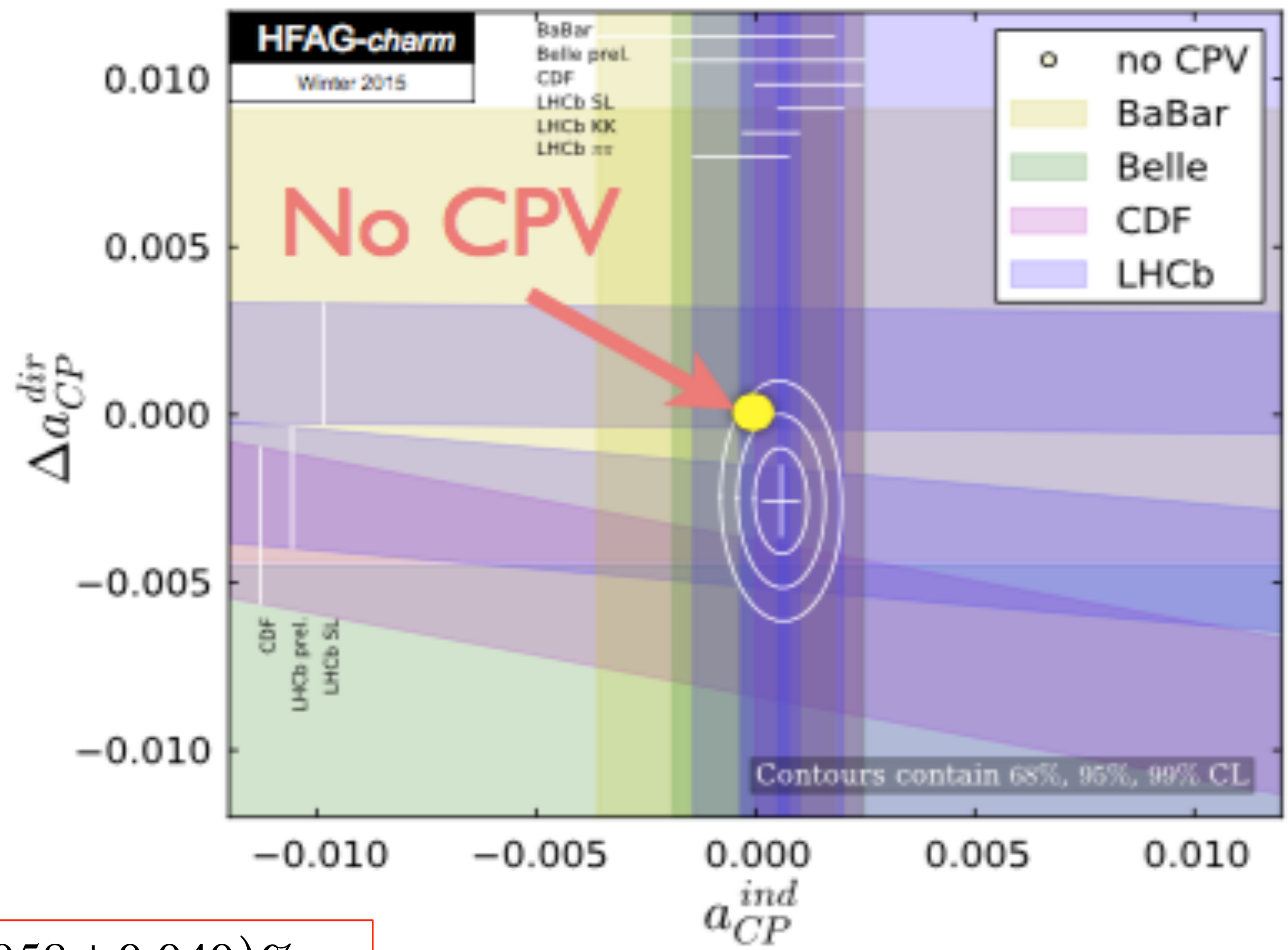
LHCb 2013

$$A_\Gamma(K^-K^+) = (-0.134 \pm 0.077\ ^{+0.026}_{-0.034})\ \%,$$

$$A_\Gamma(\pi^-\pi^+) = (-0.092 \pm 0.145\ ^{+0.025}_{-0.033})\ \%,$$

LHCb, JHEP04(2015)043

CPV in Simple Cabibbo Suppressed (II)



$$a_{CP}^{ind} = (0.058 \pm 0.040)\%$$

$$\Delta a_{CP}^{dir} = (-0.257 \pm 0.104)\%$$

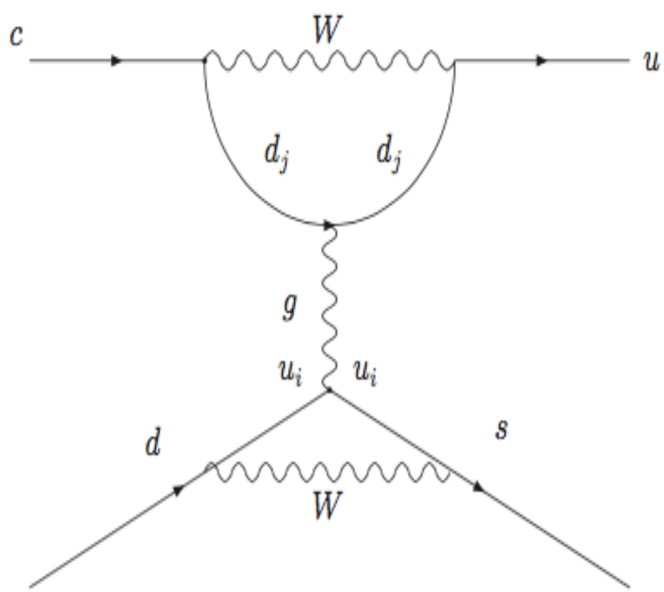
The data is consistent with no CP violation at 1.8% CL

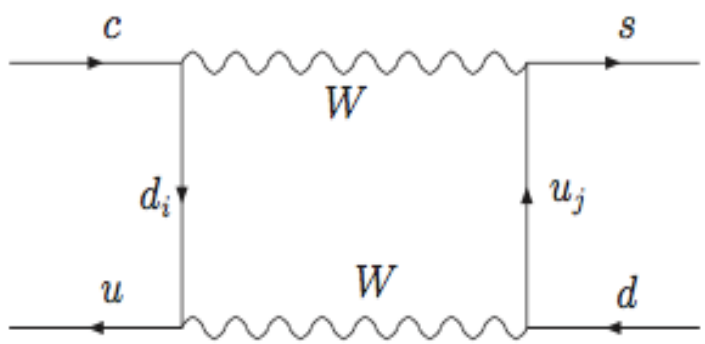
CPV in Cabibbo Favour Decays (I)

$$D^0 \to K^-\pi^+, D^+ \to K^-\pi^+\pi^+$$

$$\mathcal{H} = \frac{G_F}{\sqrt{2}} V_{cs}^* V_{ud} \left(c_1 \bar{s}\gamma_\mu c_L \bar{u}\gamma^\mu d_L + c_2 \bar{u}\gamma_\mu c_L \bar{s}\gamma^\mu d_L \right) + \text{h.c.}$$

CPV form SM induced by radiatives corrections:





CPV in SM <<< 1

CPV in Cabibbo Favour Decays (II) : $D^0 \to K^- \pi^+$

CPV IN CF = SMOKING GUN FOR NEW PHYSICS

D.D, G. Faisel and C. Ramirez, Phys.Rev. D87 (2013) 7, 075017

- Non-manifest Left- Rigth model: A_{CP} up to 10%

$$\begin{pmatrix} W_L \\ W_R \end{pmatrix} = \begin{pmatrix} \cos\xi & -\sin\xi \\ e^{i\omega}\sin\xi & e^{i\omega}\cos\xi \end{pmatrix} \begin{pmatrix} W_1 \\ W_2 \end{pmatrix} \simeq \begin{pmatrix} 1 & -\xi \\ e^{i\omega}\xi & e^{i\omega} \end{pmatrix} \begin{pmatrix} W_1 \\ W_2 \end{pmatrix}$$

$$A_{CP} = \frac{4(g_R/g_L)\xi}{V_{cs}^* V_{ud} |1+r|^2} \left(1 + 2\chi^{D^0}\right) \mathrm{Im}\left(\bar{V}_{cs}^{R*} V_{ud} - V_{cs}^* \bar{V}_{ud}^{R}\right) \mathrm{Im}(r)$$

- Models with charged Higgs exchange:

$m_{H^\pm} = 250$ GeV the predicted $A_{CP} \simeq 1.5 \times 10^{-2}$

NEW LHCb Results

$$A_\Gamma(K^-\pi^+) = (\ \ 0.009 \pm 0.032)\%\,,$$

LHCb, JHEP04(2015)043

CPV in Cabibbo Favour Decays (III) : $D^+ \to K^-\pi^+\pi^+$

CP Asymmetry with a toy model where a weak phase is added to a_2 amplitude

Model-fract.	I	II	III	IV	Tot.
Toy mod. f_i.	5.1	22.5	63.9	8.6	
A_{CP}	-0.5	-3.3	-1.2	26.6	0.3
f_i	5.1	24.2	65.6	5.1	
A_{CP}	0.5	3.3	1.1	-26.4	-0.3

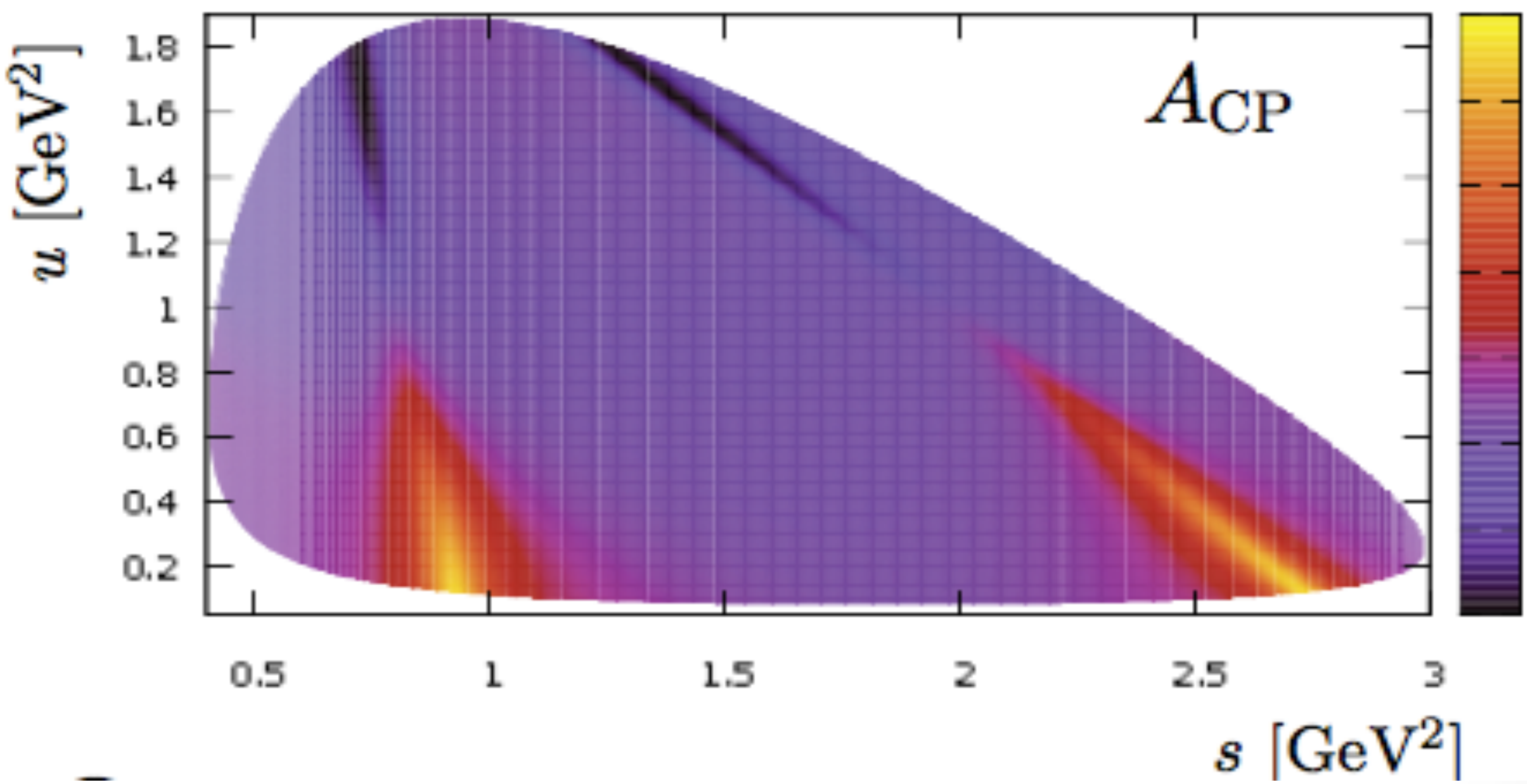
I $s < 0.7$ GeV^2, II 0.7 GeV$^2 < s < 1$ GeV^2, III 1 GeV$^2 < s < 2.25$ GeV^2 and IV $s > 2.25$ GeV^2.

D.D., G. Faisel, C. Ramirez, arXiv: 1409.3611 [hep-ph]

$$A_{CP}(D^+ \to K^-\pi^+\pi^+) = -0.16 \pm 0.15 \pm 0.09\%$$

V. M. Abazov et al. [D0 Collaboration], Phys. Rev. D 90, no. 11, 111102 (2014)

CPV in Cabibbo Favour Decays (IV) :

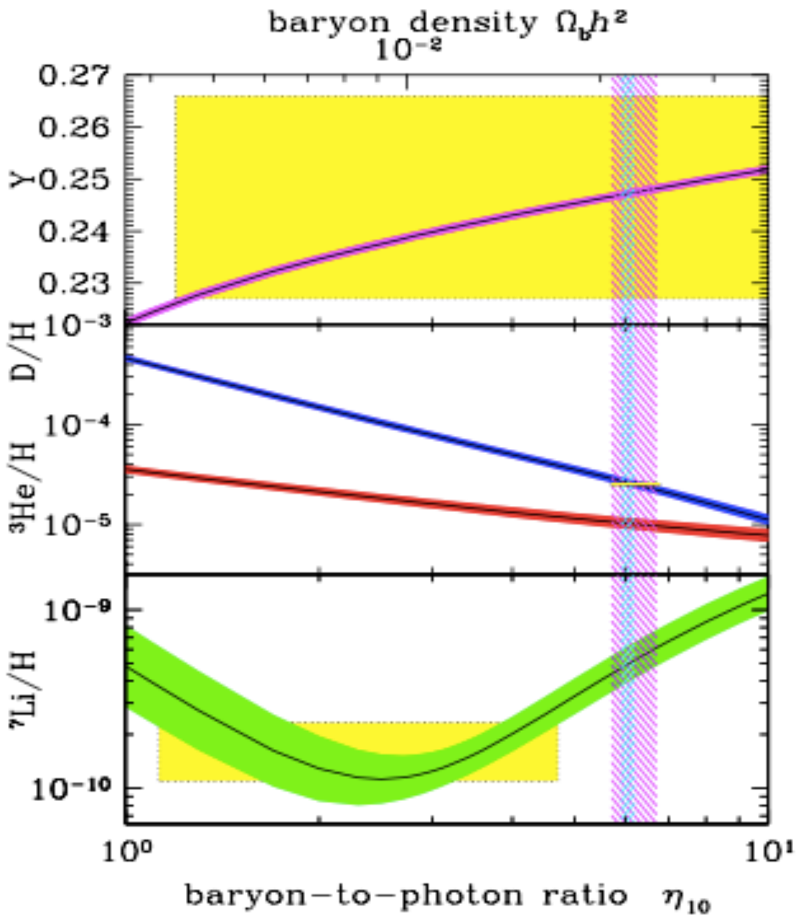


CPV in Cabibbo Favour Decays (V) :

Model-fract.	I	II	III	IV	
Higgs-frac	5	23.4	65	6.5	
Higgs-$10^4 \times A_{CP}$	1.4	-1.6	-8.2	-19	-6.9
Higgs-$10^4 \times A_{CP}$	2.5	-2.8	-14	-33	-12
Higgs-$10^4 \times A_{CP}$	2.9	-3.2	-17	-39	-14
Higgs-$10^4 \times A_{CP}$	2.6	-2.8	-14	-34	-12
Higgs-$10^4 \times A_{CP}$	1.5	-1.6	-8.3	-20	-7

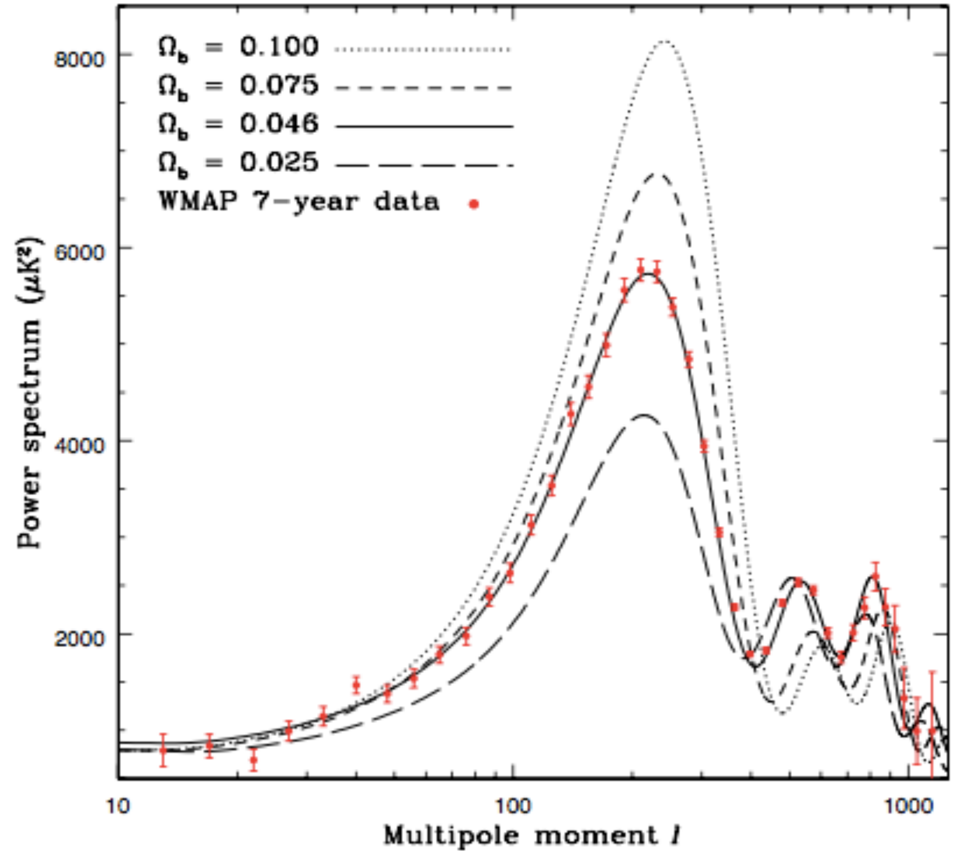
Baryon Asymmetry of the Universe (I)

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



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

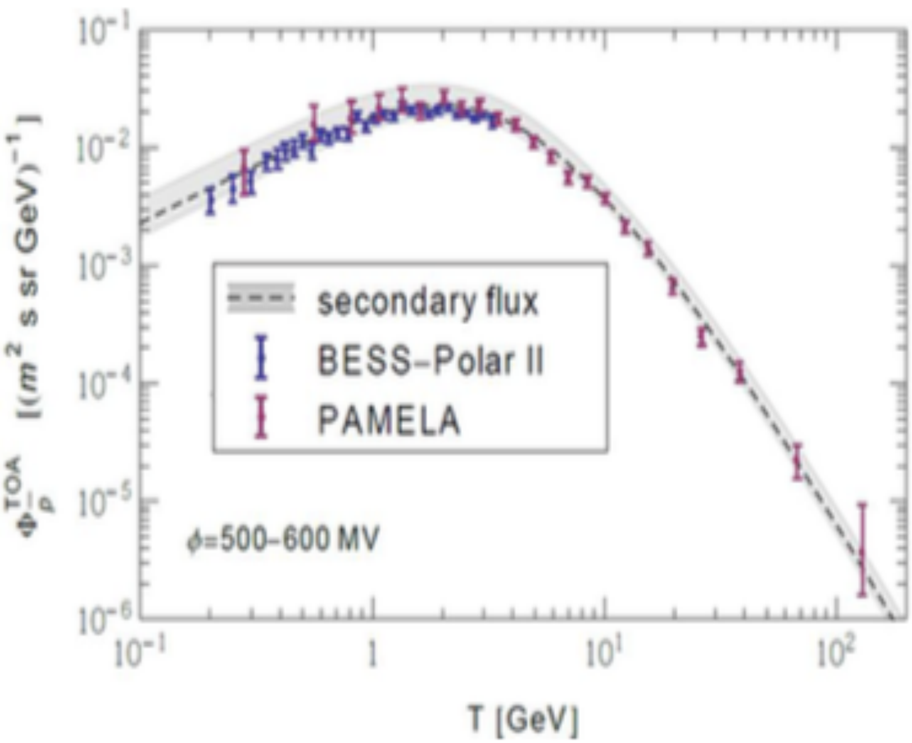
Planck:

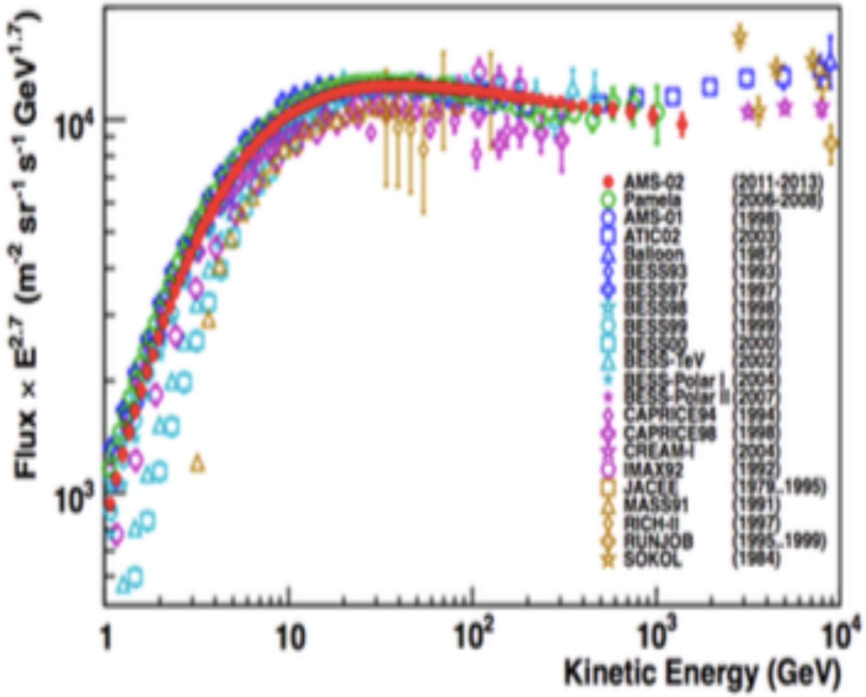


$$\Omega_b = 0.0490 \pm 0.0007.$$

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

Baryon Asymmetry of the Universe (II)





Antiproton cosmic ray flux as measured by AMS-02 and other experimental collaborations. The observed antiproton flux is consistent with secondary production that is due to collisions of baryons, leptons or photons in the interstellar medium

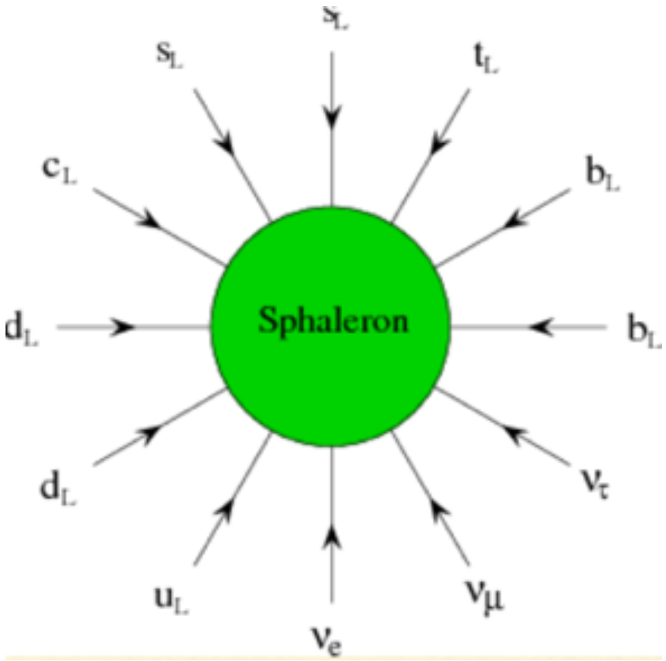
Rolf Kappl and Martin Wolfgang Winkler. The Cosmic Ray Antiproton Background for AMS-02. JCAP, 1409(09):051, 2014.

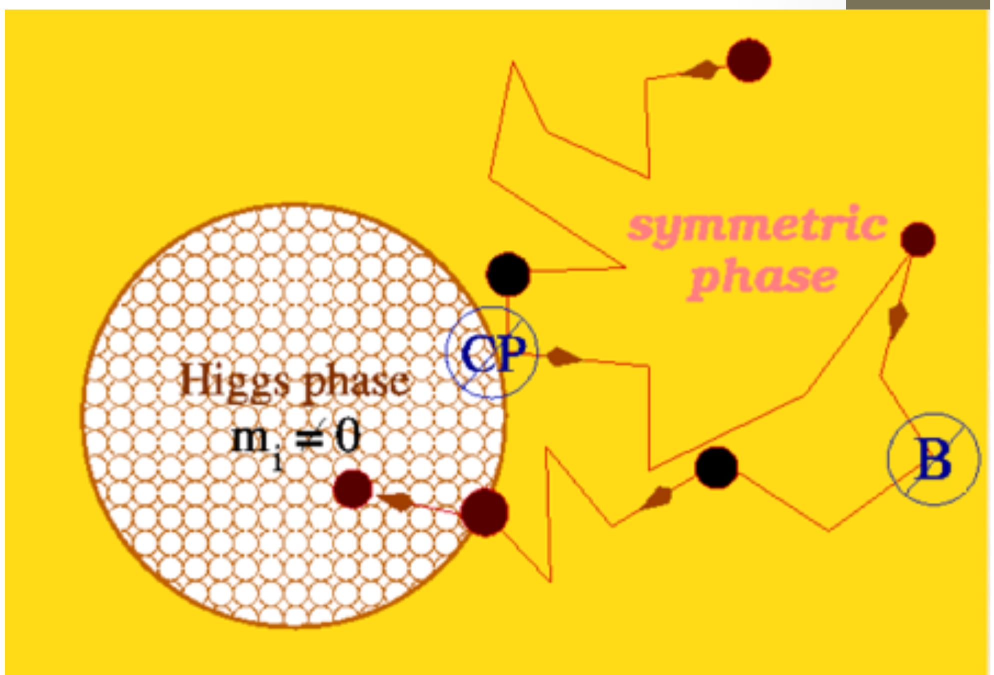
Baryon Asymmetry of the Universe (III)

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.

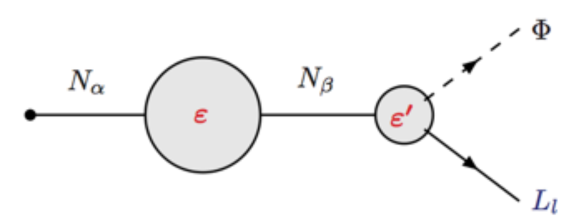


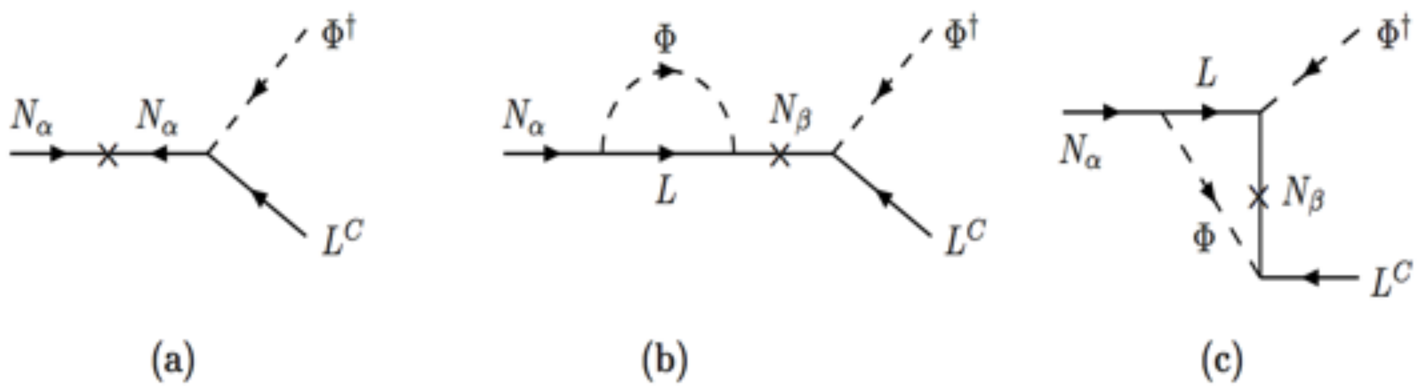


Baryogenesis: beyond the SM (I)

- Leptogenesis:

to produce an asymmetry in left-handed lepton at very high energy and to convert it into a baryon asymmetry through sphalerons processes.

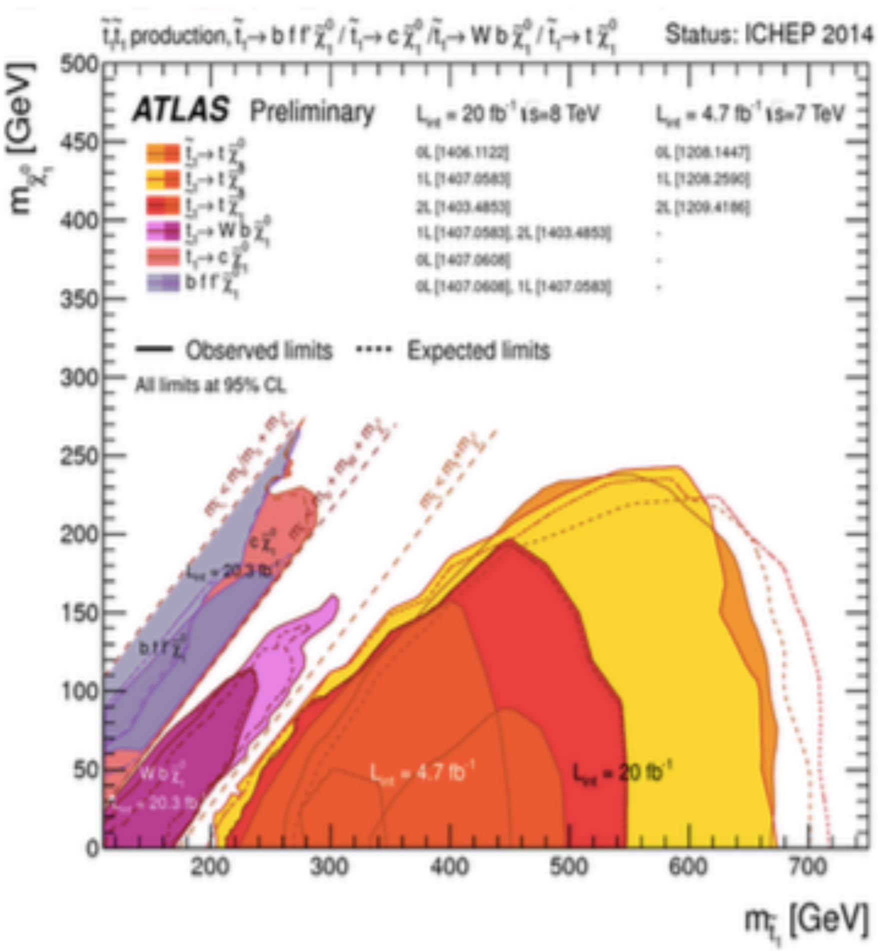


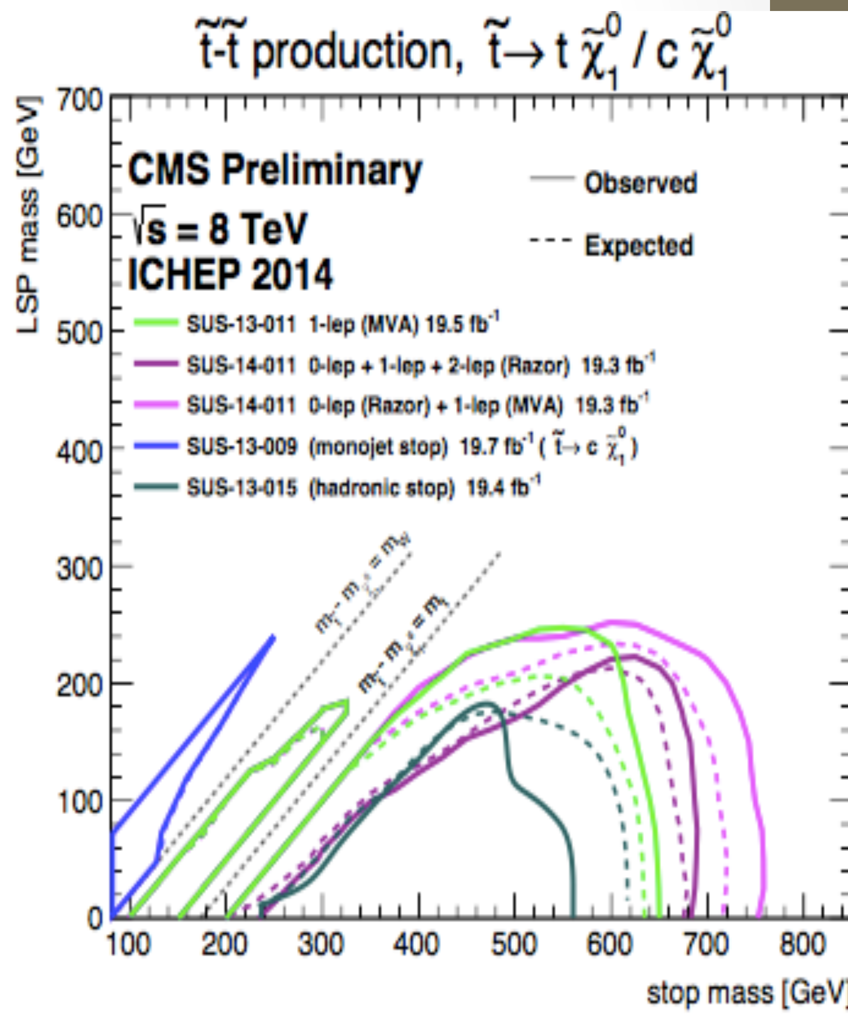


Baryogenesis: beyond the SM (II)

- Supersymmetric models with light stops

Right handed top squark is lighter than the top quark





Baryogenesis and Dark Matter

A Old dream coming back to live

$$\eta \sim \theta_{CP}$$

Baryogenesis from Strong Violation and the QCD Axion, Geraldine Servant
Phys.Rev.Lett. 113 (2014) 17, 171803

→ Cold Electroweak baryogenesis scenario with candidate to Dark Matter

Conclusions:

- **Possible maximal CP violation** in neutrino sector
- LHCb and B factories will strongly improved at short term our experimental data on CPV

  → **Strong constraints on New Physics Models**

- The **Baryon Asymmetry of the Universe** is the only proof that we need **CPV beyond Standard Models**:

  Astro-particules Physics: the New Chalenge for CPV

- New Scenarii for baryogenesis linked to Dark matter problems.

Thanks !