CP violation in gauged $U(1)_B$

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Baryon Asymmetry of the Universe

- EW baryogenesis
- Sakharov conditions
  - Baryon number violation: Sphaleron process
  - C and CP violation: CP phases
  - Out of equilibrium: strongly 1st order EWPT
- In the SM, KM phase is too small & EWPT is cross over
- New physics is needed

CP violation

- Consider *CP* violation with vector-like leptons (VLLs)
- Singlet-doublet fermion model
  - Minimal model

Fields	$\Psi_{L,R}$	$E_{L,R}$	$N_{L,R}$	H
$SU(2)_L$	$\mathbf{2}$	$\mathbf{1}$	$\mathbf{1}$	$\mathbf{2}$
$U(1)_Y$	$\mathcal{Y}$	$\mathcal{Y}-1/2$	$\mathcal{Y}+1/2$	$1/2$

0510064 (PRD), R. Mahbubani, L. Senatore
0705.4493 (PRD), F. D'Eramo
1109.2604 (PRD), T. Cohen, J. Kearney, A. Pierce, D. Tucker-Smith
1311.5896 (JCAP), C. Cheung, D. Sanford
1411.1335 (PRD), T. Abe, R. Kitano, R. Sato
, …

- **Our work**
  - Extend the model for EW baryogenesis
  - Discuss constraints of *CP* phases such as EDMs.

Model for EW baryogenesis

- Our extension to solve baryon asymmetry of the Universe
  1. Baryon number violation ← assign the baryon number to VLLs
  2. C and CP violation ← CP phases in interactions of VLLs
  3. Out of equilibrium (1st order PT @EW scale) ← multi-Higgs extension
- We propose a model with gauged $U(1)_B$ symmetry

Fields	Ψ_L	Ψ_R	E_L	E_R	N_L	N_R	H_1	H_2	φ
$SU(2)_L$	$\mathbf{2}$	$\mathbf{2}$	$\mathbf{1}$	$\mathbf{1}$	$\mathbf{1}$	$\mathbf{1}$	$\mathbf{2}$	$\mathbf{2}$	$\mathbf{1}$
$U(1)_Y$	$-1/2$	$-1/2$	-1	-1	0	0	$1/2$	$1/2$	0
$U(1)_B$	B_1	B_2	B_2	B_1	B_2	B_1	$-(B_1+B_2)\neq 0$	0	$(B_1-B_2)=-3$

$$\frac{\langle H_2\rangle}{\langle H_1\rangle} \equiv \tan\beta$$

$$\langle\varphi\rangle \equiv v_\varphi/\sqrt{2}$$

- VLLs have $B_{1,2}$ same as the baryon number in SM, but no color charge.
  - To avoid FCNC, f_{SM} only couples to H_2 by $U(1)_B$ (type-I 2HDM)
  - Anomaly cancellation $B_1 - B_2 = -3$
  - To obtain $m_{12}^2 H_1^\dagger H_2$, $(B_1, B_2) = (-3, 0)$ is chosen: $\Delta V = \frac{\mu}{\sqrt{2}} H_2^\dagger H_1 \varphi \rightarrow m_A^2 \propto \mu\, v_\varphi \propto m_{12}^2$
- VLLs are assigned Z_2-odd to forbit $\overline{e_R} E_L$ and $\overline{L_L}\psi_R$, and to stabilize DM

Model parameters

- Neutral Gauge bosons: $(m_Z, m_{Z'}, \epsilon)$ $\epsilon \ll 1$
- Scalar bosons: $(m_{H^\pm}, m_A, m_H, m_h, m_S; \tan\beta, \sin(\beta-\alpha), \alpha_1, \alpha_2)$ [2HDM+S]
- Fermions: $$-\mathcal{L}_{\mathcal{Y}_{\rm new}} = (y_{\Psi N}\overline{\Psi}_L N_R + \widetilde{y}_{\Psi N}\overline{\Psi}_R N_L)\,\widetilde{H}_2 + (y^c_{\Psi N}\overline{\Psi^c_L} N_L + \widetilde{y}^c_{\Psi N}\overline{\Psi^c_R} N_R)\,\widetilde{H}^*_1 + (y_{\Psi E}\overline{\Psi}_L E_R + \widetilde{y}_{\Psi E}\overline{\Psi}_R E_L)\,H_2 + y_\Psi \overline{\Psi}_L \Psi_R\,\varphi + (y_{N_{LR}}\overline{N}_L N_R + y_E \overline{E}_L E_R)\,\varphi^* + \frac{1}{2} m_N \overline{N_L} N^c_L + \text{h.c.}\,,$$
  - We can remove phases of $(y_\Psi, y_E, y_{N_{LR}}, m_N)$
  - In the remained 6 Yukawa's, **3 dof** are taken as CPV independently
    - Charged fermion: mass(2) $m_{\psi^\pm_{1,2}}$ + mixing angle(1) + ***CP*-phase(1)** $\theta_{\Psi E}$
    - Neutral fermion: mass(4) $m_{\psi^0_{1,2,3,4}}$ + mixing angle(6) + ***CP*-phase(2)** $(\widetilde{\theta}_{\Psi N}, \widetilde{\theta}^c_{\Psi N})$

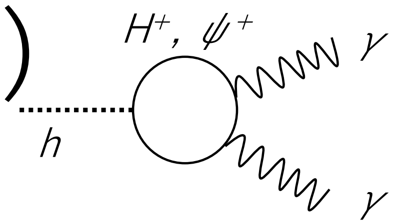
Outline

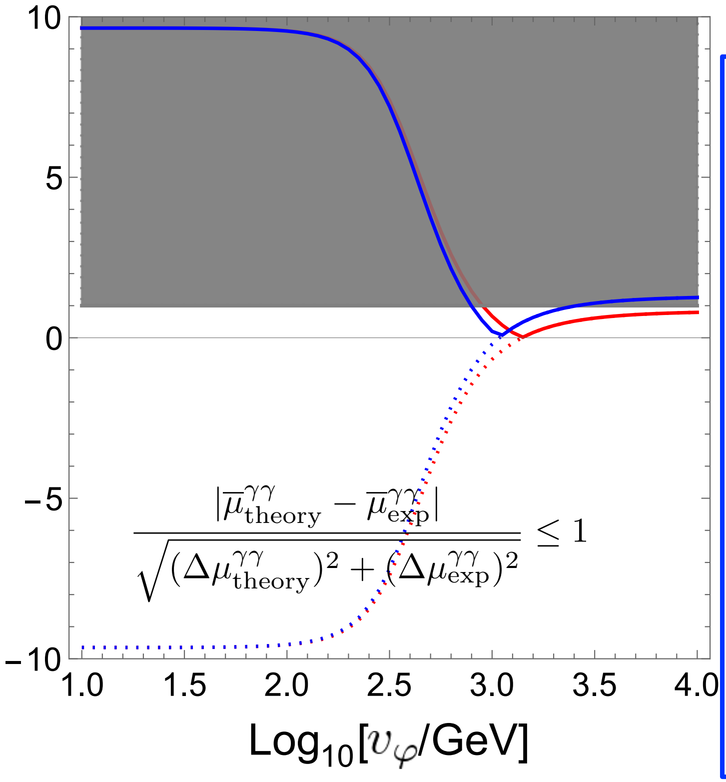
- Signal strength ($gg \to h \to \gamma\gamma$) $\to v_\varphi$
- Scalar mass constraints $\to m_A$ & $m_{H^\pm}$
- Higgs coupling measurement (κ_V, κ_f) $\to \tan\beta$ & $\sin(\beta - \alpha)$
- Predictions
  - EW-ino searches $\to m_{\psi^0}$ & $m_{\psi^\pm}$
  - Rho parameter $\to m_{Z'}$
  - Electric Dipole Moment
  - Dark matter

  } $(\widetilde{\theta}_{\Psi N}, \widetilde{\theta}^c_{\Psi N}, \theta_{\Psi E})$

  3-independent *CP*-phases
- Discussion
- Conclusion

Signal strength ($gg \to h \to \gamma\,\gamma$)





- Charged fermion contribution

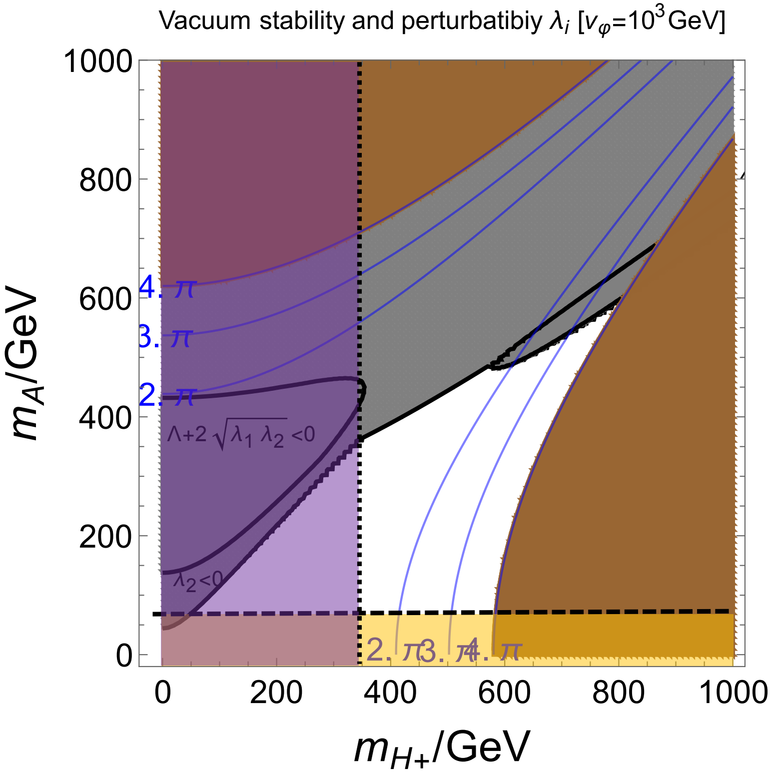
  $v_\varphi \gtrsim 800\,\mathrm{GeV}$

- Charged scalar contribution
  - $\lambda_{hH+H-} \propto m_{H\pm}{}^2 - M^2$ $M \propto m_A$
  - Small m_A → non-decoupling limit (blue)

    $v_\varphi \lesssim \mathcal{O}(1)\,\mathrm{TeV}$

  - Large m_A → decoupling limit (red)

Scalar mass constraints



Vacuum stability

$$\min\left\{\lambda_{1,2,\varphi},\quad a+2\sqrt{bc},\quad 4\Lambda\lambda_\varphi-2\lambda_{1\varphi}\lambda_{2\varphi}+\sqrt{(\lambda_{1\varphi}^2-4\lambda_1\lambda_\varphi)(\lambda_{2\varphi}^2-4\lambda_2\lambda_\varphi)}\right\}>0,$$

where $\quad (a,b,c)=(\Lambda,\lambda_1,\lambda_2),(\lambda_{1\varphi},\lambda_1,\lambda_\varphi),(\lambda_{2\varphi},\lambda_2,\lambda_\varphi);\Lambda\equiv\lambda_3+\min(0,\lambda_4).$

$$m_A \lesssim 364\,\mathrm{GeV}\quad (m_{H^\pm}=350\,\mathrm{GeV})$$

Perturbativity $\quad \lambda_i < 4\pi$

$$m_{H^\pm}\lesssim 600\,\mathrm{GeV}$$

$h\to AA$ is avoided by $m_A \gtrsim m_h/2$

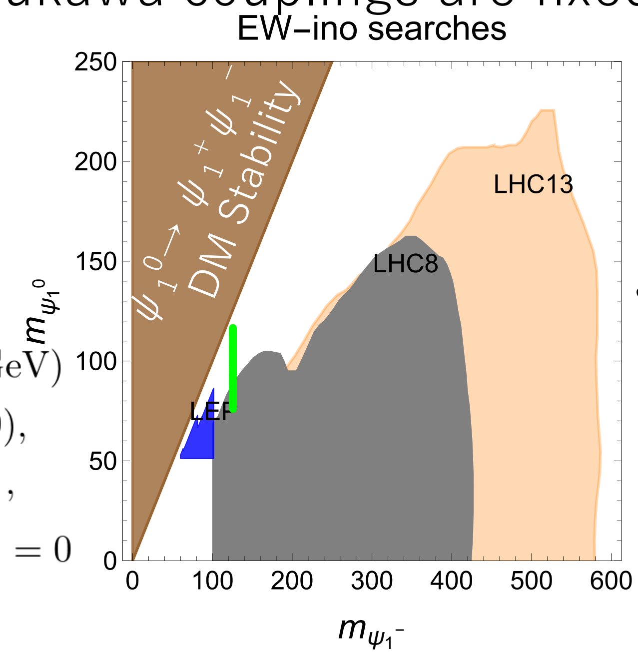
Flavor experiments : it would be safe if

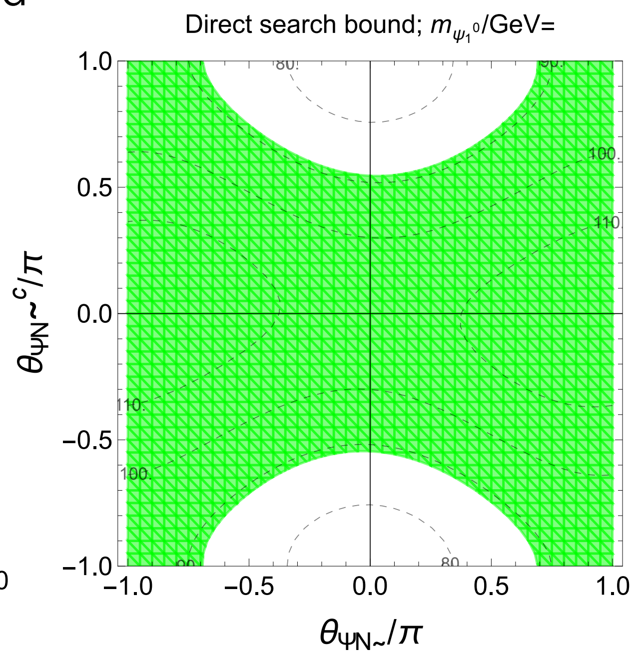
$$m_{H^\pm}\gtrsim 350\,\mathrm{GeV},\quad \tan\beta \gtrsim 2$$

① EW-ino searches

- Two *CP* phases for neutral fermions are scanned
  - Absolute value of Yukawa couplings are fixed
  - Input parameter:

$(m_{H^\pm}, m_H, m_A, m_S; m_{Z'})$
$= (350, 350, 100, 96; 0.1)\,\text{GeV},$
$(v_\varphi/\text{GeV}; t_\beta, s_{\beta-\alpha}, \alpha_1, \alpha_2; \epsilon)$
$= (800, 2, 0.99, 0, 0.1; -10^{-3}),$
$(y_{\Psi N}, y^c_{\Psi N}, y_{\Psi E}, y_\Psi, y_{N_{LR}}, y_{\Psi E}, m_N/\text{GeV})$
$= (0.15, 0.15, 0.60, 0.20, 0.30, 1.00, 500),$
$\widetilde{y}_{\Psi N} = y_{\Psi N}\,, \widetilde{y}^c_{\Psi N} = y^c_{\Psi N}\,, \widetilde{y}_{\Psi E} = y_{\Psi E}\,,$
$\theta_{\Psi N} = \theta^c_{\Psi N} = \widetilde{\theta}_{\Psi E} = \theta_E = \theta_\Psi = \theta_{N_{LR}} = 0$





② rho parameter

(*1)

$$\rho_{\rm tree} \equiv 1 - \frac{m_{Z^0}^2}{m_Z^2} \neq 1$$

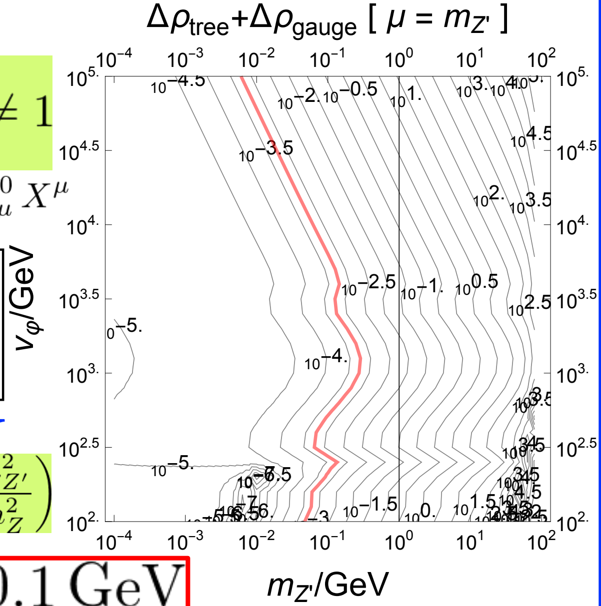
due to mass mixing $\Delta^2 Z_\mu^0 X^\mu$

Z-Z' mixing @tree level

$$\tan 2\xi_{\rm tree} \equiv \frac{2\Delta^2}{m_{Z^0}^2 - m_X^2}$$

1-loop correction

$$\Delta\rho_{\rm gauge} = \xi_{\text{1-loop}}^2 \left(1 - \frac{m_{Z'}^2}{m_Z^2}\right)$$



$$m_{Z'} \lesssim 0.1\,\mathrm{GeV}$$

(*2)

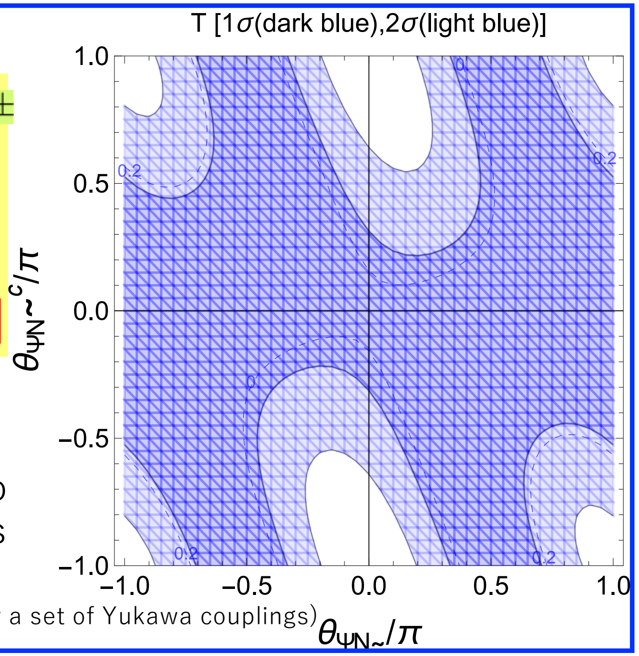
$$m_H = m_{H^\pm}$$

(custodial symmetry)

$$v_\varphi \gg v$$

$$\Rightarrow T_{\rm scalar} \simeq 0$$

S parameter is not sensitive to two *CP*-phases

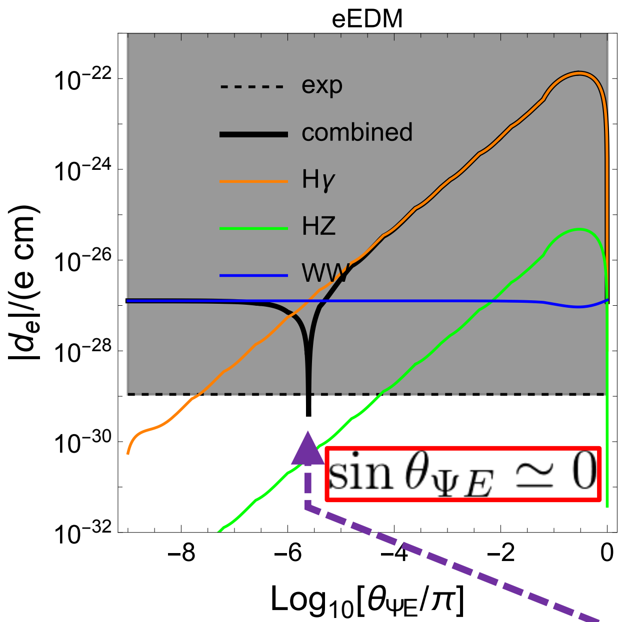


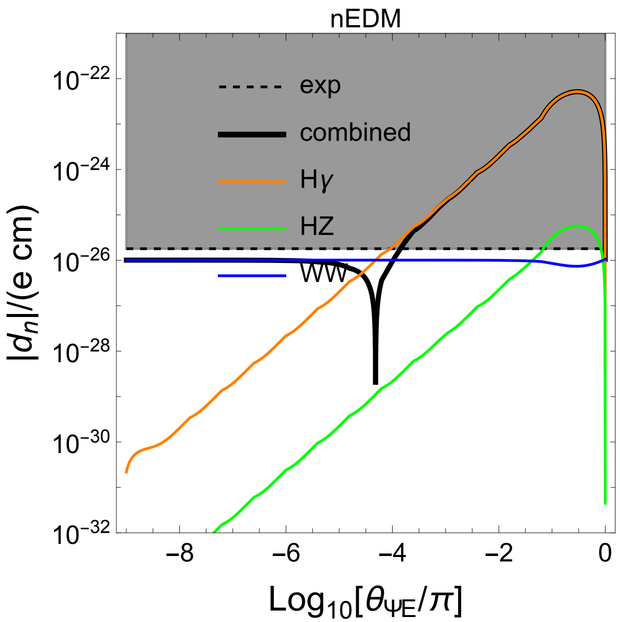
(taken an example for a set of Yukawa couplings)

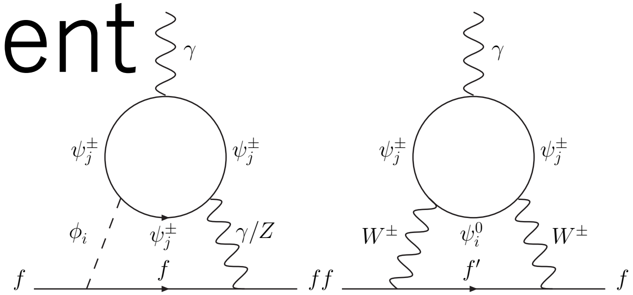
$$\rho_{\text{1-loop}} = 1 - \underbrace{(\Delta\rho_{\rm tree} + \Delta\rho_{\rm gauge})}_{(*1)} + \alpha_{\rm em}\underbrace{(T_{\rm scalar} + T_{\rm fermion})}_{(*2)}$$

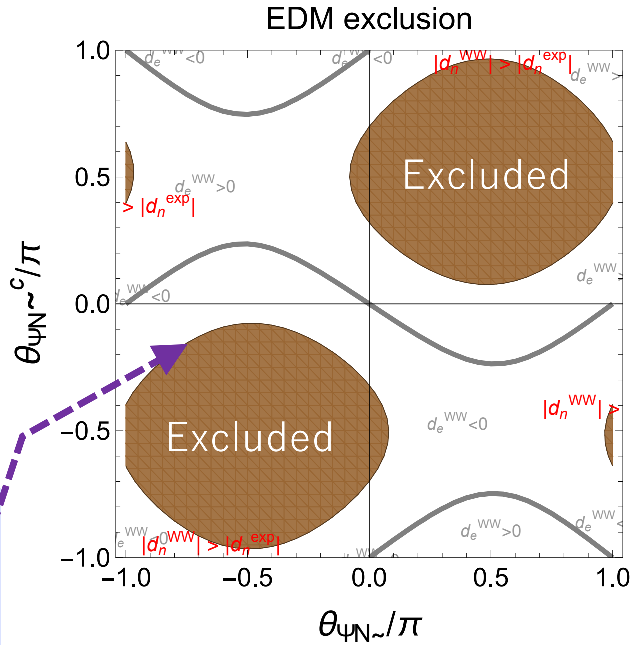
$$\rho_{\rm exp} \equiv 1.00039 \pm 0.00019 \quad (1\sigma)$$

③ Electric Dipole Moment





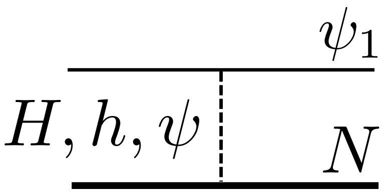


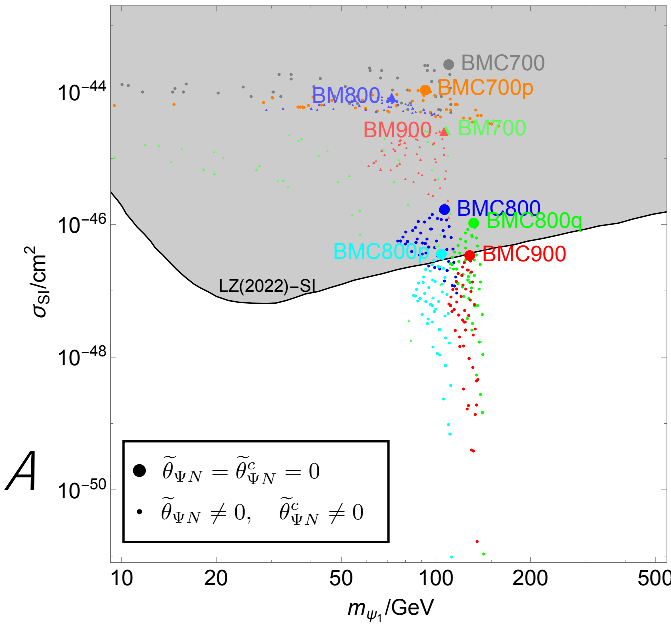


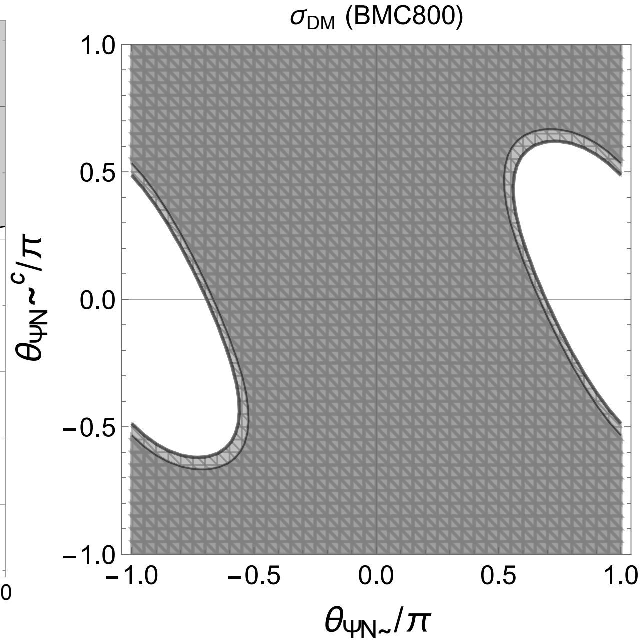
- Electron EDM: Cancellation $d_e^{\rm exp} \geq d_e^{\rm tot} \simeq d_e^{H\gamma} + d_e^{WW}$
- Neutron EDM: Impose a condition $d_n^{\rm exp} \geq d_n^{\rm tot} \simeq d_n^{WW}$

④ Dark Matter

- Direct search
  - Scalar mediating processes (Spin-independent) are dominant

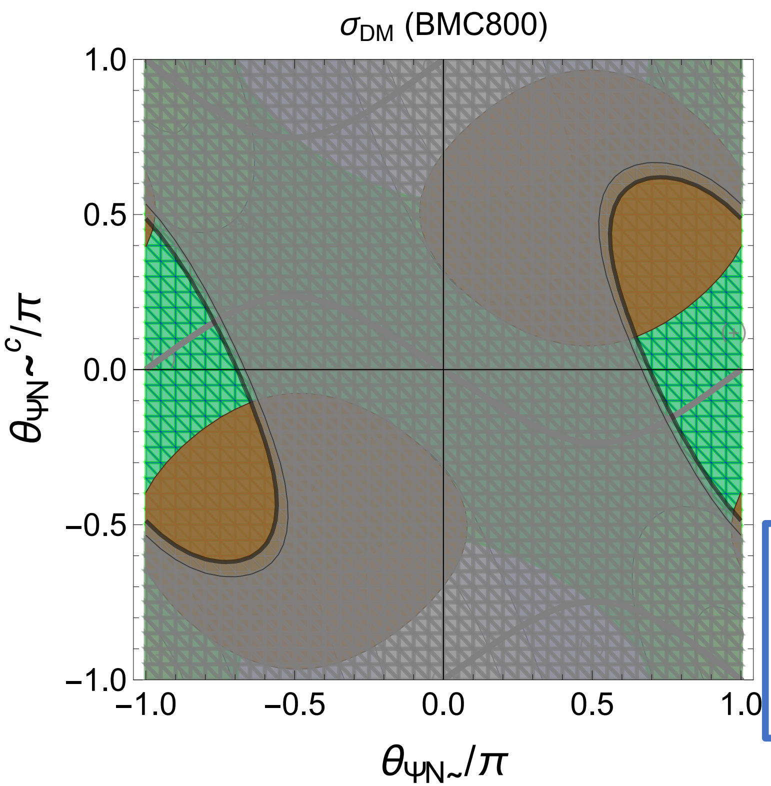






- Relic abundance
  - $\psi_1 \psi_1 \rightarrow W^+W^-/ZZ/AA$

Combined all constraints



① EW-ino searches (**green**: allowed)
② *T* parameter (**blue**: allowed)
③ electric dipole moment (**brown**: excluded)
④ dark matter direct searches (**gray**: excluded)

Conclusion

- We have proposed a model for EWBG with gauged $U(1)_B$
  - New fermions with *CP* phases are needed by gauged $U(1)_B$
  - $U(1)_B$ is broken by $(H_{1,2}, S)$ for FOPT & generates fermion masses
- We have derived constraints in v_φ, $(m_{Z'}, m_A, m_{H^\pm})$, $(t_\beta, s_{\beta-\alpha})$
- At fixed Yukawa couplings, we have shown predictions in *CP*-phases considering (EW-ino searches, *T* parameter, EDMs, dark matter)
- Complete work for successful EWBG is planed as future work

Backup

Model

	$SU(3)_C$	$SU(2)_L$	Isospin	$U(1)_Y$	$U(1)_{EM}$	$U(1)_B$	Flavor	Z_2
Fields			T^3	Q_Y	$Q = T^3 + Q_Y$	Q_X	i	
$Q_L^i = (u_L^i \quad d_L^i)^T$	3	2	(1/2,−1/2)	1/6	(+2/3,−1/3)	1/3	3	+1
u_R^i	3	1	0	2/3	+2/3	1/3	3	+1
d_R^i	3	1	0	−1/3	−1/3	1/3	3	+1
$L_L^i = (\nu_L^i \quad e_L^i)^T$	1	2	(1/2,−1/2)	−1/2	(0,−1)	0	3	+1
e_R^i	1	1	0	−1	−1	0	3	+1
$\Psi_L = (\Psi_L^0 \quad \Psi_L^-)^T$	1	2	(1/2,−1/2)	−1/2	(0,−1)	−3	1	−1
$\Psi_R = (\Psi_R^0 \quad \Psi_R^-)^T$	1	2	(1/2,−1/2)	−1/2	(0,−1)	0	1	−1
E_L^-	1	1	0	−1	−1	0	1	−1
E_R^-	1	1	0	−1	−1	−3	1	−1
N_L	1	1	0	0	0	0	1	−1
N_R	1	1	0	0	0	−3	1	−1
$H_1 = (\phi_1^+ \quad \varphi_1^0)^T$	1	2	(1/2,−1/2)	1/2	(+1,0)	3	1	+1
$H_2 = (\phi_2^+ \quad \varphi_2^0)^T$	1	2	(1/2,−1/2)	1/2	(+1,0)	0	1	+1
φ	1	1	0	0	0	−3	1	+1

Lagrangian

$$\mathcal{L} = \mathcal{L}_{\rm YM} + \mathcal{L}_{\rm gauge} - V + \mathcal{L}_{\rm kin} + \mathcal{L}_{\mathcal{Y}_{\rm SM}} + \mathcal{L}_{\mathcal{Y}_{\rm new}} ,$$

where

$$\begin{aligned}
\mathcal{L}_{\rm YM} &= -\frac{1}{4}\mathbf{W}_{\mu\nu}\cdot\mathbf{W}^{\mu\nu} - \frac{1}{4}\hat{B}_{\mu\nu}\hat{B}^{\mu\nu} - \frac{1}{4}\hat{X}_{\mu\nu}\hat{X}^{\mu\nu} + \frac{\epsilon'}{2}\hat{B}^{\mu\nu}\hat{X}_{\mu\nu} ,\\
\mathcal{L}_{\rm gauge} &= |D_\mu H_1|^2 + |D_\mu H_2|^2 + |D_\mu \varphi|^2 ,\\
V &= \lambda_1 |H_1|^4 + \lambda_2 |H_2|^4 + \lambda_3 |H_1|^2 |H_2|^2 + \lambda_4 \left| H_1^\dagger H_2 \right|^2 + \lambda_\varphi (\varphi^*\varphi)^2 \\
&\quad + (\lambda_{1\varphi}\varphi^*\varphi + m_1^2)|H_1|^2 + (\lambda_{2\varphi}\varphi^*\varphi + m_2^2)|H_2|^2 + m_\varphi^2 \varphi^*\varphi + \Delta V + \text{h.c.} ,\\
-i\,\mathcal{L}_{\rm kin} &= \overline{\Psi}_L D\Psi_L + \overline{\Psi}_R D\Psi_R + \overline{E}_L D E_L + \overline{E}_R D E_R + \overline{N}_L D N_L + \overline{N}_R D N_R ,\\
-\mathcal{L}_{\mathcal{Y}_{\rm SM}} &= y_u\,\overline{Q}_L\,u_R\,\widetilde{H_2} + (y_d\,\overline{Q}_L\,d_R + y_e\,\overline{L}_L\,e_R)\,H_2 + \text{h.c.} ,\\
-\mathcal{L}_{\mathcal{Y}_{\rm new}} &= (y_{\Psi N}\overline{\Psi}_L N_R + \widetilde{y}_{\Psi N}\overline{\Psi}_R N_L)\,\widetilde{H}_2 + (y_{\Psi N}^c\overline{\Psi_L^c} N_L + \widetilde{y}_{\Psi N}^c\overline{\Psi_R^c} N_R)\,\widetilde{H}_1^* \\
&\quad + (y_{\Psi E}\overline{\Psi}_L E_R + \widetilde{y}_{\Psi E}\overline{\Psi}_R E_L)\,H_2 \\
&\quad + y_\Psi\overline{\Psi}_L\Psi_R\,\varphi + (y_{N_{LR}}\overline{N}_L N_R + y_E\overline{E}_L E_R)\,\varphi^* + \frac{1}{2}m_N\overline{N_L}N_L^c + \text{h.c.} ,
\end{aligned}$$

CP phases

- 3 physical phases

$$\mathrm{Im}\left(y_{\Psi E}\widetilde{y}^{*}_{\Psi E}e^{-i\,(\theta_{y_\Psi}+\theta_{y_E})}\right)=\sin(\theta_{\Psi E}-\widetilde{\theta}_{\Psi E}-\theta_{\Psi}-\theta_{E})\,,$$

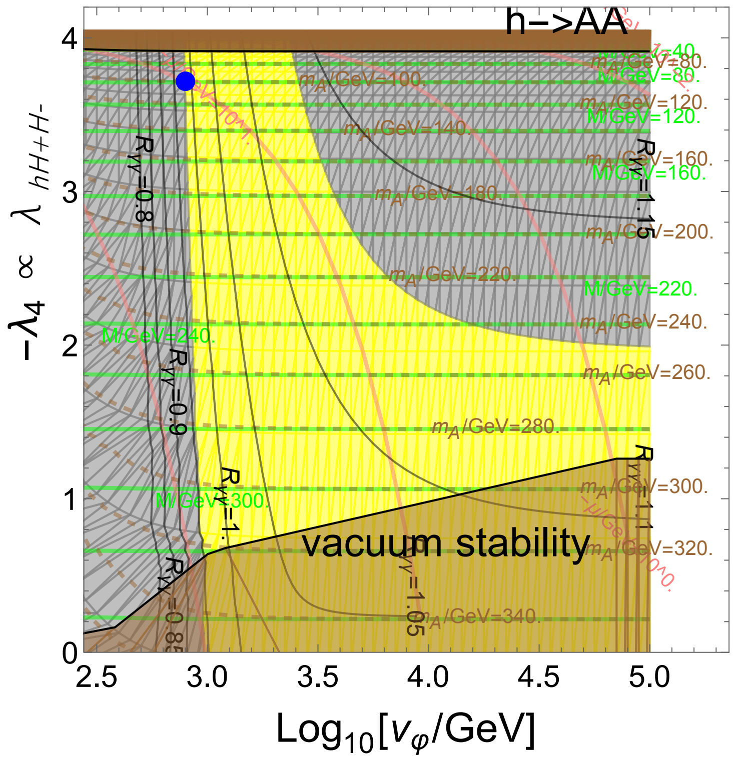
$$\mathrm{Im}\left(\widetilde{y}_{\Psi N}y^{c}_{\Psi N}e^{i\,\theta_{y_\Psi}}\right)=\sin(\widetilde{\theta}_{\Psi N}-\theta^{c}_{\Psi N}+\theta_{\Psi})\,,$$

$$\mathrm{Im}\left(y_{\Psi N}\widetilde{y}^{c}_{\Psi N}e^{-i\,(\theta_{y_\Psi}+2\,i\,\theta_{N_{LR}})}\right)=\sin(\theta_{\Psi N}-\widetilde{\theta}^{c}_{\Psi N}-\theta_{\Psi}-2\,\theta_{N_{LR}})$$

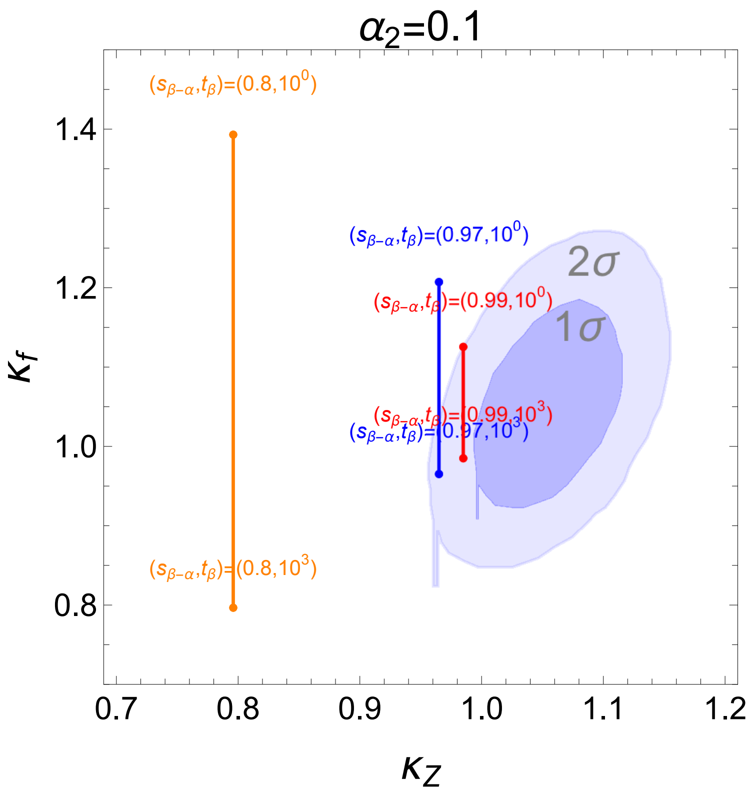
- We define 3 independent phases as

$$(\widetilde{\theta}_{\Psi N}\,,\widetilde{\theta}^{c}_{\Psi N}\,,\theta_{\Psi E})$$

taking $\theta_{\Psi N}=\theta^{c}_{\Psi N}=\widetilde{\theta}_{\Psi E}=\theta_{E}=\theta_{\Psi}=\theta_{N_{LR}}=0$.


h->AA
vacuum stability
Log10[vφ/GeV]
−λ4 ∝ λ hH+H-
2.5
3.0
3.5
4.0
4.5
5.0
0
1
2
3
4
Rγγ=0.8
Rγγ=0.9
Rγγ=1.
Rγγ=1.05
Rγγ=1.15
mA/GeV=100.
mA/GeV=140.
mA/GeV=180.
mA/GeV=200.
mA/GeV=220.
mA/GeV=240.
mA/GeV=260.
mA/GeV=280.
mA/GeV=300.
mA/GeV=320.
mA/GeV=340.
M/GeV=120.
M/GeV=160.
M/GeV=220.
M/GeV=240.
M/GeV=300.

Higgs coupling measurement



$$\kappa_X \equiv \frac{c_{hXX}}{c_{hXX}^{\rm SM}}$$

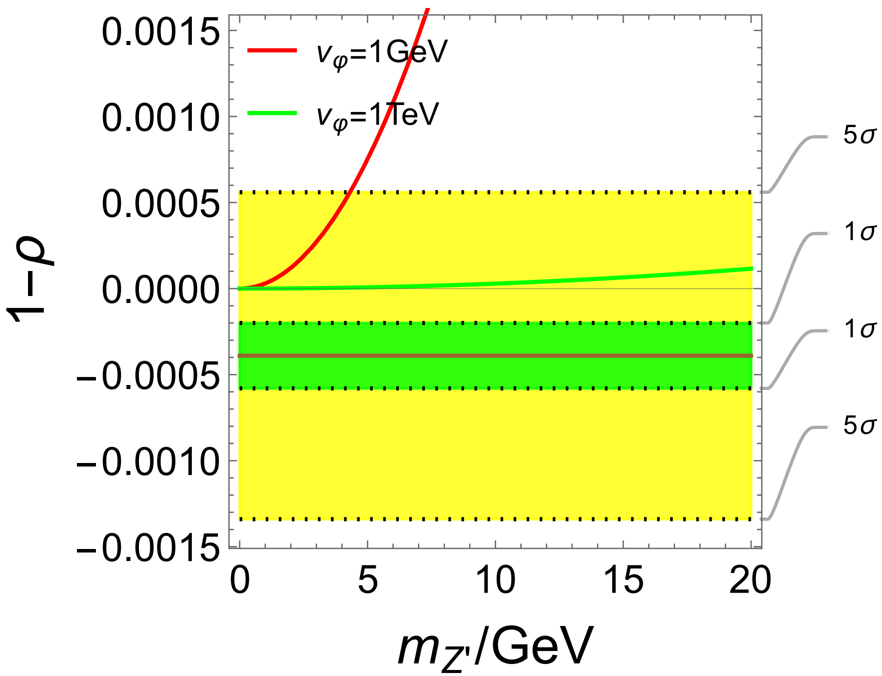
$$\kappa_f = c_{\alpha_2}\left(s_{\beta-\alpha} + \frac{c_{\beta-\alpha}}{t_\beta}\right)$$

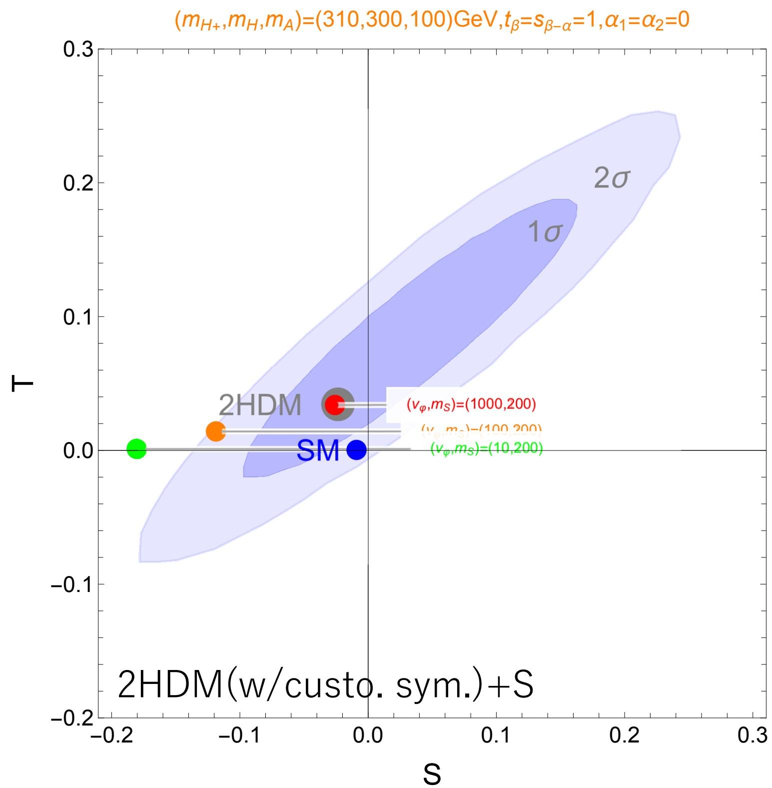
$$\kappa_Z \simeq \kappa_W = c_{\alpha_2}\, s_{\beta-\alpha}$$

$$\frac{m_{Z'}}{m_Z} \ll 1$$

$$\sin(\beta-\alpha) \gtrsim 0.99 \quad \text{if} \quad \tan\beta = \mathcal{O}(1)$$

rho parameter at tree / $(S, T)_{scalar}$





benchmark

- Two *CP* phases for neutral fermions are scanned
  - Absolute value of Yukawa couplings are fixed
  - Input parameter:

$$
\begin{aligned}
&(m_{H^\pm}, m_H, m_A, m_S; m_{Z'}) \\
&= (350, 350, 100, 96; 0.1)\,\mathrm{GeV}, \\
&(v_\varphi/\mathrm{GeV}; t_\beta, s_{\beta-\alpha}, \alpha_1, \alpha_2; \epsilon) \\
&= (800, 2, 0.99, 0, 0.1; -10^{-3}), \\
&(y_{\Psi N}, y^c_{\Psi N}, y_{\Psi E}, y_\Psi, y_{N_{LR}}, y_{\Psi E}, m_N/\mathrm{GeV}) \\
&= (0.15, 0.15, 0.60, 0.20, 0.30, 1.00, 500), \\
&\widetilde{y}_{\Psi N} = y_{\Psi N}\ , \widetilde{y}^c_{\Psi N} = y^c_{\Psi N}\ , \widetilde{y}_{\Psi E} = y_{\Psi E}\ , \\
&\theta_{\Psi N} = \theta^c_{\Psi N} = \widetilde{\theta}_{\Psi E} = \theta_E = \theta_\Psi = \theta_{N_{LR}} = 0
\end{aligned}
$$

Dark Matter

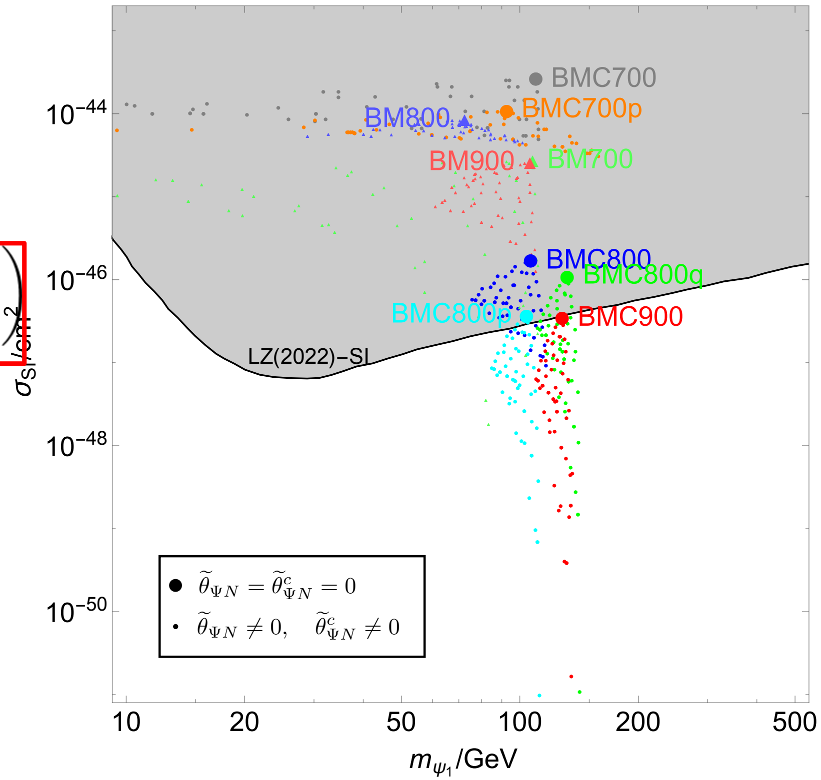
- Fermion DM with scalar mediator

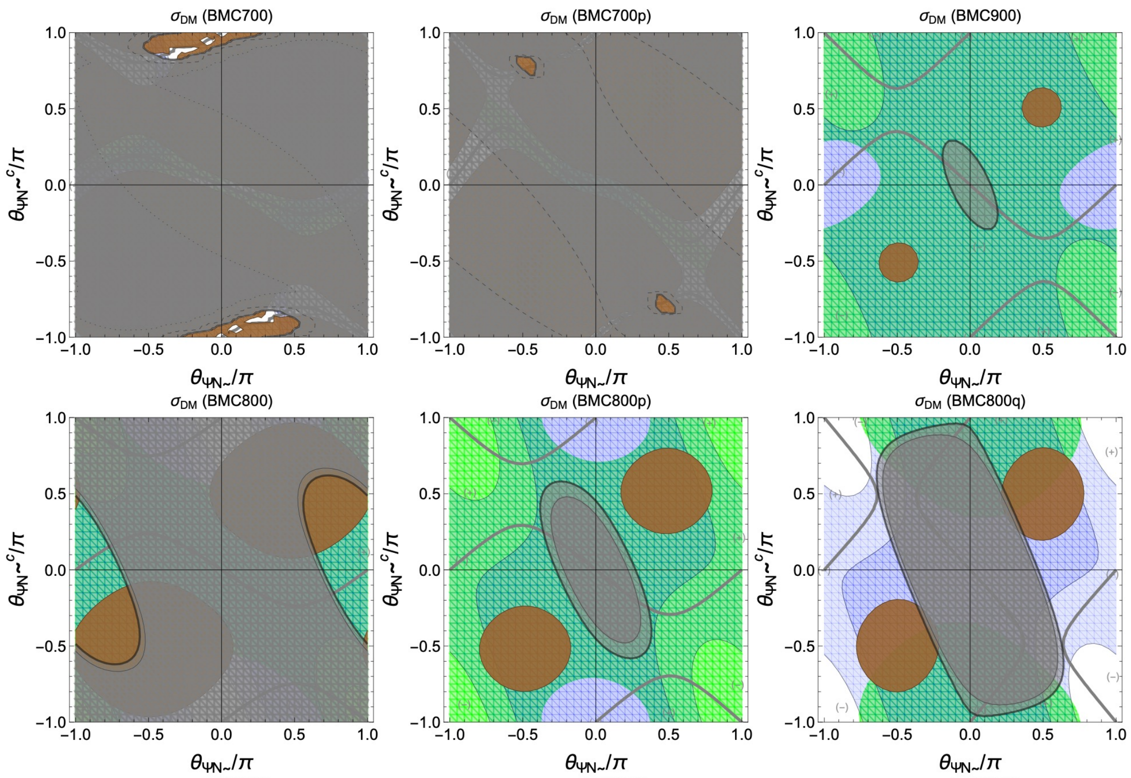
$$\sigma_{\rm SI} \equiv c^2 \frac{4\mu^2}{\pi} f_N^2 \,, \quad \mu \equiv \frac{m_N m_{\psi_1^0}}{m_N + m_{\psi_1^0}} \text{: reduced mass}$$

$$c \equiv \sum_{\phi=h,H,S} \frac{c_{\phi\psi_1^0\psi_1^0}\kappa_{\phi ff}}{v(t-m_\phi^2)} \overset{t\to 0}{\simeq} \frac{c_\alpha c_{\alpha_2} s_{\alpha_2}}{s_\beta v} \frac{m_{\psi_1^0}}{v_\varphi} \left(\frac{1}{m_h^2} - \frac{1}{m_S^2} \right)$$

(α_1=0 is taken)

- Can be suppressed by $m_S \sim m_h$.





σ_{DM} (BMC700)
σ_{DM} (BMC700p)
σ_{DM} (BMC900)
σ_{DM} (BMC800)
σ_{DM} (BMC800p)
σ_{DM} (BMC800q)
$\theta_{\Psi N^{\sim}}/\pi$
$\theta_{\Psi N^{\sim c}}/\pi$

CP-violating signal at ATLAS

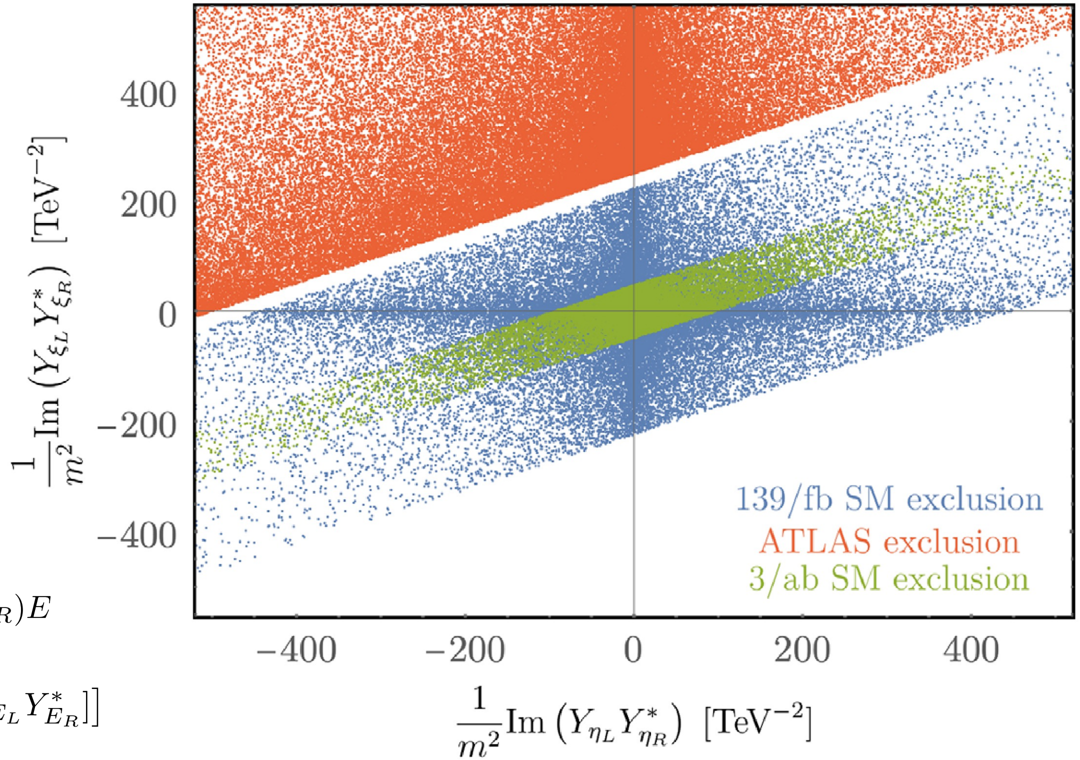
$$\mathcal{L}^{CPV}_{\rm SMEFT} \ni \frac{C_{H\widetilde{W}B}}{\Lambda^2} O_{H\widetilde{W}B}$$

$$\frac{C_{H\widetilde{W}B}}{\Lambda^2} \in [0.23, 2.34]\ {\rm TeV}^{-2}$$

[2006.15458 (EPJC), ATLAS collaboration]

$$\mathcal{L}_{\rm VLL} = \overline{\Psi}(i\not{D} - m_\Psi)\Psi + \overline{N}(i\not{D} - m_N)N + \overline{E}(i\not{D} - m_E)E \\ - \overline{\Psi}\widetilde{H}(Y_{N_L}P_L + Y_{N_R}P_R)N - \overline{\Psi}\widetilde{H}(Y_{E_L}P_L + Y_{E_R}P_R)E$$

$$C_{H\widetilde{W}B} = \frac{g_W g_Y}{96\pi^2 m^2}\left[(1+6\mathcal{Y}){\rm Im}[Y_{N_L}Y^*_{N_R}] + (1-6\mathcal{Y}){\rm Im}[Y_{E_L}Y^*_{E_R}]\right]$$



[2009.13394 (PRD), S. Bakshi, J. Chakrabortty , C. Englert, M. Spannowsky, P. Stylianou]

CP-violating signal at ATLAS

- ATLAS observed a new *CP*-odd effect in the *Zjj* channel
- Dim-6 *CP*-violating op. in SMEFT

$$\frac{C_{H\widetilde{W}B}}{\Lambda^2}\,(H^\dagger\,\tau^a\,H)\,\widetilde{W}^a_{\mu\nu}\,B^{\mu\nu} \ni \frac{C_{H\widetilde{W}B}}{\Lambda^2}\left(-\frac{1}{2}\,(v+h)^2\right)\,(-c_\xi^2\,s_W\,c_W)\widetilde{Z}_{\mu\nu}\,Z^{\mu\nu}$$

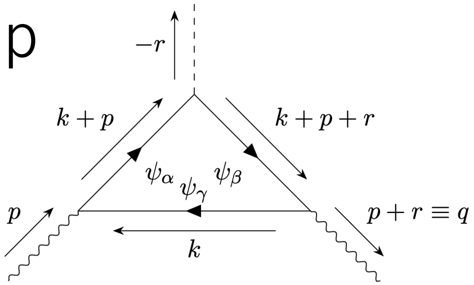
$$\frac{C_{H\widetilde{W}B}}{\Lambda^2} \in [0.23, 2.34]\,\mathrm{TeV}^{-2}$$

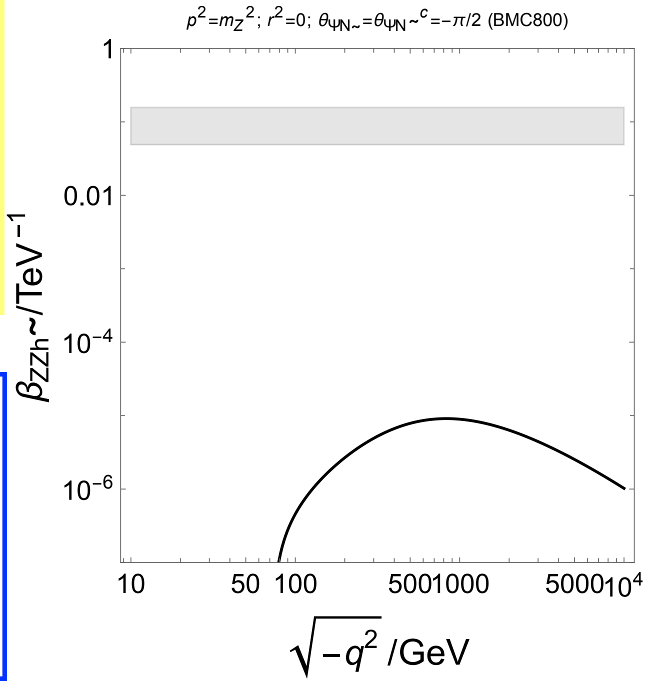
[2006.15458 (EPJC), ATLAS collaboration]

- *ZZh* interaction at 1-loop

$$\mathcal{A}_{ZZh} \ni \widetilde{\beta}_{ZZh}\,h\,\widetilde{Z}_{\mu\nu}\,Z^{\mu\nu}$$

$$\widetilde{\beta}_{ZZh} \in [0.049, 0.157]\,\mathrm{TeV}^{-1}$$





EW baryogenesis (future work)

- Strong 1st order phase transition at EW scale & Gravitational waves
- Estimation of the baryon number