THE MINIMAL FERMIONIC MODEL OF ELECTROWEAK BARYOGENESIS

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THE BARYON ASYMMETRY OF THE UNIVERSE

$$\frac{n_{B\,,\,\mathrm{obs}}}{s} = (8.6\,\pm\,0.09)\times 10^{-11}$$

Planck coll. 1502.01589

Standard Model prediction is essentially <u>zero</u>

Electroweak baryogenesis

Super-testable 😀

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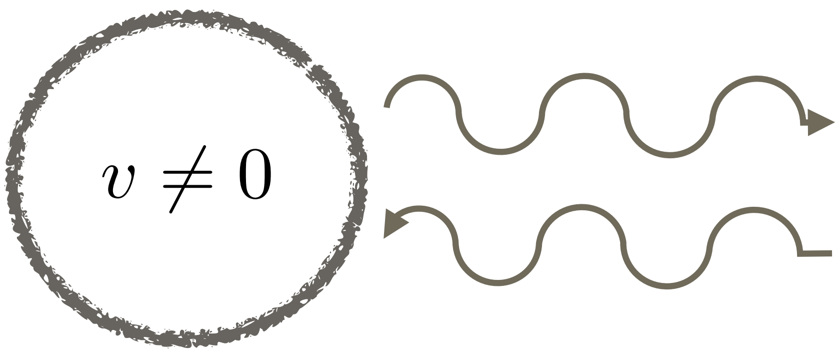
EWBG: HOW DOES IT WORK?

Vacuum bubbles
created in EW phase transition



Fermions reflect
asymmetrically on bubble
due to ***CP violation***

Kuzmin, Rubakov, Shaposhnikov,
Phys. Lett 155B 36

Cohen, Kaplan, Nelson
Phys. Lett. B 245, 561-564

Sphalerons process
the asymmetry
into a baryon asymmetry.
Must avoid washout

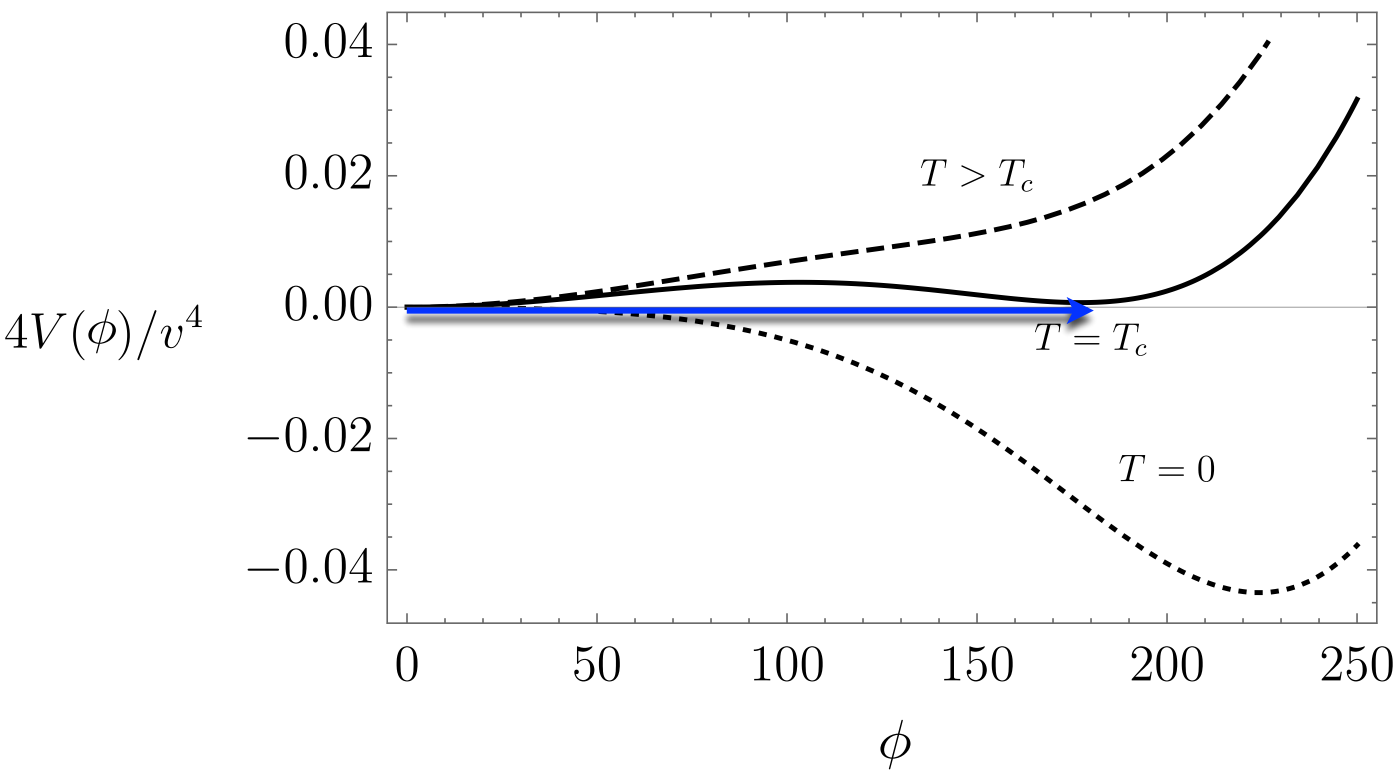
REQUIREMENTS OF EWBG

I. "*Good*" electroweak vacuum bubbles (strong 1st order phase transition)

II. A new source of CP violation

ELECTROWEAK VACUUM BUBBLES

- At the temperature of the electroweak phase transition, we need a potential barrier to form *good bubbles*.



We need

$\phi_c/T_c > 1$

NEW SCALARS OR NEW FERMIONS?

- Need new order one couplings to new *scalars* or *fermions*

$$S H^\dagger H$$

$$S^2 H^\dagger H$$

$$\psi_1 \psi_2 H$$

Scalars induce a barrier

Introduce additional tuning,
and no EW quantum numbers

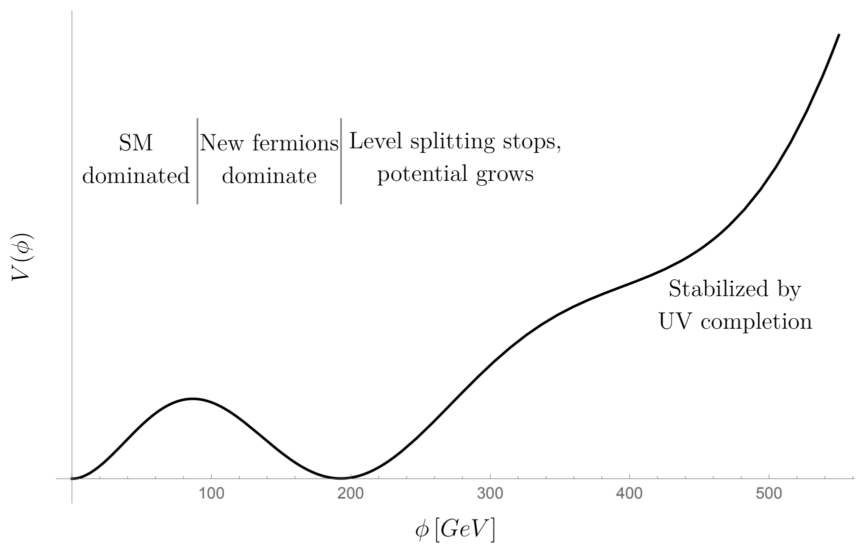
Can fermions induce a barrier?

No tuning, and
they must have EW quantum numbers.
Great for 13 TeV LHC!

FERMION INDUCED BARRIER

- Thermal potential monotonically increases with the masses of fields coupling to the Higgs.
- With more than one fermion "flavor" mixing through the Higgs.

$$m_{lightest} \sim M - y^2\phi^2/M$$ *Level Splitting*



THE MINIMAL REALIZATION

$$\frac{1}{2}m_S\,\psi_S\psi_S + m_L\psi_L\psi_{\bar{L}} - \lambda_d\,\psi_{\bar{L}}\,H^c\,\psi_S + \lambda_u\,\psi_L H\,\psi_S + \text{h.c.}$$

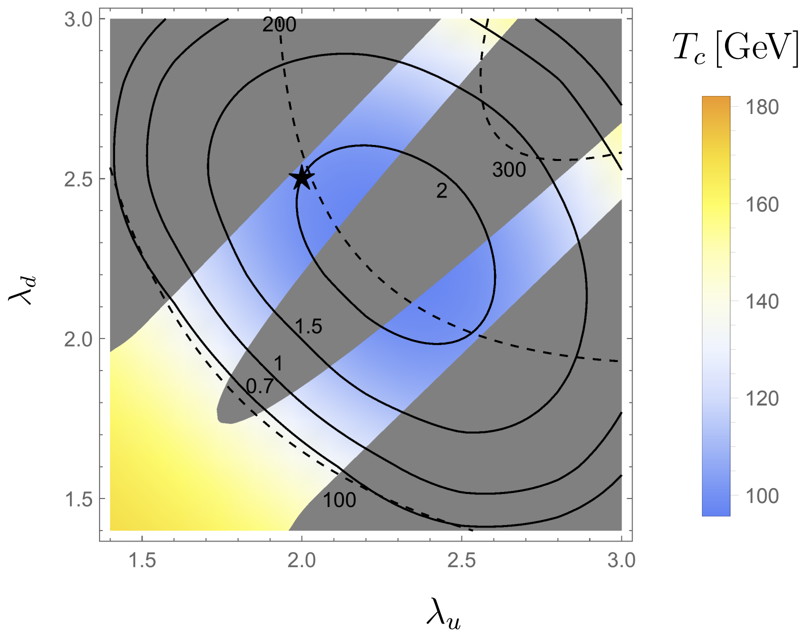
Vector-like masses at the EW scale

Order one interactions with the Higgs

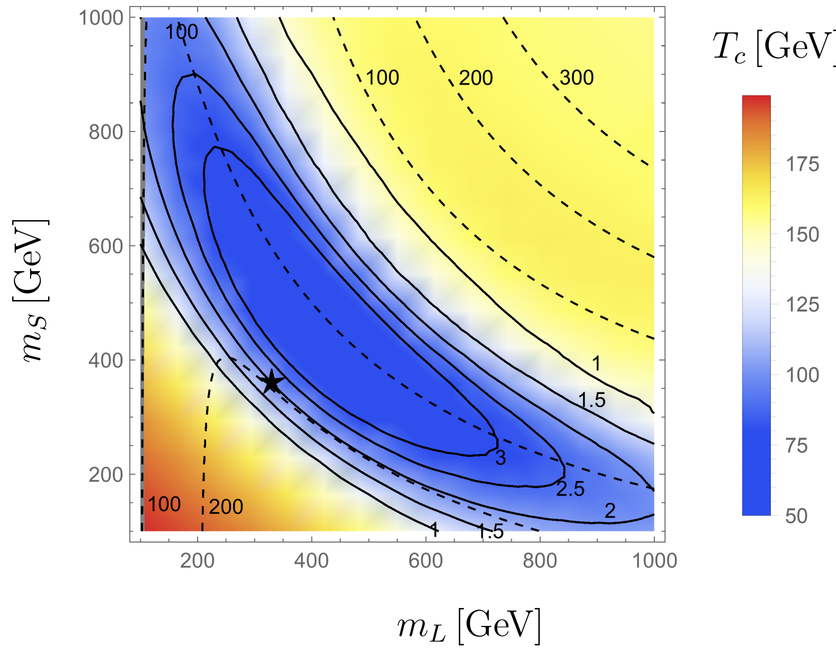
$$\mathcal{M} \equiv \begin{pmatrix} m_S & \frac{\lambda_u \phi}{\sqrt{2}} & \frac{\lambda_d \phi}{\sqrt{2}} \\ \frac{\lambda_u \phi}{\sqrt{2}} & 0 & m_L \\ \frac{\lambda_d \phi}{\sqrt{2}} & m_L & 0 \end{pmatrix}$$

Counting: two masses and two Yukawas

1ST ORDER PHASE TRANSITION FROM EW SCALE FERMIONS



$m_S = 360\text{GeV}, m_L = 330\text{GeV}$



$\lambda_u = 2, \lambda_d = 2.5$

Black: contours of strength of phase transition ϕ_c/T_c

See also Carena et.al. 0410352, Davoudiasl et. al. 1211.3449, Baldes et.al. 1604.04526

REQUIREMENTS OF EWBG

I. Electroweak vacuum bubbles

II. A new source of CP violation

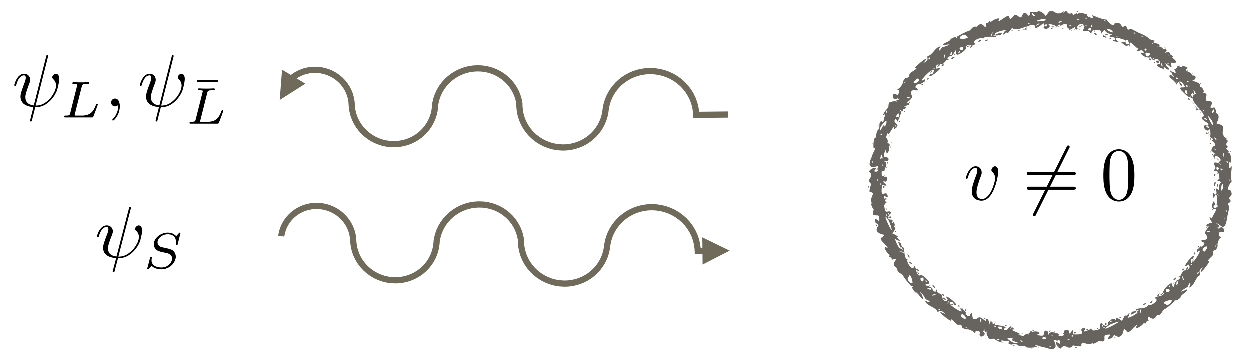
THE MODEL CONTAINS A SINGLE CP VIOLATING PHASE

- The new CP odd invariant is

$$\delta_{\rm CP} = {\rm Arg}\big[\,\lambda_u\,\lambda_d m_S^* m_L^*\,\big]$$

- Leads to an EDM through Barr-Zee diagrams.

CHIRAL ASYMMETRY



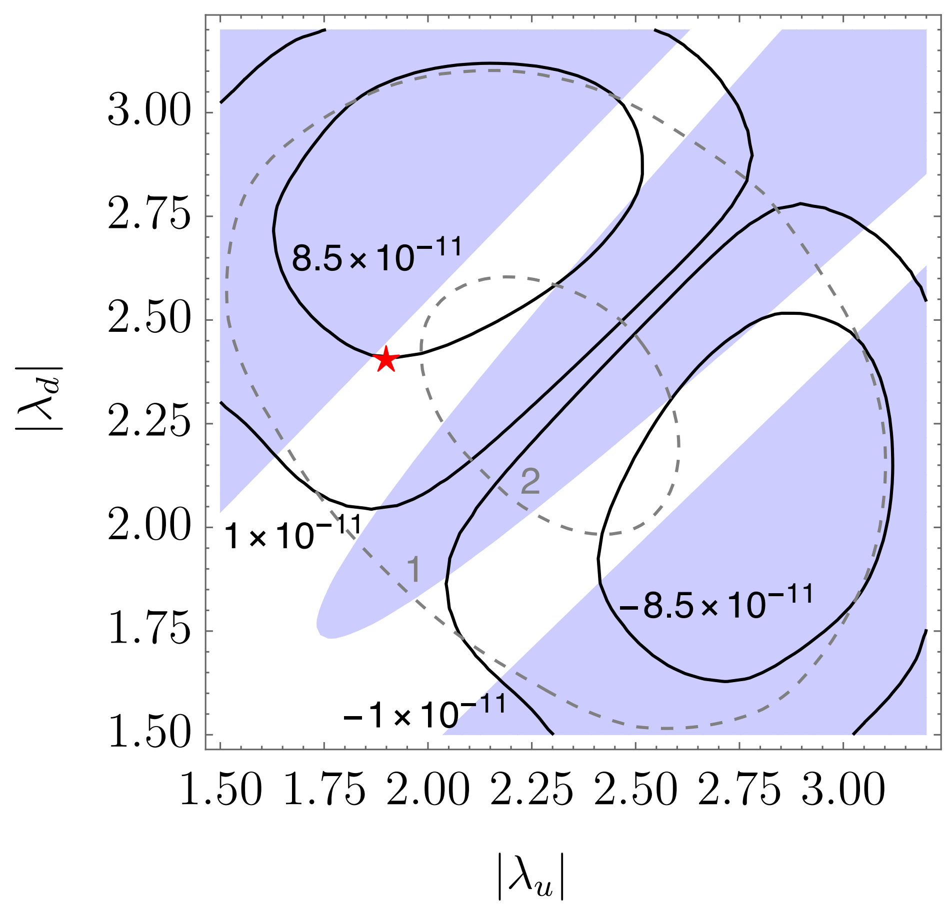
- The asymmetry in the reflection coefficients is

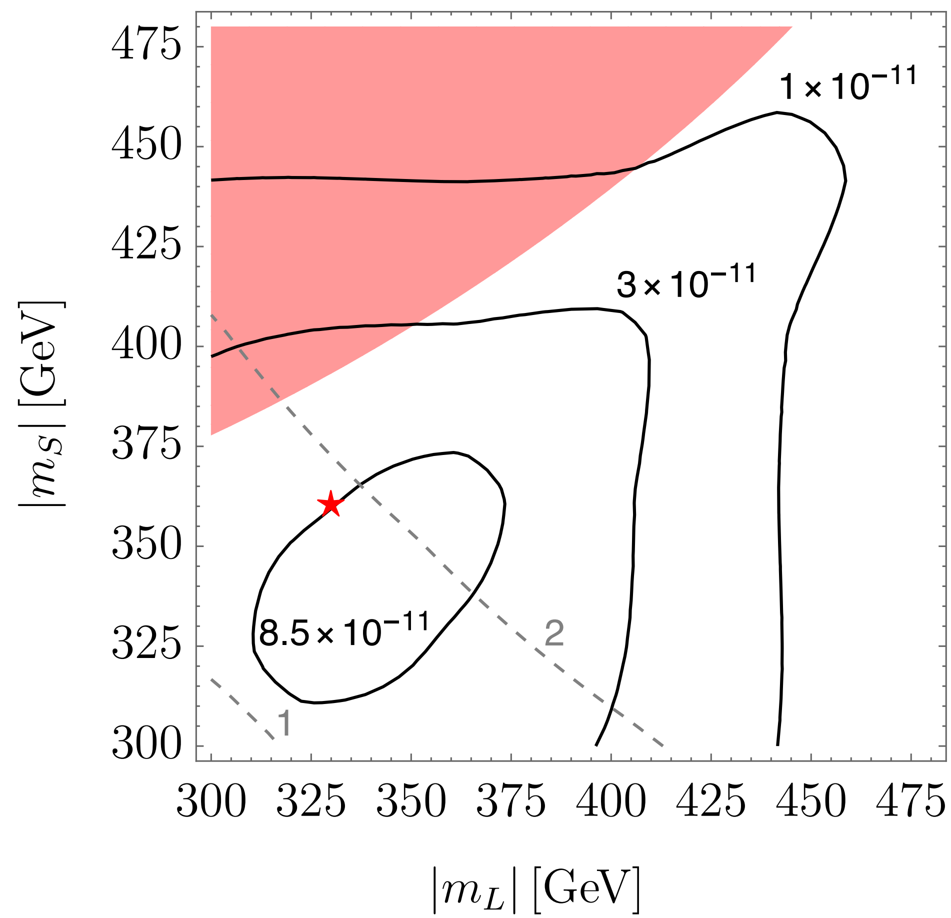
$$n(\omega)(R^\dagger R - \bar{R}^\dagger R) \propto$$

$$n(\omega)\frac{m_S m_L \phi^4}{\omega^6}|\lambda_u \lambda_d|(\lambda_d^* \lambda_d - \lambda_u^* \lambda_u)\sin\delta_{\mathrm{CP}}\,\Xi(l\omega)$$

Fermion abundance — High energy suppression — CP odd invariant — Wall width v/s wavelenght suppression

THE MINIMAL, COMPLETE FERMIONIC MODEL OF EWBG





$$\sin\delta = 4 \cdot 10^{-2}$$
$$l \times T_c = 0.3$$

Blue excluded by EWP

Red: $d_e \geq 8.7 \times 10^{-29}$e cm

ACME coll., 1310.7534

CONCLUSIONS

- We presented the minimal, **complete** fermionic model of EWBG.

Only fermions responsible for 1st order PT!

- Interesting for 13 TeV LHC: ***very rich and different phenomenology*** **with respect to EWBG with new scalars. Similar to ewkino phenomenology.**

  - Minimality of the model ensures that collider bounds are the weakest (with respect to other extensions with higher SU(2) representations)