

Nikhef

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# SOURCE TERMS IN ELECTROWEAK BARYOGENESIS

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**CATCH May 2024**

**with G. White & J. v/d Vis**  
**2107.05971, 2206.01120**

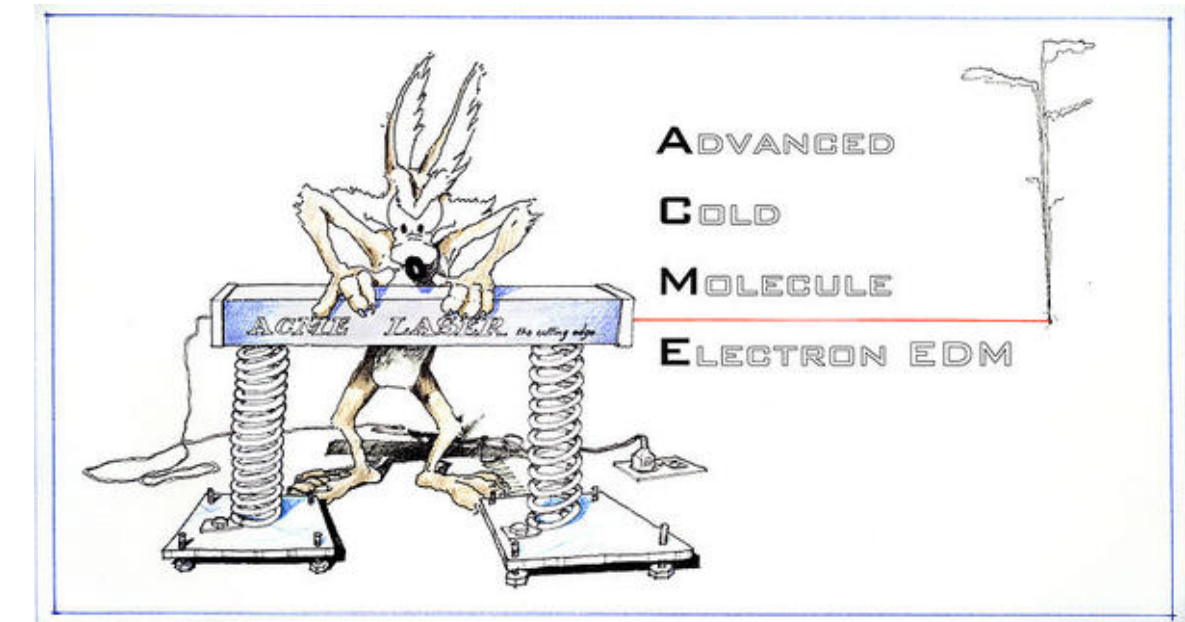
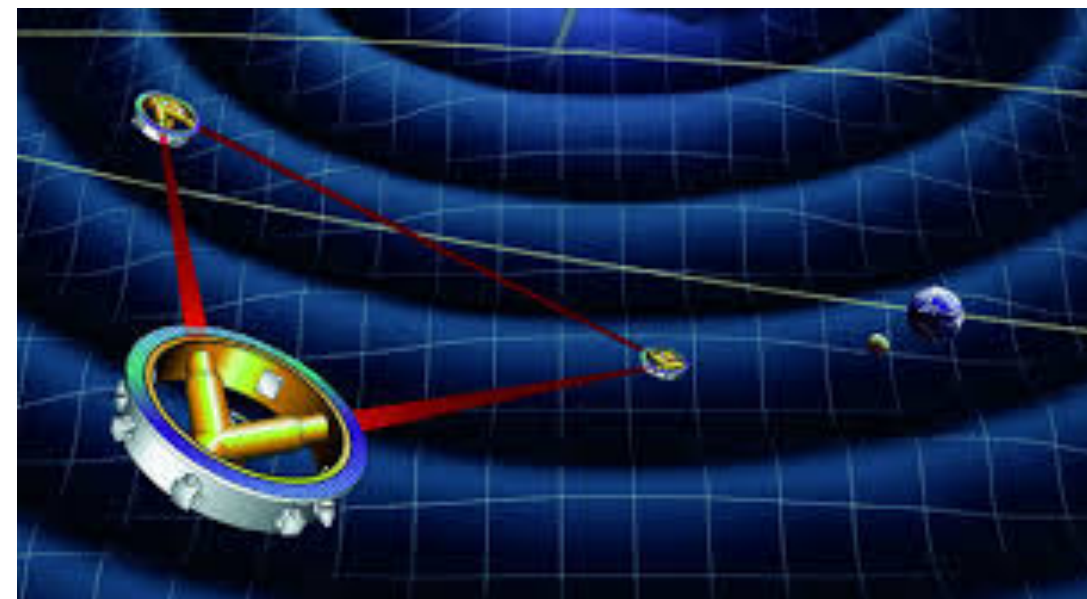
# Why is everything made out of matter?



# ELECTROWEAK BARYOGENESIS

new physics at the EW scale:

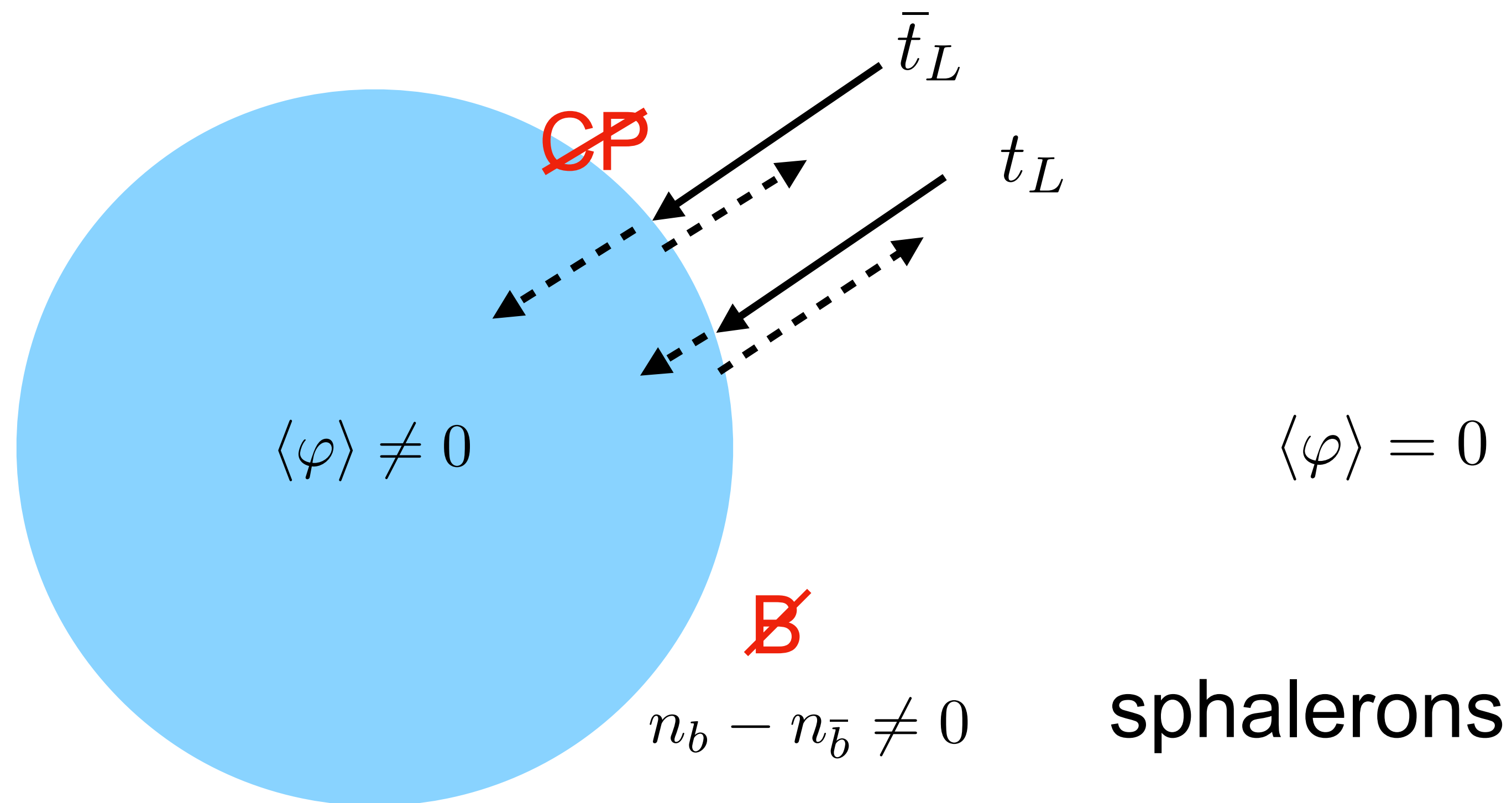
- $\not{C}\not{P}$  operators
- extended Higgs sector: 1st order EW phase transition



# EW BARYOGENESIS IN A NUTSHELL

$$\mathcal{L} \supset \frac{y_t}{\sqrt{2}} \varphi \left( 1 + i \frac{\varphi^2}{\Lambda^2} \right) \bar{t}_L t_R + \text{h.c.}$$

CP violation

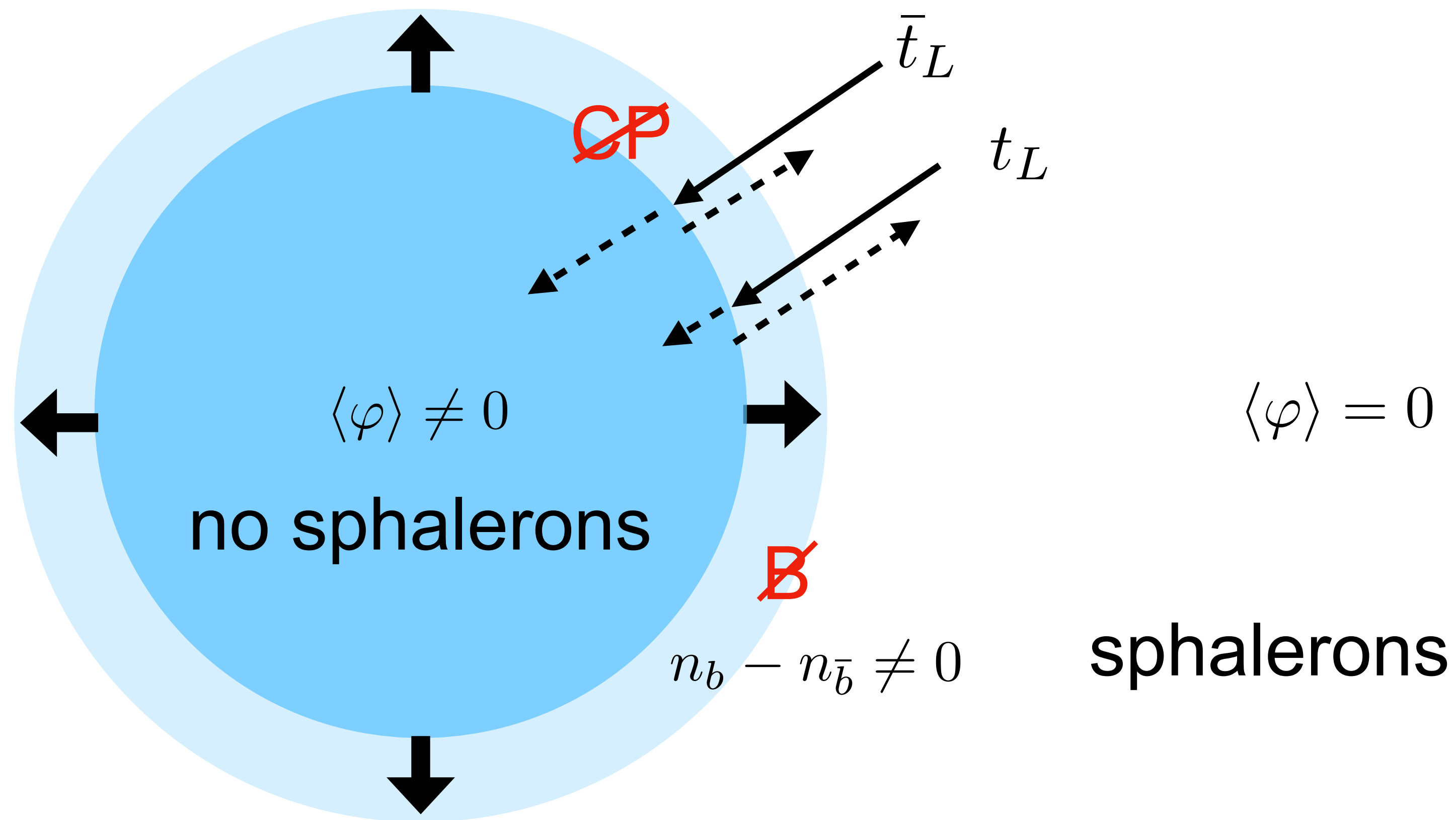




# EW BARYOGENESIS IN A NUTSHELL

$$\mathcal{L} \supset \frac{y_t}{\sqrt{2}} \varphi \left( 1 + i \frac{\varphi^2}{\Lambda^2} \right) \bar{t}_L t_R + \text{h.c.}$$

CP violation



# BOLTZMANN EQUATIONS

$$\mathcal{L} \supset \frac{y_t}{\sqrt{2}} \varphi \left( 1 + i \frac{\varphi^2}{\Lambda^2} \right) \bar{t}_L t_R + \text{h.c.}$$

CP violation

Boltzmann eqs:  $\partial f_i + \text{interactions} = \text{source}$

Source

1. semi-classical source
2. flavour source
3. vev-insertion-approximation (VIA)

Joyce, Cline, Prokopec, Kainulainen,  
Konstandin, Schmidt, Turok, Weinstock, ...

Cirigliano, Lee, Tulin, Ramsey-Musolf,  
Prokopec, Konstandin, Schmidt, Seco

Riotto, Cirigliano, Lee, Tulin,  
Ramsey-Musolf

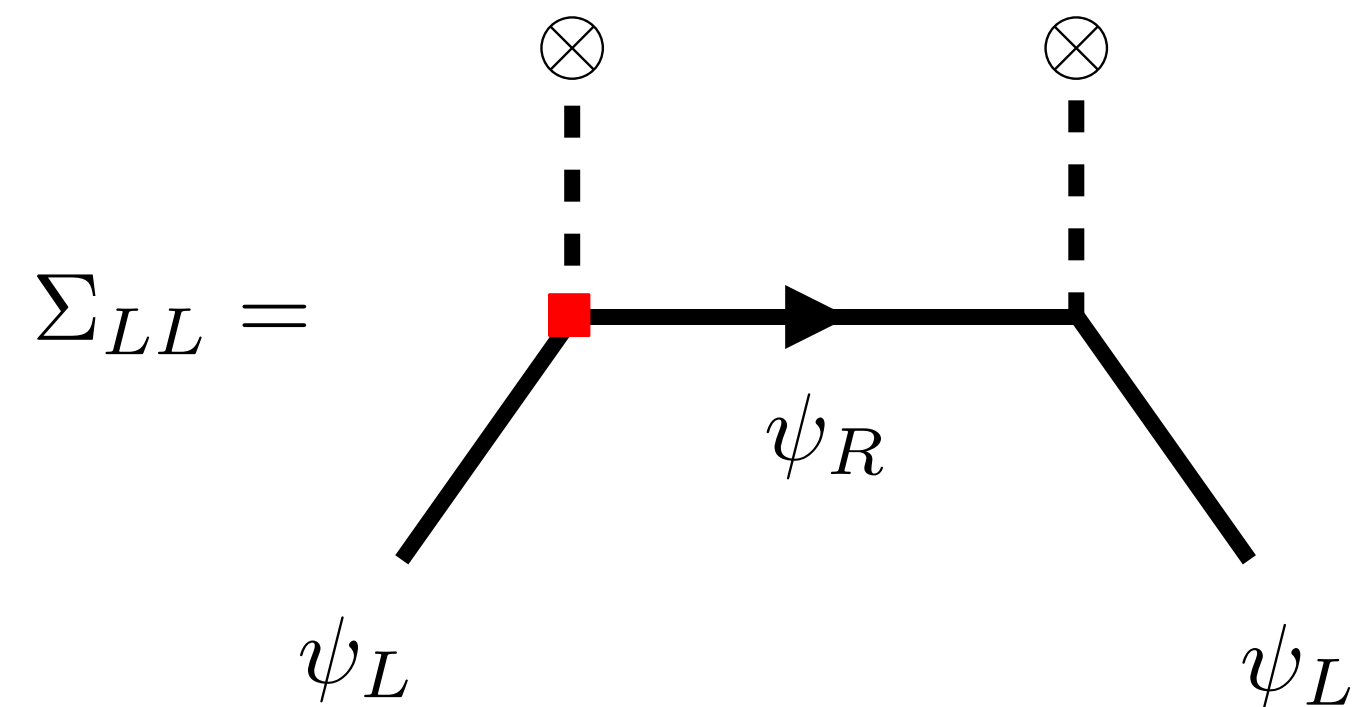
Kainulainen '21



# RESULTS

$$S_{LL} \sim \text{Tr} P_+ \left( [M^2, G^<] + \frac{1}{2} (\{\Sigma^>, G^h\} - \{\Sigma^<, G^>\}) + \dots \right)$$

old calculation



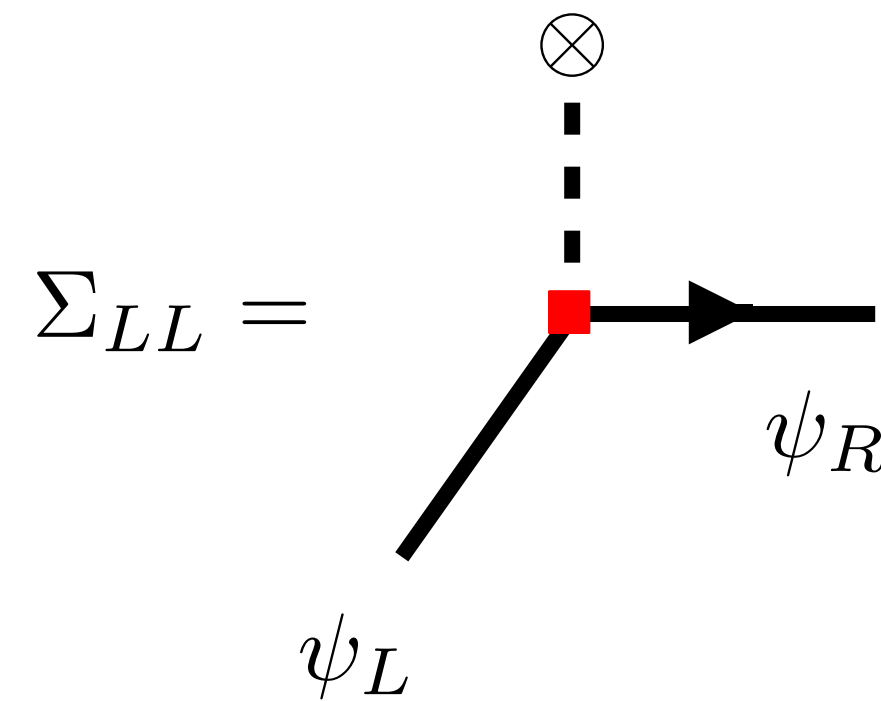
not 1PI!



# RESULTS

$$S_{LL} \sim \text{Tr} P_+ \left( [M^2, G^<] + \frac{1}{2} (\{\Sigma^>, G^h\} - \{\Sigma^<, G^>\}) + \dots \right)$$

new calculation



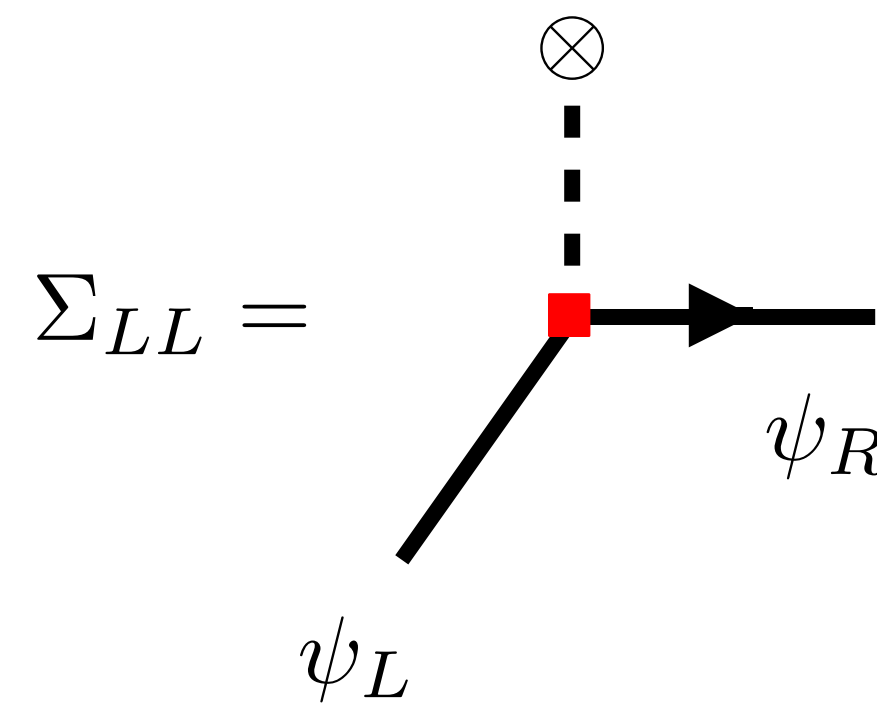
1PI!

# RESULTS

$$S_{LL} \sim \text{Tr} P_+ \left( [M^2, G^<] + \frac{1}{2} (\{\Sigma^>, G^h\} - \{\Sigma^<, G^>\}) + \dots \right) = 0$$

no VIA expansion needed

new calculation



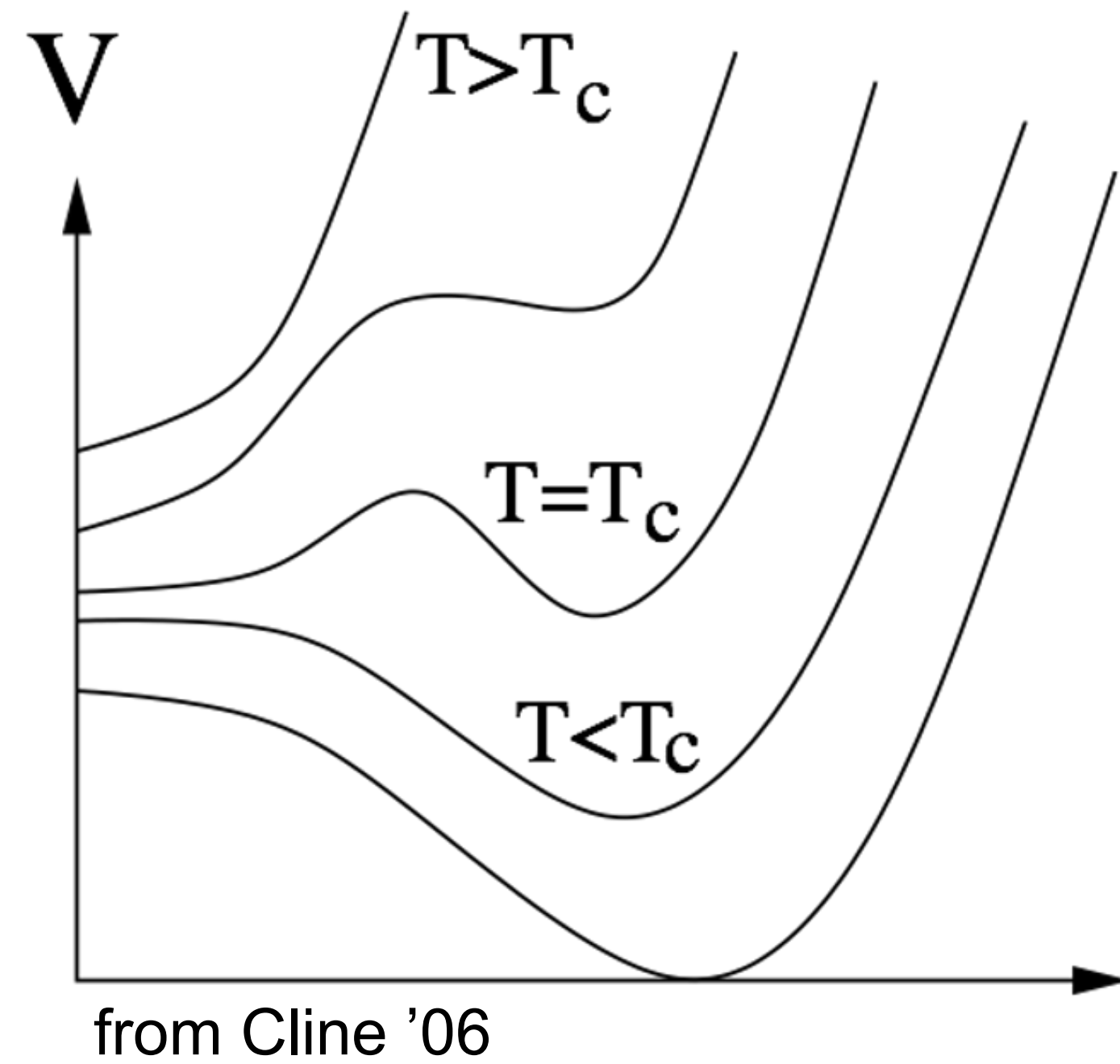
1PI!

# CONCLUSIONS

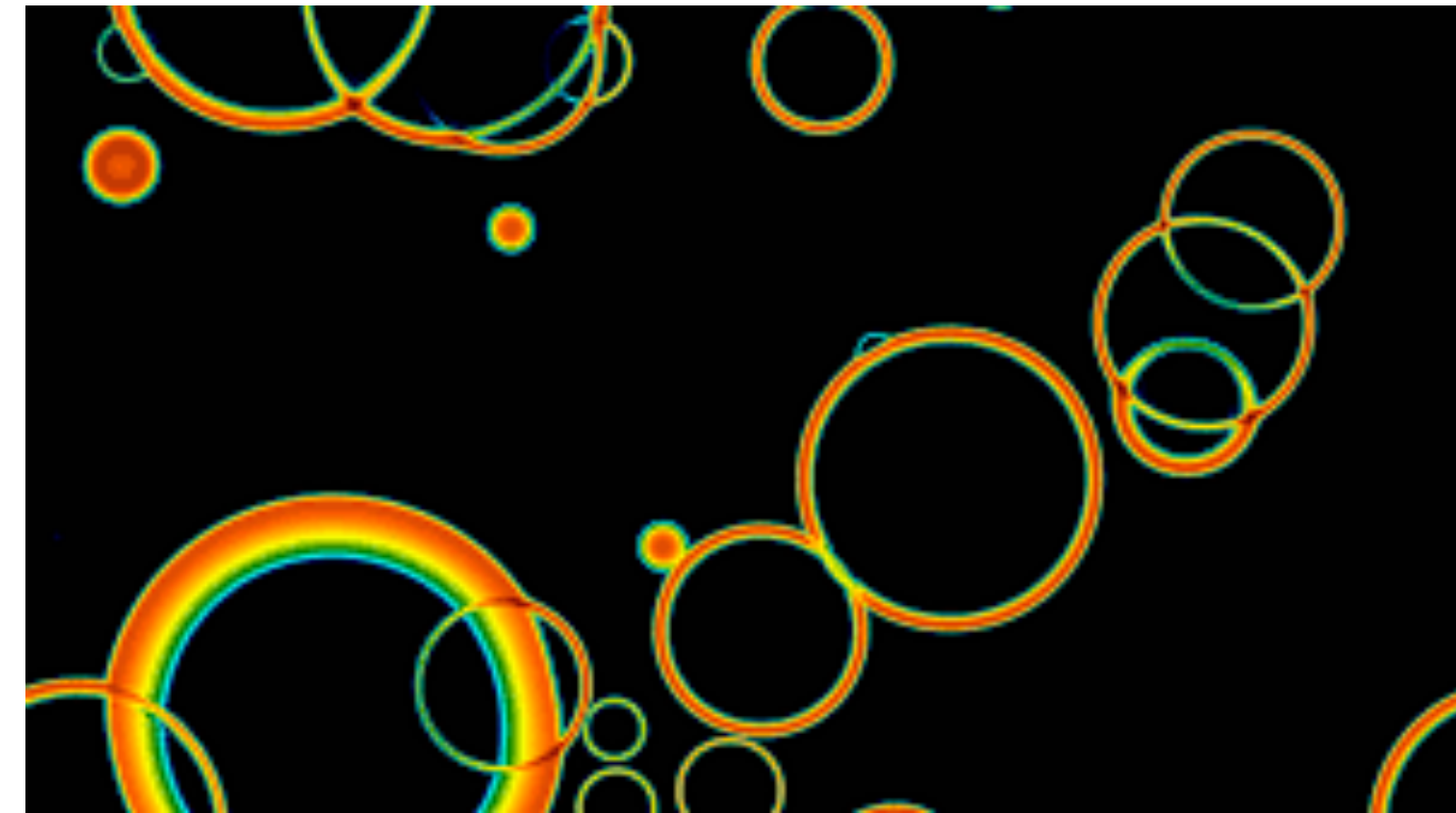
- EW baryogenesis is testable: precise theoretical predictions needed
- VIA source vanishes at leading order in gradient expansion  
generalizes Kainnulainen '21 to chiral theories

To do: NLO

# EW PHASE TRANSITION



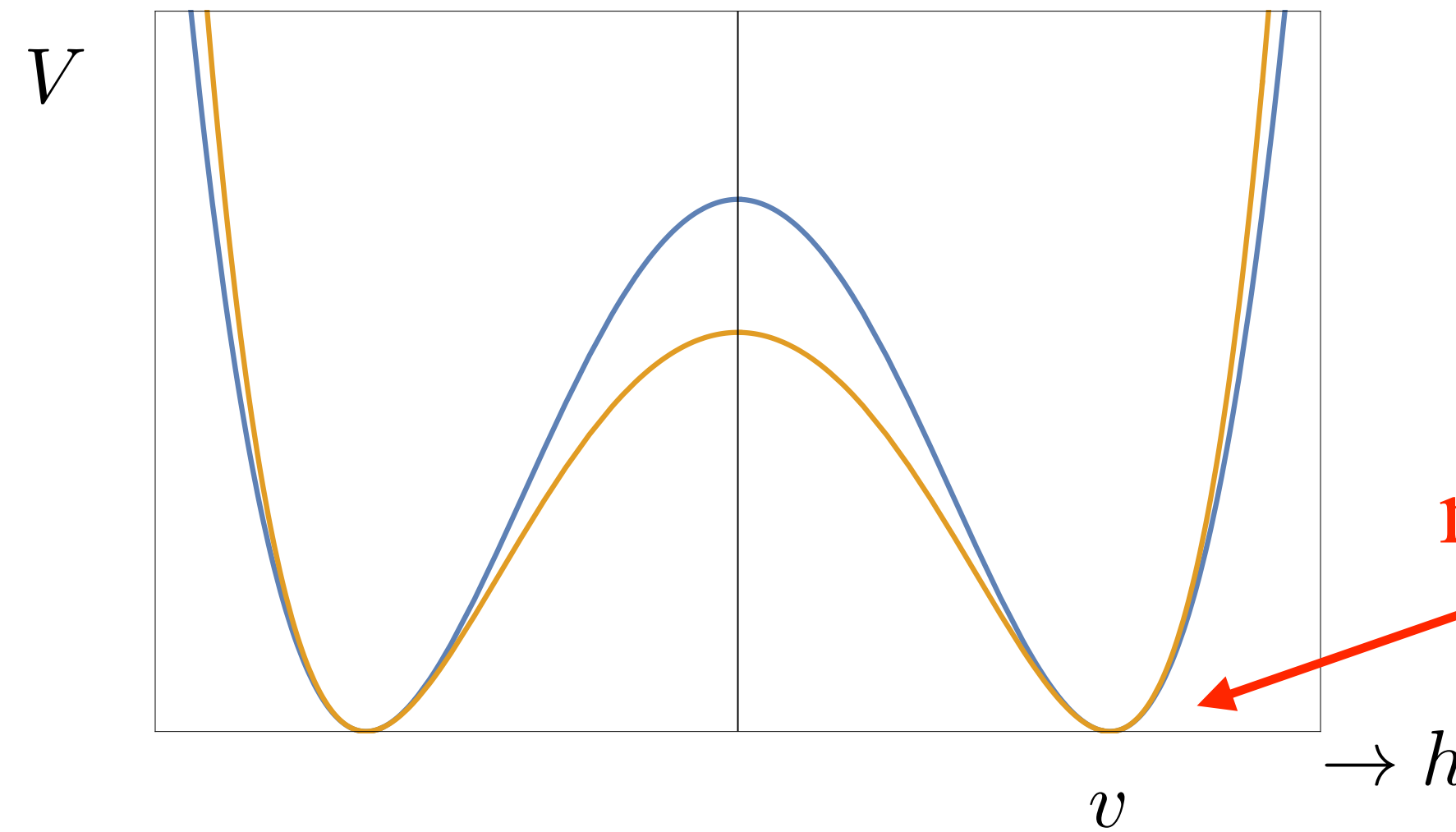
1st order



# EW PHASE TRANSITION

how much room for new physics?

$$-1 \lesssim \frac{\lambda_{hhh}^{\text{BSM}}}{\lambda_{hhh}^{\text{SM}}} \lesssim 7$$



$$m_h = 125.3 \text{ GeV}$$

$$v = 246 \text{ GeV}$$

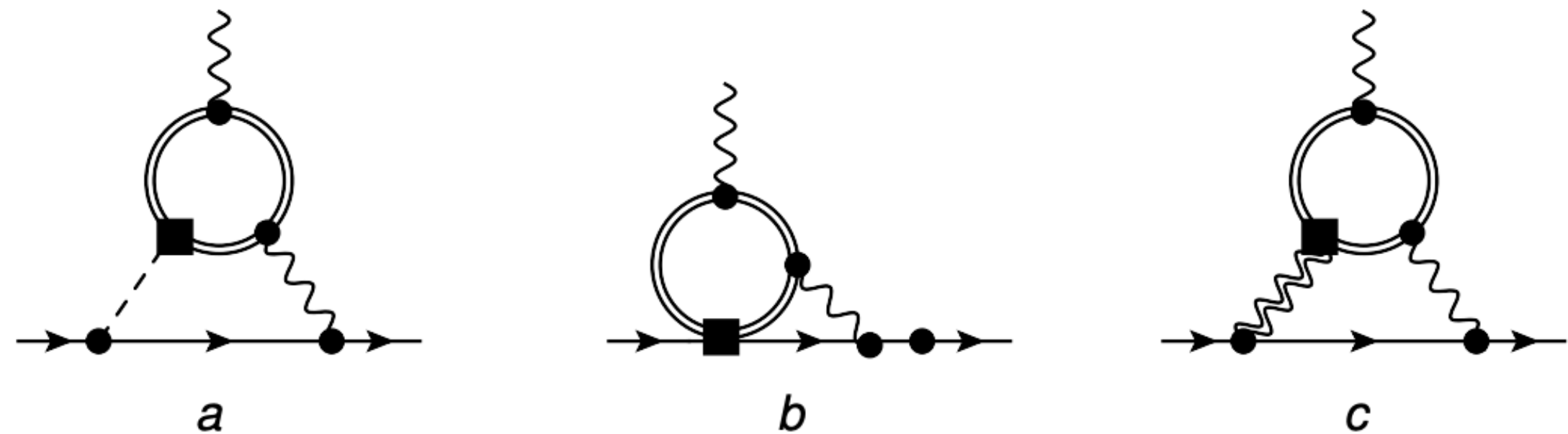


# ELECTRIC DIPOLE MOMENT OF ELECTRON

measured  $|d_e| \lesssim 4 \times 10^{-30} e \text{ cm}$

new physics  $\mathcal{L} \supset \frac{y_t}{\sqrt{2}} \phi \left( 1 + c \frac{\phi^2}{\Lambda^2} \right) \bar{t}_L t_R + \text{h.c.}$

Rules out simplest scenarios



$$\Lambda \gtrsim 10 \text{ TeV}$$

# GRAVITATIONAL WAVES

- bubble collisions
- colliding sound waves
- turbulence

