Electroweak phase transition in a spontaneously magnetized plasma

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Outline

- Spontaneous magnetization in QGP
- Sakharov's conditions for baryon asymmetry
- Phase transition in one Higgs doublet Standard Model with magnetic fields
- Phase transition in two Higgs doublet Standard Model without fields
- Conclusion

Dirac's Equation for quark's field

$$\left(i\gamma^{\mu}D_{\mu} + m_f\right)\psi^{a} = 0$$

- $D_{\mu} = \partial_{\mu} + iq_f|e|A_{\mu}^{EM} + igT^{a}B_{\mu}^{a};$
- $B_{\mu}^{a} = H_3 x_1 \delta^{a3}\delta_{\mu 2} + H_8 x_1 \delta^{a8}\,\delta_{\mu 2};$
- $A_{\mu}^{EM} = H x_1 \delta_{\mu 2}.$

Energy spectrum of quarks

$$H_f^1 = q_f|e|H + \frac{g}{2}\left(\frac{H_8}{\sqrt{3}} + H_3\right);$$

$$H_f^2 = q_f|e|H + \frac{g}{2}\left(\frac{H_8}{\sqrt{3}} - H_3\right);$$

$$H_f^3 = q_f|e|H + g\frac{H_8}{\sqrt{3}};$$

$$\varepsilon_{i,n,\sigma,f}^2 = m_f^2 + p_z^2 + (2n+1)H_f^i - \sigma H_f^i$$

Energy of Quarks at the finite temperature

$$V^{(1)}_{quark} = \frac{1}{8\pi} \sum_{f} \sum_{i=1}^{3} \sum_{l=-\infty}^{\infty} (-1)^l \times$$

$$\times \int_0^\infty \frac{ds}{s^3} e^{-m_f s - \frac{\beta^2 l^2}{4s}} \left[H_f^i s \coth\left(H_f^i s\right) - 1 \right]$$

β - *inverse temperature*

f – *flavor index*

Magnetization of QGP at LHC energies

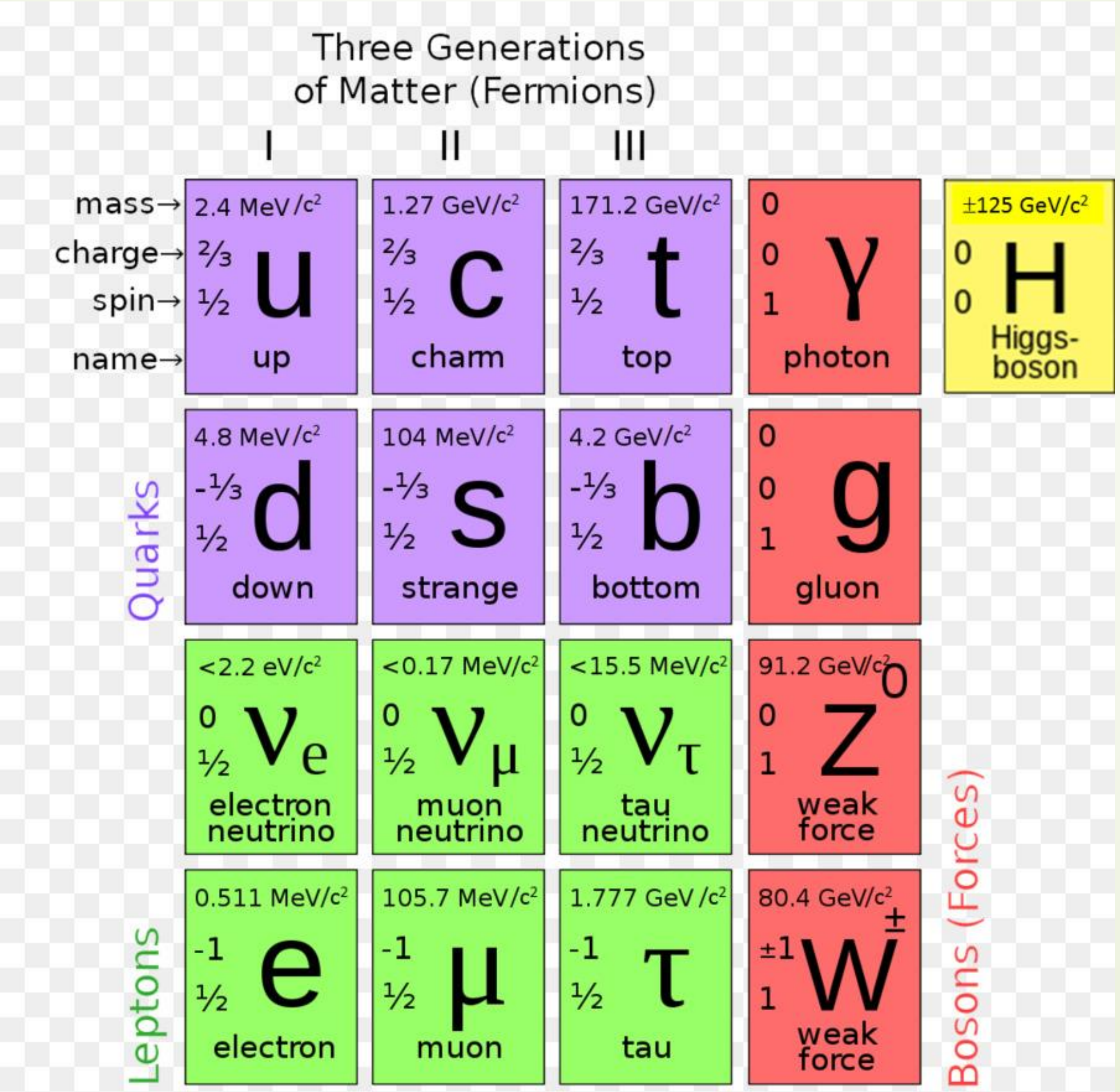
- One of distinguishable properties of nonabelian gauge fields at high temperature is a spontaneous vacuum magnetization. It is closely related with asymptotic freedom. In fact, asymptotic freedom at high temperature is always accompanied by the background stable, temperature dependent and long range chromo(magnetic) fields
- The critical temperature for the magnetized plasma is found to be $T_d(H) \sim 110 - 120\, MeV$. This is essentially lower compared to the zero field value $T_d(H = 0) \sim 160 - 180\, MeV$ usually discussed in the literature. Due to contribution of quarks, the color magnetic fields act as the sources generating H. The strengths of the fields are $B_3(T); B_8(T) \sim 10^{18} \sim 10^{19} G,\ H(T) \sim 10^{16} - 10^{17} G$ for temperatures $T \sim 160 - 220\, MeV$.

P. Minaiev, V. Skalozub, "Magnetized quark-gluon plasma at the LHC", Physics of Particles and Nuclei Letters, Vol. 15, No. 6, 2018.

Sakharov's conditions for baryon asymmetry (1967)

- 1) Baryon number non-conservation;
- 2) C- and CP-symmetry violation;
- 3) Deviation from thermal equilibrium.

Standard Model of elementary particles



Phase transition in Standard Model

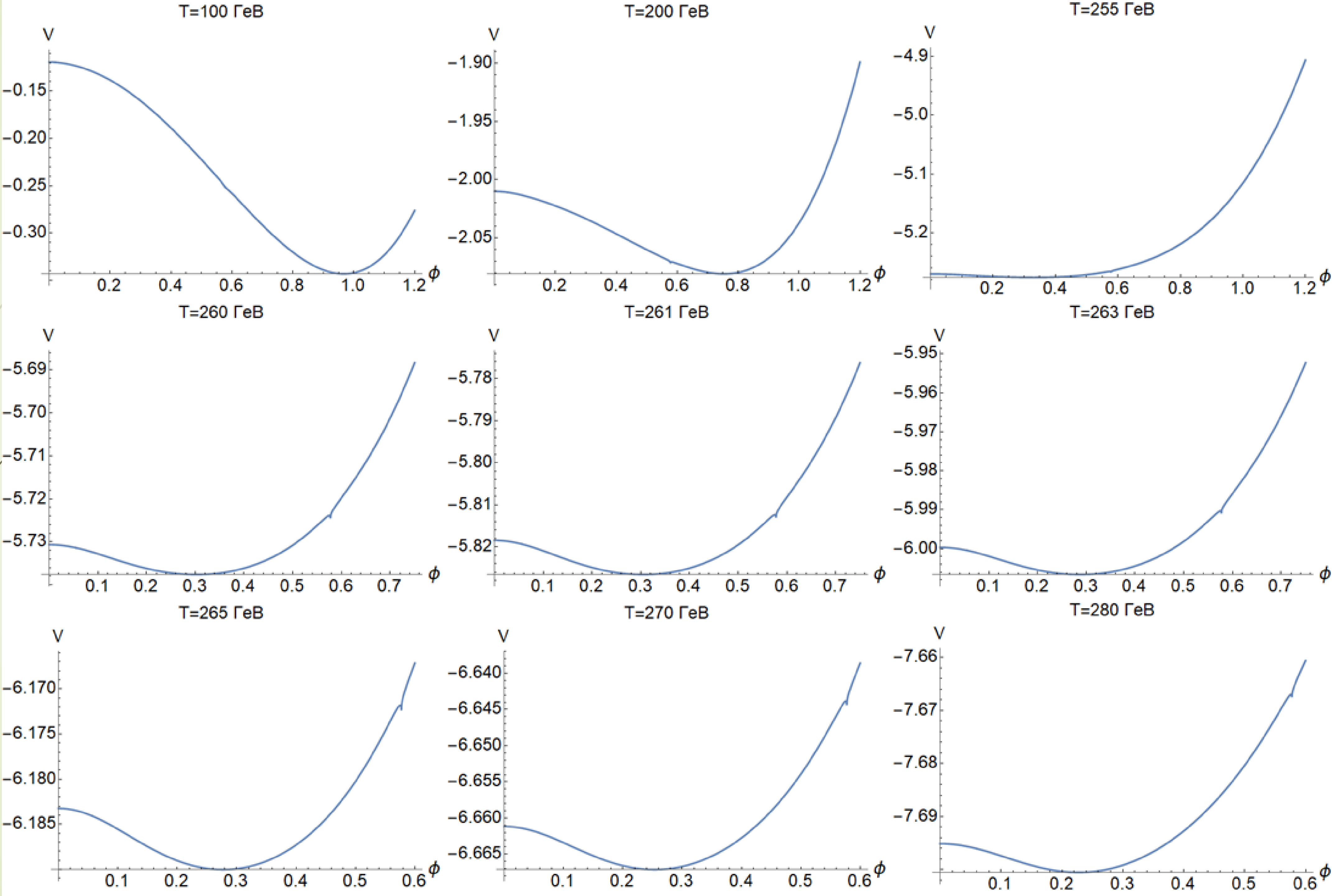
- $V_{SM}(H_3, H_8, H, \phi, T) = \frac{H^2}{2} + \frac{H_3^2}{2} + \frac{H_8^2}{2} + V_{Scalar}^0(\phi) + V_{Gluon}(H_3, H_8, T) + V_{Quark}(H_3, H_8, H, \phi, T) + V_{WZ}(H, \phi, T) + V_{Leptons}(H, \phi, T) + V_{Daisy}(T, H)$
- $V^{(1)} = -\frac{1}{2} Tr\, ln G_k^{ab}(H, T)$
- $G_k^{ab}(H, T) - Matsubara\ Green\ function$

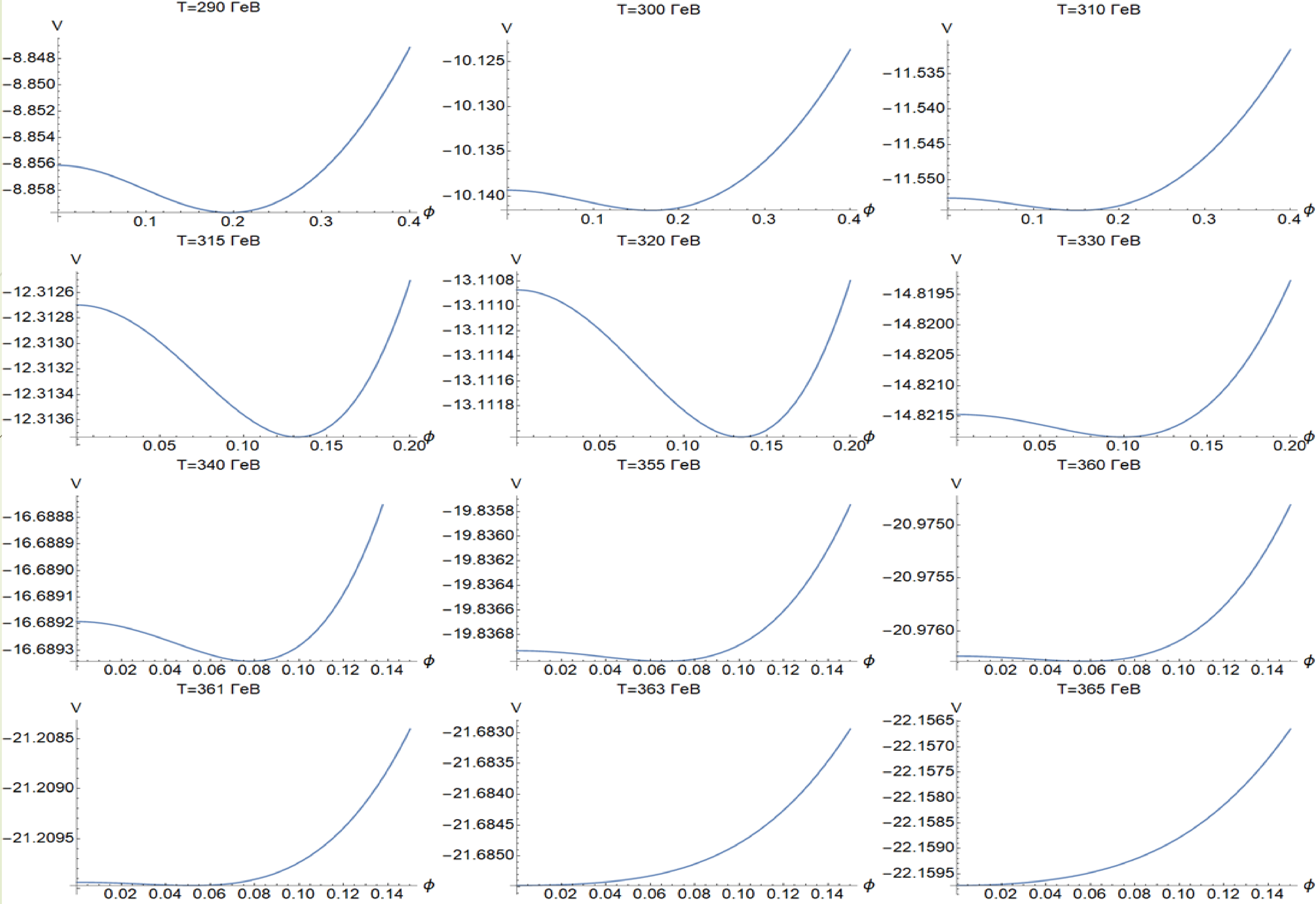
Masses of elementary particles

- $M_u = 2.3\ MeV$ $Q_u = \frac{2}{3}|e|$
- $M_d = 4.8\ MeV$ $Q_d = -\frac{1}{3}|e|$
- $M_s = 95\ MeV$ $Q_s = -\frac{1}{3}|e|$
- $M_c = 1275\ MeV$ $Q_c = \frac{2}{3}|e|$
- $M_b = 4180\ MeV$ $Q_b = -\frac{1}{3}|e|$
- $M_t = 174340\ MeV$ $Q_t = \frac{2}{3}|e|$

- $M_W = 80385\ MeV$ $Q_W = \pm|e|$
- $M_Z = 91188\ MeV$ $Q_Z = 0$
- $M_{Higgs} = 125260\ MeV$ $Q_{Higgs} = 0$

- $M_e = 0.5\ MeV$ $Q_e = -|e|$
- $M_\mu = 105.66\ MeV$ $Q_\mu = -|e|$
- $M_\tau = 1776.8\ MeV$ $Q_\tau = -|e|$


T=100 ГеВ
T=200 ГеВ
T=255 ГеВ
T=260 ГеВ
T=261 ГеВ
T=263 ГеВ
T=265 ГеВ
T=270 ГеВ
T=280 ГеВ
V
ϕ


T=290 ГеВ
V
−8.848 −8.850 −8.852 −8.854 −8.856 −8.858
0.1 0.2 0.3 0.4 ϕ
T=300 ГеВ
V
−10.125 −10.130 −10.135 −10.140
0.1 0.2 0.3 0.4 ϕ
T=310 ГеВ
V
−11.535 −11.540 −11.545 −11.550
0.1 0.2 0.3 0.4 ϕ
T=315 ГеВ
V
−12.3126 −12.3128 −12.3130 −12.3132 −12.3134 −12.3136
0.05 0.10 0.15 0.20 ϕ
T=320 ГеВ
V
−13.1108 −13.1110 −13.1112 −13.1114 −13.1116 −13.1118
0.05 0.10 0.15 0.20 ϕ
T=330 ГеВ
V
−14.8195 −14.8200 −14.8205 −14.8210 −14.8215
0.05 0.10 0.15 0.20 ϕ
T=340 ГеВ
V
−16.6888 −16.6889 −16.6890 −16.6891 −16.6892 −16.6893
0.02 0.04 0.06 0.08 0.10 0.12 0.14 ϕ
T=355 ГеВ
V
−19.8358 −19.8360 −19.8362 −19.8364 −19.8366 −19.8368
0.02 0.04 0.06 0.08 0.10 0.12 0.14 ϕ
T=360 ГеВ
V
−20.9750 −20.9755 −20.9760
0.02 0.04 0.06 0.08 0.10 0.12 0.14 ϕ
T=361 ГеВ
V
−21.2085 −21.2090 −21.2095
0.02 0.04 0.06 0.08 0.10 0.12 0.14 ϕ
T=363 ГеВ
V
−21.6830 −21.6835 −21.6840 −21.6845 −21.6850
0.02 0.04 0.06 0.08 0.10 0.12 0.14 ϕ
T=365 ГеВ
V
−22.1565 −22.1570 −22.1575 −22.1580 −22.1585 −22.1590 −22.1595
0.02 0.04 0.06 0.08 0.10 0.12 0.14 ϕ

Strengths of magnetic fields and scalar condensate (G)

T GeV	$H_8\ 10^{23}$	$H_3\ 10^{23}$	$H\ 10^{21}$	ϕ	V
100	1.092	0.131	0.436	0.97	- 0.34
200	3.17	0.601	1.97	0.75	- 2.09
260	4.91	0.928	3.28	0.31	- 5.738
270	5.46	0.983	3.71	0.25	- 6.667
280	6.01	1.00	3.93	0.22	- 7.695
290	6.33	1.04	4.15	0.19	- 8.597
300	6.66	1.20	4.70	0.17	- 10.1415
310	7.10	1.53	4.91	0.15	- 11.554
320	7.54	1.69	5.35	0.13	- 13.112
330	7.86	1.76	5.68	0.13	- 14.822
340	8.22	1.99	6.39	0.13	- 16.686
350	9.28	2.13	6.66	0.12	- 18.728
360	9.51	2.18	6.69	0.057	- 20.9764

Phase transition in 2 HDSM

- **V. Skalozub,** A. Kozhushko **“The parametric space of the two-Higgs-Douplet Model and Sakharov’s Baryogenesis conditions”, Ukr. J. Phys. Vol 56, 2011.**

Conclusions

- 1) Magnetic fields should be generated in high temperature in plasma.
- 2) Sakharov's conditions for baryon asymmetry do not hold in one Higgs doublet Standard Model
- 3) In Standard Model, the electroweak phase transition is of second type
- 4) Critical temperature is $T_{SM} = 360\ GeV$
- 5) Calculation in 2HDSM is in progress

Thank you for attention!

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