SPONTANEOUS MAGNETIZATION OF QUARK-GLUON PLASMA AT THE LHC

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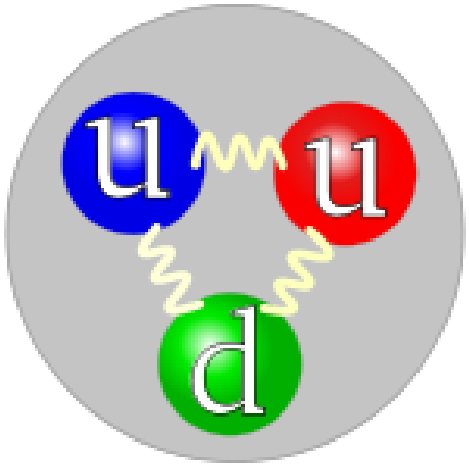
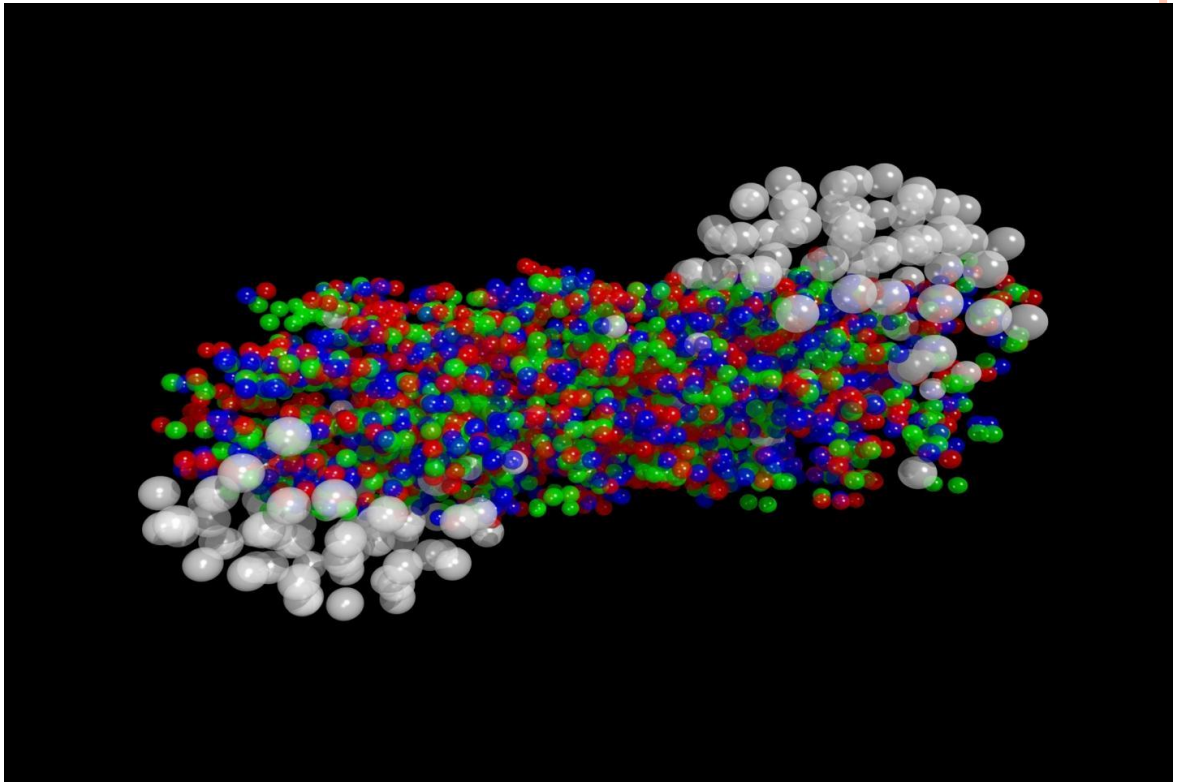
Quark Model.
QCD at the finite temperature

Quark–gluon plasma (**QGP**) is a state of matter in quantum chromodynamics (QCD) which exists at extremely high temperature and/or density. This state is thought to consist of asymptotically free strong-interacting quarks and gluons, which are ordinarily confined by color confinement inside atomic nuclei or other hadrons.





CHROMOMAGNETIC(MAGNETIC) FIELDS AFTER DECONFINEMENT PHASE TRANSCRIPTION

- **On the generation of Abelian magnetic fields in SU(3) gluodynamics at high temperature** /

V.V. Skalozub, A.V. Strelchenko // Eur. Phys. J. C – 2004.

- **Spontaneous magnetization of a vacuum in the hot Universe and intergalactic magnetic fields** /

V. Demchik, V. Skalozub // Phys. Part. Nucl. – 2015

- **Gluon Spectrum in Quark-Gluon Plasma under Strong Magnetic Fields** /

K. Hattori, D. Satow// Phys. Rev. D 97, 014023 – 2018

- **Spontaneous magnetization of the vacuum and the strength of the magnetic field in the hot Universe** /

V. Skalozub, E. Elizaldea // Eur. Phys. J. C – 2012.

THE MATSUBARA GREEN FUNCTIONS

- $\boldsymbol{G_k^{ab}}(x, x', T) =$

$$= \sum_{n=-\infty}^{\infty} (-1)^{(n+[x])\sigma_k} \times G_k^{ab}(x - [x]\beta u, x' - n\beta u)$$

- σ_k=1 for fermions fields, σ_k=0 for bosons fields
- $\beta = \frac{1}{T}$; $[x] - whole\ part\ of\ \frac{x_4}{\beta}$; $u = (0,0,0,1)$

$$\boldsymbol{V^{(1)}} = Tr\ Log\boldsymbol{G_k^{ab}}$$

- A. Cabo, O.K. Kalashnikov, A.E. Shabad. **Finite temperature gluonic gas in a magnetic field.**

Nuclear Physics B 185, 2, 1981

Should Magnetic fields be created in Quark-Gluon Plasma?

Dirac's Equation for quark's field

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

- $D_{\mu}=\partial_{\mu}+iq_{f}|e|A_{\mu}^{ext}+igT^{a}B_{\mu}^{a};$
- $B_{\mu}^{a}=H_{3}x_{1}\delta^{a3}\delta_{\mu2}+H_{8}x_{1}\delta^{a8}\,\delta_{\mu2};$
- $A_{\mu}^{ext}=Hx_{1}\delta_{\mu2}.$

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

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

$$\times\int_{0}^{\infty}\frac{ds}{s^{3}}\,e^{-m_{f}s-\frac{\beta^{2}l^{2}}{4s}}\left[H^{i}_{f}s\,coth\left(H^{i}_{f}s\right)-1\right]$$

β - *inverse temperature*

f – *flavor index*

Energy of Gluons at the finite temperature

- **On the generation of Abelian magnetic fields in SU(3) gluodynamics at high temperature /**
V.V. Skalozub, A.V. Strelchenko // Eur. Phys. J. C – 2004.

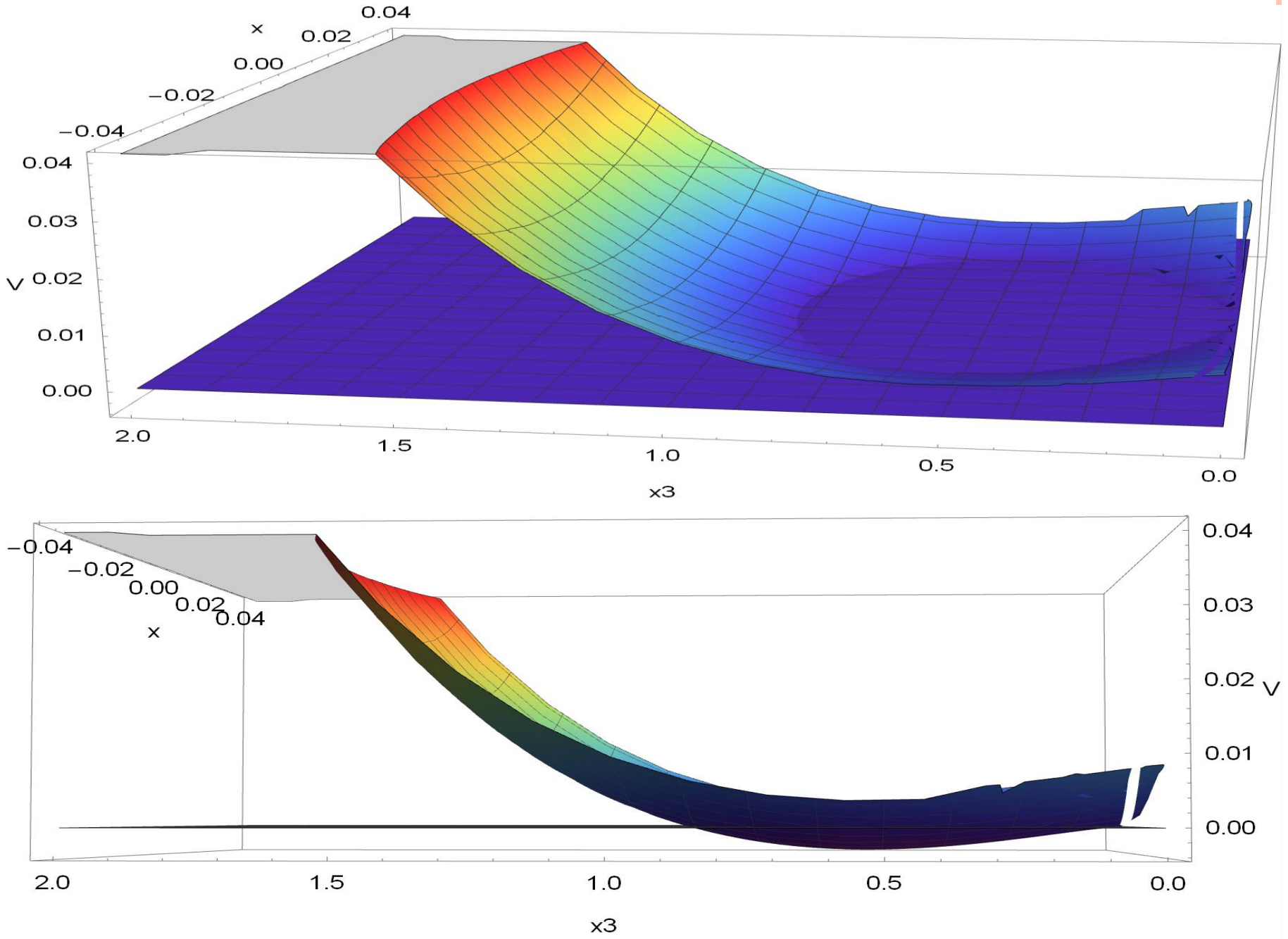
- $$V^{(1)}_{Gluon} = -\frac{1}{3\pi\beta}\left((gH_3)^{\frac{3}{2}} + \left(\frac{3}{2}\right)^{\frac{3}{4}}\left(\left(gH_8 - \frac{gH_3}{\sqrt{6}}\right)^{\frac{3}{2}} + \left(gH_8 + \frac{gH_3}{\sqrt{6}}\right)^{\frac{3}{2}}\right)\right)$$

Full Potential

$$V_{Full} =$$

$$V_0 + V^{(1)}_{quark} + V^{(1)}_{gluon} + V_{ring}$$

$$V_0 = \frac{H^2}{2} + \frac{H_3^2}{2} + \frac{H_8^2}{2}$$



Full potential for T=150 MeV

The strength values of the fields generated at the typical LHC temperatures

$m_u = 334\ MeV,$ $m_d = 340\ MeV,$ $m_s = 486\ MeV,$

T, MeV	H_3, 10^{18}G	H_8, 10^{19}G	H, 10^{17}G	V
120	0.97	0.59	−0.08	−0.002
140	1.67	0.99	0.06	−0.006
→ Temperature where QGP should appear				
160	1.93	1.15	0.37	−0.011
180	2.15	1.27	0.71	−0.017
200	2.35	1.39	1.08	−0.024
220	2.54	1.50	1.49	−0.031

Solution and Discussion

- We have shown that temperature dependent magnetic field is created in QGP. It's strength is increasing with temperature.
- Spectrum of energy of quarks in magnetic field is discrete and could give new signals of QGP.
- This magnetic fields can change properties of matter at temperatures between Deconfinement and Electroweak phase transitions

P. Minaiev, V. Skalozub, "Magnetized quark-gluon plasma at the LHC", Physics of Particles and Nuclei Letters, Vol. 15, No. 5, 2018

THANK YOU FOR ATTENTION

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