Density and pressure distribution of proton

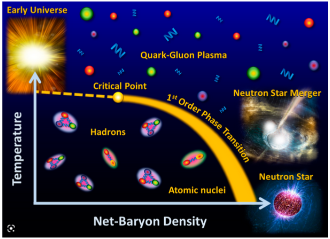
Thandar Zaw Win

in collaboration with Dani Rose J Marattukalam, Cho Win Aung, Sabyasachi Ghosh
Department of Physics
Indian Institute of Technology Bhilai

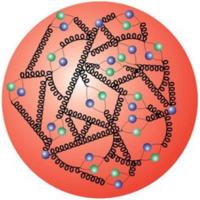
zawwin@iitbhilai.ac.in

October 16-19, 2023

Contents




nature
Explore content About the journal Publish with us
nature > letters > article
Letter | Published: 16 May 2018
The pressure distribution inside the proton
V. D. Burkert, L. Elouadhriri & F. X. Girod
Nature 557, 396–399 (2018) | Cite this article



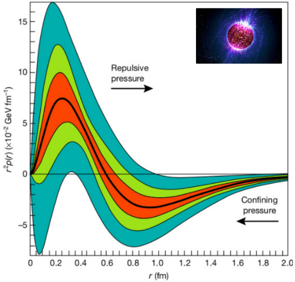


Figure: 5. The pressure distribution inside the proton.

Formalism (Pressure from form factors)

International Journal of Modern Physics A | Vol. 33, No. 26, 1830025 (2018) | Reviews

No Access

Forces inside hadrons: Pressure, surface tension, mechanical radius, and all that

Maxim V. Polyakov and Peter Schweitzer

em:	$\partial_\mu J^\mu_{\text{em}} = 0$	$\langle N' \vert J^\mu_{\text{em}} \vert N \rangle$	$\longrightarrow$	Q_{prot}	$=$	$1.602176487(40) \times 10^{-19}\text{C}$
	vector			μ_{prot}	$=$	$2.792847356(23)\mu_N$
weak:	PCAC	$\langle N' \vert J^\mu_{\textbf{weak}} \vert N \rangle$	$\longrightarrow$	g_A	$=$	$1.2694(28)$
	axial			g_p	$=$	$8.06(0.55)$
gravity:	$\partial_\mu T^{\mu\nu}_{\textbf{grav}} = 0$	$\langle N' \vert T^{\mu\nu}_{\textbf{grav}} \vert N \rangle$	$\longrightarrow$	M_{prot}	$=$	$938.272013(23)\,\text{MeV}/c^2$
				J	$=$	$\frac{1}{2}$
	tensor			D	$=$	**?**

Figure: 2. The global properties of the proton are defined in terms of matrix elements of the conserved currents associated with respectively electromagnetic, weak, and gravitational interaction.

Cont.....

International Journal of Modern Physics A | Vol. 33, No. 26, 1830025 (2018) | Reviews

No Access

Forces inside hadrons: Pressure, surface tension, mechanical radius, and all that

Maxim V. Polyakov and Peter Schweitzer

$$T^{ij}(\vec{r}) = s(r)\left(\frac{r^i r^j}{r^2} - \frac{1}{3}\delta^{ij}\right) + p(r)\delta^{ij}. \tag{1}$$

$$s(r) = \frac{1}{4m}\, r\, \frac{d}{dr}\, \frac{1}{r}\, \frac{d}{dr}\, \tilde{D}(r),$$

$$p(r) = \frac{1}{6m}\, \frac{1}{r^2}\, \frac{d}{dr} r^2 \frac{d}{dr} \tilde{D}(r)$$

$$\tilde{D}(r) = \int \frac{d^3\Delta}{(2\pi)^3}\, e^{-i\Delta r}\, D(-\Delta^2).$$

Formalism (Guess Function)

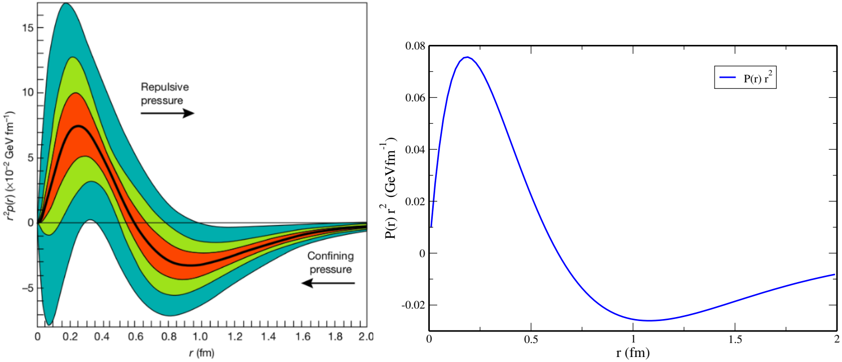


Figure: 3.The Pressure distribution inside the proton by using guess function.

$$y = p(r)r^2 = 0.2593\,(4 - 6.325r)r\;exp^{(-6.325r/2)}, \qquad (2)$$

Formalism (Pressure from Statistical Approaches)

Let us assume the proton being an ideal fermi gas system in a grand canonical ensemble.

$$\Phi(T, V, \mu) = -PV = -k_B T \ln Z_{GCE(tot)} \; , \tag{3}$$

From the second law of thermodynamics,

$$TdS = dU + PdV - \mu dN \; . \tag{4}$$

$$d\Phi = -PdV - SdT - Nd\mu \; . \tag{5}$$

The fermi dirac distribution function is given by:

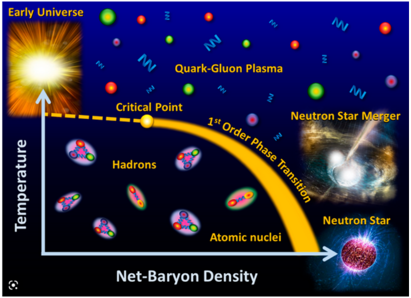
$$f(\epsilon_i) = \frac{1}{e^{(\epsilon_i - \mu)/k_B T} + 1}$$

For ultra-relativistic case at temperature $T \approx 0$, for energy states $\epsilon_i < \mu$, all the states will be occupied.

$$P(r)V = \frac{g}{h^3} \int_V \int_0^\infty \left(\frac{pv}{3}\right) f(\epsilon_i)\, d\tau\, d^3p$$

$$P(r) = \frac{4\pi\, g}{h^3} \int_0^{p_f(r)} \left(\frac{pv}{3}\right) p^2\, dp$$

Cont....



Case-1 $\mu \neq 0$, $T = 0$ case,

$$P(r) = \frac{g}{24\,\pi^2}\,\mu^4\,, \quad \mu(r) = [\,\frac{24\,\pi^2}{g}\,P(r)\,]^{\frac{1}{4}}\;. \quad (6)$$

For number density and the energy density are,

$$n(r) = \frac{g}{6\,\pi^2}\,\mu(r)^3\,, \quad (7)$$

$$\epsilon(r) = \frac{g}{8\pi^2}\,\mu(r)^4\;. \quad (8)$$

Case-2 $\mu = 0$, $T \neq 0$ case,

$$P = \frac{\epsilon}{3} = \frac{g}{\pi^2}\,\frac{7}{8}\,\zeta\,(4)\;\; T^4\;. \quad (9)$$

$$n = \frac{N}{V} = \frac{g}{\pi^2}\,\frac{3}{4}\,\zeta\,(3)\;\; T^3\;. \quad (10)$$

$$\epsilon = \frac{3g}{\pi^2}\,\frac{7}{8}\,\zeta\,(4)\;\; T^4\;. \quad (11)$$

Results and Discussion

$$1 GeV^4 = 2.0852 \times 10^{37} Jm^{-3} \quad (12)$$

Alexei Bazavov, Tanmoy Bhattacharya, Carleton DeTar, H-T Ding, Steven Gottlieb, Rajan Gupta, P Hegde, UM Heller, Frithjof Karsch, Edwin Laermann, et al.
Equation of state in (2+ 1)-flavor qcd.
Physical Review D, 90(9):094503, 2014.

Eduardo S. Fraga, Aleksi Kurkela, and Aleksi Vuorinen.
Neutron star structure from qcd.
The European Physical Journal A, 52:1–9, 2016.

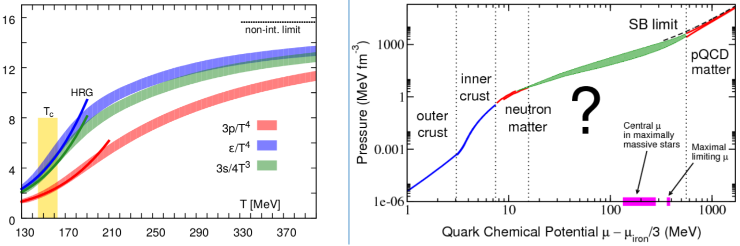


Figure: 4. On the left, thermodynamic properties calculated with Lattice QCD , pressure, energy and entropy densities. On the right, the band region of the known limits of the stellar EoS on a logarithmic scale. On the horizontal axis we have the quark chemical potential with vertical axis the pressure (right).

Results and Discussion

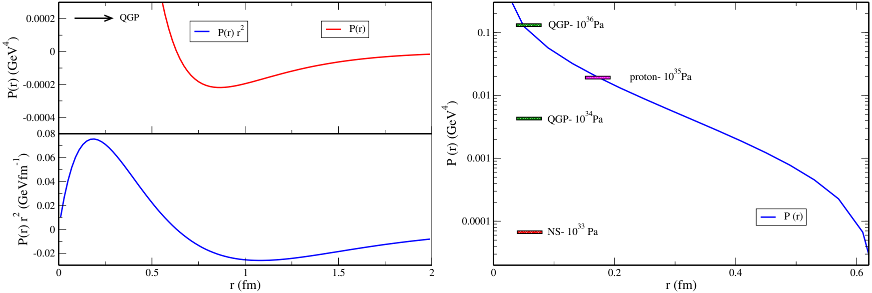
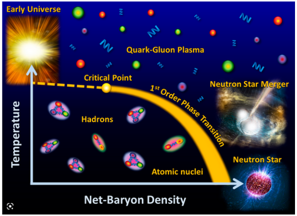


Figure: 5. The pressure distribution inside the proton (Left) and the comparison of pressure value with QGP and NS cases (right).



	$P(GeV)^4$
QGP	10^{34}-10^{36} Pa $0.004 - 0.124$
NS	10^{33} Pa 6.69×10^{-5}
proton	10^{35} Pa 0.0199

Results and Discussion

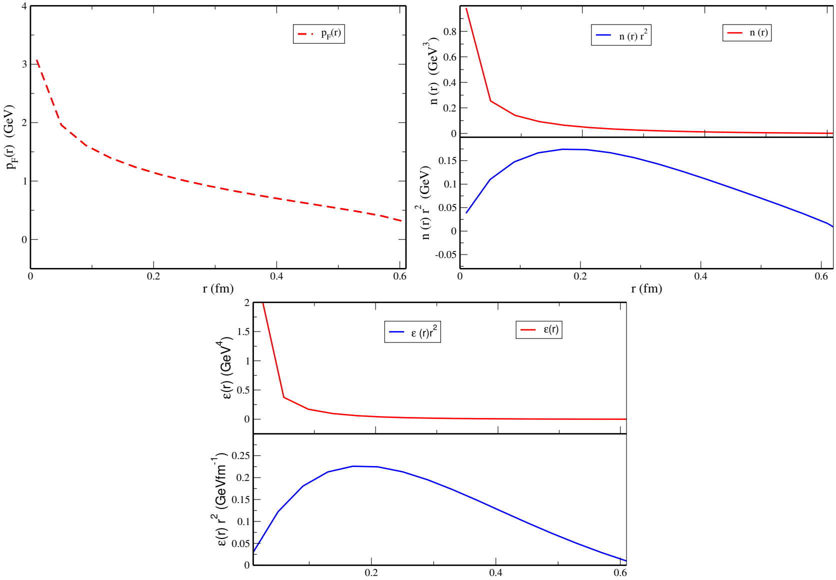
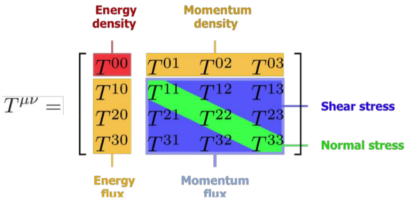


Figure: 6. (a)Fremi momentum , (b)the number density (c) the energy density for the proton case.

Conclusion

- ”V. D. Burkert. et al. ”The pressure distribution inside the proton”, Nature, 054911 2018 and M. V. Polyakov et al., ”Forces inside hadrons: pressure, surface tension, mechanical radius, and all that” focused on the proton pressure distribution in terms of radial distance from the form factors point of view.
- We have estimated these profiles from the guess function and statistical perspectives.
- We described the parameterization of the analytical guess function.
- We assumed that our proton system is assumed as a degenerate quark fluid motion.
- From the above pressure guess function, our tuning parameter is effective chemical potential in terms of the proton radius.
- We derived the other thermodynamics quantities and compared the results with others: QGP, and NS cases.
- The proton’s central peak pressure is larger than the neutron star case.

Thank you!



$$T_{ij}(\vec{r}\,) = s(r)\left(\frac{r_i r_j}{r^2} - \frac{1}{3}\delta_{ij}\right) + p(r)\delta_{ij}$$