Isospin physics in holographic QCD

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- Dense D4/D6 model
- “Nuclear” matter to “strange” matter transition
- “Nuclear” symmetry energy
- Compact stars
- Meson mass splitting in asymmetric dense matter
- Remark

A slide for hQCD

- Gluon dynamics
- (de)confinement
- Flavor (meson) dynamics
- Baryon

- Warped geometry
- Again by geometry
- Classical fields in warped geometry
- Baryon vertex (compact D-brane with N_c fundamental string attatched)

Ex: D4/D6/D6 + compact D4 model

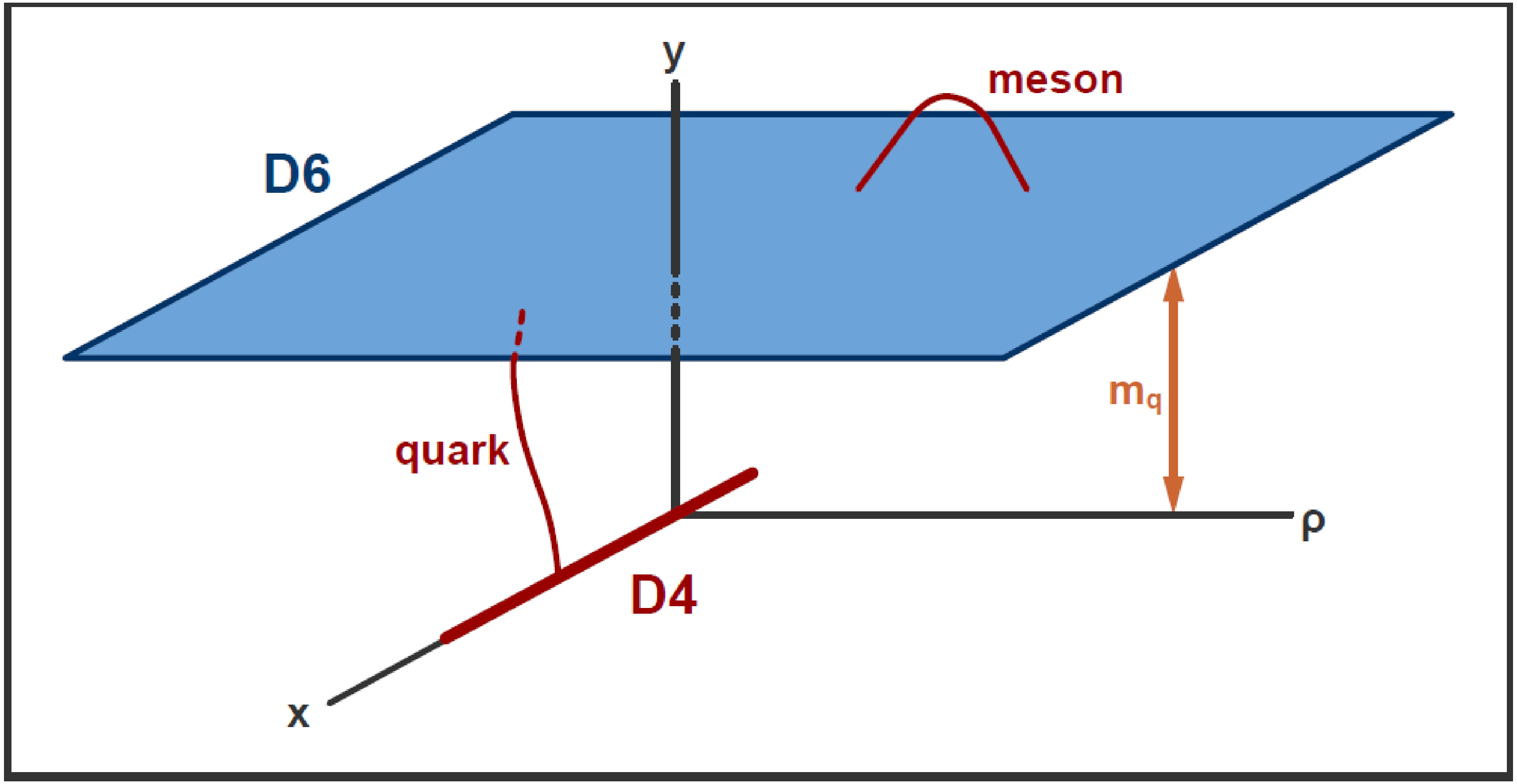
Dense D4/D6 model

- One flavor D4/D6 model in free space

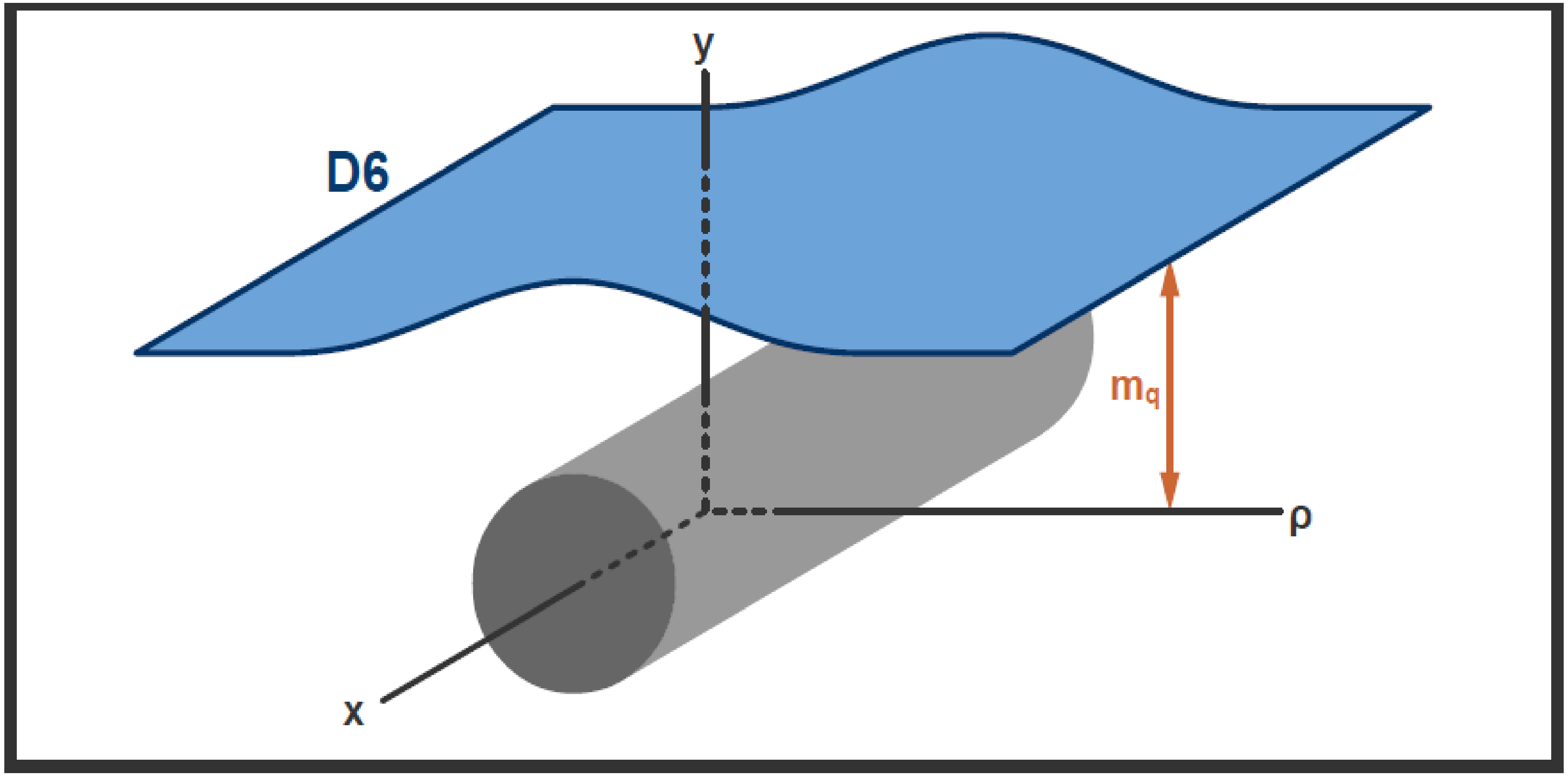
	t	1	2	3	(τ)	ρ	ψ_1	ψ_2	y	ϕ
D4	•	•	•	•	•					
D6	•	•	•	•		•	•	•		

The brane configurations : the background D4 and the probe D6

M. Kruczenski, D. Mateos, R. C. Myers and D. J. Winters, JHEP **0405**, 041 (2004)



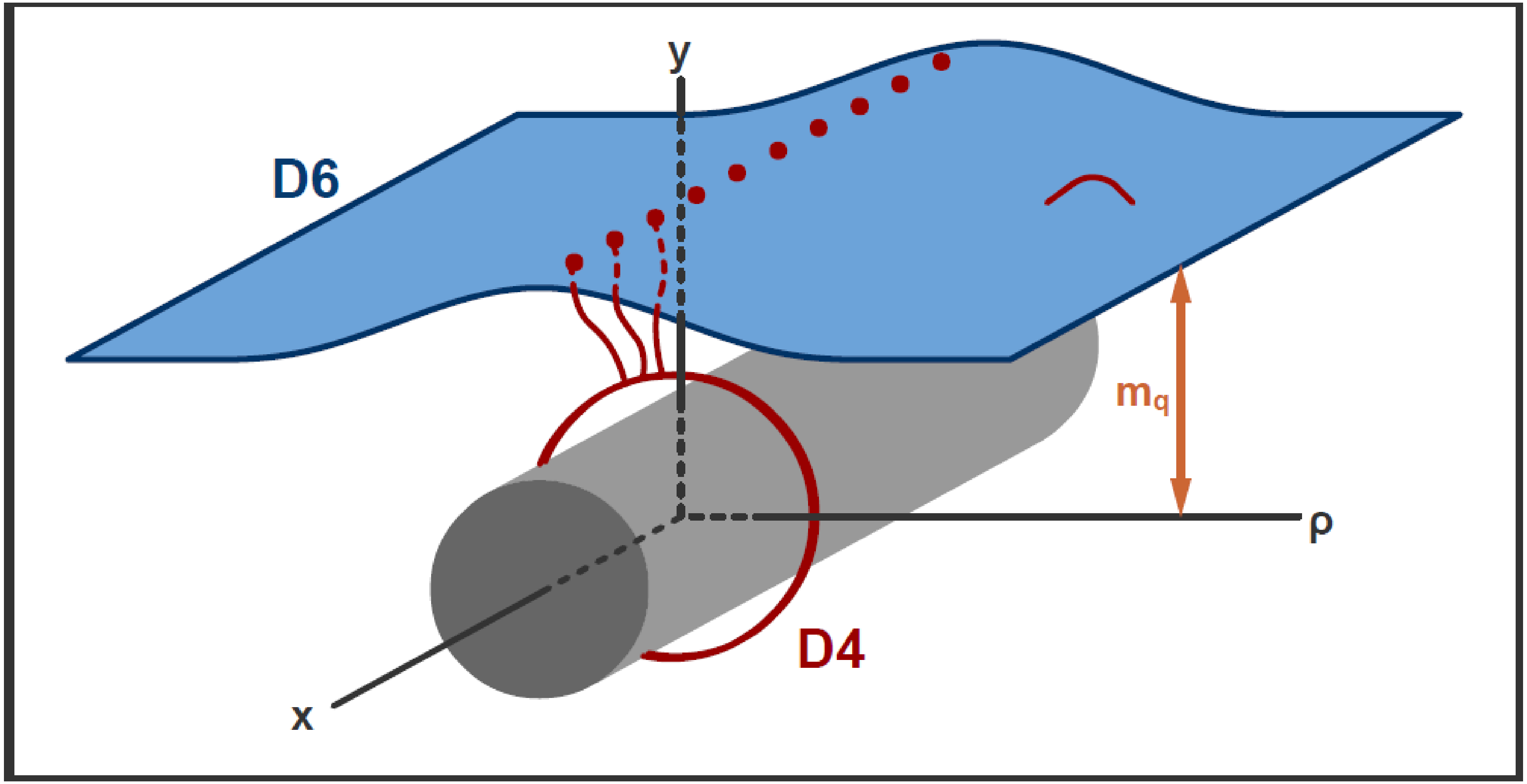
Figures from Deokhyun Yi



$$ds^2 = \left(\frac{U}{R}\right)^{3/2}(dt^2 + d\vec{x}^2 + f(U)dx_4^2) + \left(\frac{R}{U}\right)^{3/2}\left(\frac{U}{\xi}\right)^2(d\rho^2 + \rho^2 d\Omega_2^2 + dy^2 + y^2 d\phi^2)\,,$$

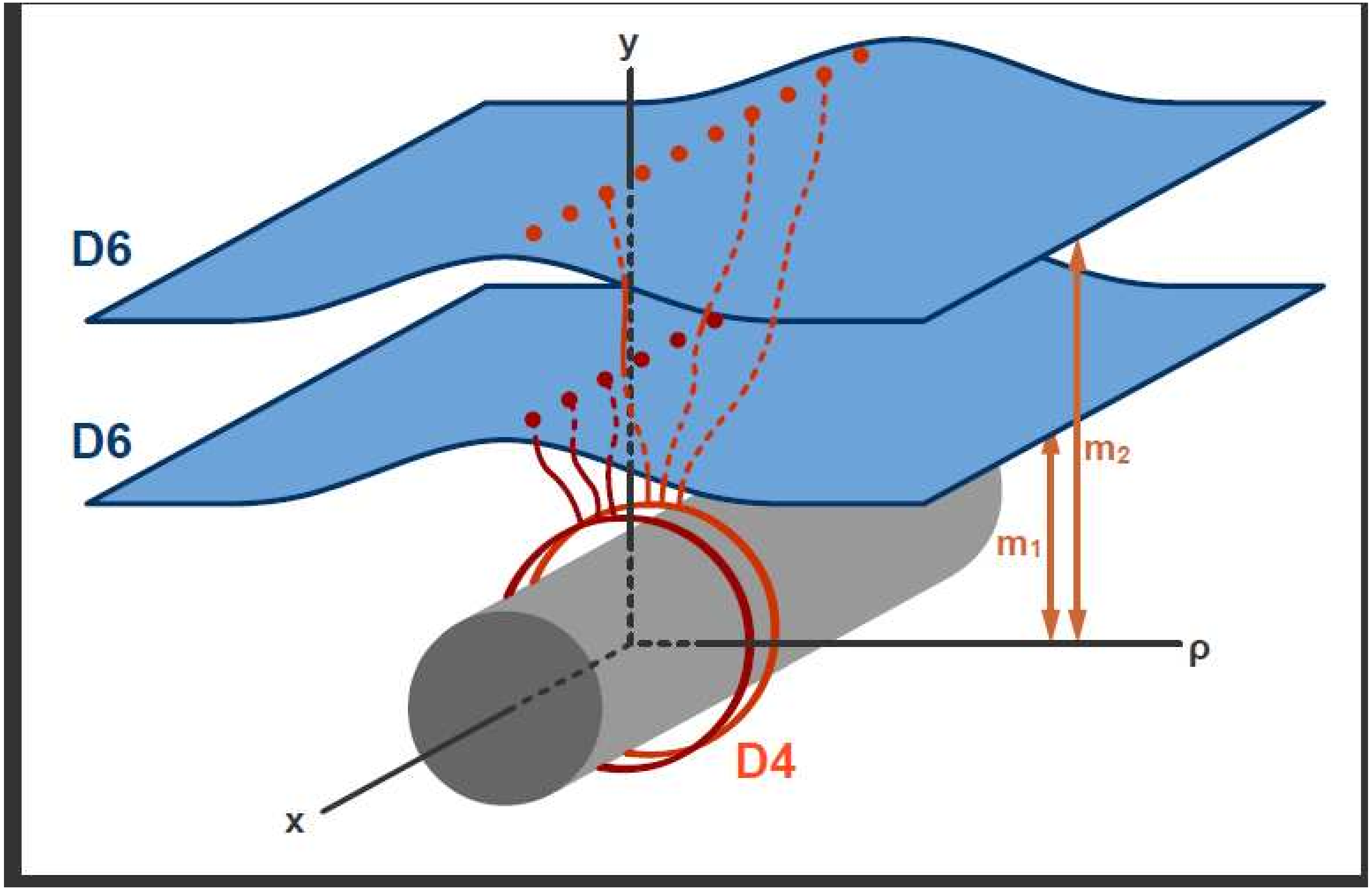
$$S_{D6} = \int dt\mathcal{L}_{D6} = -\mu_6 \int e^{-\phi}\sqrt{\det(g + 2\pi\alpha' F)}$$

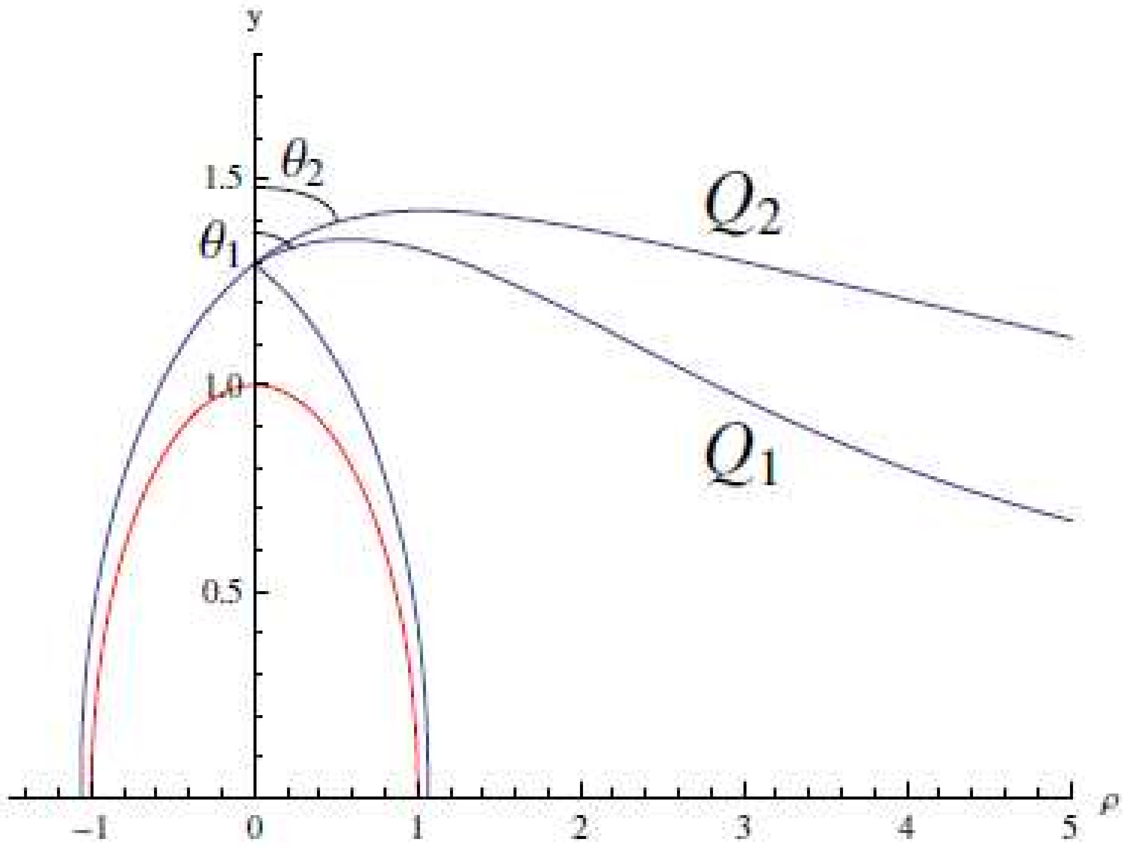
$$= -\tau_6 \int dt d\rho \rho^2 \omega_+^{4/3}\sqrt{\omega_+^{4/3}(1+\dot{y}^2) - \tilde{F}^2}$$



In holographic QCD, a compact D4 brane wrapping on the 4-sphere S^4 transverse to $\mathbb{R}^{1,3}$ is introduced as a baryon

- Dense D4/D6/D6 (N_f =2)



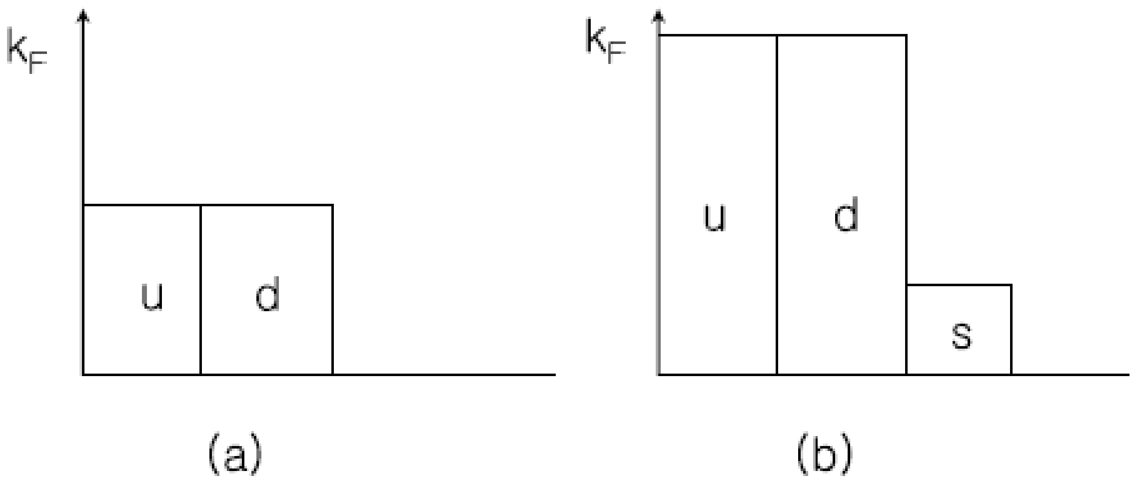


To make the system stable, following force balancing condition should be satisfied;

$$\frac{Q}{N_c} F_{D4} = F_{D6}^{(1)}(Q_1) + F_{D6}^{(2)}(Q_2),$$

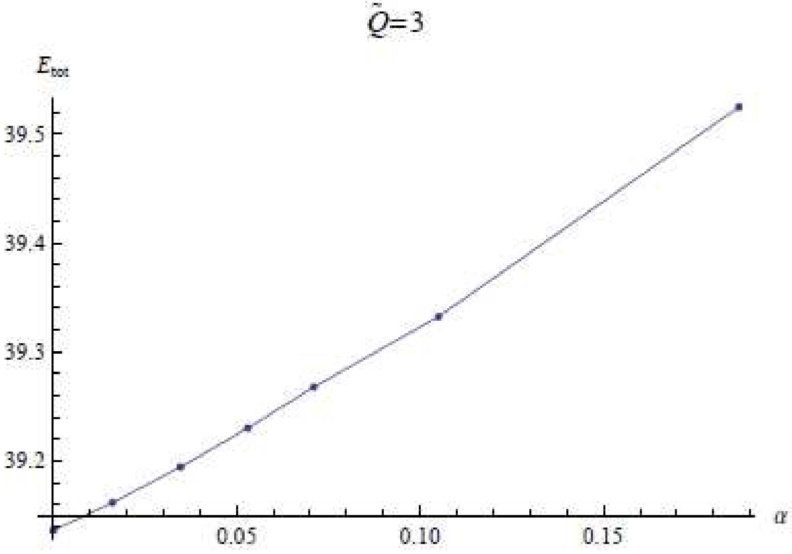
$$Q_1 = (1-\alpha)Q \text{ and } Q_2 = \alpha Q \text{ with } 0 \le \alpha \le 1$$

"Nuclear" matter to "strange" matter transition

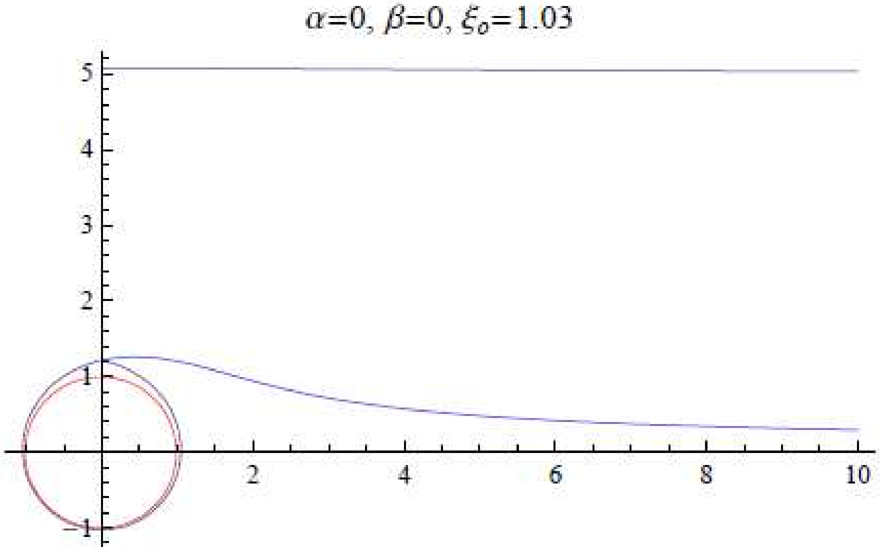


Schematic picture for the nuclear matter (a) to strange matter (b) transition.

$$E_{tot} = \frac{Q}{N_C}\mathcal{H}_{D4} + \mathcal{H}_{D6}(Q_1) + \mathcal{H}_{D6}(Q_2)$$
$$= \tau_6\left[\frac{\tilde{Q}}{4}E_4 + E_6(\tilde{Q}_1) + E_6(\tilde{Q}_2)\right],$$

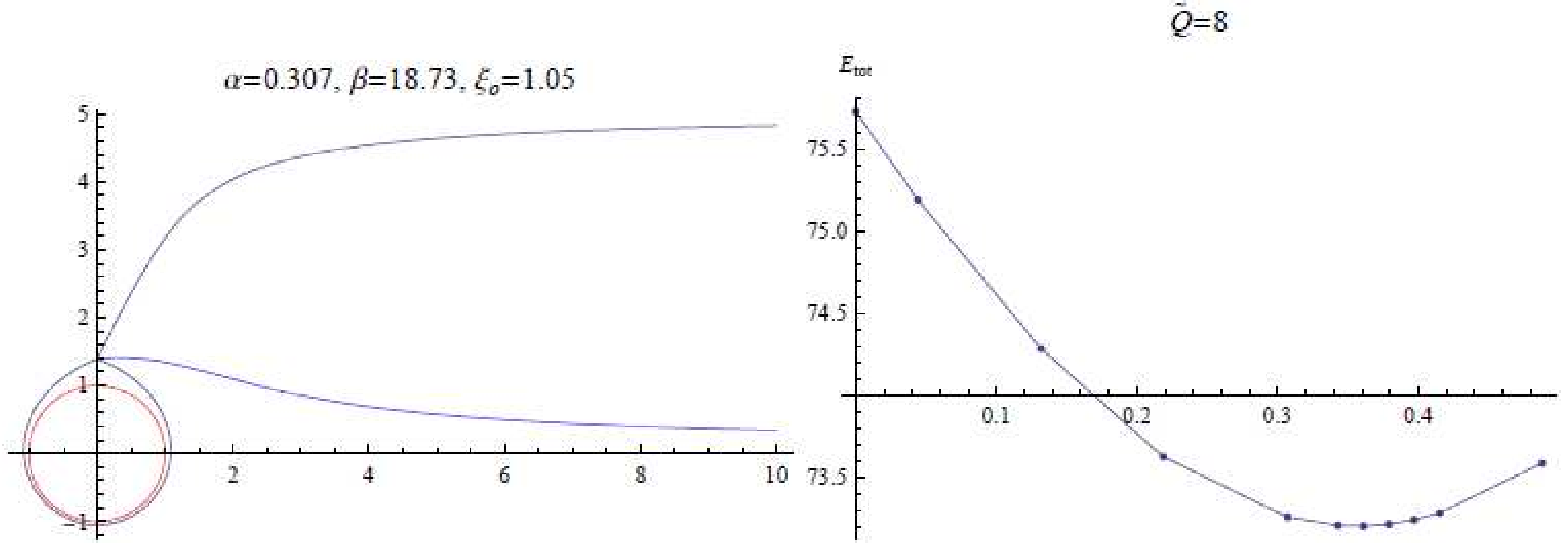


(a)



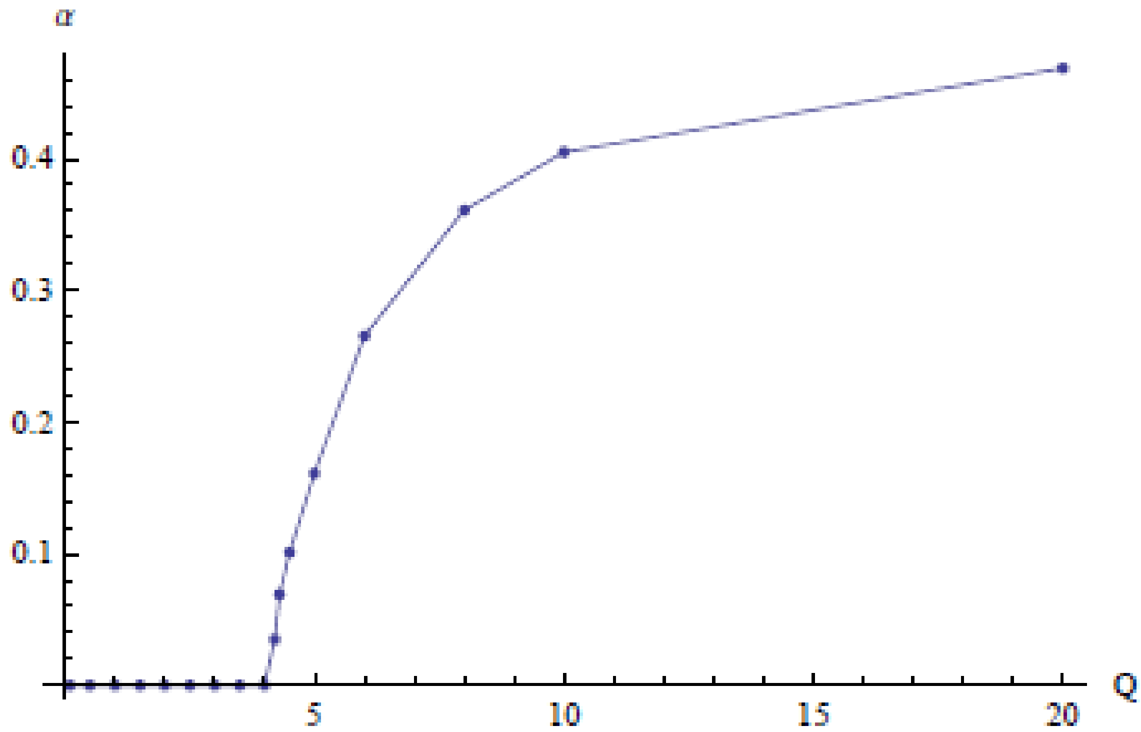
(b)

$m_1 = 0.1$ and $m_2 = 5$

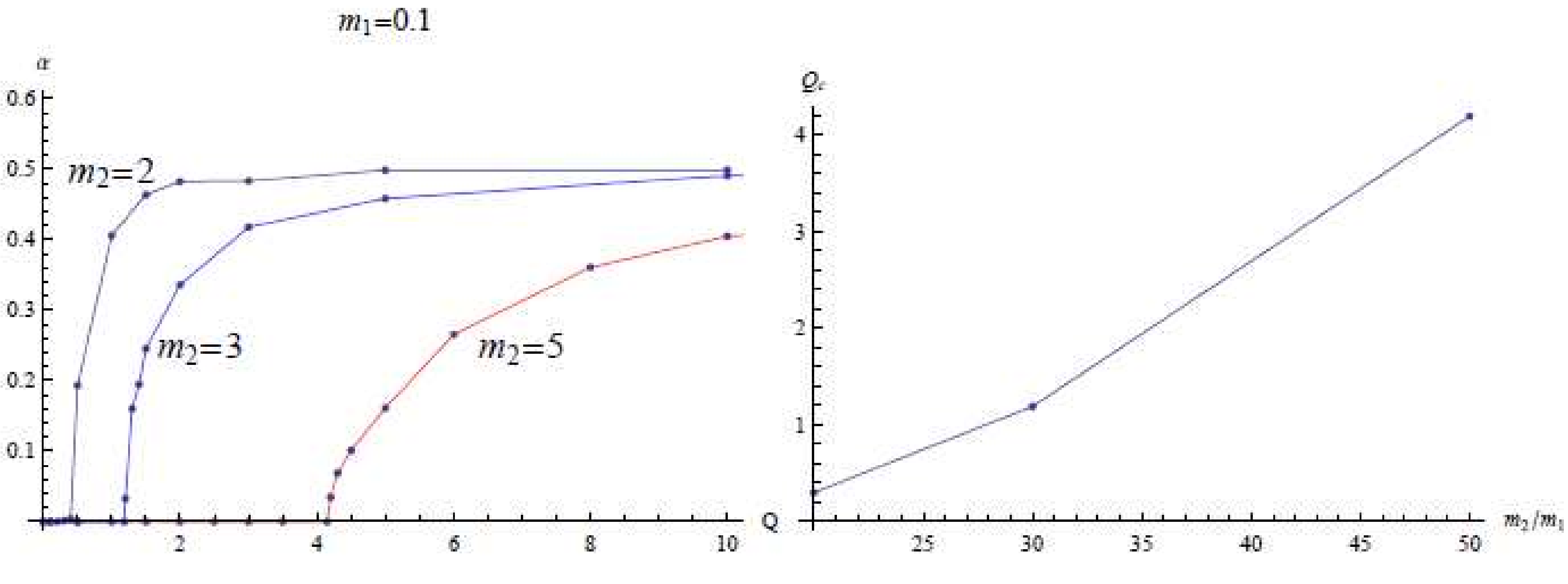


α=0.307, β=18.73, ξ_o=1.05
5
4
3
2
1
-1
2
4
6
8
10
Q̃=8
E_tot
75.5
75.0
74.5
73.5
0.1
0.2
0.3
0.4
α

(a) (b)



Y. Kim, Y. Seo, and S.-J. Sin, JHEP **1003**, 074 (2010)



(a) (b)

Y. Kim, Y. Seo, and S.-J. Sin, JHEP **1003**, 074 (2010)

“Nuclear” symmetry energy

$$m = Zm_p + Nm_n - \frac{E_B}{c^2}$$

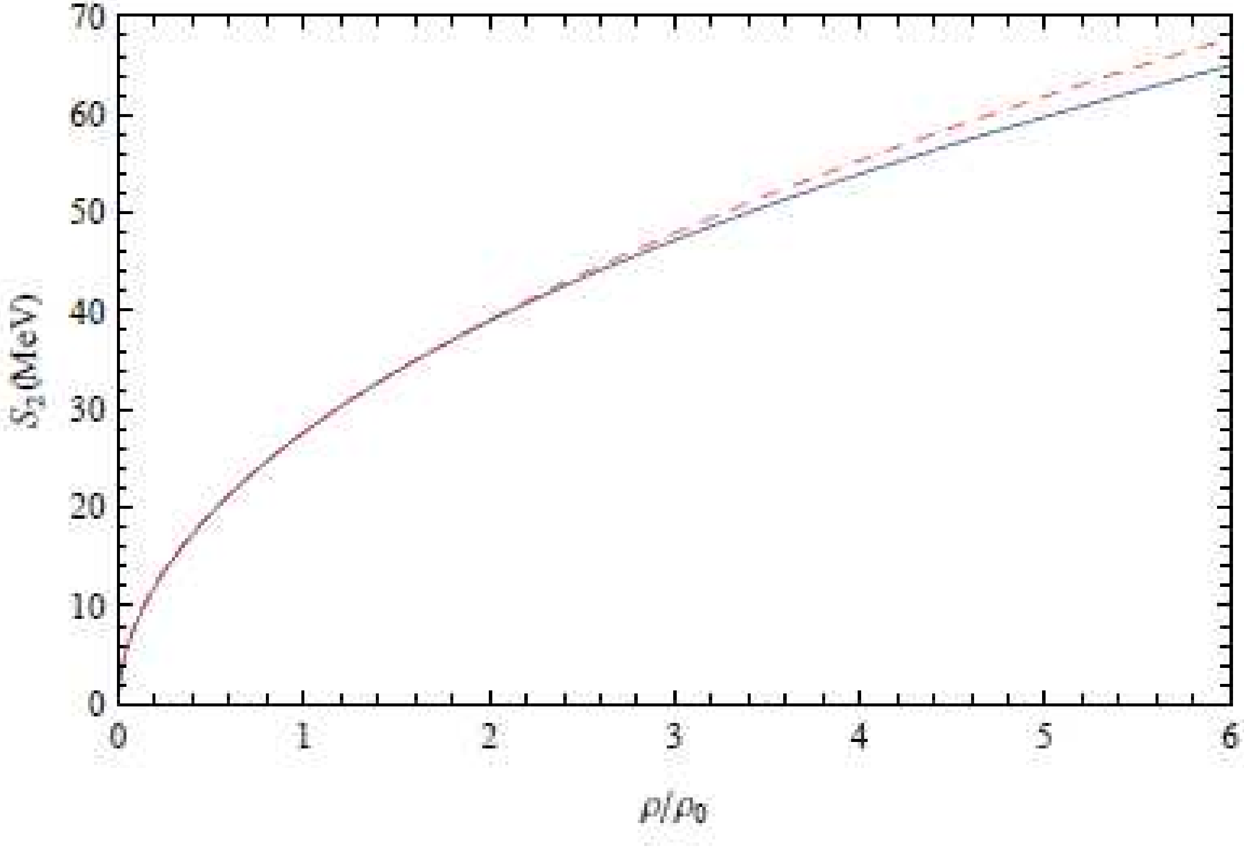
$$E_{\mathrm{B}} = a_{\mathrm{v}} A - a_a (N - Z)^2/A - a_c Z^2/A^{1/3} \\ - a_s A^{2/3} \pm a_\delta / A^{3/4}$$

$$E(\rho, \tilde{\alpha}) \simeq E(\rho, 0) + S_2(\rho)\tilde{\alpha}^2 ,$$

$$\tilde{\alpha} \equiv (N - Z)/A$$

Z (N) is the number of protons (neutrons) in a nucleus.

$$E_{tot} = \frac{Q}{N_C}\mathcal{H}_{D4} + \mathcal{H}_{D6}(Q_1) + \mathcal{H}_{D6}(Q_2)$$
$$= \tau_6 \left[\frac{\tilde{Q}}{4}E_4 + E_6(\tilde{Q}_1) + E_6(\tilde{Q}_2)\right],$$

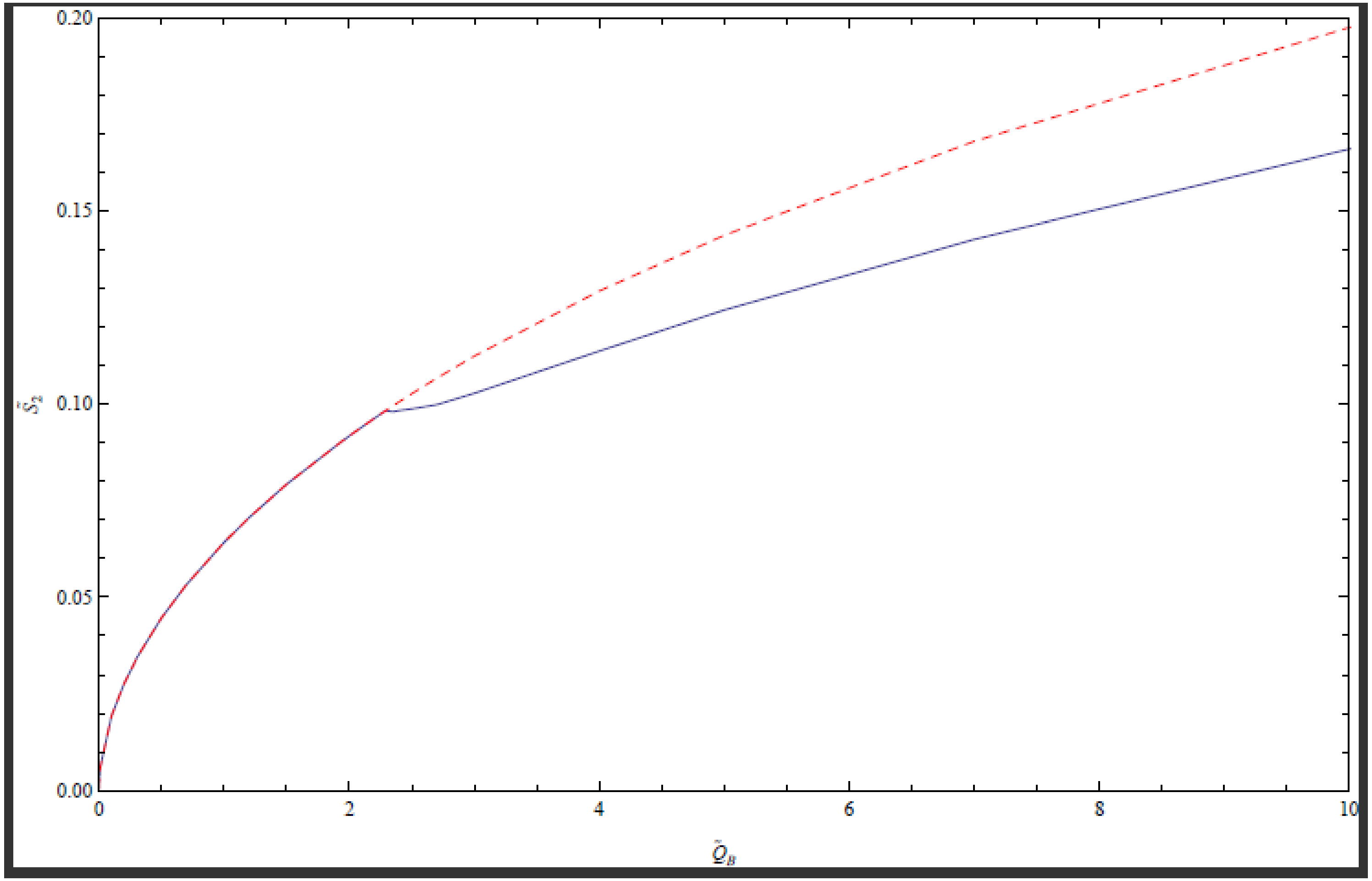


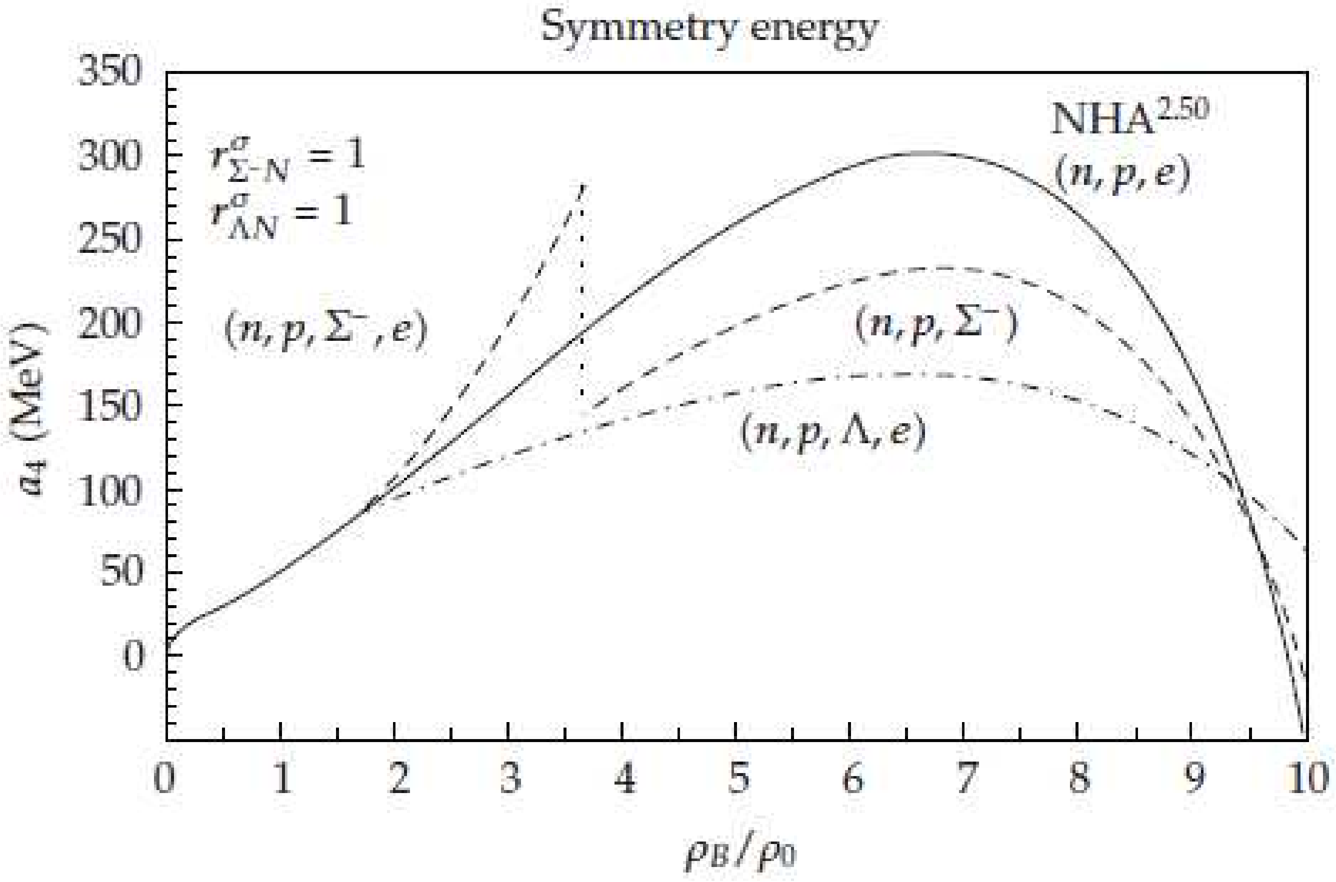
Y. Kim, Y. Seo, I. J. Shin, and S.-J. Sin, JHEP 1106:011,2011

Symmetry energy in hyperonic matter

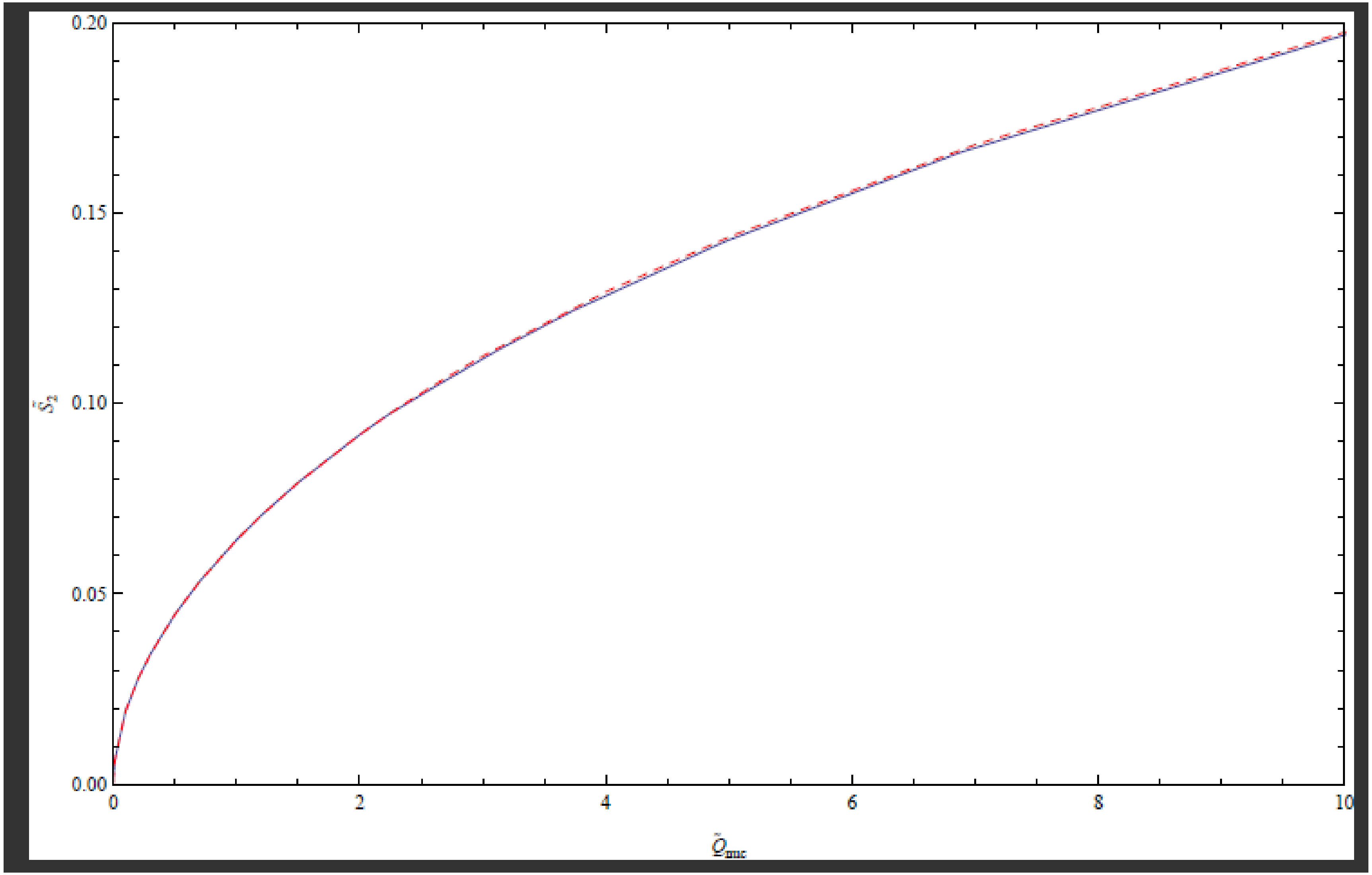
(yet without beta equilibrium and charge neutrality conditions)

YK, Y. Seo, I. J. Shin, and S.-J. Sin, in progress





Schun T. Uechi, and, Hiroshi Uechi,
Adv.High Energy Phys.2009:640919,2009.



0.20
0.15
0.10
0.05
0.00
$\tilde{S}_2$
0
2
4
6
8
10
$\tilde{Q}_{mc}$

Compact stars

- What do EoSs from some hQCd models say about our nature?
- Mass-radius relation of a neutron star, which is rather insensitive to its crust structure, might be a good testing ground.

- Tolman-Oppenheimer-Volkoff equation

$$\frac{dp}{dr} = -\frac{1}{2}(\epsilon + p)\frac{2m + 8\pi r^3 p}{r(r-2m)},$$

$$m(r) \equiv 4\pi \int_0^r \epsilon(r')r'^2 dr'$$

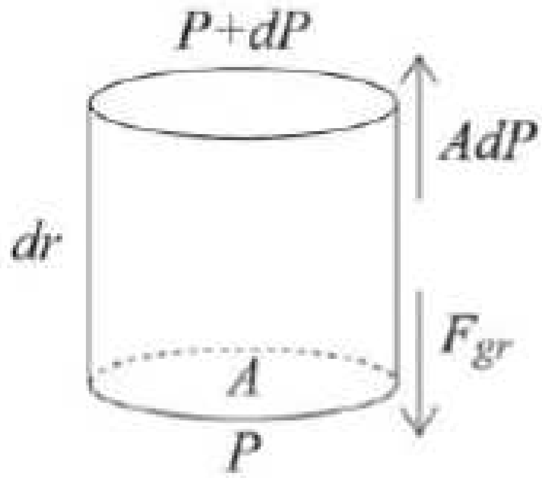
ϵ is given by $\epsilon \equiv (E/A + m_b)\rho$, where E/A is the energy per baryon

Once the energy density and pressure are given, one can find a star with mass M and radius R from pressure-zero condition at the surface.

$$-\frac{GM(r)dm}{r^2} - AdP = 0.$$

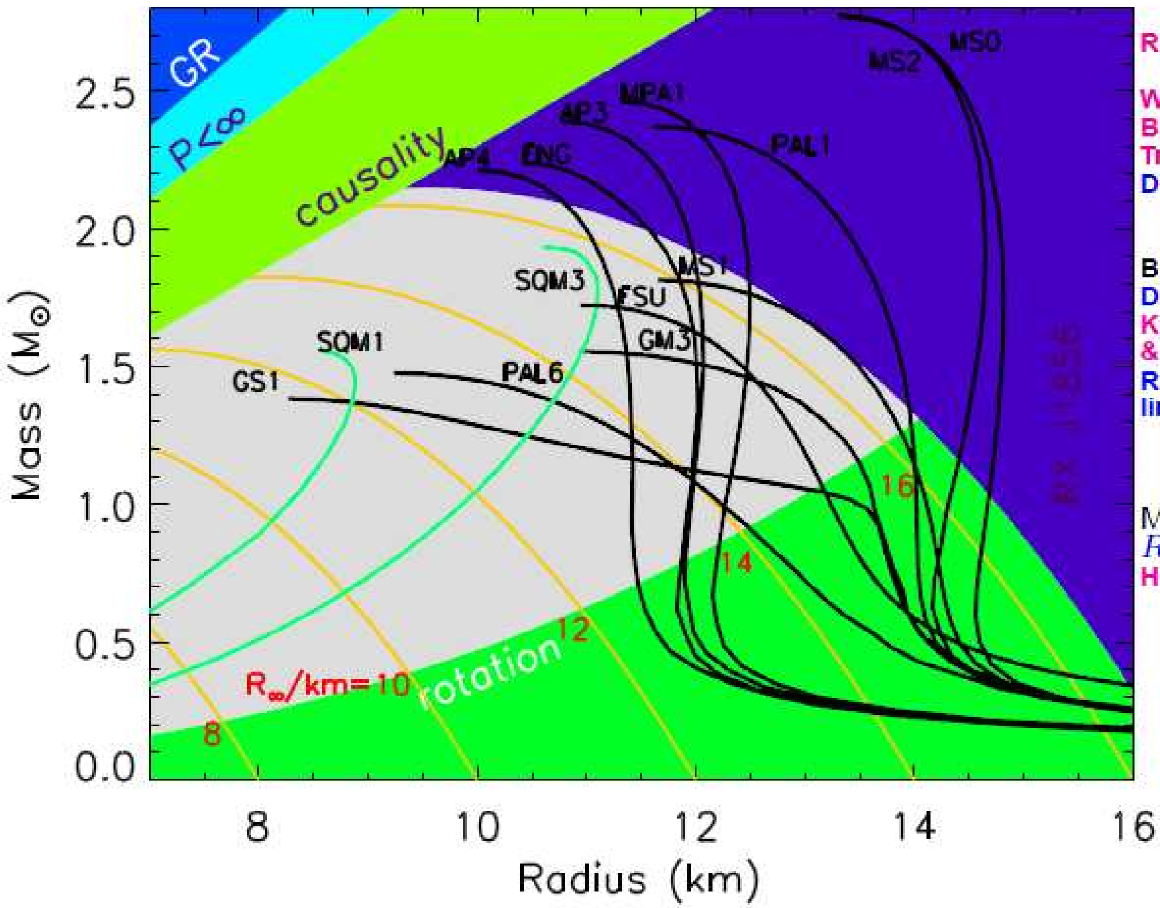
$$dm = \rho(r)Adr$$

$$\frac{dP(r)}{dr} = -\frac{GM(r)\rho(r)}{r^2}.$$



Hydrostatic equilibrium, non-relativistic case

Radiation Radius: Nearby Neutron Star



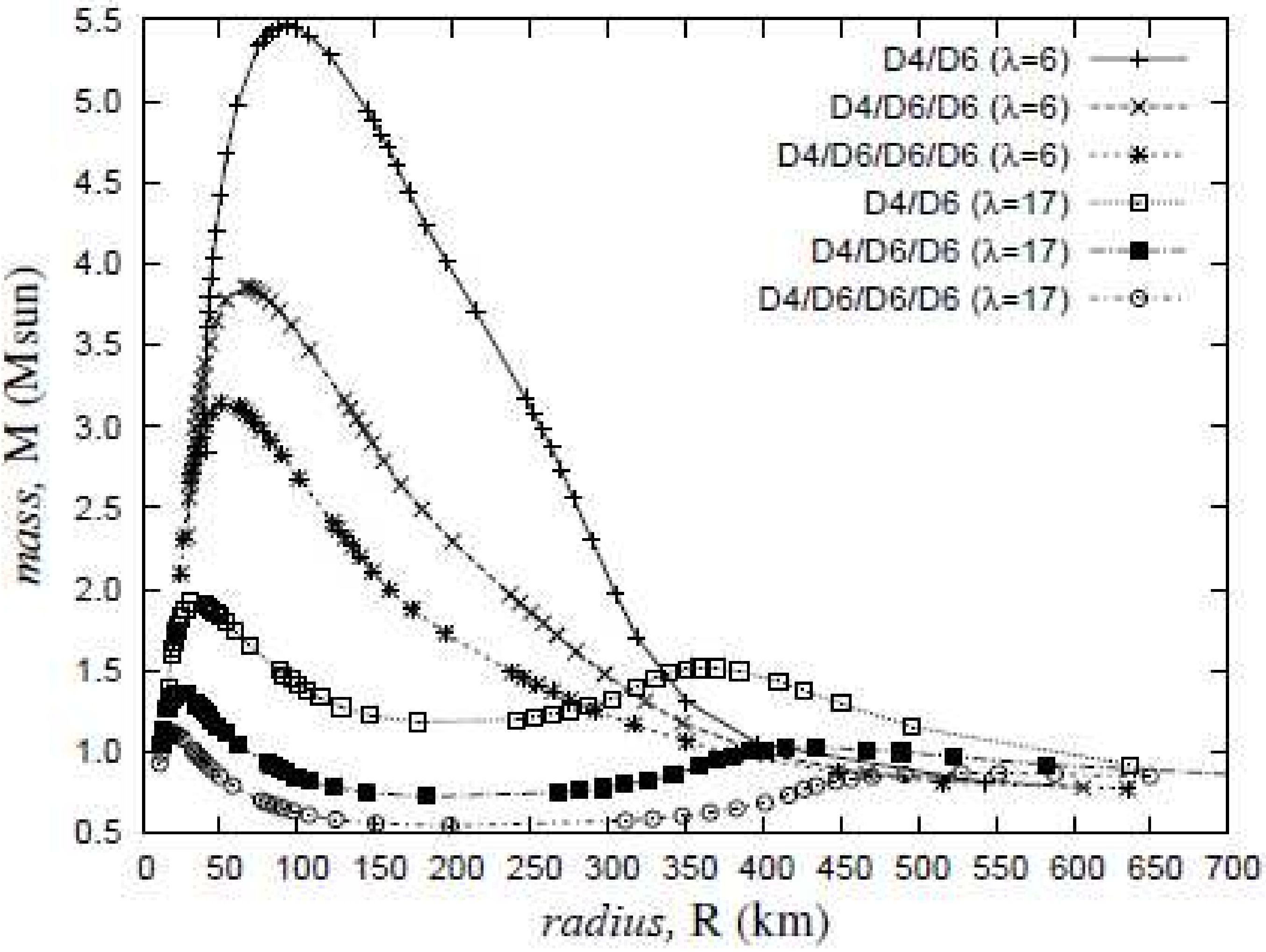
RX J1856-3754:

Walter & Lattimer 2002
Braje & Romani 2002
Truemper 2005
D=120 pc

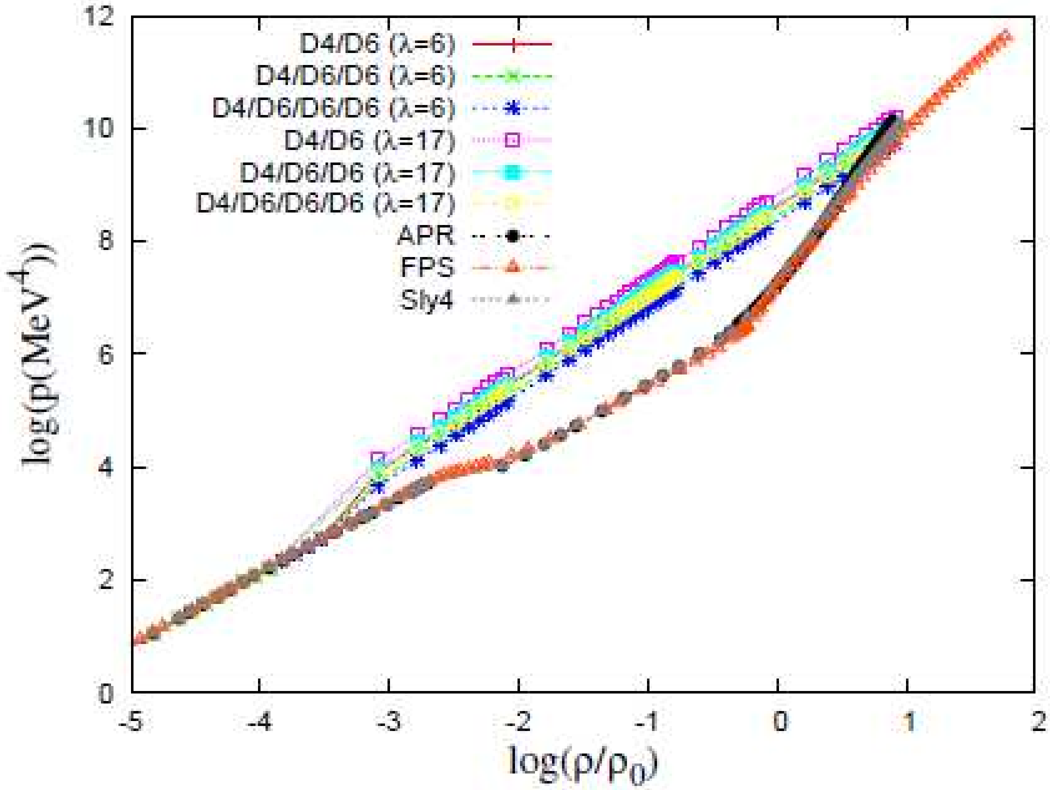
BUT
D=140 pc
Kaplan, van Kerkwijk
& Anderson 2002
Raises R_∞
limit to 19.5 km

Magnetic H atmospher
$R_\infty \approx 17$ km
Ho et al. 2007

YK, Chang-Hwan Lee, Ik Jae Shin, Mew-Bing Wan, JHEP 1110:11,2011



Lack of attraction? non-Abelian chiral symmetry? Fermi sea?



Comparison of the pressure from D4/D6 models with those from a few typical EoSs

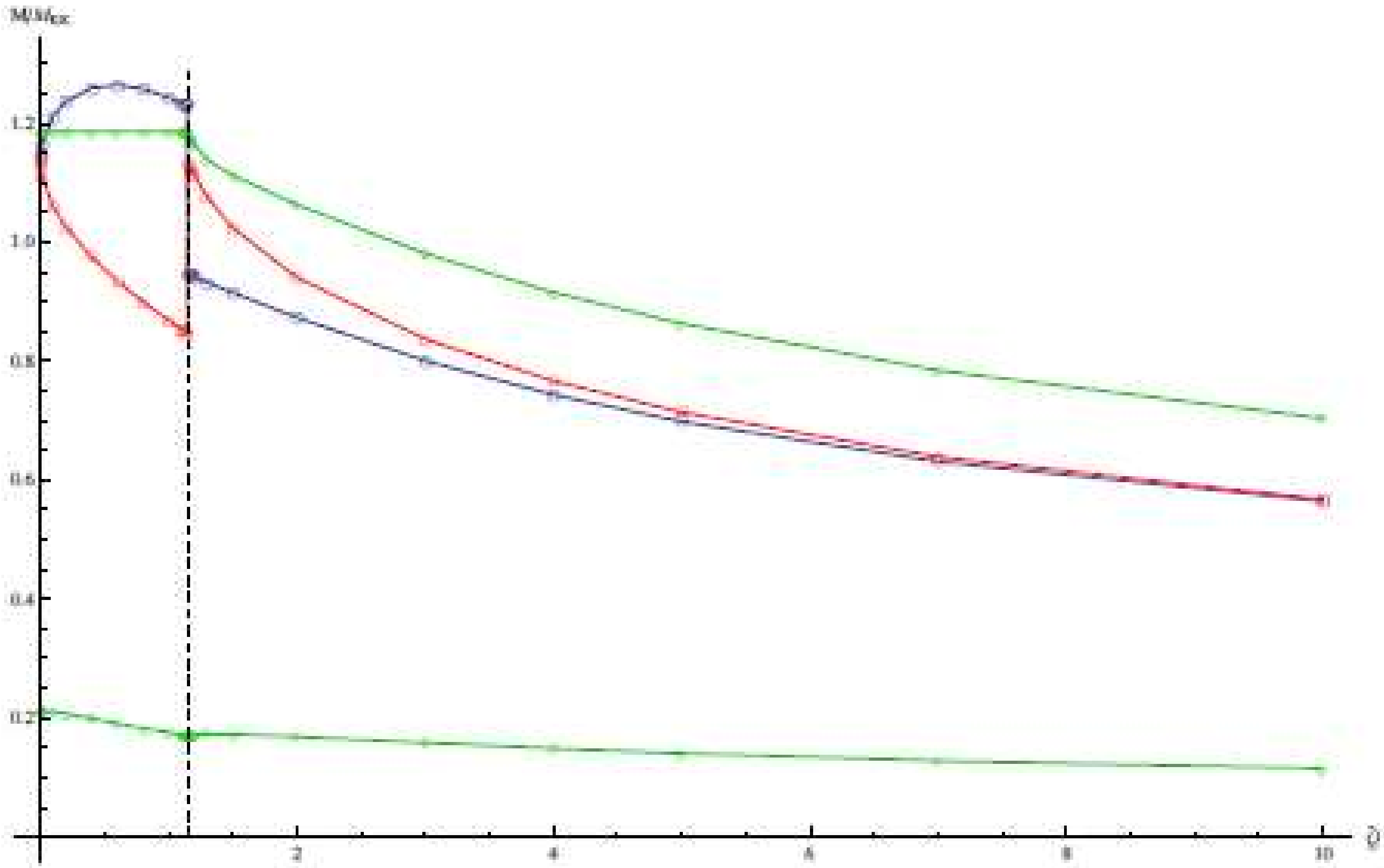
Meson mass splitting in asymmetric dense matter

At small (negative) isospin chemical potential μ_I with zero isospin number density, the mass of the pion is given by

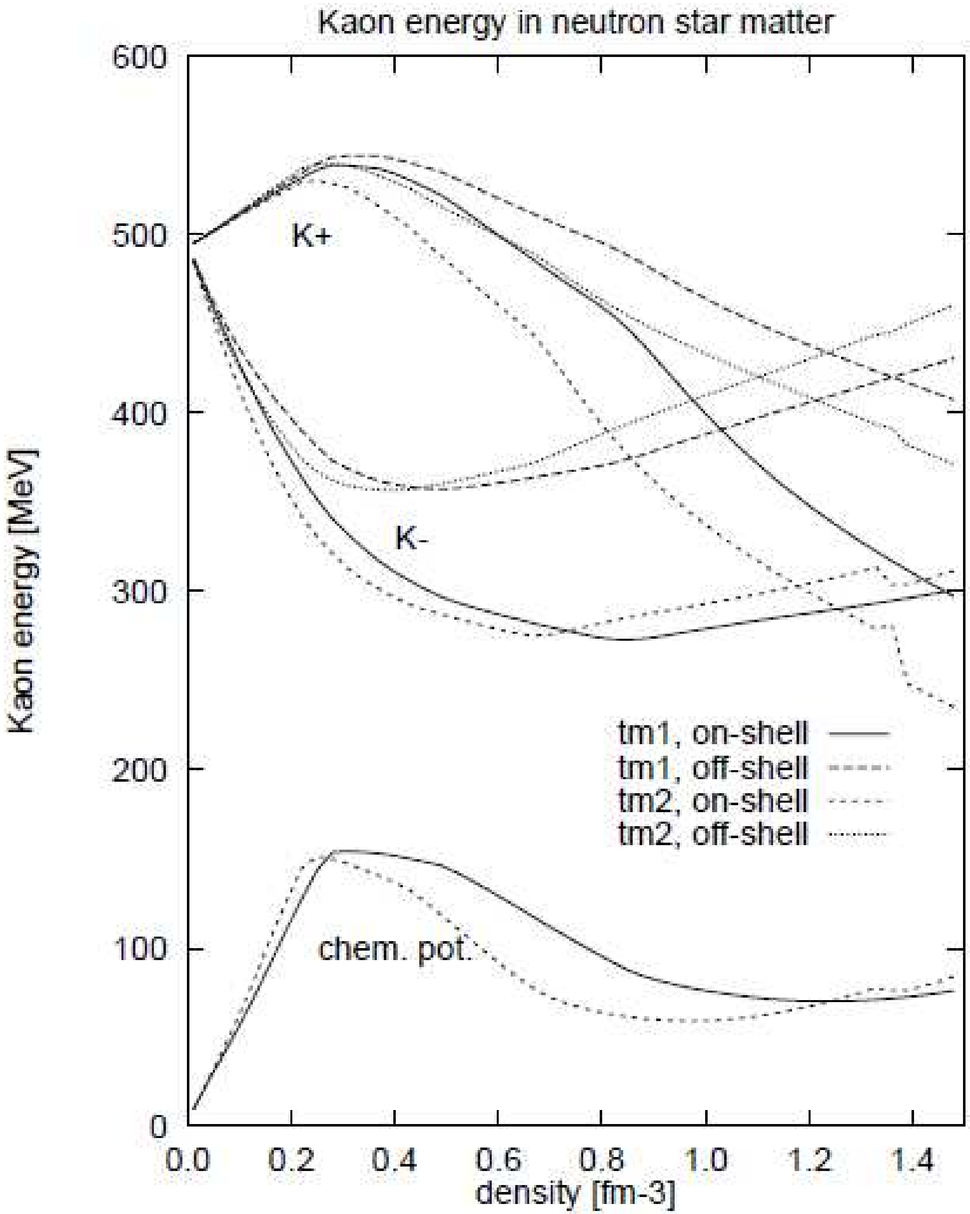
$$m_{\pi^\pm} = m_{\pi^0} + q|\mu_I|\,,$$

where q is the isospin charge of the particle.

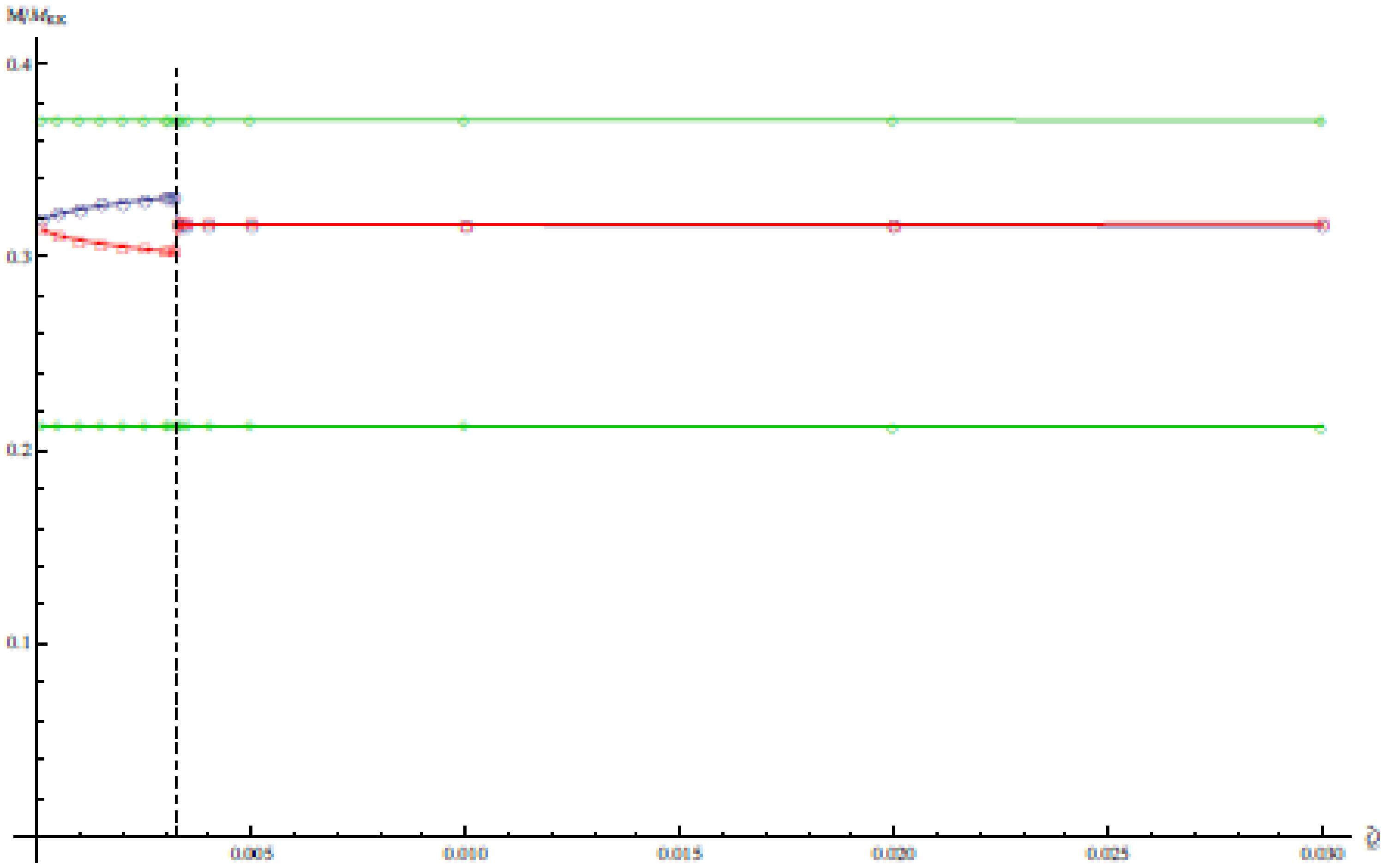
$$\begin{pmatrix} \varphi_+ & \varphi 12 \\ \varphi 21 & \varphi_- \end{pmatrix}$$



For $m^+/m^- = 30$



Jurgen Schaffner and Igor N. Mishustin, Phys. Rev. C53:1416-1429,1996.



For $m^+/m^- = 3$

Y. Kim, Y. Seo, I. J. Shin, and S.-J. Sin, arXiv:1108.2751 [hep-ph]

Remark

- If non-Abelian chiral symmetry is not essential for dense matter, D4/D6 models could be a good tool for dense nuclear matter, especially for isospin physics.
- Still long way to go for nuclear matter: Fermi sea? Intermediate attraction? 1/N corrections?