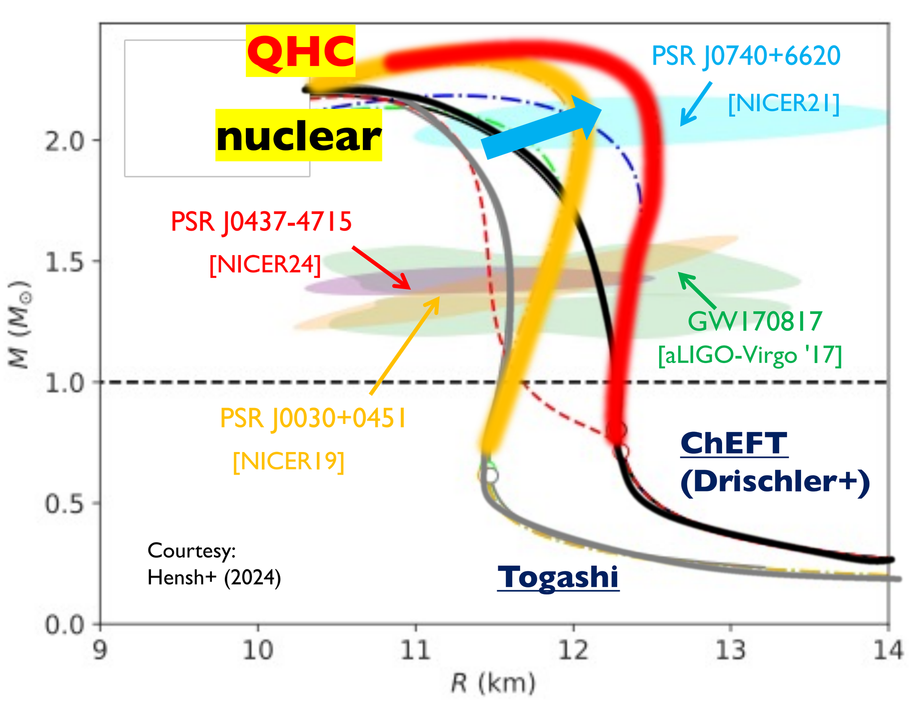
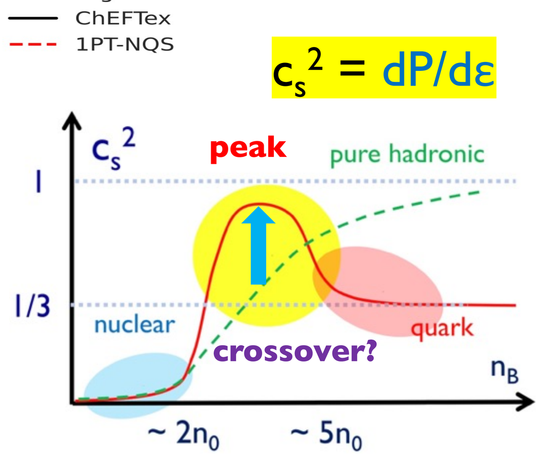
A quarkyonic matter model

Toru Kojo (KEK), Yuki Fujimoto (iTHEMS), Larry McLerran (INT)

Summary: *Quark saturation* drives rapid stiffening of EOS at ~2-3n_{sat}. It also suppresses the hyperon production in dense matter with a shift "$\mu_B^{onset} = M_Y \Rightarrow 2M_Y - M_N$". The new onset density is large, $n_B^{Y,\Xi\text{-onset}} \sim 6n_0$, even before NY repulsions are included.

Soft-to-stiff EOS: rapid evolution of pressure



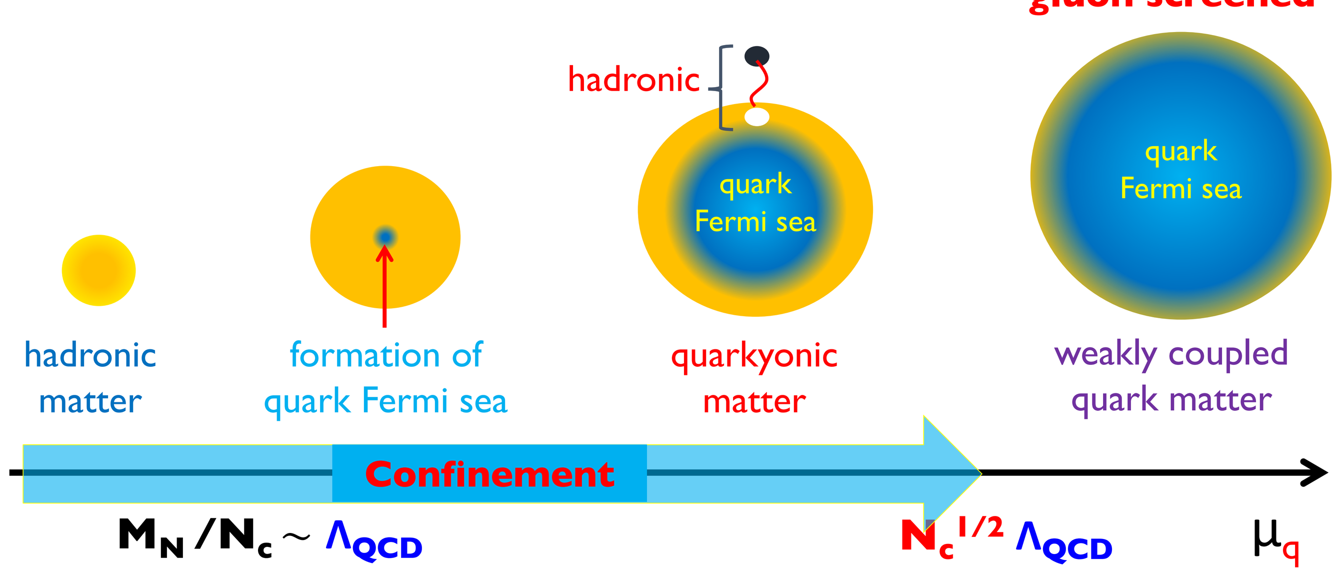


[predicted in Masuda+'12, TK+'14,..]

Evolution from nuclear to quark matter

[McLerran-Pisarski '07]

Quarkyonic matter picture on confinement



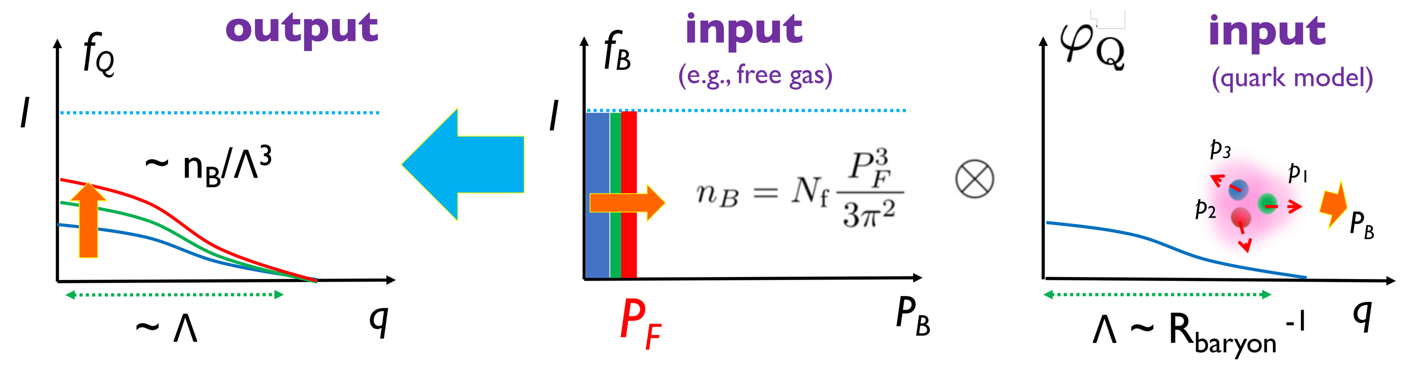
Sum rules for occupation probabilities

cf) [TK '21]

occupation probability of quark state with p | occupation probability of baryon state with P_B | quark mom. distribution in a baryon

$$f_Q(\mathbf{q}) = \int_{\mathbf{P}_B} f_B(\mathbf{P}_B)\,\varphi_Q^B(\mathbf{q} - \mathbf{P}_B/N_c)$$

e.g.) in ideal baryonic matter



An ideal model (IdylliQ model)

[Fujimoto-TK-McLerran, PRL'24]

1) neglect interactions *except* confining forces

e.g.) 2-flavor hamiltonian: $\varepsilon_B[f_B] = 4\int_k E_B(k) f_B(k)$ $\quad E_B(k) = \sqrt{M_B^2 + k^2}$

2) keep using the same φ_Q (quarkyonic; quarks always confined)

3) use a special quark distribution → sum rules analytically *invertible*

$$\varphi_{3d}(\mathbf{q}) = \frac{2\pi^2}{\Lambda^3}\frac{e^{-q/\Lambda}}{q/\Lambda} \qquad \hat{L} = -\nabla^2 + \frac{1}{\Lambda^2} \qquad \hat{L}[\varphi(\mathbf{p}-\mathbf{q})] = \frac{(2\pi)^3}{\Lambda^2}\delta(\mathbf{p}-\mathbf{q})$$

nontrivial output $\qquad$ nontrivial output

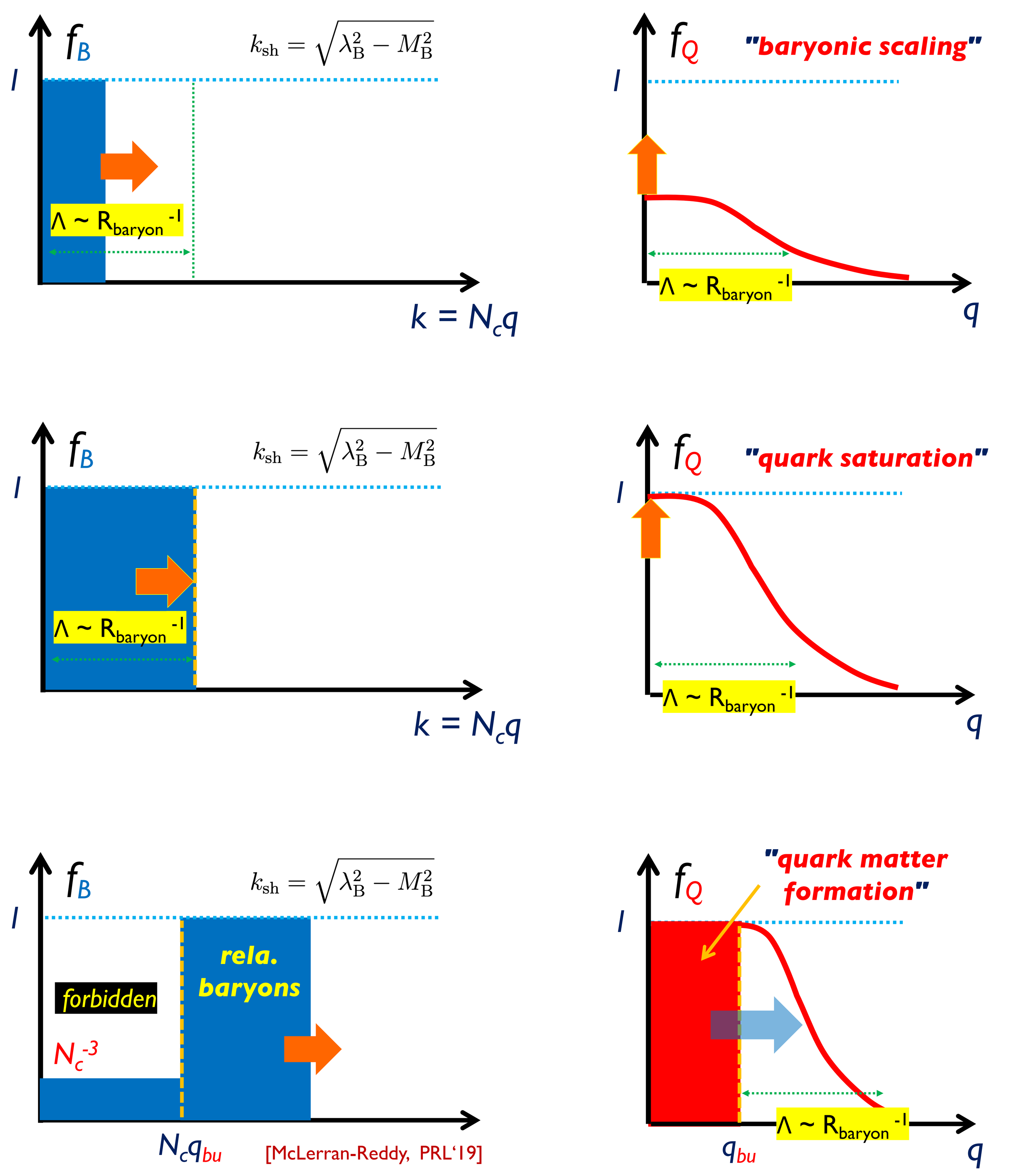
$$f_Q(\mathbf{q}) = \int_{\mathbf{P}_B} f_B(\mathbf{P}_B)\varphi_Q^B(\mathbf{q} - \mathbf{P}_B/N_c) \quad \rightleftarrows \quad f_B(N_c\mathbf{q}) = \frac{\Lambda^2}{N_c^3}\hat{L}[f_Q(\mathbf{q})]$$

natural at low density $\qquad$ natural at high density

Quark saturation, quark matter formation, and stiffening

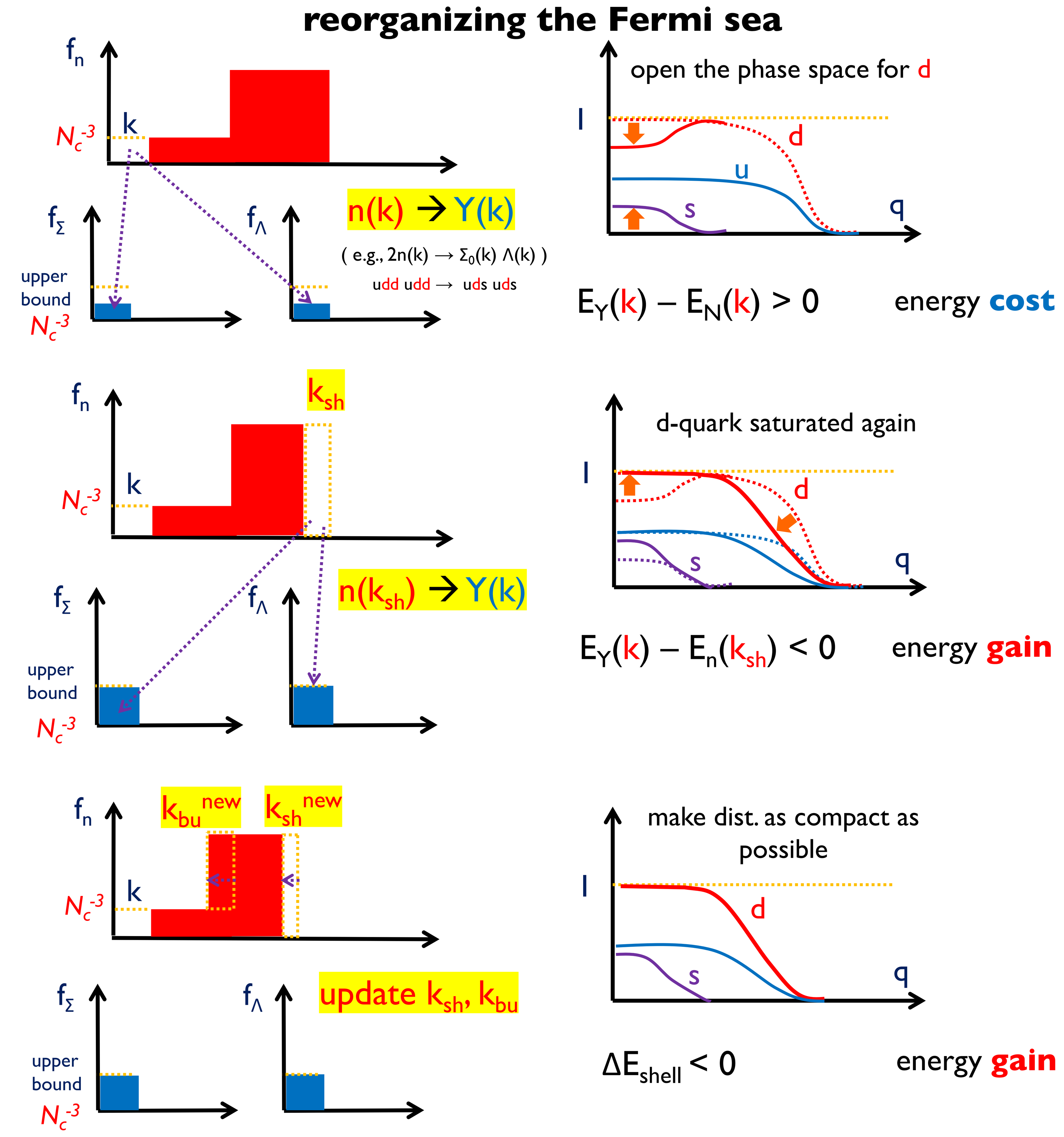
isospin symmetric matter

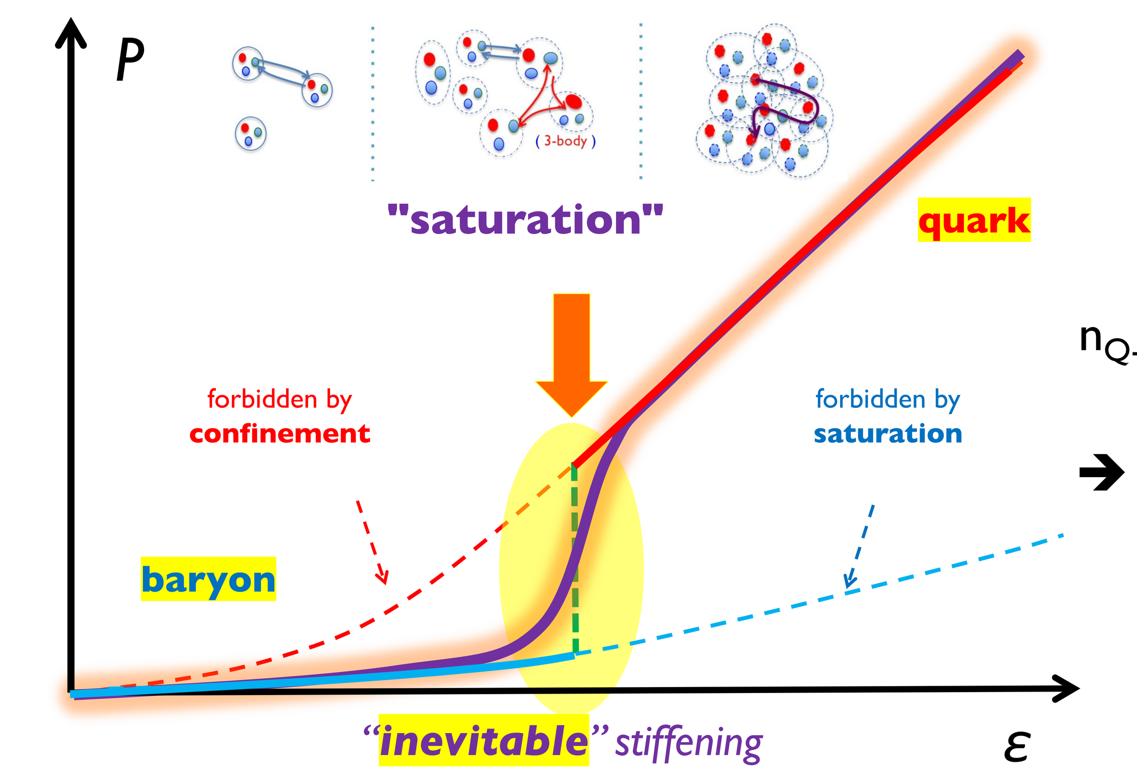
Density evolution



with hyperons (S=-1)

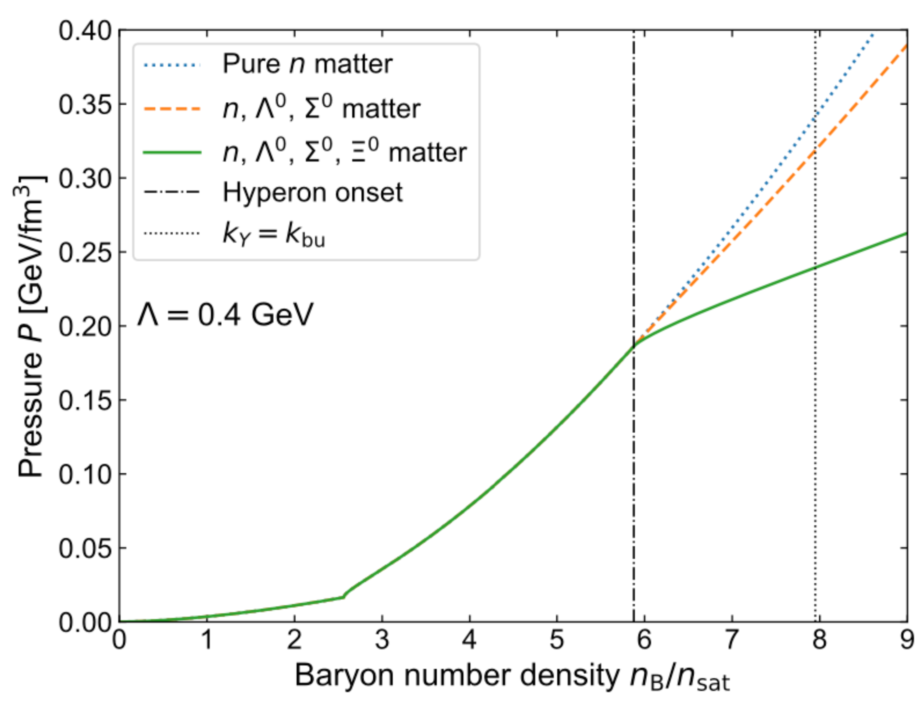
reorganizing the Fermi sea





$n_{Q\text{-sat}} \sim 0.5\, n_{overlap}$

→ $n_{Q\text{-sat}} \sim 2\text{-}3n_0$



Total change in energy :

$$\Delta E_{tot}(k) = 2E_Y(k) - E_N(k) - E_N(k_{sh}) + \Delta E_{shell}$$

$(= -\mu_n = -\mu_B)$

$\Delta E_{tot}(k=0) = 0$

→ $\mu_B^{onset} = 2M_Y - M_N$

$n_B^{Y,\Xi\text{-onset}} \sim 6n_0$