Isospin asymmetry in perspective of QCD symmetry breaking

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Outline

I. **QCD symmetry breaking**

II. Hadron phase – QCD sum rules
- Symmetry energy
- Nucleon and hyperons
- Delta resonances

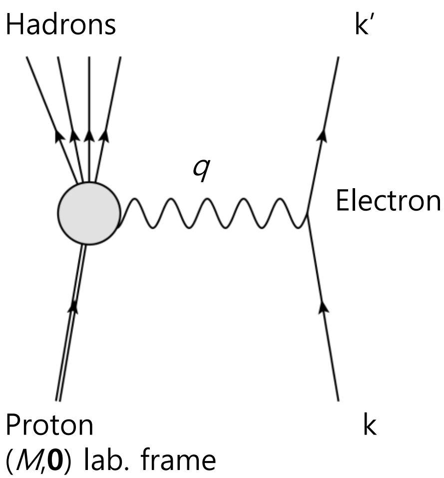
III. Another pairing in cold dense limit
- 2-color superconductivity

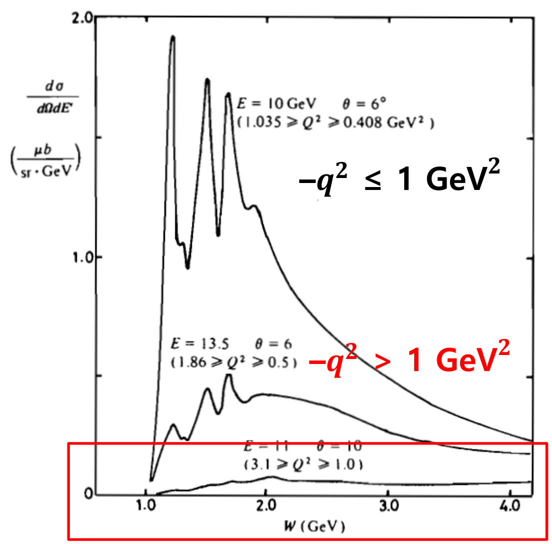
Parton in hadron

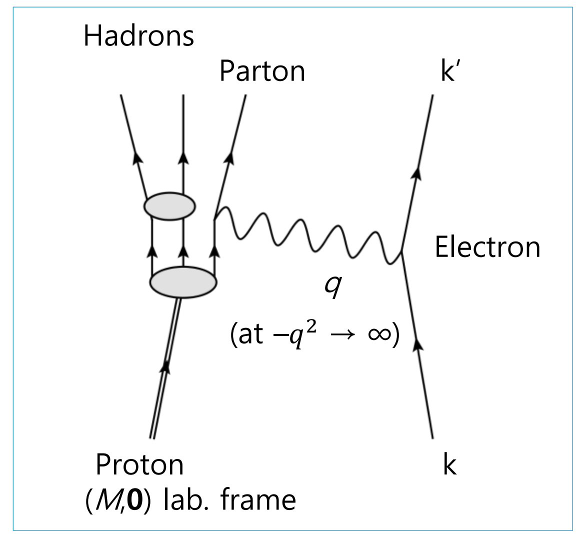
- **Proton** is not a point-like particle

Inelastic scattering: **ep** → **e** + **hadrons**

$$\frac{d\sigma}{d\Omega dE'} = \left(\frac{d\sigma}{d\Omega}\right)_M \left[2W_1(\nu,-q^2)\tan^2\frac{\theta}{2} + W_2(\nu,-q^2)\right] \Big/ 2M$$







In Bjorken limit (large-momentum transferred region), there are no resonances
→ the scattering can be approximated by point-like free particles (parton)

OPE (at $-q^2 \to \infty$, $-q^2/(2M(k'_0 - k_0)) = \xi$) reproduces Bjorken scaling
→ quantum number of hadron can be interpolated with explicit quark current in QCD

QCD symmetry breaking

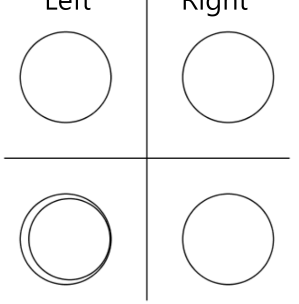
- Classical symmetry

$$\mathcal{L}_{\mathrm{E}}^{\mathrm{QCD}} = \frac{1}{2}\mathrm{Tr}[F^{\mu\nu}F_{\mu\nu}] + \sum_i \bar{q}_i \not{D} q_i + \mathcal{L}_{\mathrm{ghost}} + \mathcal{L}_{\mathrm{g.f.}} + \cdots \qquad \mathrm{U}(1) \times \underbrace{\mathrm{SU}(2)_L \times \mathrm{SU}(2)_R}_{\text{flavor}} \times \underbrace{\mathrm{SU}(3)}_{\text{color}}$$

- After quantum correction

$$\mathcal{L}_{\mathrm{E}}^{\mathrm{QCD}} = \frac{1}{2}\mathrm{Tr}[F^{\mu\nu}F_{\mu\nu}] + \sum_i \bar{q}_i \not{D} q_i + \mathcal{L}_{\mathrm{ghost}} + \mathcal{L}_{\mathrm{g.f.}} + \frac{ig^2}{8\pi^2}\mathrm{Tr}[F^{\mu\nu}\tilde{F}_{\mu\nu}]\theta + \cdots$$

$$\partial^\mu j^a_{5\mu} = \partial^\mu(\bar{q}\gamma_5\gamma_\mu\tau^a q) = \frac{g^2}{8\pi^2}\mathrm{Tr}[F^{\mu\nu}\tilde{F}_{\mu\nu}] \equiv \boxed{\nu = n_L - n_R} \quad \left(\tilde{F}_{\mu\nu} \equiv \frac{\epsilon_{\mu\nu\alpha\beta}}{2!}F^{\alpha\beta} \right)$$



Axial charge is not conserved

For ν=1 configuration, classical solution (instanton) can be found as

$$A_\mu^{\mathrm{inst.}a}(x) = \frac{2}{g}\frac{\eta_{a\mu\nu}(x-x_0)^\nu}{(x-x_0)^2+\lambda^2}, \quad \mathrm{O}(4) \simeq \mathrm{SU}(2) \times \mathrm{SU}(2) \;\rightarrow\; \text{trapped color already breaks symmetry}$$

which resides in closed Wilson loop $\exp \oint_c dx^\mu A_\mu(x)$, $F^{\mu\nu} = 0$ (zero curvature on the contour)

(Belavin, Polyakov, Schwartz, Tyupkin, PLB59(1975)85)

QCD symmetry breaking

- Fermionic zero-modes in **ν>0** configuration

$i\not{D}_{\text{inst.}} q = 0$, $(i\not{D}_{\text{inst.}})^2 q = 0$

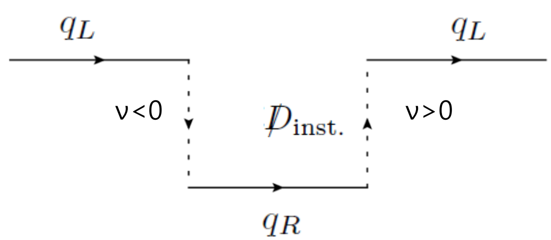
$(i\not{D}_{\text{inst.}})^2 q = 0$ leads $\left(-D^2_{\text{inst.}} + \frac{1}{2}\sigma_{\mu\nu}F^{\mu\nu}_{\text{inst.}}\right) q_L = 0$ and $-D^2_{\text{inst.}} q_R = 0$ ($-D^2_{\text{inst.}} > 0$)

different topological configuration measures different axial charge

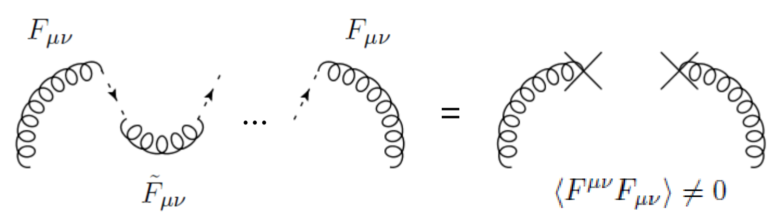
- *Θ* vacuum

$\mathcal{Z}_\theta = \sum_\nu \exp\left[-\int d^4x_E \mathcal{L}^{\text{QCD}}_{\text{E},\nu}\right]$ → all possible topological configuration contributes

helicity bases can be correlated via Instantons



$\Rightarrow$ $\langle \bar{q}q \rangle \neq 0$



For a given gauge configuration $\langle \bar{q}q \rangle \neq 0$ breaks chiral symmetry

$\mathrm{U}_V(1)\times$ ~~$\mathrm{U}_A(1)$~~ $\times\mathrm{SU}(2)_V\times$ ~~$\mathrm{SU}(2)_A$~~ $\times\mathrm{SU}(3)$ flavor color

hadron property can be described via the symmetry breaking pattern

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II. Hadron phase – QCD sum rules

- **Nucleon and symmetry energy**
- **Hyperons**
- **Delta resonances**

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QCD Sum Rules - overview

- Correlator for baryon current

$$\Pi(q) \equiv i \int d^4x \; e^{iqx} \langle \Psi_0 | \mathrm{T}[\eta(x)\bar{\eta}(0)] | \Psi_0 \rangle$$
$$= \Pi_s(q^2, q \cdot u) + \Pi_q(q^2, q \cdot u)\not{q} + \Pi_u(q^2, q \cdot u)\not{u}$$

Correlation of the quantum number contained in **η**
q stands for external momentum
u stands for medium velocity → (1,**0**) in rest frame

- Energy dispersion relation and OPE (in **QCD degree of freedom**)

$$\Pi_i(q_0, |\vec{q}|) = \frac{1}{2\pi i} \int_{-\infty}^{\infty} d\omega \frac{\Delta \Pi_i(\omega, |\vec{q}|)}{\omega - q_0} + \text{polynomials},$$

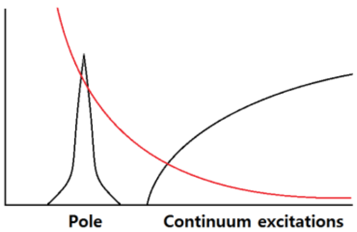
- Phenomenological Ansatz (in **hadronic degree of freedom**)

$$\Pi(q_0, |\vec{q}|) \sim \frac{1}{(q^\mu - \tilde{\Sigma}_v^\mu)\gamma_\mu - M_N^*}$$

Mean-field type pole structure is adopted

- Weighting - Borel transformation

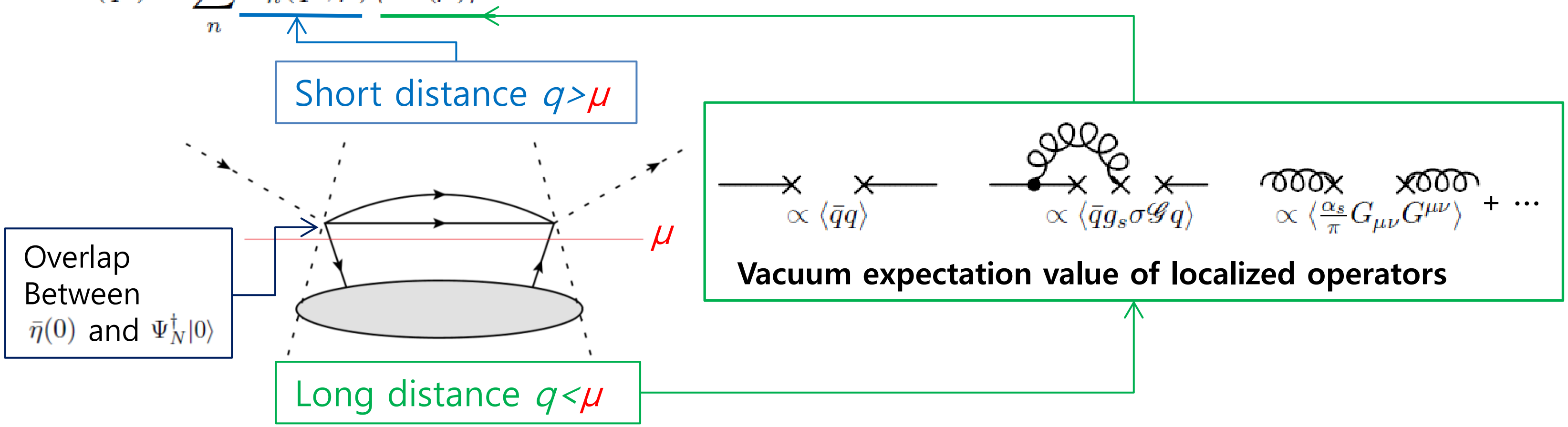
$$\mathcal{B}[\Pi_i(q_0, |\vec{q}|)] \equiv \lim_{\substack{-q_0^2, n \to \infty \\ -q_0^2/n = M^2}} \frac{(-q_0^2)^{n+1}}{n!} \left(\frac{\partial}{\partial q_0^2} \right)^n \Pi_i(q_0, |\vec{q}|)$$



QCD SR - operator product expansion

- Operator product expansion (Example: 2-quark condensate diagram)

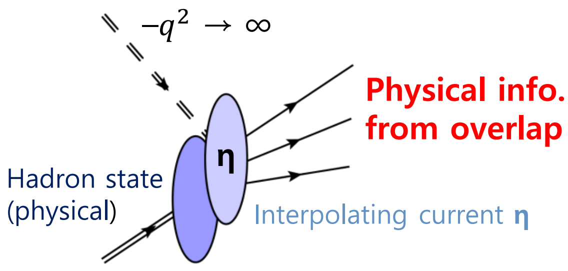
$$\Pi_i(q^2) = \sum_n C_n^i(q^2, \mu)\langle \hat{O}_n(\mu)\rangle_0$$



- Separation scale is set to be hadronic scale (≤ 1 GeV)
  - **Wilson coefficient** contains perturbative contribution above separation scale – short-ranged partonic propagation in hadron
  - **Condensate** contains non-perturbative contribution below separation scale – long ranged correlation in low energy part of hadron
  - Quark confinement inside hadron is low energy QCD phenomenon
  - Genuine properties of hadron are reflected in **the condensates**

Interpolating current for baryons

- To obtain physical information



a. Quasi-particle state will be extracted from the overlap
b. We need to construct proper interpolating current which can be strongly overlapped with object hadron state
c. Our object: **N**, **P**, **Λ**, **Σ**, and **Δ resonances**

- Constructing **proton** current

Required quantum number: $\boldsymbol{I = 1/2,\ J^P = (1/2)^+}$

Simplest structure: **[$I = 0, J = 0$ di-quark structure] X [single quark with $I = 1/2,\ J = 1/2$]**

Di-quark structure: $\epsilon_{abc}(u_a^T C\gamma_5 d_b)$, $\epsilon_{abc}(u_a^T C d_b)$ ***u*** and ***d*** flavor in antisymmetric combination

Positive parity matching: $\eta_1 = \epsilon_{abc}(u_a^T C d_b)\gamma_5 u_c$, $\eta_2 = \epsilon_{abc}(u_a^T C\gamma_5 d_b)u_c$

$$\eta_{p(t)} = 2\epsilon_{abc}\left([u_a^T C d_b]\gamma_5 u_c + t[u_a^T C\gamma_5 d_b]u_c\right)$$
$$= \left(\frac{1-t}{2}\right)\epsilon_{abc}[u_a^T C\gamma_\mu u_b]\gamma_5\gamma^\mu d_c + \left(\frac{1+t}{4}\right)\epsilon_{abc}[u_a^T C\sigma_{\mu\nu} u_b]\gamma_5\sigma^{\mu\nu} d_c$$

Ioffe's choice (t=-1) → chiral order parameter $\langle\bar{q}q\rangle \neq 0$ appears in the leading order of OPE

Interpolating current for baryons

- Current for **Δ resonances**

Requirement: spin-3/2, isospin-3/2 configuration

$$\left[\left(\frac{1}{2},0\right)\oplus\left(0,\frac{1}{2}\right)\right]^3 = \left[\left(\frac{3}{2},0\right)\oplus\left(0,\frac{3}{2}\right)\right] + 3\left[\left(\frac{1}{2},1\right)\oplus\left(1,\frac{1}{2}\right)\right] + \left[\left(I=\frac{1}{2}\right)\ \text{representations}\right]$$

For $\left(\frac{3}{2},0\right)\oplus\left(0,\frac{3}{2}\right)$ representation $\eta^{\Delta}_{\mu\nu} \equiv (u^T C\sigma^{\alpha\beta}u)\sigma_{\alpha\beta}\sigma_{\mu\nu}u$

→ chiral condensate appears as $(\alpha_s)^n$ correction in OPE

For $\left(\frac{1}{2},1\right)\oplus\left(1,\frac{1}{2}\right)$ representation $\eta^{(1)}_{\mu} \equiv (u^T C\sigma^{\alpha\beta}u)\sigma_{\alpha\beta}\gamma_\mu u = 4\eta^{(2)}_{\mu} = 4(u^T C\gamma_\mu u)u$

→ chiral condensate appears as the leading order in OPE

- **Δ** in Rarita-Schwinger field description ($q^\mu\psi^{(s)}_\mu(q)=0,\quad \gamma^\mu\psi^{(s)}_\mu(q)=0$)

$$S^{3/2}_{\mu\nu}(q) = \frac{1}{\not{q}-m_\Delta}\left(g_{\mu\nu} - \frac{1}{3}\gamma_\mu\gamma_\nu - \frac{2q_\mu q_\nu}{3q^2} - \frac{1}{3q^2}(\not{q}\gamma_\mu q_\nu + q_\mu\gamma_\nu\not{q})\right) \Rightarrow \frac{\lambda^{*2}}{\not{q}-\Sigma_v\not{u}-m_\Delta-\Sigma_s}g_{\mu\nu}+\cdots$$

quasiparticle pole extracted from $g_{\mu\nu}$ dependent term

s=3/2, I=3/2 configuration can couple to ***π-N*** system

the continuum contribution is subtracted by using $J^\mu_{\pi N}(x) = \epsilon^{\mu\alpha\nu\beta}\gamma_5\gamma_\alpha\partial_\nu\Psi_p(x)\partial_\beta\pi(x)$

Interpolating current for baryons

- **Σ** interpolating current

$$\eta_{\Sigma^0} = \epsilon_{abc}\left([u_a^T C s_b]\gamma_5 d_c + [d_a^T C s_b]\gamma_5 u_c + t\left([u_a^T C\gamma_5 s_b]d_c + [d_a^T C\gamma_5 s_b]u_c\right)\right)$$
$$= \left(\frac{1-t}{2}\right)\epsilon_{abc}[u_a^T C\gamma_\mu d_b]\gamma_5\gamma^\mu s_c + \left(\frac{1+t}{4}\right)\epsilon_{abc}[u_a^T C\sigma_{\mu\nu} d_b]\gamma_5\sigma^{\mu\nu} s_c.$$

Two possible diquark ($\boldsymbol{I} = \mathbf{1}$) structure

$$\epsilon_{abc}[u_a^T C\gamma_\mu d_b]\gamma_5\gamma^\mu s_c = 2\epsilon_{abc}\left([u_{R,a}^T C s_{R,b}]d_{L,c} + [d_{R,a}^T C s_{R,b}]u_{L,c} - (L \leftrightarrow R)\right)$$
$$\epsilon_{abc}[u_a^T C\sigma_{\mu\nu} d_b]\gamma_5\sigma^{\mu\nu} s_c = 4\epsilon_{abc}\left([u_{R,a}^T C s_{R,b}]d_{R,c} + [d_{R,a}^T C s_{R,b}]u_{R,c} - (L \leftrightarrow R)\right)$$

- Special case **Λ**

Possible $\boldsymbol{I} = \mathbf{0}$ combination in terms of spin-0 diquark structure

$$\{\epsilon_{abc}[u_a^T C d_b]\gamma_5 s_c,\ \epsilon_{abc}[u_a^T C\gamma_5 d_b]s_c,\ \underline{\epsilon_{abc}\left([u_a^T C s_b]\gamma_5 d_c - [d_a^T C s_b]\gamma_5 u_c\right)},\ \underline{\epsilon_{abc}\left([u_a^T C\gamma_5 s_b]d_c - [d_a^T C\gamma_5 s_b]u_c\right)}\}$$

4^{th} basis can be expressed in terms of the first two and 3^{rd} basis
→ basis set can be reduced to 3 independent bases set

General form of **Λ** interpolating field

$$\eta_{\Lambda(\tilde{a},\tilde{b})} = A_{(\tilde{a},\tilde{b})}\epsilon_{abc}\left([u_a^T C d_b]\gamma_5 s_c + \tilde{a}[u_a^T C\gamma_5 d_b]s_c + \tilde{b}[u_a^T C\gamma_5\gamma_\mu d_b]\gamma^\mu s_c\right)$$

$\tilde{a} \sim -0.2$ and $\tilde{b} \sim -0.2$ is determined by requiring stable Borel behavior

In-medium condensates

- Simplest guess: linear Fermi gas approximation

$$\langle \hat{O}\rangle_{\rho,I} = \langle \hat{O}\rangle_{\rm vac} + \langle n|\hat{O}|n\rangle\rho_n + \langle p|\hat{O}|p\rangle\rho_p$$
$$= \langle \hat{O}\rangle_{\rm vac} + \tfrac{1}{2}(\langle n|\hat{O}|n\rangle + \langle p|\hat{O}|p\rangle)\rho$$
$$+ \tfrac{1}{2}(\langle n|\hat{O}|n\rangle - \langle p|\hat{O}|p\rangle)I\rho.$$

[Vacuum condensate] +
[nucleon expectation value] **x** [density]

Iso-spin symmetric and asymmetric part

- Example: chiral condensates

Iso-spin symmetric part

$$\langle \bar{q}q\rangle_\rho = \langle \bar{q}q\rangle_{\rm vac} + \frac{\sigma_N}{2m_q}\rho$$

Nucleon-pion sigma term

$$\sigma_N = \frac{1}{3}\sum_{a=1}^{3}\left(\langle\tilde{N}|[\mathcal{Q}_A^a,[\mathcal{Q}_A^a,H_{QCD}]]|\tilde{N}\rangle - \langle 0|[\mathcal{Q}_A^a,[\mathcal{Q}_A^a,H_{QCD}]]|0\rangle\right)$$
$$= 2m_q\int d^3x\left(\langle\tilde{N}|\bar{q}q|\tilde{N}\rangle - \langle 0|\bar{q}q|0\rangle\right) \equiv 2m_q\langle N|\bar{q}q|N\rangle$$

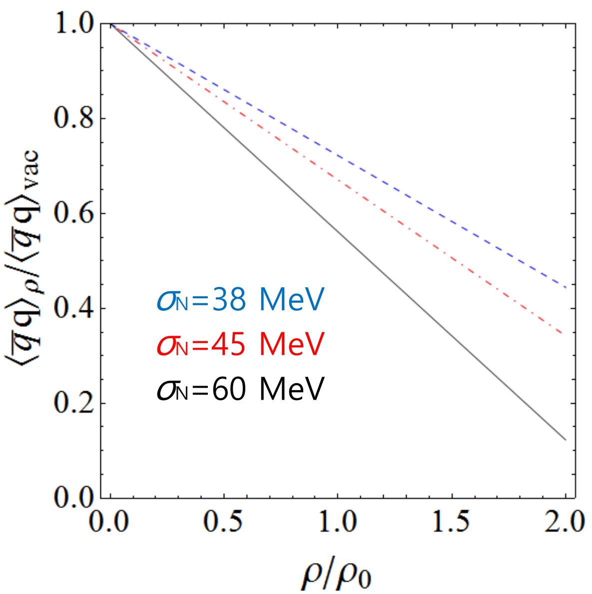
where, $H_{QCD} = \int d^3x(2m_q\bar{q}q + m_s\bar{s}s + \cdots)$

With Hellman-Feynman theorem

$$2m_q\langle\psi|\bar{q}q|\psi\rangle = m_q\frac{d}{dm_q}\langle\psi|H_{QCD}|\psi\rangle$$

and linear density approximation $\mathcal{E} \sim M_N\rho$

Sigma term determines dropping rate

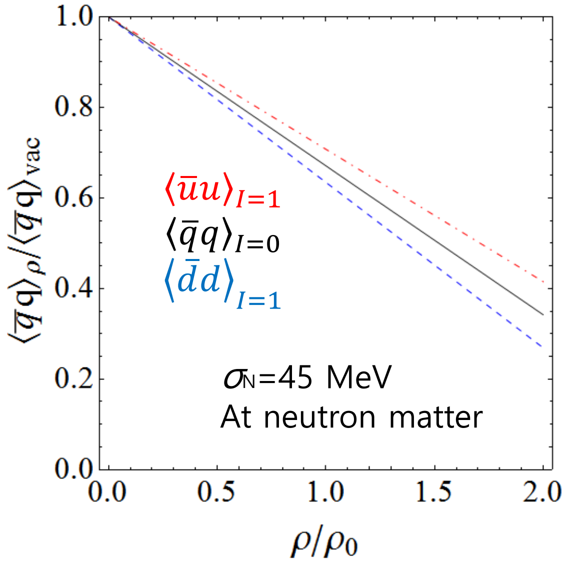


In-medium condensates

- **Asymmetric part**

From trace anomaly and heavy quark expansion

$$T^{\mu}_{\ \mu} = m_u \bar{u}u + m_d \bar{d}d + m_s \bar{s}s + \sum_{h=c,t,b} m_h \bar{h}h + \cdots$$
$$= \left(-\frac{9\alpha_s}{8\pi}\right) G^2 + m_u \bar{u}u + m_d \bar{d}d + m_s \bar{s}s + O(\mu^2/4m_h^2)$$



Low-lying baryon octet mass relation

$$\begin{aligned} m_p &= A + m_u B_u + m_d B_d + m_s B_s \\ m_n &= A + m_u B_d + m_d B_u + m_s B_s \\ m_{\Sigma^+} &= A + m_u B_u + m_d B_s + m_s B_d \\ m_{\Sigma^-} &= A + m_u B_s + m_d B_u + m_s B_d \\ m_{\Xi^0} &= A + m_u B_d + m_d B_s + m_s B_u \\ m_{\Xi^-} &= A + m_u B_s + m_d B_d + m_s B_u \end{aligned}$$

$$\Rightarrow \quad \frac{1}{2}\left(\langle p|\bar{u}u|p\rangle - \langle p|\bar{d}d|p\rangle\right) = \frac{1}{2}\left(\frac{(m_{\Xi^0} + m_{\Xi^-}) - (m_{\Sigma^+} + m_{\Sigma^-})}{2m_s - (m_u + m_d)}\right)$$

where $A \equiv \langle(\bar{\beta}/4\alpha_s)G^2\rangle_p, \quad B_u \equiv \langle\bar{u}u\rangle_p, \quad B_d \equiv \langle\bar{d}d\rangle_p$

- **Strange contents**

$$\begin{aligned} \langle\bar{s}s\rangle_\rho &= \langle\bar{s}s\rangle_{vac} + \langle\bar{s}s\rangle_N \rho \\ &= (0.8)\langle\bar{q}q\rangle_{vac} + y\frac{\sigma_N}{2m_q}\rho \end{aligned}$$
$$y = \langle\bar{s}s\rangle_N / \langle\bar{q}q\rangle_N$$

Ratio **0.8** is determined from vacuum sum rule for hyperon

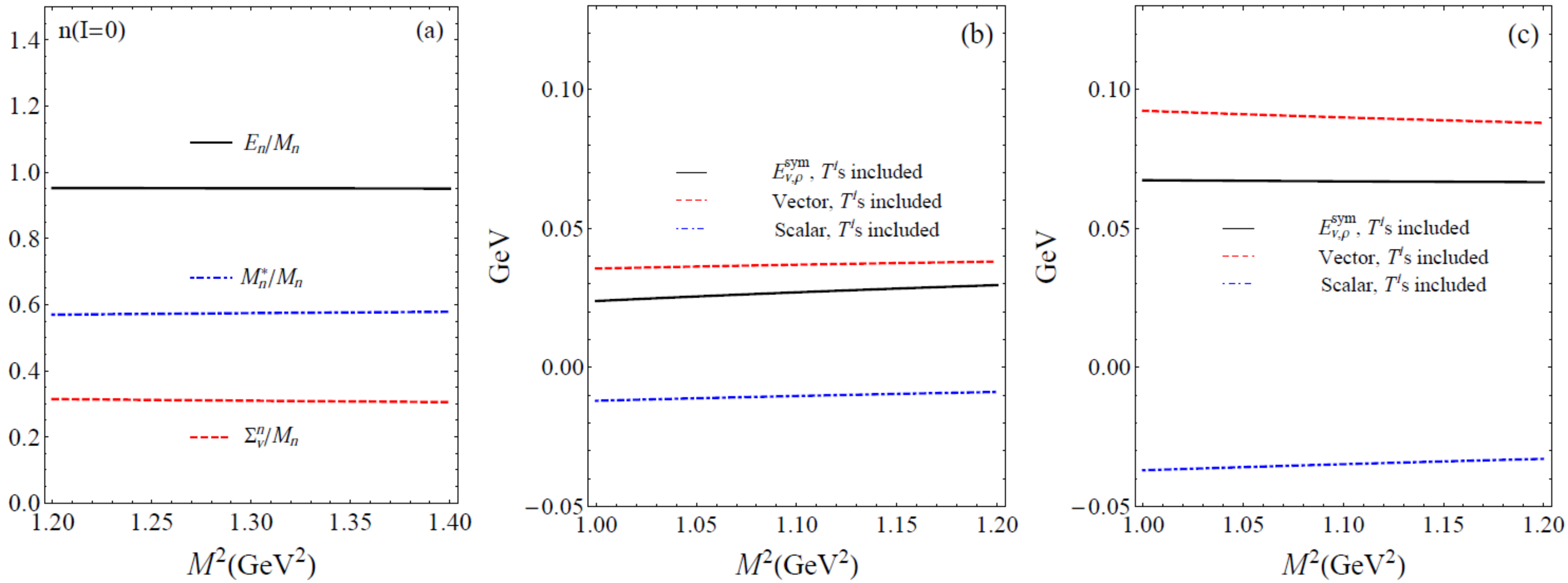
y can be determined from direct lattice QCD
→ recent lattice results says ***y*** should be small
***y*~0.05** (PRD87 074503, PRD91 051502, PRD94 054503)

We confined ***y* → 0.1**

Sum rule result I – Nucleons

- **Neutron** sum rules and symmetry energy

Neutron sum rules (***I=0***) Sym. energy without twist-4 ops. Sym. energy with twist-4 ops.

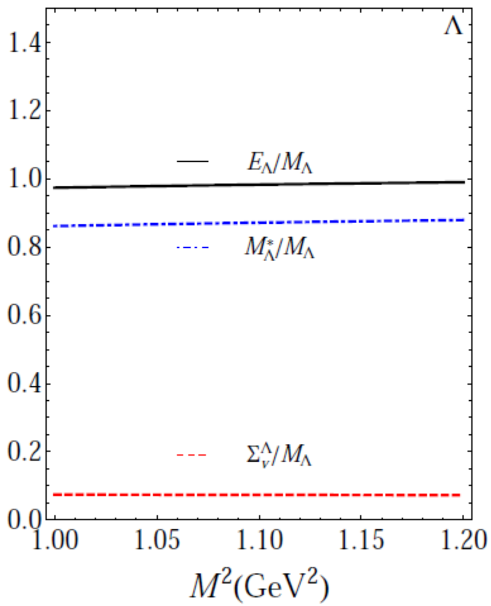


1. The quasi-**neutron** energy is slightly reduced → represents bounding at $\rho=\rho_0$
2. Large cancelation mechanism in both of the quasi-neutron and the symmetry energy
3. Twist-4 matrix elements enhance the strength of cancelation mechanism

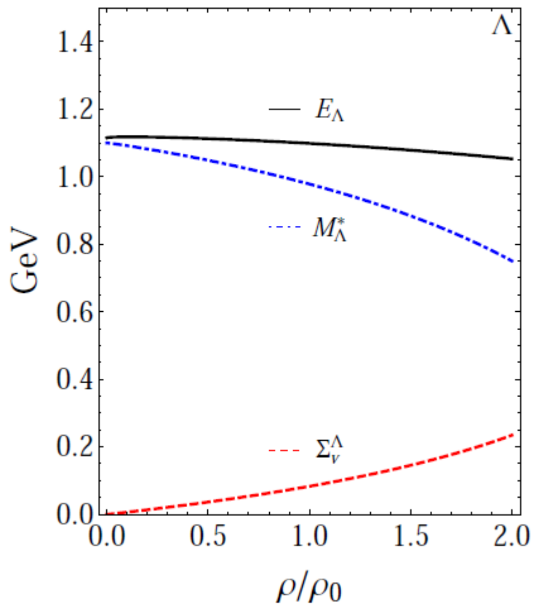
Sum rule result II – Λ hyperon

- Λ sum rules with new interpolating field

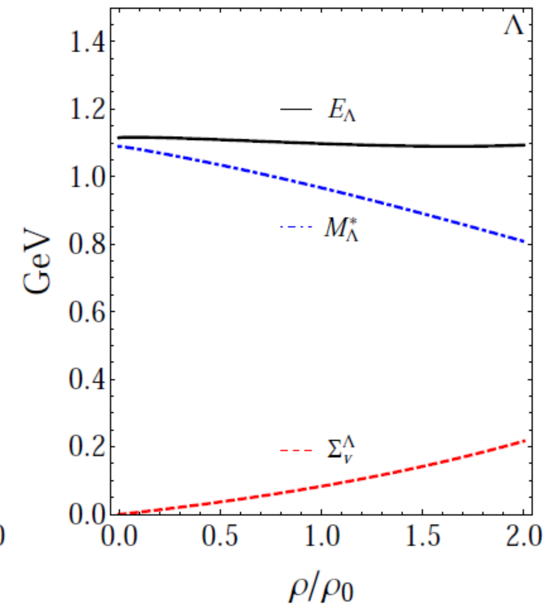
Λ sum rules



Constant negative pole



Density dependent negative pole



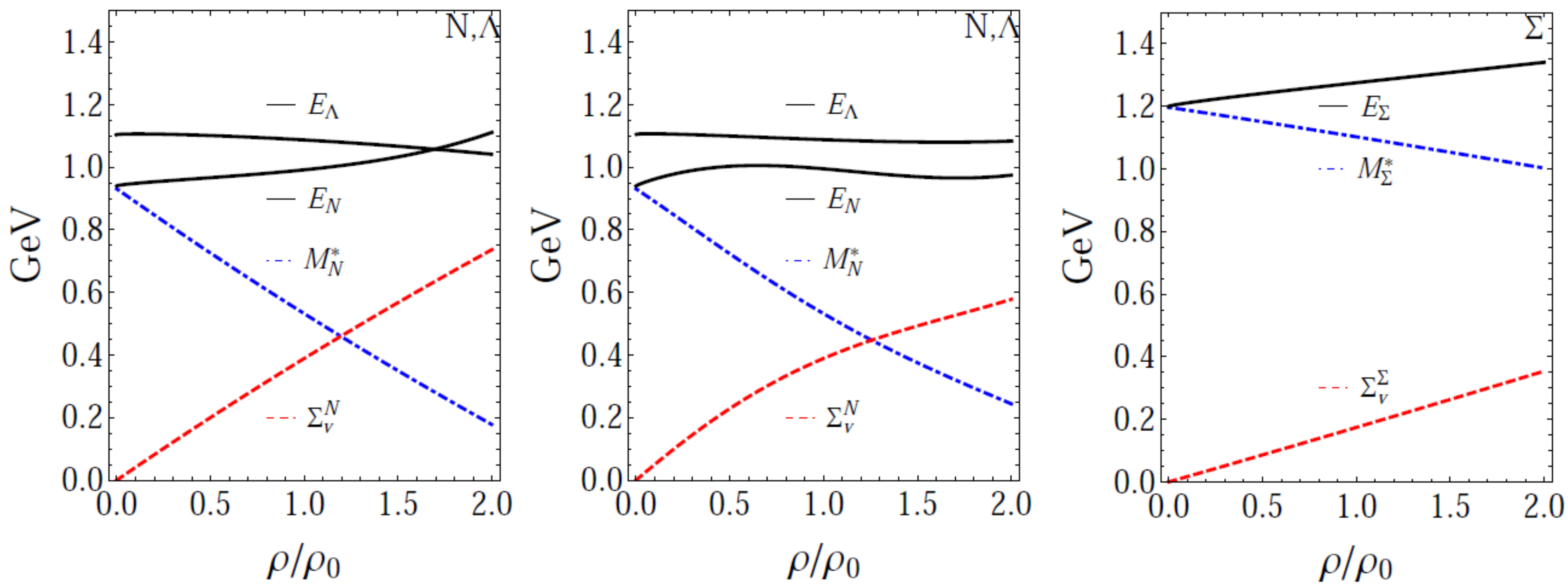
1. The quasi-Λ energy is slightly reduced → represents bounding at normal nuclear density
2. Weak attraction and weak repulsion → **scalar**: $V_{s\Lambda}$ / V_{sN} ~ 0.31 **vector**: $V_{v\Lambda}$ / V_{vN} ~ 0.26
   → naïve quark counting for determination of N-H force strength may not be good
3. Constant negative anti-Λ pole case (2nd graph) and density dependent case (3rd graph)

$$\bar{E}_q = \Sigma_v(\bar{E}_q) - \sqrt{\vec{q}^2 + M^*(\bar{E}_q)^2}$$ (anti-Λ pole)

Sum rule result III – density behavior

- Comparison of density behavior (neutron matter)

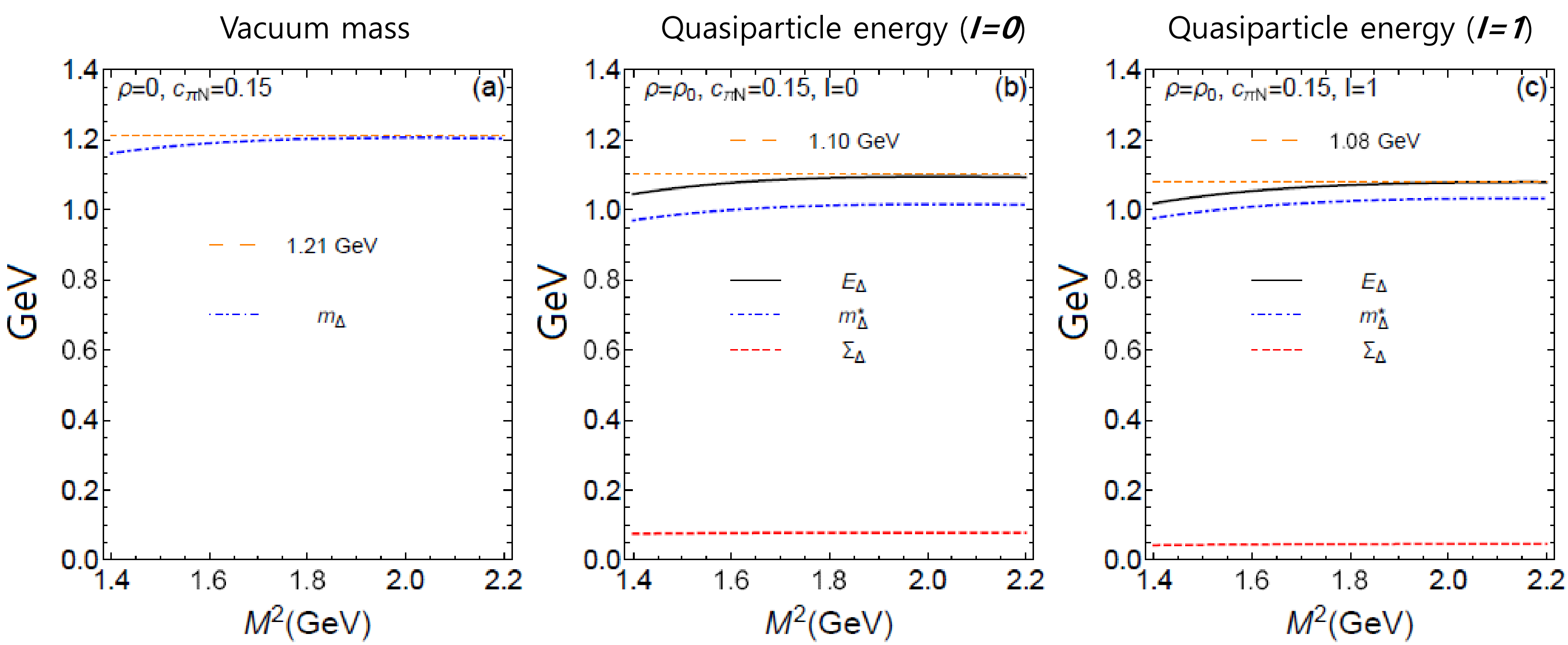
Constant negative pole | Density dependent negative pole | Density dependent negative pole (Σ_+)



1. Constant negative pole case: the quasi energy of **Λ** and **neutron** crosses at $\rho/\rho_0 = 1.8$
2. Density dependent case: never crosses
3. In Σ_+ sum rules, there is only small difference between constant- and density dependent-case
4. **Within new interpolating field for Λ, the early onset of the hyperon in the dense nuclear matter is unlikely**

Sum rule result IV – Δ resonance

- Δ^{++} in neutron matter (considering π-N continuum)



1. Negative mass shift in 100 MeV order (120 MeV in sym. matter, 150 MeV in neutron matter)
2. Current in $\left(\frac{1}{2},1\right)\oplus\left(1,\frac{1}{2}\right)$ representation does not strongly couple with ***π*-*N*** continuum
3. Weak isospin dependence → comparing with quasi-neutron case, $x_\rho \equiv g_{\rho\Delta}/g_{\rho N}$**~0.13**
   → it is very likely for early appearance of **Δ resonances (PRC92.105802 (B. J. Cai et al.))**

Outline

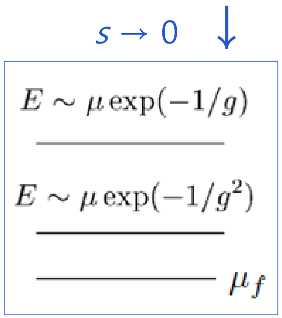
I. QCD symmetry breaking

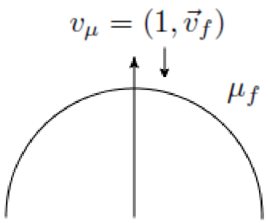
II. QCD approaches – QCD sum rules
- Symmetry energy
- Nucleon and hyperons

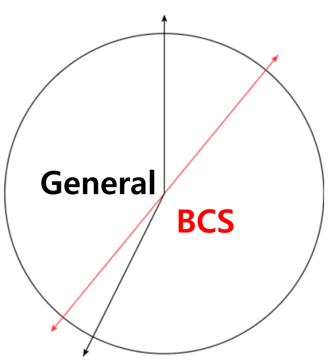
III. Another pairing in cold dense limit
- **2-color superconductivity**

At extremely low temperature

- **At T~0 limit,** quark is mainly confined near Fermi sea







If one scales longitudinal momentum to near Fermi surface

$$\int d^4p \to \mu_f^2 \int d\Omega \int dl^2 s^2 \quad \text{where} \quad l = (l_0, (\vec{l} \cdot \vec{v}_f)\vec{v}_f)$$

Free fermion part should be invariant under scaling

$$\int d^2 l s^2 \psi^\dagger_{\vec{v}_f} s(l_0 - l_{\|})\psi_{\vec{v}_f} \quad \to \quad \psi \sim s^{-\frac{3}{2}}$$

Four-quark interaction

General scattering

$$\int \Pi_i^4 \left(dk_\perp^2 dl^2\right)_i \left[\psi^\dagger(k_3)\psi(k_1)V(k)\psi^\dagger(k_4)\psi(k_2)\right] \delta(k_1 + k_2 - (k_3 + k_4))$$

scales as s^2 : irrelevant in $s \to 0$ scaling

Interaction **between opposite velocity (BCS type)**

$$\int \Pi_i^4 \left(dk_\perp^2 dl^2\right)_i \left[\psi^\dagger(k_3)\psi(k_1)V(k)\psi^\dagger(-k_3)\psi(-k_1)\right] \delta(l_1 + l_2 - (l_3 + l_4))$$

scales as s^0 : **marginal** in $s \to 0$ scaling

In QCD, there is no relevant interaction which scales as s^{-n}
→ **BCS** type interaction becomes most important at scaling

Quasi-quark states in 2SC phase

- **2SC** description in linear combination of Gellman matrices

Gapped (A=0,1,2,3) and un-gapped (A=4,5) quasi-state

$$\psi_{+,\alpha i} = \sum_{A=0}^{5} \frac{(\tilde{\lambda}_A)_{\alpha i}}{\sqrt{2}} \psi_+^A \qquad \chi = \begin{pmatrix} \psi_+ \\ C\psi_-^* \end{pmatrix}$$

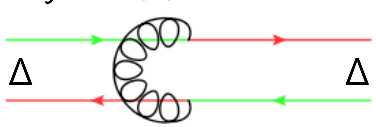
+ and – represents direction of Fermi velocity

$$\tilde{\lambda}_0 = \frac{1}{\sqrt{3}}\lambda_8 + \frac{2}{3}I;\ \tilde{\lambda}_A = \lambda_A\ (A = 1, 2, 3);\ \tilde{\lambda}_4 = \frac{1}{\sqrt{2}}(\lambda_4 - i\lambda_5);\ \tilde{\lambda}_5 = \frac{1}{\sqrt{2}}(\lambda_6 - i\lambda_7),$$

These Hermitian representations $(\tilde{\lambda}_A)_{\alpha i}$ are color(α)-flavor(i) matrix

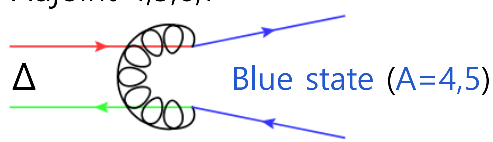
Color interaction can mediate transition of quasi-quark state

Adjoint 1,2,3



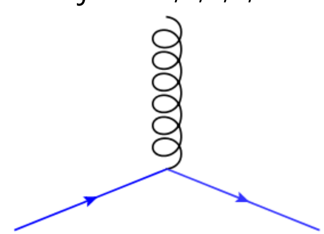
Gluon in adjoint 1,2,3 is trapped in gapped states

Adjoint 4,5,6,7



Gluon in adjoint 4,5,6,7 can dissolve gapped state into liberated state
(Requires large momentum transf.)

Adjoint 4,5,6,7,8



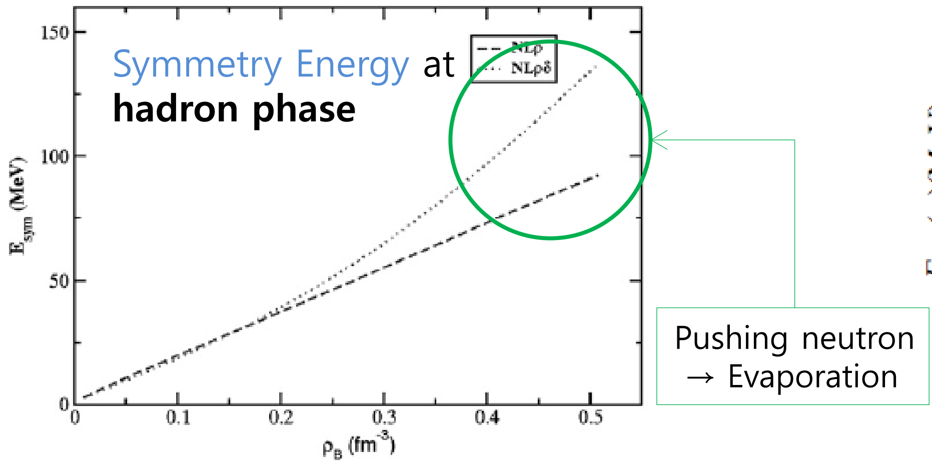
Blue state (A=4,5)

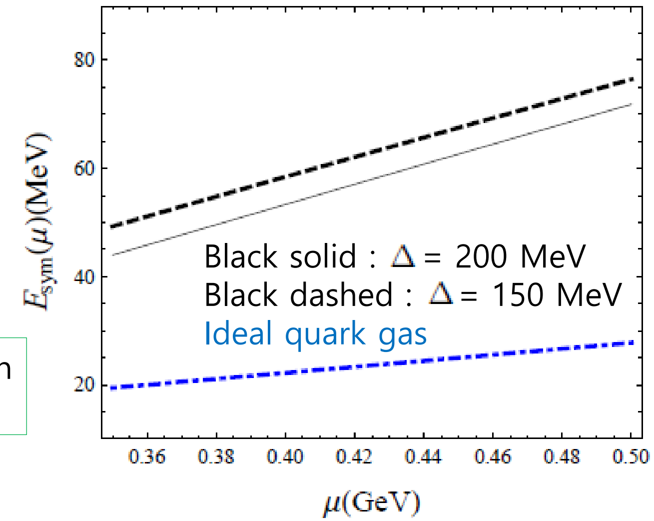
Paring pattern is quite similar with the chiral breaking via instantons

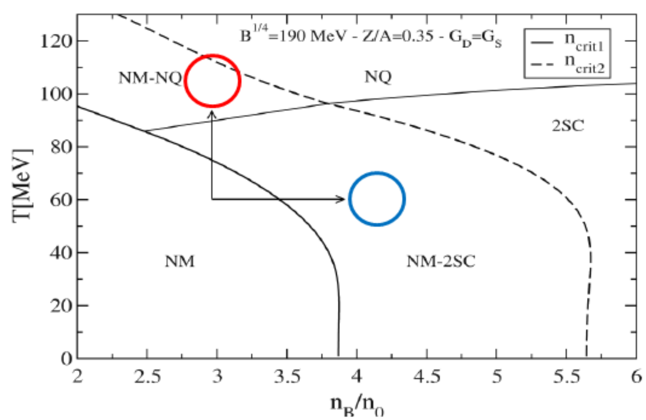
Some phenomenological anticipation

- Iso-spin distillation and π^-/π^+ ratio (in agreement with PRD81 (2010) 094024)

(Phys.Rept. 410 (2005) 335 V. Baran et al.)







Large symmetry energy leads iso-spin evaporation

$E_{\rm sym}^{\rm nuclear}(\mu) \gg E_{\rm sym}^{\rm quark}(\mu)$ (*NLρδ* model and this calculation)
→ Iso-spin distillation can occur at mixed phase

At **2SC phase** the distillation will be **reduced**

Eventually, π^-/π^+ ratio will be **reduced**

Further understanding and experimental observation is needed