１次元トーラス内における BF混合系の動的性質

発表者　柴藤亮介（首都大理工）
共同研究者　西村拓史（お茶大アカプロ）

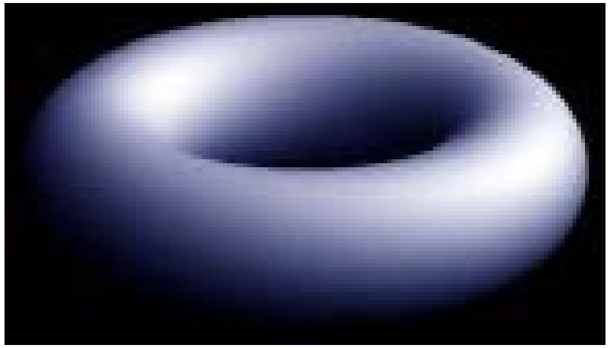
研究背景・対象

◎１次元ボーズ系

＊１次元ボーズ系の厳密解（斥力・一様系）
E. H. Lieb et al., Phys. Rev **130,** 1605(1963)

＊１次元ボーズ系の厳密解（引力・一様系）
J. B. McGuire J. Math. Phys. **5,** 622(1964)

＊LG光による擬１次元系の実現
T. Kuga et al., PRL **78**, 4713(1997)

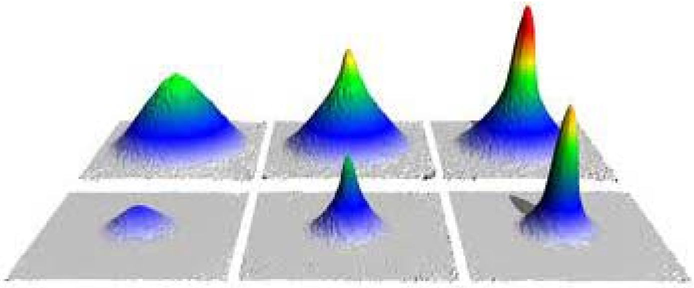


【図１：１次元トーラス】

◎ボーズ・フェルミ混合系

＊ボーズ・フェルミ系におけるBFクーパー対
A. Storozhenko et al., PRA **71** 063617(2005)

＊ボーズ・フェルミ混合系におけるBFペア相関
T. Watanabe et al., PRA **73** 033601(2008)



【図２：ボーズ凝縮とフェルミ縮退】

研究動機

（１）平均場近似を越えた領域における相関

→厳密解と平均場近似の比較

（２）実験と理論の橋渡し

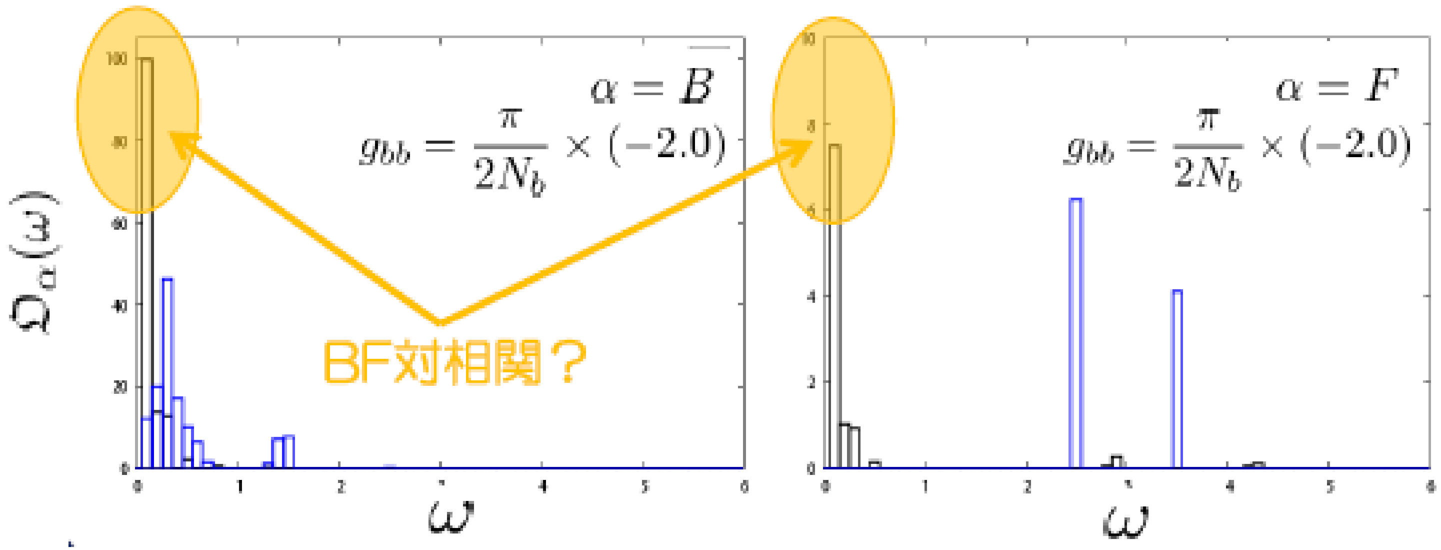
→スペクトル関数の計算

（３）自発的対称性の破れと量子多体相関

→弱結合における多体相関に着目（例：変形核）

結果

◎ボーズ・フェルミ系における各粒子のスペクトル
（BF間が引力相互作用の場合： $g_{bf} = -1$ ）



【図３；平均場近似（青）と厳密解（黒）の比較】

【結果】B, Fともにピークの位置が異なる
→<u>多体相関</u>によってBのNGモードがFに影響を与えている！

Analysis of chiral phase transition by evaluating the Wilsonian effective potential in thermal gauge theories

金沢大数物，愛知淑徳大人情[A]，金沢大自然[B]

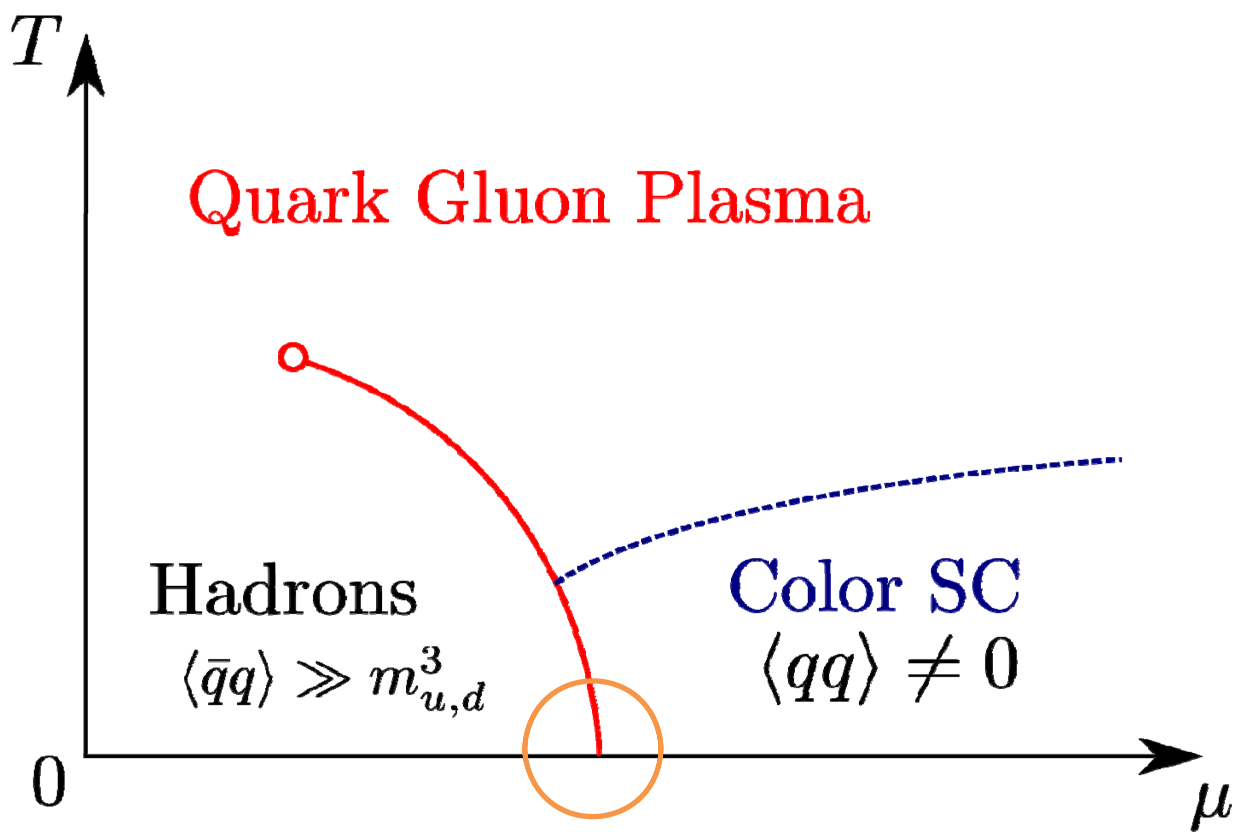
青木健一，宮下和洋[A]，○佐藤大輔[B]

Kanazawa University, Shukutoku University [A]

Ken-Ichi Aoki, Kazuhiro Miyashita [A] and ○ Daisuke Sato

2012年 熱場の量子論とその応用 @ 京都大学基礎物理学研究所

QCD phase diagram

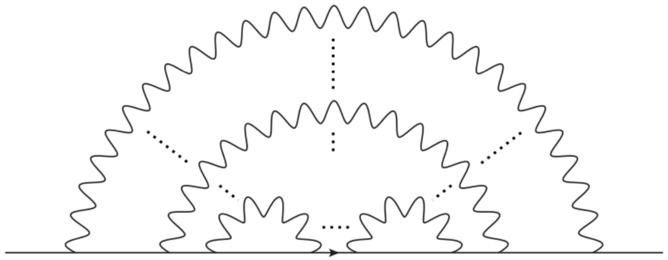


$T \sim 0$, $\mu \neq 0$ and chiral limit $m_{u,d,s} = 0$

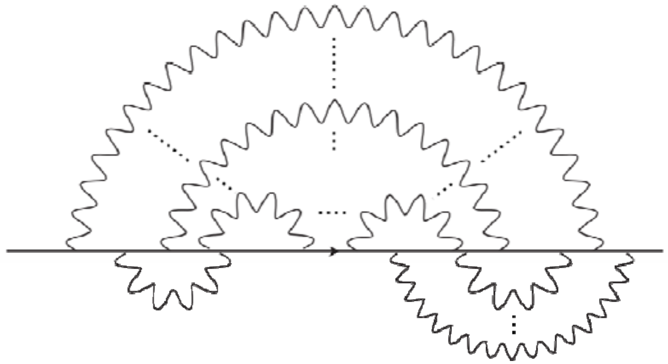
Beyond the ladder approximation

The Dyson-Schwinger Eq. approach is limited to the ladder approximation.

Ladder diagram



Non-ladder diagram



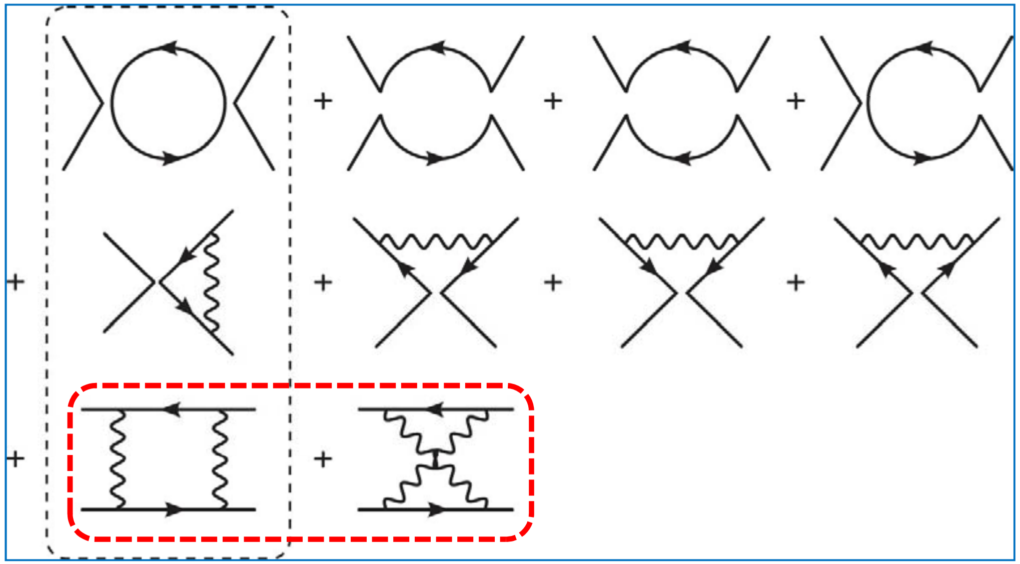
We can approximately solve the Non-perturbative renormalization group equation with the non-ladder effects.

Non-Perturbative Renormalization Group (NPRG)

Wilsonian effective action: $S_{\text{eff}}[\phi;\Lambda]$

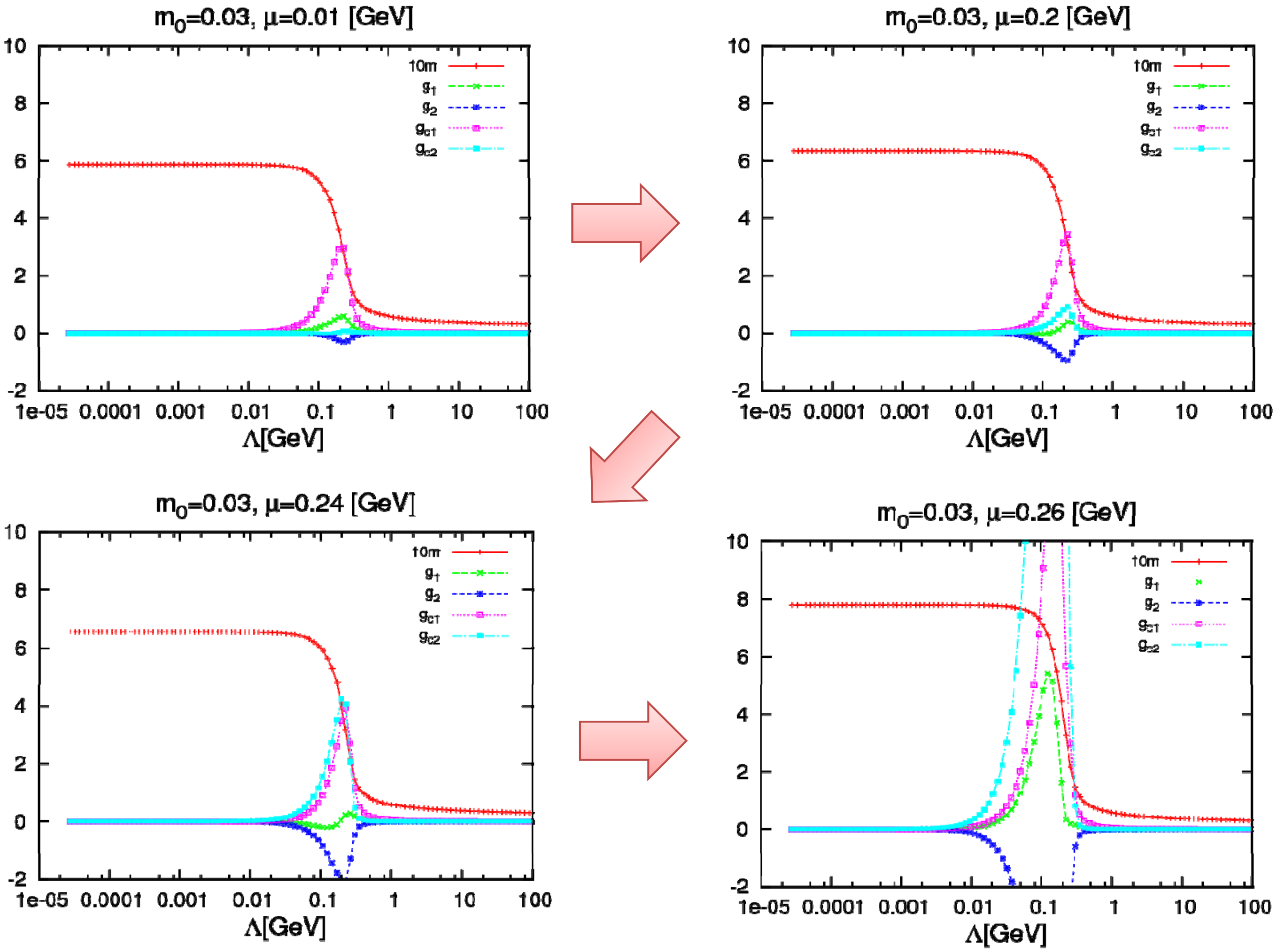
Λ : renormalization (momentum cut-off) scale

NPRG equation: $\Lambda\dfrac{\partial}{\partial\Lambda}S_{\text{eff}}[\phi;\Lambda]=\beta(S_{\text{eff}})$



At low energy, 4-fermi operators, generated by gauge interactions, spontaneously break the chiral symmetry.

Change of renormalization group flows due to finite density



The renormalization group flows tell us about the phase transition

Details are in the poster...

AM and T. Hirano, arXiv:1102.5053 [nucl-th] (to appear in PLB)

Hydrodynamic Effects on the Color Glass Condensate in Non-Equilibrium and Non-Boost Invariant Systems

Akihiko Monnai

Department of Physics, The University of Tokyo

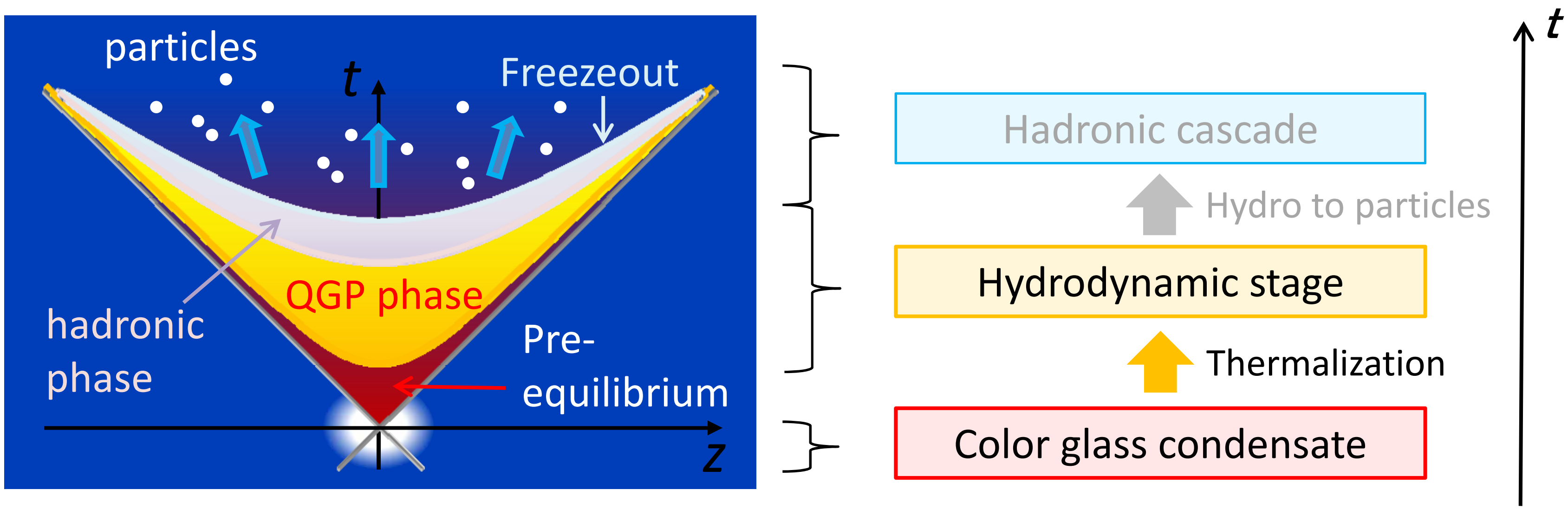
Collaborator: Tetsufumi Hirano

Thermal Quantum Field Theory and Their Applications 2011

Aug 22nd-24th 2010, YITP, Kyoto University, Japan

Introduction

- Models for high-energy heavy ion collisions (RHIC and LHC)



Color glass condensate (CGC)

Description of saturated gluons in the nuclei before a collision ($\tau < 0$ fm/c)

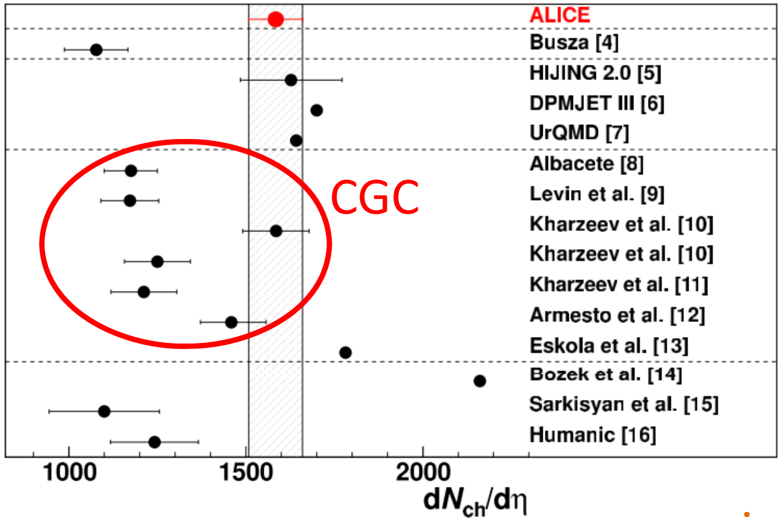
Relativistic hydrodynamics

Description of collective motion of the QGP ($\tau \sim 1\text{-}10$ fm/c)

Motivation

- Heavy ion collisions at Large Hadron Collider (LHC)

Pb+Pb, 2.76 TeV at η = 0



ALICE data (most central 0-5%)

$$\frac{dN_{\rm ch}}{d\eta} = 1584 \pm 4({\rm stat}) \pm 76({\rm phys})$$

⇔ ?

CGC predictions (fit to RHIC)

$$\frac{dN_{\rm ch}}{d\eta} \sim 1200$$

a missing piece!

Initial condition from the CGC ⇨ Hydrodynamic evolution ⇨ Observed particle distribution

⇨ We need to estimate hydrodynamic effects with

(i) non-boost invariant expansion
(ii) non-equilibrium corrections

} for the CGC

Hydrodynamic Model

- Full 2nd order viscous hydrodynamic equations

$$D = u^\mu \partial_\mu$$
$$\nabla^\mu = \Delta^{\mu\nu}\partial_\nu$$

Energy-momentum conservation $\partial_\mu T^{\mu\nu} = 0$ +

AM and T. Hirano, NPA 847, 283

EoM for bulk pressure

$$D\Pi = \frac{1}{\tau_\Pi}\Big(-\Pi - \zeta_{\Pi\Pi}\frac{1}{T}\nabla_\mu u^\mu - \zeta_{\Pi\delta e} D\frac{1}{T} + \chi^b_{\Pi\Pi}\Pi D\frac{1}{T} + \chi^c_{\Pi\Pi}\Pi\nabla_\mu u^\mu + \chi_{\Pi\pi}\pi^{\mu\nu}\nabla_{\langle\mu}u_{\nu\rangle}\Big)$$

EoM for shear tensor

$$D\pi^{\mu\nu} = \frac{1}{\tau_\pi}\Big(-\pi^{\mu\nu} + 2\eta\nabla^{\langle\mu}u^{\nu\rangle} + \chi^b_{\pi\pi}\pi^{\mu\nu}D\frac{1}{T} + \chi^c_{\pi\pi}\pi^{\mu\nu}\nabla_\rho u^\rho + \chi^d_{\pi\pi}\pi^{\rho\langle\mu}\nabla_\rho u^{\nu\rangle} + \chi_{\pi\Pi}\Pi\nabla^{\langle\mu}u^{\nu\rangle}\Big)$$

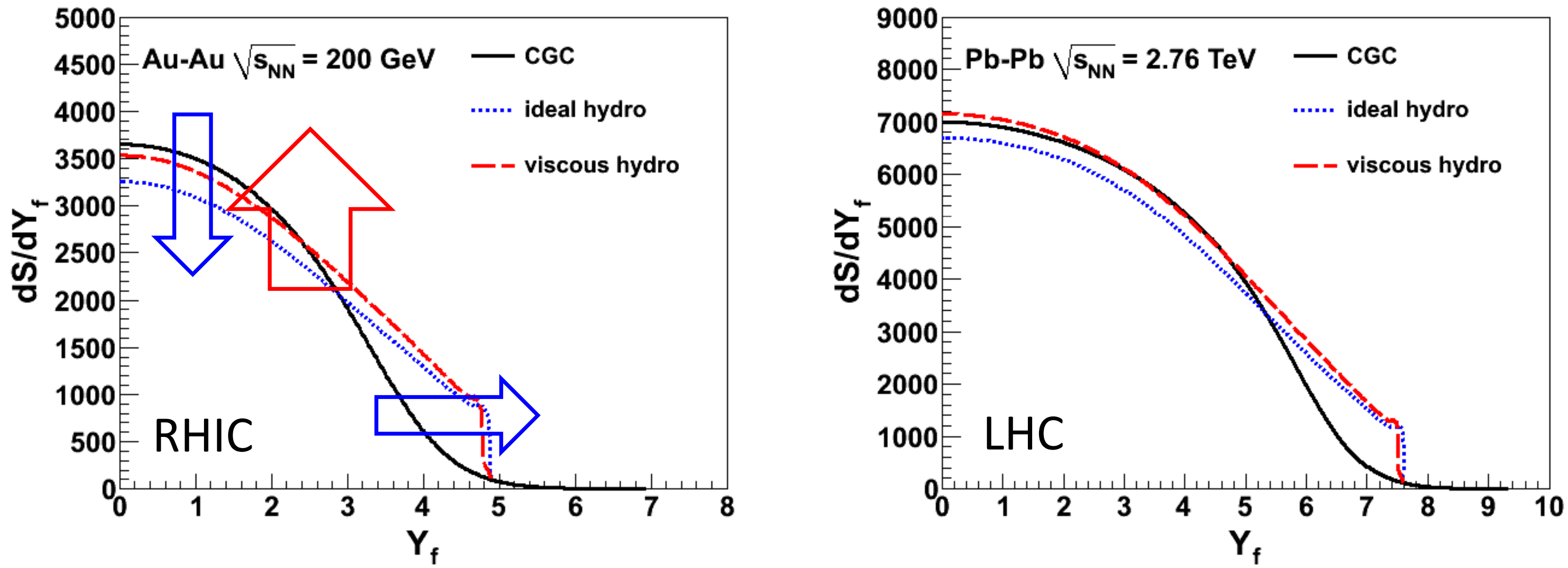
All the terms are kept

⇨ Solve in (1+1)-D relativistic coordinates (= no transverse flow) with piecewise parabolic + iterative method

Note: (2+1)-D viscous hydro assumes boost-invariant flow

Results

- CGC initial distributions + longitudinal viscous hydro



Outward entropy flux ⇨	Flattening
Entropy production ⇨	Enhancement

$$\frac{dN_{\mathrm{ch}}^{\mathrm{hydro}}}{dy} \approx \frac{2}{3} \times \frac{1}{3.6} \times \frac{dS}{dY_f}$$

If the flattening is stronger at RHIC, the true dN/dy is larger at LHC;
Hydro effect is a candidate for explaining the "gap" at LHC

Novel Kinetic Theory Describing Ultrasoft Fermionic Mode

Daisuke Satow (Kyoto Univ.)
Collaborator: Yoshimasa Hidaka (RIKEN)

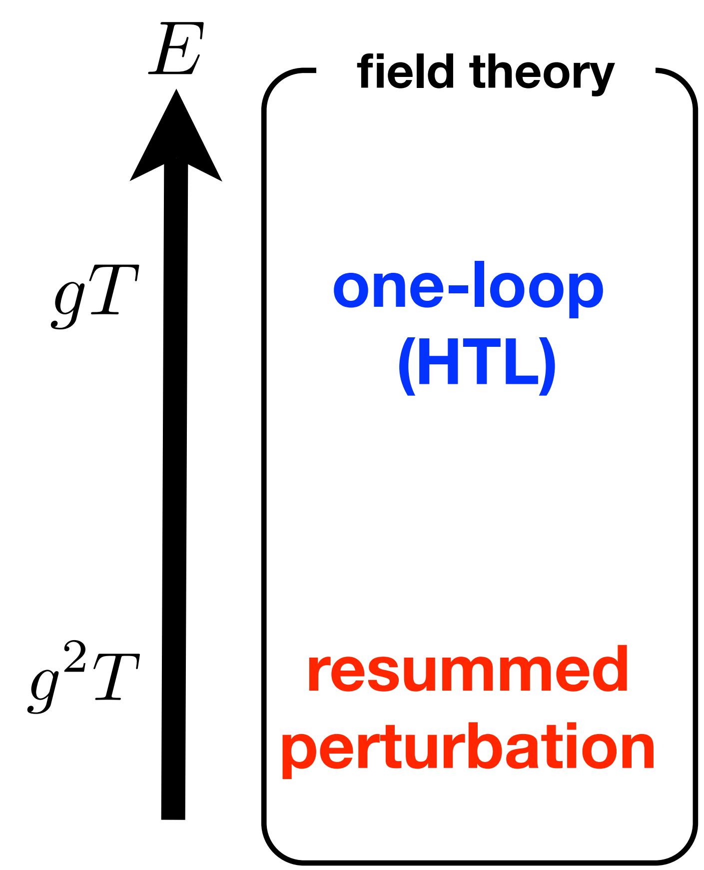
Introduction

System: **fermion-boson system** at high temperature ($T >> $ any mass)

Yukawa theory, QED (plasma), QCD (quark-gluon plasma)

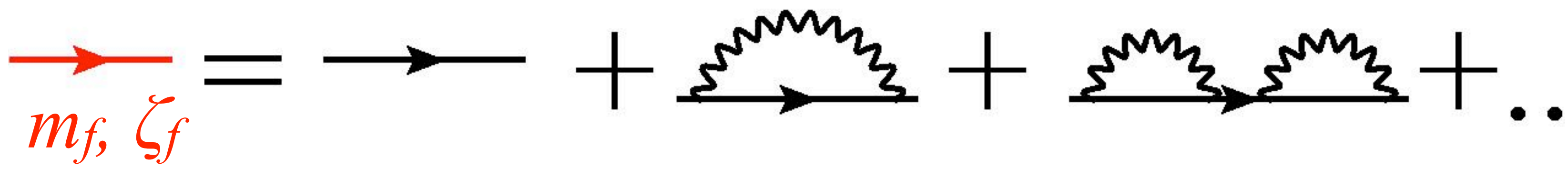
Perturbative calculation in this system is generally difficult.

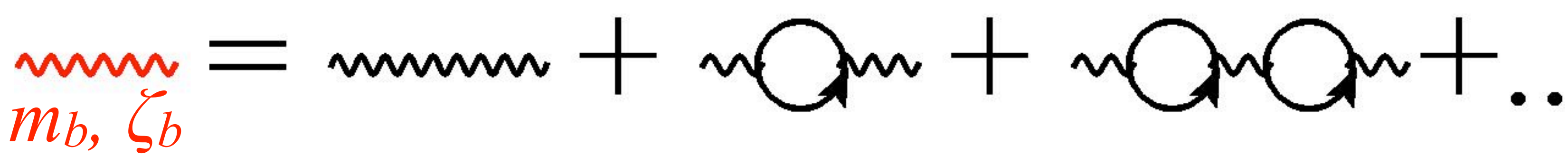
- $E \sim gT$ → One loop analysis (Hard Thermal Loop approximation: HTL) is reliable.
  (g: coupling constant)
- $E << g^2T$ → Reorganization of perturbative expansion is necessary.



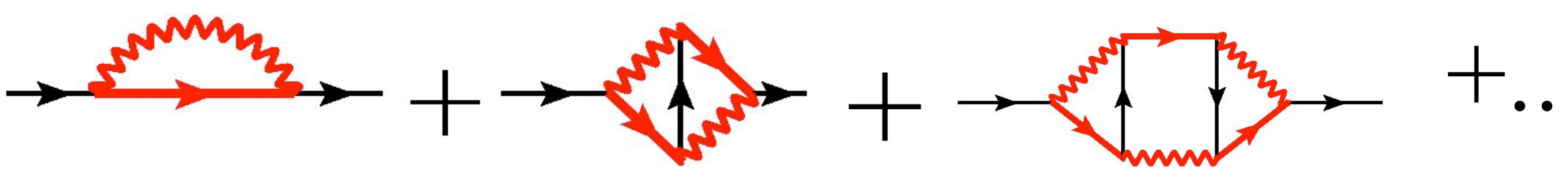
Resummation scheme

1. Resummation of **thermal mass** and **decay width**





2. Summation of **ladder diagrams**



Motivation

- Systematical derivation of this resummation scheme

- Physical interpretation of the scheme

What we did

- We derived the resummed perturbation, corresponding to the novel kinetic equation, from the Kadanoff-Baym equation in a systematic way.

resummed perturbation	Kinetic equation
thermal mass, decay width	**mass correction, collision term**
ladder diagram	**external force correction**

Please come to my poster for further information!!

Stochastic Equations in Black Hole Backgrounds
and
Non-equilibrium Fluctuation Theorems

岡澤　晋
with 磯　暁
(総研大,KEK)

arXiv:1104.2461 [hep-th], Nucl.Phys.B851 (2011)

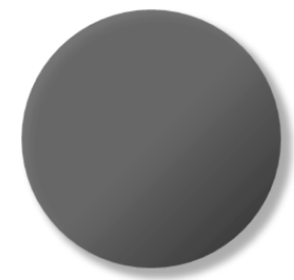
ブラックホール熱力学

- 古典重力 + 場の量子論

  ➡ ブラックホールからの黒体輻射

  Hawking温度: $T_H = \dfrac{1}{8\pi G_N M}$

質量 M



“事象の地平面”の面積 A_{BH}

- 第一法則: $T_H \Delta S_{BH} = \Delta M$

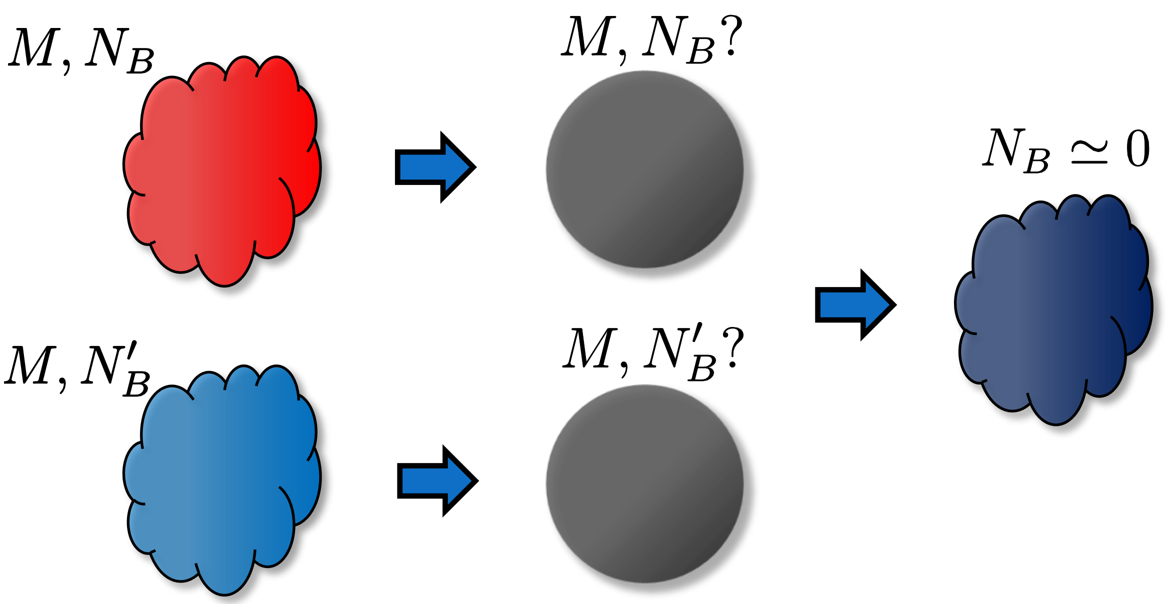
$$\boxed{S_{BH} = \frac{A_{BH}}{4G_N}}$$

- 拡張された第二法則: $\Delta S_{BH} + \Delta S_{\mathrm{matter}} \geq 0$

情報喪失問題

- Hawking輻射は互いに無相関（熱的輻射）
- BHが蒸発しきるとユニタリティが破れる

例：バリオン数非保存



揺らぎの定理

- 非平衡統計力学における定理

$$\frac{\mathrm{Prob}(\text{entropy difference} = \Delta S)}{\mathrm{Prob}(\text{entropy difference} = -\Delta S)} = e^{\Delta S}$$

- ミクロには $\Delta S < 0$ のトラジェクトリが存在
- 全トラジェクトリの平均の意味で $\langle \Delta S \rangle \geq 0$ が成立

- 研究の動機

  エントロピー減少確率はBH情報喪失問題にヒントを与えないか？

ポスターの内容

- BH背景でのQFT → Schwinger-Keldysh formalism
- “環境系”を積分して、Langevin方程式を導出

$$(\partial_t - \partial_{r_*})\phi(t)_{|r=r_H+\epsilon} = \xi(t)$$

$$,\langle\xi(t)\xi(t')\rangle \simeq T_H\delta(t-t').$$

- ブラックホールと物質場に対する揺らぎの定理を導出

$$\frac{\rho(\Delta S_{BH} + \Delta S_{\mathrm{matter}})}{\rho(-(\Delta S_{BH} + \Delta S_{\mathrm{matter}}))} = e^{\Delta S_{BH} + \Delta S_{\mathrm{matter}}}$$

Chiral symmetry restoration in graphene induced by Kekulé distortion

グラフェンにおけるカイラル対称性の破れ・回復とKekulé歪み

荒木 康史
Yasufumi Araki

Dept. of Physics, The Univ. of Tokyo

<References>

YA, arXiv:1105.0369[cond-mat.str-el].
(Accepted for publication in Phys. Rev. B)

YA, J. Phys.: Conf. Ser. **302**, 012022 (2011).

東京大学
THE UNIVERSITY OF TOKYO

Aug. 22-24, 2011: 熱場の量子論とその応用

Effective field theory of graphene

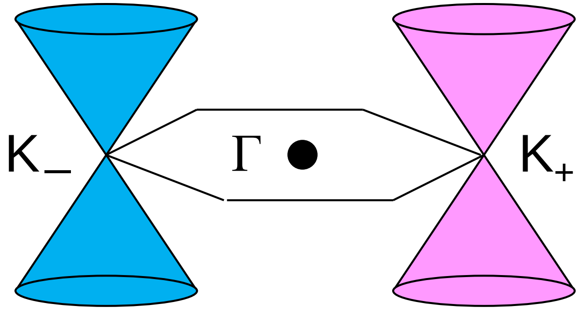
Graphene = Monoatomic layer material of carbon atoms.

(Honeycomb lattice structure)

- Non-interacting electrons/holes:

Linear dispersion around two Dirac points

in the 1st Brillouin zone Ω



$$\boxed{E(\mathbf{K}_\pm + \mathbf{k}) \simeq v_F\,|\mathbf{k}|}$$

[Wallace,1947]

(Fermi velocity $v_F = (3/2)ah \sim c/300$)

⇨ Described as (2+1)-dim. massless Dirac fermions.

[Semenoff,1984]

- Coulomb interaction strength:

"Fine structure const." $\alpha_{\rm eff} = \dfrac{e^2}{4\pi\epsilon v_F} \quad (\gg \alpha_{\rm QED})$

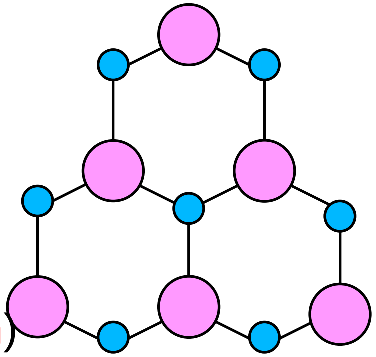
⇨ Effectively strong coupling (in vacuum-suspended graphene).

Gap-opening patterns

<u>Spontaneous:</u>

Sublattice symmetry breaking
(Charge density wave)

▶ Mechanism:



Strong coupling

⇩

e-h pairing
(exciton condensation)

⇩

"Effective mass" term.

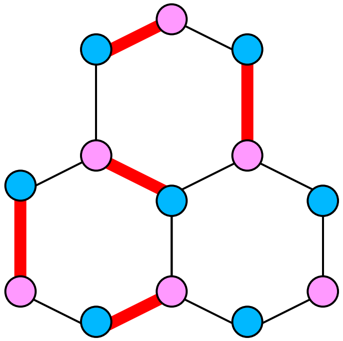
$$ma^\dagger a + (-m)b^\dagger b \Longleftrightarrow m\bar{\psi}\psi$$

Analogous to dynamical chiSB in QCD.

A. H. Castro Neto, Physics **2**, 30 (2009).

<u>External:</u>

"Kekulé distortion"
(spatially varying
bond strengths)



Introduced by
- substrates
- adatoms

[Farjam & Rafii-Tabar,2009]

Opens a gap without breaking the sublattice (chiral) symmetry.

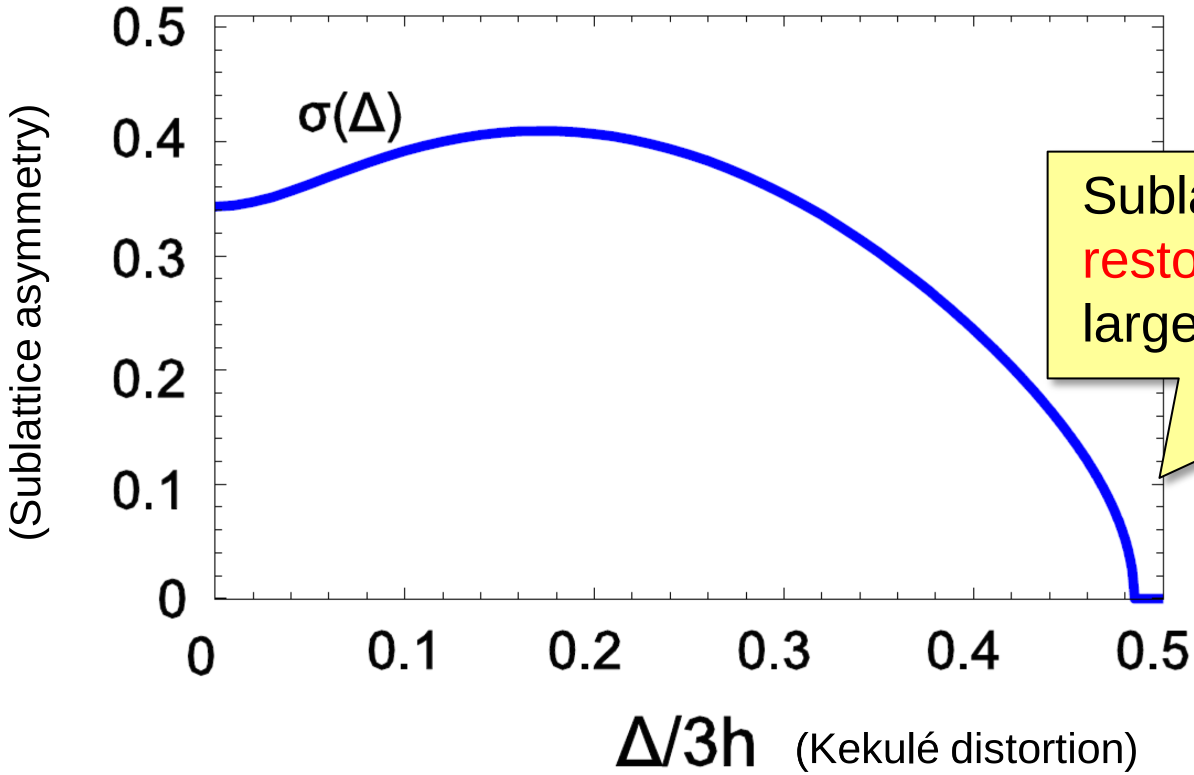
$$\sim \Delta\bar{\psi}\gamma_3\psi$$

Q. Is there any interplay effect between them?

This work

- Study the properties of monolayer graphene:
  in the presence of the external Kekulé distortion
  by strong coupling expansion of U(1) lattice gauge theory.

Result:

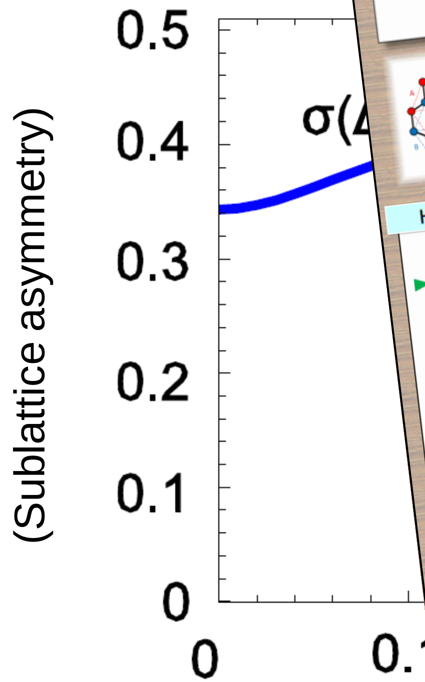


Sublattice (chiral) symmetry is restored under a sufficiently large Kekulé distortion.

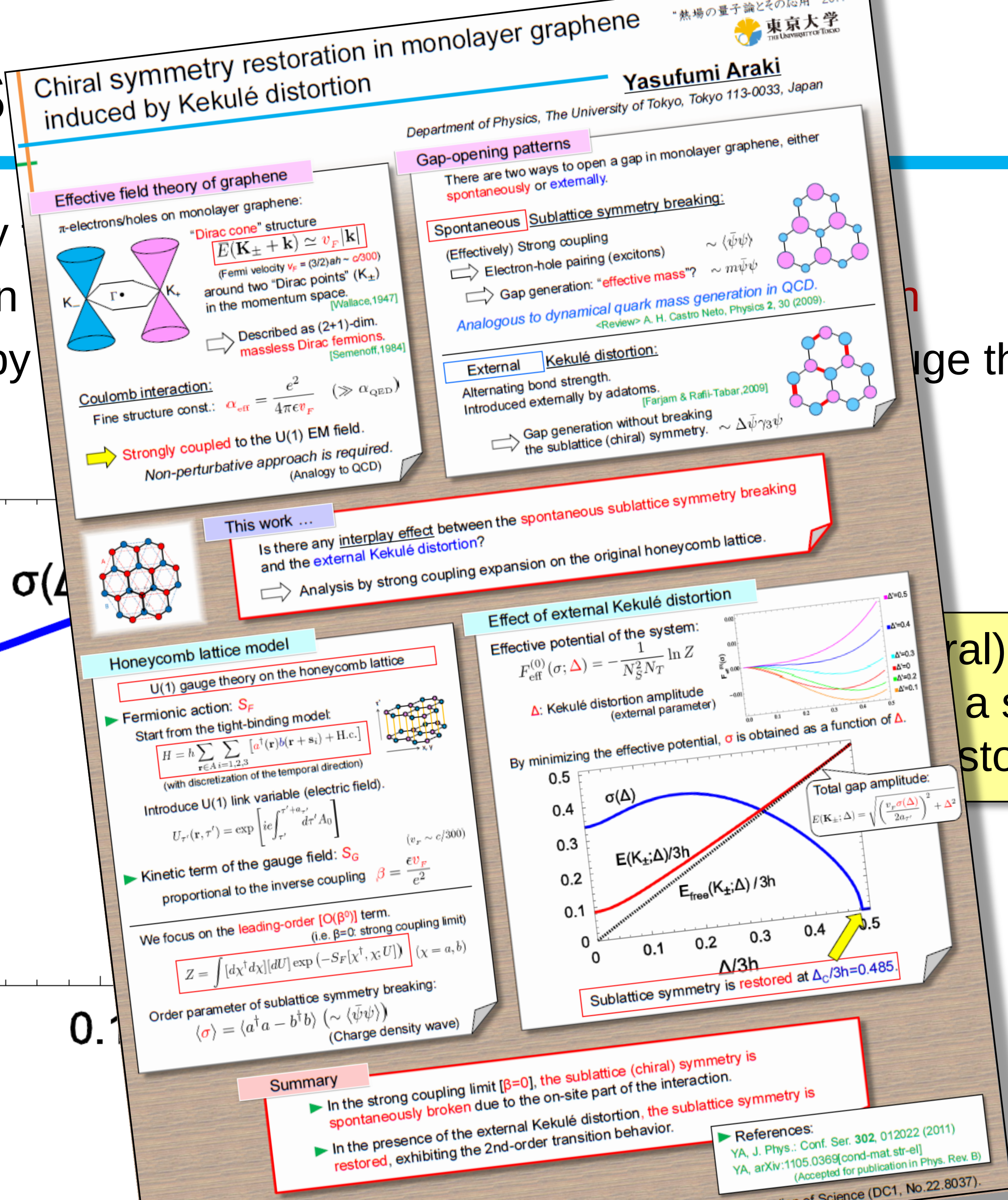
This

- Study
  in
  by ge theory.

Result:



al) symmetry is
a sufficiently
stortion.



"熱場の量子論とその応用" 東京大学 THE UNIVERSITY OF TOKYO

Chiral symmetry restoration in monolayer graphene induced by Kekulé distortion

Yasufumi Araki

Department of Physics, The University of Tokyo, Tokyo 113-0033, Japan

Effective field theory of graphene

π-electrons/holes on monolayer graphene:

"Dirac cone" structure $E(\mathbf{K}_\pm + \mathbf{k}) \simeq v_F|\mathbf{k}|$

(Fermi velocity v_F = (3/2)ah ~ c/300)

around two "Dirac points" ($K_\pm$) in the momentum space. [Wallace,1947]

Described as (2+1)-dim. massless Dirac fermions. [Semenoff,1984]

Coulomb interaction:

Fine structure const.: $\alpha_{\mathrm{eff}} = \frac{e^2}{4\pi\epsilon v_F}$ ($\gg \alpha_{\mathrm{QED}}$)

Strongly coupled to the U(1) EM field.

Non-perturbative approach is required. (Analogy to QCD)

Gap-opening patterns

There are two ways to open a gap in monolayer graphene, either spontaneously or externally.

Spontaneous Sublattice symmetry breaking:

(Effectively) Strong coupling

⇨ Electron-hole pairing (excitons) $\sim \langle\bar\psi\psi\rangle$

⇨ Gap generation: "effective mass"? $\sim m\bar\psi\psi$

Analogous to dynamical quark mass generation in QCD. <Review> A. H. Castro Neto, Physics **2**, 30 (2009).

External Kekulé distortion:

Alternating bond strength.

Introduced externally by adatoms. [Farjam & Rafii-Tabar,2009]

⇨ Gap generation without breaking the sublattice (chiral) symmetry. $\sim \Delta\bar\psi\gamma_3\psi$

This work ...

Is there any interplay effect between the spontaneous sublattice symmetry breaking and the external Kekulé distortion?

⇨ Analysis by strong coupling expansion on the original honeycomb lattice.

Honeycomb lattice model

U(1) gauge theory on the honeycomb lattice

- Fermionic action: S_F

Start from the tight-binding model:

$H = h\sum_{\mathbf{r}\in A}\sum_{i=1,2,3}[a^\dagger(\mathbf{r})b(\mathbf{r}+\mathbf{s}_i) + \mathrm{H.c.}]$

(with discretization of the temporal direction)

Introduce U(1) link variable (electric field).

$U_{\tau'}(\mathbf{r},\tau') = \exp\left[ie\int_{\tau'}^{\tau'+a_{\tau'}} d\tau' A_0\right]$ ($v_F \sim c/300$)

- Kinetic term of the gauge field: S_G proportional to the inverse coupling $\beta = \frac{\epsilon v_F}{e^2}$

We focus on the leading-order [O(β⁰)] term. (i.e. β=0: strong coupling limit)

$Z = \int [d\chi^\dagger d\chi][dU]\exp(-S_F[\chi^\dagger,\chi;U])$ $(\chi = a, b)$

Order parameter of sublattice symmetry breaking:

$\langle\sigma\rangle = \langle a^\dagger a - b^\dagger b\rangle$ $(\sim\langle\bar\psi\psi\rangle)$ (Charge density wave)

Effect of external Kekulé distortion

Effective potential of the system:

$F_{\mathrm{eff}}^{(0)}(\sigma;\Delta) = -\frac{1}{N_S^2 N_T}\ln Z$

Δ: Kekulé distortion amplitude (external parameter)

By minimizing the effective potential, σ is obtained as a function of Δ.

Total gap amplitude:

$E(\mathbf{K}_\pm;\Delta) = \sqrt{\left(\frac{v_F\sigma(\Delta)}{2a_{\tau'}}\right)^2 + \Delta^2}$

Sublattice symmetry is restored at $\Delta_c/3h$=0.485

Summary

- In the strong coupling limit [β=0], the sublattice (chiral) symmetry is spontaneously broken due to the on-site part of the interaction.
- In the presence of the external Kekulé distortion, the sublattice symmetry is restored, exhibiting the 2nd-order transition behavior.

References:

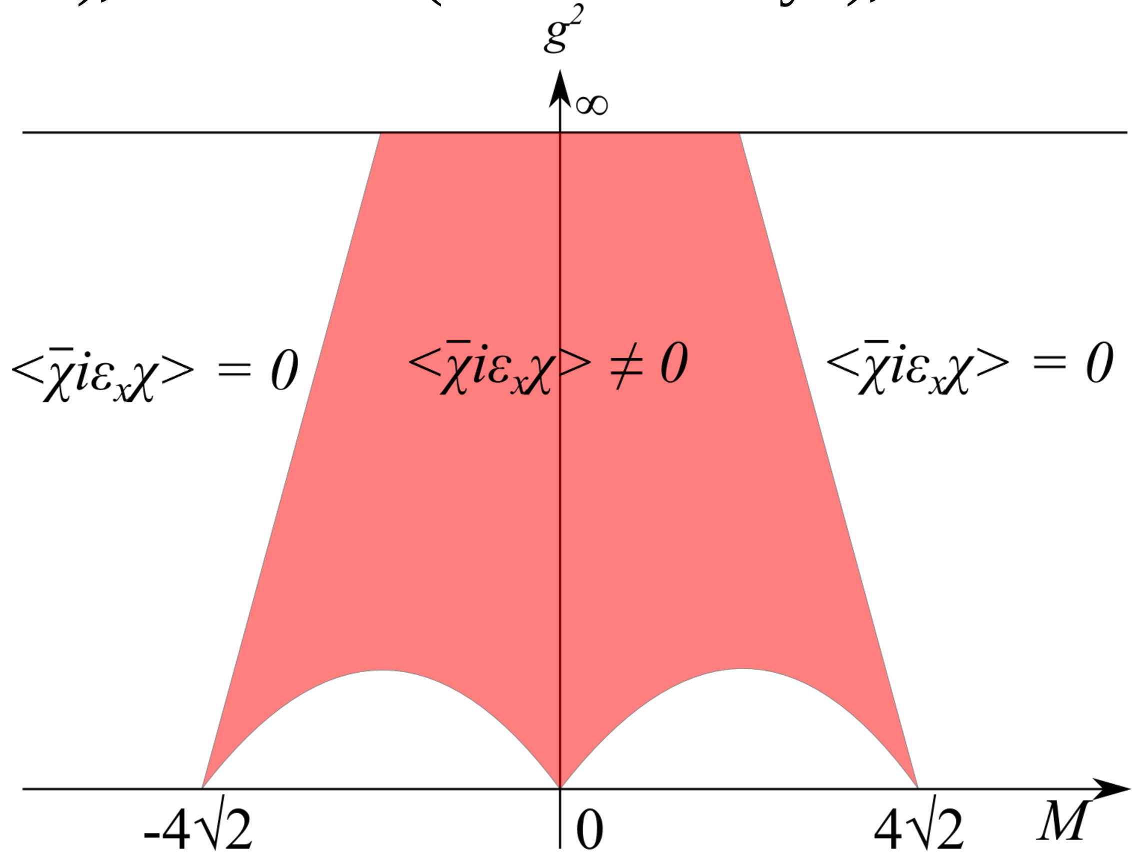
YA, J. Phys.: Conf. Ser. **302**, 012022 (2011)

YA, arXiv:1105.0369[cond-mat.str-el] (Accepted for publication in Phys. Rev. B)

of Science (DC1, No.22.8037).

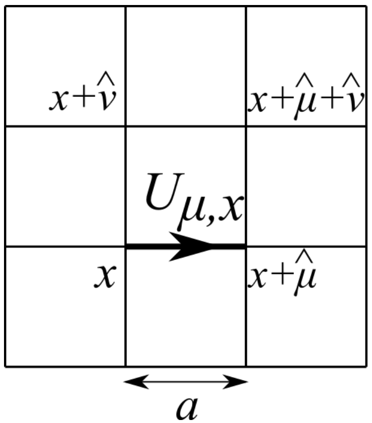
Strong-coupling study of Aoki phases in Staggered-Wilson fermion

T. Z. Nakano (YITP, Kyoto Univ.),
T. Misumi (YITP), T. Kimura (Univ. of Tokyo), and A. Ohnishi (YITP)



Lattice QCD and Doubling Problem

- Doubling Problem on the lattice QCD
  - Doublers (#16)
    : Extra degree of freedom in fermion on the lattice



- Nielsen-Ninomiya's theorem Nielsen, Ninomiya (1981)

Chiral symmetry ⇔ doublers

$SU(N_f)_L \times SU(N_f)_R$

Lattice Fermion

- Many kinds of lattice fermion : Simulation cost is high

Naive → Wilson → Overlap

#16

Chiral broken
(Wilson term)

#1

"Exact chiral sym."
(Ginsparg-Wilson relation)

#1

Doublers
→flavors

Staggered

#4

Staggered-Wilson Fermion

- New lattice fermion : Simulation cost is lower

Naive → Wilson → Overlap

#16 | Chiral broken (Wilson term) | #1 | "Exact chiral sym." (Ginsparg-Wilson relation) | #1

Doublers
→ flavors

Generalization

Adams (2011), Hoelbling (2011).
Creutz, Kimura, Misumi (2010)

D. H. Adams (2010)

Staggered → **Staggered -Wilson** → **Staggered -Overlap**

#4

Flavored mass

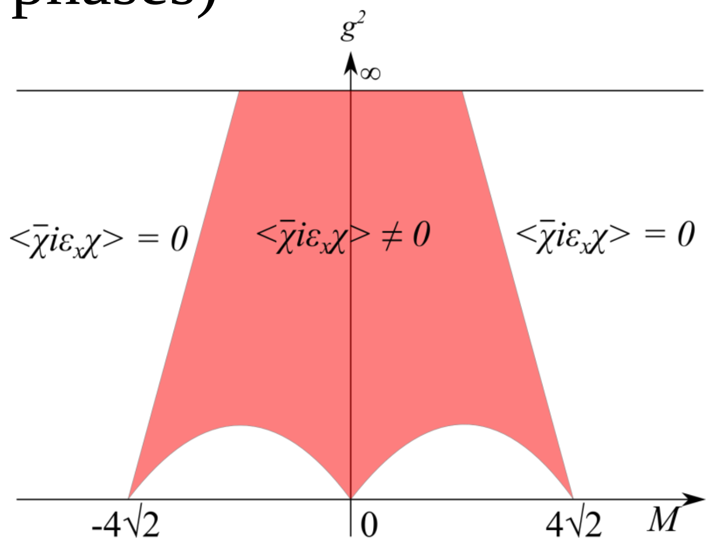
#1

#1

Aoki Phases in Staggered-Wilson fermion

- Check the properties of this fermion for the lattice QCD simulation.

- Study Aoki phases (Parity-broken phases) in Staggered-Wilson fermion at strong coupling limit.



ゼロおよび純虚数化学ポテンシャルにおける、3フレーバーQCDのクォーク質量依存性

arXiv : hep-ph/1105.3959

佐々木崇宏

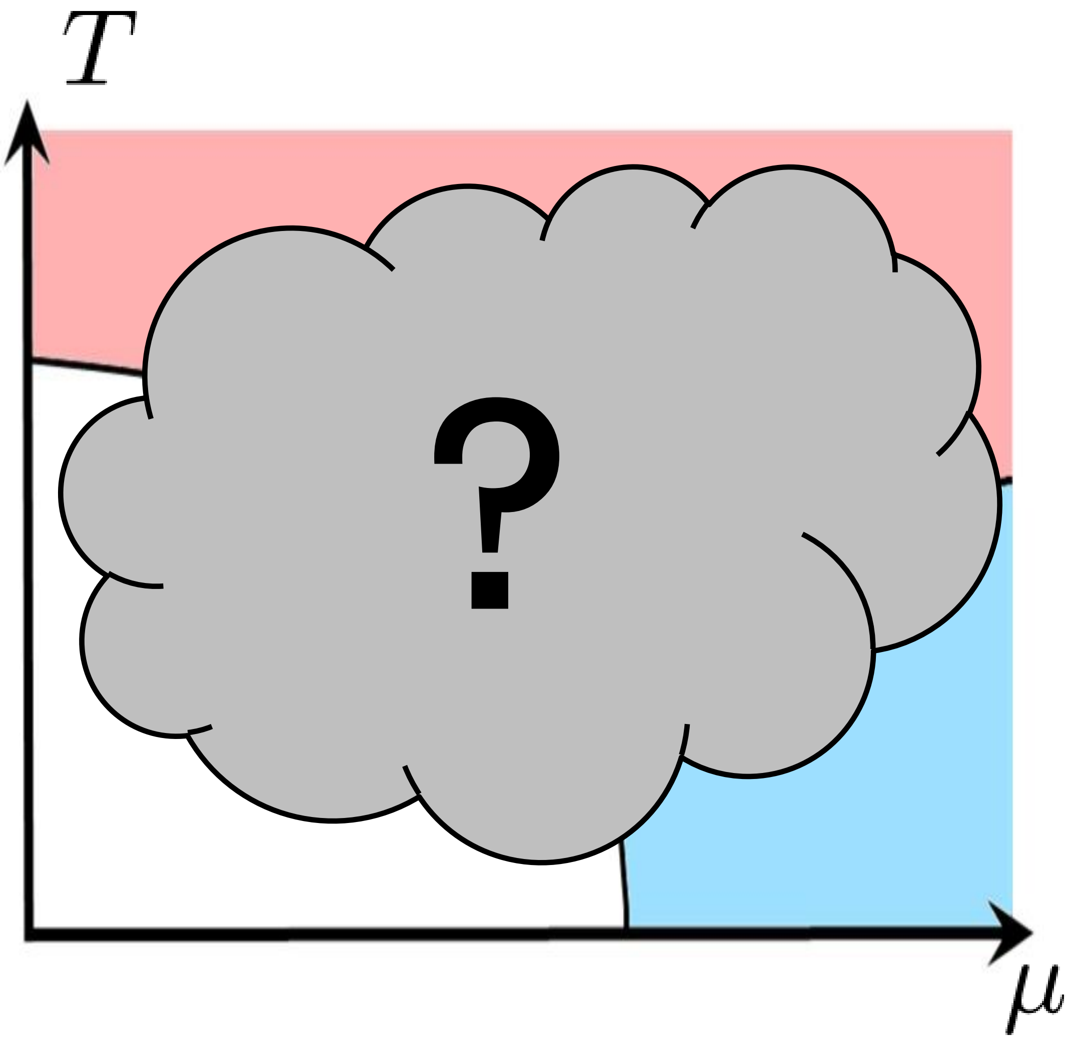
境祐二、河野宏明[A]、八尋正信

九大院理、佐賀大理工[A]

九州大学
KYUSHU UNIVERSITY

2011.8.22＠京都大学基礎物理学研究所
基研研究会「熱場の量子論とその応用」

目的　QCD相図の解明

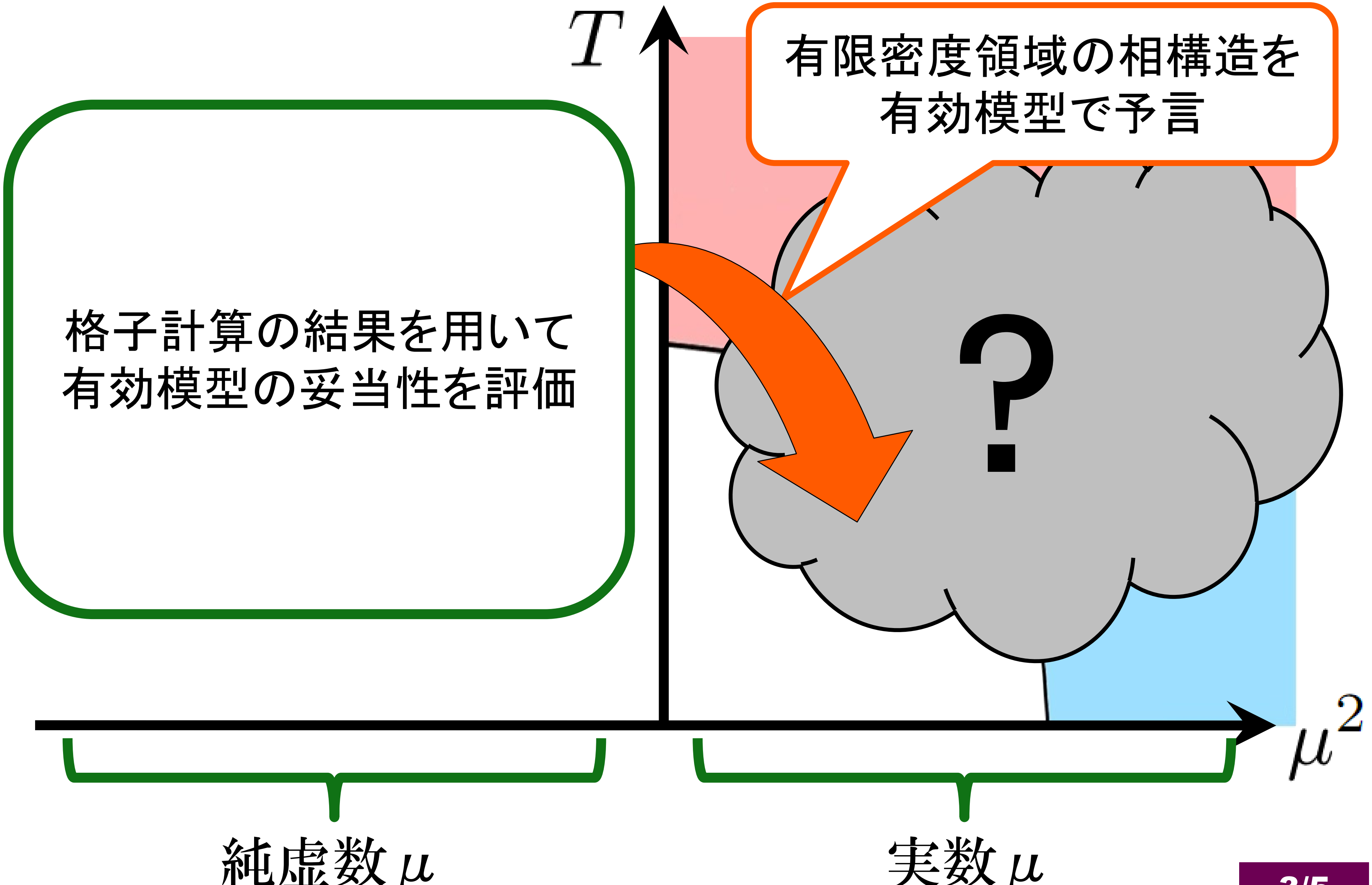


QCD相図は
宇宙進化の過程や
中性子星の構造を解析
するのに重要

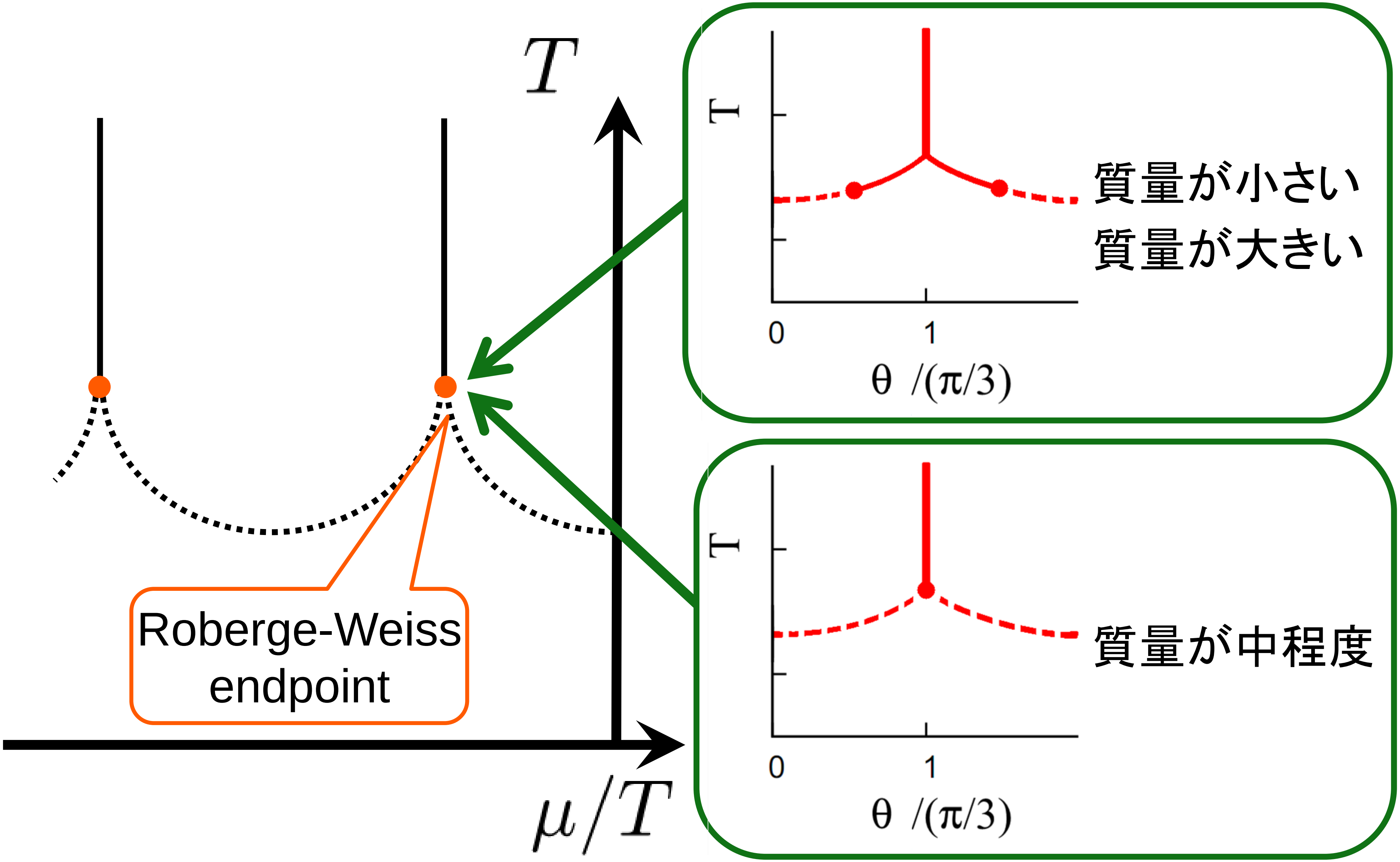
⇕

第一原理計算(格子QCD)が
有限密度で困難

方針　信頼性の高い有効模型で解析



情報 RW endpoint のクォーク質量依存性



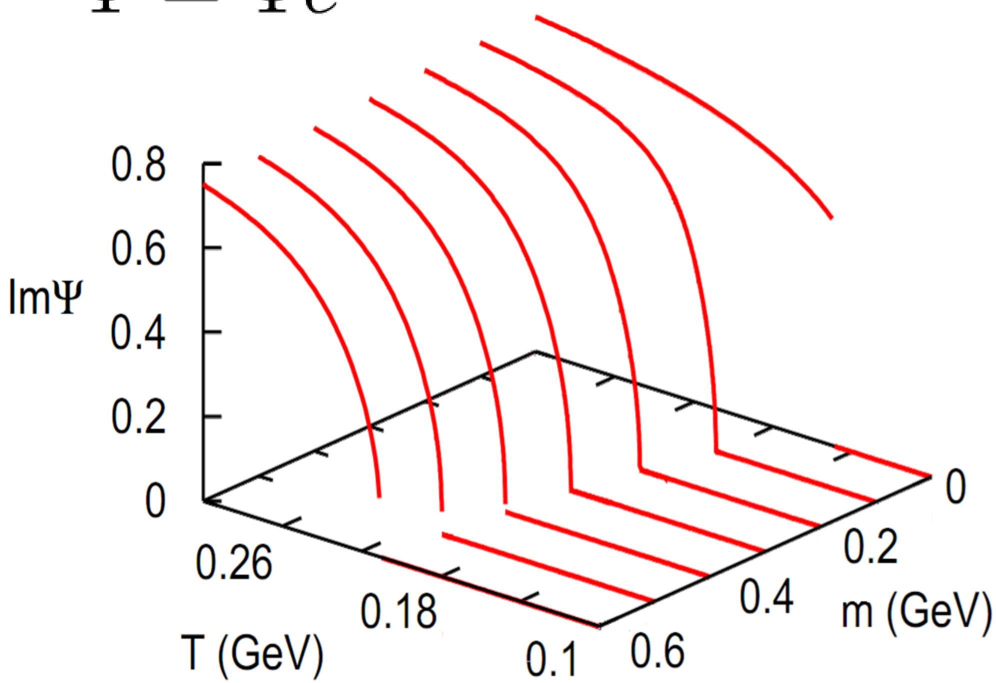
P. de Forcrand and O. Philipsen, Phys. Rev. Lett **105**, 152001, (2010)

結果

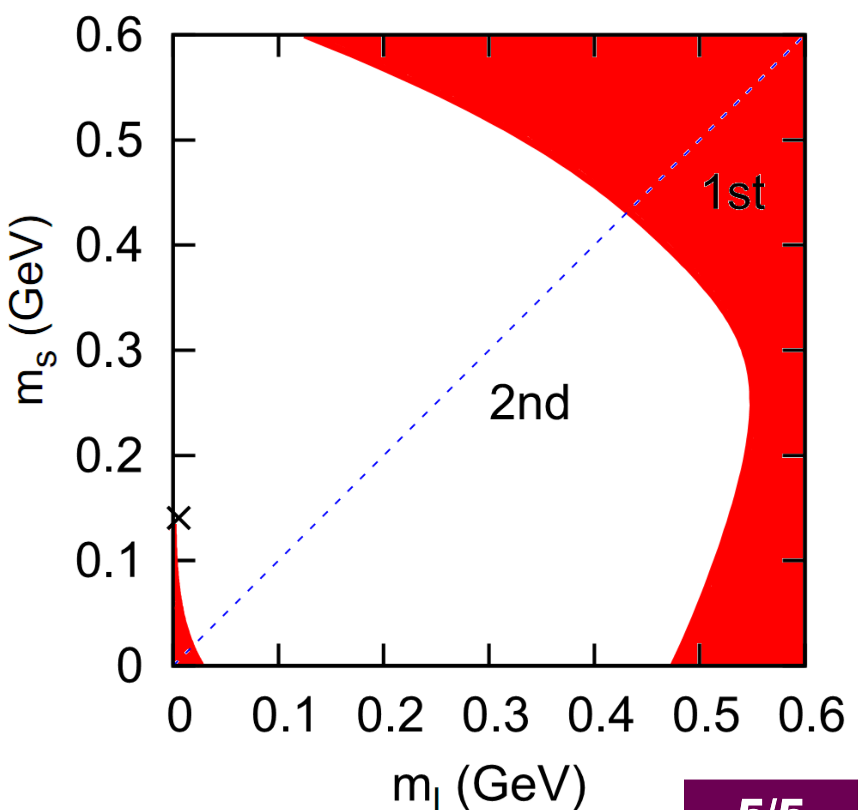
**Entanglement PNJL 模型は
格子計算の結果を再現できる**

$$m_l = m_s = m$$

$$\Psi = \Phi e^{i\theta}$$



RW endpoint の質量依存性

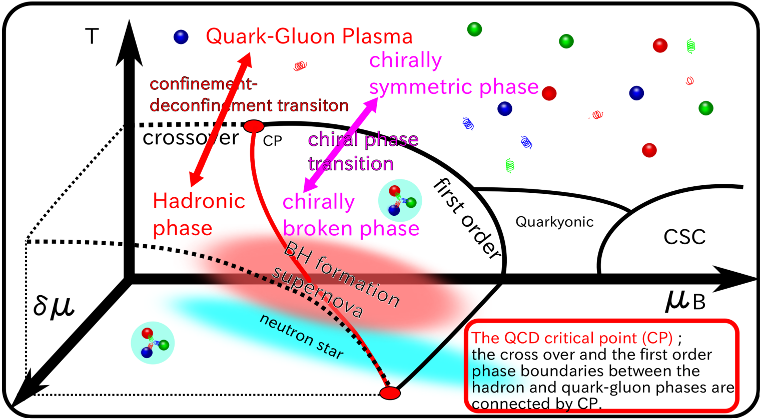


拡張されたPQM模型を用いたコンパクト天体現象におけるQCD相転移

H. Ueda[1] T. Z. Nakano[1,2] M. Ruggieri[2]
A. Ohnishi[2] K. Sumiyoshi[3]

Department of Physics, Faculty of Science, Kyoto University[1]
Yukawa Institute for Theoretical Physics, Kyoto University[2]
Numazu College of Technology[3]

The QCD phase diagram



- In compact astorophysical phenomena,

$$\delta\mu = \frac{\mu_d - \mu_u}{2} \neq 0$$

- In the dynamical black hole formation and supernova, neutrinoless β equilibrium is not realized.

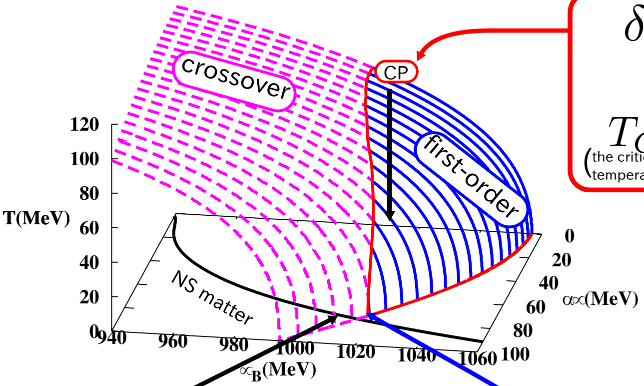
Objective and Methods

Objective

- We investigate the QCD phase diagram of asymmetric nuclear matter by using chiral effective model.
- We discuss the QCD phase transition during the BH formation and in compact stars.

Methods

- The QCD phase diagram
  - We calculate the phase boudary by using chiral effective model. $\cdots$ Polyakov quark meson model(PQM)*[Schaefer et al.,'07, V. Skokov et al.,'10]*.
- Compact astrophysical phenomena
  - BH formation $\cdots$ We use the BH formation profile, thermodynamical variable$(T, \mu_B, \delta\mu)$ calculated in the neutrino-radiation hydrodynamics.*[K. Sumiyoshi et al., Phys. Rev. Lett. 97 (2006) 091101.]*
  - NS core $\cdots$ We calculate thermodynamical variable$(\mu_B, \delta\mu)$ in NS by using a RMF model. *[A. Ohnishi et al., Phys. Rev. C 80, 038202(2009).]*



$\delta\mu \rightarrow$ large

$T_{CP} \rightarrow$ low

(the critical point temperature)

In NS,the quark matter transition becomes the crossover transition in this model and parameter set.

The first-order phase boudary vanish for large $\delta\mu$.

Please come to see our poster!

Thank you.

QCD Sum Rules Based on Canonical Commutator Relations

Tomoya Hayata
Phys. Dep. Univ. Tokyo

Collaborators: Tetsuo Hatsuda and Shoichi Sasaki

@基研研究会「熱場の量子論とその応用」

QCD Sum Rules [Shifman, Vainshtein & Zakharov, 79]

○ QCD sum rules = Dispersion relations + OPE;

$$\mathrm{T}[j_\mu(x), j_\nu(0)] = \sum_n c_n \hat{O}_n \ ,$$

$$(q_\mu q_\nu - q^2 g_{\mu\nu})\Pi(q^2) = i\mathrm{F.T.}\langle 0|\mathrm{T}[j_\mu(x), j_\nu(0)]|0\rangle \ ,$$

$$\Pi(Q^2) = \int \mathrm{d}s \frac{\rho(s)}{s+Q^2} \ .$$

E.g., rho meson $j^\mu = (\bar{u}\gamma^\mu u - \bar{d}\gamma^\mu d)/2$,

$$\int \frac{\mathrm{d}s}{2\pi} \frac{\rho(s)}{s+Q^2} = -\frac{1}{8\pi^2} \ln \frac{Q^2}{\mu^2} + \frac{1}{2Q^4}\big(\langle 0|m_q \bar{q} q|0\rangle + \langle 0|\frac{\alpha_s}{12\pi} G^2|0\rangle\big) + \frac{1}{Q^6} \cdots \ .$$

$$\int \frac{\mathrm{d}s}{2\pi} (\rho(s) - \frac{1}{4\pi}) = 0 \ ,$$

$$\int \frac{\mathrm{d}s}{2\pi} s(\rho(s) - \frac{1}{4\pi}) = -\frac{1}{2}\big(\langle 0|m_q \bar{q} q|0\rangle + \langle 0|\frac{\alpha_s}{12\pi} G^2|0\rangle\big) \ ,$$

$$\vdots \quad .$$

Thomas-Reiche-Kuhn Sum Rules in QFT

$$
\begin{aligned}
(q_\mu q_\nu - q^2 g_{\mu\nu})\Pi(q^2) &= i\mathrm{F.T.}\langle 0|\mathrm{T}[j_\mu(x), j_\nu(0)]|0\rangle \ , \\
(q_\mu q_\nu - q^2 g_{\mu\nu})\rho(q^2) &= \sum_p (2\pi)^4 \delta^{(4)}(q-p)\langle 0|j_\mu(0)|p\rangle\langle p|j_\nu(0)|0\rangle \ , \\
\Pi(Q^2) &= \int \mathrm{d}s \frac{\rho(s)}{s+Q^2} \ .
\end{aligned}
$$

Naïve TRK sum rules in the relativistic theory;

$$
\int_0^\infty \mathrm{d}s\ s^n \rho(s) = -\frac{1}{3}\int \mathrm{d}^3x\ \langle 0|[[j_\mu(0,x), \underline{H]\cdots]}_{2n-1}, j^\mu(0,0)]|0\rangle \ .
$$

For an asymptotic free theory, we can calculate the UV behavior of spectral function.

$$
\rho(s) \to \mathrm{const}(s \to \infty)
$$

We consider the renormalization.

○ UV divergence = Pertubative divergence.

$$
\int_0^\infty \mathrm{d}s\ s^n (\rho(s) - \rho^{\mathrm{con}}(s)) = -\frac{1}{3}\int \mathrm{d}^3x\ \langle 0|[[j_\mu(0,x), \underline{H]\cdots]}_{2n-1}, j^\mu(0,0)]|0\rangle_{\mathrm{NP}} \ .
$$

Canonical QCD Sum Rules

$$\int_0^\infty \frac{\mathrm{d}s}{2\pi}\, s(\rho_V(s) - \rho_V^{\mathrm{con}}(s)) = -\frac{1}{2}\Big(\langle 0|m_u\bar{u}u|0\rangle_{\mathrm{NP}} + \langle 0|m_d\bar{d}d|0\rangle_{\mathrm{NP}}\Big)\ ,$$

$$\int_0^\infty \frac{\mathrm{d}s}{2\pi}\, s(\rho_A(s) - \rho_A^{\mathrm{con}}(s)) = \frac{5}{6}\Big(\langle 0|m_u\bar{u}u|0\rangle_{\mathrm{NP}} + \langle 0|m_d\bar{d}d|0\rangle_{\mathrm{NP}}\Big)\ ,$$

$$\int_0^\infty \frac{\mathrm{d}s}{2\pi}\, s(\Delta\rho(s) - \Delta\rho^{\mathrm{con}}(s)) = \frac{4}{3}\Big(\langle 0|m_u\bar{u}u|0\rangle_{\mathrm{NP}} + \langle 0|m_d\bar{d}d|0\rangle_{\mathrm{NP}}\Big)\ ,$$

$$\begin{aligned}\int_0^\infty \frac{\mathrm{d}s}{2\pi}\, s^2(\Delta\rho(s) - \Delta\rho^{\mathrm{con}}(s)) &= -\frac{4}{3}(\langle 0|m_u^3\bar{u}u|0\rangle_{\mathrm{NP}} + \langle 0|m_u^3\bar{u}u|0\rangle_{\mathrm{NP}}) \\ &+ 8\pi\alpha_s\langle 0|(\bar{u}_L\gamma_\mu t^a u_L - \bar{d}_L\gamma_\mu t^a d_L)(L \leftrightarrow R)|0\rangle_{\mathrm{NP}}\ .\end{aligned}$$

○ Ch-SB part CQSR = OPE.
○ There is no pure gluon condensation.
○ Up to linear order of quark mass, CQSR reduces Weinberg's Sum rule (V-A) .

有限温度での ボトモニウムにおける QCD和則のMEM解析

発表者　鈴木 渓[A]

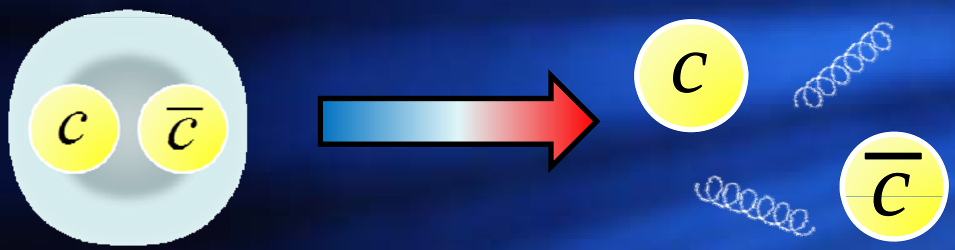
共同研究者　Philipp Gubler[A]、森田 健司[B]、岡 真[A]

所属　東工大[A]、京大基研[B]

研究概要 outline

- 研究の背景

  臨界温度付近で<u>クォーコニウムが溶ける</u>



- 研究の目的

  <u>溶ける温度</u>を求める

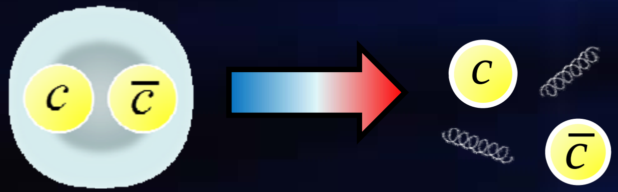
- 研究方法

  <u>MEM</u>を用いた<u>QCD sum rule</u>

クォーコニウム抑制 quarkonium suppression

- J /Ψ抑制　T. Matsui and H. Satz, Phys. Lett. B**178**, 416 (1986)
  T. Hashimoto et al. , Phys. Rev. Lett. **57**, 2123 (1986)

  高温・高密度状態でJ /Ψの収量が抑制される　⇒QGP生成のシグナル？

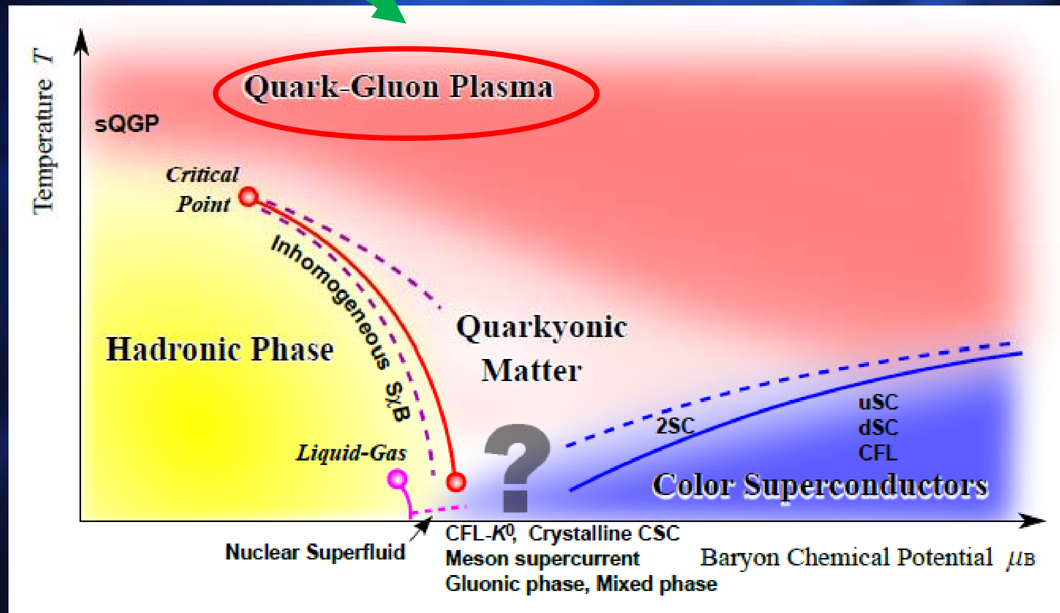


- この現象を理論的に再現するには？

—クォーク間ポテンシャルを見る

—スペクトル関数を見る

—波動関数を見る



QCD和則 QCD sum rule

- QCD和則

M.A. Shifman, A.I. Vainshtein, and V.I. Zakharov, Nucl. Phys. B**147**, 385 (1979); B**147**, 448 (1979)

—QCDの非摂動的な情報を扱う手法

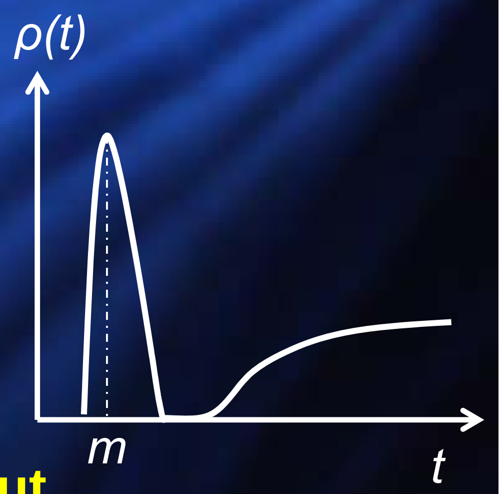
—<u>演算子積展開(OPE)</u>から得られる相関関数と<u>スペクトル関数</u>を結ぶ関係式

$$\Pi_{\mathrm{OPE}}(q^2) = \int_0^\infty \frac{\rho(t)}{t - q^2} dt$$

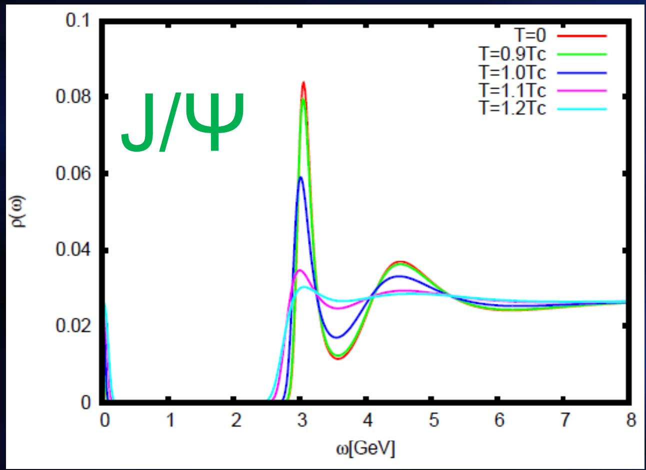
OPEをinput

<u>MEM</u>を用いて
スペクトル関数をoutput

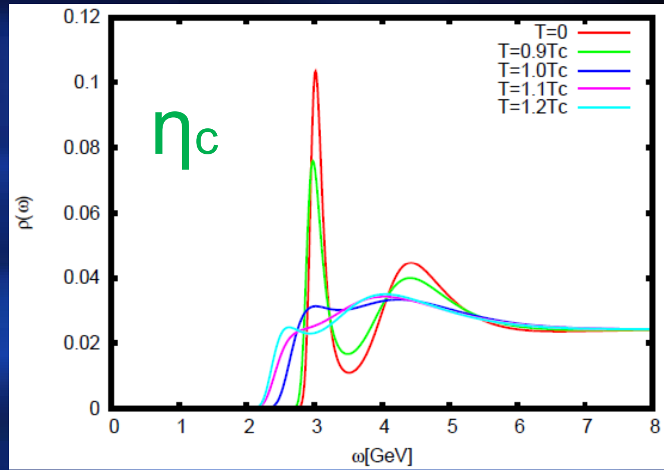
→ <u>一粒子状態</u>が求まる



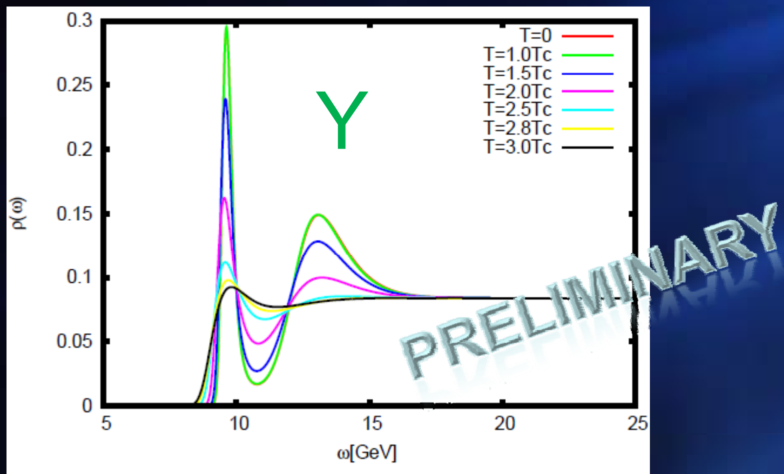
解析結果



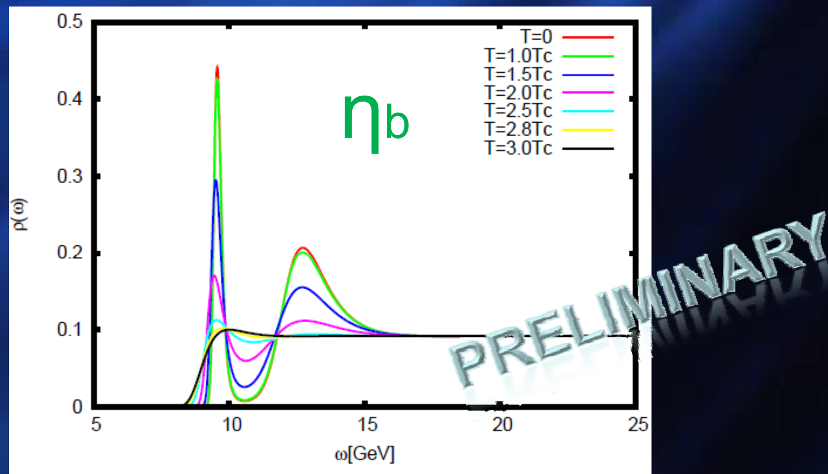
J/Ψの消失温度は1.0Tc～1.1Tc



ηcの消失温度は0.9Tc～1.0Tc



Υの消失温度は2.8Tc以上



ηbの消失温度は2.5Tc以上

純粋状態量子力学の
熱力学への変質

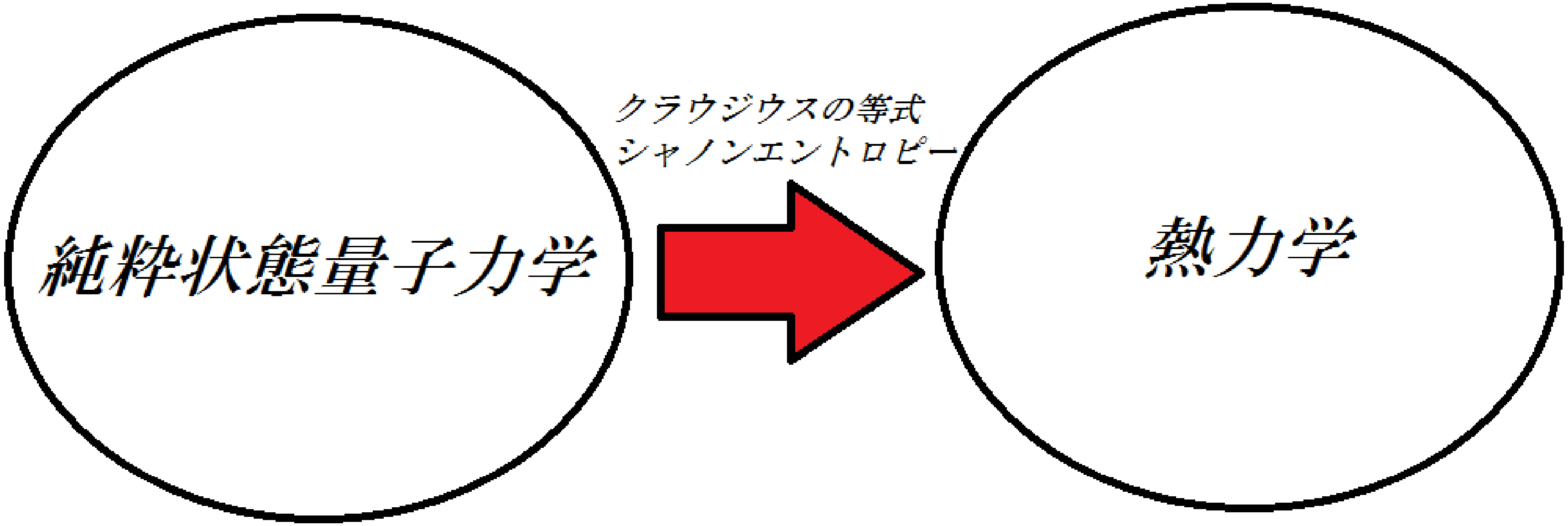
三重大学工学研究科　博士前期課程　奥山進治

アウトライン

1. 序論
2. 純粋状態量子力学における類似物の決定
3. 井戸型ポテンシャルの2準位モデル
4. Entropyと温度を基本とした類似性の解釈
5. 結論

S. Abe and S. Okuyama, Phys. Rev. E **83**, 021121 (2011).

概要



カルノーサイクルの効率はどうなるか？

純粋状態から混合状態への顕わな崩壊は現れるか？

どう考察するか？

① Hamiltonianの期待値を
内部エネルギーEと対応させる。

$$E = \langle\psi| H |\psi\rangle$$

② Hamiltonianの変化を仕事の変化と対応させ、熱力学第一法則と比較する。

$$\underbrace{\delta E}_{\delta E} = \underbrace{(\delta \langle\psi|) H |\psi\rangle + \langle\psi| H (\delta |\psi\rangle)}_{\delta' Q} + \underbrace{\langle\psi| \delta H |\psi\rangle}_{-\delta' W}$$

δE
内部エネルギーの変化

$\delta' Q$
熱量の変化

$-\delta' W$
仕事の変化

ぜひ見に来てご意見お聞かせください。