Study of the QGP physics in center vortex picture
センターボーテックス描像によるQGP物理の研究

(1) Thermal gluon propagators in the infrared region and
(2) a trial for transport coefficients
in terms of the center (magnetic) vortex mechanism

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Quark gluon plasma (1)

- sQGP
  - Heavy-ion experiment (RHIC,2004) produces a quark gluon plasma, which may exceed the temperature of the deconfinement phase.
  - *Not free gas but …* :
    - Perfect fluid , Hydro calc. and elliptic flow,
    - Jet-quenching,
    - Small shear viscosity (also by lattice simulations); short mean-free path, etc.
  - Picture of *strongly interacting QGP (sQGP)* has been established now.

Quark gluon plasma (2)

- *Properties of sQGP ?*
  - Some peculiar lattice results (*spatial Wilson loop, magnetic masses, instantaneous potential*, etc.) show a confining behavior above T_c. Its temperature dependence may be described as magnetic scaling ($g^2(T)T$).
  - *Are magnetic degrees of freedom so important ?*
  - Interesting idea: Magnetic plasma made of monopole and/or center (magnetic) vortex:
    I. Liao and Shuryak, PRC75(2007)054907;PPNP62(2009)48.
    II. Chernodub and Zakharov, PRL98(2007)082002.
    III. Chernodub, Nakamura, Zakharov, PRD78,074021(2008).
  - However, there is *no clear connection between thermal gluons as a basic element of QCD (or QGP) and topological objects*.

Maximal center projection

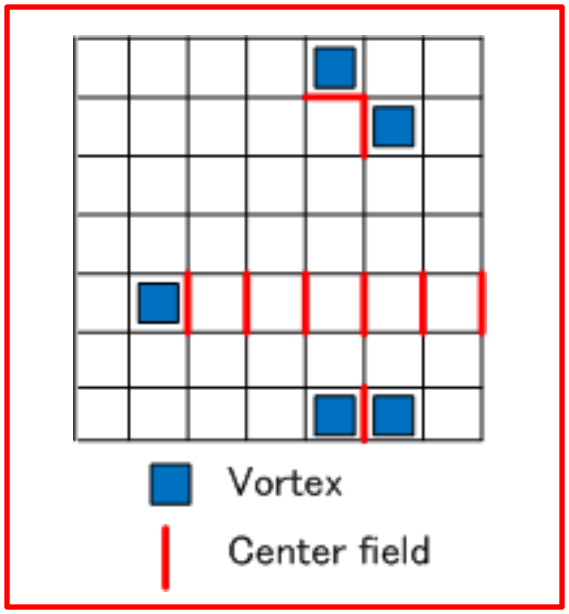
- Numerical technique
  - Direct Maximal Center Projection (MCP) by *Debbio, et. al, PRDv58,094501*
- We apply the MCP to all configurations of the SU(2) gauge field

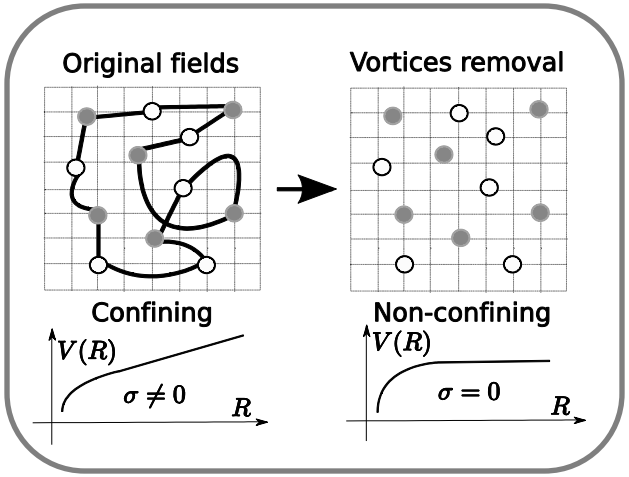
$$\text{All the Us} \Rightarrow \pm \mathrm{I} \quad \text{Maximize } R = \frac{1}{VT}\sum_{x,t} \mathrm{Tr}\left[U_\mu(x,t)\right]^2$$
$$Z_\mu(x) = \mathrm{sgn}\,\mathrm{Tr}\left[U_\mu(x)\right]$$

- Removing center vortex (via *de Forcrand – D'Elia procedure,PRL82,4582(1999)*):

$$U_\mu(x) \to U'_\mu(x) = Z_\mu(x) U_\mu(x)$$

→ *Color confinement disappears and chiral symmetry restores.*

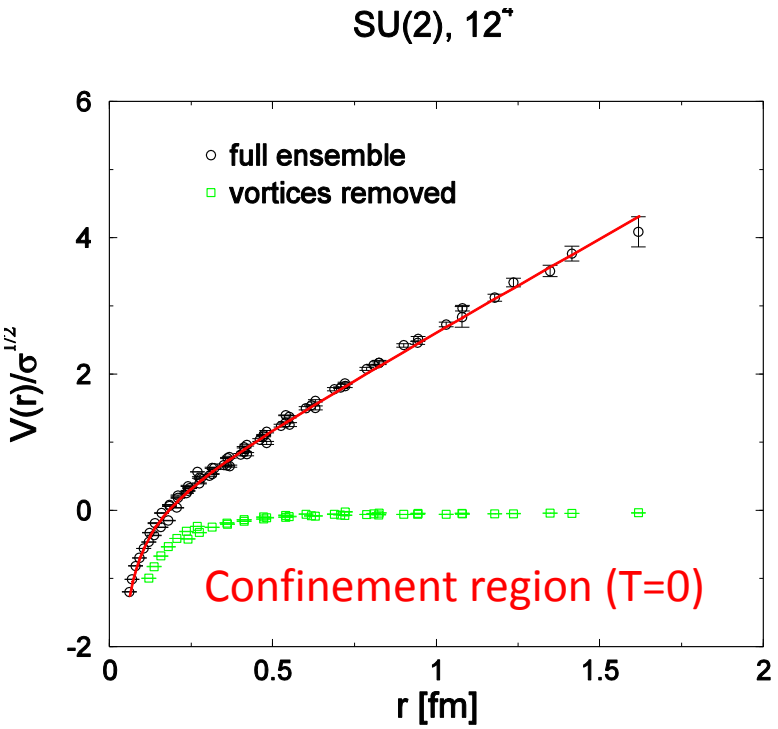




- *Vortices carry the non-perturbative IR physics of QCD*
- *Handling vortices numerically enables us to switch on/off non-perturbative mode !! In particular, this technique shall be applied to the QGP physics.*

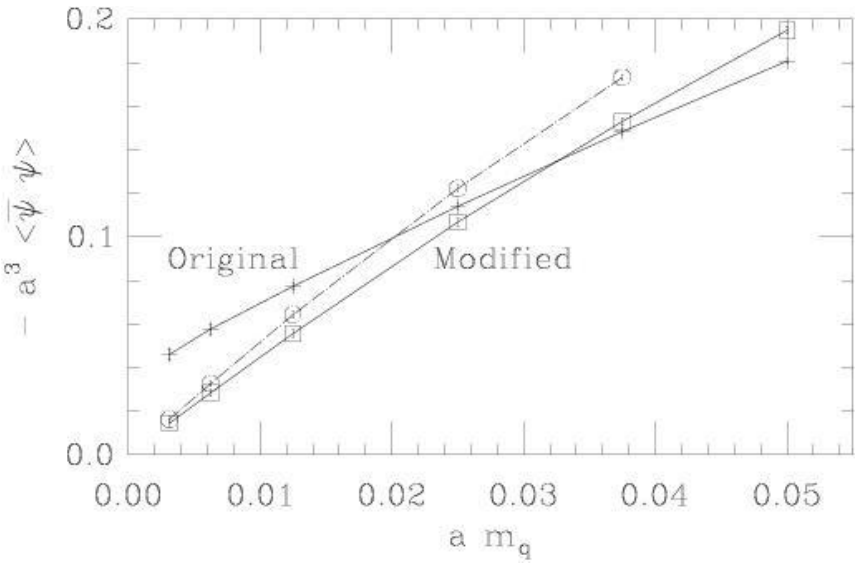
Example on the lattice

Removing vortices eliminates confinement.



"SU(2) gluon propagators from the lattice – a preview", hep-lat/0104003, Kurt Langfeld

Removing vortices restores chiral symmetry



Relevance of Center Vortices to QCD; Forcrand and D'Elia, PRL82,4582

Lattice setup

◆ SU(2) lattice calculation with quenched Wilson-gauge action

◆ Landau (Coulomb) gauge on the lattice in the path-integral formula satisfies the following condition:

$$\partial_\mu A_\mu(x,t)=0 \;\Rightarrow\; \text{Maximize } R=\frac{1}{VT}\sum_{x,t}\text{Re}\,\text{Tr}\,U_\mu(x,t)\left|\sum_\mu \text{Tr}\,\sigma^a\left(U_\mu(x)-U_\mu(x-\hat{\mu})\right)\right|^2 \le 10^{-eps}$$

Wilson-Mandula Method (PLB185,127(1987))

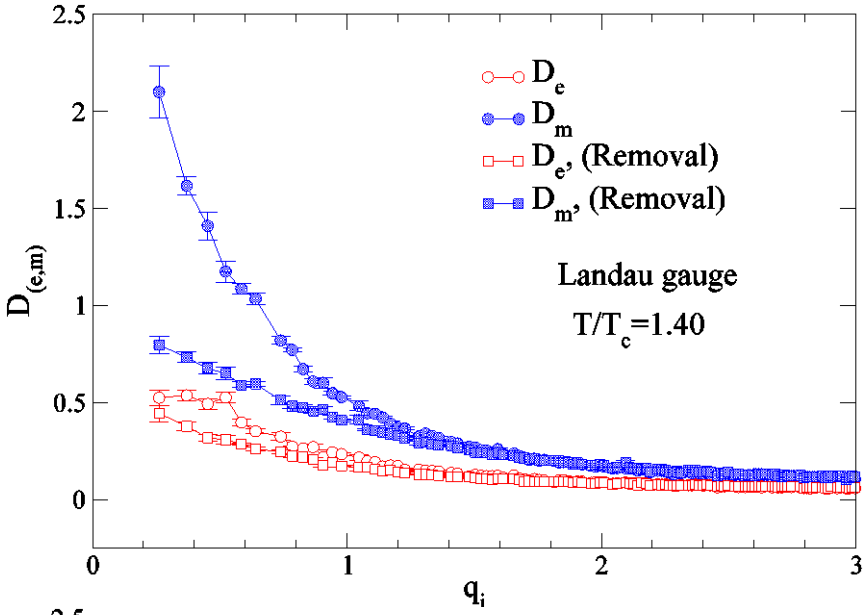
◆Parameters:

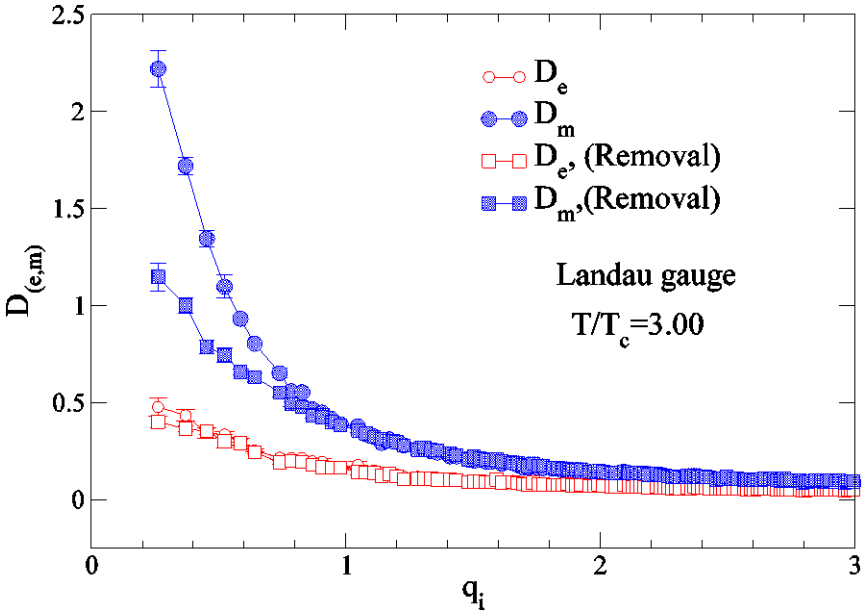
- ◆ Lattice size : 24x24x24x4
- ◆ beta : 2.2-2.6, corresponding to the temperatures T/T_c are approx. 1.40, 3.00 and 6.00.
- ◆ Configurations: 10k dicarded and about 20-30 confs. are used to measure.
- ◆ Convergence criteria: eps = 10^{-8} for gauge fixing and eps = 10^{-16} for maximal center projection.

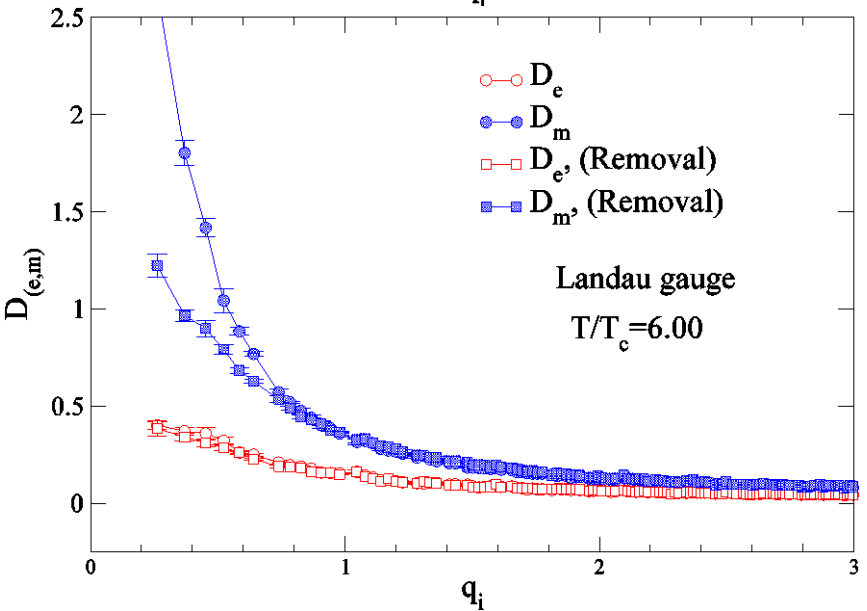
◆Procedure:

Gauge updated --> Maximal center projection --> Gauge fixing

Gluon propagators in the Landau gauge



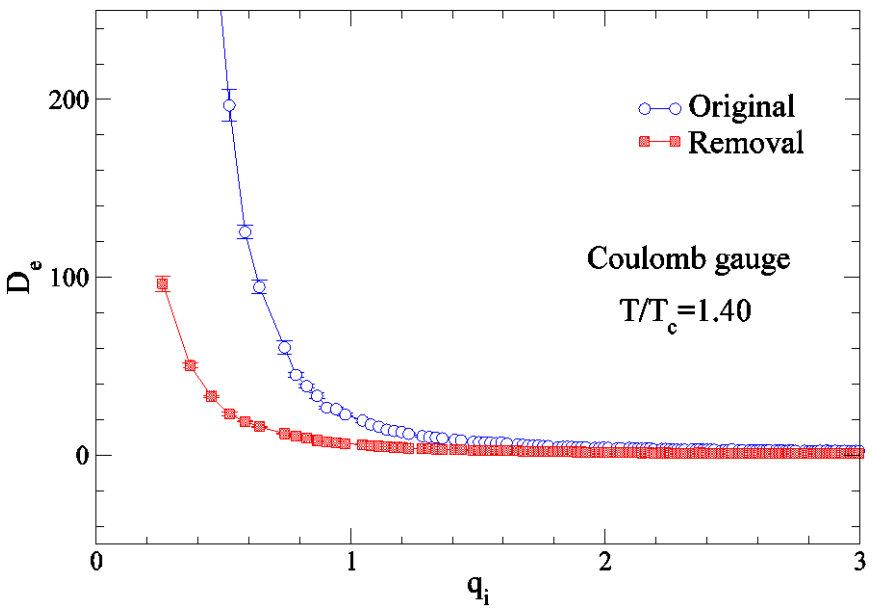


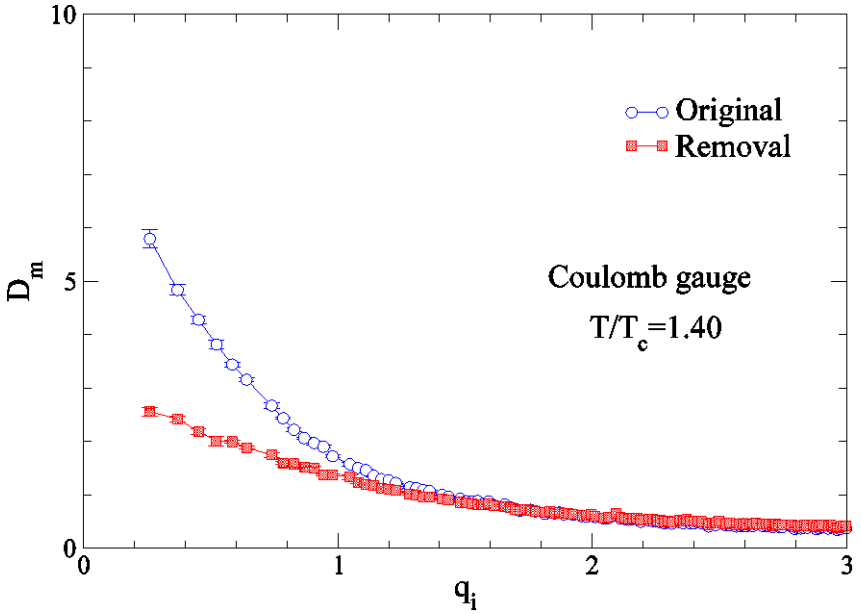


- *Gluon propagators drastically change in infrared regions, in particular for magnetic sector.*
- *At higher T (LHC temp.), the center vortices affect the gluon propagators.*

Gluon propagators in the confinement regions; *Gattnar, et. al. PRL93(2004)061601*

Gluon propagators in the Coulomb gauge





Gribov-Zwanziger confinement scenario for the Coulomb gauge QCD survives in QGP.

(*Greensite, et. al, PRD67,094503(2003);PRD69,074506(2004);*
Nakagawa, et.al, PRD73 (2006) 094504)

◆Time-time (electric) correlator diverges in the infrared limit.

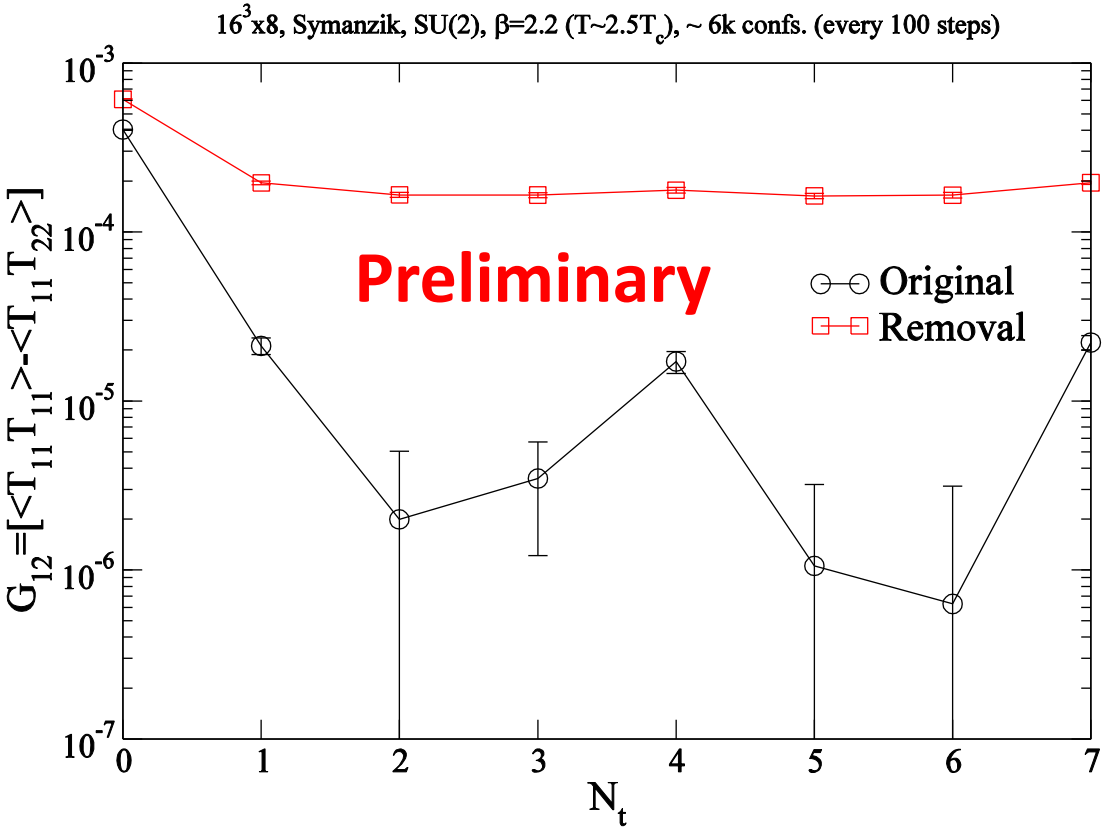
→ Instantaneous linearly rising potential and non-zero thermal string tension that depends on magnetic scaling. (*More detail will be given by Nakagawa's talk and poster.*)

◆Spatial-Spatial (magnetic) correlator is suppressed in the infrared limit.

◆The same behavior occurs in the deconfinement phase; *there exists confinement caused by magnetic degrees of freedom in the QGP phase*.

Transport coefficient

◆ Calculation of trasport coefficient after/before center removal (in progress).



Thermal correlator of energy-momentum tensor relating to the shear viscosity after/before center removal.

Transport coefficients are affected in center vortices in the QGP phase.

(It needs more statistics !)

Summary of this talk

◆We have studied the sQGP physics *via the lens of center vortex mechanism*.

◆In Landau and Coulomb gauges, the magnetic sector is very singular even in the QGP phase.

◆ *Magnetic degrees of freedom cause (magnetic) confinement in the deconfinement phase*. We have to consider this point properly to understand sQGP.

◆ Also, transport coefficients know center vortices in the QGP phase.