

DISCOVERING NOVEL PHASES OF HOT NUCLEAR MATTER WITH FLUCTUATIONS (HotDISCO)

Alexander Rothkopf

Department of Physics
Korea University
South Korea

A FKPPN / PHC STAR / 한 프랑스 협력기반조성사업 project

PIs: Marlene Nahrgang (SUBATECH, IMT Atlantique), Alexander Rothkopf (Korea University)

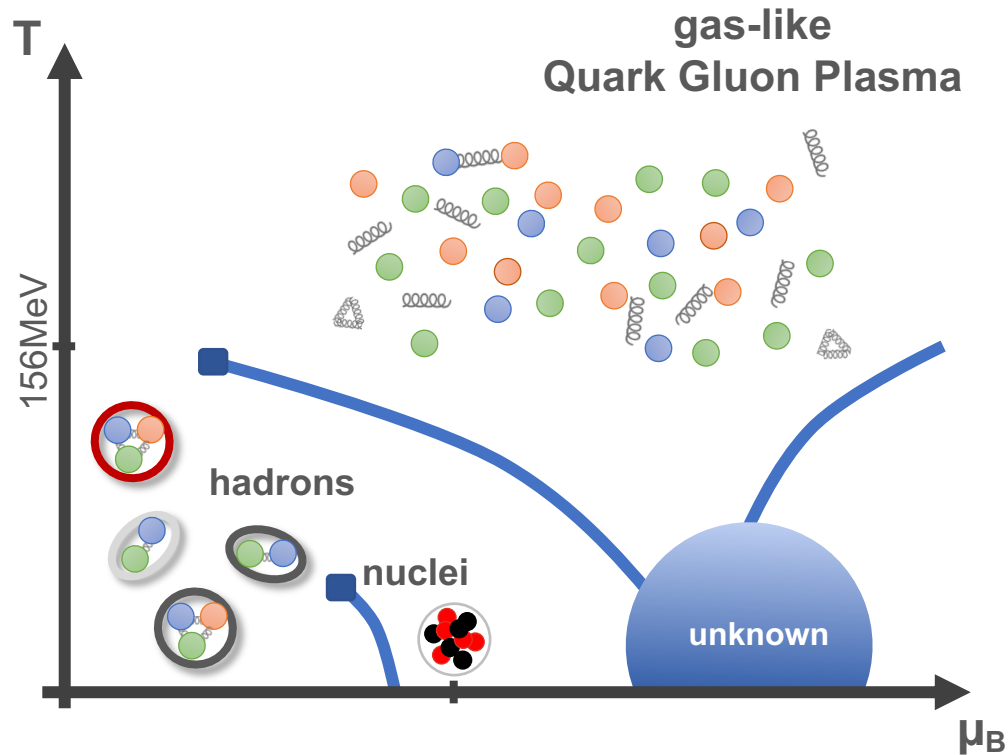
Project members: Marcus Bluhm, Kirill Boguslavski, Stéphane Peigné (SUBATECH)

HotDISCO workshop – Korea University – March 18-19 2027

- Physics motivation: hints for novel phases of QCD
- HotDISCO collaboration (Team & Workpackages)
- Status report: fiscal year 2025 & 2026

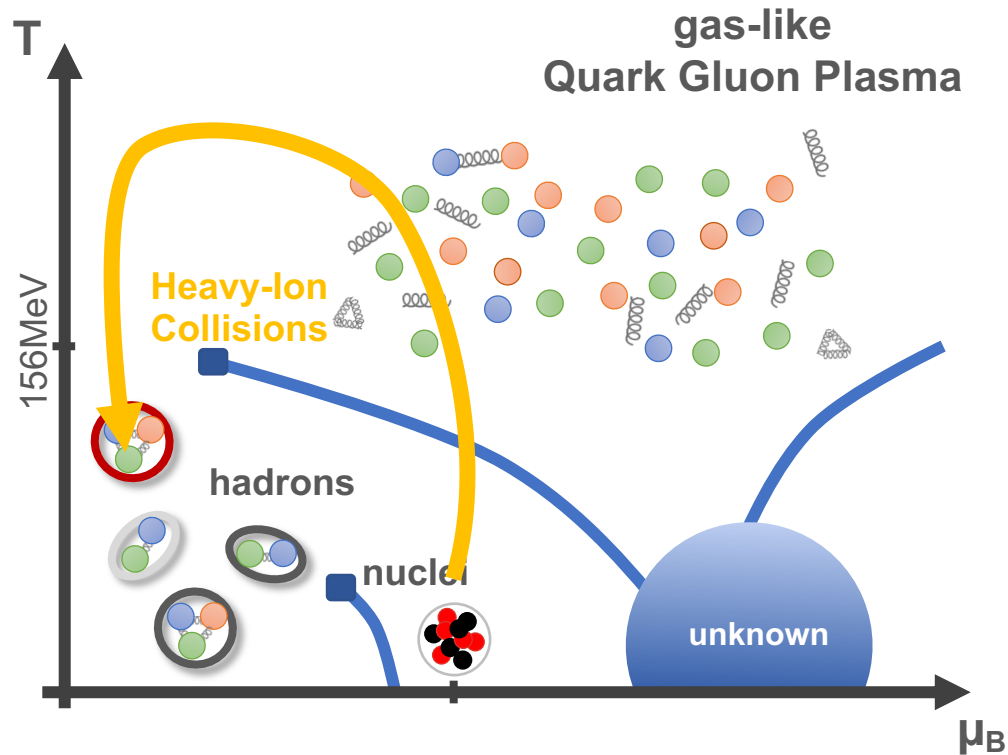
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The phases of nuclear matter



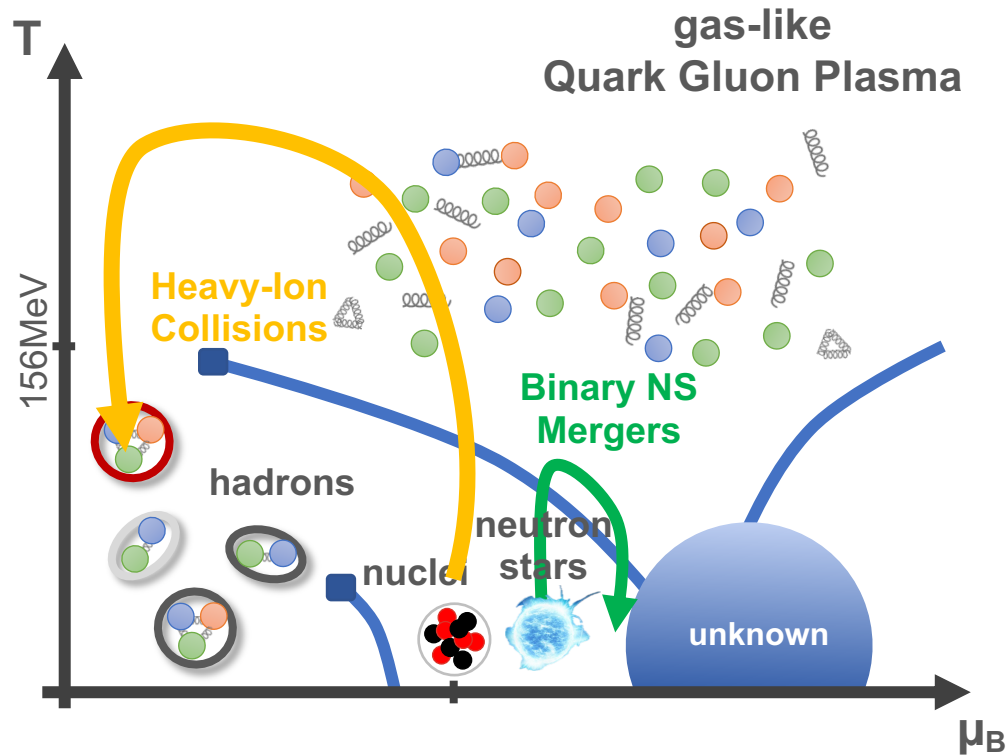
see e.g. Hatsuda & Fukushima RPP 74 (2011) 014001

The phases of nuclear matter



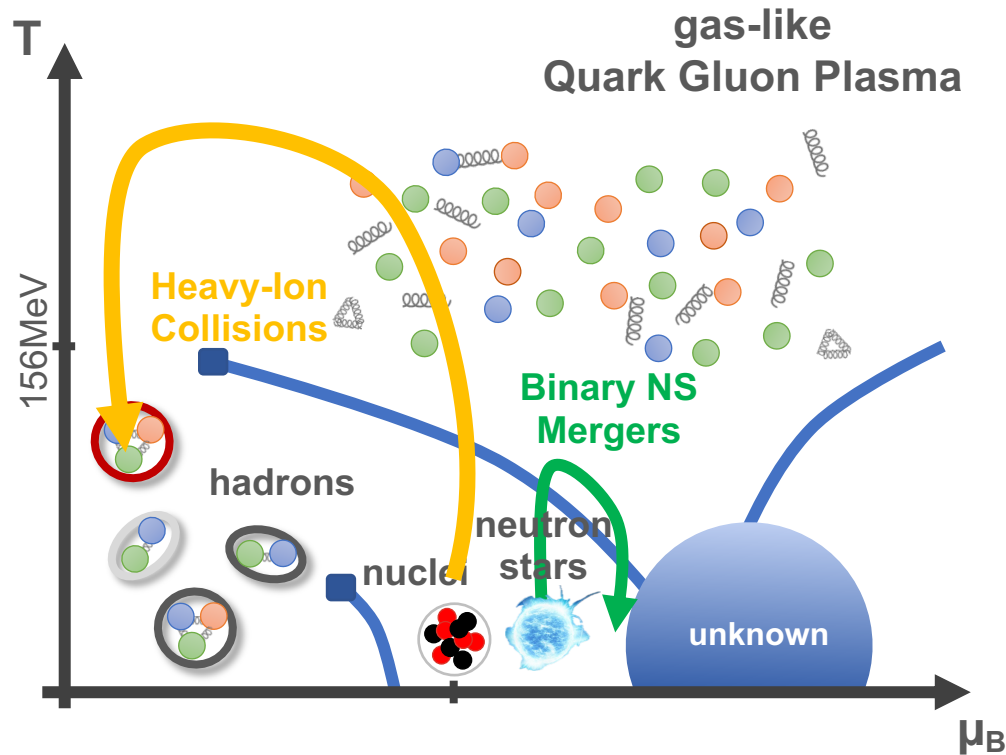
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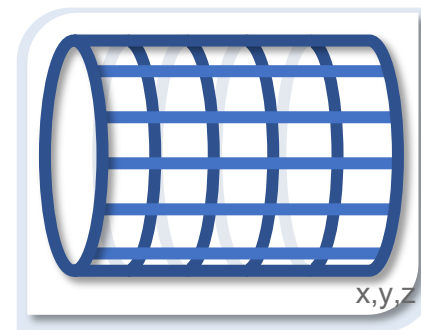
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chiral symmetry restoration & deconfinement as key indicators of phase change

Lattice QCD – a first principle tool

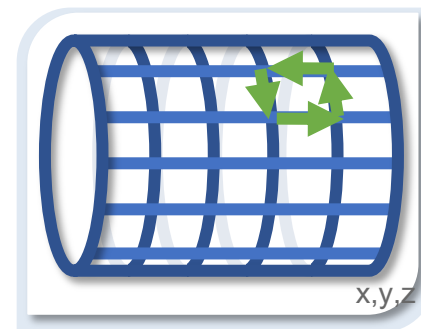


- Non-perturbative 1st principles approach to Quantum Chromo Dynamics



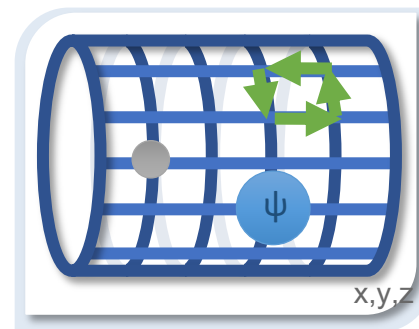
Lattice QCD – a first principle tool

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 - Gauge fields as links: $U_\mu(x) = \exp[i g \Delta x_\mu A_\mu(x)]$



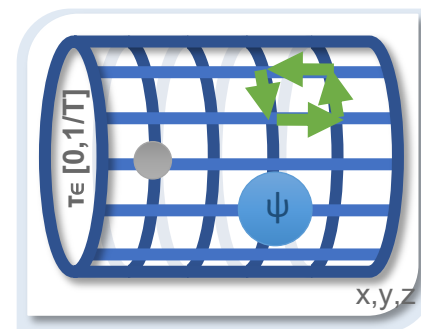
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 - Finite extent in **imaginary** time: $1/T = \beta = N_\tau a_\tau$

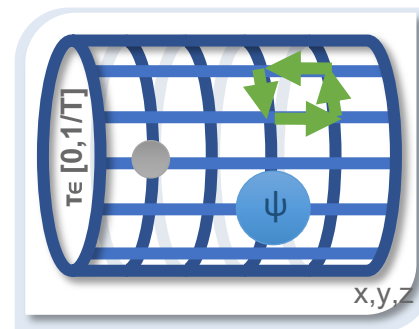


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$$\langle O(\mathbf{u}) \rangle = \int \mathcal{D}\mathbf{u} O(\mathbf{u}) e^{-S_E^{\text{QCD}}[\mathbf{u}]}$$

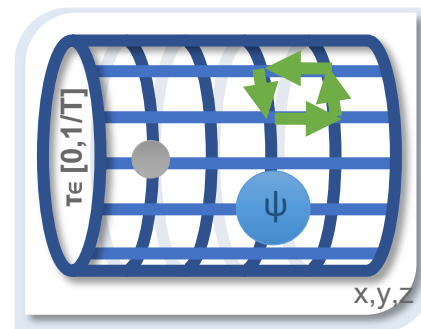


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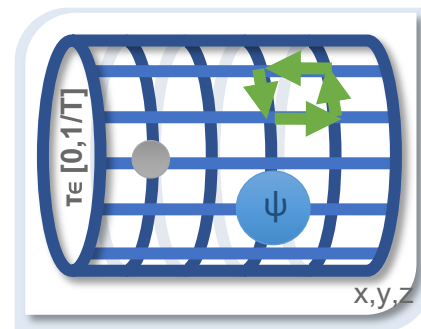
$$\langle O \rangle = \frac{1}{N} \lim_{N \rightarrow \infty} \sum_{k=1}^N O(U^k) \quad P[U] \propto e^{-S_E[U, \psi, \bar{\psi}]}$$



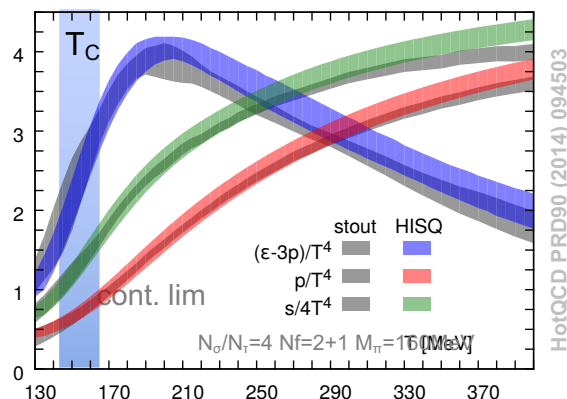
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Successful at $T > 0$: QCD medium properties at $\mu_B = 0$

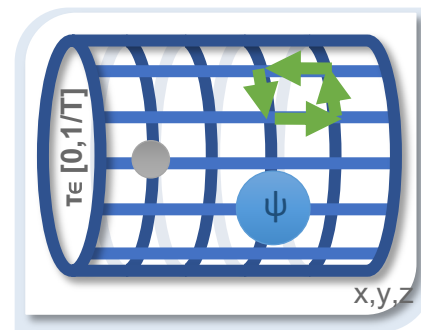
- Crossover from **chiral restoration**: 156.5 ± 1.5 MeV

HotQCD PLB 795 (2019) 15

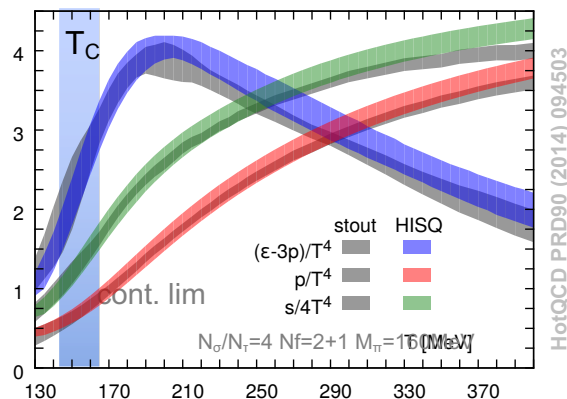
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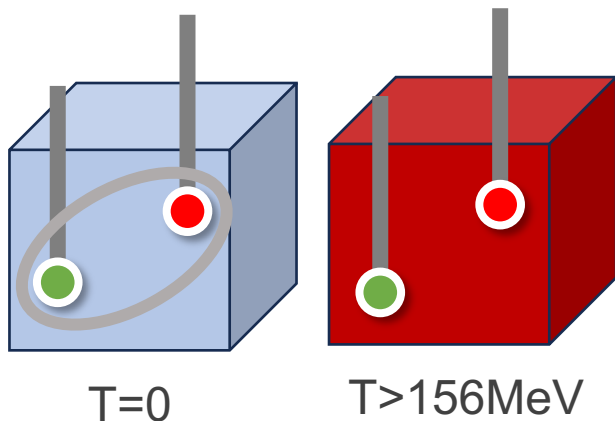
HotQCD PLB 795 (2019) 15

- Equation of state as input for hydro-dynamics

HotQCD PRD90 (2014) 094503 - WB PLB730 (2014) 99-104

The heavy quark potential – gluonic medium

Fate of **deconfinement**?



Intuition from QED plasmas:

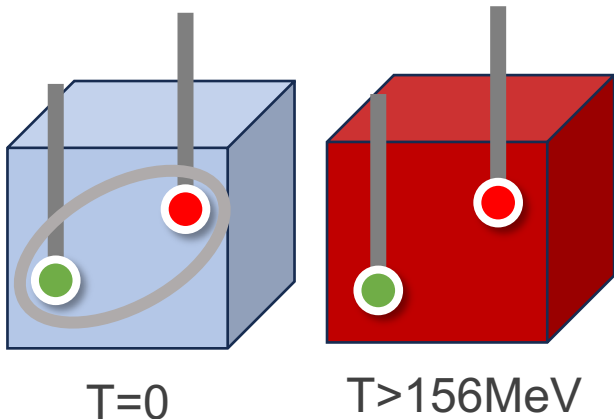
1) Free charge carriers **screen** $\text{Re}[V]$

Color d.o.f. in QCD:

2) Color **decoherence** induces $\text{Im}[V]$

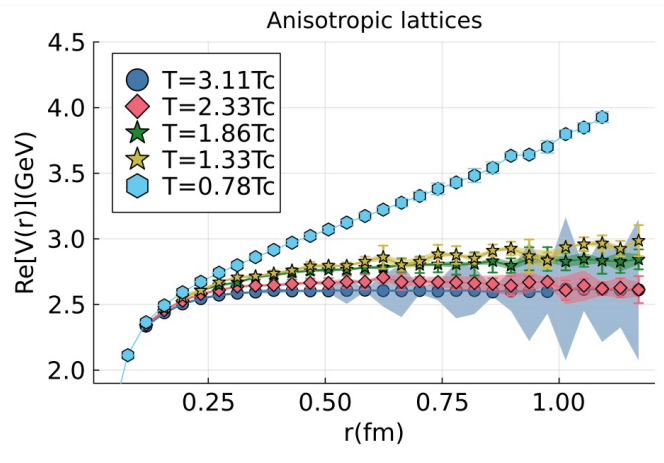
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$\beta=7 \quad \xi=3.5$

$N_\tau=20-96$

$N_s=64$

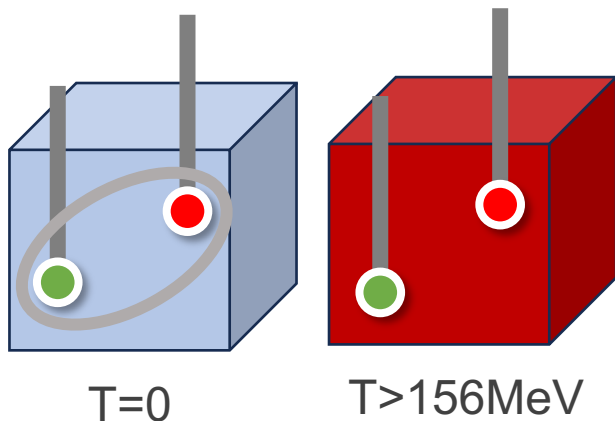
naive anisotropic

Wilson action

R. Larsen et.al.
 PRD 110 (2024) 11, 114501

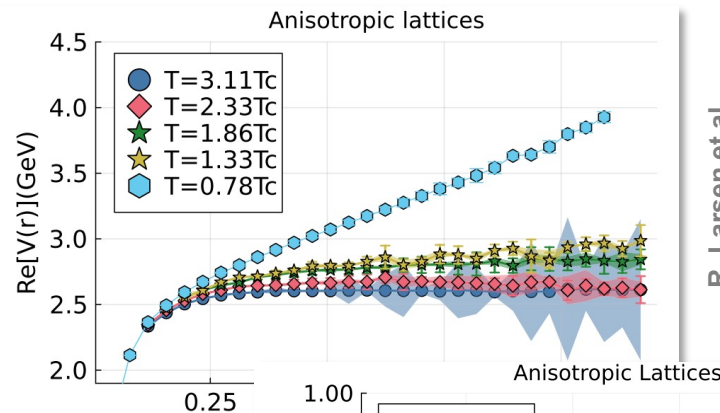
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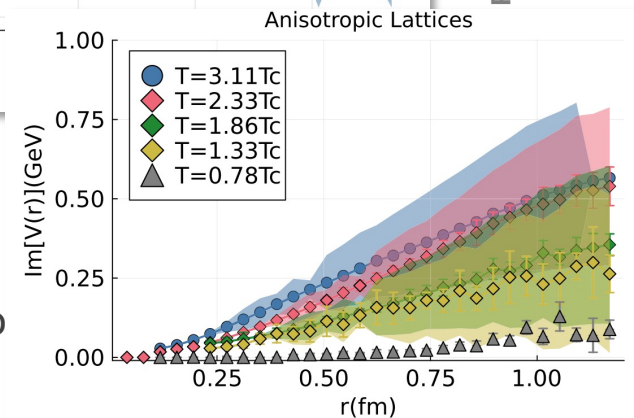
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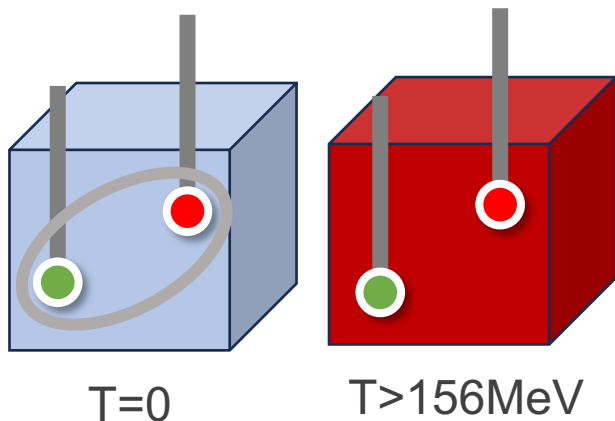
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The heavy quark potential – full QCD

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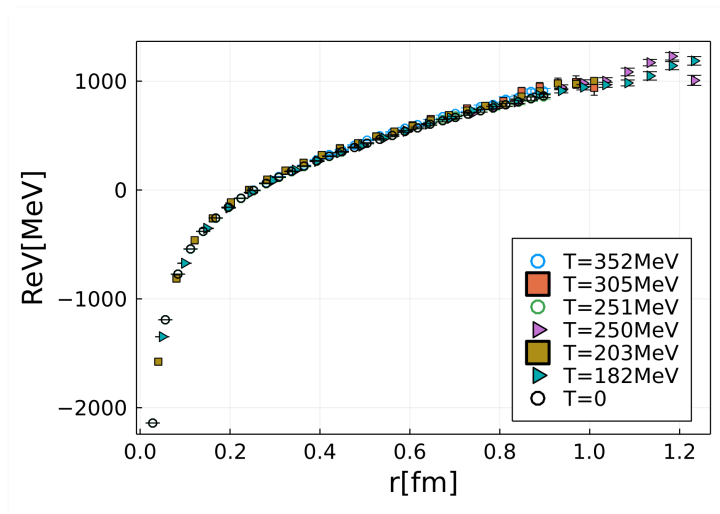


Intuition from QED plasmas:

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$N_\tau = 16-36$

$N_s = 96$

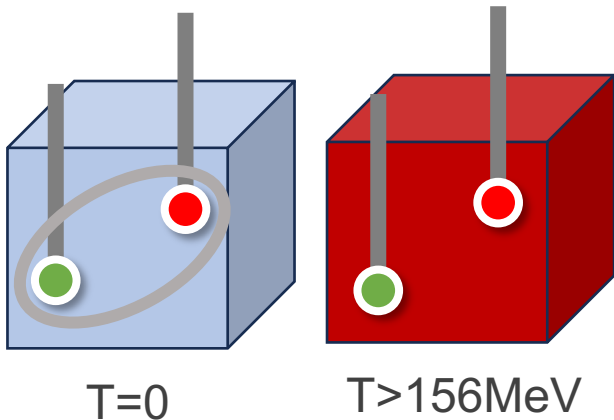
$N_f = 2+1$

HISQ action

HotQCD et.al.
 PRD 109 (2024) 7, 074504

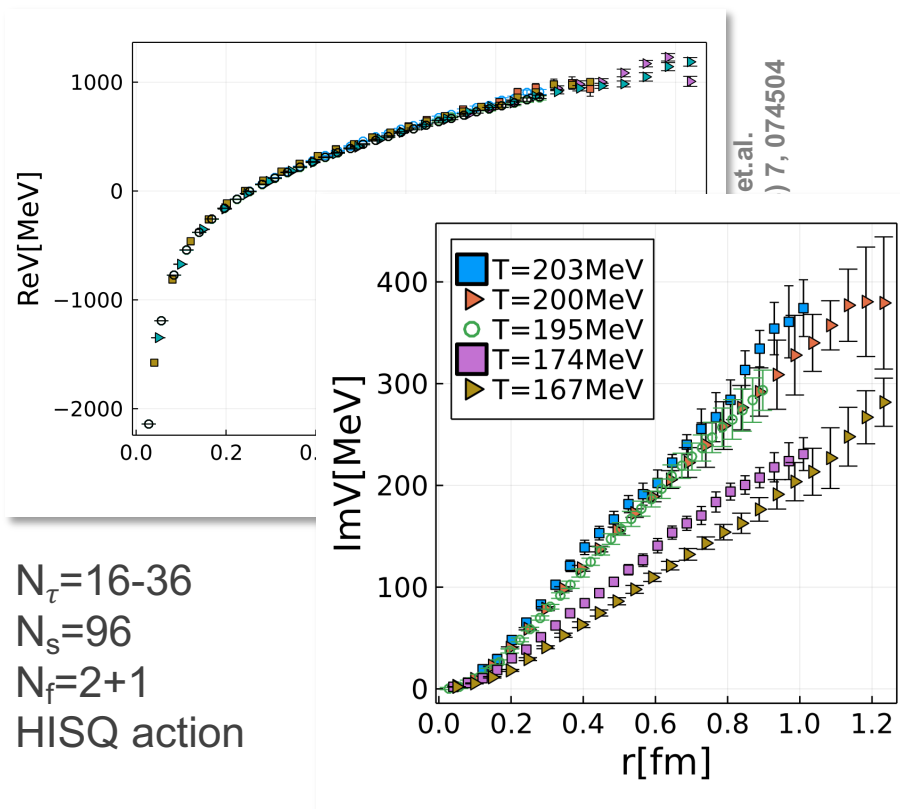
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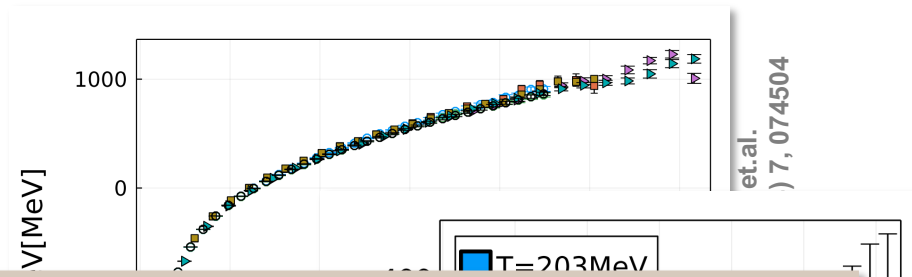
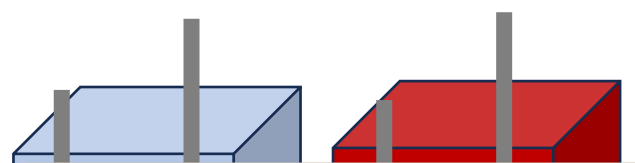
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The heavy quark potential – full QCD

Fate of deconfinement?



Is it possible that an intermediate phase exists where chiral symmetry is restored but confinement persists?

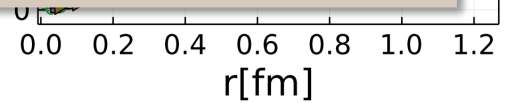
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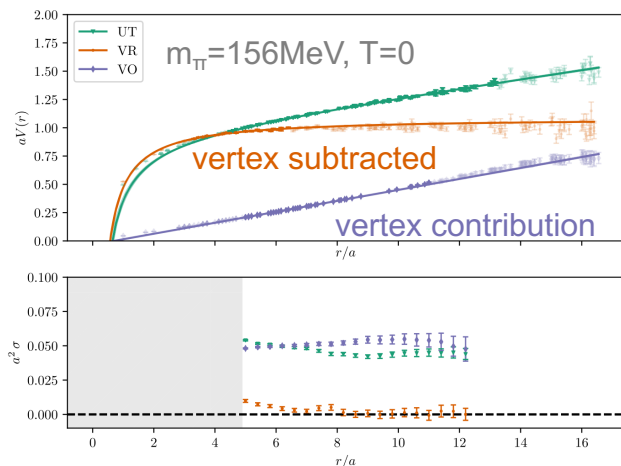
Tantalizing hints for additional structure



- Recent study of topological center vortices at zero & finite temperature

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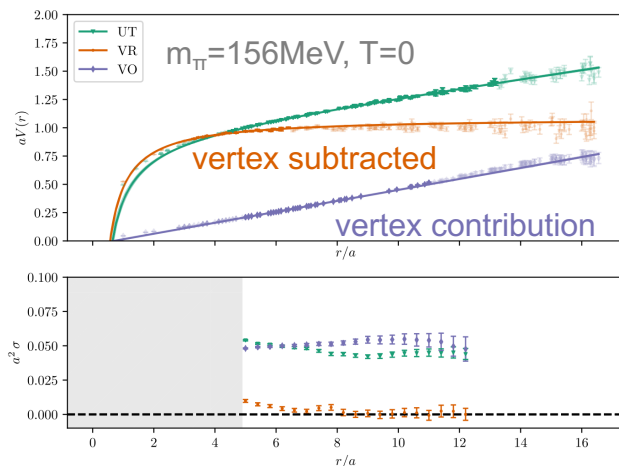


J. Biddle et.al. PRD 106 (2022) 5, 054505

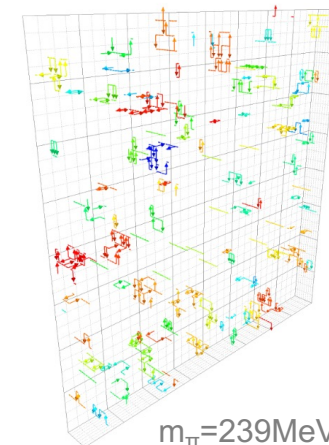
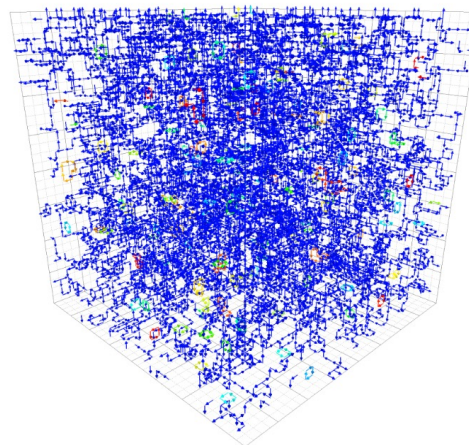
- At $T=0$, removing vortices depletes the string tension.

Tantalizing hints for additional structure

- Recent study of topological center vortices at zero & finite temperature



J. Biddle et.al. PRD 106 (2022) 5, 054505



$m_\pi = 239 \text{ MeV}, T=0$

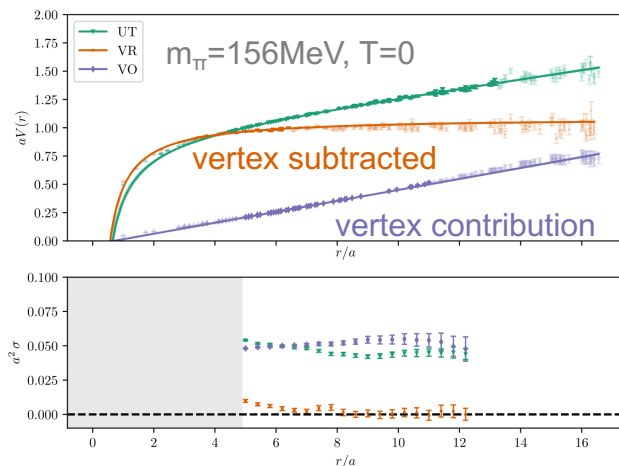
O(a) improved Wilson fermions

J. Mickley et.al. PRD 111, 034508

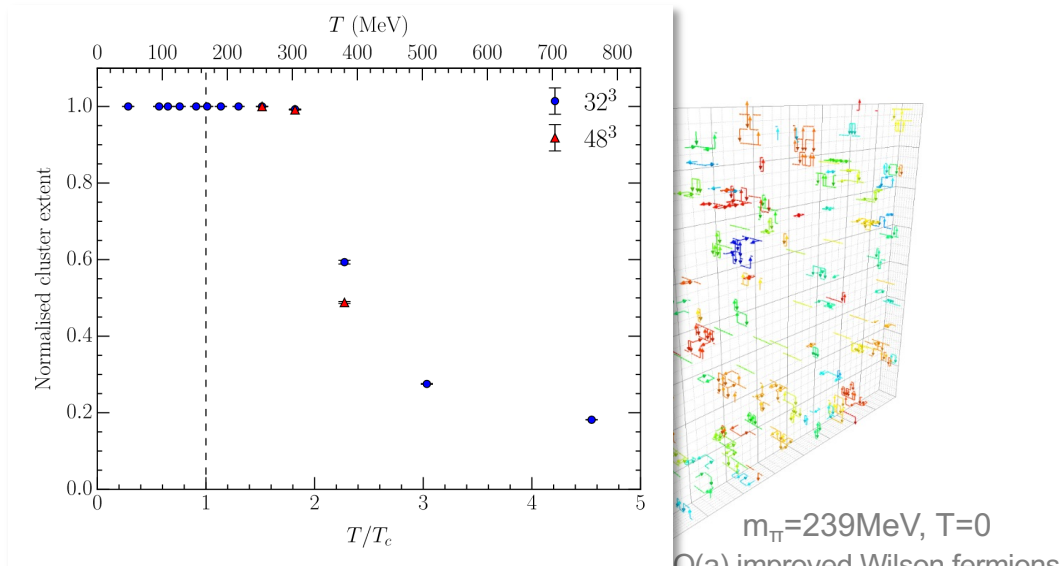
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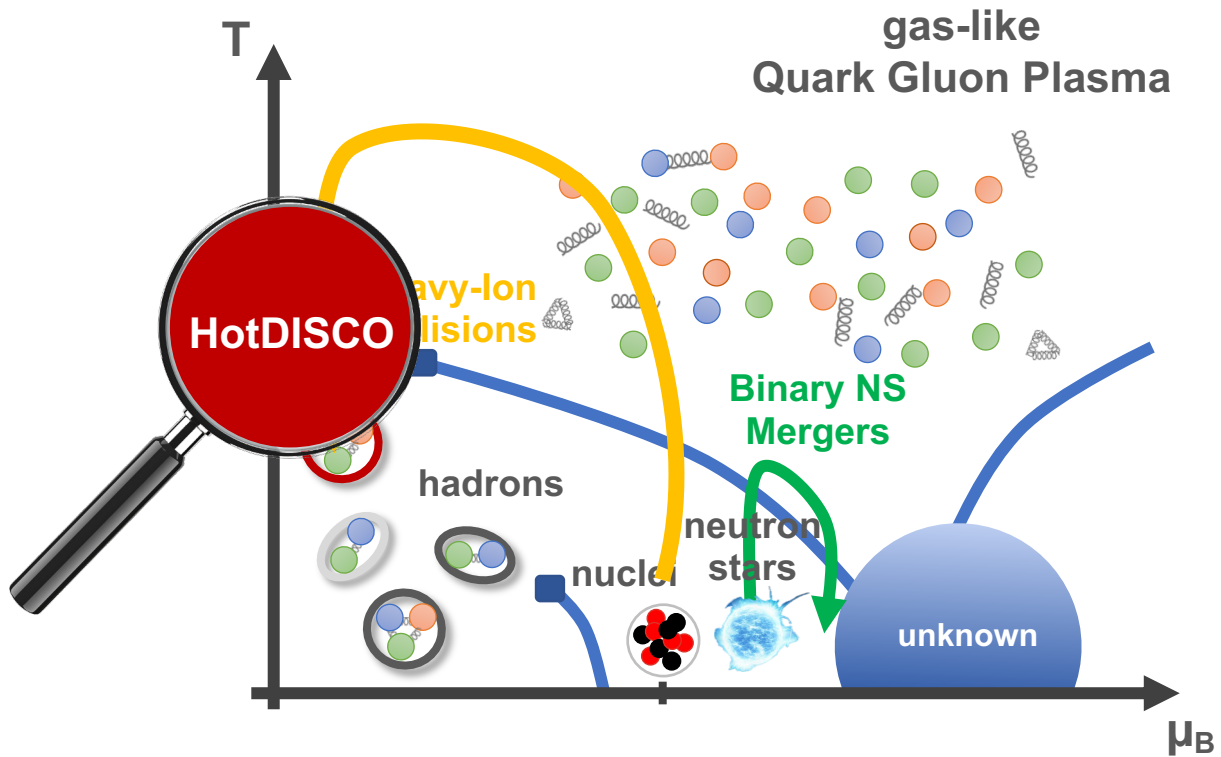
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J. Mickley et.al. PRD 111, 034508

- At $T=0$, removing vortices depletes the string tension.
- At $T > 2T_c^x$ show percolation transition which may indicate confinement persists

The phases of nuclear matter



see e.g. Hatsuda & Fukushima RPP 74 (2011) 014001

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Outline



- Physics motivation: hints for novel phases of QCD
- HotDISCO collaboration (Team & Work packages)
- Status report: fiscal year 2025 & 2026

Korea University & SUBATECH



Comprehensive private research university
In Seoul, South Korea, founded in 1905.
~4400 academic staff
~31000 students / ~10000 graduate students

Laboratory of Subatomic Physics and
Associated Technologies (SUBATECH)

Joint research unit supported by IMT Atlantique,
the National Institute of Nuclear Physics and
Particle Physics (IN2P3) at CNRS and the
University of Nantes. Founded in 1994.




Founding Team Members



Marlene Nahrgang (PI France):

- Phenomenology of Heavy-Ion Collisions
- Search for QCD critical point
- Transport properties of QCD
- Fluctuating Hydrodynamics



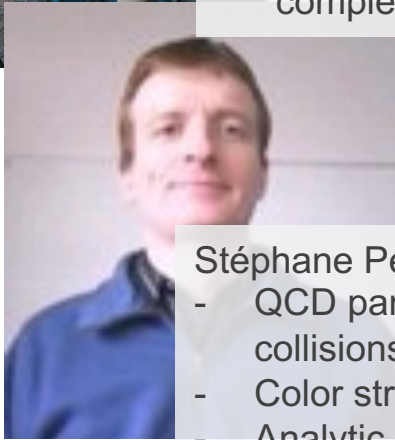
Alexander Rothkopf (PI Korea):

- Quarkonium in extreme conditions
- Lattice QCD at $T > 0$
- QCD spectral functions & inverse problems
- Real-time simulations: 2PI and complex Langevin



Marcus Bluhm

- Phenomenology of Heavy-Ion Collisions
- Quasi-particle models
- Transport properties of QCD
- Fluctuating Hydrodynamics



Stéphane Peigné:

- QCD parton energy loss in AA and pA collisions.
- Color structure (Birdtrack)
- Analytic many-body theory (2PI, PT)

Project work packages

WP1: Modeling of novel phases of nuclear matter (short term)

Goal: Improved **quasi-particle** based model for a tentative new QCD phase

Connect to **lattice QCD**: calculations of the equation of state, quark-number susceptibilities from the model

Investigation of quark–hadron duality and the **persistence of hadron-like excitations**

Calculation of **transport coefficients** for use in hydrodynamic simulations

WP2: Unveiling novel phases from lattice QCD and 2PI (intermediate term)

Goal: Identification of experimental & lattice-QCD signatures of novel phases, including heavy-quark observables

Use of **analytic** QCD methods (2PI techniques, effective color-electric theories, Birdtrack methods) to study chiral-spin symmetric and color-confined regimes in the crossover region

Calculate **color correlations**, fluctuations, and **transport coefficients** relevant for heavy-ion phenomenology

WP3: Unveiling novel phases from stochastic hydrodynamics and experiment (long term)

Goal: Development of a consistent framework for **stochastic hydrodynamics**

Numerical implementation of **event-by-event relativistic hydrodynamic** simulations using modern implicit solvers

Use of **statistical and machine-learning** methods to identify fluctuation and correlation **observables most sensitive** to novel phases of QCD matter

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Status Report – collaboration activities

- Regular bi-weekly zoom meetings since 2025/2
- New member joined in 2026: Kirill Boguslavski (SUBATECH)
- Research visits for in-depth collaboration (conducted & planned):



2025/2	2026/1	2026/2	2027/1
Prep-visit FR -> KO 2 weeks (Jul.) 2x seminar	Visit KO -> FR 1 week (Jan.) 1x seminar	Visit FR -> KO 2 weeks (tbc.) 2x seminar	Visit KO->FR 1 week (tbc.) 1x seminar
			Visit FR->KO 2 weeks (tbc) workshop & QM

Kirill Boguslavski:

- Initial stages of HIC & thermalization
- Jet quenching
- Classical statistical simulations of gluon dynamics
- Real-time complex Langevin

The 2027 HotDISCO workshop

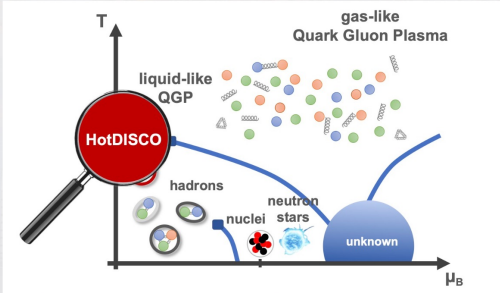
HotDISCO - Discovering novel phases of hot nuclear matter

18–19 Mar 2027
Korea University
Asia/Seoul timezone


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- Overview
- Timetable
- Registration
- Participant List

Welcome to the homepage of the HotDISCO workshop



It is a pleasure to announce the HotDISCO workshop, which will be held at
Korea University - March 18.-19. 2027 - Seoul, South Korea

This workshop is part of the  France Korea Particle Physics Network / Korea-France Cooperation Foundation Building Project (한 프랑수아 협력기반조성사업) HotDISCO, Discovering novel phases of hot nuclear matter with fluctuations.

Its aim is to bring together international leading experts in the study of the phase diagram of hot nuclear matter and to discuss recent developments regarding the existence of novel phase structure located

March 18-19 2027 – Korea University – Seoul

<https://moim.korea.ac.kr/event/9/>

A QM2027 satellite event



Quark Matter 2027

21–27 Mar 2027
Jeju International Convention Center, Jeju, Korea
Asia/Seoul timezone

Enter your search term

Overview

Conference Venue
Important Dates
Program at a Glance
Proceedings
Committee
Call for Abstracts
Registration
Supported by
Participant List
Accommodation
Code of Conduct
Miscellaneous
Excursions

Satellite Meetings

01 / HotDISCO - Discovering novel phases of hot nuclear matter

Date Mar 18 – 19, 2027
Venue Korea University, Seoul
Website <https://moim.korea.ac.kr/event/9/>

02 / C3NT Workshop: QM2027 Satellite Workshop on Spin Polarization and Chirality in Nuclear Collisions

Date Mar 28–31, 2027
Venue Central China Center for Nuclear Theory, Central China Normal University, Wuhan
Website <https://indico.pnp.uustc.edu.cn/event/6218/>

<https://indico.cern.ch/event/1622375/>

Summary



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restoration of chiral symmetry & persistence of confinement

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Merci de votre attention
 경청해 주셔서 감사드립니다
 ご清聴ありがとうございました

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