

New proposal: HAD_07

Quarkyonic Matter in and out of equilibrium

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with

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Aim: to identify observable signatures of Quarkyonic Matter
by connecting its equilibrium equation of state to dynamical transport modeling

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What is Quarkyonic?

Coined in McLerran, Pisarski (2007)

quarkyonic

English [edit]

Etymology [edit]

Blend of *quark* + *baryonic*

Adjective [edit]

quarkyonic (*not comparable*)

1. (*physics*) Describing elements of *quantum chromodynamics* that have characteristics both of *quarks* and of *baryons*. ... **a kind of duality**

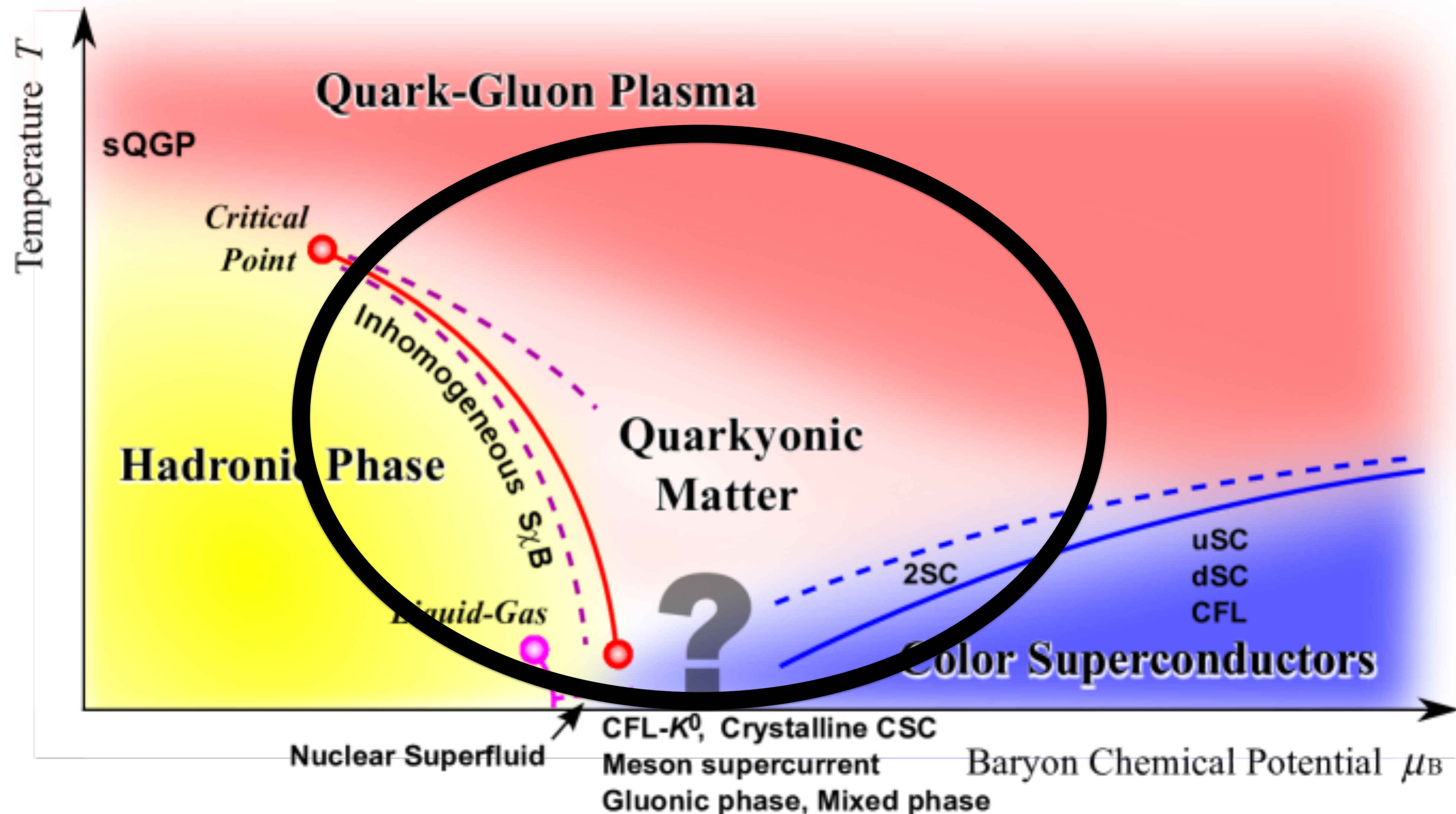
**Quarkyonic matter arises in hot/dense QCD matter
- heavy ion collisions / neutron stars, etc...**



From <https://www.wiktionary.org/>

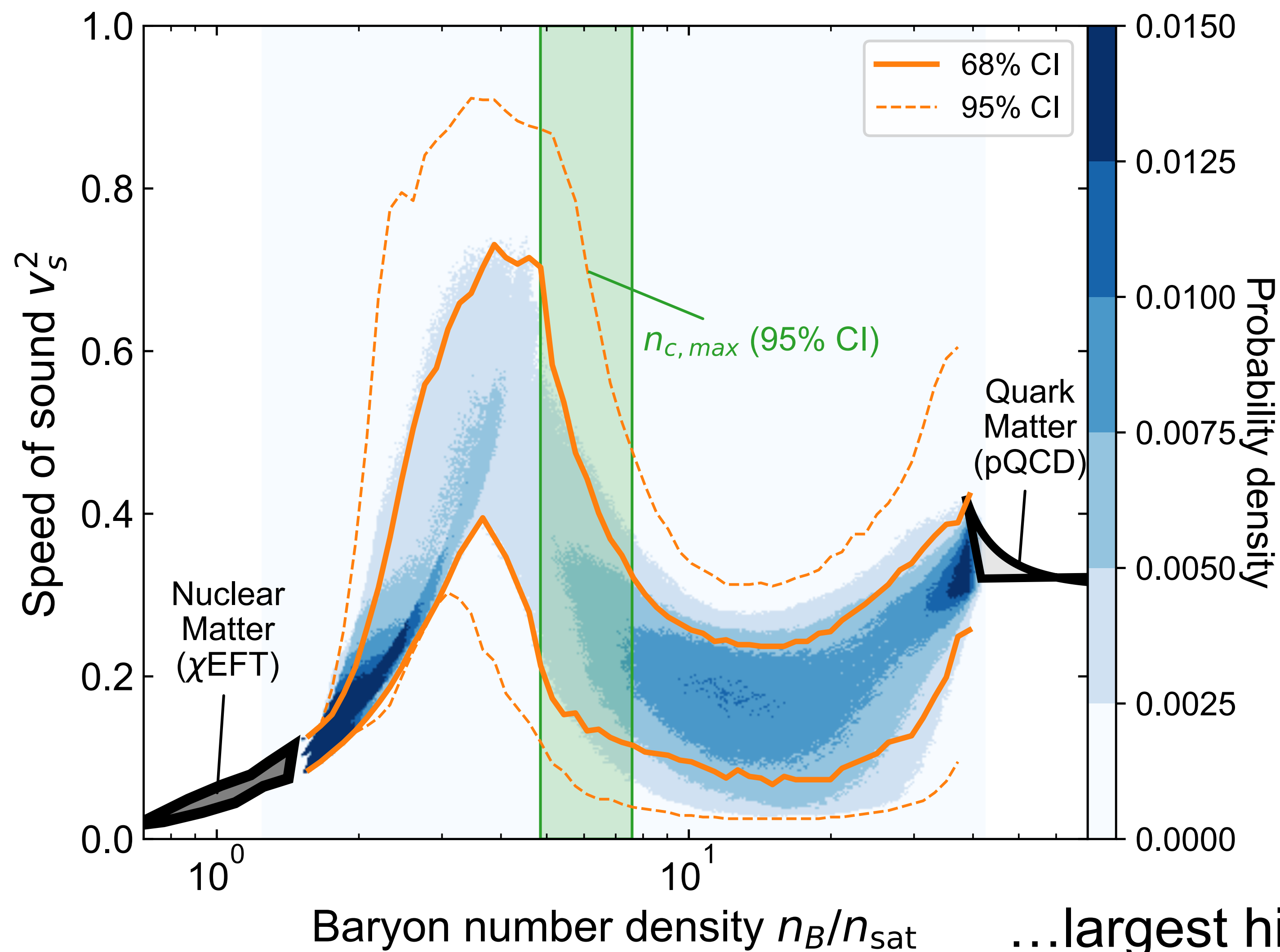
Quarkyonic Matter in the QCD phase diagram

McLerran, Pisarski (2007); Fukushima, Hatsuda (2010)



Why it matters?

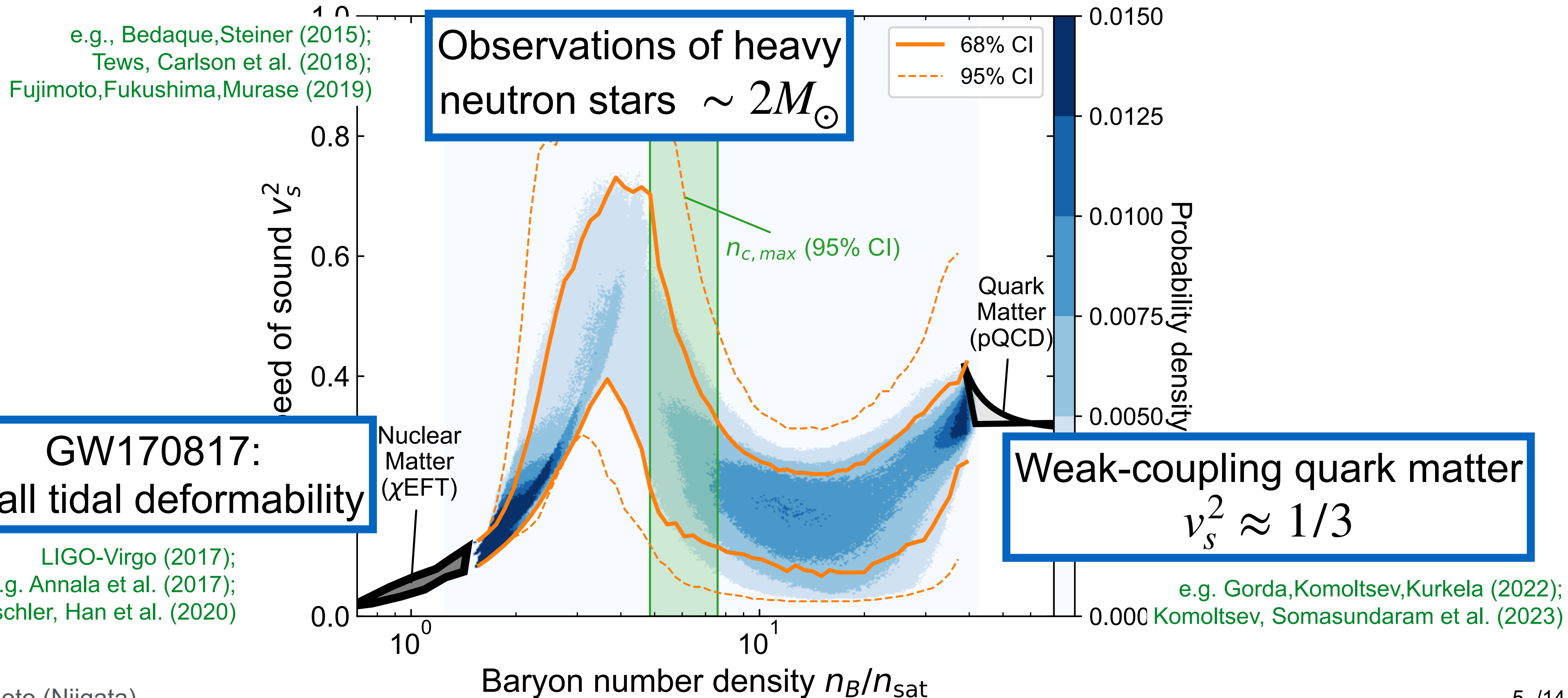
Emerging picture of dense QCD equation of state (EoS) from neutron stars
the plot of speed of sound



...largest hint we have so far 4 / 14

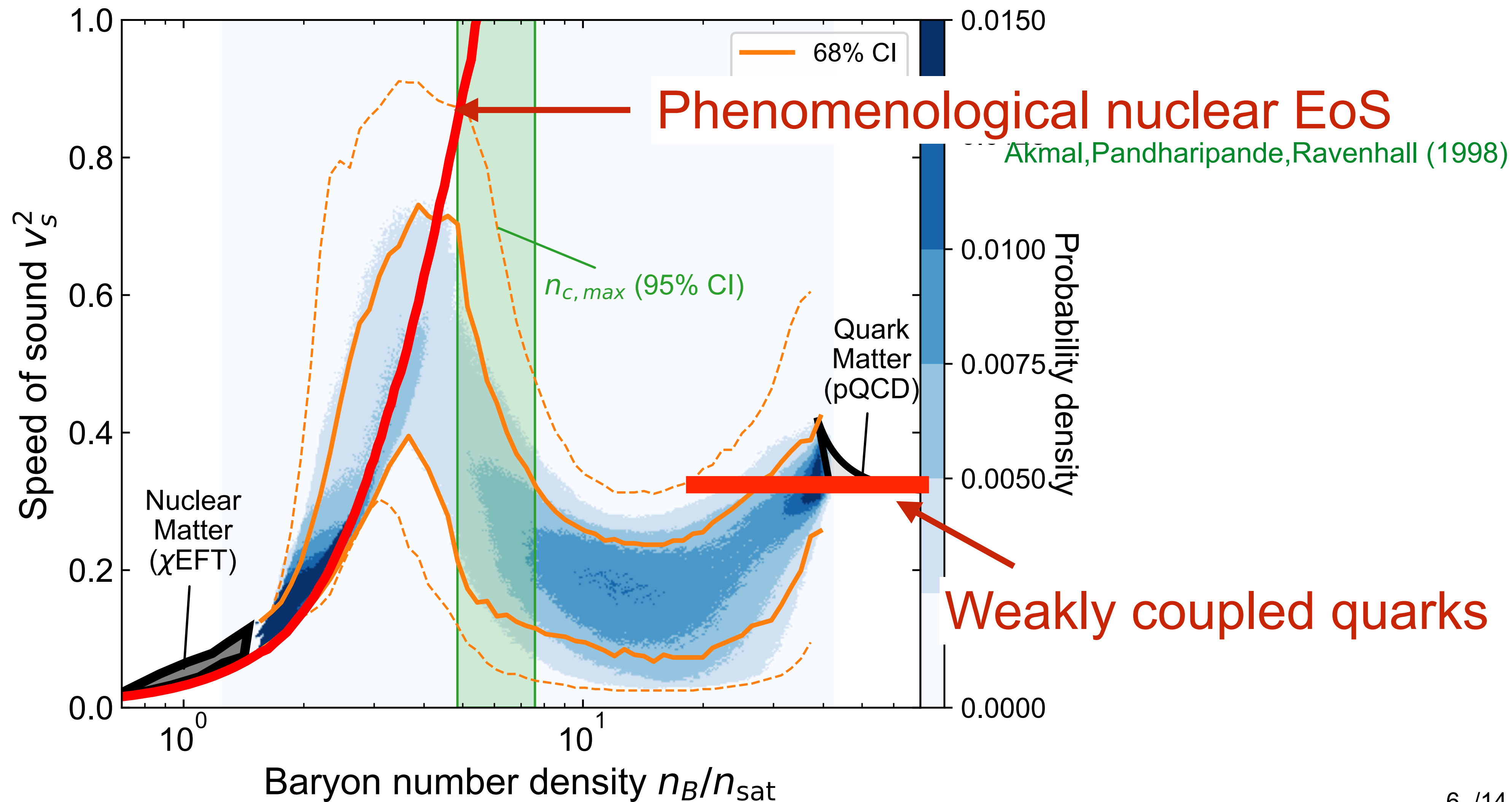
Why it matters?

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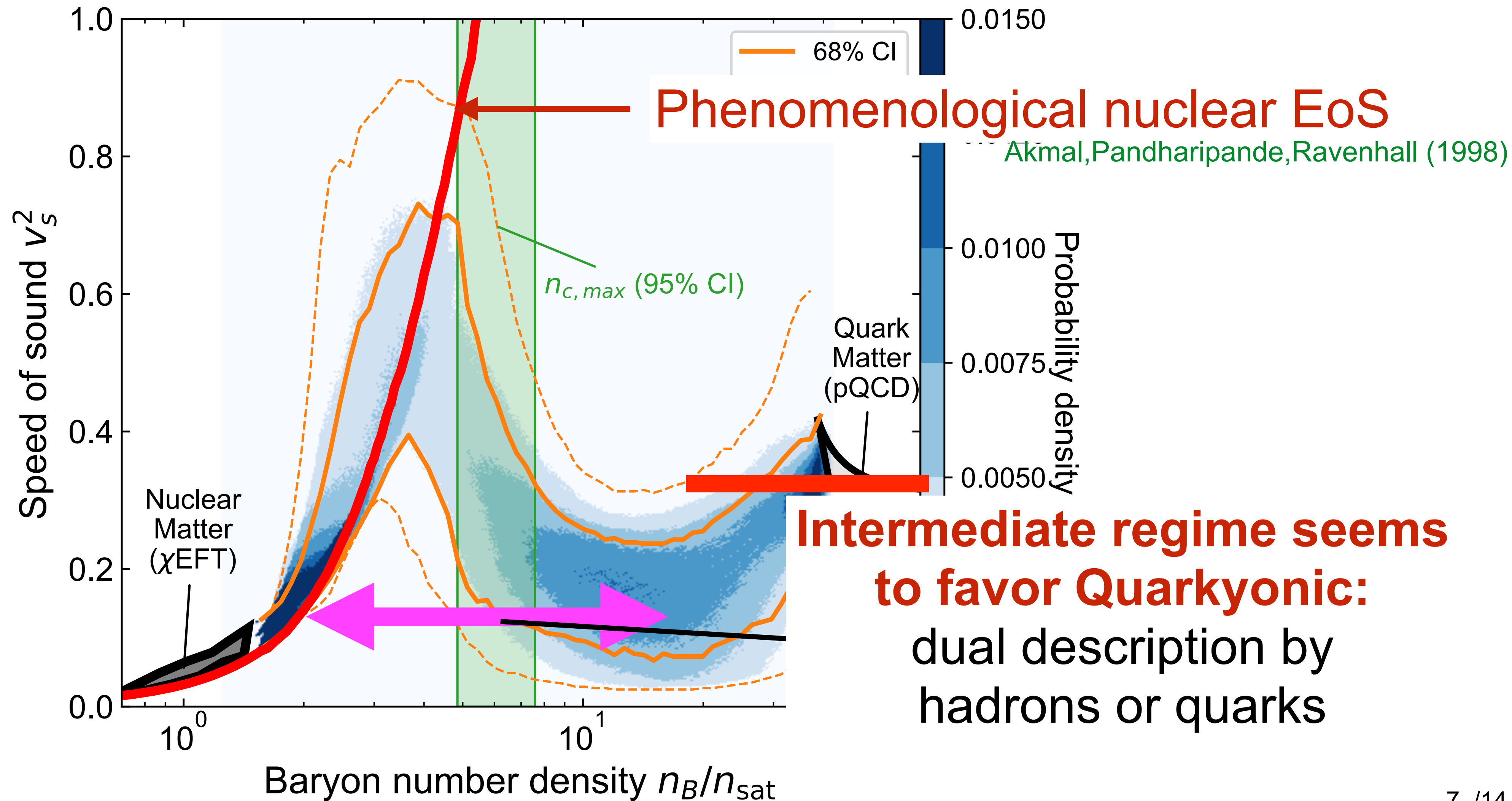
Why it matters?

Phenomenological nuclear EoS describes the behavior well up to certain density...



Why it matters?

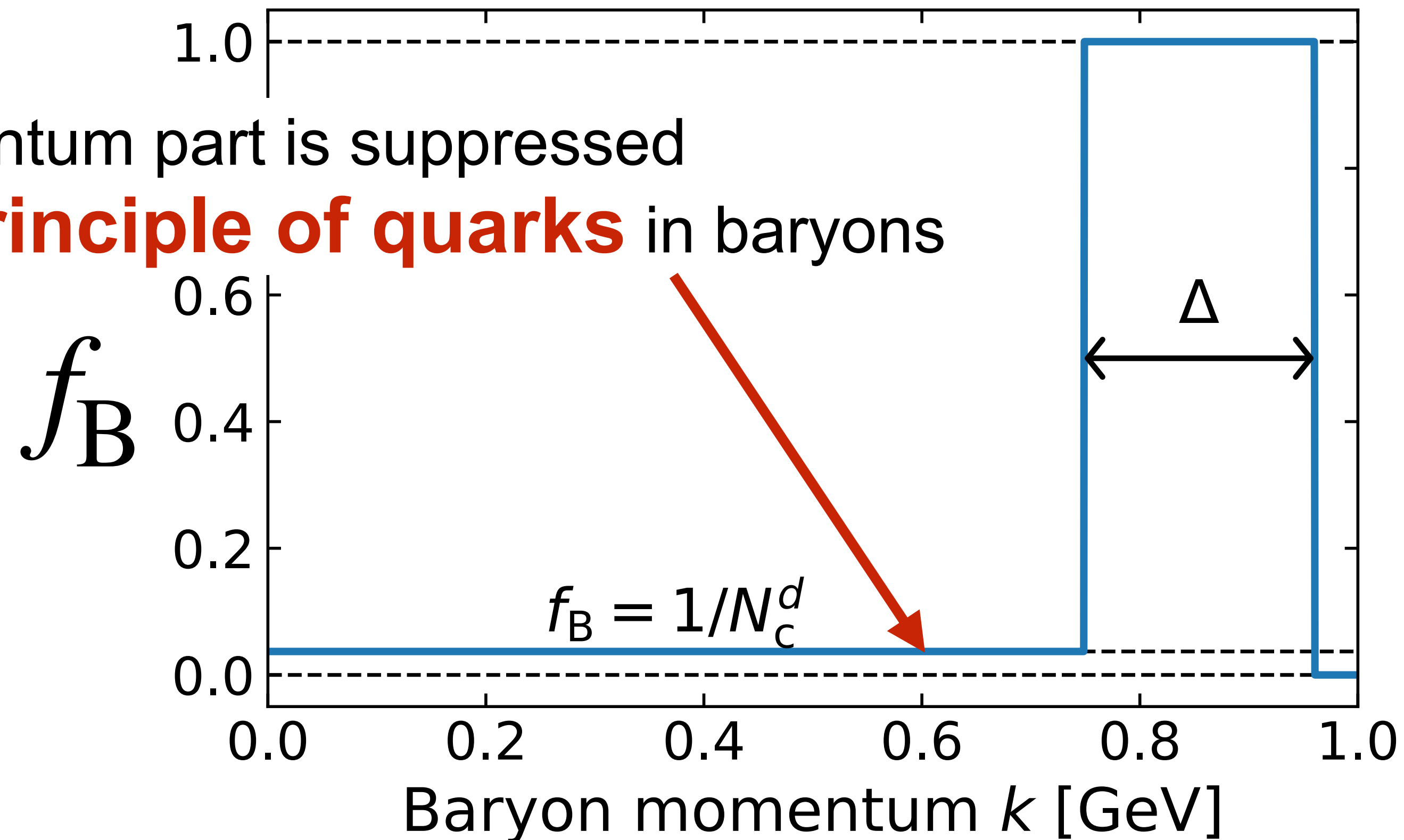
Phenomenological nuclear EoS describes the behavior well up to certain density...



Existing theoretical progress

[Fujimoto, Kojo, McLerran, PRL 132 \(2023\)](#)

**Defining characteristic feature of Quarkyonic matter:
modification of baryon Fermi-Dirac distribution**

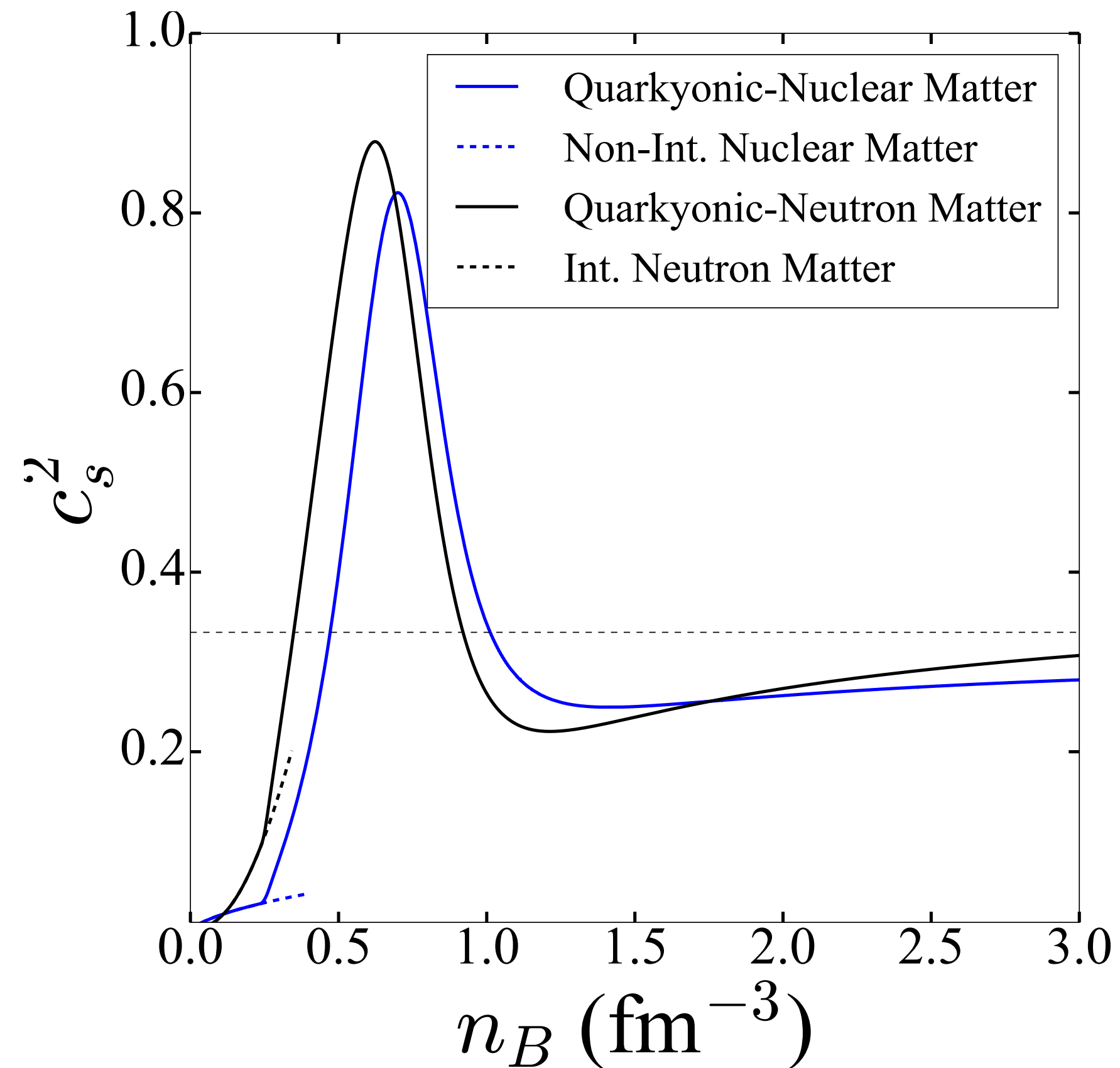


this can be understood fundamentally on the statistical mechanical ground

[Bluhm, Fujimoto, Nahrgang, 2604.00247](#)

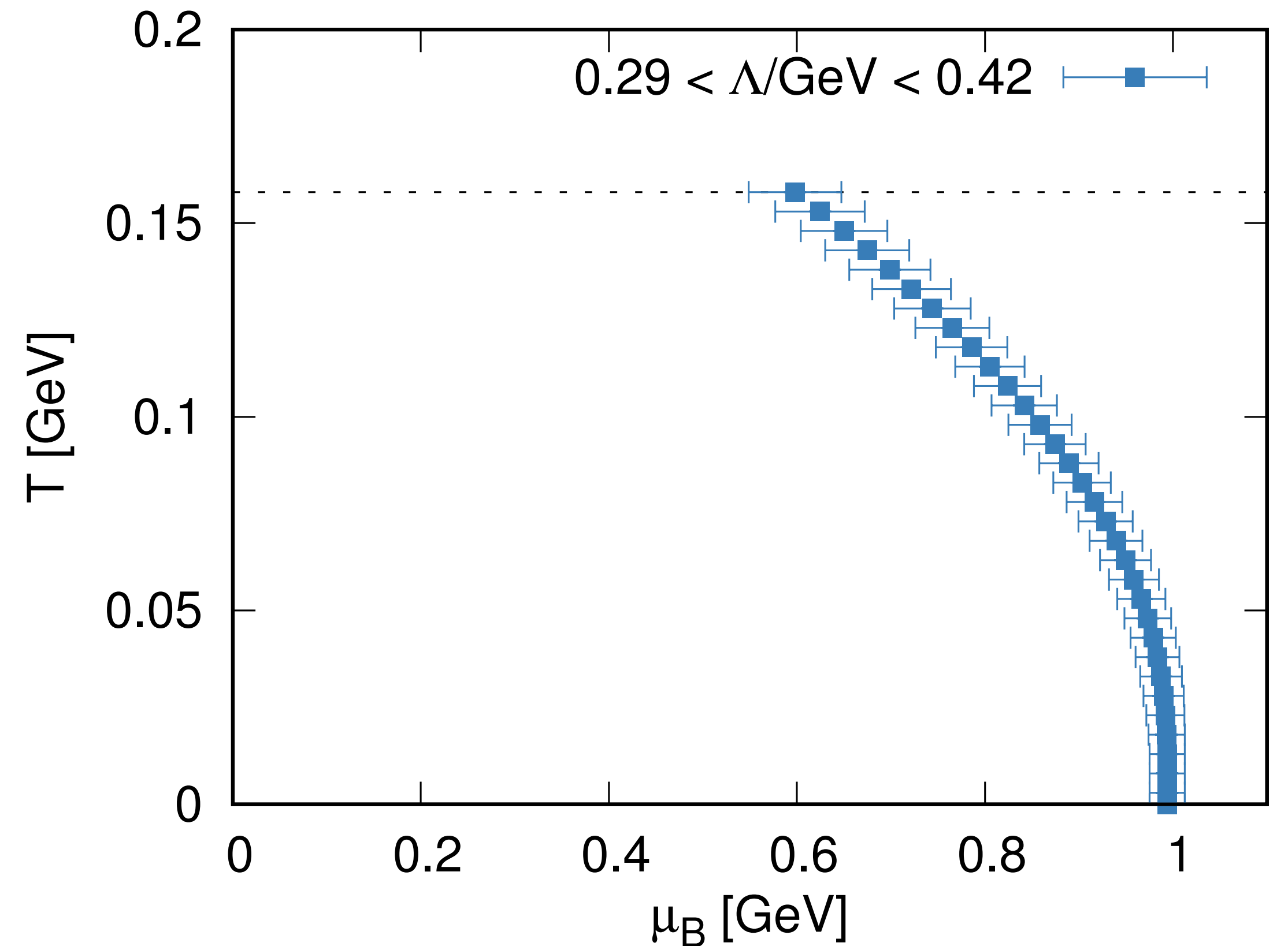
Characteristic equilibrium signatures

Modeling of the QCD equation of state



McLerran, Reddy, PRL 122 (2019)

Possible onset of quark Pauli principle in the QCD phase diagram



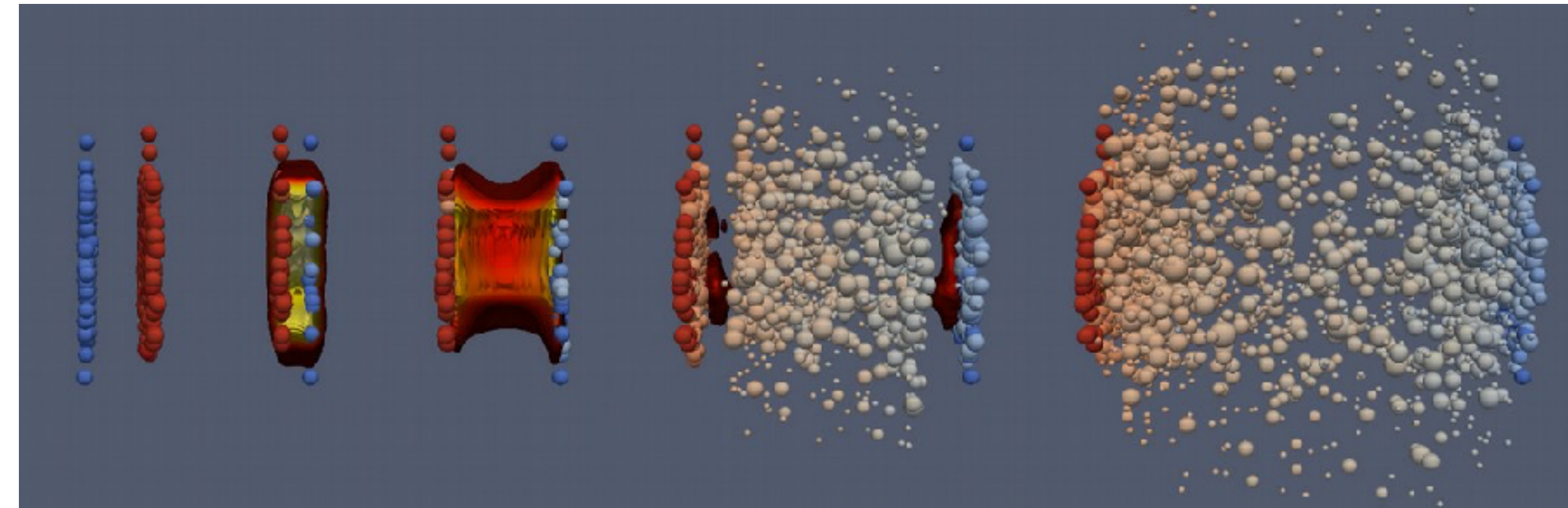
Bluhm, Fujimoto, McLerran, Nahrgang, PRC 111 (2025)

The missing piece: dynamics and transport

Equilibrium properties: not directly observable in heavy-ion collisions or in binary neutron star mergers

We know equil. properties such as:

- Equation of state
- Quark/hadron phase space distribution



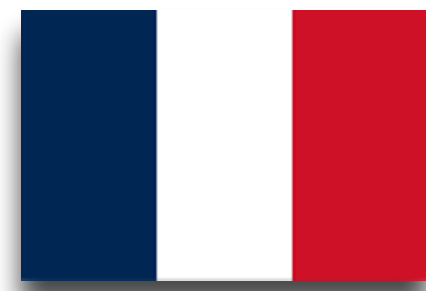
We need non-eq. properties such as:

- Transport coefficients
- Fluctuations & correlations
- Kinetic/hydrodynamic formalism taking into account Quarkyonic features such as quark Pauli principles



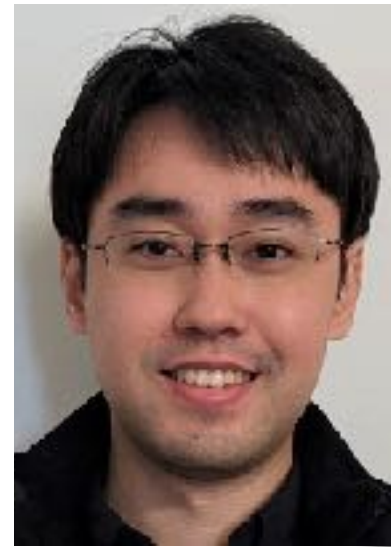
Key question: How does Quarkyonic Matter evolve in hot and dense matter?

France-Japan complementarity, work plan (HAD_07)



French side

Heavy-ion physics
Transport modeling
(Chiral-fluid model)



Japanese side

Neutron-star physics
EoS modeling
(Quarkyonic model)

cf. already successful collaboration:
[Bluhm, Fujimoto, McLerran, Nahrgang, PRC 111 \(2025\)](#)
[Bluhm, Fujimoto, Nahrgang, 2604.00247](#)

Joining goal

Observable signagures
Dynamical simulations
Testable predictions

Year 1

- formulate common EOS/transport input
- continue ongoing projects
- dedicated discussions during Japan visit

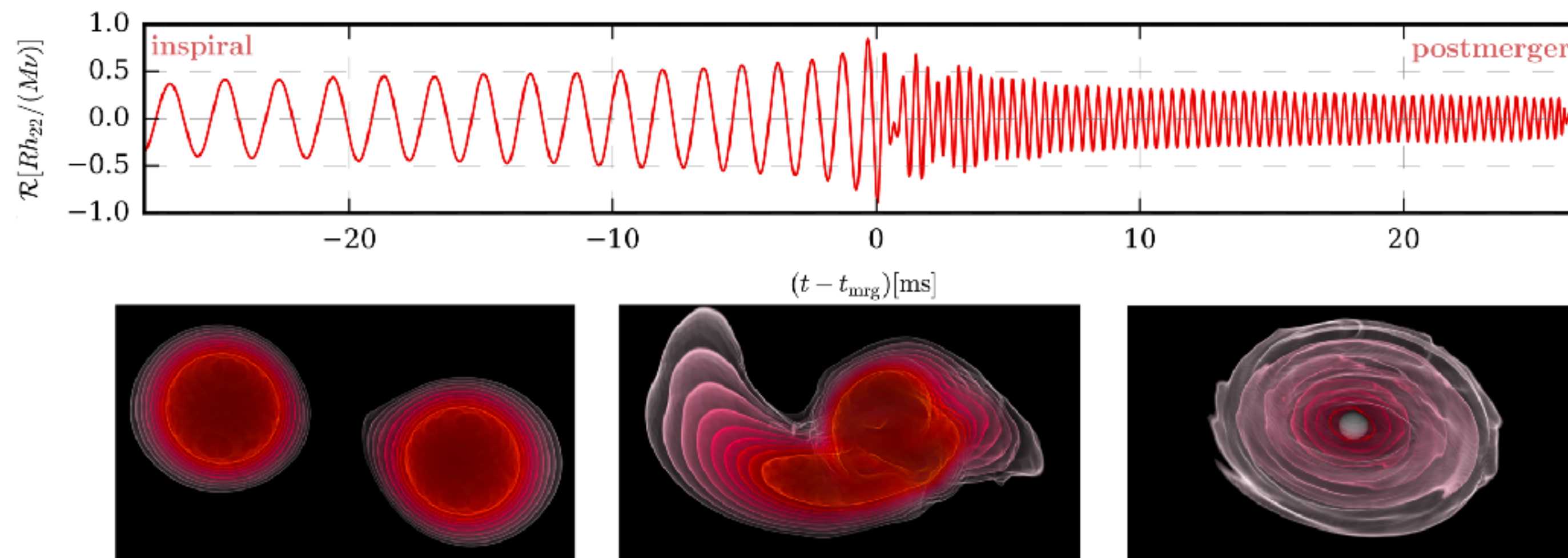
Later stage

- compare with HIC observables
+ connect with NS constraints
- prepare new joint publications
- involve younger participants, students

Example: neutrino transport

- Observable signature of Quarkyonic Matter in astrophysical observation?
→ Post-merger signal

from: Dietrich, Hinderer, Samajdar (2020)



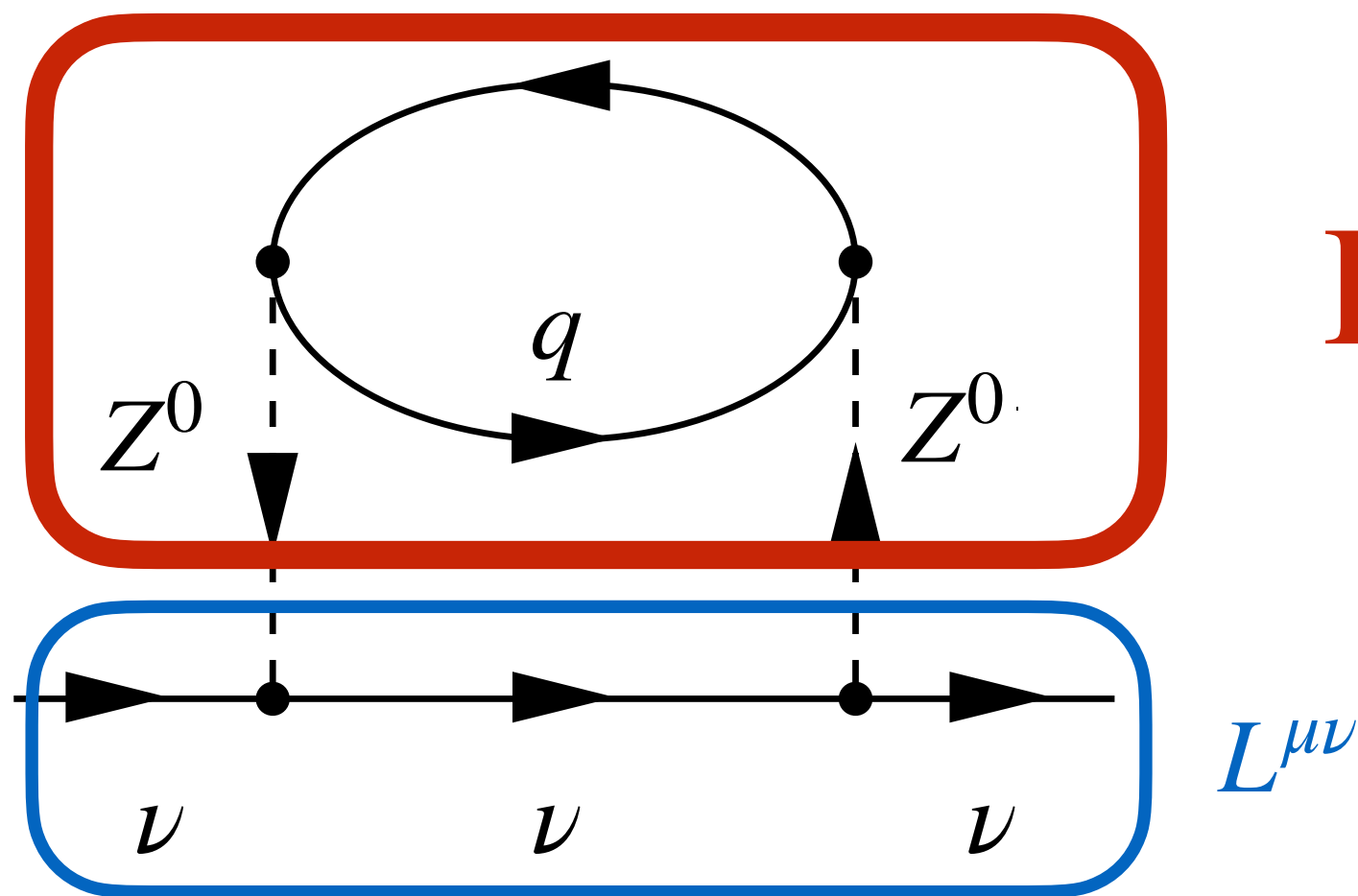
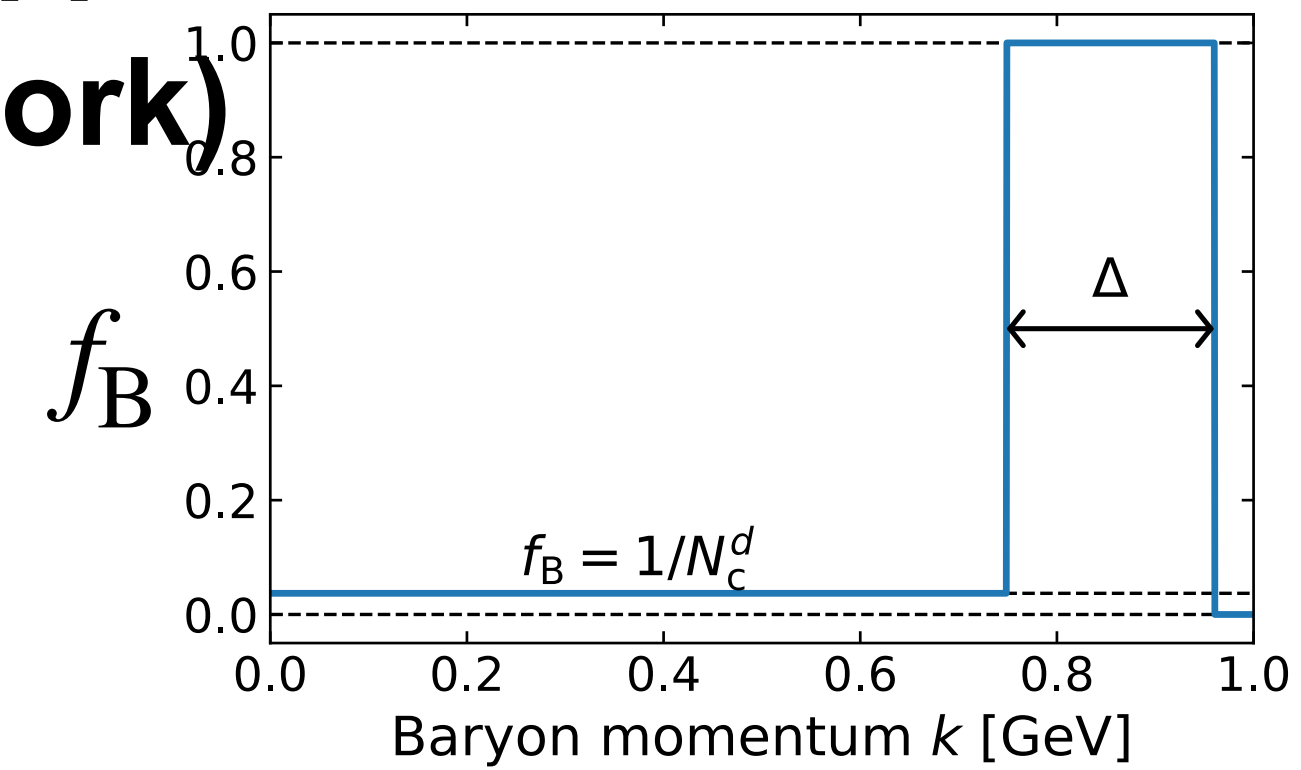
- Post-merger depends on the transport property
→ Bulk viscosity / thermal conductivity is believed to be dominant
Alford, Bovard, Hanauske, Rezzolla, Schwenzer (2018)
- Effect of heat conduction by neutrinos?

Example: neutrino transport

$\nu q \rightarrow \nu q$ cross section standard formula:

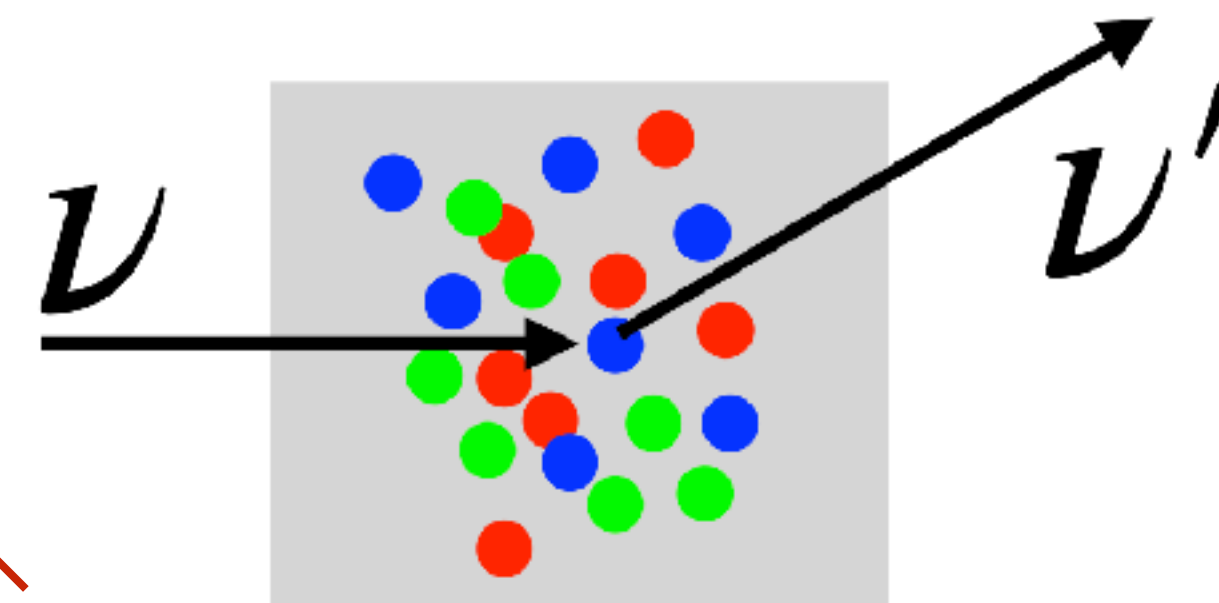
$$\frac{1}{V} \frac{d^3\sigma}{d^2\Omega dE'_\nu} = \alpha \operatorname{Im}(L^{\mu\nu} \Pi_{\mu\nu})$$

Modification of the formula in
Quarkyonic matter?
(quarkyonic framework)



$\Pi_{\mu\nu}$

$L^{\mu\nu}$



Collective effect in hot/dense QCD matter
(phenomenology from heavy-ion collisions)

cf) References:
Iwamoto (1980); Carter,Reddy (2000);
Alford,Nishimura,Sedrakian (2014)...

Transport coefficient is calculated rigorously from the cross section
within variational formalism Arnold,Moore,Yaffe (2000)

Summary - expected outcomes for HAD_07

- **Quarkyonic matter is crucial to QCD matter study at finite baryon density:**
 - Heavy-ion collisions (FAIR@GSI, J-PARC-HI, CERN ...)
& binary neutron star mergers
 - Development of transport framework is urging task
- **Already several successful joint publication records:**
 - [1] M. Bluhm, Y. Fujimoto, L. McLerran, M. Nahrgang, Phys. Rev. C 111 (2025)
 - [2] M. Bluhm, Y. Fujimoto, M. Nahrgang, 2604.00247
 - + more to come in the near future as an outcome from this TYL/FJPPN network
- **Broadening the bilateral collaboration to broader network:**
 - Young researcher involvement (students from Nantes and Niigata)
 - Connecting to the existing France-Berkeley network / FKPPN

Thank you

Merci

감사합니다

ご清聴ありがとうございました