Equation of state of cold dense QCD matter in resummed perturbation theory

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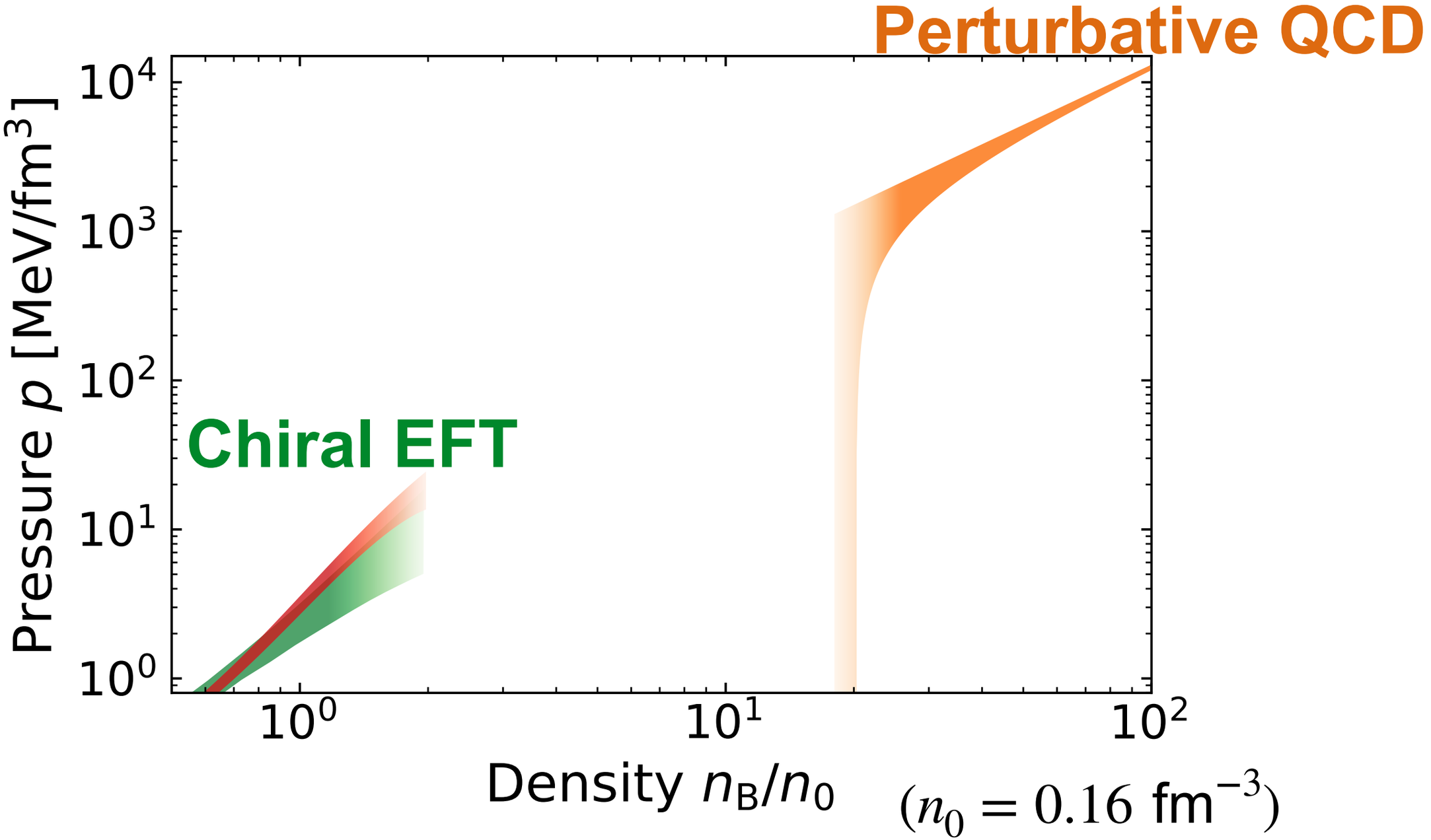
参考文献:

Yuki Fujimoto, Kenji Fukushima, “Equation of state of cold and dense QCD matter in resummed perturbation theory,” arXiv:2011.10891.

29 March 2021, KEK joint colloquium @ online

Dense matter Equation of State (EoS)

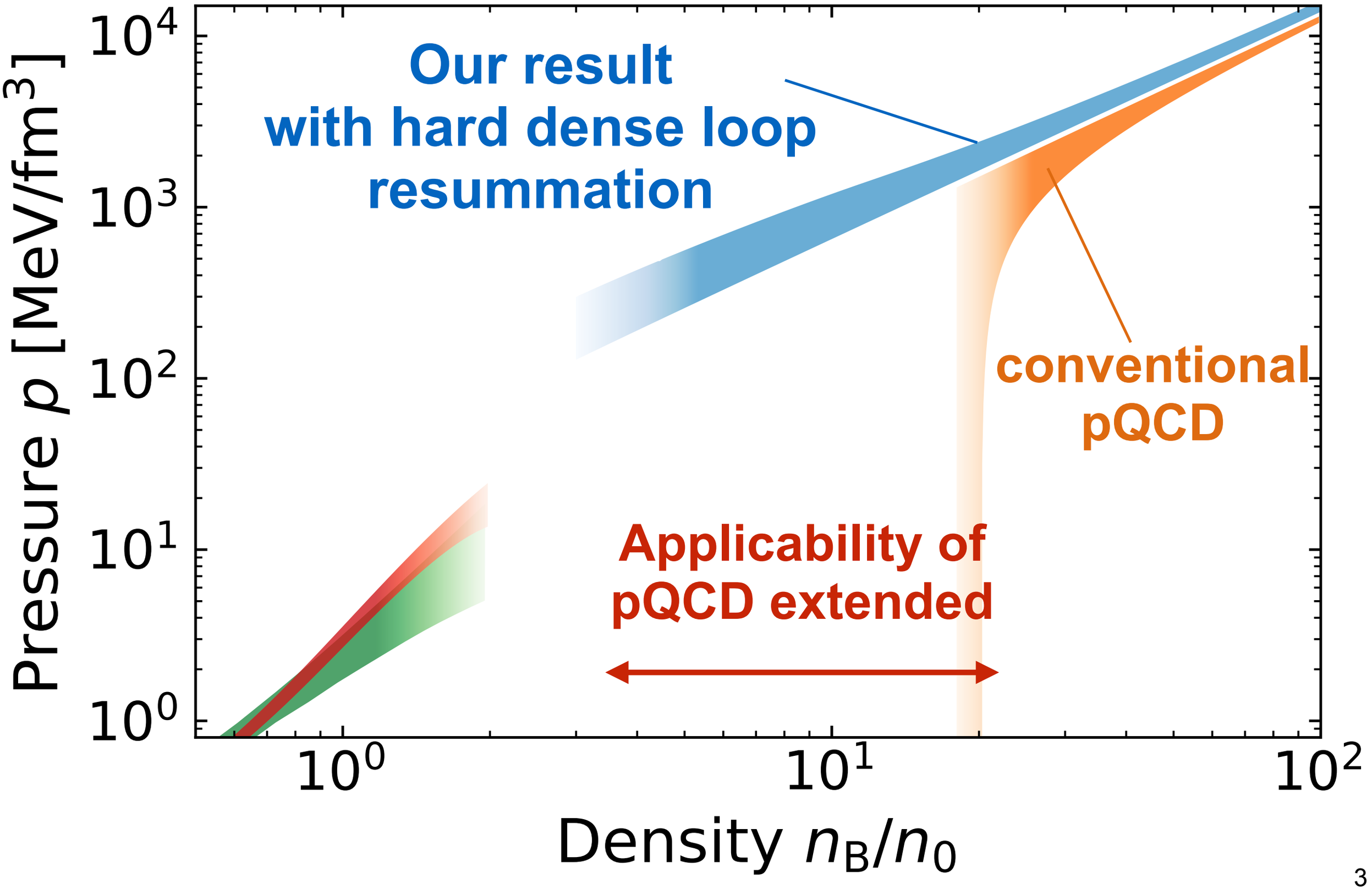
Constraints from QCD:



ChEFT: Tews,Carlson,Gandolfi,Reddy (2018); Drischler,Furnstahl,Melendez,Phillips (2020)

pQCD: Freedman,McLerran (1978); Baluni (1979); Kurkela,Romatschke,Vuorinen,Gorda,Sappi (2009-)

Our result in a nutshell



Hard Thermal Loops (HTL)

- The problem of the gauge-dependent **gluon damping rate**:

$$\gamma_g = a\frac{g^2 T}{8\pi}$$

$a = 1$ (in Coulomb gauge), $a = -5$ (in covariant gauge)

Heinz,Kajantie,Toimela,… (1987)

- **Hard thermal loop (HTL) resummation:**
  resum certain kinds of diagrams called HTLs, and use effective resummed propagator

$a \simeq 6.635$ (both in Coulomb and covariant gauge)

Braaten,Pisarski (1990)

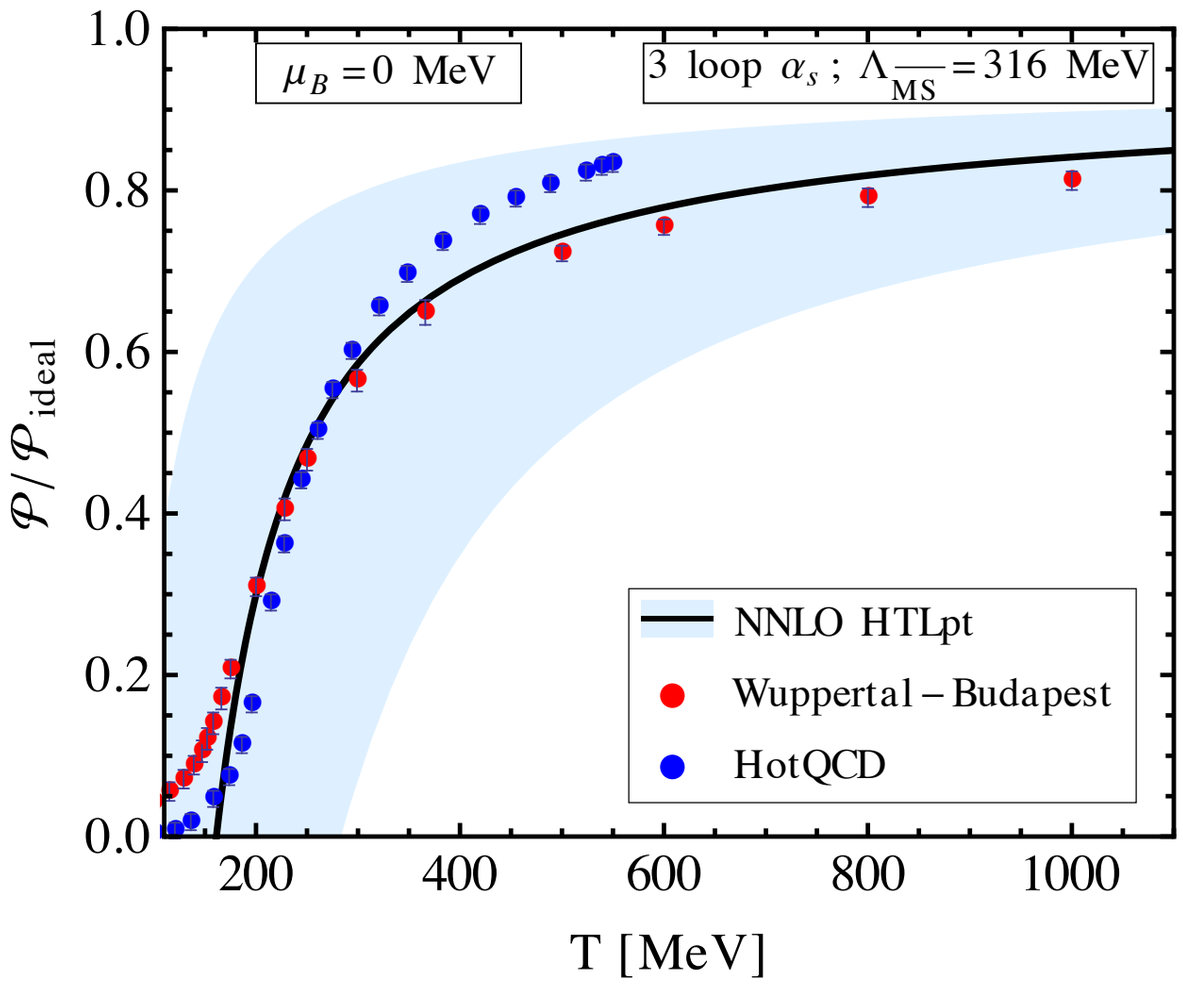
HTL perturbation theory

- **HTL perturbation theory** is one way to implement HTL resummation

Andersen,Braaten,Strickland,… (1998)

- Hot QCD EoS confronting lattice data:

Haque,Bandyopadhyay,Andersen, Mustafa,Strickland,Su (2014)



Hard Dense Loops (HDLs)

- **Hard dense loops (HDLs):**

  $T = 0$ and $\mu > 0$ counterpart of the HTLs

  cf. thermal quark mass:

$$m_q^2 = \frac{g^2}{8}\frac{N_c^2 - 1}{2N_c}\left(T^2 + \frac{\mu^2}{\pi^2}\right)$$

Manuel (1996)

- Parallelism between $T \leftrightarrow \mu$ has been established

- What we calculate here:

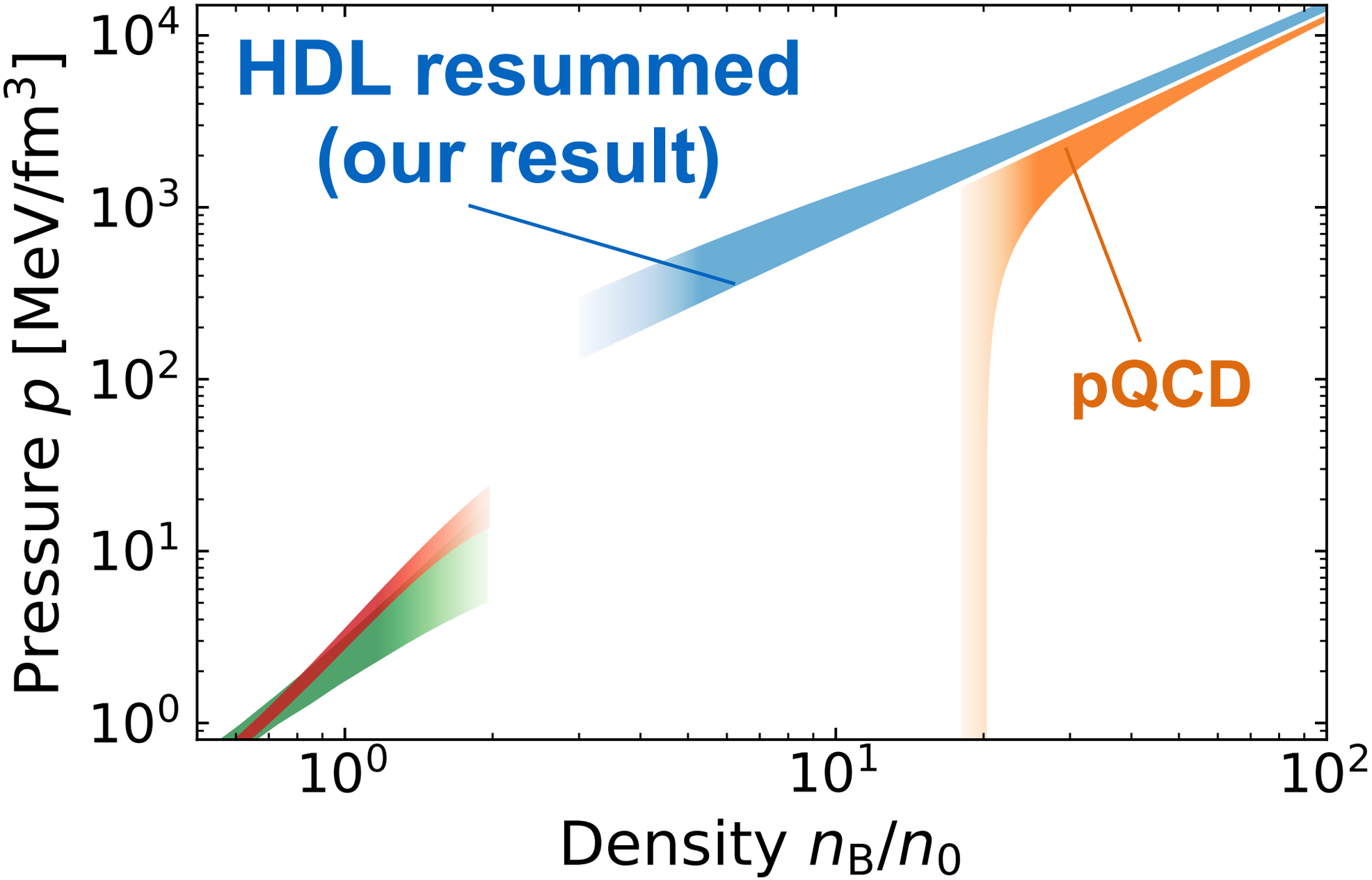
$$p(\mu) = \mathrm{Tr}\log D^{-1}$$

HDL resummed full propagator

(evaluated within 2+1 flavor)

Result from the HDL resummed QCD

Fujimoto,Fukushima (2020)

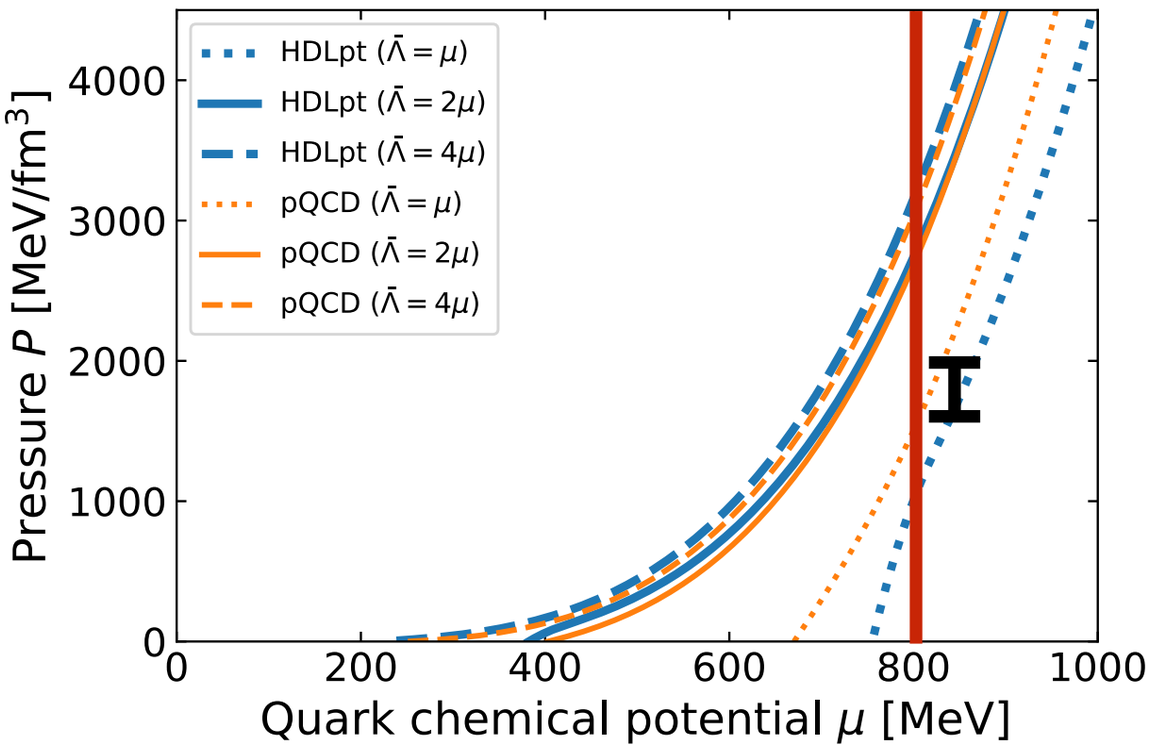


"uncertainty" band: evaluated by changing $\bar{\Lambda} \in [\mu, 4\mu]$

$$\alpha_s(\bar{\Lambda}) = \frac{4\pi}{\beta_0 \log(\bar{\Lambda}^2/\Lambda^2_{\overline{\rm MS}})}\left[1 - \frac{2\beta_1}{\beta_0^2}\frac{\log^2(\bar{\Lambda}^2/\Lambda^2_{\overline{\rm MS}})}{\log(\bar{\Lambda}^2/\Lambda^2_{\overline{\rm MS}})}\right]$$

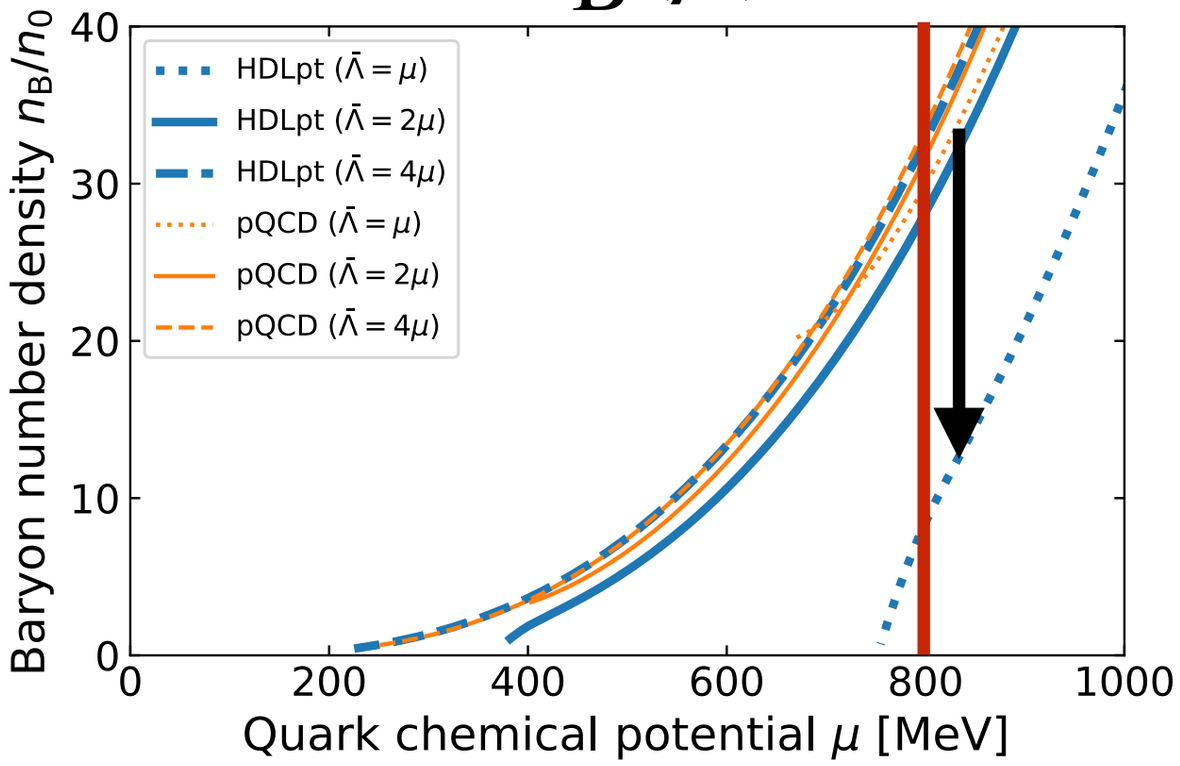
Heuristic argument

$p(\mu)$



Pressure does not differ at constant μ

$n_{\mathrm{B}}(\mu)$

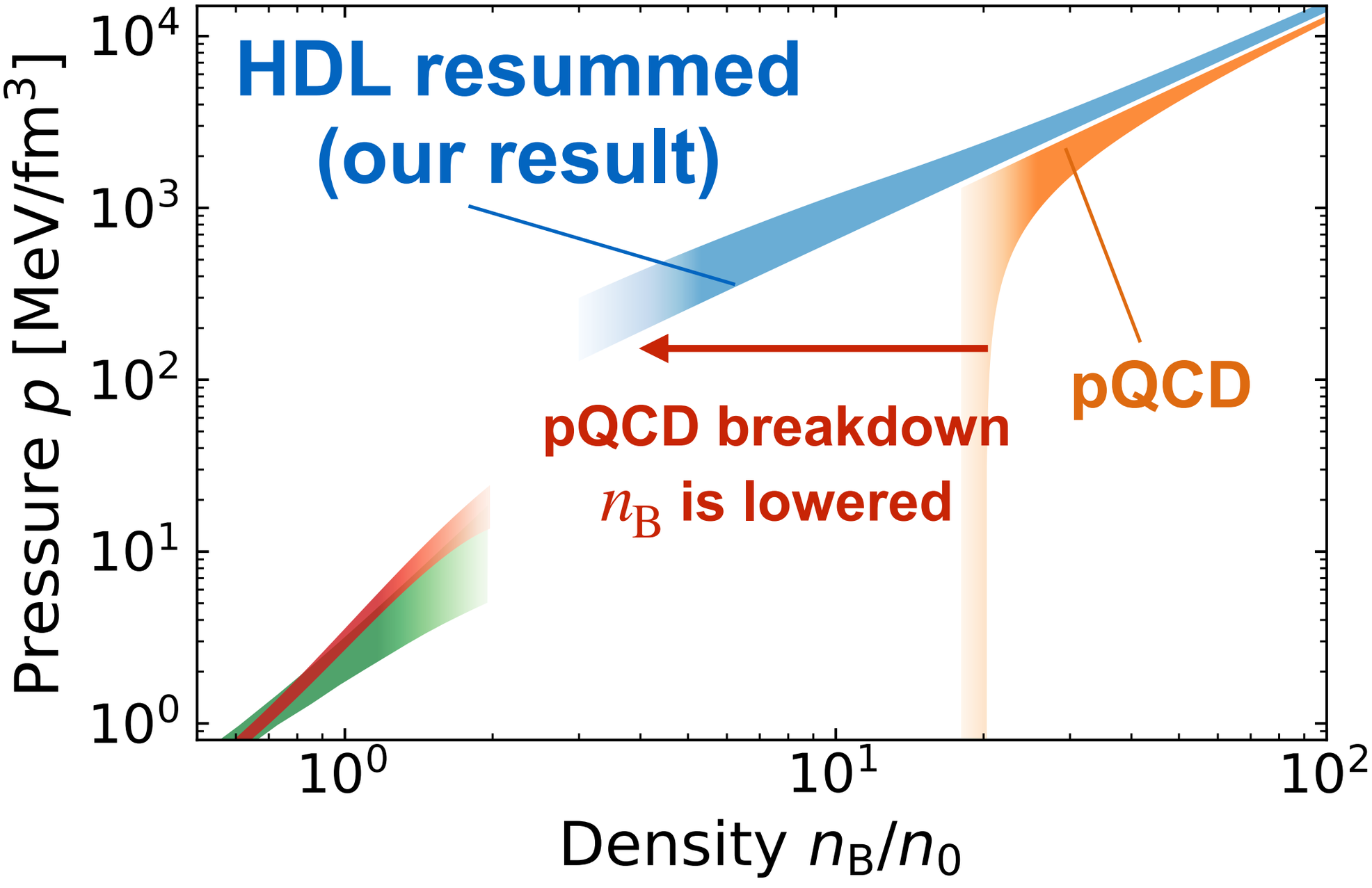


Density is screened in HDL resummation at constant μ

→ in HDL resummation,
the same value of p realizes at lower n_{B}

Result from the HDL resummed QCD

Fujimoto,Fukushima (2020)



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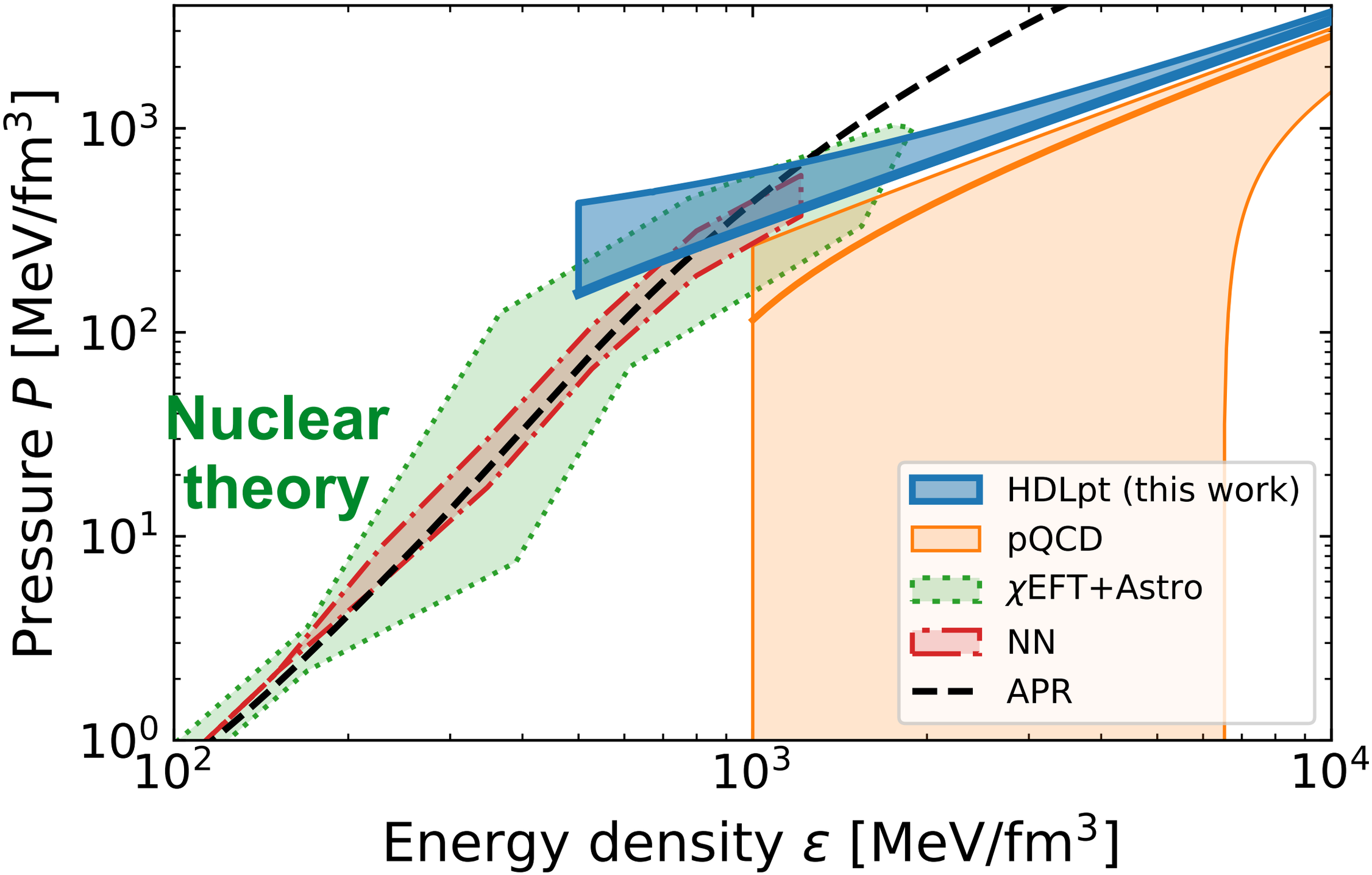
Smooth matching to the nuclear EoS?

Fujimoto,Fukushima (2020)



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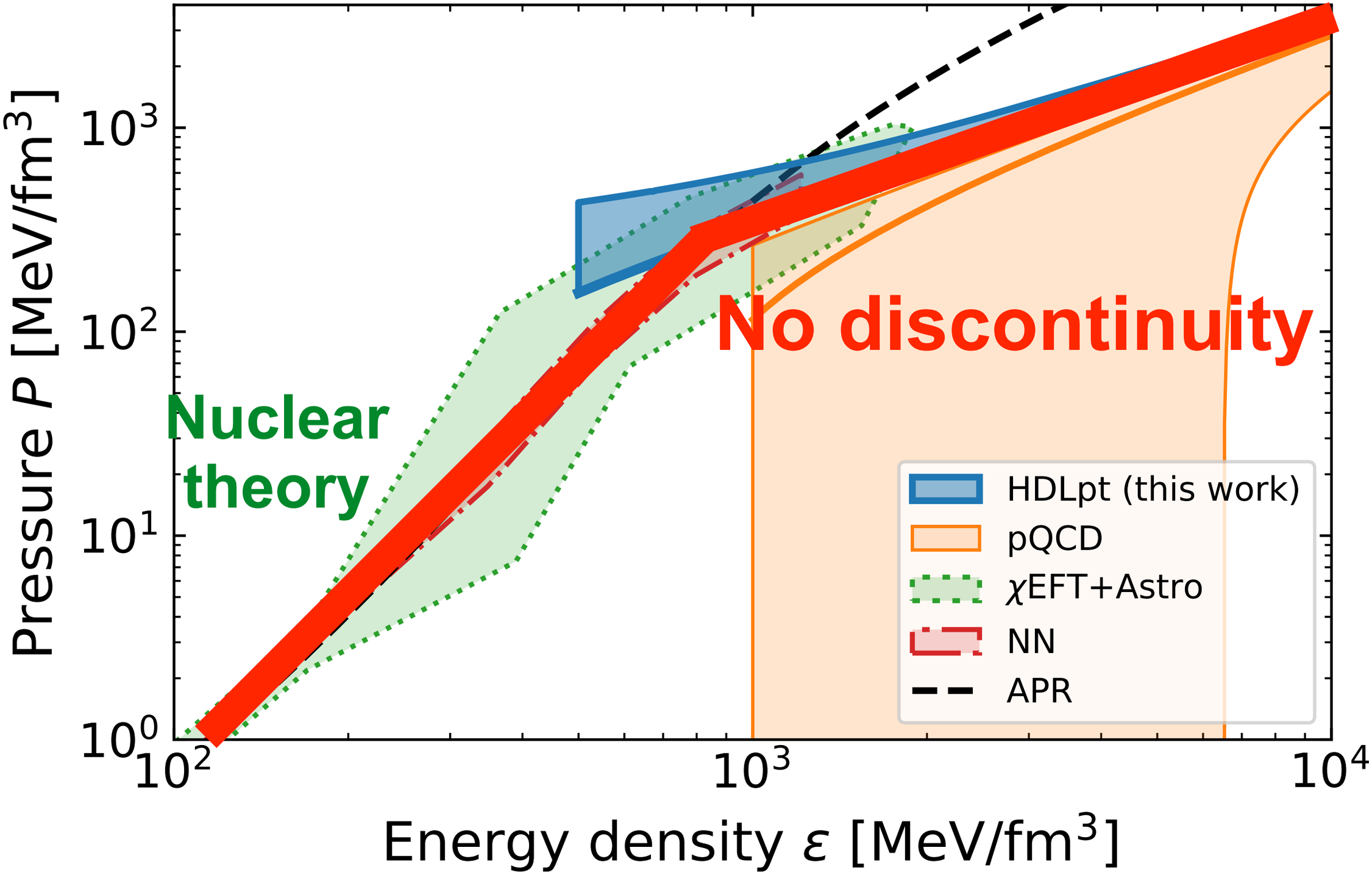

cf. Annala,Gorda,Kurkela,Nattila,Vuorinen (2019)

Summary and outlook

- Hard dense loop resummed perturbation theory: systematic reorganization of perturbative QCD, calculated EoS

- The result turned out to extend the pQCD applicability down to the realistic density in neutron stars

- Several issues to be explored:
  * Deeper reason why uncertainty is smaller?
  * Evaluating higher order 2PI skeleton diagrams
  * Multi-pronged *ab initio* approach to the EoS:

    QCD + ChEFT + NS observation + (QHC?) + …