Equilibration of Charm Quarks at Ultrarelativistic Energies

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Work in collaboration with

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- Jan Steinheimer
- Marcus Bleicher
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- Chinorat Kobdaj
- Yupeng Yan

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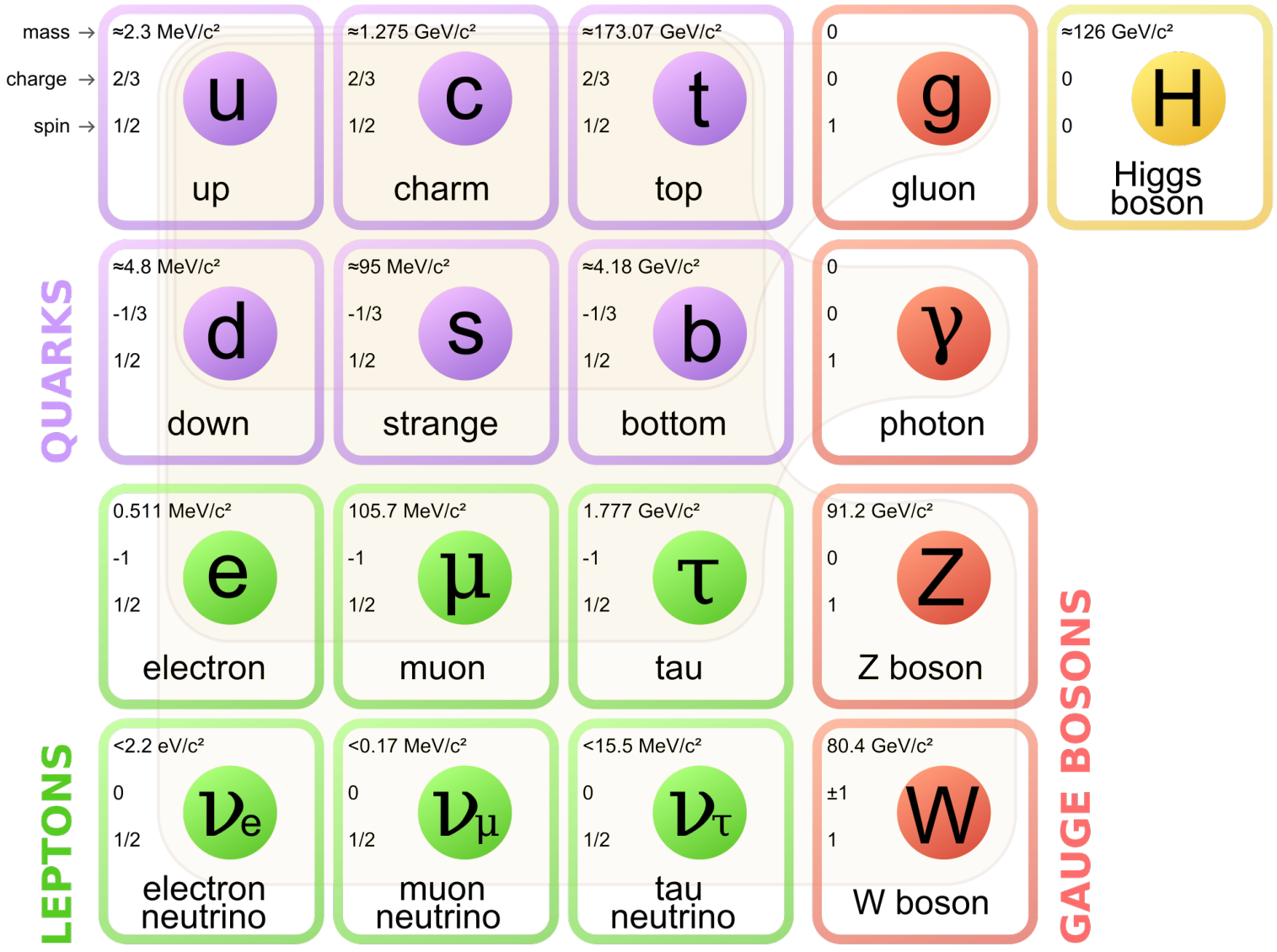
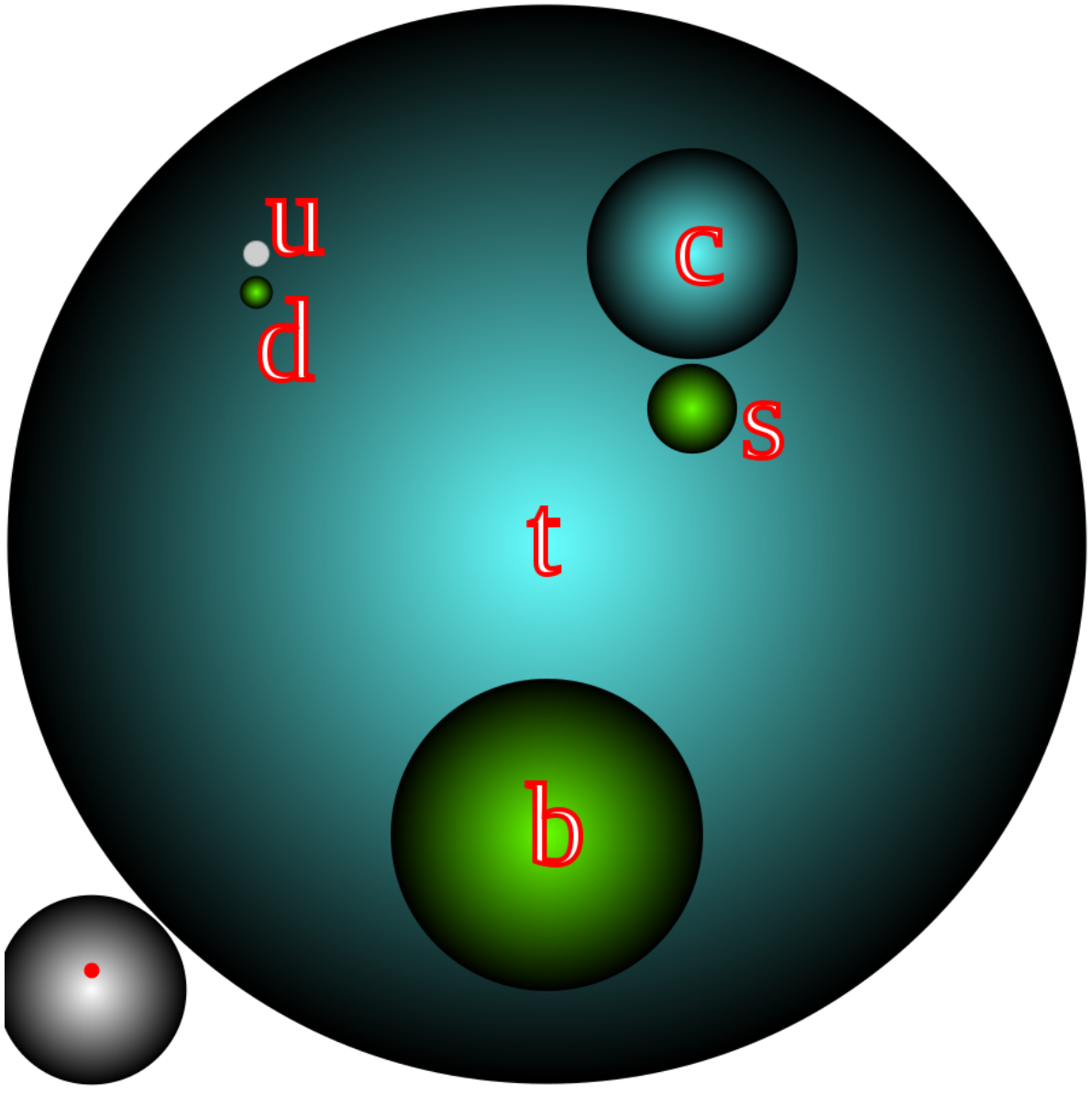
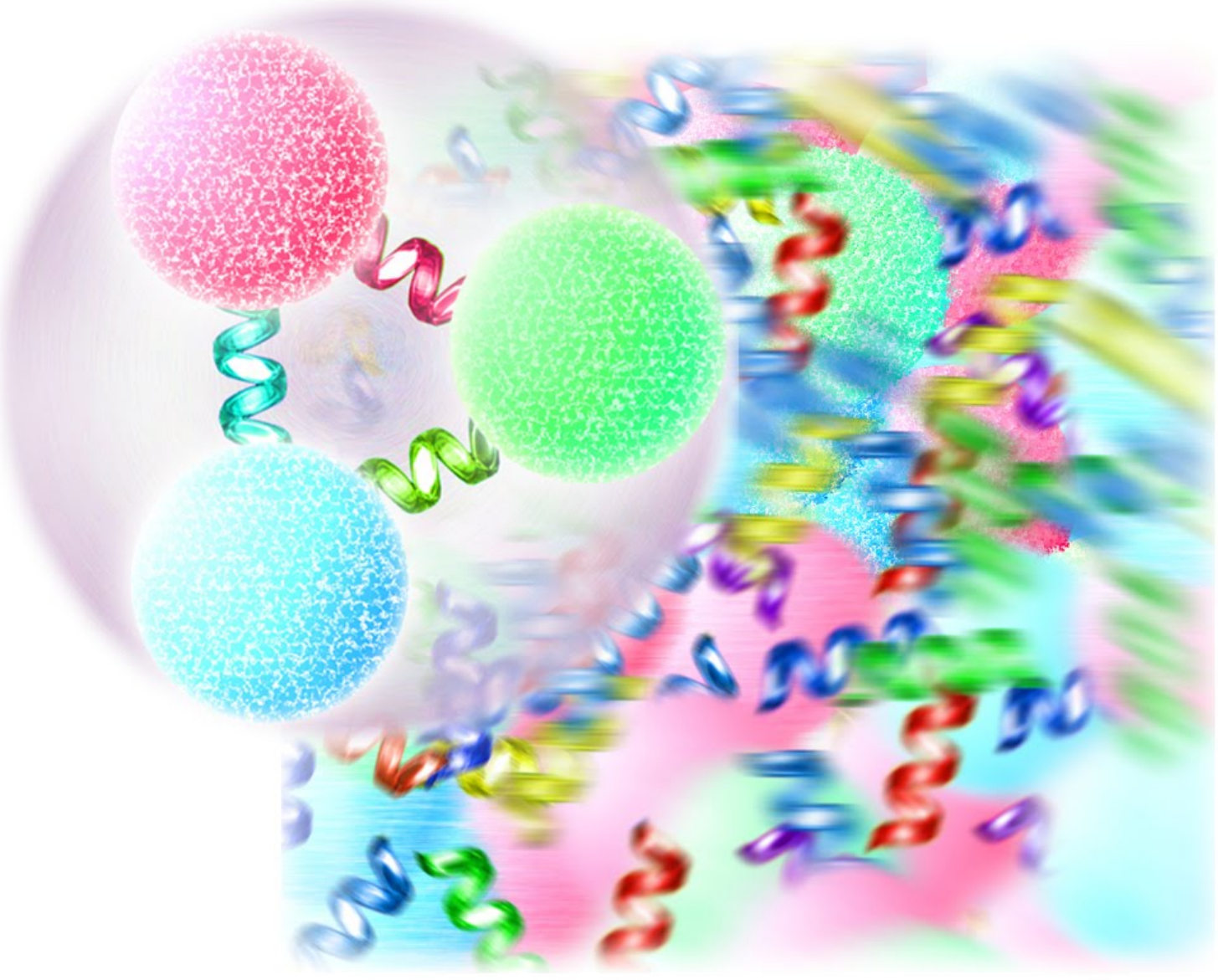
Standard Model of Particle Physics



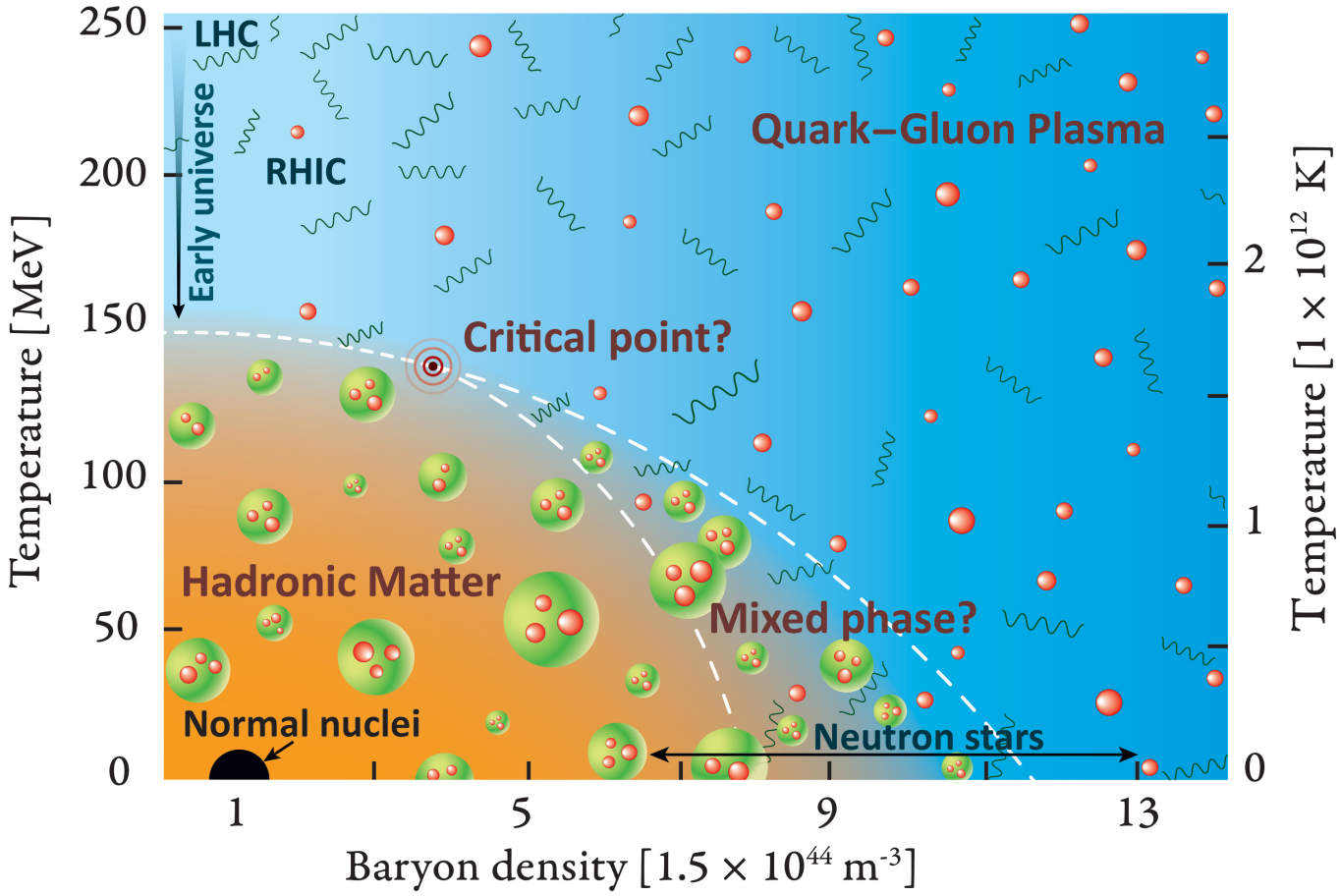
Quarks



The Quark-Gluon Plasma



The QCD phase diagram



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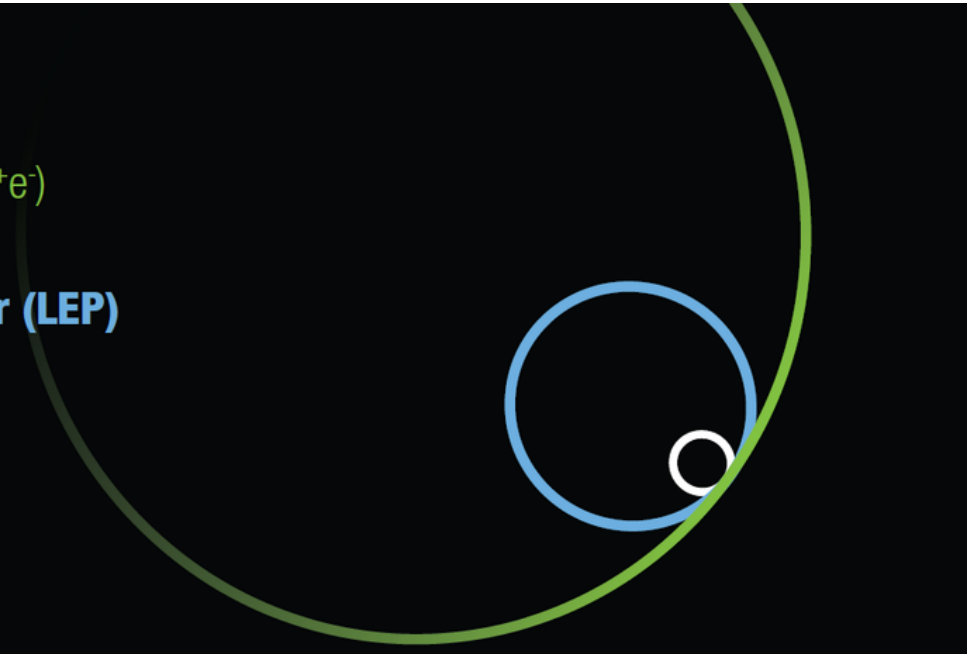
Colliders now and in the future

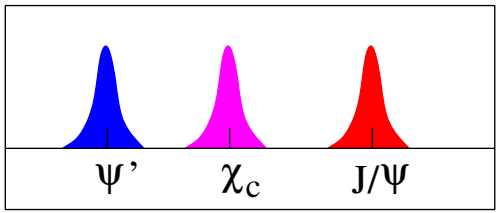
- **Future Circular Collider (FCC)**
  Circumference: 90 -100 km
  Energy: 100 TeV (pp) 90-350 GeV (e^+e^-)
- **Large Hadron Collider (LHC)**
  Large Electron-Positron Collider (LEP)
  Circumference: 27 km
  Energy: 14 TeV (pp) 209 GeV (e^+e^-)
- **Tevatron**
  Circumference: 6.2 km
  Energy: 2 TeV ($p\bar{p}$)



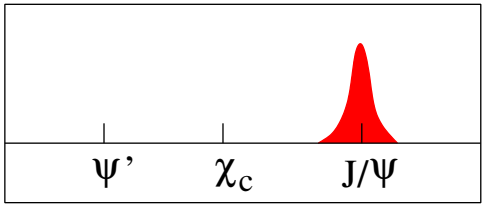
The Quark-Gluon Plasma

Sequential suppression of charmonium states

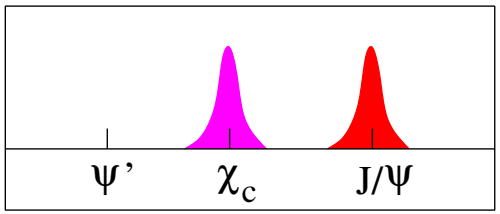
(H. Satz: "The Quark-Gluon Plasma")



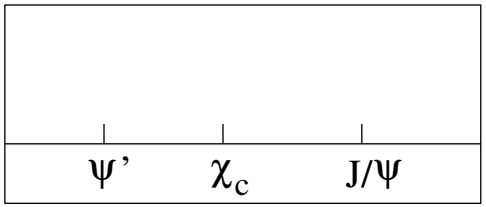
$T < T_c$



$T_\chi < T < T_\psi$



$T_{\psi'} < T < T_\chi$



$T > T_\psi$

Charm Quark Equilibration

From kinetic theory (weak coupling):

- Low $\sqrt{s_{NN}}$: Thermal production negligible
- FCC energies: $T_0 = 840$ MeV
- Thermal production efficient

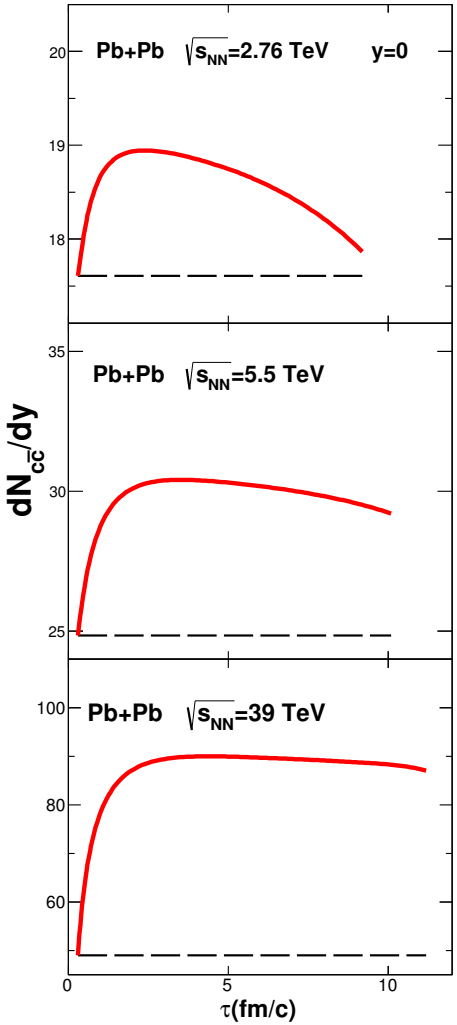
(Zhou et al., Phys. Lett. B **758** (2016))

On the other hand:

- $\Gamma^{-1}_{\mathrm{chem}} \sim 10$ fm/c

(Bödeker, Laine, JHEP (2012))

$\rightarrow$ Relevant at LHC
$\rightarrow$ Dominant at FCC



(Zhou et al., Phys. Lett. B **758** (2016))

Equilibration T and V

- Susceptibilities correspond to conserved charge fluctuations:

$$\chi^2 = \frac{1}{TV}\langle \delta N^2 \rangle$$

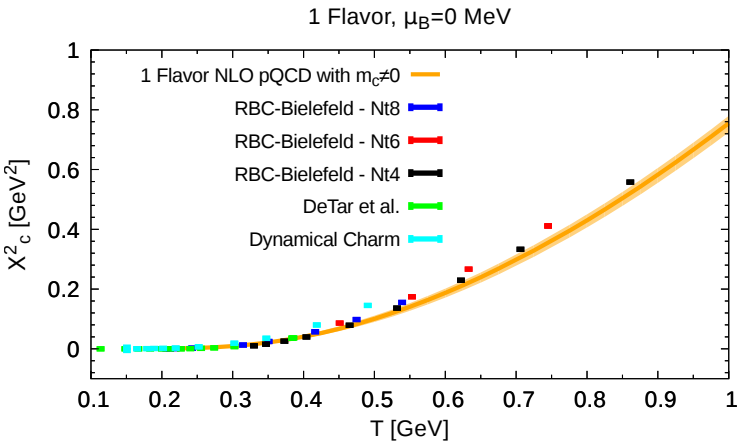
- Use Charm Quark Number Susceptibilities, order i:

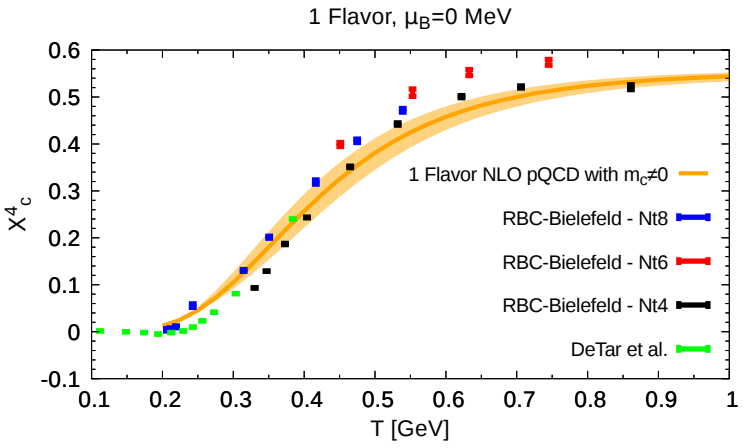
$$\chi_c^i(T) = \left. \frac{\partial^i p(T, \vec{\mu})}{\partial \mu_c^i} \right|_{\vec{\mu}=0}$$

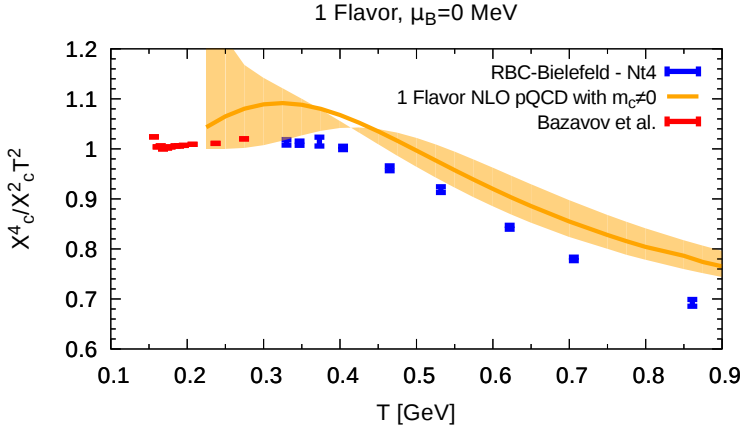
- Two equations with two unknowns T and V:

$$\frac{\langle (\delta N_{c-\bar{c}})^2 \rangle}{\chi_c^2} = TV \text{ and } \frac{\chi_c^4}{\chi_c^2/T^2} = \kappa\sigma^2 \equiv \frac{\langle (\delta N_{c-\bar{c}})^4 \rangle}{\langle (\delta N_{c-\bar{c}})^2 \rangle} - 3\langle \delta N_{c-\bar{c}} \rangle^2$$

Susceptibilities - lattice and pQCD



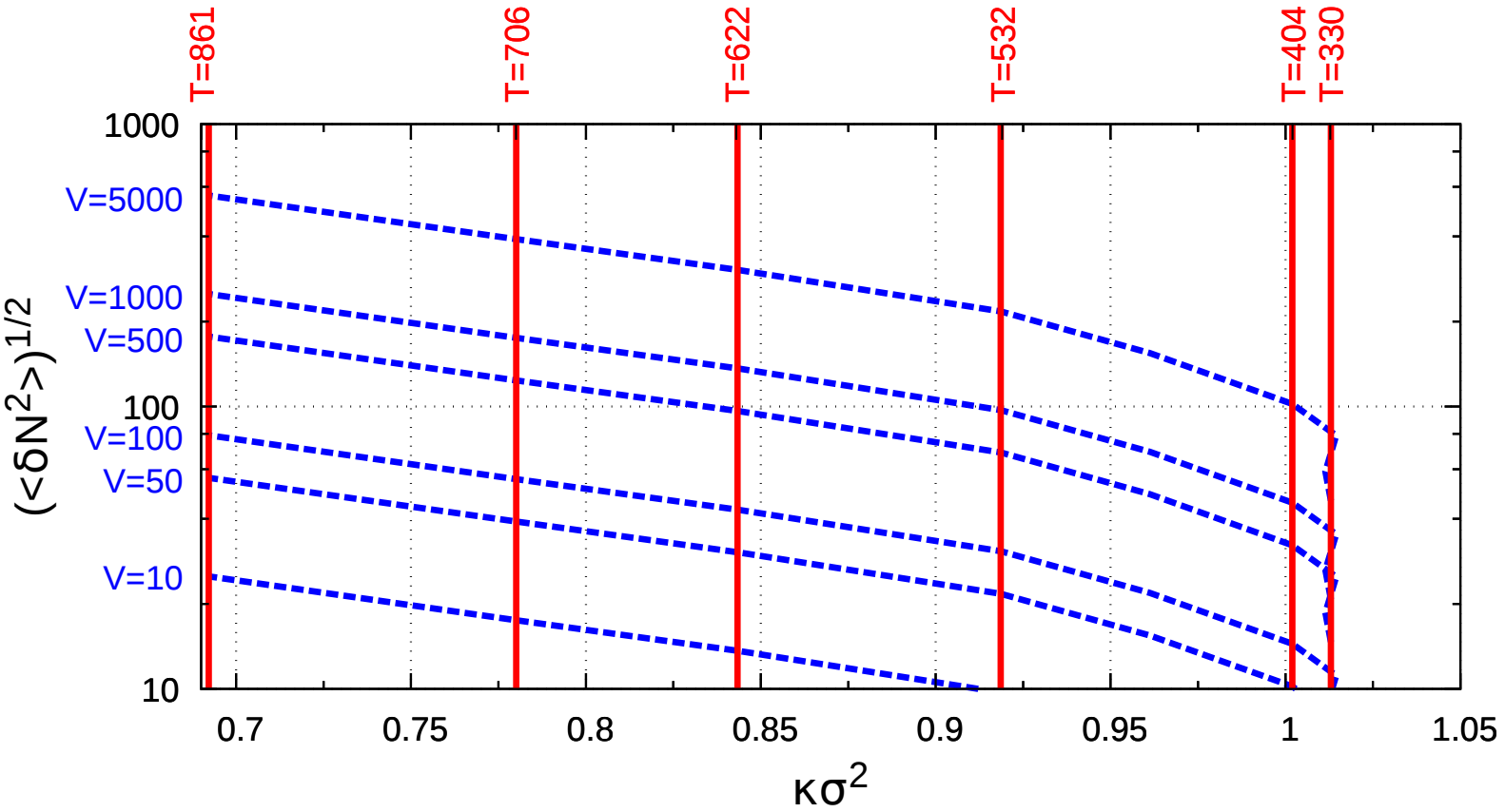




(Graf, Bleicher, Steinheimer, Herold, PRC **97** (2018))

- Unquenched lQCD only for $T < 0.5$ GeV

Susceptibilities - lattice and pQCD



(Graf, Bleicher, Steinheimer, Herold, PRC **97** (2018))

Summary

Charm Quark Equilibration

- Thermal Charm Quark Production
- Important at FCC, relevant at LHC
- Possible to explore equilibration T, V via susceptibilities
- Future: Additional constraints from higher-order fluctuations