

# Observing Critical Fluctuations in the Dynamics of Heavy Ion Collisions

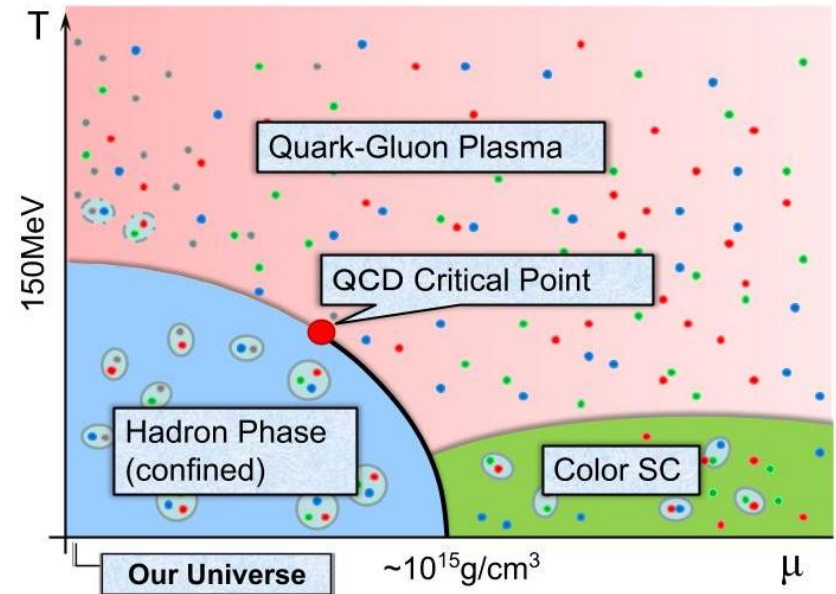
Proposal HAD\_03

M. Kitazawa (Osaka U./ KEK) & M. Nahrgang (Subatech)

# Motivation: explore the QCD phase diagram

Understanding the dynamics of the strong interaction under extreme conditions of temperature and density!

Is there a critical point and an adjacent line of first order phase transition between the quark-gluon plasma and the hadronic gas at large net-baryon density?

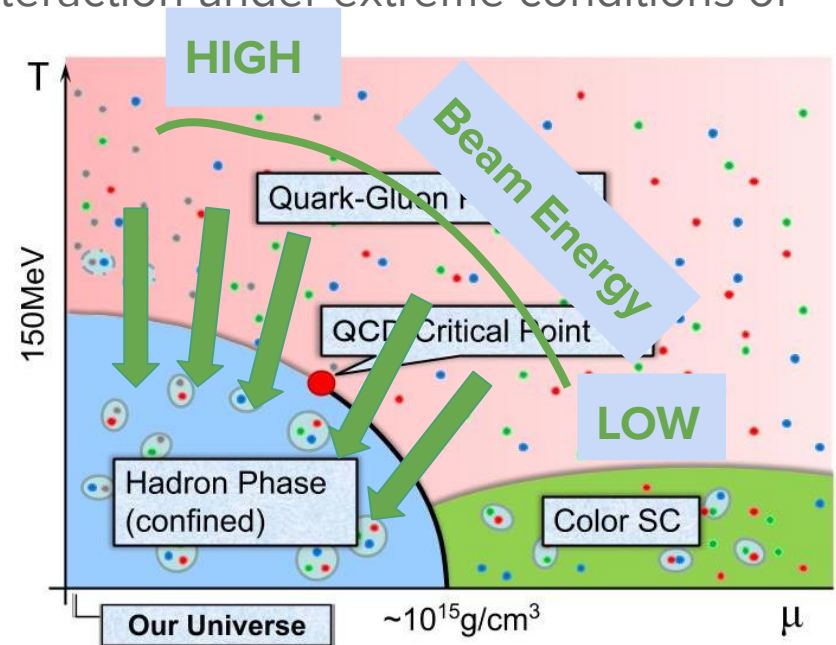


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=> **Study experimentally within a Beam Energy Scan Program!**

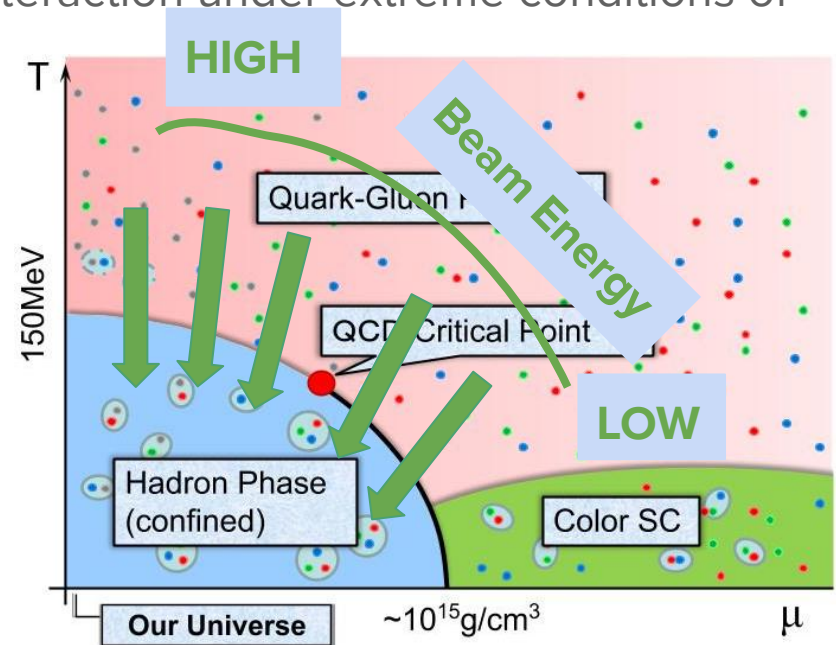


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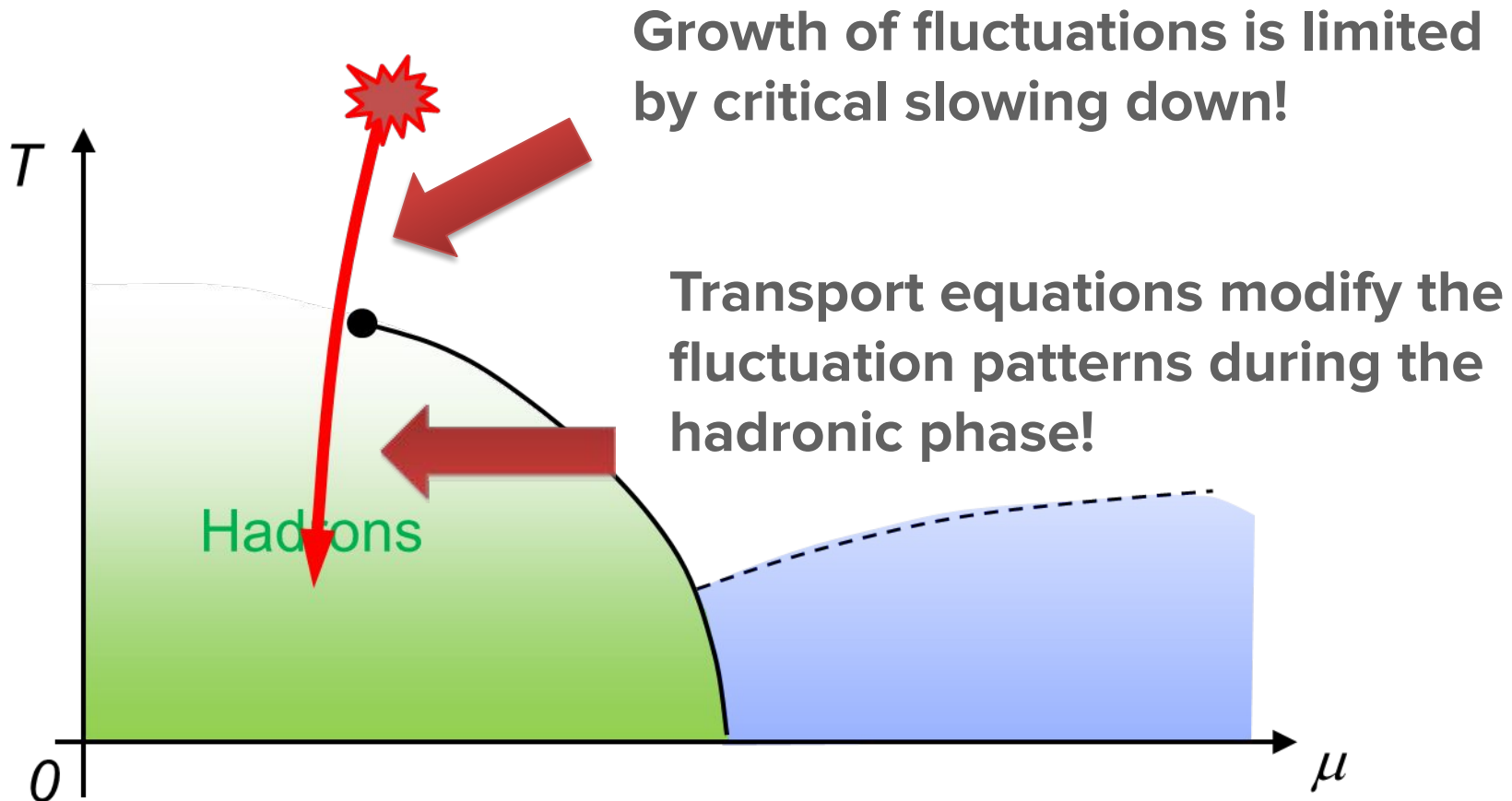
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- Fluctuation observables, in particular higher-order cumulants of net-baryon number, are sensitive to critical phenomena at the phase transition.
- So far predictions are based on grand-canonical thermodynamics, but HIC are highly dynamical!

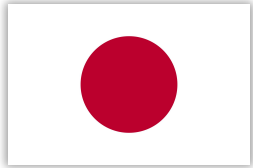
=> **Need to include the fluctuation dynamics into descriptions of HIC!**

## Effect of dynamics



**The goal of our proposal is to study these effects systematically in realistic descriptions of heavy-ion collisions! This allows us to compare to experimentally data in a meaningful way!**

# Two dynamic-al groups



Osaka

**M. Kitazawa,**  
H. Ito,  
T. Nishimura



- Diffusion of hadrons in Brownian models
- Late stage hadronic effects on net-baryon number fluctuations, thermal blurring and isospin randomization
- Stochastic Diffusion equation in Gaussian limit - analytical study



Nantes

**M. Nahrgang,**  
M. Bluhm,  
G. Pihan,  
N. Touroux

- Dynamics of chiral fluctuations and fluid - analytical study, numerical implementation
- Noncritical effects on fluctuations in transport and hadron resonance gas models
- Stochastic Diffusion equation with nonlinear terms - numerical study

**Perfect overlap/complementarity of expertise!**

# Research Project HAD\_03

Achieved goals in 2019/2020:

- Implementation of C++ code to run on graphic cards (GPU), important to be able to run enough simulations to investigate higher-order cumulants ([Master student N. Touroux](#)).
- Extension of Cartesian stochastic diffusion with nonlinear terms to Milne coordinates => comparison of numerical and analytical results for a Bjorken, boost-invariant expansion; study of higher-order cumulants for model with nonlinear interaction terms ([PhD student G. Pihan](#)).
- Visit of M. Kitazawa to Subatech, Nantes, in September 2019.
- Presentation of M. Kitazawa at Quark Matter 2019, Wuhan, China

Problems in 2019/2020:

- Corona-Virus: no visit of Nantes group to Osaka (planned for April 2020), probably no research stay of Nantes Master student N. Touroux to Osaka (planned for April-June 2020)

# Research Project HAD\_03

Plans for 2020/2021:

- Coupling of the net-baryon fluctuations to fluctuations in energy and momentum density =>
  - investigate a full equation of state of QCD, including regular and critical parts
  - restore the dynamical universality class of QCD, model H(PhD student G. Pihan)
- Investigate the Cartesian stochastic diffusion with nonlinear terms in 3+1 dimensions =>
  - systematic study of lattice space dependence
  - explore possibilities of numerical renormalization(Master student N. Touroux)

Problems probably to arise in 2020/2021:

- Corona-Virus: unclear at which time travel between the two countries will be unrestricted...



# Summary

- **Beam Energy Scan Programs** are gaining interest worldwide, e.g. the planned heavy-ion program at J-PARC!
- **Dynamics of fluctuations** are crucial to understand in theoretical models in order to interpret the results of these experiments!
- **Many conceptual and practical challenges** in the development of these models can best be met by our **bilateral Nantes-Osaka collaboration!**



# Appendix

10GeV

$10^2$  GeV

1TeV

$\sqrt{s_{NN}}$

AGS  
-1996

SPS  
1994-2000

RHIC  
2000-

LHC  
2010-

RHIC-BES  
2010-

BES-II  
2019-

NICA  
2020-?

FAIR  
2023-?

J-PARC-HI  
2026~?

creation of quark-gluon plasma,  
strongly-interacting QGP

~2010

History of HIC = increasing energy

2010~  
Beam-energy scan  
Low-energy exp.

Overview of heavy-ion  
collision programs

