Spinodal instability with varying criticality in holography

Maximilian Attems (CERN TH)

arXiv:2012.15687 (JHEP)

HI Group - TH Retreat 2021

before MSCA at CERN TH:

PhD Technical University of Vienna

View from TU Freihaus to National Librational

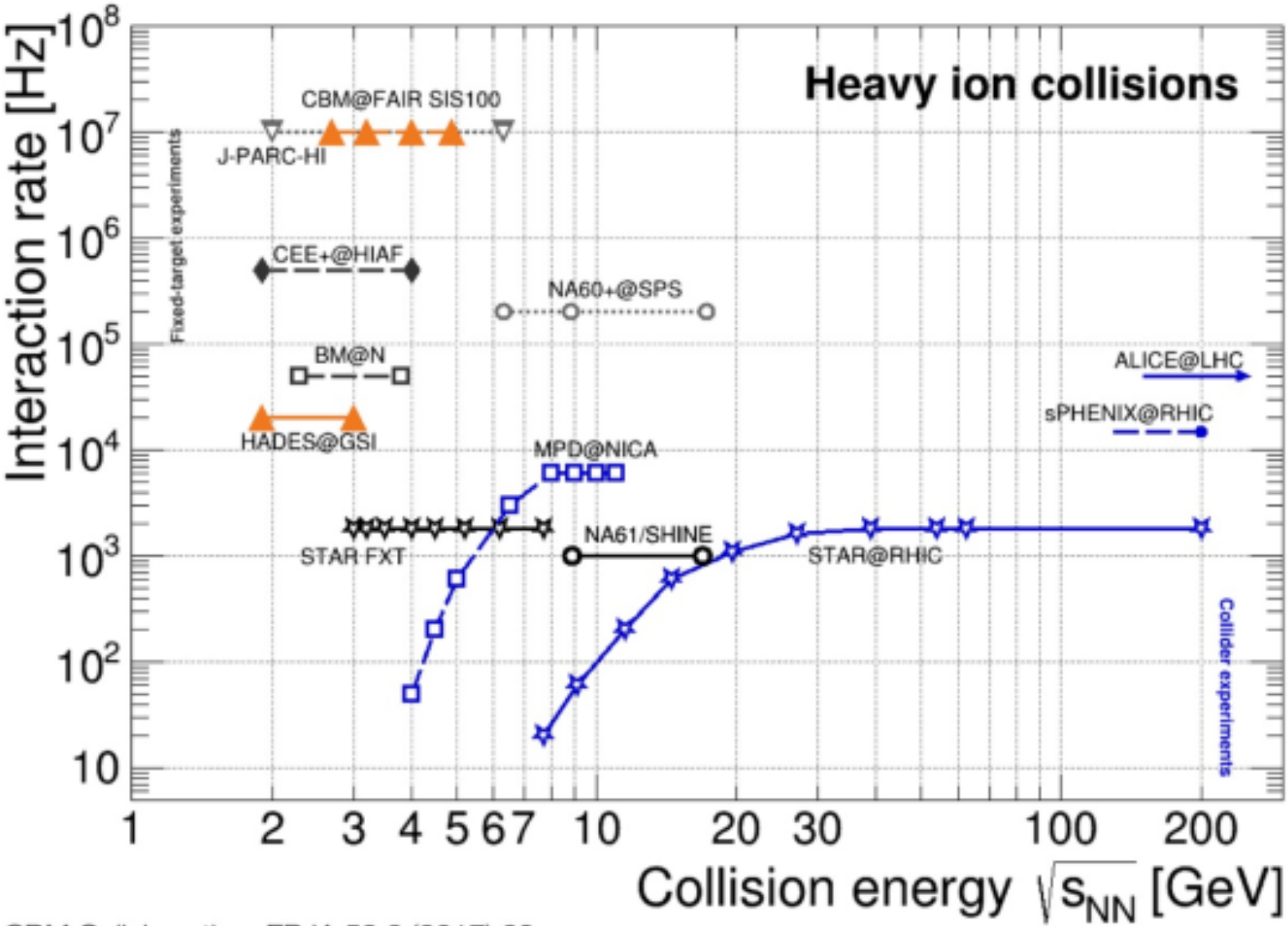
before MSCA at CERN TH:

IGFAE

ICC,
UB

FIAS

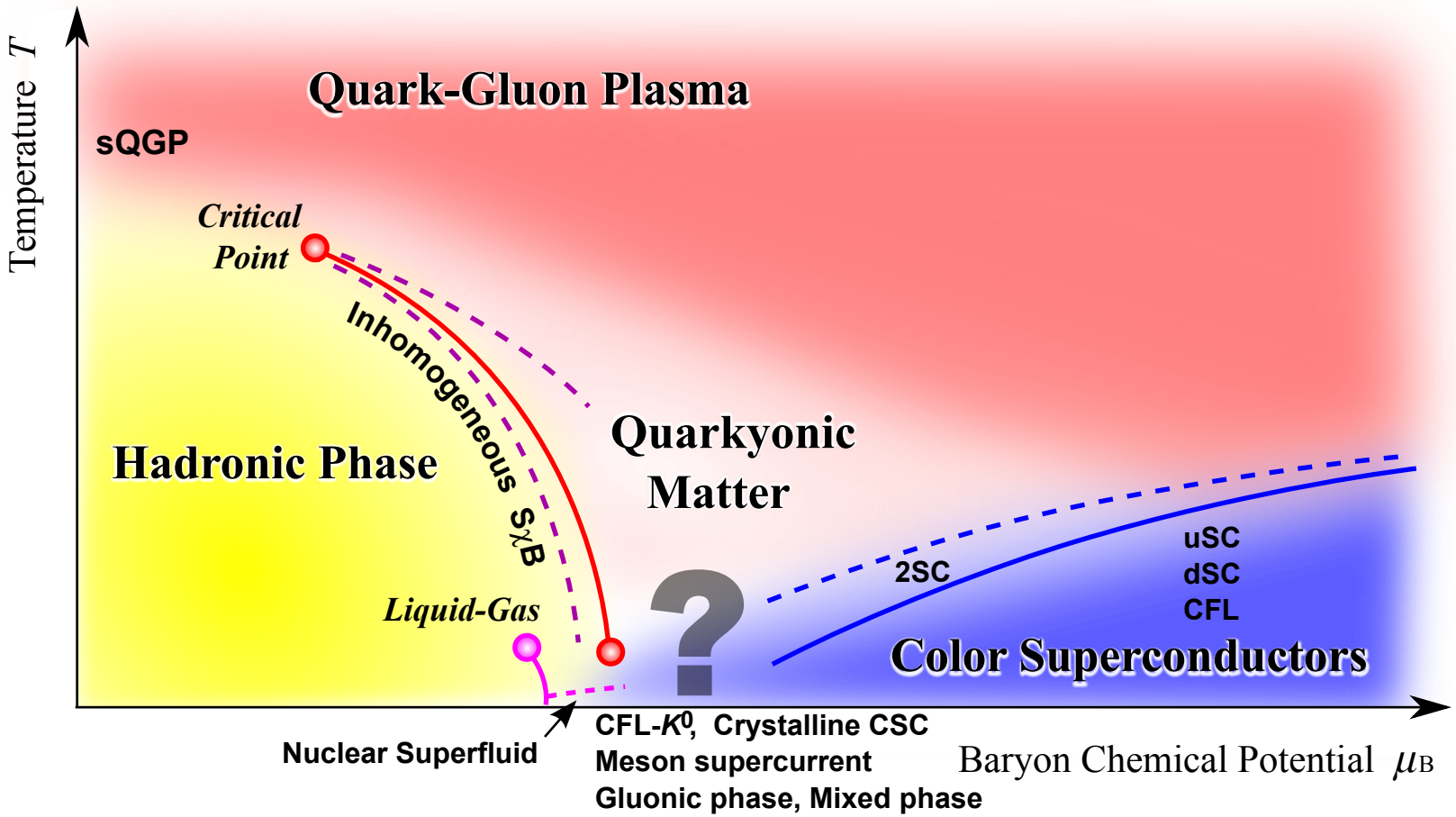
Motivation - world wide HI ex



CBM Collaboration, EPJA 53 3 (2017) 60
T. Galatyuk, NPA982 (2019), update (2021)

Motivation - many unknows in the QCD phase diagram

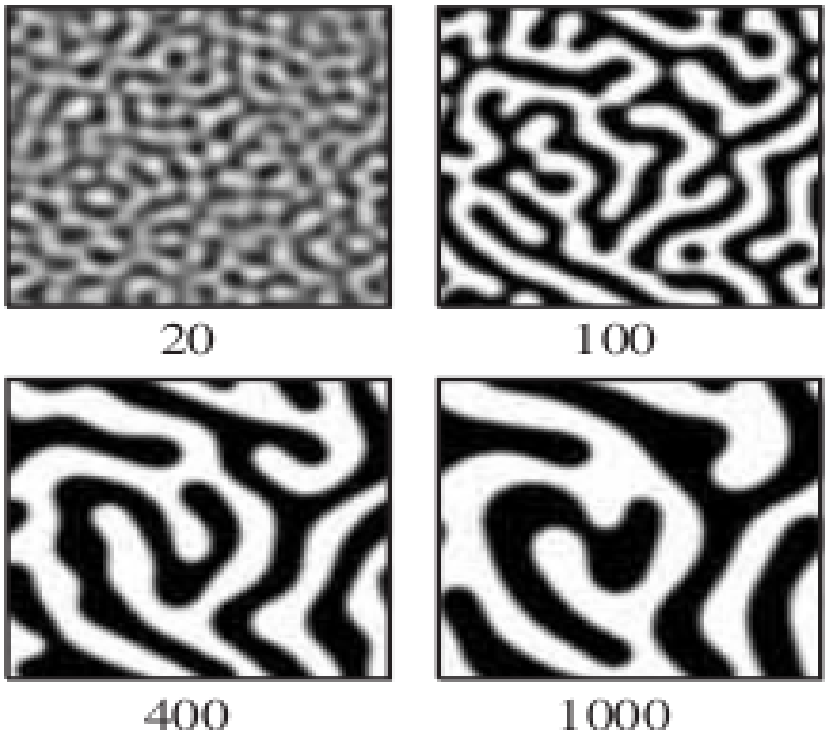
The critical point (CP) is the endpoint of the 1st order phase transition between the Quark-Gluon Plasma and the hadrons:



Assumed QCD phase diagram [Fukushima, Hatsudo 2010]

Holographic setup

spinodal instability:



spinodal decomposition in a two phase system

[Onuki 1987]

Gregory-Laflamme instability:

thin black ring pinching off

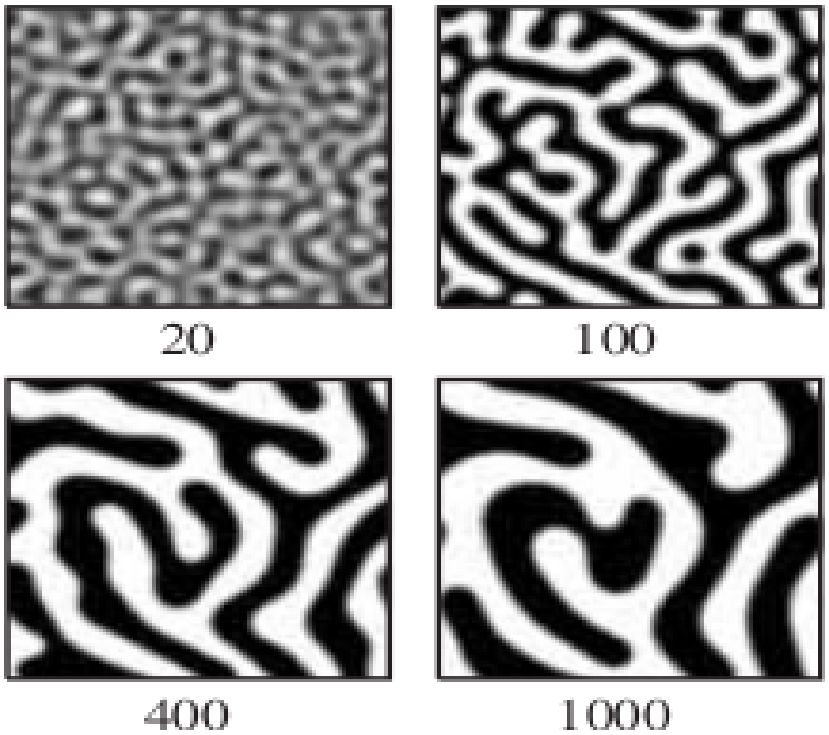
[Figueras, Kunesch, Tunyasuvunakool 2015]

gauge/gravity correspondence:

bridge between physical phenomena in gauge theories and gravity.

Holographic setup

spinodal instability:



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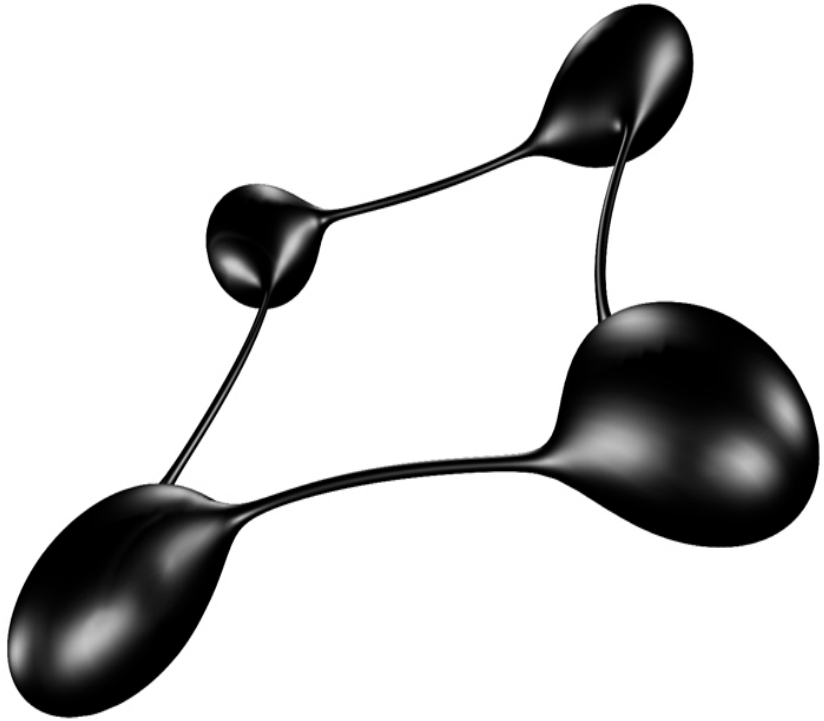

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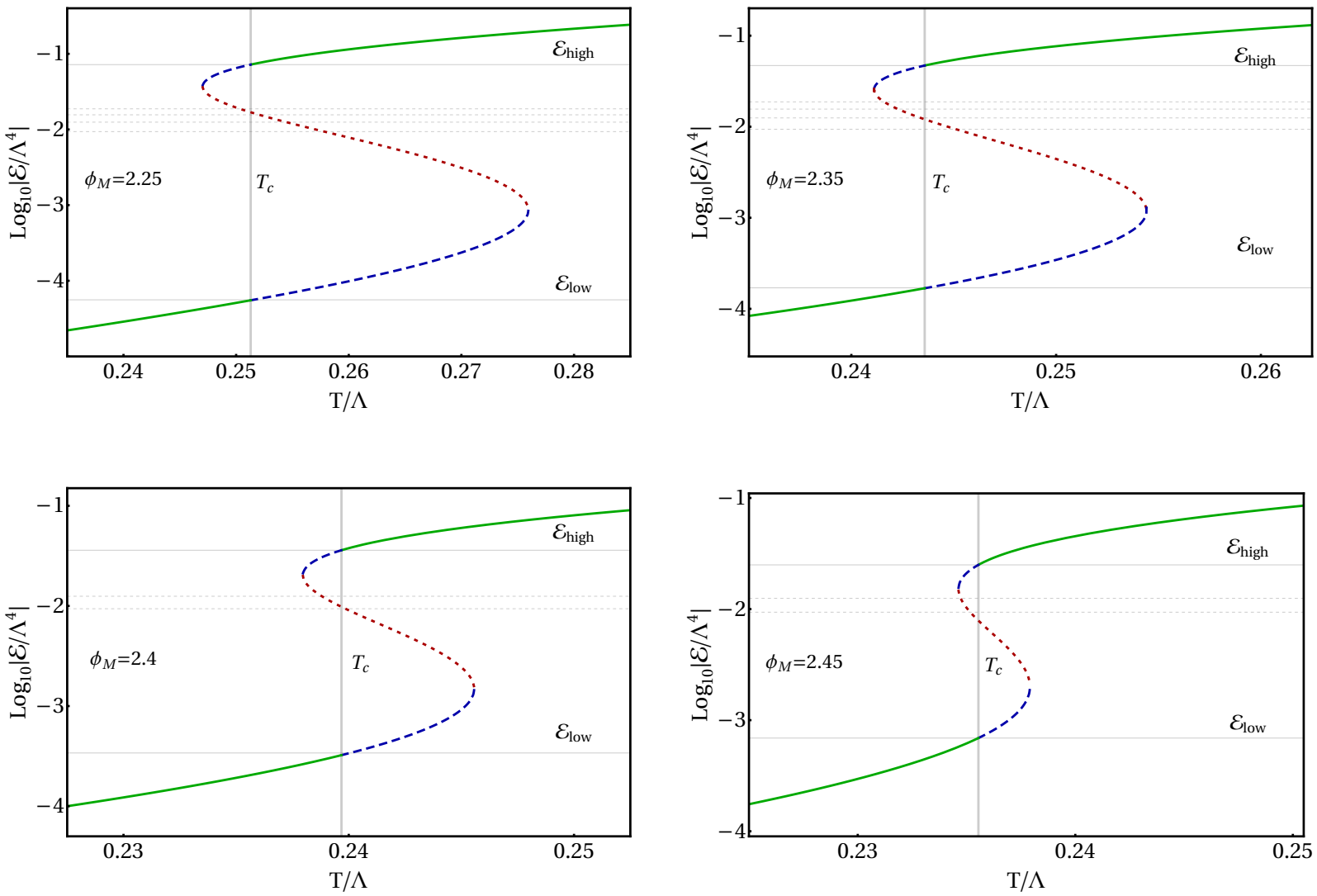
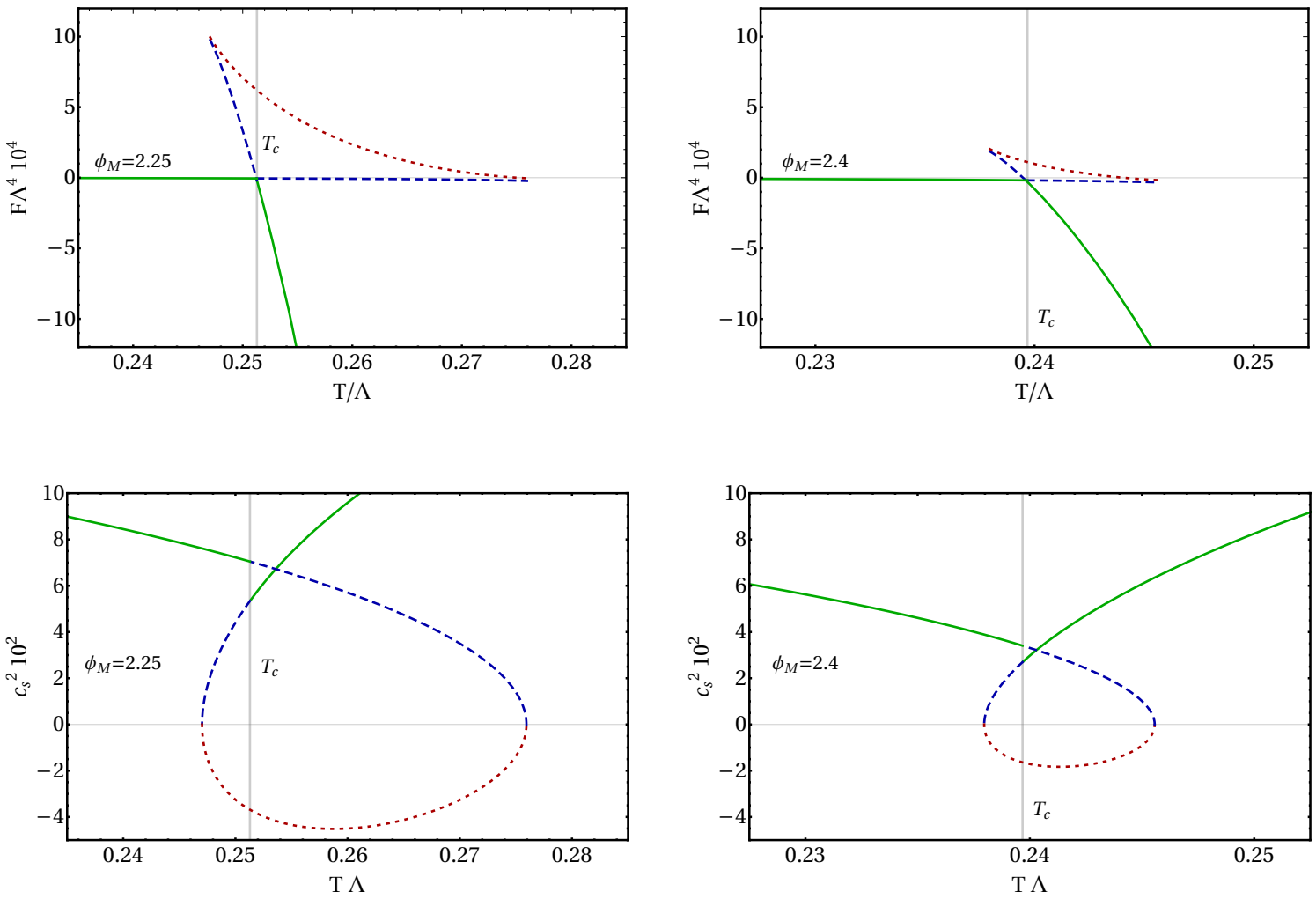
Bottom-up model: tuning criticality



Energy density over T for theories with first order phase transition (blue) metastable (red) spinodal region (green) stable phases

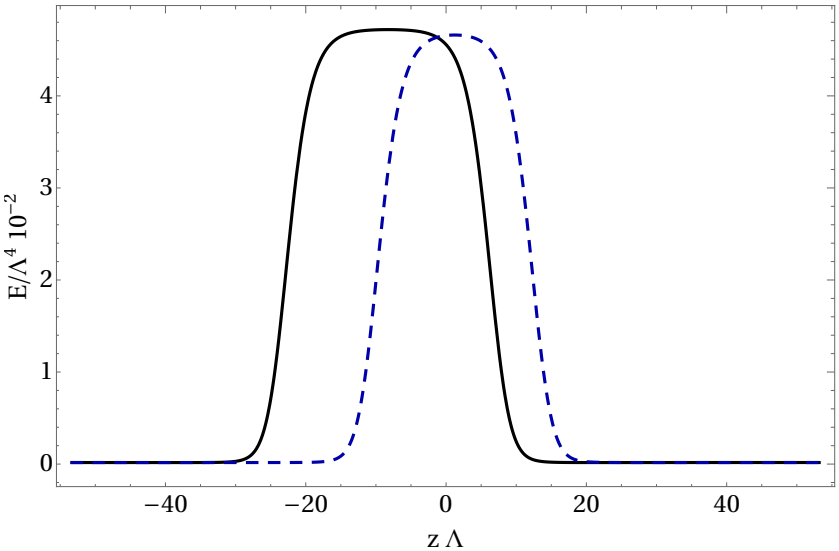
Bottom-up model: tuning criticality II

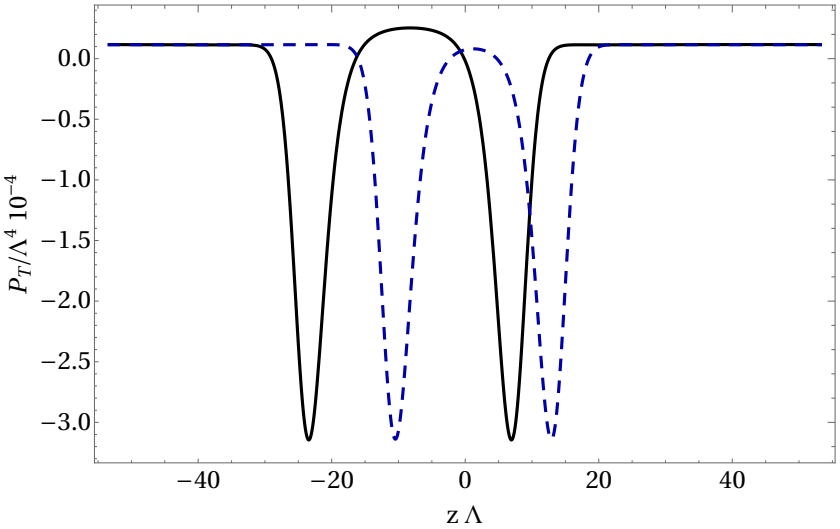


Thermodynamical properties of hard/soft transition:
(top row) Free energy over temperature
(bottom row) Speed of sound squared over temperature

Spinodal instability - criterium

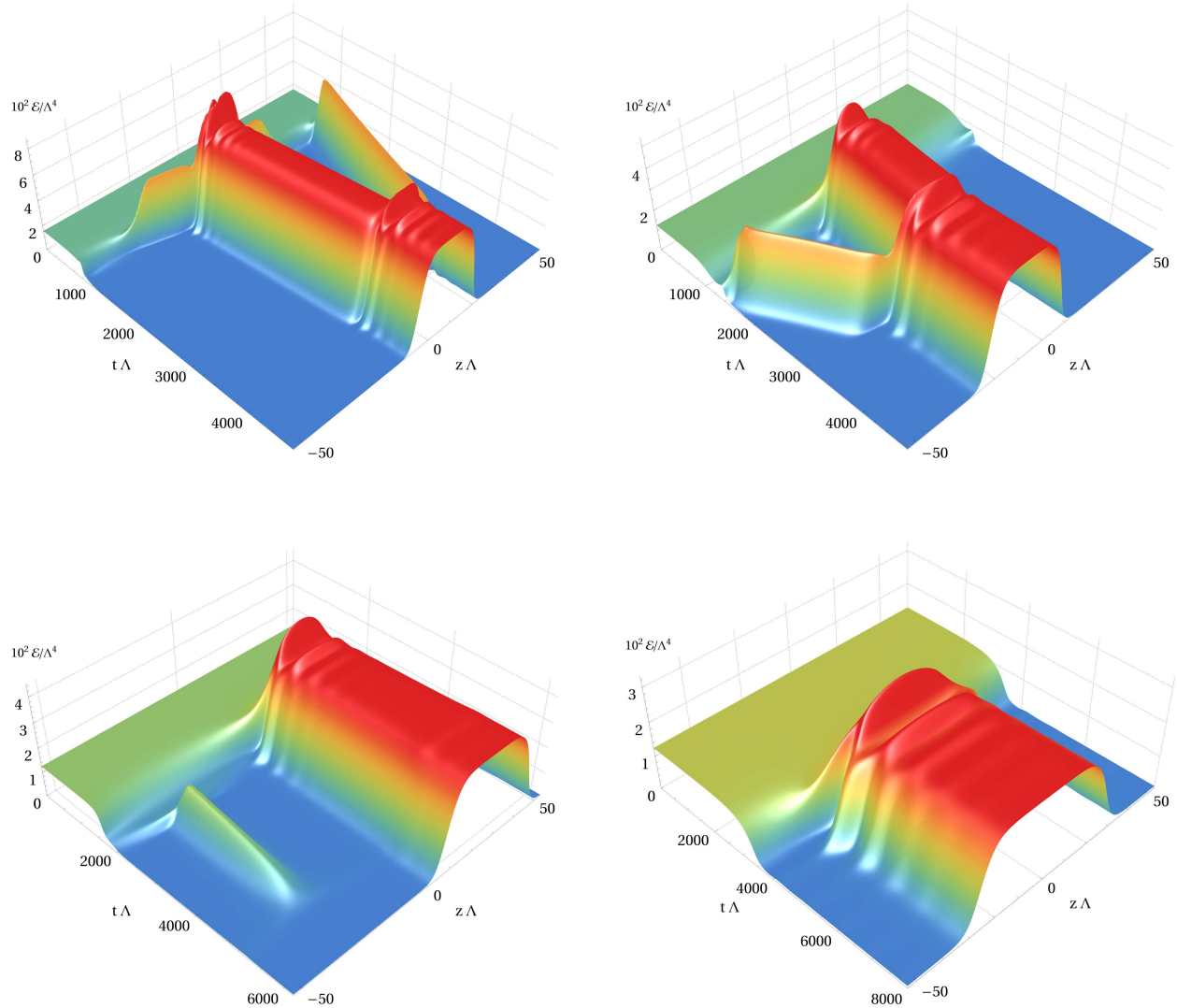
New criterium plateau (full black) where $P_T \geq 0.8 P_c$ versus peak (dashed blue) where $P_T < 0.8 P_c$





Longitudinal profiles of (left) local energy density (right) transverse pressure PT

Spinodal instability evolution



Phase separated final solution seen in the evolution of the local energy density of harder/softer phase transitions

Summary: spinodal instability approaching a critical point

Demonstration of the full dynamics of strongly coupled spinodal instability first order phase transitions.

Near a critical point the interface between cold and hot stable phases, given by its width and surface tension, features

- a **wider phase separation**,
- a **smaller surface tension** and
- a **longer formation time**.

Hence the spinodal instability is easier to detect far from a critical point along the first order phase transition.

New discovery of an atypical setup with dissipation of a peak into a plateau.

Private outdoor acitivies

Backup: spinodal instability - formation time

The formation time is defined as the time from the start of the evolution to when the system first reaches one of the two stable phases.

Formation time of the spinodal instability with varying criticality:

ϕ_{M}	2.25	2.35	2.4	2.45
$t_{\mathrm{formation}}\Lambda$	880	1380	1725	2660

The formation time correlates with the strength of the first order phase transition: the strongest phase transition with the largest spinodal region shows the fastest formation time.

Backup: Literature

1) "Holographic approach of the spinodal instability to criticality" By Maximilian Attems arXiv:2012.15687 [hep-th].

2) "Dynamics near a first order phase transition" By Loredana Bellantuono, Romuald A. Janik, Jakub Jankowski, Hesam Soltanpanahi arXiv:1906.00061 [hep-th], JHEP 10 (2019) 146.

3) "Dynamics of Phase Separation from Holography" By Maximilian Attems, Yago Bea, Jorge Casalderrey-Solana, David Mateos, Miguel Zilhao, arXiv:1905.12544 [hep-th], JHEP 01 (2020) 106.

Backup: setup bottom-up model

Dual field theory: 'mimics'a deformation of N=4 SYM with a dimension 3 operator O and source Λ as 'mass'

$$S_{\mathrm{GaugeTheory}} = S_{\mathrm{conformal}} + \int d^4x \Lambda O$$

Einstein-Hilbert action coupled to a scalar with non-trivial potential in five-dimensional bottom-up model:

$$S = \frac{2}{\kappa_5^2} \int d^5x \sqrt{-g} \left[\frac{1}{4}\mathcal{R} - \frac{1}{2}(\nabla\phi)^2 - V(\phi) \right]$$

We derive the potential from the superpotential [Bianchi, Freedman, Skenderis 2002]: $V(\phi) = -\frac{4}{3}W(\phi)^2 + \frac{1}{2}W'(\phi)^2$

$$\ell^2 W(\phi) = -\frac{3}{2} - \frac{\phi^2}{2} - \frac{\phi^4}{4\phi_M^2}$$

using a single parameter with critical value $\phi_M = 2.521$

$$\ell^2 V(\phi) = -3 - \frac{3\phi^2}{2} - \frac{\phi^4}{3} - \frac{\phi^6}{3\phi_M^2} + \frac{\phi^6}{2\phi_M^4} - \frac{\phi^8}{12\phi_M^4}$$

Backup: thermodynamics bottom-up model

Dual field theory: 'mimics'a deformation of N=4 SYM with a dimension 3 operator O and source Λ as 'mass'

$$S_{\mathrm{GaugeTheory}} = S_{\mathrm{conformal}} + \int d^4x \Lambda O$$

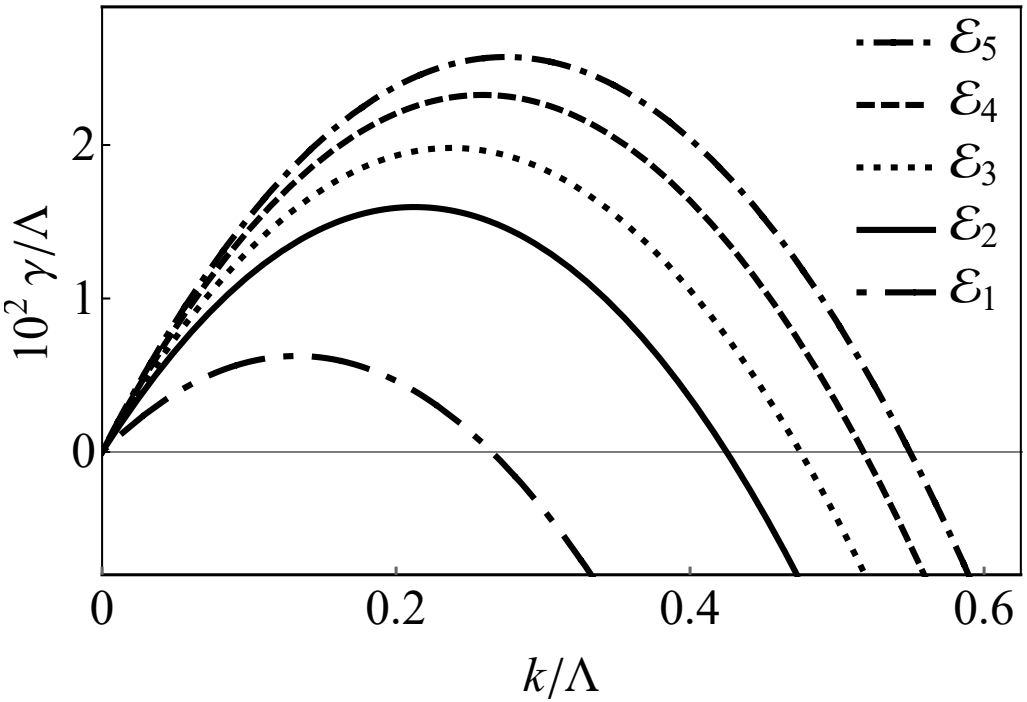
Growth rate

$$\gamma(k) = |c_s|\, k - \Gamma k^2$$

sound attenuation constant

$$\Gamma = \frac{1}{2T}\left(\frac{4}{3}\frac{\eta}{s} + \frac{\zeta}{s}\right)$$

raise dynamical instability

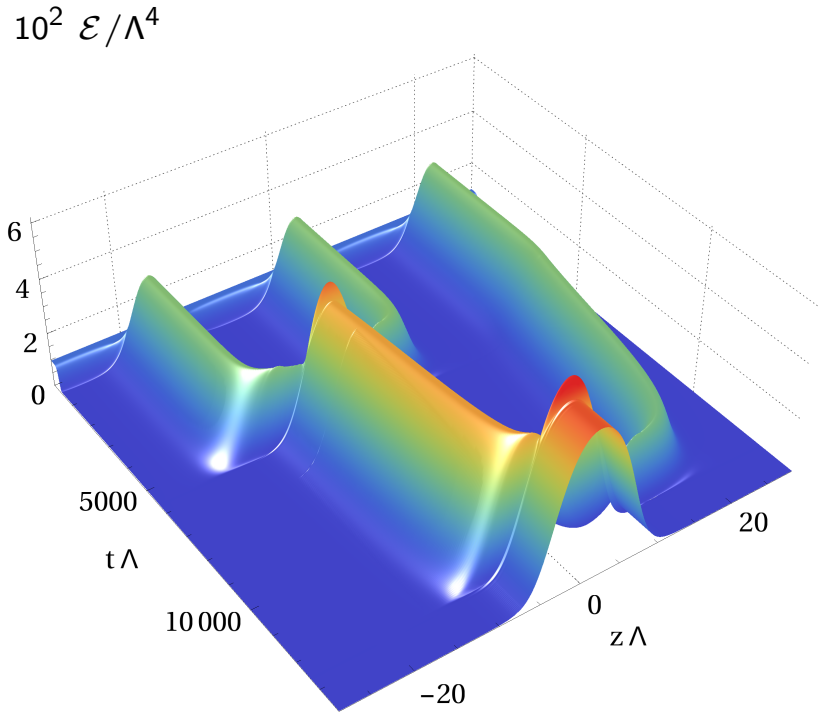


Backup: pinodal instability - stages

four generic stages:

1. linear stage
2. reshaping
3. merger
4. final:
   static + phase-separated

endstate:
phase-separated configuration

conjecture:
all static, non-phase separated configurations are dynamically unstable

Homogeneous initial state in periodic unstable region, initial instability triggered by $n = 3$