Photon emission within a quark meson model

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Introduction

QCD = theory of strong interactions
(success of quark model, cross sections,
hadron masses from lattice,...)

[textbook of YNDURAIN]
[DURR *et al.* Science 322 (2008)]

Open questions:
nature and properties of sQGP, mass generation,
chiral + deconfinement phase transition, ...

[CBM Physics book]

large scale experiments running
or under construction
(RHIC, LHC, FAIR, NICA,...)

one particular question:
existence, position and
properties of a CP

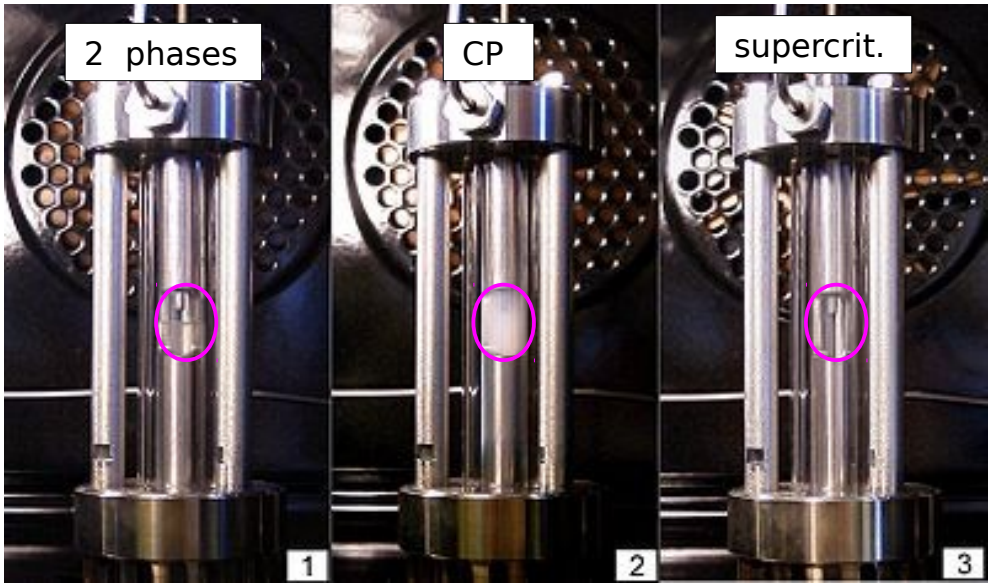
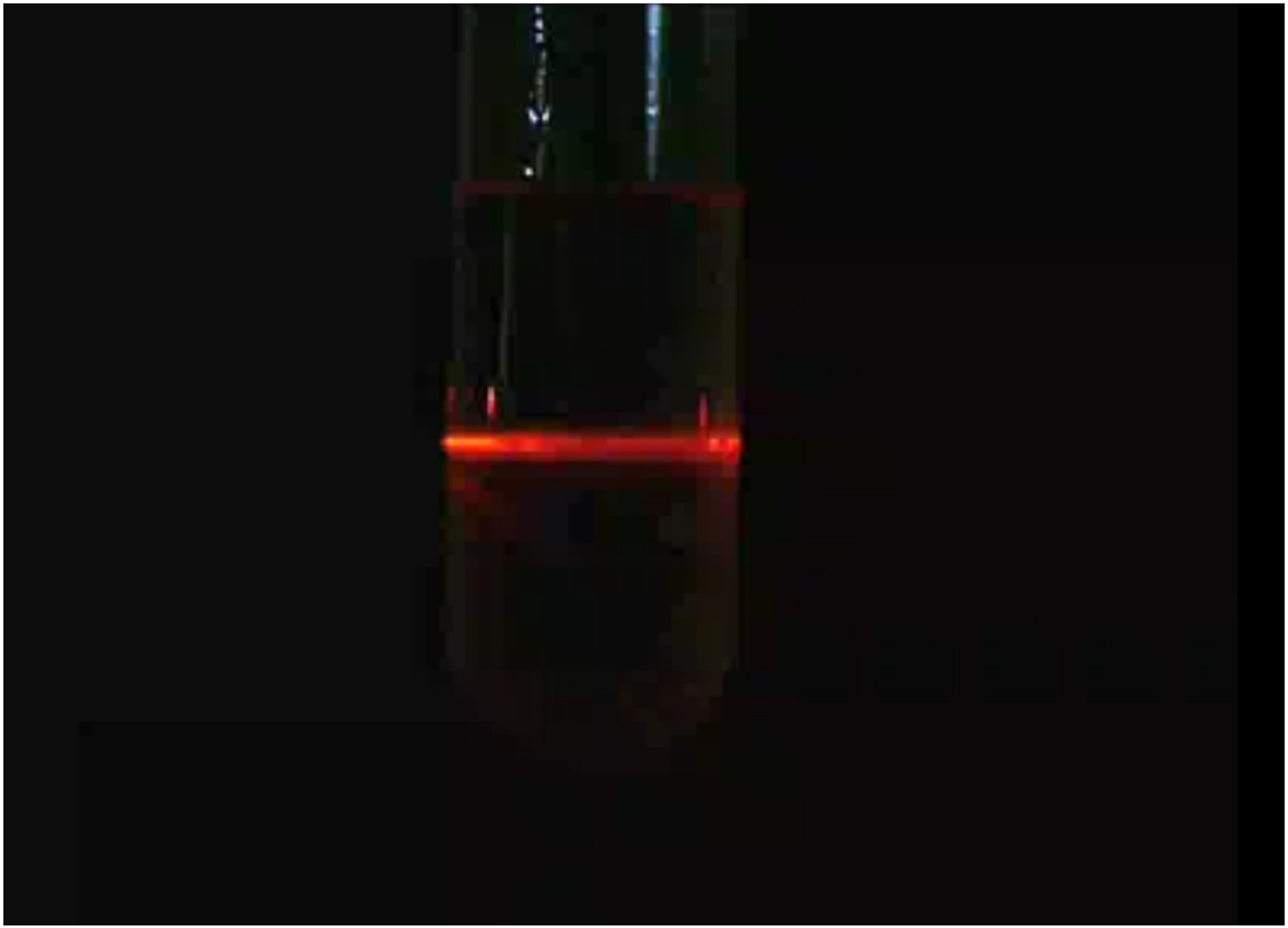


figure from: [Wikipedia.org]

Introduction



Screenshots from: [http://www.msm.cam.ac.uk/doitpoms/tlplib/solid-solutions/videos/laser1.mov]

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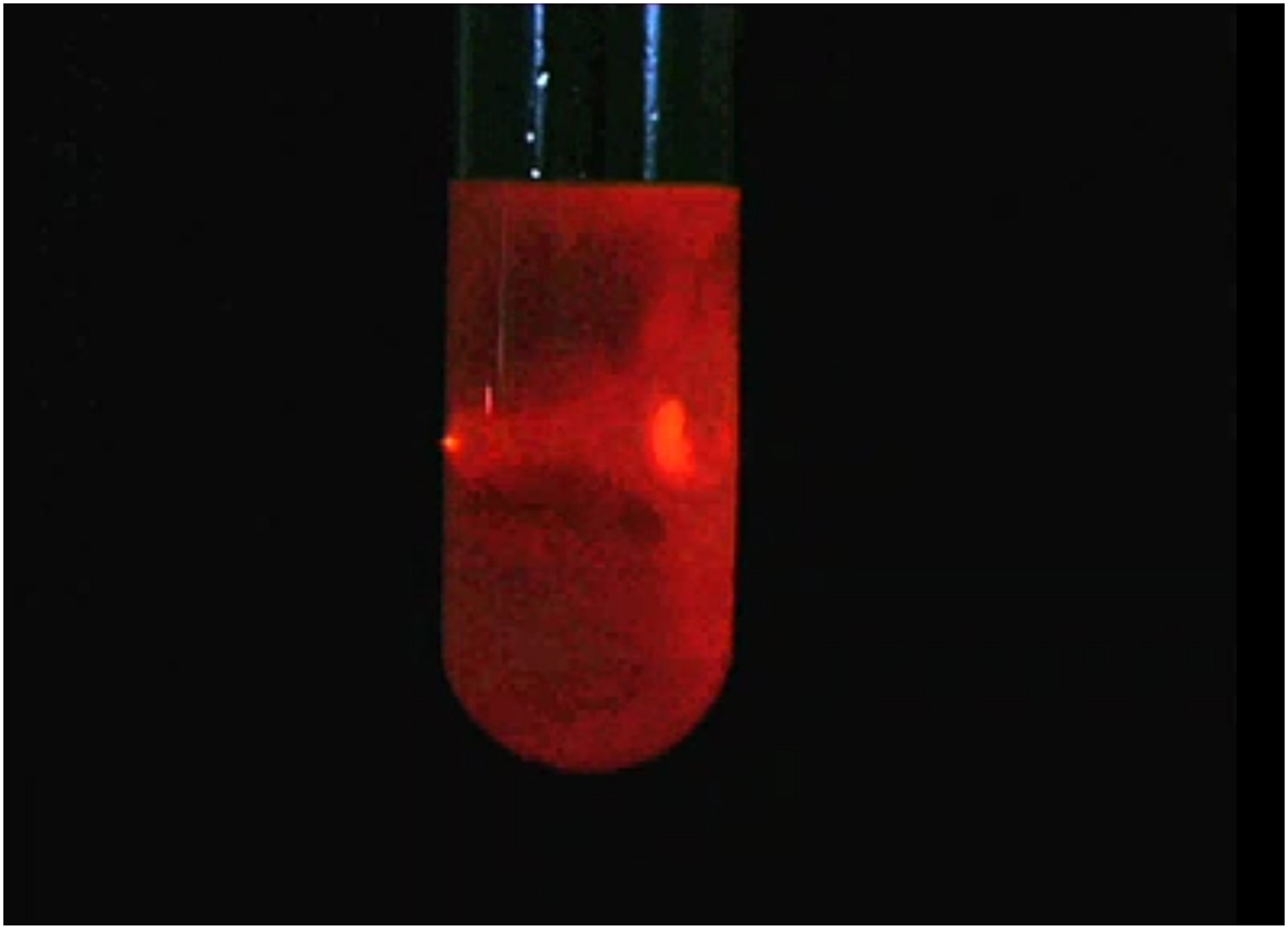

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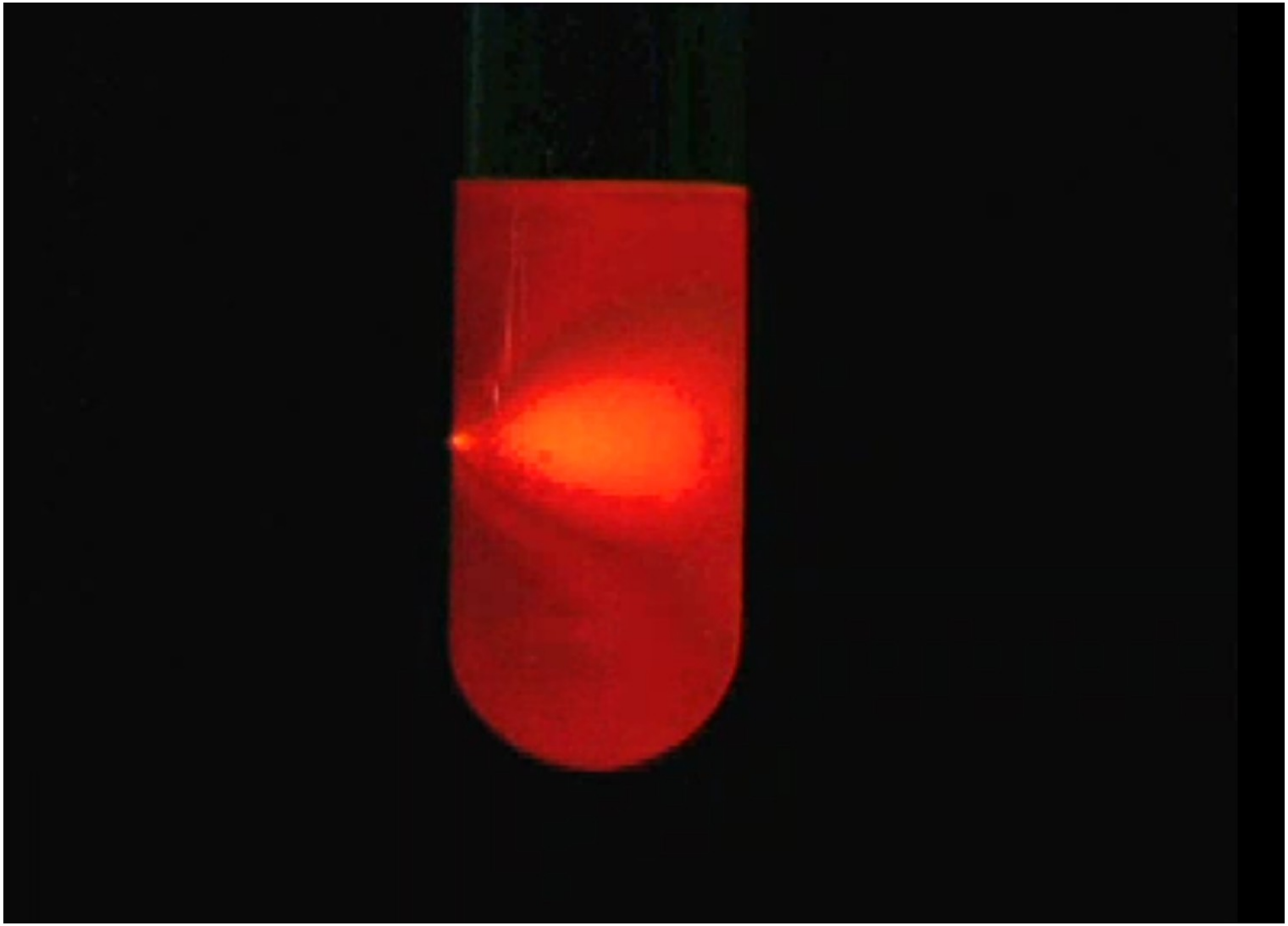

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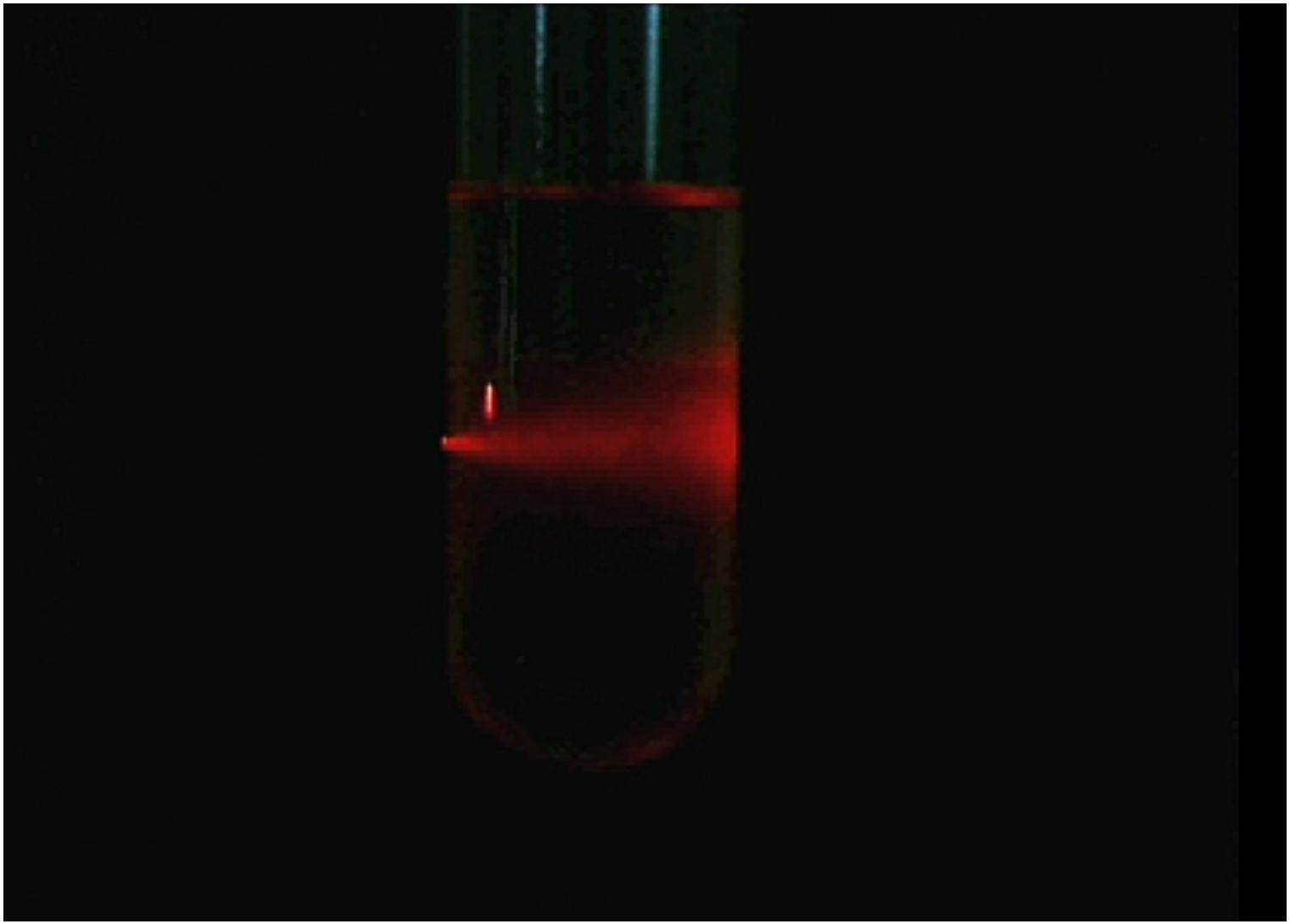
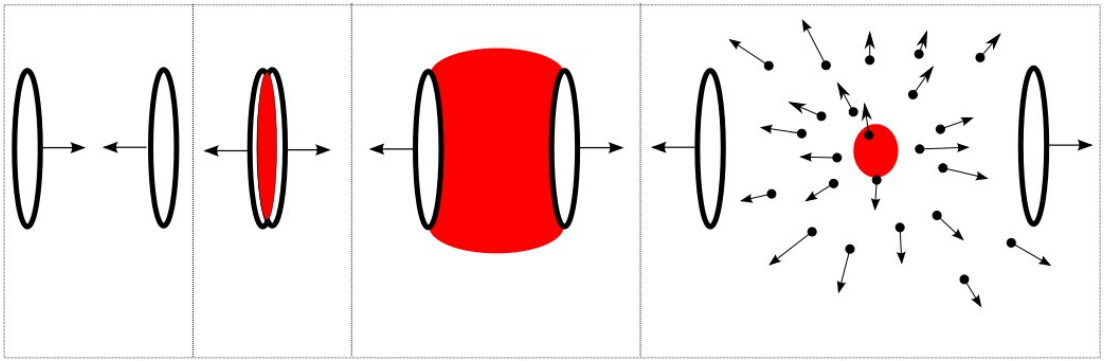


Screenshots from: [http://www.msm.cam.ac.uk/doitpoms/tlplib/solid-solutions/videos/laser1.mov]

Introduction



HIC create region of hot and dense QCD matter

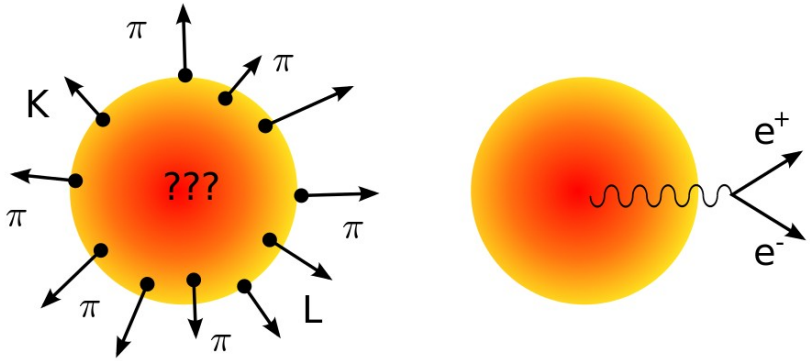
→ explosion

→ detection

most particles: pions created at the edge of the fireball

want: information from the hot interior

one way: electromagnetic probes

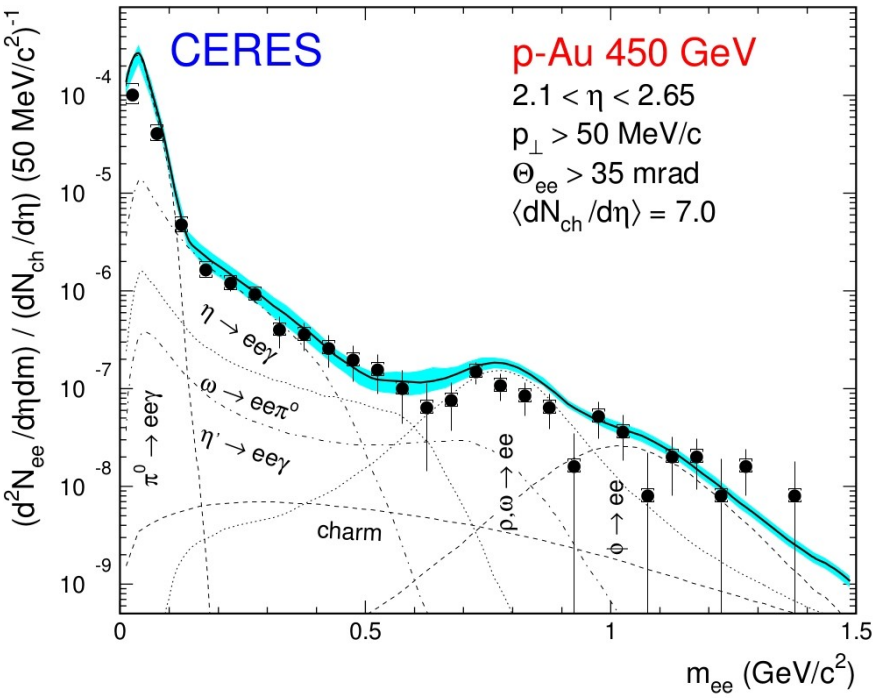


Remark on photons from HIC

[RAPP,WAMBACH Adv.Nucl.Phys. 25 (2000)]

many sources of photons:

- hard photons from parton collisions
- thermal photons from the hydro stage
- decay of hadrons



this work: focus on medium (equilibrium) properties, i.e. emissivity

The qm-model

Our question: “Are there em signatures charakteristic for a CP?”

Due to universality: replace in a 1st step QCD by effective model with appropriate symmetries: qm-model

[SCHAEFER, WAMBACH Nucl.Phys. A757 (2005)]
[SCAVENIUS *et al.* Phys.Rev. C64 (2001)]

$$L_{qm\gamma} = L_{qm} + L_{em} + L_{\gamma}$$

$$L_{qm} = \bar{\psi}\left(i\gamma^{\mu}\partial_{\mu} - g\left(\sigma + i\gamma^{5}\vec{\tau}\vec{\pi}\right)\right)\psi$$
$$+\frac{1}{2}\left(\partial_{\nu}\sigma^{\nu}\right)^{2} + \frac{1}{2}\left(\partial_{\rho}\vec{\pi}^{\rho}\right)^{2} + \frac{\lambda}{4}\left(\sigma^{2} + \vec{\pi}^{2} - v^{2}\right)^{2} - H\sigma$$

$$L_{em} = -eq_{f}\bar{\psi}\gamma^{\mu}A_{\mu}\psi + \frac{1}{2}e\pi^{+}\pi^{-}A_{\nu}A^{\nu} + \frac{1}{2}e\pi A_{\nu}\pi^{+}\pi^{-}\left(p_{+}^{\nu} - p_{-}^{\nu}\right)$$

$$L_{\gamma} = \frac{1}{4}F^{\rho\kappa}F_{\rho\kappa}$$

Photon emission - general remarks

photon rate essentially given by the imaginary part of the retarded photon self energy

[Textbook of KAPUSTA and GALE]

$$\omega \frac{d^3 R}{dk^3} \sim \mathrm{Im}\,\Pi_R{}^{\nu}{}_{\nu}(k^{\nu}; T, \mu) n_B(p^{\nu} u_{\nu}; T, \mu)$$

two important restrictions:

- size: $\lambda^{\gamma}_{\mathrm{m.f.p.}} \gg r_{\mathrm{fireball}} \gg \lambda^{\mathrm{strong}}_{\mathrm{m.f.p}}$

- (local) thermal equilibrium

HIC: OK (success of hydro)

Separation of scales

strong interaction: much shorter timescale, much higher energy scale (compared to em)

→ separation of scales

→ em interaction “sees“ only particles dressed by strong interaction
em interaction is small correction to thermodynamic properties

→ for thermodynamic properties: ignore em contribution

→ for photon emission: insert quasiparticle properties (e.g. masses) into formulas

Mean field analysis

[SCAVENIUS *et al.* Phys.Rev. C64 (2001)]

qualitative correct results with simple approx

In this context:

- setting meson fields to their expectation values.
  Expectation value minimizes free energy

$$\Omega(T,\mu) \equiv \tilde{\Omega}(\langle\sigma\rangle,\langle\pi\rangle,T,\mu)$$

  Curvatures of free energy at minimum → masses

$$m_\varphi = \frac{\partial^2 \tilde{\Omega}(\varphi,T,\mu)}{\partial \varphi^2}\Big|_{\varphi=\langle\varphi\rangle}$$

- exactly solving the remaining fermionic path integral

- including photons: like QED

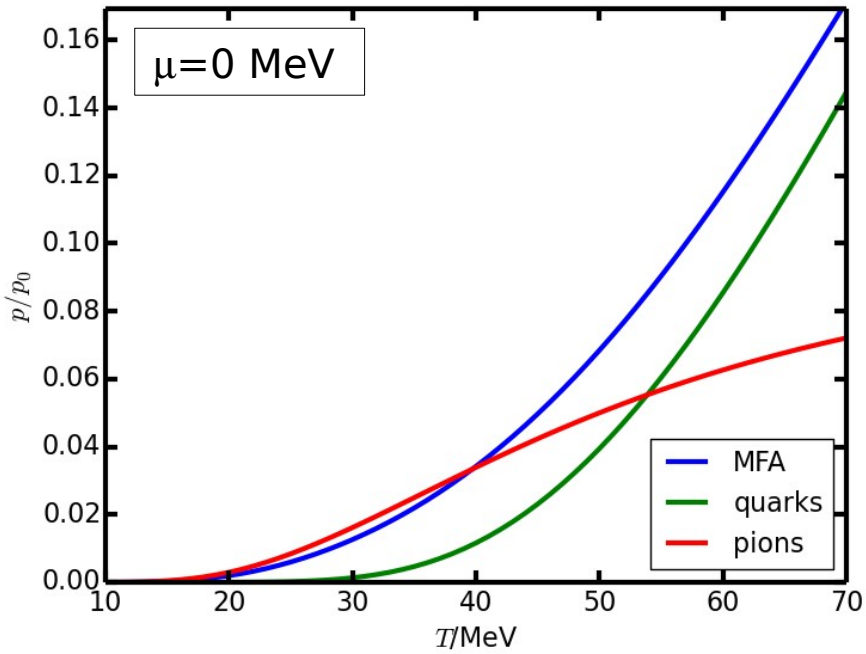
Mean field analysis - drawbacks

no dynamic mesons

→ missing contribution to pressure

→ only photon-quasiquark-coupling,
no pion-photon-vertex

missing pressure in MFA



Linearized fluctuations

Self consistent method to introduce (small) fluctuations

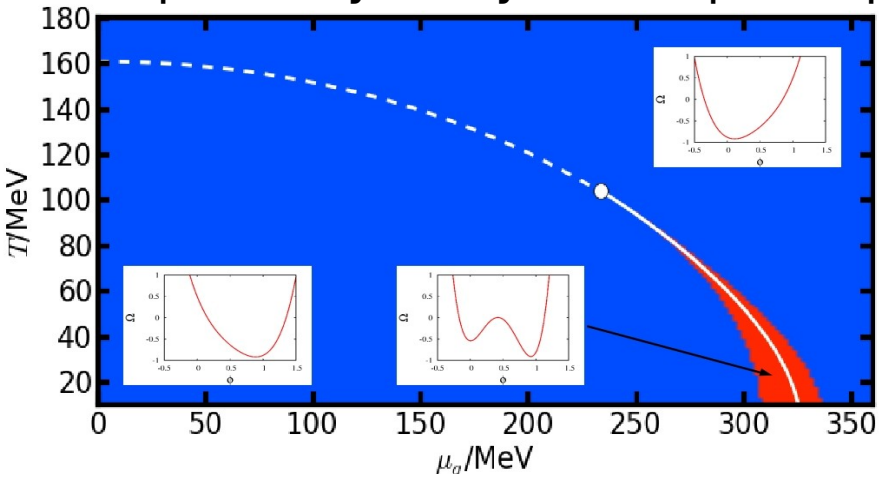
detailed description: [BOWMAN,KAPUSTA: Phys.Rev. C79 (2009)],[BOWMAN, diss.]
[MOCSY *et al.* Phys.Rev. C70 (2004)]

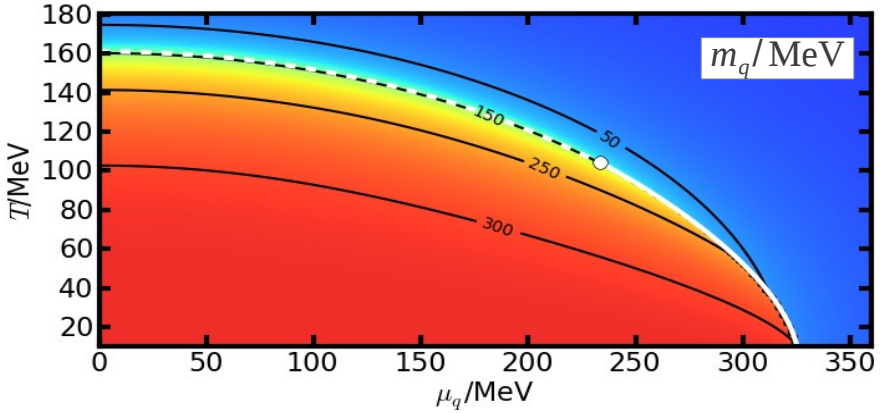
- integrate out quarks
- quadratic approximation for the remaining
  effective mesonic potential
- solve self consistency relations for meson masses

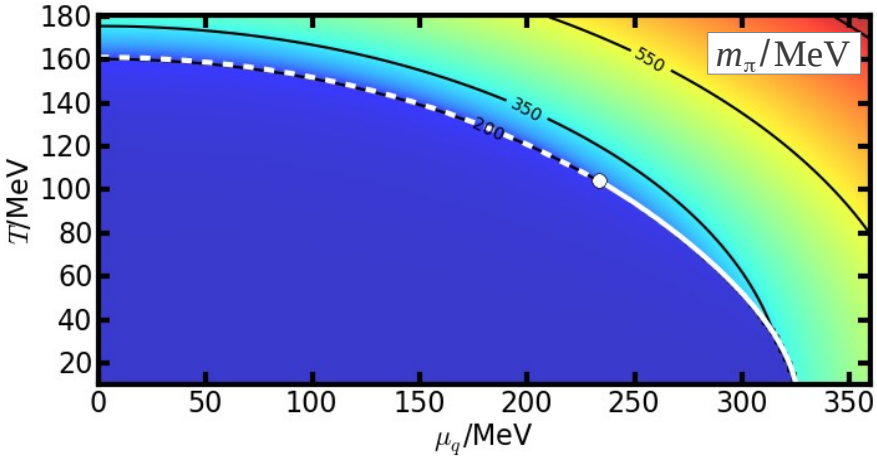
Thermodynamics - MFA

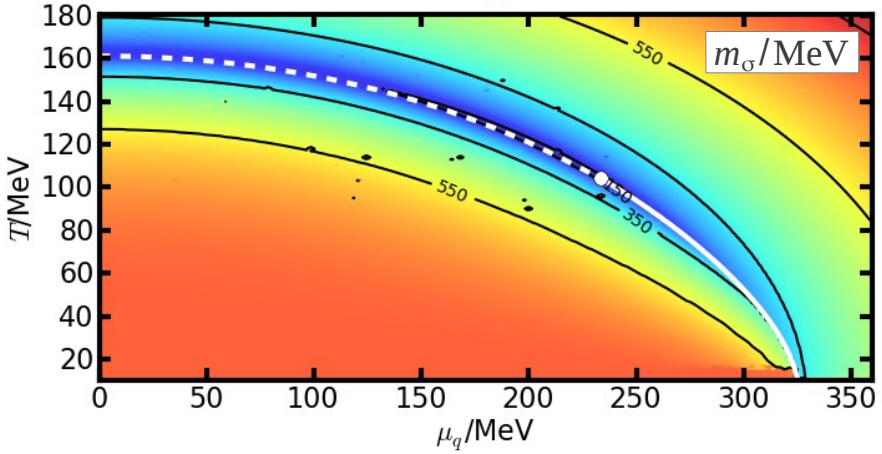
model parameters fixing: $m_\sigma^{\mathrm{vac}} = 700\,\mathrm{MeV}$, $m_\pi^{\mathrm{vac}} = 135\,\mathrm{MeV}$, $m_q^{\mathrm{vac}} = 312\,\mathrm{MeV}$, $f_\pi = 93\,\mathrm{MeV}$

exploratory study: as simple as possible → MFA



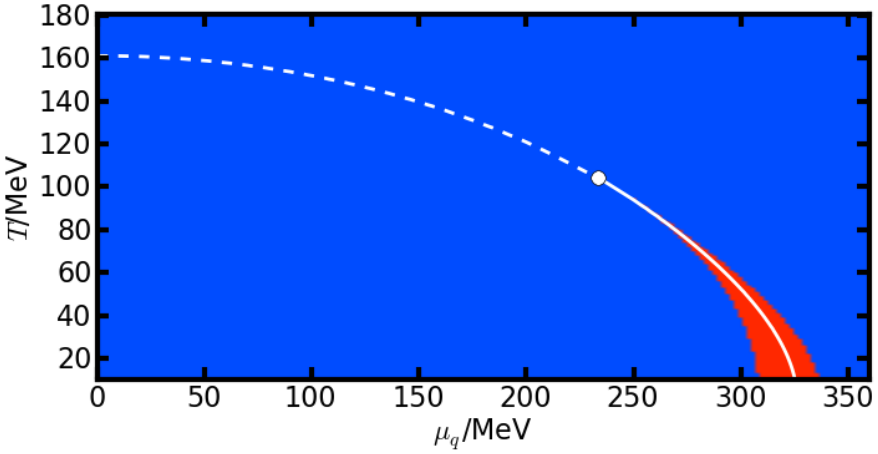


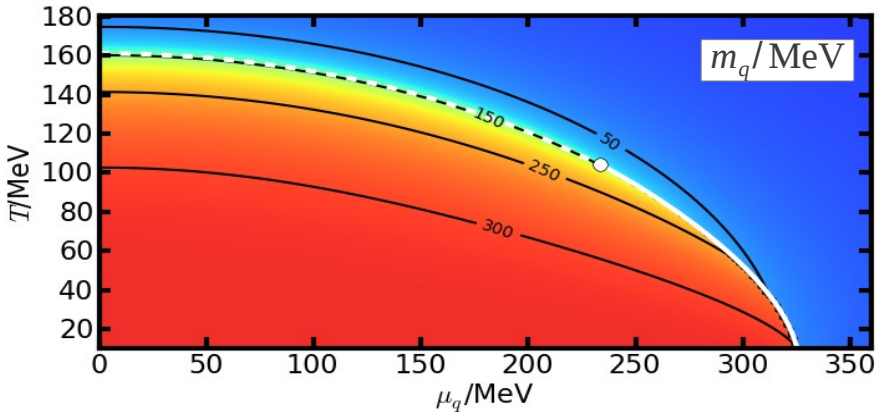


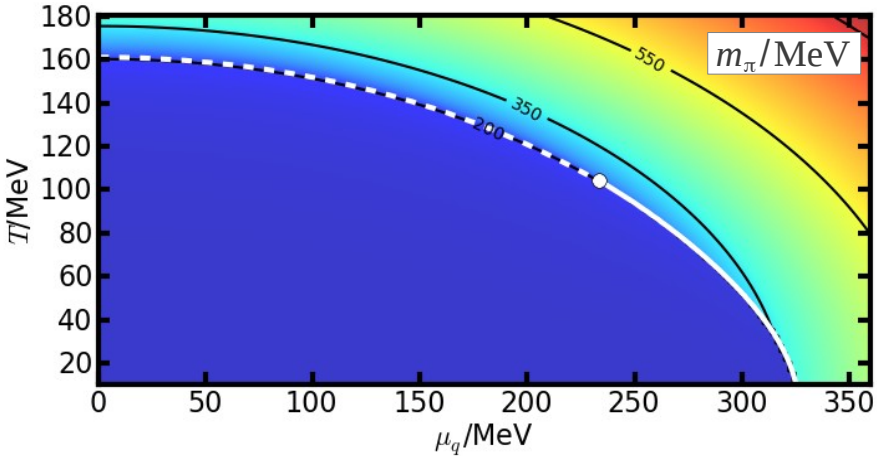


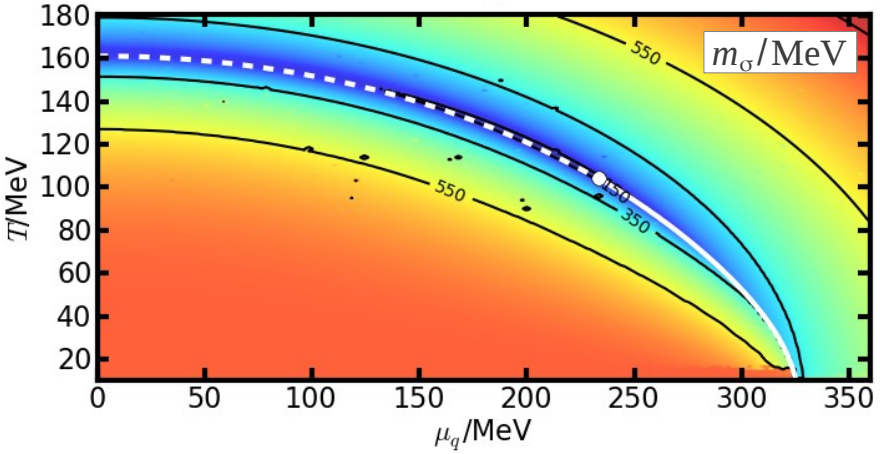
Thermodynamics - MFA

exploratory study: as simple as possible → MFA

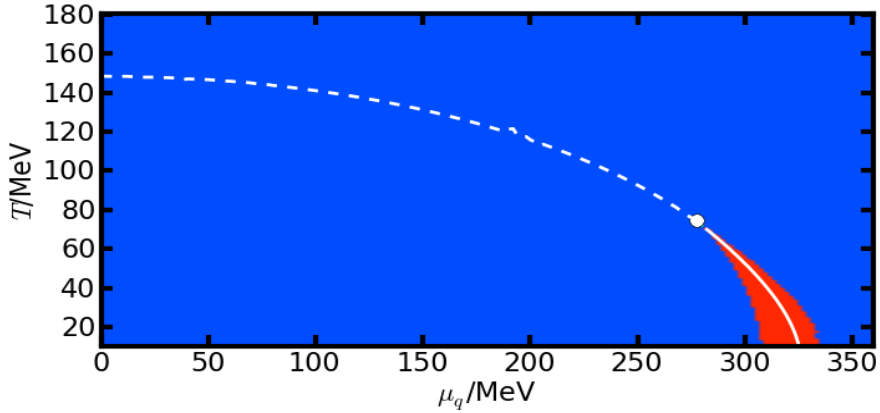


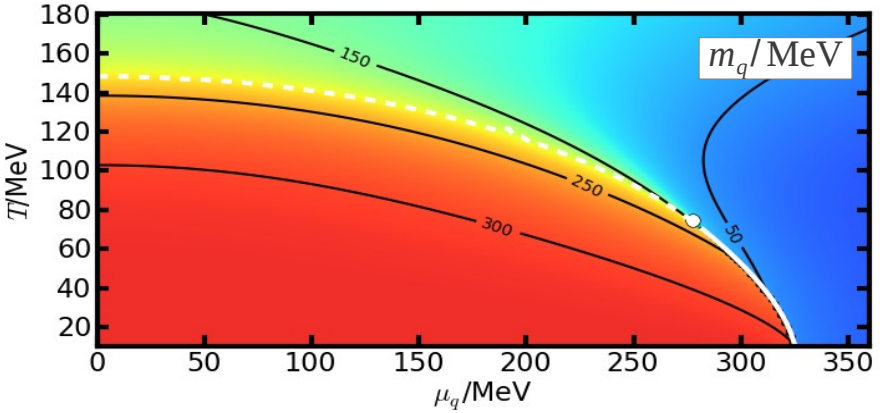


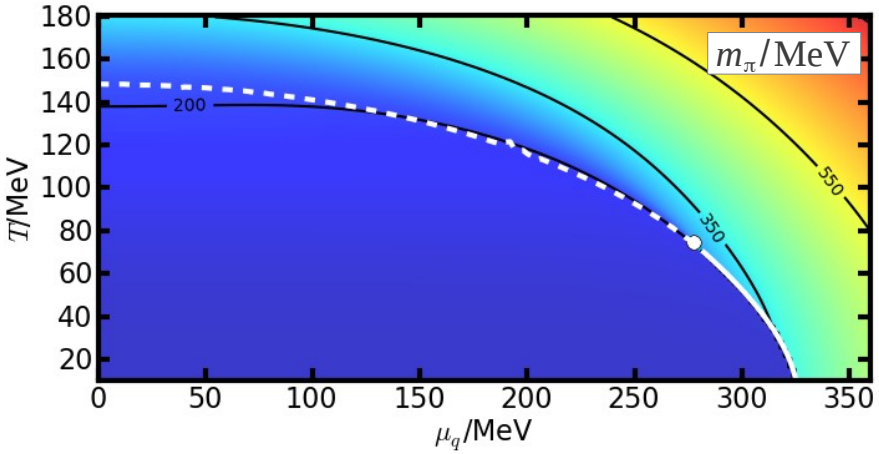


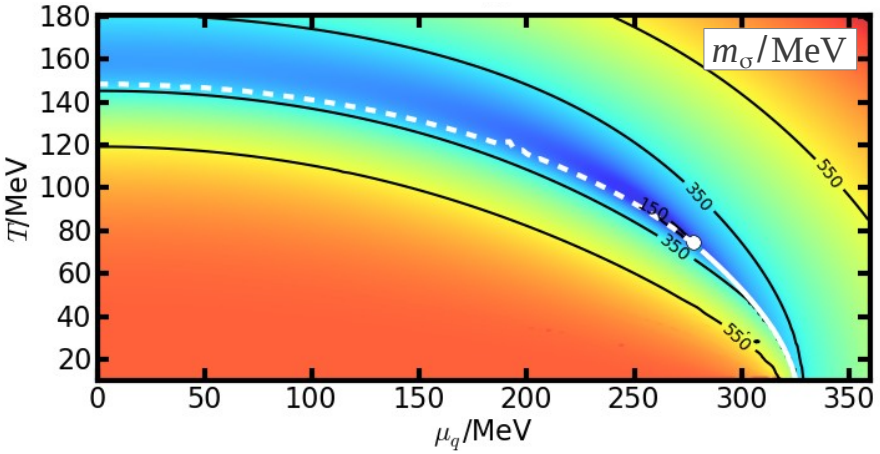


Thermodynamics – linearized fluctuations



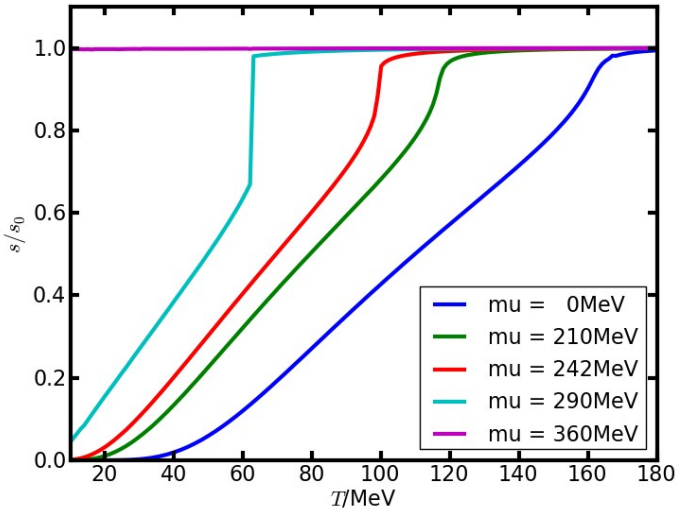




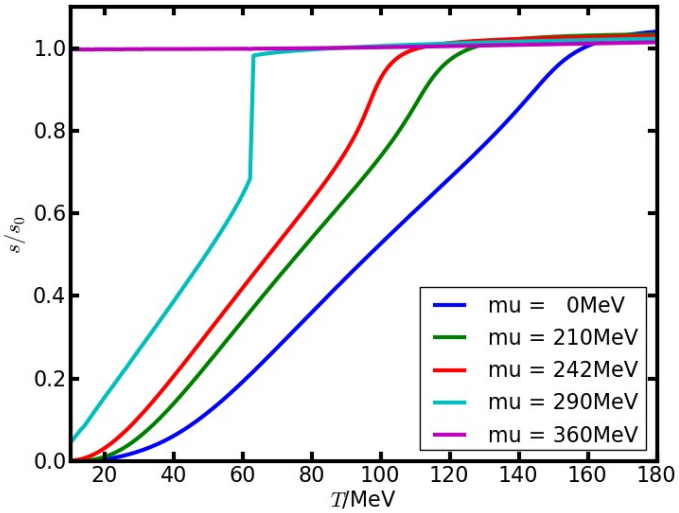


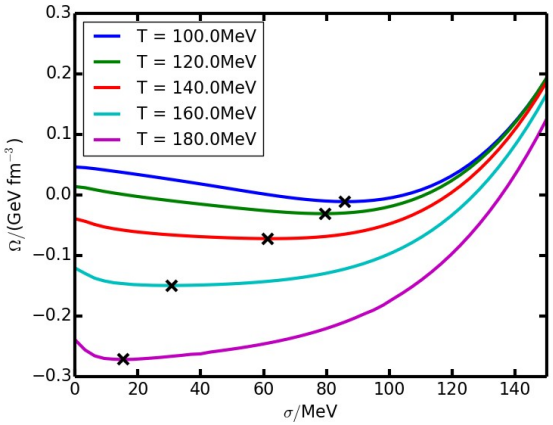
Character of the PT

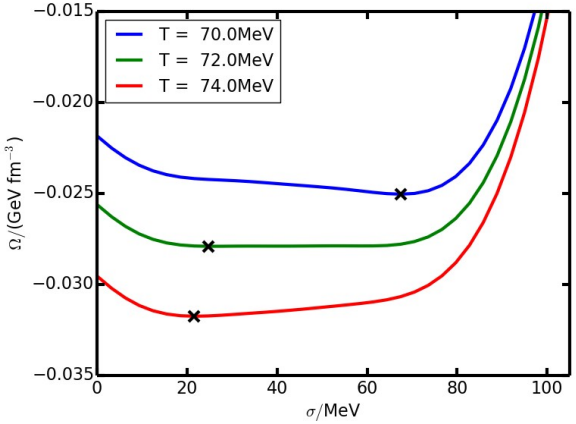
MFA

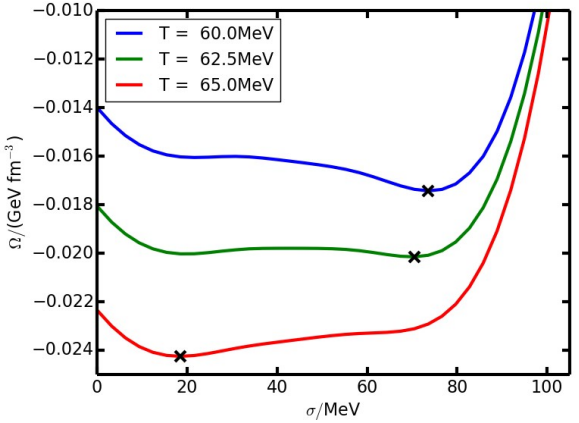


lin. fluc.



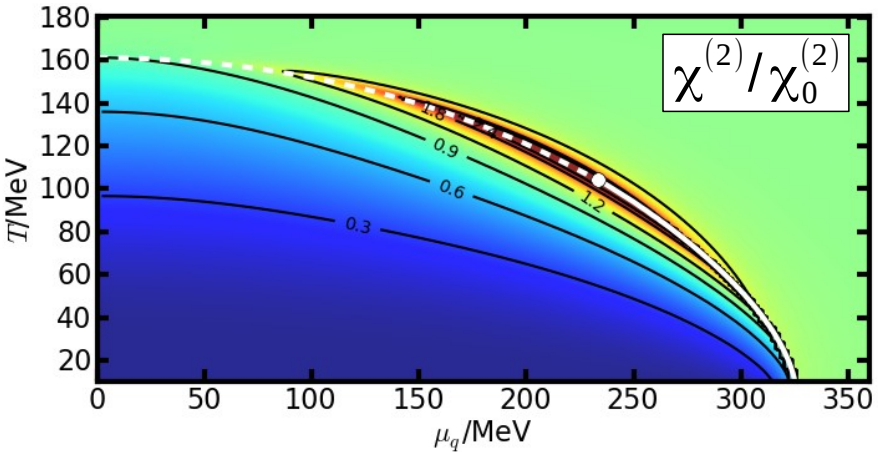




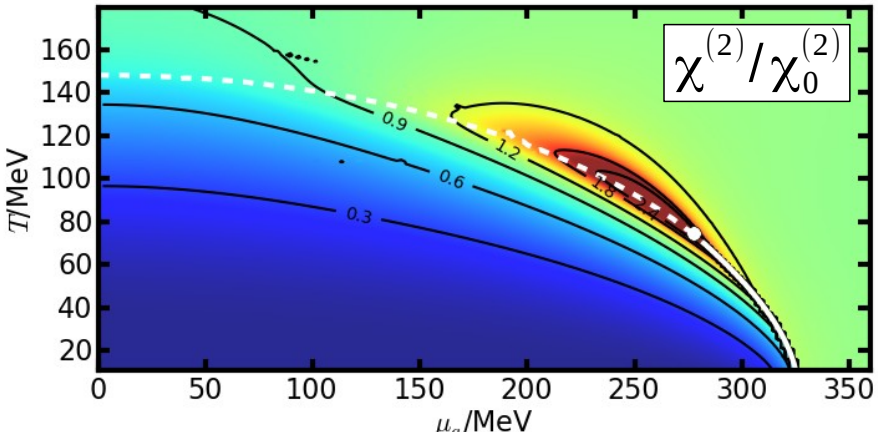


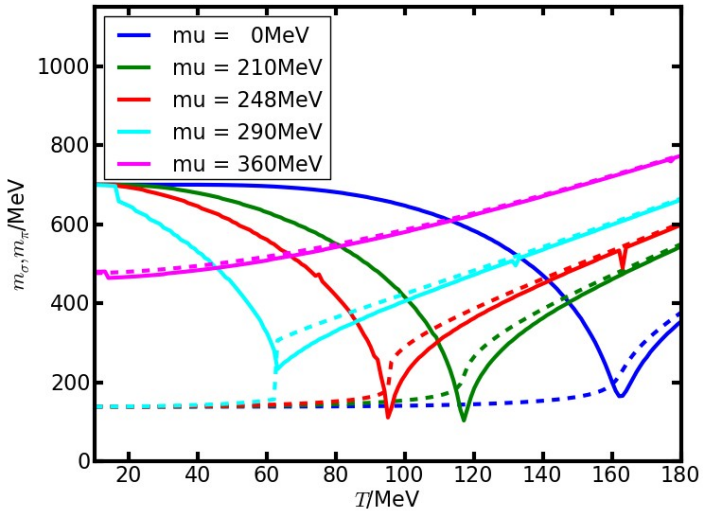
Influence of meson fluctuations

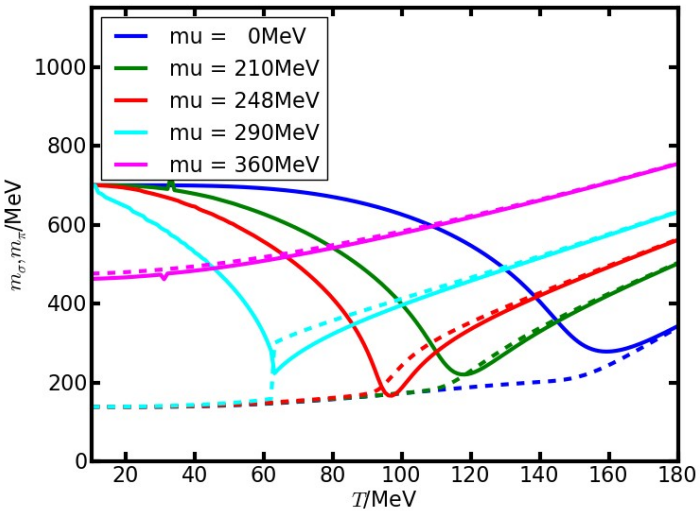
MFA



lin. fluc.

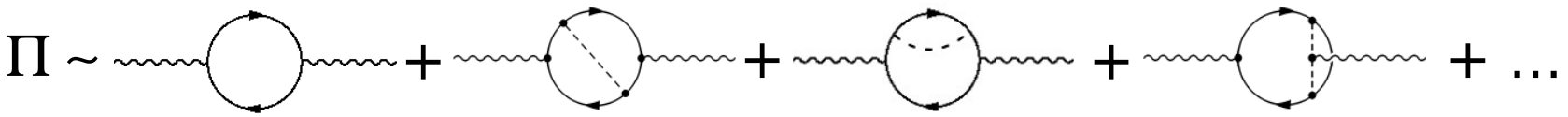




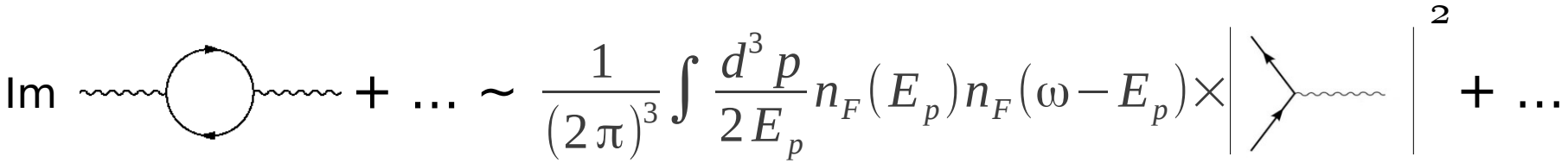


The retarded photon self energy

leading order



After Matsubara summation:

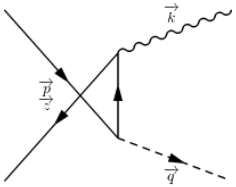
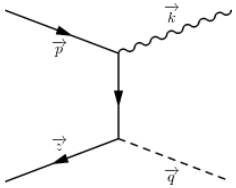
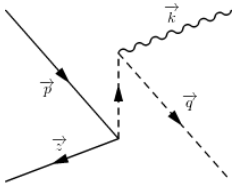


This looks exactly like kinetic theory!

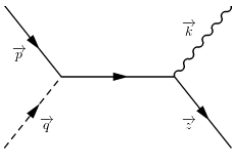
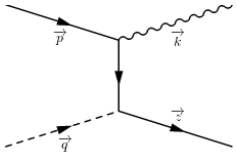
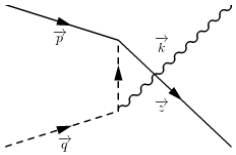
So: forget photon propagator! Just specify all
photon producing processes and calculate momentum integrals.

Interpretation

annihilation:

Compton scattering:

application of optical theorem

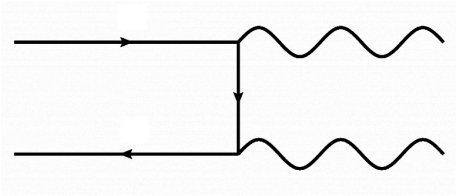
$$\mathrm{Im}\,\Pi = C \times \sum |M(i \to f + \gamma)|^2$$

Photon emission MFA:

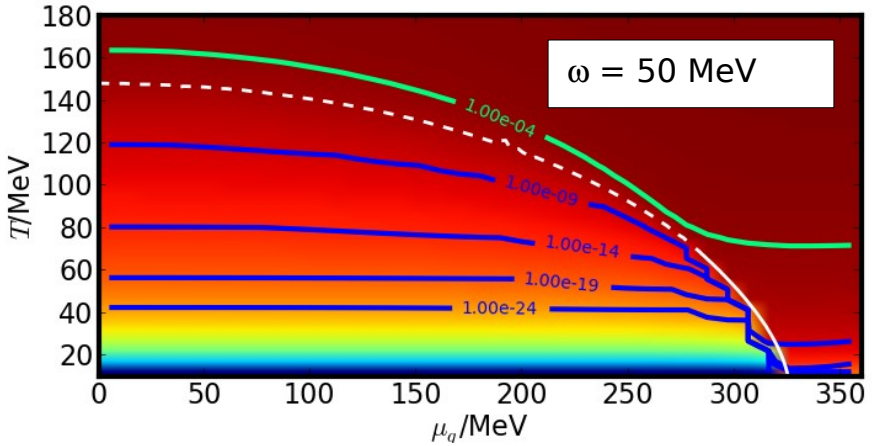
only quarks emitt photons

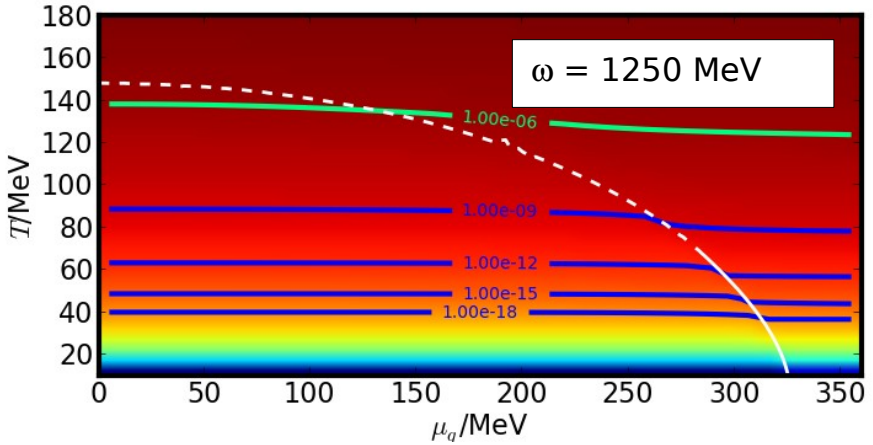
QED-like rates

leading order:



no Compton-contrib.
(photons are not in equilib.)



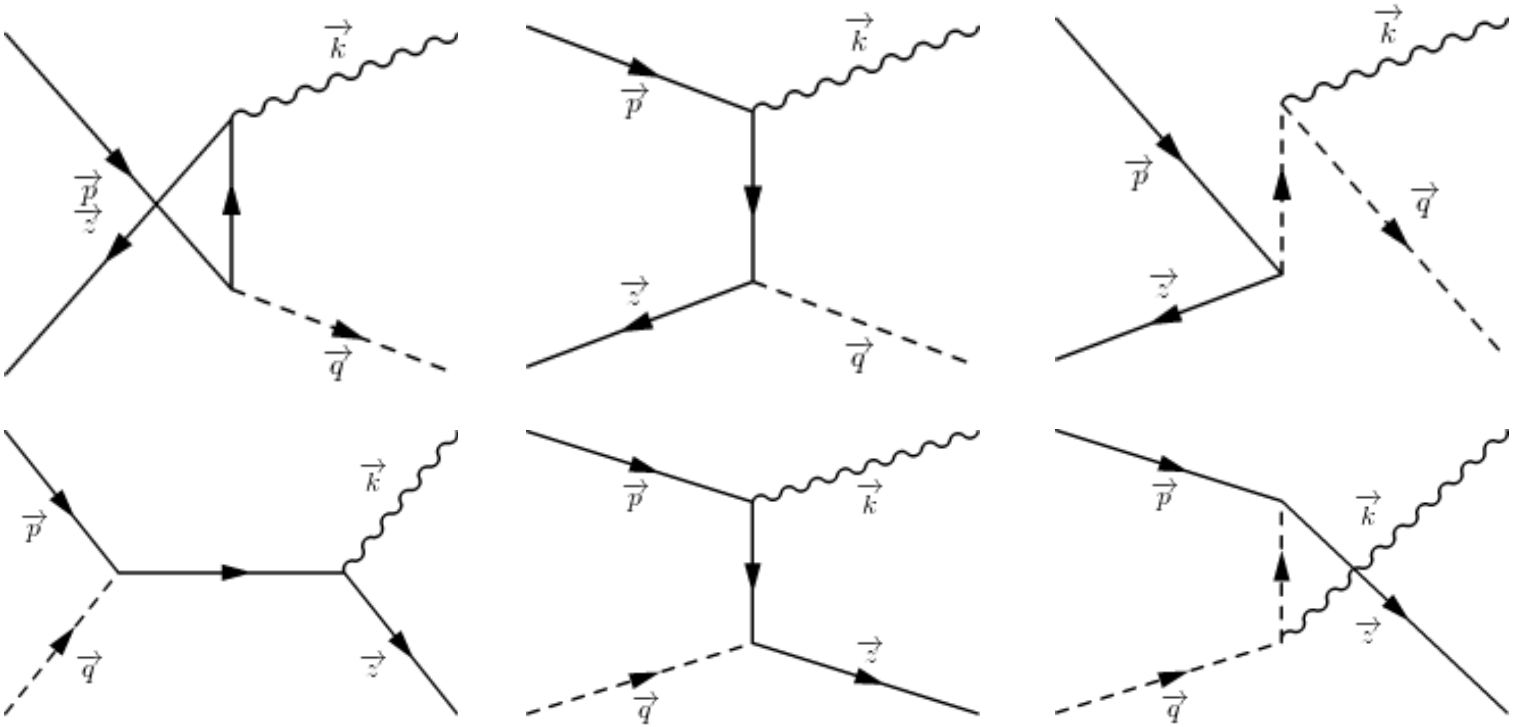


Photon emission, lin. fluct:

Quarks and pions emit photons

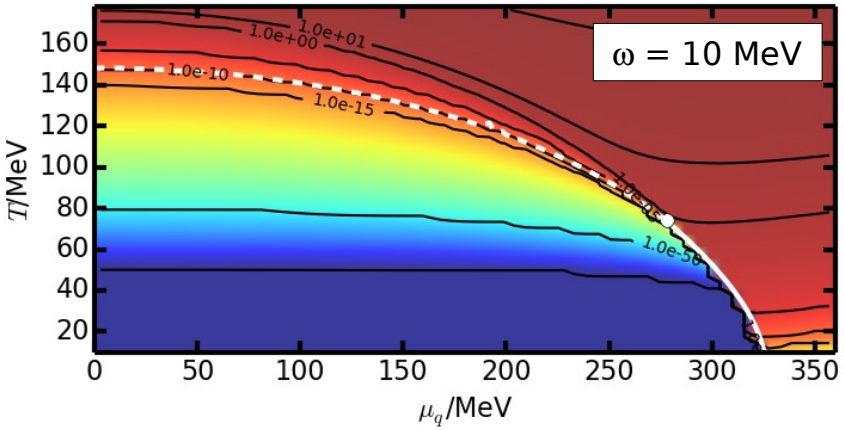
Compton processes possible

LO with π:

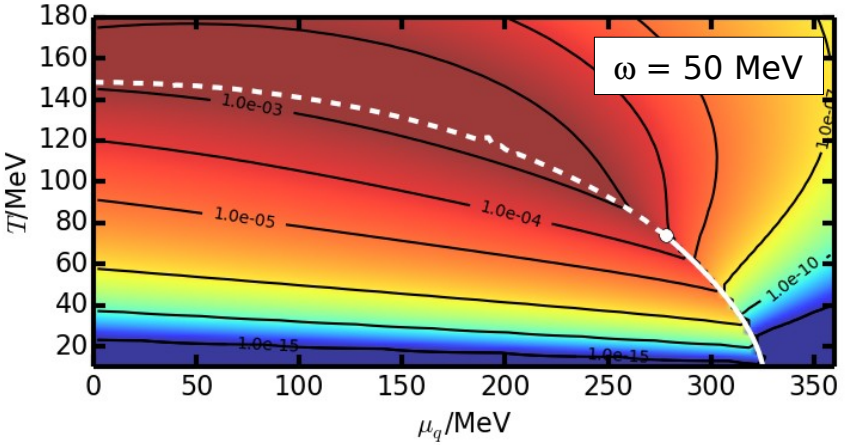


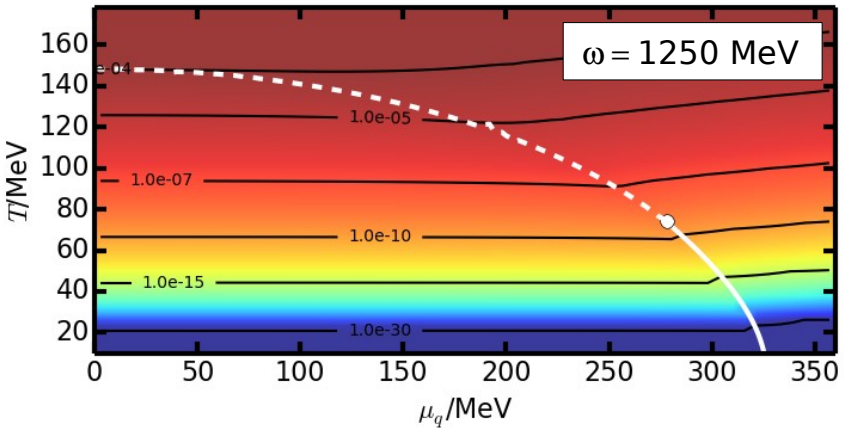
Photon emission lin. fluct:

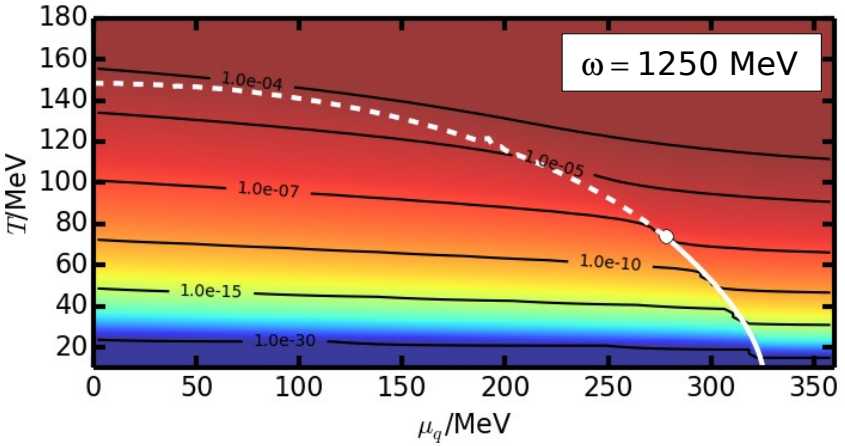
$q+\bar{q} \rightarrow \gamma+\pi$



$q+\pi \rightarrow \gamma+q$

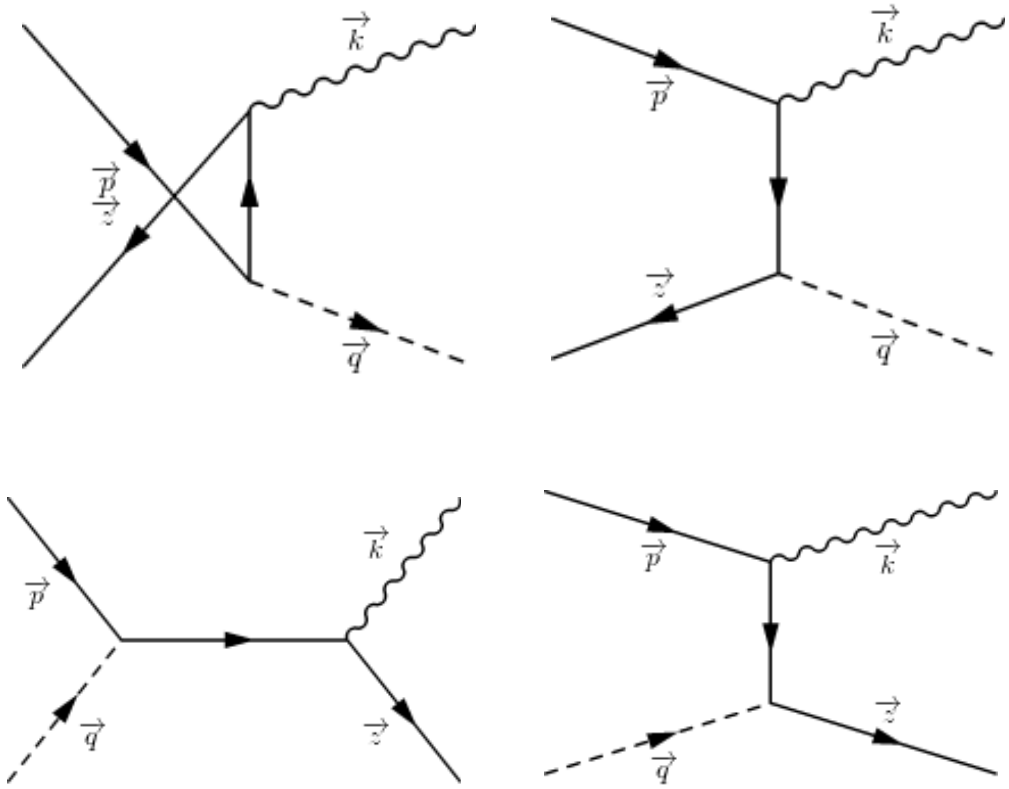






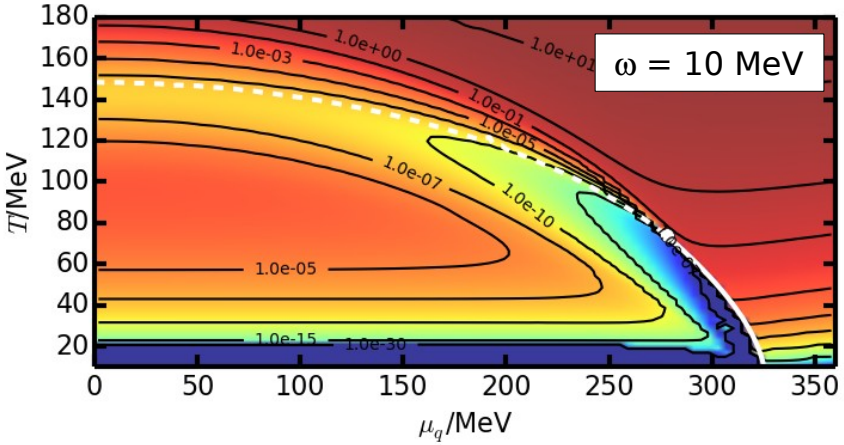
Photon emission, lin. fluct:

LO with σ:

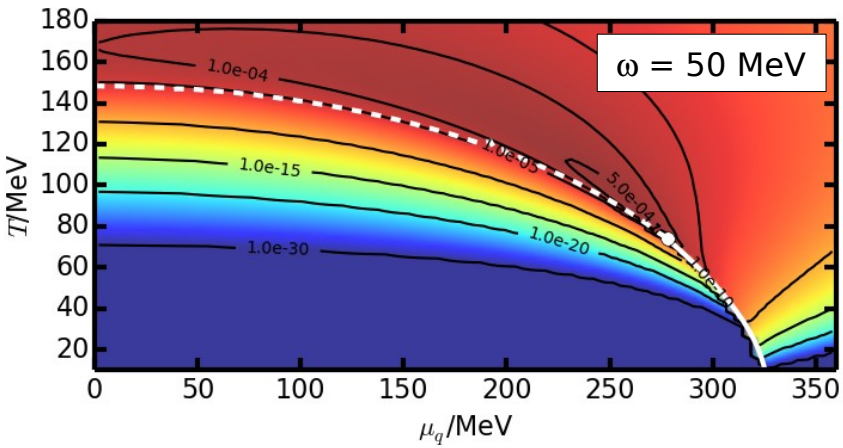


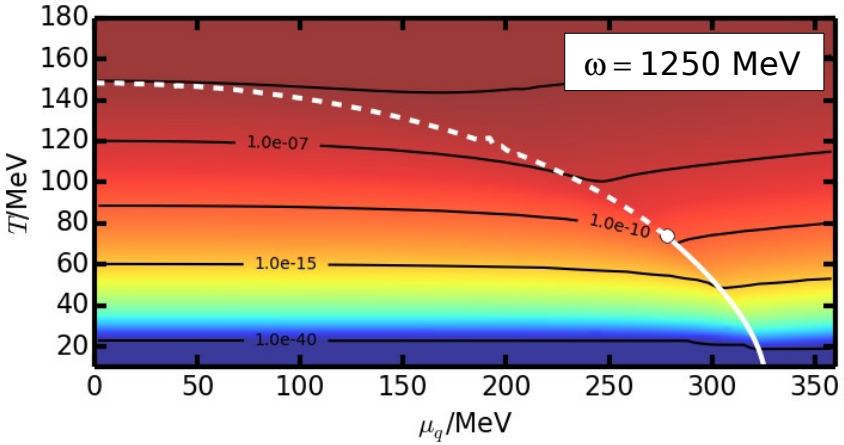
Photon emission lin. fluct:

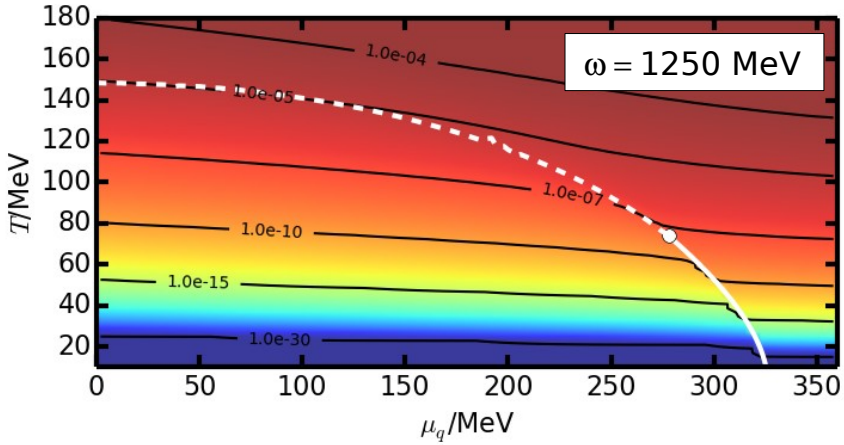
$q+\bar{q} \rightarrow \gamma+\sigma$



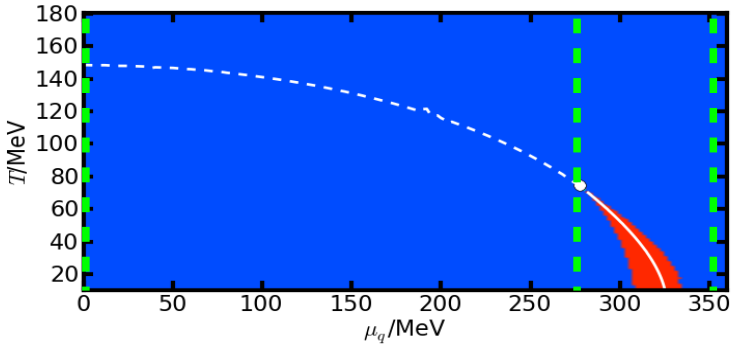
$q+\sigma \rightarrow \gamma+q$

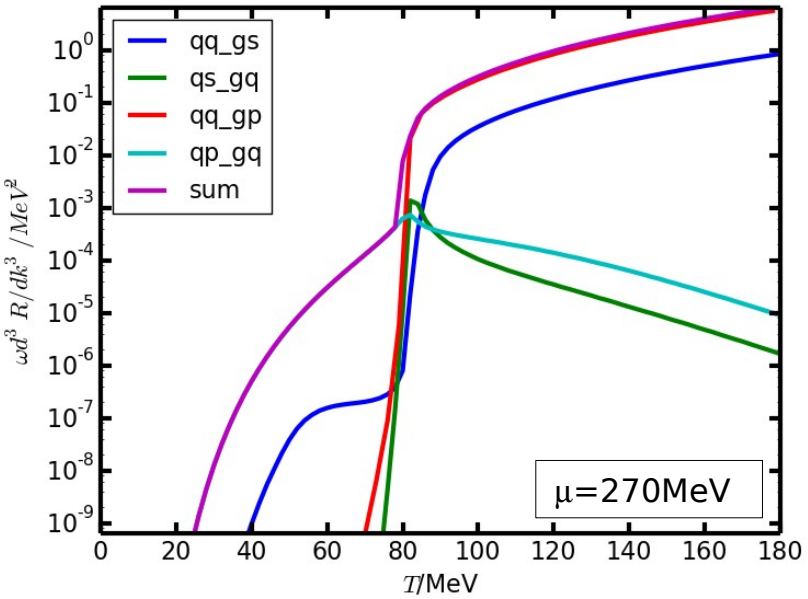


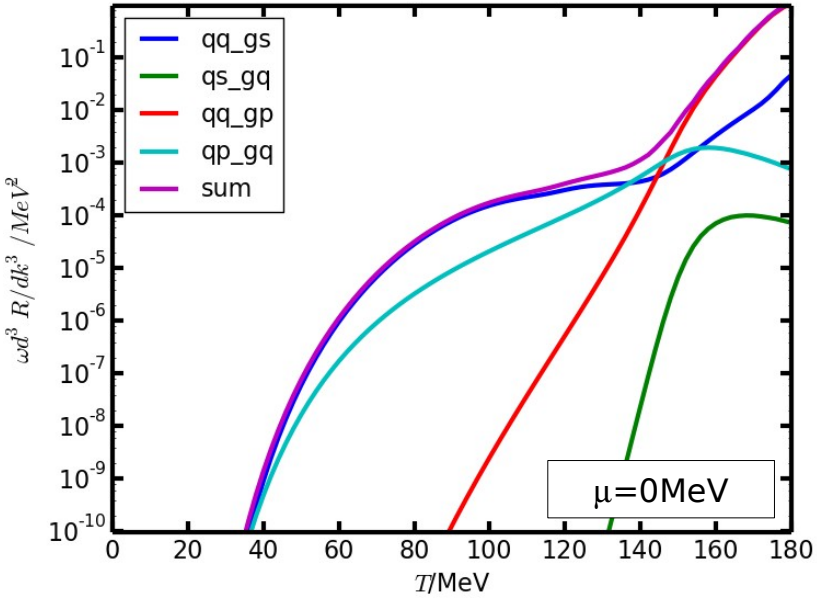


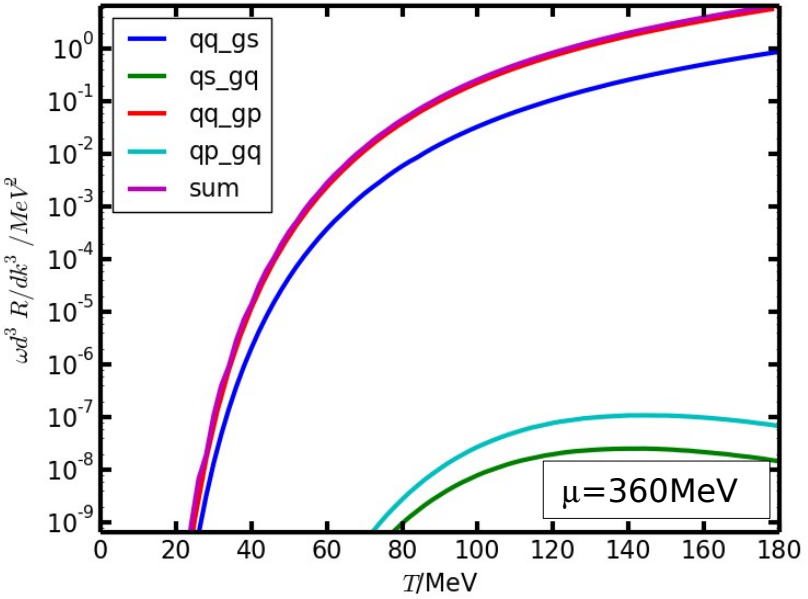


Photon rates









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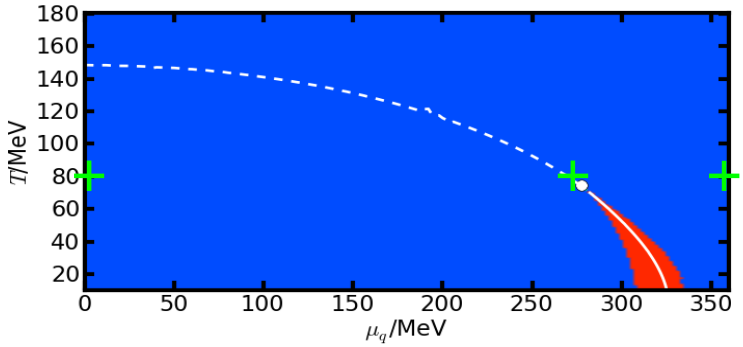
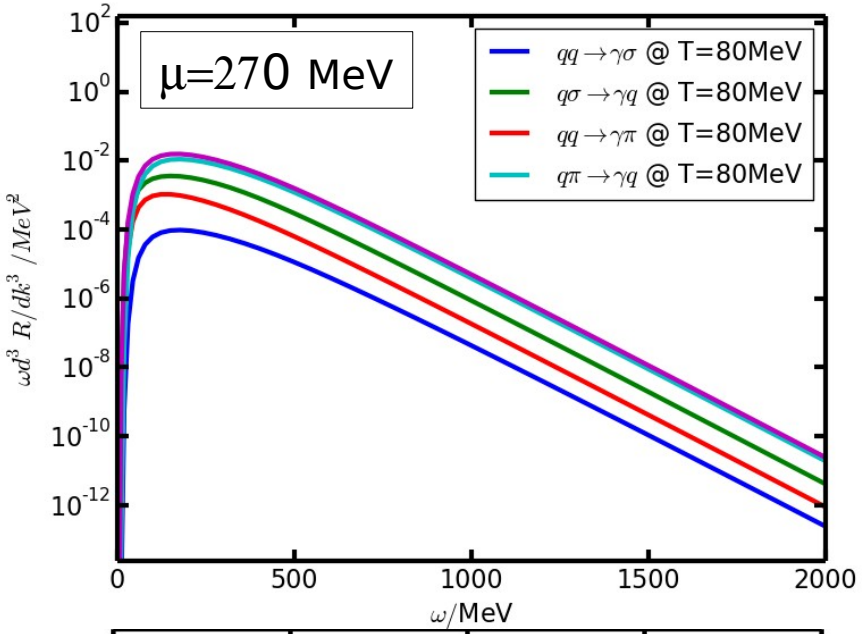
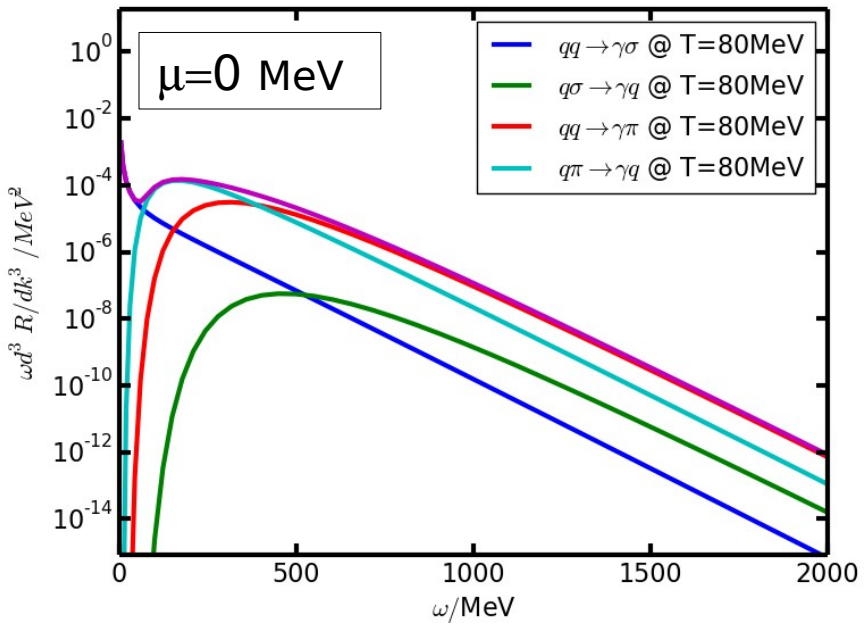
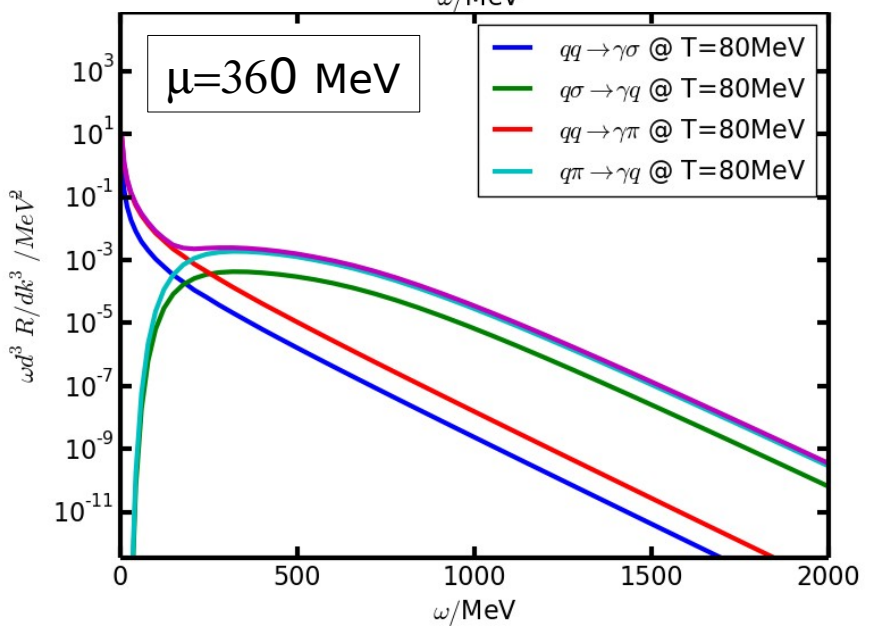
Photon rates









Summary and outlook

calculated thermodynamics and photon emissivity to 1st order within the QMM (linear sigma model with quarks)

MFA + beyond MFA

more fluctuations / FRG

folding with hydro evolution

Thank you for your attention!

Fluctuation measures