Locating the critical end point of QCD

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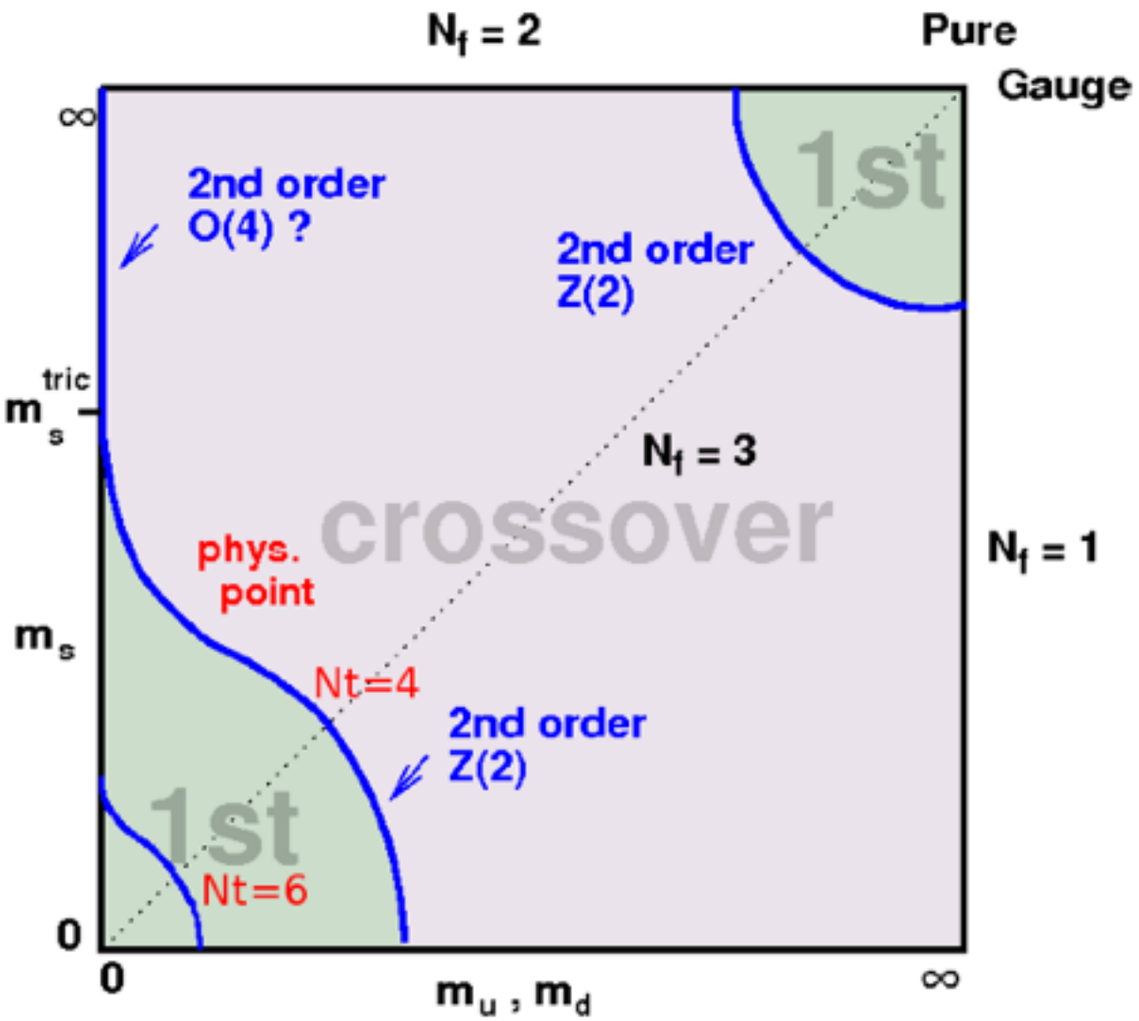
HELMHOLTZ GEMEINSCHAFT

with Jan Luecker and Christian Welzbacher, arXiv:1405.4762

and Leonard Fister, Axel Maas, Jan Pawlowski

QCD phase transitions II



Plot: O. Philipsen

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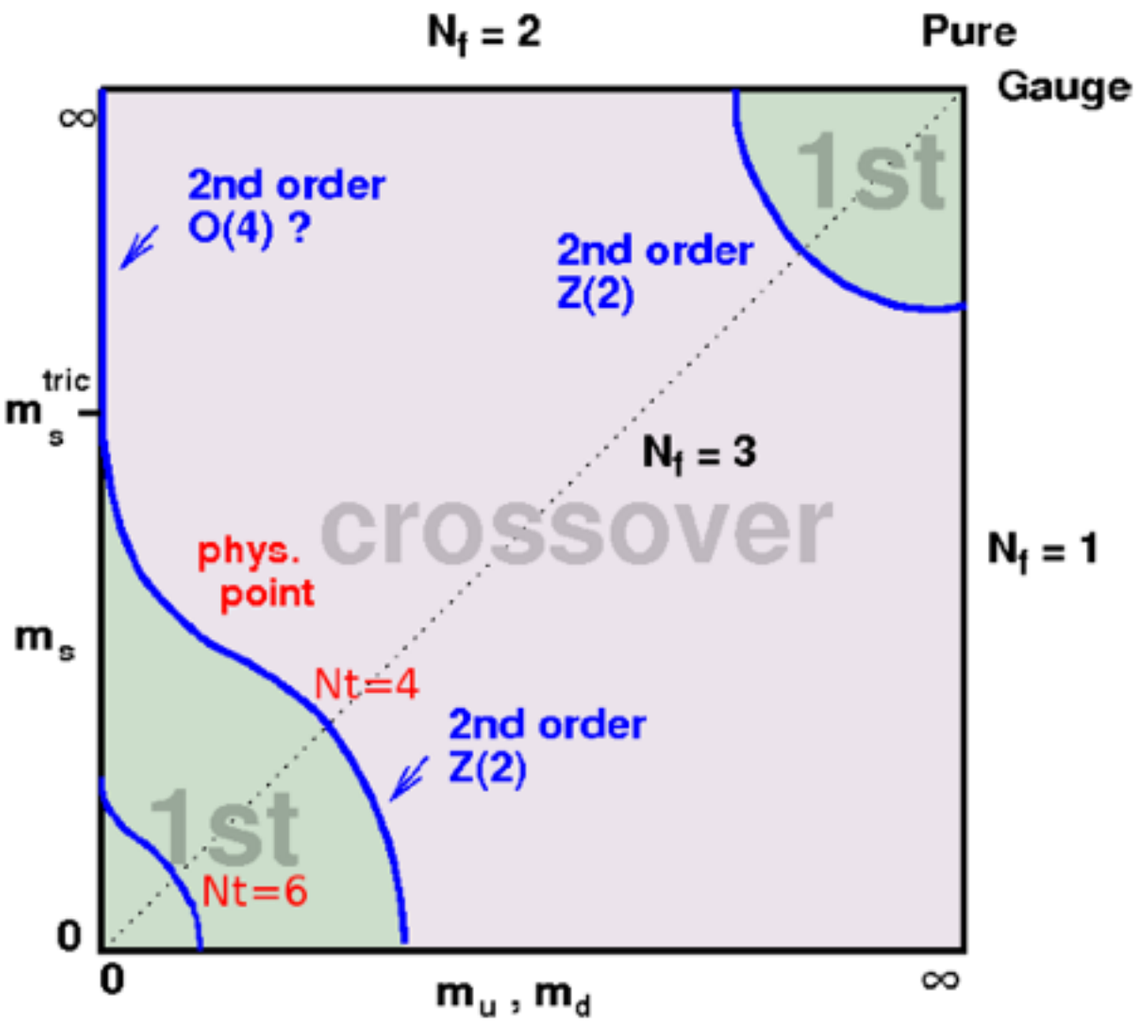

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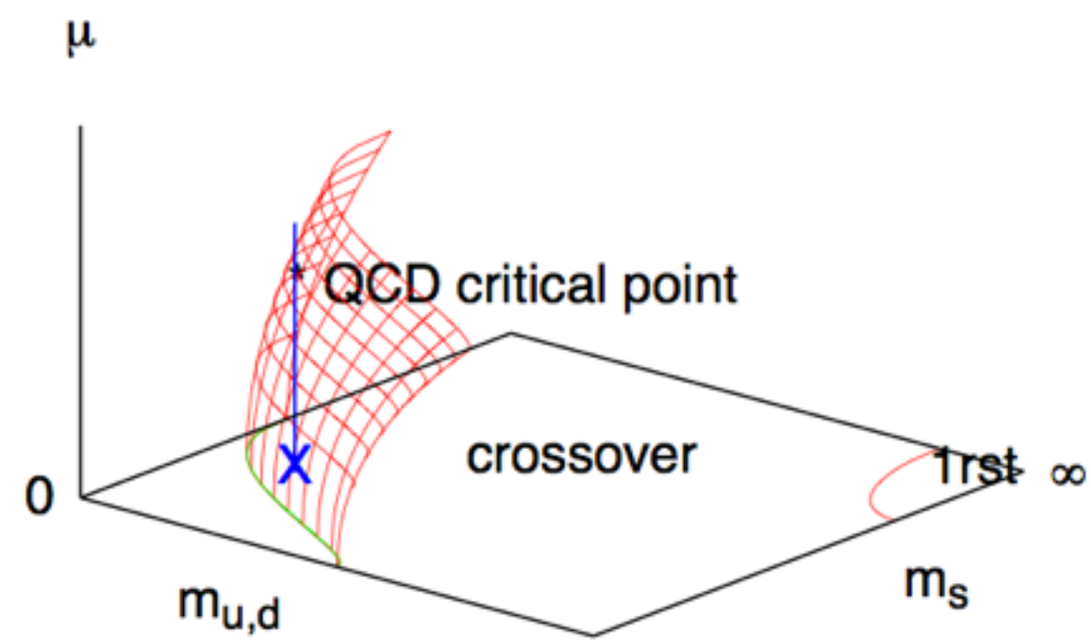

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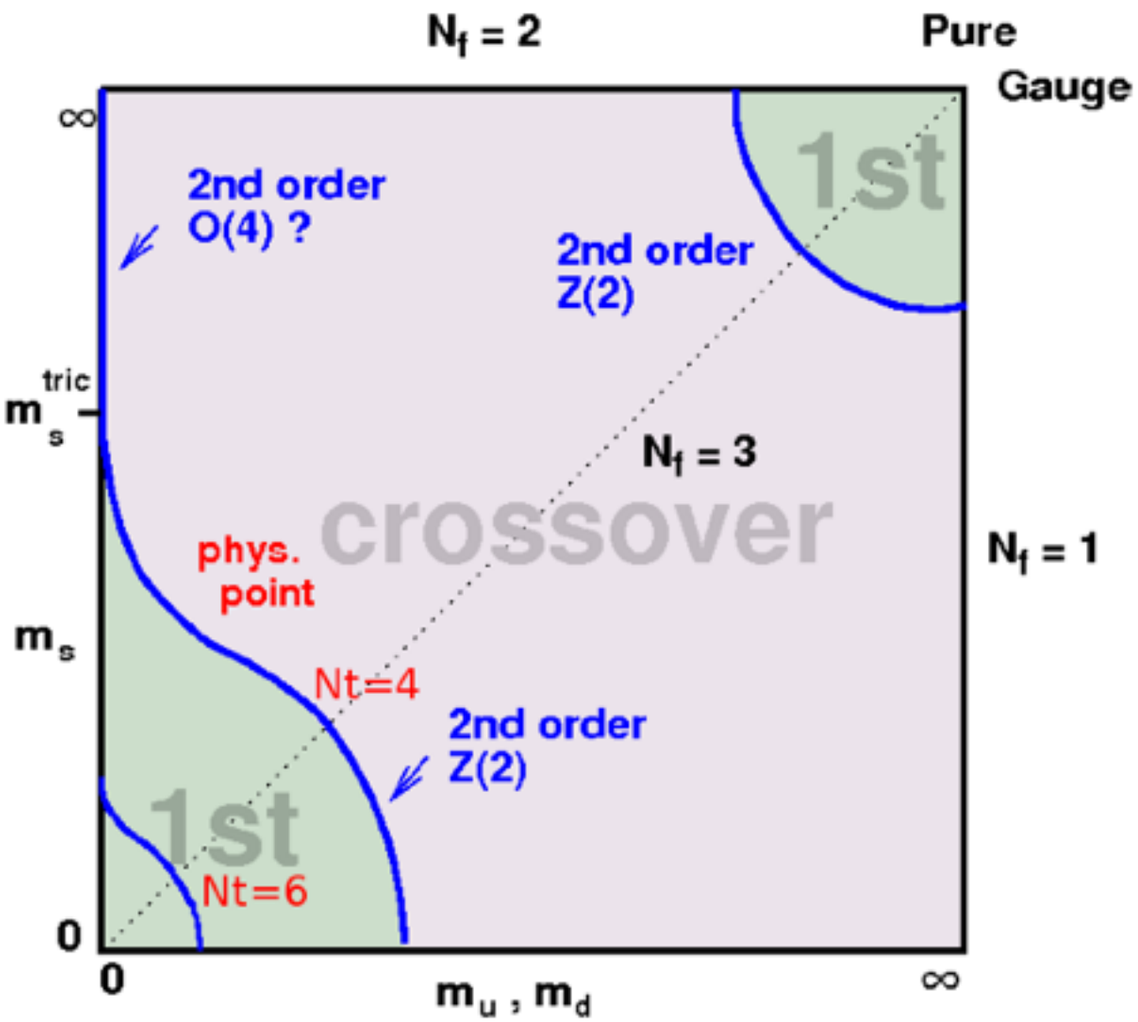

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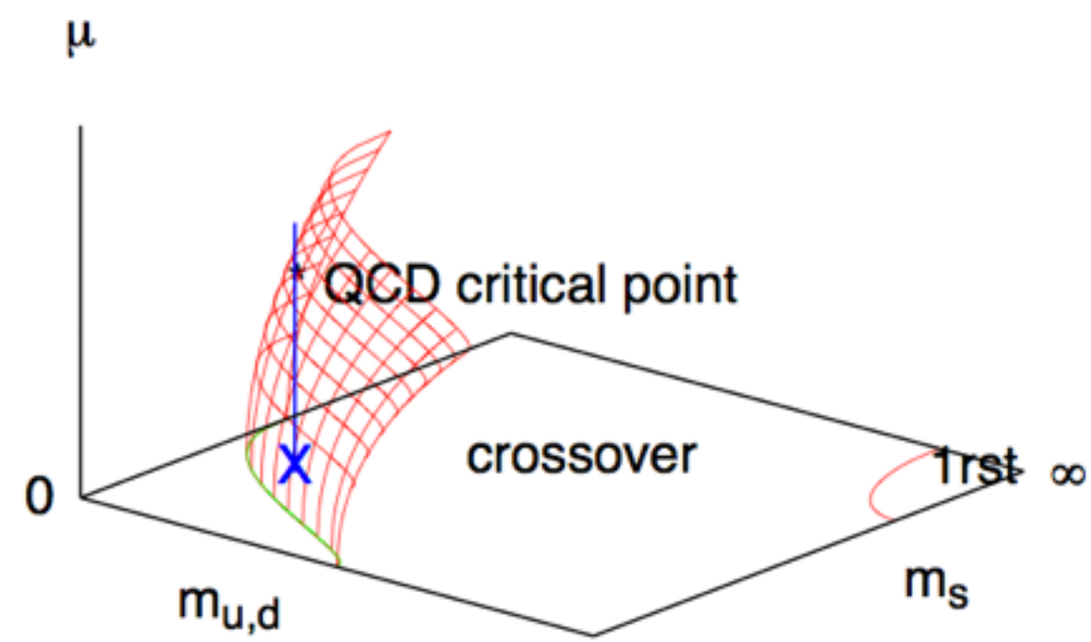
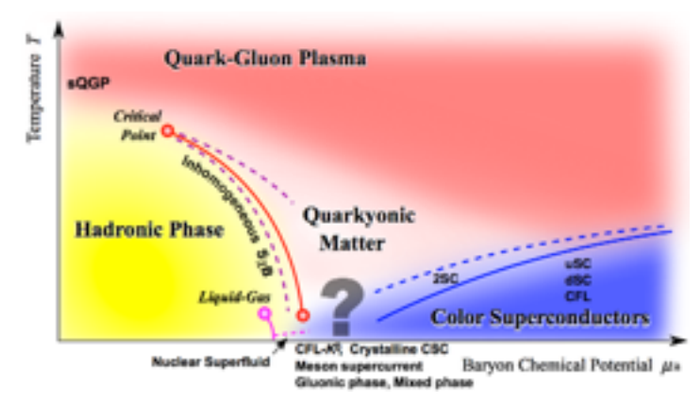
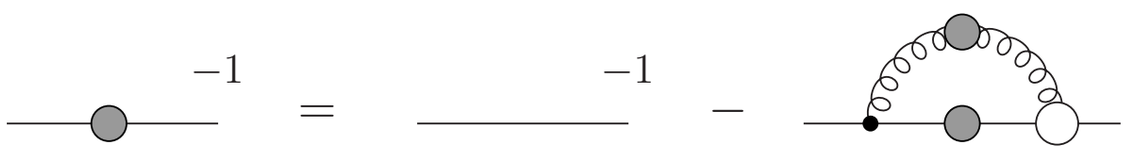


Is this happening ??



QCD order parameters from propagators



Chiral order parameter:

$$\langle\bar{\Psi}\Psi\rangle = Z_2 N_c Tr_D \frac{1}{T}\sum_\omega \int \frac{d^3p}{(2\pi)^3} S(\vec{p},\omega)$$

Deconfinement:

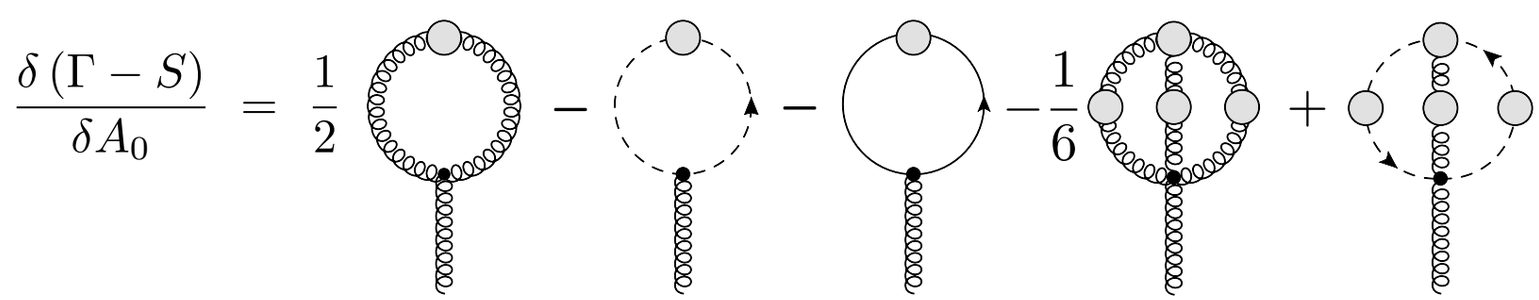
- dressed Polyakov loop

$$\Sigma = -\int_0^{2\pi} \frac{d\varphi}{2\pi} e^{-i\varphi} \langle\bar{\Psi}\Psi\rangle_\varphi$$

Synatschke, Wipf, Wozar, PRD 75, 114003 (2007)
Bilgici, Bruckmann, Gattringer, Hagen, PRD 77 094007 (2008)
CF, PRL 103 052003 (2009)

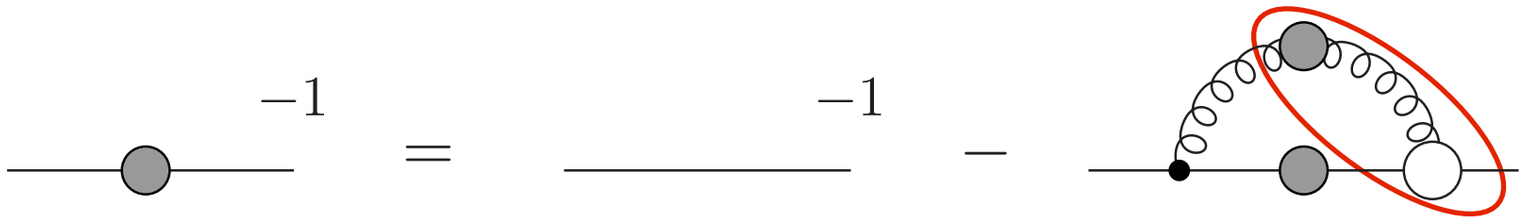
- Polyakov loop potential

$$L = \frac{1}{N_c} Tr\, e^{ig\beta A_0}$$



Braun, Gies, Pawlowski, PLB 684, 262 (2010)
Braun, Haas, Marhauser, Pawlowski, PRL 106 (2011)
Fister, Pawlowski, PRD 88 045010 (2013)
CF, Fister, Luecker, Pawlowski, arXiv:1306.6022

The DSE for the quark propagator



$$[S(p)]^{-1} = [-i\not{p} + M(p^2)]/Z_f(p^2)$$

Input:
- dressed Gluon propagator
- dressed Quark-Gluon-Vertex

Two strategies:

I. use model for gluon and vertex

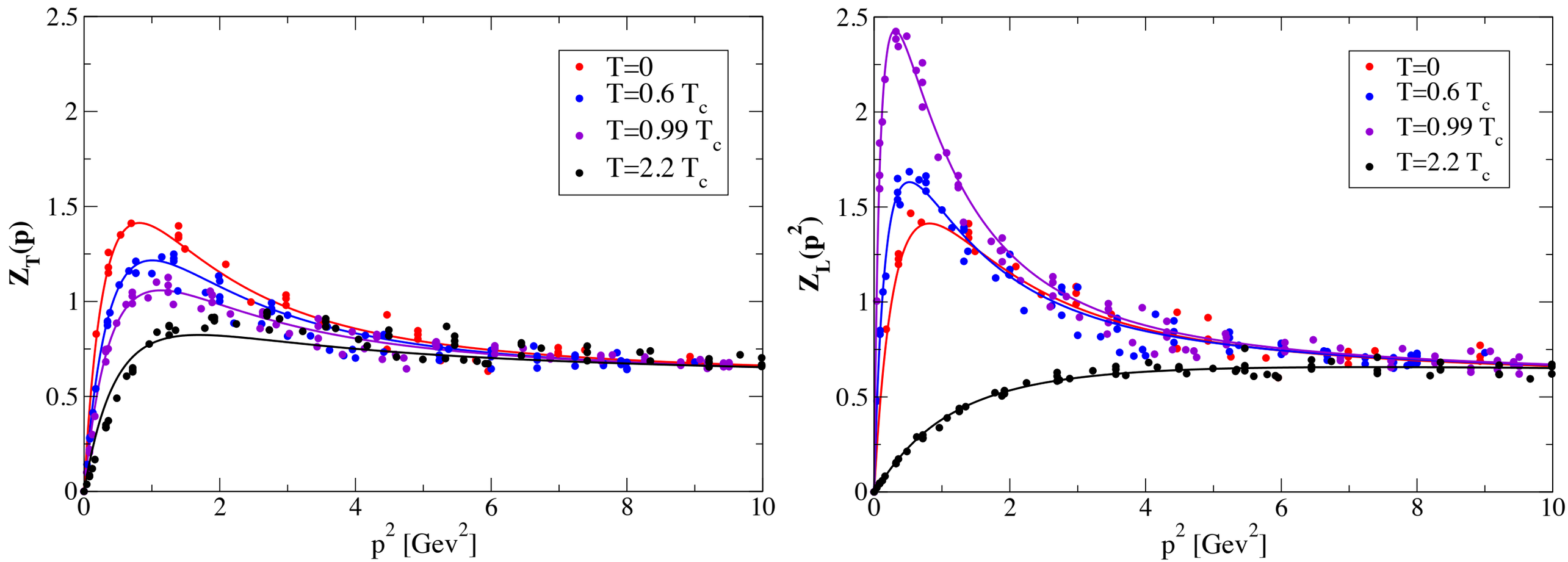
Qin, Chang, Chen, Liu and Roberts, PRL 106 (2011) 172301
Gutierrez, Ahmad, Ayala, Bashir and Raya, JPG 41 (2014) 075002

→ ok for first insights
→ not good enough for systematic study

II. determine gluon and vertex explicitly

Glue at finite temperature (T≠0)

T-dependent gluon propagator from quenched lattice simulations:

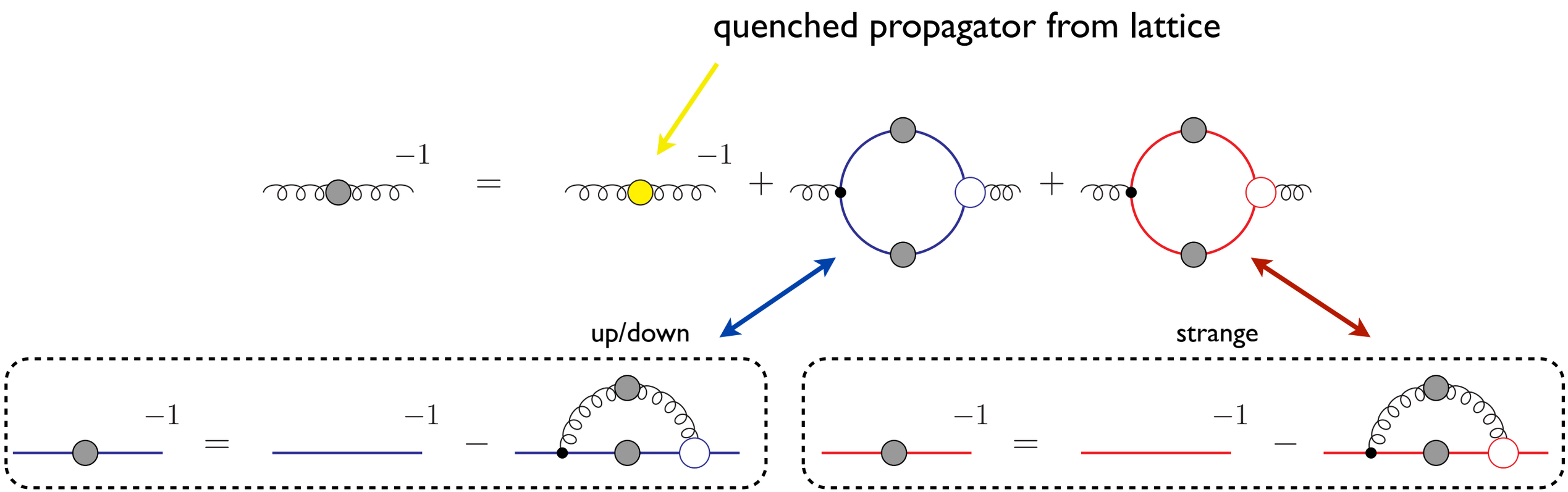


- Crucial difference between magnetic and electric gluon
- Maximum of electric gluon near Tc

Cucchieri, Maas, Mendes, PRD 75 (2007)
CF, Maas, Mueller, EPJC 68 (2010)
Cucchieri, Mendes, PoS FACESQCD 007 (2010)
Aouane, Bornyakov, Ilgenfritz, Mitrjushkin, Muller-Preussker and Sternbeck, PRD 85 (2012) 034501
Silva, Oliveira, Bicudo, Cardoso, PRD 89 (2014) 074503

FRG: Fister, Pawlowski, arXiv:1112.5440

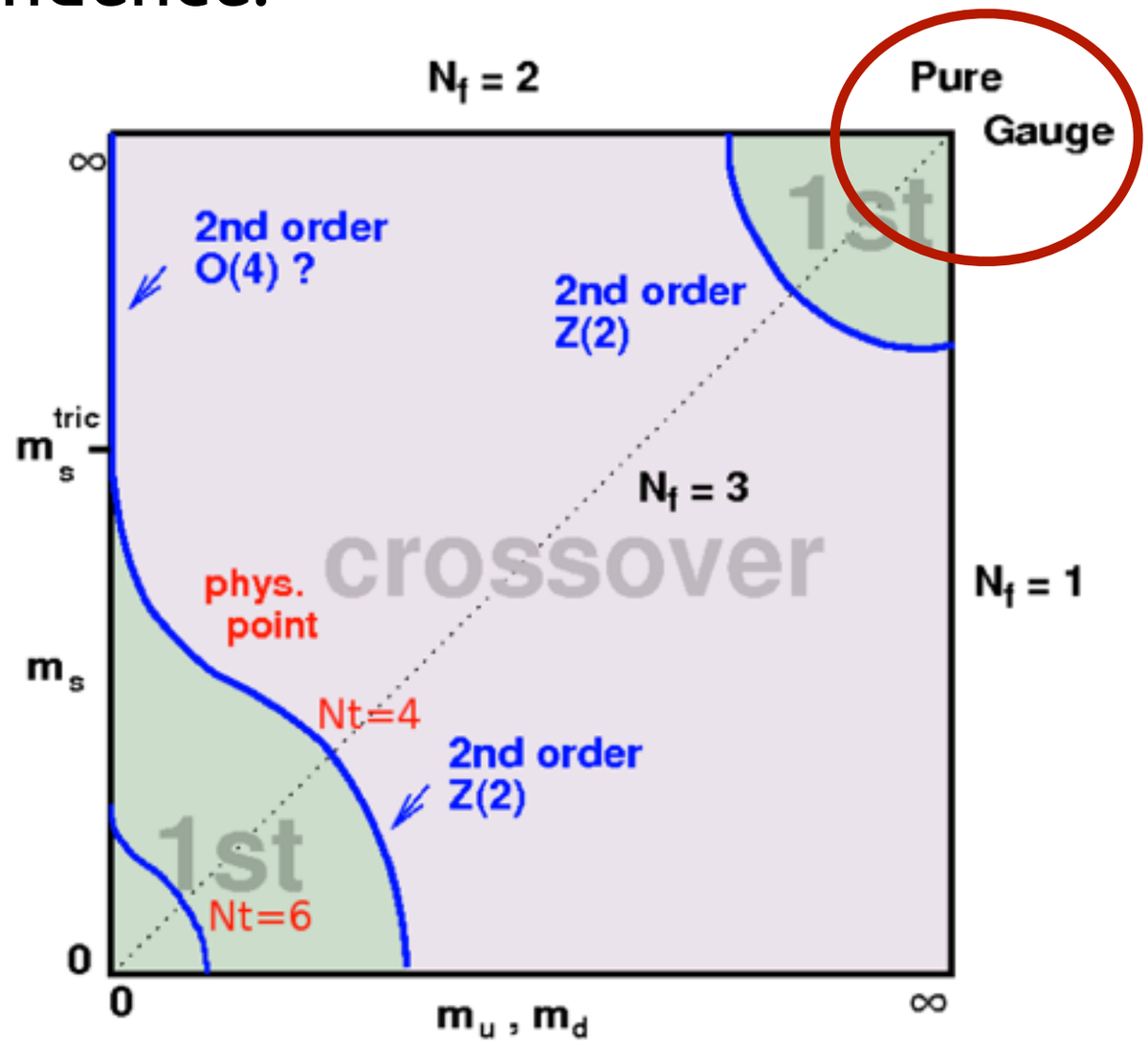
N_f=2+1-QCD with DSEs



- quenched: without quark-loop
- Nf=2: isospin symmetry
- Nf=2+1: solve coupled system of 2+3+3 equations

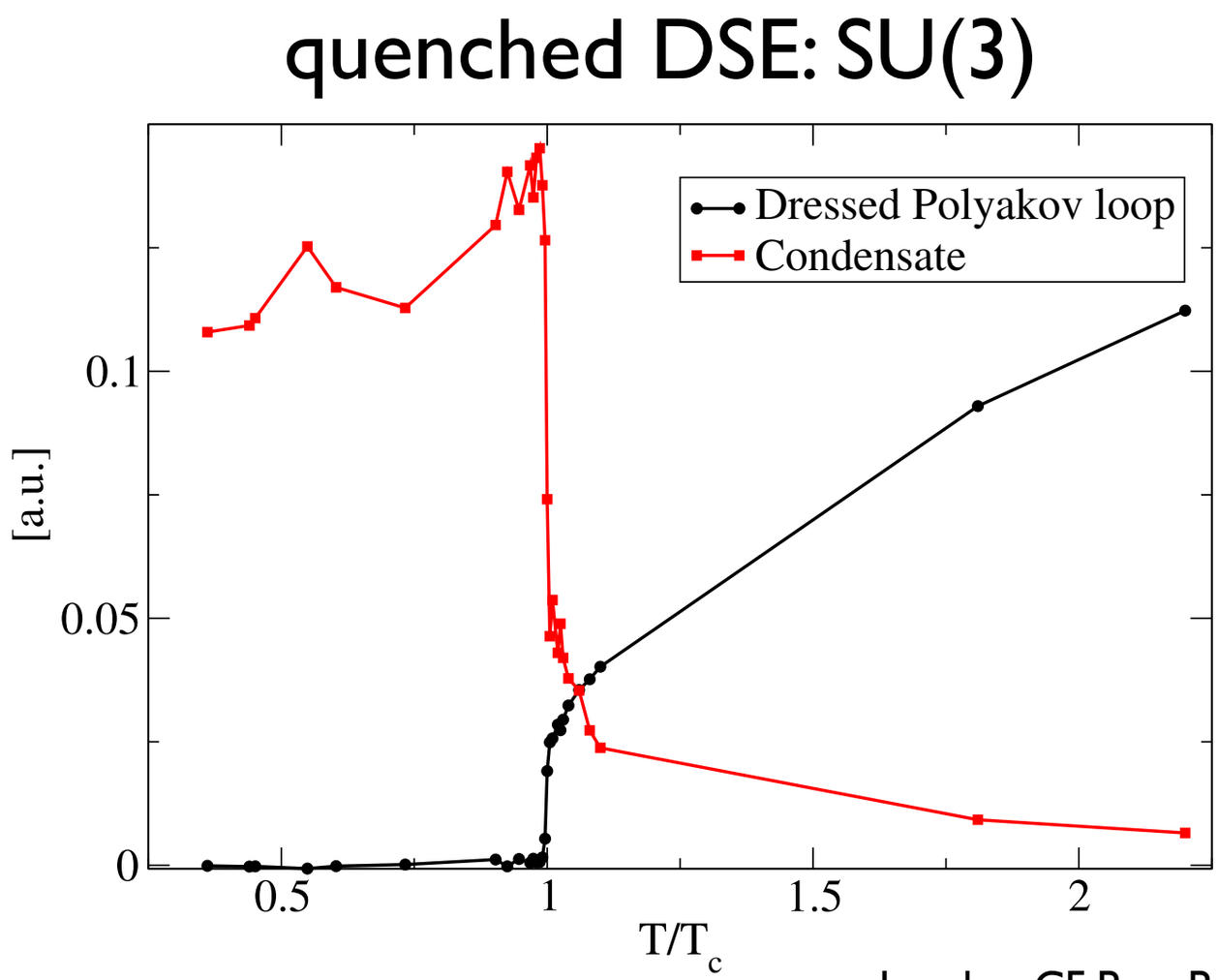
QCD phase transition: heavy quark limit/quenched

Quark mass dependence:



- Expect: Transitions controlled by deconfinement
- SU(2) second order, SU(3) first order

Transition temperatures, quenched

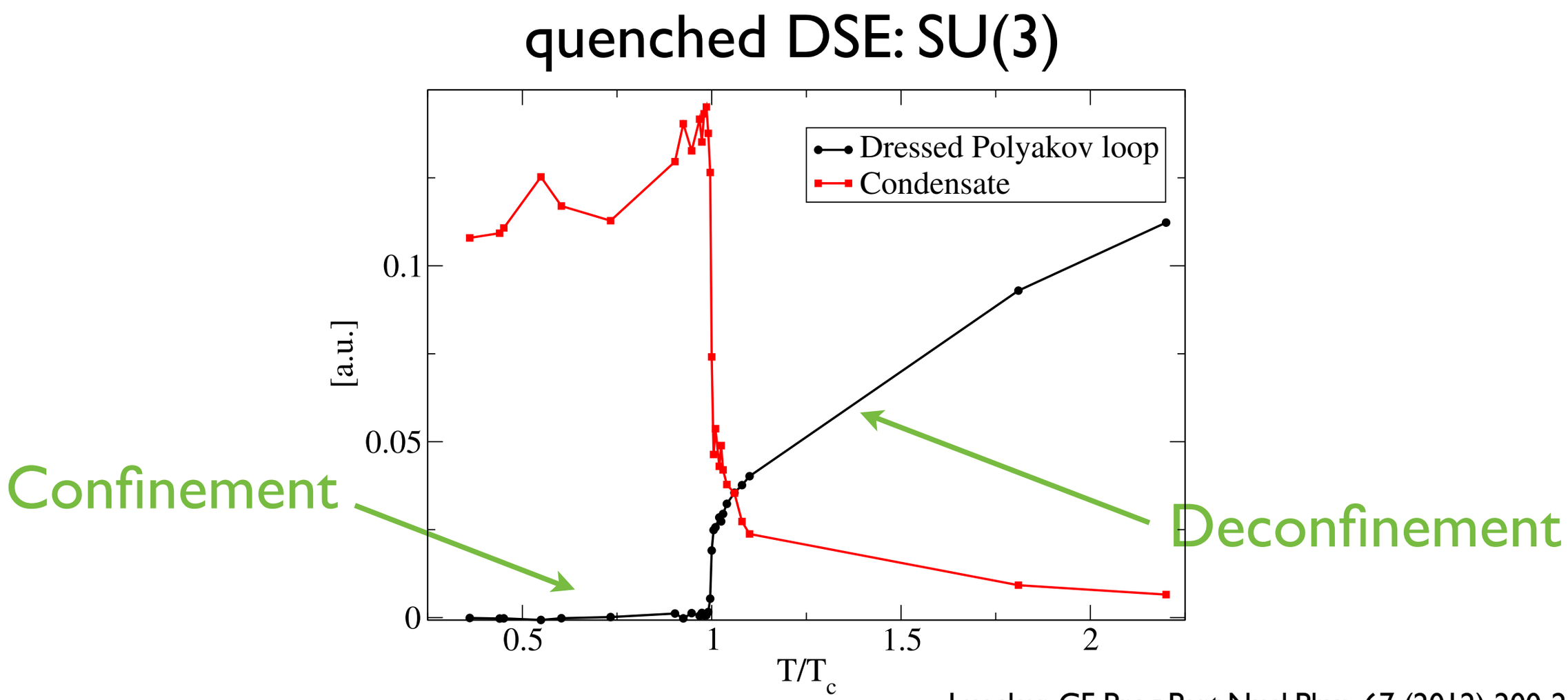


Luecker, CF, Prog.Part.Nucl.Phys. 67 (2012) 200-205
CF, Maas, Mueller EPJC 68 (2010)

- SU(2): $T_c \approx 305$ MeV
- SU(3): $T_c \approx 270$ MeV
- $T \leq T_c$: increasing condensate due to electric part of gluon

cf. Buividovich, Luschevskaya, Polikarpov, PRD 78 (2008) 074505
cf. Braun, Gies, Pawlowski, PLB 684 (2010) 262.

Transition temperatures, quenched



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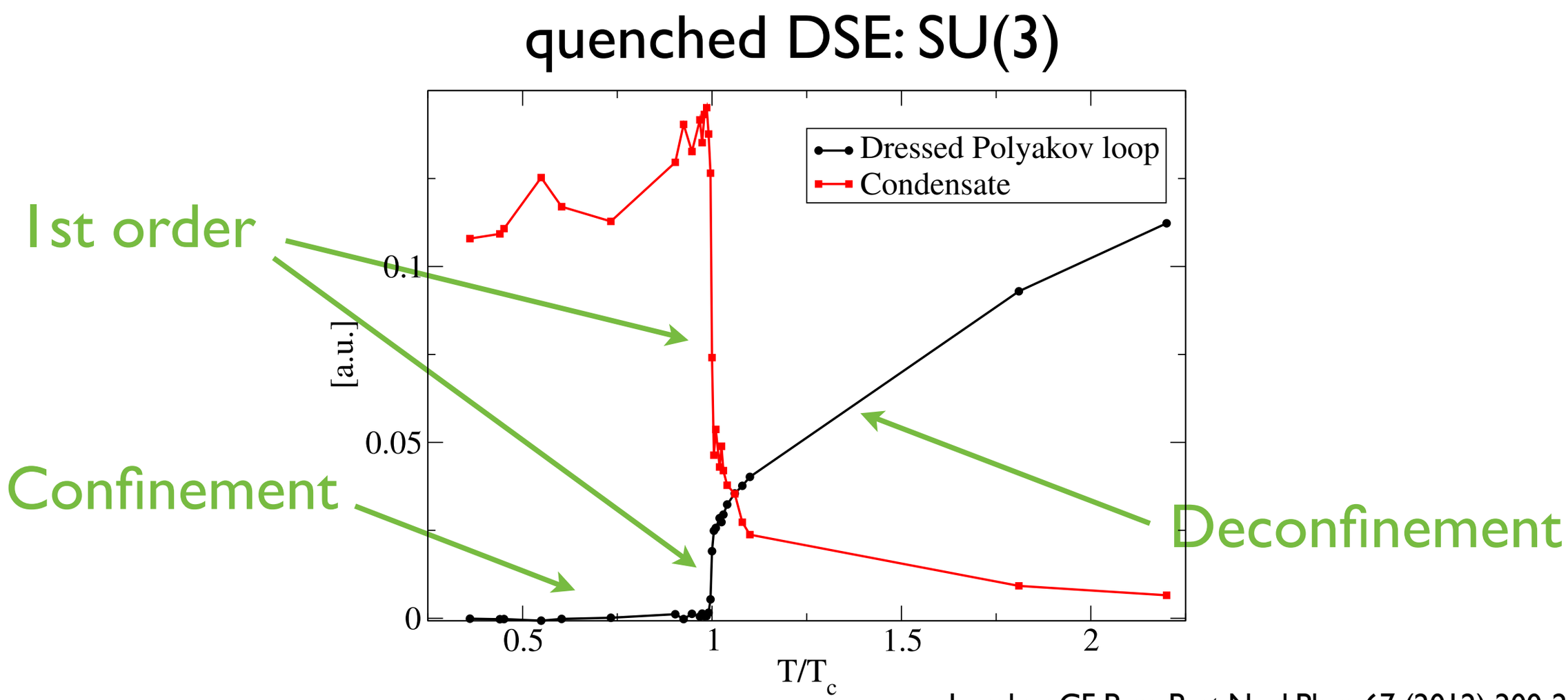

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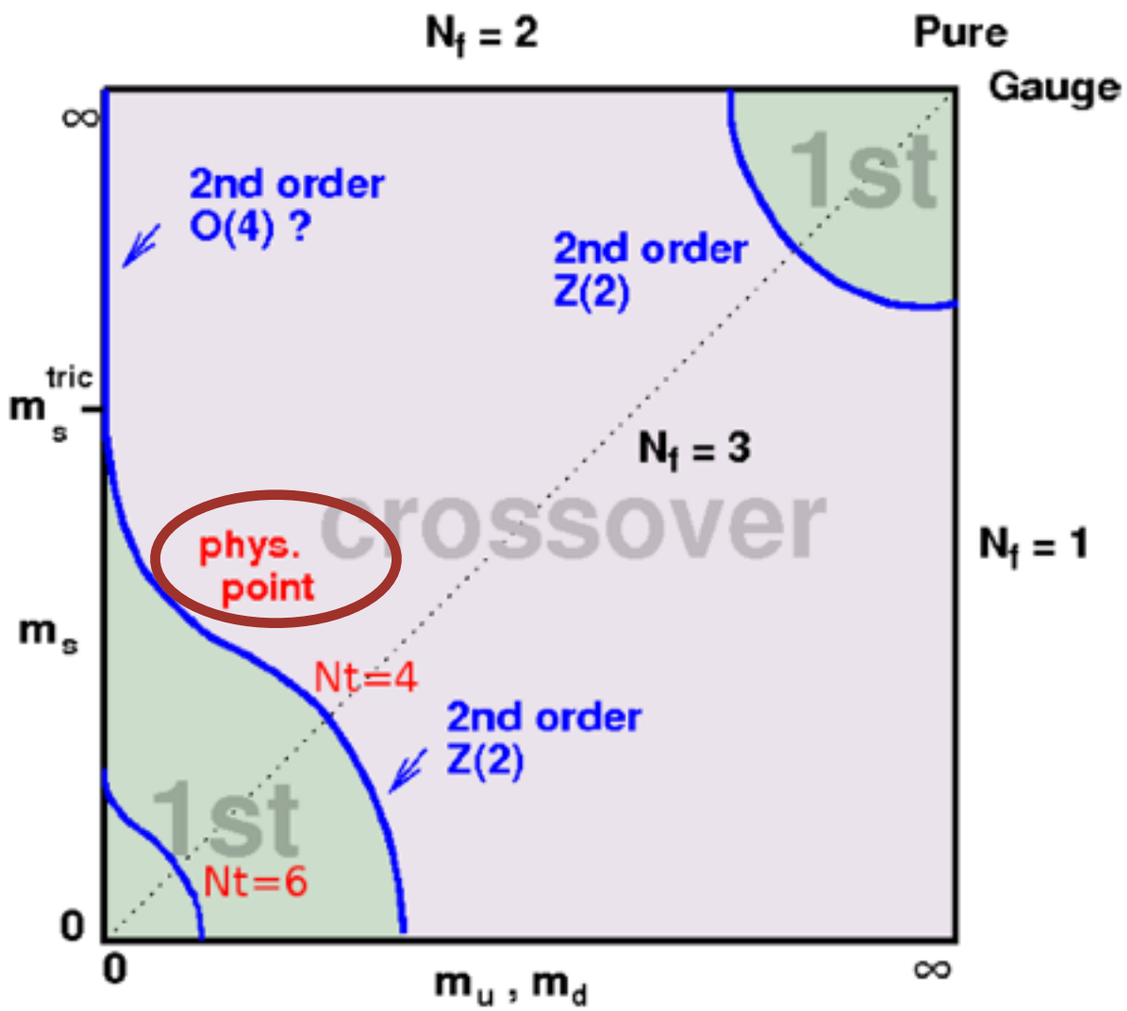
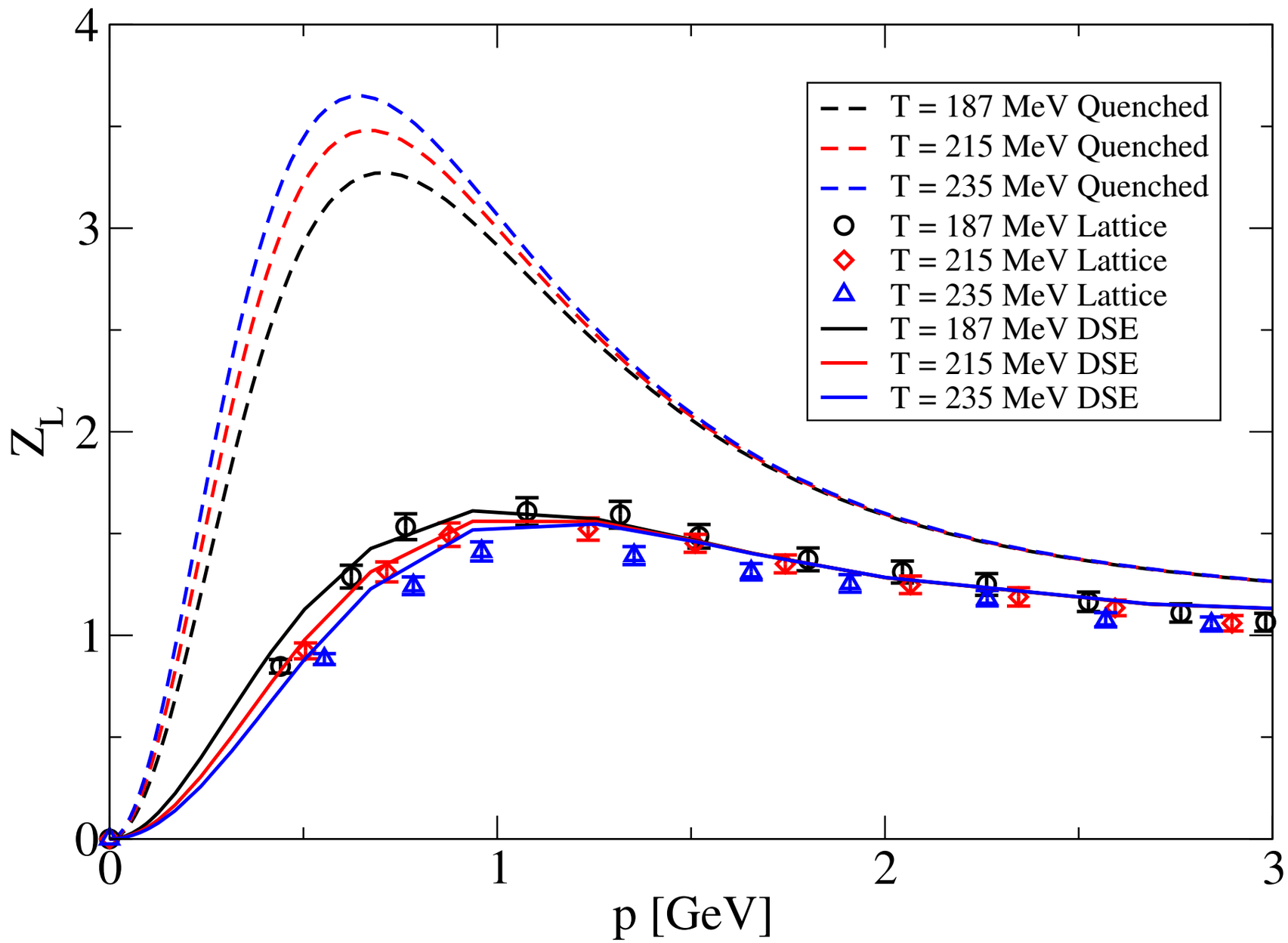
QCD phase transitions: N_f=2+1



- Physical up/down and strange quark masses
- Transition controlled by chiral dynamics
- at μ=0: compare to available lattice results

Unquenched Gluon DSE vs Lattice

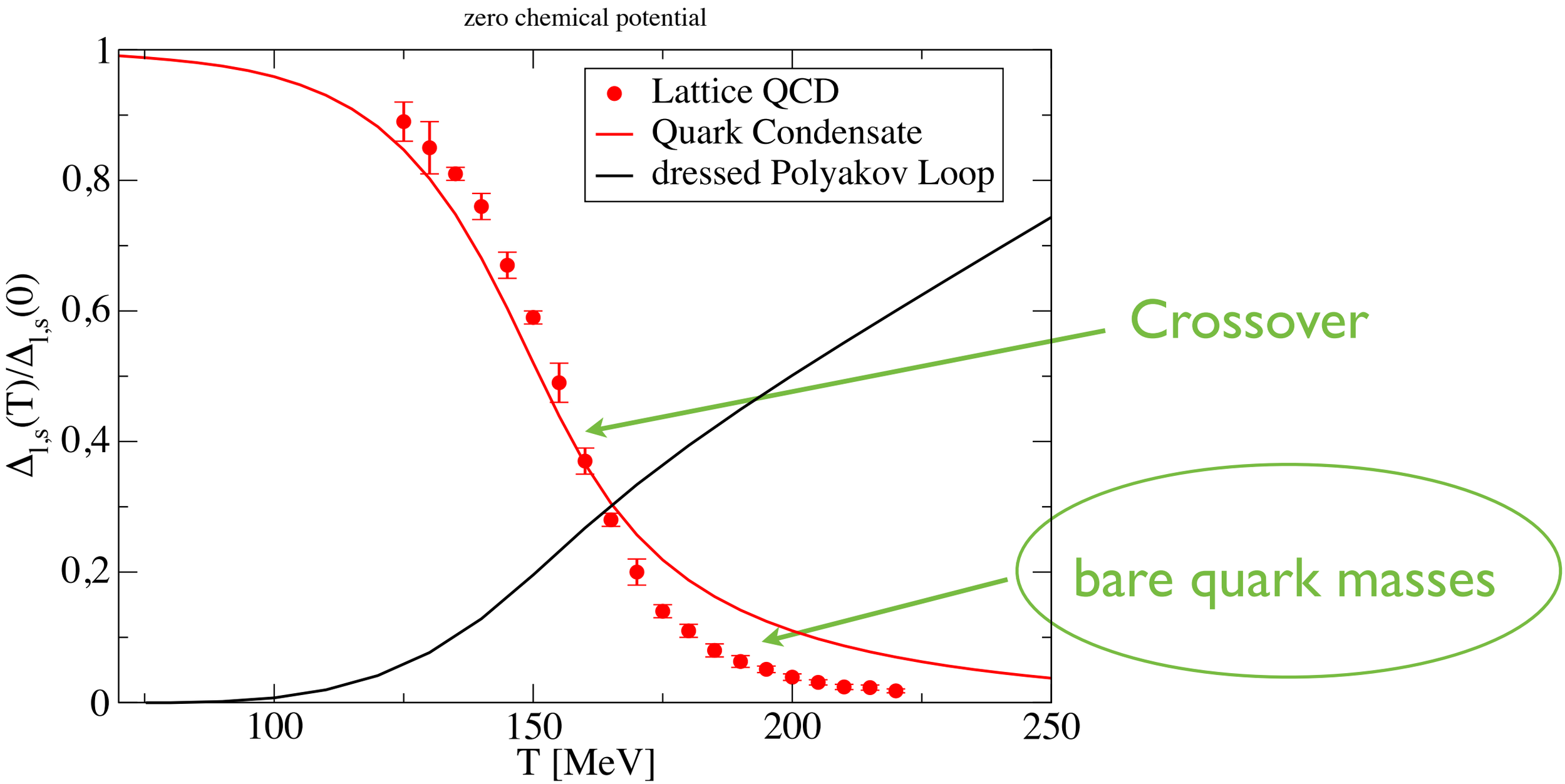


- quantitative agreement: DSE prediction verified by lattice

DSE: CF, Luecker, PLB 718 (2013) 1036 [arXiv:1206.5191]

Lattice: Aouane, Burger, Ilgenfritz, Muller-Preussker and Sternbeck, PRD D87 (2013), [arXiv:1212.1102]

N_f=2+1, zero chemical potential



Lattice: Borsanyi *et al.* [Wuppertal-Budapest Collaboration], JHEP 1009(2010) 073
DSE: CF, Luecker, PLB 718 (2013) 1036, CF, Luecker, Welzbacher, arXiv:1405.4762

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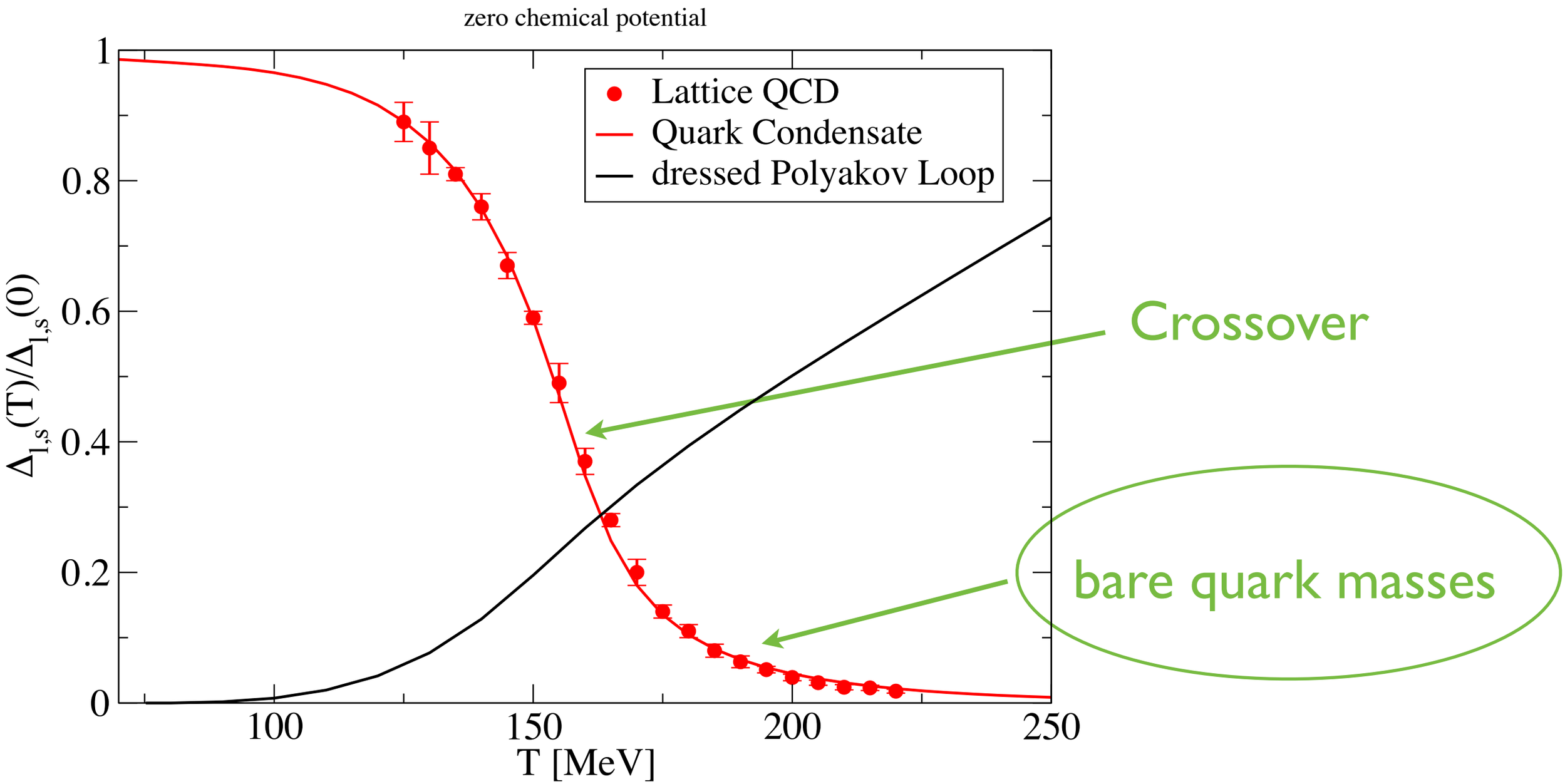

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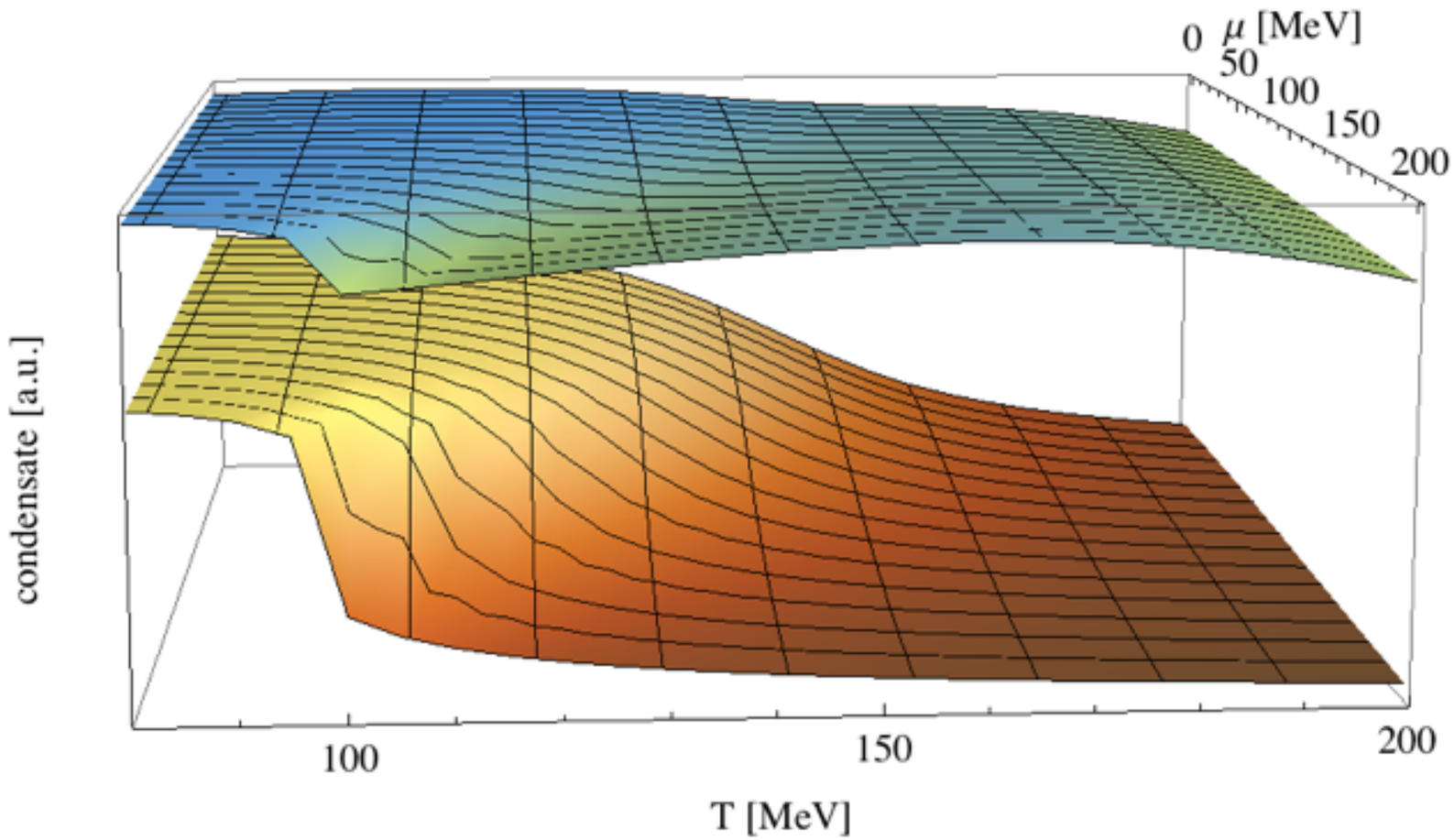
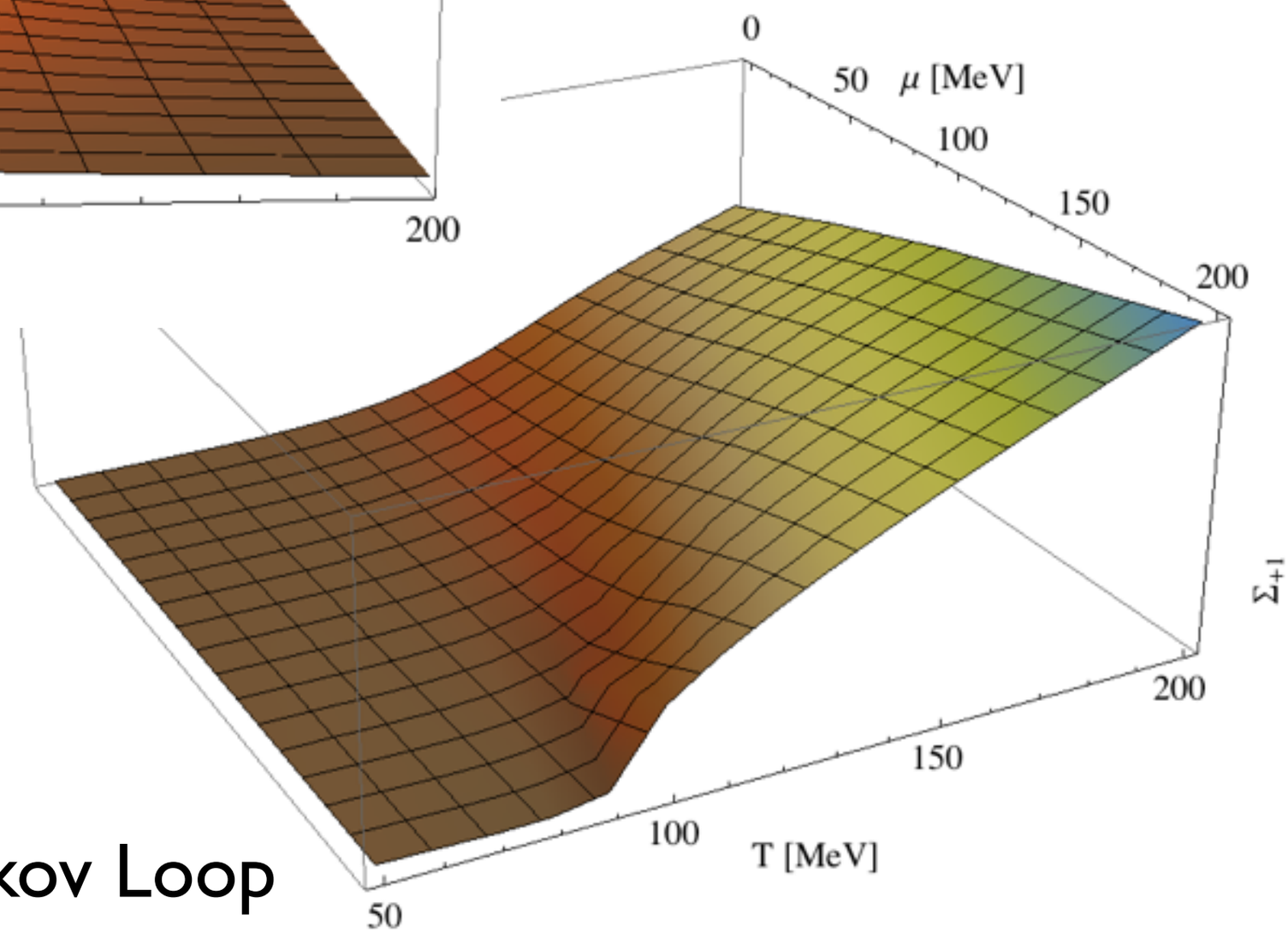
- quantitative agreement

Nf=2+1: Condensate and dressed Polyakov Loop

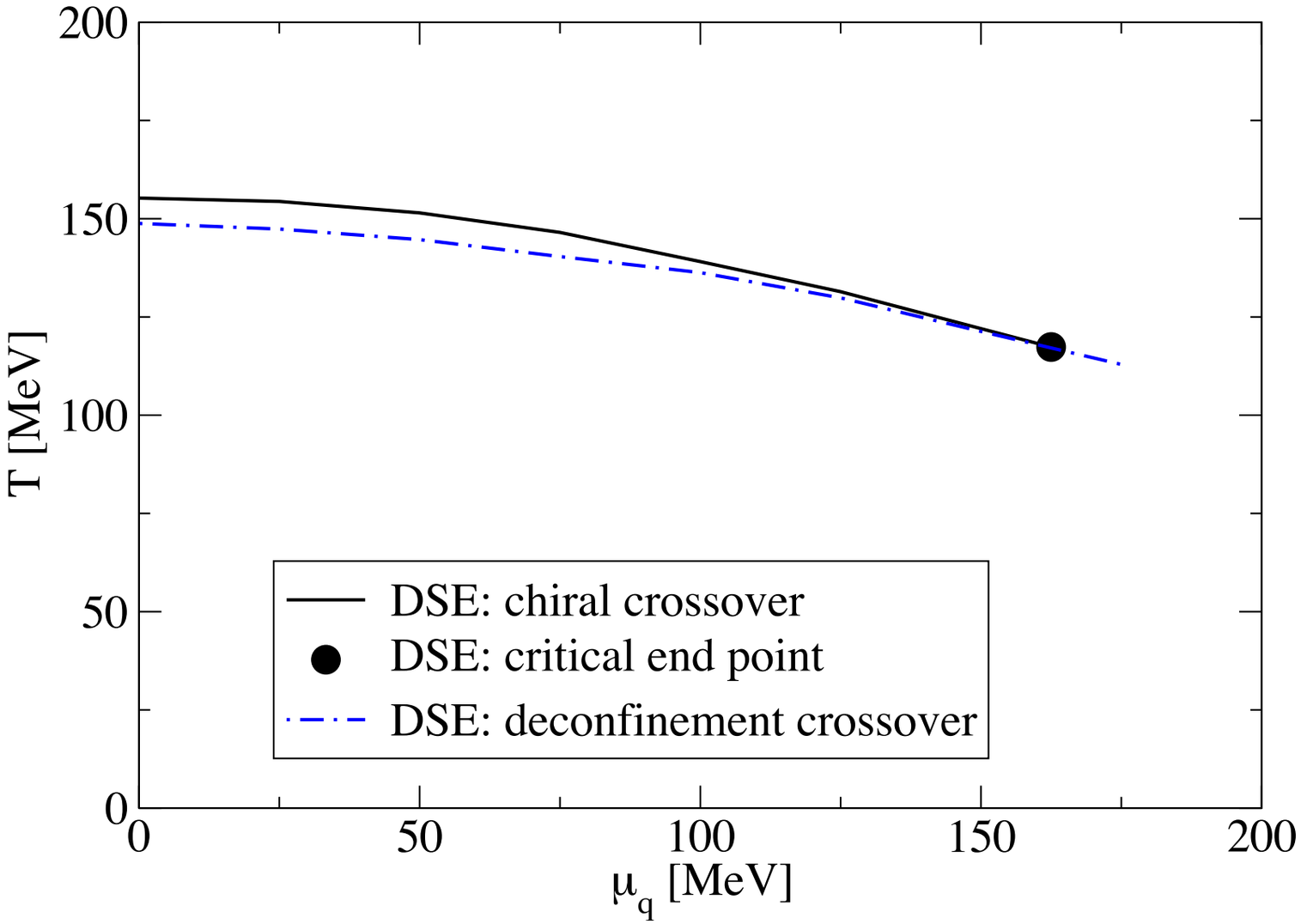


Quark condensate



Dressed Polyakov Loop

N_f=2+1: Polyakov loop and phase diagram



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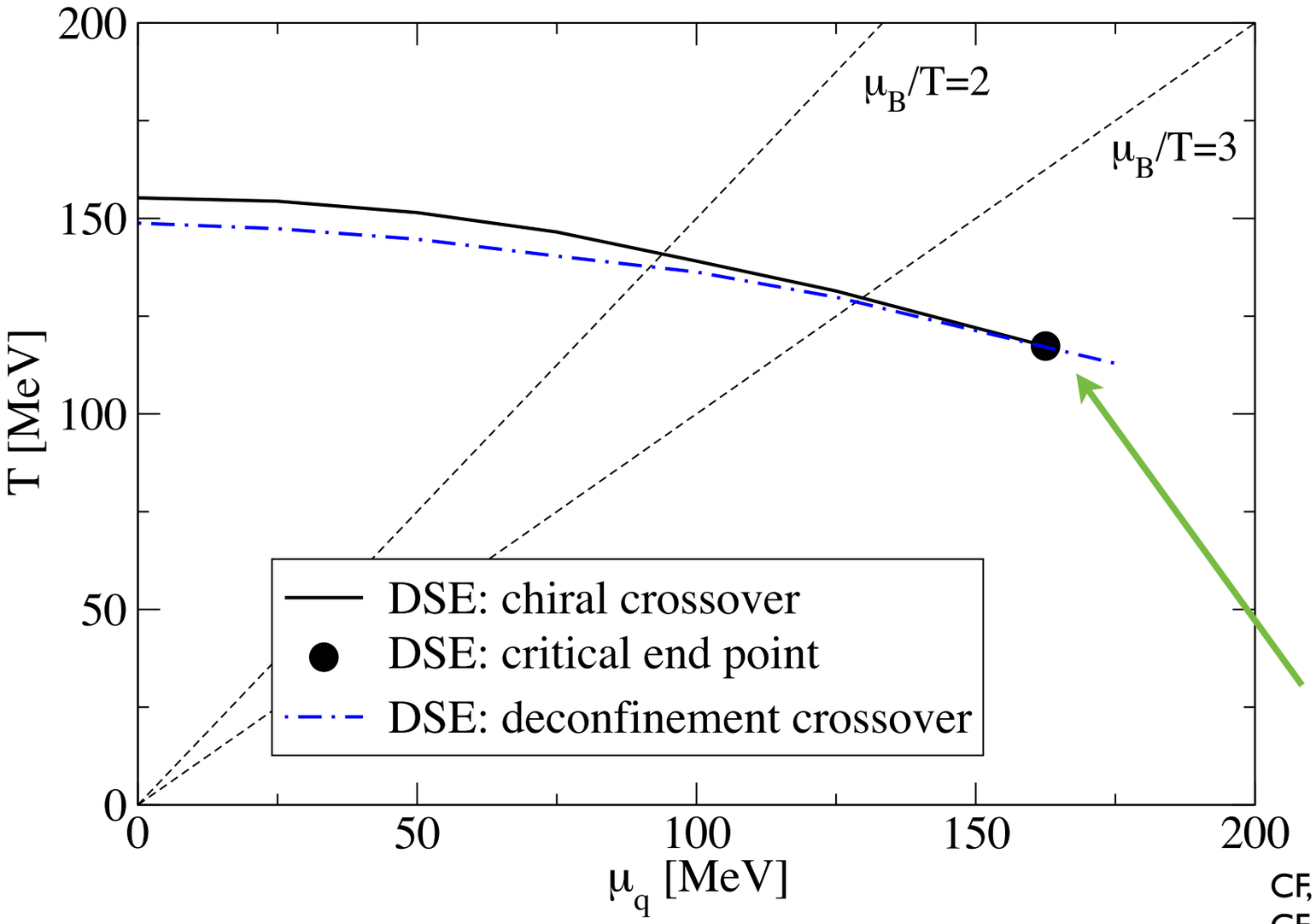

CEP at large μ

CF, Luecker, PLB 718 (2013) 1036,
CF, Fister, Luecker, Pawlowski, PLB in press, arXiv:1306.6022
CF, Luecker, Welzbacher, arXiv:1405.4762

- no CEP at $\mu_B/T < 2$

de Forcrand, Philipsen, JHEP 0811 (2008) 012; Nucl Phys. B642 (2002) 290-306

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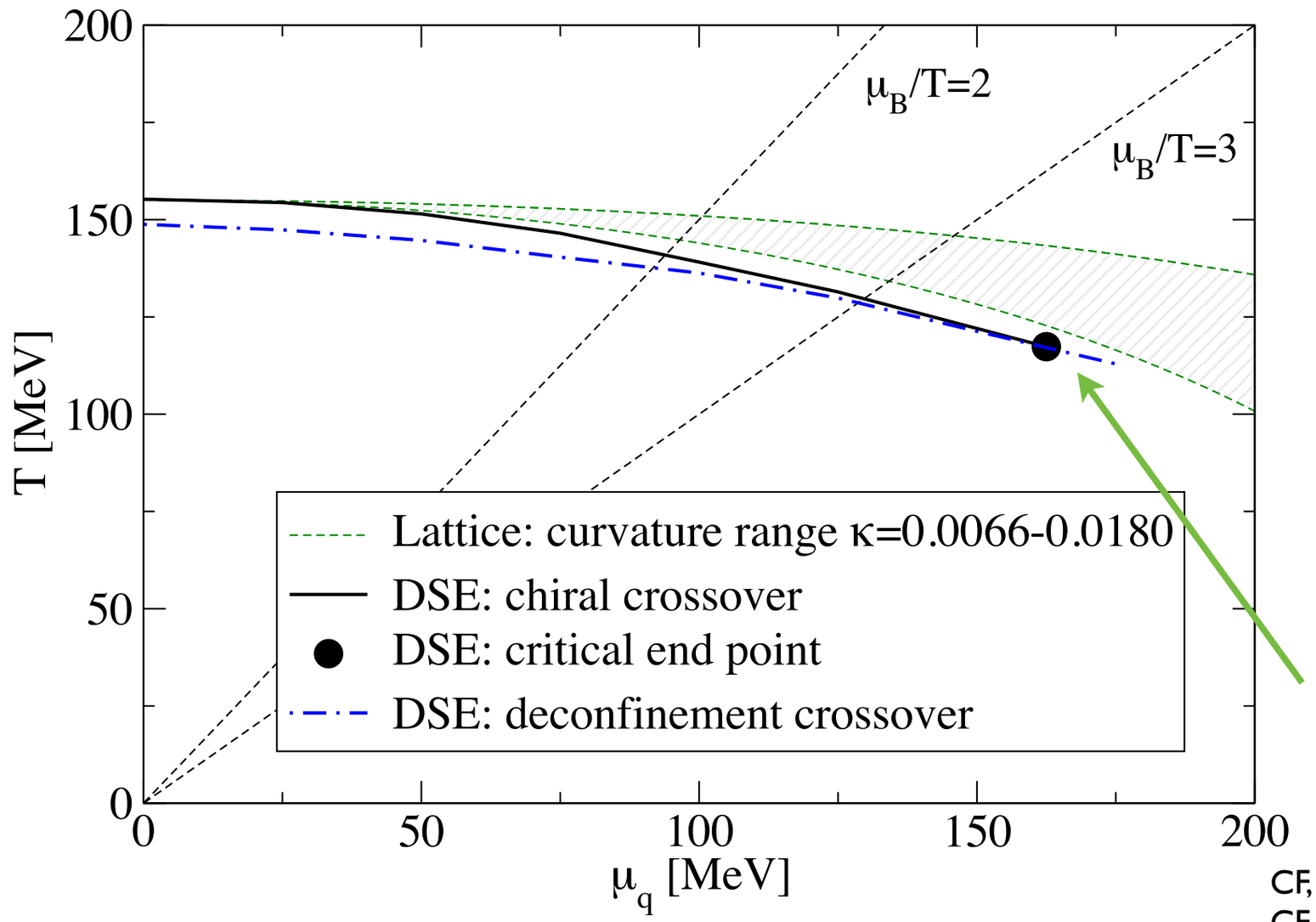

Extrapolated curvature from lattice

Kaczmarek at al. PRD 83 (2011) 014504,
Endrodi, Fodor, Katz, Szabo, JHEP 1104 (2011) 001
Cea, Cosmai, Papa, PRD 89 (2014) 074512

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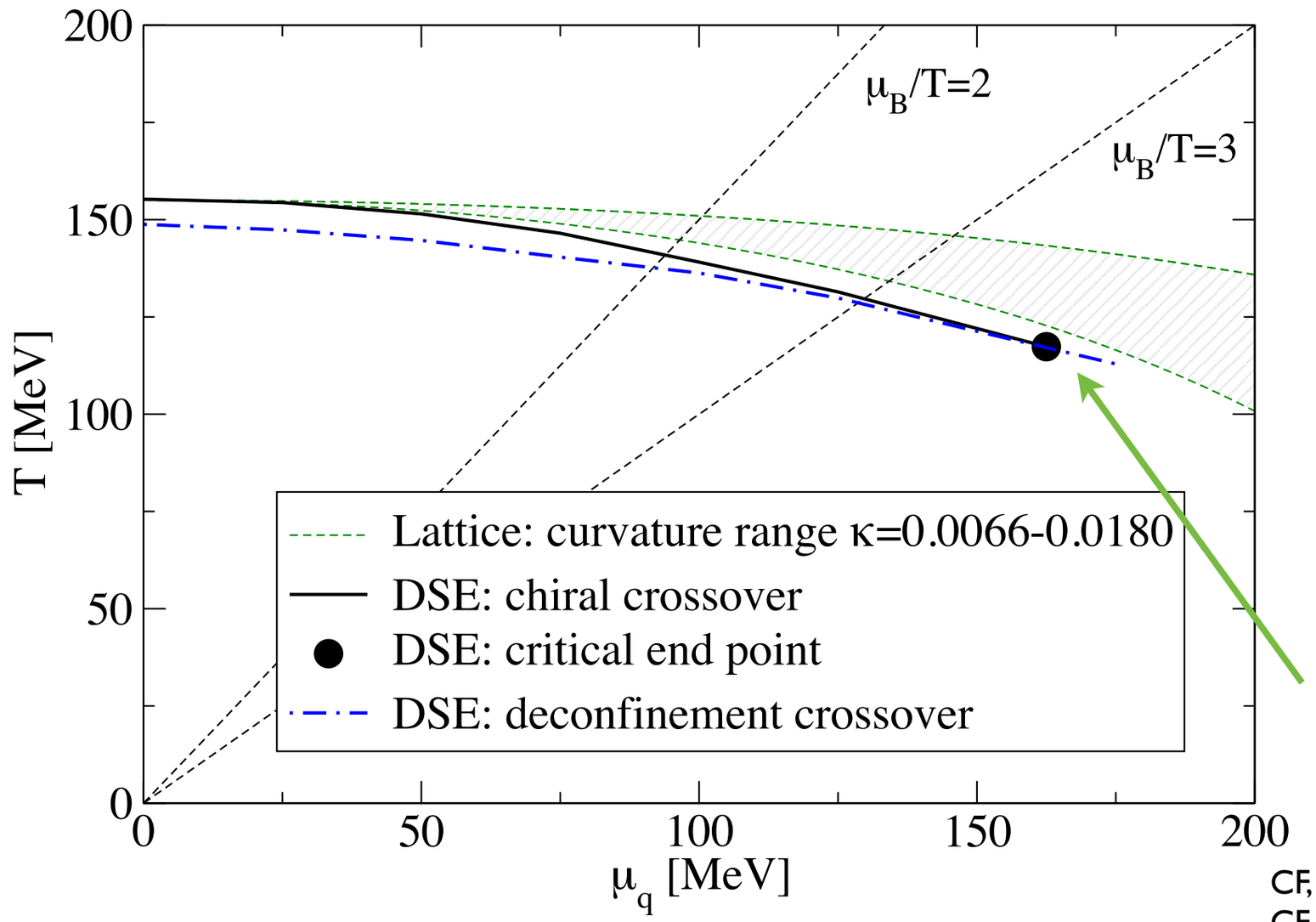

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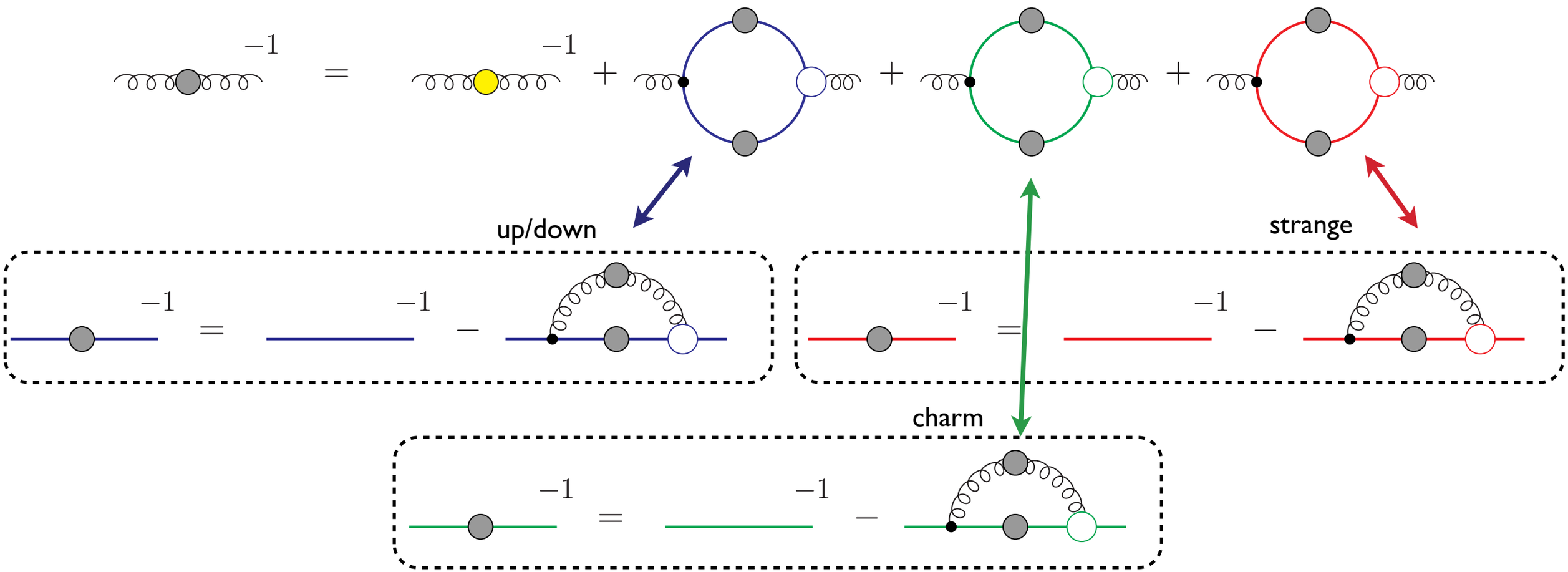
Caveat: baryon effects missing...

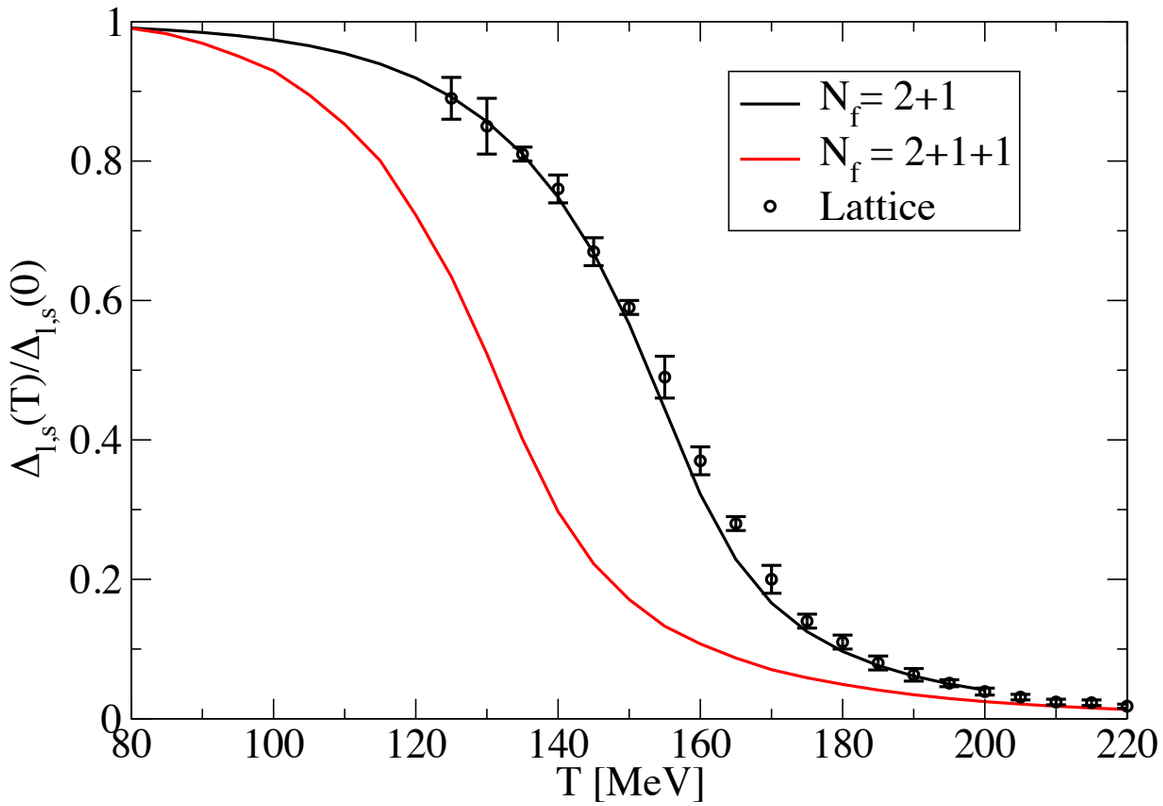
Nc=2: Brauner, Fukushima and Hidaka, PRD 80 (2009) 74035
Strodthoff, Schaefer and Smekal, PRD 85 (2012) 074007

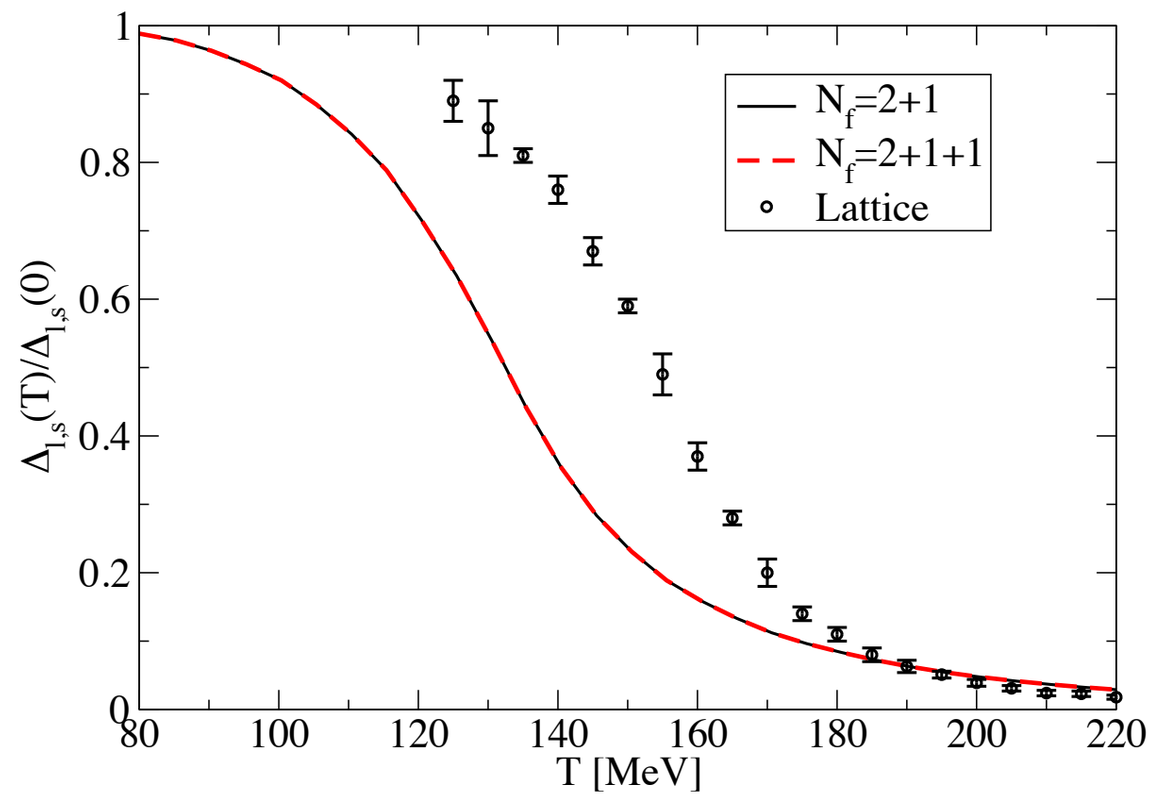
Nf=2+1+1-QCD with DSEs



- Physical up/down, strange and charm quark masses
- Transition controlled by chiral dynamics
- *no lattice or model results available yet*

Nf=2+1+1-QCD with DSEs

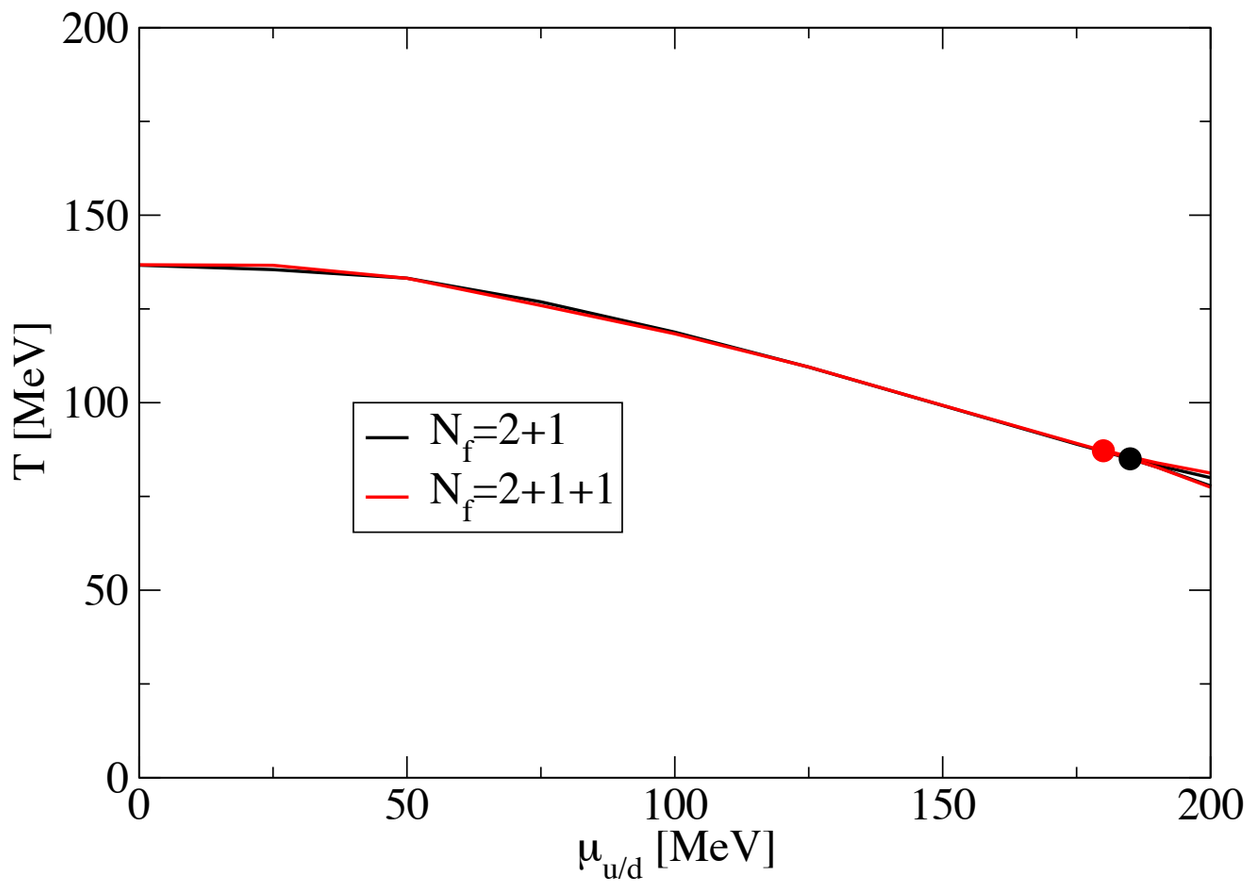




CF, Luecker, Welzbacher, arXiv:1405.4762

- Left: Interaction fixed: T_{PC} decreases by O(20 MeV)
- Right: Physics fixed (m_π, f_π): T_{PC} similar

Nf=2+1+1-QCD with DSEs



CF, Luecker, Welzbacher, arXiv:1405.4762

- Physics fixed (m_π, f_π): T_C similar
- Charm quark has no influence on QCD phase diagram

Summary

- Temperature dependent gluon propagator
  - characteristic behavior of electric gluon
  - 'melting' of magnetic gluon with temperature
- Deconf. T_{pc} from dressed Polyakov-loop/Polyakov-loop potential
- QCD with finite chemical potential (beyond mean field)
  - backreaction of quarks onto gluons important
  - N_f=2+1 and N_f=2+1+1: CEP at $\mu_c/T_c > 2$

Work in progress: include baryons...
include magnetic field...

Mueller, Bonnet, CF, PRD 89 (2014)