Yang-Mills correlation functions from the functional renormalization group

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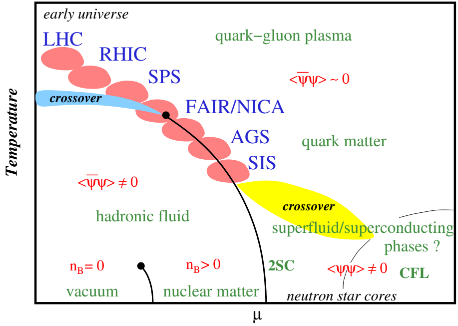
fQCD collaboration - QCD (phase diagram) with FRG:

J. Braun, A. K. Cyrol, L. Fister, W. J. Fu, T. K. Herbst, MM
N. Müller, J. M. Pawlowski, S. Rechenberger, F. Rennecke, N. Strodthoff

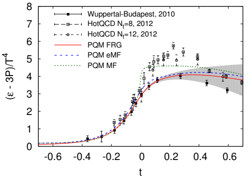


Outline

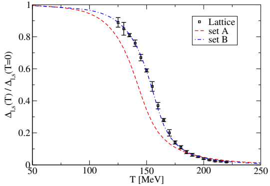
1. Why Yang-Mills theory in the vacuum?
2. Vertex Expansion of effective action with FRG
3. YM correlation functions
4. A glimpse at unquenching
5. Conclusion

QCD phase diagram with functional methods

- works well at $\mu = 0$: agreement with lattice



[Herbst, MM, Pawlowski, Schaefer, Stiele, '13]



[Luecker, Fischer, Welzbacher, 2014]

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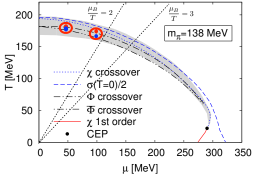
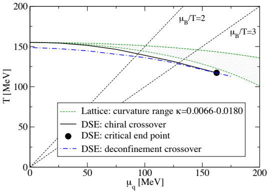


[Herbst, Pawlowski, Schaefer, 2013]

[Braun, Haas, Pawlowski, unpublished]



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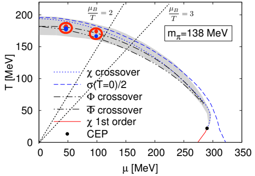
  - Polyakov-quark-meson model with FRG:
    - inital values at $\Lambda \approx \mathcal{O}(\Lambda_{\mathrm{QCD}})$
    - input for Polyakov loop potential
  - quark propagator DSE:
    - IR quark-gluon vertex



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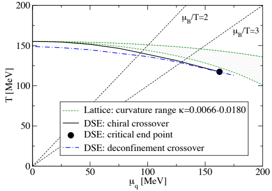

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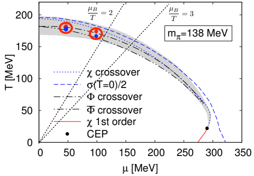

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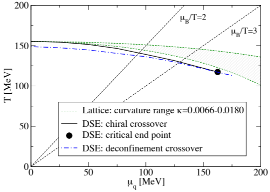

possible explanation for disagreement:

- $\mu \neq 0$: relative importance of diagrams changes
  $\Rightarrow$ summed contributions vs. individual contributions

[Luecker, Fischer, Fister, Pawlowski, '13]

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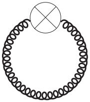
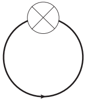
$\partial_k \Gamma_k[A, \bar{c}, c, \bar{q}, q] = \frac{1}{2}$  $-$ 

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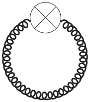
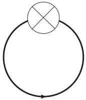
$\partial_k \Gamma_k[A, \bar{c}, c, \bar{q}, q] = \frac{1}{2}$  $-$ 

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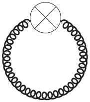

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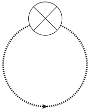

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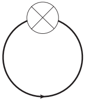

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- ∂_k: integration of momentum shells controlled by regulator
- full field-dependent equation with $(\Gamma_k^{(2)}[\Phi])^{-1}$ on rhs
- gauge-fixed approach (Landau gauge):
  - ghosts appear
  - gauge invariance: $\Gamma_{(k)}$ fulfills (modified) Slavnov-Taylor identities

Vertex Expansion

- approximation necessary - vertex expansion

$$\Gamma[\Phi] = \sum_n \int_{p_1,\ldots,p_{n-1}} \Gamma^{(n)}_{\Phi_1\cdots\Phi_n}(p_1,\ldots,p_{n-1})\Phi^1(p_1)\cdots\Phi^n(-p_1-\cdots-p_{n-1})$$

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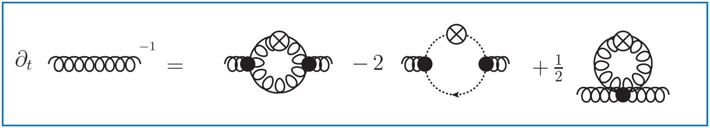
  $\Rightarrow$ equations for 1PI n-point functions, e.g. gluon propagator:



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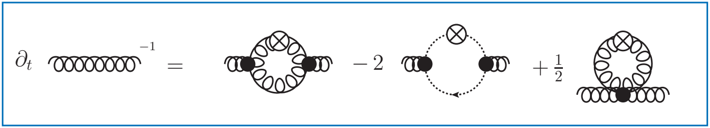

- want "apparent convergence" of $\Gamma[\Phi] = \lim_{k\to 0} \Gamma_k[\Phi]$

“Quenched” Landau gauge QCD

- two crucial phenomena: SχSB and confinement
- similar scales - hard to disentangle see e.g. [Williams, Fischer, Heupel, 2015]
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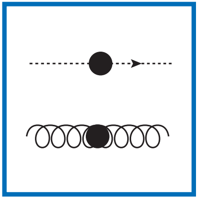
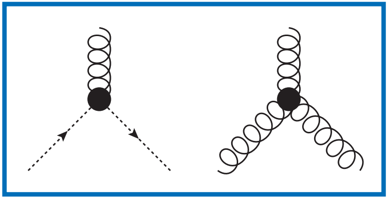
- recent results for YM propagators [Cyrol, Fister, MM, Pawlowski, Strodthoff, to be published]
- matter part (only one slide) [MM, Strodthoff, Pawlowski, 2014]

Vertex Expansion in YM theory [Cyrol, Fister, MM, Strodthoff, Pawlowski, to be published]



full. mom. dep.



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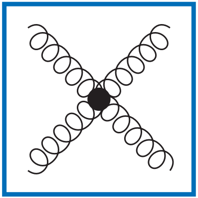

sym. point and tadpole config.

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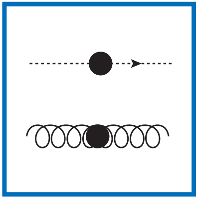

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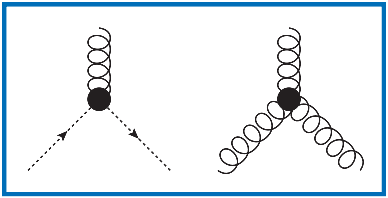

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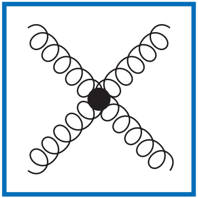

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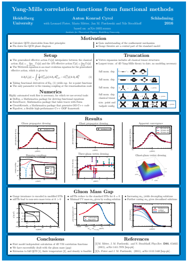
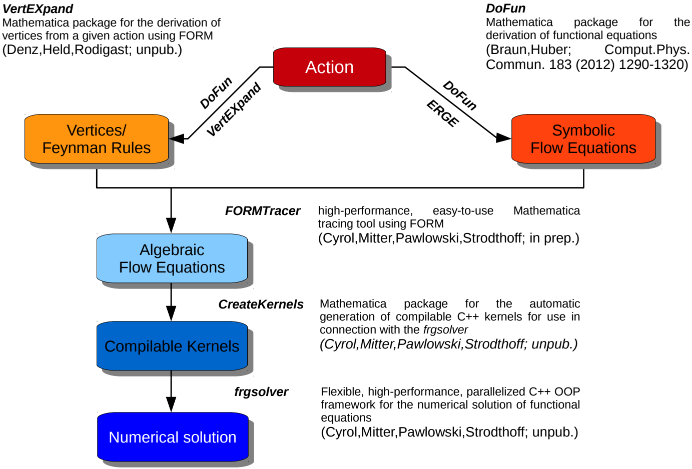
⇒ cf. poster Anton K. Cyrol



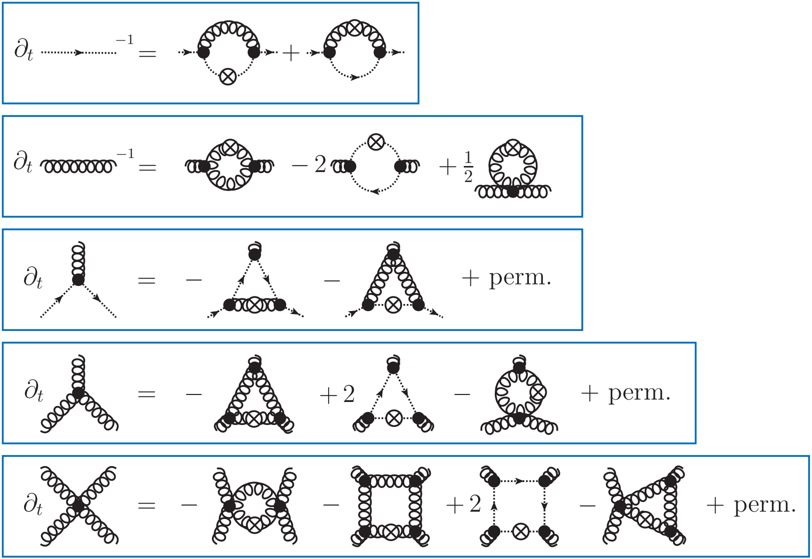
Derivation of equations



[Cyrol, MM, Pawlowski, Strodthoff, 2013-2016]

(Truncated) Equations

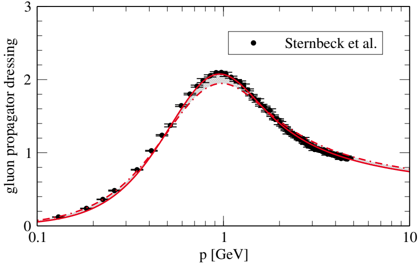
[Cyrol, Fister, MM, Strodthoff, Pawlowski, to be published]

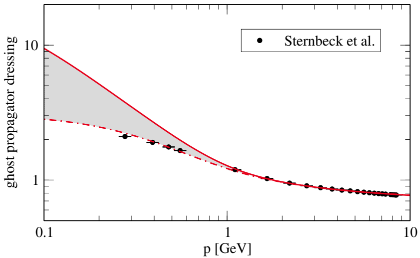


YM propagators

[Cyrol, Fister, MM, Pawlowski, Strodthoff, to be published]

- $\Gamma^{(2)}_{AA}(p) \propto Z_A(p)\, p^2 \, \left(\delta^{\mu\nu} - p^\mu p^\nu / p^2\right)$
- $\Gamma^{(2)}_{\bar{c}c}(p) \propto Z_c(p)\, p^2$



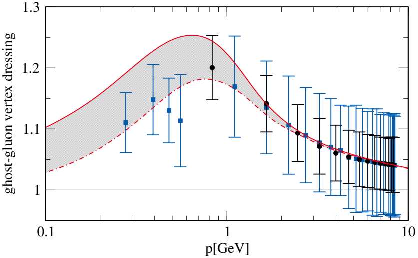


- band: family of decoupling solutions bounded by scaling solution

YM vertices I

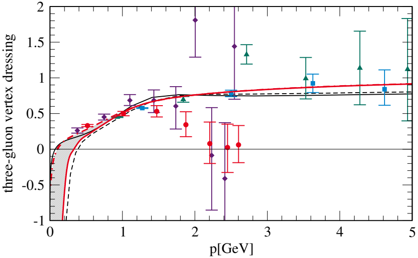
[Cyrol, Fister, MM, Pawlowski, Strodthoff, to be published]

- comparison to Sternbeck '06



- comparison to Cucchieri, Maas, Mendes, '08

  Blum, Huber, MM, von Smekal '14 (black lines)



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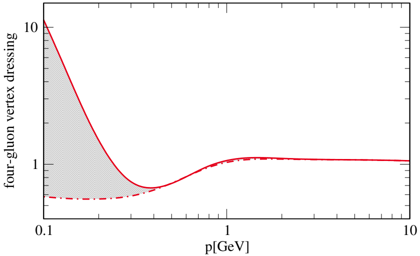
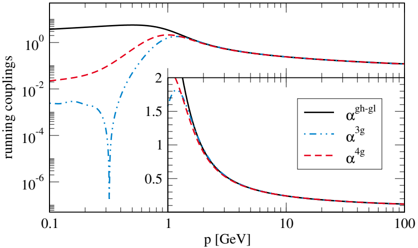
YM vertices II

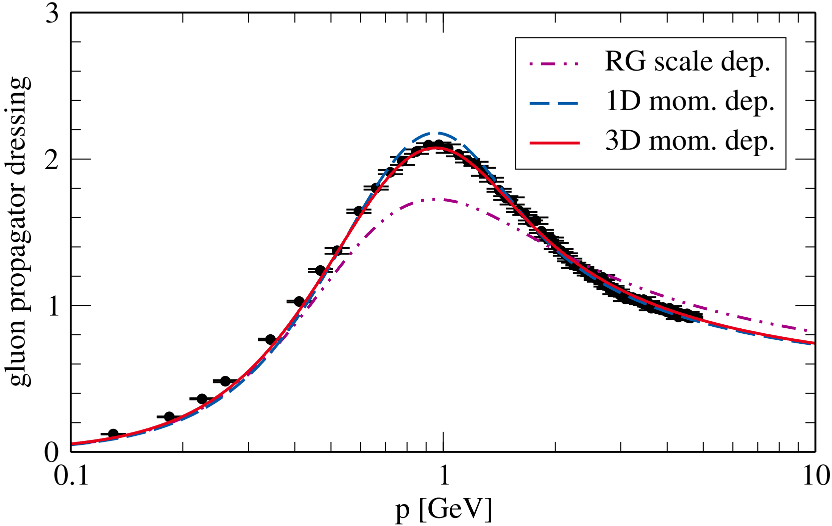
[Cyrol, Fister, MM, Pawlowski, Strodthoff, to be published]





Apparent Convergence

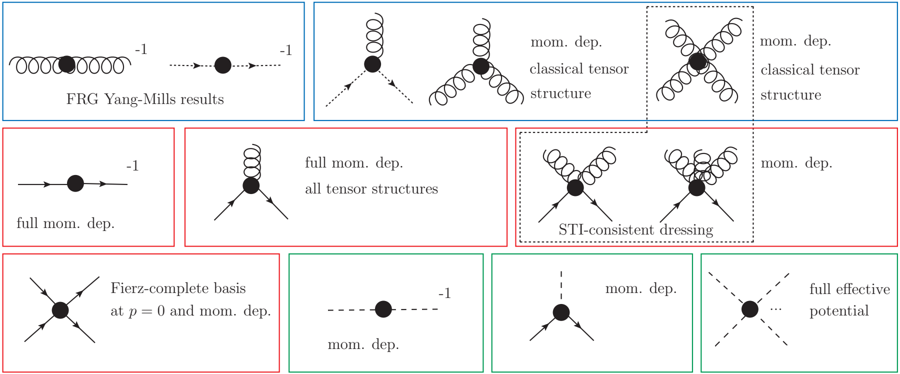
[Cyrol, Fister, MM, Pawlowski, Strodthoff, to be published]



Quenched quark propagator

[MM, Pawlowski, Strodthoff, 2014]

- $\Gamma^{(2)}_{\bar{q}q}(p) \propto Z_q(p)\ \not{p} + M(p)$



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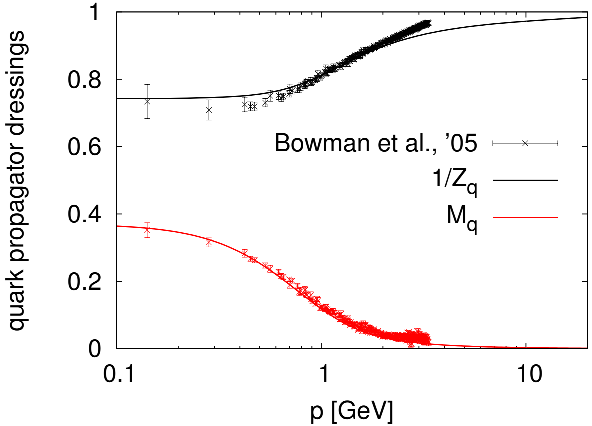
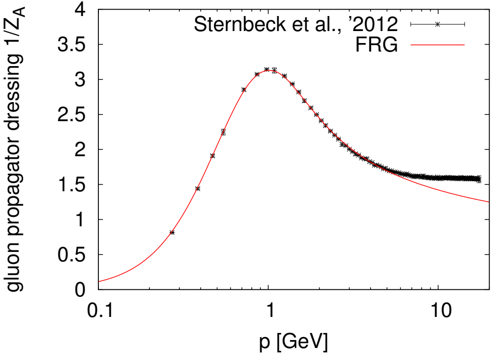


- FRG vs. lattice: bare mass, quenched, scale
- agreement not sufficient: need apparent convergence at $\mu \neq 0$

Outlook: unquenched gluon propagator



[Cyrol, MM, Pawlowski, Strodthoff, in preparation]

- self-consistent solution of classical propagators and vertices (1D)
- massless quarks

Summary and Outlook

(quenched) QCD with functional RG

- QCD phase diagram: need for quantitative precision
- quenched QCD in vacuum:
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- unquenching (first results)
- finite temperature/chemical potential
- more checks on convergence of vertex expansion
- bound-state properties (form factor,PDA...)