

How the string reflects itself in the properties of particles

Axel Maas

14th of September 2010

Hadrons, Lattice QCD and Chiral perturbation theory

Graz

Austria

FWF

**UNI
GRAZ**

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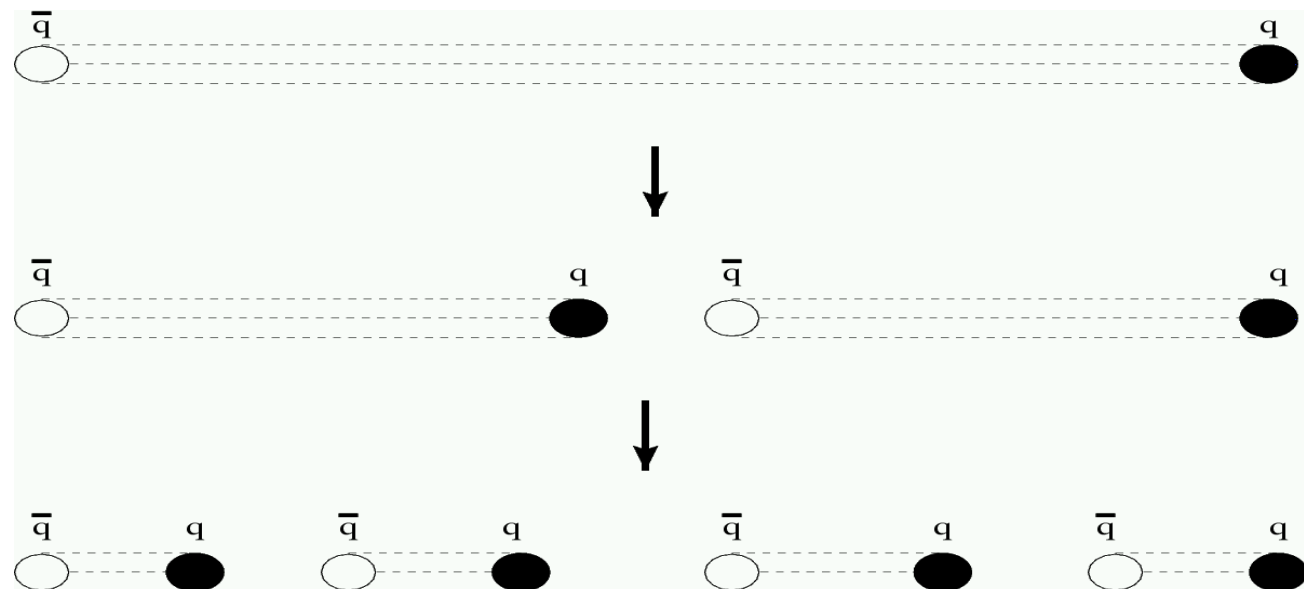
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Particles and the string

- **Binding interaction between quarks is associated with a **string****

Particles and the string

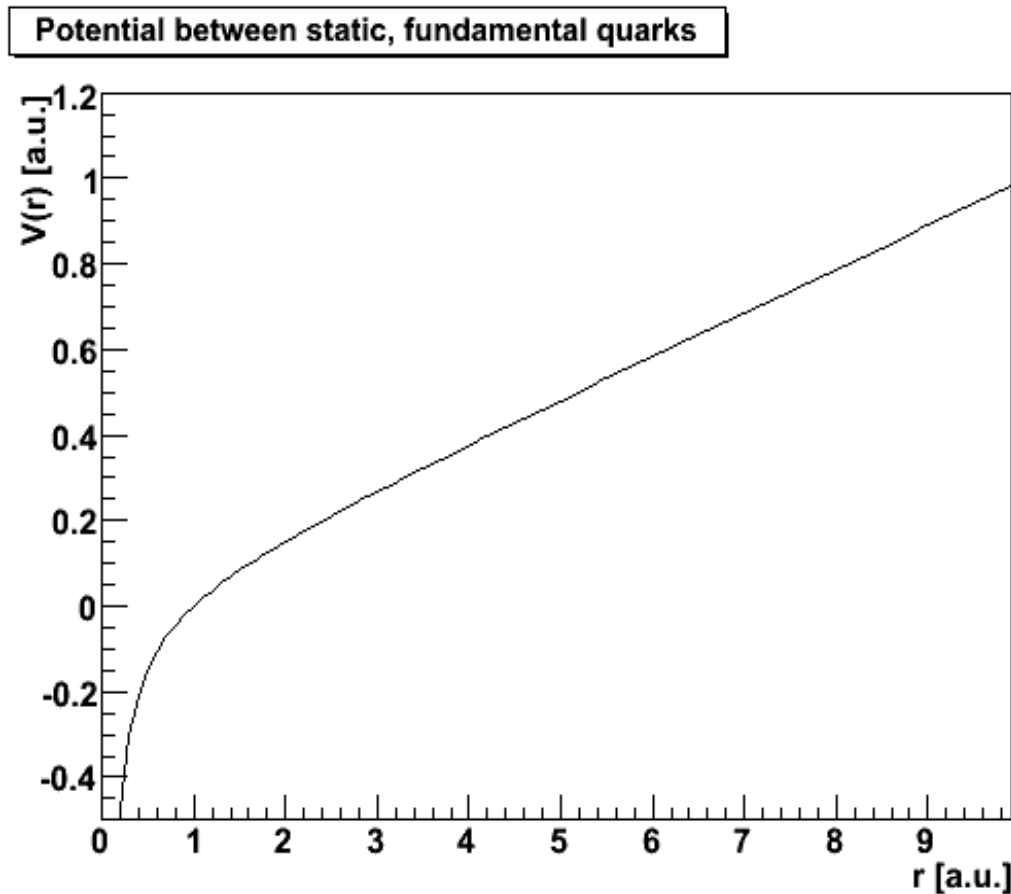
- Binding interaction between quarks is associated with a **string**
- The **string breaks** when sufficiently excited to generate additional particles
 - Requires the possibility to screen



[Greensite PPP03]

When is string-breaking possible?

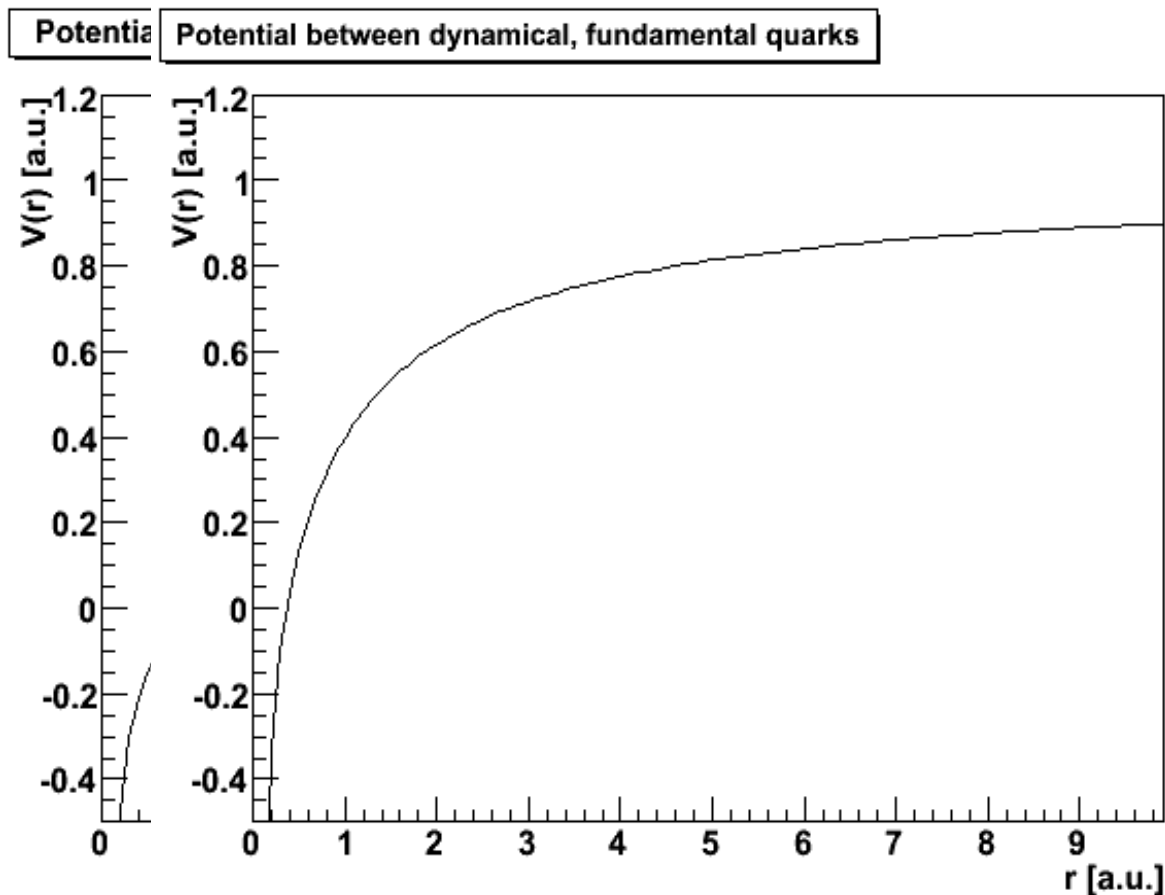
String-breaking can be read of the 2-particle 'potential'



- **No string-breaking possible**
- **Confinement according to the Wilson criterion**

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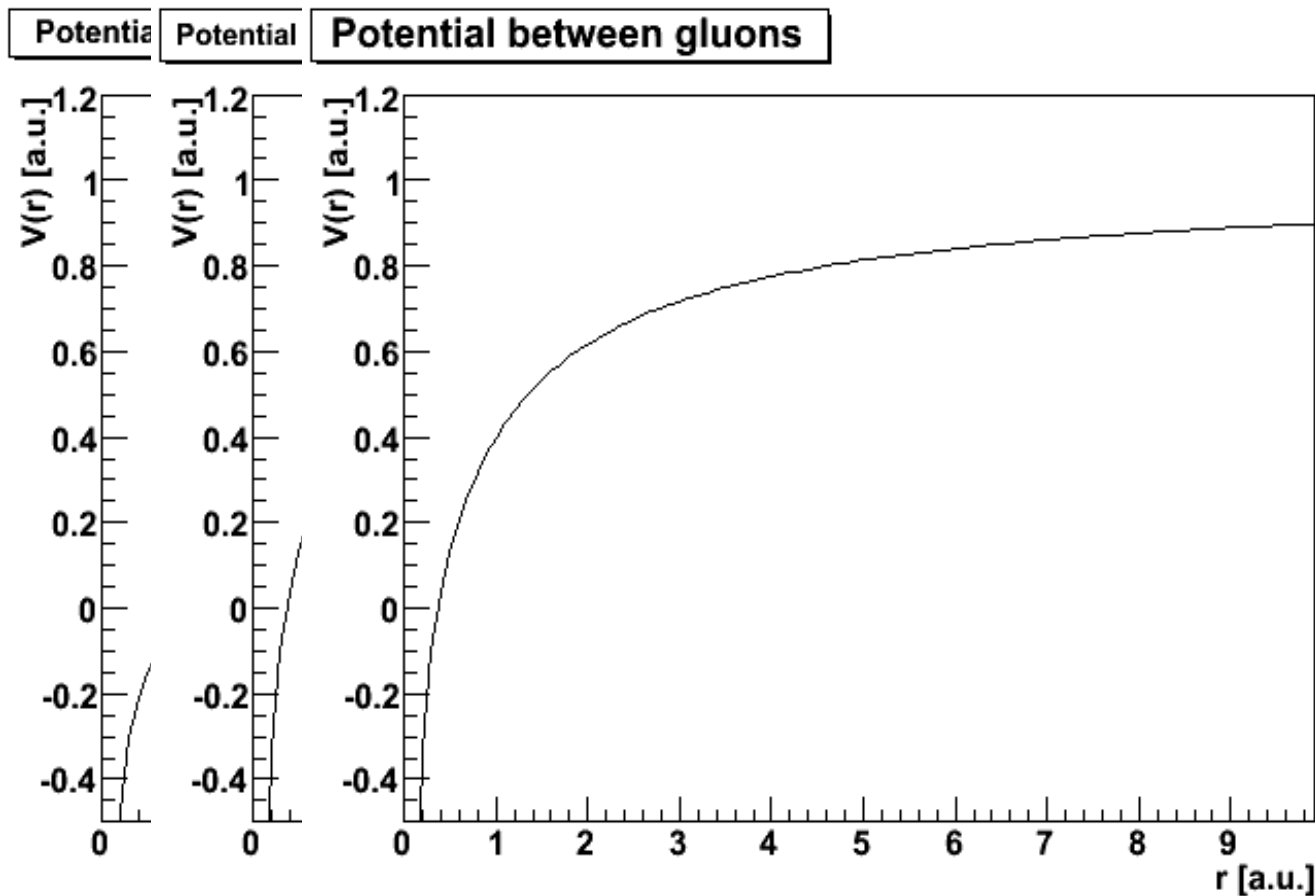
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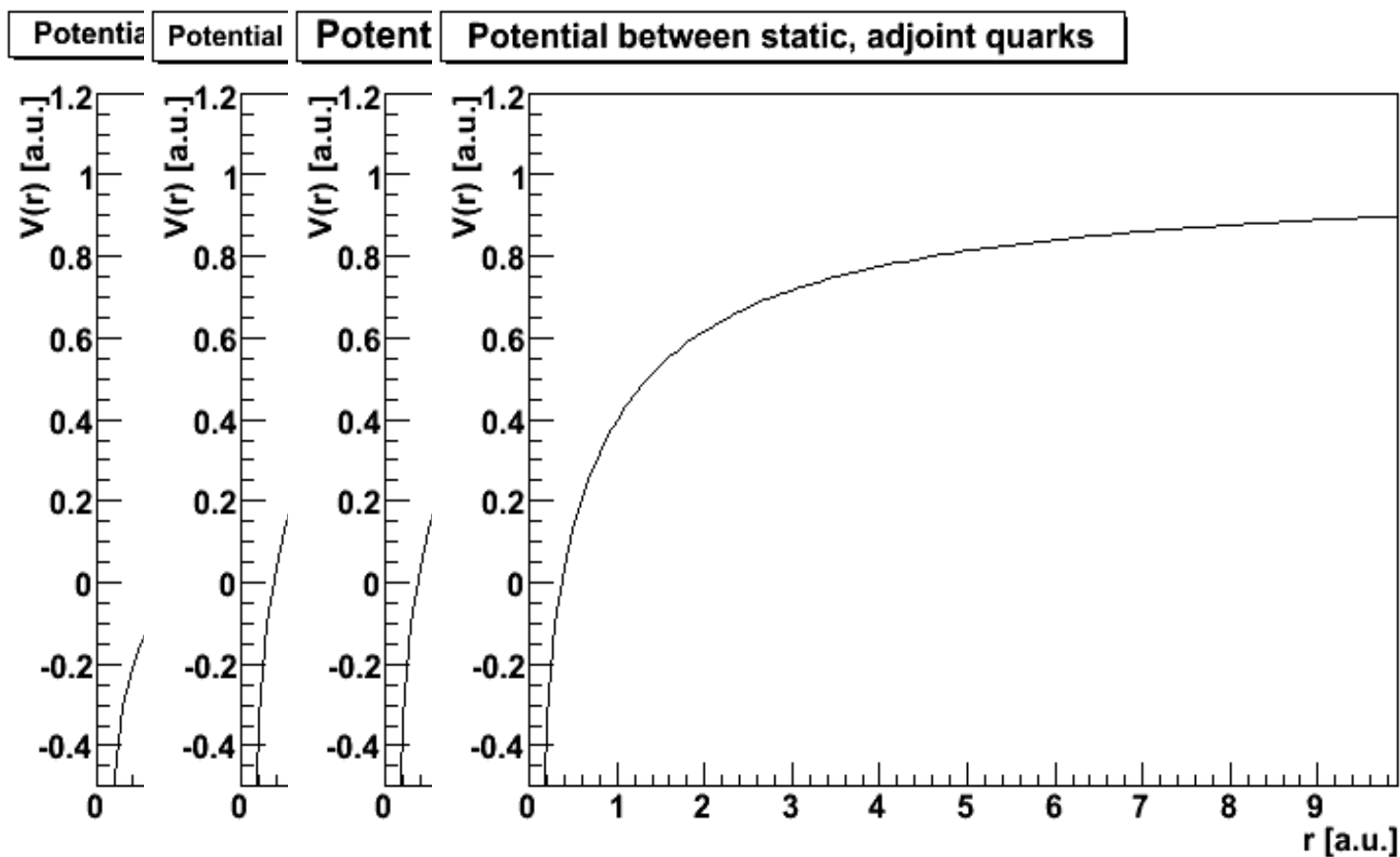
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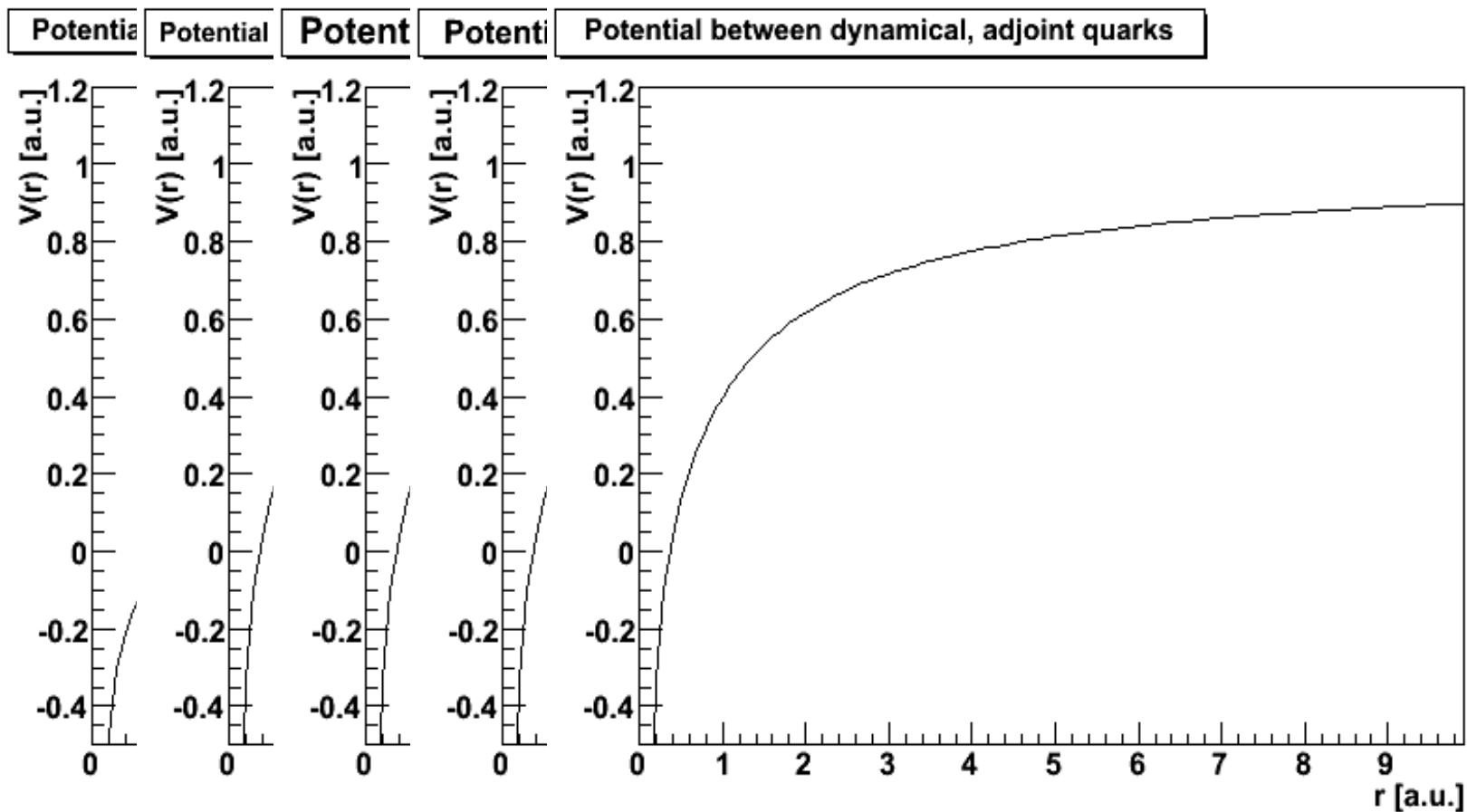
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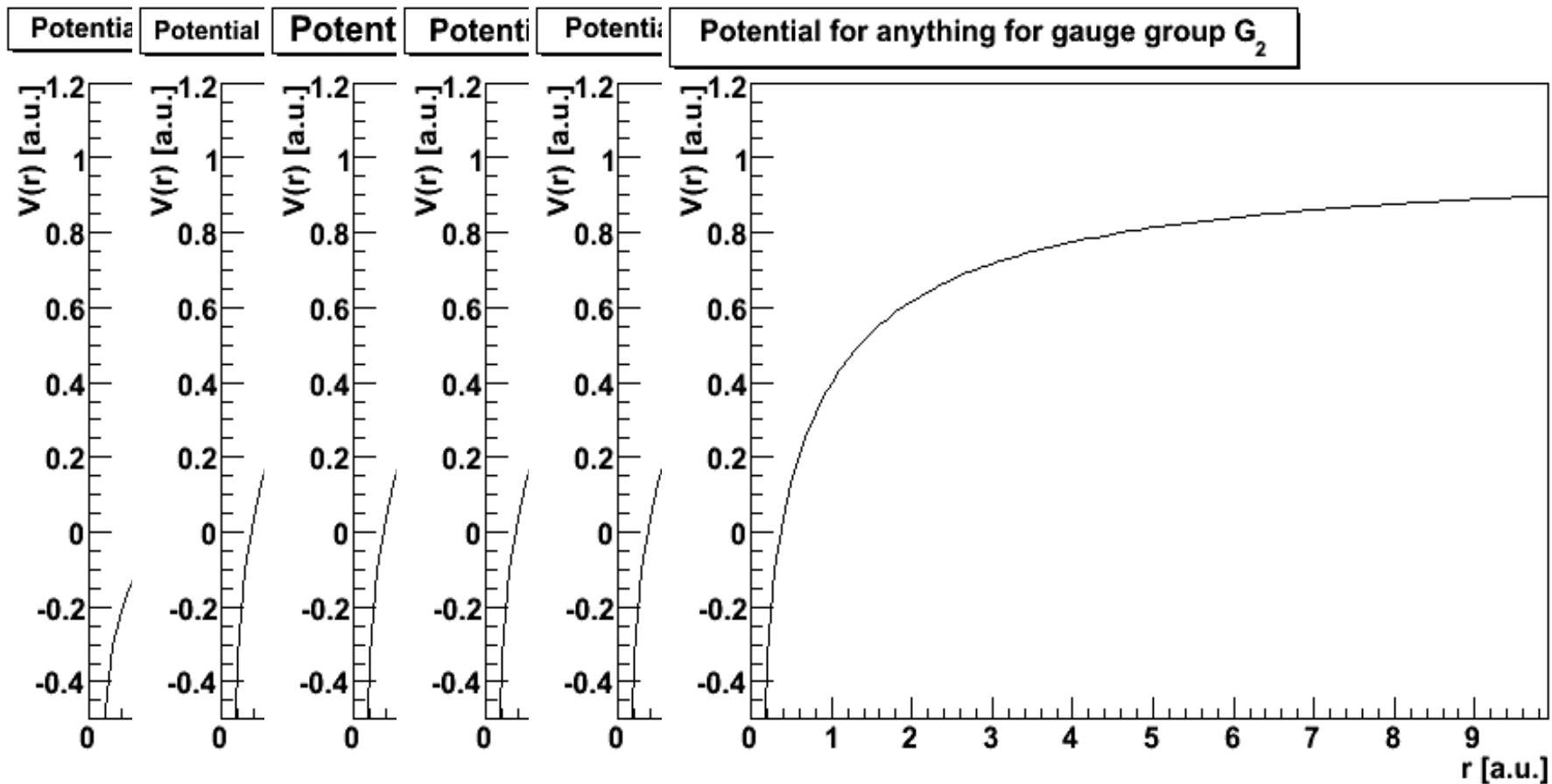
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When is string-breaking possible?

String-breaking can be read of the 2-particle 'potential'



- String-breaking by bound-state formation
- No confinement according to the Wilson criterion

Looking for the string

- **String-breaking is a very common phenomena**
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 - **Irrespective of Lorentz structure**
- **Remnants of the strings are still visible**
 - **E. g. Regge trajectories**
- **Simplest setups for studying string formation string breaking: Scalars**
 - **No complications due to chiral symmetry**
 - **Simple tensor structures**

Questions about the string

- **Is there are difference between string-breaking for **static** and **dynamical** particles?**
 - **Look at static fundamental vs. static adjoint vs. dynamical fundamental scalars**

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- **Is there are difference between string-breaking for **static** and **dynamical** particles?**
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- **Are there **local operators** knowing about the string?**
 - **2-particle 'potential' defined via the Wilson loop: highly non-local**

Local operators and the string

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- **Can this be accessed?**
 - **Yes...but not well-defined without gauge-fixing**

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Does it make sense then to ask?

- **Gauge-fixing in itself is just a tool to make calculations convenient**
- **Results are just in a particular coordinate system, but fully valid**
 - **But it is in principle hard to disentangle physics and gauge**
- **Why does it then still make sense to ask about the string on the level of the elementary particles?**

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 - **What is the scattering cross-section for $\pi\pi \rightarrow q\bar{q}$?**
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- **Two questions with a string in it:**
 - **What is the scattering cross-section for $\pi\pi \rightarrow q\bar{q}$?**
 - **Experimentally essentially zero, and the experimental definition of confinement**
 - **What about Higgs production in pp in the presence of strong initial or final state interactions?**
 - **Factorization fails**
 - **Even if not: Huge systematic uncertainties even at energies of 1 TeV**

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- **Need to develop further...and combine**

One (out of many) avenues

- **Functional methods extend perturbation theory non-perturbatively**
 - **Correlation functions can be combined as in perturbation theory to get gauge-invariant, observable results**
 - **Possible also in Minkowski**
 - **But suffer severely from truncation artifacts**

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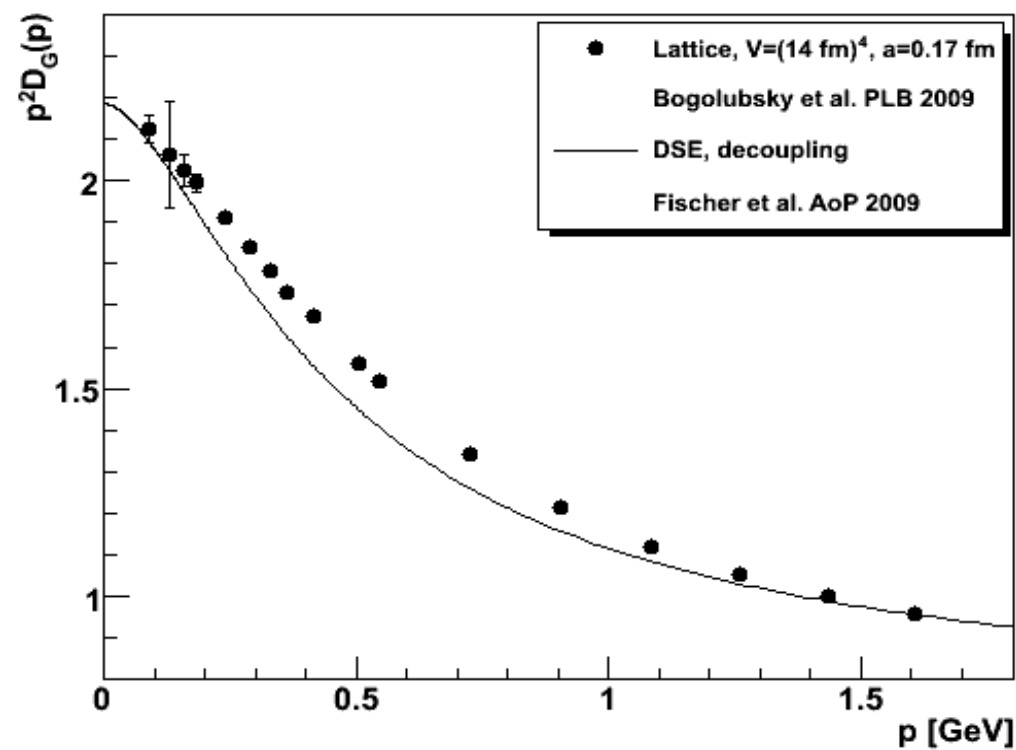
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- **What is the minimum to see string-effects?**

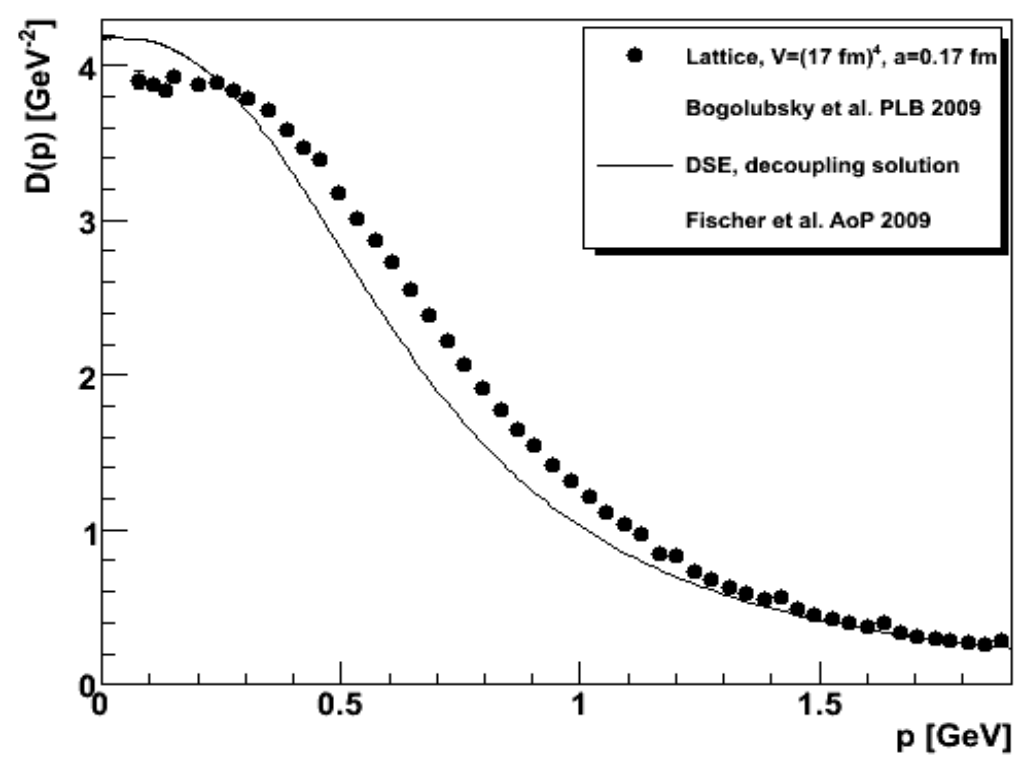
Step 1: Pure glue

$p^2 D_G(p)$ for SU(3)

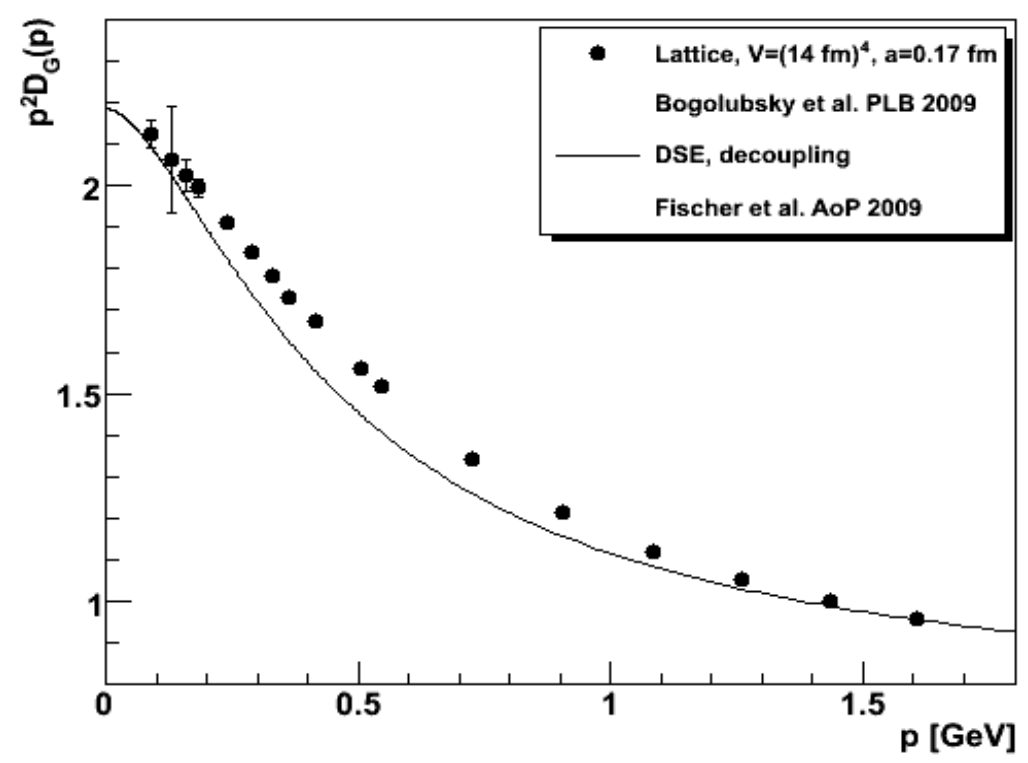


Step 1: Pure glue

Gluon propagator for SU(3)

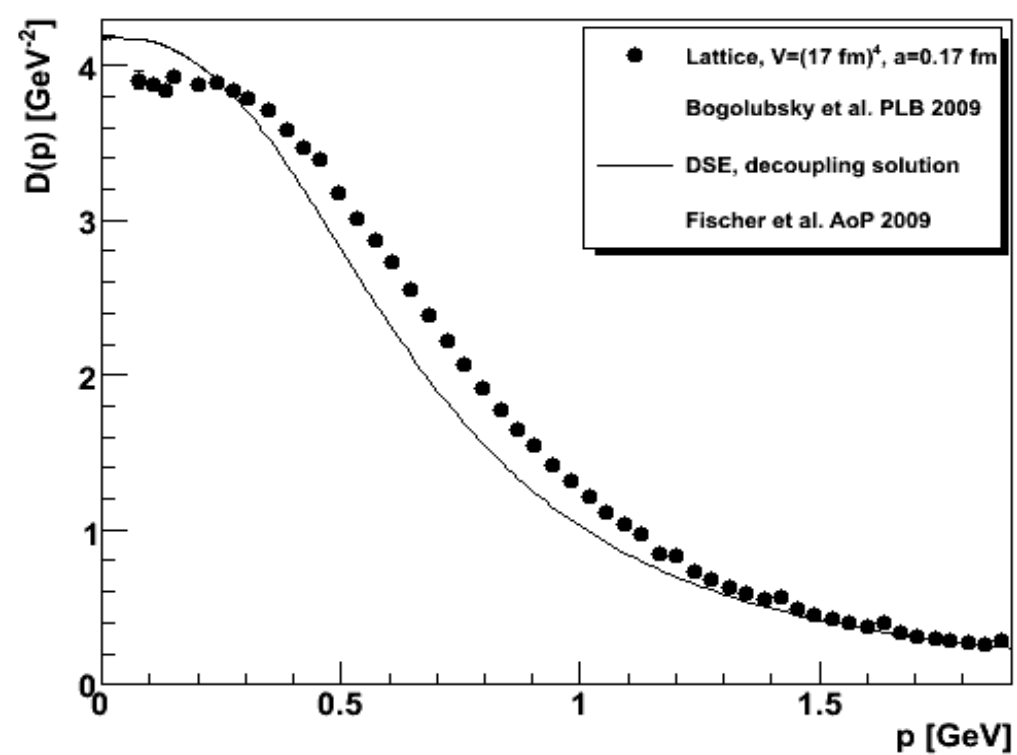


$p^2 D_G(p)$ (Ghost propagator) for SU(3)

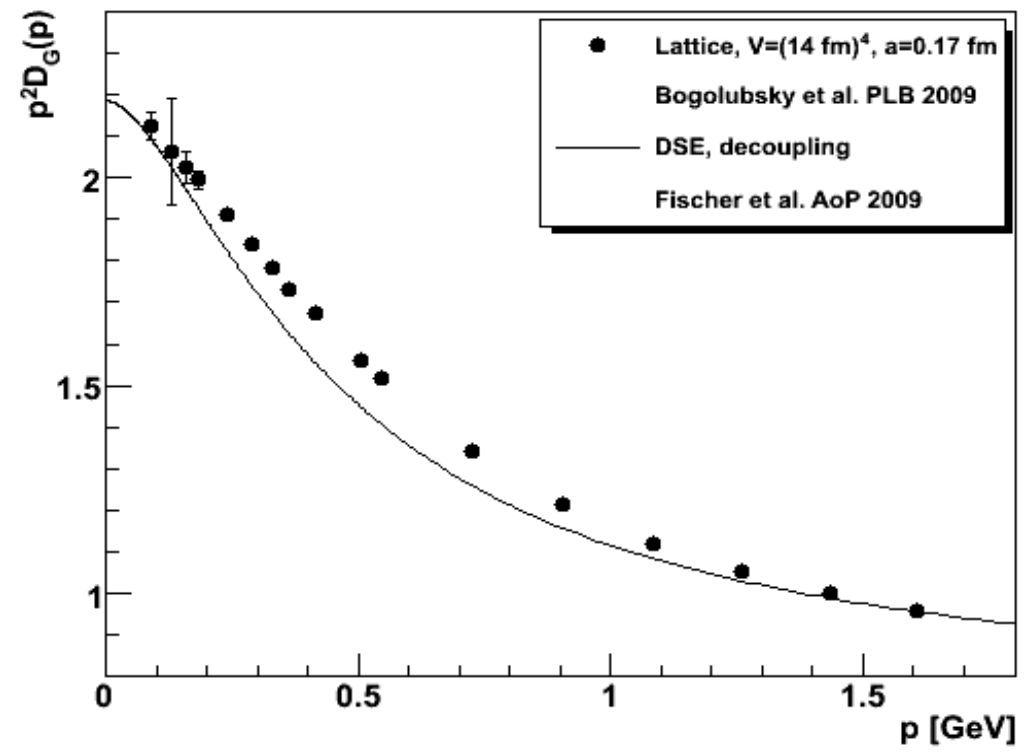


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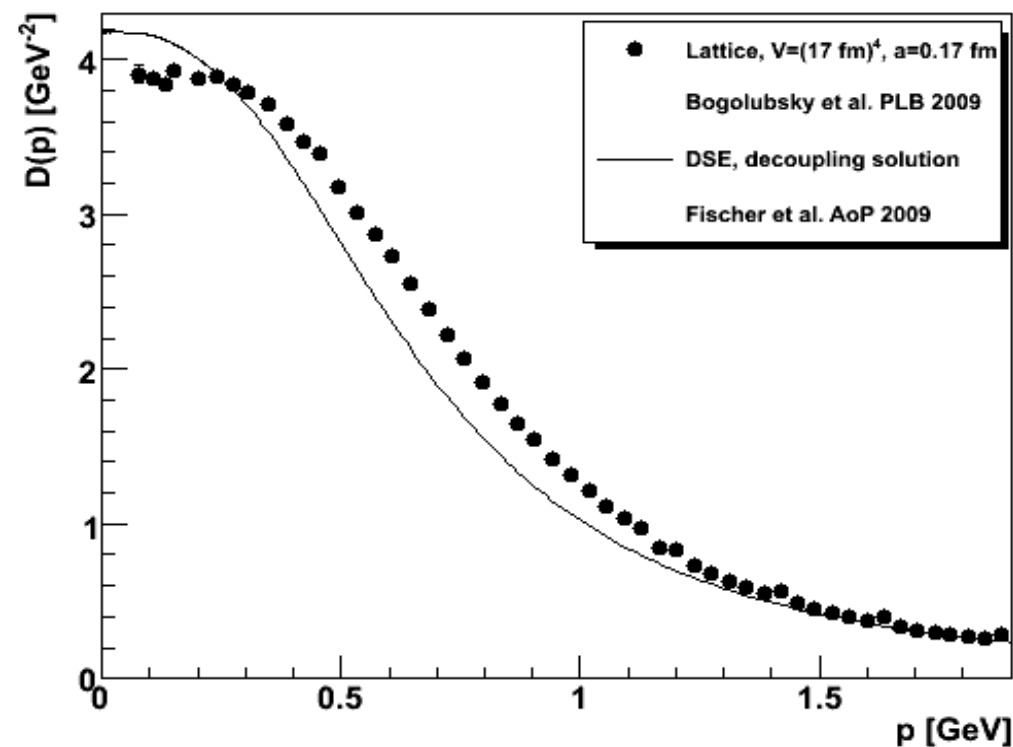


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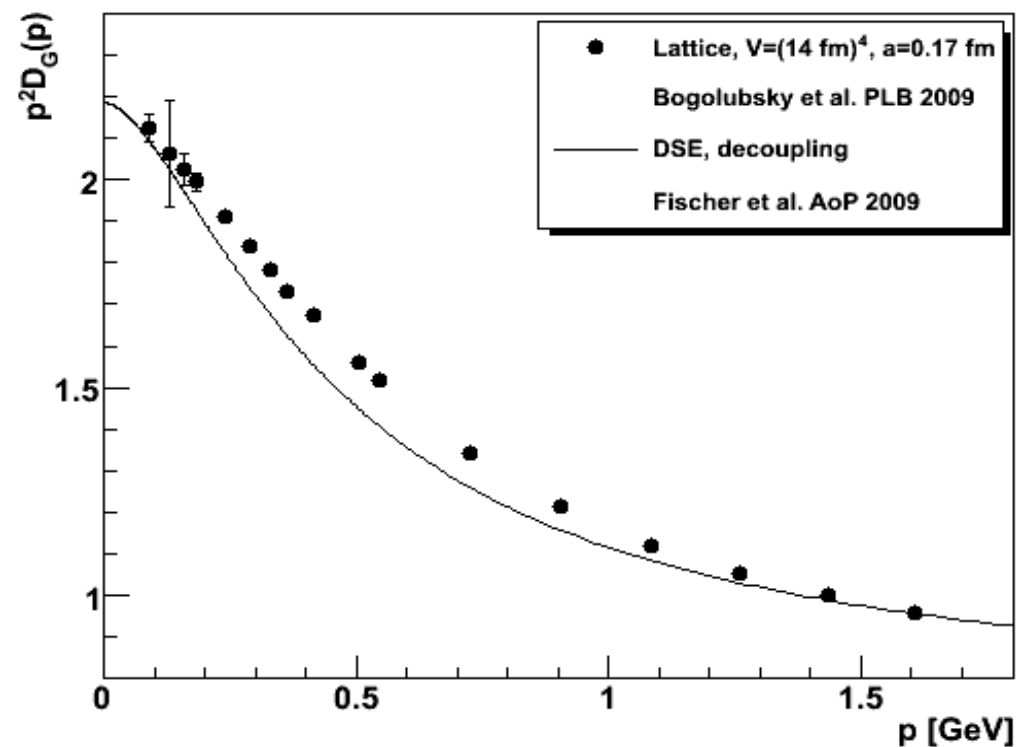


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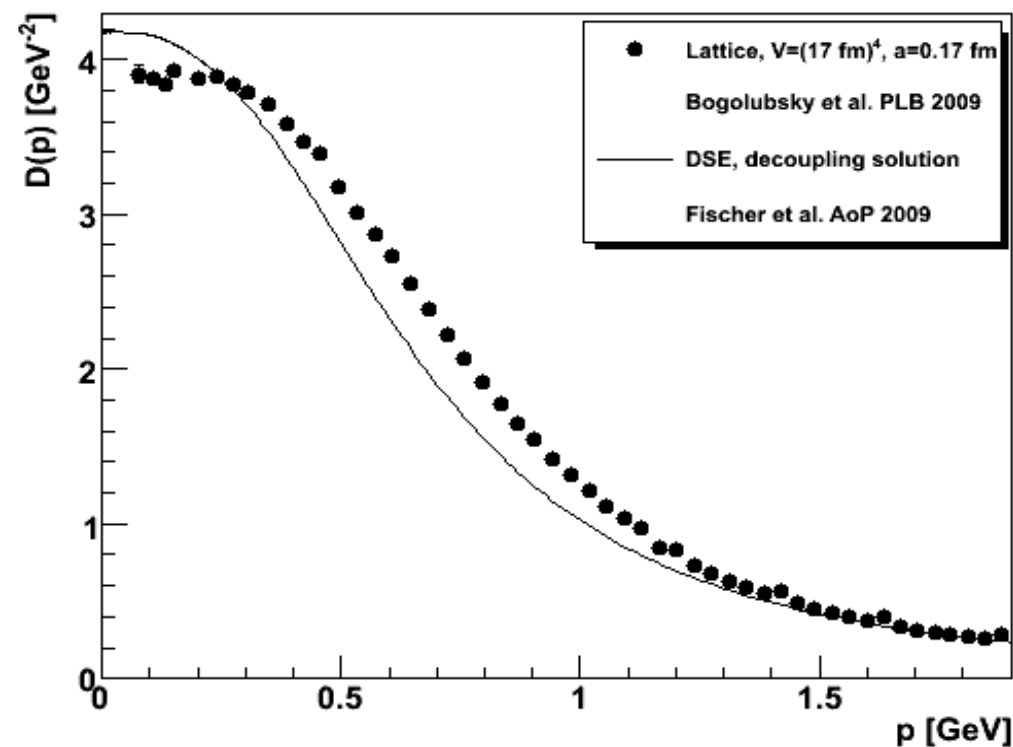
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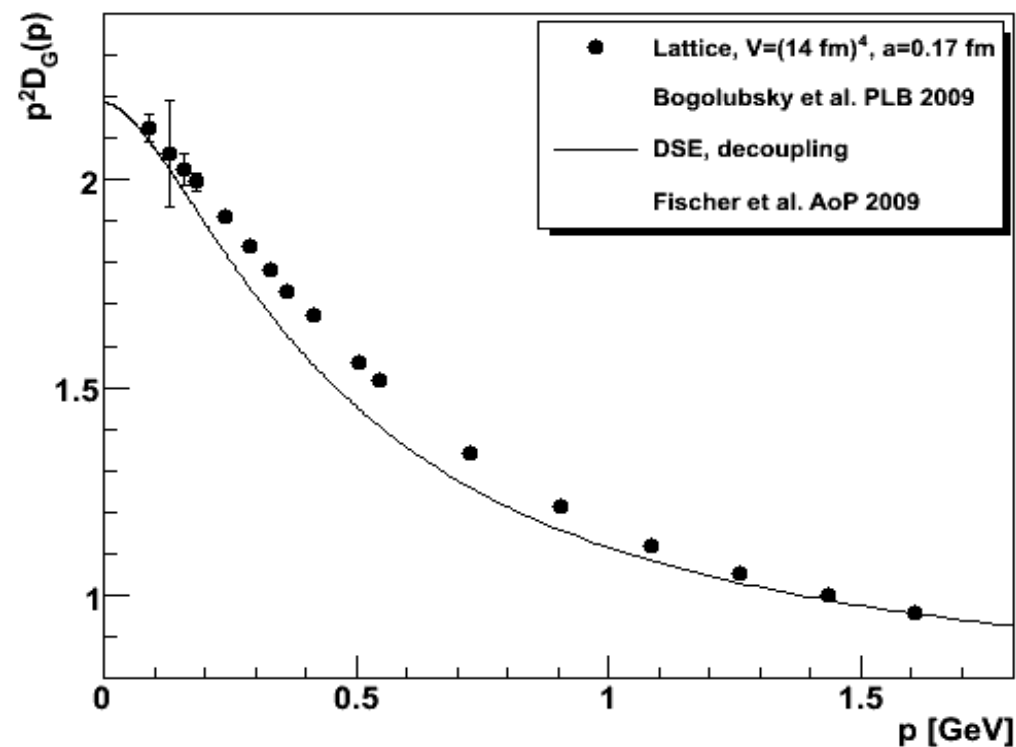
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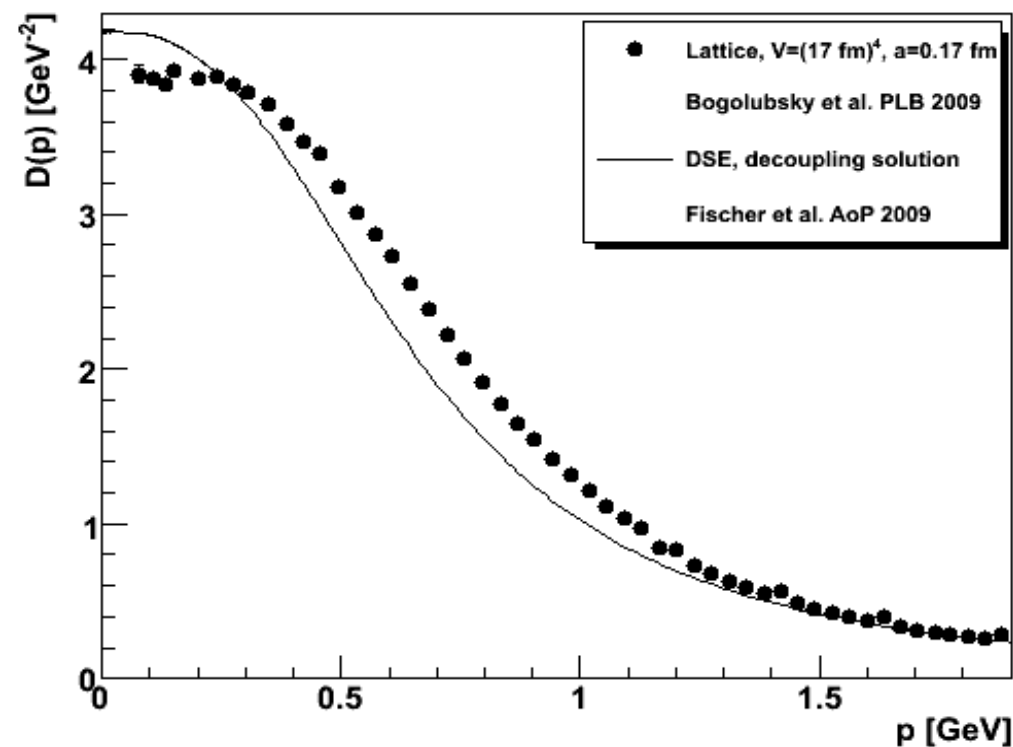
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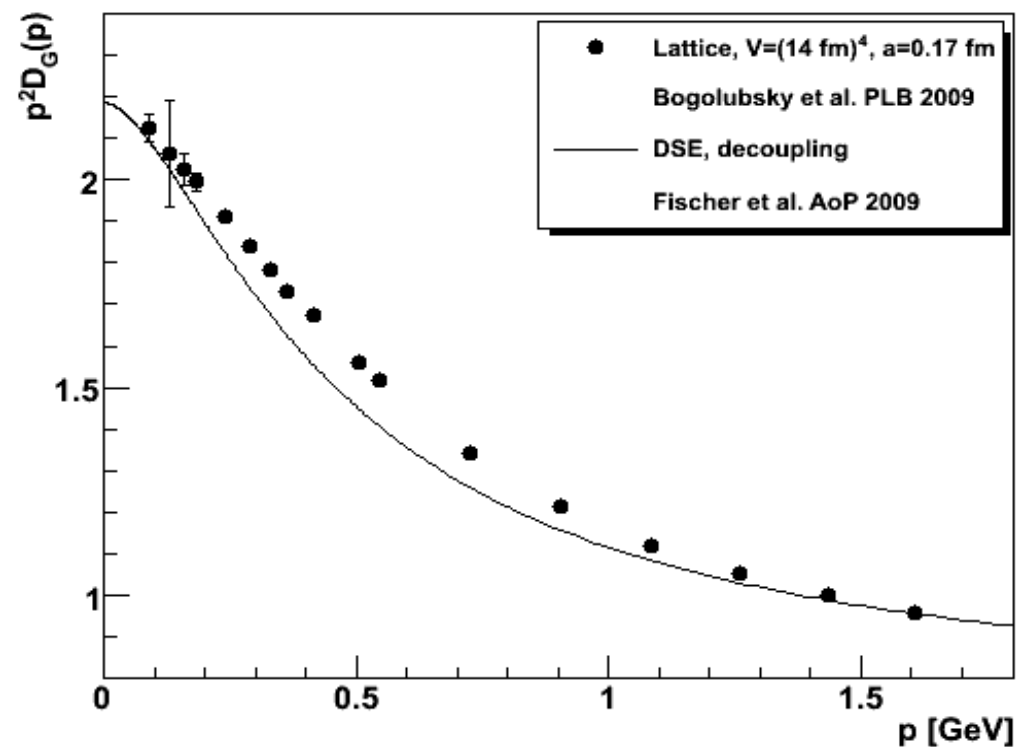
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- **First observables: Phase transition properties** [Fischer, Maas, Müller, EPJC10], **meson properties** [Fischer, Watson PRD05]

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- **First observables: Phase transition properties** [Fischer, Maas, Müller, EPJC10], **meson properties** [Fischer, Watson PRD05]
- **Explains why models work well** [Blank, Krassnigg, Maas 10]

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 - **Here: Simpler case of scalars**
 - **Investigate the interactions on the lattice**
 - **Where is the string? Can it be seen?**
 - **Functional methods indicate that it may be seen in the 2-scalar-gluon vertex**

[Fister, Alkofer, Schwenzer PLB10]

Quenched scalars

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 - **Shows the 2-scalar-gluon vertex differences for both cases?**

Quenched scalars

- **Minimal Landau gauge results**
- **Tree-level mass dependence**

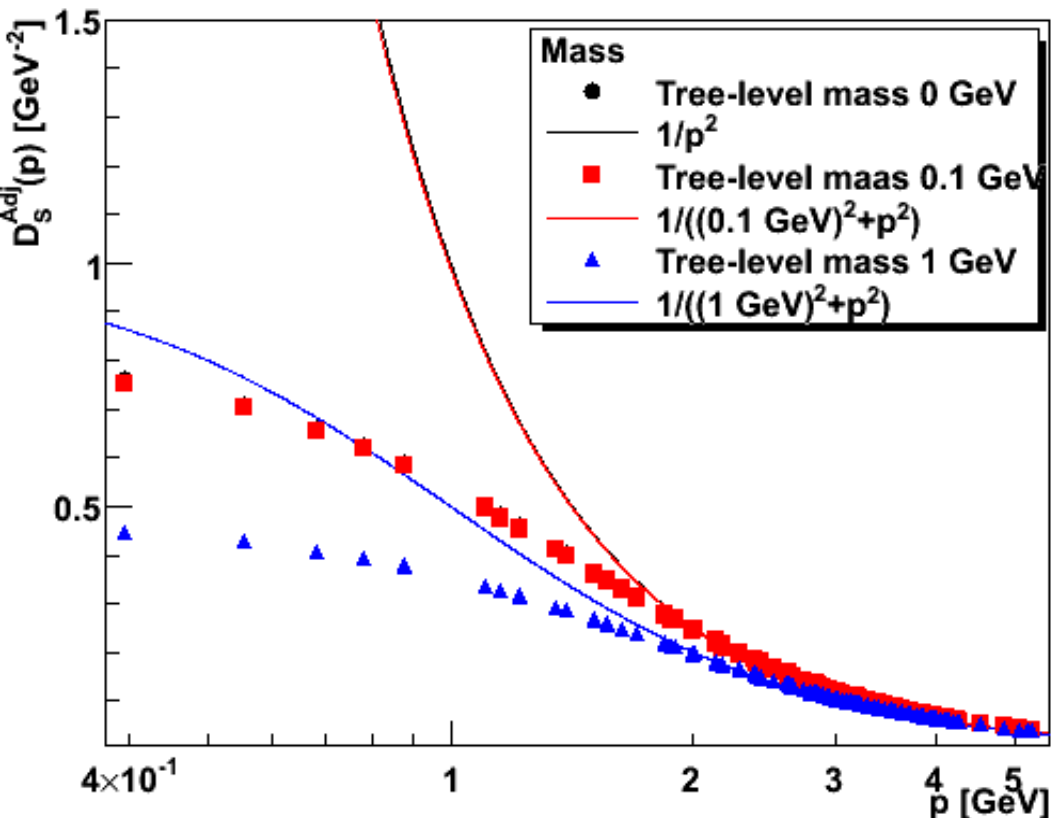
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 - **Single scalar function**
 - **No distinction between a mass function and a wave-function as for fermions**
 - **Two independent renormalizations necessary**

Propagators: Adjoint vs. Fundamental

Adjoint scalar propagator

[Maas unpublished]



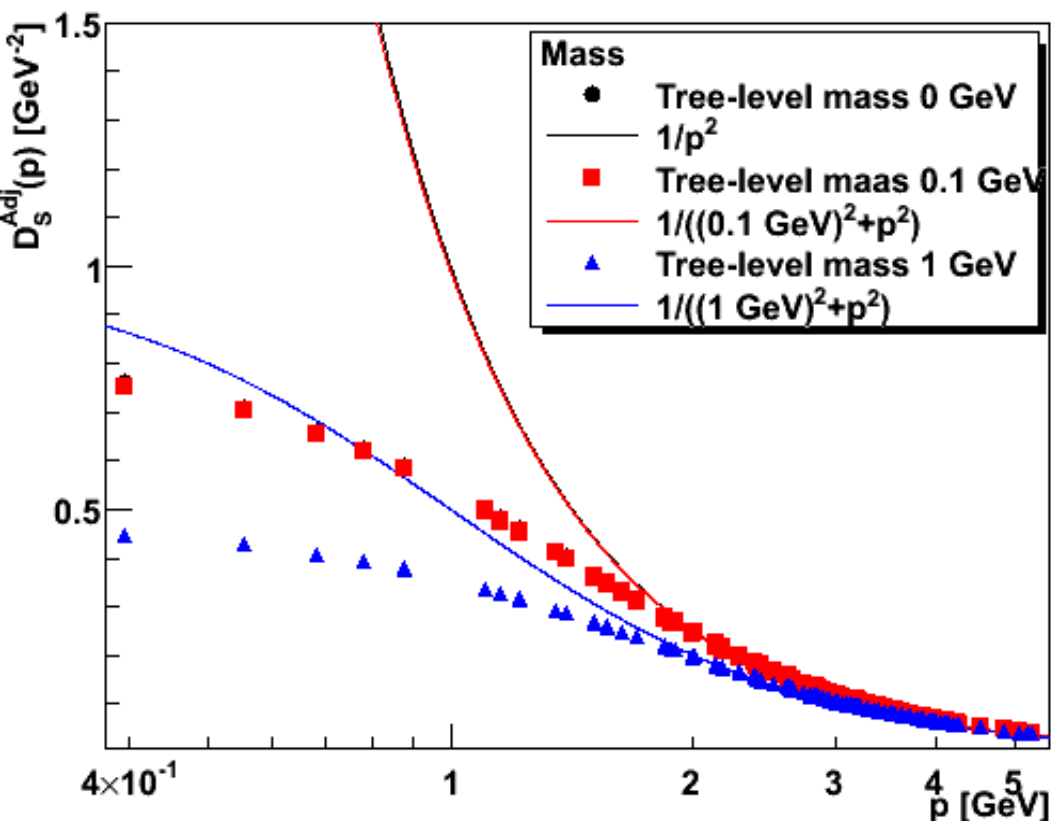
3d, $L=3.1 \text{ fm}$, $a=0.13 \text{ fm}$

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Propagators: Adjoint vs. Fundamental

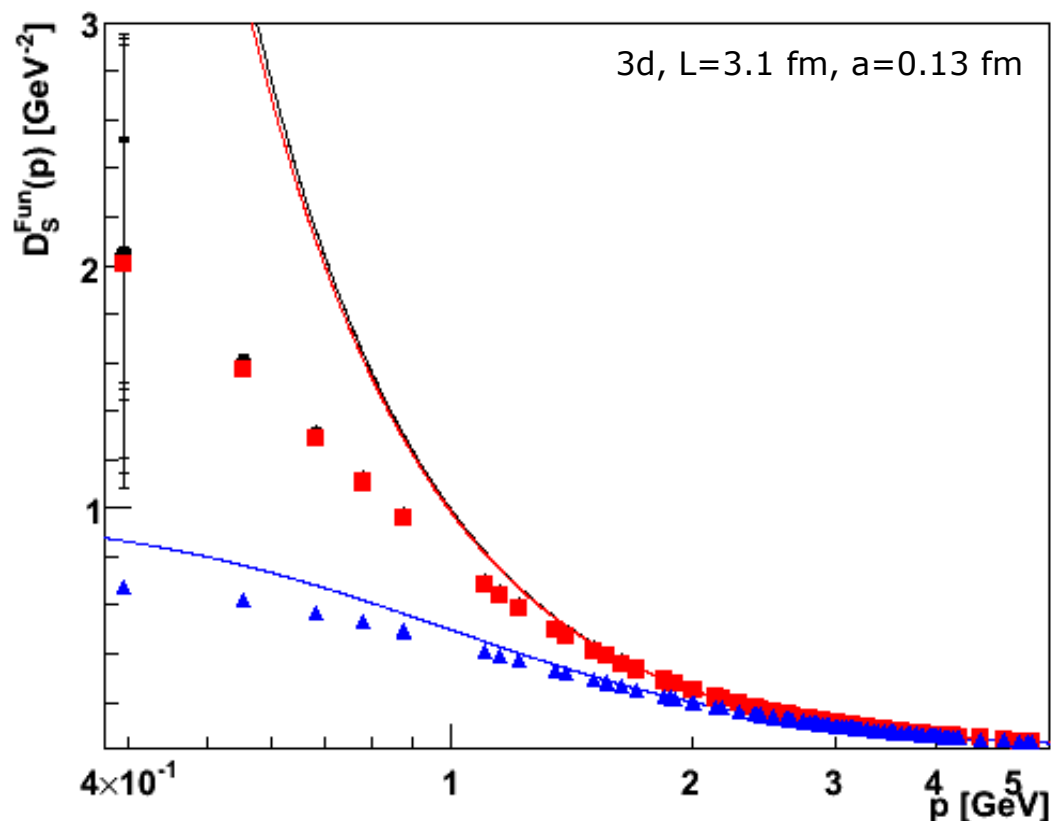
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Fundamental scalar propagator

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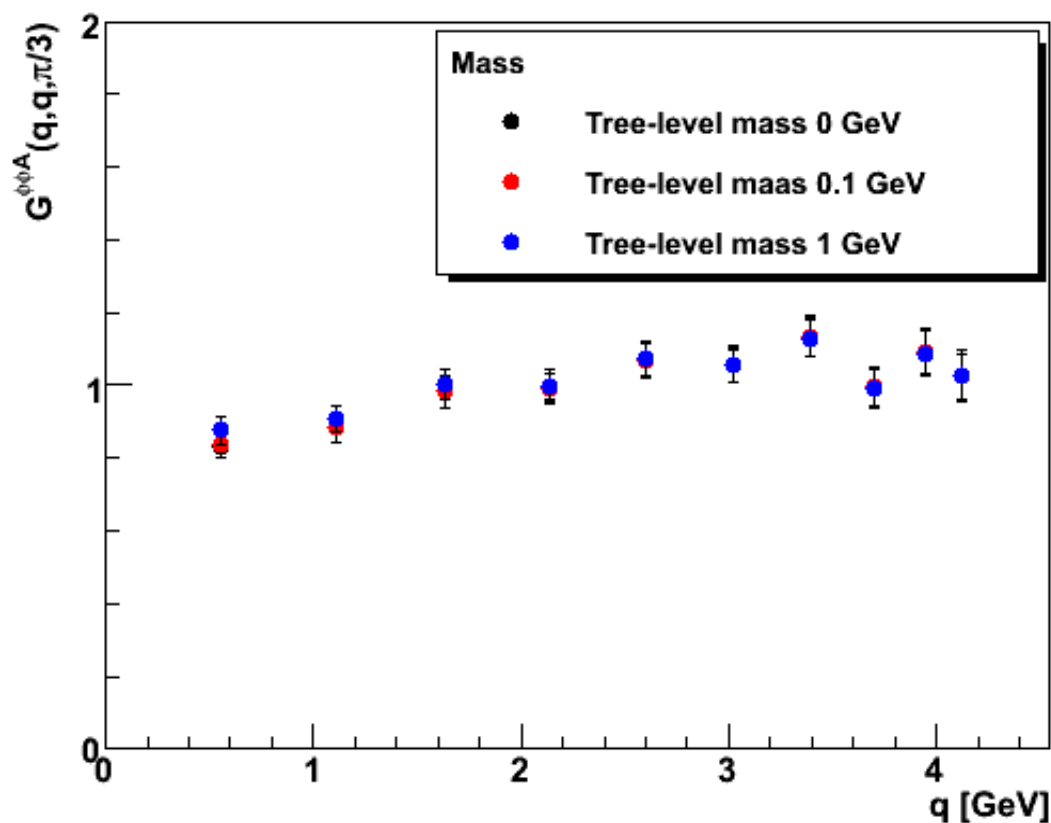
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- **Fundamental similar, but possibly different IR slope: Convex vs. concave?**

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 - **Single scalar function**
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- **2-scalar-gluon vertex**
 - **Only one relevant tensor structure**
 - **Only one renormalization necessary**
 - **Symmetric and one momentum vanishing**

Gluon-2-scalar vertex

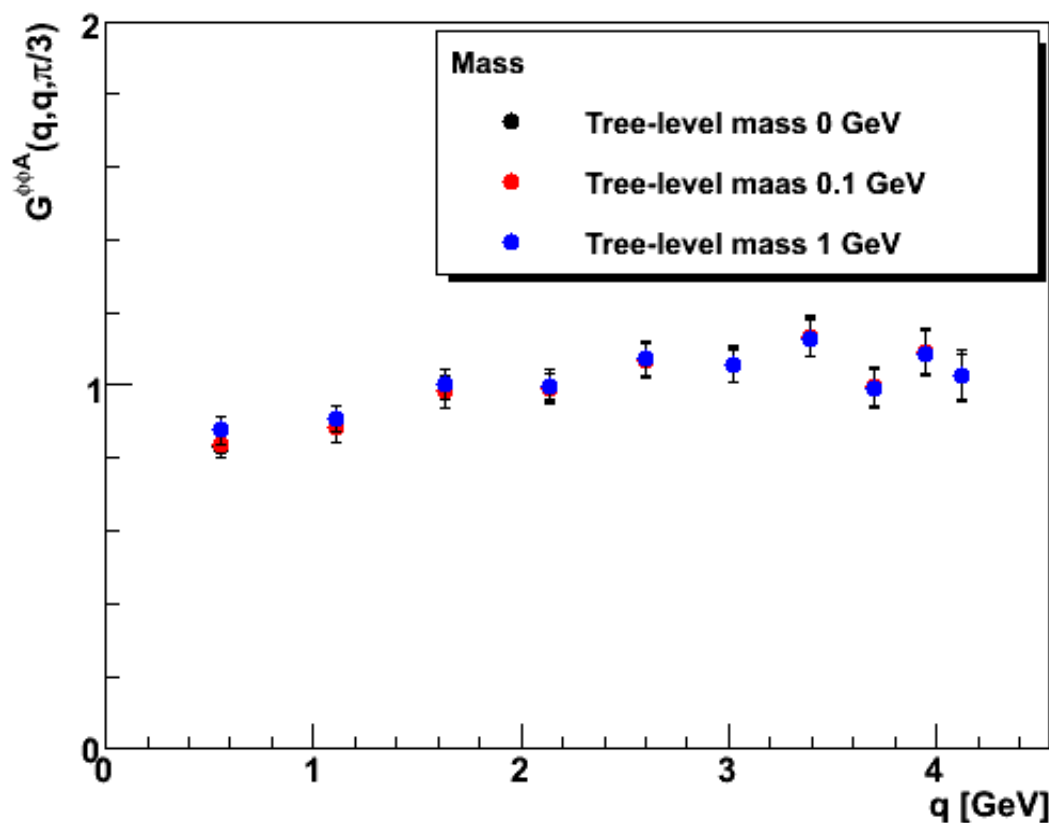
Gluon-2-adjoint-scalar vertex, symmetric point



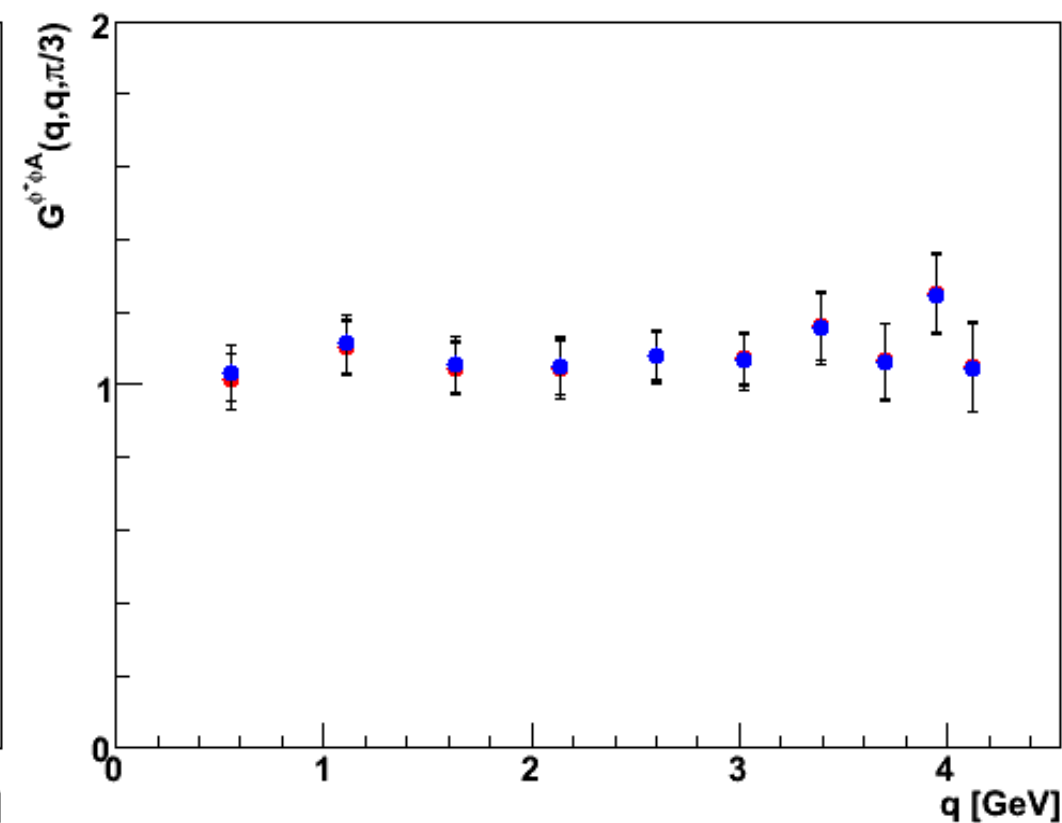
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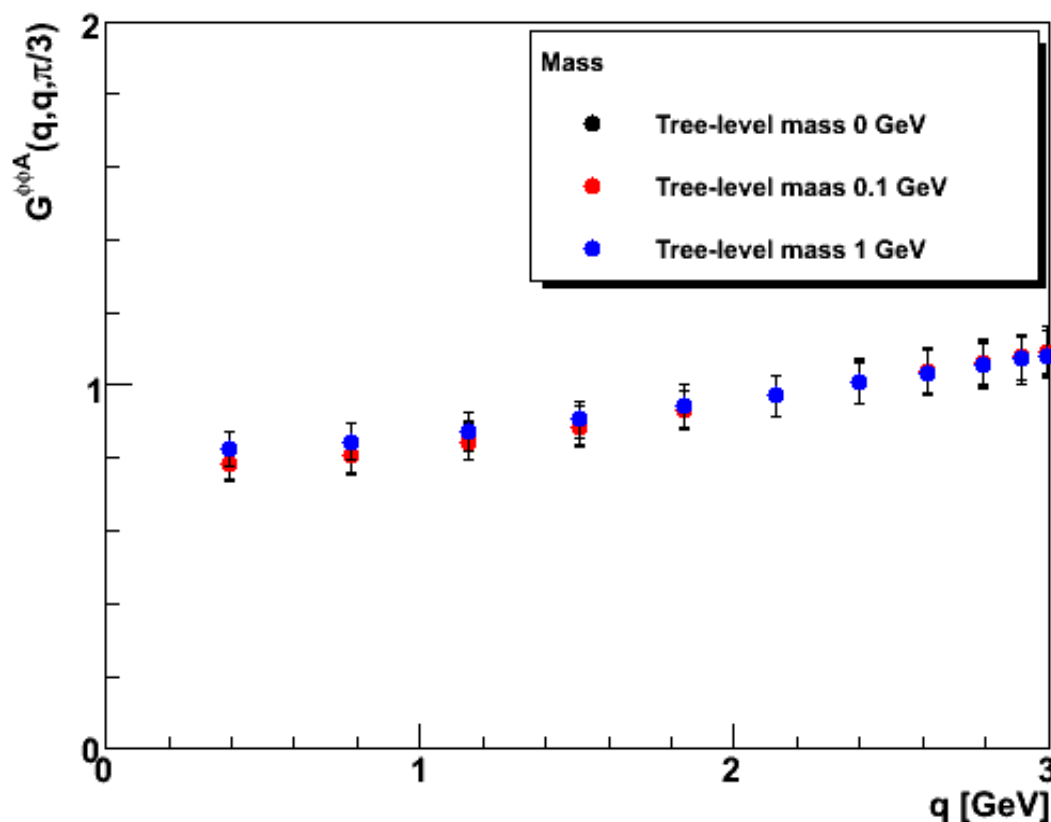
Gluon-2-fundamental-scalar vertex, symmetric point



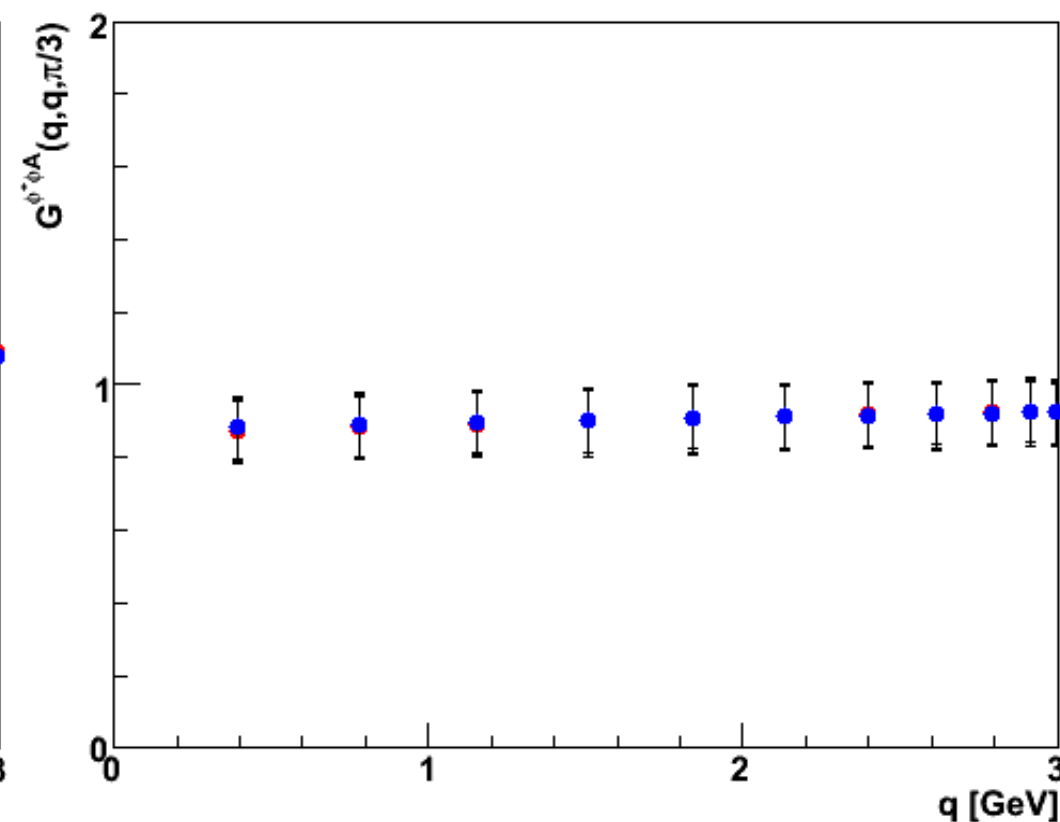
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Gluon-2-scalar vertex

Gluon-2-adjoint-scalar vertex, soft point



Gluon-2-fundamental-scalar vertex, soft point



- **Almost no difference to tree-level (=1)**
 - Same for vanishing gluon/orthogonal scalar momenta
- **No divergences**

Dynamical fundamental scalars

- **Scalar matter**

$$L = -\frac{1}{4} F_{\mu\nu} F^{\mu\nu} - \phi^\dagger \left(\frac{1}{2} D_\mu D^\mu + m^2 \right) \phi + \lambda (\phi^\dagger \phi)^2 - \bar{c} \partial^\mu D_\mu c$$

$$D_\mu = \partial_\mu - ie A_\mu^a \tau_R^a$$

- **R denotes the representation**

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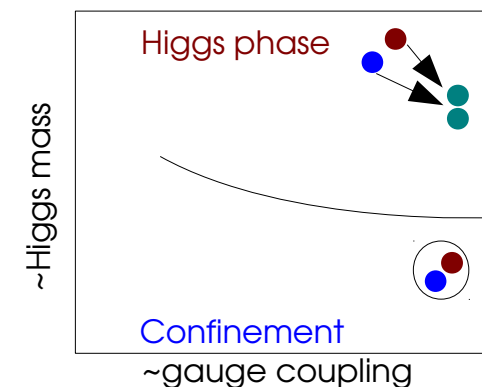
- **R denotes the representation**
- **Self-interaction not present for quarks**
 - **Dependency not yet explored**
 - **Triviality? Interactions are gauge-dependent!**

Dynamical fundamental scalars

- **Interesting questions:**
 - **Changes compared to the quenched case: String breaking?**

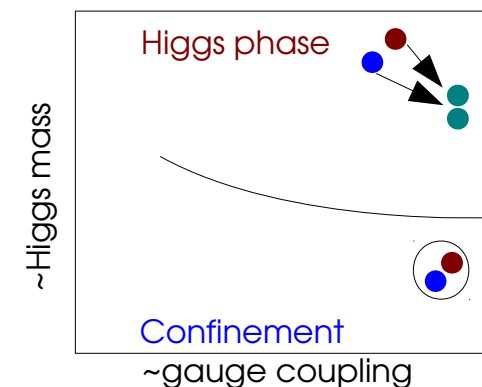
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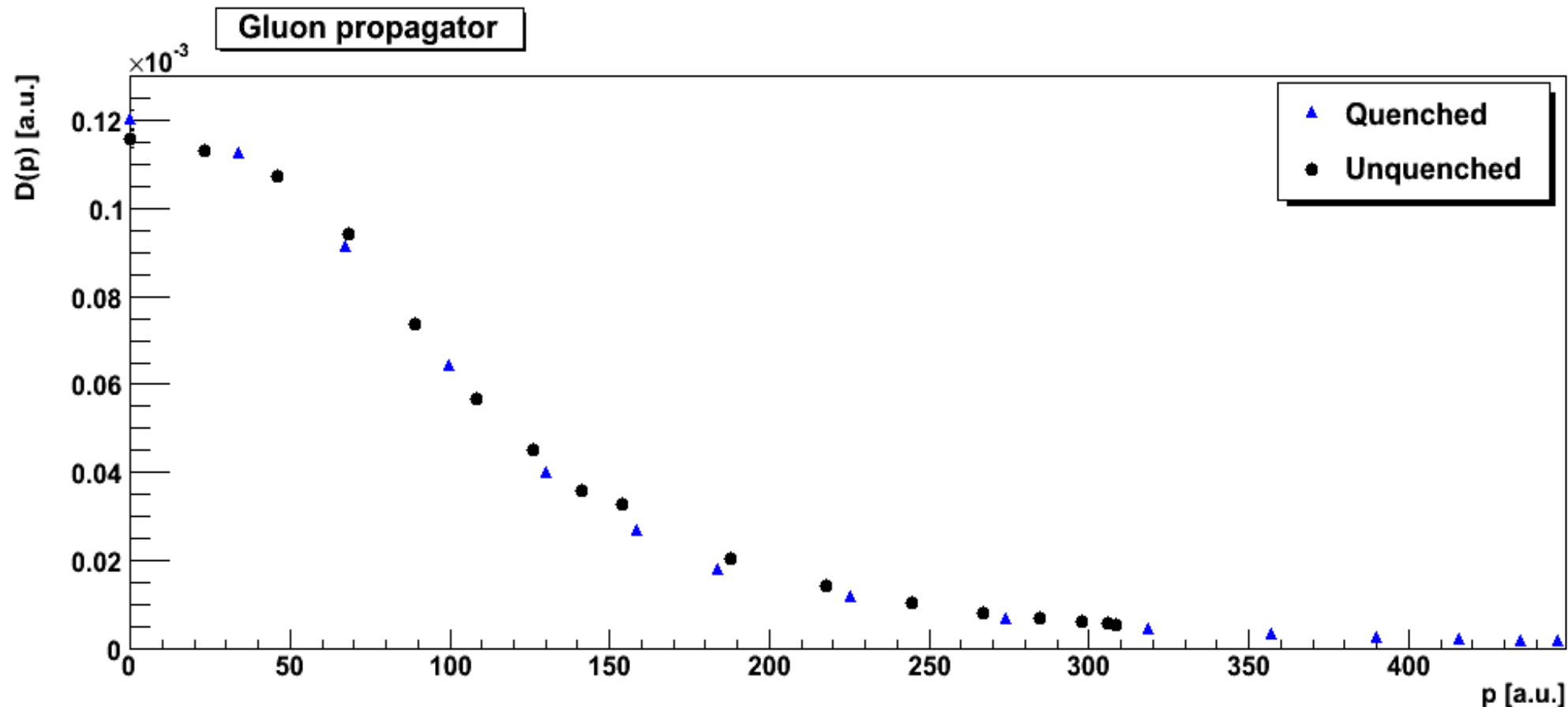
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- **Propagators in minimal Landau-'t Hooft gauge**



Gauge bosons

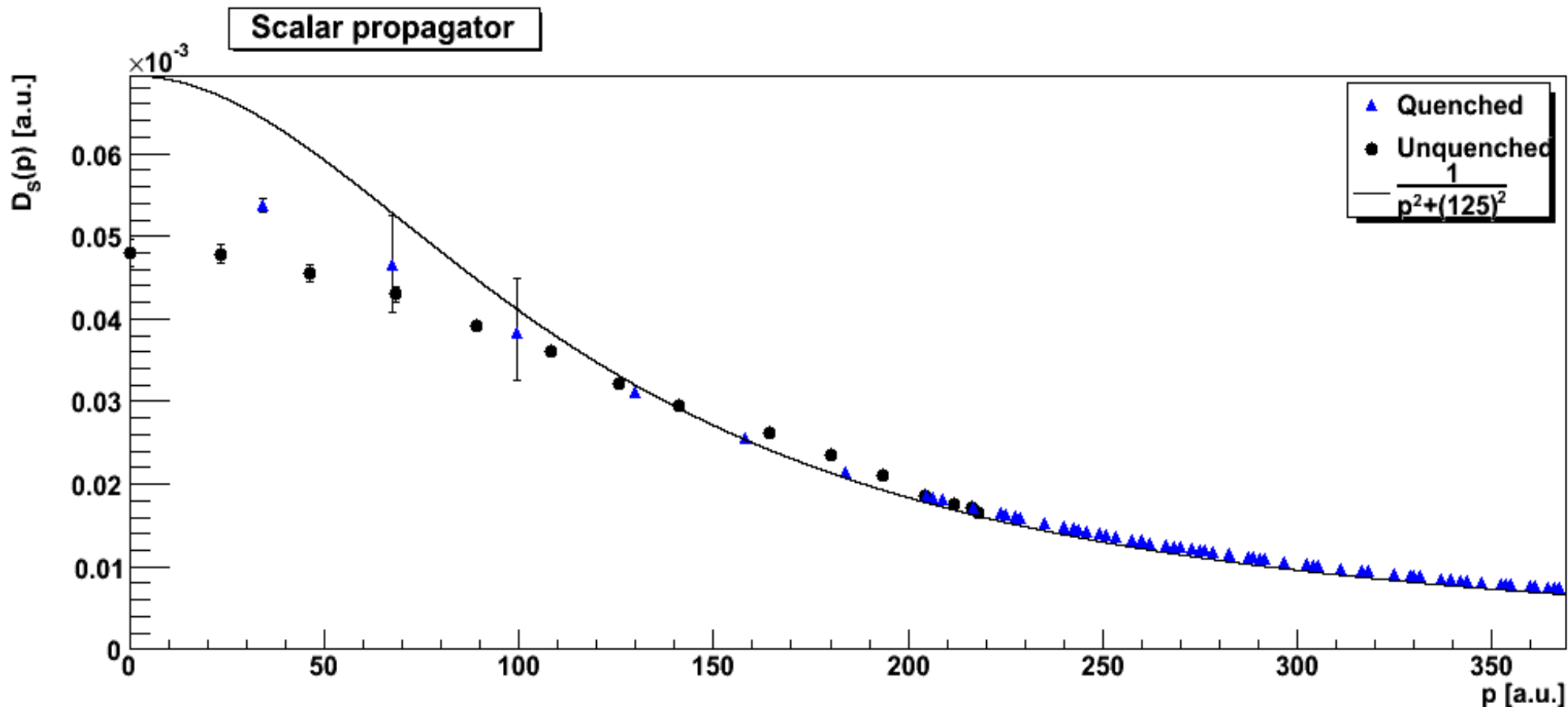
4d, unquenched: 24^4 beta=2.0, kappa=0.25, lambda=0.5
 4d, quenched: 24^4 beta=2.2 [Maas 2010]



- **Little qualitative difference – impact of matter small**
- **As in QCD** [Fischer, Alkofer PRD03, Kamleh et al. PRD07]

Scalar

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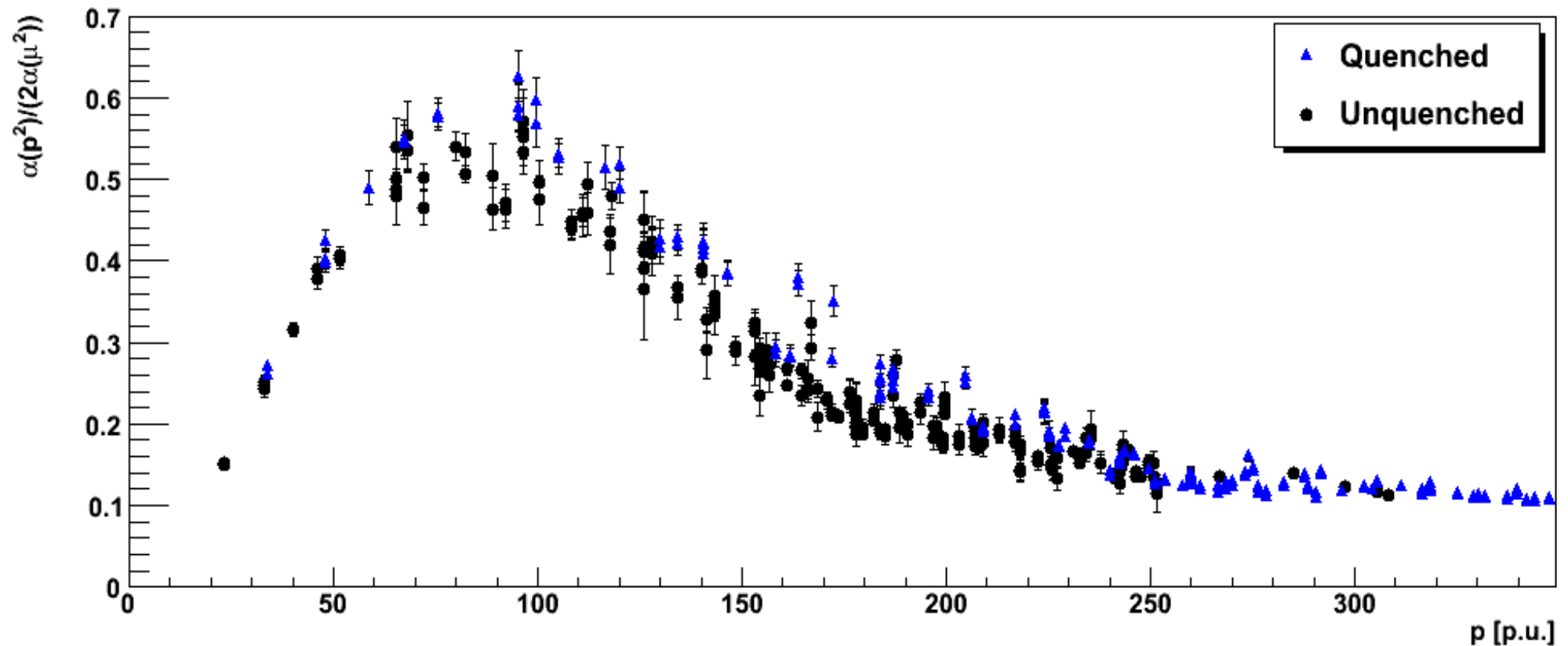


- Close to tree-level with renormalized mass
- Little difference between quenched and unquenched

Running coupling

4d, unquenched: 24^4 beta=2.0, kappa=0.25, lambda=0.5
 4d, quenched: 24^4 beta=2.2 [Maas 2010]

Running coupling



- No qualitative difference seen
- Screening leads to suppression of interactions at small momenta

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- **2-point and 3-point functions in scalar-gauge theories show no obvious signal of it**
 - **Lattice artifacts?**
 - **4-point functions necessary?**
 - **Because of Regge trajectories sufficient!**