

Scalar particles

Axel Maas

7th of May 2010
Delta 2010
Heidelberg
Germany

FWF

**UNI
GRAZ**

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-

Properties in Landau gauge(s)

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Masses, widths, couplings, ...
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 - Determine properties of the elementary particles: Masses, widths, couplings, ...
 - In a gauge theory in general **gauge-dependent**
 - Stick together correlation functions to determine gauge-invariant observables: Cross-sections, thermodynamic properties, ...
 - As in perturbation theory
 - Requires **gauge-dependent** correlation functions in intermediate steps
 - **Gauge-fixing is an intermediate step**

Overview

- Odds and ends: Gauge-fixing beyond perturbation theory

Supported by **FWF**

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 - 'Confinement vs. Higgs'
 - Higgs and W bosons
- Summary

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Work in progress

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 - Method-independent

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 - Experience: In Landau gauge propagators

Basic building blocks

- **Gluon propagator** $D_{\mu\nu}^{ab}$ [Zwanziger, 1990s+2000s, many others]
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 - B-parameter $B = \lim_{p \rightarrow 0} p^2 D_G^{aa}(p) / \mu^2 D_G^{aa}(\mu)$
 - Generates a one-parameter family of correlation functions in the continuum [Fischer, Maas, Pawłowski 2008]

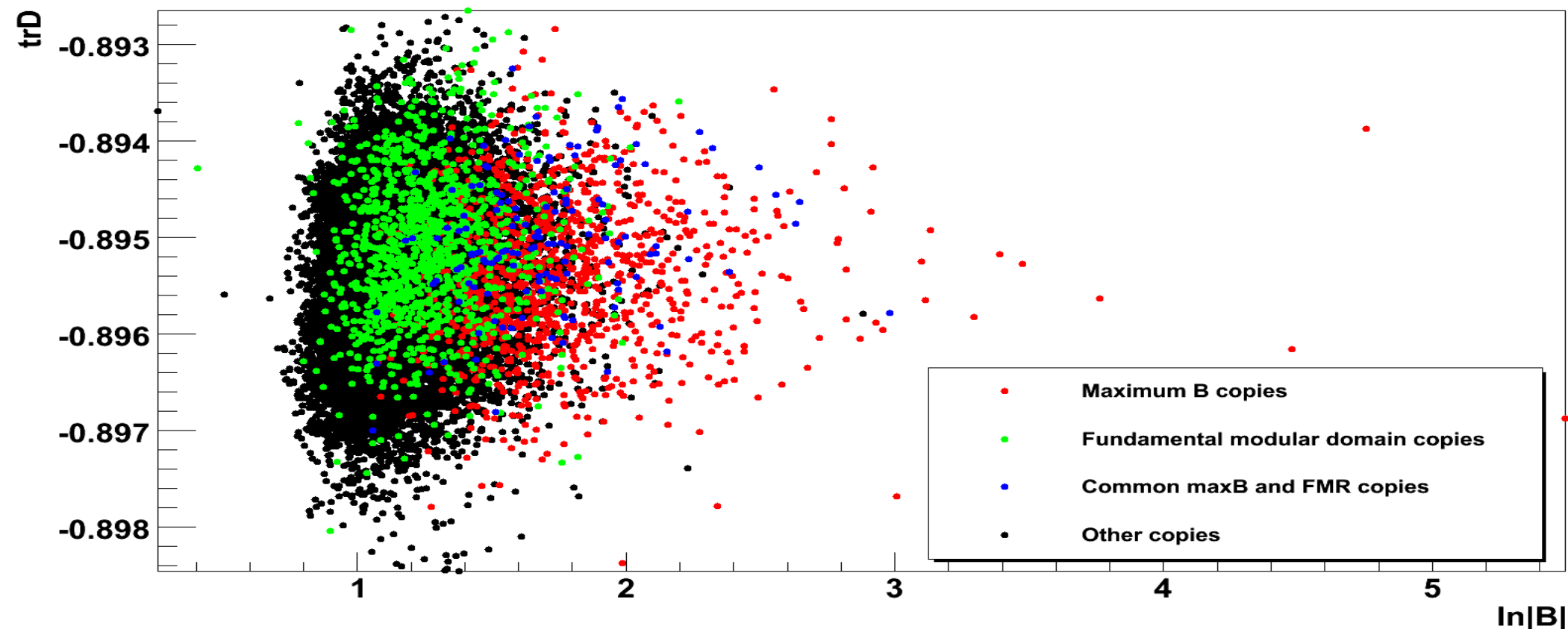
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 - Generates a one-parameter family of correlation functions in the continuum [Fischer, Maas, Pawłowski 2008]
 - Conjecture: Positive for the first Gribov region

Distribution in $\text{tr}D$ - B -space [Maas 2009, unpublished]

$$V=(5.7 \text{ fm})^3$$

3d, 26^3 , $\beta=3.47$, 39 copies per configuration



- Same B implies same or very similar $\text{tr}D$
- Almost uncorrelated otherwise

Constructing gauges - independent of a method

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 - **Select randomly among degenerate Gribov copies**
 - Resulting correlation functions will be averages over all other possible constraints

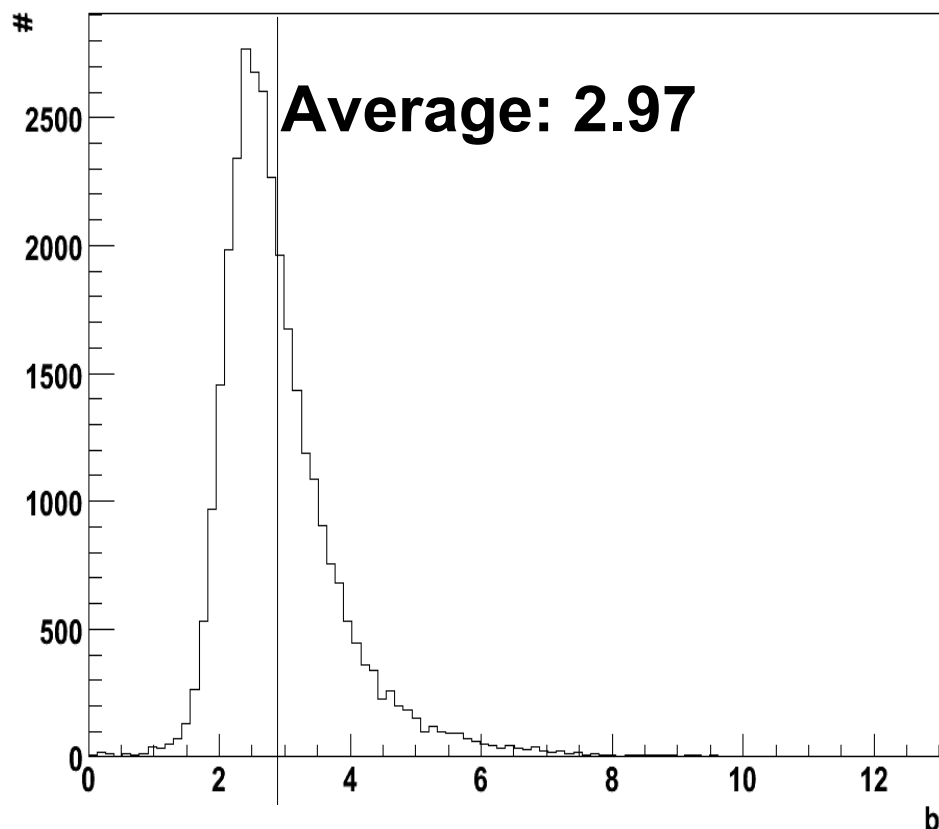
Possible gauges [Maas 2009, unpublished]

- Minimal Landau gauge:
No further constraint

Possible gauges

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$$b = G(0.280 \text{ GeV}) / G(\infty \text{ GeV}) \text{ for } V = (4.4 \text{ fm})^3$$



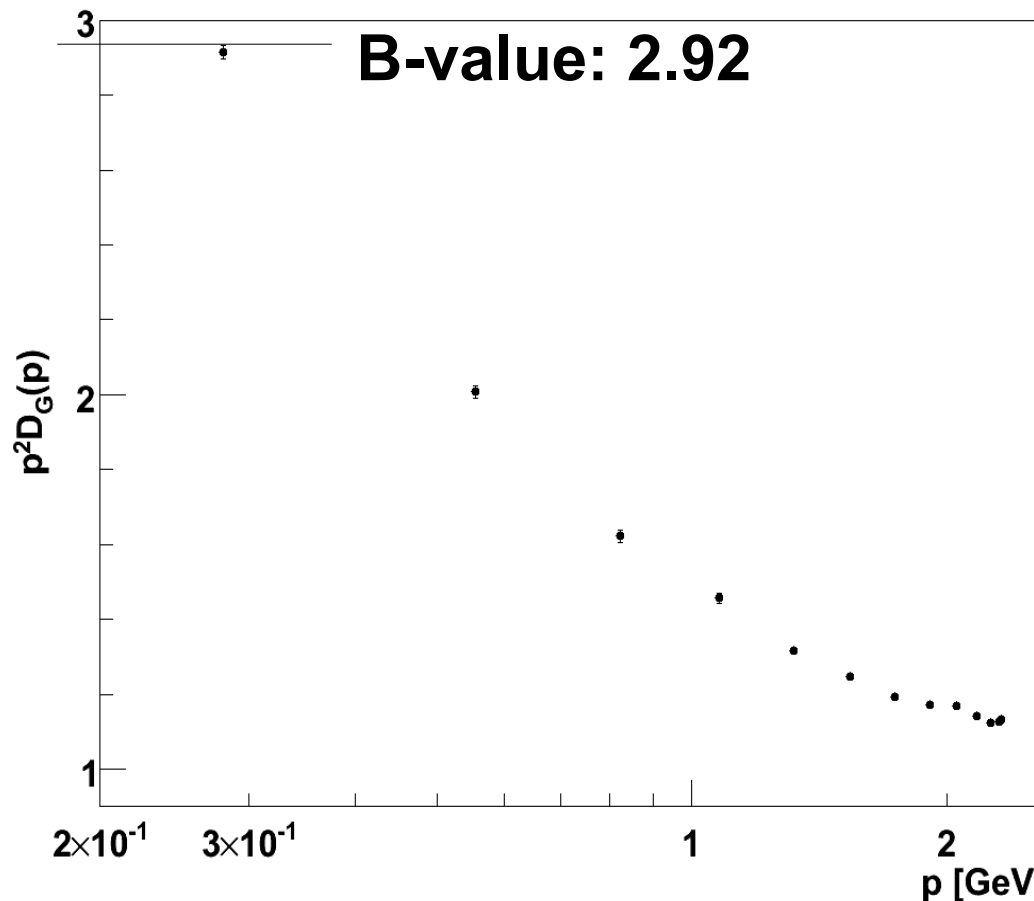
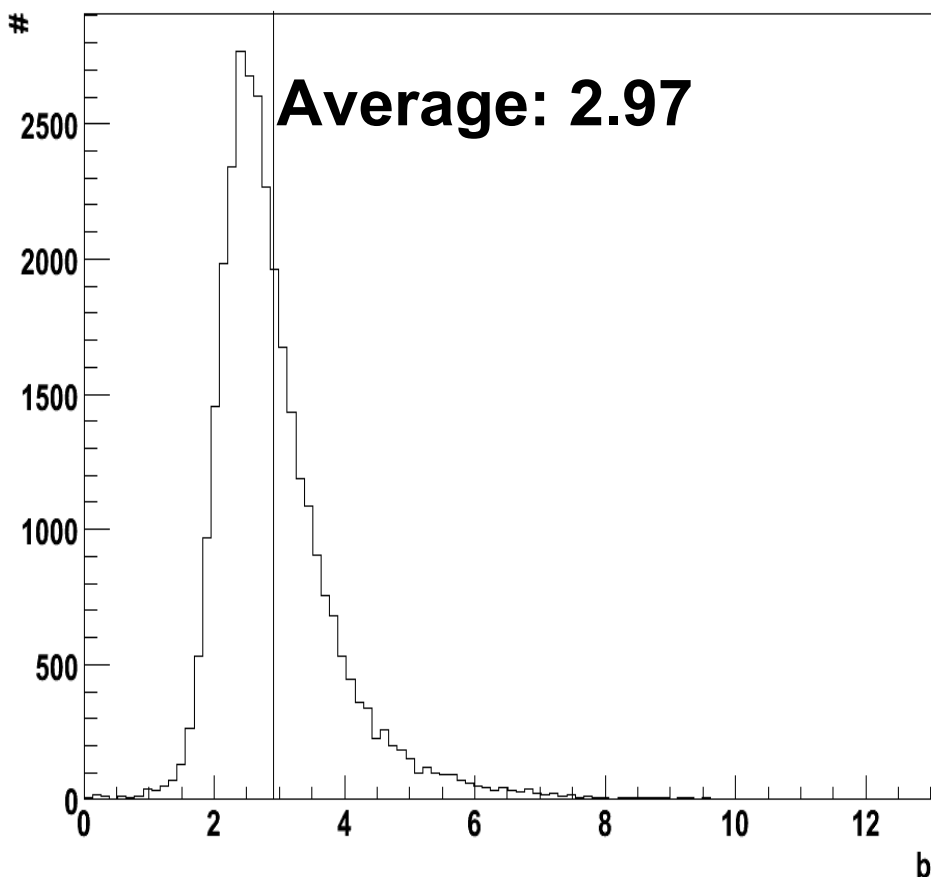
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Ghost dressing function



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Constructing gauges - independent of a method

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 - If a complete specification: Done
 - If not: There exist Gribov copies degenerate in the constraints
 - **Select randomly among degenerate Gribov copies**
 - Resulting correlation functions will be averages over all other possible constraints
- **Always: Inside first Gribov region**
 - Can be implemented in all methods

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Require minimal $|\text{tr}D|$

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- Others possible
 - Minimize B or $\text{tr}D$, combined constraints, averages, ...

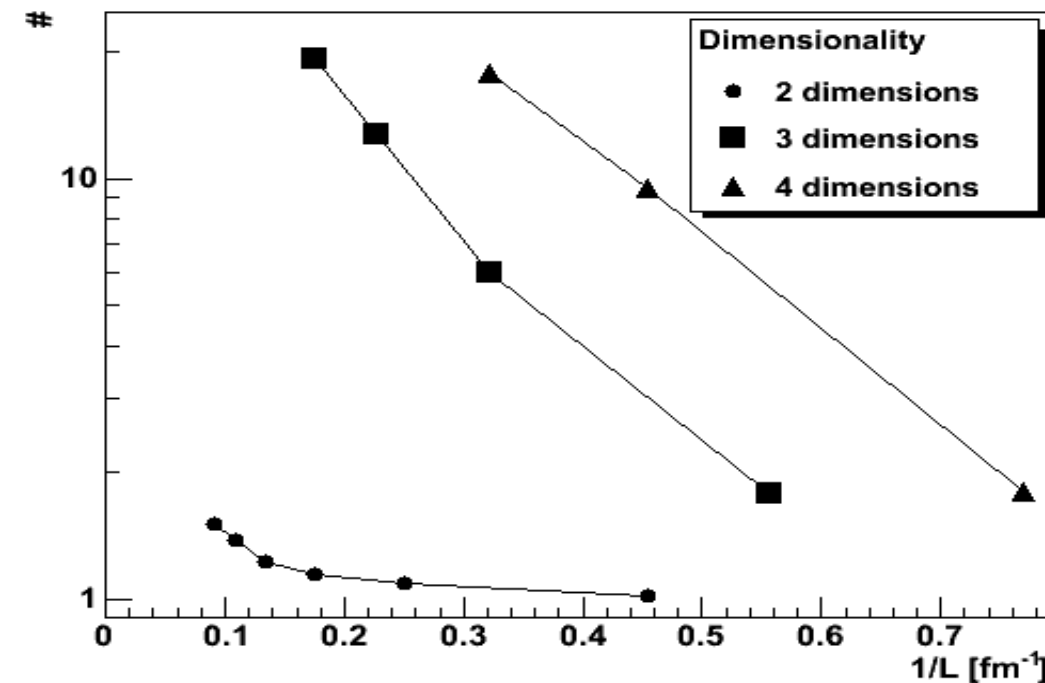
Obstacles...

- What are permitted constraints?
 - Requires knowledge of all Gribov copies: Gribov problem

Severity of the Gribov problem

[Maas 2009,
Mehta et al. 2009]

Number of Gribov copies at $a \approx 0.22$ fm

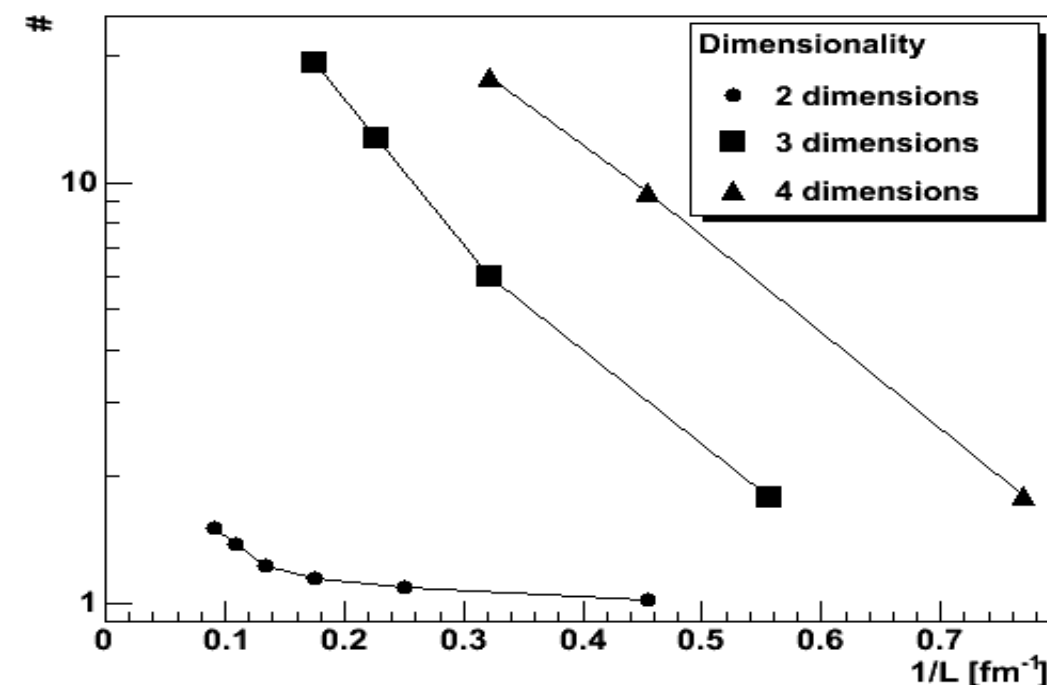


- Number of Gribov copies rises strongly with volume

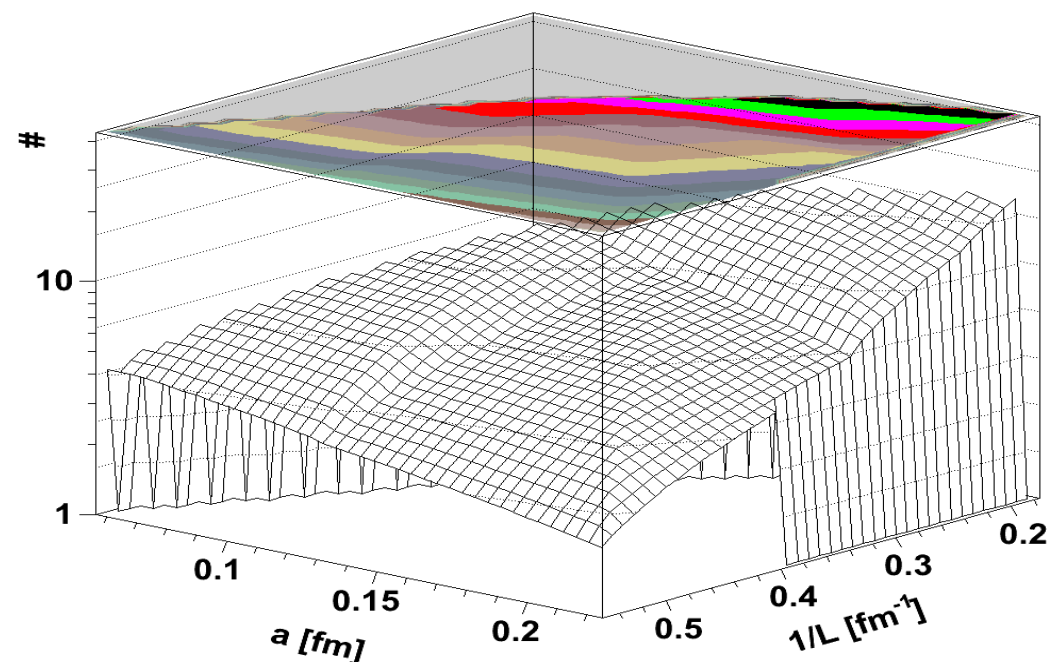
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Number of Gribov copies



- Number of Gribov copies rises strongly with volume...
- ...but also with discretization!

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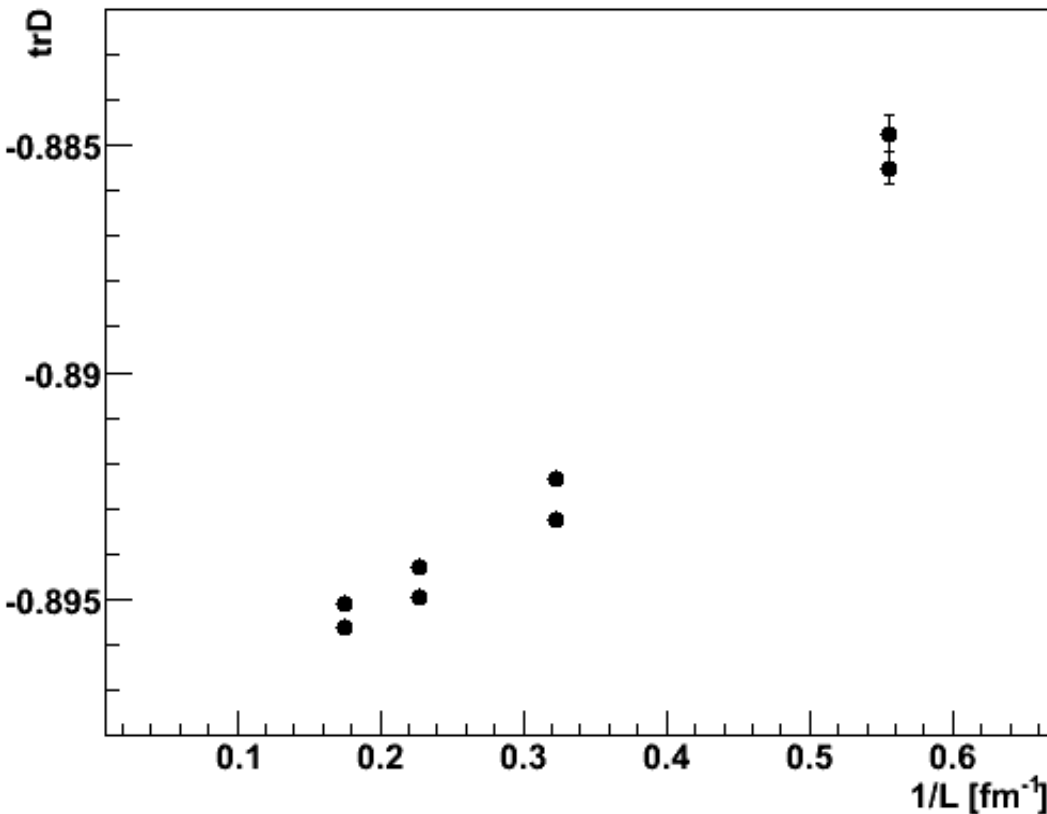
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Permitted corridors

[Maas 2009, unpublished]

TrD corridor

3d, $\alpha=0.22$ fm

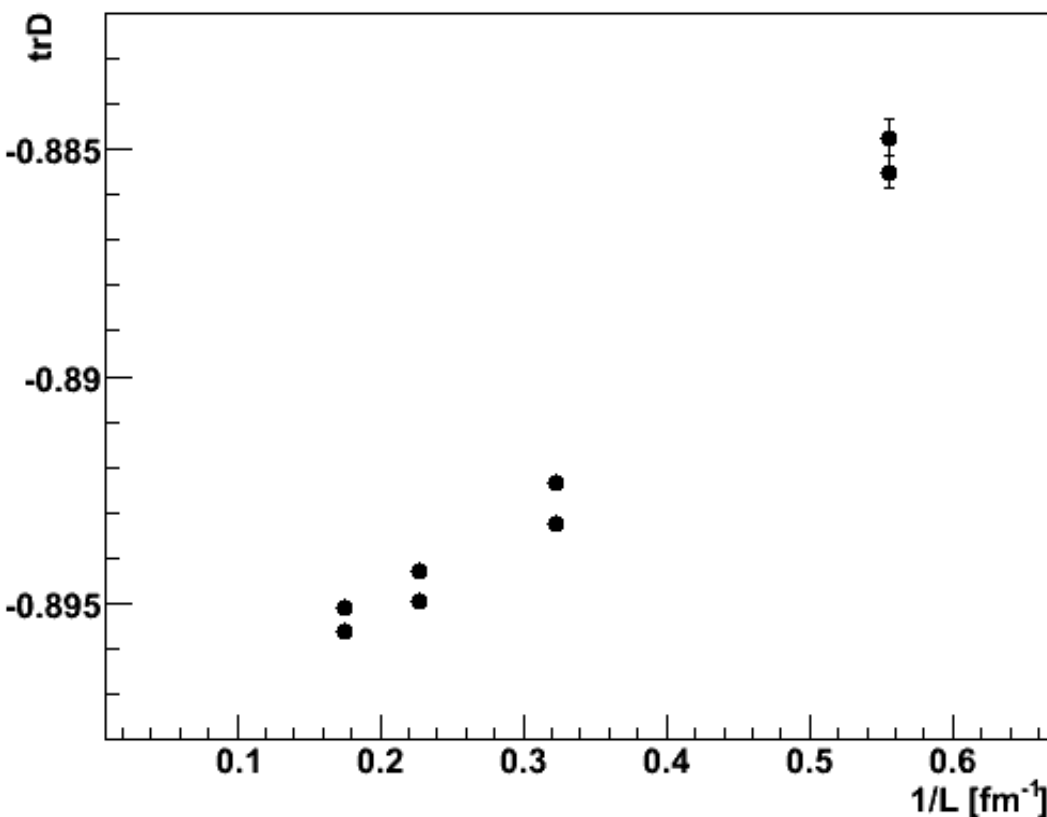


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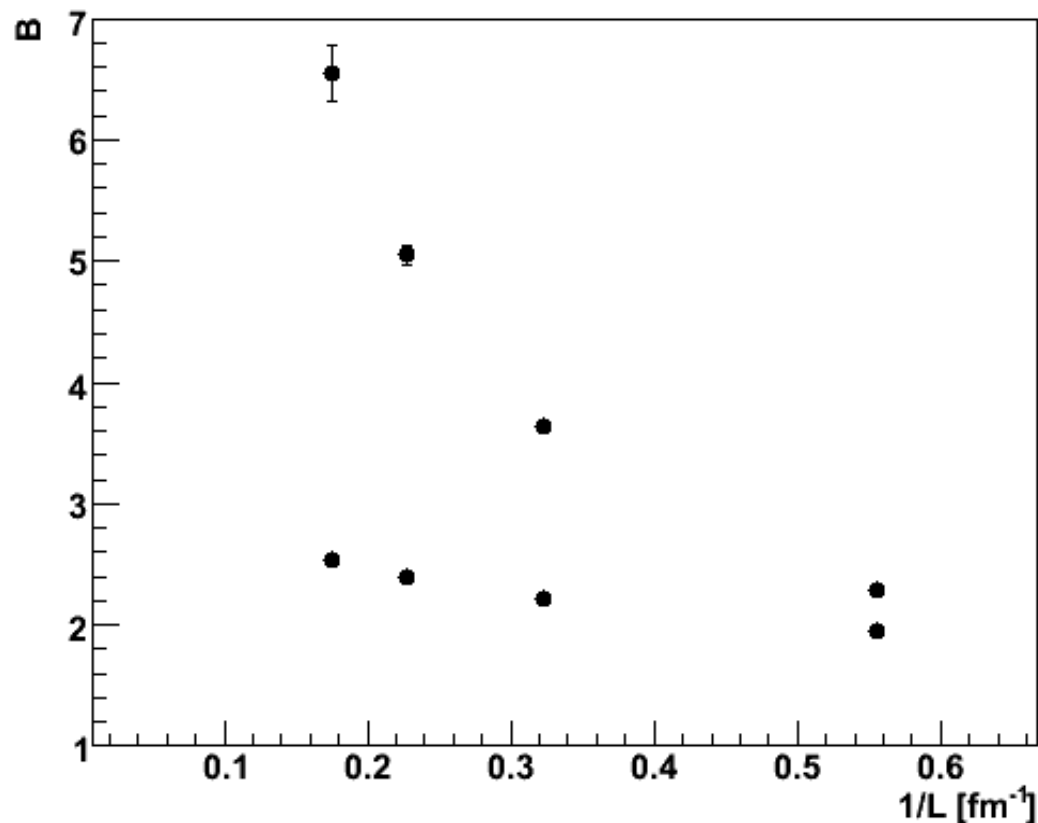
Permitted corridors

[Maas 2009, unpublished]

TrD corridor



B corridor

3d, $a=0.22$ fm

- trD : (small) range scales strongly with discretization
- B : Opens up with volume

Obstacles...

- **What are permitted constraints?**
 - Requires knowledge of all Gribov copies: Gribov problem
 - Requires eg to know permitted range of B or $\text{tr}D$ value
- **How many constraints are possible?**
 - Unknown – but no hints for more than just one
 - Constraints are equivalent to impose renormalization conditions – limited by number of possible (unphysical) free renormalization constants? Then only one in Landau gauge!

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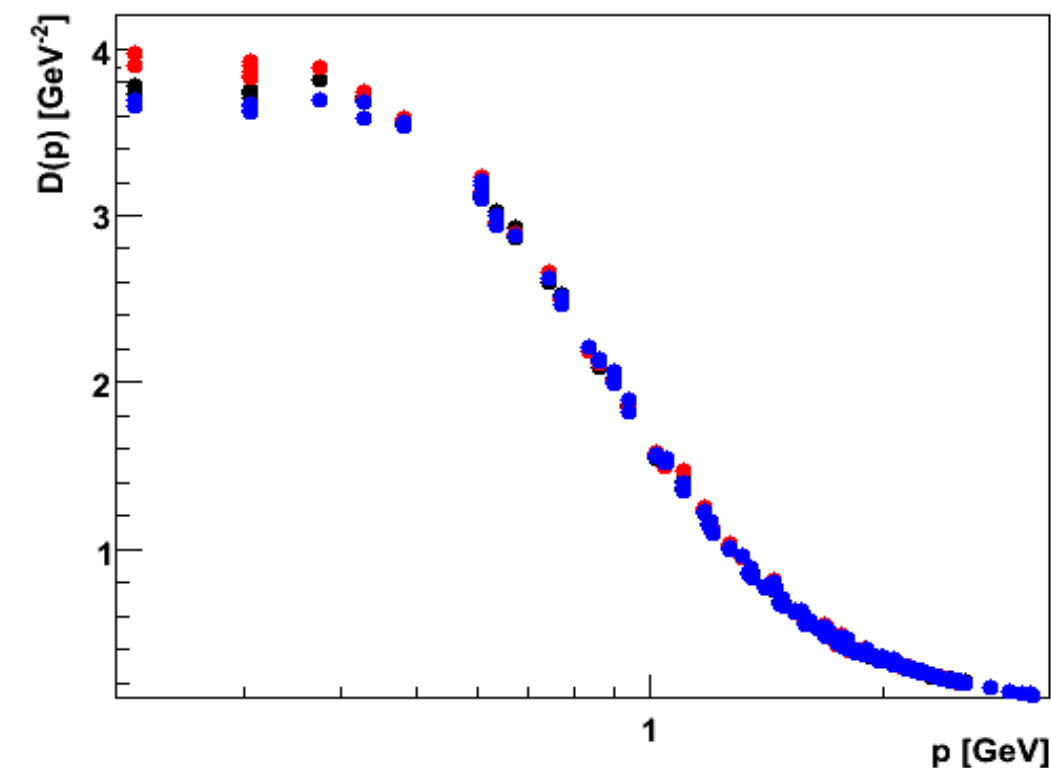
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- Unspecified constraints: Outside lattice gauge theory knowledge of undetermined averages required

Gluons (in 3d)

[Maas 2009, unpublished]

Gluon propagator

3d, $L=5.7\text{fm}$, $a=0.22\text{ fm}$

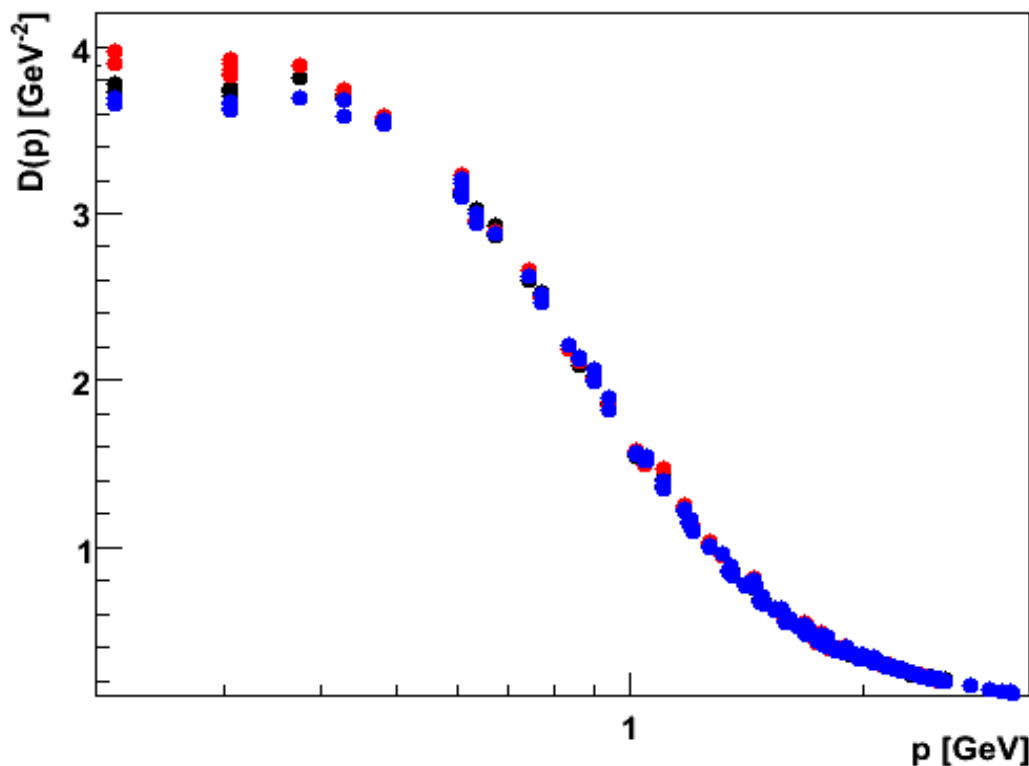


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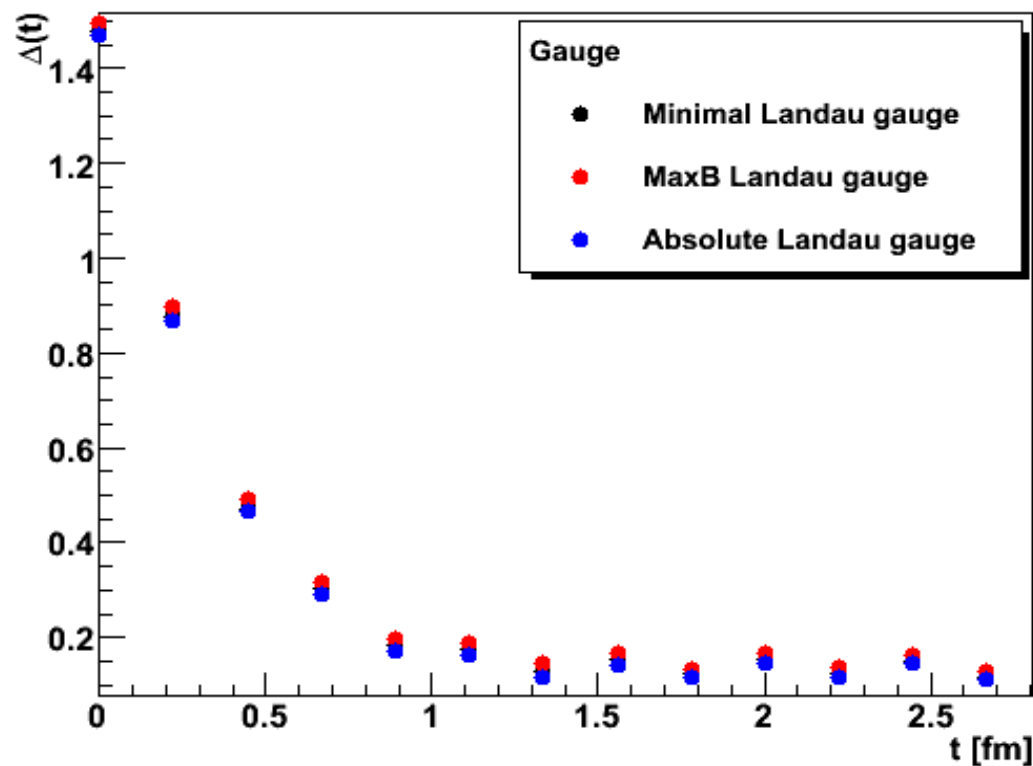
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Schwinger function

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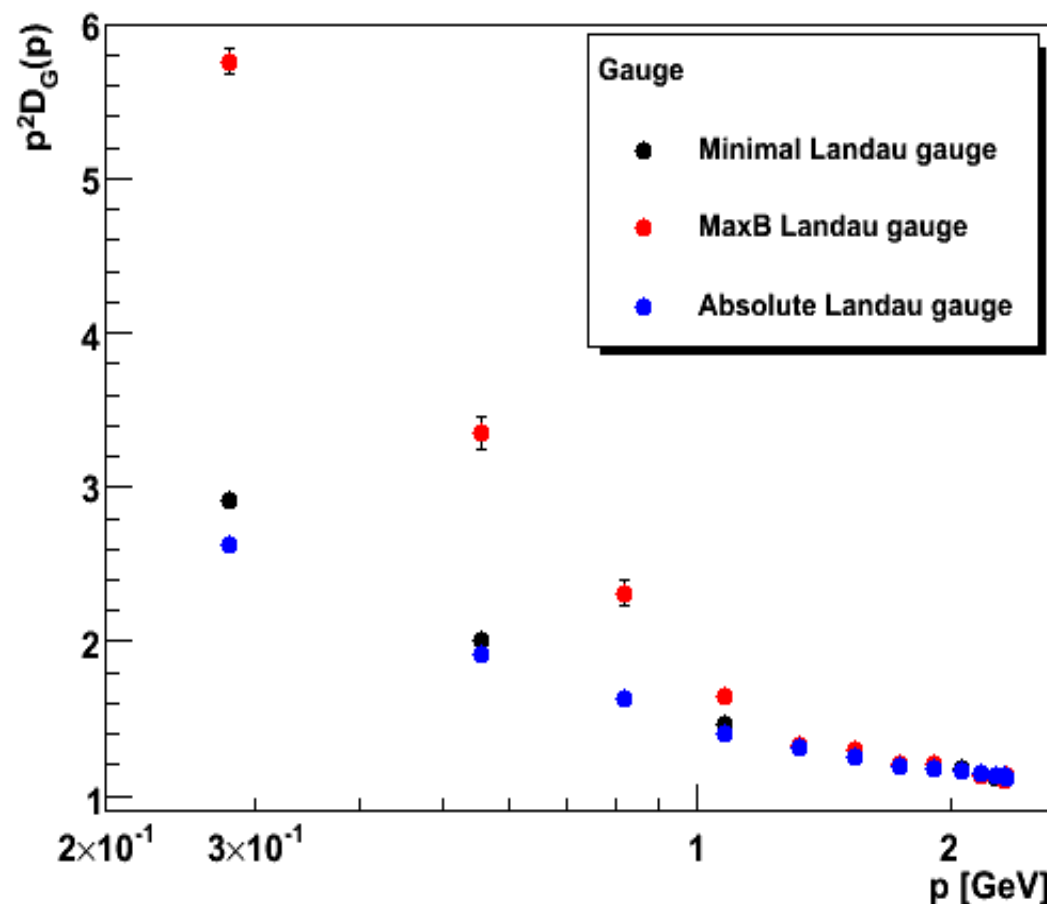
- Little sensitivity to the gauge
- Schwinger function unaltered
 - Not a physical particle

Ghosts and coupling (in 3d)

[Maas 2009, unpublished]

3d, $L=4.4$ fm, $a=0.17$ fm

Ghost dressing function



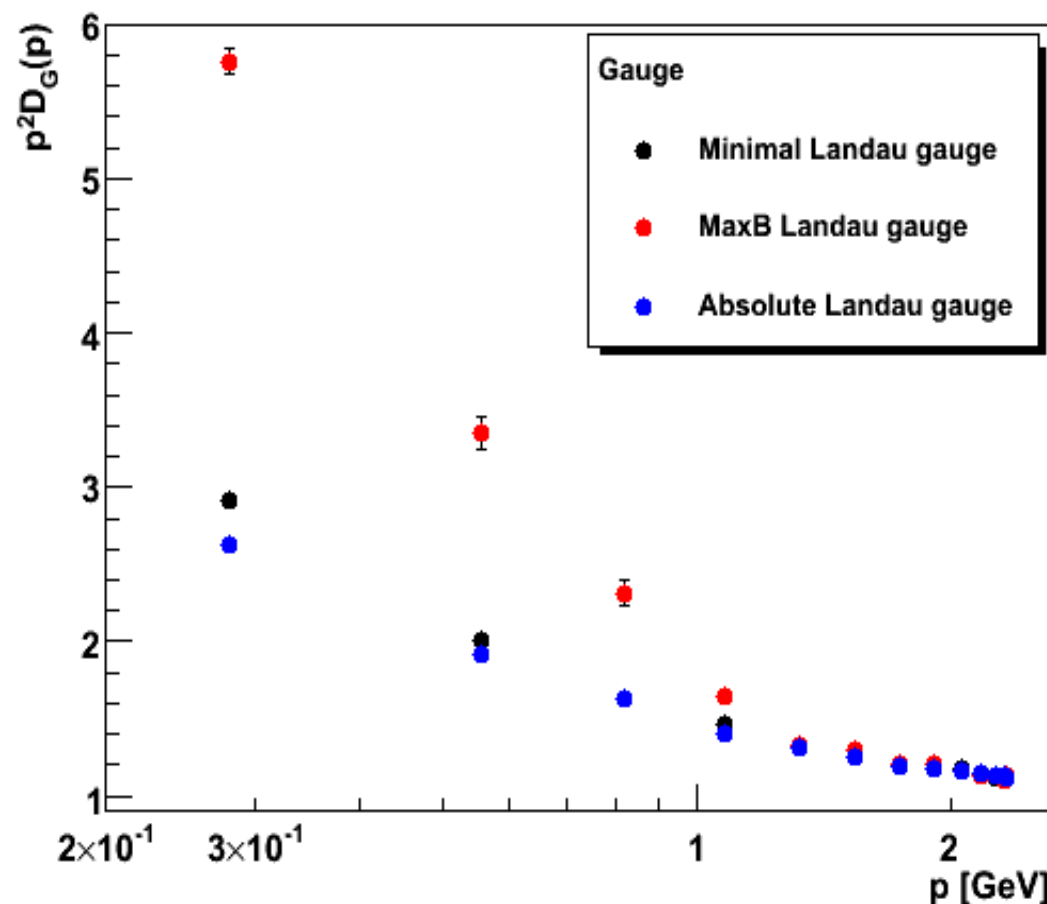
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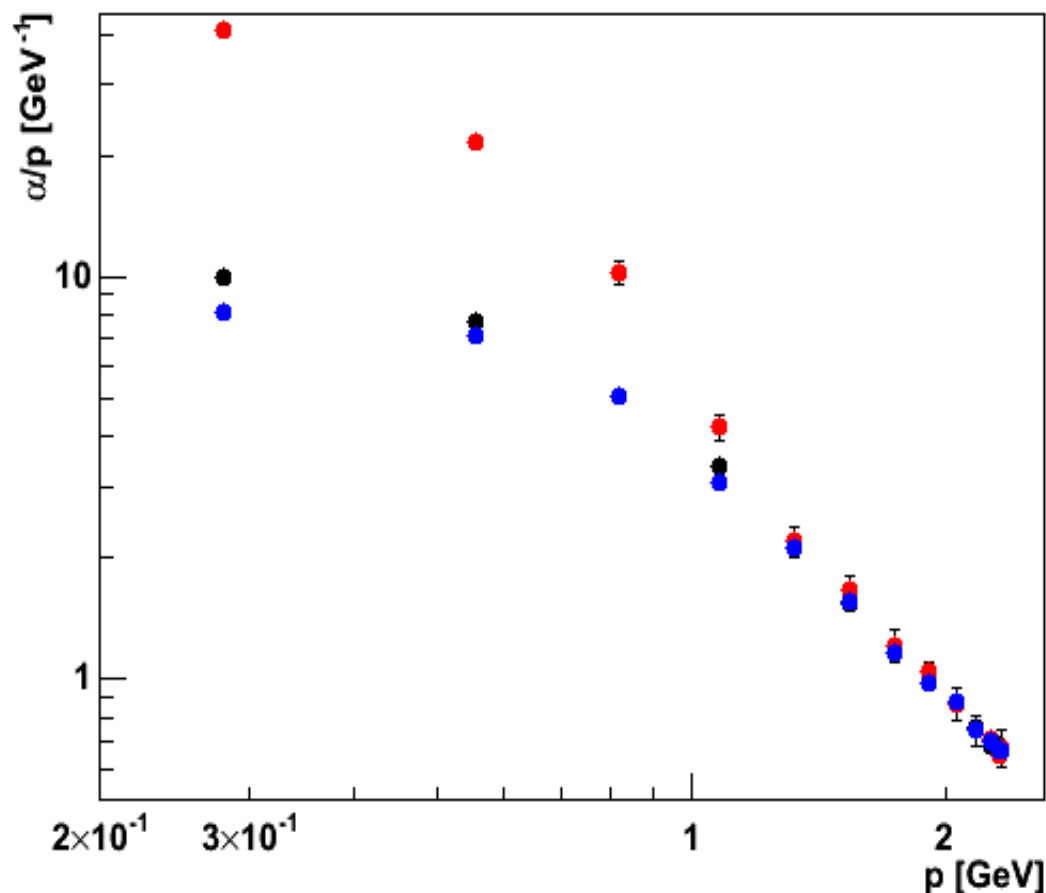
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Ghost dressing function



Effective coupling



- Ghost depends strongly on gauge choice
- So does the coupling

Scalars

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Scalars

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 - Model for fermions in the confined phase
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- Quenched: Adjoint vs. fundamental matter
 - Is string-breaking and string formation reflected in the correlation functions (propagators/vertices)?
- Unquenched: Fundamental
 - Higgs vs. confinement: How do they differ?
 - No gauge-invariant distinction possible!

Quenched scalars

- Propagators

Quenched scalars

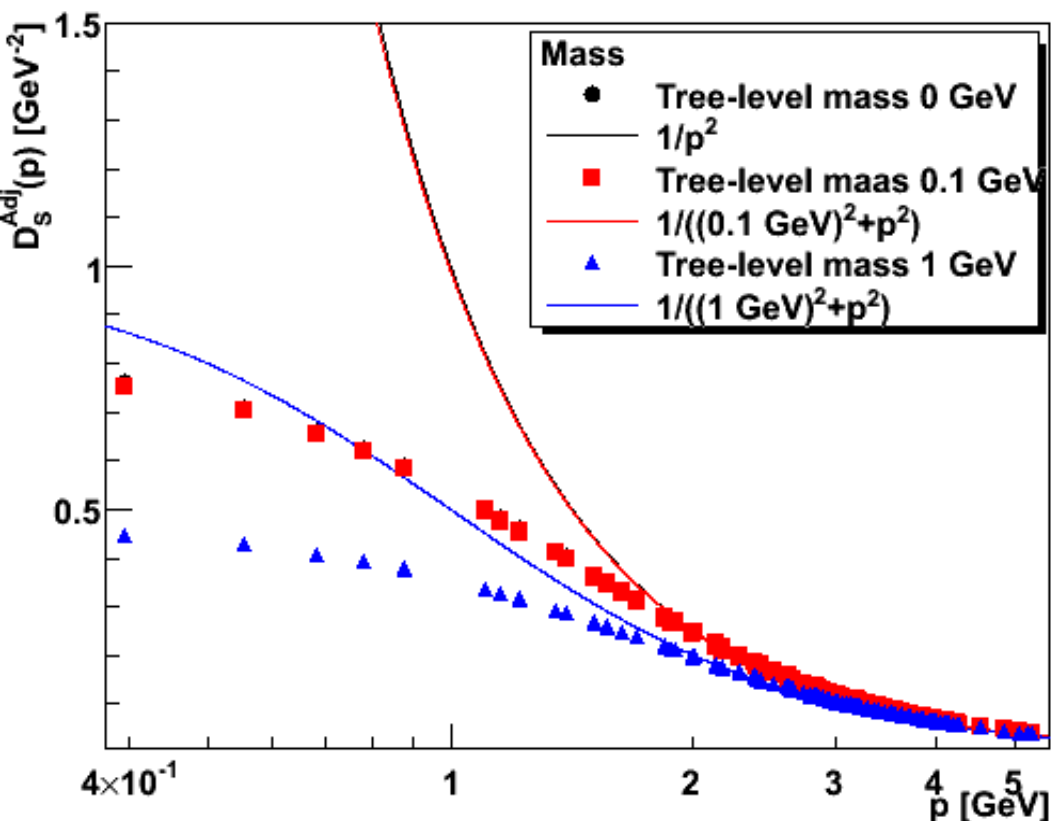
- Propagators
 - Single scalar function
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 - Here: Tree-level behavior at 2 GeV required
 - Tree-level mass dependence
 - Minimal Landau gauge only

Propagators: Adjoint vs. Fundamental

Adjoint scalar propagator



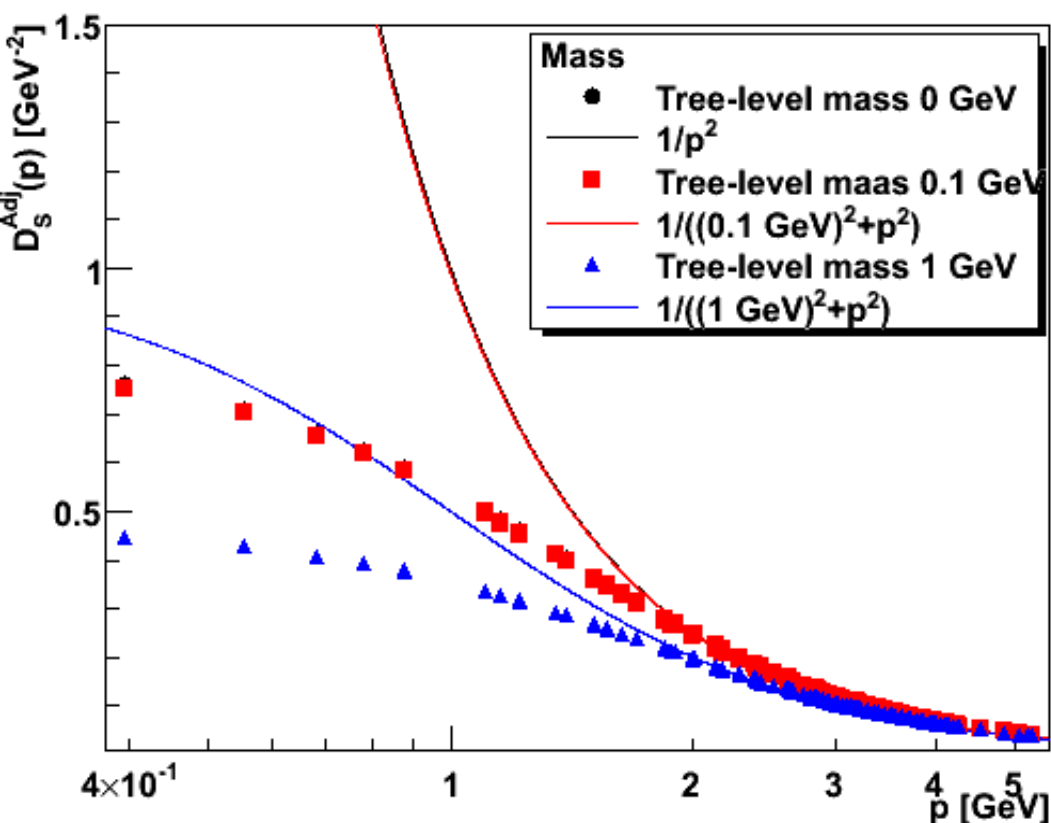
- Screening-mass unequal renormalized mass
 - Mass-dependent screening mass generation

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

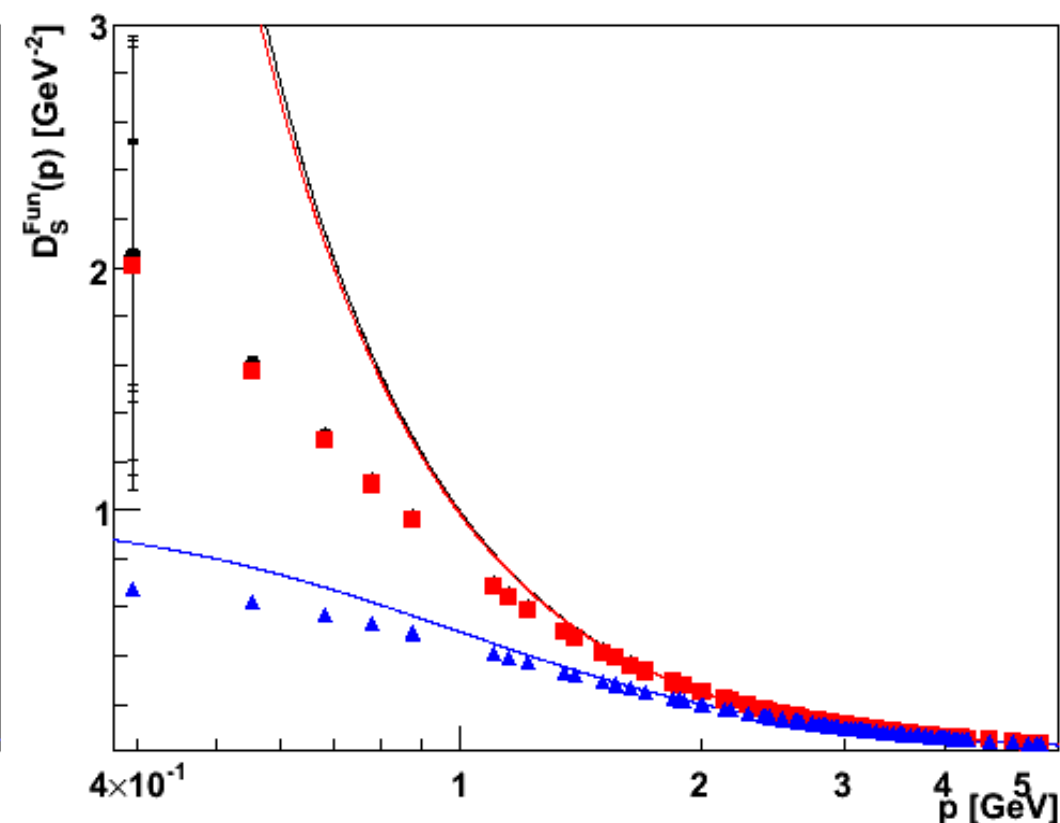
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Propagators: Adjoint vs. Fundamental

Adjoint scalar propagator



Fundamental scalar propagator



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- Mass-dependent screening mass generation

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

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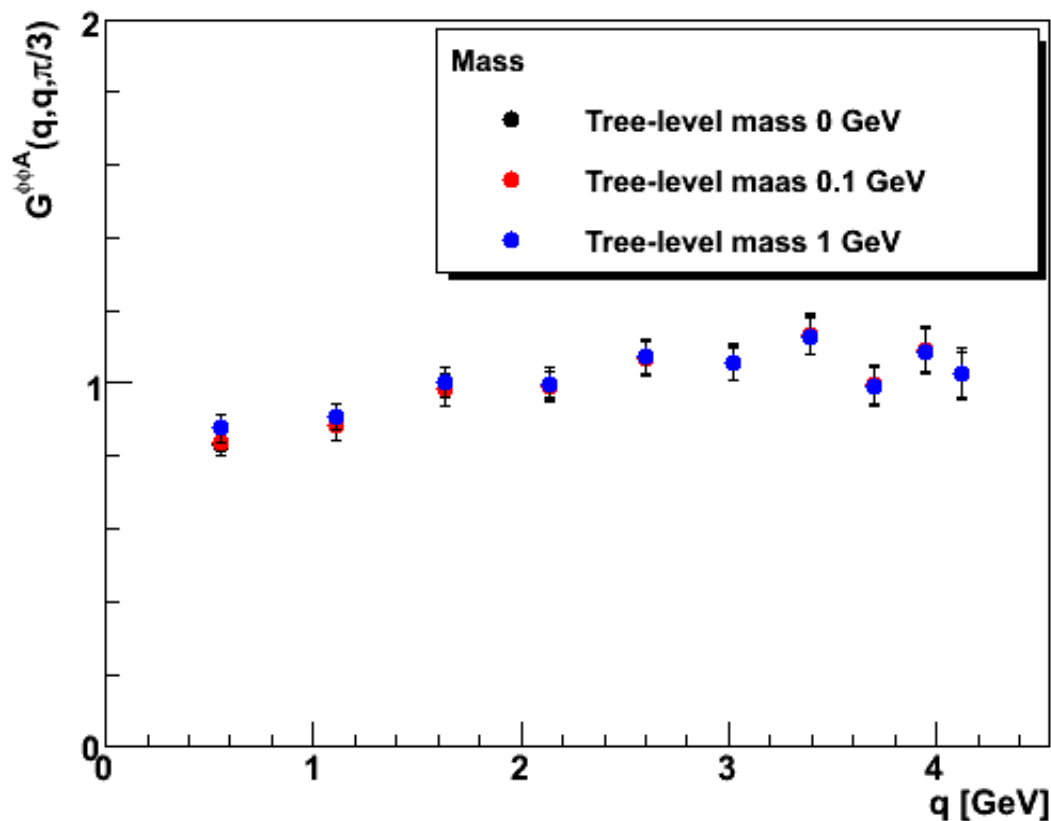
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- **Only one tensor structure for $SU(2)$**
- Determine as ratio over tree-level tensor

Gluon-2-scalar vertex: Symmetric point

Gluon-2-adjoint-scalar vertex, symmetric point

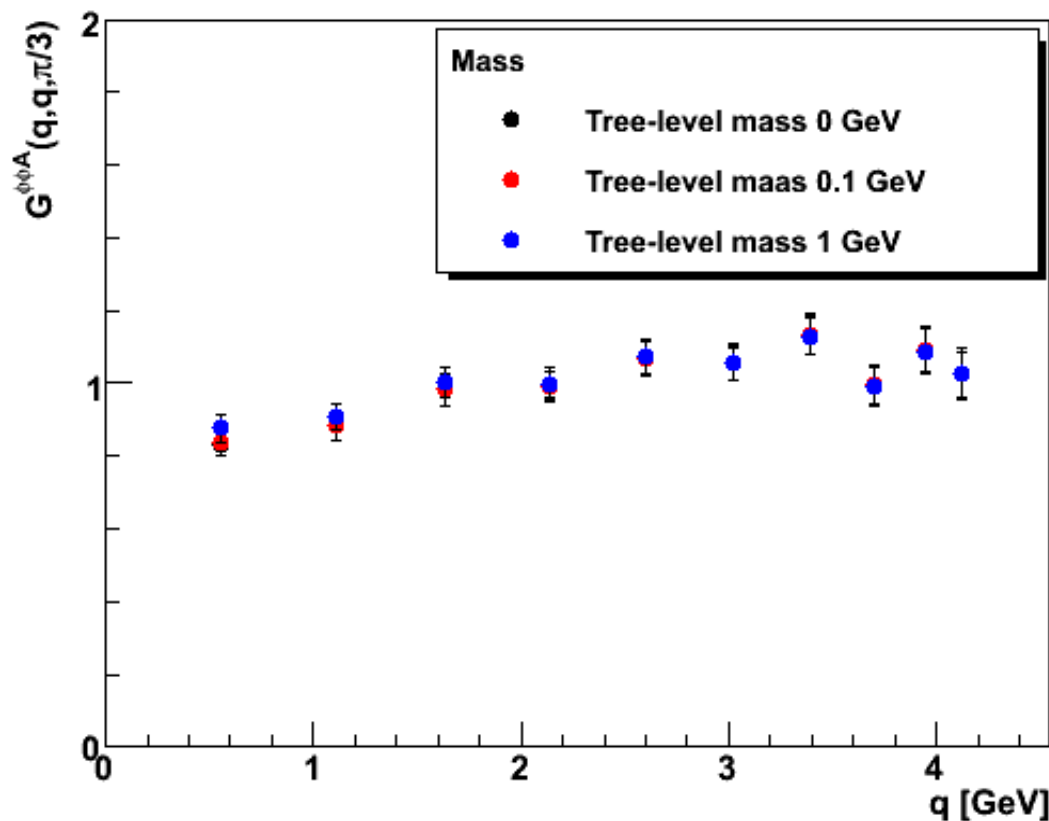


- Almost no difference to tree-level
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- No divergences

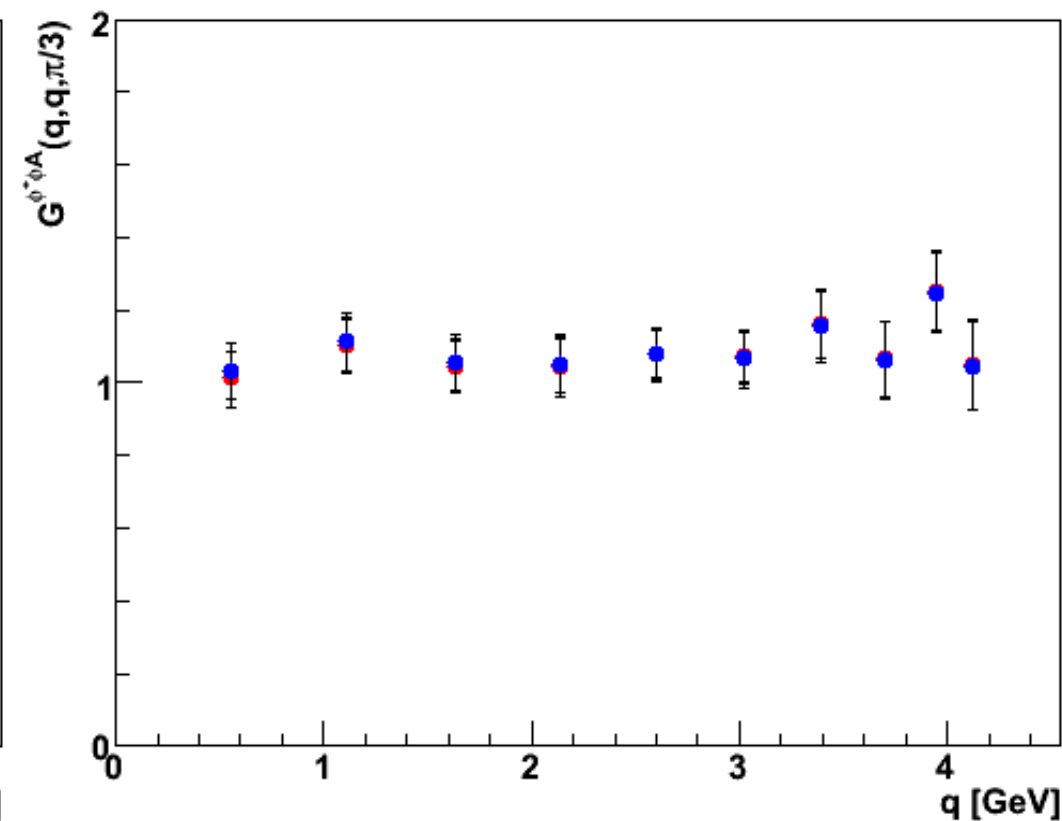
3d, L=3.1 fm, $\alpha=0.13$ fm
[Maas unpublished]

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Gluon-2-adjoint-scalar vertex, symmetric point



Gluon-2-fundamental-scalar vertex, symmetric point



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Dynamical fundamental scalars

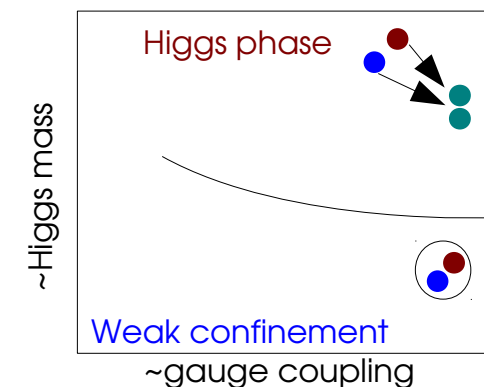
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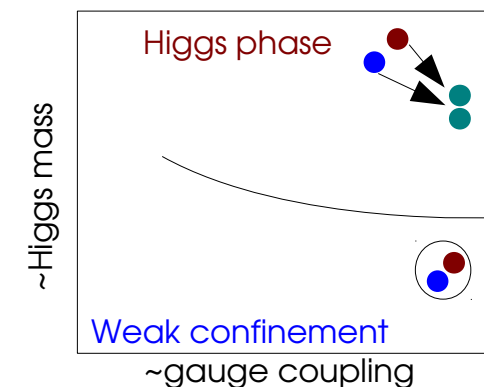
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 - **Higgs mechanism**
 - Application to the standard model
 - No (gauge-invariant) difference of confinement and Higgs phase



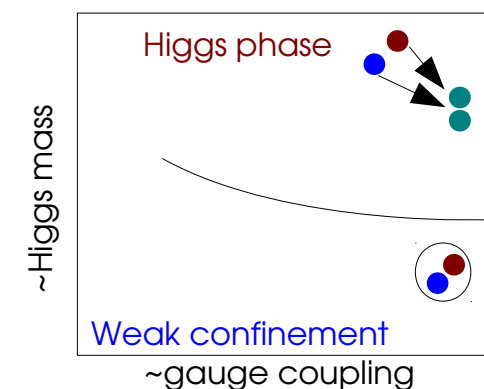
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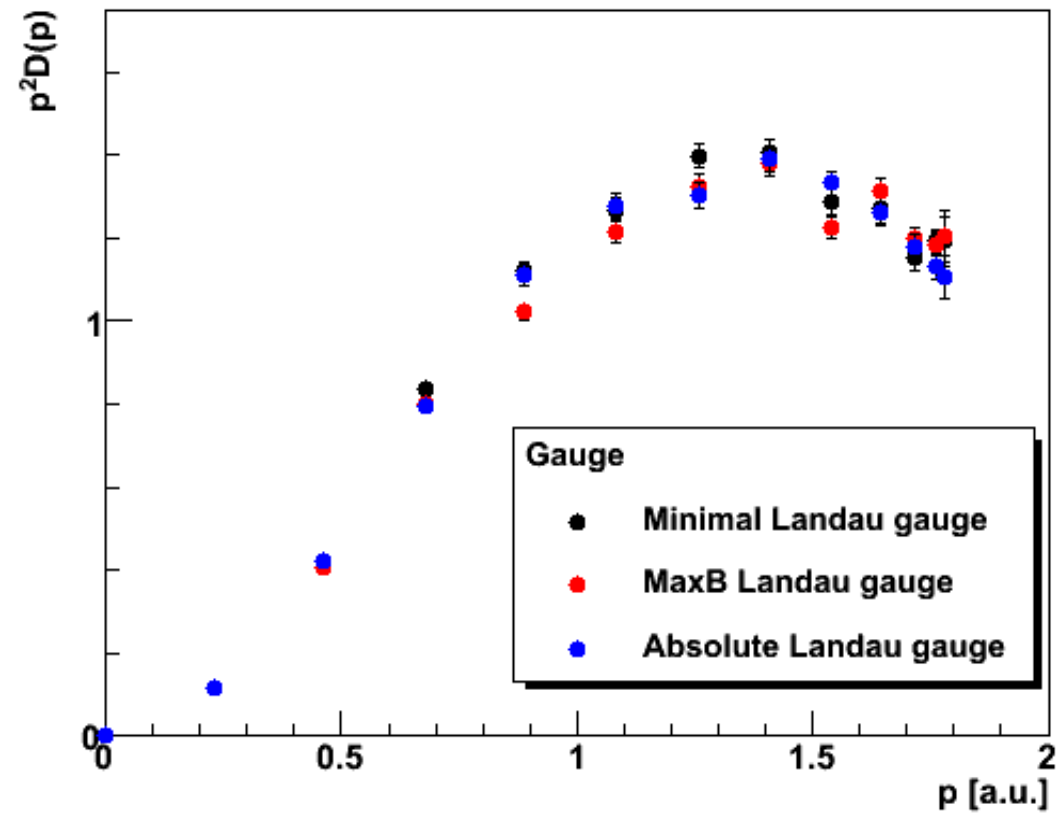


Gauge bosons

4d, confinement: beta=2.0, kappa=0.25, lambda=0.5

4d, Higgs: beta=2.3, kappa=0.32, lambda=1

Gauge boson - confinement phase



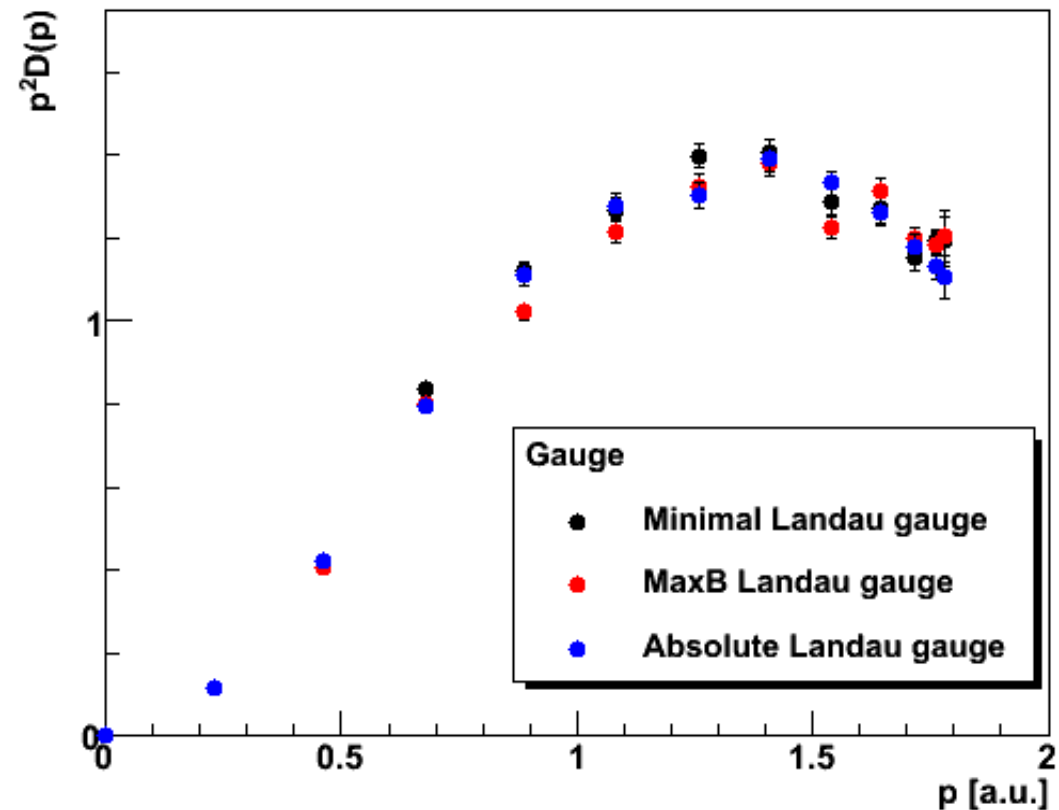
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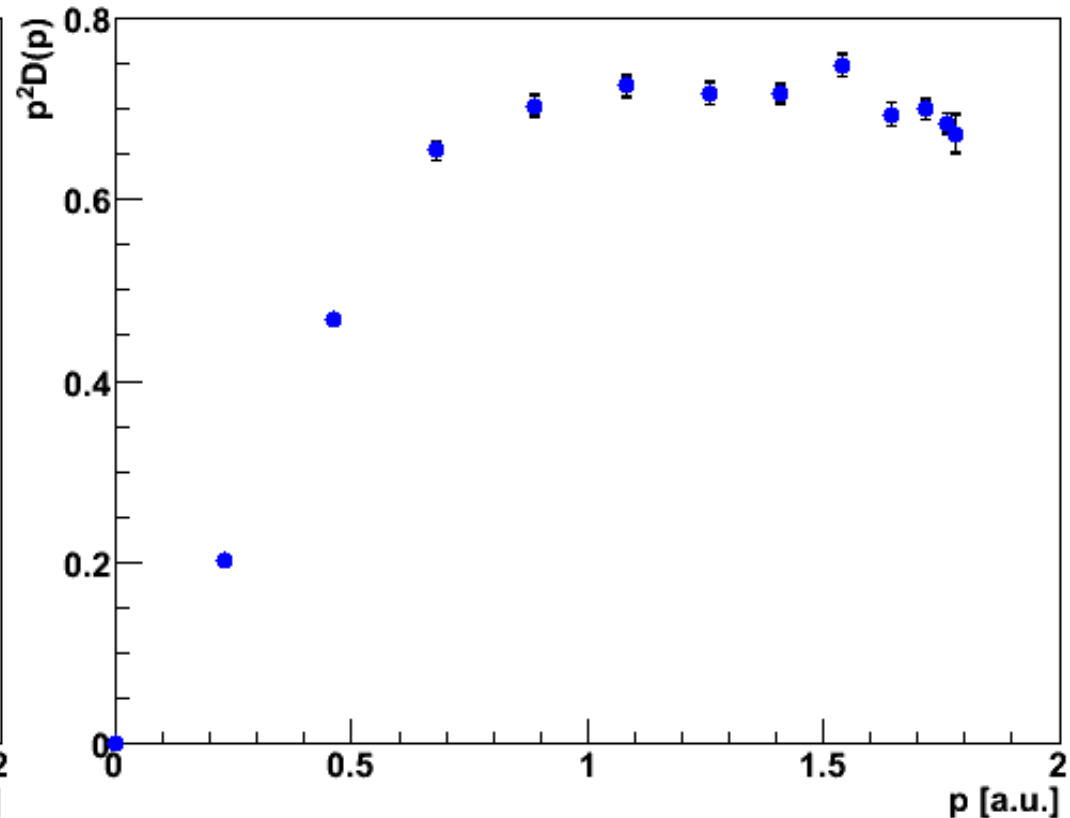
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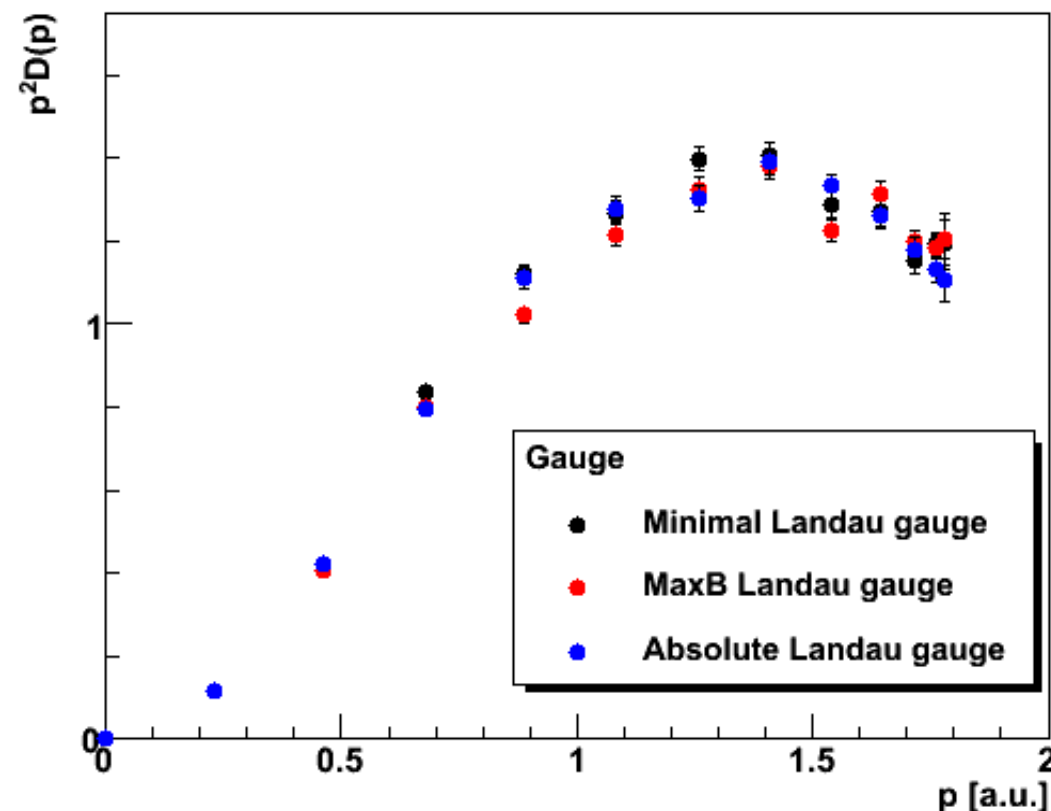


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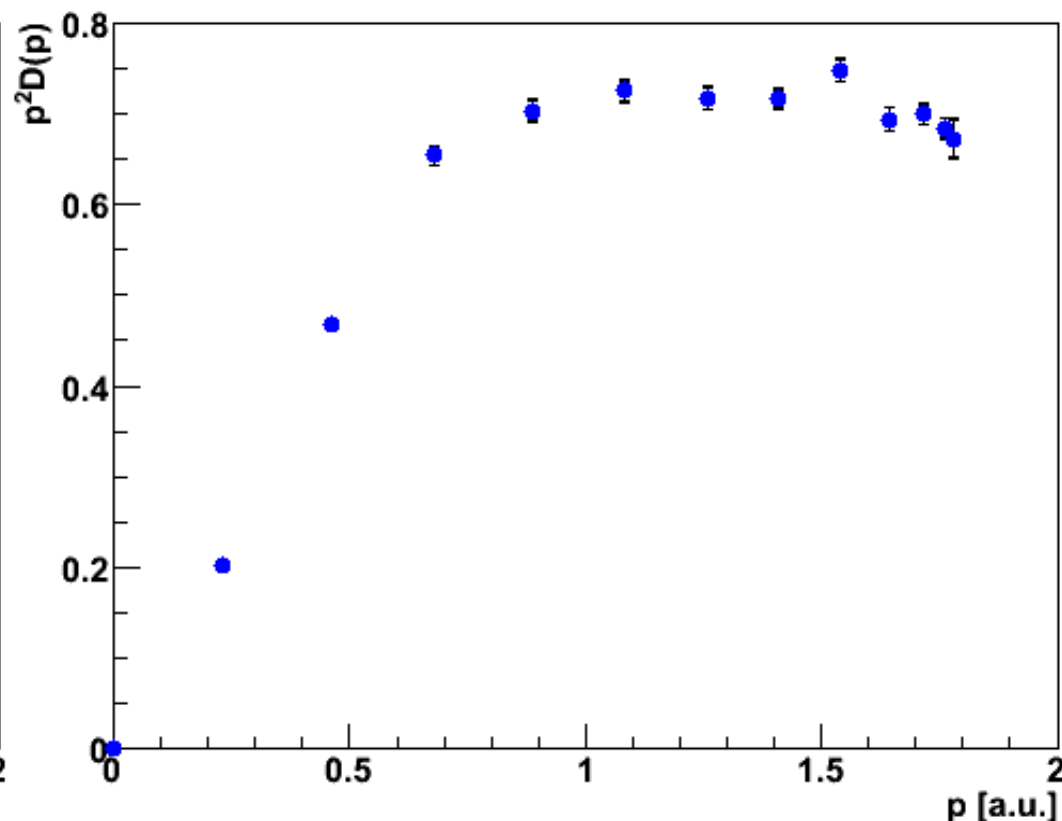
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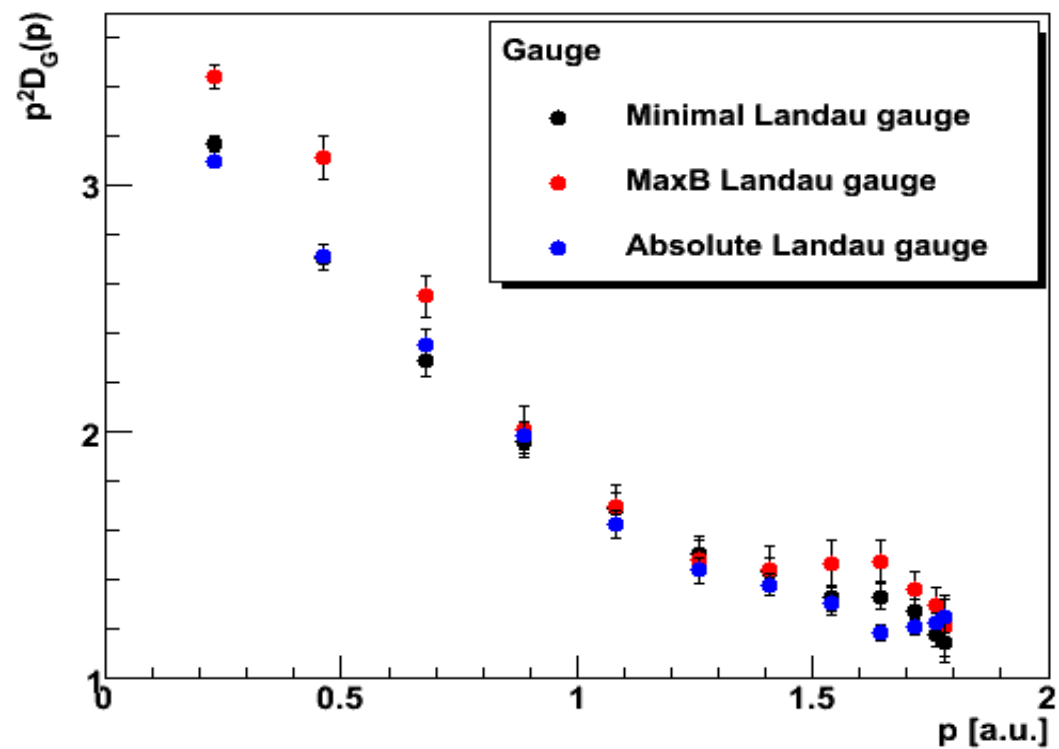
- Little qualitative difference - impact of matter small
- Few (or none?) Gribov copies in Higgs phase
 - Physical volume and other questions...

[Maas unpublished]

Ghosts

[Maas unpublished]

Ghost - confinement phase



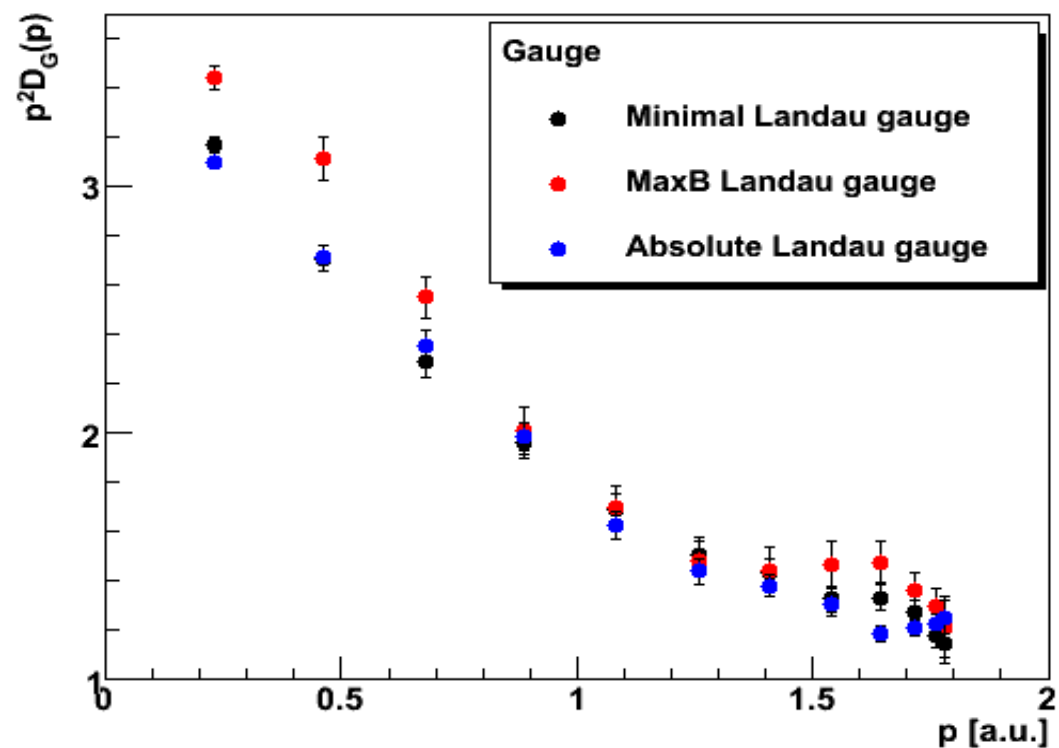
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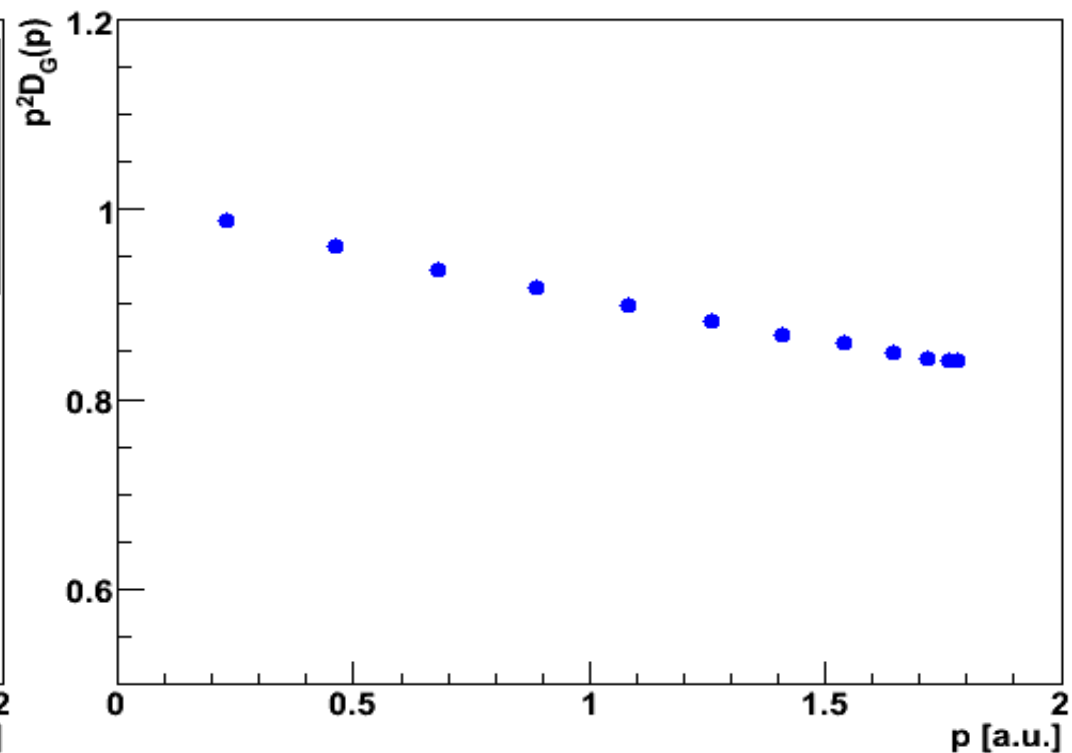
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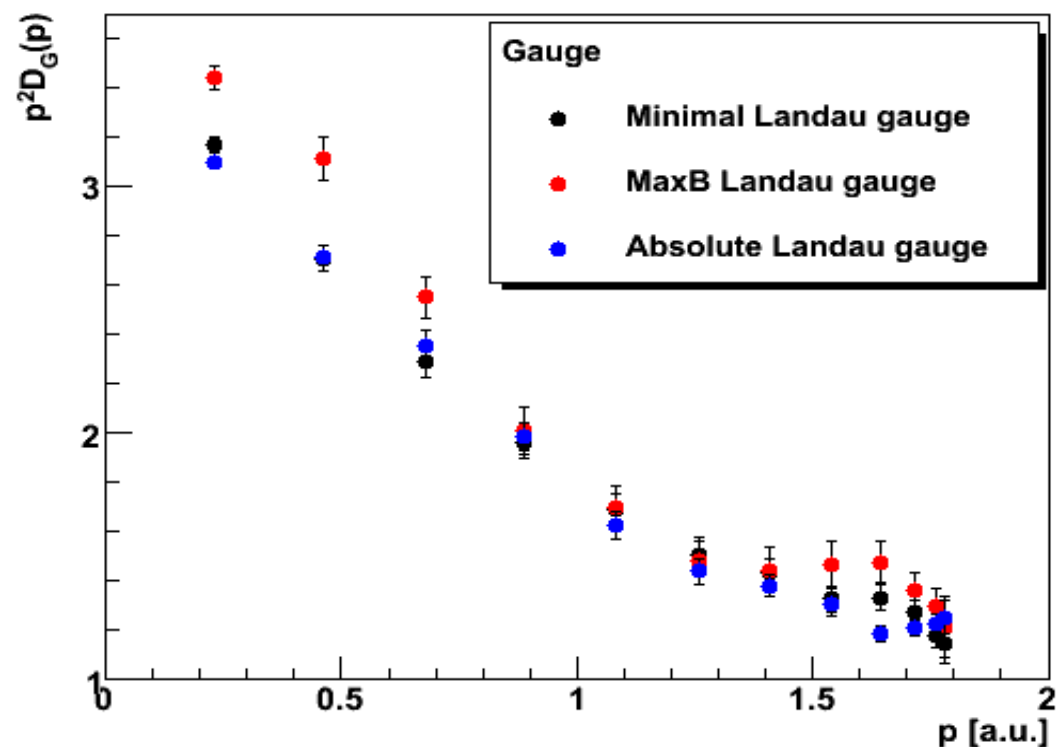
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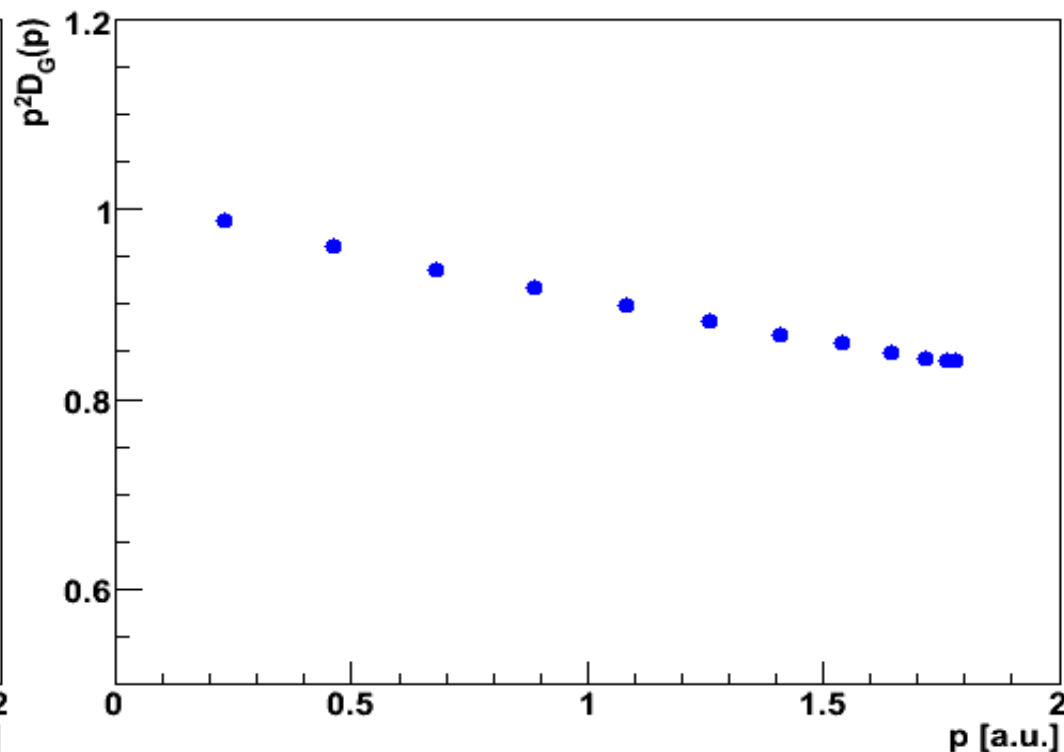
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- **Strong qualitative difference**

4d, confinement: beta=2.0, kappa=0.25, lambda=0.5

4d, Higgs: beta=2.3, kappa=0.32, lambda=1

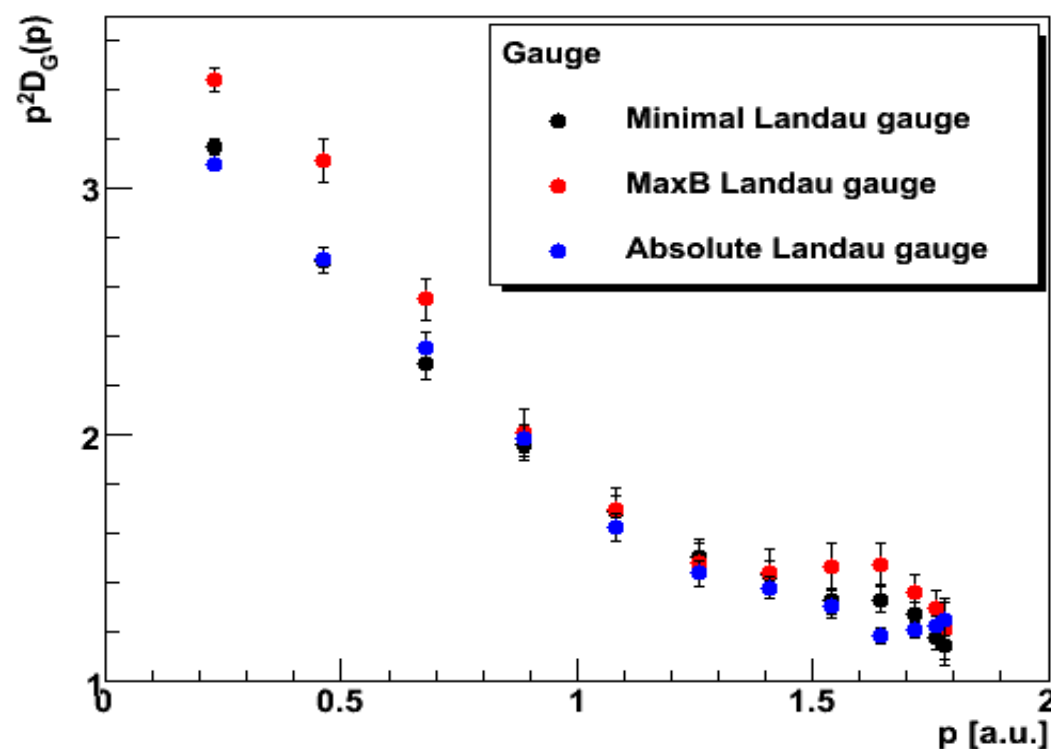
- Ghost essentially tree-level in the Higgs phase

- Compatible with Coulomb-gauge [Greensite, Olejnik 2004]

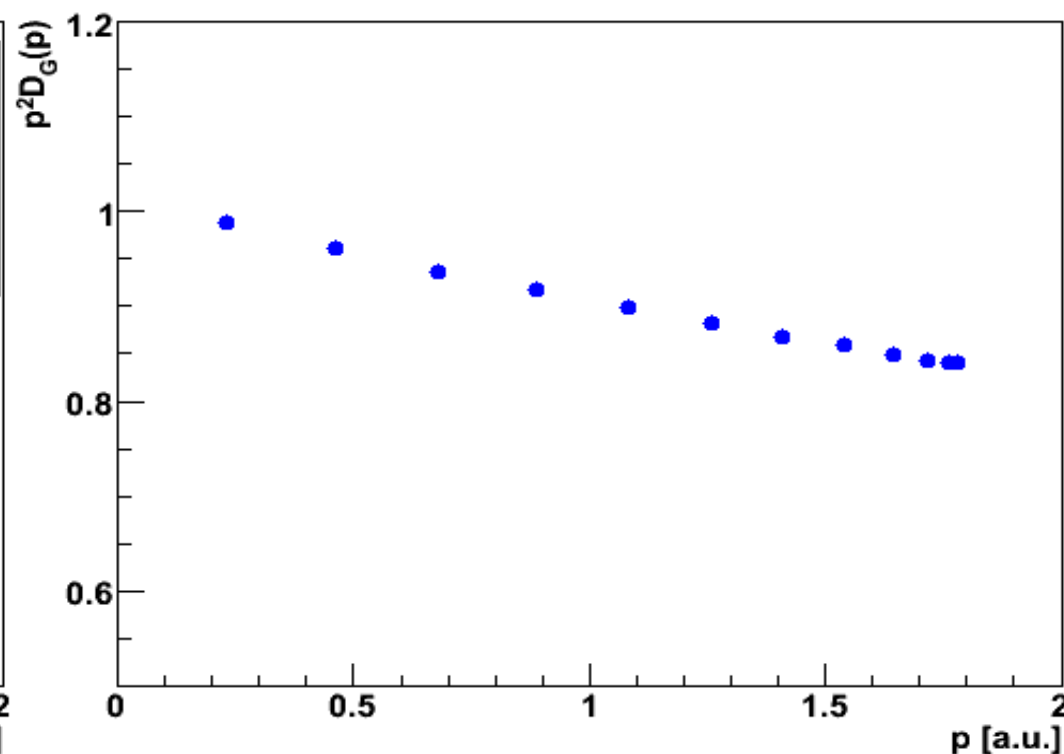
Ghosts

[Maas unpublished]

Ghost - confinement phase



Ghost - Higgs phase



- Strong qualitative difference

- Ghost essentially tree-level in the Higgs phase

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- Characterization of the phases? [Caudy, Greensite 2007]

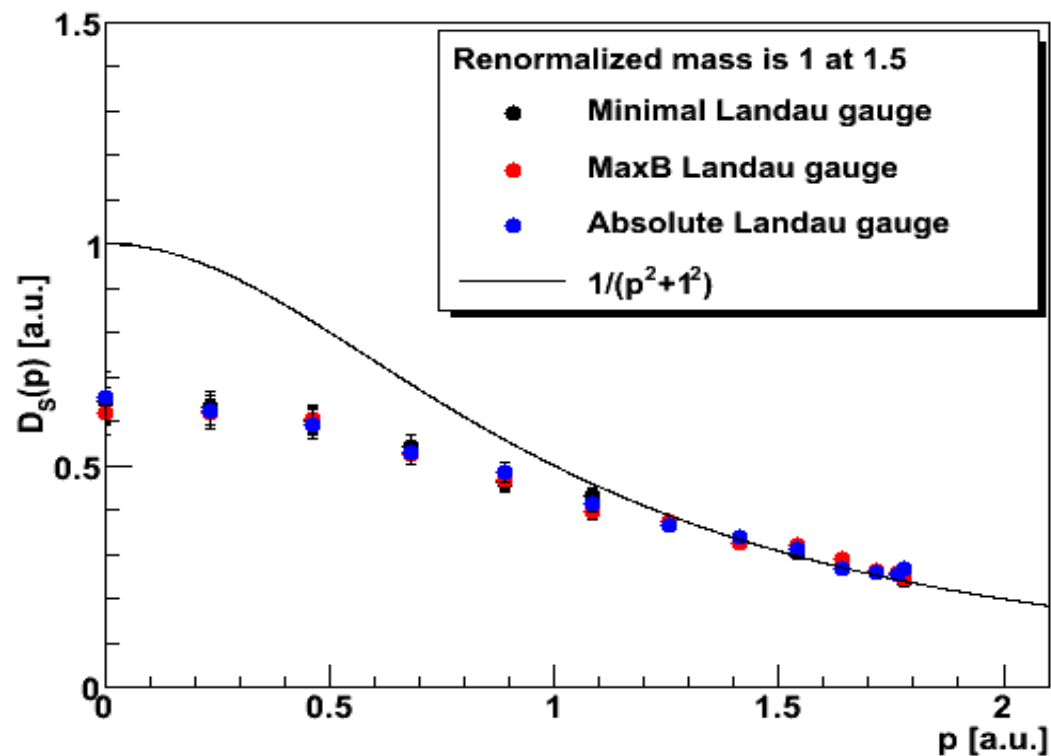
4d, confinement: beta=2.0, kappa=0.25, lambda=0.5

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Higgs

[Maas unpublished]

Scalar - Confinement phase



- Close to tree-level

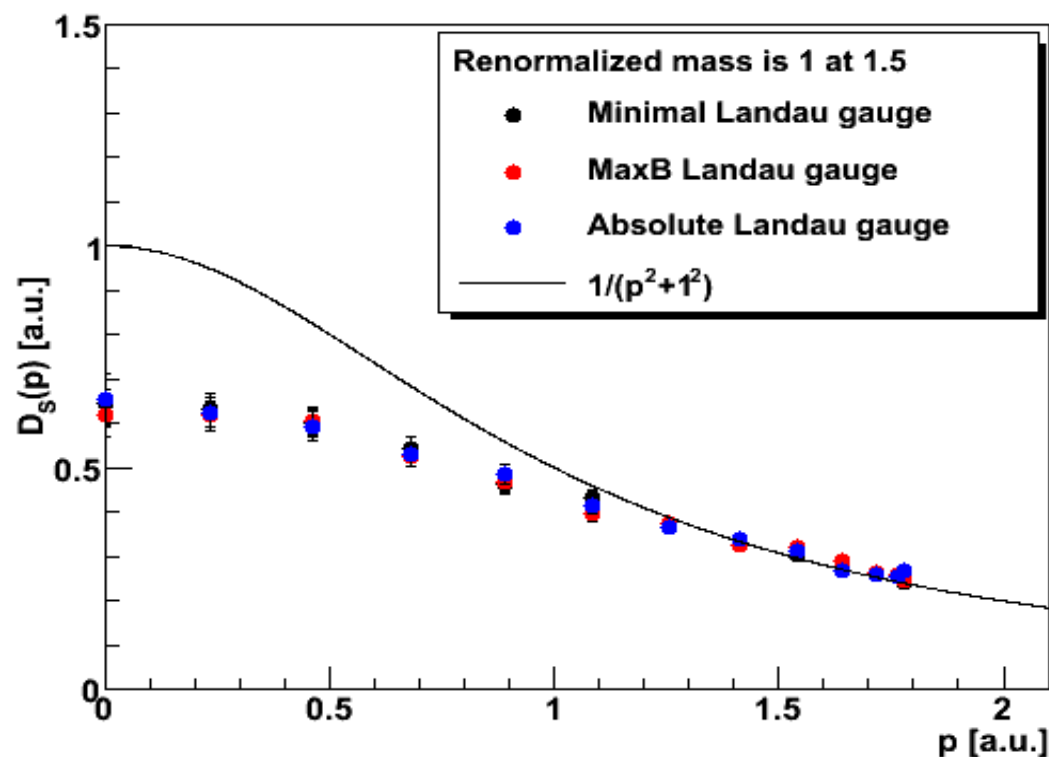
4d, confinement: $\beta=2.0$, $\kappa=0.25$, $\lambda=0.5$

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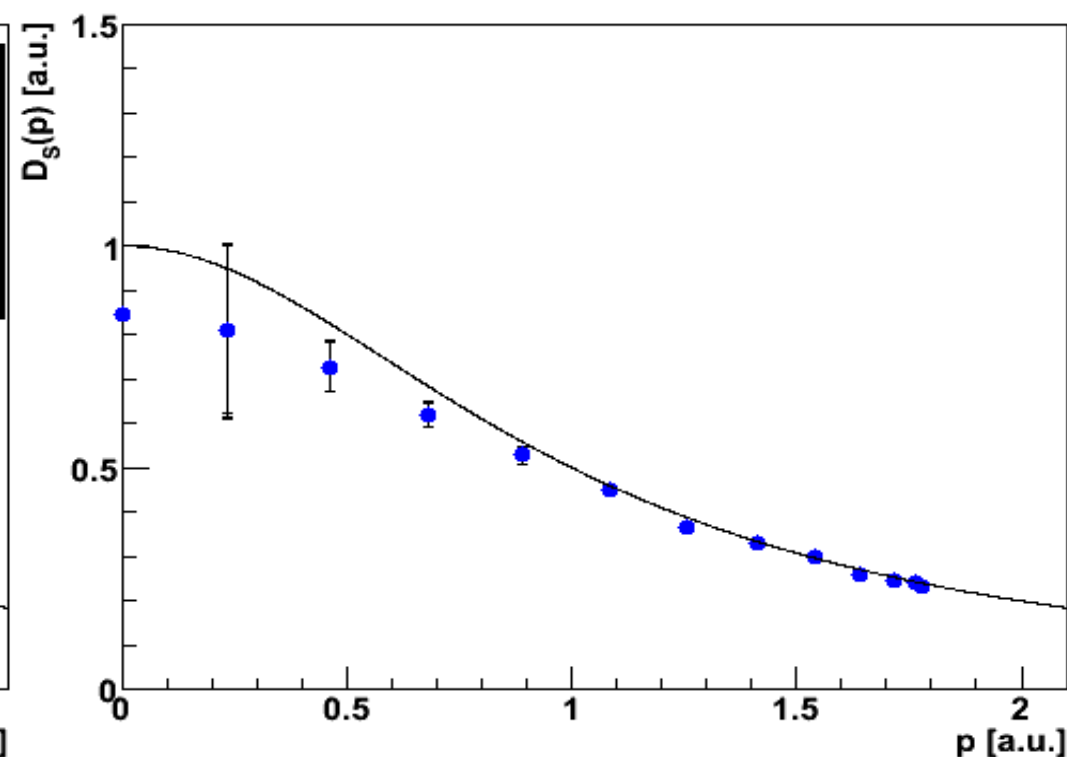
Higgs

[Maas unpublished]

Scalar - Confinement phase



Scalar - Higgs phase



- Close to tree-level
- Little difference in both phases

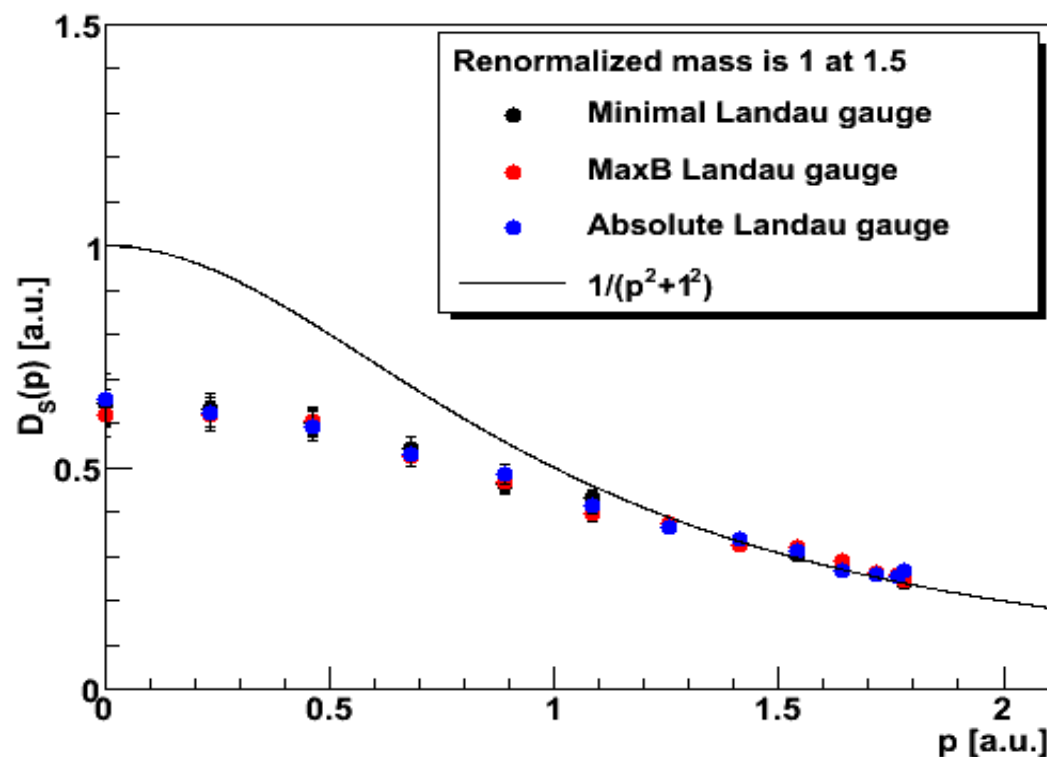
4d, confinement: beta=2.0, kappa=0.25, lambda=0.5

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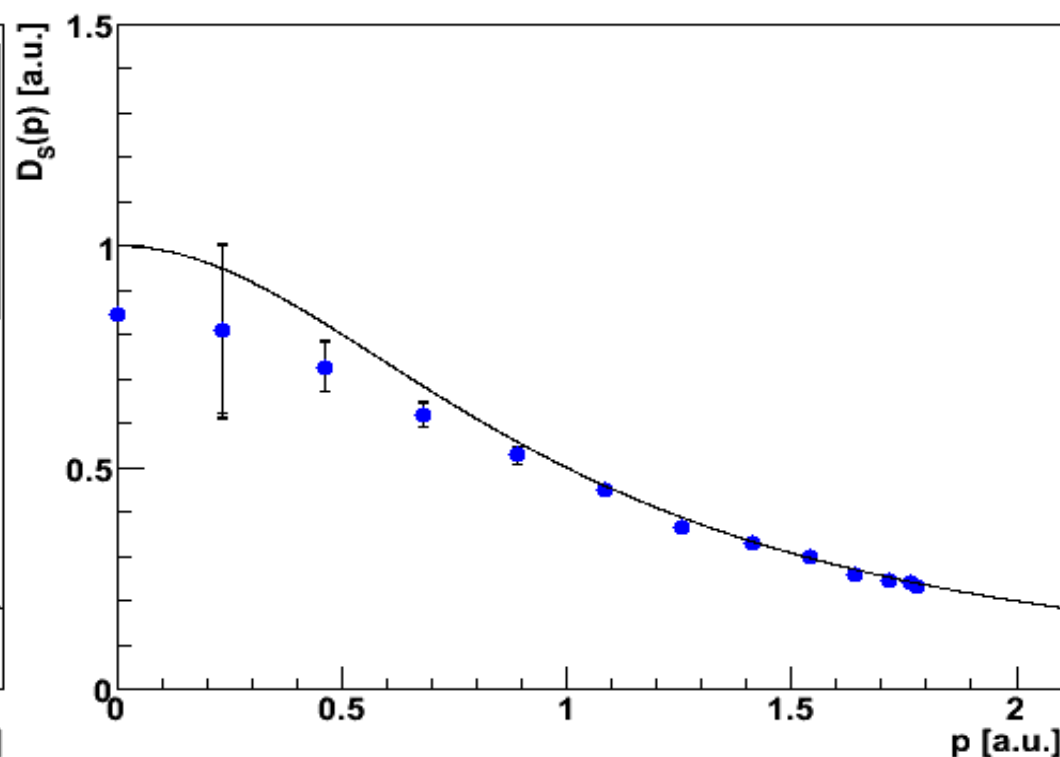
Higgs

[Maas unpublished]

Scalar - Confinement phase



Scalar - Higgs phase



- Close to tree-level
- Little difference in both phases
- Small to no impact of Gribov copies

4d, confinement: beta=2.0, kappa=0.25, lambda=0.5

4d, Higgs: beta=2.3, kappa=0.32, lambda=1

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- Well-defined non-perturbative gauges possible
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- **Quenched scalars**
 - Little difference between adjoint and fundamental
 - Requires more details to tell if and how the string shows up in correlation functions
- **Unquenched scalars**
 - Little impact of matter in the confinement phase
 - Higgs phase most distinct for the ghost