Gauge Dependence of Correlation Functions

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Oberwölz - Austria

Overview

- Gauge-fixing in the non-perturbative domain

Supported by the FWF

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- Propagators in Landau gauges

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- Gauge-fixing in the non-perturbative domain
- Propagators in Landau gauges
- Propagators outside the Landau gauges

  (Together with A. Cucchieri and T. Mendes)

  - Linear covariant gauges
  - Gauges between the Landau and the Coulomb gauge
- Summary

Supported by the FWF

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- QCD is a gauge theory with a Lie-algebra-element valued gauge-field $A_\mu = \tau^a A_\mu^a$
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- Correlation functions are in general gauge-dependent
  - Gauge-fixing is required
- Gauge-dependent quantities are interesting
  - Manifestation of confinement mechanism
    - Gribov-Zwanziger scenario
    - Topologial mechanisms

Unique gauge-fixing [For an introduction: Sobreiro & Sorella, 2005]

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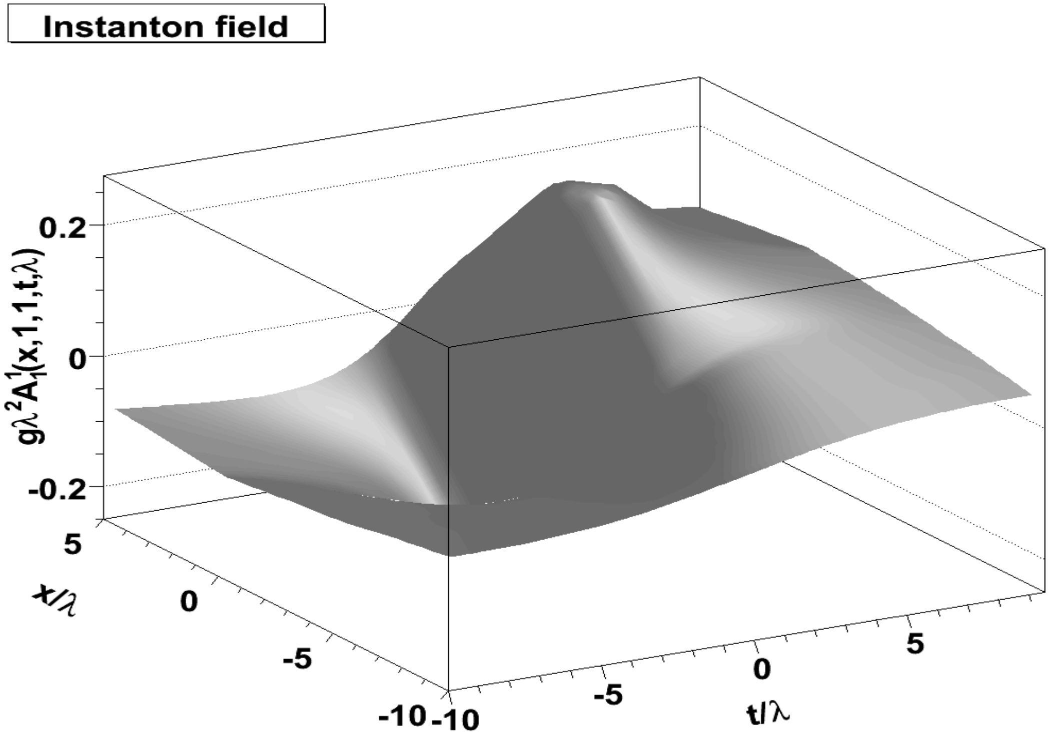
  - There are gauge-equivalent configurations which obey the same local gauge-condition: Gribov copies

Example: Instanton [Maas, EPJC 2006]



- **Instanton field configuration is** $A_\mu^a(r,\lambda)=2\mathrm{r}_\nu\eta_{\nu\mu}^a/(g(r^2+\lambda^2))$

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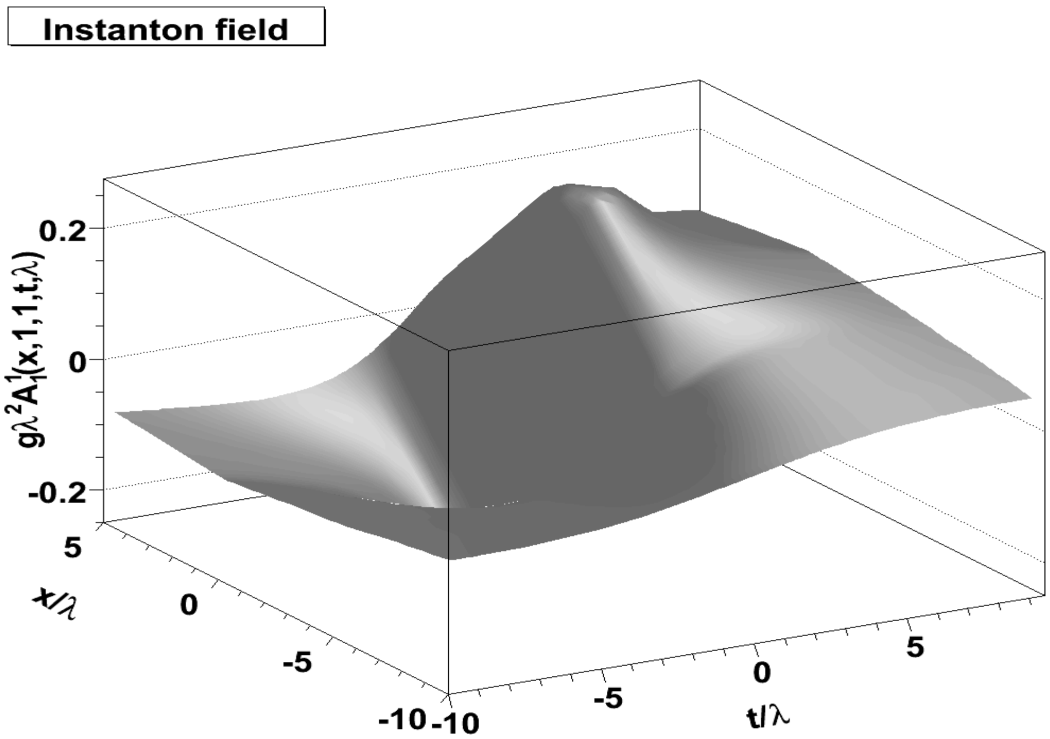

- Instanton field configuration is $A_\mu^a(r,\lambda)=2\mathrm{r}_\nu\eta_{\nu\mu}^a/(g(r^2+\lambda^2))$
  - It is a Landau-gauge configuration, satisfying $\partial_\mu A_\mu^a=0$

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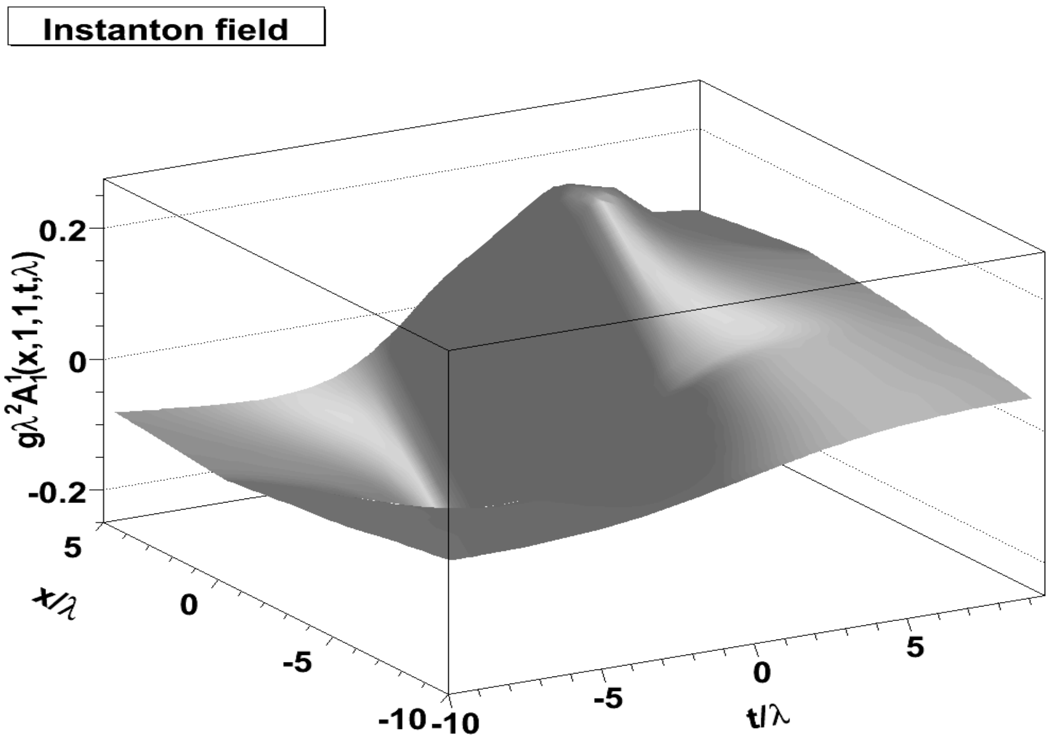

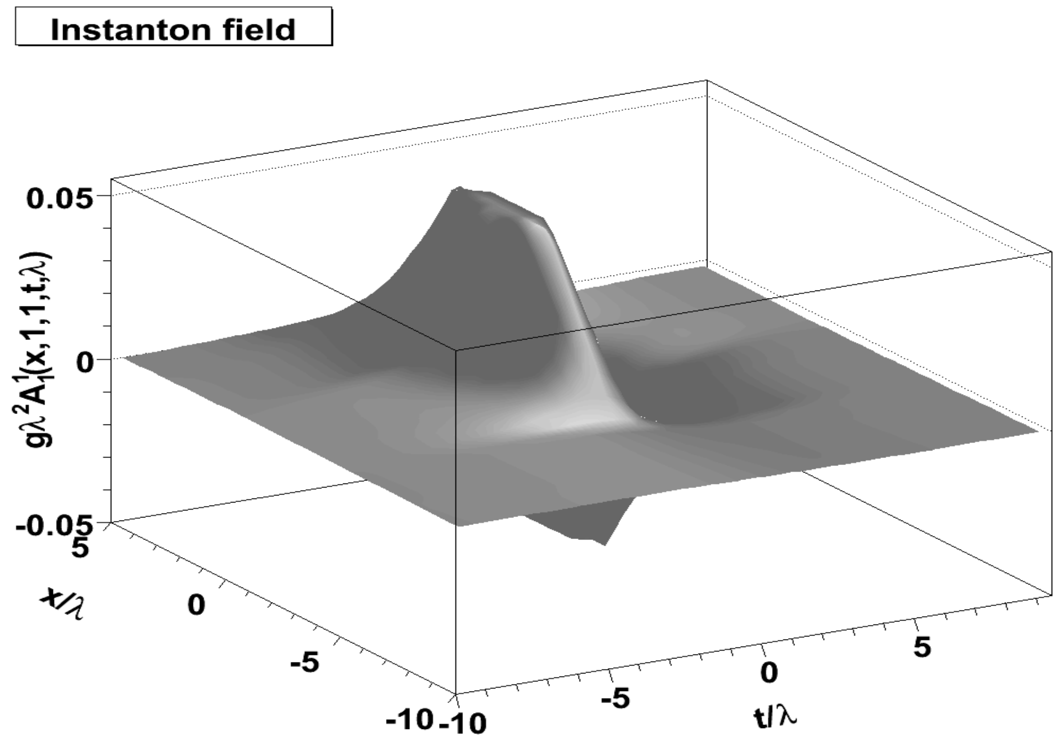

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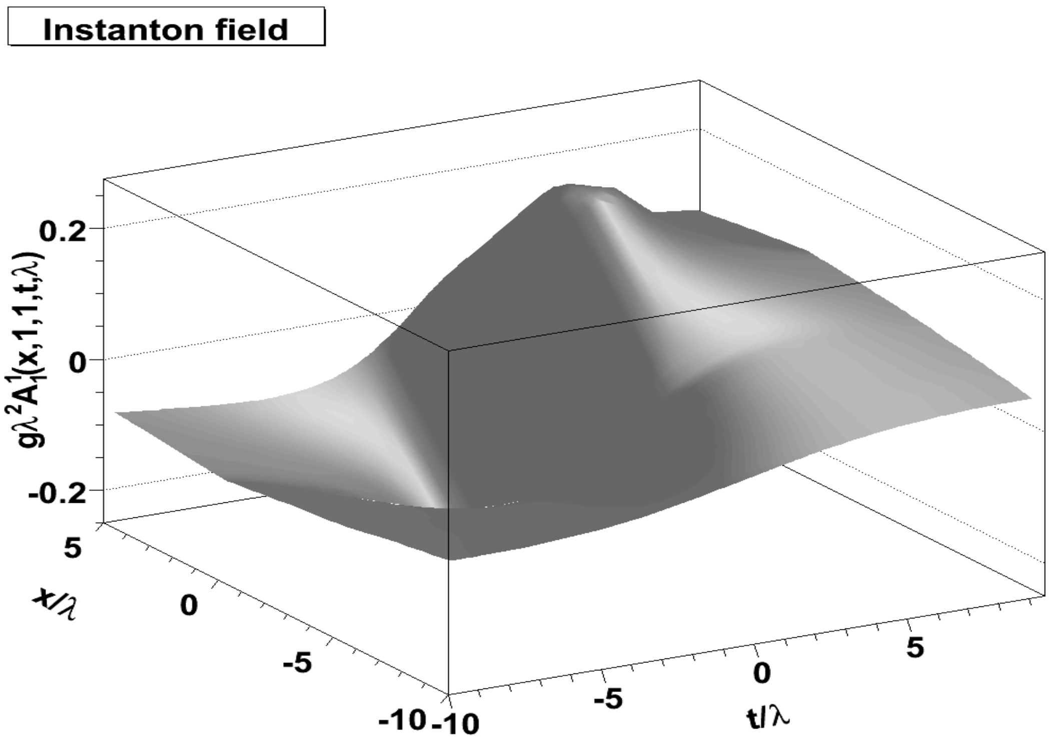

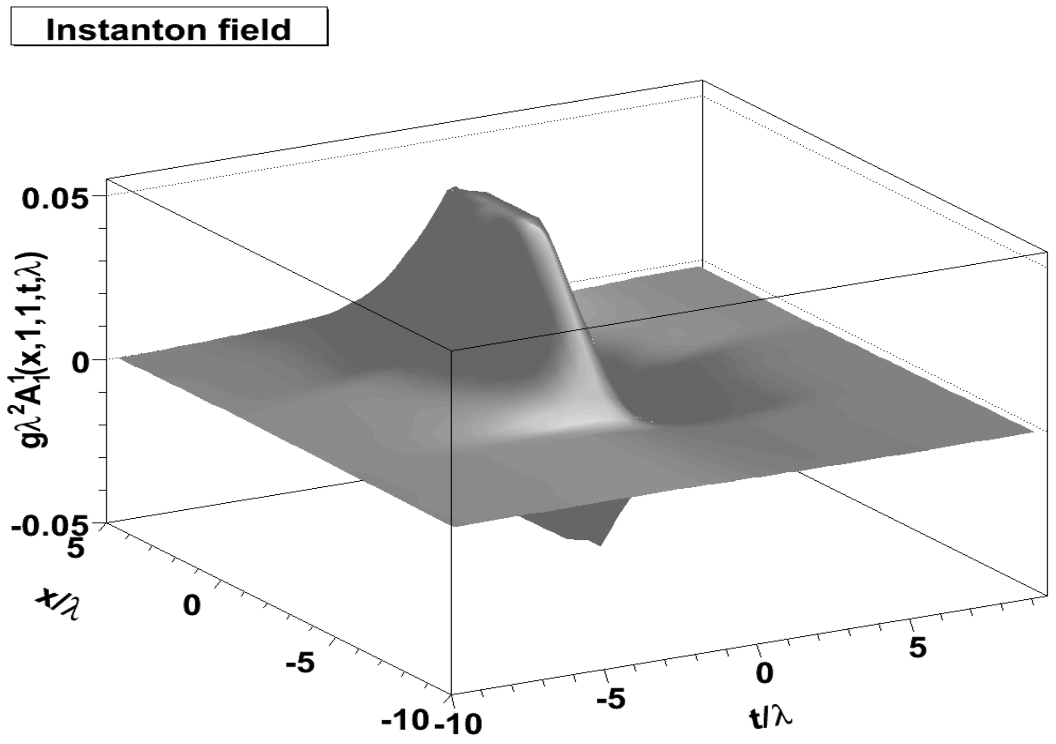

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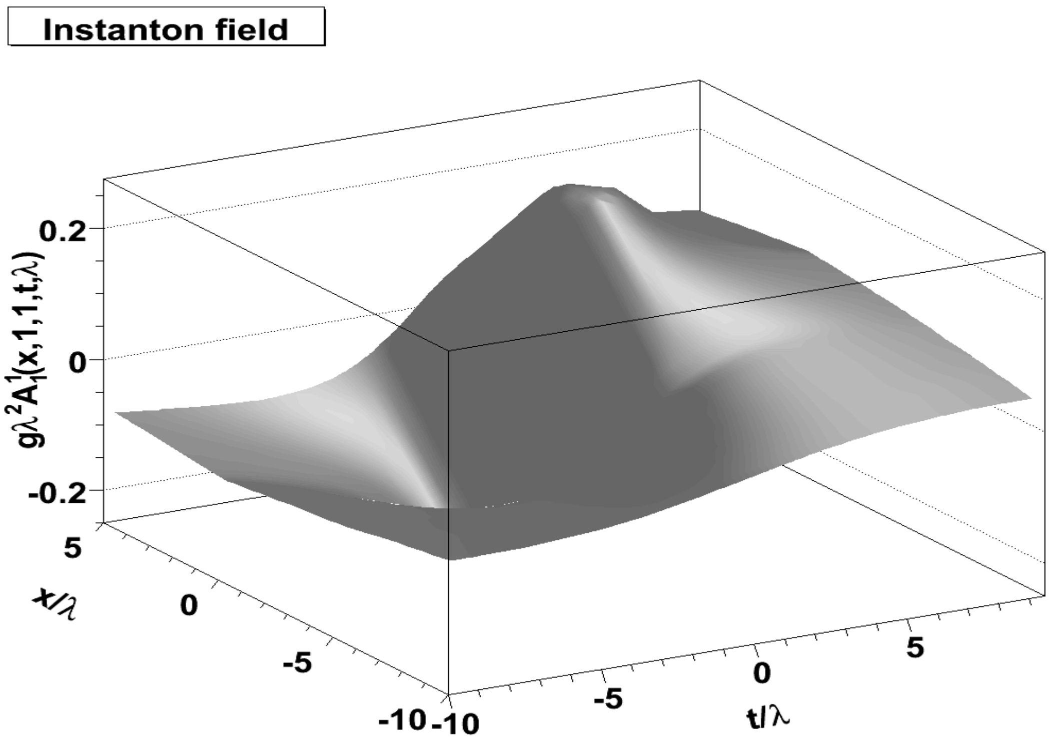

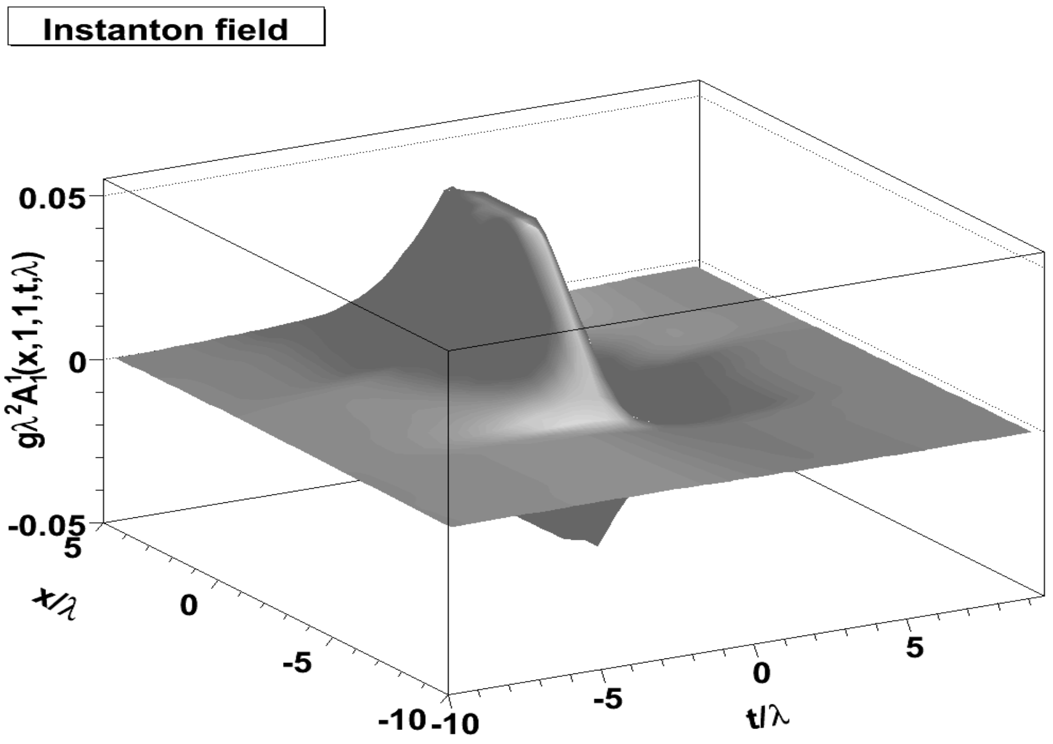

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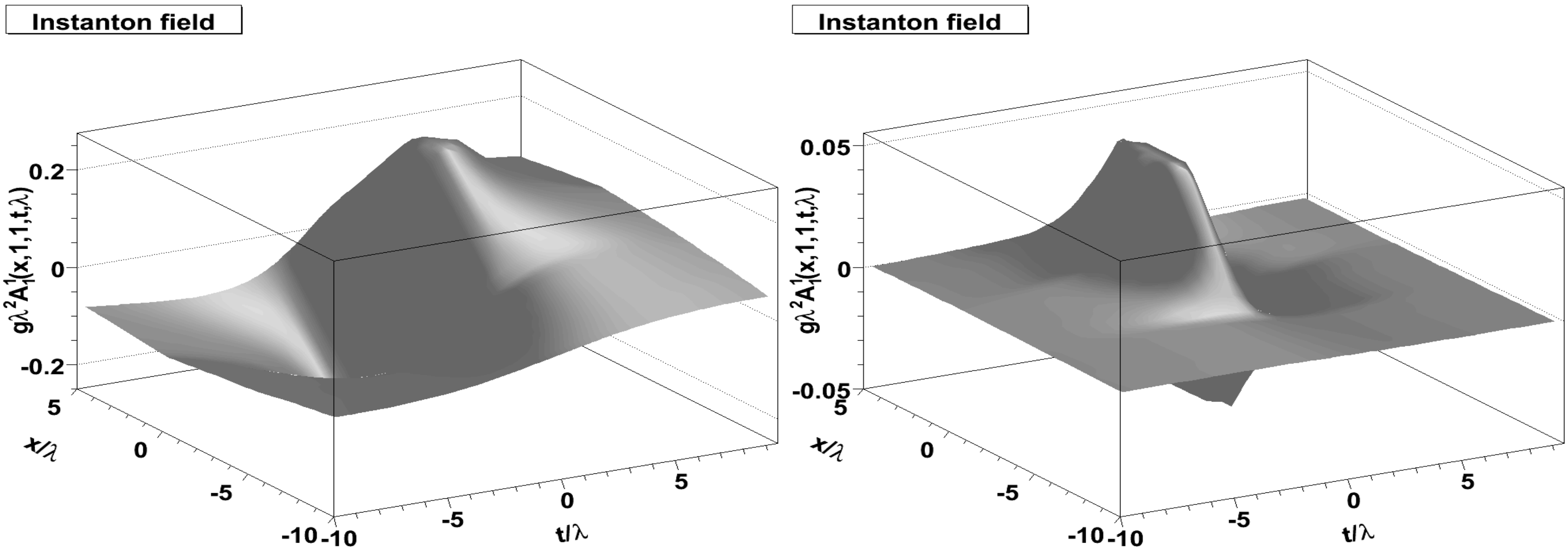

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  - Gribov copy
  - Non-perturbative: Depends on $1/g$

Unique gauge-fixing [For an introduction: Sobreiro & Sorella, 2005]

- In perturbation theory: Local gauge condition
  - Landau gauge: $\partial_\mu A_\mu^a = 0$
- Sufficient for perturbation theory
- Insufficient beyond perturbation theory
  - There are gauge-equivalent configurations which obey the same local gauge-condition: Gribov copies
- There are no known local gauge conditions, which lead to a unique gauge configuration
  - Non-local conditions possible, but impractical outside lattice gauge theory

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  - Reduces configuration space to a hypersurface

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  - There is no possibility using a local condition to restrict to one representative of the residual gauge orbit

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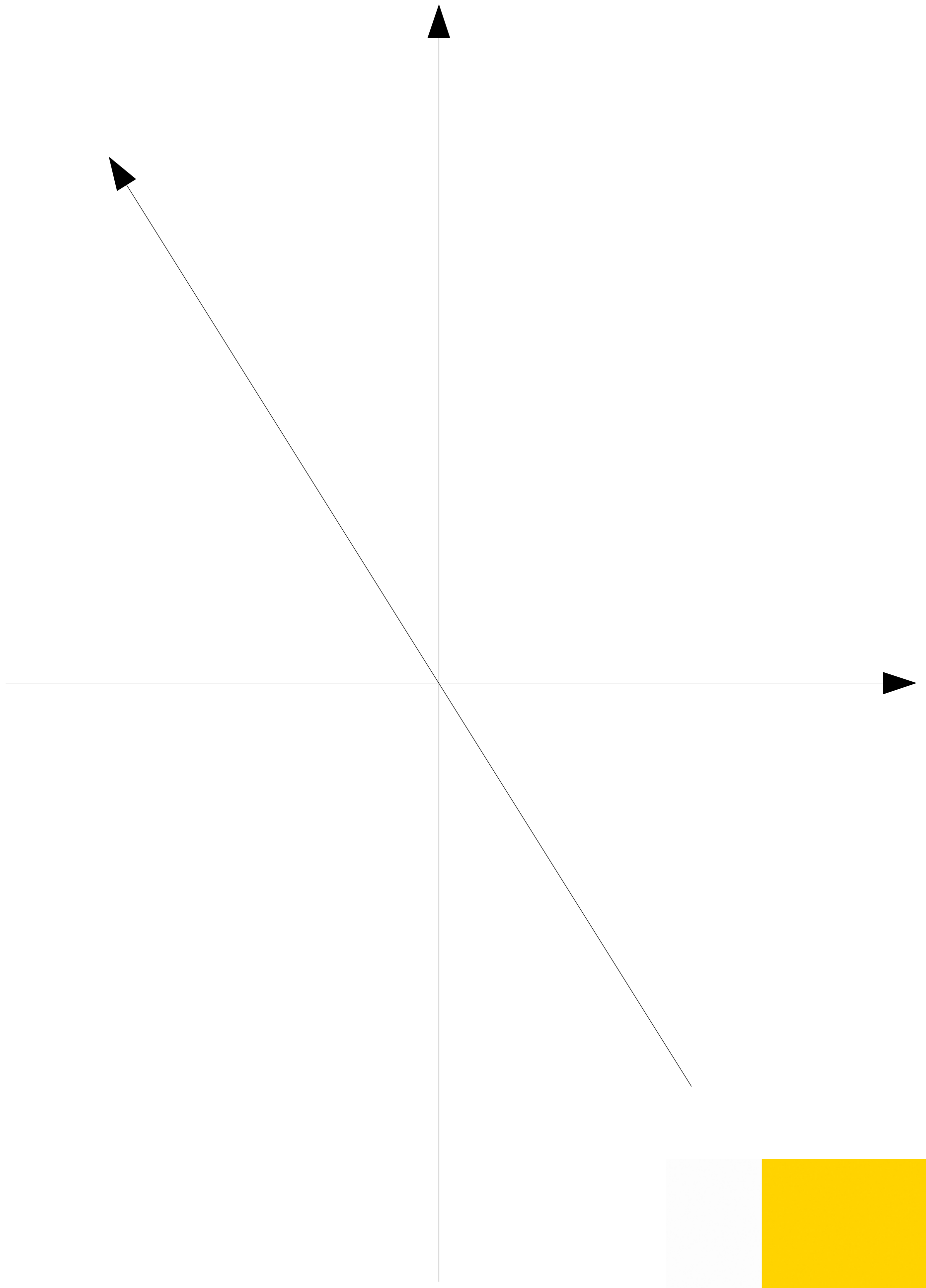
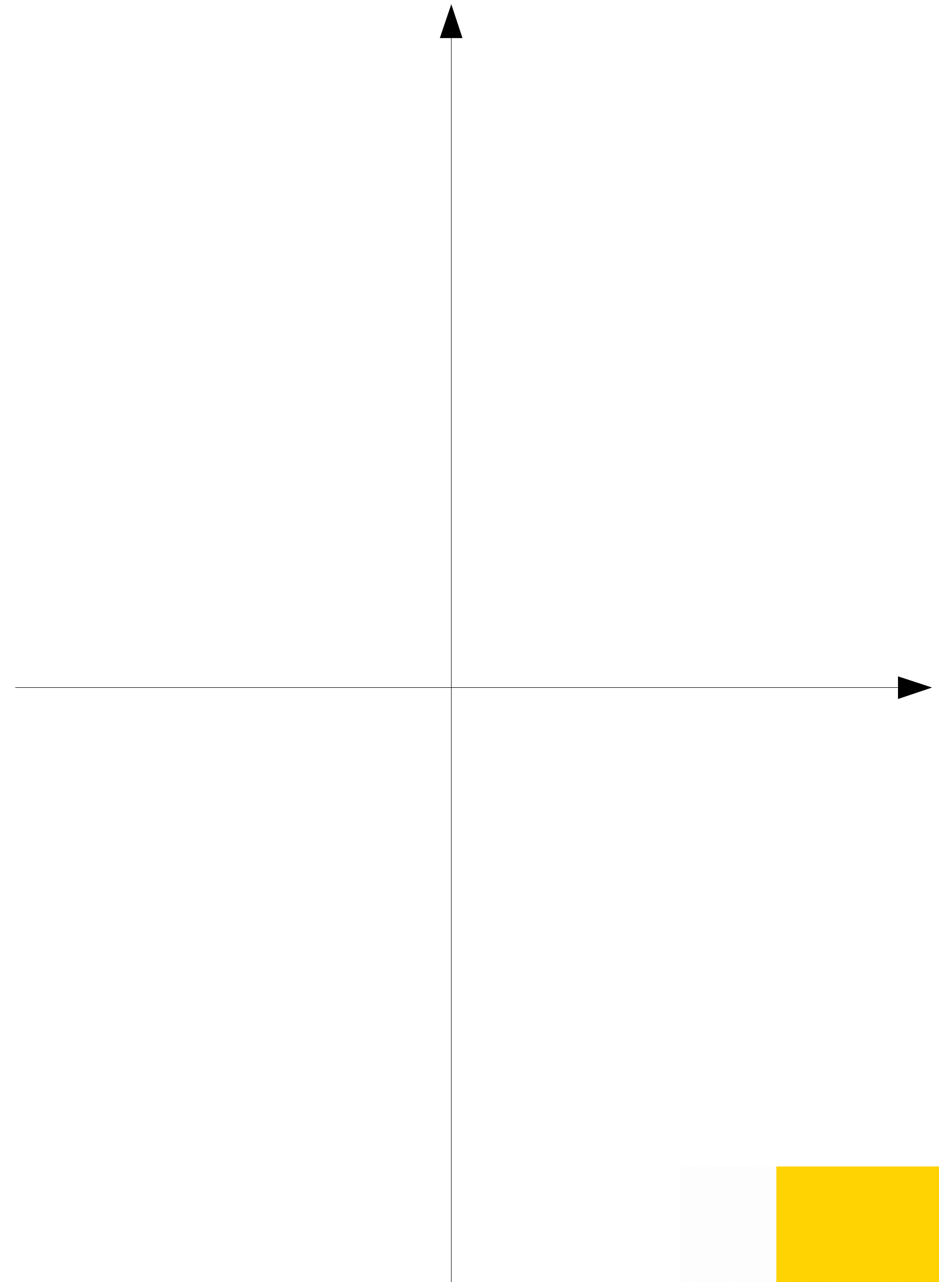
- Take a random representative of the residual gauge orbit: Minimal Landau gauge
- Other possibility: Average over (part of) the residual gauge orbit
  - Landau-Feynman-type
  - Average the complete residual orbit: Hirschfeld-like

Configuration space (artist's view)



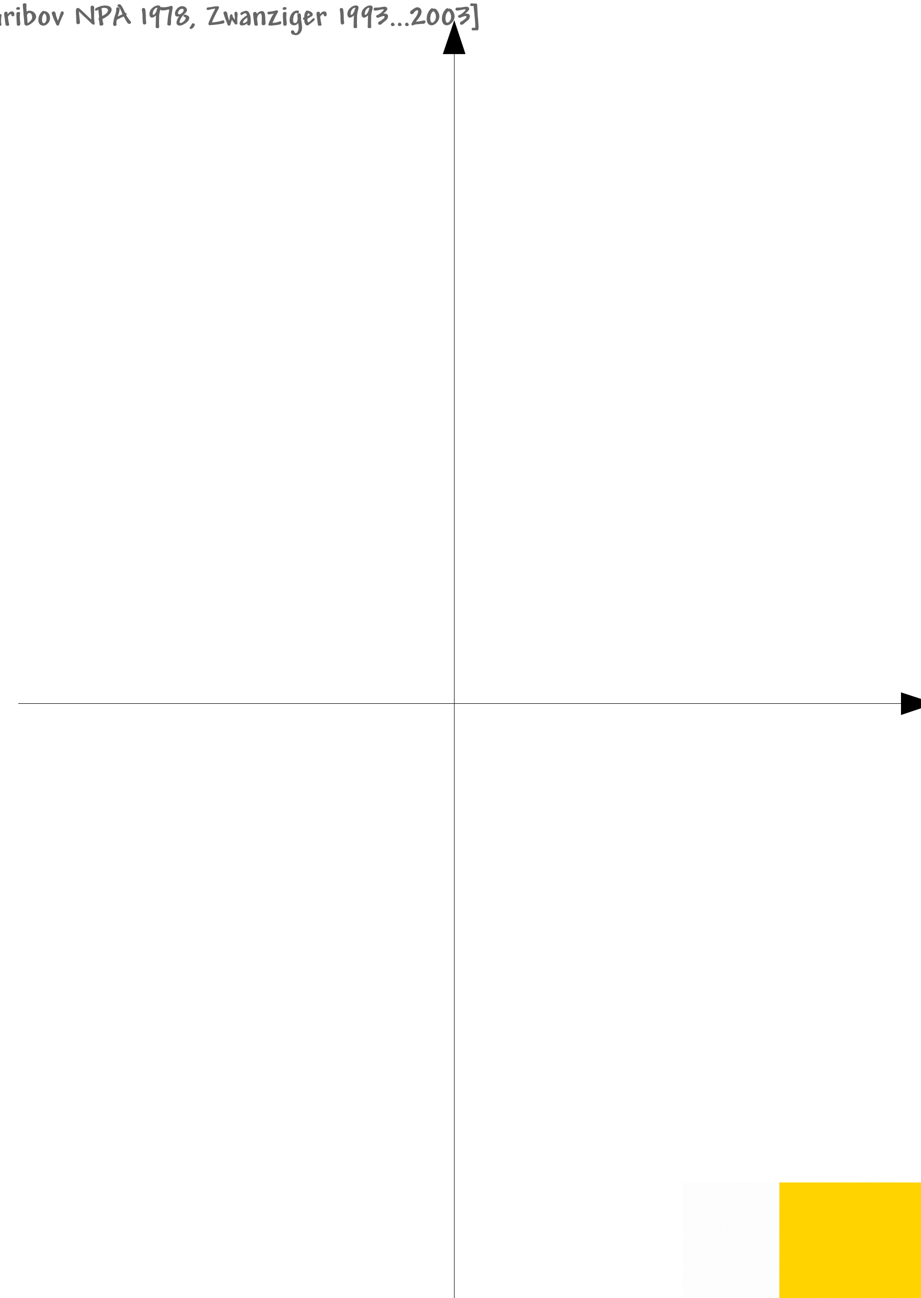
Configuration space (artist's view)

- Impose Landau gauge condition
  - Reduces configuration space to a hypersurface
  - Only residual gauge orbits left



Configuration space (artist's view) [Gribov NPA 1978, Zwanziger 1993...2003]

- Minimal Landau gauge



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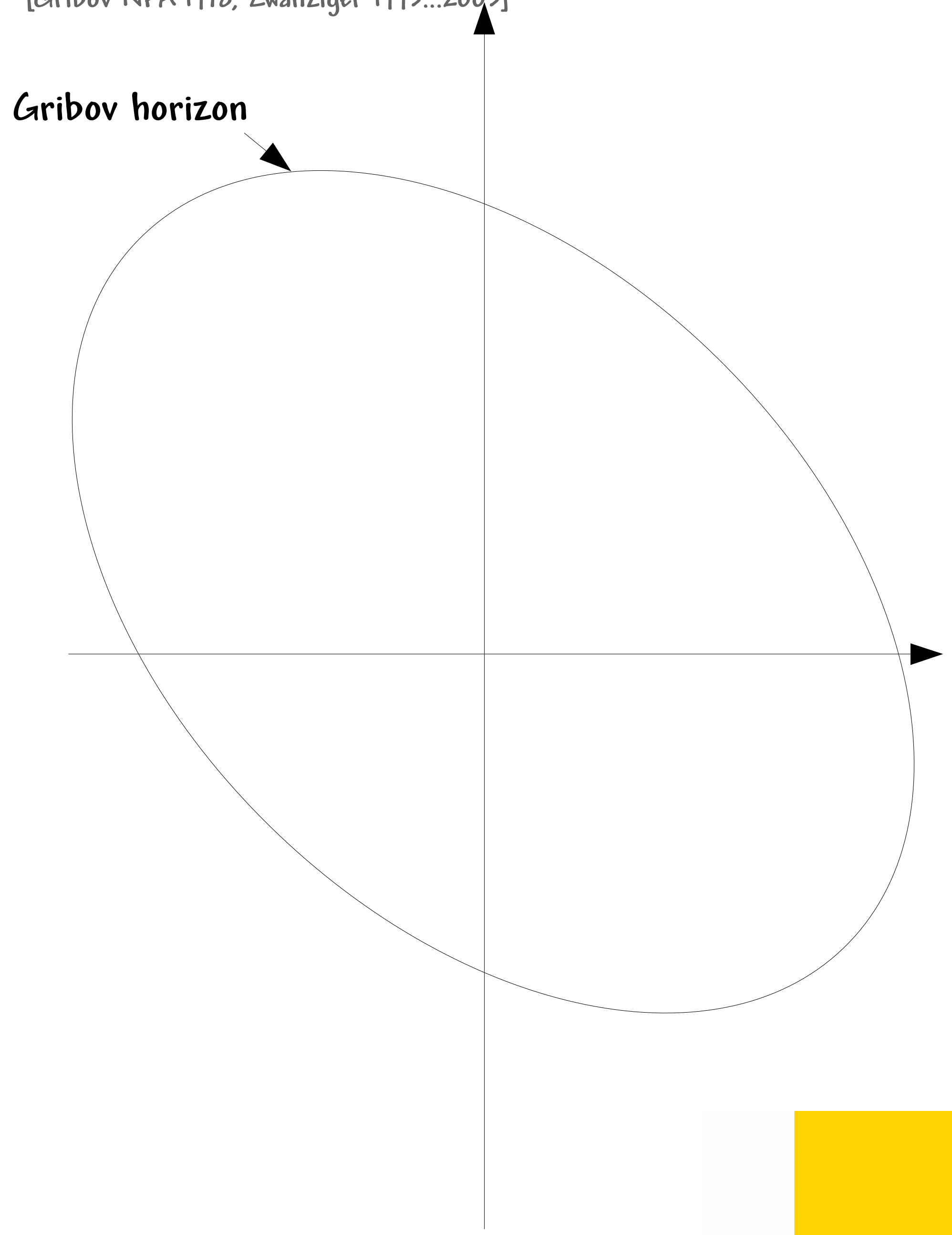
$$-\int d^d x\, A_\mu^a(x) A_\mu^a(x)$$

defines the first Gribov region



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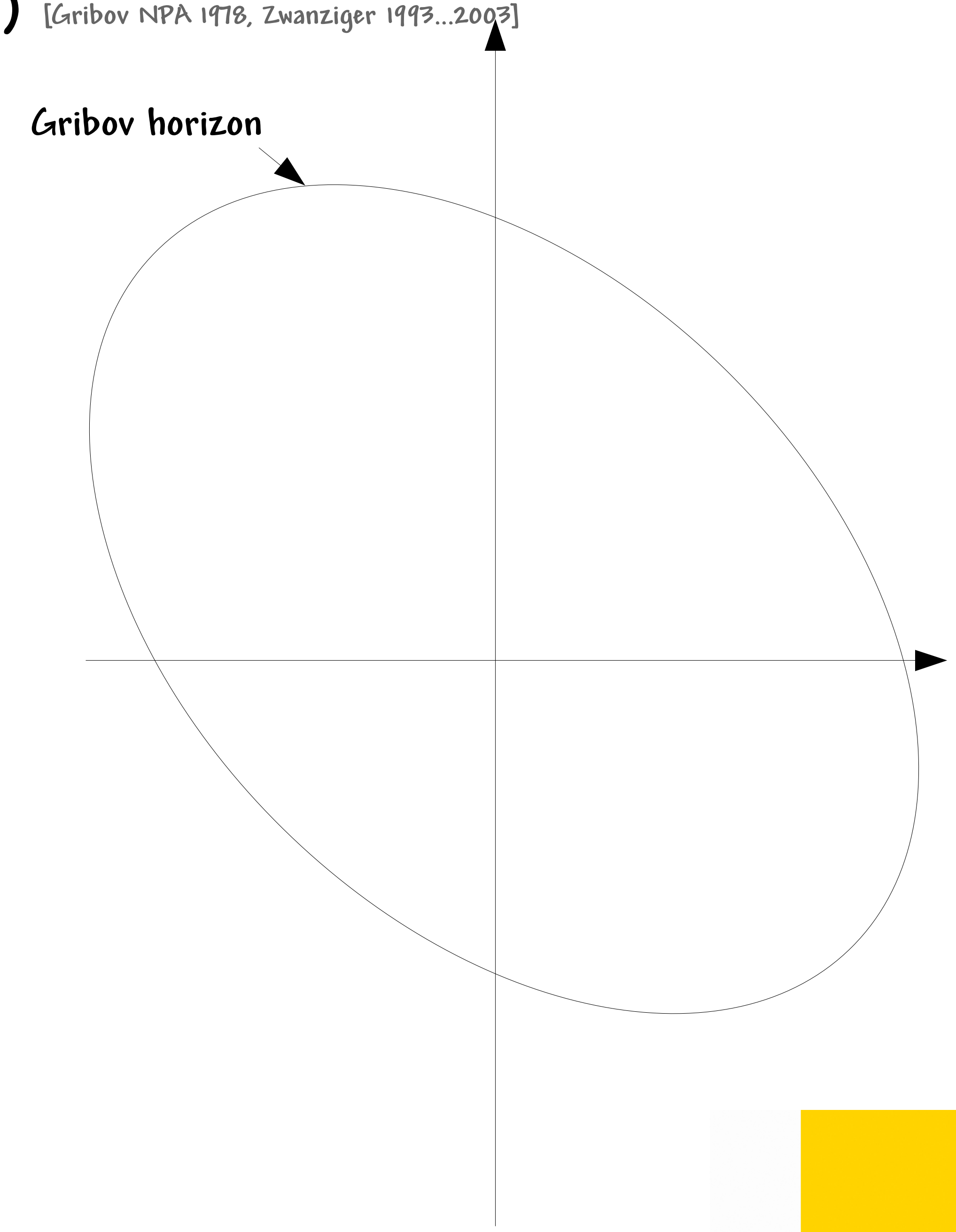

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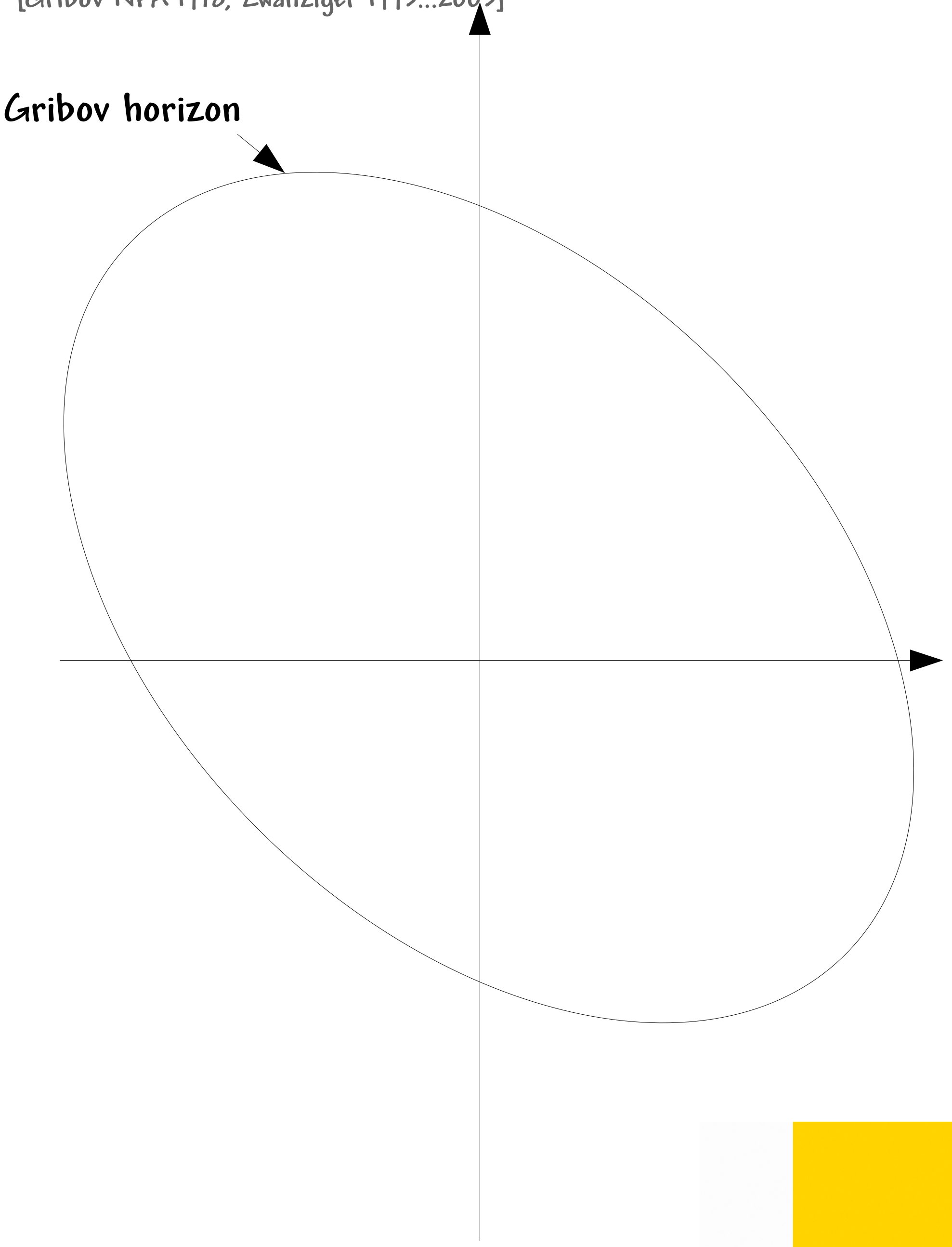

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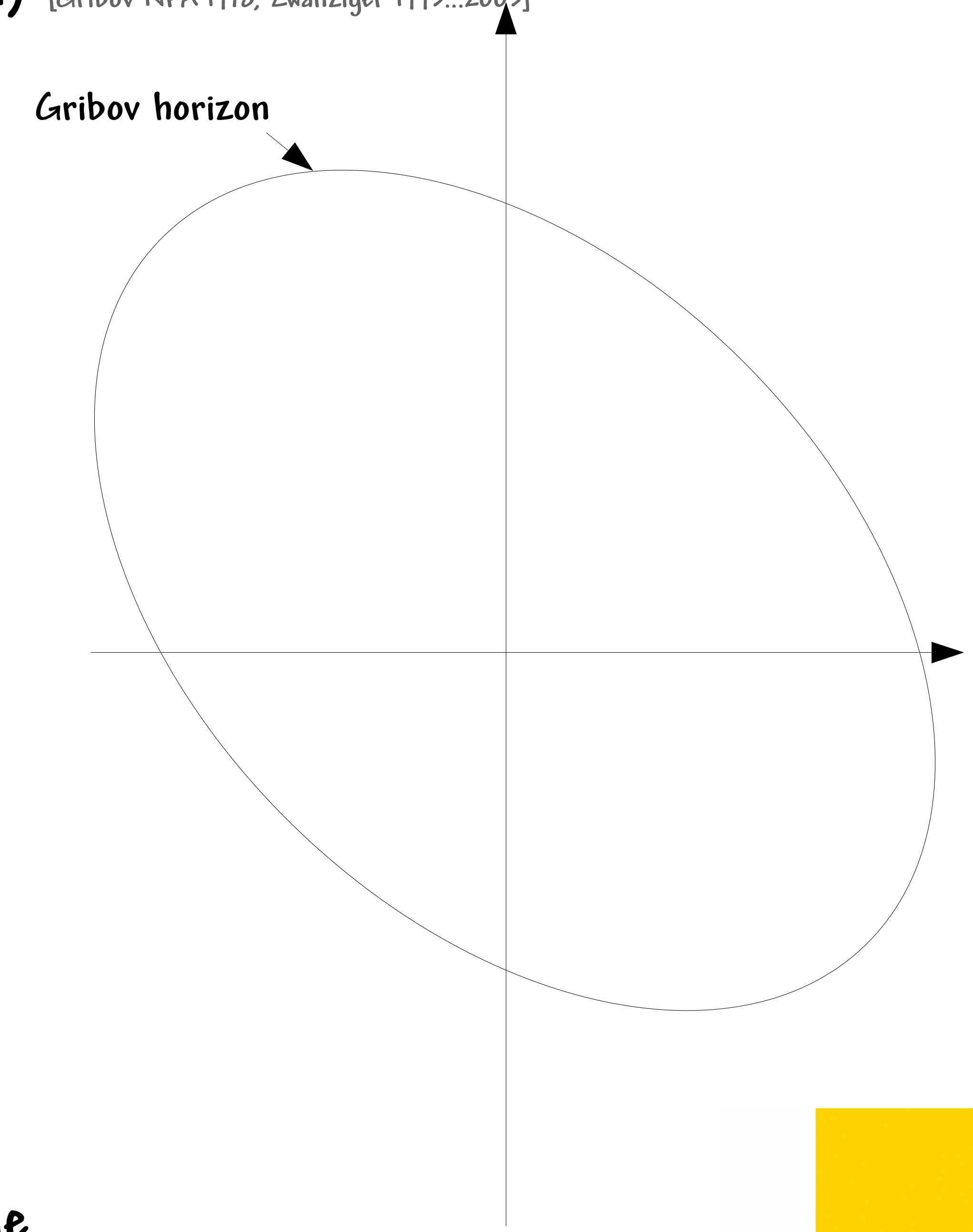
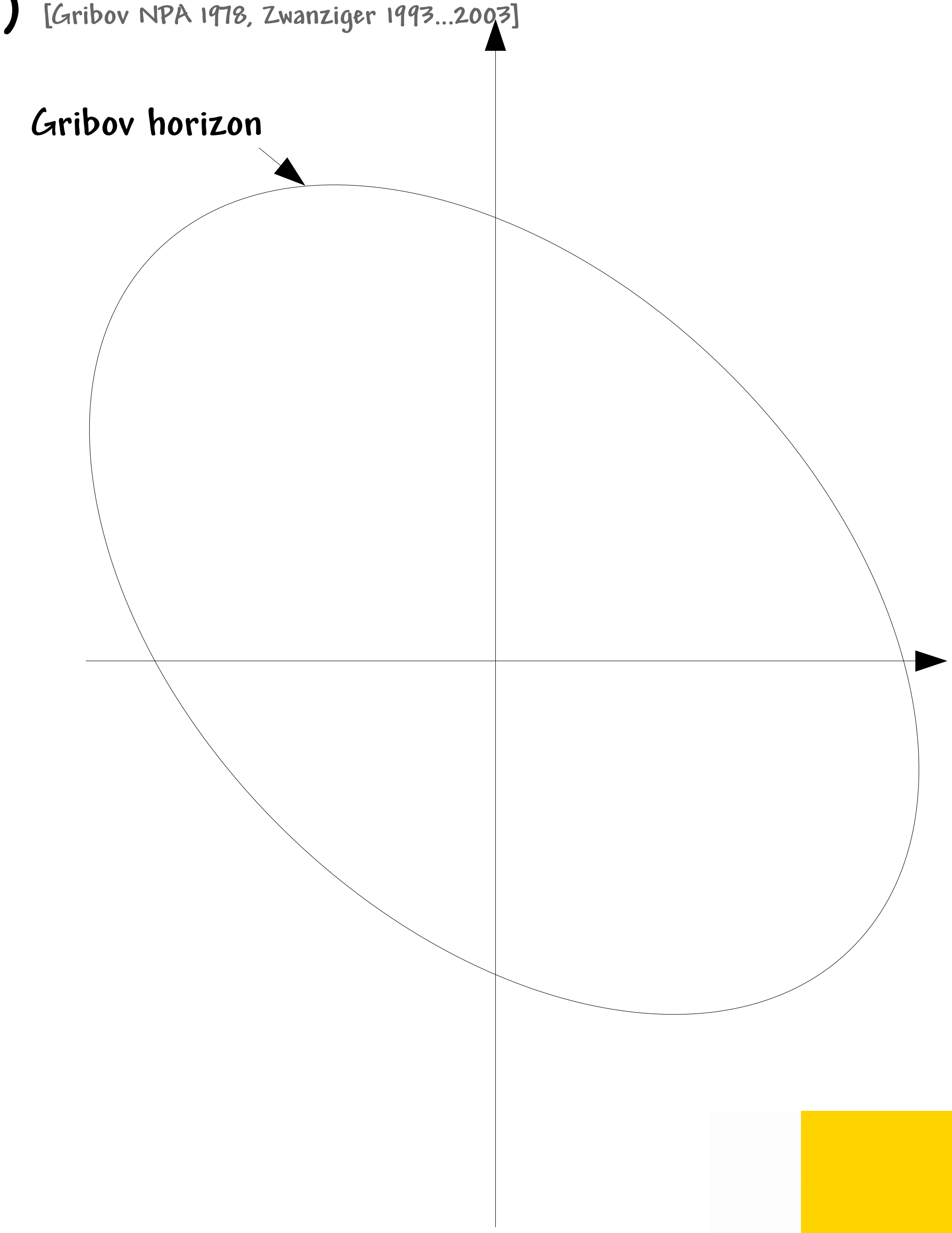
- Take an arbitrary representative out of this region: Minimal Landau gauge



Configuration space (artist's view) [Gribov NPA 1978, Zwanziger 1993...2003]

- Absolute Landau gauge



Configuration space (artist's view) [Gribov NPA 1978, Zwanziger 1993...2003]

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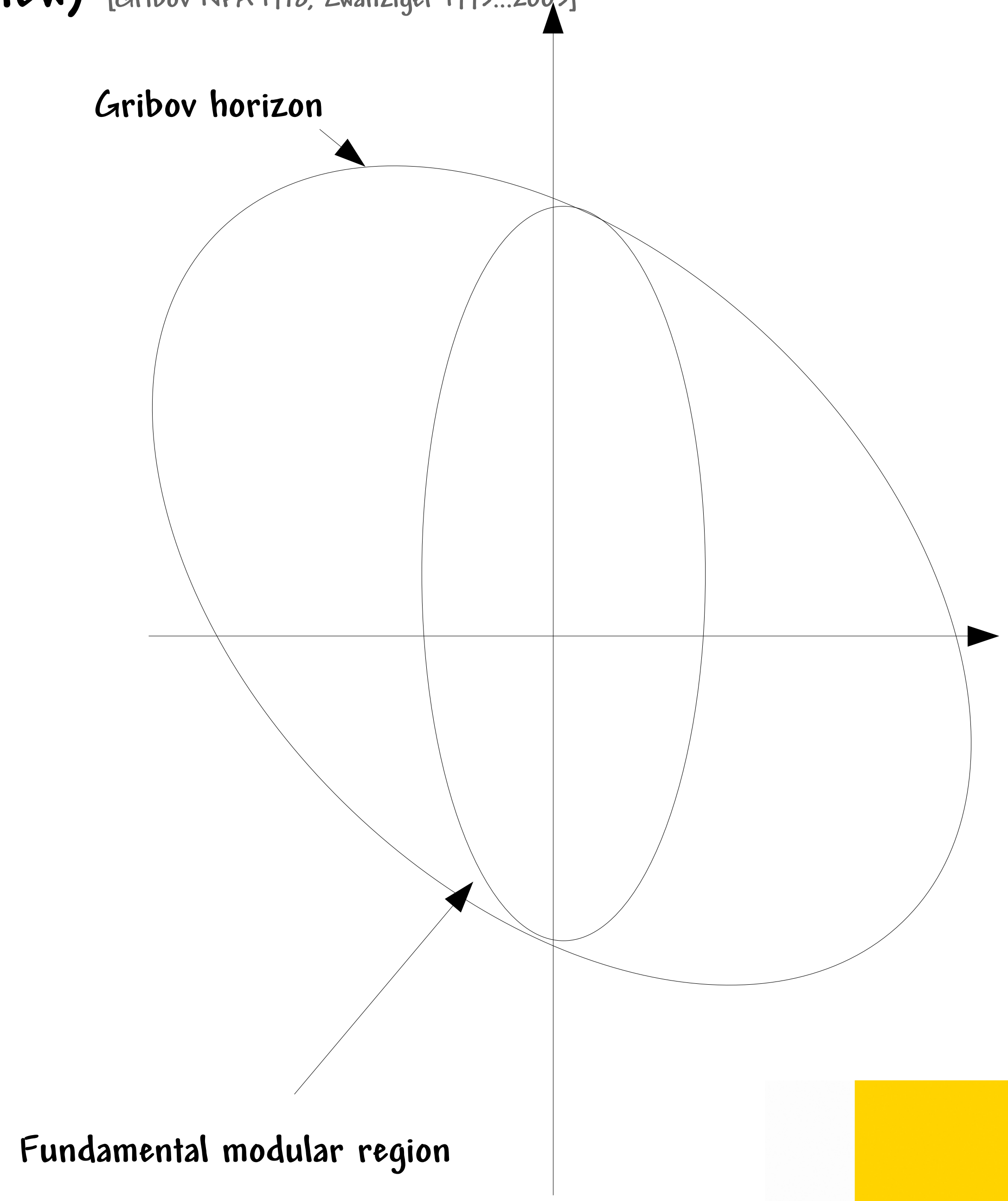

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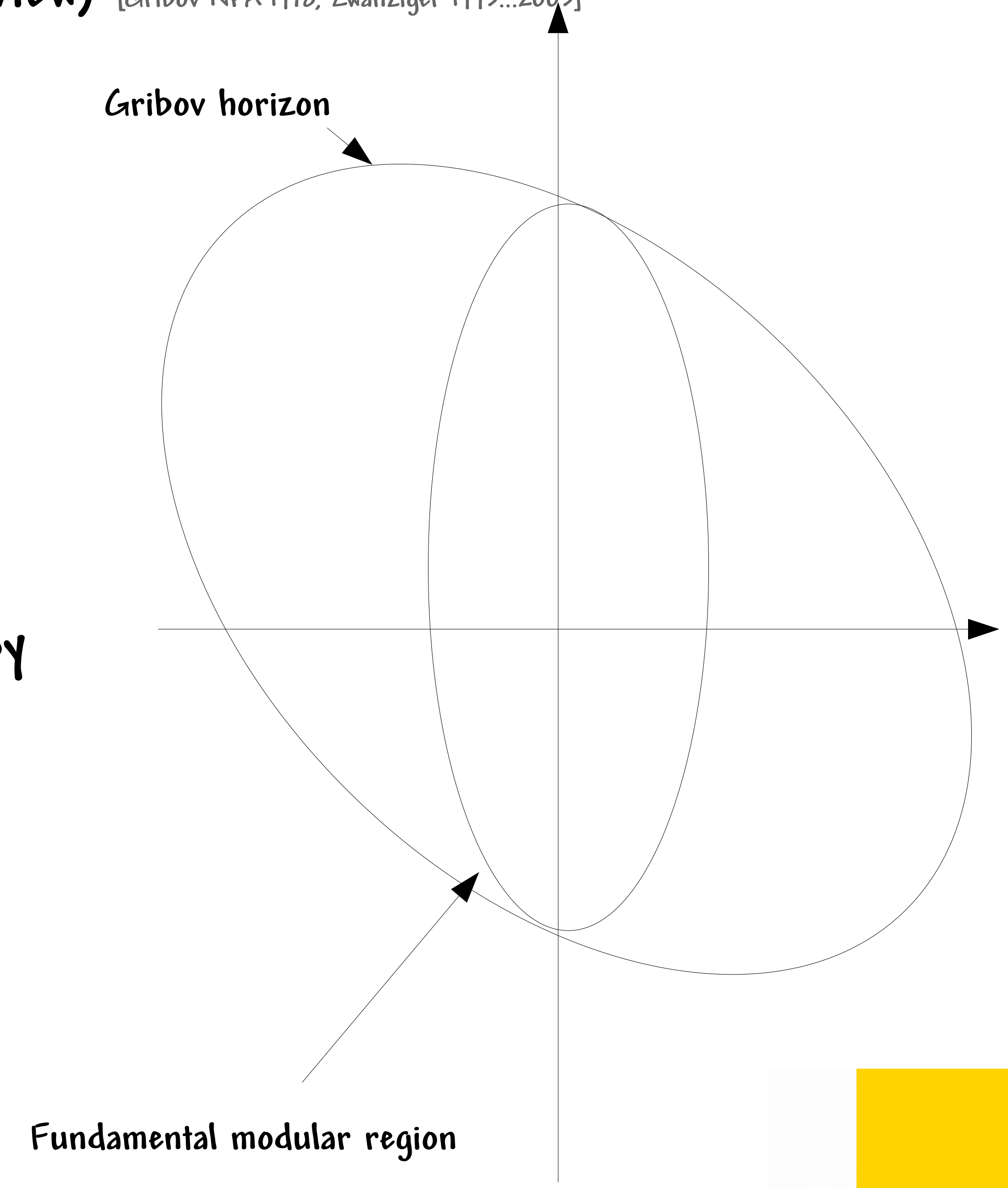

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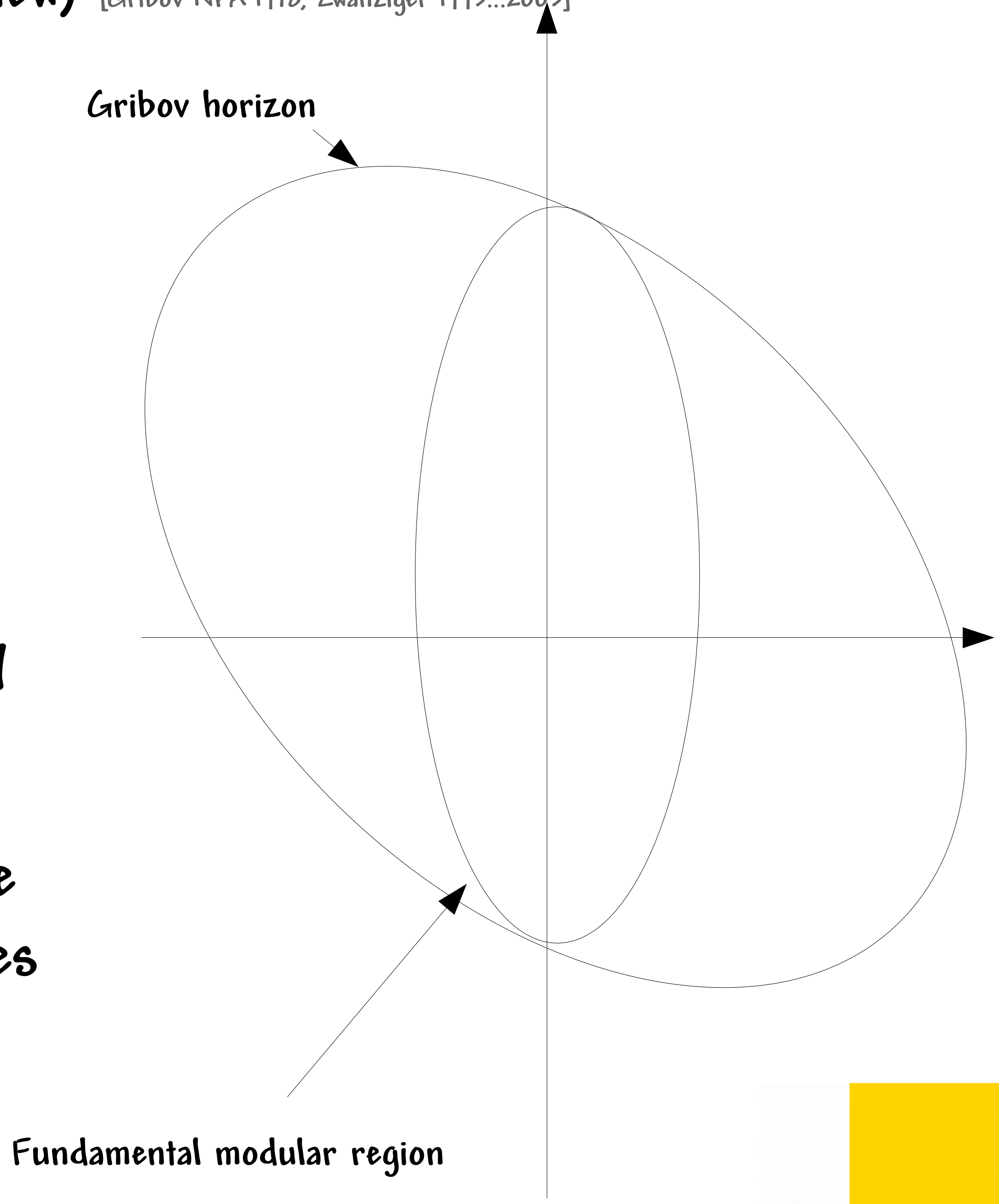
- Equivalent: Take the representative of the gauge orbit, which maximizes the trace of the gluon propagator

  $$\int dp\, D_{\mu\mu}^{aa}(p)$$



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- Here: Compare absolute and minimal Landau gauge
- Exponentially hard problem on the lattice
  - Simpler the lower dimension
  - Study also lower-dimensional systems

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  - Here: Comparison to those without color-superselection sectors (confining phase), BRST-preserving and being valid in the absolute Landau gauge [Fischer et al., 2008]
- Higher n-point functions are also been studied

Propagators [Introduction: Alkofer & von Smekal, 2001]

- Gauge-fixed Lagrangian in Landau gauge

$$L = F^a_{\mu\nu} F^a_{\mu\nu} - \bar{c}^a \partial_\mu D^{ab}_\mu c^b$$

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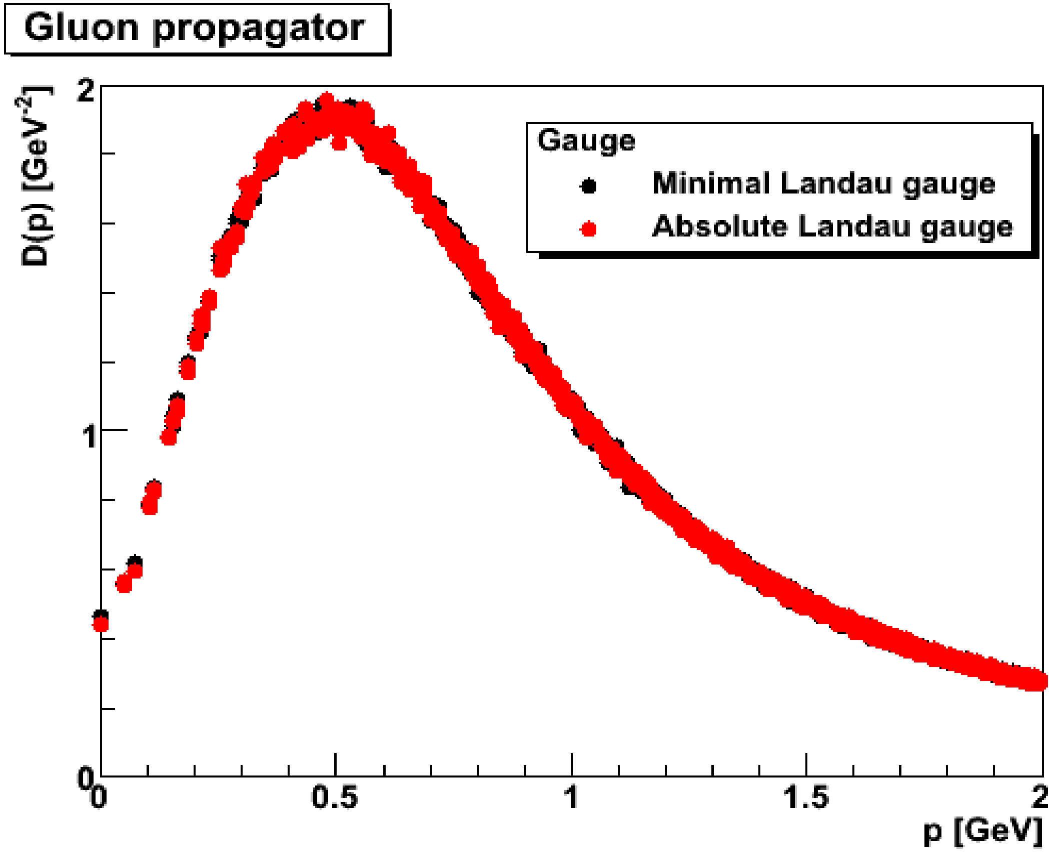
- Ghost:

$$D^{ab}_G(x-y) = \langle \bar{c}^a(x) c^b(y) \rangle$$

$$D_G(p) = \frac{-G(p)}{p^2}$$

Impact on the propagators in 2d [136^2, beta=10, Maas, 2008]



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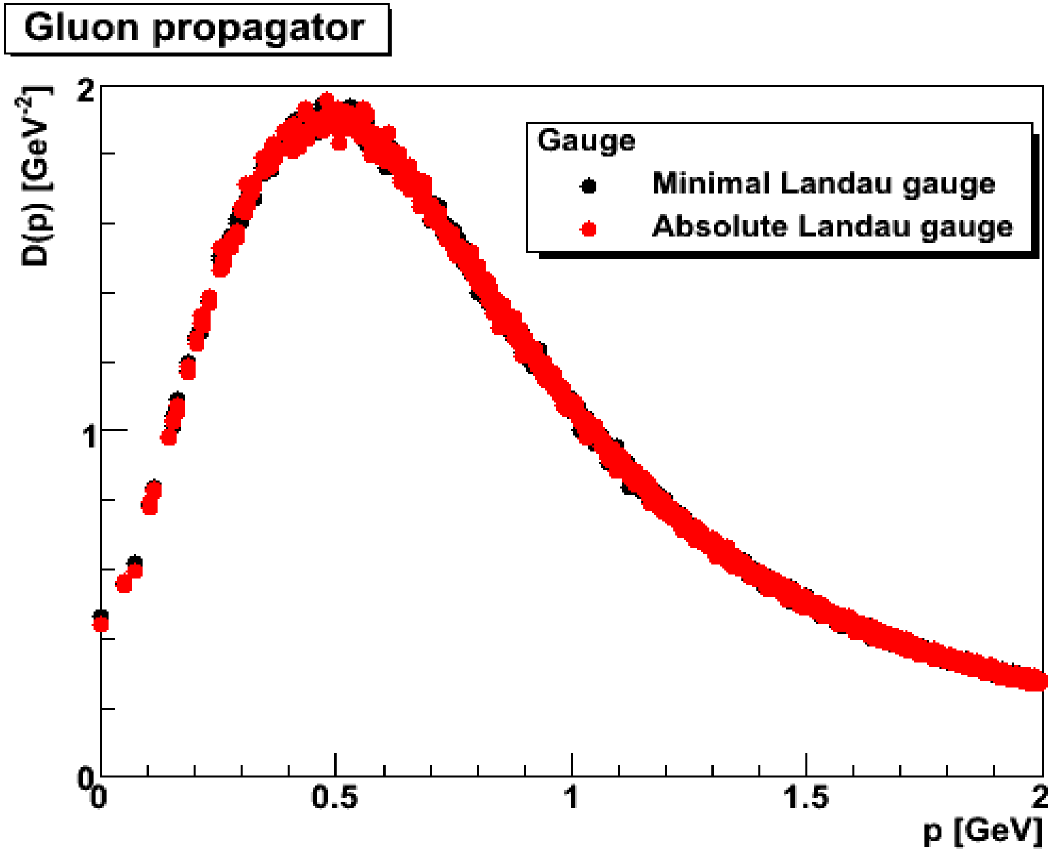

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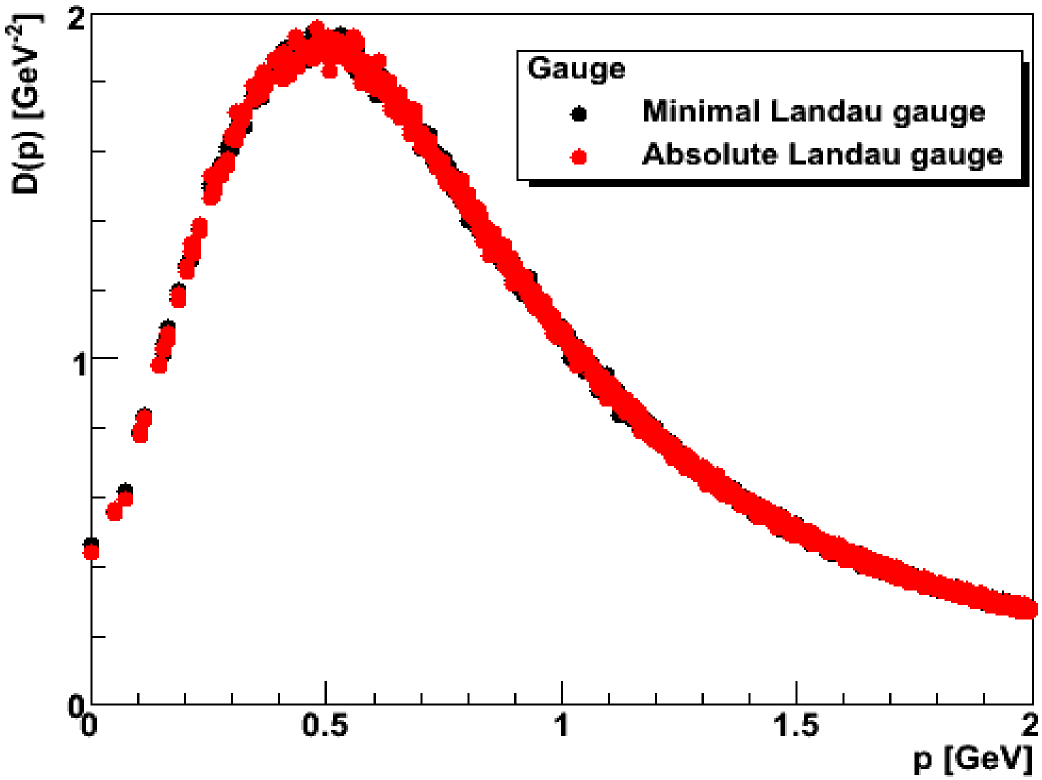
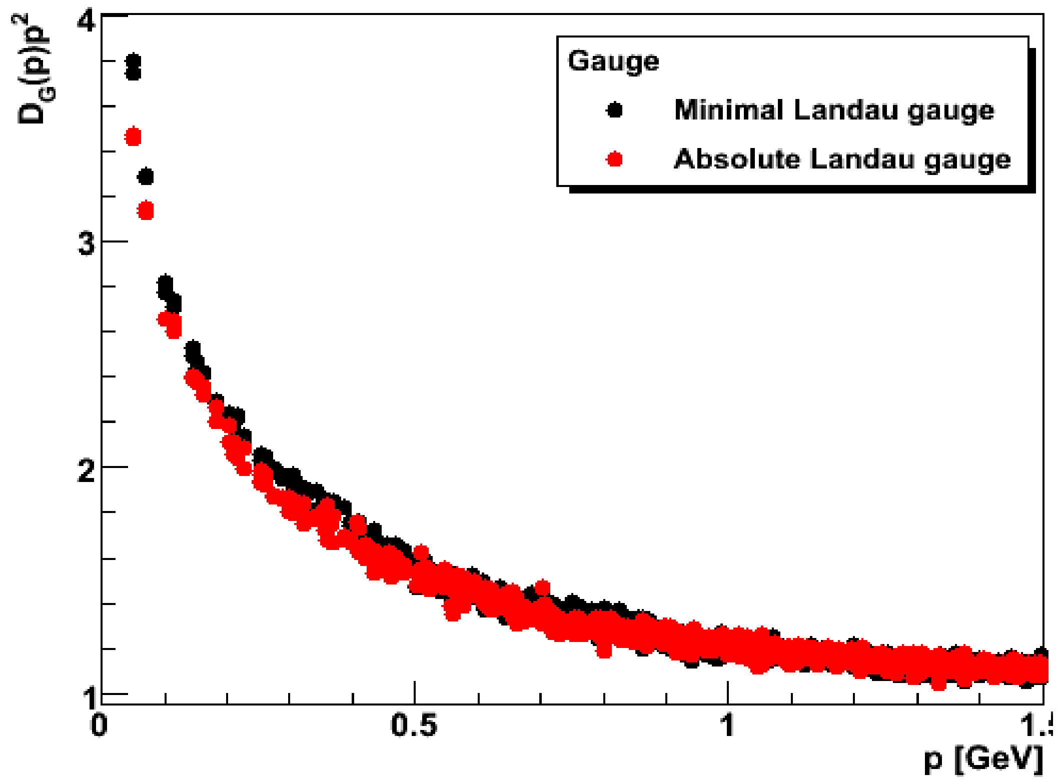


Ghost dressing function



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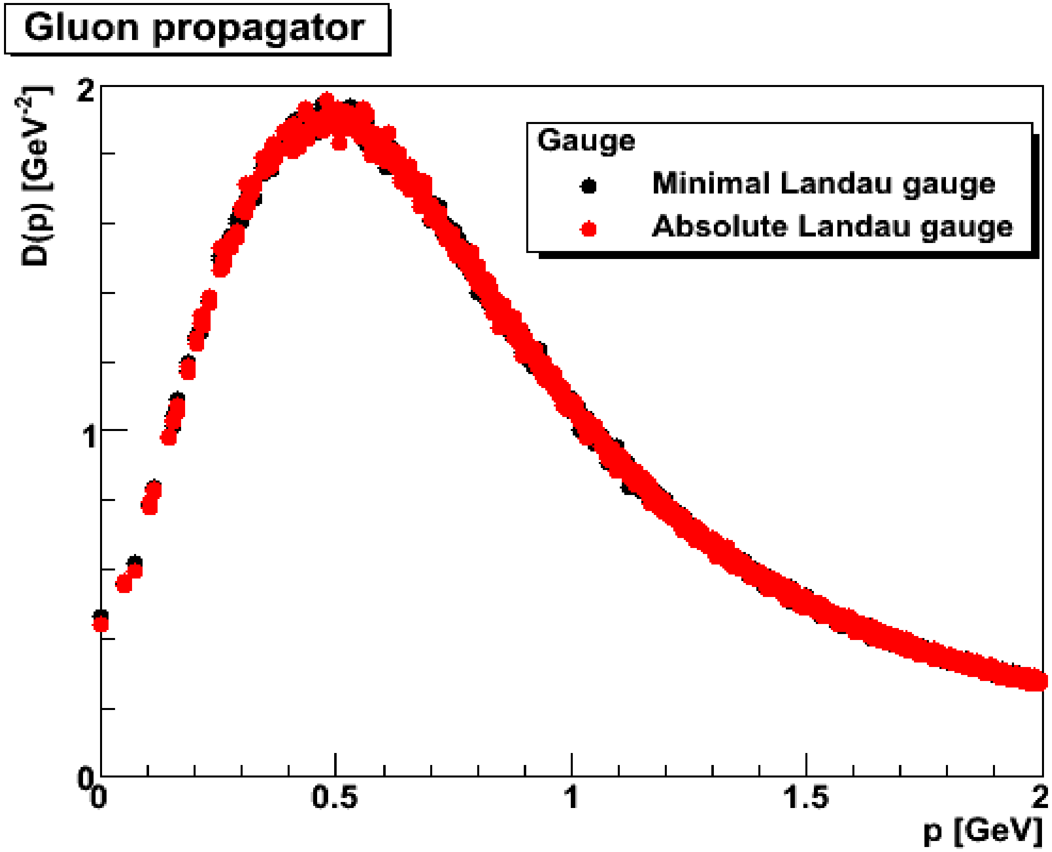

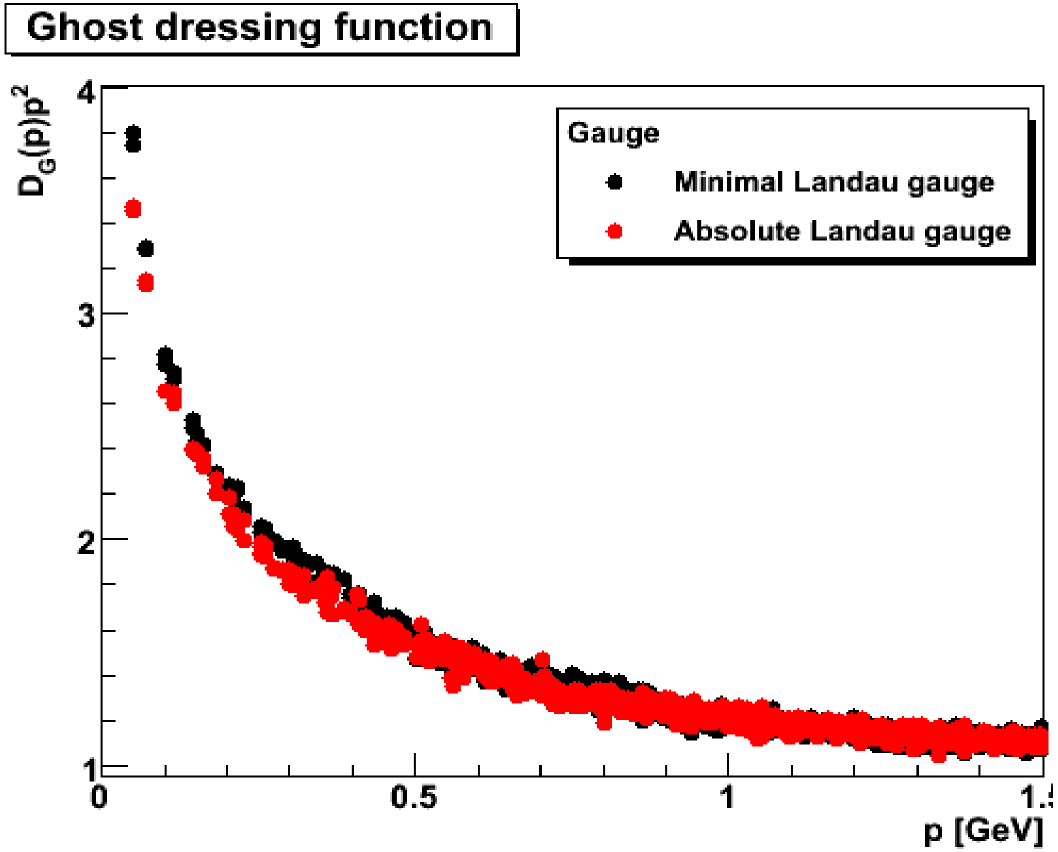

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- Ghost propagator somewhat less enhanced
  - Only the pre-factor changes

The running coupling

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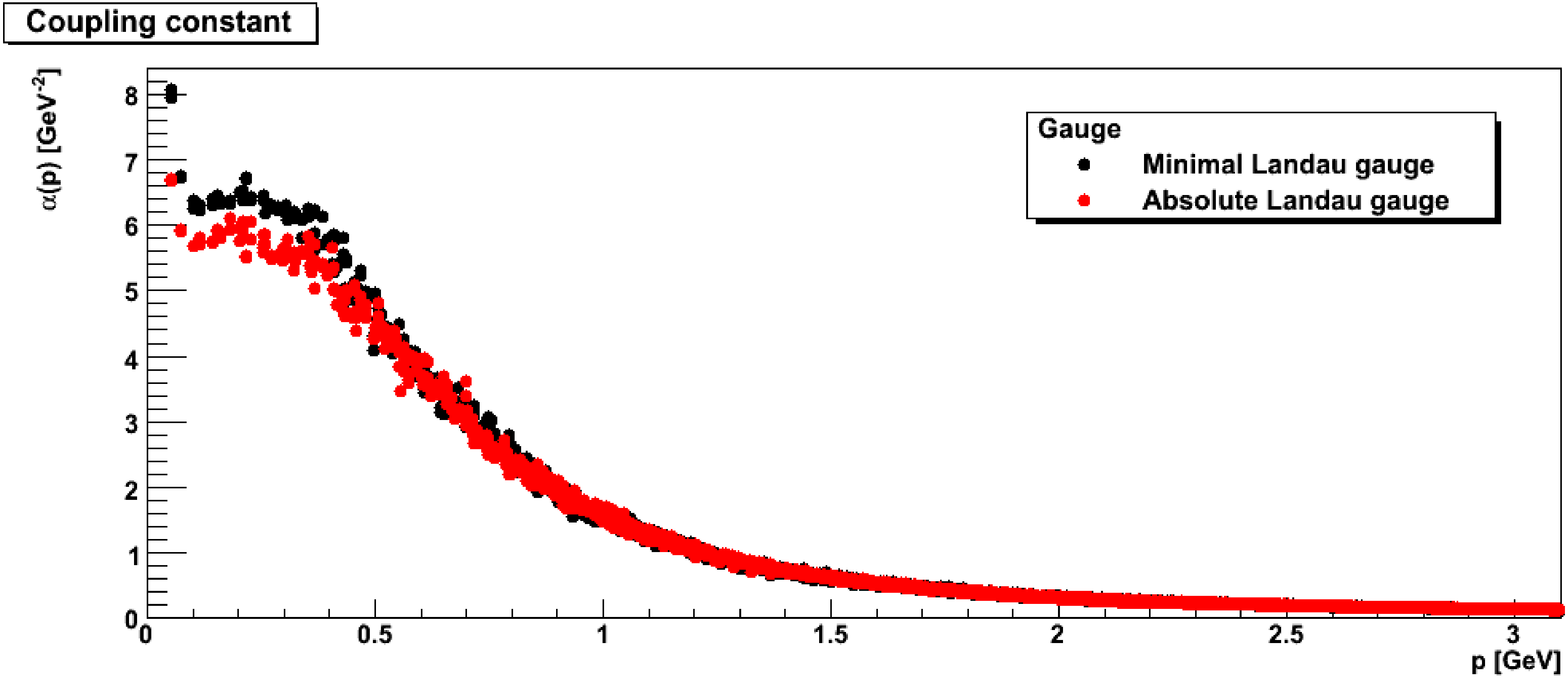

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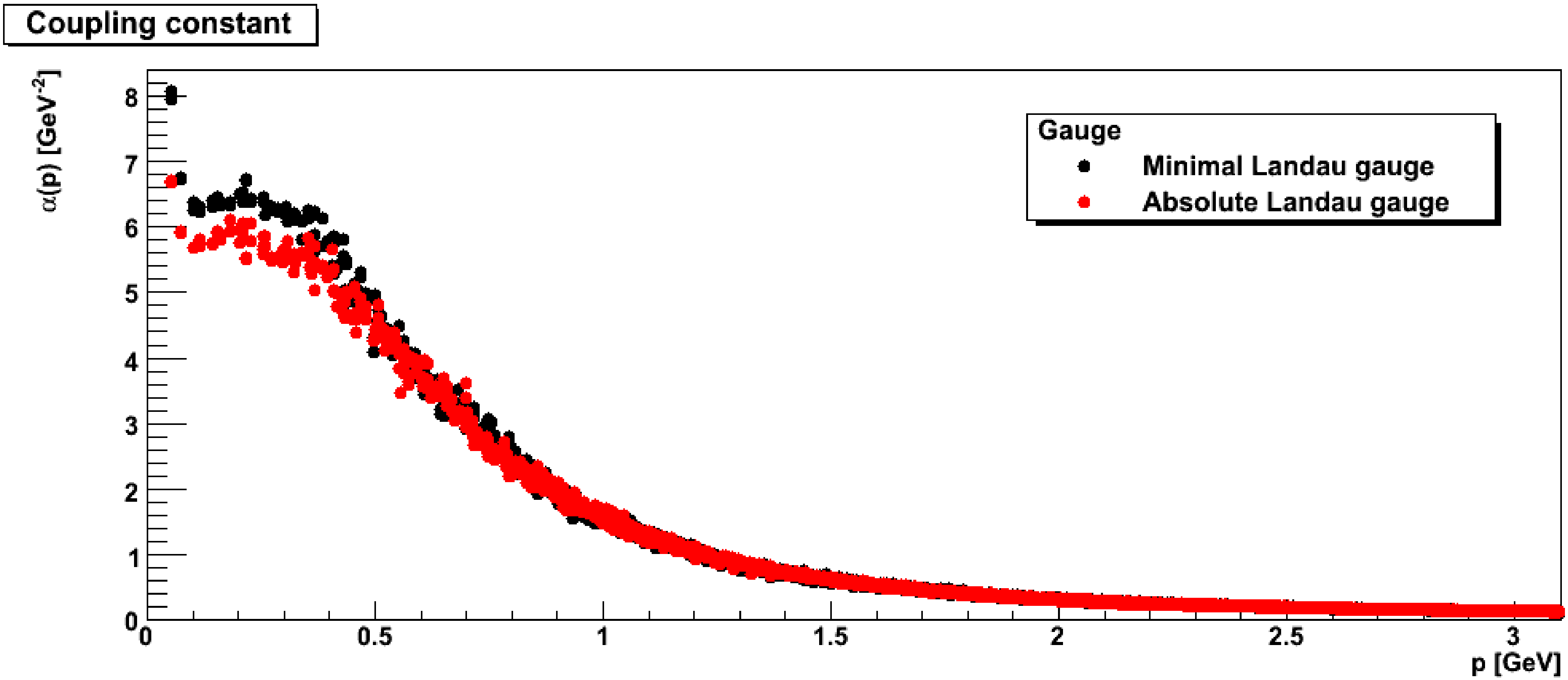

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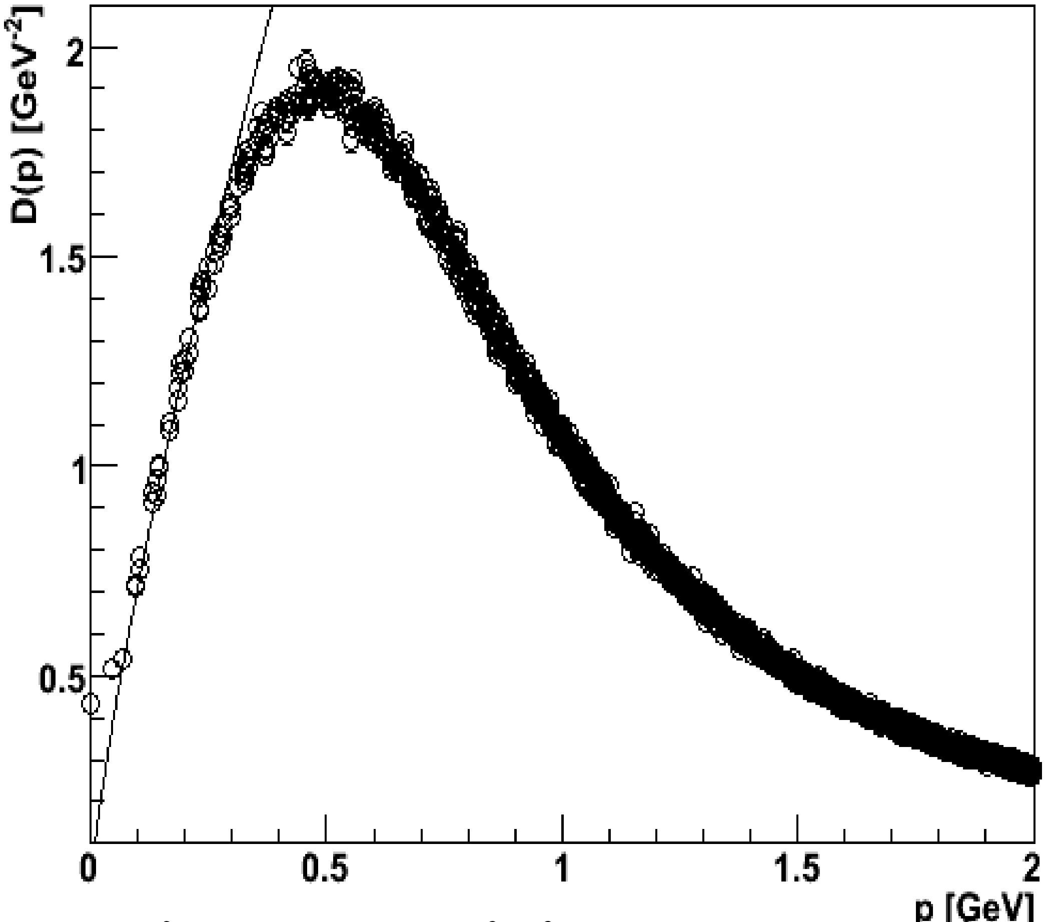
- Infrared fixed-point in both gauges

Comparison to functional results in 2d

Gluon propagator

[Maas, 2008, 136^2, beta=10]



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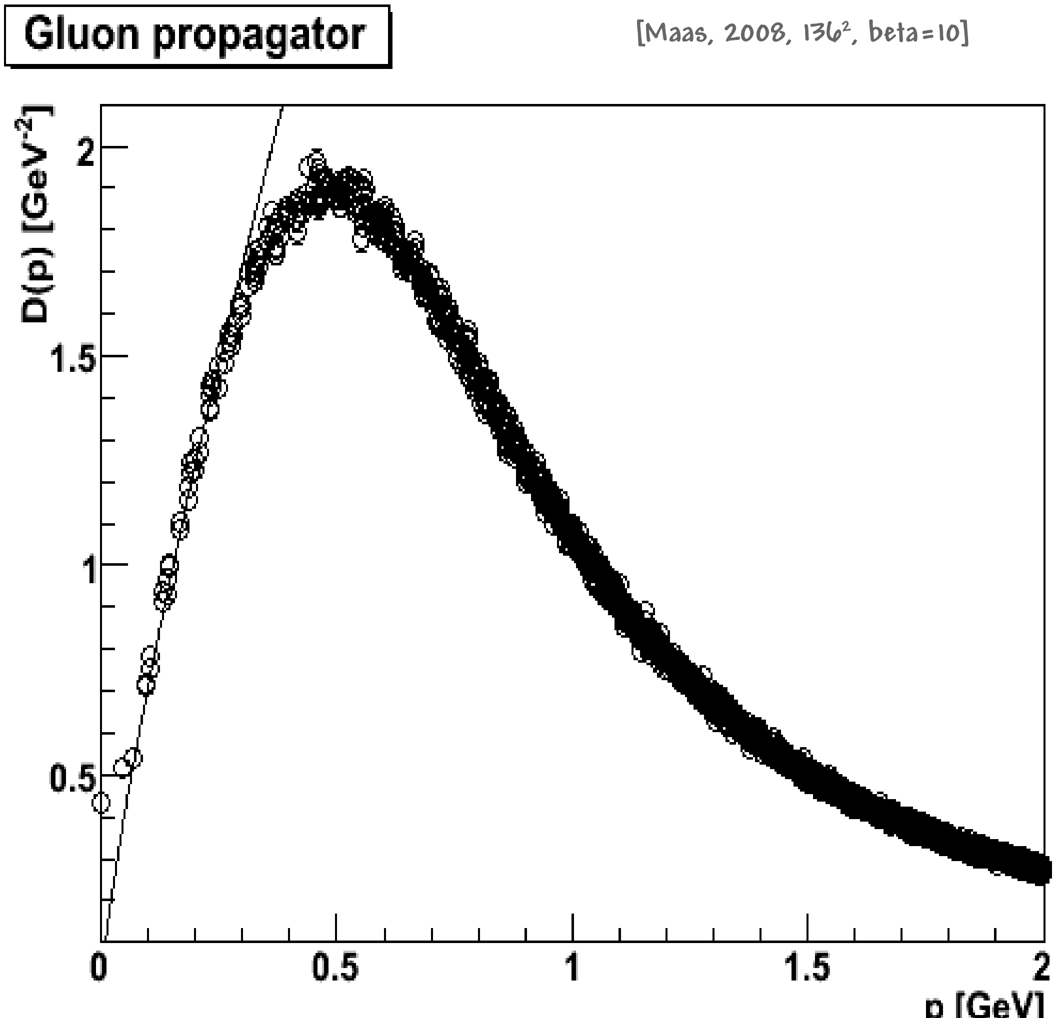

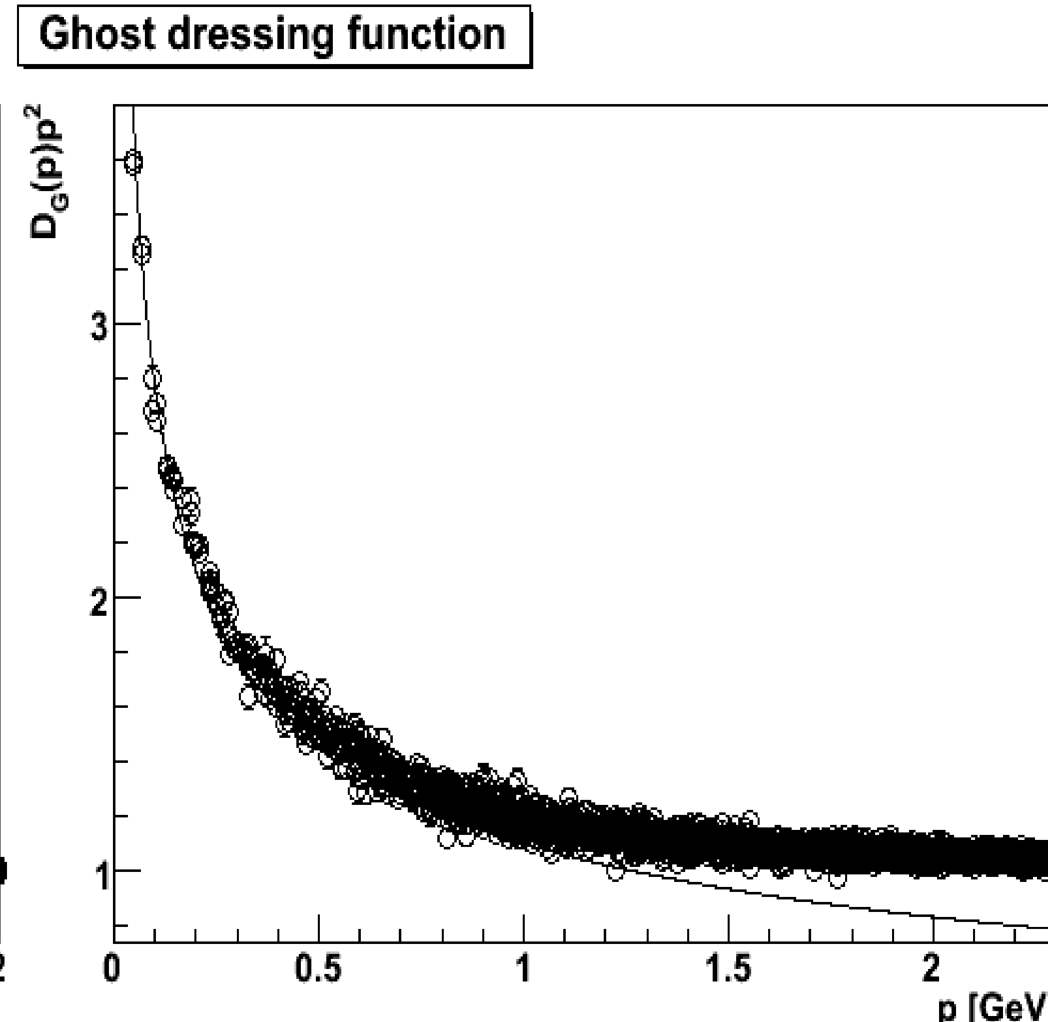

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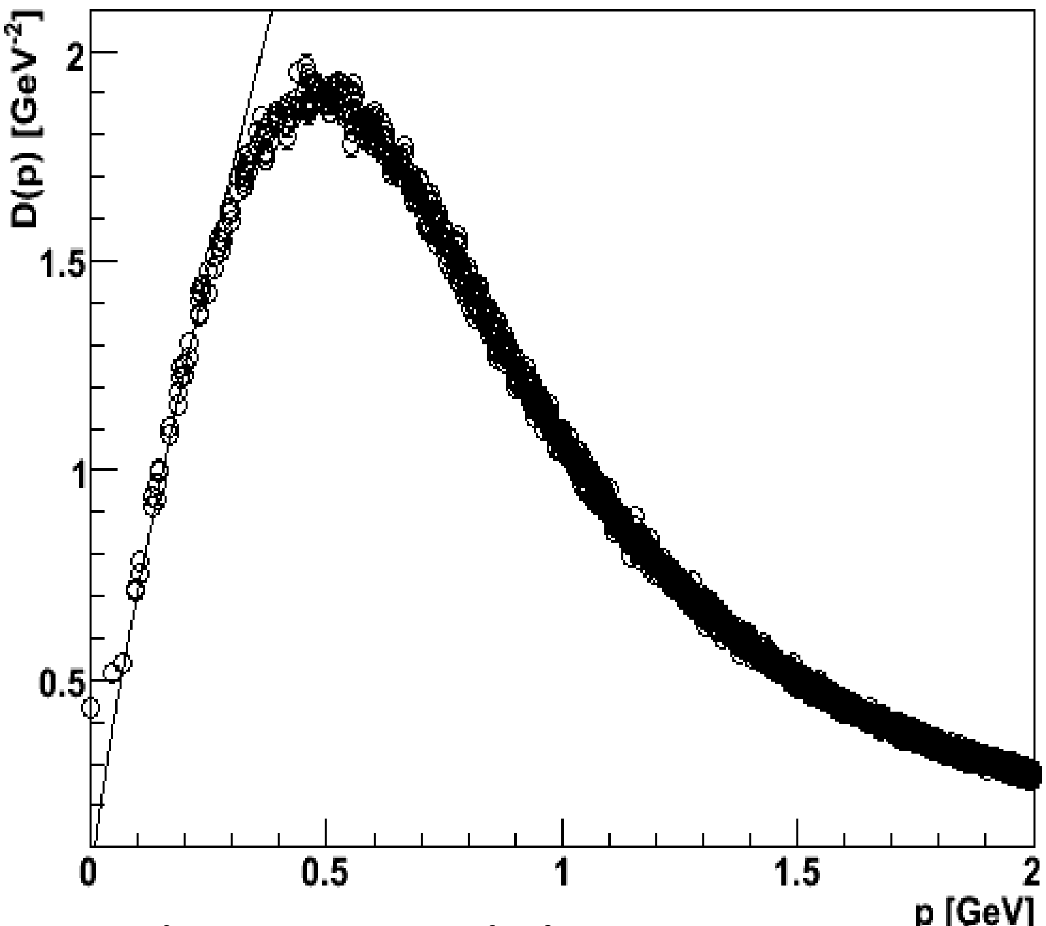

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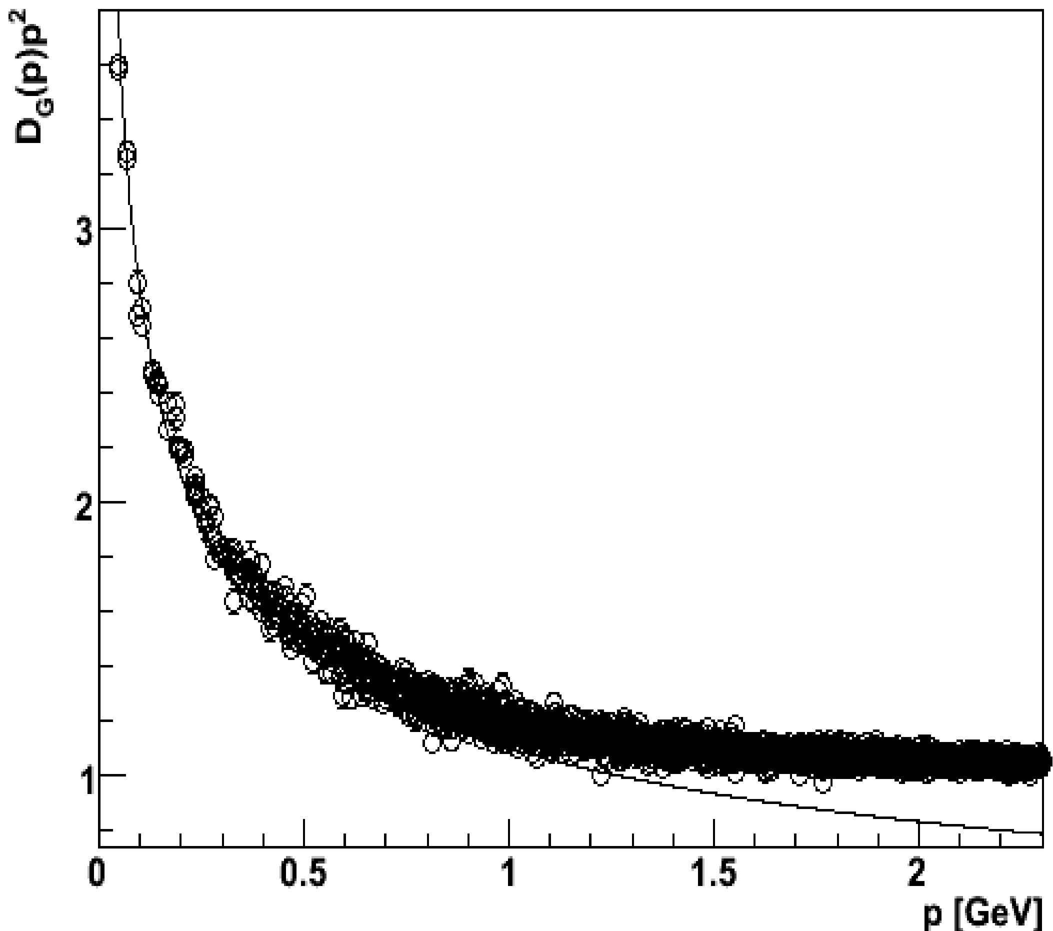
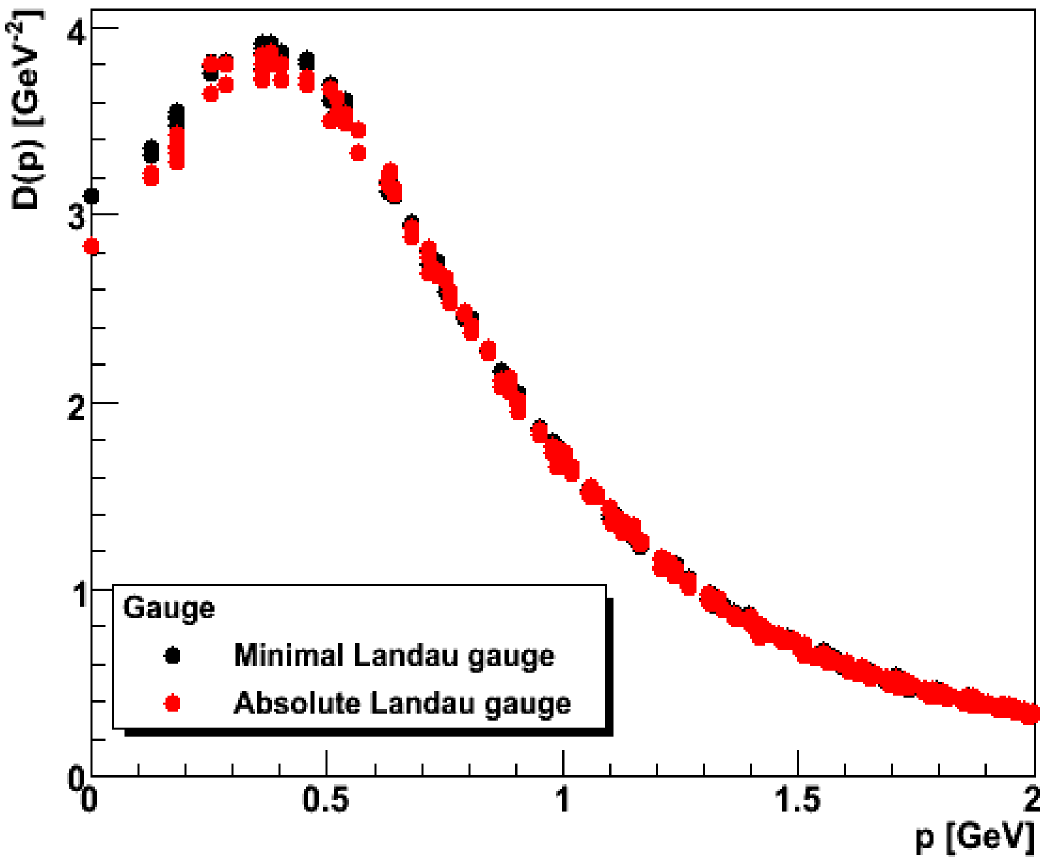


- Only asymptotic behavior known in the continuum
- Quantitative in agreement – power-law with the same exponent for both propagators

Impact on the gluon propagator in 3d [56^3, beta=4.24, Maas, 2008]

Absolute vs. minimal Landau gauge



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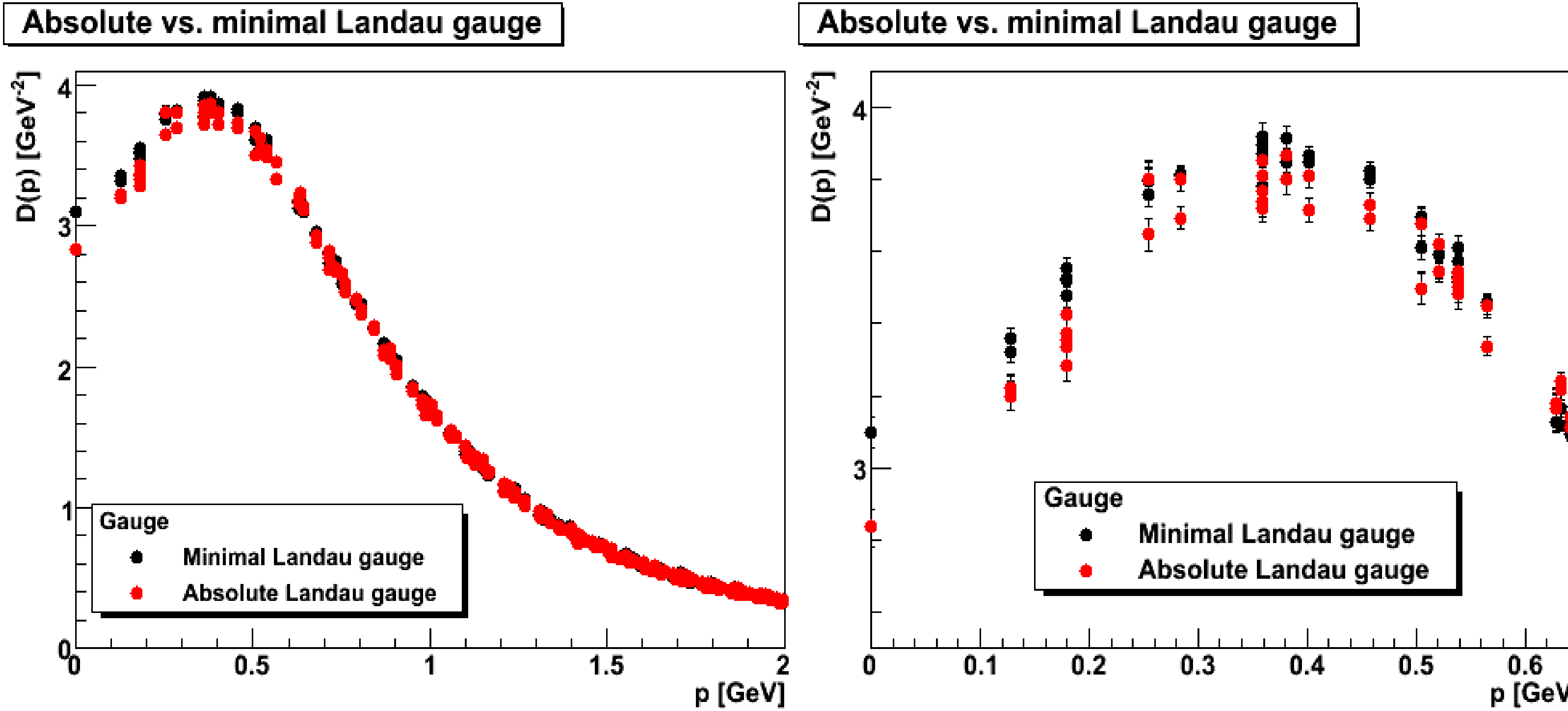

- Small effect
  - Most pronounced in the far infrared, and decays with increasing momentum

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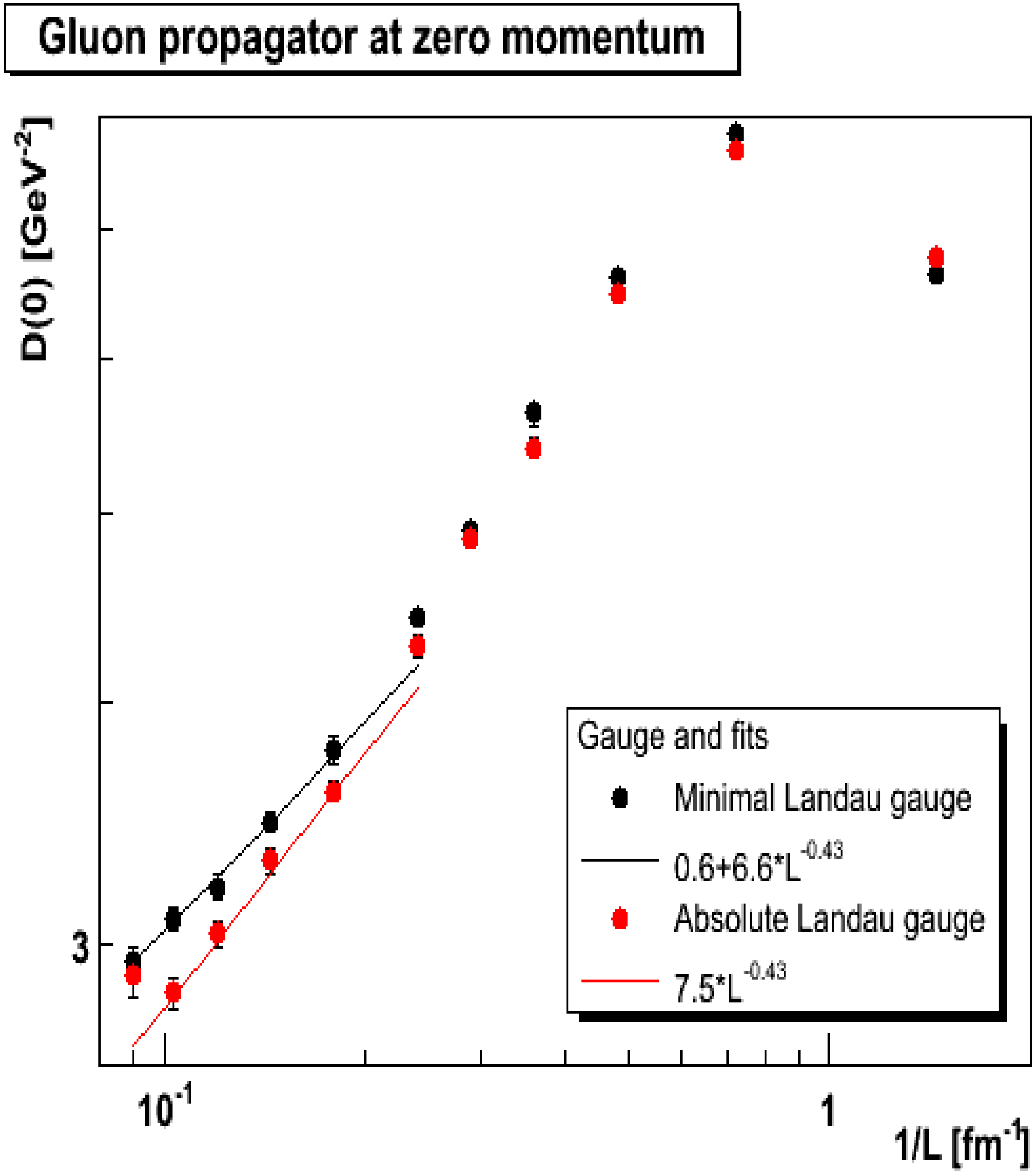
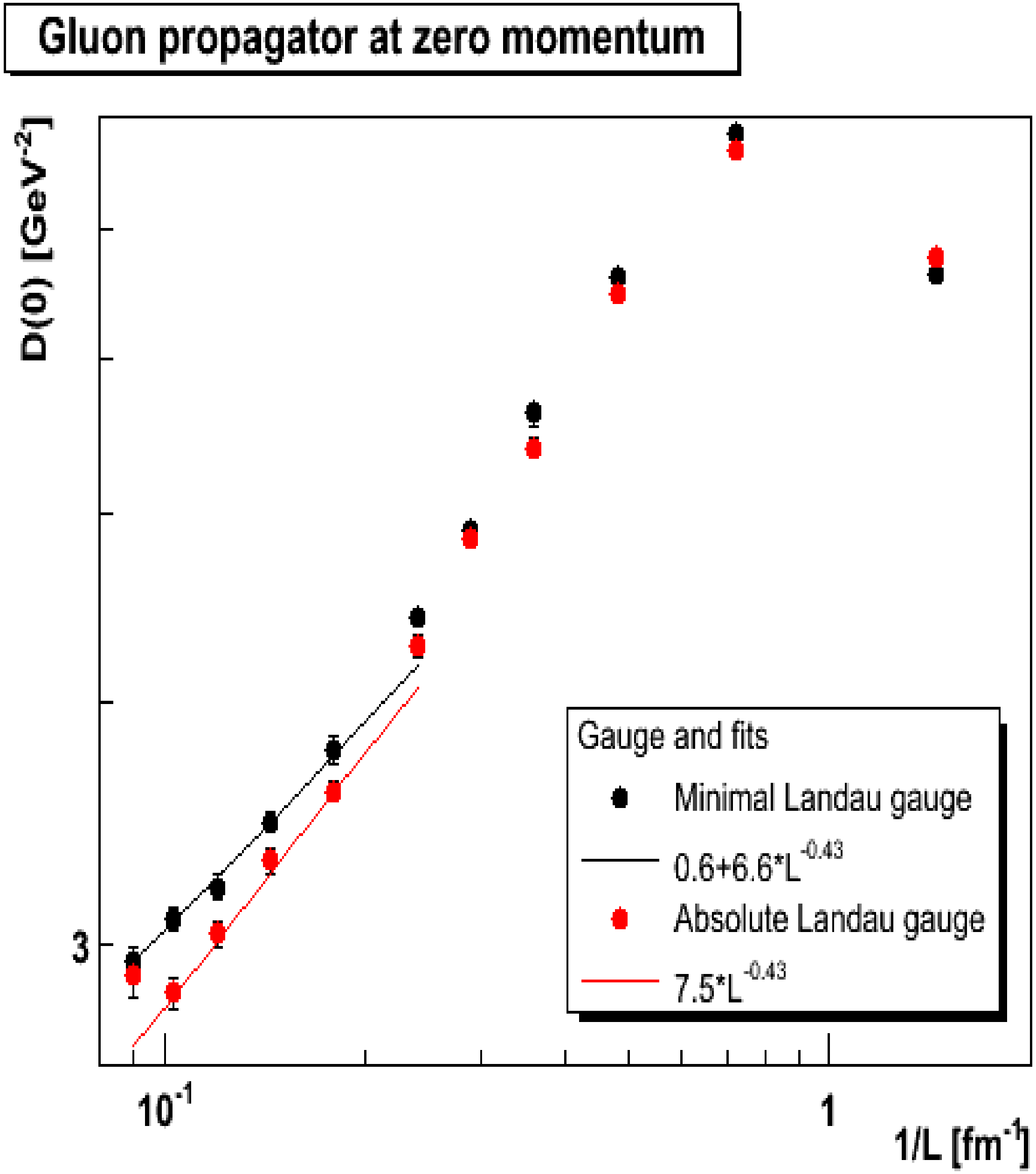


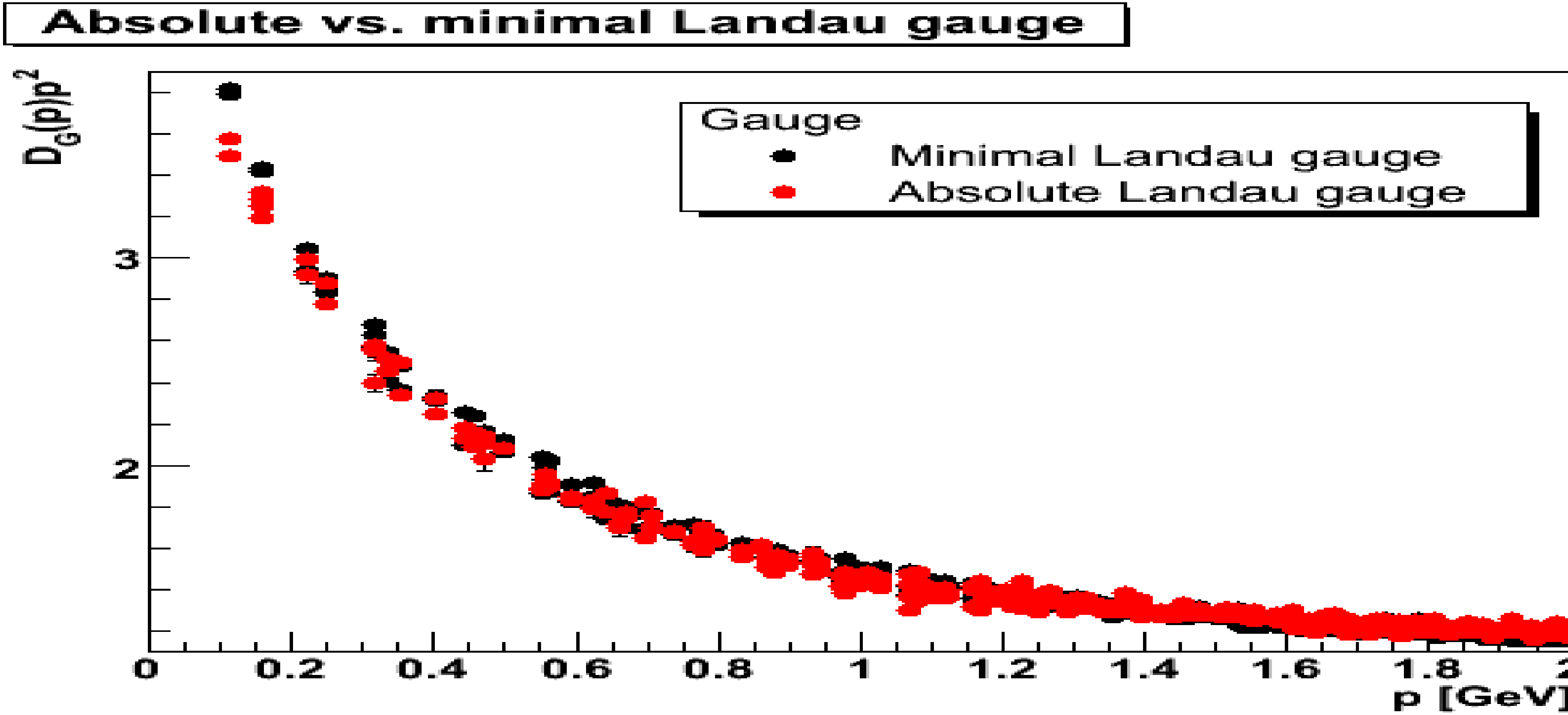
- Changes the asymptotic behavior of the gluon propagator at zero momentum
  - Gauge-fixing fails at the largest volume

Impact on the gluon propagator [Maas, 2008]



- Changes the asymptotic behavior of the gluon propagator at zero momentum
  - Gauge-fixing fails at the largest volume
- Absolute Landau gauge: Decay with approximately the expected exponent (~-0.3) [Fischer et al. 2007]

Impact on the ghost propagator in 3d [beta=4.24, Maas 2008]



- Difference rather small

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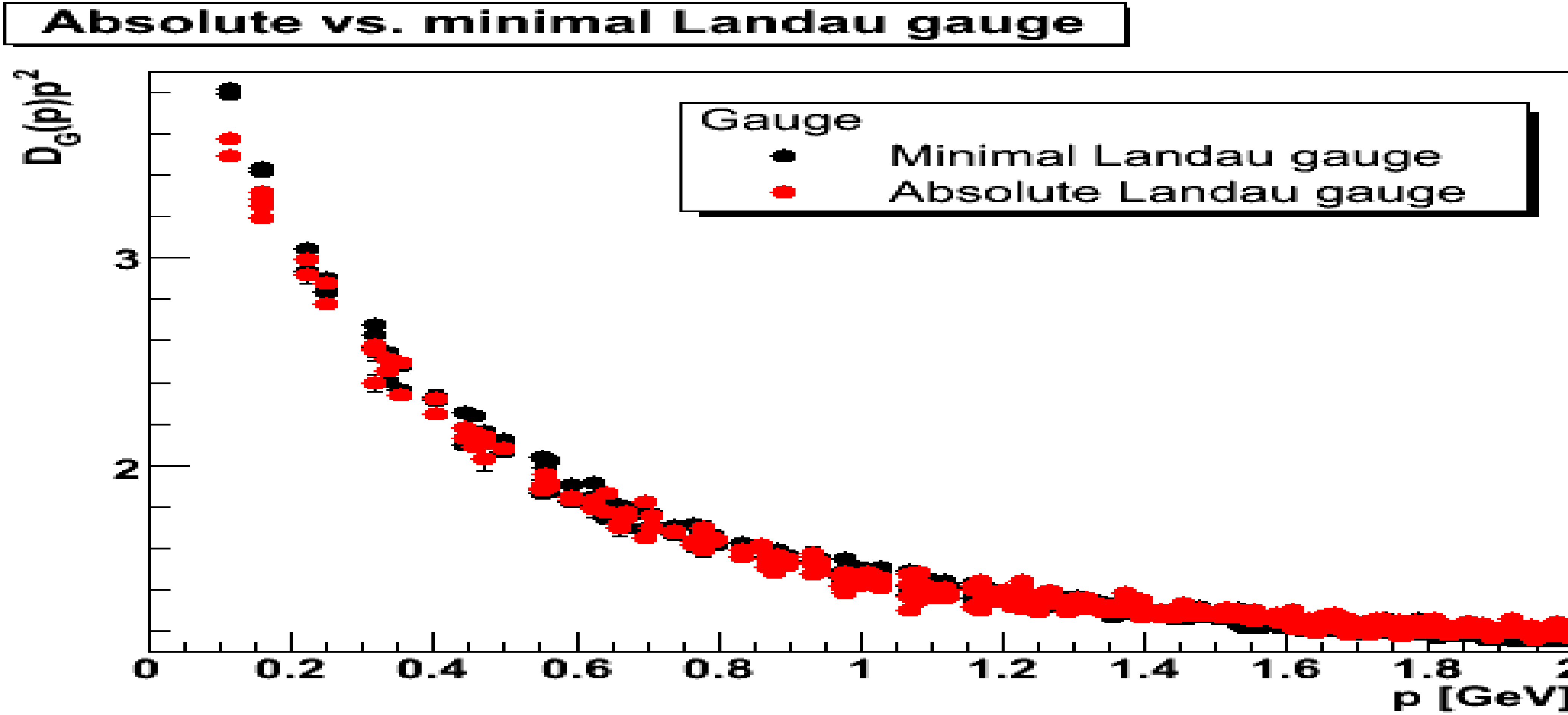

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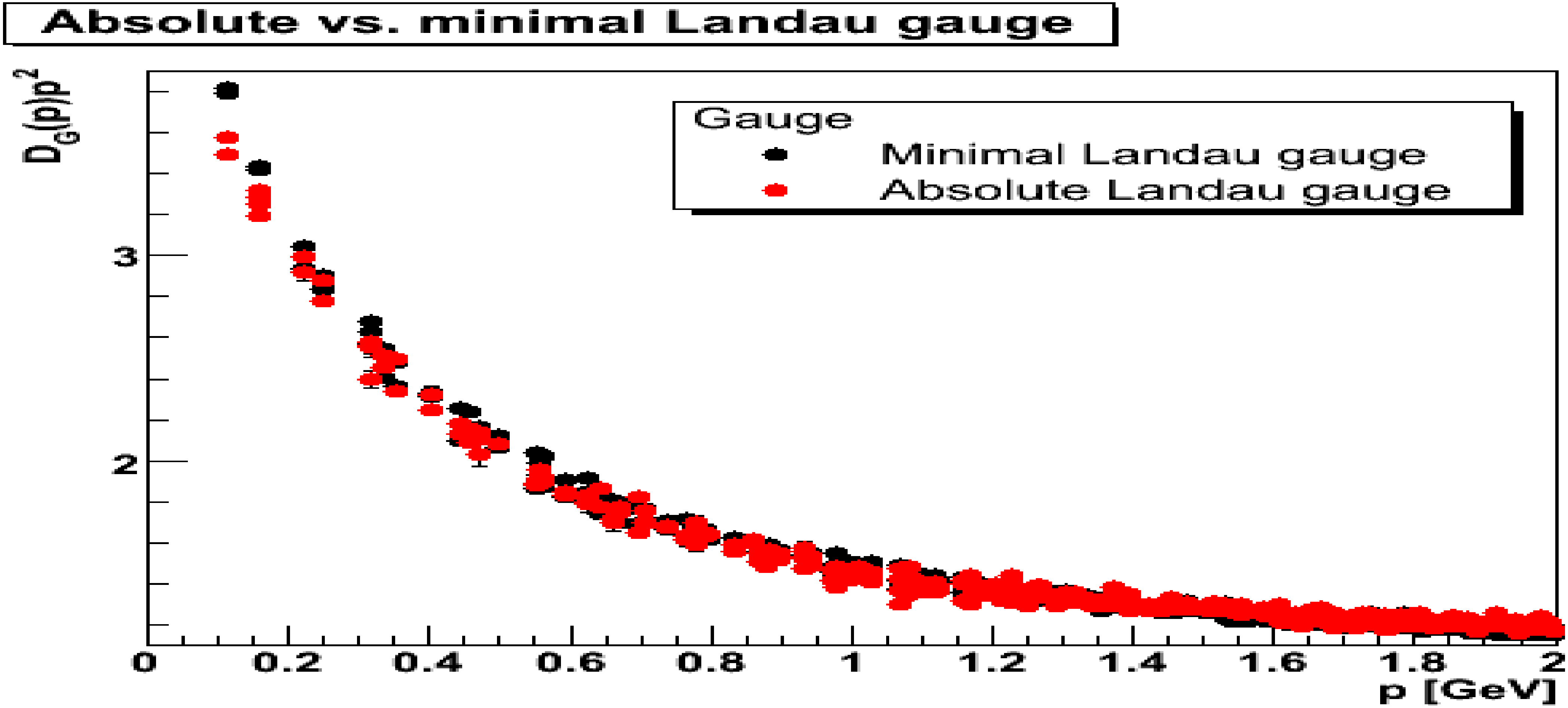

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- Volume dependence interesting

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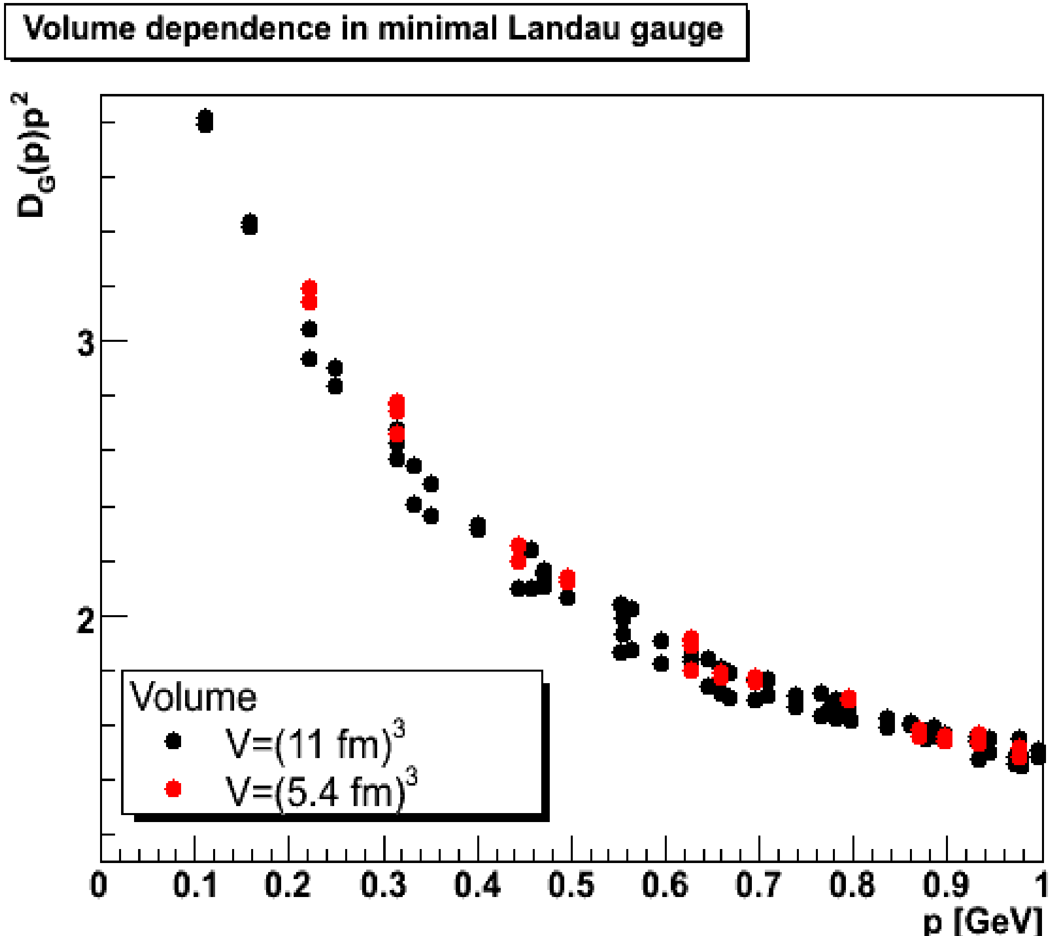

- Becomes less divergent in minimal Landau gauge with volume

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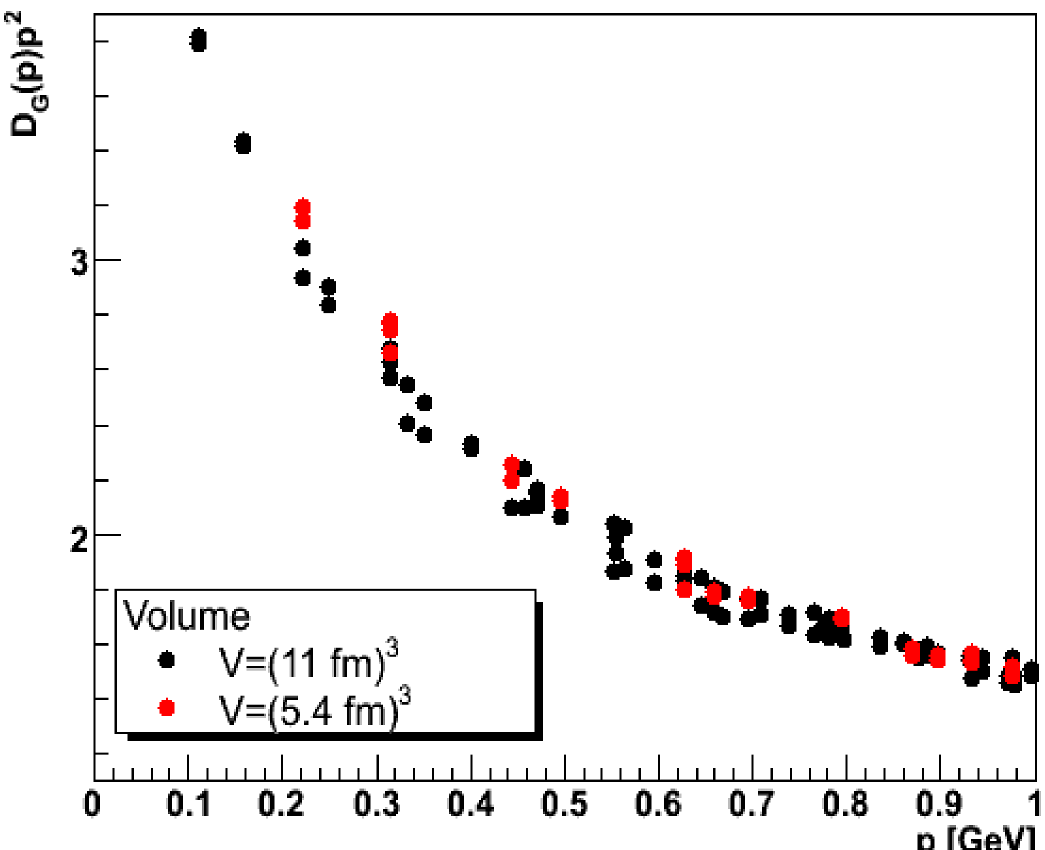
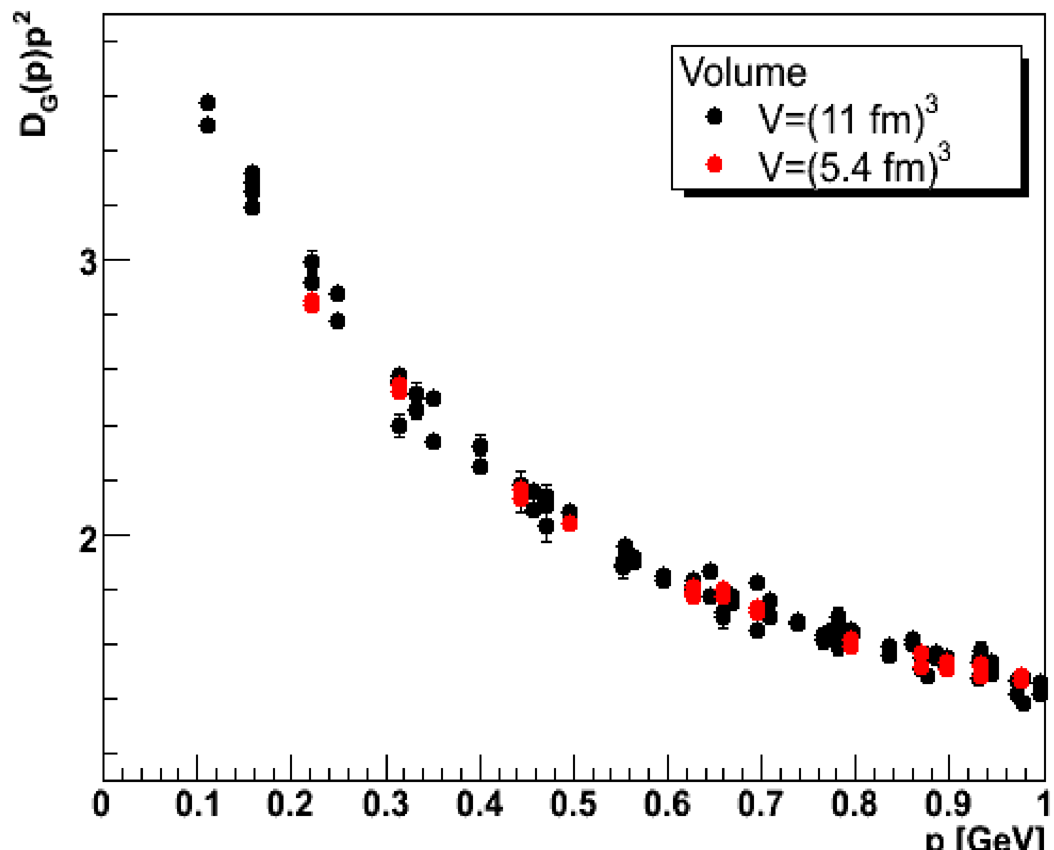
Volume dependence in minimal Landau gauge



Volume dependence in absolute Landau gauge



- Becomes less divergent in minimal Landau gauge with volume
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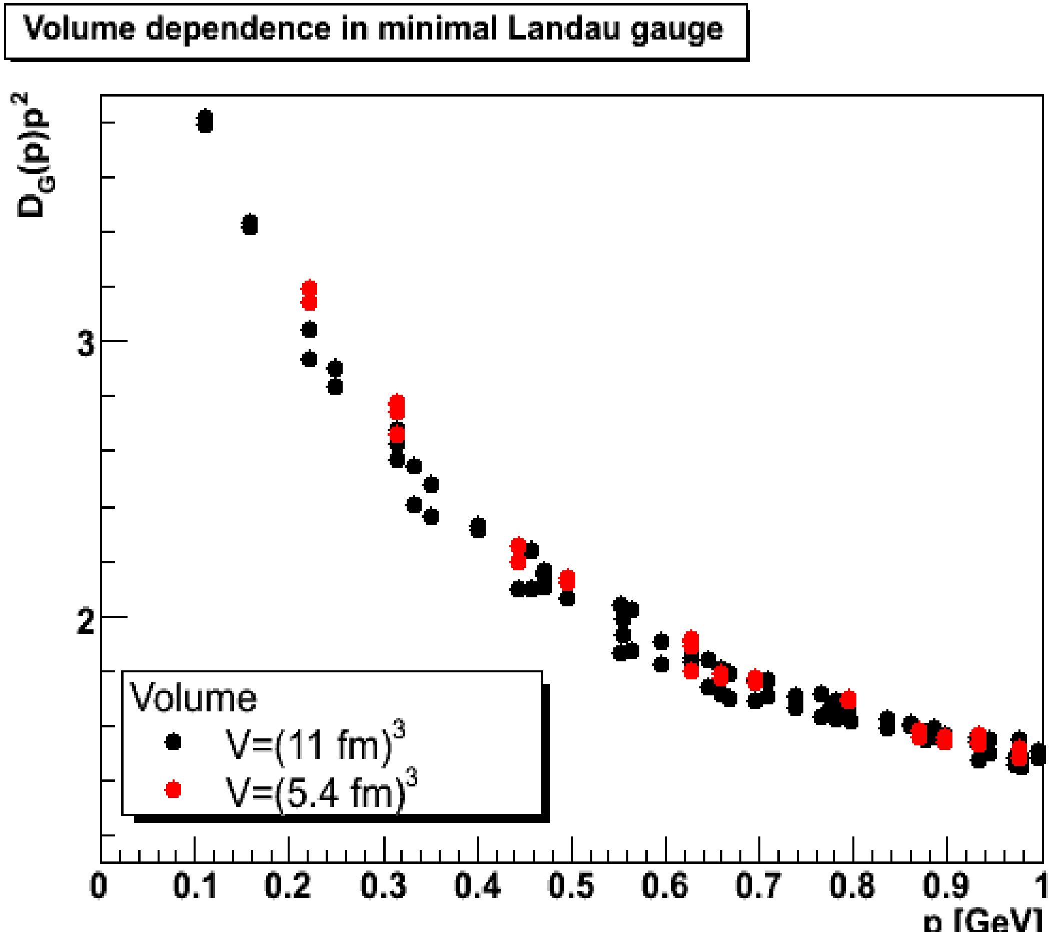
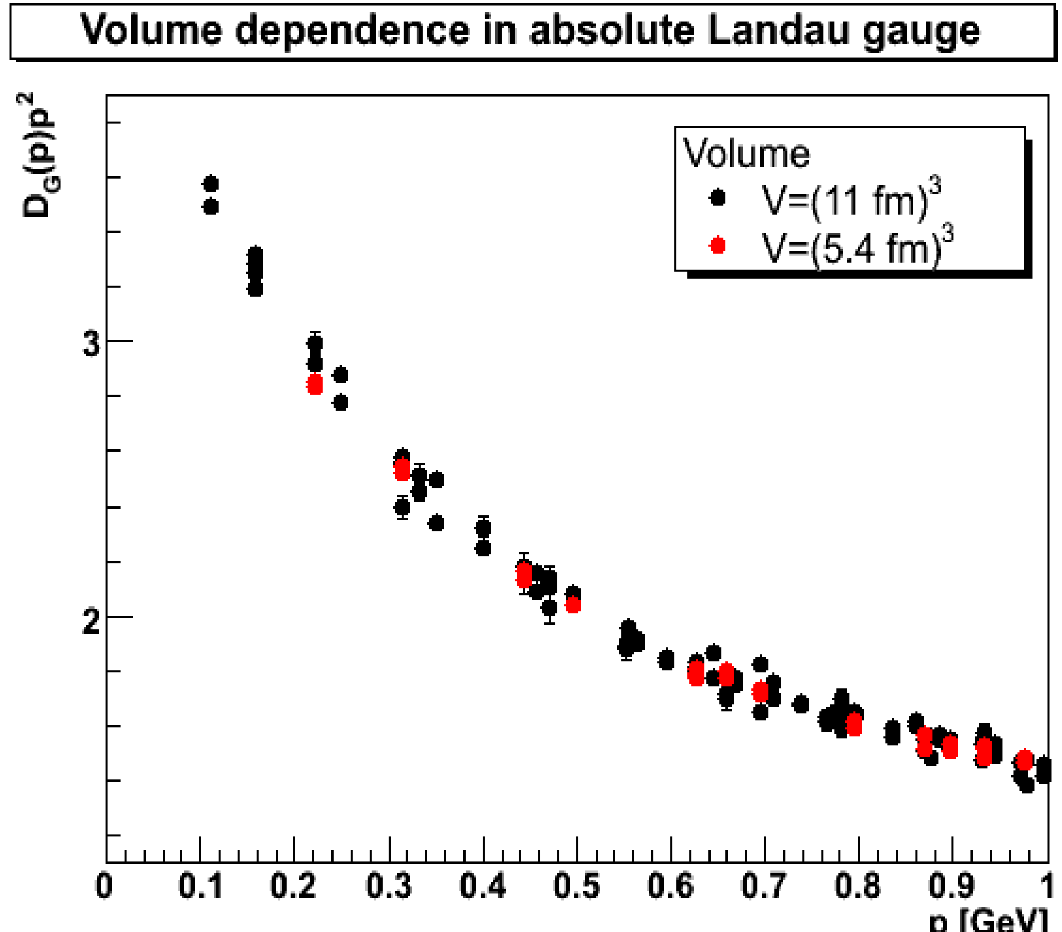
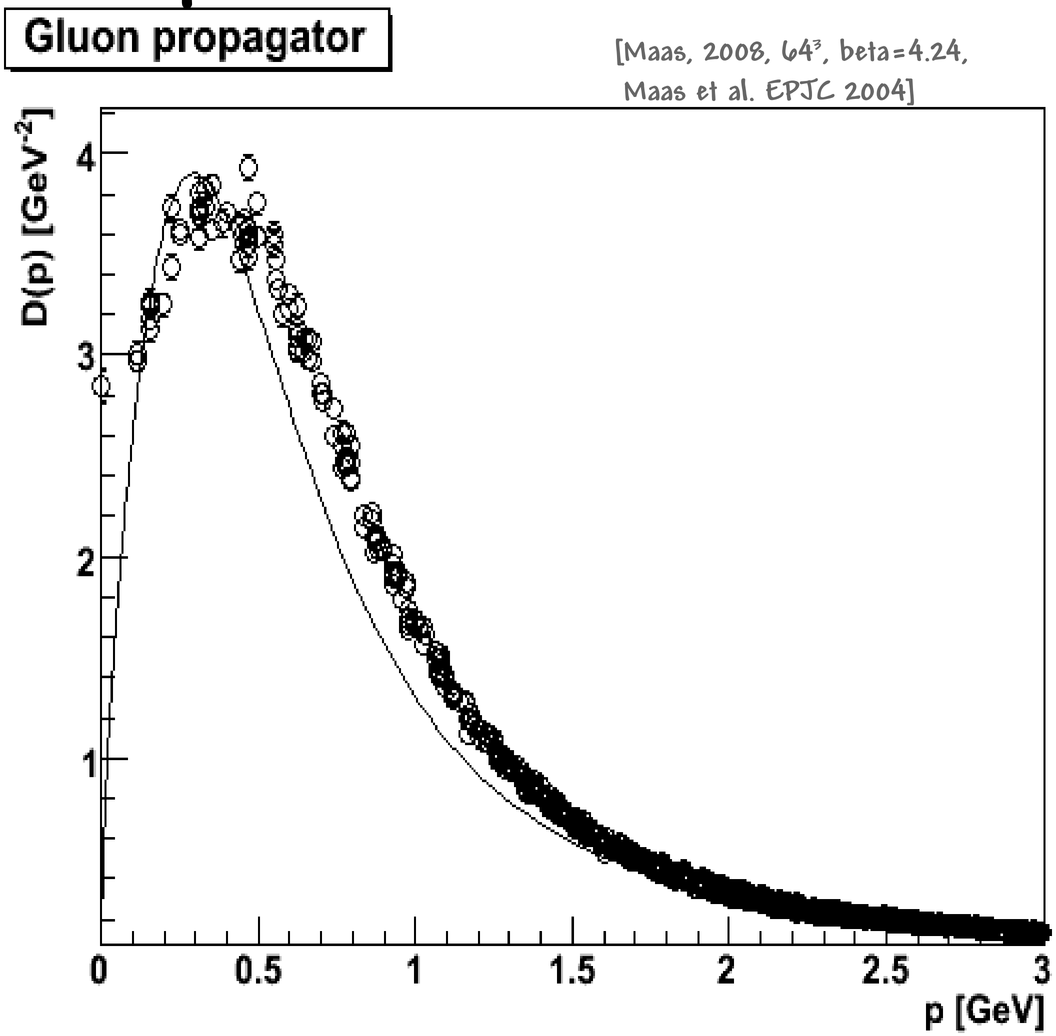




- Becomes less divergent in minimal Landau gauge with volume
- Becomes more divergent/is unaffected in absolute Landau gauge with volume
  - Divergence in the infinite volume limit!

Comparison to functional calculations in 3d



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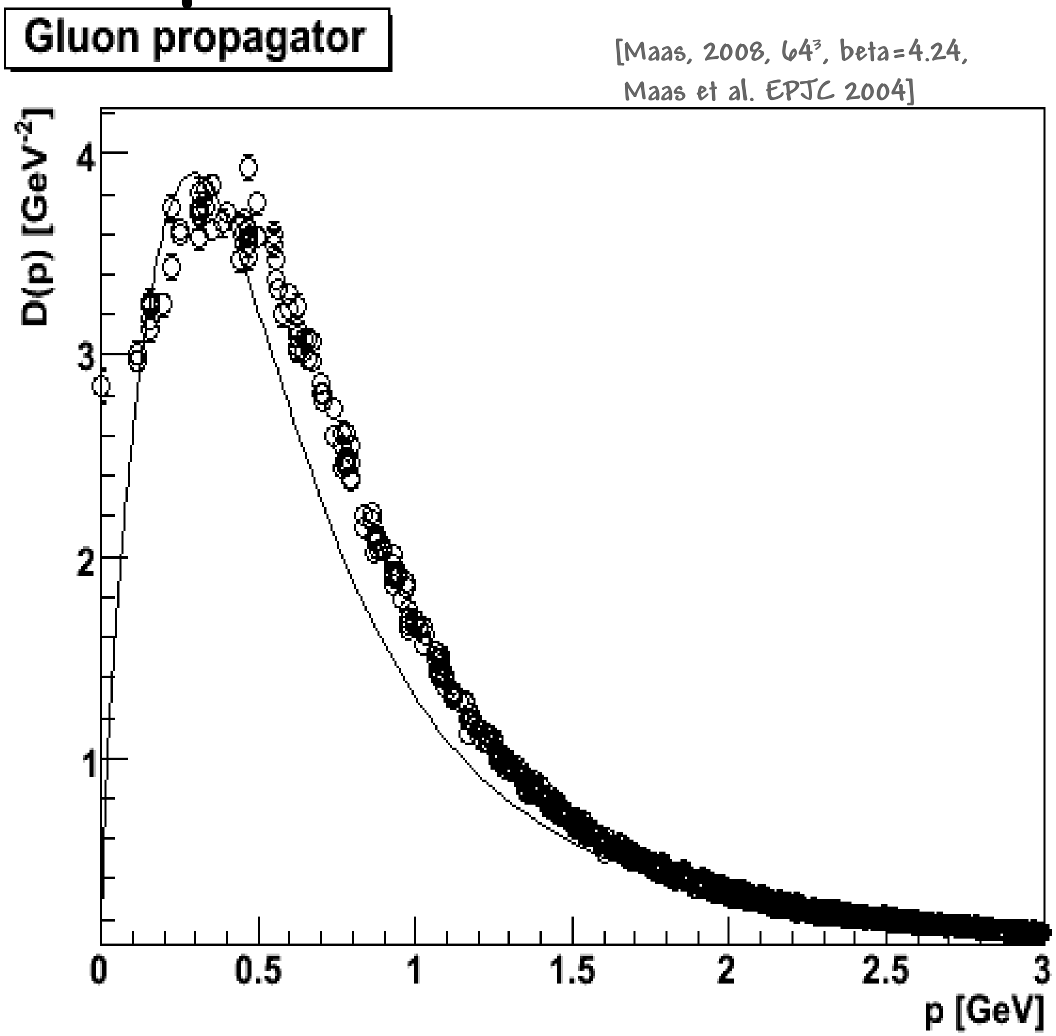

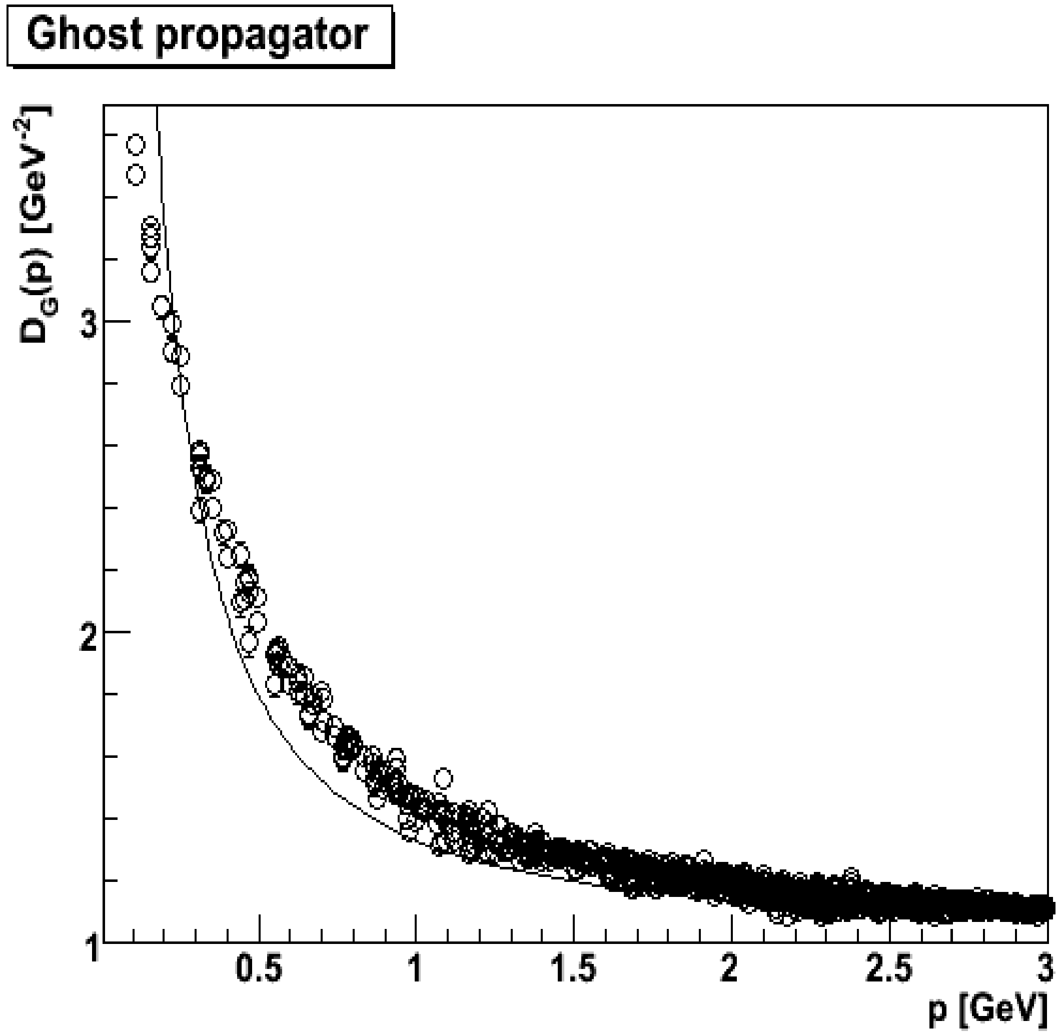

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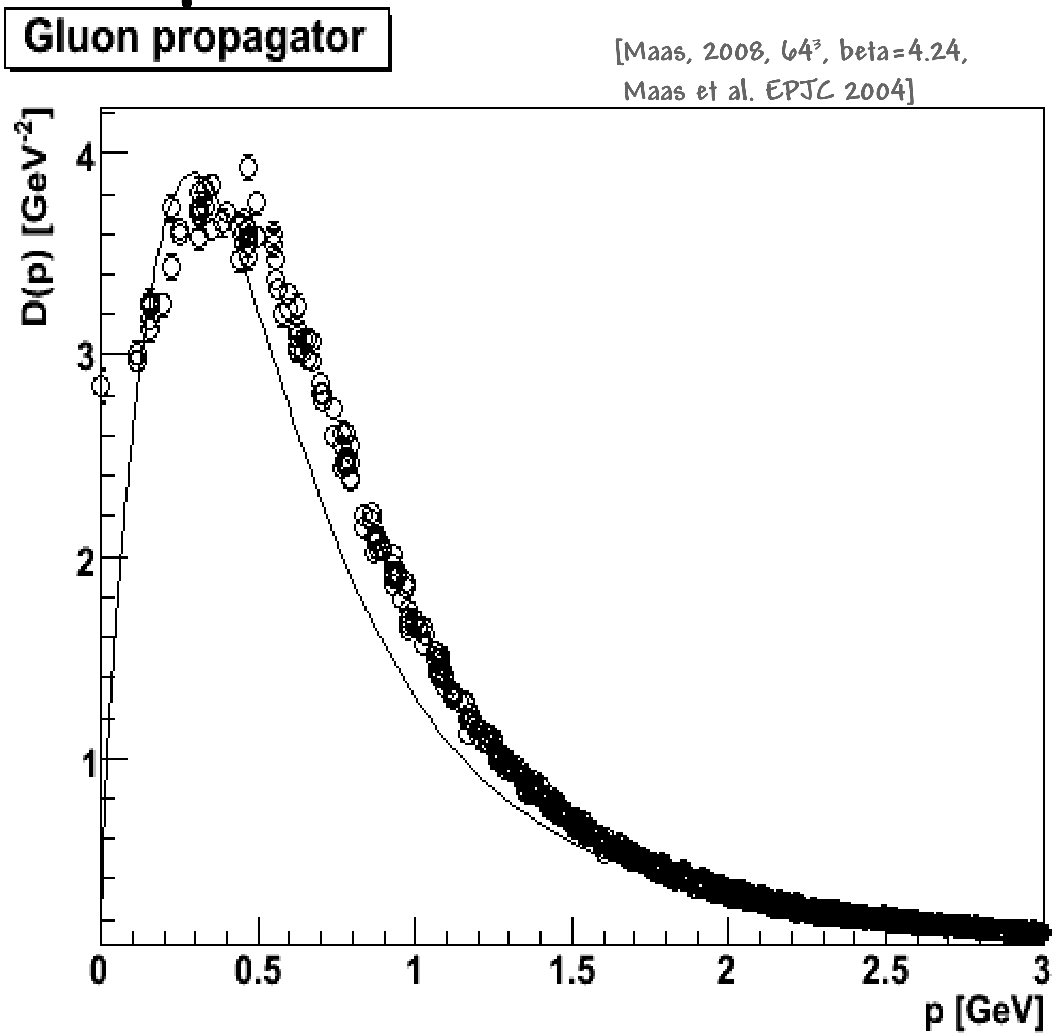
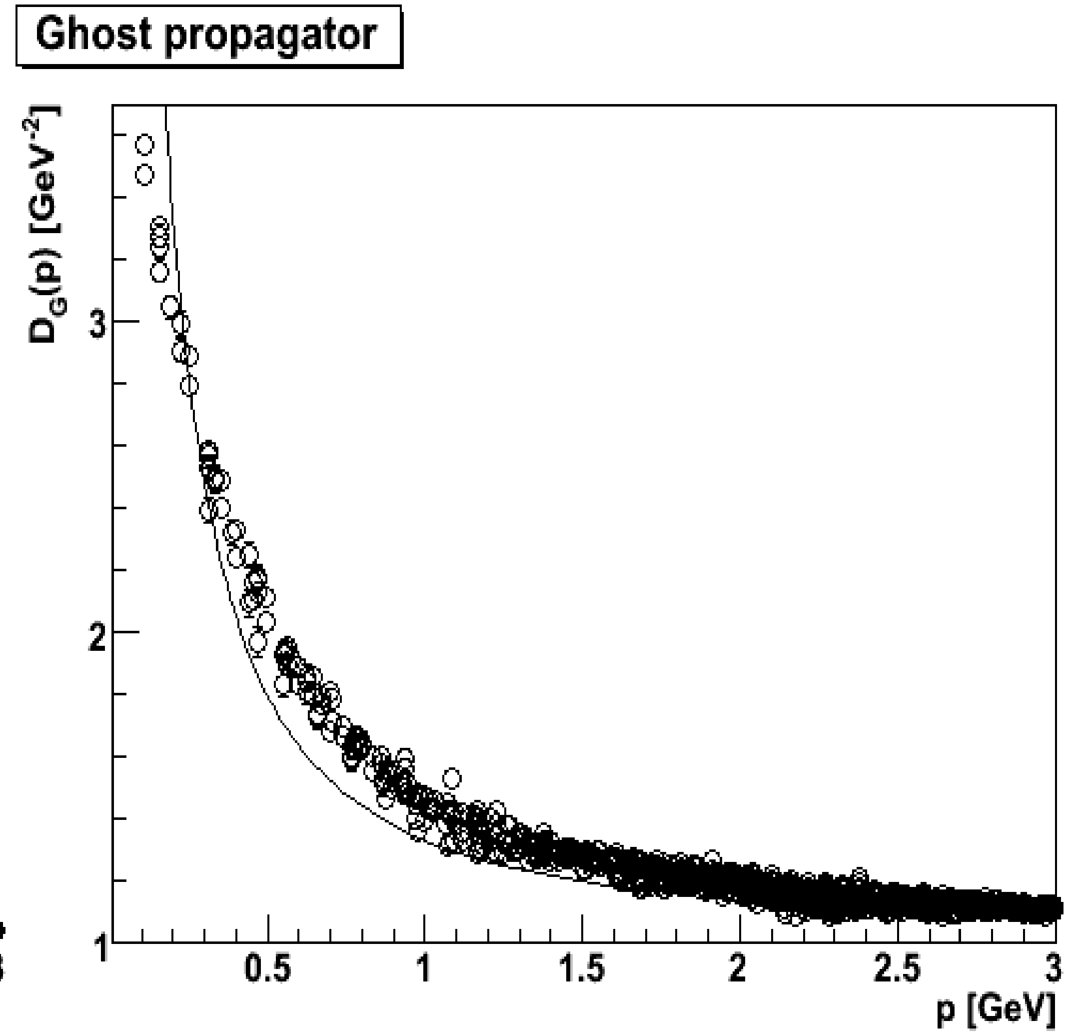
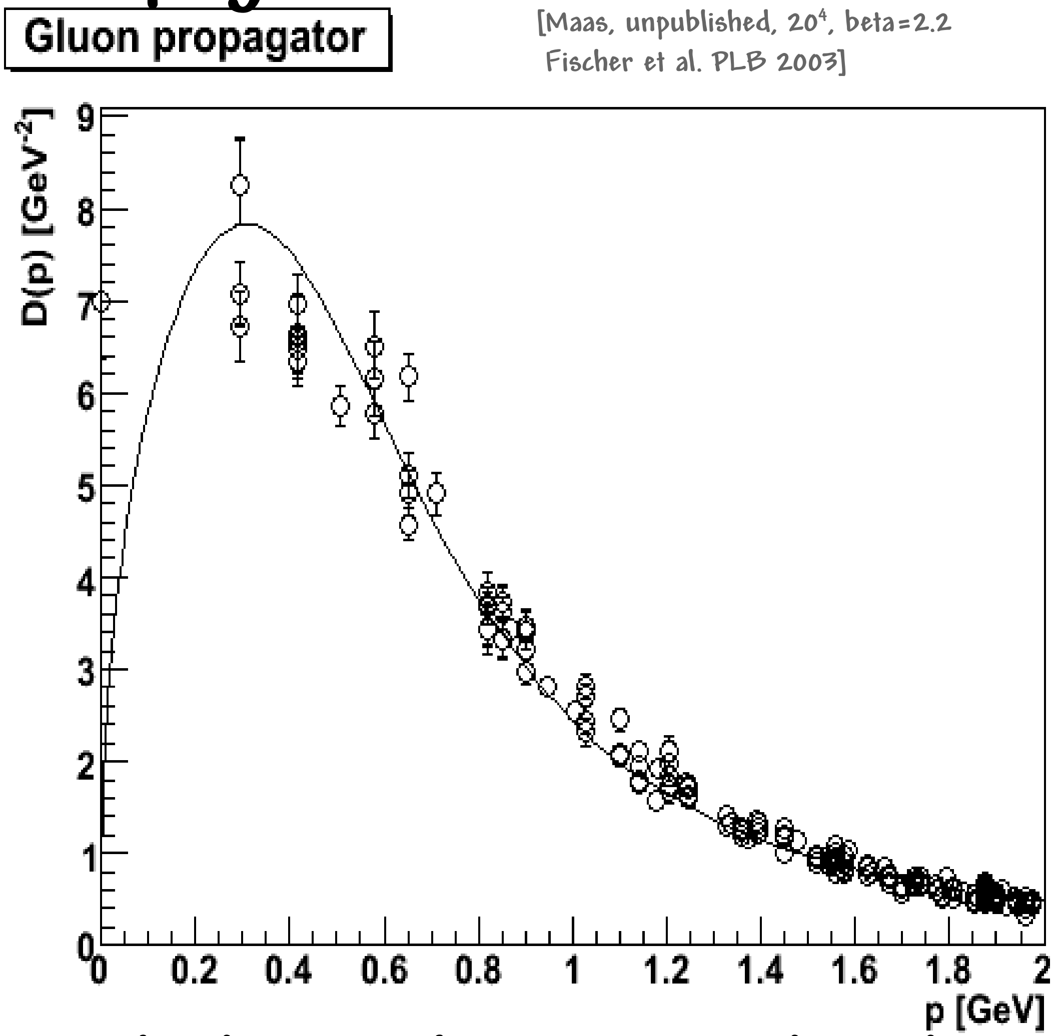




- Qualitative agreement between lattice and continuum results
- Larger volumes necessary
- Gribov-Zwanziger/Kugo-Ojima scenario confirmed

Propagators in four dimensions

[Maas, unpublished, 20^4, beta=2.2
Fischer et al. PLB 2003]



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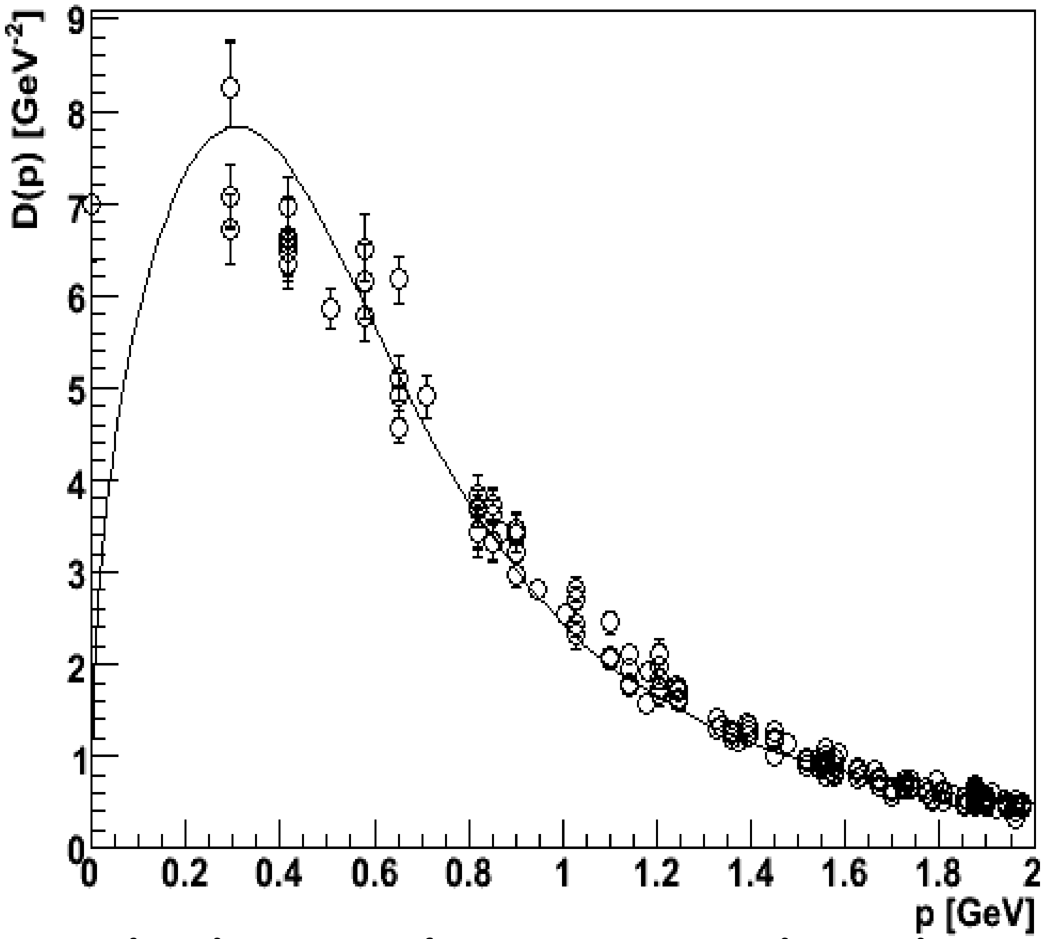

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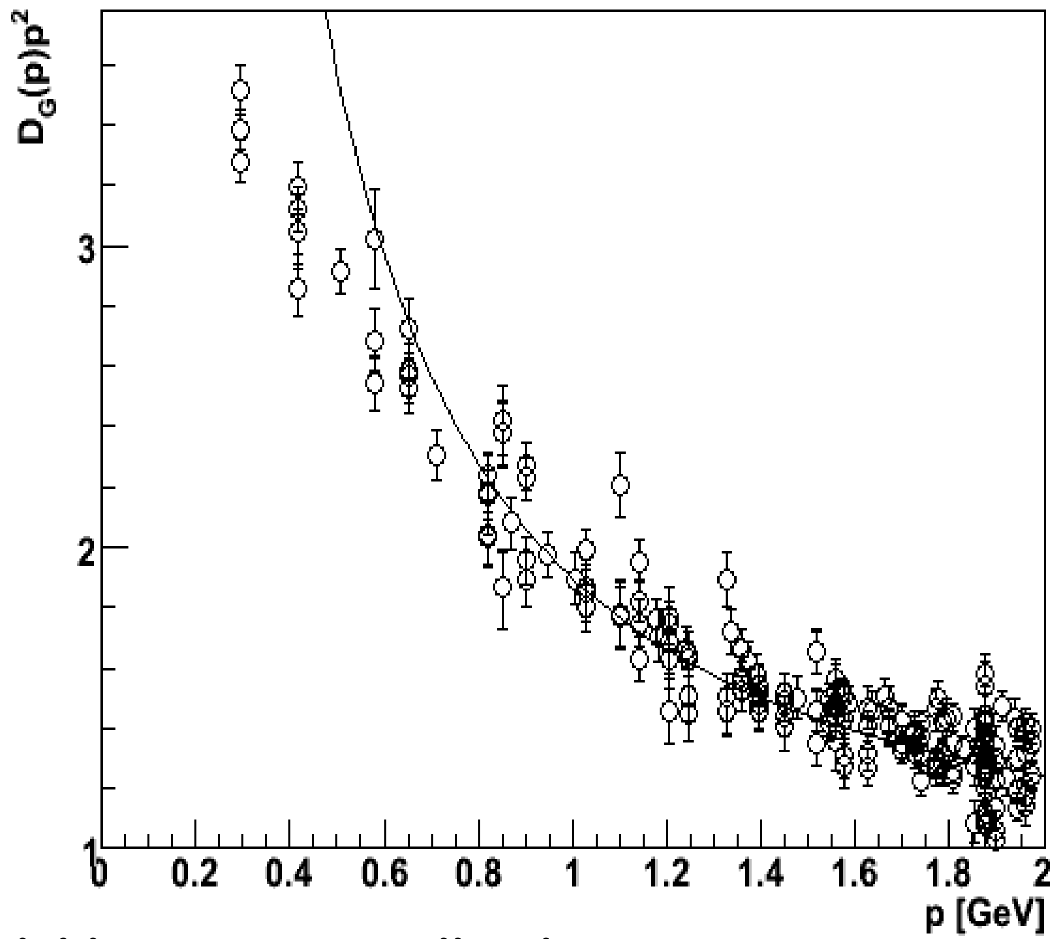

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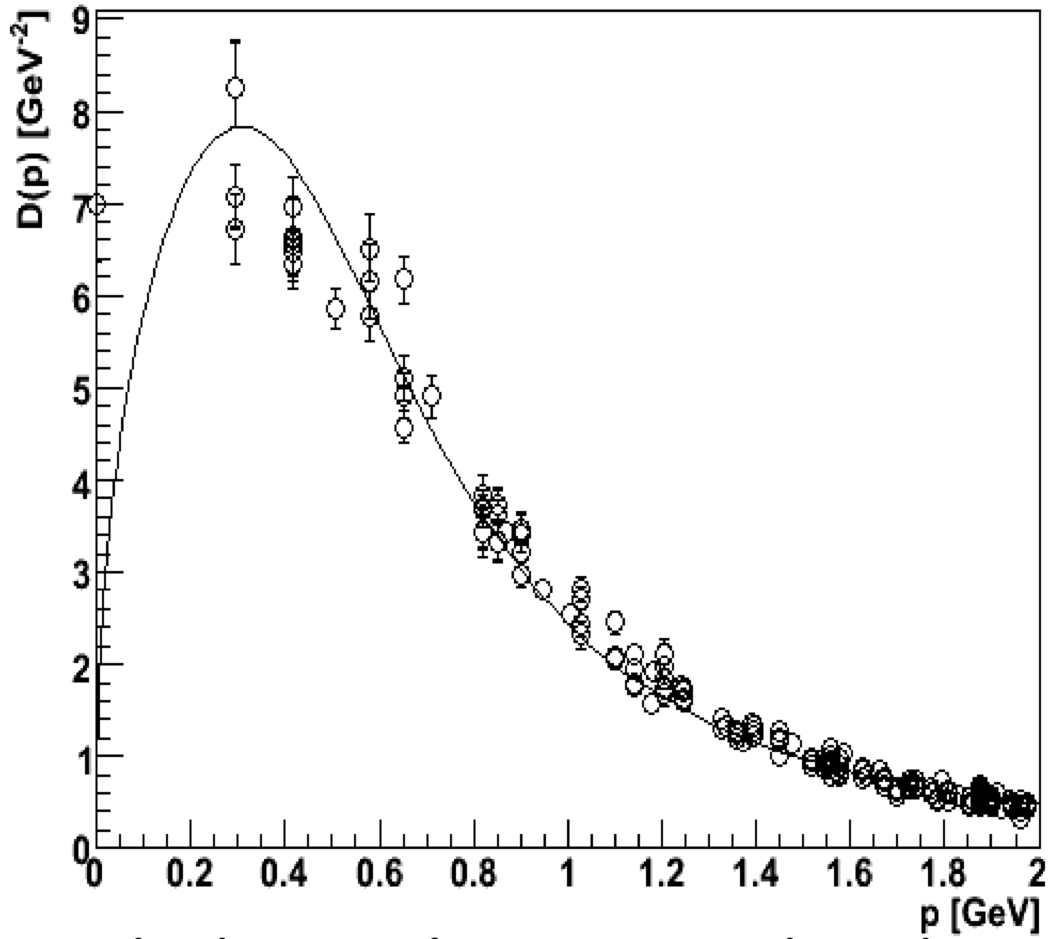

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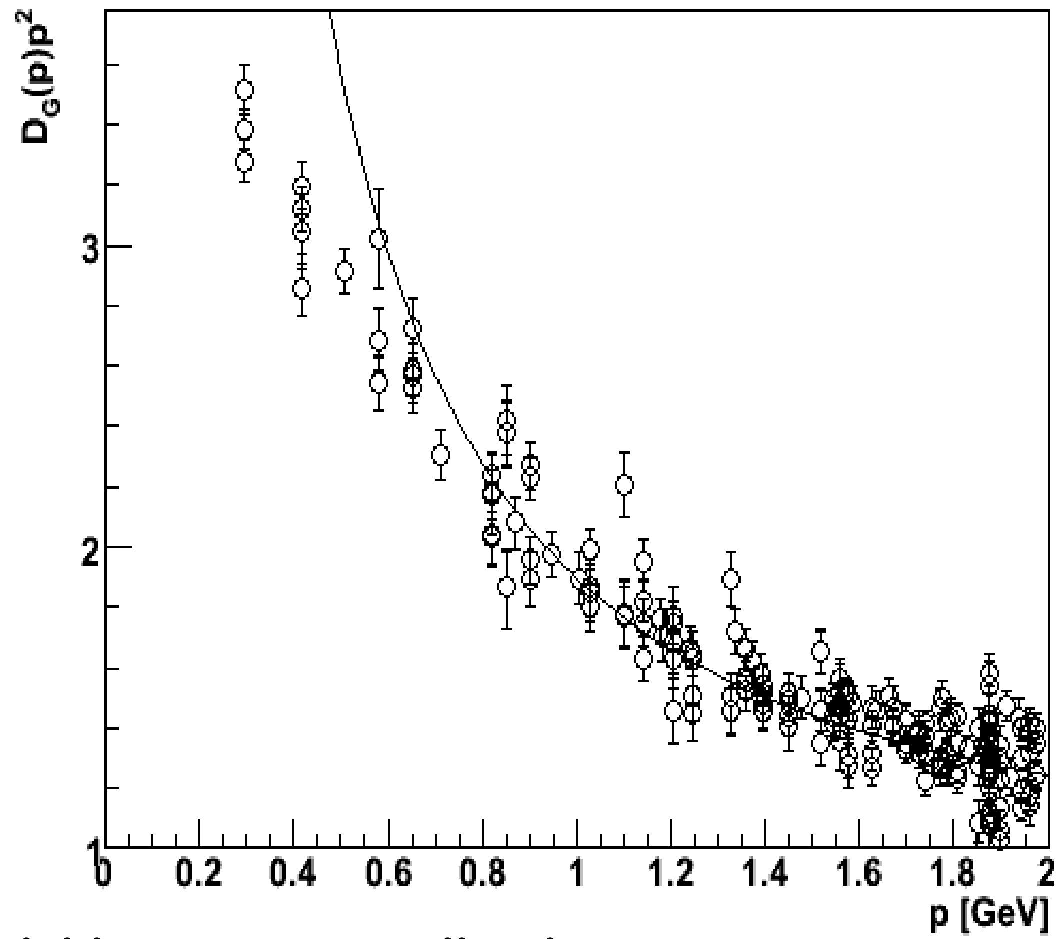

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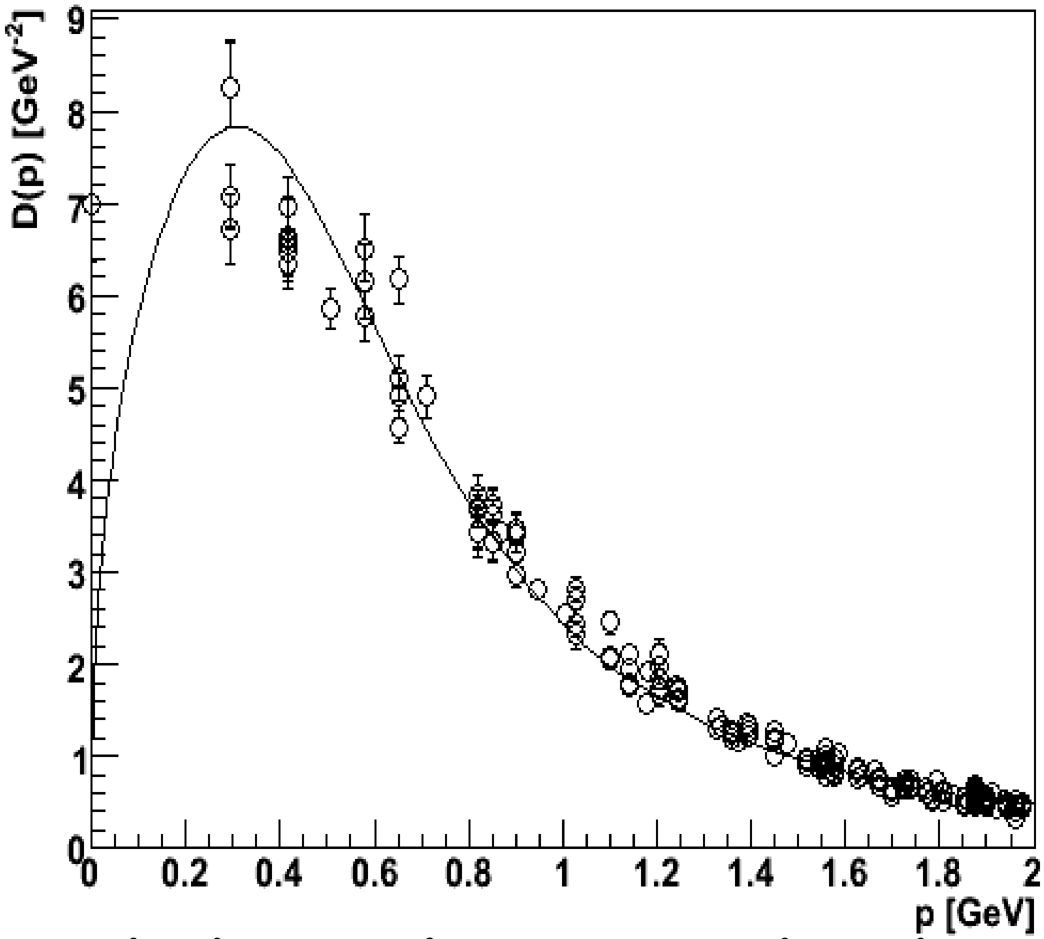

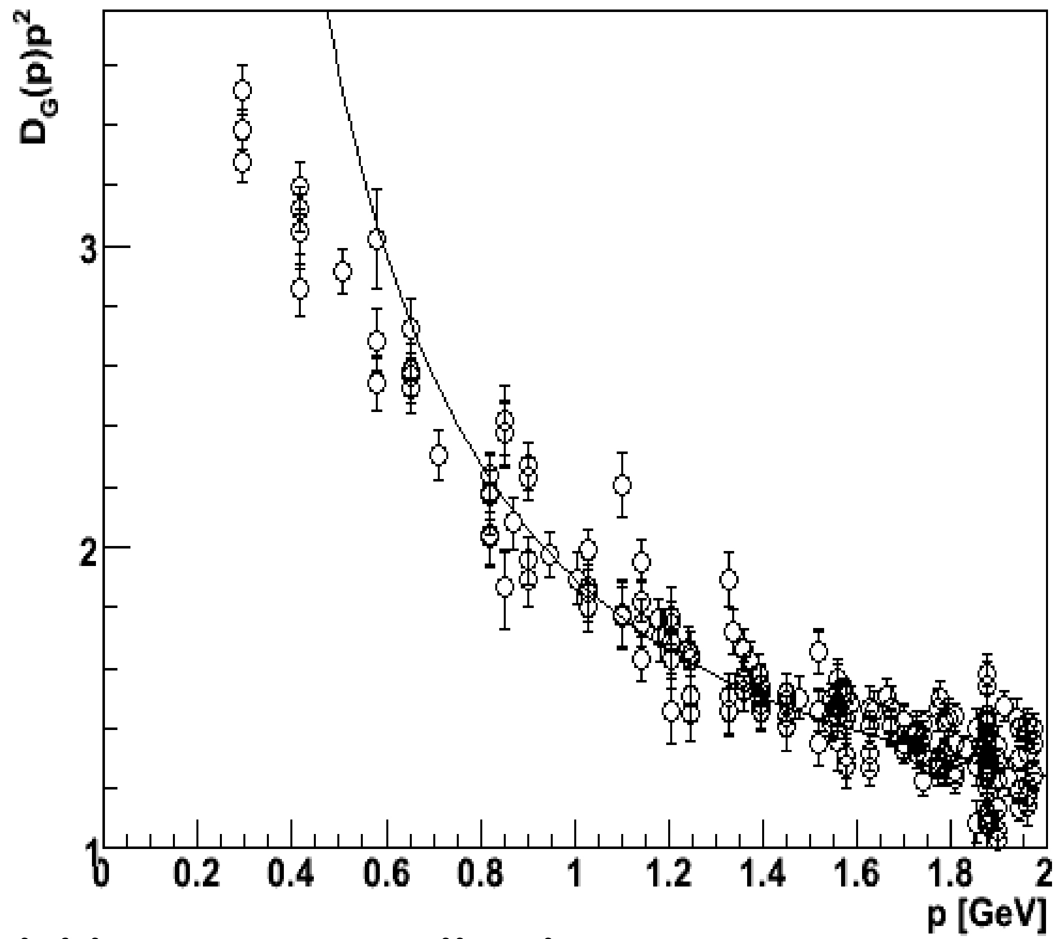

- Absolute Landau gauge results only available on very small volumes
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- DSEs give predictions for infinite volume approach [Fischer et al., AP 2008]

Interpolating and linear covariant gauges

- Gauge sector:

$$L=-\frac{1}{4}F_{\mu\nu}^{a}F^{\mu\nu,a}-\bar{c}^{a}\partial'^{\mu}D_{\mu}^{ab}c^{b}+\frac{1}{2\xi}\partial'^{\mu}A_{\mu}^{a}\partial'^{\nu}A_{\nu}^{a}$$

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- Here: Only along one direction away from Landau gauge

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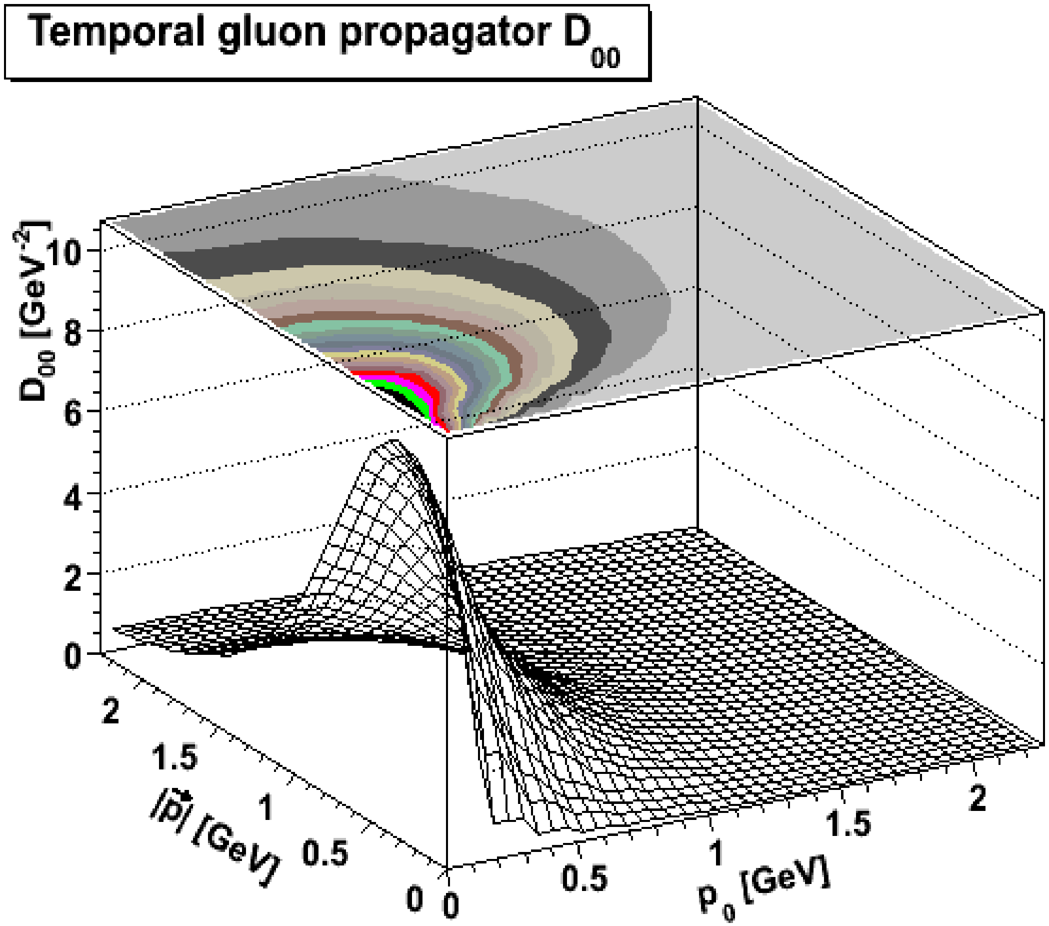
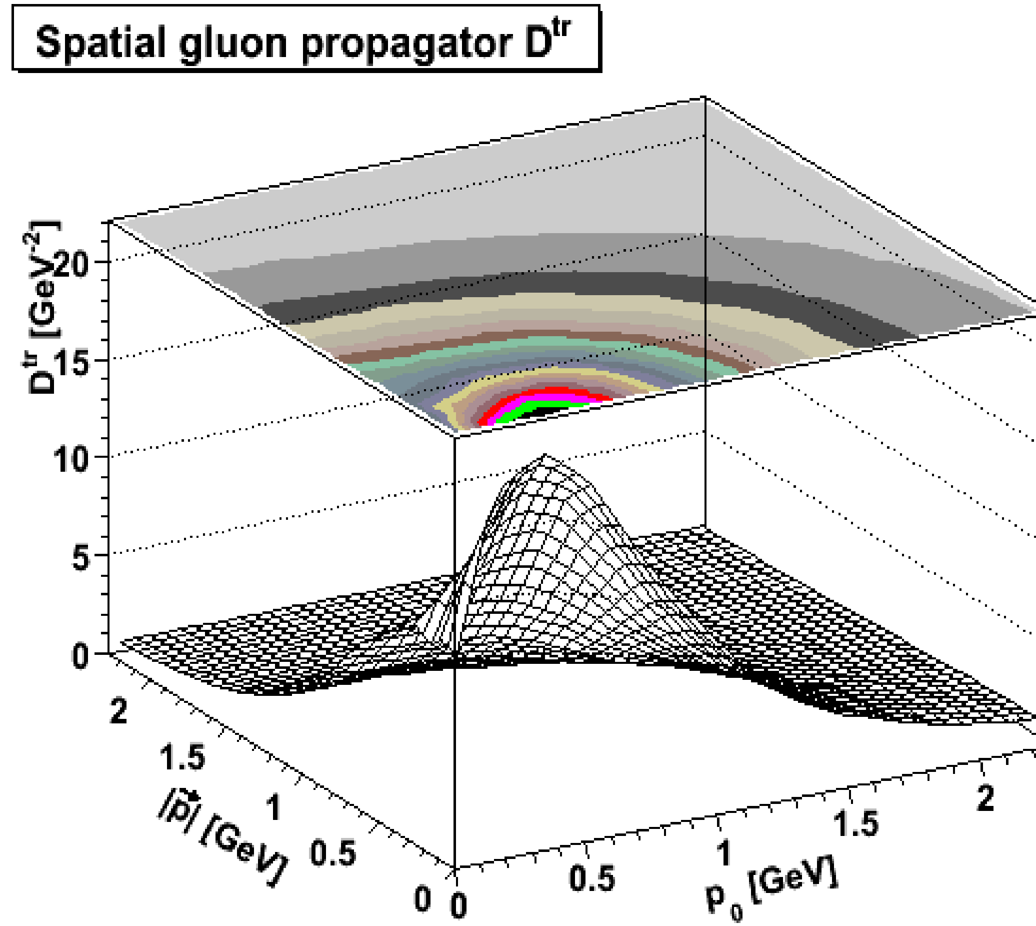
- Limit to Coulomb gauge? [Fischer et al., PRD 2005]
- Gribov-Zwanziger scenario predicts vanishing gluon propagator and enhanced ghost propagator at small 4-momentum [Firscher et al., PRD 2005]

Gluon propagator - Landau

[Lattice 40^3, beta=4.2, λ=1:
Cucchieri et al., 2007, unpublished]





- Different in Landau gauge because the gluon is a vector particle
- Distinct maximum and infrared suppressed

Gluon propagator

[Lattice 40^3, beta=4.2, λ=1/2:
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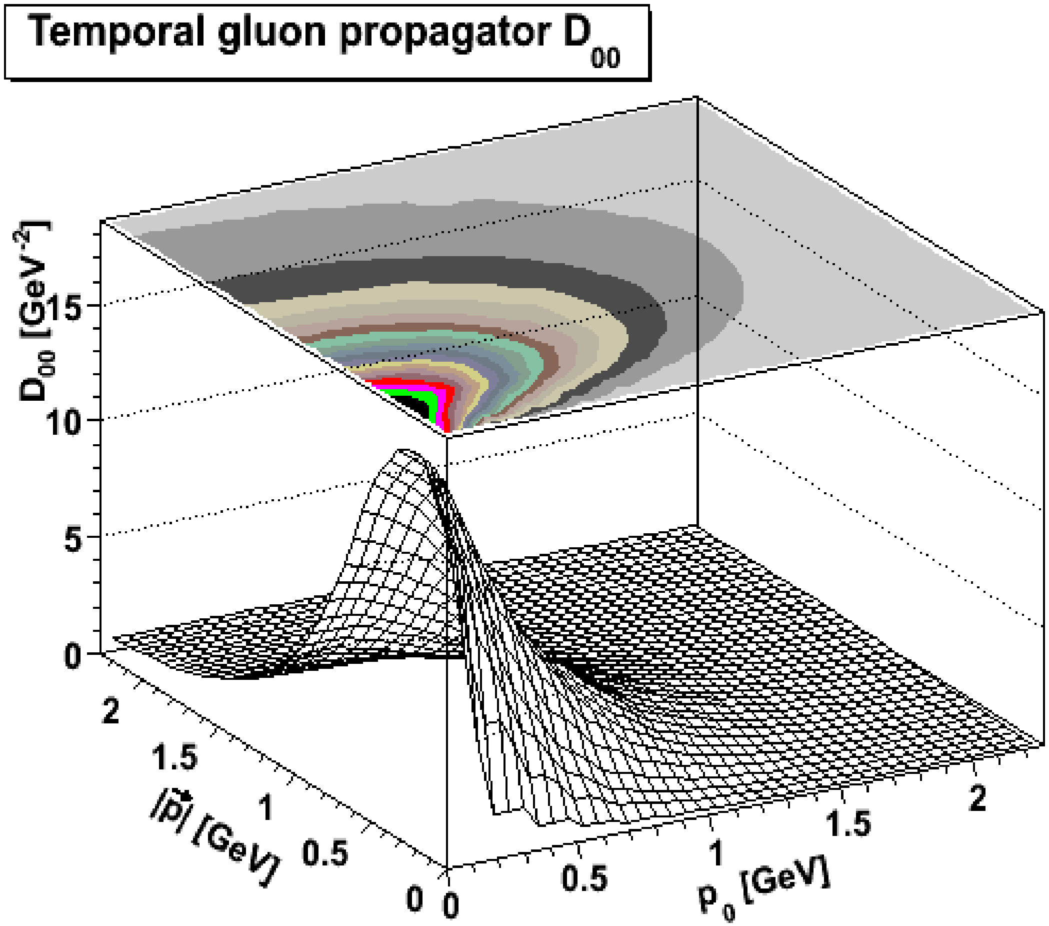

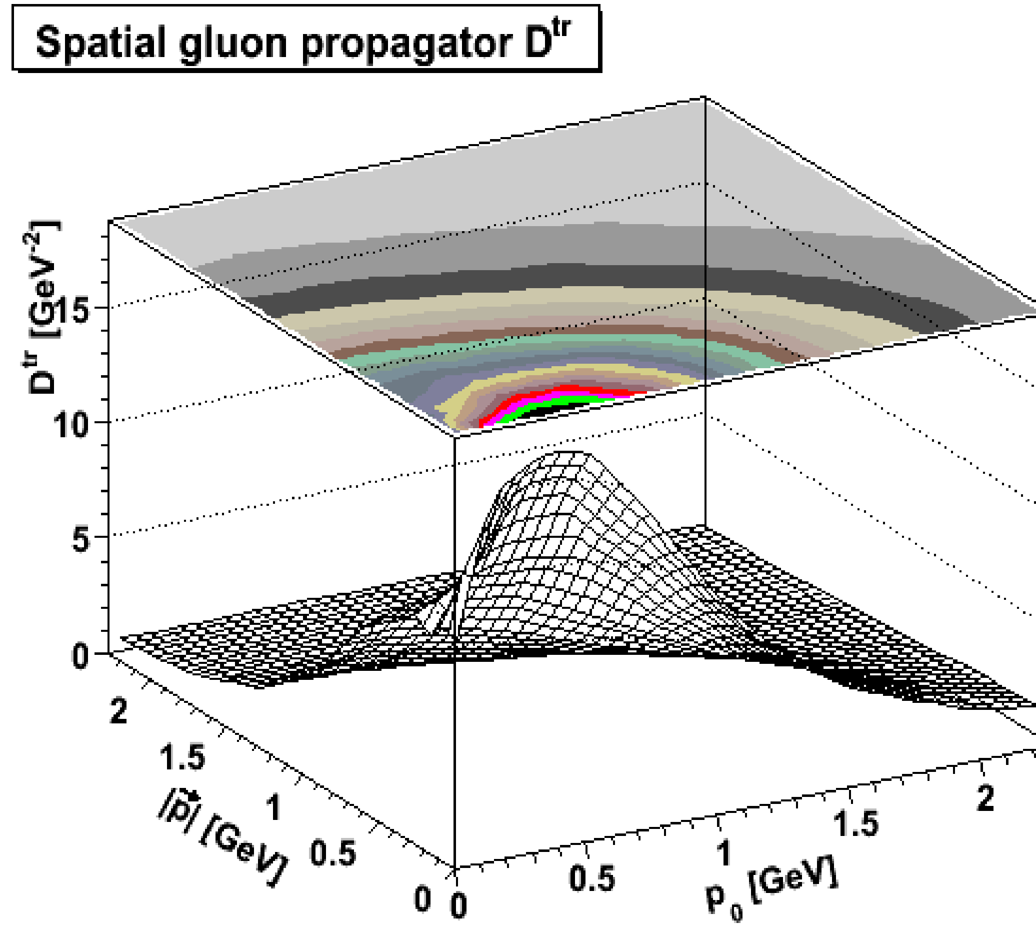

- No visible changes

Gluon propagator

[Lattice 40^3, beta=4.2, λ=1/10:
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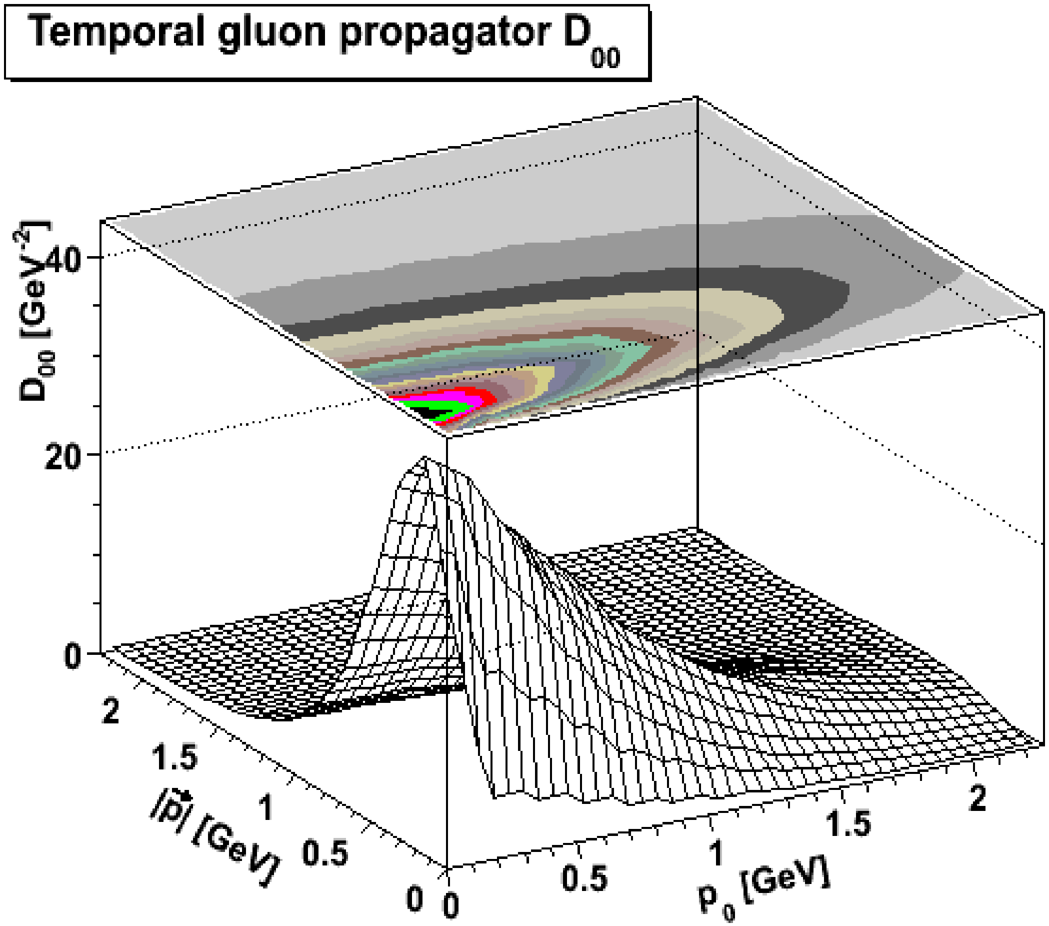
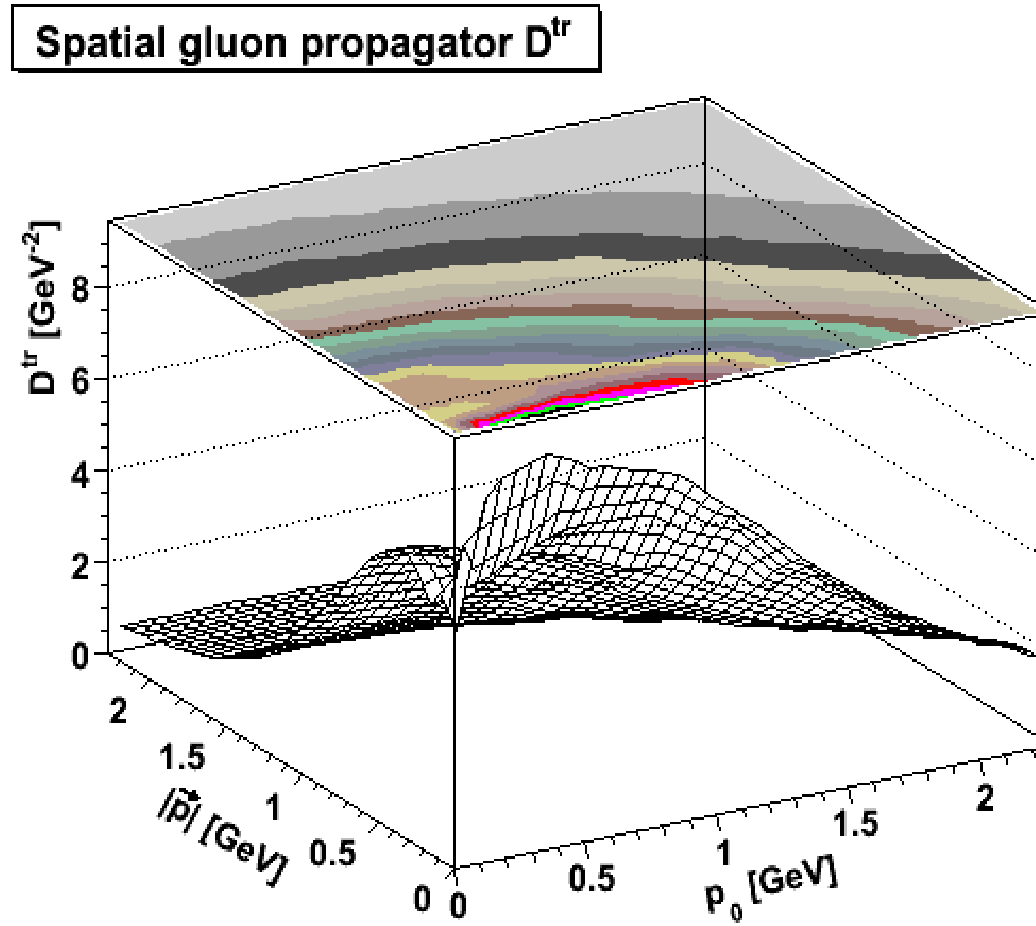
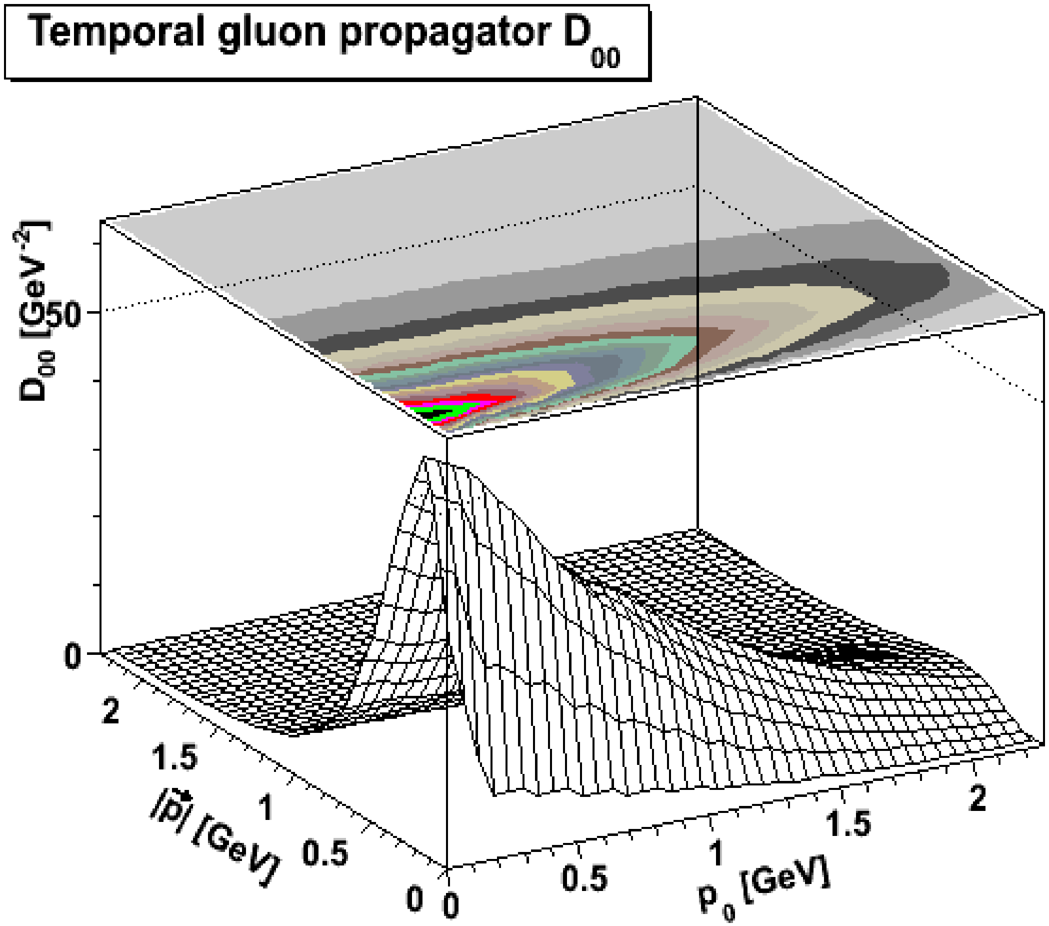


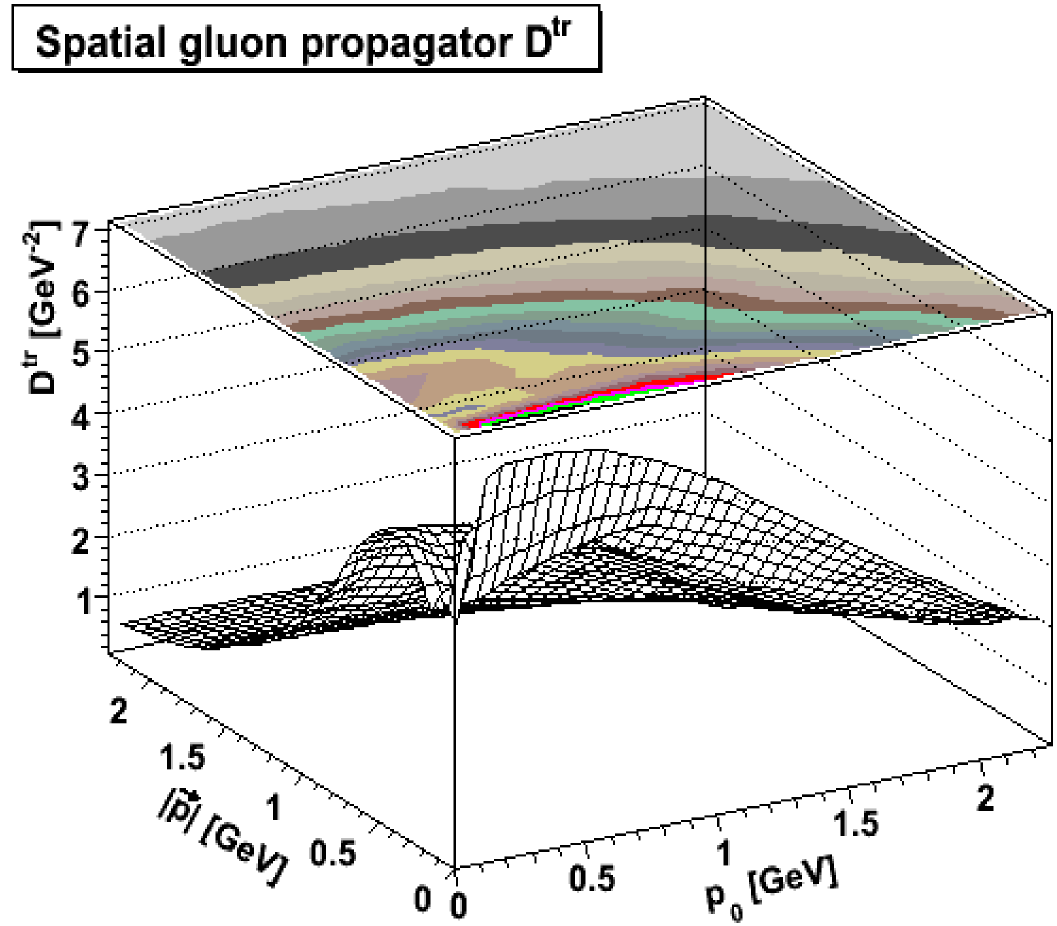


- Temporal: Maximum becomes more pronounced, more infrared
- Spatial: Spatial maximum at larger momenta

Gluon propagator

[Lattice 40^3, beta=4.2, λ=1/20: Cucchieri et al., 2007, unpublished]

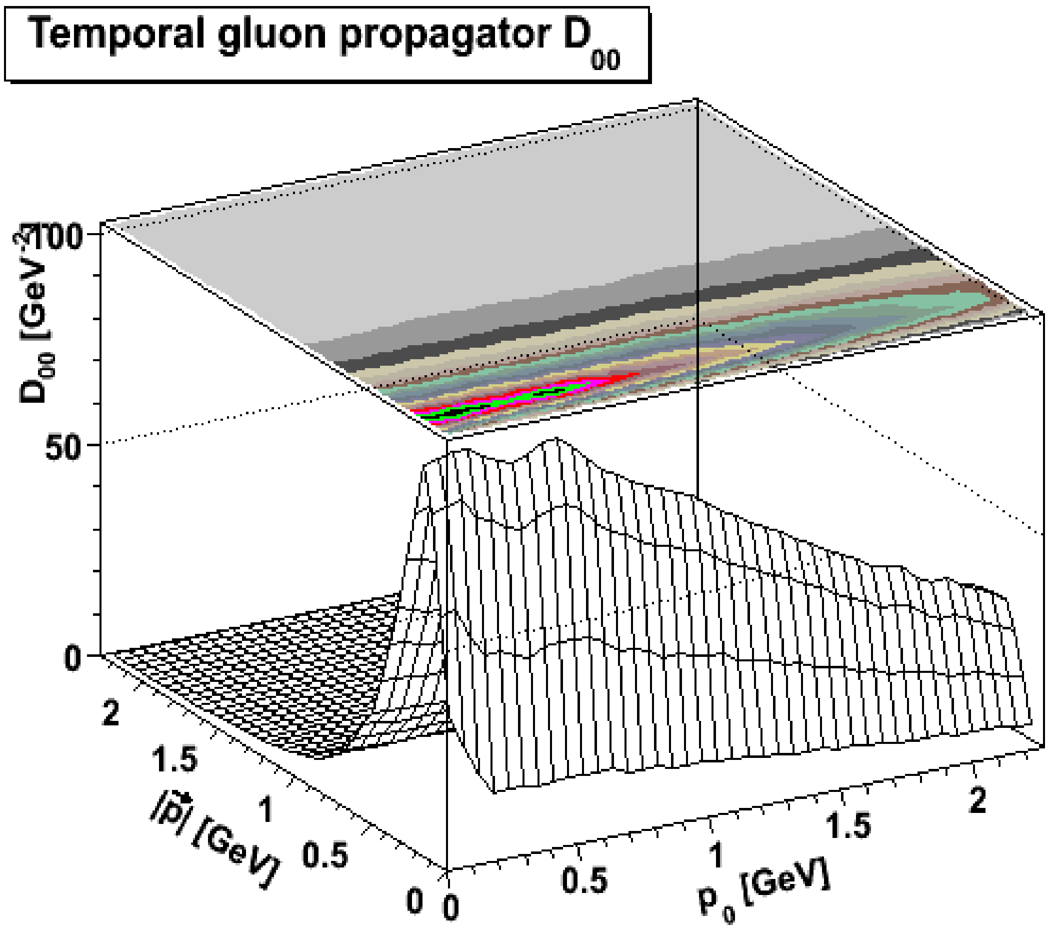


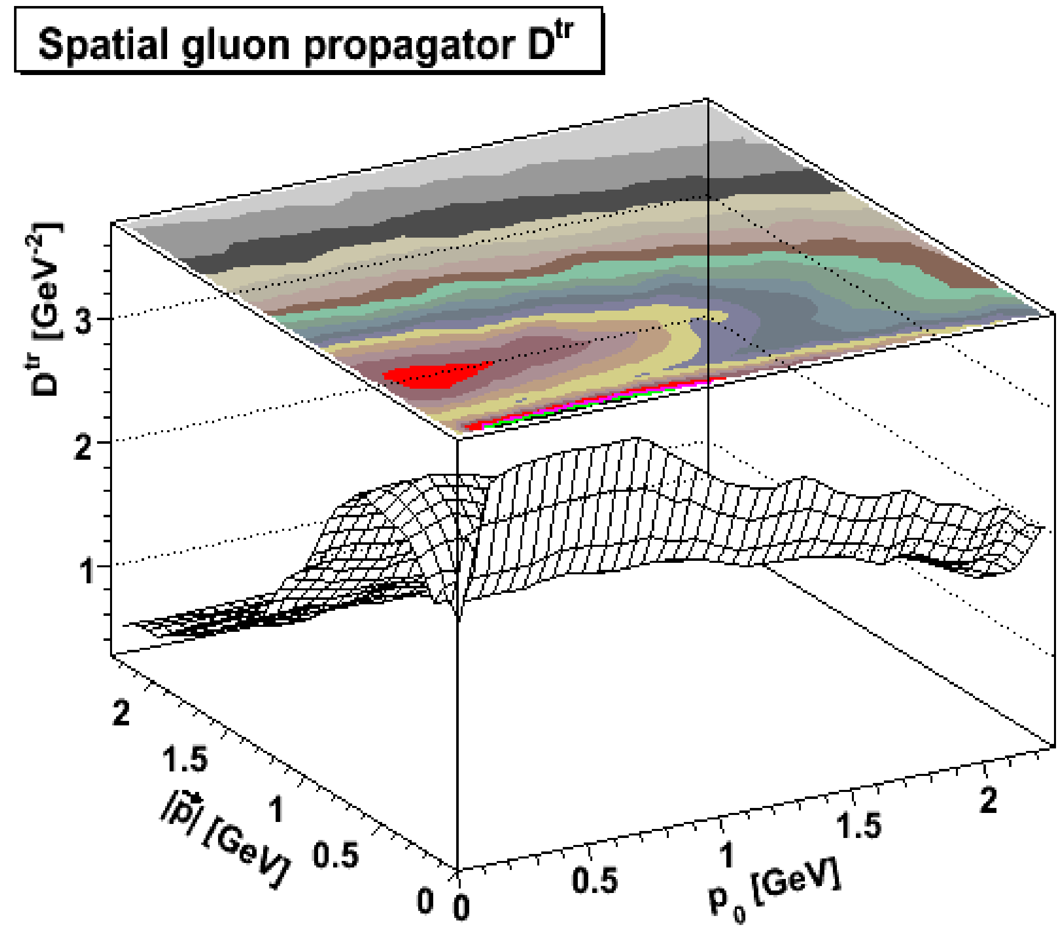


- Resolution of maxima more complicated
- Larger volumes required

Gluon propagator

[Lattice 40^3, beta=4.2, λ=1/100: Cucchieri et al., 2007, unpublished]

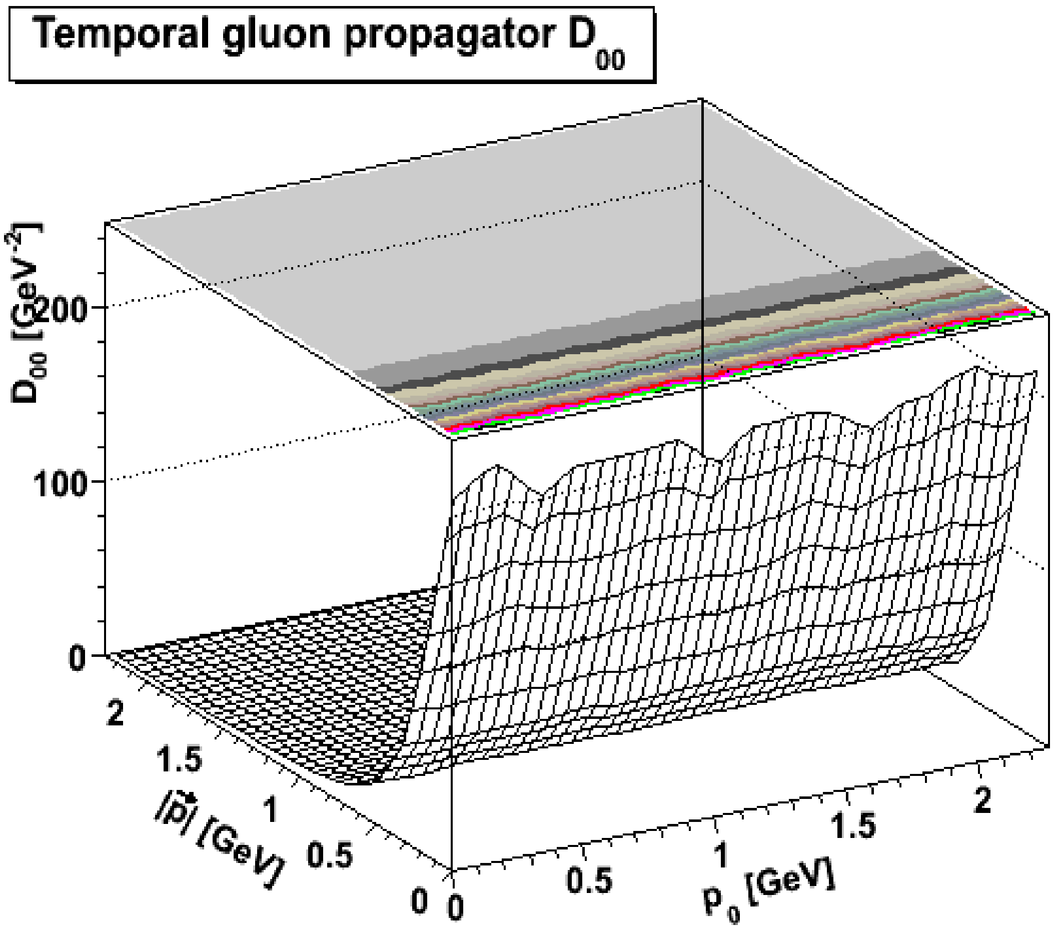


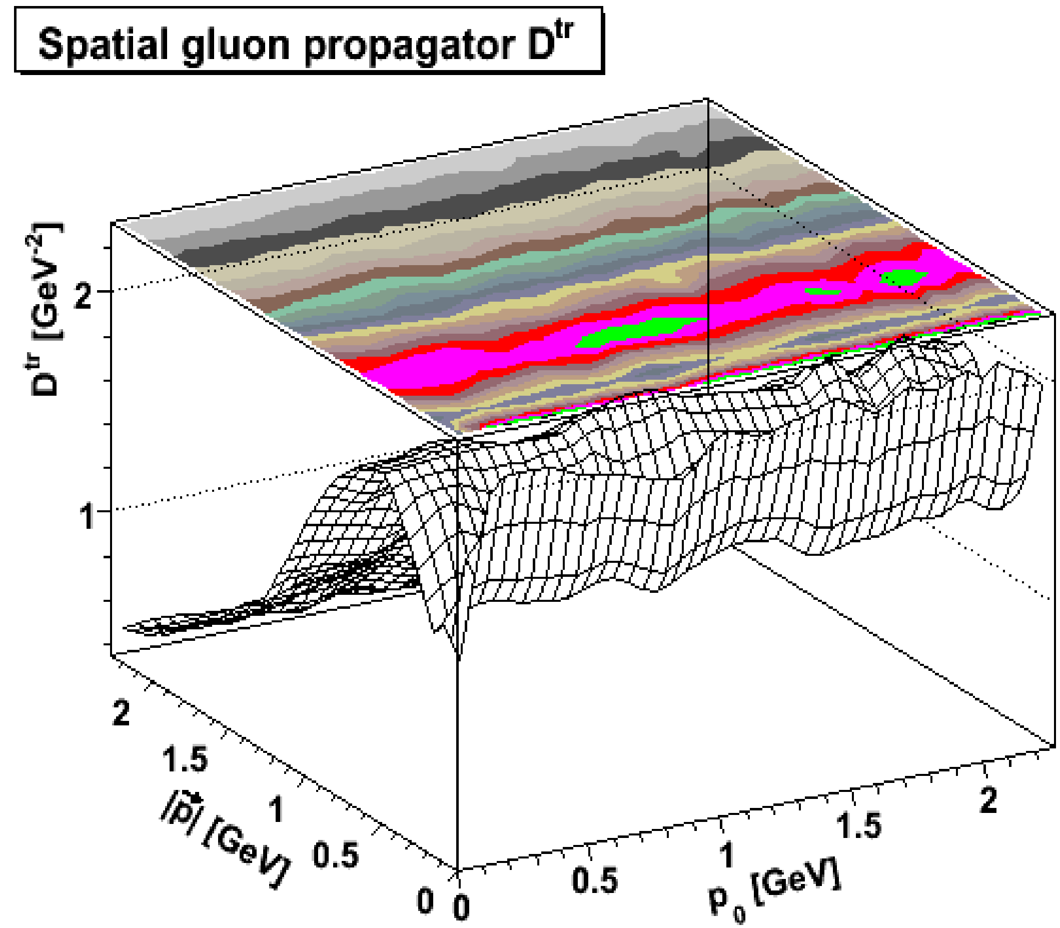


- Coulomb-like at large momenta - Landau-like at small momenta
- Separation momentum, decreasing with λ

Gluon propagator - Coulomb

[Lattice 40^3, beta=4.2, Coulomb: Cucchieri et al., 2007, unpublished]



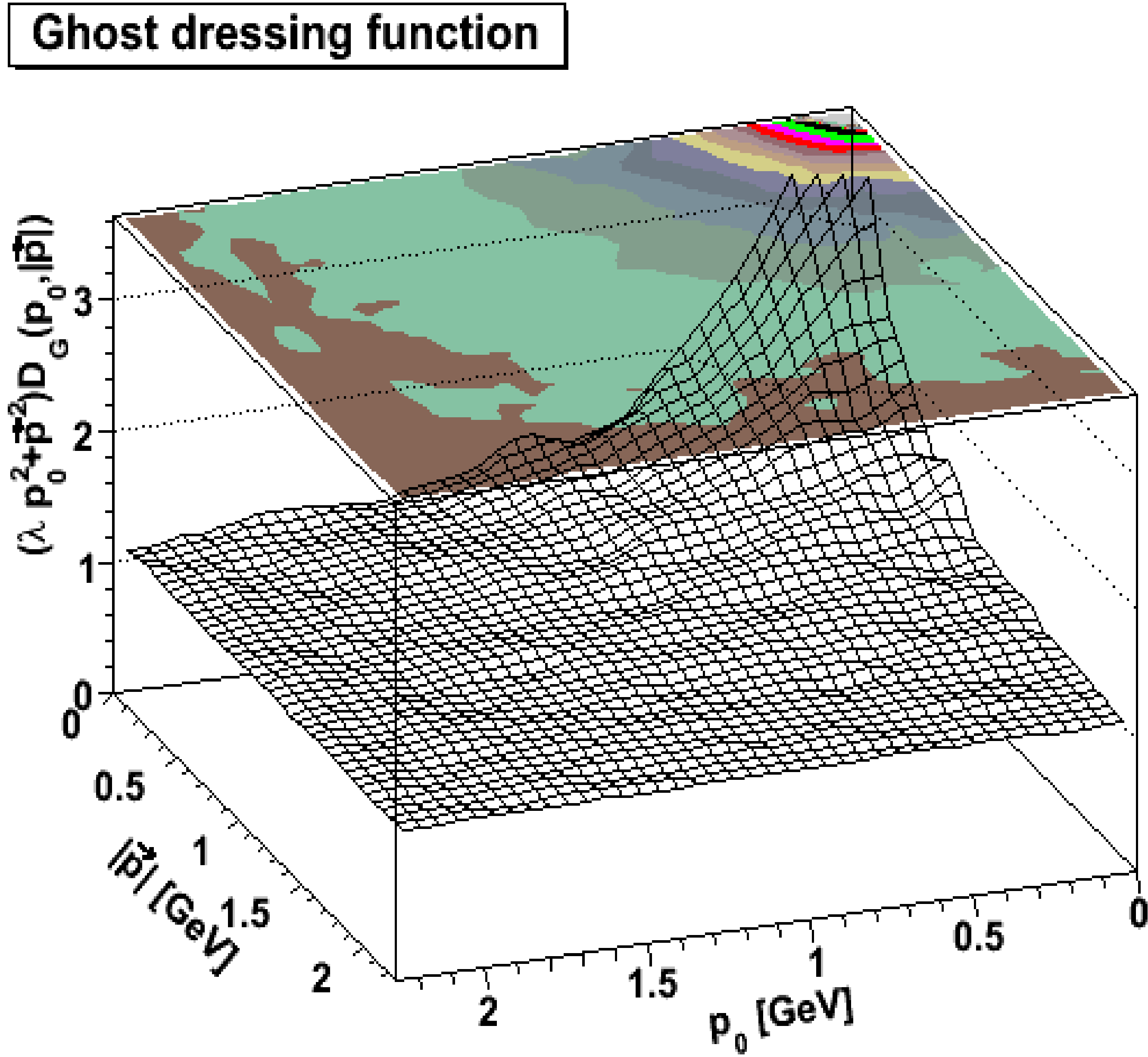


- Temporal propagator infrared divergent – discontinous change
- Spatial propagator only vanishing at zero energy

Ghost dressing function - Landau

[Lattice 40^3, beta=4.2, λ=1: Cucchieri et al., 2006, unpublished]

- Scalar particle
  - Isotrope
- Infrared strongly enhanced



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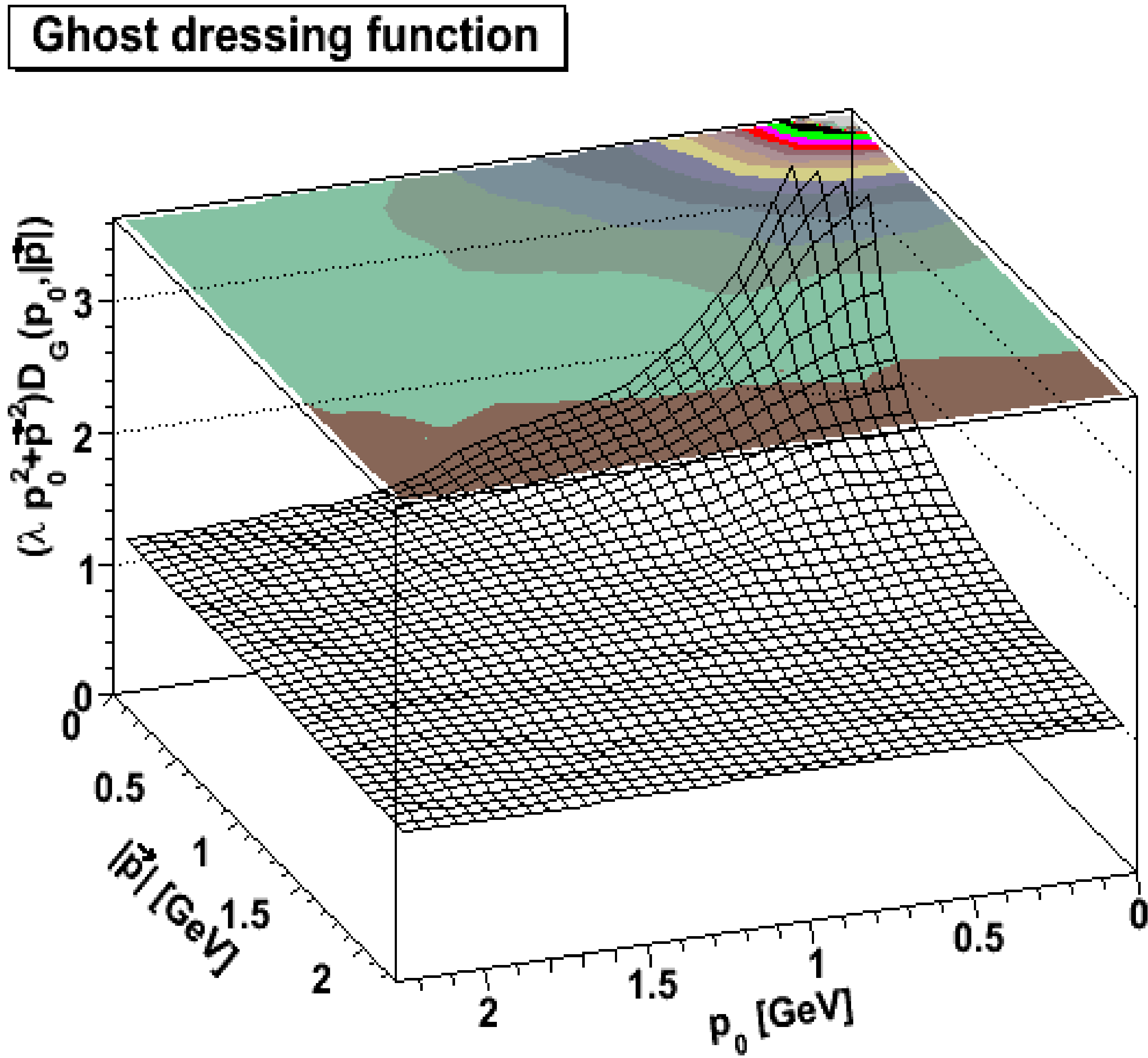
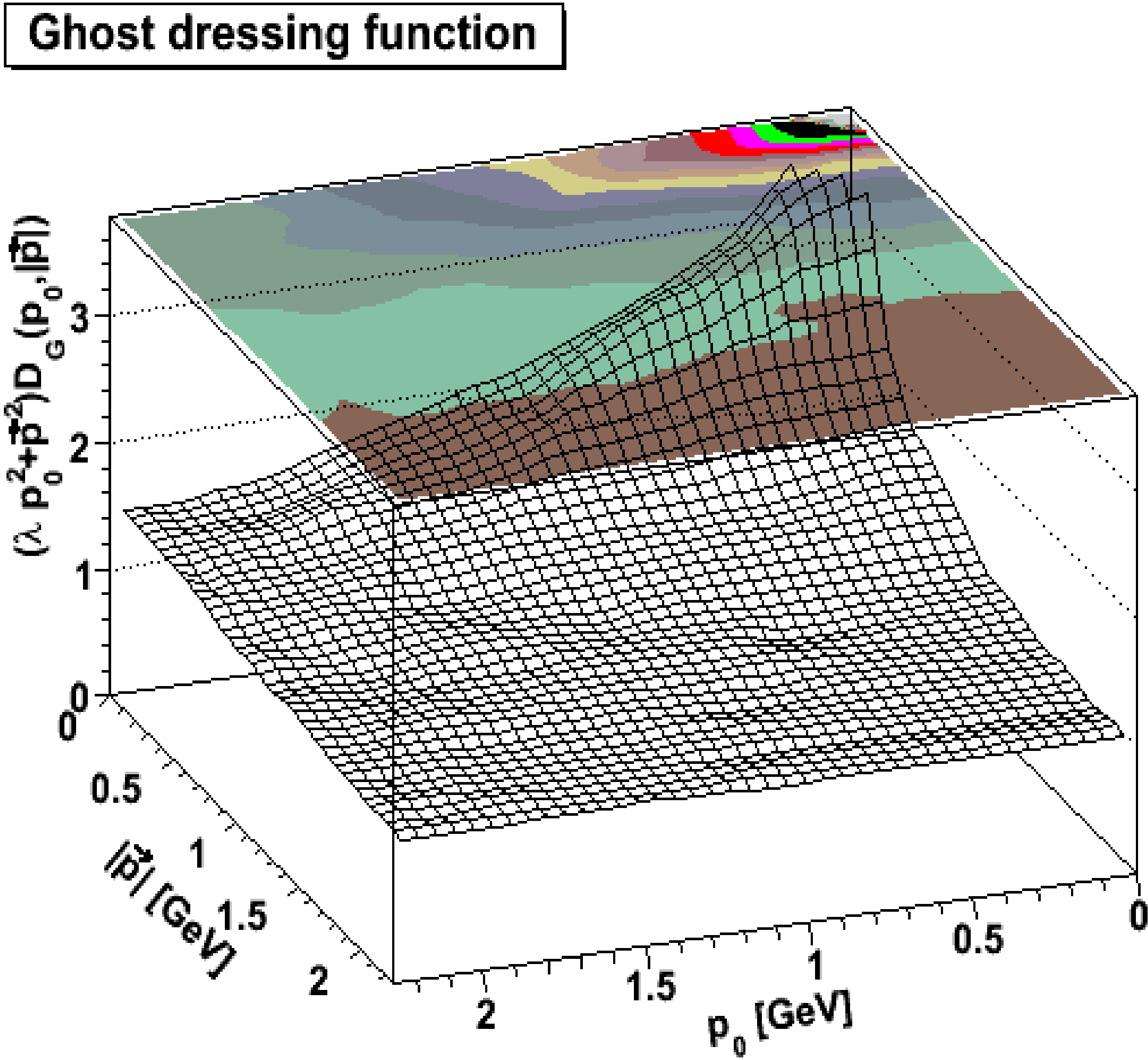


Ghost dressing function

[Lattice 40^3, beta=4.2, λ=1/10: Cucchieri et al., 2006, unpublished]

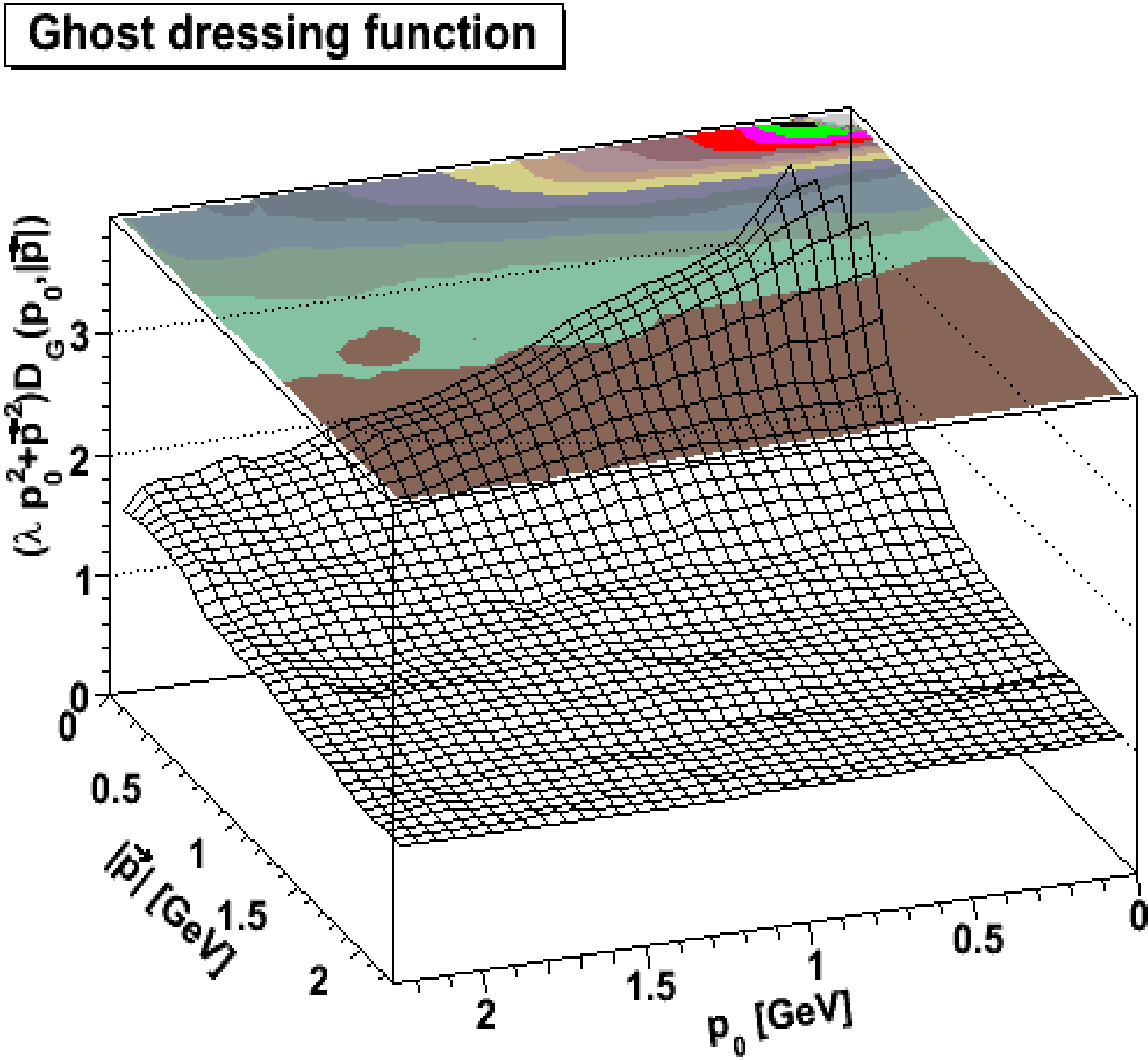
- Increase at all temporal momenta for infrared spatial momenta



Ghost dressing function

[Lattice 40^3, beta=4.2, λ=1/20: Cucchieri et al., 2006, unpublished]

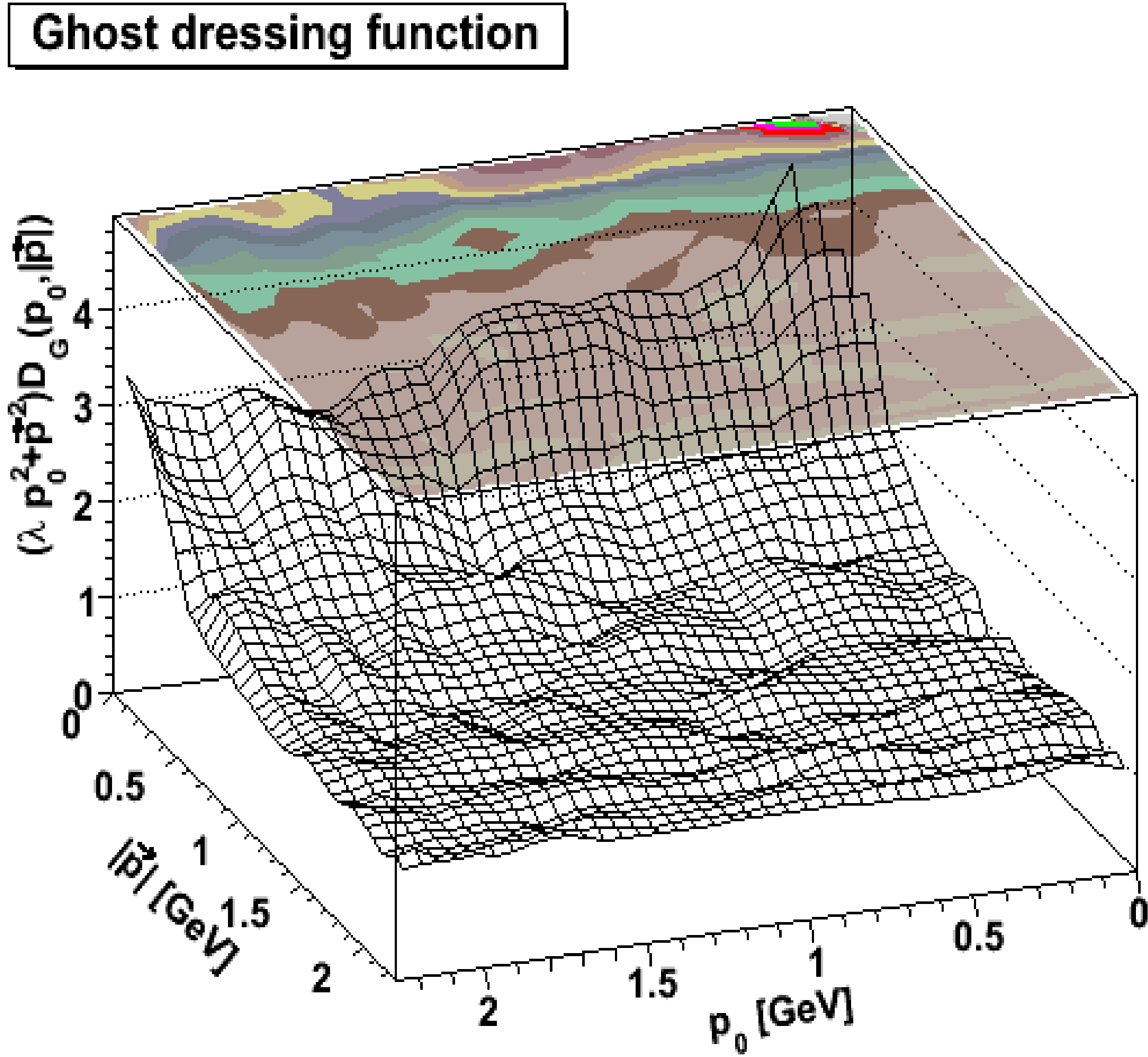
- Effects increase



Ghost dressing function

[Lattice 40^3, beta=4.2, λ=1/100: Cucchieri et al., 2006, unpublished]

- Strong enhancement at all temporal momenta for infrared spatial momenta



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UNI GRAZ

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- Early stage: Only 2d results yet

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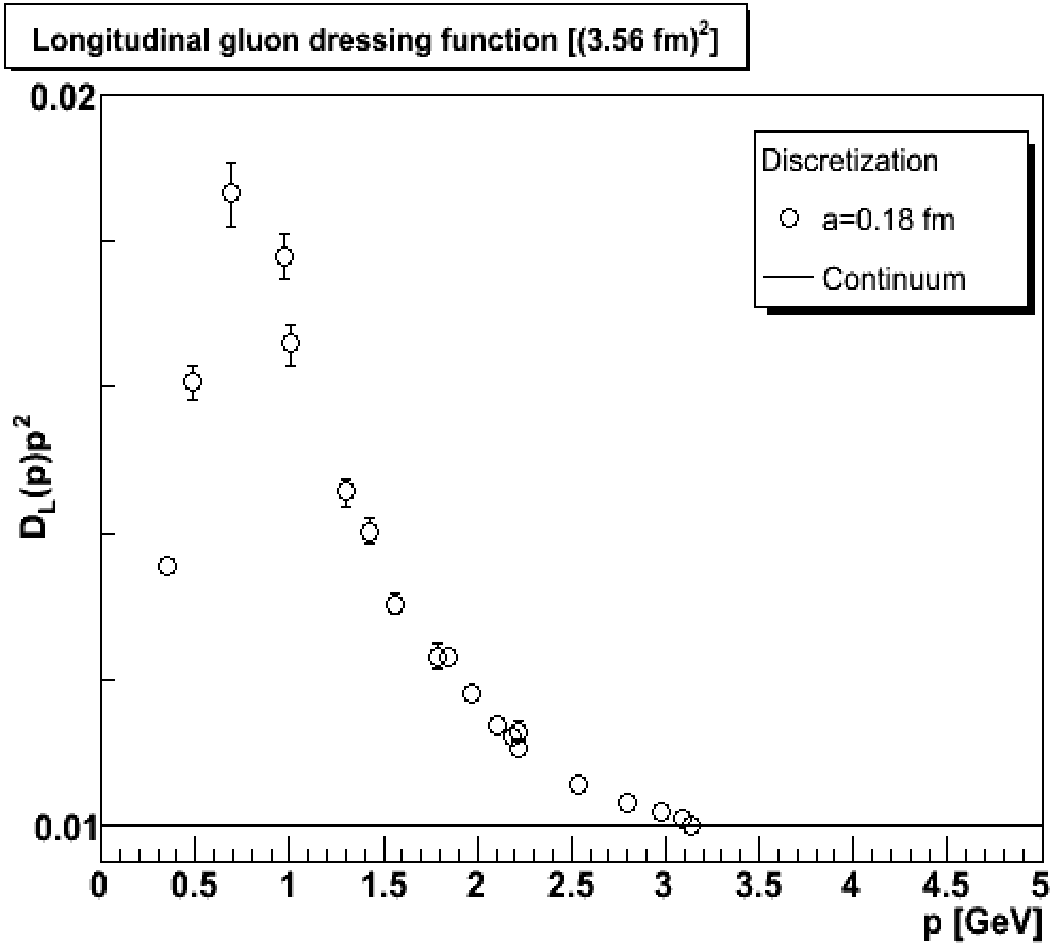

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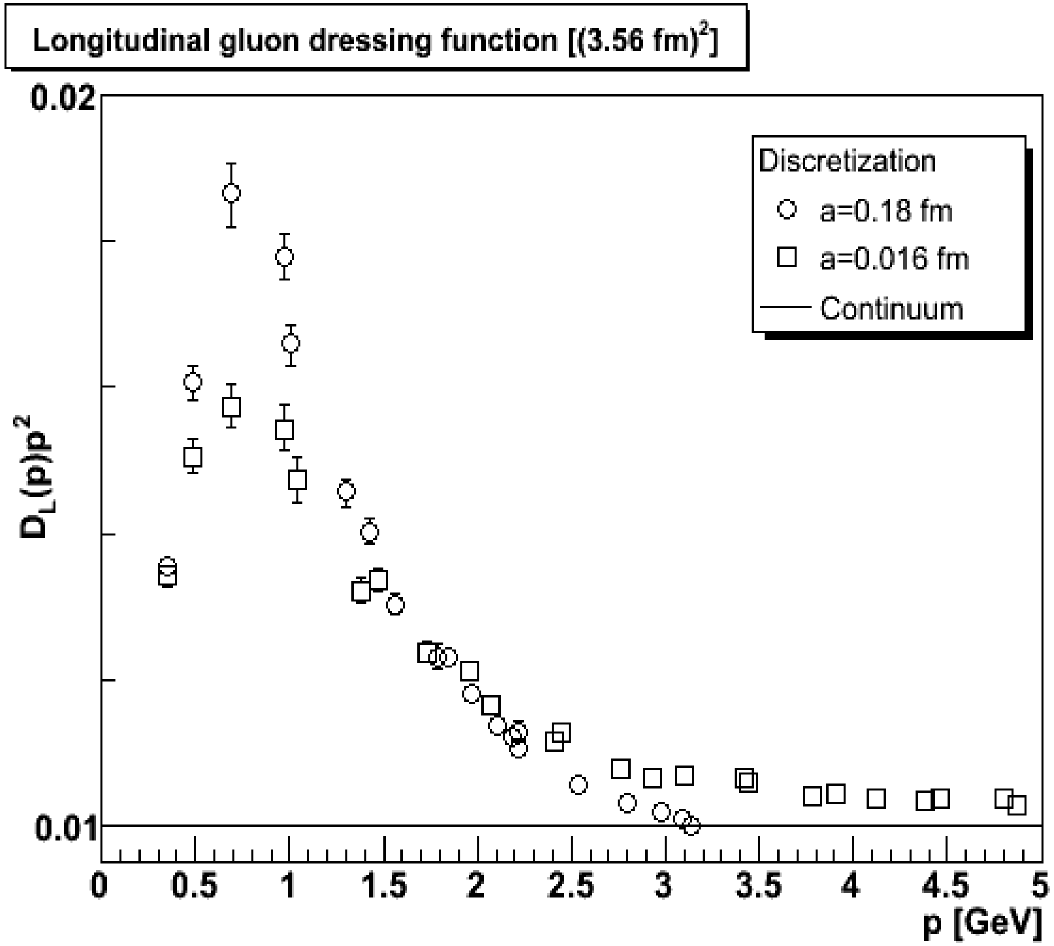

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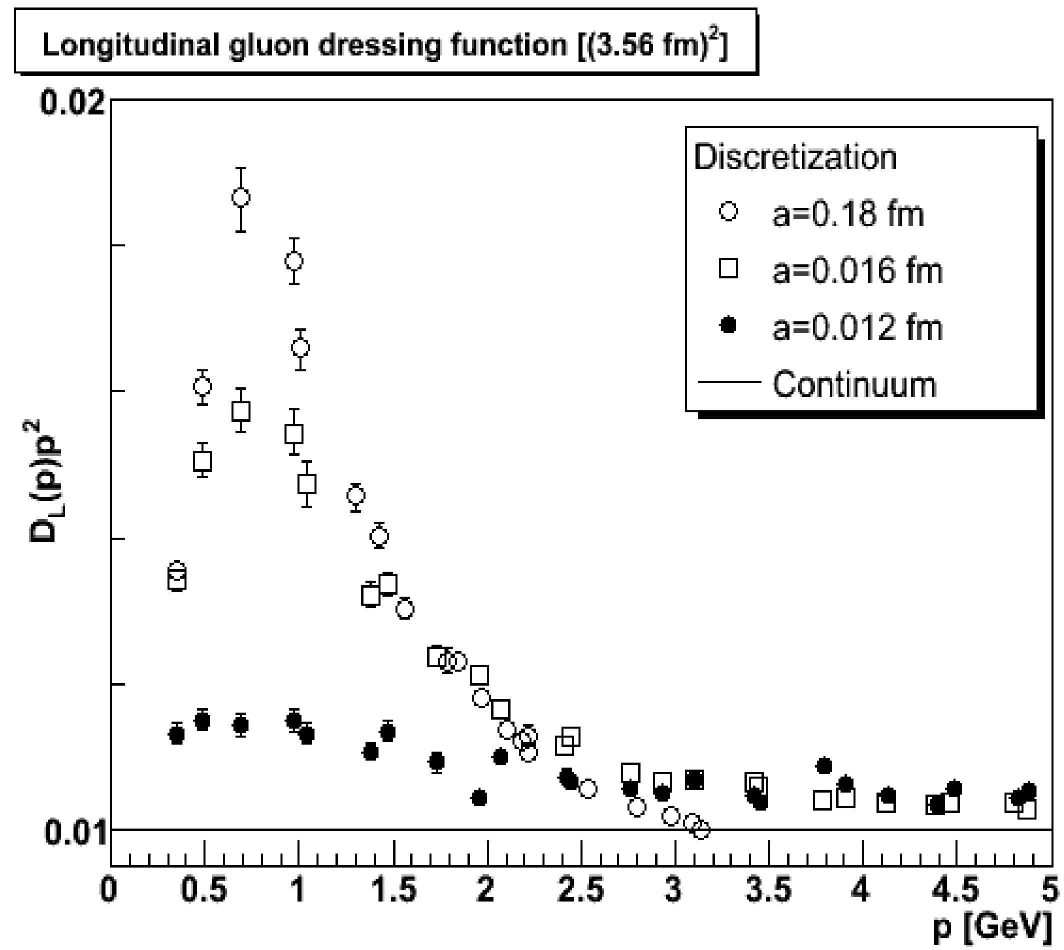

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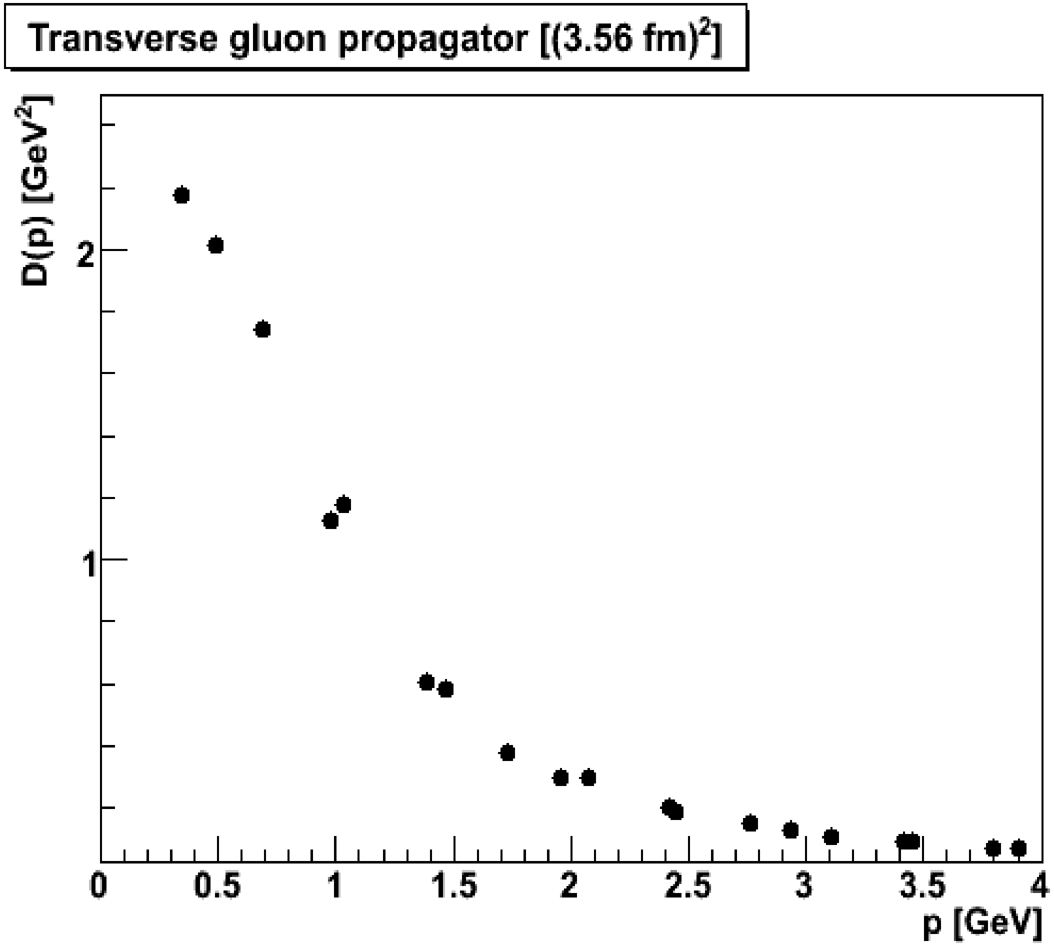

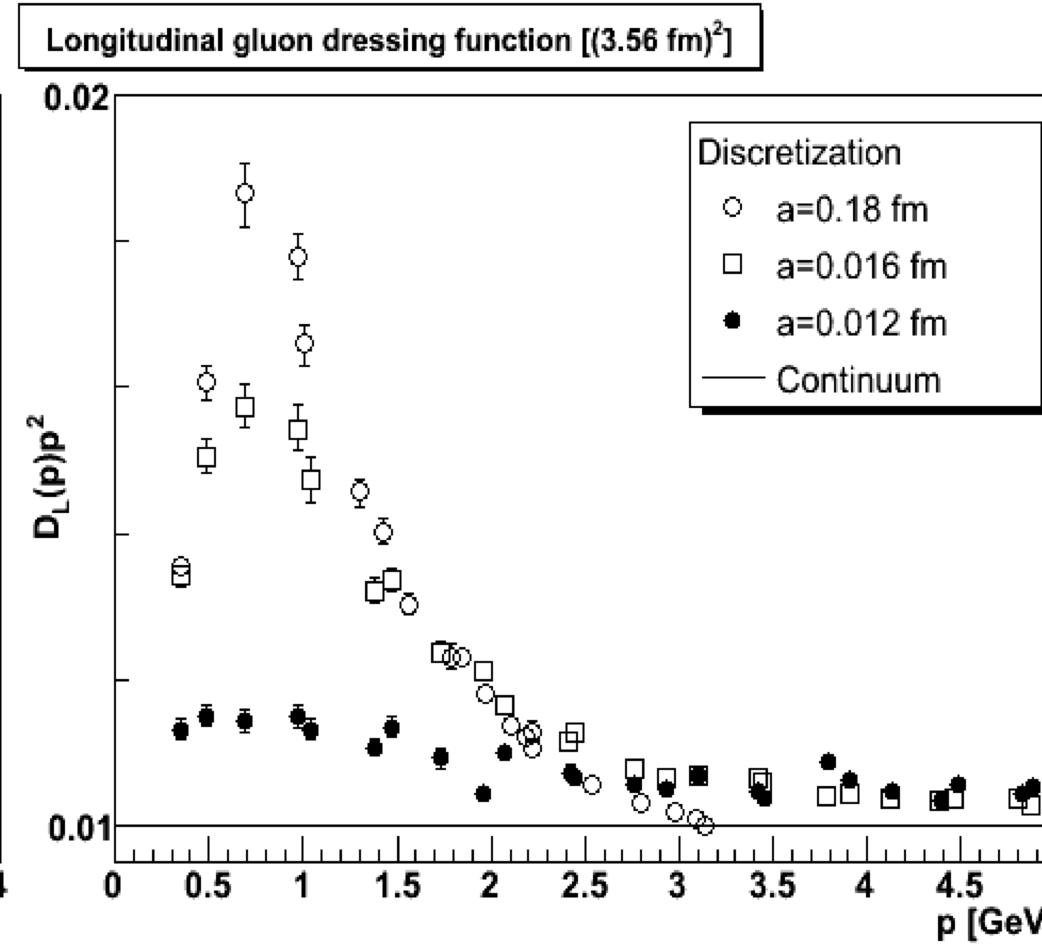

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