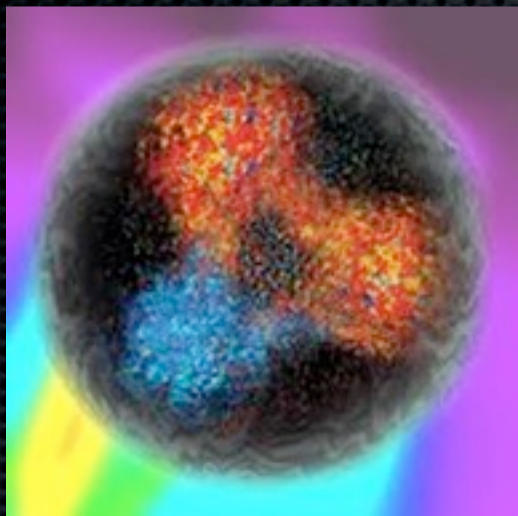
From Running Gluon Mass to Chiral Symmetry Breaking



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11th workshop non-perturbative QCD - Paris 2011

Outline

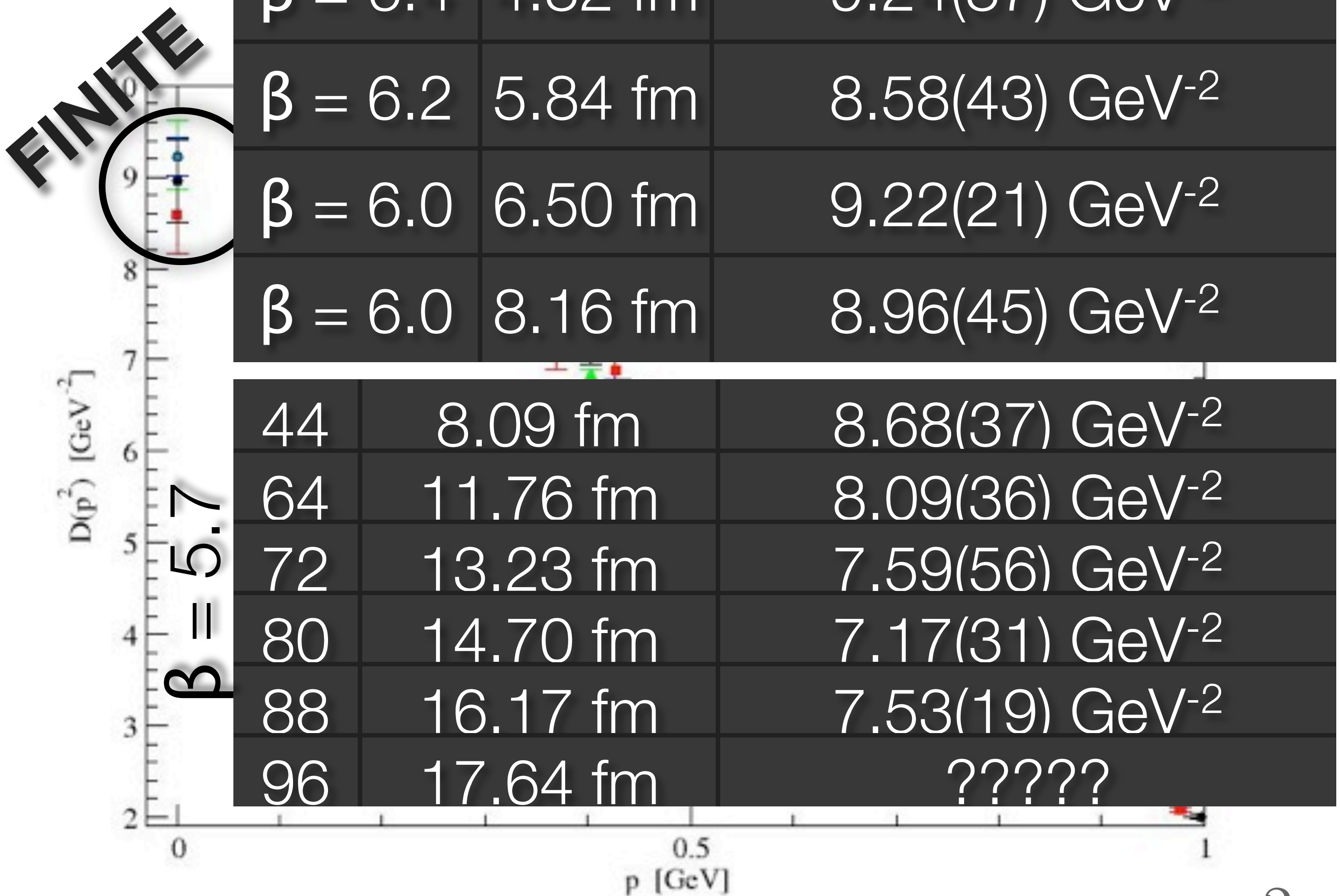
- **Lattice Gluon Propagator**
- **What are the implications of having a gluon mass**

Lattice Gluon Propagator

- Landau gauge
- Finite volume with periodic boundary conditions
- be aware of possible finite volume and lattice spacing effects
- Large discussion about $D(0)$

$$D(p^2) = \delta^{ab} \left(\delta_{\mu\nu} - \frac{p_\mu p\nu}{p^2} \right) D(p^2)$$

How well do we know $D(p^2)$

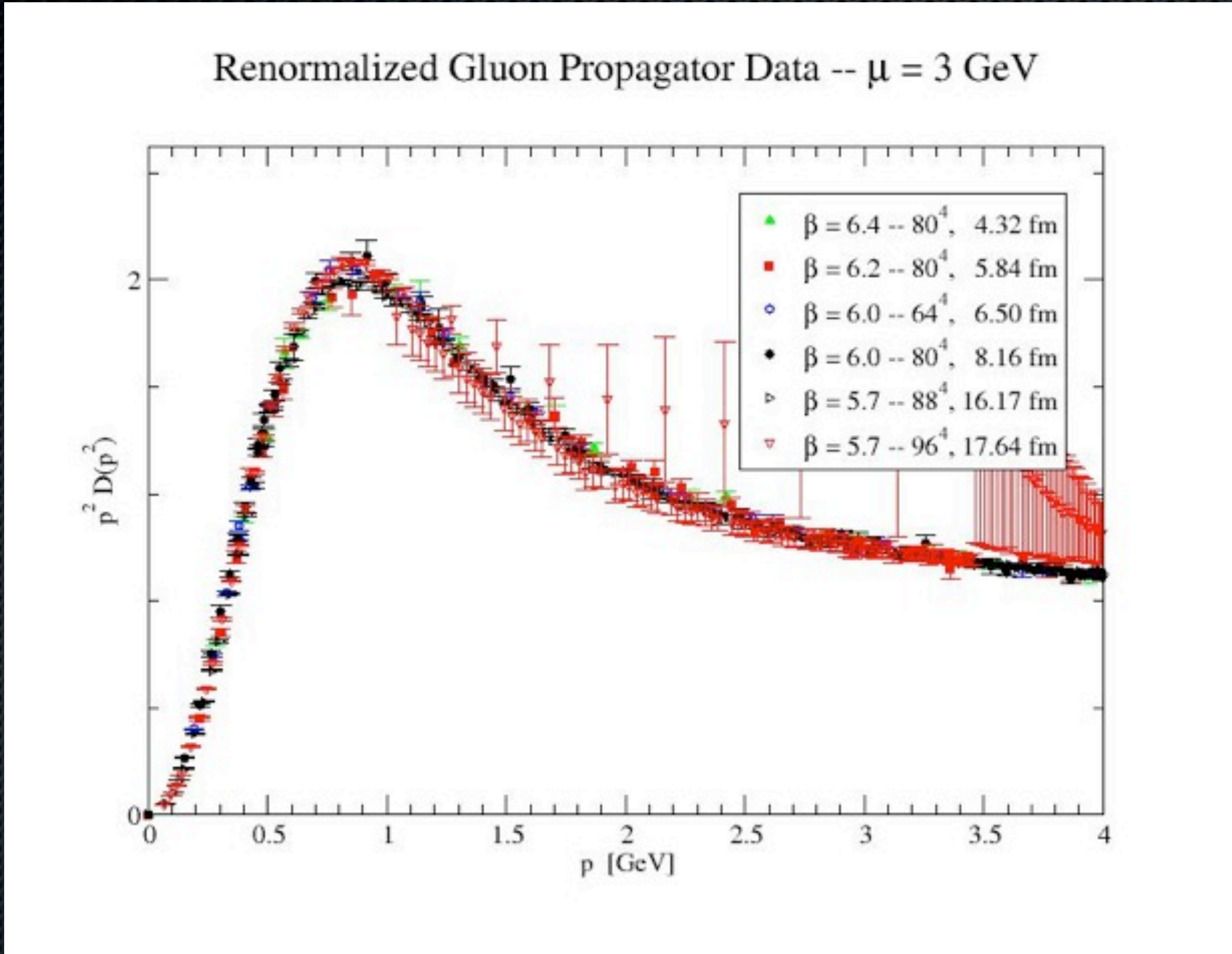


β = 6.4	4.32 fm	9.24(37) GeV^{-2}
β = 6.2	5.84 fm	8.58(43) GeV^{-2}
β = 6.0	6.50 fm	9.22(21) GeV^{-2}
β = 6.0	8.16 fm	8.96(45) GeV^{-2}

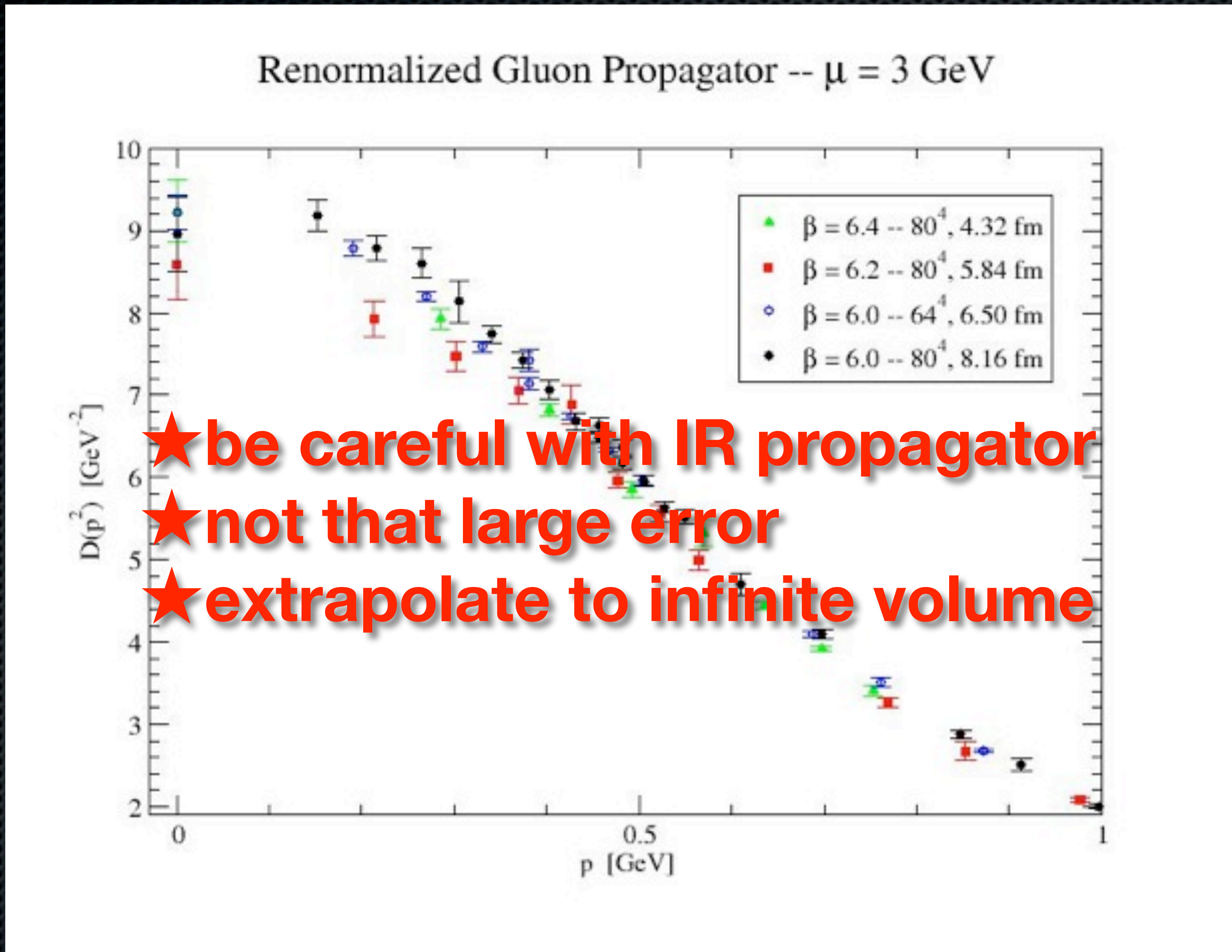
44	8.09 fm	8.68(37) GeV^{-2}
64	11.76 fm	8.09(36) GeV^{-2}
72	13.23 fm	7.59(56) GeV^{-2}
80	14.70 fm	7.17(31) GeV^{-2}
88	16.17 fm	7.53(19) GeV^{-2}
96	17.64 fm	?????

$7.17 - 9.24$ $\quad$ $D(0) \sim 8.2\text{GeV}^{-2}$

How well do we know $D(p^2)$



How well do we know $D(p^2)$



- ★be careful with IR propagator
- ★not that large error
- ★extrapolate to infinite volume

How well do we know $D(p^2)$

$D(0) \sim 8.2\mathrm{GeV}^{-2}$ $\rightarrow$ finite mass

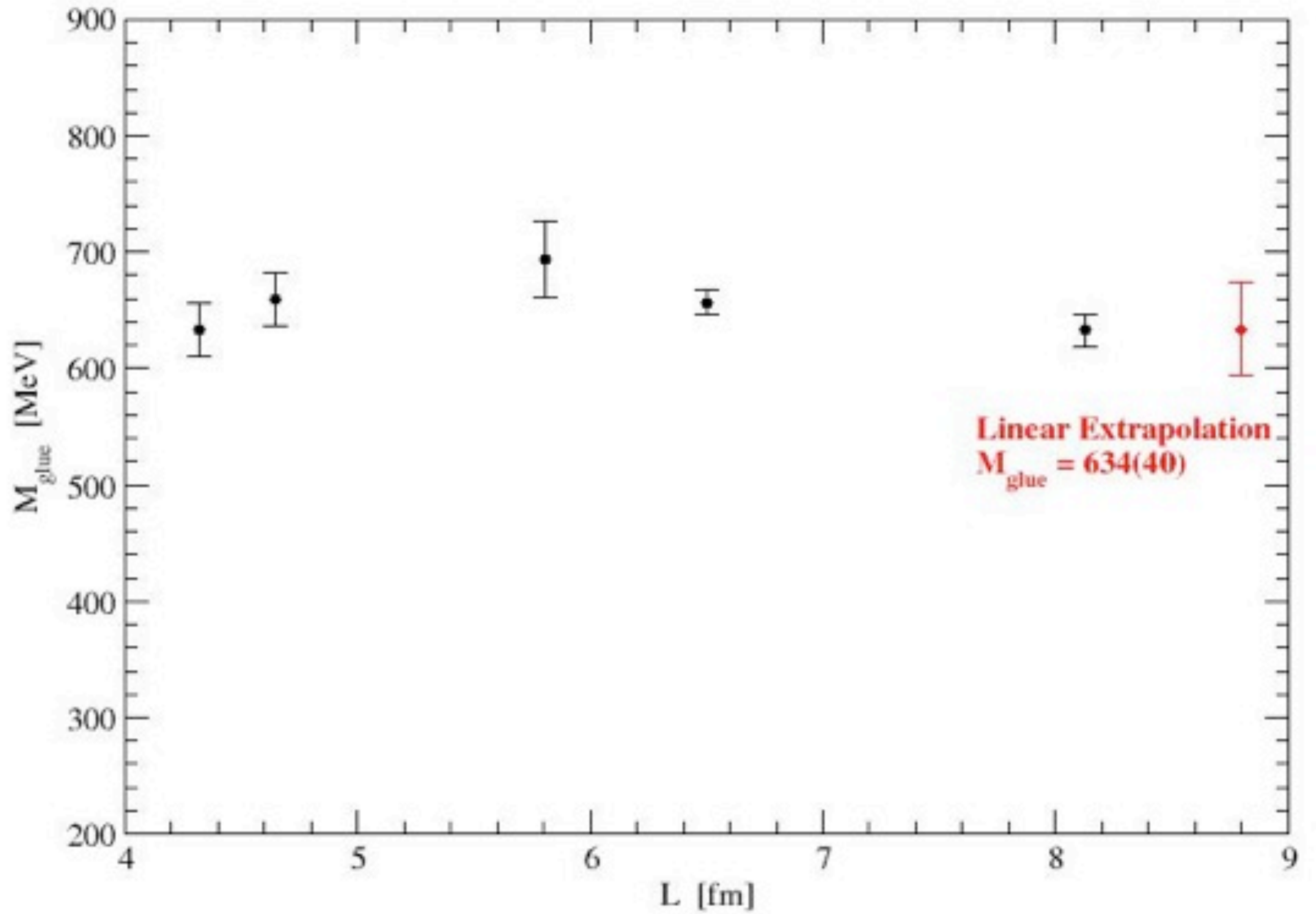
$$D(p^2) = \frac{Z}{p^2 + M^2}$$

$$D(p^2) = \frac{Z(p^2)}{p^2 + M^2(p^2)}$$

don't forget the log here

how can one measure the running mass?

Low Energy Propagator



Running Gluon Mass

sliding window analysis:

$$Z(p^2) = Z_0 \left[A + \ln(p^2 + m_0^2)\right]^{-\gamma} \qquad M^2(p^2) = p^2 \ln p^2$$

model:

$$Z(p^2) = \frac{z_0}{\left[\ln \frac{p^2 + r m_0^2}{\Lambda}\right]^{\gamma}} \qquad M^2(p^2) = \frac{m_0^2}{p^2 + m_0^2}$$

$$z_0 = 1.189(20)$$

$$\Lambda = 1.842(39)\ \text{GeV} \qquad m_0 = 671(9)\ \text{MeV}$$

$$r = 7.49(59)$$

$$p_{max} = 4.2\ \text{GeV}$$

O. Oliveira, P. Bicudo, J. Phys. **G38**, 045003 (2011)

Refined Gribov-Zwanziger Action

- Gribov copies
- Restriction of the functional integration space

$$D(p^2) = \frac{p^2 + M^2}{p^4 + (M^2 + m^2)\,p^2 + 2g^2N\gamma^4 + M^2m^2}$$

mass

Describes well the Lattice Data up to 1.5 GeV

$$M^2(p^2) = \frac{m^2p^2 + 2g^2N\gamma^4 + M^2m^2}{p^2 + M^2}$$

meter

D. Dudal, O. Oliveira, N. Vandersickel, PRD81, 074505 (2010)

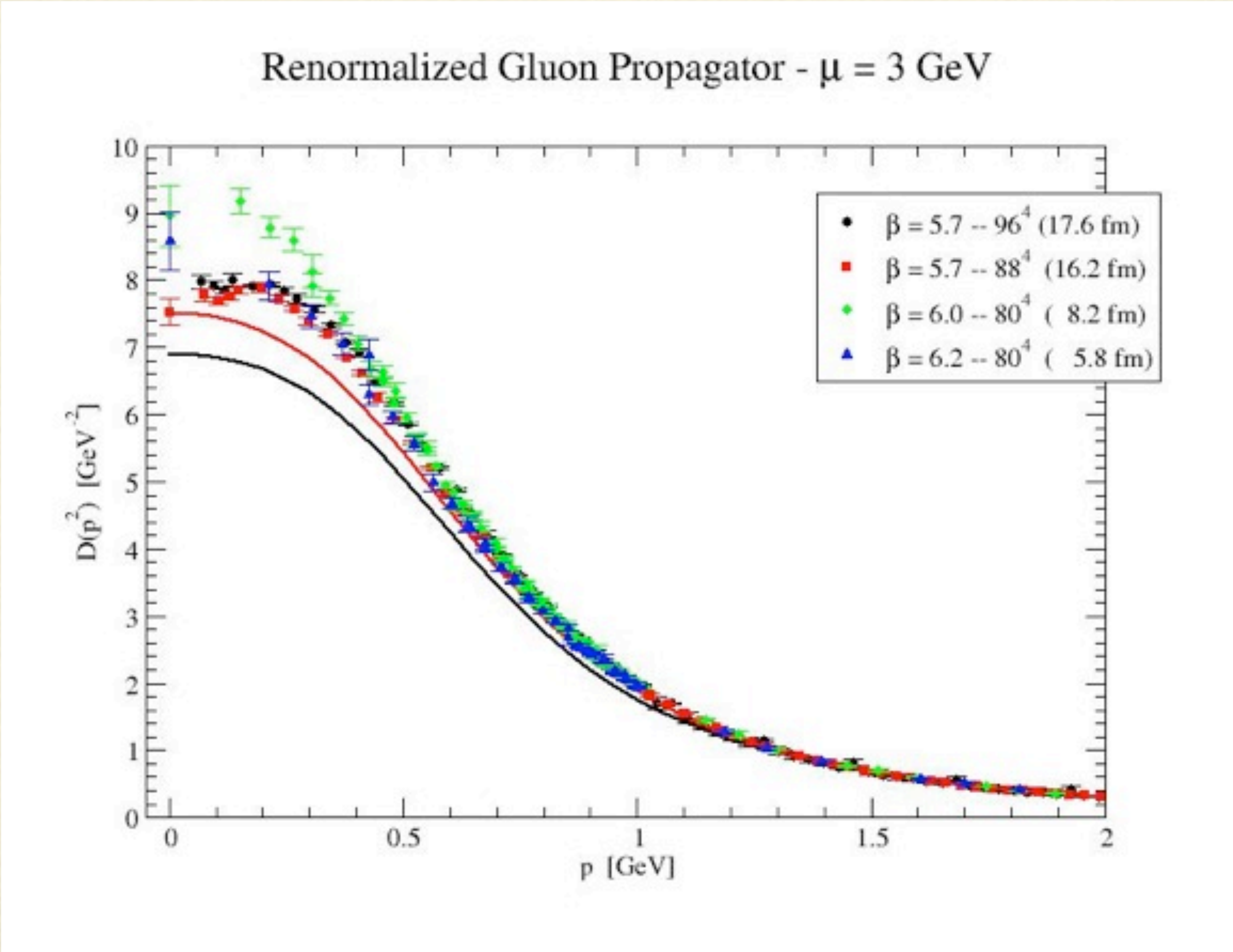
Fitting the Lattice Data

β	La	χ^2/dof	M^2	M^2+m^2	λ^4	p_{max}
6.0	4.88	1.6	2.81(9)	0.62(3)	0.284(7)	1.2
	6.50	1.1	2.66(6)	0.54(2)	0.288(5)	0.95
	8.13	1.1	2.41(5)	0.47(2)	0.261(4)	1.6
6.2	3.49	1.1	2.5(1)	0.48(4)	0.28(1)	1.4
	4.65	1.4	2.44(7)	0.48(3)	0.276(6)	1.5
	5.81	1.2	2.3(1)	0.42(4)	0.273(9)	1.6

β	M^2	M^2+m^2	λ^4
6.0	1.80(22)	0.329(20)	0.2610(38)
6.2	2.10(24)	0.36(11)	0.280(10)

$D(0) = 7.50(90)$ $\qquad$ $D(0) = 6.90(85)$

Extrapolated Propagator



Gluon Condensate

$$\langle g^2 A^2 \rangle = -\zeta_0 \, m^2$$

$$\zeta_0 = \frac{9}{13} \frac{N^2 - 1}{N}$$

$\langle g^2 A^2 \rangle\big|_{3 \text{ GeV}} =$	$2.71(41)$	$3.21(48)$	GeV
$\langle g^2 A^2 \rangle\big|_{10 \text{ GeV}} =$	$2.45(38)$	$2.90(43)$	GeV
	$\beta = 6.0$	$\beta = 6.2$	

$\langle g^2 A^2 \rangle\big|_{10 \text{ GeV}} = 5.1^{+0.7}_{-1.1} \text{ GeV}$ glue

$\langle g^2 A^2 \rangle\big|_{10 \text{ GeV}} = 4.4 \pm 0.4 \text{ GeV}$ quark

P. Boucaud et al
PR**D63**,114003 (2001)
PR**D66**, 034504 (2002)
PR**D79**, 014508 (2009)

Why a Gluon Mass?

Effective Degrees of Freedom

$$8 \otimes 8 = 1 \otimes \underline{8 \otimes 8} \otimes 10 \otimes \overline{10} \otimes 27$$

color octet

singlet = glueballs

lightest glueball - 1.7 GeV
to heavy for a low energy theory

$$\begin{matrix} \not{f}_{abc} \\ d_{abc} \end{matrix} \Bigg| \; F^b_{\mu\nu} F^{c\,\mu\nu} \quad + \quad \bar{q}\, t^a q \quad \sim \quad \phi^a$$

O. Oliveira, W. de Paula, T. Frederico, arXiv:1105.4899

Effective Degrees of Freedom

$$\phi^a = \frac{d_{abc}F^b F^c}{\Lambda^3} + \frac{\overline{q}\, t^a q}{\Lambda^2}$$

$$\sim \frac{\langle F^2 \rangle}{\Lambda^3} + \frac{\langle \overline{q}\, q \rangle}{\Lambda^2}$$

$\alpha_s \langle F^2 \rangle = 0.04\ \mathrm{GeV}^4$ $\quad \langle \overline{q}\, q \rangle = (-270\ \mathrm{MeV})^3$ $\quad \Lambda = 0.3\ \mathrm{GeV}$

$$\frac{\text{glue}}{\text{quark}} \sim 7$$

Effective Lagrangian

$$\mathcal{L} = -\frac{1}{4} F^a_{\mu\nu} F^{a\,\mu\nu} + \sum_f \bar{q}_f \{ i\gamma^\mu D_\mu - m \} q_f$$
$$+ \frac{1}{2} (D^\mu \phi^a)(D_\mu \phi^a) - V_{oct}(\phi^a \phi^a) + \mathcal{L}_{GF} + \mathcal{L}_{gh} + \mathcal{L}_{new}$$

$$G_4 \sum_f \left[\bar{q}\, t^a\, q \right] \phi^a$$

$$G_5 \sum_f \left[\bar{q}\, q \right] \phi^a \phi^a + F_1 \sum_f \left[\bar{q}\, t^a q \right] d_{abc} \phi^b \phi^c$$
$$+ F_2 \sum_f \left[\bar{q}\, t^a \gamma^\mu q \right] D_\mu \phi^a + F_3 \sum_f \left[\bar{q}\, t^a \gamma^\mu D_\mu q \right] \phi^a$$

Mass Generation

$$\frac{1}{2}(D^\mu\phi^a)(D_\mu\phi^a) \qquad \frac{1}{2}g^2\,\phi^c(T^aT^b)_{cd}\phi^d A^a_\mu A^{b\,\mu}$$

$$\langle\phi^a\rangle = 0 \quad \text{and} \quad \langle\phi^a\phi^b\rangle = v^2\delta^{ab}$$

$$m_g^2 = N\,g^2 v^2$$

$$G_5\;\overline{q}\,q\;\phi^a\phi^a \qquad -\frac{G_5}{g^2}\frac{N^2-1}{N}m_g^2$$

Chiral Symmetry Breaking

$$\langle \overline{q}\, q \rangle = -\frac{4NN_f}{16\pi^2}\, M\, m_g^2 \left\{ \left(\frac{M}{m_g}\right)^2 \ln \frac{M^2}{M^2+\overline{\omega}^2} + \left(\frac{\overline{\omega}}{m_g}\right)^2 \right\}$$

No Gluon Mass

No quark Mass

No chiral condensate

does not necessarily hold in all conditions

- other degrees of freedom
- $\langle \phi^a \rangle = 0 \qquad \langle \phi^a \phi^b \rangle = v^2 \delta^{ab}$

Parameters Estimation

$M = 330 \text{ MeV}$ $m_g = 634(40) \text{ MeV}$ $\langle \bar{q}\, q \rangle = (-270 \text{ MeV})^3$

$$\langle \bar{q}\, q \rangle = -\frac{4NN_f}{16\pi^2} M\, m_g^2 \left\{ \left(\frac{M}{m_g} \right)^2 \ln \frac{M^2}{M^2 + \overline{\omega}^2} + \left(\frac{\overline{\omega}}{m_g} \right)^2 \right\}$$

$\overline{\omega} = 879 \text{ MeV}$

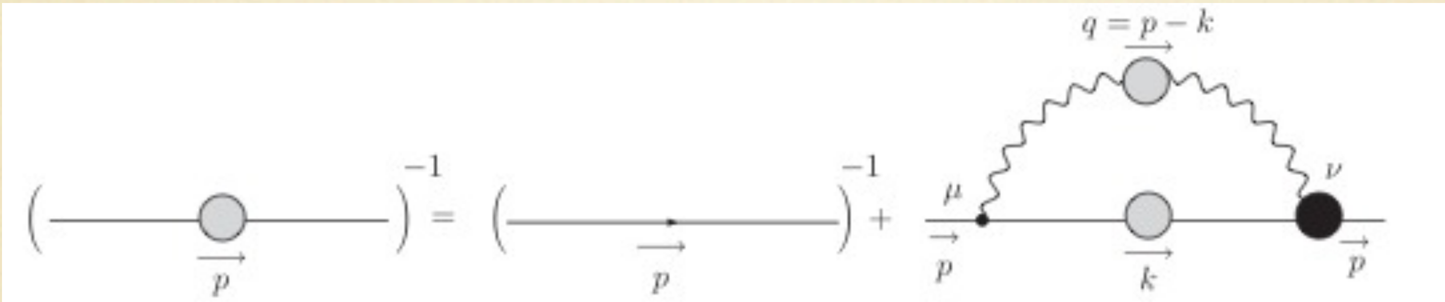
$m_g = \sqrt{N} g v$ $gv = 366 \text{ MeV}$

$$M = -\frac{G_5}{g^2} \frac{N^2 - 1}{N} m_g^2$$

$$\frac{G_5}{g^2} = -0.31 \text{ GeV}^{-1}$$

Schwinger-Dyson Equations

A.C. Aguilar, J. Papavassiliou, PRD**83**, 014013 (2011)



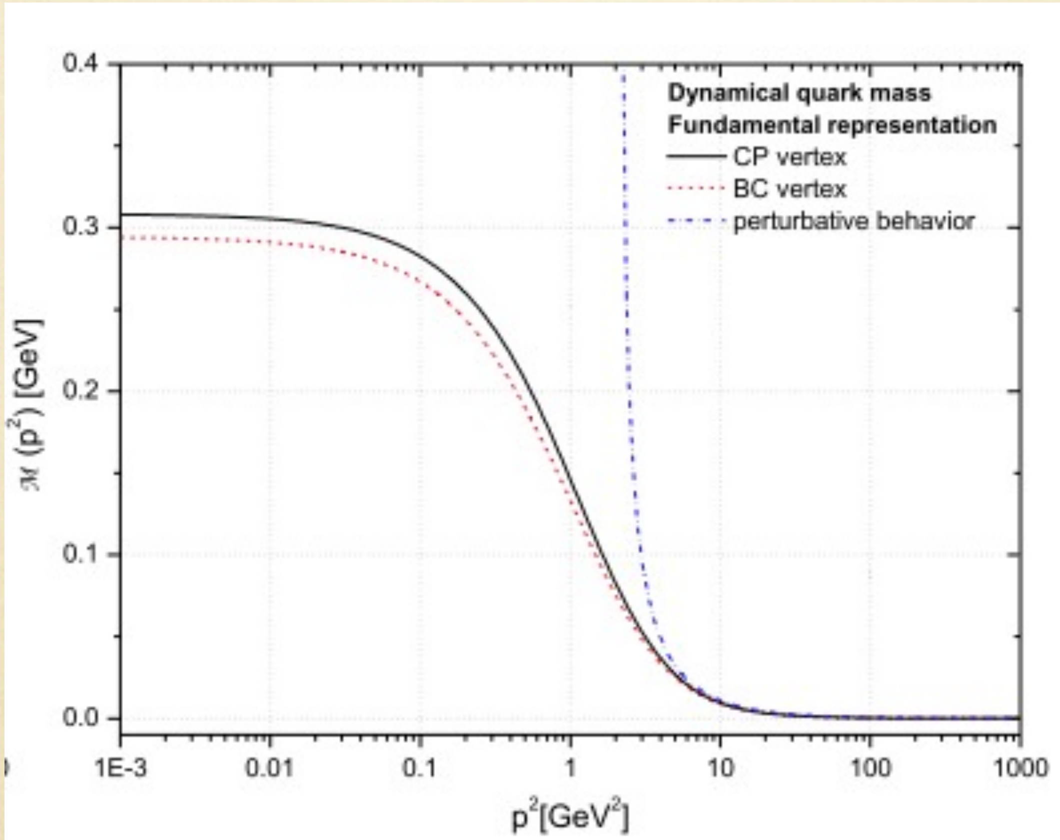
gluon propagator from the lattice $\beta = 5.7$ for $80^4 = (14.7\ \mathrm{fm})^4$

two different anzatse for quark-gluon vertex

ghost improved Ball-Chiu (BC) + Curtis-Pennington

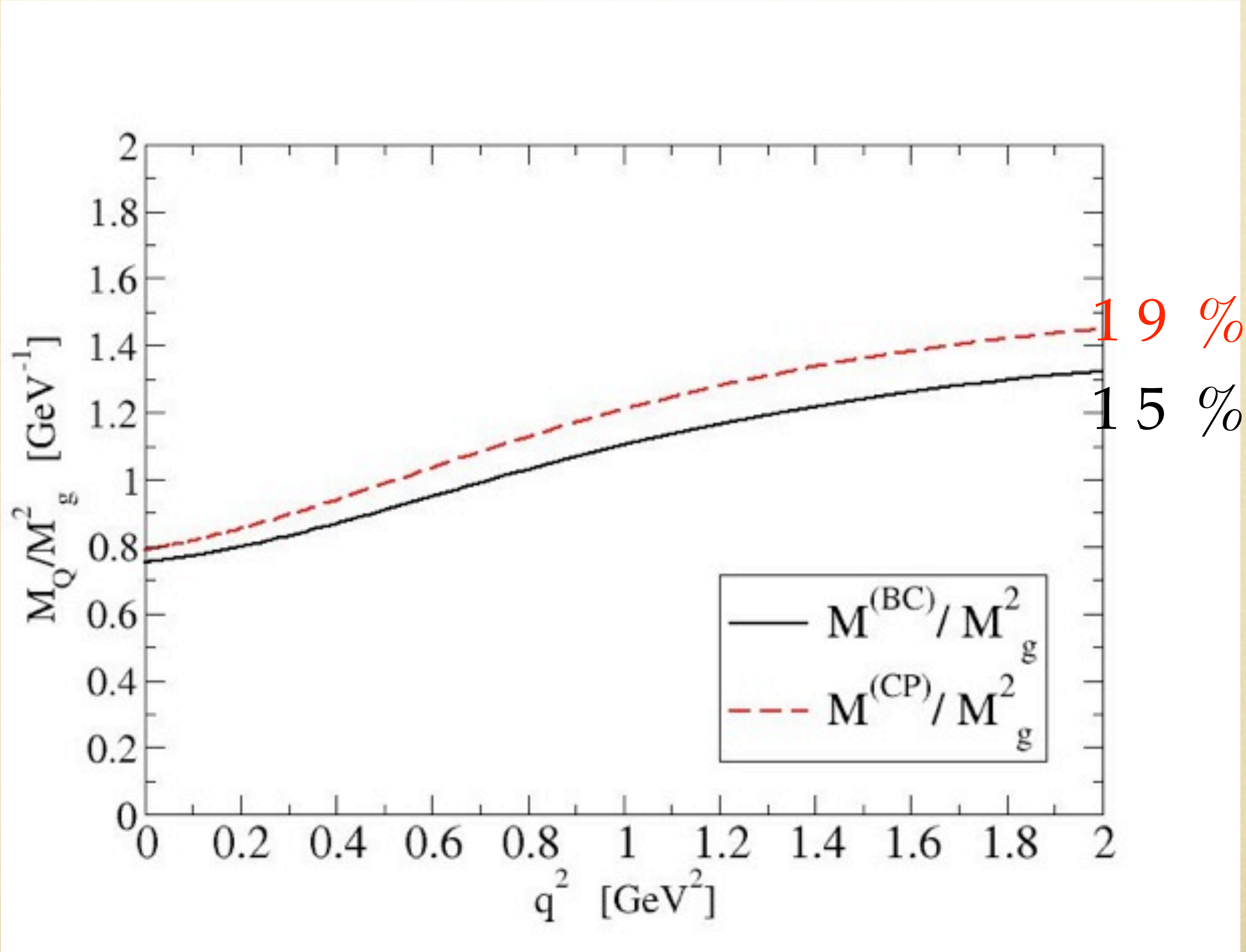
different renormalization point - μ = 4.3 GeV

Schwinger-Dyson Equations



dynamical generation of fermion mass = chiral symmetry breaking

Schwinger-Dyson Equations



Results and Conclusions

✓Gluon Propagator is well known both in UV and IR
✓ Higher Statistics to get its details

✓Gluon massive in IR
✓Gluon mass implies chiral symmetry breaking
✓It remains to investigate possible phenomenological implications of the low energy effective model

Thank You !!!