

Non-Perturbative Information from QCD Green Functions

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PRD 102 (2020) 114518 (2008.02615 [hep-lat])

2009.08961 [hep-lat]

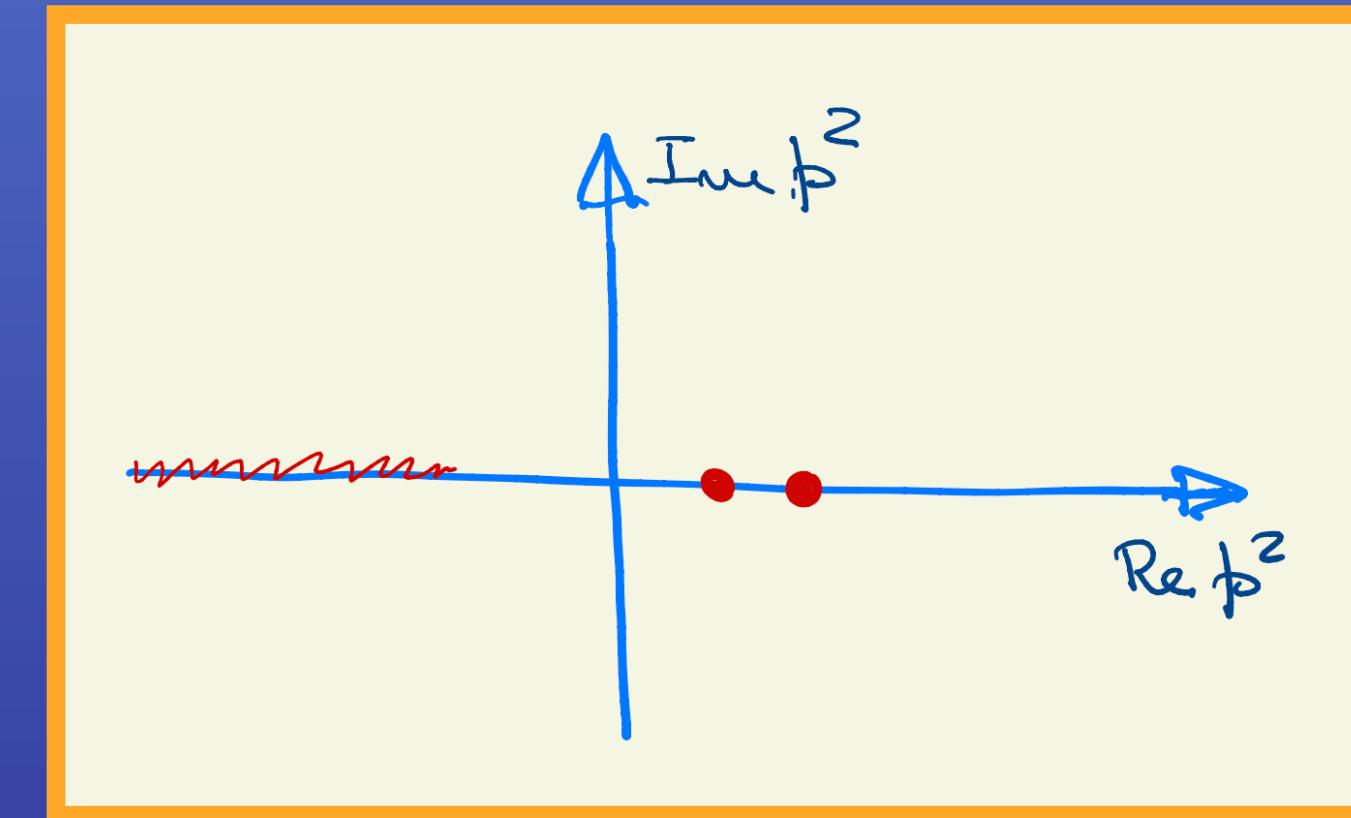
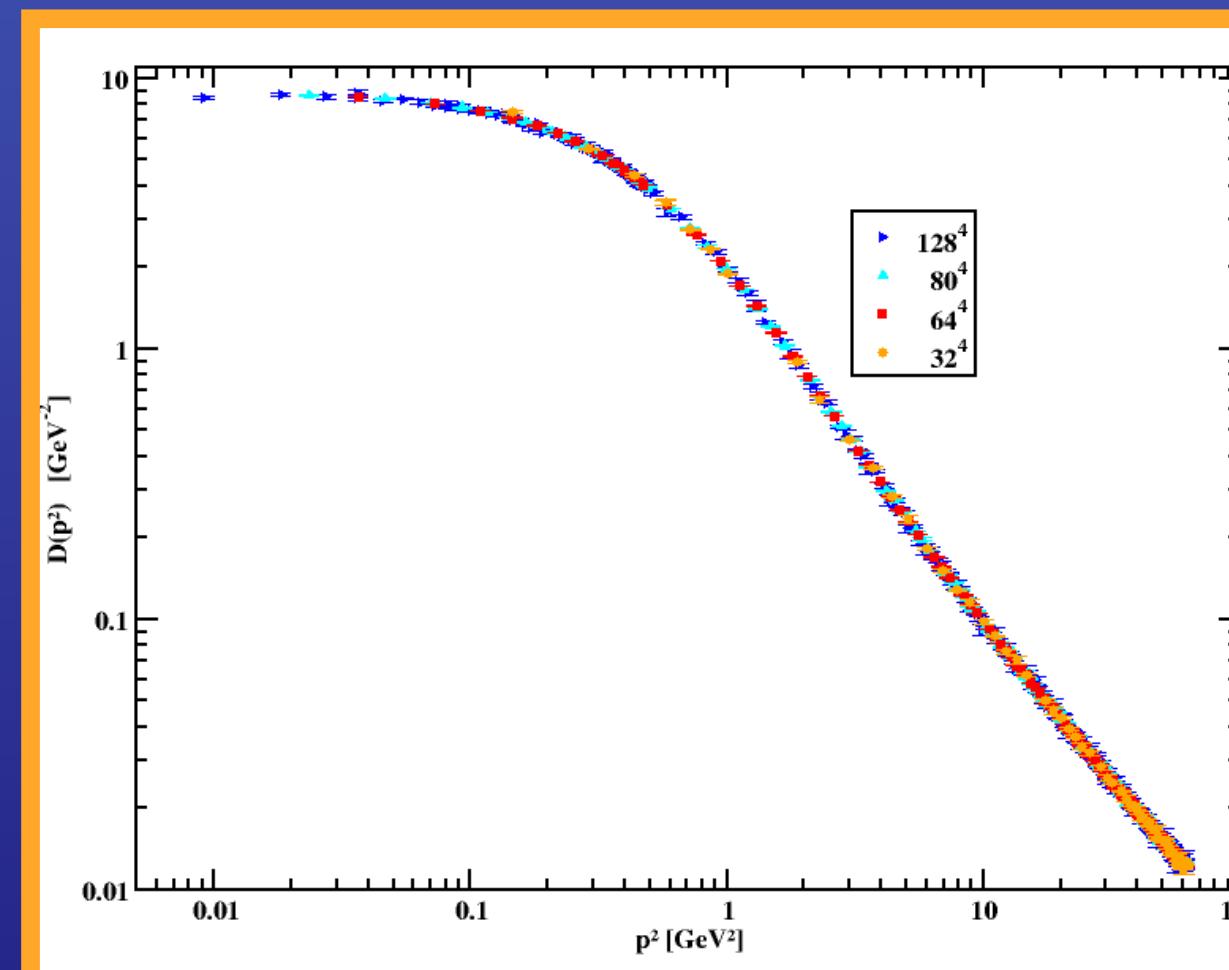
Two point correlation functions

QCD Dynamics

Physical Spectra
Confinement
Generation of Mass Scales
Euclidean to Minkowski

What about its Analytic Structure?

Can we get it from lattice simulations?



Landau Gauge !

Pommerenke's Theorem

For a meromorphic function $f(z)$, the Padé sequences $[M | M+k]$, with fixed k , converge to $f(z)$ in any compact set of the complex plane.

In the Padé approximant, single poles of $f(z)$, are sets of zero area, and appear in the $[M | N]$ approximants as stable poles for sufficiently large values of M .

[M | N] Padé approximant

$$D(p^2) \approx P_N^M(p^2) = \frac{Q_M(p^2)}{R_N(p^2)}$$

$$Q_M(p^2) = q_0 + \cdots + q_N (p^2)^M$$

$$R_N(p^2) = 1 + \cdots + r_N (p^2)^N$$

Near diagonal **M = N, N + 1, N - 1** sequences

$$f(z) = \int_0^{+\infty} \frac{d\mu(t)}{1 + z t} , \quad |Arg(z)| < \pi$$

Stieltjes Function

$$f(z) = \int_0^{+\infty} \frac{d\mu(t)}{1 + z t}, \quad |Arg(z)| < \pi$$

Stieltjes Function

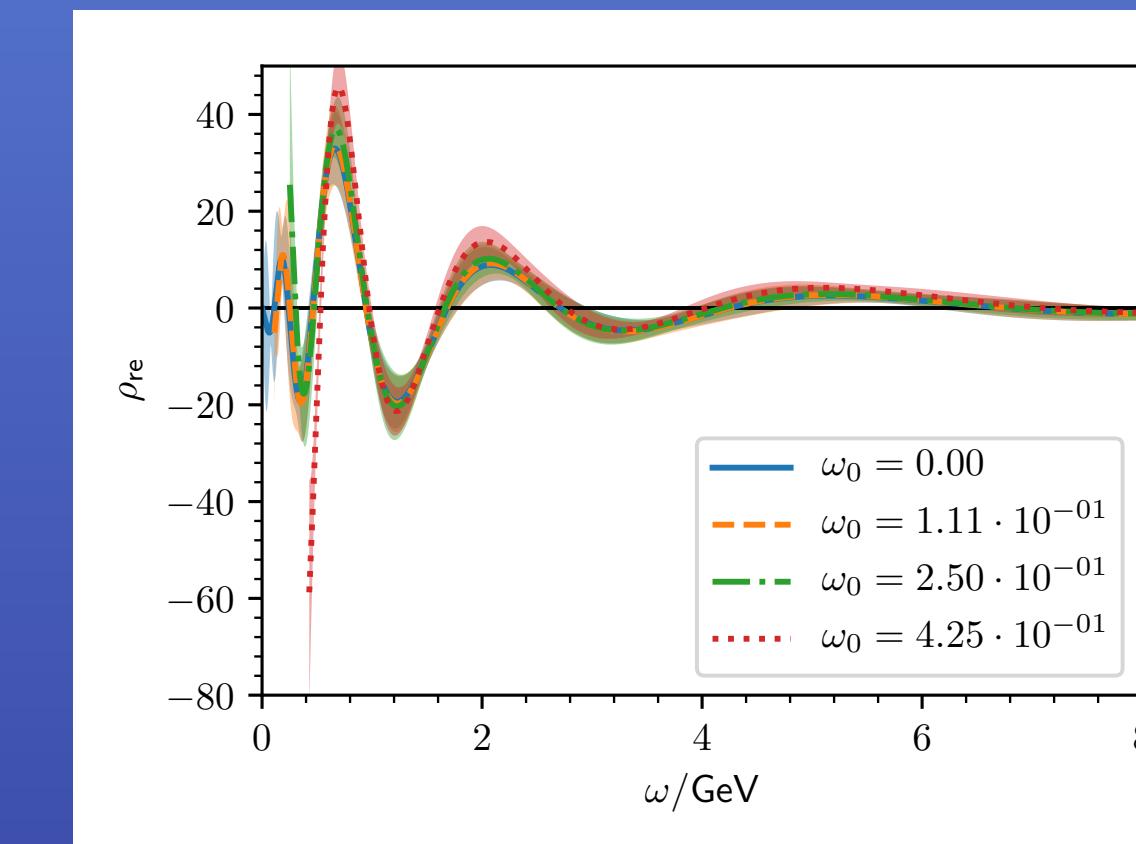
Positive defined

$$f(z) = \int_0^{+\infty} \frac{d\mu(t)}{1 + z t},$$

Positive defined

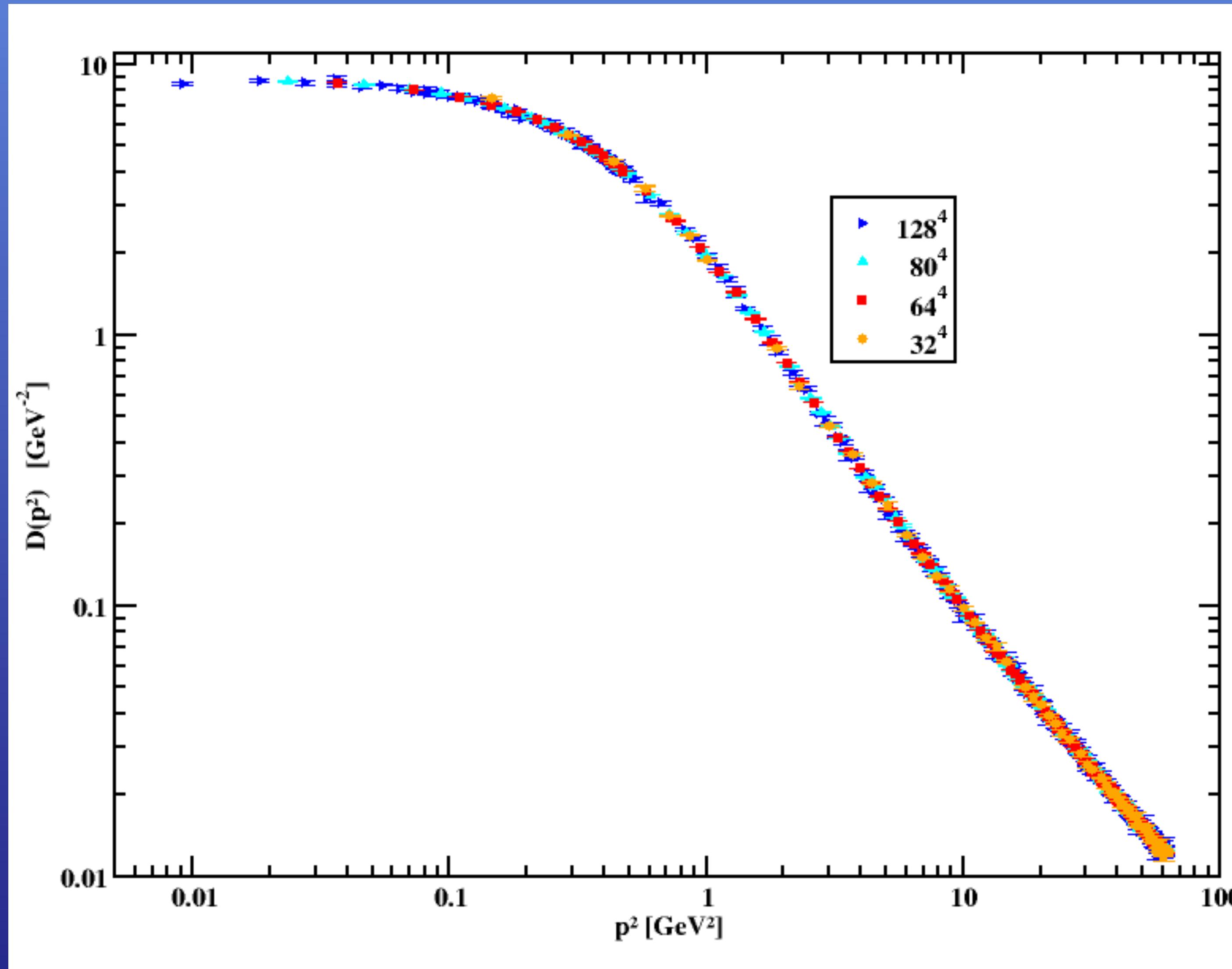
$$|Arg(z)| < \pi$$

Stieltjes Function



D Dудal, O O, M Roelfs, P Silva, Nucl Phys B 952, 114912 (2020)

Gluon Propagator



From 3.25 fm up to 13.01 fm

$$a = 0.101 \text{ fm}$$

Define Padé approximant by minimising

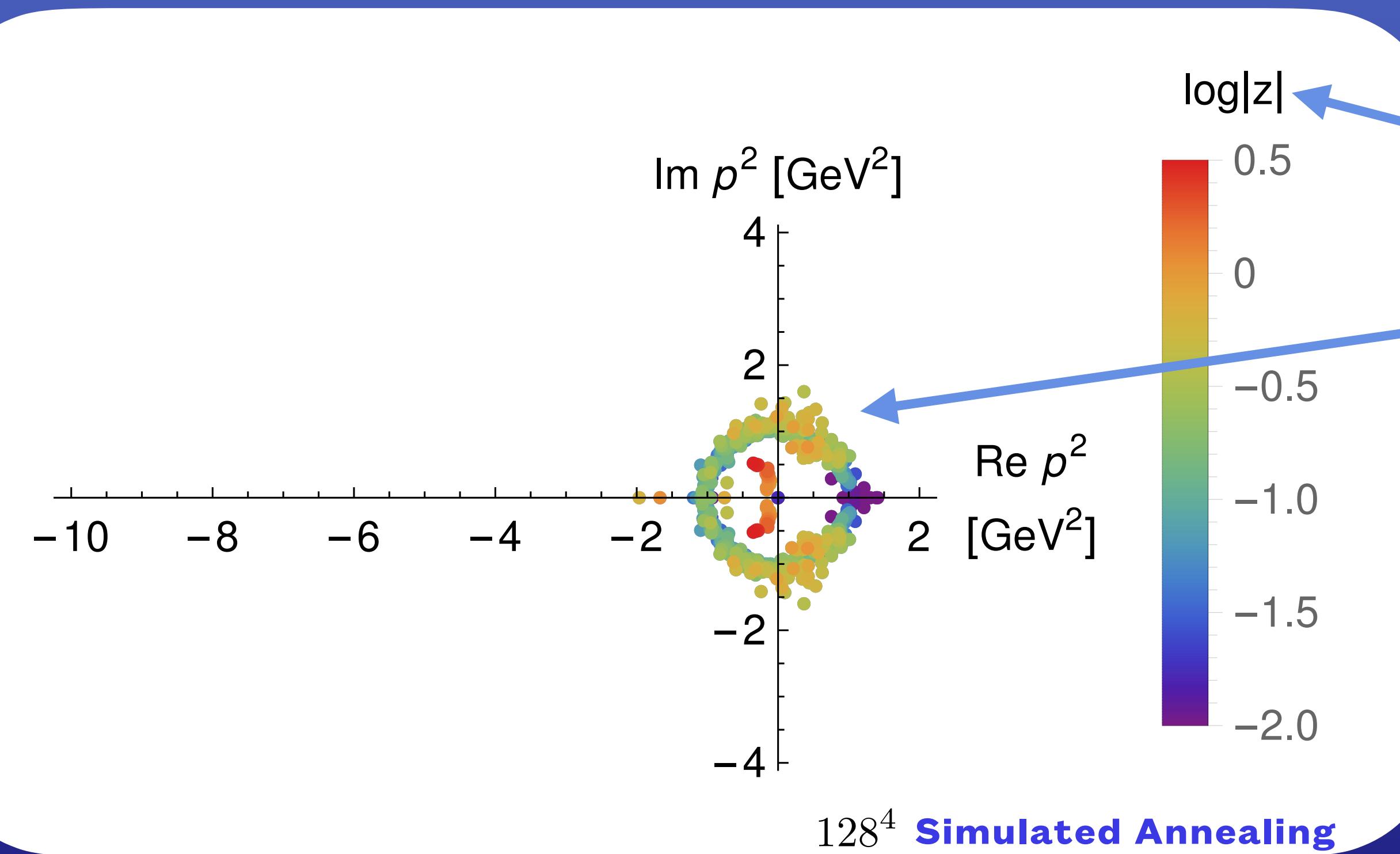
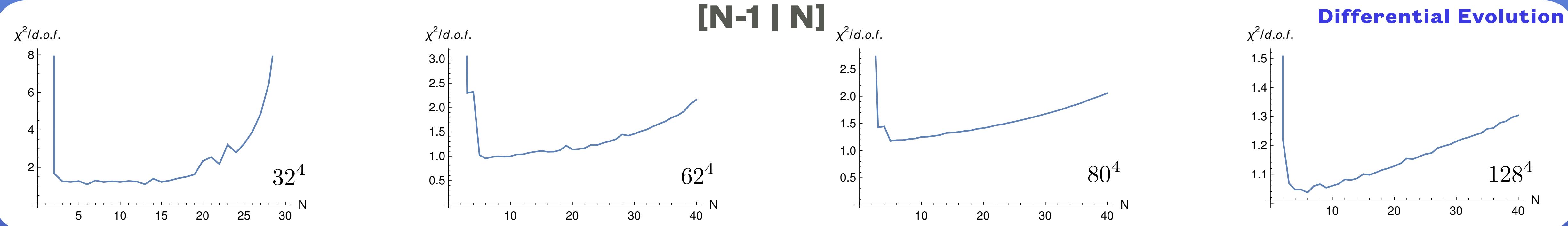
$$\chi^2 = \sum_{j=1}^N \left(\frac{D(p_j^2) - D_i(p_j^2)}{\sigma(p_j^2)} \right)^2$$

Global optimisation methods:

Differential Evolution

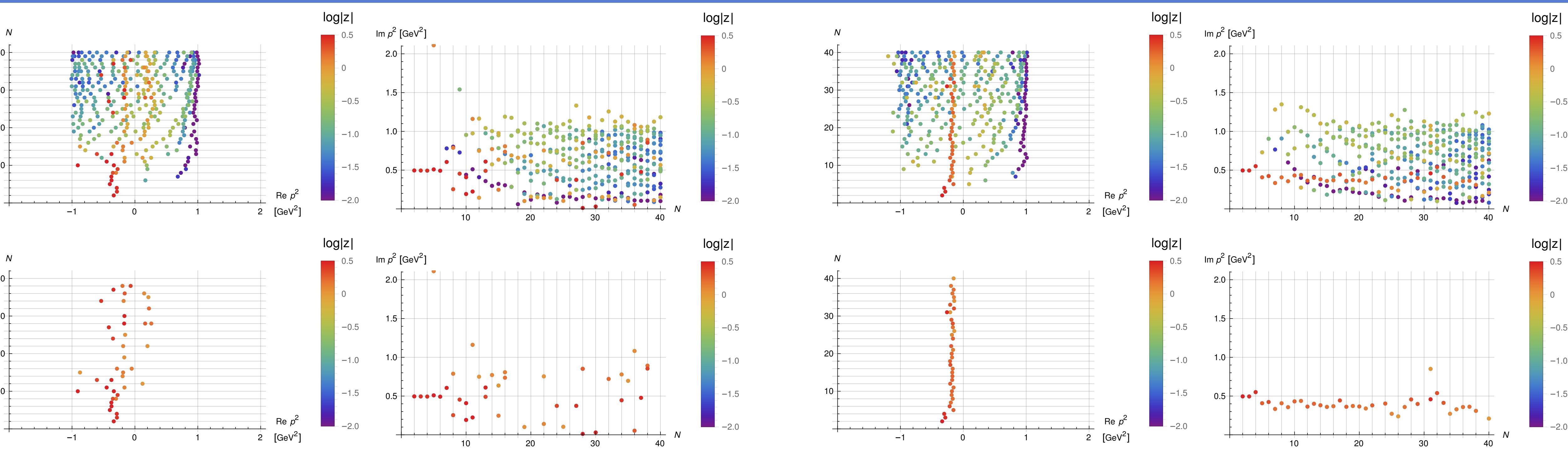
Simulated Annealing

Gluon Propagator



Gluon Propagator

80^4

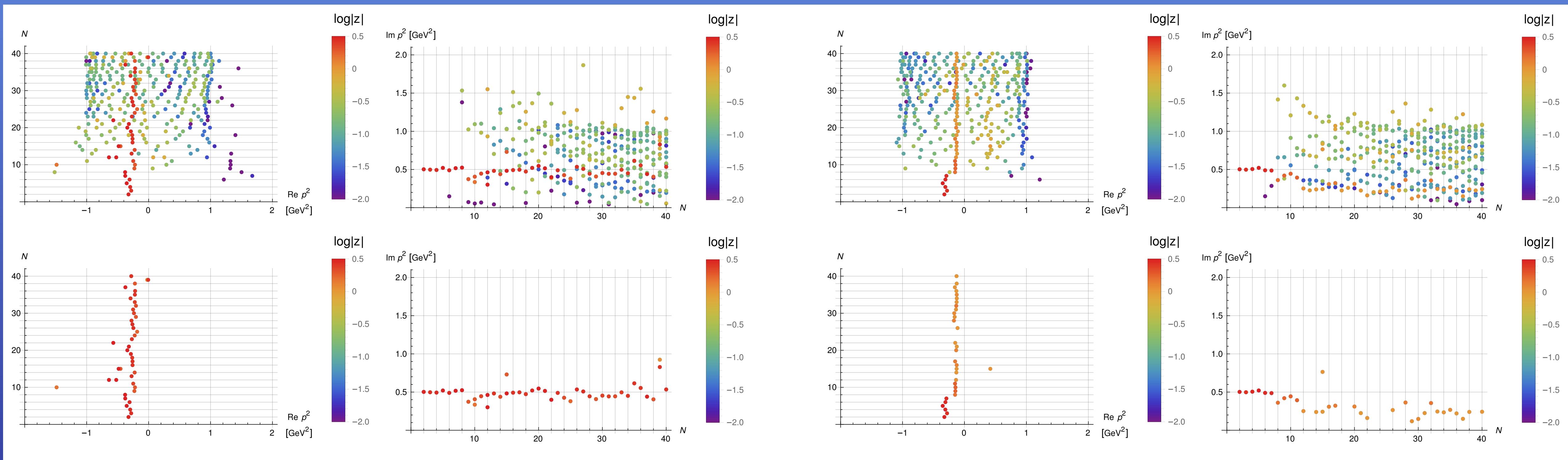


Differential Evolution

Simulated Annealing

Gluon Propagator

128^4

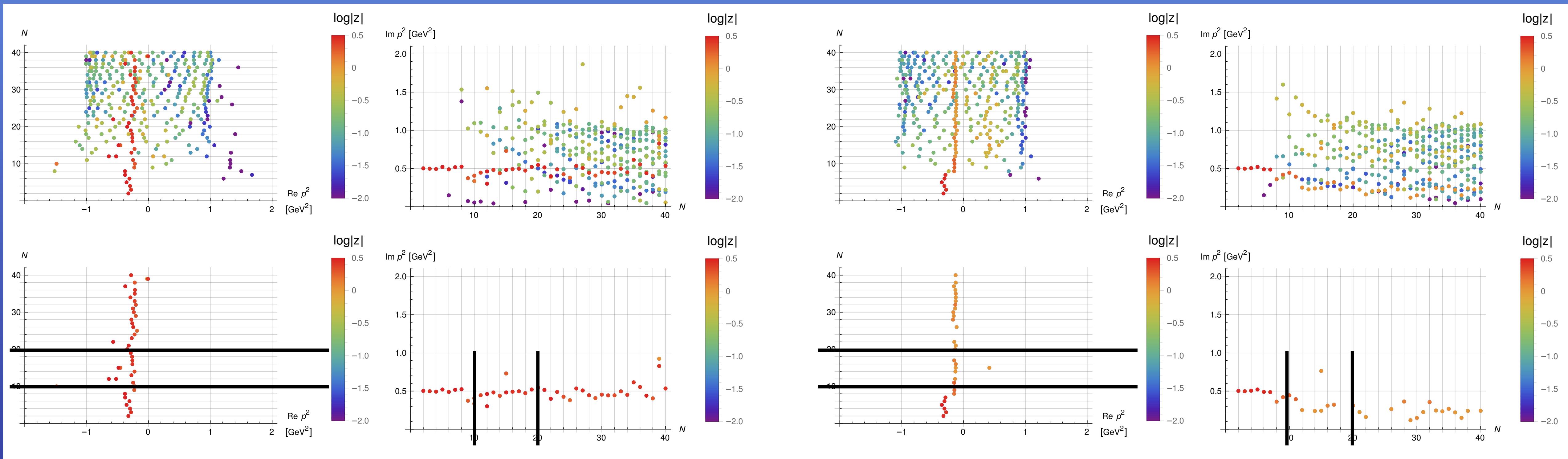


Differential Evolution

Simulated Annealing

Gluon Propagator

128^4



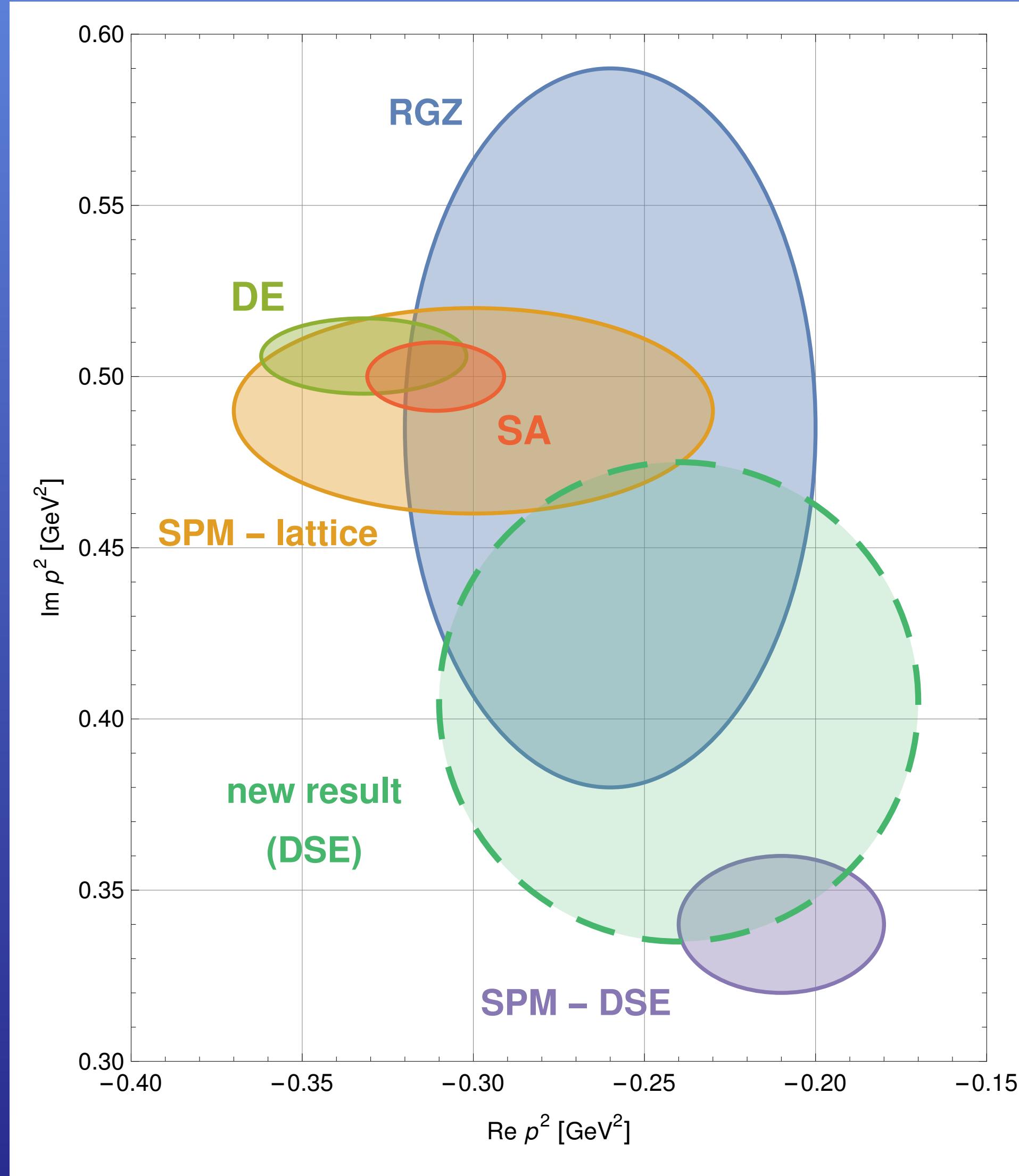
Differential Evolution

$$p^2 = -(0.343 - 0.220) \pm i(0.301 - 0.546) \text{ GeV}^2$$

Simulated Annealing

$$p^2 = -(0.220 - 0.150) \pm i(0.227 - 0.444) \text{ GeV}^2$$

Gluon Propagator

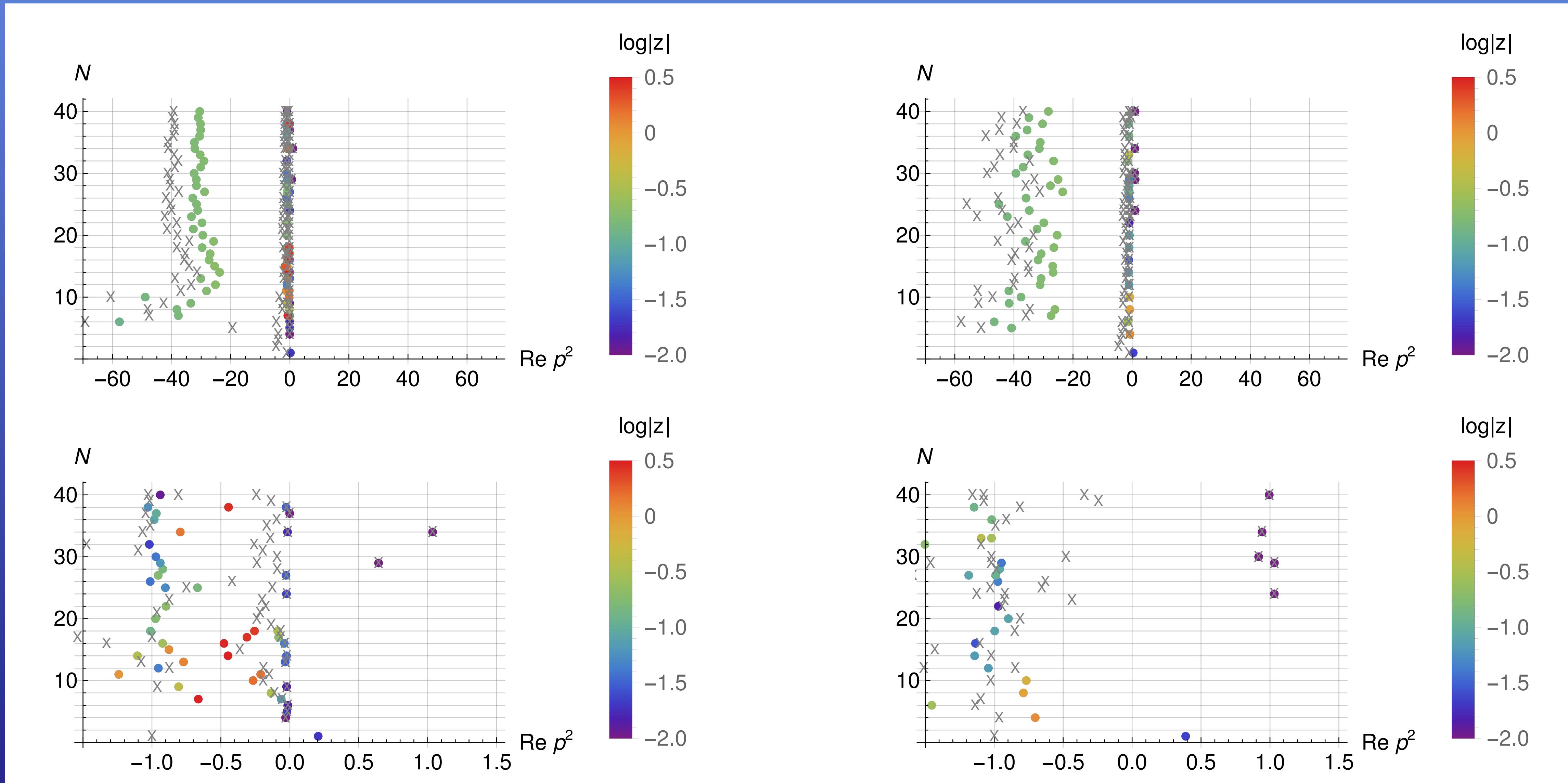


- D. Dudal, O. Oliveira, N. Vandersickel, PRD 81, 074505 (2010)
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D. Binosi, R. A. Tripolt, PLB 801, 135171 (2020)
C. S. Fischer, M. Q. Huber, PRD 102, 094005 (2020)

Complex pole associated with IR momentum

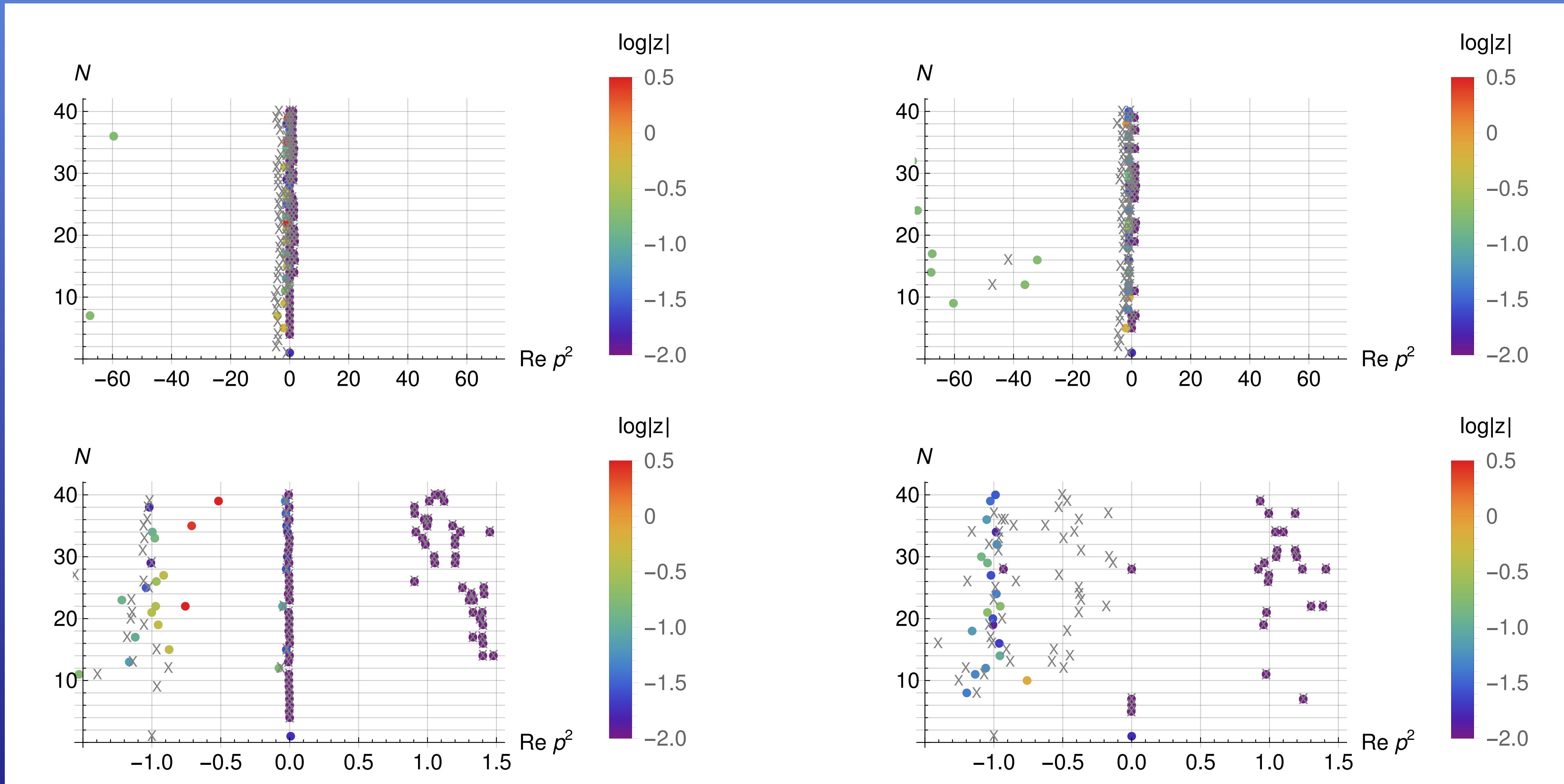
Landau Gauge Gluon Propagator

80^4



Landau Gauge Gluon Propagator

128^4

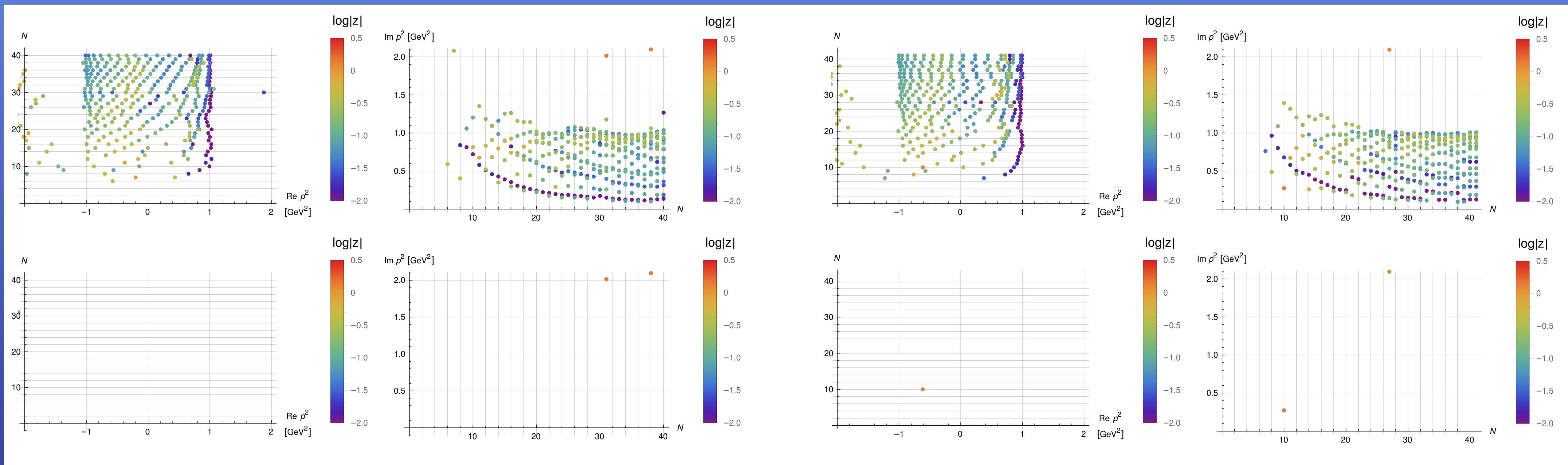


Gluon Propagator

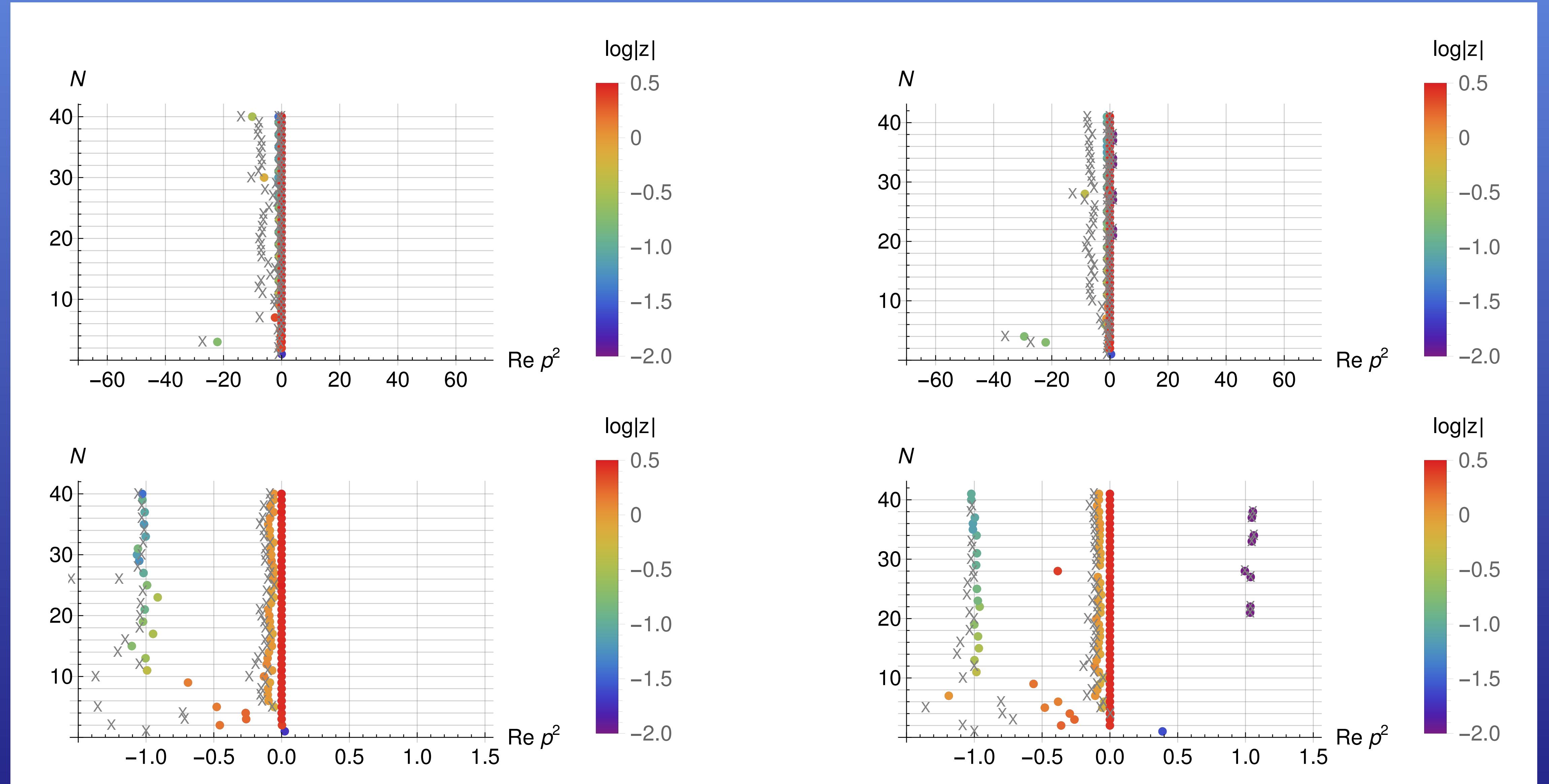
Poles $\longrightarrow p^2 = -0.31 \pm i 0.5 \text{ GeV}^2 = 0.59 e^{\pm i 0.68 \pi} \text{ GeV}^2$

Branch Cut $\longrightarrow \Re(p^2) \sim -0.5 \text{ GeV}^2 \quad \text{or smaller}$

Ghost Propagator



Ghost Propagator



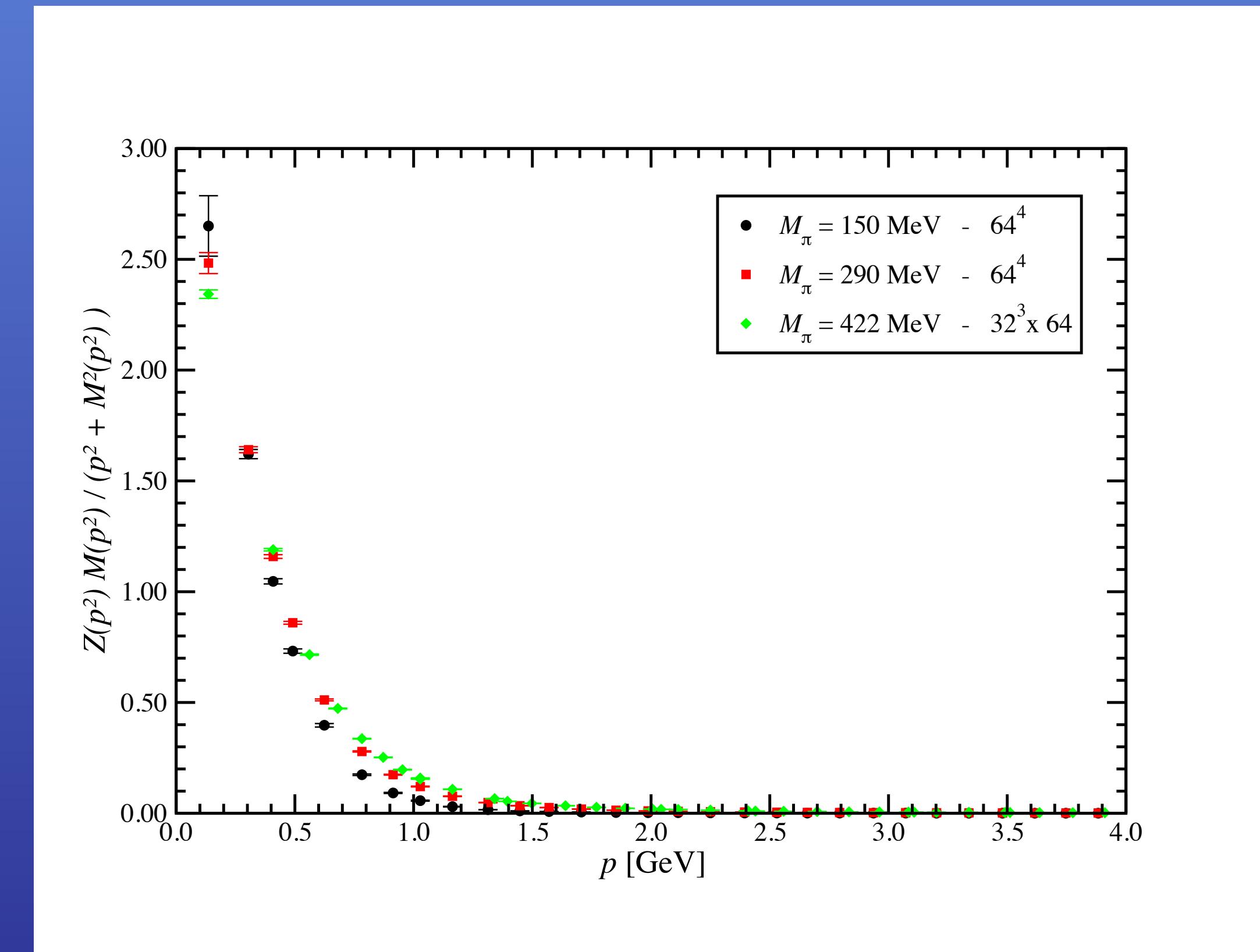
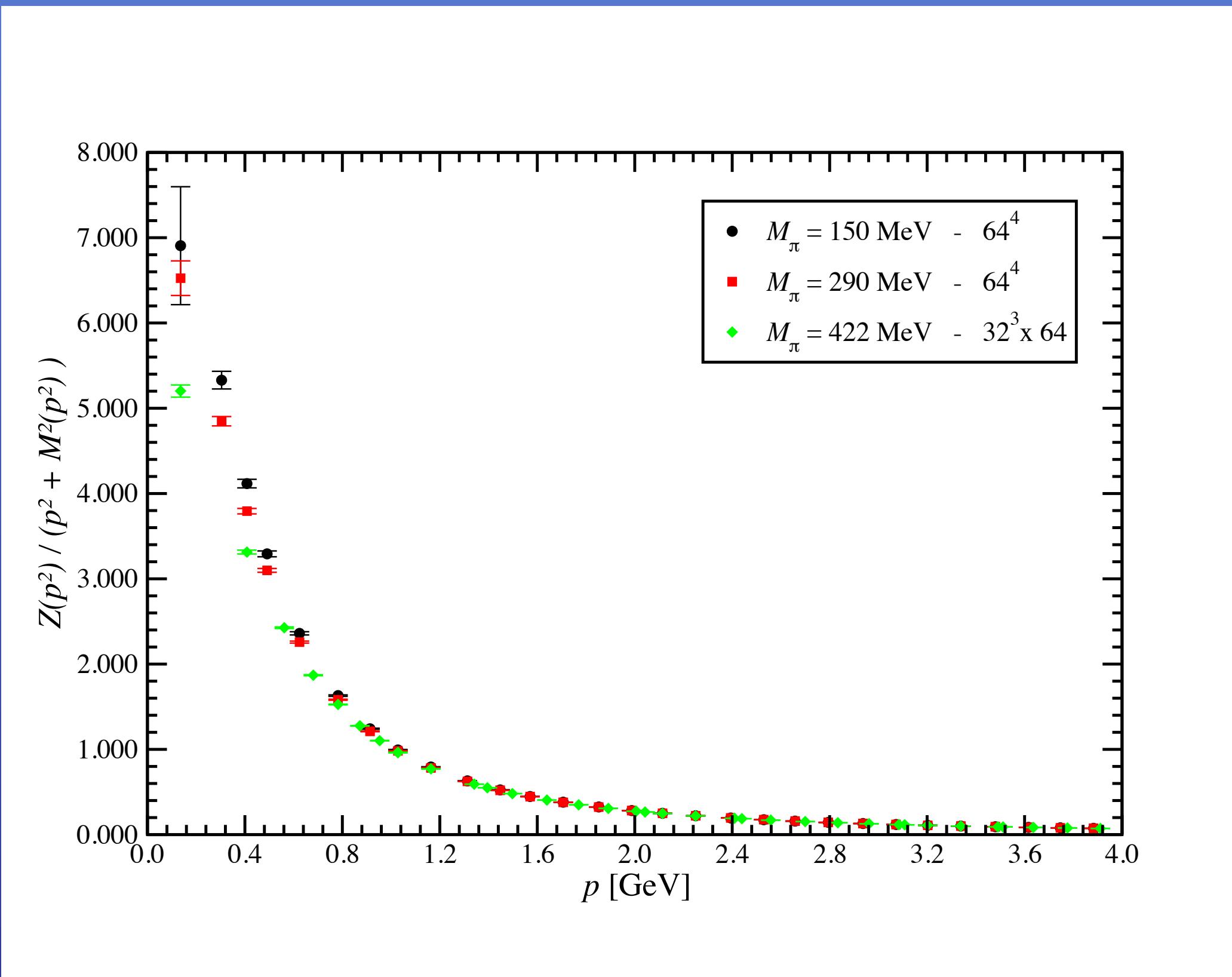
Ghost Propagator

$$p^2 = 0 \quad \text{GeV}^2$$

Branch Cut  $\Re(p^2) \sim -0.1 \text{ GeV}^2$

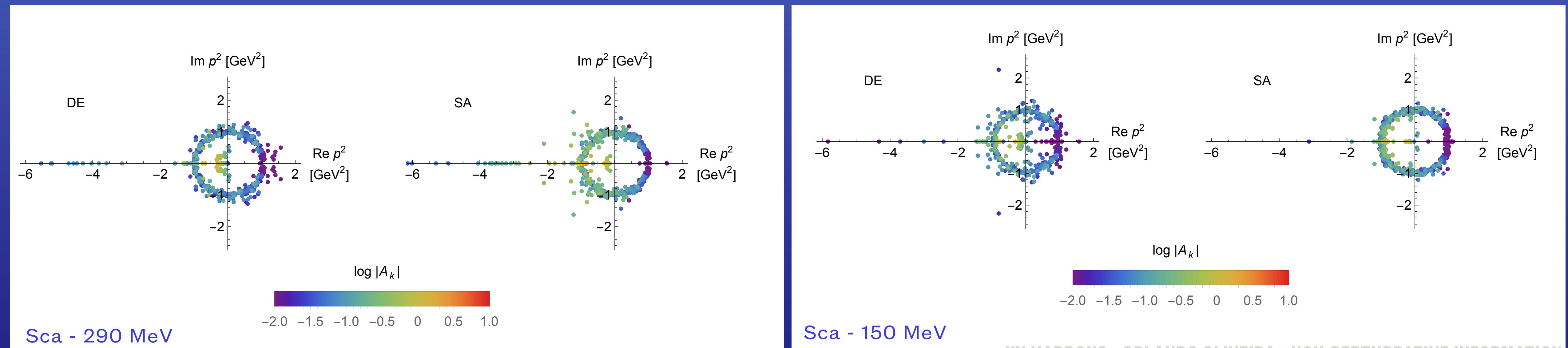
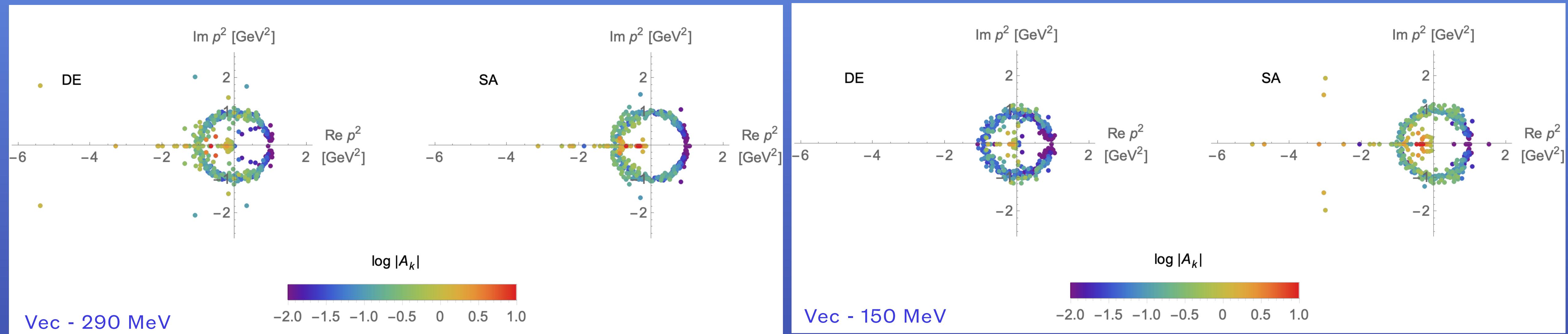
Quark Propagator

$$Z(p^2) \frac{\not{p} + M(p^2)}{p^2 + M^2(p^2)}$$

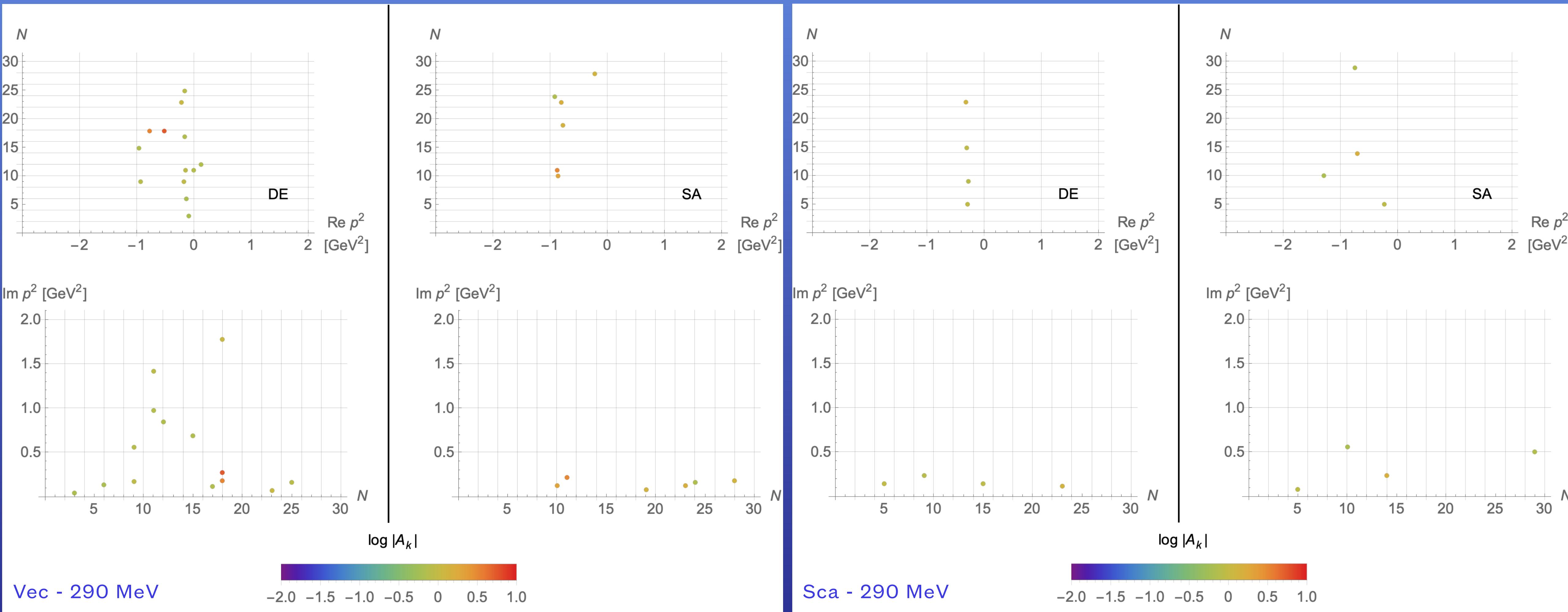


Data from PRD 99, 094506 (2019)

Quark Propagator

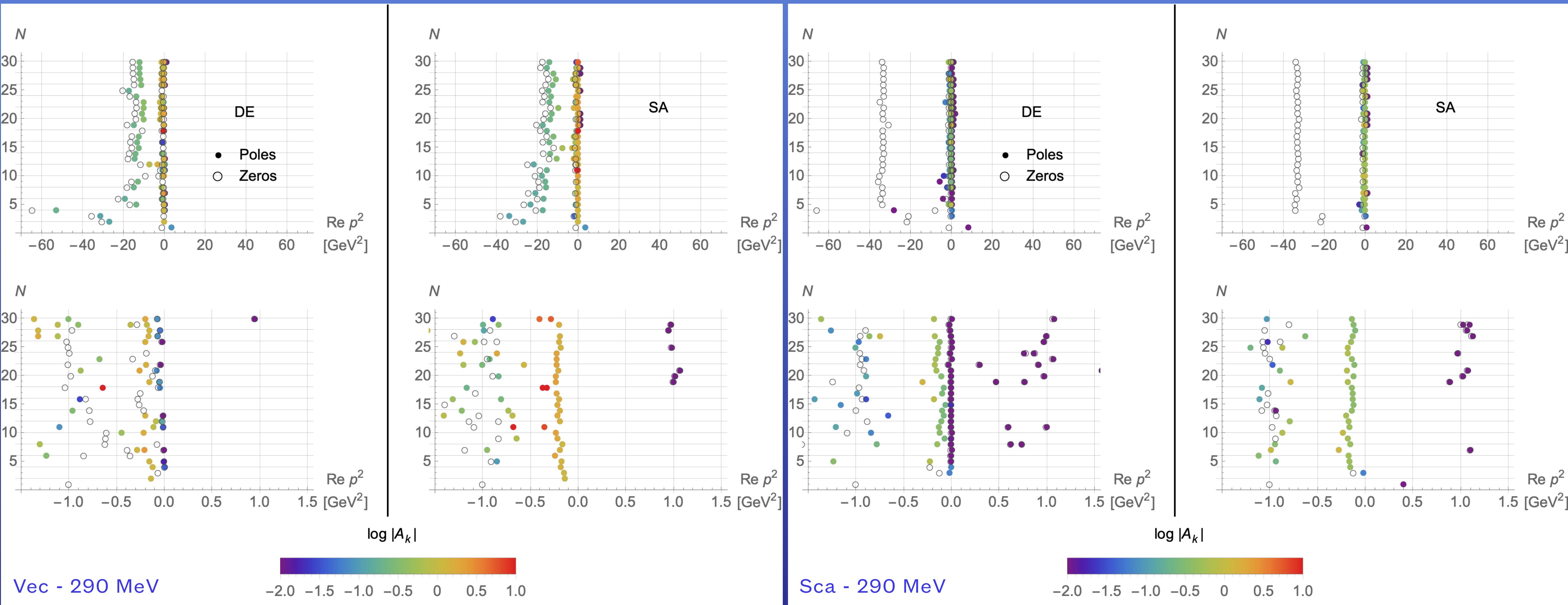


Quark Propagator



No clear sign of complex poles

Quark Propagator



Quark Propagator

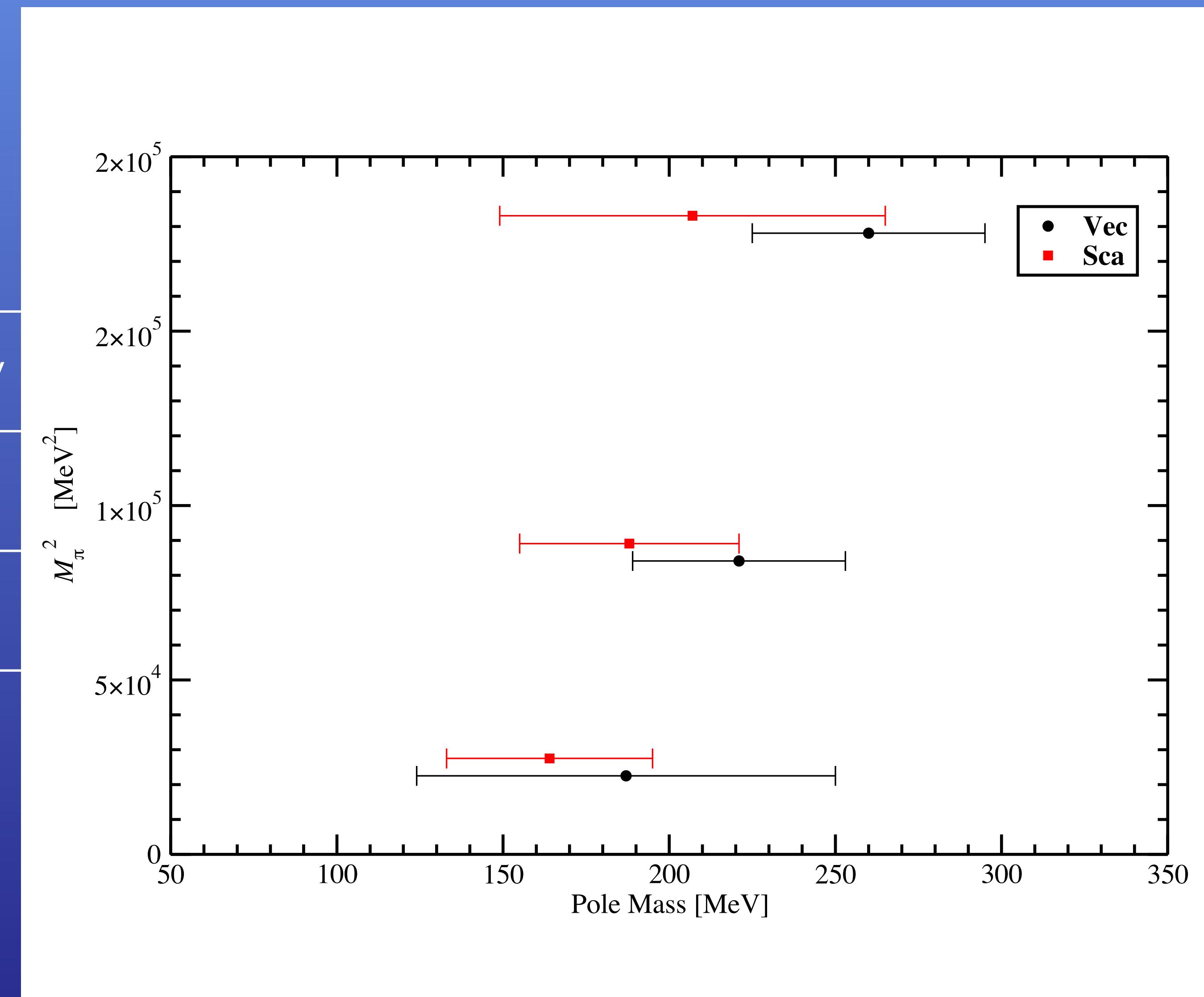
Vec - 290 MeV

M_π	150 MeV	290 MeV	422 MeV
Vec	0.19(6)	0.22(3)	0.26(3)
Soa	0.16(3)	0.19(6)	0.21(6)

Quark Propagator

Vec - 290 MeV

M_π	150 MeV
Vec	0.19(6)
Sca	0.16(3)



Conclusions

Padé Approximants allow to access the analytic structure from Landau gauge lattice propagators

Landau gauge gluon propagator: pair of complex conjugate poles + branch cut

Landau gauge ghost propagator: pole at zero momentum + branch cut with precise location of the branch point

Landau gauge quark propagator: pole at Minkowski momenta that grows (linearly) with the pion mass squared; not clear if there is a branch cut for $p < 1$ GeV

Problems and Future work:

Improve the analysis by better statistics and adding extra information

Precise location of branch cut (gluon propagator)

Investigate for the presence of multiple poles

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