Gauge Engineering and Propagators

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Greece

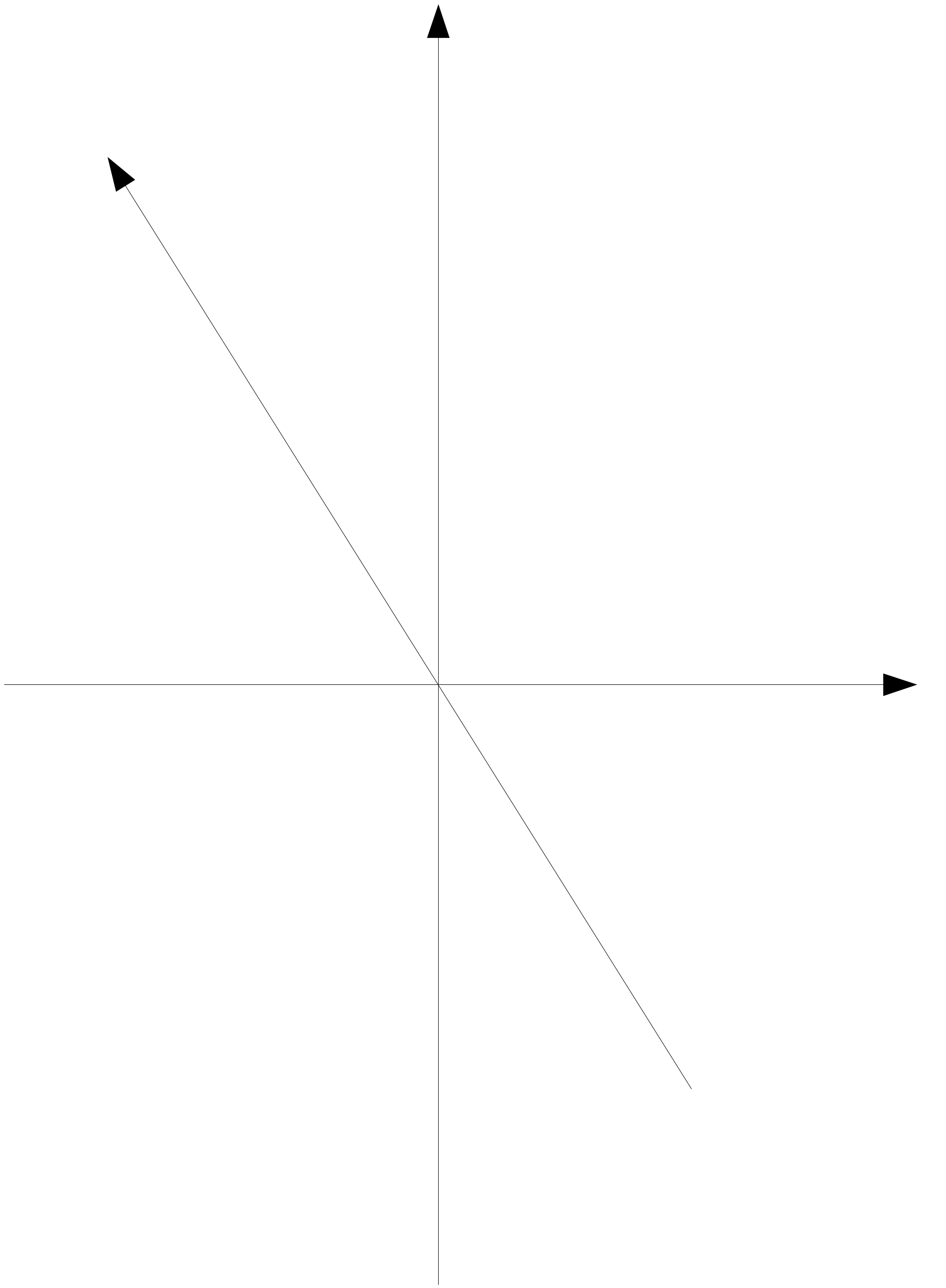
UNI GRAZ

NAWI Graz
Natural Sciences

Gauge-fixing is engineering

- All information of a theory is encoded in gauge-, renormalization-point, and renormalization-scheme-invariant quantities
  - I.e. measurable quantities, observables
- Other quantities helpful in determining these
  - Gauge-fixed quantities are helpful tools
- Engineering useful gauges is like choosing an appropriate coordinate system

Configuration space (artist's view)



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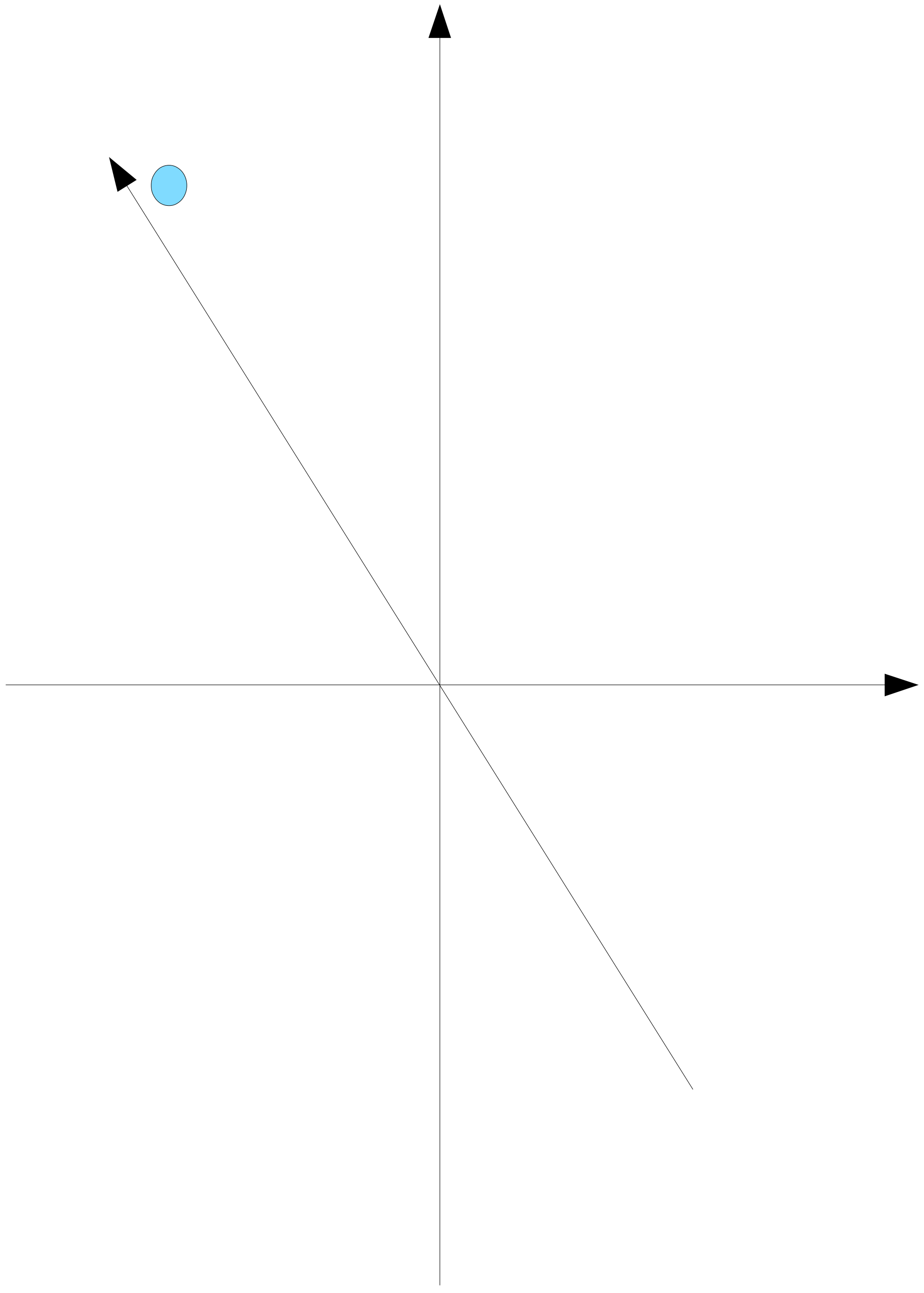

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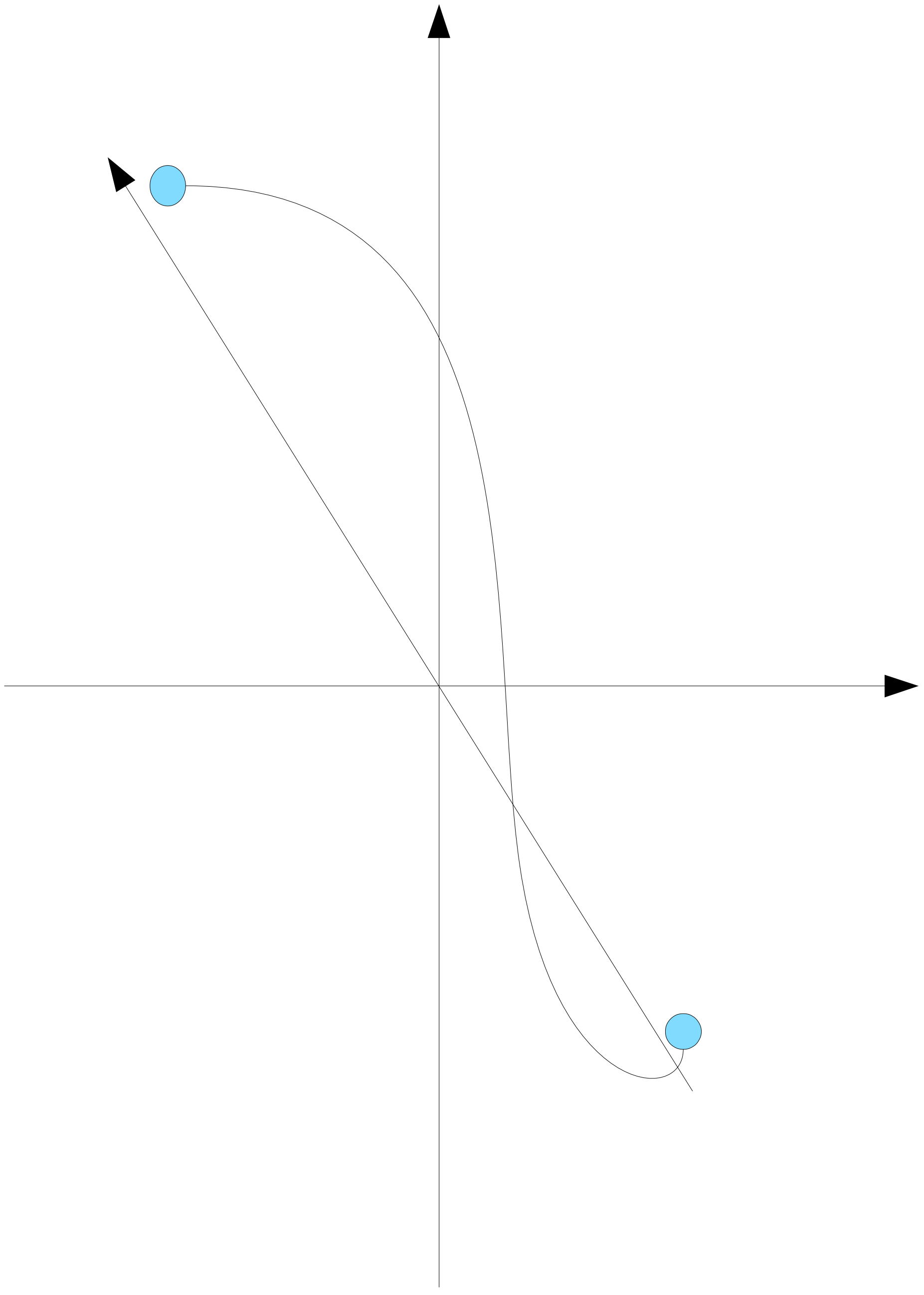

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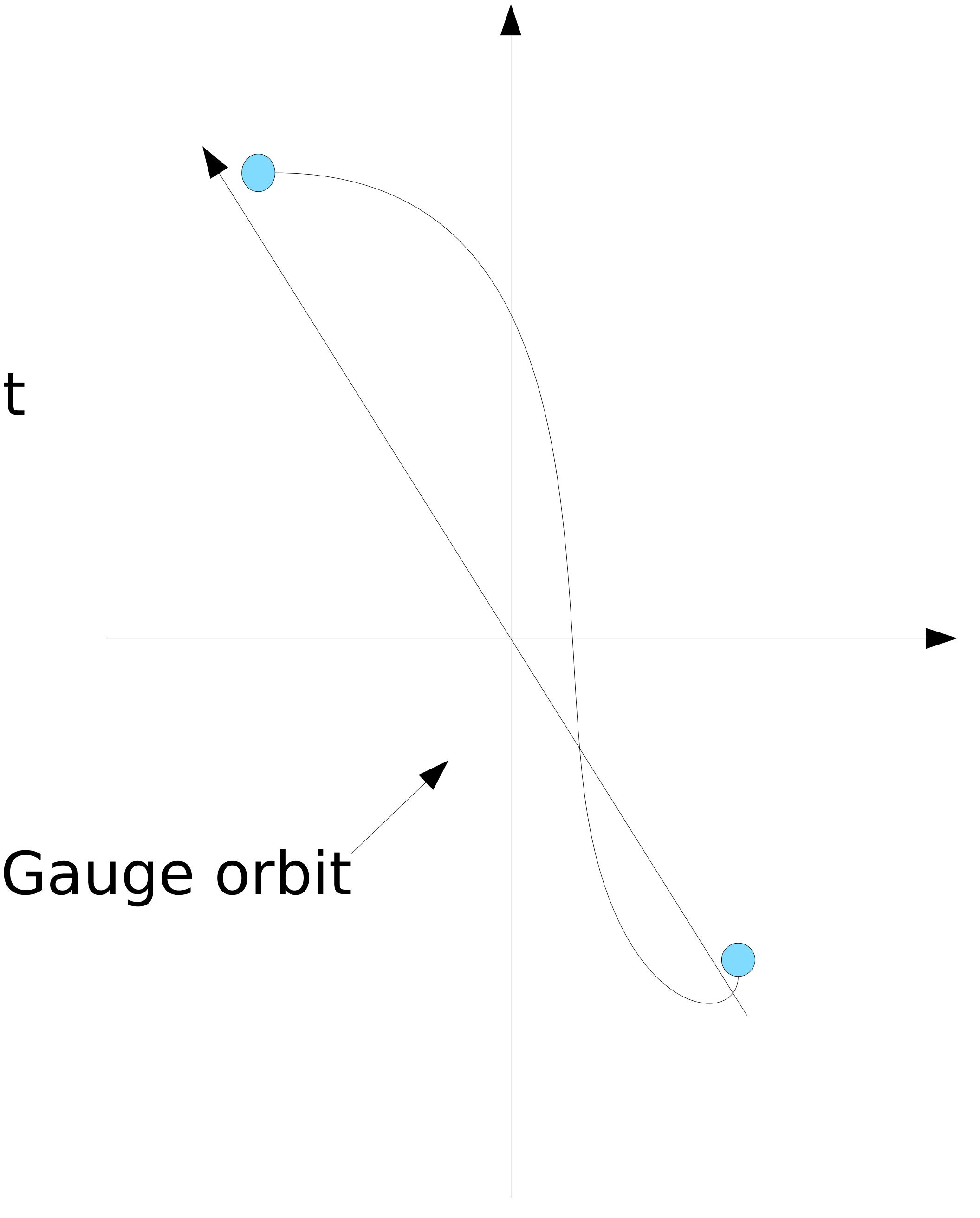
  - Set of all gauge-equivalent copies is a gauge orbit



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- Fields and most correlation functions change under gauge transformations
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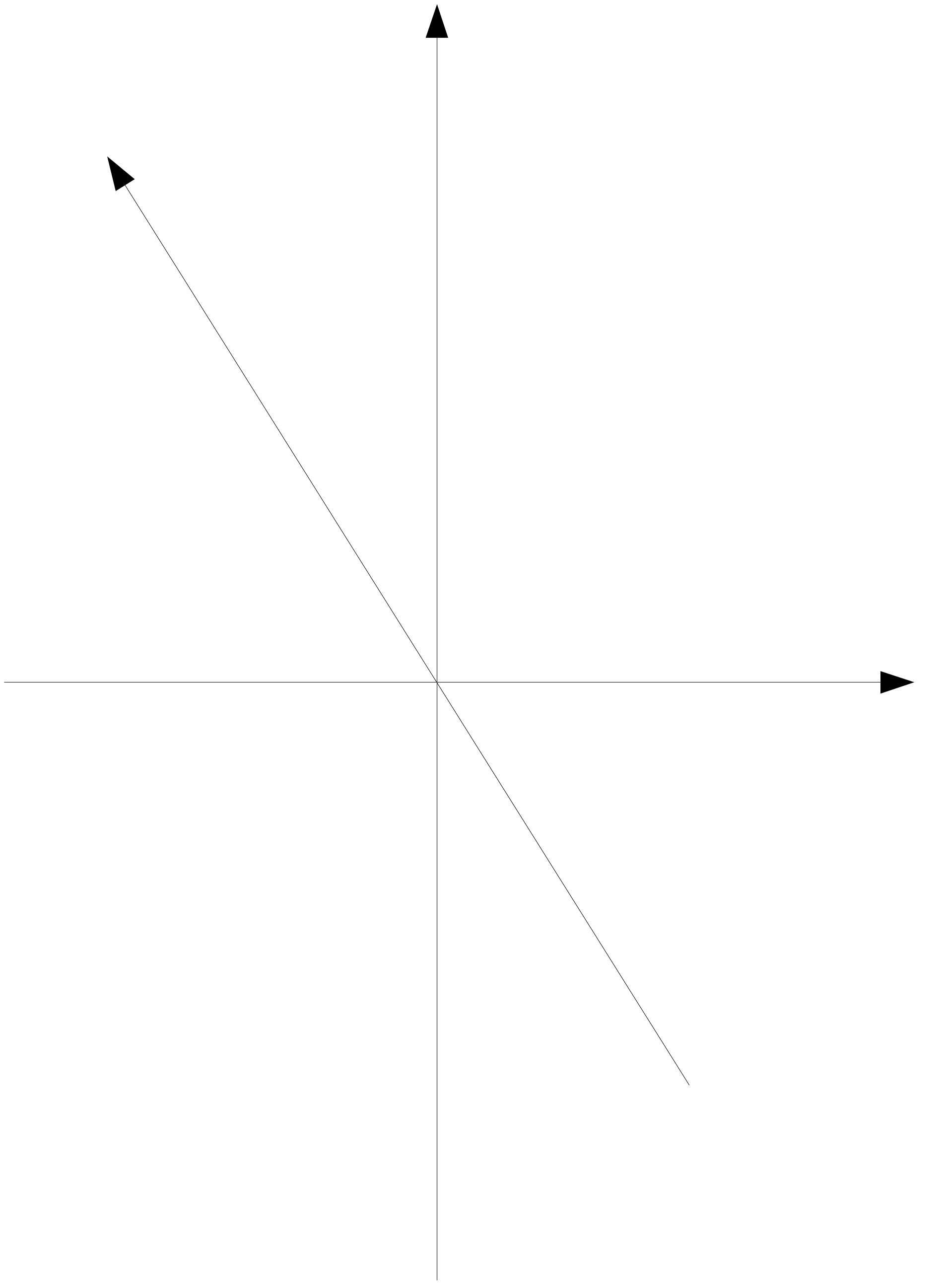

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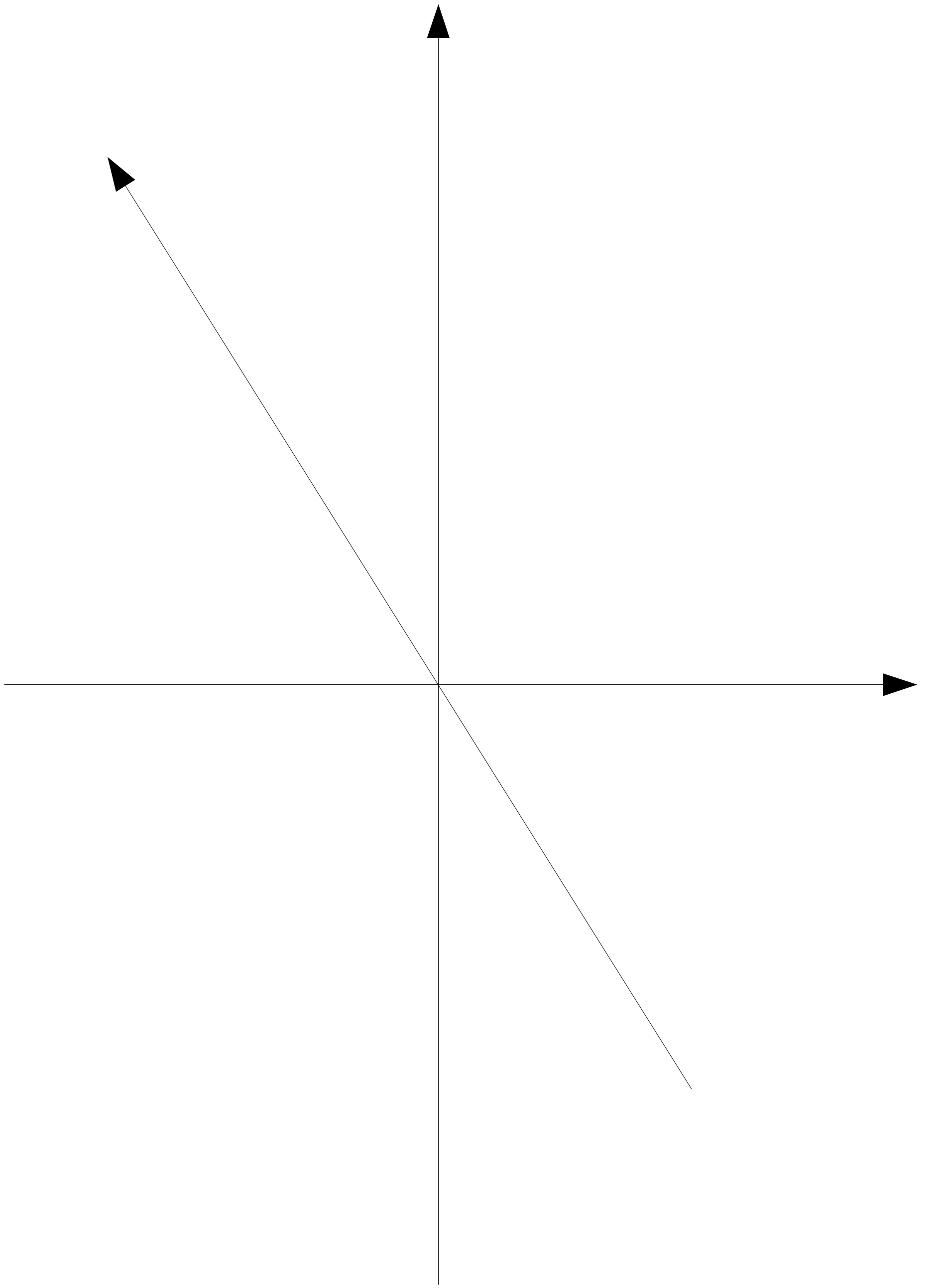

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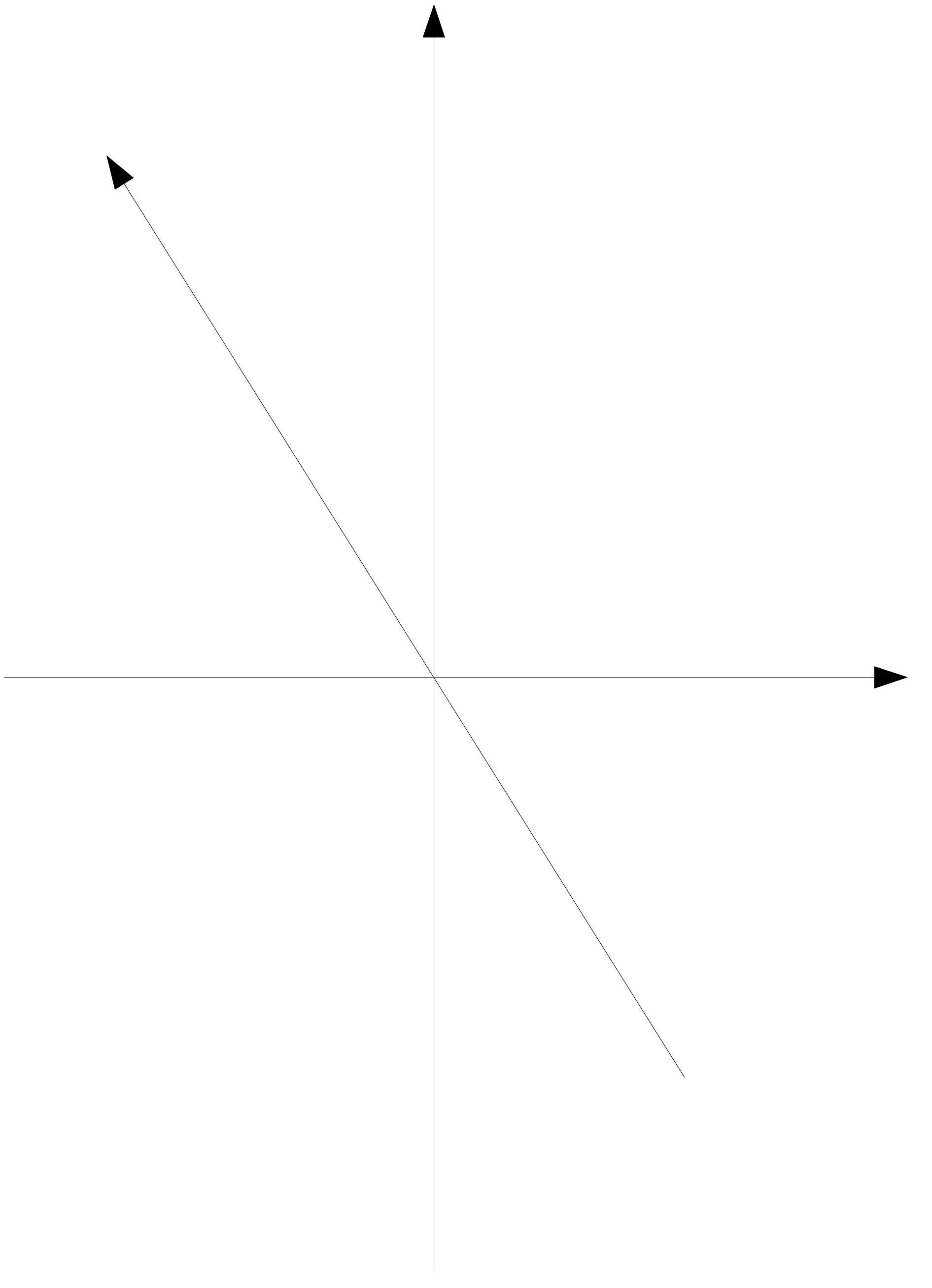

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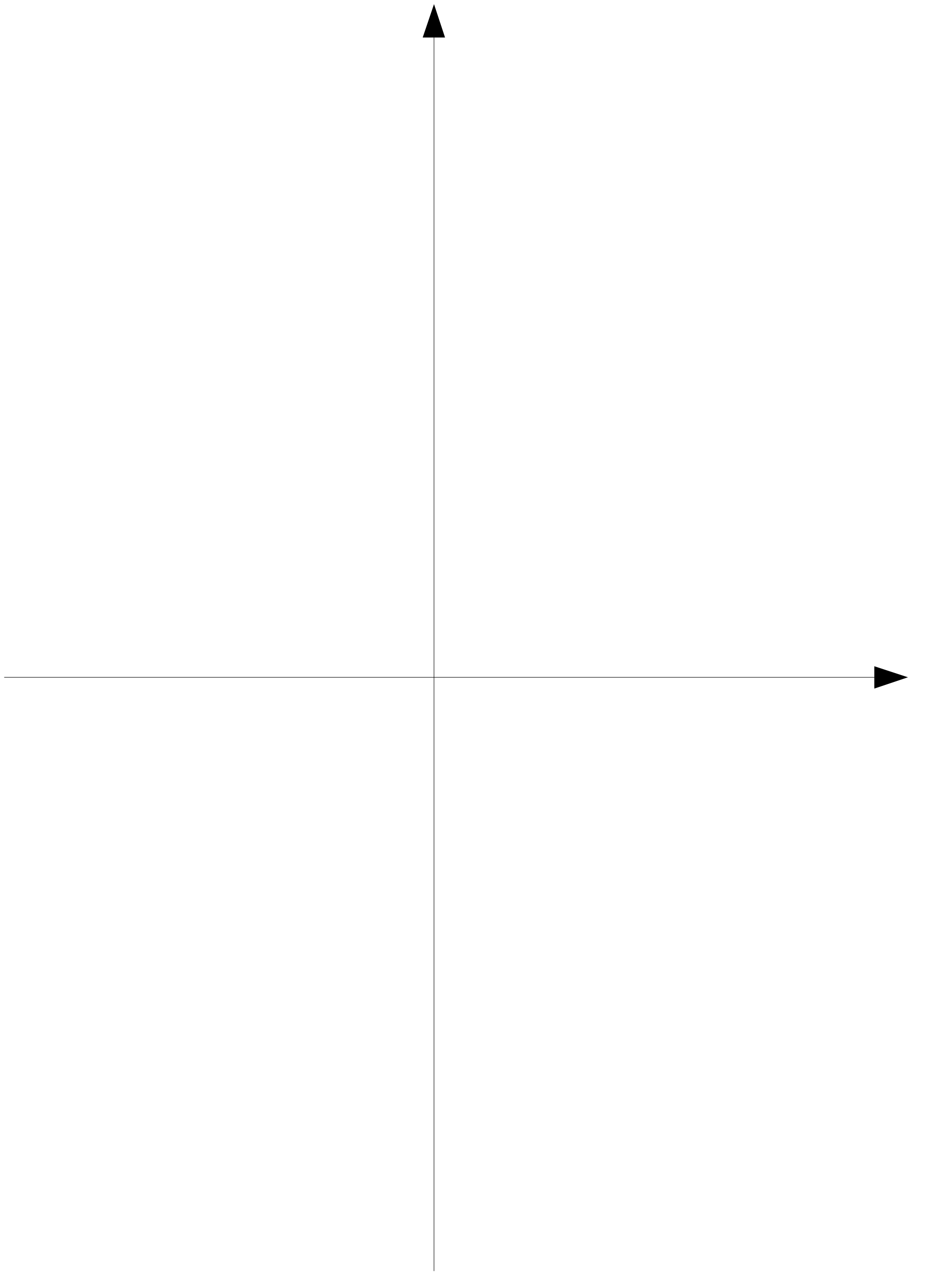
  - Reduces configuration space to a hypersurface



(Perturbative) Landau gauge

- Condition can be implemented using auxiliary fields, the ghost fields
- Lagrangian: $$L = -\frac{1}{4} F^a_{\mu\nu} F^a_{\mu\nu} - \bar{c}^a \partial_\mu D^{ab}_\mu c^b$$

$$D^{ab}_\mu = \delta^{ab} \partial_\mu - g f^{abc} A^c_\mu$$

$$\lim_{\zeta \to 0} \int DAc\bar{c} \exp\left(\int dx \left(-\frac{1}{4} F^2 - \bar{c}\,\partial D c - \frac{1}{2\zeta} (\partial A)^2\right)\right)$$

- Degrees of freedom: Gluons A^a_μ Ghosts $\bar{c}^a, c^a$
  - Not physical objects
  - Pure mathematical convenience

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- Local gauge condition
  - Landau gauge: $\partial_\mu A_\mu^a = 0$
- Sufficient for perturbation theory
- Insufficient beyond perturbation theory
  - There are gauge-equivalent configurations: Gribov copies [Gribov NPB 78]
- No local gauge conditions known to select a unique gauge copy: Gribov-Singer ambiguity [Singer CMP 78]

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- Method: Lattice

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  - Momentum-integrated gluon propagator $F \sim -\int dp\, D_{\mu\mu}^{aa}(p)$
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- Why these two?

First horizon gauges

[Gribov NPA 78, Zwanziger 93...03]

- A global minimum of

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

  defines the fundamental modular domain

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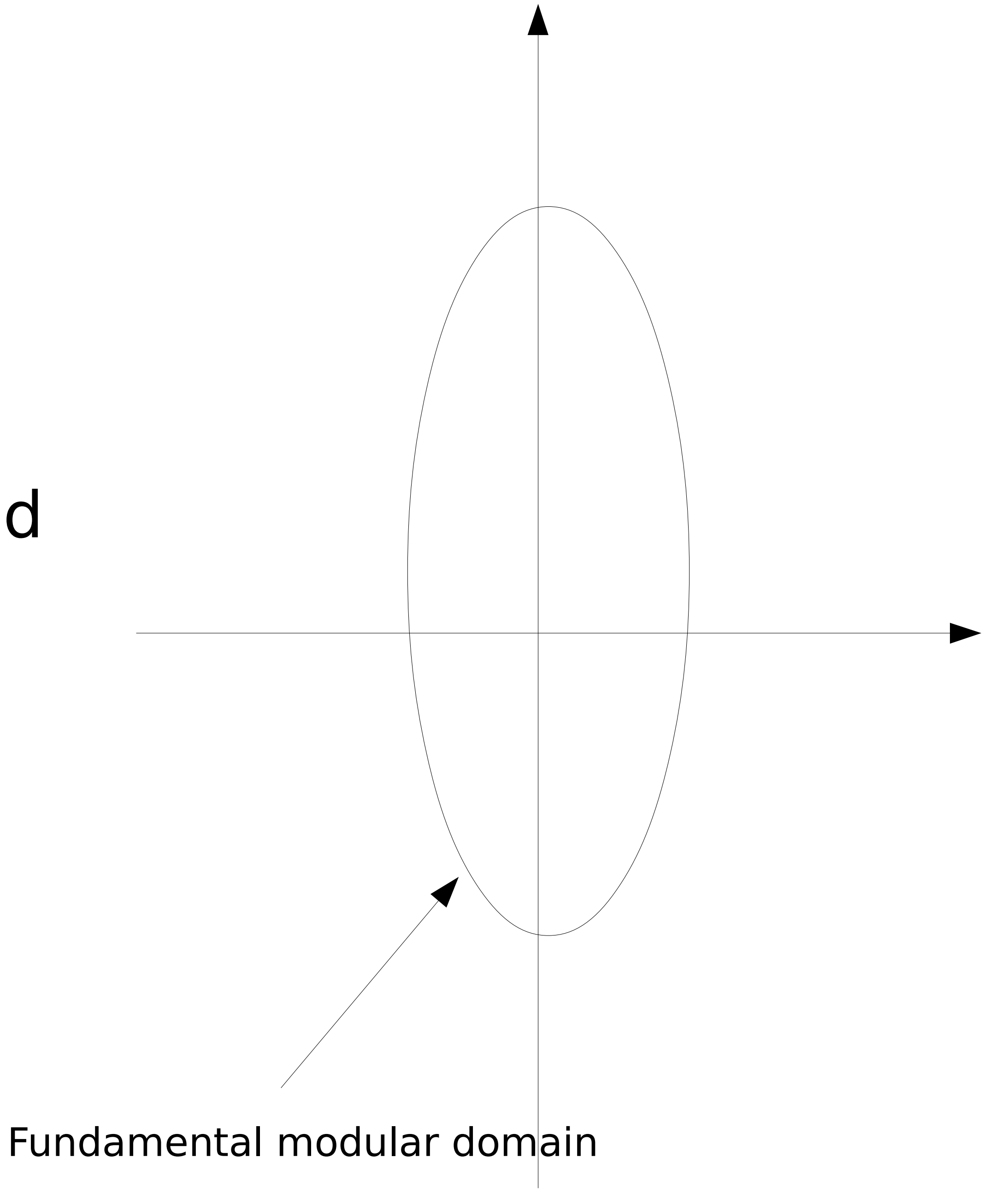

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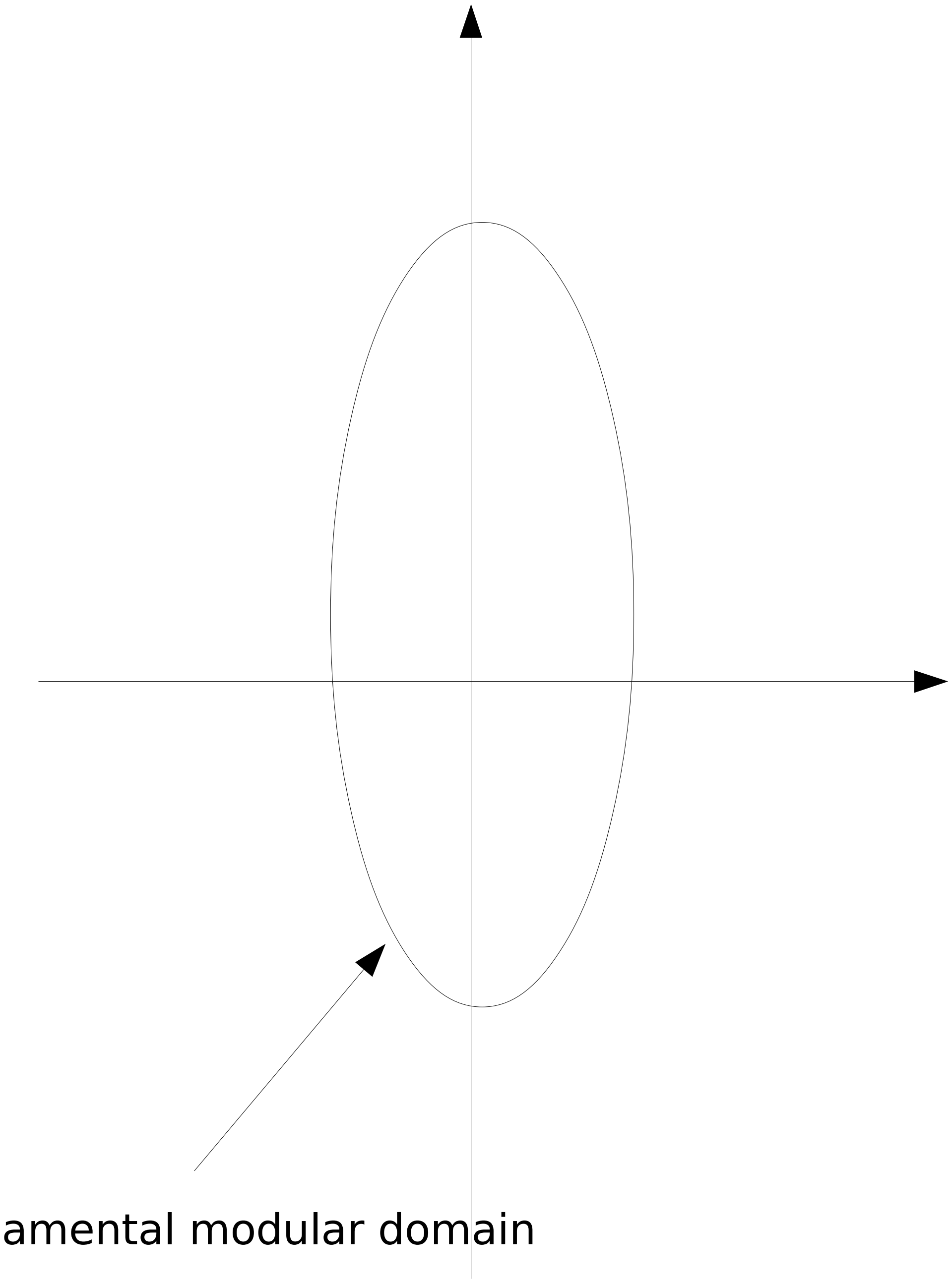
- This region is bounded and convex
- Singles out exactly one gauge copy
  - Defines absolute Landau gauge
  - Boundary subtle



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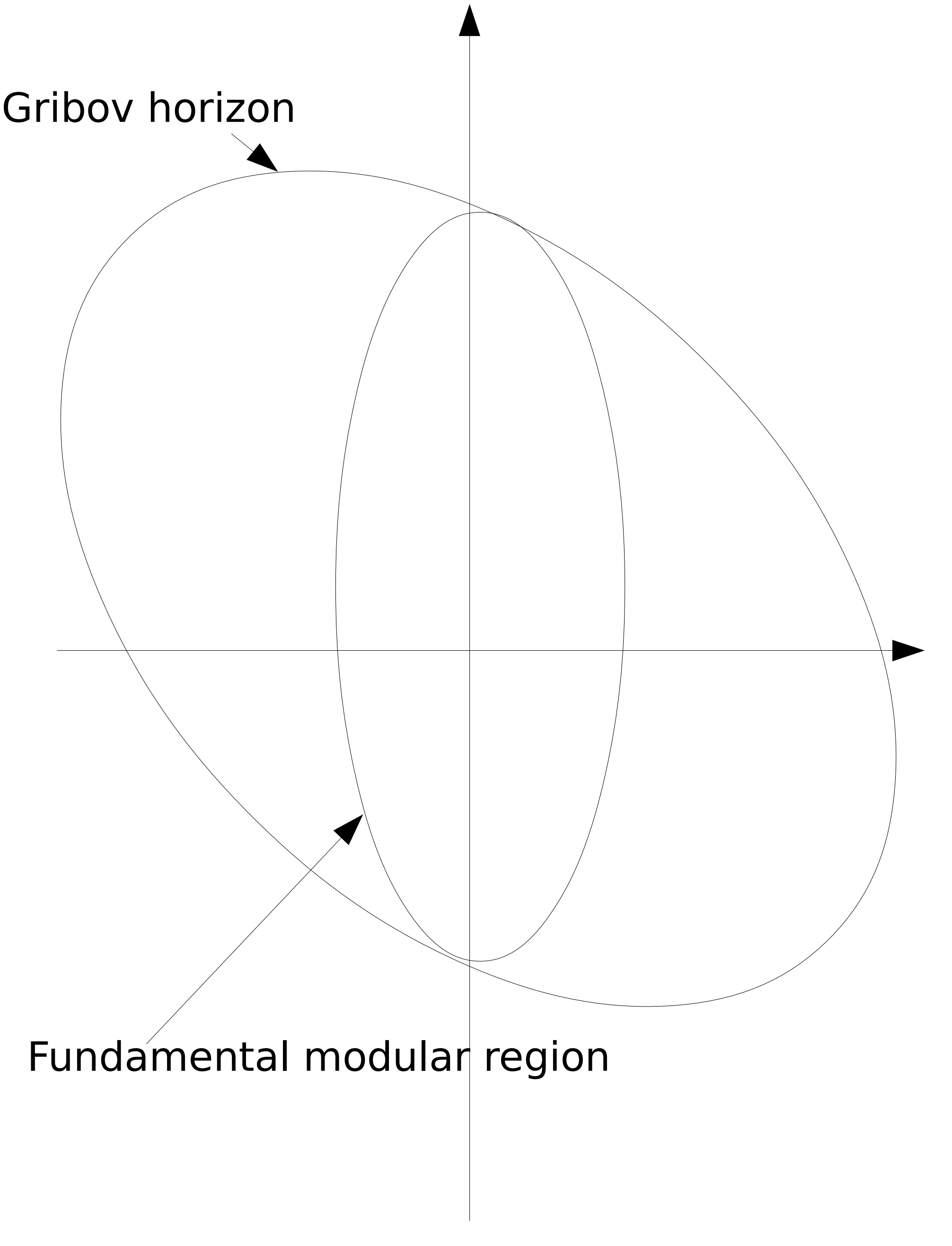

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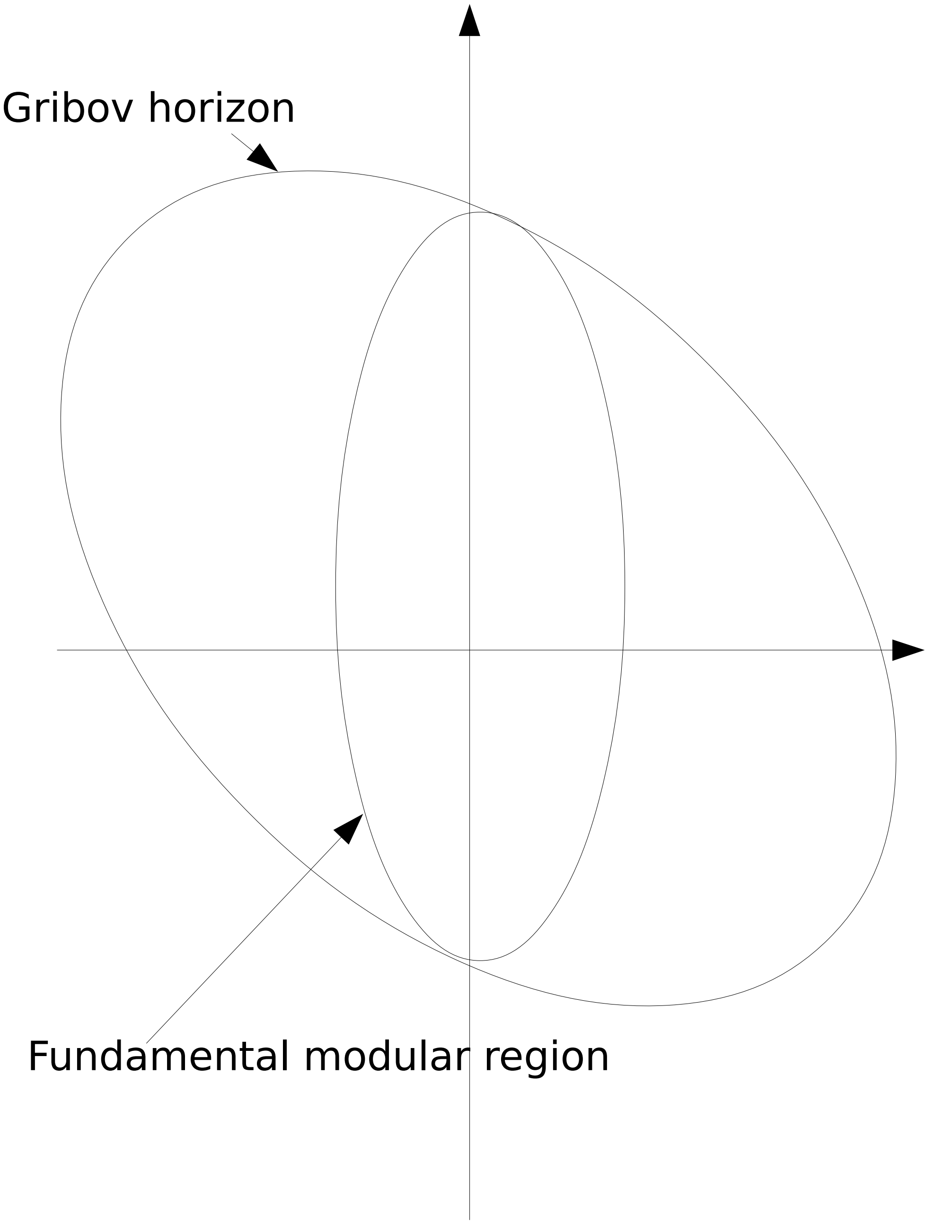

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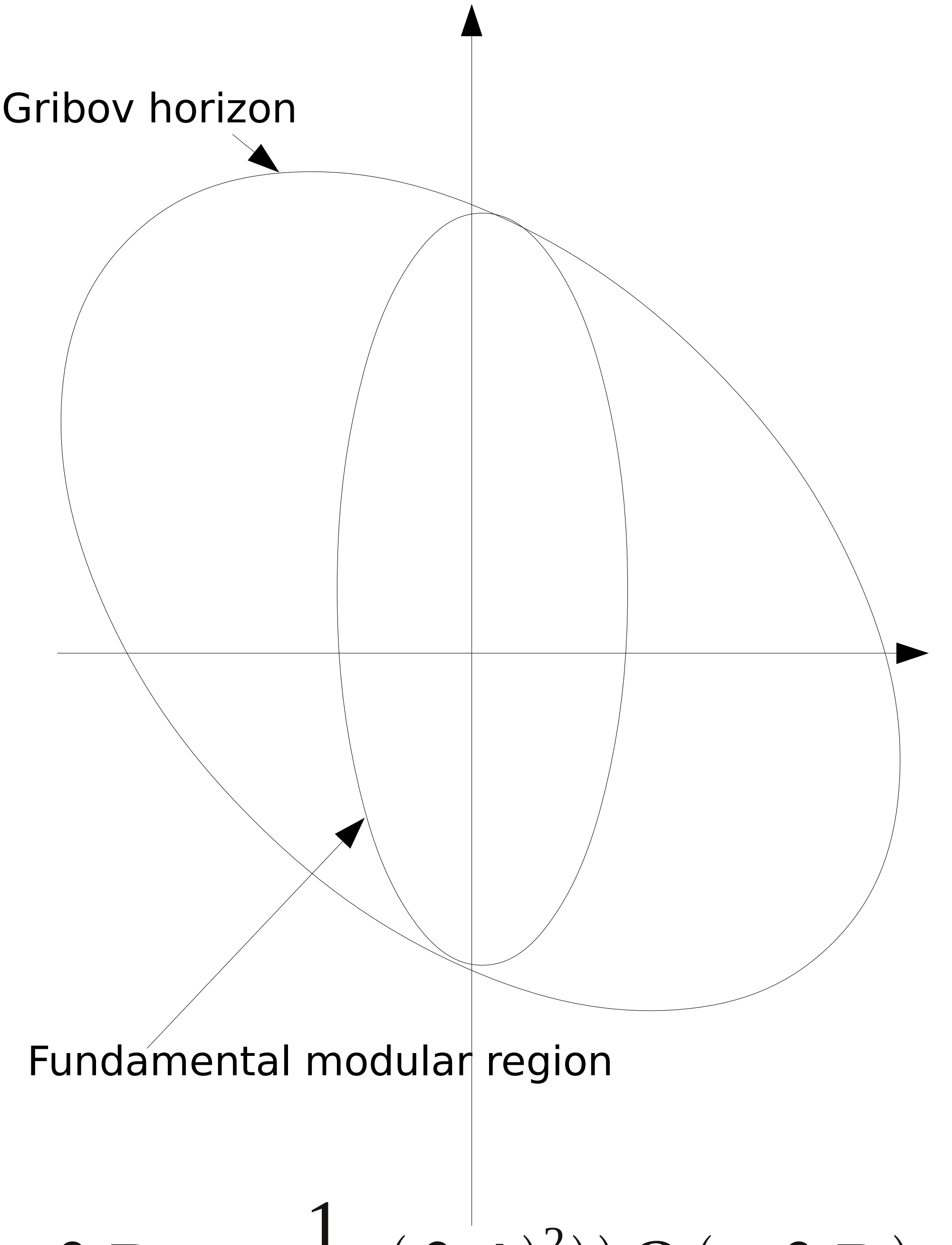

$$\lim_{\zeta\to 0}\int DAc\,\bar{c}\exp\left(\int dx\left(-\frac{1}{4}F^2-\bar{c}\,\partial D\,c-\frac{1}{2\zeta}(\partial A)^2\right)\right)\Theta(-\partial D)$$

Identifying Gribov copies

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  - Practical solution: Generate for each residual gauge orbit many random copies and select different ones [Cucchieri NPB 97]

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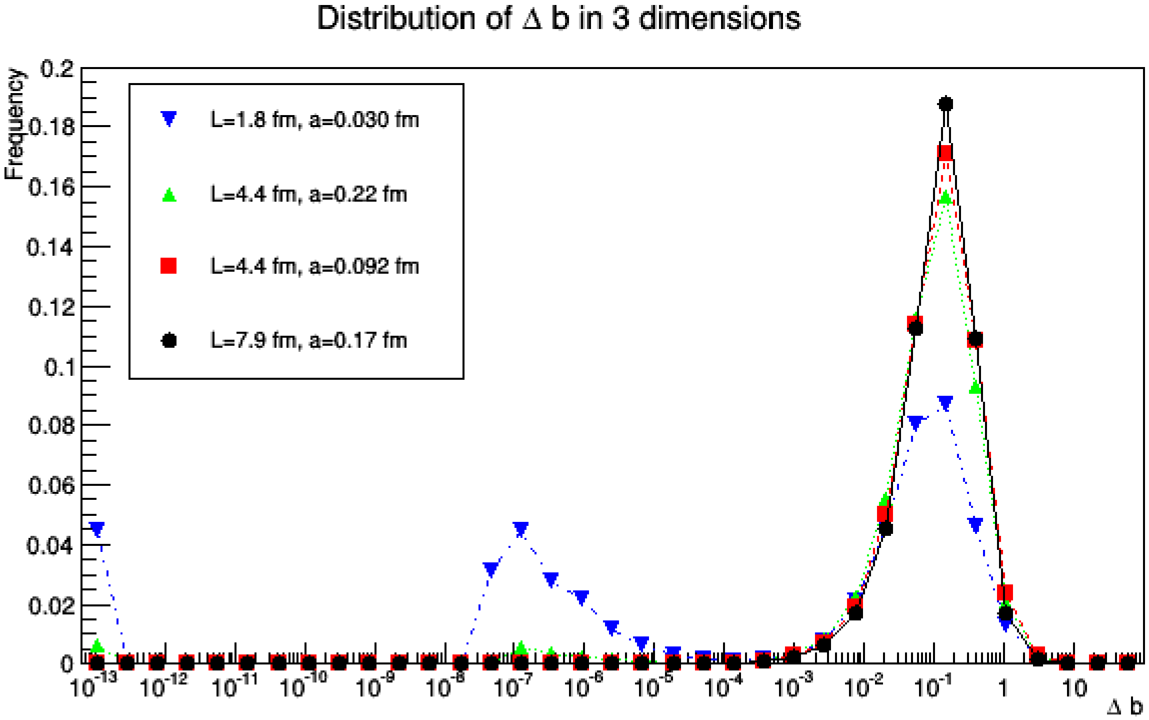
  - First know them!
- Identifying Gribov copies non-trivial task
  - No construction to generate Gribov copies
  - Practical solution: Generate for each residual gauge orbit many random copies and select different ones [Cucchieri NPB 97]
    - When are two copies different? [Maas PRD 15]
      - Connected by non-trivial transformation
      - Practical: Sufficiently different value of F and B
        - Distinguishing power of B much better
      - Other dismissed as numerical/lattice artifacts

Separating Gribov copies

[Maas PRD 15]



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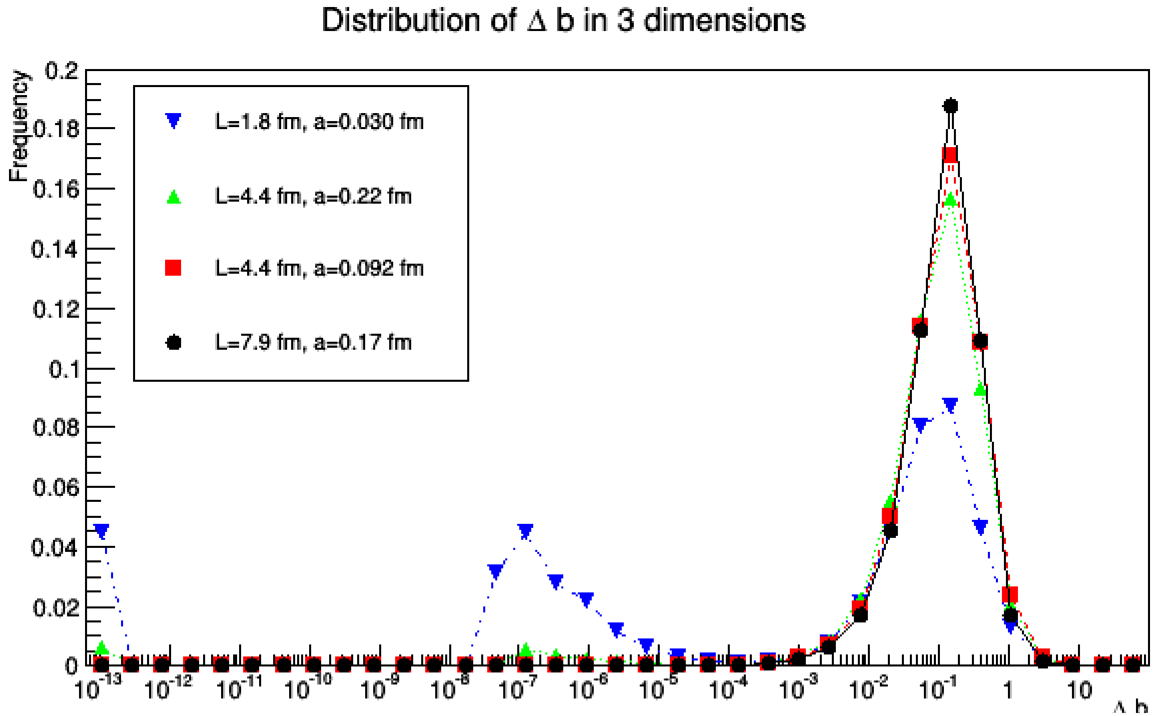

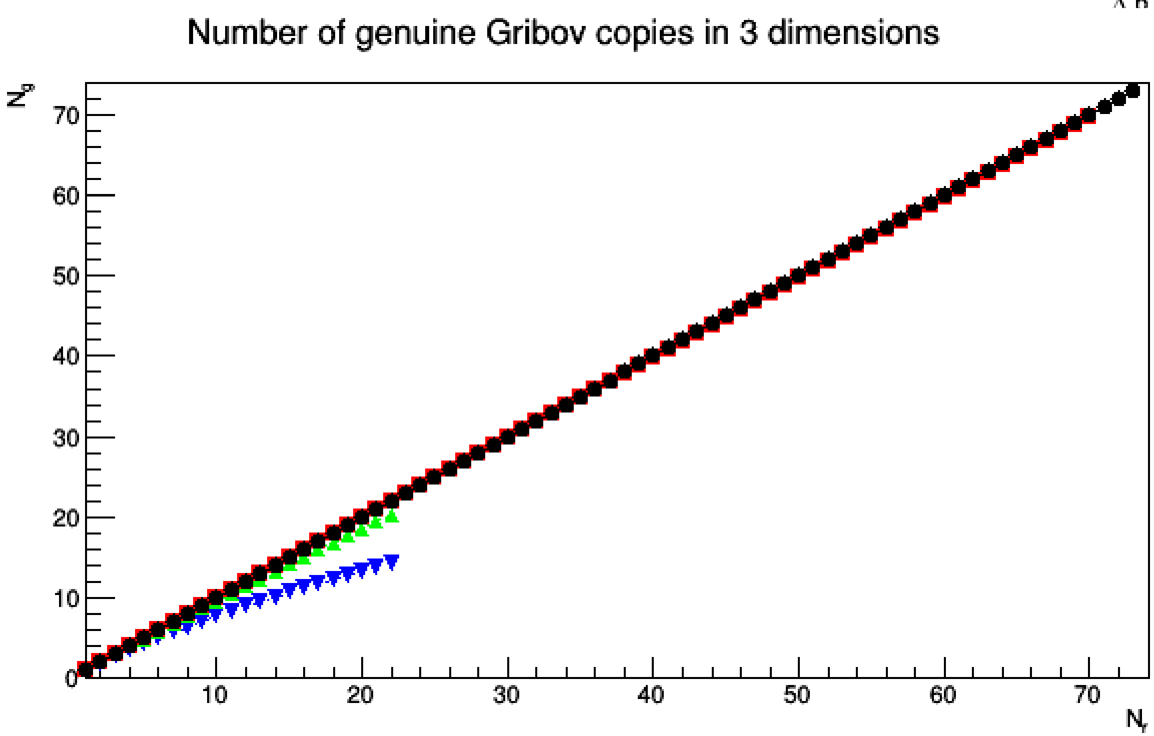

- Distinction better for larger volume and dimension
- Number of identified Gribov copies rises quickly
  - Linear on large volumes
  - No extrapolation to infinite-volume limit possible

Structure of the residual gauge orbit

[Maas PRD 15]

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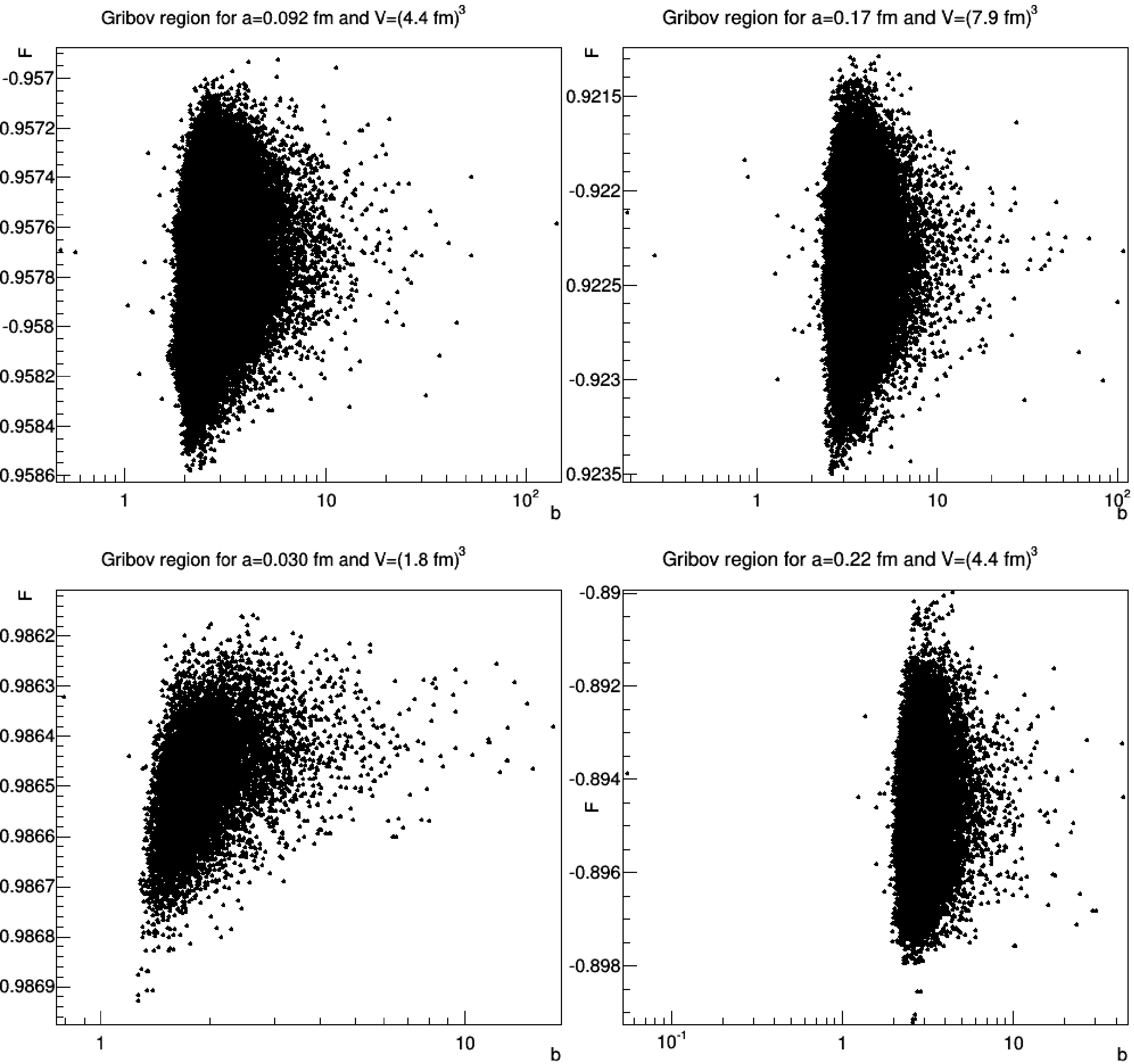

- Projection of first Gribov region to B and F
- Independent coordinates at sufficiently large volumes and fine lattices

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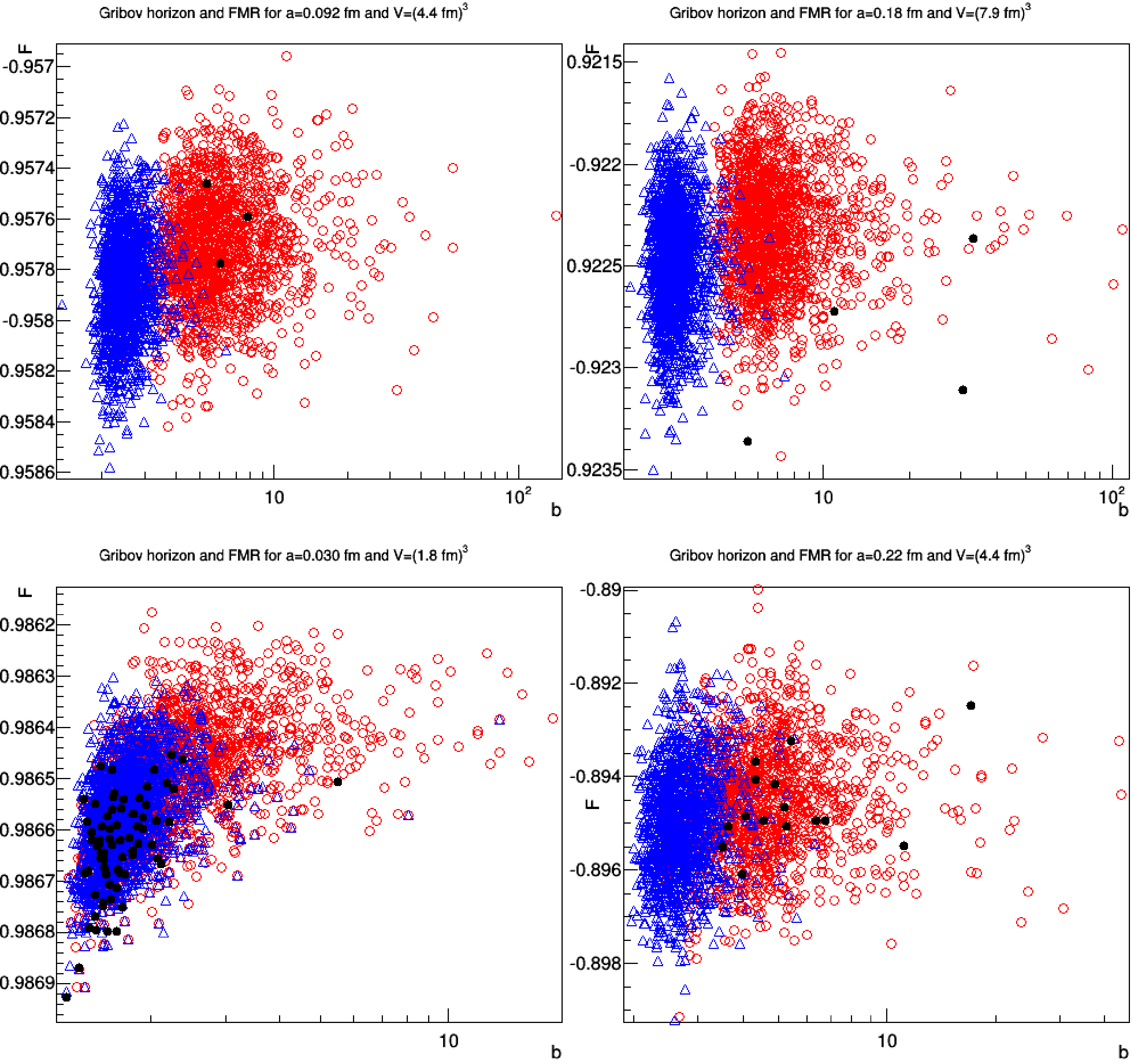

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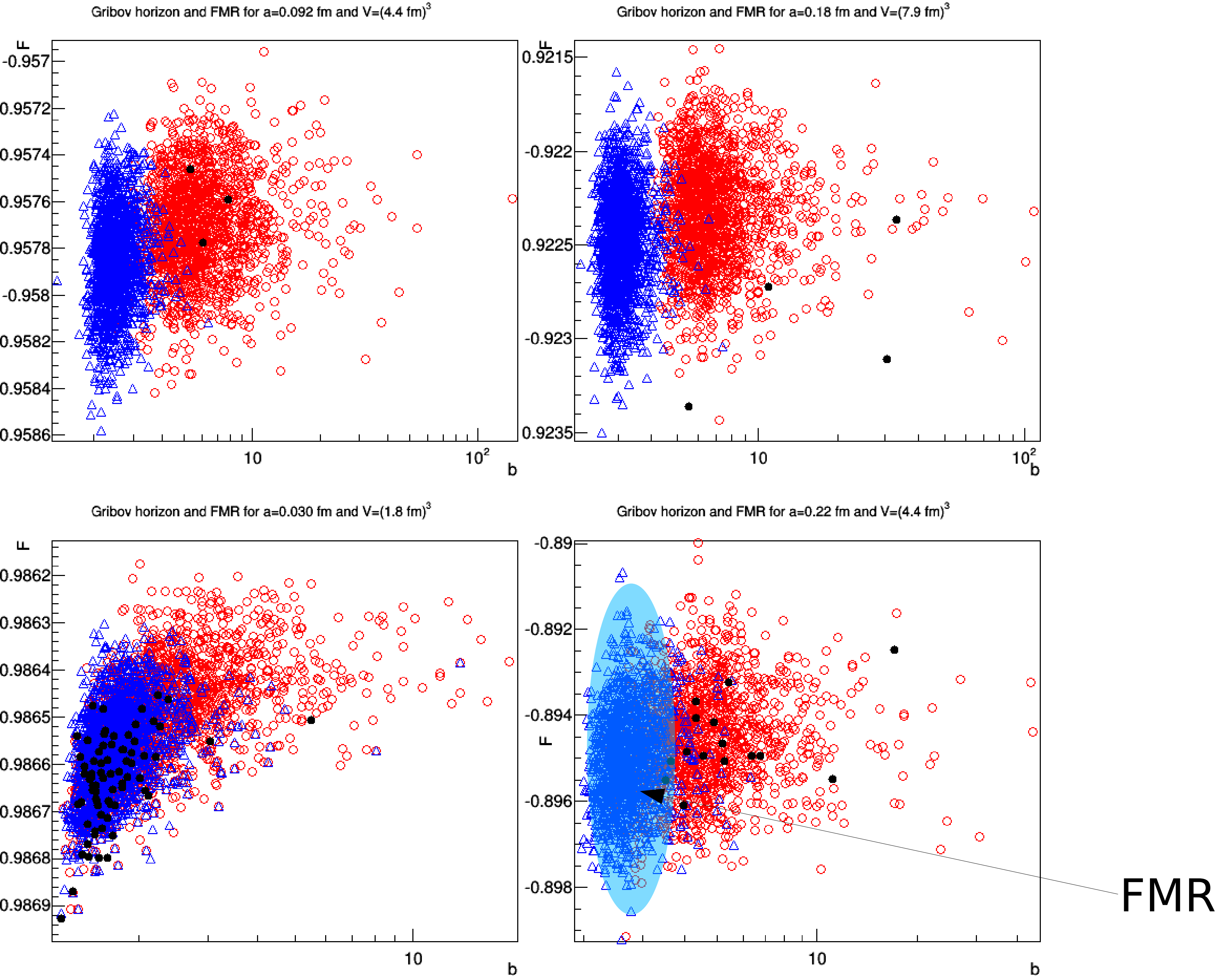

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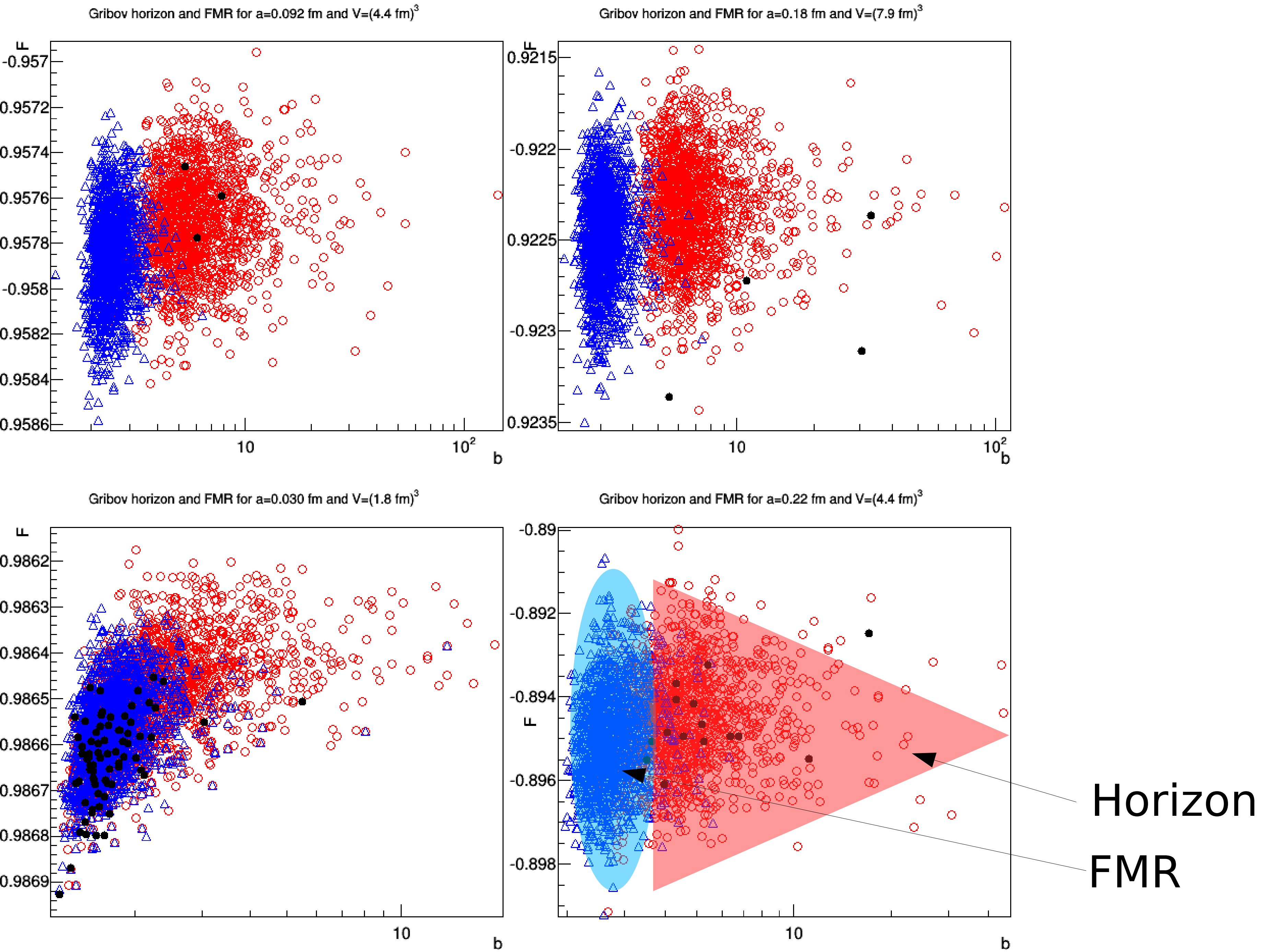

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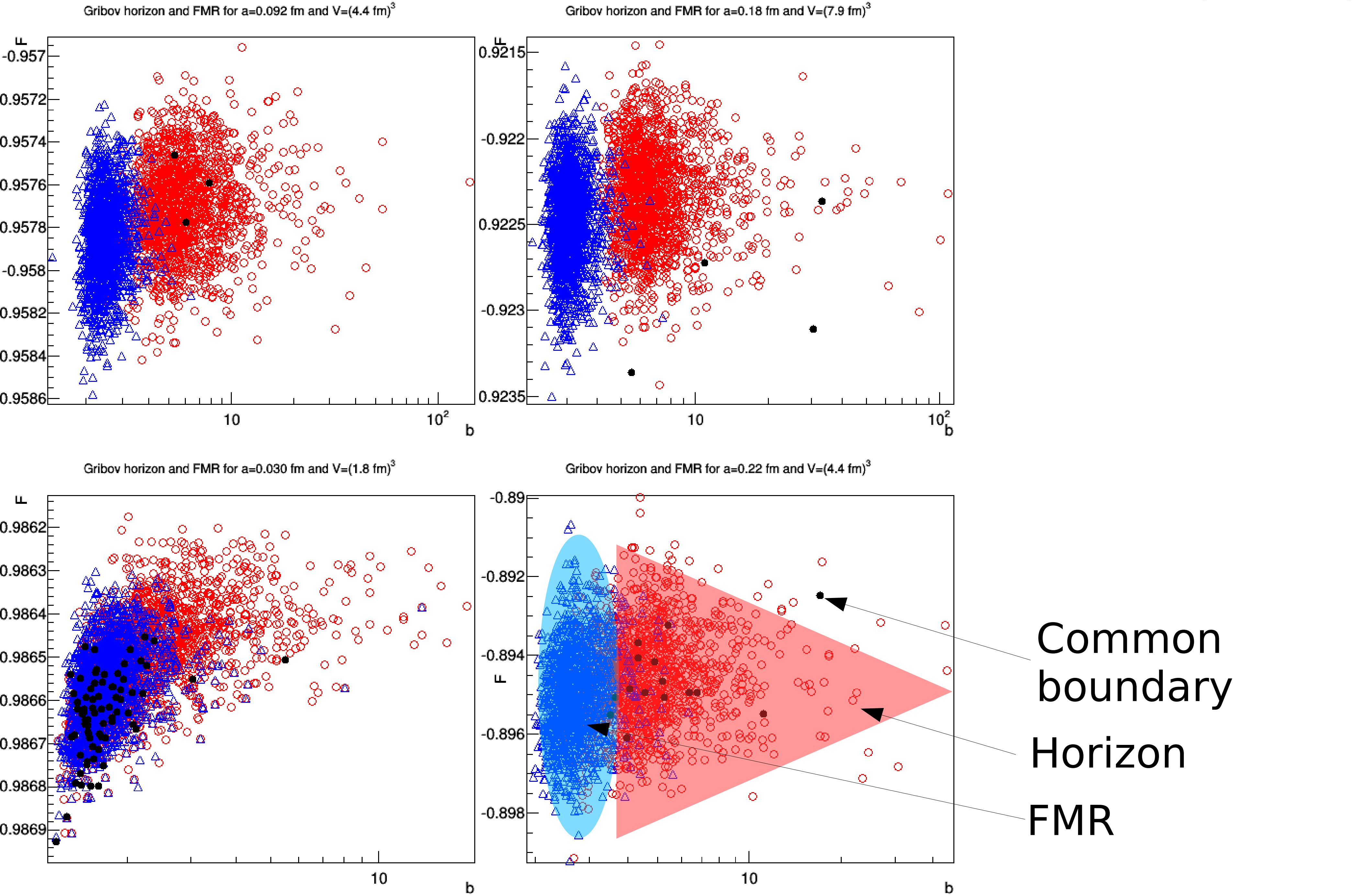

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  - Average among still equal copies

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Gluon propagator

[Maas PoS 12, unpublished]

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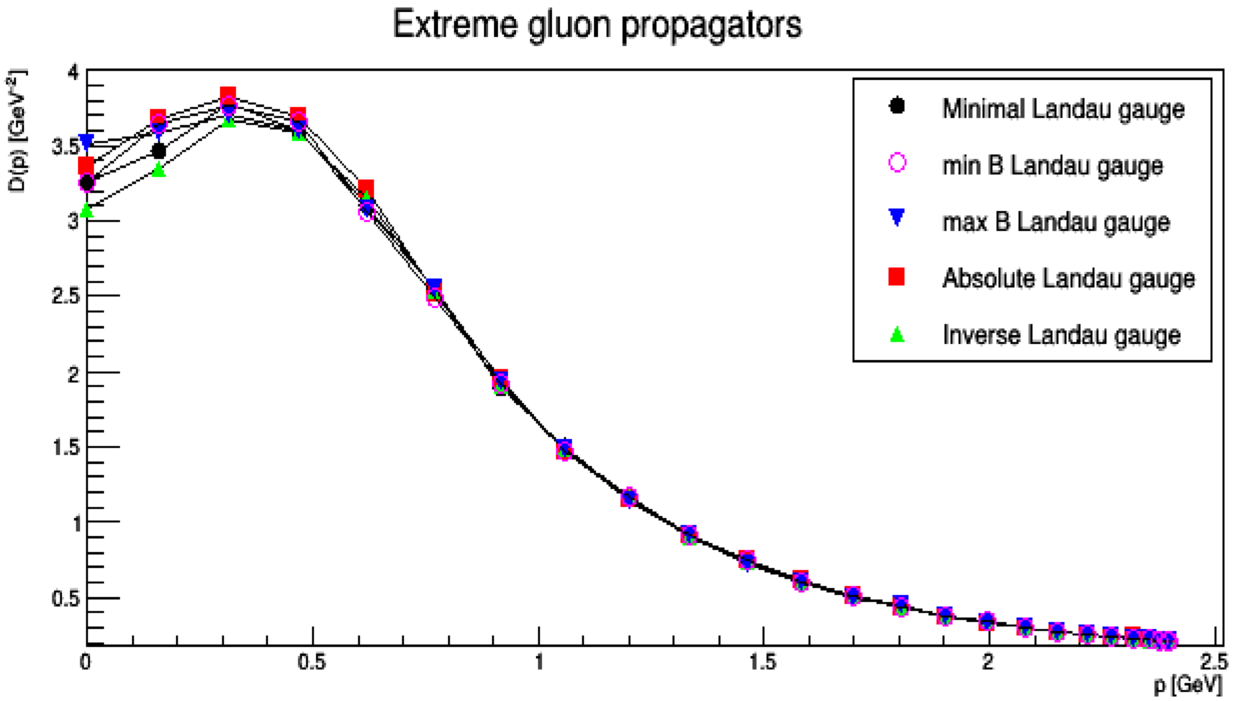

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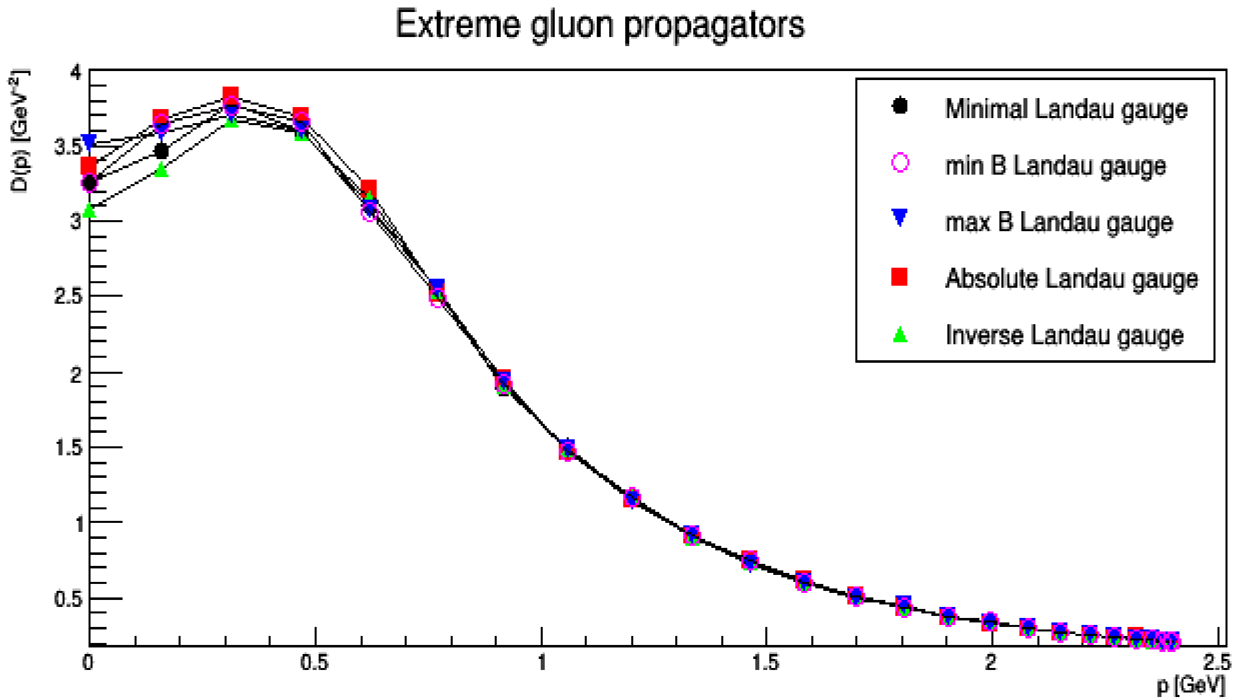

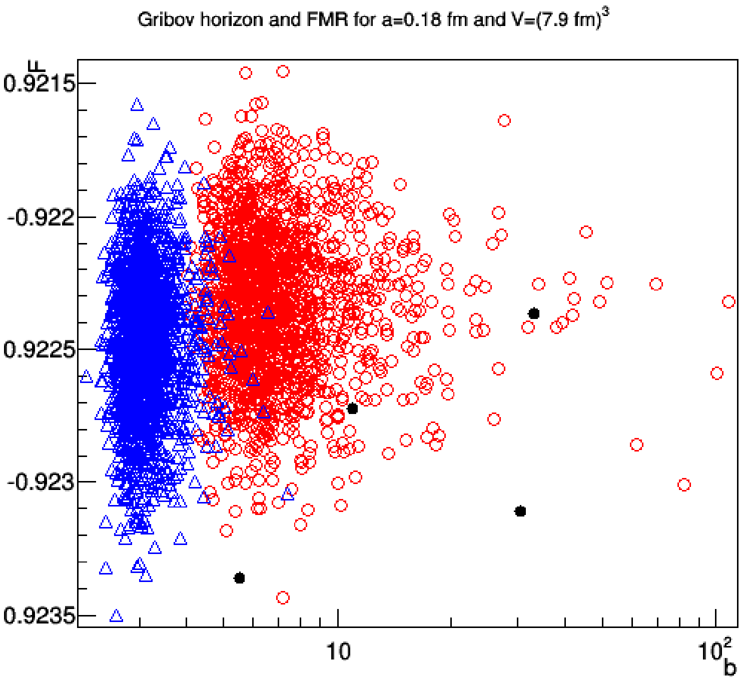

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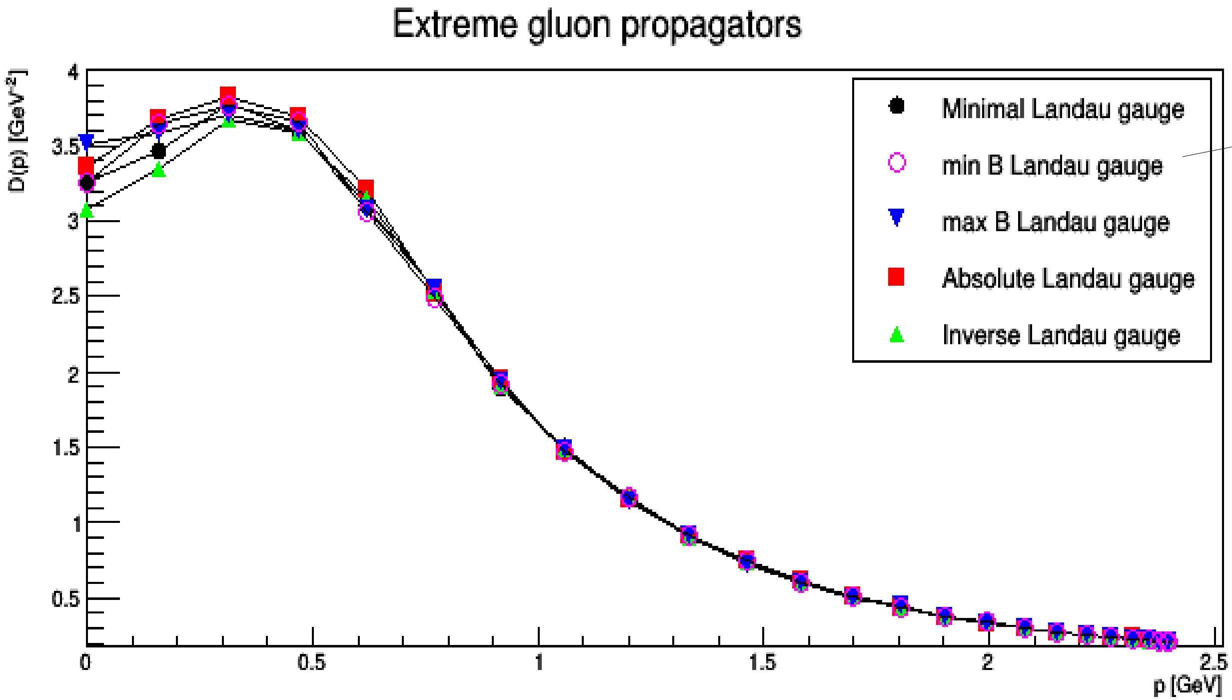

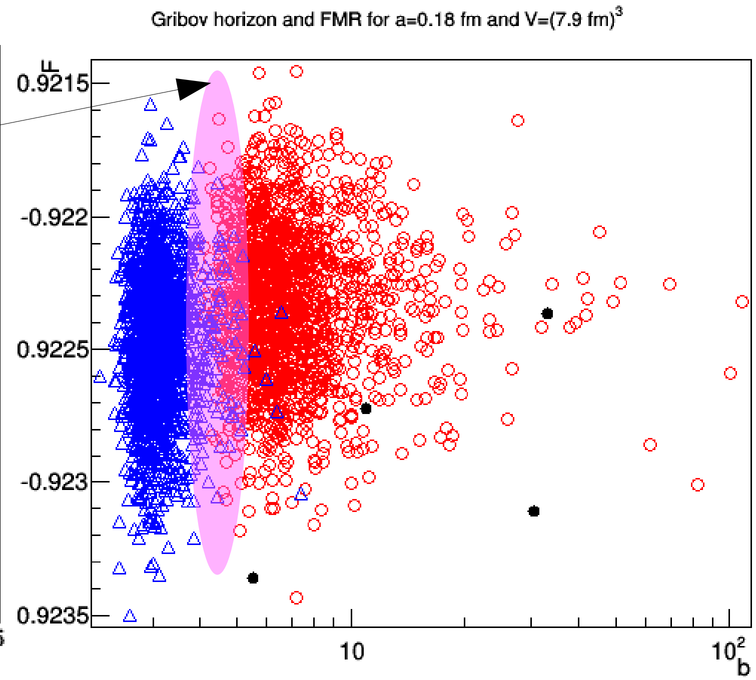

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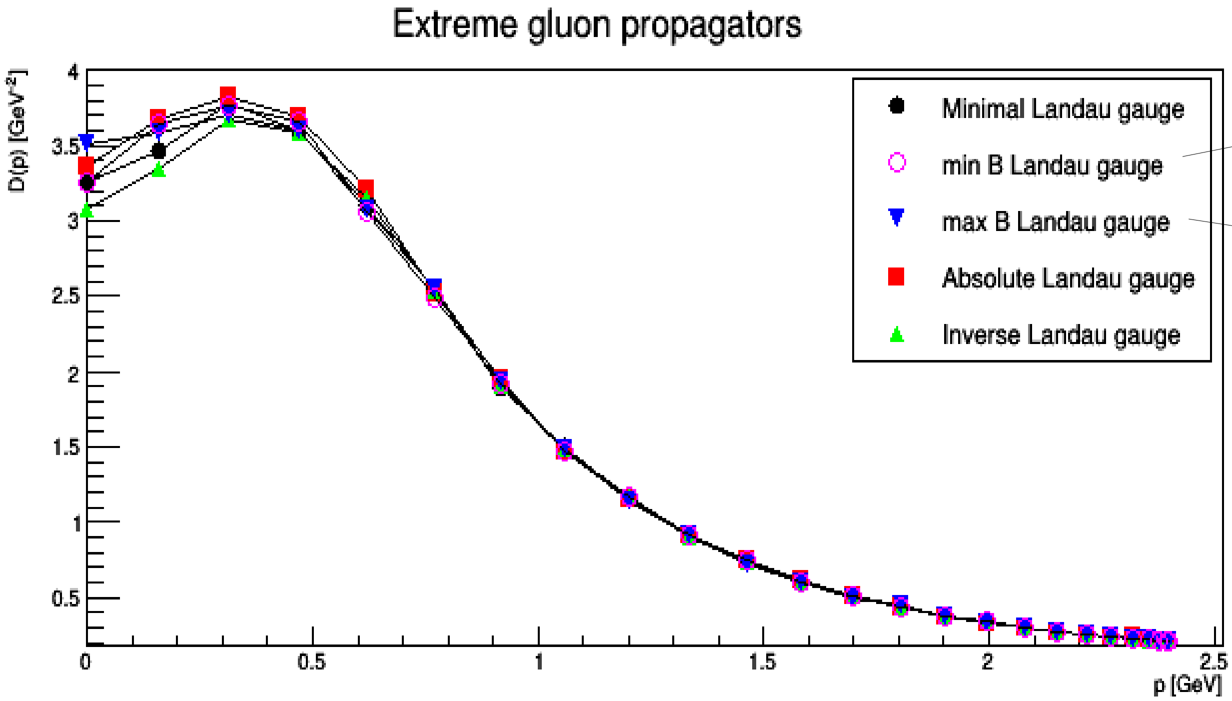

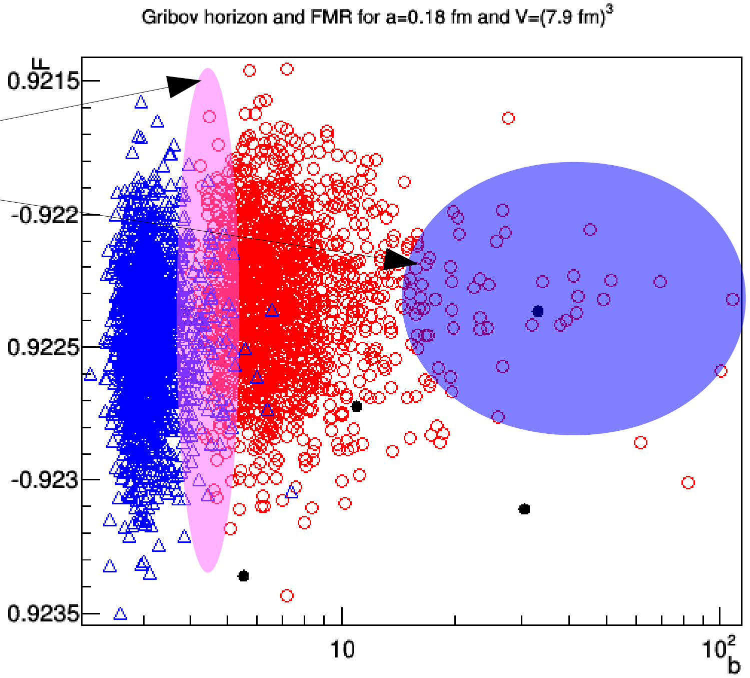

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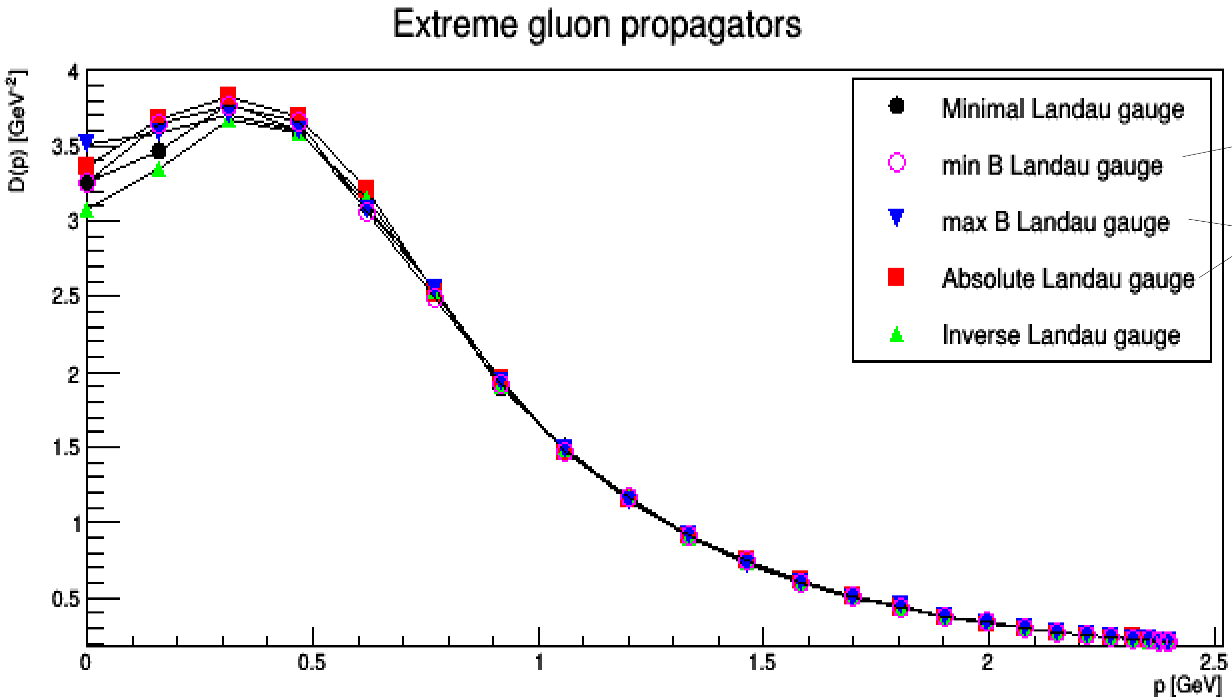

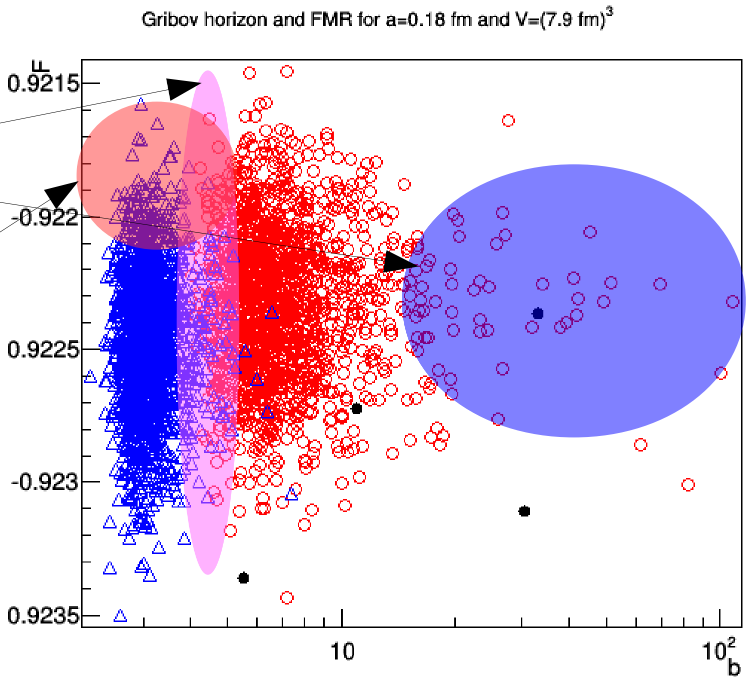

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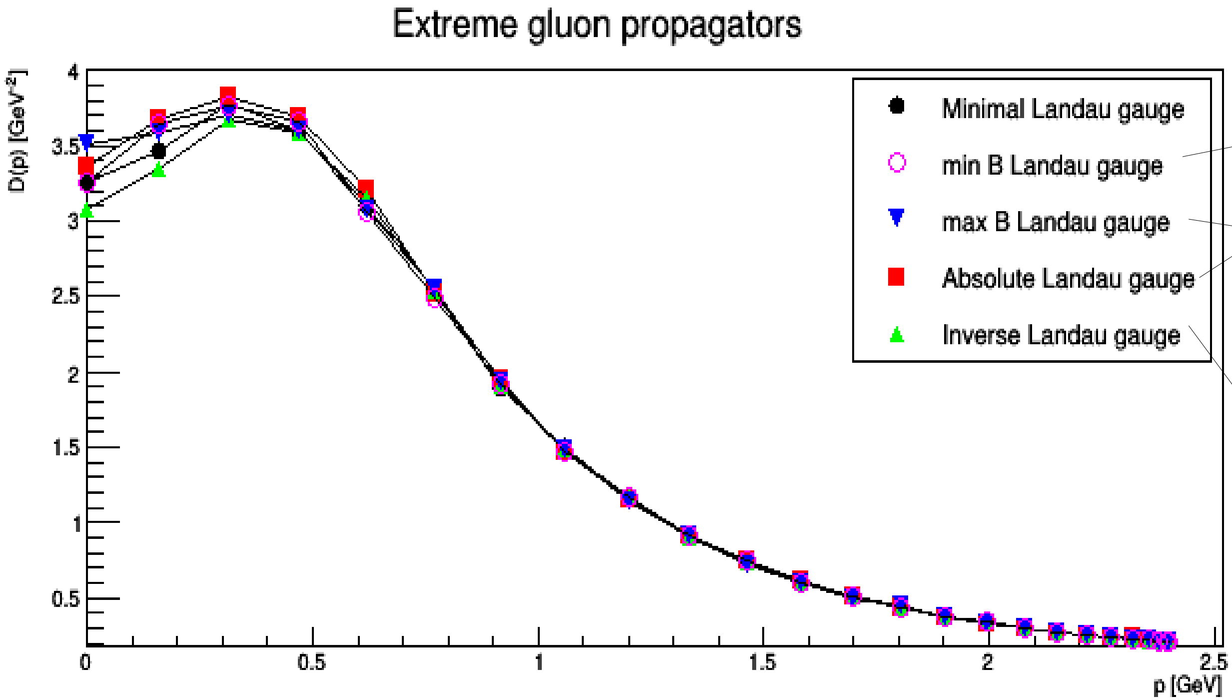

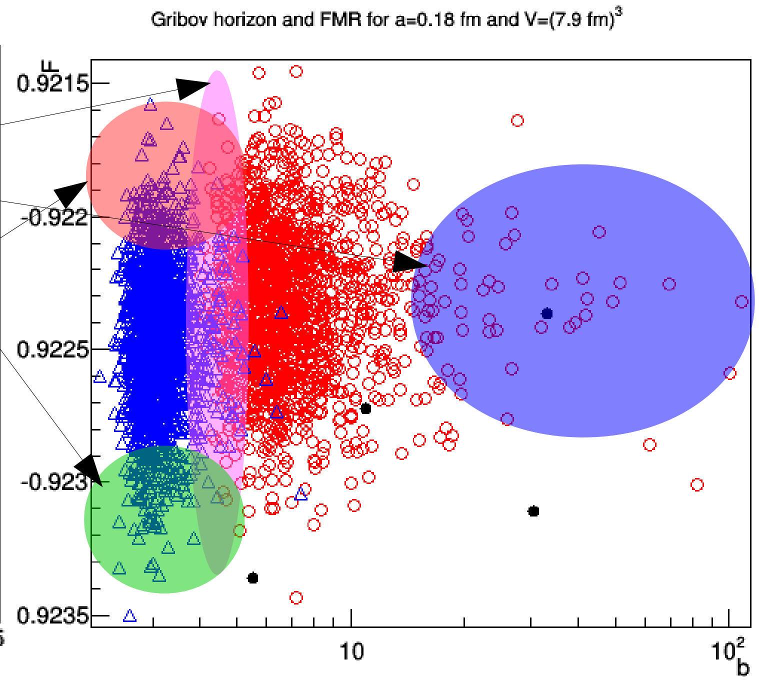

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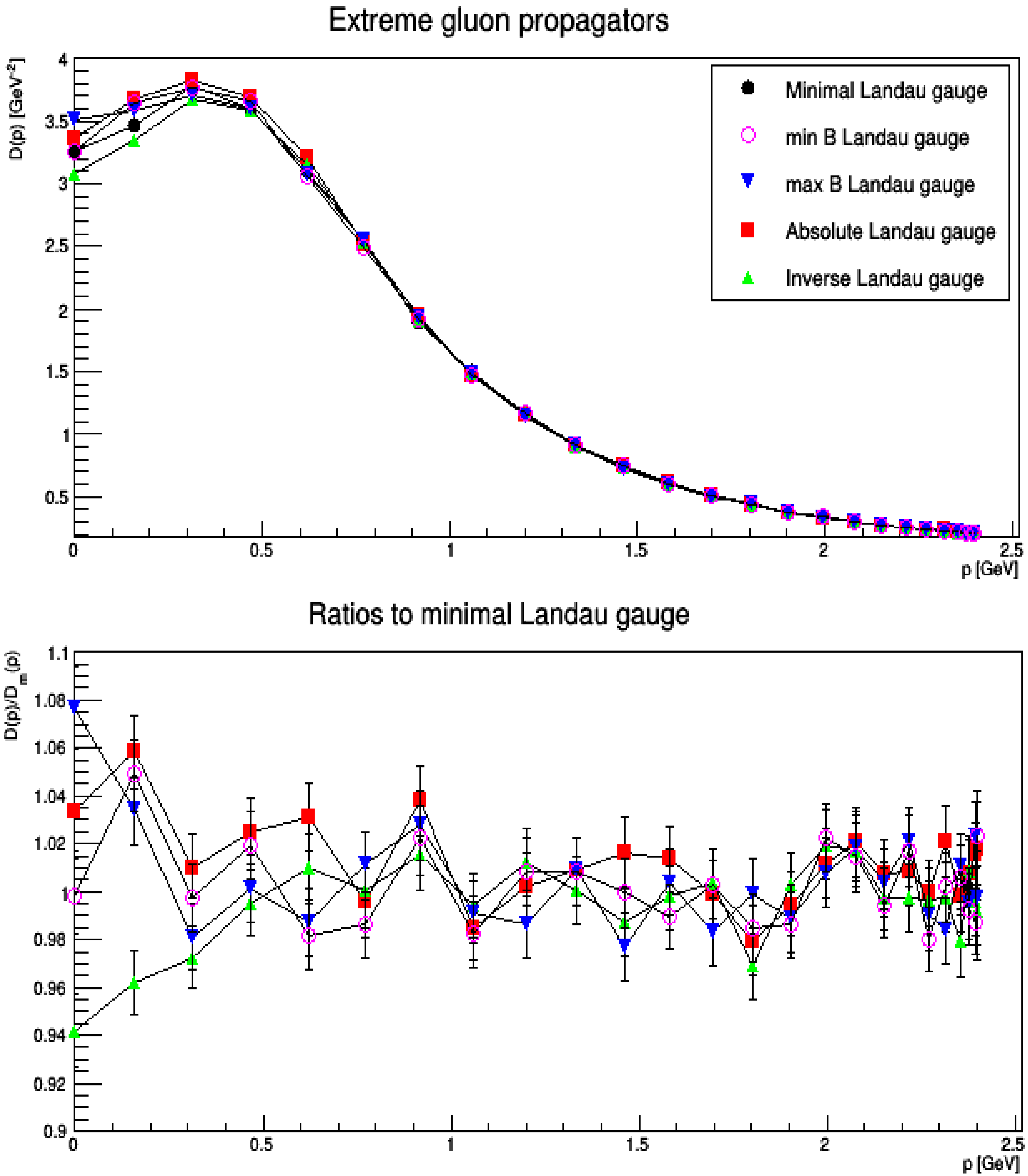

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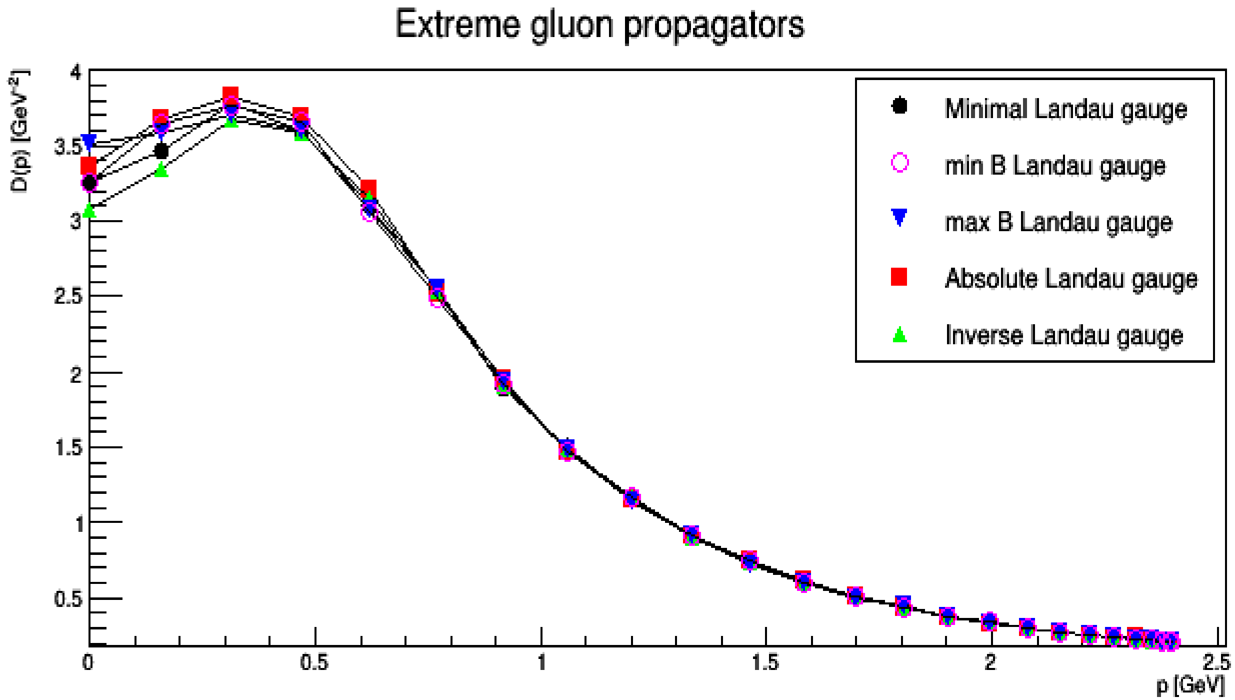

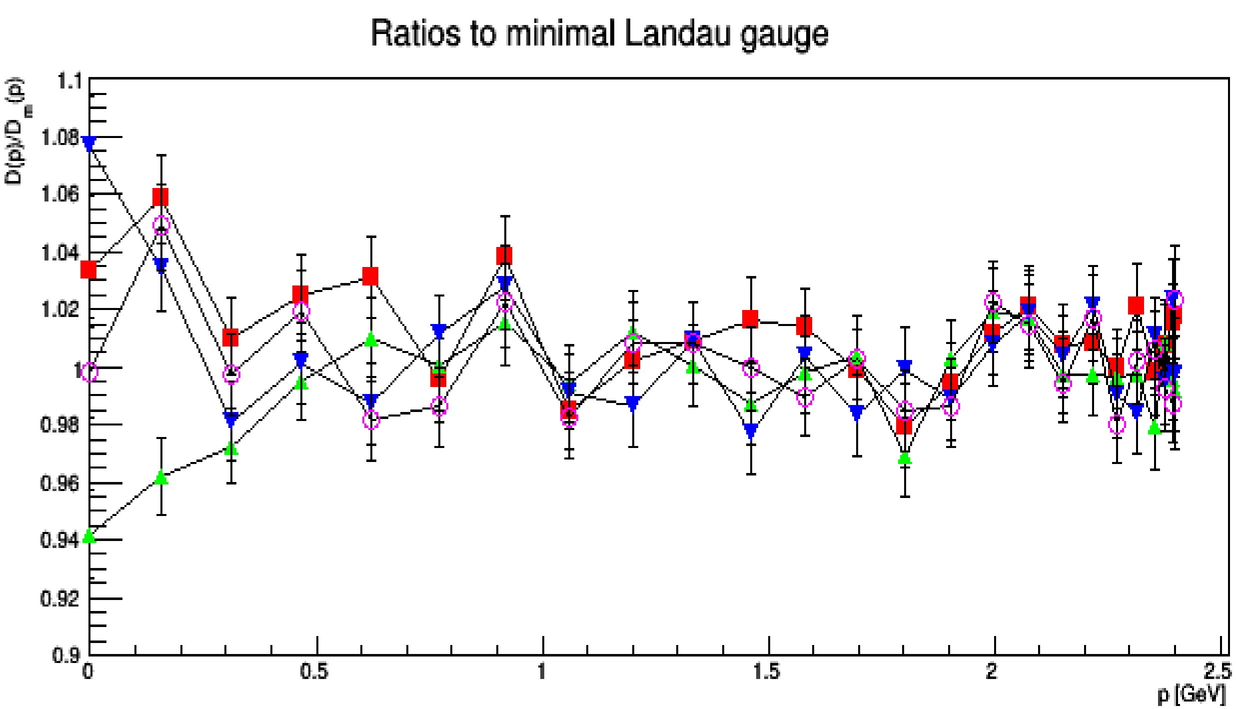

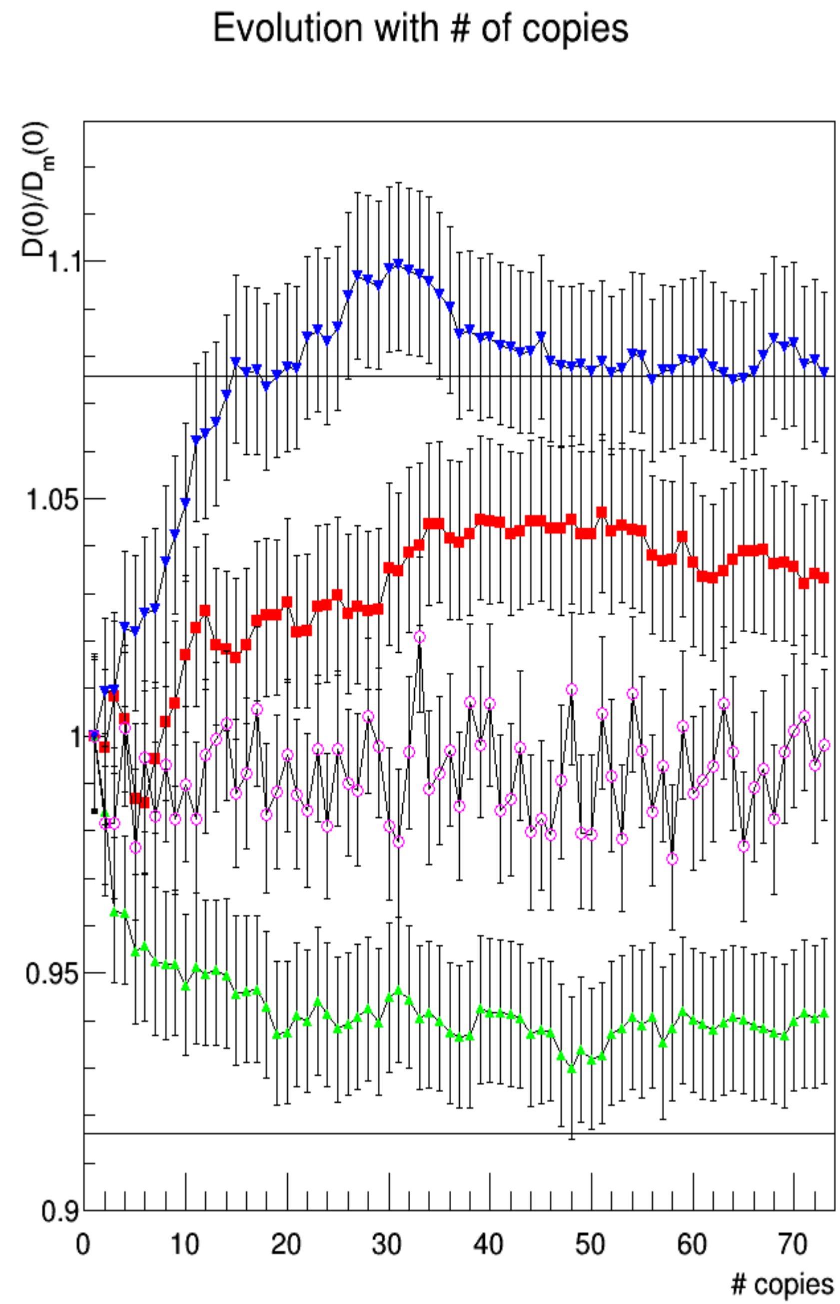

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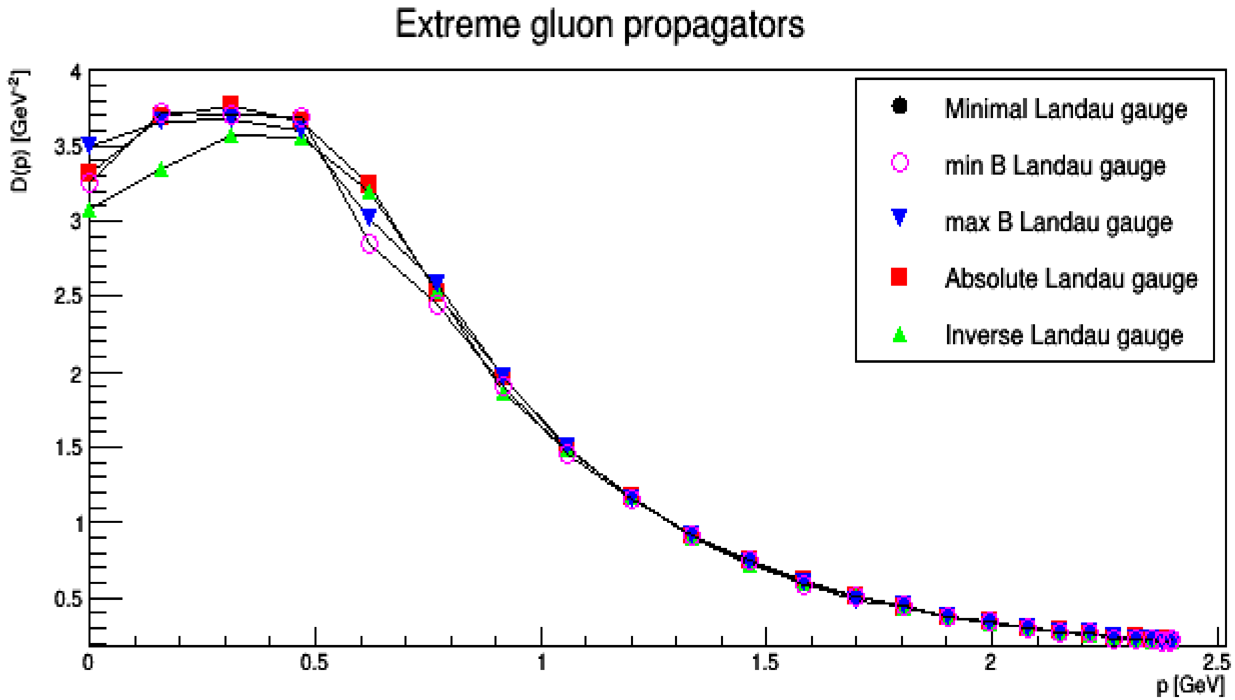

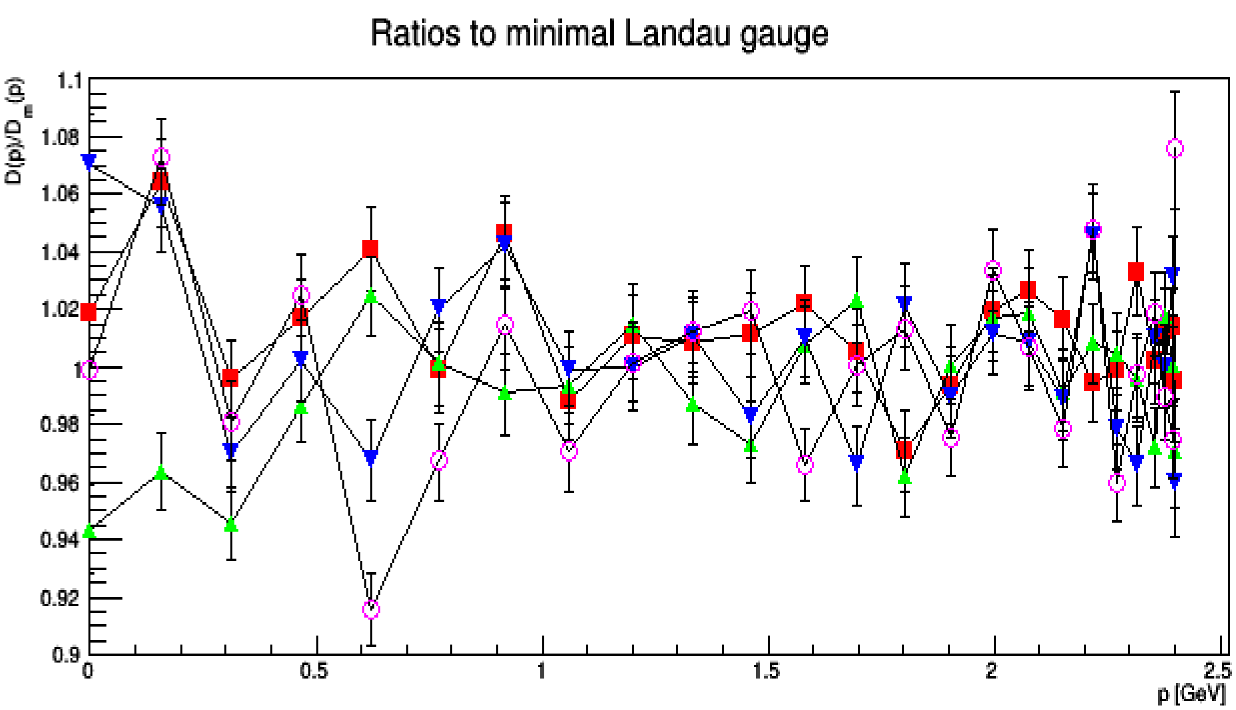

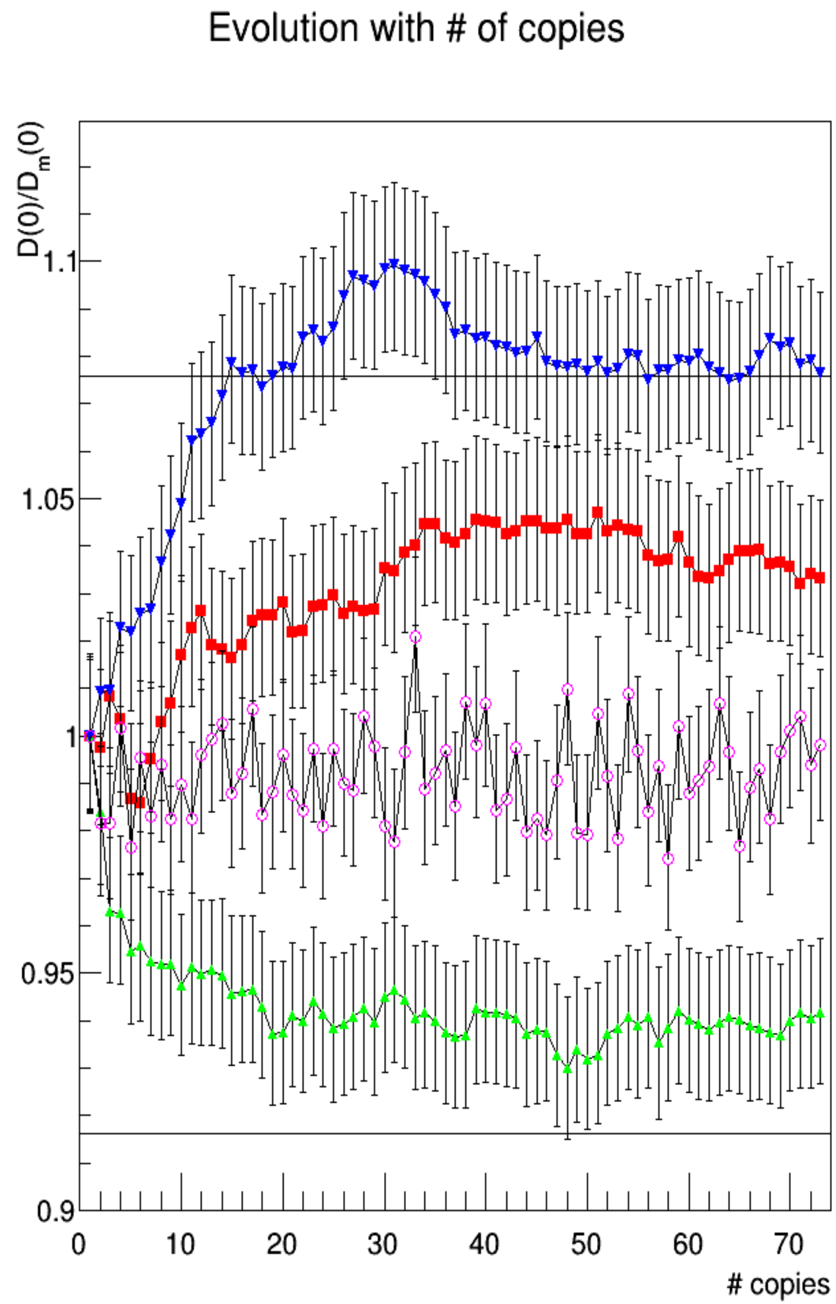

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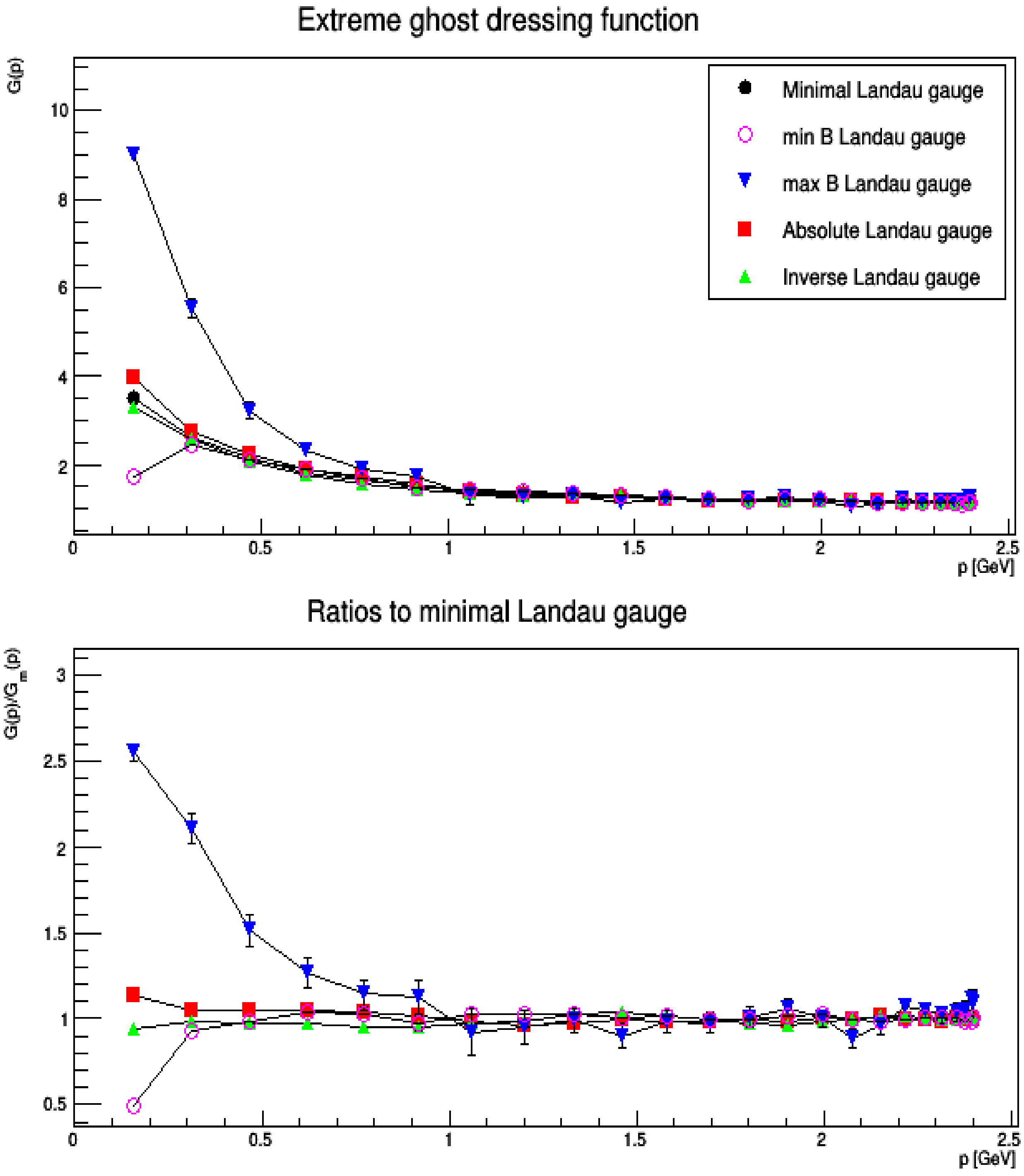

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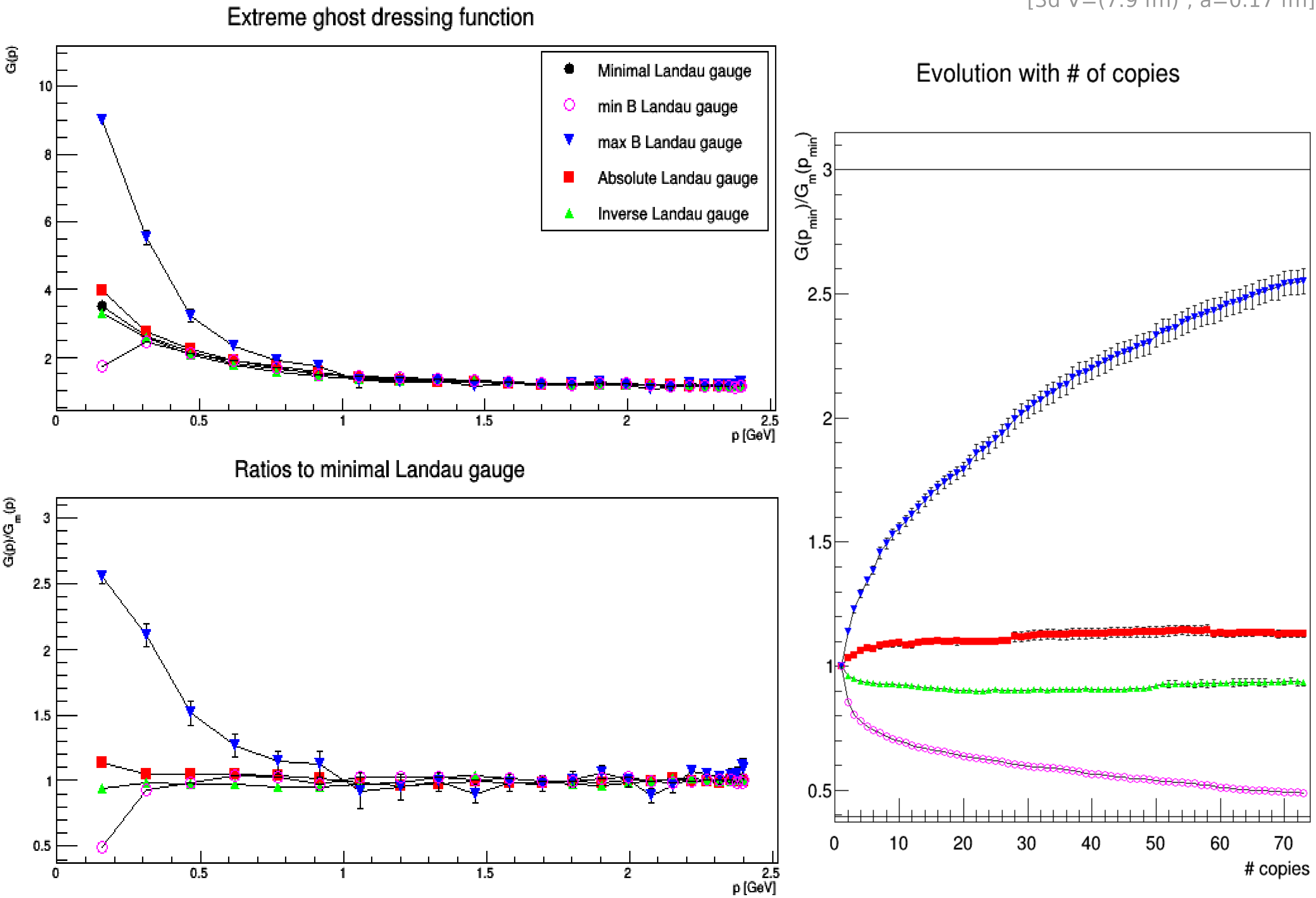

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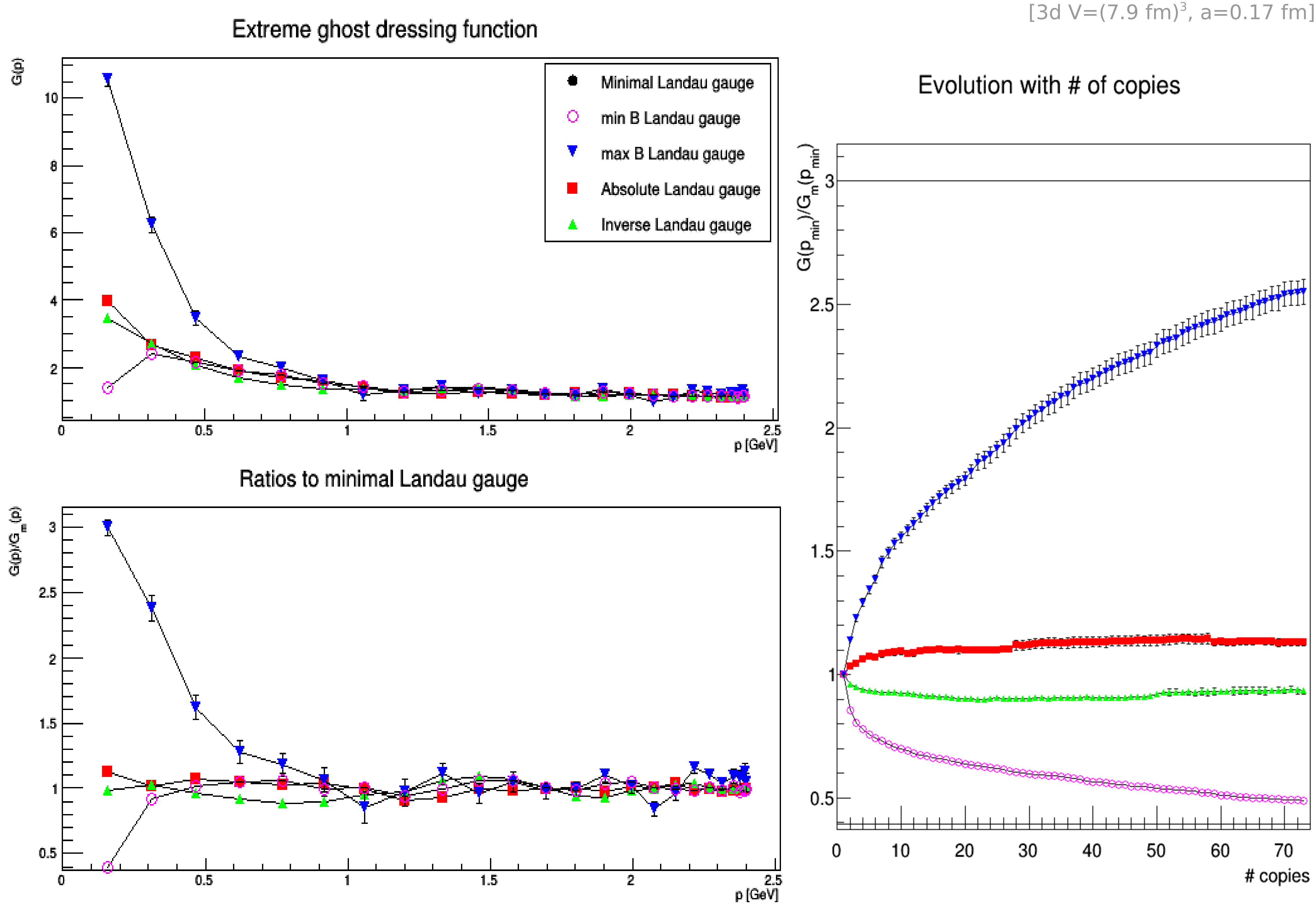

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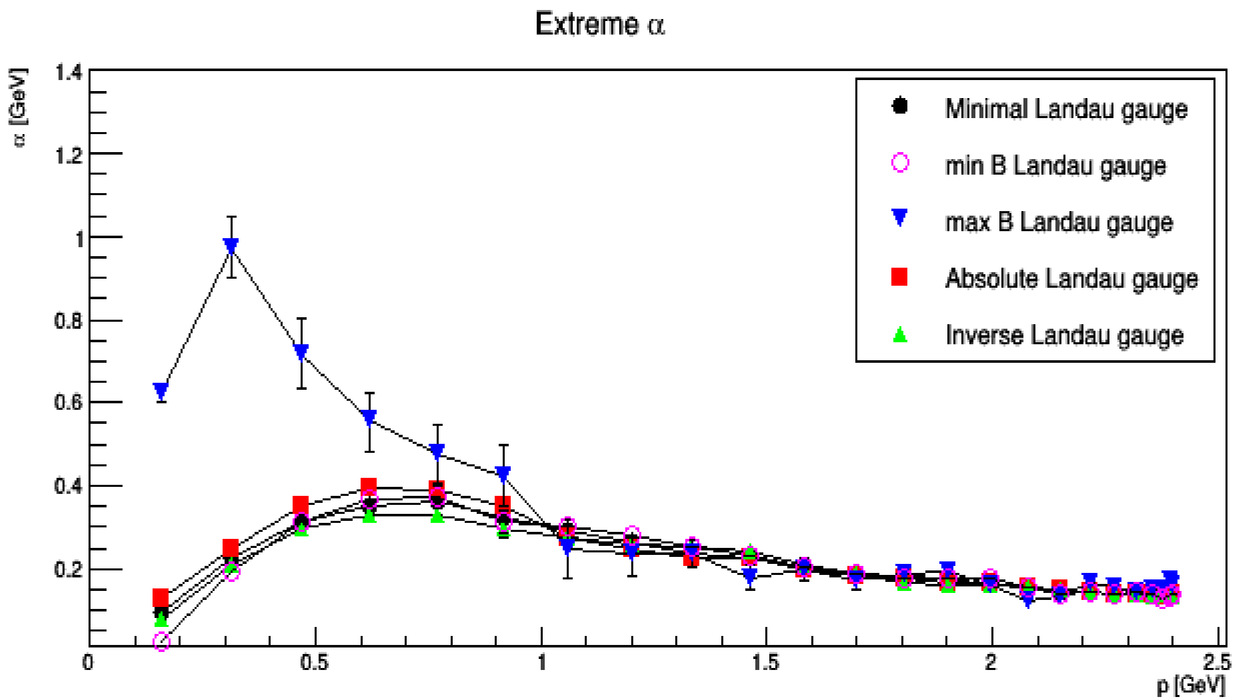

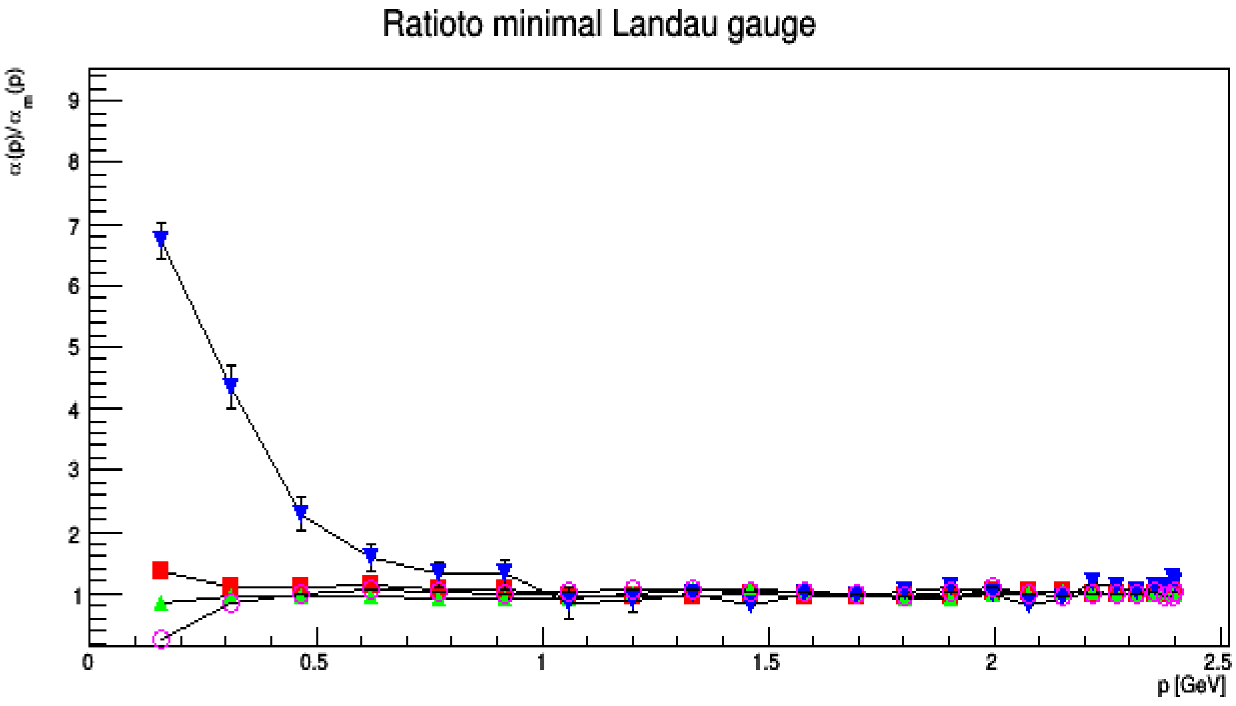

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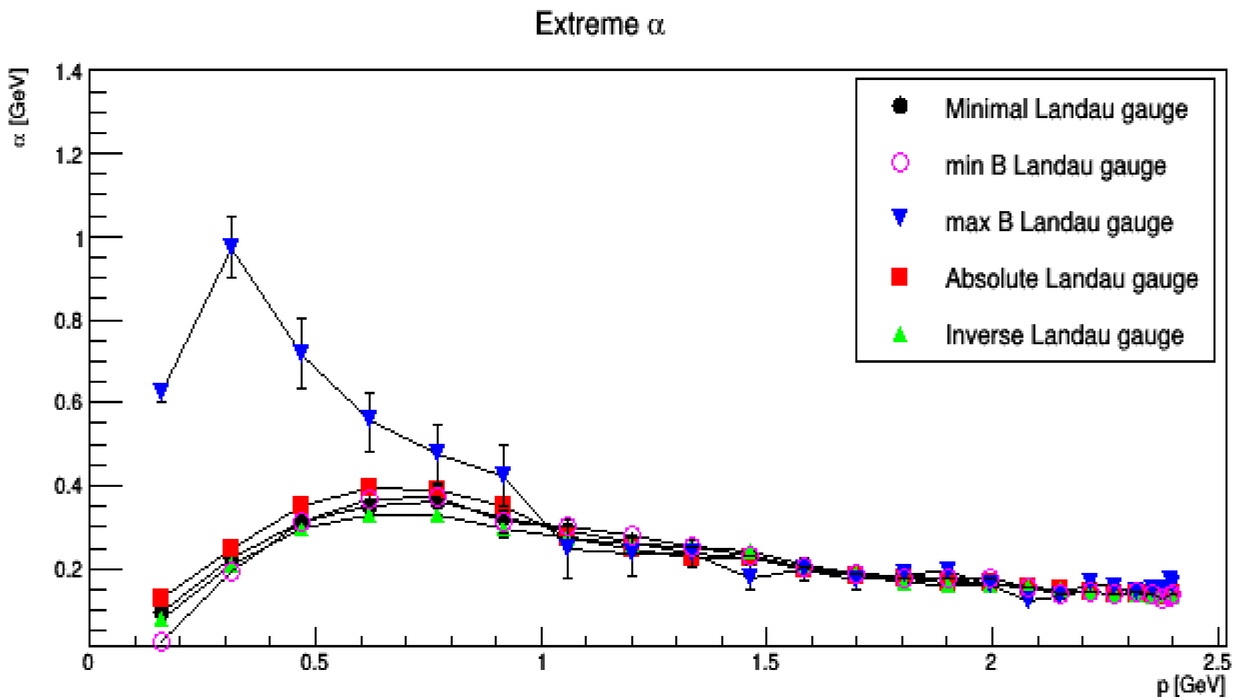

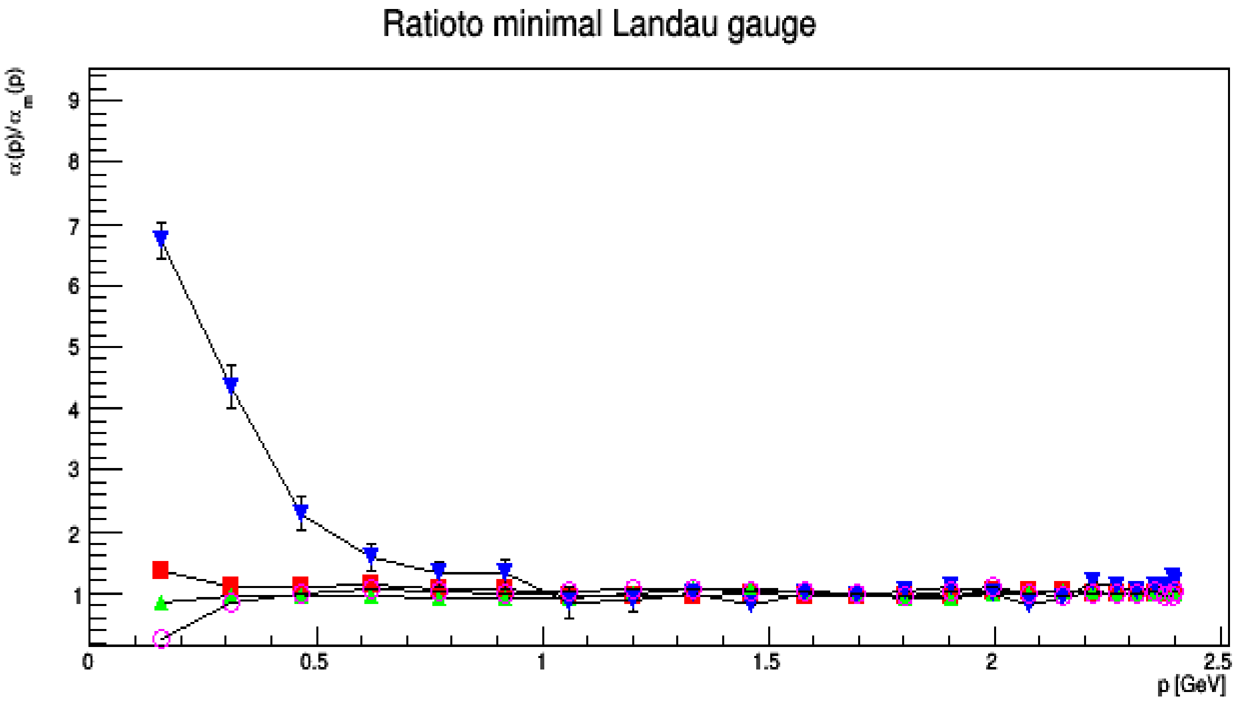

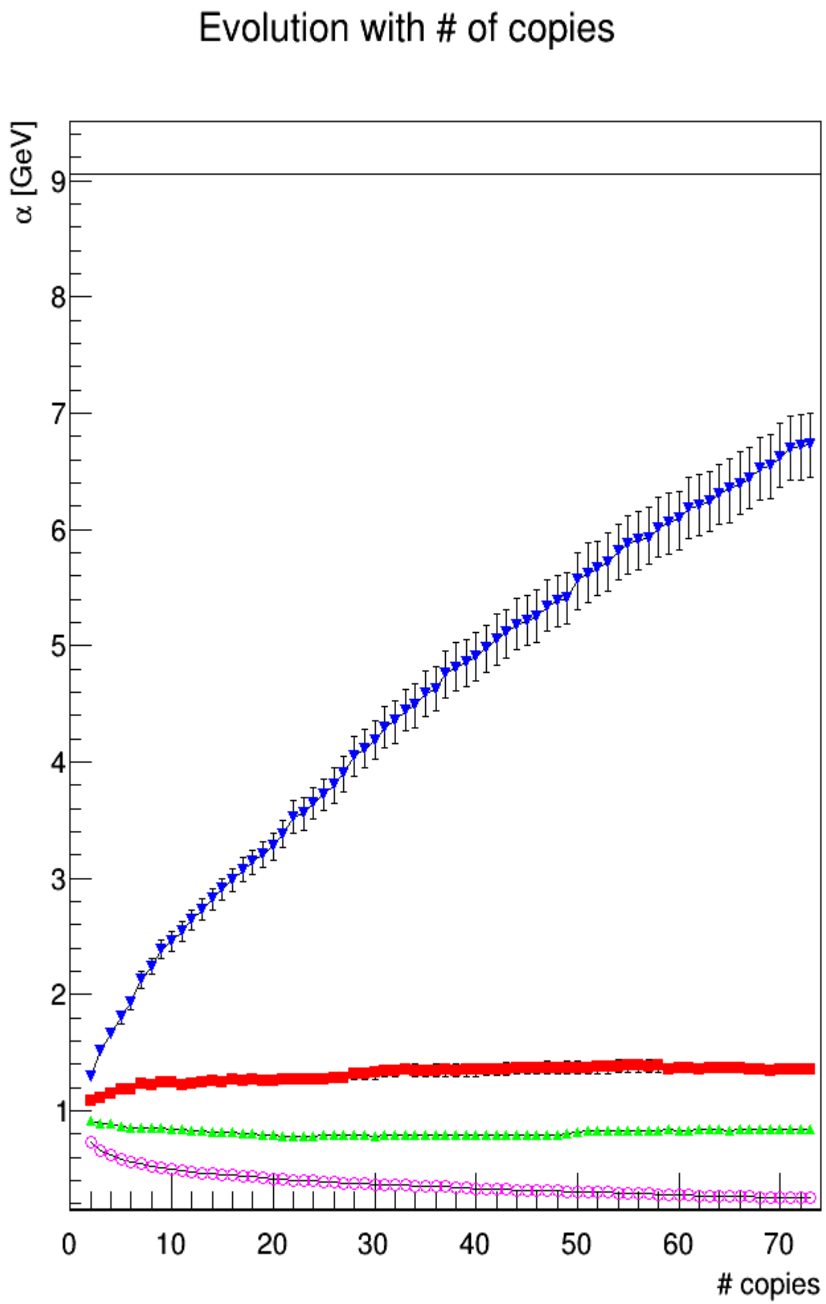

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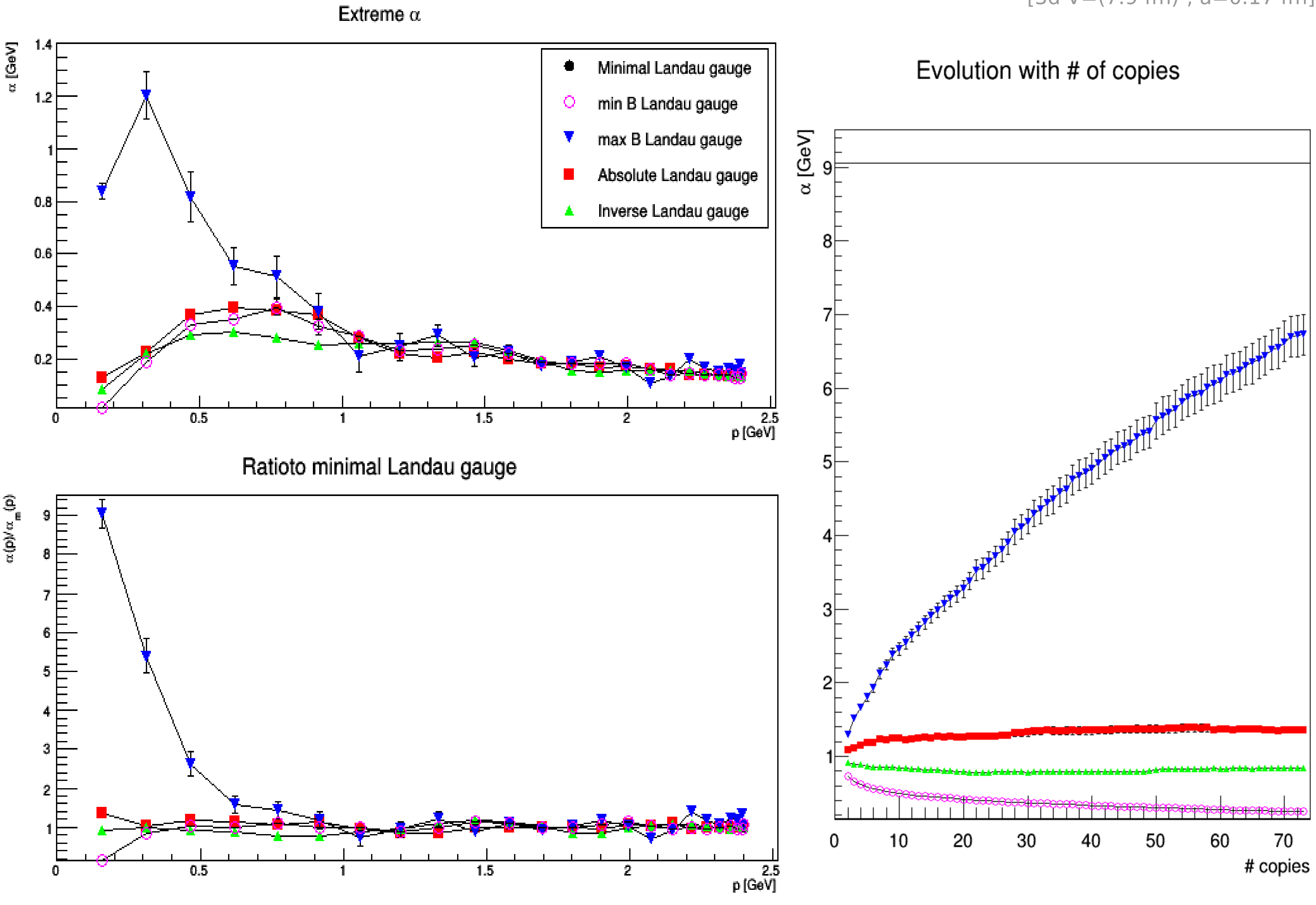

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  - Superconformal theories [Capri et al. PLB 14, Maas & Zitz EPJC 16]
    - No lattice yet, claim of difference/absence

Summary

[Maas PR 13]

- The structure of the residual gauge orbit is complicated due to the Gribov-Singer ambiguity
- Number of gauge copies very large
  - Multiple coordinates required for distinction
- Requires additional gauge conditions
- Influence on correlation functions substantial
  - Especially ghost and ghost-dependent quantities
  - Requires extrapolation in Gribov copies
- Not yet resolved
  - Especially in the continuum

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