Effects of the lowest Dirac modes on the spectrum of ground state mesons

Mario Schröck
Advisor: Christian B. Lang

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Outline

Introduction

The Dirac spectrum

Eigenmode truncated meson correlators

Summary

Discretizing space-time

The free fermionic action in Euclidean space is given by

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discretize fermionic action:

- replace integral over continuous x by sum over discrete n
- replace derivative by finite difference

$$S_F^0[\psi,\overline{\psi}] = \sum_{n\in\Lambda} \overline{\psi}(n)\left(\sum_{\mu=1}^{4} \gamma_\mu \frac{\psi(n+\hat{\mu}) - \psi(n-\hat{\mu})}{2} + m\psi(n)\right)$$

Gauge fields

- We require the discrete fermionic action to be invariant under local gauge transformations

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The Lattice Dirac operator

Then the discrete fermionic action including gluons is

$$S_F[\psi, \overline{\psi}, U] = \sum_{n\in\Lambda} \overline{\psi}(n) \left(\sum_{\mu=1}^{4} \gamma_\mu \frac{U_\mu(n)\psi(n+\hat{\mu}) - U^\dagger_\mu(n-\hat{\mu})\psi(n-\hat{\mu})}{2} + m\psi(n) \right)$$

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with the *naive* Dirac operator

$$D[U](n,m) = \frac{1}{2}\sum_{\mu=1}^{4}\left[\gamma_\mu U_\mu(n)\delta_{n,m-\hat{\mu}}-\gamma_\mu U^\dagger_\mu(n-\hat{\mu})\delta_{n,m+\hat{\mu}}\right]+m\delta_{nm}$$

Correlators in Lattice QCD

Consider the correlator of an arbitrary operator, e.g., a meson $O(n) = \overline{\psi}_d(n)\Gamma\psi_u(n)$:

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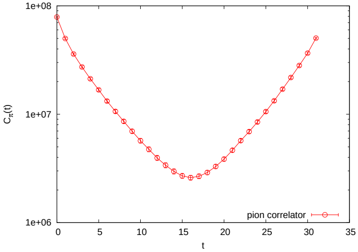

Why Dirac eigenmodes?

The Banks-Casher relation

$$\langle \overline{\psi}\psi \rangle \propto \rho(0)$$

relates the density of the Dirac modes near the origin $\rho(0)$ to the chiral condensate.

Properties of D

- the Dirac operator is (except for GW-type operators) non-normal $[D, D^\dagger] \neq 0$
- i.e. left and right eigenvectors differ

$$\langle L_i | \, D = \lambda_i \, \langle L_i | \, , \quad D \, | R_i \rangle = \lambda_i \, | R_i \rangle \, , \quad i = 1, \ldots, N$$

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$$S \equiv D^{-1} = \sum_{i=1}^{N} \lambda_i^{-1} |R_i\rangle \langle L_i|$$

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which can be obtained by

$$S_{\mathrm{trunc}(k)} = S - S_{\mathrm{LM}(k)}$$

where S is the full propagator and $S_{\mathrm{LM}(k)}$ only contains the lowest modes

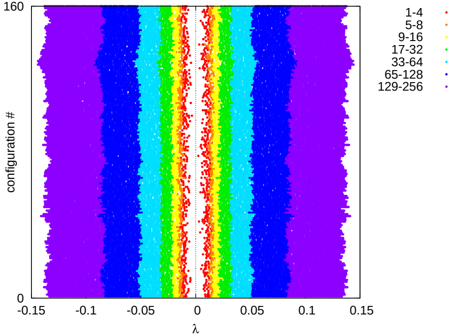
$$S_{\mathrm{LM}(k)} = \sum_{i\leq k} \lambda_i^{-1} \left| R_i \right\rangle \left\langle L_i \right|$$

The Setup

- 161 configurations [Gattringer, Hagen, Lang, Limmer, Mohler, Schäfer, Phys. Rev. D 79, 2009]
- size $16^3 \times 32$
- two degenerate flavors of light fermions, $m_\pi = 322(5)\,\mathrm{MeV}$
- lattice spacing $a = 0.1440(12)\,\mathrm{fm}$
- Chirally Improved Dirac operator [Gattringer, Phys. Rev. D 63, 2001] (approximate solution of the Ginsparg-Wilson equation)
- Jacobi smeared quark sources

Eigenvalues

D_5



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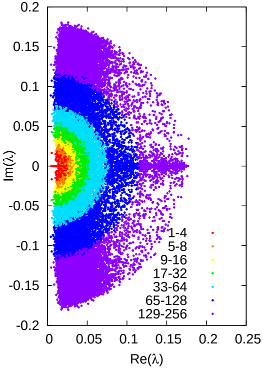
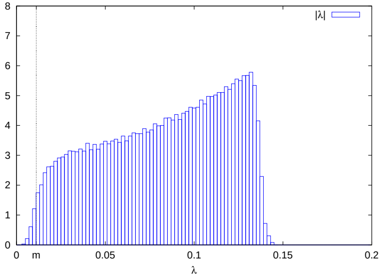


Histograms

D_5



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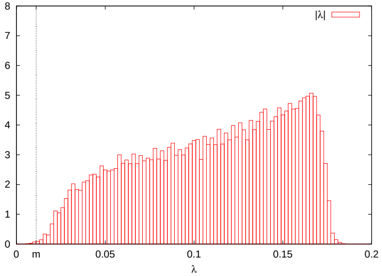

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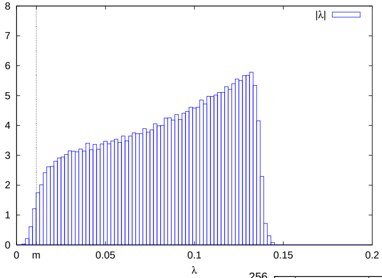

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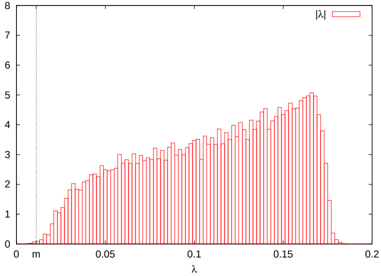

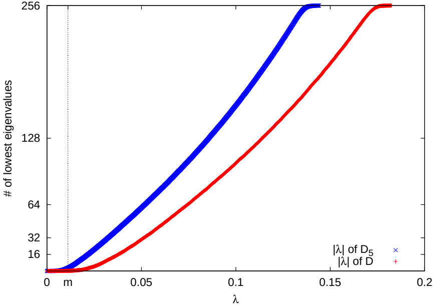

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Chiral symmetry and light mesons

Two dynamical flavors of quarks (neglect mass), underlying symmetry group is

$$SU(2)_L \times SU(2)_R \times U(1)_A$$

whereas the chiral symmetry $SU(2)_L \times SU(2)_R$ is broken spontaneously in the vacuum and the $U(1)$ axial symmetry is broken explicitly in the quantized theory (axial anomaly).

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We will explore following particles which would be connected via the above symmetries [L.Ya. Glozman, Physics Reports, Volume 444, 2007]

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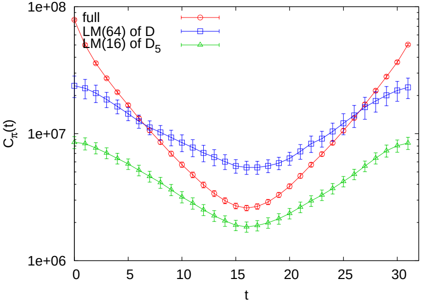
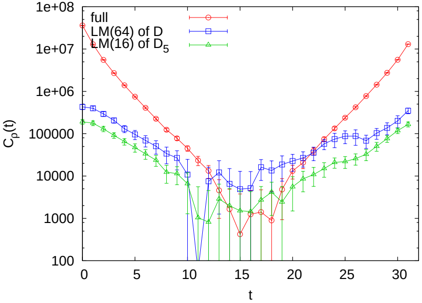
	$\pi \longleftrightarrow f_0$
	$a_0 \longleftrightarrow \eta$

Low-mode contribution of D and D_5 to the π and ρ correlators





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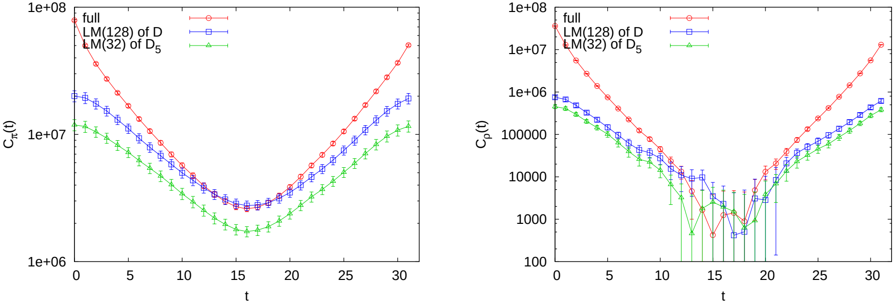

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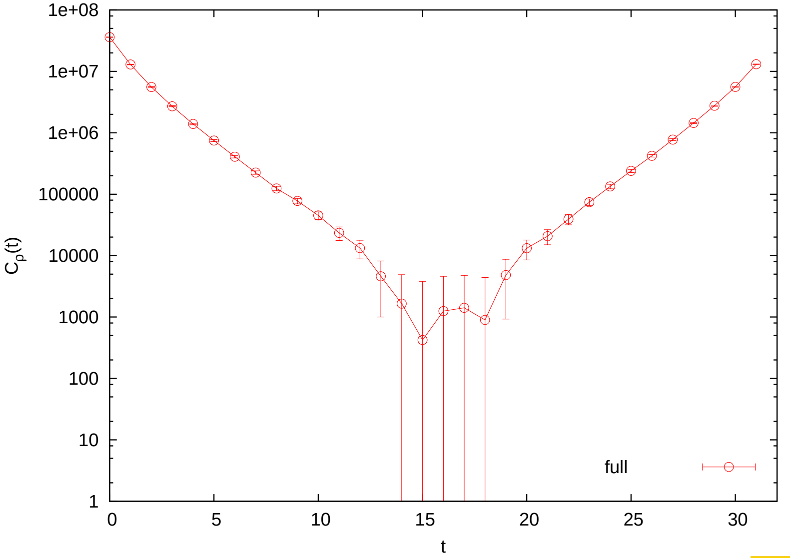

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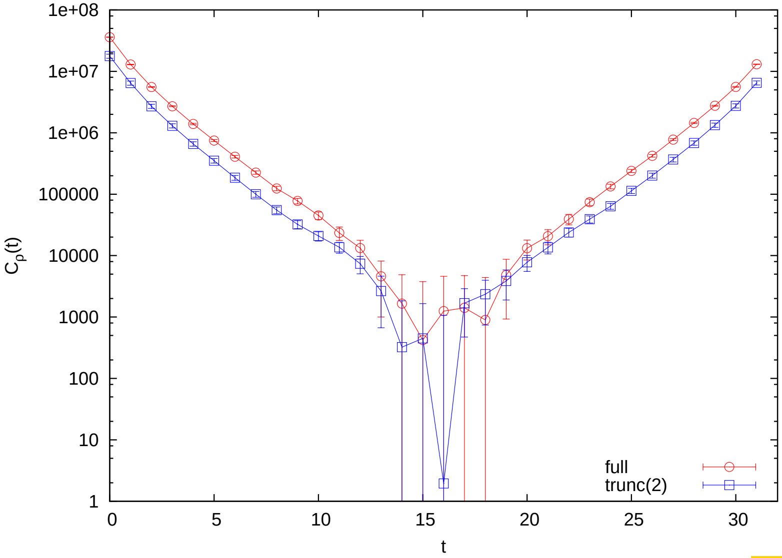

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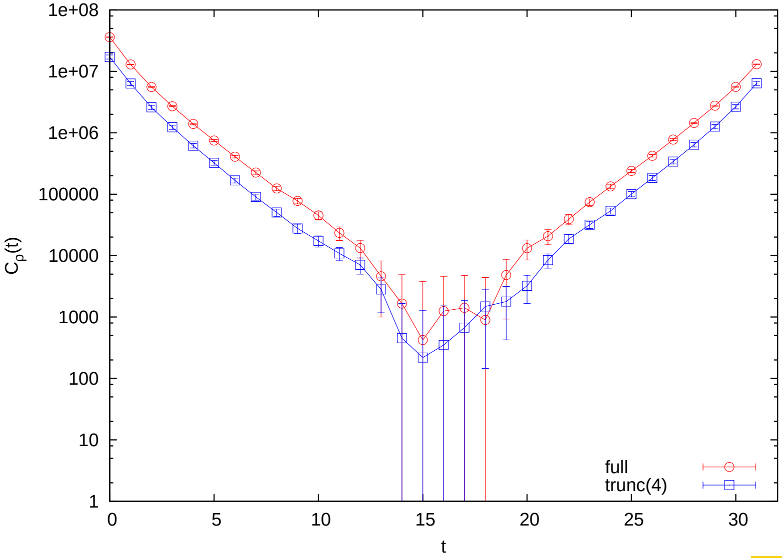

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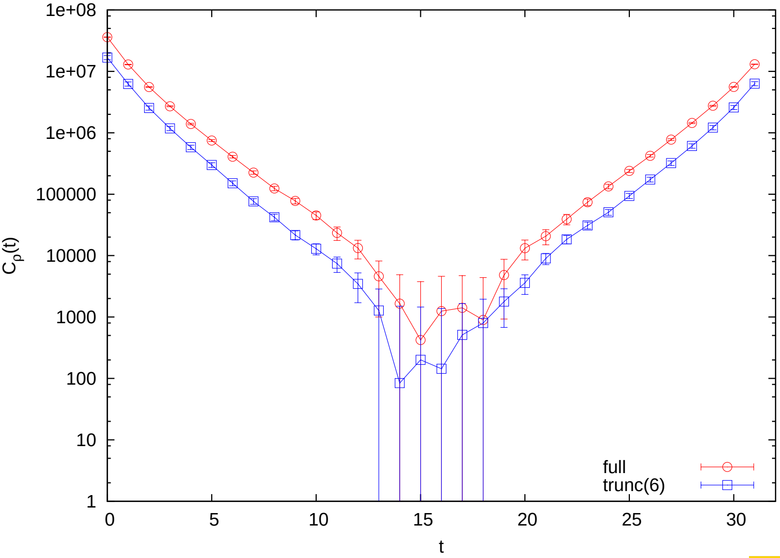

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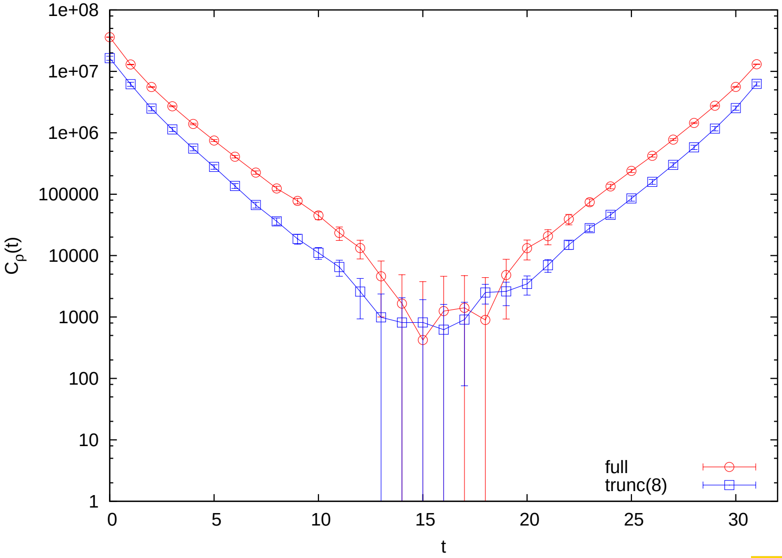

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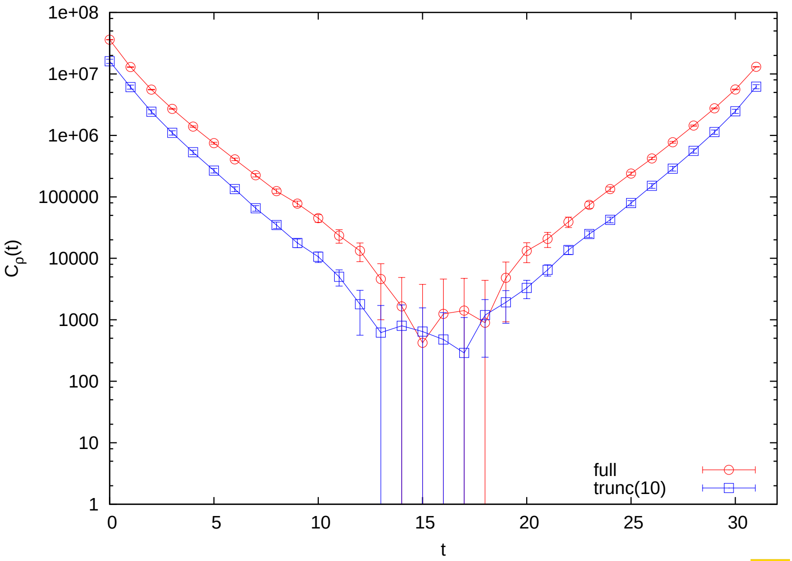

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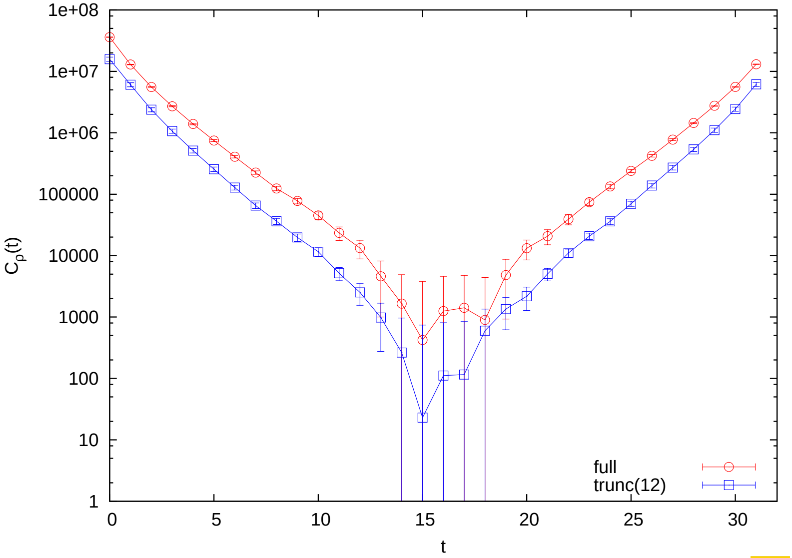

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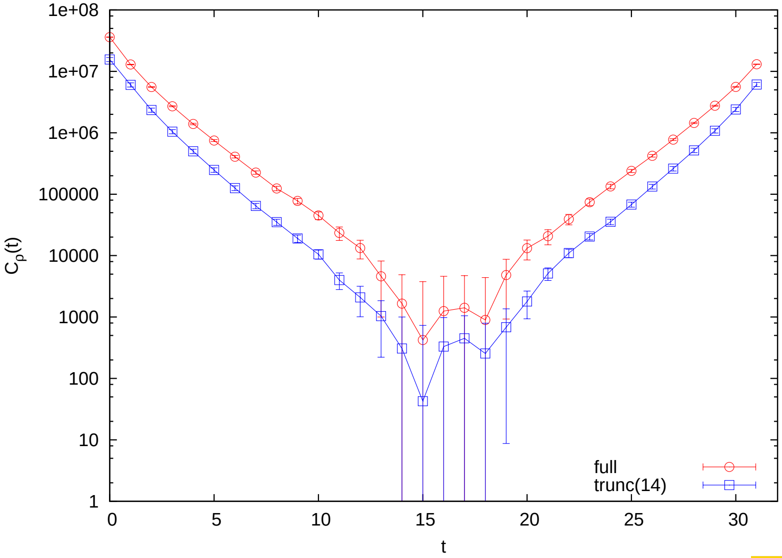

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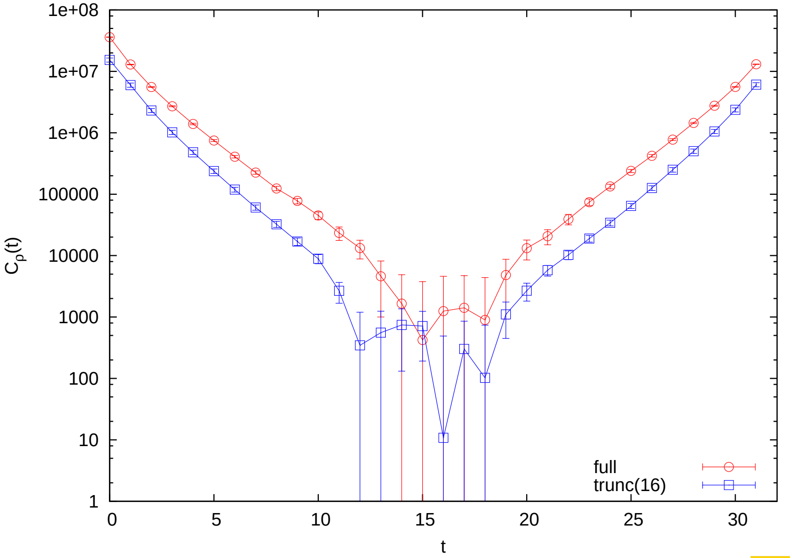

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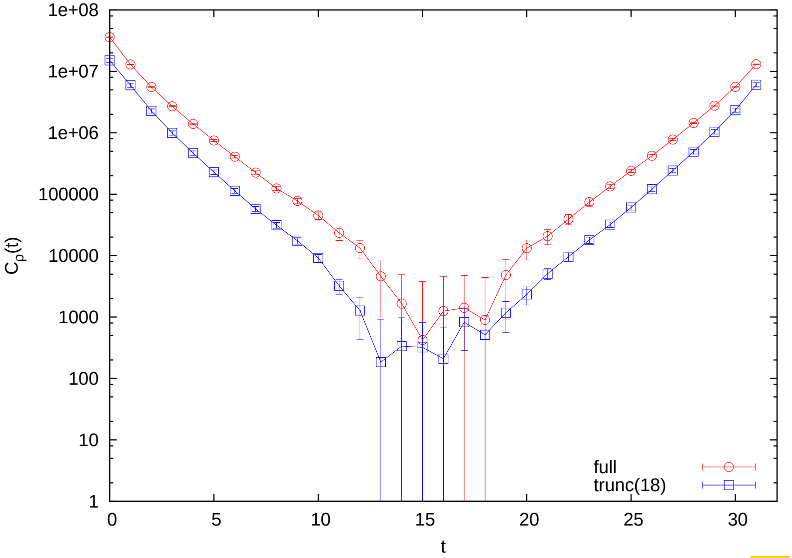

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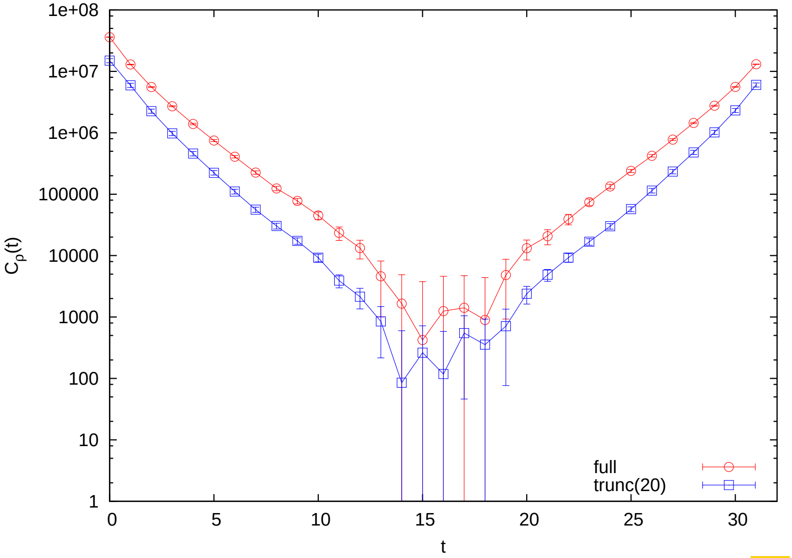

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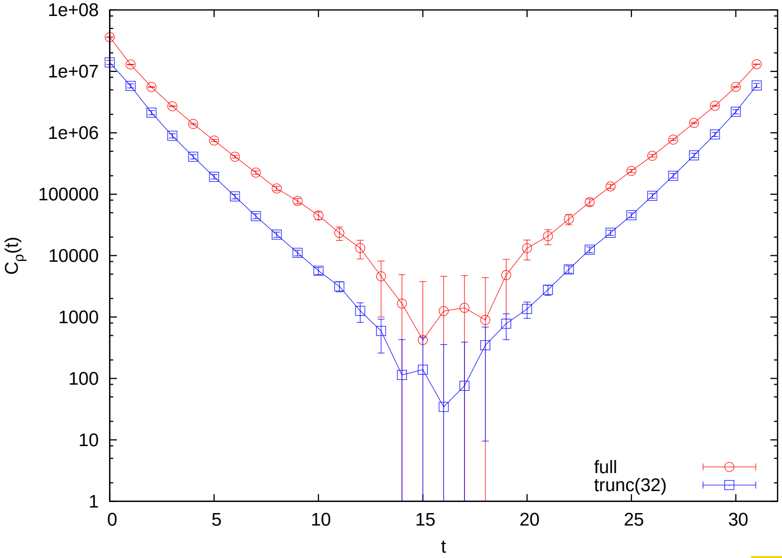

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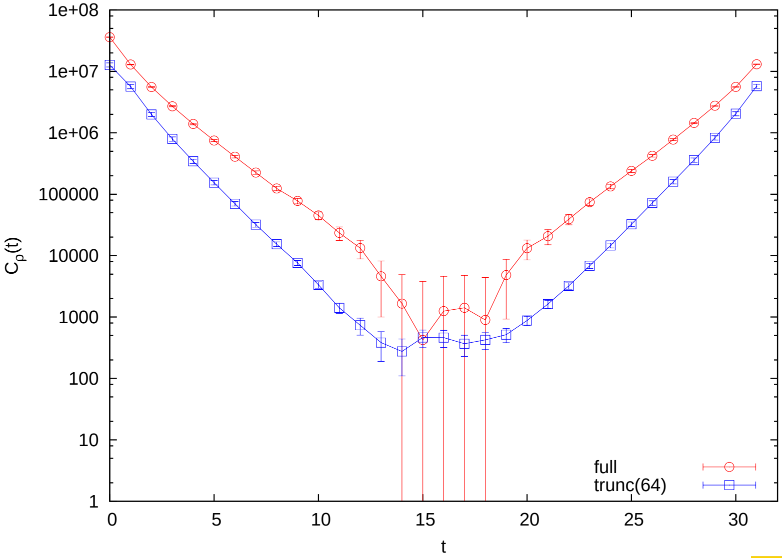

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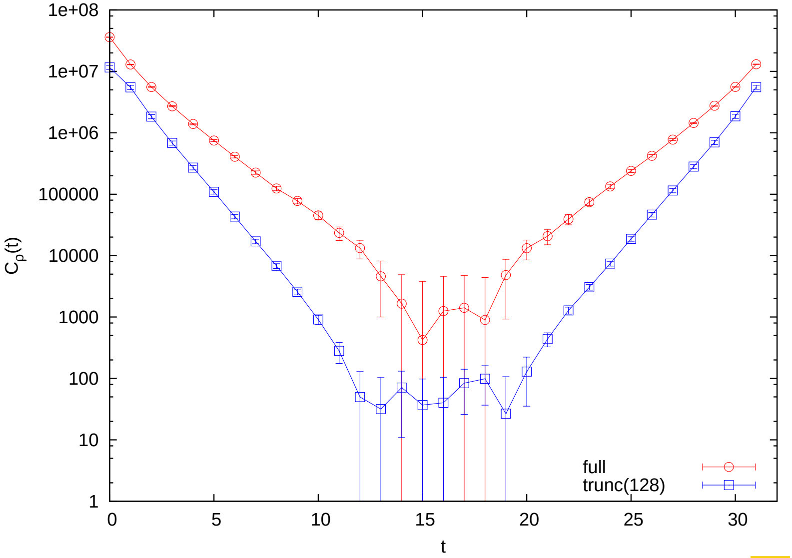

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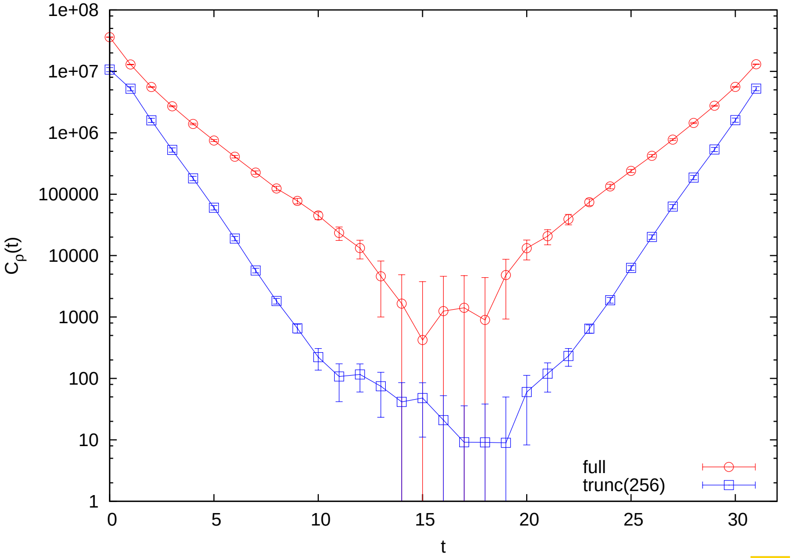

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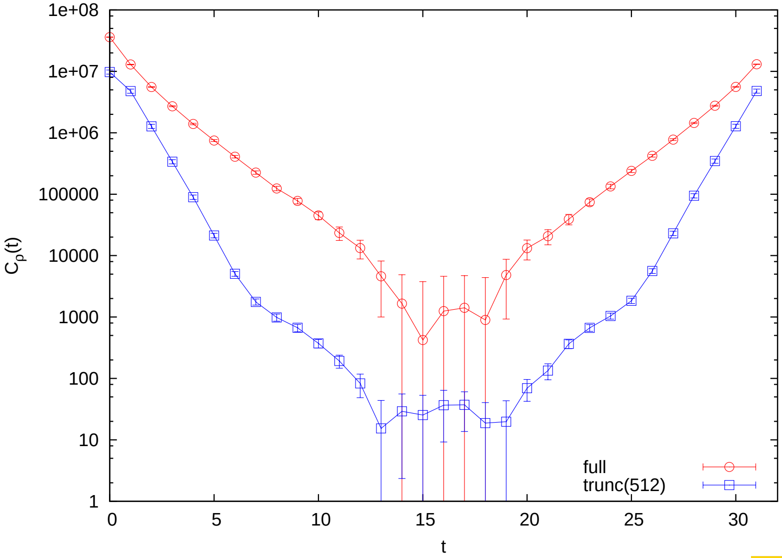

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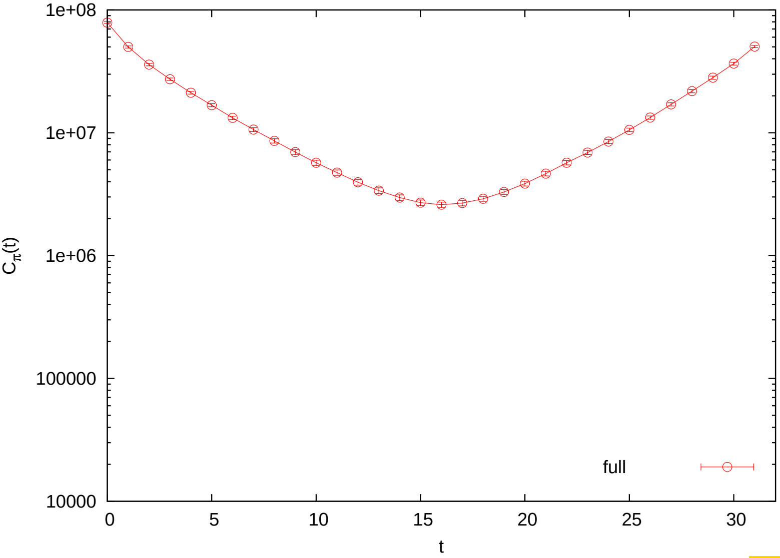

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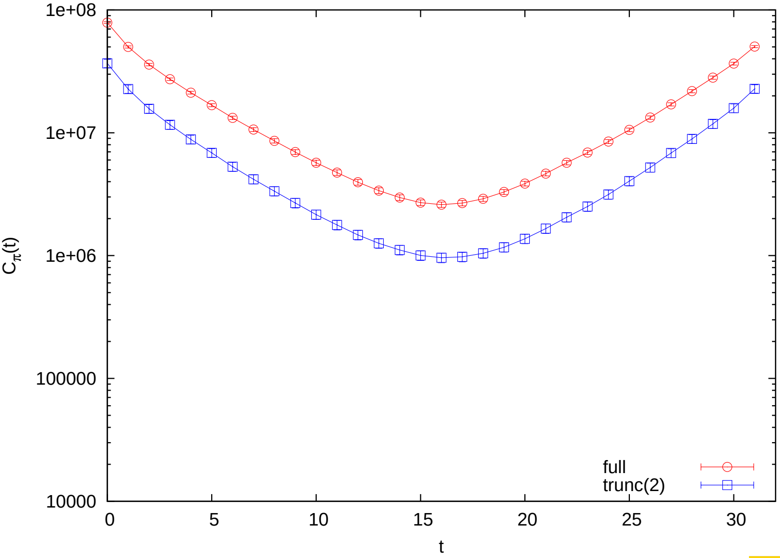

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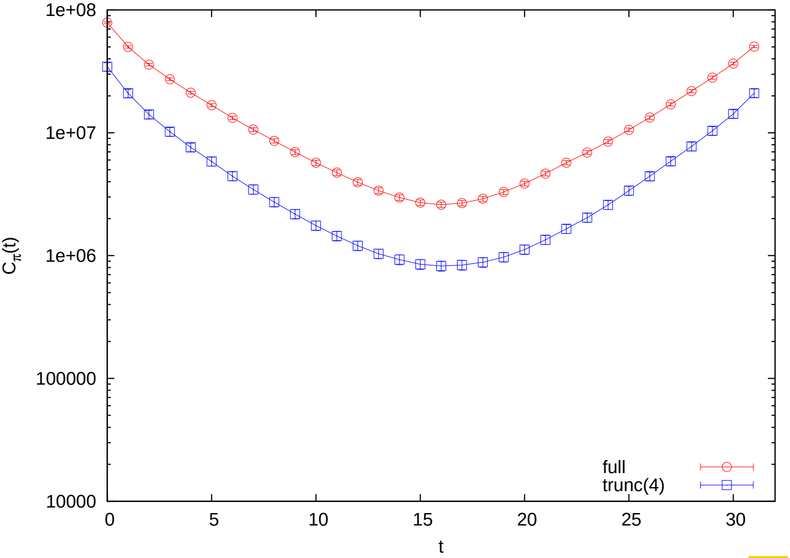

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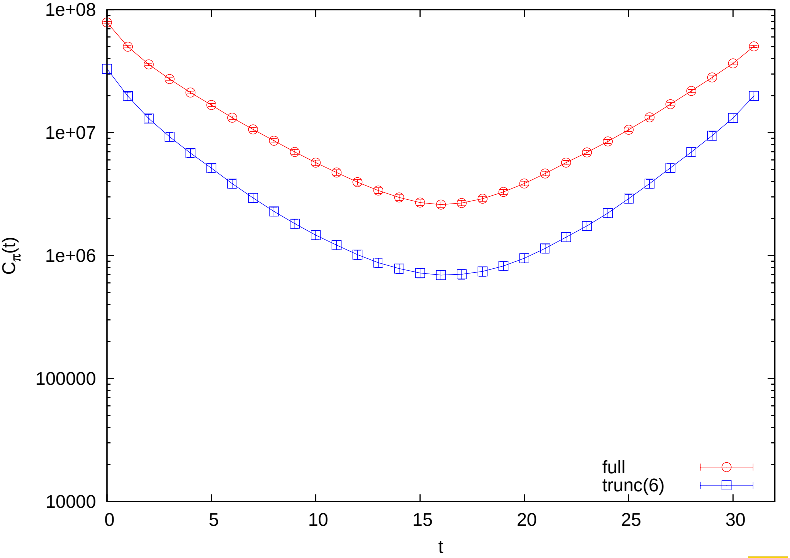

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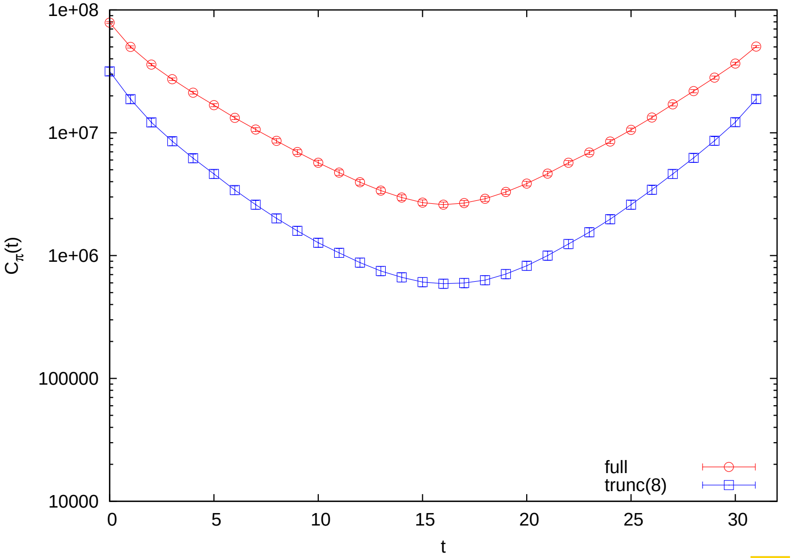

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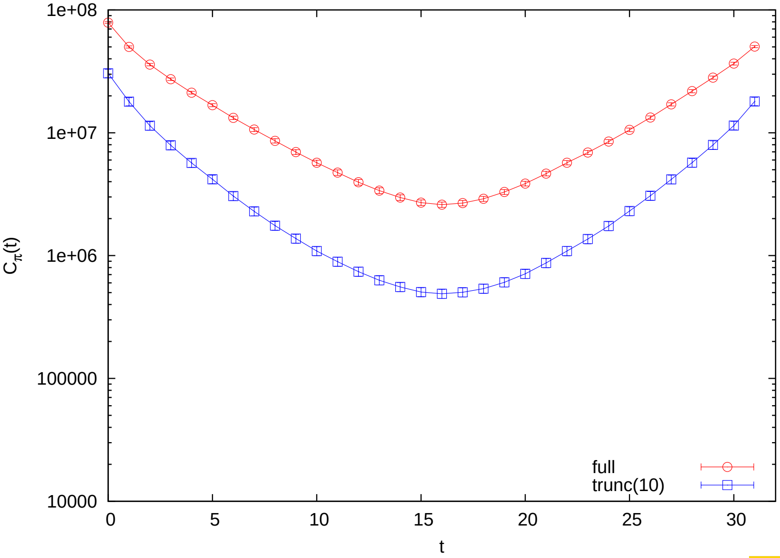

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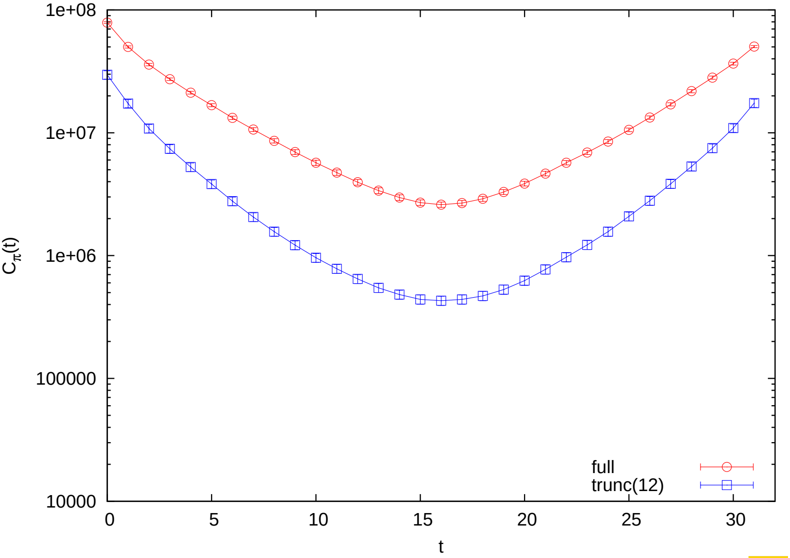

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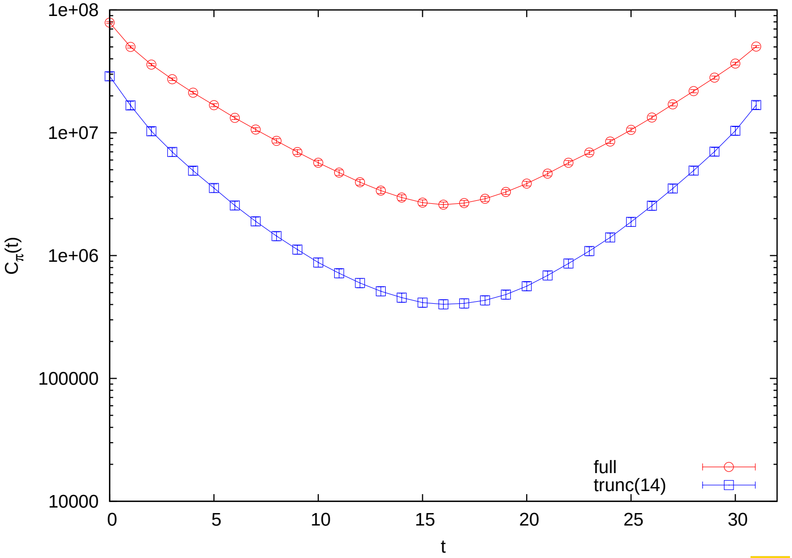

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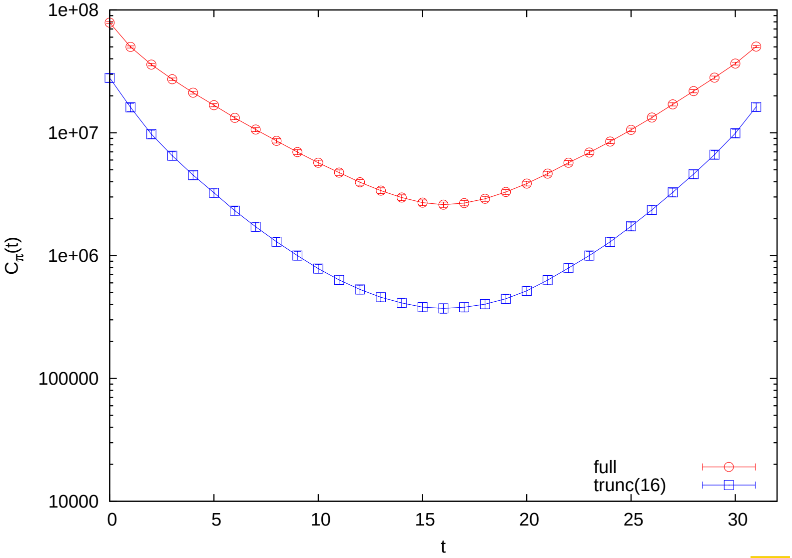

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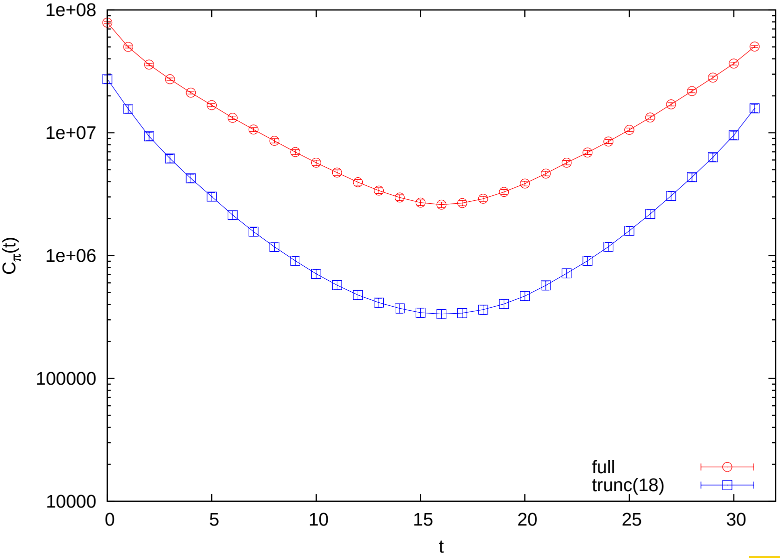

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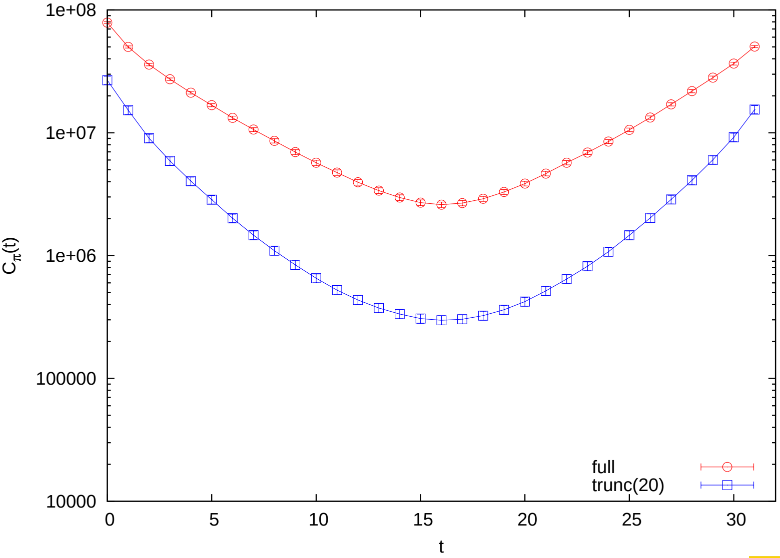

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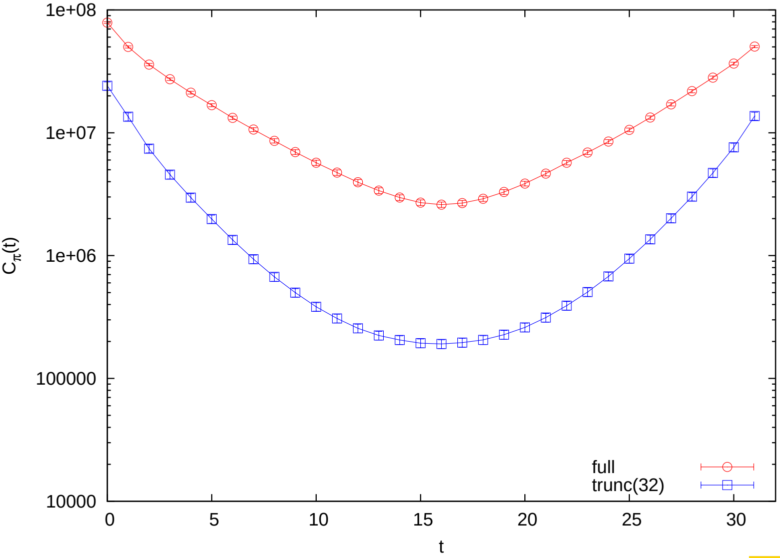

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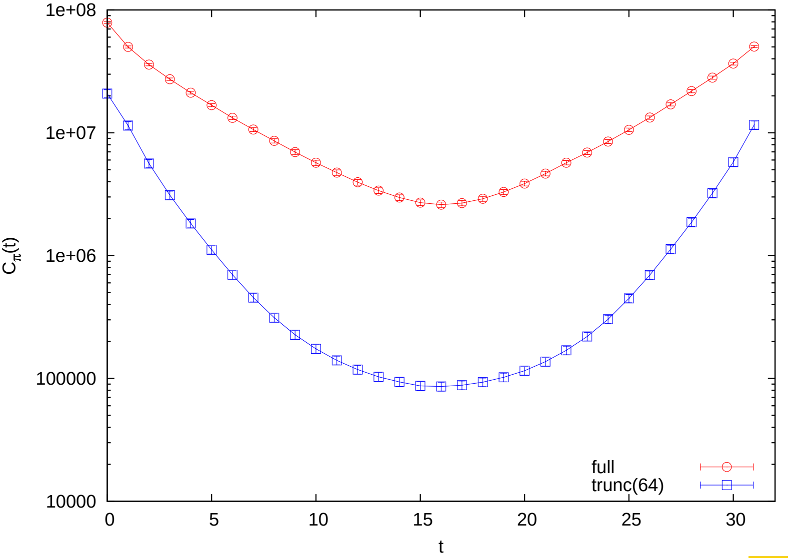

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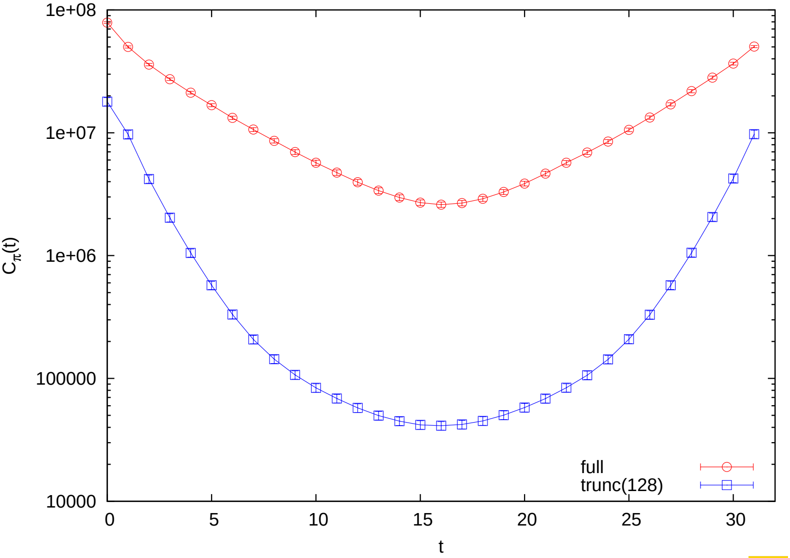

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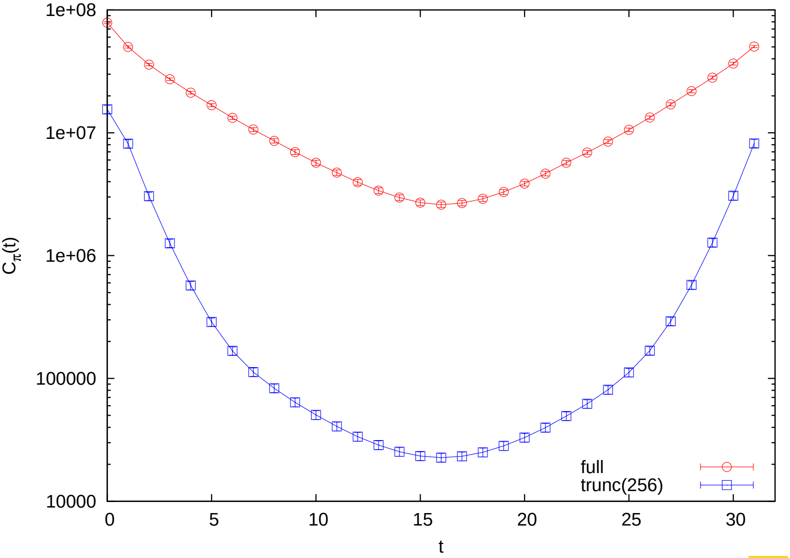

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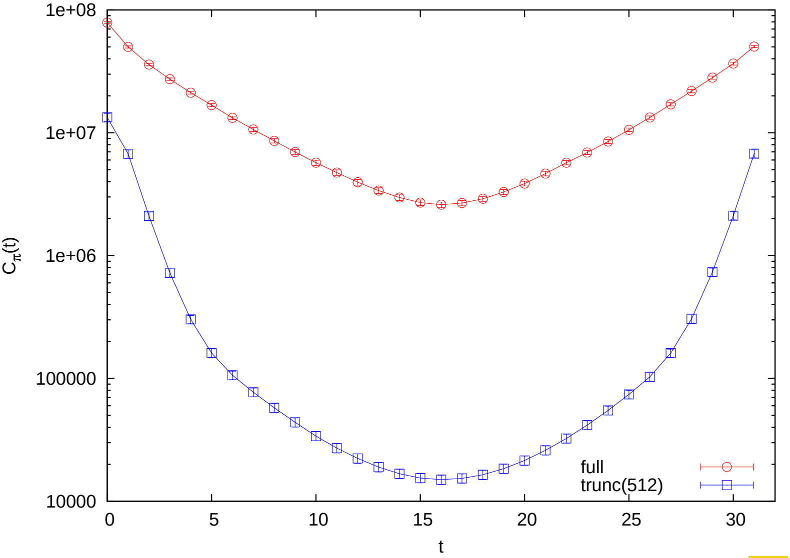

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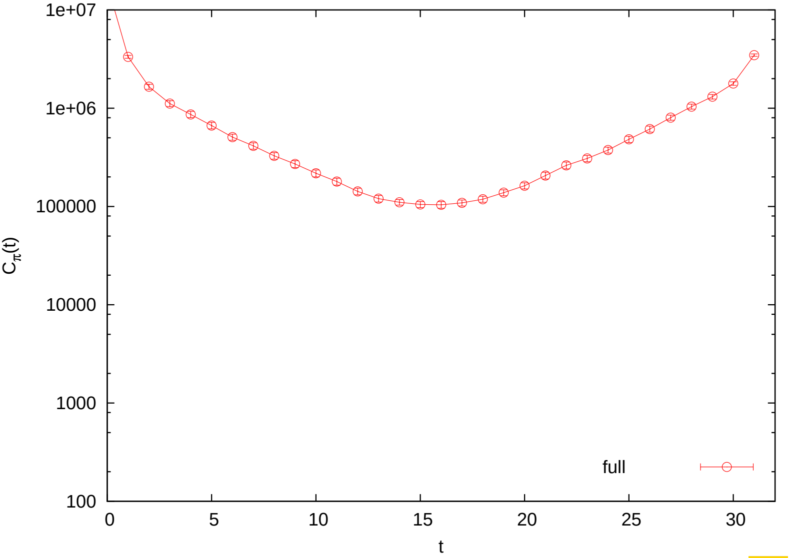

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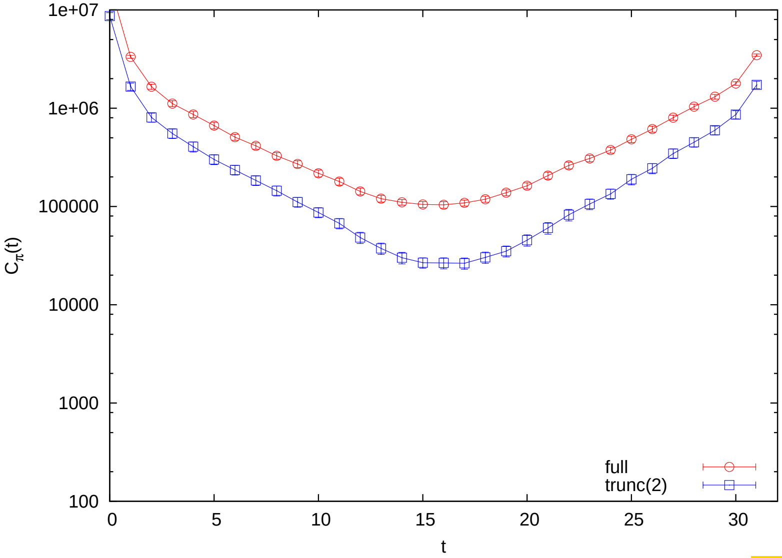

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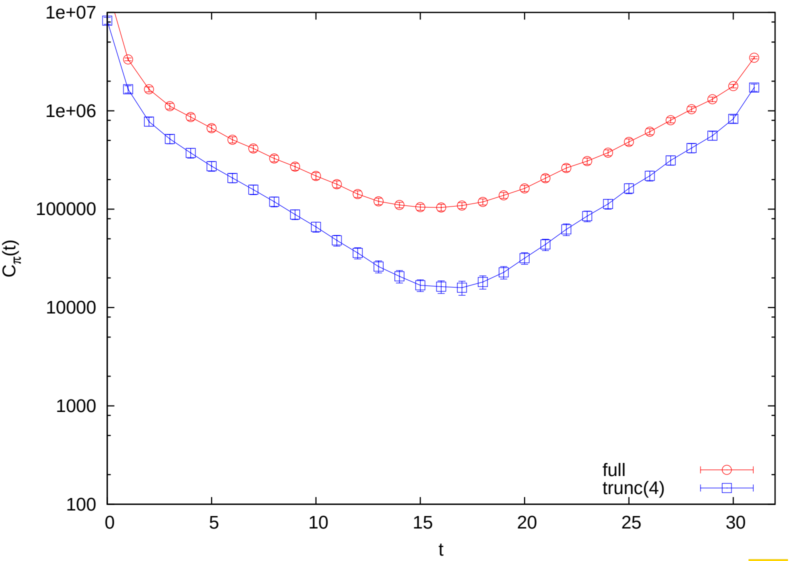

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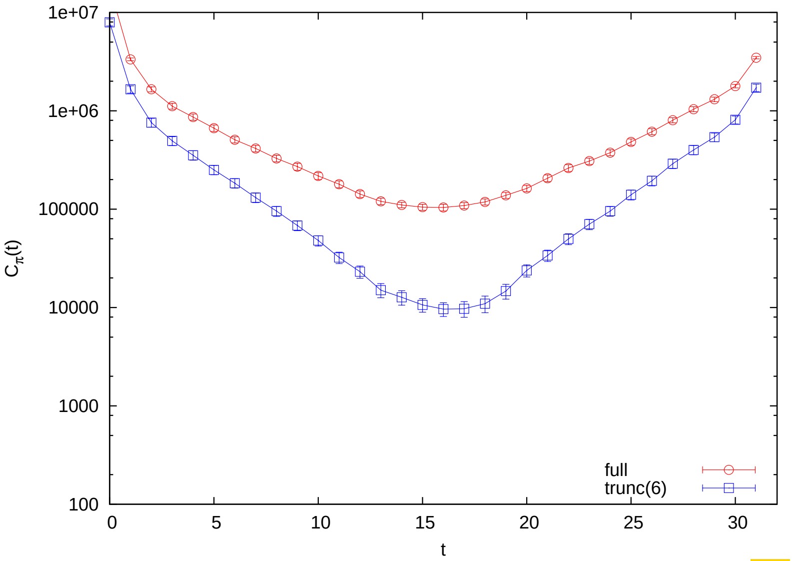

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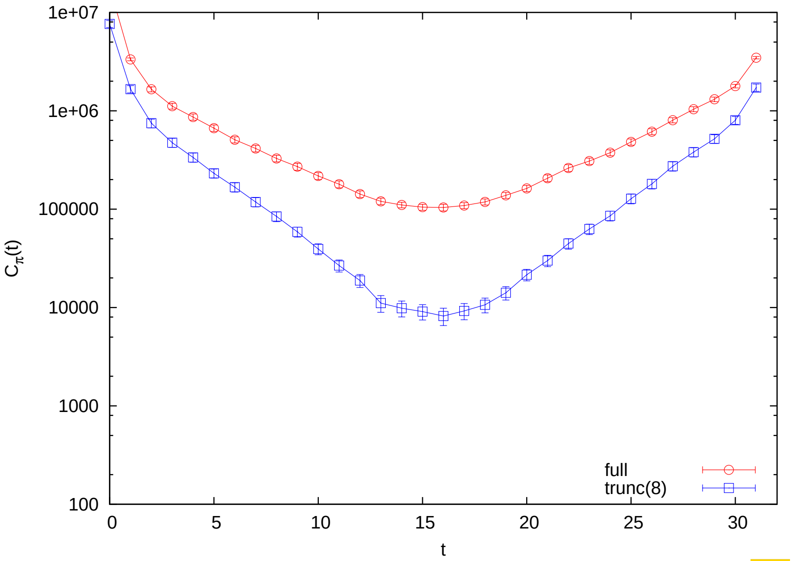

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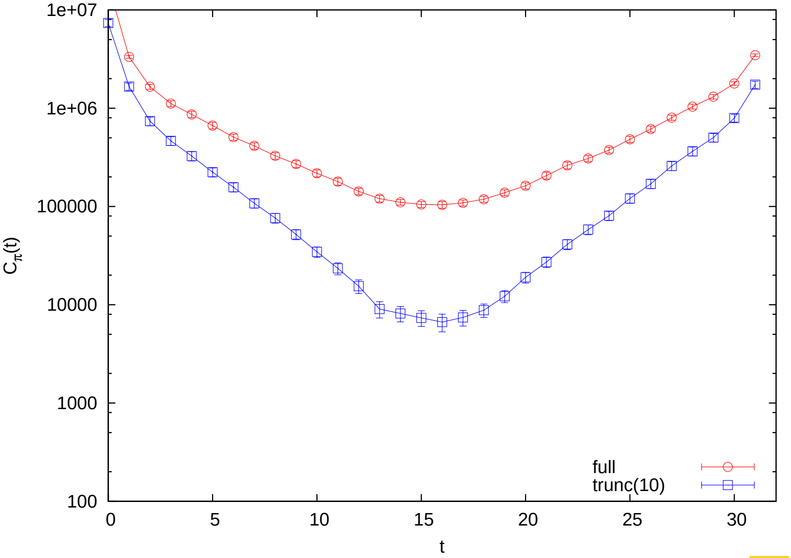

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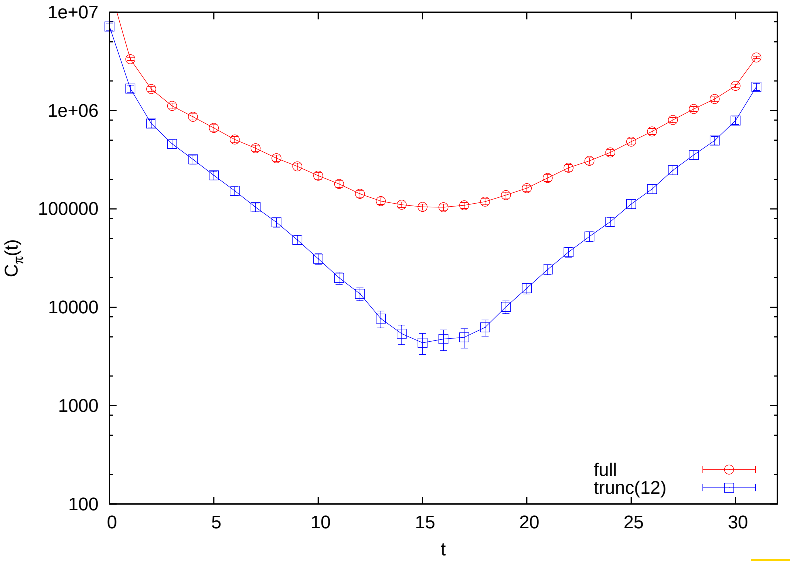

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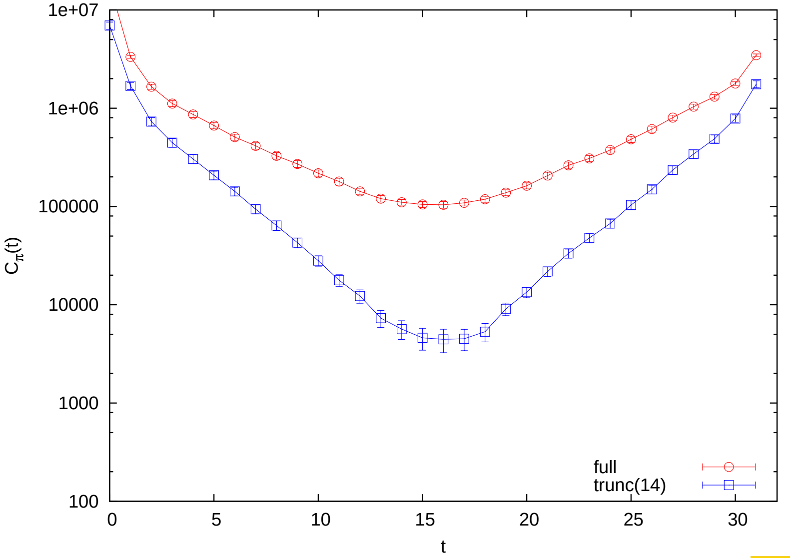

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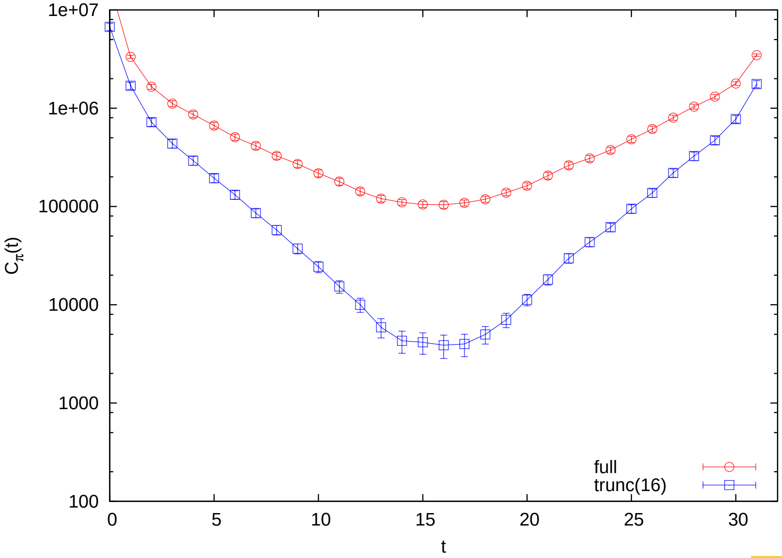

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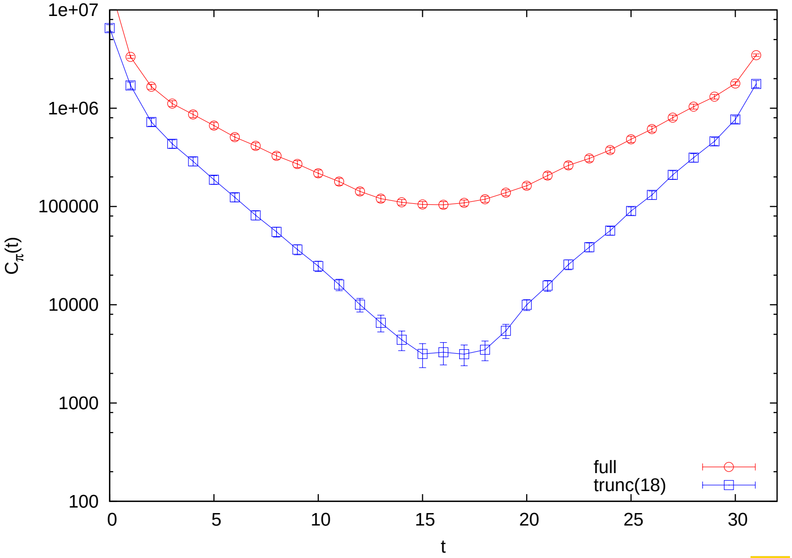

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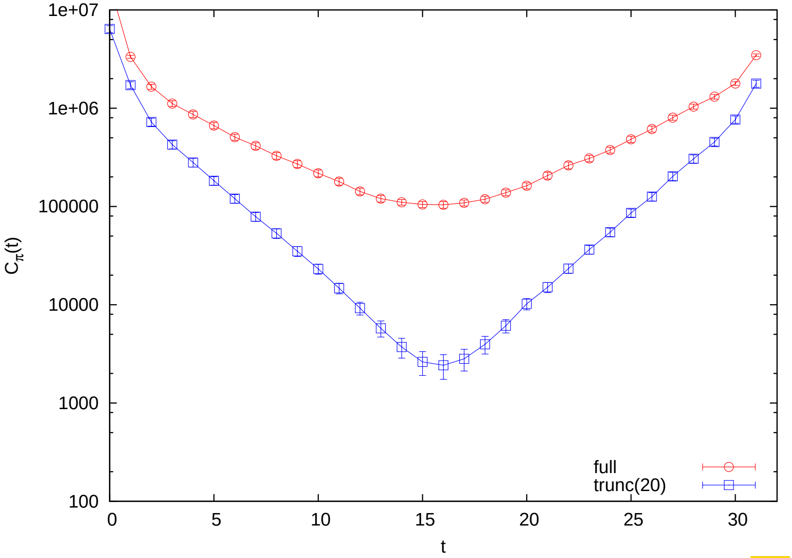

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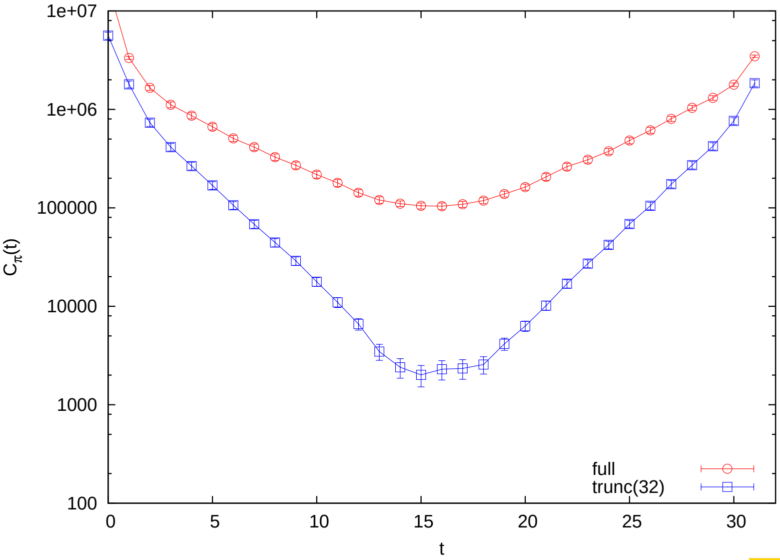

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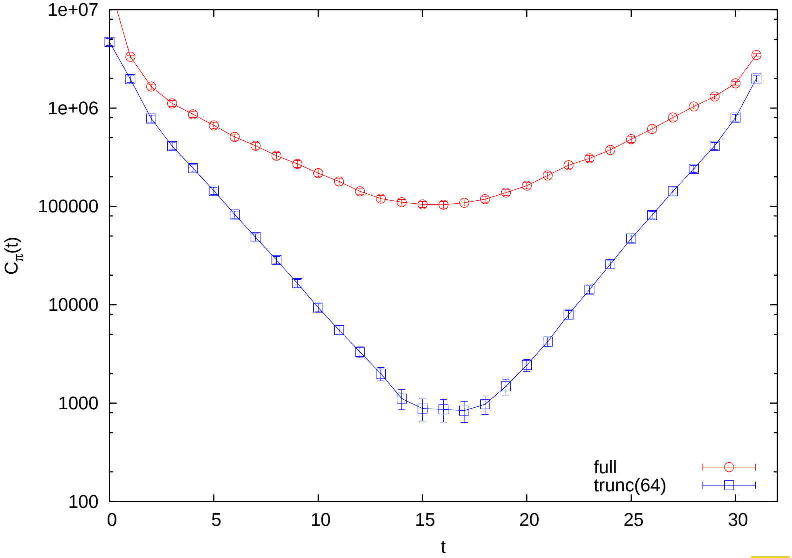

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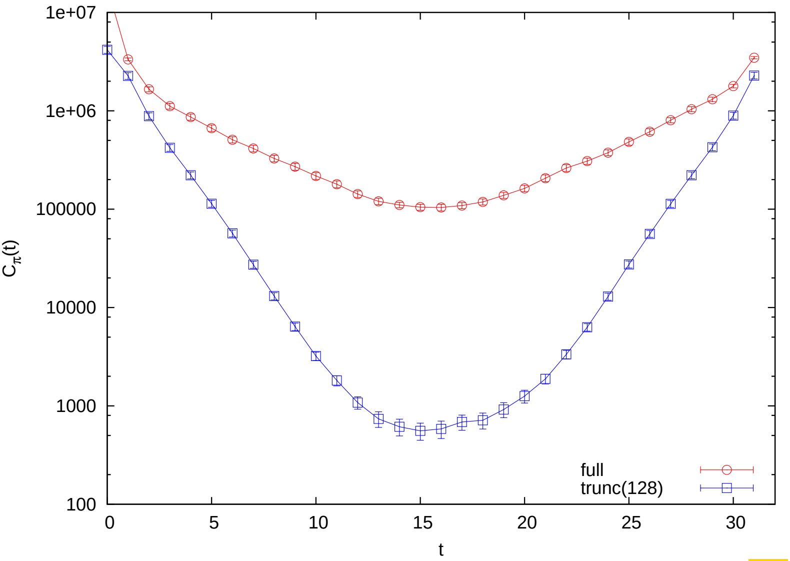

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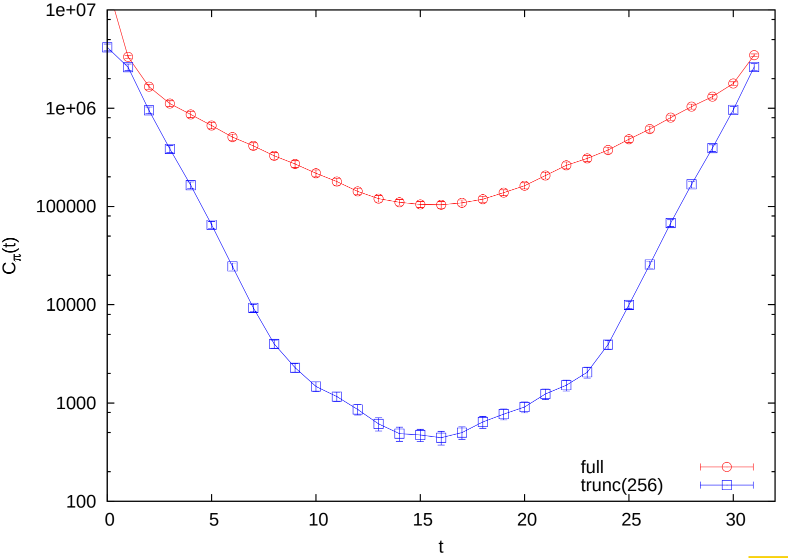

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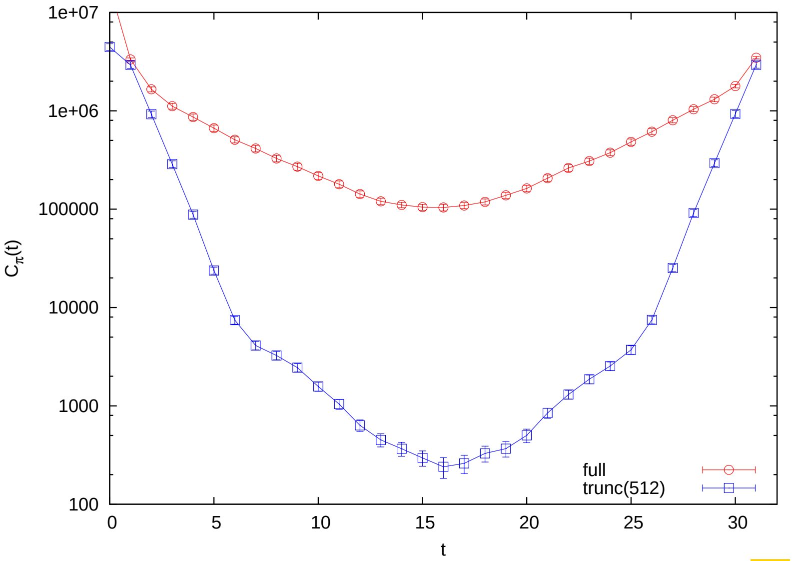
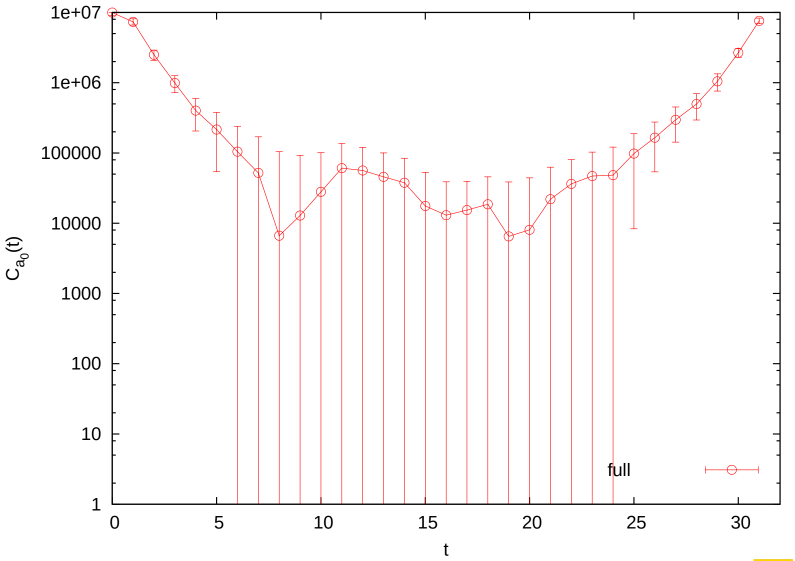


a_0, $J^{PC} = 0^{++}$, $\overline{u}d$



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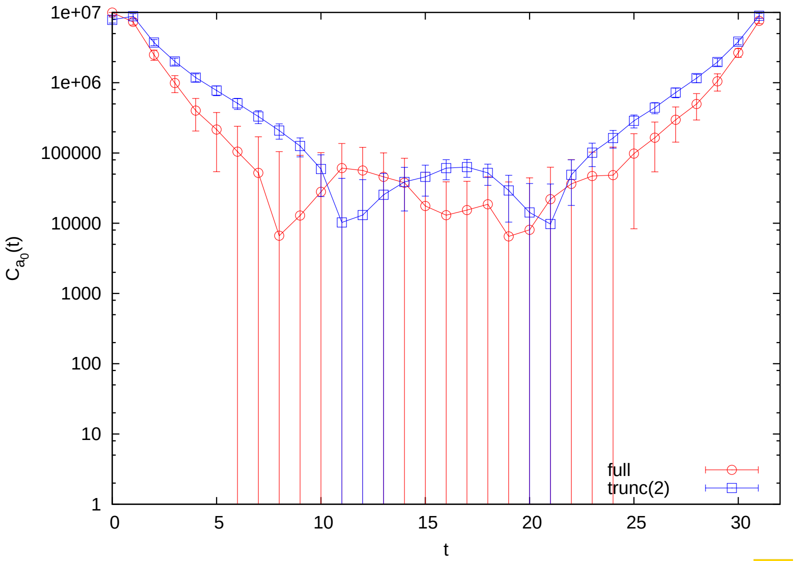

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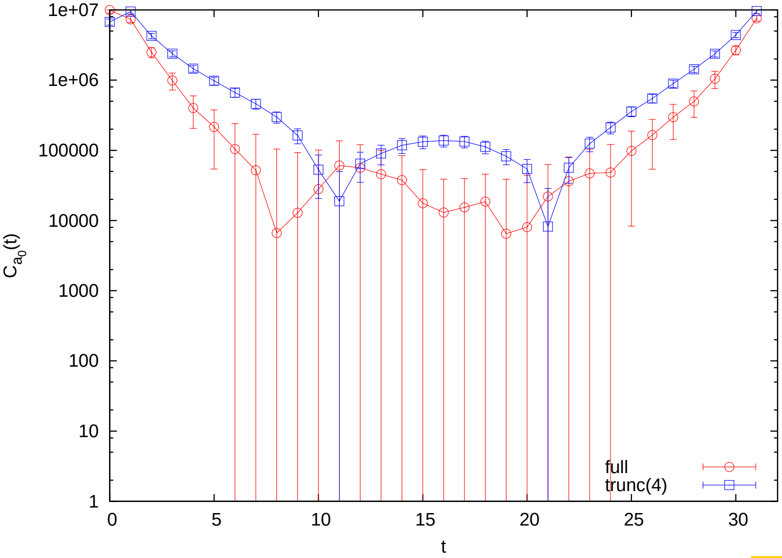

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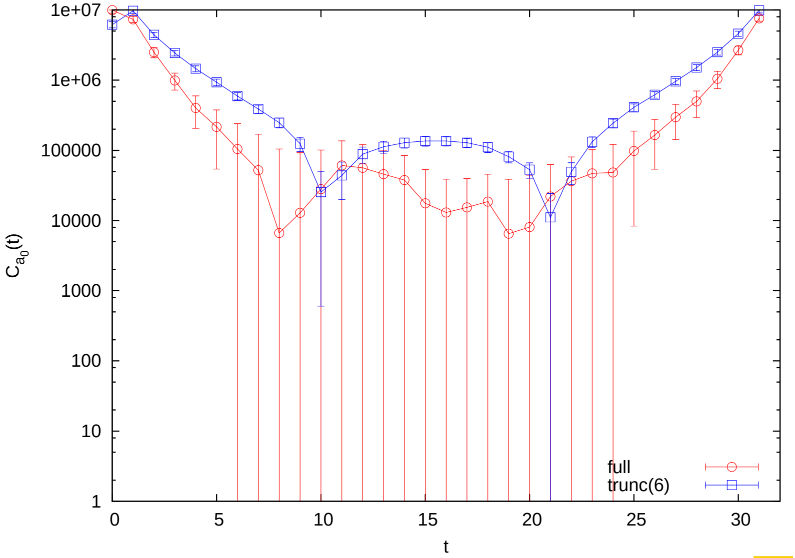

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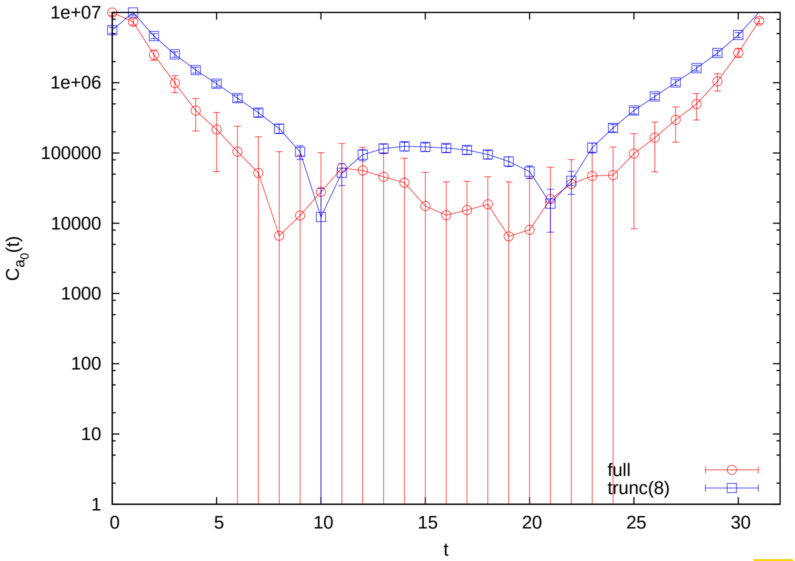

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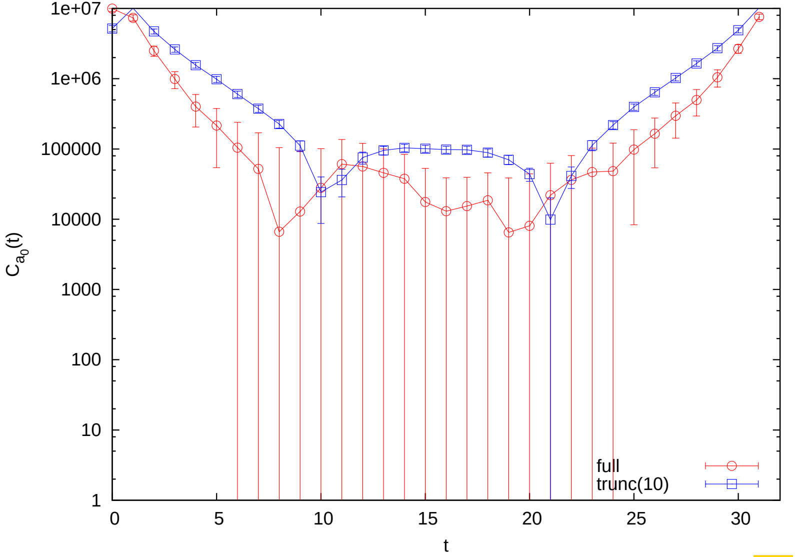

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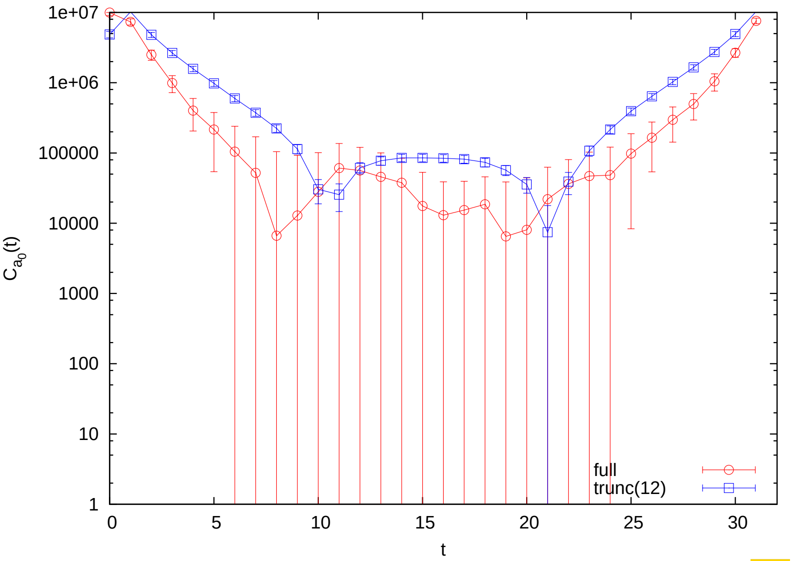

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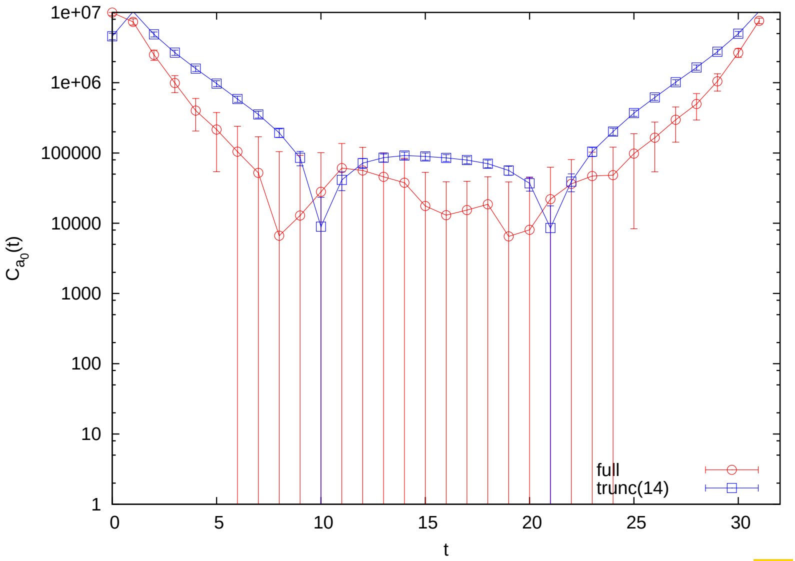

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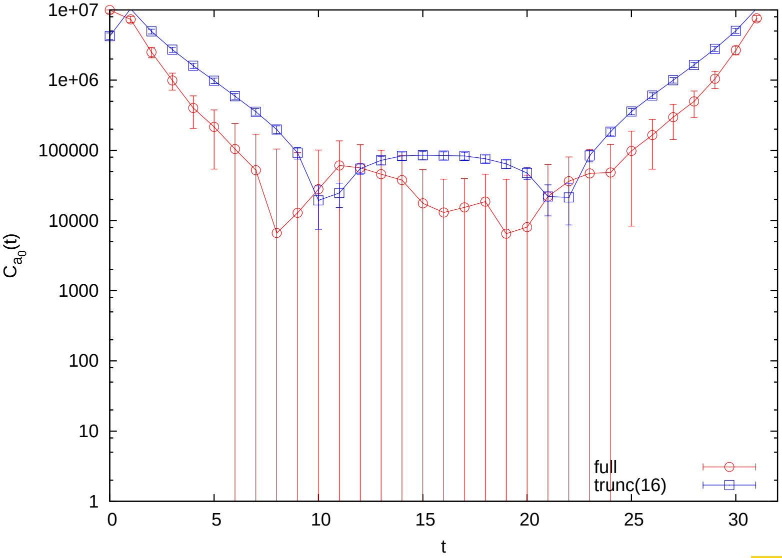

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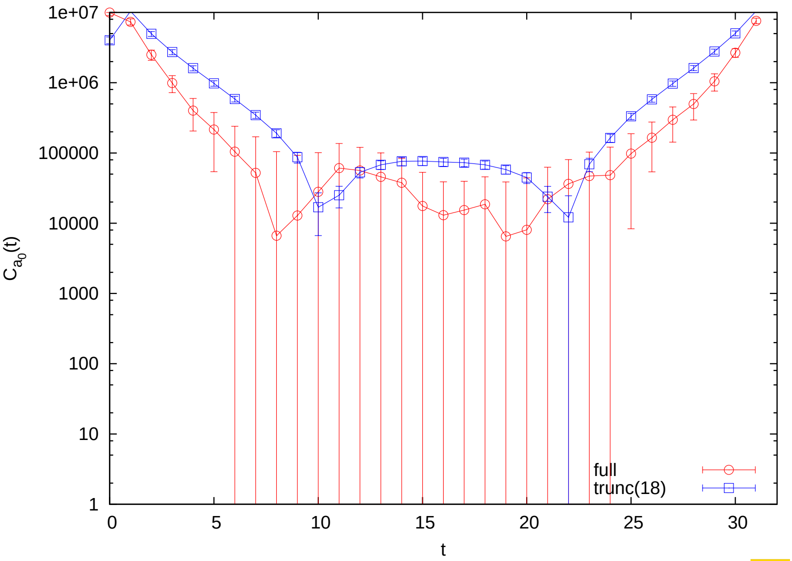

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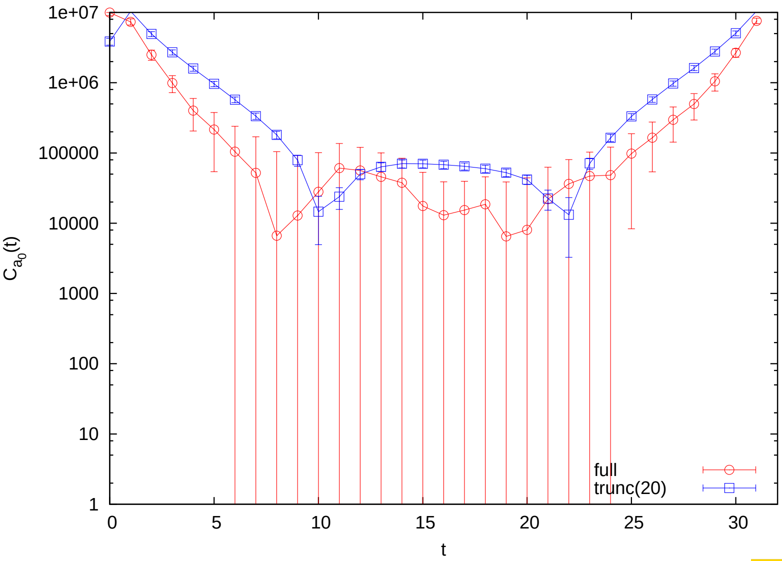

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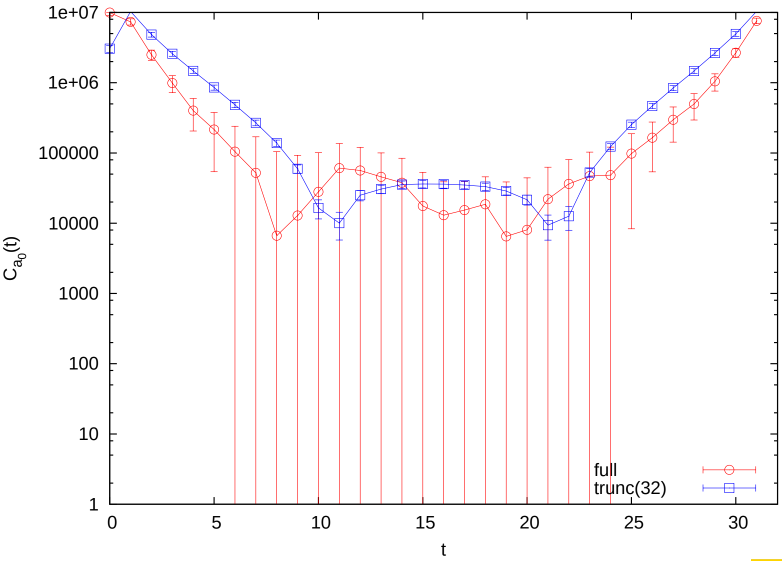

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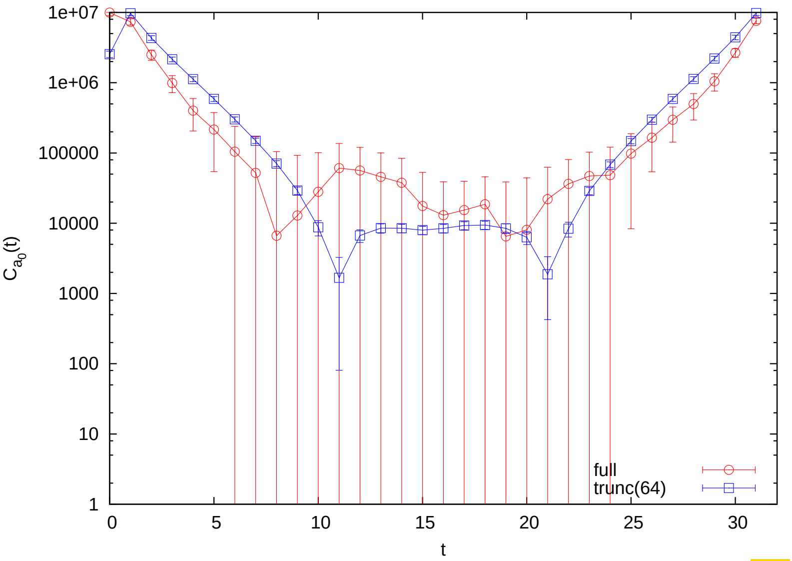

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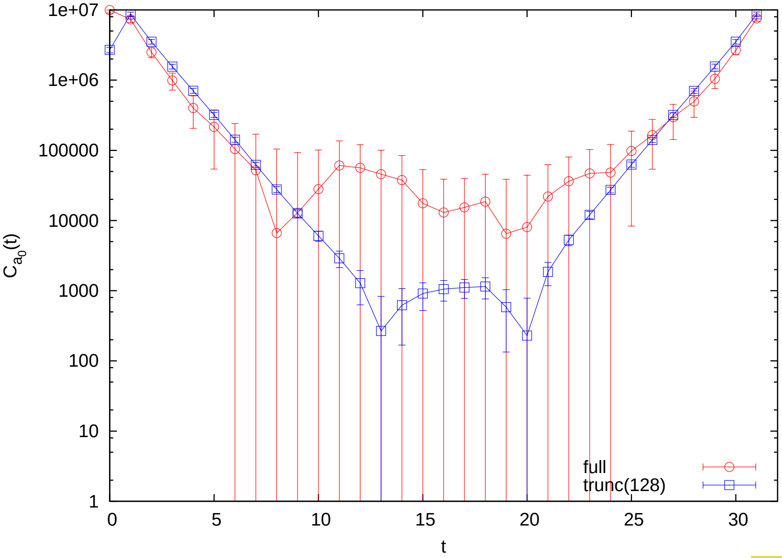

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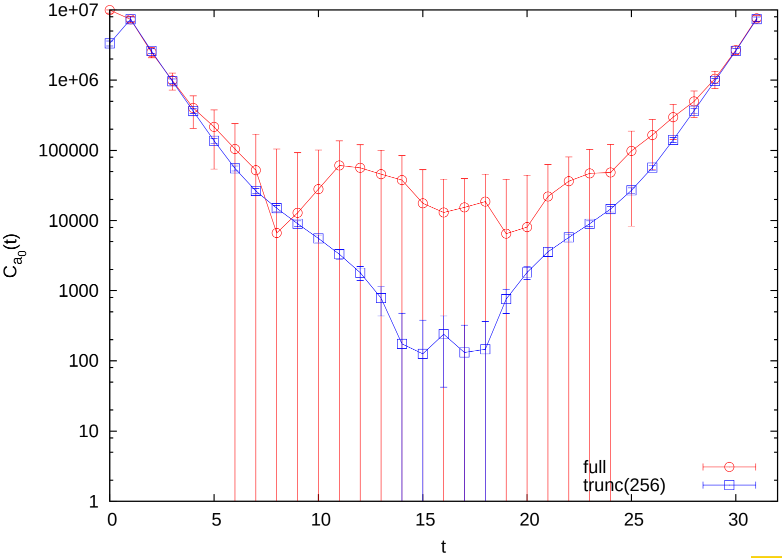

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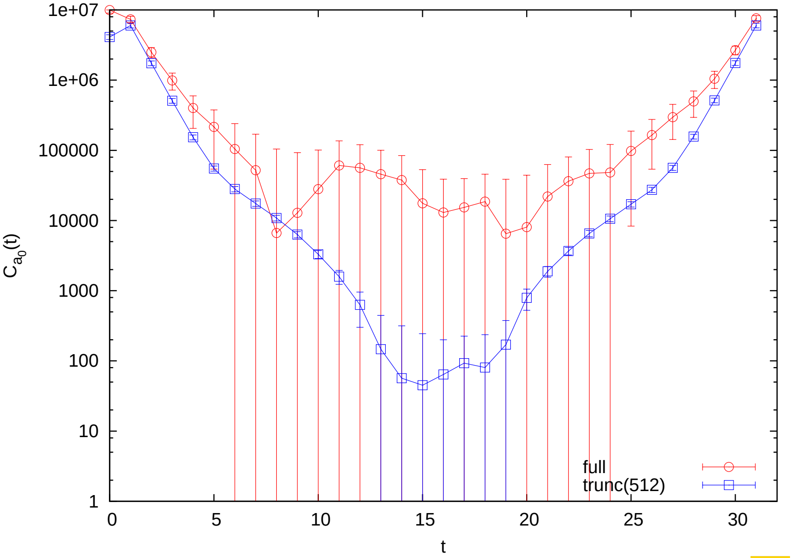
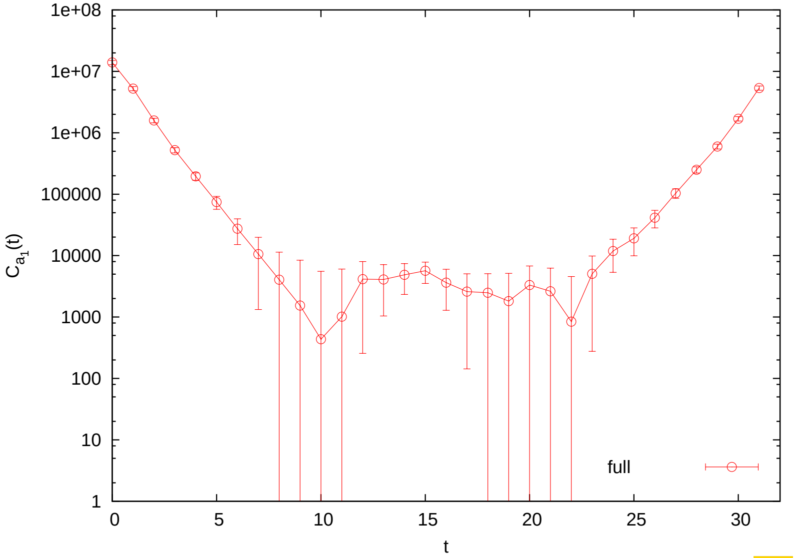


$a_1,\ J^{PC} = 1^{++},\ \overline{u}\gamma_i\gamma_5 d$



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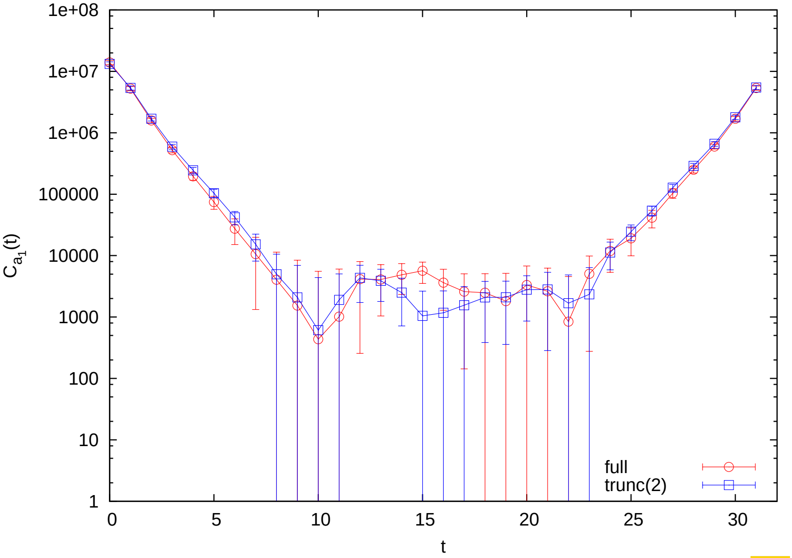

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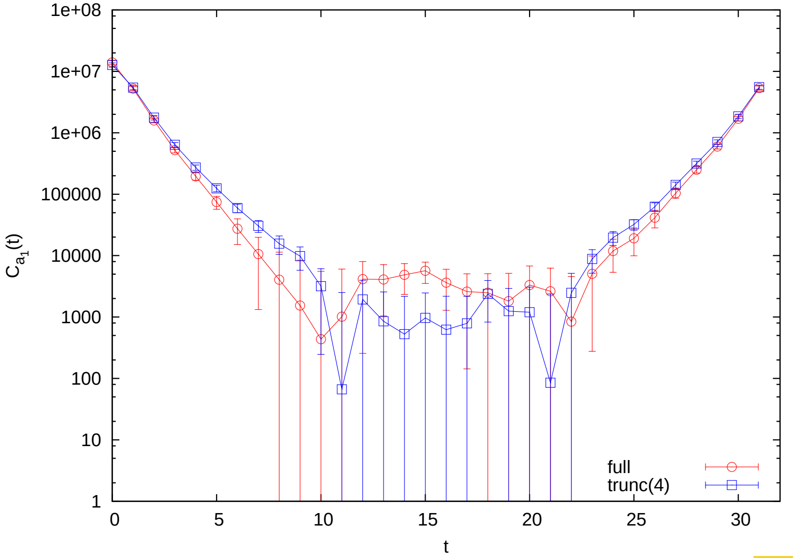

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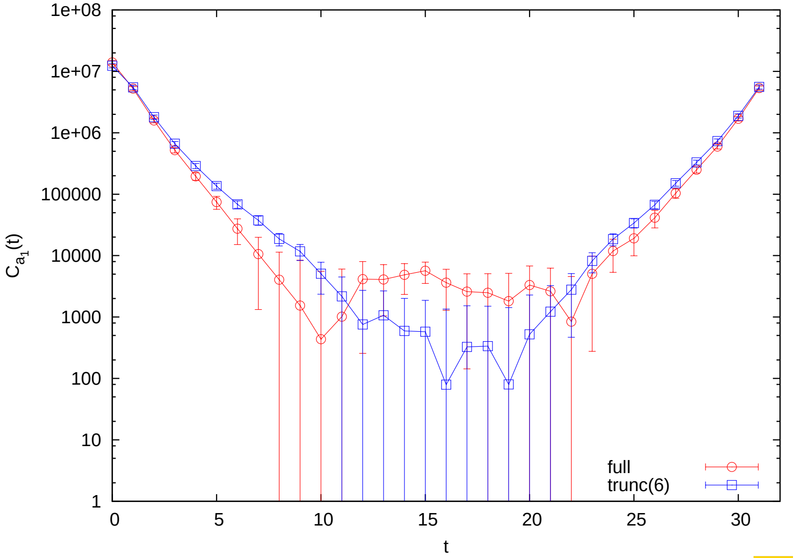

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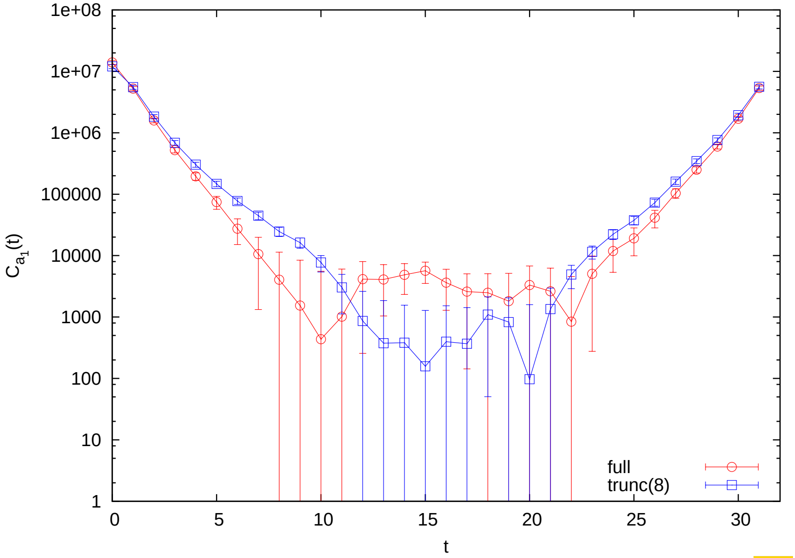

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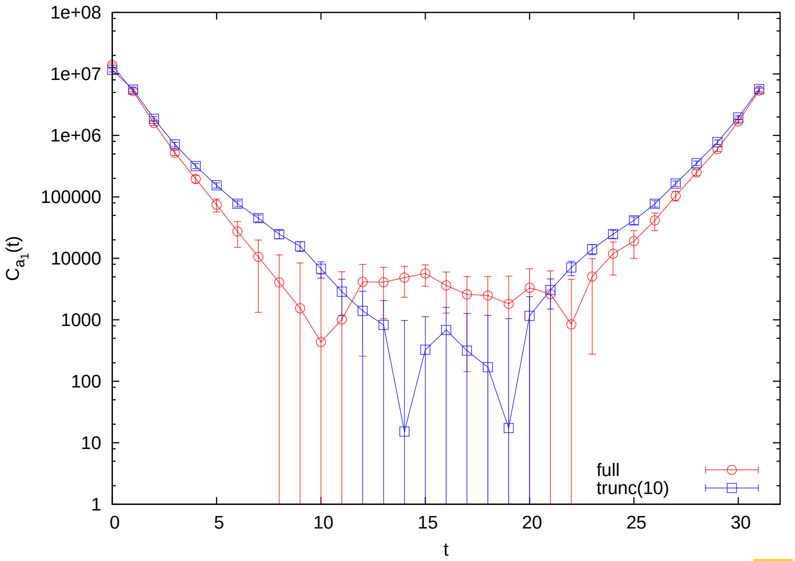

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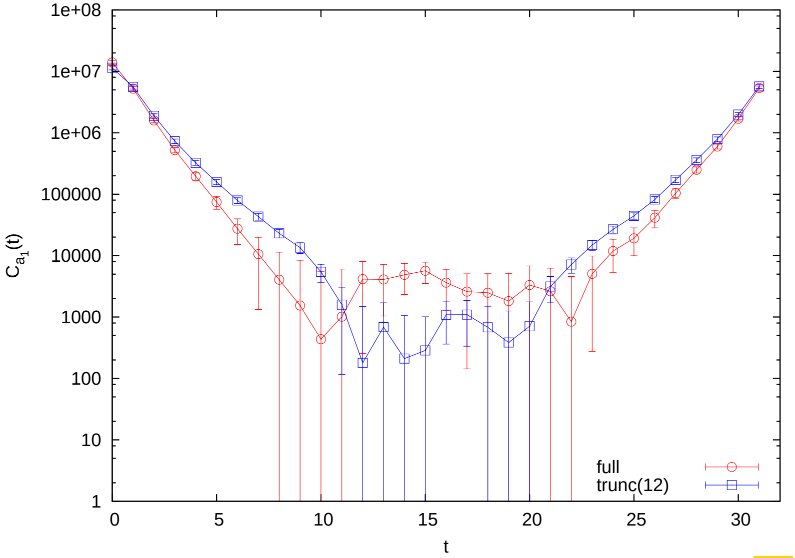

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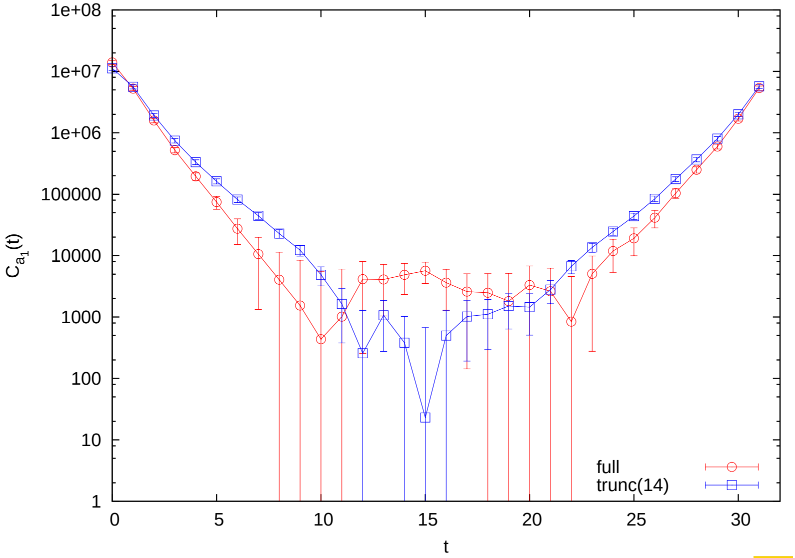

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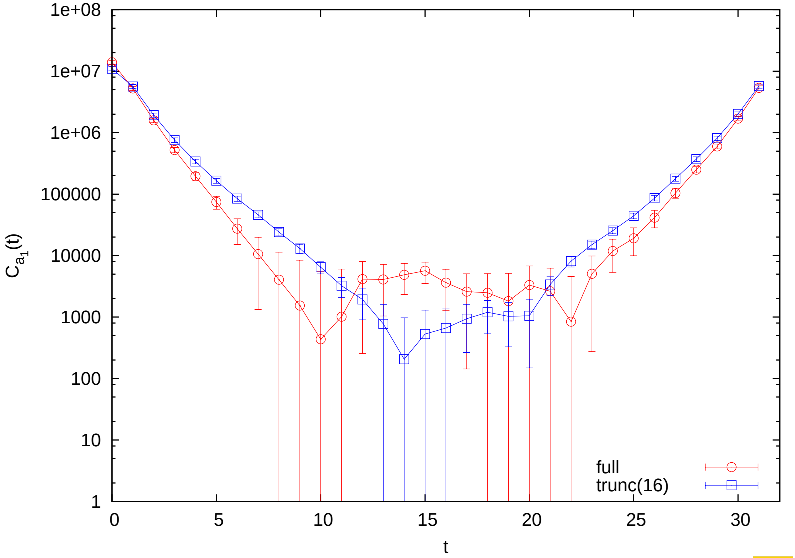

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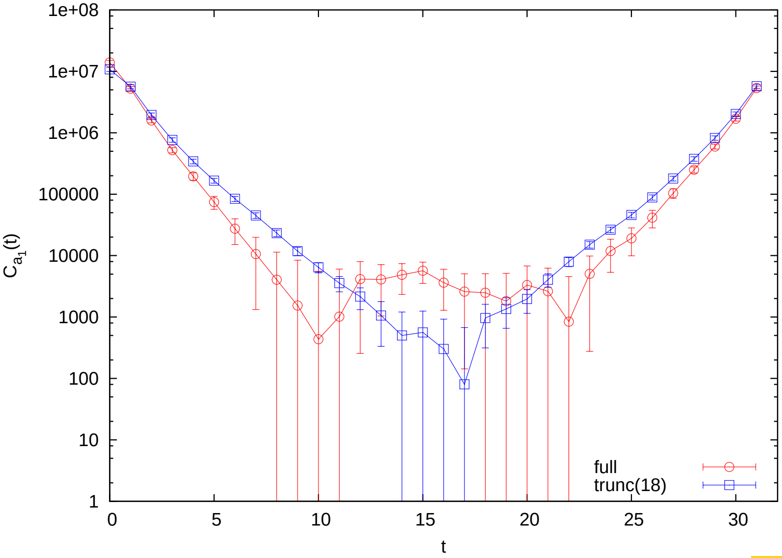

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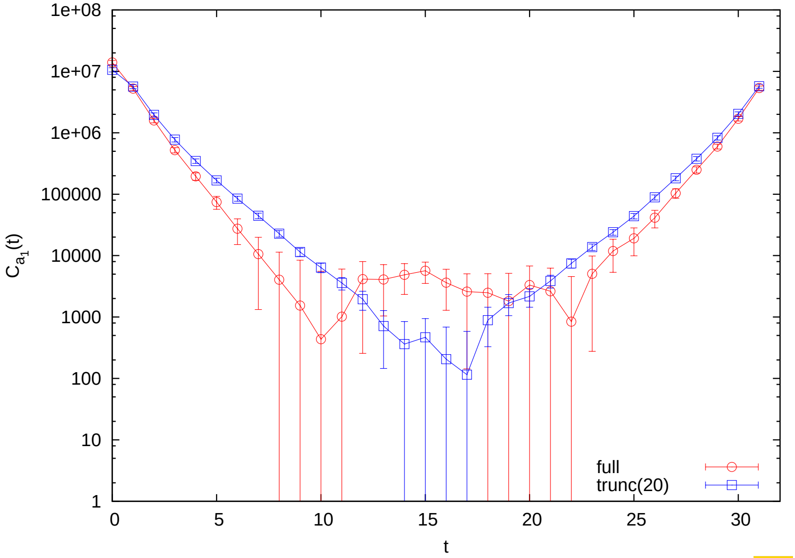
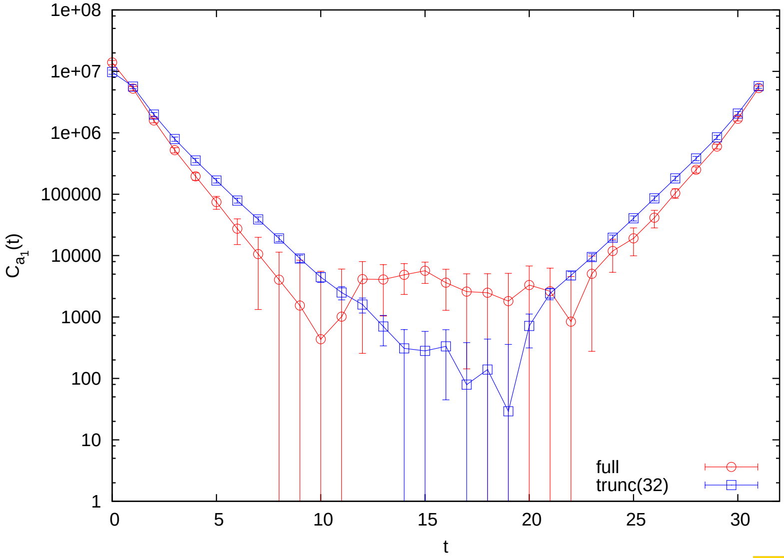


a_1, $J^{PC} = 1^{++}$, $\overline{u}\gamma_i\gamma_5 d$



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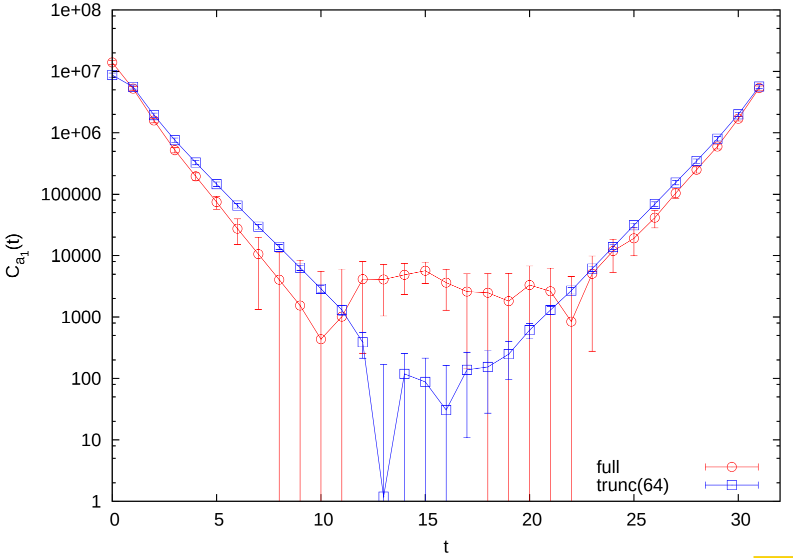
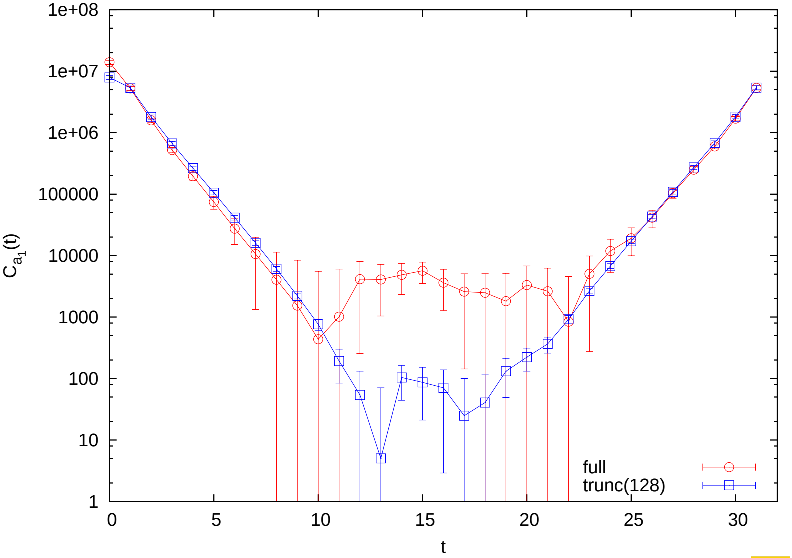
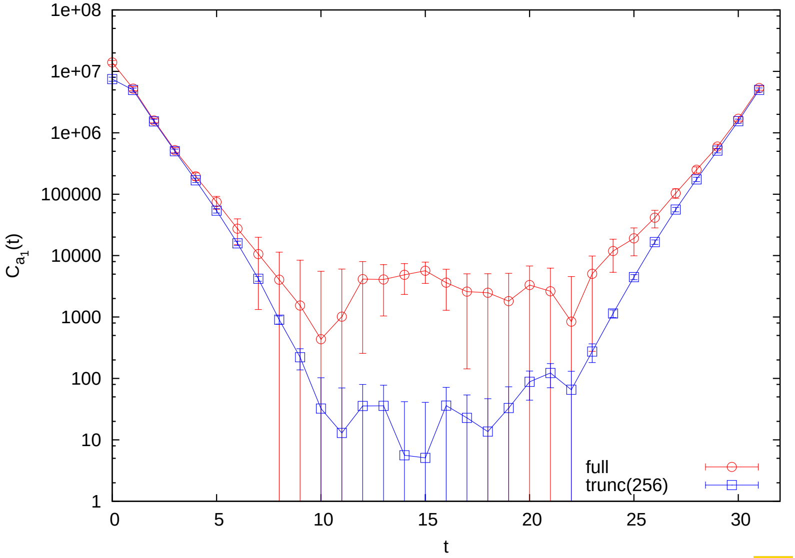


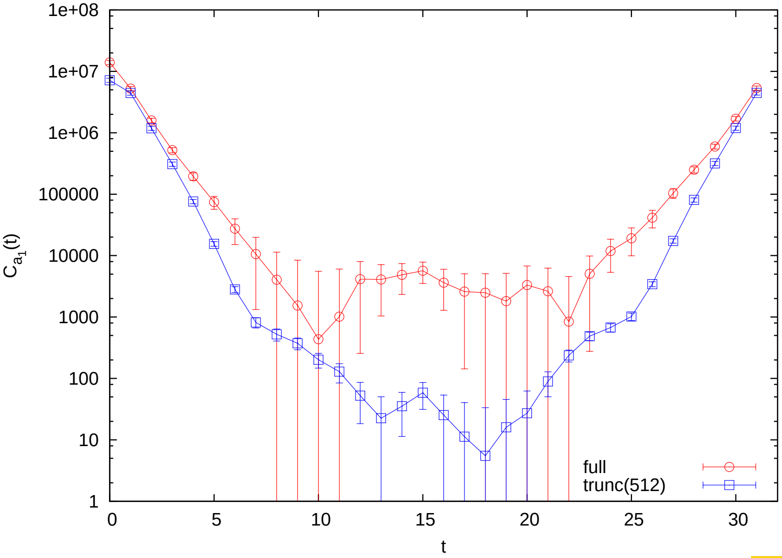
a_1, $J^{PC} = 1^{++}$, $\overline{u}\gamma_i\gamma_5 d$



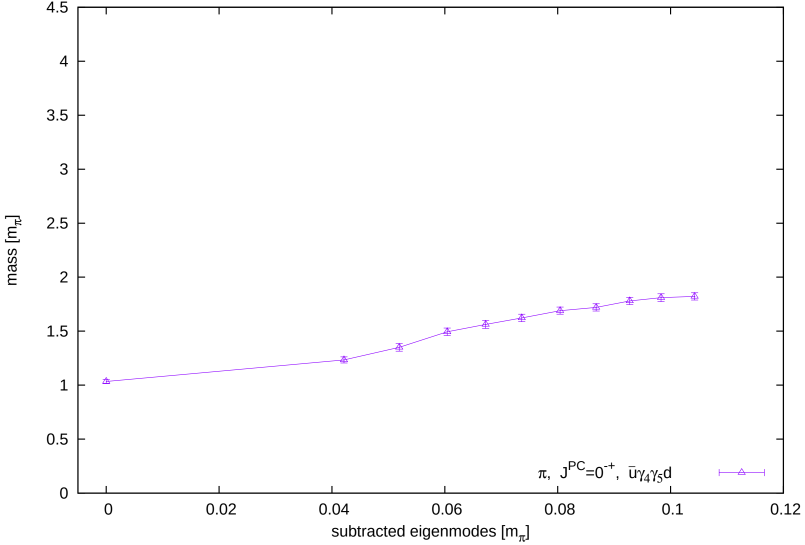
a_1, $J^{PC} = 1^{++}$, $\overline{u}\gamma_i\gamma_5 d$



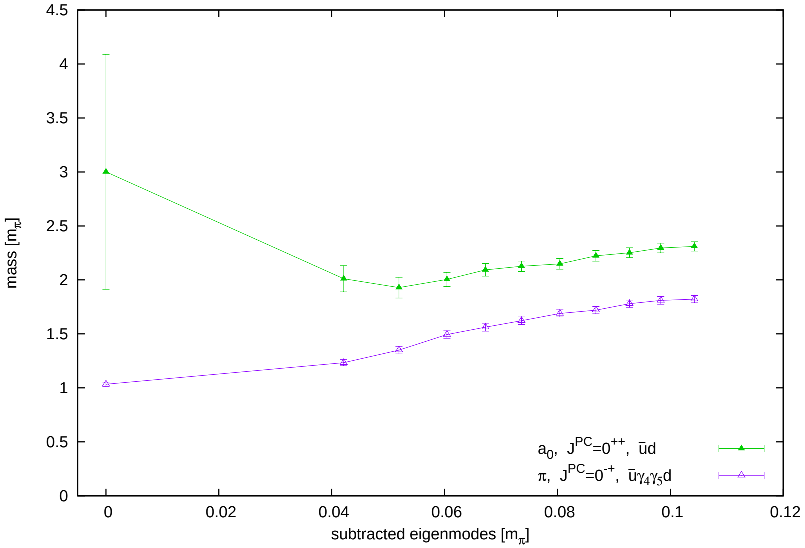
a_1, $J^{PC} = 1^{++}$, $\overline{u}\gamma_i\gamma_5 d$



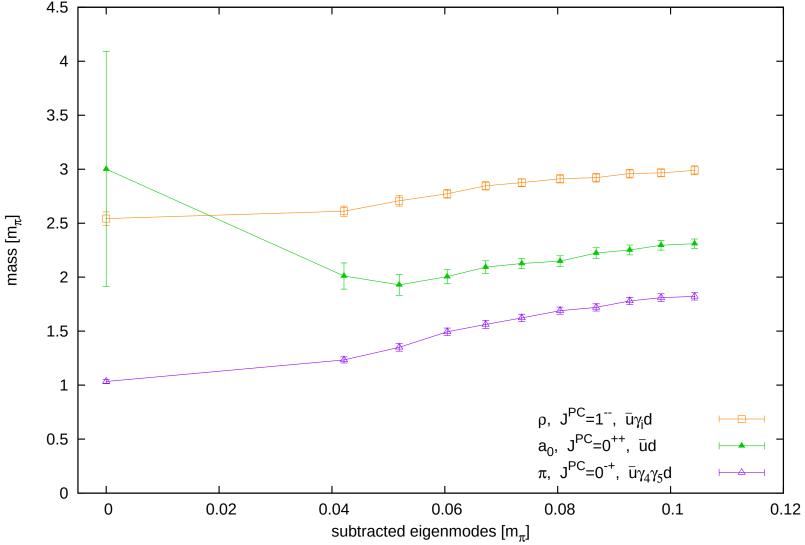
Meson masses under removal of the lowest Dirac modes



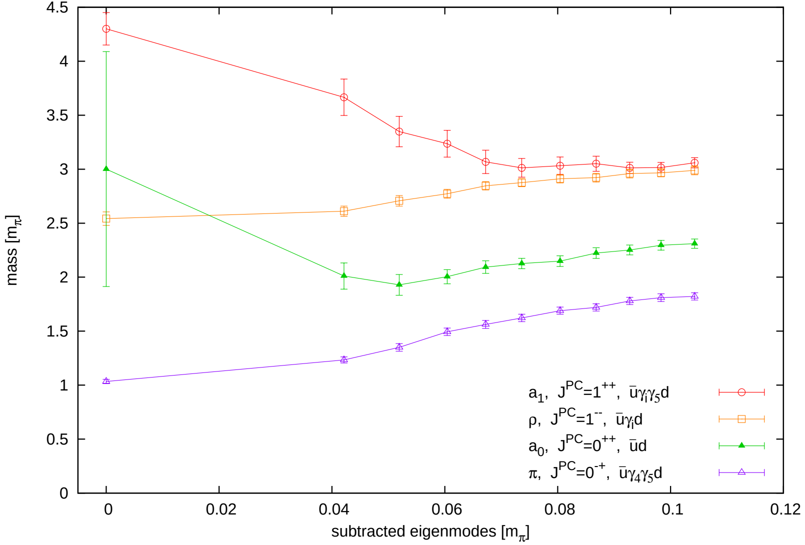
Meson masses under removal of the lowest Dirac modes



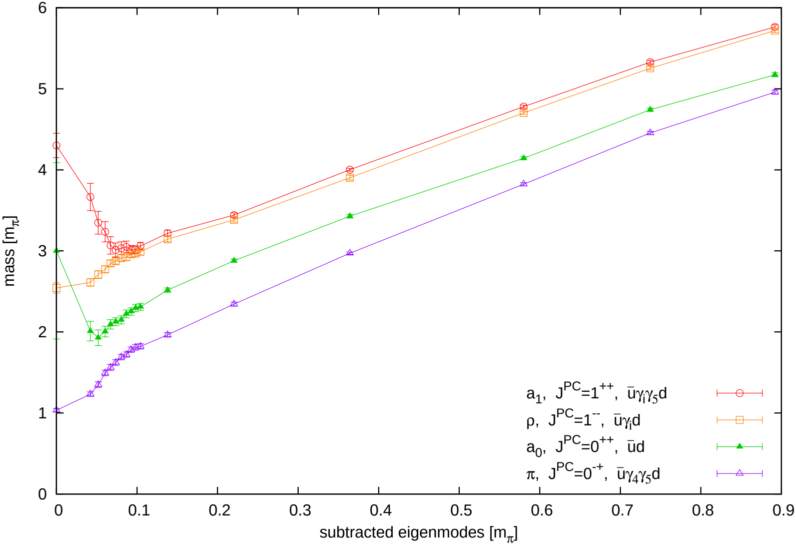
Meson masses under removal of the lowest Dirac modes



Meson masses under removal of the lowest Dirac modes



Meson masses under removal of the lowest Dirac modes



Introduction

The Dirac spectrum

Eigenmode truncated meson correlators

Summary

Summary

- the low-modes of the Dirac operator are related to $D\chi SB$
- we constructed truncated quark propagators which exclude a variable number of Dirac eigenmodes
- therewith we built meson correlators
- by subtracting the lowest 16 eigenmodes corresponding to an energy of roughly $0.1 m_\pi$ we find
  - negative parity mesons become heavier
  - positive parity mesons become lighter
  - the degeneracy in the ground state spectrum of the ρ and the a_1 got restored
- subtracting more than 16 eigenmodes results in a linear growing of the masses of all four considered mesons