The Charmed Strange Mesons from Lattice QCD with Overlap Fermions

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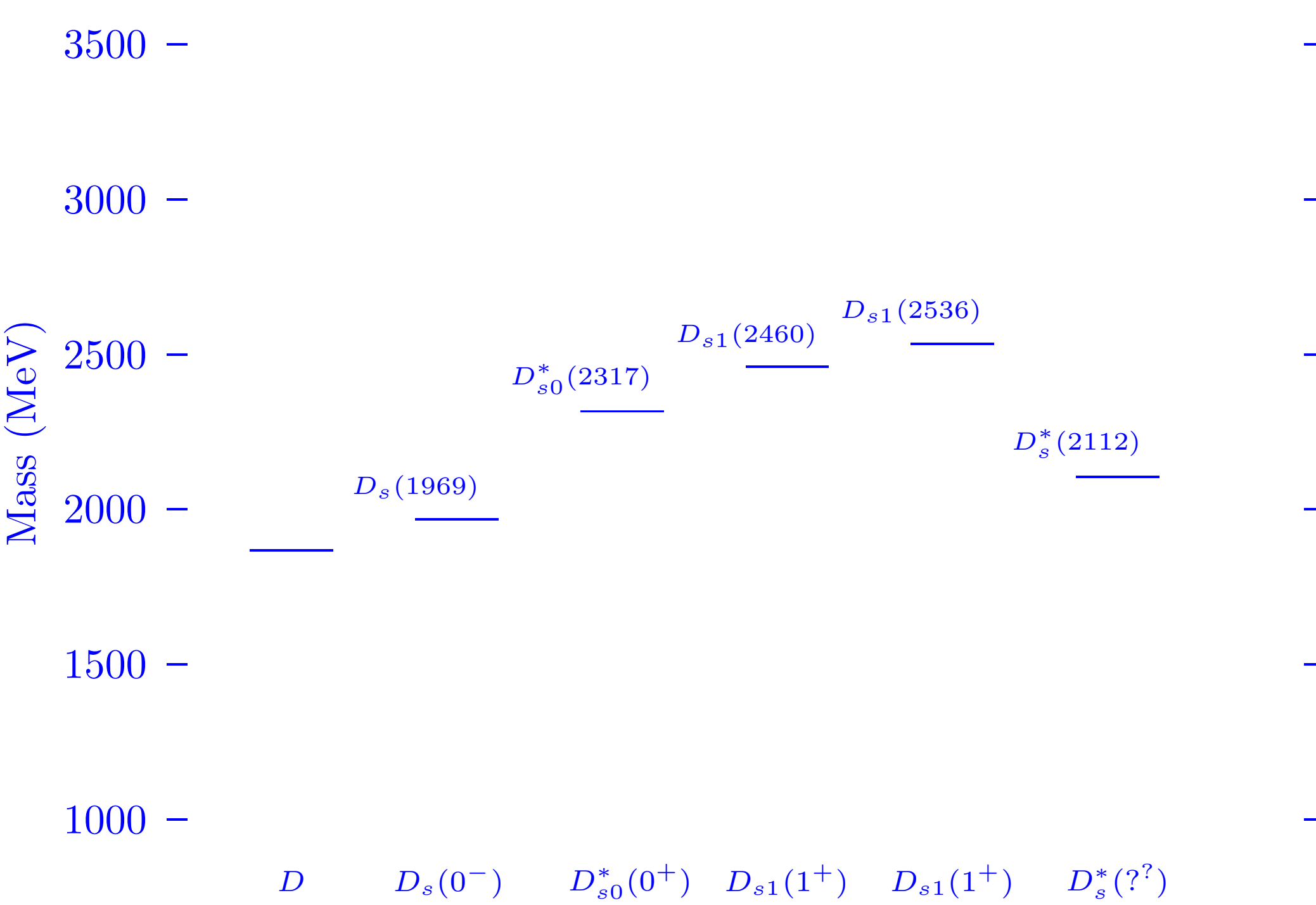
The Contents


3500
3000
2500
2000
1500
1000
Mass (MeV)
$D_s(1969)$
$D^*_{s0}(2317)$
$D_{s1}(2460)$
$D_{s1}(2536)$
$D^*_s(2112)$
D
$D_s(0^-)$
$D^*_{s0}(0^+)$
$D_{s1}(1^+)$
$D_{s1}(1^+)$
$D^*_s(?^?)$

The $D^*_{s0}(2317)$ and questions

- BaBar collaboration (Phys. Rev. lett.(90)242001, 2003) and CLEO collaboration (arXiv:hep-ex/0305017). PDG gives $M \approx 2317.8(6)$MeV and $J^P = 0^+$ (2007)
- The quark potential model gives 2.48GeV (S. Godfrey, N. Isgur Phys. Rev. D32(1985) 189).
- T. Banes and collaborators thought it could be a DK molecule since $D^*_{s0}(2317)$ is 160MeV lighter than that predicted in the potential model.
- W. Bardeen et al discuss the $0^- - 0^+$ splitting in terms of chiral symmetry and gives $\Delta M \approx 338$MeV. It is very close experimental 349MeV. However, the chiral loop will reduce this expectation. (P. Colangelo et al hep-ph/0305140, S. Godfrey hep-ph/0305122)
- Lattice prediction in static limit with NRQCD charm correction gives 2.57(11)GeV (Gunnar Bali hep-ph/0305209)
- Lattice NRQCD quenched 2.50(2)GeV (R. Lewis et al hep-lat/0003011)

Overlap Fermions

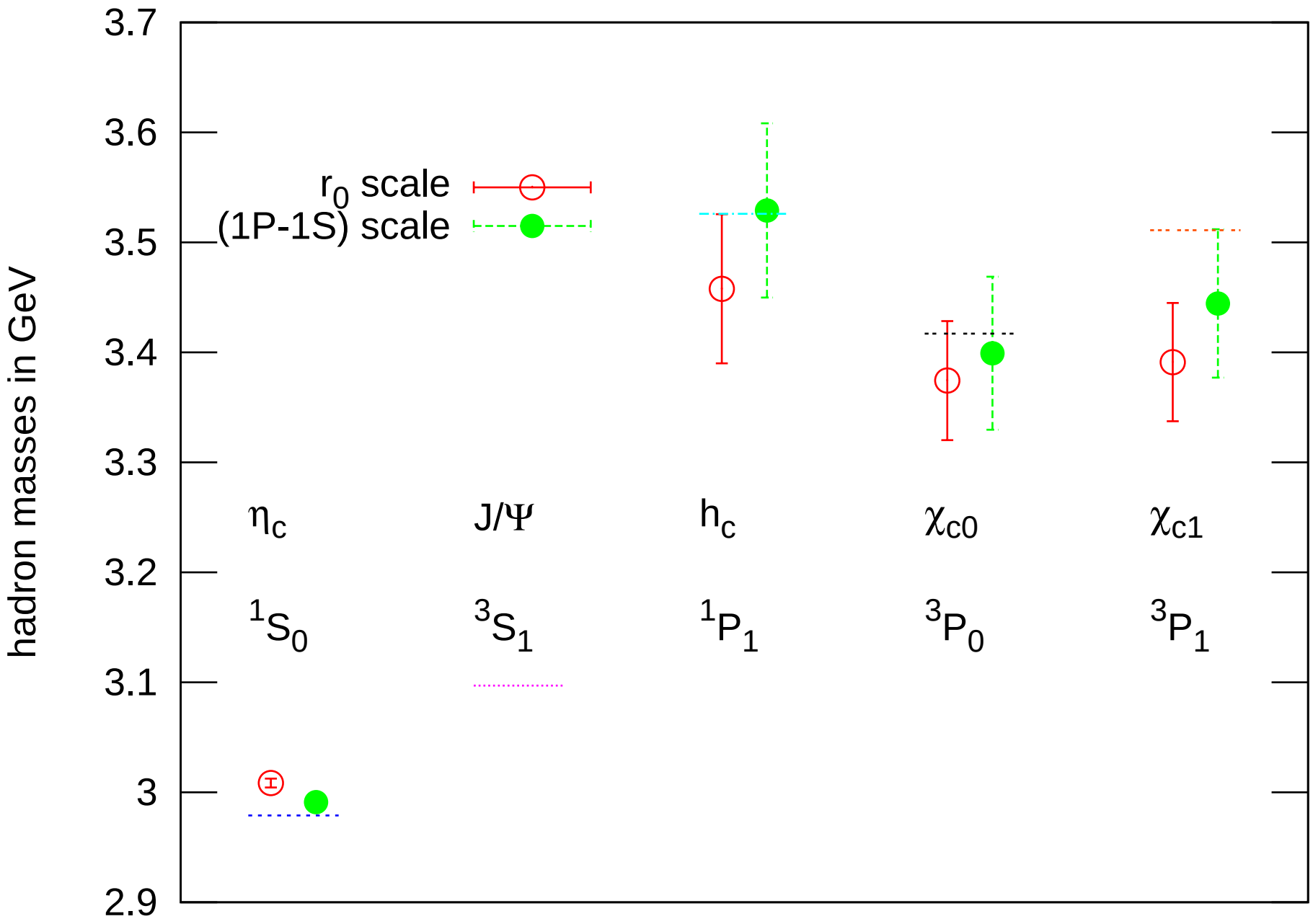
- Massive Overlap Fermion does not have order ma error

$$\begin{aligned} D(m) &= D + ma(1 - \frac{1}{2}D) \\ \psi^c &= (1 - \frac{1}{2}D)\psi; \quad D_c = \frac{D}{1 - \frac{1}{2}D} \\ \Rightarrow \text{propagator} &= \frac{1}{D_c + m}; \quad \{D_c, \gamma_5\} = 0 \end{aligned}$$

- The order a^2 error is small too. (T. Draper et all hep-lat/0609034)
- By examining the dispersion relation and the hyperfine splitting, we showed that one could use ma smaller than 0.5 and keep the systematic $O(ma^2)$ and $O(m^2a^2)$ errors to less than 3% to 4% (S.J. Dong, K. F. Liu arXiv:07103038(hep-lat))

The Lattice Detail

- $16^3 \times 72$ lattice with Wilson gauge action (S. Tamhankar, A. Alexandru, Y. Chen, S. J. Dong, T. Draper, I. Horváth, F. X. Lee, K. F. Liu, N. Mathur, J. B. Zhang; hep-lat/0409128)
- $\beta = 6.3345$, $a = 0.0560$fm with $r_0 = 0.5$fm scale.
- Multi-mass inverter with 26 quark masses ($ma = 0.020 - 0.85$), the bare mass correspond to 70 MeV to 3.0 GeV.
- From Charmonium spectrum the charm mass in lattice units is $m_c a = 0.431(1)$ with r_0 scale which is less than 0.5.
- From $\phi(1^-) = 1020$MeV the strange mass in lattice units is $m_s a = 0.0205(32)$ with r_0 scale.


hadron masses in GeV
3.7
3.6
3.5
3.4
3.3
3.2
3.1
3
2.9
r0 scale
(1P-1S) scale
ηc
J/Ψ
hc
χc0
χc1
1S0
3S1
1P1
3P0
3P1

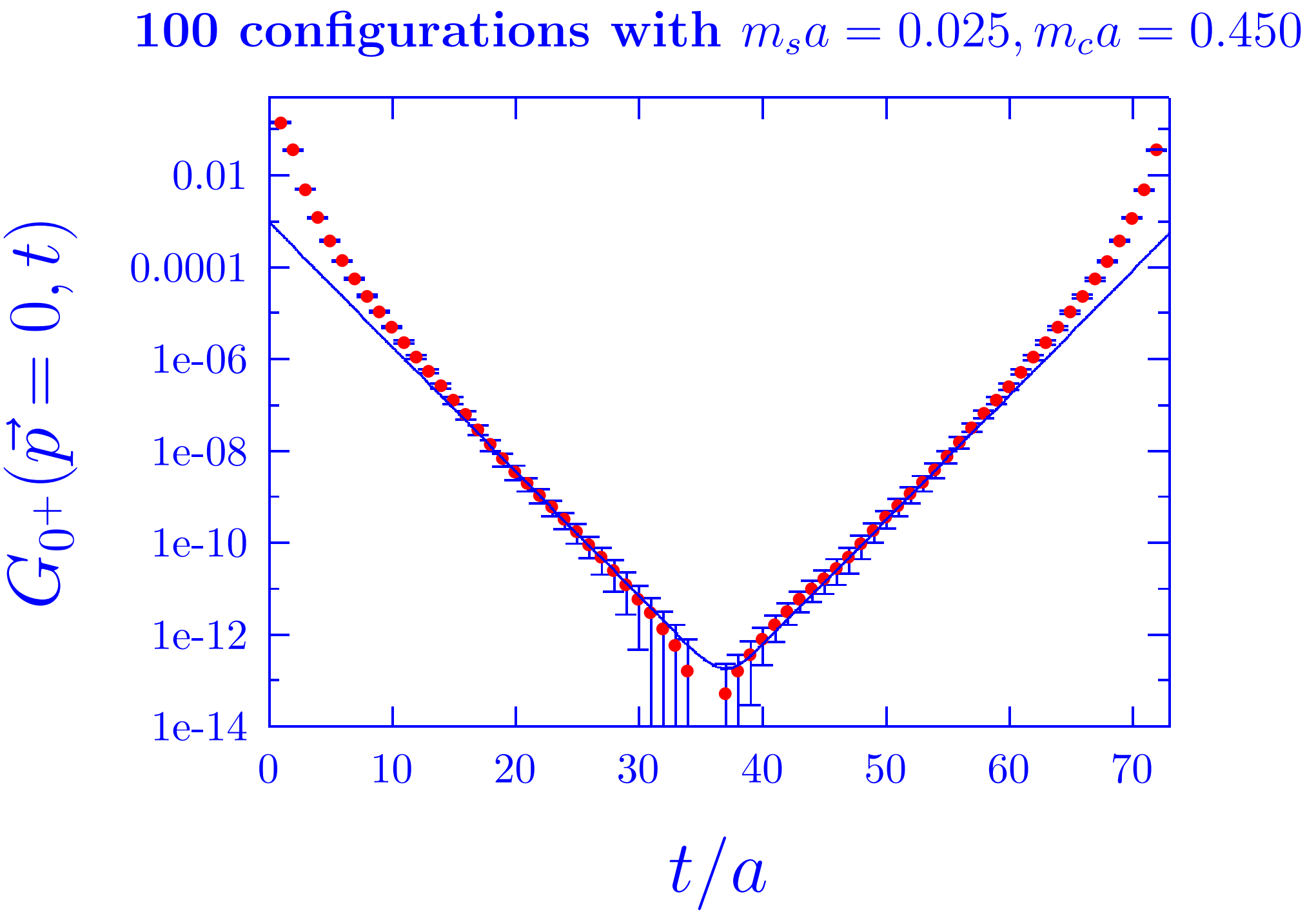
The charmed strange meson calculation

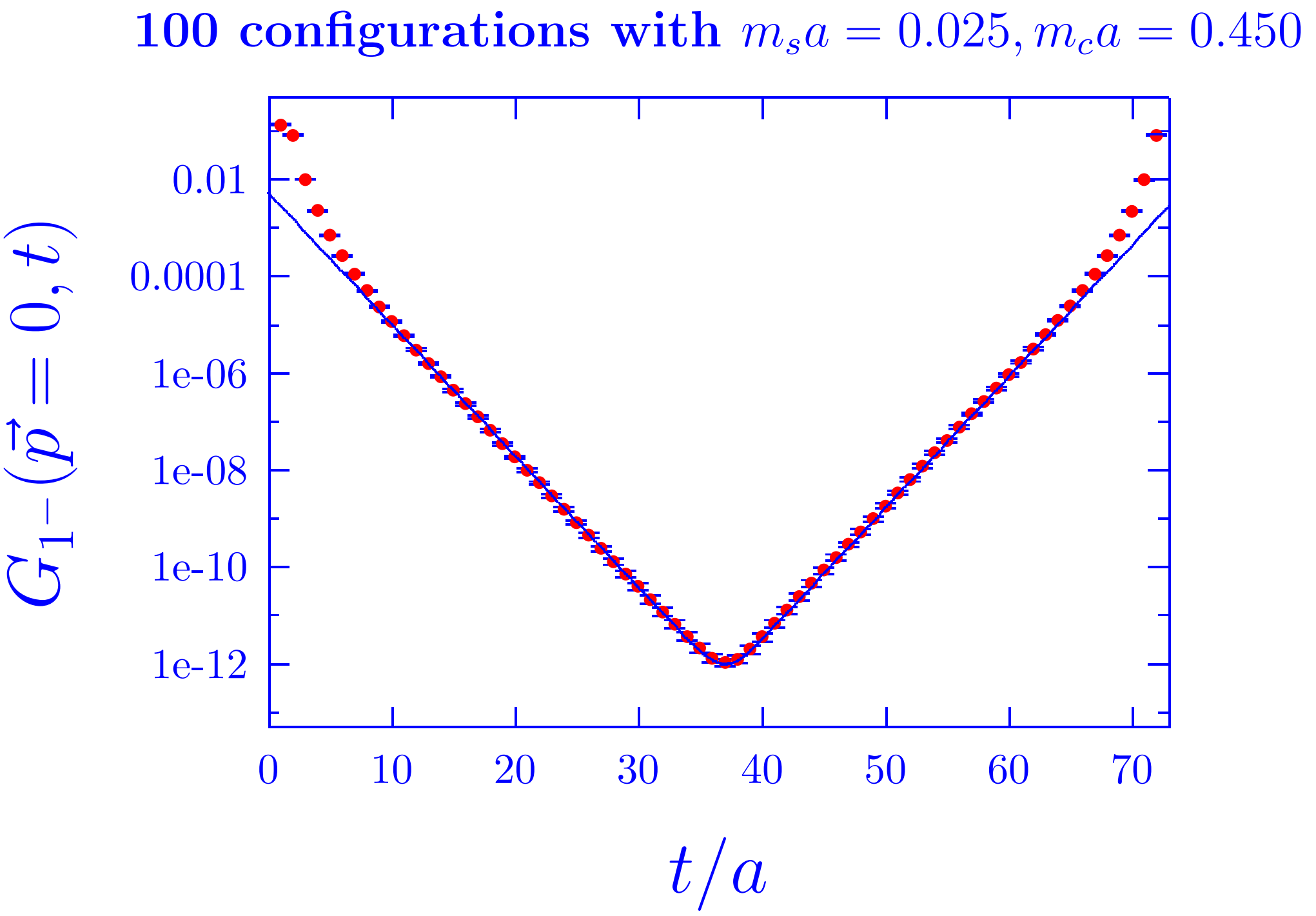
- On the same lattice with the same overlape fermion action for charm and strange quarks.
- For meson correlators, we use standard local interpolating fields

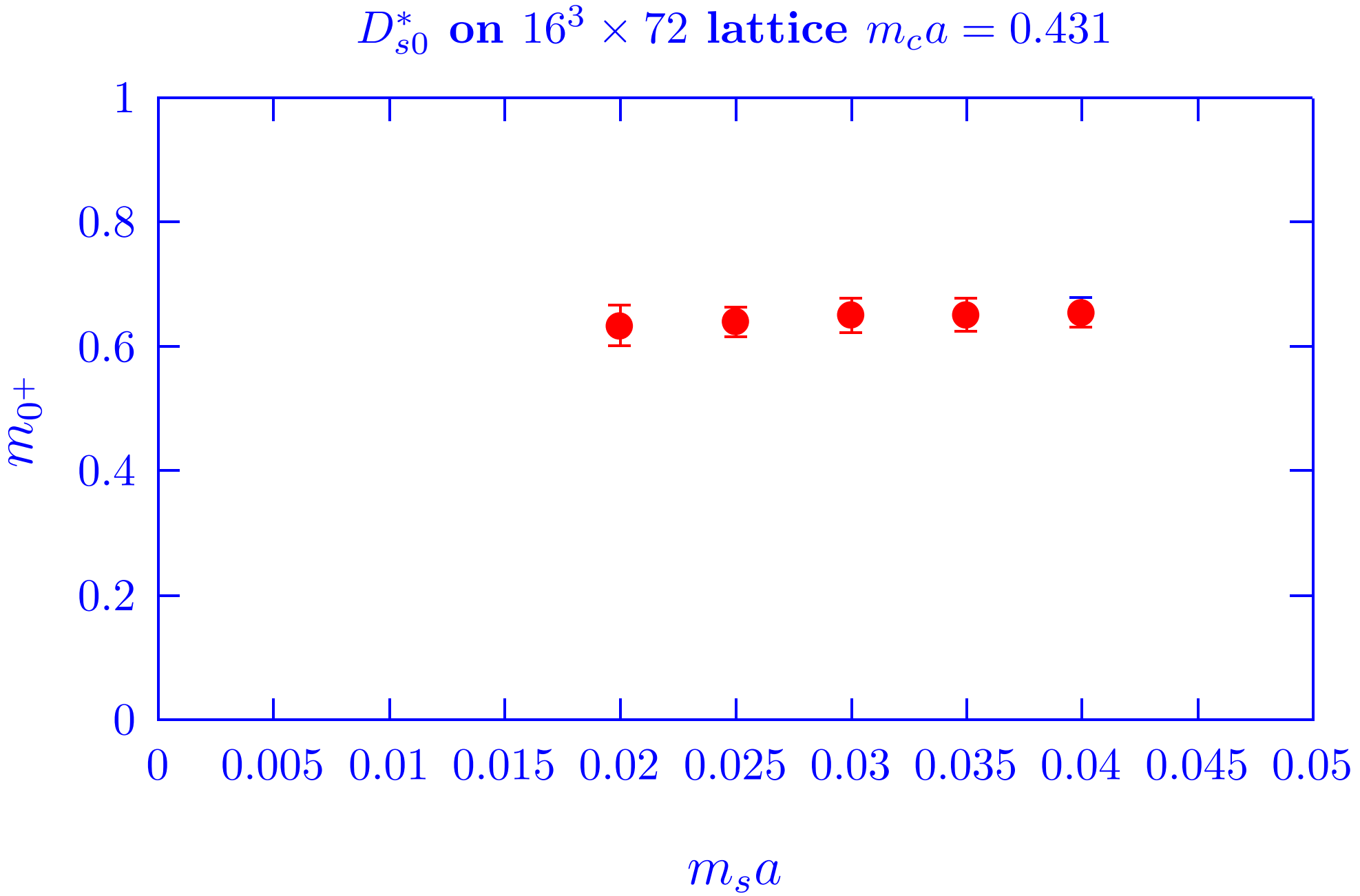
$$
\begin{aligned}
0^- &\Longrightarrow \quad \chi(x) = \bar{\psi}(x)\gamma_5\psi(x) \\
0^+ &\Longrightarrow \quad \chi(x) = \bar{\psi}(x)\psi(x) \\
1^- &\Longrightarrow \quad \chi(x) = \bar{\psi}(x)\gamma_j\psi(x) \qquad j = 1,2,3 \\
1^+ &\Longrightarrow \quad \chi(x) = \bar{\psi}(x)\gamma_5\gamma_j\psi(x) \qquad j = 1,2,3
\end{aligned}
$$

and

$$
1^+ \Longrightarrow \quad \chi_b(x) = \bar{\psi}(x)\gamma_i\gamma_j\psi(x) \qquad \{ij\} = \{12\},\{23\},\{31\}
$$


100 configurations with $m_s a = 0.025, m_c a = 0.450$
$G_{0^+}(\vec{p} = 0, t)$
0.01
0.0001
1e-06
1e-08
1e-10
1e-12
1e-14
0
10
20
30
40
50
60
70
t/a


100 configurations with $m_s a = 0.025, m_c a = 0.450$
$G_{1^-}(\vec{p} = 0, t)$
0.01
0.0001
1e-06
1e-08
1e-10
1e-12
0
10
20
30
40
50
60
70
t/a


D^*_{s0} **on** $16^3 \times 72$ **lattice** $m_c a = 0.431$
1
0.8
0.6
0.4
0.2
0
m_{0^+}
0
0.005
0.01
0.015
0.02
0.025
0.03
0.035
0.04
0.045
0.05
$m_s a$

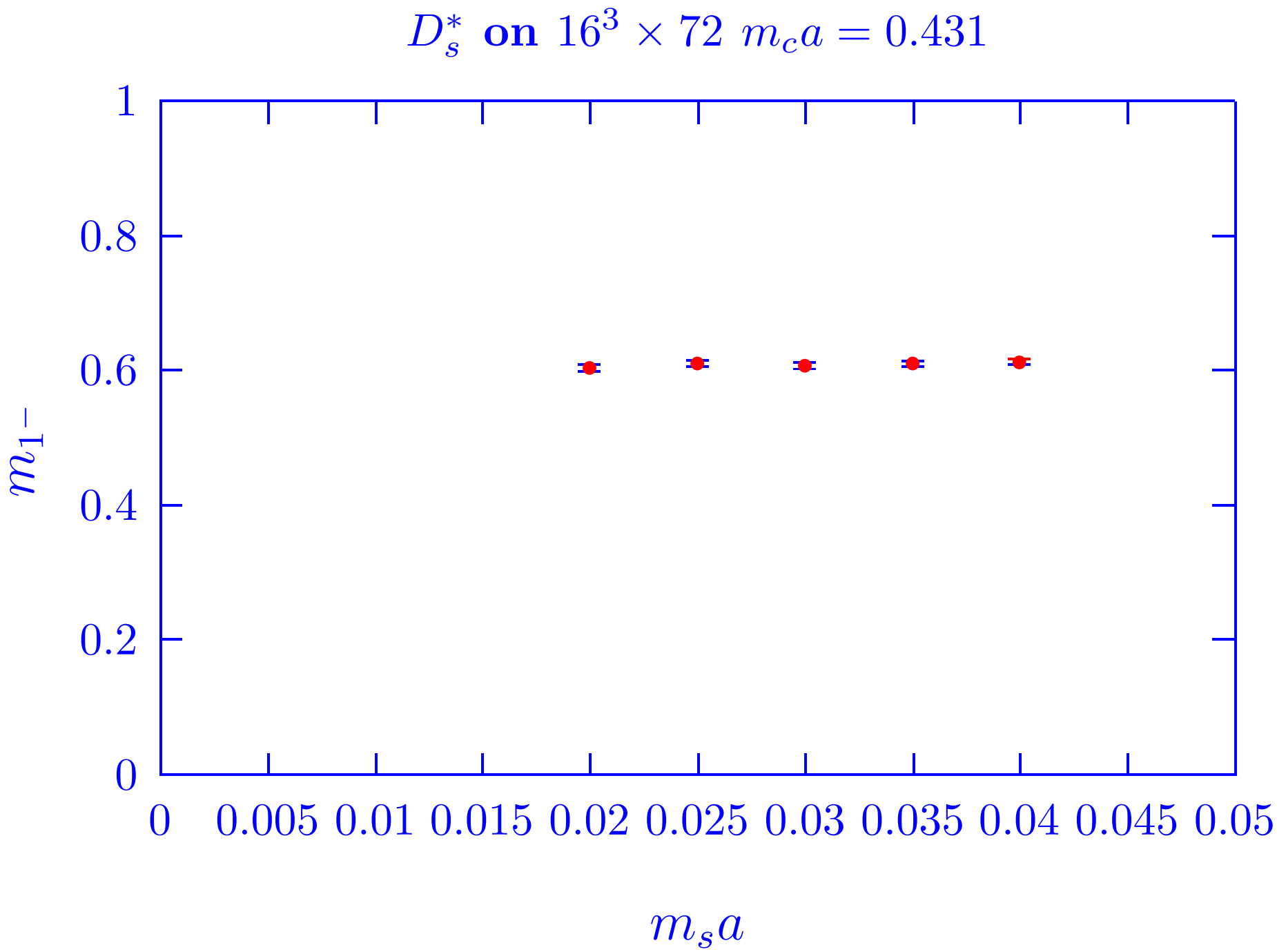
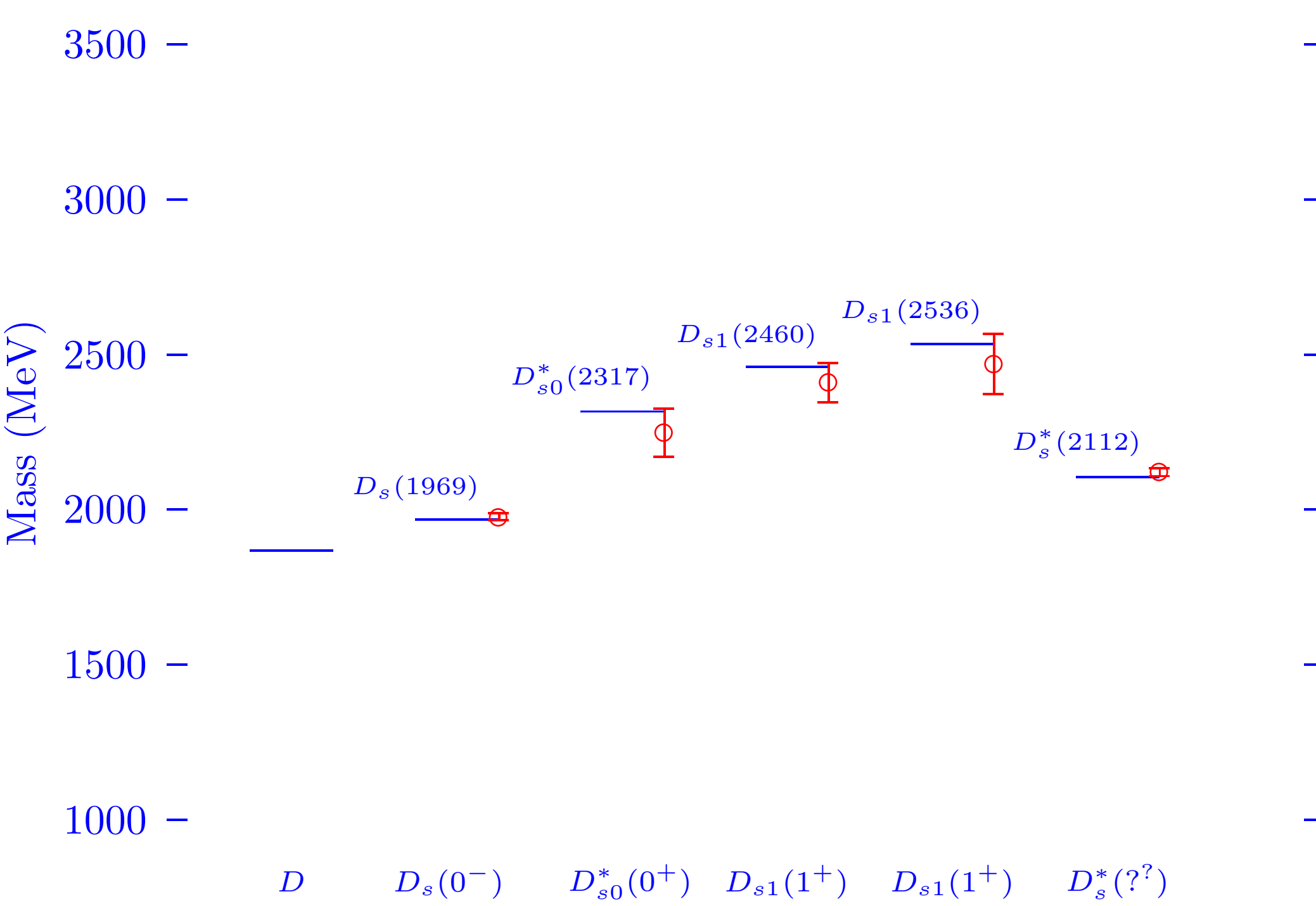

D_s^* **on** $16^3 \times 72$ $m_c a = 0.431$
1
0.8
0.6
0.4
0.2
0
m_{1^-}
0
0.005
0.01
0.015
0.02
0.025
0.03
0.035
0.04
0.045
0.05
$m_s a$

Table 1: charmed strange meson masses

Particle	Mass($\times a$)	Lattice (MeV)	Exp. (MeV)
$D_s(0^-)$	0.5608(31)	1976(11)	1968.49(34)
$D_s^*(1^-)$	0.6049(36)	2131(13)	2112.3(5)
$D_{s0}^*(0^+)$	0.638(22)	2248(78)	2317.8(6)
$D_{s1}(1^+)$	0.684(18)	2410(63)	2459.6(6)
$D_{s1}(1_b^+)$	0.703(26)	2476(92)	2535.35(84)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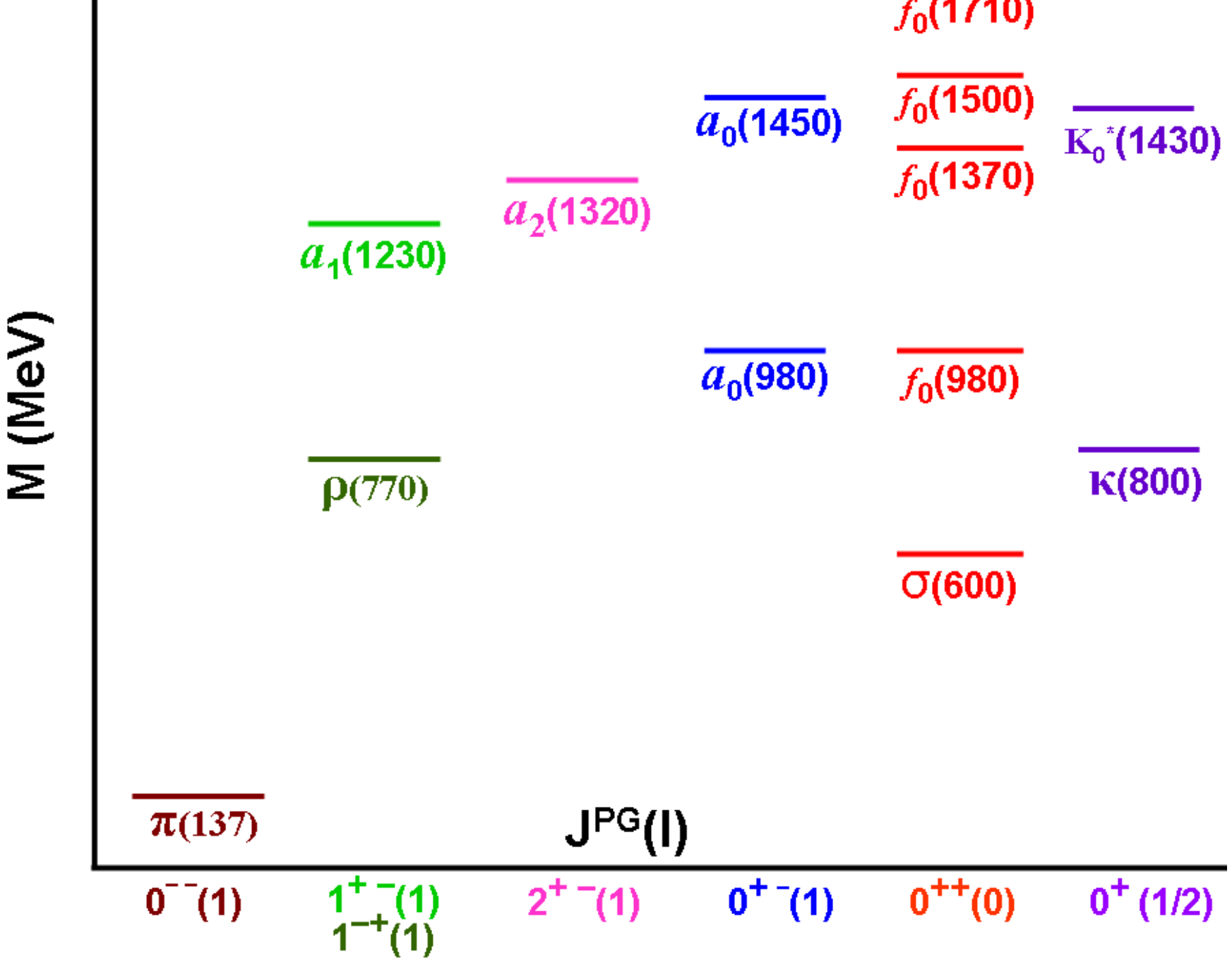
$D^*_{s0}(0^+)$
$D_{s1}(1^+)$
$D_{s1}(1^+)$
$D^*_s(?^?)$

The Summary and Outlook

- The overlap fermion quenched approximation results with $\bar{\psi}\psi$ interpolating fields are consistent with experimental results withing error.
- Comparison with static limit lattice results shows that the 0^+ mass is lower that NRQCD and static limit predicted. However is heavier than RHQ action predicted (CP-PACS hep-lat/0611033v3).
- Four quark interpolating field for $D^*_{s0}(2317)$?
  $D_s K$ molecule for $D^*_{s0}(2317)$?
- The 1^- meson mass is a good match to $D^*_s(2112)$.
- This work uses lattice $La \approx 0.9$fm, the volumn maybe small. Larger lattice are needed to check our results.


M (MeV)
$f_0(1710)$
$f_0(1500)$
$a_0(1450)$
$K_0^*(1430)$
$f_0(1370)$
$a_2(1320)$
$a_1(1230)$
$a_0(980)$
$f_0(980)$
$\kappa(800)$
$\rho(770)$
$\sigma(600)$
$\pi(137)$
$J^{PG}(I)$
$0^{--}(1)$
$1^{+-}(1)$
$1^{-+}(1)$
$2^{+-}(1)$
$0^{+-}(1)$
$0^{++}(0)$
$0^{+}(1/2)$