Twisted reduction in large N QCD with two adjoint Wilson fermions

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The twisted reduced model of large N QCD with two adjoint Wilson fermions is studied numerically using the Hybrid Monte Carlo method.

It is shown that the phase structure and N dependence of the model with twisted boundary condition differ significantly from those of the model with periodic boundary condition.

A preliminary result for the string tension calculated at N=289 is also presented.

Motivation

SU(N) LGT with two adjoint fermions is thought to be conformal or nearly conformal for any value of N since the first two coefficient of beta functions expressed in term of ‘t Hooft coupling is independent of N.

Many studies have been made for N=2 so far.

The purpose of the present talk is to study the large N LGT directly by using the twisted reduced model of LGT.

- Twisted reduced model of large N QCD
  with two adjoint Wilson fermions

We consider gauge group $SU(N),\ N = L^2$

$$S = \sum_{\mu \neq \nu = 1}^{d} Tr\left(I - Z_{\mu\nu} U_\mu U_\nu U_\mu^\dagger U_\nu^\dagger \right) + \sum_{j=1}^{N_f = 2} \bar{\Psi}_j D_W \Psi_j$$

$$Z_{\mu\nu} = \exp\left(k \frac{2\pi i}{L} \right), \quad Z_{\nu\mu} = Z_{\mu\nu}^*, \qquad \mu > \nu$$

$$D_W = 1 - \kappa \sum_{\mu=1}^{4} \left[(1-\gamma_\mu) U_\mu^{adj} + (1+\gamma_\mu) U_\mu^{\dagger adj} \right], \qquad U_\mu^{adj} \Psi = U_\mu \Psi U_\mu^\dagger$$

k , L : co-prime

$k = 0$ corresponds to periodic boundary condition

$k \neq 0$ corresponds to twisted boundary condition

Simulations have been done with $SU(N),\ N = L^2$

$$N = 25, 49, 81, 121, 169, 225, 289$$

$$(\ L = \ 5,\ \ 7,\ \ 9,\ \ 11,\ \ 13,\ \ 17,\ \ 19\ )$$

Our model is related to ordinary SU(N) lattice theory on $V = L^4$ space-time volume up to $O(1/N^2)$ corrections

$$N = 25,\ 49,\ 81,\ 121,\ 169,\ 225,\ 289$$

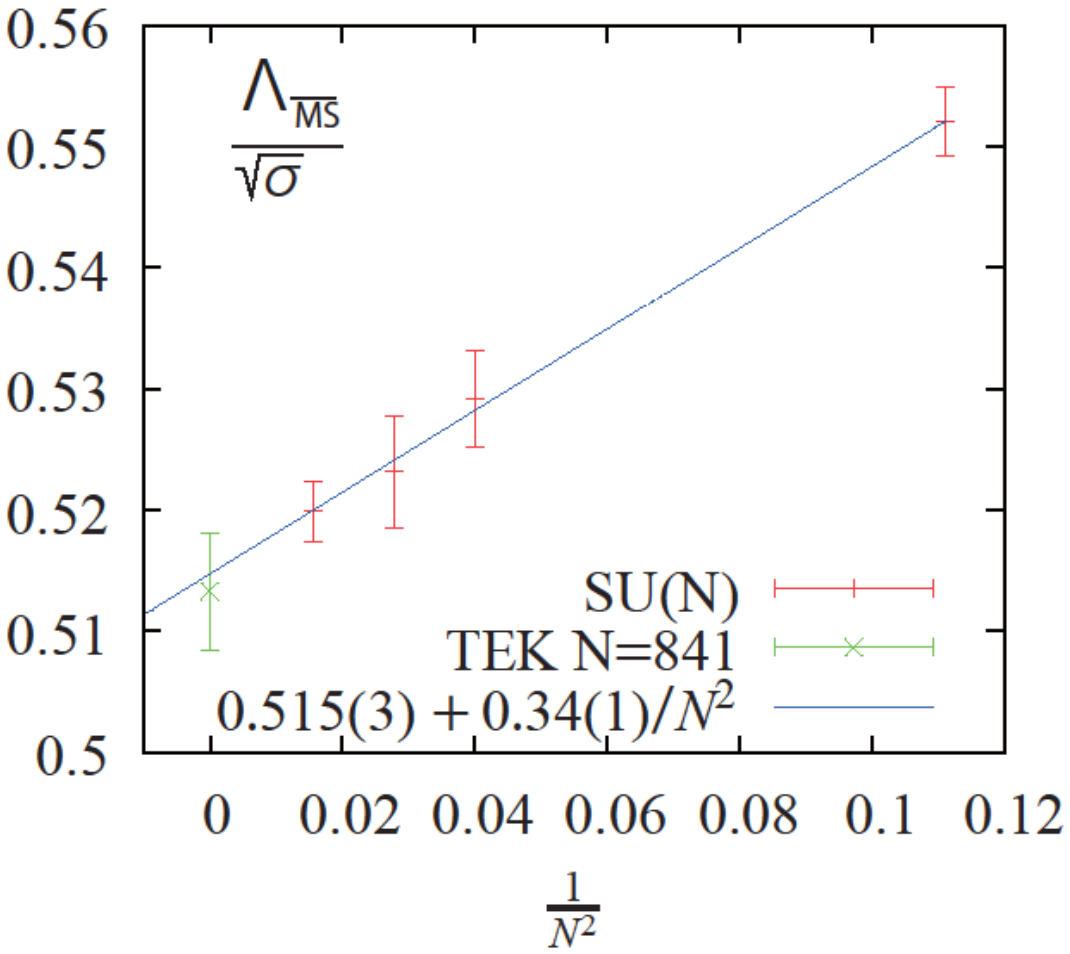
$$V = \ 5^4,\ 7^4,\ 9^4,\ 11^4,\ 13^4,\ 17^4,\ 19^4$$

We can, then, calculate Wilson loop W(R,R) up to

$$R = \ 2,\ \ 3,\ \ \ 4,\ \ \ 5,\ \ \ \ 6,\ \ \ \ 7,\ \ \ \ 8$$

For TEK model without fermions, we took $SU(841 = 29^2)$,
k=9, then, we can study Wilson loops up to 14x14

talk by Gonzalez-Arroyo on Monday



- Simulations have been done on Hitachi SR16000-M1 computer Installed last September at KEK

  The whole system at KEK has 56 nodes

  One node: 32 core power 7,
  peak speed 980 GFlops/sec
  256 GB shared memory

  Sustained speed of our code in one node is
  300 – 600 Gflops/sec at N=289,
  depending on the value of kappa $= 0.12 \sim 0.16$

- $Z(N)$ symmetry should not be broken
  to have a correspondence to ordinary LGT

Known properties at kappa = 0
(TEK model without fermion)

$k=0$: $Z(N)$ symmetry is broken for all $N>0$

$k=1$: $Z(N)$ symmetry is broken for $N>100$

$k=3$: $Z(N)$ symmetry is broken for $N>784$

$k=5$: $Z(N)$ symmetry is expected
to be broken for $N>2200$

- $Z(N)$ symmetry is not broken for appropriately

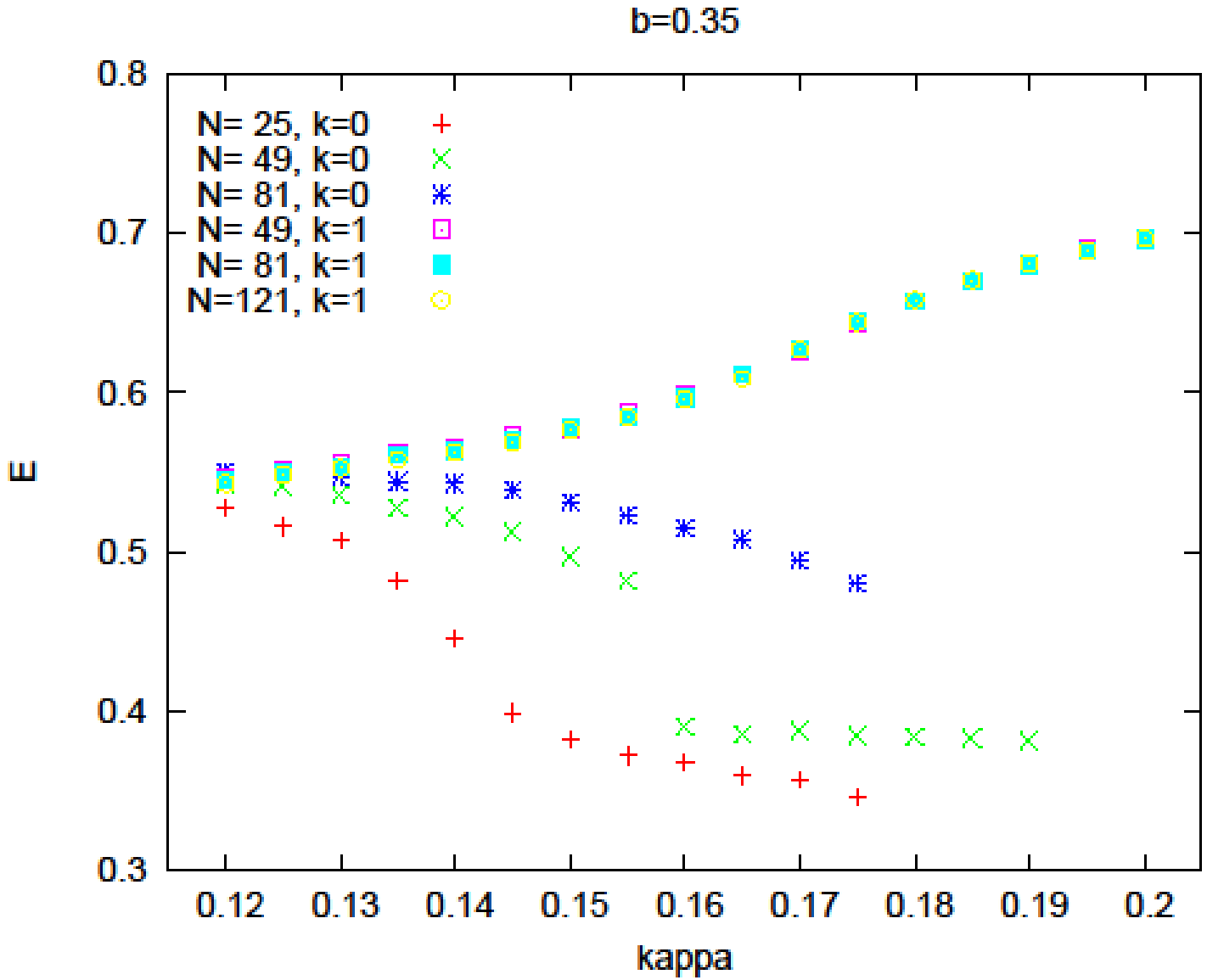
  chosen kappa $\neq$ 0 for all cases

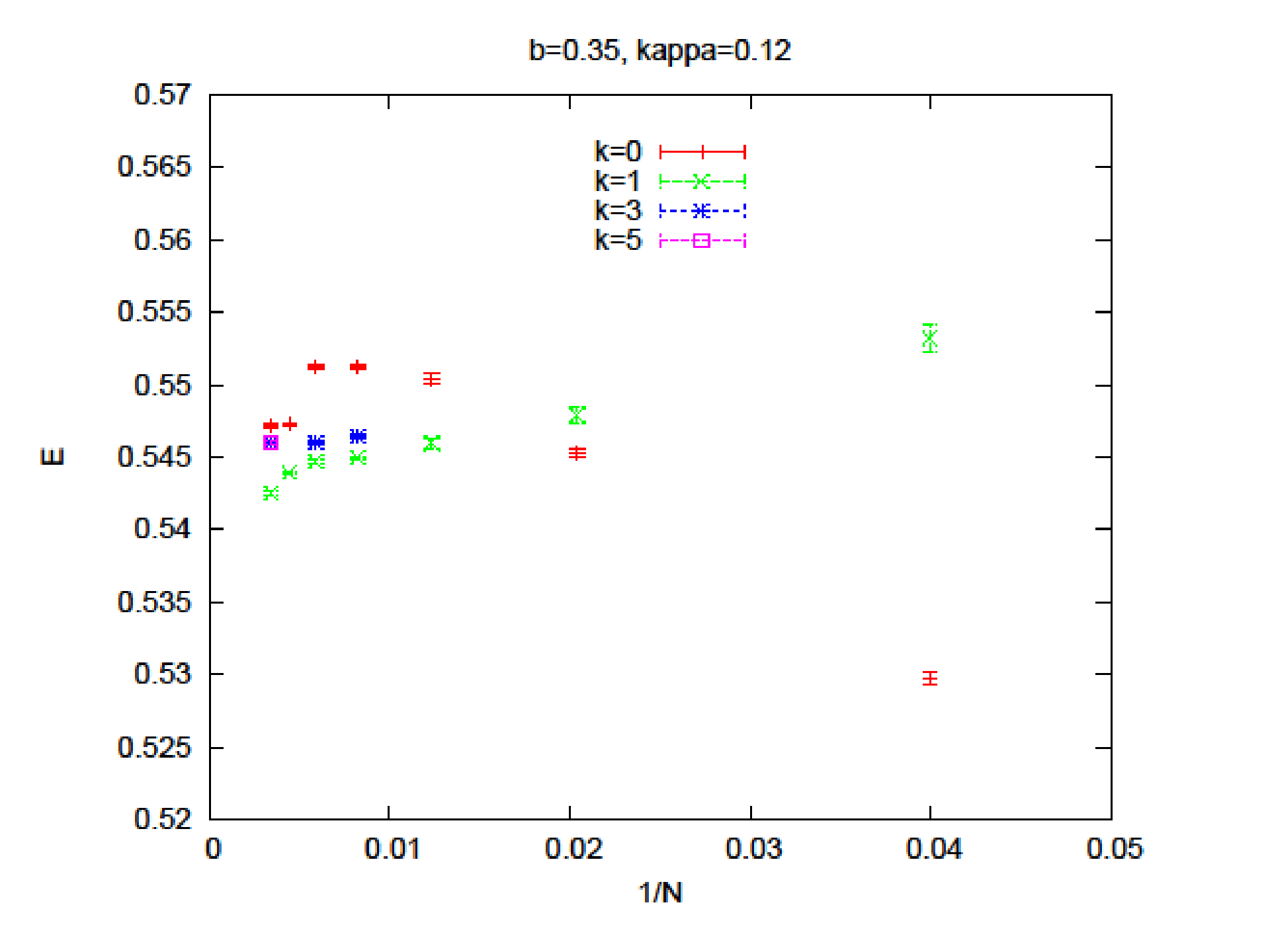
For k=0, Bringoltz, Koren, Sharpe

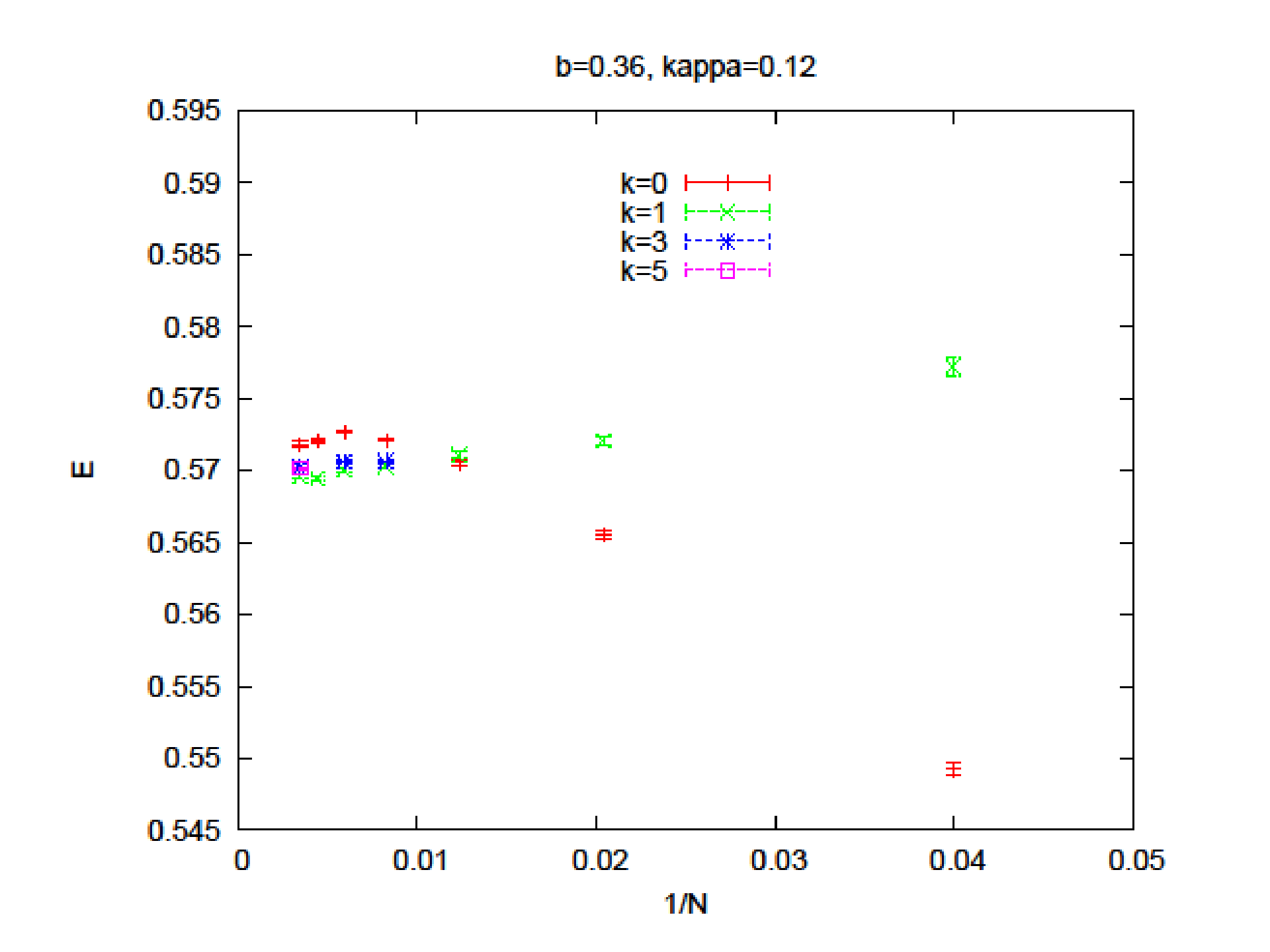
But there remain problems

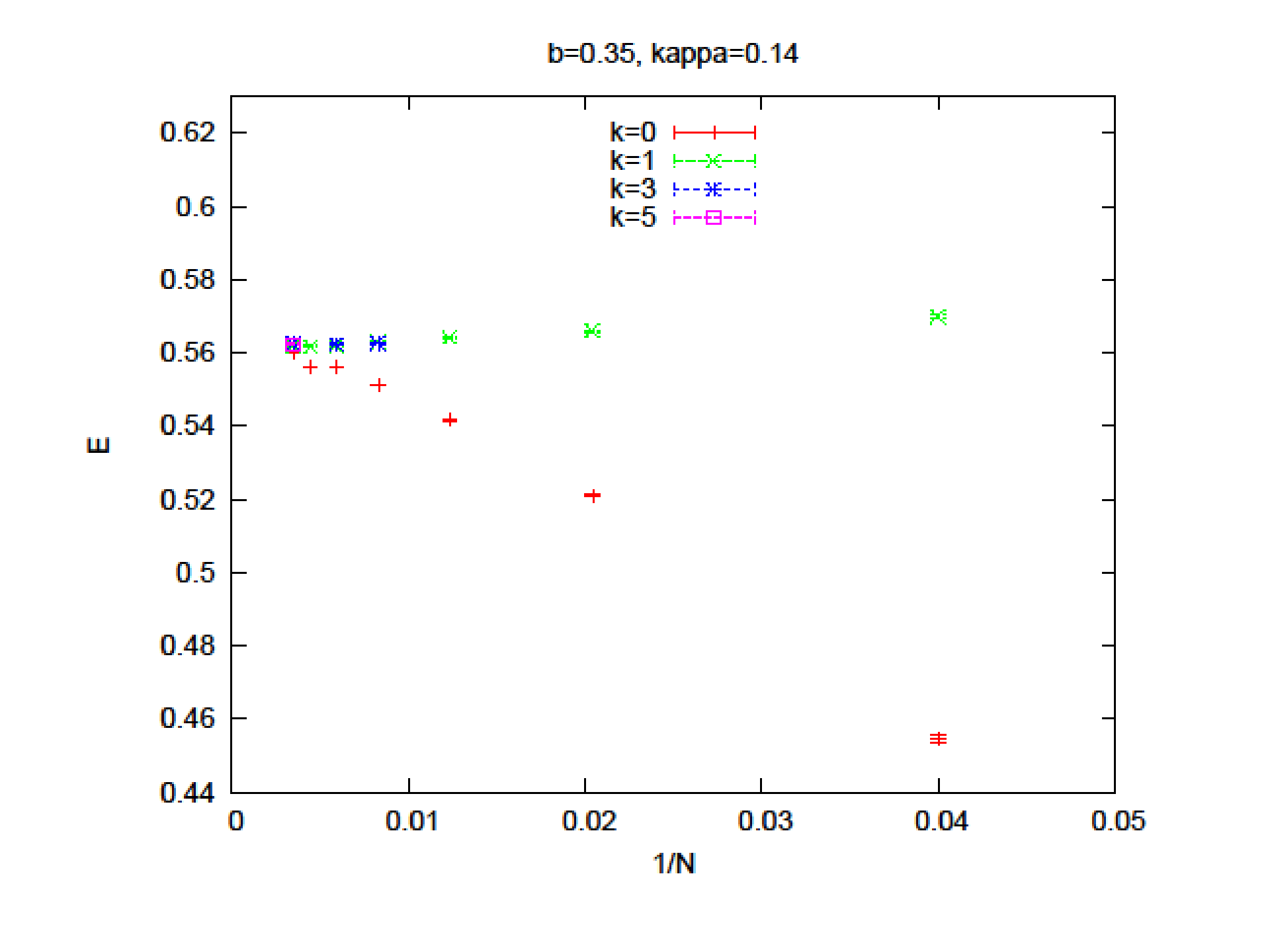
especially for k=0

- Plaquette value E versus kappa for various N with k = 0, 1




b=0.35, kappa=0.12
k=0
k=1
k=3
k=5
E
1/N
0.57
0.565
0.56
0.555
0.55
0.545
0.54
0.535
0.53
0.525
0.52
0
0.01
0.02
0.03
0.04
0.05


b=0.36, kappa=0.12
k=0
k=1
k=3
k=5
E
1/N
0.595
0.59
0.585
0.58
0.575
0.57
0.565
0.56
0.555
0.55
0.545
0
0.01
0.02
0.03
0.04
0.05


b=0.35, kappa=0.14
k=0
k=1
k=3
k=5
E
1/N
0.62
0.6
0.58
0.56
0.54
0.52
0.5
0.48
0.46
0.44
0
0.01
0.02
0.03
0.04
0.05

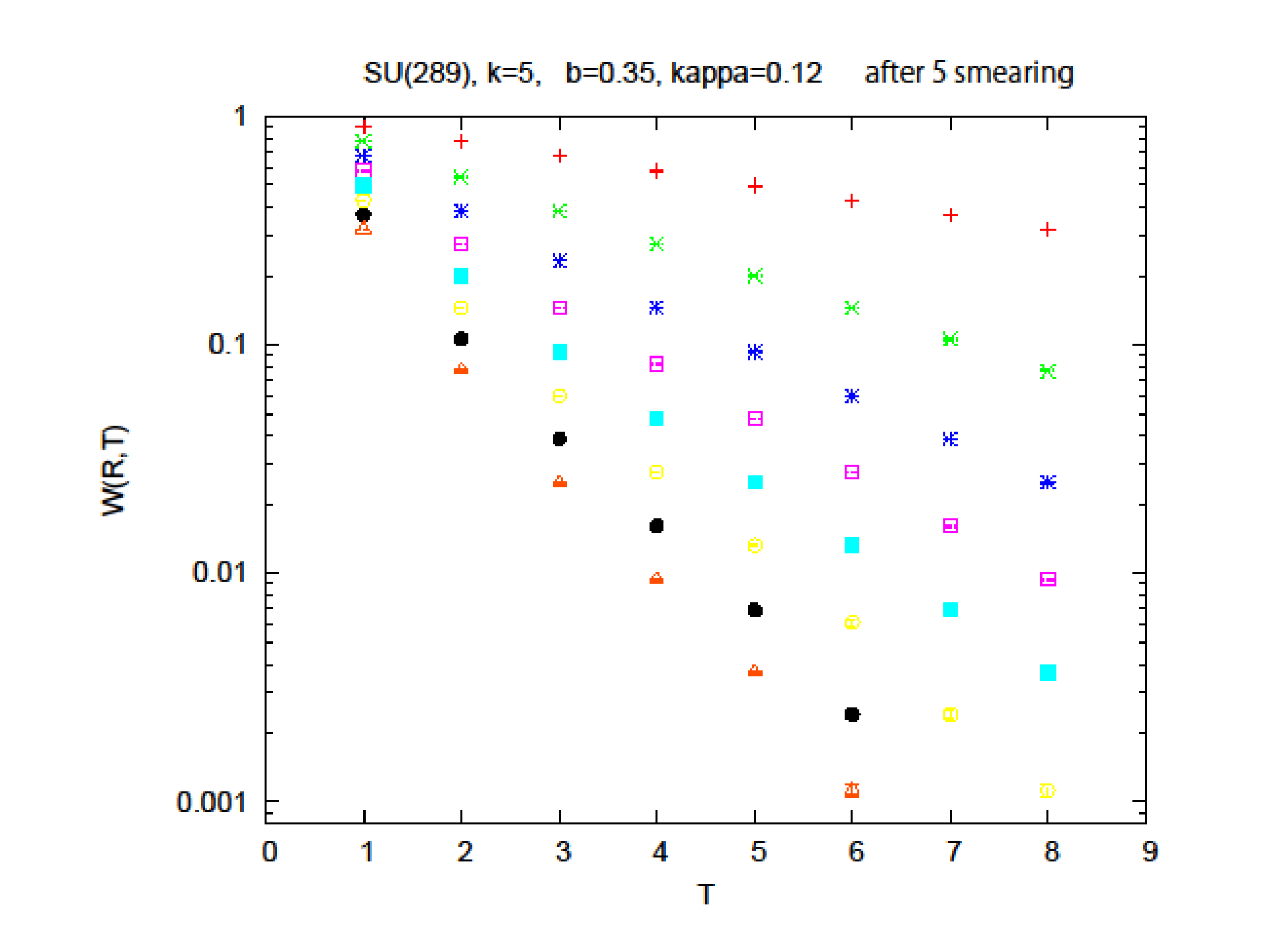
- Large Wilson loop at N=289 and k=5

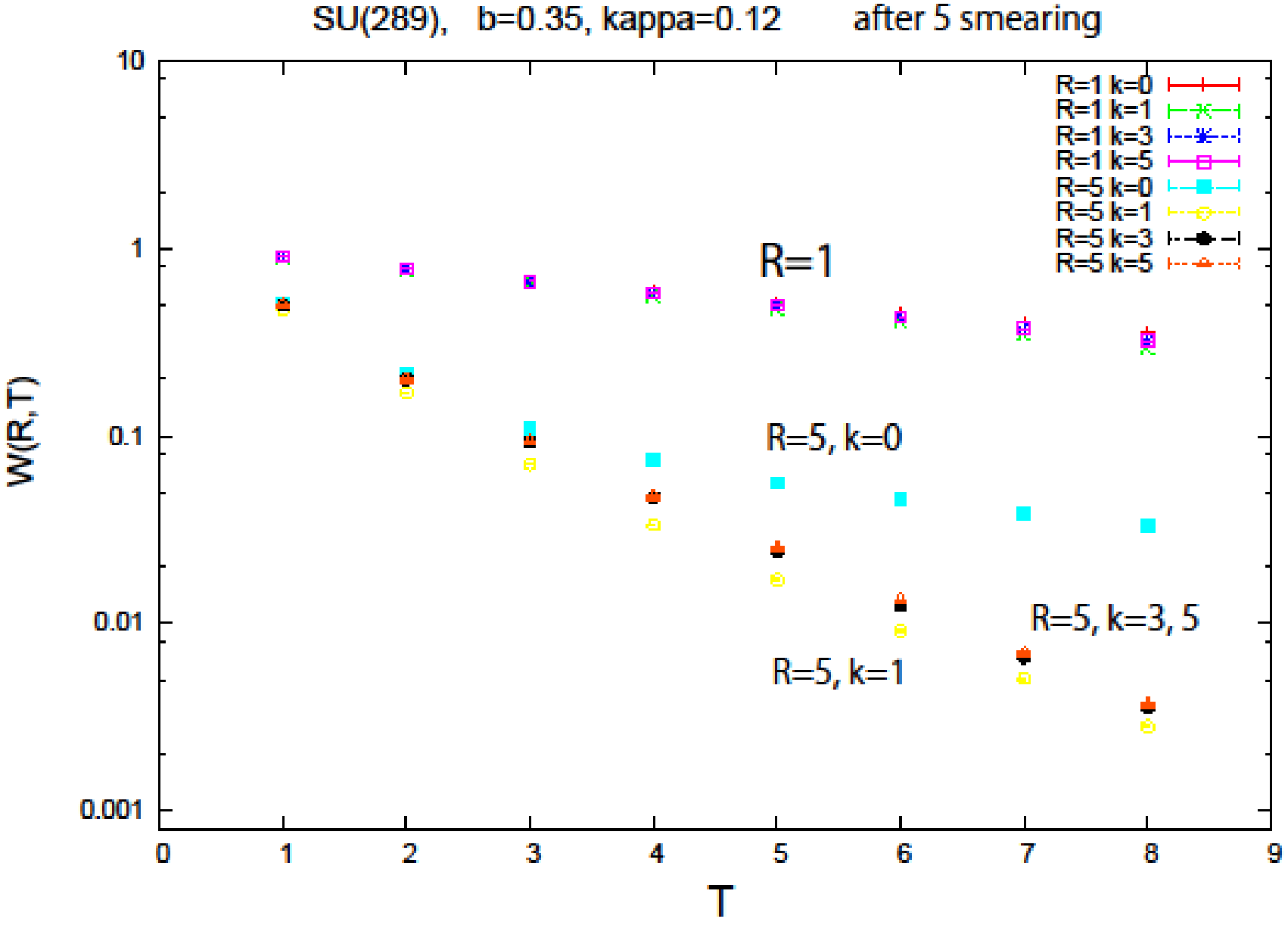
We use smearing method to obtain good statistics

$$U_{\mu}^{smeared} = \Pr oj_{SU(N)}\left[U_{\mu} + c\sum_{\nu\neq\mu}(z_{\nu\mu}U_{\nu}U_{\mu}U_{\nu}^{\dagger} + z_{\mu\nu}U_{\nu}^{\dagger}U_{\mu}U_{\nu})\right]$$

with $z_{\mu\nu}$ the twist tensor and $\Pr oj_{SU(N)}$ stands for the operator that projects onto the SU(N) matrices.

We choose c=0.1 and made 20 smearing.


SU(289), k=5, b=0.35, kappa=0.12 after 5 smearing
W(R,T)
T
1
0.1
0.01
0.001
0
1
2
3
4
5
6
7
8
9

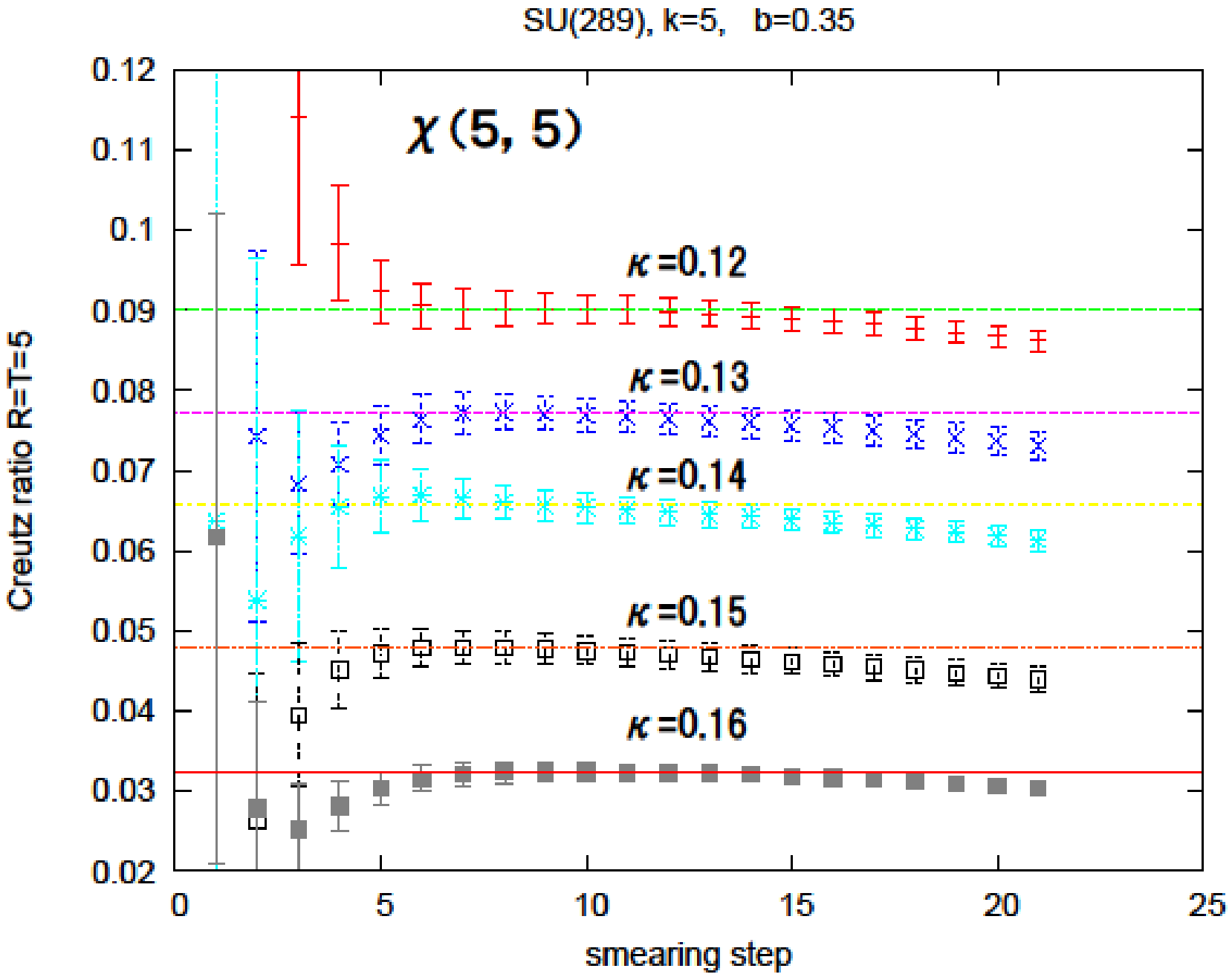

SU(289), b=0.35, kappa=0.12 after 5 smearing
W(R,T)
T
10
1
0.1
0.01
0.001
0
1
2
3
4
5
6
7
8
9
R=1 k=0
R=1 k=1
R=1 k=3
R=1 k=5
R=5 k=0
R=5 k=1
R=5 k=3
R=5 k=5
R=1
R=5, k=0
R=5, k=3, 5
R=5, k=1

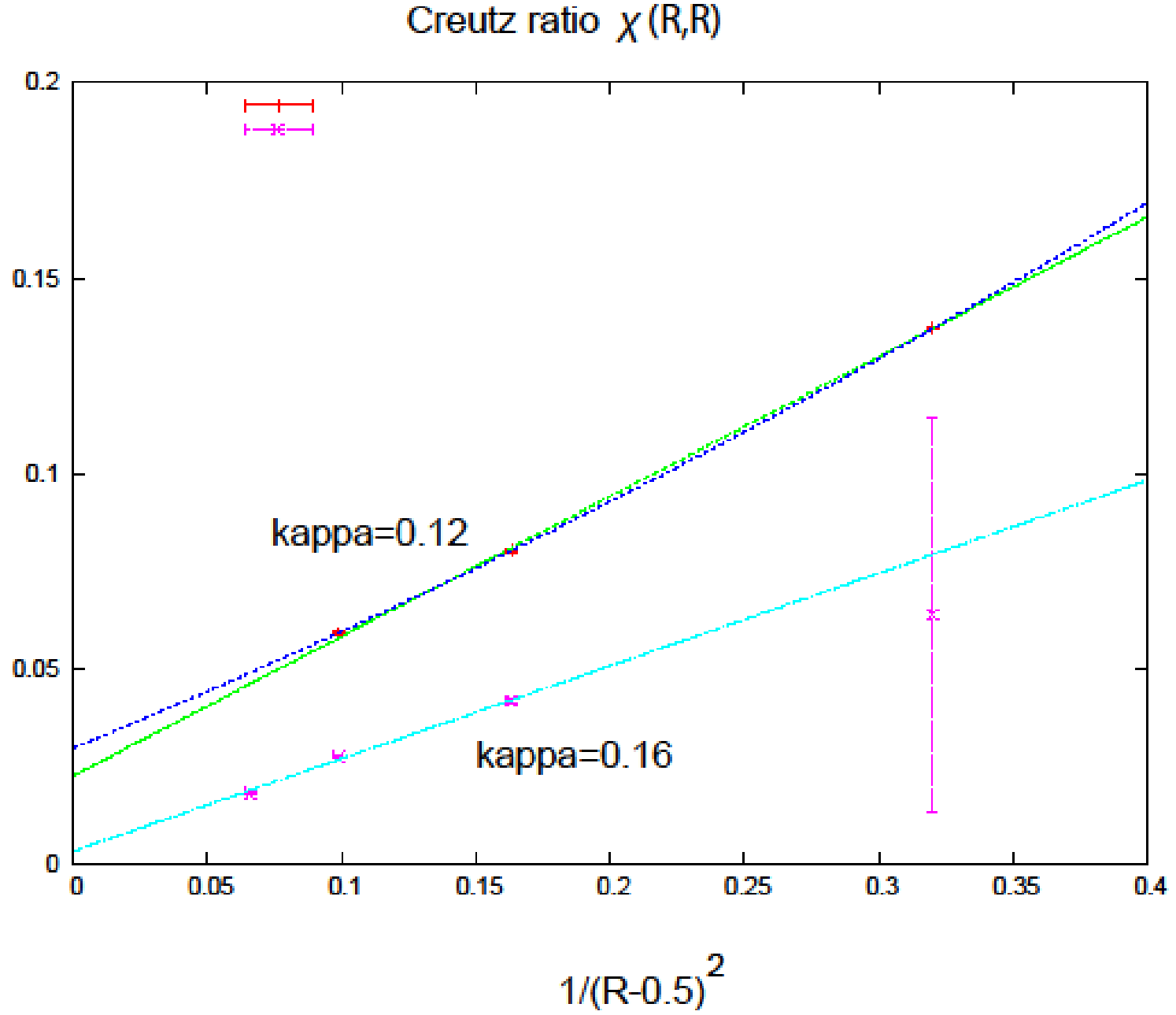
- String tension

String tension is extracted from the Creutz ratio

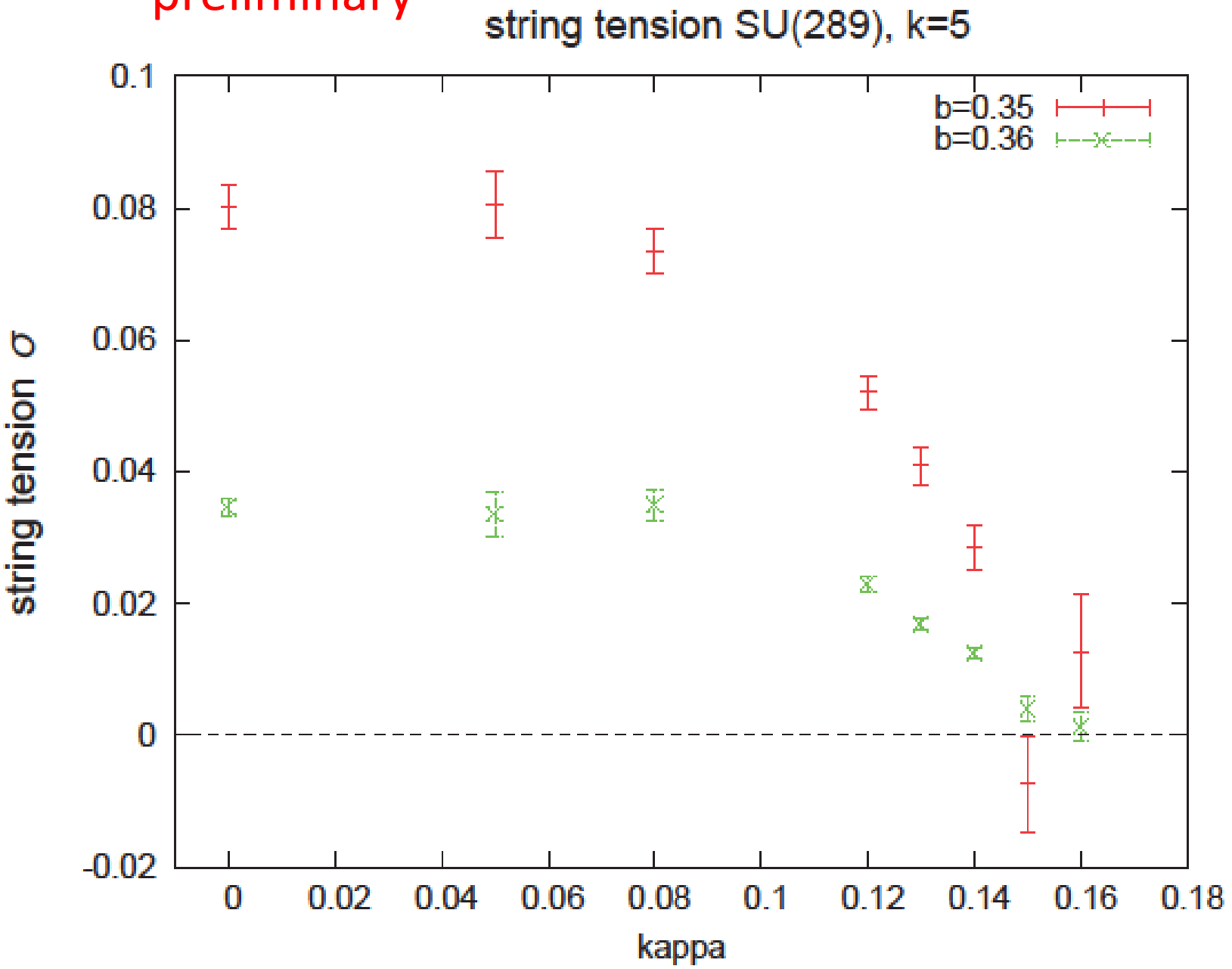
$$\chi(R,R) = -\log \frac{W(R,R)W(R-1,R-1)}{W(R,R-1)W(R-1,R)}$$

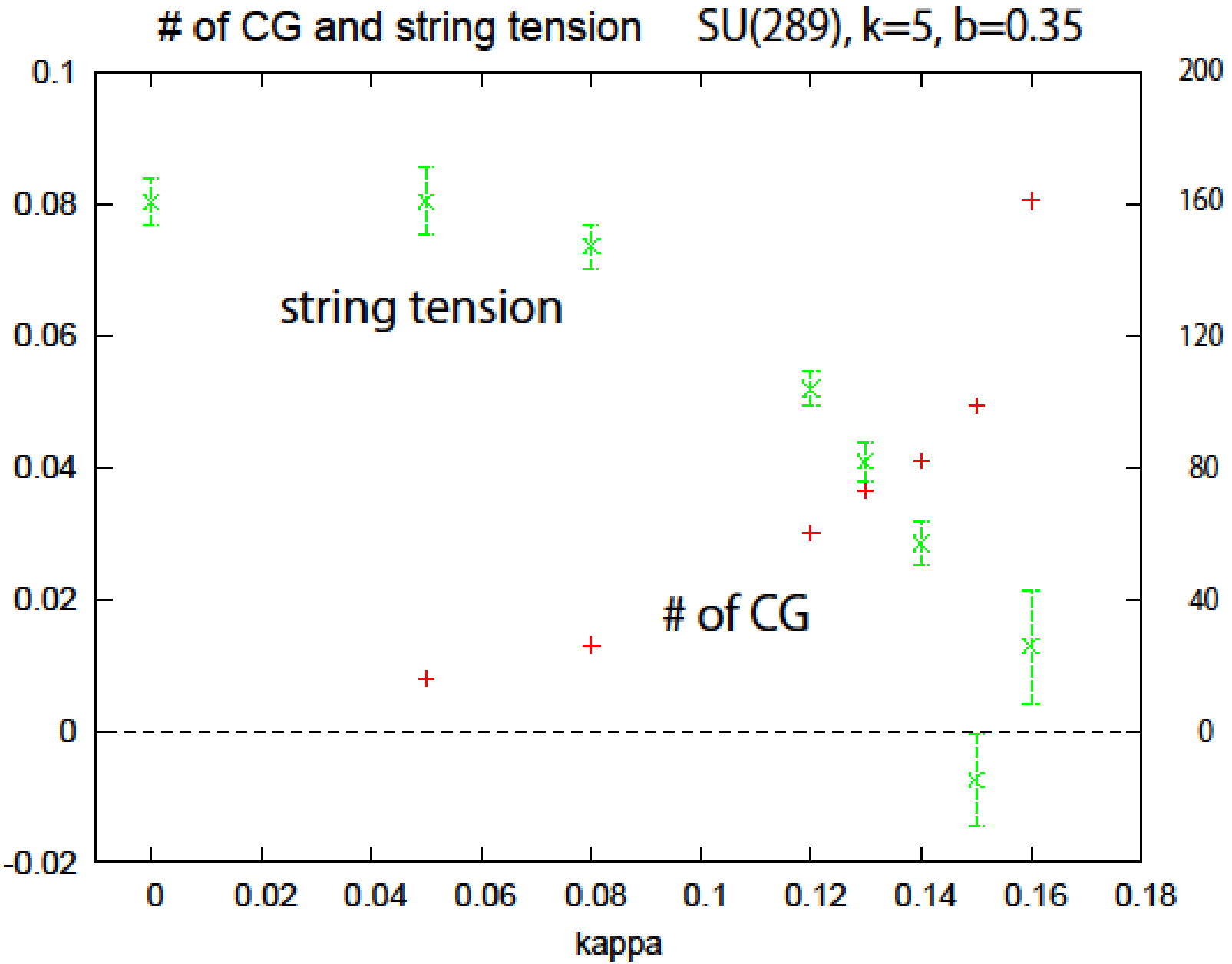
$$\sim \sigma + \frac{\gamma}{(R-0.5)^2}$$

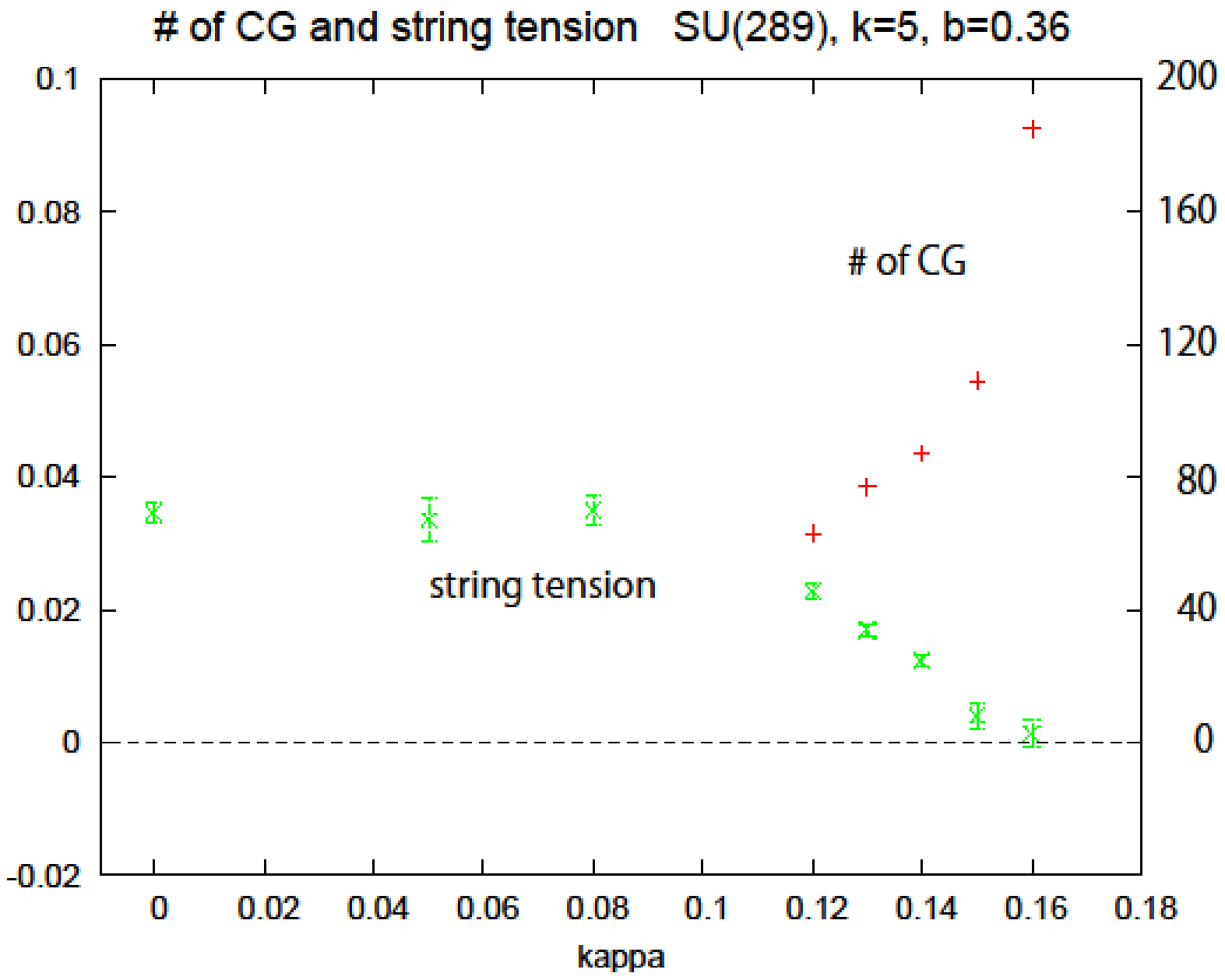

SU(289), k=5, b=0.35
χ(5, 5)
κ=0.12
κ=0.13
κ=0.14
κ=0.15
κ=0.16
Creutz ratio R=T=5
smearing step
0.12
0.11
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0
5
10
15
20
25

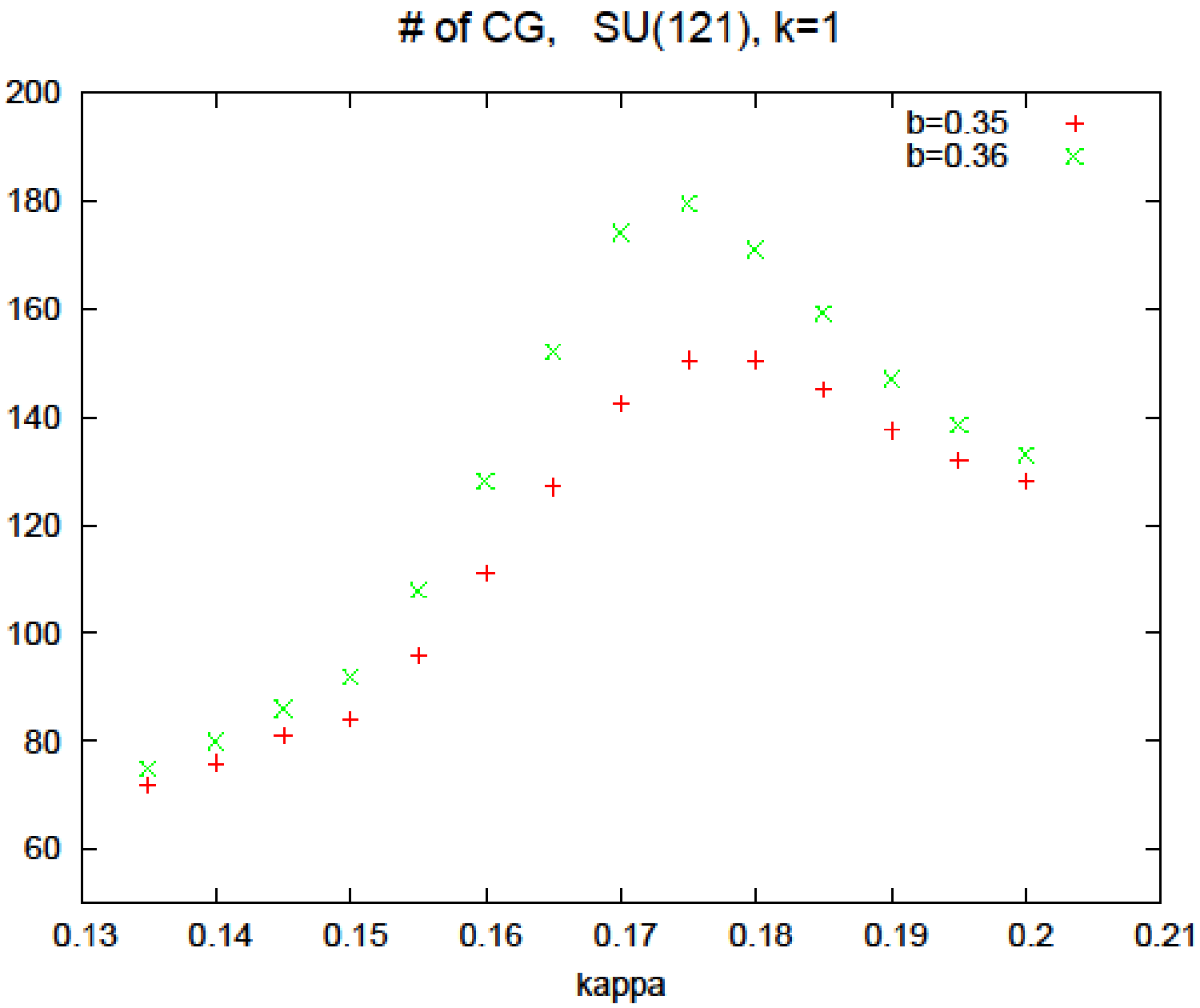

Creutz ratio $\chi(R,R)$
0.2
0.15
0.1
0.05
0
kappa=0.12
kappa=0.16
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
$1/(R-0.5)^2$

preliminary




# of CG and string tension SU(289), k=5, b=0.35
string tension
# of CG
kappa
0.1
0.08
0.06
0.04
0.02
0
-0.02
200
160
120
80
40
0
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18


# of CG and string tension SU(289), k=5, b=0.36
0.1
0.08
0.06
0.04
0.02
0
-0.02
200
160
120
80
40
0
# of CG
string tension
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
kappa


# of CG, SU(121), k=1
b=0.35
b=0.36
200
180
160
140
120
100
80
60
0.13
0.14
0.15
0.16
0.17
0.18
0.19
0.2
0.21
kappa

Conclusion

We have demonstrated that the twisted reduced model of large N QCD with two adjoint Wilson fermions works quite well.

The N dependences of the model with twisted boundary condition are significantly smaller than those of the model with periodic boundary condition.

String tension is calculated at N=289, which clearly decreases as we increase kappa and seems to vanish around kappa $\sim$ 0.16 - 0.17 .

We plan to study the twisted reduced model with one adjoint Wilson fermion .