# Charmonium spectrum with the disconnected diagram in full QCD

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# Contents

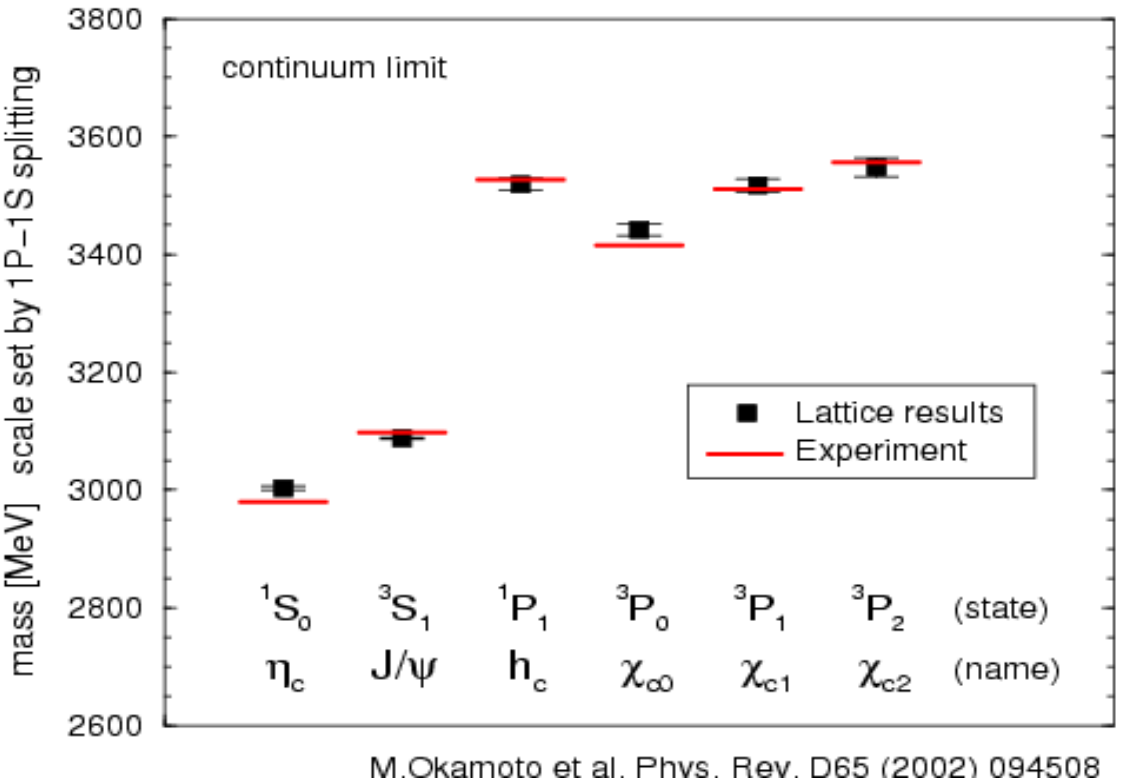
## Charmonium hyperfine splitting on the lattice

1) Introduction
2) Quenched study
3) Neglected effects
4) Calculation of disconnected diagrams
   - Lattice setup
   - Numerical results
5) Summary & Outlook

# Introduction

Charmonium spectrum on the lattice QCD

- NRQCD
- HQET
- Fermilab
- Anisotropic lattice

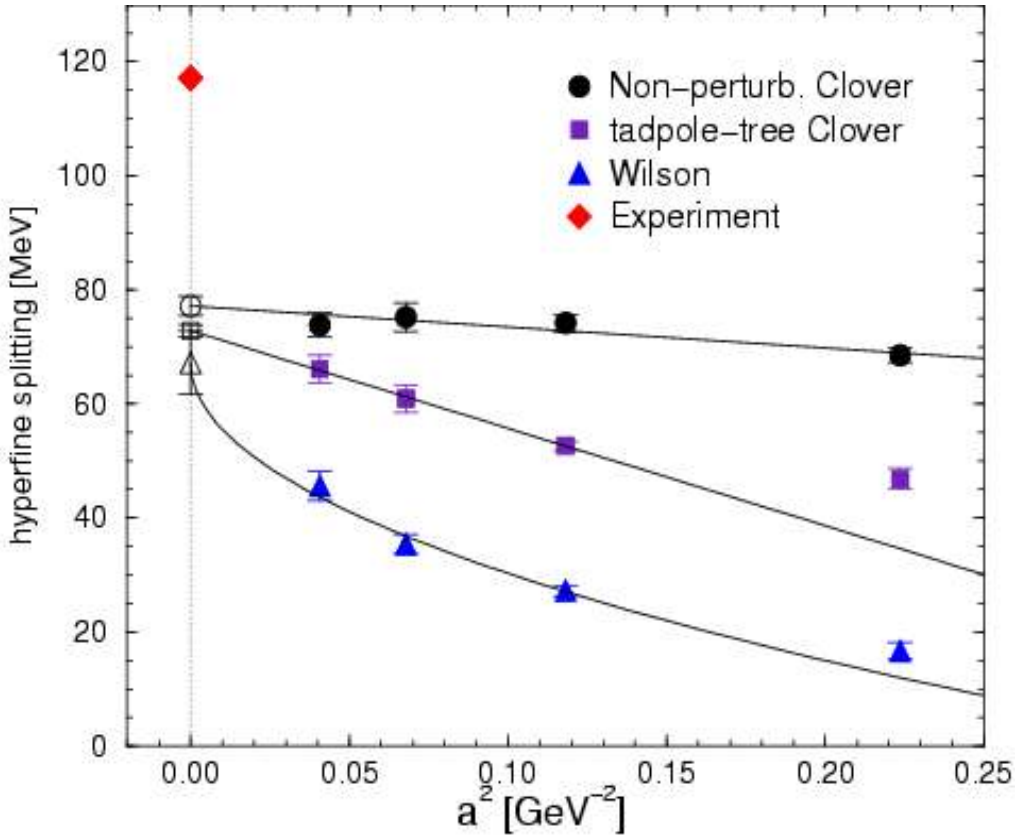



M.Okamoto et al. Phys. Rev. D65 (2002) 094508

Good agreement with the experimental value

except for the hyperfine splitting

# Quenched lattice QCD



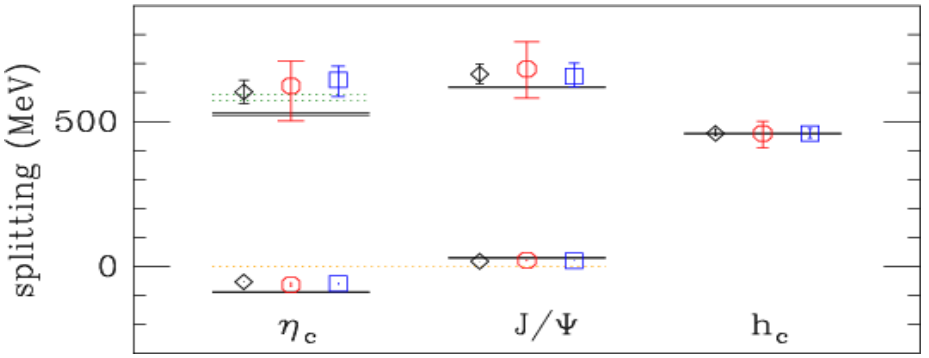

*JHEP08(2003)022*
*QCD-TARO Collabration*

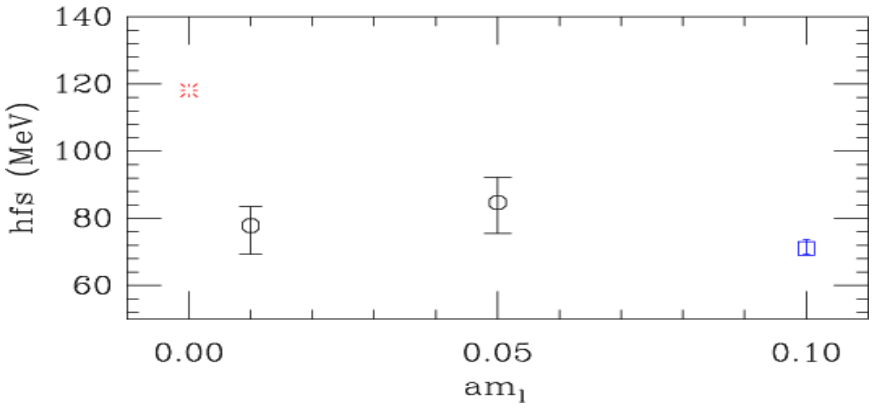
- Isotropic lattice
  with a = 0.1~0.04 fm
  ( 1/a = 2~5 GeV )
- Non-perturbative *Csw*
  *Nucl.Phys.B491(1997)323*
  *M. Lüscher et al.*

m(J/psi) – m(eta_c) = 77(2)(6) MeV in the continuum limit

30–40% smaller than the experimental value = 117 MeV

# Dynamical quark effects




*Nucl. Phys. B(PS)119(2003)586*

*M.di Pierro et al.*

- valenc quark : Fermilab action
- sea quark : KS quark

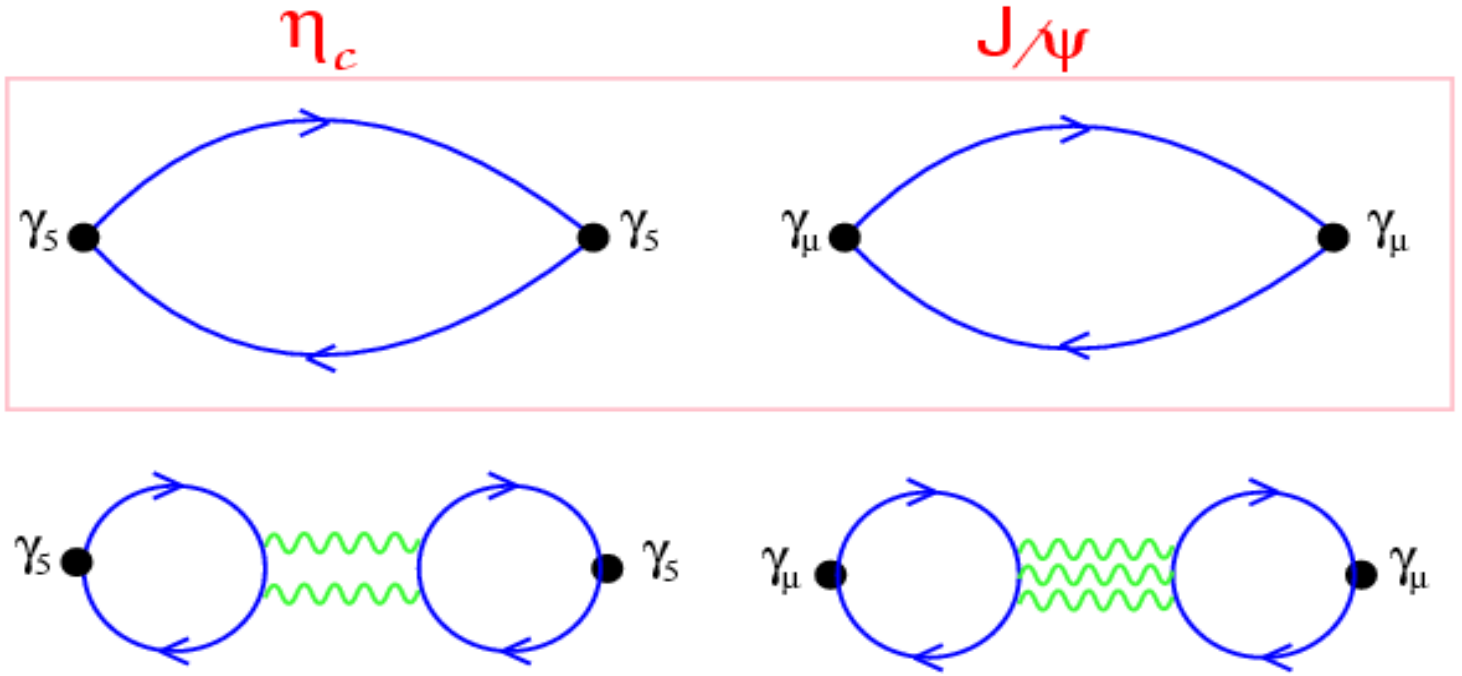
  Nf = 0, 3, 2+1
- no continuum limit a = 0.13 fm

Other full QCD studies → Dynamical quark effects ~ 10%

*T.Manke et al., Phys. Rev. D62 (2000) 114508.*

*C.Stewart and R.Koniuk, Phys. Rev. D63(2001) 054503.*

# OZI forbidden "disconnected" diagram




Disconnected diagrams are neglected

because high cost & very small contribution

however, it may contribute to HFS ~ O(10) MeV ?

# Charmonium correlators

$$C(t)=\sum_{\vec{x}}\langle \mathrm{Tr}[\Gamma D^{-1}(0,\vec{0};t,\vec{x})\Gamma D^{-1}(t,\vec{x};0,\vec{0})]\rangle$$

$$D(t)=\sum_{\vec{x}}\langle \mathrm{Tr}[\Gamma D^{-1}(0,\vec{0};0,\vec{0})]\mathrm{Tr}[\Gamma D^{-1}(t,\vec{x};t,\vec{x})]\rangle$$

$D^{-1}(t,\vec{x};t',\vec{x}')$ : quark propagator

- $\Gamma=\gamma_5,\gamma_\mu$ ( Pseudoscalar, Vector )
- source & sink operators are extended with $\phi(\vec{x})\propto\exp(a|\vec{x}|^p)$
- disconnected diagrams are evaluated with

  the complex Z2-noise method

# Lattice setup

- Sea quark : Nf=2 KS quark : m_q=0.1

  plaquette gauge : beta=5.50

  lattice size : 12^3 x 24

  lattice spacing : a=0.16fm (1/a=1.2GeV) set by r_0

  16,000 traj. ( measurement at every 5 traj. )

- Valence quark : Fermilab action

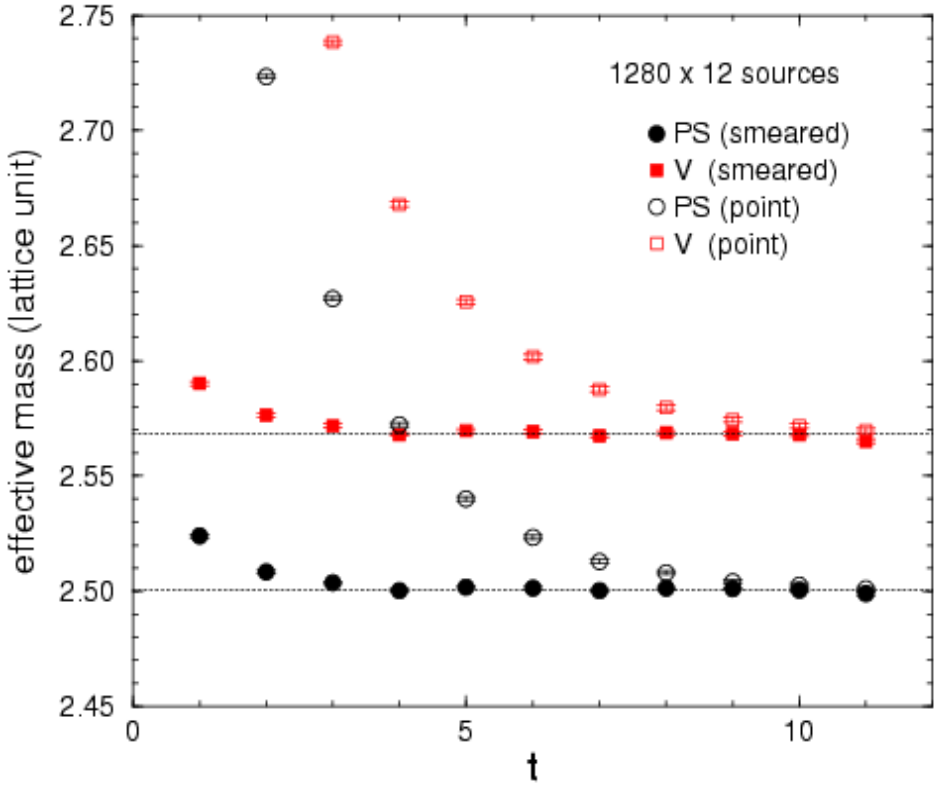
  Csw : tadpole improved tree-level (u_0 in Landau gauge)

  kappa=0.09342 set by m(J/psi)

- Z2-noise method

  N_noise=600

# Smeared operators



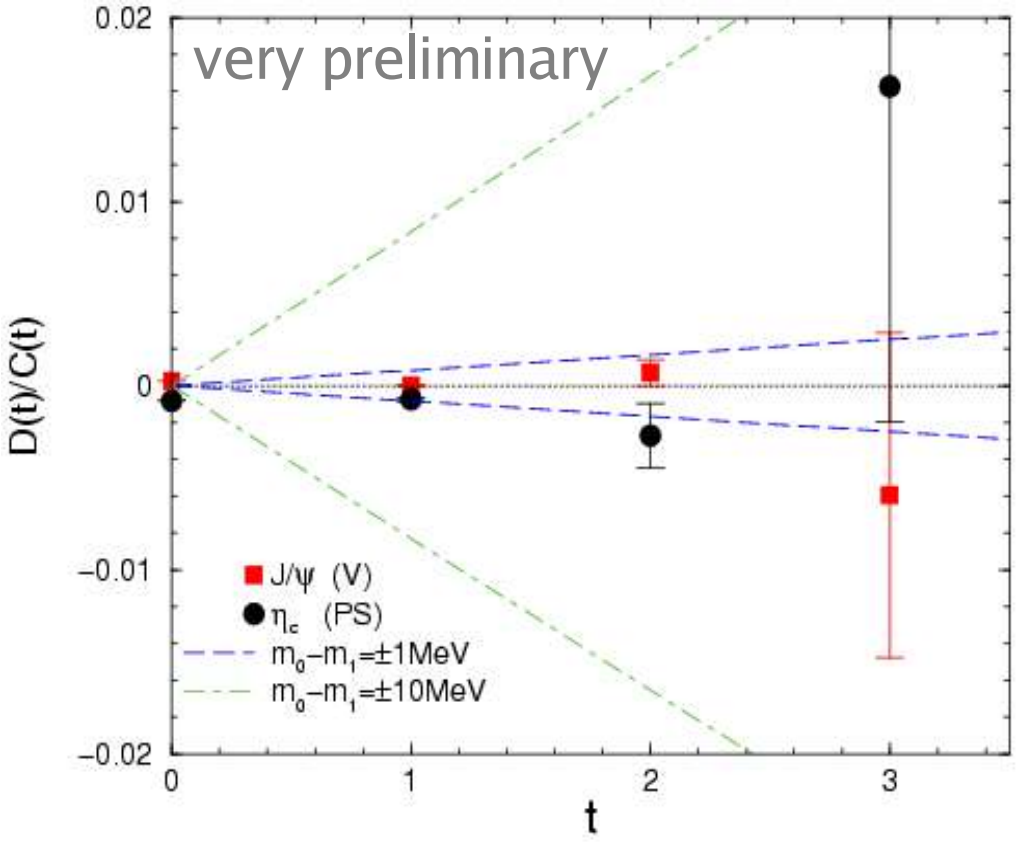

Effective mass plot
of connected diagram C(t)

Smearing functions $\phi(\vec{x})$ are determined from wavefunction

Ground states dominate at t~2

m(J/psi) – m(eta_c) = 0.0676 ( ~ 81 MeV )

# Disconnected diagram contributions




When ground state dominates,

We have

$$C(t) = c\exp(-m_1 t)$$

$$C(t) + D(t) = d\exp(-m_0 t)$$

$$\Downarrow$$

$$\frac{D(t)}{C(t)} = \frac{d}{c}\exp[(m_1 - m_0)t] - 1$$

- Too noisy at large t
- Contributions of the disconnected diagram to HFS ~ O(1)MeV ?

# Summary & Outlook

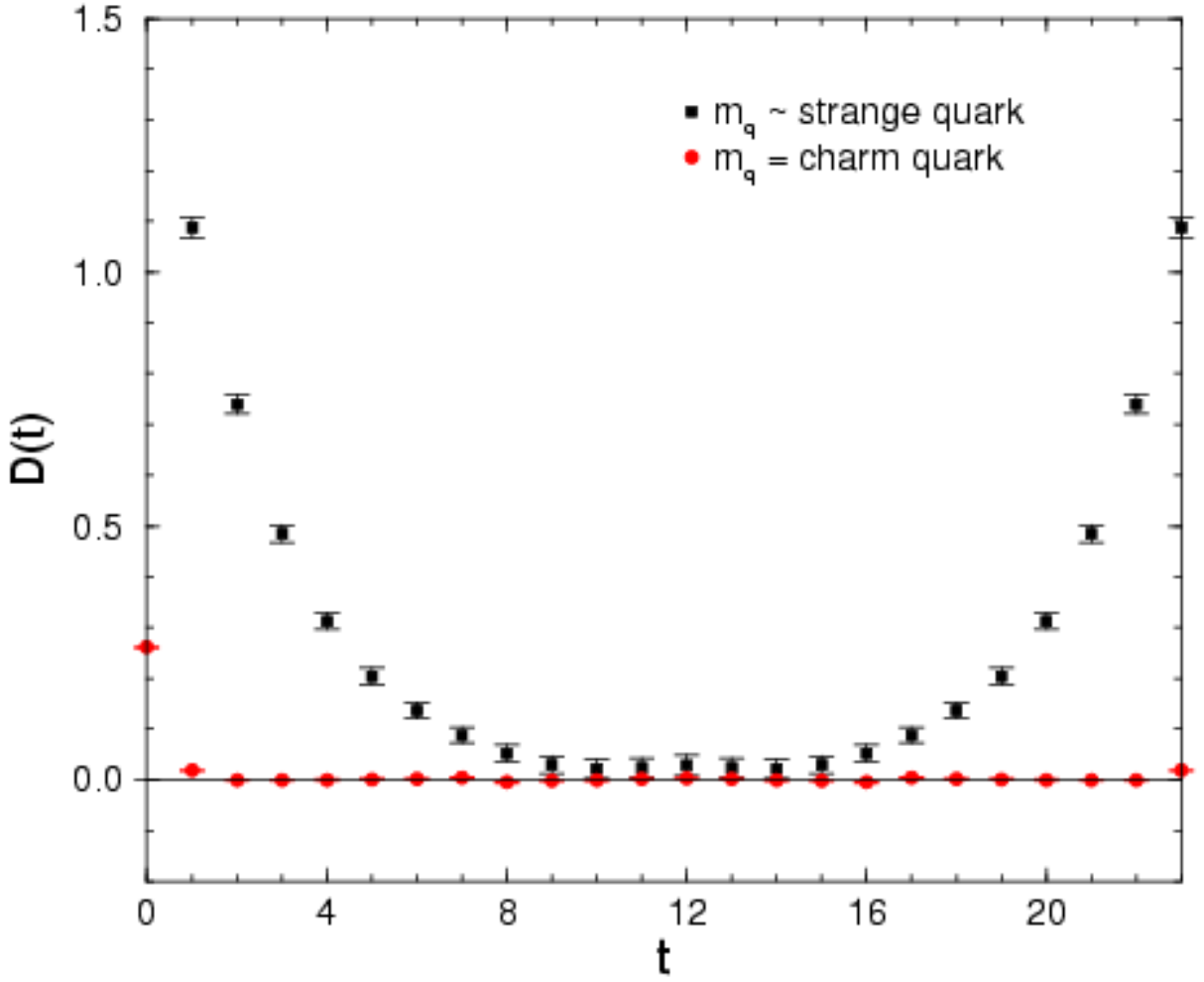
We discuss the problem of charmonium HFS
and consider a possibility of disconnected diagram contributions

Disconnected diagram contributions are very small
or hidden by large error

- ✔ more config. or/and Z2-noise sample
- ✔ improved noise method

- Same calculations with smaller valence quark mass
  - ➔ extrapolation from light quark mass region
- Cutoff & sea-quark mass dependences

# Appendix: light quark region



# Appendix: Z2-noise method