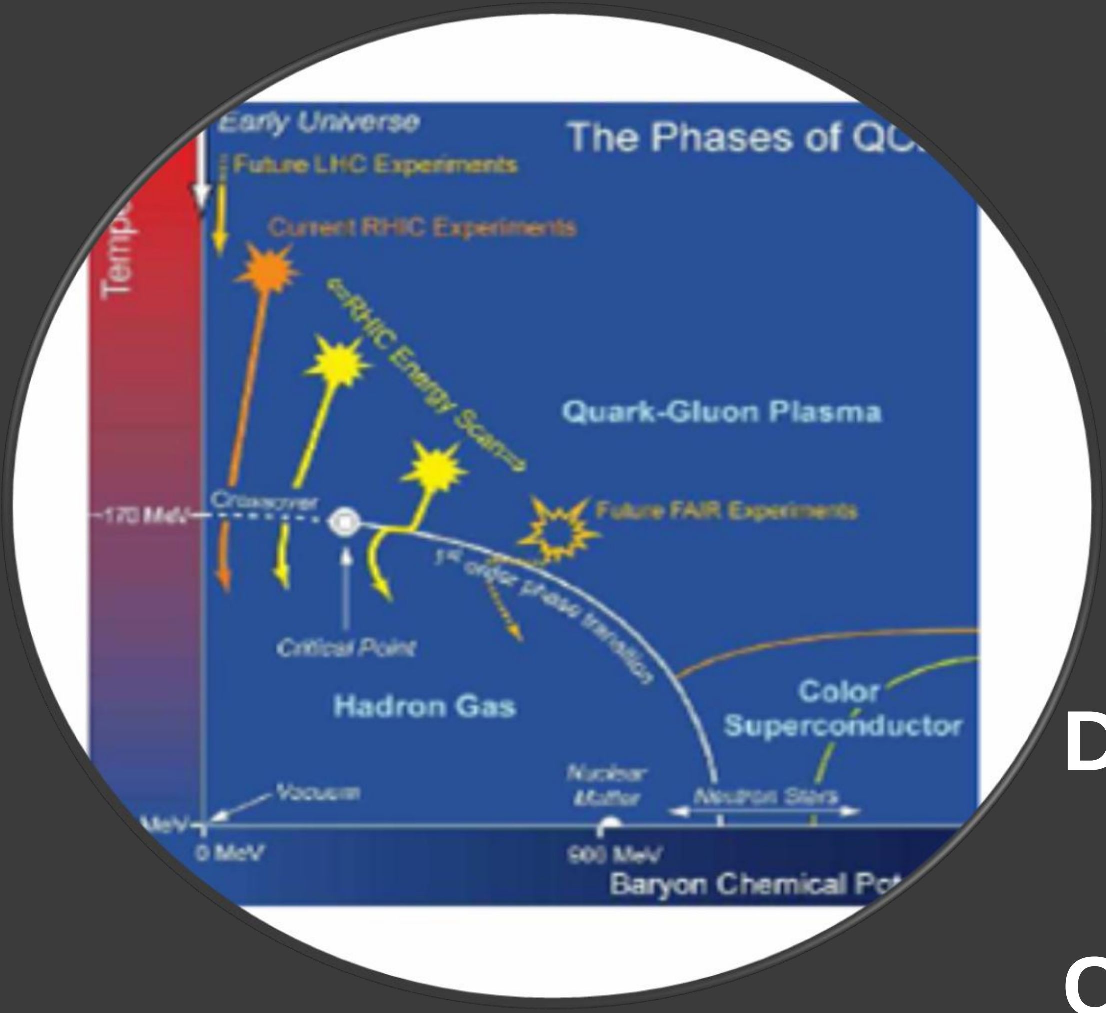
Maria Paola Lombardo

BOTTOMONIUM AND QUARK GLUON PLASMA

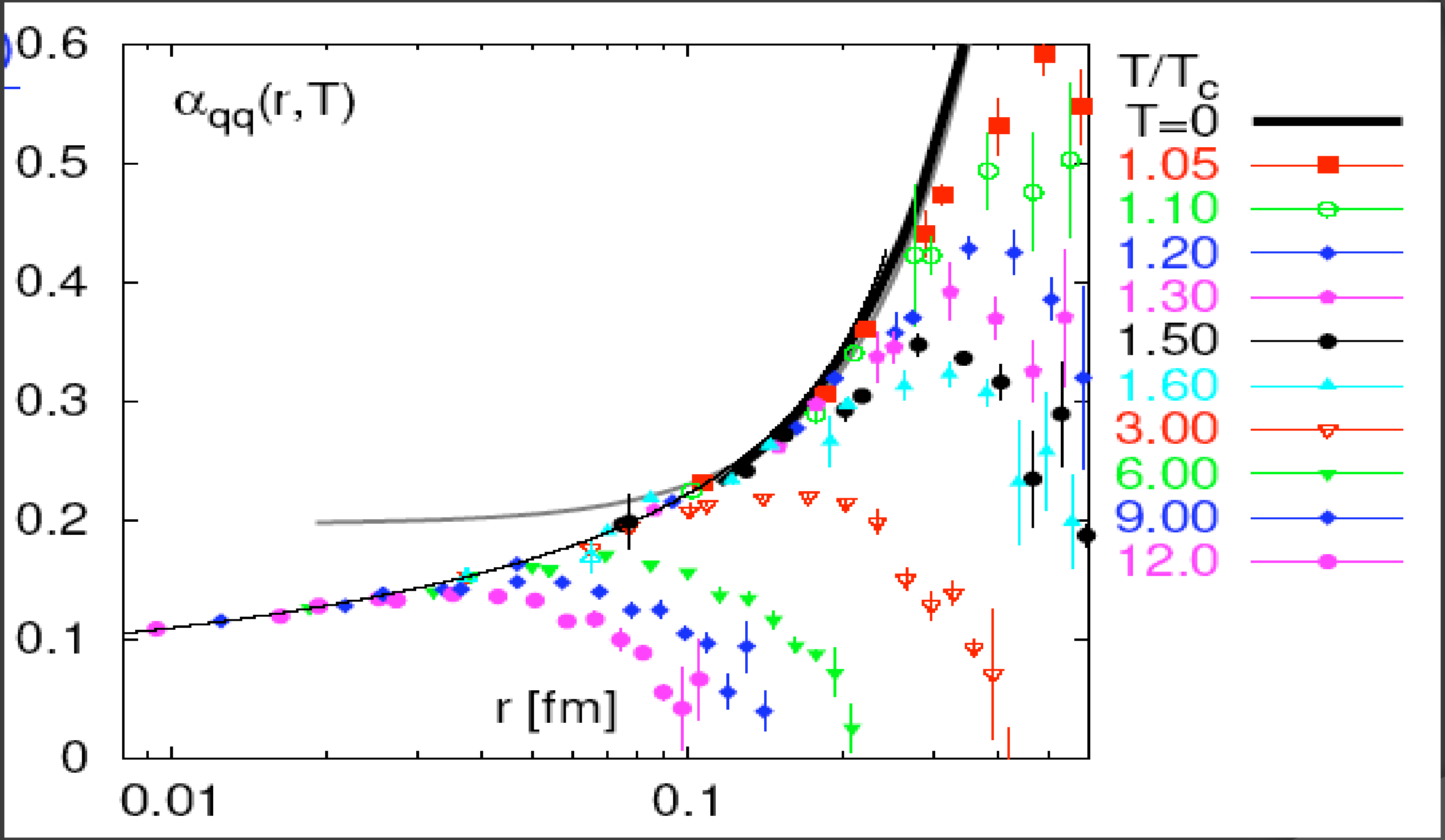
Quark Gluon Plasma



Deconfinement

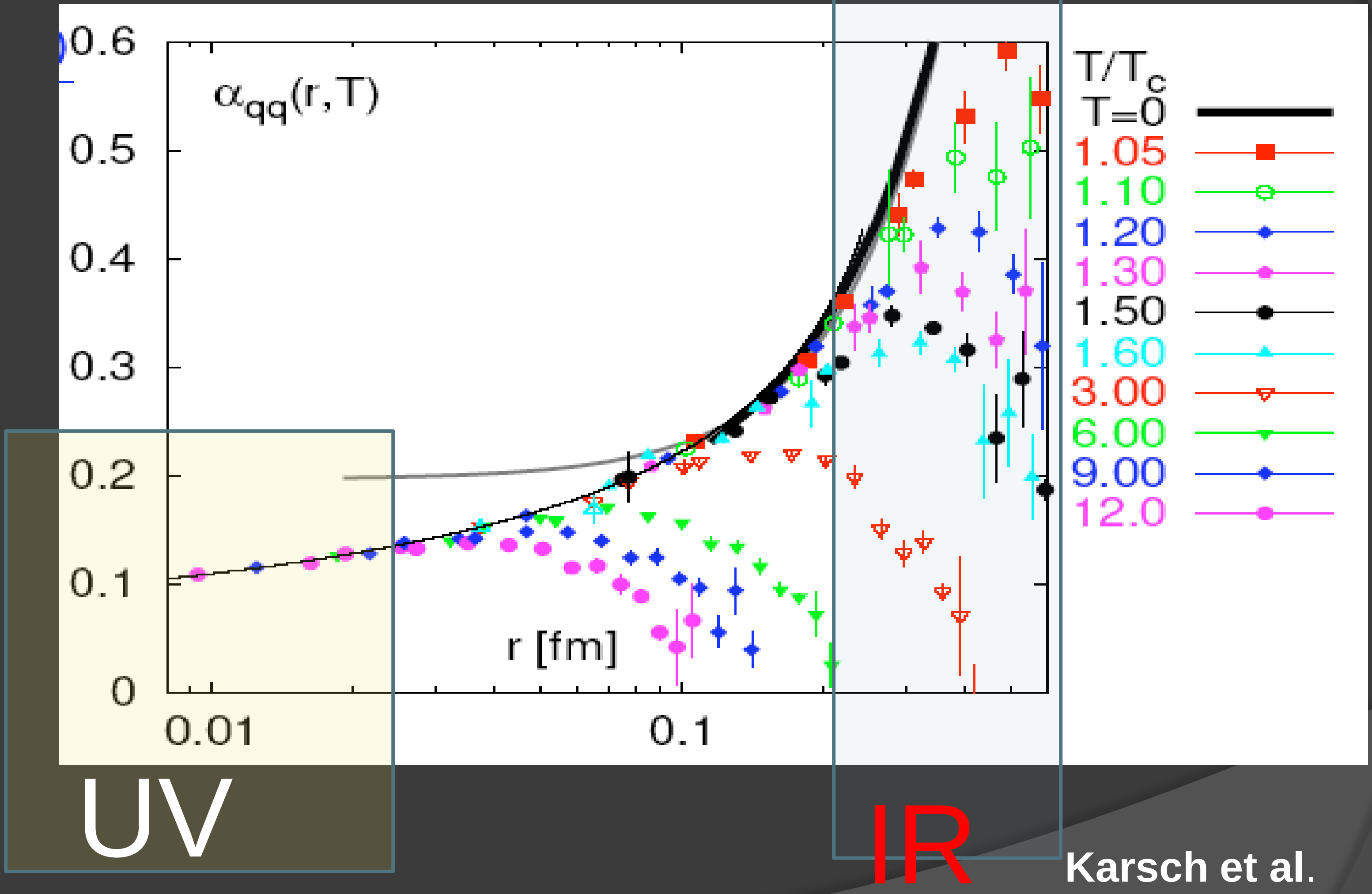
Chiral Symmetry Restoration

Running coupling from confinement to QGP



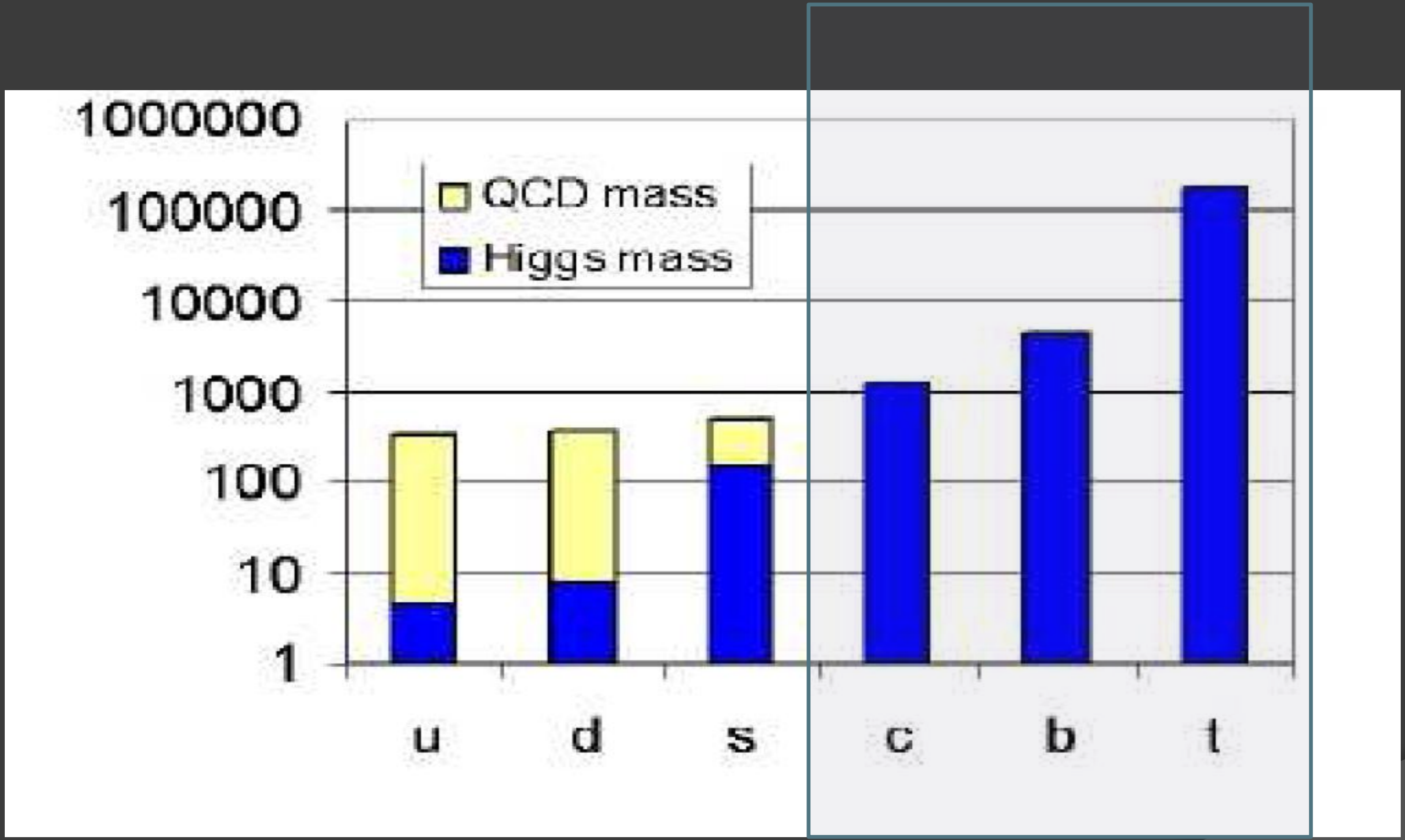
Karsch et al.

Running coupling from confinement to QGP



Karsch et al.

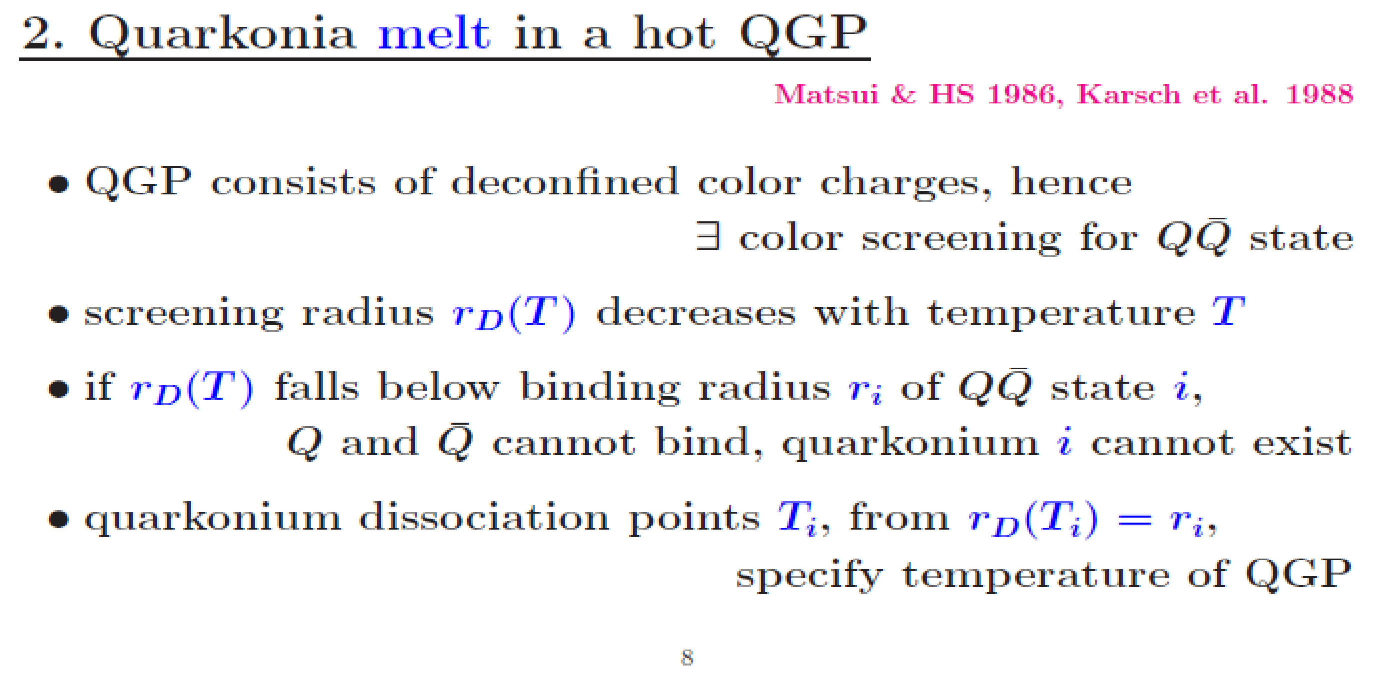
Heavy Quarks insensitive to Chiral Symmetry : Quarkonia probe Dynamics of Confinement



Picture from B. Mueller

Quarkonia and Quark Gluon Plasma

From Helmut Satz, Lecture III @ LNFI :

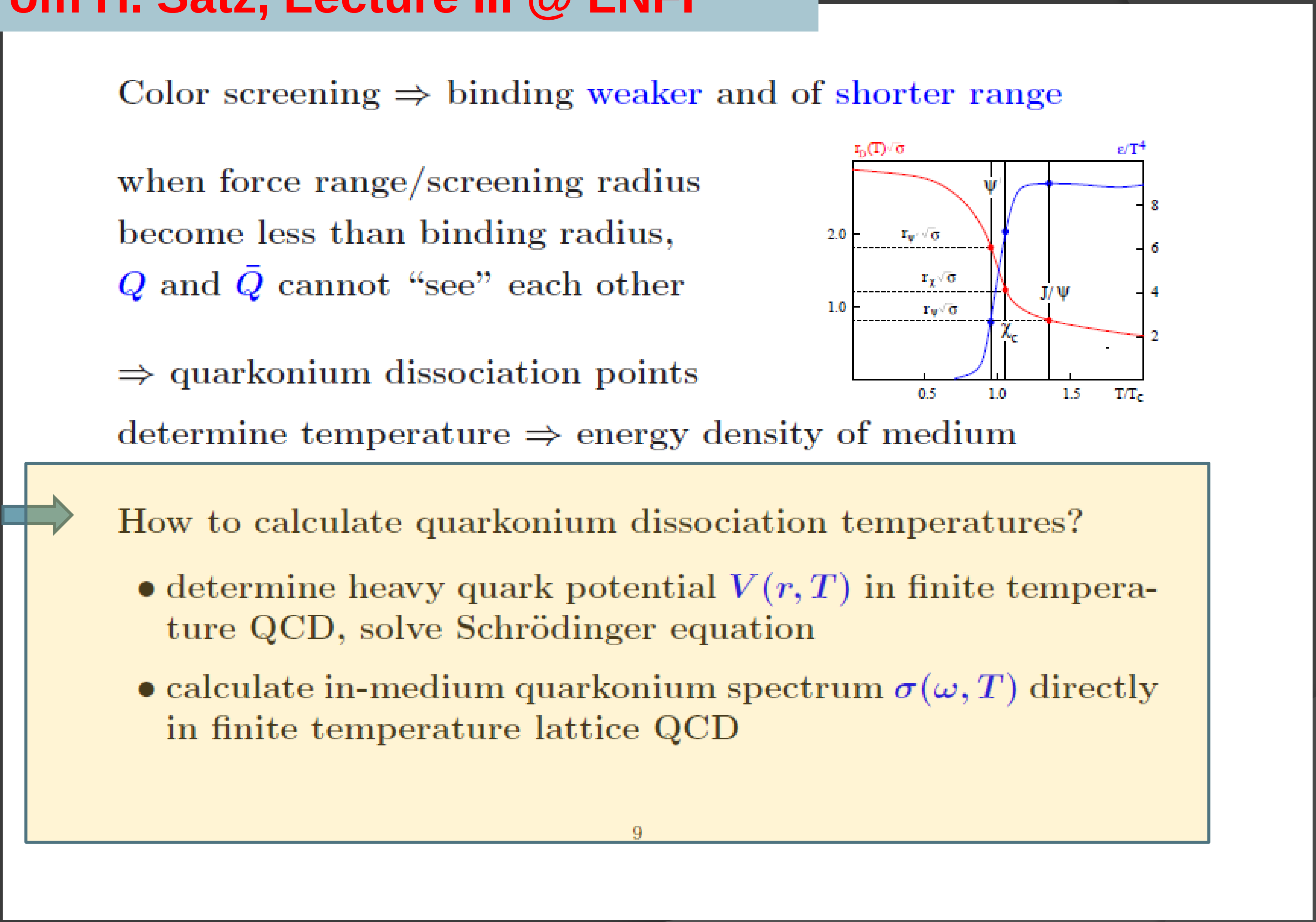


2. Quarkonia melt in a hot QGP

Matsui & HS 1986, Karsch et al. 1988

- QGP consists of deconfined color charges, hence $\exists$ color screening for $Q\bar{Q}$ state
- screening radius $r_D(T)$ decreases with temperature T
- if $r_D(T)$ falls below binding radius r_i of $Q\bar{Q}$ state i, Q and $\bar{Q}$ cannot bind, quarkonium i cannot exist
- quarkonium dissociation points T_i, from $r_D(T_i) = r_i$, specify temperature of QGP

From H. Satz, Lecture III @ LNFI



Color screening ⇒ binding weaker and of shorter range

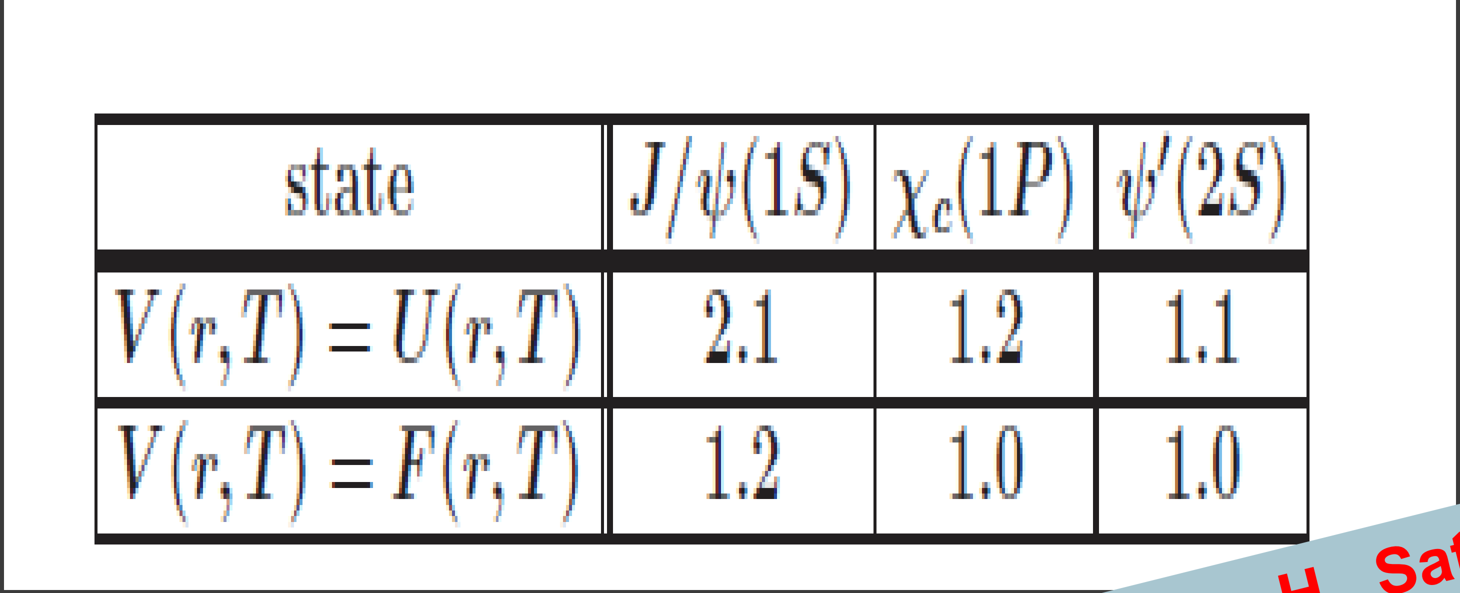
when force range/screening radius become less than binding radius, Q and $\bar{Q}$ cannot "see" each other

⇒ quarkonium dissociation points determine temperature ⇒ energy density of medium

How to calculate quarkonium dissociation temperatures?

- determine heavy quark potential $V(r,T)$ in finite temperature QCD, solve Schrödinger equation
- calculate in-medium quarkonium spectrum $\sigma(\omega,T)$ directly in finite temperature lattice QCD

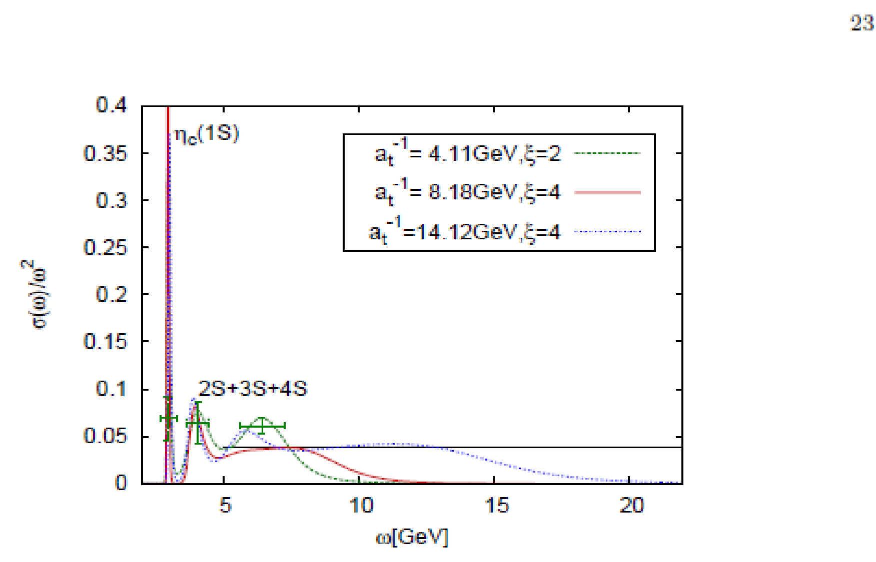
T melting from potential models: ambiguous results, pure QM not really justifiable

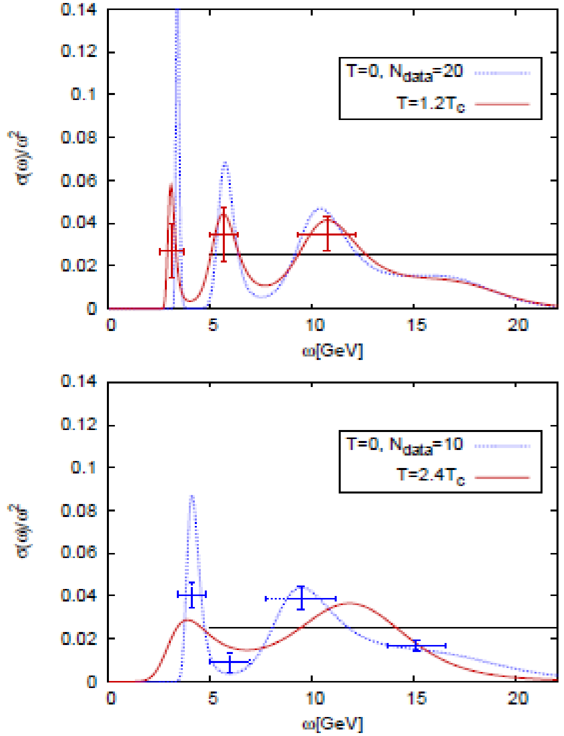


state	$J/\psi(1S)$	$\chi_c(1P)$	$\psi'(2S)$
$V(r,T)=U(r,T)$	2.1	1.2	1.1
$V(r,T)=F(r,T)$	1.2	1.0	1.0

From H. Satz

T melting from lattice QCD + MEM analysis



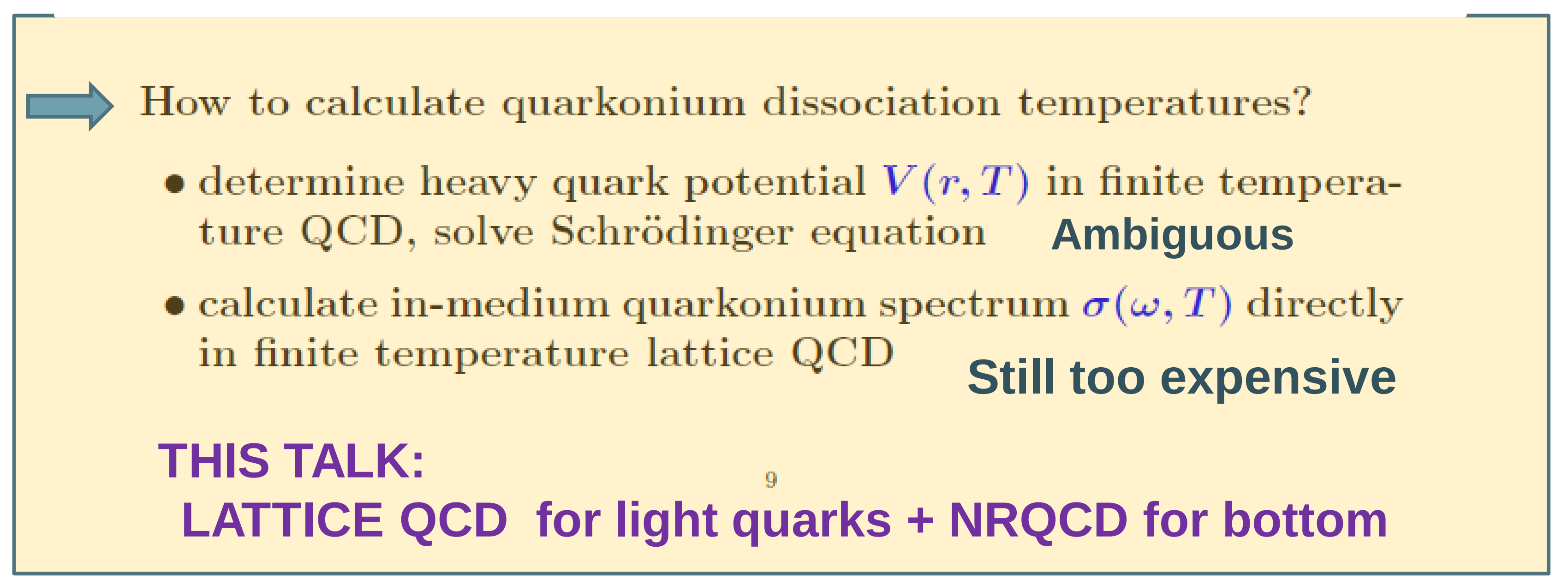


ction for $\beta = 6.5$ and $N_t = 40$, 20 corresponding to temperatures
the default model $m(\omega) = 0.01$ has been used.

Petreczky , 2009

Tentative summary of present results **(H. Satz)**

- J/ψ survives up to $T \simeq 1.5 - 2.0\ T_c$
- χ and ψ' dissociated at or slightly above T_c
- in accord with U-based potential studies



How to calculate quarkonium dissociation temperatures?

- determine heavy quark potential $V(r,T)$ in finite temperature QCD, solve Schrödinger equation **Ambiguous**
- calculate in-medium quarkonium spectrum $\sigma(\omega,T)$ directly in finite temperature lattice QCD **Still too expensive**

THIS TALK:

LATTICE QCD for light quarks + NRQCD for bottom

BOTTOMONIUM AND QUARK GLUON PLASMA

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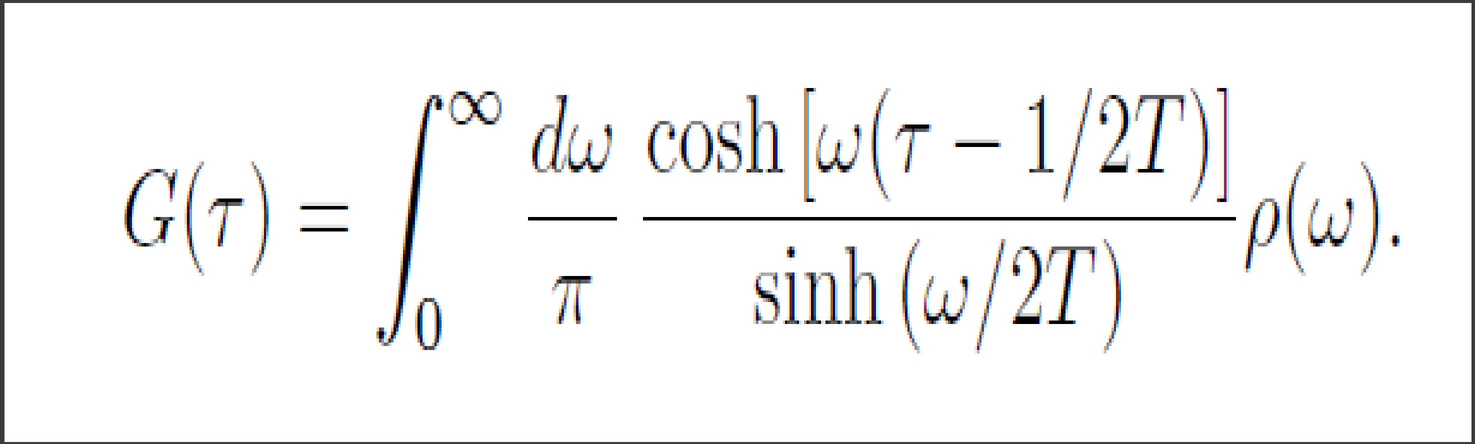
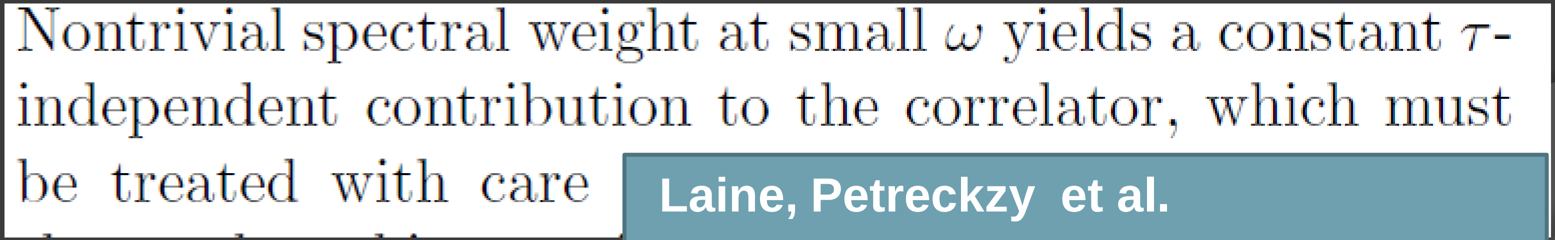
PHYS. REV. LETT. 106 (2011)

WORK IN PROGRESS +C. ALLTON :
FASTSUM COLLABORATION

Three steps to Bottomonium:
1. Work in Euclidean space…..



$$G(\tau) = \int_0^\infty \frac{d\omega}{\pi} \frac{\cosh\left[\omega(\tau - 1/2T)\right]}{\sinh\left(\omega/2T\right)} \rho(\omega).$$



Nontrivial spectral weight at small ω yields a constant τ-independent contribution to the correlator, which must be treated with care

Laine, Petreckzy et al.

..use NRQCD – still valid in our T range

$$\omega = 2M + \omega'$$

$$M \gg T$$

$$G(\tau) = \int_{-2M}^{\infty} \frac{d\omega'}{\pi} \exp(-\omega'\tau)\rho(\omega') \qquad \text{(NRQCD)}$$

and consider free behaviour for S and P waves

$$G_S(\tau) \sim \int \frac{d^3p}{(2\pi)^3} \exp(-2E_{\mathbf{p}}\tau) \sim \tau^{-3/2},$$

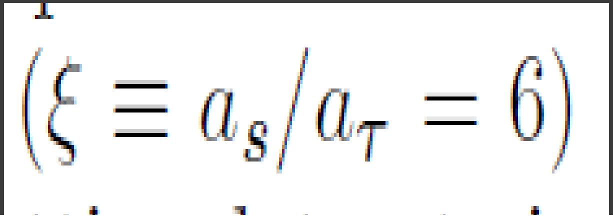
$$G_P(\tau) \sim \int \frac{d^3p}{(2\pi)^3} \mathbf{p}^2 \exp(-2E_{\mathbf{p}}\tau) \sim \tau^{-5/2},$$

Laine et al 2010

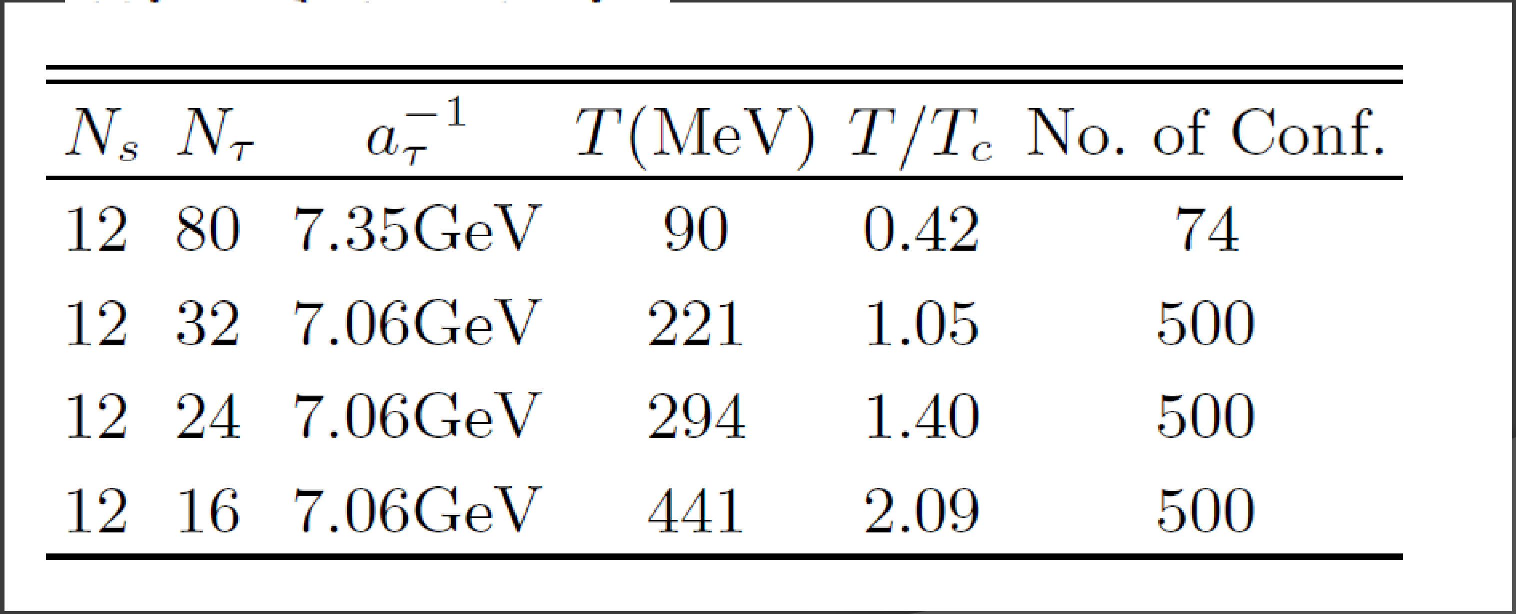
$$E_{\mathrm{p}} = \mathrm{p}^2/2M$$

Step 2:

Full Relativistic Lattice QCD for light quarks with asymmetric gauge couplings to increase number of points in t-direction



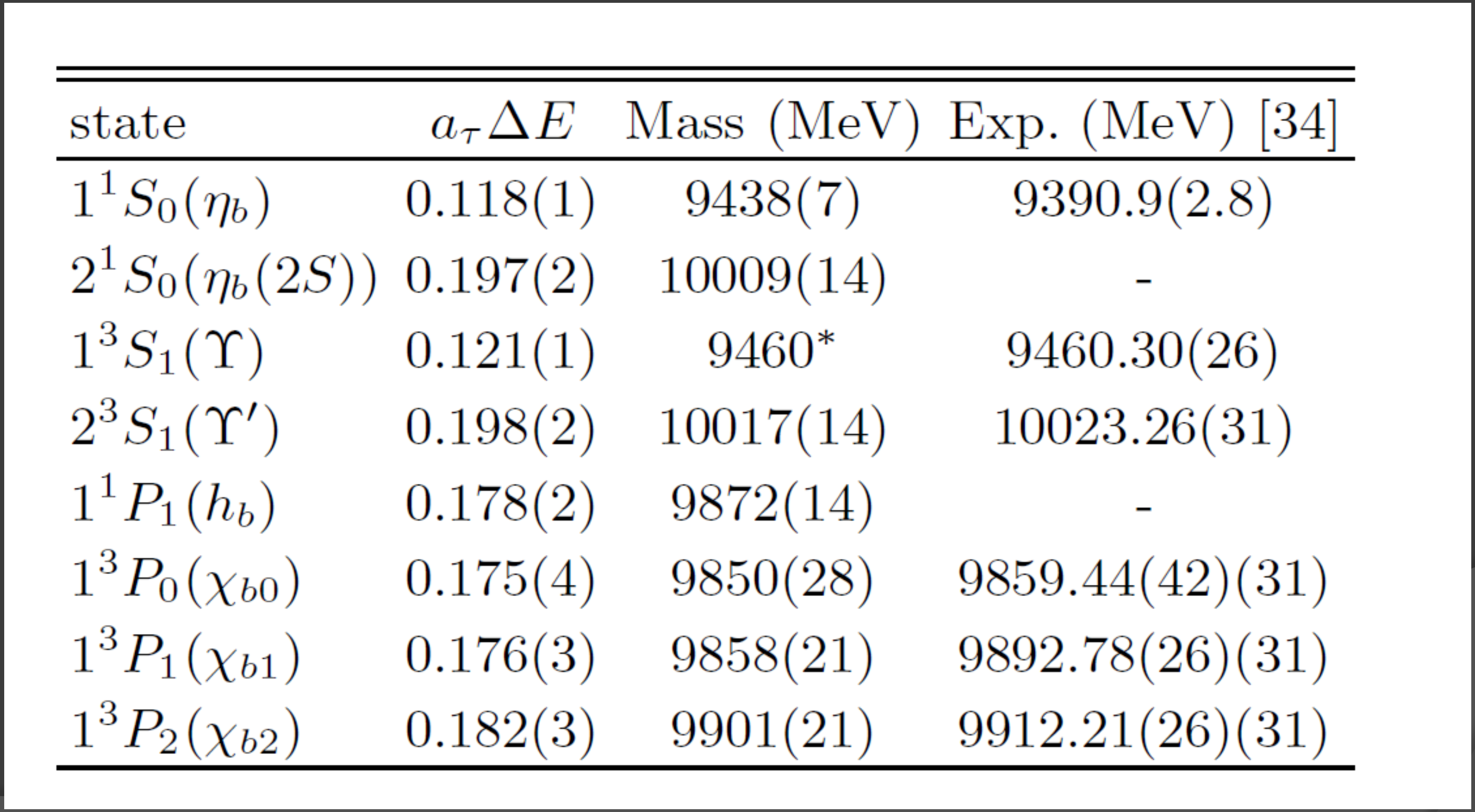
$(\xi \equiv a_s/a_\tau = 6)$



N_s	N_τ	a_τ^{-1}	T(MeV)	T/T_c	No. of Conf.
12	80	7.35GeV	90	0.42	74
12	32	7.06GeV	221	1.05	500
12	24	7.06GeV	294	1.40	500
12	16	7.06GeV	441	2.09	500

Step 3 : NRQCD for bottom quarks

Check: Zero Temperature Results



state	$a_\tau \Delta E$	Mass (MeV)	Exp. (MeV) [34]
$1^1S_0(\eta_b)$	0.118(1)	9438(7)	9390.9(2.8)
$2^1S_0(\eta_b(2S))$	0.197(2)	10009(14)	-
$1^3S_1(\Upsilon)$	0.121(1)	9460*	9460.30(26)
$2^3S_1(\Upsilon')$	0.198(2)	10017(14)	10023.26(31)
$1^1P_1(h_b)$	0.178(2)	9872(14)	-
$1^3P_0(\chi_{b0})$	0.175(4)	9850(28)	9859.44(42)(31)
$1^3P_1(\chi_{b1})$	0.176(3)	9858(21)	9892.78(26)(31)
$1^3P_2(\chi_{b2})$	0.182(3)	9901(21)	9912.21(26)(31)

Υ *and* χ_b *in the plasma* :RESULTS

Bound states

$$G(\tau) \sim \exp(-\Delta E \tau),$$

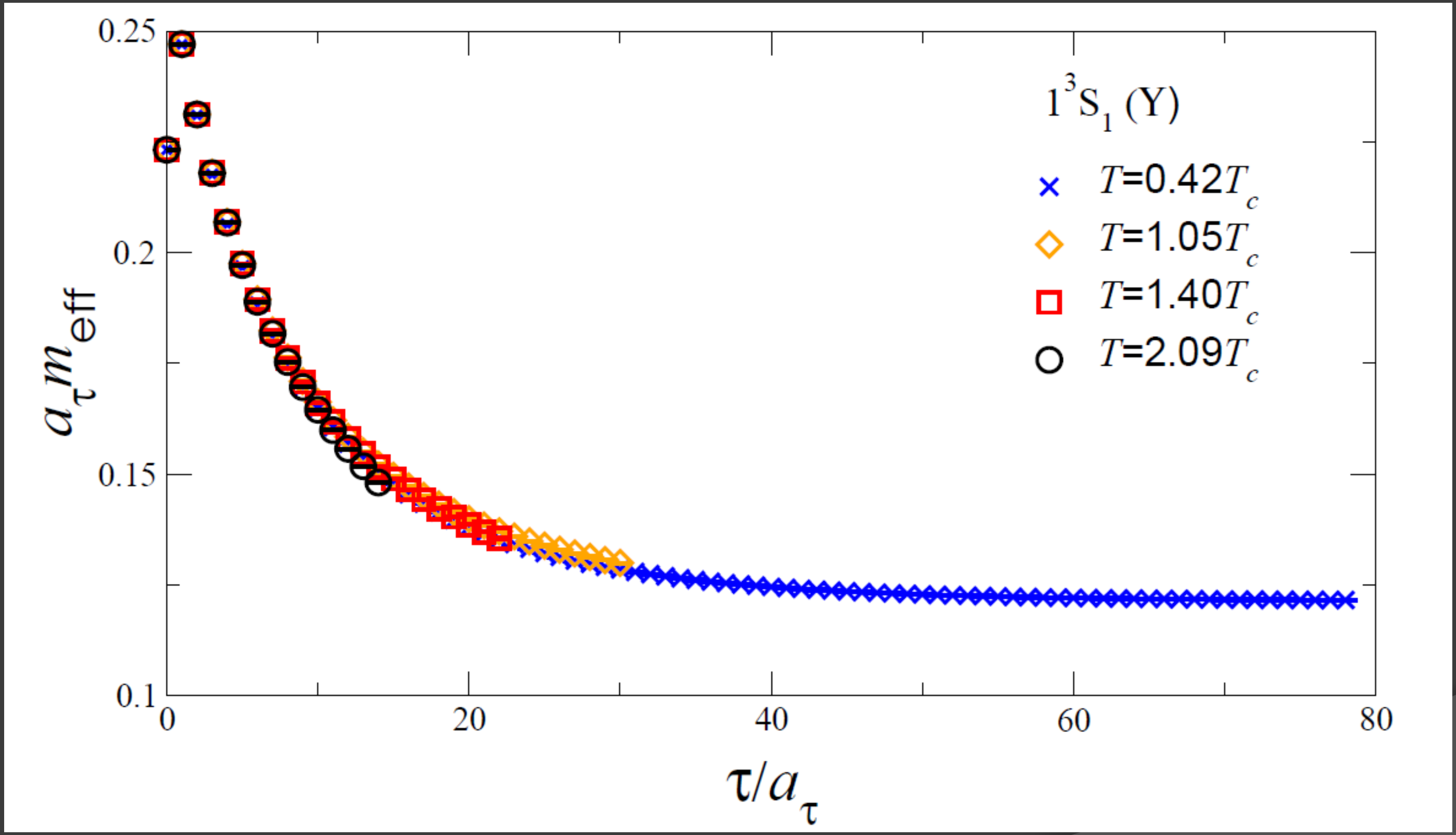
$$m_{\rm eff}(\tau) = -\log[G(\tau)/G(\tau - a_\tau)],$$

Free quarks

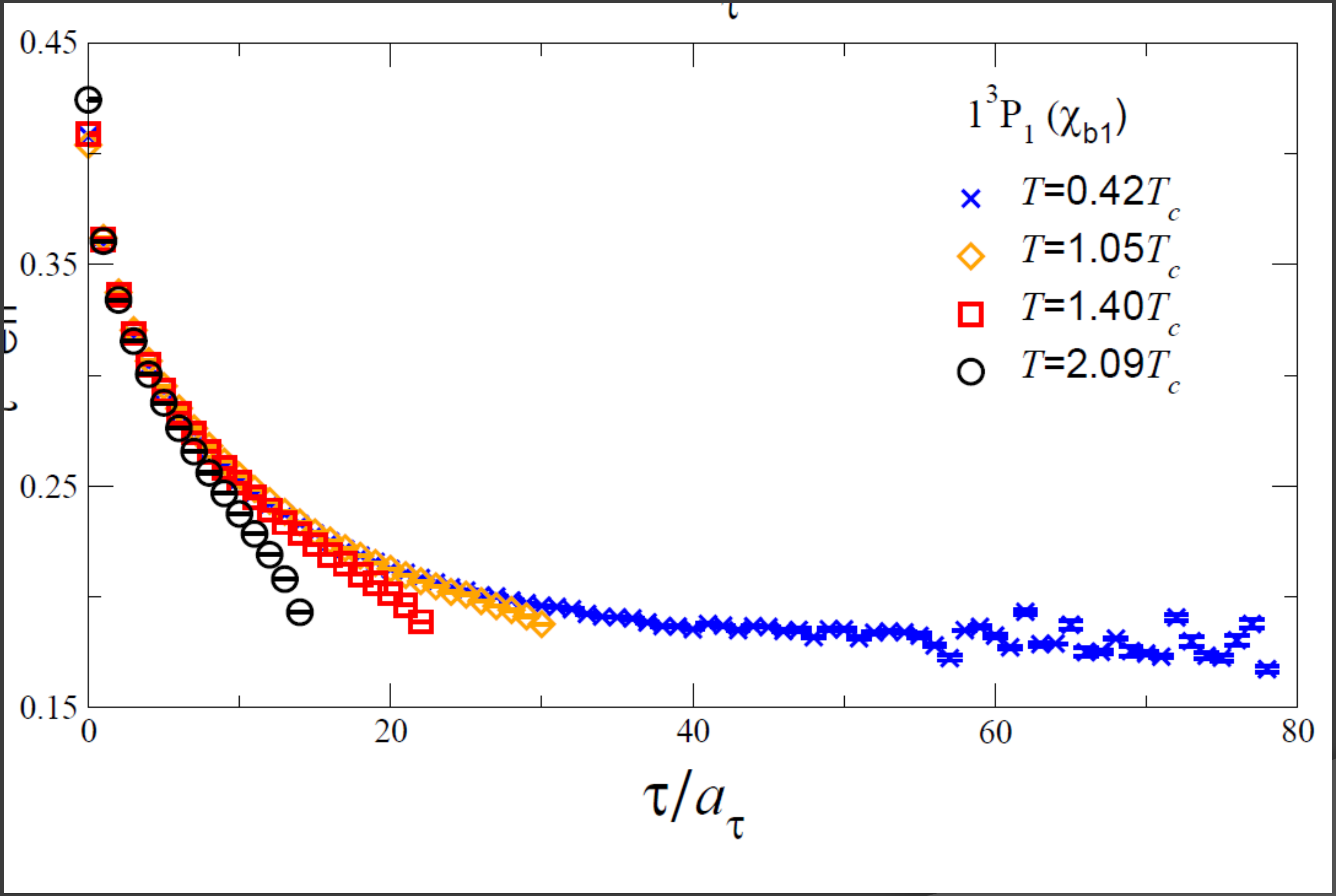
$$G(\tau) \sim \tau^{-\gamma}$$

$$\gamma_{\rm eff}(\tau) = -\tau \frac{G'(\tau)}{G(\tau)} = -\tau \frac{G(\tau + a_\tau) - G(\tau - a_\tau)}{2a_\tau G(\tau)},$$

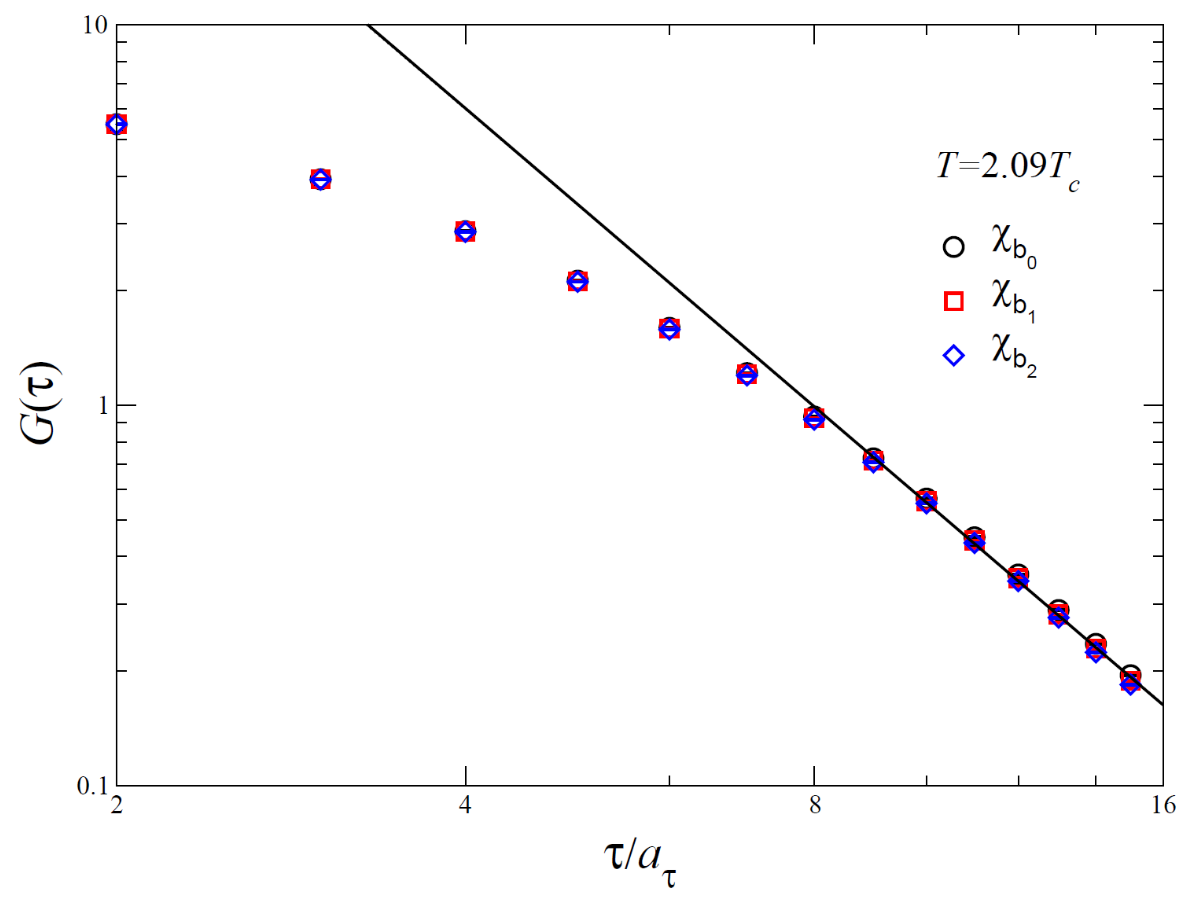
Effective mass for the Υ



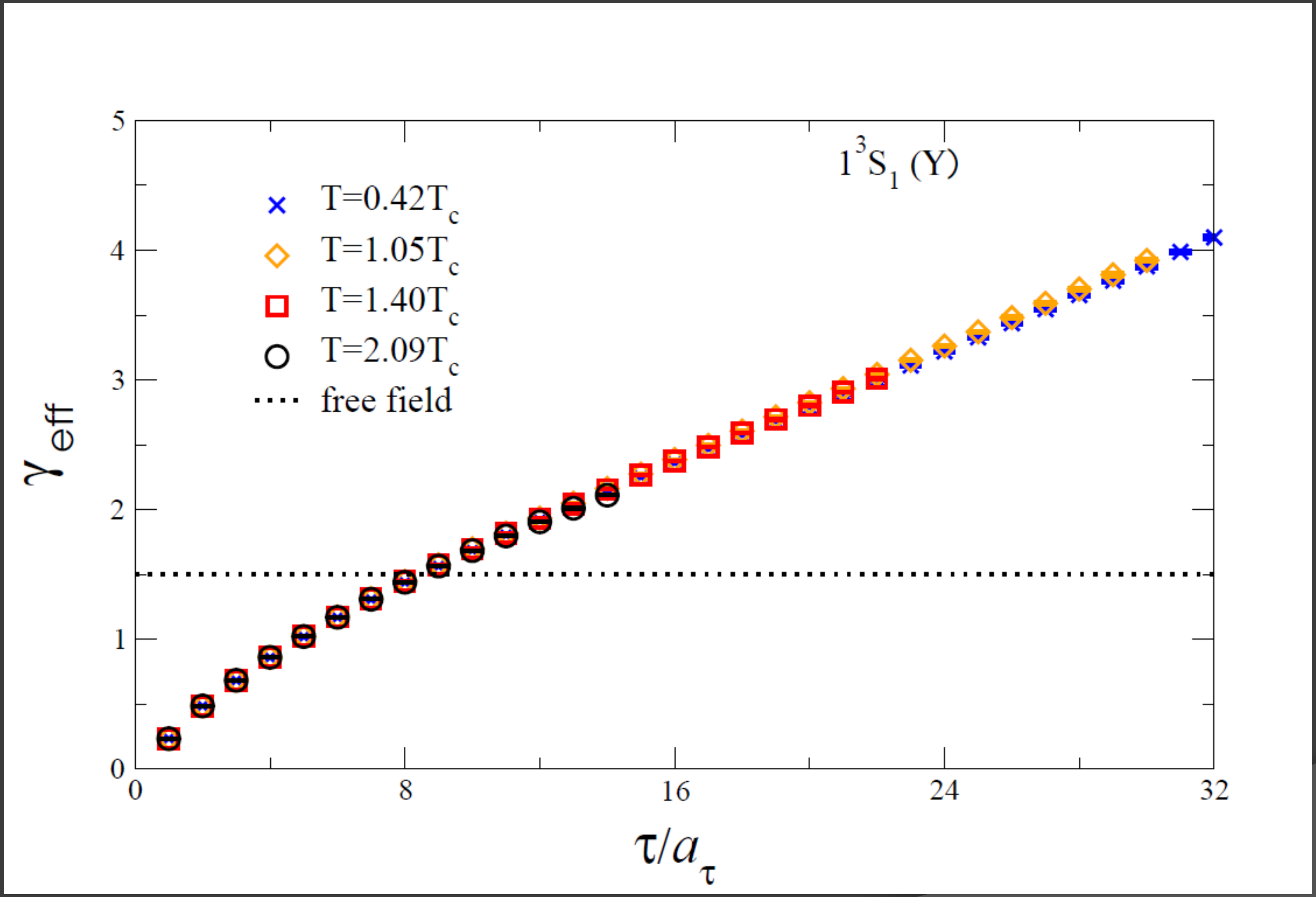
Effective mass for the χ



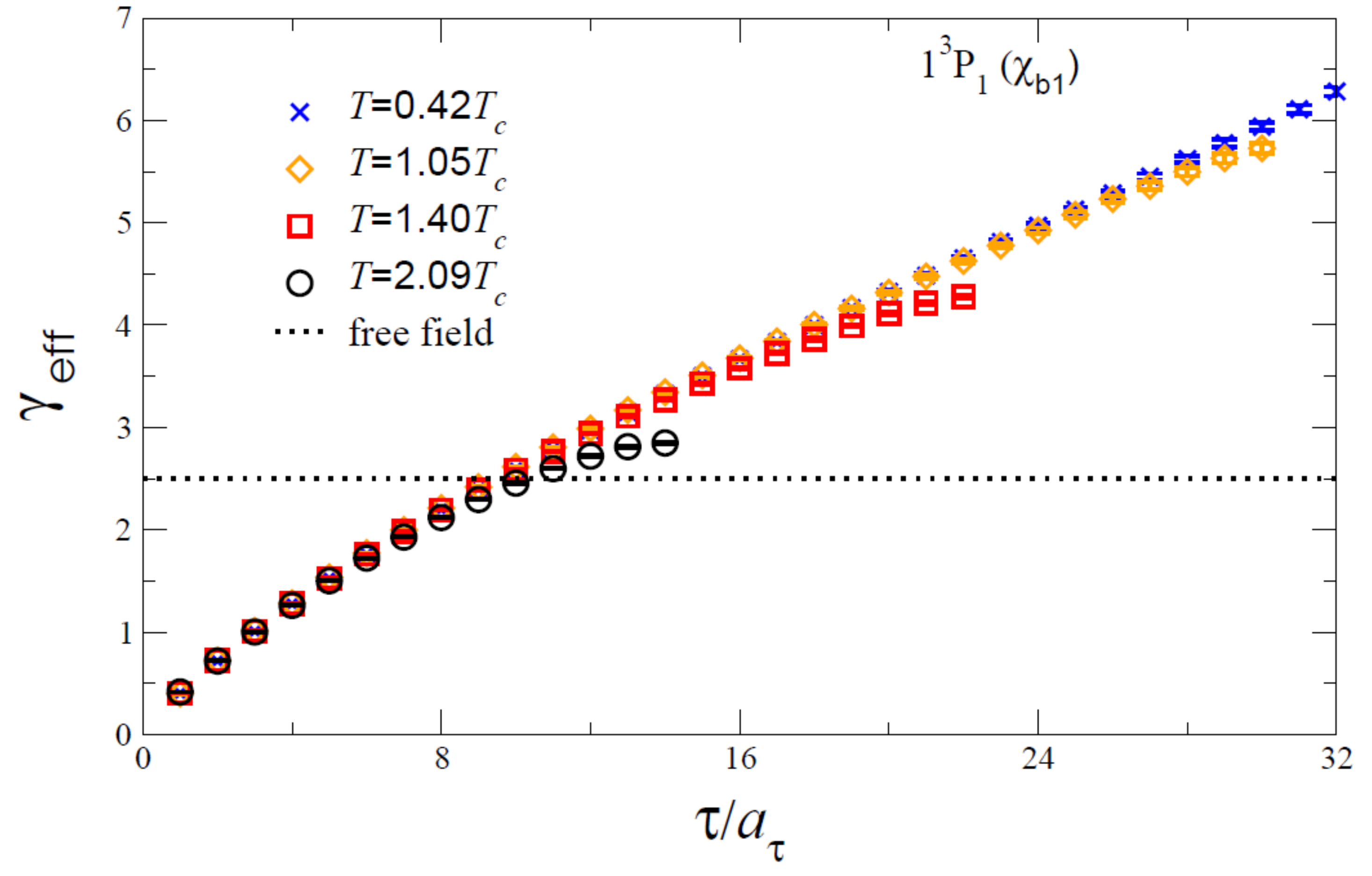
χ propagators and power law at T = 2.09 Tc : consistent with a free behaviour!



Υ and (NO) free behaviour



χ free behaviour at T = 2.09Tc



Summary

- We have studied the temperature dependence of bottomonium for T < T 2.1 Tc, using nonrelativistic dynamics for the bottom quark and full relativistic QCD for two light quarks
- The U is insensitive to the temperature in this range
- The χ show a crossover from an exponential decay characterizing the hadronic phase to a power-law behaviour consistent with nearly-free dynamics at 2Tc