Deconfining Effects and Dissociation Temperature of Quarkonia States

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INTRODUCTION

- The heavy-ion collision programs of current and past experiments, aim to identify and characterize the properties of strongly interacting matter at high temperature with high density (QGP).
- One of their goals is to produce de-confined quark matter (QGP).
- QGP generated in heavy ion collision at high relativistic energies provides us a laboratory to study both the high energy regime of perturbative QCD and the low energy regimes (as it cools) where non-perturbative effects dominates.
- Energetic partons (jets), EM signals, suppression of heavy flavour, etc., are the experimental signatures of the de-confined state.
- Suppression of heavy flavour is one of the most striking characteristic due to the formation of QGP.
- H.Satz and T.Matsui were the first to present an idea to probe QGP via colour screening.
- The de-confinement occurs when colour screening shields a quark from the binding potential of any other quark or antiquark.

- Because of this colour screening the attraction between the quarks is finite and it is characterized by Debye radius (r_D).

- When the distance between quarks is more than the Debye radius, (i.e. $r_D << r_{QQ}$) then it will no longer represent a bound system in a medium.

- Hence, it can be used as a probe, to find whether plasma of colour charges has been produced in an extended volume beyond the size of hadronic state or not.

- Assuming an electric dipole whose length is longer than Debye radius (r_D) then it will no longer be a dipole rather will dissociate and become a part of the medium.

- The similar kind of effect has been expected in Quark-Gluon Plasma where the particles carry colour charge and are in random motion. Instead of an electric dipole, a colour dipole in de-confined medium.

- Quarks and gluons are screened in similar way the electric charges experiences the Debye screening in ordinary plasma.

- Though there exist Effective Field Theory methods and lattice simulations to study the de-confinement mechanisms, study based on phenomenological model is very simple and an important tool to understand the screening effects on the binding energy of quarkonium.

Quantum Mechanical Approach

- The two body Schrodinger eqn. with spherically symmetric potential can be reduced to simple particle Schrodinger eqn. for the reduced wave function $\phi_{n,l}(r)$ given by

$$\left[\frac{1}{2\mu}\left(-\frac{d^2}{dr^2}+\frac{l(l+1)}{r^2}\right)+V(r)\right]\phi_{n,l}(r) = E_{n,l}(r)\,\phi_{n,l}(r)$$

Where, μ is reduce mass and the potential used here is

$$V\big(r,\mu(T)\big) = -\frac{\alpha}{r}e^{-\mu(T)r} + \frac{\sigma}{\mu(T)}\left(1-e^{-\mu(T)r^{\upsilon}}\right)$$

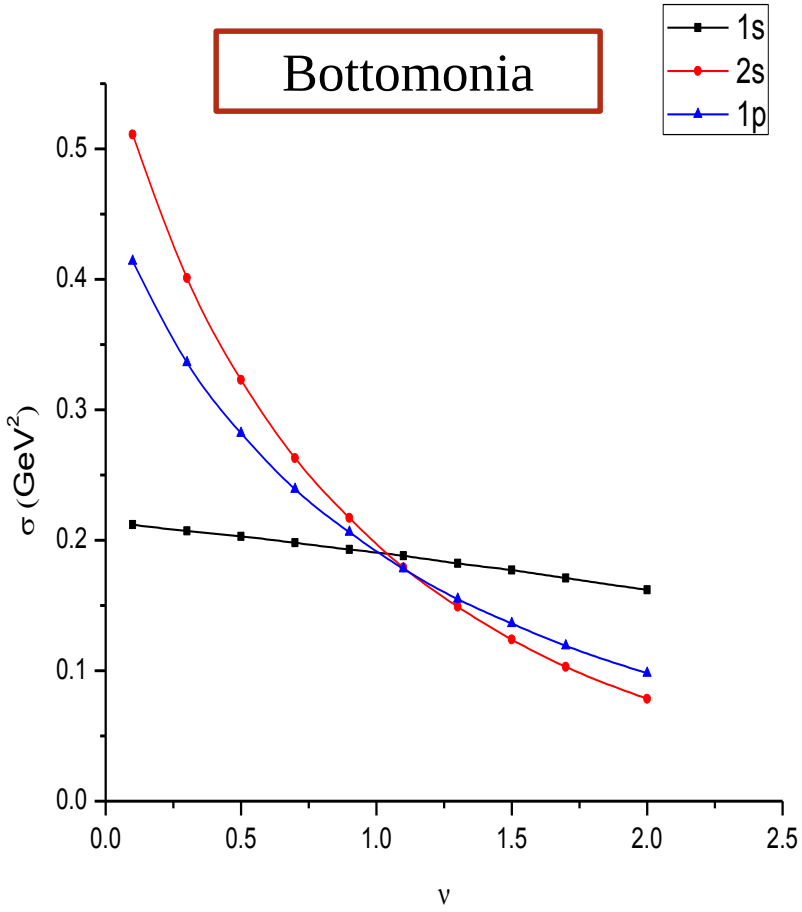
- Spin average mass $M_{n,CM} = \dfrac{\sum_J (2J+1)\, Mn_j}{\sum_J (2J+1)}$

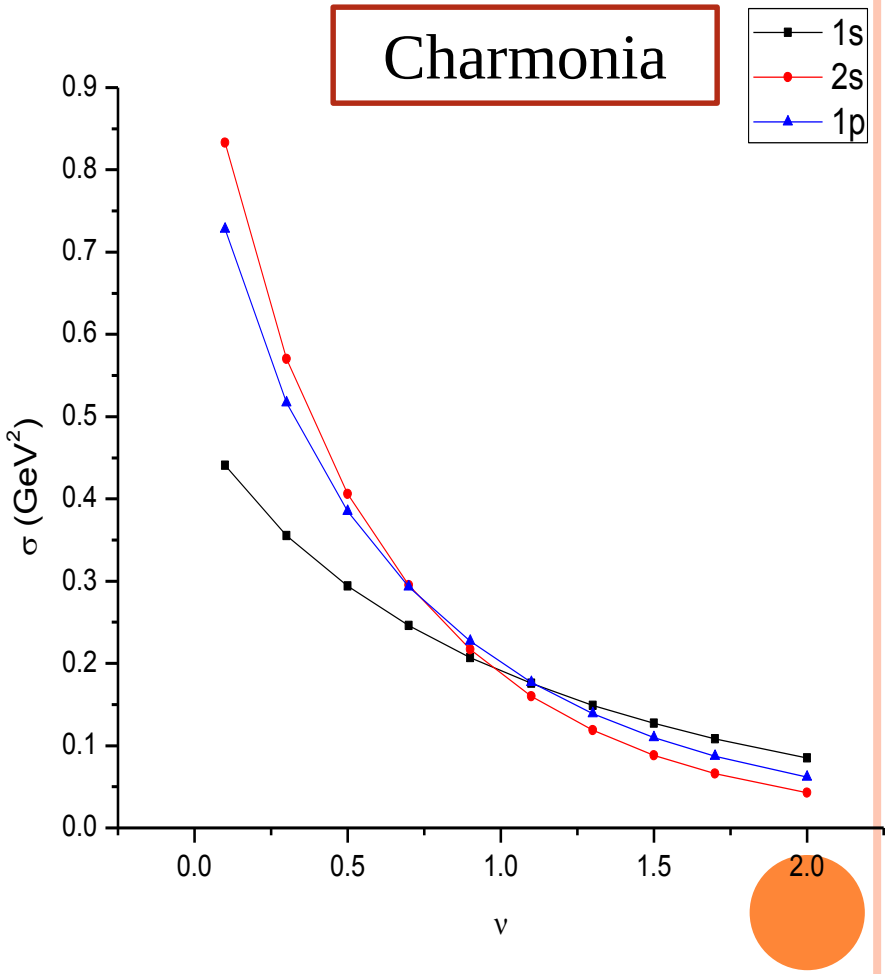
Here, we have determine the confinement strength (σ) corresponding to the spin average masses of charmonia and bottomonia (1s, 2s and 1p) states for the different choices of power exponent υ.

- Mean square radii

$$\langle r^2\rangle_{n,l} = \int_0^\infty r^4\,|R_{n,l}(r)|^2\,dr$$

THE BEHAVIOR OF CONFINEMENT POTENTIAL STRENGTH (SIGMA) WITH RESPECT TO POTENTIAL EXPONENT U (WITHOUT SCREENING EFFECTS) HAS BEEN GIVEN BY





Properties of quarkonia state with screening (M≠0)

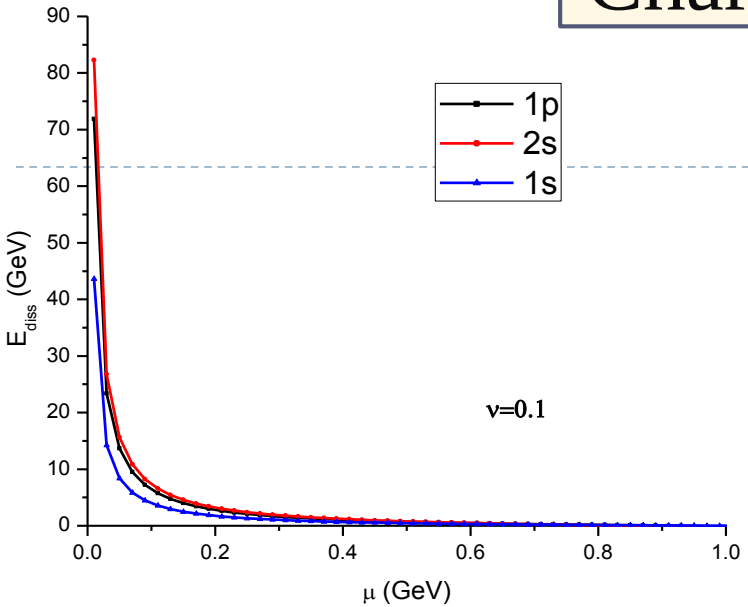
- The energy eigenvalue $E_{n,l}$ (μ) as a function of μ and using the corresponding radial wave function $\phi_{n,l}(r)$, we have calculated the bound state radii.
- The binding energy is $E_{nl}(r, \mu(T)) = M + \frac{p^2}{2\,M_1} + V(r, T)$

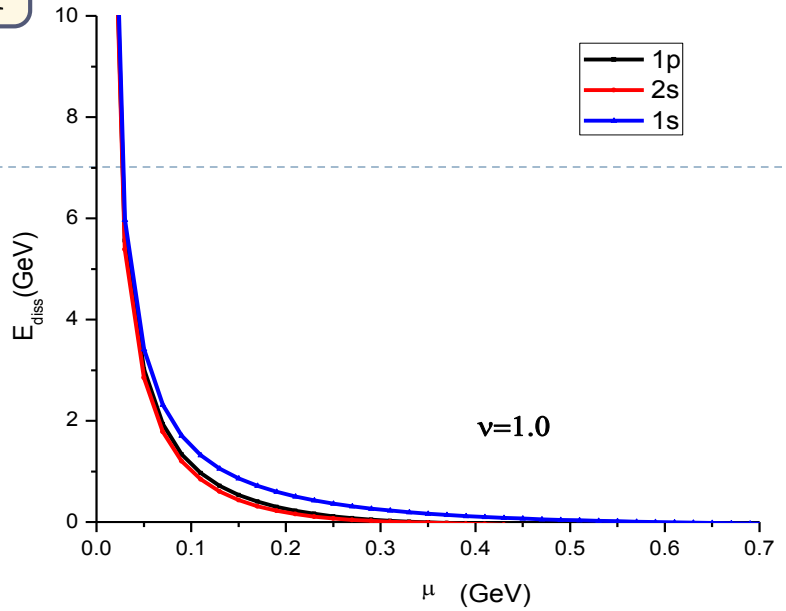
$$E_{eff}(r, \mu(T)) = 2m + \frac{\sigma}{\mu(T)} + E_{nl}$$

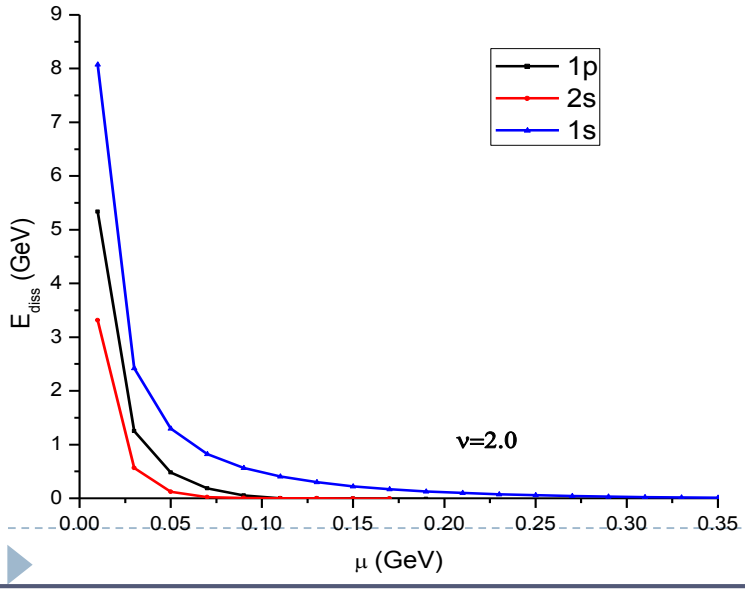
The above eqn. provides a positive value for the bound states and as μ increases to become zero and goes to the negative value for the continuum

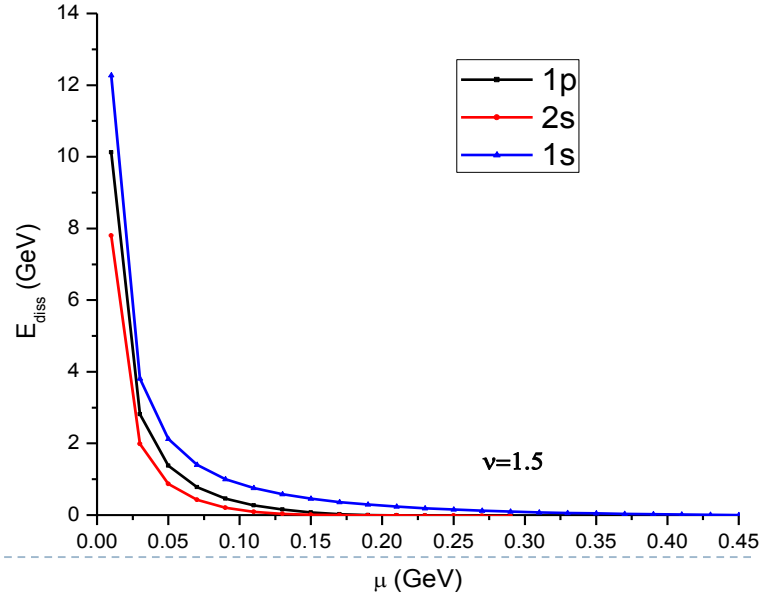
- Hence $E_{eff}(\mu=\mu_c) = 0$ defines beyond the critical value of the screening mass parameter μ_c, no more binding is possible and hence bound states will not exists for the given quantum numbers (n, l).
- The effective binding energy as a function of μ for charmonia and bottomonia has been described graphically for these figs for the different choices of power potential υ.

Charmonia

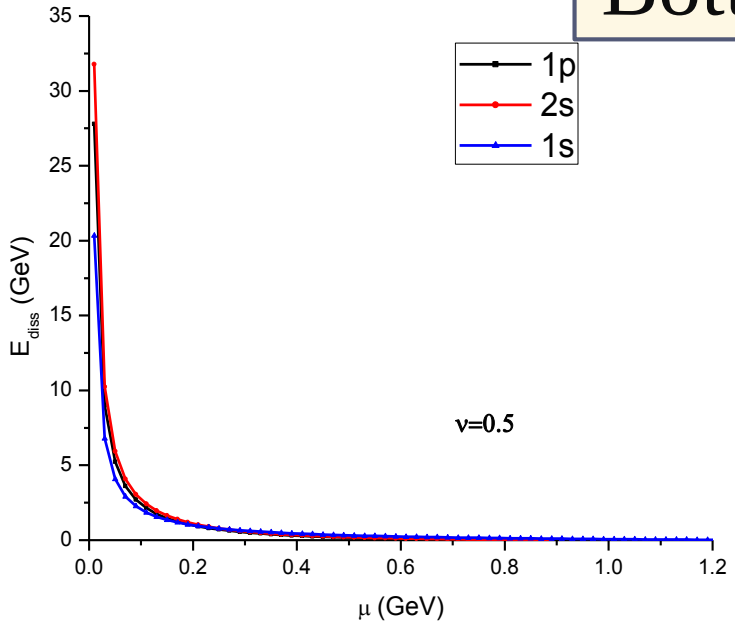

1p
2s
1s
ν=0.1
E_diss (GeV)
μ (GeV)

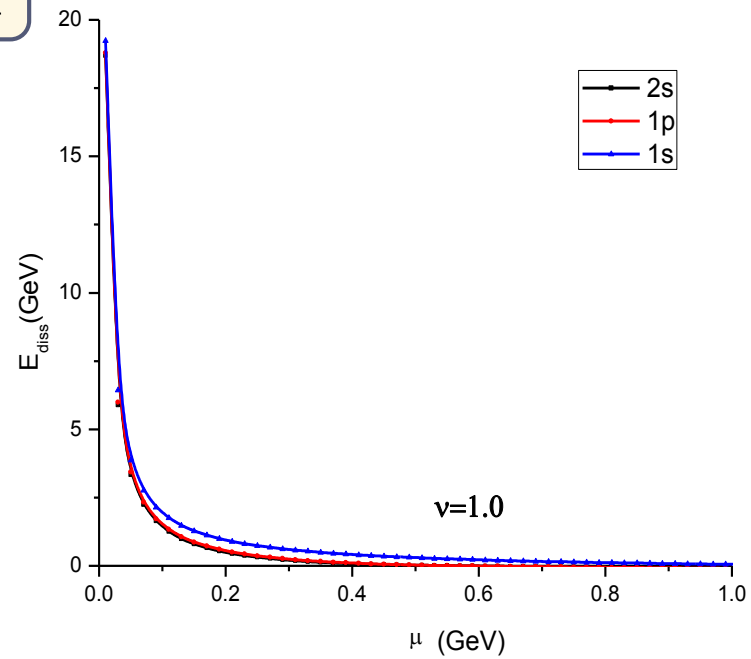

1p
2s
1s
ν=1.0
E_diss (GeV)
μ (GeV)

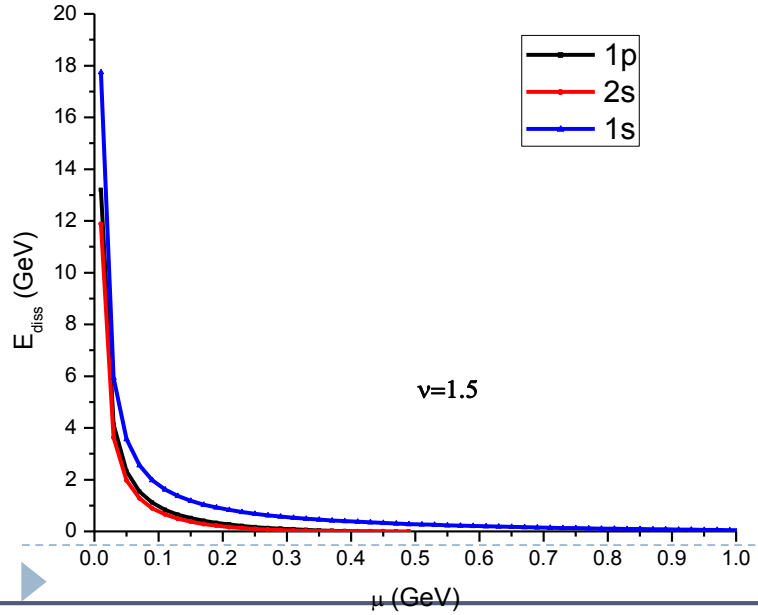

1p
2s
1s
ν=2.0
E_diss (GeV)
μ (GeV)

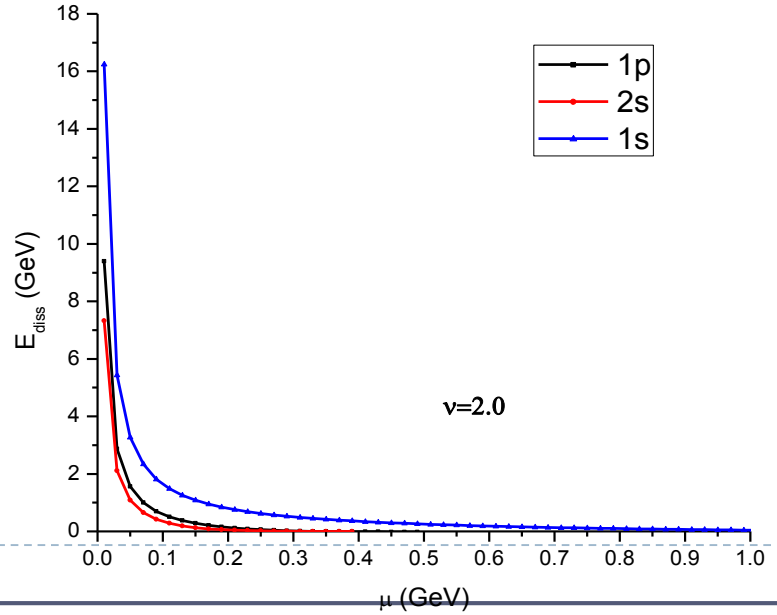

1p
2s
1s
ν=1.5
E_diss (GeV)
μ (GeV)

Bottomonia


1p
2s
1s
ν=0.5
E_diss (GeV)
μ (GeV)


2s
1p
1s
ν=1.0
E_diss (GeV)
μ (GeV)


1p
2s
1s
ν=1.5
E_diss (GeV)
μ (GeV)


1p
2s
1s
ν=2.0
E_diss (GeV)
μ (GeV)

ν	σ	μ_c	r	M	r_D
	$GeV^{\nu+1}$	GeV	fm	GeV	fm
0.1	0.441	1.01547	0.67704	3.07428	0.19433
0.3	0.355	0.90442	0.72658	3.03252	0.21819
0.5	0.294	0.80337	0.77376	3.00595	0.24564
0.7	0.246	0.71047	0.81914	2.98624	0.27775
0.9	0.207	0.62863	0.86436	2.96929	0.31392
1	0.192	0.59417	0.88668	2.96314	0.33212
1.1	0.176	0.5612	0.9136	2.95361	0.35163
1.3	0.149	0.50597	0.97351	2.93448	0.39002
1.5	0.127	0.46265	1.04001	2.9145	0.42654
1.7	0.108	0.42787	1.1094	2.89241	0.46121
2	0.085	0.3889	1.20957	2.85856	0.50743

For 1s-state

ν	σ	μ_c	r	M	r_D
	$GeV^{\nu+1}$	GeV	fm	GeV	fm
0.1	0.833	0.83193	0.96962	3.64128	0.23690
0.3	0.57	0.70145	1.14599	3.45259	0.34620
0.5	0.406	0.58339	1.35904	3.33593	0.48605
0.7	0.295	0.47153	1.60487	3.26562	0.66894
0.9	0.217	0.36723	1.86448	3.23091	0.90939
1	0.192	0.32305	1.98204	3.23433	0.61086
1.1	0.16	0.27809	2.14255	3.21535	1.23337
1.3	0.119	0.21129	2.50665	3.2032	1.65831
1.5	0.088	0.16417	3.04708	3.17603	2.24249
1.7	0.066	0.1342	3.69515	3.1318	2.98999
2	0.043	0.11535	4.34165	3.05612	4.58929

For 2s-state

charmonia

ν	σ	μ_c	r	M	r_D
	$GeV^{\nu+1}$	GeV	fm	GeV	fm
0.1	0.728	0.92101	0.90081	3.43043	0.21426
0.3	0.517	0.76931	1.03515	3.31203	0.25651
0.5	0.385	0.63324	1.18696	3.24798	0.31163
0.7	0.293	0.50668	1.35569	3.21827	0.38947
0.9	0.227	0.42629	1.40402	3.32733	0.46292
1	0.192	0.34172	1.58942	3.20186	0.57748
1.1	0.177	0.30429	1.62205	3.22168	0.64852
1.3	0.139	0.25813	1.61366	3.3257	0.76449
1.5	0.11	0.18859	1.92708	3.22327	1.04639
1.7	0.087	0.15148	2.24087	3.21433	1.30274
2	0.062	0.11197	3.02153	3.19371	1.76243

For 1p-state

ν	σ	μ_c	r	M	r_D
	$GeV^{\nu+1}$	GeV	fm	GeV	fm
0.1	0.212	1.364	0.39804	9.64742	0.14467
0.3	0.207	1.3374	0.39389	9.64676	0.14755
0.5	0.203	1.31557	0.3896	9.6463	0.15000
0.7	0.198	1.29695	0.38611	9.64467	0.15215
0.9	0.193	1.2823	0.38369	9.6425	0.15389
1	0.192	1.27767	0.38253	9.64227	0.15445
1.1	0.188	1.2712	0.38228	9.63989	0.15523
1.3	0.1821	1.26195	0.38184	9.6363	0.15637
1.5	0.177	1.25525	0.3818	9.633	0.15721
1.7	0.171	1.249	0.38231	9.6289	0.15799
2	0.162	1.2408	0.38343	9.62256	0.15904

1s-state

ν	σ	μ_c	r	M	r_D
	$GeV^{\nu+1}$	GeV	fm	GeV	fm
0.1	0.511	1.06003	0.71679	9.97405	0.18616
0.3	0.401	0.94723	0.79303	9.91534	0.20833
0.5	0.323	0.83591	0.86467	9.8784	0.23607
0.7	0.263	0.72545	0.93271	9.5453	0.27202
0.9	0.217	0.6228	0.99571	9.84042	0.31685
1	0.192	0.57257	1.03308	9.82733	0.34465
1.1	0.179	0.534	1.06148	9.8272	0.36955
1.3	0.149	0.4646	1.14111	9.8127	0.42475
1.5	0.124	0.4128	1.23972	9.79239	0.47805
1.7	0.103	0.3761	1.34601	9.76586	0.52470
2	0.0784	0.3436	1.47302	9.72016	0.57433

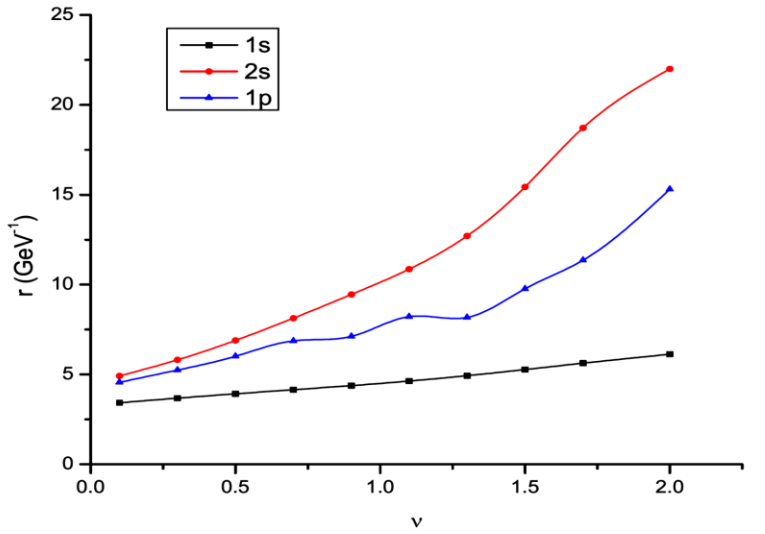
2s-state

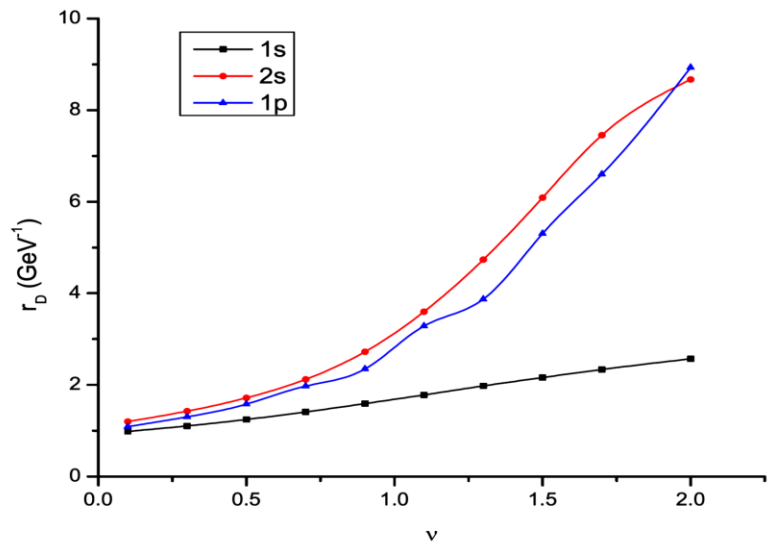
ν	σ	μ_c	r	M	r_D
	$GeV^{\nu+1}$	GeV	fm	GeV	fm
0.1	0.414	1.07177	0.69182	9.87827	0.18412
0.3	0.336	0.94305	0.75084	9.84829	0.20925
0.5	0.282	0.8238	0.80592	9.83431	0.23954
0.7	0.239	0.7115	0.85072	9.8279	0.27735
0.9	0.206	0.61433	0.87292	9.82732	0.32122
1	0.192	0.5725	0.87716	9.82728	0.34469
1.1	0.178	0.5349	0.88272	9.82477	0.36892
1.3	0.155	0.4731	0.90015	9.81962	0.41712
1.5	0.136	0.4249	0.93709	9.81207	0.46443
1.7	0.119	0.3857	0.99319	9.80052	0.51163
2	0.098	0.34075	1.1046	9.77959	0.57913

1p-state

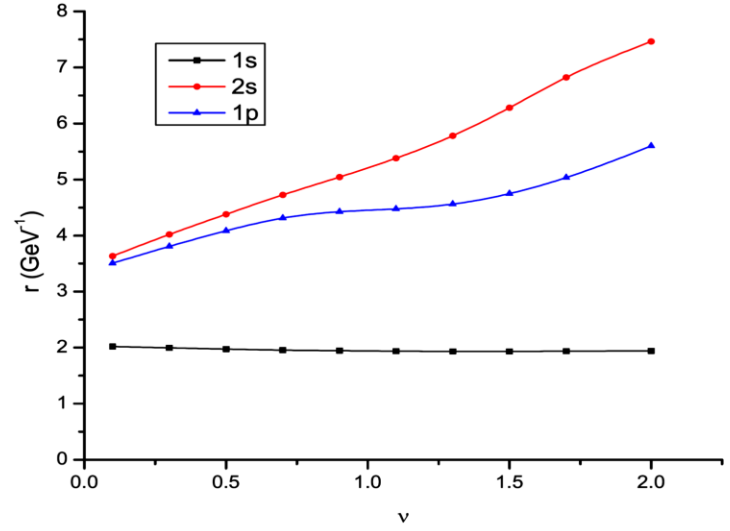
bottomonia

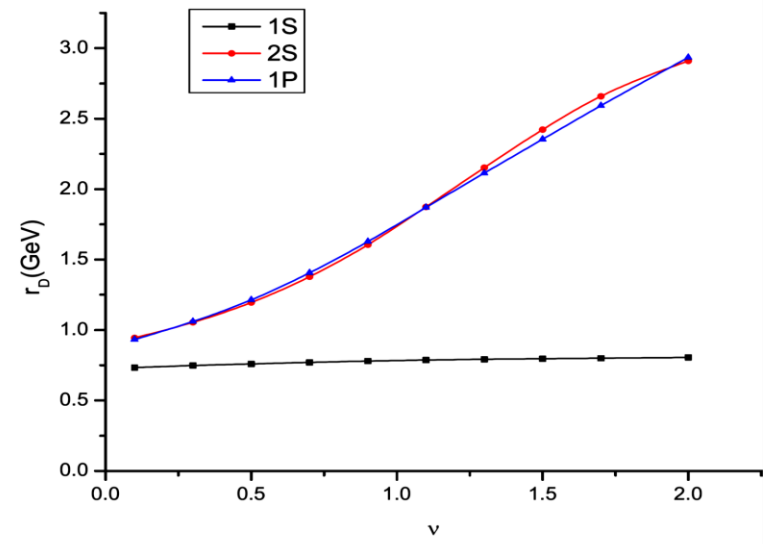
CHARMONIA





BOTTOMONIA





Vacuum Screening Mass

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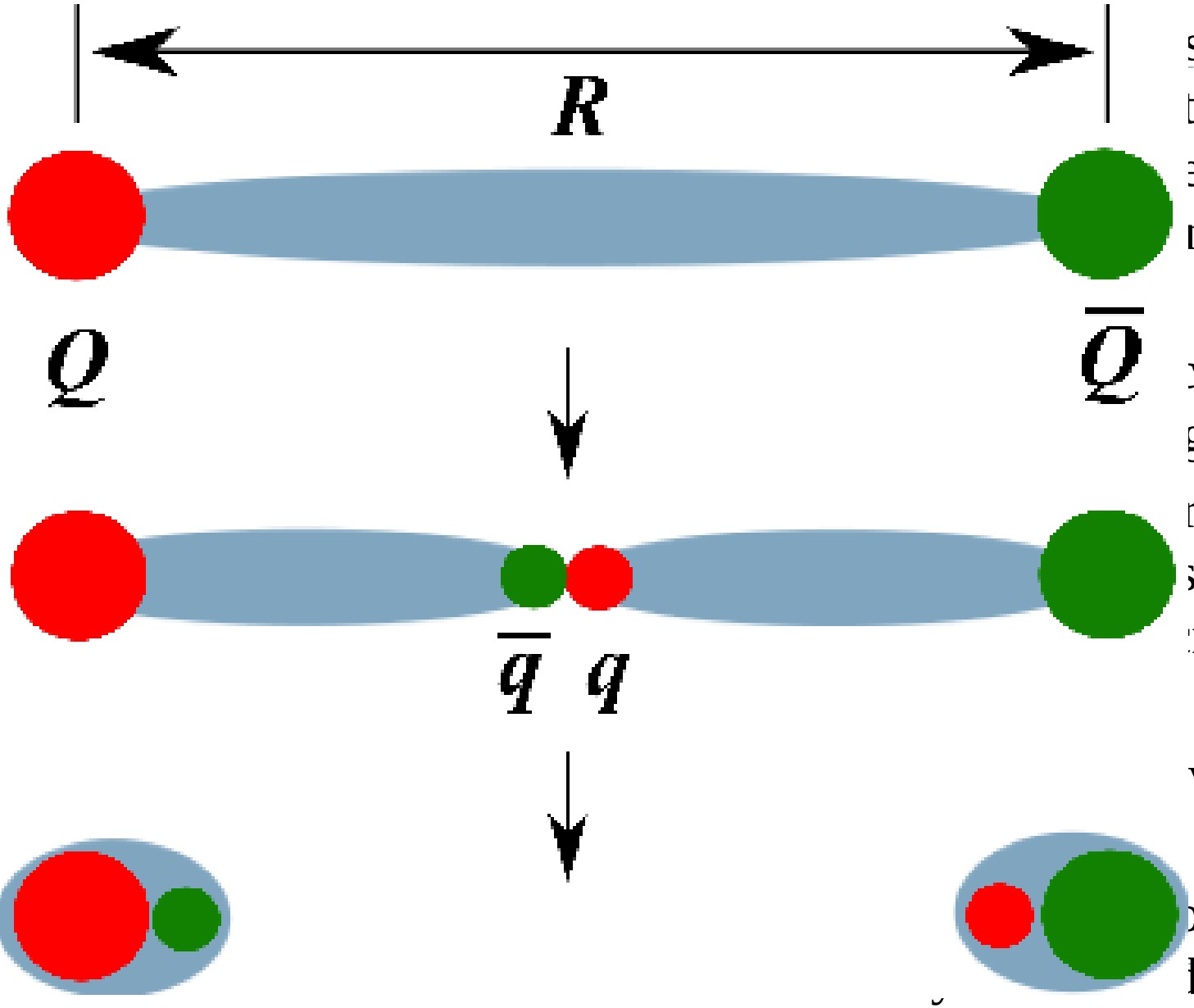


- For charmonia and bottomonia system at T=0, vacuum screening implies its breakup when sufficient amount of energy is applied and created the light quark q= u, d.

Mass of charmed and beauty meson

Mass	GeV
m_D	1.86962
m_B	5.27925

$$c\bar{c} \rightarrow c\bar{q}(D) + \bar{c}q(\bar{D}) \qquad b\bar{b} \rightarrow b\bar{q}(B) + \bar{b}q(\bar{B})$$

- The vacuum screening binding energy

$$E_{vs}(T=0) = 2mQ_{Q^-} - m(QQ^-)$$

State Mass (GeV)	$c\bar{c}$	State Mass (GeV)	$b\bar{b}$
J/ψ	3.067	Υ	9.4432
ψ'	3.674	Υ'	9.8961
χ_c	3.522	χ_c	10.0156

$$E_{eff}(\mu(T)) = 2m + \frac{\sigma}{\mu} - E(\mu(T))$$

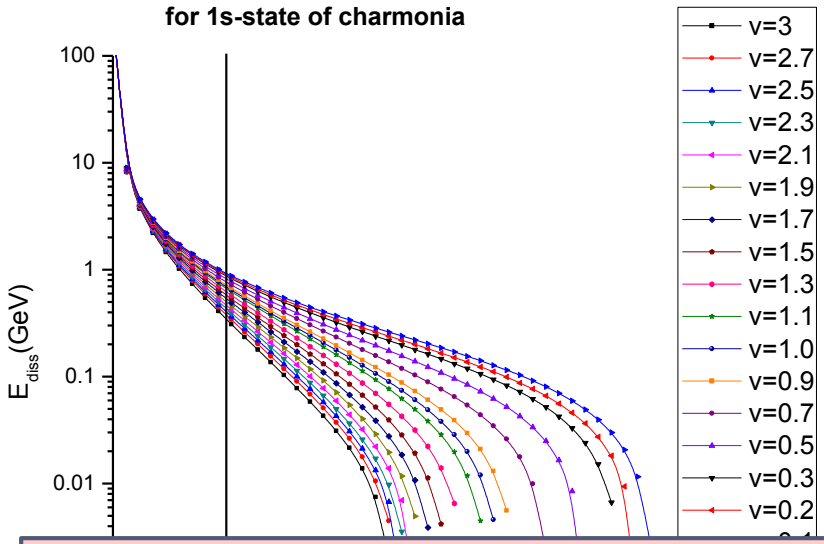
(Previously)

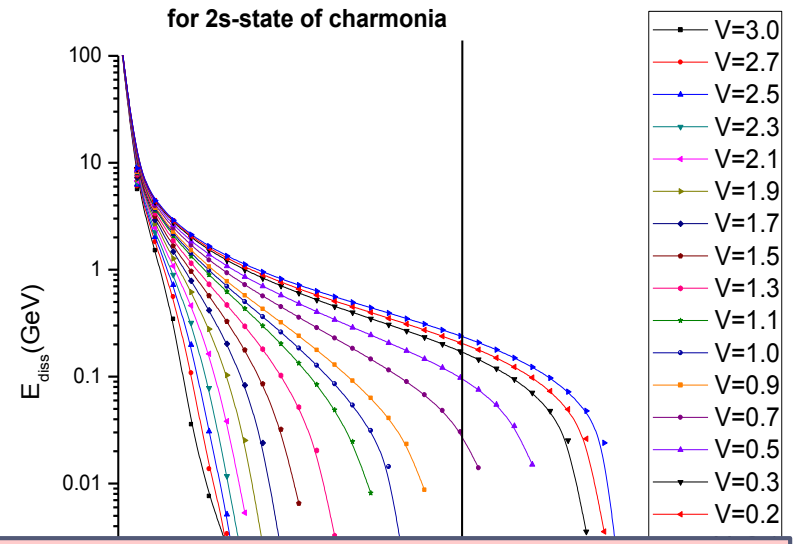
Charmonia

ν	μ_{vs}(GeV)		
	J/Ψ	Ψ'	
E_{diss}	0.6423	0.05314	0.3245
0.1	0.2173	0.9049	0.3792
0.2	0.2132	0.8233	0.3625
0.3	0.2091	0.7775	0.3460
0.5	0.2015	0.6256	0.3261
0.7	0.1929	0.5171	0.3005
0.9	0.1842	0.4258	0.2806
1.0	0.1776	0.3857	0.2359
1.1	0.1729	0.2218	0.2229
1.3	0.1630	0.2090	0.1873
1.5	0.1533	0.1599	0.1603
1.7	0.1500	0.1880	0.1471
1.9	0.1423	0.1521	0.1263
2.1	0.1259	0.1220	0.1098
2.3	0.1299	0.0994	0.0951
2.5	0.1086	0.0642	0.0644
2.7	0.0969	0.0292	0.0549
3.0	0.0841	0.0189	0.0654

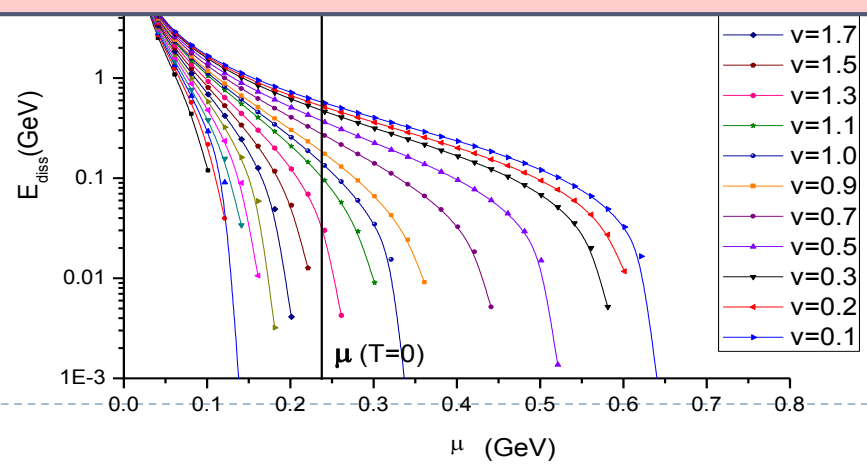
Bottomonia

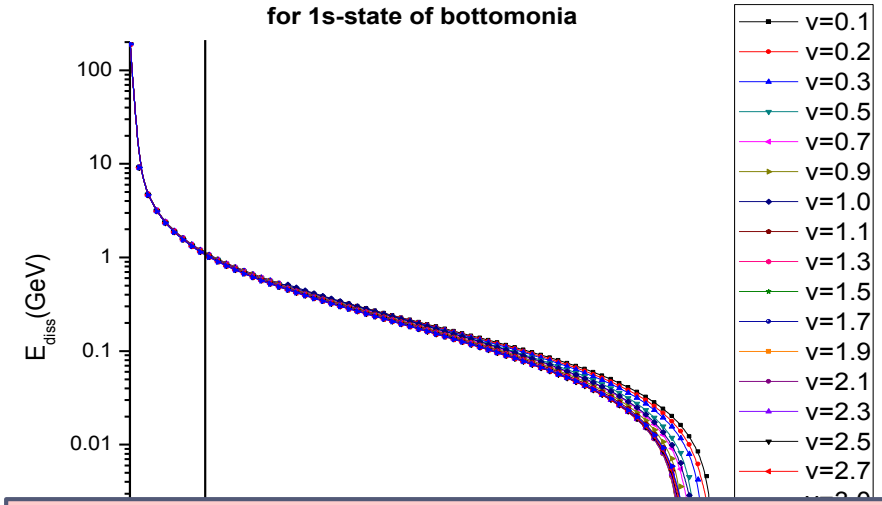
ν	μ_{vs}(GeV)		
	Υ	Υ'	χ_b
E_{diss}	1.0982	0.5352	0.6931
0.1	0.1712	0.3093	0.2534
0.2	0.1708	0.3004	0.2486
0.3	0.1704	0.2915	0.2438
0.5	0.1698	0.2779	0.2356
0.7	0.1690	0.2613	0.2260
0.9	0.1682	0.2453	0.2164
1.0	0.1676	0.2283	0.2085
1.1	0.1671	0.2195	0.2033
1.3	0.1663	0.2022	0.1930
1.5	0.1654	0.1856	0.1827
1.7	0.1645	0.1695	0.1725
1.9	0.1637	0.1543	0.1624
2.1	0.1628	0.1416	0.1528
2.3	0.1619	0.1288	0.1433
2.5	0.1610	0.1174	0.1342
	0.1601	0.0927	0.1218
3.0	0.1587	0.0752	0.1081

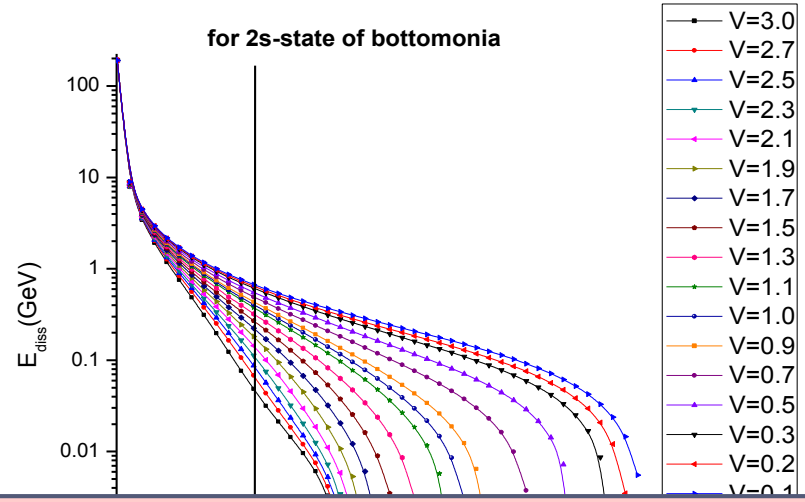




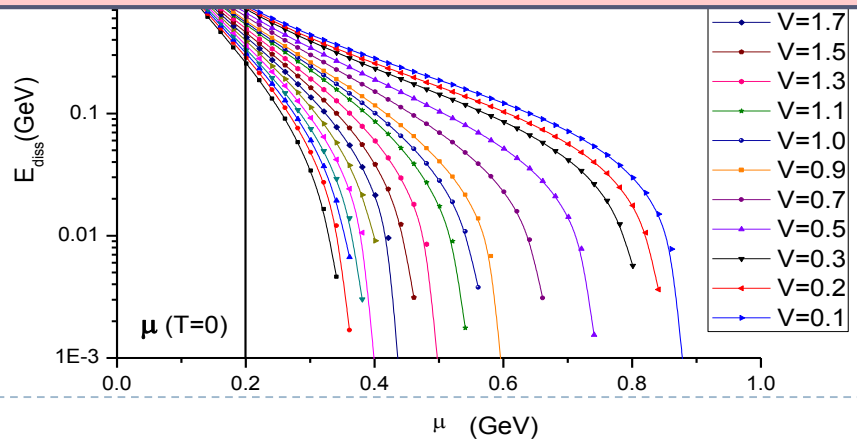
Dissociation energy for the 1s,2s and 1p-state of charmonia, the line μ(T=0) indicates the vacuum screening limit at T=0 for the case of potential exponent υ=1.0



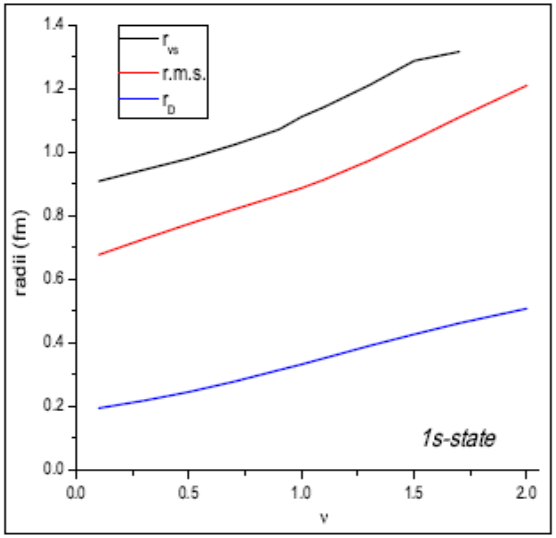


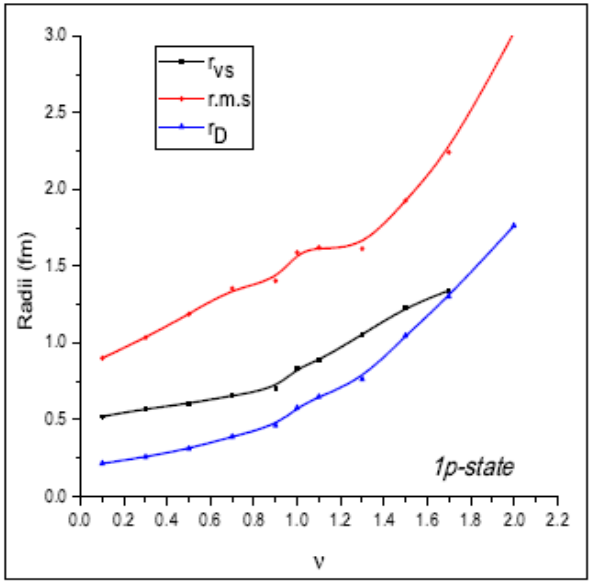


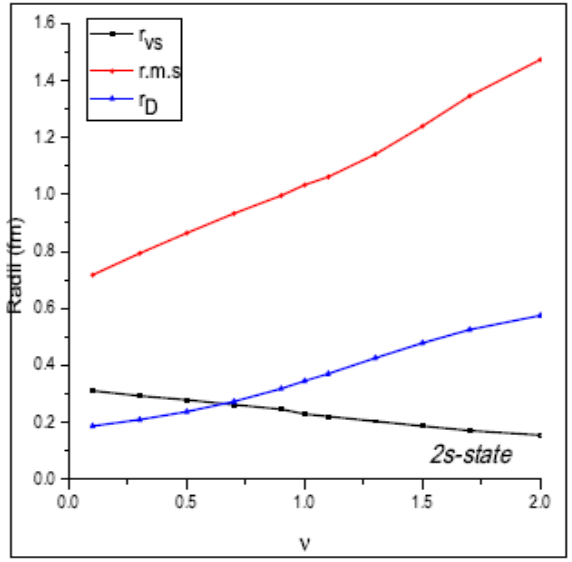
Dissociation energy for the 1s, 2s and 1p-state of bottomonia, the line μ(T=0) indicates the vacuum screening limit at T=0 for the case of potential exponent υ=1.0



Conclusion

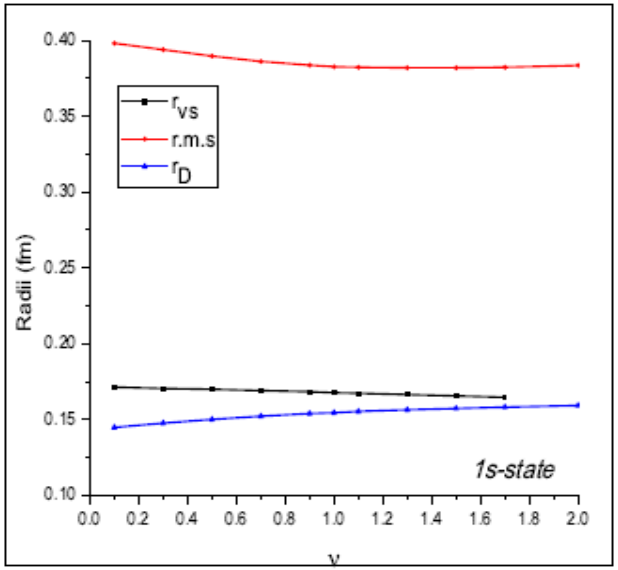


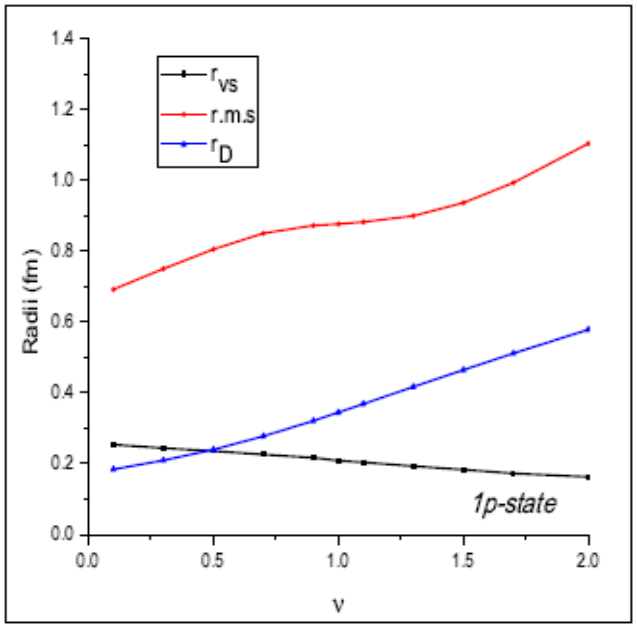


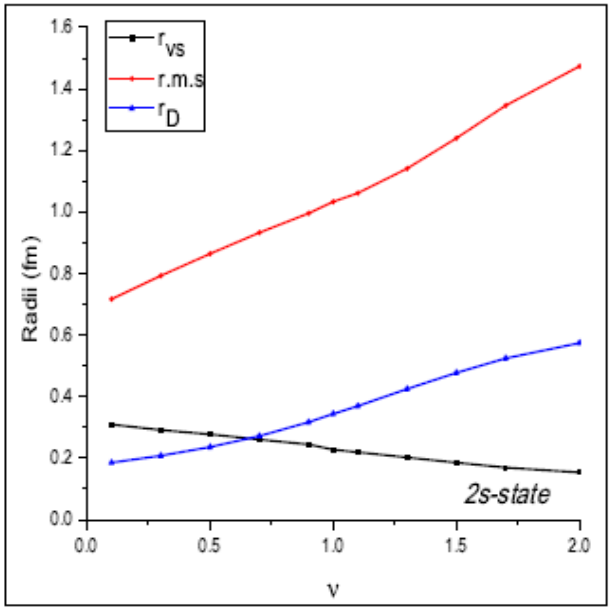


FOR CHARMONIA

Here, plot of rms radii at μ_c, colour screening radii ($r_D=1/\mu_c$) and vaccum screening radii ($r_{VS}=1/\mu_{VS}$) as a fuction of power exponent ν. The states of charmonia gets screened under vacuum screening effect, except the 1s-state of charmonia.







FOR BOTTOMONIA

Here, plot of rms radii at μ_c , colour screening radii ($r_D=1/\mu_c$) and vaccum screening radii ($r_{VS}=1/\mu_{VS}$) as a fuction of power exponent ν. The states of bottomonia gets screened under vacuum screening and medium screening effects.

bottomonia

ν	μ_c	T/T_c	μ_c	T/T_c	μ_c	T/T_c
	1s-state		2s-state		1p-state	
0.1	1.364	4.62	1.06003	3.64	1.07177	3.68
0.3	1.3374	4.54	0.94723	3.28	0.94305	3.26
0.5	1.31557	4.447	0.83591	2.92	0.8238	2.88
0.7	1.29695	4.41	0.72545	2.56	0.7115	2.52
0.9	1.2823	4.36	0.6228	2.23	0.61433	2.21
1	1.27767	4.35	0.57257	2.07	0.5725	2.07
1.1	1.2712	4.32	0.534	1.95	0.5349	1.95
1.3	1.26195	4.29	0.4646	1.72	0.4731	1.75
1.5	1.25525	4.27	0.4128	1.55	0.4249	1.59
1.7	1.249	4.25	0.3761	1.44	0.3857	1.47
2	1.2408	4.23	0.3436	1.33	0.34075	1.32

charmonia

ν	μ_c	T/T_c	μ_c	T/T_c	μ_c	T/T_c
	1s-state		2s-state		1p-state	
0.1	1.01547	3.5	0.83193	2.9	0.92101	3.19
0.3	0.90442	3.14	0.70145	2.49	0.76931	2.71
0.5	0.80337	2.82	0.58339	2.11	0.63324	2.26
0.7	0.71047	2.51	0.47153	1.75	0.50668	1.86
0.9	0.62863	2.25	0.36723	1.41	0.42629	1.6
1	0.59417	2.14	0.32305	1.27	0.34172	1.33
1.1	0.5612	2.03	0.27809	1.12	0.30429	1.21
1.3	0.50597	1.86	0.21129	0.91	0.25813	1.06
1.5	0.46265	1.71	0.16417	0.76	0.18859	0.83
1.7	0.42787	1.61	0.1342	0.66	0.15148	0.71
2	0.3889	1.48	0.11535	0.59	0.11197	0.59

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Thank You

Backup slides

CONFINEMENT POTENTIAL STRENGTH (SIGMA)

CHARMONIA

ν	1s		2s		1p	
	σ	r	σ	r	σ	r
	$GeV^{\nu+1}$	fm	$GeV^{\nu+1}$	fm	$GeV^{\nu+1}$	fm
0.1	0.441	0.83199	0.833	1.90652	0.728	1.55146
0.3	0.355	0.63798	0.570	1.29889	0.517	1.03821
0.5	0.294	0.54927	0.406	1.08735	0.385	0.85950
0.7	0.246	0.49669	0.295	0.97275	0.293	0.76310
0.9	0.207	0.46134	0.217	0.89875	0.227	0.70084
1.0	0.192	0.44654	0.192	0.86294	0.192	0.68640
1.1	0.176	0.43519	0.160	0.84755	0.177	0.65779
1.3	0.149	0.41598	0.119	0.80826	0.139	0.62575
1.5	0.127	0.40043	0.088	0.77936	0.110	0.60057
1.7	0.108	0.38820	0.066	0.75381	0.087	0.58110
2.0	0.085	0.37349	0.043	0.72328	0.062	0.55730

BOTTOMONIA

ν	1s		2s		1p	
	σ	r	σ	r	σ	r
	$GeV^{\nu+1}$	fm	$GeV^{\nu+1}$	fm	$GeV^{\nu+1}$	fm
0.1	0.212	0.29176	0.511	0.87515	0.414	0.73766
0.3	0.207	0.26903	0.401	0.68484	0.336	0.56925
0.5	0.203	0.25164	0.323	0.59869	0.282	0.49185
0.7	0.198	0.23838	0.263	0.54770	0.239	0.44616
0.9	0.193	0.22781	0.217	0.51251	0.206	0.41478
1.0	0.192	0.22299	0.192	0.51004	0.192	0.40239
1.1	0.188	0.21925	0.179	0.48738	0.178	0.39242
1.3	0.1821	0.21236	0.149	0.46747	0.155	0.37519
1.5	0.177	0.20646	0.124	0.45190	0.136	0.36125
1.7	0.171	0.20162	0.103	0.43952	0.119	0.35045
2.0	0.162	0.19565	0.0784	0.42431	0.098	0.33748