Effective Field Theories for Quarkonium

recent progress

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Outline

1. Scales and EFTs for quarkonium at zero and finite temperature

2.1 Static energy at zero temperature

2.2 Charmonium radiative transitions

2.3 Bottomoniun thermal width

3. Conclusions

Scales and EFTs

Scales

Quarkonia, i.e. heavy quark-antiquark bound states, are systems characterized by hierarchies of energy scales. These hierarchies allow systematic studies.

They follow from the quark mass M being the largest scale in the system:

- $M \gg p$
- $M \gg \Lambda_{\mathrm{QCD}}$
- $M \gg T \gg$ other thermal scales

The non-relativistic expansion

- $M \gg p$ implies that quarkonia are non-relativistic and characterized by the hierarchy of scales typical of a non-relativistic bound state:

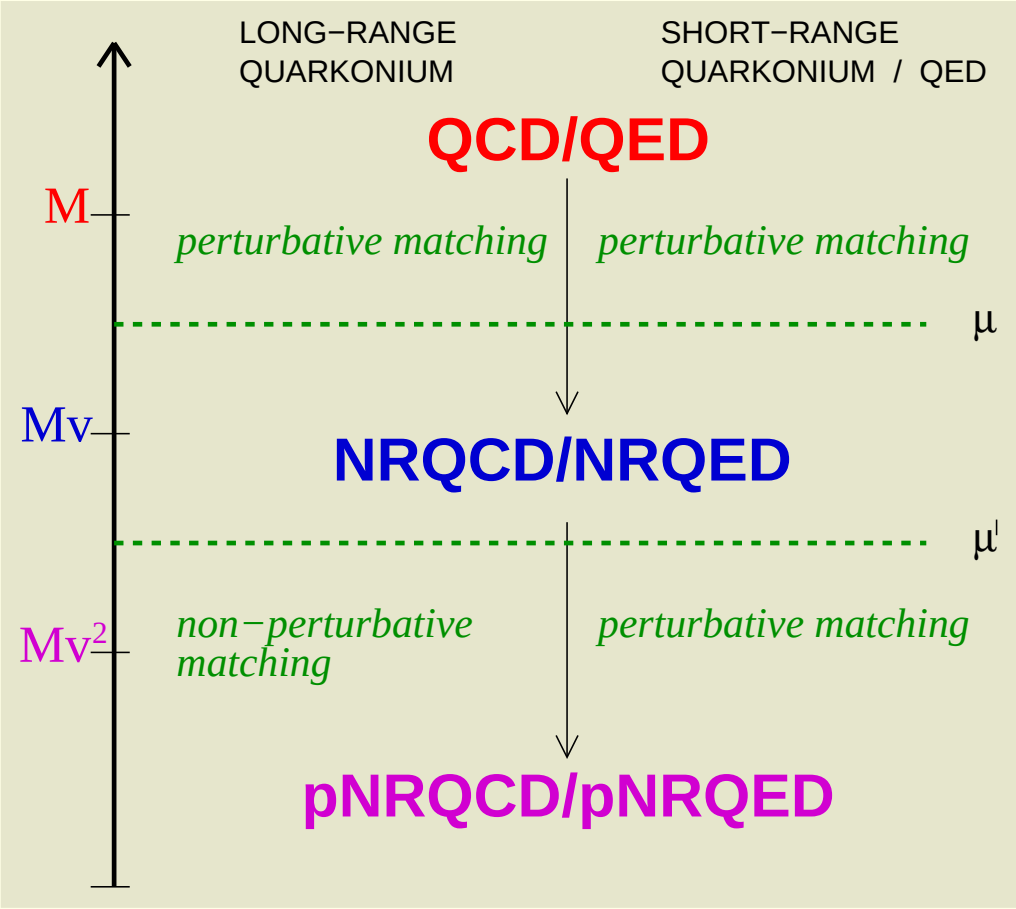
$$M \gg p \sim 1/r \sim Mv \gg E \sim Mv^2$$

The hierarchy of non-relativistic scales makes the very difference of quarkonia with heavy-light mesons, which are just characterized by the two scales M and $\Lambda_{\rm QCD}$.

Systematic expansions in the small heavy-quark velocity v may be implemented at the Lagrangian level by constructing suitable effective field theories (EFTs).

○ Brambilla Pineda Soto Vairo RMP 77 (2004) 1423

Non-relativistic Effective Field Theories



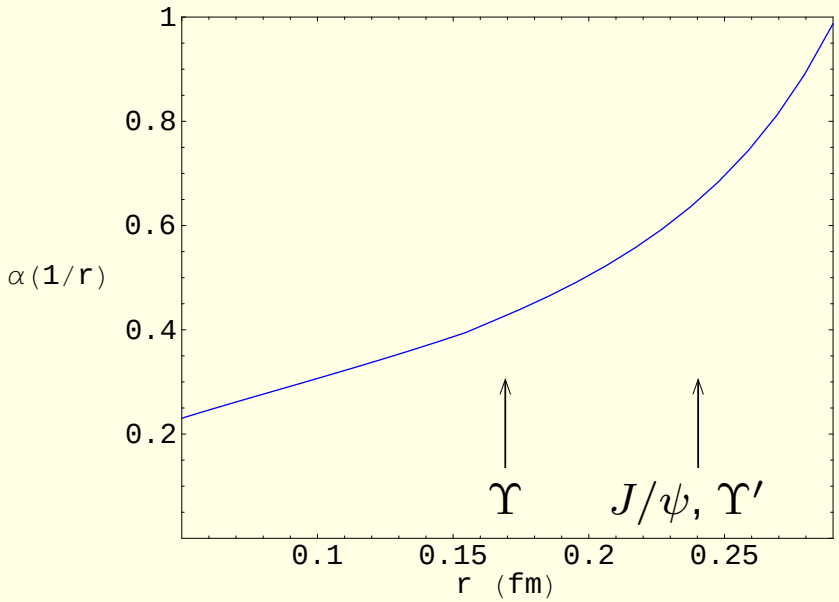
- Caswell Lepage PLB 167(86)437
- Lepage Thacker NP PS 4(88)199
- Bodwin et al PRD 51(95)1125, ...

- Pineda Soto PLB 420(98)391
- Pineda Soto NP PS 64(98)428
- Brambilla et al PRD 60(99)091502
- Brambilla et al NPB 566(00)275
- Kniehl et al NPB 563(99)200
- Luke Manohar PRD 55(97)4129
- Luke Savage PRD 57(98)413
- Grinstein Rothstein PRD 57(98)78
- Labelle PRD 58(98)093013
- Griesshammer NPB 579(00)313
- Luke et al PRD 61(00)074025
- Hoang Stewart PRD 67(03)114020, ...

The perturbative expansion

- $M \gg \Lambda_{\rm QCD}$ implies $\alpha_{\rm s}(M) \ll 1$: phenomena happening at the scale M may be treated perturbatively.

  We may further have small couplings if $Mv \gg \Lambda_{\rm QCD}$ and $Mv^2 \gg \Lambda_{\rm QCD}$, in which case $\alpha_{\rm s}(Mv) \ll 1$ and $\alpha_{\rm s}(Mv^2) \ll 1$ respectively. This is likely to happen only for the lowest charmonium and bottomonium states.



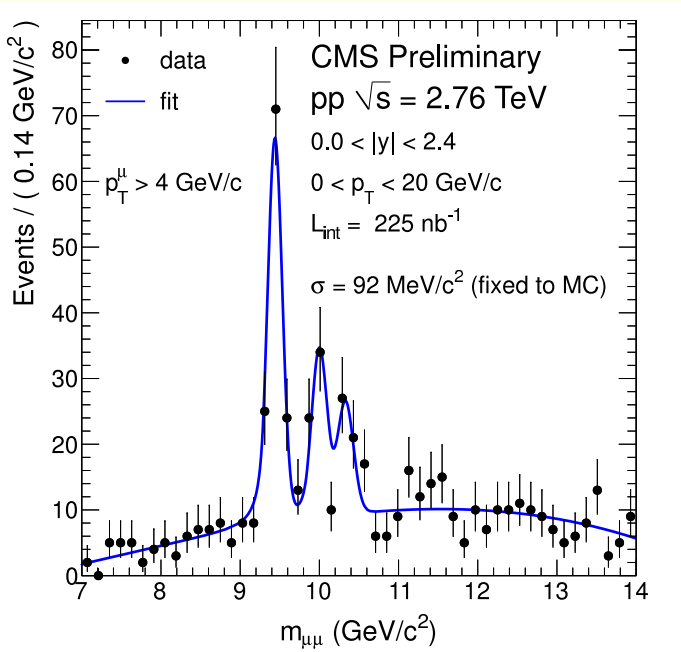
The different quarkonium radii provide different measures of the transition from a Coulombic to a confined bound state.

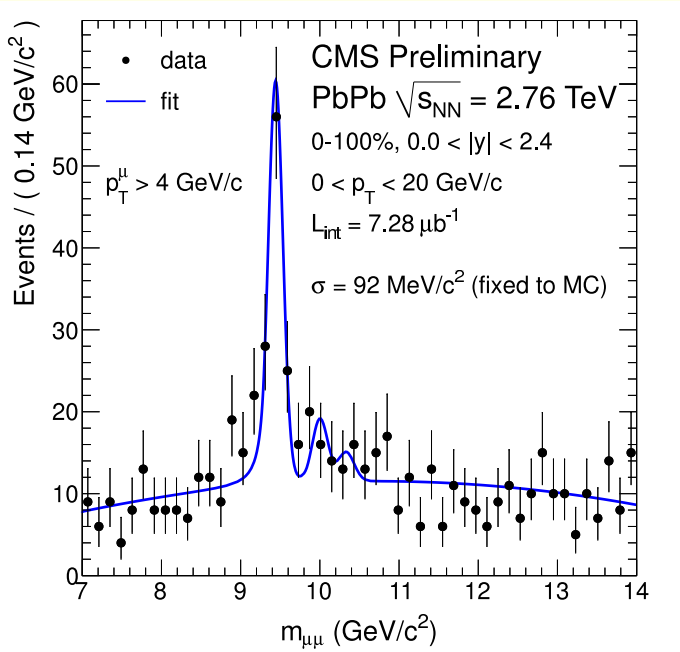
The thermal expansion

- $M \gg T$ implies that quarkonium remains non-relativistic also in the thermal bath. $T \gg$ other thermal scales implies a hierarchy also in the thermal scales.

  Different quarkonia will dissociate in a medium at different temperatures, providing a thermometer for the plasma.

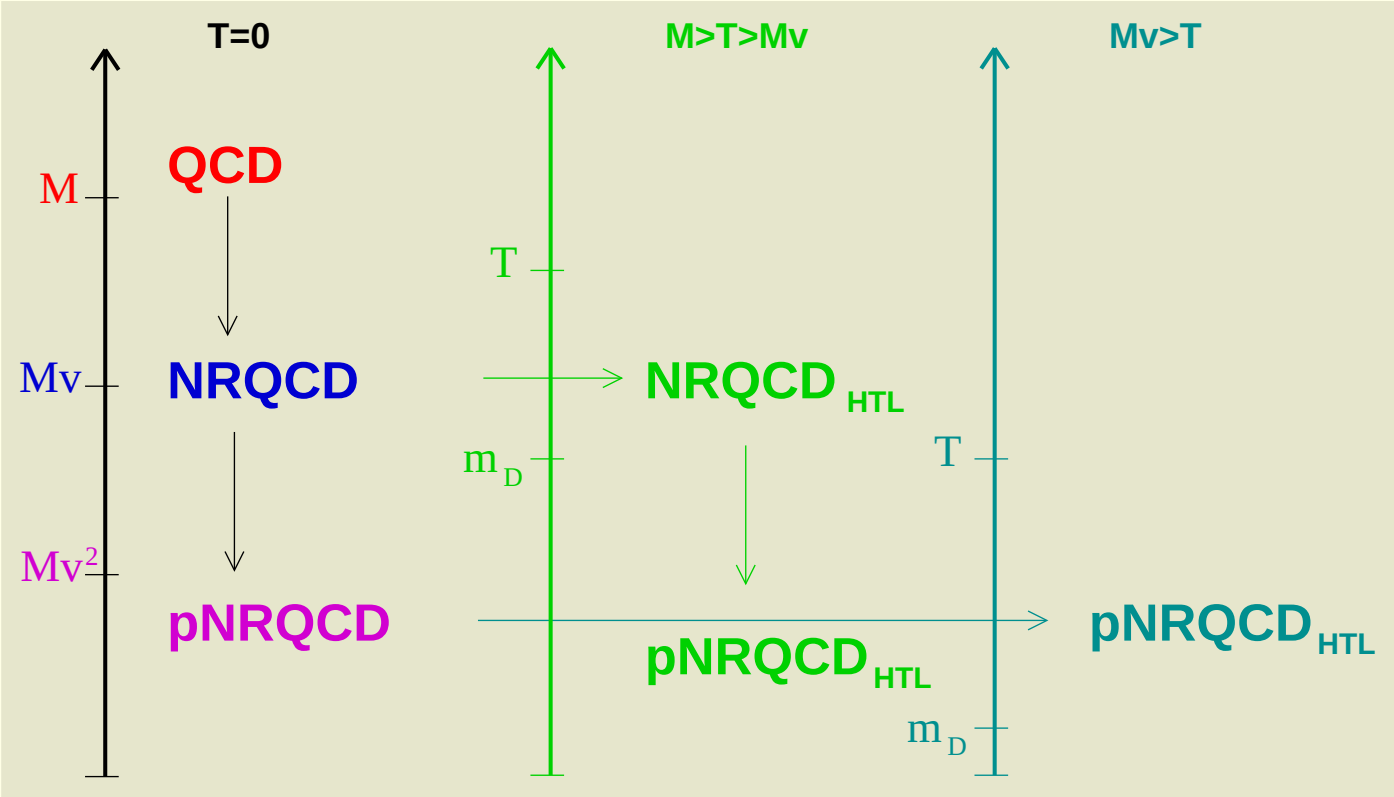
  - Matsui Satz PLB 178 (1986) 416





  - CMS 1012.5545, CMS-HIN-10-006

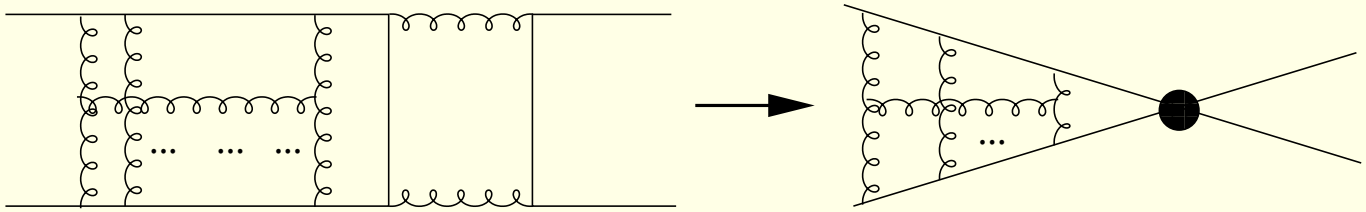
Thermal non-relativistic Effective Field Theories



- Laine Philipsen Romatschke Tassler JHEP 0703 (2007) 054
- Beraudo Blaizot Ratti NPA (2008) 806
- Escobedo Soto PRA 78 (2008) 032520
- Brambilla Ghiglieri Vairo Petreczky PRD 78 (2008) 014017, ...

Physics at the scale M: annihilation and production

Quarkonium annihilation and production happens at the scale M.
The suitable EFT is NRQCD.



QCD NRQCD

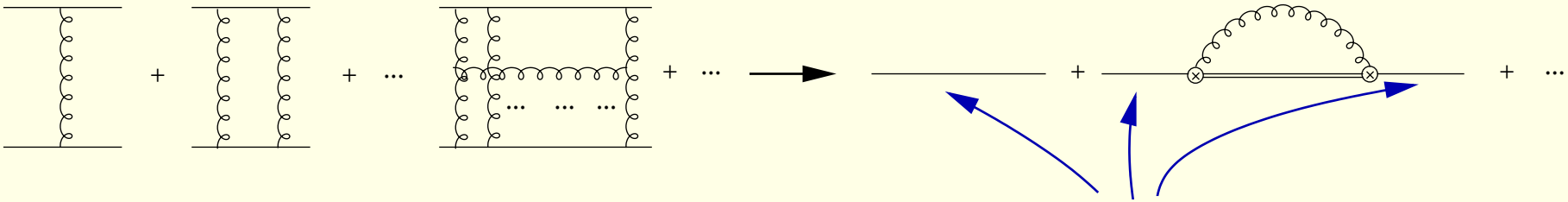
The effective Lagrangian is organized as an expansion in $1/M$ and $\alpha_s(M)$:

$$\mathcal{L}_{\mathrm{NRQCD}} = \sum_n \frac{c_n(\alpha_s(M), \mu)}{M^n} \times O_n(\mu, Mv, Mv^2, ...)$$

- `see talk by Mathias Butenschön`

Physics at the scale Mv: bound state formation

Quarkonium formation happens at the scale Mv. The suitable EFT is pNRQCD.



$$\frac{1}{E - p^2/m - V(r, \mu', \mu)}$$

NRQCD pNRQCD

The effective Lagrangian is organized as an expansion in $1/M$, $\alpha_s(M)$ and r:

$$\mathcal{L}_{\rm pNRQCD} = \int d^3r \sum_n \sum_k \frac{c_n(\alpha_s(M), \mu)}{M^n} \times V_{n,k}(r, \mu', \mu)\, r^k \times O_k(\mu', Mv^2, ...)$$

- $V_{n,0}$ are the potentials in the Schrödinger equation.
- $V_{n,k\neq 0}$ are the couplings with the low-energy degrees of freedom, which provide corrections to the potential picture.

Physics of the quarkonium ground state

- c and b masses at NNLO, N^{3}LO*, NNLL*;
- B_c mass at NNLO;
- B_c^*, η_c, η_b masses at NLL;
- Quarkonium 1P fine splittings at NLO;
- $\Upsilon(1S)$, η_b electromagnetic decays at NNLL;
- $\Upsilon(1S)$ and J/ψ radiative decays at NLO;
- $\Upsilon(1S) \to \gamma\eta_b$, $J/\psi \to \gamma\eta_c$ at NNLO;
- $t\bar{t}$ cross section at NNLL;
- QQq and QQQ baryons: potentials at NNLO, masses, hyperfine splitting, ... ;
- Thermal effects on quarkonium in medium: potential, masses (at $m\alpha_s^5$), widths, ...;
- ...

○ *for reviews* `QWG coll.` *Heavy Quarkonium Physics* `CERN Yellow Report CERN-2005-005`
`QWG coll. Eur. Phys. J. C71 (2011) 1534`

Weakly coupled pNRQCD

The suitable EFT for the quarkonium ground states is weakly coupled pNRQCD, because

$$mv \sim m\alpha_{\rm s} \gg mv^2 \sim m\alpha_{\rm s}^2 \gtrsim \Lambda_{\rm QCD}$$

- The degrees of freedom are quark-antiquark states (color singlet S, color octet O), low energy gluons and photons, and light quarks.
- $$\begin{aligned}\mathcal{L}_{\rm pNRQCD} \;=\; \int d^3r\, {\rm Tr}\, \Big\{ & {\rm S}^\dagger \left(i\partial_0 - \frac{\mathbf{p}^2}{m} + \cdots - V_s \right) {\rm S} \\ & + {\rm O}^\dagger \left(iD_0 - \frac{\mathbf{p}^2}{m} + \cdots - V_o \right) {\rm O} \Big\} \\ & - \frac{1}{4} F^a_{\mu\nu} F^{\mu\nu\, a} - \frac{1}{4} F_{\mu\nu} F^{\mu\nu} + \sum_{i=1}^{n_f} \bar{q}_i\, i\not{D} q_i + \Delta\mathcal{L}\end{aligned}$$
- At leading order in r, the singlet S satisfies the QCD Schrödinger equation with potential V_s.

Dipole interactions

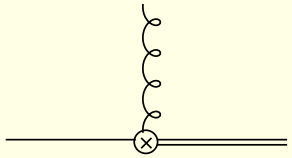
$\Delta\mathcal{L}$ describes the interaction with the low-energy degrees of freedom, which at leading order are dipole interactions

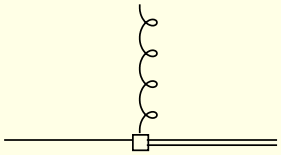
$$\Delta\mathcal{L} = \int d^3r \; \mathrm{Tr}\Big\{ V_A \mathrm{O}^\dagger \mathbf{r}\cdot g\mathbf{E}\,\mathrm{S} + \cdots$$

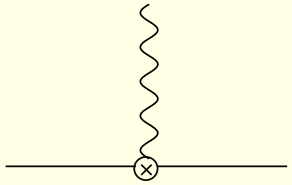
$$+\frac{1}{2m}\, V_1 \; \Big\{\mathrm{S}^\dagger, \boldsymbol{\sigma}\cdot g\mathbf{B}\Big\}\,\mathrm{O} + \cdots$$

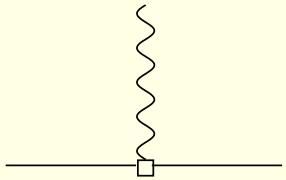
$$+V_A^{\mathrm{em}}\; \mathrm{S}^\dagger \mathbf{r}\cdot ee_Q\mathbf{E}^{\mathrm{em}}\mathrm{S} + \cdots$$

$$+\frac{1}{2m}\, V_1^{\mathrm{em}} \; \Big\{\mathrm{S}^\dagger, \boldsymbol{\sigma}\cdot ee_Q\mathbf{B}^{\mathrm{em}}\Big\}\,\mathrm{S} + \ldots \Big\}$$



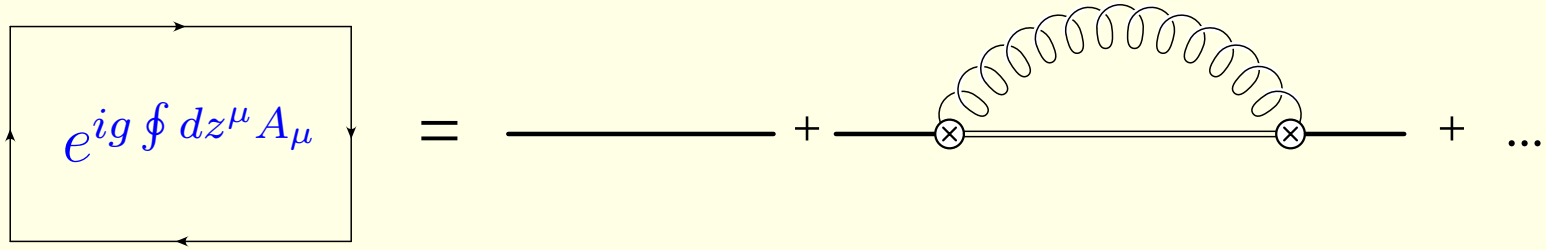






Static energy and potential at $T = 0$

The static potential in perturbation theory



NRQCD pNRQCD

$$\lim_{T\to\infty}\frac{i}{T}\ln\langle\,\square\,\rangle = V_s(r,\mu) - i\frac{g^2}{N_c}V_A^2\int_0^\infty dt\, e^{-it(V_o-V_s)}\,\langle \mathrm{Tr}(r\cdot E(t)\, r\cdot E(0))\rangle(\mu) + \ldots$$

[chromoelectric dipole interactions]

The μ dependence cancels between the two terms in the right-hand side:

- $V_s \sim \ln r\mu, \ln^2 r\mu$, ...
- *ultrasoft contribution* $\sim \ln(V_o - V_s)/\mu, \ln^2(V_o - V_s)/\mu, \ldots \ln r\mu, \ln^2 r\mu, \ldots$

- The static Wilson loop is known up to N^{3}LO.
  - Schröder PLB 447 (1999) 321
    Brambilla Pineda Soto Vairo PRD 60 (1999) 091502
    Brambilla Garcia Soto Vairo PLB 647 (2007) 185
    Smirnov Smirnov Steinhauser PLB 668 (2008) 293
    Anzai Kiyo Sumino PRL 104 (2010) 112003
    Smirnov Smirnov Steinhauser PRL 104 (2010) 112002
- The octet potential is known up to NNLO.
  - Kniehl Penin Schröder Smirnov Steinhauser PLB 607 (2005) 96
- $V_A = 1 + \mathcal{O}(\alpha_s^2)$.
  - Brambilla Garcia Soto Vairo PLB 647 (2007) 185
- The chromoelectric correlator $\langle \mathrm{Tr}(r \cdot E(t)\, r \cdot E(0)) \rangle$ is known up to NLO.
  - Eidemüller Jamin PLB 416 (1998) 415

The static potential at N^{4}LO

$$
\begin{aligned}
V_s(r,\mu) \;=\; & -C_F \frac{\alpha_s(1/r)}{r}\Bigg[1 + a_1 \frac{\alpha_s(1/r)}{4\pi} + a_2 \left(\frac{\alpha_s(1/r)}{4\pi}\right)^2 \\
& + \left(\frac{16\,\pi^2}{3} C_A^3 \,\ln r\mu + a_3\right)\left(\frac{\alpha_s(1/r)}{4\pi}\right)^3 \\
& + \left(a_4^{L2} \ln^2 r\mu + \left(a_4^L + \frac{16}{9}\pi^2\, C_A^3 \beta_0(-5 + 6\ln 2)\right)\ln r\mu + a_4\right)\left(\frac{\alpha_s(1/r)}{4\pi}\right)^4\Bigg]
\end{aligned}
$$

The static potential at N^{3}LL

$$V_s(r,\mu) = V_s(r,1/r) + \frac{2}{3} C_F r^2 \left[V_o(r,1/r) - V_s(r,1/r)\right]^3 \times \left(\frac{2}{\beta_0} \ln \frac{\alpha_s(\mu)}{\alpha_s(1/r)} + \eta_0 \left[\alpha_s(\mu) - \alpha_s(1/r)\right]\right)$$

$$\eta_0 = \frac{1}{\pi}\left[-\frac{\beta_1}{2\beta_0^2} + \frac{12}{\beta_0}\left(\frac{-5n_f + C_A(6\pi^2+47)}{108}\right)\right]$$

- Pineda Soto PLB 495 (2000) 323
- Brambilla Garcia Soto Vairo PRD 80 (2009) 034016

Static quark-antiquark energy at N^{3}LL

$$E_0(r) = V_s(r,\mu) + \Lambda_s(r,\mu) + \delta_{\rm US}(r,\mu)$$

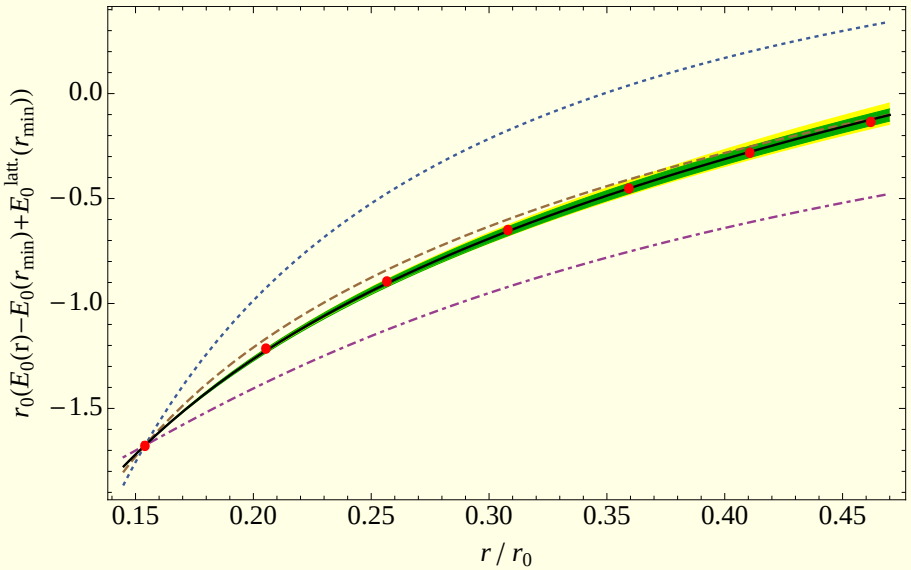
$$\Lambda_s(r,\mu) = N_s\Lambda + 2\,C_F(N_o - N_s)\Lambda\, r^2\,[V_o(r,1/r) - V_s(r,1/r)]^2 \times \left(\frac{2}{\beta_0}\ln\frac{\alpha_{\rm s}(\mu)}{\alpha_{\rm s}(1/r)} + \eta_0\,[\alpha_{\rm s}(\mu) - \alpha_{\rm s}(1/r)]\right)$$

$$\delta_{\rm US}(r,\mu) = C_F\,\frac{C_A^3}{24}\,\frac{1}{r}\,\frac{\alpha_{\rm s}(\mu)}{\pi}\,\alpha_{\rm s}^3(1/r)\left(-2\ln\frac{\alpha_{\rm s}(1/r)N_c}{2r\,\mu} + \frac{5}{3} - 2\ln 2\right)$$

N_s, N_o are two arbitrary scale-invariant dimensionless constants

Λ is an arbitrary scale-invariant quantity of dimension one

Static quark-antiquark energy at N^{3}LL vs lattice



- `Brambilla Garcia Soto Vairo PRL 105 (2010) 212001`
  `quenched lattice data from Necco Sommer NPB 622 (2002) 328`

  - Perturbation theory (known up to NNNLO) + renormalon subtraction describes well the static potential up to about 0.25 fm ($r_0 \approx 0.5$ fm).
  - Indeed one can use this to extract $\Lambda_{\overline{\rm MS}} r_0 = 0.622^{+0.019}_{-0.015}$ and in perspective r_0 (high precision unquenched lattice data is needed).

Radiative transitions

$J/\psi \to X\,\gamma$ for 0 MeV $\leq E_\gamma \lesssim$ 500 MeV

Scales:

- $\langle p \rangle \sim 1/\langle r \rangle \sim M_c v \sim$ 700 MeV - 1 GeV $\gg \Lambda_{\rm QCD}$
- $E_{J/\psi} \equiv M_{J/\psi} - 2M_c \sim M_c v^2 \sim$ 400 MeV - 600 MeV $\ll 1/\langle r \rangle$
- 0 MeV $\leq E_\gamma \lesssim$ 400 MeV - 500 MeV $\ll 1/\langle r \rangle$

It follows that the system is

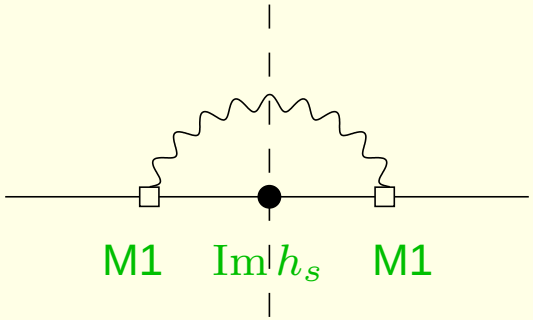
(i) non-relativistic,
(ii) weakly-coupled at the scale $1/\langle r \rangle$: $v \sim \alpha_{\rm s}$,
(iii) that we may mutipole expand in the external photon energy.

- `Brambilla Jia Vairo PRD 73 (2006) 054005`
- `see talk by Piotr Pietrulewicz for E1 transitions`

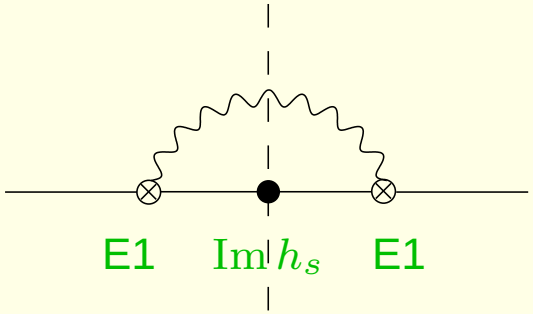
$J/\psi \to X\,\gamma$ for 0 MeV $\leq E_\gamma \lesssim$ 500 MeV

Three main processes contribute to $J/\psi \to X\,\gamma$ for 0 MeV $\leq E_\gamma \lesssim$ 500 MeV:

- $J/\psi \to \eta_c\,\gamma \to X\,\gamma$ [magnetic dipole interactions]



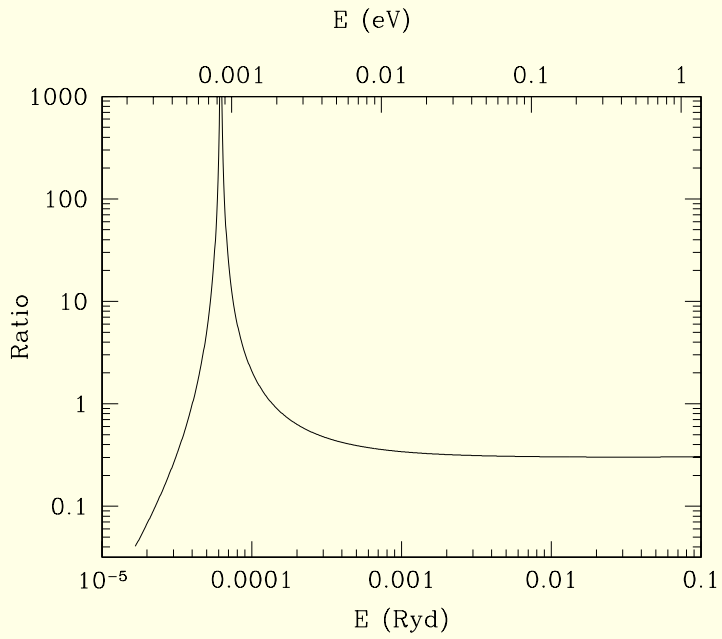
- $J/\psi \to \chi_{c0,2}(1P)\,\gamma \to X\,\gamma$ [electric dipole interactions]



- fragmentation and other background processes, included in the background functions.

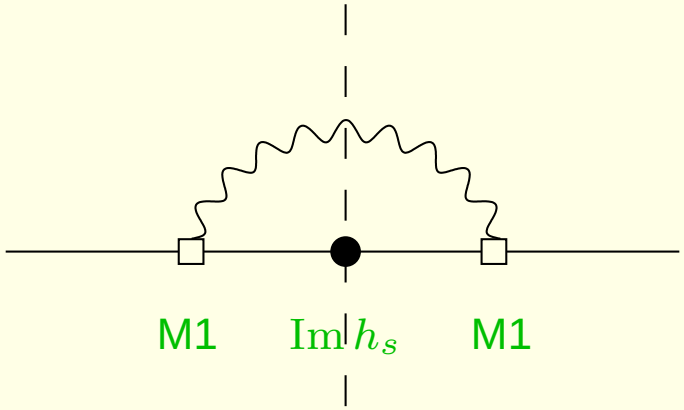
The orthopositronium decay spectrum

The situation is analogous to the photon spectrum in orthopositronium $\to 3\gamma$



- Manohar Ruiz-Femenia PRD 69(04)053003
  Ruiz-Femenia NPB 788(08)21, arXiv:0904.4875

$$J/\psi \to \eta_c\,\gamma \to X\,\gamma$$

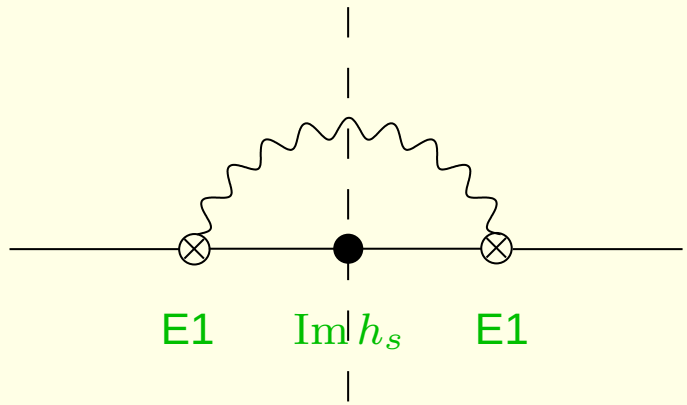


$$\frac{d\Gamma}{dE_\gamma} = \frac{64}{27}\,\frac{\alpha}{M_{J/\psi}^2}\,\frac{E_\gamma}{\pi}\,\frac{\Gamma_{\eta_c}}{2}\,\frac{E_\gamma^2}{(M_{J/\psi} - M_{\eta_c} - E_\gamma)^2 + \Gamma_{\eta_c}^2/4}$$

- For $\Gamma_{\eta_c} \to 0$ one recovers $\Gamma(J/\psi \to \eta_c\,\gamma) = \dfrac{64}{27}\alpha\dfrac{E_\gamma^3}{M_{J/\psi}^2}$
- The non-relativistic Breit–Wigner distribution goes like:

$$\frac{E_\gamma^2}{(M_{J/\psi} - M_{\eta_c} - E_\gamma)^2 + \Gamma_{\eta_c}^2/4} = \begin{cases} 1 & \text{for } E_\gamma \gg M_c\alpha_s^4 \sim M_{J/\psi} - M_{\eta_c} \\ \frac{E_\gamma^2}{(M_{J/\psi} - M_{\eta_c})^2} & \text{for } E_\gamma \ll M_c\alpha_s^4 \sim M_{J/\psi} - M_{\eta_c} \end{cases}$$

$$J/\psi \to \chi_{c0,2}(1P)\,\gamma \to X\,\gamma$$



$$\frac{d\Gamma}{dE_\gamma} = \frac{32}{81}\,\frac{\alpha}{M_{J/\psi}^2}\,\frac{E_\gamma}{\pi}\left[\frac{21\,\alpha_{\rm s}^2}{2\,\pi\,\alpha^2}\right]|a(E_\gamma)|^2$$

- $a(E_\gamma) = \dfrac{(1-\nu)(3+5\nu)}{3(1+\nu)^2} + \dfrac{8\nu^2(1-\nu)}{3(2-\nu)(1+\nu)^3}\,{}_2F_1(2-\nu,1;3-\nu;-(1-\nu)/(1+\nu))$

  $\nu = \sqrt{-E_{J/\psi}/(E_\gamma - E_{J/\psi})}$

  ○ Voloshin MPLA 19 (2004) 181

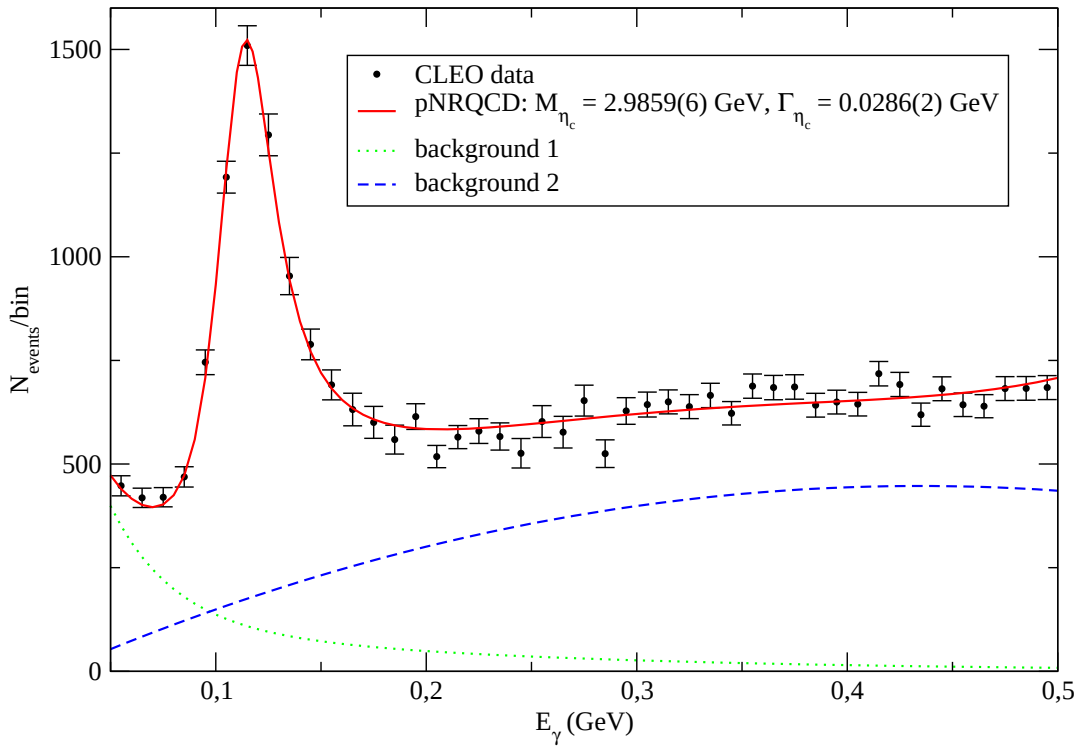
- $|a(E_\gamma)|^2 = \begin{cases} 1 & \text{for } E_\gamma \gg M_c\alpha_{\rm s}^2 \sim E_{J/\psi} \\ E_\gamma^2/(2E_{J/\psi})^2 & \text{for } E_\gamma \ll M_c\alpha_{\rm s}^2 \sim E_{J/\psi} \end{cases}$

- The two contributions are of equal order for $M_c\alpha_{\rm s} \gg E_\gamma \gg M_c\alpha_{\rm s}^2 \sim -E_{J/\psi}$;

- the magnetic contribution dominates for $-E_{J/\psi} \sim M_c\alpha_{\rm s}^2 \gg E_\gamma \gg M_c\alpha_{\rm s}^4 \sim M_{J/\psi} - M_{\eta_c}$;

- it also dominates by a factor $E_{J/\psi}^2/(M_{J/\psi} - M_{\eta_c})^2 \sim 1/\alpha_{\rm s}^4$ for $E_\gamma \ll M_c\alpha_{\rm s}^4 \sim M_{J/\psi} - M_{\eta_c}$.

Fit to the CLEO data



$M_{\eta_c} = 2985.9 \pm 0.6$ (fit) MeV $\qquad \Gamma_{\eta_c} = 28.6 \pm 0.2$ (fit) MeV

- Besides M_{η_c} and Γ_{η_c} the fitting parameters are the overall normalization, the signal normalization, and the (three) background parameters.

- `Brambilla Roig Vairo arXiv:1012.0773`

Thermal width at $T > 0$

The bottomonium ground state at finite T

The bottomonium ground state produced in the QCD medium of heavy-ion collisions at the LHC may possibly realize the hierarchy

$$M_b \approx 5 \text{ GeV} > M_b\alpha_{\rm s} \approx 1.5 \text{ GeV} > \pi T \approx 1 \text{ GeV} > M_b\alpha_{\rm s}^2 \approx 0.5 \text{ GeV} \gtrsim m_D, \Lambda_{\rm QCD}$$

- The bound state is weakly coupled: $v \sim \alpha_{\rm s} \ll 1$
- The temperature is lower than $M_b\alpha_{\rm s}$,
  implying that the bound state is mainly Coulombic
- Effects due to the scale $\Lambda_{\rm QCD}$ and to the other thermodynamical scales
  may be neglected

pNRQCD$_{\mathrm{HTL}}$

Integrating out T from pNRQCD modifies pNRQCD into pNRQCD$_{\mathrm{HTL}}$ whose

- Yang–Mills Lagrangian gets the additional hard thermal loop (HTL) part; e.g. the longitudinal gluon propagator becomes

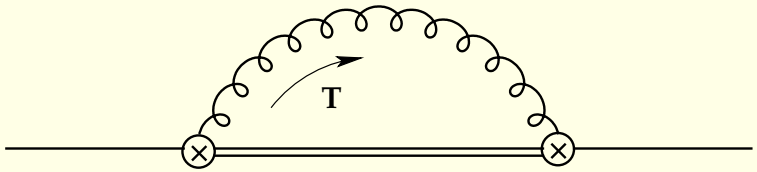
$$\frac{i}{\mathbf{k}^2} \to \frac{i}{k^2 + m_D^2 \left(1 - \frac{k_0}{2k} \ln \frac{k_0 + k \pm i\eta}{k_0 - k \pm i\eta}\right)}$$

  where "$+$" identifies the retarded and "$-$" the advanced propagator;

- potentials get additional thermal corrections δV.

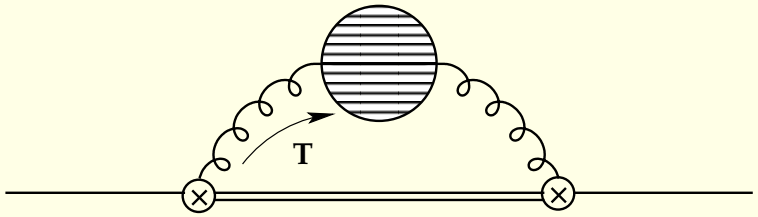
Integrating out T

The relevant diagram is (through chromoelectric dipole interactions)



and radiative corrections. The loop momentum region is $k_0 \sim T$ and $k \sim T$.

Integrating out T: thermal width



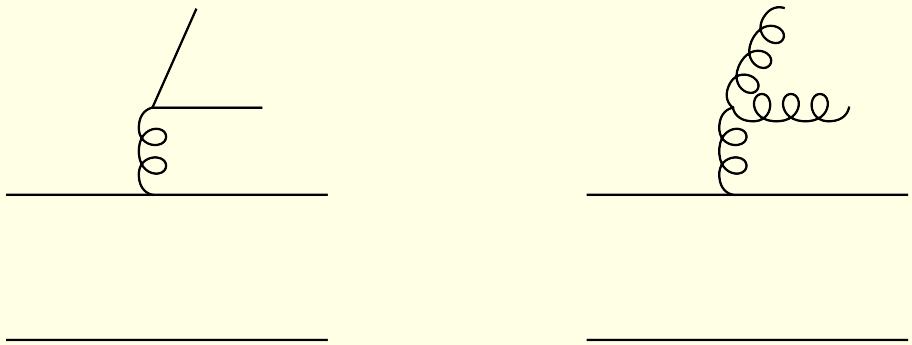
Landau-damping contribution

$$\Gamma_{1S}^{(T)} = \left[-\frac{4}{3}\alpha_{\rm s} T m_D^2 \left(-\frac{2}{\epsilon} + \gamma_E + \ln\pi - \ln\frac{T^2}{\mu^2} + \frac{2}{3} - 4\ln 2 - 2\frac{\zeta'(2)}{\zeta(2)} \right) - \frac{32\pi}{3}\ln 2\, \alpha_{\rm s}^2\, T^3 \right] a_0^2$$

where $E_1 = -\dfrac{4M_b\alpha_{\rm s}^2}{9}$ and $a_0 = \dfrac{3}{2M_b\alpha_{\rm s}}$

Landau damping

The Landau damping phenomenon originates from the scattering of the quarkonium with hard space-like particles in the medium.



- When $\mathrm{Im}\ V_s(r)|_{\mathrm{Landau-damping}} \sim \mathrm{Re}\ V_s(r) \sim \alpha_{\mathrm{s}}/r$, the quarkonium dissociates:

$$\pi T_{\mathrm{dissociation}} \sim M_b g^{4/3}$$

- When $\langle 1/r \rangle \sim m_D$, the interaction is screened; note that

$$\pi T_{\mathrm{screening}} \sim M_b g \gg \pi T_{\mathrm{dissociation}}$$

- Laine Philipsen Romatschke Tassler JHEP 0703 (2007) 054

$\Upsilon(1S)$ dissociation temperature

The $\Upsilon(1S)$ dissociation temperature:

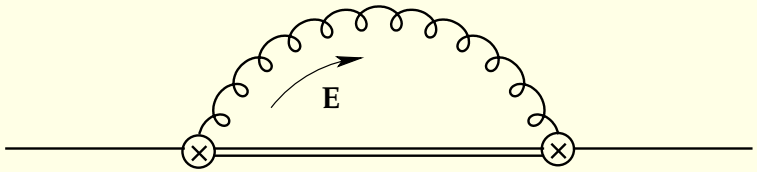
M_c (MeV)	$T_{\text{dissociation}}$ (MeV)
∞	480
5000	480
2500	460
1200	440
0	420

A temperature πT about 1 GeV is below the dissociation temperature.

- `Escobedo Soto PRA 82 (2010) 042506`

Integrating out E

The relevant diagram is (through chromoelectric dipole interactions)



where the loop momentum region is $k_0 \sim E$ and $k \sim E$. Gluons are HTL gluons.

Integrating out E: thermal width

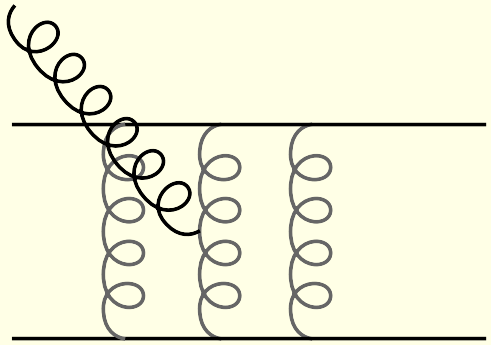
$$\Gamma_{1S}^{(E)} = 4\alpha_s^3 T - \frac{64}{9M_b}\alpha_s T E_1 + \frac{32}{3}\alpha_s^2 T \frac{1}{M_b a_0} + \frac{7225}{162} E_1 \alpha_s^3 - \frac{4\alpha_s T m_D^2}{3}\left(\frac{2}{\epsilon} + \ln\frac{E_1^2}{\mu^2} + \gamma_E - \frac{11}{3} - \ln\pi + \ln 4\right) a_0^2 + \frac{128\alpha_s T m_D^2}{27}\frac{\alpha_s^2}{E_1^2} I_{1,0}$$

where $E_1 = -\frac{4M_b\alpha_s^2}{9}$ and $a_0 = \frac{3}{2M_b\alpha_s}$ and $I_{1,0} = -0.49673$ (similar to the Bethe log)

- The UV divergence at the scale $M_b\alpha_s^2$ cancels against the IR divergence identified at the scale T.

Singlet to octet break up

The thermal width at the scale E, which is of order $\alpha_{\rm s}^3 T$, is generated by the break up of a quark-antiquark colour-singlet state into an unbound quark-antiquark colour-octet state: a purely non-Abelian process that is kinematically allowed only in a medium.



- The singlet to octet break up is a different phenomenon with respect to the Landau damping, the relative size of which is $(E/m_D)^2$. In the situation $M_b \alpha_{\rm s}^2 \gg m_D$, the first dominates over the second by a factor $(M_b \alpha_{\rm s}^2/m_D)^2$.

○ `Brambilla Ghiglieri Petreczky Vairo PRD 78 (2008) 014017`

The complete thermal width up to $\mathcal{O}(m\alpha_s^5)$

$$\Gamma_{1S}^{(\mathrm{thermal})} = \frac{1156}{81}\alpha_s^3 T + \frac{7225}{162}E_1\alpha_s^3 + \frac{32}{9}\alpha_s T m_D^2 a_0^2 I_{1,0} - \left[\frac{4}{3}\alpha_s T m_D^2 \left(\ln\frac{E_1^2}{T^2} + 2\gamma_E - 3 - \ln 4 - 2\frac{\zeta'(2)}{\zeta(2)}\right) + \frac{32\pi}{3}\ln 2\, \alpha_s^2 T^3\right] a_0^2$$

where $E_1 = -\frac{4M_b\alpha_s^2}{9}$, $a_0 = \frac{3}{2M_b\alpha_s}$

- Brambilla Escobedo Ghiglieri Soto Vairo JHEP 1009 (2010) 038
- see talk by Jacopo Ghiglieri

Conclusions

Our understanding of the theory of quarkonium has dramatically improved over the last decade. An unified picture has emerged that describes large classes of observables for quarkonium in the vacuum and in a medium.

For the ground state, precision physics is possible and lattice data provide a crucial complement. In the case of quarkonium in a hot medium, this has disclosed new phenomena that may be eventually responsible for the quarkonium dissociation.

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QWG2011: Workshop on Quarkonium

international workshop on heavy quarkonia, organized by the quarkonium working group

october 4 - 7, 2011

qwg2011.gsi.de

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