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Heavy Flavor Mesons in Strong Magnetic Fields

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The response of heavy pseudoscalar and vector mesons to the strong magnetic fields created in heavy ion collisions is studied. Interaction of the constituent quark magnetic moments with the external magnetic field is described using the analogy of mesons with Positronium and Muonium bound states. Magnetic moments of open-flavor vector mesons are estimated and magnetic polarizability of pseudoscalar mesons is discussed. For heavy Quarkonium we predict a quantum mixing of spin singlet states η_c, η_b with (m_z=0) substates of J/ψ and Υ mesons, which results in the modification of their decay widths (lifetimes) and decay channels. We also consider the case of $\varphi(1020)$ meson. The influence of the Quarkonium states mixing on dilepton spectrum observed in heavy ion collisions is discussed.

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1. Introduction

Magnetic fields created in relativistic heavy ion collisions [1] are predicted to be extremely large: $B \approx 10^{15}$ Tesla. During their short-time existence, such fields can interact with the magnetic moments of quarks, influence properties of strongly interacting partonic matter [2] and possibly also change the internal structure of hadrons.

Quarks, having electric charge, color charge and weak-hypercharge, should have magnetic, chromo-magnetic and also weak-magnetic moments, as can be infered from Dirac equation [3]. Magnetic dipole moment is generated "automatically" around any charged massive body with the angular momentum, due to non-diagonal metric tensor $g^{\mu\nu}$ in the space surrounding such objects[1].

Chromo-magnetic moments of quarks, originating from the color charge, are responsible for the hyperfine splitting of hadronic masses. Different orientations of constituent quark spins can change the interaction energy of quark chromo-magnetic moments in hadrons by hundreds MeV. Typical examples are $\eta_c - \psi(1S)$ or $N - \Delta$ mass differences. At the same time, ordinary magnetic moments of quarks also interact with each other inside hadrons. Being unconfined, dipole magnetic fields of quarks contribute to baryon magnetic moments, which respond to external magnetic fields. Typical examples are NMR experiments with protons or the precession of polarized hyperons [4].

Mesons, composed of quarks and antiquarks should (similarly to baryons) possess magnetic moments provided their angular momentum $J{\neq}0$. We will show that magnetic moments of vector mesons are comparable in size to the magnetic moment of proton or neutron ($2.79\mu_N$, $-1.91\mu_N$). Due to the short lifetime of vector mesons ($c\tau < 500\mu m$), precession of their spin in the magnetic field of laboratory magnets ($B < 10$Tesla) is not measurable, contrary to the case [4] of hyperons. However, in the magnetic fields $B \approx 10^{14}$ Tesla created in relativistic nucleus-nucleus collisions, electromagnetic structure of mesons may become important and have measurable consequences.

In this contribution we assume mesons to be composed of the constituent quark and anti-quark, both of them having its own static magnetic moment μ_q^* and $\mu_{\bar{q}}^*$. Response of QCD vacuum (chiral condensates) to strong magnetic fields [5] is not considered here.

2. Magnetic moments of Quarks and Mesons

Magnetic moments of hyperons and lightest baryons can be understood assuming the existence of the magnetic moment of constituent quarks. Indeed, dividing the low-mass s=1/2 baryons into categories: a) $q_a(q_b q_a)$ containing two quarks of the same flavor, and b) $q_a(q_b q_c)$ with all three quarks different, and observing that s=3/2 baryons have all quarks spins parallel, one can approximate magnetic moments of $p, n, \Sigma^+, \Sigma^-, \Xi^o, \Xi^-$ baryons as $\mu = 4(\mu_a^* - \mu_b^*)/3$, moments of $\Omega^-, \Delta^+, \Delta^{++}$ as $\mu = \sum \mu_{q_i}^*$ and for Λ^o hyperon $\mu = \mu_s^*$. Convincing agreement with experimental data is obtained assuming $\mu_u^* = 1.85\mu_N$, $\mu_d^* =$-0.97μ_N, and $\mu_s^* =$-0.61μ_N, where μ_N is the nuclear magneton $\mu_N = 5 \cdot 10^{-27}$ J/T.

From Dirac equation we know that elementary particles with spin s=1/2 and charge Q should have magnetic moment $\mu = \hbar Q/2mc$, as can be shown by F-W transformation [3] of Dirac equation. Magnetic moments μ_q^* of constituent u, d, s quarks are in agreement with equation $\mu^* = \hbar Q/2mc$,

[1] Kerr-Neuman solutions for charged rotating singular massive objects have gyromagnetic factor $g = 2$ similarly to electron, and other speculations on relation between general theory of relativity and particle physics are known [6].

if constituent quark masses ($m_u^* \approx m_d^* \approx 330$MeV, and $m_s^* = 510$MeV) are used for the mass m. One can predict $\mu_c^* = 0.40\mu_N$, $\mu_b^* =$-0.066μ_N using $m_c^* = 1550$MeV and $m_b^* = 4730$MeV.

Vector mesons are bound states of quark-antiquark with parallel spins. Magnetic moment of vector ($J^P = 1^-$) mesons should then be calculable as $\mu = \sum \mu_{q_i}^*$, similarly to s=3/2 baryons Ω^-, and $\Delta(1232)$. For charged vector mesons $\rho^-, K^{*+}, D^{*-}, D_s^{*-}$ and B^{*-} one obtains $\mu^* = -2.82\mu_N$, $2.46\mu_N$, $-1.37\mu_N$, $-1.02\mu_N$, and $-1.92\mu_N$, which agrees well with theoretical calculations [7]. For the neutral open-flavor vector mesons B^{o*}, B_s^{o*}, K^{o*} and D^{o*} one has $\mu^* = -0.9\mu_N$, $-0.5\mu_N$, $-0.3\mu_N$ and $-1.4\mu_N$. These predictions are summarized in Table 1.

Table 1: Magnetic moment estimates for charged and neutral open-flavor J^P=1$^-$ mesons.

	ρ^-	K^{*+}	D^{*-}	D_s^{*-}	B^{*-}	B^{*o}	B_s^{*o}	K^{o*}	D^{o*}
m [MeV]	770	892	2010	2112	5325	5325	5415	896	2007
$q\bar{q}$	$d\bar{u}$	$u\bar{s}$	$d\bar{c}$	$s\bar{c}$	$b\bar{u}$	$d\bar{b}$	$s\bar{b}$	$d\bar{s}$	$c\bar{u}$
μ^* [μ_N]	-2.82	2.46	-1.37	-1.02	-1.92	-0.9	-0.5	-0.3	-1.4

Magnetic interaction of hidden-flavor vector mesons J/ψ, Υ, φ and of pseudoscalar mesons is however more complex. We describe it in the next section based on the similarity with Positronium or Muonium bound states. Interaction of QCD condensates with strong magnetic fields [5], which have influence on the meson properties, is neglected here.

3. Positronium and Quarkonium in the Magnetic field

Behavior of Positronium (e^+e^-) ground state in magnetic fields ($B \approx 1$Tesla) has been investigated many years ago [8]. The interaction of external magnetic field B with positron and electron magnetic moments μ_{e^-}=$-|\mu_{e^+}|$ leads to the quantum interference (mixing) of ortho-Positronium (J=1, m_z=0) state $\Psi_o = (\uparrow\downarrow + \downarrow\uparrow)/\sqrt{2}$ with para-Positronium state $\Psi_p = (\uparrow\downarrow - \downarrow\uparrow)/\sqrt{2}$. Two ($m_z = \pm 1$) ortho-Positronium states ($\uparrow\uparrow$) and ($\downarrow\downarrow$) have zero magnetic moment, remain intact by the magnetic field, and decay into 3γ, 5γ with unchanged lifetime τ_o=1/λ_o=1.4$\cdot$10^{-7}s. New mixed ortho-state $\Psi_o^+ = \cos(\alpha)\Psi_o + \sin(\alpha)\Psi_p$ can decay also into 2γ with the probability determined by the admixture of para-Positronium state in Ψ_o^+ wave-function. As a consequence, the lifetime of Ψ_o^+ state is strongly reduced and up to 33% of 3γ decays of ortho-Positronium disappear [9] in the static magnetic field ($B \approx 1$T). At the same time, para-Positronium state in the magnetic field gets admixture of ortho-state and new state $\Psi_p^- = \cos(\alpha)\Psi_p - \sin(\alpha)\Psi_o$ decays also into 3γ besides its natural 2γ and 4γ annihilation channels. The original lifetime τ_p=1/λ_p=1.2$\cdot$10^{-10}s of para-Positronium is only slightly increased. Decay rates of new mixed states Ψ_p^- and Ψ_o^+ are [8]

$$\lambda_p^- = (\lambda_p + y^2\lambda_o)/(1+y^2) \qquad \lambda_o^+ = (\lambda_o + y^2\lambda_p)/(1+y^2) \tag{3.1}$$

and their energies depend on the magnetic field as

$$E_p^- = \frac{1}{2}\Delta E_{hf}(1 - \sqrt{1+x^2}) \qquad E_o^+ = \frac{1}{2}\Delta E_{hf}(1 + \sqrt{1+x^2}) \tag{3.2}$$

where $y = x/(1+\sqrt{1+x^2})$ and $x = 4\mu_e' B/\Delta E_{hf}$. (Here $\Delta E_{hf} = 8.4 \cdot 10^{-4}$eV is hyperfine energy splitting of Positronium, and μ_e' is the magnetic moment of bound electron [10]). The mixing parameter α in states Ψ_o^+ and Ψ_p^- depends on the magnetic field as: $\sin(\alpha) = y/\sqrt{1+y^2}$.

Fraction F of all ortho-Positronium decays via original (3γ) channel is [8]: F=2/3+1/3(1+R), where R=$y^2(\lambda_p/\lambda_o)$. For $B \approx$ 1T one has x=0.27 (using μ_e=5.79$\cdot$10^{-5}eV) and y=0.12. This gives R=16.4 and F=2/3+0.02: almost all Ψ_o^+ states decay via (originally C-parity violating) 2γ channel.

Quarkonium $(c\bar{c}),(b\bar{b})$ in the ground state can be found in spin-triplet configuration known as vector mesons J/ψ, Υ(9460) or in the spin-singlet state observed as pseudoscalars η_c(2980), η_b(9389). Due to chromo-magnetic hyperfine interaction of quarks, energies of para-Quarkonium (J=0^{-+}) and ortho-Quarkonium (J=1^{--}) are separated by $\Delta E_{hf}^{c\bar{c}}$=116.4MeV and 71.4MeV for $(b\bar{b})$.

Magnetic moments μ_c,μ_b of quarks are small compared to μ_e, however they can interact with the external magnetic field. Hamiltonian term $\mathcal{H}_i = \mu_q B[\sigma_z(q) - \sigma_z(\bar{q})]$ will induce mixing of two orthogonal $m_z = 0$ quantum states similarly to Positronium. Thus, in a sufficiently strong magnetic fields (e.g. in heavy ion collisions) one can anticipate that quantum mixing of ortho- and para-Quarkonium happens (quantum numbers of $q\bar{q}$ states correspond to Positronium). The mixing of states is controlled by simple parameter $x = 4\mu_q B/\Delta E_{hf}^{q\bar{q}}$ in Eq.(3.2). For the Positronium $x = 0.27$ in magnetic field $B = 1$ Tesla. This is achieved for $B = 6.2\cdot 10^{14}$T in the case of Charmonium and for $B = 2.3\cdot 10^{15}$ Tesla for the Bottomium ground states.

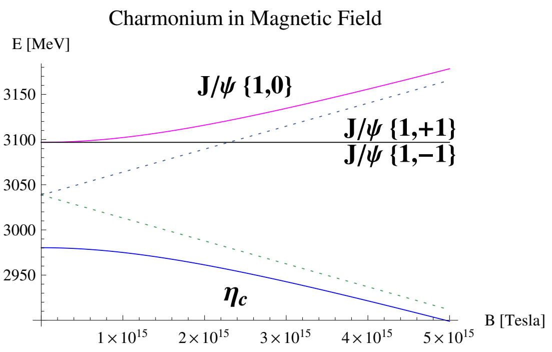

Figure 1: Energy of η_c and J/Ψ in magnetic field.

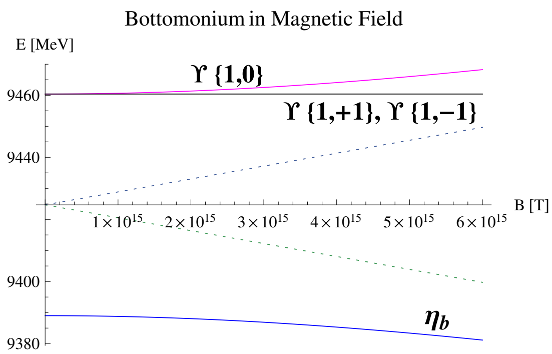

Figure 2: Energy of η_b and Υ in magnetic field.

Energy (mass) of para-Charmonium state $\tilde{\eta}_c$ is lowered according to Eq.(3.2) by 2MeV for B=6$\cdot$10^{14}Tesla, while its decay width $\lambda_p = 26.7$MeV is not affected significantly (see Eq.3.1). Similarly to ortho-Positronium, mixed $(q\bar{q})$ state Ψ_o^+ is allowed to decay via new channels. For example, J/$\psi \to ggg$ decay normally happens in 64% of cases, but in the case of quantum mixing $\Psi_o^+ \to gg$ is possible, which increases its decay width λ_o=93keV $\to$ 527keV at B=6$\cdot$10^{14}T (see Eq.3.1). This means reduction of $\Psi_{J/\psi}^+$ lifetime by factor 5x. Similar behavior can be expected for $\psi(2S)$ coupled to $\eta_c(2S)$ with $\Delta E_{hf}^{c\bar{c}} = 47$MeV and for the Bottomium states $\Upsilon(1S)$ and $\eta_b(9391)$. Assuming[2] $\lambda_p = \Gamma_{\eta_b} \approx 10$MeV in Eq.3.1, one has λ_o=54keV $\to$ 102keV in the static magnetic field $B = 1.2\cdot 10^{15}$T, reducing the lifetime of mixed state Ψ_Υ^+ by factor 2x. Mass of $(m_z = 0)$ vector state Ψ_Υ^+ increases according to Eq.3.2 by 1 MeV at 2$\cdot$10^{15}T and therefore it should experience repulsive (diamagnetic) interaction in the magnetic field.

The above mentioned modifications of heavy Quarkonium properties are of purely electro-magnetic origin. Changes due to gluonic or quark condensates [11] in hot QCD medium (which are influenced also by strong magnetic fields [12]) are not considered here.

[2]Decay width of η_b is only estimated [13], experimental verification is needed.

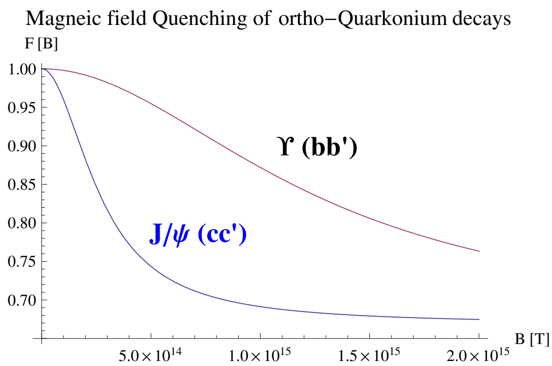

Figure 3: Fraction of J/Ψ and Υ particles decaying into original (l^+l^-) channels in the magnetic field.

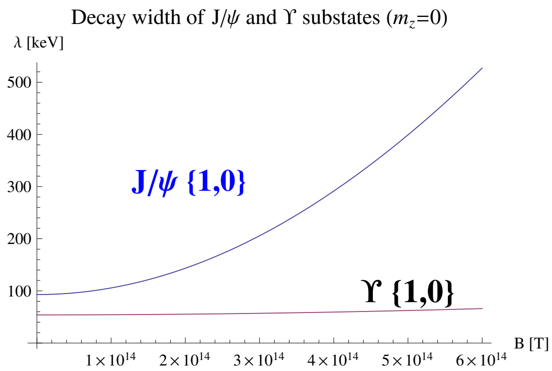

Figure 4: The increase of decay widths for $\Psi^+_{J/\psi}$ and Ψ^+_Υ states $(m_z = 0)$ in the magnetic field.

4. Dilepton signatures of Quarkonium states mixing in the magnetic field

In the strong magnetic field (B=6·10^{14}Tesla), new ortho-Charmonium state Ψ^+_o can decay also via 2-gluon (gg) channel due to the admixture of pseudoscalar $\Psi_p = \eta_c$ state in its wave function. Therefore, a significant fraction of hadronic $(ggg, gg\gamma)$ and leptonic (e^+e^-, $\mu^+\mu^-$) decays of new Ψ^+_o state will disappear, being replaced by the competing (gg) decays. $R = y^2(\lambda^{\eta_c}/\lambda^{\Psi}) = 4.13$ for $y = 0.12$, $x = 0.27$, and thus [8] $(1-F) = R/3(1+R) = 26.8\%$ of dilepton decays of all J/ψ mesons in the static magnetic field B=6·10^{14}Tesla should be quenched (see Fig.3) analogously to Positronium [9]. Those missing dilepton pairs belong to Ψ^+_o mixed state, for which the energy (see Fig.1) is increased by $\delta E = \sqrt{1+x^2}(\Delta E^{c\bar{c}}_{hf}/2)$, compared to two $(m_z = \pm 1)$ states J/Ψ. Therefore, just above the observed J/Ψ peak in the measured dilepton mass spectrum, those missing (l^+l^-) pairs might produce a little dip after the subtraction of Gaussian J/Ψ peak at 3096MeV from the experimentally measured dilepton mass spectrum.

At the same time, new mixed para-Charmonium state $\Psi^-_p = \tilde{\eta}_c$ can decay into dilepton pairs, proportionally to the admixture of ortho-state Ψ_o $(m_z = 0)$ in its wave function. A small bump below J/ψ mass can appear in the observed dilepton spectrum due to dileptons originating from $\tilde{\eta}_c \to l^+l^-$ decays in the magnetic field. Dilepton pairs originating from $\tilde{\eta}_c \to l^+l^-$ decays can be produced only in extreme magnetic fields, which disappear soon when partonic plasma expands. Since lifetime of $\tilde{\eta}_c$ and $\tilde{\eta}_b$ quarkonium states is almost unchanged in the magnetic fields (see Eq.3.1), total yield of such anomalous dilepton pairs depends on the ratio τ_B/τ_{η_c} of the magnetic field lifetime τ_B and the lifetime of $\tilde{\eta}_c$. For bottomium states ϒ(1s), ϒ′(2s) and light vector mesons $(\varphi$, ω, $\rho^o)$ one may expect similar effects to happen.

5. Open-flavor mesons in magnetic field

The interaction of heavy flavor mesons containg quarks of different mass, for example $(b\bar{d})$=B^+ or $(c\bar{u})$=D^o, with magnetic fields can be understood using the analogy with Muonium (μ^+e^-). Spin-triplet Muonium ground state [14] corresponds to $J = 1$ open-flavor mesons, e.g. $B^{o*}(5325)$, $D^{o*}(2007)$, while para-Muonium (spin-singlet) state corresponds to pseudoscalar $(J = 0)$ mesons

B^o, D^o, B^o_s. Similarly to Muonium, magnetic moments of the constituents are different $|\mu_1| \neq |\mu_2|$ and therefore $(m_z = \pm 1)$ ortho-states $|\uparrow\uparrow\rangle$ and $|\downarrow\downarrow\rangle$ have magnetic moment $\vec{\mu}_{12} = \vec{\mu}_1 + \vec{\mu}_2$. For example, B^{+*} magnetic moment is $\mu_{B^{*+}} \approx |\mu_u| + |\mu_{\bar{b}}| = 1.92\mu_N$, for B^{-*} meson $\mu_{B^{*-}} \approx -1.92\mu_N$ (compare to neutron $\mu_n = -1.91\mu_N$) and for D^{o*} meson one has: $\mu_{D^{o*}} \approx |\mu_c| - |\mu_{\bar{u}}| = -1.4\mu_N$.

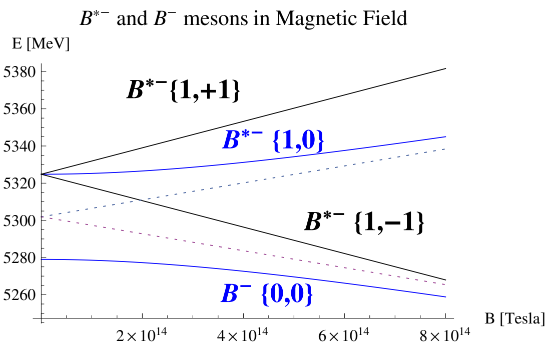

Figure 5: Energy of B^- and B^{-*} in magnetic field.

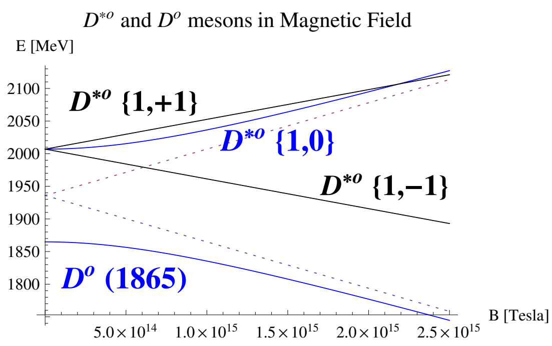

Figure 6: Energy of D^o and D^{o*} in magnetic field.

Two $(m_z = 0)$ states $\Psi_p = (\uparrow\downarrow - \downarrow\uparrow)/\sqrt{2}$ and $\Psi_o = (\uparrow\downarrow + \downarrow\uparrow)/\sqrt{2}$ have zero magnetic moment similarly to Positronium and Quarkonium. Electromagnetic interaction of mesons with external magnetic field is described by Hamiltonian term $\hat{\mathscr{H}}_i = -B \cdot \hat{\mu}_{q\bar{q}}$. For charged meson $B^- = (b\bar{u})$ we have $\hat{\mu}_{q\bar{q}} = -|\mu_b|\hat{\sigma}_z - |\mu_{\bar{u}}|\hat{\sigma}_z$ and for neutral $(c\bar{u}) = D^o$ meson: $\hat{\mu}_{q\bar{q}} = |\mu_c|\hat{\sigma}_z - |\mu_{\bar{u}}|\hat{\sigma}_z$. In the magnetic field, quantum interference (mixing) of Ψ_p and Ψ_o states takes place similarly to Muonium [14] or Positronium [8]. New mixed states Ψ_o^+ and Ψ_p^- can be expressed as

$$\Psi_o^+ = \frac{c_\alpha + s_\alpha}{\sqrt{2}}|\uparrow\downarrow\rangle + \frac{c_\alpha - s_\alpha}{\sqrt{2}}|\downarrow\uparrow\rangle \qquad \Psi_p^- = \frac{c_\alpha - s_\alpha}{\sqrt{2}}|\uparrow\downarrow\rangle - \frac{c_\alpha + s_\alpha}{\sqrt{2}}|\downarrow\uparrow\rangle \tag{5.1}$$

where $c_\alpha = 1/\sqrt{1+y^2}$ and $s_\alpha = y/\sqrt{1+y^2}$, while $y = x/(1+\sqrt{1+x^2})$ and $x = 2\mu_{12}B/\Delta E_{hf}$. As the magnetic field increases, the states Ψ_o^+ and Ψ_p^- "rotate" by mixing angle $\alpha = \arctan(y)$ as shown in Fig.7. For very large magnetic fields angle α approaches maximum value $\alpha \to \frac{\pi}{2}$ and (using Eq.5.1) we have $\Psi_o^+ = |\uparrow\downarrow\rangle$ and $\Psi_p^- = -|\downarrow\uparrow\rangle$. In such extreme case the magnetic moment $\langle\hat{\mu}\rangle$ of spin-singlet D^o meson becomes $\langle\downarrow\uparrow|\hat{\mu}_{q\bar{q}}|\downarrow\uparrow\rangle = |\mu_c| + |\mu_u|$. Thus, *induced* magnetic moment of D^o meson can be larger than magnetic moment of $(m_z = \pm 1)$ states of D^{o*}, which corresponds to the behavior of para- and ortho-states of Muonium [14]. For intermediate magnetic fields

$$\langle\Psi_p^-|\hat{\mu}_{c\bar{u}}|\Psi_p^-\rangle = (|\mu_c| + |\mu_u|)\sin(2\alpha) \quad , \quad \langle\Psi_o^+|\hat{\mu}_{c\bar{u}}|\Psi_o^+\rangle = -(|\mu_c| + |\mu_u|)\sin(2\alpha) \tag{5.2}$$

where $\sin(2\alpha) \to 1$ for $B \to \infty$. The intrinsic magnetic polarizability [15] of meson, originating from the mixing of singlet and the lowest triplet $(m_z = 0)$ states, is $\beta_M^{int} = 2\langle\Psi_p^-|\hat{\mu}_{q\bar{q}}|\Psi_o^+\rangle^2/\Delta E_{hf}$. This gives $\beta_M^{int} = 2(|\mu_c| + |\mu_u|)^2/\Delta E_{hf}^{c\bar{u}}$ for D^o and $\bar{D}^o$ mesons. For charged B^- mesons the magnetic polarizability is $\beta_M^{int} = 2(|\mu_b| - |\mu_u|)^2/\Delta E_{hf}^{b\bar{u}}$. Maximal *induced* magnetic moment of B^- meson $\langle\uparrow\downarrow|\hat{\mu}_{b\bar{u}}|\uparrow\downarrow\rangle = |\mu_{\bar{u}}| - |\mu_b|$, which cannot exceed magnetic moment of B^{-*} state: $\mu = |\mu_b| + |\mu_u|$.

Open-flavor neutral and charged mesons do not annihilate into $\gamma\gamma$, gg or 3γ, ggg. Vector states D^*, B^* usually decay into the spin-singlet configurations by the emission of γ, π^o, or $\pi^\pm$. For example, $D^{*+}(2010)$ meson (Γ=96±22keV, $\tau \approx 7\cdot10^{-21}$s) decays in 68% of cases into $D^o + \pi^+$,

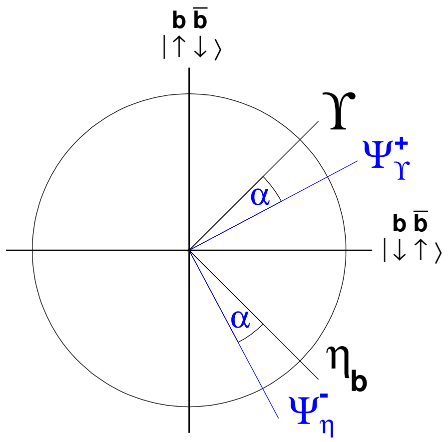

Figure 7: Rotation of new states Ψ^+_Υ and $\Psi^-_{\eta_b}$ relative to Υ (m_z=0) and η_b in magnetic field.

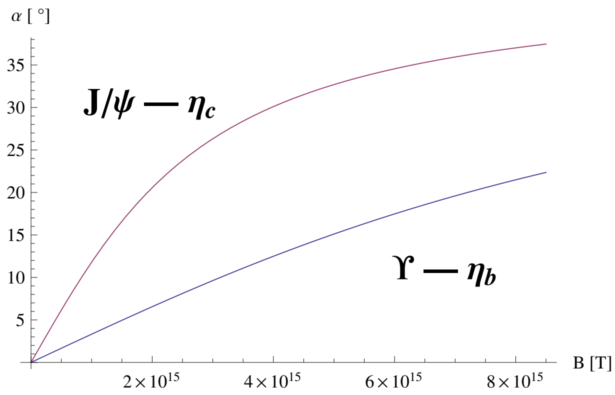

Figure 8: Angle α for the mixing of quarkonium states in strong magnetic fields: $\tan(\alpha) = x/(1+\sqrt{1+x^2})$.

while its long-lived spin-singlet partner D^+ ($\tau \approx 10^{-12}$s) contributes to e^+, μ^+ lepton spectra in heavy ion collisions. Hyperfine splitting in D^+, D^{*+} system is ΔE_{hf}=140MeV, and $\mu_{D^{*+}} \approx 1.37\mu_N$, ratio $\tau_{D^{+*}}/\tau_{D^+} \approx 7{\cdot}10^{-9}$. If the magnetic field $B \approx 10^{15}$ Tesla lasts for a sufficiently long time, quantum superposition of D^+ meson with ($m_z = 0$) ortho-state D^{*+}(2010) can occur. However, due to the mass (energy conservation) restriction, the mixed $\Psi^-_{D^+}$ para-state cannot decay into $D^o + \pi^+$. Therefore, we do not expect consequences of the quantum mixing in large magnetic fields to be significant in this case.

6. The case of φ(1020) and ω, ρ mesons

Similarly to the case of Charmonium and Bottomium described above, one may expect that φ(1020) meson ($s\bar{s}$ state with J=1) should have a spin-singlet ($s\bar{s}$ J=0) partner, which is lighter compared to φ due to the hyperfine interaction of quark chromo-magnetic moments. Pure η_s state is however not identified in the mass spectrum of hadrons. The only reasonable partner for φ is $\eta'(958)$. We have $\Delta M(\Upsilon - \eta_b) = 71.4$MeV and $\Delta M(J/\psi - \eta_c) = 116.6$MeV, which agrees with chromo-magnetic moments of heavy b,c quarks to be inversely proportional to the constituent quark masses. In the sense of Rújula-Georgi-Glashow [16] picture of mesons, one can proceed to the light mass region and observe: $\Delta M(\omega - \eta(547)) = 234.8$MeV and $\Delta M(\rho - \pi) = 640$MeV. The mass splitting of $\Delta M(\varphi - \eta_s)$ should then be located inbetween 116MeV and 235MeV. However, $\Delta M(\varphi - \eta'(958)) = 61.7$MeV. This is too small if chromo-magnetic moment of s-quark is inversely proportional to its constituent mass. Clearly, mass of $\eta'(958)$ meson has a contribution of different origin [17] if compared to heavy Quarkonium states η_b, η_c.

Nevetherless, let us assume $\eta'(958)$ to be the mixing partner (e.g. with 66% $s\bar{s}$ content) for φ. The mass of φ state with (m_z=0) is then expected to increase (see Fig.9) in the magnetic field, while φ (m_z=$\pm$1) states remain unaffected. At the same time, mass of pseudoscalar $K^\pm$ mesons ($s\bar{u}$) and K^o mesons ($d\bar{s}$) is expected to decrease (see Fig.10), due to $K - K^*$ quantum mixing in the magnetic field.

Such changes of φ and K meson masses will enhance phase-space for $\varphi \to KK$ decays. It is interesting to observe that due to different magnetic polarizabilities, mass decrease of $K^{\pm}$ and K^o mesons in the magnetic field is significantly different. Our preliminary estimate for the static field $B = 10^{15}$ Tesla gives $\Delta M_{K^{\pm}}$=-3.8MeV and ΔM_{K^o}=-14.6MeV. Decays $\phi \to K^+K^-$ and $\phi \to K^o\bar{K}^o$ are competing with each other with similar probabilities: $P_{K_{\pm}}$=48.9% and $P_{K_{\pm}}$=34.2%. Larger enhancement of phase-space for $\phi \to K^o\bar{K}^o$ means less $\phi \to K^+K^-$ decays than expected. Since dilepton channel $\phi \to l^+l^-$ is not affected by the change of K meson masses, ratio $\Gamma_{l^+l^-}/\Gamma_{K^+K^-}$ gets modified in strong magnetic fields. This may be related to subtle differencies in p_t slopes and total yields of φ mesons observed via l^+l^- and K^+K^- decays in heavy ion collisions at SPS [18] and RHIC [19]. All changes in φ and K meson masses considered here are of purely electromagnetic origin. Taking into account also QCD effects can modify the situation very substantially.

A possibility of mixed $\Psi^-_{\eta'} = \cos(\alpha)\eta' + \sin(\alpha)\varphi$ state to decay into $\to K^+K^-$ is forbidden due to the mass (energy) constraints: $M_{\eta'} < 2M_{K^{\pm}}$. Additionally, mass of η' is expected to decrease significantly in dense QCD environment [20]. Decays of state $\Psi^-_{\eta'}$ directly to $\to l^+l^-$ are possible proportionally to the admixture of (m_z=0) φ meson ortho-state in the $\Psi^-_{\eta'}$ wave function. Spectrum of dileptons below φ meson mass may get contaminated by such dileptons.

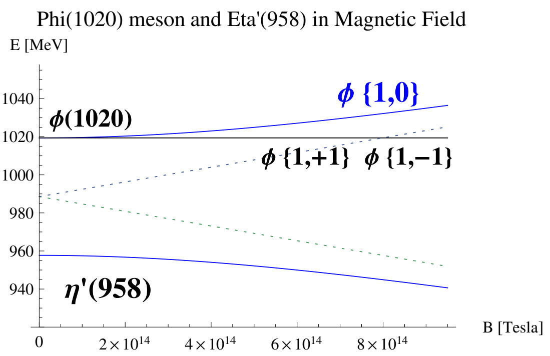

Figure 9: Energy of $\varphi(s\bar{s})$ and η'_s in magnetic field.

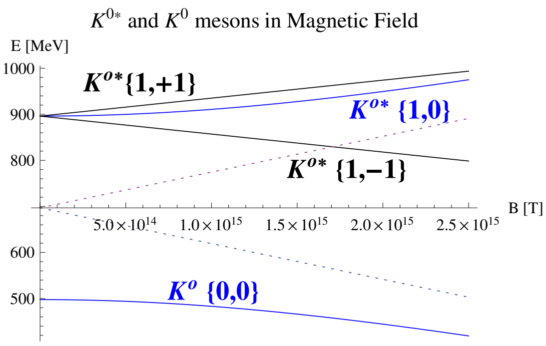

Figure 10: K^o and K^{o*} mesons in magnetic field.

One may also speculate that in the strong magnetic fields created in heavy-ion collisions a mixing of *para* and *ortho* ($m_z = 0$) $q\bar{q}$ states may happen also for light mesons $\omega, \rho^o, \eta, \pi^o$. Such mixing would mean that $\eta(547)$, for example, would become a mixed Ψ^-_{η} state, being able to decay into dilepton pairs with invariant masses in the region 400-550MeV. If mixing of $\pi^o - \rho^o$ states takes place, then dilepton spectrum can become contaminated via direct decays of mixed state $\Psi^-_{\pi^o} \to e^+e^-$. In such preliminary considerations, one should take into account the lifetimes of $\rho^o(770)$, $\omega(782)$ and $\eta(547)$ mesons ($\Gamma_\rho = 149$MeV, $\Gamma_\omega = 8.5$MeV and $\Gamma_\eta = 1.3$keV). Mesons ω and η decay outside the expanding fireball, when magnetic fields already disappeared. However, ρ^o meson decays early, and $\rho^o - \pi^o$ superposition may have significant measurable effects.

Masses of light pseudoscalar mesons are expected to be modified also due to instanton-induced effects in dense QCD medium [20]. Non-trivial interplay of singlet-triplet states mixing in the magnetic field and flavor-mixing effects [20] may possibly take place. The mechanism of dilepton production, originating from the quantum mixing of states in magnetic field, may alternatively contribute to the usual explanation [21] of the excess of di-electron pairs below ρ meson mass.

7. Summary and conclusions

We have discussed the interaction of constituent quark magnetic moments with large magnetic fields created in heavy ion collisions. For the open-flavor vector mesons, magnetic moments are estimated, and for pseudoscalar mesons the magnetic polarizability is assessed.

Based on the analogy with Positronium behavior [8] in the magnetic field, we suggest that quantum superposition of spin-singlet and spin-triplet ($m_z = 0$) states of Quarkonium can also take place. Magnetic field quenching of ortho-Quarkonium is predicted to happen in the static magnetic fields comparable in strength to those created in heavy ion collisions.

If magnetic field quenching of ortho-Quarkonium takes place, J/ψ mesons in $m_z = 0$ quantum substate may decay rapidly via new open channels (gg, for example) due to the mixing with η_c state. Substantial fraction (up to 30%) of J/ψ mesons can thus dissapear from dilepton spectrum if strong magnetic fields last for sufficiently long time. This can directly influence one of the main signatures of deconfinement: total yield of J/ψ mesons [22] in the nucleus-nucleus collisions.

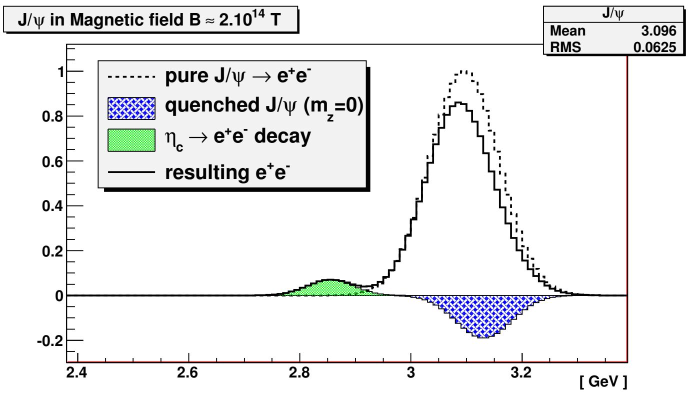

Figure 11: Dilepton spectrum modification for J/Ψ mesons decaying in strong magnetic field.

Energy of the mixed ortho-Charmonium (m_z=0) state $\Psi^+_{J/\psi}$ increases in the magnetic field when compared to J/ψ(3096) particles, and missing dilepton pairs from quenched $\Psi^+_{J/\psi}$ decays slightly modify dilepton spectrum (see Fig.11). New para-Charmonium state $\Psi^-_{\eta_c}$ can decay to dilepton l^+l^- pairs directly (in the magnetic field) and little bump below J/ψ peak may appear.

For bottomium Υ and $\varphi(s\bar{s})$ states, dilepton signatures of the quantum mixing can be similar to J/ψ. Since direction of the magnetic field created in heavy ion collisions is directly dependent on the reaction plane orientation, the azimuthal distribution of dilepton pairs from quenched quarkonium decays can be azimuthally asymmetrical, modifying the elliptic flow of vector-meson Quarkonium states J/ψ, Υ and φ. For φ meson, the modification of ratio $\Gamma_{l^+l^-}/\Gamma_{K^+K^-}$ of φ decay widths due to the changes of K^+ and K^o masses in strong magnetic fields may also take place.

Our simple predictions are obtained while ignoring QCD effects, e.g. the dependence of hadron masses on quark condensates [11] in the dense QCD medium.

We suggest that more precise and quantitative analysis of the phenomena discussed is needed.

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