SEARCH FOR THE RADIAL EXCITED STATES OF CHARMONIUM IN EXPERIMENTS USING LOW ENERGY ANTIPROTON BEAMS WITH MOMENTUM RANGING FROM 1 GeV/c TO 15 GeV/c.

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The calculation of the spectrum of the radial excited states of charmonium in the relativistic spherical symmetric top model for decay products was carried out. Using the integral formalism for hadron resonance decay products the widths of these states have been calculated. The values of masses and widths of charmonium are in good agreement with experimental data. Six new radial excited states of charmonium in mass region over $D\overline{D}$-threshold equals 3.73 GeV/c were predicted. Four of them (two scalar and two vector states) were experimentally revealed. The possibility of usage of antiproton beams with momentum ranging from 1 GeV/c to 15 GeV/c for studying of charmonium spectroscopy especially over $D\overline{D}$ - threshold is discussed. The advantage of antiproton beams consists that in antiproton-proton annihilation the intensive appearance of particle-antiparticle pares is observed. This fact allows carry out spectroscopic researches with good statistics and high accuracy. Hence, the possibility of measuring of masses and widths of scalar and vector charmonium states with high accuracy is emerging.

One can find the results of our calculations for charmonium spectrum in Table 1a for the scalar states and in Table 1b for the vector states.

Table 1a. The spectrum of radial excited scalar states of charmonium and their widths.

charmonium states	quant. numbers $I^G(J^{PC})$	decay channel	M_{exp} MeV	M_{th} MeV	$\Gamma(M)$ MeV	$\Gamma(M)_{th}$ MeV
$h_c(1S)$	$0^+(0^{-+})$	$p\overline{p}$	2980.4±1.2	2974.86	25.5±3.4	18
$h_c(1S)$	$0^+(0^{-+})$	$r^{\pm}p^{\mp}$	2980.4±1.2	2994.78	25.5±3.4	21
$h_c(1S)$	$0^+(0^{-+})$	$\Sigma^0\overline{\Sigma^0}$	2980.4±1.2	2979.44	17.3±2.5	12
$h_c(2S)$	$0^+(0^{-+})$	$p\overline{p}$	3638±4	3581.30	14±7	20
$h_c(2S)$	$0^+(0^{-+})$	$r^{\pm}p^{\mp}$	3638±4	3625.00	14±7	27
$h_c(2S)$	$0^+(0^{-+})$	$\Sigma^0\overline{\Sigma^0}$	3638±4	3586.30	14±7	16
X(3940)	$?^?(?^{??})$	$p\overline{p}$	3936±14	3922.56	39±26	56
X(3940)	$?^?(?^{??})$	$r^{\pm}p^{\mp}$	3936±14	3967.28	39±26	68
X(3940)	$?^?(?^{??})$	$\Sigma^0\overline{\Sigma^0}$	3936±14	3930.82	39±26	46
Y(4260)	$?^?(?^{??})$	$p\overline{p}$	4295±10	4305.18	133±26	94
Y(4260)	$?^?(?^{??})$	$r^{\pm}p^{\mp}$	4295±10	4312.88	133±26	112
Y(4260)	$?^?(?^{??})$	$\Sigma^0\overline{\Sigma^0}$	4259±8	4294.14	88±23	76

Table 1b. The spectrum of radial excited vector states of charmonium and their widths.

charmonium states	quant. numbers $I^G(J^{PC})$	decay channel	Mexp MeV	M_{th} MeV	$\Gamma(M)$ MeV	$\Gamma(M)_{th}$ MeV
$J/\Psi(1S)$	$0^-(1^{--})$	$p\bar{p}$	3096.95±0.1	3092.50	0.099±0.012	0.096
$J/\Psi(1S)$	$0^-(1^{--})$	$r^{\pm}p^{m}$	3096.95±0.1	3102.40	0.099±0.012	0.112
$J/\Psi(1S)$	$0^-(1^{--})$	$\Sigma^0\bar{\Sigma}^0$	3096.95±0.1	3098.20	0.099±0.012	0.098
$\Psi(2S)$	$0^-(1^{--})$	$p\bar{p}$	3685.98±0.1	3683.12	0.306±0.036	0.290
$\Psi(2S)$	$0^-(1^{--})$	$r^{\pm}p^{m}$	3685.98±0.1	3681.95	0.306±0.036	0.328
$\Psi(2S)$	$0^-(1^{--})$	$\Sigma^0\bar{\Sigma}^0$	3685.98±0.1	3682.05	0.306±0.036	0.302
$\Psi(3770)$	$0^-(1^{--})$	$p\bar{p}$	3770.0±2.4	3765.25	25.3±2.9	27
$\Psi(3770)$	$0^-(1^{--})$	$r^{\pm}p^{m}$	3770.0±2.4	3776.64	25.3±2.9	31
$\Psi(3770)$	$0^-(1^{--})$	$\Sigma^0\bar{\Sigma}^0$	3770.0±2.4	3772.14	25.3±2.9	23
$\Psi(3836)$	$0^-(2^{--})$	$p\bar{p}$	3836±13	3841.15	24.0±5.0	45
$\Psi(3836)$	$0^-(2^{--})$	$r^{\pm}p^{m}$	3836±13	3853.25	24.0±5.0	48
$\Psi(3836)$	$0^-(2^{--})$	$\Sigma^0\bar{\Sigma}^0$	3836±13	3813.63	24.0±5.0	41
$\Psi(4040)$	$0^-(1^{--})$	$p\bar{p}$	4039±1	4045.80	52 ±10	56
$\Psi(4040)$	$0^-(1^{--})$	$r^{\pm}p^{m}$	4039±1	4025.18	52 ±10	64
$\Psi(4040)$	$0^-(1^{--})$	$\Sigma^0\bar{\Sigma}^0$	4039±1	4050.01	52 ±10	51
$\Psi(4160)$	$0^-(1^{--})$	$p\bar{p}$	4153±3	4157.41	78 ±20	81
$\Psi(4160)$	$0^-(1^{--})$	$r^{\pm}p^{m}$	4153±3	4140.10	78 ±20	92
$\Psi(4160)$	$0^-(1^{--})$	$\Sigma^0\bar{\Sigma}^0$	4153±3	4171.24	78 ±20	68
$\Upsilon(4350)$	$0^-(1^{--})$	$p\bar{p}$	4354±16	4348.12	106 ±19	110
$\Upsilon(4350)$	$0^-(1^{--})$	$r^{\pm}p^{m}$	4354±16	4370.07	106 ±19	122
$\Upsilon(4350)$	$0^-(1^{--})$	$\Sigma^0\bar{\Sigma}^0$	4354±16	4294.14	106 ±19	87
$\Psi(4415)$	$0^-(1^{--})$	$p\bar{p}$	4421±4	4423.52	43 ±15	48
$\Psi(4415)$	$0^-(1^{--})$	$r^{\pm}p^{m}$	4421±4	4428.34	43 ±15	59
$\Psi(4415)$	$0^-(1^{--})$	$\Sigma^0\bar{\Sigma}^0$	4421±4	4418.22	43 ±15	38
$\Psi(4540)$	$?^?(?^{??})$	$p\bar{p}$	---	4529.05	---	78
$\Psi(4540)$	$?^?(?^{??})$	$r^{\pm}p^{m}$	---	4543.97	---	92
$\Psi(4540)$	$?^?(?^{??})$	$\Sigma^0\bar{\Sigma}^0$	---	4544.57	---	70
$\Psi(4660)$	$?^?(?^{??})$	$p\bar{p}$	4664±11	4679.60	48±15	96
$\Psi(4660)$	$?^?(?^{??})$	$r^{\pm}p^{m}$	4664±11	4659.76	48±15	112
$\Psi(4660)$	$?^?(?^{??})$	$\Sigma^0\bar{\Sigma}^0$	4664±11	4671.87	48±15	83
$\Psi(5060)$	$?^?(?^{??})$	$p\bar{p}$	---	5059.92	---	108
$\Psi(5060)$	$?^?(?^{??})$	$r^{\pm}p^{m}$	---	5066.28	---	126
$\Psi(5060)$	$?^?(?^{??})$	$\Sigma^0\bar{\Sigma}^0$	---	5060.78	---	92

Figure 2 illustrates the possible spectrum of scalar and vector states of charmonium. Blue boxes correspond to the established charmonium states, green-blue boxes - recently experimentally revealed states. The possible existence of the states marked by green-blue boxes was predicted in our calculations. One can find that *X(3940)* and *Y(4260)* can be interpreted as radial excited scalar states of charmonium, *Y(4350)* and *Y(4660)* - as radial excited vector states of charmonium. Finally, green boxes correspond to the states which are not found yet. But possibility of existence of these states is predicted in our approach. They can also be interpreted as radial excited states of charmonium.

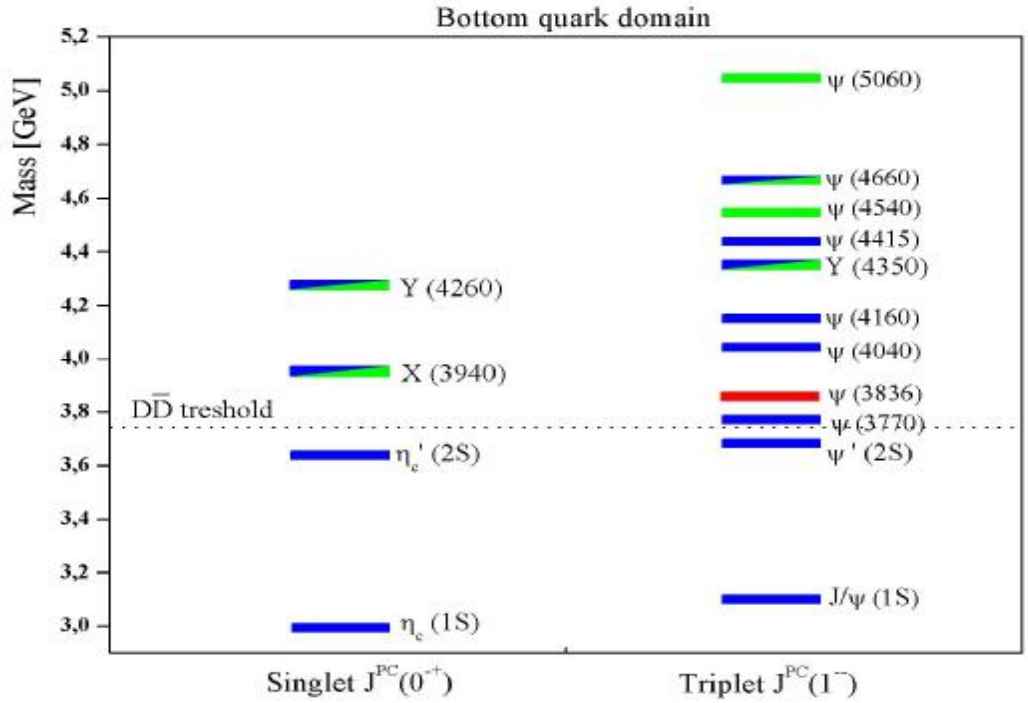

Figure2. The possible spectrum of scalar and vector states of charmonium.