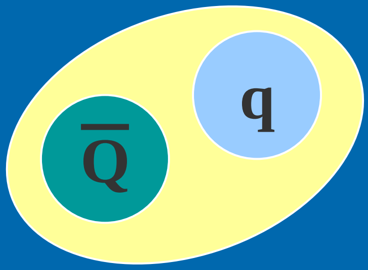
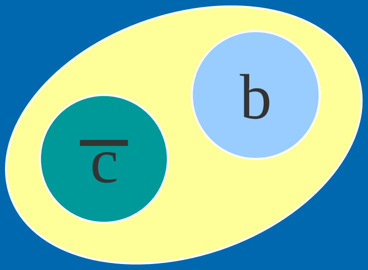
Open Flavour Charmed mesons





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Plan of the Talk

- Introduction
- Spectroscopy & New Particles from Recent experiments
- Quark model Analysis:
  - A Potential model Predictions of Open Charm mesons (CPP)
- Puzzles about these new states
- A Potential model study of *Di* - mesonic systems
- Weak processes and related Aspects of Heavy flavour Physics
- Future Experiments and Expectations

Introduction

Field of hadron spectroscopy has under gone a revival in recent years with the observation of many new states such as

$$D_0^{*0}(2351),\ D_0^{*+}(2403),\ D_1^{'0}(2438),\ D_{sJ}^{*}\ 2317),\ D_{SJ}^{+}(2460)$$

$$X(3872), Y(3140)\ etc.$$

Could be new excited charmed mesonic states.

But require more confirmatory mesurments for defenite identification.

Spectroscopy & New Particles from BaBar, Belle, Cleo and Focus Collaborations

Evidence of Broad cū, c$\bar{d}$ states D_0^{*0}, D_0^{*+} and $D_1^{'0}$:–

The first evidence of $c\bar{q}$ broad states was provided by Cleo Collaboration (2000).

Further support came recently from Belle (2003) and Focus (2004) Collaborations.

	$D_0^{*0}(2351)$	$D_0^{*+}(2403)$	$D_1^{'0}(2438)$
$M(MeV)$	$2308 \pm 17 \pm 15$ (Belle)	$2403 \pm 14 \pm 35$ (Focus)	$2427 \pm 26 \pm 20$ (*Belle*)
	$2407 \pm 21 \pm 35$ (Focus)		$2461^{+41}_{-34} \pm 10$ (*Cleo*)
$\Gamma(MeV)$	$276 \pm 21 \pm 18$ (Belle)	$283 \pm 24 \pm 34$ (Focus)	$384^{+107}_{-75} \pm 24$ (Belle)
	$240 \pm 55 \pm 59$ (Focus)		$290^{+101}_{-79} \pm 26$ (Cleo)

BABAR experiment is an $e^{+}e^{-}$ collider experiment running just below $\gamma(4s)$ resonance designed to perform precision measurements of CP violation in B-system, but has proven to have significantlly broader physics reach. Among many things it was the first experiment to observe $D_{SJ}^{+}(2317)$ state.

$D_{sJ}^{*}(2317)$		$D_{sJ}(2460)$		Collaboration
$M(MeV)$	$\Gamma(MeV)$	$M(MeV)$	$\Gamma(MeV)$	
$2317.3\pm0.4\pm0.8$	<10	$2458.0\pm1.0\pm1.0$	<10	BaBar[PRL(2003),PRD(2004)]
$2317.2\pm0.5\pm0.9$	<4.6	$2456.5\pm1.3\pm1.3$	<5.5	Belle[PRL(2003)]
$2318.5\pm1.2\pm1.1$	<7	$2463.6\pm1.7\pm1.2$	<7	Cleo [PRD(2003)]

- **Quark model Analysis:**

Potential Models

HQET

QCD Sum rule

Chiral Model

Lattice

***etc*…**

A potential model Predictions (CPP)

The Hamiltonian for the case be written as [Hwang et al,1996]

$$H = M + \frac{p^2}{2M} + \sqrt{p^2 + m^2} + V(r)$$

Where M is the heavy quark mass, m is the light quark mass, p is the relativistic momentum of each quark and V(r) is the quark-antiquark potential.

$$V(r) = \frac{-\alpha_c}{r} + Ar^{\nu}$$

Mesonic System	ν	$M_V - M_P$ Present	$M_V - M_P$ Lattice*	M_P Present	M_P Exp**	M_V Present	M_V Exp**
	0.5	0.017		5.319		5.336	
	0.7	0.035		5.390		5.425	
$u\bar{b}$	0.9	0.063		5.453		5.516	
(B^*, B)	1.0	0.080	0.034	5.519	5.279	5.599	5.325
	1.4	0.172		5.543		5.715	
	1.8	0.288		5.563		5.851	
	2.0	0.352		5.737		6.089	
	0.5	0.019		5.382		5.401	
	0.7	0.032		5.441		5.481	
$s\bar{b}$	0.9	0.052		5.500		5.552	
(B_s^*, B_s)	1.0	0.065	0.027	5.558	5.369	5.623	5.416
	1.4	0.131		5.601		5.731	
	1.8	0.214		5.641		5.855	
	2.0	0.260		5.781		6.041	

Mesonic System	ν	$M_V - M_P$ Present	$M_V - M_P$ Lattice*	M_P Present	M_P Exp**	M_V Present	M_V Exp**
	0.5	0.060		2.016		2.076	
	0.7	0.095		2.080		2.175	
$c\bar{s}$	0.9	0.148		2.134		2.282	
(D_s^*, D_s)	1.0	0.181	0.066	2.154	1.968	2.335	2.112
	1.4	0.359		2.196		2.555	
	1.8	0.593		2.177		2.770	
	2.0	0.724		2.150		2.874	
	0.5	0.054		1.947		2.001	
	0.7	0.102		2.019		2.120	
$c\bar{u}$	0.9	0.177		2.066		2.243	
(D^*, D)	1.0	0.225	0.067	2.080	1.865	2.305	2.007
	1.4	0.475		2.077		2.552	
	1.8	0.802		1.994		2.796	
	2.0	0.985		1.930		2.915	

$*$ Ma J P and Mckellar B H J (1998).

** Caso et al (1998) Particle Data Group.

S-Wave and P-Wave masses (in GeV) of *D* meson

ν	1^1S_0	$1\,^3S_1$	$1\,^3P_0$	$1\,^3P_1$	1^1P_1	$1\,^3P_2$	2^1S_0	$2\,^3S_1$	3^1S_0	$3\,^3S_1$
0.5	1.922	1.992	2.195	2.203	2.210	2.218	2.286	2.294	2.497	2.501
1.0	1.912	1.993	2.347	2.367	2.390	2.414	2.580	2.639	3.342	3.357
1.5	1.905	2.003	2.388	2.435	2.481	2.527	2.599	2.709	3.920	3.959
2.0	1.870	2.015	2.297	2.385	2.472	2.560	2.790	2.903	–	–
Expt.[1]	1.864	2.006						2.540 [7]		
Ebert[8]	1.875	2.009	2.414	2.438	2.459	2.501	2.579	2.629		
Pandya[9]	1.815	1.909	2.385	2.417	2.449	2.481	2.653	2.690	3.162	3.175

S-Wave and P-Wave masses (in GeV) of D_s meson

ν	1^1S_0	$1\,^3S_1$	$1\,^3P_0$	$1\,^3P_1$	1^1P_1	$1\,^3P_2$	2^1S_0	$2\,^3S_1$	3^1S_0	$3\,^3S_1$
0.5	2.042	2.089	2.353	2.364	2.375	2.386	2.466	2.476	2.723	2.728
1.0	2.003	2.104	2.512	2.544	2.576	2.608	2.813	2.847	3.412	3.432
1.5	1.937	2.135	2.607	2.678	2.750	2.821	3.149	3.228	4.027	4.098
2.0	1.913	2.152	2.463	2.597	2.731	2.865	3.104	3.276	3.982	4.126
Expt.[1]	1.9685	2.112			2.535	2.5735				
Ebert[8]	1.981	2.111	2.508	2.515	2.560	2.569	2.670	2.716		
Pandya[9]	2.009	2.110	2.385	2.417	2.449	2.481	2.778	2.2805	3.264	3.277

[1] PDG 2006; [7] G. L. Wang PLB633,2006; [8] D. Ebert et. al PRD57,1998; [9] JNP & PCV Pramana57, 2001.

Decay Constant of D meson

Models	$R_p(0)$ $GeV^{3/2}$	$R_v(0)$ $GeV^{3/2}$	f_P MeV	$f_P(cor.)$ MeV	f_V MeV	$f_V(cor.)$ MeV	$\Gamma(total)$ $10^{-4}eV$	τ ps
$v =$ 0.5	0.3288	0.3412	231	157	236	160	6.126	1.074
1.0	0.3541	0.3698	250	170	256	174	6.142	1.072
1.5	0.3800	0.4113	276	187	284	195	6.167	1.067
2.0	0.5082	0.4687	335	277	350	237	6.165	1.068
Others				230[15] 195±20[16] 243±25[17]		339±22[7]		1.040± 0.007[1]

Decay Constant of D_s meson

Models	$R_p(0)$ $GeV^{3/2}$	$R_v(0)$ $GeV^{3/2}$	f_P MeV	$f_P(cor.)$ MeV	f_V MeV	$f_V(cor.)$ MeV	$\Gamma(total)$ $10^{-4}eV$	τ ps
$v =$ 0.5	0.3189	0.3263	218	156	221	158	9.148	0.719
1.0	0.4053	0.4901	321	229	330	236	12.630	0.521
1.5	0.6419	0.7160	451	322	479	342	18.515	0.356
2.0	0.6993	0.8011	494	353	534	381	20.771	0.317

Some Results f_D=208MeV and F_{D_s}=241 Mev hep-lat/0706.1726
f_D=215MeV f_{D*}=348MeV and F_{D_s}=222 Mev, F_{D*_s}=329 Mev
M.A. Ivanov, J.G. Körner, O.N. Pakhomova, Physics Letters B 555 (2003)

[1] PDG 2006; [7] G. L. Wang, PLB633,2006; [15] G Cvetic et. al, PLB596,2004;

[16] A.A Peninand et. al, PRD65, 2002; [17] D Ebert et. al, MPLA17, 2002.

Quark model analysis: a summary of the masses of p-wave $c\bar{q}$ and $c\bar{s}$ mesons:

$D_0^*(GeV)$	$D_{s0}^*(GeV)$	$D_1^{'}(GeV)$	$D_{s1}^{'}(GeV)$
2.200	2.357	2.350	2.453 [Fayyazuddin & Riazuddin,PRD(2004)]
2.200	2.288	2.383	2.465 [M Sadzikowski,PLB(2004)]
2.195	2.353	2.206	2.369 [$\nu = 0.5$ CPP_ν model, A K Rai & P C V 2007]
2.347	2.512	2.378	2.560 [$\nu = 1.0$ CPP_ν model, A K Rai & P C V 2007]
2.388	2.607	2.458	2.714 [$\nu = 1.5$ CPP_ν model, A K Rai & P C V 2007]
	2.420 [Y B Dai et al.(QCD sum rule), PRD68(2003)]		
	2.303 [$\rightarrow$	Chiral model $\leftarrow$	2.552 [E E Kolomeitsev & M F M Lutz, PLB582(2004)]

Pre 2003 Predictions:

2.385	2.514	2.417	2.550 [JNP&PCV, Pramana57(2001)]
2.377	2.487	2.490	2.535 [M Di Pierro and E Eichten,PRD64(2001)]
2.341	2.455	2.389	2.502 [T A Lahde et al.,NPA674(2000)]

In general, adjustment of input parameters produce *a posteriori* results in better agreement with observation. But in the case of Coulomb plus linear potential with lowest order relativistic corrections, the two newly observed $c\bar{s}$ states do not fit with the theoretical results. Thus suggesting a different interpretations.

Lattice : Yes [A Dougall et al.,PLB569(2003)] and No [G S Bali PRD68(2003)] for simple $q\bar{q}$ interpretation.

By incorporating the subleading terms in the chiral expansion and adjusting three new input parameters to reproduce the observed spectrum, the values of 2.352 and 2.416 GeV for 0^+ and 1^+ states are obtained together with prediction of a scalar S=0 state with mass 2.389GeV
[J Hofmann and M F M Lutz, NPA733(2004)].

However no evidence has been collected of the new predicted state.
The question that remains : Why previous predictions resulted to be incorrect and what is the new physics information that must be encoded in models to reproduce the experimental measurements?

Are $D_{sJ}^{*}(2317)$, and $D_{sJ}(2460)$ unconventional States?

Possibilities of Multi-quark states such as Four quark states or molecular like are being considered :

$D_{sJ}^{*}(2317)$ as $c\bar{s}q\bar{q}$ four quark state -with $I=0,\ q=u,\ d;$ the observed transition to $D_s^{+}\pi^{0}$ would be isospin violating,that explains the observed narrowness.

On the otherhand with $I=1,$ predicted with nearby mass, would be broad.

In the molecular interpretation $D_{sJ}^{*}(2317)$ could be viewed as DK molecule, mass very close to DK threshold [H J Lipkin(2004)]. Corresponding interpretation for $D_{sJ}(2460),$ would be $D^{*}K$ molecule.

Numerical estimates are infavour of molecular interpretation. In this interpretation, two other scalar resonances $(D_0^{*},\ D_{s0}^{*})$ with masses of :

$M_{D_0^{*}}=2.15-2.30GeV,$ and $M_{D_{s0}^{*}}=2.44-2.55GeV,$

are to be experimentally confirmed.

Puzzles about these states

* Near equality of the masses of non strange and strange charmed states – Not theoretically reproduced.

* The missing evidence of the radiative decay mode $D^{*}_{sJ}(2317) \rightarrow D^{*}_{s}\gamma$ (deserve further Experimental Investigations)

- One could look at The modes-

$B \rightarrow D_{sJ}M$ $(M= D,K,\pi)$ → can further discriminate between quark antiquark and multiquark interpretations.

$\psi(4415) \rightarrow D^{*}_{s}\, D_{sJ}(2317)$ → can also investigate charmed resonances

Spectroscopy and new particles at Belle

There is an impressive list of new particles diascovered by Belle in the last few years. $X(3872)$ when analysing B^+ decay $\to J/\psi\ \pi^+\pi^- K^+$ soon confirmed by CDF, Dϕ and BaBar.

$\Rightarrow$ New decay modes have been found and the J^{PC} assignment has been estabhised.

$\Rightarrow$ Found difficult to identify with any conventional charmonium state.

$\Rightarrow$ $X(3872)$ mass equal to the $D^0\bar{D}^{0*}$ threshold suggests that it could be $D\bar{D}^*$ like meson-meson state.

$\Rightarrow$ $J^{PC} = 1^{++}$ assignment for $D\bar{D}^{0*}$ molecule is strongly favoured [Swanson Phys. Lett. B588(2004)189]

$\Rightarrow$ Further the observation of the decay $X \to \gamma\ J/\psi$ would unambiguously establish $C = +1$ for X.

$\Rightarrow$ This has been achieved by Belle in consistent with Swanson's prediction.

$\Rightarrow$ Further $J^{PC} = 0^{-+}, 0^{++}$ has proved disfavoured while $J^{PC} = 1^{++}$ is compatible with fit and strongly supports its molecular interpretation.

Potential model study of *Di* - mesonic systems:

$$H = M + \frac{P_i^2}{2\mu} + V(R_{12}) + V_{SD}(S_i S_j)$$

$$V(R_{12}) = \frac{-k_{mol}}{R_{12}} e^{-C^2 \; R_{12}^2/2}$$

$$V_{SD}(S_i S_j) = \frac{8}{9}\frac{\alpha_s}{m_{h_1} m_{h_2}} \; \vec{S}_i \cdot \vec{S}_j \; 4\pi\delta(r)$$

$$E(\Omega) = M + \frac{3\Omega}{4\mu} - \frac{4k_{mol}\Omega^{3/2}}{c^2 + 2\Omega} + \frac{8}{9}\frac{\alpha_s}{m_{h_1} m_{h_2}} \; \vec{S}_i \cdot \vec{S}_j \; 4\pi\delta(r)$$

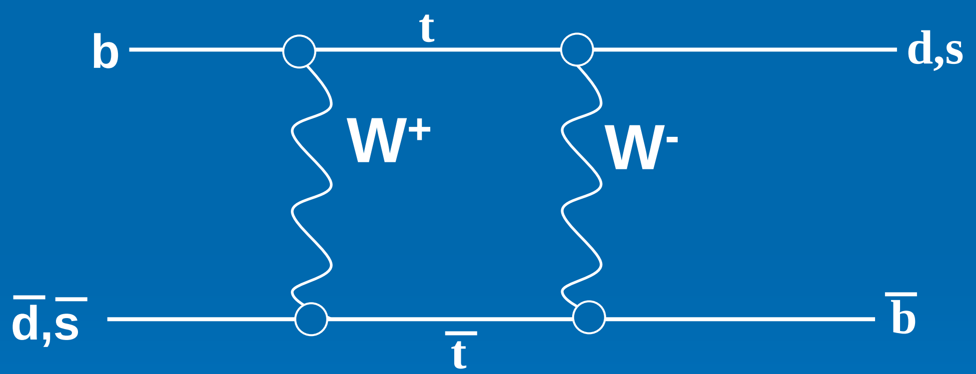
Low-lying masses of tetraquarks as di-mesons molecule

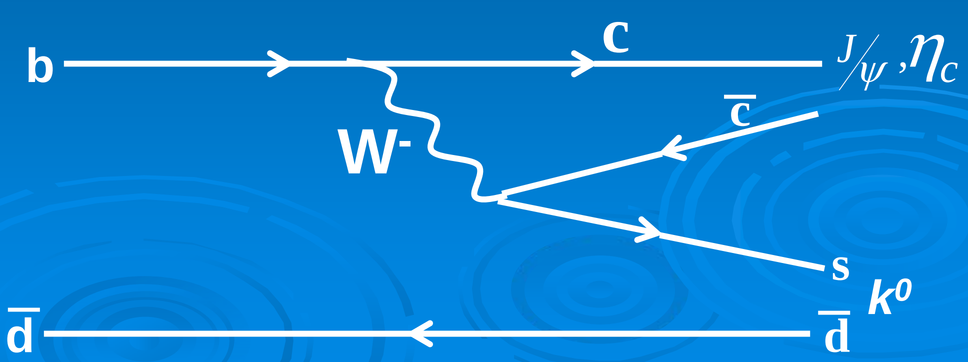
Systems $h_1 - h_2$	J^{PC}	Ω GeV^2	ψ $GeV^{3/2}$	BE GeV	Mass GeV	Expt[Ref] GeV	Theory[Ref] GeV
π-D	0^{++}	0.0186	0.0757	0.022	2.027		
π-D^*	1^{+-}	0.0188	0.0762	0.022	2.169		
K-D	0^{++}	0.1415	0.3465	0.015	2.344	$D^+_{sj}(2.317)$	
K-D^*	1^{+-}	0.1455	0.3539	0.016	2.485	$D^+_{sj}(2.460)$	
ρ -D	1^{+-}	0.2684	0.5602	0.033	2.603		$D_{sJ}(2.632)$
K^*-D	1^{+-}	0.3265	0.6489	0.039	2.718		
	cw	0.2795	0.5775	0.034	2.744		
	0^{++}			0.235	2.543		
ρ -D^*	1^{++}			0.134	2.644		
	2^{++}			0.064	2.845		
	cw	0.3420	0.6718	0.040	2.859		
	0^{++}			0.158	2.624		
K^*-D^*	1^{++}			0.040	2.741		
	2^{++}			0.077	2.976		
D-D	0^{++}	0.3568	0.6935	0.008	3.738		
D-D^*	1^{+-}	0.3810	0.7285	0.006	3.878	X(3.870)	
	cw	0.4081	0.7670	0.004	4.018		
	0^{++}			0.084	3.930		
D^*-D^*	1^{++}			0.040	3.974		
	2^{++}			0.048	4.062	$\psi(4.040)$	

Weak processes and related Aspects of Heavy flavour Physics

B meson mixing & Lifetimes

B_d and B_s meson systems play fundamental role to test and improve our under standing of SM flavour dynamics. The mixing parameter $\Delta m_{d,s}$ represents important constraints in the unitary triangle analysis. Their theoretical estimates requires non-pertarbative calculations of *B*-meson decay constants and *B*- parameters.





TEVATRON, Fermi Lab's $\bar{p}p$ Collider: $D\phi$ CDF detectors

The B_s Program in RUN II Offers large sample of semileptonic B_s decays.

B_s lifetime$(\tau) = 1.434 \pm 0.05\, ps$ (average)

$B_s \to D_s \mu X\ : (\tau =\ 1.42 \pm 0.043 \pm 0.057\, ps\ (D\phi 2002-04))$

Searches for : $B_s^0, B_d^0 \to \mu^+\mu^-$ and $B_s^0 \to \mu^+\mu^-\phi$ rare decays and measurements of $\bar{B}_c$ meson are persued at CDF & $D\phi$ using RUN-II data

HQE (Heavy quark expansions) have become a powerful tool for calculating perturbative and non perturbative QCD corrections. $\left(\frac{1}{m_b} \text{ Expn \& } \alpha_s(m_b) \right)$

To order $O\left(\frac{1}{m_b^3}\right)$ there are six parameters:

The running kinetic masses of the *b*, *c* quarks: $m_b(\mu),\ m_c(\mu)$

and four non perturbative parametrs: $\mu_\pi^2(\mu),\ \mu_G^2(\mu),\ \rho_D^3(\mu)$

and $\rho_{LS}^3(\mu)$ – The expectation values of the kinetic chrmomagnetic, Darwin and spin-orbit operators - respectively.

All these parameters depend on the scale μ, separating short distance from long distance QCD effects.

Pseudoscalar Decay Constants of the Mesons (f_P) in GeV.

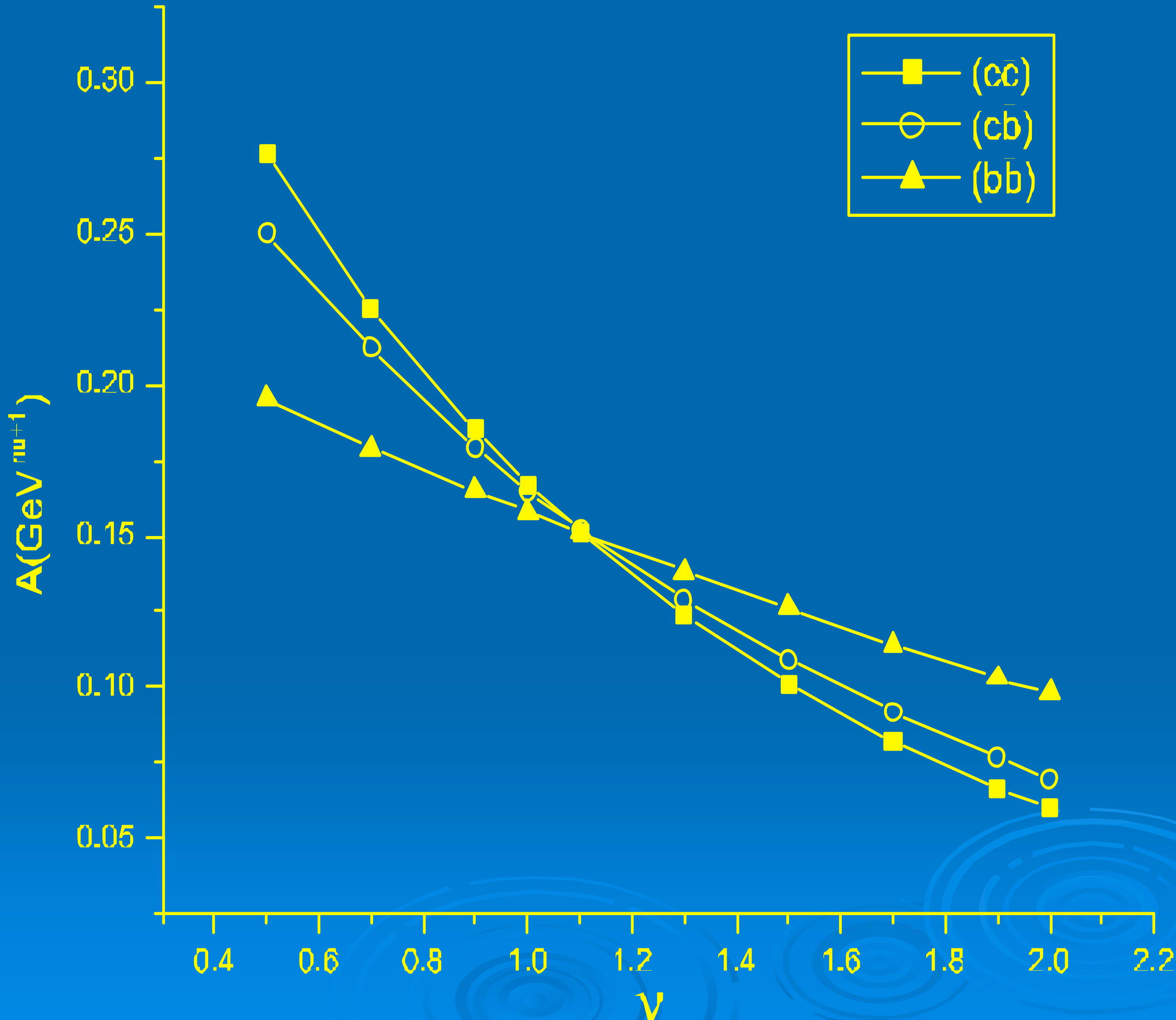
Power	Pseudoscalar Decay Constants of the Mesonic Systems					
ν	η_b	B_s	B	η_c	D_s	D
0.5	0.346	0.133	0.106	0.200	0.186	0.152
0.7	0.390	0.171	0.151	0.251	0.233	0.207
0.9	0.429	0.216	0.202	0.298	0.285	0.269
1.0	0.447	0.239	0.226	0.321	0.305	0.291
1.4	0.513	0.338	0.331	0.414	0.413	0.405
1.8	0.572	0.430	0.427	0.496	0.515	0.510
2.0	0.595	0.467	0.462	0.526	0.561	0.558

B_c meson mass spectrum (in GeV)

State $n^{2S+1}L_J$	*Our*	ALV[4]	EQ[3]	EFG[5]	Lattice[6]
1^1S_0	6.300	6.356	6.264	6.270	6.280±30 ± 190
1^3S_1	6.327	6.397	6.337	6.332	6.321±20
1^3P_0	6.691	6.673	6.700	6.699	6.727±30
1^3P_1	6.704	-	6.730	6.734	6.743±30
1^1P_1	6.718	-	6.736	6.749	6.765±30
1^3P_2	6.732	6.751	6.747	6.762	6.783±30
2^1S_0	6.805	6.888	6.856	6.835	6.960±80
2^3S_1	6.857	6.910	6.899	7.072	6.990±80
2^3P_0	7.142	-	7.108	7.091	-
2^3P_1	7.164	-	7.135	7.126	-
2^1P_1	7.188	-	7.142	7.145	-
$2\ ^3P_2$	7.211	-	7.153	7.156	-
3^1S_0	7.205	-	7.244	7.193	-
3^3S_1	7.285	-	7.280	7.235	-

Pseudoscalar decay constant of B_c meson (f_P) (in MeV)

Models		M_{B_c}	f_{B_c}
potential models with $\nu =$	0.5	6.311	399
	0.7	6.309	457
	0.9	6.305	506
	1.0	6.303	528
	1.1	6.302	548
	1.3	6.300	585
	1.5	6.298	618
	2.0	6.292	679
EQ[3]		6.264	500
ALV[4]		6.356	578
EFG[5]		6.270	562
FL[7]		6.286	500±80
GKLT [8]		6.253	517
EXPT.[PDG,2006]		6.286	



$(c\bar{c})$
$(c\bar{b})$
$(b\bar{b})$
0.30
0.25
0.20
0.15
0.10
0.05
$A(GeV^{\nu+1})$
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
ν

Comparison of the lifetime of B_c meson (in ps) in different models.

Our	Expt[1]	ALV[4]	GKLT [8]	VVK[14]	SG[15]
0.47	$\tau = 0.46^{+0.18}_{-0.16}$	0.47	0.55±0.15	0.50	0.75

Future Experiments and Expectations:

LHCb(Cern) can contribute studies of B_S, B_c & Λ_b and numerous excited states.

Super *B*-factories (Future) Expected to be in operation by 2007

- High statistics samples of *B*-decays

  $\Rightarrow$ Unique & clean envirment to study meson spectroscopy from light to charmed & charmonium mesons.

  $\Rightarrow$ Many new particles have been discovered and others are being accurately studied.

  $\Rightarrow$ Broad resonaces can be reliably studied.

- Charmless *B*-decays allows search for still missing pieces in meson spectroscopy: the Glueballs & hybrid mesons.

  $\Rightarrow$ $B \to \eta' X (b \to sg)$ can be a window for discovering glueballs.

  $\Rightarrow$ Unfortunately branching fractions of these decays are very small and can be studied only at very high luminicity collider.

  $\Rightarrow$ May new charm baryons are also expected with better statisics.

$\Rightarrow$ Exotic gluonim excitation by lattice QCD predicts $J^{PC} = 1^{-+}$ between 4.04 and 4.4 GeV proximity of $D^{*}D$ threshold could make it narrow.

$\Rightarrow$ Some hybrids can have exotic quantum numbers such as $J^{PC} = 0^{-+}, 2^{+-}, 1^{-+}$

$\Rightarrow$ $\eta_{c}(2s)$ has been observed in $\gamma\gamma$ collisions

B.Albert *et. al*, PRL 92(2004),142002

$\Rightarrow$ The $Y(3940)$, $Y(4260)$ resonances have been discovered.but large luminocity at super $B-$factory can not only provide its status but also can discover new charmonium states.

Thanks