



赵忠尧奖学金评审答辩

王广娟（北京大学）

合作导师：朱世琳教授

个人简历



研究生：北京大学物理学院，2013-2018;

专业：理论物理， 导师：朱世琳教授

联合培养：德国波恩大学，2016.09-2017.09;

合作外导：Ulf.G-Meissner 教授

本科：山东大学 2009.09-2013.09;

专业：物理学

XYZ奇特态相关工作:

- ✓ Z_b 与 Z_c 态强衰变行为的研究
- ✓ $Z_c(3900), Z_c(4020) \rightarrow J/\psi\pi, h_c\pi$

五夸克态相关工作:

- ✓ 分子态框架下, $P_c(4380)$ 与 $P_c(4450)$ 强衰变
- ✓ 利用磁矩探究隐粲味五夸克态的内部结构
- ✓ 隐粲味五夸克态的轴矢荷

重味重子相关工作:

- ✓ 自旋1/2粲重子的磁矩
- ◆ 自旋3/2粲重子的磁矩
- ◆ 粲重子的电磁衰变

重味介子相关工作:

- ◆ 介子圈对于高激发态 D_s 与 B_s 介子质量谱修正
 - ✓ 已完成
 - ✓ 文章准备中
 - ◆ 研究中
 - ◆ 参与研究中

博士期间发表及待发表文章



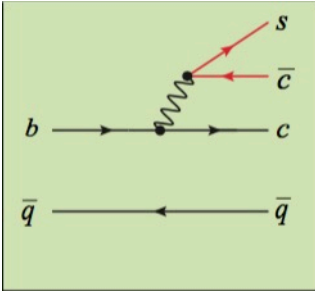
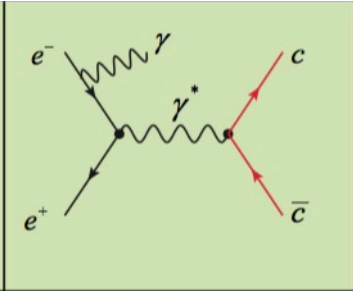
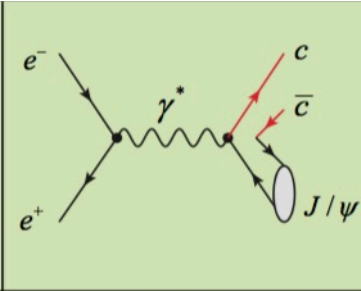
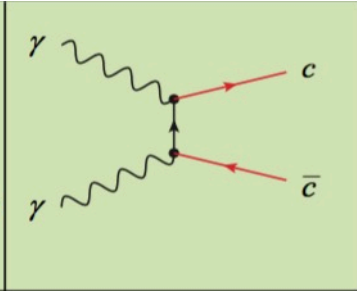
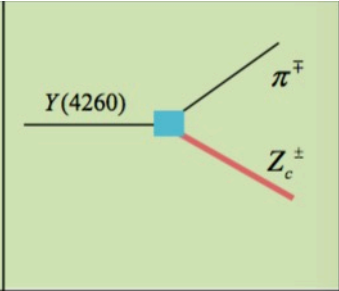
- [1] **G.J.Wang**, Z.W.Liu and S.L.Zhu, “Axial charges of the hidden-charm pentaquark states”, Phys. Rev. C 94, no. 6, 065202 (2016); (cited by 1 times.)
- [2] **G. J. Wang**, R. Chen, L. Ma, X. Liu and S. L. Zhu, “Magnetic moments of the hidden-charm pentaquark states”, Phys. Rev. D 94, no. 9, 094018 (2016); (cited by 9 times.)
- [3] **G.J.Wang**, L.Ma, X.Liu and S.L.Zhu, “Strong decay patterns of the hidden-charm pentaquark states Pc(4380) and Pc(4450)”, Phys. Rev. D 93, no. 3, 034031 (2016); (cited by 22 times.)
- [4] **Guang-Juan Wang**, Lu Meng, Hao-Song Li, Zhan-Wei Liu and Shi-Lin Zhu, “The magnetic moments of the $S = \frac{1}{2}$ heavy baryons in chiral perturbation theory.” arXiv:1803.00229, submitted to Phys. Rev. D.

Papers in preparation:

- [1] Guang-Juan Wang, Xiao-Hai Liu, Li Ma, Xiang Liu, and Shi-Lin Zhu, “Investigating the strong decay patterns of Zc and Zb states in the quark-interchange model”.
- [2] Guang-Juan Wang, Yun-Hua Chen, Qian Wang, and Ulf-G. Meißner, “The strange decay patterns of the Zc(3900) and the Zc(4020)”.

XYZ奇特态

五种产生机制:

				
<p>X(3872) Y(3940) Z⁺(4430) Z⁺(4051) Z⁺(4248) Y(4140) Y(4274) Z_c⁺(4200) Z⁺(4240) X(3823)</p>	<p>Y(4260) Y(4008) Y(4360) Y(4630) Y(4660)</p>	<p>X(3940) X(4160)</p>	<p>X(3915) X(4350) Z(3930)</p>	<p>Z_c(3900) Z_c(4025) Z_c(4020) Z_c(3885)</p>



Physics Reports

Volume 639, 10 June 2016, Pages 1-121



The hidden-charm pentaquark and tetraquark states

Hua-Xing Chen ^{a, b, 1}, Wei Chen ^{c, 1}, Xiang Liu ^{d, e, 2}, Shi-Lin Zhu ^{a, f, 3}



XYZ奇特态

共振

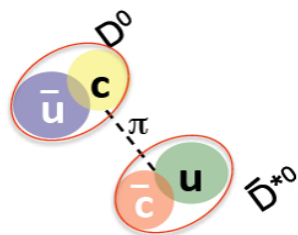
VS

非共振

传统强子态

重夸克偶素态

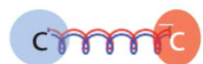
奇特态



• **分子态**: 一对介子由剩余相互作用束缚在一起的松散束缚态



• **四夸克态**: 四个夸克经带颜色的相互作用束缚在一起的紧束缚态



• **混杂态**: 一对夸克与一个激发胶子形成的束缚态

许多XYZ态位于一对介子质量阈附近

阈附近增强效应并不一定对应共振态

- 运动学效应
- 新阈打开
- Cusp效应
- 末态相互作用
- 连续态与重夸克偶素的干涉效应
- 三角奇点

Z_b 与 Z_c 奇特态强衰变模式



- 奇特态的强衰变行为十分特殊:

✓ 例如, 相比于基态 $J/\psi\pi$, $Z_c(4430)$ 更容易衰变到 $\psi(2S)\pi$, Belle 上测得:

$$\frac{Br(Z_c(4430)^+ \rightarrow \psi(2S)\pi^+)}{Br(Z_c(4430)^+ \rightarrow J/\psi\pi^+)} \approx 10$$

K.Chilikin, *et al.* PRD 88, 074026

K. Chilikin, *et al.* PRD 90 (11), 112009

- 分子态框架,

✓ $Z_c(4430)$: $\bar{D}^*D(2s)$ 或 $\bar{D}D^*(2s)$

✓ $Z_c(3900)$: $\bar{D}D^* + c.c.$

✓ $Z_c(4020)$: \bar{D}^*D^*

✓ $Z_b(10610)$: $\bar{B}B^* + c.c.$

✓ $Z_b(10650)$: \bar{B}^*B^*

- 相对论化的夸克交换模型。

相对论化夸克交换模型

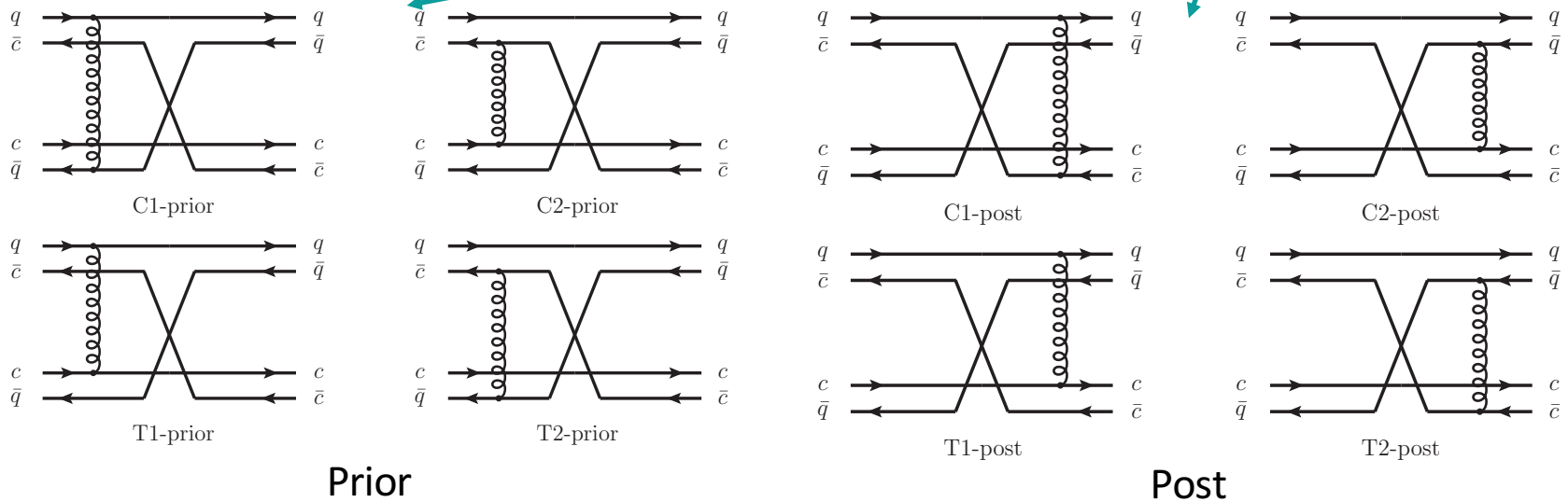
对于过程 $Z_{c(b)} \rightarrow \bar{c}c(\bar{b}b) + \pi$, 领头阶近似为

$$A(q\bar{Q}) + B(Q\bar{q}) \rightarrow C(q\bar{q}) + D(Q\bar{Q})$$

E. S. Ackleh et al. PRD 45,232

A, B, C 与 D 为介子。 q, Q 与 \bar{q}, \bar{Q} 分别代表组分夸克与反夸克。

$$H = \sum_{i=1}^4 \sqrt{\mathbf{p}_i^2 + m_i^2} + \sum_{i<j} V_{ij} = H_{AB}^0 + H_{AB}^I = H_{CD}^0 + H_{CD}^I$$



S. Godfrey and N. Isgur, PRD 32,189

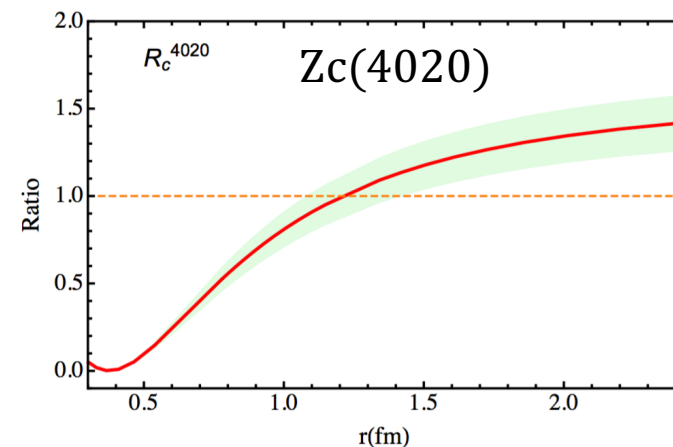
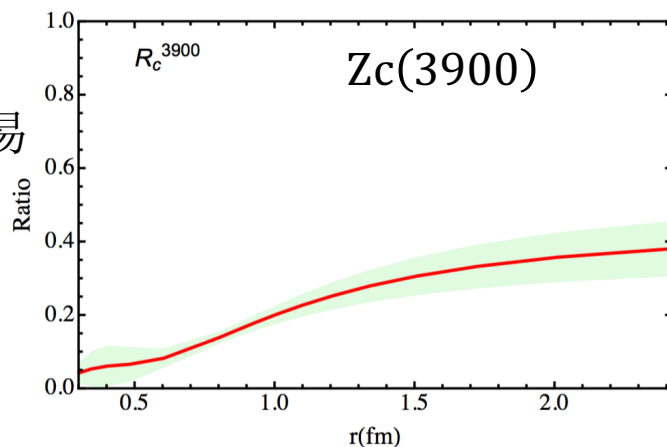
X.H. Liu et al. PRD90,074020

Z_c 奇特态强衰变

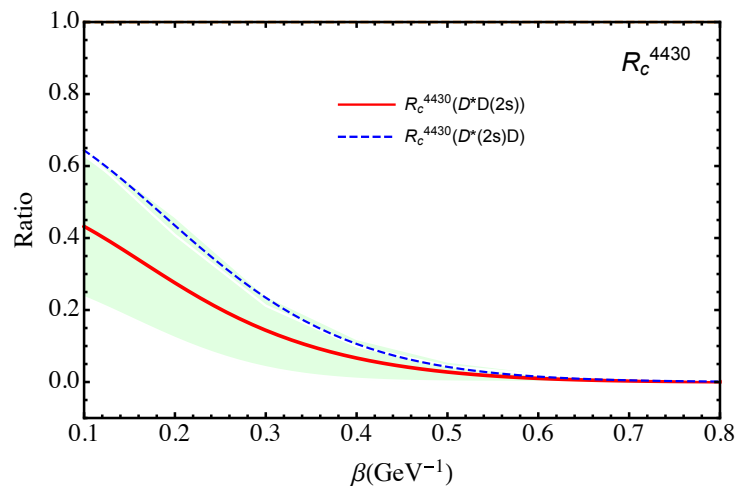


$$R_c = \frac{\Gamma(Z_c \rightarrow \psi'(2S)\pi)}{\Gamma(Z_c \rightarrow J/\psi\pi)}$$

- $Z_c(3900)$ 更容易衰变到 $J/\psi\pi$ 。



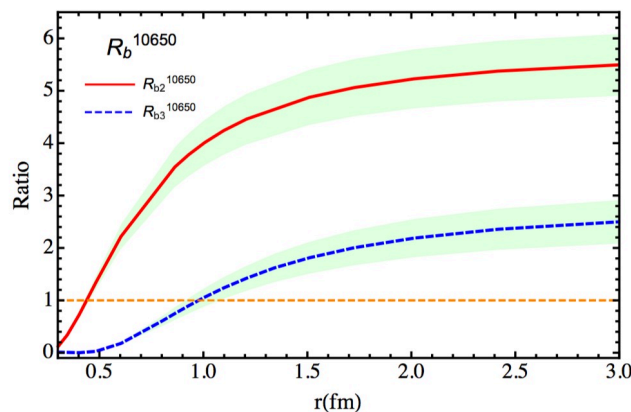
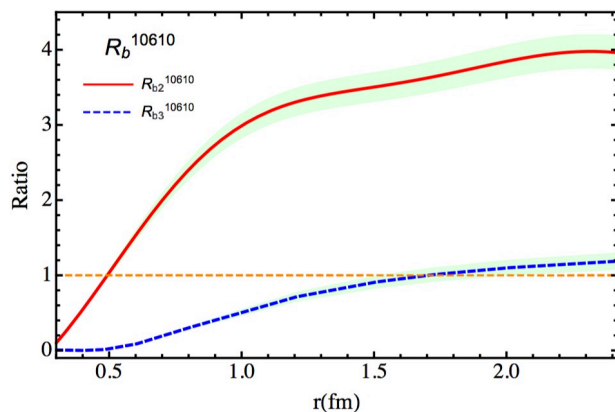
- $Z_c(4430)$ 与实验结果 ~ 10 偏差较大。



$Z_b(10610)$ 与 $Z_b(10650)$

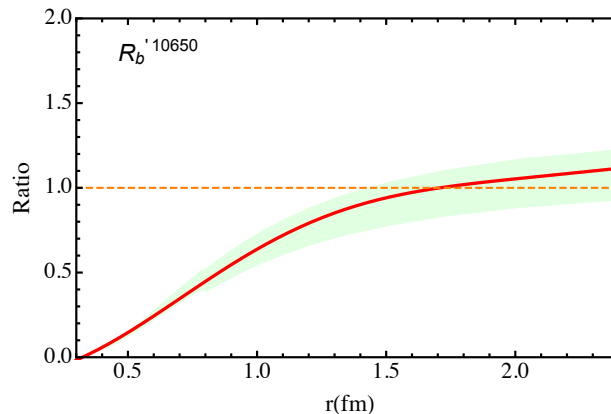
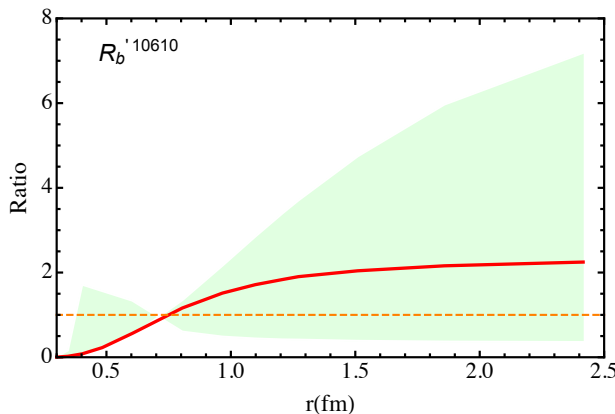


$$R_{b2} = \frac{\Gamma(Z_b \rightarrow \Upsilon(2S)\pi)}{\Gamma(Z_b \rightarrow \Upsilon(1S)\pi)}, \quad R_{b3} = \frac{\Gamma(Z_b \rightarrow \Upsilon(3S)\pi)}{\Gamma(Z_b \rightarrow \Upsilon(1S)\pi)}$$



$$R'_b = \frac{\Gamma(Z_b \rightarrow h_b(2p)\pi)}{\Gamma(Z_b \rightarrow h_b(1p)\pi)}$$

在实验变化范围以内



重味重子磁矩



- 单重味重子 (heavy baryon) : qqQ

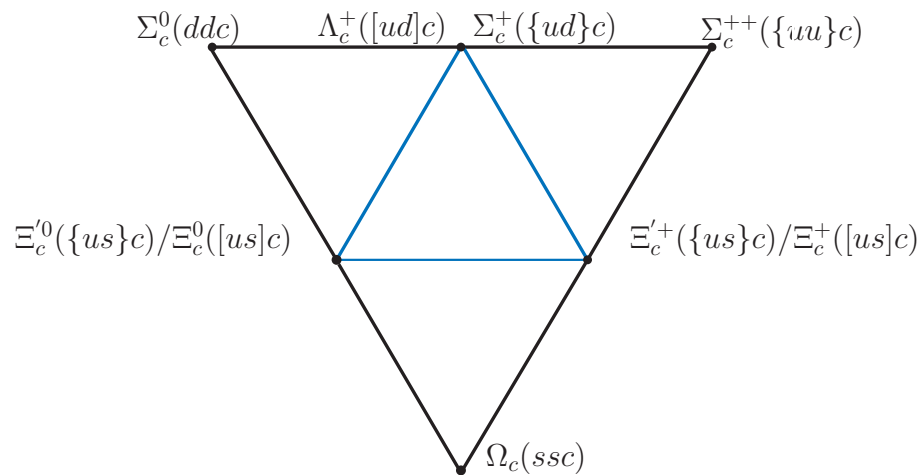
$$\Rightarrow \bar{3}_f (s_l = 0)$$

$$\Rightarrow 6_f (s_l = 1)$$

- 自旋1/2: $\psi_{\bar{3}}$ 与 ψ_6

$$\text{自旋3/2: } \psi_6^{*\mu}$$

- $m_Q \rightarrow \infty$, ψ_6 与 $\psi_6^{*\mu}$ 简并



$$\psi_{\bar{3}} = \begin{pmatrix} 0 & \Lambda_c^+ & \Xi_c^+ \\ -\Lambda_c^+ & 0 & \Xi_c^0 \\ -\Xi_c^+ & -\Xi_c^0 & 0 \end{pmatrix},$$

$$\psi_6 = \begin{pmatrix} \Sigma_c^{++} & \frac{\Sigma_c^+}{\sqrt{2}} & \frac{\Xi_c'^+}{\sqrt{2}} \\ \frac{\Sigma_c^+}{\sqrt{2}} & \Sigma_c^0 & \frac{\Xi_c'^0}{\sqrt{2}} \\ \frac{\Xi_c'^+}{\sqrt{2}} & \frac{\Xi_c'^0}{\sqrt{2}} & \Omega_c^0 \end{pmatrix}, \quad \psi_6^{*\mu} = \begin{pmatrix} \Sigma_c^{*++} & \frac{\Sigma_c^{*+}}{\sqrt{2}} & \frac{\Xi_c^{*+}}{\sqrt{2}} \\ \frac{\Sigma_c^{*+}}{\sqrt{2}} & \Sigma_c^{*0} & \frac{\Xi_c^{*0}}{\sqrt{2}} \\ \frac{\Xi_c^{*+}}{\sqrt{2}} & \frac{\Xi_c^{*0}}{\sqrt{2}} & \Omega_c^{*0} \end{pmatrix}^\mu$$



手征微扰理论

- 轻夸克质量 $m_q \ll \Lambda_{QCD}$ ，手征极限下为0。

- 手征对称性 $SU(3)_R \times SU(3)_L \times U(1)$

$$\mathcal{L}_{QCD}^0 = \sum_{l=u,d,s} (\bar{q}_{R,l} i \not{D} q_{R,l} + \bar{q}_{L,l} i \not{D} q_{L,l}) - \frac{1}{4} \mathcal{G}_{\mu\nu,a} \mathcal{G}_a^{\mu\nu}.$$

- $SU(3)_R \times SU(3)_L \rightarrow SU(3)_V \longrightarrow 8 \text{ Goldstone 玻色子}$

- 手征微扰理论是QCD的低能近似。

- 拉氏量：对称性，CPT.. \longrightarrow 低能常数 \longleftarrow 实验拟合

- 展开系数： $p/\Lambda_{QCD} \longrightarrow$ 数幂律



重重子有效理论

- 重重子质量 $M_B \gg \Lambda_{QCD}$ 且手征极限下 $M_B \neq 0$ 。 → 数幂律破坏

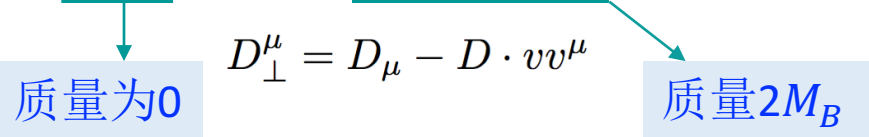
- 交换动量 $\sim \Lambda_{QCD}$, 重重子速度 v 为好量子数:

$$p^\mu = M_B v^\mu + k^\mu$$

- 将重重子场 ψ_n 分解为“轻”场与“重”场,

$$B_v^n(x) = e^{iM_B v \cdot x} \frac{1 + \not{v}}{2} \psi_n, \quad H_v^n(x) = e^{iM_B v \cdot x} \frac{1 - \not{v}}{2} \psi_n$$

$$\mathcal{L} = i\bar{B}_v(v \cdot D)B_v - \bar{H}_v(i\not{v} \cdot D + 2M_B)H_v + i\bar{B}_v\not{D}_\perp H_v + i\bar{H}_v\not{D}_\perp B_v$$



- 将“重”场自由度 H_v 积分,

$$\begin{aligned} \mathcal{L} &= \bar{B}_v(i\not{v} \cdot D + i\not{D}_\perp \frac{1}{i\not{v} \cdot D + 2M_B} \not{D}_\perp)B_v \\ &= \bar{B}_v(i\not{v} \cdot D)B_v - \mathcal{O}\left(\frac{1}{M_B}\right) + \dots \end{aligned}$$

E. E. Jenkins et al. Phys. Lett, B255

T. R. Hemmert et al. J. Phys. 1998, G24

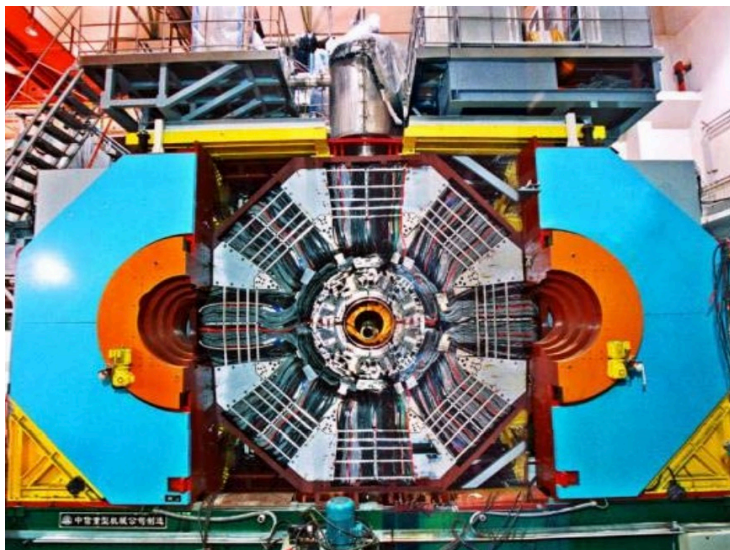
重味重子磁矩



	This work	Lattice [6, 7, 31]	[11]	[12]	[13]	[15]	[20]	[23]	[24]	[25]	[28]
$\mu_{\Lambda_c^+}$	$0.21^{+0.02}_{-0.02}$	-	0.41	0.42	0.392	0.341	0.411	-	0.37	0.385	-
$\mu_{\Xi_c^+}^\dagger$ [7]	$0.24^{+0.02}_{-0.02}$	0.235(25)	0.39	0.41	0.40	0.341	0.257	-	0.37	-	-
$\mu_{\Xi_c^0}^\dagger$ [7]	$0.19^{+0.02}_{-0.02}$	0.192(17)	0.39	0.39	0.28	0.341	0.421	-	0.36	-	-
$\mu_{\Sigma_c^{++}}^\dagger$	$1.50^{+0.18}_{-0.20}$	1.499(202)	3.07	1.76	2.20	2.44	1.679	2.1(3)	2.18	2.279	2.15(10)
$\mu_{\Sigma_c^+}$	$0.12^{+0.06}_{-0.10}$	-	0.65	0.36	0.30	0.525	0.318	-	0.63	0.501	0.46(3)
$\mu_{\Sigma_c^0}$	$-1.25^{+0.08}_{-0.08}$	-0.875(103)	-1.78	-1.04	-1.60	-1.391	-1.043	-1.6(2)	-1.17	-1.015	-1.24(5)
$\mu_{\Xi_c'^+}^\dagger$ [7]	$0.32^{+0.13}_{-0.11}$	0.315(141)	1.13	0.47	0.76	0.796	0.591	-	0.76	0.711	0.60(2)
$\mu_{\Xi_c'^0}^\dagger$ [7]	$-0.95^{+0.08}_{-0.05}$	-0.599(71)	-1.51	-0.95	-1.32	-1.12	-0.914	-	-0.93	-0.950	-1.05(4)
$\mu_{\Omega_c^0}^\dagger$	$-0.67^{+0.09}_{-0.09}$	-0.667(96)	-0.90	-0.85	-0.90	-0.85	-0.774	-	-0.92	-0.960	-0.85(5)

[6,7] Lattice	JHEP1405,125(2014); PLB772,121(2017)	[20] The bag model	arXiv:1209.2900
[11] RQM	NPA739,69 (2004)	[23] QCD sum rule	PRD56,7273(1997)
[12] RQM	PRD73,094013(2006)	[24] Effective mass and screened charge scheme	JPG31,141(2005)
[13] χ CQM	PRD81,073001(2010)	[25] Hyper central model	JPG35,065001
[15]QM based on Dirac equation	PRD28,2823(1993)	[28] Mean-field approach	arXiv:1802.05416

未来工作计划—新强子实验平台



北京谱仪实验 (BESIII)



大型强子对撞机(LHC) 实验

CLEO-c, BaBar, Belle, CDF and DØ, CMS and the Belle-II in the future.

未来工作计划



- 区分奇特态与非共振态（例如阈效应）。
- 若将XYZ理解为奇特态，研究其内部结构，例如分子态，四夸克态，混杂态等等。
- XYZ态的伴随态。
- 不同XYZ态之间的联系。
- 研究XYZ的强衰变以及电磁衰变行为（对于其内部结构比较敏感）。
- 对于重味重子的研究。



谢谢！

XYZ奇特态

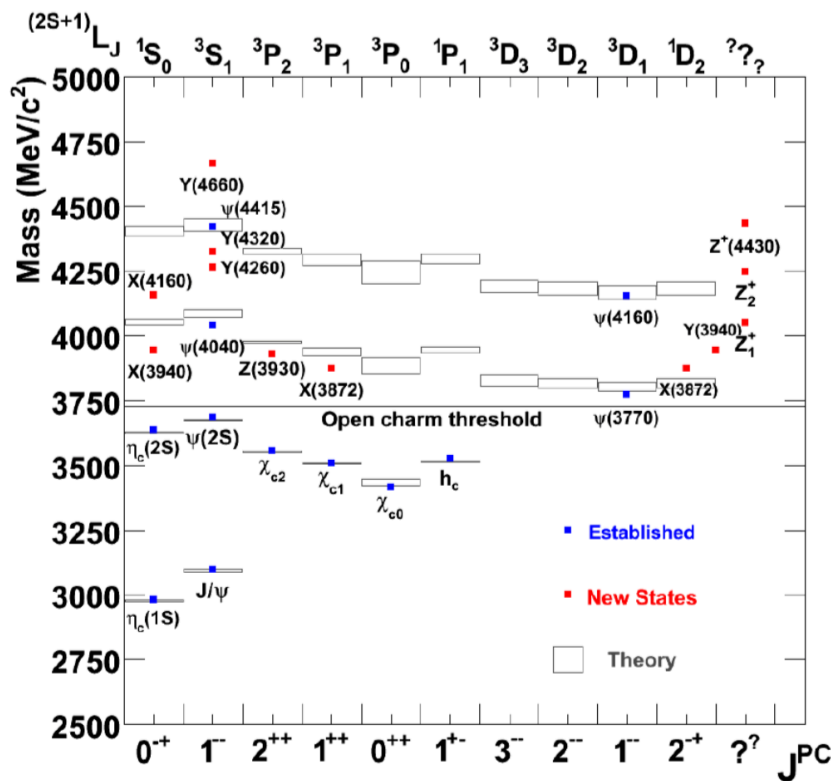


Figure: Charmonium-like XYZ states

在 $D\bar{D}$ 阈值附近观测到了许多新的态，其中大部分态不能被归入到粲偶素谱中，称为“XYZ”奇异态。