

Heavy exotic hadrons

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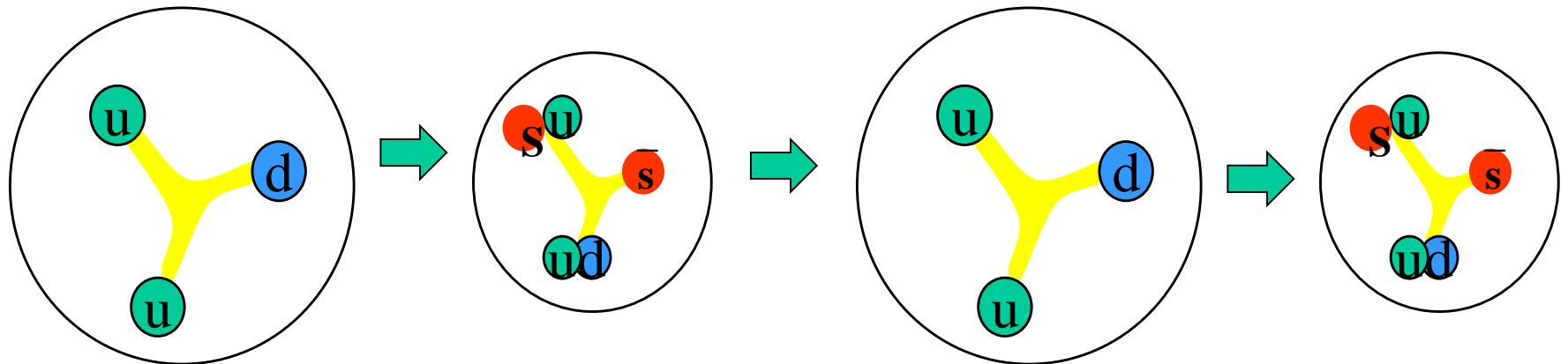
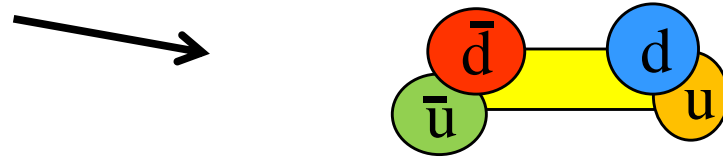
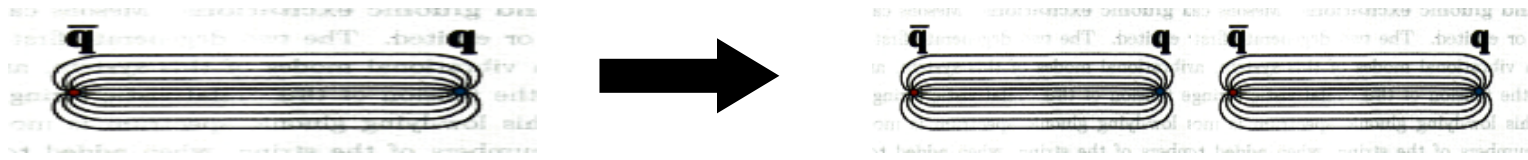
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Outline :

- 1. Importance of unquenching dynamics**
- 2. Hadron spectroscopy with strangeness**
- 3. From Strangeness to charm & beauty**
- 4. Conclusions**

1. Importance of unquench dynamics

Unquench dynamics: **gluons \rightarrow $\bar{q}q$**
crucial for quark confinement & hadron structure



quenched or unquenched quark models give very different predictions of hadron spectrum

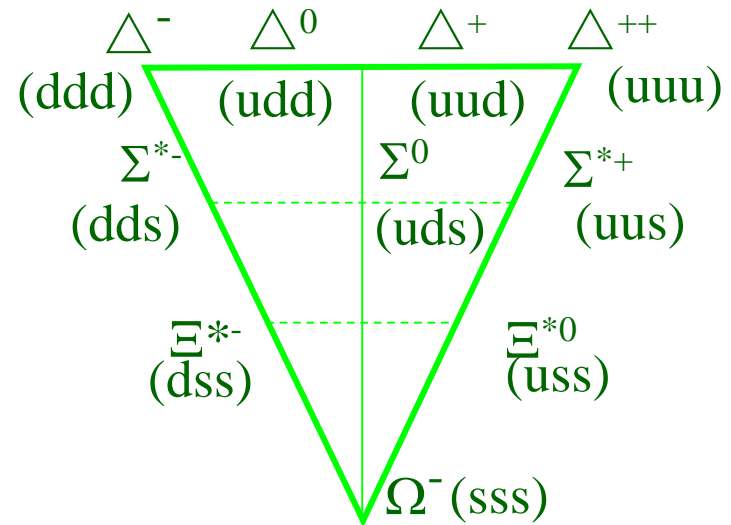
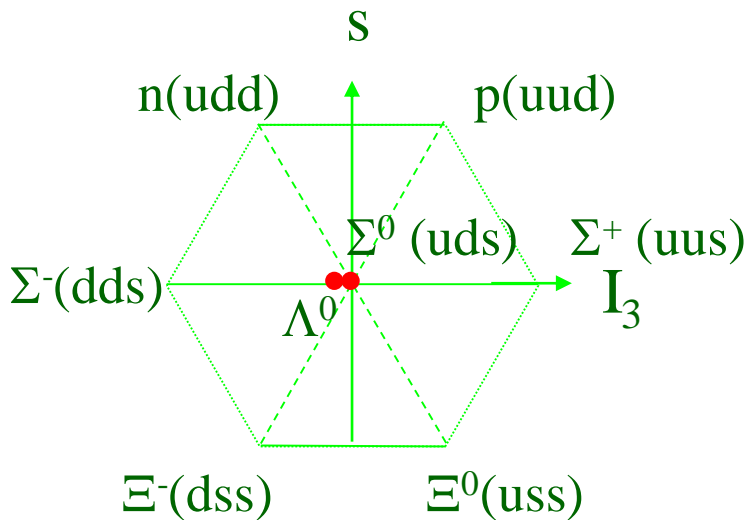
2. Hadron spectroscopy with strangeness

SU(3) 3q-quark model for baryons

1/2 +

spin-parity

3/2 +



Successful for spatial ground states !

Prediction $m_{\Omega} \cong 1670 \text{ MeV}$

experiment $m_{\Omega} \cong 1672.45 \pm 0.29 \text{ MeV}$

quenched vs un-quenched for mesons

$\bar{q}q$ 3S_1 nonet

$\phi(1020)$ $\bar{s}s$

$K(892)$ $\bar{s}d$

$\omega(782)$ $\bar{u}u + \bar{d}d$

$\rho(770)$ $\bar{u}u - \bar{d}d$

$\bar{q}q$ 3P_0 or \bar{q}^2q^2 nonet ?

$a_0(980)$ $\bar{u}u - \bar{d}d$, $[\bar{u}s][us] - [\bar{d}s][ds]$

$f_0(980)$ $\bar{s}s$, $[\bar{u}s][us] + [\bar{d}s][ds]$

$\kappa(800)$ $\bar{s}d$, $[\bar{s}u][ud]$

$f_0(600)$ $\bar{u}u + \bar{d}d$, $[\bar{u}d][ud]$

1/2⁻ baryon nonet with strangeness

- Mass pattern : quenched or unquenched ?

$$\text{uds (L=1) } 1/2^- \sim \Lambda^*(1670) \sim [\text{us}][\text{ds}] \bar{s}$$

$$\text{uud (L=1) } 1/2^- \sim \text{N}^*(1535) \sim [\text{ud}][\text{us}] \bar{s}$$

$$\text{uds (L=1) } 1/2^- \sim \Lambda^*(1405) \sim [\text{ud}][\text{su}] \bar{u}$$

$$\text{uus (L=1) } 1/2^- \sim \Sigma^*(1390) \sim [\text{us}][\text{ud}] \bar{d}$$

Wu-Dulat-Zou, PRD80(2009)017503; CLAS, PRC87(2013)035206

- Strange decays of N*(1535) : PDG → large $g_{\text{N}^*\text{N}\eta}$

$$\text{J}/\psi \rightarrow \bar{p}\text{N}^* \rightarrow \bar{p} (\text{K}\Lambda) / \bar{p} (\text{p}\eta) \rightarrow \text{large } g_{\text{N}^*\text{K}\Lambda}$$

Liu&Zou, PRL96 (2006) 042002; Geng,Oset,Zou&Doring, PRC79 (2009) 025203

$$\gamma\text{p} \rightarrow \text{p}\eta' \text{ \& } \text{pp} \rightarrow \text{pp}\eta' \rightarrow \text{large } g_{\text{N}^*\text{N}\eta'}$$

M.Dugger et al., PRL96 (2006) 062001; Cao&Lee, PRC78(2008) 035207

$$\pi^- \text{p} \rightarrow \text{n}\phi \text{ \& } \text{pp} \rightarrow \text{pp}\phi \text{ \& } \text{pn} \rightarrow \text{d}\phi \rightarrow \text{large } g_{\text{N}^*\text{N}\phi}$$

Xie, Zou & Chiang, PRC77(2008)015206; Cao, Xie, Zou & Xu, PRC80(2009)025203

- Strange decays of $\Lambda^*(1670)$: PDG → large $g_{\Lambda^*\Lambda\eta}$

narrower width (35MeV) than $\Lambda^*(1405)$

3/2⁻ baryon nonet with strangeness

- Mass pattern : quenched or unquenched ?

uds (L=1) 3/2⁻ ~ $\Lambda^*(1670)$ ~ [ud]{ss} \bar{s}

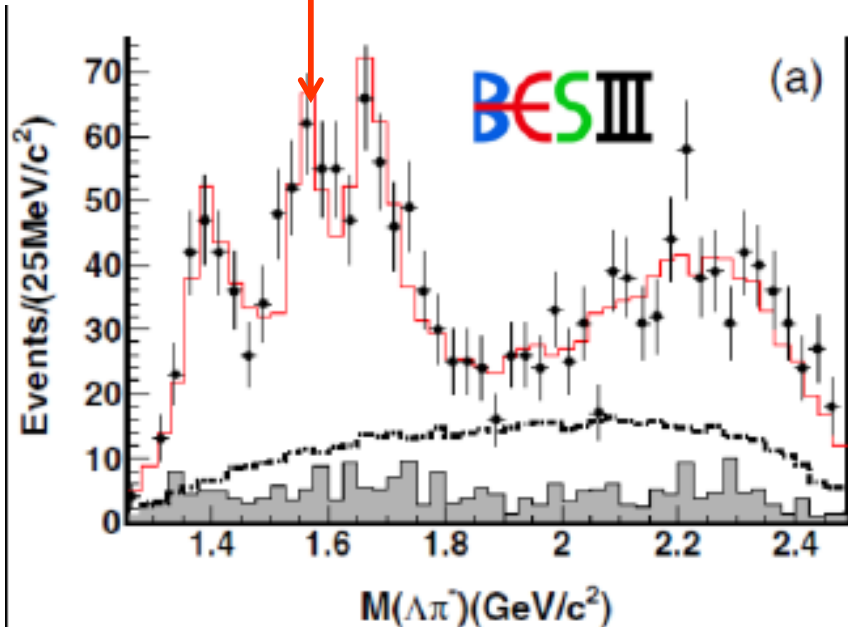
uud (L=1) 3/2⁻ ~ $N^*(1520)$ ~ [ud]{uq} \bar{q}

uds (L=1) 3/2⁻ ~ $\Lambda^*(1520)$ ~ [ud]{sq} \bar{q}

uus (L=1) 3/2⁻ ~ $\Sigma^*(1540)$ ~ [ud]{sq} \bar{q}

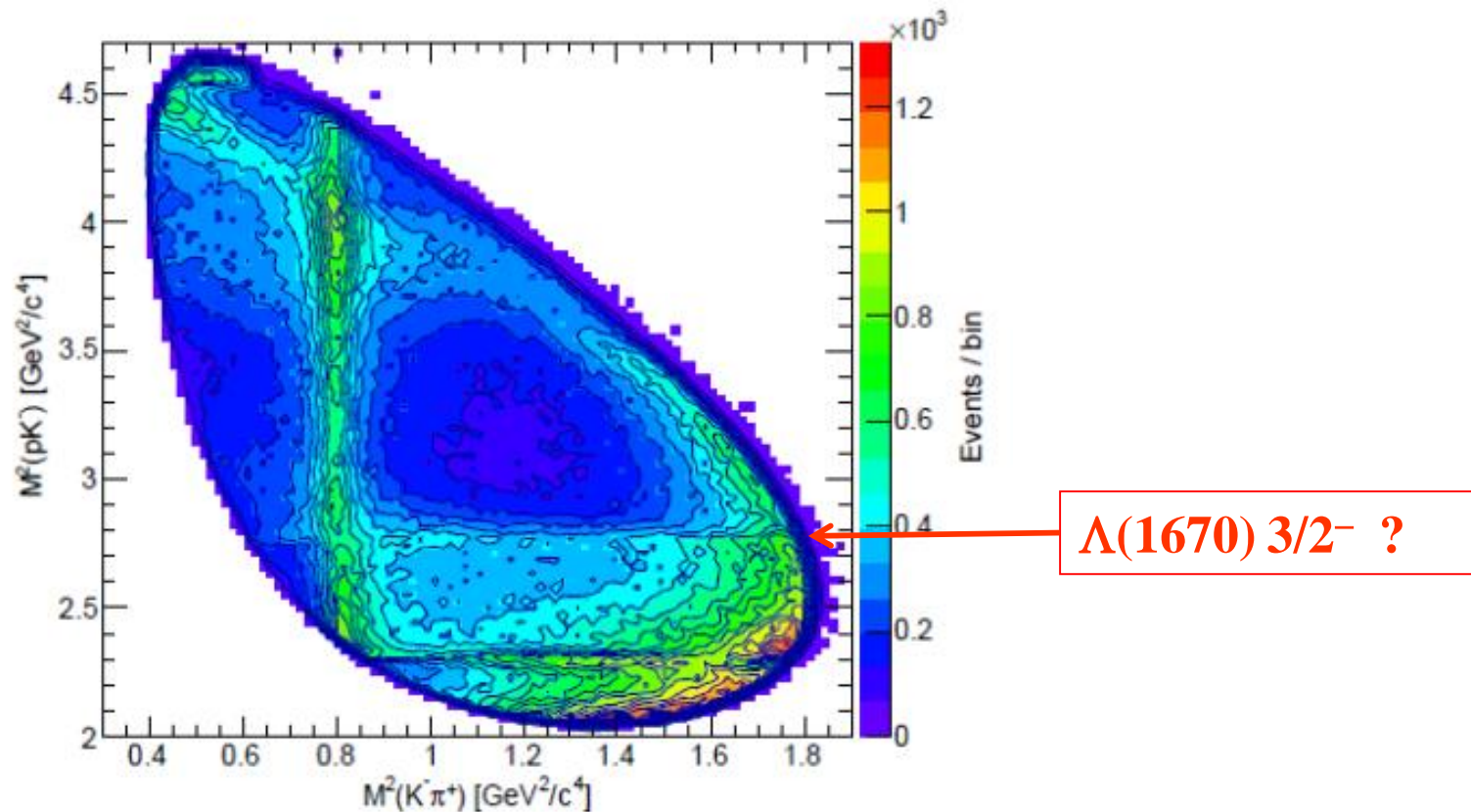
$\Sigma(1580)$ 3/2⁻

BESIII, PRD88 (2013) 112007



Shi&Zou, PRC91(2015) 035202 :
possible new $\Sigma^*(1542)$ 3/2⁻
in $K^-p \rightarrow \pi^0 \Lambda$

new $\Lambda^*(1670)3/2^-$ with width of 1.5 MeV [ud]{ss} \bar{s}
from $K^-p \rightarrow \Lambda\eta$ Liu&Xie, PRC86(2012)055202



Belle: $\Lambda_c^+ \rightarrow p K^- \pi^+$, PRL117 (2016) 011801

May be checked by BelleII & BESIII on $\Lambda_c^+ \rightarrow \Lambda\eta \pi^+$

Alternative pictures :

Hadronic molecules

$$N^*(1440) \sim N\sigma$$

$$N^*(1535) \sim K\Sigma-K\Lambda$$

$$\Lambda^*(1405) \sim KN-\Sigma\pi$$

$$\Lambda^*(1520) \sim \Sigma^*\pi$$

Penta-quark states

$$N^*(1440) \sim [ud][ud] \bar{q}$$

$$N^*(1535) \sim [ud][us] \bar{s}$$

$$\Lambda^*(1405) \sim [ud][sq] \bar{q}$$

$$\Lambda^*(1520) \sim [ud]\{sq\} q$$

**Kaiser, Weise, Oset, Ramos,
Oller, Meissner, Hyodo, Jido,
Hosaka, ...**

Successful extension to 1^+ & 2^+ meson nonets (Oset et al.)

eg., $f_1(1420) \sim \bar{K}K^*$

Important implications:

- $\bar{q}q\underline{q}q$ in S-state more favorable than $\underline{q}q$ with $L=1$!
& $\underline{q}q\underline{q}q$ in S-state more favorable than $\bar{q}q$ with $L=1$!

$1/2^-$ baryon nonet $\sim \bar{q}q^2q^2$ state + ...

0^+ meson octet $\sim \bar{q}^2q^2$ state + ...

multi-quark components are important for hadrons!

Totally different predictions for $1/2^-$ hyperons:

unquenched

$$\Sigma^* \quad [us][du] \bar{d} \quad \sim \quad 1400 \text{ MeV}$$

$$\Xi^* \quad [us][ds] \bar{d} \quad \sim \quad 1550 \text{ MeV}$$

$$\Omega^* \quad [us] ss \bar{u} \quad \sim \quad 1800 \text{ MeV}$$

quenched

$$uus \text{ (L=1)} \quad \sim \quad 1650 \text{ MeV}$$

$$uss \text{ (L=1)} \quad \sim \quad 1760 \text{ MeV}$$

$$sss \text{ (L=1)} \quad \sim \quad 2000 \text{ MeV}$$

Meson-Baryon states

Y.S.Oh

$$\Sigma^* \quad \sim \quad 1475 \text{ MeV}$$

$$\Xi^* \quad \sim \quad 1616 \text{ MeV}$$

$$\Omega^* \quad \sim \quad 1837 \text{ MeV}$$

K. P. Khemchandani et al.

$$\sim \quad 1426 \text{ MeV}$$

$$\sim \quad 1606 \text{ MeV}$$

Ramos & Oset

Experiment knowledge on hyperon states still very poor !

Ω^* in PDG:

- **** $\Omega(1672) 3/2^+$,
- *** $\Omega(2250)$
- ** $\Omega(2380), \Omega(2470)$

Ξ^* in PDG:

- **** $\Xi(1320) 1/2^+, \Xi(1530) 3/2^+$
- *** $\Xi(1690), \Xi(1820) 3/2^-, \Xi(1950), \Xi(2030)$
- ** $\Xi(2250), \Xi(2370)$
- * $\Xi(1620), \Xi(2120), \Xi(2500)$

Σ^* in PDG

**** $\Sigma(1189)1/2^+$ $\Sigma^*(1385)3/2^+$ $\Sigma^*(1670)3/2^-$
 $\Sigma^*(1775)5/2^-$ $\Sigma^*(1915)5/2^+$ $\Sigma^*(2030)7/2^+$

*** $\Sigma^*(1660)1/2^+$ $\Sigma^*(1750)1/2^-$ $\Sigma^*(1940)3/2^-$
 $\Sigma^*(2250)??$

** $\Sigma^*(1620)1/2^-$ $\Sigma^*(1690)??$ $\Sigma^*(1880)1/2^+$
 $\Sigma^*(2080)3/2^+$ $\Sigma^*(2455)??$ $\Sigma^*(2620)??$

* $\Sigma^*(1480)??$ $\Sigma^*(1560)??$ $\Sigma^*(1580)3/2^-$
 $\Sigma^*(1770)1/2^+$ $\Sigma^*(1840)3/2^+$ $\Sigma^*(2000)3/2^-$
 $\Sigma^*(2070)5/2^+$ $\Sigma^*(2100)7/2^-$ $\Sigma^*(3000)??$
 $\Sigma^*(3170)??$

All from old experiments of 1970-1985 !!

No established $1/2^- \Sigma^*$, Ξ^* , Ω^* !

K^- , K_L beam experiments at JPARC&Jlab



Elegant new source for Λ^* , Σ^* , Ξ^* & Ω^* hyperon spectroscopy

$K^-p \rightarrow \Sigma^0 \pi^0, \Sigma^{*0} \pi^0, \Lambda \eta, \Lambda \pi^0 \pi^0$: $\Lambda^*(1680) 3/2^+, \Lambda^*(1670) 3/2^-$

$K^-p \rightarrow \Sigma^0 \pi^0 \pi^0$: $\Sigma^*(1380) 1/2^-, \Sigma^*(1540) 3/2^-$

$K_L p \rightarrow \Lambda \pi^+, \Sigma^0 \pi^+, \Sigma^+ \pi^0, \Sigma^{*0} \pi^+, \Sigma^{*+} \pi^0$: $\Sigma^*(1540) 3/2^-$

$K_L p \rightarrow \Sigma^0 \eta \pi^+, \Lambda \eta \pi^+$: $\Sigma^*(1380) 1/2^-, \Sigma^*(1540) 3/2^-, \Lambda^*(1670) 3/2^-$

$K^-p \rightarrow K^+ K^0 \Omega^*$ $\Omega^*(1800) ?!$

BEPCII & BelleII → important role for hyperon spectroscopy

J/Ψ decay branching ratios ($\text{BR} \times 10^3$) for some interested channels

$p\bar{p}$	$\Lambda\bar{\Lambda}$	$\Sigma^0\bar{\Sigma}^0$	$\Xi\bar{\Xi}$	$\Lambda\bar{\Sigma}^-\pi^+$	$pK^-\bar{\Lambda}$	$pK^-\bar{\Sigma}^0$
2.1 ± 0.1	1.4 ± 0.1	1.3 ± 0.2	1.8 ± 0.4	1.1 ± 0.1	0.9 ± 0.2	0.3 ± 0.1
$p\bar{n}\pi^-$	$p\bar{p}\pi^0$	$p\bar{p}\pi^+\pi^-$	$p\bar{p}\eta$	$p\bar{p}\eta'$	$p\bar{p}\omega$	$K^-\Lambda\bar{\Xi}^+ ?$
2.0 ± 0.1	1.1 ± 0.1	6.0 ± 0.5	2.1 ± 0.2	0.9 ± 0.4	1.3 ± 0.3	$K^+\bar{\Lambda}\Xi^- ?$

BEPCII $10^{10} J/\Psi$ & $10^9 \Psi'$



Completing N^* , Λ^* , Σ^* , Ξ^* spectra

Establish the lowest $1/2^-$ Λ^* , Σ^* , Ξ^* and Ω^* !

BelleII $Y(\text{ns}) \rightarrow$ all Λ^* , Σ^* , Ξ^* and Ω^* ?!

3. From strangeness to charm & beauty

Many N^* & Λ^* are proposed dynamically generated states and multi-quark states

Problem:

None of them can be clearly distinguished from qqq due to tunable ingredients and possible large mixing of various configurations

PDG2010: “The clean Λ_c spectrum has in fact been taken to settle the decades-long discussion about the nature of the $\Lambda(1405)$ —true 3-quark state or mere $\bar{K}N$ threshold effect—unambiguously in favor of the first interpretation.”

although $\Lambda_c(2595) 1/2^-$ was proposed to be DN molecule by Tolos et al., CPC33(2009)1323. Haidenbauer et al., EPJA47(2011)18

Solution: Extension to hidden charm and beauty for baryons

$N^*(1535)$ $\bar{s}suud$

$N^*(4260)$ $\bar{c}cuud$ J.J.Wu, R.Molina, E.Oset, B.S.Zou.
Phys.Rev.Lett. 105 (2010) 232001

$N^*(11050)$ $\bar{b}buud$ J.J.Wu, L.Zhao, B.S.Zou. PLB709(2012)70

$\Lambda^*(1405)$ $\bar{q}quds$

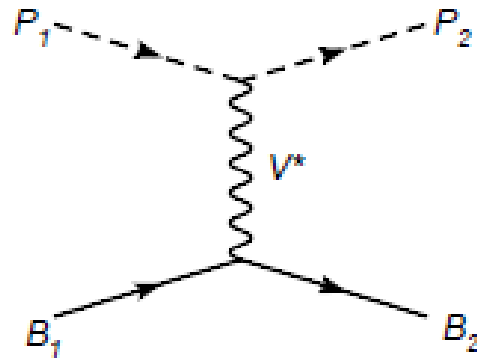
$\Lambda^*(4210)$ $\bar{c}cuds$ J.J.Wu, R.Molina, E.Oset, B.S.Zou.
Phys.Rev.Lett. 105 (2010) 232001

$\Lambda^*(11020)$ $\bar{b}buds$ J.J.Wu, L.Zhao, B.S.Zou. PLB709(2012)70

$K\Sigma, \bar{K}p \rightarrow \bar{D}\Sigma_c, \bar{D}_s\Lambda_c \rightarrow B\Sigma_b, B_s\Lambda_b$ bound states

J.J.Wu, R.Molina, E.Oset, B.S.Zou, PRL 105 (2010) 232001

J.J.Wu, L.Zhao, B.S.Zou. PLB709(2012)70



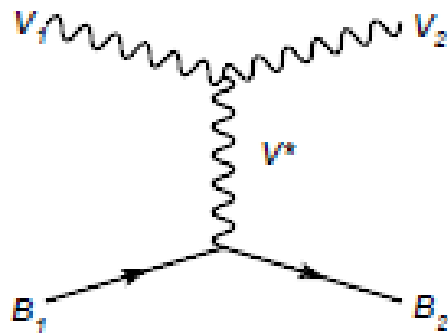
$$\mathcal{L}_{VVV} = ig\langle V^\mu [V^\nu, \partial_\mu V_\nu] \rangle$$

$$\mathcal{L}_{PPV} = -ig\langle V^\mu [P, \partial_\mu P] \rangle$$

$$\mathcal{L}_{BBV} = g(\langle \bar{B}\gamma_\mu [V^\mu, B] \rangle + \langle \bar{B}\gamma_\mu B \rangle \langle V^\mu \rangle)$$

$$V_{ab}(P_1 B_1 \rightarrow P_2 B_2) = \frac{C_{ab}}{4f^2} (E_{P_1} + E_{P_2}),$$

$$V_{ab}(V_1 B_1 \rightarrow V_2 B_2) = \frac{C_{ab}}{4f^2} (E_{V_1} + E_{V_2}) \vec{\epsilon}_1 \cdot \vec{\epsilon}_2,$$



$$T = [1 - VG]^{-1}V$$

$$T_{ab} = \frac{g_a g_b}{\sqrt{s} - z_R}$$

	(I, S)	z_R (MeV)	g_a		J^P
N^*	$(1/2, 0)$		$\bar{D}\Sigma_c$	$\bar{D}\Lambda_c^+$	$1/2^-$
		4269	2.85	0	
Λ^*	$(0, -1)$		$\bar{D}_s\Lambda_c^+$	$D\Xi_c$	$D\Xi'_c$
		4213	1.37	3.25	0
		4403	0	0	2.64

TABLE III: Pole positions z_R and coupling constants g_a for the states from $PB \rightarrow PB$.

	(I, S)	z_R (MeV)	g_a		
N^*	$(1/2, 0)$		$\bar{D}^*\Sigma_c$	$\bar{D}^*\Lambda_c^+$	$1/2^-, 3/2^-$
		4418	2.75	0	
Λ^*	$(0, -1)$		$\bar{D}_s^*\Lambda_c^+$	$\bar{D}^*\Xi_c$	$\bar{D}^*\Xi'_c$
		4370	1.23	3.14	0
		4550	0	0	2.53

TABLE IV: Pole position and coupling constants for the bound states from $VB \rightarrow VB$.

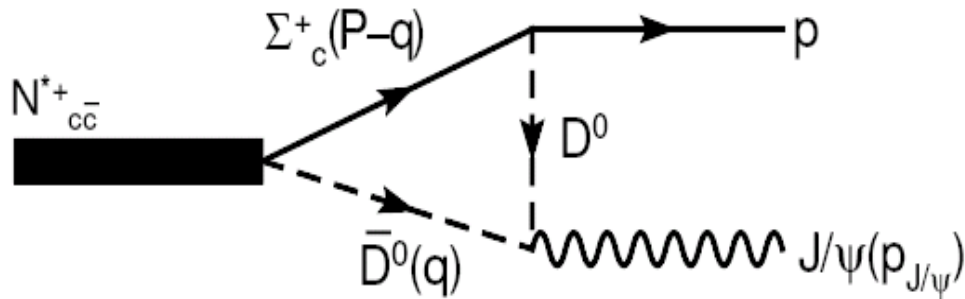
	(I, S)	M	Γ	Γ_i					J^P
N^*	$(1/2, 0)$			πN	ηN	$\eta' N$	$K\Sigma$	$\eta_c N$	$1/2^-$
		4261	56.9	3.8	8.1	3.9	17.0	23.4	
Λ^*	$(0, -1)$			KN	$\pi\Sigma$	$\eta\Lambda$	$\eta'\Lambda$	$K\Xi$	$\eta_c\Lambda$
		4209	32.4	15.8	2.9	3.2	1.7	2.4	5.8
		4394	43.3	0	10.6	7.1	3.3	5.8	16.3

TABLE V: Mass (M), total width (Γ), and the partial decay width (Γ_i) for the states from $PB \rightarrow PB$, with units in MeV.

	(I, S)	M	Γ	Γ_i					J^P
N^*	$(1/2, 0)$			ρN	ωN	$K^*\Sigma$	$J/\psi N$	$1/2^-, 3/2^-$	
		4412	47.3	3.2	10.4	13.7	19.2		
Λ^*	$(0, -1)$			K^*N	$\rho\Sigma$	$\omega\Lambda$	$\phi\Lambda$	$K^*\Xi$	$J/\psi\Lambda$
		4368	28.0	13.9	3.1	0.3	4.0	1.8	5.4
		4544	36.6	0	8.8	9.1	0	5.0	13.8

TABLE VI: Mass (M), total width (Γ), and the partial decay width (Γ_i) for the states from $VB \rightarrow VB$ with units in MeV.

Super-heavy narrow N^* and Λ^* with hidden charm
Definitely not qqq states !



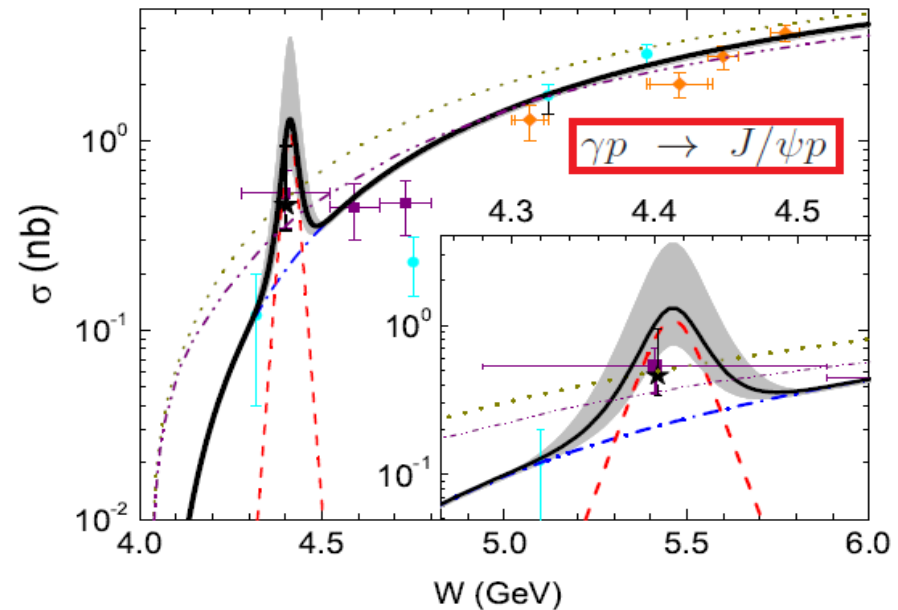
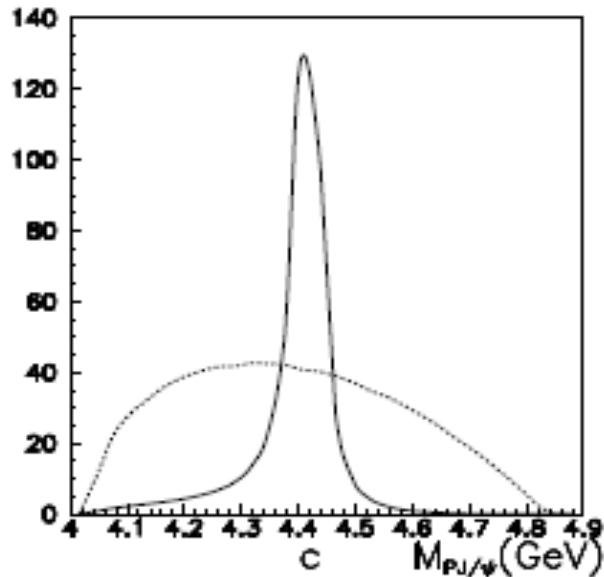
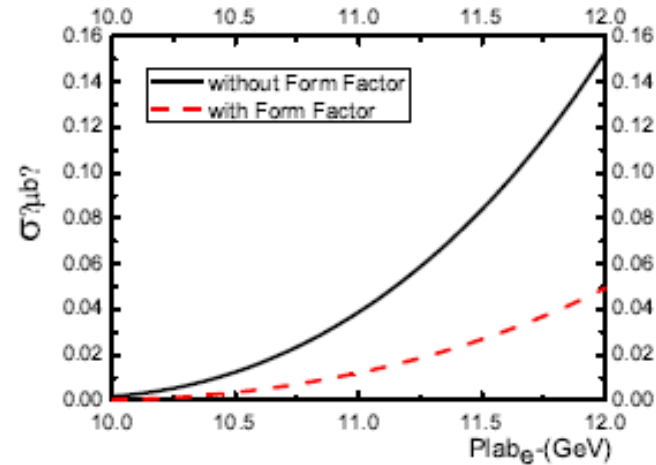
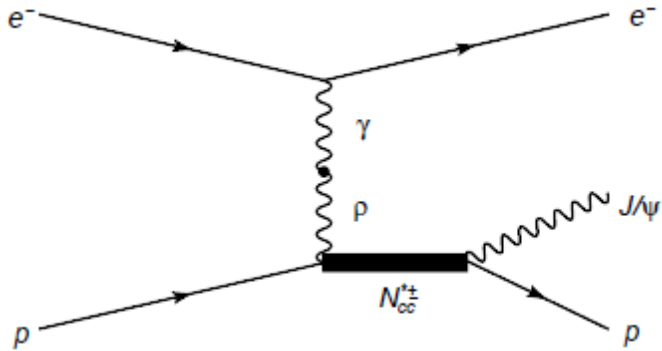
3 orders of magnitude smaller than $N^* \rightarrow p\eta_c$

$$\bar{p}p \rightarrow \bar{p}pJ/\psi \sim 0.03 \text{ nb}$$

~ 250 events per day at PANDA/FAIR by $L=10^{31} \text{ cm}^{-2}\text{s}^{-1}$

These Super-heavy narrow N^* and Λ^* can be found at PANDA !

Prediction for 12GeV@JLab

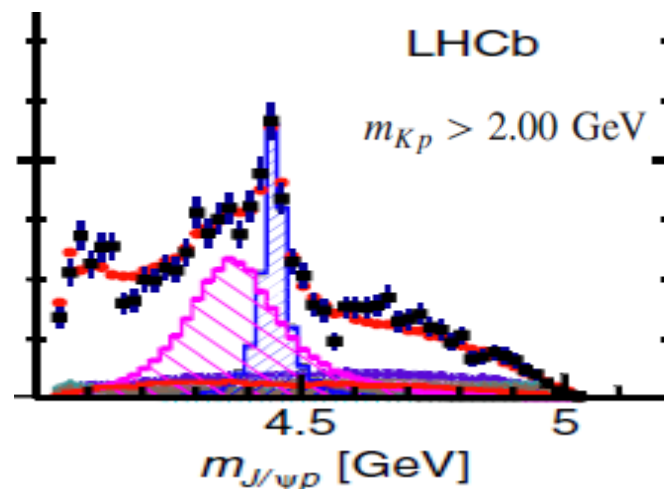
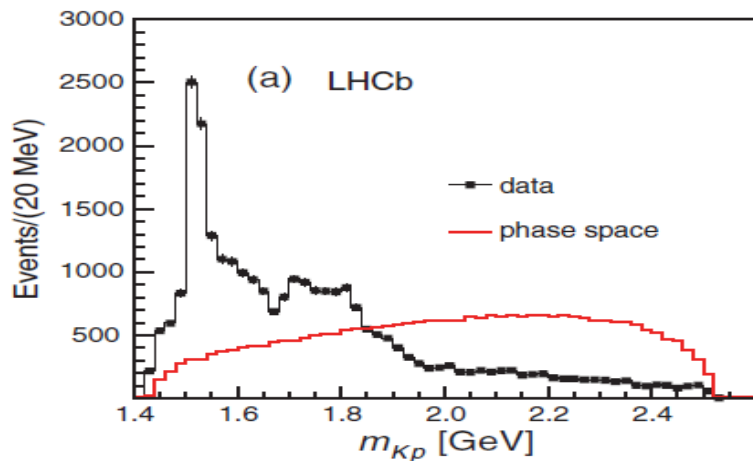
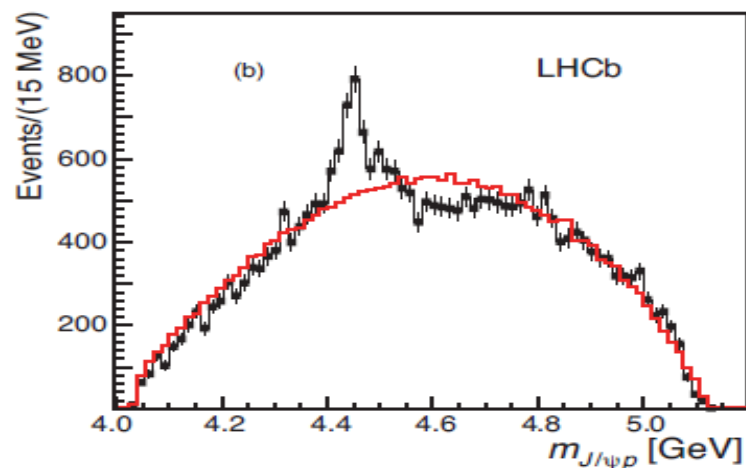
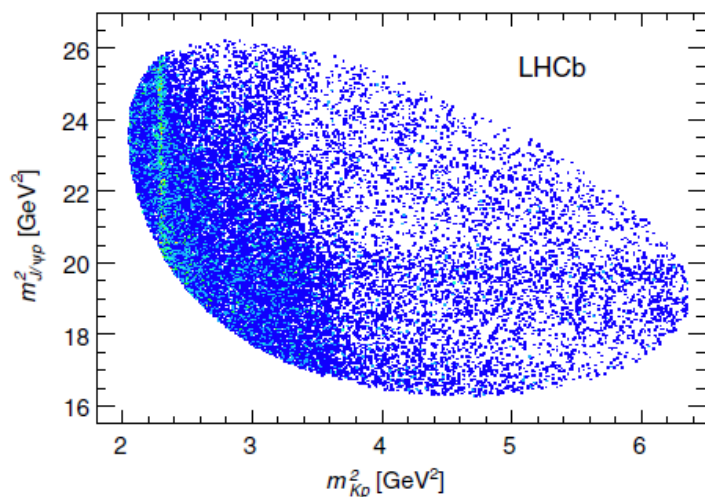
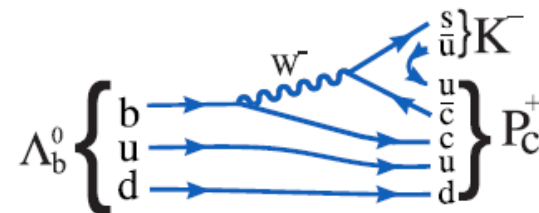


Y. Huang, J.He, H.F.Zhang and X.R.Chen, JPG41, 115004 (2014)

Observation of $P_c^+(4380)$ & $P_c^+(4450)$ by LHCb

LHCb, Phys.Rev.Lett. 115 (2015) 072001 :

Observation of two N^* from $\Lambda_b^0 \rightarrow J/\psi K^- p$



Explanations after LHCb observation

Thresholds $\bar{D}\Sigma_c^*$ (4383MeV), $\bar{D}^*\Sigma_c$ (4460MeV), $p\chi_{c1}$ (4449MeV)

1) $\bar{D}\Sigma_c^*$, $\bar{D}^*\Sigma_c$, $\bar{D}^*\Sigma_c^*$ molecular states

R.Chen, X.Liu, X.Q.Li, S.L.Zhu, PRL115 (2015) 132002;

H.X.Chen, W.Chen, X.Liu, T.G.Steele, S.L.Zhu, PRL115 (2015)172001

L.Roca, J.Nieves, E.Oset, PRD92 (2015) 094003;

J.He, PLB 753 (2016)547 ;

2) diquark cu & triquark $\bar{c}(ud)$ states

L.Maiani, A.D.Polosa, V. Riquer, PLB749 (2015) 289;

R.Lebed, PLB749 (2015) 454;

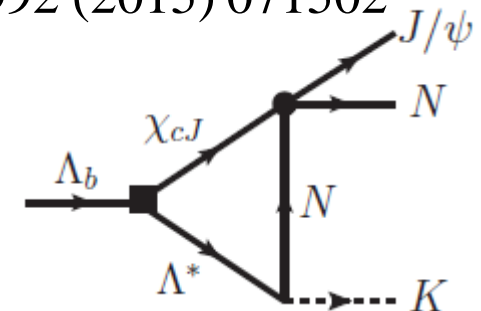
G.N.Li, M.He, X.G.He, JHEP 1512 (2015) 128;

R.Zhu, C.F.Qiao, PLB756 (2016) 259;

3) Kinematic triangle-singularity

F.K.Guo, Ulf-G.Meißner, W.Wang, Z.Yang, PRD92 (2015) 071502

X.H.Liu, Q.Wang, Q.Zhao, PLB757 (2016) 231

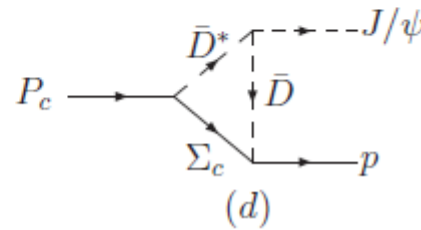
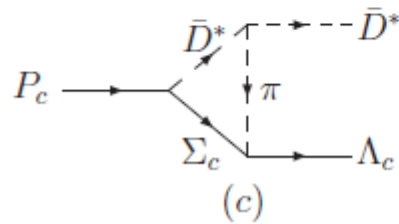
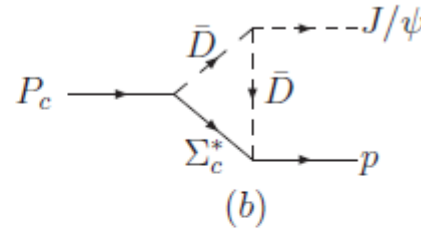
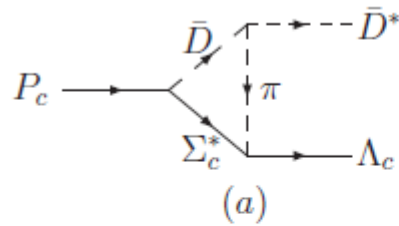


For a comprehensive review, cf.:

H.X.Chen, W.Chen, X.Liu, S.L.Zhu, Phys.Rept. 639 (2016) 1

Disentangling $\bar{D}\Sigma_c^* / \bar{D}^*\Sigma_c$ nature of P_c^+ states from their decays

C.W.Shen, F.K.Guo, J.J.Xie, B.S.Zou, NPA 954(2016)393



$$\frac{\Gamma(P_c(4380) \rightarrow \bar{D}^*\Sigma_c \rightarrow \bar{D}^*\Lambda_c)}{\Gamma(P_c(4380) \rightarrow \bar{D}^*\Sigma_c \rightarrow J/\psi p)} \sim \mathbf{1}$$

$$\frac{\Gamma(P_c(4380) \rightarrow \bar{D}\Sigma_c^* \rightarrow \bar{D}^*\Lambda_c)}{\Gamma(P_c(4380) \rightarrow \bar{D}\Sigma_c^* \rightarrow J/\psi p)} \sim \mathbf{20}$$

Natural explanation for the larger decay width of $P_c^+(4380)$

**S.G.Yuan, K.W.Wei, J.He, H.S.Xu, B.S.Zou, “Study of $\bar{c}cqqq$ five quark system with three kinds of quark-quark hyperfine interaction,”
Eur. Phys. J. A48 (2012) 61**

J^P	<i>CM</i>		<i>FS</i>		<i>Inst.</i>	
	<i>udsc\bar{c}</i>	<i>uudc\bar{c}</i>	<i>udsc\bar{c}</i>	<i>uudc\bar{c}</i>	<i>udsc\bar{c}</i>	<i>uudc\bar{c}</i>
$\frac{1}{2}^-$	4273	4267	4084	3933	4209	4114
$\frac{1}{2}^-$	4377	4363	4154	4013	4216	4131
$\frac{1}{2}^-$	4453	4377	4160	4119	4277	4204
$\frac{1}{2}^-$	4469	4471	4171	4136	4295	4207
$\frac{1}{2}^-$	4494	4541	4253	4156	4360	4272
$\frac{1}{2}^-$	4576		4263		4362	
$\frac{1}{2}^-$	4649		4278		4416	
$\frac{3}{2}^-$	4431	<u>4389</u>	4154	4013	4216	4131
$\frac{3}{2}^-$	4503	<u>4445</u>	4171	4119	4295	4204
$\frac{3}{2}^-$	4549	4476	4263	4136	4362	4272
$\frac{3}{2}^-$	4577	4526	4278	4236	4416	<u>4322</u>
$\frac{3}{2}^-$	4629		4362		4461	
$\frac{5}{2}^-$	4719	4616	4362	4236	4461	4322

J^P	<i>CM</i>		<i>FS</i>		<i>Inst.</i>	
	<i>udsc\bar{c}</i>	<i>uudc\bar{c}</i>	<i>udsc\bar{c}</i>	<i>uudc\bar{c}</i>	<i>udsc\bar{c}</i>	<i>uudc\bar{c}</i>
$\frac{1}{2}^+$	4622	4456	4291	4138	4487	4396
$\frac{1}{2}^+$	4636	4480	4297	4140	4501	4426
$\frac{1}{2}^+$	4645	4557	4363	4238	4520	4426
$\frac{1}{2}^+$	4658	4581	4439	4320	4540	4470
$\frac{1}{2}^+$	4690	4593	4439	4367	4557	4482
$\frac{1}{2}^+$	4696	4632	4467	4377	4587	4490
$\frac{1}{2}^+$	4714	4654	4469	4404	4590	4517
$\frac{1}{2}^+$	4728	4676	4486	4489	4614	4518
$\frac{1}{2}^+$	4737	4714	4492	4508	4616	4549
$\frac{1}{2}^+$	4766	4720	4510	4515	4626	4566
$\frac{3}{2}^+$	4623	<u>4457</u>	4291	4138	4487	4396
$\frac{3}{2}^+$	4638	4515	4297	4140	4501	4426
$\frac{3}{2}^+$	4680	4561	4363	4238	4520	4426
$\frac{3}{2}^+$	4692	4582	4439	4320	4540	4470
$\frac{3}{2}^+$	4695	4625	4439	4367	4557	4482
$\frac{5}{2}^+$	4705	4539	4297	4140	4501	<u>4426</u>
$\frac{5}{2}^+$	4719	4649	4439	4320	4540	4470
$\frac{5}{2}^+$	4773	4689	4467	4367	4587	4482
$\frac{5}{2}^+$	4793	4696	4486	4404	4615	4490
$\frac{5}{2}^+$	4821	4710	4492	4515	4632	4517
$\frac{7}{2}^+$	4945	4841	4638	4508	4698	4566
$\frac{7}{2}^+$	4955	4862	4671	4551	4712	4634
$\frac{7}{2}^+$	4974	4919	4705	4587	4765	4669
$\frac{7}{2}^+$	5010		4759		4797	

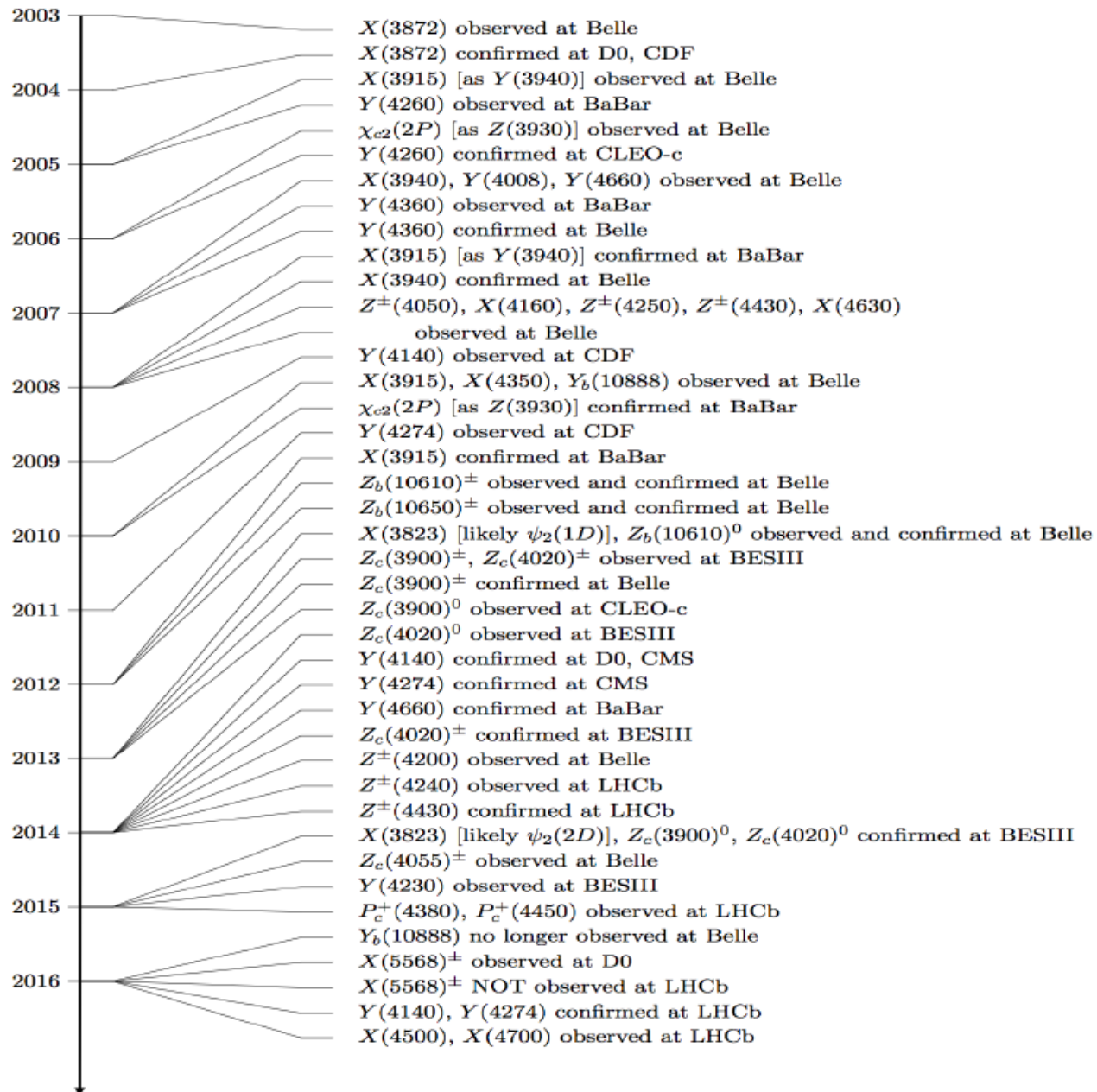
$M(5/2^+) - M(3/2^-) : 130 \sim 300 \text{ MeV}$

- **New penta-quark spectroscopy provides a new ideal platform for understanding multiquark dynamics**
- **Further experimental confirmation and extension for whole penta-quark spectroscopy from $\gamma N, \pi N, KN, e^+e^- \rightarrow \bar{\Lambda}_b \Lambda_b$, etc.**
 $\pi 10/K 10 @ JPARC$, BelleII may play important role here!
- **Systematic theoretical study of the penta-quark spectroscopy**

$\bar{c}cuud$ & $\bar{c}cuds \rightarrow sss - \bar{q}qsss \rightarrow$ light baryons

$\bar{c}c \bar{u}d$ & $\bar{c}s \bar{u}d \rightarrow \bar{c}c - \bar{q}q \bar{c}c \rightarrow$ light mesons

Discovery Timeline: [Lebed, Mitchell, Swanson; arXiv : 1610.04528]



Meson sector:

If $f_0(980)$ as $\bar{K}K$ molecule, then $\rightarrow DK, \bar{D}D, \bar{B}B$ molecules
 $D_{s0}(2317)$

Y.J.Zhang, H.C.Chiang, P.N.Shen, B.S.Zou, PRD74 (2006) 014013

If $f_1(1420)$ as \bar{K}^*K state, then $\rightarrow \bar{D}^*D, \bar{B}^*B$ molecules
 $X(3872), Z_c, Z_b$

X. Liu, Luo, Y. Liu, S.L.Zhu, EPJC61, 411 (2009); PRD84 (2011) 054002

$\bar{K}^*K^* \rightarrow \bar{D}^*D^*, \bar{B}^*B^*$

T.Fernandez-Carames, A.Valcarce, J.Vijande, PRL103 (2009) 222001

$Z_b(10610) \sim B^*(5325)B(5280); Z_c(10650) \sim B^*(5325)B^*(5325);$

$Z_c(3900) \sim D^*(2010)D(1870); Z_c(4025) \sim D^*(2010)D^*(2010);$

$Z_c(4250) \sim D(1870)D_1(2420); Z_c(4430) \sim D^*(2010)D_1(2420)$

For a comprehensive review, cf.:

H.X.Chen, W.Chen, X.Liu, S.L.Zhu, Phys.Rept. 639 (2016) 1-121

Conclusions

JPARC & BelleII may play a leading role in studying further heavy exotic hadrons from strangeness to charm and beauty !

Thanks !