Progress on hadronic molecules
from strangeness to charm and beauty

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"Hadronic Molecules", Rev. Mod. Phys. 90 (2018)015004

Outline :

1. Hadronic molecules with strangeness
2. Hadronic molecules with hidden charm & LHCb P_c states
3. Strange & beauty partners of P_c states
4. Prospects

1. Hadronic molecules with strangeness

Brief history for the discovery of hadronic molecules

1932: Neutron & Deuteron - the 1-st hadronic molecule

1947: π, K

1959: KN &molecule predicted by Dalitz Tuan, PRL2, 425

1961: Λ(1405) → Σπ observed by Alston et al., PRL6, 698

post-1962:

$f_0(980)$ & $a_0(980)$	$\bar{K}K$ molecules?	Isgur, …
$f_1(1420)$	$\bar{K}K^*$ molecule ?	Tornqvist, …
$f_0(1710)$	$\bar{K}^*K^*$ molecule ?	Oset, …
N*(1535)	$\bar{K}\Sigma$ - $\bar{K}\Lambda$ molecule ?	Kaiser, …
$D^*_{s0}(2317)$ & $D^*_{s1}(2460)$	$\bar{K}D$ & $\bar{K}D^*$ molecules?	Barnes, …

…….

$\bar{K}$ p p molecule → F. Sakuma's talk yesterday

Akaishi,Yamazaki, PRC65(2002) 044005
Shevchenko,Gal,Mares, PRL98 (2007) 082301

Many hadrons are proposed to be hadronic molecules

Problem:

None of them can be clearly distinguished from qqq or $\bar{q}q$ 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

Λ*(1405) $\bar{q}quds$

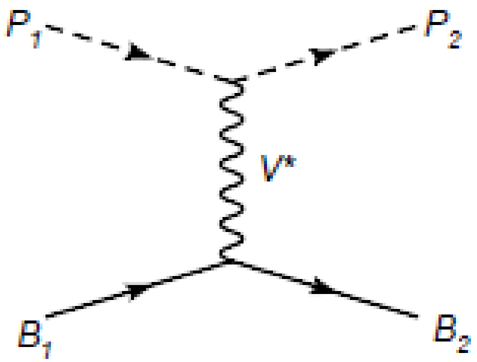
Λ*(4210) $\bar{c}cuds$ J.J.Wu, R.Molina, E.Oset, B.S.Zou. Phys.Rev.Lett. 105 (2010) 232001

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

2. Hadronic molecules with hidden charm & LHCb P_c states

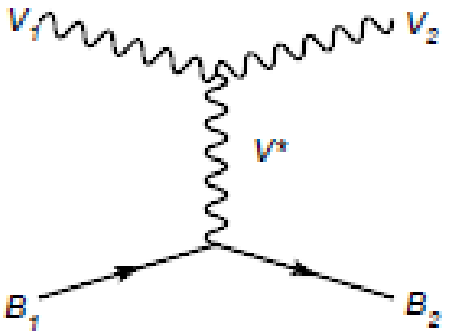
"Prediction of narrow N* and Λ* resonances with hidden charm above 4 GeV",
Wu, Molina, Oset, Zou, PRL105 (2010) 232001

$K\Sigma$, Kp → $\bar{D}^{(*)}\Sigma_c$, $\bar{D}_s^{(*)}\Lambda_c$ bound states



$$\mathcal{L}_{VVV} = ig\langle V^\mu[V^\nu, \partial_\mu V_\nu]\rangle$$
$$\mathcal{L}_{PPV} = -ig\langle V^\mu[P, \partial_\mu P]\rangle$$
$$\mathcal{L}_{BBV} = g(\langle \bar{B}\gamma_\mu[V^\mu, B]\rangle + \langle \bar{B}\gamma_\mu B\rangle\langle V^\mu\rangle)$$

$$V_{ab(P_1B_1\to P_2B_2)} = \frac{C_{ab}}{4f^2}(E_{P_1} + E_{P_2}),$$



$$V_{ab(V_1B_1\to V_2B_2)} = \frac{C_{ab}}{4f^2}(E_{V_1} + E_{V_2})\vec{\epsilon}_1\cdot\vec{\epsilon}_2,$$

$$T = [1 - VG]^{-1}V \qquad T_{ab} = \frac{g_a g_b}{\sqrt{s} - z_R}$$

	(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*	$(0,-1)$		$\bar{D}_s\Lambda_c^+$	$\bar{D}\Xi_c$	$\bar{D}\Xi'_c$	
		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 $PB \to PB$.

	(I,S)	z_R (MeV)		g_a		J^P
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 $VB \to VB$.

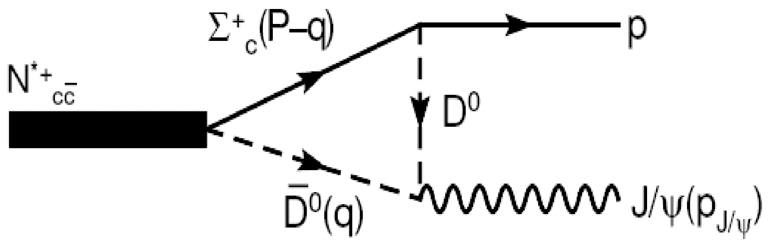
	(I,S)	M	Γ	Γ_i						J^P
N*	$(1/2,0)$			πN	ηN	$\eta' N$	$K\Sigma$		$\eta_c N$	
		4261	56.9	3.8	8.1	3.9	17.0		23.4	$1/2^-$
	$(0,-1)$			$\bar{K}N$	$\pi\Sigma$	$\eta\Lambda$	$\eta'\Lambda$	$K\Xi$	$\eta_c\Lambda$	
Λ*		4209	32.4	15.8	2.9	3.2	1.7	2.4	5.8	
		4394	43.3	0	10.6	7.1	3.3	5.8	16.3	

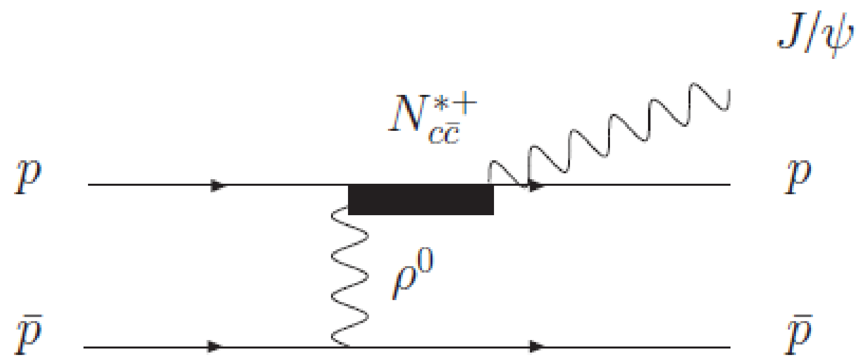
TABLE V: Mass (M), total width (Γ), and the partial decay width (Γ_i) for the states from $PB \to PB$, with units in MeV.

	(I,S)	M	Γ	Γ_i						J^P
N*	$(1/2,0)$			ρN	ωN	$K^*\Sigma$			$J/\psi N$	
		4412	47.3	3.2	10.4	13.7			19.2	$1/2^-$, $3/2^-$
	$(0,-1)$			$\bar{K}^* N$	$\rho\Sigma$	$\omega\Lambda$	$\phi\Lambda$	$K^*\Xi$	$J/\psi\Lambda$	
Λ*		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 $VB \to VB$ with units in MeV.

Prediction for PANDA





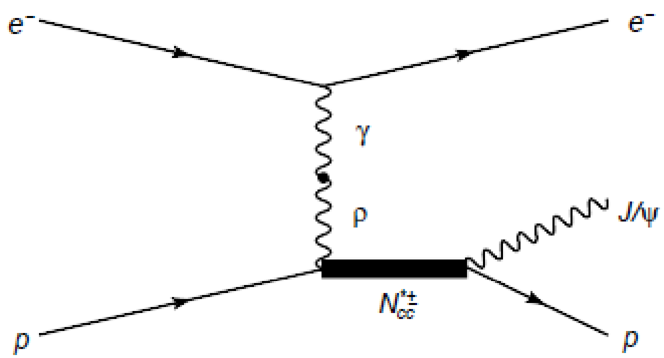
$\bar{p}p \rightarrow \bar{p}pJ/\psi$ > 0.1 nb

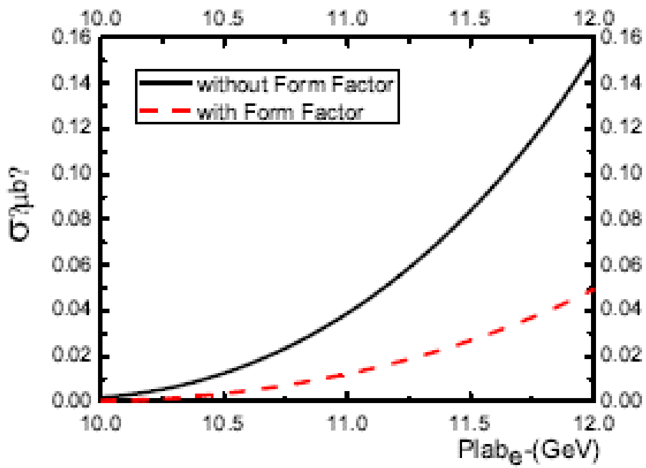
> 100 events per day at PANDA/FAIR by $L=10^{31}$ $cm^{-2}s^{-1}$

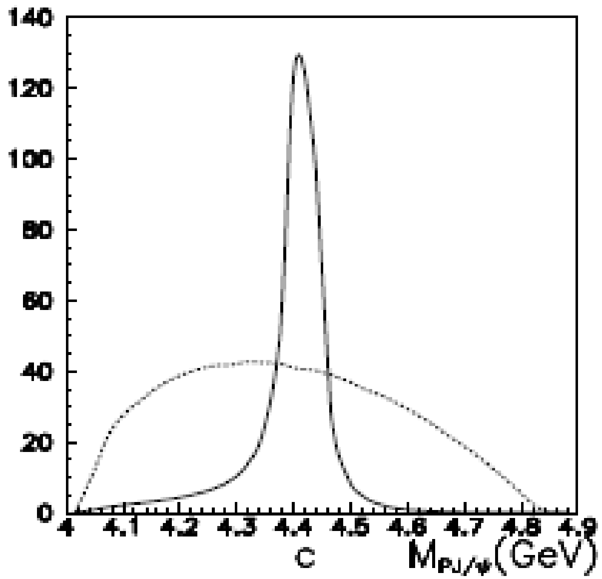
These Super-heavy narrow N* and Λ*
can be found at PANDA !

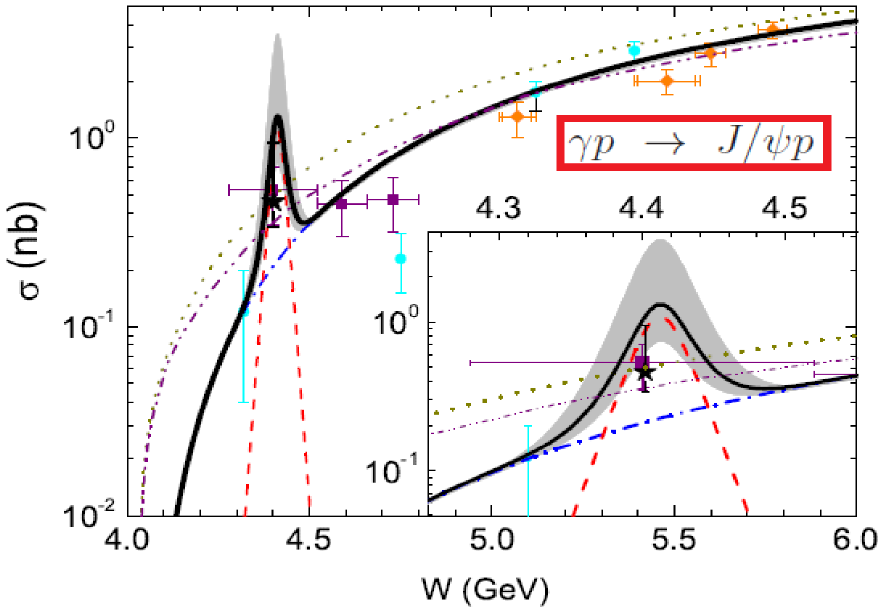
Albrecht Gillitzer@Juelich had a plan to find them at PANDA

Prediction for 12GeV@JLab









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

Proposals for looking for $N_{c\bar{c}}$ & $\Lambda_{c\bar{c}}$ with π^-, K beams at JPARC

a) X.Y.Wang, X.R.Chen, "The production of hidden charm baryon N*(4261) from $\pi^- p \rightarrow \eta_c n$ reaction", EPL109 (2015) 41001.

b) E.J.Garzon, J.J.Xie, "Effects of a $N_{c\bar{c}}$ resonance with hidden charm in the $\pi^- p \rightarrow D^- \Sigma_c^+$ reaction near threshold", PRC 92 (2015) 035201

c) X.Y.Wang, X.R.Chen, "Production of the superheavy baryon Λ*(4209) in kaon-induced reaction", EPJA51 (2015) 85

Hidden charm N* above 4 GeV decaying to pJ/ψ are supported by other approaches

$\bar{D}\Sigma_c$ state in a chiral quark model ~ 4.3 GeV

W.L.Wang, F.Huang, Z.Y.Zhang, B.S.Zou, PRC84(2011)015203

$\bar{D}\Sigma_c$ state in EBAC-DCC model ~ 4.3 GeV

J.J.Wu, T.S.H.Lee, B.S.Zou, PRC85(2012)044002

$\bar{D}\Sigma_c$ & $\bar{D}^*\Sigma_c$ state in Schoedinger Equation method ~ 4.3 GeV

Z.C.Yang, Z.F.Sun, J.He, X.Liu, S.L.Zhu, Chin. Phys. C36 (2012) 6

$\bar{D}\Sigma_c^*$, $\bar{D}^*\Sigma_c$, $\bar{D}^*\Sigma_c^*$ states with $J^P = 3/2^-$

C.W.Xiao, J.Nieves, E.Oset, PRD 88 (2013) 056012

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

	CM		*FS*		*Inst.*	
J^P	$uds c\bar{c}$	$uud c\bar{c}$	$uds c\bar{c}$	$uud c\bar{c}$	$uds c\bar{c}$	$uud c\bar{c}$
$\frac{1}{2}^-$	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	4389	4154	4013	4216	4131
$\frac{3}{2}^-$	4503	4445	4171	4119	4295	4204
$\frac{3}{2}^-$	4549	4476	4263	4136	4362	4272
$\frac{3}{2}^-$	4577	4526	4278	4236	4416	4322
$\frac{3}{2}^-$	4629		4362		4461	
$\frac{5}{2}^-$	4719	4616	4362	4236	4461	4322

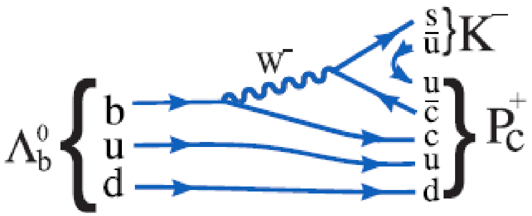
	CM		*FS*		*Inst.*	
J^P	$uds c\bar{c}$	$uud c\bar{c}$	$uds c\bar{c}$	$uud c\bar{c}$	$uds c\bar{c}$	$uud c\bar{c}$
$\frac{1}{2}^+$	4622	4456	4291	4138	4487	4396
$\frac{1}{2}^+$	4636	4480	4297	4140	4501	4426
$\frac{1}{2}^+$	4645	4557	4363	4238	4520	4426
$\frac{1}{2}^+$	4658	4581	4439	4320	4540	4470
$\frac{1}{2}^+$	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	4457	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	4426
$\frac{5}{2}^+$	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	

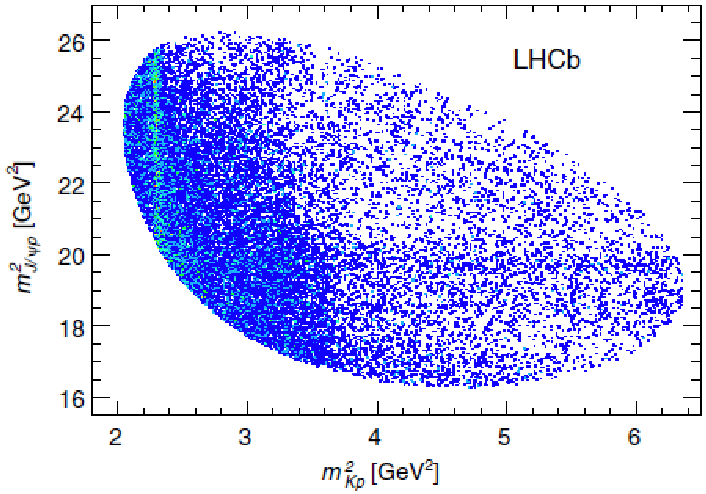
$M(5/2^+) - M(3/2^-)$: 130 ~300 MeV

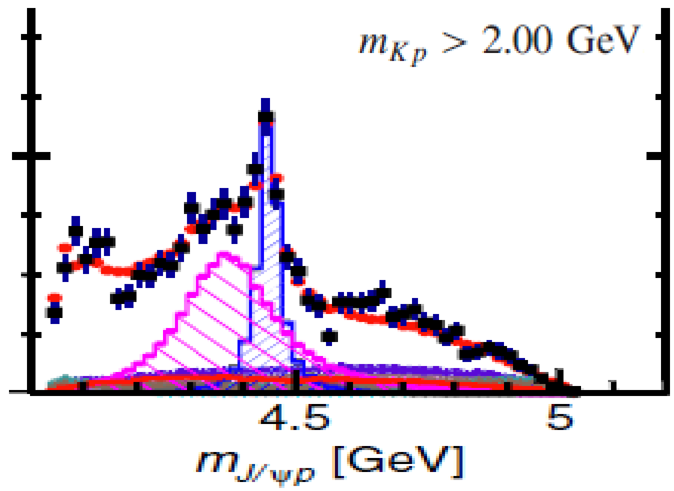
LHCb observation of 2 pentaquarks

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

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







1) **4380±8±29 MeV , 205±18±86 MeV, $P_c^+(4380)$**
2) **4450±2±3 MeV , 39±5±19 MeV, $P_c^+(4450)$**

The preferred J^P assignments are of opposite parity, with one state having spin 3/2 and the other 5/2.

LHCb pentaquark states   vs   Predictions

Consistence :   mass of $P_c\,(3/2^-)$, pJ/ψ decay mode

Problems:

1) $P_c^+(4380)$ -- larger decay width than prediction

2) Where are lower $P_c\,(1/2^-)$ states ?

Progress on P_c states 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

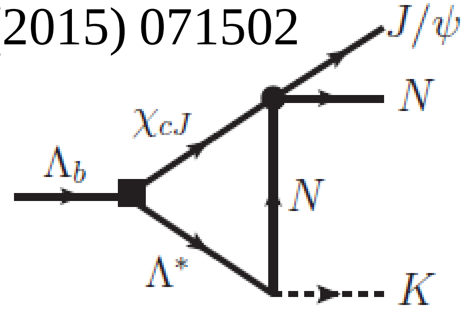
R.Chen, X.Liu, X.Q.Li, S.L.Zhu, PRL115 (2015) 132002;
H.X.Chen, W.Chen, X.Liu, T.G.Steele, S.L.Zhu, PRL115 (2015)172001
L.Roca, J.Nieves, E.Oset, PRD92 (2015) 094003;
J.He, PLB 753 (2016)547 ;

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 comprehensive reviews, cf.:

H.X.Chen, W.Chen, X.Liu, S.L.Zhu, Phys.Rept. 639 (2016) 1
F.K.Guo, C.Hanhart, U.Meissner, Q.Wang, Q.Zhao, B.S.Zou, RMP 90 (2018)015004

$\bar{D}\Sigma_c^*$, $\bar{D}^*\Sigma_c$, $\bar{D}^*\Sigma_c^*$ bound states

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

$P_c^+(4380)$ -- $\bar{D}^*\Sigma_c$ $3/2^-$; $P_c^+(4450)$ -- $\bar{D}^*\Sigma_c^*$ $5/2^-$

[2] Y.Yamaguchi, E. Santopinto, PRD96 (2017) 014018

$P_c^+(4380)$ -- $\bar{D}^{(*)}\Sigma_c^{(*)}$ - $\bar{D}^{(*)}\Lambda_c$ $3/2^+$; $P_c^+(4450)$ -- $\bar{D}^{(*)}\Sigma_c^{(*)}$ - $\bar{D}^{(*)}\Lambda_c$ $5/2^-$

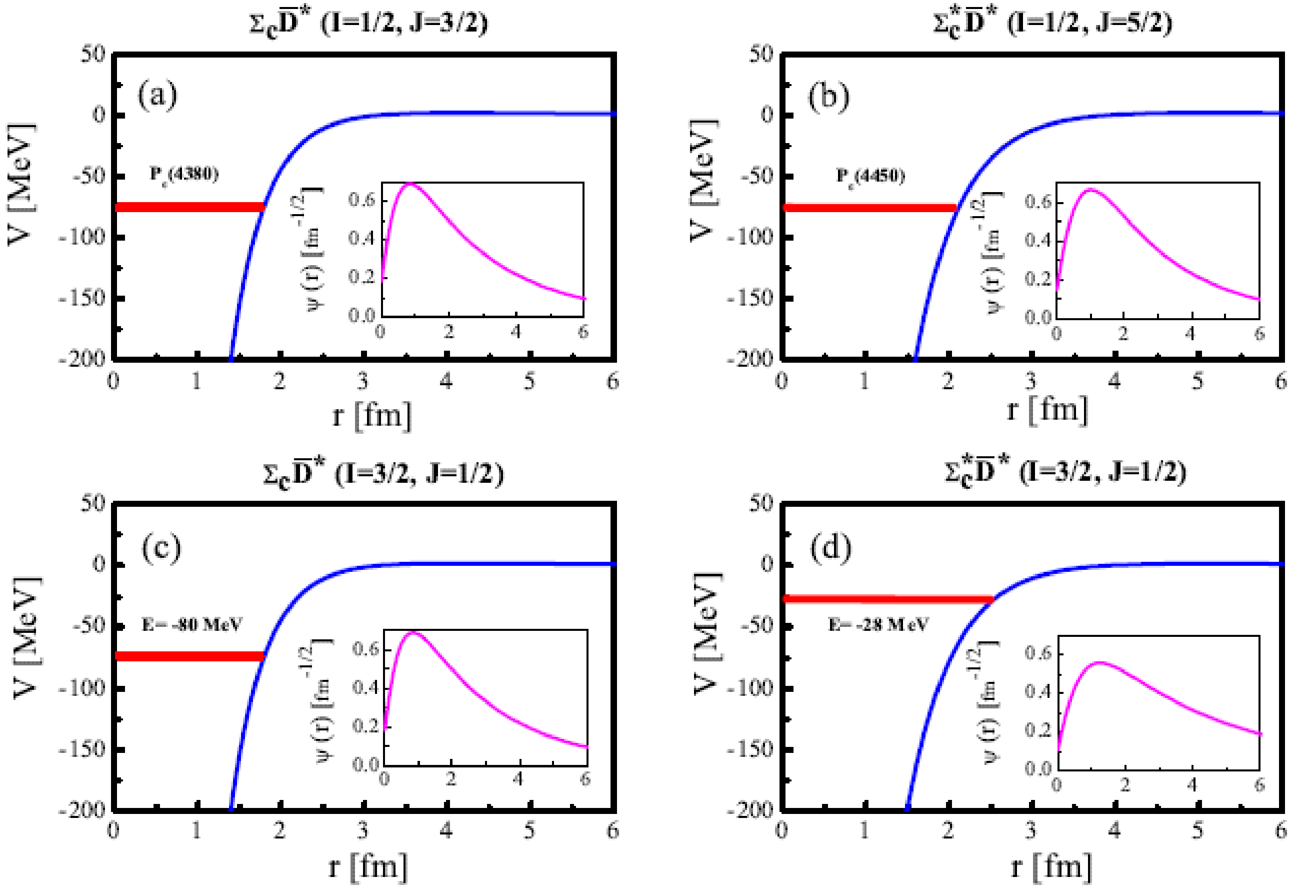
[3] J.He, PLB 753 (2016)547 ; PRD95 (2017)074004
Y.H.Lin, C.W.Shen, F.K.Guo, B.S.Zou, PRD95(2017)114017

$P_c^+(4380)$ -- $\bar{D}\Sigma_c^*$/ $\bar{D}^*\Sigma_c$ $3/2^-$; $P_c^+(4450)$ -- $\bar{D}^*\Sigma_c$ $5/2^+$

→ **Different predictions to be checked !**

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

OPE: Prediction of I=3/2 pentaquarks !



[2] Y.Yamaguchi, E. Santopinto, PRD96 (2017) 014018

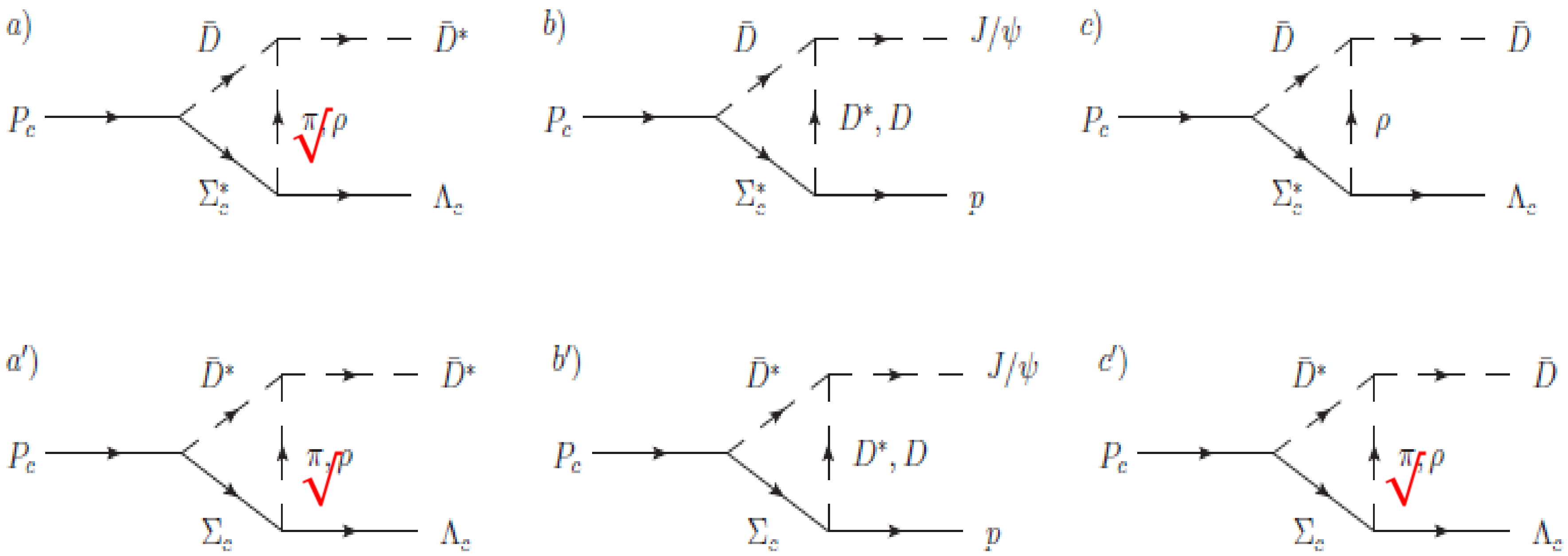
Prediction of a few more J=3/2 pentaquarks !

Λ [MeV]	1300	1400	1500	1600
$J^P = 3/2^-$	$4236.9 - i0.8$	4136.0	4006.3	3848.2
	$4381.3 - i11.4$	$4307.9 - i18.8$	$4242.6 - i1.4$	4150.1
	$4368.5 - i64.9$	$4348.7 - i21.1$	$4312.7 - i16.0$	$4261.0 - i7.0$
$J^P = 3/2^+$	$4223.0 - i97.9$	$4206.7 - i41.2$	$4169.3 - i5.3$	4104.2
	$4363.3 - i57.0$	$4339.7 - i26.8$	$4311.8 - i6.6$	$4268.5 - i1.3$
$J^P = 5/2^-$	—	$4428.6 - i89.1$	$4391.7 - i88.8$	$4338.2 - i56.2$
$J^P = 5/2^+$	—	—	$4368.0 - i9.2$	$4305.8 - i1.9$
	—	—	—	—

Problem: much larger width than observed $P_c^+(4450)$
meanwhile too small width for $P_c^+(4380)$

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

Y.H.Lin, C.W.Shen, F.K.Guo, B.S.Zou, PRD95(2017)114017



One pion exchange is important !

Partial decay widths of $P_c^+(4380)$ & $P_c^+(4450)$

	Widths (MeV)			
	$P_c(4380)$		$P_c(4450)$	
Mode	$\bar{D}\Sigma_c^*(\frac{3}{2}^-)$	$\bar{D}^*\Sigma_c(\frac{3}{2}^-)$	$\bar{D}^*\Sigma_c(\frac{3}{2}^-)$	$\bar{D}^*\Sigma_c(\frac{5}{2}^+)$
$\bar{D}^*\Lambda_c$	131.3 √	35.3 √	72.3 √	20.5 √
$J/\psi p$	3.8	16.6	16.3	4.0
$\bar{D}\Lambda_c$	1.2	17.0 √	41.4 √	18.8 √
πN	0.06	0.07	0.07	0.2
$\chi_{c0}p$	0.9	0.004	0.02	0.002
$\eta_c p$	0.2	0.09	0.1	0.04
ρN	1.4	0.15	0.14	0.3
ωp	5.3	0.6	0.5	0.3
$\bar{D}\Sigma_c$	0.01	0.1	1.2	0.8
$\bar{D}\Sigma_c^*$	...	...	7.7	1.4
$\bar{D}\Lambda_c\pi$	11.6	...	...	...
Total	144.3	69.9	139.8	46.4

It is very important to study $P_c \rightarrow \bar{D}^*\Lambda$ & $\bar{D}\Lambda$!

LHCb pentaquark states vs Post-explanations

Consistent for $P_c^+(4380)$ to be a $\bar{D}\Sigma_c^*$ $(3/2^-)$ molecule with a large decay width to $\bar{D}^*\Lambda_c$

Consistent for $P_c^+(4450)$ to be a $\bar{D}^*\Sigma_c$ $(5/2^+)$ molecule

Problems:

1) Where are lower P_c $(1/2^-)$ states ?

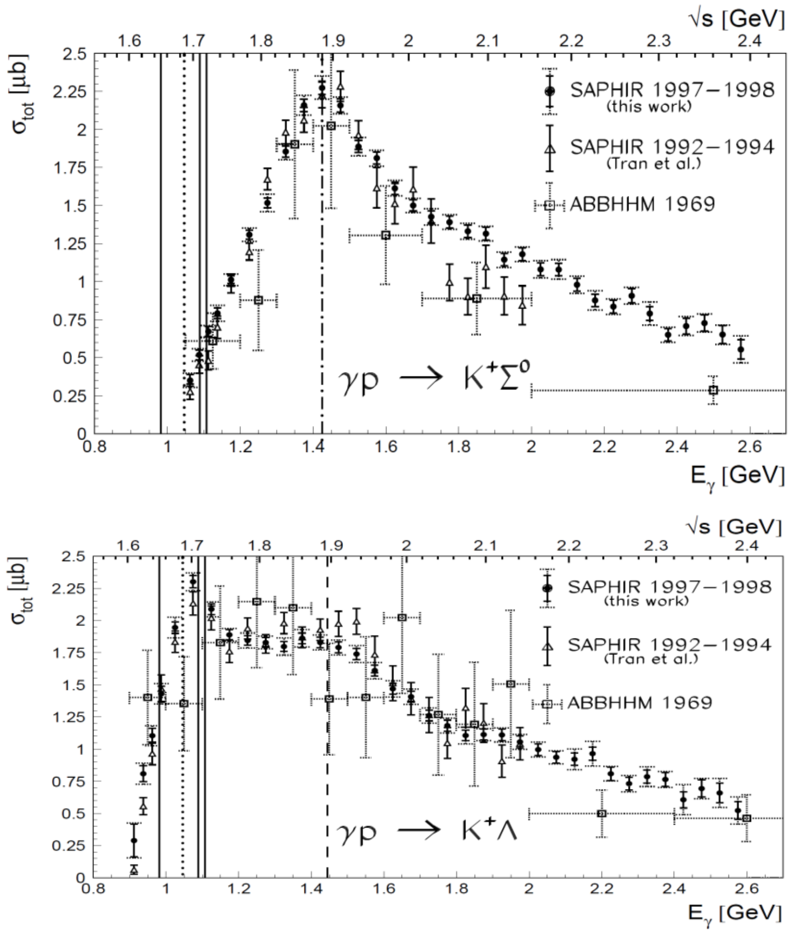
2) Where are predicted $\Lambda_{c\bar{c}}$ states ?

Many more pentaquarks are expected !

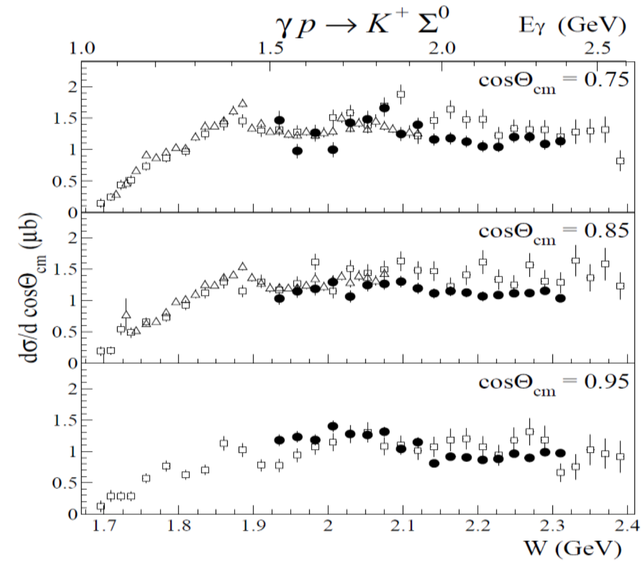
3. Strange & beauty partners of P_c states

Strangeness partners of P_c states: N*(1875) & N*(2080)

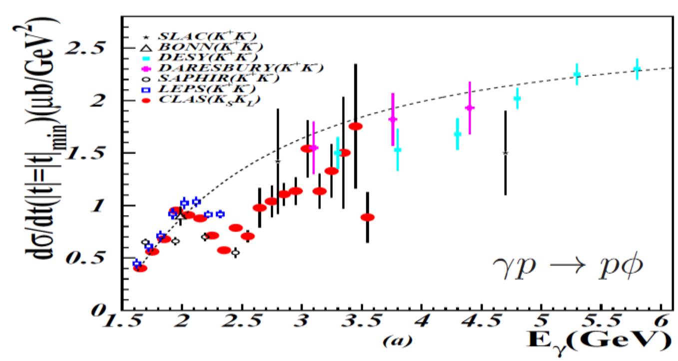
$K\Sigma^*$ ~1880 $K^*\Sigma$ ~ 2086



Glander, K.H. *et al.* EPJA19 (2004) 251-273

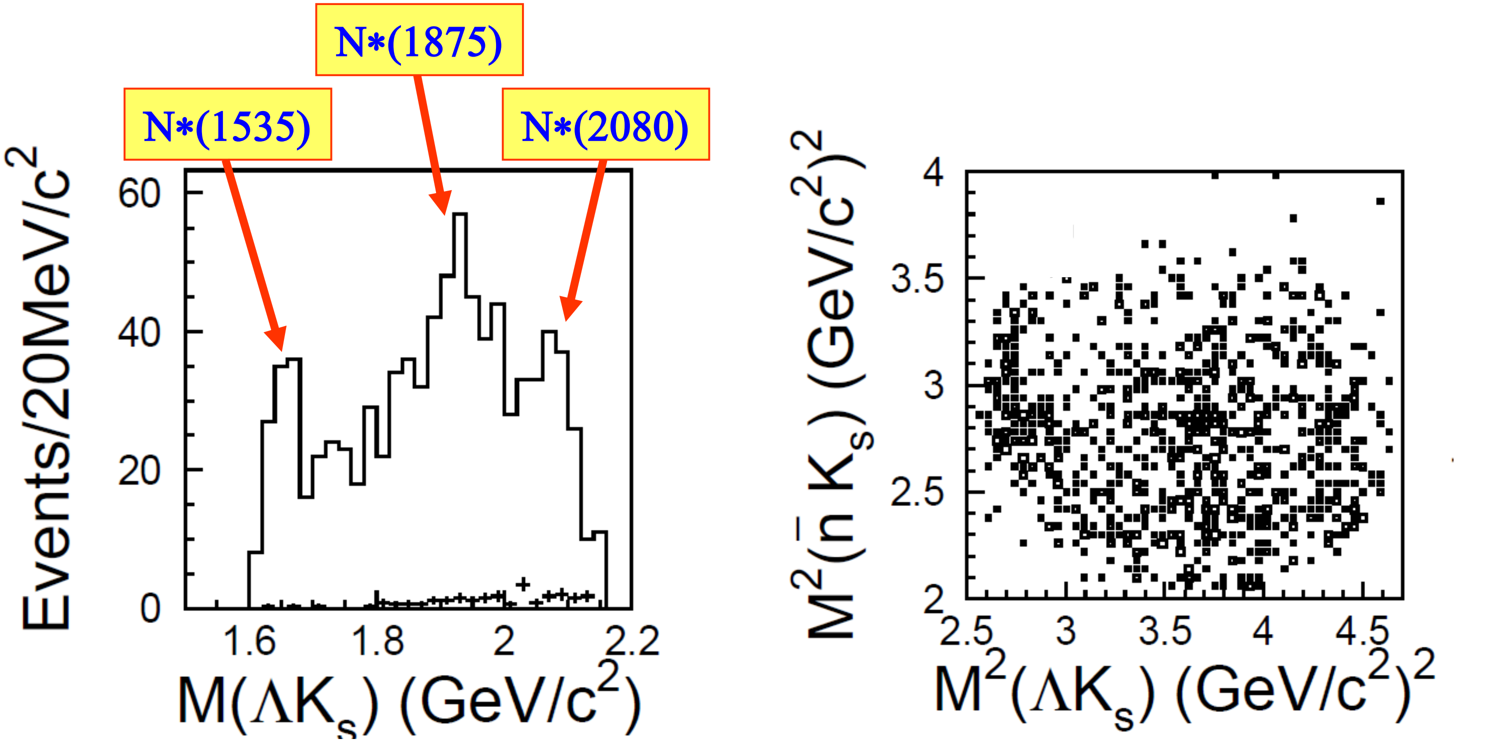


LEPS, PRC73 (2006) 035214



CLAS, PRC89 (2014) 055206

$N_{s\bar{s}}$ penta-quarks at BES ?!



$J/\psi \rightarrow nK_S^0\overline{\Lambda}$

BESII, Phys. Lett. B659 (2008) 789

Physics Letters B 709 (2012) 70–76

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Physics Letters B

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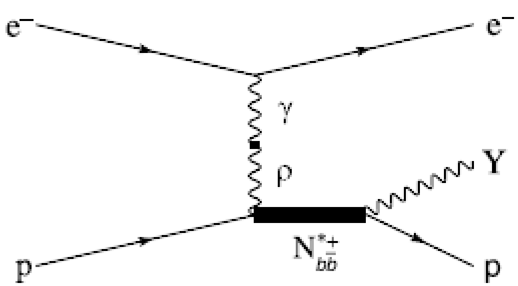
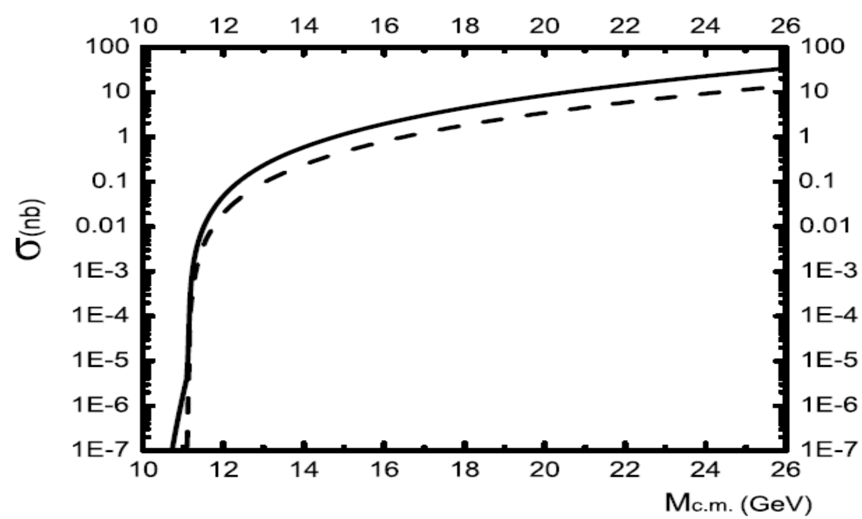
Prediction of super-heavy N^* and Λ^* resonances with hidden beauty

Jia-Jun Wu [a,*], Lu Zhao [a], B.S. Zou [a,b]

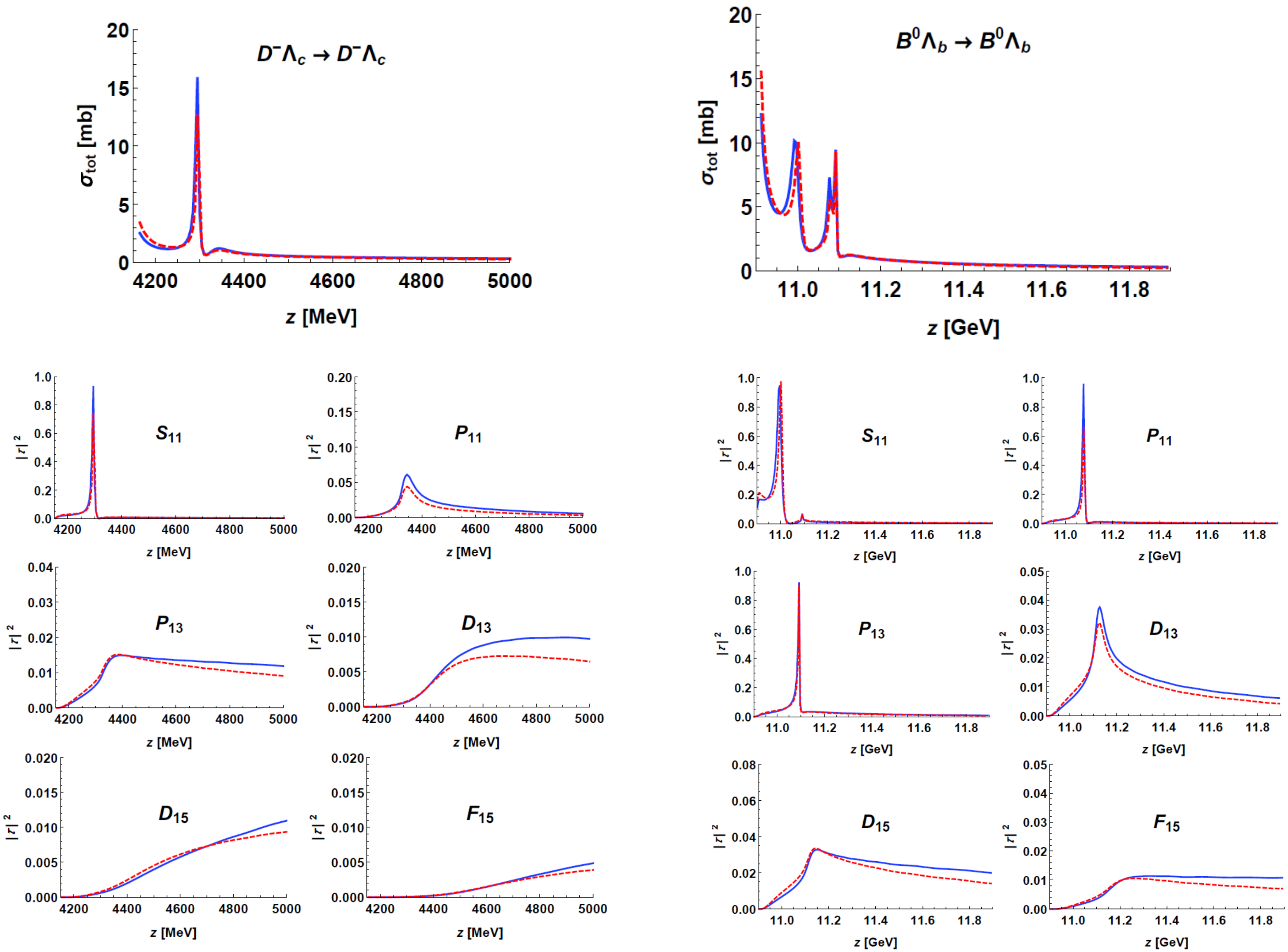
M (MeV)	Γ (MeV)	Γ_i (MeV)					
		πN	ηN	$\eta' N$	$K\Sigma$	$\eta_b N$	
11 052	1.38	0.10	0.21	0.11	0.42	0.52	$1/2^-$
		ρN	ωN	$K^*\Sigma$	ΥN		
11 100	1.33	0.09	0.30	0.39	0.51		$1/2^-$, $3/2^-$





$\bar{D}\Lambda_c - \bar{D}\Sigma_c$ and $B\Lambda_b - B\Sigma_b$ dynamical coupled channel study

C.W.Shen, Roechen, Meissner, Zou, CPC42(2018) 023106



More pentaquarks with hidden beauty than with hidden charm

Decay behavior of P_s & P_b pentaquark states

Y.H.Lin, C.W.Shen, B.S.Zou, ArXiv: 1805.06843

Mode	Widths (MeV)		
	$J^P = 3/2^-$		$J^P = 1/2^-$
	$N(1875)\ K\Sigma^*$	$N(2080)\ K^*\Sigma$	$N(2080)\ K^*\Sigma$
$N\sigma(500)$	2.6	0.05	0.3
πN	3.8	0.2	22.7
ρN	2.3	3.8	6.1
ωp	6.6	11.3	18.2
$K\Sigma$	0.03	1.4	9.1
$K\Lambda$	0.7	3.7	19.3
ηp	0.6	0.4	1.8
$\pi\Delta$	201.4	82.6	46.9
$K^*\Lambda$	-	2.4	7.9
ϕp	-	19.2	27.0
$K\Sigma^*$	-	7.3	1.3
$K\Lambda(1520)$	-	0.1	1.3
$K\Lambda(1405)$	-	8.0	8.8
$K\pi\Lambda$	10.1	-	-
$K\pi\Sigma$	-	41.3	46.1
Total	228.2	181.7	216.8

Mode	Widths (MeV)		
	$J^P = 3/2^-$		$J^P = 1/2^-$
	$B\Sigma_b^*$	$B^*\Sigma_b$	$B^*\Sigma_b$
$B^*\Lambda_b$	271.1	19.9	167.0
Υp	0.3	0.04	0.1
ρN	5.5	0.02	0.1
ωp	20.9	0.07	0.4
$B\Lambda_b$	-	7.3	135.9
$B\Sigma_b$	-	-	-
$\eta_b p$	0.02	0.0001	0.0009
$\chi_{b0} p$	1.4	0.0008	0.2
πN	0.7	0.005	0.003
$B\Sigma_b^*$	-	-	-
Total	299.9	27.4	303.8

Guidance for P_s & P_b search

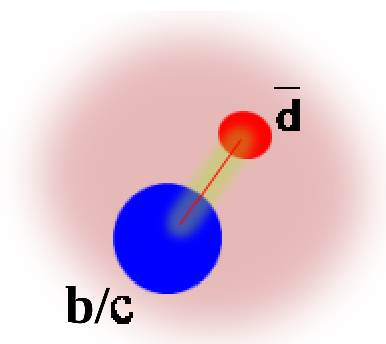
4. Prospects

- **my favorite strategy for hadron spectroscopy:**

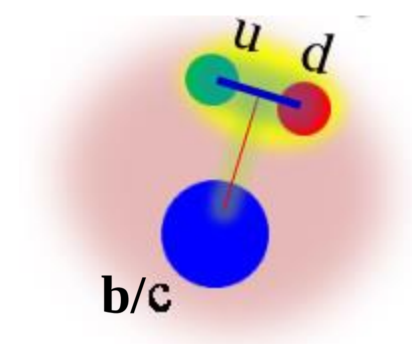
$\bar{c}cuud$ & $\bar{c}cuds$ → sss - $\bar{q}qsss$ → cqq - $\bar{q}qcqq$
→ hyperons → light baryons

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

s → c → b



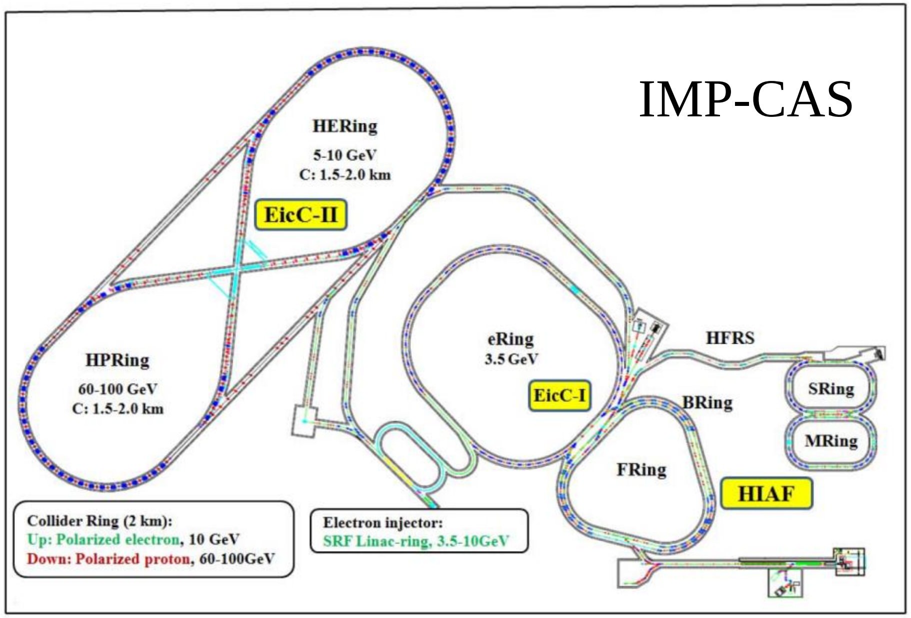
charm & beauty meson

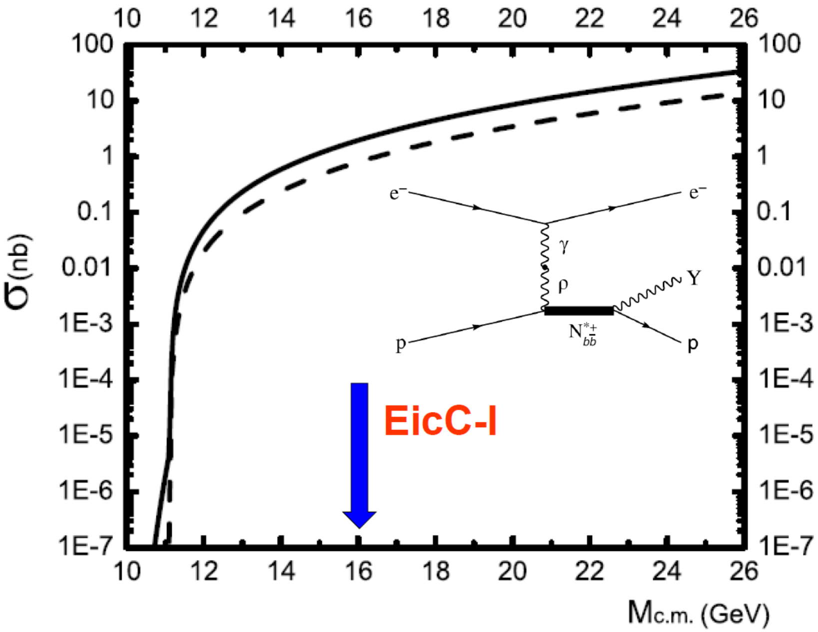


charm & beauty baryon

- New penta-quark spectroscopy provides a new ideal platform for understanding multiquark dynamics
- Further experimental confirmation and extension for whole penta-quark spectroscopy from γN, πN, KN, $e^+e^- \rightarrow \bar{\Lambda}_b \Lambda_b$, etc.

ep/γp@JLab, π10/K10@JPARC, BelleII, BESIII, Eic/EicC, PANDA@FAIR, STCF etc. may play important role here!



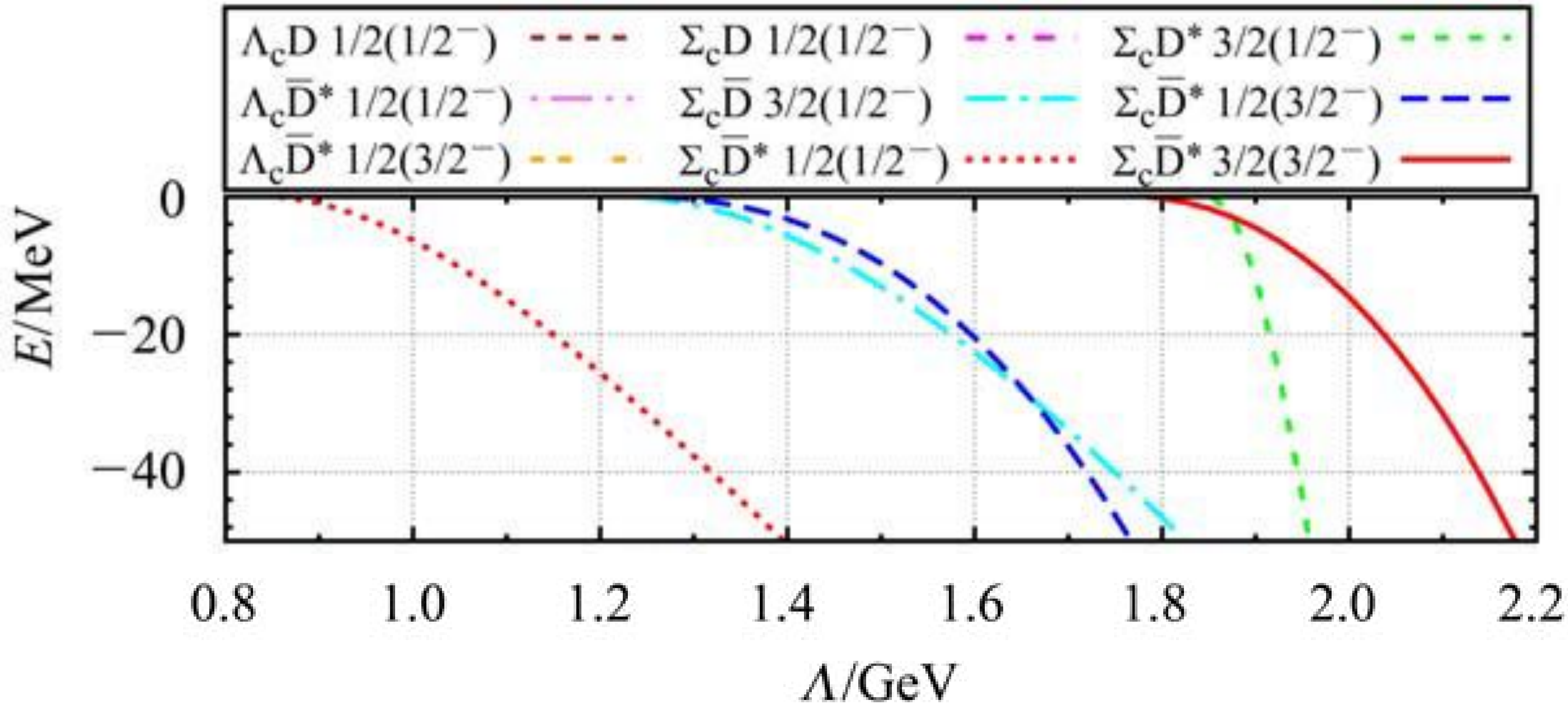


Thank you for your attention!

[2] Z.C.Yang, Z.F.Sun, J.He, X.Liu, S.L.Zhu, "The possible hidden-charm molecular baryons composed of anti-charmed meson and charmed baryon," Chin. Phys. C36 (2012) 6

Schoedinger Equation method with π, η, ρ, ω, σ exchanges:

$\bar{D}^*\Sigma_c$ ($3/2^-$) N* state -- 4360 ~ 4460 MeV



[3] C.W.Xiao, J.Nieves, E.Oset, "Combining heavy quark spin and local hidden gauge symmetries in the dynamical generation of hidden charm baryons", PRD 88 (2013) 056012

3 $J^P = 3/2^-$ P_c^+ states : $\bar{D}\Sigma_c^*$, $\bar{D}^*\Sigma_c$, $\bar{D}^*\Sigma_c^*$ states

TABLE II. The coupling constants to various channels for certain poles in the $J = 3/2$, $I = 1/2$ sector.

$4334.45 + i19.41$	$J/\psi N$	$\bar{D}^*\Lambda_c$	$\bar{D}^*\Sigma_c$	$\bar{D}\Sigma_c^*$	$\bar{D}^*\Sigma_c^*$
g_i	$1.31 - i0.18$	$0.16 - i0.23$	$0.20 - i0.48$	$2.97 - i0.36$	$0.24 - i0.76$
$\|g_i\|$	1.32	0.28	0.52	2.99	0.80

$4417.04 + i4.11$	$J/\psi N$	$\bar{D}^*\Lambda_c$	$\bar{D}^*\Sigma_c$	$\bar{D}\Sigma_c^*$	$\bar{D}^*\Sigma_c^*$
g_i	$0.53 - i0.07$	$0.08 - i0.07$	$2.81 - i0.07$	$0.12 - i0.10$	$0.11 - i0.51$
$\|g_i\|$	0.53	0.11	2.81	0.16	0.52

$4481.04 + i17.38$	$J/\psi N$	$\bar{D}^*\Lambda_c$	$\bar{D}^*\Sigma_c$	$\bar{D}\Sigma_c^*$	$\bar{D}^*\Sigma_c^*$
g_i	$1.05 + i0.10$	$0.18 - i0.09$	$0.12 - i0.10$	$0.22 - i0.05$	$2.84 - i0.34$
$\|g_i\|$	1.05	0.20	0.16	0.22	2.86

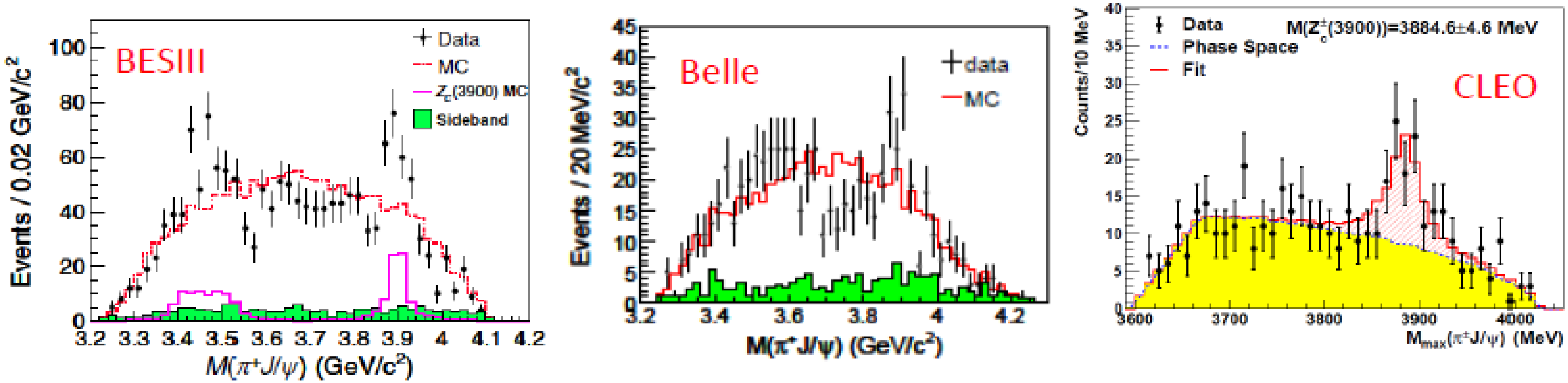
a $J^P = 5/2^-$ P_c^+ state : $\bar{D}^*\Sigma_c^*$ bound states at 4487 MeV

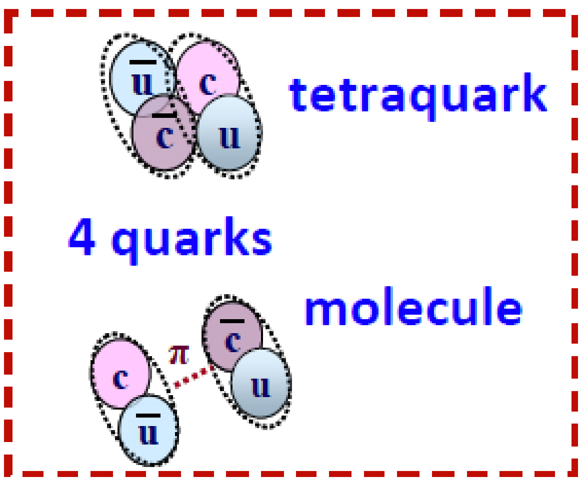
“Y(4260)的结构以及带电Zc(3900)的产生”

a

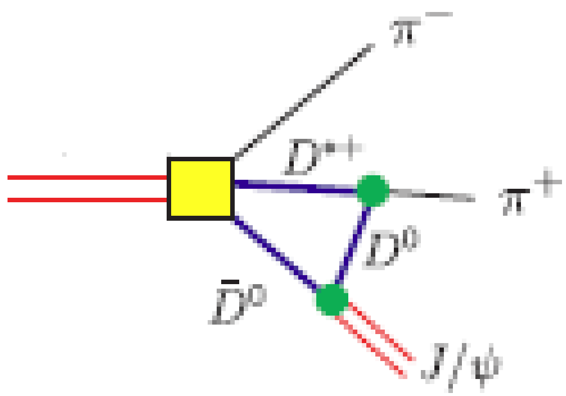
PRL 110, 252001 (2013) PHYSICAL REVIEW LETTERS week ending 21 JUNE 2013

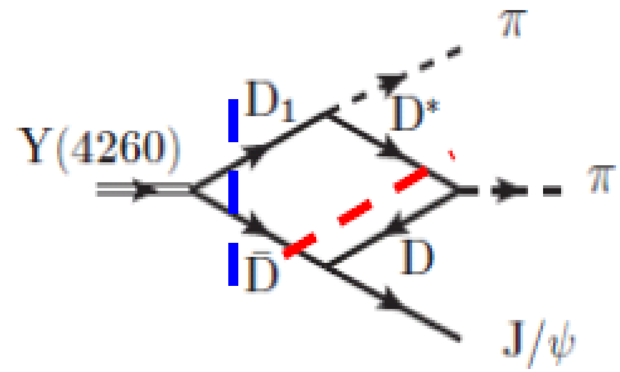
Observation of a Charged Charmoniumlike Structure in $e^+e^- \to \pi^+\pi^- J/\psi$ at $\sqrt{s} = 4.26$ GeV





Exotic!





D.Y.Chen, X.Liu, PRD84(2011)034032

Q.Wang,C.Hanhart,Q.Zhao PRL111(2013)132003