



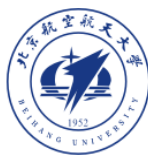
北京航空航天大学
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Three body mesonic and baryonic molecules from heavy quark and chiral symmetries

Lisheng Geng @ Beihang U.

第十八届全国中高能核物理大会暨第十二届全国中高能核物理专题研讨会
2019. 06. 21~25日, 湖南长沙

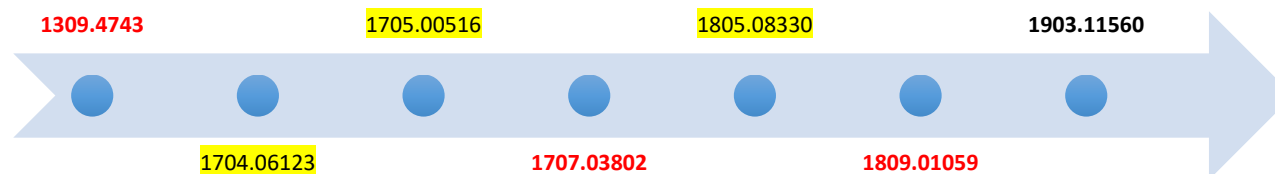


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DK、DDK、DDDK molecules --new forms of matter

Lisheng Geng @ Beihang U.



+some preliminary results ₂

Contents

- Motivation: new types of clusters of color singlets in addition to nuclei
- $Ds0^*(2317)$ and $Ds1(2460)$ as DK/D^*K molecules: theory & lattice
- Explicit studies of the DDK & $DDDK$ systems
- A $K^*(4307)$ with hidden charm as $KX(3872)/Z_c(3900)$ molecule
- Summary and outlook

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- Motivation: new types of clusters of color singlets in addition to nuclei
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IUPAC Periodic Table of the Elements

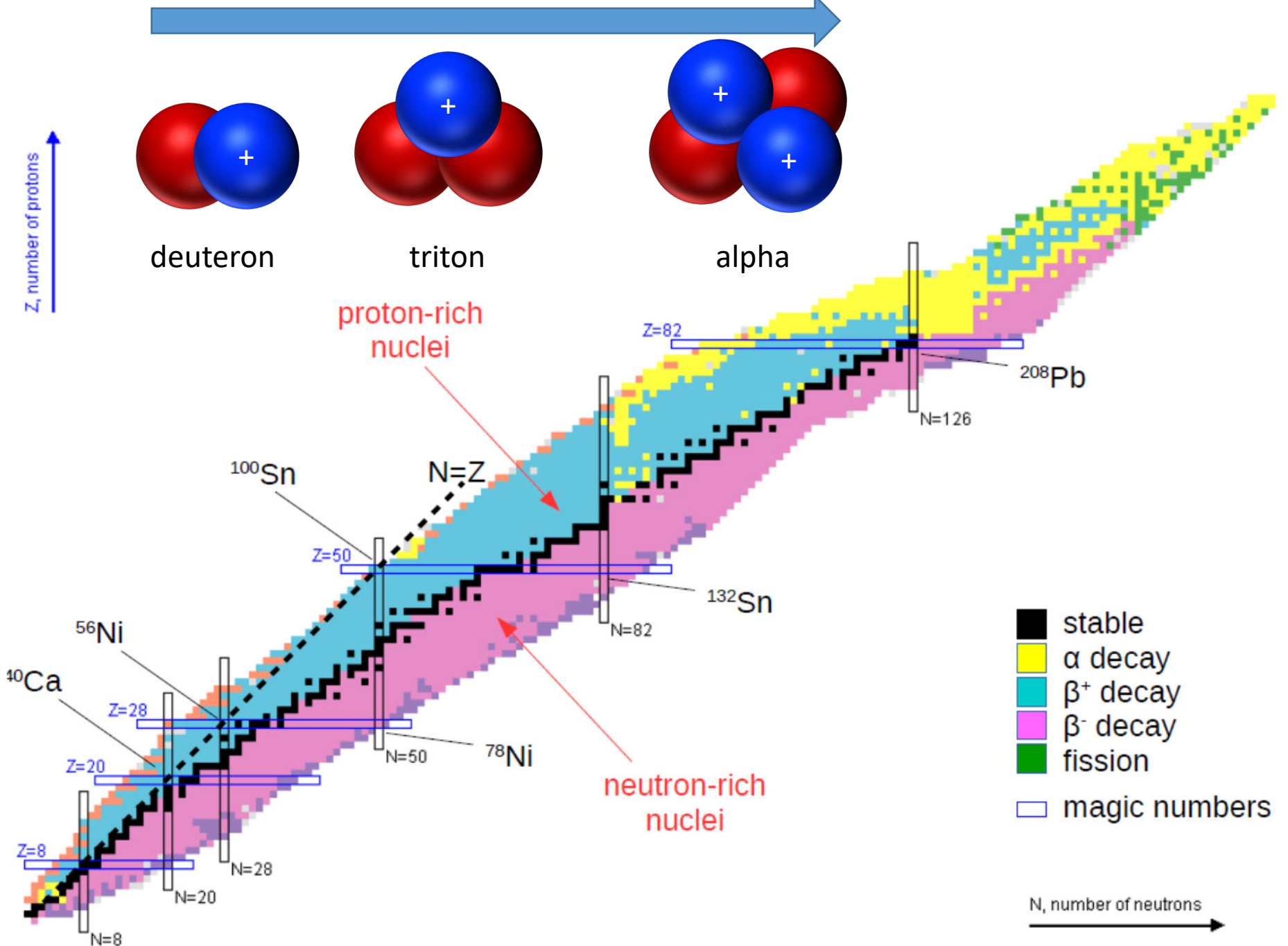
1 H hydrogen (1.00784, 1.00823)																	18 He helium 4.0026																																									
3 Li lithium (6.941, 6.971)	4 Be beryllium 9.0122	<div>Key:</div> <div> <div>atomic number</div> <div>Symbol</div> <div>element name</div> <div>element group</div> <div>element weight</div> </div>										5 B boron (10.81, 10.83)	6 C carbon (12.01, 12.012)	7 N nitrogen (14.006, 14.007)	8 O oxygen (15.999, 16.003)	9 F fluorine (18.998, 19.003)	10 Ne neon (20.180, 20.183)																																									
11 Na sodium 22.990	12 Mg magnesium (24.305, 24.307)	13 Al aluminum (26.982, 26.987)	14 Si silicon (28.086, 28.089)	15 P phosphorus (30.974, 30.976)	16 S sulfur (32.06, 32.07)	17 Cl chlorine (35.45, 35.47)	18 Ar argon (39.948, 39.963)	19 K potassium 39.098	20 Ca calcium 40.078	21 Sc scandium 44.956	22 Ti titanium 47.88	23 V vanadium 50.942	24 Cr chromium 51.996	25 Mn manganese 54.938	26 Fe iron 55.845	27 Co cobalt 58.933	28 Ni nickel 58.69	29 Cu copper 63.546	30 Zn zinc 65.38	31 Ga gallium 69.723	32 Ge germanium 72.63	33 As arsenic 74.922	34 Se selenium 78.96	35 Br bromine 79.904	36 Kr krypton 83.798																																	
37 Rb rubidium 85.468	38 Sr strontium 87.62	39 Y yttrium 88.906	40 Zr zirconium 91.224	41 Nb niobium 92.906	42 Mo molybdenum 95.94	43 Tc technetium 98.906	44 Ru ruthenium 101.07	45 Rh rhodium 102.91	46 Pd palladium 106.42	47 Ag silver 107.87	48 Cd cadmium 112.41	49 In indium 114.82	50 Sn tin 118.71	51 Sb antimony 121.76	52 Te tellurium 127.60	53 I iodine 126.90	54 Xe xenon 131.29	55 Cs cesium 132.91	56 Ba barium 137.33	57-71 lanthanides				72 Hf hafnium 178.49	73 Ta tantalum 180.95	74 W tungsten 183.84	75 Re rhenium 186.21	76 Os osmium 190.23	77 Ir iridium 192.22	78 Pt platinum 195.08	79 Au gold 196.97	80 Hg mercury 200.59	81 Tl thallium 204.38	82 Pb lead 207.2	83 Bi bismuth 208.98	84 Po polonium 209	85 At astatine 210	86 Rn radon 222	87-118 actinides	119 Fr francium 223	120 Ra radium 226	121-152 actinides	153 La lanthanum 138.905	57 La lanthanum 138.905	58 Ce cerium 140.12	59 Pr praseodymium 140.91	60 Nd neodymium 144.24	61 Pm promethium 144.912	62 Sm samarium 150.36	63 Eu europium 151.96	64 Gd gadolinium 157.25	65 Tb terbium 158.93	66 Dy dysprosium 162.50	67 Ho holmium 164.93	68 Er erbium 167.26	69 Tm thulium 168.93	70 Yb ytterbium 173.05	71 Lu lutetium 174.967
89 Ac actinium 227.03	90 Th thorium 232.04	91 Pa protactinium 231.04	92 U uranium 238.03	93 Np neptunium 237.05	94 Pu plutonium 244.06	95 Am americium 243.06	96 Cm curium 247.07	97 Bk berkelium 247.07	98 Cf californium 251.08	99 Es einsteinium 252.08	100 Fm fermium 257.10	101 Md mendelevium 258.10	102 No nobelium 259.10	103 Lr lawrencium 262.10																																												

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AND APPLIED CHEMISTRY

For notes and updates to this table, see www.iupac.org. This version is dated 1 December 2018.
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Nucleons are the essential building blocks of Matter!

Adapted from LHC the guide



The existence of triton can be inferred from that of deuteron with reasonable confidence

“In nature, are there other clusters of color singlet hadrons, similar to atomic nuclei, bound by the residual strong force? ? ? ”

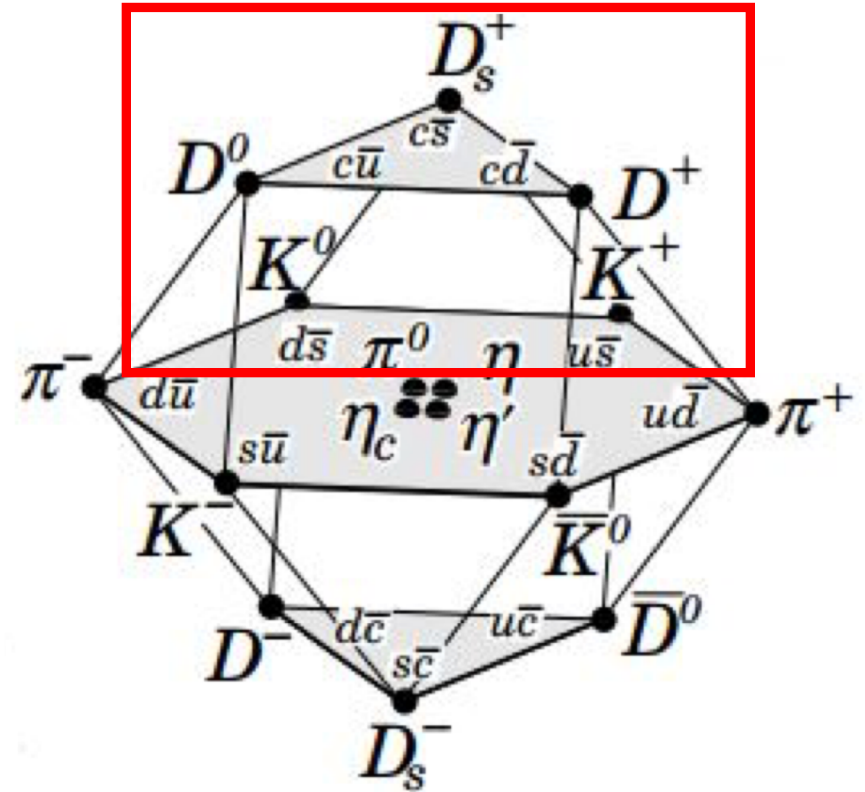


DK/DDDK molecules???

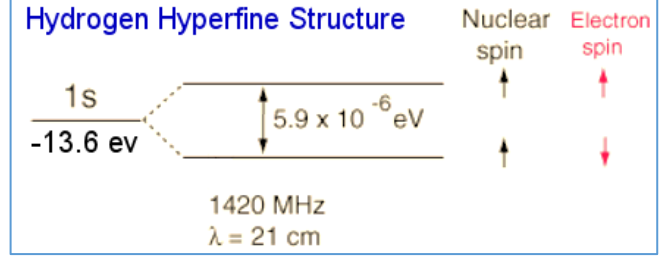
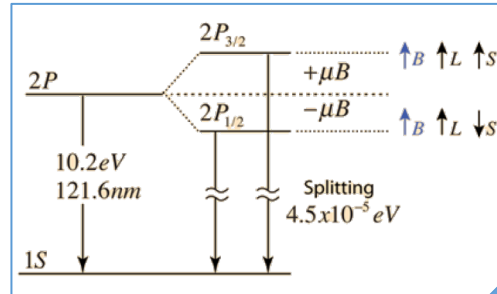
Standard Model of Elementary Particles

three generations of matter (fermions)			interactions / force carriers (bosons)	
I	II	III		
mass: $\approx 2.2 \text{ MeV}/c^2$ charge: $\frac{2}{3}$ spin: $\frac{1}{2}$ u up	mass: $\approx 1.28 \text{ GeV}/c^2$ charge: $\frac{2}{3}$ spin: $\frac{1}{2}$ c charm	mass: $\approx 173.1 \text{ GeV}/c^2$ charge: $\frac{2}{3}$ spin: $\frac{1}{2}$ t top	mass: 0 charge: 0 spin: 1 g gluon	mass: $\approx 125.09 \text{ GeV}/c^2$ charge: 0 spin: 0 H higgs
mass: $\approx 4.7 \text{ MeV}/c^2$ charge: $-\frac{1}{3}$ spin: $\frac{1}{2}$ d down	mass: $\approx 96 \text{ MeV}/c^2$ charge: $-\frac{1}{3}$ spin: $\frac{1}{2}$ s strange	mass: $\approx 4.18 \text{ GeV}/c^2$ charge: $-\frac{1}{3}$ spin: $\frac{1}{2}$ b bottom	mass: 0 charge: 0 spin: 1 γ photon	
mass: $\approx 0.511 \text{ MeV}/c^2$ charge: -1 spin: $\frac{1}{2}$ e electron	mass: $\approx 105.66 \text{ MeV}/c^2$ charge: -1 spin: $\frac{1}{2}$ μ muon	mass: $\approx 1.7768 \text{ GeV}/c^2$ charge: -1 spin: $\frac{1}{2}$ τ tau	mass: $\approx 91.19 \text{ GeV}/c^2$ charge: 0 spin: 1 Z Z boson	
mass: $< 2.2 \text{ eV}/c^2$ charge: 0 spin: $\frac{1}{2}$ ν_e electron neutrino	mass: $< 1.7 \text{ MeV}/c^2$ charge: 0 spin: $\frac{1}{2}$ ν_μ muon neutrino	mass: $< 15.5 \text{ MeV}/c^2$ charge: 0 spin: $\frac{1}{2}$ ν_τ tau neutrino	mass: $\approx 80.39 \text{ GeV}/c^2$ charge: ± 1 spin: 1 W W boson	

QUARKS (left side of fermion table)
LEPTONS (left side of fermion table)
SCALAR BOSONS (right side of boson table)
GAUGE BOSONS VECTOR BOSONS (right side of boson table)



Why spectroscopy—Atomic



$$\frac{1}{\lambda_{\text{vac}}} = R \left(\frac{1}{n_1^2} - \frac{1}{n_2^2} \right)$$

Fine structure

Hyperfine structure



Johannes Rydberg

Rydberg formula



Niels Henrik David Bohr



Edward W. Morley



Arnold Sommerfeld



Albert Abraham Michelson



Wolfgang Pauli

Single particle motion



10

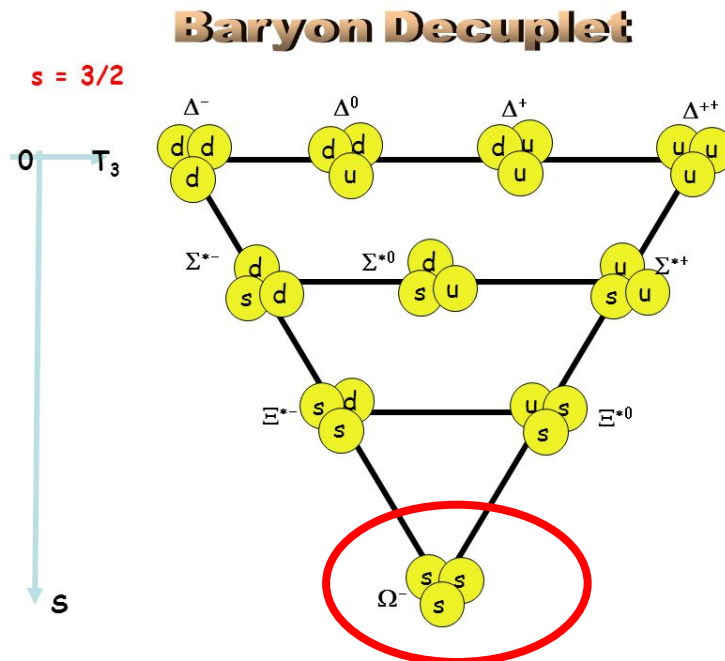
Why spectroscopy—particle/hadron



Murray Gell-Mann



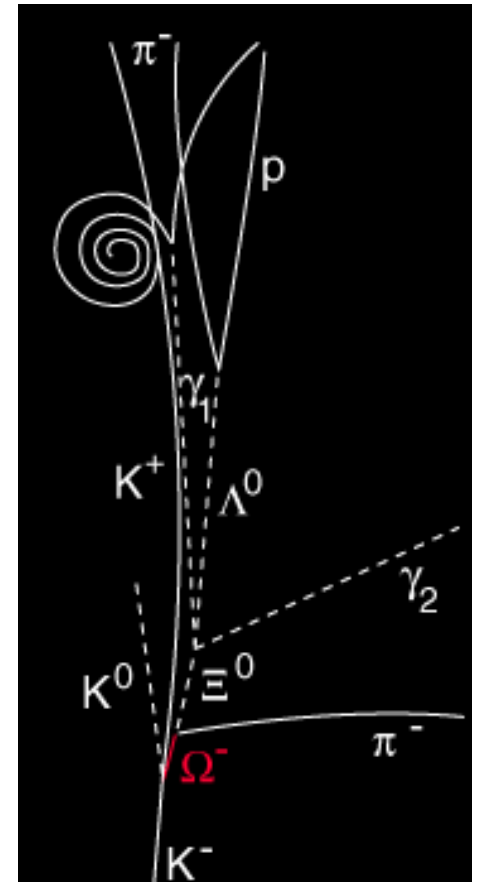
Yuval Ne'eman.



Eightfold
way

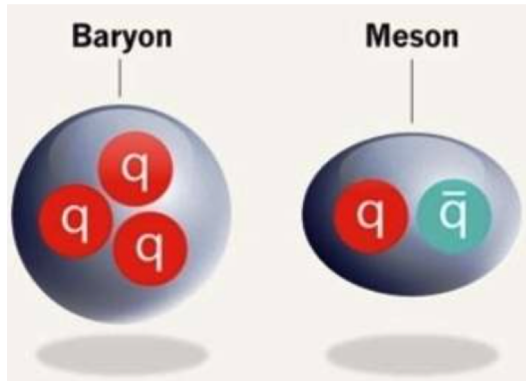
Quark
model

QCD/SM



V. E. Barnes et al., Phys. Rev. Lett. 12, 204 (1964)

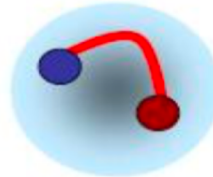
Why spectroscopy—particle/hadron



In the **naïve quark model**

In principle,
QCD **allows**

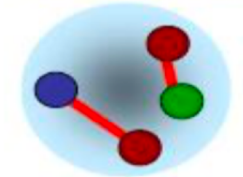
Hybrid



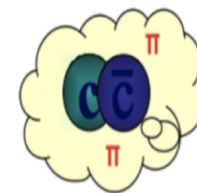
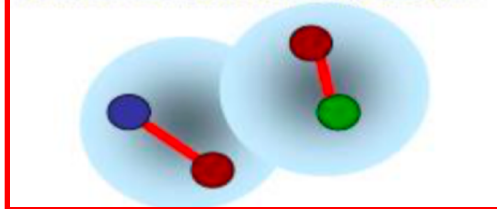
Glueball



Tetraquark

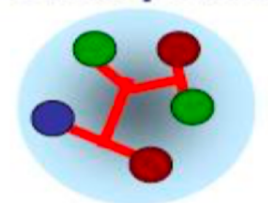


Hadronic molecule



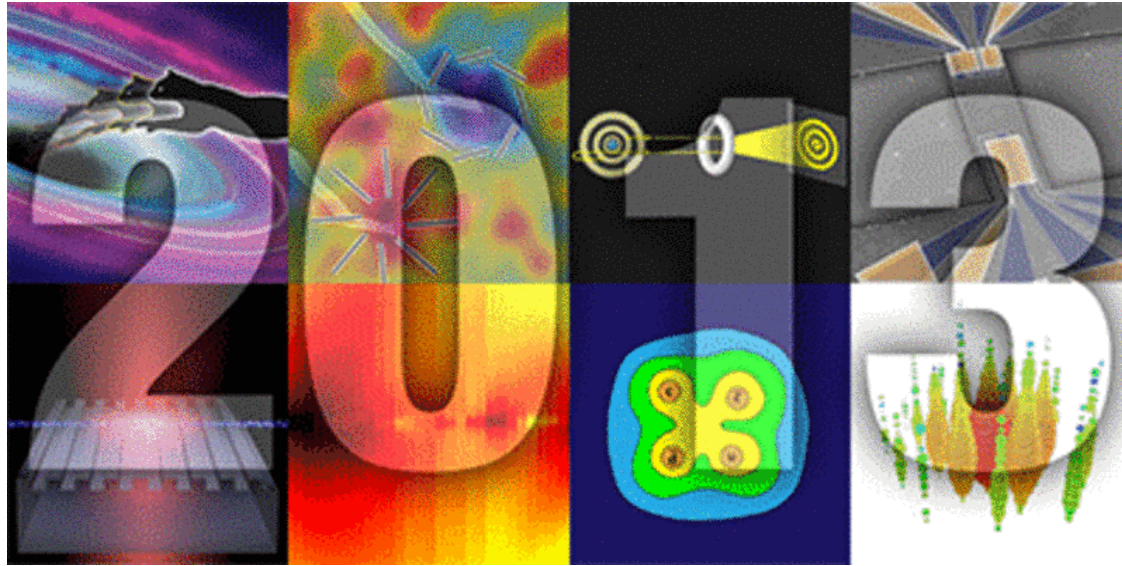
Hadro-
quarkonium

Pentaquark



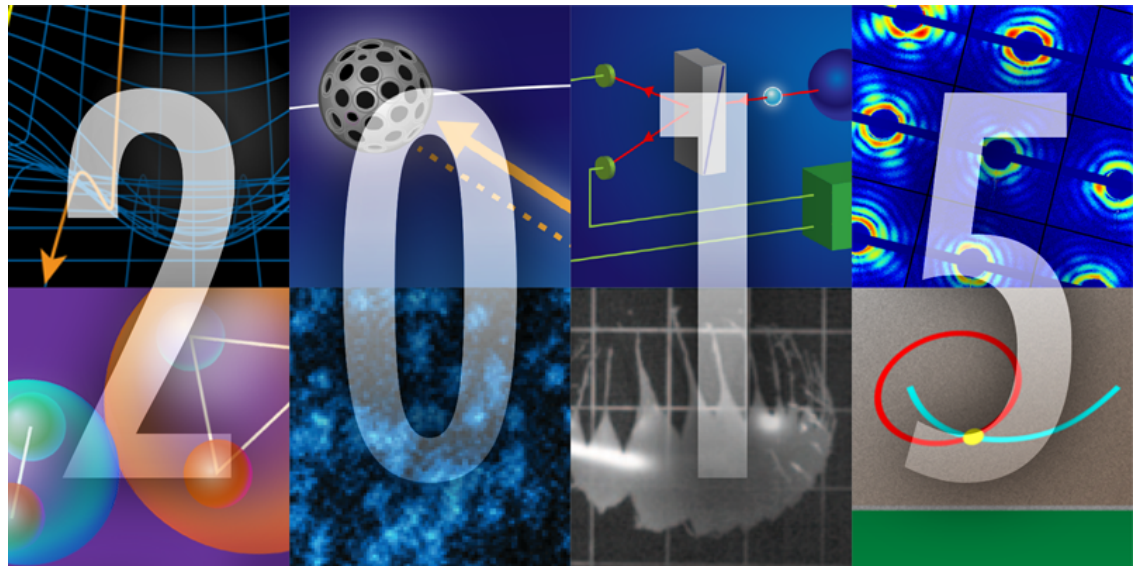
Highlights of the year

the research covered in Physics that **really made waves in and beyond the physics community.**



Four-Quark Matter

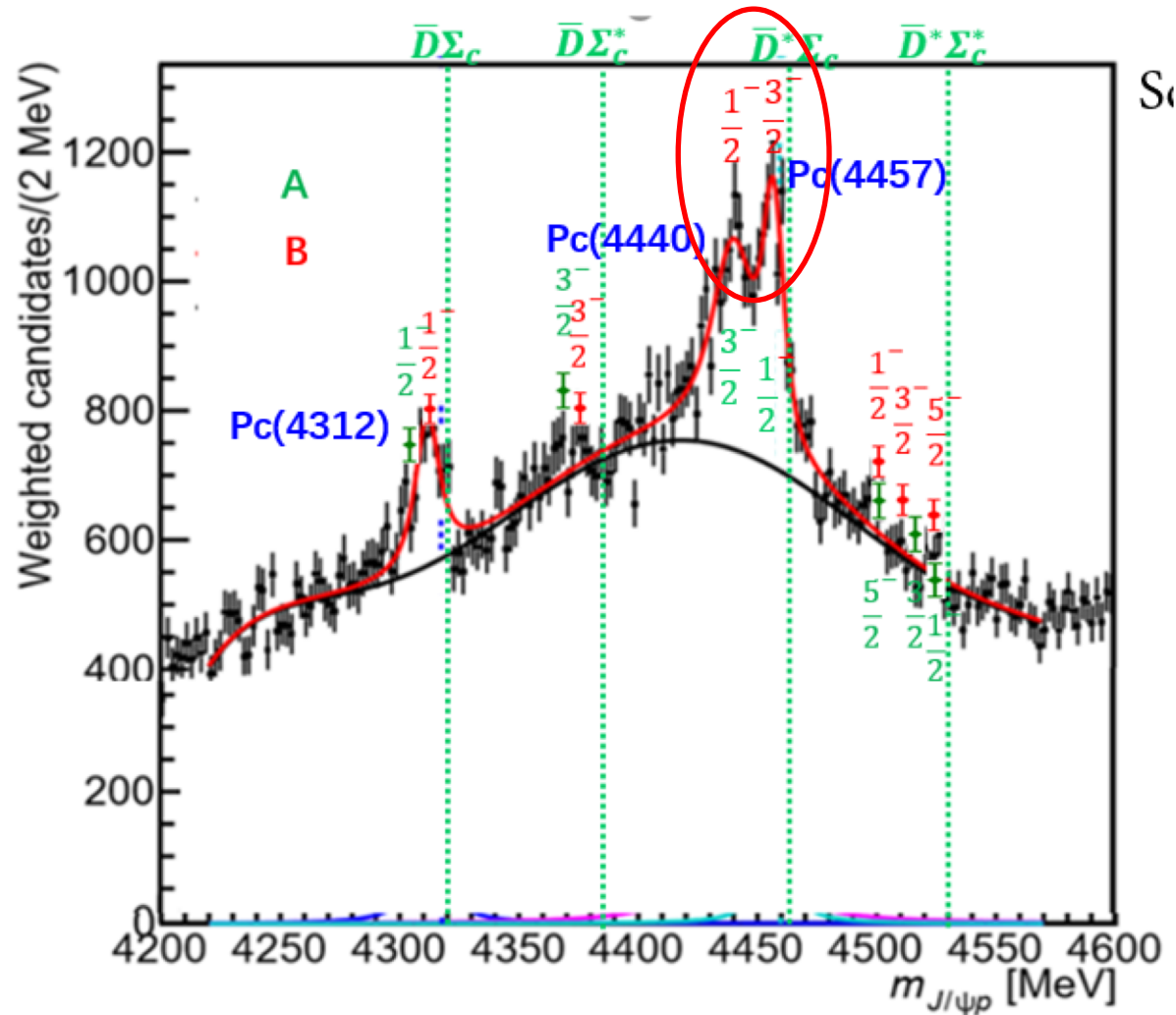
Particle High Five



Latest LHCb discovery:



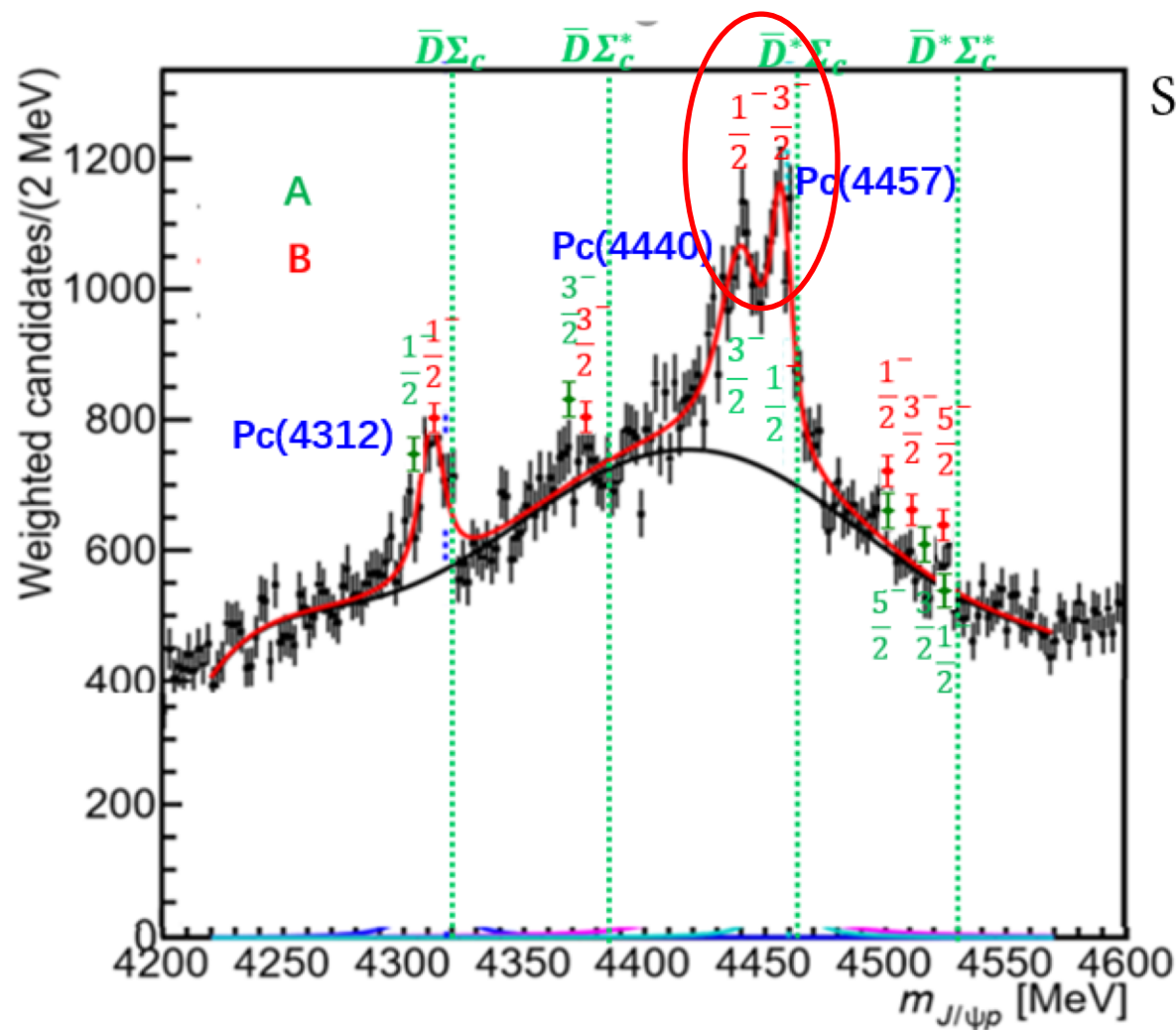
Fine structure observed by LHCb, 1904.03947



Latest LHCb discovery:



Fine structure observed by LHCb, 1904.03947



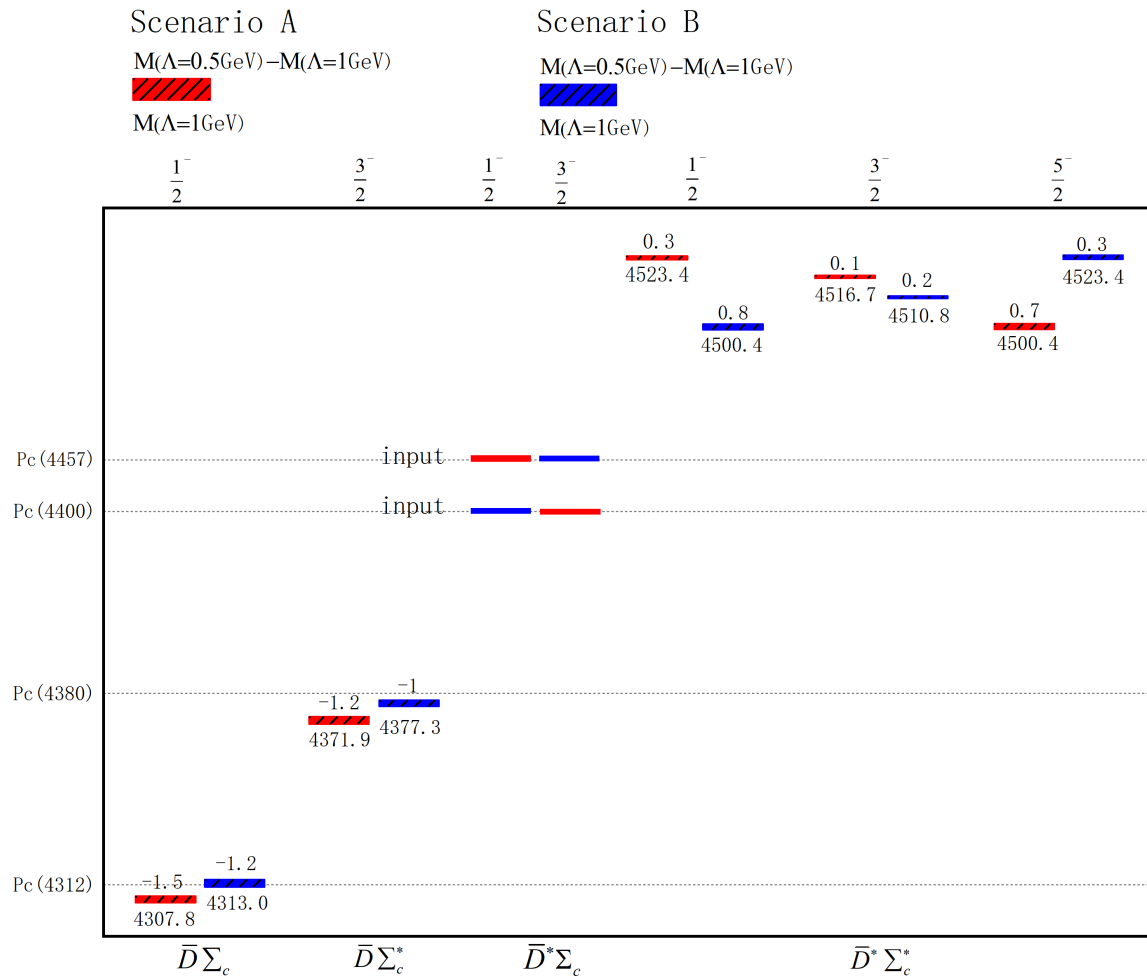
S

- 09:00 **Pentaquark theory overview 30'**
Speaker: 邹冰松 (中国科学院高能物理研究所)
- 09:30 **LHCb 上强子谱学的实验进展 30'**
Speaker: 张黎明 (清华大学)
- 10:00 **Pentaquark and tetraquark states 30'**
Speaker: 陈伟 (University of Saskatchewan)
- 11:50 **近阈共振结构与强子分子态 30'**
Speaker: 何军 (Nanjing Normal University)

孟璐
刘明珠
肖楮文
刘雪杰
...

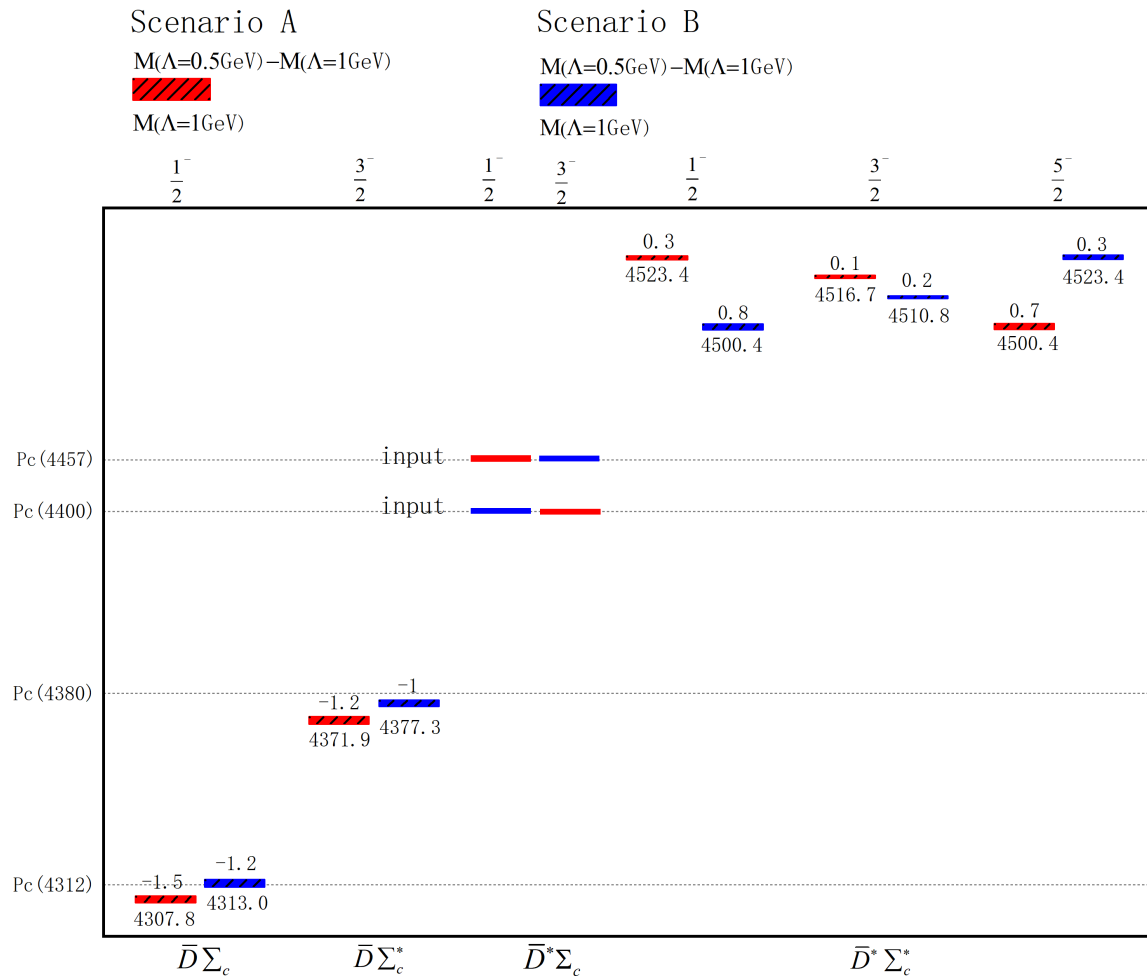
Emergence of a complete heavy-quark spin symmetry multiplet

1903.11560



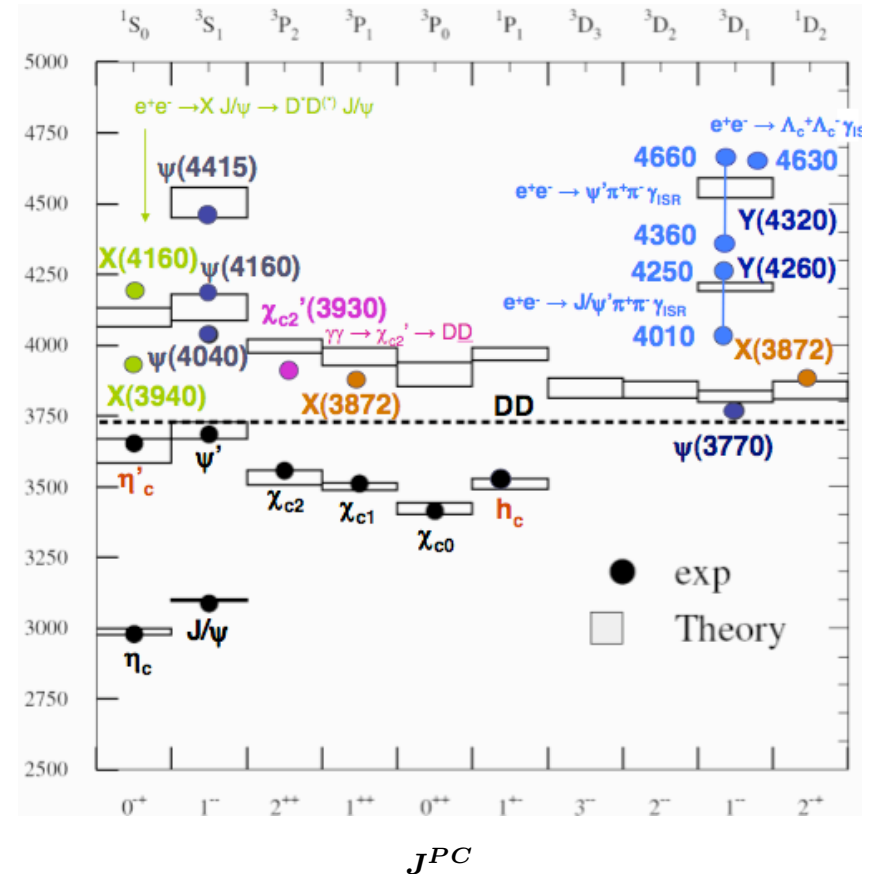
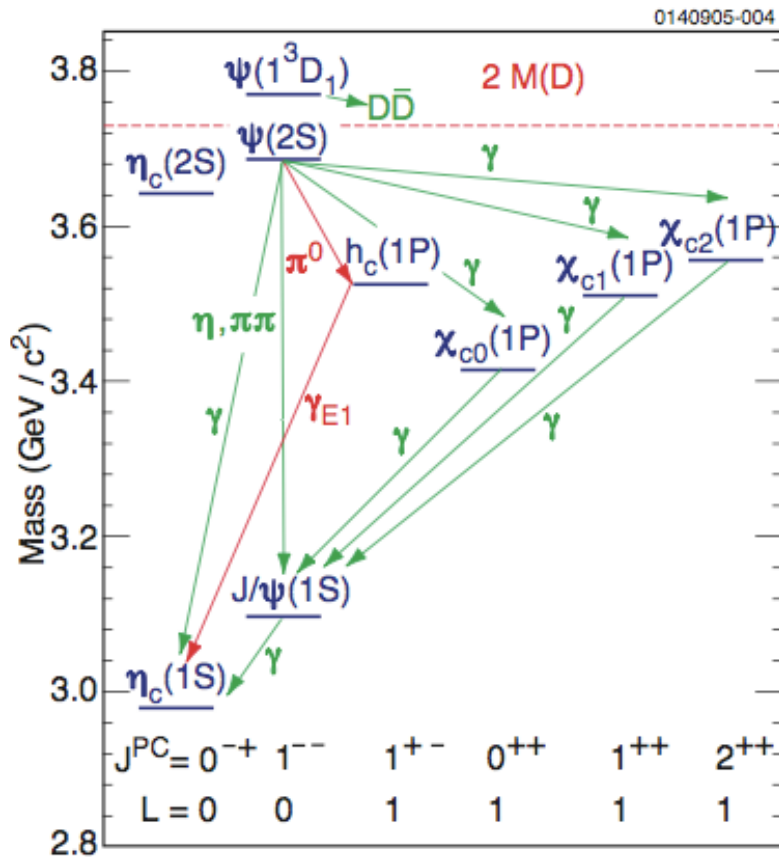
Emergence of a complete heavy-quark spin symmetry multiplet

1903.11560



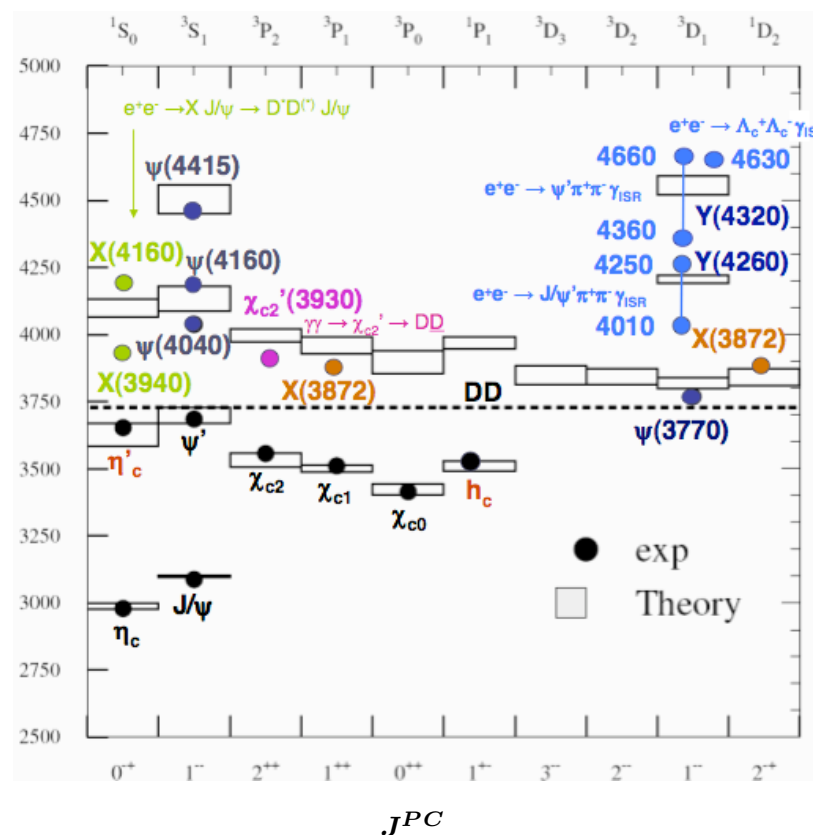
三楼1 号厅, 周日下午18: 05, 刘明珠

Charmonium spectroscopy before/after B factories



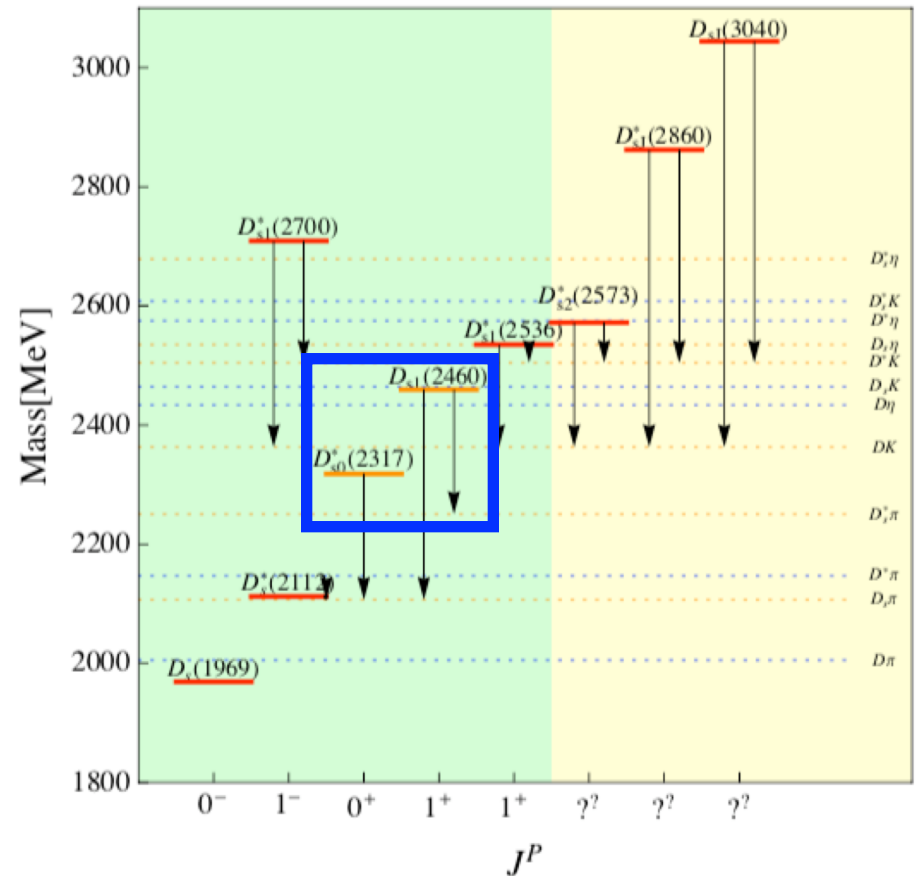
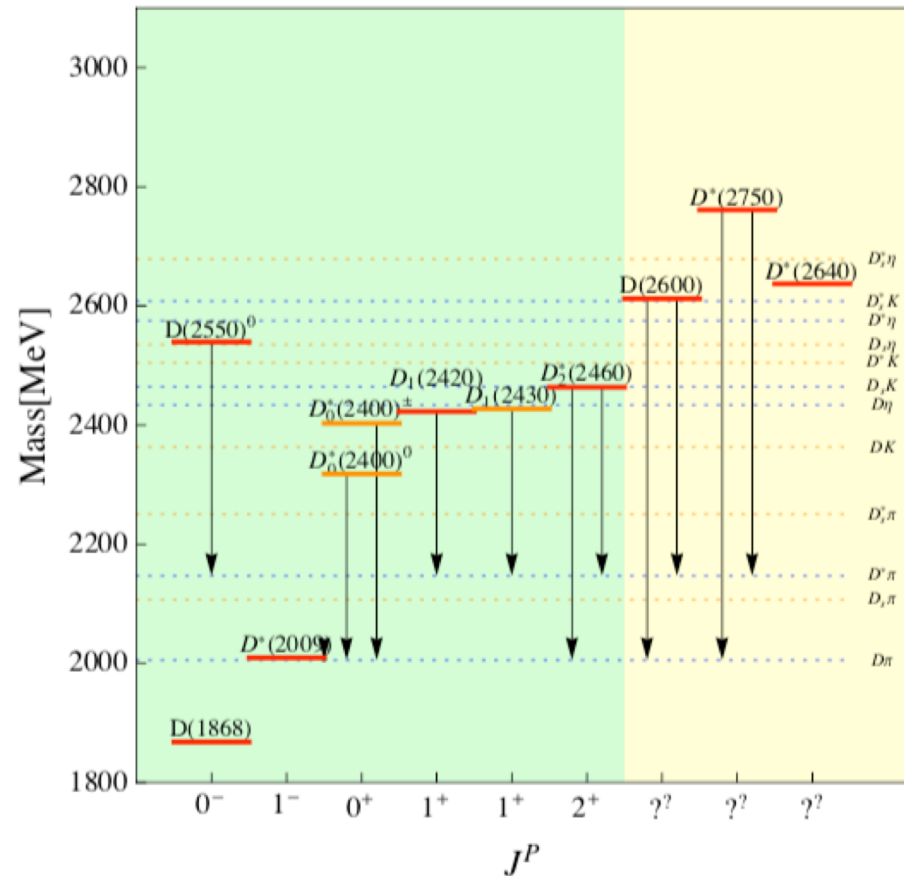
- A lot of new states, but the nature of some states are not well understood, e.g. **Y(4260)**, **X(3872)**, **Z_c(3900)**
- In complete contrast to the before-B-factory period, when potential models worked quite well.

Coupled channel effects?



Channel	Threshold Energy (MeV)
$D^0 \bar{D}^0$	3729.4
$D^+ D^-$	3738.8
$D^0 \bar{D}^{*0}$ or D^{*+}	3871.5
$\rho^0 J/\psi$	3872.7
$D^\pm D^{*\mp}$	3879.5
$\omega^0 J/\psi$	3879.6
$D_s^+ D_s^-$	3936.2
$D^{*0} \bar{D}^{*0}$	4013.6
$D^{*+} D^{*-}$	4020.2
$\eta' J/\psi$	4054.7
$f^0 J/\psi$	≈ 4077
$D_s^+ \bar{D}_s^{*-}$ or D_s^{*-}	4080.0
$a^0 J/\psi$	4081.6
$\varphi^0 J/\psi$	4116.4
$D_s^{*+} D_s^{*-}$	4223.8

Open charm systems

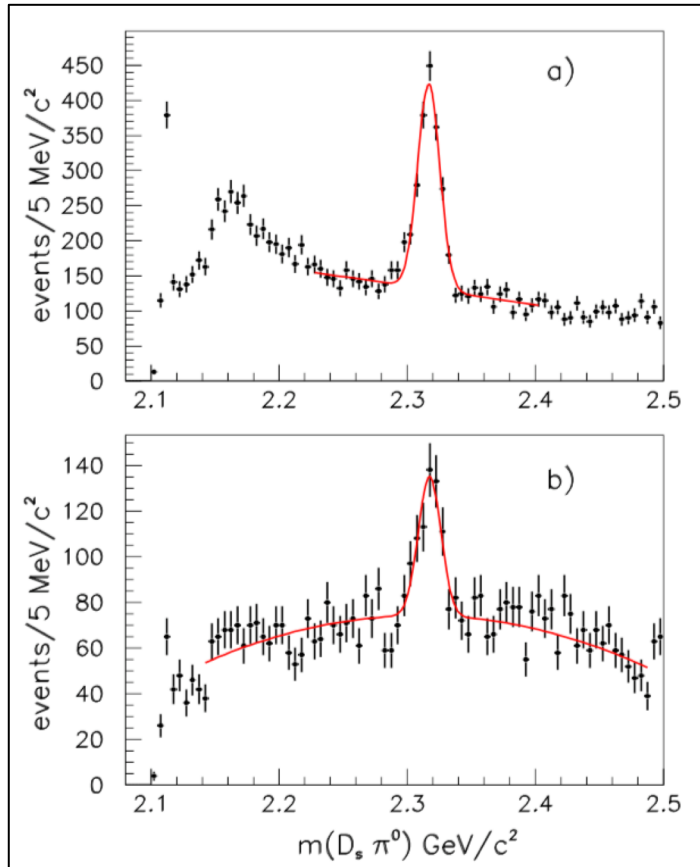


$D_{s0}^*(2317)$

$D_{s1}(2460)$

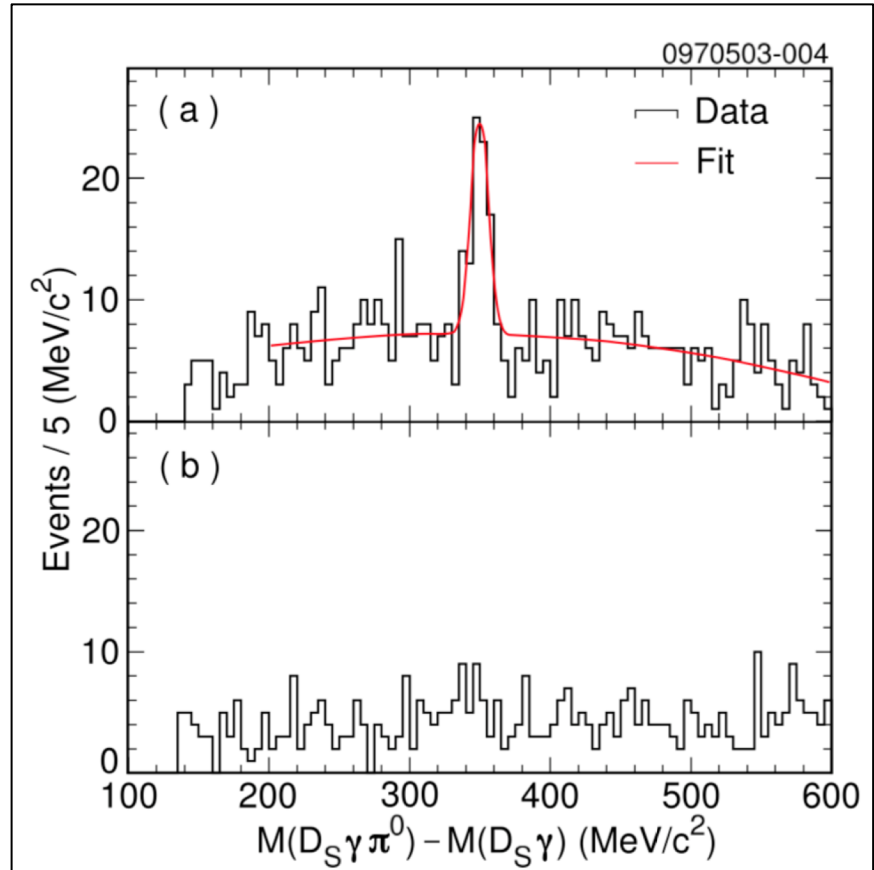
Two peculiar states

Ds0*(2317)



BaBar PRL90,242001(2003)

Ds1(2460)



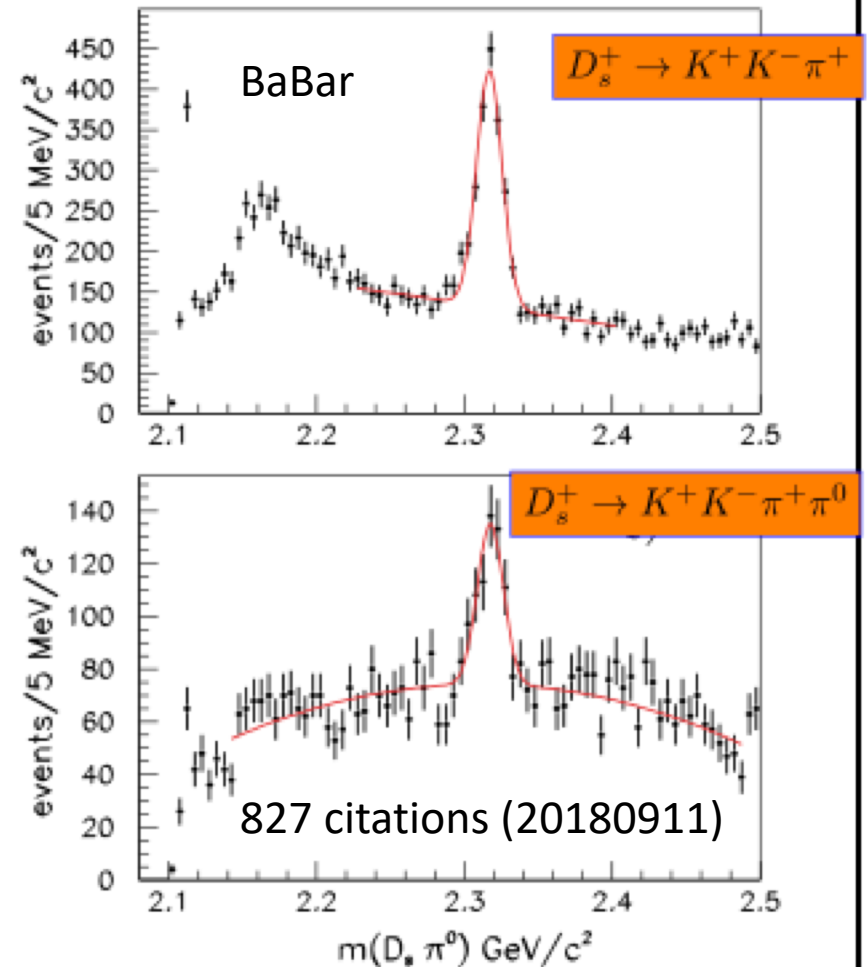
CLEO PRD68,032002(2003)

Two peculiar states

- $D_{s0}^*(2317)$, $D_{s1}(2460)$
- 160/70 MeV lower than quark model predictions--difficult to be understood as conventional $c\bar{s}$ bar states.
- “Dynamically generated” from strong DK interaction
 - ✓ E. E. Kolomeitsev 2004,
 - ✓ F. K. Guo 2006,
 - ✓ D. Gamermann 2007

$$m_{D_{s1}(2460)} - m_{D_{s0}^*(2317)} \approx m_{D^*} - m_D$$

$M = 2317.8 \pm 0.6$ and $\Gamma < 3.8$ MeV

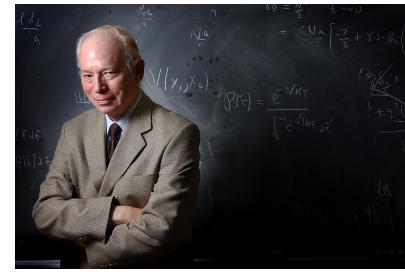


PRL90,242001(2003)

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UChPT in Bethe-Salpeter equation

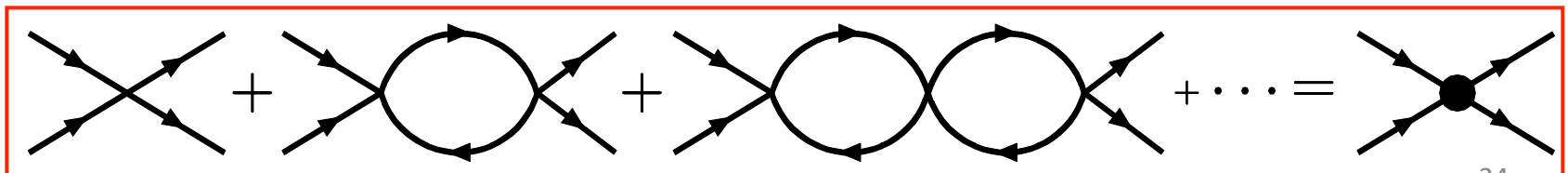


□ Model independent DK interaction from ChPT

$$\mathcal{V}_{\text{WT}}(P(p_1)\phi(p_2) \rightarrow P(p_3)\phi(p_4)) = \frac{1}{4f_0^2} \mathcal{C}_{\text{LO}} (s - u) \quad \text{Weinberg-Tomazawa}$$

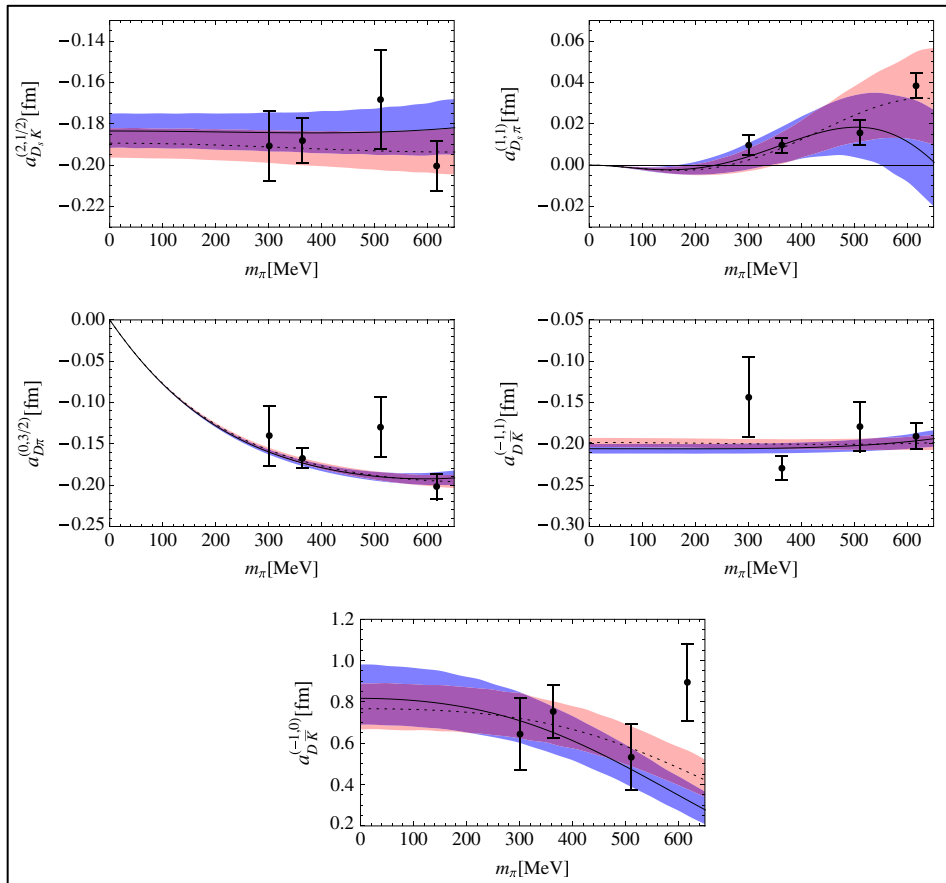
$$\begin{aligned} \mathcal{V}_{\text{NLO}}(P(p_1)\phi(p_2) \rightarrow P(p_3)\phi(p_4)) = & -\frac{8}{f_0^2} C_{24} \left(c_2 p_2 \cdot p_4 - \frac{c_4}{m_P^2} (p_1 \cdot p_4 p_2 \cdot p_3 + p_1 \cdot p_2 p_3 \cdot p_4) \right) \\ & -\frac{4}{f_0^2} C_{35} \left(c_3 p_2 \cdot p_4 - \frac{c_5}{m_P^2} (p_1 \cdot p_4 p_2 \cdot p_3 + p_1 \cdot p_2 p_3 \cdot p_4) \right) \\ & -\frac{4}{f_0^2} C_6 \frac{c_6}{m_P^2} (p_1 \cdot p_4 p_2 \cdot p_3 - p_1 \cdot p_2 p_3 \cdot p_4) \\ & -\frac{8}{f_0^2} C_0 c_0 + \frac{4}{f_0^2} C_1 c_1, \end{aligned} \quad (11)$$

□ Resummed in the Bethe-Salpeter equation (two-body elastic unitarity)

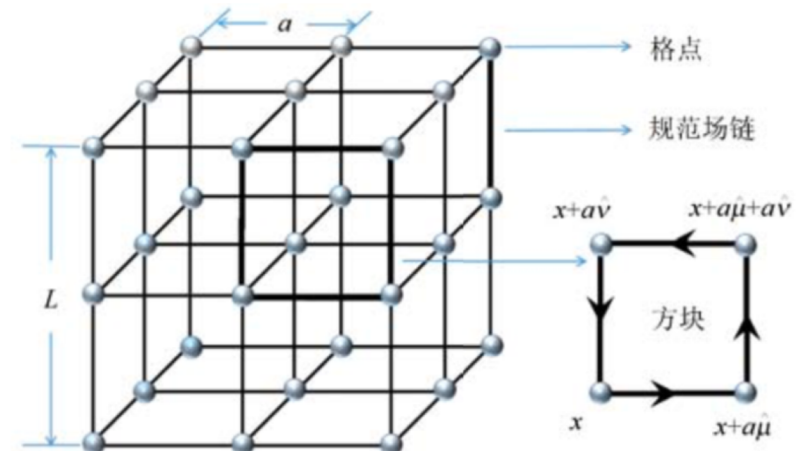


Fixing the LECs using latest LQCD* data

Liuming Liu et al., PRD87 (2013) 014508



- NLO ChPT kernel: 5 LECs
- A quite good description of the 20 Lattice **scattering lengths of pseudoscalar mesons and D mesons** (I=0 DK excluded) can be achieved.



Ds0 and Ds1 dynamically generated

“Post-diction”

● Charm sector

$D_{s0}^*(2317)$, $D_{s1}(2460)$

TABLE V. Pole positions $\sqrt{s} = M - i\frac{\Gamma}{2}$ (in units of MeV) of charm mesons dynamically generated in the HQS UChPT.

(S, I)	$J^P = 0^+$	$J^P = 1^+$
$(1, 0)$	2317 ± 10	2457 ± 17
$(0, 1/2)$	$(2105 \pm 4) - i(103 \pm 7)$	$(2248 \pm 6) - i(106 \pm 13)$

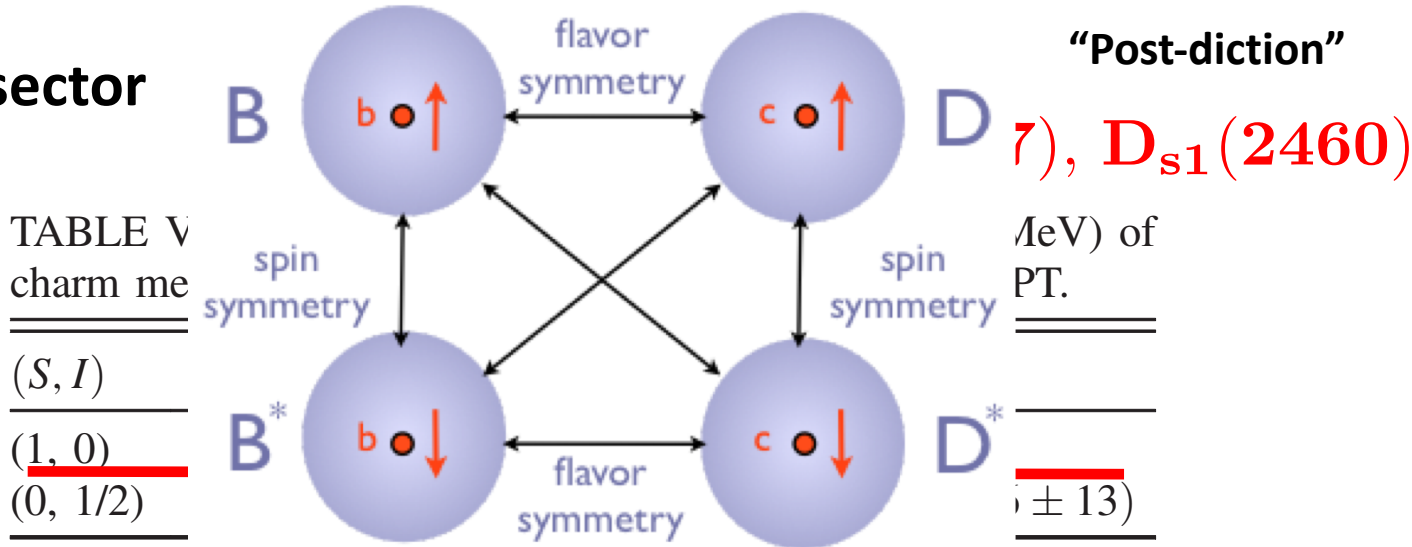
● Bottom Sector

TABLE VI. Pole positions $\sqrt{s} = M - i\frac{\Gamma}{2}$ (in units of MeV) of bottom mesons dynamically generated in the HQS UChPT.

(S, I)	$J^P = 0^+$	$J^P = 1^+$
$(1, 0)$	5726 ± 28	5778 ± 26
$(0, 1/2)$	$(5537 \pm 14) - i(118 \pm 22)$	$(5586 \pm 16) - i(124 \pm 25)$

Ds0 and Ds1 dynamically generated

● Charm sector



● Bottom Sector

TABLE VI. Pole positions $\sqrt{s} = M - i\frac{\Gamma}{2}$ (in units of MeV) of bottom mesons dynamically generated in the HQS UChPT.

(S, I)	$J^P = 0^+$	$J^P = 1^+$
$(1, 0)$	5726 ± 28	5778 ± 26
$(0, 1/2)$	$(5537 \pm 14) - i(118 \pm 22)$	$(5586 \pm 16) - i(124 \pm 25)$

Predicted Bs0 and Bs1 states

Physics Letters B 750 (2015) 17–21



Contents lists available at ScienceDirect

Physics Letters B

www.elsevier.com/locate/physletb



Predicting positive parity B_s mesons from lattice QCD



C.B. Lang^a, Daniel Mohler^{b,*}, Sasa Prelovsek^{c,d}, R.M. Woloshyn^e

^a Institute of Physics, University of Graz, A-8010 Graz, Austria

^b Fermi National Accelerator Laboratory, Batavia, IL 60510-5011, USA

^c Department of Physics, University of Ljubljana, 1000 Ljubljana, Slovenia

^d Jozef Stefan Institute, 1000 Ljubljana, Slovenia

^e TRIUMF, 4004 Wesbrook Mall, Vancouver, BC V6T 2A3, Canada

Table 5

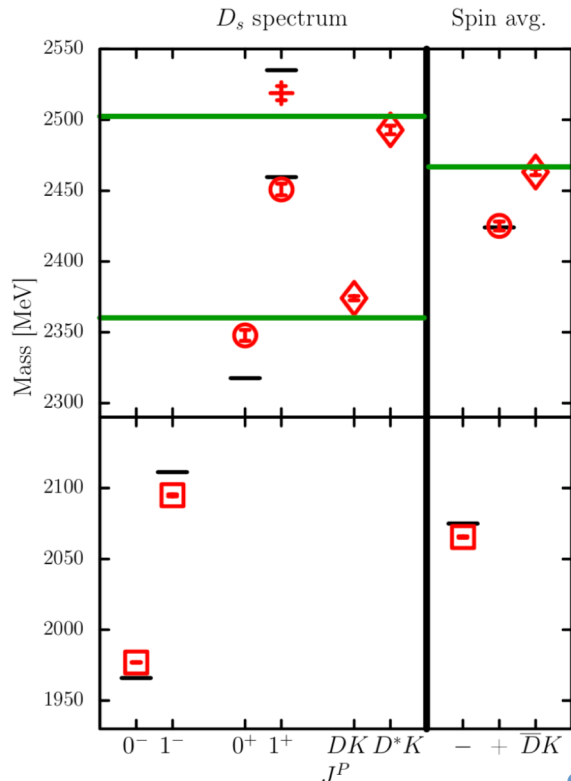
Comparison of masses from this work to results from various model based calculations; all masses in MeV.

J^P	0^+	1^+
Covariant (U)ChPT [24]	5726(28)	5778(26)
NLO UHMChPT [19]	5696(20)(30)	5742(20)(30)
LO UChPT [17,18]	5725(39)	5778(7)
LO χ -SU(3) [16]	5643	5690
HQET + ChPT [20]	5706.6(1.2)	5765.6(1.2)
Bardeen, Eichten, Hill [15]	5718(35)	5765(35)
rel. quark model [5]	5804	5842
rel. quark model [22]	5833	5865
rel. quark model [23]	5830	5858
HPQCD [30]	5752(16)(5)(25)	5806(15)(5)(25)
this work	5713(11)(19)	5750(17)(19)

In agreement with IQCD

Support from lattice QCD studies

- [G. S. Bali et al., arXiv:1706.01247 \[hep-lat\]](#).
- [C. B. Lang et al., arXiv:1403.8103 \[hep-lat\]](#).
- [D. Mohler et al., arXiv:1308.3175 \[hep-lat\]](#).



“DK components substantial”

FIG. 12. On the left, our final results for the lower lying D_s spectrum as detailed in Table VII. The short horizontal black lines indicate the corrected experimental values (see Section II) while the green horizontal lines give the positions of the DK and D^*K non-interacting thresholds. Our lattice results for the finite volume thresholds are labelled DK and D^*K , respectively. The errors indicated are statistical only. On the right, the negative parity spin-averaged $1S$ mass $m_- = \frac{1}{4}(m_{0^-} + 3m_{1^-})$ is shown and denoted $-$, while the same spin-average of the positive parity 0^+ and 1^+ states is labelled with $+$ and the weighted average of the threshold is labelled as \overline{DK} .

Further **tests** of the DK interaction

- Experiments, theory, and lattice QCD all show that DK or D^*K interaction is strong enough to form the $Ds0^*(2317)$ or $Ds1(2460)$
- A natural question is: if we add one more $D(\bar{D})$ or $D^*(\bar{D}^*)$, can they form molecules of three hadrons?
- This seems to **be a rather straightforward and naive question**, but **remains unexplored** until quite recently

Contents

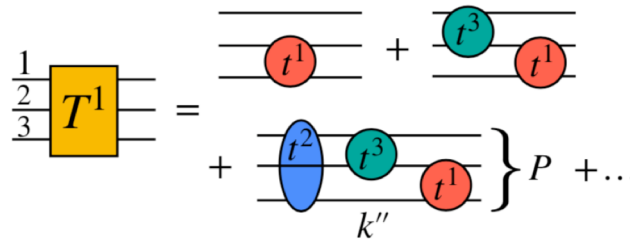
- Motivation: new types of clusters of color singlets in addition to nuclei
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An explicit three-body study of DDK

A. Martínez Torres, K. P. Khemchandani, and **LSG** 1809.01059

- Coupled-three-channel problem: $D(\text{DK} - D_S\pi - D_S\eta)$
- Three-body scattering matrix (Faddeev)

$$T = \sum_{i=1}^3 T^i$$



$$T^i = t^i \delta^3(\vec{k}'_i - \vec{k}_i) + \sum_{j \neq i=1}^3 T_R^{ij}, \quad i = 1, 2, 3,$$

$$T_R^{ij} = t^i g^{ij} t^j + t^i \left[G^{iji} T_R^{ji} + G^{ijk} T_R^{jk} \right],$$

A. Martínez Torres, K. P. Khemchandani, and E. Oset PRC **77**, 042203(R)

A. Martínez Torres, K.P. Khemchandani, **LSG**, M. Napsuciale, E. Oset, PRD78 (2008) 074031

Two-body inputs

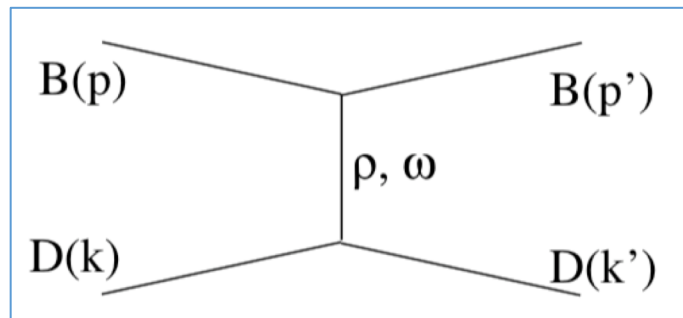
- **DK: leading order UChPT** DK , $D_s\eta$ and $D_s\pi$

$$V_{ij} = -\frac{C_{ij}}{4f^2}(s - u)$$

$$a(\mu) = -1.846, \mu = 1000 \text{ MeV} \Rightarrow \text{Pole} = 2318 \text{ MeV}$$

F.-K. Guo, P.-N. Shen, H.-C. Chiang, R.-G. Ping, and B.-S. Zou, PL B641, 278 (2006).

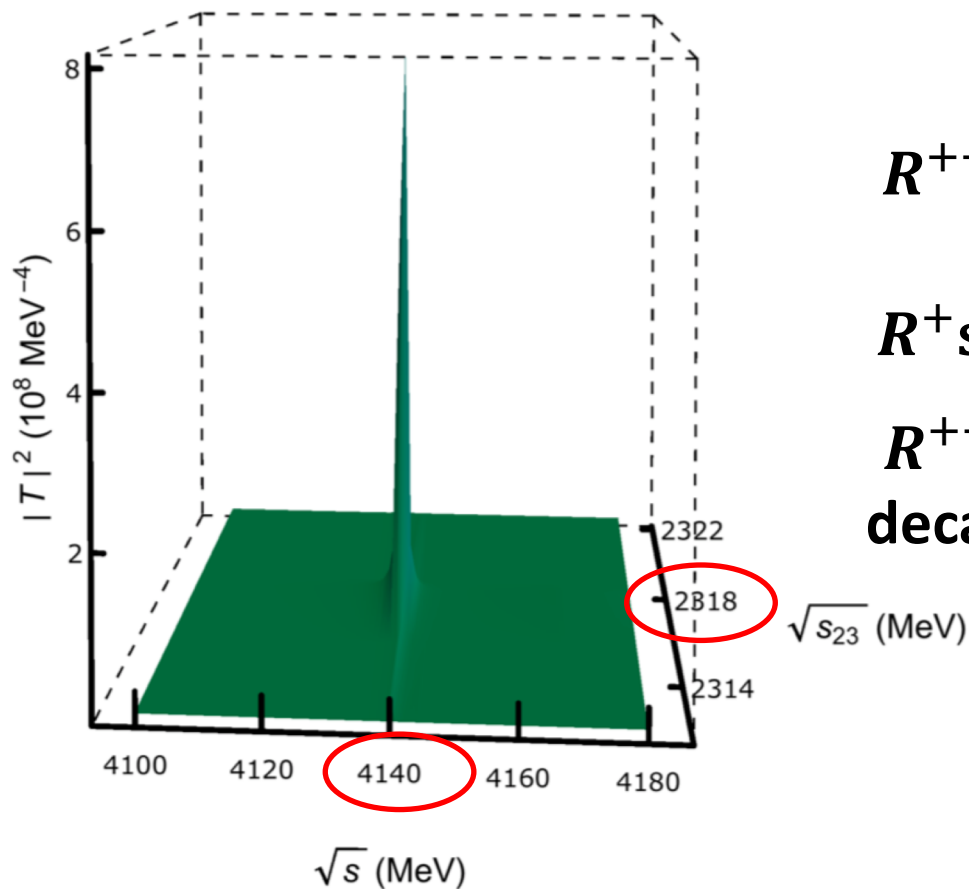
- **DD(Ds): local hidden gauge theory**



$$a(\mu) = -1.3 \sim -1.5, \mu = 1500 \text{ MeV} \Leftarrow \text{fixed from } D\bar{D}/D\bar{D}^* \rightarrow X(3700) / X(3872)$$

S. Sakai, L. Roca, and E. Oset, PRD96, 054023³³ (2017).

Three-body amplitudes



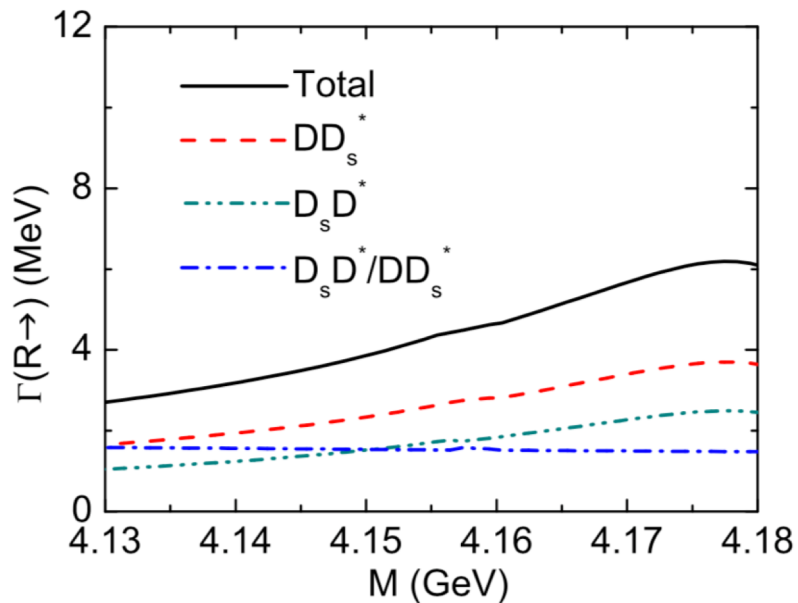
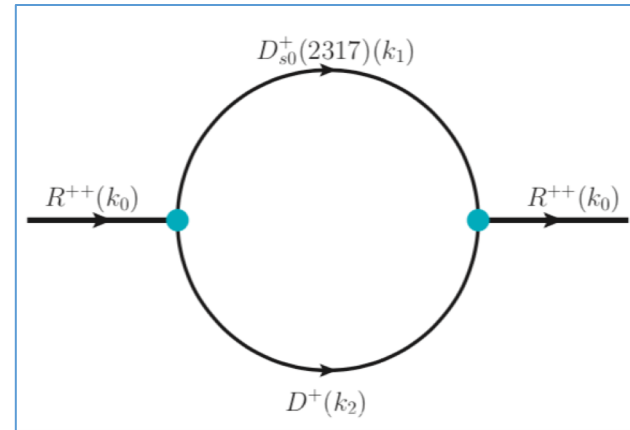
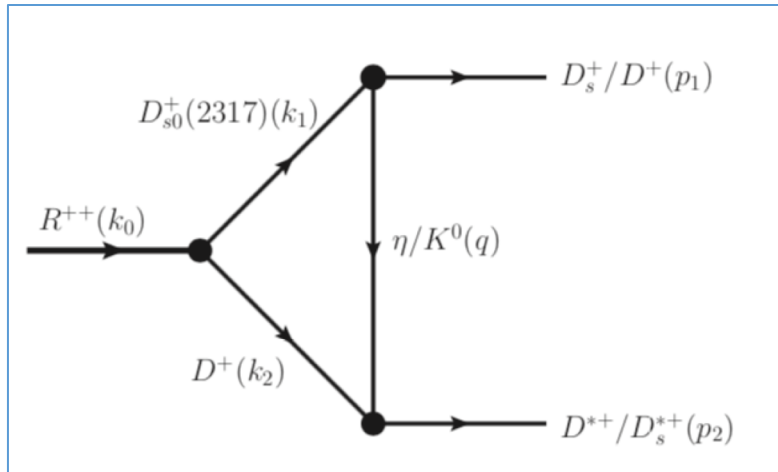
$$R^{++} = (I, I_{23}) = \left(\frac{1}{2}, 0\right)$$

R^+ should also exist

R^{++} is a bound state, but can decay strongly

Two-body decay width

Yin Huang, *LSG*, et al., in preparation



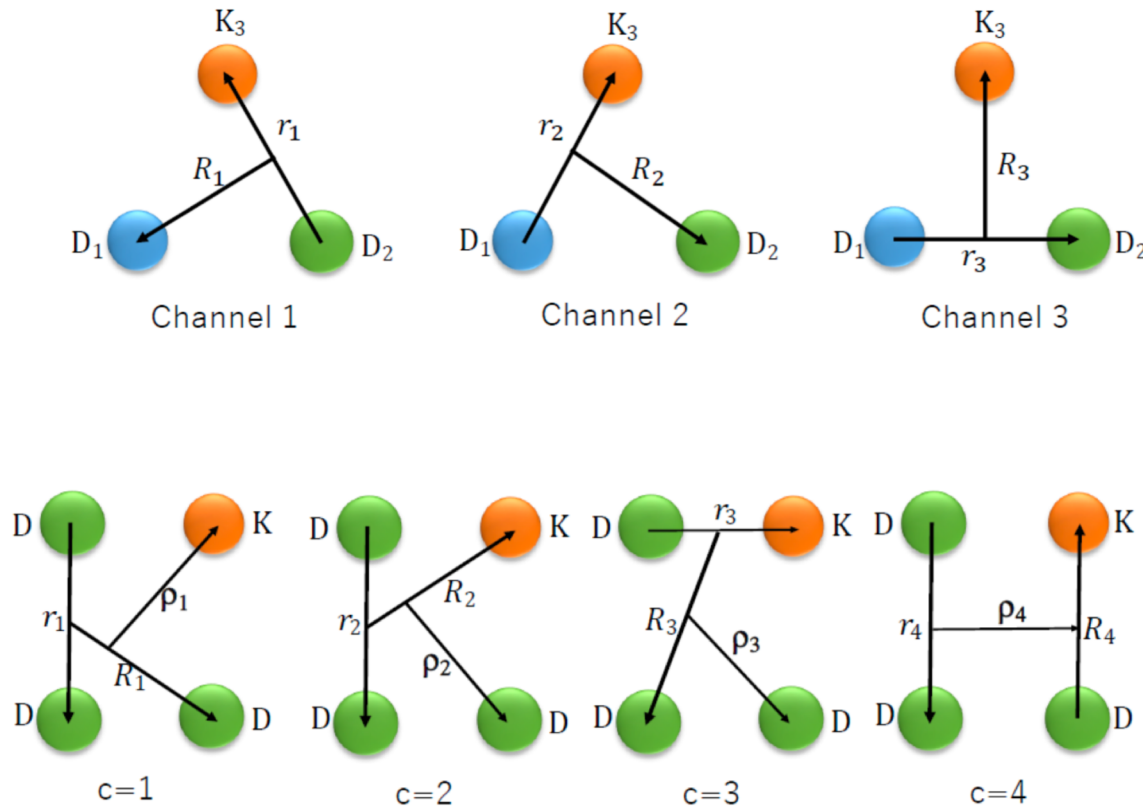
Preliminary result:
 $\Gamma \sim 10$ MeV

A DDDK state

$1(0^+)$

Gaussian Expansion Method

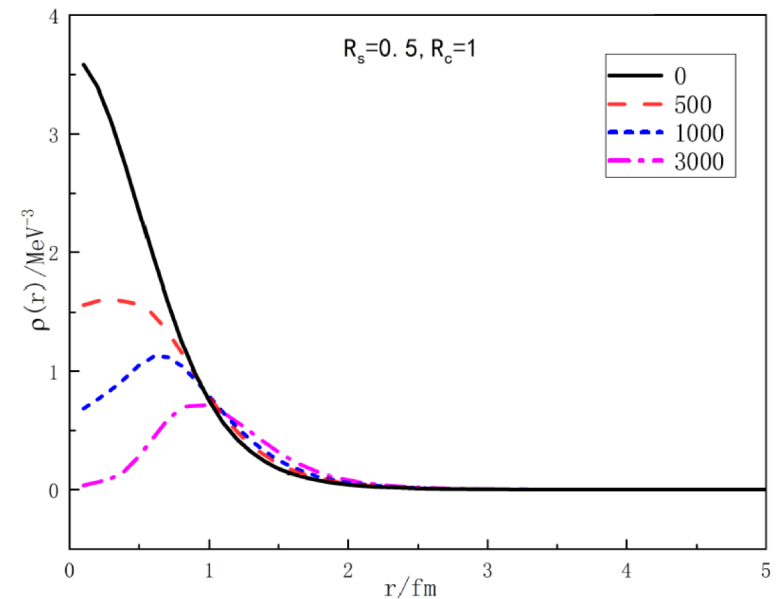
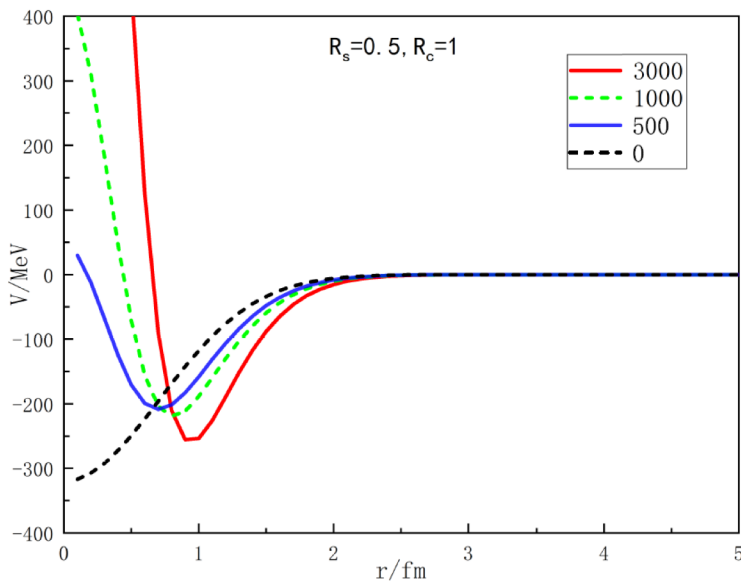
What if we add one more D?



A DDDK state $1(0^+)$

Gaussian Expansion Method

What if we add one more D? **Preliminary results** show that such a state exists as well



Uncertainties are at **the order of 10-20 MeV**

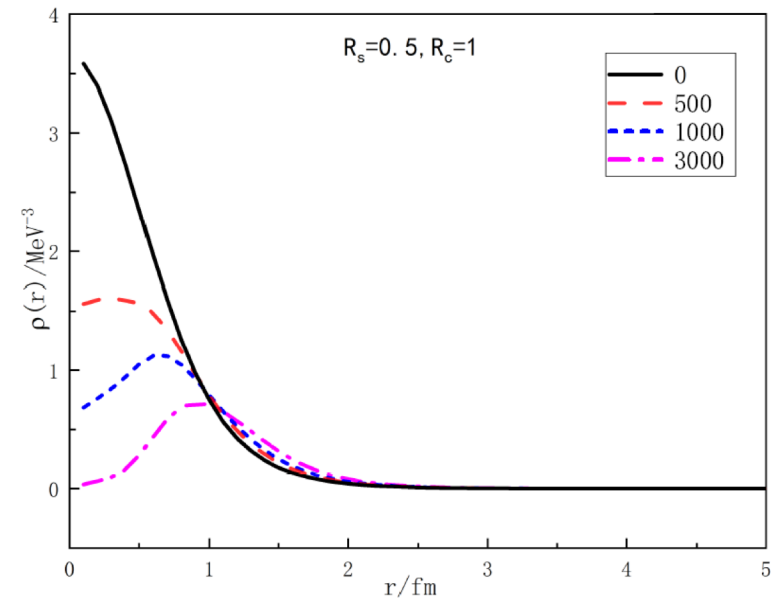
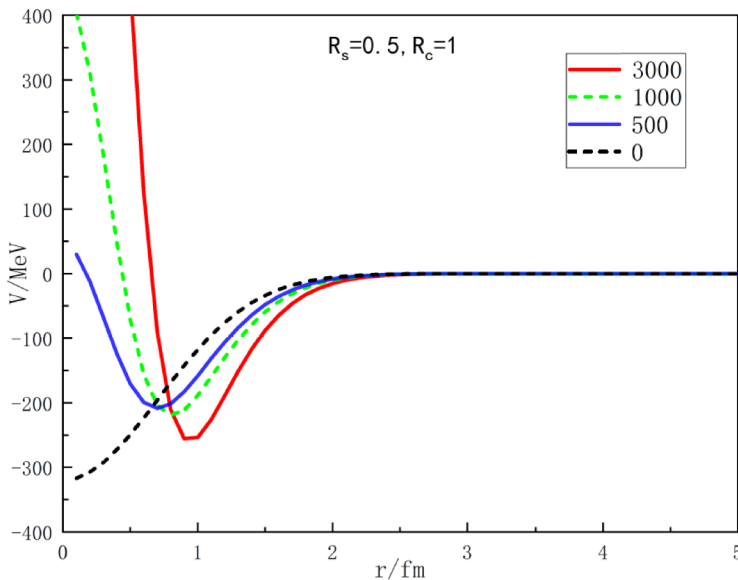
$$V_{DK}(\vec{r}; R_c) = C_S \frac{e^{-(r/R_S)^2}}{\pi^{3/2} R_S^3} + C(R_C) \frac{e^{-(r/R_c)^2}}{\pi^{3/2} R_c^3},$$

	DK*	DDK	DDDK
Binding	45 MeV	(67-71) MeV	91-107 MeV

A DDDK state $1(0^+)$

Gaussian Expansion Method

What if we add one more D? **Preliminary results** show that such a state exists as well



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$$V_{DK}(\vec{r}; R_c) = C_S \frac{e^{-(r/R_S)^2}}{\pi^{3/2} R_S^3} + C(R_C) \frac{e^{-(r/R_c)^2}}{\pi^{3/2} R_c^3},$$

	DK*	DDK	DDDK
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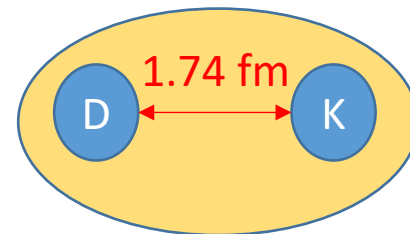
DD interactions play a minor role

$\frac{C_S}{\pi R_S^3}$	$\frac{C(R_c)}{\pi R_c^3}$	E_2	$E_3(\text{only } V_{DK})$	$E_3(V_{DK} + V_{DD})$	$E_4(\text{only } V_{DK})$	$E_4(V_{DK} + V_{DD})$
		$R_S = 0.5\text{fm}$		$R_c = 1\text{fm}$		
0	-320.1	-45.0	-65.8	-71.2	-89.4	-106.8
500	-455.4	-45.0	-65.8	-70.4	-89.2	-103.5
1000	-562.6	-45.0	-65.7	-69.7	-88.8	-101.4
3000	-838.7	-45.0	-65.0	-68.4	-87.0	-97.3
		$R_S = 0.5\text{fm}$		$R_c = 2\text{fm}$		
0	-149.1	-45.0	-66.0	-68.8, -45.1	-88.7, -66.3	-97.6, -70.7
500	-178.4	-45.0	-65.9	-68.2, -45.5	-88.5, -66.7	-95.5, -70.9
1000	-195.0	-45.0	-65.8, -45.2	-67.9, -45.8	-88.2, -66.9	-94.5, -71.2
3000	-225.9	-45.0	-65.3, -45.6	-67.2, -46.6	-87.0, -67.0	-92.6, -71.7
		$R_S = 0.5\text{fm}$		$R_c = 3\text{fm}$		
0	-107.0	-45.0	-66.2, -47.3	-68.0, -48.3	-88.8, -70.2	-94.4, -74.3
500	-119.4	-45.0	-66.2, -48.2	-67.7, -49.3	-88.7, -71.0	-93.2, -74.8
1000	-125.6	-45.0	-66.1, -48.7	-67.5, -49.8	-88.4, -71.3	-92.5, -75.2
3000	-136.2	-45.0	-65.8, -49.4	-67.1, -50.7	-87.6, -71.7	-91.4, -75.7

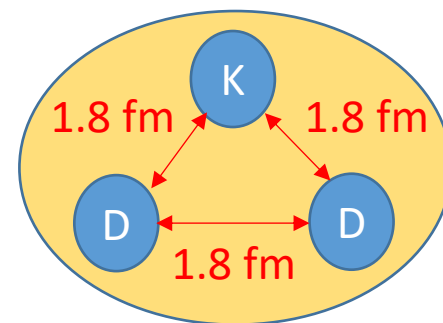
Spatial distributions

$\frac{C_S}{\pi R_S^3}$	$\frac{C(R_c)}{\pi R_c^3}$	$r_2(DK)$	$r_3(DK)$	$r_3(DD)$	$\langle T \rangle$	$\langle V_{DK} \rangle$	$\langle V_{DD} \rangle$
$R_S = 0.5\text{fm } R_c = 1\text{fm}$							
0	-320.1	1.28	1.32	1.36	124.37	-189.61	-5.98
500	-455.4	1.39	1.44	1.47	99.51	-164.83	-5.03
1000	-562.6	1.46	1.53	1.54	91.43	-156.67	-4.51
3000	-838.7	1.61	1.69	1.68	93.24	-157.80	-3.82
$R_S = 0.5\text{fm } R_c = 2\text{fm}$							
0	-149.1	1.74	1.80	1.80	60.20	-125.74	-3.23
500	-178.4	1.91	1.98	1.96	51.00	-116.59	-2.64
1000	-195.0	1.99	2.07	2.04	50.63	-116.12	-2.43
3000	-225.9	2.13	2.22	2.15	53.61	-118.59	-2.24
$R_S = 0.5\text{fm } R_c = 3\text{fm}$							
0	-107.0	2.13	2.19	2.17	39.49	-105.35	-2.13
500	-119.4	2.31	2.38	2.34	34.80	-100.73	-1.77
1000	-125.6	2.37	2.47	2.42	34.90	-100.77	-1.65
3000	-136.2	2.53	2.61	2.53	36.66	-102.24	-1.54

Ds0*(2317)



R(4140)

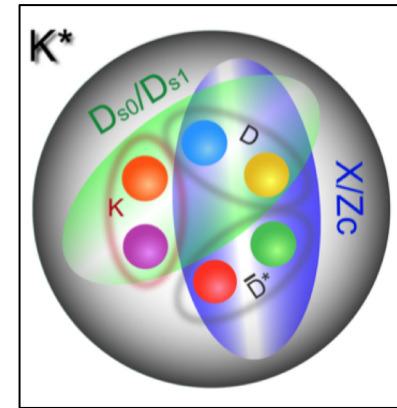


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$K^*(4307)$

Instead of a D , what happens if we add a \bar{D}^* to the DK pair



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K^* mesons with hidden charm arising from $KX(3872)$ and $KZ_c(3900)$ dynamics



Xiu-Lei Ren^a, Brenda B. Malabarba^b, Li-Sheng Geng^{c,d}, K.P. Khemchandani^{e,c},
A. Martínez Torres^{b,c,*}

^a Institut für Theoretische Physik II, Ruhr-Universität Bochum, D-44780 Bochum, Germany

^b Instituto de Física, Universidade de São Paulo, C.P. 66318, 05389-970 São Paulo, São Paulo, Brazil

^c School of Physics and Nuclear Energy Engineering & Beijing Key Laboratory of Advanced Nuclear Materials and Physics, Beihang University, Beijing 100191, China

^d Beijing Advanced Innovation Center for Big Data-Based Precision Medicine, Beihang University, Beijing 100191, China

^e Universidade Federal de São Paulo, C.P. 01302-907, São Paulo, Brazil

$K^*(4307)$

- Fixed center approximation (FCA):

$$K(D\bar{D}^* + \bar{D}D^*) \sim KX(3872)/Zc(3900)$$

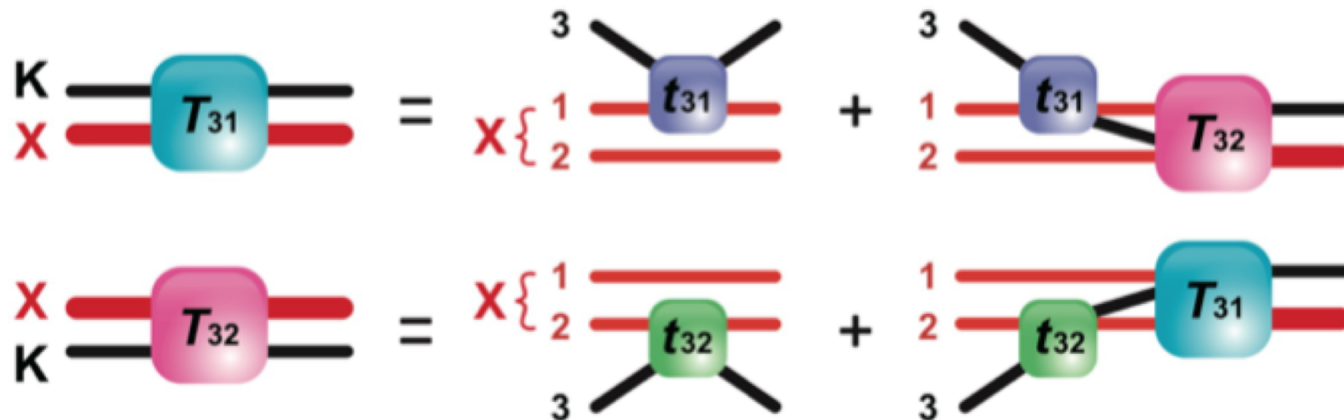
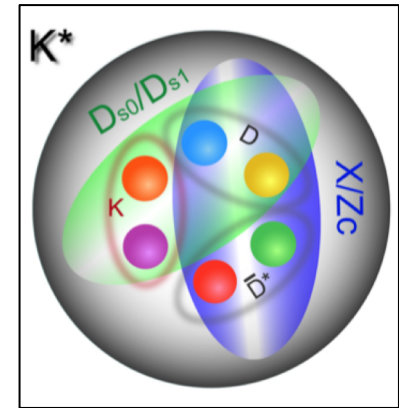
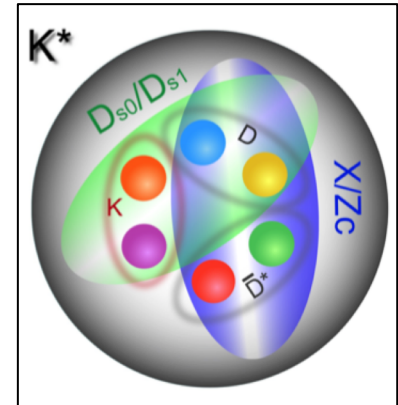
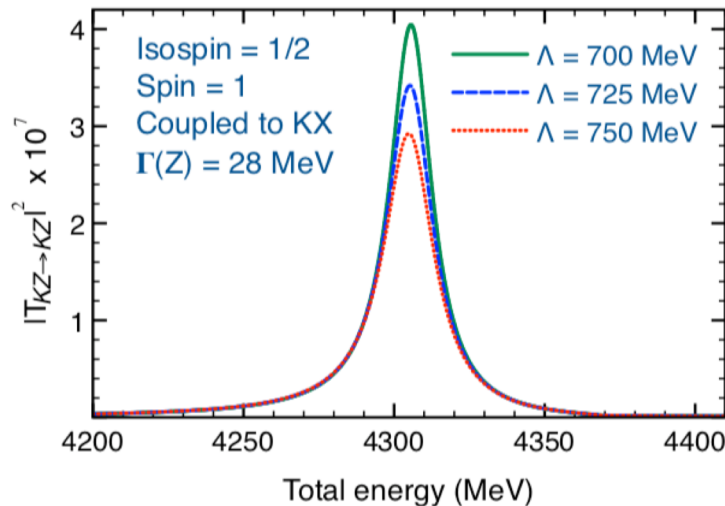
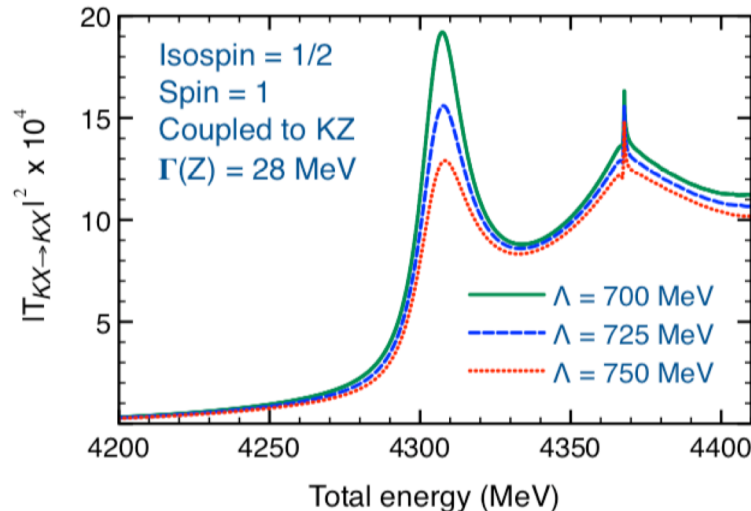


Figure 2: Diagrams showing the scattering of the particle labeled “3” (K) on a cluster (X) made of particles 1 (D) and 2 (\bar{D}^*).

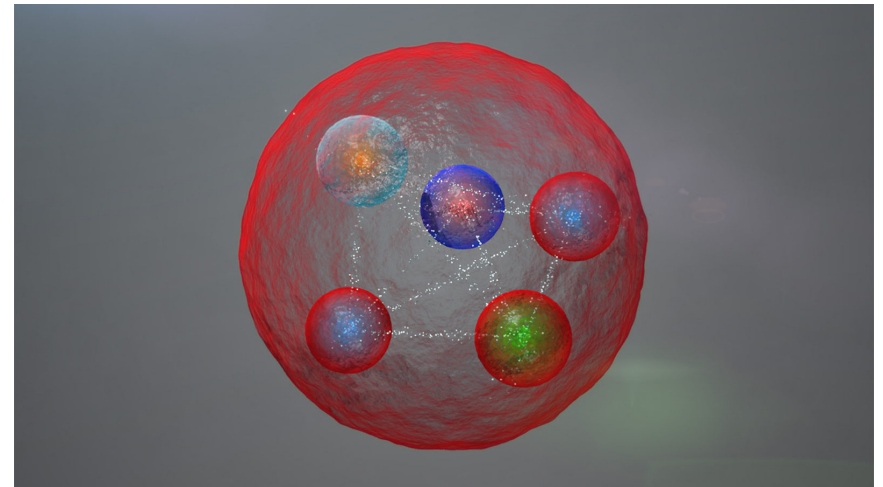
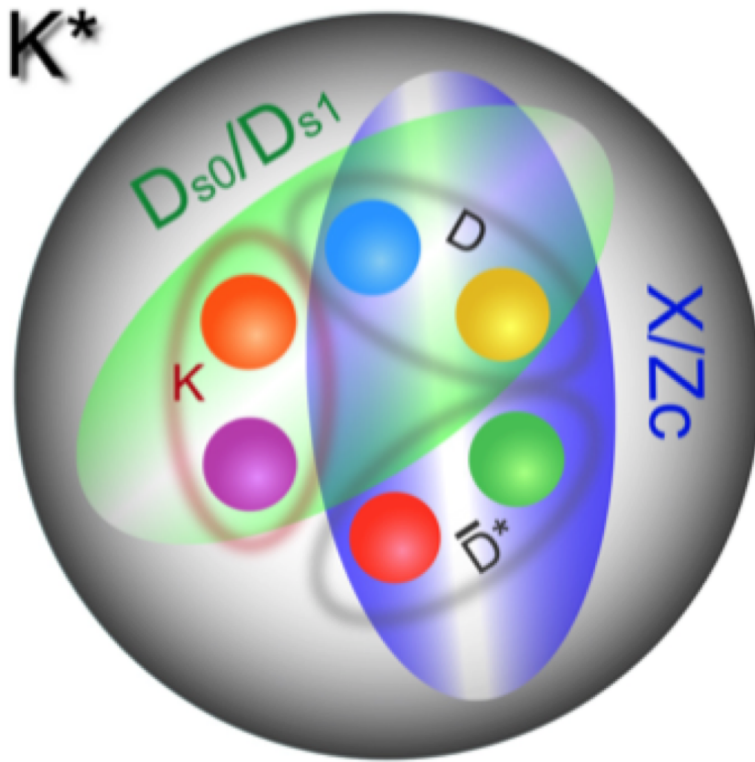
K*(4307)



- Treating KX and KZ as coupled channel systems
- A resonance with $M=(4307 \pm 2) - i(9 \pm 2) \text{ MeV}$ with $I(J^P) = 1/2(1^-)$

In agreement with Li Ma, Qian Wang, [Ulf-G. Meißner](#), 1711.06143, but with completely different dynamics

$K^*(4307)$ —bosonic counterpart of P_c



Pentaquark (N^*) by LHCb

Phys.Rev.Lett. 115 (2015) 072001

Prediction of narrow N^* and Λ^* resonances with hidden charm above 4 GeV,
Jia-Jun Wu, R. Molina, E. Oset, B.S. Zou, 1007.0573

Analogy between KD and Kbar N

$D_{s0}^*(2317)$

- DK bound state
- **Dynamically generated**--
Unitary heavy hadron
chiral perturbation theory
- Coupled channels

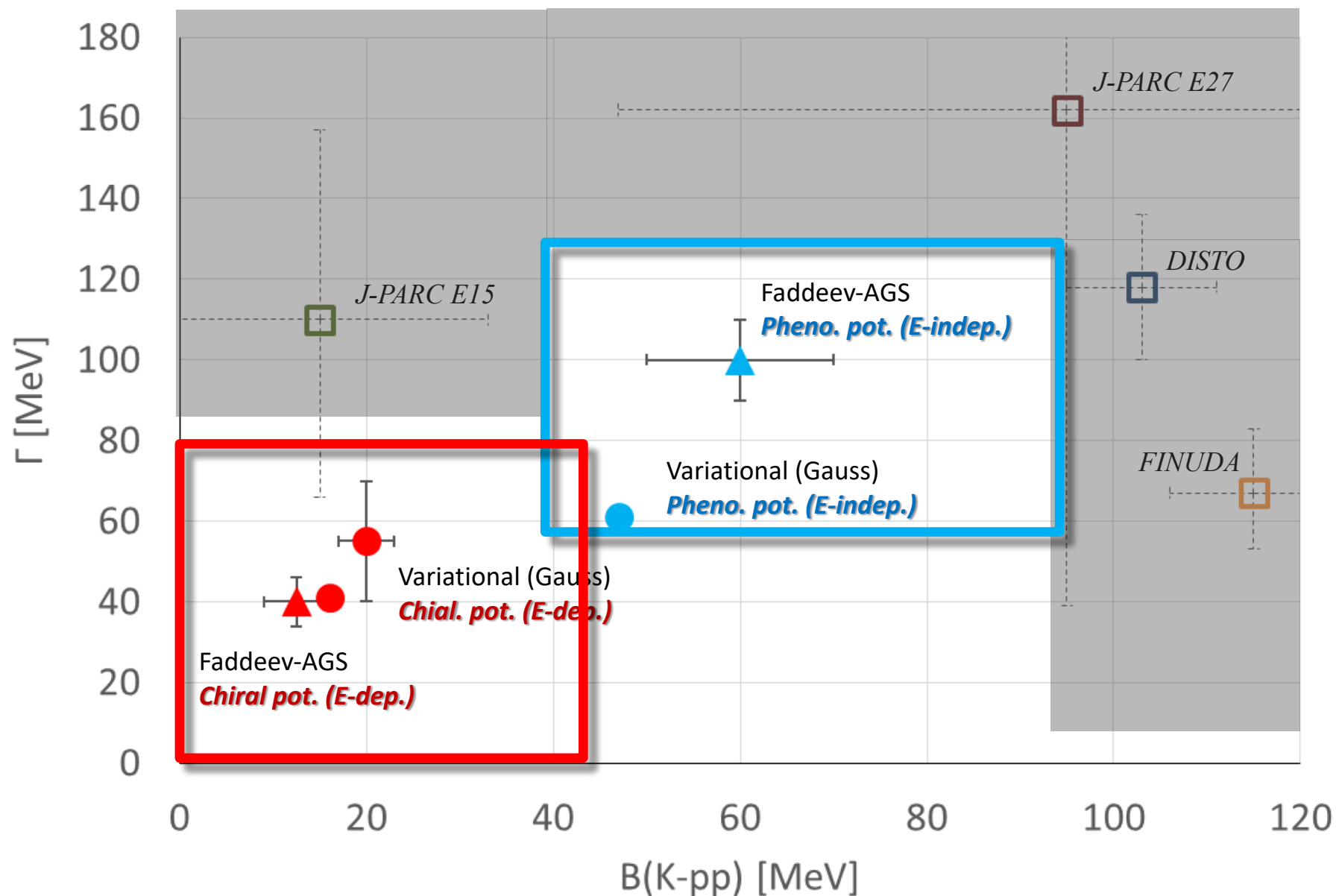
$\Lambda(1405)$

- N-Kbar bound state
- **Dynamically generated**--
Unitary baryon chiral
perturbation theory
- Coupled channels

The interaction between a **kaon and a heavy particle** seems to play an important role

Current status on “ K^-pp ”

A. Dote, Menu2019



Summary and outlook

- From nucleons, we can build nuclei, based on which the whole visible universe is formed
- If the $Ds_0^*(2317)$ is indeed a molecule of DK , then new forms of matter may be built upon them
- We have performed explicit few-body studies—demonstrating that indeed both DDK and $DDDK$ bound states **exist**
- Now we need experimental or lattice QCD confirmations and further theoretical studies on their production and decay mechanisms



北京航空航天大学
BEIHANG UNIVERSITY

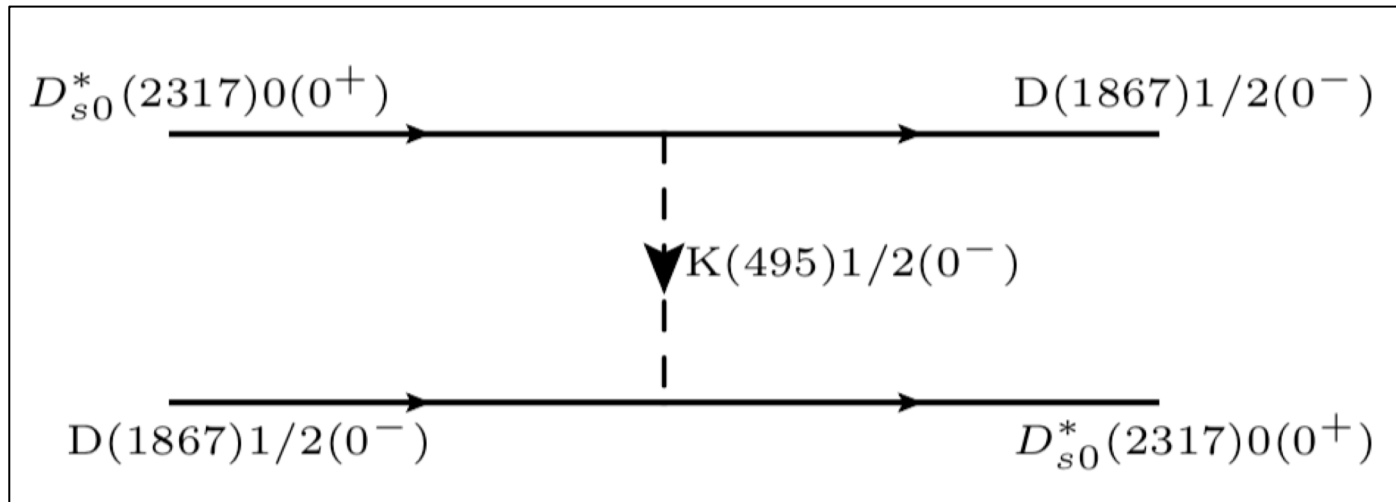


Thanks for your attention !

June 22, 2019

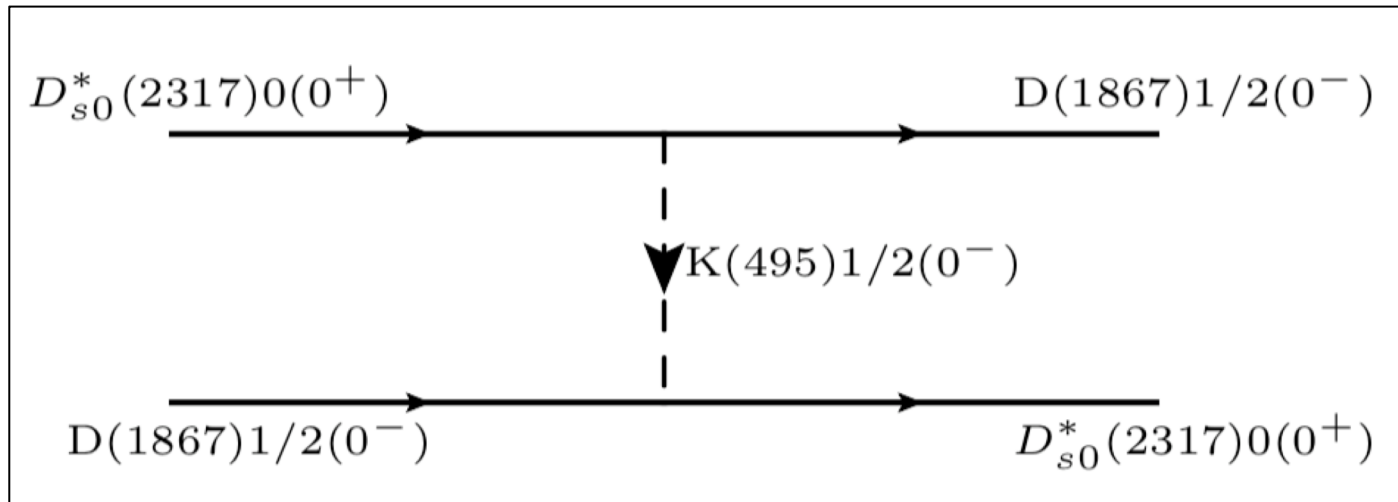
Even if the D_{s0} is a csbar state, $D_{s0} D$ binds

Interestingly, the explicit three-body result is consistent with the **quasi two body** study, where one treats the DK pair as the D_{s0}^* and describes the interaction between the D_{s0}^* with the D using one-kaon exchange

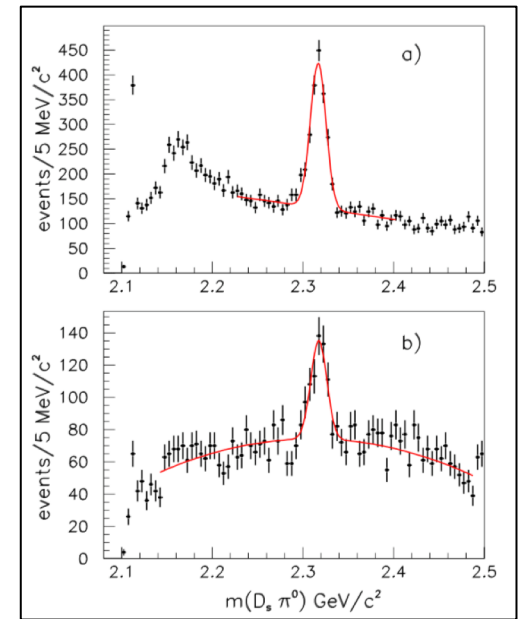
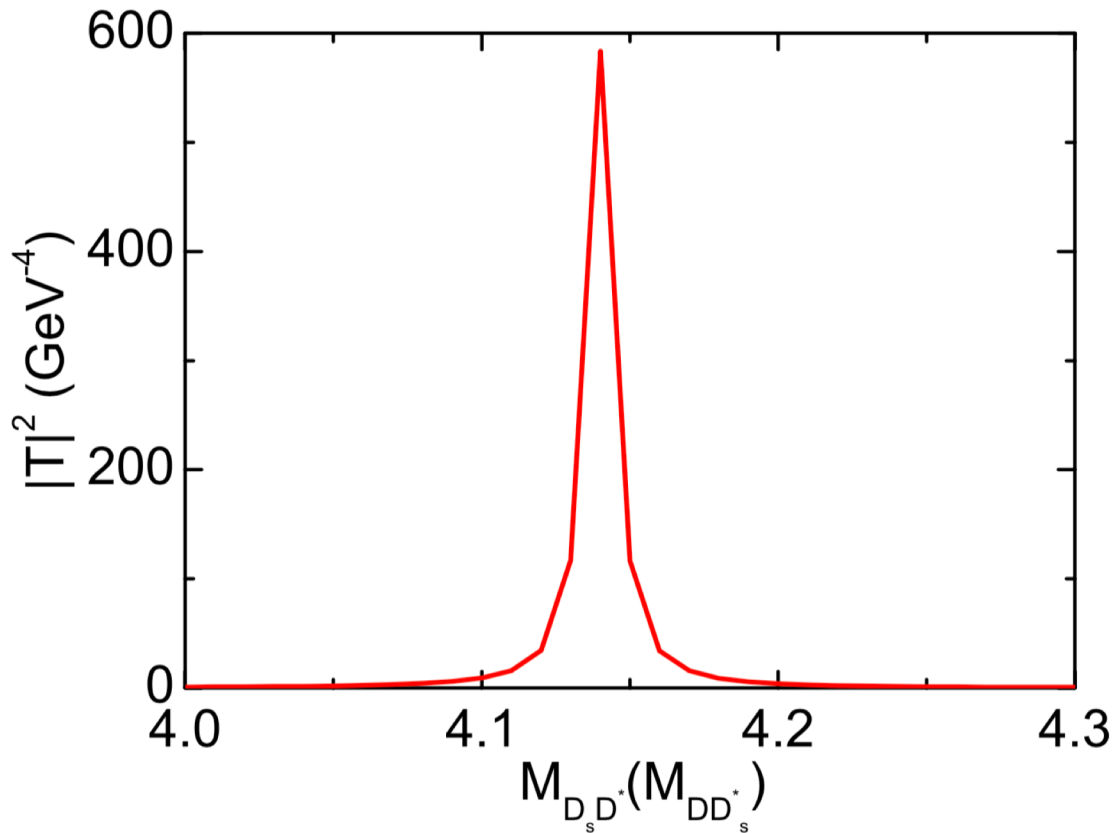


Even if the D_{s0} is a $c\bar{s}$ state, D_{s0} D binds

Interestingly, the explicit three-body result is consistent with the **quasi two body** study, where one treats the DK pair as the D_{s0}^* and describes the interaction between the D_{s0}^* with the D using one-kaon exchange



Where to look for the R^{++}/R^+



□ Belle/BelleII

$$e^+e^- \rightarrow X R \rightarrow X D^+ D_s^+ \pi^0$$

□ LHCb

$$p\bar{p} \rightarrow X R \rightarrow X D^+ D_s^+ \pi^0$$