X(5568): understandings and status

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兰州，2018.4.1

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  (1) molecule picture
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Hadrons with exotic properties

- 2003: X(3872), D_{sJ}(2317), D_{sJ}(2460), ~~Θ(1540)~~
- 2004: X(3915), ~~D_{sJ}(2632)~~
- 2005: Y(4260)
- 2007: Y(4008), Y(4360), Y(4660), X(4160), Z(4430)
- 2008: Z_1(4050), Z_2(4250)
- 2009: X(4140)
- 2010: X(4274), X(4350), X(4315)?
- 2011: Zb(10610), Zb(10650)
- 2013: Zc(3900), Zc(3885), Zc(4020), Zc(4025)
- 2014: Zc(4200)
- 2015: Pc(4380), Pc(4450)
- 2016: X(4500), X(4700), X(5568) ?

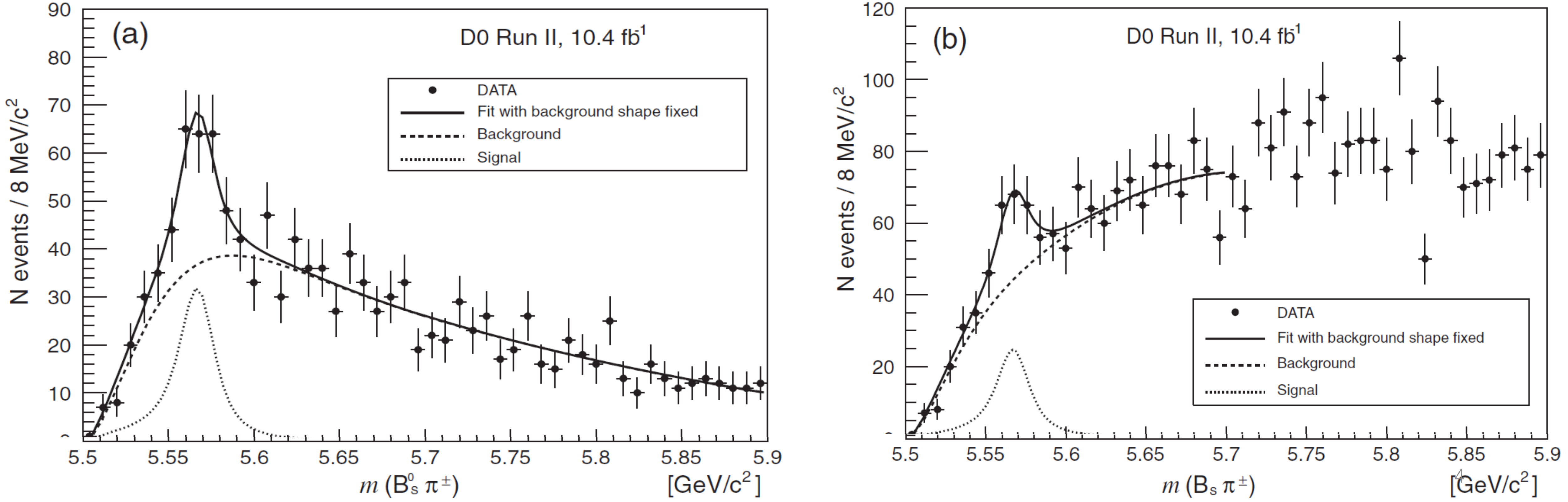
Narrow X(5568)

$J^P = 0^+$ $J^P = 1^+$

- 1602.07588 (D0): $X(5568) \to B_s^0\pi^\pm$ $[X(5568+49) \to B_s^*\pi^\pm \to B_s^0\gamma\pi^\pm]$

$m = 5567.8 \pm 2.9^{+0.9}_{-1.9}$ MeV $\Gamma = 21.9 \pm 6.4^{+5.0}_{-2.5}$ MeV

- Four different flavors: $b\bar{s}u\bar{d}$ or $b\bar{s}\bar{u}d$



Narrow X(5568)

- 1608.00435 (LHCb): No significant excess is found
- 1712.06144 (CMS): No statistically significant peaks

  "central kinematic region of B_s^0 candidates similar to D0"
- 1712.09620 (CDF): No evidence for this state is found

  "the same collision conditions and similar kinematic range as in the original observation of this state by D0"
- 1712.10176 (D0): Evidence for a narrow structure, again

$$B_s^0 \to J/\psi_{(\to\mu^+\mu^-)} + \phi_{(\to K^+K^-)}$$

$$B_s^0 \to \mu^\mp + D_s^\pm{}_{(\to\phi\pi^\pm)} + X$$

$$m = 5566.9^{+3.2+0.6}_{-3.1-1.2}\ \mathrm{MeV}$$

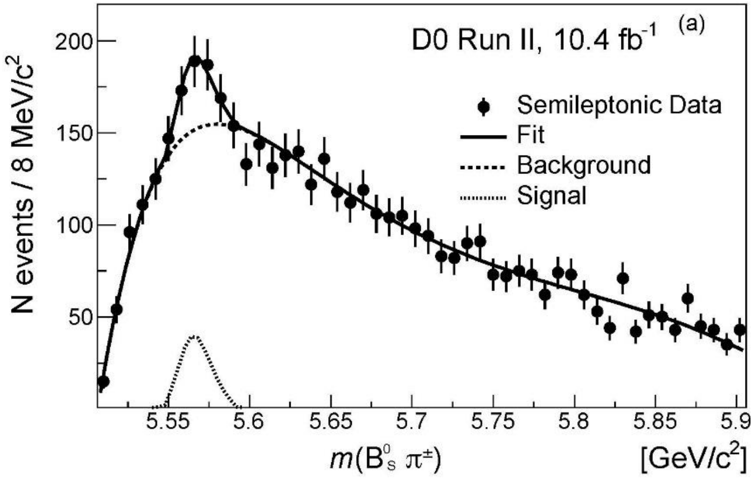
$$\Gamma = 18.6^{+7.9+3.5}_{-6.1-3.8}\ \mathrm{MeV}$$

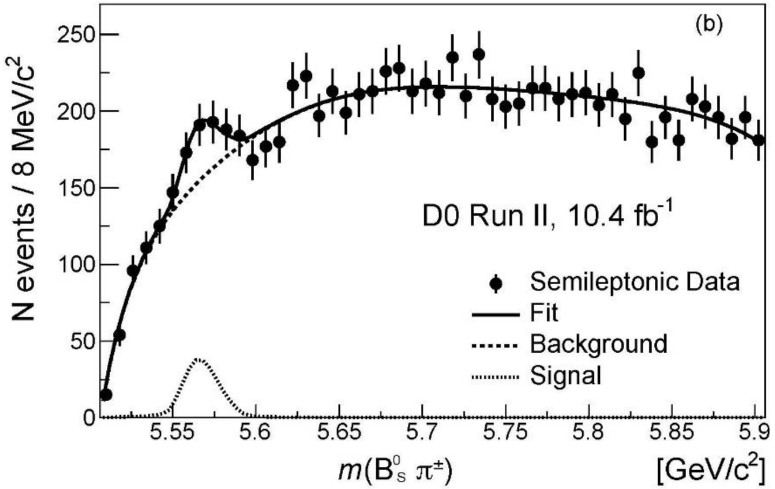
- 1802.01840 (ATLAS): No significant signal was found

Narrow X(5568): cone cut/line shape

$$\Delta R = \sqrt{\Delta\eta^2 + \Delta\phi^2} < 0.3$$

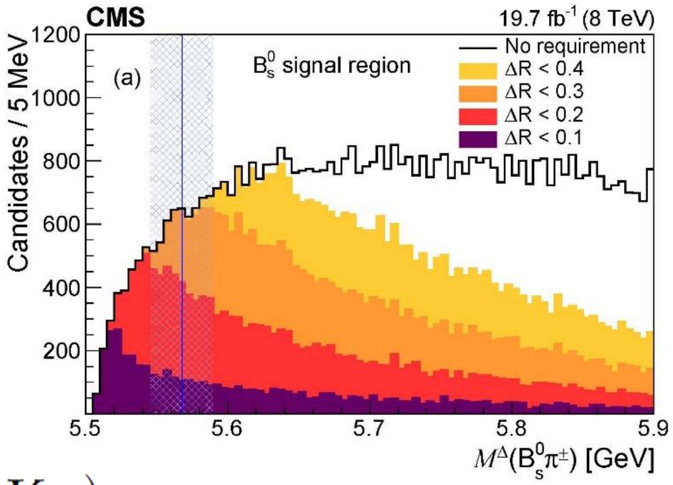
η: pseudorapidity
ϕ: azimuthal angle

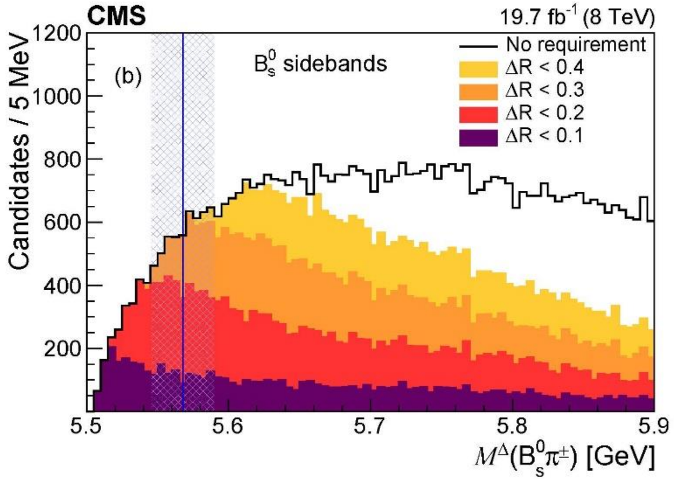




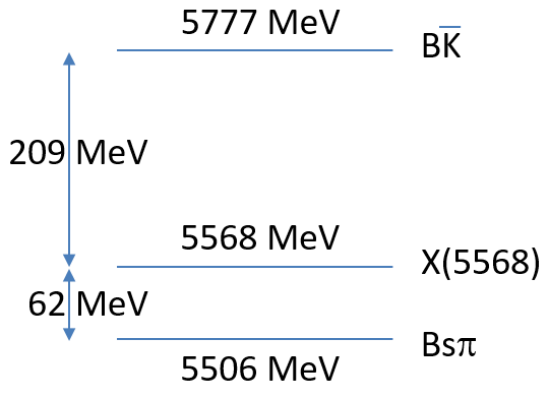
D0: w./w.o. cone cut: 5.1/3.9 σ

CMS: cone cut changes the $M^{\Delta}(B_s^0\pi^\pm)$ distribution and can even produce a peaking shape. Not used





$$M^{\Delta}(B_s^0\pi^\pm) = M(J/\psi K^+K^-\pi^\pm) - M(J/\psi K^+K^-) + m_{B_s^0}$$



X(5568): molecule?

- Agaev, Azizi, Sundu, 1603.02708 [QSR, $\mathbf{0}^{+}$ $B\bar{K}$]

$$J^{X_b}(x) = \left[\bar{d}^a(x)\gamma_5 s^a(x)\right]\left[\bar{b}^b(x)\gamma_5 u^b(x)\right]$$

  $\Rightarrow$ mass, decay constant, width: NO
- C.J. Xiao, D.Y. Chen, 1603.00228 [assume]

  $\Rightarrow$ decay: unnatural molecule
- Albaladejo, Nieves, Oset, Z.F. Sun, X. Liu, 1603.09230 [CC]

  $\Rightarrow$ mass, width: NO
- X.W. Kang, Oller, 1606.06665 [EFT: P-wave $\mathbf{1}^{-}$]

  $\Rightarrow$ NO

X(5568): molecule?

- Lang, Mohler, Prelovsek, 1607.03185 [lat.: 0^+ $B_s\pi$-$B\bar{K}$]
  ⇒ scattering: NO
- R, Chen, X. Liu, 1607.05566 [OBE: 0^+, 1^+]
  ⇒ mass: NO
- J.X. Lu, X.L. Ren, L.S. Geng, 1607.06327 [sym., fin.vol.χPT, comp.]
  ⇒ NO
- B.X. Sun, F.Y. Dong, JL. Ping, 1609.04068 [0^+ CC BSE]
  ⇒ pole: OK
- Z.Y. Wang, J.J. Qi, C. Wang, X.H. Guo, 1802.04566 [BSE: 0^+]
  ⇒ mass, width: OK
- H.W. Ke, X.Q. Li, 1801.00675 [assume 0^+ in LFQM]; 1802.08823 [mole-tetra]
  ⇒ decay: OK

X(5568): tetraquark?

- Agaev, Azizi, Sundu, 1602.08642, 1603.00290 [QSR: diquark]

  0^{++}: $J^{X_b}(x)=\varepsilon^{ijk}\varepsilon^{imn}[s^j(x)C\gamma_\mu u^k(x)][\bar{b}^m(x)\gamma^\mu C\bar{d}^n(x)]$ (5584±137) MeV

  $\Rightarrow$ mass, decay constant, width: OK [not 1^+ in 1608.04785]
- W. Chen, H.X. Chen, X. Liu, T.G. Steele, S.L. Zhu, 1602.08916 [QSR]

  0^+: $J_3=s_a^TC\gamma_5u_b(\bar{b}_a\gamma_5C\bar{d}_b^T-\bar{b}_b\gamma_5C\bar{d}_a^T)$ 5.58±0.14 GeV

  1^+: $J_{3\mu}=s_a^TC\gamma_5u_b(\bar{b}_a\gamma_\mu C\bar{d}_b^T-\bar{b}_b\gamma_\mu C\bar{d}_a^T)$ 5.59±0.15 GeV

  $\Rightarrow$ mass: OK
- Z.G. Wang, 1602.08711, 1603.02498 [QSR, diquark]

  0^+: $J(x)=\epsilon^{ijk}\epsilon^{imn}u^j(x)C\gamma_5s^k(x)\bar{d}^m(x)\gamma_5C\bar{b}^n(x)$ (5.57±0.12) GeV

  $\Rightarrow$ mass,width: OK

X(5568): tetraquark?

- M. Nielsen et. al., 1602.09041, 1603.02249 [QSR]

  0^+: $j_S = \epsilon_{abc}\epsilon_{dec}(u_a^T C\gamma_5 s_b)(\bar{d}_d \gamma_5 C \bar{b}_e^T)$ ~6.4 GeV

  ⇒ mass: NO, width: OK

- L. Tang, C.F. Qiao, 1603.04761 [QSR, 8c*8c]

  0^+: $j_A(x) = [i\,\bar{b}^j(x)\gamma_5(t^a)_{jk}s^k(x)][i\,\bar{d}^m(x)\gamma_5(t^a)_{mn}u^n(x)]$ 5.57±0.15 GeV

  0^+: $j_C(x) = [\bar{b}^j(x)\gamma^\mu(t^a)_{jk}s^k(x)][\bar{d}^m(x)\gamma_\mu(t^a)_{mn}u^n(x)]$ 5.58±0.15 GeV

  ⇒ mass: OK

- J.R. Zhang, J.L. Zou, J.Y. Wu, 1703.09043 [QSR: 0^+ diquark-diquark]

  scalar-scalar: $5.57^{+0.35}_{-0.23}$ GeV; axial-axial: $5.77^{+0.44}_{-0.33}$ GeV

  ⇒ mass: OK

X(5568): tetraquark?

- Albuquerque,Narison,Rabemananjara,Rabetiarivony, 1604.05566 [QSR]

Molecule		
BK	0^+	$(\bar{b}\, i\gamma_5\, u)(\bar{d}\, i\gamma_5\, s)$
$B_s\pi$	0^+	$(\bar{b}\, i\gamma_5\, s)(\bar{d}\, i\gamma_5\, u)$
B^*K	1^+	$(\bar{b}\, i\gamma_\mu\, u)(\bar{d}\, i\gamma_5\, s)$
$B_s^*\pi$	1^+	$(\bar{b}\, i\gamma_\mu s)(\bar{d} i\gamma_5\, u)$
Four-quark		
	1^-	$(s^T C\gamma_5\, u)(\bar{b}\,\gamma_\mu\gamma_5 C\, \bar{d}^T) + k(s^T C\, u)(\bar{b}\,\gamma_\mu\, C\, \bar{d}^T)$
	1^+	$(s^T C\gamma_5\, u)(\bar{b}\,\gamma_\mu C\, \bar{d}^T) + k(s^T C\, u)(\bar{b}\,\gamma_\mu\gamma_5 C\, \bar{d}^T)$

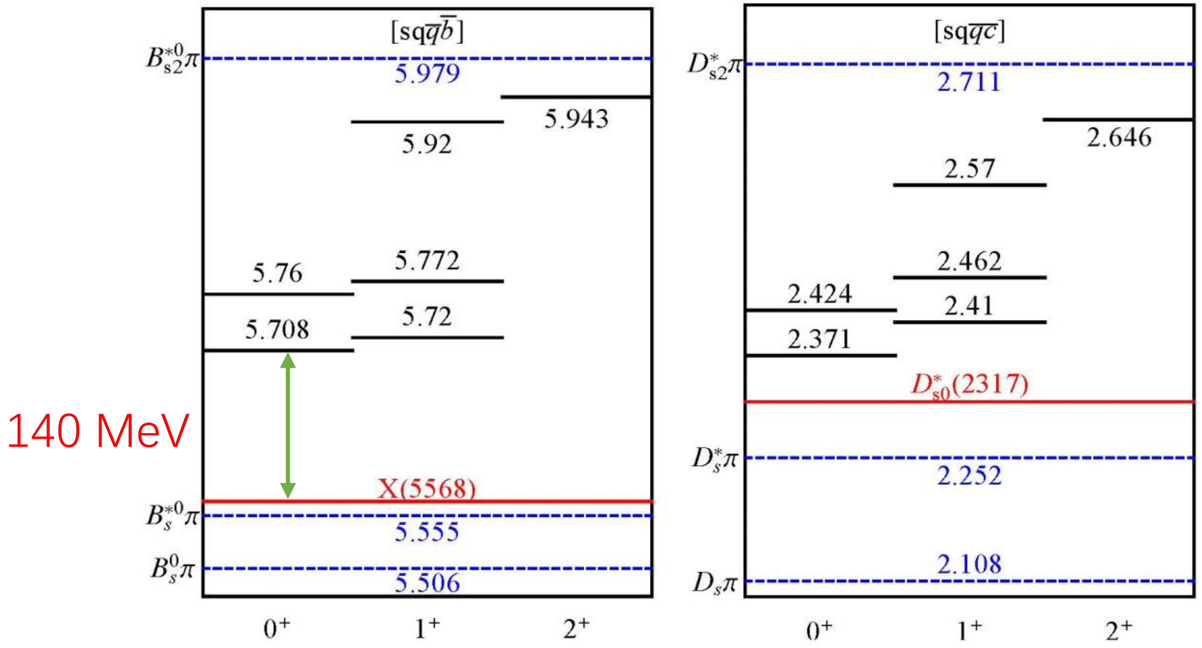
Molecule		
B^*K	1^+	5186 ± 13
BK	0^+	5195 ± 15
$B_s^*\pi$	1^+	5200 ± 18
$B_s\pi$	0^+	5199 ± 24
Four-quark $(su)(\overline{bd})$		
A_b	1^+	5186 ± 16
S_b	0^+	5196 ± 17

$\Rightarrow$ not pure molecule or 4-quark state, can mix $B\bar{K}$ & S_b ($\sin 2\theta$=0.15)

X(5568): tetraquark?

- W. Wang, R.L. Zhu, 1602.08806 [CMI: diquark]

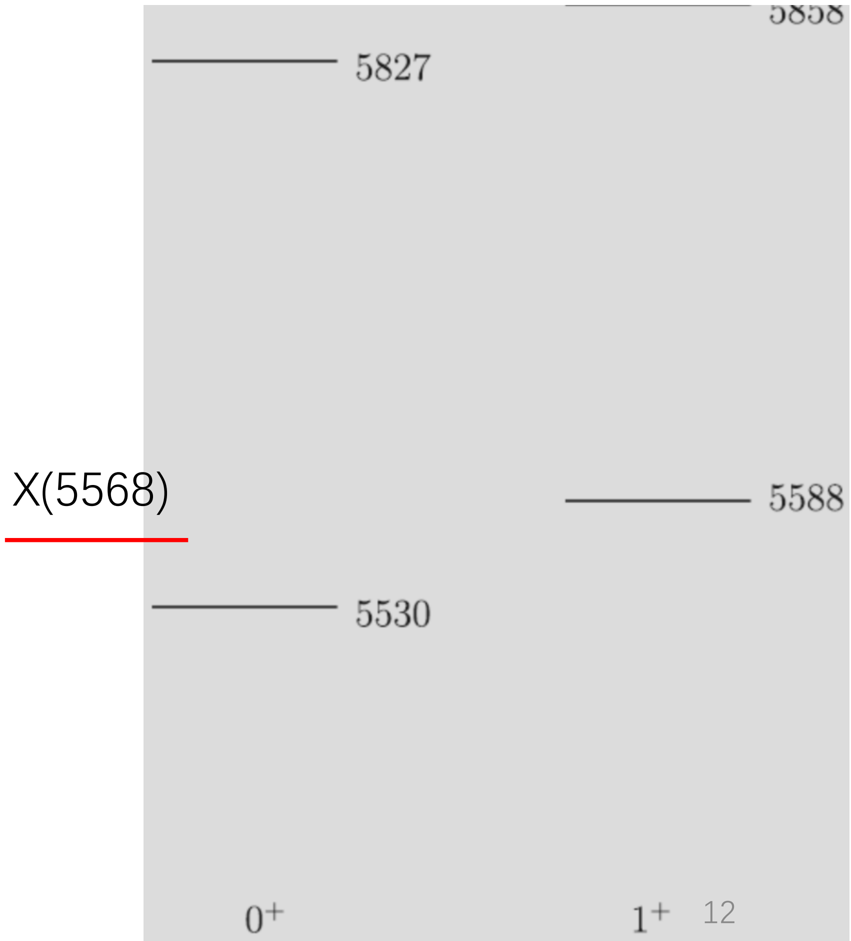
  ⇒ mass: not favored



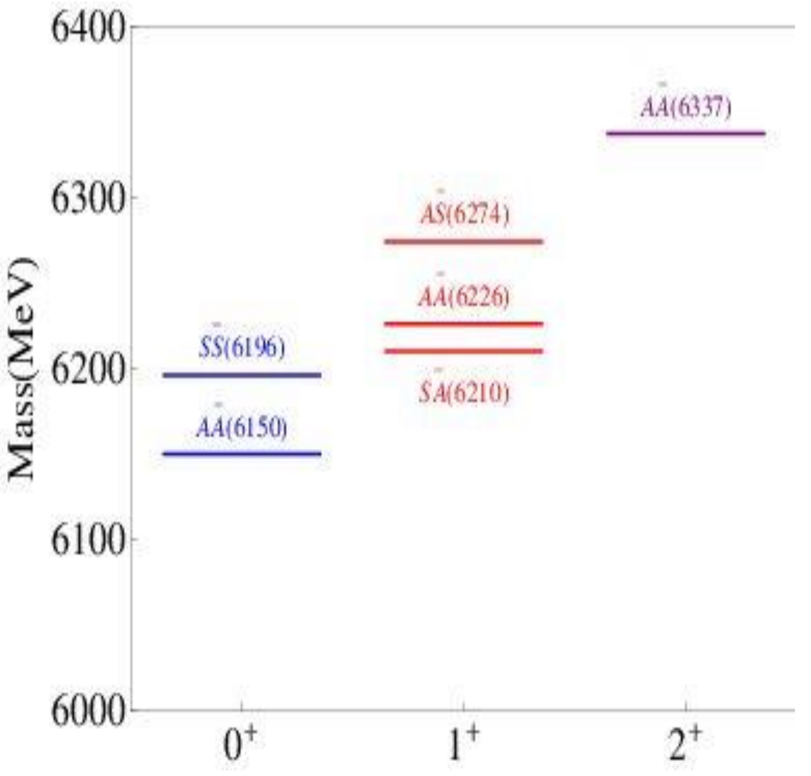
- Fl. Stancu, 1603.03322 [CMI]

  ⇒ mass: OK

- Y.R.Liu, X.Liu, S.L.Zhu, 1603.01131 [CMI]



X(5568): tetraquark?



- Q.F. Lv, Y.B. Dong, 1603.06316 [GI model: diquark]
  ⇒ mass: NO
- Espositoa, Pilloni, Polosa, 1603.07667 [hybridized tetraquark]
  ⇒ mass: NO
- Ali,Maiani, Polosa, Riquer, 1604.01731 [diquark]
  ⇒ mass: NO
- X.Y. Chen, J.L. Ping, 1604.05651 [CQM, $\mathbf{0}^+$]

$qq-\bar{q}\bar{q}$	$E_{\bar{3}\otimes 3}$	$E_{6\otimes\bar{6}}$	E_{cc}
$su\bar{d}\bar{b}$	6397.6	6466.4	6351.0

  ⇒ mass: diquark too high, no mole
- Goerke et.al., 1608.04656 [4-quark]
  ⇒ can fit width with 5568 or 5771

X(5568): more discussions

- X.H. Liu, G. Li, 1603.00708 [triangle singularity]
  $\Rightarrow$ not rescattering effects
- Y. Jin, S.Y. Li, S.Q. Li, 1603.03250 [production]
  $\Rightarrow$ difficult to understand large production rate
- T.J. Burns, E.S. Swanson, 1603.04366 [th., cusp, mole., tetra.]
  “none of the interpretations seems a natural fit for X(5568)”
- F.K. Guo, U.-G. Meissner, B.S. Zou, 1603.06316 [tetra,mole,th.]
  $\Rightarrow$ NO
- Z. Yang, Q. Wang, U.-G. Meißner, 1609.08807
  $\Rightarrow$ kinematic reflection

X(5568): more related discussions

- X.G. He, P. Ko, 1603.02915 [EFT]: partners, decays, mass sum rules
- X.H. Liu, Ulf-G. Meißner, 1703.09043 [TS]

  "Generating a resonance-like structure in the reaction $B_c \to B_s\pi\pi$"
- W. Chen, H.X. Chen, X. Liu, T.G. Steele, S.L. Zhu, 1705.10088 [QSR]

  $\Rightarrow sq\bar{q}\bar{c}$, $qq\bar{q}\bar{c}$, $sq\bar{q}\bar{b}$, $qq\bar{q}\bar{b}$
- F.S. Yu, 1709.02571

  $\Rightarrow$ detectable weakly decaying $bs\bar{u}\bar{d}$ [X(5568): $b\bar{s}u\bar{d}$ or $b\bar{s}\bar{u}d$]

Content

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  - (1) molecule picture
  - (2) tetraquark picture
  - (3) more discussions

  } ~40

- Spectra in CMI model
- Production problem
- Puzzles to be answered
- Summary

HEP 找到 1 笔记录

1. **Evidence for a $B_s^0\pi^\pm$ state**
D0 Collaboration (V.M. Abazov (Dubna, JINR) *et al.*). Feb 24, 2016. 8 pp.
Published in **Phys.Rev.Lett. 117 (2016) no.2, 022003**
FERMILAB-PUB-16-038-E
DOI: 10.1103/PhysRevLett.117.022003
e-Print: **arXiv:1602.07588 [hep-ex]** | PDF
References | BibTeX | LaTeX(US) | LaTeX(EU) | Harvmac | EndNote
CERN Document Server; ADS Abstract Service; OSTI.gov Server; Link
详细记录 - Cited by 129 records 100+

Decay ?

Spectra in CMI model

- $H = \sum_i m_i^{eff} + \sum_{i<j} C_{ij}\lambda_i \cdot \lambda_j \, \sigma_i \cdot \sigma_j$

  simple, basic features, mass differences
- Stancu, 1603.03322:

  "difficulty of extracting effective quark masses, from mesons and baryons, to be used in multiquark systems" ,

  "large value of $C_{u\bar{d}}$ and color-mixing play key role"
- Even can be used: mass uncertainty?
- Ours: "X(5568)&partners" where low quark mass to recover DsJ(2632)?
- Improvments in applying the model to multiquark states!

Spectra in CMI model

- Our strategy:

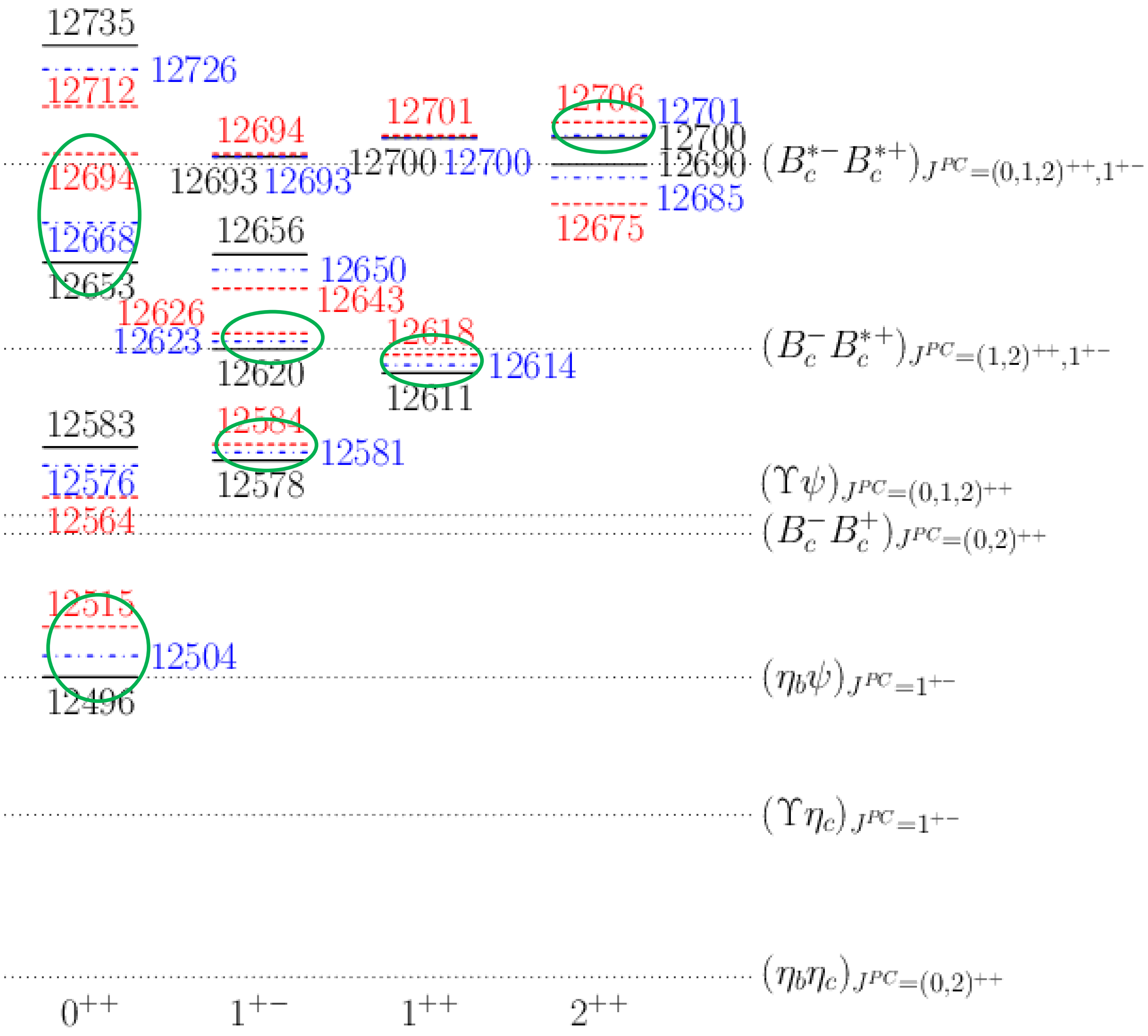
 (1) Important color-mixing (basis independent results?)

 (2) M= $\sum_i m_i^{eff} + < H_{CMI} >$ as upper limit

 (3) M= $M_{ref} - < H_{CMI} >_{ref} + < H_{CMI} >$, find lower limit and roughly reasonable masses

 (4) Effective force within diquark: stable or narrow multiquarks

- With these considerations, non-existence of X(5568) is expected.



Even if X(5568) does not exist, more interesting exotics are worthwhile search for

[Y.R. Liu, X. Liu, S.L. Zhu, 1603.01131 and following CMI studies]

Production problem [Y. Jin, S.Y. Li, 1603.03250]

- Most general hadrons can be produced both in decay and directly in multiproduction process of high energy collisions
- Exotic hadrons produced in decays of heavier hadrons, but difficult in direct production in multiproduction processes
- High mass: X(5568) in decay hard.
- Production in D0: multiproduction process

production mechanism must be quite special if exist.

Difficulty of production of multiquark states (Unitarity)

ALL quarks go into hadrons (confinement--Tous les hommes sont mortels！）

Formal descriptions: by a unitary time evolution operator

$$\sum_h |<h|U|q>|^2 = <q|U^+U|q> = \sum |q><q| = \sum |h><h| = 1 \qquad \sum_{h=B,\bar{B},M} |<h|U|q>|^2 \sim 1-\varepsilon, \ \varepsilon \to 0^+$$

Total probability to become any state of hadron system is 1
'Reversal employment' of the Gell-Mann–Zweig constituent quark model, where all the quark states and the hadron states are different bases of the *same* Hilbert space of states/static -> production

Most of the limited space has been occupied by general hadrons, not any more left for the populated exotics---they really of large population even only considering the heavy

See, Unitarity and Entropy Change in Exclusive Quark Combination Models, arXiv:1005.4664 [hep-ph] ; Exotic hadron production in quark combination model, Phys.Rev. C80 (2009) 035202;talks here at Moriond QCD'11(unitarity and exotic) , and some recent ones to repeat this observation

Difficulty of production of multiquark states (colour connection)

- **Complexity of the colour structure of the multiquark hadrons**
- **Eg, qqbar qqbar four quark sysytem**

$$(3_1 \otimes 3_3) \otimes (3_2^* \otimes 3_4^*) = (3_{13}^* \oplus 6_{13}) \otimes (3_{24} \oplus 6_{24}^*) = (3_{13}^* \otimes 3_{24}) \oplus (6_{13} \otimes 6_{24}^*) \oplus \cdots$$

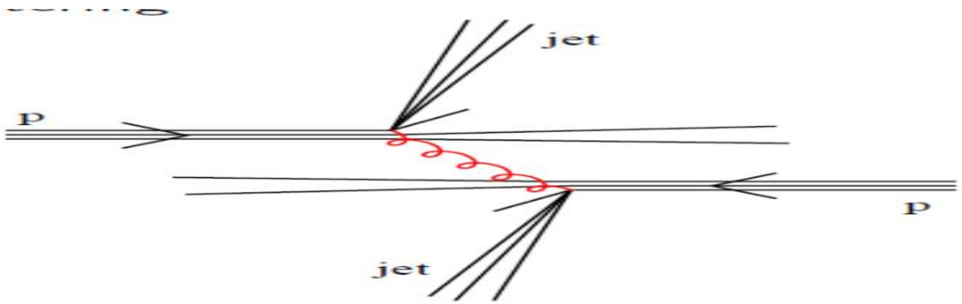
$$(3_1 \otimes 3_2^*) \otimes (3_3 \otimes 3_4^*) = (1_{12} \oplus 8_{12}) \otimes (1_{34} \oplus 8_{34}) = (1_{12} \otimes 1_{34}) \oplus (8_{12} \otimes 8_{34}) \oplus \cdots,$$

$$(3_1 \otimes 3_4^*) \otimes (3_3 \otimes 3_2^*) = (1_{14} \oplus 8_{14}) \otimes (1_{32} \oplus 8_{32}) = (1_{14} \otimes 1_{32}) \oplus (8_{14} \otimes 8_{32}) \oplus \cdots,$$

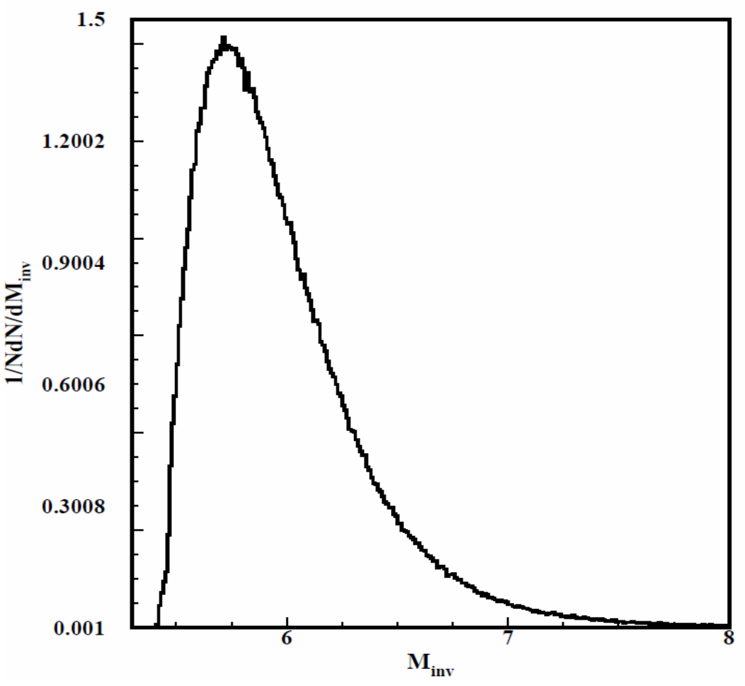
- **--->N-body problem? sub-clusters? This is a problem both in hadron (static properties) as well as in production**

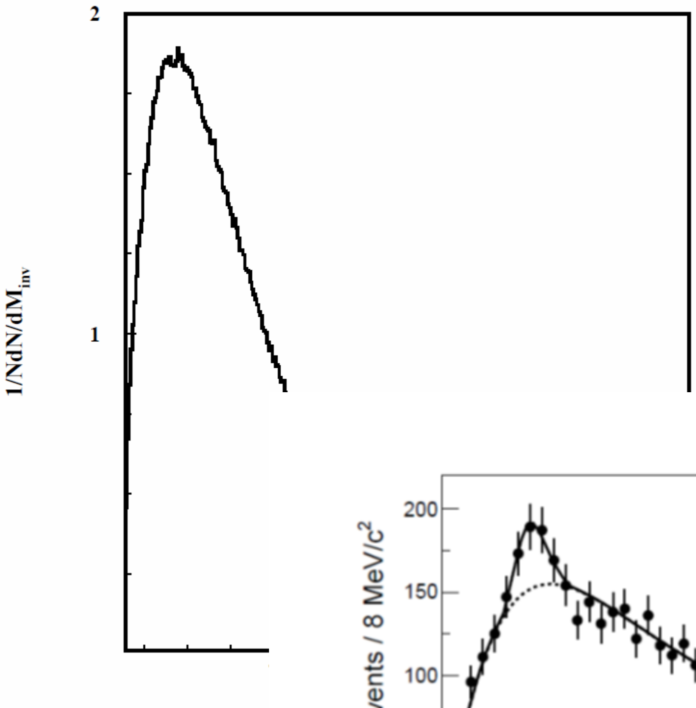
- Colour reconnecion, colour recombination…, total probability again 1
- Probability of rare connection is small
- See, e.g, Studying color connection effects of e+e−→cc¯cc¯→Ξcc+Xe+e−→cc¯cc¯→Ξcc+X process within Quark Combination Model , P.R. D91 (2015) no.11, 114017 ,Search for a doubly charmed hadron at B factories, P.R.D89 (2014) no.9, 094006, Colour connections of four quark QQ¯Q′Q¯′ system and doubly heavy baryon production in e+e-e+e- annihilation, P.L.B727 (2013) 468-473

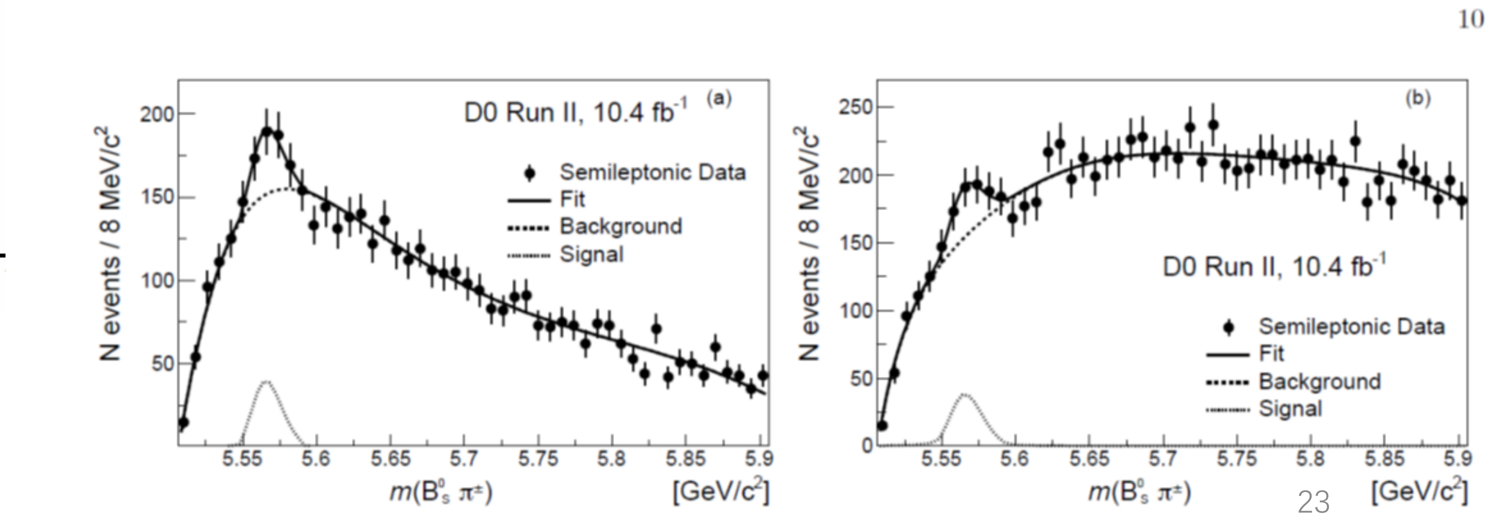
- e+e- → jet +jet,



Line shape: peak around threshold, l-Bpi,R-Dpi







Puzzles to be answered

- Is X(5568) a resonance?

  If Yes: D_{sJ}(2632)? other exotic hadrons?

  production mechanism? why not in other experiments?

  is there any decisive channel?

  similar to Ξcc (SELEX: 3519 MeV LHCb: 3621.40 MeV)?

  ...

  If No: why is there a signal at D0? How to apply theoretical models?

  [Recall Θ(1540) and D_{sJ}(2632).]
- Whether X(5568) exists or not:

  inconsistency in theories? challenging methods? need improvements? ···

Summary

- Most studies disfavor molecule, tetraquark, or non-resonance interpretations for X(5568).
- Inconsistent results (ex. & th.) need to be understood.
- X(5568) motivates other exotic multiquarks which are worthwhile search in hadron decays or e^+e^- collisions.

Thank you very much!