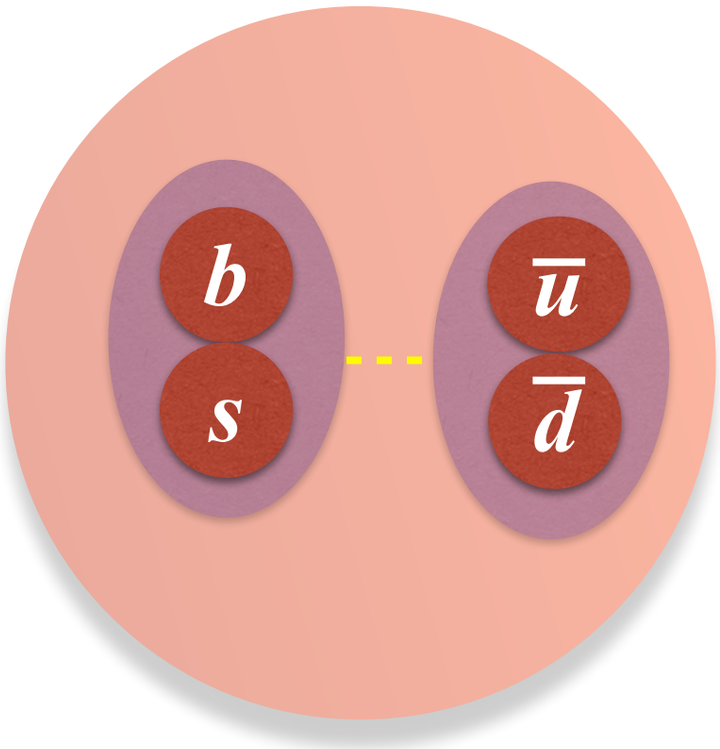
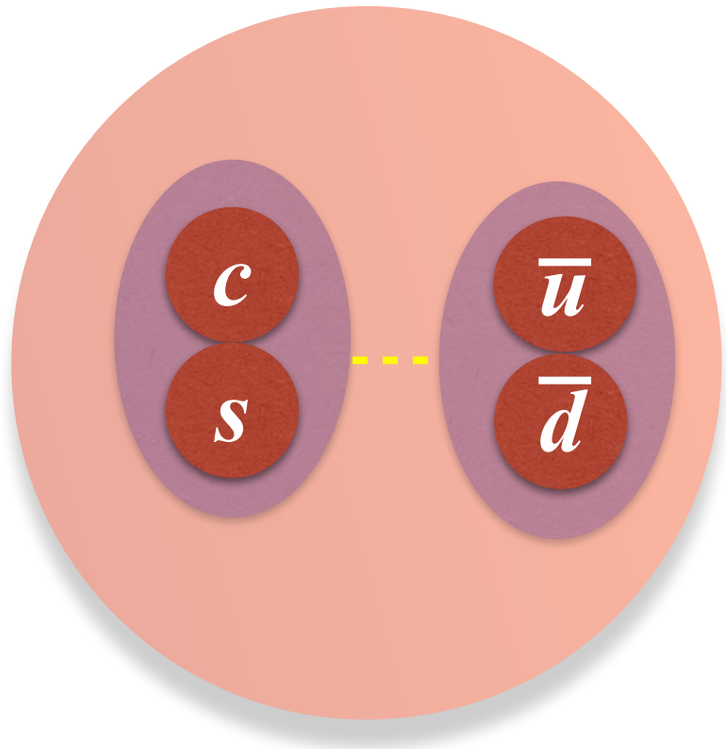
$bs\bar{u}\bar{d}$ and $cs\bar{u}\bar{d}$

Promising Detectable Tetraquarks



Fu-Sheng Yu

Lanzhou University



12th International Workshop on Heavy Quarkonium

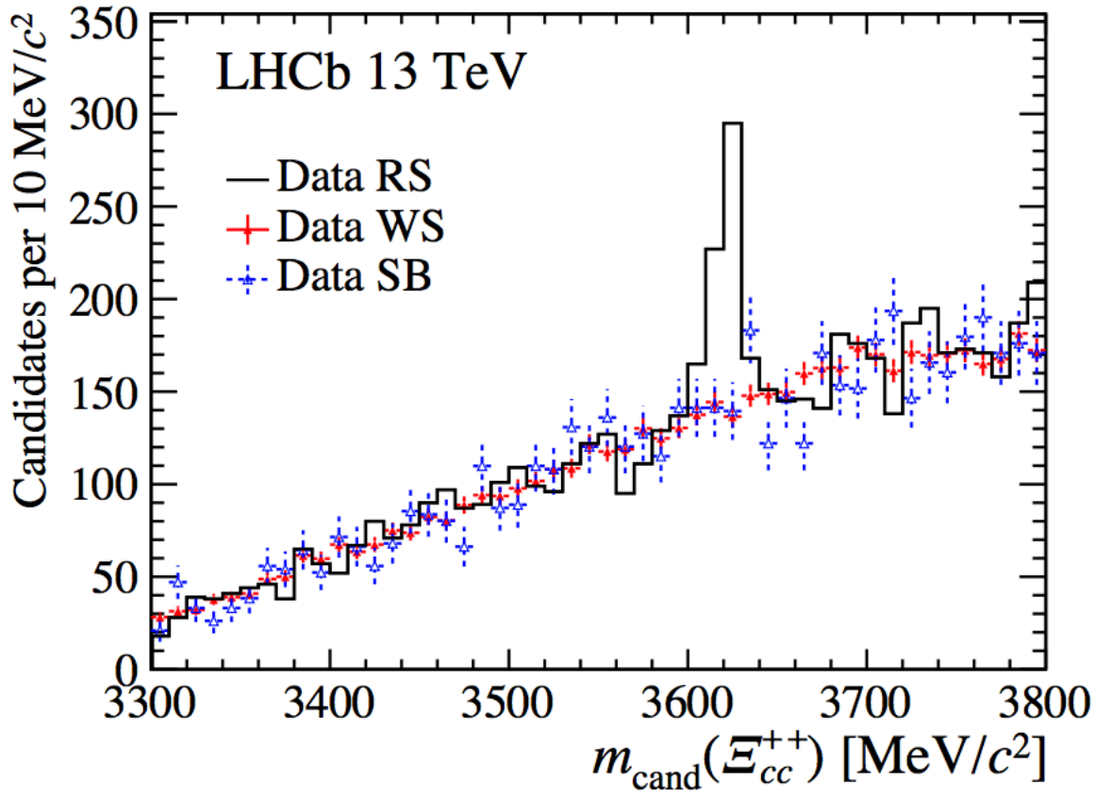
@ Peking University 2017.11.06

based on [**FSY**, arXiv:1709.02571]

Before the tetraquarks

LHCb observed Ξ_{cc}^{++} recently via $\Xi_{cc}^{++} \rightarrow \Lambda_c^+ K^- \pi^+ \pi^+$

[LHCb, PRL119,112001(2017)]

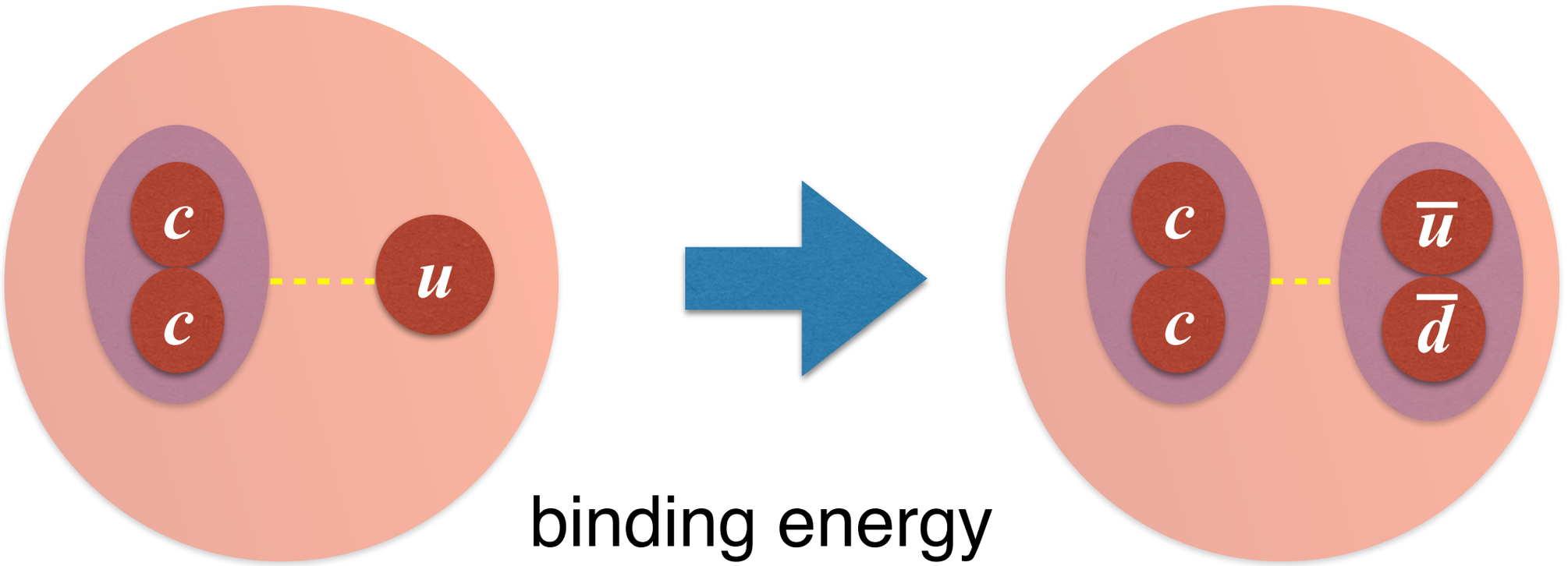


Giovanni Passaleva:

"A group of Chinese theorists provided fundamental inputs to drive the analysis to the right direction and gave key suggestions to achieve this result."

[**FSY**, H.Y.Jiang, R.H.Li, C.D.Lü, W.Wang, Z.X.Zhao, arXiv:1703.09086]

What can we do further?

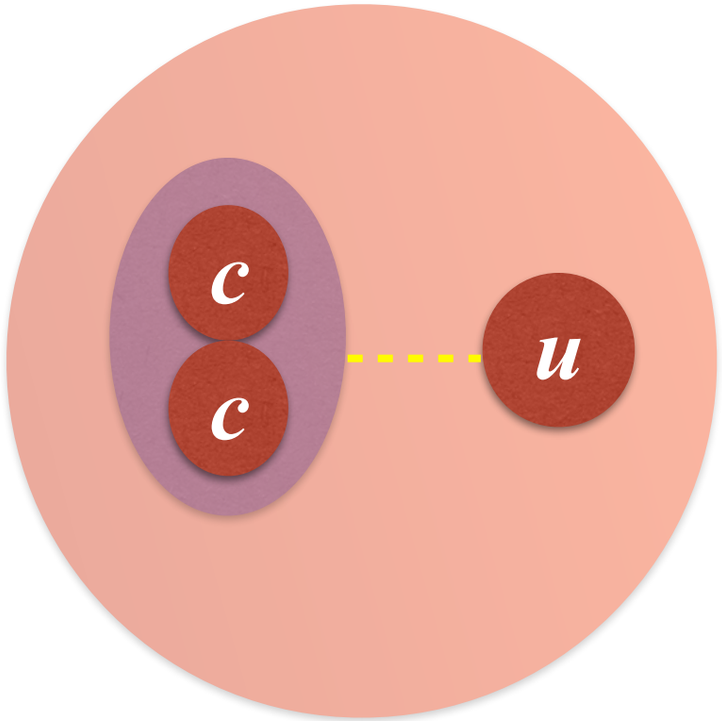


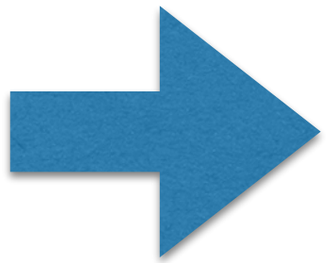
binding energy
of cc-diquark

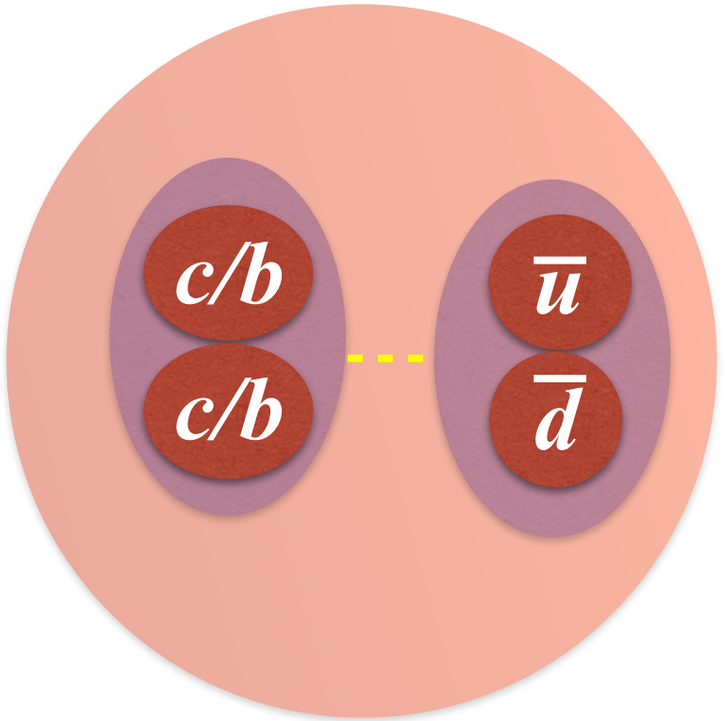
Ξ_{cc}^{++}

cc-Tetraquark

Search for tetraquarks?







Ξ_{cc}^{++}

T_{cc}, T_{cb}, T_{bb}

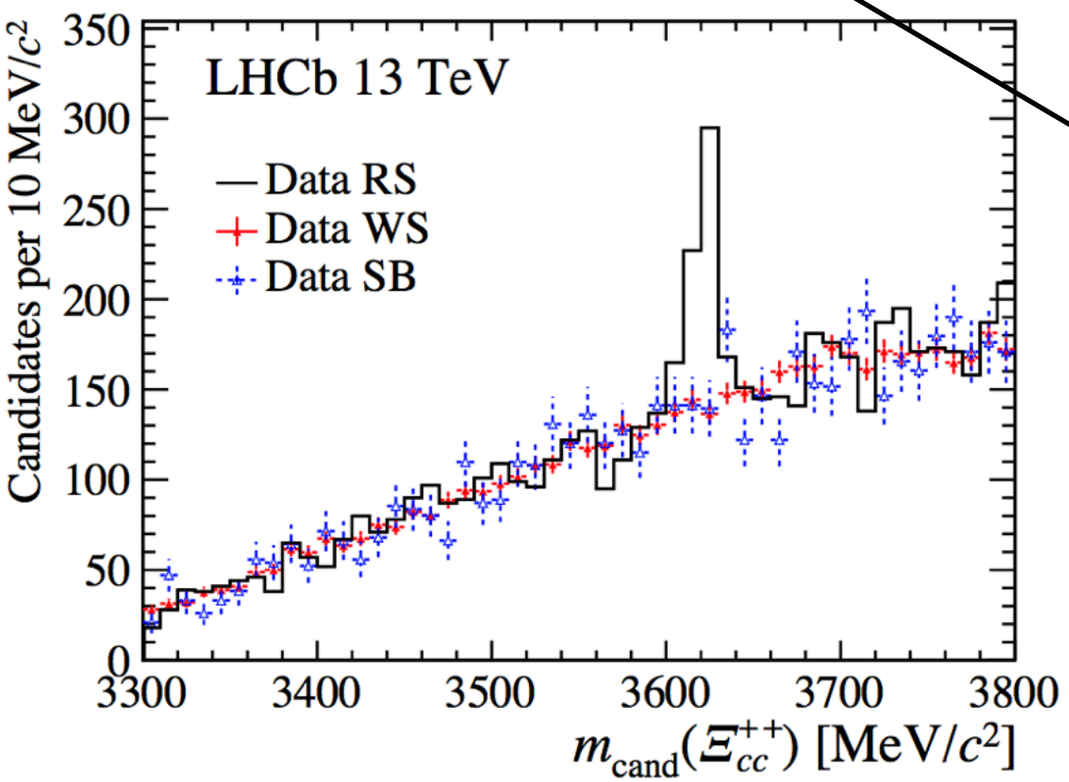
Karliner, Rosner, 1707.07666
Eichten, Quigg, 1707.09575
Z.G.Wang, 1708.04545
Mehen, 1708.05020
Ader, Richard, Taxil, PRD82'
Du,Chen,Chen,Zhu,PRD13'
Karliner, Nussinov, JHEP13'
Francis,Hudspith,Lewis,Maltman,PRL17'
Bicudo,Scheunert,Wagner,PRD17'
Luo,Chen,Liu,Liu,Zhu,EPJC17'

See Eichten's, Karliner's, Maltman's and Mehen's talks

$$\Xi_{cc}^{++} \to \Lambda_c^+ K^- \pi^+ \pi^+$$

yield ~ 300 @ LHCb2016

[LHCb, PRL119,112001(2017)]



strong decay of $T_{cc} \to D^0 D^+$
or weak decay of $T_{cc} \to D^+ K^- \pi^+$

- Production suppressed by one order

$$f_{B_u} : f_{\Lambda_b} \sim 1 : 0.1$$

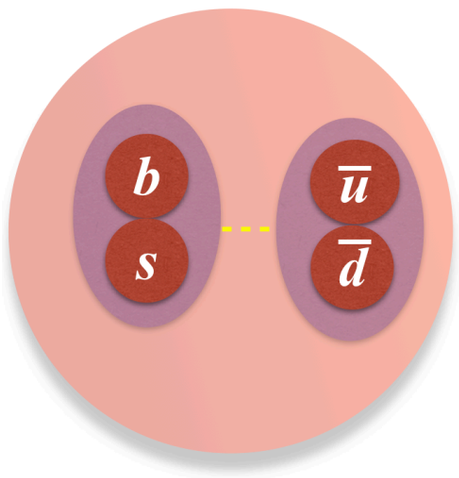
- Expected O(10) events
- Waiting more data @ LHCb RUN-II for *cc*-tetraquark

$$\frac{\sigma(b)\times Br(b\to J/\Psi)}{\sigma(c)\times Br(c\to s)} \sim 10^{-3}$$

⇒ **Impossible** to observe T_{bc} & T_{bb} @ LHCb Run2

What are detectable?

$[\bar{b}\bar{s}][ud]$ Tetraquarks



Lowest-lying state, 0^+

Strong decay $\longrightarrow B^0K^+$

5773

BK

Weak decay $\longrightarrow J/\Psi K^+K^+\pi^-$

$X(5568) : [\bar{b}\bar{d}][su]$ or $[\bar{b}\bar{u}][sd]$

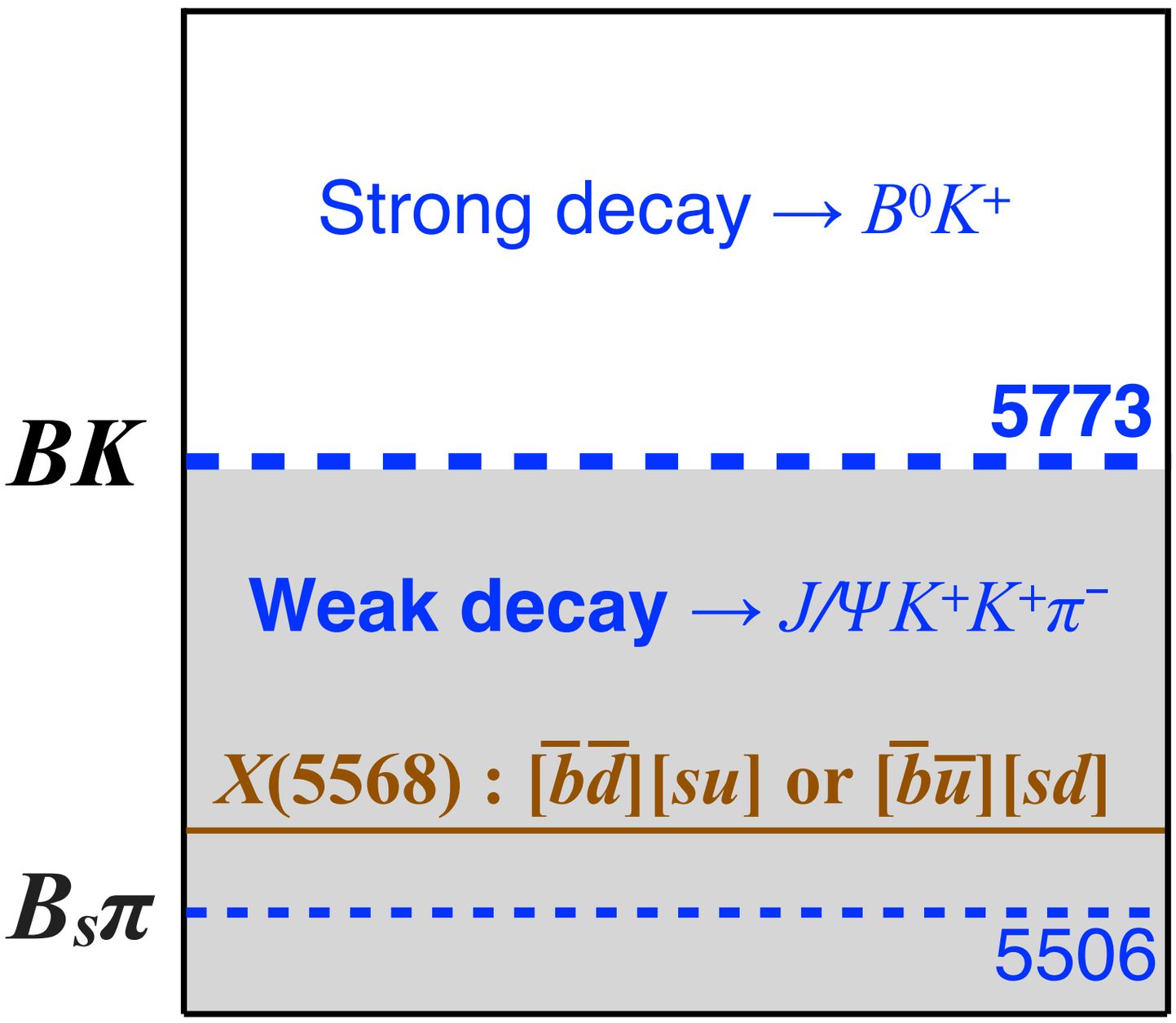
$B_s\pi$

5506

1. Higher threshold, BK is 270MeV over $B_s\pi$
2. If X(5568) exists, in SU(3) symmetry bs-tetraquark is below threshold, and weakly decay.
3. If above threshold, *Kaon* suppresses background. better than $B_s\pi$

$[\bar{b}\bar{s}][ud]$ Tetraquarks

Lowest-lying state, 0^+



@ LHCb

1. Large production
2. If below threshold, easy to observe by rejecting backgroud:
   - $\tau \sim \tau_B$ in heavy quark symmetry
   - J/Ψ involving.
3. If above threshold, $Kaon$ reduce bkg. better than $B_s\pi$

If exists below threshold

Lifetime of bs-tetraquark is expected to be $\tau \approx 1.5$ps

Lifetimes of b-hadrons

Particle	Lifetime [ps]
B^+	1.638 ± 0.004
B^0	1.520 ± 0.004
B_s (flavor-specific)	1.511 ± 0.014
B_s $(1/\Gamma_s)$	1.510 ± 0.005
Λ_b^0	1.466 ± 0.010
Ξ_b^-	1.560 ± 0.040
Ξ_b^0	1.464 ± 0.031
Ω_b^-	$1.57^{+0.23}_{-0.20}$

Long enough for observation
by **rejecting background** via real-time event selection

Production @ LHCb

3×10^5 yields of $B^- \to J/\Psi K^-$ @ 3 fb^{-1} [LHCb, arXiv:1612.06116]

$$B^+ : B^0 : B_s^0 : \Lambda_b = 1 : 1 : \lambda : \frac{\lambda}{2} \qquad \lambda \sim 0.2 - 0.3$$

[Y.Jin, S.Y.Li, S.Q.Li, PRD16']

- Production Ratio $\frac{P_{T_{bs}^-}}{P_{B^-}} = \lambda \times \frac{\lambda}{2} \times \frac{\lambda}{2} \sim (0.2 - 0.7)\% = \mathcal{O}(10^{-3})$

- Decaying branching fractions:

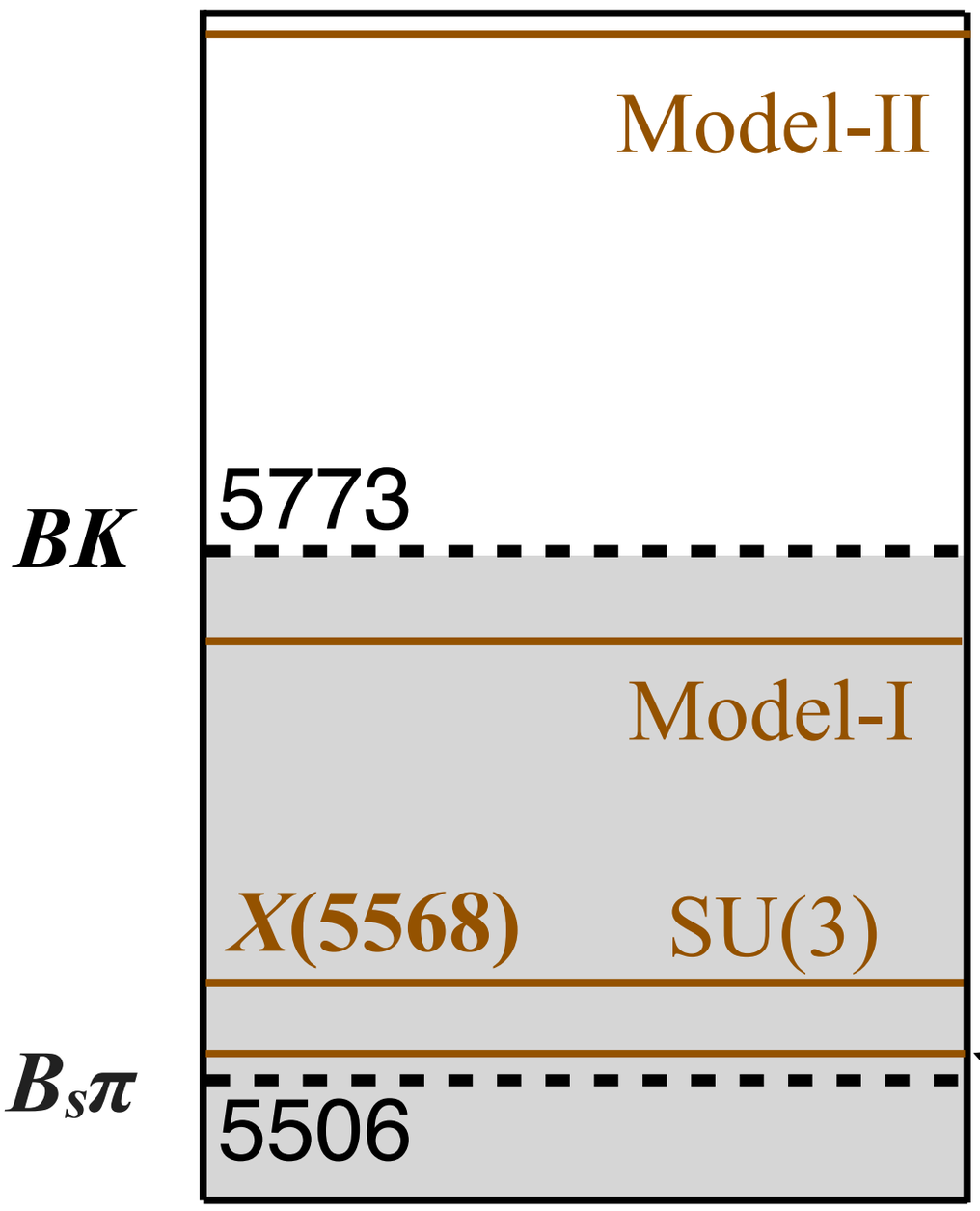
$$\mathrm{Br}(T_{bs} \to J/\Psi K^+ K^+ \pi^-) \sim \mathrm{Br}(b \to s\, J/\Psi) \sim \mathrm{Br}(B^+ \to J/\Psi K^+)$$

Expected to have hundreds of signal yields

If exists below threshold,
it must be discovered @ LHCb RUN II

$[bs][\bar{u}\bar{d}]$ Tetraquarks

Lowest-lying state, 0^+



← Model-II: simple quark model

$$=m_b^b + m_s^b + 2m_q^b + a_{bs}/(m_b^b m_s^b) - 3a/(m_q^b)^2 + B(bs)$$

[Karliner, Rosner, PRD14']

Model-I: diquark-antidiquark

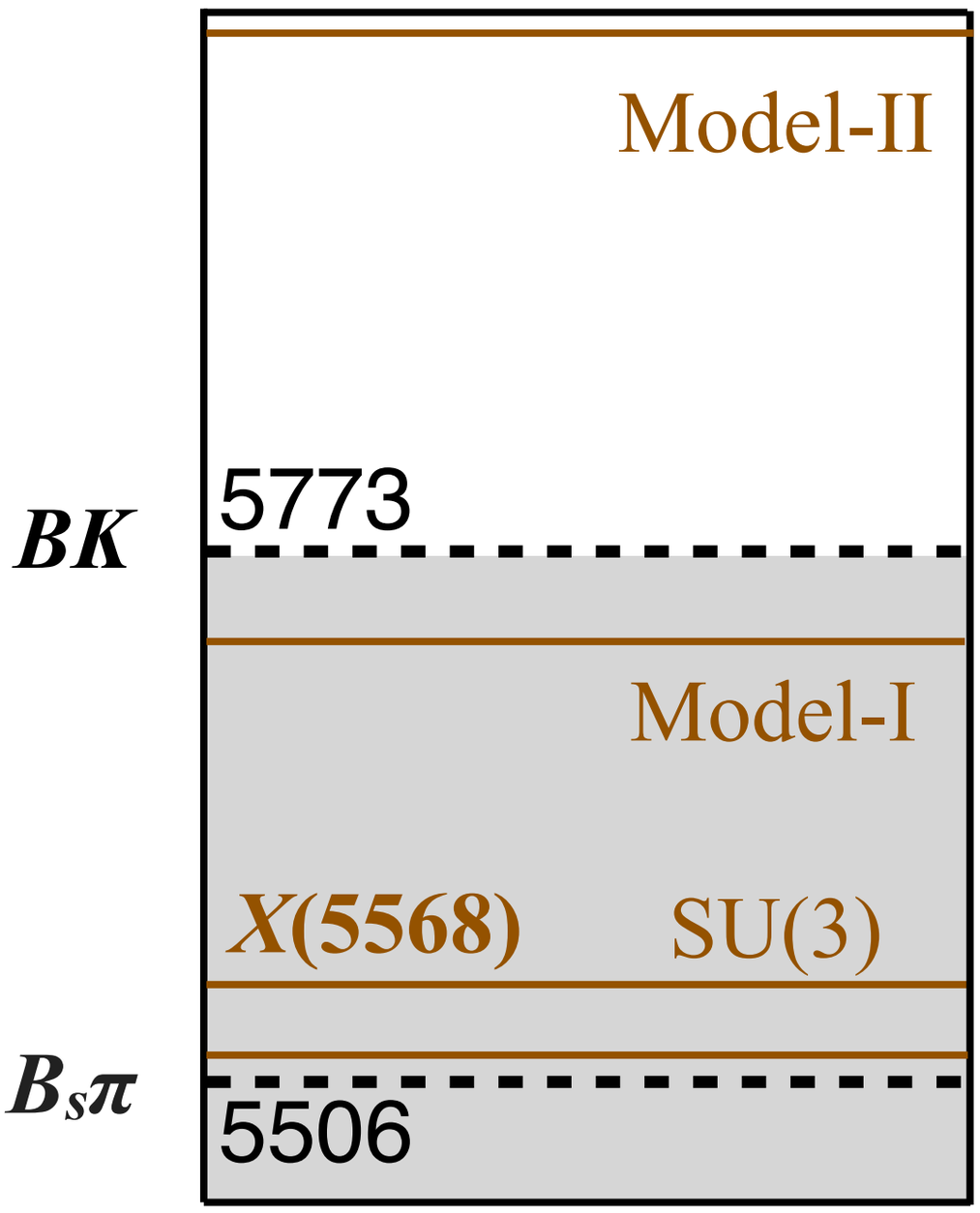
$$H = m_{[bs]} + m_{[ud]} + \sum_{i<j} 2\kappa_{ij}(\mathbf{S}_i \cdot \mathbf{S}_j)$$

[Maiani, Piccinini, Polosa, Riquer, PRD04']

[Y.R.Liu, X.Liu, S.L.Zhu, PRD93,074023]

$[bs][\bar{u}\bar{d}]$ Tetraquarks

Lowest-lying state, 0^+



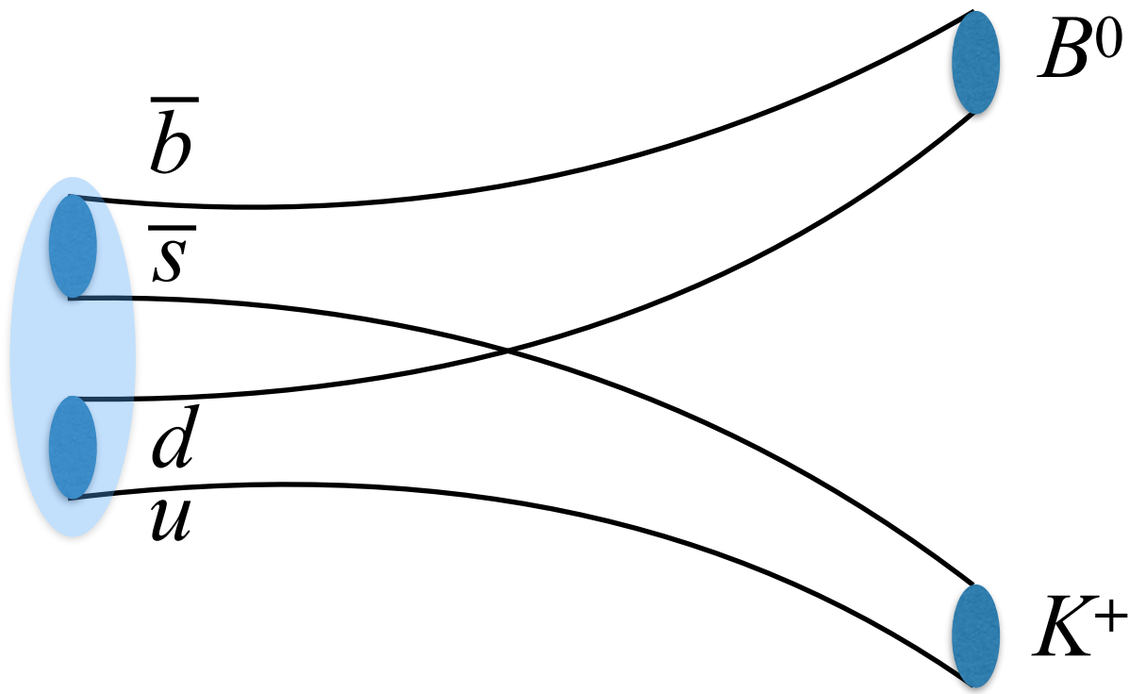
- If exists above threshold, to control background, and wait more data @ LHCb
- If nothing observed, wide width?

- If exists below threshold, must be observed @ LHCb Run II
- If nothing observed, constrain on the lower mass limit.

Strong Decays

Tetraquark

Narrow width



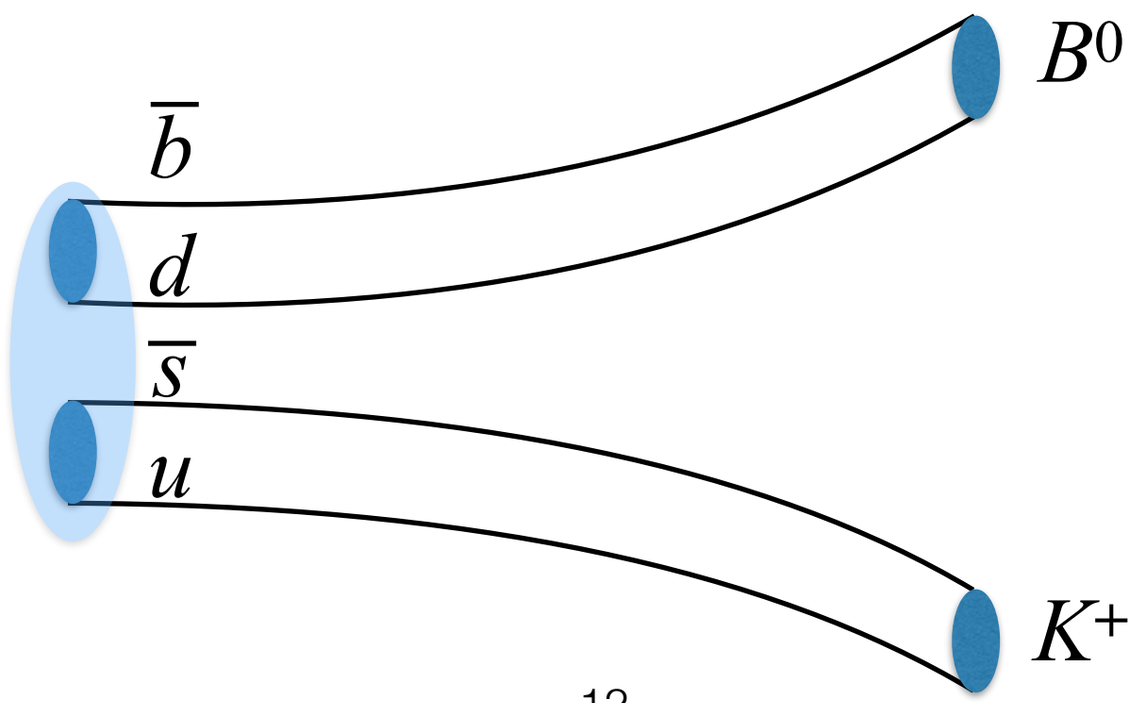
Nc

Large Nc analysis [S.Weinberg, PRL110,261601(2013)]

Molecule

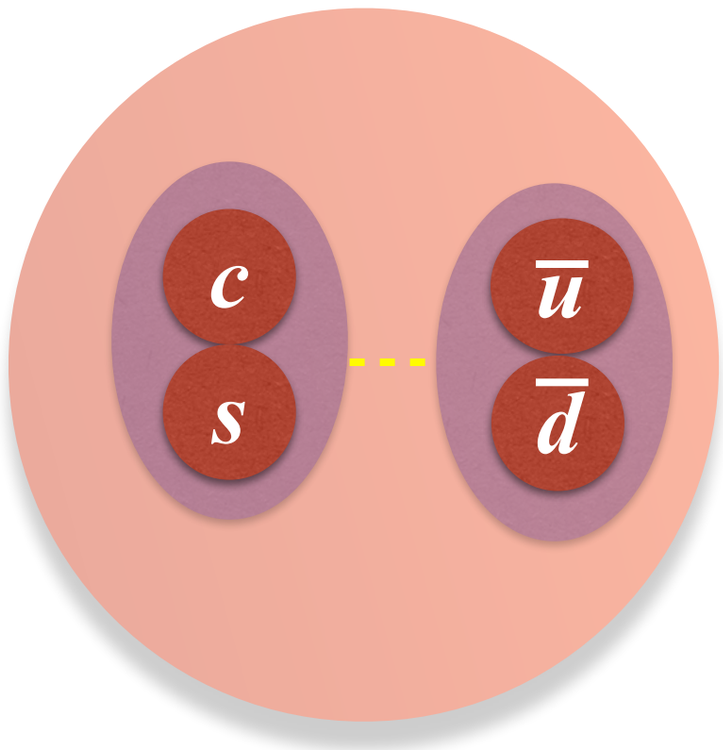
B^0K^+

Broad width

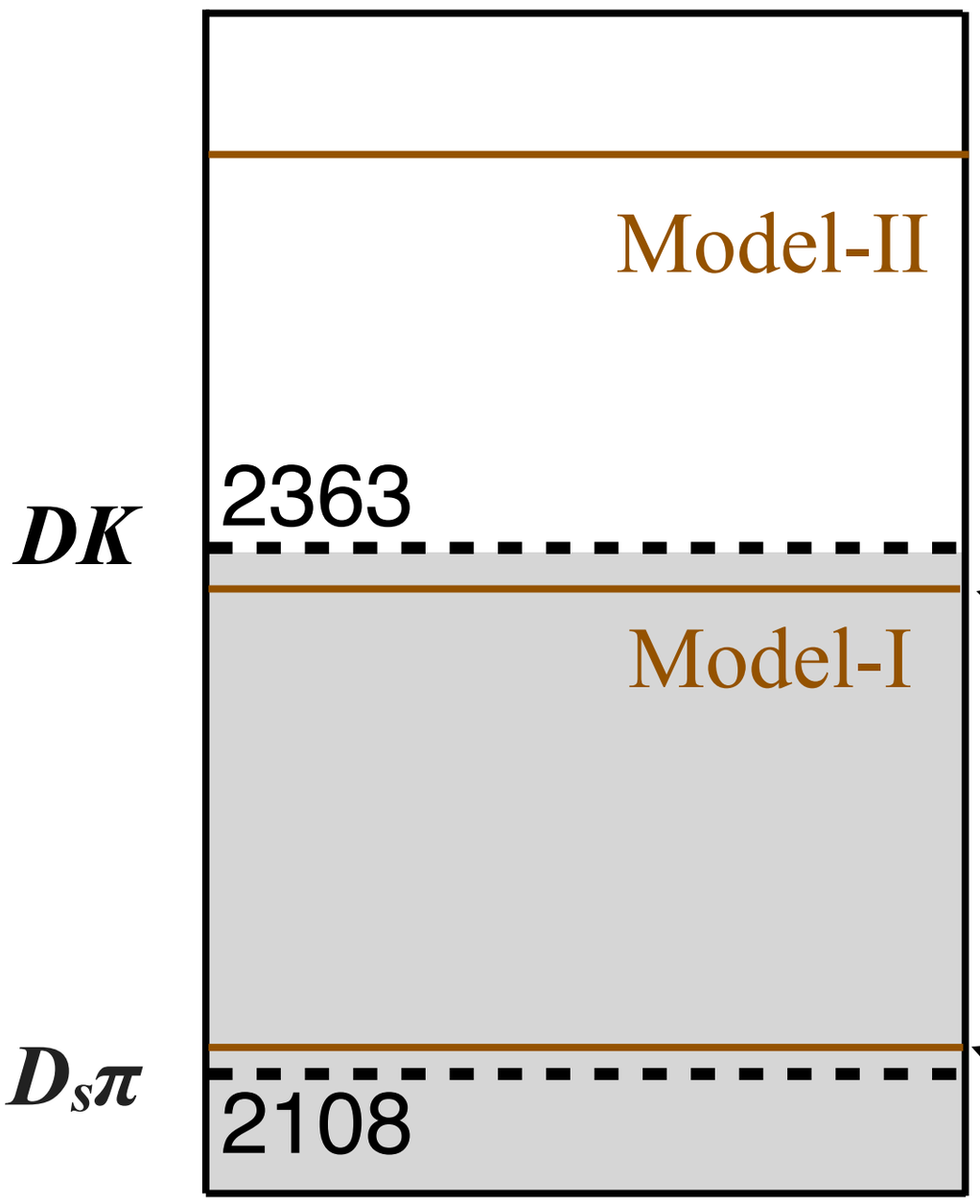


Nc × Nc

$[cs][\bar{u}\bar{d}]$ Tetraquarks



Lowest-lying state, 0^+



Strong decay

$\rightarrow D^+K^-$

[X.G.He, W.Wang, R.L.Zhu, JPG44,014003]

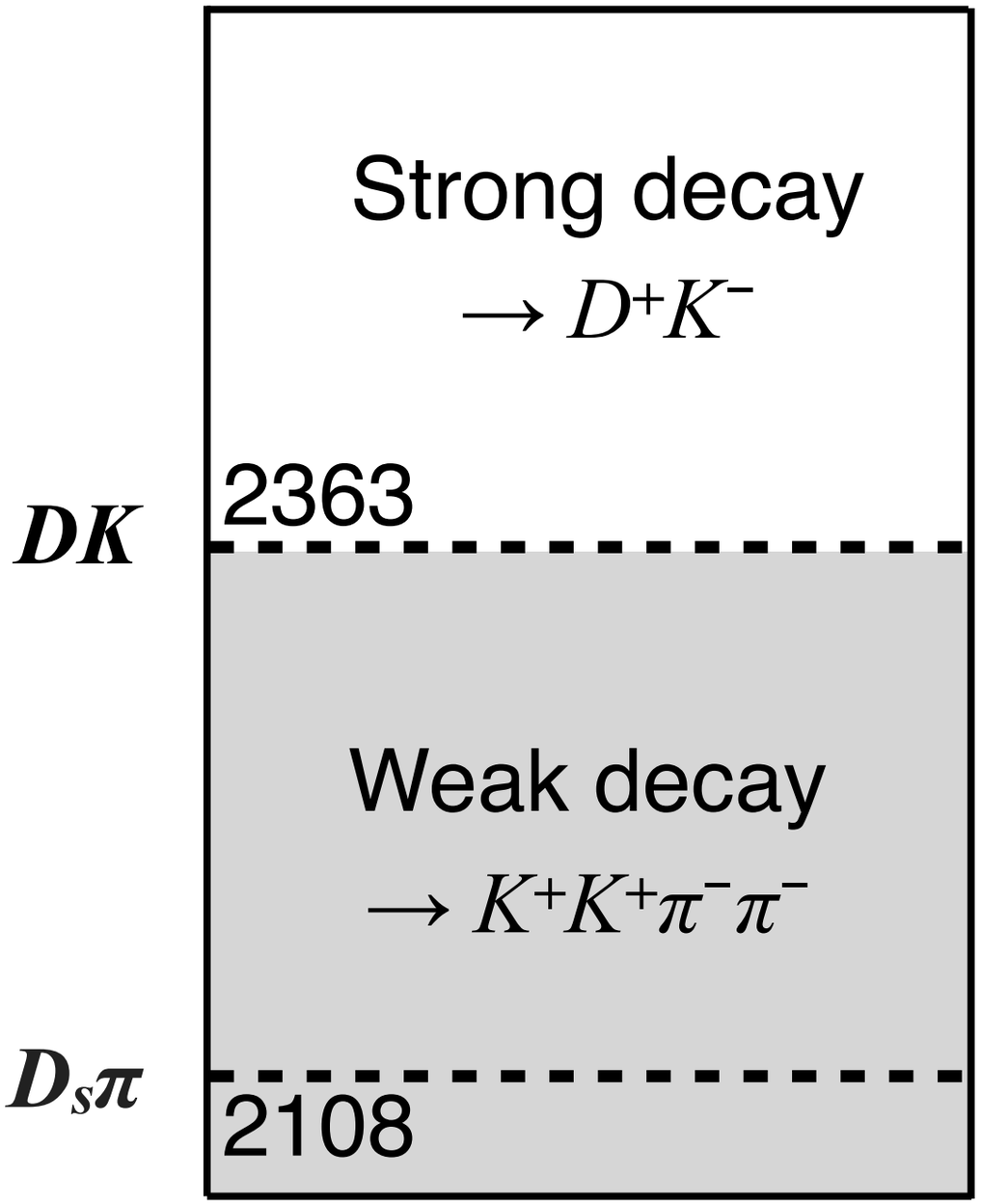
Weak decay

$\rightarrow K^+K^+\pi^-\pi^-$

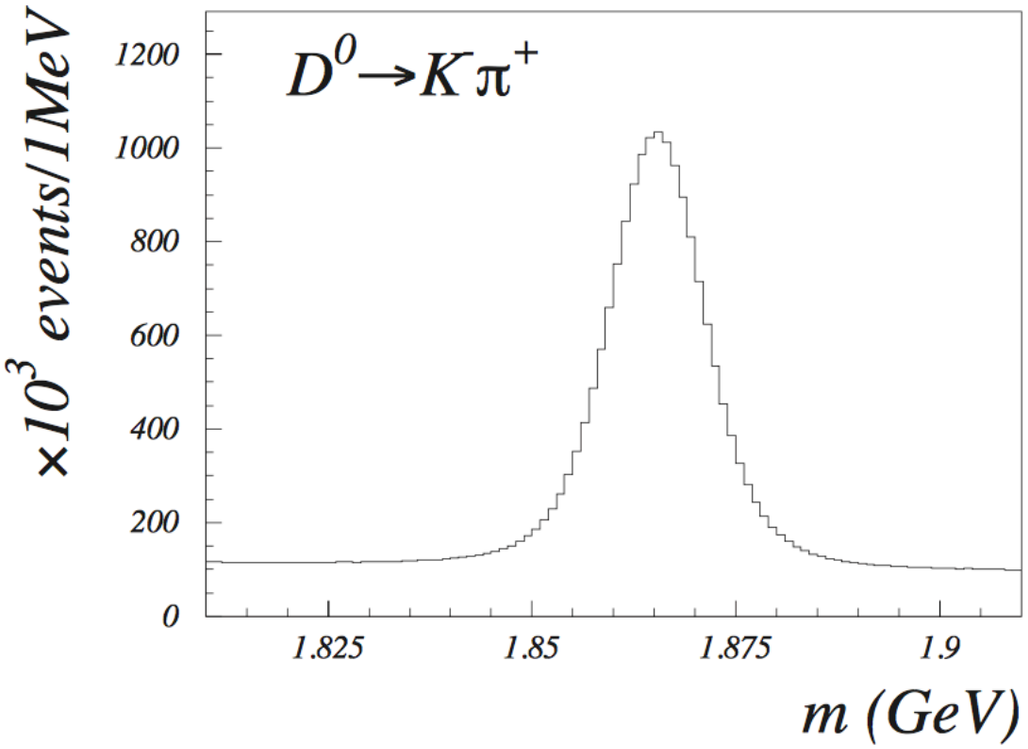
[Y.R.Liu, X.Liu, S.L.Zhu, PRD93,074023]

$[cs][\bar{u}\bar{d}]$ Tetraquarks

Lowest-lying state, 0^+



@ Belle (II)



1.5×10^7 events of $D^0 \rightarrow K^-\pi^+$
[Belle,1310.3891]

Expected O(10^4) events of cs-tetraquark @ Belle

$[bs][\bar{u}\bar{d}]$ and $[cs][\bar{u}\bar{d}]$

are the most promising

detectable

open heavy flavor

tetraquark states

Call for more theoretical calculations on the spectrum of

$[bs][\bar{u}\bar{d}]$ and $[cs][\bar{u}\bar{d}]$ Tetraquarks

Lattice? And models?

Summary

- $bs\bar{u}\bar{d}$ and $cs\bar{u}\bar{d}$ are promising detectable tetraquarks
- If exists, it must be observed in the near future
- If observed, less theoretical ambiguity:
  directly produced at pp or ee collision, it must be a resonance but not kinematic effects
- If nothing observed in the end, constrain parameters (masses or widths)
- Call for more theoretical predictions on the masses.