Discovery and Discovery Potential

of Doubly Heavy Hadrons

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*Phys.Lett.B*782(2018)412, Ali,Parkhomenko,**QQ**,Wang
*Phys.Lett.B*785(2018)605, Ali,**QQ**,Wang
*Chin.Phys.C*45(2021)103106, **QQ**,Shen,Yu
*Phys.Rev.D*104(2021)114009, Jin,Li,Liu,**QQ**,Si,Yu
*Phys.Rev.D*105(2022)L031902, **QQ**,Shi,Wang,Yang,Yu,Zhu

第八届手征有效场论研讨会

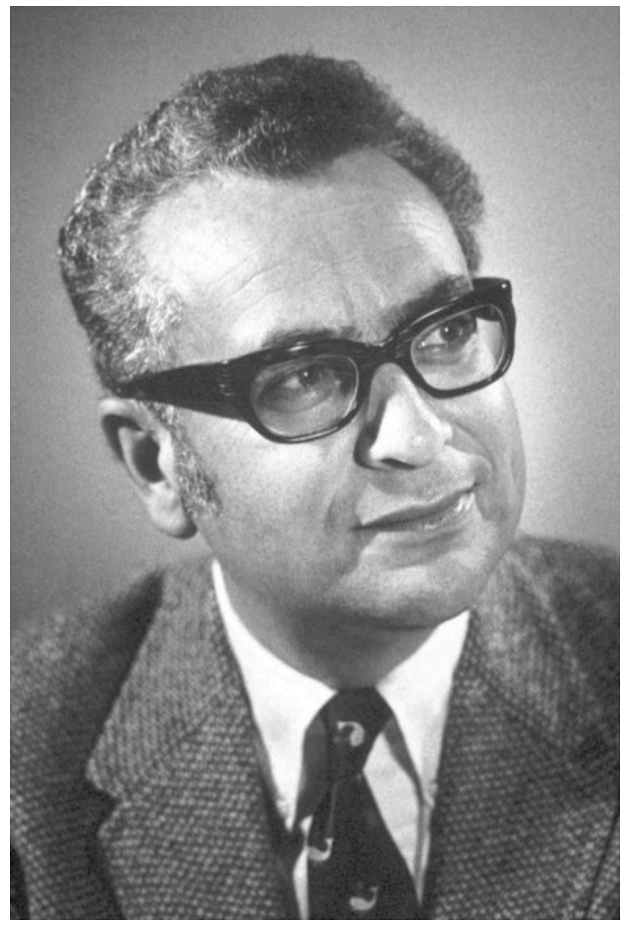
2023年10月27-31日@河南大学（开封）

Contents

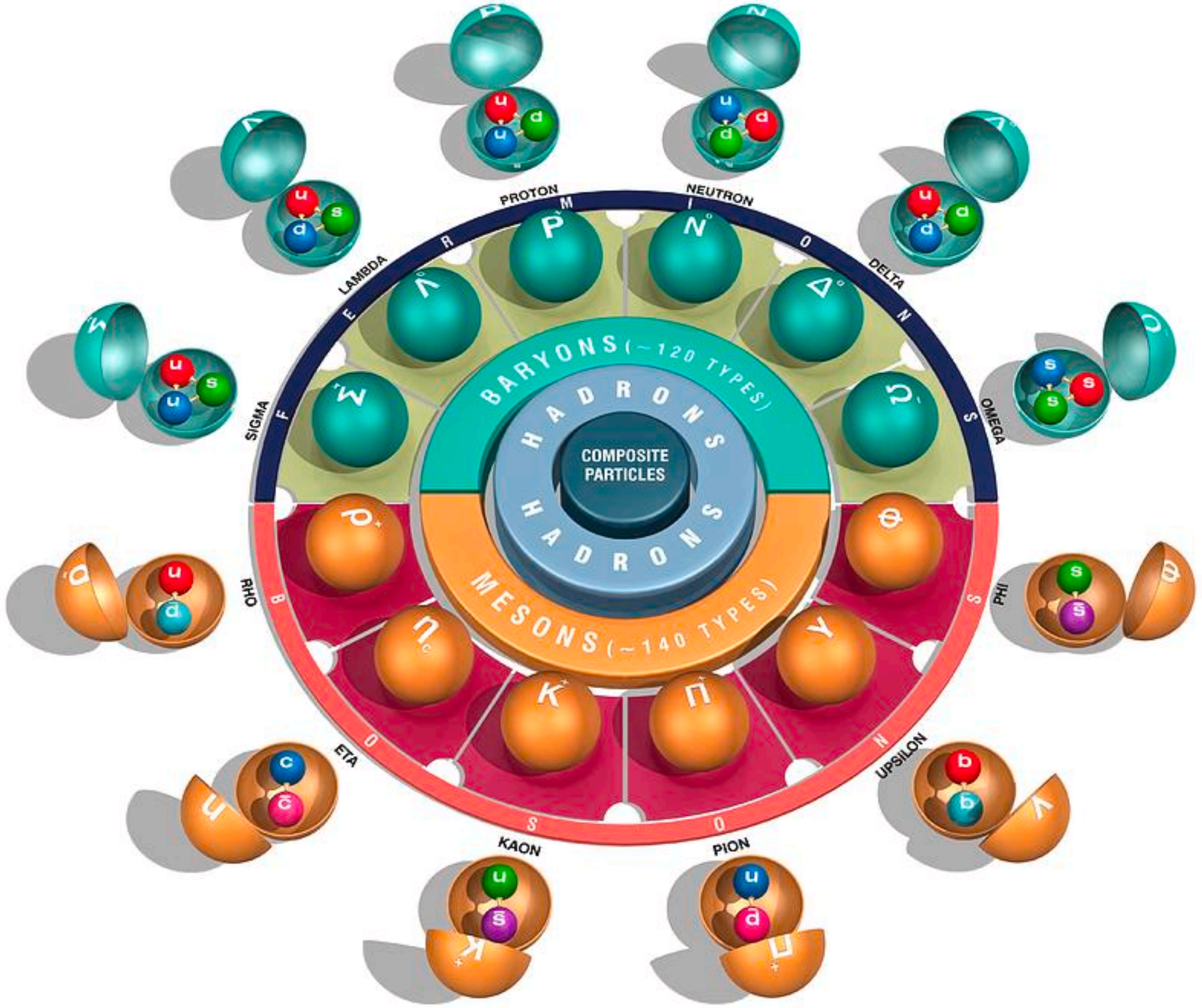
- Why do we need doubly heavy hadrons?
- Discovery of T_{cc}
- Discovery potential of Ξ_{bc}

The quark model

- Old myth
- New life



Murry Gell-Mann
1969 Nobel Prize for physics



Three new milestones

- Observation of tetraquarks

  [BESIII, *Phys.Rev.Lett.* 110 (2013) 252001]

  The ***Physics*** 2013 “Highlights of the Year” (rank 1st)

- Observation of pentaquarks

  [LHCb, *Phys.Rev.Lett.* 115 (2015) 072001]

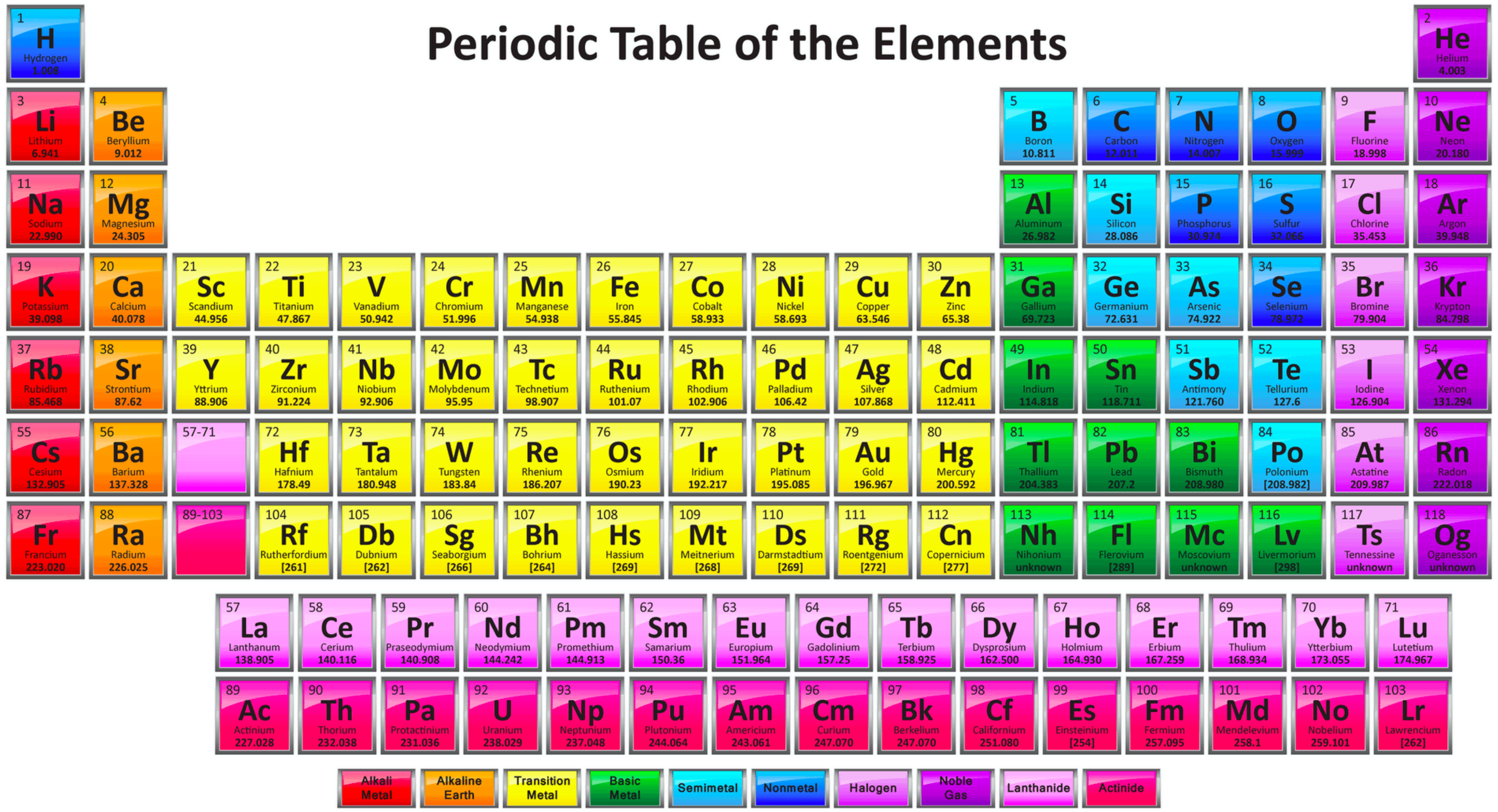
  The ***Physics World*** 2015 “top-10 breakthroughs”

- Observation of a double-charm baryon Ξ_{cc}^{++}

  [LHCb, *Phys.Rev.Lett.* 119 (2017) 112001]

  国家科技部“2017年度中国科学十大进展”

“Periodic table of the hadrons”



$\pi, K,$ …	D	B	η_c	B_c	η_b				
p, n, …	Λ_c	Λ_b				Ξ_{cc}	Ξ_{bc}	Ξ_{bb}	
	X(2900)		Z_c			T_{cc}	T_{bc}	T_{bb}	X(6900)
			P_c						

Z_c, P_c: a new period

Ξ_{cc}, X(6900): a new main group

Beyond stamp collecting

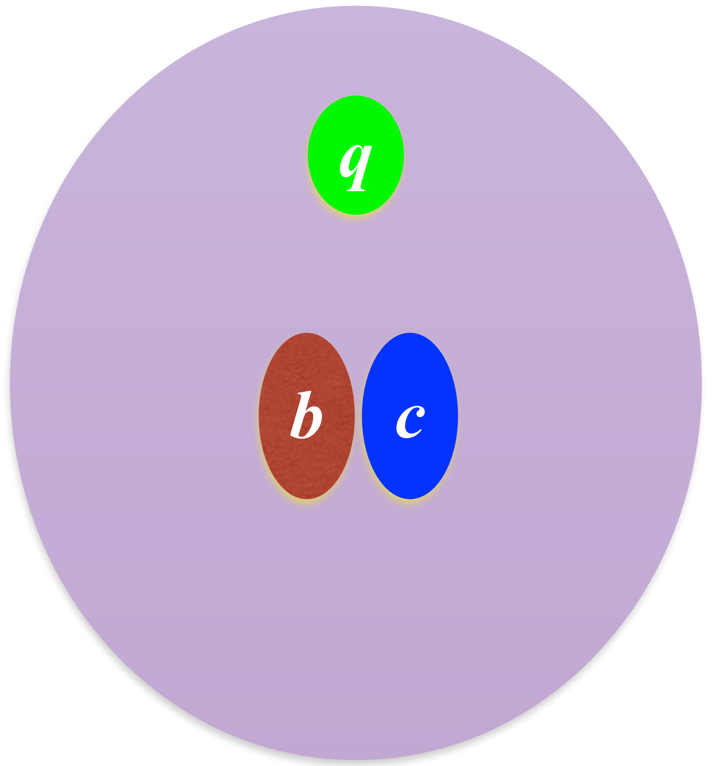
- Because of color confinement, properties of quarks are studied via hadrons

- New types of hadrons provide new visual angles into QCD and also electroweak dynamics

  e.g., doubly heavy baryons have a unique structure, resembling a ‘double star’ with a ‘planet’ attached

  analogous to a heavy meson, but also different: bosonic, sizable heavy element

  e.g., the doubly heavy tetraquarks help us probe the nature of exotic hadronic states, cusps or true resonances



- More is better

Who is to be shot next?

$\pi, K,$ …	D	B	η_c	B_c	η_b				
p, n, …	Λ_c	Λ_b				Ξ_{cc}	Ξ_{bc}	Ξ_{bb}	
	X(2900)		Z_c			T_{cc}		T_{bb}	X(6900)
			P_c						

<u>Two targets</u> after the Ξ_{cc}^{++} discovery.

T_{cc}: [**QQ**,Shen,Yu,2008.08026]
"<u>Discovery potential of double-charm tetraquarks</u>"

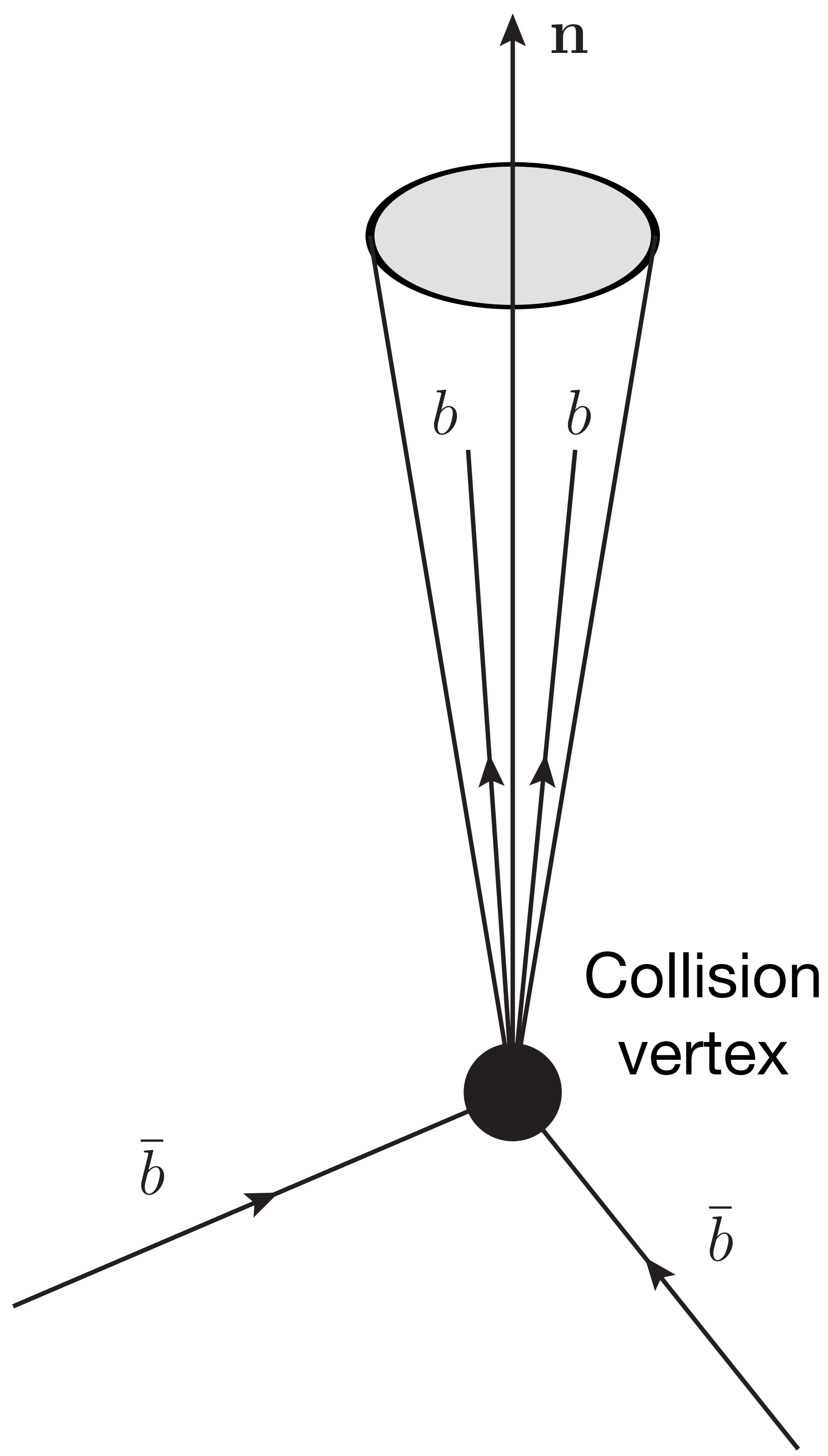
One year later —— T_{cc} discovery was reported by LHCb on 28 July 2021.

[LHCb,2109.01038;2109.01056]

Ξ_{bc}: [**QQ**,Shi,Wang,Yang,Yu,Zhu,2108.06716]
<u>"Inclusive approach for beauty-charmed baryon Ξ_{bc} search"</u>

Discovery of T_{cc} $\left\{ \begin{array}{l} \textbf{Production} \\ \\ \textbf{Detection} \end{array} \right.$

Production Mechanism



- It was proposed for double-bottom hadron production

1. Two produced heavy quarks stay close enough to form a heavy diquark

2. The heavy diquark further fragments into doubly heavy hadrons

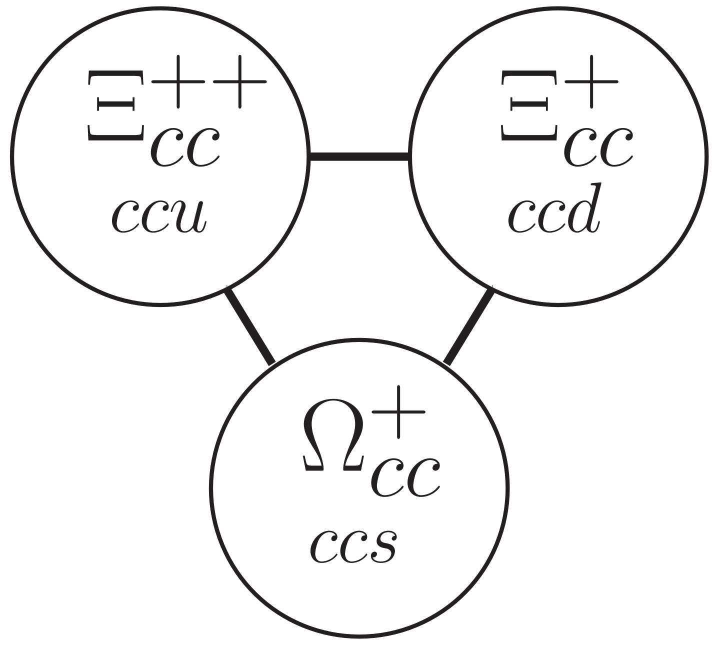
- Assuming T_{cc} a real tetraquark, the same mechanism applies

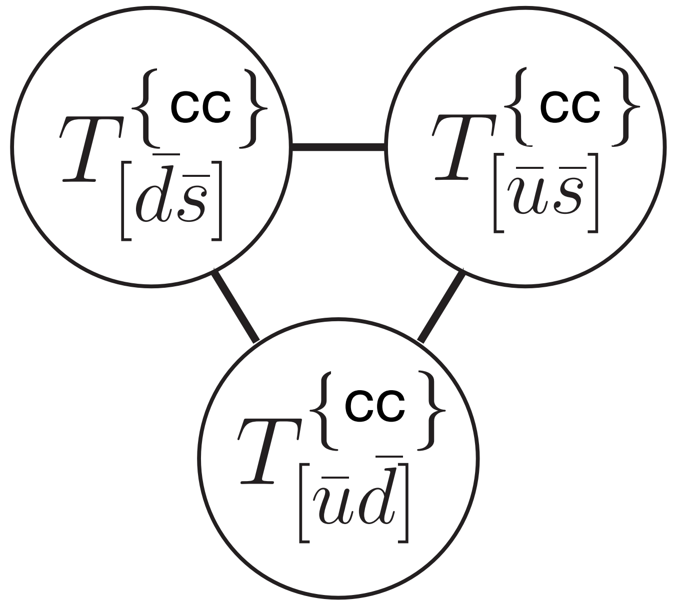
- Stay close enough? One parameter — —

$$\Delta M \equiv M_{cc} - 2m_c \leq (2.0^{+0.5}_{-0.4})\ \text{GeV}$$

Determined by matching the B_c production rate to $\bar{b}b\bar{c}c$

[Ali,Parkhomenko,**QQ**,Wang,1805.02535;Ali,**QQ**,Wang,1806.09288]





SU(3) triplets

Fragmentation of cc diquark

- Heavy quark symmetry

  1. Heavy quark **flavor** symmetry; 2. Heavy quark **spin** symmetry

- Heavy quark-diquark symmetry

  The cc diquark is just a static $\bar{3}$ color source

  → Similar fragmentation with heavy quarks

All ratios determined!

$$\left[\frac{\Lambda_b^0}{B_d^0}\right](p_\mathrm{T}) = 0.151 + \exp\left[-0.57 - 0.095 p_\mathrm{T}(\mathrm{GeV})\right]$$

[LHCb,1405.6842]

$$\left[\frac{f_s}{f_d}\right](p_\mathrm{T}) = 0.263 - 17.6 \times 10^{-4} \cdot p_\mathrm{T}(\mathrm{GeV})$$

[LHCb,2103.06810]

Ground state ratio → $r_g = 0.48 \pm 0.08$ [Belle,1706.06791]

$$\frac{T_{\bar{u}\bar{d}}^{\{cc\}}}{\Xi_{cc}^{+(+)}}$$

$$\frac{T_{\bar{u}\bar{s}}^{\{cc\}}}{T_{\bar{u}\bar{d}}^{\{cc\}}}, \frac{\Omega_{cc}^{+}}{\Xi_{cc}^{+}}$$

$$\frac{T_{\bar{u}\bar{d}}^{\{cc\}}}{T_{\bar{u}\bar{d}}^{\{cc\}} + \text{excited}}$$

Production of double-charm hadrons

With partonic simulation by MadGraph & Pythia, we obtain

- The cross section for all double-charm hadrons

$\sigma(pp \to H_{cc} + X) = (310^{+170}_{-70})$ nb;

- For double-charm baryons, e.g.

$\sigma(\Xi_{cc}^{++}) = (103^{+56}_{-22})$ nb

- For double-charm tetraquarks, e.g.

$\sigma(T_{cc}^{+}) = (24^{+14}_{-7})$ nb

The cuts are $4 < p_{\mathrm{T}} < 15$ GeV, $2 < \eta < 4.5$ @ 13 TeV LHCb

[**QQ**,Shen,Yu,2008.08026]

Comparison with theory

vs 62 nb (NRQCD)

[Chang,Qiao,Wang,Wu,0601032]

Comparison with experiment

vs [30, 130] nb
(LHCb with theory inputs)

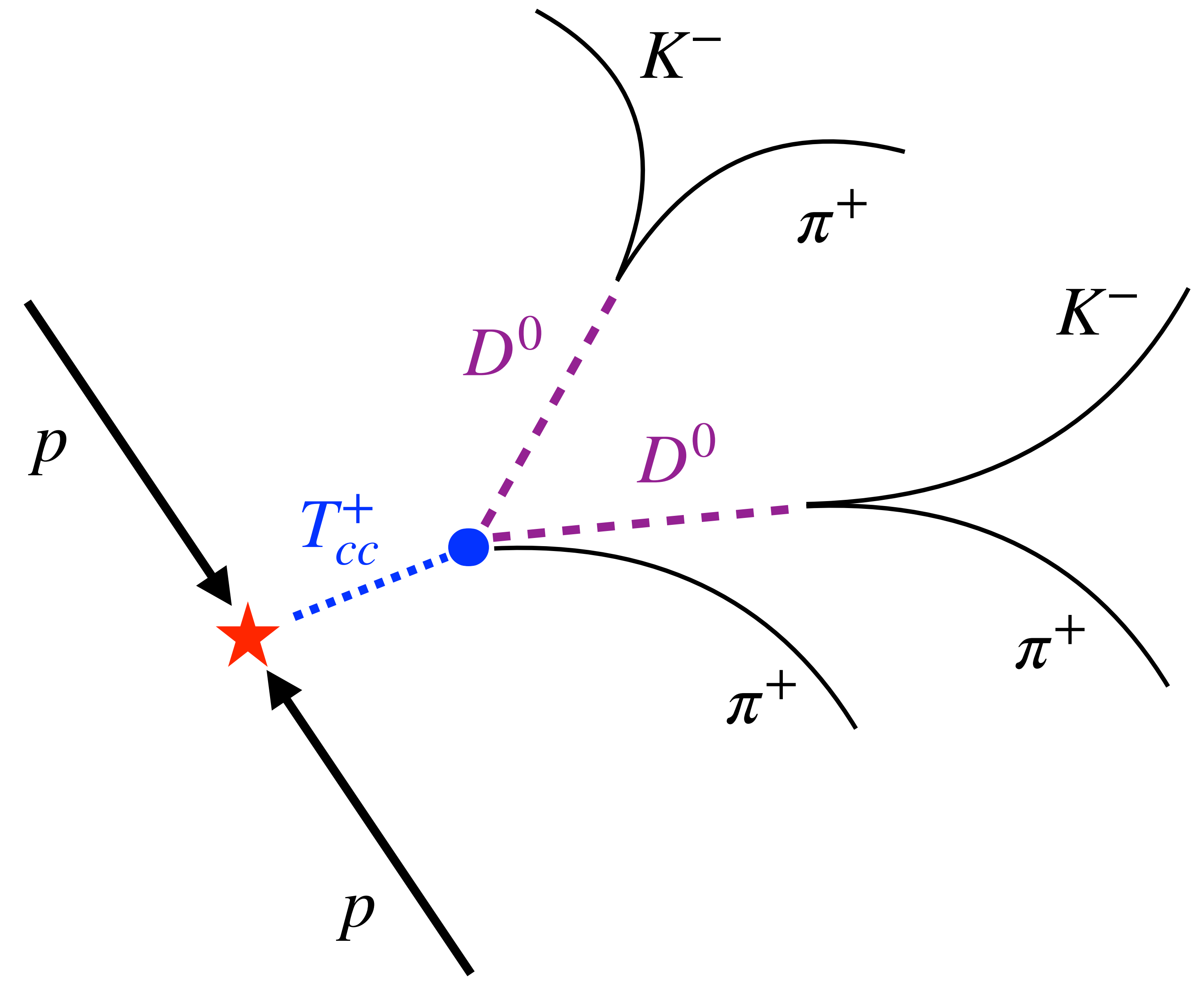
$$\frac{\sigma(\Xi_{cc}^{++}) \times \mathcal{B}(\Xi_{cc}^{++} \to \Lambda_c^+ K^- \pi^+ \pi^+)}{\sigma(\Lambda_c^+)} = (2.22 \pm 0.27 \pm 0.29) \times 10^{-4}$$

[LHCb,1910.11316]

Detection of T_{cc}

Propose the golden channel $T_{cc}^{+} \to D^0 D^{*+} \to D^0 D^0 \pi^+$

- Big branching ratio
- Big detection efficiency (all charged particles)



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

Production

$\sigma(\Xi_{cc}^{++}) = (103^{+56}_{-22})$ nb

$\sigma(T_{cc}^{+}) = (24^{+14}_{-7})$ nb

$\frac{f_{T_{cc}}}{f_{\Xi_{cc}}} \sim \frac{1}{4}$

Decay

$Br(\Xi_{cc}^{++} \to \Lambda_c^+ K^- \pi^+ \pi^+)$ $Br(\Lambda_c^+ \to p K^- \pi^+)$ one more track

10% 6% 1/3

$Br(T_{cc} \to D^0 D^{*+})$ $Br(D^{*+} \to D^0 \pi^+)$ $Br(D^0 \to K^- \pi^+)^2$

1/2 2/3 $(4\%)^2$

$Br(T_{cc})/Br(\Xi_{cc}^{++}) \sim 1/4$

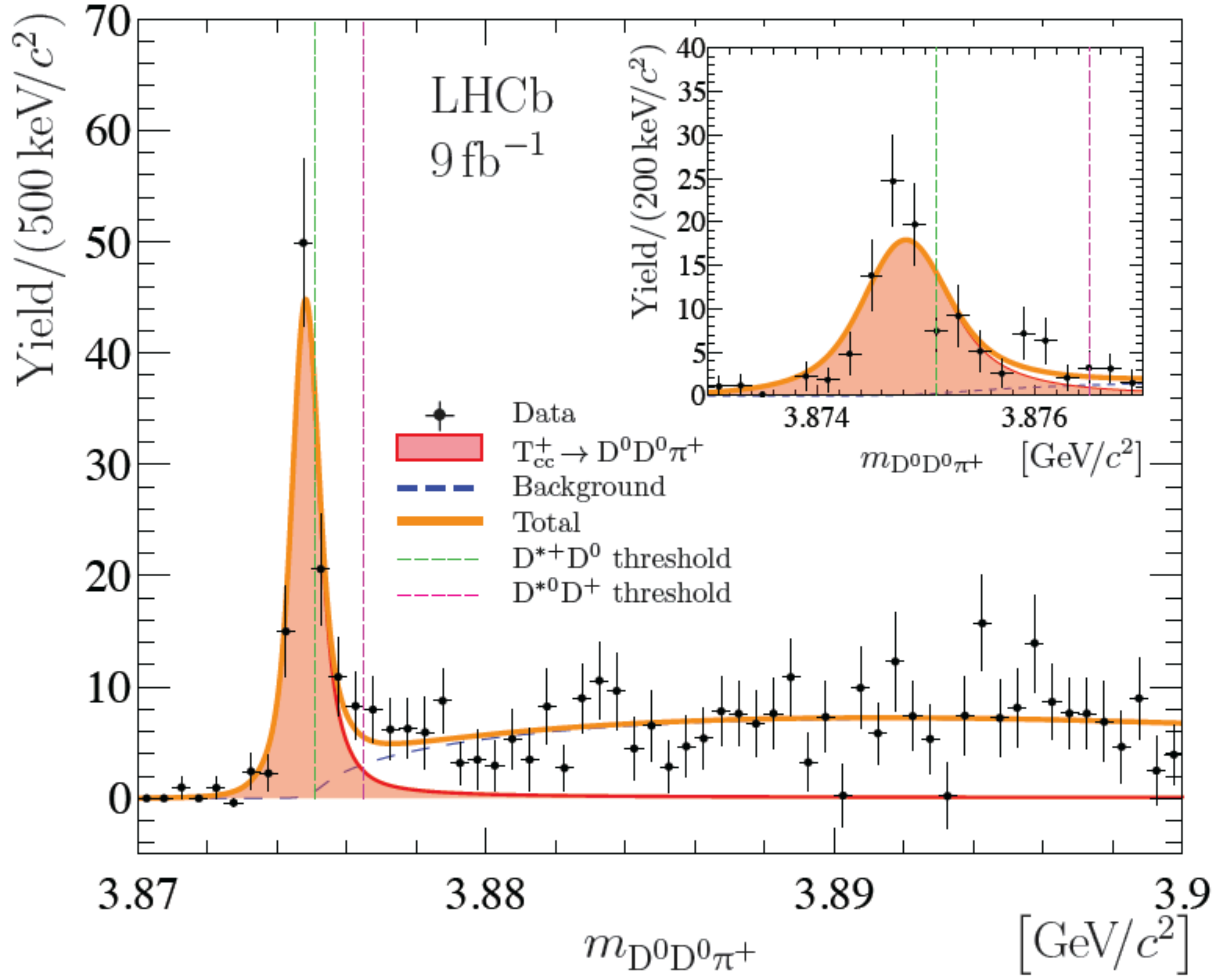
Detection of T_{cc}

$f_{T_{cc}}/f_{\Xi_{cc}} \sim 1/4$

$Br(T_{cc})/Br(\Xi_{cc}^{++}) \sim 1/4$

1500 events of $\Xi_{cc}^{++} \to \Lambda_c^+ K^- \pi^+ \pi^+$

T_{cc}^{+}: $N_s \sim 100$



Parameter	Value
N	117 ± 16
δm_{BW}	-273 ± 61 keV/c^2
Γ_{BW}	410 ± 165 keV

[**QQ**,Shen,Yu, 2008.08026]

[LHCb,2109.01038;2109.01056]

Discovery potential of Ξ_{bc}

Who is to be shot next?

$\pi, K, \ldots$	D	B	η_c	B_c	η_b			
p, n, …	Λ_c	Λ_b				Ξ_{cc}	Ξ_{bc}	Ξ_{bb}
	X(2900)		Z_c			T_{cc}	T_{bc}	T_{bb}
			P_c					

$\sigma(\Xi_{bc}) =$ 37 nb at 14 TeV LHCb

[X.G.Wu, et al 1101.1130]

	2011	2012	2018	2023	2029	2035
LHCb	Run I		Run II	Run III	Run IV	Run V
Integrated luminosity	1 fb^{-1}	3 fb^{-1}	9 fb^{-1}	23 fb^{-1}	50 fb^{-1}	300 fb^{-1}

Billions of Ξ_{bc} will be produced @ LHCb Run3.

Difficulties in experimental searches for Ξ_{bc}

- Detection efficiency —— small exclusive branching ratios

channels	Γ/ GeV	$\mathcal{B}$	channels	Γ/ GeV	$\mathcal{B}$
$\Xi_{bc}^0 \to \Lambda_c^+ \pi^-$	1.13×10^{-18}	1.60×10^{-7}	$\Xi_{bc}^0 \to \Lambda_c^+ \rho^-$	3.31×10^{-18}	4.68×10^{-7}
$\Xi_{bc}^0 \to \Lambda_c^+ a_1^-$	4.42×10^{-18}	6.24×10^{-7}	$\Xi_{bc}^0 \to \Lambda_c^+ K^-$	9.36×10^{-20}	1.32×10^{-8}
$\Xi_{bc}^0 \to \Lambda_c^+ K^{*-}$	1.70×10^{-19}	2.41×10^{-8}	$\Xi_{bc}^0 \to \Lambda_c^+ D^-$	2.27×10^{-19}	3.21×10^{-8}
$\Xi_{bc}^0 \to \Lambda_c^+ D^{*-}$	2.42×10^{-19}	3.42×10^{-8}	$\Xi_{bc}^0 \to \Lambda_c^+ D_s^-$	6.23×10^{-18}	8.80×10^{-7}
$\Xi_{bc}^0 \to \Lambda_c^+ D_s^{*-}$	5.82×10^{-18}	8.22×10^{-7}			
$\Xi_{bc}^0 \to \Sigma_c^+ \pi^-$	1.12×10^{-18}	1.58×10^{-7}	$\Xi_{bc}^0 \to \Sigma_c^+ \rho^-$	3.53×10^{-18}	4.99×10^{-7}
$\Xi_{bc}^0 \to \Sigma_c^+ a_1^-$	5.24×10^{-18}	7.41×10^{-7}	$\Xi_{bc}^0 \to \Sigma_c^+ K^-$	9.16×10^{-20}	1.29×10^{-8}
$\Xi_{bc}^0 \to \Sigma_c^+ K^{*-}$	1.86×10^{-19}	2.63×10^{-8}	$\Xi_{bc}^0 \to \Sigma_c^+ D^-$	1.96×10^{-19}	2.77×10^{-8}
$\Xi_{bc}^0 \to \Sigma_c^+ D^{*-}$	3.85×10^{-19}	5.44×10^{-8}	$\Xi_{bc}^0 \to \Sigma_c^+ D_s^-$	5.34×10^{-18}	7.55×10^{-7}
$\Xi_{bc}^0 \to \Sigma_c^+ D_s^{*-}$	9.73×10^{-18}	1.38×10^{-6}			

[W. Wang, F.S. Yu, Z.X. Zhao, 1707.02834]

- First experimental attempts

(LHCb, 13 TeV, ~ 5 fb^{-1})

$$\frac{\sigma(\Xi_{bc}^0)}{\sigma(\Lambda_b^0)} \frac{B(\Xi_{bc}^0 \to D^0 p K^-)}{B(\Lambda_b^0 \to D^0 p K^-)} < [1.7,30]\,\%$$

[LHCb, 2009.02481]

< [0.6, 3] × 10^{-4}

$$\frac{\sigma(\Xi_{bc}^0)}{\sigma(\Lambda_b^0)} \frac{B(\Xi_{bc}^0 \to \Lambda_c^+ \pi^-)}{B(\Lambda_b^0 \to \Lambda_c^+ \pi^-)} < [0.5,2.5] \times 10^{-4}$$

$$\frac{\sigma(\Xi_{bc}^0)}{\sigma(\Lambda_b^0)} \frac{B(\Xi_{bc}^0 \to \Xi_c^+ \pi^-)}{B(\Lambda_b^0 \to \Xi_c^+ \pi^-)} < [1.4,6.9] \times 10^{-3}$$

[LHCb, 2104.04759]

$$\left(B(\Lambda_b^0 \to \Lambda_c^+ \pi^-) = 4.9 \times 10^{-3}, \sigma(\Lambda_b^0) \sim 10\ \mu b, \sigma(\Xi_{bc}^0) \sim\ 40\ nb\right)$$

A novel approach —— inclusive Ξ_{bc} search

- Generally, inclusive decays have (1) larger branching ratios but (2) lower detection efficiencies

  Basically impossible at hadron colliders

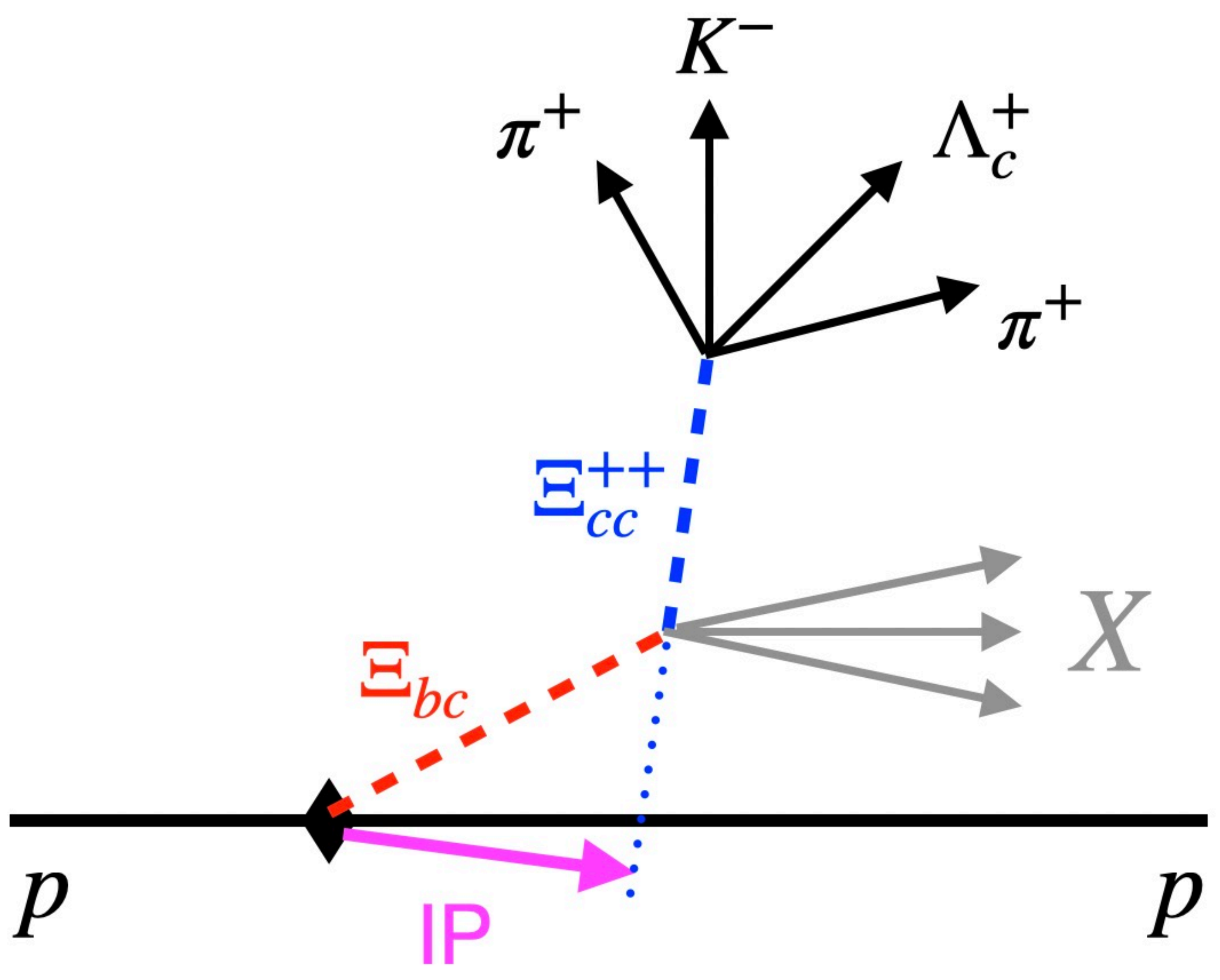
- However, for $\Xi_{bc} \to \Xi_{cc}^{++} + X$, the efficiency can be large by making use of the inform of displaced vertex

  Inspired by the proposal to search for Ξ_{bb} via $\Xi_{bb} \to B_c + X$

  [Gershon,Poluektov,1810.06657]

- Ξ_{bc} is (almost) the only source for displaced Ξ_{cc}'s

- The $B_c \to \Xi_{cc}^{++} + X$ decay is highly suppressed



[**QQ**,Shi,Wang,Yang,Yu,Zhu,2108.06716]

Calculation of $\Xi_{bc} \to \Xi_{cc} + X$

- First important fact: $\Xi_{bc} \to \Xi_{cc} + X$ = $\Xi_{bc} \to H_{cc} + X$

  H_{cc} include excited states of Ξ_{cc}, which still decay into Ξ_{cc}

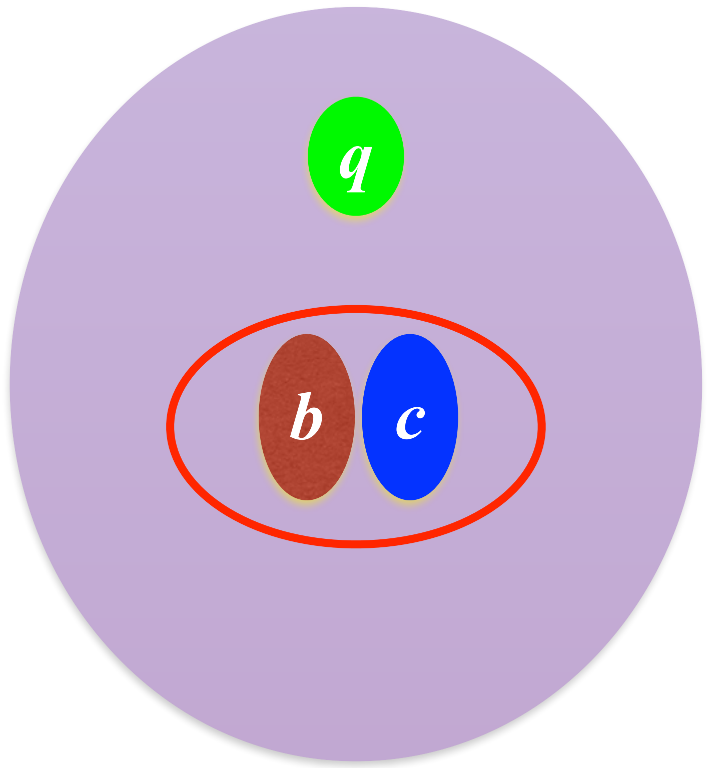
- Regarding the heavy diquarks χ_{bc} and χ_{cc} as point-like particles, the decay at the quark-diquark level is

$$\chi_{bc} \to \chi_{cc} + \ell^- \bar{\nu},\ \chi_{cc} + \bar{q} q'$$

  It is reasonable because $r_{QQ'} \sim 1/(m_Q v) \ll 1/\Lambda_{\rm QCD}$ [e.g.,Brodsky,Guo,Hanhart,Meissner,1101.1983]

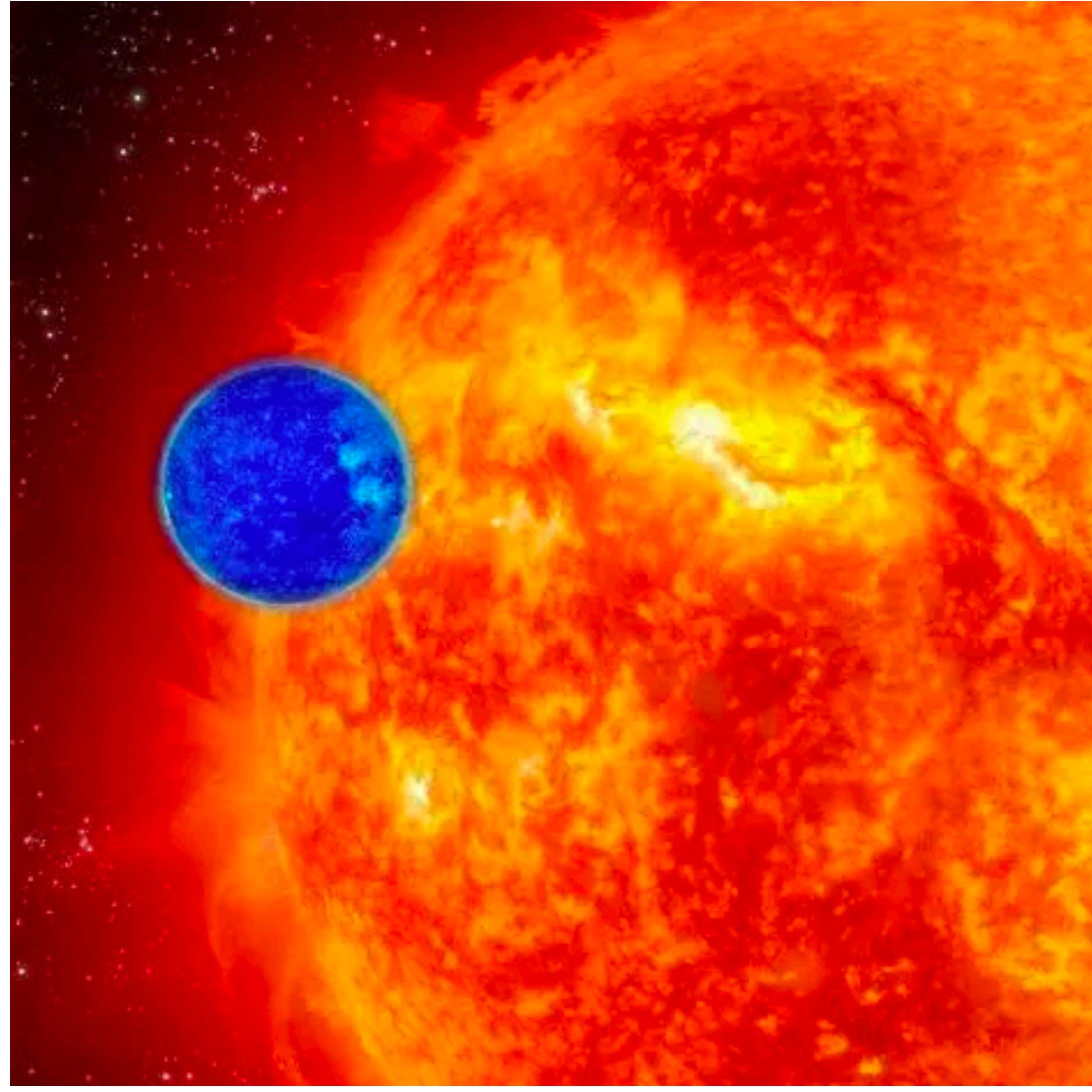
- By making use of OPE, the inclusive decay rate is expanded by powers of $1/M_{QQ'}$ within the Heavy Diquark Effective Theory

[Y.J.Shi, W.Wang, Z.X.Zhao,Meissner,2002.02785]



3 body → 2 body

Heavy diquark effective theory



- Integrating out the degrees of freedom above $\Lambda_{\rm QCD}$, the two heavy quark system can be regarded as a point-like heavy diquark, scalar or axial-vector

$$\mathscr{L}_S = \frac{1}{2}(D_\mu S^i)^\dagger (D^\mu S^i) - \frac{1}{2} m_X^2 S^{i\dagger} S^i$$
$$\mathscr{L}_X = -\frac{1}{2}[(D_\mu X_\nu^i)^\dagger (D^\mu X^{i\nu}) - (D_\mu X_\nu^i)^\dagger (D^\nu X^{i\mu})] + \frac{1}{2} m_X^2 X_\mu^{i\dagger} X^{i\mu}$$

- As HEQT for a heavy-light system (heavy meson), the big momentum $M_{X,S} v$ of a heavy diquark inside a doubly-heavy baryon can be integrated out by

$$X^\mu = e^{-i m_X v\cdot x}(X_v^\mu + Y_v^\mu)$$

[Y.J.Shi, W.Wang, Z.X.Zhao,Meissner,2002.02785]

- Then only the $\Lambda_{\rm QCD}$ degrees of freedom are left, the expansion $(\Lambda_{\rm QCD}/M_{X,S})^n$ for inclusive decays can be performed. At the leading power,

$$B(\Xi_{bc} \to \Xi_{cc} + X) = B(\chi_{bc} \to \chi_{cc} + \ell^- \bar{\nu}, \chi_{cc} + \bar{q} q') + \mathcal{O}(1/M_{QQ'})$$

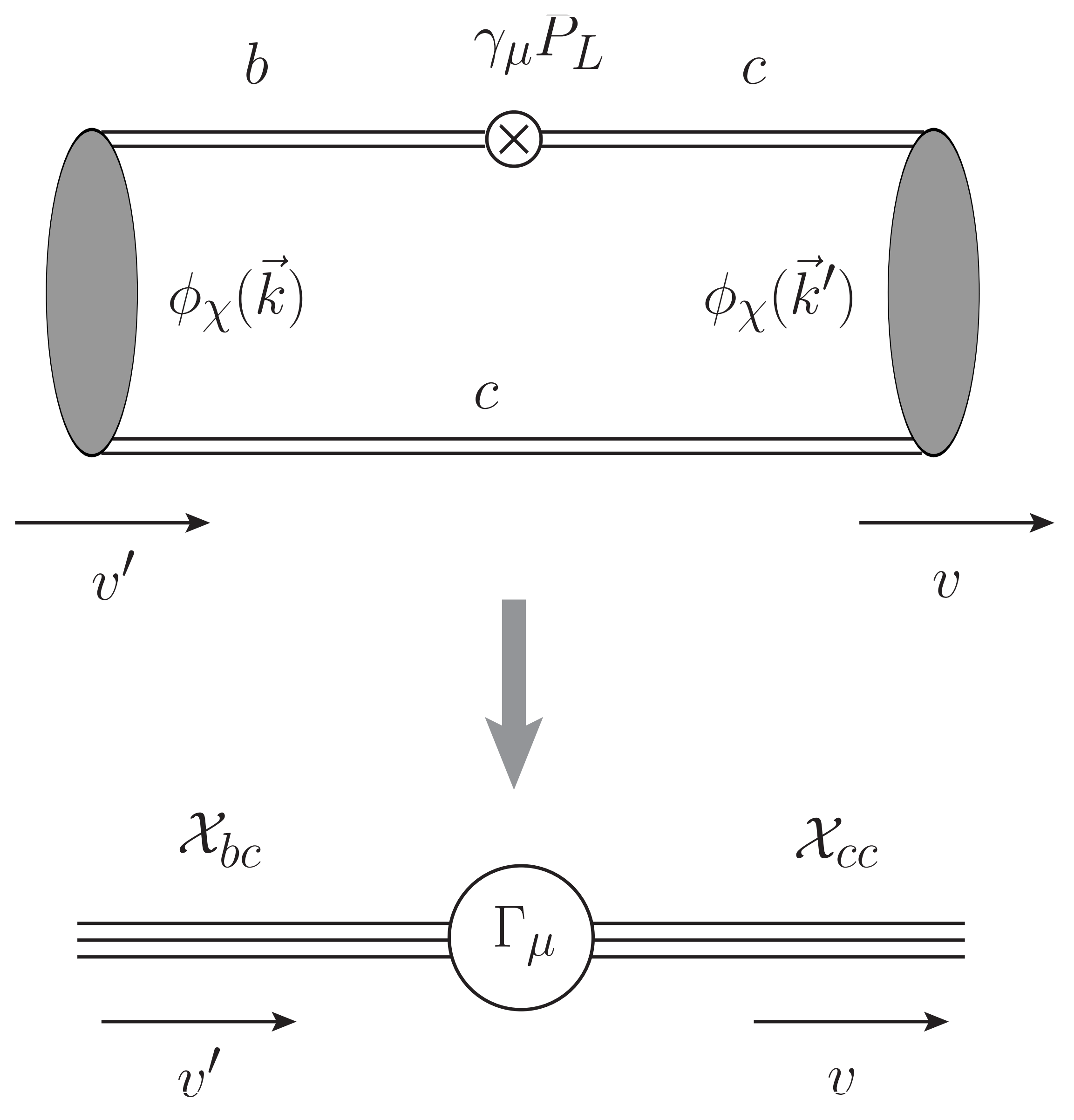
Hadron $\Rightarrow$ Diquark

Heavy diquark current

- The key issue is the 2-diquark-2-fermion interaction vertex, i.e. the $\chi_{bc} \to \chi_{cc}$ diquark current

$$\langle \chi_{cc}(v,\epsilon)\,|\,\bar{c}\gamma^\mu b\,|\,\chi_{bc}(v',\epsilon')\rangle \propto -\, a_0\epsilon^* \cdot \epsilon' v'^\mu - \, a_1\epsilon^* \cdot \epsilon' v^\mu + \, a_2\epsilon^* \cdot v'\epsilon'^\mu + \, a_3 v \cdot \epsilon' \epsilon^{*\mu}$$

$$\langle \chi_{cc}(v,\epsilon)\,|\,\bar{c}\gamma^\mu\gamma_5 b\,|\,\chi_{bc}(v',\epsilon')\rangle \propto -\, ib_0\epsilon^{\epsilon'\epsilon^* v'\mu} - ib_1\epsilon^{\epsilon'\epsilon^* v\mu}$$



- Matching the $b \to c$ current to the $\chi_{bc} \to \chi_{cc}$ diquark current (analogous to a transition form factor)

Diquark $\Rightarrow$ Quark

- The matching is performed differently for different kinematic regions, because of different dynamics

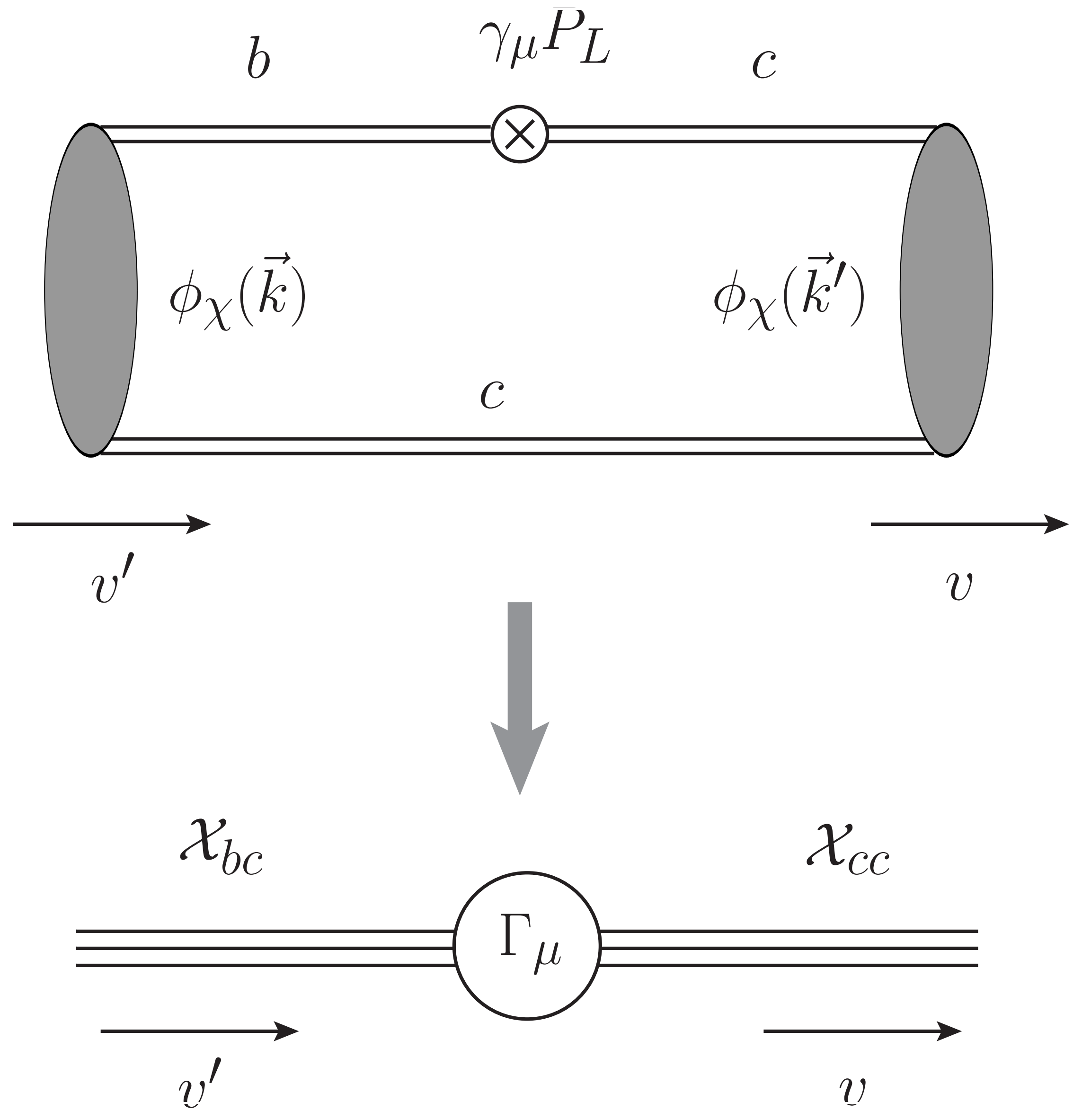
    1. Small recoil region (large q^2)

    2. Large recoil region (small q^2)

[**QQ**,Shi,Wang,Yang,Yu,Zhu,2108.06716]

Heavy diquark current

- **Small recoil region:** in the heavy quark limit, the two heavy quarks in the heavy diquark are relatively static —— sharing the same velocity v



- Heavy diquarks can be represented by a Lorentz bilinear field

$$D_v^{QQ'}(x) = \frac{1+v\cdot\gamma}{2}[\gamma^\mu A_\mu(x) + i\gamma_5 S(x)]C$$

Axial-vector   Scalar

- Its Lorentz transformation $D_v(x) \to D'_{v'}(x') = \Lambda_{1/2} D_v(\Lambda^{-1}x)\Lambda_{1/2}^{\mathsf{T}}$

- Its conjugate field $\bar{D}_v = \gamma^0 D_v^\dagger \gamma^0$, which transforms as $\bar{D}_v(x) \to \bar{D}_{v'}(x') = [\Lambda_{1/2}^{-1}]^{\mathsf{T}} \bar{D}_v(\Lambda^{-1}x)\Lambda_{1/2}^{-1}$

- Then the matching comes to $\bar{c}\Gamma b = \mathrm{tr}\left[L^{\mathsf{T}}\, \bar{D}_{v'}^{cQ}\, \Gamma D_v^{bQ}\right]$, with $L = L_0 + L_1 v\cdot\gamma + L_2 v'\cdot\gamma + L_3(v\cdot\gamma)(v'\cdot\gamma)$

[**QQ**,Shi,Wang,Yang,Yu,Zhu,2108.06716]

Heavy diquark current

- Calculating the trace $\bar{c}\Gamma b = \mathrm{tr}\left[L^{\mathsf{T}}\, \bar{D}^{cQ}_{v'}\, \Gamma D^{bQ}_{v}\right]$ for $\Gamma = \gamma_\mu, \gamma_\mu\gamma_5$, using $(v\cdot\gamma)D_v = D_v$

- It simplifies into

$$\frac{1}{\sqrt{2M_{bc}M_{cc}}}\langle \chi_{cc}(v,\epsilon)\,|\,\bar{c}\gamma^\mu b\,|\,\chi_{bc}(v',\epsilon')\rangle = \xi(w)\Big[-\epsilon^*\cdot\epsilon' v'^\mu - \epsilon^*\cdot\epsilon' v^\mu + \epsilon^*\cdot v'\epsilon'^\mu + v\cdot\epsilon'\epsilon^{*\mu}\Big]$$

$$\frac{1}{\sqrt{2M_{bc}M_{cc}}}\langle \chi_{cc}(v,\epsilon)\,|\,\bar{c}\gamma^\mu\gamma_5 b\,|\,\chi_{bc}(v',\epsilon')\rangle = \xi(w)\Big[-i\epsilon^{\epsilon'\epsilon^* v'\mu} - i\epsilon^{\epsilon'\epsilon^* v\mu}\Big]$$

Only one function $\xi(w)$ with $w = v\cdot v'$ to be determined, similar to the famous Isgur-Wise function.

- Making use of the state normalization we can fix $\xi(w=1)=1$ $\Rightarrow$ $a_{0,1,2,3}(q^2_{\max}) = b_{0,1}(q^2_{\max}) = 1$

[**QQ**,Shi,Wang,Yang,Yu,Zhu,2108.06716]

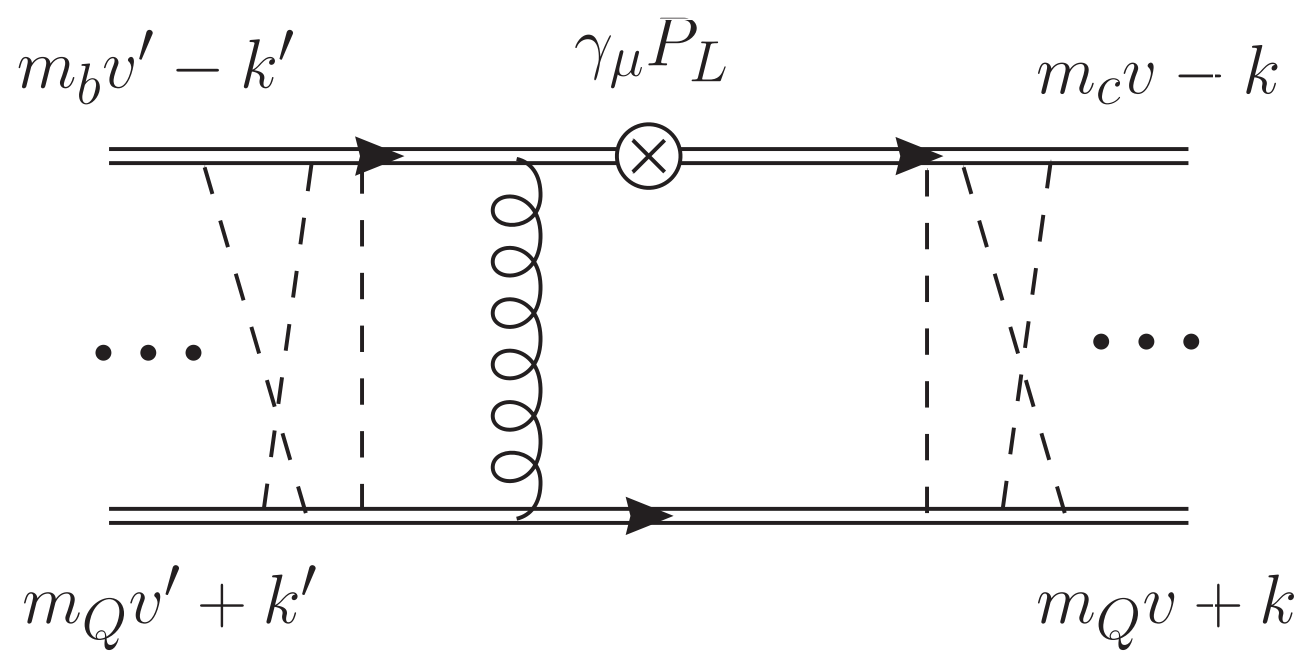
Heavy diquark current

- **Large recoil region:** at least one hard gluon is to be exchanged, and is thus perturbatively calculable

- The calculation via NRQCD gives

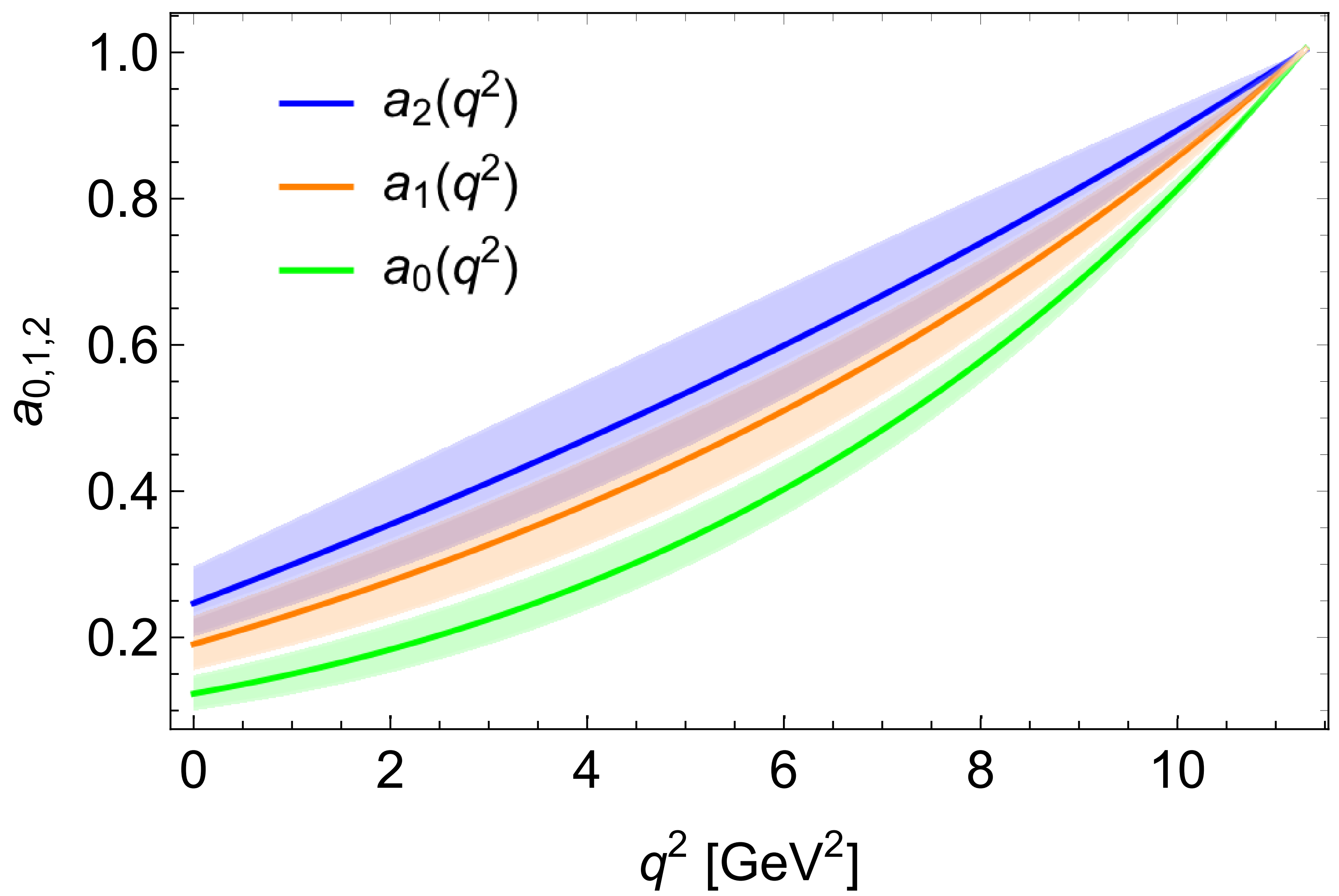
$$a_{2,3}(q^2) = \frac{\alpha_s}{2(1-w)^2\sqrt{w}} \frac{N_c+1}{N_c} \frac{1}{m_c^3} R_{bc}(0) R_{cc}^*(0)$$

$$a_0(q^2) = b_0(q^2) = \bar{\xi}_2 a_{2,3}(q^2),\ a_1(q^2) = b_1(q^2) = \bar{\xi}_1 a_{2,3}(q^2)$$



- **At last**, we connect the two regions by making a numerical fit accepting the z-series expansion formula

$$f(q^2) = \frac{f(0)}{1 - q^2/m_{B_c}^2} \left[1 + b\zeta(q^2) + c\zeta^2(q^2)\right]$$



[**QQ**,Shi,Wang,Yang,Yu,Zhu,2108.06716]

Calculation of $\Xi_{bc} \to \Xi_{cc} + X$

- Numerical result for the decay width

$$\Gamma(\Xi_{bc} \to \Xi_{cc} + X) = (1.9 \pm 0.1 \pm 0.3 \pm 0.4) \times 10^{-13}\ \text{GeV}$$

Uncertainties from quark mass, wave function at origin, scale dependence

- Lifetime [H.Y.Cheng, F.R.Xu, 1903.08148]

$$93\text{fs} < \tau(\Xi_{bc}^0) < 108\ \text{fs},\ 409\ \text{fs} < \tau(\Xi_{bc}^+) < 607\ \text{fs}$$

- The branching ratio is

$$B(\Xi_{bc}^+ \to \Xi_{cc} + X) \approx 14\,\%\,, \quad B(\Xi_{bc}^0 \to \Xi_{cc} + X) \approx 3\,\%$$

- Ξ_{cc}^{++} fragmentation suffers a factor of 1/2

$$B(\Xi_{bc}^+ \to \Xi_{cc}^{++} + X) \approx 7\,\%\,, \quad B(\Xi_{bc}^0 \to \Xi_{cc}^{++} + X) \approx 1.5\,\%$$

Search for $\Xi_{bc}^{+} \to \Xi_{cc}^{++} + X$ with displaced Ξ_{cc}^{++}

- Estimation of signal yield

$$N(\Xi_{bc}^{+} \to \Xi_{cc}^{++} + X) = N_p(\Xi_{bc}^{+}) \cdot B(\Xi_{bc}^{+} \to \Xi_{cc}^{++} + X) \cdot \epsilon(\Xi_{cc}^{++})$$

$$= N_d(\Xi_{cc}^{++}) \cdot \frac{\sigma(\Xi_{bc})}{\sigma(\Xi_{cc})} \cdot B(\Xi_{bc}^{+} \to \Xi_{cc}^{++} + X)$$

(The detection efficiency is identical to that of Ξ_{cc}^{++})

Three ingredients:

1. Number of signals of Ξ_{cc}^{++}: 10000 for 23 fb^{-1} (Run III, by 2024)

2. Production ratio $\sigma(\Xi_{bc})/\sigma(\Xi_{cc}) \approx 40\ \%$ [X.G.Wu et al, 1101.1130]

3. Branching fraction of inclusive decay of $\Xi_{bc}^{+} \to \Xi_{cc}^{++} + X$

Search for $\Xi_{bc} \to \Xi_{cc}^{++} + X$ with displaced Ξ_{cc}^{++}

- Final number of estimated signal events @ LHCb Run3

$$N(\Xi_{bc}^{+} \to \Xi_{cc}^{++} + X) = N(\Xi_{cc}^{++}) \cdot \frac{\sigma(\Xi_{bc}^{+})}{\sigma(\Xi_{cc})} \cdot B(\Xi_{bc}^{+} \to \Xi_{cc}^{++} + X)$$

$$\approx 10^4 \times 40\% \times 7\,\%$$

$$\approx 280$$

- With possible efficiency lost, it should still be detectable @ LHCb Run3

[**QQ**,Shi,Wang,Yang,Yu,Zhu,2108.06716]

Conclusion

- **More is better**: we want more new hadrons.

- We predicted the correct discovery channel and the correct signal yield for the T_{cc}^{+} discovery at the LHCb.

- We propose to search for Ξ_{bc} via inclusive $\Xi_{bc}^{+} \to \Xi_{cc}^{++} + X$ with a displaced Ξ_{cc}^{++}, with about 280 signal events to be observed @ LHCb Run 3.

Thank you!