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Two-pion emission decays of singly heavy baryons

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RIKEN

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Our related studies

- Ponkhuha, **Arifi**, Samart. Arxiv: 2407.10063 (PRD in press)
- **Arifi**, Suenaga, Hosaka. PRD105, 094006 (2022)
- **Arifi**, Nagahiro, Hosaka, Tanida. PRD101, 111502(R) (2020)
- **Arifi**, Nagahiro, Hosaka, Tanida. PRD101, 094023 (2020)
- **Arifi**, Nagahiro, Hosaka. PRD98, 114007 (2018)
- **Arifi**, Nagahiro, Hosaka. PRD95, 114018 (2017)

Heavy baryons

Heavy baryons

Past and present

- Λ_c was discovered in 1975
- In PDG, now we have
  - 34 charmed baryons
  - 28 bottom baryons
- Experiments:
  Belle, BES, J-PARC, LHC, etc

- V. Crede & J. Yelton. RPP87, 106301(2024)
- H.X. Chen et al. RPP86, 026201 (2023)

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- Production
- Mass spectrum
- Decay pattern
- Structure
- Interaction
- Medium modification
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Problems

- Many missing states?
- Unknown quantum number?
- Branching fractions?
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Opportunity

- Narrow resonances
- Heavy-quark symmetry
- Isotope shift
- Insight to hyperon/exotics
- …

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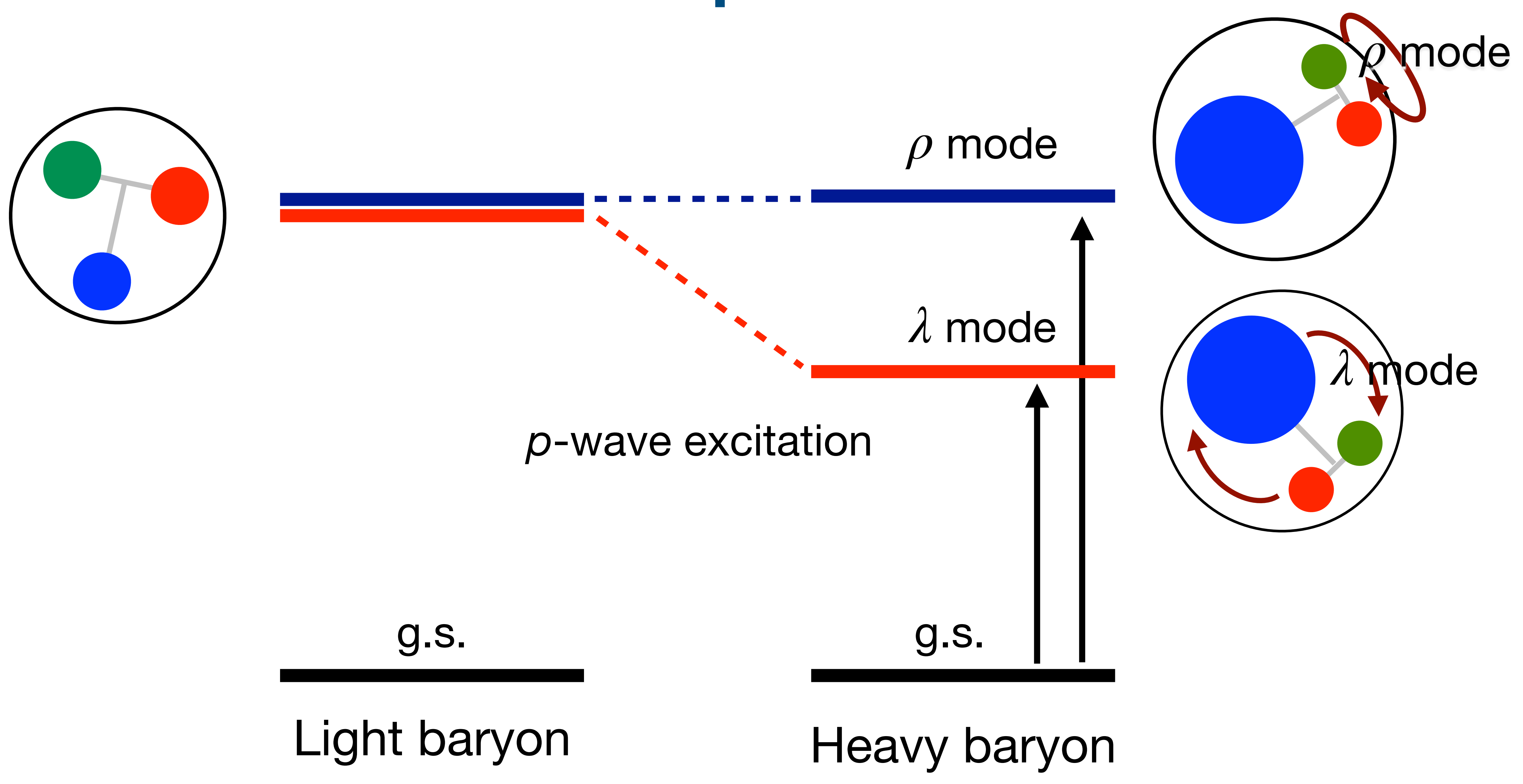
General feature

General feature

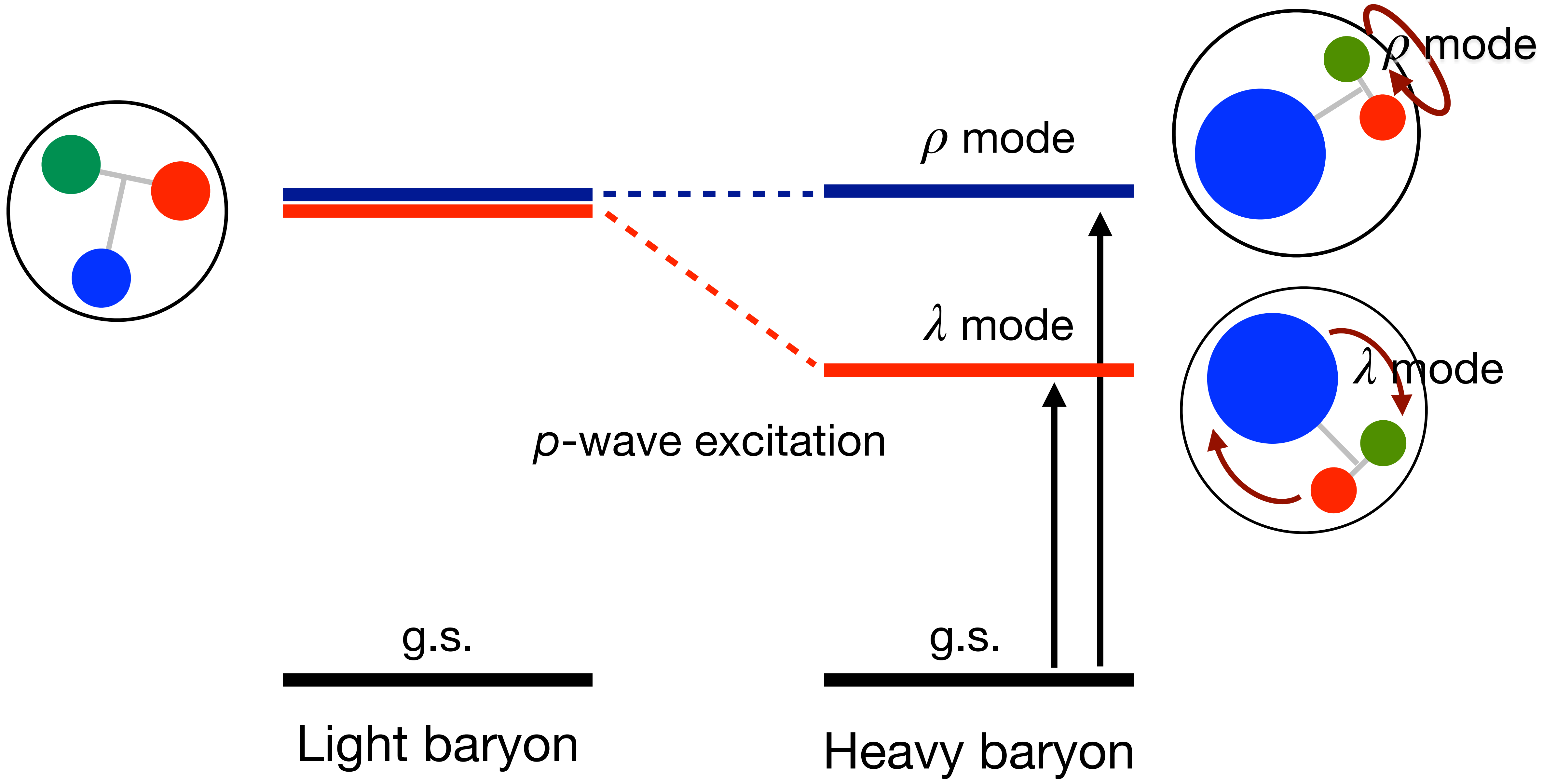
Isotope shift



Light quark | u d s | c b | Heavy quark

General feature

Isotope shift



Light quark | u d s | **c b** | Heavy quark

How to identify λ and ρ mode excitations?

General feature

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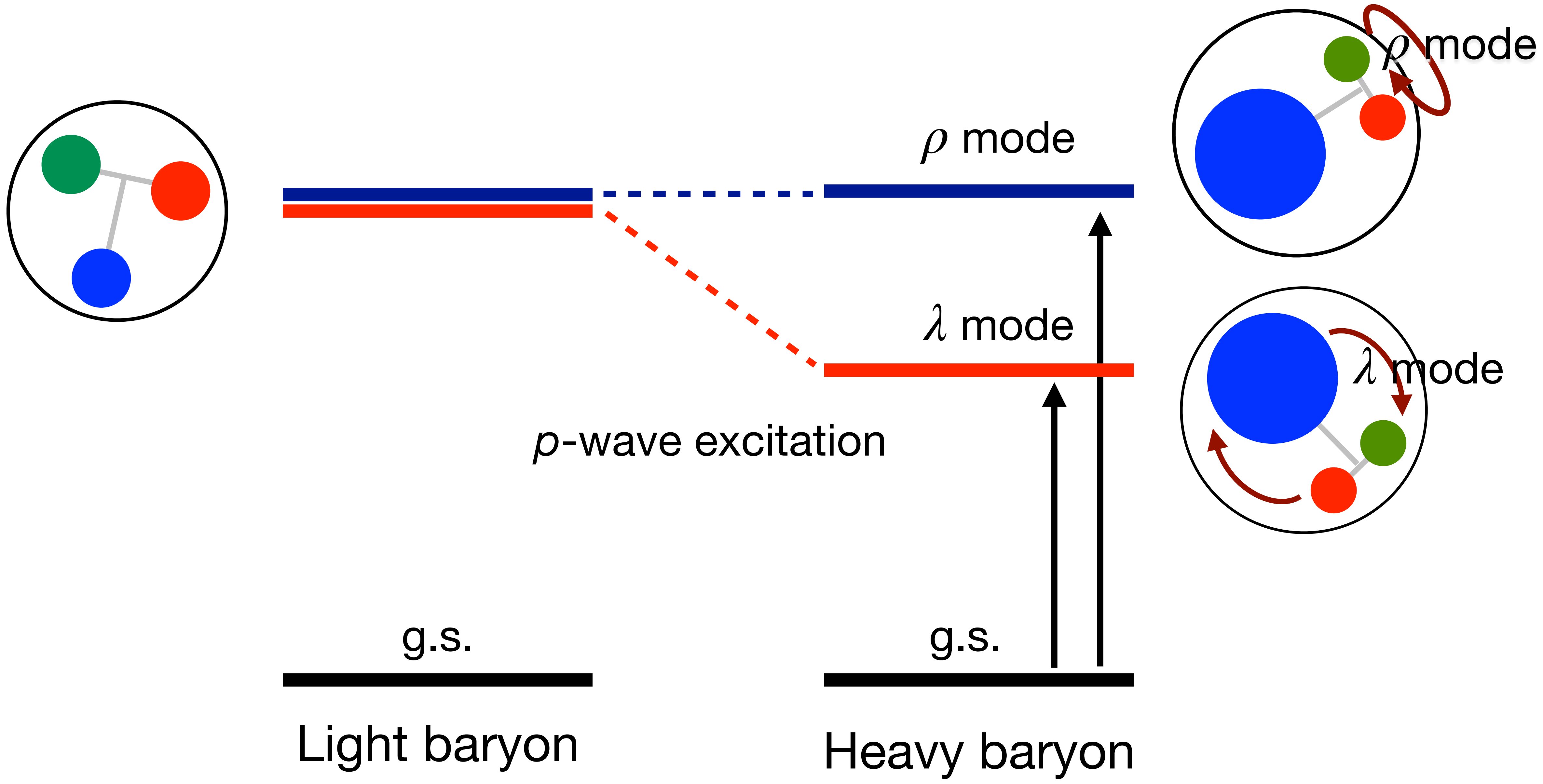

Light quark | u d s | **c b** | Heavy quark

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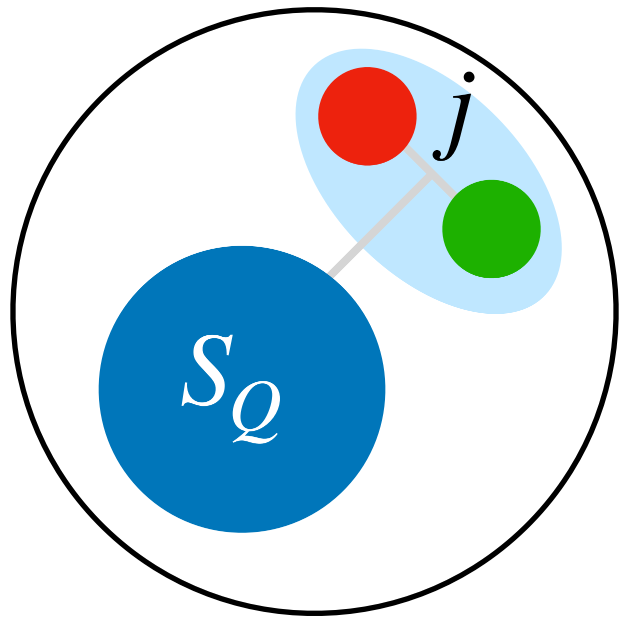
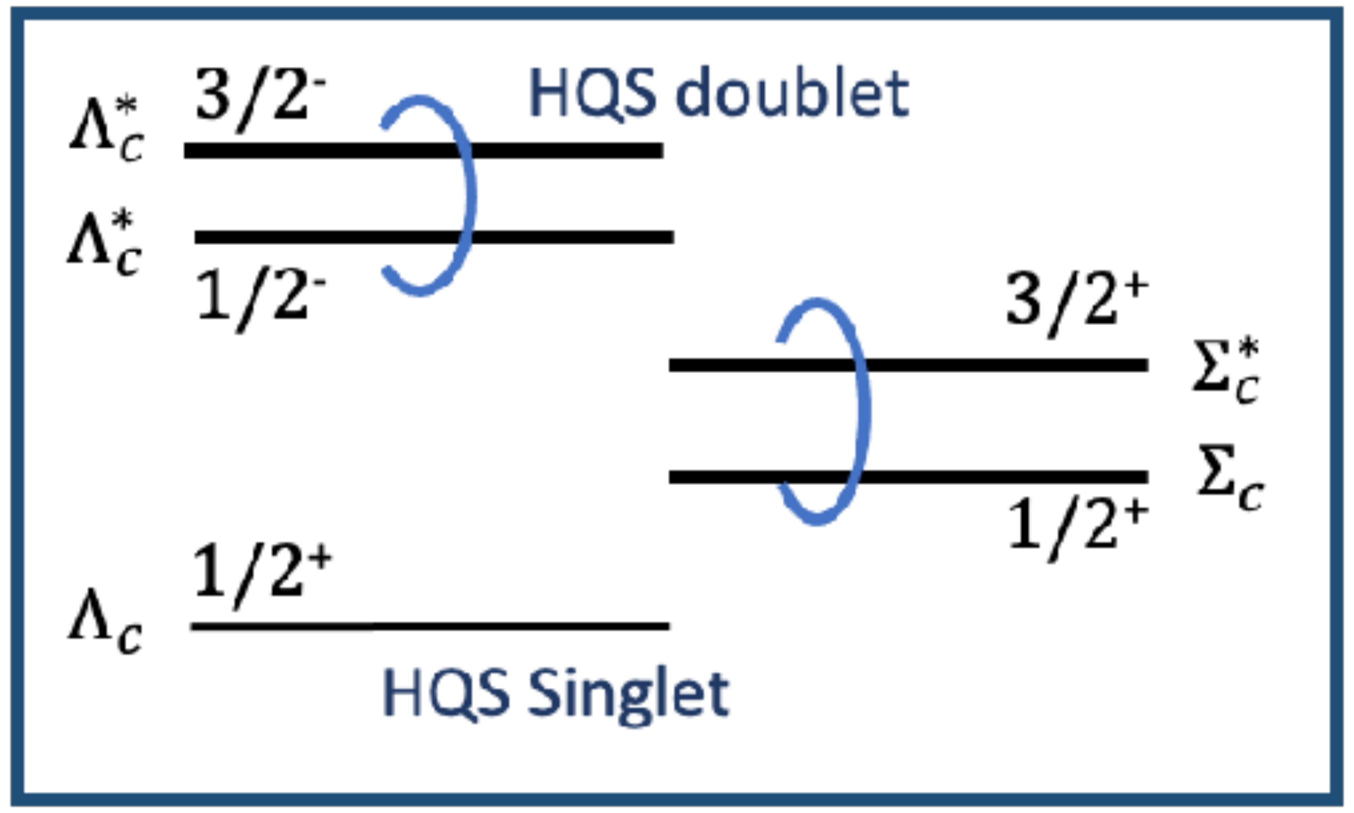


Brown-muck spin j

$$J = s_Q + j$$



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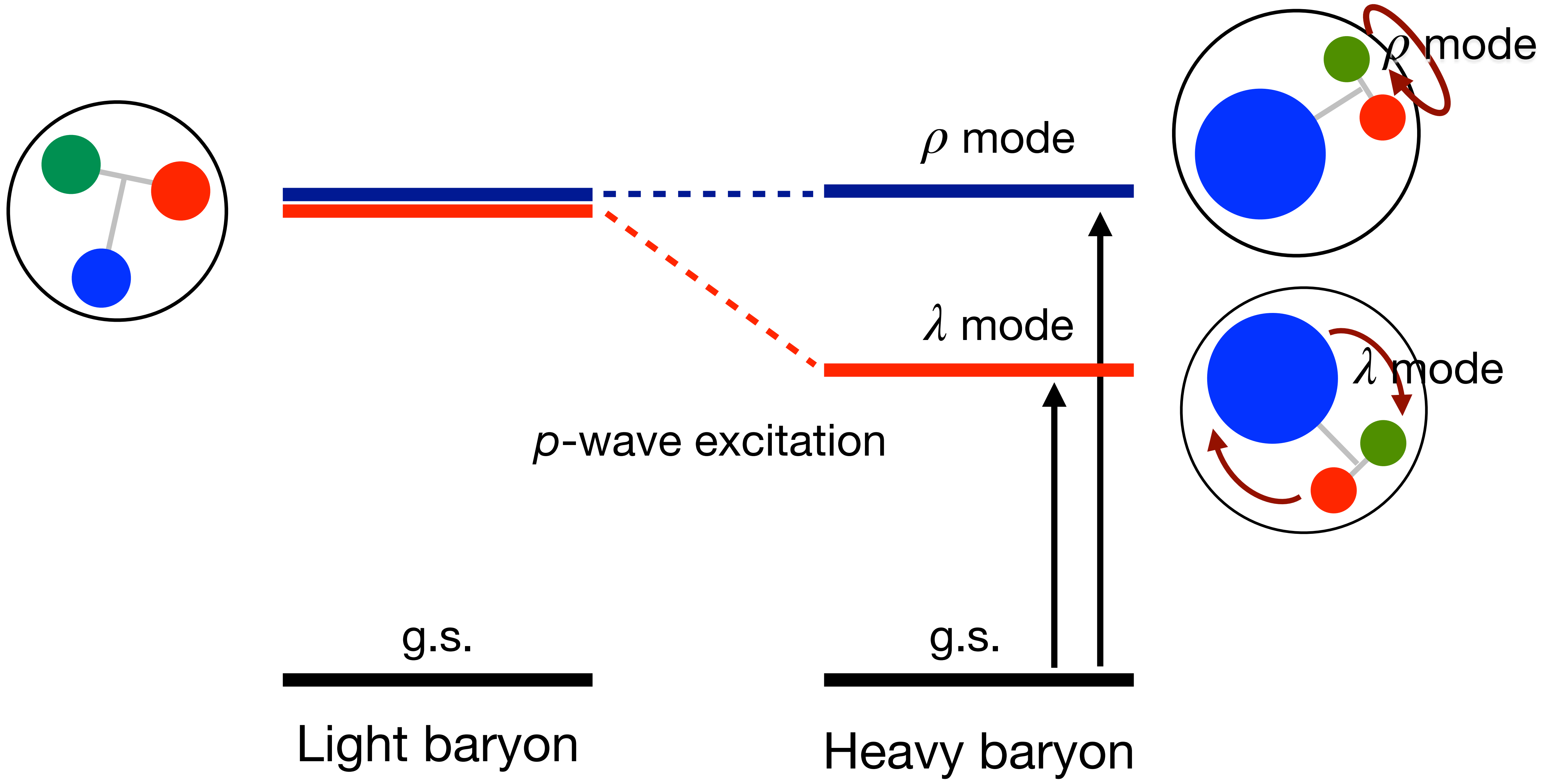

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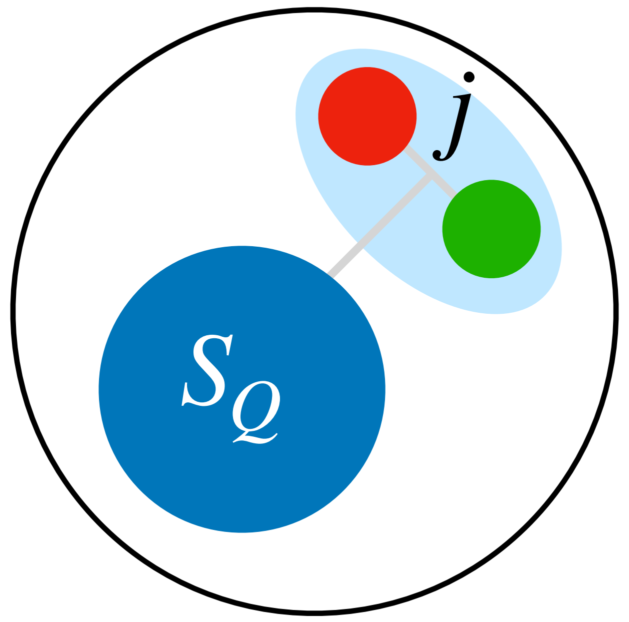

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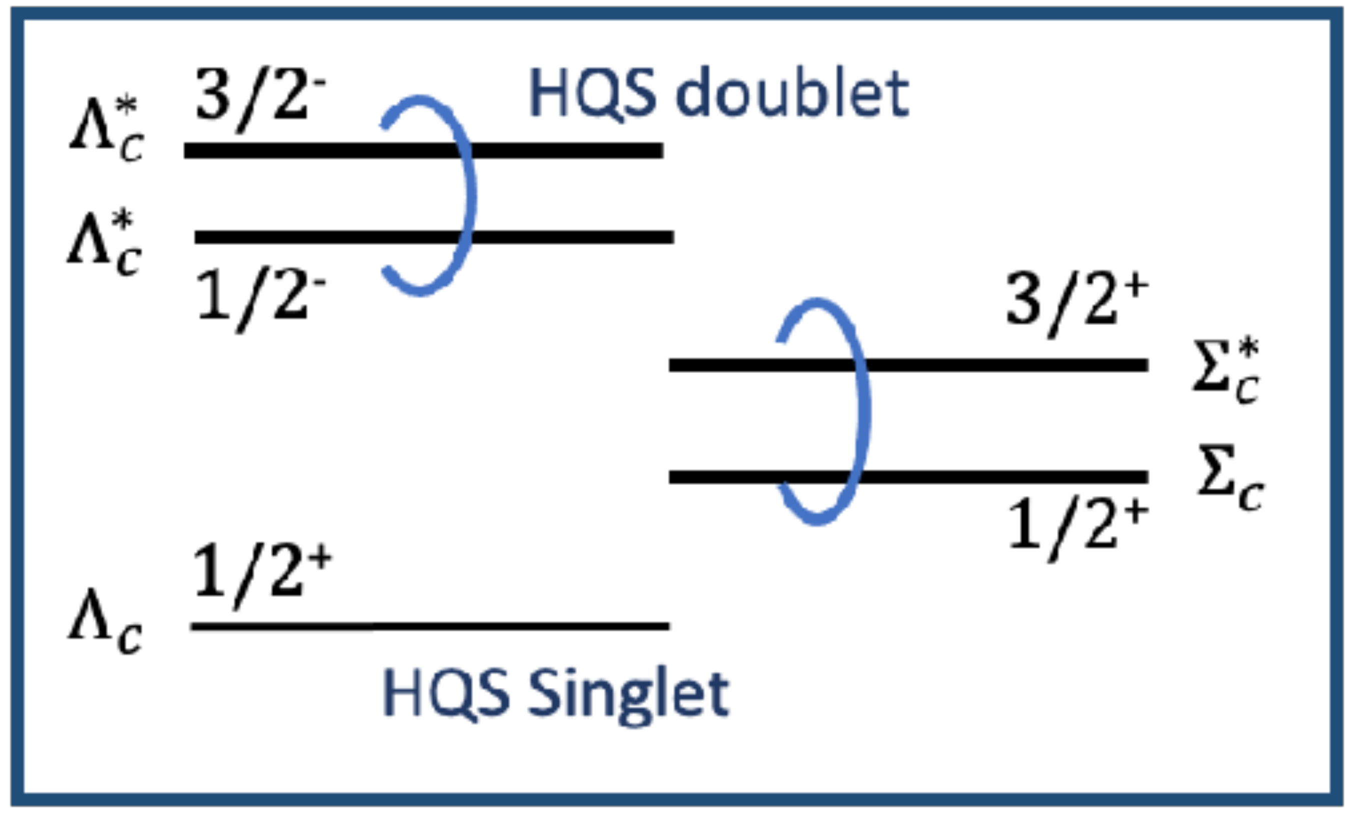

How to identify the HQS partner?

Wave function

Wave function

Total WF

Orbital motion Heavy quark spin

$$B_Q(J^P) = \Big[[\psi_{n_\lambda l_\lambda}(\lambda)\psi_{n_\rho l_\rho}(\rho), s_d]^j, S_Q \Big]^J \cdot \phi_{flavor} \cdot \phi_{color}$$

Light quark spin

Wave function

Total WF

Orbital motion

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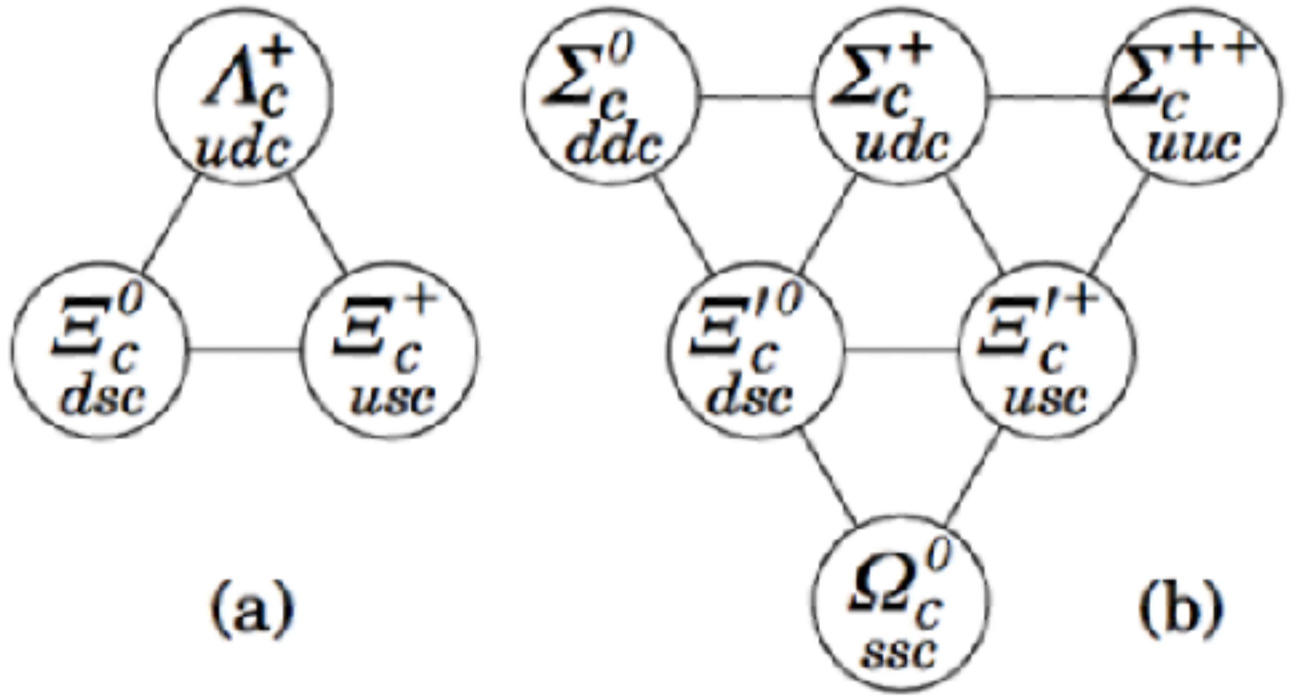
Light quark spin

Flavor WF

$$3_F \times 3_F = \bar{3}_F + 6_F$$



Anti-symmetric

Symmetric

Wave function

Total WF

Orbital motion Heavy quark spin

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Light quark spin

Ground states $(l = 0)$

$$\Lambda_c\left(\frac{1}{2}^+\right) = \left[[\psi_0(\lambda)\psi_0(\rho), s_d^0]^0, S_Q \right]^{\frac{1}{2}}$$ Singlet

$$\Sigma_c\left(\frac{1}{2}^+, \frac{3}{2}^+\right) = \left[[\psi_0(\lambda)\psi_0(\rho), s_d^1]^1, S_Q \right]^{\frac{1}{2}, \frac{3}{2}}$$ Doublet

Flavor WF

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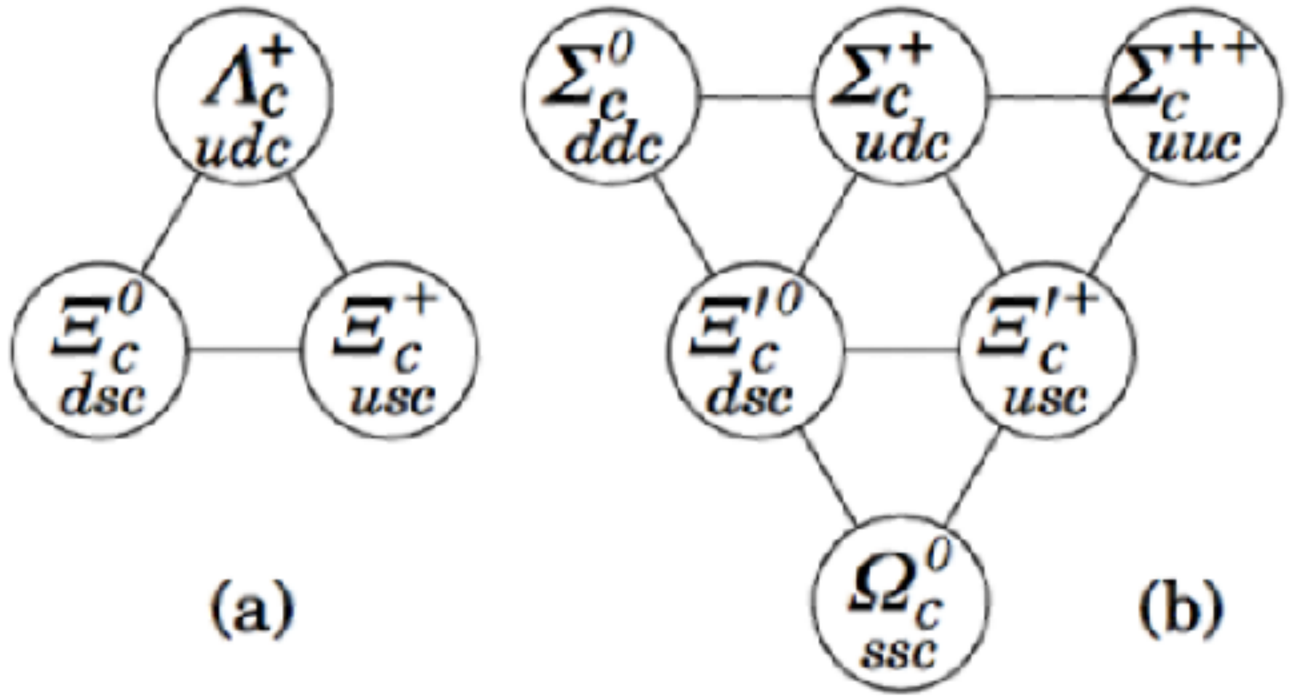

Anti-symmetric Symmetric

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Total WF

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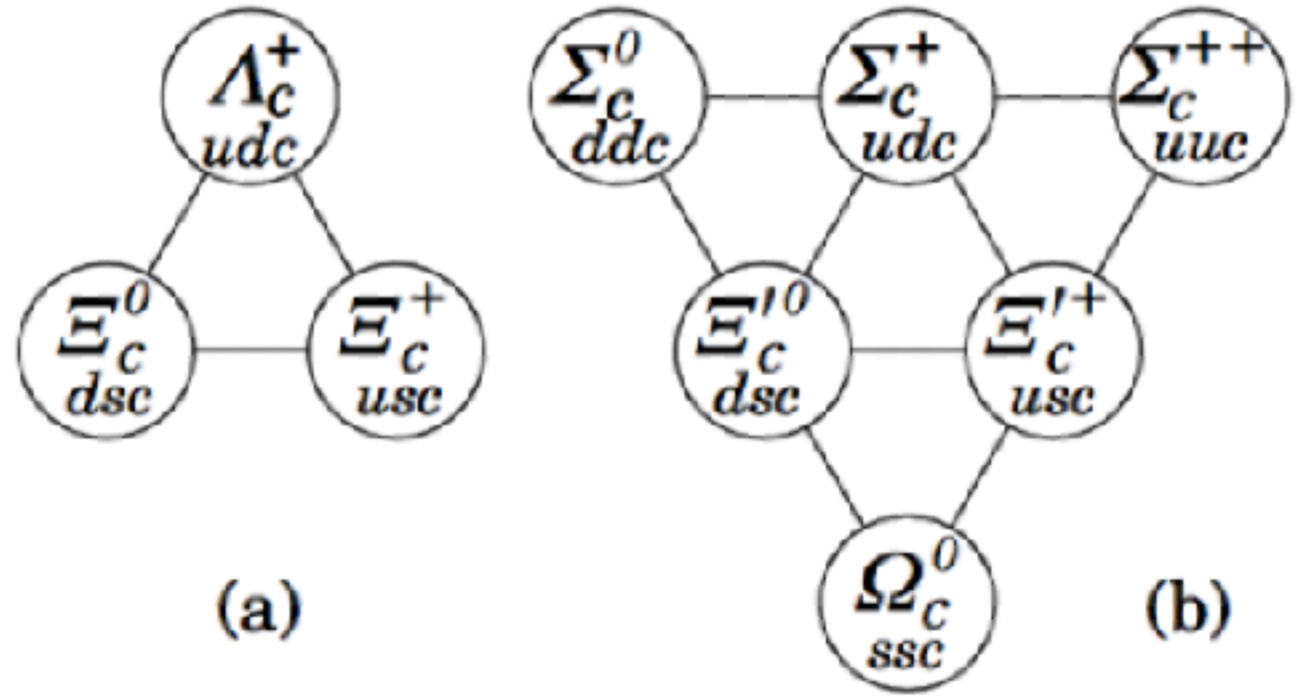

Anti-symmetric   Symmetric

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Singlet

$$\Sigma_c\left(\frac{1}{2}^+, \frac{3}{2}^+\right) = \Big[[\psi_0(\lambda)\psi_0(\rho), s_d^1]^1, S_Q \Big]^{\frac{1}{2}, \frac{3}{2}}$$

Doublet

Orbital excited states $(l = 1)$

λ mode

$j = 1$	$1/2^-$ $3/2^-$

ρ mode

$j = 0$	$1/2^-$
$j = 1$	$1/2^-$ $3/2^-$
$j = 2$	$3/2^-$ $5/2^-$

Mass spectra

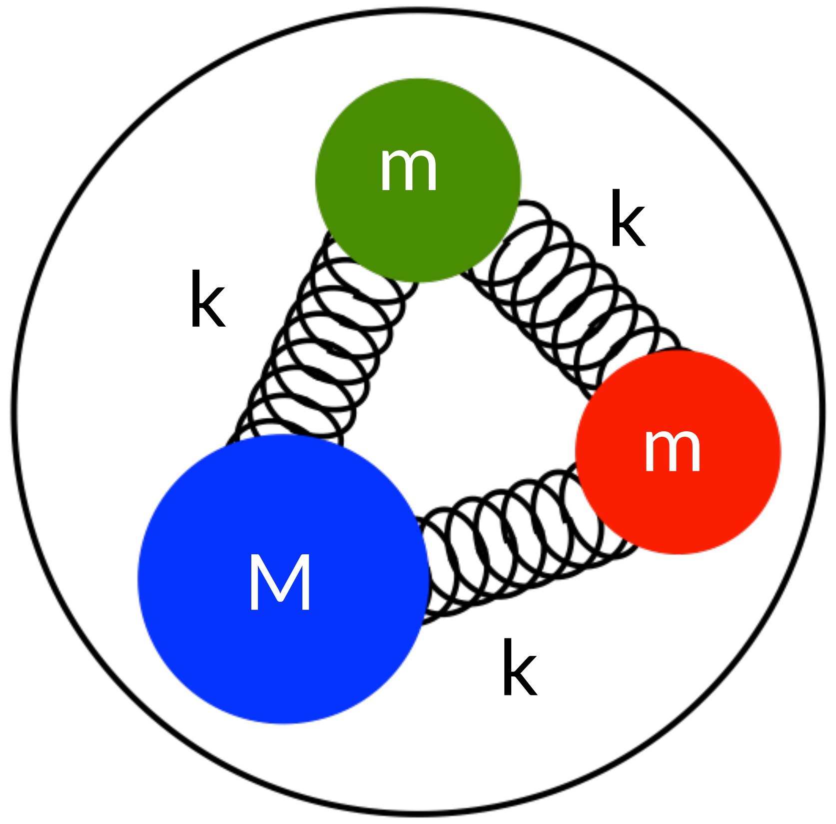
✦ Yoshida et al. PRD92, 114029 (2015)

Mass spectra

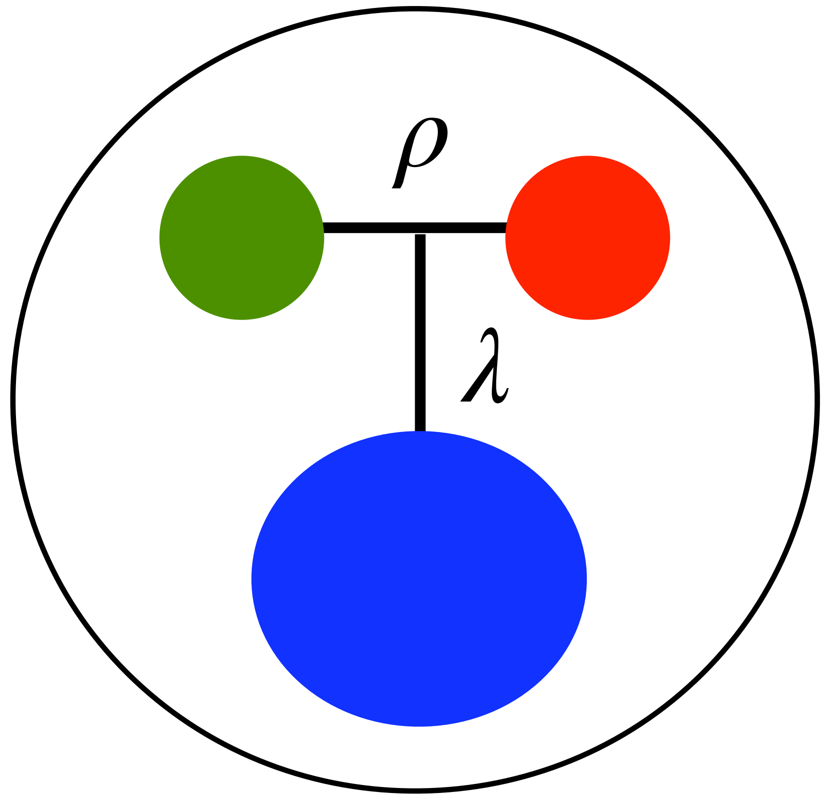
NR quark model

- Diagonalizing Hamiltonian with GEM

$$H = K + V_{\rm short} + V_{\rm conf}$$



Two-body interaction



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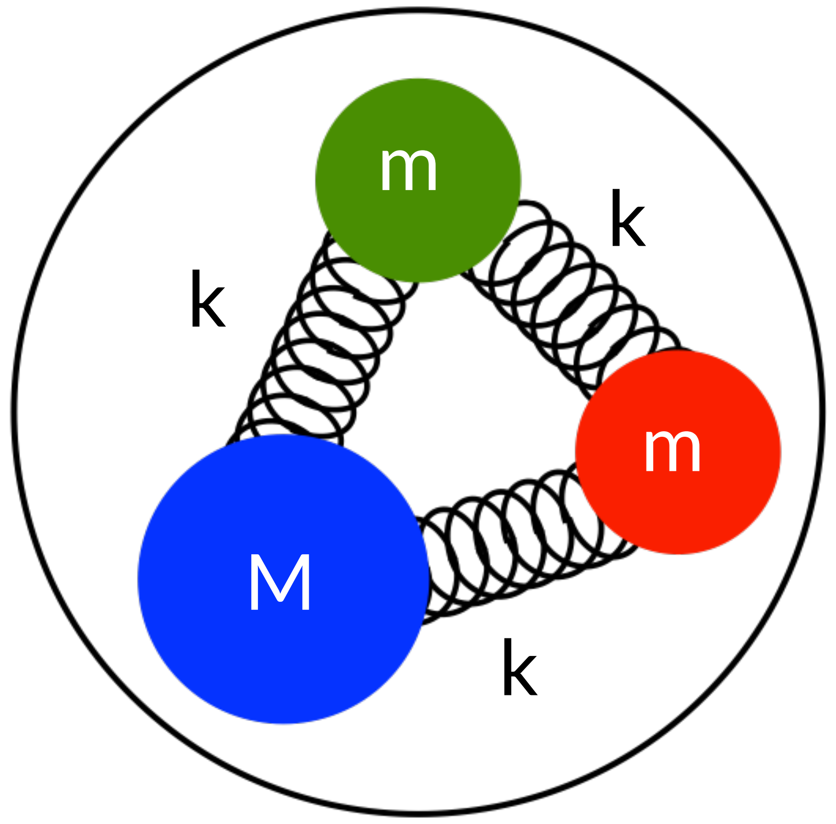

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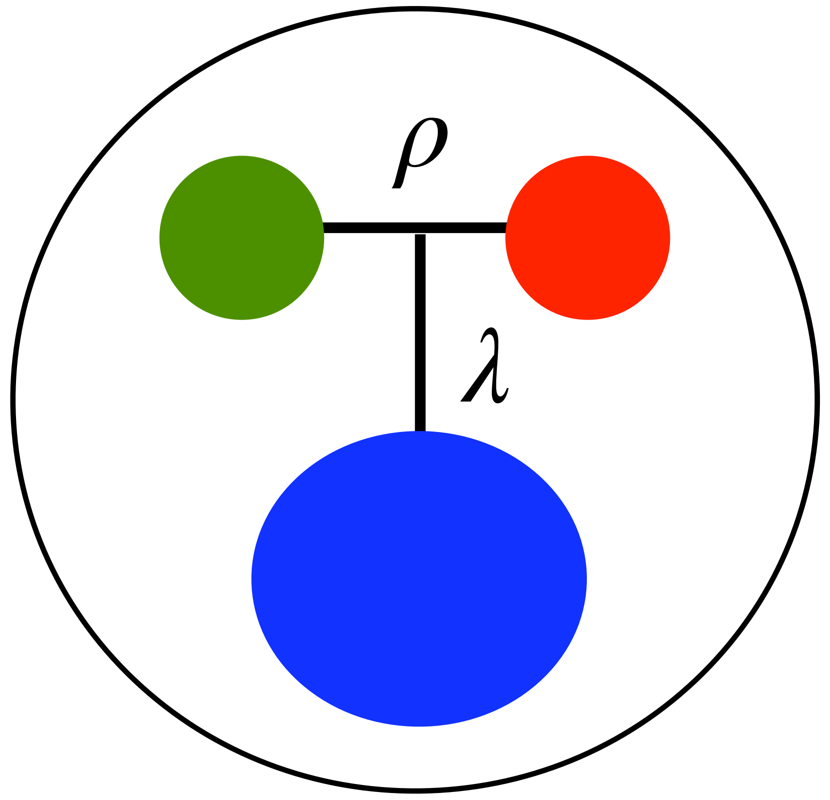

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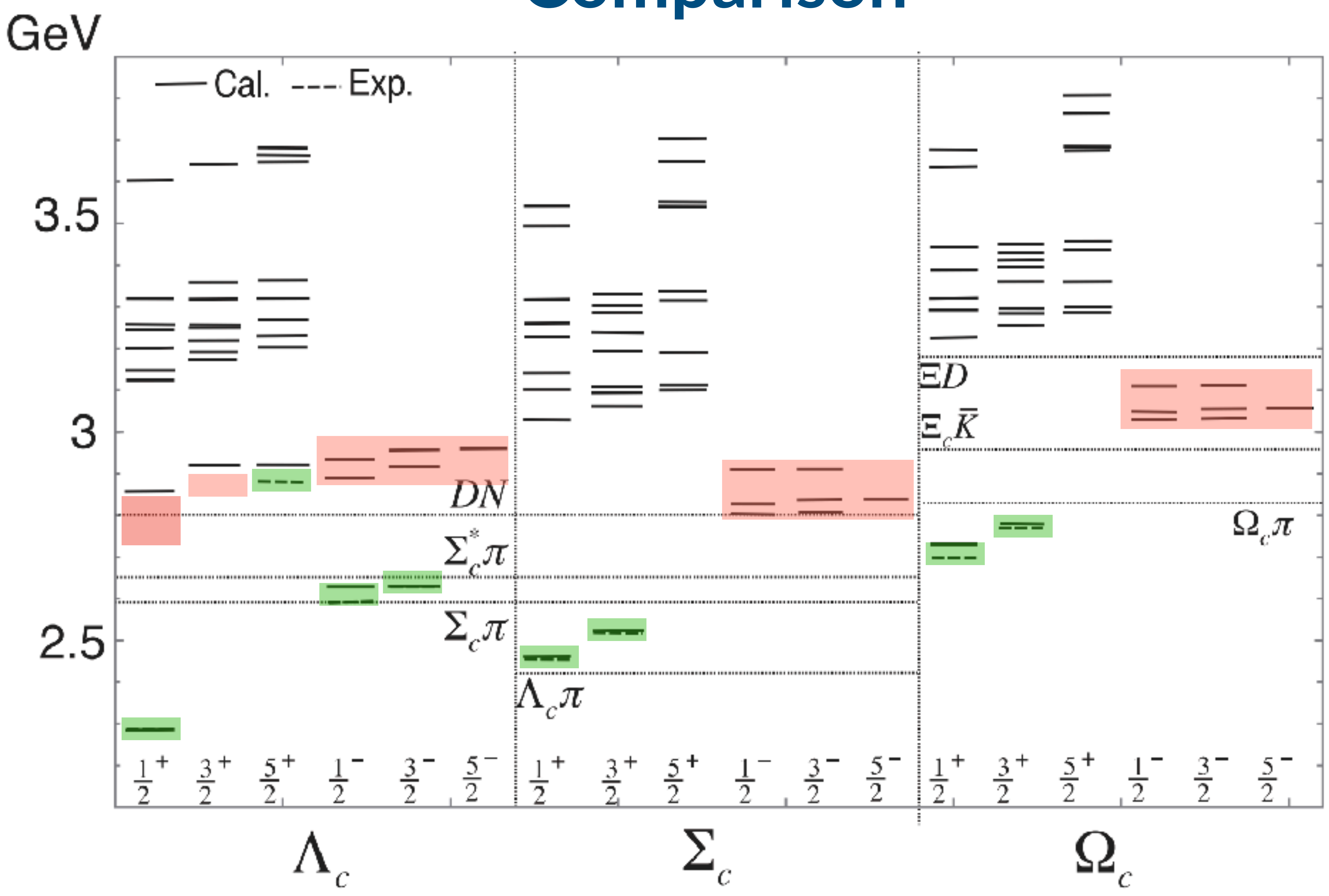
Comparison



- There are many unobserved states. Too wide?
- We also need to clarify their structure and quantum number.

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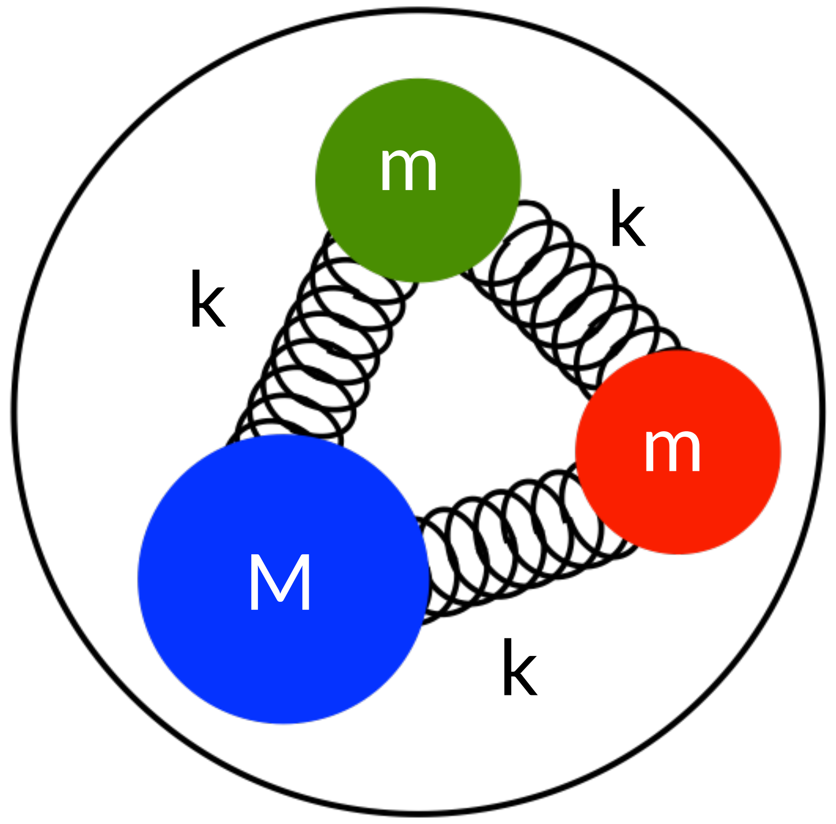

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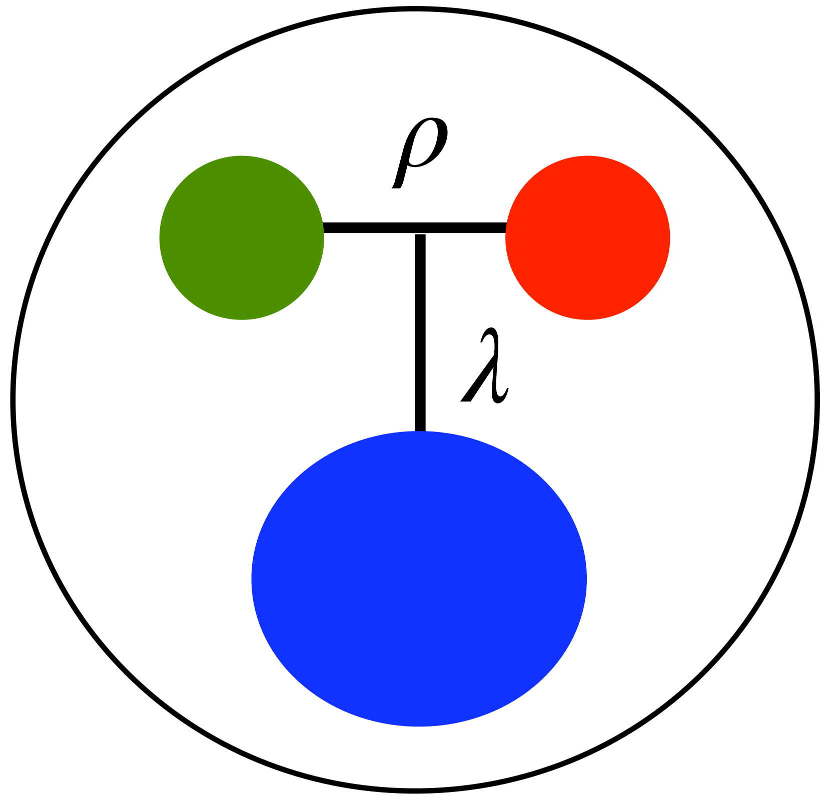

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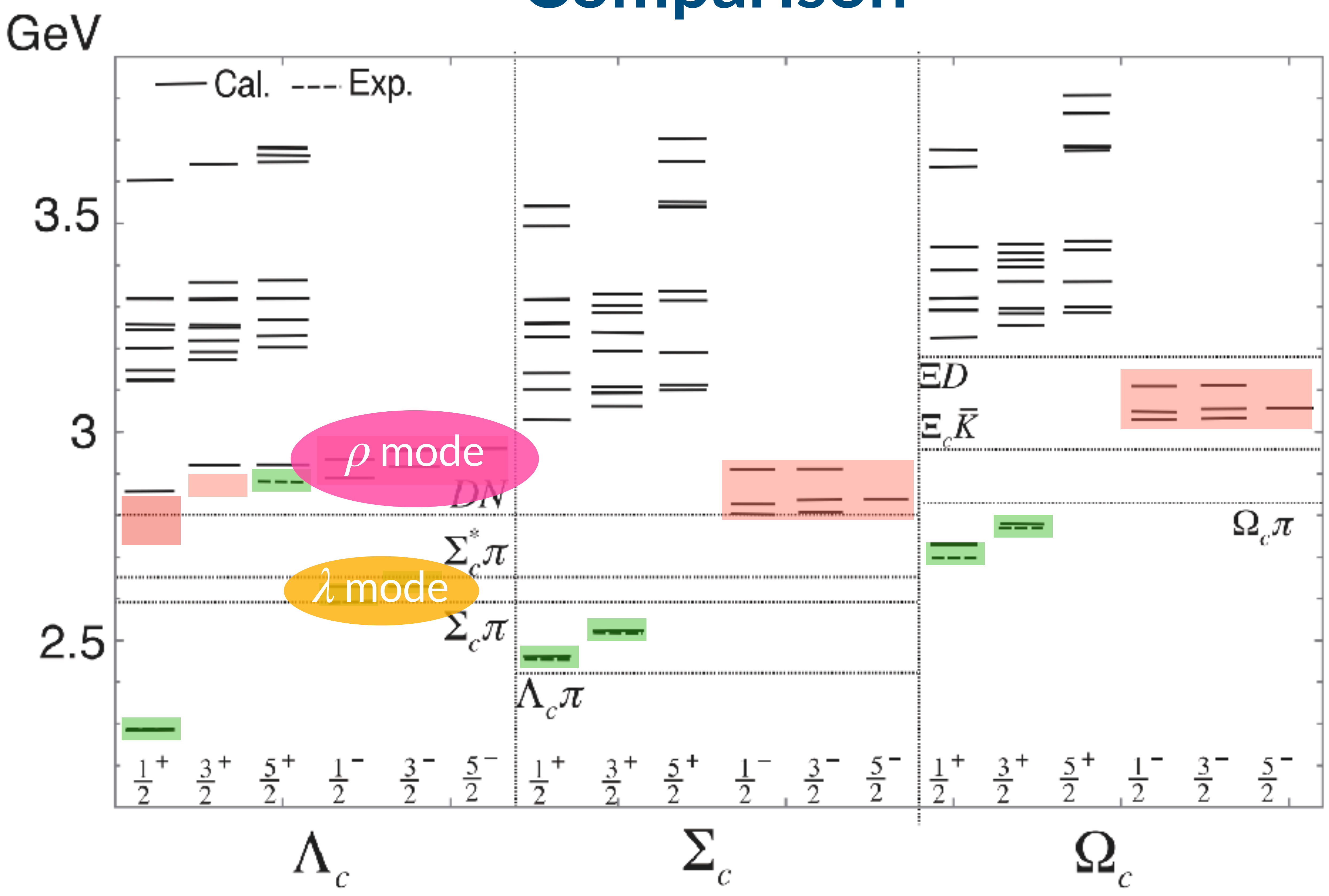

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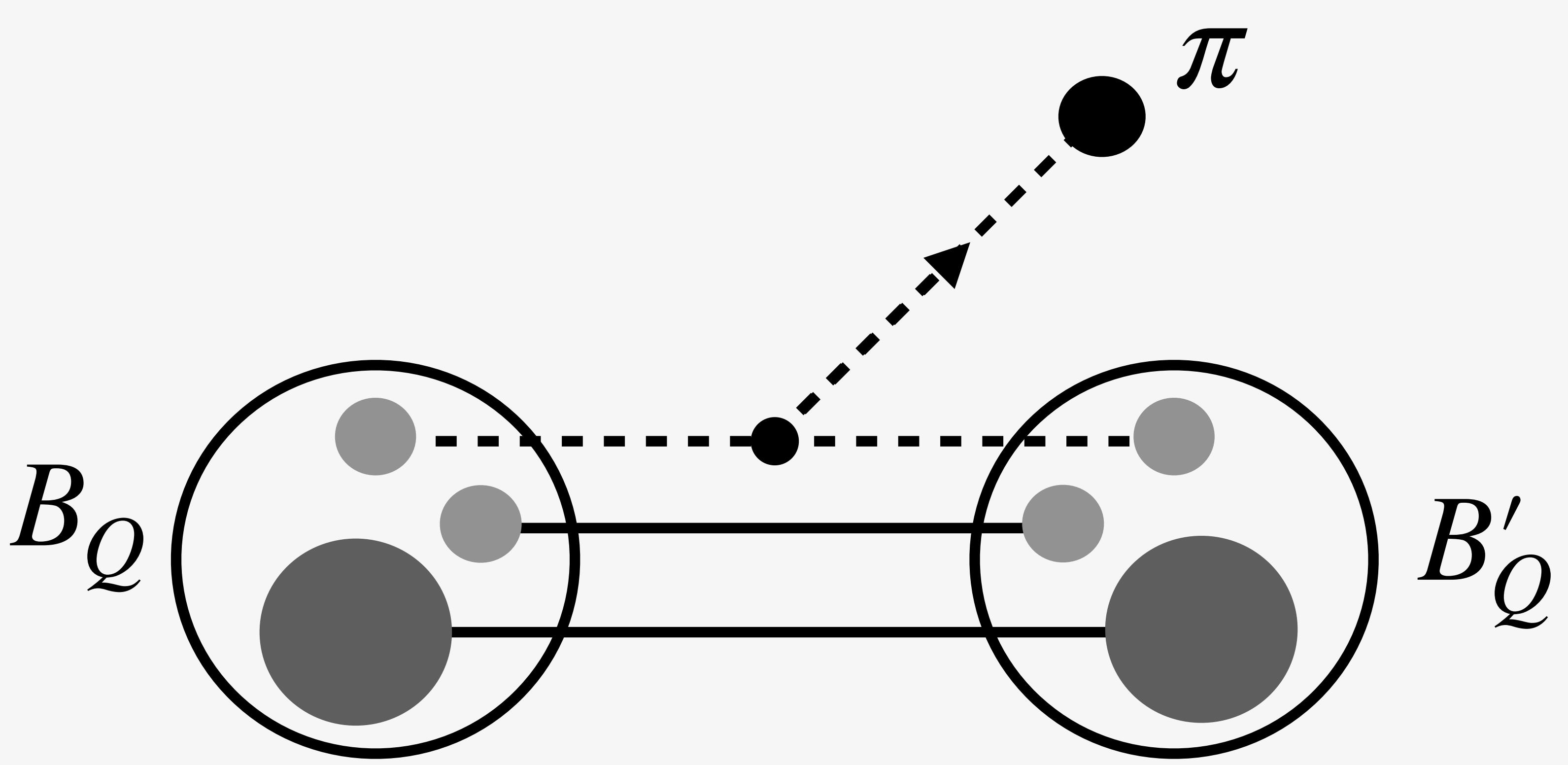
Decay pattern

✦ Nagahiro et al. PRD95, 014023 (2017)

Decay pattern

One-pion emission

$$B_Q \to B'_Q + \pi$$



- Baryon wave function
- Quark-pion coupling

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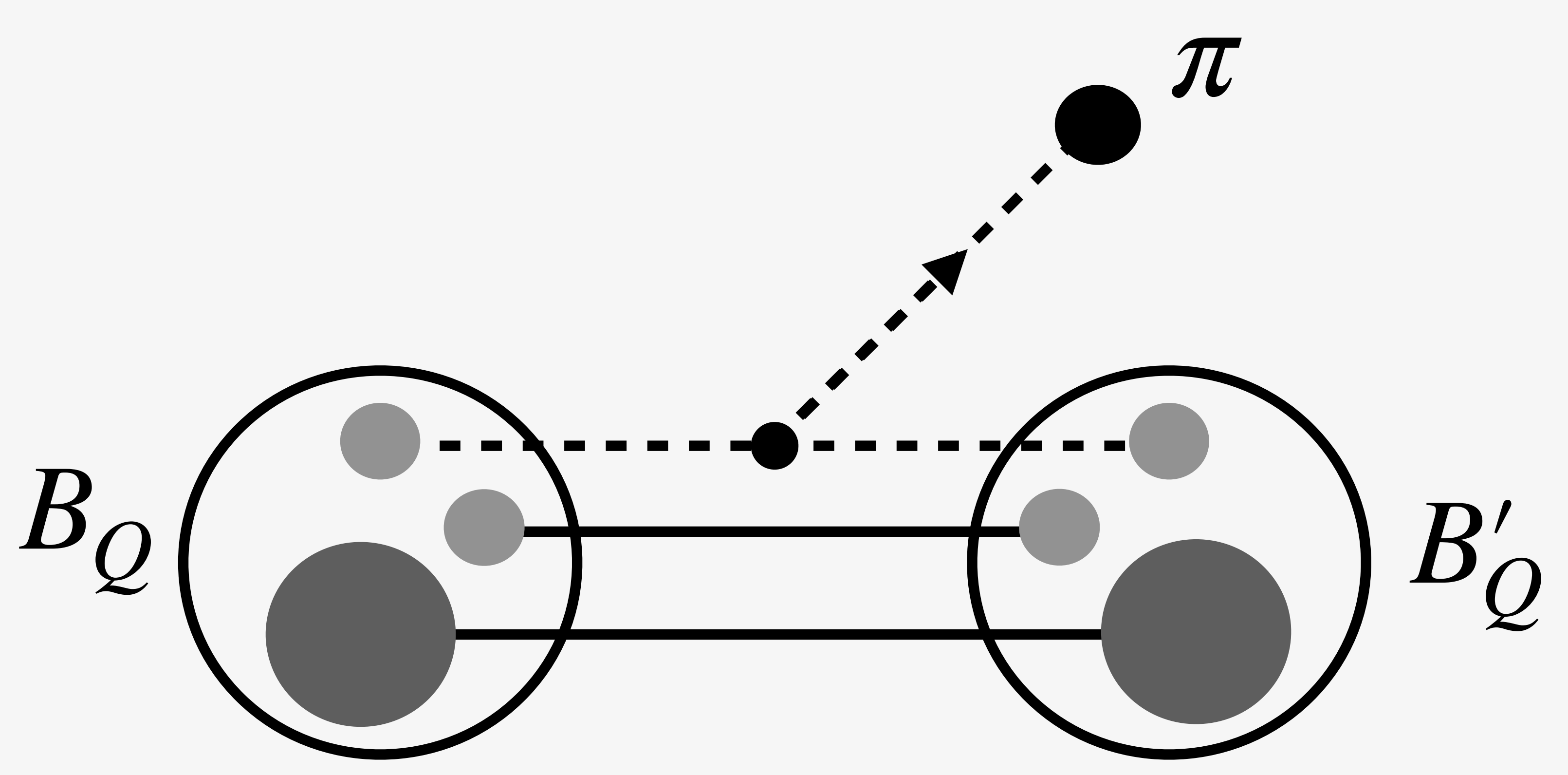
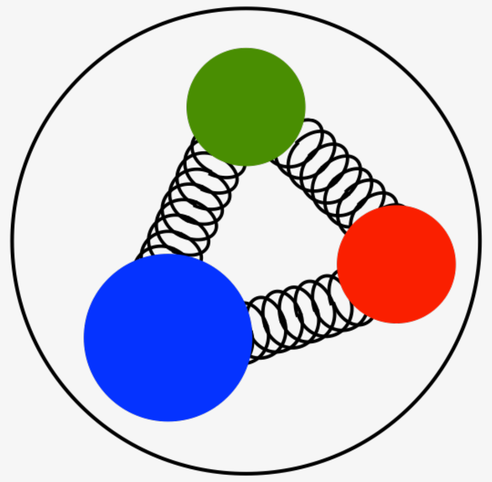


- Baryon wave function
- Quark-pion coupling

Chiral quark model

- HO wave function



$$V = \sum_{i<j} \frac{1}{2} k r_{ij}^2$$

- Analytic solution
- Realistic WF (GEM)

- Axial-vector type coupling

$$\mathcal{L}_{\pi qq} = \frac{g_A^q}{2f_\pi} \bar{q}\gamma^\mu\gamma_5 \vec{\tau} q \cdot \partial_\mu \vec{\pi}$$

Nonrelativistic reduction

$$\mathcal{H}_{\pi qq} \propto \left[\sigma \cdot q - \frac{\omega_\pi}{2m} \sigma \cdot (p_i + p_f)\right]$$

✦ Nagahiro et al. PRD95, 014023 (2017)

Orbital excitations: Status

Anti-symmetric flavor $\bar{3}_F$

- LHCb. PRL 131, 171901 (2023)
- CMS. PRL 126, 252003 (2021)

Orbital excitations: Status

Charmed baryon

$\Lambda_c(2595)$	$\Lambda_c(2625)$
$J^P = 1/2^-$	$J^P = 3/2^-$
$\Gamma = 2.6(6)\ \mathrm{MeV}$	$\Gamma < 0.97\ \mathrm{MeV}$

$\Xi_c(2790)$	$\Xi_c(2815)$
$J^P = 1/2^-$	$J^P = 3/2^-$
$\Gamma = 8.9(1.0)\ \mathrm{MeV}$	$\Gamma = 10.0(1.1)\ \mathrm{MeV}$

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Bottom baryon

$\Lambda_b(5912)$	$\Lambda_b(5920)$
$J^P = 1/2^-$	$J^P = 3/2^-$
$\Gamma < 0.25$ MeV	$\Gamma < 0.19$ MeV

$\Xi_b(6087)$	$\Xi_b(6100)$
$J^P = 1/2^-$	$J^P = 3/2^-$
$\Gamma = 2.43(51)$ MeV	$\Gamma = 0.94(30)$ MeV

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- Narrow resonances
- Dominant decay: two-pion emission

Anti-symmetric flavor $\bar{3}_F$

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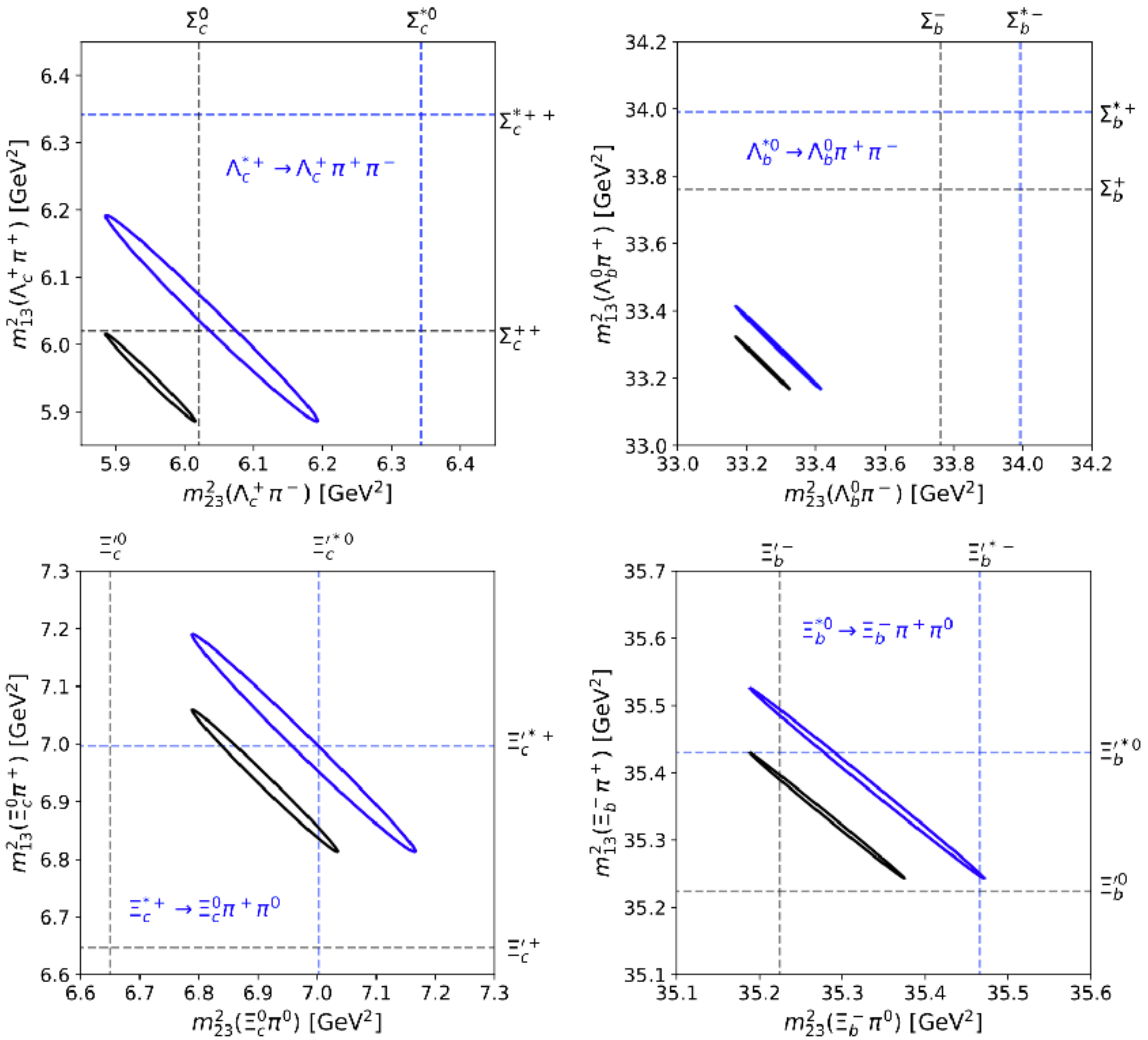
Two-pion emission decay

Two-pion emission decay

Phase space



Two-pion emission decay

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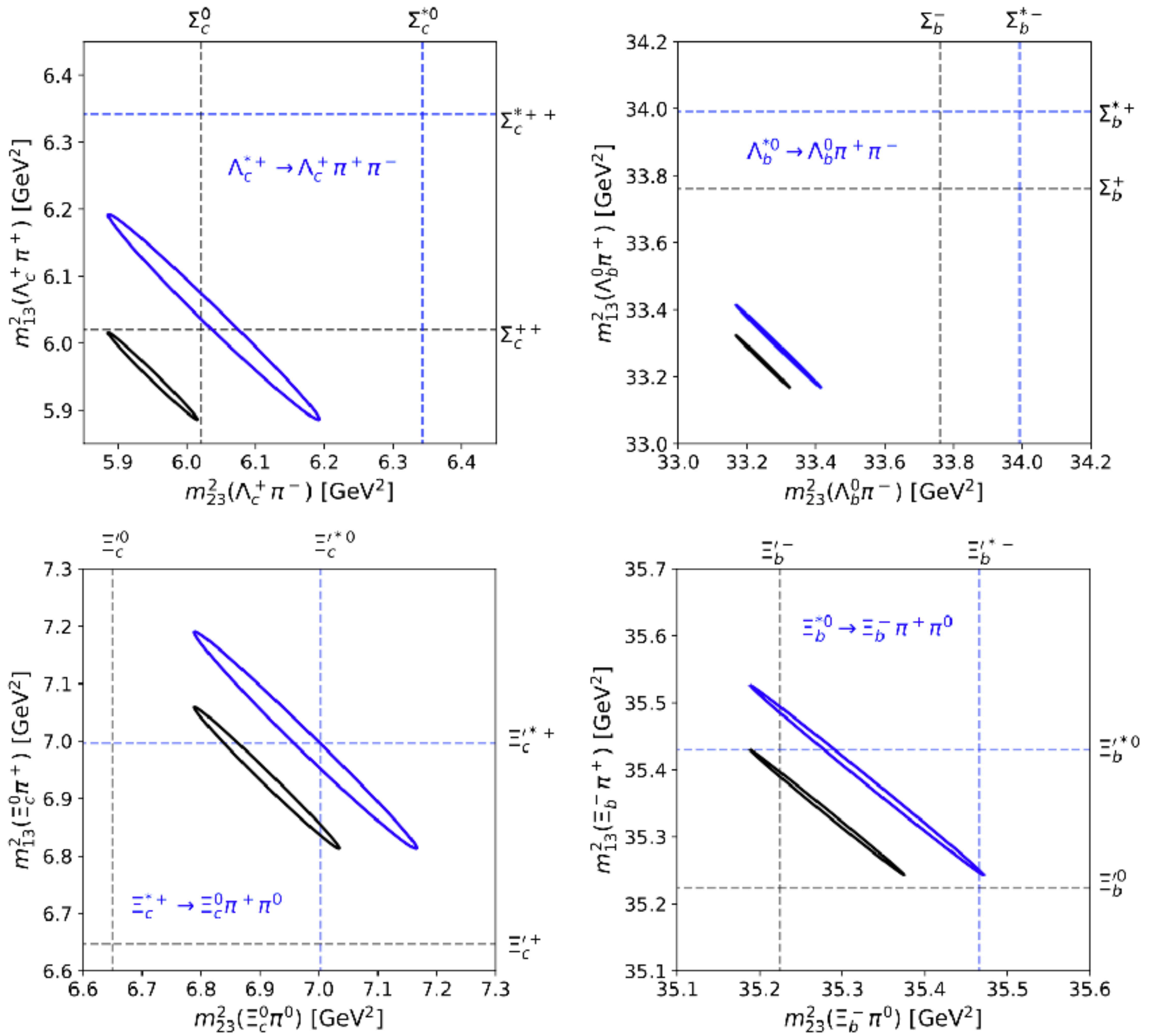


Sequential decays

$\Lambda_c(1/2^-) \rightarrow \Sigma_c(1/2^+) + \pi$ **(S wave)**

$\quad\hookrightarrow \Lambda_c + \pi$

$\Lambda_c(1/2^-) \rightarrow \Sigma_c(3/2^+) + \pi$ **(D wave)**

$\quad\hookrightarrow \Lambda_c + \pi$

$\Lambda_c(3/2^-) \rightarrow \Sigma_c(1/2^+) + \pi$ **(D wave)**

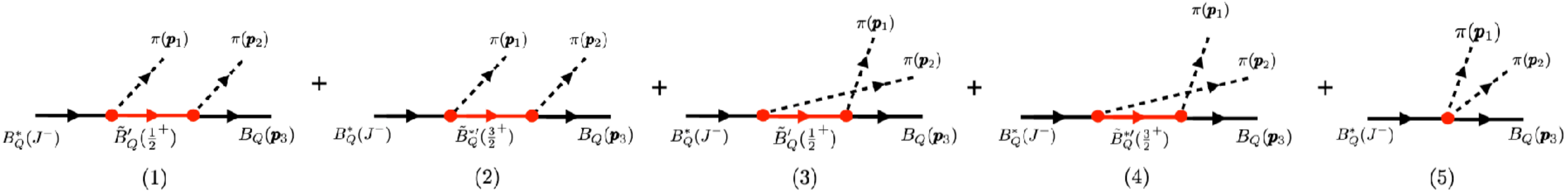
$\quad\hookrightarrow \Lambda_c + \pi$

$\Lambda_c(3/2^-) \rightarrow \Sigma_c(3/2^+) + \pi$ **(S wave)**

$\quad\hookrightarrow \Lambda_c + \pi$

Decay amplitudes

Decay amplitudes



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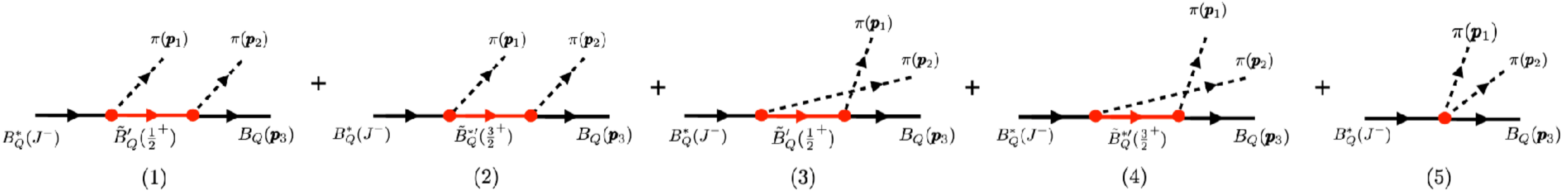


$B_Q^*(1/2^-) \to B_Q\pi\pi$

$$\mathcal{M}_1(\tilde{B}_Q) = \frac{g^a_{11} g^b_{11} N \chi^\dagger_{B_Q} (\boldsymbol{\sigma}\cdot\boldsymbol{p}_2)\chi_{B_Q^*}}{m_{\pi_2 B_Q} - M_{\tilde{B}_Q(\frac{1}{2}^+)} + \frac{i}{2}\Gamma_{\tilde{B}_Q(\frac{1}{2}^+)}},$$ **(S wave)**

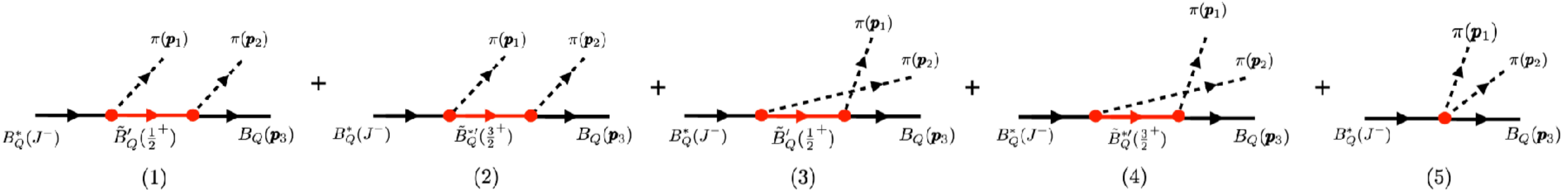
$$\mathcal{M}_2(\tilde{B}^*_Q) = \frac{g^a_{13} g^b_{31} N \chi^\dagger_{B_Q} (\boldsymbol{S}\cdot\boldsymbol{p}_2)(\boldsymbol{S}^\dagger\cdot\boldsymbol{p}_1)(\boldsymbol{\sigma}\cdot\boldsymbol{p}_1)\chi_{B_Q^*}}{m_{\pi_2 B_Q} - M_{\tilde{B}_Q(\frac{3}{2}^+)} + \frac{i}{2}\Gamma_{\tilde{B}_Q(\frac{3}{2}^+)}},$$ **(D wave)**

$$\mathcal{M}_3(\tilde{B}'_Q) = \frac{g^{a\prime}_{11} g^{b\prime}_{11} N \chi^\dagger_{B_Q} (\boldsymbol{\sigma}\cdot\boldsymbol{p}_1)\chi_{B_Q^*}}{m_{\pi_1 B_Q} - M_{\tilde{B}'_Q(\frac{1}{2}^+)} + \frac{i}{2}\Gamma_{\tilde{B}'_Q(\frac{1}{2}^+)}},$$ **(S wave)**

$$\mathcal{M}_4(\tilde{B}^{*\prime}_Q) = \frac{g^{a\prime}_{13} g^{b\prime}_{31} N \chi^\dagger_{B_Q} (\boldsymbol{S}\cdot\boldsymbol{p}_1)(\boldsymbol{S}^\dagger\cdot\boldsymbol{p}_2)(\boldsymbol{\sigma}\cdot\boldsymbol{p}_2)\chi_{B_Q^*}}{m_{\pi_1 B_Q} - M_{\tilde{B}^{*\prime}_Q(\frac{3}{2}^+)} + \frac{i}{2}\Gamma_{\tilde{B}^{*\prime}_Q(\frac{3}{2}^+)}},$$ **(D wave)**

$$\mathcal{M}_5(\mathrm{dir}) = \frac{g^d_{11} N}{f_\pi} \chi^\dagger_{B_Q} (\boldsymbol{\sigma}\cdot(\boldsymbol{p}_1 + \boldsymbol{p}_2))\chi_{B_Q^*}.$$ **(P wave)**

Decay amplitudes



$B_Q^*(1/2^-) \to B_Q\pi\pi$

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$$\mathcal{M}_3(\tilde{B}'_Q) = \frac{g^{a\prime}_{11} g^{b\prime}_{11} N \chi^\dagger_{B_Q} (\boldsymbol{\sigma}\cdot\boldsymbol{p}_1)\chi_{B^*_Q}}{m_{\pi_1 B_Q} - M_{\tilde{B}'_Q(\frac{1}{2}^+)} + \frac{i}{2}\Gamma_{\tilde{B}'_Q(\frac{1}{2}^+)}},$$ (S wave)

$$\mathcal{M}_4(\tilde{B}^{*\prime}_Q) = \frac{g^{a\prime}_{13} g^{b\prime}_{31} N \chi^\dagger_{B_Q} (\boldsymbol{S}\cdot\boldsymbol{p}_1)(\boldsymbol{S}^\dagger\cdot\boldsymbol{p}_2)(\boldsymbol{\sigma}\cdot\boldsymbol{p}_2)\chi_{B^*_Q}}{m_{\pi_1 B_Q} - M_{\tilde{B}^{*\prime}_Q(\frac{3}{2}^+)} + \frac{i}{2}\Gamma_{\tilde{B}^{*\prime}_Q(\frac{3}{2}^+)}},$$ (D wave)

$$\mathcal{M}_5(\mathrm{dir}) = \frac{g^d_{11} N}{f_\pi}\chi^\dagger_{B_Q}(\boldsymbol{\sigma}\cdot(\boldsymbol{p}_1+\boldsymbol{p}_2))\chi_{B^*_Q}.$$ (P wave)

$B_Q^*(3/2^-) \to B_Q\pi\pi$

$$\mathcal{M}_1(\tilde{B}_Q) = \frac{g^a_{31} g^b_{11} N \chi^\dagger_{B_Q} (\boldsymbol{\sigma}\cdot\boldsymbol{p}_2)(\boldsymbol{\sigma}\cdot\boldsymbol{p}_1)(\boldsymbol{S}\cdot\boldsymbol{p}_1)\chi_{B^*_Q}}{m_{\pi_2 B_Q} - M_{\tilde{B}_Q(\frac{1}{2}^+)} + \frac{i}{2}\Gamma_{\tilde{B}_Q(\frac{1}{2}^+)}},$$ (D wave)

$$\mathcal{M}_2(\tilde{B}^*_Q) = \frac{g^a_{33} g^b_{31} N \chi^\dagger_{B_Q} (\boldsymbol{S}\cdot\boldsymbol{p}_2)\chi_{B^*_Q}}{m_{\pi_2 B_Q} - M_{\tilde{B}_Q(\frac{3}{2}^+)} + \frac{i}{2}\Gamma_{\tilde{B}_Q(\frac{3}{2}^+)}},$$ (S wave)

$$\mathcal{M}_3(\tilde{B}'_Q) = \frac{g^{a\prime}_{31} g^{b\prime}_{11} N \chi^\dagger_{B_Q} (\boldsymbol{\sigma}\cdot\boldsymbol{p}_1)(\boldsymbol{\sigma}\cdot\boldsymbol{p}_2)(\boldsymbol{S}\cdot\boldsymbol{p}_2)\chi_{B^*_Q}}{m_{\pi_1 B_Q} - M_{\tilde{B}'_Q(\frac{1}{2}^+)} + \frac{i}{2}\Gamma_{\tilde{B}'_Q(\frac{1}{2}^+)}},$$ (D wave)

$$\mathcal{M}_4(\tilde{B}^{*\prime}_Q) = \frac{g^{a\prime}_{33} g^{b\prime}_{31} N \chi^\dagger_{B_Q} (\boldsymbol{S}\cdot\boldsymbol{p}_1)\chi_{B^*_Q}}{m_{\pi_1 B_Q} - M_{\tilde{B}^{*\prime}_Q(\frac{3}{2}^+)} + \frac{i}{2}\Gamma_{\tilde{B}^{*\prime}_Q(\frac{3}{2}^+)}},$$ (S wave)

$$\mathcal{M}_5(\mathrm{dir}) = \frac{g^d_{31} N}{f_\pi}\chi^\dagger_{B_Q}(\boldsymbol{S}\cdot(\boldsymbol{p}_1+\boldsymbol{p}_2))\chi_{B^*_Q},$$ (P wave)

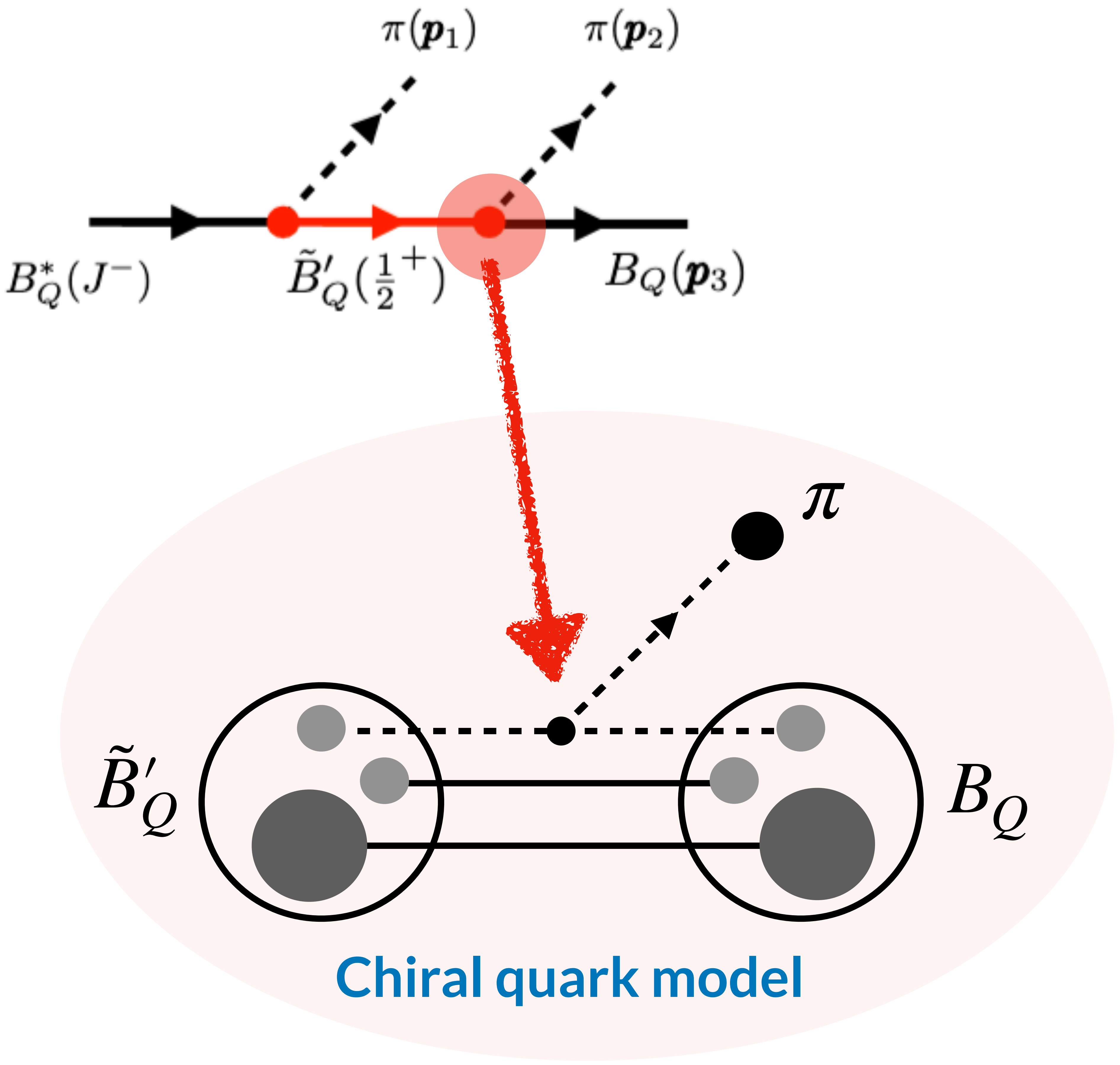
Coupling constants

✦ Nagahiro et al. PRD95, 014023 (2017)

✦ Kawakami et al. PRD97, 114024 (2018)

Coupling constants

Sequential process

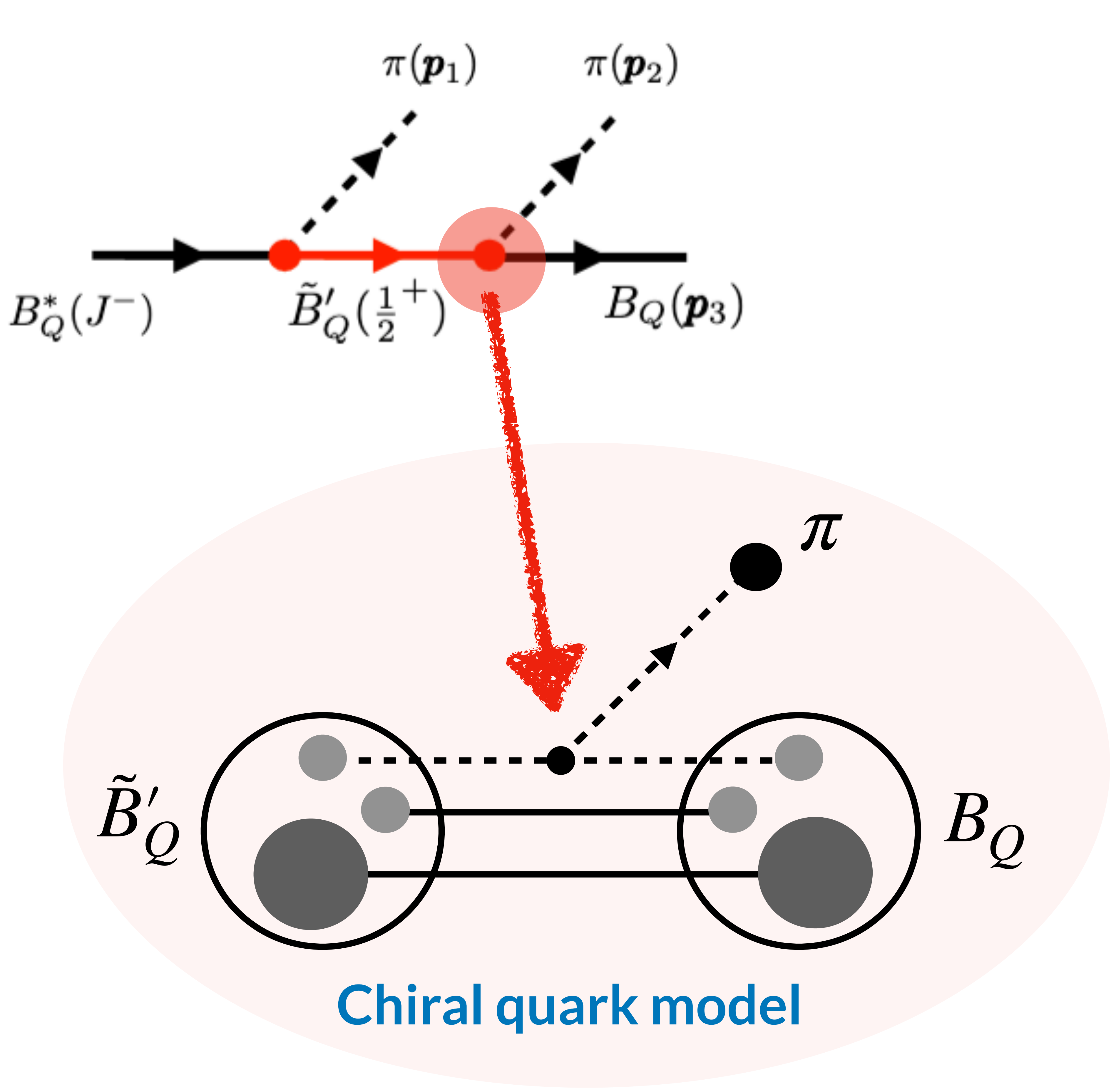


✦ Nagahiro et al. PRD95, 014023 (2017)

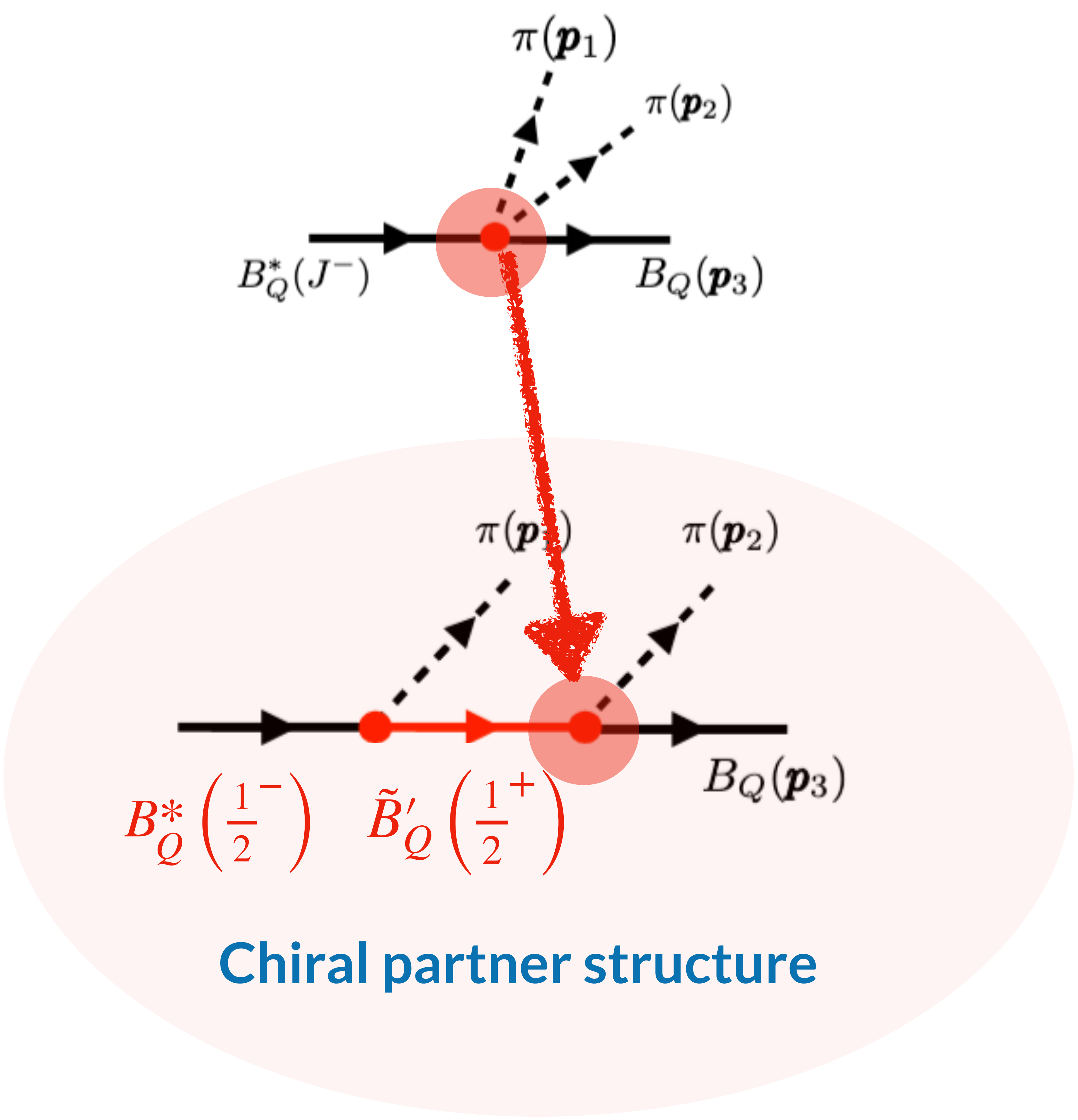
✦ Kawakami et al. PRD97, 114024 (2018)

Coupling constants

Sequential process



Direct process



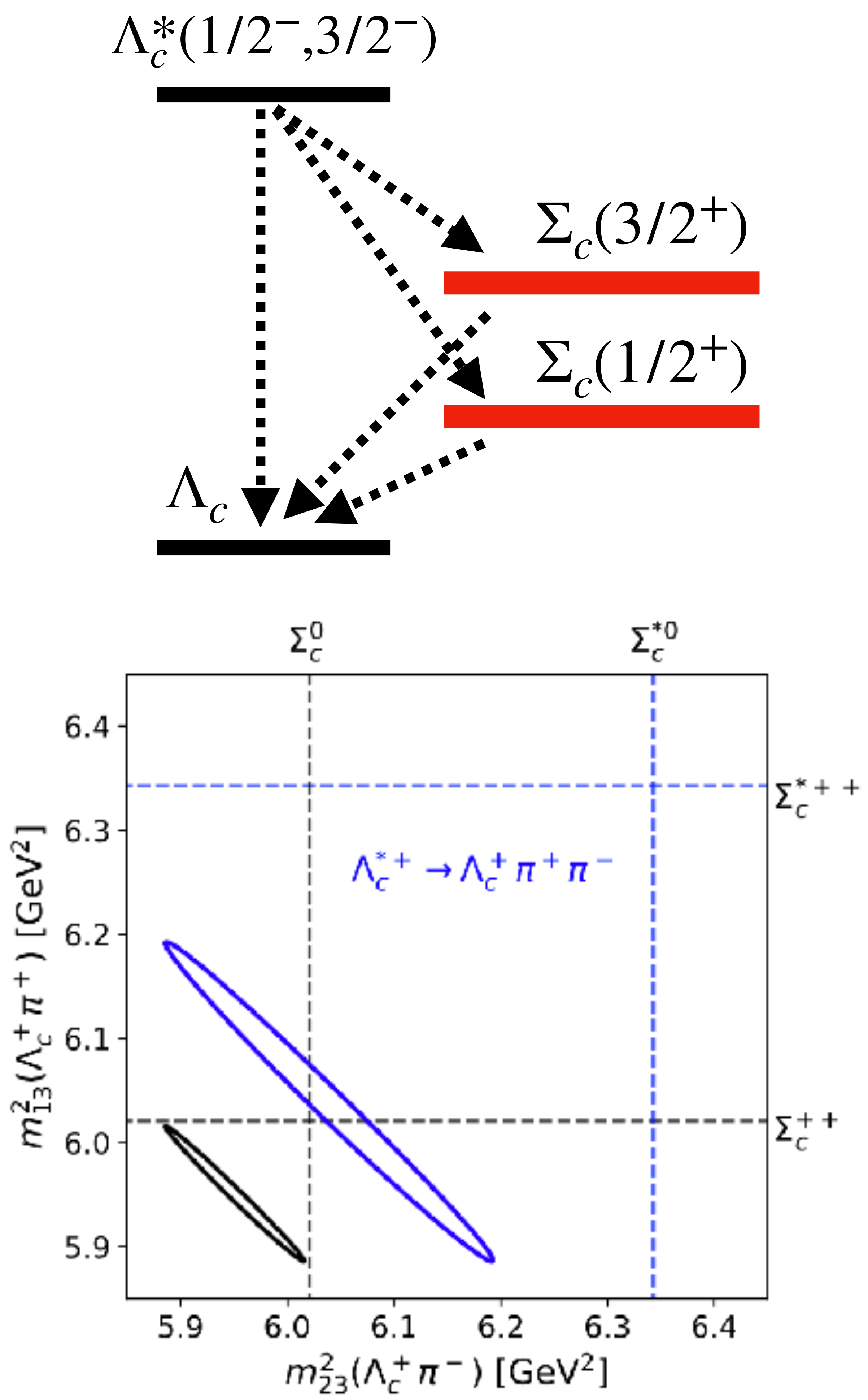
✦ Nagahiro et al. PRD95, 014023 (2017)

✦ Kawakami et al. PRD97, 114024 (2018)

$\Lambda_c(2595)$ and $\Lambda_c(2625)$

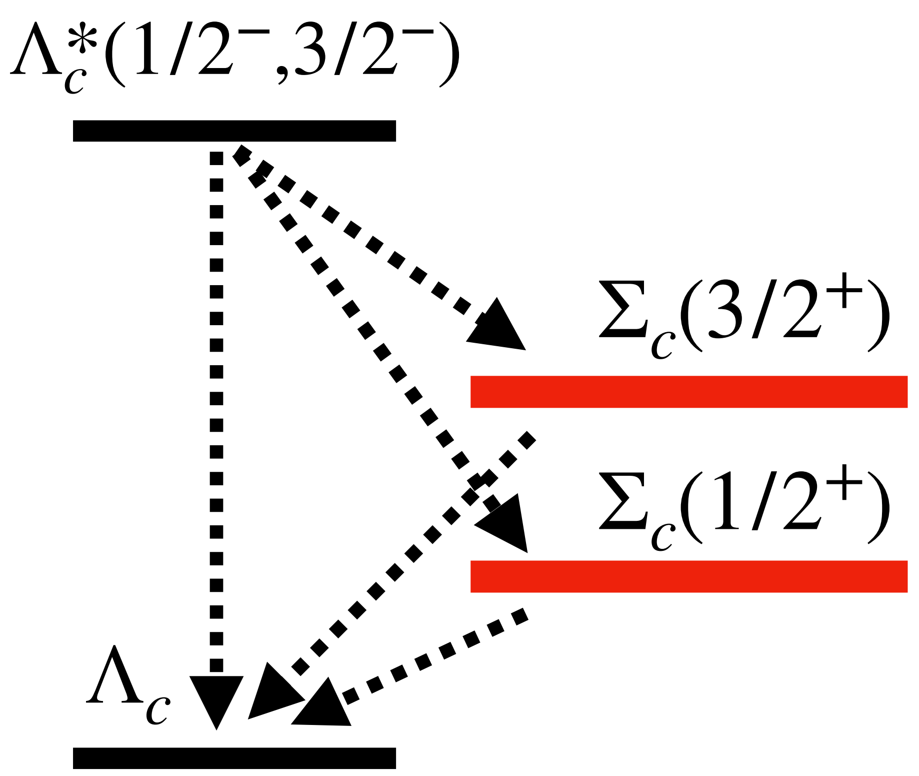
- ✦ Belle. PRD107, 032008 (2023)
- ✦ Arifi et al. PRD98, 114007 (2018)
- ✦ Arifi et al. PRD95, 114018 (2017)

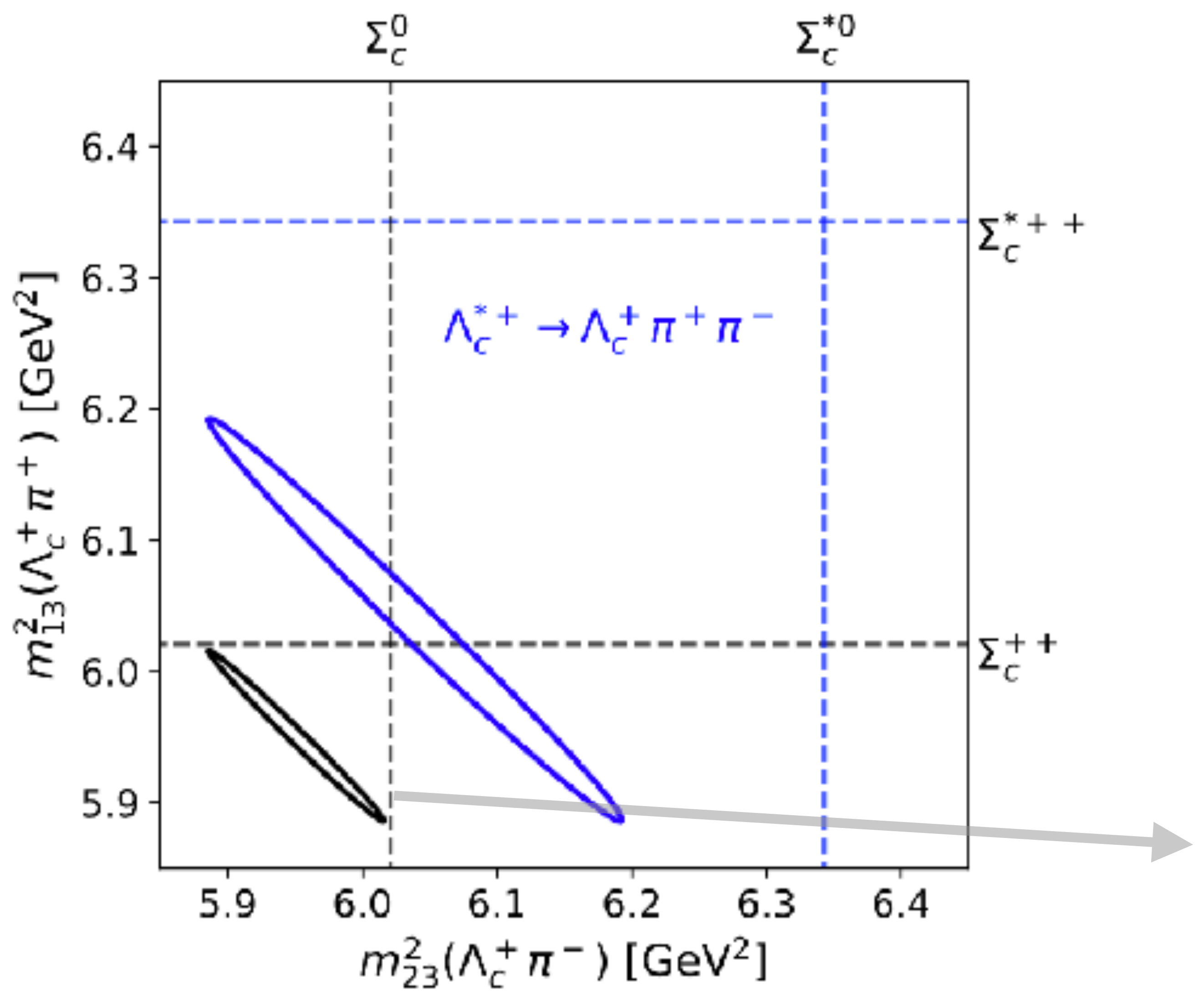
$\Lambda_c(2595)$ and $\Lambda_c(2625)$



- Belle. PRD107, 032008 (2023)
- Arifi et al. PRD98, 114007 (2018)
- Arifi et al. PRD95, 114018 (2017)

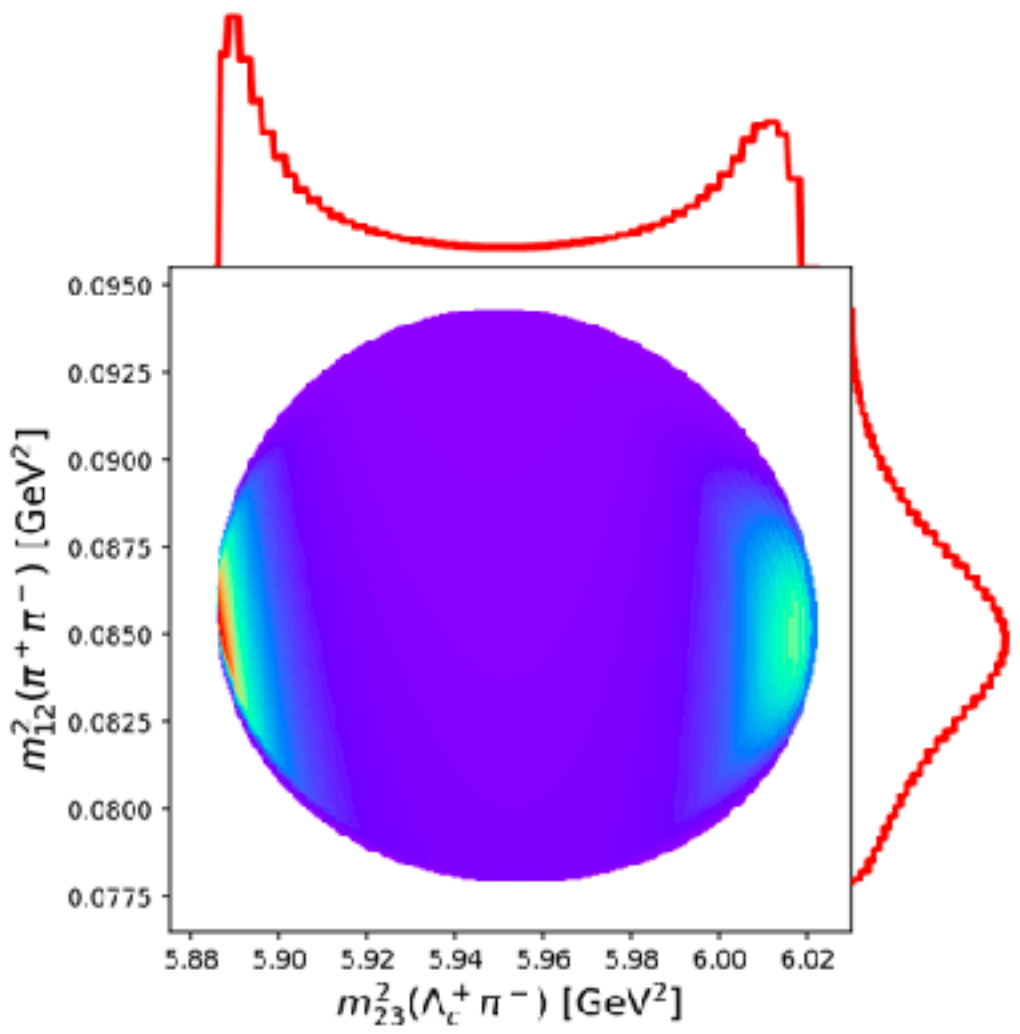
$\Lambda_c(2595)$ and $\Lambda_c(2625)$



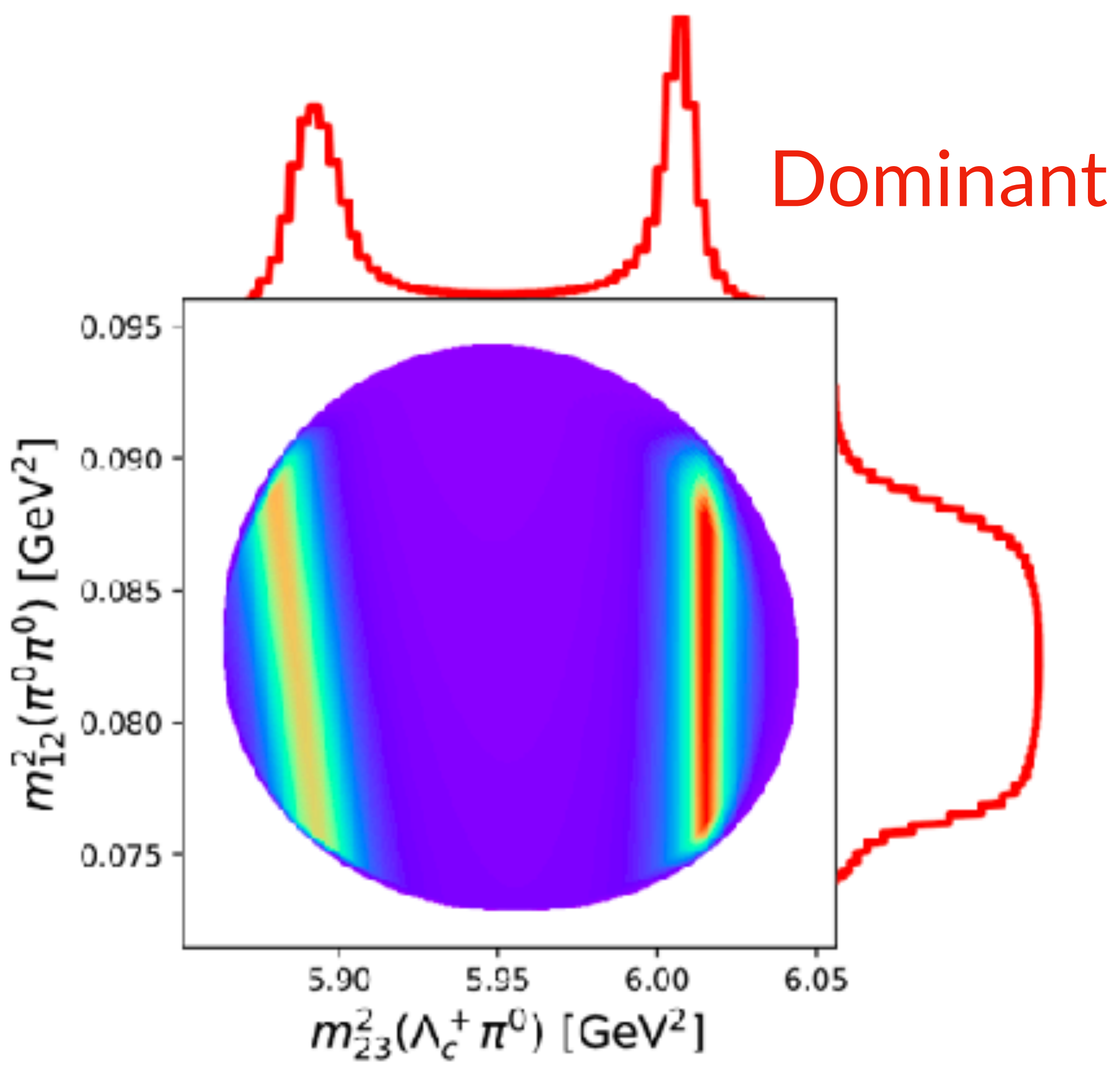


$\Lambda_c(2595)$

$1/2^-$



$\Lambda_c^+\pi^+\pi^-$

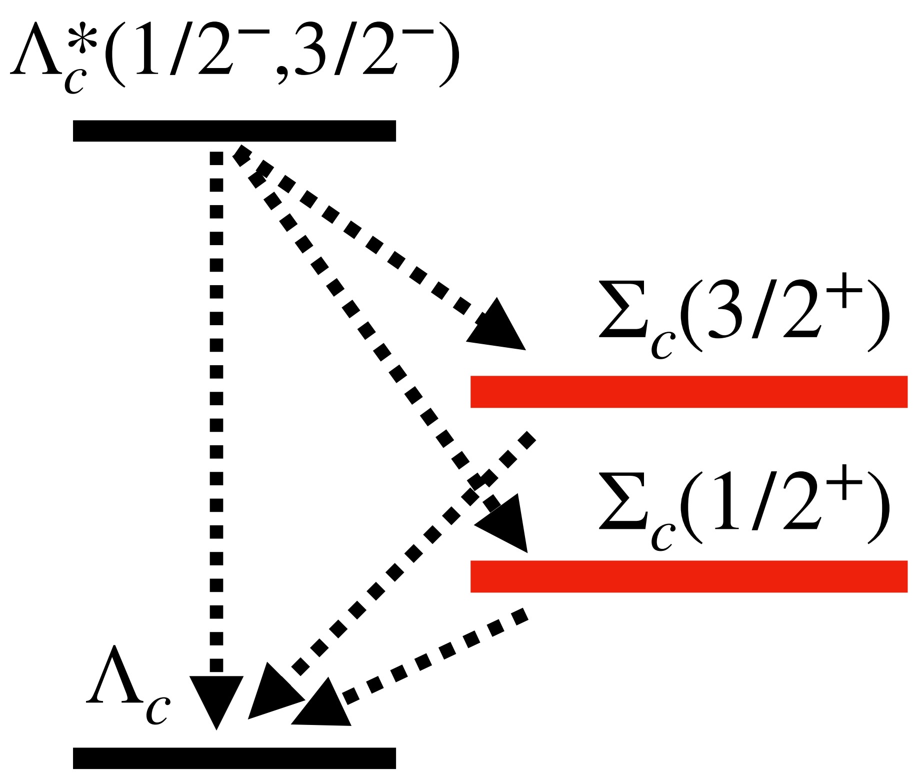


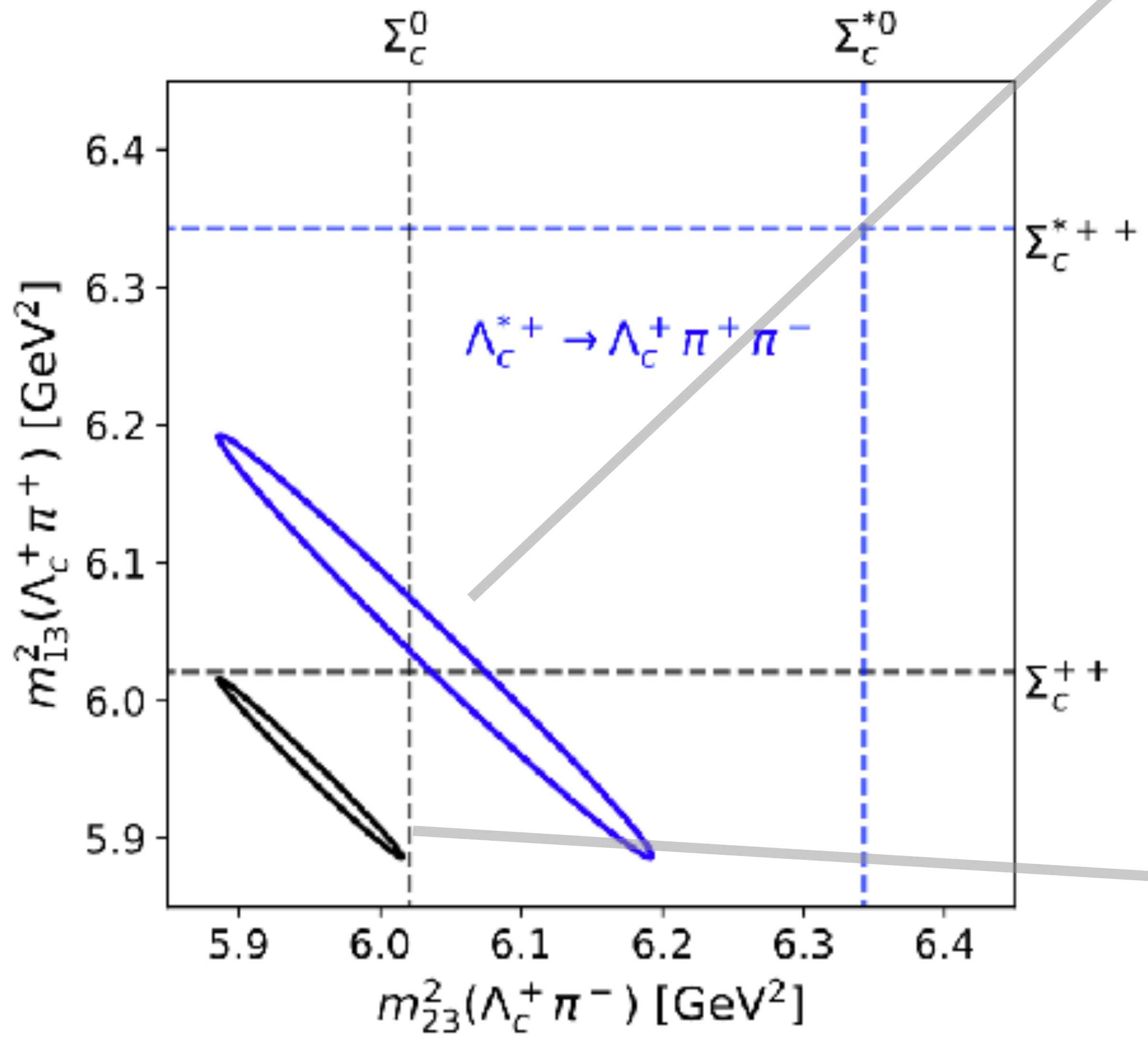
$\Lambda_c^+\pi^0\pi^0$

Back-up slide #1

- Belle. PRD107, 032008 (2023)
- Arifi et al. PRD98, 114007 (2018)
- Arifi et al. PRD95, 114018 (2017)

$\Lambda_c(2595)$ and $\Lambda_c(2625)$



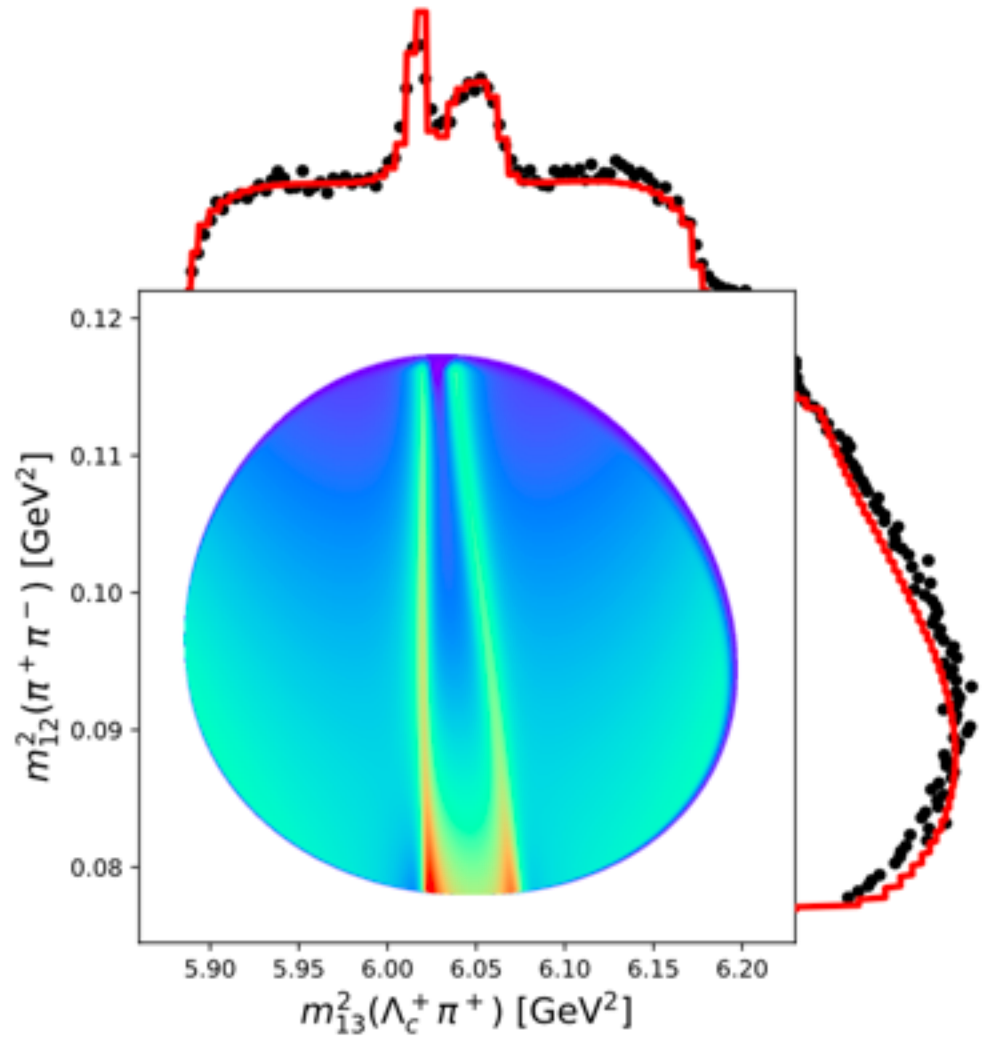


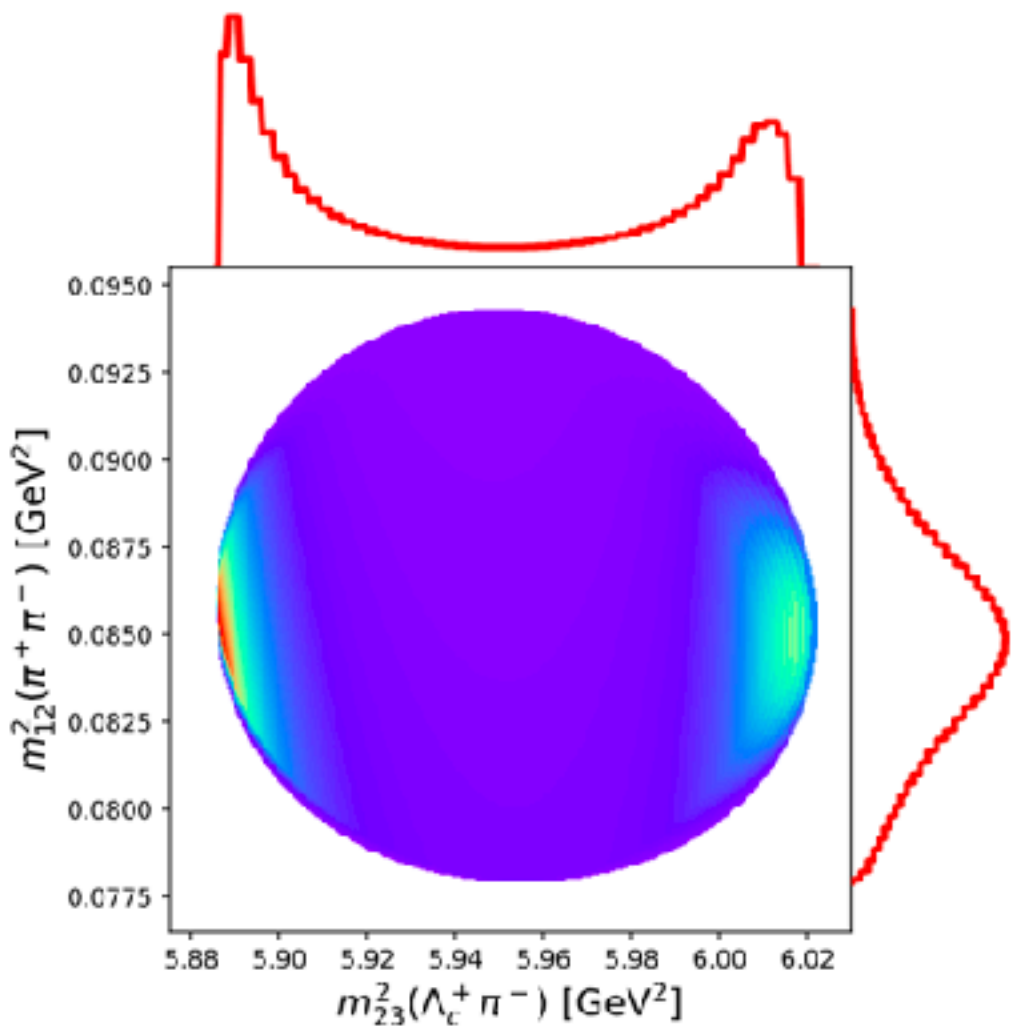
$\Lambda_c(2625)$

$3/2^-$

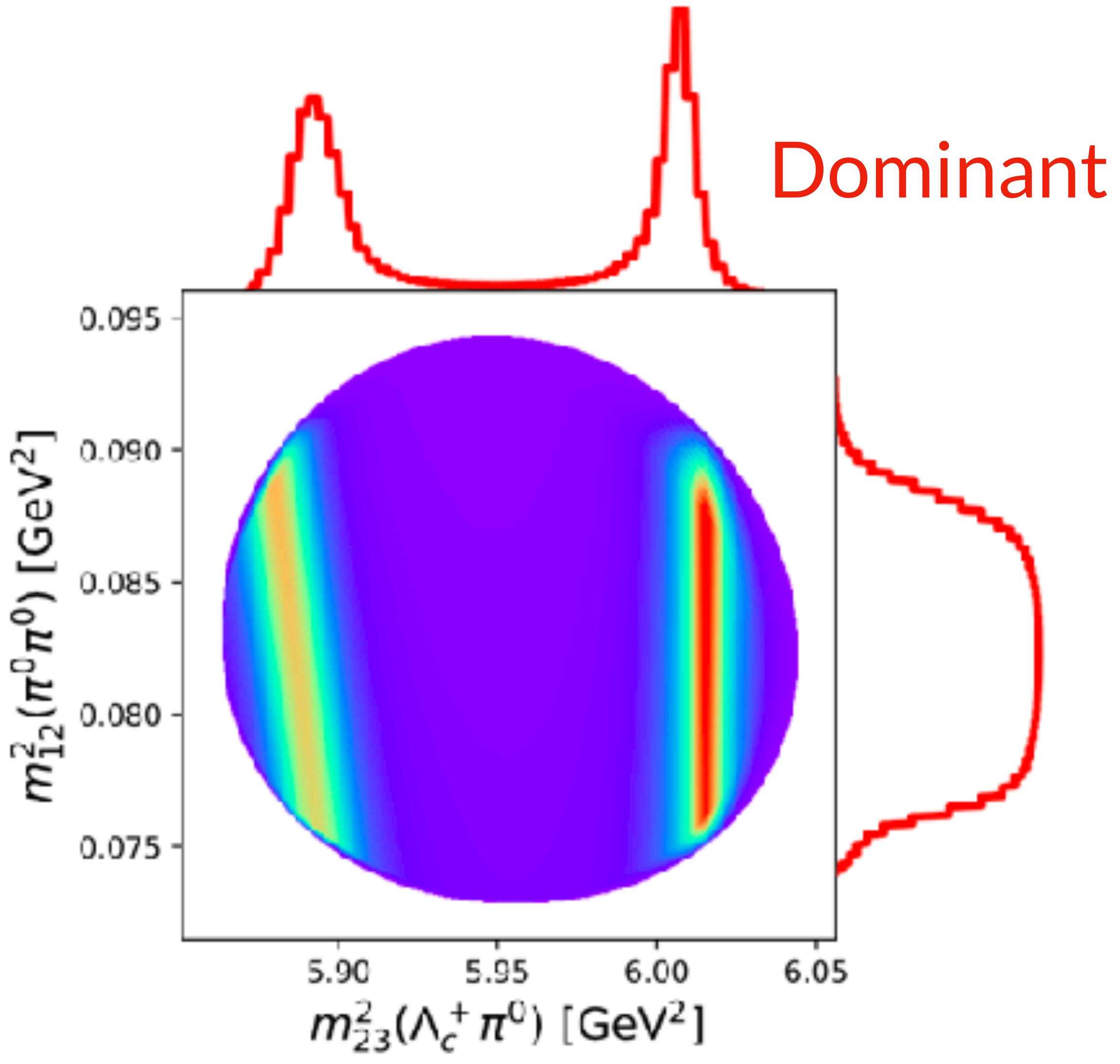
$\Lambda_c(2595)$

$1/2^-$





$\Lambda_c^+ \pi^+ \pi^-$

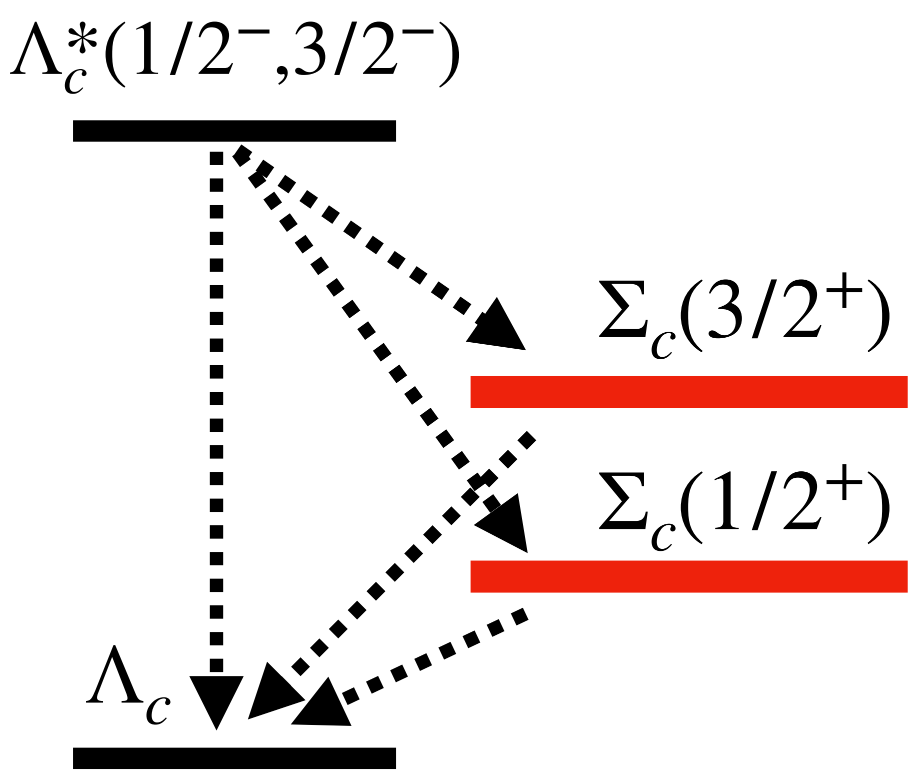


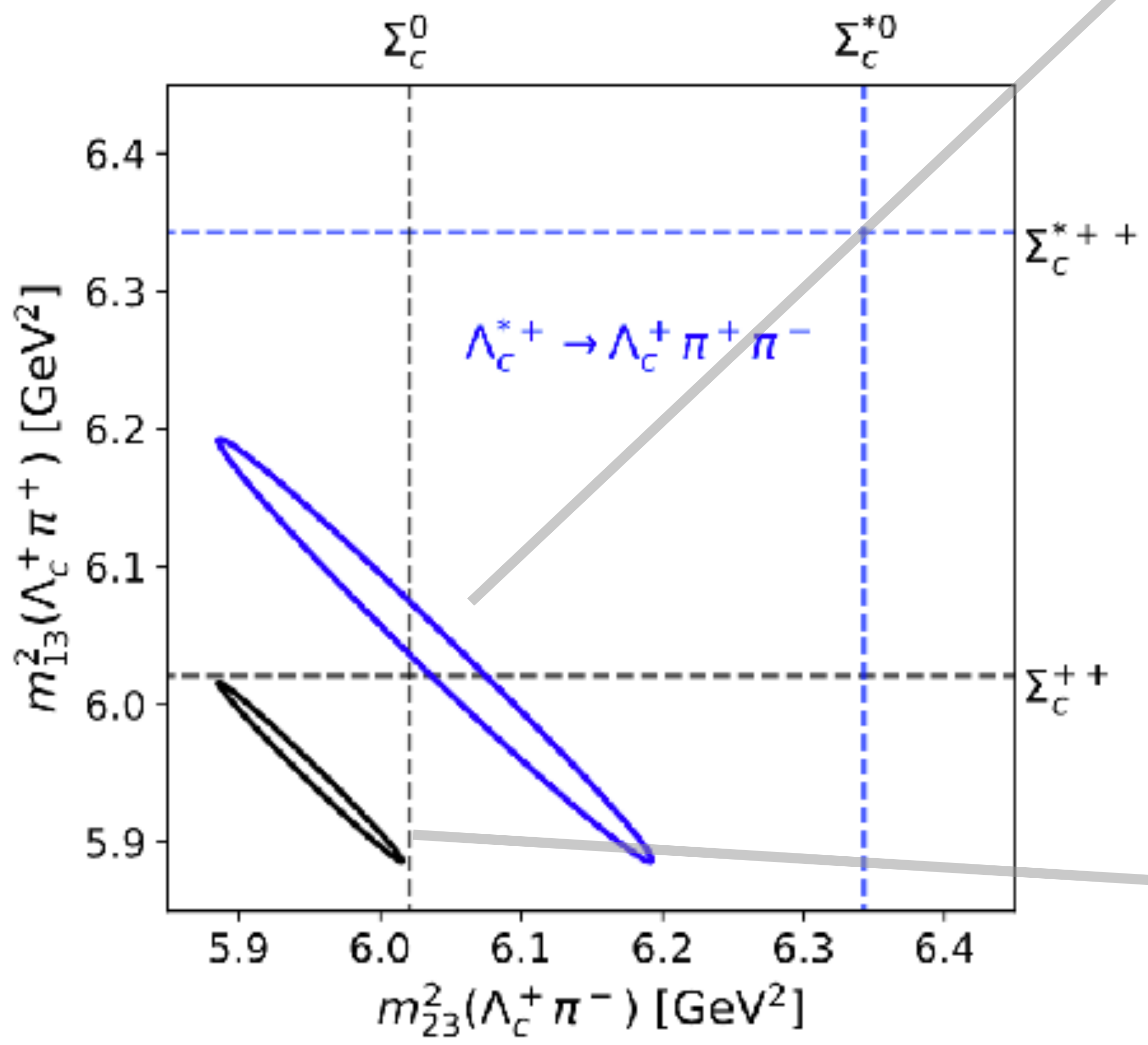
$\Lambda_c^+ \pi^0 \pi^0$

- Belle. PRD107, 032008 (2023)
- Arifi et al. PRD98, 114007 (2018)
- Arifi et al. PRD95, 114018 (2017)

Back-up slide #1

$\Lambda_c(2595)$ and $\Lambda_c(2625)$



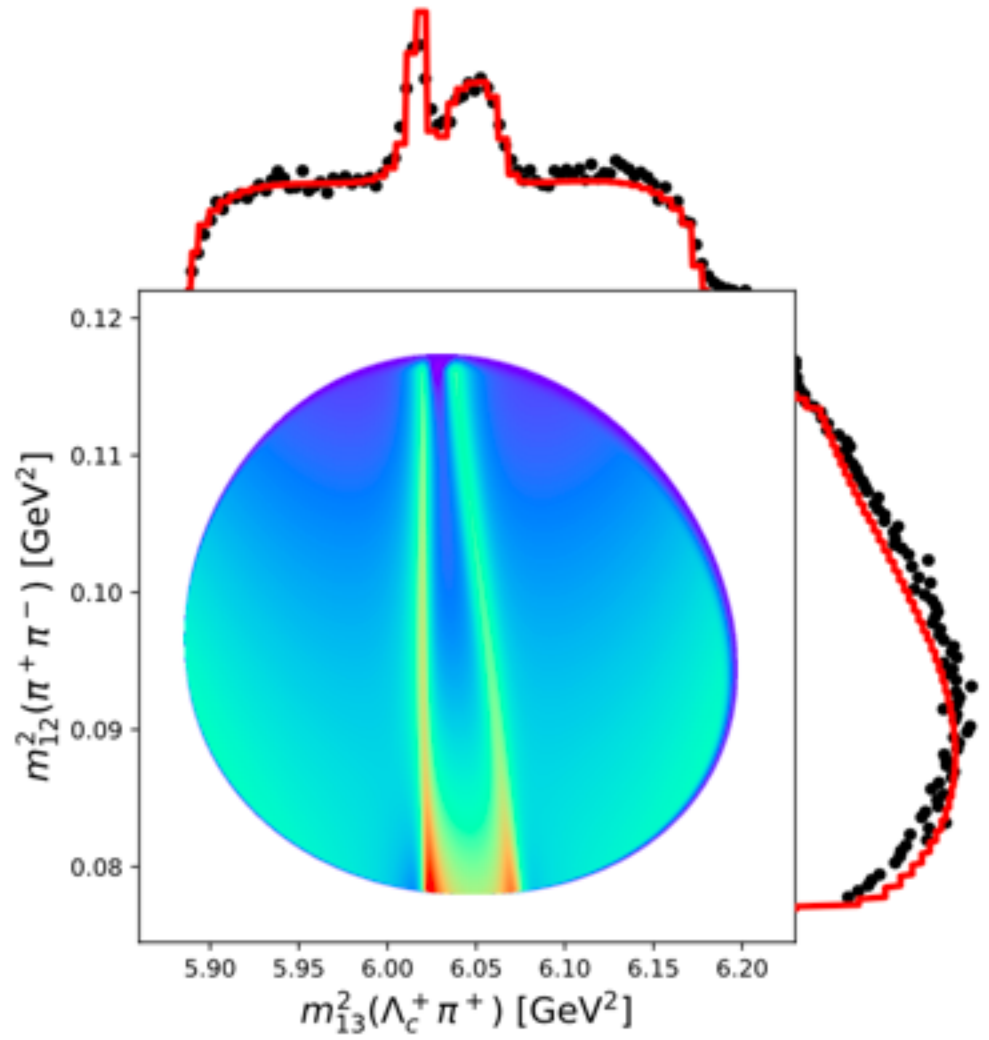


$\Lambda_c(2625)$

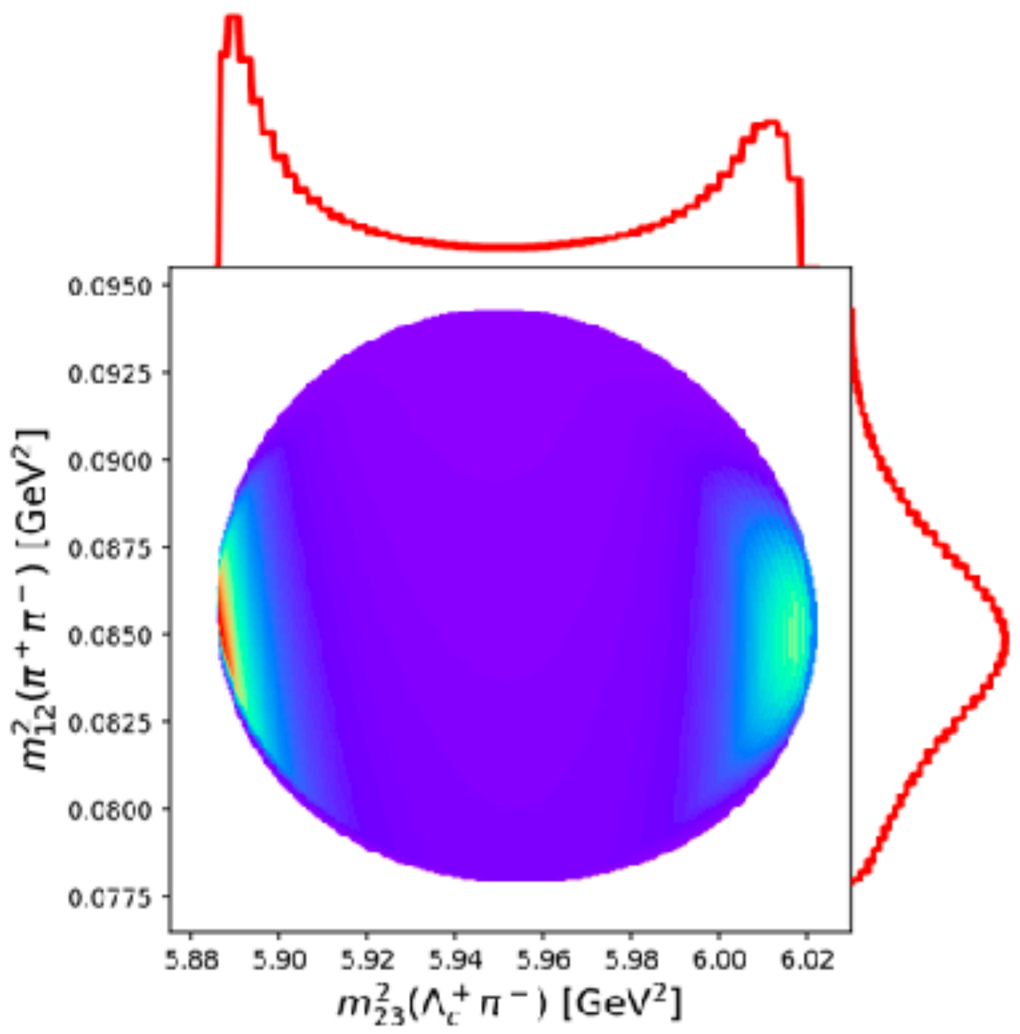
$3/2^-$

$\Lambda_c(2595)$

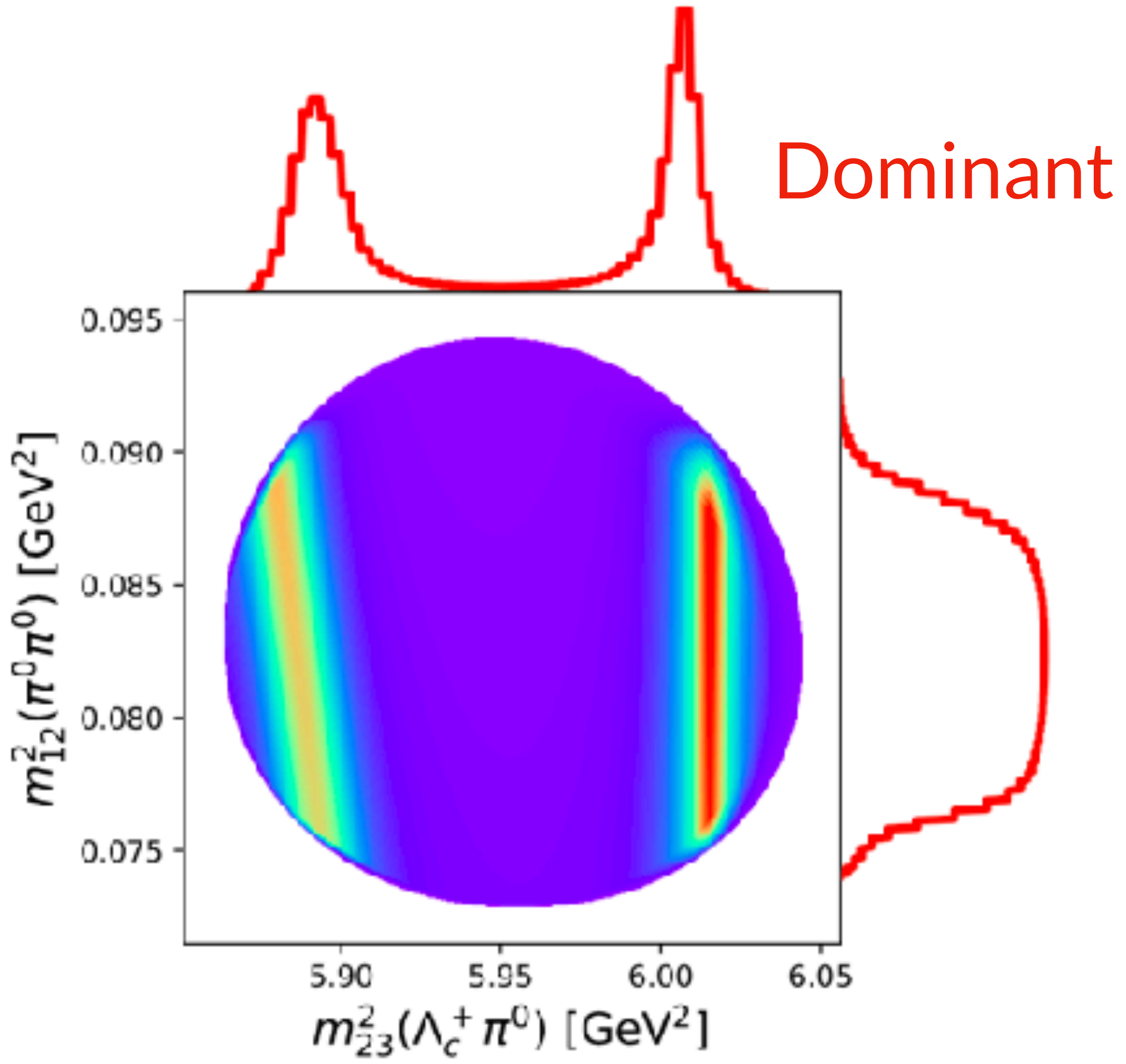
$1/2^-$



- **Support**
  - λ-mode assignment can naturally explain the invariant mass.



$\Lambda_c^+\pi^+\pi^-$



$\Lambda_c^+\pi^0\pi^0$

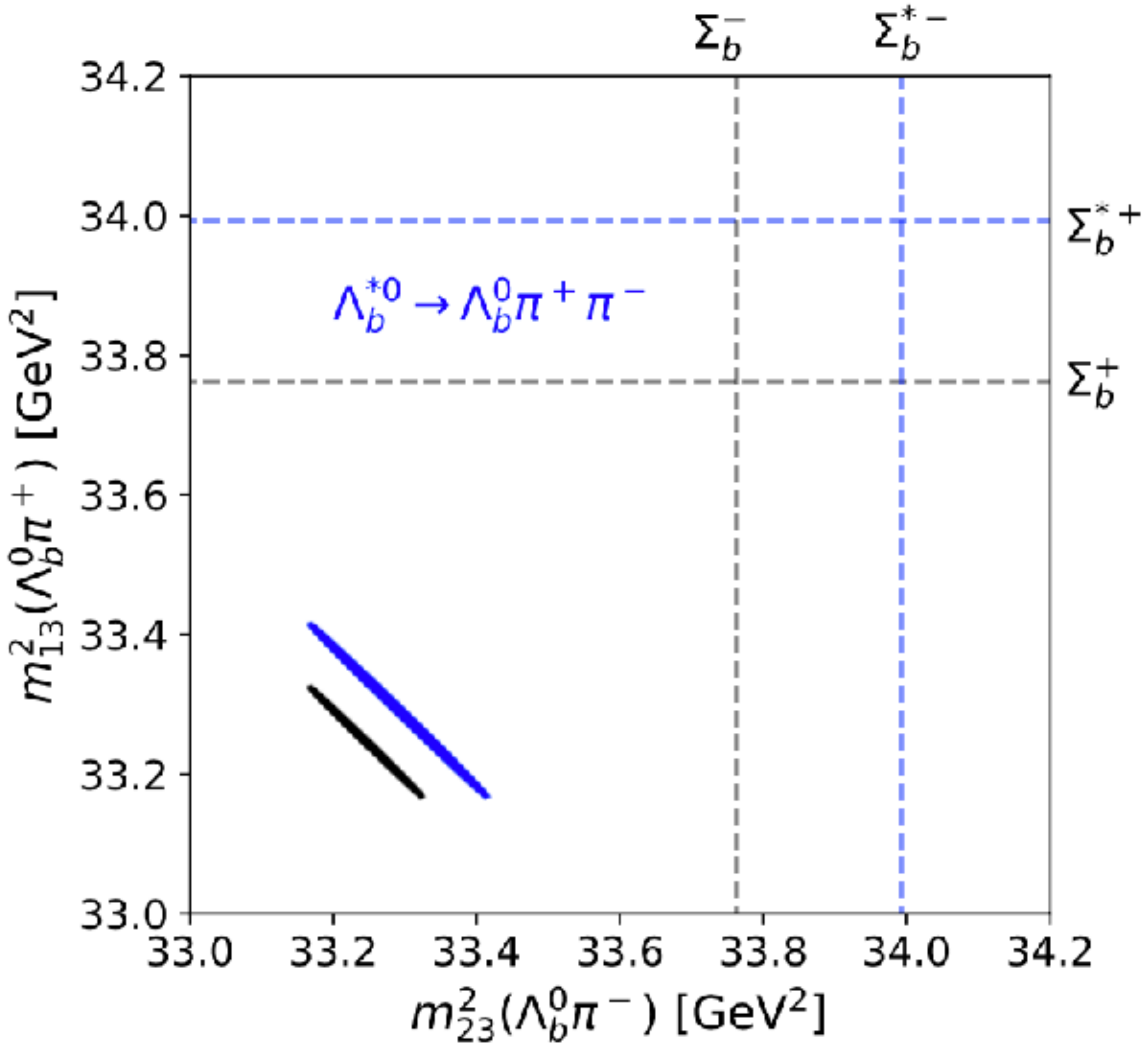
- Belle. PRD107, 032008 (2023)
- Arifi et al. PRD98, 114007 (2018)
- Arifi et al. PRD95, 114018 (2017)

Back-up slide #1

$\Lambda_b(5912)$ and $\Lambda_b(5920)$

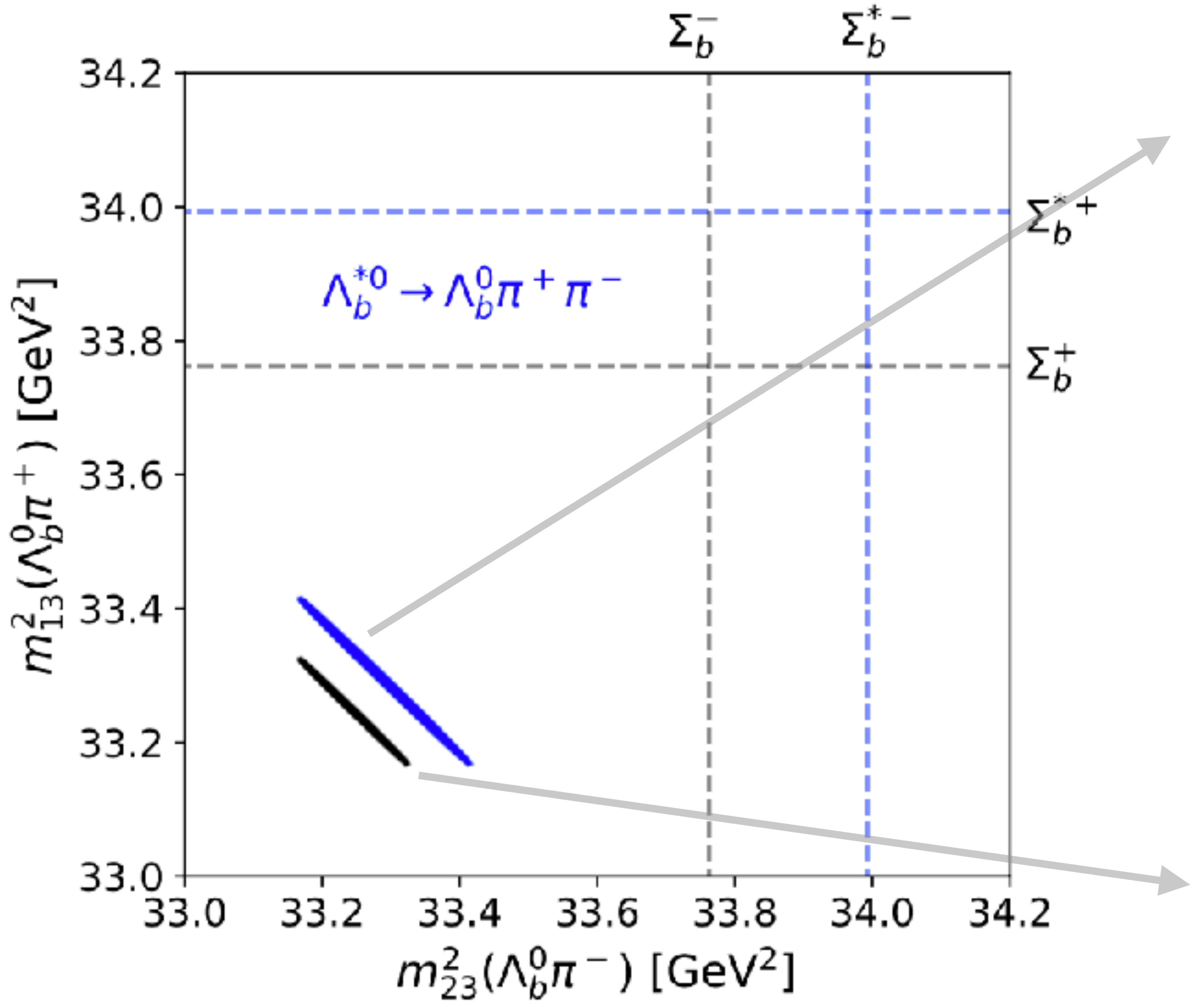
✦ Nongnaphat. Arxiv: 2407.10063

$\Lambda_b(5912)$ and $\Lambda_b(5920)$



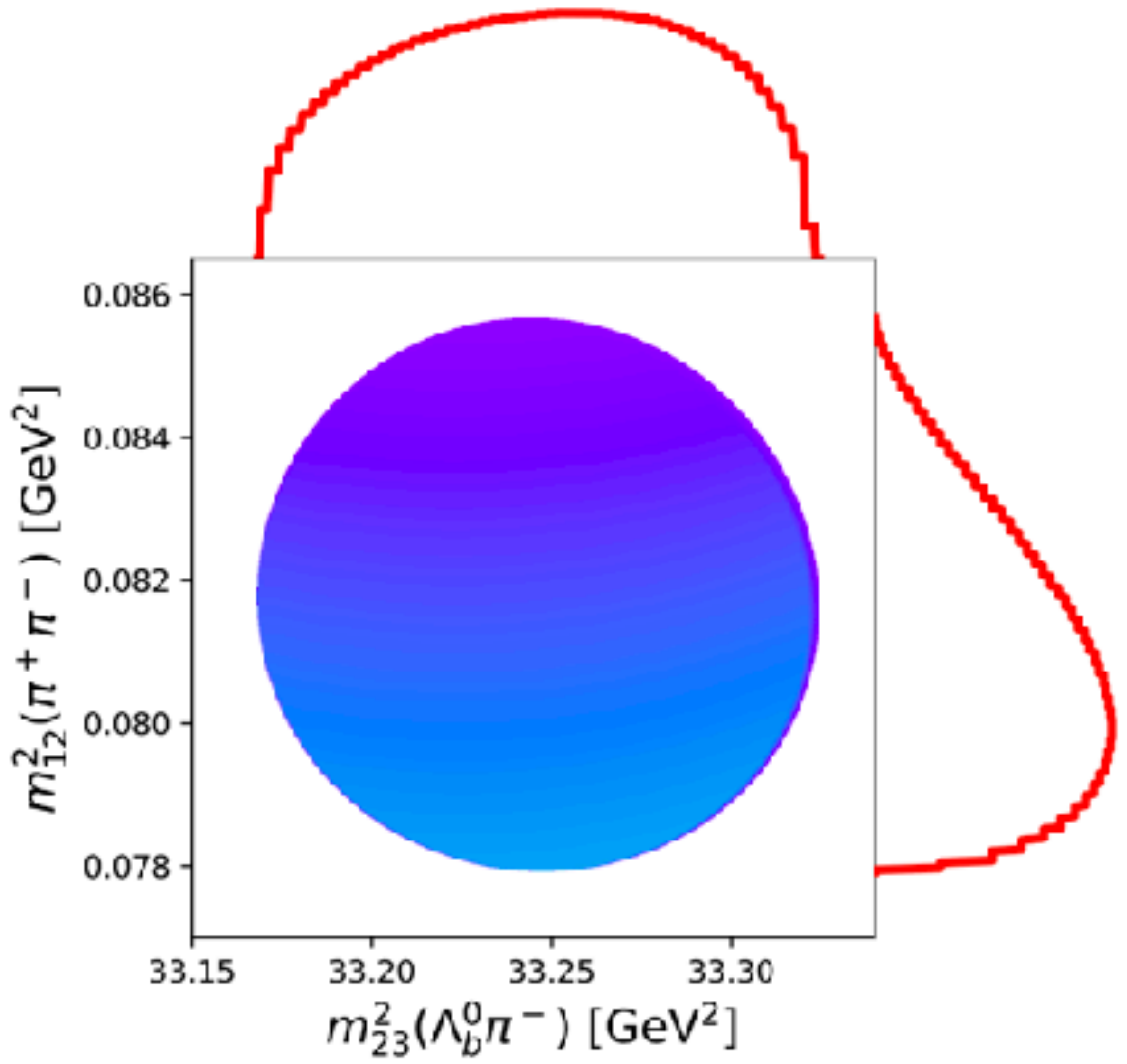
✦ Nongnaphat. Arxiv: 2407.10063

$\Lambda_b(5912)$ and $\Lambda_b(5920)$



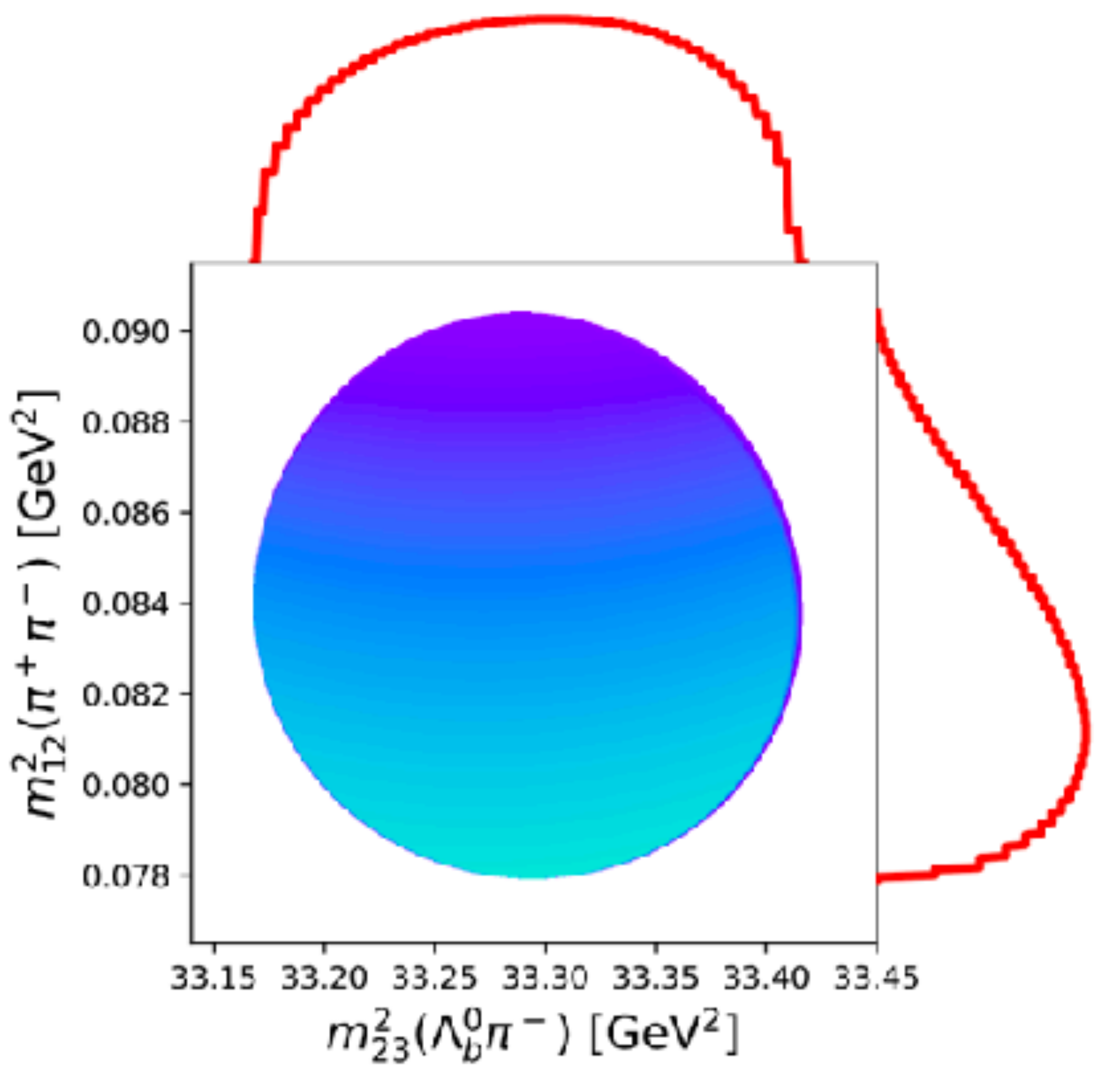
$\Lambda_b(5920)$

$3/2^-$



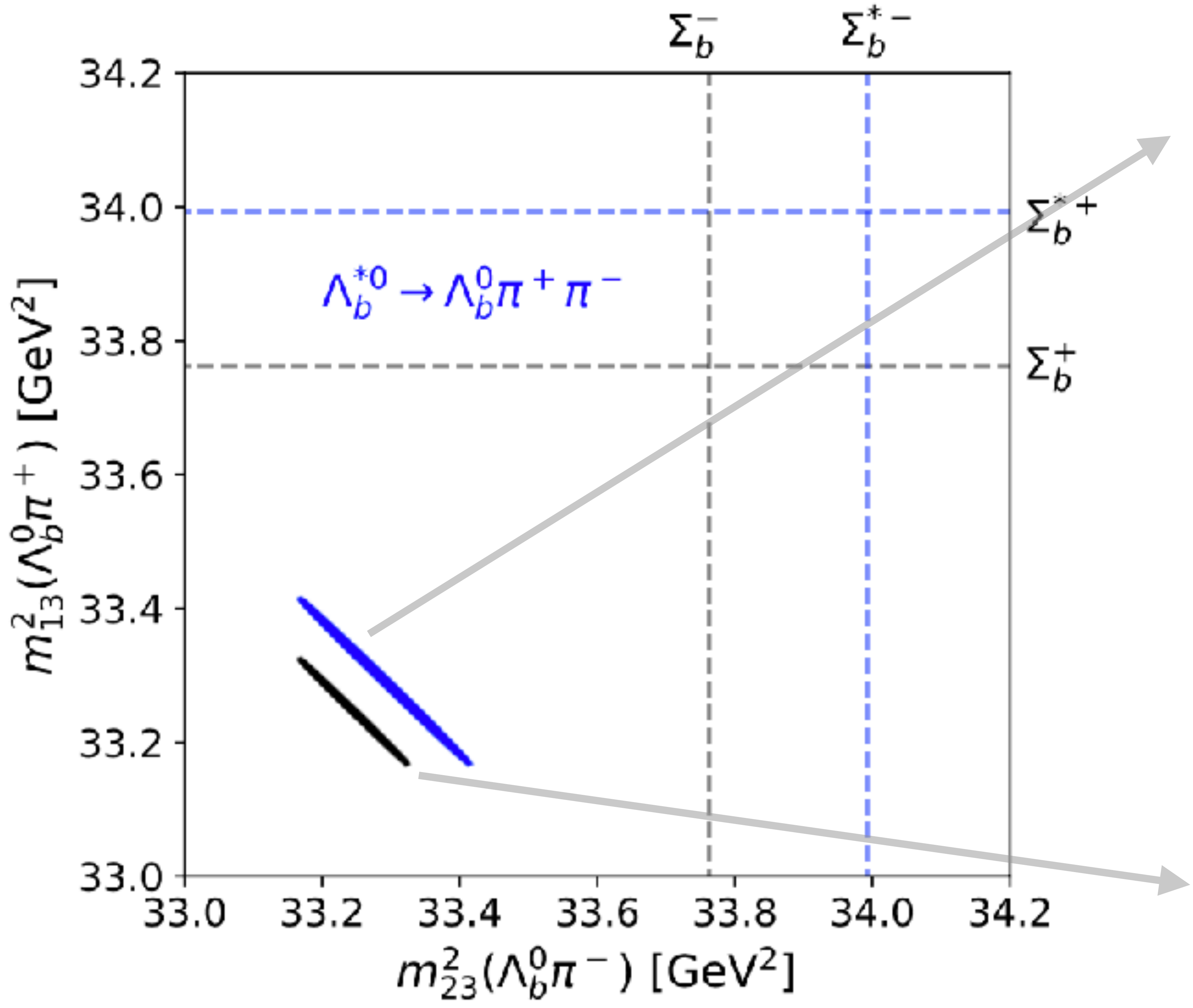
$\Lambda_b(5912)$

$1/2^-$



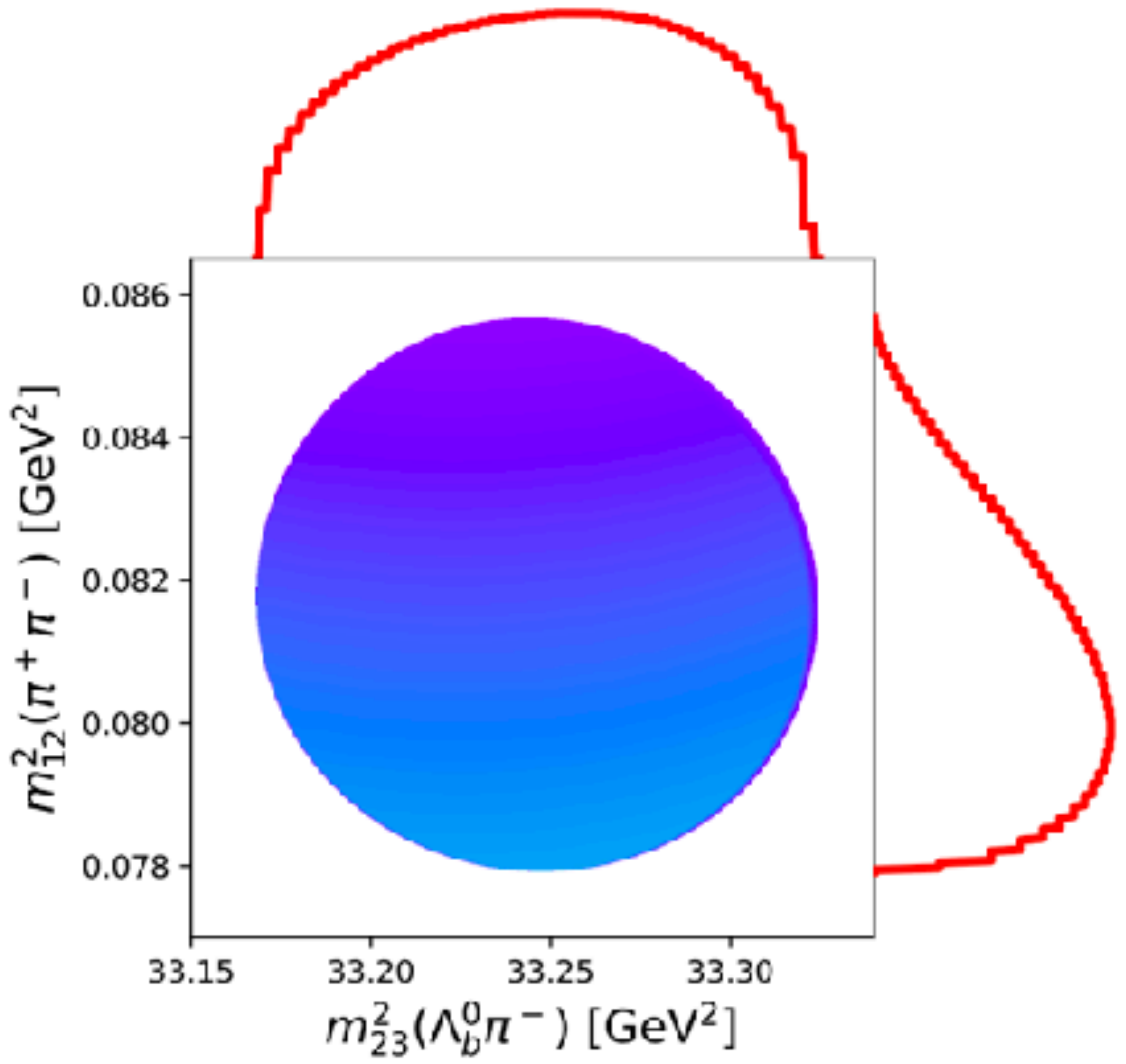
✦ Nongnaphat. Arxiv: 2407.10063

$\Lambda_b(5912)$ and $\Lambda_b(5920)$



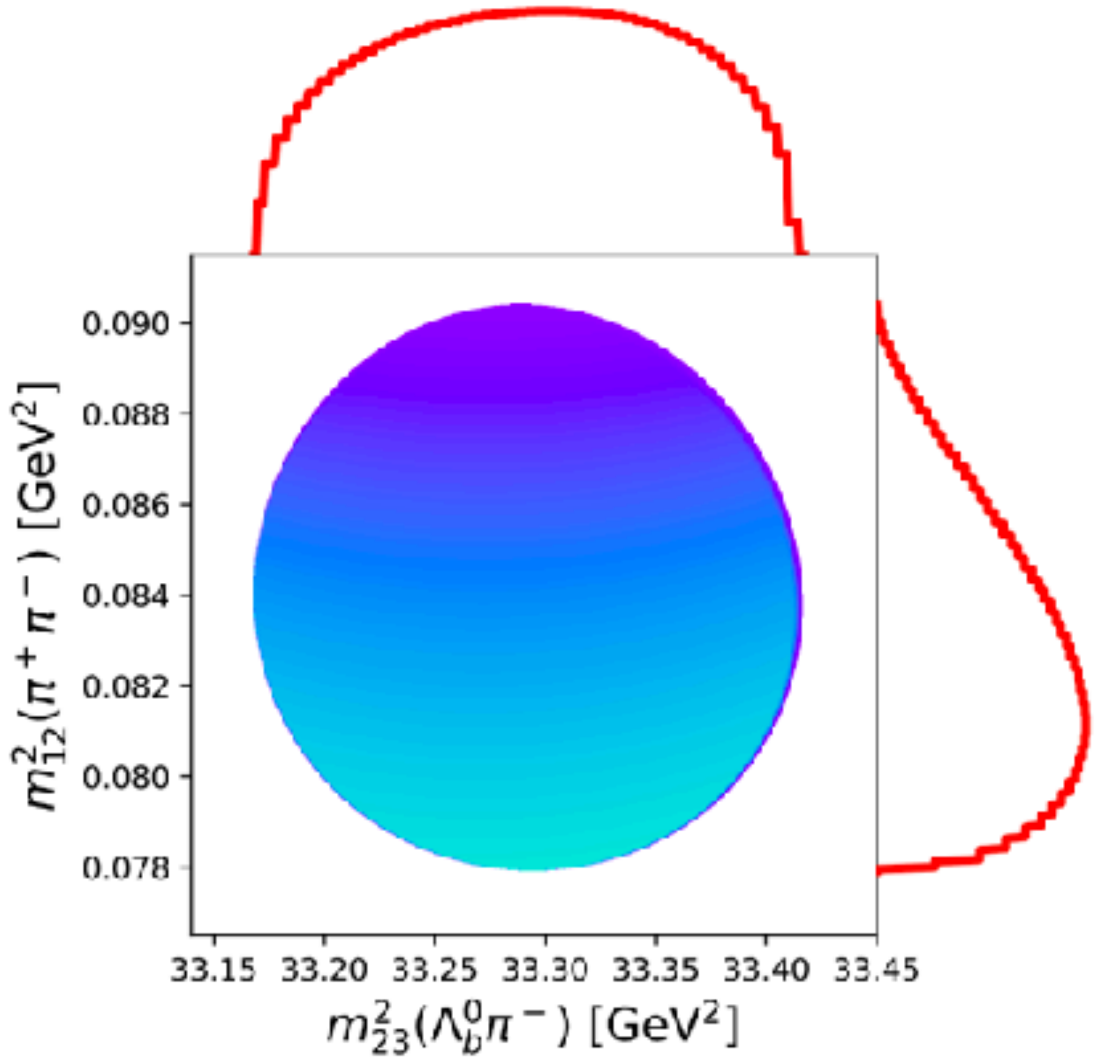
$\Lambda_b(5920)$

$3/2^-$



$\Lambda_b(5912)$

$1/2^-$



- **Observation**
  - ✦ Dominated by non-resonance (Tail + direct) contributions.
  - ✦ Decay width becomes tiny.
  - ✦ Asymmetry in $\pi\pi$ invariant mass.

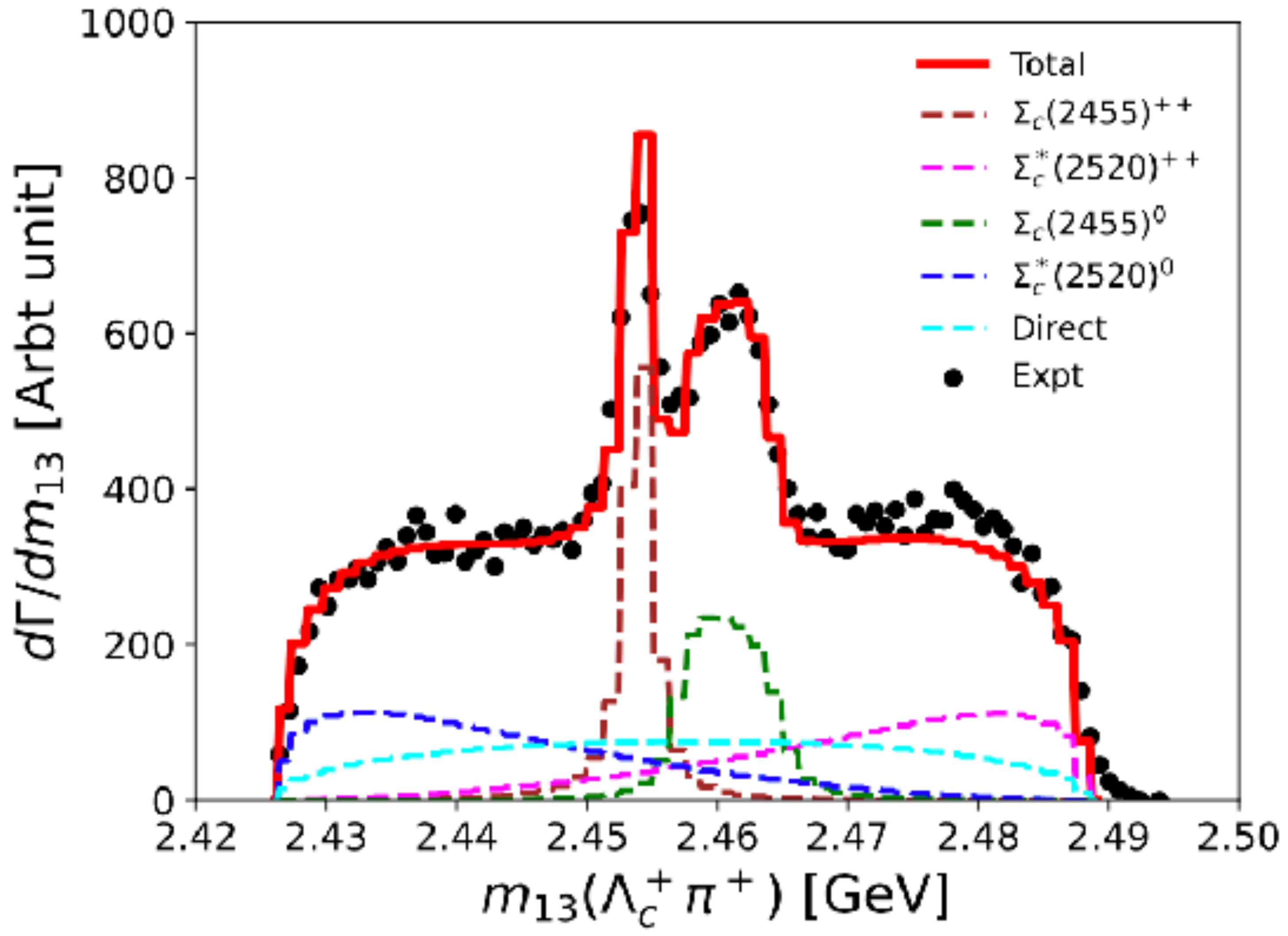
✦ Nongnaphat. Arxiv: 2407.10063

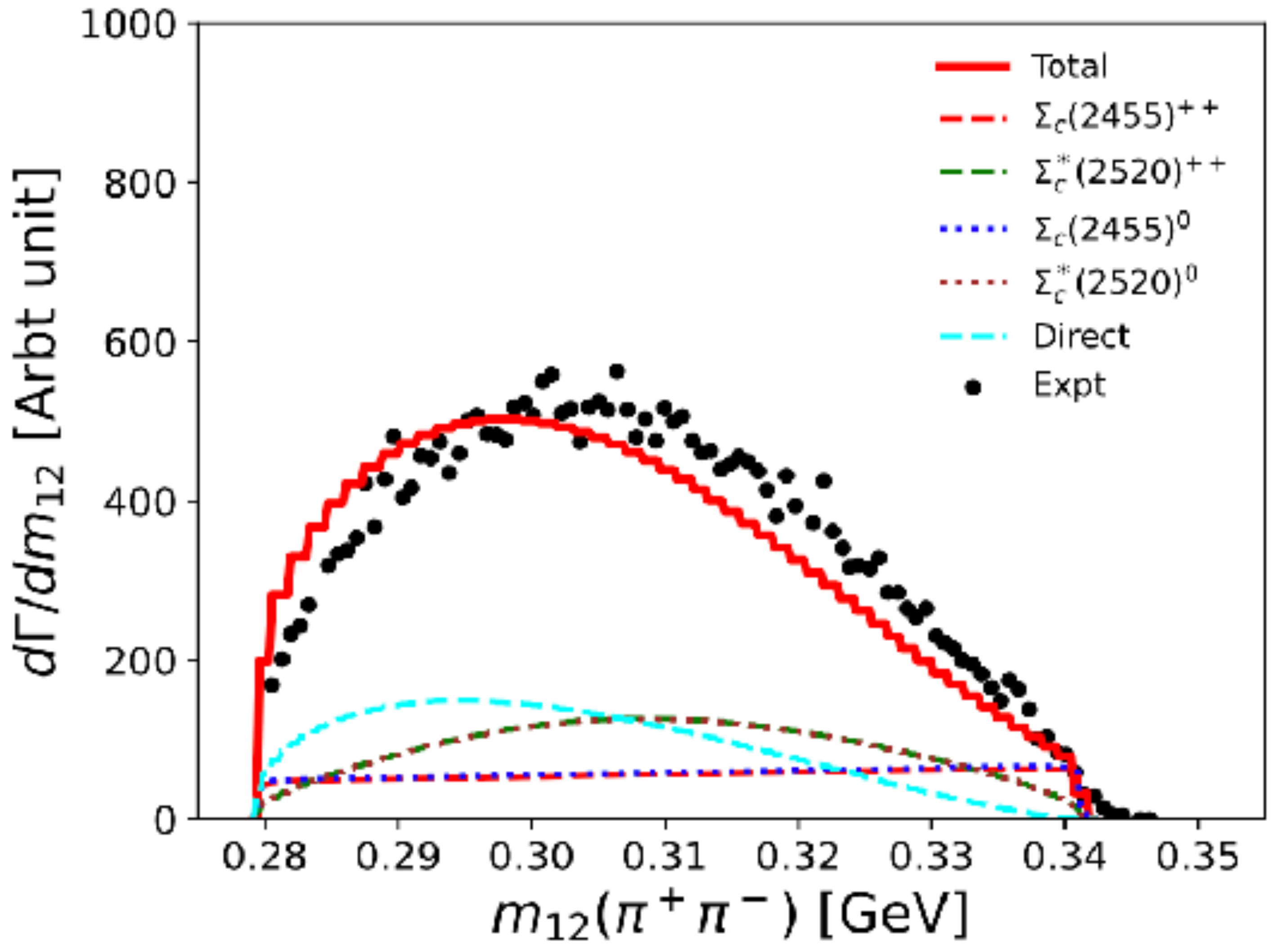
Invariant mass distribution

Invariant mass distribution

$\Lambda_c(2625)$

$3/2^-$



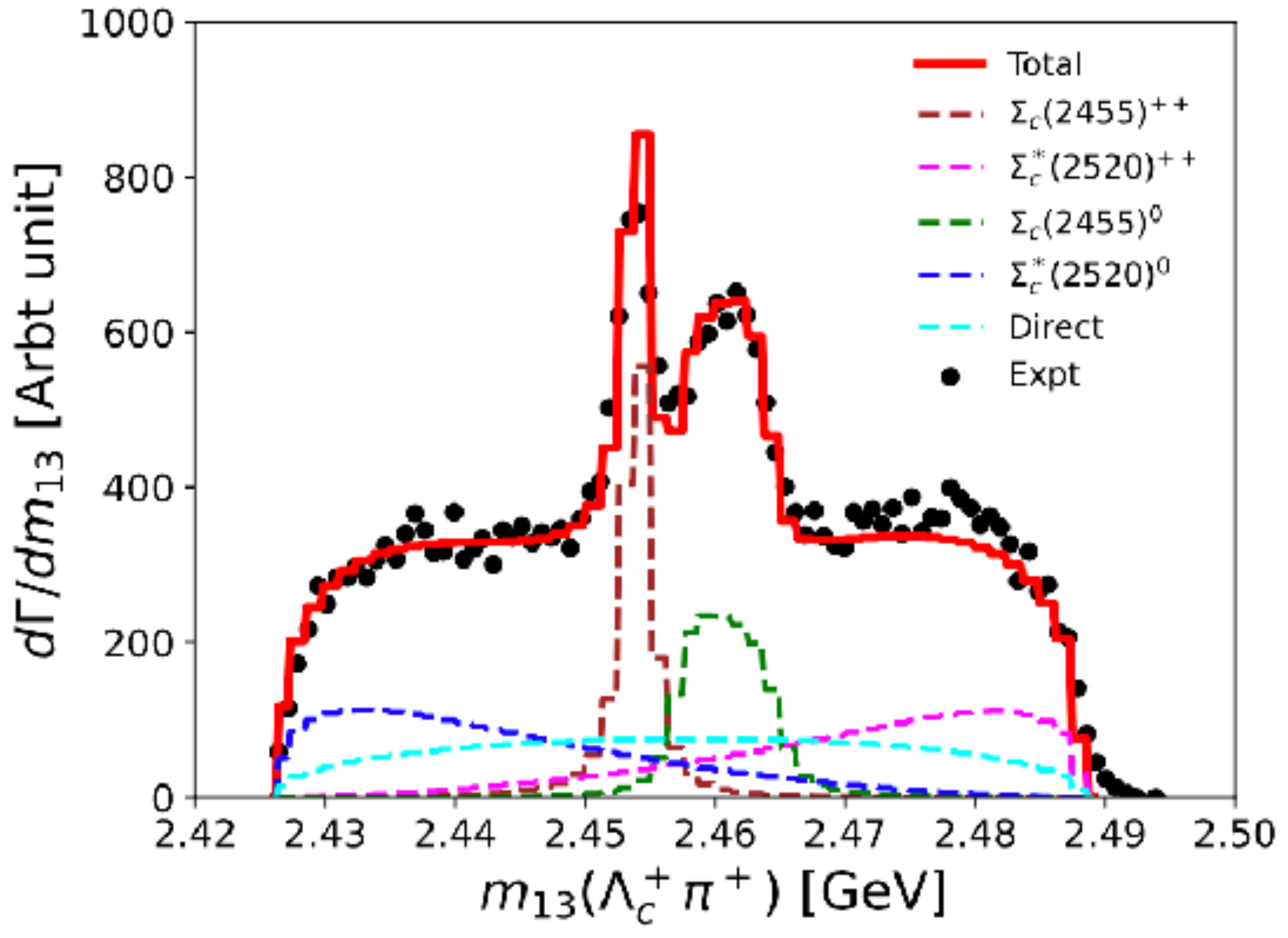


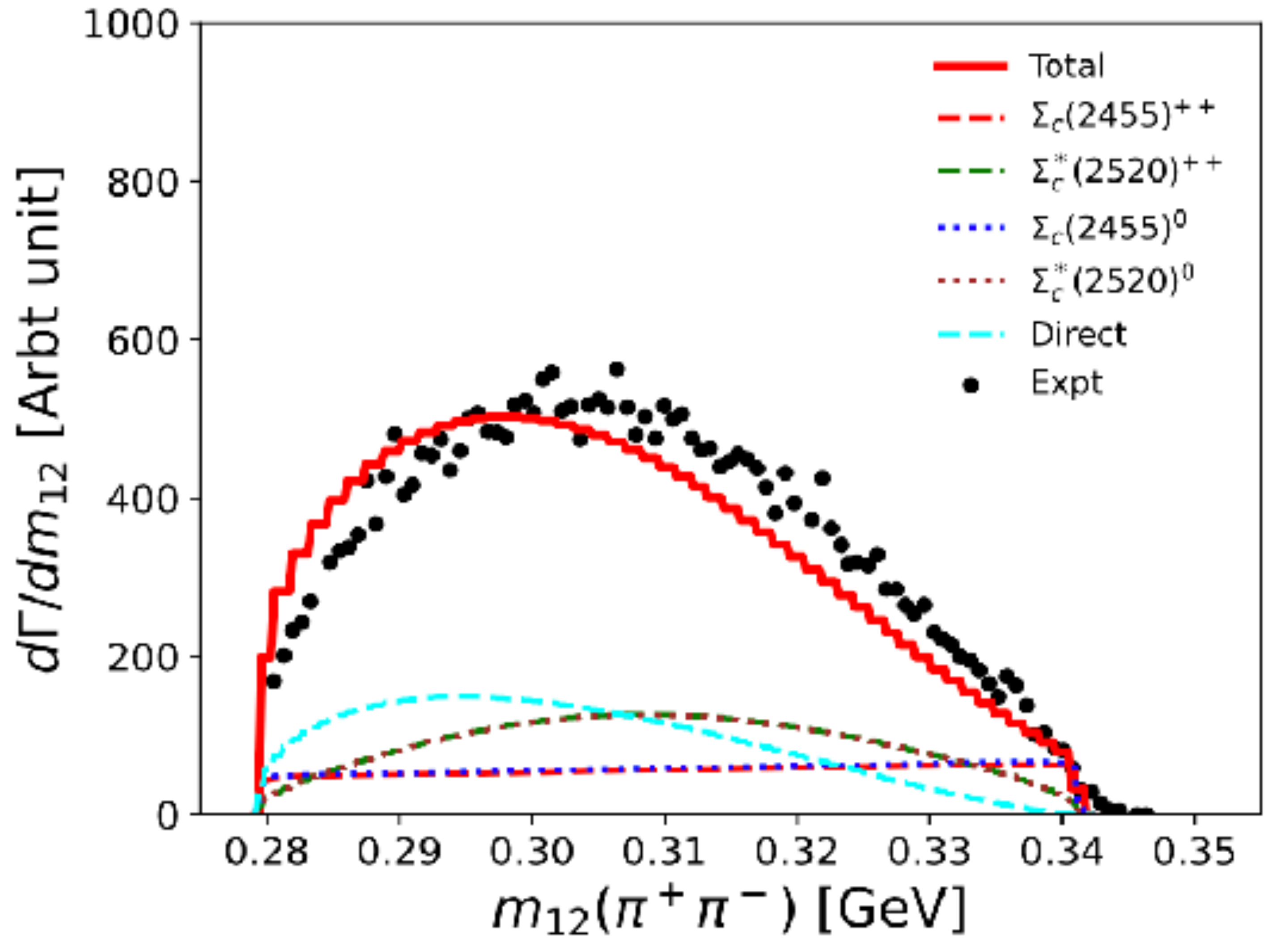
✦ Nongnaphat. Arxiv: 2407.10063

Invariant mass distribution

$\Lambda_c(2625)$

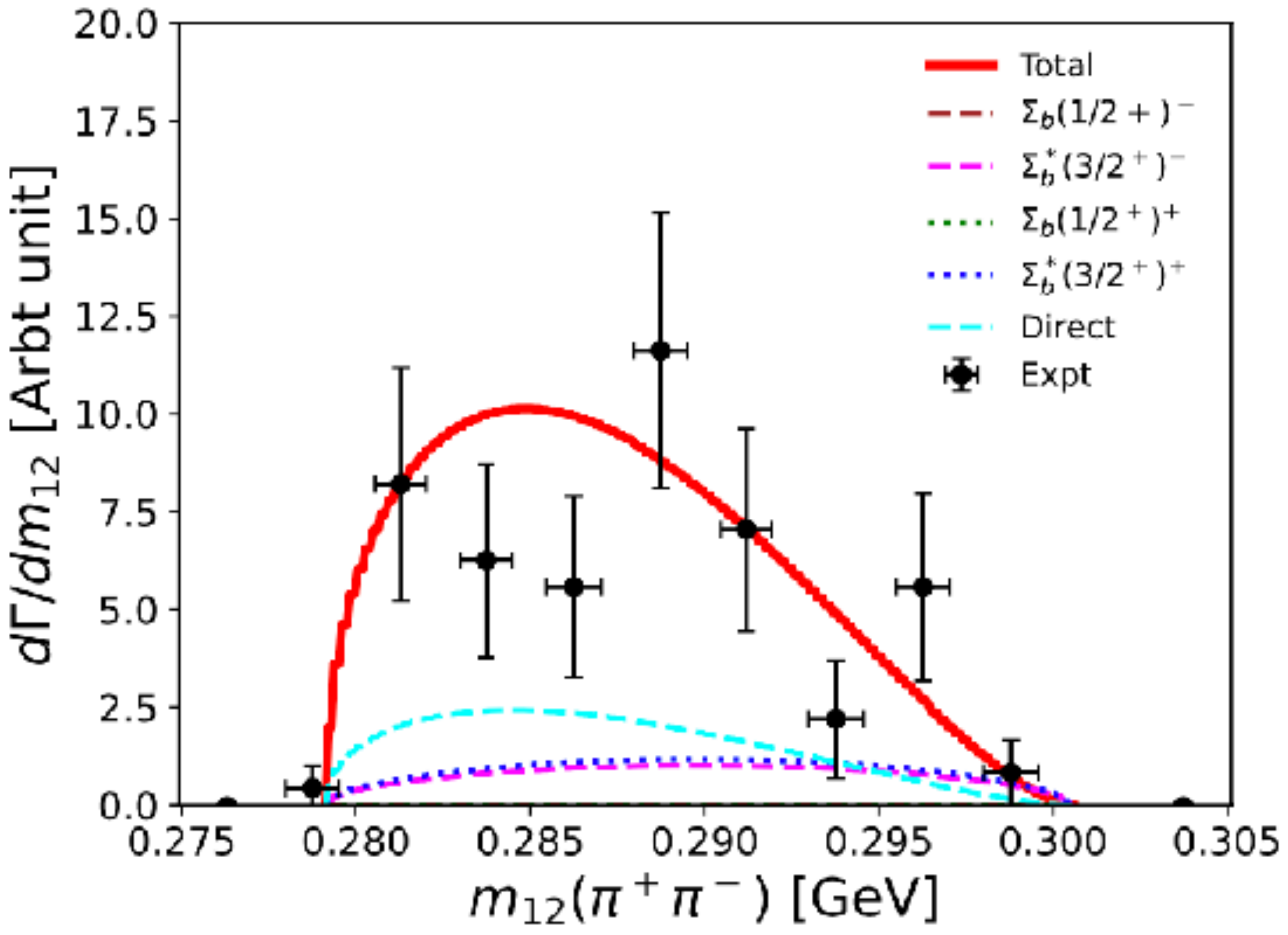
$3/2^-$





$\Lambda_b(5920)$

$3/2^-$

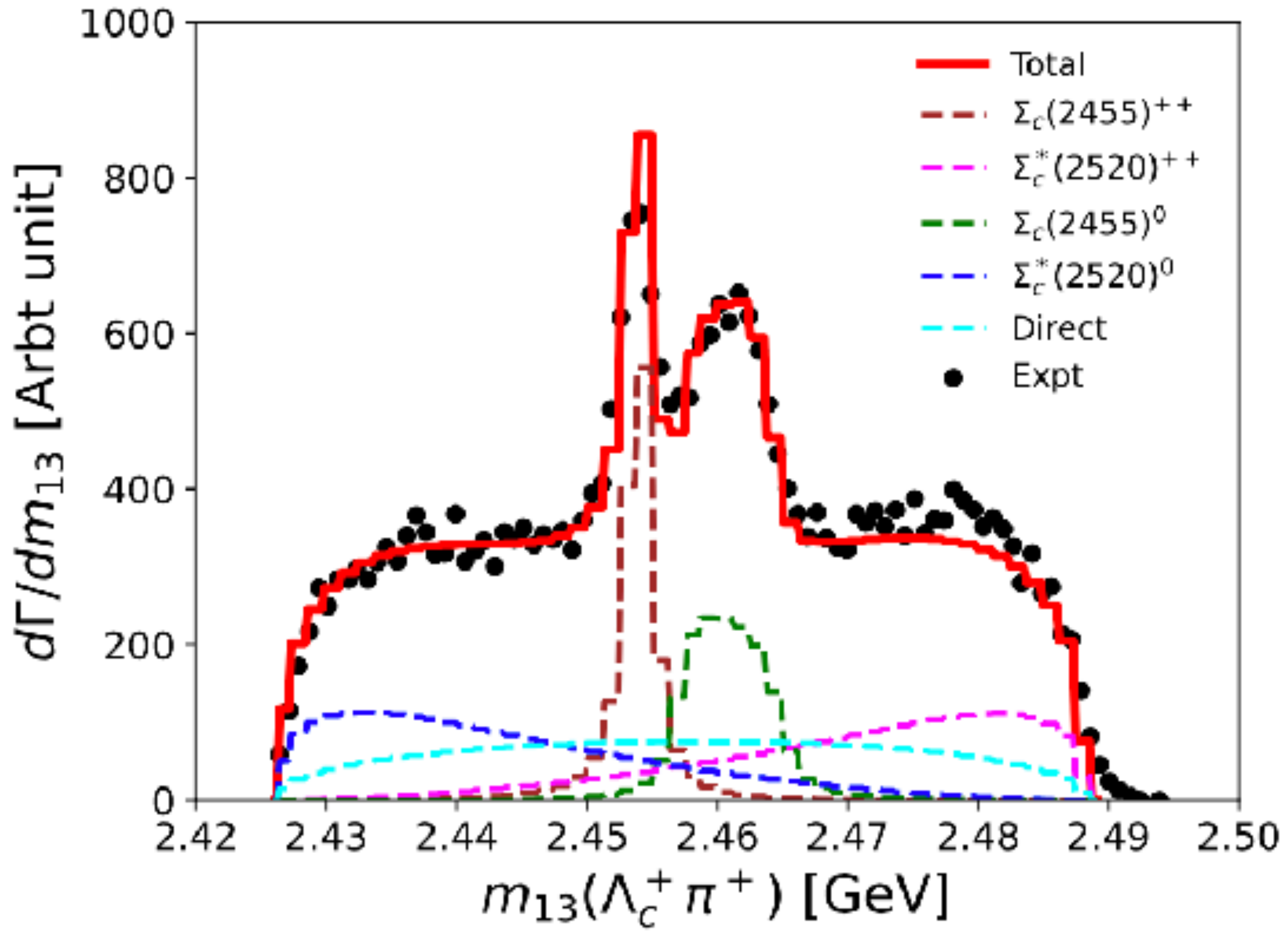


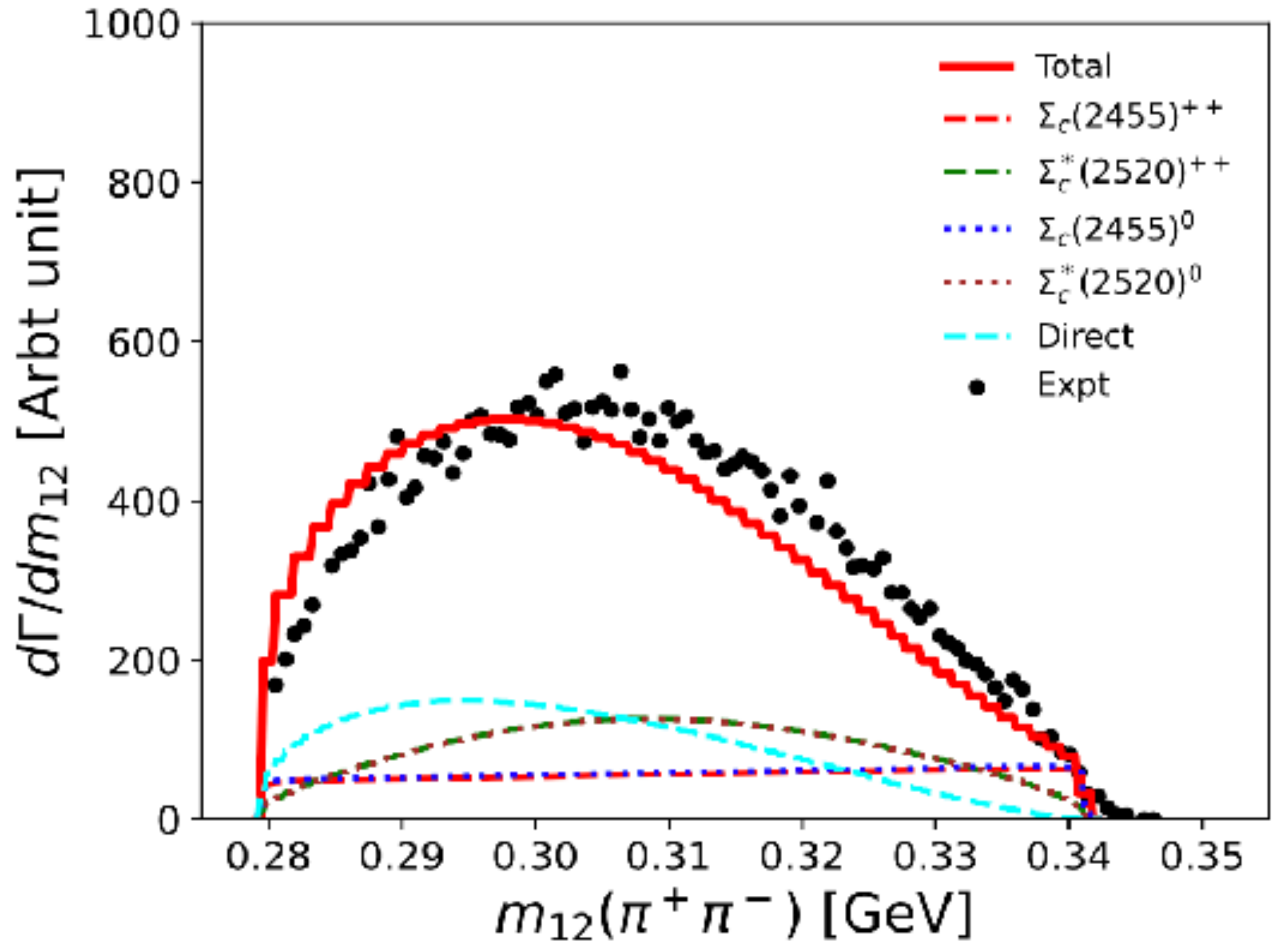
✦ Nongnaphat. Arxiv: 2407.10063

Invariant mass distribution

$\Lambda_c(2625)$

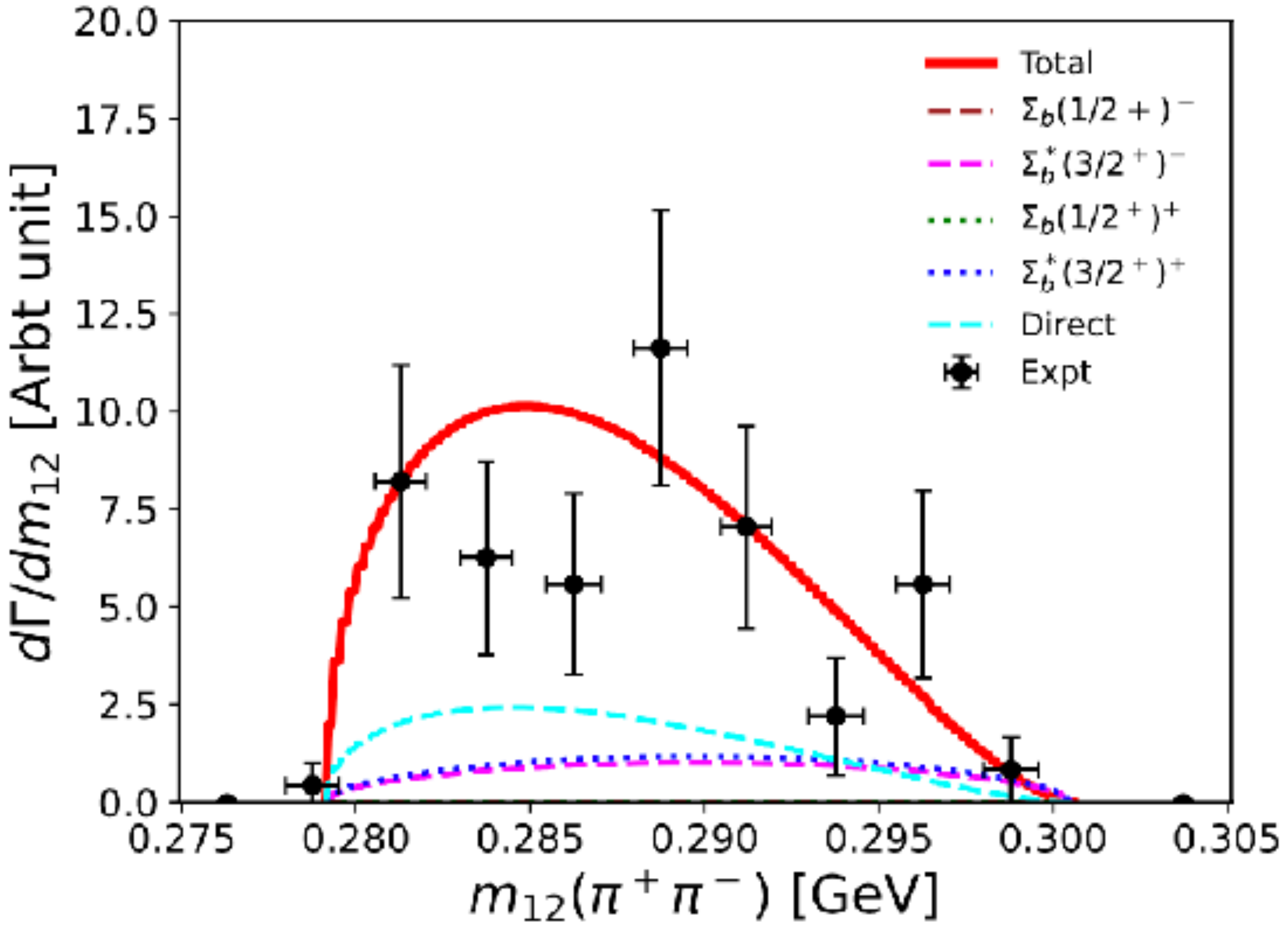
$3/2^-$





$\Lambda_b(5920)$

$3/2^-$

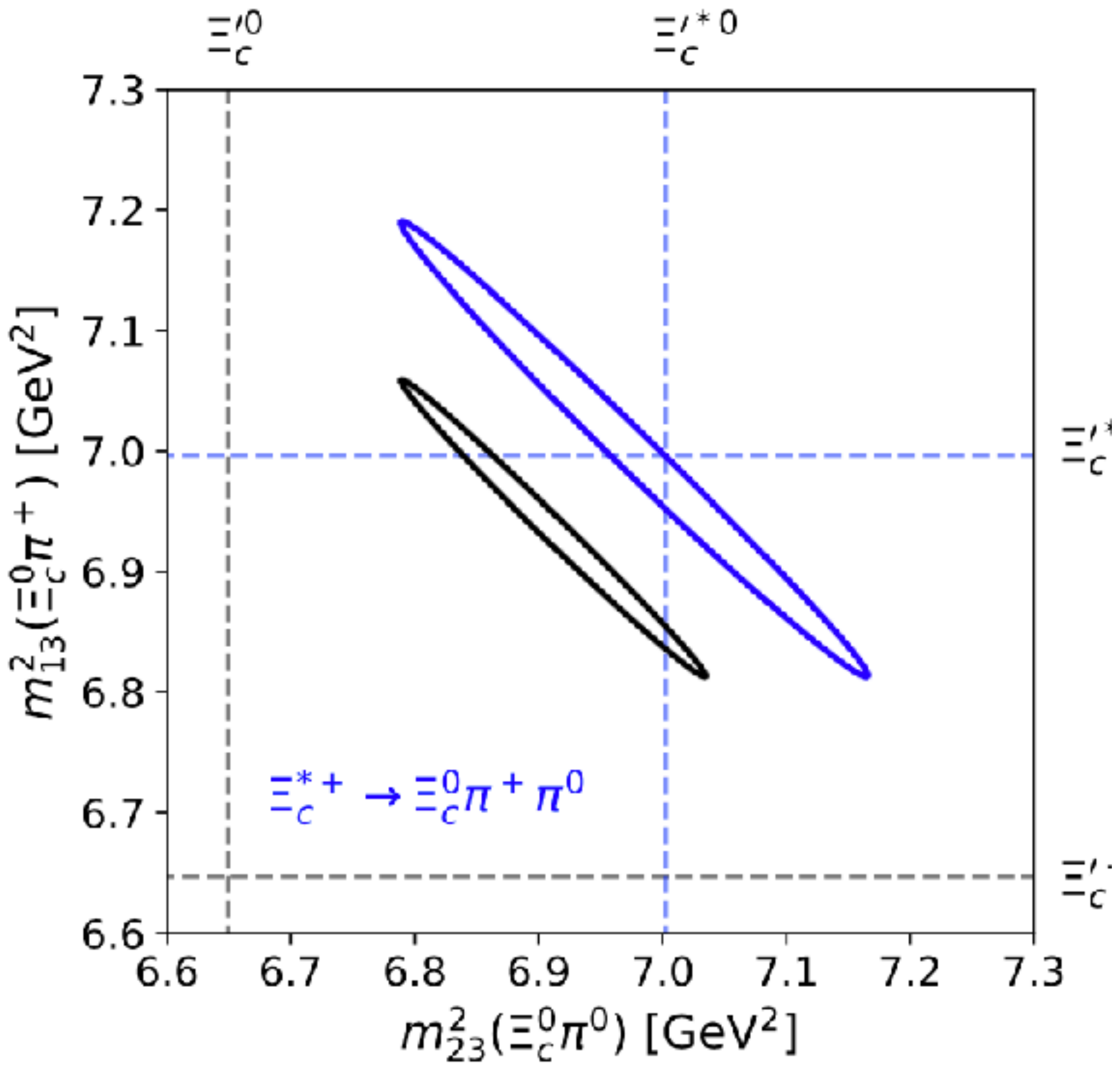


- ✦ $m_{\Lambda_c^+\pi^+}$ further supports $J^P = 3/2^-$.
- ✦ Assymmetry due to the direct process.
- ✦ Visible when S-wave resonance is suppressed.

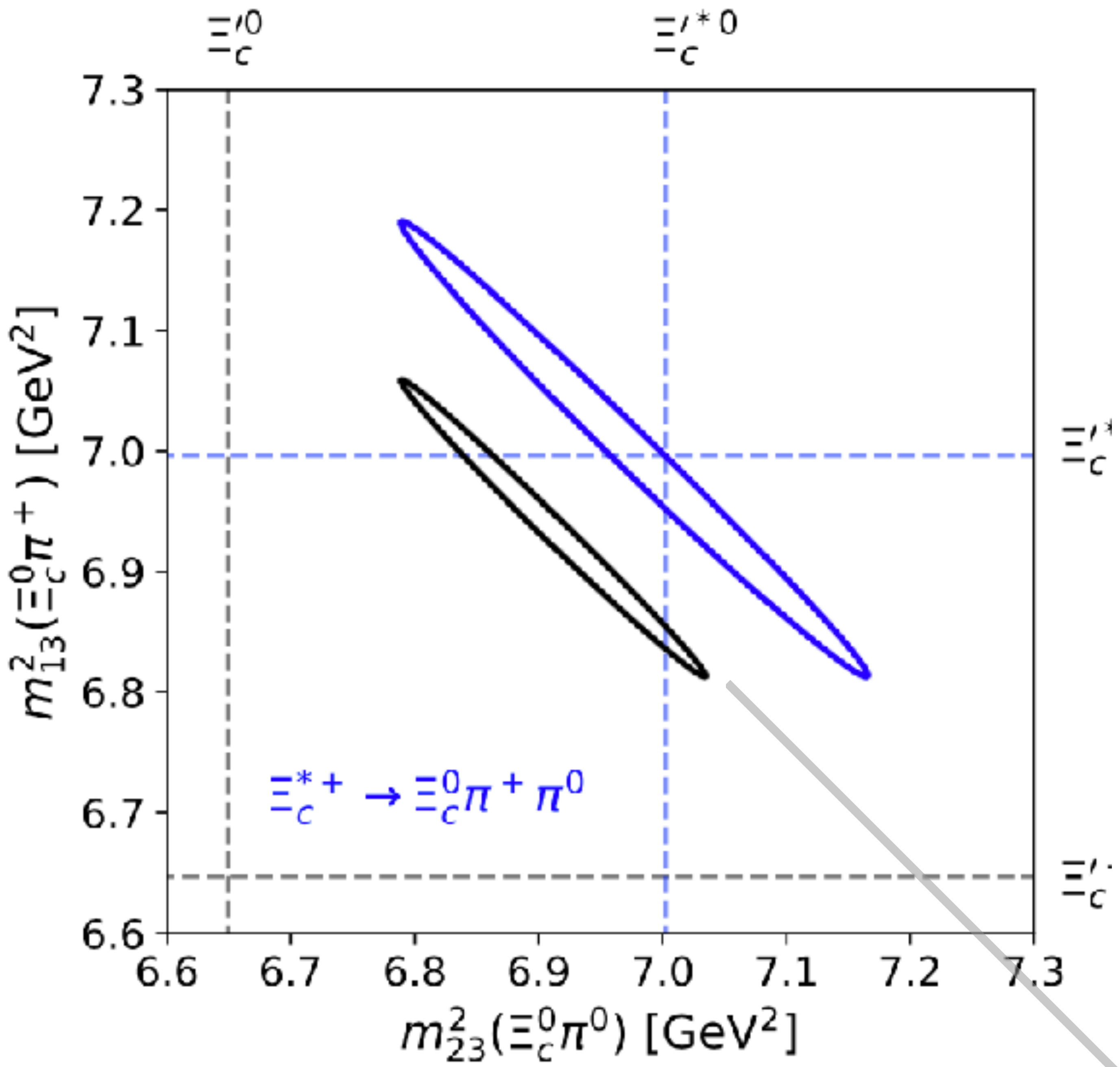
✦ Nongnaphat. Arxiv: 2407.10063

$\Xi_c(2790)$ and $\Xi_c(2815)$

$\Xi_c(2790)$ and $\Xi_c(2815)$

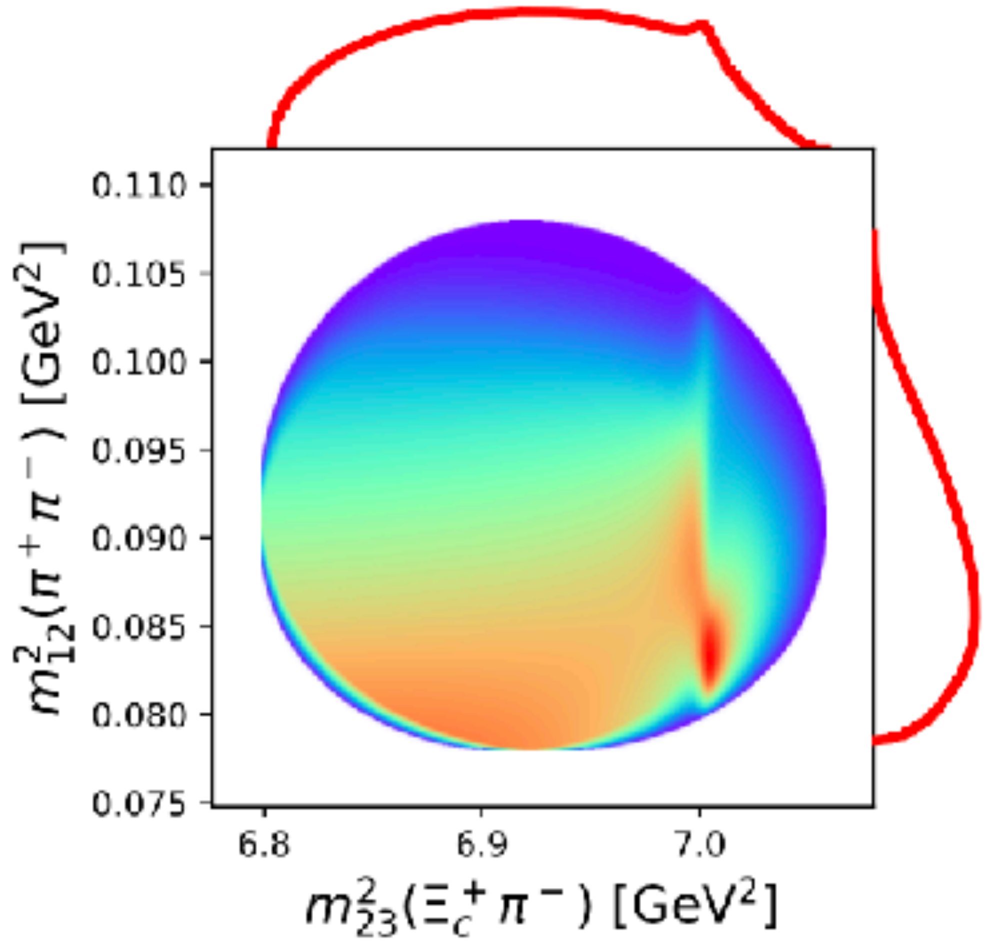


$\Xi_c(2790)$ and $\Xi_c(2815)$

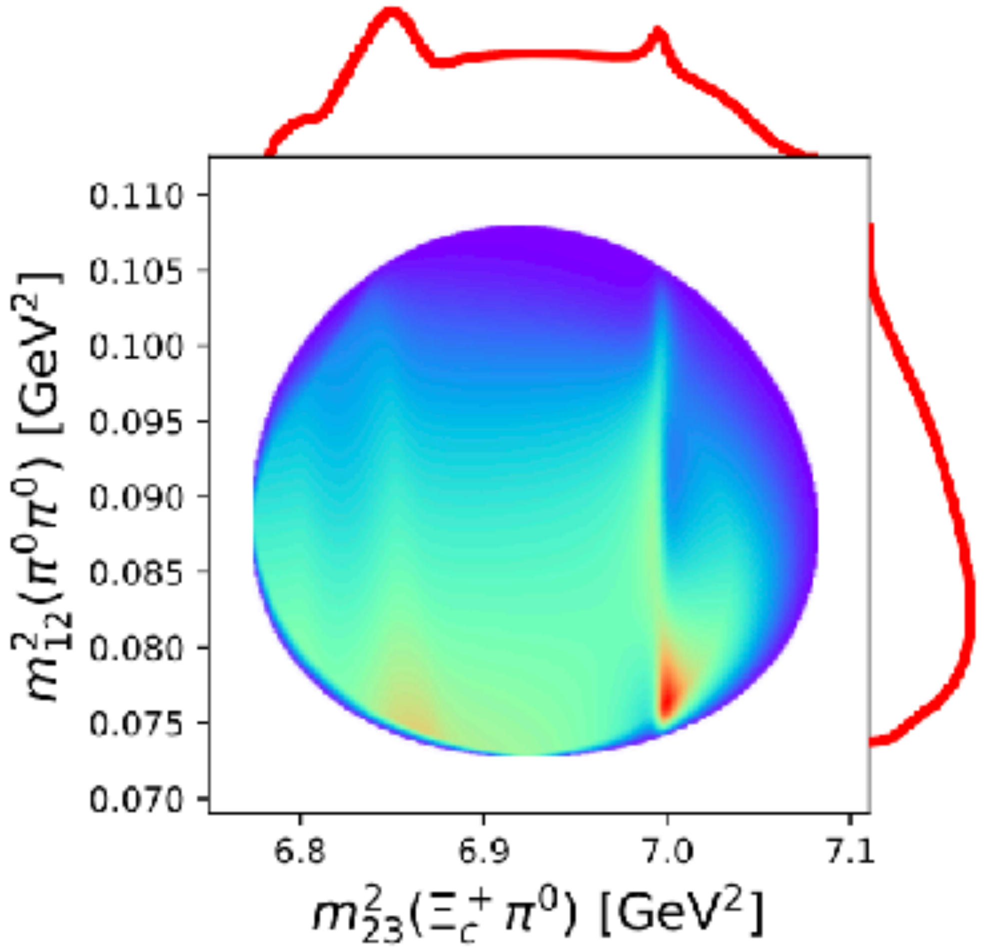


$\Xi_c(2790)$

$1/2^-$



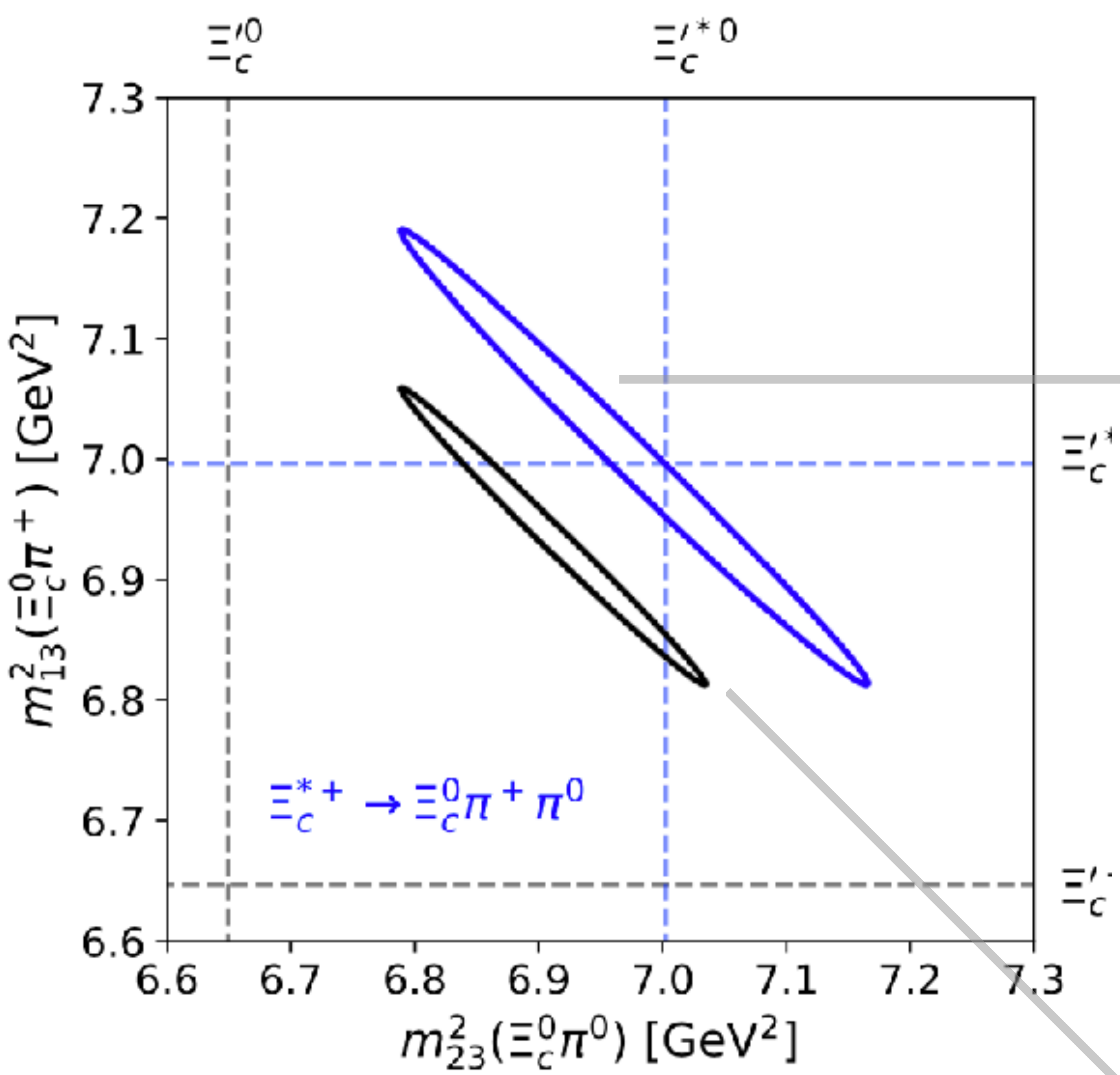
$\Xi_c^+\pi^+\pi^-$



$\Xi_c^+\pi^0\pi^0$

$\Xi_c^+\pi^+\pi^0$

$\Xi_c(2790)$ and $\Xi_c(2815)$

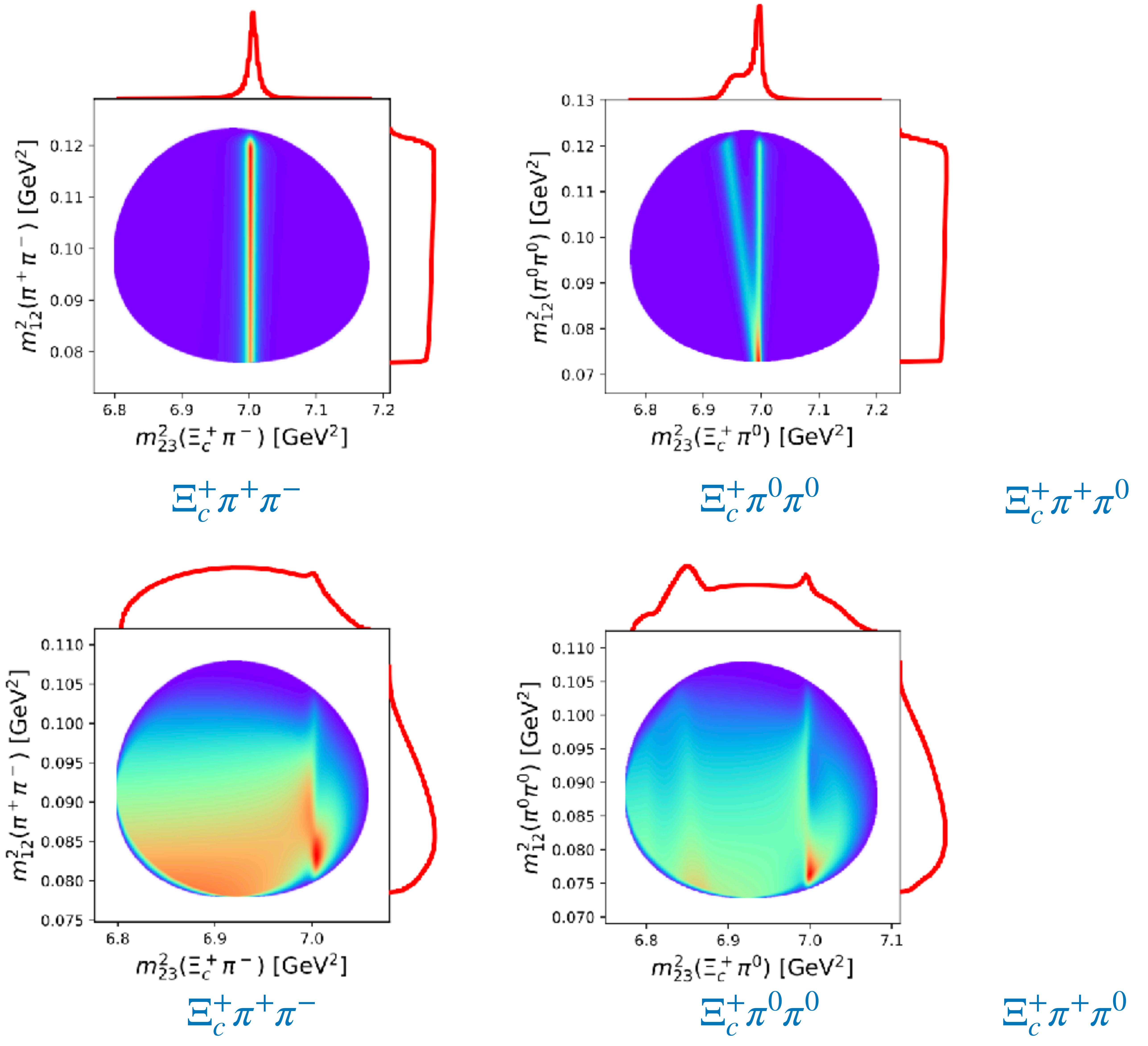


$\Xi_c(2815)$

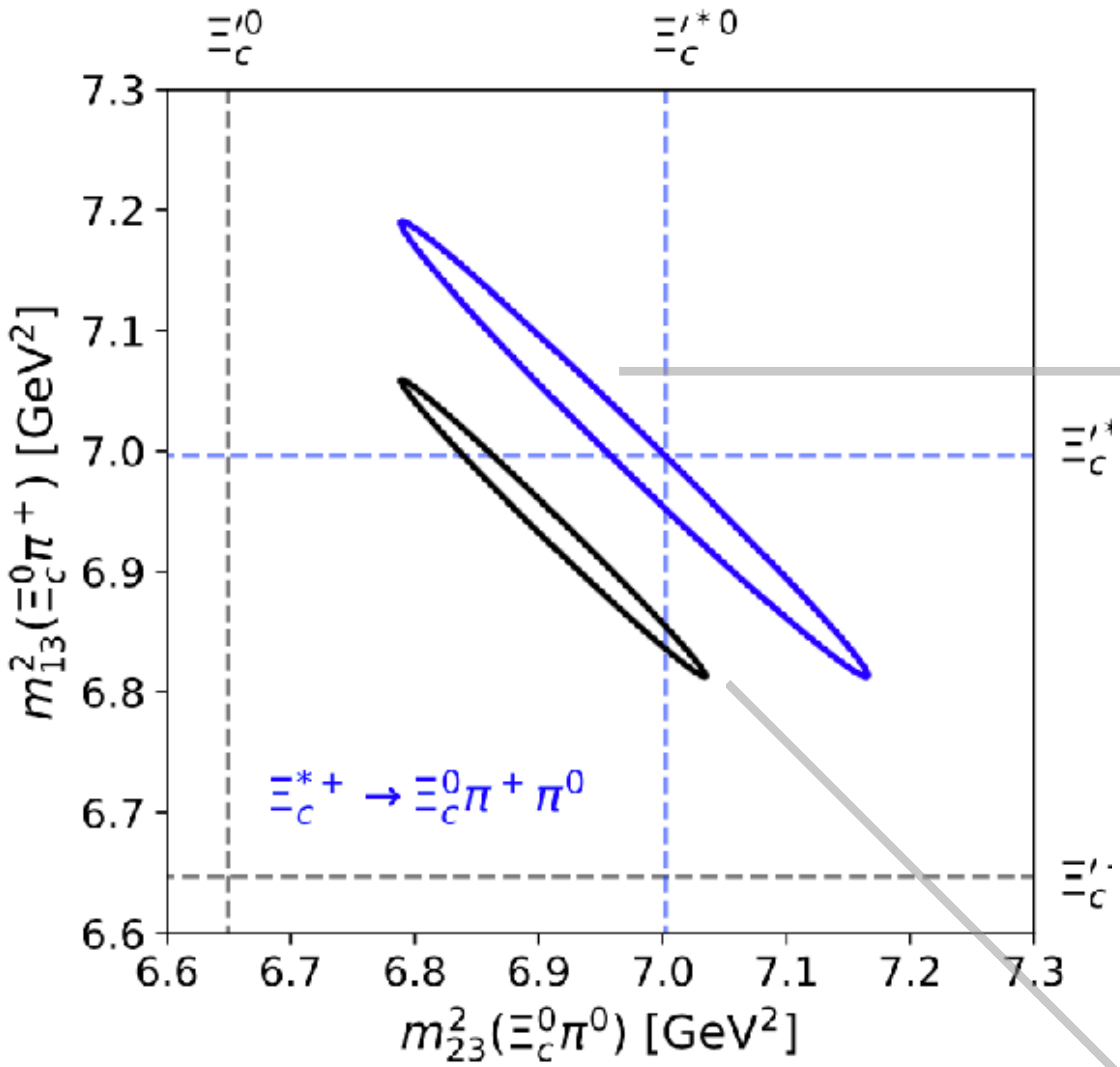
$3/2^-$

$\Xi_c(2790)$

$1/2^-$



$\Xi_c(2790)$ and $\Xi_c(2815)$

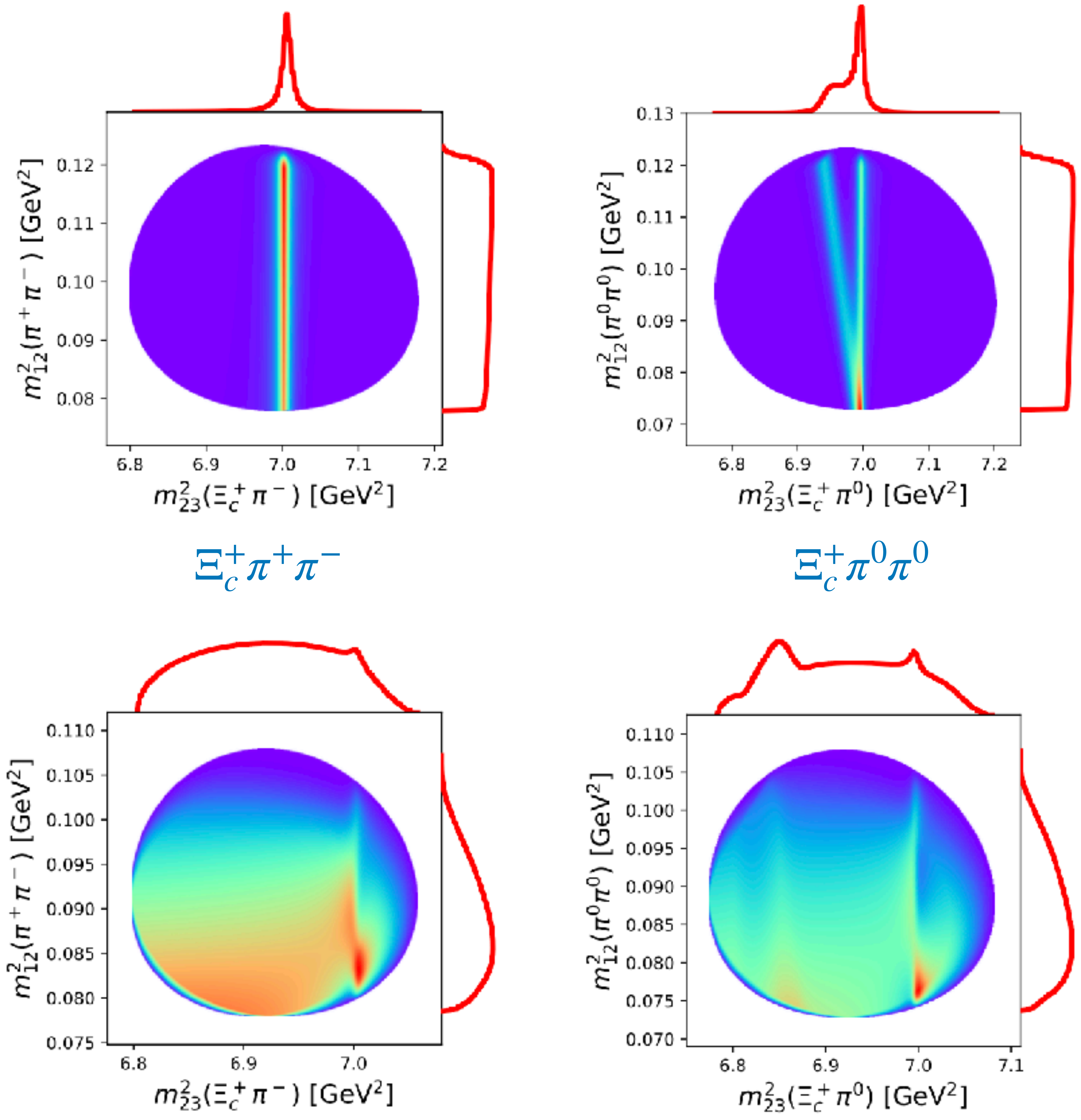


$\Xi_c(2815)$

$3/2^-$

$\Xi_c(2790)$

$1/2^-$



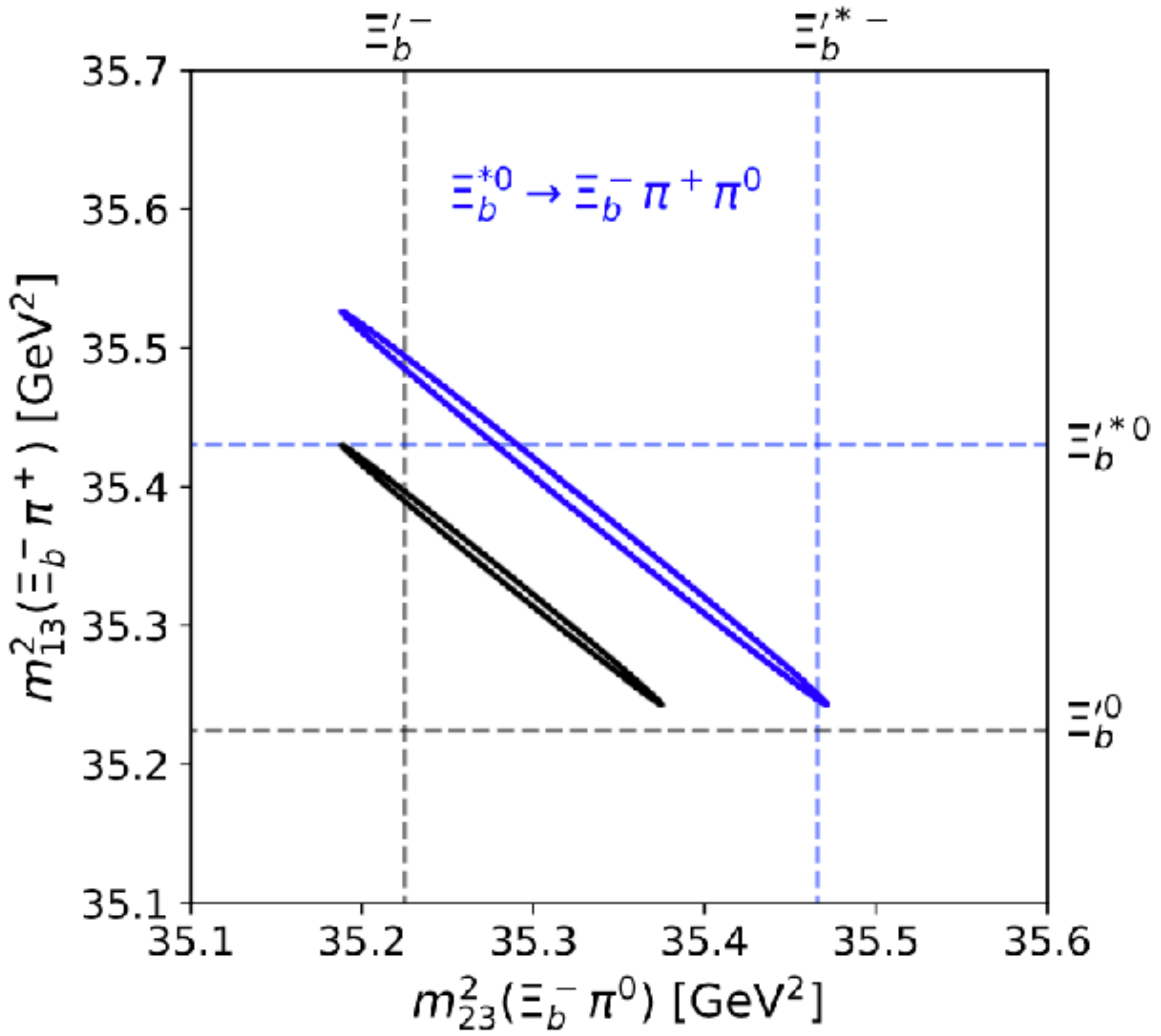
$\Xi_c^+\pi^+\pi^-$ $\Xi_c^+\pi^0\pi^0$ $\Xi_c^+\pi^+\pi^0$

$\Xi_c^+\pi^+\pi^-$ $\Xi_c^+\pi^0\pi^0$ $\Xi_c^+\pi^+\pi^0$

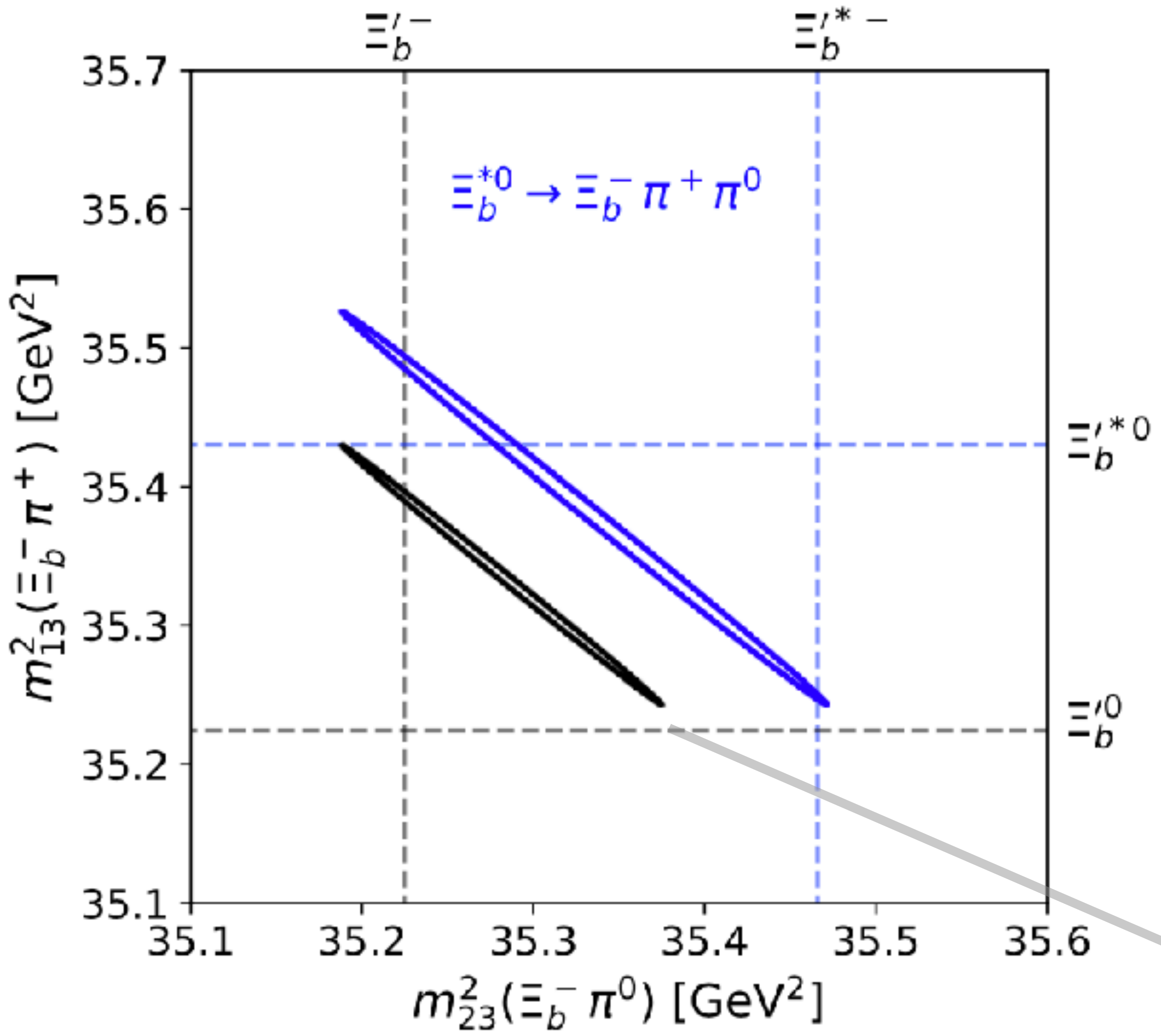
- $\Xi_c(3/2^-)$:
  S-wave resonance is dominant.
- $\Xi_c(1/2^-)$:
  Direct process is large, but two-body decay is cominant.

$\Xi_b(6087)$ and $\Xi_b(6100)$

$\Xi_b(6087)$ and $\Xi_b(6100)$

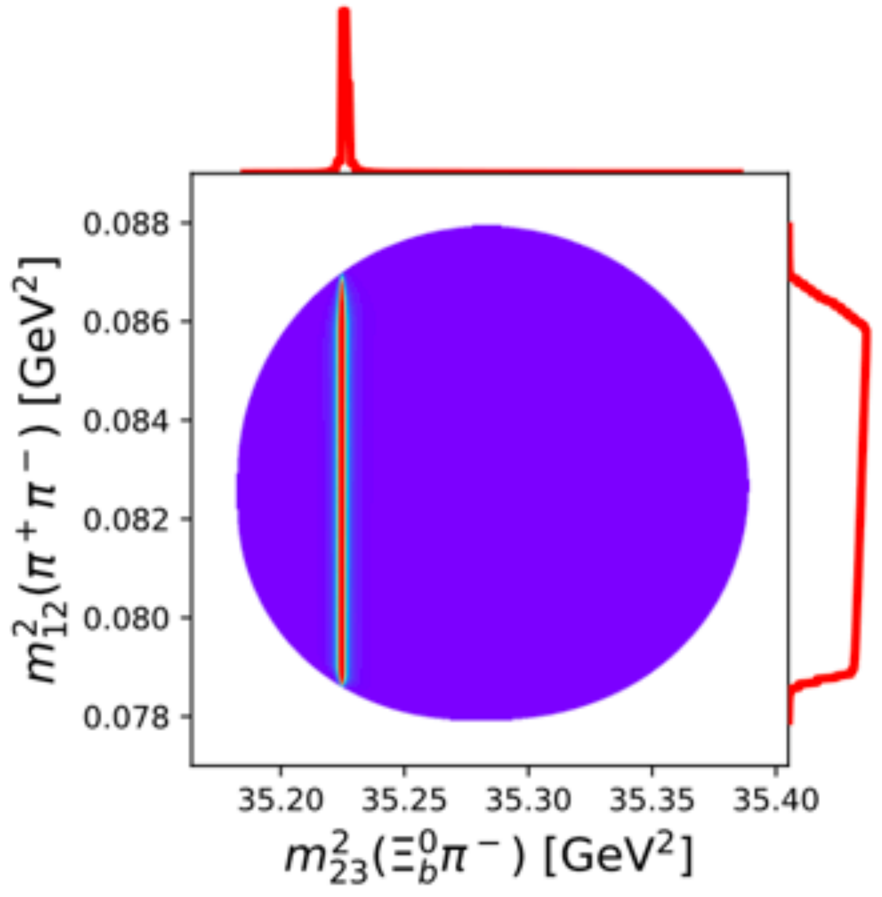


$\Xi_b(6087)$ and $\Xi_b(6100)$

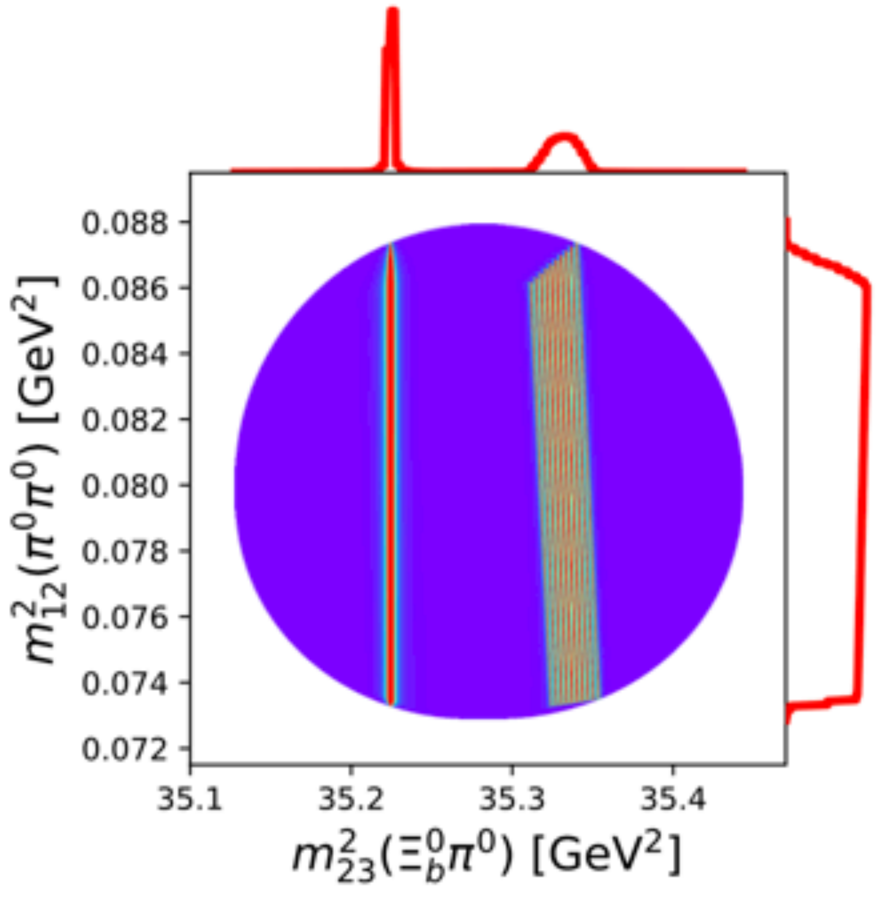


$\Xi_b(6087)$

$1/2^-$



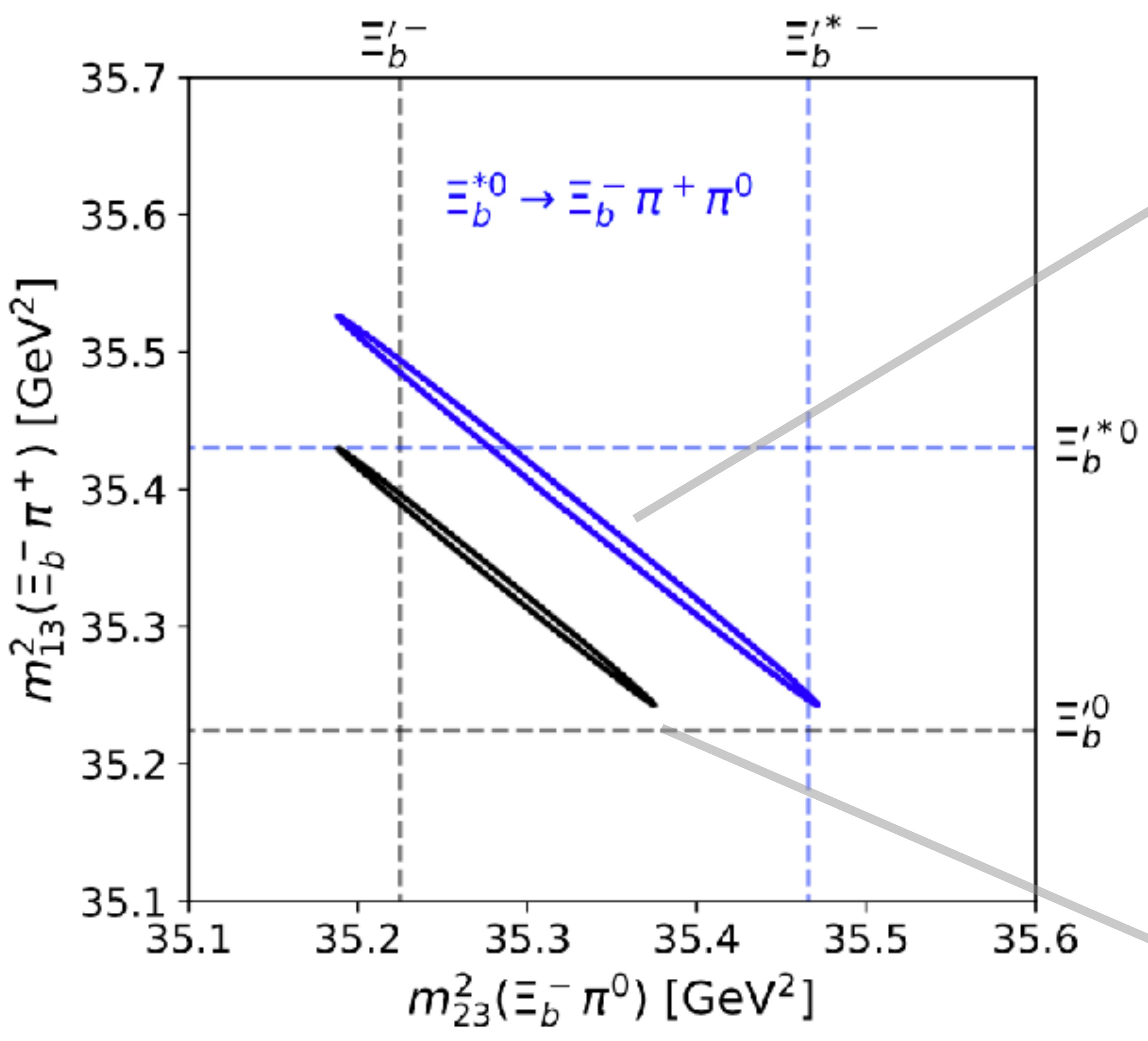
$\Xi_b^0\pi^+\pi^-$



$\Xi_b^0\pi^0\pi^0$

$\Xi_b^-\pi^+\pi^0$

$\Xi_b(6087)$ and $\Xi_b(6100)$

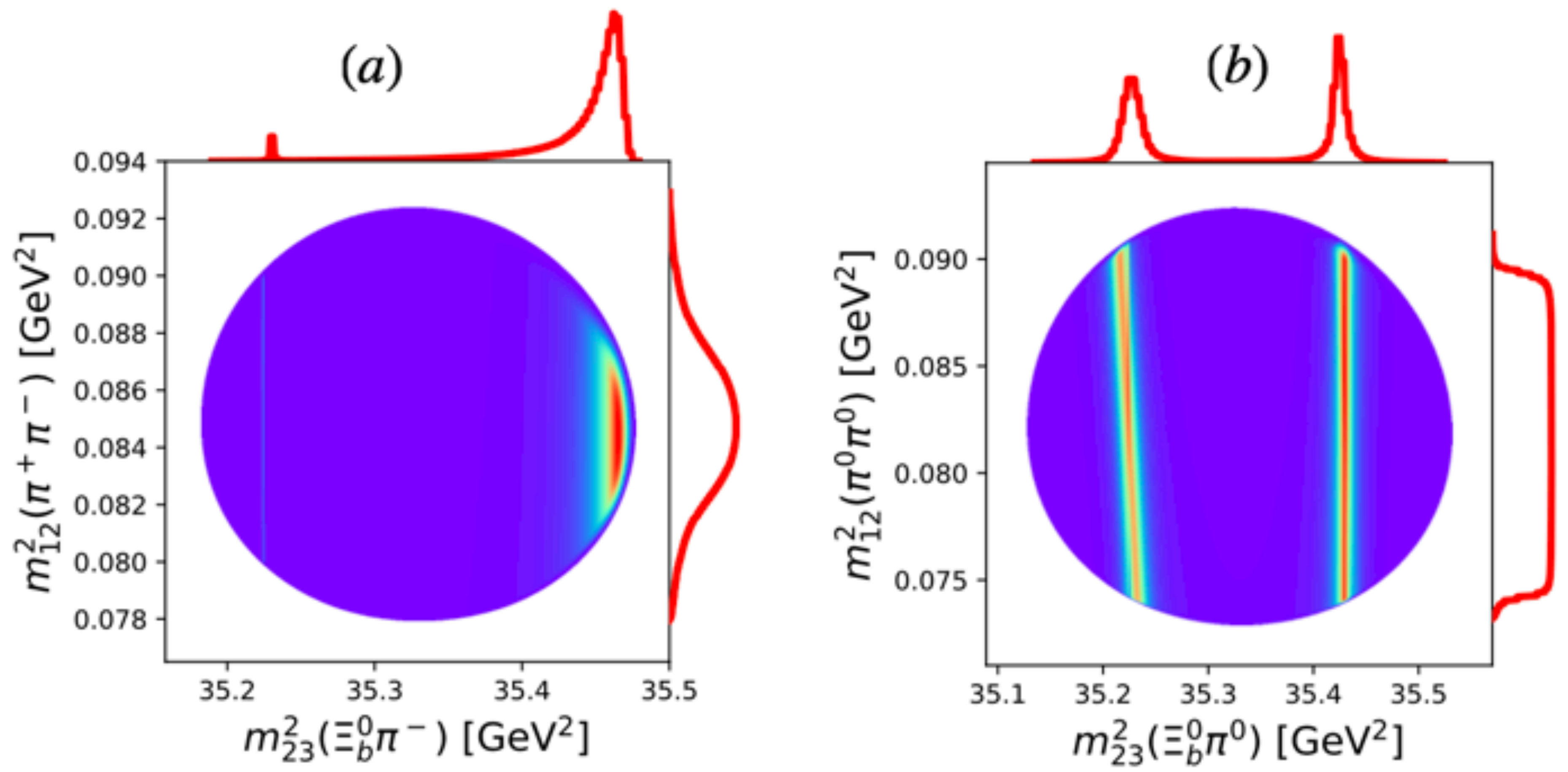


$\Xi_b(6100)$

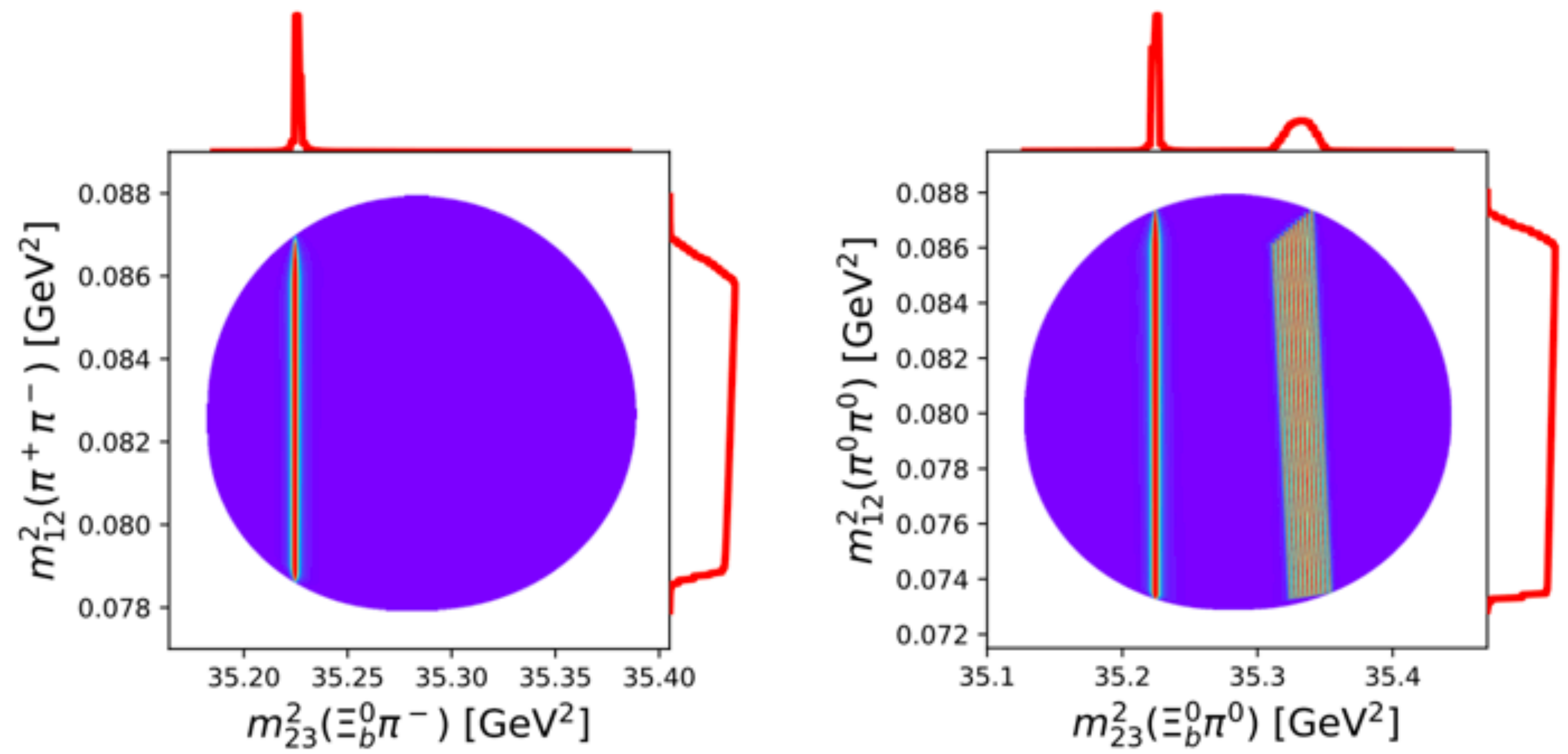
$3/2^-$

$\Xi_b(6087)$

$1/2^-$

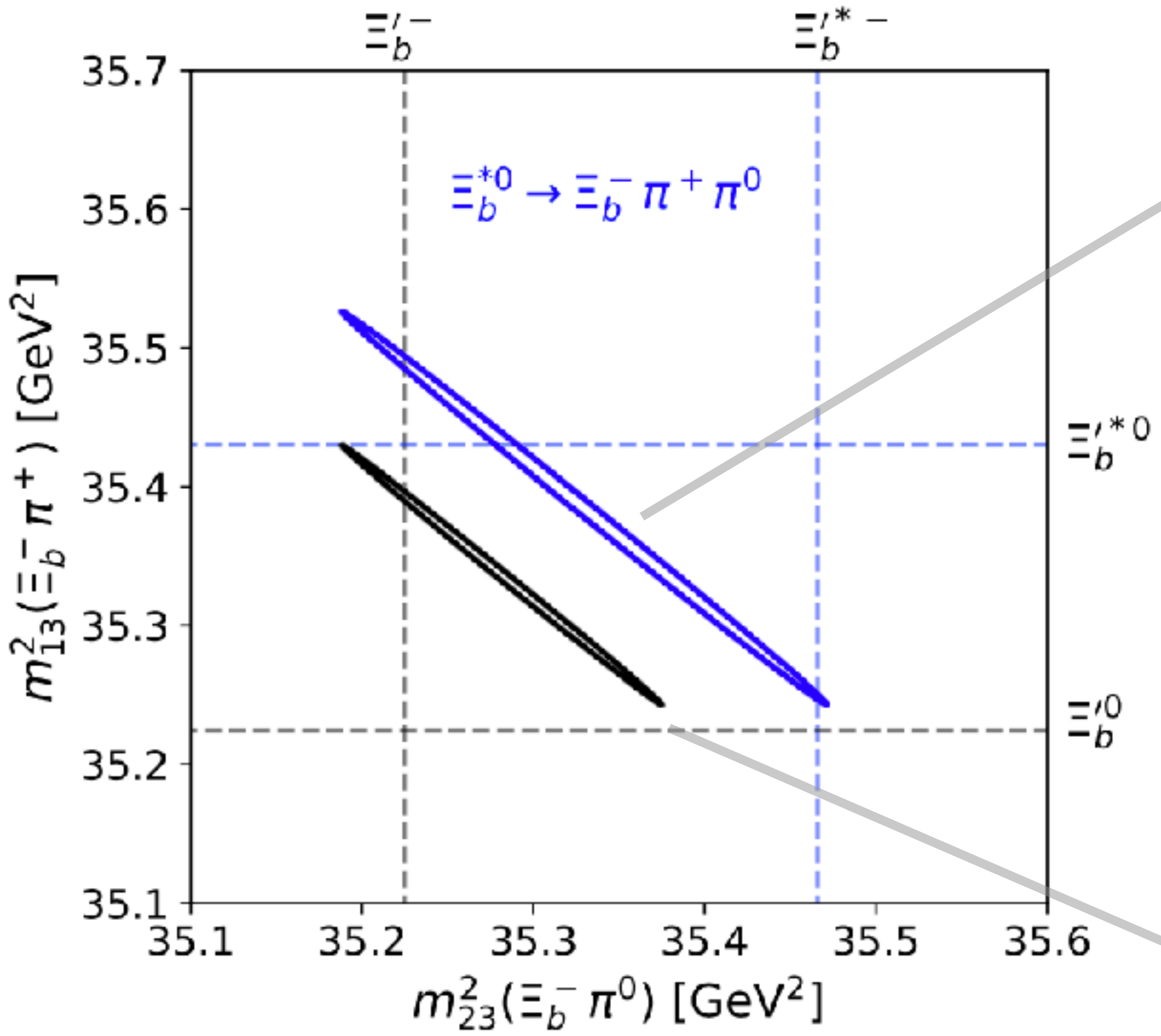


$\Xi_b^0\pi^+\pi^-$ $\Xi_b^0\pi^0\pi^0$ $\Xi_b^-\pi^+\pi^0$



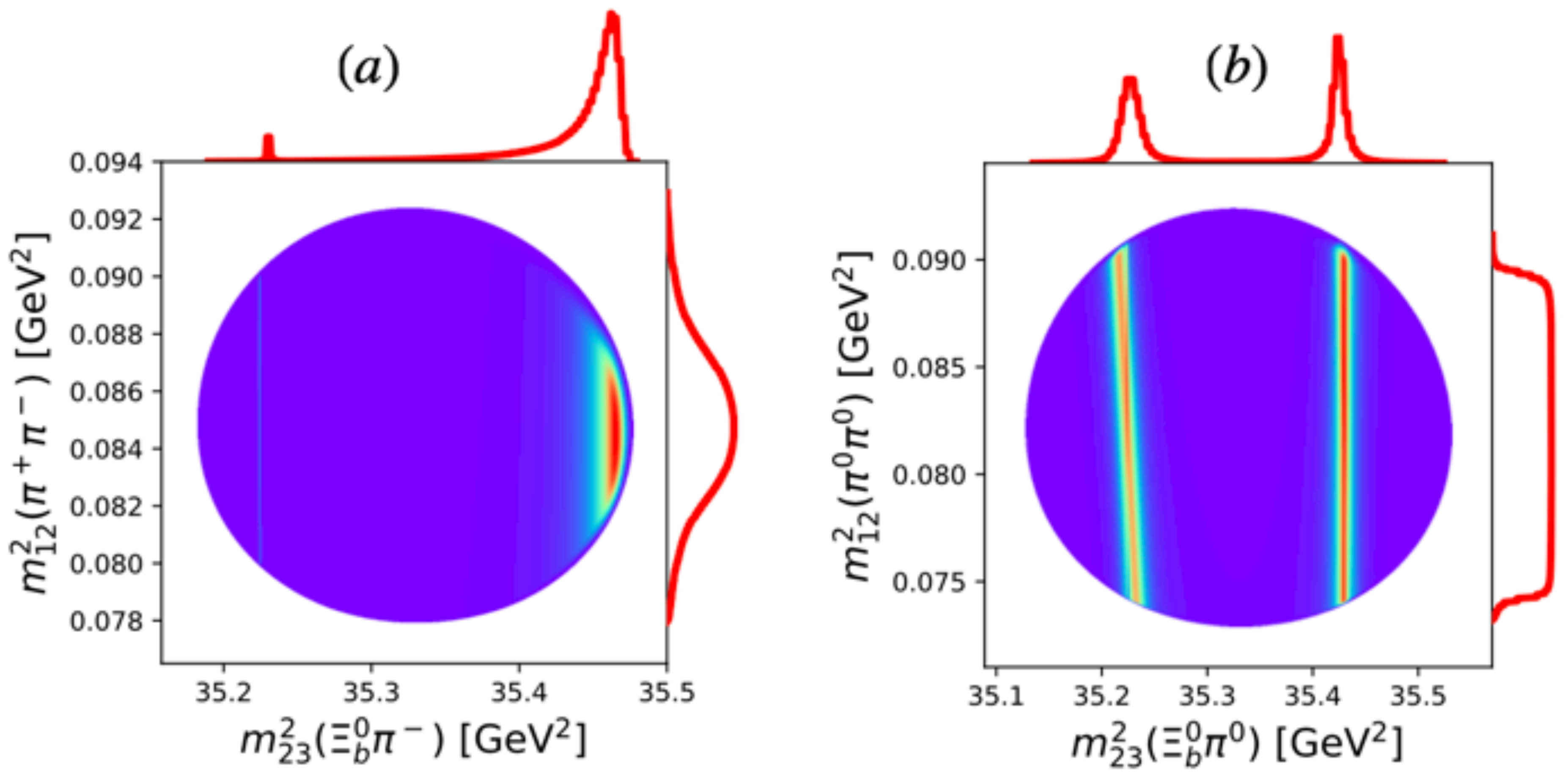
$\Xi_b^0\pi^+\pi^-$ $\Xi_b^0\pi^0\pi^0$ $\Xi_b^-\pi^+\pi^0$

$\Xi_b(6087)$ and $\Xi_b(6100)$



$\Xi_b(6100)$

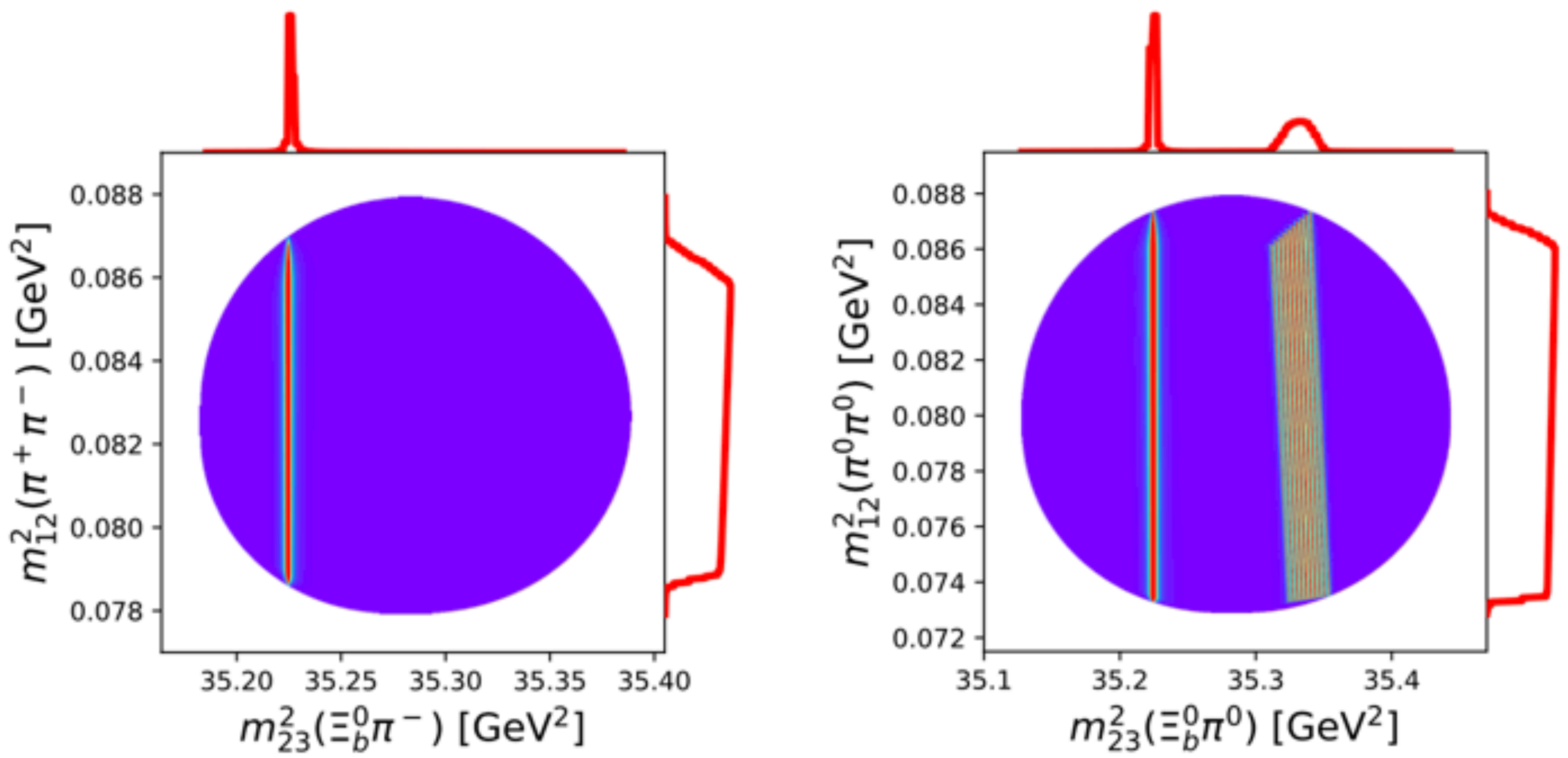
$3/2^-$



$\Xi_b^0\pi^+\pi^-$ $\Xi_b^0\pi^0\pi^0$ $\Xi_b^-\pi^+\pi^0$

$\Xi_b(6087)$

$1/2^-$



$\Xi_b^0\pi^+\pi^-$ $\Xi_b^0\pi^0\pi^0$ $\Xi_b^-\pi^+\pi^0$

- ✦ S-wave resonance is dominant.
- ✦ No visible direct process.

Radial excitations

✦ Arifi et al. PRD101, 094023 (2020)

Radial excitations

$\Lambda_c(2765)^+$ **or** $\Sigma_c(2765)$ $\quad I(J^P) = ?(?^?)$

The information is still poor (1 star)

(Broad resonance ~ 50 MeV)

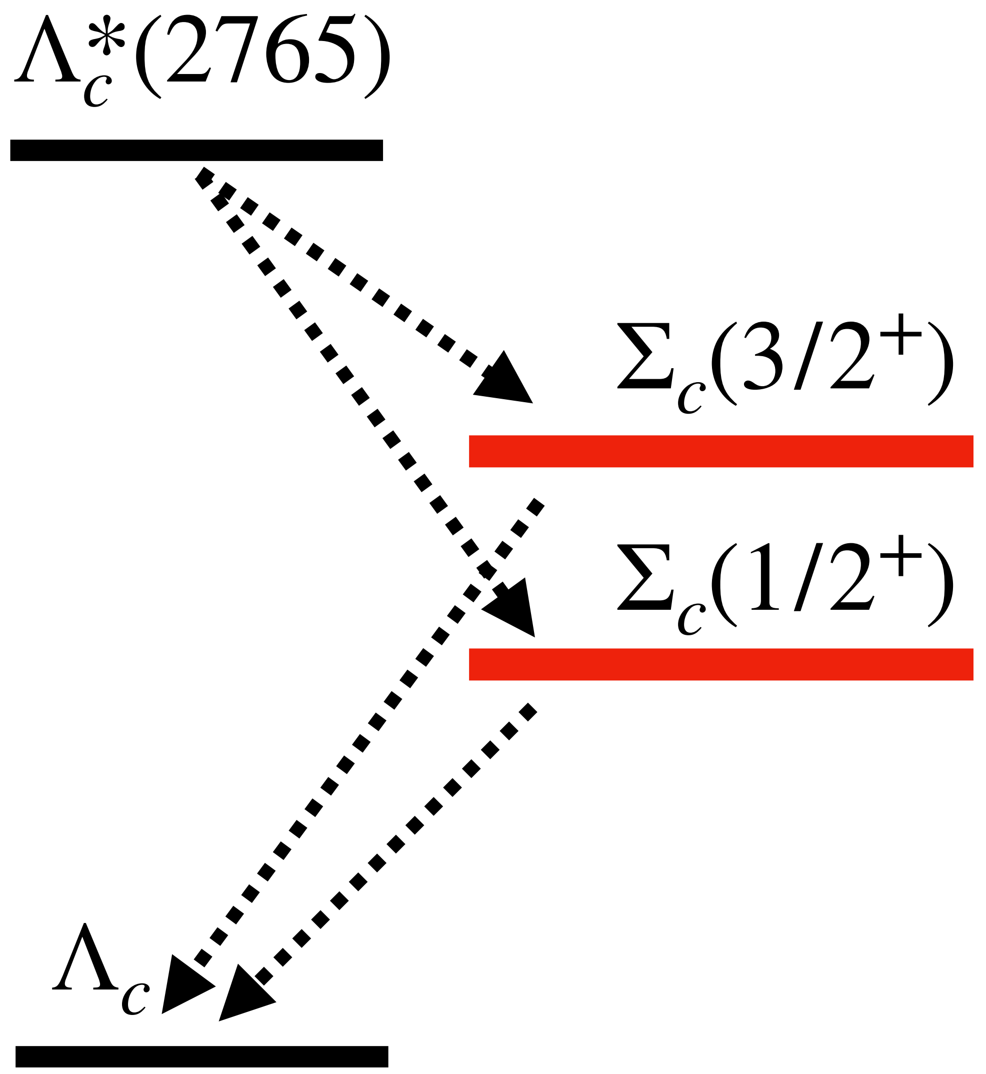
✦ Arifi et al. PRD101, 094023 (2020)

Radial excitations

$\Lambda_c(2765)^+$ or $\Sigma_c(2765)$ $I(J^P) = ?(?^?)$

The information is still poor (1 star)

(Broad resonance ~ 50 MeV)



Sequential process

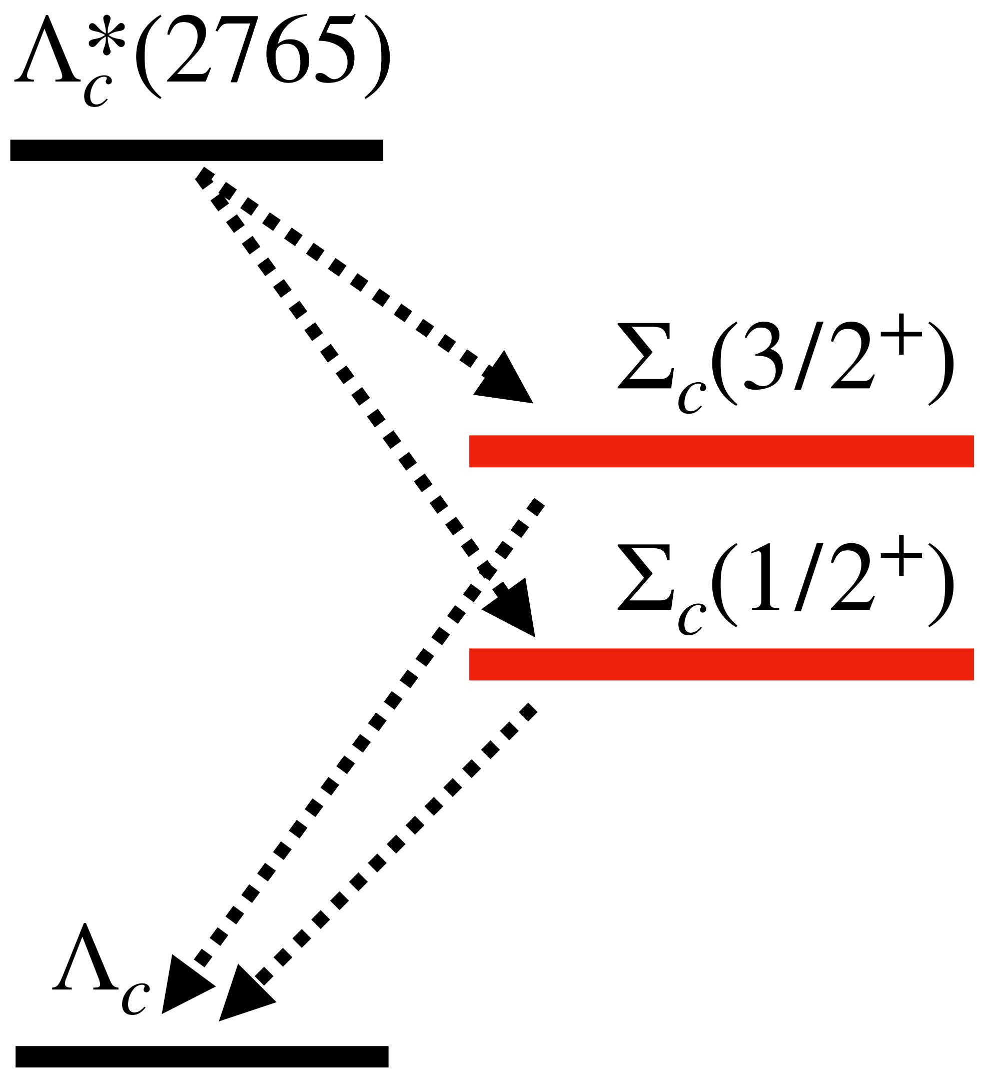
✦ Arifi et al. PRD101, 094023 (2020)

Radial excitations

$\Lambda_c(2765)^+$ or $\Sigma_c(2765)$ $\quad I(J^P) = ?(?^?)$

The information is still poor (1 star)

(Broad resonance ~ 50 MeV)



Sequential process

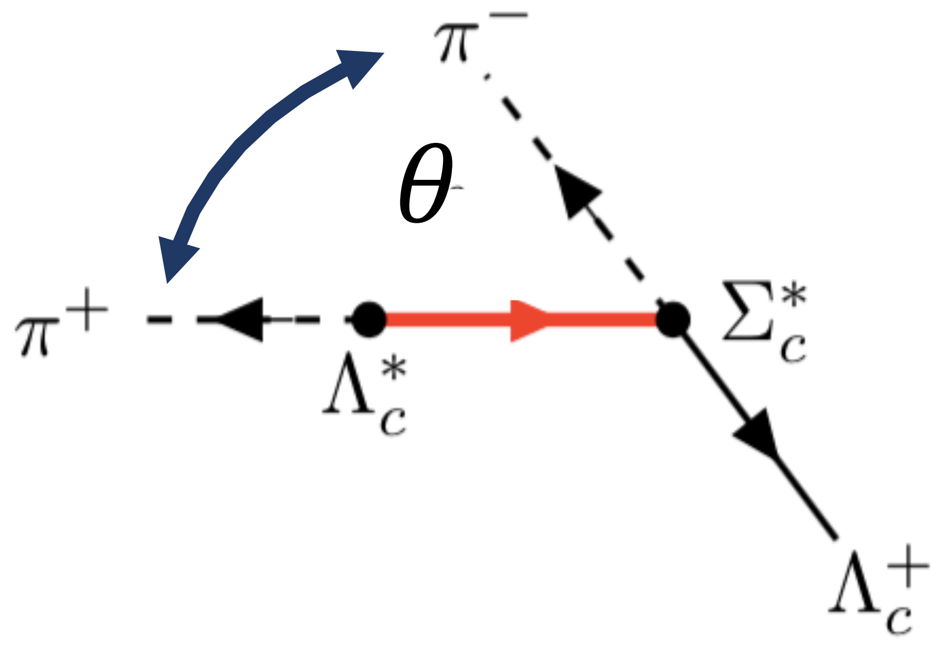
Spin-parity determination

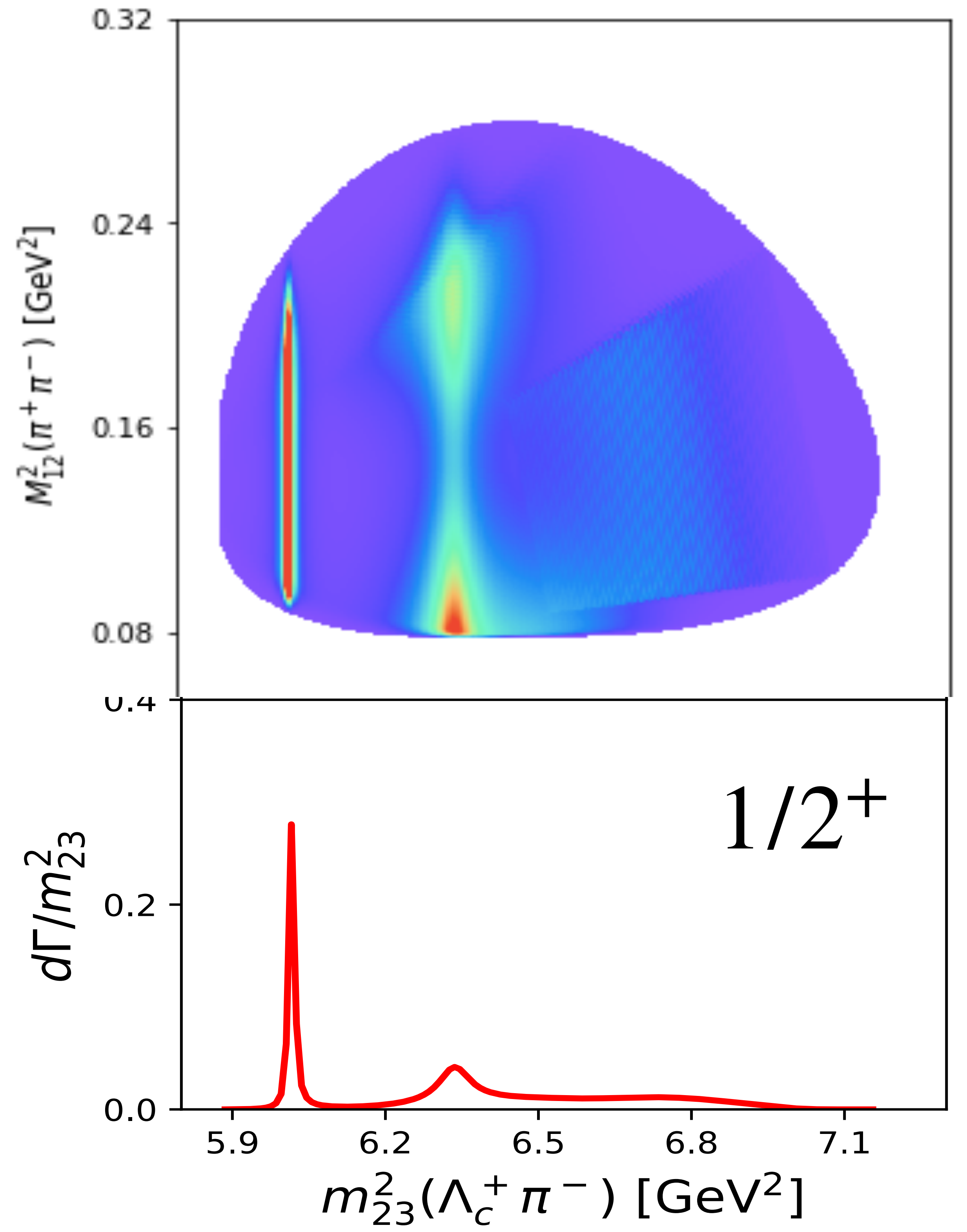
Branching ratio

$$R = \frac{\Gamma(\Lambda_c^* \to \Sigma_c^* \pi)}{\Gamma(\Lambda_c^* \to \Sigma_c \pi)}$$

Heavy-quark symmetry

Angular correlation





✦ Arifi et al. PRD101, 094023 (2020)

***Note**: finite width effect.*

Back-up slide #2

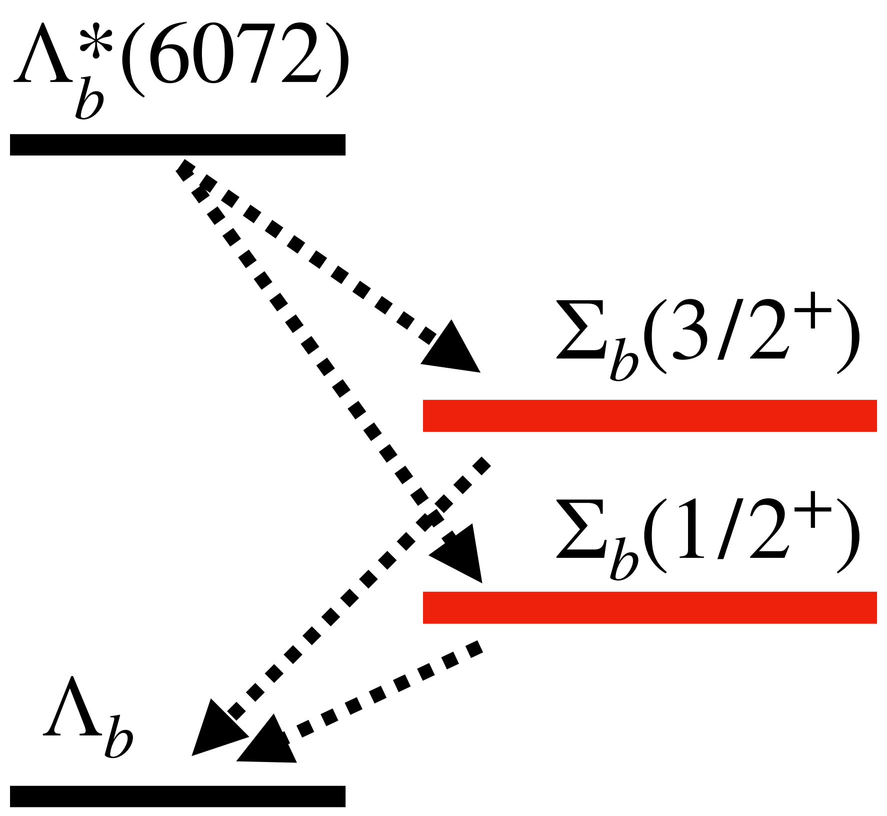
Spin-parity determination

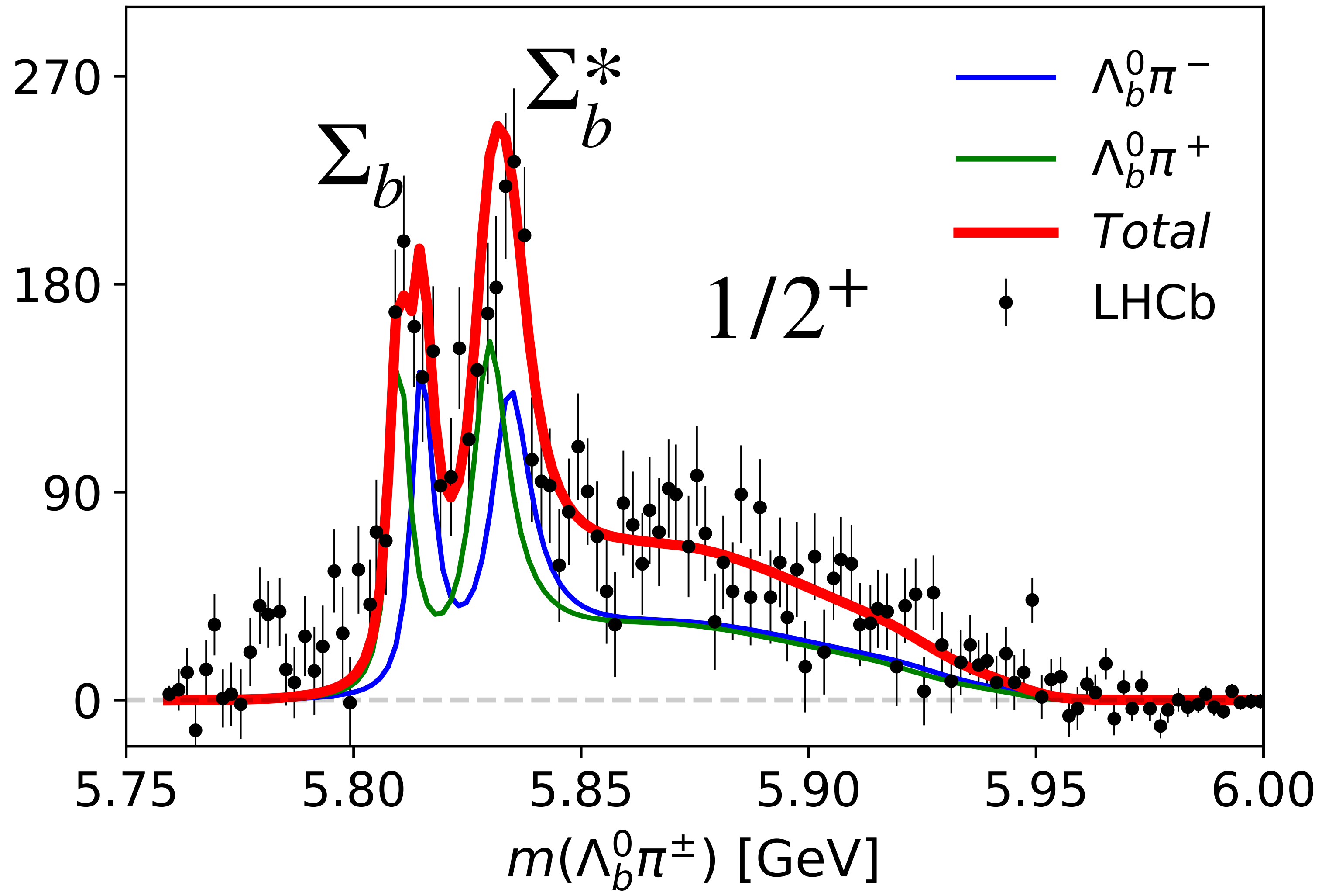
✦ Arifi et al. PRD101, 111502(R) (2020)
✦ LHCb. JHEP06, 136 (2020)

✦ Belle. PRD103, 111101 (2021)

Spin-parity determination

$\Lambda_b(6072)$





- Invariant mass distribution is consistent with $1/2^+$.
- Ratio of Σ_b and Σ_b^* peaks is crucial.

✦ Arifi et al. PRD101, 111502(R) (2020)
✦ LHCb. JHEP06, 136 (2020)
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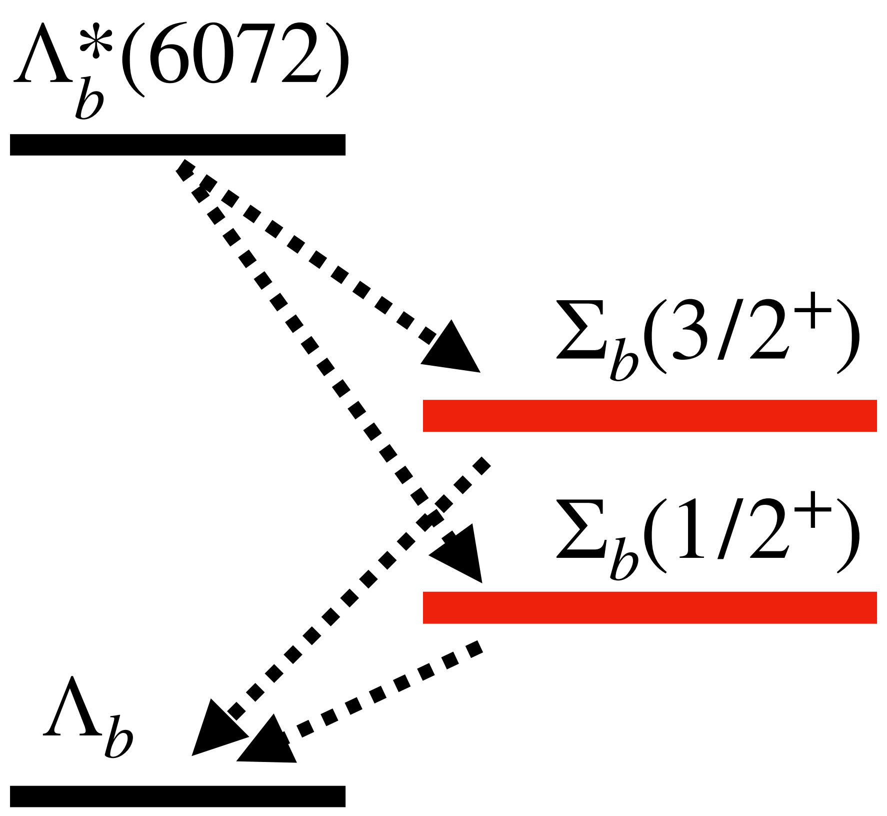
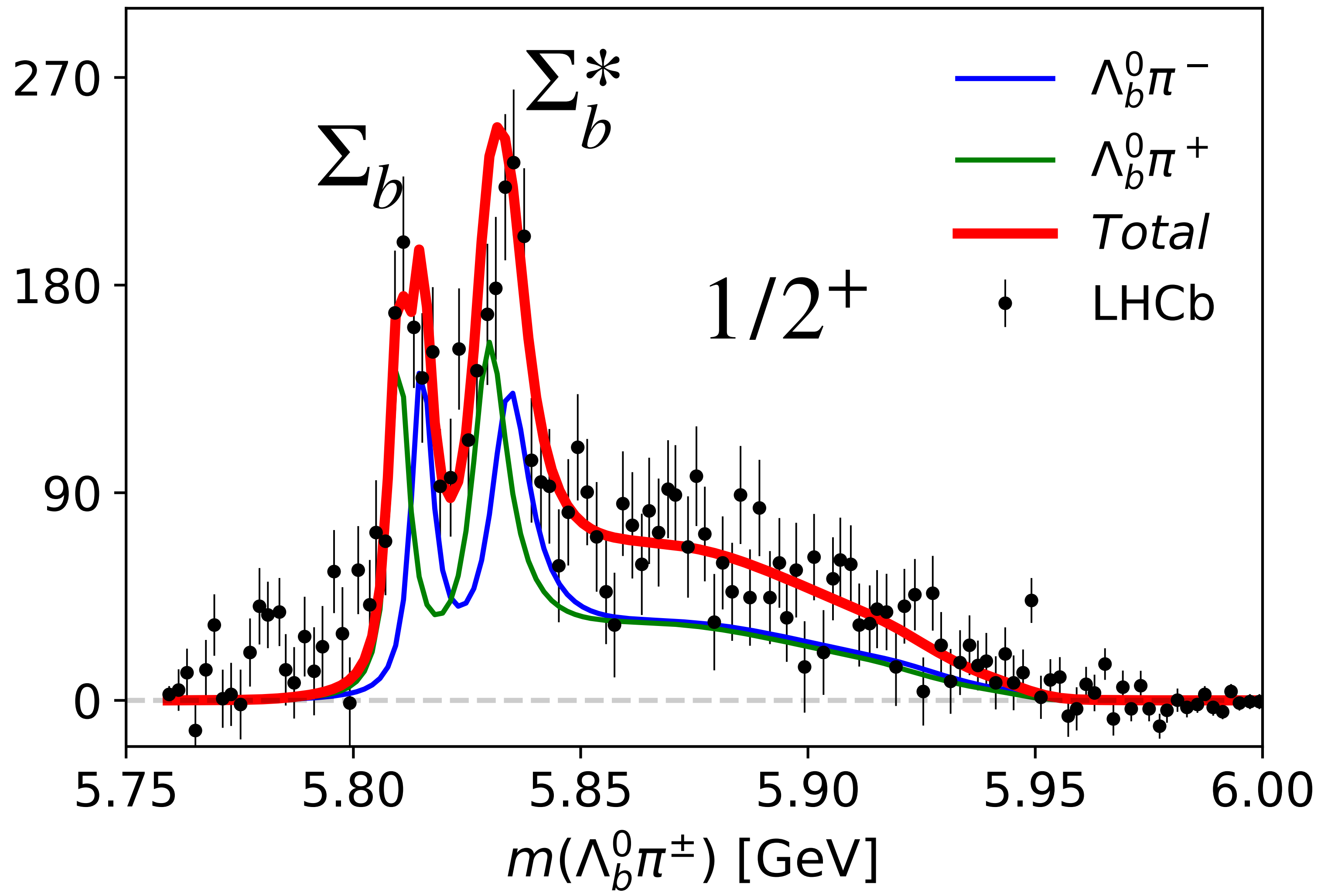
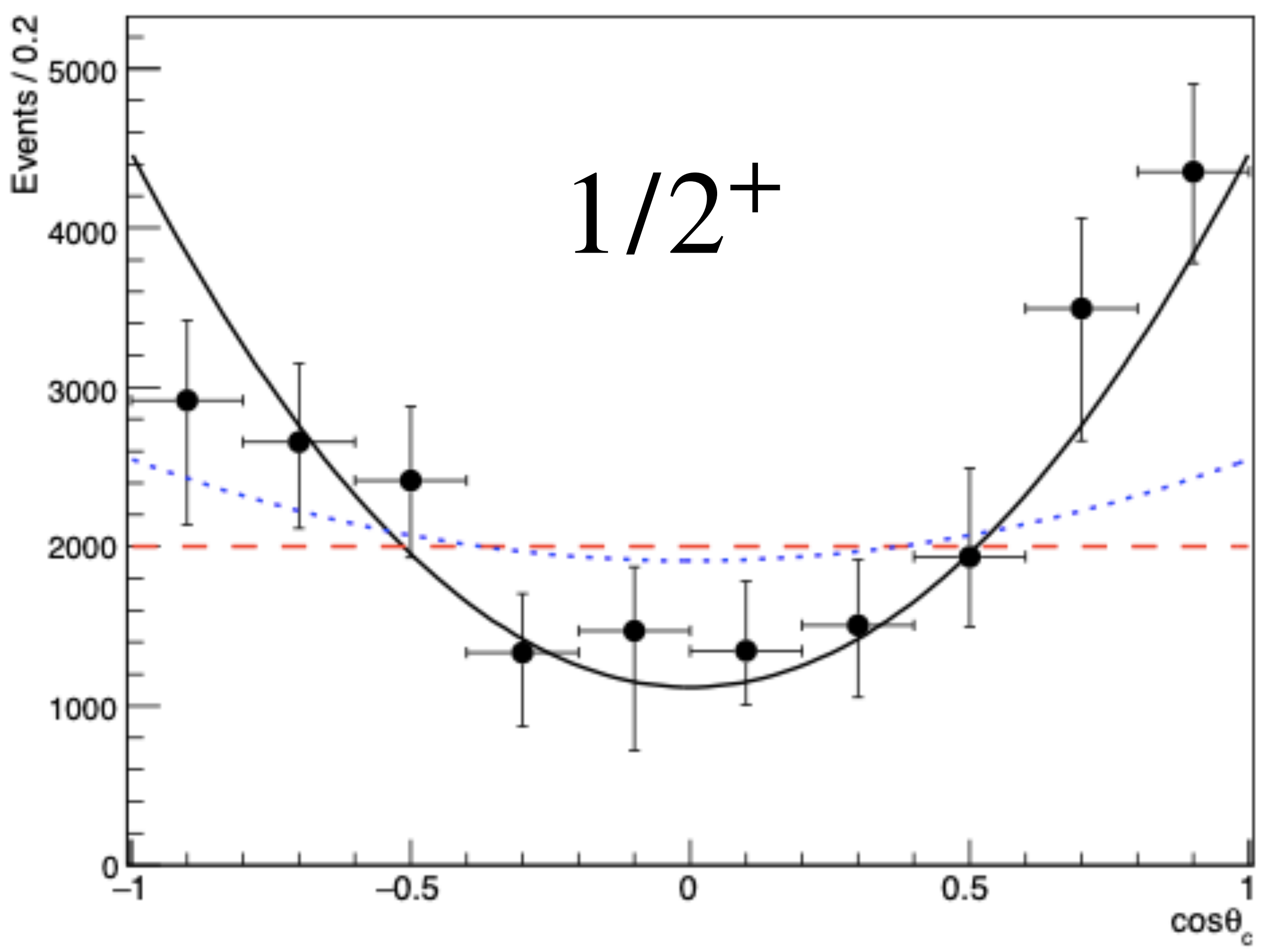
Spin-parity determination

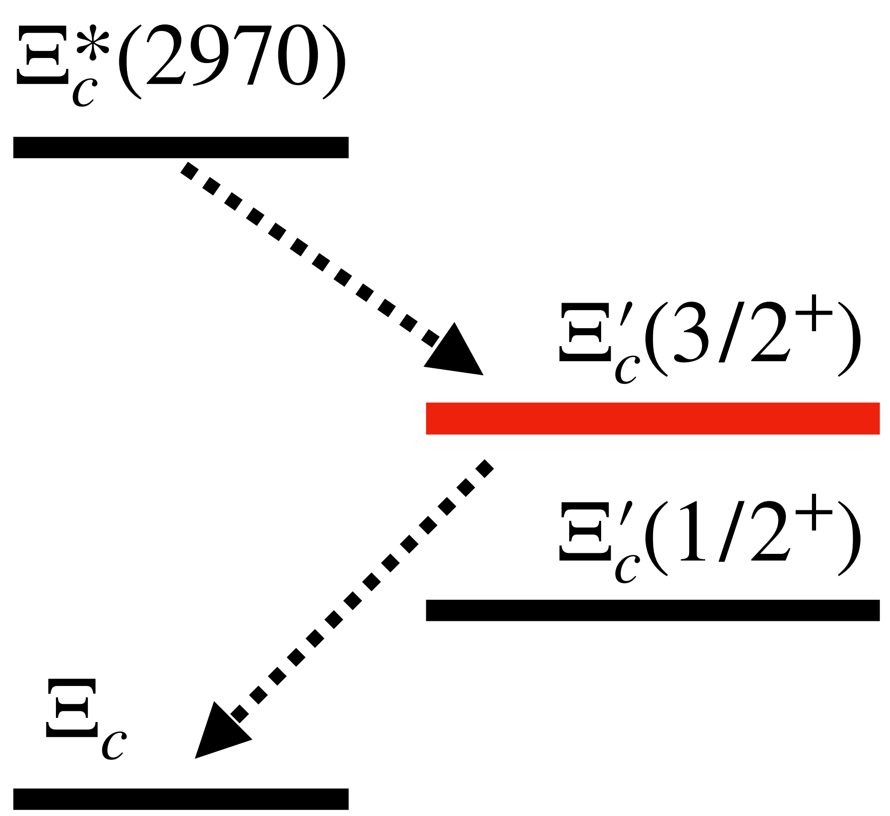
$\Lambda_b(6072)$





$\Xi_c(2970)$





- Invariant mass distribution is consistent with $1/2^+$.
- Ratio of Σ_b and Σ_b^* peaks is crucial.

- The angular distribution is convex.
- Evidence to have spin-1/2.
- Positive parity is infered from Branching ratio (R=1.67).

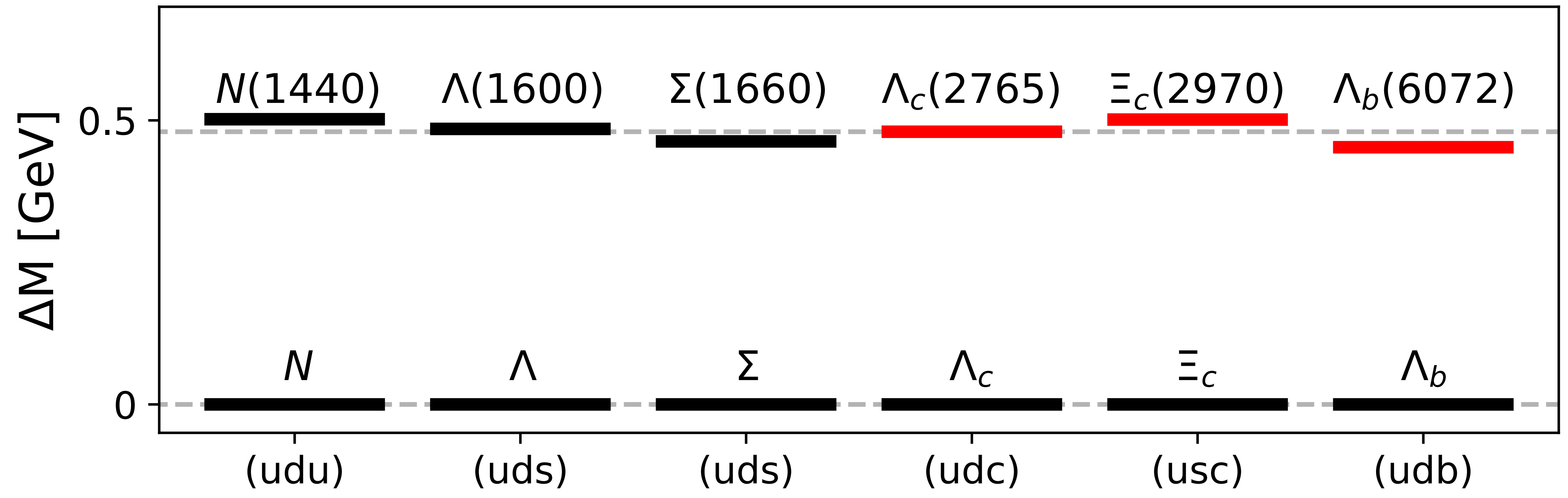
✦ Arifi et al. PRD101, 111502(R) (2020)
✦ LHCb. JHEP06, 136 (2020)
✦ Belle. PRD103, 111101 (2021)

Mass gap ($\Delta M = M_{2S} - M_{1S}$)

✦ Arifi et al. PRD106, 014009 (2022)

Mass gap ($\Delta M = M_{2S} - M_{1S}$)

Baryon $\quad \Delta M \approx 500 \text{ MeV}$



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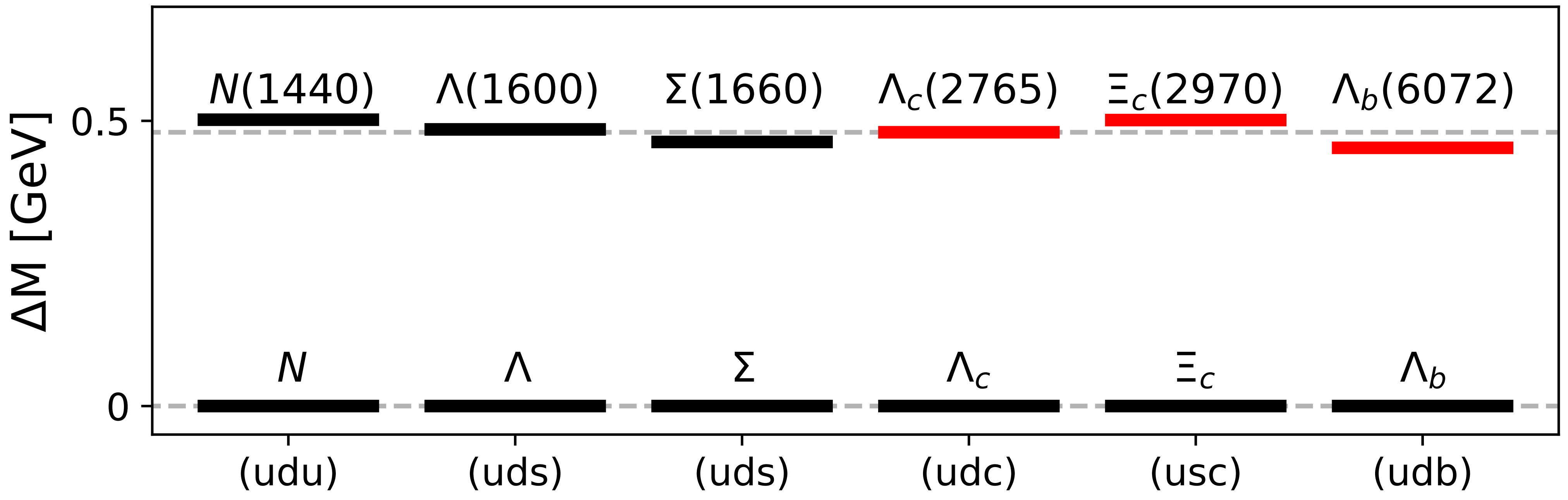
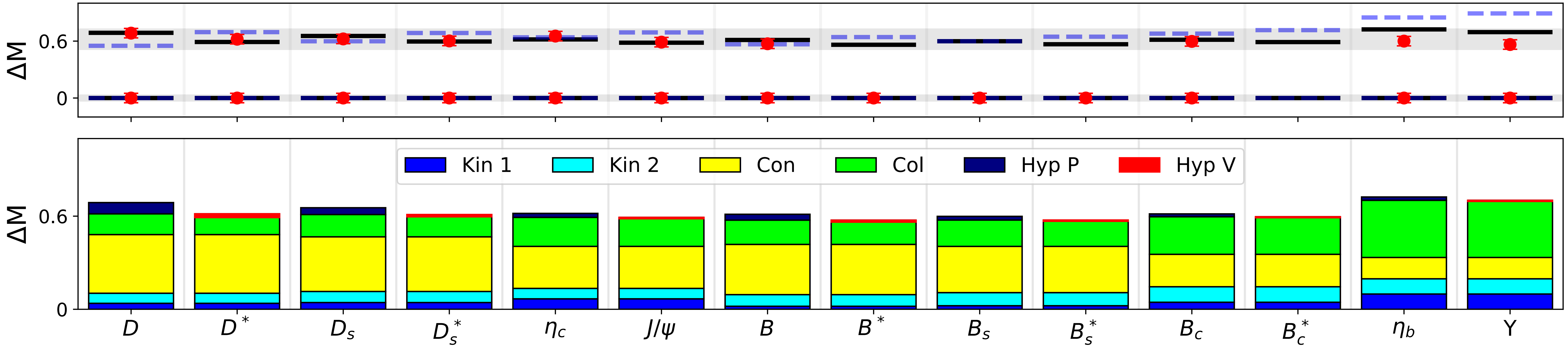


Meson $\Delta M \approx 600$ MeV



- For NG bosons, pion & kaon, the mass gap is badly broken.

- Arifi et al. PRD106, 014009 (2022)

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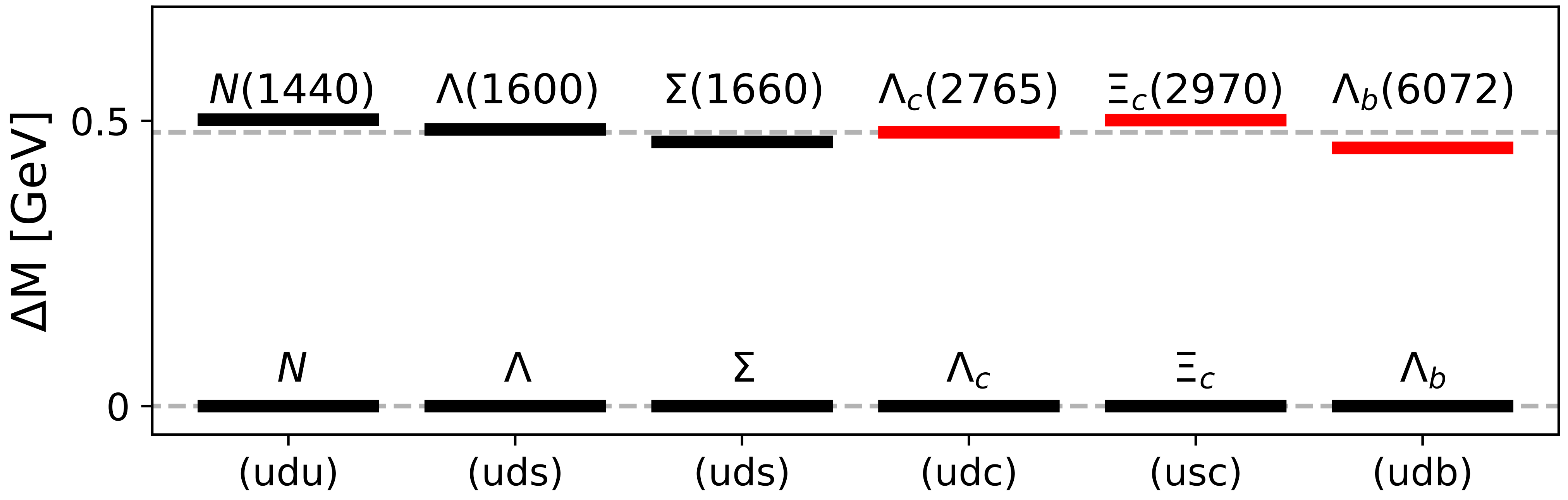
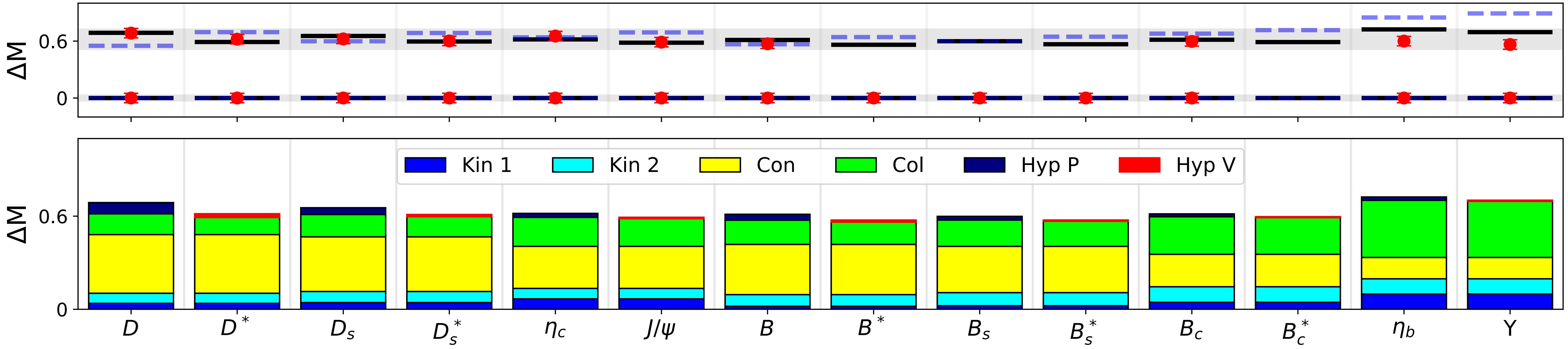


- There is a competition between short-range interaction and Confinement

Meson $\quad \Delta M \approx 600$ MeV



- For NG bosons, pion & kaon, the mass gap is badly broken.

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Summary

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Summary

- **Decay analysis**
  - Give insight to the internal structure
  - Help determining their spin & parity
- **Problems**
  - Large width & mass gap of radial excitations?
  - ρ mode excitations? exotic states? HQS partner?
- **Plans**
  - More realistic WF, relativistic quark model analysis, applications to other systems, etc.

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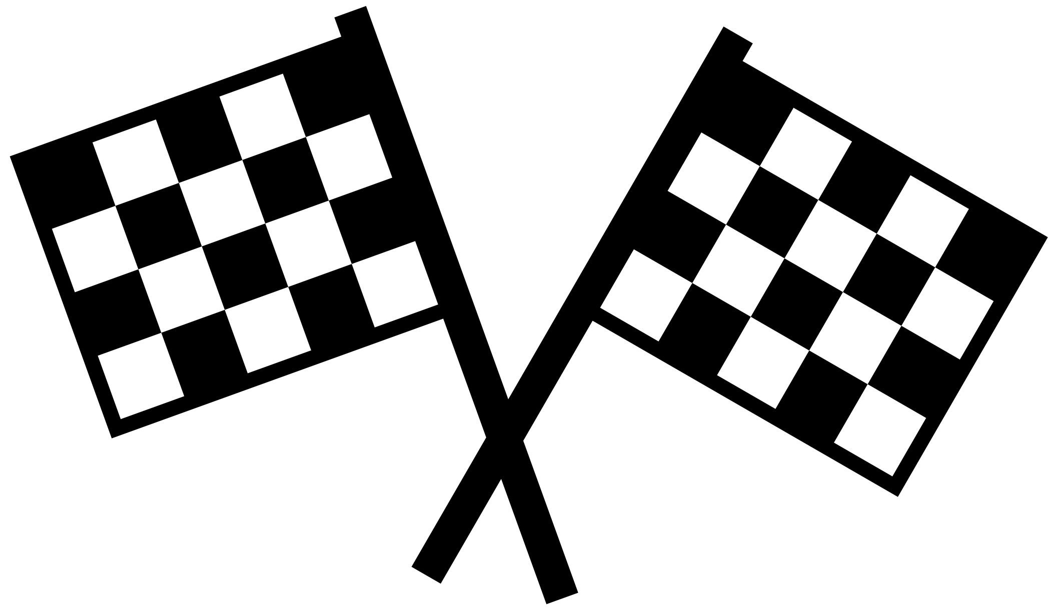
Thank you for your attention!



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Appendix

Radial excitations (2S states)