Doubly Heavy Baryons: Lifetimes and Some Weak Decays

A. V. Luchinsky

IHEP, Protvino, Russia

November 13, 2020

Content

1. Introduction
2. Lifetimes
3. Decays
   - 2π
   - 3π
   - 4π
   - 5π
4. Conclusion

Introduction

- $(Q_1 Q_2)q$ — a laboratory to study h.q. interactions

Introduction

- $(Q_1 Q_2)q$ — a laboratory to study h.q. interactions
- Nicely studied theoretically:

Introduction

- $(Q_1 Q_2)q$ — a laboratory to study h.q. interactions
- Nicely studied theoretically:
  - Masses, Production, Decays

Introduction

- $(Q_1 Q_2)q$ — a laboratory to study h.q. interactions
- Nicely studied theoretically:
  - Masses, Production, Decays
- Ξ_{cc}^{++} observed: with good mass, bad τ

Introduction

- $(Q_1 Q_2)q$ — a laboratory to study h.q. interactions
- Nicely studied theoretically:
  - Masses, Production, Decays
- Ξ_{cc}^{++} observed: with good mass, bad τ
  - TODO: Update the model parameters

Introduction

- $(Q_1 Q_2)q$ — a laboratory to study h.q. interactions
- Nicely studied theoretically:
  - Masses, Production, Decays
- Ξ_{cc}^{++} observed: with good mass, bad τ
  - TODO: Update the model parameters
  - TODO: lifetime predictions

Introduction

- $(Q_1 Q_2)q$ — a laboratory to study h.q. interactions
- Nicely studied theoretically:
  - Masses, Production, Decays
- Ξ_{cc}^{++} observed: with good mass, bad τ
  - TODO: Update the model parameters
  - TODO: lifetime predictions
- B_c is visible $\Rightarrow$ Ξ_{bc} could be detected too

Introduction

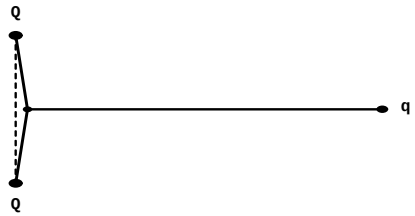
- $(Q_1 Q_2)q$ — a laboratory to study h.q. interactions
- Nicely studied theoretically:
  - Masses, Production, Decays
- Ξ_{cc}^{++} observed: with good mass, bad τ
  - TODO: Update the model parameters
  - TODO: lifetime predictions
- B_c is visible $\Rightarrow$ Ξ_{bc} could be detected too
  - TODO: Decays

Introduction

- $(Q_1 Q_2)q$ — a laboratory to study h.q. interactions
- Nicely studied theoretically:
  - Masses, Production, Decays
- Ξ_{cc}^{++} observed: with good mass, bad τ
  - TODO: Update the model parameters
  - TODO: lifetime predictions
- B_c is visible $\Rightarrow$ Ξ_{bc} could be detected too
  - TODO: Decays
  - $\Xi_{bc} \to \Xi_{cc} + \mathcal{R}$, $\mathcal{R} = 2\pi, 3\pi, \ldots$

Doubly Heavy Baryons

Quark-diquark approximation: light quark interact with the heavy diquark (and not with heavy quarks separately)

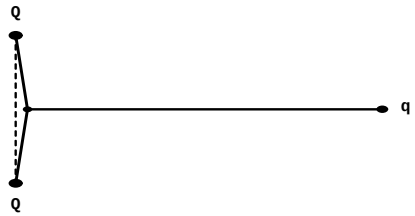


Nice theoretical predictions for

- Masses: S.S. Gershtein et al, YF63,334(2000), V.V. Kiselev et al, Phys.Rev.D66, 034030 (2002)

Doubly Heavy Baryons

Quark-diquark approximation: light quark interact with the heavy diquark (and not with heavy quarks separately)

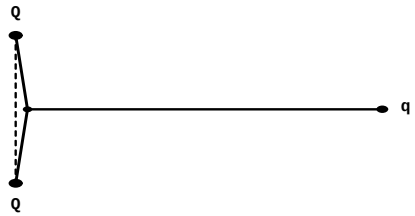


Nice theoretical predictions for

- Masses: S.S. Gershtein et al, YF63,334(2000), V.V. Kiselev et al, Phys.Rev.D66, 034030 (2002)
- Production A. V. Berezhnoy et al, Yad.Fiz.59,909(1996), V. V. Braguta et al, hep-ph/0005149

Doubly Heavy Baryons

Quark-diquark approximation: light quark interact with the heavy diquark (and not with heavy quarks separately)

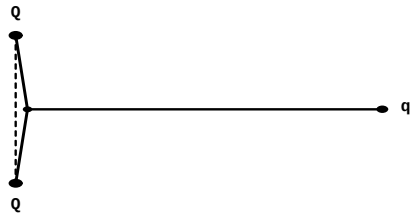


Nice theoretical predictions for

- Masses: S.S. Gershtein et al, YF63,334(2000), V.V. Kiselev et al, Phys.Rev.D66, 034030 (2002)
- Production A. V. Berezhnoy et al, Yad.Fiz.59,909(1996), V. V. Braguta et al, hep-ph/0005149
- Decays: A. I. Onishchenko, arXiv:hep-ph/0006271, A. V. Berezhnoy et al Phys. Rev. D 98 (2018)

Doubly Heavy Baryons

Quark-diquark approximation: light quark interact with the heavy diquark (and not with heavy quarks separately)



Nice theoretical predictions for

- Masses: S.S. Gershtein et al, YF63,334(2000), V.V. Kiselev et al, Phys.Rev.D66, 034030 (2002)
- Production A. V. Berezhnoy et al, Yad.Fiz.59,909(1996), V. V. Braguta et al, hep-ph/0005149
- Decays: A. I. Onishchenko, arXiv:hep-ph/0006271, A. V. Berezhnoy et al Phys. Rev. D 98 (2018)
- Lifetimes: M. Karliner et al, r, Phys.Rev.D90, 094007 (2014), A. Likhoded et al, YF 81, 737 (2018)

Total width within OPE

$$\Gamma_{\Xi_{cc}} = \frac{1}{2M_{\Xi_{cc}}} \langle \Xi_{cc}^{\diamond} | \mathcal{T} | \Xi_{cc}^{\diamond} \rangle$$

$$\langle \Xi_{cc} | \Xi_{cc} \rangle = 2EV$$

$$\mathcal{T} = \mathrm{Im} m \int d^4x \, \{ \mathrm{T} H_{eff}(x) H_{eff}(0) \}$$

where H_{eff} is the standard effective hamiltonian describing the low energy weak interactions of initial quarks with the decay products. For the transition of c-quark, u-quark and the quarks $q_{1,2}$ with the charge $-1/3$, the lagrangian has the form

$$H_{eff} = \frac{G_F}{2\sqrt{2}} V_{uq_1} V_{cq_1}^* [C_+(\mu) O_+ + C_-(\mu) O_-] + \mathrm{h.c.}$$

where V is the matrix of mixing between the charged currents, and

$$O_{\pm} = [\bar{q}_{1\alpha} \gamma_\nu (1 - \gamma_5) c_\beta][\bar{u}_\gamma \gamma^\nu (1 - \gamma_5) q_{2\delta}](\delta_{\alpha\beta}\delta_{\gamma\delta} \pm \delta_{\alpha\delta}\delta_{\gamma\beta}),$$

α, β are color states of quarks and

$$C_+ = \left[\frac{\alpha_s(M_W)}{\alpha_s(\mu)} \right]^{\frac{6}{33-2n_f}}, \quad C_- = \left[\frac{\alpha_s(M_W)}{\alpha_s(\mu)} \right]^{\frac{-12}{33-2n_f}}$$

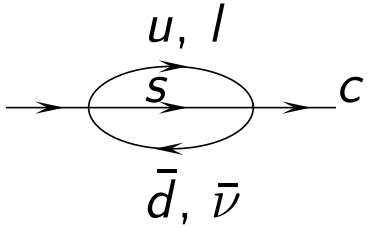
where n_f is the number of flavors.

OPE for the transition operator $\mathcal{T}$

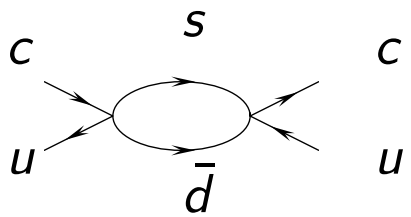
Main features:

- $\bar{c}c$ — spectator decays of c-quarks;
- no operators of dimension 4 contribute;
- the only operator of dimension 5 ;
- Pauli interference (operators of dimension 6) essentially contribute to Ξ_{cc}^{++} life time;
- weak scattering (operators of dimension 6) essentially contribute to Ξ_{cc}^{+} life time.

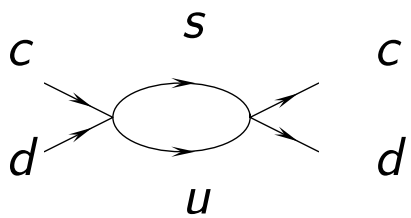
Spectator contribution:



Pauli interference:



Weak scattering:



Ξ_{cc}^{++}, Ξ_{cc}^{+} lifetimes

$$\mathcal{T}^{(\Xi_{cc}^{++})} = 2(\mathcal{T}_{35c} + \mathcal{T}^{c}_{\mathrm{PI},u\bar{d}}), \qquad \mathcal{T}^{(\Xi_{cc}^{+})} = 2(\mathcal{T}_{35c} + \mathcal{T}_{\mathrm{WS},cd}),$$

$$\mathcal{T}^{c}_{\mathrm{PI},u\bar{d}} = -\frac{G_F^2}{4\pi} m_c^2 \left(1 - \frac{m_u}{m_c}\right)^2 \times$$
$$\left\{ \left[G_1(z_-)(\bar{c}c)^{ii}_{V-A}(\bar{u}u)^{jj}_{V-A} + G_2(z_-)(\bar{c}c)^{ii}_{A}(\bar{u}u)^{jj}_{V-A} \right] \left[F_3 + \frac{1}{3}(1 - k^{\frac{1}{2}})F_4 \right] + \right.$$
$$\left. \left[G_1(z_-)(\bar{c}c)^{ij}_{V-A}(\bar{u}u)^{ji}_{V-A} + G_2(z_-)(\bar{c}c)^{ij}_{A}(\bar{u}u)^{ji}_{V-A} \right] k^{\frac{1}{2}} F_4 \right\},$$

$$\mathcal{T}_{\mathrm{WS},cd} = \frac{G_F^2}{4\pi} m_c^2 \left(1 + \frac{m_d}{m_c}\right)^2 (1 - z_+)^2 \left[(F_6 + \frac{1}{3}(1 - k^{\frac{1}{2}})F_5)(\bar{c}c)^{ii}_{V-A}(\bar{d}d)^{jj}_{V-A} + \right.$$
$$\left. k^{\frac{1}{2}} F_5 (\bar{c}c)^{ij}_{V-A}(\bar{d}d)^{ji}_{V-A} \right],$$

$$F_{1,3} = (C_+ \mp C_-)^2, \qquad F_{2,4} = 5C_+^2 + C_-^2 \pm 6C_+C_-, \quad F_{5,6} = C_+^2 \mp C_-^2,$$

$$G_1(z) = \frac{(1-z)^2}{2} - \frac{(1-z)^3}{4}, \quad G_2(z) = \frac{(1-z)^2}{2} - \frac{(1-z)^3}{3},$$

$$z_- = \frac{m_s^2}{(m_c - m_u)^2}, \qquad z_+ = \frac{m_s^2}{(m_c + m_d)^2}$$

$$(\bar{c}c)^{ii}_{V-A}(\bar{q}q)^{jj}_{V-A} = -(\bar{c}c)^{ij}_{V-A}(\bar{q}q)^{ji}_{V-A} = 12(m_c + m_q)|\Psi(0)|^2$$

Model parameters and life time estimation

m_c, m_q, $M(\Xi_{cc}^{++})$, $M(\Xi_{cc}^{+})$, T and $\psi_{dd}(0)$

- $m_c = 1.6$ GeV — the pole c-quark mass (lifetime and semileptonic decays of D^0 meson).
- $T = 0.4$ GeV — the kinetic energy of diquark and light quark (potential models).
- $M(\Xi_{cc}^{++}) \approx M(\Xi_{cc}^{+}) \approx 3.56$ GeV – mean values (PM and SR).
- $\psi_{dd}(0) = 0.17$ GeV$^{3/2}$

$$\tau(\Xi_{cc}^{++}) = 0.48 \text{ ps} \qquad \tau(\Xi_{cc}^{+}) = 0.12 \text{ ps}$$

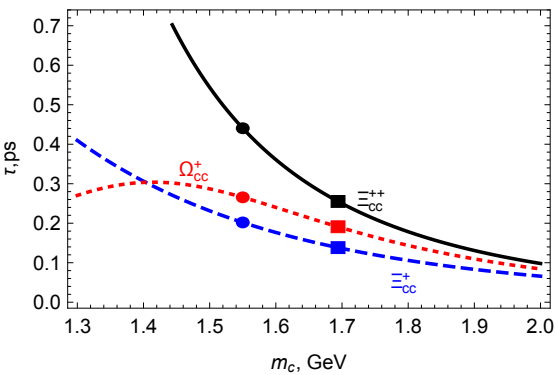
Experimental value:

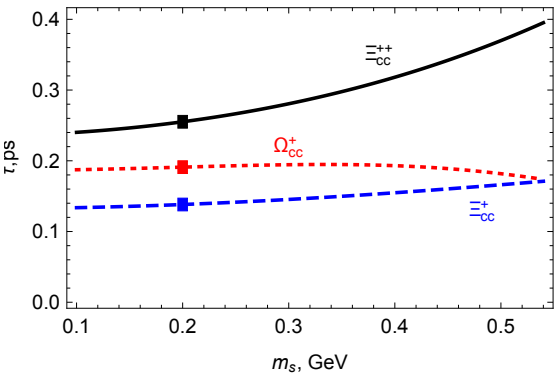
$$\tau(\Xi_{cc}^{++}) = 0.256^{+0.025}_{-0.023}(\text{stat}) \pm 0.014(\text{syst})\,\text{ps}$$

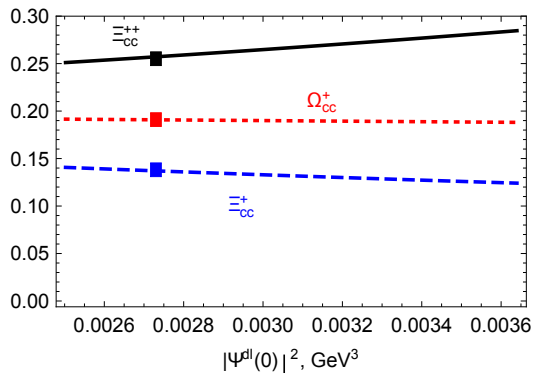
Dependence on parameter values: Ξ_{cc}, Ω_{cc}

Quarks' masses for meson and baryon could be different

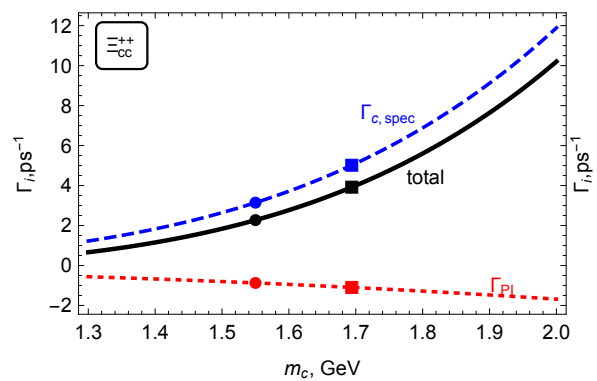
$$m_c = 1.694 \pm 0.03\,\mathrm{GeV}$$

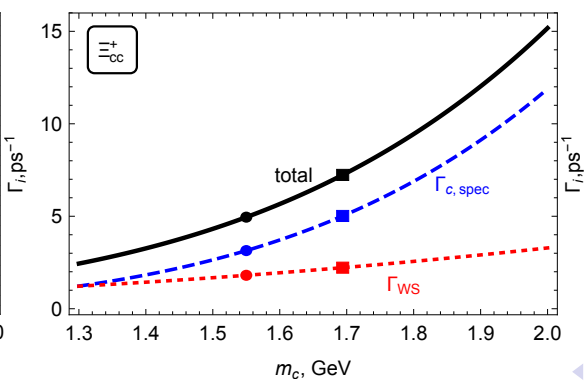


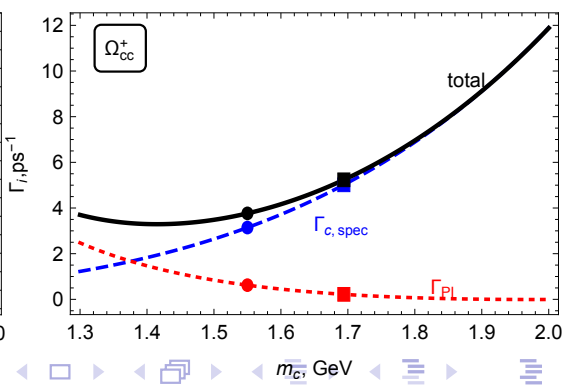




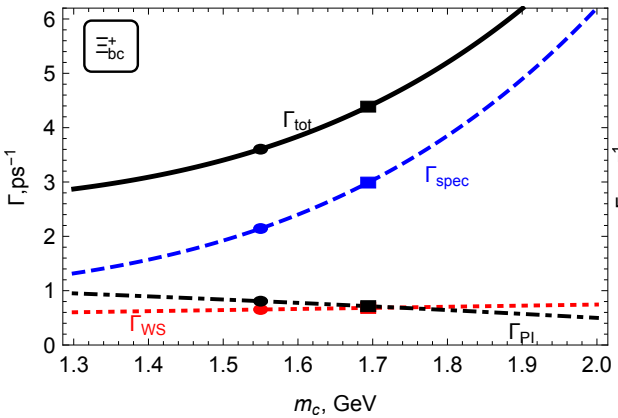
$$\tau(\Xi_{cc}^{++}) = 0.26 \pm 0.03\,\mathrm{ps}, \qquad \tau(\Xi_{cc}^{+}) = 0.14 \pm 0.01\mathrm{ps}, \quad \tau(\Omega_{cc}^{+}) = 0.19 \pm 0.01\,\mathrm{ps}$$

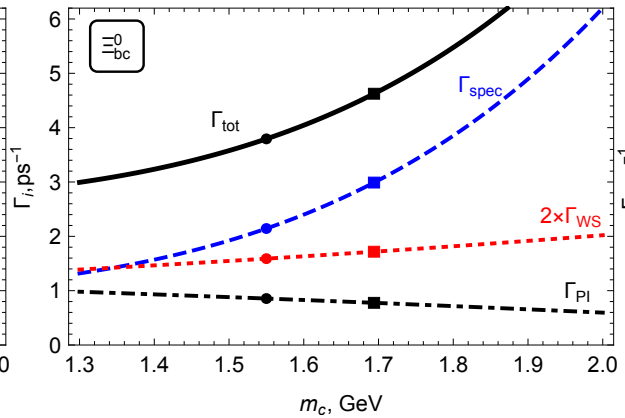


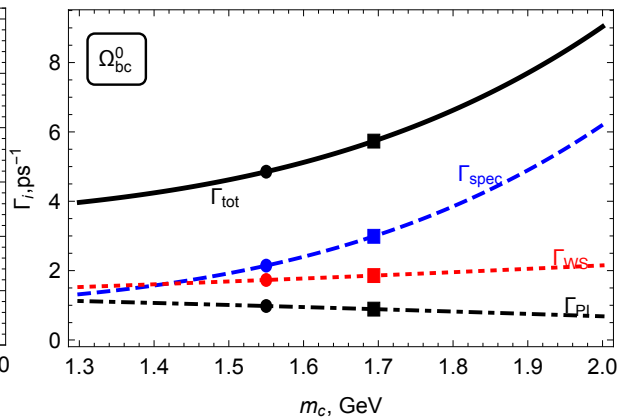


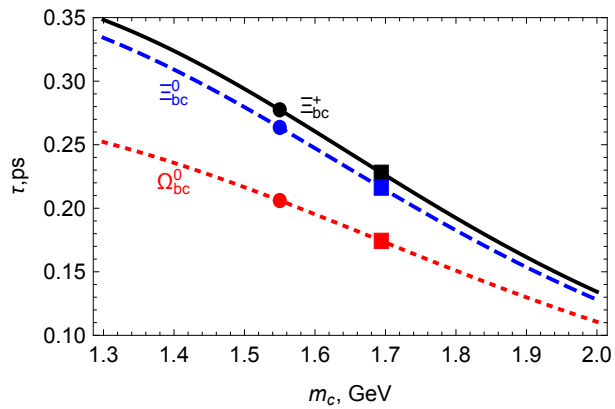


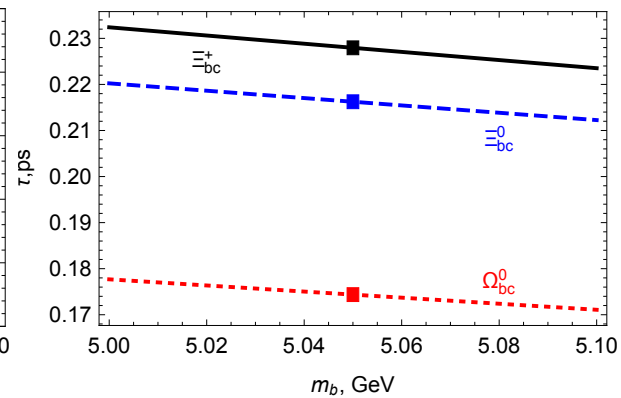
Dependence on parameter values: Ξ_{bc}, Ω_{bc}

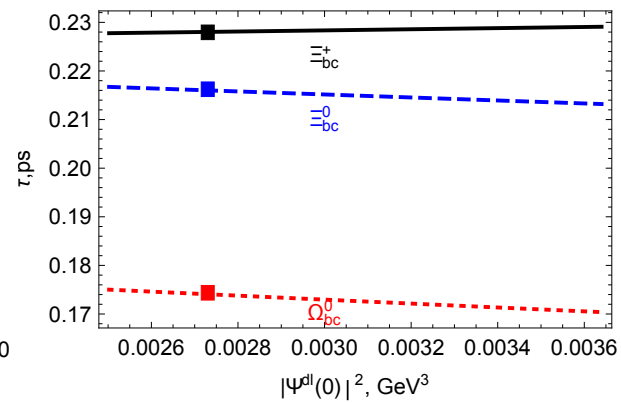












Why lifetimes are very important

The contributions of different terms to the life time essentially depend on baryon composition (40-50%).

The lifetimes of doubly heavy baryons

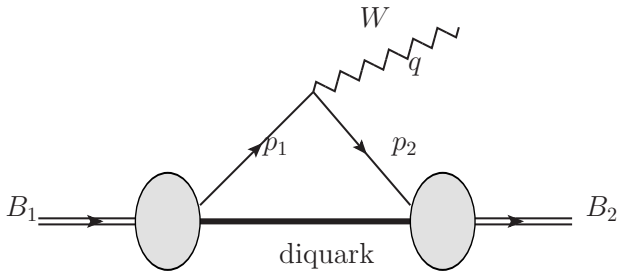
baryon	τ, ps	baryon	τ, ps	baryon	τ, ps
Ξ_{cc}^{++}	0.26 ± 0.03	Ξ_{bc}^{+}	0.23 ± 0.01	Ξ_{bb}^{0}	0.82 ± 0.01
Ξ_{cc}^{+}	0.14 ± 0.01	Ξ_{bc}^{0}	0.22 ± 0.01	Ξ_{bb}^{-}	0.84 ± 0.01
Ω_{cc}^{+}	0.19 ± 0.02	Ω_{bc}^{0}	0.17 ± 0.01	Ω_{bb}^{-}	0.84 ± 0.01

The strong splitting of lifetimes contributions of nonspectator terms, especially in the presence of charmed quark:

$$\begin{aligned} \tau[\Xi_{cc}^{++}] &> \tau[\Omega_{cc}^{+}] > \tau[\Xi_{cc}^{+}], \\ \tau[\Xi_{bc}^{+}] &> \tau[\Xi_{bc}^{0}] > \tau[\Omega_{bc}^{0}], \\ \tau[\Xi_{bb}^{-}] &\approx \tau[\Omega_{bb}^{-}] > \tau[\Xi_{bb}^{0}]. \end{aligned}$$

The measurements of doubly heavy baryons would be the crucial test of the OPE approach.

$\Xi_{bc}^{+} \to \Xi_{c}^{++}$: Decay Vertex and Form Factors

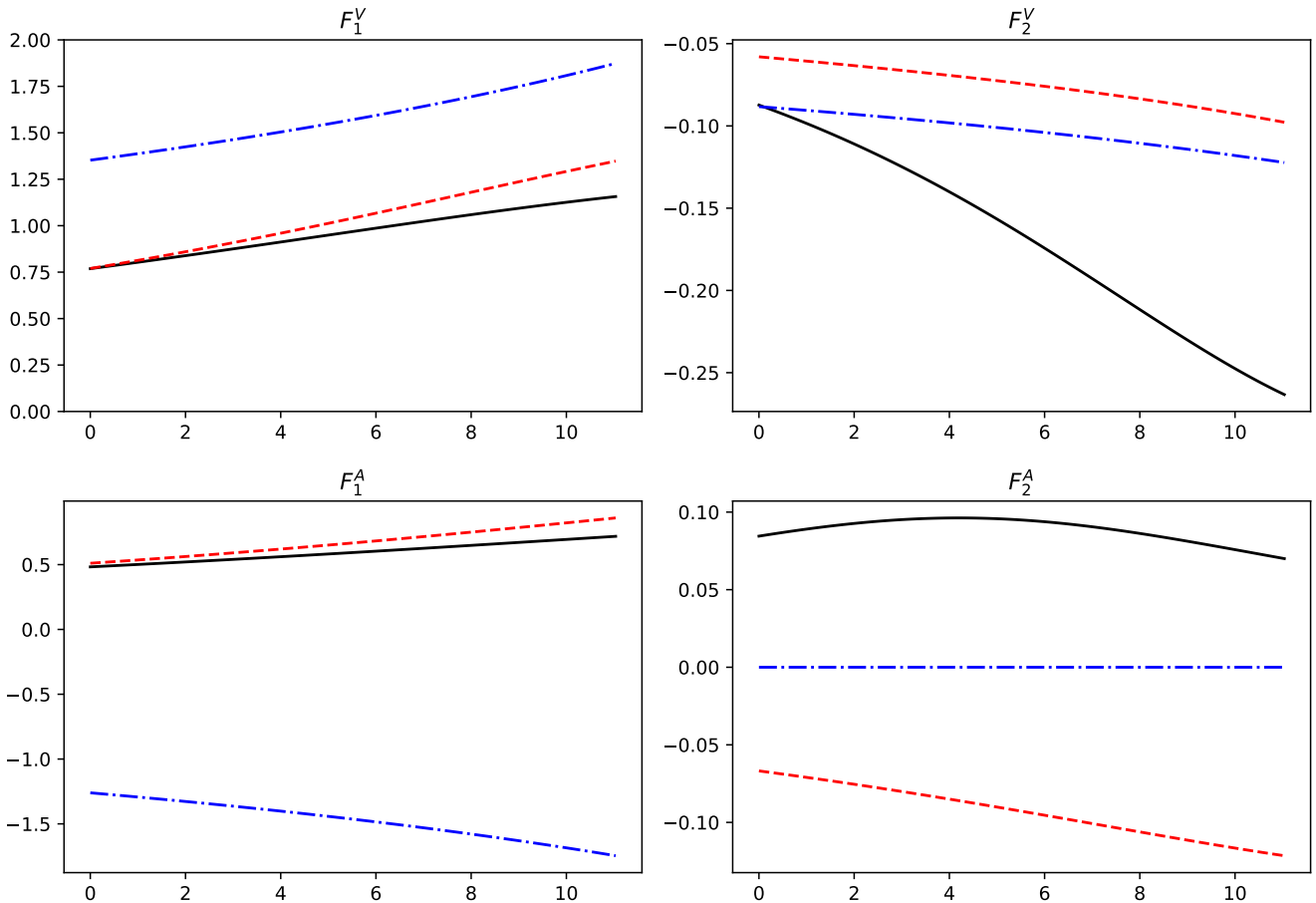


$$\begin{aligned}
\mathcal{M} &= \frac{G_F V_{CKM}}{\sqrt{2}} H^{\mu} \epsilon_{\mu}^{(\mathcal{R})}, \\
H_{\mu} &= \bar{u}(P_1)\left[G_1^V(q^2)\gamma_{\mu} + v_{1\mu} G_2^V(q^2) + v_{2\mu} G_3^V(q^2)\right] u(P_2) + \\
&+ \bar{u}(P_1)\gamma_5\left[G_1^A(q^2)\gamma_{\mu} + v_{1\mu} G_2^A(q^2) + v_{2\mu} G_3^A(q^2)\right] u(P_2),
\end{aligned}$$

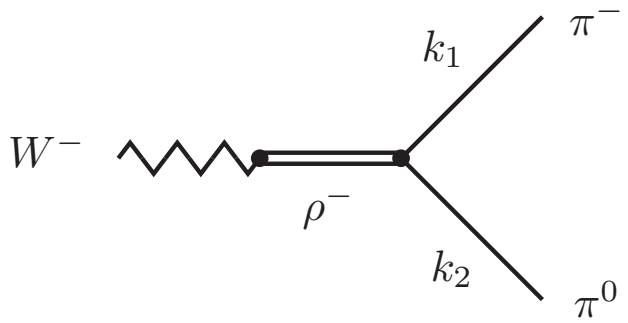
- Form Factors: Potential Models, Light Front, etc
- $\epsilon_{\mu}^{(\mathcal{R})}$: Resonance model, spectral functions, τ decays

$\Xi_{bc}^{+} \to \Xi_{c}^{++}$: Decay Vertex and For, Factors

- On_00: A. I. Onishchenko, arXiv:hep-ph/0006271
- W_17: W. Wang et al, arXiv:1707.02834 [hep-ph]
- H_20 X.-H. Hu et al, arXiv:2001.06375 [hep-ph]



$\pi^+\pi^-$



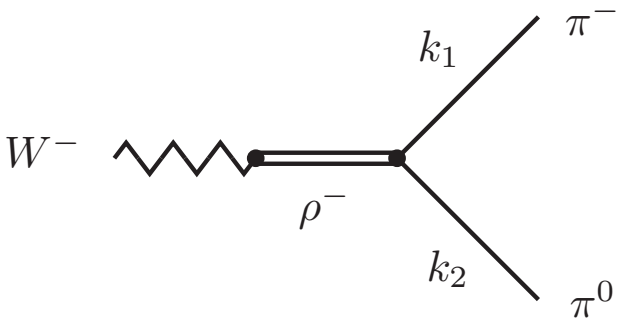
$$\epsilon_\mu^{(\rho)} \sim (k_1 - k_2)_\mu \hat{D}_\rho(q^2)$$

$$D_\rho(q^2) = \frac{m_\rho^2}{m_\rho^2 - q^2 - i m_\rho \Gamma_\rho(q^2)}$$

$$\Gamma_\rho(q^2) = \left(\frac{1 - 4m_\pi^2/q^2}{1 - 4m_\pi^2/m_\rho^2}\right)^{3/2} \Gamma_\rho^{(exp)}.$$

	[On_00]	[W_17]	[H_20]
$\mathrm{Br}[\Xi_{bc}^+ \to \Xi_{cc}^{++} + 2\pi]$, %	1.86	0.45	0.47

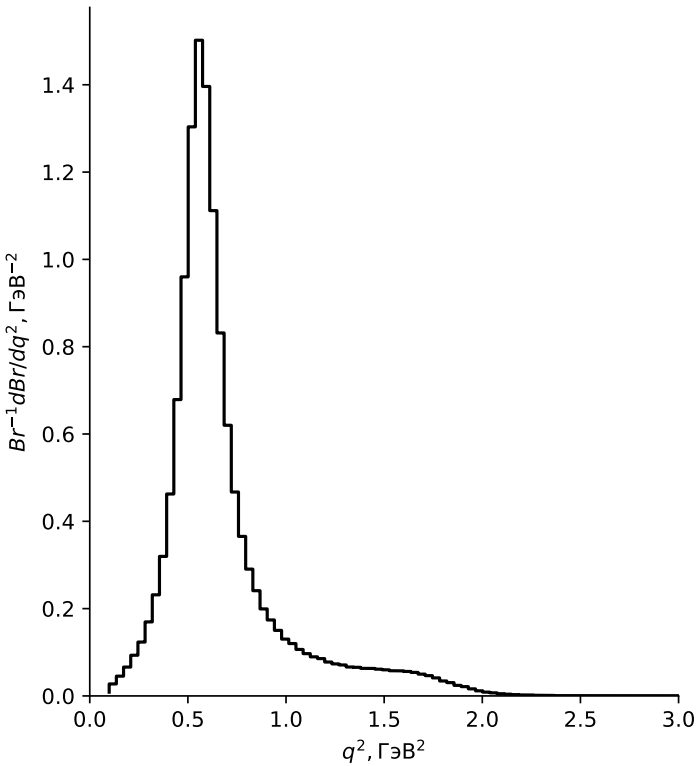
$\pi^+\pi^-$



$$\epsilon_\mu^{(\rho)} \sim (k_1 - k_2)_\mu \hat{D}_\rho(q^2)$$

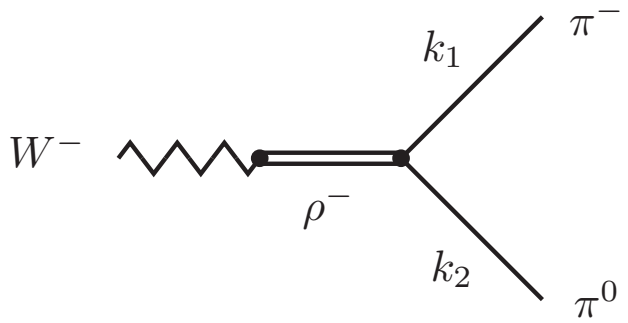
$$D_\rho(q^2) = \frac{m_\rho^2}{m_\rho^2 - q^2 - i m_\rho \Gamma_\rho(q^2)}$$

$$\Gamma_\rho(q^2) = \left(\frac{1 - 4m_\pi^2/q^2}{1 - 4m_\pi^2/m_\rho^2}\right)^{3/2} \Gamma_\rho^{(exp)}.$$



	[On_00]	[W_17]	[H_20]
$\mathrm{Br}[\Xi_{bc}^+ \to \Xi_{cc}^{++} + 2\pi]$, %	1.86	0.45	0.47

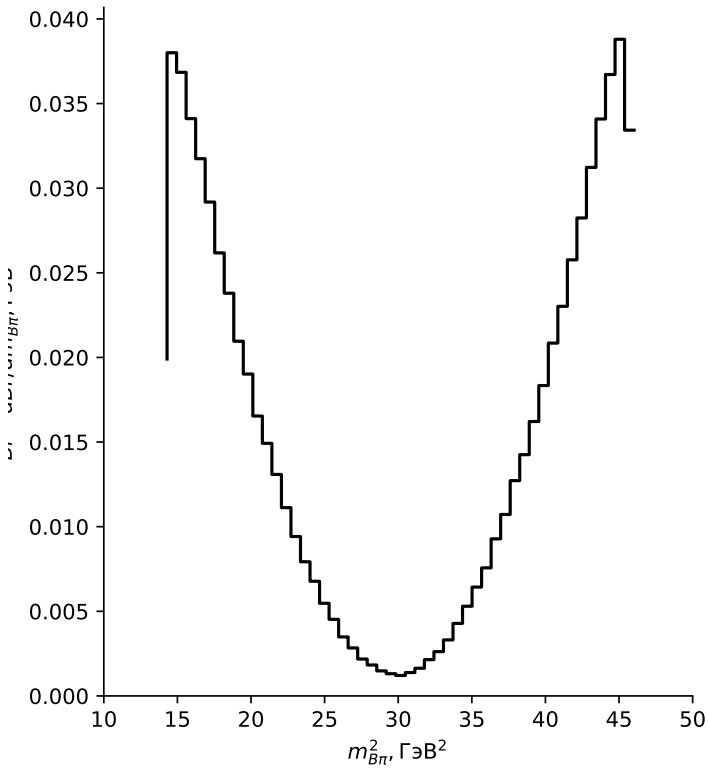
$\pi^+\pi^-$



$$\epsilon_\mu^{(\rho)} \sim (k_1 - k_2)_\mu \hat{D}_\rho(q^2)$$

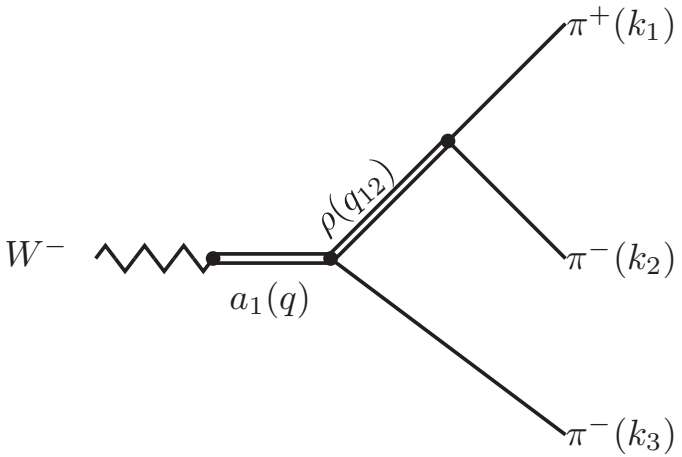
$$D_\rho(q^2) = \frac{m_\rho^2}{m_\rho^2 - q^2 - i m_\rho \Gamma_\rho(q^2)}$$

$$\Gamma_\rho(q^2) = \left(\frac{1 - 4m_\pi^2/q^2}{1 - 4m_\pi^2/m_\rho^2}\right)^{3/2} \Gamma_\rho^{(exp)}.$$



	[On_00]	[W_17]	[H_20]
$\mathrm{Br}[\Xi_{bc}^+ \to \Xi_{cc}^{++} + 2\pi]$, %	1.86	0.45	0.47

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

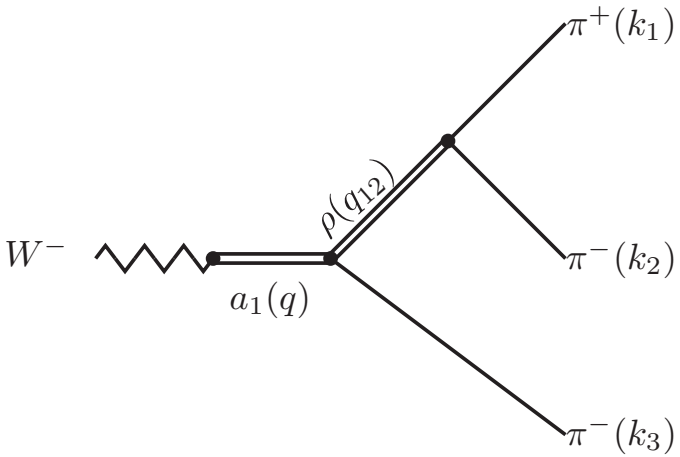


$$\epsilon_\mu^{(3\pi)} \sim D_{a_1} \hat{D}_\rho \left[g_{\mu\nu} - \frac{q_\mu q_\nu}{q^2} \right] (k_1 - k_2)^\nu$$

$$D_{a_1}\left(q^2\right) = \frac{m_{a_1}^2}{m_{a_1}^2 - q^2 + i m_{a_1} \Gamma_{a_1}(q^2)}$$

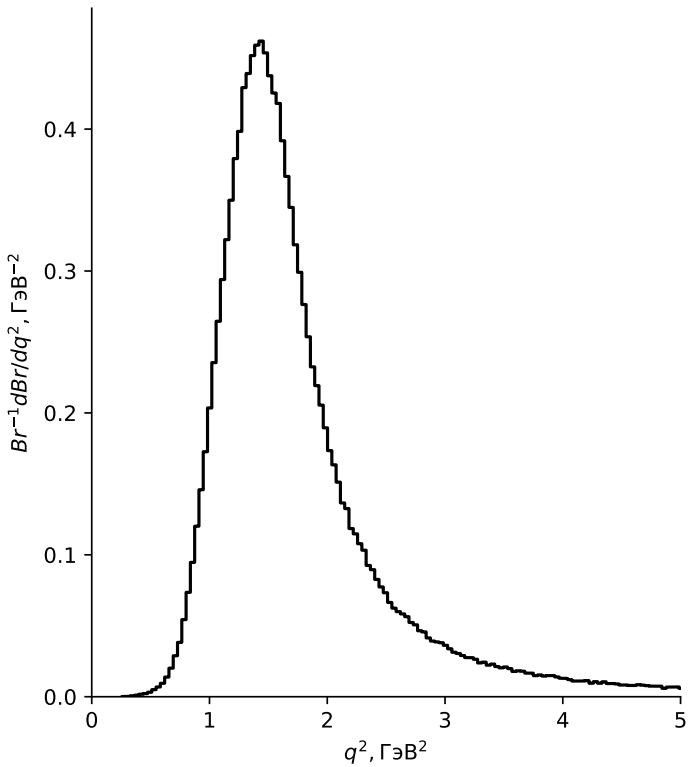
	[On_00]	[W_17]	[H_20]
$\mathrm{Br}[\Xi_{bc}^+ \to \Xi_{cc}^{++} + 3\pi]$, %	1.29	0.31	0.33

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



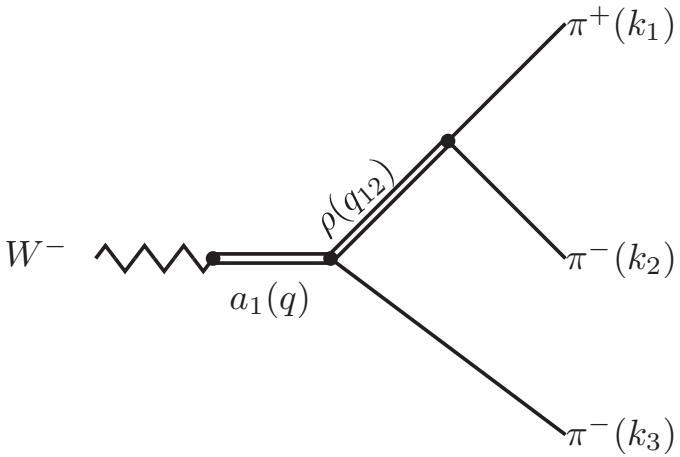
$$\epsilon_\mu^{(3\pi)} \sim D_{a_1} \hat{D}_\rho \left[g_{\mu\nu} - \frac{q_\mu q_\nu}{q^2} \right] (k_1 - k_2)^\nu$$

$$D_{a_1}\left(q^2\right) = \frac{m_{a_1}^2}{m_{a_1}^2 - q^2 + i m_{a_1} \Gamma_{a_1}(q^2)}$$



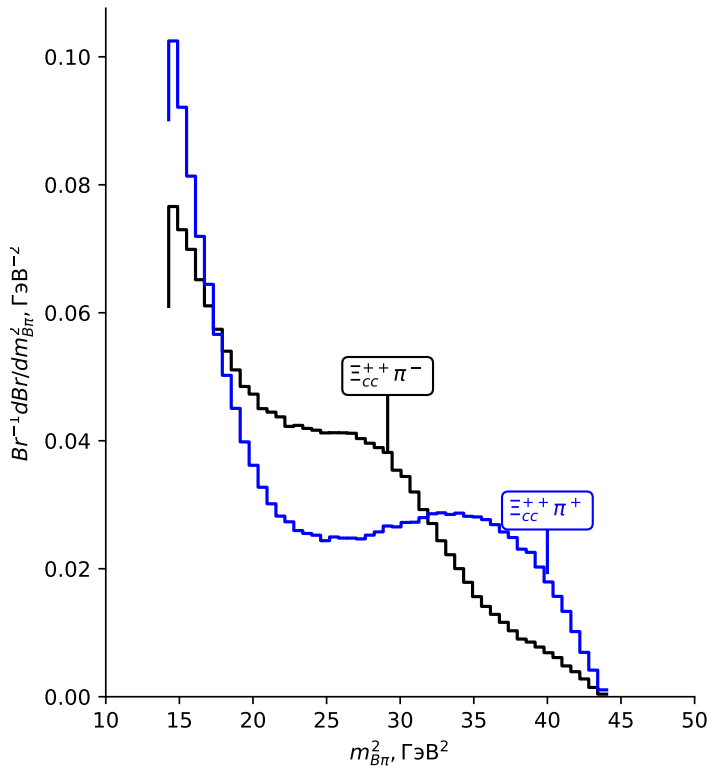
	[On_00]	[W_17]	[H_20]
$\mathrm{Br}[\Xi_{bc}^+ \to \Xi_{cc}^{++} + 3\pi]$, %	1.29	0.31	0.33

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



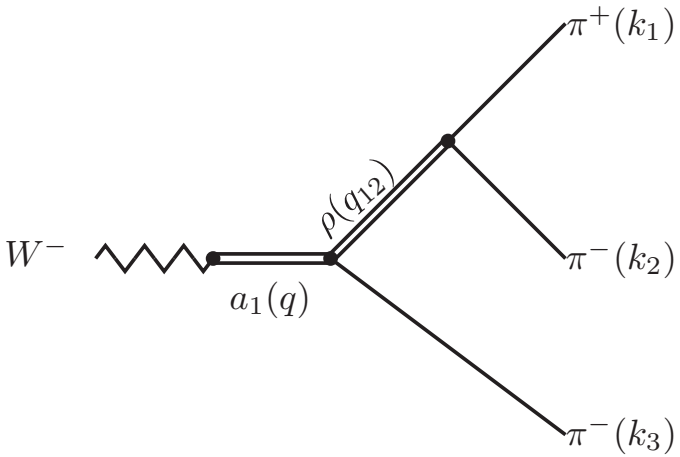
$$\epsilon_\mu^{(3\pi)} \sim D_{a_1} \hat{D}_\rho \left[g_{\mu\nu} - \frac{q_\mu q_\nu}{q^2} \right] (k_1 - k_2)^\nu$$

$$D_{a_1}\left(q^2\right) = \frac{m_{a_1}^2}{m_{a_1}^2 - q^2 + i m_{a_1} \Gamma_{a_1}(q^2)}$$



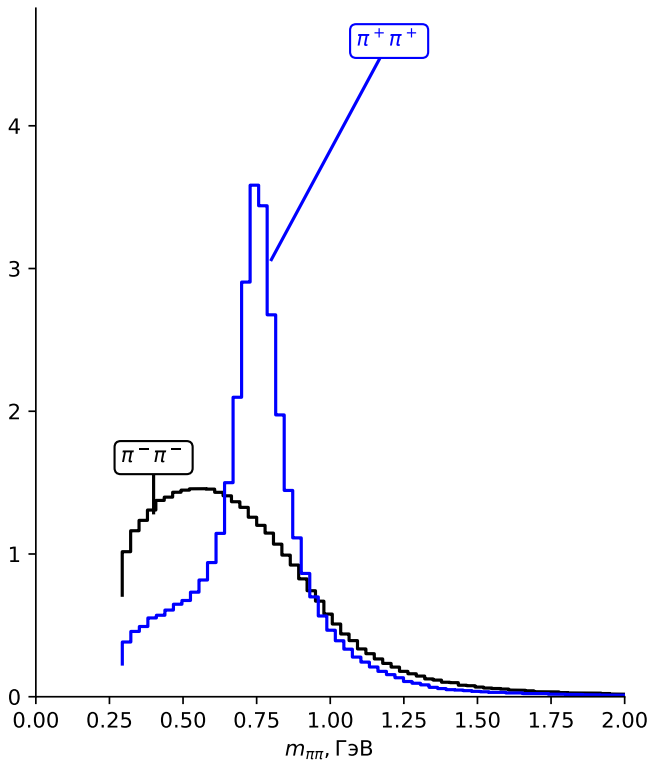
	[On_00]	[W_17]	[H_20]
$\mathrm{Br}[\Xi_{bc}^+ \to \Xi_{cc}^{++} + 3\pi]$, %	1.29	0.31	0.33

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



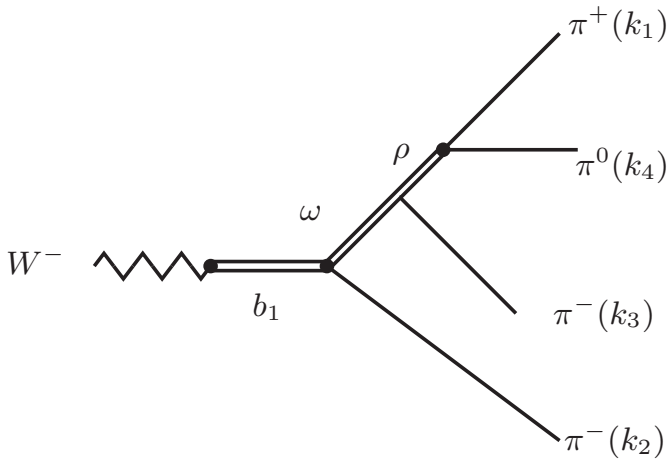
$$\epsilon_\mu^{(3\pi)} \sim D_{a_1} \hat{D}_\rho \left[g_{\mu\nu} - \frac{q_\mu q_\nu}{q^2} \right] (k_1 - k_2)^\nu$$

$$D_{a_1}\left(q^2\right) = \frac{m_{a_1}^2}{m_{a_1}^2 - q^2 + i m_{a_1} \Gamma_{a_1}(q^2)}$$



	[On_00]	[W_17]	[H_20]
$\mathrm{Br}[\Xi_{bc}^+ \to \Xi_{cc}^{++} + 3\pi]$, %	1.29	0.31	0.33

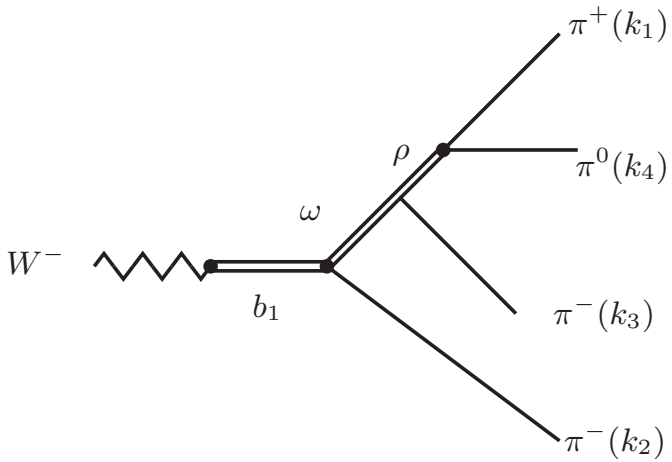
$\pi^-\pi^-\pi^+\pi^0$ — ω

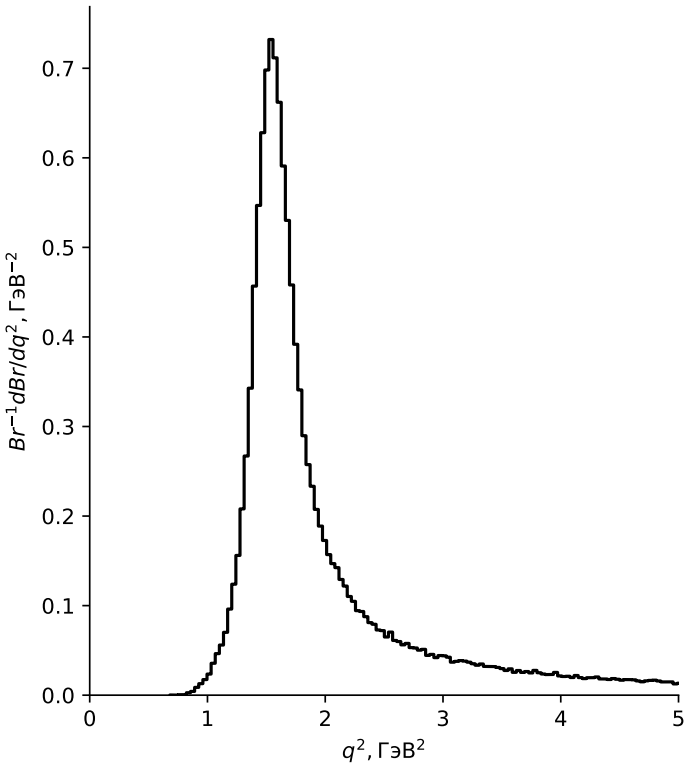


$$\epsilon_\mu^{(4\pi,b_1)} \sim D_{b_1} D_\omega D_\rho e_{\mu\nu\alpha} q_{123}^\nu q_{12}^\alpha (q_1 - q_2)^\beta$$

	[On_00]	[W_17]	[H_20]
$\mathrm{Br}[\Xi_{bc}^+ \to \Xi_{cc}^{++} + (4\pi)_\omega]$, %	0.31	0.07	0.08

$\pi^-\pi^-\pi^+\pi^0$ — ω

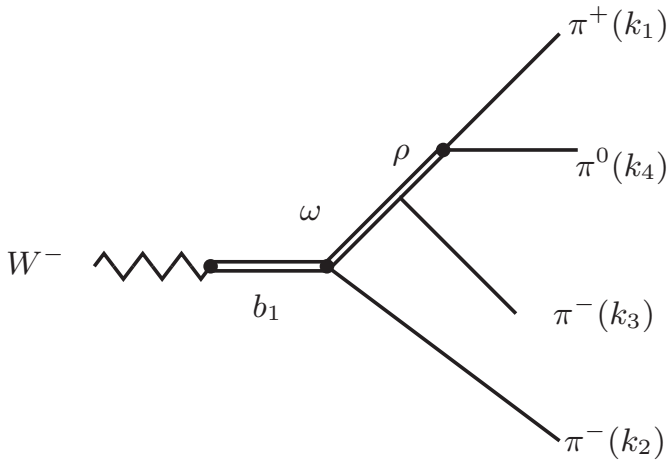


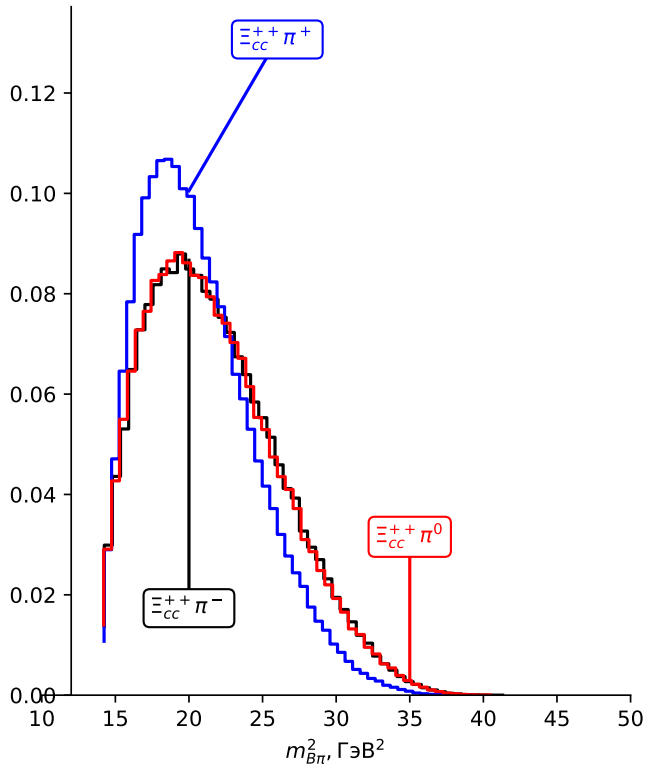


$$\epsilon_\mu^{(4\pi,b_1)} \sim D_{b_1} D_\omega D_\rho e_{\mu\nu\alpha} q_{123}^\nu q_{12}^\alpha (q_1 - q_2)^\beta$$

	[On_00]	[W_17]	[H_20]
$\mathrm{Br}[\Xi_{bc}^+ \to \Xi_{cc}^{++} + (4\pi)_\omega]$, %	0.31	0.07	0.08

$\pi^-\pi^-\pi^+\pi^0$ — ω

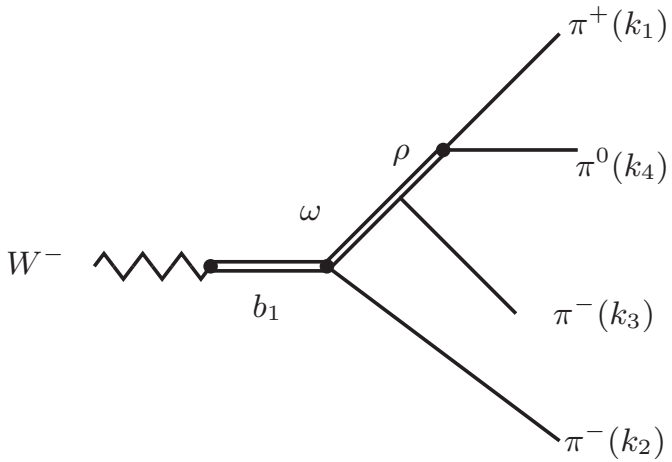


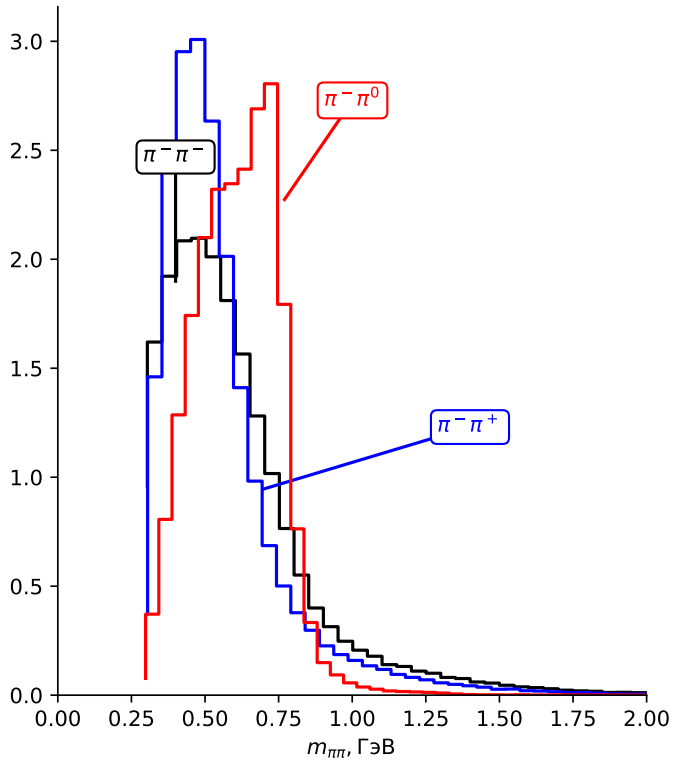


$$\epsilon_\mu^{(4\pi,b_1)} \sim D_{b_1} D_\omega D_\rho e_{\mu\nu\alpha} q_{123}^\nu q_{12}^\alpha (q_1 - q_2)^\beta$$

	[On_00]	[W_17]	[H_20]
$\mathrm{Br}[\Xi_{bc}^+ \to \Xi_{cc}^{++} + (4\pi)_\omega]$, %	0.31	0.07	0.08

$\pi^-\pi^-\pi^+\pi^0$ — ω

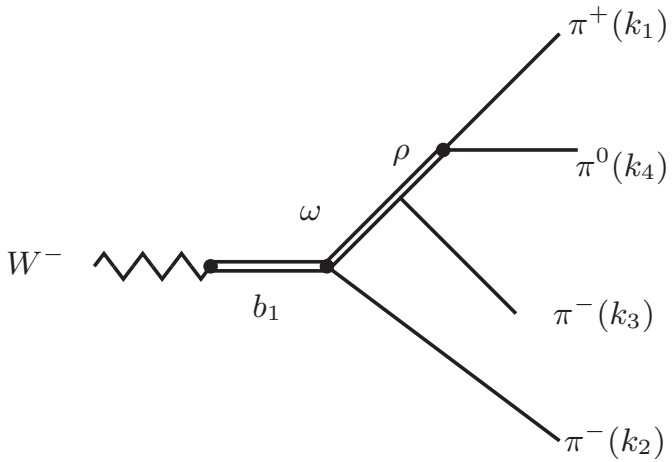


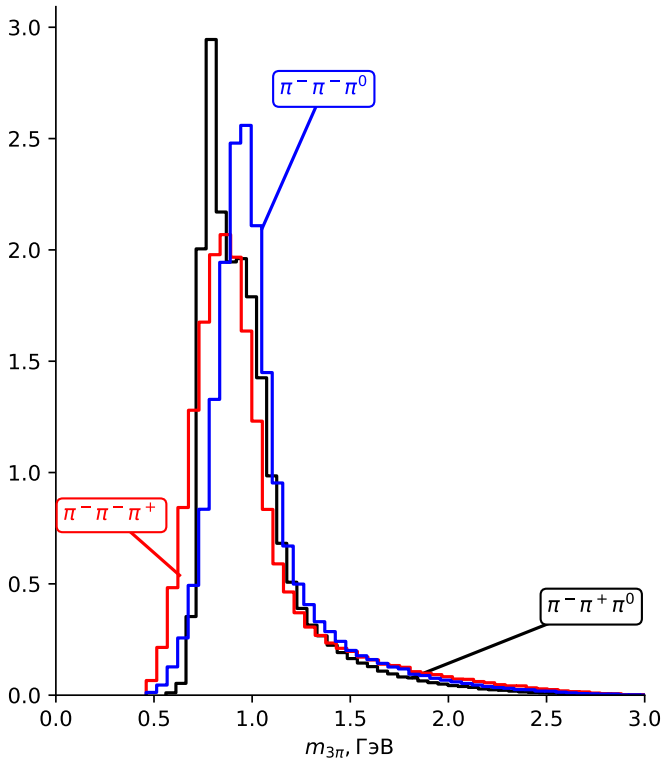


$$\epsilon_\mu^{(4\pi,b_1)} \sim D_{b_1} D_\omega D_\rho e_{\mu\nu\alpha} q_{123}^\nu q_{12}^\alpha (q_1 - q_2)^\beta$$

	[On_00]	[W_17]	[H_20]
$\mathrm{Br}[\Xi_{bc}^+ \to \Xi_{cc}^{++} + (4\pi)_\omega]$, %	0.31	0.07	0.08

$\pi^-\pi^-\pi^+\pi^0$ — ω

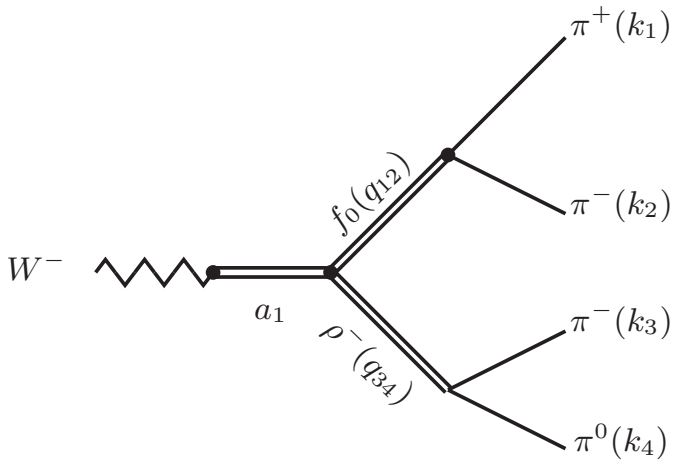




$$\epsilon_\mu^{(4\pi,b_1)} \sim D_{b_1} D_\omega D_\rho e_{\mu\nu\alpha} q_{123}^\nu q_{12}^\alpha (q_1 - q_2)^\beta$$

	[On_00]	[W_17]	[H_20]
$\mathrm{Br}[\Xi_{bc}^+ \to \Xi_{cc}^{++} + (4\pi)_\omega]$, %	0.31	0.07	0.08

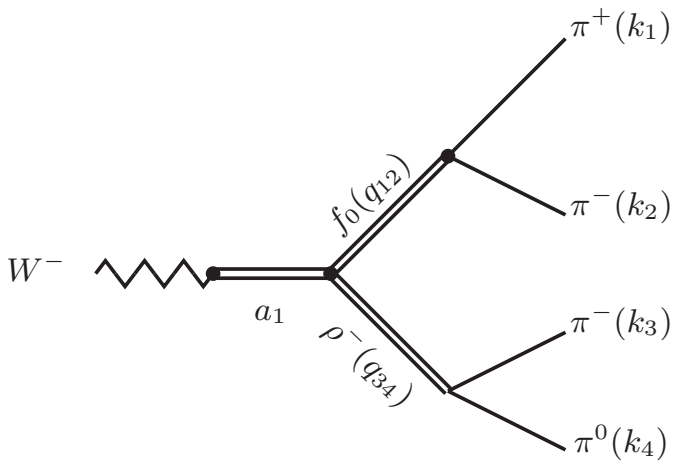
$\pi^-\pi^-\pi^+\pi^0$ — a_1

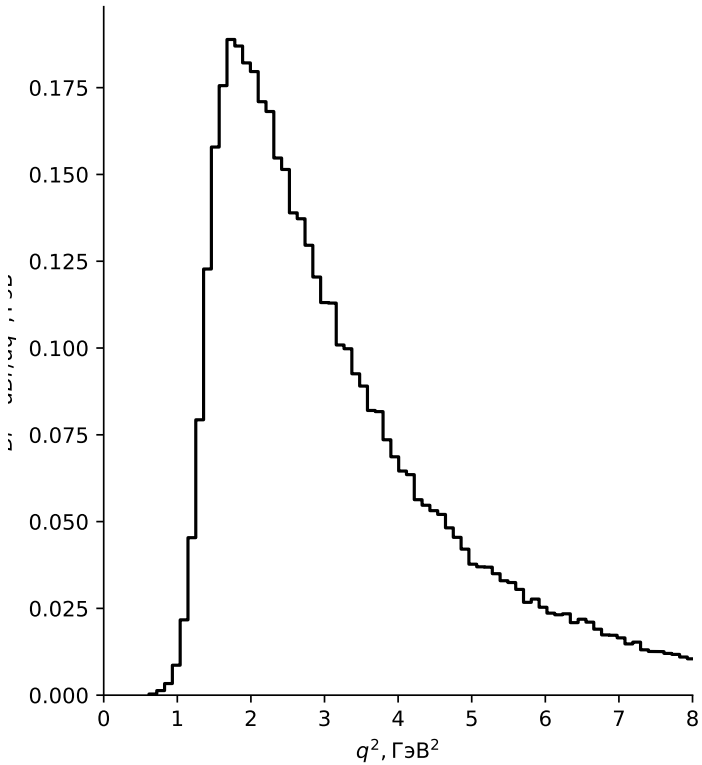


$$\epsilon \sim D_{a_1} D_f D_\rho \left[g_{\mu\nu} - \frac{q_\mu q_\nu}{q^2} \right] (k_3 - k_4)^\nu$$

	[On_00]	[W_17]	[H_20]
$\mathrm{Br}[\Xi_{bc}^+ \to \Xi_{cc}^{++} + (4\pi)_{a_1}]$, %	1.16	0.28	0.29

$\pi^-\pi^-\pi^+\pi^0$ — a_1

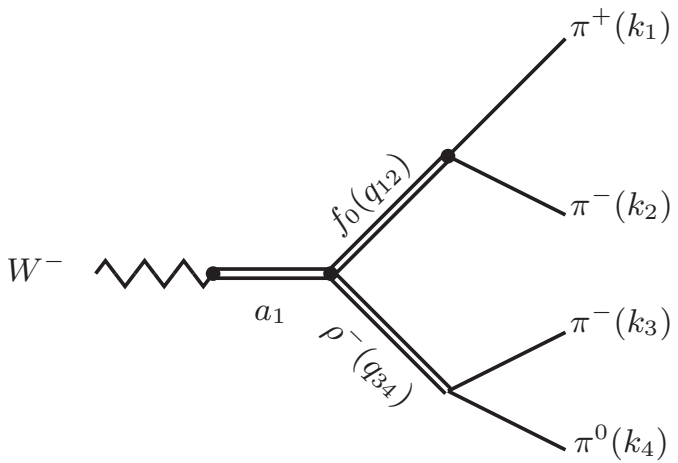




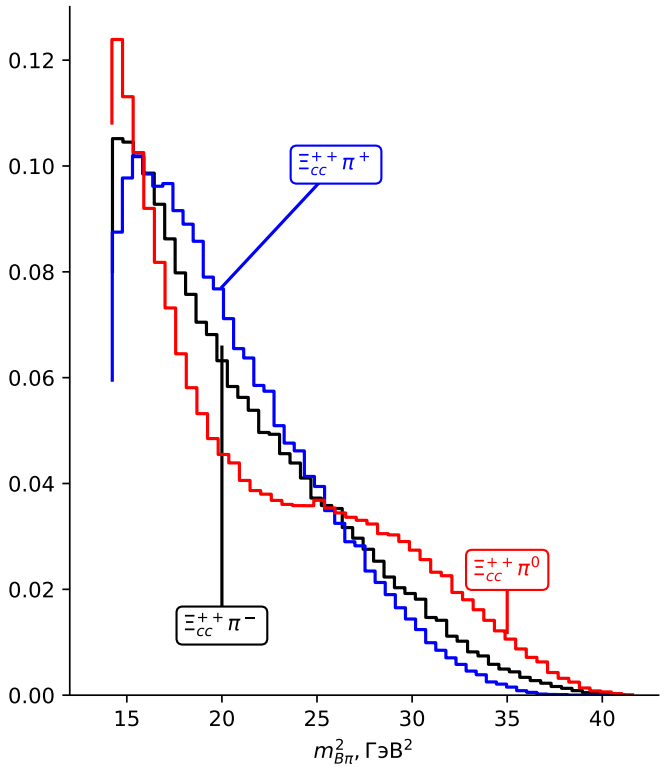
$$\epsilon \sim D_{a_1} D_f D_\rho \left[g_{\mu\nu} - \frac{q_\mu q_\nu}{q^2} \right] (k_3 - k_4)^\nu$$

	[On_00]	[W_17]	[H_20]
$\mathrm{Br}[\Xi_{bc}^+ \to \Xi_{cc}^{++} + (4\pi)_{a_1}]$, %	1.16	0.28	0.29

$\pi^-\pi^-\pi^+\pi^0$ — a_1

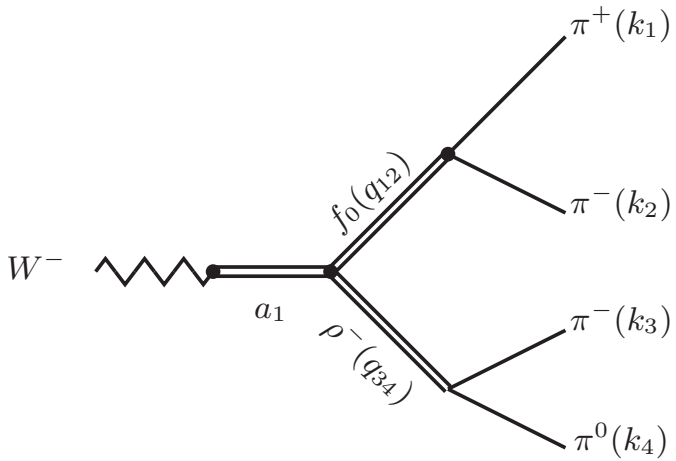


$$\epsilon \sim D_{a_1} D_f D_\rho \left[g_{\mu\nu} - \frac{q_\mu q_\nu}{q^2} \right] (k_3 - k_4)^\nu$$

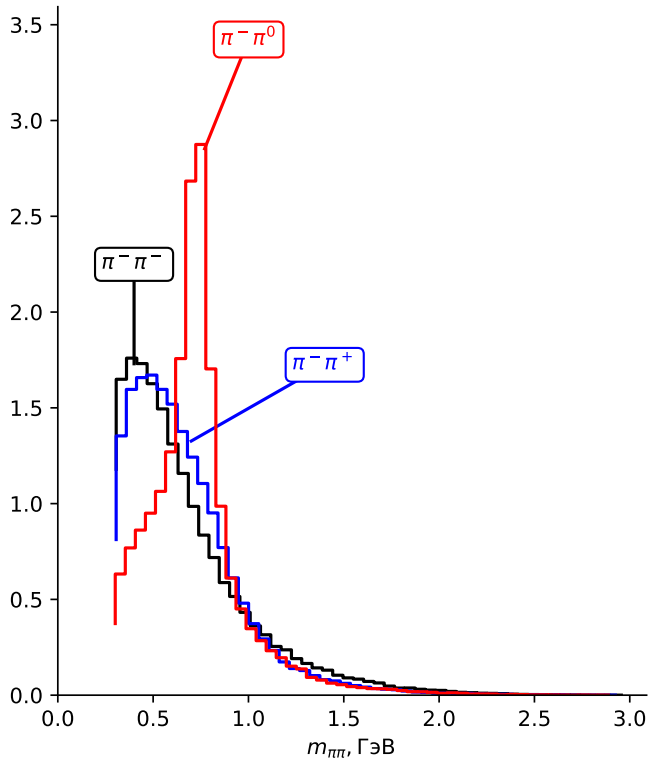


	[On_00]	[W_17]	[H_20]
$\mathrm{Br}[\Xi_{bc}^+ \to \Xi_{cc}^{++} + (4\pi)_{a_1}]$, %	1.16	0.28	0.29

$\pi^-\pi^-\pi^+\pi^0$ — a_1

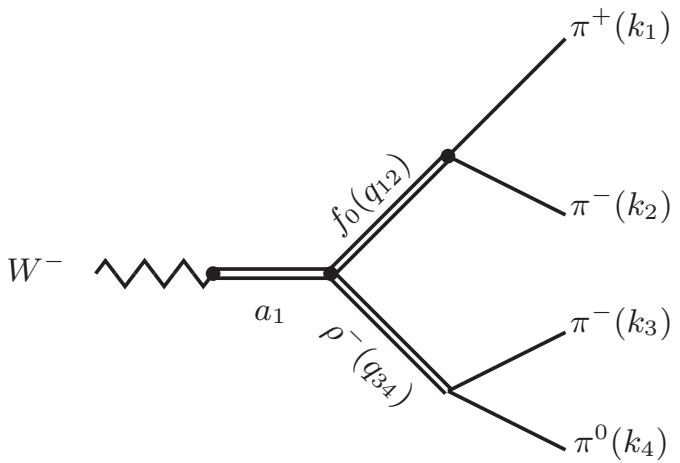


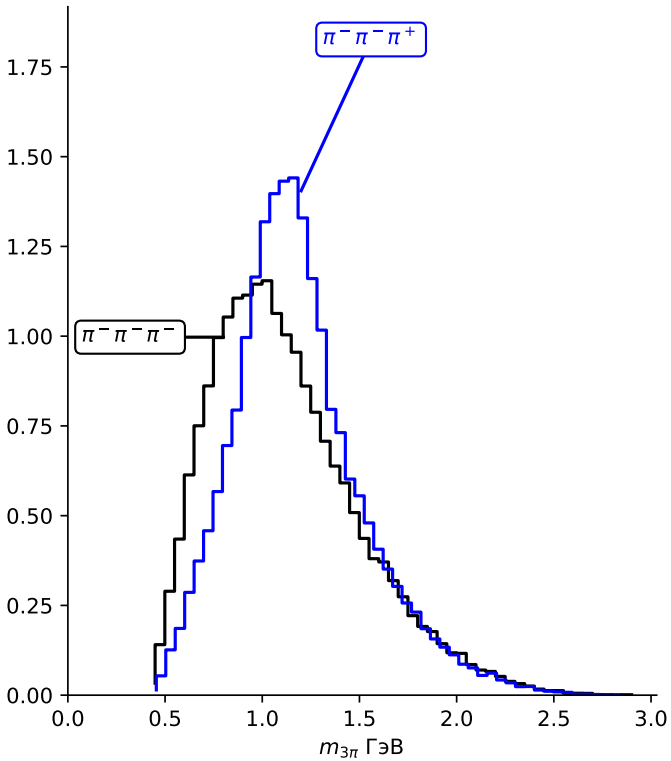
$$\epsilon \sim D_{a_1} D_f D_\rho \left[g_{\mu\nu} - \frac{q_\mu q_\nu}{q^2} \right] (k_3 - k_4)^\nu$$



	[On_00]	[W_17]	[H_20]
$\mathrm{Br}[\Xi_{bc}^+ \to \Xi_{cc}^{++} + (4\pi)_{a_1}]$, %	1.16	0.28	0.29

$\pi^-\pi^-\pi^+\pi^0$ — a_1

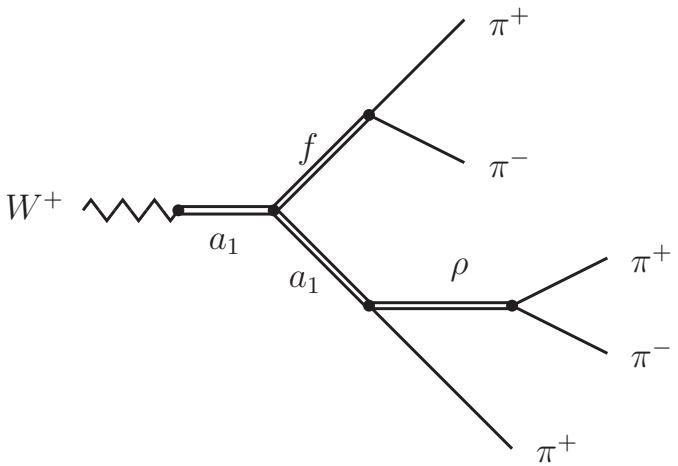




$$\epsilon \sim D_{a_1} D_f D_\rho \left[g_{\mu\nu} - \frac{q_\mu q_\nu}{q^2} \right] (k_3 - k_4)^\nu$$

	[On_00]	[W_17]	[H_20]
$\mathrm{Br}[\Xi_{bc}^+ \to \Xi_{cc}^{++} + (4\pi)_{a_1}]$, %	1.16	0.28	0.29

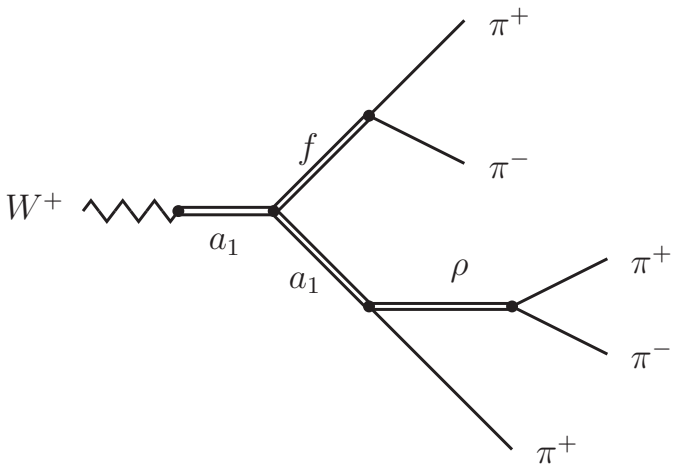
$\pi^-\pi^-\pi^-\pi^+\pi^+$

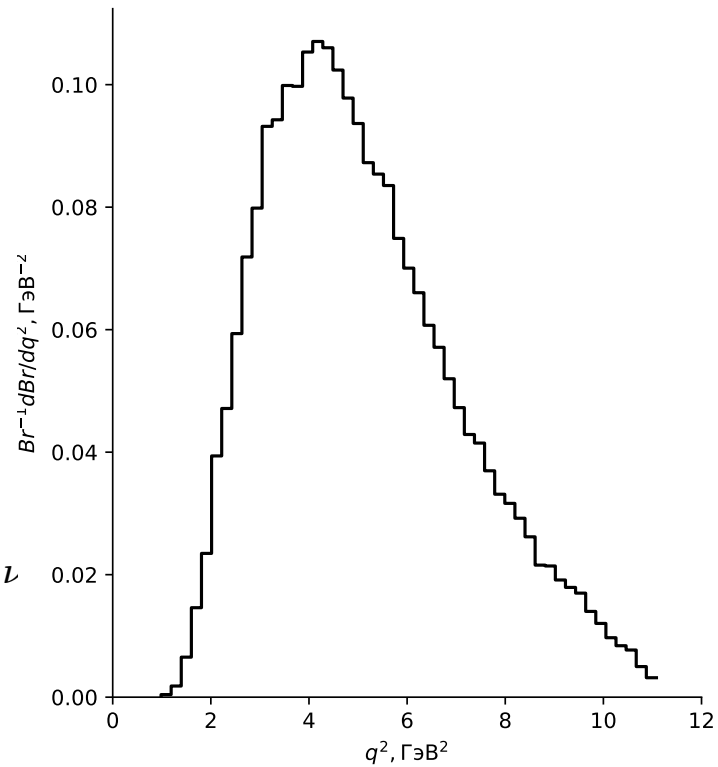


$$\epsilon \sim D_{a_1} D_{a_1} D_f D_\rho \left[g_{\mu\nu} - \frac{q_\mu q_\nu}{q^2} \right] (k_3 - k_4)^\nu$$

	[On_00]	[W_17]	[H_20]
$\mathrm{Br}[\Xi_{bc}^+ \to \Xi_{cc}^{++} + 5\pi]$, %	0.33	0.08	0.08

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

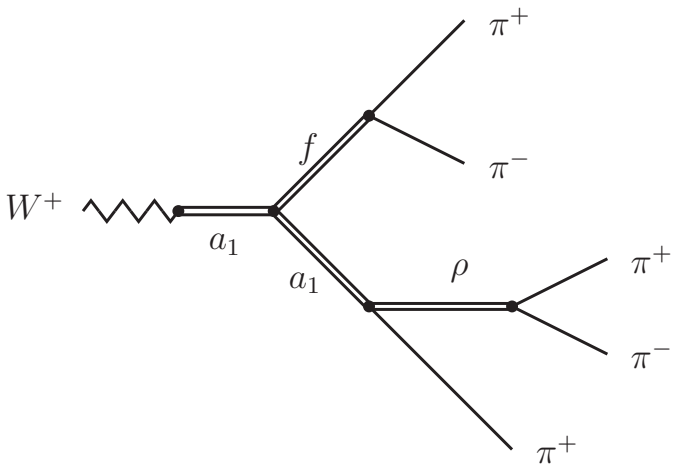




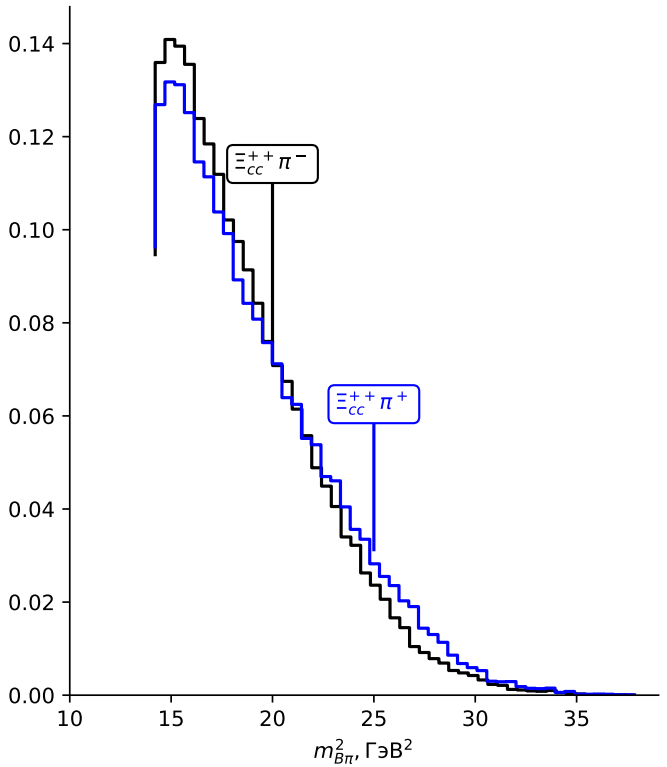
$$\epsilon \sim D_{a_1} D_{a_1} D_f D_\rho \left[g_{\mu\nu} - \frac{q_\mu q_\nu}{q^2} \right] (k_3 - k_4)^\nu$$

	[On_00]	[W_17]	[H_20]
$\mathrm{Br}[\Xi_{bc}^+ \to \Xi_{cc}^{++} + 5\pi]$, %	0.33	0.08	0.08

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

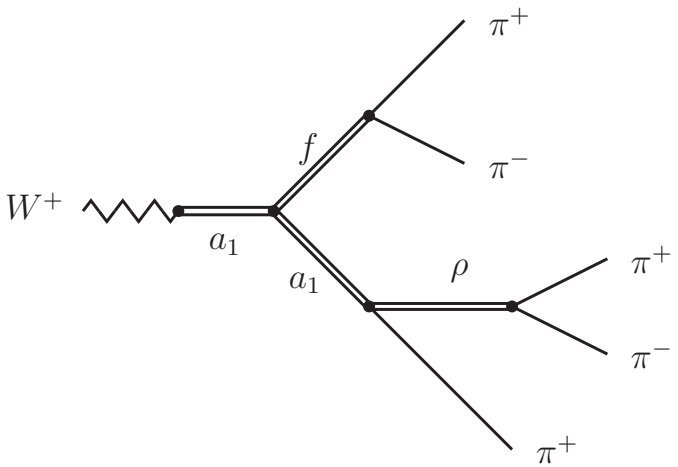


$$\epsilon \sim D_{a_1} D_{a_1} D_f D_\rho \left[g_{\mu\nu} - \frac{q_\mu q_\nu}{q^2} \right] (k_3 - k_4)^\nu$$

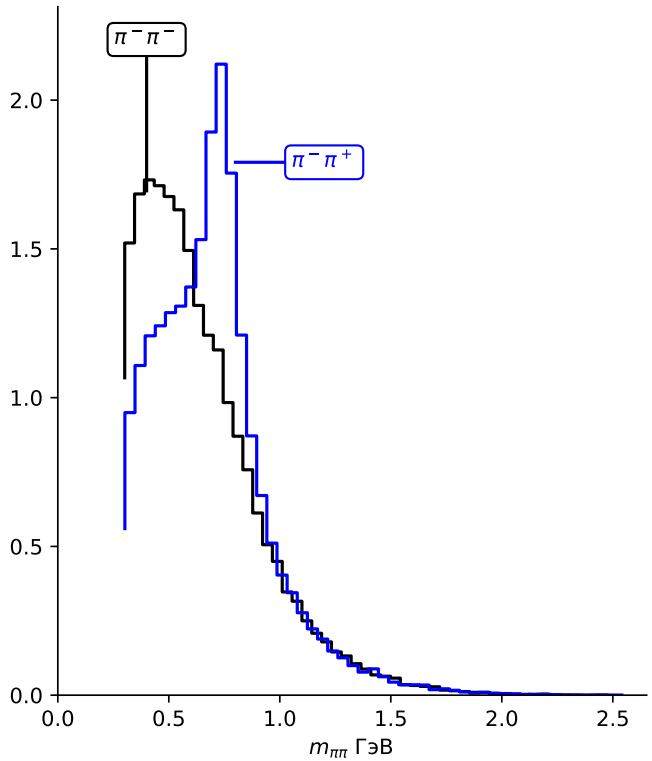


	[On_00]	[W_17]	[H_20]
$\mathrm{Br}[\Xi_{bc}^+ \to \Xi_{cc}^{++} + 5\pi]$, %	0.33	0.08	0.08

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

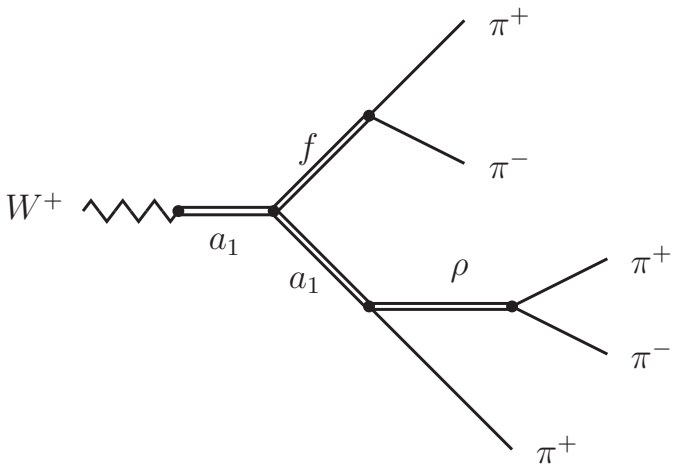


$$\epsilon \sim D_{a_1} D_{a_1} D_f D_\rho \left[g_{\mu\nu} - \frac{q_\mu q_\nu}{q^2} \right] (k_3 - k_4)^\nu$$

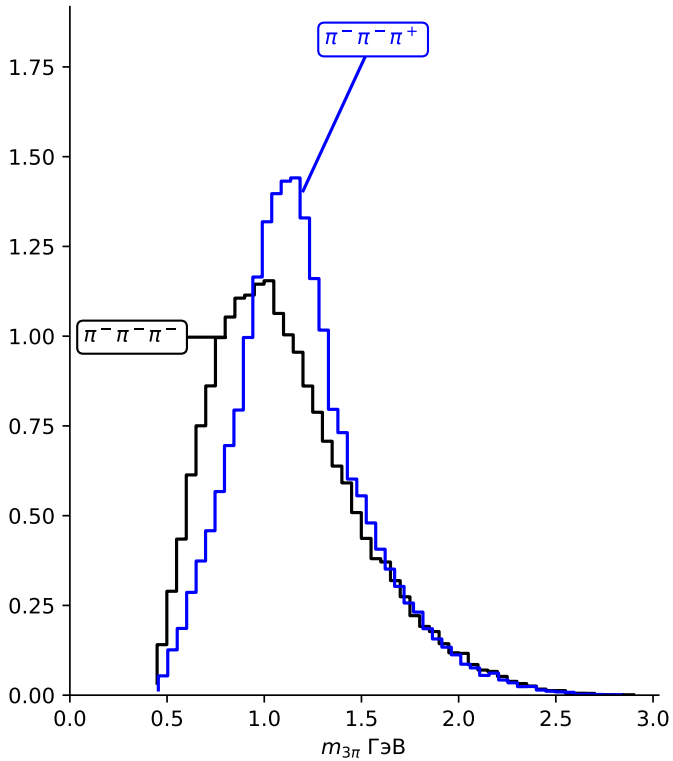


	[On_00]	[W_17]	[H_20]
$\mathrm{Br}[\Xi_{bc}^+ \to \Xi_{cc}^{++} + 5\pi]$, %	0.33	0.08	0.08

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



$$\epsilon \sim D_{a_1} D_{a_1} D_f D_\rho \left[g_{\mu\nu} - \frac{q_\mu q_\nu}{q^2} \right] (k_3 - k_4)^\nu$$



	[On_00]	[W_17]	[H_20]
$\mathrm{Br}[\Xi_{bc}^+ \to \Xi_{cc}^{++} + 5\pi]$, %	0.33	0.08	0.08

Conclusion

- Double Heavy Baryons are well studied theoretically

Conclusion

- Double Heavy Baryons are well studied theoretically
- After observation of the Ξ_{cc} baryon a new chapter started

Conclusion

- Double Heavy Baryons are well studied theoretically
- After observation of the Ξ_{cc} baryon a new chapter started
- Update on the lifetime predictions

Conclusion

- Double Heavy Baryons are well studied theoretically
- After observation of the Ξ_{cc} baryon a new chapter started
- Update on the lifetime predictions
- Analysis of some $\Xi_{bc} \to \Xi_{cc}\mathcal{R}$ decays:

$\mathcal{R}$	[On_00]	[W_17]	[H_20]
$e\nu_e$	6.74	1.58	1.67
2π	1.86	0.45	0.47
3π	1.29	0.31	0.33
$(4\pi)_{a_1}$	1.16	0.28	0.29
$(4\pi)_{b_1}$	0.31	0.07	0.08
5π	0.33	0.08	0.08

Conclusion

The presented results were published in

- A.V. Berezhno, A.K. Likhoded, A.V. Luchinsky, Phys.Rev.D 98 (2018) 11, 113004
- A. K. Likhoded1 and A. V. Luchinsky, Yad.Phys. 81 (2018)
- A. S. Gerasimov, A. V. Luchinsky, Phys. Rev. D 100, 073015 (2019)
- A. V. Luchinsky, A. K. Likhoded, Phys. Rev. D 102, 014019 (2020)

Thank you for your attention