Weak decays of J/ψ into charmed mesons

Sukhanov Ivan

Department of Quantum Theory and High Energy Physics,
Lomonosov Moscow State University;
Federal Research Center Computer Science
and Control of the Russian Academy of Sciences

with Galkin V.O.

Experimental searches

1.Ablikim, M., et al. "Search for the rare decays $J/\psi \to D^0 e^+ e^- + c.c.$ and $\psi(3686) \to D^0 e^+ e^- + c.c.$" Physical Review D 96.11 (2017): 111101.
2.Ablikim, M. "Search for J/ψ weak decays containing a D meson." Phys Rev D 110 (2024): 032020.
3.Ablikim, Medina, et al. "Search for the semi-muonic charmonium decay $J/\psi \to D^- \mu^+ \nu_\mu$ cc." Journal of High Energy Physics 2024.1 (2024): 1-19.
4.Ablikim, M., et al. "Search for the charmonium weak decays $J/\psi \to D_s^- \rho^+ + cc$ and $J/\psi \to D_s^- \pi^+ + cc$." arXiv preprint arXiv:2506.09386 (2025).
5.Ablikim, M., et al. "Search for the FCNC charmonium decay $J/\psi \to D^0 \mu^+ \mu^- +$ cc." arXiv preprint arXiv:2501.08080 (2025).

Introduction

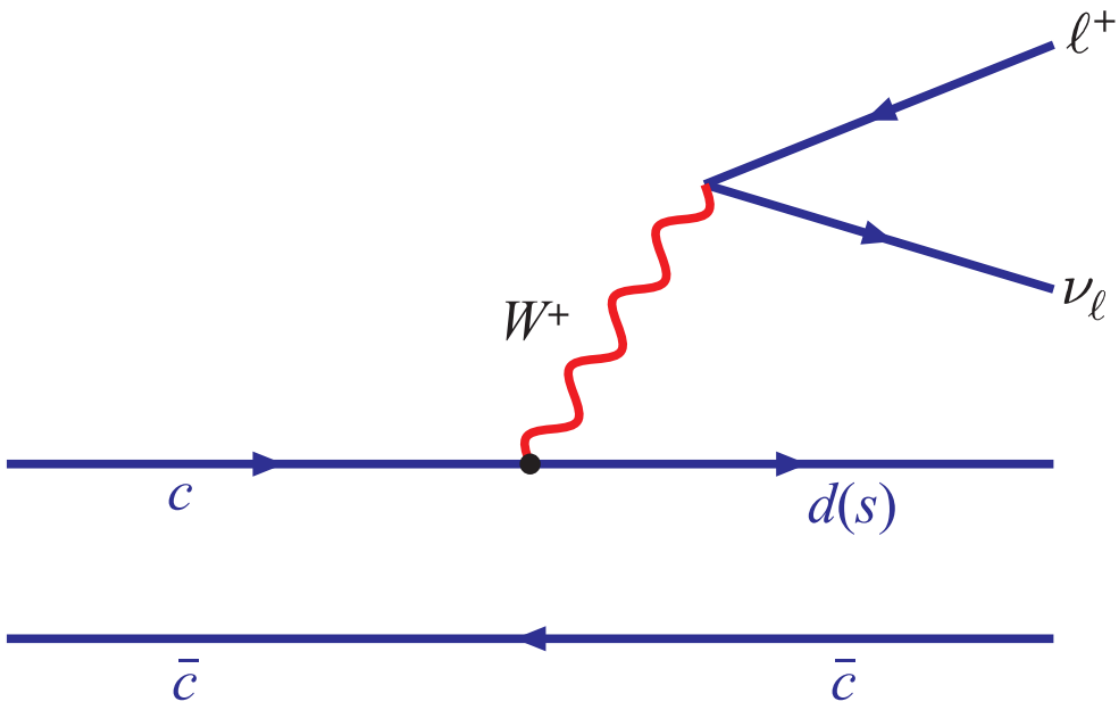

Figure: Feynman diagram of semileptonic J/ψ decay

Matrix elements

In the SM, the matrix element for the semileptonic decays of a $J/\psi-$meson into a pseudoscalar (P) or vector (V) meson is written as:

$$\mathcal{M}(J/\psi \to F l^+ \nu_l) = \frac{G_F}{\sqrt{2}} V_{cf}^* H^\mu L_\mu, \tag{1}$$

where G_F is the Fermi constant. The lepton current and the hadron matrix element are defined as:

$$L_\mu = \overline{\nu}_l \gamma_\mu (1-\gamma_5) l, \tag{2}$$

$$H^\mu = \langle F | J_\mu^W | D \rangle, \tag{3}$$

where $J_\mu^W = \overline{f}\gamma_\mu(1-\gamma_5)c$ is the weak current of semileptonic decays of $D-$ mesons, and $f = s, d-$ is the final quark.

Relativistic Quarks Model

In this model, a meson of mass M is described by the wave function $\Psi_M(\mathbf{p})$ of the bound quark-antiquark state, satisfying the quasipotential equation of the Schrödinger type:

$$\left(\frac{b^2(M)}{2\mu_R} - \frac{\mathbf{p}^2}{2\mu_R}\right)\Psi_M(\mathbf{p}) = \int \frac{d^3q}{2\pi^3} V(\mathbf{p},\mathbf{q};M)\Psi_M(\mathbf{q}), \qquad (4)$$

where $\mathbf{p}$ is the relative momentum of the quark,

$$b^2(M) = \frac{\left[M^2 - (m_1+m_2)^2\right]\left[M^2 - (m_1-m_2)^2\right]}{4M^2}, \qquad (5)$$

$$\mu_R = \frac{M^4 - (m_1^2 - m_2^2)^2}{4M^3}, \qquad (6)$$

where $m_{1,2}$ are the quark masses.

Kernel

The kernel of equation (4) is the QCD-motivated quark-antiquark potential $V(\mathbf{p}, \mathbf{q}; M)$, which is constructed using the off-shell scattering amplitude projected onto positive-energy states. The quasipotential is given as follows:

$$V(\mathbf{p}, \mathbf{q}; M) = \bar{u}_1(p)\bar{u}_2(-p)\mathcal{V}(\mathbf{p}, \mathbf{q}; M)u_1(q)u_2(-q), \qquad (7)$$

In this case:

$$\mathcal{V}(\mathbf{p}, \mathbf{q}; M) = \frac{4}{3}\alpha_s D_{\mu\nu}(\mathbf{k})\gamma_1^\mu\gamma_2^\nu + V_{conf}^V(\mathbf{k})\Gamma_1^\mu(\mathbf{k})\Gamma_{2;\nu}(\mathbf{k}) + V_{conf}^S(\mathbf{k}),$$

Form factors

The weak current matrix elements for the decays of $J\psi$-mesons to D-mesons can be expressed in terms of four invariant form factors:

$$\langle D_{(s)}(p_F)|\overline{f}\gamma^\mu c|J/\psi(p_{J/\psi})\rangle = \frac{2iV(q^2)}{M_{D_{(s)}}+M_{J/\psi}}\epsilon^{\mu\nu\rho\sigma}\epsilon^*_\nu p_{J/\psi\rho}p_{D_{(s)}\sigma},$$

$$\langle D_{(s)}(p_F)|\overline{f}\gamma^\mu\gamma_5 c|J/\psi(p_{J/\psi})\rangle = 2M_{J/\psi}A_0(q^2)\frac{\epsilon^* q}{q^2}q^\mu +$$

$$+(M_{D_{(s)}}+M_{J/\psi})A_1(q^2)\left(\epsilon^{*\mu}-\frac{\epsilon^* q}{q^2}q^\mu\right) -$$

$$-A_2(q^2)\frac{\epsilon^* q}{M_{D_{(s)}}+M_{J/\psi}}\left[p^\mu_{D_{(s)}}+p^\mu_{J/\psi}-\frac{M^2_{J/\psi}-M^2_{D_{(s)}}}{q^2}q^\mu\right],$$

where M_V and ϵ^μ are the mass and polarization vector of the vector meson.

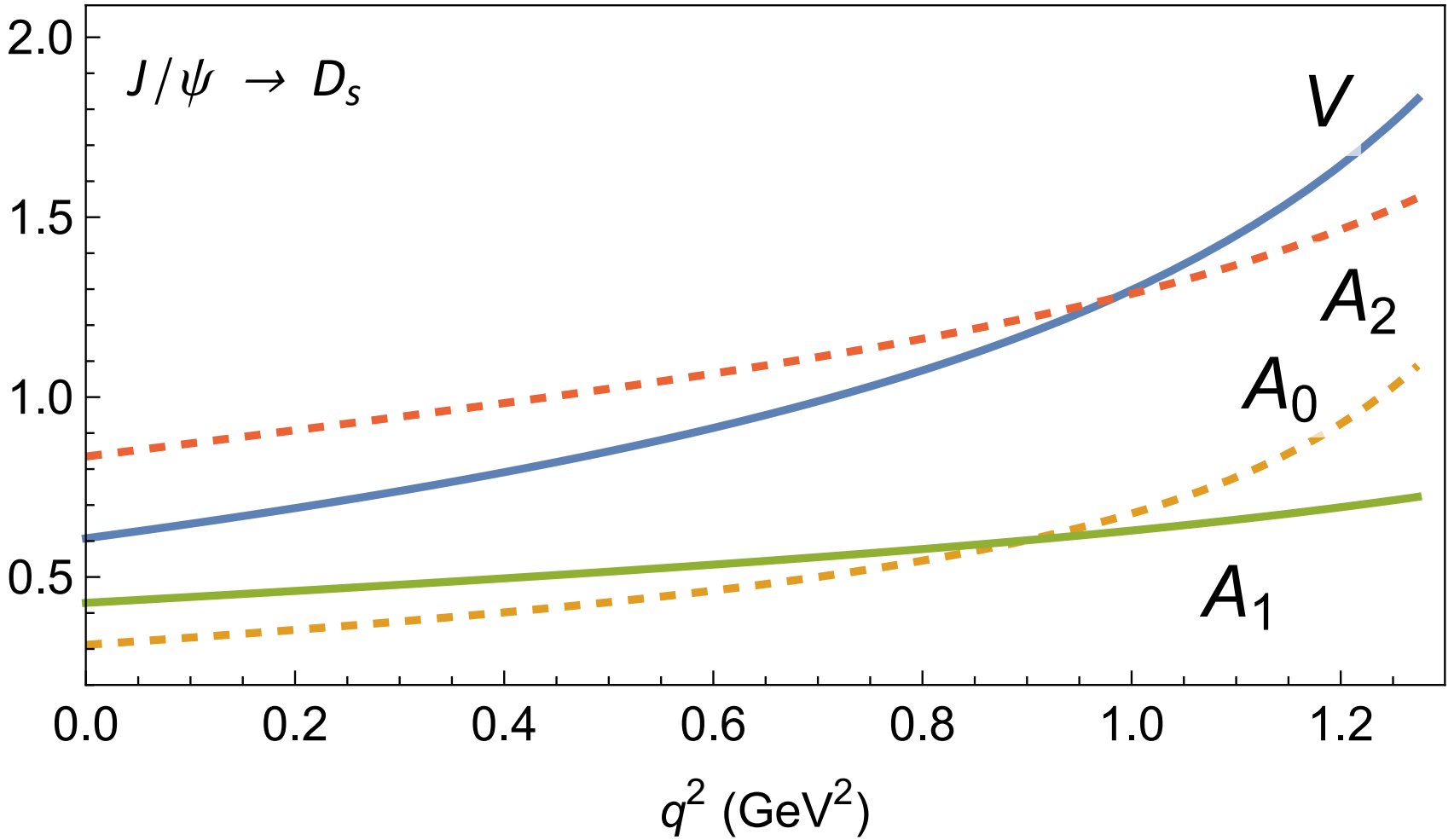

Figure: $J/\psi \to D_s$

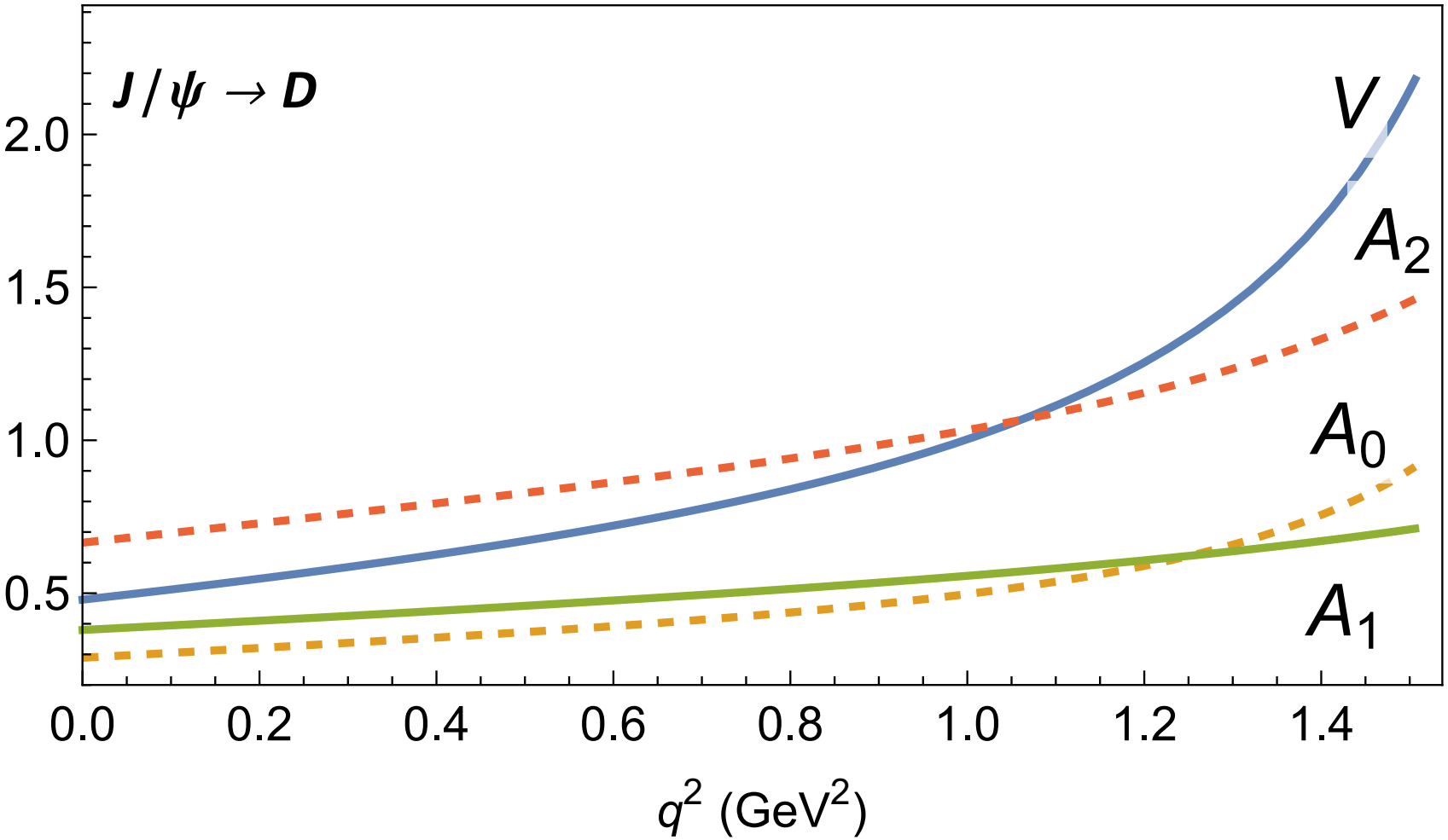

Figure: $J/\psi \to D$

Decay wight

$$\frac{d\Gamma(J/\psi \to D_{(s)} l^+ \nu_l)}{dq^2} = \frac{G_F^2}{(2\pi)^3} |V_{cq}|^2 \frac{1}{3} \frac{\lambda^{1/2}(q^2)(q^2 - m_l^2)^2}{24 M_{J/\psi}^3 q^2} \times H_{tot}. \quad (8)$$

Nonleptonic decay

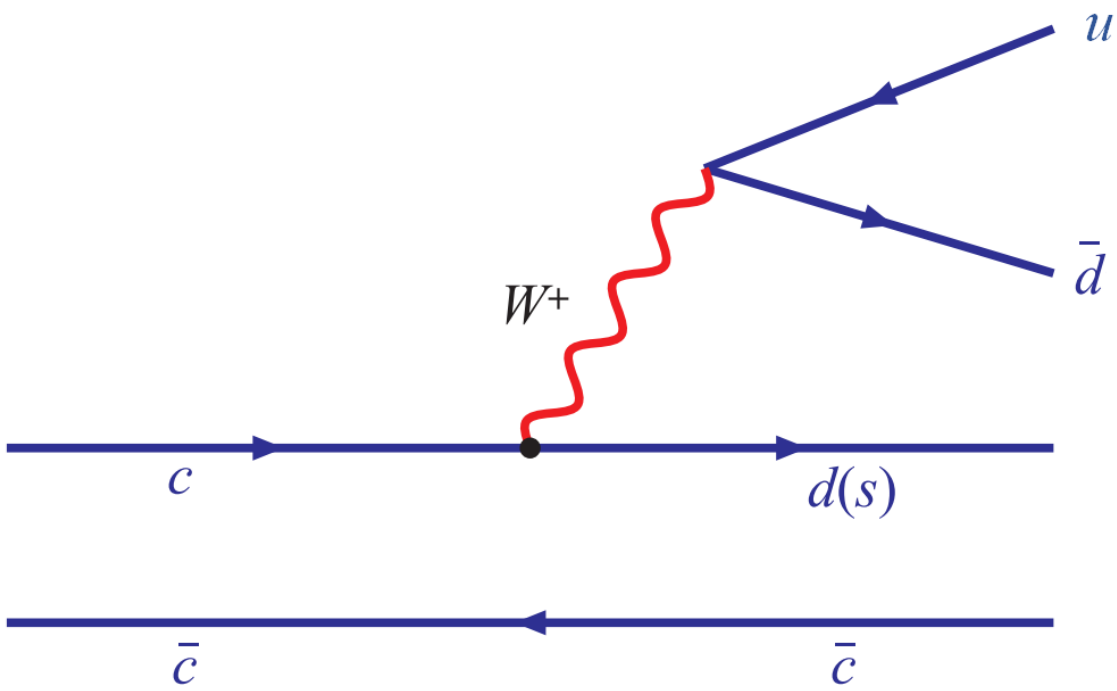

Figure: Feynman diagram of nonleptonic J/ψ decay

Decay wight

$$X_{J/\psi \to D_{(s)} P} = -i f_P m_P H_t \tag{9}$$

$$|X_{J/\psi \to D_{(s)} V}|^2 = f_V^2 m_V^2 (|H_0|^2 + |H_+|^2 + |H_-|^2) \tag{10}$$

$$|A| = \frac{G_F}{\sqrt{2}} V_{cq}^* V_{uq} a_1 X \tag{11}$$

$$Br(J/\psi \to D_{(s)} P(V)) = \frac{1}{3} \frac{\sqrt{\lambda}}{16\pi M_{J/\psi}^3 \Gamma} |A|^2 \tag{12}$$

Branching fraction

Table: Branching fraction weak semileptonic J/ψ decay

	Theory($\times 10^{-11}$)				Exp. data
Decay	RQM	CCQM[1]	BS[2]	LQCD[3]	PDG
$J/\psi \to D^- e^+ \nu_e$	1.30 ± 0.19	1.71 ± 0.26	$2.03^{+0.29}_{-0.25}$	1.21 ± 0.11	$< 7.1 \times 10^{-8}$
$J/\psi \to D^- \mu^+ \nu_\mu$	1.27 ± 0.18	1.66 ± 0.25	$1.98^{+0.28}_{-0.24}$	1.18 ± 0.11	$< 5.6 \times 10^{-7}$
$J/\psi \to D_s^- e^+ \nu_e$	19.9 ± 2.1	33 ± 5	$36.7^{+5.2}_{-4.4}$	$19.0 + 0.8$	$< 1.3 \times 10^{-6}$
$J/\psi \to D_s^- \mu^+ \nu_\mu$	19.3 ± 2.0	31.8 ± 4.8	$35.4^{+5.0}_{-4.3}$	18.4 ± 0.8	

Branching fraction

Table: Branching fraction weak nonleptonic J/ψ decay

	Theory($\times 10^{-11}$)				Exp. data
Decay	RQM	BSW[4]	BS[2]	QCDSR[5]	PDG
$J/\psi \to D\pi$	0.77 ± 0.11		$1.83^{+0.27}_{-0.25}$	$0.80^{+0.20}_{-0.20}$	$< 14.0 \times 10^{-8}$
$J/\psi \to D\rho$	4.4 ± 0.5		$11.3^{+1.6}_{-1.4}$	$4.2^{+1.8}_{-0.8}$	$< 12.0 \times 10^{-7}$
$J/\psi \to D_s\pi$	14.4 ± 1.5	$74.1^{+1.3}_{-2.3}$	$47.5^{+6.7}_{-5.9}$	20^{+4}_{-2}	$< 8.2 \times 10^{-7}$
$J/\psi \to D_s\rho$	98.7 ± 10.2	511^{+76}_{-60}	262^{+37}_{-32}	126^{+30}_{-10}	$< 16.0 \times 10^{-7}$

Results and discussion

1.Semileptonic and nonleptonic decays of $J/\psi-$mesons into charmed mesons are studied in detail within the framework of the relativistic quark model.
2.The invariant form factors that parameterize these matrix elements are obtained as the overlap integrals of the initial and final meson wave functions. Their dependence on the square of the transferred momentum q^2 is explicitly determined within the whole accessible kinematic range.
3.These form factors and helicity formalism are employed for the calculation of the differential and total semileptonic decay rates of charm meson into charmed mesons. The obtained results are compared with experimental upper limits.

Bibliography

1.Tran, C. T., et al. "Polarization observables in semileptonic $V \to P$ decays of quarkonia." Journal of Physics: Conference Series. Vol. 3040. No. 1. IOP Publishing, 2025.
2.Wang, Tianhong, et al. "Weak decays of J/ψ and $\Upsilon(1S)$." Journal of Physics G: Nuclear and Particle Physics 44.4 (2017): 045004.
3. Wang, Yu-Ming, et al. "The transition form factors for semi-leptonic weak decays of J/ψ in QCD sum rules." The European Physical Journal C 54 (2008): 107-121.
4.R. Dhir and R. C. Verma, Effects of Flavor Dependence on Weak Decays of J/ψ. Energy Phys. 2013 (2013) 706543. [arXiv:0903.1201]
5.Y. M. Wang, H. Zou, Z. T. Wei, X. Q. Li and C. D. Lu, Weak decays of J/ψ: The Non-leptonic case, Eur. Phys. J. C 55 (2008) 607. [arXiv:0802.2762]

Thank you
for your attention!

This work was supported by the Foundation for the Advancement of Theoretical Physics and Mathematics “BASIS” grant №23-2-2-11-1.