

Search for the leptonic decay $D^+ \rightarrow e^+ \nu_e$ *

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Abstract: We search for the leptonic decay $D^+ \rightarrow e^+ \nu_e$ using an e^+e^- collision data sample with an integrated luminosity of 20.3 fb^{-1} collected with the BESIII detector at the center-of-mass energy of 3.773 GeV . No significant signal is observed and an upper limit on the branching fraction of $D^+ \rightarrow e^+ \nu_e$ is set as 9.7×10^{-7} , at the 90% confidence level. Our upper limit is an order of magnitude smaller than the previous limit for this decay mode.

Keywords: BESIII, Charm Physics, Leptonic decay

DOI: **CSTR:**

I. INTRODUCTION

Leptonic decays of charmed mesons offer a clean and direct way to understand weak decays of the c quark (see e.g. [1] for a recent review). The leptonic decays

$D^+ \rightarrow \ell^+ \nu_\ell$ ($\ell = e, \mu$ or τ) occur via the annihilation of the c and \bar{d} quarks into an $\ell^+ \nu_\ell$ mediated by a virtual W^+ boson, as depicted in Fig. 1. The weak and strong interaction effects factorize, leading to a simple expression for the partial decay width of $D^+ \rightarrow \ell^+ \nu_\ell$ at the lowest order

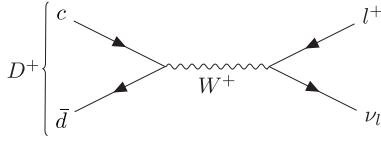


Fig. 1. Feynman diagram of $D^+ \rightarrow \ell^+ \nu_\ell$.

in the Standard Model (SM). It is proportional to the product of the decay constant f_{D^+} , which characterizes the strong-interaction effects between the initial-state quarks, and the magnitude of the Cabibbo-Kobayashi-Maskawa (CKM) matrix element $|V_{cd}|$, representing the $c \rightarrow d$ flavor-changing interaction. In the SM, the decay width can be written as [2]

$$\Gamma_{D^+ \rightarrow \ell^+ \nu_\ell} = \frac{G_F^2}{8\pi} |V_{cd}|^2 f_{D^+}^2 m_\ell^2 m_{D^+} \left(1 - \frac{m_\ell^2}{m_{D^+}^2}\right)^2, \quad (1)$$

where G_F is the Fermi coupling constant, m_ℓ is the lepton mass, and m_{D^+} is the D^+ mass. Thus, the ratio of branching fractions between different lepton channels depends only on the lepton masses and is accurately predicted to be

$$e^+ \nu_e : \mu^+ \nu_\mu : \tau^+ \nu_\tau = 2.35 \times 10^{-5} : 1 : 2.67, \quad (2)$$

with negligible uncertainty. Any observation of violation of this relation indicates new physics beyond the SM.

The $D^+ \rightarrow e^+ \nu_e$ decay, with an expected branching fraction less than 10^{-8} , has not yet been observed experimentally. The CLEO Collaboration searched for $D^+ \rightarrow e^+ \nu_e$ [3] and reported an upper limit of the branching fraction of 8.8×10^{-6} at the 90% confidence level using 818 pb^{-1} of the $\psi(3770)$ data. In this paper, we search for $D^+ \rightarrow e^+ \nu_e$ by using 20.3 fb^{-1} of $e^+ e^-$ collision data [4, 5], approximately 25 times larger than the CLEO measurement, collected with the BESIII detector at the center-of-mass energy of 3.773 GeV. Charge-conjugate modes are always implied throughout the text.

II. DESCRIPTION OF BEPCII AND THE BESIII DETECTOR

The BESIII detector [6] records symmetric $e^+ e^-$ collisions provided by the BEPCII storage ring [7] operating in the center-of-mass energy (\sqrt{s}) range from 1.84 to 4.95 GeV, with a peak luminosity of $1.1 \times 10^{33} \text{ cm}^{-2} \text{ s}^{-1}$ achieved at $\sqrt{s} = 3.773 \text{ GeV}$. BESIII has collected large data samples in this energy region [8–10]. The cylindrical core of the BESIII detector covers 93% of the full solid angle and consists of a helium-based multilayer drift chamber (MDC), a plastic scintillator time-of-flight system (TOF), and a CsI (TI) electromagnetic calorimeter (EMC), which are all enclosed in a superconducting

solenoidal magnet providing a 1.0 T magnetic field. The solenoid is supported by an octagonal flux-return yoke with resistive plate counter muon identification modules interleaved with steel. The charged-particle momentum resolution at 1 GeV/c is 0.5%, and the dE/dx resolution is 6% for electrons from Bhabha scattering. The EMC measures photon energies with a resolution of 2.5% (5%) at 1 GeV in the barrel (end-cap) region. The time resolution in the TOF barrel region is 68 ps, while that in the end-cap region was 110 ps. The end-cap TOF system was upgraded in 2015 using multi-gap resistive plate chamber technology, providing a time resolution of 60 ps [11–13]. About 85% of the data used here benefits from this upgrade.

III. MONTE CARLO SIMULATION

Monte Carlo (MC) simulated data samples produced with a GEANT4-based [14] software package, which includes the geometric description of the BESIII detector and the detector response, are used to determine detection efficiencies and to estimate backgrounds. The simulation models the beam energy spread and initial state radiation (ISR) in the $e^+ e^-$ annihilations with the generator KKMC [15]. The inclusive MC sample includes the production of $D\bar{D}$ pairs (and treats quantum coherence for the neutral D channels), non- $D\bar{D}$ decays of the $\psi(3770)$, ISR production of the J/ψ and $\psi(3686)$ states, and continuum processes incorporated in KKMC [15, 16]. All particle decays are modelled with EVTGEN [17, 18] using branching fractions either taken from the Particle Data Group (PDG) [19] when available, or otherwise estimated with LUNDCHARM [20]. Final state radiation (FSR) from charged final state particles is incorporated using PHOTOS [21]. The leptonic decay $D^+ \rightarrow e^+ \nu_e$ is simulated with the SLN model [22]. A signal MC sample comprising 5 million simulated signal events is used to determine the selection efficiencies and model the signal shape.

IV. ANALYSIS METHOD

The process $e^+ e^- \rightarrow \psi(3770) \rightarrow D^+ D^-$, without accompanying hadrons, allows studies of D^+ decays with a double tag technique [1, 23]. There are two types of samples used in this technique: single tag (ST) and double tag (DT). In the ST sample, a D^- meson is reconstructed via the six hadronic decay modes of $D^- \rightarrow K^+ \pi^- \pi^-, K_S^0 \pi^-, K^+ \pi^- \pi^0, K_S^0 \pi^- \pi^0, K_S^0 \pi^+ \pi^-,$ and $K^+ K^- \pi^-$. In the DT sample, both charged D mesons in the event are reconstructed: a ST D^- , and a signal $D^+ \rightarrow e^+ \nu_e$ decay is reconstructed with the remaining tracks.

The branching fraction of the $D^+ \rightarrow e^+ \nu_e$ decay is determined by

$$\mathcal{B}_{D^+ \rightarrow e^+ \nu_e} = \frac{N_{\text{DT}}}{N_{\text{ST}}^{\text{tot}} \bar{\epsilon}_{\text{sig}}}, \quad (3)$$

where $N_{\text{ST}}^{\text{tot}}$ is the total yield of ST D^- mesons, N_{DT} is the DT yield, and $\bar{\epsilon}_{\text{sig}}$ is the averaged signal efficiency weighted by the ST yields of the i^{th} tag mode in data. This efficiency is calculated as

$$\bar{\epsilon}_{\text{sig}} = \frac{\sum_i (N_{\text{ST}}^i \epsilon_{\text{DT}}^i / \epsilon_{\text{ST}}^i)}{N_{\text{ST}}^{\text{tot}}}, \quad (4)$$

where N_{ST}^i is the number of ST D^- mesons for the i^{th} tag mode in data, ϵ_{ST}^i is the efficiency of reconstructing the ST mode i , and ϵ_{DT}^i is the efficiency of finding the tag mode i and the $D^+ \rightarrow e^+ \nu_e$ decay simultaneously.

V. PARTICLE RECONSTRUCTION

All charged tracks detected in the MDC must satisfy $|\cos\theta| < 0.93$, where θ is the polar angle with respect to the z -axis, which is the symmetry axis of the MDC. For charged tracks not originating from K_S^0 decays, the distance of closest approach to the interaction point (IP) is required to be less than 1 cm in the transverse plane, and less than 10 cm along the z -axis. Particle identification (PID) for charged tracks combines the dE/dx measurement in the MDC with the time of flight measurement of the TOF to define the likelihood function $\mathcal{L}(h)$ ($h = K, \pi, e$) for each particle (h) hypothesis. Charged kaons and pions are identified by requiring $\mathcal{L}(K) > \mathcal{L}(\pi)$ and $\mathcal{L}(\pi) > \mathcal{L}(K)$, respectively, while positron candidates must satisfy $\mathcal{L}(e) > 0.001$ and $\mathcal{L}(e)/(\mathcal{L}(e) + \mathcal{L}(K) + \mathcal{L}(\pi)) > 0.8$. To further reduce mis-identifications between positrons and hadrons, we require $E/p > 0.8$, where E is the energy deposit in the EMC from the track and p is its momentum reconstructed in the MDC. To partially recover the energy loss due to FSR and bremsstrahlung, the four-momenta of photon(s) within 5° of the initial positron direction are added to the positron candidate's four-momentum.

The K_S^0 candidates are reconstructed from pairs of oppositely charged tracks, each with a distance of closest approach to the IP less than 20 cm along the z -axis. The tracks are assigned as $\pi^+ \pi^-$ without imposing any PID criteria. They are constrained to originate from a common vertex and are required to have an invariant mass within (0.487, 0.511) GeV/c^2 . The decay length of the K_S^0 candidate is required to be greater than twice the vertex resolution away from the IP. The quality of both primary and secondary vertex fits is ensured by requiring $\chi^2 < 100$. The fitted K_S^0 four-vectors are used for later kinematic calculations.

The photon candidates are reconstructed from isolated EMC showers. The deposited energy of each shower

in the end-cap region ($0.86 < |\cos\theta| < 0.92$) and in the barrel region ($|\cos\theta| < 0.80$) must be greater than 50 MeV or 25 MeV, respectively. To exclude showers that originate from charged tracks, the angle subtended by the EMC shower and the position of the closest charged track at the EMC must be greater than 10° as measured from the IP. The difference between the EMC time and the event start time is required to be within [0, 700] ns to suppress electronic noise and showers unrelated to the event.

The π^0 candidates are reconstructed from photon pairs with a $\gamma\gamma$ invariant mass within (0.115, 0.150) GeV/c^2 . A mass-constrained (1C) fit is imposed constraining the $\gamma\gamma$ invariant mass to the π^0 nominal mass [19] to improve the momentum resolution. The χ^2 must be less than 50, and the four-momentum of the π^0 candidate updated by the fit is used for further analysis.

VI. THE SINGLE-TAG SELECTION AND YIELDS

To separate ST D^- mesons from combinatorial backgrounds, we make use of two kinematic observables, the energy difference $\Delta E \equiv E_{D^-} - E_{\text{beam}}$ and the beam-constrained mass $M_{\text{BC}} \equiv \sqrt{E_{\text{beam}}^2/c^4 - |\vec{p}_{D^-}|^2/c^2}$, where E_{beam} is the beam energy, and E_{D^-} and \vec{p}_{D^-} are the energy and momentum of the ST \bar{D} meson in the e^+e^- center-of-mass frame. If there is more than one D^- candidate in a given ST mode, the one with the smallest $|\Delta E|$ is kept for further analysis. The ΔE requirements on the different tag modes are summarized in Table 1.

For each tag mode, the yield of ST D^- meson is extracted by fitting the corresponding M_{BC} distribution. In the fit, the signal shape is described by the MC-simulated signal shape convolved with a double-Gaussian function to account for the data-MC resolution difference. The background shape is described by an ARGUS function [23], with the endpoint fixed at $E_{\text{beam}} = 1.8865$ GeV. Figure 2 shows the fit results for the tag modes in data. The ST efficiencies are obtained by analyzing the inclusive MC sample. The candidates with M_{BC} within (1.863, 1.877) GeV/c^2 are kept for further analysis. The ST yields and efficiencies are summarized in Table 1.

Table 1. The requirements on ΔE , ST D^- yields (N_{ST}^i) in data, ST efficiencies (ϵ_{ST}^i), and DT efficiencies (ϵ_{DT}^i). The uncertainties on N_{ST}^i are statistical only.

Tag mode	ΔE (MeV)	$N_{\text{ST}}^i (\times 10^3)$	ϵ_{ST}^i (%)	ϵ_{DT}^i (%)
$K^+ \pi^- \pi^-$	[-25, 24]	5567.2 ± 2.5	51.08	33.92
$K_S^0 \pi^-$	[-25, 26]	656.5 ± 0.8	51.42	35.00
$K^+ \pi^- \pi^- \pi^0$	[-57, 46]	1740.2 ± 1.9	24.53	17.86
$K^+ K^- \pi^-$	[-24, 23]	481.4 ± 0.9	40.91	25.46
$K_S^0 \pi^- \pi^0$	[-62, 49]	1442.4 ± 1.5	26.45	20.12
$K_S^0 \pi^- \pi^- \pi^+$	[-28, 27]	790.2 ± 1.1	29.68	20.08

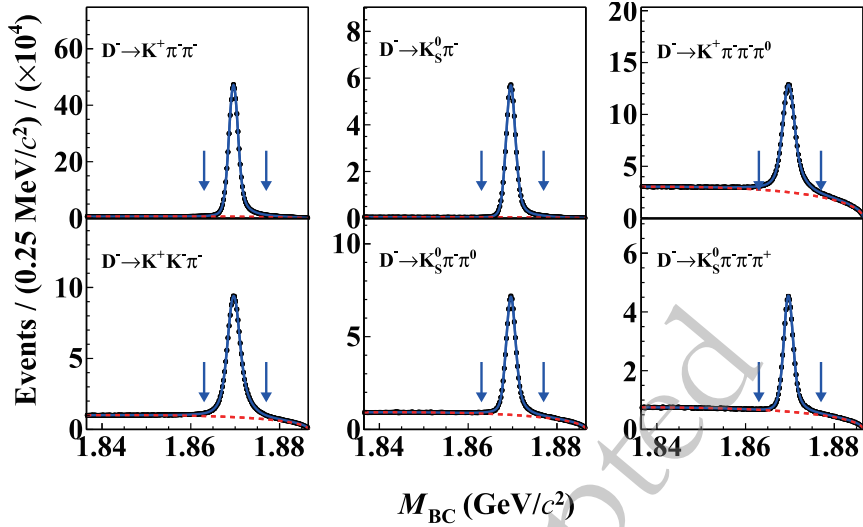


Fig. 2. (color online) Fits to the M_{BC} distributions of the ST D^- candidates. The dots with error bars are data, the solid blue lines are the total fit and the red dashed curves describe the fitted combinatorial background shapes. The pairs of blue arrows indicate the M_{BC} signal window.

VII. THE DOUBLE-TAG SELECTION AND YIELDS

For the signal side of $D^+ \rightarrow e^+ \nu_e$, only the one positron can be reconstructed. The neutrino carries away energy and momentum that are not directly detectable, but may be inferred from four-momentum conservation. The recoiling positron and D^- tag are combined with the known initial-state four-momentum to achieve this and help select signal events. A kinematic fit is performed, constraining the total four-momentum to the four-momentum of the initial state and constraining the invariant masses of the D^- tag and the D^+ signal to the known D^\pm mass. The four-momentum of the missing neutrino is determined by the fit, and the χ^2 of this kinematic fit is required to be less than 50. To further suppress backgrounds, it is required that there are no extra π^0 ($N_{\pi^0}^{\text{extra}} = 0$) or good tracks ($N_{\text{char}}^{\text{extra}} = 0$) that are not used in the DT reconstruction. The maximum energy of any extra photon ($E_{\text{max},\gamma}^{\text{extra}}$) is also required to be less than 0.2 GeV; this is optimized by maximizing $\frac{\epsilon}{1.5 + \sqrt{B}}$ [24], where ϵ is the signal efficiency and B is the background yield estimated by the inclusive MC sample. The signal yield is determined from a fit to the missing-mass squared, M_{miss}^2 , defined as

$$M_{\text{miss}}^2 = (E_{\text{beam}} - E_{e^+})^2 - (-\vec{p}_{D^-} - \vec{p}_{e^+})^2, \quad (5)$$

where E_{e^+} (\vec{p}_{e^+}) is the energy (momentum) of the candidate positron.

We fit the M_{miss}^2 distribution in data to obtain the yield of $D^+ \rightarrow e^+ \nu_e$. The signal shape is derived from the signal

MC sample, and the background shape is derived from the inclusive MC sample, smoothed with the tool RooKeysPDF [26]. The decay $D^+ \rightarrow \pi^0 e^+ \nu_e$ is the main background, which is well-modeled in the MC simulation. The fit result is shown in Fig. 3; the yield of $D^+ \rightarrow e^+ \nu_e$ is $N_{\text{DT}} = 0.3^{+2.9}_{-3.4}(\text{stat})$.

VIII. SYSTEMATIC UNCERTAINTIES

Most systematic uncertainties related to the efficiency of reconstructing the D^- mesons on the tag side are canceled due to the DT method. The multiplicative systematic uncertainty on the number of single tags, $N_{\text{ST}}^{\text{tot}}$, is estimated by varying the signal and background shapes, and allowing the parameters of the Gaussian to vary in

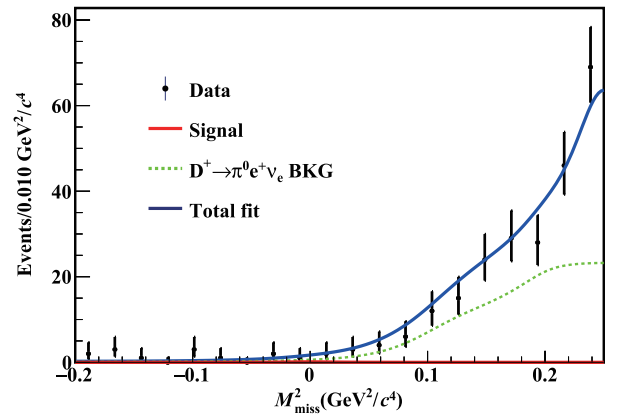


Fig. 3. (color online) Fit to the M_{miss}^2 distribution of the accepted candidates for $D^+ \rightarrow e^+ \nu_e$. The dots with error bars are data. The blue solid curve is the fit result. The red line is the fitted signal shape.

the fit. It is assigned to be 0.1%. The e^+ tracking and PID efficiencies are studied by using a control sample of $e^+e^- \rightarrow \gamma e^+e^-$. The differences of the efficiencies between data and MC are 1.002 ± 0.005 for e^+ tracking and 0.972 ± 0.005 for PID. After correcting for the data/MC discrepancy, we assign 0.5% and 0.5% as the multiplicative systematic uncertainties for the e^+ tracking and PID, respectively. The efficiency for the combined requirements on $E_{\text{max},\gamma}^{\text{extra}}, N_{\text{char}}^{\text{extra}}$ and $N_{\pi^0}^{\text{extra}}$ is studied with a control sample of DT hadronic events where both D^+ and D^- decay to one of the six ST hadronic final states. The efficiency difference between data and MC simulation, 1.3%, is taken as the multiplicative systematic uncertainty. We adjust the fit range between $(-0.25, 0.25)$ GeV^2/c^4 for M_{miss}^2 , with maximum upper limit and minimum values set as 1.0×10^{-6} and 9.7×10^{-7} , so we take into account 3% as additive systematic uncertainty. All systematic uncertainties are summarized in Table 2; adding them in quadrature results in a total systematic uncertainty of 4.3%.

IX. UPPER LIMIT OF THE BRANCHING FRACTION

Since no significant signal is found, an upper limit on the branching fraction of $D^+ \rightarrow e^+ \nu_e$ is estimated using the Bayesian approach. The sources of systematic uncertainties on the upper limit measurements are classified into two types: additive and multiplicative (σ_s). To incorporate the multiplicative systematic uncertainty in the calculation of the upper limit, the likelihood distribution is smeared by a Gaussian function with a mean of zero and a width equal to σ_s as described below [27],

$$L(\mathcal{B}) \propto \int_0^1 L\left(\frac{\epsilon_S}{\epsilon_S'} \mathcal{B}\right) e^{-\left[\frac{(\epsilon_S - \epsilon_S')^2}{2\sigma_S^2}\right]} dS, \quad (6)$$

where we associate ϵ_S with the nominal efficiency, ϵ_S with the expected efficiency and $L(\mathcal{B})$ is the likelihood distribution obtained from a fit to the likelihood of \mathcal{B} (branching fraction) and parameterized as a Gaussian. The only significant additive uncertainty comes from the normalization of the $D^+ \rightarrow \pi^0 e^+ \nu_e$ branching fraction. We repeat the maximum-likelihood fit, varying this BF by the PDG uncertainty and choose the most conservative upper limit among these results. The distribution of the likelihood versus the assumed branching fraction is shown in Fig. 4. Finally, the upper limit on the branching fraction of $D^+ \rightarrow e^+ \nu_e$ at the 90% confidence level is set at 9.7×10^{-7} .

Table 2. The systematic uncertainties on the branching fraction measurement.

Multiplicative Uncertainty	Uncertainty (%)
$N_{\text{ST}}^{\text{tot}}$	0.1
e^+ tracking	0.5
e^+ PID	0.5
$E_{\text{max},\gamma}^{\text{extra}}, N_{\text{char}}^{\text{extra}}, N_{\pi^0}^{\text{extra}}$	3.0
Additive Uncertainty	Uncertainty (%)
M_{miss}^2 fit region	3.0
Total	4.3

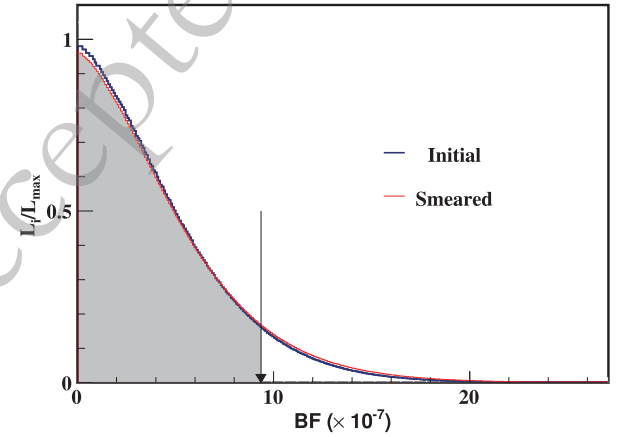


Fig. 4. (color online) Distribution of likelihood versus the branching fraction of $D^+ \rightarrow e^+ \nu_e$. The likelihood in each bin is denoted as L and the maximum of the likelihood is L_{max} . The results obtained with and without incorporating the systematic uncertainties are shown as the red and blue curves, respectively. The black arrow shows the upper limit corresponding to the 90% confidence level.

X. SUMMARY

In summary, by analyzing 20.3 fb^{-1} of e^+e^- collision data collected at $\sqrt{s} = 3.773 \text{ GeV}$ with the BESIII detector, we search for the leptonic decay $D^+ \rightarrow e^+ \nu_e$. No significant signal is observed and an upper limit on the branching fraction of $D^+ \rightarrow e^+ \nu_e$ is set at 9.7×10^{-7} at the 90% confidence level. The sensitivity is improved by an order of magnitude compared to the CLEO measurement.

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References

- [1] B.-C. Ke, J. Koponen, H.-B. Li, and Y. Zheng, *Ann. Rev. Nucl. Part. Sci.* **73**, 285 (2023), arXiv: 2310.05228[hep-ex]
 [2] D. Silverman and H. Yao, *Phys. Rev. D* **38**, 214 (1988)

- [3] B. I. Eisenstein, *et al.*, *Phys. Rev. D* **78**, 052003 (2008)
- [4] M. Ablikim, *et al.*, *Chin. Phys. C* **48**, 123001 (2024), arXiv: 2406.05827[hep-ex]
- [5] M. Ablikim, *et al.*, *Chin. Phys. C* **37**, 123001 (2013), arXiv: 1307.2022[hep-ex]
- [6] M. A., *et al.*, *Nucl. Instrum. Meth. A* **614**, 345 (2010)
- [7] C. Yu *et al.*, BEPC II Performance and Beam Dynamics Studies on Luminosity, in *7th International Particle Accelerator Conference* (2016) p. TUYA01.
- [8] M. A., *et al.*, *Chin. Phys. C* **44**, 040001 (2020)
- [9] J. Lu, Y. Xiao, and X. Ji, *Radiat. Detect. Technol. Methods* **4**, 337 (2020)
- [10] J.-W. Zhang, *et al.*, *Radiat. Detect. Technol. Methods* **6**, 289 (2022)
- [11] X. Li, *et al.*, *Radiat. Detect. Technol. Methods* **1**, 13 (2017)
- [12] Y.-X. Guo, *et al.*, *Radiat. Detect. Technol. Methods* **1**, 15 (2017)
- [13] P. Cao, *et al.*, *Nucl. Instrum. Meth. A* **953**, 163053 (2020)
- [14] S. Agostinelli, *et al.*, *Nucl. Instrum. Meth. A* **506**, 250 (2003)
- [15] S. Jadach, B. F. L. Ward, and Z. Was, *Comput. Phys. Commun.* **130**, 260 (2000)
- [16] S. Jadach, B. F. L. Ward, and Z. Was, *Phys. Rev. D* **63**, 113009 (2001)
- [17] D. J. Lange, *Nucl. Instrum. Meth. A* **462**, 152 (2001)
- [18] R. G. Ping, *Chin. Phys. C* **32**, 599 (2008)
- [19] R. Workman, *et al.*, *PTEP* **2022**, 083C (2022)
- [20] J. C. Chen, G. S. Huang, X. R. Qi, D. H. Zhang, and Y. S. Zhu, *Phys. Rev. D* **62**, 034003 (2000)
- [21] E. Barberio, B. van Eijk, and Z. Was, *Comput. Phys. Commun.* **66**, 115 (1991)
- [22] A. Ryd, D. Lange, and N. Kuznetsova, documentation available at: <https://evtgen.hepforge.org/doc>.
- [23] J. Adler, *et al.*, *Phys. Rev. Lett.* **62**, 1821 (1989)
- [24] H. Albrecht, *et al.*, *Phys. Lett. B* **241**, 278 (1990)
- [25] G. Punzi, *et al.*, *Phys. Lett. B* **10**, 48550 (2003)
- [26] W. Verkerke and D. Kirkby, https://root.cern/download/doc/RooFit_Users_Manual_2.91-33.pdf (2019).
- [27] K. Stenson *et al.*, A more exact solution for incorporating multiplicative systematic uncertainties in branching ratio limits, <https://doi.org/10.48550/arXiv.physics/0605236>.