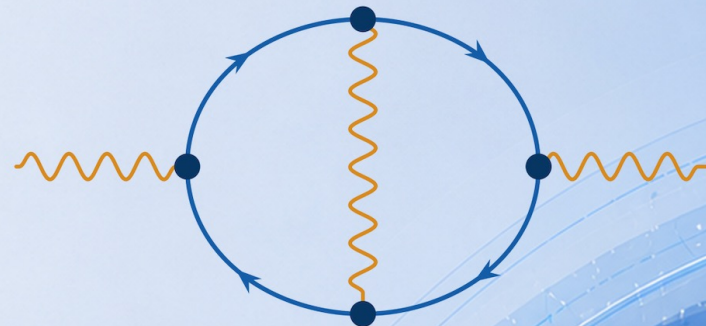


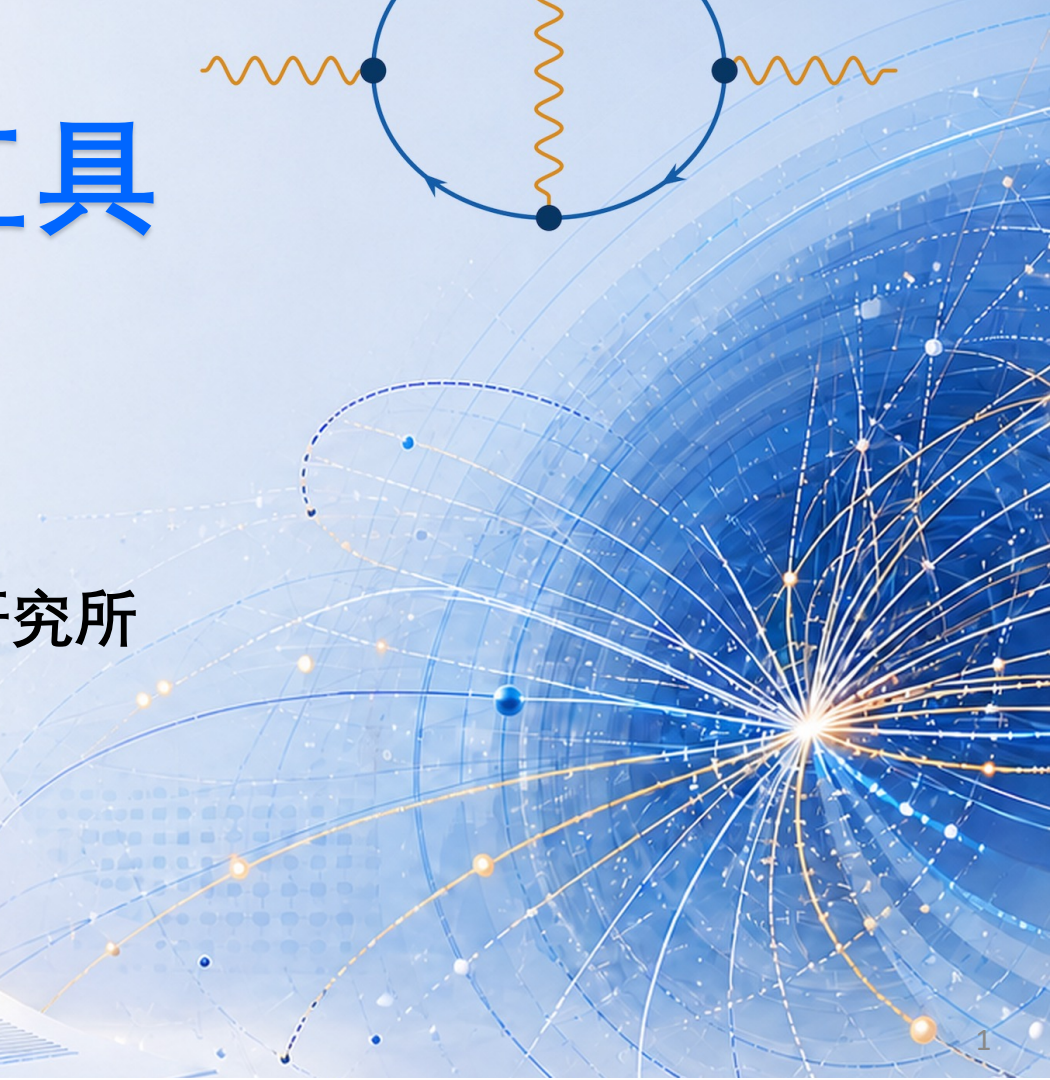
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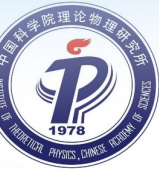
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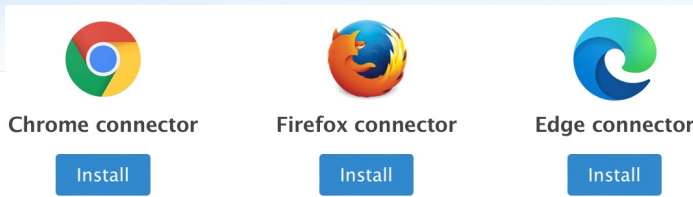
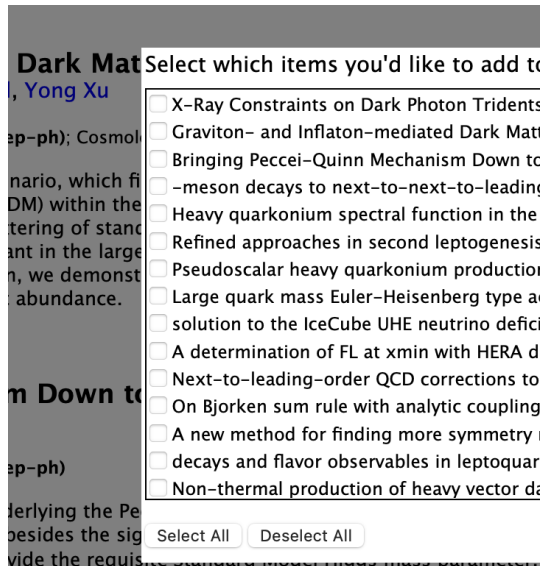
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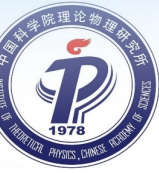
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Quantum steering and discord in hyperon-antihyperon system in electron-positron annihilation

Sihao Wu,^{1,*} Chen Qian,^{2,†} Qun Wang,^{1,3,‡} and Yang-Guang Yang^{4,§}

¹Department of Modern Physics and Anhui Center for fundamental sciences in theoretical physics, University of Science and Technology of China, Hefei 230026, China

²Beijing Academy of Quantum Information Sciences, Beijing 100193, China

³School of Mechanics and Physics, Anhui University of Science and Technology, Huainan, Anhui 232001, China

⁴Institute of Modern Physics, Chinese Academy of Sciences, Lanzhou 730000, China

Hyperon-antihyperon pairs produced in high-energy electron-positron annihilation are promising systems for the study of quantum information properties. In this work, we make an analysis of two types of quantum correlations, the quantum steering and discord, in hyperon-antihyperon systems produced in electron-positron annihilation based on the X-shaped spin density matrix. The behaviors of these quantum correlations differ from those in elementary particle-antiparticle systems such as the top quark and tau lepton due to the polarization effect. The hierarchy of quantum correlations is examined and partially confirmed in hyperon-antihyperon systems: Bell Nonlocality $\subset$ Steering $\subset$ Entanglement $\subset$ Discord. The loopholes and quantum steering effect are also discussed in our work.

I. INTRODUCTION

In recent years, testing quantum nonlocal correlations at colliders has attracted a lot of interest in high-energy physics (HEP). Historically, studies of fundamental problems in quantum mechanics were primarily conducted in photonic and atomic systems [1, 2]. However, with the progress in high-energy experiments, particularly in particle detection technology and accumulation of huge amount of experimental data, there has been a growing interest in the investigation of quantum information properties at smaller length and higher energy scales [3].

Generally, the spin states of unstable particles produced in high energy experiments which have weak decays can be extracted based on the quantum state tomography [4]. Recently, all known fundamental physics has provided a solid ground for the study of quantum entanglement in $t\bar{t}$ has

Schrodinger [24]. It refers to the entanglement of one subsystem can be even when the subsystem is regarded as a subsystem is less restrictive than the quantum discord quantum correlation [27]. The nature of the correlation by classical physics between the subsystems is fundamental, aspect of quantum communication [29-31]

Steering, Entanglement, Nonlocality, and the Einstein-Podolsky-Rosen Paradox

H. M. Wiseman, S. J. Jones, A. C. Doherty

Phys.Rev.Lett. 98 (2007) 140402

arXiv:quant-ph/0612147 · DOI:10.1103/PhysRevLett.98.140402

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The concept of steering was introduced by Schrodinger in 1935 as a generalization of the EPR paradox for arbitrary pure bipartite entangled states and arbitrary measurements by one party. Until now, it has never been rigorously defined, so it has not been known (for example) what mixed states are steerable (that is, can be used to exhibit steering). We provide an operational definition, from which we prove (by considering Werner states and isotropic states) that steerable states are a strict subset of entangled states.

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[10] L. Barbieri, M. P. Almeida, A. G. White: [Quantum Computing without Entanglement](#); Phys.Rev.Lett. 98 (2007) 050501 [arXiv:0807.0668]

or two types of quantum correlations, the quantum steering and discord, in hyperon-antihyperon systems produced in electron-positron annihilation based on the X-shaped spin density matrix. The behaviors of these quantum correlations differ from those in elementary particle-antiparticle systems such as the top quark and tau lepton due to the polarization effect. The hierarchy of quantum correlations is examined and partially confirmed in hyperon-antihyperon systems: Bell Nonlocality $\subset$ Steering $\subset$ Entanglement $\subset$ Discord. The loopholes and quantum decoherence effect are also discussed in our work.

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Generally, the spin states of unstable particles produced in high energy experiments which have weak decays can be extracted based on the quantum state tomography [4]. Recently, top quarks as the heaviest of all known fundamental particles, serve as an ideal testing ground for the study of quantum energy physics [5–7]. The experimental entanglement in $t\bar{t}$ has been identified at the Large Hadron Collider (LHC) as the entangled system with possible energy [8]. Apart from top quarks, other particle systems at colliders [9–11], massive gauge bosons [12–14], other quarks [20] and vector meson decays carried out. Among these works, quantum entanglement in the hyperon-antihyperon system decays were proposed and can be tested at BESIII [17, 18]. The Bell nonlocality (or violation) and Bell entanglement are a quantum correlation.

quantum correlation, the quantum steering or Einstein-Podolsky-Rosen (EPR) steering was first introduced by Schrödinger [24]. It refers to the ability that the measurement of one subsystem can influence the state of another, even when the subsystems are spatially separated. Steering ability is regarded as a kind of quantum nonlocality that is less restrictive than the Bell nonlocality [25, 26].

The quantum discord represents another form of the quantum correlation [27, 28]. It captures the quantum nature of the correlation that cannot be explained purely by classical physics, even when there is no entanglement between the subsystems. It reflects more subtle, yet fundamental, aspect of quantum mechanics, especially in the context of quantum computation and quantum communication [29–31]. Nowadays, the quantum steering and discord have been introduced into particle physics such as in the neutrino oscillation [32, 33] and top quark system [34, 35].

Test of local realism via entangled $\Lambda\bar{\Lambda}$ system

M. Ablikim et al.

Nature Commun. 16 (2025) 4948

arXiv:2505.14988 · DOI:10.1038/s41467-025-59498-4

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The non-locality of quantum correlations is a fundamental feature of quantum theory. The Bell inequality serves as a benchmark for distinguishing between predictions made by quantum theory and local hidden variable theory (LHVT). Recent advancements in photon-entanglement experiments have added observed significant violations of various examples of Bell inequalities violation. In this study, we utilize...

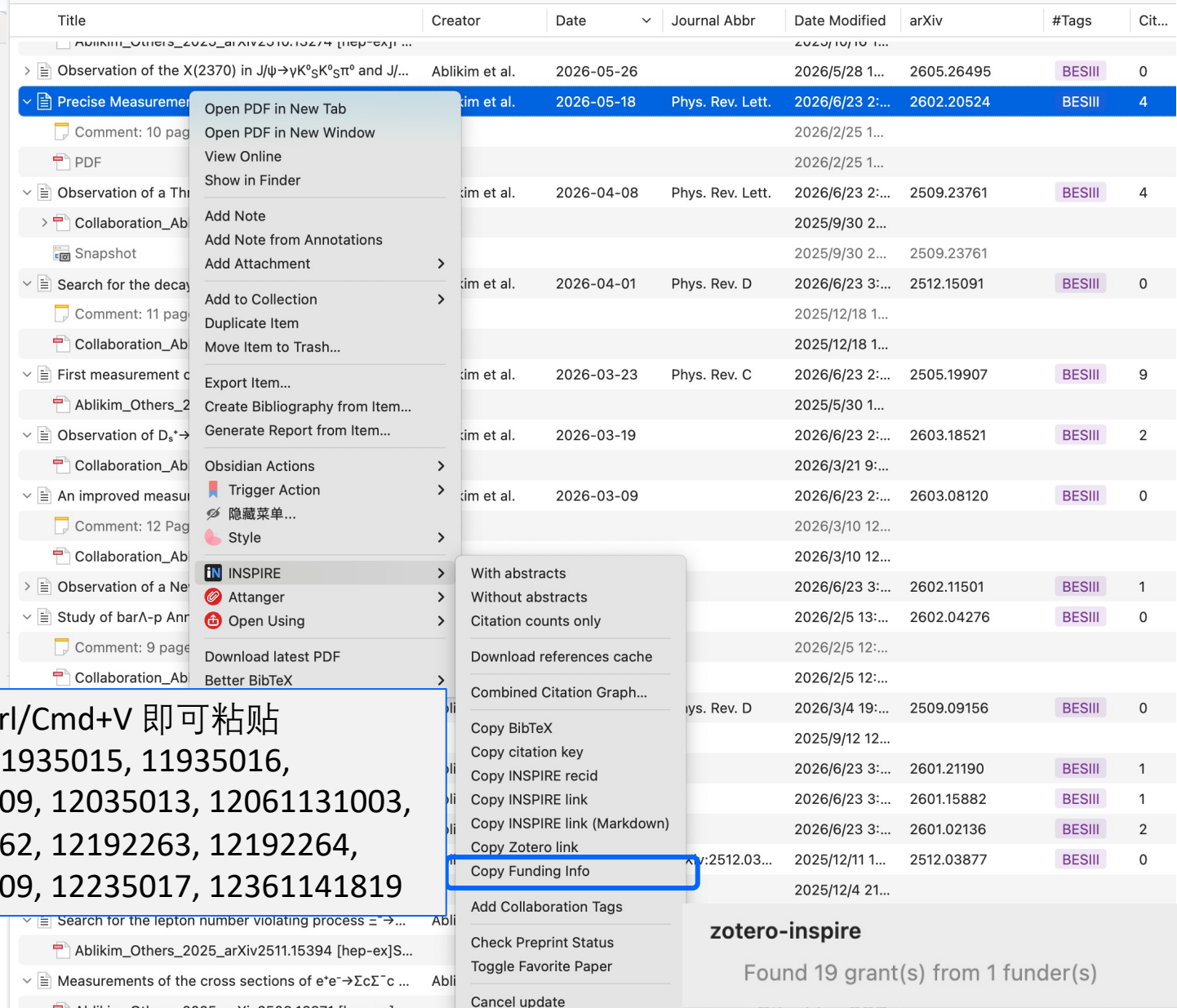
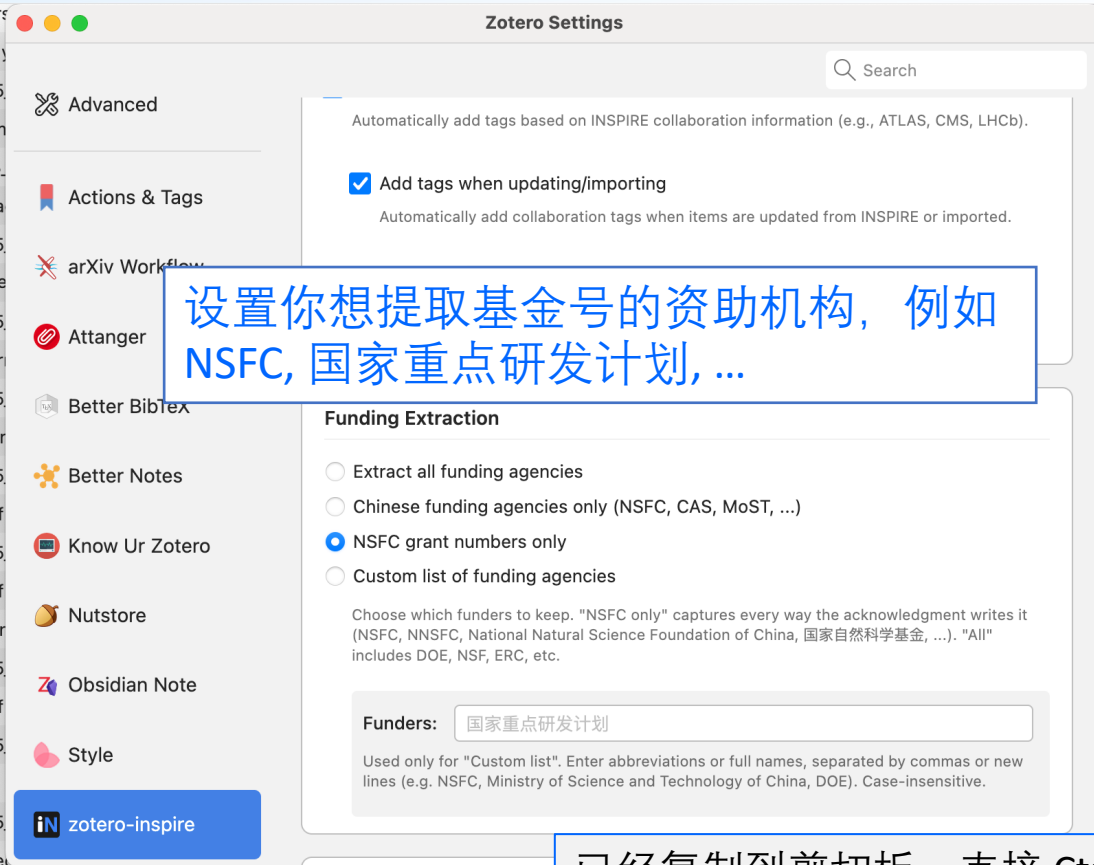
ron-antihyperon system $Y\bar{Y}$ and study the $Y\bar{Y}$ system in a quantum state. Our investigation is based on the density operator. We use the three-body decay $Y\bar{Y} \rightarrow \Lambda\bar{\Lambda} + \text{other}$ and give an analysis of quantum discord from its origin. Our results can provide a full understanding of the Bell nonlocality in the hyperon-antihyperon system.

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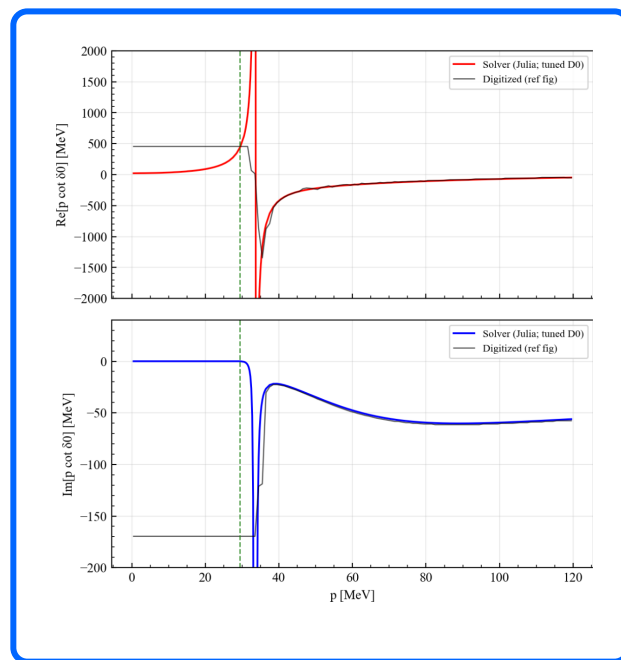
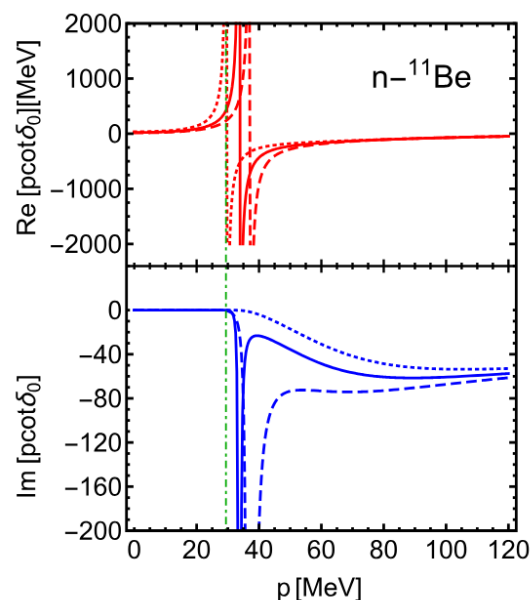
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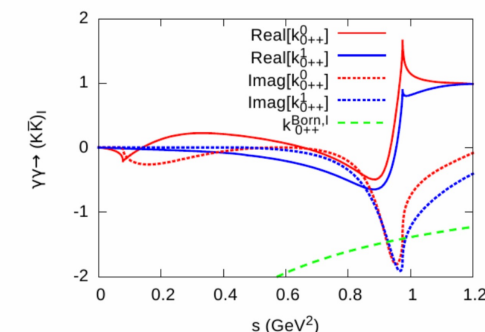
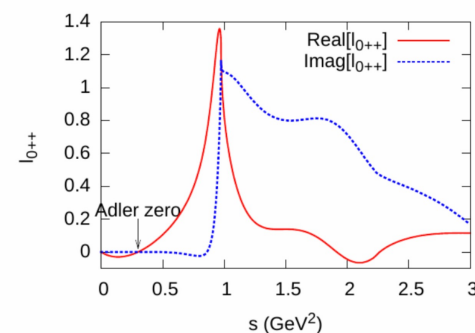
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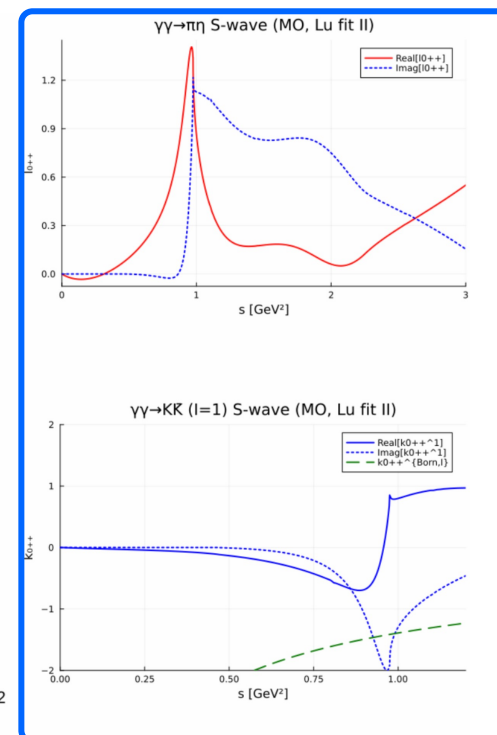
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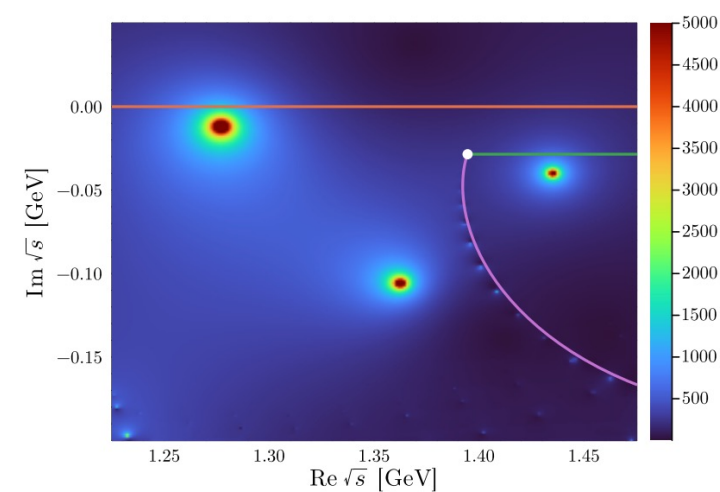
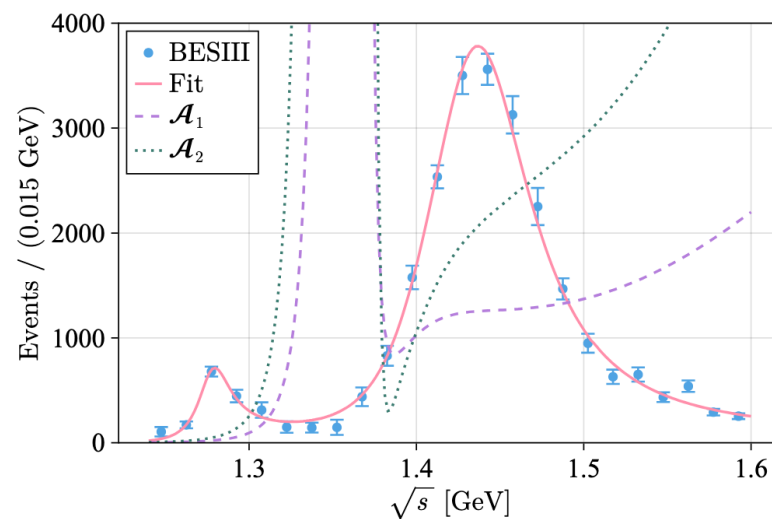
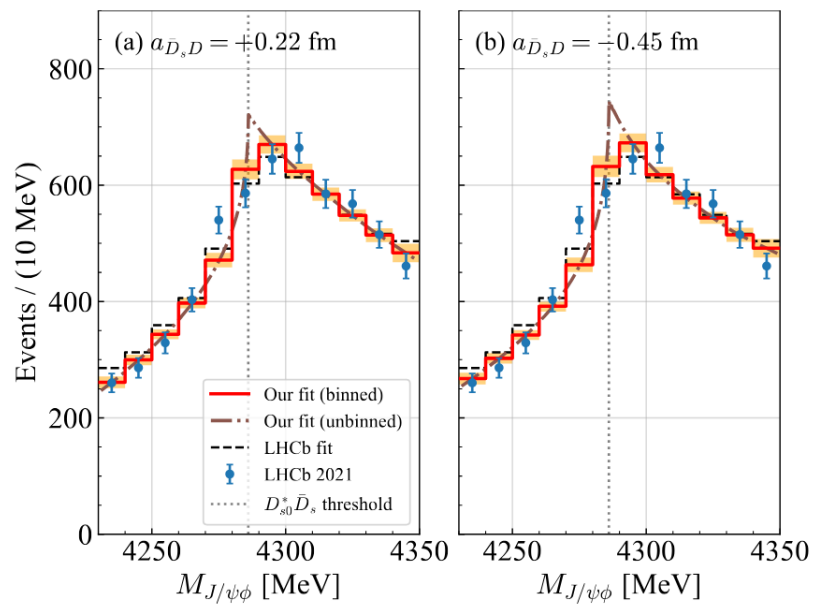
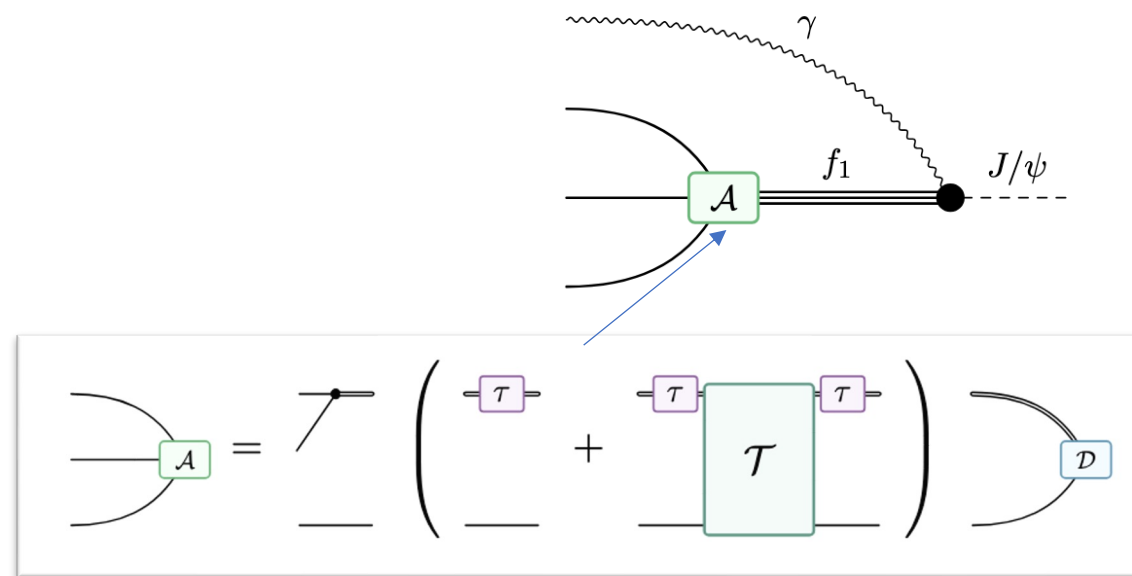
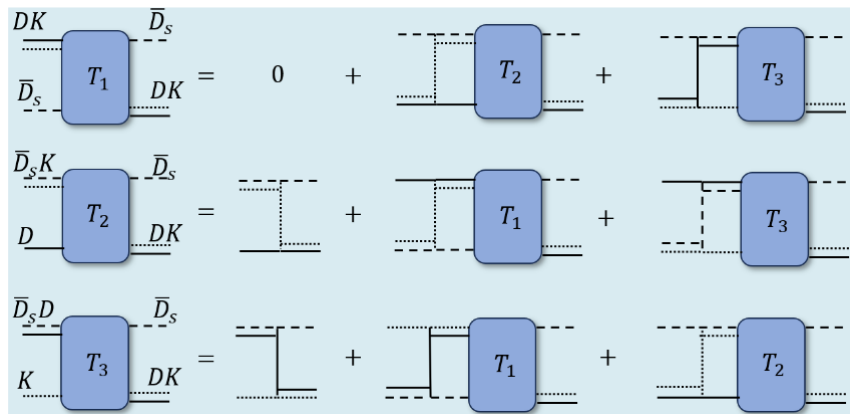
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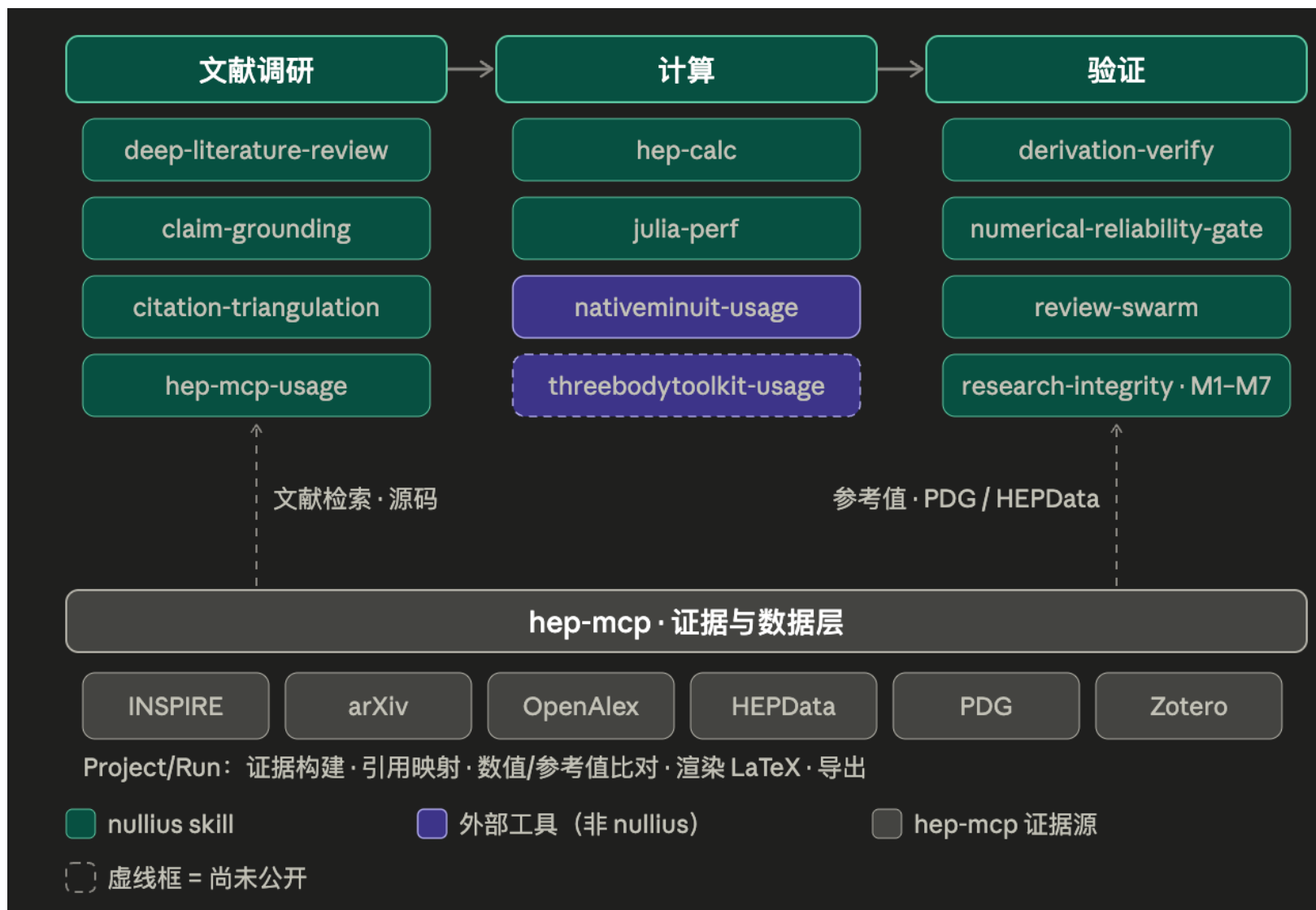
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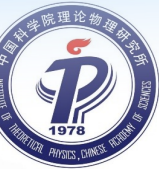
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