The 2025 Beijing Particle Physics and Cosmology Symposium (BPCS 2025): early Universe, gravitational-wave templates, collider phenomenology

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[illegible]Chun Hui Yuan Hot Spring Resort Hotel[illegible]

Book of Abstracts

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A Dynamical Quasigluon Description of the Confinement Phase Transition

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AI enhanced event reconstruction and physics measurements: impact at CEPC Physics reach

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The Higgs factory is regarded as the highest priority future collider priority, as it could provide decisive data on our exploration to multiple profound mysteries, including the origin of mass, origin of matter, nature of dark matter, etc. Take the Circular Electron Positron Collider as an example, it is expected to deliver 4 million Higgs bosons, hundreds of Millions of W bosons, 4 Tera Z bosons, and potentially also 1 million top quarks in an extremely clean collision environment. The CEPC could well be the gateway towards the profound physics principles, by hundreds of promising observations though not only the precise Higgs measurements, but also Electroweak, Flavor physics measurements and direct New Physics signal hunting.

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The extremely rich physics program at the CEPC poses stringent requirements on the detector performa
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Anatomy of Family Trees in Cosmological Correlators

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Cosmological correlators encode rich information about quantum field theories in a cosmological background and are key observables of cosmological collider physics. However, their analytical computation is a hard problem due to the inherent complexities of these functions. Recently, we solved this problem for all tree-level massive correlators and revealed a universal structure of family trees. In this talk, I will introduce the recent progress on this front.

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Anatomy of Parity-violating Trispectra in Galaxy Surveys

Yiming Zhong[1]

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Parity-violating interactions are ubiquitous phenomena in particle physics. If they are significant during cosmic inflation, they can leave imprints on primordial perturbations and be observed in correlation functions of galaxy surveys. Importantly, parity-violating signals in the four-point correlation functions (4PCFs) cannot be generated by Einstein gravity in the late universe on large scales, making them unique and powerful probes of high-energy physics during inflation. However, the complex structure of the 4PCF poses challenges in diagnosing the underlying properties of parity-violating interactions from observational data. We introduce a general framework that provides a streamlined pipeline directly from a particle model in inflation to galaxy 4PCFs in position space. We demonstrate this framework with a series of toy models and the tree-level exchange-type processes with chemical-potential-induced parity violation. We further showed the detection sensitivity of these models from BOSS data and highlighted potential challenges in data interpretation and model prediction.

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Bell Inequality Violation of Light Quarks in Dihadron Pair Production at Lepton Colliders

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Spin correlations between particles produced at colliders provide valuable insights for quantum information studies. While traditional studies of quantum information at colliders are typically limited to massive particles with perturbative decay, we propose an innovative method to explore the Bell inequality in massless quark pair systems by analyzing the azimuthal correlations in $\pi^+\pi^-$ dihadron pair production at lepton colliders. Revisiting the Belle data, we have shown the potential to detect Bell inequality violation of light quarks by introducing an additional angular cut, achieving a significance of 2.5 σ even in the worst-case scenario of 100\% correlated systematic uncertainties in each bins. The significance substantially exceeds 5σ when considering uncorrelated systematic uncertainties. Our approach opens avenues for exploring spin quantum information with non-perturbative processes as spin analyzer and leverages existing data for quantum information research.

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Bubble wall velocity from Kadanoff-Baym equations: fluid dynamics and microscopic interactions

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We establish a first principles, systematic framework for determining the bubble wall velocity during a first order cosmological phase transition. This framework, based on non-local Kadanoff-Baym equations, incorporates both macroscopic fluid dynamics and microscopic interactions between the bubble wall and particles in the plasma. Previous studies have generally focused on one of these two sources of friction pressure that govern the wall velocity. As a precursor, we utilize background field quantum field theory to obtain the relevant local Boltzmann equations, from which we derive the forces associated with variation of particle masses across the bubble wall and the microscopic wall-particle interactions. We subsequently show how these equations emerge from the Kadanoff-Baym framework under various approximations. We apply this framework in the ballistic regime to compute the new friction force arising from the $2 \to 2$ scattering processes in scalar field theory. We obtain a linear relationship between this force and the Lorentz factor γ_w that would preclude runaway bubbles with such effects.

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Cosmic Phase Transitions: The Gravitational Wave - Collider Interplay

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Cosmological Signatures of Neutrino Seesaw Mechanism

Chengcheng Han[None]

The tiny neutrino masses are most naturally explained by the seesaw mechanism through singlet right-handed neutrinos, which can further explain the matter-antimatter asymmetry in the universe. In this work, we propose a new approach to study cosmological signatures of neutrino seesaw through the interaction between inflaton and right-handed neutrinos. After inflation the inflaton predominantly decays into right-handed neutrinos and its decay rate is modulated by the fluctuations of Higgs field which act as the source of curvature perturbations. We demonstrate that this modulation produces primordial non-Gaussian signatures, which can be measured by the forthcoming large-scale structure surveys. We find that these surveys have the potential to probe a large portion of the neutrino seesaw parameter space, opening up a new window for testing the high scale seesaw mechanism.

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Cosmological Stasis and Its Observational Signatures

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Cosmological stasis is a phenomenon in which multiple energy components with different equation-of-state parameters maintain constant abundances for an extended period despite the expansion of the universe. In this talk, I review the how stasis arises and discuss the possible implications of this

phenomenon in observations. These include characteristic imprints in the stochastic gravitational-wave background and the enhancement in the growth of matter density perturbations on small scales.

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Dark Radiation Isocurvature from Cosmological Phase Transitions

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Cosmological first-order phase transitions are typically associated with physics beyond the Standard Model, and thus of great theoretical and observational interest. In this talk, I will show that a broad class of non-thermal first-order phase transitions could generate distinct large-scale isocurvature in dark radiation that can be observable in the CMB. We derive constraints on $\Delta N_{\rm eff}$ from phase transitions based on CMB+BAO data, which can be much stronger than those from adiabatic initial conditions. I will also demonstrate that since perturbations of dark radiation have a non-Gaussian origin, searches for non-Gaussianity in the CMB could also place a stringent bound on $\Delta N_{\rm eff}$.

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Darkogenesis via Supercooled Phase Transition

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We discuss the intriguing possibility that the recently reported nano-Hz gravitational wave signal by Pulsar Timing Array (PTA) experiments is sourced by a strong first-order phase transition in a dark sector. The phase transition has to be strongly supercooled to explain the signal amplitude. However, such strong supercooling exponentially dilutes away any pre-existing baryon asymmetry and dark matter, calling for a new paradigm of their productions. We then develop a mechanism of cold darkogenesis that generates a dark asymmetry during the phase transition from the textured dark SU(2) Higgs field. This dark asymmetry is transferred to the visible sector via neutron portal interactions, resulting in the observed baryon asymmetry. Furthermore, the mechanism naturally leads to the correct abundance of asymmetric dark matter. Collider searches for mono-jets and dark matter direct detection experiments can dictate the viability of the model. We also discuss another scenario of darkogenesis where the number asymmetry is generated from the decay of a mother particle produced via parametric resonance during the phase transition induced due to its coupling to the order parameter scalar. It is shown that the correct baryon asymmetry and dark matter abundance can be realized for a dark phase transition at O(1) GeV. The scenario will be tested further in neutron-antineutron oscillation experiments.

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Detecting Gravitational Waves from Cosmic Phase Transitions in Space

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This presentation explores the detection and analysis of stochastic gravitational wave backgrounds (SGWB) originating from first-order cosmological phase transitions, with a focus on the sound wave contributions. It begins by introducing the relevant detector configurations, including space-based interferometers like LISA and Taiji, and the construction of AET channels to extract clean gravitational wave signals. Simulated data are generated in both time and frequency domains, incorporating realistic noise and signal models. A comprehensive statistical analysis framework is developed, combining likelihood functions, Fisher matrix forecasts, and MCMC sampling to extract and constrain physical parameters. Finally, the talk connects the phenomenological gravitational wave parameters to the underlying extended Standard Model (xSM) parameters, demonstrating how SGWB observations can inform particle physics beyond the Standard Model.

Plenary / **2**

Effective field theory for general baryon-number-violating nucleon decays

Yi Liao[None] ; Xiao-Dong Ma[None] ; Hao-Lin Wang[None]

Baryon number violation (BNV) is a requisite to explain the overwhelming dominance of matter over antimatter in our Universe. Yet it has never been observed after decades of heroic searches for BNV nucleon decays. In this circumstance, it is important that all possible decays, exotic as well as conventional, should be attempted. In this talk, I will present our recent work about new BNV interactions among the nucleons, leptons, and mesons, with or without new light particles, in the framework of effective field theory. We construct the leading-order chiral Lagrangian for these general |Delta B|=1 interactions. In particular, we develop the first consistent chiral framework for nucleon decays involving vector mesons.

Plenary / **9**

Emulating gravitational wave spectra from sound waves during the cosmological FOPT

Chi Tian[None] ; Xiao Wang[None] ; Csaba Balázs[None]

We present DeepSSM, an open-source code powered by neural networks (NNs) to emulate gravitational wave (GW) spectra produced by sound waves during cosmological first-order phase transitions in the radiation-dominated era. The training data is obtained from an enhanced version of the Sound Shell Model (SSM), which accounts for the effects of cosmic expansion and yields more accurate spectra in the infrared regime. The emulator enables instantaneous predictions of GW spectra given the phase transition parameters, while achieving agreement with the enhanced SSM model within 10% accuracy in the worst case scenarios. The emulator is highly computationally efficient and fully differentiable, making it particularly suitable for direct Bayesian inference on phase transition parameters without relying on empirical templates, such as broken power-law models. We demonstrate this capability by successfully reconstructing phase transition parameters and their degeneracies from mock LISA observations using a Hamiltonian Monte Carlo sampler.

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Enhancing Phase Transition Calculations with Action Curve Fitting

Ligong Bian[None] ; Hongxin Wang[None] ; Yang Xiao[None] ; Jicong Yang[None] ; Jin Min Yang[None] ; Yang Zhang[1]

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The computation of bounce action in a phase transition involves solving partial differential equations, inherently introducing non-negligible uncertainty. Deriving characteristic temperatures and properties of this transition necessitates both differentiation and integration of the action, thereby exacerbating the uncertainty. We fit the action curve as a function of temperature to mitigate the uncertainties inherent in the calculation of the nucleation temperature, percolation temperature, and inverse transition duration. We find that, after extracting a factor, the sixth-order polynomial yields an excellent fit for the action in the toy model. In a realistic model, the singlet extension of the Standard Model, this method performs satisfactorily across most of the parameter space after trimming the fitting data. This approach not only enhances the accuracy of phase transition calculations but also systematically reduces computation time and facilitates error estimation, particularly in models involving multiple scalar fields.

Plenary / **4**

Entanglement features from intermediate heavy particle in scattering

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The amount of information propagated by an intermediate heavy particle exhibits characteristic features in inelastic scatterings with n≥3 final particles. As the total energy increases, the entanglement entropy, between its decay products and other final particles, exhibits a universal sharp dip, suppressed by its small decay rate. This indicates an entanglement suppression from a low-energy effective theory to a channel dominated by an on-shell heavy particle. As demonstrations of these entanglement features, we study concrete models of 2→3 and 2→4 scatterings, which shed light on the entanglement structure beyond the area law derived for 2→2 scattering. In practice, these features may be probed by suitably marginalizing the phase-space distribution of final particles.
References: 2507.03555

Plenary / **34**

First-order phase transitions in the early Universe: gravitational waves, black holes, and feebly-interacting particles

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The possibility of first-order phase transition in the early Universe is drawing attention in view of gravitational wave observations planned for the 2030's. In this talk I will first report updates on Higgsless simulations for gravitational wave production, and then report (negative) results regarding

primordial black hole formation from strong phase transitions. Then I will discuss possible characteristic imprints on the gravitational waves when feebly interacting particles are produced during first-order phase transitions.

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Freeze-in of Composite Dark Sector

Lingfeng Li[None]

We consider the generic picture of DM freeze-in when the dark sector is strongly coupled and confined at low energy scales. Two scenarios, namely the UV and IR freeze-in production and accompanying unique phenomena.

Plenary / **1**

Gauge-Invariant Analysis of Phase Transitions in Dark U(1) Sectors

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U(1) dark and darker sectors accommodating viable dark matter candidate(s) will be discussed. When the additional U(1) symmetry undergoes spontaneous breaking, the dark sector often exhibits a characteristic phase transition pattern capable of producing detectable gravitational wave signals. A gauge-invariant formulation of the scalar potential associated with this phase transition will be discussed in detail.

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Glueball Dark Matter

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We explore a generic class of composite dark matter candidates arising from confining dark sectors, where phase transitions—especially deconfinement-confinement and chiral symmetry breaking—can generate stochastic gravitational waves. Using a combination of lattice results and effective field theory approaches such as the Polyakov Loop and PNJL models, we analyze the dynamics of these phase transitions and demonstrate that the resulting gravitational wave signals are highly sensitive to the fermionic content and representation in the dark sector. These signals are significantly enhanced near conformal symmetry and may be detectable by upcoming experiments such as DECIGO and the Big Bang Observer.
As a concrete realization, we focus on glueball dark matter arising from a pure Yang-Mills sector, where glueballs develop axion-like couplings to photons through radiative effects induced by heavy fermion portals. These glueball ALPs (GALPs) feature a coupling-mass relation determined by two fundamental scales: the dark fermion mass and the confinement scale. Without requiring fine-tuning

or large mass assumptions, GALPs naturally populate previously unexplored ALP parameter space with suppressed electromagnetic interactions. Importantly, our framework yields a robust prediction for the GALP relic abundance—an order of magnitude below previous estimates—providing a new benchmark for both cosmological modeling and future detection strategies.

Plenary / **24**

Gravitational Waves from Sound Waves

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First-order phase transitions in the early universe can produce a stochastic background of gravitational waves (GWs), where sound waves in the plasma are expected to be the dominant source in the absence of extreme supercooling. A precise prediction of the GW spectrum therefore requires a careful treatment of the plasma dynamics. In this work we investigate three key effects: inverse hydrodynamics, the role of cosmic expansion, and the impact of time-varying bubble wall velocities. We perform a systematic analysis of these effects on the GW signal and demonstrate how they alter both the amplitude and spectral shape. Our results provide a step toward more accurate GW templates for cosmological phase transitions, which will be crucial for interpreting data from upcoming GW observatories.

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Gravitational-Wave Experiments and Collider Synergies: Unveiling First-Order Phase Transitions

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The detection of the stochastic gravitational-wave background (SGWB) offers a powerful window into both astrophysical and cosmological phenomena. In this talk, we provide a brief overview of the current status of SGWB measurements and their implications for cosmological first-order phase transitions. We explore search strategies that future space-based interferometers – using LISA as a benchmark – may employ, and present forecasts for the achievable reconstruction accuracy. The forecasts highlight the significant potential of gravitational-wave observatories to deepen our understanding of first-order phase transitions in the early universe, with profound consequences for particle physics. Indeed, by detecting or constraining the SGWB from such transitions, these experiments can prove the existence of BSM physics and/or tightly restrict the viable parameter space of particle physics models, in compelling synergy with present and future collider experiments.

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Hints of an electroweak phase transition and electroweak baryogenesis?

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We know from the discovery of the Higgs boson that electroweak symmetry is broken through the Higgs mechanism, but we expect this should be restored at high temperatures in the early universe. Thus we believe the matter in the universe underwent a dramatic change of state as the universe cooled down. Electroweak phase transitions have many important consequences, for example if strongly first order they may provide an explanation of the baryon asymmetry of the Universe and could produce observable gravitational waves. I will talk about some interesting recent developments related to these possibilities. This includes looking at whether the signal from pulsar timing arrays could originate from a supercooled electroweak phase transition and if there may already be a hint of successful electroweak baryogensis coming from flavour anomalies.

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Implications of Topological Field Configurations for Baryon Asymmetry and Dark Matter

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Topological field solutions – such as sphaleron, monopole, and cosmic strings – can have important implications on the unsolved questions of our universe, notably the origin of baryon asymmetry and the nature of dark matter. Many baryogenesis mechanisms (for example, electroweak baryogenesis and leptogenesis) depend on sphaleron transition; consequently, a theoretical rubost and consistent computation of sphaleron rate is essential. Monopoles or cosmic strings (e.g., in Abelian–Higgs models) that arise in many beyond the Standard Model (BSM) scenarios can alter the relic abundance of WIMPs and/or axion-like particles (ALPs). I discuss recent progress in computing sphaleron rate and examine the impact of topological defects on dark-matter relic densities.

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Leptogenesis triggered by an electroweak phase transition

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In this talk, I will review the new physics mechanisms based on first-order phase transitions in recent years.

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Leptogenesis via new spectator process

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In this talk, I will present a novel mechanism that may provide either the B-L violating source term or a brand-new spectator process for Leptogenesis mechanism. Given initial densities for various SM fermions that keep B-L=0, non-zero baryon asymmetry of the universe can be generated.

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Long lived Particle searches of Higgs sector

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TBD

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Machine Learning Left-Right Breaking from Gravitational Waves

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First-order phase transitions in the early universe can generate stochastic gravitational waves (GWs), offering a unique probe of high-scale particle physics. The Left-Right Symmetric Model (LRSM), which restores parity symmetry at high energies and naturally incorporates the seesaw mechanism, allows for such transitions — particularly during the spontaneous breaking of $SU(2)_R \times SU(2)_L \times U(1)_{B-L} \to SU(2)_L \times U(1)_Y$.
This initial step, though less studied, is both theoretically motivated and potentially observable via GWs.
In this talk, we investigate the GW signatures associated with this first-step phase transition in the minimal LRSM. Due to the complexity and dimensionality of its parameter space, traditional scanning approaches are computationally intensive and inefficient. To overcome this challenge, we employ a Machine Learning Scan (MLS) strategy, integrated with the high-precision three-dimensional effective field theory framework — using PhaseTracer as an interface to DRalgo — to efficiently identify phenomenologically viable regions of the parameter space. Through successive MLS iterations, we identify a parameter region that yields GW signals detectable at forthcoming gravitational wave observatories, such as BBO and DECIGO. Additionally, we analyse the evolution of the MLS-recommended parameter space across iterations and perform a sensitivity analysis to identify the most influential parameters in the model. Our findings underscore both the observational prospects of gravitational waves from LRSM phase transitions and the efficacy of machine learning techniques in probing complex beyond the Standard-Model landscapes.

Plenary / **6**

Neutrino reheating predictions with non-thermal leptogenesis

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Connecting inflation with neutrino physics through non-thermal leptogenesis via direct inflaton-right-handed neutrino (RHN) coupling naturally incorporates neutrino reheating, leaving no ambiguity regarding the early history of the Universe. We demonstrate that non-thermal leptogenesis from inflaton decay expands the viable parameter space compared to thermal leptogenesis and provides a natural link to inflation. By closely examining the dynamics of neutrino reheating, we establish a direct connection between baryon asymmetry and the spectral index for the first time. This approach places these two important observables on the same plane and yields specific predictions that help break the degeneracy among inflationary models. The well-motivated and economical framework offers a simple, natural, and testable description of the early Universe.

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New sources of gravitational waves from the early universe

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We explore new sources of gravitational waves from the early universe in well motivated new physics models.

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Numerical simulations on vacuum decay

Ligong Bian[None]

In this talk, I will review our recent progress on the numerical simulation of vacuum decay at finite temperature.

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On-shell Approaches for Gravitational Wave Physics

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The detection of gravitational waves has created a pressing need for high-precision theoretical models for binary systems. In this talk, I will review recent progress in the analytic computation of physical observables for binary black hole and neutron star systems using modern on-shell methods. This research program represents a concerted effort between the fields of quantum field theory and classical general relativity to push the precision frontier of gravitational waveform prediction. We will see how on-shell approaches, which focus directly on gauge-invariant observables, offer significant simplifications over traditional formalisms. I will conclude the talk with an outlook on future developments in this rapidly evolving field, including the growing synergy with QCD effective theories, energy correlators, and various boostrap program.

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Operator Basis Construction in Effective Field Theories and Its Applications

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We present a general algorithm—the Young Tensor Method—for systematically constructing complete and independent operator bases in effective field theories. This method is applied to a variety of theories, including the Standard Model Effective Field Theory (SMEFT) and low-energy effective field theories. In the process, we introduce the concept of the J-basis, a generalized partial wave basis that facilitates the study of partial wave unitarity bounds and enables the classification of all possible tree-level ultraviolet (UV) completions of effective operators. Furthermore, by constructing the 4-fermion operator basis in Georgi–Glashow-type models, we investigate dynamical chiral symmetry breaking using the functional renormalization group (FRG) approach.

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PBH from EWPT and its GW signal

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The PBH can be formed during a delayed EWPT. Using xSM as a benchmark, we identify the features of the parameter space that tend to generate large fraction of PBH, which can be explored by collider searches and GW experiments aiming at the GW signal from EWPT. On the other hand, the PBH can form binaries either with another PBH or with astrophysical BH. GW will also be emitted from the evolution of such binaries. We performed the analysis based on such GW signals which can also cover the interesting parameter space of BSM models.

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Perturbative cosmological phase transitions in a broad temperature range

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Cosmological phase transitions, particularly the electroweak one, continue to draw attention due to their potential to generate a stochastic gravitational wave background and to provide a possible mechanism for baryogenesis.

In this talk, I will discuss the perturbative description of such transitions, focusing on recent developments in high-temperature effective field theory (EFT) relevant to transition thermodynamics. Key aspects include the automated construction of the high-temperature EFT, the identification of the effective transition scale for nucleation, and the incorporation of the final perturbative order of soft fluctuations in the effective potential. Ultimately, by examining the structure of higher-dimensional operators in the EFT, we gain an appreciation for the limitations of the high-temperature expansion, particularly in describing the strongest transitions.

Confronted with these limitations, I will conclude by outlining old and new strategies to systematically extend perturbative control beyond the high-temperature regime, enabling descriptions valid across a broader temperature range.

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Physics Opportunities at the Muon Collider

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The muon collider, a proposed facility that combines high collision energies with a clean experimental environment, offers compelling opportunities for advancing particle physics. This talk will explore its dual strengths: enabling precision measurements within the Standard Model and extending the search for new physics. We will specifically highlight its exceptional potential for probing the quartic Higgs–gauge boson coupling, taking advantage of the dominance of vector boson fusion processes at high energies, which effectively transform the collider into a 'gauge boson collider'. Furthermore, we will discuss the unique capability of the muon collider to investigate Heavy Neutral Leptons (HNLs), emphasizing how its well-defined initial state can be exploited to distinguish between Dirac and Majorana scenarios.

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Probing Dark Matter with Gravitational-wave Laser Interferometers in Space

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interesting abstract …

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Probing Lepton-Number-Violating New Physics at Colliders

Gang Li[1]

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While lepton number is conserved in the Standard Model, its violation is a requisite for generating neutrino Majorana masses. Consequently, the search for lepton number violation is a critical pathway for elucidating the origin of neutrino mass and exploring beyond-the-Standard-Model physics. If lepton-number-violating (LNV) new physics occurs at the TeV scale, it can be assessed at colliders through direct searches for new particles and precision measurements of their couplings. In this talk, I will review recent developments, with a focus on the ultraviolet completions of the LNV effective operators and flavor effects inherent in LNV new physics.

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Probing New Physics through the Cosmological Collider

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The correlation functions of primordial cosmological perturbations encode valuable information about the early universe. In particular, higher-order correlations, known as non-Gaussianities, can reveal additional insights, including the mass and spin of heavy particles, through characteristic oscillatory signatures. Remarkably, such particles can have masses as large as the Hubble scale during inflation, far beyond the reach of terrestrial experiments. This approach to uncovering new particles through primordial non-Gaussianity is known as the cosmological collider program, and it has emerged as a promising avenue for probing physics beyond the Standard Model. In this talk, I will briefly outline the cosmological collider framework, comment on some recent developments, and discuss my own contributions to this growing field.

Plenary / 40

Probing heavy quarkonium hadronization by energy correlators

This talk discusses studies of non-perturbative (NP) effects using Energy Correlators at colliders. I will explore the adaptation of energy correlators to heavy quarkonium studies, highlighting their potential for elucidating hadronization processes.

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Radiative Corrections for Precision Neutrino Physics

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Reaching the Ultimate Quantum Precision Limit at Colliders: Conditions and Case Studies

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We investigate whether collider experiments can reach the quantum limit of precision, defined by the quantum Fisher information (QFI), using only classical observables such as particle momenta. As a case study, we focus on the $\tau+\tau-$ system and the decay channel $\tau \longrightarrow \pi\nu$, which offers maximal spin-analyzing power and renders the decay a projective measurement. We develop a general framework to determine when collider measurements can, in principle, saturate the QFI in an entangled biparticle system, and this framework extends naturally to other such systems. Within this framework, QFI saturation occurs if and only if the symmetric logarithmic derivative (SLD) commutes with a complete set of orthonormal separable projectors associated with collider-accessible measurements. This separability condition, reflecting the independence of decay amplitudes, is highly nontrivial. To meet this condition, a key requirement is that the spin density matrix be rank-deficient, allowing the SLD sufficient freedom. We show that the classical Fisher information asymptotically saturates the QFI for magnetic dipole moments and CP-violating Higgs interactions in selected phase-space regions, but not for electric dipole moments. These results bridge quantum metrology and collider physics, providing a systematic method to identify quantum-optimal sensitivity in collider experiments.

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Scalar-induced gravitational waves with non-Gaussianity up to all orders

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Scalar-induced gravitational waves (SIGWs) are ubiquitous in many early-Universe processes accompanied by non-Gaussianity; hence, precise calculations of SIGWs involve a full understanding of non-Gaussianity. Therefore, we propose to use the lattice simulations to directly calculate the energy density spectra of SIGWs with non-Gaussianity up to all orders. Our proposal has been first verified to match the existing semi-analytical results with non-Gaussianity, and then applied to more general cases, including high-order primordial non-Gaussianities, the logarithmic dependence in curvature perturbations, the curvaton model, and the ultra slow-roll model. We find that even a modest non-Gaussianity can significantly alter ultraviolet behaviors in SIGW spectra, necessitating special cautions in future detections as well as mutual constraints on/from primordial black holes.

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Search for Higgs Boson Pair Production at the ATLAS Experiment

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The study of Higgs boson pair production at the LHC and potential future high-energy colliders offers a unique opportunity to probe the dynamics of electroweak symmetry breaking. In the Standard Model, non-resonant di-Higgs production enables direct access to the Higgs trilinear self-coupling, serving as a crucial test of the Higgs mechanism. Beyond the Standard Model, both resonant and non-resonant di-Higgs production are sensitive to extensions of the Higgs sector, which could imply a first-order electroweak phase transition in the early universe. Experimentally, di-Higgs production presents a rich variety of decay channels to investigate, along with associated challenges. In this talk, I will present recent experimental results on di-Higgs production from the ATLAS experiment.

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Searching for axions with gravitational waves

In this talk, I will review recent progress of using LIGO observations to constrain parameter space of axion-like particles. I will also discuss the frontiers of understanding the co-evolution of axion clouds and binary systems, including both stellar-mass black hole binaries and extreme mass-ratio inspirals.

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Sound waves from primordial black hole formations

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We present a numerical investigation of primordial black hole (PBH) formation from super-horizon curvature perturbations and the subsequent generation and propagation of sound waves, which can serve as a new source of stochastic gravitational wave backgrounds (SGWBs) presented in a companion letter. Using the Misner-Sharp formalism with an excision technique, our simulations extend to significantly later times than previous work and indicate that the near-critical perturbations produce a distinct compression wave featuring both overdense and underdense shells, while significantly supercritical perturbations yield only an underdense shell. We also show that a softer equation of state suppresses the formation of compression waves. Furthermore, the comoving thickness of sound shells remains nearly constant during propagation and scales with the Hubble radius at horizon re-entry, thereby serving as a key link between the gravitational-wave peak frequency and PBH mass in the companion letter. These results offer new insights into the dynamics of PBH formation and suggest potential observational signatures of PBHs in the gravitational wave (GW) spectrum from associated sound waves.

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Strong backreaction of gauge quanta produced during inflation and the sourced GWs

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In this report, I will introduce our recent studies about the axion-gauge system during inflation, mainly focusing on the strong backreaction region. With a linear axion potential, we found that a steeper slope can enhance the gauge quanta production, while a larger coupling cannot increase it. We then apply this result to a realistic model with cosine axion potential, finding the quantum fluctuation can limit the max GW spectrum.

Plenary / **8**

Sub-GeV Sterile Neutrino as a Probe of Neutrino Mass Generation in the Minimal Left-Right Symmetric Model

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The minimal left-right symmetric model (mLRSM) provides an elegant and testable
framework for addressing the origin of neutrino masses. We examine the constraints on the sub-GeV sterile neutrino in the type-II seesaw scenario of the mLRSM without left-right mixing, taking limits from collider searches, meson decays, supernovae, neutrinoless double beta ($0\nu\beta\beta$) decay and cosmology. Specifically, we derive the $0\nu\beta\beta$ decay constraints using the advanced effective field theory approach and up-to-date nuclear matrix element calculations. Besides, we update the SN1987A cooling bound with the state-of-the-art simulations, provide new constraints from the energy deposition in the supernova ejecta, and incorporate the stringent sterile neutrino lifetime upper limit from the big bang nucleosynthesis. Our results identify the parameter region compatible with all current experimental and observational constraints, where the sterile neutrino mass lies between 700 MeV and 1 GeV and the right-handed W boson mass is slightly below 20 TeV. This region is exclusively probed by the future tonne-scale $0\nu\beta\beta$ decay experiments, providing a unique window to test the mLRSM and the possible origin of neutrino masses.

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Testing GUT phase transition via inflated gravitational waves

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GUT phase transition is generally considered as an unobservable process due to its ultra-high energy scale, and the monopole problem associated with GUT phase transition is one motivation of inflation. We propose that if a first-order GUT phase transition happens during inflation, the induced gravitational waves (GWs) are redshifted and deformed, and might be observed today in GW observatories. We show that the e-folding number at 15 or 25 can shift the GWs to 10 Hz or mHz hands, respectively, which might be tested in the future ground-based or space-based interferometers. Presentation based on https://arxiv.org/abs/2501.01491

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Testing Phase Transition and cosmological history at colliders

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A strong first-order electroweak phase transition (SFOEWPT) is a critical prerequisite for realizing electroweak baryogenesis in the early universe. However, lattice simulations indicate that the contribution from the Standard Model (SM) Higgs alone is insufficient to produce a strong first-order phase transition. New physics, particularly beyond-the-SM (BSM) scenarios with scalar masses around 700 GeV, is required to achieve SFOEWPT. This has motivated physicists to search for such particles at current and future colliders. In this talk, I will present two representative models that shed light on the status of electroweak phase transition searches at colliders. Additionally, I will explore how the evolution of dark matter in the early universe influences electroweak symmetry breaking.

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The roles of bound state in dark sectors

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There is a growing interesting in studying dark sectors, which are only feebly coupled to the Standard Model sector, but could be strongly self-coupled. The potential existence of bound state in dark sectors, motivated by hints of strongly self-interacting dark matter, results in novel phenomenology. This talk discusses its applications in dark matter physics and beyond, as well as the methods developed to qualitatively study such dark bound states.

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Wess-Zumino-Witten Interactions of Axions with Three-Flavor

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We present a complete Lagrangian describing axion interactions with pseudoscalar and (axial-)vector mesons within the three light-flavor quark framework. This formulation incorporates both the standard chiral Lagrangian and the full Wess-Zumino-Witten (WZW) term. By including instanton effects associated with the anomalous U(1)_A symmetry, we demonstrate that physical observables remain invariant under arbitrary chiral phase rotations of the quark fields. This comprehensive Lagrangian provides a robust and consistent framework for exploring axion phenomenology through its interactions with mesons and gauge bosons. As a demonstration, we compute the decay widths of GeV-scale axions into various mesonic final states for several benchmark axion models.