The 4th Asian-European-Institutes Workshop for BSM

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Tsung-Dao Lee Institute

Book of Abstracts

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Testability of GUTs in neutrino and GW experiments

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Grand Unified Theories (GUTs) aim to unify all fundamental particle interactions including electromagnetic, strong and weak interactions. Thanks to the recent fast progress in neutrino precision measurements and gravitational wave (GW) observations, two complementary tests become more and more important in addition to the traditional proton decay measurements. One is to test correlations of masses and mixing in the quark sector and lepton sector. Another is to measure spectrum of cosmic GW background from cosmic strings, which is predicted in most GUT framework. I will address all these phenomenological constraints on GUTs and further comment on the influence of the recent Pulsar Timing Array measurements.

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Exploring New Physics with Axion Like Particle

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Embedded within the Axion's multifaceted role in resolving the Strong CP problem and its emergence as a compelling dark matter (DM) candidate is the intriguing potential of Axion-Like Particle (ALP) DM to interact with Standard Model particles as effective magnetic fields. The search for axions is therefore crucial for uncovering new physics beyond the Standard Model.

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Cosmic magnetic monopole search experiment SCEP

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Whether the magnetic monopole (MM) exists is a long-standing question in particle physics. It is postulated to be crucially related to the quantization of the electric charge. Under the framework of the Grand Unified Theory (GUT), a certain amount of MMs are produced during the splitting between strong and electroweak forces, which occurred very shortly after the big bang. Past efforts were focused on searching for such GUT-MMs using super-conducting coils or large low-background detectors, which demand ultra-low temperatures or underground environment. In this talk, I will introduce SCEP experiment which searches for coincidental signals of MMs in high-precision magnetometers and plastic scintillators. The recent progress of the experiment will also be given.

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Constraining neutrino-dark matter interactions

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We present a comprehensive analysis of nonstandard neutrino interactions with the dark sector in an effective field theory framework. We implement the full catalog of constraints on the parameter space of the neutrino–dark matter (DM)/mediator couplings and masses, including cosmological and astrophysical bounds coming from Big Bang Nucleosynthesis, Cosmic Microwave Background, DM and neutrino self-interactions, DM collisional damping, thermal relic density, and SN1987A, as well as laboratory constraints from double-beta decays, rare meson, tau and Z boson decays. We find that most of the benchmarks in the DM mass-coupling plane adopted in previous studies to get an observable neutrino-DM interaction effect are actually ruled out by a combination of the above-mentioned constraints, especially the laboratory ones which are robust against any astrophysical uncertainty.
To illustrate the practical consequences of our new results, we take the galactic supernova neutrinos in the MeV energy range as a concrete example and highlight the difficulties in finding any observable effect of neutrino-DM interactions. Finally, we identify new benchmark points potentially promising for future observational prospects of the attenuation of the galactic supernova neutrino flux, compute the full set of cascade equations and sky maps for different DM density profiles in the Galaxy, and comment on their implications for the detection prospects in future large-volume neutrino experiments such as DUNE, Hyper-K and JUNO.

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Searching for MeV-scale Axion-like Particles and Dark Photons with PandaX-4T

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Axion-like particles (ALPs) and dark photons (DPs) are viable dark matter particle candidates that multiple underground experiments have investigated. We have searched for possible ALP/DP signals in the PandaX-4T liquid xenon detector using 94.8 days of data. A binned likelihood fit is constructed to scan for possible mono-energetic peaks induced by the absorption processes between ALPs/DPs and atomic electrons of xenon. A detailed temporal model of decays associated with xenon isotopes is introduced to constrain the number of background events. No signal excess over background expectations is observed, and we have established the most stringent exclusion limits for most ALP/DP masses ranging from 150 keV/c^2 to 1 MeV/c^2.

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Probing dark matter halos with extreme mass ratio inspirals

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Spin Asymmetry and Dipole Moments in τ-Pair Production from Photon-Photon Fusion

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The anomalous magnetic dipole moment (MDM) and electric dipole moment (EDM) of the τ lepton are vital probes for new physics beyond the Standard Model. Utilizing azimuthal angular asymmetry as an innovative tool in ultraperipheral collisions (UPCs), we achieve unprecedented precision in studying these properties. This approach, driven by the highly linear polarization of coherent photons, allows both the MDM and EDM to contribute to the $\cos 2\phi$ angular distribution with comparable significance. Crucially, our method significantly reduces the parameter space, excluding more than half of it compared to expected UPC-based measurements that rely solely on total cross-section analysis. This technique not only offers enhanced constraints but also minimizes the need for additional theoretical assumptions, providing a novel pathway for probing EDM effects.

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Belle II excess in $B + \to K + \nu \bar{\nu}$ and Muon $g - 2$ Illuminating Light Dark Sector with Higgs Portal

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The Belle II collaboration recently announced that they observed the $B+\to K+\nu\bar{\nu}$ decay process for the first time. This dineutrino mode of $B+\to K+\nu\bar{\nu}$ has been theoretically identified as a very clean channel. However, their result encounters a 2.7σ deviation from the Standard Model (SM) calculation. On the other hand, last year, Fermilab released new data on muon $g-2$ away from the SM expectation with 5σ. In this letter, we study the simplest UV-complete U(1)□μ−□τ-charged complex scalar Dark Matter (DM) model. Thanks to the existence of light dark Higgs boson and light dark photon, we can explain the observed relic density of DM and resolve the results reported by both Belle II and Fermilab experiments simultaneously. As a byproduct, the Hubble tension is alleviated by taking ΔN□□□□0.3 induced by the light dark photon.

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Dark Supercooled Phase Transition as a Key to Unlock the Universe

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We build upon 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 from a nearly conformal dark sector. The phase transition has to be strongly supercooled to explain the signal amplitude, while the critical temperature has to be in the O(GeV) range, as dictated by the peak frequency of the gravitational wave spectrum. However, the resulting 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 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, with self-interaction of the scale that is of the right order to solve the diversity problem in galactic rotation curves. Collider searches for mono-jets and dark matter direct detection experiments can dictate the viability of the model.

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Future proton decay search experiments

Grand Unified Theories (GUTs) generically predict direct transition processes between quarks and leptons, making the search for proton decay a crucial method for directly testing these theories. The current limits on the proton (and neutron) decay lifetimes have primarily been established by the Super-Kamiokande (Super-K) experiment, which utilizes the world' s largest underground water Cherenkov detector. In addition to the Super-K experiment, a few underground experiments are planned to start their data-taking in this decade, Hyper-K in Japan, DUNE in the U.S., and JUNO in China. This presentation will discuss the fundamental principles of proton decay searches, the current experimental status, and the anticipated future sensitivities of these experiments. Furthermore, it will introduce an ongoing study focused on designing a large-scale proton decay search detector in deep-water to significantly enhance the potential for discovery.

1011C / **11**

Cosmology of heavy quarks in preferred axion models

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I will discuss the cosmological impact of the heavy fermions that are often invoked in axion models that solve the strong CP problem. These additional fermions can lead to phases of early matter domination which would alter the predicted mass for axion dark matter as well as contributing to additional relativistic degrees of freedom which can be constrained by measurements of the Cosmic Microwave Background.

1009B / **12**

P and CP tests with entangled octet baryon pairs from J/psi decay

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Symmetries are at the heart of modern particle physics, and the violation of certain discrete symmetries such as parity (P) and its combination with the charge-conjugate symmetry (CP) has been playing a significant role in our understaning of nature. In this talk, I will discuss how to test the P and the CP discrete symmetries with the angular distribution of octet baryons from J/psi decay.

1008D / **13**

Gemini dark matter

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The S_8/σ_8 tension in the large scale structure can be explained by decaying dark matter with an almost degenerate spectrum and small enough decay width. Here we propose the Gemini dark matter model, which contains a heavy mother particle χ_3 and two twins $\chi_{1/2}$ which are almost degenerate in mass and are produced at the same time. The dark sector is charged under the same Froggatt-Nielsen symmetry that can explain the hierarchy of the Standard model Yukawa couplings. The slightly heavier χ_2 decays into χ_1 and the axionic component of the flavon, which washes out the small scale structure and resolves S_8/σ_8 tension. We present the production mechanism of Gemini dark matter and viable parameter regions. We find that despite the preferred dark matter mass being $\mathcal{O}(1)$–$\mathcal{O}(100)$ keV, they constitute cold dark matter. The Gemini dark matter model predicts an abundance of dark radiation that will be probed in future measurements of the CMB.

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Searching for the Origin of Cosmic Rays and New Physics with TRIDENT

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The TRopIcal DEep-sea Neutrino Telescope (TRIDENT) will instrument about 8kmˆ3 of seawater with optical detection modules approximately 3.5km deep in the South China Sea. With the use of advanced photon-detection technology in large dimensions, TRIDENT expects to observe the IceCube steady source candidate NGC 1068 within one year of operation. This telescope will open a new domain searching for the origin of cosmic rays and probing the frontier of the fundamental physics over astronomical baselines. In addition, neutrino telescopes like TRIDENT have unique potentials in BSM physics searches, this talk will review several BSM searches and provide a few highlights.

1009C / 15

Probing Light Dark Matter with Collective Excitations

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Plasmon, a collective mode of electronic excitation in solid-state detectors, provides a novel way to detect light dark matter (DM). In this work, we present the conditions of DM to produce plasmon resonance, requiring relativistic velocities for light DM, and generalize the collective excitation framework to account for relativistic DM. As a demonstration, we consider the cosmic ray boosted DM (CRDM) and find that the plasmon resonance can be significantly enhanced in the scenario with a light mediator. Utilizing the first data from the SENSEI experiment with the skipper-CCDs at SNOLAB, we obtain a new strong limit on the sub-MeV DM-electron scattering cross section.

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Two-Loop Generalized Splitting Amplitude for N=4 Super-Yang-Mills Theory

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Collinear factorization of gauge theory amplitudes is violated in the spacelike region due to the effect of long-range Coulomb interactions mediated by Glauber gluons.
We analytically calculate the spacelike collinear limit of the full color two-loop five-point amplitudes in N=4 Super-Yang-Mills theory. The result was obtained from two complementary methods. This talk will focus on the study of discontinuity of pentagon functions.
Our result explicitly shows the exponentiation of Glauber phase in the generalized splitting amplitudes. Thus we prove that factorization is restored at the level of color-summed unpolarized squared amplitudes at next-to-next-to-next-to leading order.

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New dark matter search channels at electron colliders.

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I will discuss two dark matter search channels at electron colliders.

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The minimal cosmological standard model

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I will introduce the minimal cosmological standard model, and discuss its various cosmological aspects.

1009C / 19

The PandaX-4T Dark Matter Experiment

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The PandaX-4T experiment, one of the most sensitive dark matter search experiments to date, employs a two-phase liquid/gas xenon time projection chamber containing 4 tonnes of liquid xenon. The primary goals are to detect dark matter and to probe neutrino properties. Located in the Jinping Underground Laboratory in Sichuan, China, with 2400 meters of rock overburden for shielding against cosmic radiation. This talk will provide a comprehensive overview of the detector design,

operational conditions during the science runs, and the latest findings in dark matter and neutrino physics.

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Primordial Black Hole catalyze the First-Order Electroweak Phase Transition and its Parameter Space

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We discuss the catalysis of the primordial black holes(PBH) on the first-order electroweak phase transition(FOEWPT). We accurately studied the nucleation rate for bubbles around the PBH by solving the Einstein and bounce equations rather than applying the thin-wall approximation. We found the ordinary thin-wall approximation will overestimate the nucleation rate. For the first time, we showed how the PBH altered the parameters space of new physics. We use the concrete model: the triplet extension of the standard model(ΣSM) to demonstrate this effect and found the PBH with suitable mass $M_{PBH} < 10^{11}g$ will nearly double the viable parameter space for the two-step FOEWPT in ΣSM. Those PBHs will also induce a supercooling FOEWPT in the new extended parameter regions and generate an observable stochastic gravitational wave signal without changing the observational signal for ordinary parameters space.

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Neutrinos as a window to MeV-TeV scale new physics

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Abstract: In this talk, I will discuss how neutrinos can act as a window to MeV-TeV scale new physics, including (1) searches for lepton number violation in neutrinoless double beta decay, as well as low-energy precision and high-energy collider experiments; (2) direct and indirect searches for sterile neutrinos; (3) complementary searches for neutrino non-standard interactions, charged lepton flavor violation, and dark matter.

1011D / 22

Effect of Ultralight Dark Matter on g-2 of the Electron

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If dark matter is ultralight, the number density of dark matter is very high and the techniques of zero-temperature field theory are no longer valid. The dark matter number density modifies the

vacuum giving it a non-negligible particle occupation number. For fermionic dark matter, this occupation number can be no larger than one. However, in the case of bosons the occupation number is unbounded. If there is a large occupation number, the Bose enhancement needs to be taken into consideration for any process involving particles which interact with the dark matter. Because the occupation number scales inversely with the dark matter mass, this effect is most prominent for ultralight dark matter. In fact, the Bose enhancement effect from the background is so significant for ultralight dark matter that, the correction to the anomalous magnetic moment is larger than experimental uncertainties for an effective coupling of of order 10^{-17} for a mass of order 10^{-20} eV if the dark matter is a dark photon or axion like particle. Furthermore, the constraint scales linearly with the dark matter mass and so new significant constraints can be placed on the dark matter mass all the way up to about 10^{-14} eV. Future experiments measuring $g-2$ will probe even smaller effective couplings.

1009D / **24**

Recent progress in relativistic heavy-ion collisions

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Quantum Chromodynamics (QCD) is the study of the strong interaction between quarks, mediated by gluons. Understanding strong interactions in hot and/or dense matter is one of the most challenging, yet fascinating, problems in modern physics. Under these conditions, a new state of matter called quark-gluon plasma (QGP) can be formed. QGP could potentially restore several symmetries, such as chiral symmetry, which are broken in the vacuum. The relativistic heavy-ion collisions (RHICs) experiments conducted at the Relativistic Heavy-Ion Collider (RHIC) at Brookhaven National Laboratory and the Large Hadron Collider (LHC) at CERN provide the facilities to create and study this new matter. One of the most important and surprising findings about QGP is that it is strongly interacting, as evidenced by its exceptionally small shear viscosity to entropy density ratio. I would like to discuss recent progress in the field of RHICs, including studies of its phase diagram, CP violation, spin phenomena, etc.

1009A / **25**

Recent Dark Matter Search Results from ATLAS and prospect with the DarkSHINE initiative at Shanghai

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Ref: https://arxiv.org/abs/2306.00641
Science Bulletin 2024,69(19):3005-3035 (doi:10.1016/j.scib.2024.06.003)
Results from a wide range of searches targeting different experimental signatures with and without missing transverse momentum (E) are used to constrain a Two-Higgs-Doublet Model (2HDM) with an additional pseudo-scalar mediating the interaction between ordinary and dark matter (2HDM+a). The analyses use up to 139 fb^{-1} of proton-proton collision data at a centre-of-mass energy √s = 13 TeV recorded with the ATLAS detector at the Large Hadron Collider between 2015-2018. The results from three of the most sensitive searches are combined statistically. These searches target signatures with large EmissT and a leptonically decaying Z boson; large E and a Higgs boson decaying to bottom quarks; and production of charged Higgs bosons in final states with top and bottom quarks, respectively. Constraints are derived for several common as well as new benchmark scenarios within the 2HDM+a.

Ref. https://arxiv.org/abs/2406.01656
JHEP 08 (2024) 153
A combination of searches for Higgs boson decaying into a visible photon and a massless dark photon (H→γγ) is presented using 139 fb^{-1} of proton–proton collision data at a centre-of-mass energy of √s = 13 TeV recorded by the ATLAS detector at the Large Hadron Collider. The observed (expected) 95% confidence level upper limit on the Standard Model Higgs boson decay branching ratio is determined to be Br(H→γγ) < 1.3% (1.5%). The search is also sensitive to higher-mass Higgs bosons decaying into the same final state. The observed (expected) 95% CL limit on the cross section times branching ratio ranges from 16 fb (26 fb) for = 400 GeV to 1.0 fb (1.5 fb) for = 3 TeV. Results are also interpreted in the context of a minimal simplified model.

Ref. https://arxiv.org/abs/2407.10549 & ATLAS-CONF-2024-004
A first dedicated search is performed for dark matter particles produced in association with a resonantly produced pair of b-quarks with m(bb) < 150 GeV using 140 fb^{-1} of proton-proton collisions recorded by the ATLAS detector at a center-of-mass energy of 13 TeV. This signature is expected in extensions of the Standard Model predicting the production of dark matter particles, in particular those containing dark Higgs bosons. This search uses a novel experimental method to extend the experimental reach to lower bb-pair invariant masses, considers a wider range of dark Higgs boson interpretations and excludes new regions of parameter space for this model. For dark Higgs boson masses between 30 and 150 GeV, Z′ mediator masses up to 3.4 TeV and 4.8 TeV are excluded for benchmark scenarios.

Ref. Sci. China-Phys. Mech. Astron., 66(1): 211062 (2023)
arXiv:2310.13926
arXiv:2401.15477 [DOI:10.1007/978-981-97-0065-3_19]
arXiv:2311.01780 [Nucl. Sci. Tech. 35, 148 (2024), DOI:10.1007/s41365-024-01502-5]
arXiv:2407.17800
arXiv:2407.20723
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DOI:10.1016/j.nuclphysbps.2024.06.019
DOI:10.1016/j.nuclphysbps.2024.07.008
DOI:10.1016/j.nuclphysbps.2024.06.014
DOI:10.1016/j.nuclphysbps.2024.07.003

Dark SHINE is a fixed-target experiment initiative to search for light Dark Matter and mediators at SHINE (Shanghai high repetition rate XFEL and extreme light facility, being the 1st hard X-ray FEL in China) under construction targeting completion in 2026. Dark SHINE aims to search for the new mediator, Dark Photon, bridging the Dark sector and the ordinary matter. In this work and presentation, we present the idea of this new project and 1^{st} prospective study in search for Dark Photon decaying into light dark matter. It also provides the opportunity to incorporate broader scope of BSM search ideas such as ALP, utilizing the fixed-target experiment of this type.

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Light neutrinophilic WIMP in the U(1)B–L model

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In light of the negative results from WIMP search experiments, attention has shifted toward light thermal DM. Moreover, light DM has the potential to address the core-cusp problem with its large self-scattering rate. However, such models may also predict a high annihilation rate, which could be constrained severely by gamma-ray telescopes. In our study, we explored the possibility of neutrinophilic DM within the U(1)B-L extension of the Standard Model. We conducted a phenomenological analysis of this model to identify viable parameter sets that explain the relic abundance via the freeze-out mechanism, resolve the core-cusp problem, and remain consistent with current observational constraints.

1010A / **27**

Mediator Decay through mixing with Degenerate Spectrum

The decay of the mediator particle into standard model (SM) particles plays a significant role in exploring the dark sector scenario. We consider such a decay, taking the dark photon mediator as an example that mixes with the SM photon. We find that it requires a careful analysis of the decay rate in the presence of an SM vector boson (e.g., Z boson, ρ meson, and true muonium, etc.) nearly degenerate with the mediator particle in mass. The decay rate of the mediator particle calculated in the mass eigenstate basis {\bf does not} agree with the correct result, given by the imaginary parts of the poles for the vector boson propagators, when the mixing parameter is smaller than a specific value. In such a case, the decay rate calculated by treating the mixing as a perturbative parameter is in agreement with the correct result. We clarify specific values for the mixing parameter quantitatively using several concrete examples of the SM vector bosons degenerate with the dark photon.
When the mass mixing between the vector boson and dark photon is smaller (larger) than the decay width of the vector boson, the latter (former) method to calculate the decay rate of the mediator particle gives the correct result.

1010D / **28**

UV Completion of Neutral Triple Gauge Couplings

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Neutral triple gauge couplings (nTGCs) are manifestation of new physics beyond the Standard Model (SM), as they are absent in the SM and are first generated by dimension-8 operators in the SM Effective Field Theory (SMEFT). We study the UV completion of nTGCs in a renormalizable model with vector-like heavy fermions. We compute the one-loop heavy fermion contributions to nTGC vertices by matching them to dimension-8 operators in the low energy limit. Such fermion loops contain either heavy fermions only or mixture of heavy fermions with light SM fermions. We find that their contributions can induce dimension-8 nTGC effective operators containing two SM Higgs-doublet fields, which are formulated with a complete set of 7 dimension-8 operators generating off-shell CP-even nTGCs. We present the results in terms of SMEFT coefficients and in terms of nTGC vertices (form factors) with two on-shell gauge bosons. In the heavy-light mixing case there appear terms that cannot be accommodated by conventional parametrizations of form factors due to extra logarithmic corrections. We further discuss the implications for probing such UV dynamics via nTGCs at the high energy colliders.

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Dark Matter Annihilation via Breit-Wigner Enhancement with Heavier Mediator

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We propose a new scenario that both the dark matter freeze-out in the early Universe and its possible annihilation for indirect detection around a supermassive black hole are enhanced by a Breit-Wigner resonance. With the mediator mass larger than the total initial dark matter mass, this annihilation is almost forbidden at late times. Thus, the stringent cosmic microwave background and indirect detection constraints do not apply. However, a supermassive black hole can accelerate the dark matter particles to reactivate this resonant annihilation whose subsequent decay to photons leaves a unique signal. The running Fermi-LAT and the future COSI satellites can test this scenario.

1011A / 30

Returning CP observables to the frames they belong

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Optimal kinematic observables are often defined in specific frames and then approximated at the reconstruction level. We show how multi-dimensional unfolding methods allow us to reconstruct these observables in their proper rest frame and in a probabilistically faithful way. We illustrate our approach with a measurement of a CP phase in the top Yukawa coupling.

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Multi-Higgs avenues

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I will review recent advancements in (multi-)Higgs physics to illustrate how the HL-LHC phase and future colliders can provide insight into the dynamics that address the limitations of the Standard Model of Particle Physics.

1011C / 32

Can gravitational wave detectors meet the Majoron?

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Optical interferometry used in the gravitational wave detectors is one of the most accurate measuring science. It enables us to detect a tiny deviation of phase velocity of laser light, and we can apply such a technological innovation to the axion detection by measuring the photon ' s polarization caused by axion dark matter. In this work, we clarify if the gravitational detectors can test a photon ' s birefringence caused by a new type of Majoron, electromagnetic-anomalous and behaving as dark matter, with current or future missions or not.

1010A / 33

Cosmological Tensions and Inelastical Dark Matter Model

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I will talk about a novel and comprehensive particle physics framework that addresses multiple cosmological tensions observed in recent measurements of the Hubble parameter, S8, and Lyman-α forest data. Our model, termed 'SIDR+zt' (Self Interacting Dark Radiation with transition redshift), is based on an inelastic dark matter (IDM) scenario coupled with dark radiation, governed by a U(1)_D gauge symmetry. This framework naturally incorporates cold dark matter (DM), strongly interacting dark radiation (SIDR), and the interactions between these components. The fluid-like behavior of the dark radiation component which originates from the self-quartic coupling of the U(1)_D breaking scalar, effectively mitigates both the Hubble and S8 tensions by suppressing free-streaming effects. Simultaneously, the interacting DM-DR system attenuates the matter power spectrum at small scales, potentially reconciling discrepancies in Lyman-α (Ly- α) observations.

1009A / **34**

Exploring Exotic Decays of the Higgs Boson to Multi-Photons at the LHC via Multimodal Learning Approaches

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The LHC has not yet fully constrained the physics associated with the Higgs boson, leaving room for such possibilities. Among the various potential mass scales of the dark sector, the sub-GeV mass range is particularly intriguing. This parameter space presents significant challenges for DM direct detection experiments that rely on nuclear recoils.
Due to the significantly lower mass of particles in the dark sector compared to the Higgs boson, these particles are expected to be highly boosted following the Higgs boson's decay.
We employ a well-motivated leptophobic Z'_B model as a prototype to analyze the distinctive signatures from Higgs boson exotic decays into multi-photons. These signatures consist of collimated photons that fail to meet the photon isolation criteria, forming jet-like objects. Conventional analyses relying solely on the purity of energy deposits in the electromagnetic calorimeter would fail to detect these signatures, as they would be overwhelmed by background events from Quantum Chromodynamics. To effectively distinguish between such novel signal signatures and SM background events, we leverage advanced machine learning techniques, specifically the transformer encoder in a multimodal network structure.

1010C / **35**

Extended Scotogenic Model of Neutrino Mass and Proton Decay

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In the talk, the focus will be on an extension of the classical scotogenic neutrino mass paradigm, where the three issues in particle physics: dark matter, smallness of neutrino mass, and stability of the proton are interconnected. The scenario encompasses the neutrino mass as well as the proton decay as a consequence of an existence of the dark matter. The study successfully achieves the correlation between the naturally small neutrino masses and naturally long proton lifetime in the present paradigm. Furthermore, all relevant cosmological, collider, and flavor physics constraints are incorporated in the detailed analysis. The scotogenic fermionic dark matter with the mass in the range from 100~GeV to 10~TeV successfully satisfies all relevant constraints. The valid range of $2.51 \times 10^{-5} < \lambda < 2 \times 10^{-3}$ is obtained for the 2HDM λ coupling. We give a brief discussion, as well as, outline some of the future prospects.
Other possible connections between smallness of neutrino mass and longevity of the proton will be discussed.

1011D / **36**

Axion Mass in High-Quality Axion Models

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Axions present a promising solution to the strong CP problem in the Standard Model. However, this solution relies on the existence of an almost exact global symmetry, known as Peccei-Quinn (PQ) symmetry, which is problematic because quantum gravity is believed to forbid global symmetries. High-quality axion models resolve this tension by realizing PQ symmetry as an accidental symmetry, thus bypassing the need for explicit global symmetries. These models introduce additional gauge interactions beyond the Standard Model, which may significantly influence key properties, such as the axion's mass. In this talk, I will examine whether and how these new gauge interactions affect the axion mass.

1008D / **37**

Multi-component dark matter and Galactic 511 keV γ-ray emission

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We study multi-component dark matter scenarios and the Galactic 511 keV gamma-ray emission line signal in the framework of a local, dark U(1)_D extension of the Standard Model. A light vector dark matter particle associated with the dark U(1)D may decay and annihilate to electron-positron pairs. The produced positrons may in turn form positroniums that subsequently annihilate to two photons, accounting for the observed line signal of the Galactic 511 keV γ-ray emission. Three scenarios are investigated. First, we consider the minimal U(1)D extension where a dark gauge boson and a dark Higgs boson are newly introduced to the particle content. As a second scenario, we consider WIMP-type dark matter with the introduction of an extra dark fermion which, in addition to the dark gauge boson, may contribute to the dark matter relic abundance. It is thus a multi-component dark matter scenario with a UV-complete dark U(1)D symmetry. In particular, the vector dark matter may account for a small fraction of the total dark matter relic abundance. Finally, we consider the scenario where the dark matter particles are of the FIMP-type. In this case, both the light vector and fermion dark matter particles may be produced via the freeze-in and super-WIMP mechanisms. Considering theoretical and observational constraints, we explore the allowed parameter space where the Galactic 511 keV γ-ray line signal and the dark matter relic can both be explained. We also discuss possible observational signatures.

1008B / **38**

The EDM inverse problem: Disentangling the sources of CP violation and PQ breaking with EDMs

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Nuclear, atomic, and molecular permanent electric dipole moments (EDMs) are CP-violating low-energy observables that serve as powerful probes for new physics potentially existing at high energies, above the TeV scale. An intriguing aspect of EDMs is that the ratios among them can vary based on specific ultraviolet (UV) sources of CP violation. This raises an important question: can we identify the UV origin of CP violation through multiple EDM measurements? This question may be referred to as the EDM inverse problem. In this talk, I will explore the extent to which we can address the EDM inverse problem, considering the theoretical uncertainties associated with hadronic matrix elements. In particular, I will emphasize how EDM measurements can provide insights into the origin of the vacuum expectation value of the QCD axion, which can be driven nonzero by BSM CP violation.

1011C / **39**

Leptogenesis during a First-Order Phase Transition

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The typical mass scale and dynamics of thermal leptogenesis is well understood in the 'vanilla' framework where the departure from equilibrium is driven by the expansion of the universe. As opposed to this slow expansion, a first-order phase transition offers a drastic and violent source of out-of-equilibrium dynamics. When coupled to models of baryogenesis, such as leptogenesis, there can be a significant departure from the conventional picture changing the predicted parameter space of the theory and may be connected to a cosmological breaking of B-L. Importantly, the lepton asymmetry generated from their decay can be free from the strong wash-out processes that conventional leptogenesis scenarios suffer from, although new and important washout channels are now predicted leading to a lower-bound on the possible scale of this FOPT if an enhancement is desired.

1008A / **40**

Precision Simulations and Their Limitations

In my talk I will summarise the state of precision simulations for the LHC and future accelerator-based experiments at high energies, such as the upcoming EIC and a possible lepton collider. I will also discuss some of the improvements - both in terms of theory and method development and in implementation - that are necessary to meet the accuracy goals of the experiments and to have strategic input to their programme.

1008A / **41**

Quantum Computing for High-Energy Physics

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I will start by reviewing the concepts of quantum computing. Then I will discuss how quantum computing and quantum machine learning can be used in the context of high-energy physics.

1010B / **42**

Three-zero texture of quark-mass matrices as a solution to the strong CP problem

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The strong charge-parity (CP) problem has been a long-standing problem in particle physics since 1976, illustrating the small CP-violation phase in quantum chromodynamics (QCD). The axion, based on the Peccei-Quinn mechanism, is the most popular solution to the problem. In this paper, we propose an alternative solution based on the three-zero texture of quark mass matrices without additional heavy quark states, which has been shown to fit data well. We show that the required three-zero texture is naturally constructed in a six-dimensional spacetime with a T2/Z3 orbifold compactification.

1009B / **43**

Dark energy under a gauge symmetry

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Dark energy is the least understood component of the universe despite its dominance. A proper understanding of the universe might require an investigation of the possible symmetries of the dark sector. We introduce a gauge symmetry to a quintessence dark energy field and discuss its implications.

1008D / **45**

Searching Accretion-Enhanced Dark Matter Annihilation Signals in the Galactic Centre

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This study reanalyzes the detection prospects of dark matter (DM) annihilation signals in the Galactic Center, focusing on velocity-dependent dynamics within a spike density near the supermassive black hole (Sgr A*). We investigate three annihilation processes –pp-wave, resonance, and forbidden annihilation – under semi-relativistic velocities, leveraging gamma-ray data from Fermi and DAMPE telescopes. Our analysis integrates a fermionic DM model with an electroweak axion-like particle (ALP) portal, exploring annihilation into two or four photons. Employing a comprehensive six-dimensional integration, we precisely calculate DM-induced gamma-ray fluxes near Sgr A*, incorporating velocity and positional dependencies in the annihilation cross-section and photon yield spectra. Our findings highlight scenarios of resonance and forbidden annihilation, where the larger ALP-DM-DM coupling constant Caχχ can affect spike density, potentially yielding detectable gamma-ray line spectra within Fermi and DAMPE energy resolution. We set upper limits for Caχχ across these scenarios, offering insights into the detectability and spectral characteristics of DM annihilation signals from the Galactic Center.

1011B / **46**

Current status of 2HDMs for muon g-2

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We show the implications of the muon anomalous magnetic moment for two-Higgs-doublet models (2HDMs), which are classified according to imposed symmetries and their resulting Yukawa sector. In the minimal setup, the muon g-2 can be accommodated by the type-X (leptophilic) 2HDM, flavor-aligned 2HDM (FA2HDM), muon-specific 2HDM (mu2HDM), and mu-tau-flavor-violating 2HDM. We clarify the available parameter spaces of these 2HDMs and investigate how to probe the remaining parameter regions in future experiments. In particular, we find that, the remaining parameter region of the FA2HDM is almost equivalent to that of the type-X 2HDM, and they are excluded by the latest collider searches for the muon g-2 solution.

1008B / **47**

Probing dark matter's particle physics parameters with the small scale structures

In this talk, I highlight the strong constraining power of small scale astrophysical observations. The small scales not only give us a window into the still not precisely measured small scale behaviour of dark matter, but it can also tell us about the particle physics properties of this component. We focus on the ultra-light dark matter models, specifically the fuzzy dark matter (FDM) model, since these models present a rich and distinct phenomenology on small scales. I will show how we can use the different predictions of this model and different astrophysical systems to put the strongest bounds to date on the mass of this ultra-light axion. We also show how these measurements can even give us hints on the spin, self-interaction, and fraction of these bosonic particles.

1010D / 48

Relic Neutrinos with Cosmic Gravitational Focusing

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The cosmic gravitational focusing (CGF) of relic neutrinos can provide an independent measurement of the absolute neutrino masses with a dependence on the fourth power of mass. In addition, CGF can help determine neutrino mass ordering. I will show that our projected CGF at DESI has a comparable sensitivity to the existing clustering method. Combining the projected CGF and clustering method can greatly constrain the neutrino mass and improve neutrino mass ordering from cosmology. Also, this result from cosmology can affect the prospects of neutrinoless double beta decay and single beta decay measurements.