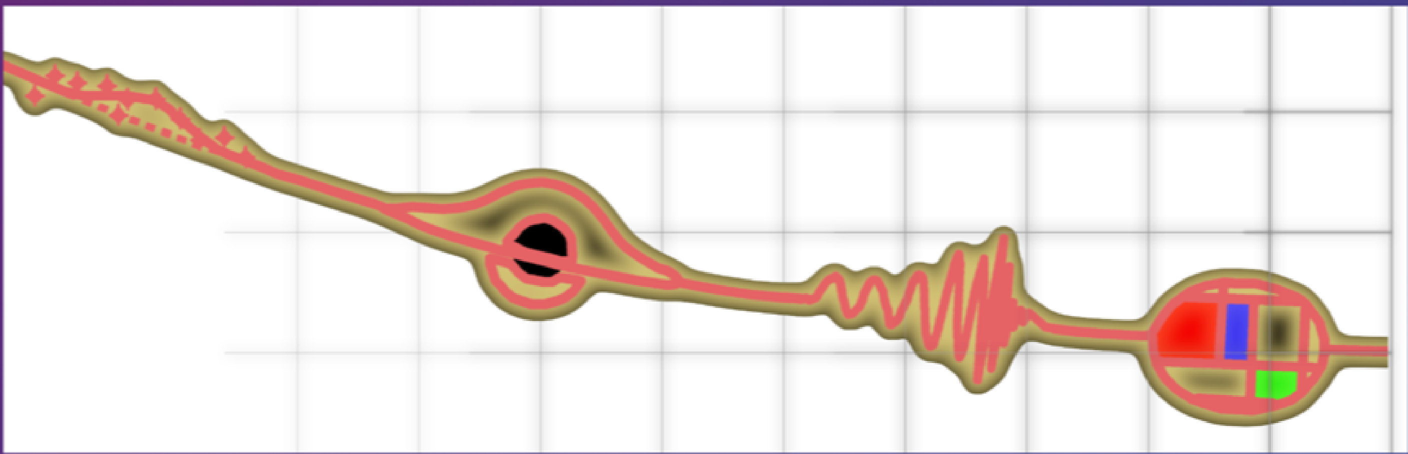
The Future is Non-Perturbative

3rd NCTS TG2.1 Hsinchu Hub Workshop
in collaboration with TG4.1

June 7 - 9, 2023, Hsinchu, TW



Topics

Dark matter, long-lived particles and neutrinos
Intersection particle & condensed matter physics
Precision QCD inputs
New computing paradigms

Sponsored by
CTC
NCTS

Organizing Committee

We-Fu Chang (NTHU)
Pochung Chen (NTHU)
Kingman Cheung (NTHU)
Chia-Min Chung (NSYSU)
Anthony Francis (NYCU)
Yi-Ping Huang (NTHU)
David Lin (NYCU)
Guey-Lin Lin (NYCU)
Martin Spinrath (NTHU)
Po-Yen Tseng (NTHU)

Keynote Speakers

Yang-Ting Chien (Georgia State U)
Shoji Hashimoto (KEK)
Cheng-Pang Liu (NDHU)
João C. Pinto Barros (ETH)
Akio Tomiya (IPUT)
Sebastian Trojanowski (NCBJ)

“The future is non-perturbative”

3rd NCTS TG2.1 Hsinchu Hub Workshop in collaboration with TG4.1

Practical information

In case of problems please contact the physics secretariat at NTHU, in particular:
Jia-Yi Hsu, jyhsu@phys.ncts.ntu.edu.tw, Tel: +886-3-5731267

Workshop location: 3F physics library in the NTHU physics building.
Address: No. 300, Section 2, Kuang-Fu Road, Hsinchu, Taiwan 30013, R.O.C.
(20 on the map), Workshop starts: 9:30 and ends 17:30.

Internet access: Eduroam is broadly available on both the NTHU and NYCU campuses. In case that does not work alternative access will be granted via guest accounts which will be provided by the physics secretariat.

Food / store options nearby: There are a number of convenience stores, canteens and restaurants near the Tsing-Hua Physics Building, both on campus and off. Some are marked with red circles on the map at the end of this booklet.

Delivery: UberEats and Foodpanda are popular apps that provide delivery options for everything from groceries to dinner to shampoo to batteries straight to your door.

Guesthouse Website: https://affairs-guesths.vm.nthu.edu.tw/en/index.php
Address: No. 101, Section 2, Kuang-Fu Road, Hsinchu, Taiwan 30013, R.O.C.
(80 on the map), Tel: +886-3-5742100, Check in: 14:00 and check out: 12:00

Welcome and motivation

Hsinchu, May 2023

It is an exciting time for particle theory as the field finds itself at the intersection of multiple, previously separated fields. Today the progress made at current and upcoming state of the art collider experiments is augmented by varied new detection principles, ranging even to gravitational wave analysis and machine learning.

In this time, where the standard model seems all but hewn in stone, we focus on the cracks in its foundations: Neutrinos, dark matter, tensions in the hadronic sector and novel condensed matter systems all point towards physics beyond what we know today. But how to interpret and understand these phenomena is difficult, partly because of a missing knowledge or appreciation of non-perturbative aspects. Bringing together the fields of non-perturbative particle and condensed matter with beyond standard model theory, we hope to push our perspective beyond the current horizon.

This event is the third installment of the workshop series *“The future is …”* initiated in 2021. After the first two installments, *“The future is dark”* and *“The future is illuminating”,* this year’s motto, *“The future is non-perturbative”,* aims to bridge the gap and to initiate the dialogue between experts in non-perturbative and beyond standard model physics. Merging and underlining the similarities between the fields towards the study of possible extensions to the standard model of particle physics we want to expand the horizon and arrive at a fuller picture of nature.

We warmly welcome you to our workshop and wish you a productive as well as inspiring time.

The organisers

Timetable

	Wednesday, 07. June	Thursday, 08. June	Friday, 09. June
9:30	**Organisers** *Welcome*	Morning welcome coffee	
10:00	**S. Trojanowski** *The Forward Physics Facility at the LHC*	**H.-N. Li** *The inverse-problem approach - a new analytical non-perturbative formalism*	J. Tristram Acuña *Probing primordial black holes from a first order phase transition…* **T. Nguyen** *Celestial Objects as Dark Matter Colliders*
11:00	**S. Kim** *Kinetic/chemical Equilibration of Heavy DM Particles in Expanding Universe via Langevin equation simulation*	**S. Hashimoto** *Taming the ill-posed inverse problem (or avoiding it): the case of spectral function*	**G. Catumba** *Scale setting and the running coupling …* **S. Aoki** *Curved domain-wall fermion and its anomaly …*
12:00	Lunch		
13:15	**J.-W. Lee** *Lattice studies of the Sp(4) gauge theory with fermions: …*	**Y.-T. Chien** *Probing hadronization and target fragments through substructure*	**C.-T. Hsieh** *Anomalies of Discrete (Gauge) Symmetries: A Modern Perspective*
14:15	Mini break		
14:30	**Akio Tomiya** *Flow based sampling for 3- and 4-dimensional model*	**C.-P. Liu** *Direct Searches of Sub-GeV Dark Matter*	**J.-C. Pinto Barros** *Towards Solving Sign Problems in Gauge Theories: …*
15:30	**C.-J. Chou** *Applications of Machine Learning on Gravitational Wave …*	**C. J. Ouseph** *Sensitivities on dark photon from the forward physics experiments*	**A. Chakraborty** Holographic study of nonperturbative features of …
16:00	Coffee break		
16:30	**G.-L. Lin** *Neutrinos*	**A. Francis** *Inverse problems*	**Y.-P. Huang** *New methods in QFT*
17:00	**C.-J. D. Lin** *BSM and QFT*	**P.-Y. Tseng** *Dark Matter*	**Open forum** *Across disciplines*
17:30	End		**Organisers** *Farewell*

List of speakers

Name	Title
Jan Tristram Acuña	Probing primordial black holes from a first order phase transition through pulsar timing and gravitational wave signals
Shoto Aoki	Curved domain-wall fermion and its anomaly inflow
Guilherme Catumba	Scale setting and the running coupling for Higgs theories on the Lattice
Adrita Chakraborty	Holographic study of nonperturbative features of 2+1D confining QCD-like YM theory on non-SUSY D2 brane
Yang-Ting Chien	Probing hadronization and target fragments through substructure
Chia-Jui Chou	Applications of Machine Learning on Gravitational Wave Research and Multi-Messenger Astronomy
Shoji Hashimoto	Taming the ill-posed inverse problem (or avoiding it): the case of spectral function
Chang-Tse Hsieh	Anomalies of Discrete (Gauge) Symmetries: A Modern Perspective
Seyong Kim	Kinetic/chemical Equilibration of Heavy DM Particles in Expanding Universe via Langevin equation simulation
Jong-Wan Lee	Lattice studies of the Sp(4) gauge theory with fermions: towards composite Higgs and composite dark matter
Hsiang-Nan Li	The inverse-problem approach---a new analytical nonperturbative formalism
Cheng-Pang Liu	Direct Searches of Sub-GeV Dark Matter
Thong Nguyen	Celestial Objects as Dark Matter Colliders
Ouseph C.J	Sensitivities on dark photon from the forward physics experiments
Joao C. Pinto Barros	Towards Solving Sign Problems in Gauge Theories: Bridging Classical and Quantum Simulations
Akio Tomiya	Flow based sampling for 3- and 4-dimensional model
Sebastian Trojanowski	The Forward Physics Facility at the LHC

Abstracts

Wednesday, 07. June

Sebastian Trojanowski
The Forward Physics Facility at the LHC

High-energy collisions at the Large Hadron Collider (LHC) produce a large number of particles along the proton beam collision axis outside of the acceptance of existing large-scale LHC experiments. Decays of forward-going hadrons produce a highly-collimated flux of neutrinos that escape proton-proton interaction points (IP) and remain undetected. Similarly, new physics species can be produced and miss observations in conventional LHC searches. A new experimental program has been proposed to address this gap and install detectors operating along the beam collision axis. These experiments have already delivered the first exciting results by observing collider neutrinos for the first time in history. While they keep operating in the ongoing LHC Run 3, we seek to extend this program in the future High-Luminosity LHC era in the proposed Forward Physics Facility (FPF). We will discuss the physics prospects of this program ranging from new physics searches to neutrino measurements with an impact on QCD and cosmic ray physics.

Seyong Kim
Kinetic/chemical Equilibration of Heavy DM Particles in Expanding Universe via Langevin equation simulation

Recently, a question about how far chemical freeze-out of heavy Dark Matter (DM) particles can be pushed down in temperature has been raised. In this case, kinetic equilibration of heavy DM through elastic collisions with strongly interacting Standard Model particles such as quarks and gluons at the temperature of a few GeV could potentially complicate the consideration. Thus, we study kinetic equilibration of heavy dark matter particles in non-perturbative regime using Langevin equation simulation. We note that the kinetic equilibration of slowly moving DM particle in the thermal bath of SM particles is analogous to kinetic equilibration of heavy quarks in Quark-Gluon Plasma and that Langevin equation method is superior to a standard formulation based on Boltzmann equation because Langevin simulation allows systematic study even in non-perturbative regime. As a concrete numerical example, we consider a scalar singlet DM particle interacting with quarks and gluons and find that the momentum distribution of DM particle retains the Gaussian form (although the spectrum becomes red-tilted) and its overall effect on the chemical equilibration of DM particles to be $O(20)$ %.

Jong-Wan Lee
Lattice studies of the Sp(4) gauge theory with fermions: towards composite Higgs and composite dark matter

Sp(4) gauge theory coupled to two fundamental flavors of Dirac fermions serves as a minimal UV model for extending the standard model based on novel composite dynamics. Particularly interesting models include composite Higgs and strongly interacting massive particles in the context of dark matter. In this talk, I will report on our recent progress in the lattice studies of this model by focusing on the mass spectra of the low-lying composite states.

Akio Tomiya
Flow based sampling for 3- and 4-dimensional model

In our study, we introduce a novel concept called CombiConv (Combinational convolution), a new type of layer in machine learning, that enhances the efficiency of flow-based sampling algorithms for lattice field theory. This CombiConv layer operates by merging the results of lower-dimensional convolutions into a higher-dimensional one, thereby using fewer parameters than traditional convolutions. When we apply this CombiConv to our flow-based sampling, we discover that it increases the success rate for 2, 3, and 4-dimensional scalar φ4 theories, especially when the value of k (the lower dimension in our convolutions) is 1. This finding suggests that our new CombiConv layer might be a promising approach to improve computational efficiency in lattice field theory computations. In my talk, I will give a brief instruction to the flow-based sampling algorithm and discuss our new development.

Chia-Jui Chou
Applications of Machine Learning on Gravitational Wave Research and Multi-Messenger Astronomy

Machine Learning can be suitable for noise subtraction, low-latency detection and sky-localization of Gravitational Wave sources which is important in Multi-Messenger Astronomy. The current status of the applications of Machine Learning in Gravitational Wave detectors (LIGO, Virgo, KAGRA) will be introduced.

Thursday, 08. June

Hsiang-nan Li
The inverse-problem approach---a new analytical nonperturbative formalism

We propose a new analytical nonperturbative formalism, in which a dispersion relation obeyed by a correlation function is treated as an inverse problem. Given the operator product expansion (OPE) of the correlation function in the deep Euclidean region as inputs, we solve for resonance properties at low energy directly from the dispersion
relation. We demonstrate the power of this approach by presenting the rho meson and glueball structures naturally appearing in the obtained nonperturbative spectral densities. The pion light-cone distribution amplitude in the whole range of a parton momentum fraction is also derived.

Shoji Hashimoto
Taming the ill-posed inverse problem (or avoiding it): the case of spectral function

Numerically reconstructing the spectral function from correlation functions in QFT is one of the famous ill-posed problem. Yet, we may consider a way to extract useful information from there. I'll discuss some application in the context of QCD.

Yang-Ting Chien
Probing hadronization and target fragments through substructure

I will discuss two aspects of nonperturbative strong interaction physics that we may have the opportunity to study with high precision at the future Electron Ion Collider (EIC). The leading dihadrons within jets and their flavor correlation points to a nonperturbative origin, which makes them an ideal system to extract properties of hadronization. Through constraining the perturbative activities we may also study the transition between perturbative regime to nonperturbative regime. On the other hand, forward detector capability may allow us to study the outcome of target fragments and nuclear breakup. By exploiting current-target correlation, we may also enhance the sensitivity to the internal structure of the proton and ions.

Cheng-Pang Liu
Direct Searches of Sub-GeV Dark Matter

In the past decade, direct searches of dark matter candidates with masses smaller than conventional weakly-interacting massive particles have become a rapidly-evolving field of dark matter physics. To look for such particles whose kinetic energies are below keV, developing particle detectors with low-thresholds have been a hot topic both experimentally and theoretically. A common feature underlying these new ideas is about the structures of the materials that make up the detectors and their responses to external perturbations. In this talk, I will give a brief overview of the current light dark matter direct searches, introduce the detector responses functions, which are the most important theory inputs for the field, and discuss the crucial roles of many-body physics at relevant scales which can be atomic, molecular, or condensed-matter.

Ouseph C.J

Sensitivities on dark photon from the forward physics experiments

Neutrino-electron scattering experiments can explore the potential presence of a light gauge bo-son A′ which arises from an additional U(1)B−L group, or a dark photon A′ which arises from a dark sector and has kinetic mixing with the SM hypercharge gauge field. We generically call it a dark photon. In this study, we investigate the effect of the dark photon on neutrino-electron scattering νe− → νe− at the newly proposed forward physics experiments such as FASERν, FASERν2, SND@LHC and FLArE(10 tons). We estimate the anticipated sensitivities to the U(1)B−L gauge coupling in a wide range of the dark photon mass MA′ . We compare the sensitivities of the proposed forward physics experiments with the current limits from TEXONO, GEMMA, BOREXINO, LSND, and CHARM II as well as NA64e experiments. We also extend the calculation to obtain the sensitivities on the kinetic mixing parameter ε in a wide range of dark photon mass MA′. We demonstrate that the sensitivities do not improve for MA′ < 1 GeV at the Forward Physics Facilities.

Friday, 09. June

Jan Tristram Acuña
Probing primordial black holes from a first order phase transition through pulsar timing and gravitational wave signals

In this work, we assessed the sensitivity of SKA-like pulsar timing measurements to probe primordial black holes, that were formed from Fermi balls that collapsed after a first order phase transition (FOPT) in the dark sector. The relevant signal that will allow us to probe these objects is the Doppler phase shift in the timing signal. Under certain conditions, we found that critical temperatures of interest lie in the 0.1-10 keV range. Knowing that FOPTs also lead to the production of gravitational waves (GWs), we proposed the idea that a simultaneous search in SKA for Doppler shifts in pulsar timing signals and stochastic GWs can be used to investigate this hypothetical FOPT scenario in the early Universe. At the fundamental level, the FOPT can be triggered by a scalar field with an associated quartic potential. We performed a parameter scan which identified the class of generic quartic potentials that could lead to FOPTs, which can be probed by pulsar timing and GW searches. The results of our scan may provide a useful reference to readily obtain phenomenological constraints on, e.g. specific models that give rise to FOPTs.

Thong Nguyen
Celestial Objects as Dark Matter Colliders

Neutron stars and Brown Dwarfs close to the Galactic center are expected to swim in a dense background of dark matter. For models in which the dark matter has efficient interactions with neutrons, they are expected to accumulate their own local cloud of dark matter, making them appealing targets for observations seeking signs of dark matter annihilation. For theories with very light mediators, the dark matter may annihilate into pairs of mediators which are sufficiently long-lived to escape the star and decay outside it into neutrinos or gamma rays. Using the dark photon mediator model, we examine the bounds on the parameter space for both sub-GeV and heavy (~ TeV to ~ PeV) dark matter theories based on this hypothesis.

Guilherme Catumba
Scale setting and the running coupling for Higgs theories on the Lattice

We study the gradient flow scale setting for a Higgs theory on the lattice. The gauge running coupling is computed for various values of the cutoff within a line of constant physics. This allows us to probe the low energy decoupling of the Higgs and W-bosons from the effective field theory description of the theory. Some preliminary results for the mass spectrum and phase structure of the two Higgs doublet model are also shown.

Shoto Aoki
Curved domain-wall fermion and its anomaly inflow

We investigate the effect of U(1) gauge field on lattice fermion systems with a curved domain-wall mass term. In the same way as the conventional flat domain-wall fermion, the chiral edge modes appear localized at the wall, whose Dirac operator contains the induced gravitational potential as well as the U(1) vector potential. In the case of S1 domain-wall fermion on a two dimensional flat lattice, we find a competition between the Aharonov-Bohm(AB) effect and gravitational gap in the Dirac eigenvalue spectrum, which leads to anomaly of the time-reversal (T) symmetry. Our numerical result shows a good consistency with the Atiyah-Patodi-Singer index theorem on a disk inside the S1 domain-wall, which describes the cancellation of the T anomaly between the bulk and edge. When the U(1) flux is squeezed inside one plaquette, and the AB phase takes a quantized value π mod 2 π Z, the anomaly inflow drastically changes: the strong flux creates another domain-wall around the flux to make the two zero modes coexist. This phenomenon is also observed in the S2 domain-wall fermion in the presence of a magnetic monopole. We find that the domain-wall creation around the monopole microscopically explains the Witten effect.

Chang-Tse Hsieh
Anomalies of Discrete (Gauge) Symmetries: A Modern Perspective

Cancellation of gauge anomalies is a fundamental constraint on a consistent quantum field theory. While the understanding of anomalies associated with continuous symmetries like U(1) is quite comprehensive, the anomalies pertaining to discrete symmetries have not been explored to the same extent. In this talk, I will present a modern perspective on discrete gauge anomalies in chiral fermion theories, building upon the theory of symmetry-protected topological phases—a concept primarily derived from advances in condensed matter physics over the past two decades. In addition to giving a reformulation of the "discrete anomaly cancellation conditions", which was first proposed by Ibáñez and Ross in 1991 [Phys. Lett. B 260 (1991) 291], I will also shed light on the role of symmetry extensions in discrete anomalies, respecting the viewpoint in the work of Banks and Dine [Phys. Rev. D 45 (1992) 1424]. The implications of our study thus offer a more profound comprehension of discrete symmetry anomalies in quantum field theory

---

Joao C. Pinto Barros
Towards Solving Sign Problems in Gauge Theories: Bridging Classical and Quantum Simulations

Classical simulations of lattice gauge theories have achieved remarkable success, while obstacles like sign problems emerging from real-time evolution or fermionic theories with finite chemical potential remain. In some instances, as in Quantum Chromodynamics (QCD), classical algorithms are not expected to entirely resolve them. The emergence of quantum simulators for gauge theories opens up a promising avenue for tackling these challenges, starting with the simulation of more tractable gauge theories using current or near-term technology.
Efficient classical approaches are not only crucial for validating quantum simulators but also serve as a means to probe quantum supremacy. This talk aims to delve into both classical and quantum approaches for tackling sign problems, with a particular focus on a novel world-line Monte Carlo algorithm. Specifically, I will discuss the extension of the meron-cluster solution to fermionic sign problems within a specific class of 1+1 gauge theories, enabling efficient classical simulations of these models. Meron-cluster algorithms represent a class of approaches capable of solving fermionic sign problems for certain models, and we demonstrate their extension to gauge theories while preserving gauge

invariance.
While these types of solutions are likely not extendable to QCD, they will play a pivotal role in exploring new physics and validating quantum simulators of gauge theories. By bridging the gap between classical and quantum approaches, we aim to advance our understanding of sign problems and pave the way for future advancements in simulating gauge theories.

Adrita Chakraborty
Holographic study of nonperturbative features of 2+1D confining QCD-like YM theory on non-SUSY D2 brane

We elucidate the nonperturbative aspects of non-conformal 2+1D Yang-Mills-like worldvolume theories on both isotropic and anisotropic non-supersymmetric D2 brane solutions of type II supergravity. Because of broken conformality, these theories possess running coupling similar to the real-world QCD. We implement the holographic notion to study some salient QCD-like confining properties, e.g., flux-tube tension and glueball masses in the low-energy nonperturbative sector of these non-SUSY theories. In the case of anisotropic D2 brane, variation of the anisotropy parameter in the low-energy scale manifests a dual picture of HP transition and QCD confinement-deconfinement phase transition from the behaviours of the above QCD features in the chosen pure YM theory. We contemplate the same from an empirical finite temperature scenario. The transition point exhibits a smooth crossover. We argue this issue by speculating the presence of "partially deconfined" mixed QCD phases where glueballs and quark-gluon plasma coexist. Holographically, one may comprehend these phases as the dual of small evaporating black holes.

Map of NTHU campus