

Quarterly Progress Report

July-September 2026

Institute of Physics, Bhubaneswar

During July-September 2026, the Institute of Physics (IOP), Bhubaneswar made significant progress across its major research programmes in theoretical and experimental condensed matter physics, high-energy physics, nuclear physics, soft matter, and statistical physics. The quarter featured peer-reviewed publications, manuscript submissions, advances in theoretical and computational studies, and continued development of experimental research and facilities. Major scientific outcomes and ongoing research activities during the period are summarised below.

1. Theoretical Condensed Matter, Soft Matter and Statistical Physics

Theoretical work by Prof. A. Saha and collaborators unveils the emergence of topological superconductivity (TSC) in twisted bilayer graphene (tBLG)-WSe₂ heterostructures within a low-energy continuum model framework. They demonstrate that the combined presence of Ising and Rashba spin-orbit couplings (SOCs) is crucial for the appearance of topological superconducting phases in tBLG, while intrinsic SOC further enhances and stabilizes these phases. The resulting phase diagrams exhibit a rich variety of topological superconducting phases characterized by the Chern number, alongside an extended nodal superconducting regime—a relatively rare feature in moiré materials. Therefore, this setup carries the potential to realize field-free TSC in proximity-coupled moiré systems. The manuscript is presently under review in *Physical Review B* as a Letter.

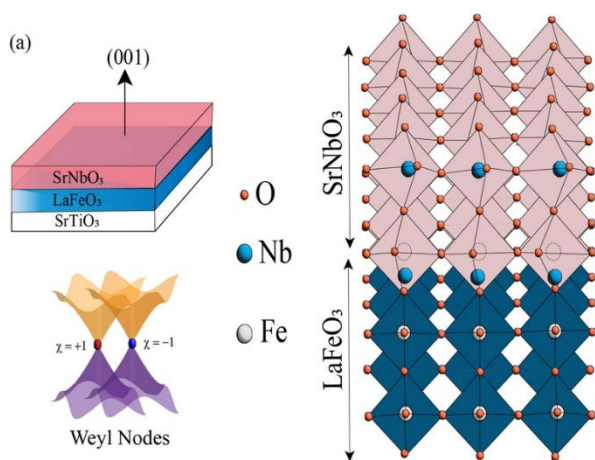
Complementing these studies on topological and quantum phases, research activities during July–September 2026 also focused on several aspects of active matter led by Prof. D. Chaudhuri. Numerical integration of hydrodynamic equations for a microscopic model of polar vectorial active matter produced a detailed phase diagram in the activity–orientational alignment parameter space, revealing pattern-forming states including polar bands and a cross-sea phase. Analytical linear stability calculations are ongoing to characterize the instabilities associated with these patterns. In a separate work, we demonstrated non-monotonic diffusivity of a driven passive particle induced by active-particle driving; the results have been communicated as *arXiv: 2607.25902*. Collaborative work on flashing ratchets was also completed and communicated as *arXiv: 2608.29991*.

In addition, theoretical studies have addressed frustrated magnetism in the Hollandite phase and its interpolation to the triangular lattice, revealing several new phases, including non-collinear and disordered states. Spin-wave spectra for these phases are currently being investigated. In studies of coupled Haldane chains, the issue of finite-energy edge states for the six-chain case has been resolved and a manuscript is under preparation. Further work is also addressing symmetry aspects of the spin-texture problem (*arXiv: 2603.11865*). During this period, work on a quantum heat engine based on the Kitaev–Heisenberg cluster was published, while the study of the Hofstadter butterfly incorporating competing effects of interaction and disorder (*arXiv:2512.15106*) was accepted in *Annals of Physics* on 29 September 2026.

2. Experimental Condensed Matter Physics

A significant advance in the area of emergent quantum materials has been achieved through the study of interface- and strain-induced electronic phases in oxide heterostructures by Prof. D. Samal and collaborators. The work provides important insights into the design and manipulation of topological

quantum phases in complex oxide systems and highlights the potential of heterostructure engineering for realizing functional quantum materials. The findings have been reported in: "S. Ithineni, P. Sahu, S. Panda, A. Mehta, D. Nayak, A. Chauhan, S. G. Bhat, N. Mohapatra, K. Senapati, B. R. K. Nanda, D. Samal, Interface and Strain Control of Emergent Weyl Semimetallic Phase in $\text{SrNbO}_3/\text{LaFeO}_3$ Heterostructures, *Advanced Functional Materials* (2026), e78127. DOI: 10.1002/adfm.78127."



Caption: a) Top left schematic illustrates the $\text{SrNbO}_3/\text{LaFeO}_3$ bilayer grown on SrTiO_3 (001). The right panel depicts the NbO_6 and FeO_6 octahedral networks in the bilayer, with Sr and La ions excluded for visual clarity. Epitaxial strain induces $a^0a^0c^-$ type octahedral rotations, while interfacial octahedral distortions lead to Nb off-center displacements, breaking inversion symmetry and generating Weyl nodes near the Fermi level in SrNbO_3 , as shown in the bottom left figure.

In another important study addressing quantum phase transitions in correlated materials, the realization of a ferromagnetic quantum critical point (QCP) has been investigated in a disordered metallic system (*Physical Review B* 114, 134428 (2026)). Realizing a quantum critical point (QCP) in clean ferromagnetic (FM) metals has remained elusive due to the coupling of magnetization to the electronic soft modes that drive the transition to be of first order. However, by introducing a suitable amount of quenched disorder, one can still establish a QCP in ferromagnets. In this study, we ascertain that the itinerant ferromagnet $\text{Ni}_{1-x}\text{Mo}_x$ exhibits a FM QCP at a critical doping of $x_c \sim 0.125$.

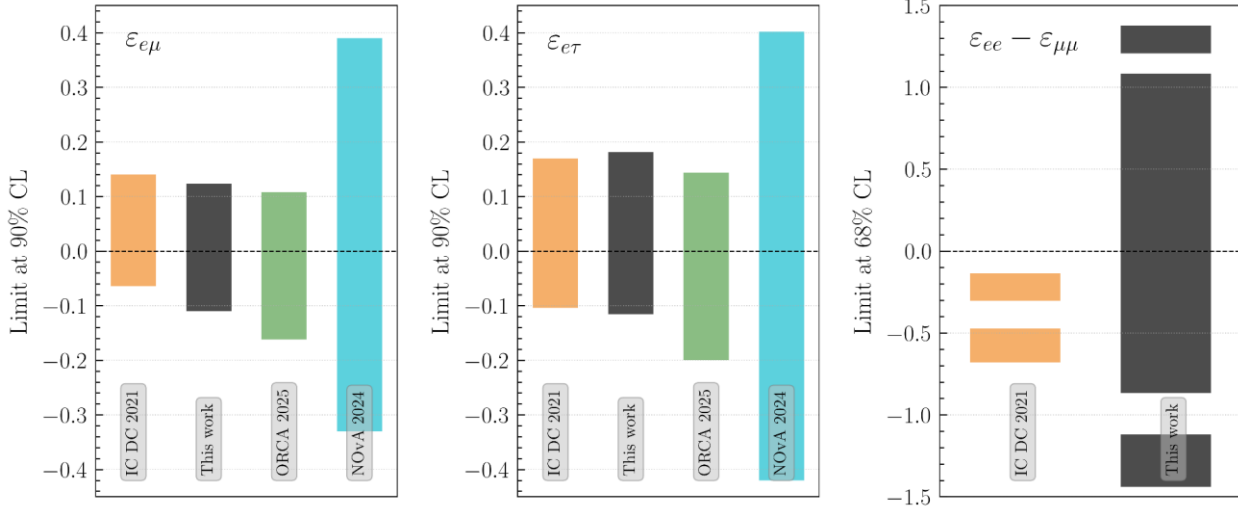
Complementing these studies of emergent phases and quantum phenomena, experimental investigations were also pursued on functional thin-film materials, particularly focusing on defect-mediated electronic transport and switching phenomena. Resistive-switching studies were carried out with emphasis on understanding the switching behaviour and the role of defects in the same. For instance, growth-parameter-dependent resistive switching studies were carried out on thin films of Ga_2O_3 and TiN_x . Such studies are important for understanding the microscopic mechanisms governing resistive switching and for exploring the potential of these materials in functional electronic and memory-device applications.

The microwave plasma chemical vapour deposition (MPCVD) system was used for the growth of single and polycrystalline diamond thin films. These studies are meant for creation of defect centres during the thin film growth and their subsequent processing.

3. High-Energy Physics

Research activities in particle and astroparticle physics during the quarter included significant advances in neutrino physics, dark matter phenomenology, and experimental searches for physics beyond the Standard Model. In neutrino physics, a publication by Prof. S. K. Agarwalla and his group in *Physical Review D* 114 (2026) 1, 015007 established robust constraints on neutrino nonstandard interactions (NSIs) using 8 years of high-purity IceCube DeepCore atmospheric-neutrino data. Notably, these constraints are independent of the unknown Dirac CP phase and complementary to accelerator-based experiments. The study demonstrated the unique capability of atmospheric neutrinos to probe new physics in neutrino propagation through Earth. By incorporating realistic uncertainties in detector, flux, cross-section, oscillation, and background, the work strengthens the experimental framework for testing physics beyond the Standard Model. It provides an important benchmark for future high-statistics atmospheric-neutrino experiments, including the IceCube Upgrade, KM3NeT/ORCA, Hyper-K and DUNE, thereby advancing the global programme of precision neutrino physics and NSI searches. This

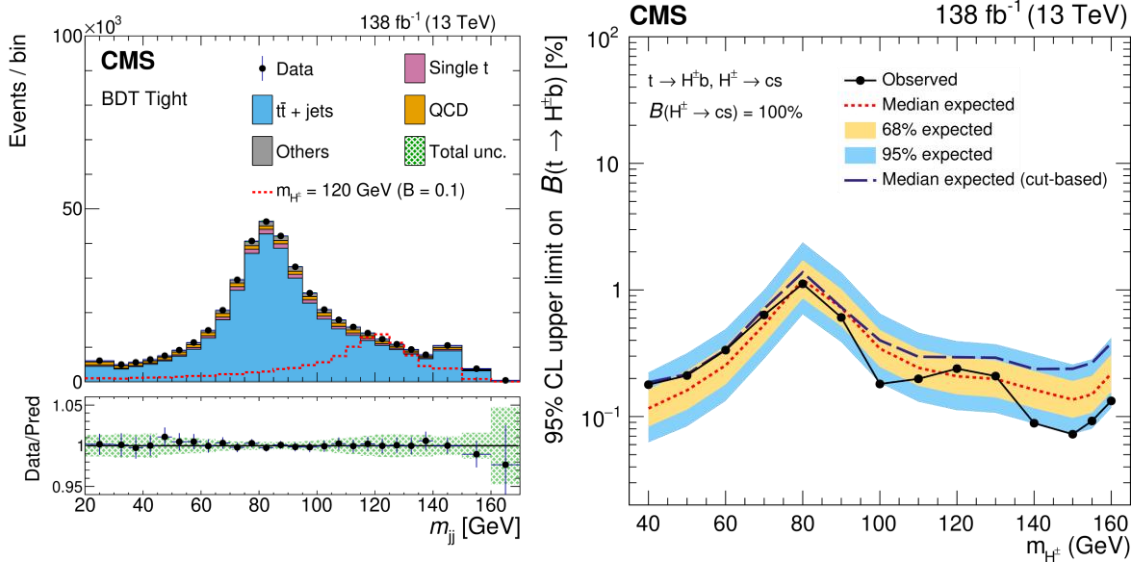
work is a complete in-house publication from the Institute of Physics, Bhubaneswar.



Caption: Constraints on the real-valued NSI parameters $\epsilon_{e\mu}$ and $\epsilon_{e\tau}$ at 90% CL, and $\epsilon_{ee} - \epsilon_{\mu\mu}$ at 68% CL from this analysis using the 8-year golden event sample of IceCube DeepCore. The NSI limits from IceCube DeepCore (2021), KM3NeT/ORCA (2025), and NOvA (2024) are also included for comparison.

Complementing these neutrino-physics studies, ongoing theoretical investigations have focused on Higgsino dark matter (DM), one of the well-motivated minimal dark-matter scenarios arising from supersymmetric extensions of the Standard Model led by Prof. D. Das. Motivated by electroweak naturalness, Higgsinos are expected to be relatively light, with masses close to the weak scale. While a pure Higgsino state typically evades current direct-detection limits, next-to-leading-order (NLO) radiative corrections may bring it within the sensitivity of upcoming experiments. Using up-to-date NLO-improved calculations of DM–nucleon scattering, the studies examine the cancellation mechanism responsible for suppressed Higgsino–nucleon scattering and identify regions of the MSSM parameter space where the spin-independent cross-section may become very small or vanish. Inelastic Higgsino-like DM–nucleon scattering through Higgs and Z exchange has also been investigated. Corresponding spin-independent inelastic scattering cross-sections for Singlino-like dark matter have been calculated in the NMSSM, and the expected number of scattering events in the latest LUX-ZEPLIN (LZ) direct-detection experiment has been evaluated. In addition, the prospects for detecting sub-TeV dark-matter scenarios through gamma-ray observations of regions surrounding the supermassive black hole Sgr A* and the black hole in the low-mass X-ray binary XTE J1118+480 have been investigated (e-Print: 2609.09830, 2609.02994, 2607.20588).

Alongside these theoretical investigations, the CMS group of IOP has completed an analysis on the search for a light charged Higgs boson, produced in the decay of a top quark, decaying to c and s-quarks ($H^\pm \rightarrow cs$) using the proton-proton collision data recorded by the CMS experiment at CERN-LHC during 2015-2018 at centre-of-mass energy of 13 TeV. The results have been published in Journal of High Energy Physics (JHEP 09 (2026) 182). The analysis used a boosted decision tree (BDT) score to categorize events, which enhances signal sensitivity. The results are the first direct limits on charged Higgs bosons produced in top quark decays for masses between 40 and 50 GeV, and the most stringent limits to date in the 70--110 GeV range, which may constrain parameter space of some of the beyond Standard Model theories that predict the existence of charged Higgs bosons.



Caption: Left: The post-fit m_{jj} distributions for data and background processes in loose, medium and tight BDT categories are shown for the combined data set. The m_{jj} variable is defined as the invariant mass of the two light jets associated with the $H^\pm$ candidate. Right: Expected and observed upper limits at 95% confidence level on the branching fraction $B(t \rightarrow H^\pm b)$ obtained using the BDT-based analysis in the combined lepton category (μ +jets and e +jets channels). The observed upper limit is below 1.1% for all assumed $H^\pm$ masses between 40 and 160 GeV.

4. Nuclear Physics

Significant progress has been achieved in the development of the ARCUS-based relativistic energy density functional, incorporating an improved description of nuclear surface properties, as proposed by Dr. M. Bhuyan. Gradient- and surface-dependent interaction terms have been explored, and their effects on finite-nucleus observables, including binding energies, charge radii, density distributions, surface diffuseness, and neutron-skin thickness, have been investigated. The parameter optimization strategy using experimental observables has also been formulated. The next phase will focus on systematic parameter optimisation, validation across isotopic chains, and investigation of shell evolution, symmetry energy, and neutron-rich nuclear matter.

5. Major research infrastructure/facility

The augmentation of the Ion Beam Laboratory has progressed rapidly during the quarter. The renovation and upgradation of the air-conditioning and chilled-water systems have been successfully completed. The Low-Energy Ion Beam Implantation Facility has also become operational and is now being actively utilized by both internal researchers and external users, thereby strengthening the Institute's experimental research capabilities and supporting a wider range of ion-beam-based research activities.

Overall Progress

Major Highlights:

- Predicted diverse topological superconducting phases in twisted bilayer graphene–WSe₂ heterostructures.
- Demonstrated strain- and interface-controlled Weyl semimetallic phases in SrNbO₃/LaFeO₃ heterostructures.
- Established robust constraints on neutrino non-standard interactions using eight years of high-purity IceCube DeepCore atmospheric-neutrino data.
- Obtained new CMS limits on light charged Higgs bosons, including the first direct limits in the 40–50 GeV mass range and the most stringent limits to date in the 70–110 GeV range.

- Commissioned the Low-Energy Ion Beam Implantation Facility, which is now operational and being utilised by both internal and external users.

The period from July to September 2026 witnessed sustained and significant progress in research and development activities across the Institute. The quarter featured important scientific outputs, including publications in peer-reviewed journals, submission of new manuscripts, advances in theoretical and computational studies, and continued progress in experimental programmes and research infrastructure. The research activities spanned a broad spectrum of contemporary areas, including condensed matter physics, active and statistical matter, particle and astroparticle physics, nuclear physics, and emerging interdisciplinary research.

Collectively, these efforts have strengthened the Institute's theoretical and experimental research capabilities, expanded its scientific contributions, and reinforced its engagement with challenging problems of national and international significance in modern physics.