Dr. Anupam Ghosh

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Personal Details

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Research Interests

- Particle physics, theoretical High Energy Physics
- Collider phenomenology
- Standard Model and BSM physics
- Dark matter phenomenology and searches at LHC and lepton collider
- Cosmology in the early Universe
- Precision higher-order computation (NLO-QCD)
- Machine Learning and data analysis

Keywords include - Boosted topology searches at the LHC, jets, fatjets, jet-substructure variables, b-jet tagging within fatjets, Multivariate Analysis, Boosted Decision Tree (BDT), study of polarization-sensitive variables, WIMP, FIMP, Axions, effective operators, multi-component dark matter, fast expansion of the universe, cosmological connection with particle physics; exotic particle searches include vector-like quarks, top and bottom quark partners, and Leptoquarks. One-loop NLO-QCD corrections for BSM particle production processes.

Publication Matrix

A full list of publications can be found in: InspireHEP, arXiv, ORCID, Google Scholar

Total Citation= 59, h-index= 05, i10-index= 03.

Publications					
Journal Name	Index	Journal Impact Factor	Number of Publication	First Author	Corresponding Author
JHEP	SCI & Scopus	5.4	2+1 (Accepted)	✓	✓
PHYSICAL REVIEW D	SCI & Scopus	5.0	2	✓	✓
Physics of the Dark Universe	SCI & Scopus	5.0	1	✓	✓
Under Journal review (arXiv)	-	-	2	✓	✓
Conference Proceedings	Scopus	-	1 (Published) 1 (Review)	✓ ✓	✓ ✓

Number of papers presented/invited talks in National/International Conferences (in person) = 06

Post Doctoral Experiences

Indian Institute of Technology Guwahati — Guwahati, Assam, India
Department of Physics — ***Dec 03, 2024*** – *Present*

- Research on High Energy Physics, Cosmology, Effective Operators, Collider and Dark matter phenomenology, and BSM physics.

Physical Research Laboratory — Ahmedabad, India
Theoretical Physics Division — ***Aug 16, 2023 – Dec 02, 2024***

- Research on High Energy Physics, Collider and Dark matter phenomenology, Leptoquarks, Vector-like quarks and leptons.

Ph.D.

Ph.D. in Physics — July 2018 – July 2023
Affiliated Institutes:
1. Physical Research Laboratory (PRL) — *Ahmedabad, India*
2. Indian Institute of Technology Gandhinagar (Degree awarded) — *Gandhinagar, India*

Thesis: *"Precision search for the new physics with hadronic final state at the LHC"*

Date of Thesis Submission: 14 July 2023
Date of Degree Award: 26 Oct 2023
Supervisor: Prof. Partha Konar (PRL) & Co-Supervisor: Dr. Satyajit Seth (PRL)

Education

Master of Science (M.Sc.) in Physics — Jun 2014 – July 2016
Indian Institute of Technology Bombay (IITB) — *Mumbai, India*
CGPA: 7.2/10.0

Bachelor of Science (B.Sc.) in Physics — Jun 2011 – Jun 2014
Burdwan Raj College, The University of Burdwan (BU) — *West-Bengal, India*
First Class Honours (70%)

Higher Secondary (H.S.) in Science — May 2009 – May 2011
West Bengal Council of Higher Secondary Education (WBCHSE) — *West-Bengal, India*
First Division (88.2%), Ranked in the top 0.1% of the board

Madhyamik (10 std.) — May 2009
West Bengal Board of Secondary Education (WBBSE) — *West-Bengal, India*
First Division (83.6%), Ranked in the top 0.1% of the board

Personal and Professional Skills

Proficient in communication, adaptable, responsible, and humble, with a never-give-up attitude and good ability in collaboration.

I have research experience on various topics, including particle physics, high energy physics, next-to-leading order (NLO) corrections, collider phenomenology, dark matter, and other exotic particle searches at the LHC. I have extensive knowledge of quantum mechanics, statistical mechanics, atomic, molecular and nuclear physics, quantum field theory, particle physics, Electroweak theory, Higgs mechanism, quantum chromodynamics (QCD), QCD beta function, one-loop

Feynmann diagram calculations. I am capable of solving hardcore theoretical problems and doing hardcore Monte Carlo simulations while handling extensive data for collider searches. I can write complicated programming codes in `C++`, `Python`, and `Mathematica`. I used advanced `Multivariate Analysis` with gradient Boosted Decision Tree (`BDT`) algorithm in our collider searches. I am experienced in calculating the `NLO-QCD` corrections for particle pairs or associated production processes at the LHC. Furthermore, I have experience in new physics model building and their searches at the collider.

Computer Application

Strong programming expertise and computational skills with a focus on `C/C++`, `Python`, and `machine learning` applications in particle physics and dark matter phenomenology.

Programming Languages:

- Proficient in `C/C++` and `Python`, with experience in developing custom analysis tools, numerical algorithms, and data pipelines.
- Working knowledge of `Fortran` and `Java` for legacy code integration and supplementary analysis tasks.

Machine Learning & Data Analysis:

- Skilled in `TMVA` and `XGBoost` for implementing gradient-boosted decision trees (`BDTs`) in classification and signal-background separation tasks.
- Proficient in `Python`-based data science tools, including `Matplotlib`, for visualization and analysis automation.

Simulation and Phenomenology Tools:

- Extensive experience with `MadGraph5_aMC@NLO`, `Pythia`, and `Delphes` for event generation, showering, hadronization and detector-level simulation.
- Extensive experience with `micrOMEGAs` and `MadDM` for relic density computation and dark matter analysis.

Symbolic Computation & Physics Model Building:

- Advanced use of `Mathematica` for solving coupled Boltzmann equations and other symbolic/numerical computations.
- Experience using `FeynRules`, `FeynArts`, `FeynCalc`, and `FORM` for new model implementation and analytical calculations.

Scientific Documentation:

- Proficient in `LaTeX` for high-quality typesetting of research papers, reports, and presentations.

Honours/ Scholarships / Awards

1. "Joint CSIR-UGC Junior Research Fellowship & Eligibility for Lecturership (NET) Exam". Roll Number - 527026, Subject- Physical Science, Total Marks obtained- 90.375, Rank- 151, ***Result: NET-JRF (CSIR)***, *Year of passing- December-2017.*
2. *"The Twentieth* ***West Bengal SET 2017*** *held on 03.12.2017"*, Roll Number – 0723233, Subject- Physical Science, Date of Qualifying- 06.06.2018.
3. "Graduate Aptitude Test in Engineering **(GATE 2018)**", Registration Number- PH18S44042090, Examination Paper- Physics (PH), *Year of passing- 2018.*

4. **INSPIRE (SHE) Fellow:** Awarded during B.Sc. and M.Sc. for **5-years (2011 - 2016)**. Awarded to top 0.1% of the qualified students in the senior secondary examinations.

5. **Merit-cum-Means Scholarship:** Awarded during Higher-secondary and B.Sc. studies for securing rank in the top 0.1% of the board exam, **5-years (2009 - 2014)**.

Presentations

Invited Talks

- **Higgs Hunting 2024, held in Orsay and Paris, France,** 23-25 September 2024, Presented a talk (in person), titled: "Inert Doublet Models: Probing Dark sector at the LHC with precision"
- **Frontiers in Particle Physics 2024** organized by CHEP, IISc Bangalore, 9-11 August 2024, Presented a talk (in person), titled: "Unveiling desert region in inert doublet model assisted by Peccei-Quinn symmetry"
- **International Conference on High Energy Particle and Astroparticle Physics 2023 (ICHEPAP2023)**, hosted by Saha Institute of Nuclear Physics, Kolkata, 11-15 December, 2023, Presented a talk (in person), titled: "Precise Probing and Discrimination of third-generation Scalar Leptoquark"
- **International Meeting on High Energy Physics (IMHEP-II)** organized by Institute of Physics, Bhubaneswar, 16-22 February 2023, Presented a talk (in person), titled: "Top-philic Dark Matter in a Hybrid KSVZ axion framework"
- **XXV DAE-BRNS High Energy Physics Symposium 2022** hosted by IISER MOHALI, Punjab, 12-16 December 2022, Presented a talk (in person), titled: "Precise probing of the inert Higgs-doublet model at the LHC"

- **YOUNG PHYSICISTS' MEET (YPM)**, 2022, organized by Physical Research Laboratory, Ahmedabad, February 23, 2022, Presented a talk (in person), titled: "On precise probing of inert Higgs doublet model at the LHC"

Oral Presentations

- **Physical Research Laboratory, India,** 29 November 2024, Presented a talk, titled: Collider fingerprints of freeze-in dark matter
- **Physical Research Laboratory, India,** July 5, 2024, Presented a talk titled: Exploring Scalar Dark Sector with Peccei-Quinn Symmetry at the LHC

Conferences/School/Workshop

- **GIAN course** on Standard Model Effective Field Theories and Application to Higgs, Neutrinos and Dark Matter, organised by the Centre of Educational Technology, IIT Guwahati, India, 9-13 December 2024
- **Higgs Hunting 2024**, held in Orsay and Paris, France, 23-25 September 2024
- **Frontiers in Particle Physics** 2024 organized by CHEP, IISc Bangalore, 9-11 August 2024
- **Workshop on Parallel Programming and Concepts of AI**, July 1-3, 2024, hosted by Physical Research Laboratory, Ahmedabad
- **Workshop on High Energy Physics Phenomenology XVII** (WHEPP), Jan 2-11, 2024, hosted by Indian Institute of Technology Gandhinagar
- **International Conference on High Energy Particle and Astroparticle Physics** (ICHEPAP) organized by Saha Institute of Nuclear Physics, Kolkata, 11-15 December, 2023
- **International Meeting on High Energy Physics** (IMHEP-II) organized by Institute of Physics, Bhubaneswar, 16-22 February 2023
- **XXV DAE-BRNS High Energy Physics Symposium** 2022 hosted by IISER MOHALI, Punjab, 12-16 December 2022
- **II Joint ICTP-Trieste/ICTP-SAIFR School** on Particle Physics, From June 22 - July 03, 2020

Teaching Experience

1. Teaching Lecture Tutorials Aug 2020 – Dec 2020
Theoretical Physics Department, Physical Research Laboratory *Ahmedabad, India*
Course Name: ***Introduction to Quantum Field Theory***
Selected to take tutorials and teach a few classes of first-year Ph.D. students.

2. Teaching Lecture Tutorials January 2020 – May 2020
Theoretical Physics Department, Physical Research Laboratory *Ahmedabad, India*
Course Name: ***Particle Physics***
Selected to take tutorials and teach a few classes of first-year Ph.D. students.

Personal Interests

Passionate about exploring diverse cultures, cuisines, and landscapes around the world. Excited about outdoor activities, particularly sea-based activities. Enjoys exploring mountainous regions and coastal beaches during travels. Since the pandemic began, I have started cooking to prepare my dinner, which helps me relax after a busy day.

Research Experience

We investigate new physics models driven by crucial theoretical and experimental considerations, such as dark matter, exotic particles beyond the Standard Model (BSM), Strong CP problem, and more. Our primary focus is to explore BSM models in detail and investigate their phenomenological signatures at the Large Hadron Collider (LHC).

✔ **One loop QCD corrections of new physics processes at the LHC:**

To enhance prediction accuracy, we include next-to-leading-order (NLO) corrections in quantum chromodynamics (QCD) for both particle pair and associated production processes at the LHC. These NLO corrections increase the total cross-sections and can substantially alter the differential distributions of various kinematic observables. Additionally, by matching the NLO fixed-order results with the parton shower, we achieve a more realistic and precise description of the entire phase space, significantly improving the overall reliability and fidelity of our simulations.

✔ **Collider Phenomenology & BSM Physics:**

- Conduct in-depth studies of Beyond-the-Standard-Model (BSM) scenarios at the LHC, including 2HDM, leptoquarks, vector-like fermions, various dark matter models, axion-like particles, top quark and bottom quark partners and many more. These BSM scenarios often predict new particle interactions, resulting in distinctive LHC signatures.

- Developed and implemented advanced signal-background analysis strategies using Multivariate Analysis (MVA) and Boosted Decision Trees (BDT) to optimize searches involving multiple kinematic observables, enhancing signal efficiency and discovery potential.

- Analyze complex and novel signatures to find anomalous events that are hidden within the vast pool of the standard model's background. The final state depends on the interactions of the new physics model. Some of the final states we analyzed at the LHC are as follows.

  1. An isolated energetic electron or muon plus multijet and a large amount of missing transverse energy. Additionally, one of the two leading jets is to be tagged as a b-jet.
  2. **Boosted Topologies:** After production, BSM particles can decay into pairs of Standard Model (SM) particles. For example, a third-generation leptoquark may decay into a top (or bottom) quark and an SM neutrino. Many dark matter models predict a rich dark sector, including dark matter candidates and other heavy particles. A heavy dark sector particle could be produced at the LHC and decay into

a dark matter candidate and SM particles. These SM particles can be a W or Z boson, a Higgs boson, or a top quark.

If there is a significant mass gap between the parent and daughter particles, the decay products will be highly boosted. This results in signatures featuring boosted top quarks or weak bosons. In search for such scenarios, we considered two types of signatures: (i) two-pronged fatjets corresponding to weak or Higgs bosons, accompanied by significant missing transverse momentum (MET), and (ii) three-pronged top-like fatjets, accompanied by MET.

- **Jet-substructure variables:**
  Large-radius fatjets can pick up additional soft contributions from underlying QCD events or pile up. To obtain more realistic predictions, removing these soft and wide-angle radiations is necessary. We use Soft Drop (SD) jets that effectively remove unassociated radiations. To characterize the internal radiation pattern of the jets, we employ substructure variables such as the N-subjettiness ratio and N-point energy correlators. These techniques help refine the jet's internal structure and enhance signal efficiency, allowing for improved signal separation from the background.

- To enhance the signal efficiency, we do a b-jet tagging within the top-fatjets, utilizing track information and Impact Parameter algorithms.

- Furthermore, we include one-loop NLO QCD corrections to the pair production or associated production processes of BSM particles at the LHC. The inclusion of these corrections helps reduce theoretical uncertainties related to scale variations (both factorization and renormalization) and refines the differential distributions of kinematic observables, leading to more accurate predictions.

- **Polarization study:** In some of our studies, we use polarization variables to differentiate between various models. For instance, third-generation leptoquark decays into a top quark and a Standard Model neutrino. Different leptoquark models predict different chiralities for the top quark arising from the leptoquark decay. To distinguish between these models, we utilize polarization-sensitive variables sensitive to the top-quark polarization. We then perform a log-likelihood ratio test to discriminate between the models.

✔ **Dark Matter Phenomenology and Searches at Collider:**

- Investigated a variety of single- and multi-component dark matter models, including Higgs-portal models (such as inert doublet and inert triplet), fermion portal models, the complex scalar extension of the KSVZ model, and top-philic dark matter scenarios, among others.

- In the case of multi-component dark matter, we conducted a detailed analysis of the WIMP-axion scenario, where both the WIMP and axion collectively account for the observed relic density. Example models studied include the complex scalar extended KSVZ model and the inert doublet model augmented with Peccei-Quinn (PQ) symmetry. Interestingly, in these models, the PQ symmetry spontaneously breaks down to a residual $\mathcal{Z}_2$ symmetry, stabilising the WIMP dark matter. Moreover, these models address two major shortcomings of the Standard Model: the strong CP problem and the dark matter puzzle.

- We explore how different processes–such as annihilation, coannihilation, and late-time decays of dark sector particles–impact the relic density and conduct a comprehensive parameter scan. Additionally, we analyze how the direct and indirect detection of dark matter are affected by new physics interactions and compare these results with current experimental limits.

- Finally, we conduct comprehensive searches for the unique topologies associated with each model at the LHC. Some of the final states include pairs of top fatjets with missing transverse momentum (MET), mono fatjet accompanied by an energetic lepton (electron or muon) plus MET, among others. After an in-depth analysis, we provide the LHC reach for current and projected luminosities for these models.

- Feebly interacting massive particles (FIMP) are very hard to probe at the LHC because of their feeble interaction. FIMP has never been in thermal contact with the SM particles, and the scattering and decay of some dark sector particles at the thermal bath populates it gradually via the so-called freeze-in mechanism. The FIMP dark matter can typically be probed at the LHC through long-lived particle or

displaced vertex signatures. We consider a minimal extension of SM, which contains a scalar dark matter (FIMP) and interacts with the SM particles through a colour triplet vector-like quark (VLQ). We study this model in the context of the fast expansion phase of the Universe. The fast expansion of the Universe significantly alters the dark matter phenomenology, requiring a substantial increase in the interaction rate to match the observed relic density, resulting in the prompt decay of the VLQ. As a result, much of the parameter space for this scenario is beyond the reach of traditional long-lived particle and displaced vertex searches. Due to this non-standard cosmic evolution, existing constraints do not cover the expanded dark matter parameter space. We propose a complementary search strategy to explore this FIMP dark matter model at the LHC. In our search, we investigated the FIMP dark matter model at the LHC using boosted fatjets and significant missing transverse momentum, and we found that a vast parameter space for this minimally extended model could be probed at the LHC.

✔ **Machine Learning in Collider Physics:**

Machine learning (ML) has become a cornerstone of modern collider phenomenology. ML techniques enable more efficient signal-background separation, enhance event selection, and optimize searches for new physics, particularly in environments where traditional methods struggle. At the LHC, ML is instrumental in improving the discovery potential for BSM particles and dark matter candidates, especially when dealing with tiny and complex signals probably hidden within overwhelming SM backgrounds.

Multivariate Analysis with Boosted Decision Trees (BDT): One of the key ML techniques we use is multivariate analysis with Boosted Decision Trees (BDT) algorithm. This method allows us to combine a large number of kinematic observables, such as transverse momentum, invariant mass, missing transverse energy, jet substructure variables and others, into a single classification tool. By training the BDT on simulated signals and background events, we can effectively differentiate between anomalous signal processes and background events. The adaptive nature of BDTs makes them particularly useful in high-dimensional feature spaces, where traditional cut-based methods would be inefficient or too simplistic.

References

Name: **Partha Konar** (PhD Supervisor) Designation: Professor Department: Theoretical Physics department Address: Physical Research Laboratory, Ahmedabad, India Phone: +91 79 2631 4479 E-mail: **konar@prl.res.in**	Name: **Satyajit Seth** (PhD Co-Supervisor) Designation: Associate Professor Department: Theoretical Physics department Address: Physical Research Laboratory, Ahmedabad, India Phone: +91 79 2631 4456 E-mail: **seth@prl.res.in**
Name: **Ritesh K. Singh** (Collaborator) Designation: Professor Department: Department of Physical Sciences Address: Indian Institute of Science Education and Research Kolkata, India Phone: 033 6136 1294 E-mail: **ritesh.singh@iiserkol.ac.in**	

A. In Refereed Journals/arXiv:

* indicates the Corresponding Author.

1. **Jet Substructure Probe on Scalar Leptoquark Models via Top Polarization**
   Anupam Ghosh*, Partha Konar, Tousik Samui, Ritesh K. Singh
   [arXiv:2505.16328] (Accepted for publication in JHEP.)

2. **Collider fingerprints of freeze-in production of dark matter amidst the fast expansion phase of Universe**
   Anupam Ghosh*, Partha Konar, Sudipta Show
   [arXiv:2411.09464] (Minor revision from PRD)

3. **Unveiling desert region in inert doublet model assisted by Peccei-Quinn symmetry**
   Anupam Ghosh*, Partha Konar
   JHEP09(2024)104 [arXiv:2407.01415]
   Journal: JHEP, **Volumn:** 09, **Pages:** 104, **Month:** September, **Year:** 2024,
   Journal Impact Factor: 5.4, **SCI & Scopus** Indexed, Scimago Journal Rank (SJR): Q1,
   DOI: 10.1007/JHEP09(2024)104

4. **Precision prediction of a democratic up-family philic KSVZ axion model at the LHC**
   Anupam Ghosh*, Partha Konar
   Phys.Dark Univ.47(2025)101746 [arXiv:2305.08662]
   Journal: Physics of the Dark Universe, **Volumn:** 47, **Pages:** 101746, **Year:** 2025,
   Journal Impact Factor: 5.0, **SCI & Scopus** Indexed, Scimago Journal Rank (SJR): Q1,
   DOI: 10.1016/j.dark.2024.101746

5. **Precise probing and discrimination of third-generation scalar leptoquarks**
   Anupam Ghosh*, Partha Konar, Debashis Saha, Satyajit Seth
   PHYSICAL REVIEW D 108, 035030 (2023) [arXiv:2304.02890]
   Journal: PHYSICAL REVIEW D, **Volumn:** 108, **Pages:** 035030, **Month:** August, **Year:** 2023,
   Journal Impact Factor: 5.0, **SCI & Scopus** Indexed, Scimago Journal Rank (SJR): Q1
   DOI: 10.1103/PhysRevD.108.035030

6. **Top-philic dark matter in a hybrid KSVZ axion framework**
   Anupam Ghosh*, Partha Konar, Rishav Roshan
   JHEP12(2022)167 [arXiv:2207.00487]
   Journal: JHEP, **Volumn:** 12, **Pages:** 167, **Month:** December, **Year:** 2022,
   Journal Impact Factor: 5.4, **SCI & Scopus** Indexed, Scimago Journal Rank (SJR): Q1
   DOI: 10.1007/JHEP12(2022)167

7. **Precise probing of the inert Higgs-doublet model at the LHC**
   Anupam Ghosh*, Partha Konar, Satyajit Seth
   PHYSICAL REVIEW D 105, 115038 (2022) [arXiv:2111.15236]
   Journal: PHYSICAL REVIEW D, **Volumn:** 105, **Pages:** 115038, **Issue:** 11, **Month:** June, **Year:** 2022,
   Journal Impact Factor: 5.0, **SCI & Scopus** Indexed, Scimago Journal Rank (SJR): Q1
   DOI: 10.1103/PhysRevD.105.115038

B. Chapter/Conference Proceedings:

1. **Precise probing of the inert Higgs-doublet model at the LHC**
   Anupam Ghosh*, Partha Konar, Satyajit Seth
   Springer Proc.Phys. 304 (2024) 128-132,
   Contribution to: 25th DAE-BRNS High Energy Physics Symposium,

Journal: Springer Proc. Phys., **Volumn:** 304, **Pages:** 128-132, **Month:** July, **Year:** 2024,
DOI: 10.1007/978-981-97-0289-3_27

Self attested,

Anupam Ghosh.