Prince Kumar

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github.com/princek880
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EDUCATION

Indian Institute of Technology Madras, India **2022 – 2026**
Engineering Physics B.Tech. (Hons.), Mathematics Minor, Computing Minor CGPA: **9.05 / 10.00**

EXPERIENCE

Summer Research Intern† (RPIT) || HEP & SEMI-SUPERVISED ML **Jun 2025 – Aug 2025**
PI: Dr. Matthew Nguyen, Dr. Shamik Ghosh *LLR, École Polytecnique, France*

- Developing a graph neural network-based clustering algorithm to group tracks originating from a common decay vertex in pp collisions within the CMS experiment for analyzing jet substructure.
- Evaluating clustering performance using t-SNE visualizations with `NetworkX` graphs and Adjusted Rand Index (ARI) scores.

Young Research Fellow† (YRF Funded) || HEP & SUPERVISED ML **Jun 2024 – May 2025**
PI: Dr. Prabhat Pujahari *EHEP Lab, IIT Madras, India*

- Worked on classification of tracks originating from b-hadron decays in pp and PbPb collisions in CMS at $\sqrt{s}$ = 5.02 TeV, with a focus on studying dead cone effect and other b flavor physics.
- Developed a novel track classifier using Graph Neural Networks (GNNs), tagging b jets as an auxiliary task [1].
- Built an end-to-end deep learning pipeline: processing `HDF5` files into `GNN` training-compatible graph datasets, training and testing with `pytorch` and `torch-geometric`, and generating informative evaluation plots.
- Implemented custom preprocessing using `uproot` and `awkward-array` to convert `ROOT` files, apply physics-based cuts, perform event-jet-track matching via `pandas`, and batch the data into `HDF5` files for scalable training.

Undergraduate Researcher || FIRMWARE DEVELOPMENT **Nov 2024 – May 2025**
PI: Dr. Prafulla Kumar Behera *HEP Lab, IIT Madras, India*

- Worked on `MALTA-to-FPGA` communication firmware for next-gen readout chain for the ATLAS experiment.
- Executed complete design-to-deployment workflow on ALINX FPGA board, including simulation, synthesis, and successful `JTAG`-based configuration using Vivado FPGA Design Suite.
- Conducted packet analysis between PC and FPGA board using loopback via Wireshark for effective debugging.
- Ported firmware from KC705 with `Kintex7` to AXKU040 with `Kintex Ultrascale` FPGA, adapting `SGMII` to `RGMII` for `MAC-PHY` Ethernet communication.

Undergraduate Researcher || HEAVY ION PHYSICS ANALYSIS **Sep 2024 – Jan 2025**
PI: Dr. Prabhat Pujahari *EHEP Lab, IIT Madras, India*

- Developed a custom gen fragment for $\Lambda_b \to \Lambda^0(p\pi^-) + J/\psi(\mu^+\mu^-)$ in PbPb collisions – filter efficiency 1.3×10^{-6}.
- Performed full Monte Carlo production using the `CMSSW` framework, from generator-level raw data to miniAOD.
- Designed and deployed a `CRAB3` configuration optimized for large-scale production, generating >1M rare events.

Undergraduate Researcher || COMPUTER VISION **Jan 2024 – May 2024**
PI: Dr. Kaushik Mitra *Computational Imaging Lab, IIT Madras, India*

- Developed `GAN`-based models with `UNET` architecture for flare artifact removal using restoration techniques.
- Utilized synthetically generated flare images from `flare7kpp/Flickr24` datasets for training & testing models.
- Integrated Uformer, Restormer, NAFNet, Mamba blocks, and Retinexformer into the GAN-UNet codebase.
- Achieved PSNR (23.52) and SSIM (0.66) scores, while also enabling extension of the flare removal to videos.

NOTABLE PROJECTS

AstroStellar Simulation (N-Body Simulation) **Jun 2023 – Mar 2024**
Centre for Innovation (CFI) *IIT Madras, India*

- Collaborated with a team of 7 to develop a `C++` code modeling N-body gravitational interactions in `3D space`.
- Generated initial galaxy conditions using grid-based, angular, and radial Gaussian mass distributions.
- Solved Hamiltonian dynamics using `Leapfrog` and `Runge-Kutta` integrators for accurate numerical evolution.
- Parallelized code to simulate over 1 Million particles and visualized the simulation results in `MATLAB`.

Speaker and LED Composite System **Jan 2024 – May 2024**
Course Project – EE2019 Analog Systems and Lab *IIT Madras, India*

- Designed & demonstrated a composite analog system to synchronize light & sound with real-world functionality.
- Integrated `DC-DC` converter-based LED driver, bandpass filters, adder, peak detector, and Class-D audio amplifier.
- Analyzed and resolved circuit non-idealities to realize clean signal filtering and modulation.
- Simulated and validated the system in `LTSpice`, showcasing analog design proficiency; awarded highest grade.

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TECHNICAL SKILLS

Programming Languages: C/C++, Python, MATLAB, VHDL, Pythia, HTML, CSS
Data Analysis Tools: ROOT, uproot, Keras, Scikit-Learn, Numpy, Scipy, Pandas, Matplotlib, Wireshark, NetworkX
Hardware Devices: Oscilloscopes, Multimeters, Function Generators, Op-amps, Xilinx FPGA, Optical CMM (Zeiss)
Computer-Aided Design: Vivado Design Suite, KiCAD PCB Designer, LTSpice, AutoCAD, Blender
Productivity Softwares: MacOS, Windows, Linux (Ubuntu), Bash/zsh, Git(Gitlab & Github), VSCode, Canva, LaTeX

POSTERS AND PUBLICATIONS

[1] CMS Collaboration, "A novel track finding algorithm to identify b-hadrons in b-jets using FusionNet: a geometric deep learning model." CMS-DP-2025-035, 2025.

[2] P. Kumar on behalf of the CMS Collaboration, "B-hadron identification in b-jets using a novel deep learning technique in pp and PbPb collisions in CMS." Poster presented at the European Committee for AI in Fundamental Physics (EuCAIF) Conference (106), Sardinia, Italy, 2025.

[3] P. Kumar, S. Ghosh, P. Pujahari, M. Nguyen, "B-hadron identification in b-jets using a novel deep learning technique in pp and PbPb collisions in CMS." Poster presented at All India Research Scholars Summit (AIRSS), IIT Madras, India, 2025.

[4] AstroStellar Team (incl. P. Kumar), "Galaxy Collision Simulation with Adaptive N-body Integration." Poster presented at CFI Open House 2024, IIT Madras, India.

AWARDS AND ACCOMPLISHMENTS

- **Research Program for International Talents (RPIT) Fellowship**, École Polytechnique **2025**
  Selected for a 3-month paid research internship at Laboratoire Leprince-Ringuet (LLR) in expt. high-energy physics.
- **CMS Collaboration Member**, CMS Experiment, CERN **2024**
- **Young Research Fellowship (YRF) Award**, IIT Madras **2024**
  Selected as one of 17 Young Research Fellows from a pool of 300+ students for funded undergraduate research.
- **Ranked Top 5** in Engineering Physics Department, IIT Madras **2024**
- **Ranked Top 5% nationally** among 150,000 students in Joint Entrance Examination (JEE) Advanced, India **2022**
- **Ranked Top 1% nationally** among 1 million students in Joint Entrance Examination (JEE) Mains, India **2022**

KEY COURSES TAKEN

Physics: Quantum Mechanics, Classical Dynamics, Mathematical Physics, High Energy Physics, Statistical Physics, Electromagnetics & its Application, Quantum Field Theory*, Solid State Physics, Advanced Quantum Mechanics.

Mathematics: Mutivariable Calculus, Series & Matrices, Algebraic Topology, Differential Equations, Combinatorics.

Electrical: Circuits and Networks, Analog & Digital Systems, Digital & Analog Signal Processing, Solid State Devices.

Computational: Programming in Python, Computer Vision, Modern Scientific Computing, Computer Architecture*.

VOLUNTEERING AND EXTRACURRICULARS

Saathi – Undergraduate Student Mentor **July 2024 – Present**

- Guiding 4 college junior undergraduate students, helping them navigate from school to college and hostel life.

Shiksha Prayas – Student Mentor **Jan 2023 – March 2024**

- Mentored two underprivileged high school students from Haryana, guiding them in their academic and personal development, leading to significant improvement and satisfactory board exam results.

Global Engagement Council – Manager **Jan 2023 – March 2024**

- Prepared a Semester Exchange BlueBook benefiting 1,000+ students, organized a University Fair with 10+ universities, and conducted an information session for 300+ students.