Raghav **Kansal**

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Professional Experience

California Institute of Technology & Fermilab — *Pasadena & Chicago, USA*
Schmidt AI Postdoctoral Fellow — *2024 -*

Education

UC San Diego, CERN, and Fermilab (AI Fellow and Graduate Scholar) — *La Jolla, USA; Geneva, Switzerland; and Chicago, USA*
PhD in Physics, **GPA: 3.97/4.00** — *2019 - 2024*
Dissertation: *Understanding the High Energy Higgs Sector with the CMS Experiment and Artificial Intelligence*

UC San Diego — *La Jolla, USA*
BS in Physics & Computer Engineering, **GPA: 3.98/4.00**, *summa cum laude* — *2015 - 2019*
Divisional and Departmental Highest Honors

Selected Publications

Primary contribution

[1] CMS Collaboration, "Search for a massive scalar resonance decaying to a light scalar and a Higgs boson in the two b quarks and four light quarks final state", *in prep*, CMS-B2G-23-007 (2024).

[2] CMS Collaboration, "Combination of searches for nonresonant Higgs boson pair production in proton-proton collisions at $\sqrt{s} = 13$ TeV", *in prep*, CMS Physics Analysis Summary CMS-HIG-20-011-PAS (2024).

[3] CMS Collaboration, *Search for Nonresonant Pair Production of Highly Energetic Higgs Bosons Decaying to Bottom Quarks and Vector Bosons*, CMS Physics Analysis Summary CMS-HIG-23-012-PAS, 2024.

[4] R. Kansal et al., "JetNet: A Python package for accessing open datasets and benchmarking machine learning methods in high energy physics", **JOSS 8**, 5789 (2023).

[5] R. Kansal et al., "Evaluating generative models in high energy physics", **Phys. Rev. D 107**, 076017 (2023), arXiv:2211.10295.

[6] R. Kansal et al., "Particle Cloud Generation with Message Passing Generative Adversarial Networks", **NeurIPS** (2021), arXiv:2106.11535.

[7] R. Kansal et al., "Graph Generative Adversarial Networks for Sparse Data Generation in High Energy Physics", **NeurIPS ML4PS Workshop** (2020), arXiv:2012.00173.

Mentorship and other contributions

[8] S. Katel*, H. Li*, Z. Zhao*, R. Kansal, et al., "Learning symmetry-independent jet representations via jet-based joint embedding predictive architecture", **NeurIPS ML4PS Workshop** (2024), arXiv:2412.05333.

[9] A. Li*, V. Krishnamohan*, R. Kansal, et al., "Induced generative adversarial particle transformers", **NeurIPS ML4PS Workshop** (2023), arXiv:2312.04757.

[10] Z. Hao, R. Kansal, et al., "Lorentz group equivariant autoencoders", **Eur. Phys. J. C 83**, 485 (2023), arXiv:2212.07347.

[11] F. Mokhtar, R. Kansal, and J. Duarte, "Do graph neural networks learn traditional jet substructure?", **NeurIPS ML4PS Workshop** (2022), arXiv:2211.09912.

[12] CMS Collaboration, "Search for Nonresonant Pair Production of Highly Energetic Higgs Bosons Decaying to Bottom Quarks", **Phys. Rev. Lett. 131**, 041803 (2023), arXiv:2205.06667.

[13] M. Touranakou et al., "Particle-based fast jet simulation at the LHC with variational autoencoders", **Machine Learning: Science and Technology 3**, 035003 (2022), arXiv:2203.00520.

[14] F. Mokhtar, R. Kansal, et al., "Explaining machine-learned particle-flow reconstruction", **NeurIPS ML4PS Workshop** (2021), arXiv:2111.12840.

[15] S. Tsan, R. Kansal, et al., "Particle graph autoencoders and differentiable, learned energy mover's distance", **NeurIPS ML4PS Workshop** (2021), arXiv:2111.12849.

Honors and Awards

2023 **Fermilab LPC Graduate Scholarship** *Fermilab*
For searches for flavour changing neutral currents, ML for simulation, and self-supervised learning for jet classification.

Nov 2021 **2021-22 Carol and George Lattimer Graduate Award for Excellence** *UCSD Division of Physical Sciences*
For "interdisciplinary approaches to problem solving and strong commitment to education, mentorship, and service."

2021-2022 **Fermilab LPC Artificial Intelligence Fellowship** *Fermilab*
For graph-based fast simulation models, ML techniques for reconstruction, compression, and anomaly detection tasks, and a boosted Higgs boson graph classifer for precision measurements. Full description.

Aug 2019 **CERN Openlab Summer Students Lightning Talks Award Runner-Up** *CERN*
For the talk 'Deep Graph Neural Networks for Fast HGCAL Simulation'

Jun 2019 **2019 IRIS-HEP Fellowship** *IRIS-HEP*
For the project 'HGCAL Fast Simulation with Graph Networks'

Jun 2019 **2019 John Holmes Malmberg Prize** *UCSD Department of Physics*
Presented annually at commencement to a graduating physics student for excellence in experimental physics.

May 2019 **2018-2019 Physical Sciences Dean's Undergraduate Award for Excellence** *UCSD Division of Physical Sciences*

Jul 2018 **2018 William A. Lee Undergraduate Research Award** *UCSD Division of Physical Sciences*
For the project 'Arbitrary ultra-cold atomic lattices using holographic optical tweezers'

Selected Talks and Posters

A complete list, as well as links, slides, posters, and videos are available at raghavkansal.com/talks.

Mar 2024 **US FCC Workshop** *MIT (Talk)*
Machine learning for future collider simulations

Feb 2024 **JHU HEP Seminar** *Johns Hopkins (Invited Talk)*
Generative transformers and how to evaluate them

Jan 2024 **SLAC FPD Seminar** *SLAC (Invited Talk)*
Enabling Di-Higgs and High Luminosity Discoveries with Machine Learning

July 2023 **BOOST Conference** *LBNL (Poster)*
Boosted Multi-Higgs with Jets in CMS

July 2023 **UC Irvine Machine Learning Seminar** *UC Irvine (Invited Talk)*
Generative transformers and how to evaluate them

Jun 2023 **CMS Deep Dive on Fast Simulation Techniques** *CERN (Talk)*
Evaluation metrics for fast simulations

June 2023 **PHYSTAT-2sample Workshop** *Virtual (Talk)*
Applications of two-sample goodness-of-fit tests to generative models

May 2023 **USCMS Collaboration Meeting** *Carnegie Mellon (Talk & Poster)*
Machine Learning for CMS FastSim

Dec 2022 **CMS Offline and Computing Upgrade R&D Meeting** *CERN (Talk)*
FastSim on GPUs

Nov 2022 **Foundation Models and Detector Simulation Workshop** *CERN (Invited Talk)*
Generative transformers and how to evaluate them

Sep 2022 **PyHEP 2022** *Virtual (Talk)*
JetNet library for machine learning in high energy physics

Sep 2022 **Machine Learning at the Galileo Galilei Institute Workshop** *Florence (Discussion)*
Generative Modelling for Physics

Sep 2022 **Machine Learning at the Galileo Galilei Institute Workshop** *Florence (Invited Talk)*
Particle Cloud Generation with Message Passing GANs

Jul 2022 **CMS Machine Learning Townhall 2022** *CERN (Invited Talk)*
Overview and Outlook: Machine Learning for Simulation

Jul 2022 **LPC Physics Forum** *Fermilab (Invited Talk)*
Machine Learning for LHC Simulation

Dec 2021 **NeurIPS 21 Main Poster Session** *Virtual (Poster)*
Particle Cloud Generation with Message Passing GANs

Nov 2021 **University of Washington EPE Machine Learning Seminar** *Virtual (Invited Talk)*
Particle Cloud Generation with Message Passing GANs

Nov 2021 **LPCC FastSim Workshop** *Virtual (Invited Talk)*
Validation Techniques for Machine-Learned FastSim

Jun 2021 **Mainz Institute for Theoretical Physics Machine Learning for Particle Physics Workshop** *Virtual (Invited Talk)*
Particle Cloud Generation with Message Passing GANs

Mar 2021 **James Madison University Artificial Intelligence and Machine Learning Seminar** *Virtual (Invited Talk)*
Graph Generative Adversarial Networks for High Energy Physics Data Generation

Mar 2021 **Berkeley Institute for Data Science Generative Models for Fundamental Physics Meeting** *Virtual (Invited Talk)*
Graph Generative Adversarial Networks for High Energy Physics Data Generation

Feb 2021 **Imperial College London DataLearning Seminar** *Virtual (Invited Talk)*
Graph Generative Adversarial Networks for High Energy Physics Data Generation

Aug 2019 **CERN Openlab Lightning Talks** *CERN (Talk)*
Deep Graph Neural Networks for Fast HGCAL Simulation, Runner-Up Award

Aug 2018 **William A. Lee Undergraduate Research Award Poster Presentations** *UCSD (Poster)*
Arbitrary Positioning and Manipulation of Ultra-Cold Atoms with Optical Tweezers

Projects

Searches for high energy Higgs boson pair production
github *Jun 2020 -*

- Leading the analysis of 2022-2024 CMS data looking for boosted Higgs pairs decaying to four beauty quarks.
- Led the analysis of 2016-2018 CMS data looking for two Higgs bosons (H) decaying to beauty quarks (b) and vector bosons (V).
- Developed a state-of-the-art transformer network to classify between H→VV jets and backgrounds.
- Led as well the search for new Higgs-like particles (X, Y) decaying to beauty quarks and vector bosons.
- Expect to set strong limits on Higgs to VV couplings and X→HY cross sections.

ML for Fast Simulations
GAPT **MPGAN** **slides** **github** *Jun 2019 -*

- Led effort to develop a graph-based generative adversarial network, MPGAN, which has proven effective at simulating particle collisions.
- Developed as well the faster attention-based generative adversarial particle transformer (GAPT), using set transformers.
- Developed efficient and sensitive two-sample goodness-of-fit tests for validating fast simulations.
- Working on extending to conditional generation and application to detector data.

JetNet Library and Dataset
github **website** *Sep 2021 -*

- Developed a library for convenient access to jet datasets, and other utilities, to increase accessibility and reproducibility in ML in particle physics.
- >50,000 downloads as of September 2024, used in several ML and particle physics projects.

Lorentz-Group Equivariant Networks
LGAE paper **PGAE paper** **review** *Dec 2020 - April 2023*

- Developed a graph-based autoencoder (PGAE) for compression of and anomaly detection in Large Hadron Collider data.
- Wrote a review of deep learning models that are equivariant to physics-relevant group transformations for the UCSD group theory course.
- Led to developing a graph-based autoencoder equivariant to Lorentz group transformations as well (LGAE).
- LGAE outperformed CNN and GNN autoencoders for compression and anomaly detection tasks.

ML for Particle Flow Reconstruction
paper **github** *May 2021 - Dec 2021*

- Developing graph neural networks to perform event reconstruction in the CMS experiment at CERN.
- Interpreted results using the Layerwise Relevance Propagation (LRP) method.

Explainable Machine Learning
GNNs paper **MLPF paper** *May 2021 - Dec 2022*

- Interpreting results of machine learning models for reconstruction and jet classification using explainable AI techniques.

Tutorials
2019 -

- Author of online statistics for HEP tutorials: https://rkansal47.github.io/stats-for-hep
- Co-author and maintainer of Fermilab LPC's ML Hands-on Advanced Tutorials: https://fnallpc.github.io/machine-learning-hats

Open Source Software Contributions **github** *2019 -*

- Lead developer of the popular JetNet Python package for ML in particle physics, >35,000 downloads as of March 2023.
- Maintainer of the fastjet Python package and interface for jet algorithms; contributor to several scikit-hep (Scientific Python for HEP) libraries.
- Contributed statistical methods to the rhalphalib and combine libraries for limit setting in particle physics.
- Contributed to PyTorch CUDA kernels for linear algebra.

Optical Tweezers and a Quantum Gas Microscope **poster** *Jun 2017 - Jun 2019*

- Created dynamic, sub-micron holographic optical tweezers and a Quantum Gas Microscope with sub-micron resolution in order to manipulate individual atoms (or qubits) for quantum computing and quantum information science experiments.
- This work won a William A. Lee Research award, and will be published soon.

GRAD: An interactive graph-based degree planning app **github** *Jan 2017 - Mar 2017*

- Created an app for visualizing course requirements with a user-friendly UI.
- I was the Back-end and Algorithms Lead for a team of 10, and personally wrote the server, scraping, and graphing algorithms for the app.
- We were one of 8 finalists out of 60 projects in the UCSD 2018 software engineering course.

Students Mentored

Andres Nava (Undergrad / SURF Program, Caltech) **github** *Jun 2023 —*

- HH→bbVV measurement in the VBF production mode.

Parveen Narula (Undergrad / USCMS PURSUE Program, Beloit) *Jun - Aug 2023*

- Early Run 3 boosted H→bb studies.

Zhaoyu (Tina) Zhang (Undergrad, UCSD) **github** *Aug 2022 —*

- GAPT for detector simulations.

Anni Li (Undergrad / IRIS-HEP Fellow, UCSD), now MS at USC **paper** **github** *Jan 2022 - Sep 2023*

- Generative adversarial particle transformers.

Rounak Sen (MS, UCSD) **github** *Mar 2023 —*

- GAPT for detector simulations.

Venkat Krishnamohan (MS, UCSD), now at Taskrabbit **github** *Jan - Aug 2023*

- Conditional generative adversarial particle transformers.

Carlos Pareja (Undergrad / EXPAND Program, UCSD) **paper** **EXPAND program** *Jan 2022 —*

- JetNet library and website

Saloni Agarwal (Undergrad / EXPAND Program, UCSD) **EXPAND program** *Jan - Aug 2022*

- JetNet library and website

Farouk Mokhtar (Grad, UC San Diego) **paper 1** **paper 2** *Jul 2021 — Dec 2022*

- Explainable machine learning for reconstruction and classification.

Ish Kaul (Undergrad / SURF program, Princeton) **github** *Jul - Sep 2021*

- Graph neural network regression for the mass of Higgs Boson jets

Priya Kamath (High School, San Diego)
Andy Cabrera (Undergrad, UNAM, Mexico)
Pablo Gomez (Undergrad, Yucatán, Mexico) **ENLACE program** **project** *Jul - Sep 2021*
Saul Glez (Undergrad, Atlixco, Mexico)
Tonatiuh Meneses (Researcher, Huichapan, Mexico)

- Learning Python and front-end development for the JetNet library and website

Steven Tsan (Undergrad, UCSD) **paper** **github** *Jan 2021 —*

- Graph neural network autoencoder for anomaly detection.
- Particle cloud diffusion models.

Zichun Hao (Undergrad, UCSD), now PhD at Caltech **paper** **github** *Jan 2021 - June 2023*

- Lorentz-equivariant autoencoder for anomaly detection.
- H→VV graph neural network classifier.

Teaching Experience

Fermilab LPC Hands-on Advanced Tutorials **website** *2021 —*

- Co-authored and led the machine learning Hands-on Advanced Tutorials (HATS) for CMS students in 2022 and 2023.
- Developed lectures and interactive exercises for deep neural networks, convolutional neural networks, and generative modeling in HEP.

Fermilab LPC Data Analysis School **website** *2022 —*

- Facilitator for the 2022–2025 data analysis schools (DAS) for CMS students.
- Co-ordinated machine learning and top mass measurement exercises.

UC San Diego Physics Department *2017 — 2021*

- Teaching assistant for the undergraduate introductory classical mechanics and quantum mechanics courses for four quarters.
- Tutor at the undergraduate tutorial center for all introductory courses for six quarters.

Service Work

- Organizer of the 2023 PHYSTAT-2sample workshop on two-sample goodness-of-fit tests.
- Reviewer for the PRD, JINST, and CSBS journals.
- Reviewer for the 2021 and 2022 NeurIPS ML4PS Workshops, and the 2023 ICML SynS & ML Workshop.