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Ultra-High-Resolution Detector Simulation with Intra-Event Aware GAN and Self-Supervised Relational Reasoning

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Simulating high-resolution detector responses is a storage-costly and computationally intensive process that has long been challenging in particle physics. Despite the ability of deep generative models to make this process more cost-efficient, ultra-high-resolution detector simulation still proves to be difficult as it contains correlated and fine-grained mutual information within an event. To overcome these limitations, we propose Intra-Event Aware GAN (IEA-GAN), a novel fusion of Self-Supervised Learning and Generative Adversarial Networks. IEA-GAN presents a Relational Reasoning Module that approximates the concept of an ''event" in detector simulation, allowing for the generation of correlated layer-dependent contextualized images for high-resolution detector responses with a proper relational inductive bias. IEA-GAN also introduces a new intra-event aware loss and a Uniformity loss, resulting in significant enhancements to image fidelity and diversity. We demonstrate IEA-GAN's application in generating sensor-dependent images for the high-granularity Pixel Vertex Detector (PXD), with more than 7.5M information channels and a non-trivial geometry, at the Belle II Experiment. Applications of this work include controllable simulation-based inference and event generation, high-granularity detector simulation such as at the HL-LHC (High Luminosity LHC), and fine-grained density estimation and sampling. To the best of our knowledge, IEA-GAN is the first algorithm for faithful ultra-high-resolution detector simulation with event-based reasoning

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