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Physics Informed Neural Networks for design optimisation of diamond particle detectors for charged particle fast-tracking at high luminosity hadron colliders

The next generation of tracking detectors at upcoming and future high luminosity hadron colliders will be operating under extreme radiation levels with an unprecedented number of track hits per proton-proton collision that can only be processed if precise timing information is made available together with state-of-the-art spatial resolution. 3D Diamond pixel sensors are considered as a promising technology to design such future detectors thanks to diamond radiation hardness and high charge carrier mobility, potentially resulting in excellent timing resolution.

Charge collection in 3D diamond detectors is usually obtained by using femtosecond pulses of infrared laser light to induce a phase transition of the diamond lattice to a mixture of graphite and amorphous carbon, which results in conductive electrodes although with relatively high resistivity. The description of ionising particle induced signals in such devices is complicated by the fact that the electric field in the material is modified by the signal propagation through the resistive electrodes, thus requiring an extended application of the classical Ramo-Shockley weighting potential methods. The optimisation of the design of these detectors from the point of view of space and time resolution requires therefore innovative signal simulation techniques.

We discuss a novel approach relying on the numerical resolution of a 3rd order, 3+1-dimensional partial differential equation (PDE) to describe the effect of signal propagation through the resistive electrodes as a time-dependent Ramo-Shockley weighting potential, then integrated with third-party software applications modelling the charge carrier transport across the detector material.

We discuss how such PDE can be obtained as the quasi-stationary approximation of Maxwell Equations and different approaches to their solution for the 3D geometry of the proposed diamond sensors.

Using a small portion of data obtained from an ad hoc devised Spectral Method simulation, we trained a Mixture-of-Experts Physics Informed Deep Neural Network, using Kolmogorov-Arnold Networks (KANs), MLPs and FourierNet as models, and various optimisation recipes, to obtain a meshless solver and used it to infer the effect of the electrode resistance on the time resolution of the diamond detector.

We conclude discussing how a parametric PINN may help in the optimisation of diamond detector design and, more generally, in the study of radiation detectors embedding resistive charge collection elements.

AI keywords

Physics Informed Neural Network; Kolmogorov-Arnold Network; Mixture-of-Experts; surrogate model

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Track Classification: Simulations & Generative Models