NPTwins 2026

Digital Twins for Nuclear and Particle Physics

Workshop Summary · ECT* Villa Tambosi, Trento · 11–15 May 2026

3rd edition · Genova 2024 → Messina 2025 → Trento 2026

Organizers: M. Battaglieri (INFN-GE) · Y. Li (Old Dominion Univ.) · A. Pilloni (Univ. Messina)

23 presentations · 6 tracks · 1 hackathon · ~60 participants

Programme Structure

Large Language Models

D.T. Murnane (Niels Bohr Inst.)

Deep Learning

N. Sato (JLab)

Real-Time AI Acquisition

M. Liu (BNL), L. Pontisso (INFN-RM)

AI for NP/HEP Theory

M. Letizia (CERN), G. Montaña (Barcelona)

Data Analysis

P. Di Nezza (INFN-LNF), R. Tyson (Glasgow)

Digital Twins

T. Britton & T. Jeske (JLab)

🔬 **Special Event — Hackathon on Digital Twins**

Wed. 13 May · Flow Matching surrogate models · 1000× faster detector simulation

Org: N. Karthik (W&M) & F. Vaselli (INFN-PI)

Keynotes & Invited Talks

Opening & Invited Talks

The big picture: data strategy, PDFs, and amplitude analysis

Genesis Mission through the Data Lens

Laura Biven (Chief Data Officer, Jefferson Lab) · Mon 11 May

DOE's Genesis Mission: connecting the fastest supercomputers, AI systems, and quantum computers with the nation's premier scientific instruments to 10–100× accelerate discovery. JLab's strategy for AI-driven data management at the EIC scale.

Global Fits of PDFs: the NNPDF Framework

Tommaso Giani · Mon 11 May

Neural-network parton distributions: methodology, uncertainty quantification, and lessons for digital-twin-style PDF inference.

Extracting Regge & Resonance Parameters with AI

Adam Szczepaniak (IU/JLab – JPAC) · Mon 11 May

AmplAI: physics-constrained generative model inverting petabyte-scale GlueX/CLAS data to recover scattering amplitudes at the complex-pole level.

Diffusion-Based Inference for Inverse Problems in Nuclear and Particle Physics

Yaohang Li (Old Dominion Univ.) · Tue 12 May

Active diffusion inference for ill-posed inverse problems: QCF parameterization and TMD extraction from SIDIS data.

Track · Deep Learning | AI for NP/HEP Theory

Physics Extraction & Interpretation

Learning QCD structure from data with ML-native approaches

Neural Network Extraction of Unpolarized TMDs

Chiara Bissolotti (Argonne NL) · Tue 12 May

First NN-based 3D transverse-momentum-dependent PDF extraction (PRL 135, 2025). Map of quark momentum distributions in the nucleon — 3D momentum portrait.

Analysis of Nucleon Spin Structures

Tianbo Liu (Shandong Univ.) · Tue 12 May

Quasi-PDF / lattice QCD approach to polarized gluon distributions $\Delta g(x)$. Renormalized matrix-element matching to light-cone PDF via perturbative QCD.

Reconstruction of Scattering Amplitudes with Physics-Informed GANs

Glòria Montaña (Univ. Barcelona & ICCUB) · Tue 12 May

GAN-based framework with built-in analyticity and unitarity for exotic hadron spectrum reconstruction. Tetraquarks, pentaquarks, and hybrid mesons from amplitude-level inversion.

Machine Learning for Hadronization and Unfolding

Ayodele Ore · ECT Trento*

Simulation-based inference (SBI) for modelling hadronization and for multidimensional detector unfolding — enabling unbinned, full-phase-space analyses.

Diffusion Models for Unfolding Detector Effects

Giorgio Foti (UniME & INFN Catania) · NPTwins 2026

Generative diffusion model for full posterior unfolding $P(\text{true}|\text{measured})$ applied to the CLAS detector at JLab — bypassing binning and response-matrix inversion.

Track · Deep Learning | AI for NP/HEP Theory

Generative Models & Lattice QCD

From gauge-equivariant diffusion to fast EIC simulation

Diffusion Models for Lattice Field Theories

Andreas Ipp (TU Wien) · Mon/Tue 2026

Generalizable equivariant diffusion models with Metropolis-adjusted annealed Langevin (MAALA) for U(2) and SU(2) non-Abelian gauge theories (arXiv:2601.19552). Lattice-CNN (L-CNN) architectures enforce gauge equivariance exactly.

Foundation Models for Fast Simulation & PID with Cherenkov Detectors

James Giroux (William & Mary / Cristiano Fanelli group) · Mon 11 May

Mixture-of-Experts foundation model for the hpDIRC (EIC) and GlueX DIRC: combines discrete + continuous detector data, enables conditional generation, particle ID, and noise filtering 1000× faster than Geant4 (arXiv:2604.24775).

ML for Charged Particle Tracking at GlueX

Ahmed Mohammed (JLab team) · Mon 11 May

Graph Neural Networks for track finding and Kalman-filter replacement at GlueX. GNNs outperform combinatorial algorithms and scale linearly with multiplicity — a critical bottleneck for future high-luminosity running.

Track · Real-Time AI Acquisition

Real-Time AI & Fast Control

Embedding ML into detector readout at microsecond latency

FAN-C: Real-Time Science with Fast Adaptive Neural Control

Nhan Tran (Fermilab) · Wed 13 May

Fast Adaptive Neural Control (FAN-C): FPGA-deployed neural networks at the CMS trigger level with µs latency. Adaptive online learning for real-time beam control and anomaly detection. Comparable throughput to global internet bandwidth.

FELIX: A Generic Platform for AI/ML in NPP Experiments

Hao Xu et al. (BNL) · Thu 14 May

FELIX (Front-End Link eXchange): open-source FPGA-based readout platform in ATLAS, ALICE, sPHENIX, ePIC, DUNE. Streaming readout + real-time ML inference at the front end.

Spiking Neural Networks for the ePIC dRICH

Pierpaolo Perticaroli (INFN Roma) · NPTwins 2026

Neuromorphic SNNs for online data reduction on the EIC dual-radiator RICH detector (300k SiPM channels). Target: 5× bandwidth reduction before the DAM FPGA stage.

Real-Time AI Triggering for SST-1M Telescope

Jakub Kvapil (SST-1M Collab.) · Thu 14 May

Gamma/hadron separation with ML in real-time Cherenkov telescope triggering. Deployed on SST-1M; input to CTAO design.

AI-Optimized Polarization at JLab (AIOP)

Patrick Moran (JLab AI&M) · NPTwins 2026

Digital twin of the GlueX diamond radiator goniometer: RL agent optimises coherent bremsstrahlung polarization in real time at sub-milliradian precision.

Track · Data Analysis | Digital Twins

Data Analysis & Digital Twins

End-to-end AI/ML in running experiments

AI/ML at CLAS12

B. Tyson (Glasgow Univ.) · Tue 12 May

Full AI/ML lifecycle at CLAS12 (JLab): denoising tracking detectors, track finding with GNNs, particle ID, fast simulation surrogates, and a chatbot assistant for experimenters. Blueprint for digital-twin-enabled experiments.

AI/ML Analysis of Nucleon Spin Structure

Spinstructure talk · Tue 12 May

NN-based extraction of transversity and TMD fragmentation functions from SIDIS data across HERMES, COMPASS, Belle. Uncertainty propagation through a neural network ansatz.

Neural-Network Extraction of TMDs (Bissolotti)

Chiara Bissolotti (ANL) · Tue 12 May

First complete NN-based 3D fit: unpolarized TMDPDFs and TMDFFs across SIDIS, Drell-Yan and e+e− data, with Monte Carlo uncertainty sets. PRL 135, 021904 (2025).

Digital Twin of the GlueX Polarimeter (AIOP)

Patrick Moran et al. (JLab) · NPTwins 2026

Closed-loop digital twin of the GlueX coherent bremsstrahlung system: real-time sensor fusion, surrogate physics model, and RL-based goniometer control for maximal beam polarization.

0512_DigitalNPTwins: Bissolotti (ANL) — May 12

Neural-network TMD fits (detailed)

Map C lab collaboration. Phys. Rev. Lett. 135, 021904 (2025). Extension to polarized sector in progress with Valerio Bertone, Matteo Cerutti, Simone Rodini.

Track · Large Language Models

LLMs & AI Agents in HEP

From documentation bots to autonomous physics agents

AI Agents Can Already Autonomously Perform Experimental HEP

Eric A. Moreno (+ Andrzej Novak, Sam Bright-Thonney, Dolores Garcia, Phil Harris) · NPTwins 2026

Based on arXiv:2603.20179: an AI agent completes a full HEP analysis pipeline — from raw data to publication-quality results — without human intervention. Raises urgent questions about what physicists should focus on to remain irreplaceable.

LLM Systems in High Energy Physics

Gabriel Facini (UCL) · Thu–Fri 2026

Survey of LLM deployments at ATLAS (6000 physicists, 40 countries): documentation chatbots, analysis assistants, onboarding accelerators. What works, what fails, and where LLMs connect to digital twins.

Supporting Theory Simulations with LLMs (MadAgents)

Daniel Schiller (+ Tilman Plehn, Nikita Schmal) · Fri 15 May

MadAgents (arXiv:2601.21015): LLM-powered agents that write, debug, and run MadGraph5 Monte Carlo simulations autonomously. Demonstrated on BSM signal generation and SM background estimation.

NPTwinsAgents: Conditional Flow Matching & DeepTS at JLab

JLab team · NPTwins 2026

Flow Matching surrogates for JLab particle physics; DeepTS: LLM-powered AI assistant curating 700+ time-series datasets with FAIR metadata for ML benchmarking in HEP.

Special Event

Hackathon on Digital Twins

Wednesday 13 May · 10:00–16:30 · ECT Villa Tambosi · Open to students from Trento, Padova, Milano, Ferrara*

Goal

Train a 1000× faster detector surrogate

Participants build a generative model mimicking a heavy physics simulation of a detector response — matching Geant4 quality at a fraction of the compute cost.

Algorithm

Flow Matching (modern diffusion variant)

Flow Matching learns optimal noise-to-data paths via ODEs. Trains efficiently on CPU/Colab. Modern, elegant, and directly applicable to physics simulation.

Format

Scaffolded notebooks in Python/PyTorch

Fill-in-the-blank code: participants implement physics logic and loss functions. Heavy engineering (data loading, network architecture) provided. Starter Kit circulated in advance.

Org

N. Karthik (W&M) & F. Vaselli (INFN-PI)

Lecture notes and supporting material provided. Outcome: every participant leaves with a working generative surrogate model.

Key Themes & Take-Aways

Generative models are the new default

Flow Matching, diffusion models, and GANs appeared in every track — from lattice gauge theory (Ipp, TU Wien) to detector simulation (Giroux, Foti), PDF extraction (Bissolotti), and the hackathon. Fast surrogates are now standard practice.

Physics constraints must be built in

Analyticity & unitarity in GANs (Montaña), gauge equivariance in L-CNNs (Ipp), S-matrix foundations in AmplAI (Szczepaniak): physics-informed ML consistently outperforms black-box approaches in data efficiency and interpretability.

Real-time AI is production-ready

FPGA-deployed nets (Tran/FAN-C), FELIX readout platform (Xu, BNL), SNN triggering (Perticaroli, Kvapil): ML is live inside running detectors at ATLAS, CMS, ALICE, ePIC, SST-1M — not just prototypes.

LLMs & agents are entering physics workflows

Autonomous HEP agents (Moreno et al.) complete full analyses. MadAgents (Schiller) automates MadGraph. ATLAS chatbots are deployed. The field is asking hard questions about what physics humans uniquely contribute.

EIC / ePIC is the shared horizon

Multiple talks converged on the EIC: dRICH SNNs (Perticaroli), hpDIRC foundation models (Giroux), ePIC streaming readout (FELIX), TMD fits for EIC predictions (Bissolotti, Li). Digital twins will be central to EIC operations.

Digital twins closing the loop

The GlueX AIOP talk (Moran) demonstrated a full closed-loop digital twin: sensor fusion → surrogate physics model → RL control → real hardware. The vision of NPTwins is becoming operational reality.

Next edition: NPTwins 2027 · indico.ectstar.eu/event/264