

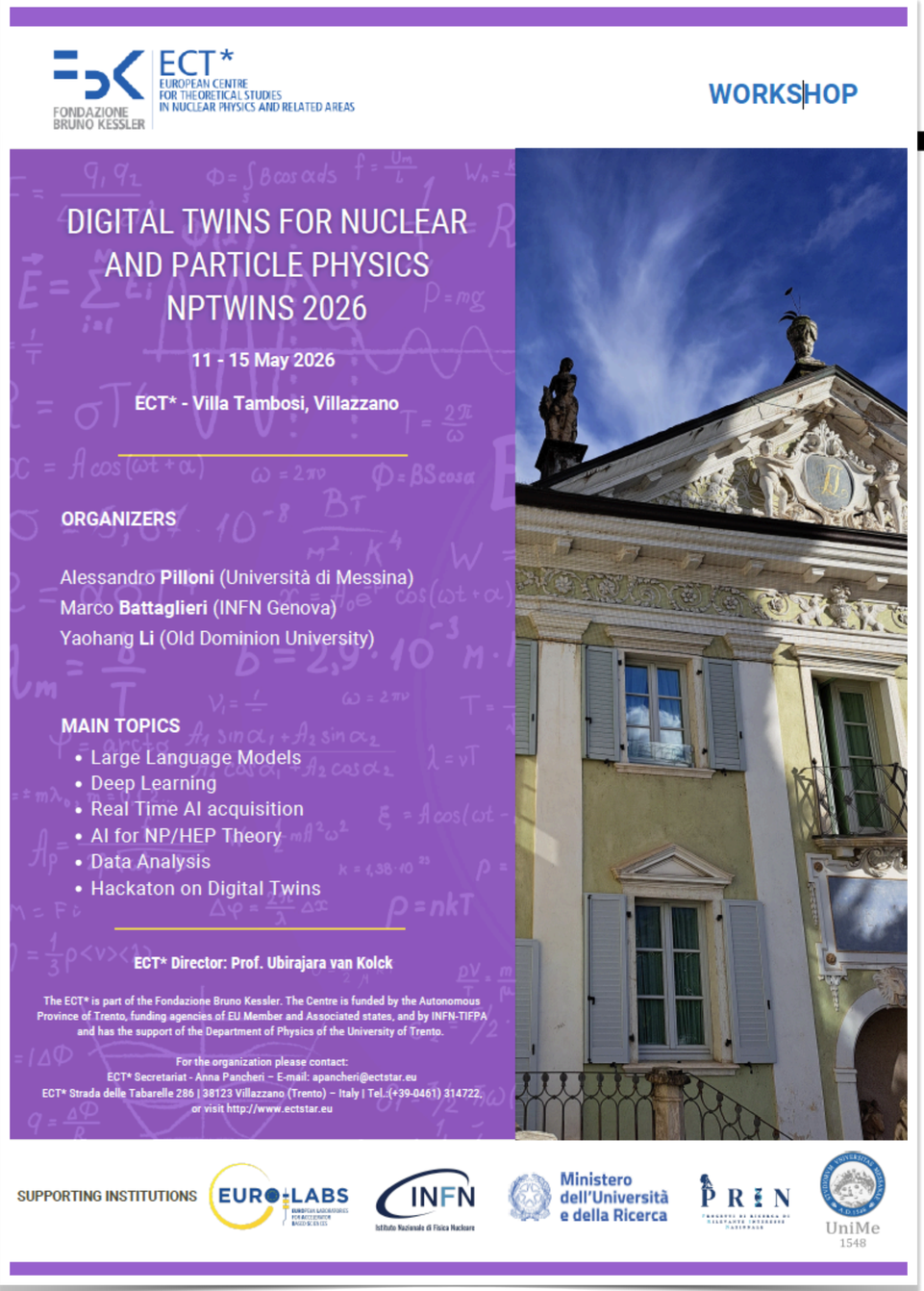

# *Digital Twins for Nuclear and particle Physics*
# *NPTwins 2026*

***11 - 15 May 2026***

***ECT* - Villa Tambosi - Villazzano (TN)***

M.Battaglieri (INFN-GE)
Y.Li (Old Dominion University)
A.Pilloni (Universita di Messina)

Jefferson Lab clas e-Lab12 Brookhaven National Laboratory ePIC INFN




# Conveners

## Tracks

- **Large Language Models**
  D.T. Murnane (Niels Bohr Institute)
- **Real Time AI acquisition**
  M.Liu (BNL), L.Pontisso (INFN-RM)
- **AI for NP/HEP Theory and deep learning**
  M.Letizia (CERN), G.Montaña (Barcelona University)
- **Data Analysis**
  P. Di Nezza (INFN-LNF), R.Tyson (Glasgow University)
- **Digital Twins**
  T. Britton (JLab), T.Jeske (JLab)

## Special event

- *Hackathon on Digital Twins*
  *TS.Karthik (William&Mary University), F.Vaselli (INFN-PI)*

# NPTWINS 2026 TRENTO (IT)

## NPTWINS 2024 GENOVA (IT)

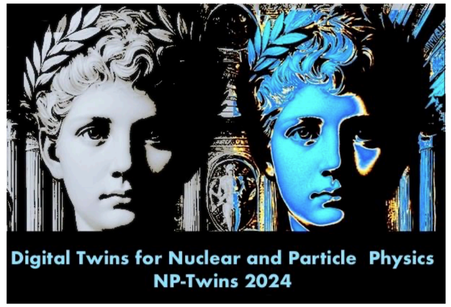
### Digital Twins for Nuclear and Particle physics - NPTwins 2024

16–18 Dec 2024
Museo Diocesano di Genova
Europe/Rome timezone

Enter your search term

- Overview
- Timetable
- Contribution List
- My Conference
  - My Contributions
- Registration
- Participant List
- Suggested lunch places
- Suggested dinner places
- Social Dinner

Nuclear and high energy physics facilities, such as CERN, Jefferson Lab, RHIC, and the forthcoming EIC, have been built around the world to study the visible universe at the fermi scale. They are already producing exabytes of data. This unprecedented amount of data holds the promise of solving many of the mysteries in elementary particle interactions such as QCD in the nonperturbative regime. However, extracting the required information is an extremely challenging task, as there is no available analytic solution to interpret data. Solving this challenge requires nuclear and particle physics to develop and adopt methods from data science, AI/ML, applied mathematics, and large-scale computing and adapt them to this goal. Digital twins, in particular, can simulate and model complex nuclear and elementary particle processes, providing a virtual replica that enhances understanding and predictive capabilities. This multidisciplinary approach, fostering cross-field collaboration and the exchange of ideas, is still in its infancy. The integration of digital twins into nuclear and particle physics could revolutionize how we approach and solve these complex challenges.




Supported by: Istituto Nazionale di Fisica Nucleare

**Starts** 16 Dec 2024, 09:00
**Ends** 18 Dec 2024, 19:00
Europe/Rome

Museo Diocesano di Genova
Sala Didattica
Via Tommaso Raggio 20r, 16123 Genova, (Italy)
Go to map

Alessandro Pilloni
Carlo Schiavi
Francesco Armando Di Bello
Marco Battaglieri
Riccardo Torre

There are no materials yet.

https://agenda.infn.it/event/43386/

## NPTWINS 2025 MESSINA (IT)

### Digital Twins for Nuclear and Particle physics - NPTwins 2025

6–8 Oct 2025
Università di Messina
Europe/Rome timezone

Enter your search term

- Overview
- Timetable
- Contribution List
- Registration
- Participant List
- How to travel to Messina
- Accommodation
- Organizing Committee
- Zoom link
- Conference picture

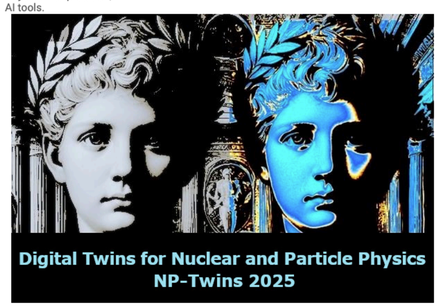
Nuclear and high energy physics facilities, such as CERN, Jefferson Lab, RHIC, and the forthcoming EIC, have been built around the world to study the visible universe at the fermi scale. They are already producing exabytes of data. This unprecedented amount of data holds the promise of solving many of the mysteries in elementary particle interactions such as QCD in the nonperturbative regime. However, extracting the required information is an extremely challenging task, as there is no available analytic solution to interpret data. Solving this challenge requires nuclear and particle physics to develop and adopt methods from data science, AI/ML, applied mathematics, and large-scale computing and adapt them to this goal. Digital twins, in particular, can simulate and model complex nuclear and elementary particle processes, providing a virtual replica that enhances understanding and predictive capabilities. This multidisciplinary approach, fostering cross-field collaboration and the exchange of ideas, is still in its infancy. The integration of digital twins into nuclear and particle physics could revolutionize how we approach and solve these complex challenges.

This is the second edition, after Genoa (2024).

The workshop will be held in the Main Building of Messina University. It will start after lunch on Monday, October 6 and continue for other two full days until 6pm on Wednesday, October 8.

The format includes contributions from experts in Physics and Data Science according to five tracks:

1. Data reconstruction;
2. Data analyses;
3. Physics extraction;
4. Physics interpretation;
5. AI tools.




Supported by:

https://agenda.infn.it/event/43958/overview

## ECT* EUROPEAN CENTRE FOR THEORETICAL STUDIES IN NUCLEAR PHYSICS AND RELATED AREAS — Digital Twins for Nuclear and Particle physics - NPTwins 2026

FONDAZIONE BRUNO KESSLER

11–15 May 2026
ECT*
Europe/Rome timezone

Enter your search term

- Overview
- Timetable
- Contribution List
- Registration
- Participant List
- Code of Conduct
- Privacy Information
- Hackaton

Contact
apancheri@ectstar.eu

**WARNING: for hotel bookings do not give your data to any external services upon email request; there are known cases of fraud**

Nuclear and high energy physics facilities, such as CERN, Jefferson Lab, RHIC, and the forthcoming EIC, have been built around the world to study the visible universe at the fermi scale. They are already producing exabytes of data. This unprecedented amount of data holds the promise of solving many of the mysteries in QCD in the nonperturbative regime. However, extracting the required information is an extremely challenging task, as there is no available analytic solution for QCD to interpret data. Solving this challenge requires nuclear physics to develop and adopt methods from data science, AI/ML, applied mathematics, and large-scale computing and adapt them to this goal. Digital twins, in particular, can simulate and model complex nuclear processes, providing a virtual replica that enhances understanding and predictive capabilities. This multidisciplinary approach, fostering cross-field collaboration and the exchange of ideas, is still in its infancy in QCD phenomenology. The integration of digital twins into nuclear and particle physics could revolutionize how we approach and solve these complex challenges. The workshop is the third of a series started in Genoa (2024) and Messina (2025).

On Wednesday, May 13 we will organize a hackaton for beginners, run by Francesco Vaselli.

Supporting project and institution

EURO-LABS — European Laboratories for Accelerator Based Sciences
INFN — Istituto Nazionale di Fisica Nucleare
Ministero dell'Università e della Ricerca
PRIN — Progetti di Ricerca di Rilevante Interesse Nazionale
Università degli Studi di Messina

**Starts** 11 May 2026, 09:00
**Ends** 15 May 2026, 19:00
Europe/Rome

ECT*
Aula Renzo Leonardi
Strada delle Tabarelle 286, I-38123 Villazzano (Trento)
Go to map

Alessandro Pilloni
Marco Battaglieri
Yaohang Li

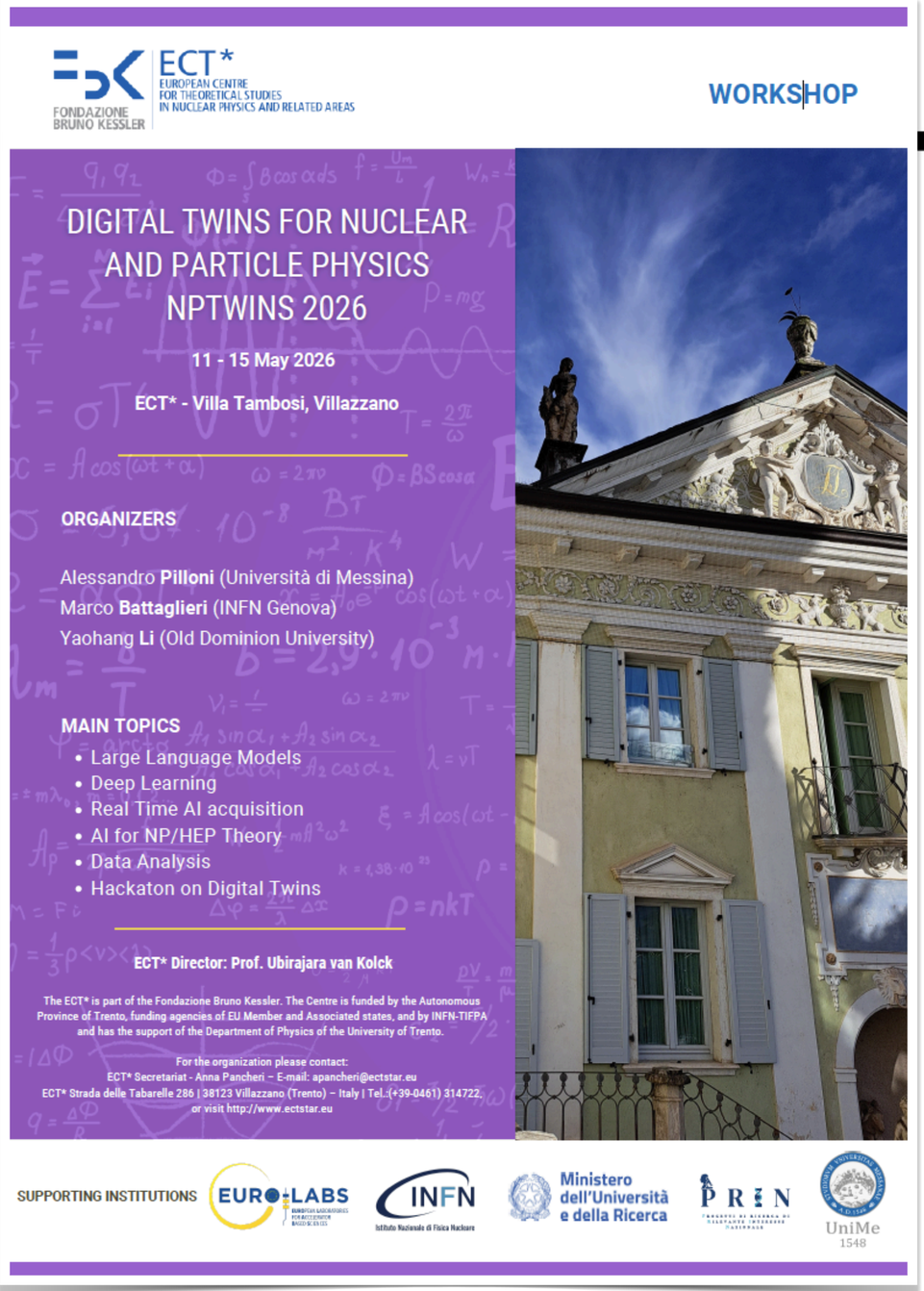
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https://indico.ectstar.eu/event/264/




# Scope

- **Quantum Chromodynamics (QCD) and Nuclear Physics**
  - Advances in the understanding of strong interactions and nuclear structure
  - Experimental and theoretical challenges in QCD data interpretation
- **Artificial Intelligence and Machine Learning for Nuclear Physics**
  - AI/ML methods for event reconstruction, classification, and analysis
  - Deep learning approaches for detector and physics applications
  - Cross-disciplinary AI/ML models adapted from other scientific domains
- **Data Science and Applied Mathematics**
  - Statistical methods and uncertainty quantification
  - High-dimensional data analysis and pattern recognition
  - Hybrid computational and data-driven frameworks
- **Digital Twins and Simulation**
  - Digital twins for detectors, accelerators, and experimental environments
  - Real-time monitoring, predictive maintenance, and optimization
  - Integration of simulations with AI-assisted analysis
- **Experimental Applications**
  - AI-supported analyses of recent results from major nuclear physics facilities
  - Applications to detector performance, calibration, and triggering
  - Synergies between experimental measurements and data-driven modeling
- **Future Directions and Cross-Disciplinary Collaboration**
  - Challenges and limitations of current data interpretation techniques
  - Emerging opportunities at the interface of NP, QCD, AI, and applied mathematics
  - Building collaborations between nuclear physicists, data scientists, and AI/ML researchers




# Goals

- **Foster Cross-Disciplinary Collaboration**
  - Bring together researchers from NP, hadron physics, data science, AI/ML, and applied math
  - Strengthen connections between theoretical and experimental communities
- **Promote AI/ML Applications in Nuclear Physics**
  - Discuss novel AI- and ML-based approaches for hadron and nuclear physics research
  - Explore advanced methods for analyzing large-scale experimental datasets
  - Assess the opportunities and limitations of AI-driven analysis techniques
- **Advance Data Interpretation in QCD**
  - Improve the understanding of complex nuclear and strong-interaction phenomena
  - Develop new strategies for extracting physics information from high-dimensional data
- **Explore Digital Twins and Computational Frameworks**
  - Investigate the role of digital twins in detector optimization and nuclear-process simulations
  - Discuss hybrid computational approaches combining simulations, theory, and AI methods
- **Share Experimental Case Studies**
  - Present practical applications of AI/ML in ongoing nuclear physics experiments
  - Highlight successes, challenges, and lessons learned from data-driven approaches
- **Develop New Tools and Methodologies**
  - Encourage the development of innovative computational and analysis frameworks
  - Identify techniques applicable to future accelerator and detector facilities
- **Build Future Research Initiatives**
  - Stimulate new collaborations bridging nuclear physics and data science
  - Define future directions for AI-assisted nuclear and hadronic physics research
  - Promote long-term integration of data science techniques into QCD studies




# Format

- From Monday May 11, 1:30 pm to Friday, May 15, 12:30 PM (CEST)
- Invited oral presentations (25' + 5'), mixed tracks
- Morning: 9:00 AM -12:30 PM, including a 30' coffee break
- Afternoon: 2:00PM - 18:00 PM, including a 30' coffee break each
- Lunches offered by ECT* and served at Villa Tambosi (green building), 12:30 PM - 2:00PM, from Tuesday to Friday
- Time for discussion at the end of the sessions
- The *hackathon* on Wednesday starts at 10:00AM and ends at 4:00PM
- Social dinner on Thursday night, 8:00 pm at restaurant Orso Grigio, Via degli Orti, 19, Trento
- <u>Please, sign the attendance sheets daily at the Rustico!</u>

# Program

## Monday

Experiment | Introduction | Theory

| | | | |
|---|---|---|---|
| 14:00 | **Introduction and plan of the workshop** | *Dr Alessandro Pilloni et al.* | *Aula Renzo Leonardi, ECT** 14:00 - 14:30 |
| | **AI-Optimized Polarization at Jefferson Lab** | *Patrick Moran* | *Aula Renzo Leonardi, ECT** 14:30 - 15:00 |
| 15:00 | **Foundation Models for Fast Simulation and Particle Identification with Cherenkov Detectors** | *James Giroux* | *Aula Renzo Leonardi, ECT** 15:00 - 15:30 |
| | **Coffee break** | | *Aula Renzo Leonardi, ECT** 15:30 - 16:00 |
| 16:00 | **Greetings from the Director** | *Ubirajara van Kolck* | *Aula Renzo Leonardi, ECT** 16:00 - 16:15 |
| | **The GENESIS program** | *Laura Biven* | *Aula Renzo Leonardi, ECT** 16:15 - 16:45 |
| | **AI for Regge Theory** | *Adam Szczepaniak* | *Aula Renzo Leonardi, ECT** 16:45 - 17:15 |
| 17:00 | **NNPDF** | *Tommaso Giani* | *Aula Renzo Leonardi, ECT** 17:15 - 17:45 |

## Tuesday

Digital twins & LLMs | Experiment | Theory

| | | | |
|---|---|---|---|
| 09:00 | **Analysis of nucleon spin structure** | *Tianbo Liu* | *Aula Renzo Leonardi, ECT** 09:00 - 09:30 |
| | **TBD** | *Yaohang Li* | *Aula Renzo Leonardi, ECT** 09:30 - 10:00 |
| 10:00 | **Generative AI for Detector Effect Modeling and Unfolding to Vertex-Level Distributions** | *Tareq Alghamdi* | *Aula Renzo Leonardi, ECT** 10:00 - 10:30 |
| | **Coffee break** | | *Aula Renzo Leonardi, ECT** 10:30 - 11:00 |
| 11:00 | **Multi-model Mixing via Bayesian Trees** | *Matthew Pratola* | *Aula Renzo Leonardi, ECT** 11:00 - 11:30 |
| | **Diffusion models for unfolding detector effects** | *Giorgio Foti* | *Aula Renzo Leonardi, ECT** 11:30 - 12:00 |
| 12:00 | **Lunch** | | *Aula Renzo Leonardi, ECT** 12:30 - 14:00 |
| | **Diffusion models for lattice field theories** | *Andreas Ipp* | *Aula Renzo Leonardi, ECT** 14:00 - 14:30 |
| | **Nucleon structure from exclusive processes with machine learning** | *Simonetta Liuti* | *Aula Renzo Leonardi, ECT** 14:30 - 15:00 |
| | **AI/ML for Generalized Parton Distributions** | *Prof. Huey-Wen Lin* | *Aula Renzo Leonardi, ECT** 15:00 - 15:15 |
| | **Neural Network extraction of TMDs** | *Chiara Bissolotti* | *Aula Renzo Leonardi, ECT** 15:15 - 15:45 |
| | **Coffee break** | | *Aula Renzo Leonardi, ECT** 15:45 - 16:15 |
| | **ML for charged particle tracking at GlueX** | *Ahmed Mohammed* | *Aula Renzo Leonardi, ECT** 16:15 - 16:45 |
| | **Agentic Digital Twin for Precision Experiments at Rare-Isotope Accelerator Facilities** | *Brooke Rickey* | *Aula Renzo Leonardi, ECT** 16:45 - 17:15 |
| | **Digital Twins for accelerators** | *Auralee Edelen* | *Aula Renzo Leonardi, ECT** 17:15 - 17:45 |

## Thursday

rning | Digital twins & LLMs | Real-time

| | | | |
|---|---|---|---|
| | **al-time analysis and ML inference at 30 MHz at LHCb** | *Maarten van Veghel* | *la Renzo Leonardi, ECT** 09:00 - 09:30 |
| | **ploring Spiking Neural Networks for Online Data Reduction in the ePIC dRICH detector** | *Pierpaolo Perticaroli* | *la Renzo Leonardi, ECT** 09:30 - 10:00 |
| | **Agents Can Already Autonomously Perform Experimental High Energy Physics** | *Eric Moreno* | *la Renzo Leonardi, ECT** 10:00 - 10:30 |
| | **ffee break** | | *la Renzo Leonardi, ECT** 10:30 - 11:00 |
| | **chine learning for hadronization and unfolding at colliders** | *Ayodele Ore* | *la Renzo Leonardi, ECT** 11:00 - 11:30 |
| | **M systems in high energy physics** | *Gabriel Facini* | *la Renzo Leonardi, ECT** 11:30 - 12:00 |
| | **ML at CLAS12** | *Richard Tyson* | *la Renzo Leonardi, ECT** 12:00 - 12:30 |
| | **nch** | | *la Renzo Leonardi, ECT** 12:30 - 14:00 |
| | **al-Time AI-Based Triggering for the SST-1M Telescope** | *Jakub Kvapil* | *la Renzo Leonardi, ECT** 14:00 - 14:30 |
| | **N-C Feats: Real-Time Science with Fast Adaptive Neural Contro** | *Nhan Tran* | *la Renzo Leonardi, ECT** 14:30 - 15:00 |
| | **LIX - a platform for AI/ML in NPP experiments** | *Hao Xu* | *la Renzo Leonardi, ECT** 15:00 - 15:30 |
| | **ffee break** | | *la Renzo Leonardi, ECT** 15:30 - 16:00 |
| | **D** | *Geoffrey Fox* | *la Renzo Leonardi, ECT** 16:00 - 16:30 |
| | **entic-AI systems for High Energy Physics research** | *Nesar Ramachandra* | *la Renzo Leonardi, ECT** 16:30 - 17:00 |
| | **uge-equivariant graph neural networks for lattice gauge theories** | *Gia-Wei Chern* | *la Renzo Leonardi, ECT** 17:00 - 17:30 |

Social dinner Orso Grigio at 8:00 pm

## Friday

| | | | |
|---|---|---|---|
| | **onstruction of scattering amplitudes with physics-informed GANs** | *Glòria Montañ* | *Renzo Leonardi, ECT** 09:00 - 09:30 |
| | **ing Electromagnetic Moments to Nuclear Interactions via Global Parametric ab-initio Emulation** | *Jose Munoz* | *Renzo Leonardi, ECT** 09:30 - 10:00 |
| | **porting Theory Simulations with Large Language Models** | *Daniel Schiller* | *Renzo Leonardi, ECT** 10:00 - 10:30 |
| | **ee break** | | *Renzo Leonardi, ECT** 10:30 - 11:00 |
| | **maries and discussions** | | *Renzo Leonardi, ECT** 11:00 - 12:30 |
| | **ch** | | *Renzo Leonardi, ECT** 12:30 - 14:00 |

Wednesday

***Hackathon***

# Hackathon on Digital Twins




*Wednesday, May 13, 10:00 AM - 4:30 PM - ECT* Villa Tambosi - Villazzano (TN)*

**Topic**

Generative Models from Differential Equations: Building a Fast Digital Twin (Generative Surrogate Modeling)

**Goal**

Train a Machine Learning model to accurately mimic a heavy physics simulation of a detector response (simulated with a dataset) but running 1000x faster

**ML Algorithm**

Flow Matching: a modern, simplified version of Diffusion Models, Efficient train on CPUs (laptop/COLAB)

**Format & Tools**

Duration: 1/2h of introduction + hands-on

Tools: Python, PyTorch libs

Strategy: Scaffolded Notebooks (fill-in-the-blank code), heavy engineering code (data loading, plotting, network architecture) provided

Participants will focus on implementing the physics logic and loss functions

**Pre-Event Communication**

Circulated in advance a "Starter Kit" to registered participants

**Supporting material**

Lecture notes provided

*Open to external participants, in particular students of Trento, Padova, Milano, and Ferrara University*




# Practicalities

Anna Pancheri

## Program & Venue

- *Updated Program: Please refer to the Indico webpage for the detailed timetable: https://indico.ectstar.eu/event/264/timetable/#20260511.detailed*
- *Registration: Registration will open at 13:30 on Monday in the foyer of the "Rustico of Villa Tambosi" (the grey building).*
- *Meeting Room: Sessions will be held in the "Aula Leonardi" (Rustico).*
- *Catering: Coffee breaks and lunches will be served at Villa Tambosi (the green building).*

## Useful Information

- *How to reach ECT* https://www.ectstar.eu/where-we-are/*
- *Wi-Fi Access: Instructions for the FBK-ECT* network can be found here. https://howto.fbk.eu/en/documenti/guide-to-accessing-wifi-networks/*
- *Trentino Guest Card: You can request this card directly from your hotel. It provides free public transport and museum entrance. More info: https://www.visittrentino.info/it/esperienze/trentino-guest-card?*

## For Speakers

*Please upload your presentation materials directly to the Indico Timetable. Alternatively, you may send your files via email to: apancheri@ectstar.eu*

## Administrative Requirements

1. *Privacy & Data Form: Please fill out the consent form regarding personal data and document dissemination at this link: https://docs.google.com/forms/d/e/1FAIpQLSdM09wfDdAkqI5Ct2Pu4qNedFNFo8YSG-AwOfFhaN1CiFNr9Q/viewform It only takes a few seconds.*
2. *Attendance & Meals: To ensure smooth administrative management, we kindly ask you to sign the attendance sheets daily at the Rustico, for our reporting records.*

## Social Events

- *Welcome Pizza: Sunday, May 10 at 20.00 – Green Tower, Via Torre Verde, 29, Trento. https://www.ristorantegreentower.com/*
- *Social Dinner: Thursday, May 14 at 20.00 – Orso Grigio, Via degli Orti, 19, Trento. https://www.orso-grigio.it/ita*




# Acknowledgements

*Special thanks to ECT* for the support, hospitality, excellent organization, and logistical assistance throughout the workshop*

*We also warmly thank the workshop secretariat,* ***Anna Pancheri****, for the efficient coordination and continuous support before and during the meeting*