



AI4EIC workshop summary

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EIC-Beam AI WG meeting

July 28, 2026



AI4EIC workshops: 2021 — 2025

- [1st AI4EIC](#) (virtual), Sep 7-10, 2021, Center for Frontiers in Nuclear Science, Stony Brook, NY
- [2nd AI4EIC](#), Oct 10- 14, 2022, William & Mary, Williamsburg, VA
- [3rd AI4EIC](#), Nov 28-Dec 1, 2023, Catholic University of America, Washington, D.C.
- [Joint Session between AI4EIC and Streaming Readout](#), Dec 2-4, 2024, Streaming Readout Workshop SRO-X
- [4th AI4EIC](#), Oct 27-Oct 30, 2025, IAIFI/MIT, Boston, MA

1st AI4EIC: AI for Accelerator Design – Todd Satogata, Yue Hao

Motivation

- EIC design requires balancing many competing objectives including luminosity, beam stability, dynamic aperture, beam-beam effects, cooling, and engineering constraints.
- Traditional optimization becomes computationally prohibitive because of nonlinear beam dynamics and large parameter spaces.

AI opportunities

- Surrogate models to replace expensive beam dynamics simulations
- Bayesian optimization and Gaussian Processes for accelerator parameter optimization
- Neural networks and XGBoost for modeling machine performance
- Reduced-order models and feature extraction for high-dimensional parameter spaces

Early demonstrations

- Dynamic aperture prediction using surrogate models
- Beam-beam interaction modeling
- Machine tuning with LEReC/RHIC operational data
- AI-assisted luminosity prediction and parameter ranking

1st AI4EIC: Accelerator Control – Auralee Edelen

Motivation

- Accelerator control involves nonlinear, time-varying systems with hundreds of controllable variables and diagnostics.
- Manual tuning is costly and limits facility availability and scientific output.
- Fast, accurate machine models are needed for real-time decision making and automation.

Emerging AI capabilities

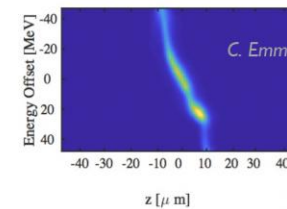
- ML surrogate models & digital twins
- AI-assisted optimization
- Virtual diagnostics
- Machine health monitoring

Several major areas for ML to play a role

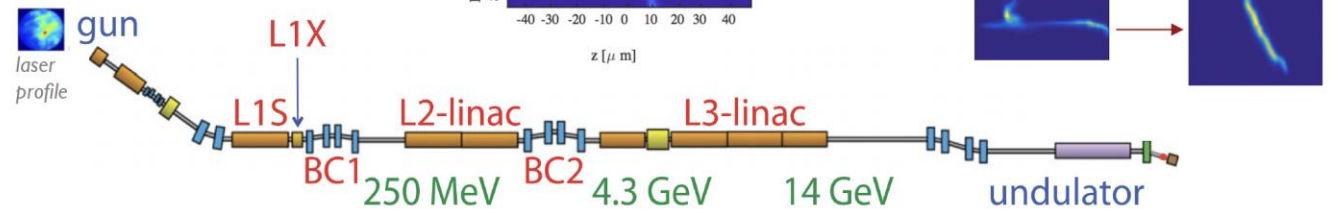
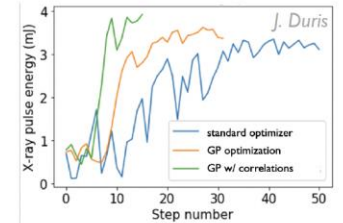
anomaly detection
failure prediction

diagnostics

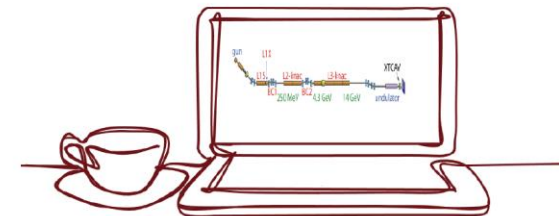
(reconstruct / analyze beam)



automated control
+ optimization



incorporate
physics
information



digital twins + online modeling
(planning, model-based control, finding differences between sim/machine)

extract unexpected
relationships
(feed into control / design)

+ need uncertainty
quantification for all

2nd AI4EIC: ML for LHC – Elena Fol

- **Fault detection**
 - Automatic identification of faulty BPMs using Isolation Forest
 - Eliminated much of the manual data cleaning before optics analysis
- **Optics correction**
 - ML reconstructed quadrupole field errors from optics measurements
 - Enabled simultaneous correction of multiple interaction regions during LHC commissioning
- **Virtual diagnostics**
 - Predicted optics quantities without dedicated measurements
 - Reduced measurement time from minutes to seconds
- **Measurement enhancement**
 - Autoencoder-based denoising improved optics reconstruction
 - Reinforcement learning explored for future HL-LHC optics control

Assisting Beam Optics Control with ML

Unreliable measurements of beam properties

Detection of instrumentation faults: Beam Position Monitors

Uncertainties in the measured optics functions

De-noising of beam measurements

What are the actual magnet errors

Predict optimal settings: local magnet errors corrections

How to reconstruct the missing data?

Virtual diagnostics: obtaining beam properties without direct measurement

2nd AI4EIC: AIML for Design – Todd Satogata

Established AI workflows

- Multi-objective genetic algorithms (MOGA) for accelerator component optimization
- Surrogate models for computationally expensive design studies
- Human-guided optimization remains essential near design singularities and engineering constraints

Emerging Community vision (2022)

- **End-to-end virtual accelerators and digital twins**
 - Integrated modeling across the full accelerator lifecycle
- **AI-enabled design ecosystem**
 - Physics-informed surrogate models
 - Advanced algorithms for nonlinear optimization
 - HPC-enabled large-scale design-space exploration
- **Open software and data infrastructure**
 - Community frameworks
 - Benchmark datasets
 - Sustainable software ecosystem

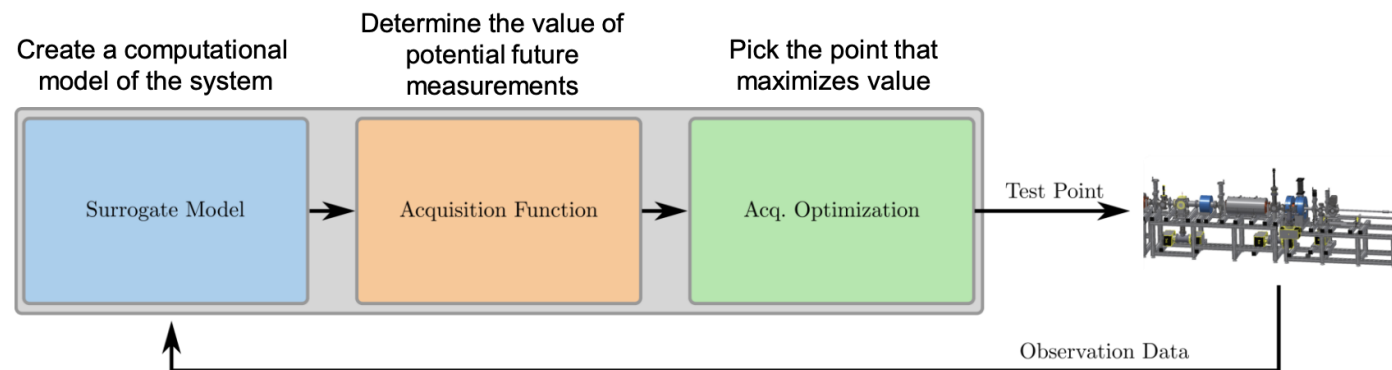
3rd AI4EIC: AI for Online Optimization and Accelerator Control

Talks

- Bayesian Optimization Techniques for Accelerator Control and Characterization – Ryan Roussel
- Machine Learning applications for collider luminosity maximization – Ji Qiang
- Reinforcement Learning applications at Jlab – Malachi Schram

Main Messages

- Bayesian optimization becoming the preferred online tuning algorithm
- Multi-objective optimization for machine performance
- Reinforcement learning beginning to be explored for sequential control
- Human-guided optimization transitioning toward autonomous optimization



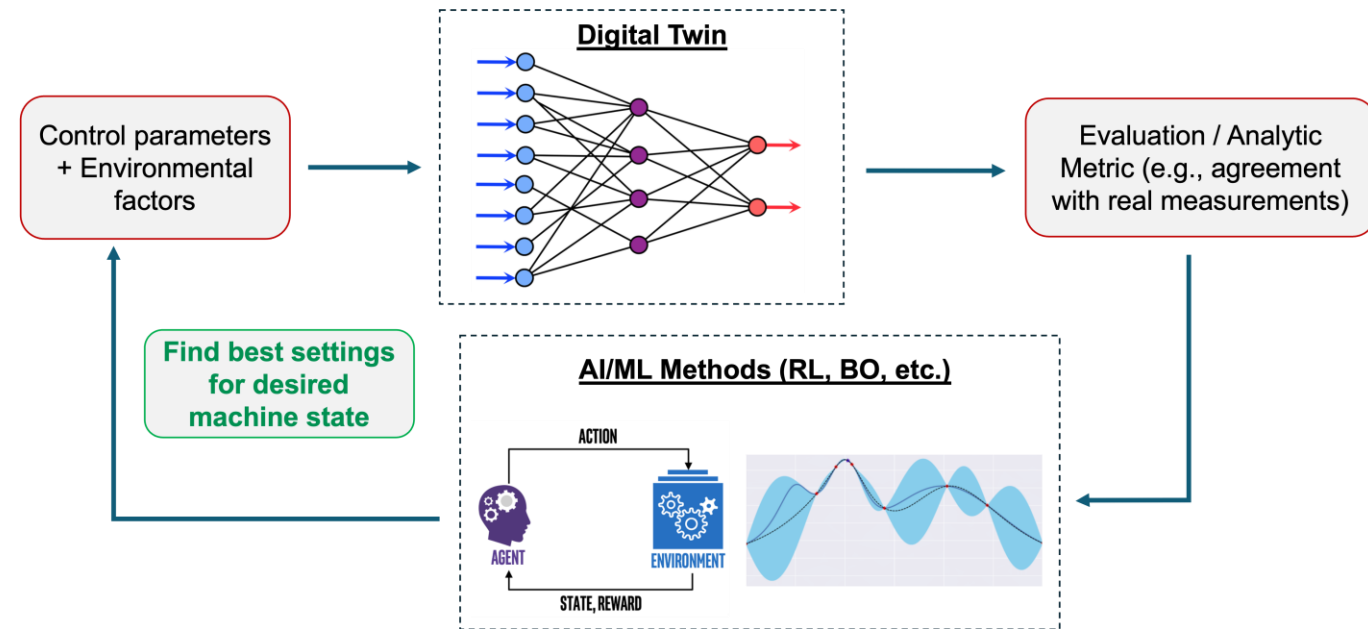
3rd AI4EIC: Digital Twins and Predictive Modeling

Talks

- Digital twin development and polarization optimization at BNL – Lucy Lin
- Beam Condition Forecasting at FACET-II – Matt Kilpatrick
- Uncertainty estimation at JLab – Malachi Schram

Main Messages

- Digital twins becoming operational tools rather than future concepts
- Predictive ML models forecasting future machine behavior
- Physics-informed models combined with uncertainty estimates
- Growing emphasis on trustworthy AI



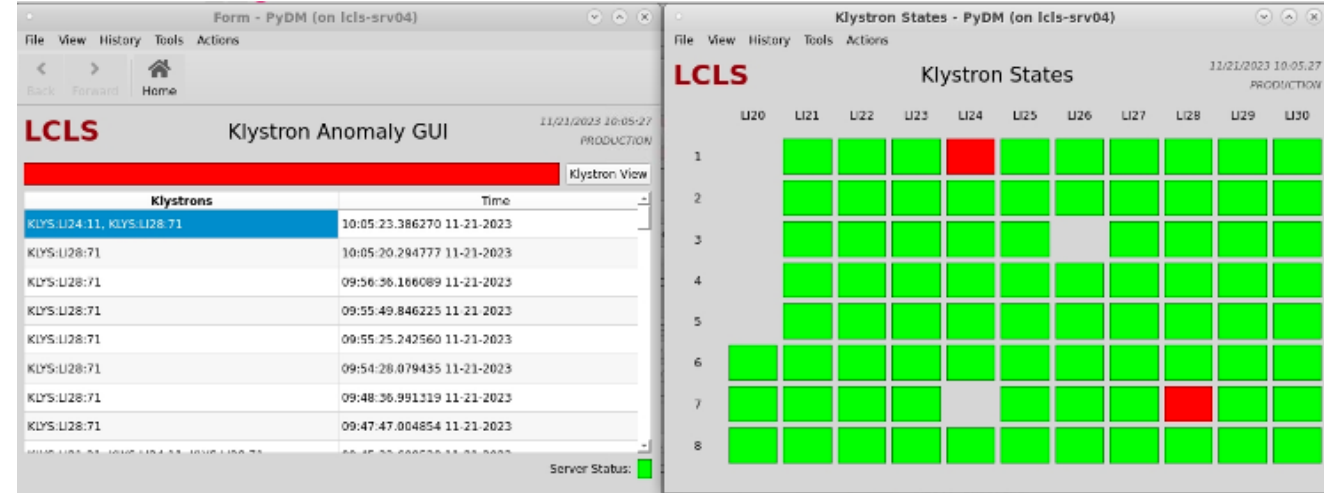
3rd AI4EIC: AI-enhanced Diagnostics and Beam Physics

Talks

- Anomaly detection at an X-ray FEL – Daniel Ratner
- Machine Learning to Improve Dynamic Aperture Estimates – Frederik Van der Veken

Main Messages

- ML extracting information from complex diagnostics
- Automatic anomaly detection
- Surrogate models accelerating expensive beam physics calculations
- AI supporting accelerator physics analysis in addition to control



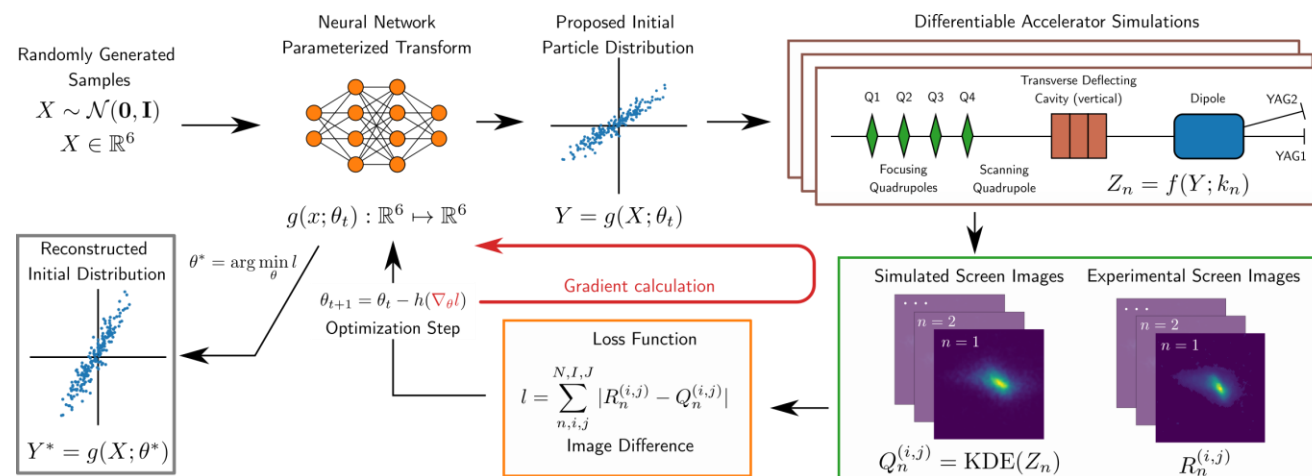
4th AI4EIC: Differentiable AI for Accelerator Modeling

Talks

- Explainable and Differential Reinforcement Learning for Multi-Objective Optimization – Kishansingh Rajput
- Differentiable beam dynamics codes – Chenran Xu
- Symplectic machine learning model for fast space-charge simulation – Jinyu Wan

Main Points

- Differentiable beam dynamics enables gradient-based optimization
- Physics-preserving ML (symplectic networks) improves simulation fidelity
- Explainable RL addresses multi-objective optimization while maintaining interpretability
- Shift from black-box surrogate models toward physics-aware AI



4th AI4EIC: Digital Twins Development

Talks

- Framework for the Development of Virtual Accelerator Models – Adwaith Ravichandran
- ML-Accelerated Bayesian UQ – Christopher Kelly
- AI/ML for higher brightness and polarization – Eiad Hamwi
- Improved Ion Profile Monitor Measurements – Christopher Hall

Main Points

- Standardized frameworks for virtual accelerators
- Bayesian uncertainty quantification for trustworthy digital twins
- Digital twins supporting online optimization and control
- Improved diagnostics provide higher-quality inputs for AI models

The screenshot displays the ATLAS - Dashboard interface. At the top, there are four tabs: 'Get/Read Settings', 'Set/Vary Settings', 'Get/Read BPMs', and 'Get/Read FCPs'. Below these, there are three sub-tabs: 'Instructions', 'Task Setup', 'Beamlines', and 'Execution'. The 'Task Setup' tab is currently active, showing instructions for setting up a task. A red box highlights the 'Task Setup' tab, with a red arrow pointing to it and the text 'Tabs to turn on/off all devices of same type'. Another red box highlights the 'Beamlines' tab, with a red arrow pointing to it and the text 'Single exit button to kill all active process'. The 'Execution' tab is also highlighted with a red box. Below the tabs, there is a large diagram of the ATLAS beamline layout. A red box highlights a specific section of the beamline, with the text 'Active beamline selected for tuning will be highlighted here'. At the bottom of the diagram, there is a terminal window with the text 'All code messages are displayed here for troubleshooting'. Below the main interface, there are two smaller screenshots. The left one is titled 'Task Setup Tab' and shows a form for setting up a task. A red box highlights the 'Initial Data Sample' field, with a red arrow pointing to it and the text 'Triggers using prior experiment data for model training'. The right one is titled 'Beamline Tab' and shows a list of beamline elements. A red box highlights the 'Set Lower Limits' button, with a red arrow pointing to it and the text 'Set steerer range in Ampere'. Another red box highlights the 'Set Upper Limits' button, with a red arrow pointing to it and the text 'Set quadrupole range in Ampere'.

ATLAS - Dashboard

Get/Read Settings Set/Vary Settings Get/Read BPMs Get/Read FCPs

Instructions Task Setup Beamlines Execution

Please, follow the instructions below:

1. On top, select which devices will be accessible, read and/or varied.
2. In Task Setup, setup the task to perform
3. In Beamlines, select which elements will be varied and which data to read and save.
4. In Execution, click to execute or run.

Active beamline selected for tuning will be highlighted here

All code messages are displayed here for troubleshooting

Task Setup Tab

Triggers using prior experiment data for model training

Beamline Tab

Beamline buttons; supported lines shown in right

toggling these selects magnet for optimization

Set steerer range in Ampere

Set quadrupole range in Ampere

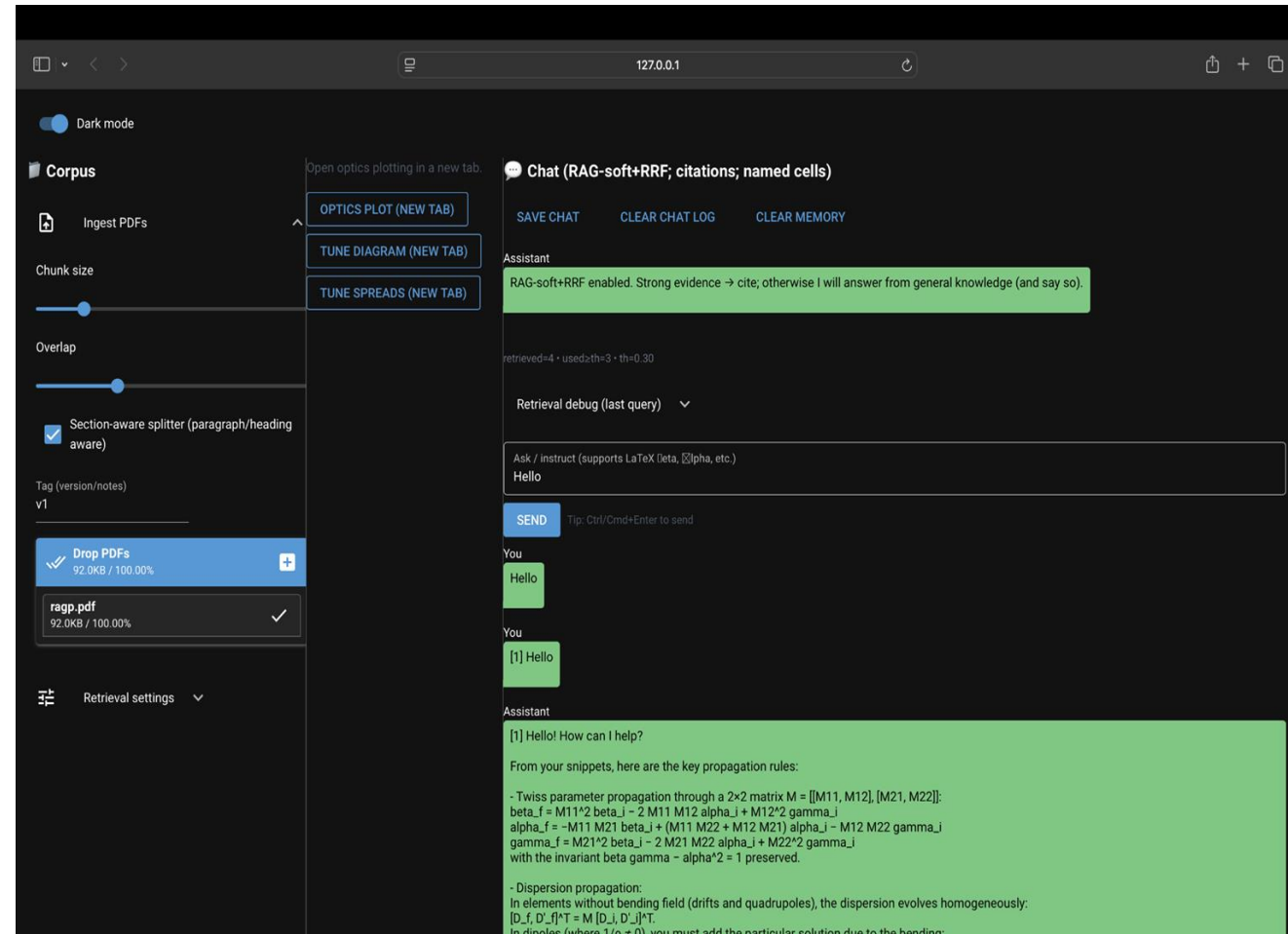
4th AI4EIC: Foundation Models and Generative AI

Talks

- Use of Generative AI and LLMs for Accelerator Design – Onur Gilanliogullari

Main Points

- LLMs begin assisting accelerator design workflows
- Natural-language interfaces to simulation and accelerator software
- Knowledge extraction from technical documentation
- AI agents emerging as workflow orchestrators rather than standalone predictors



Evolution of AI for Accelerators (2021–2025)

Workshop	Main Focus	Representative Technologies
2021	AI for accelerator design & control	Surrogate models, BO, GP, virtual diagnostics
2022	AI deployment & community roadmap	LHC applications, digital twins, modeling ecosystem
2023	AI-assisted accelerator operations	Online optimization, digital twins, forecasting, anomaly detection
2025	AI-native accelerators	Differentiable physics, trustworthy digital twins, agentic AI

Overall trend: AI evolved from individual algorithms toward integrated AI-native accelerator ecosystems.