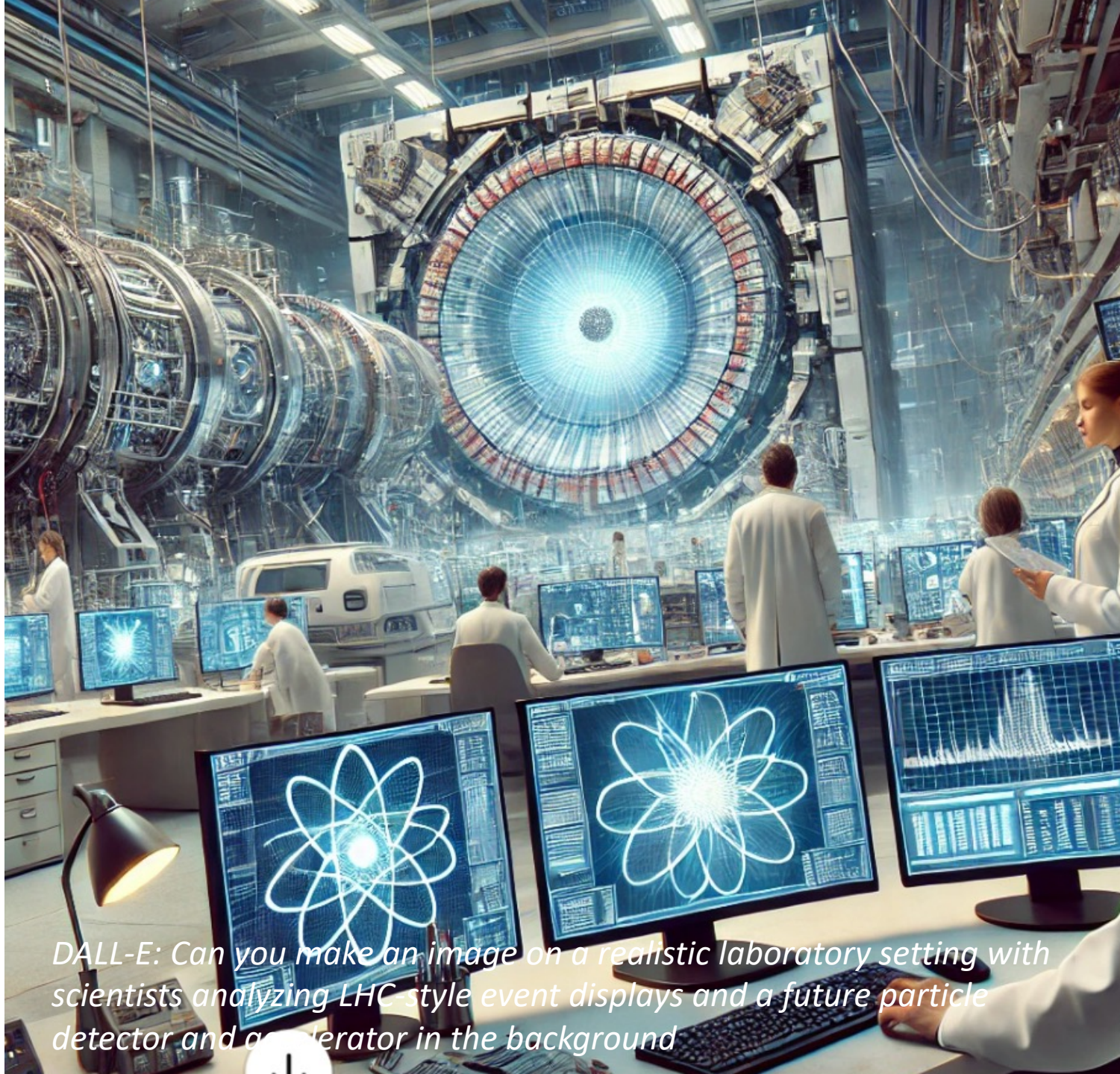
AI/ML for Particle Physics

Building an Infrastructure with EuCAIF and Beyond

Sascha Caron

(Radboud University and Nikhef)



DALL-E: Can you make an image on a realistic laboratory setting with scientists analyzing LHC-style event displays and a future particle detector and accelerator in the background

2024: Recognizing AI as a fundamental tool for science

- Horizon Europe and FP 10 "**Heitor Report**"*:*

"AI (particularly GenAI) have great potential to support the process of science and may change how future research is done."

- **Draghi report**:

"Europe must profoundly refocus its collective efforts on closing the innovation gap… , especially in advanced technologies" (AI)

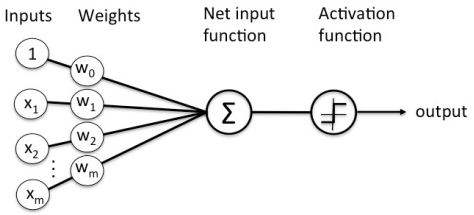
Nobel Prices in Physics and Chemistry

(physics: use of physics for AI !, Chemistry: use of AI for chemistry)

Enormous opportunities for high-energy physics that need to be exploited

The speed of AI (r)evolution

AI is evolving quicker than we are …
Deep Learning + generative AI changed the game.
HEP has been a user and developer for decades.



perceptron

1957

Hopfield network

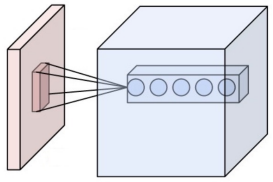
1982

Backprop *(Hinton et al.)*

1986

1st Workshop on AI In High energy & Nuclear Physics (AIHENP)

1990



CNN

1998

Start of LHC

-Higgs boson Kaggle challenge
-First deep learning Paper in HEP

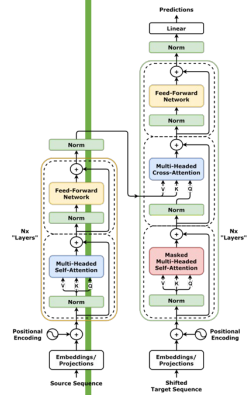
”Deep Learning” (DBN, AlexNet)

2010

GAN

2014

IML working group at CERN



transformer

2017

Particle Transformer

Chatgpt 3.5

2022

New Collider?

Physics AI ?

2040

Timetable for AI and HEP
(with some examples of developments)

2024:AI/Deep Learning (DL) in HEP

AI – unfolding

AI – inference

AI - event selection

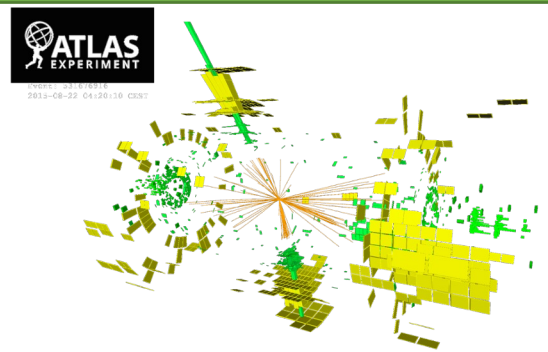
AI - reconstruction

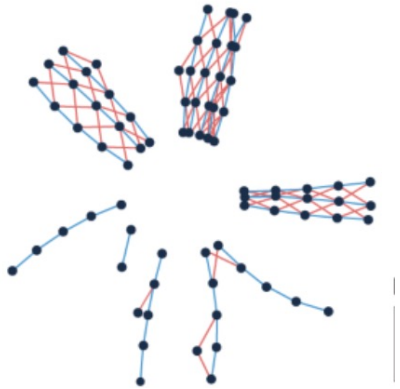
AI - tracking

AI - detector simulation

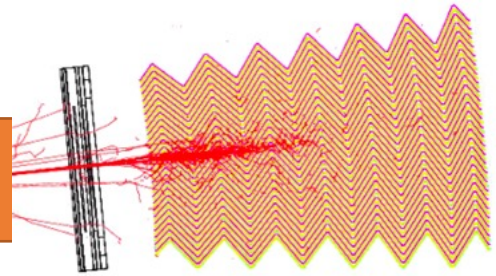
AI - event generation

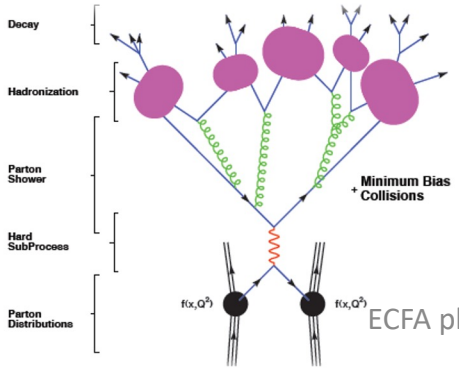
Energy and angles of reconstructed particles





Detector Simulator





AI - trigger

2024:AI/Deep Learning (DL) in HEP

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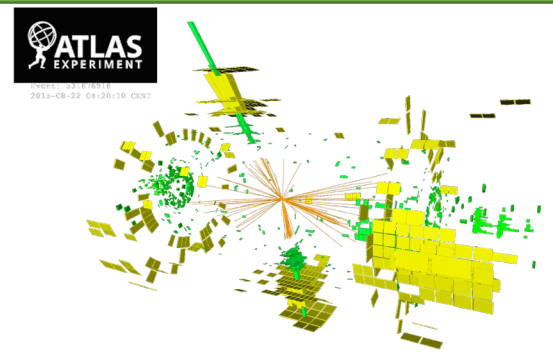
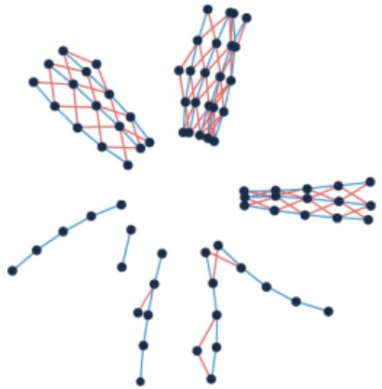
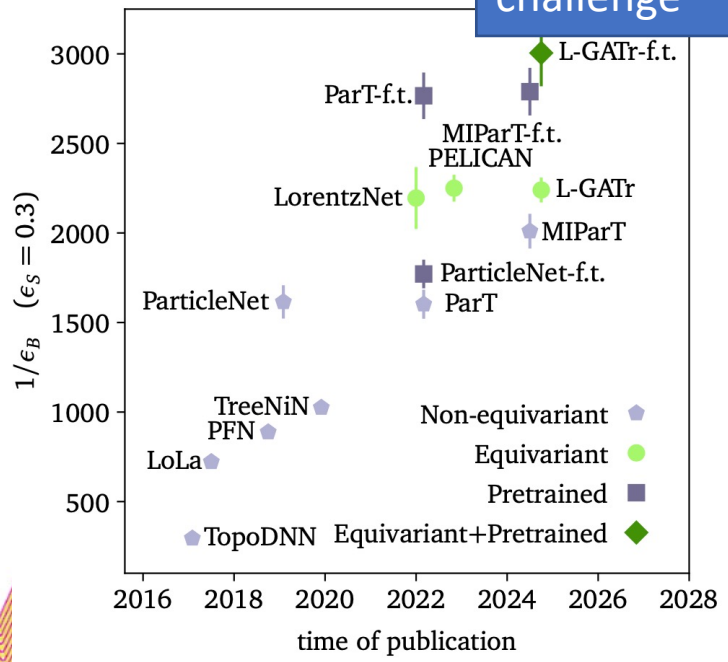
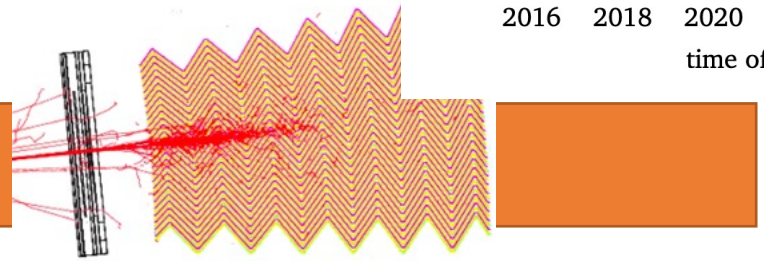


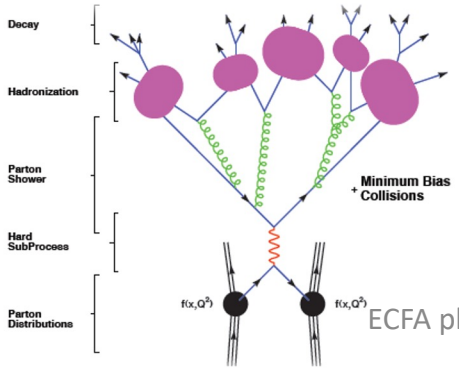


Top-tagging challenge



Detector Simulator





AI - trigger

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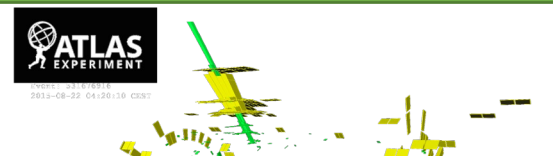
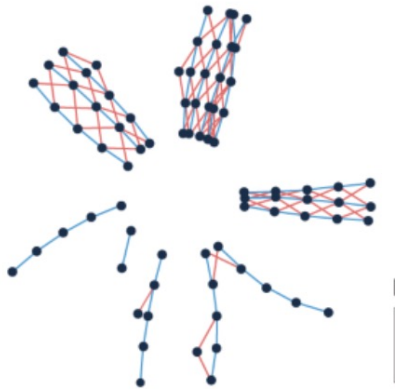
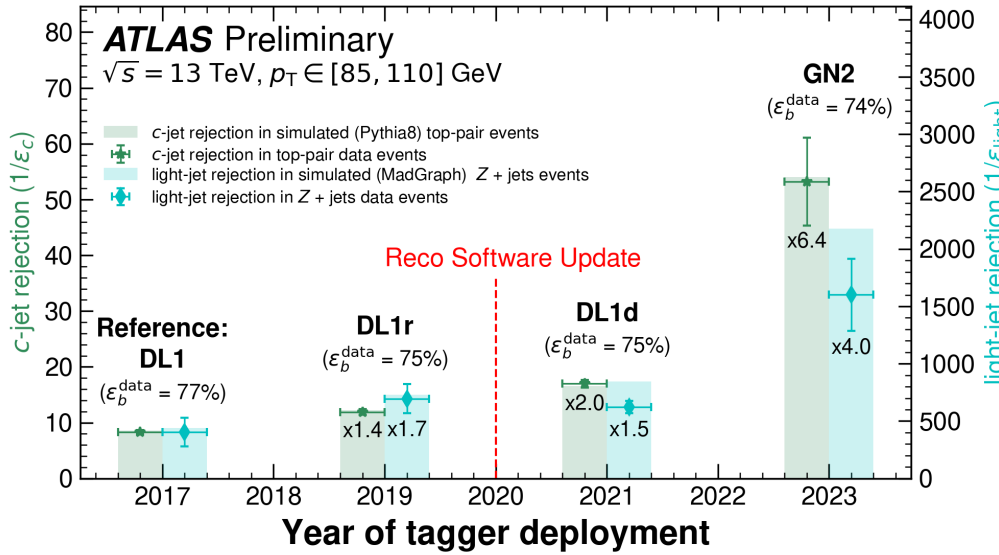
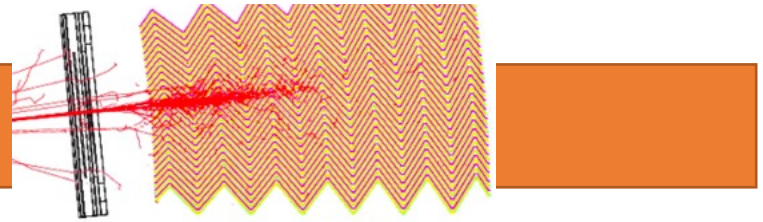


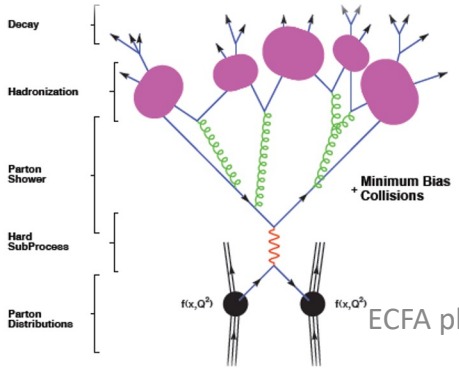




c & light jet rejection

Detector Simulator





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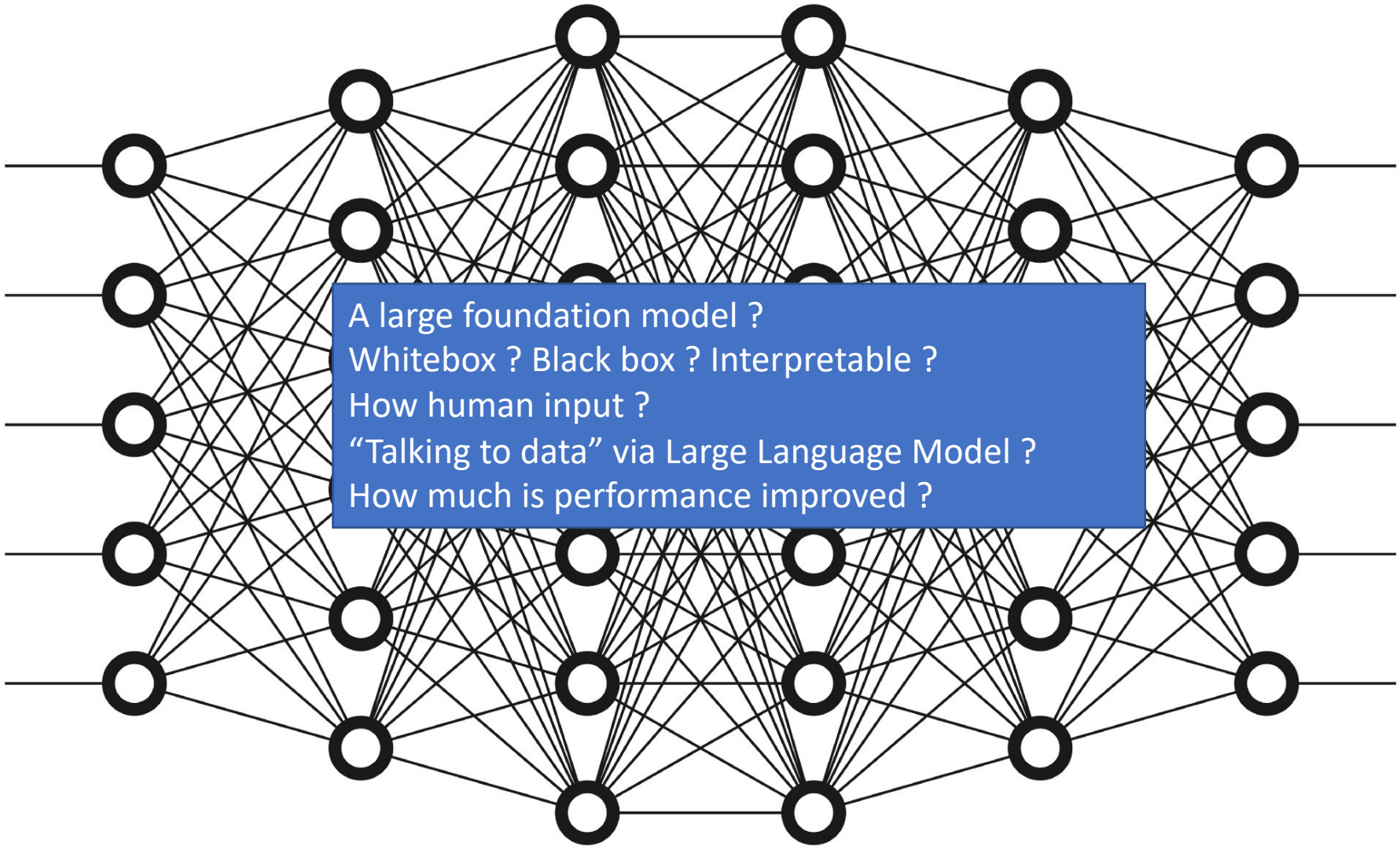

A large foundation model ?
Whitebox ? Black box ? Interpretable ?
How human input ?
“Talking to data” via Large Language Model ?
How much is performance improved ?

2024:AI/Deep Learning (DL) in HEP

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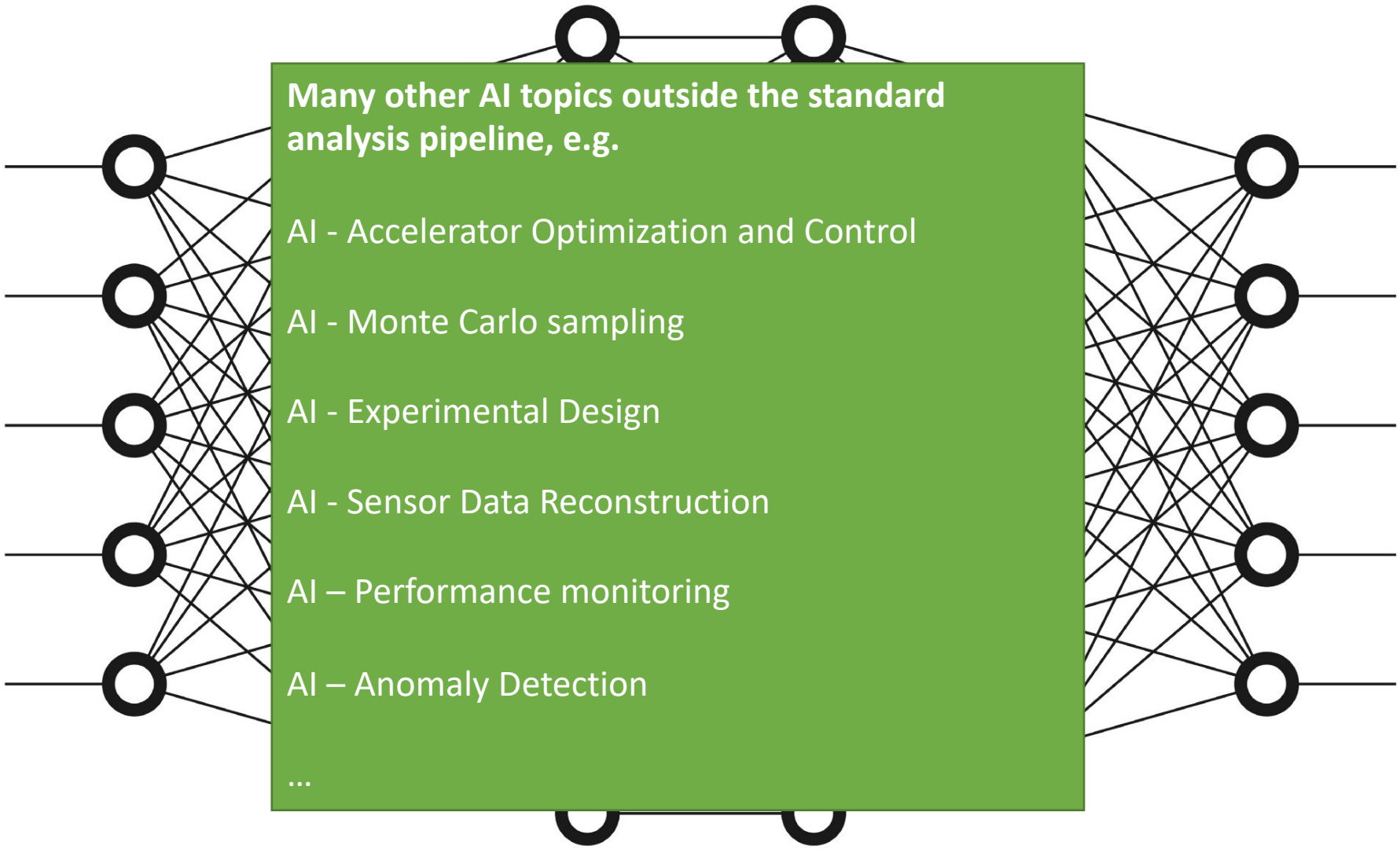

Many other AI topics outside the standard analysis pipeline, e.g.

AI - Accelerator Optimization and Control

AI - Monte Carlo sampling

AI - Experimental Design

AI - Sensor Data Reconstruction

AI – Performance monitoring

AI – Anomaly Detection

…

How will artificial intelligence affect the design decisions for the future collider?

“Complexity is not a problem, but a strength”

Opportunities for Fundamental Physics

AI@HEP = A template for AI@science

Can fundamental physics pioneer AI use cases applicable across fields ?

Can particle physics (again) serve as a driver in scientific AI ?

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AI's role in physics is growing but requires careful Stewardship by a group specifically dedicated to AI.


EuCAIF
Home
Activities
Members
How to join
Contact
European Coalition for AI in Fundamental Physics
Upcoming
EuCAIFCon 2025
June 16 - 20, Sardinia
Now:
https://eucaif.wpcomstaging.com/
Next week:
www.eucaif.org

EuCAIF organizational structure

EuCAIF management board

(5 people, rotating)

EuCAIF "Fellows"

(about 40 staff scientists, organizers of EuCAIF rotating to management board)

+ International Advisory Board

EuCAIF "members":

Scientists will be able to ask for membership (members are working on AI in fundamental physics, tasks: coming to the conferences + working groups, system *to be installed*)

EuCAIF Working groups

WG 1: Foundation models & discovery

WG 2: AI-assisted co-design of future ground- and space-based detectors

WG 3: FAIR-ness & Sustainability

WG 4: Machine Learning and Artificial Intelligence Infrastructure (JENA WP4)

WG 5: Building bridges - Community, connections and funding

EuCAIF "core group"

Management board

- Sascha Caron (Radboud University and Nikhef, Netherlands)
- Elena Cuoco (European Gravitational Observatory and Scuola Normale Superiore, Italy)
- Johan Messchendorp (GSI/FAIR, Germany)
- Tilman Plehn (Heidelberg University, Germany)
- Christoph Weniger (University of Amsterdam, Netherlands)

EuCAIF "Fellows":

Helena Albers (GSI/FAIR, Germany), Lucio Anderlini (INFN Firenze, Italy), Anastasios Belias (GSI/FAIR, Germany), Valerio Bertone (IRFU, CEA, Université Paris-Saclay, France), Elena Cuoco (European Gravitational Observatory and Scuola Normale Superiore, Italy), Sascha Caron (Radboud University and Nikhef, Netherlands), Stefano Carrazza (Milan University & INFN, Italy), Caterina Doglioni (University of Manchester, endorser, United Kingdom), Tommaso Dorigo (INFN Padova and University of Padova, Italy), Thomas Eberl (ECAP / FAU Erlangen-Nürnberg, Germany), Martin Erdmann (RWTH Aachen University, Germany), Stefano Forte (Milan University, Italy), Julian Garcia Pardinas (CERN), Tobias Golling (University of Geneva, Switzerland), Stephen Green (University of Nottingham, United Kingdom), Eilam Gross (Weizmann Institute, Israel), Will Handley (University of Cambridge, United Kingdom), Lukas Alexander Heinrich (CERN), Ik Siong Heng (University of Glasgow, United Kingdom), Verena Kain (CERN), Gregor Kasieczka (University of Hamburg, Germany), Andreas Ipp (TU Wien, Austria), Johan Messchendorp (GSI/FAIR, Germany), Lorenzo Moneta (CERN), Daniel Nieto (IPARCOS, Universidad Complutense de Madrid, Spain), Adrian Oeftiger (GSI/FAIR, Germany), Hiranya Peiris (University of Cambridge, United Kingdom), Maurizio Pierini (CERN), Annalisa Pillepich (MPI, Heidelberg, Germany), Tilman Plehn (Heidelberg University, Germany), David Rousseau (IJCLab, CNRS/IN2P3, U Paris-Saclay, France), Roberto Ruiz de Austri (IFIC/CSIC and University of Valencia, Spain), Veronica Sanz (Sussex&Valencia, United Kingdom & Spain), Steven Schramm (University of Geneva, Switzerland), Steffen Schumann (University of Göttingen, Germany), Nicola Serra (University of Zürich, Switzerland), Roberto Trotta (SISSA and Imperial College London, Italy & United Kingdom), Sofia Vallecorsa (CERN), Pietro Vischia (Universidad de Oviedo and ICTEA, Spain), Benjamin Wandelt (Institut d'Astrophysique de Paris, Sorbonne Université, France), Christoph Weniger (University of Amsterdam, Netherlands), Gabrijela Zaharijas (Center for Astrophysics and Cosmology (CAC), University of Nova Gorica, Slovenia)

If you like to follow the activities of EuCAIF please join the following e-group: eucaif-info@cern.ch

- How? If you would like to apply for membership of a CERN e-group, visit http://cern.ch/egroups and search for the e-group (e.g. eucaif-info) you would like to join.

The EuCAIFCon Conference Series

The Annual European Conference for AI in Fundamental Physics

Our aim is to provide a platform for establishing new connections between AI activities across various branches of fundamental physics, by bringing together researchers that face similar challenges and/or use similar AI solutions. The conferences are organized “horizontally”: sessions are centered on specific AI methods and themes, while being cross-disciplinary regarding the scientific questions.

The first “European AI for Fundamental Physics Conference” (EuCAIFCon 2024) was held in Amsterdam, from 30 April to 3 May 2024.

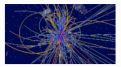
EuCAIFCon 2025 will take place in Sardinia, June 16 - 20 2025.

More information

EuCAIFCon 2024 in Amsterdam

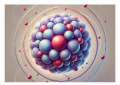
Theoretical physics

Crafting mathematical frameworks to predict and explain the fundamental laws of nature.



Particle physics

Unlocking the secrets of the tiniest building blocks of the universe.



Nuclear physics

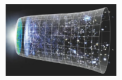
Studying atomic nuclei to understand the forces that power stars and shape the elements around us.

Astroparticle physics

Exploring cosmic rays, neutrinos, and dark matter to reveal the universe's mysteries.

Gravitational waves

Listening to the ripples in spacetime to witness the most violent cosmic events.



Cosmology

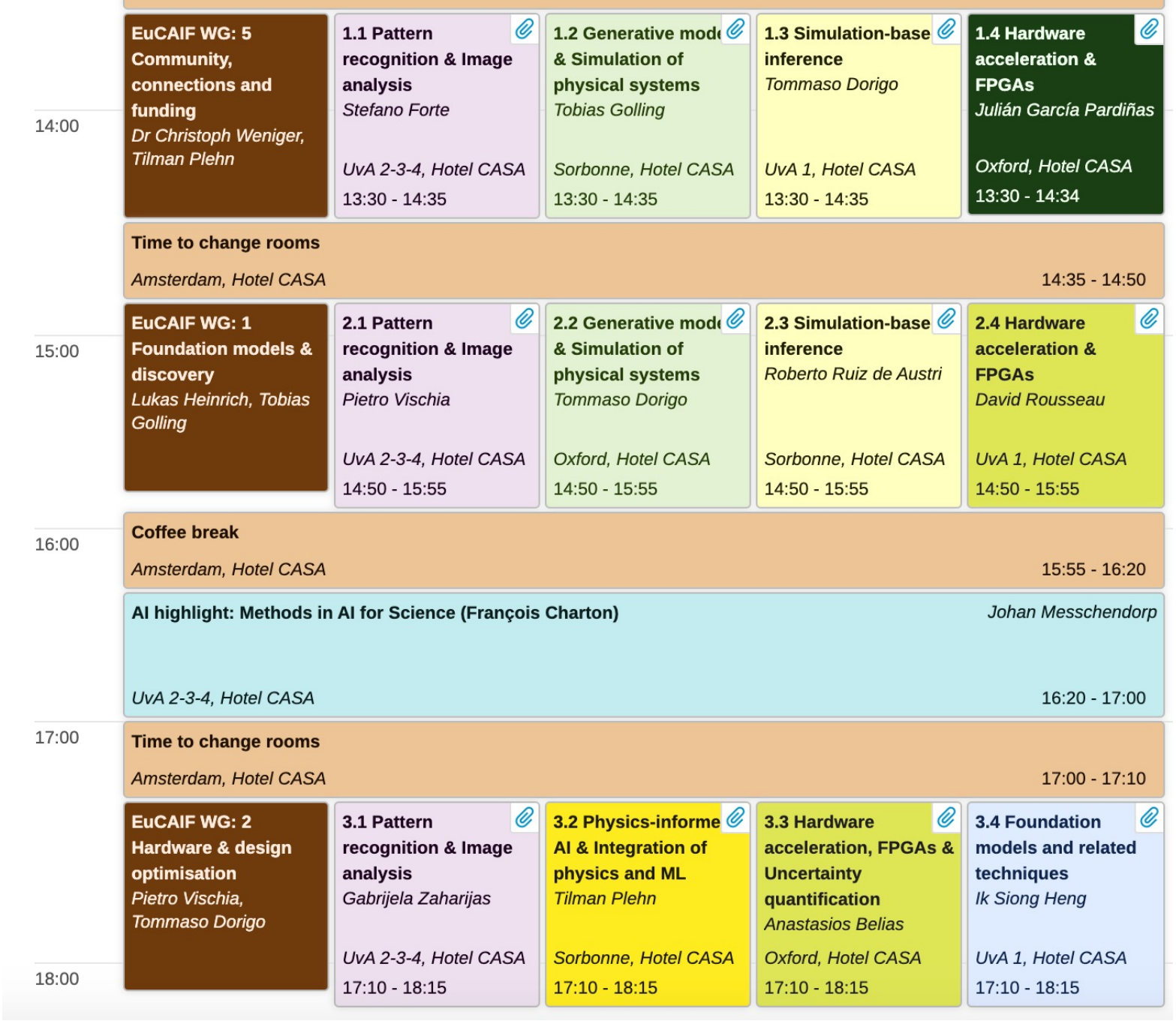
Investigating the origins, evolution, and ultimate fate of the universe on the grandest scales.

Accelerator physics

Pushing the frontiers of technology to accelerate particles and probe the structure of matter.

Program Tuesday afternoon

> 270 participants (fully booked)
122 posters
45 Parallel talks



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JENA report and AI infrastructure

This Inititative is part of JENAA "Computing Working Group" & a EuCAIF WG

(discussed in Madrid in 2022 & Bologna in 2023)

Machine Learning and Artificial Intelligence (AI): WG4

convener: Sascha Caron (NIKHEF); Andreas Ipp (TU, Vienna)

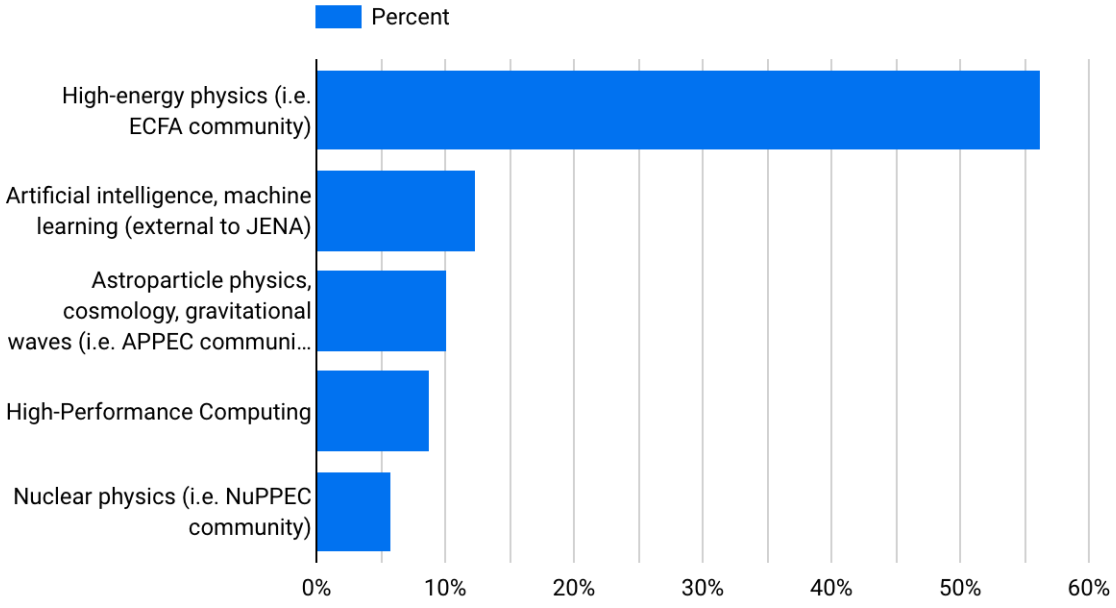
→**Main topic:**

Whitepaper on the "ML/AI infrastructure that will be required in approx. >= 5 years" (by the end of 2024)

Strategic White Paper on AI/ML infrastructure for particle physics, nuclear physics and astroparticle physics.

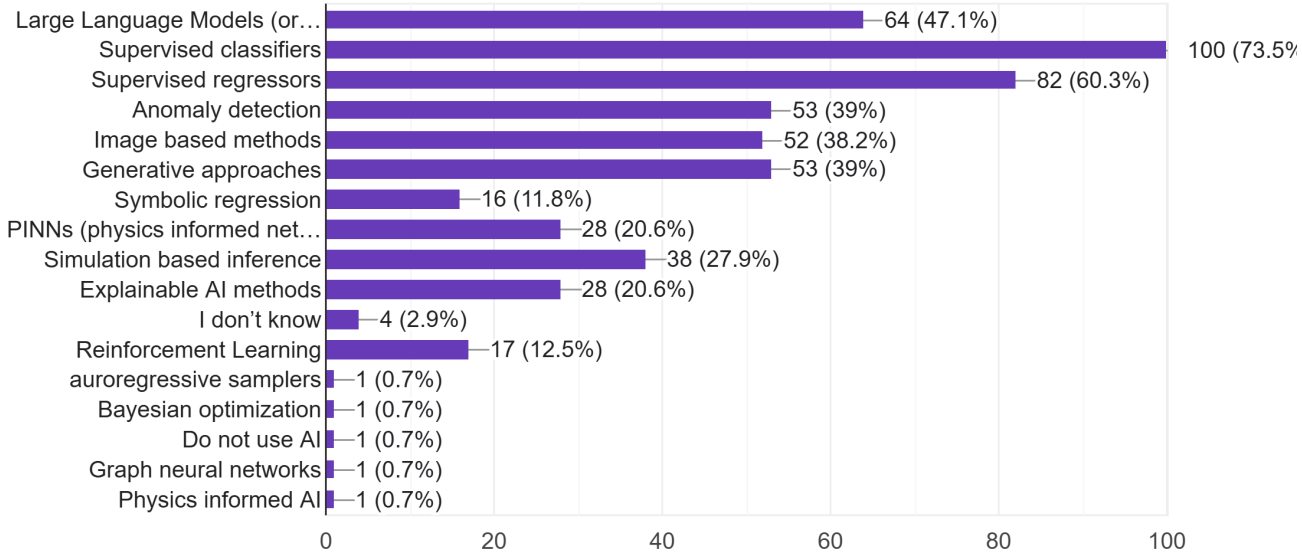
Survey results: First lessons from JENA report on AI infrastructure

[2/40] What is your main scientific field (or JENA community)?



[5/40] What is your usage of AI? Which ML techniques do you use?

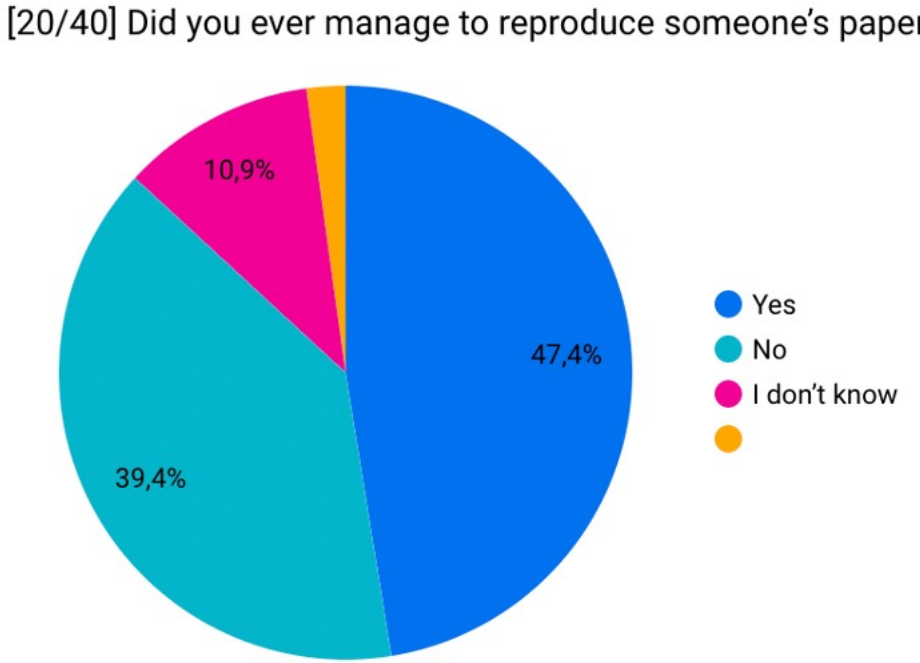
136 responses



137 participants , dominated by HEP

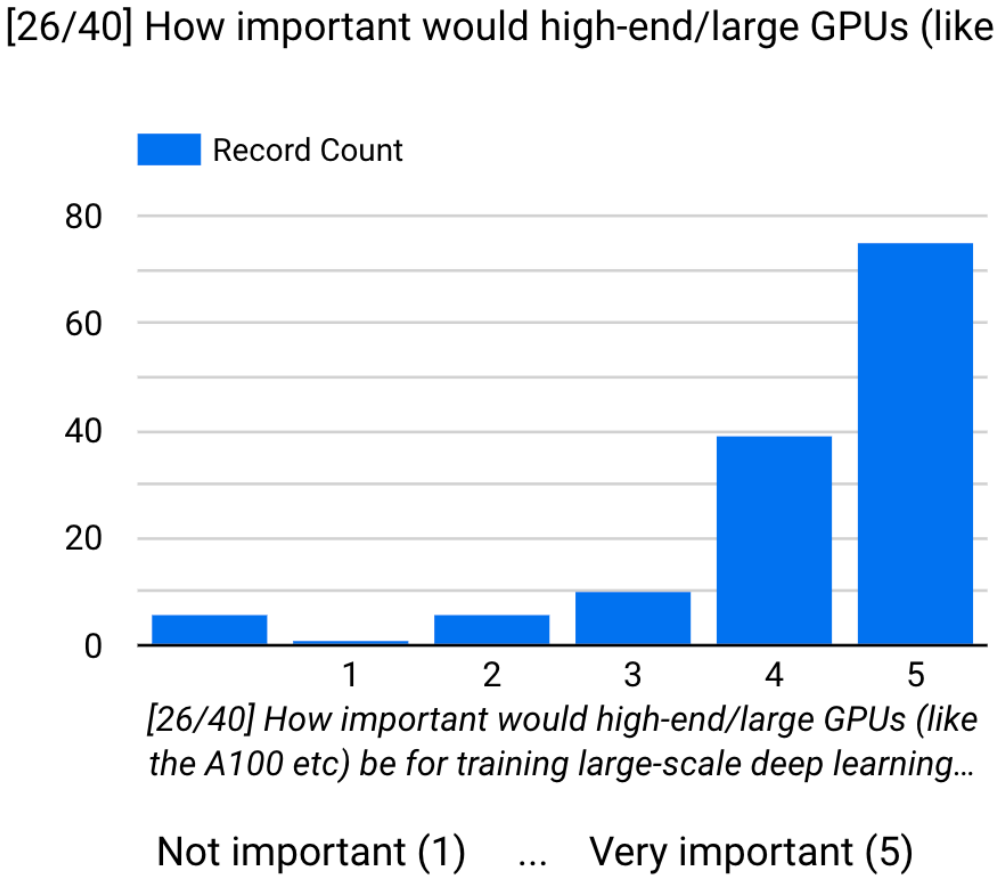
Very diverse list of ML techniques + applications

Survey results: First lessons from JENA report on AI infrastructure



People reproduce the work of others
Need benchmark, open data, public ML models

Survey results: First lessons from JENA report on AI infrastructure: Future needs ?



→ *Need for Large/high-end GPU (due to larger AI models)*

We also need a critical view of AI

Chatgpt etc: Use and ownership of research (code, ideas, data, ...)

When Do Models Fail in HEP Applications?

Interpretability: Whitebox vs Blackbox Models ?

Human AI collaboration and education

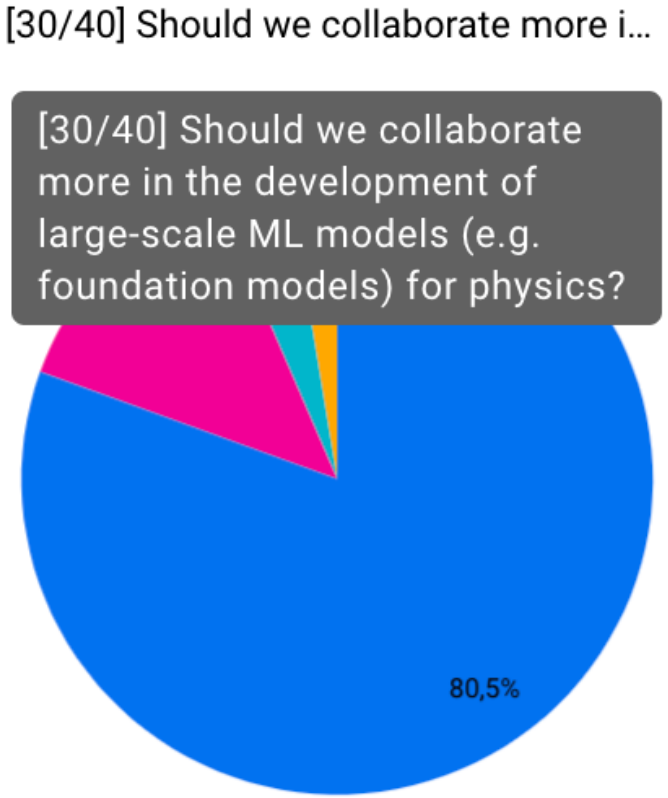
Ethics and Sustainability in our AI applications

...

Conclusion and Future Directions

AI's role in physics is growing but requires careful Stewardship by a group specifically dedicated to AI.

Conclusion and Future Directions



AI's role in physics is growing but requires careful Stewardship by a group specifically dedicated to AI.

Future Vision for EuCAIF:

- Expansion of cooperation, development of new AI instruments and methods for fundamental physics.
- Creating a template for an AI infrastructure for Europe in fundamental physics that can be adopted by other scientific fields.

>80 % see need to collaborate in the development on large-scale ML models