

AI & (Q)Computing & Software work and R&D

Eduardo Rodrigues, for many colleagues (see names in pages)

- Paper “**Fault-Tolerant Resource Comparison of Qudit and Qubit Encodings for Diagonal Quadratic Operators**”

<https://arxiv.org/abs/2604.26792>

- Developing and comparing qudit and qubit algorithms for quantum-simulation for lattice field theories
- Recent work focuses on fault-tolerant resource estimates, identifying regimes where qudits may offer benefits savings over qubit-based implementations

- Early fault-tolerant algorithm applications
- Using sampling quantum circuits to understand physical systems of interest, with a focus on nuclear-model spectra and ground-state energies

Sampling quantum circuits to reconstruct nuclear-model energy spectra.

Fault-Tolerant Resource Comparison of Qudit and Qubit Encodings for Diagonal Quadratic Operators

Samuel Godwood,^{1,*} Doğa Murat Kürkçüoğlu,² Gabriel N. Perdue,² Marina Maneyro,¹ and Alessandro Roggero^{3,4}

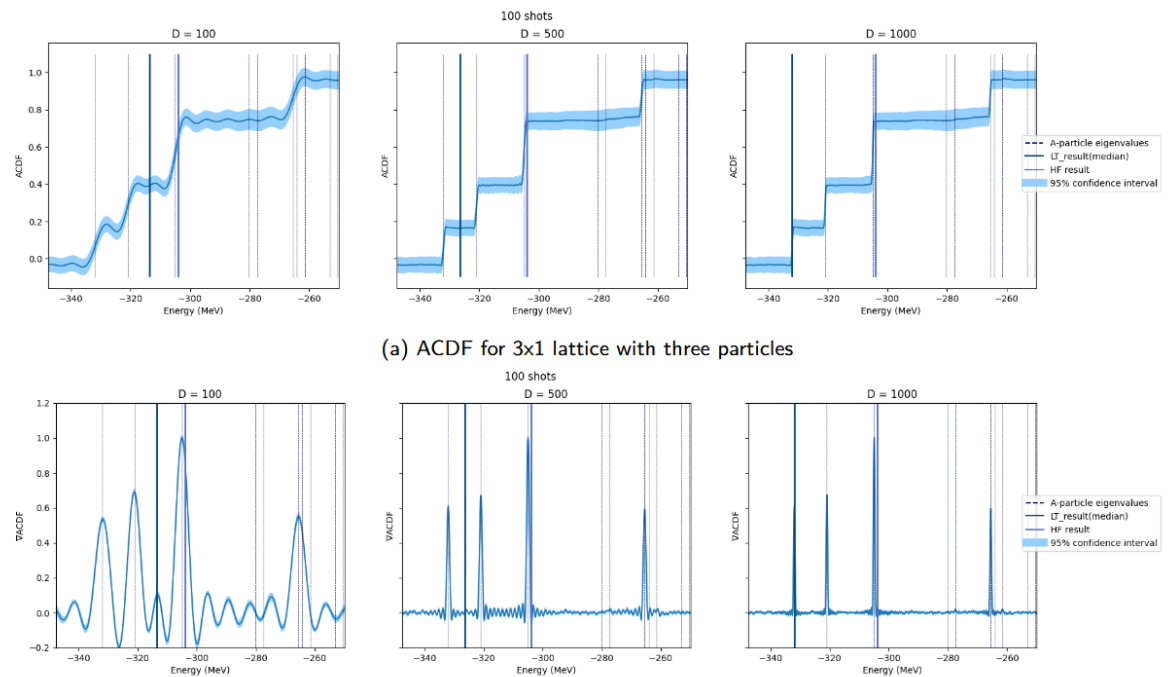
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Finite local Hilbert-space truncations arise naturally in quantum simulations of lattice field theories and motivate qudit encodings, but their fault-tolerant advantage over qubit encodings remains unclear. We compare the non-Clifford cost of implementing quadratic diagonal evolutions, exemplified by $U = e^{-it\phi^2}$ in a uniform field-amplitude discretization of a real scalar field, using either one logical d -level qudit or $n_b = \lceil \log_2 d \rceil$ logical qubits. We analyze two standard settings: product-formula simulation and LCU/block encoding, taking the resource metric to be the number of non-Clifford gates after synthesis into a discrete logical gate set. Because tight synthesis bounds for general single-qudit rotations are not known, we express the qudit constructions in terms of embedded two-level $SU(2)$ rotations and derive explicit finite- d break-even conditions for their synthesis cost; these serve as compiler targets for when qudit encodings can outperform the qubit baseline. Within the constructive models studied here, product-formula implementations would require an exponentially stronger per-primitive synthesis advantage for qudits to win asymptotically, while in the LCU setting the qubit encoding is asymptotically cheaper in d . Nevertheless, the finite- d threshold analysis identifies low dimensional regions in which qudits can yield meaningful constant-factor savings, particularly for LCU-based implementations. As a secondary analysis of the LCU construction, we use an idealized negligible-overhead qubit-qudit code-switching model to give an absolute T -count comparison, and reinterpret the savings as an allowable per-switch overhead budget.

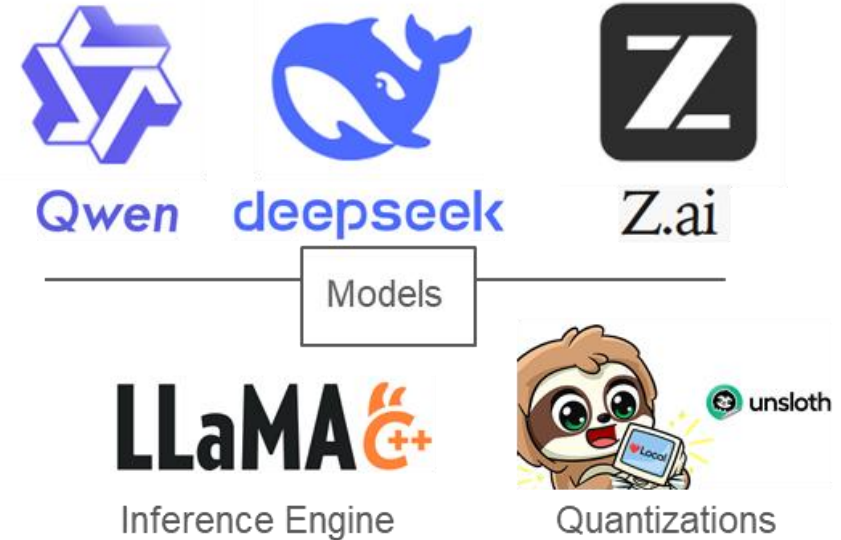


Several analyses using ML (tools) – most relevant contributions from Liverpool are:

- **Physics object:** b-jet, c-jet tagging (Nikos, Andy) and **tau-hadronic reconstruction** (Jordy, Monica, Mehul, and Lennox + Rob in previous years)
- **Di-Higgs analysis in bbtautau** (Carl, Jordy, Buphesh, Lennox)
- **Higgs invisible** (Stephen, Monica, Andy)
- **Higgs into long-lived axion-like particles** (Oliver, John, Monica, Nikos)
- **Compressed-scenario SUSY searches** (John, Monica + had MPhys student this year working on this, and there is a new PhD coming in October 2026 shared with RAL)

ATLAS presentation from yesterday talks about several of these analyses ...

- Exploring the use of LLMs for VHDL/Verilog
- Using both paid and free models
 - Even with paid models - **open weights preferred**
 - 50/50 running locally vs. cloud
 - Stealing time on **RTX 5060 Ti 16GB @ CERN**
- Very rapid pace of change
 - In 9 months, models went from “jank” to “usable”
 - A lot to learn
- FPGA development is still very niche
 - Nowhere near the generated code of Python or JS
- **What’s it good for?**
 - Testbenches and simulations
 - Boilerplate
 - Documentation/Explanation
- **What’s it bad at?**
 - Timing (laughably bad - “just add 1 clock cycle delay idiot”)



```
Then in GTKWave, add these signals to get a clear picture:
```

Group	Suggested signals
Top I/O	tb_bitslipper.clk, tb_bitslipper.rst, tb_bitslipper.bitslip, tb_bitslipper.inword, tb_bitslipper.outword, tb_bitslipper.outword_valid, tb_bitslipper.busy
Internals	tb_bitslipper.dut.bs_cnt, tb_bitslipper.dut.s_inword, tb_bitslipper.dut.s_inword_1, tb_bitslipper.dut.s_busy, tb_bitslipper.dut.s_bitslip

```
### Quick timing reference (per bitslip)
The FSM takes 3 clock cycles for each bitslip:
1. init - detects s_bitslip = '1', transitions to incr, asserts s_busy
2. incr - increments bs_cnt, transitions to done
3. done - pulses outword_valid for one cycle, returns to init

The output word is computed combinatorially before the FSM state transitions, using the current bs_cnt. So after a bitslip completes, the new shifted value appears on outword in the same cycle outword_valid goes high.

Resumed session
```

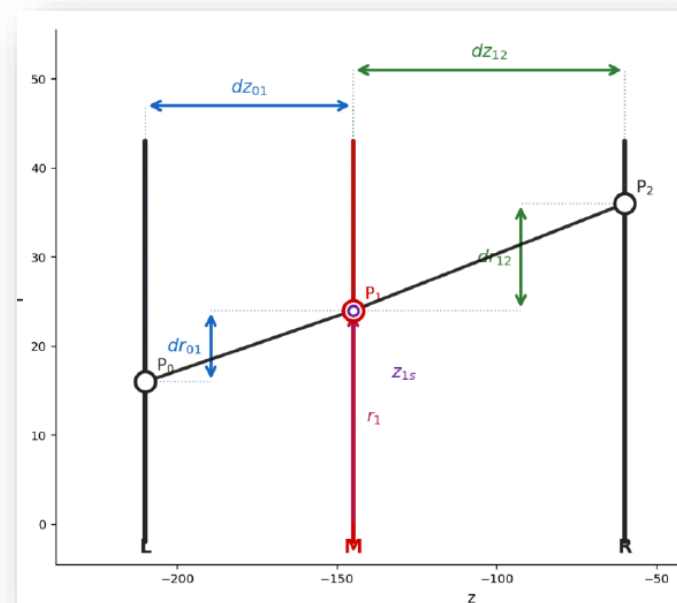
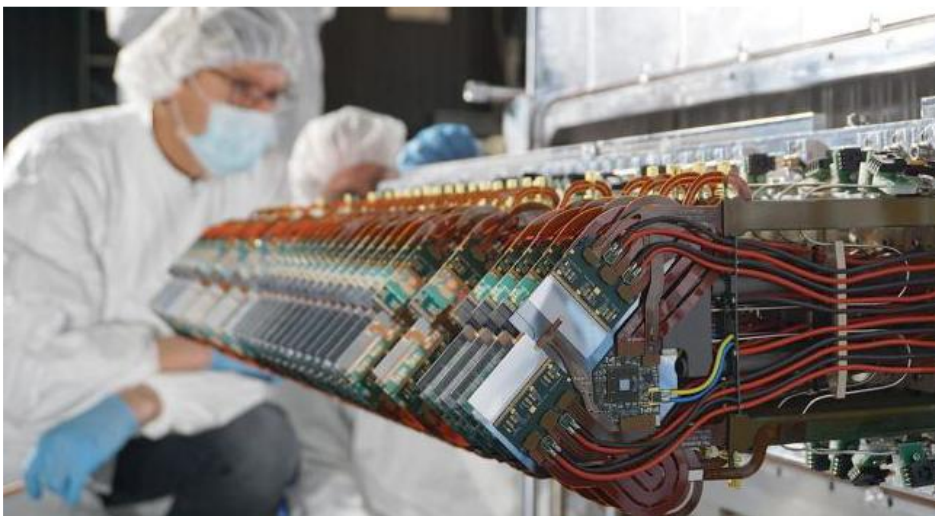
deepseek/deepseek-v4-flash:high · 0:23 · data_processing · ctx [] 1% 8.4k/1.05M · 10 iB · \$0.0000

Pi coding harness

- **ML for tracking is a big, important and interest topic**
- Liverpool LHCb investigating with the VELO as a use case – Giuseppe's PhD

See Giuseppe's talk from yesterday ...

- **Prototype algorithm for real-time reconstruction of particle tracks in the VELO detector runs on GPUs**
(exploit CUDA-based parallelism)
- WIP, lots of ideas in the pipeline ...



General idea: exploit the LHCb trigger CPU and GPU resources as Analysis Facilities for offline analysis related work

- SWAN is an analysis facility, hence collaborate with the CERN-IT / SWAN team to leverage as much as possible – joint pilot project since 2025 :)
- **Proceed in steps, taking into account internal and external constraints:**
 - 8-GPU mini cluster set up and running since late Summer 2025
 - Independent of the special Online environment, validates the end-to-end chain, accessible via a SWAN QA private instance
 - Attach the Online GPUs as external SWAN resources during LS3
- Along the way, also got the **default LHCb software environment available in SWAN** (custom envs work)

- CHEP 2026 talk jointly with CERN's SWAN team next week:

The image shows two side-by-side screenshots of the SWAN service configuration interface. The left screenshot is titled '(standard) SWAN service' and the right is '(LHCb-private) SWAN QA service'. Both have identical settings for 'Software stack' (107 CUDA 12.5 (GPU)), 'Platform' (AlmaLinux 9 (gcc11)), and 'Environment script'. The 'Session resources' section shows 'CPU' (4) and 'Memory' (16 GB) are the same. The 'GPU' section differs: the standard service lists 'Tesla T4 (15 GB)', 'A100 partition (10 GB)', and 'A100 partition (20 GB)'. The LHCb-private service lists 'NVIDIA-GeForce-RTX-2080-TI (11 GB)' and 'NVIDIA-GeForce-RTX-2080-TI (11 GB)'. A red arrow points from the text 'Our GPUs, a single type' to the GPU selection in the LHCb-private service.

The slide features a dark blue background with white text. The main title is 'Exploiting LHCb trigger CPU and GPU resources as Analysis Facilities'. Below it is the subtitle 'a SWAN integration story'. The 'SWAN team' is listed as Diogo Castro, Enric Tejedor Saavedra, Laura Llinares, Pedro Maximino, Rodrigo Sobral. The 'LHCb team' is listed as Eduardo Rodrigues, Francesco Sborzacchi, Apostolos Karvelas, Pierfrancesco Cifra, Karol Sawczuk. Logos for SWAN and LHCb are at the bottom left, and the date 'May 25th 2026' is at the bottom right.

- **Strategically very important grant for us, a step towards much more**
- Project started in Jan. 2026, £200k together with UCL, IC, Sheffield; Monica is a co-PI
- Several mini-projects funded via the grant. Liverpool runs a more substantial project (see next slide) and takes care of the website <https://ai.hep.ac.uk/>
- AI4HEP ran the [3rd Workshop on Enabling AI in HEP experiments and theory](#) in London in March 2026
- 18 May, contribution from Monica to US Blueprint Workshop “Towards a National-Scale AI Collaboration in HEP”, where AI for Particle Physics in the UK (hence AI4HEP) was presented

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Enabling AI for High Energy Physics in the UK

Mission

Over the past three decades, HEP has successfully leveraged AI across numerous aspects, including data analysis, real-time data selection, detector calibration/monitoring, and theory calculations. It is essential to the future of the field that it fully exploits its potential. Establishing a UK AI HEP framework allows to overcome common barriers and challenges while harnessing opportunities in areas such as hardware, software, AI-ops, skills/training, knowledge exchange, capacity building, industry engagement, and fast-AI.

Our goal is to bring together researchers across experiment, theory/phenomenology, but also computing and software experts, to review progress, identify barriers and opportunities for enabling AI in HEP, sharing tools, promoting successful use-cases, and improving skills/training and knowledge transfer.

Collaborations and synergies

- CCP-TEPP - Collaborative Computational Project on Theoretical and Experimental Particle Physics
- EuCAIF - European Coalition for AI in Fundamental Physics
- HSF - HEP Software Foundation

News and announcements

- Mar 5, 2026 [3rd Workshop on Enabling AI in HEP experiments and theory](#)
- Jan 1, 2026 [AI4HEP projects starts!](#)

Contacts and communication lists

- Contacts AI4HEP: Alex Tapper, Davide Costanzo, Monica d'Onofrio, Tim Scanlon
- Mailing list AI4HEP-UK@jiscmail.ac.uk (subscribe [here](#))
- [CERN Mattermost channel](#)
- [Project GitHub repository](#)

Sharing/contributing software

We welcome software libraries and tools in our GitHub organisation [AI4HEP-UK](#). Feel encouraged to get in touch with the team.

AI4HEP is a project funded by [UKRI](#). Built with [GitHub Pages](#), [Hugo](#), [Bootstrap](#).

Feel encouraged to subscribe !

“Smart Monitoring: AI-Driven Analysis of Distributed Systems”

Can we move towards a more efficient usage of resources through “intelligent” monitoring? [see [full talk](#)]

Implement proof-of-concept focused on LHC-related computing operations

- Use local (small) AI models to detect and analyse issues through monitoring frameworks
- Leverage monitoring platform [Zabbix](#) connected to locally run AI model to query state of monitored systems and services (interactively or automatically)
 - enable dynamic detection and analysis

Results so far (on a local computing site / Tier-2):

- Demonstrator model provides insight into state of system & faster responses
- Plans to expand with further interactive investigation and autonomous actions

Key Considerations for scaling up:

- Accuracy / insight, efficiency / responsiveness, safety in autonomous actions, maintainability / environmental sustainability
- If we get things right, we can reduce efforts and improve response with minimal environmental cost

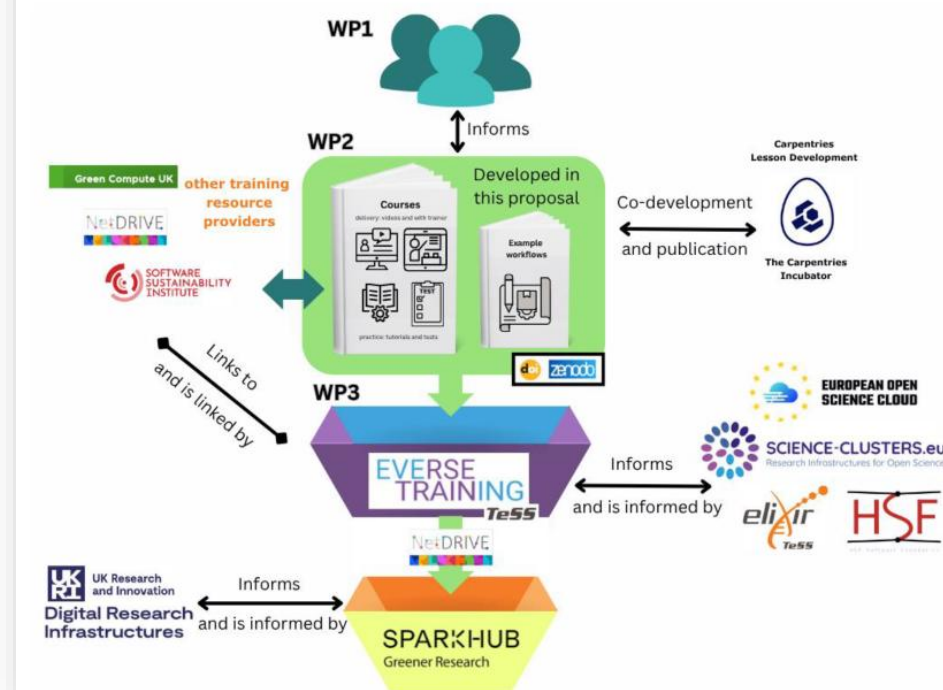
SusTraiN = Sustainable Training Initiative for NetDRIVE:

- NetDRIVE (UKRI Net-Zero Digital Research Infrastructure Vision and Expertise) Community Project
- Started in April 2026 jointly between Manchester (PI), Liverpool (Monica and Eduardo as co-PIs), Sheffield, the SSI (UK Software Sustainability Institute)
- Rather small grant but still important to be on the map on sustainable computing (+ training)
- **3 main topics towards green/sustainable computing:**
Review of training and needs (WP1),
training material (WP2), training catalogue (WP3)

Liverpool contributions:

- **Liverpool** is responsible for WP2, **to develop short, hands-on training modules and reproducible workflow examples**, integrating CPU/GPU energy-profiling, FAIR metadata, and Zenodo-ready releases
- **Translate requirements** (particularly around AI/ML examples) **into executable training artefacts and student-tested materials**
- **Connect also with the HSF**

Figure 1 - sketch of the SusTraiN proposal work and interactions





<https://hepsoftwarefoundation.org/>

Roles:

- HEP Software Foundation (HSF) Steering Group chair, since June 2025
- Worldwide LHC Computing Grid (WLCG) Management Board software representative, 09/2023 – 08/2025
- Joint WLCG/HSF workshop committee programme member for 2025 and future 2026 editions

Talks:

- Invited talk "**HEP software: past, present, future**" at the [Open Symposium on the European Strategy for Particle Physics](#), Palazzo del Casinò, Venice Lido (Italy), 23 - 27 June 2025
- [EVERSE Community Engagement Event](#), CERN, Geneva (Switzerland), 5 February 2026
HSF - The HEP Software Foundation
- [XVII CPAN Days](#), ADEIT, Valencia (Spain), 19 - 21 November 2025
HSF - The HEP Software Foundation

“Scikit-HEP is an open-source community-driven and community-oriented project with the goal of providing an ecosystem for particle physics data analysis in Python, fully integrated with the wider scientific Python ecosystem.

It expands the typical Python data analysis tools for particle physicists with packages spanning the spectrum from general scientific libraries for data manipulation to domain-specific libraries.”



- **Recent work** focused on consolidating the project – it is turning 10 later in the year!
- Continue maintaining several libraries
- Project libraries continue to be cited, see [here](#)

Talks:

- **The Scikit-HEP project**, [Future of SHiP computing workshop](#), CERN, February 2026
- **The Scikit-HEP project - news and future directions**, [WLCG/HSF Workshop 2025](#), IJCLab, May 2025

Seminars:

- **The Scikit-HEP project: overview and future**, PUNCHLunch Seminar, Germany, June 2025

Scientific publications using Scikit-HEP

▼ TABLE OF CONTENTS

- Peer reviewed journal papers
 - Experimental Particle Physics
 - Particle Physics Phenomenology
 - Experimental and Theoretical Nuclear Physics
 - Data Analysis, Machine Learning, Statistics and Probability
 - Instrumentation and Detectors
 - Astronomy, Astrophysics and Cosmology
 - Physics in Medicine and Biology
 - Physics Education
- Conference proceedings and reports
- General articles
 - Experimental Particle Physics
 - Particle Physics Phenomenology
 - Astronomy, Astrophysics and Cosmology
 - Computational Physics
 - Computer Science, Machine Learning
 - Data Analysis, Statistics and Probability
 - Chemical Physics
- PhD theses

Other collaborations

Healthcare (*Monica, Nikos, Rob*):

- **CNN and Graph Transformer-based pipelines for healthcare applications** (predictions of eye disease evolution), with HLS team from Yalin Zheng
- Also looking at the possibility to develop further **collaborations with Engineering** (Dr Yifan Zhou, in the group of Simon Maskell) to work on **AI and xAI pipelines for healthcare applications**, and get further support under the Civic Health Innovation Liverpool (CHI-L) centre

Space Engineering & ESA (*Monica*) :

- **Collaboration with Space engineers at Liverpool and ESA** through PhD student Amelia Samuel:
<https://www.liverpool.ac.uk/doctoral-training/innovation-in-data-intensive-science/meet-our-students/amelia-samuel/>
- Monica is 2nd supervisor of project with Dr Stefania Soldini from Aerospace Engineering Department in the School of Engineering. Amelia is also part of the LIV.INNO programme

- Outcome of a *panel discussion at an Economist Fusion Fest event*
 - Tara was co-chair
- **“Challenges and opportunities for AI to help deliver fusion energy”**
(<https://arxiv.org/abs/2603.25777>)

Abstract. There is great potential for the application of AI tools in fusion research, and substantial worldwide benefit if fusion power is realised. However, using AI comes with its own challenges, many of which can be mitigated if responsible and robust methodologies are built into existing approaches. To do that requires close, long-term collaborations between fusion domain experts and AI developers and awareness of the fact that not all problems in fusion research are best tackled with AI tools. In April 2025, experts from academia, industry, UKAEA and STFC discussed how AI can be used to advance R&D in fusion energy at the first edition of The Economist *FusionFest* event. This Perspective is an expanded and updated summary of the round table discussion, providing more context and examples.

ARTIFICIAL INTELLIGENCE | FEATURE

How AI can help (and hopefully not hinder) physics

29 Jul 2025

The use of artificial intelligence is already becoming commonplace in physics, but could physics also help AI? **Tara Shears** examines the relationship between the two fields following a survey and report by the Institute of Physics

- **Physicsworld** article [[link](#)]

Eduardo – on LHCb, HSF/community, Scikit-HEP:

- **The LHCb Stripping Project: Sustainable Legacy Data Processing for High-Energy Physics**
N. Grieser et al., Comput Softw Big Sci 9, 21 (2025); [doi:10.1007/s41781-025-00151-6](https://doi.org/10.1007/s41781-025-00151-6) ← LHCb work
- **The LHCb Sprucing and Analysis Productions**
A. Abdelmottaleb et al., Comput Softw Big Sci 9, 15 (2025); [doi:10.1007/s41781-025-00144-5](https://doi.org/10.1007/s41781-025-00144-5)
- **Vector: JIT-compileable mathematical manipulations of ragged Lorentz vectors**
Saransh Chopra et al., Journal of Open Source Software, 10 (109), 7791; [doi:10.21105/joss.07791](https://doi.org/10.21105/joss.07791) ← Scikit-HEP work
- **The Critical Importance of Software for HEP**
Christina Agapopoulou et al., HSF prepared inputs for the European Particle Physics Strategy Update
Eur. Phys. J. C 85 (2025) 1142; [doi:10.1140/epjc/s10052-025-14571-6](https://doi.org/10.1140/epjc/s10052-025-14571-6), [arXiv:2504.01050 \[hep-ex\]](https://arxiv.org/abs/2504.01050) ← HSF work

Marina Maneyro, Samuel Godwood – on Quantum Computing:

- **Fault-Tolerant Resource Comparison of Qudit and Qubit Encodings for Diagonal Quadratic Operators**
<https://arxiv.org/abs/2604.26792>

Hands up who is using Generative AI in one form or another for their work?

- Interesting to assess the percentage of colleagues
- (We won't have time in this talk to separate academics from PhD students + early career)

Who is paying subscriptions on their own?

- Corollary: should one be sending a message higher up on providing subscriptions for free to people ...?

Thank you for listening !