Automation and AI for accelerators

Geoff collaboration between GSI & CERN

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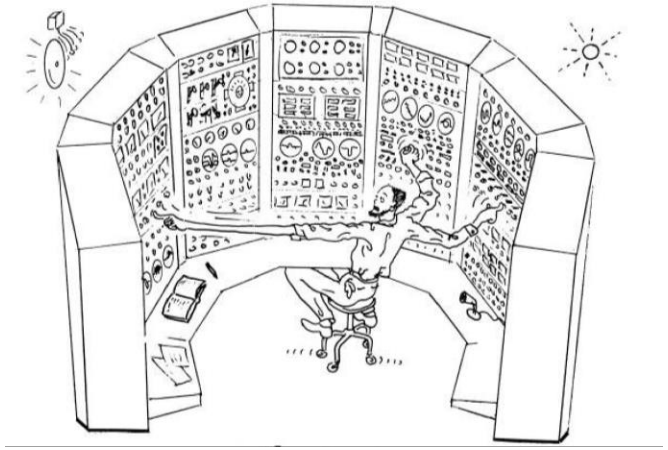
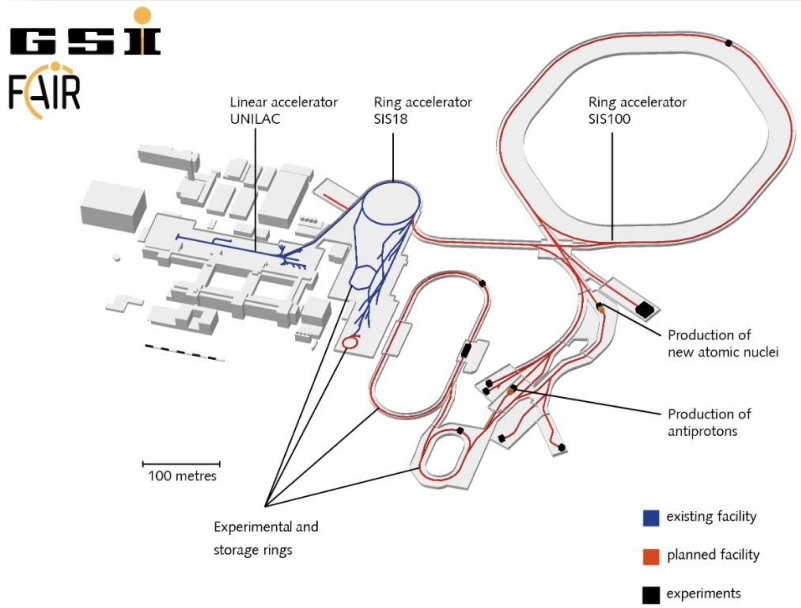
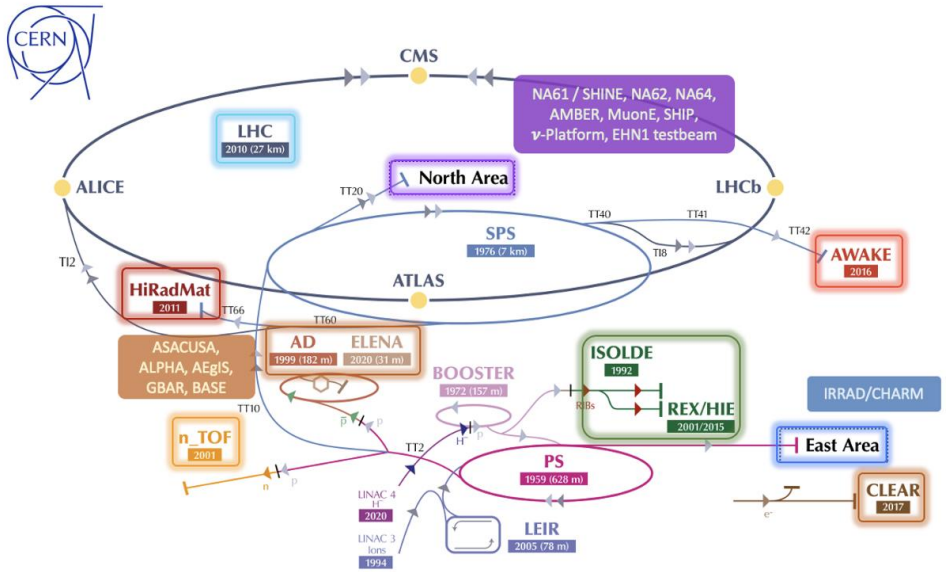
Beam operation challenges
Motivation

- **Machine availability** & **beam quality** are essential to reach **physics objectives**
  parameter drifts, fault recovery & prediction, testing, …
- Broad spectrum of **machine & beam types** with **multi-destination** operation
  beam commissioning & preparation, hysteresis & eddy-currents, scheduling, …

➡ **Exploit automation & technological advances (ML / AI) where possible**





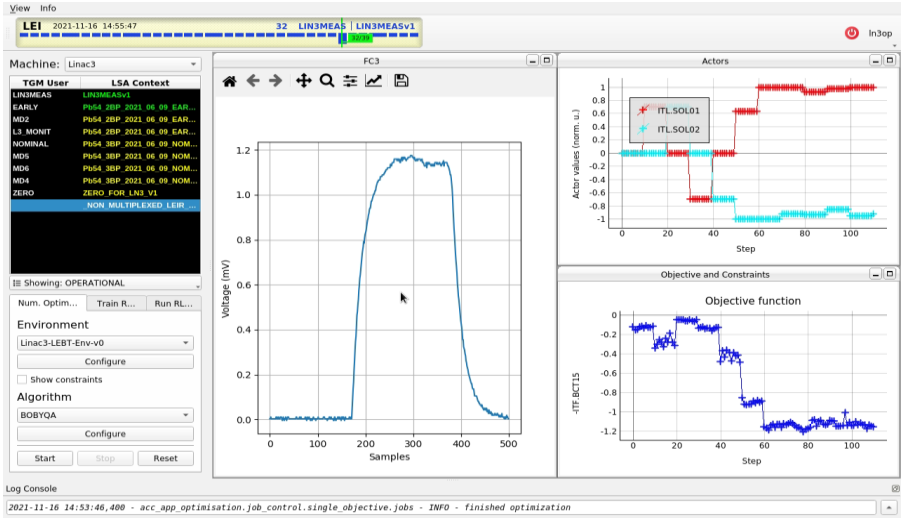


Geoff Collaboration

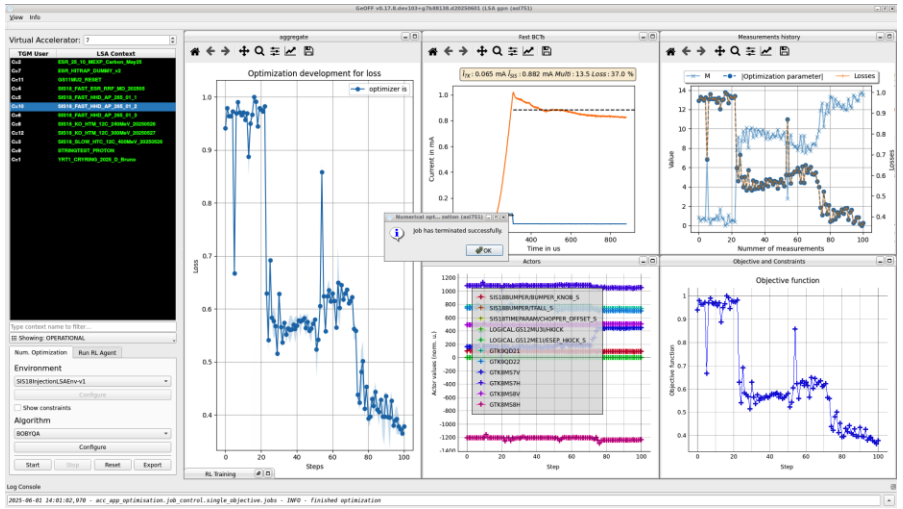
History & scope

- Focus on **parameter optimization & drift compensation** here
- Address in **generic & flexible manner** ➡ framework
- **Generic Optimization Framework & Frontend** (Geoff)
  - **Python framework** to unify **different optimization approaches**
  - **Standardized interfaces**, **tools** for developers & **docs**
  - **GUI application** that wraps everything together
  - *"Facilitate implementation of parameter optimization task with primary focus on problem itself"*
- **Initiated and originally developed at CERN**
- **Effective collaboration since 2022, formalised in 2025 (ADDENDUM NO. 21)**

  focus on AI, optimization algorithm & tools development, knowledge sharing



Example: *CERN Linac3*



Example: *GSI SIS18*

Geoff Collaboration

History & scope

➢ Joint Geoff publication in SoftwareX

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Reading Assistant

Outline

- Abstract
- Keywords
- 1. Motivation and significance
- 2. Software description
- 3. Illustrative examples
- 4. Impact
- 5. Conclusions
- CRediT authorship contribution statement
- Declaration of competing interest
- Acknowledgments
- References

ELSEVIER

SoftwareX

Volume 32, December 2025, 102335

Original software publication

Geoff: The generic optimization framework & frontend for particle accelerator controls

P. Madysa [a], S. Appel [a], V. Kain [b], M. Schenk [b]

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a) GSI

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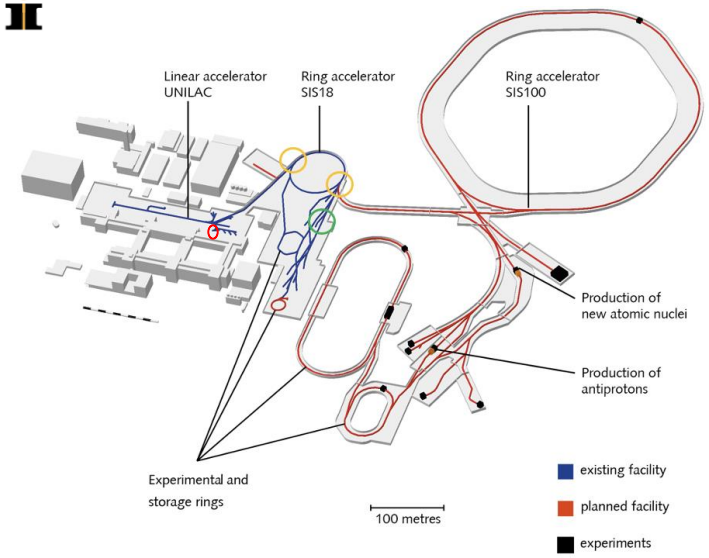
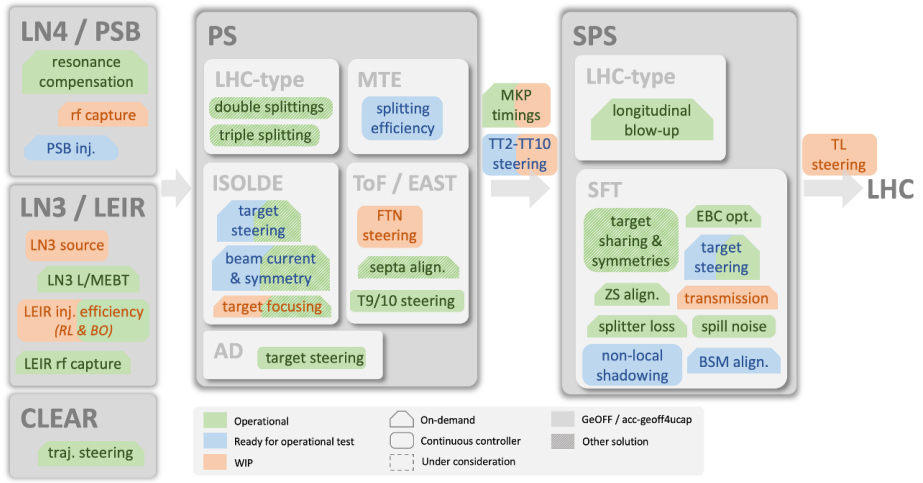
Geoff: status

… at CERN & GSI/FAIR



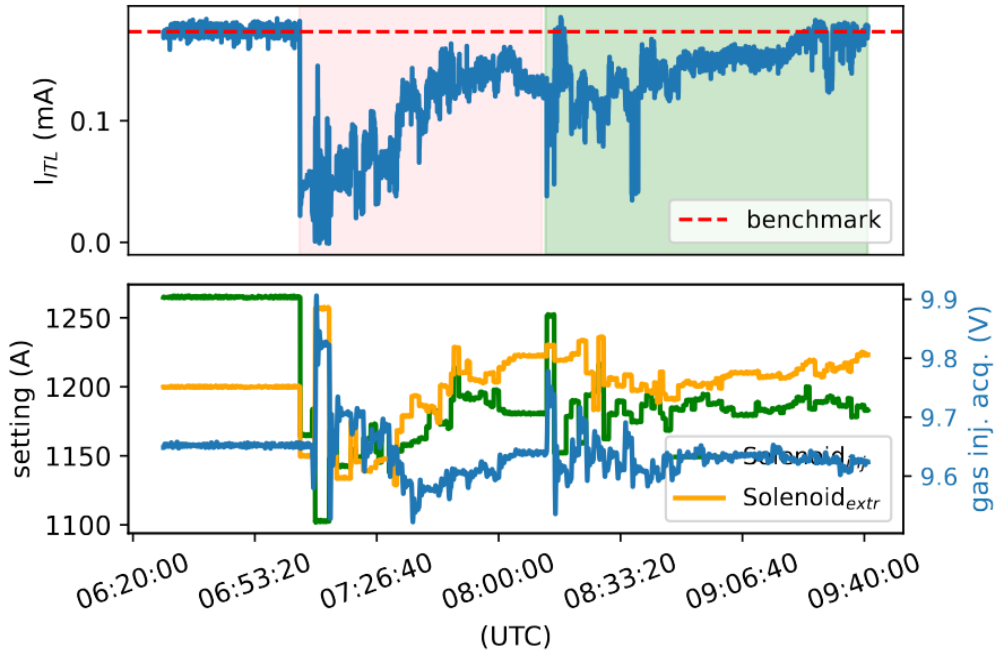
Optimisers & autopilots in the injector complex



- Since 2023: **successful optimization** runs using Geoff at **TK** / ***X2***, **SIS18**, **FRS**
- Using **Python Bridge** to access LSA & FESA
- **GSI GUI available**
- Investigation of **safe Python deployment** in control-room applications

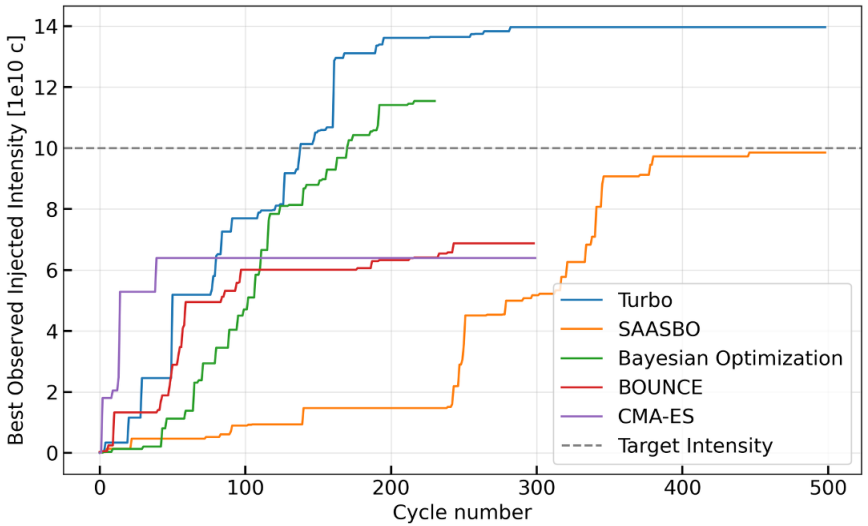
- **Geoff** since LS2 **main optimization framework** in use
  beam commissioning & day-to-day operation, further auto-pilots under development
- **Trend from on-demand to continuous control**
  Using Geoff concept with **UCAP*** infrastructure incl. **Python & GPU** support
  * *Unified Controls Acquisition and Processing: data processing pipelines on server*
- **Geoff has become mainstream**

Geoff: R&D and operations highlights
CERN



- Ex. 1: **Linac3 source recovery & stabilization**
  - Online source recovery after induced detuning
  - R&D with significant progress
    time-dependent source steady-state
  - Geoff flexibility is key to allow fast prototyping and different approaches (e.g. hierarchical setups)
    interactive coding during beam time

- Ex. 2: **LEIR commissioning suite**
  - High-dimensional Bayesian optimization (40 params.)
    Transfer line, injection bump, electron cooler, etc.
  - Beam optimization "from scratch" (< 1 h)
  - Extensive use in operations



Courtesy: B. Rodriguez Mateos

Geoff: achievements in 2025
… at CERN & GSI/FAIR

GSI:

- ✓ **Non-CERN GUI**
- ✓ **Remote Geoff**
  Secure system / high-performance compute split
- ✓ **User control**
  Reset to previous optimization states

CERN + GSI:

- ✓ **Integration of Xopt**
  The SLAC optimizer interface

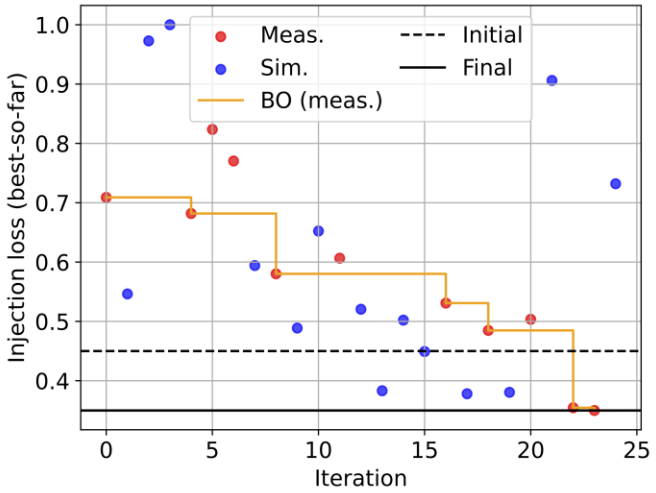
GSI + TU Darmstadt (TU DA):

- ✓ **Joint development of advanced optimization algorithms**
  Multi-Fidelity Bayesian Optimization (MFBO)
- ✓ **Geoff integration with EPICS (PUMA)**

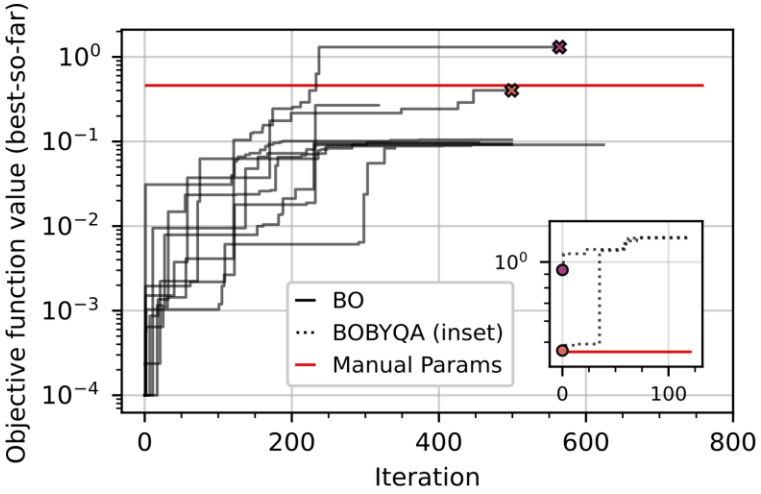
CERN:

- ✓ **New use cases / users**: e.g. LN3 rf optimizer, LEIR rf capture, PSB BTY line opt. for ISOLDE
- ✓ **Using pyda** (pyjapc successor) for new use cases
- ✓ **Draft implementation in COI for multi-output problems,** such as multi-objective BO

- GSI: MFBO for SIS18 injection



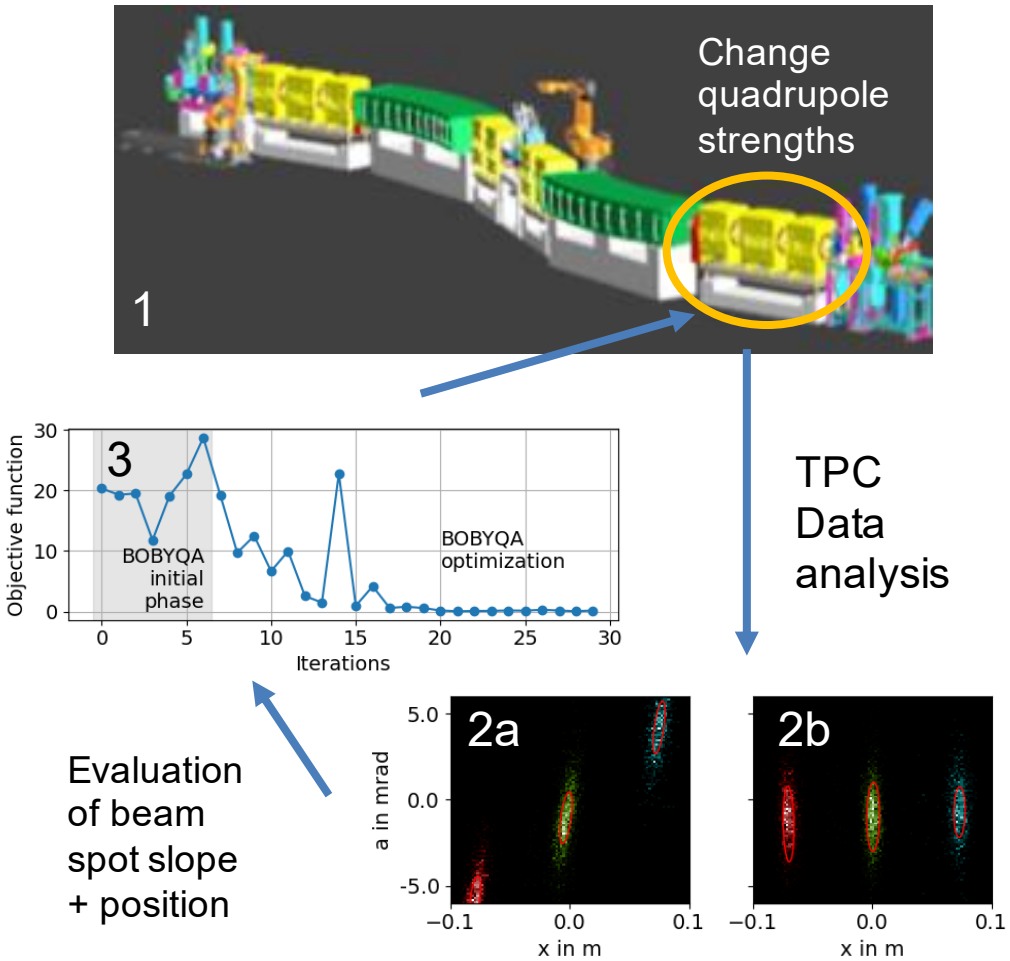
- TU DA: PUMA ion-source test setup



Geoff: plans
Algorithms & framework

- **Algorithms**
  - **GSI & CERN:**
    - Digital twin modelling, phase space reconstruction, sample-efficient RL algorithms and more
    - Requested joint beam time at CLEAR
- **Upgrades and maintenance**
  - **CERN**
    - Make Geoff ready for pyda (pyjapc end of life)
  - **GSI**
    - Preparation for additional automation of Super-FRS
      Image correction, transmissions and resolution optimization
    - Further updates following evolution of ecosystem
- **Geoff mini-workshop at CERN (end of 2026)**
  - **Possible Topics:**
    - Controls strategy, new requirements and algorithms, ...

- FRS: Automation beam setup



Geoff: resources

… at CERN & GSI/FAIR

GSI/FAIR

- From EURO-LABS-funded to permanent GSI position
  Maintenance and co-development of Geoff
- Secure **Python deployment** in the control room (3 FTE)
  "Acc-Py at GSI"
- Strong **student** involvement (BSc – PhD, TU Da)
  Algorithm development & accelerator applications
- **EU projects**: From EURO-LABS to iRIS / TwinRISE / HADRON-2030
  Starting end of this year: ~ 700 k€ for 5 FTE

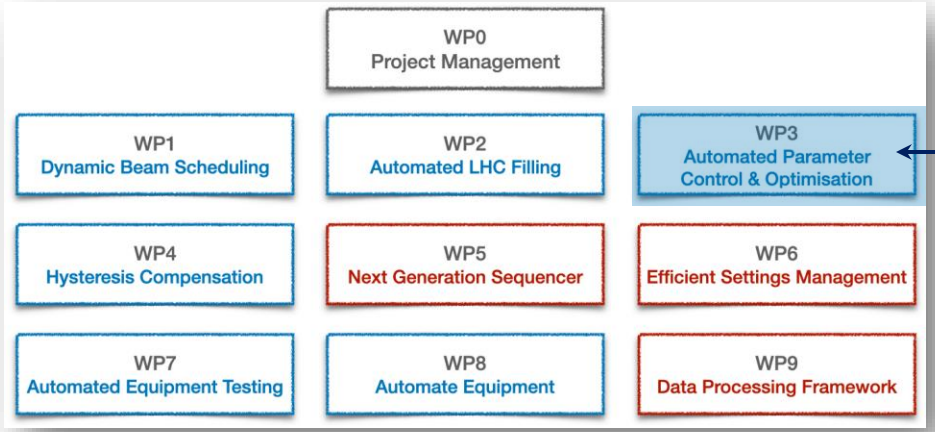
TwinRISE
Trusted AI-Generated Digital Twins for Research

INTELLIGENT RESEARCH INFRASTRUCTURE SUSTAINABILITY (IRIS)

HADRON-2030
Transnational Access, ML-Tune

CERN

- **Geoff is a core product for daily operations**
  - Two staff part time for user support, maintenance, improvements, and evolution
- **Efficient Particle Accelerators project** (EPA)
  - **Goal:** explore and exploit **automation & ML/AI** systematically **across complex**
  - **Approved** in autumn 2023 for a **5-year period**



Conclusions

- **GSI-CERN collaboration on Geoff has been highly successful and will continue**
  - Collaboration is **formalized (ADDENDUM NO. 21)**
  - Labs are in **direct collaboration** and through **EU projects**
  - **CERN** has a lot of experience in **automation and AI**
  - **GSI** offers **valuable contributions** in terms of **manpower** and through **universities associated with GSI** (TU Da)
  - Both labs are facing **similar control problems**
    e.g.: parameter optimization, resonance compensation, spill noise cancellation, drift compensation in general

- **Geoff is a great example where GSI & CERN profit from common infrastructure and share expertise**

Thank you