Doing more with less.

A case study in sustainable frontier science: fewer wasted trials, smarter control, and more discovery from rare resources.

$$\bar{p} + \mathrm{Ps}^* \longrightarrow \bar{H}^* + e^-$$

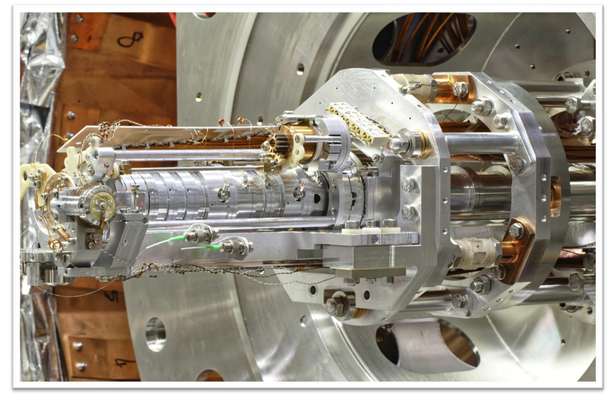
A pulsed antihydrogen beam is formed by charge exchange between cold antiprotons ($\bar{p}$) and Rydberg positronium (Ps).*

What AEgIS is, and why resourcefulness is the whole point

AEgIS, the **A**ntimatter **E**xperiment: **g**ravity, **I**nterferometry, **S**pectroscopy, runs at CERN's Antiproton Decelerator (AD). It asks a simple question: **does antimatter fall like matter?** [1]

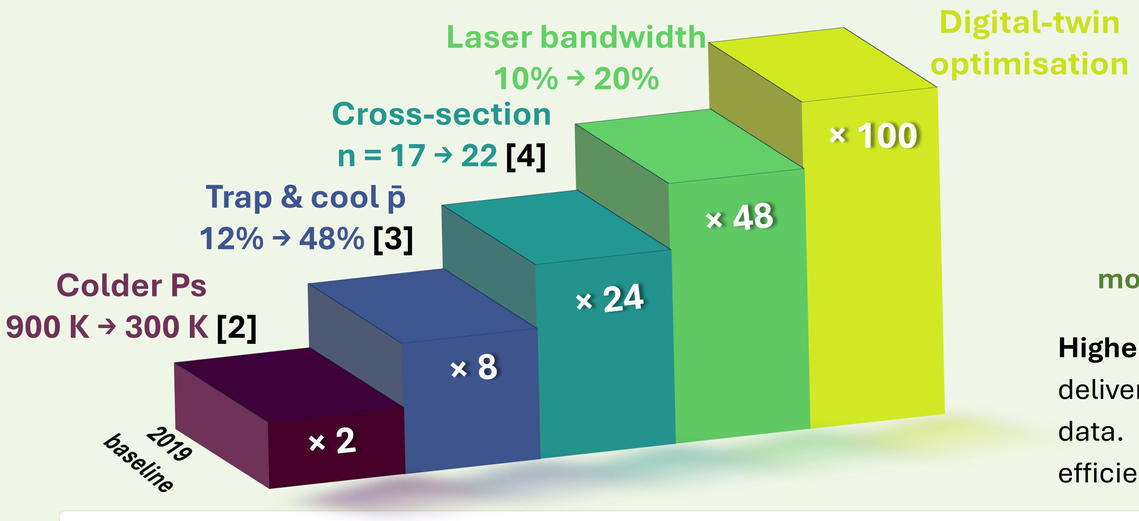
Antimatter is vanishingly rare. None is lying around to collect. Fundamental science often creates value in unexpected ways.

For AEgIS, the immediate sustainability question is how to produce knowledge responsibly, by making limited beam time, cryogenic operation, specialist hardware and expert effort count with as little waste as possible.



formation region: 1 T · T < 20 K · UHV · ns precision

SCIENCE GOAL $\bar{g}_{\bar{H}} \longrightarrow 1\,\%$ Test whether antimatter falls like matter by measuring the gravitational acceleration of antihydrogen to the 1% level.



EFFICIENCY BY DESIGN

1 Compound the gains, not the beam

≈100×

more antihydrogen per antiproton from the same delivered beam, 2019 → 2026.

Higher antihydrogen yield is more than a performance gain. It means the same delivered beam, cryogenic operation and experimental setup produce more useful data. In a high-resource experiment, this reduces repeated cycles and makes efficiency a direct form of waste reduction.

Sustainability in practice: more useful data from each resource-intensive beam cycle, cryogenic run and experimental setup.

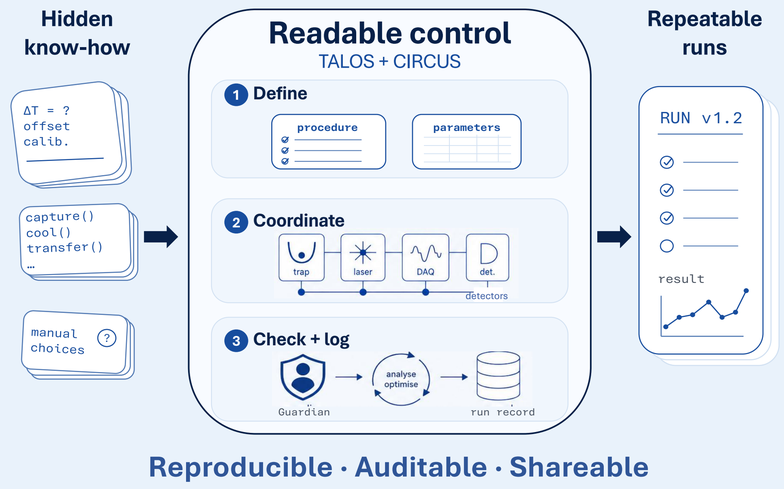
READABLE CONTROL

2 Lowering the hidden cost of doing science

In frontier experiments, sustainability is also about hidden operational cost: failed runs, repeated setup, scarce beam access, power, cryogenic operation and specialist human effort.

The **TALOS** [5] and the **CIRCUS** [6] code environments, developed by AEgIS, reduce this waste by turning expert know-how into readable control procedures that can be checked, repeated and improved by the next user.

- ✓ Featured by National Instruments: TALOS selected as an NI academic-research case study (LabVIEW automation for CERN's antimatter research).
- ✓ ~1 week to first experiment: new users write their own antimatter run within a week, safely driving every object through pre-written control functions.

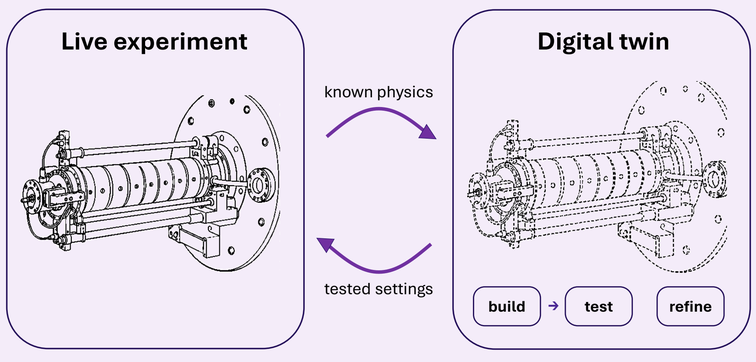


Reproducible · Auditable · Shareable

Sustainability in practice: fewer failed runs, less repeated setup and less lost know-how.

THE DIGITAL TWIN

3 Moving trial and error out of the live experiment



AEgIS is building toward a digital twin: a computer model used to test ideas before the live experiment is run.

By narrowing choices in simulation first, the team can make more deliberate use of shared resources: accelerator access, cryogenic operation, specialist equipment, energy and expert shifts. For publicly funded high-resource science, the goal is better-prepared runs, fewer blind choices and more learning from each campaign.

Sustainability in practice: better-prepared live runs, fewer blind choices, more learning from each campaign, and smarter resource use.

THE BOTTOM LINE

≈ 100×
better use of infrastructure: more useful output from the same high-resource run.

the code
better transfer of know-how: readable codes others can check, repeat and improve.

twin-first
better informed operation: simulations test choices first, supporting better-informed live runs.

Sruthy Chandran and Benjamin Rienäcker on behalf of the **AEgIS Collaboration**

QUASAR Group, University of Liverpool · Cockcroft Institute · CERN AD / ELENA

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[4] D. Krasnicky, R. Caravita, C. Canali, G. Testera, Cross section for Rydberg antihydrogen production via charge exchange, Phys. Rev. A 94, 022714 (2016). DOI: 10.1103/PhysRevA.94.022714
[5] M. Volponi et al., Rev. Sci. Instrum. 95, 085116 (2024). DOI: 10.1063/5.0196806
[6] M. Volponi et al., EPJ Quantum Technol. 11, 10 (2024). DOI: 10.1140/epjqt/s40507-024-00220-6