AEgIS experiment: recent developments and upgrades

Kamila Kempny on behalf of the AEgIS Collaboration

30.07.2025, ICNFP 2025

Outline

1. About AEgIS
   - Goals
   - Methods and apparatus
   - Control system

2. Key recent upgrades and R&D

3. Latest experimental runs in 2024

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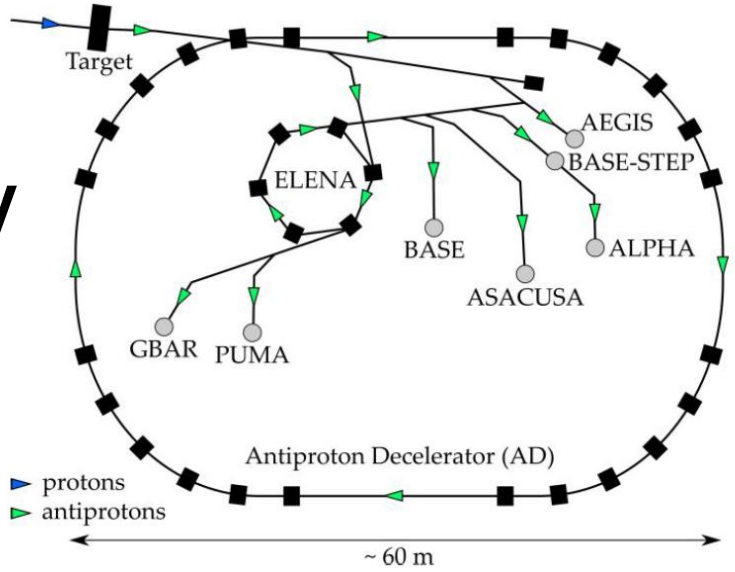
Antimatter **E**xperiment: **G**ravity, **I**nterferometry, and **S**pectroscopy



Primary goal: direct measurement of antihydrogen gravitational acceleration – WEP test for antimatter

- Pulsed production of antihydrogen
- Positronium physics
- Antiprotonic atoms

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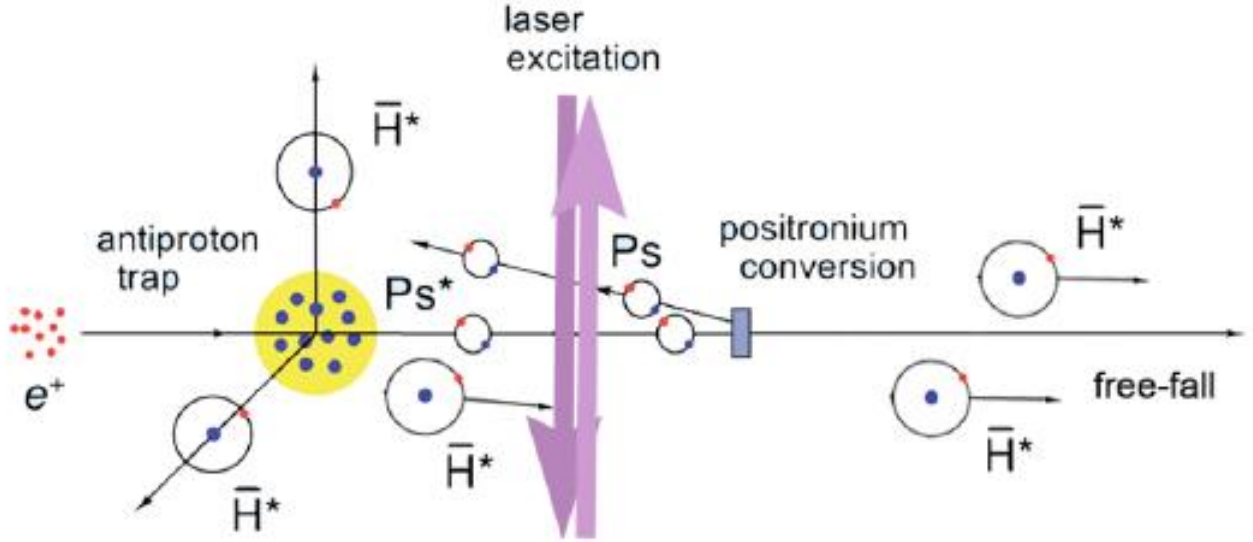
Pulsed production of antihydrogen

Charge-exchange reaction between positronium and antiproton:

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



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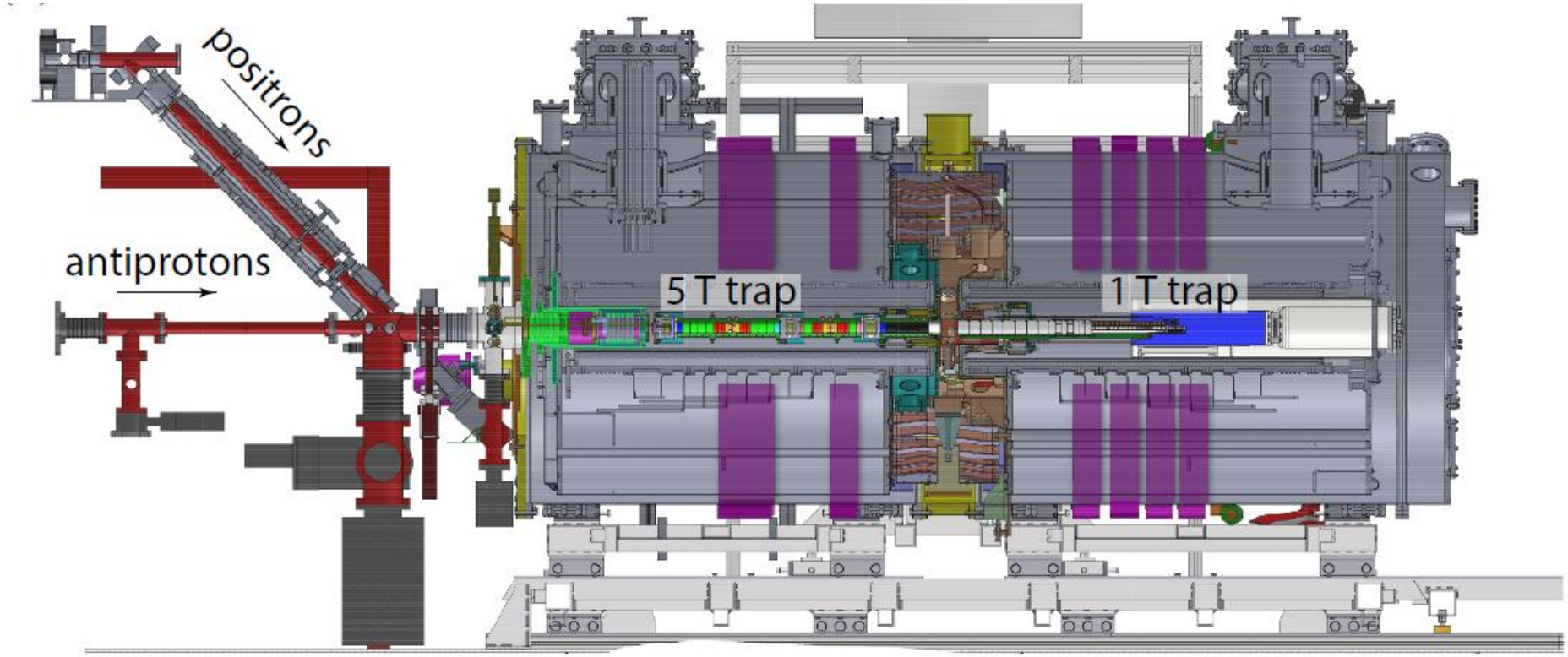
Apparatus



N. Zurlo et. al, Pulsed Production of Antihydrogen in AEgIS, EPJ Web of Conferences **290**, 07001 (2023) https://doi.org/10.1051/epjconf/202329007001

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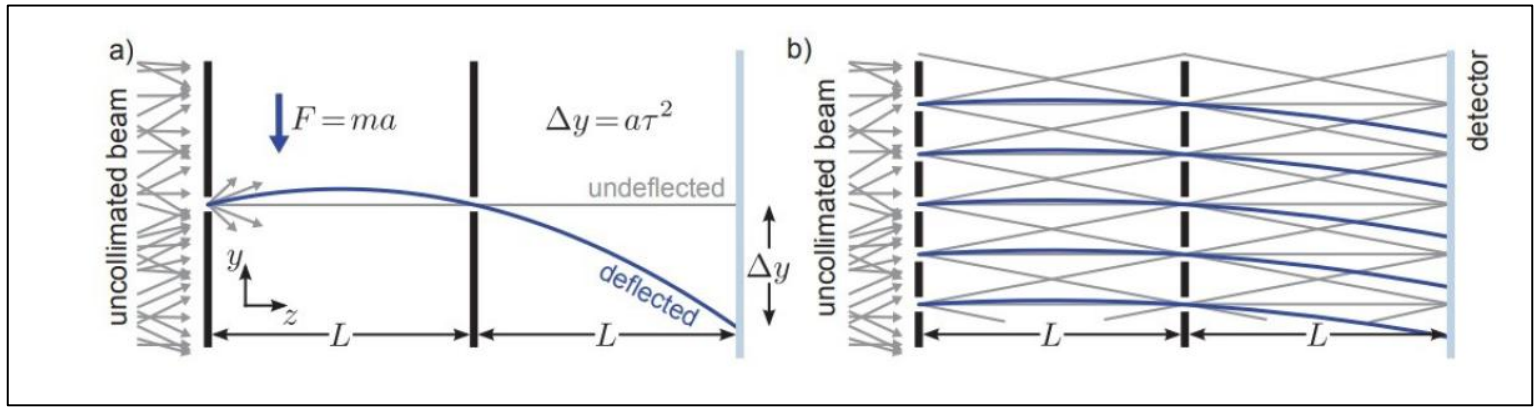
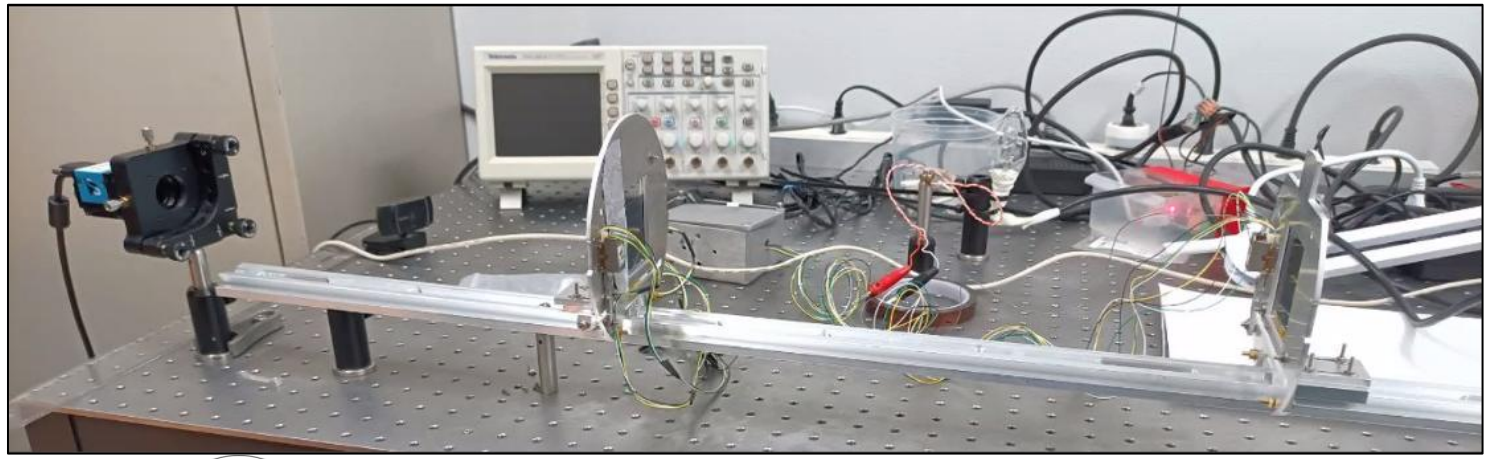
Moire deflectometry



Aghion, S., Ahlén, O., Amsler, C. *et al.* A moiré deflectometer for antimatter. *Nat Commun* **5**, 4538 (2014). https://doi.org/10.1038/ncomms5538



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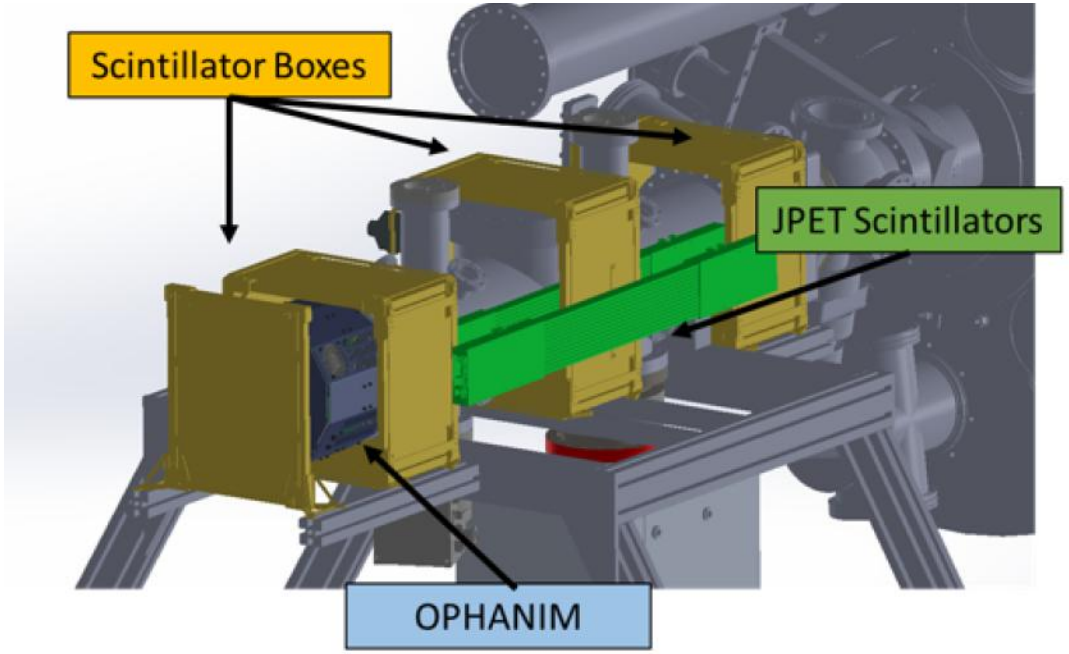
Gravity module

- Outside the trap area, low magnetic fields

Three detection systems:

- OPHANIM
- SARA – annihilations on gratings
- JPET detectors – $\overline{\mathrm{H}}$ trajectories



R. C. Ferguson, Probing the Weak Equivalence Principle with a Moire Deflectometer Using Antihydrogen at AEgIS, ICPA20 proceedings

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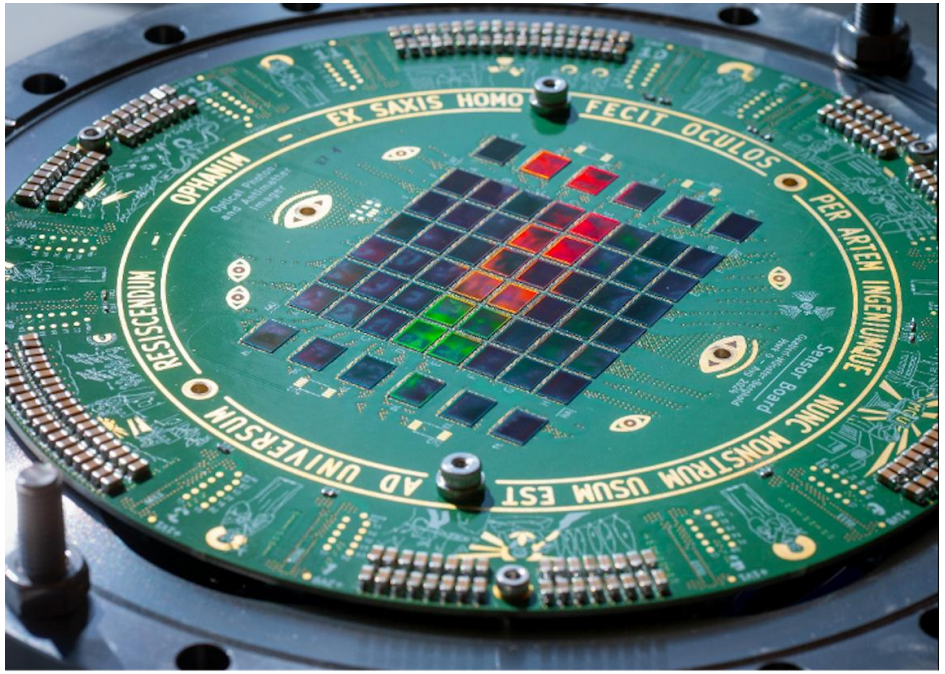
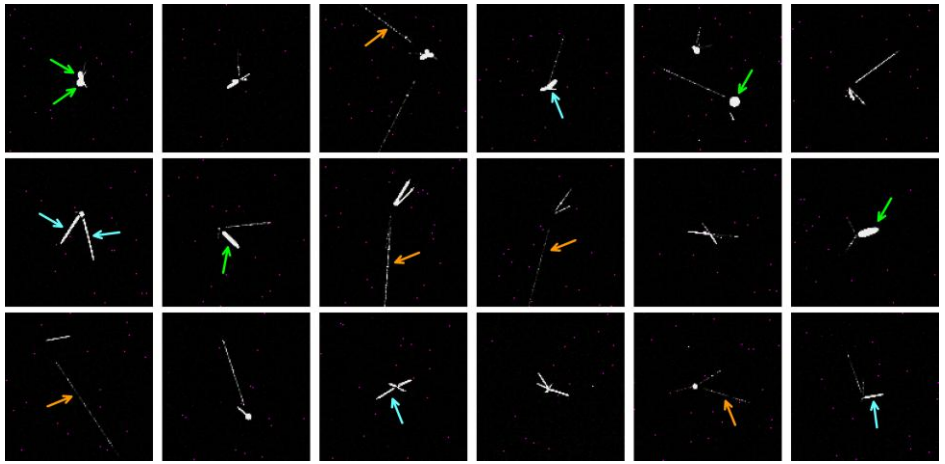
OPHANIM

- Position-sensitive antimatter detector
- 60x SONY IMS219 (CMOS) (3840 MPx)
- Resolution of 0.6 μm
  - 35-fold improvement over the previous state of the art detector





Michael Berghold *et al.*, Real-time antiproton annihilation vertexing with submicrometer resolution. *Sci. Adv.* **11**,eads1176(2025). DOI:10.1126/sciadv.ads1176

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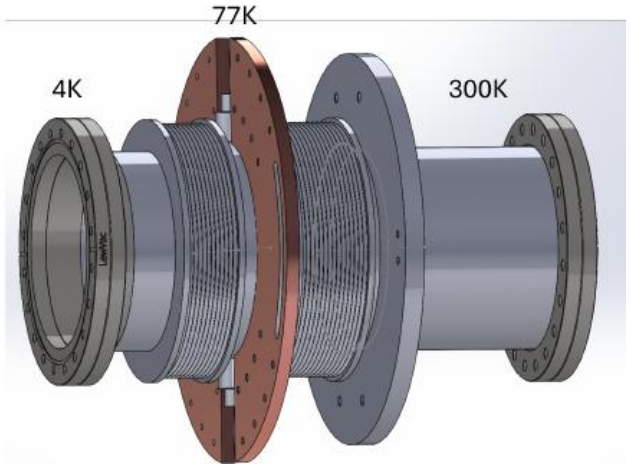
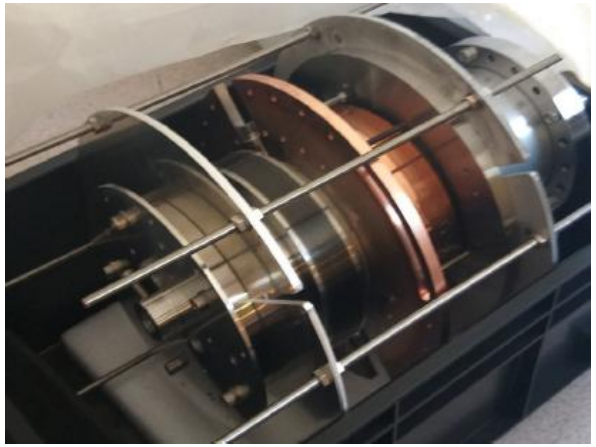
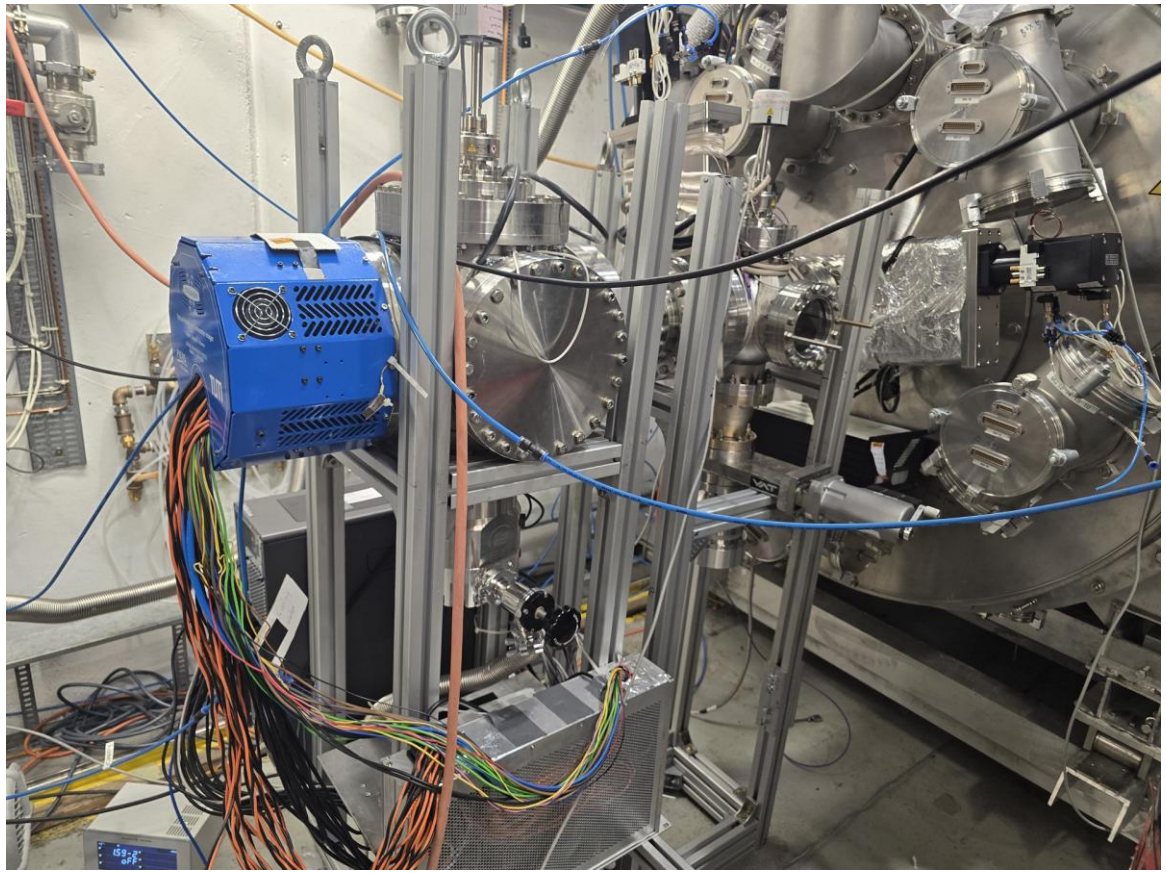
Extraction beamline







R. Caravita, Progress report of the AEgIS experiment (2024), https://cds.cern.ch/record/2922828

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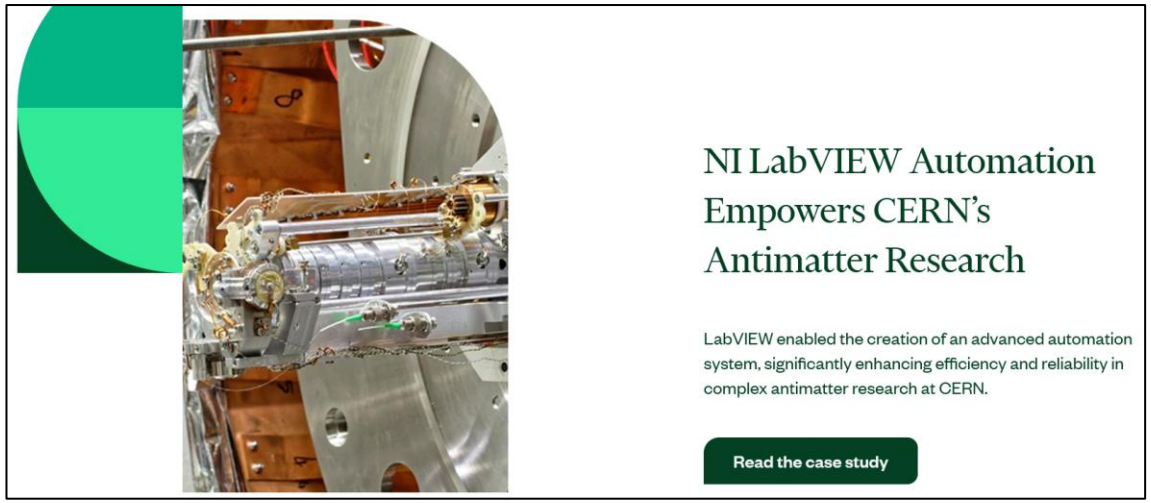
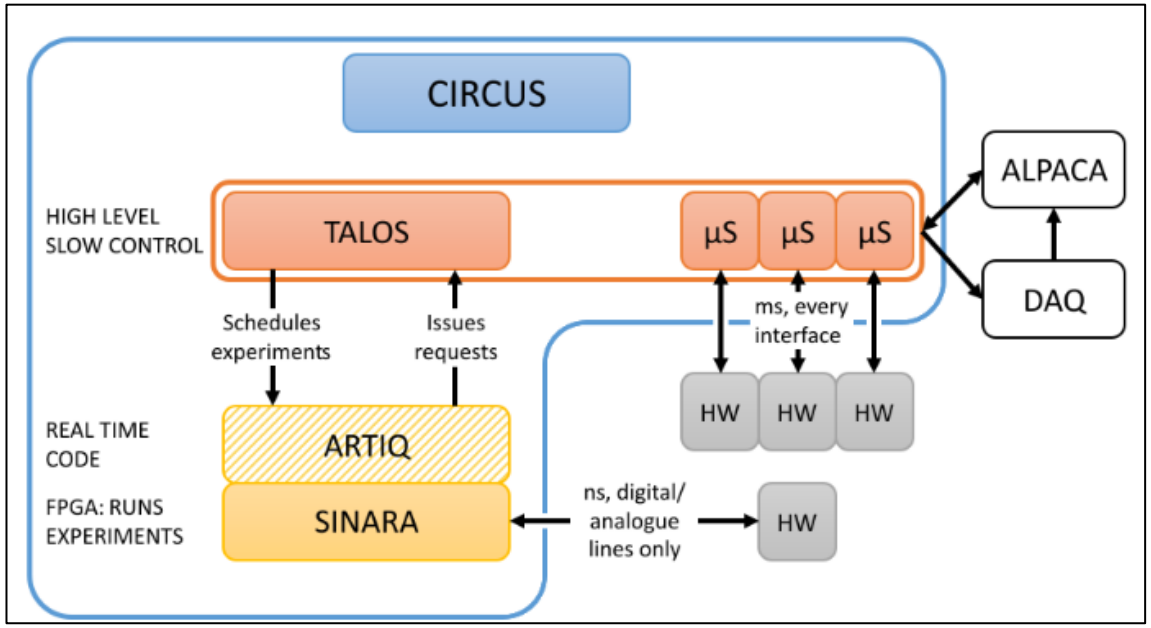
Control system

CIRCUS – autonomous control system managing most of the AEgIS hardware

- Optimised for time-critical experiments
- High degree of automation – can run unsupervised
- Available open-source
- Based on ARTIQ + LabVIEW (+ ALPACA)

https://www.ni.com/en/solutions/academic-research/case-studies/labview-automation-empowers-cerns-antimatter-research.html





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Positronium laser cooling

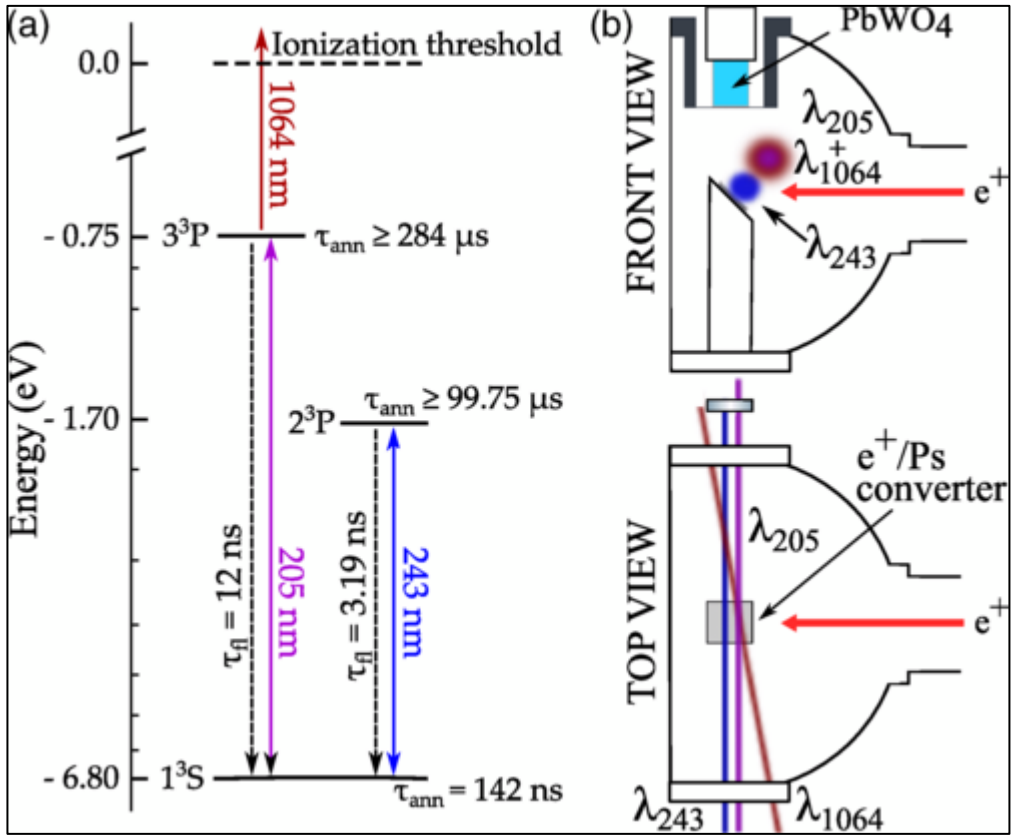
Method based on a broadband laser pulses and Doppler effect:

370 K → 170 K, aiming for **10 K**

Possible outlooks:

- High-precision measurements on positronium
- Ps Bose-Einstein condensate

  → candidate for coherent gamma rays production



L. T. Glöggler et al. (AEgIS Collaboration), Positronium Laser Cooling via the $1^3S–2^3P$ Transition with a Broadband Laser Pulse, Phys. Rev. Lett. 132, 083402
DOI: https://doi.org/10.1103/PhysRevLett.132.083402

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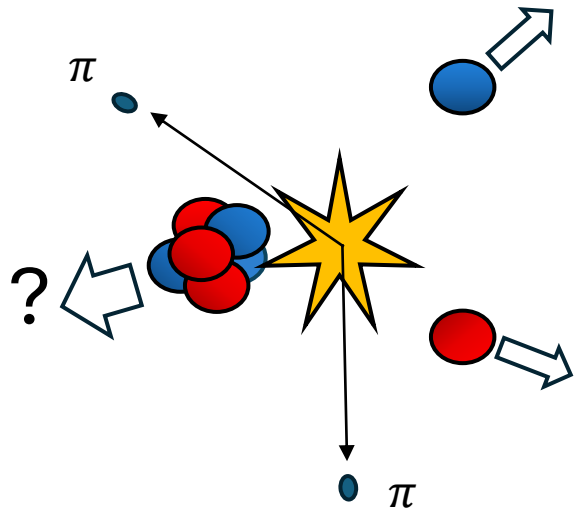
Exotic atoms and highly charged ions

Nuclear fragments formation with $\bar{p}$ annihilations:



Nuclear fragments produced are often radioactive highly charged ions and can be studied with TOF spectrometry

Probes for studying:

- QED
- Nuclear structure

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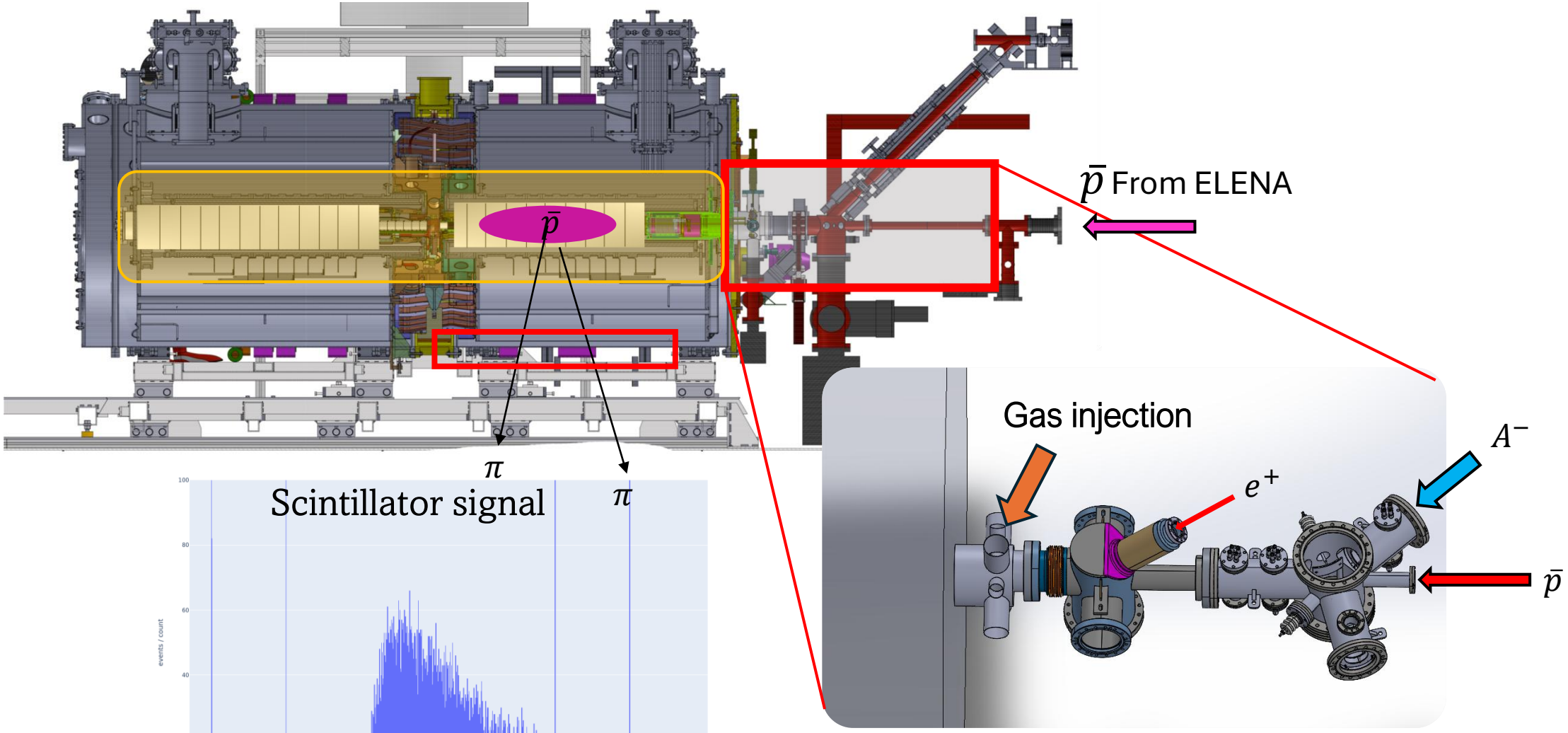

slide by F. P. Gustafsson, Towards the controlled formation of antiprotonic atoms at AEGIS, PSAS'2024

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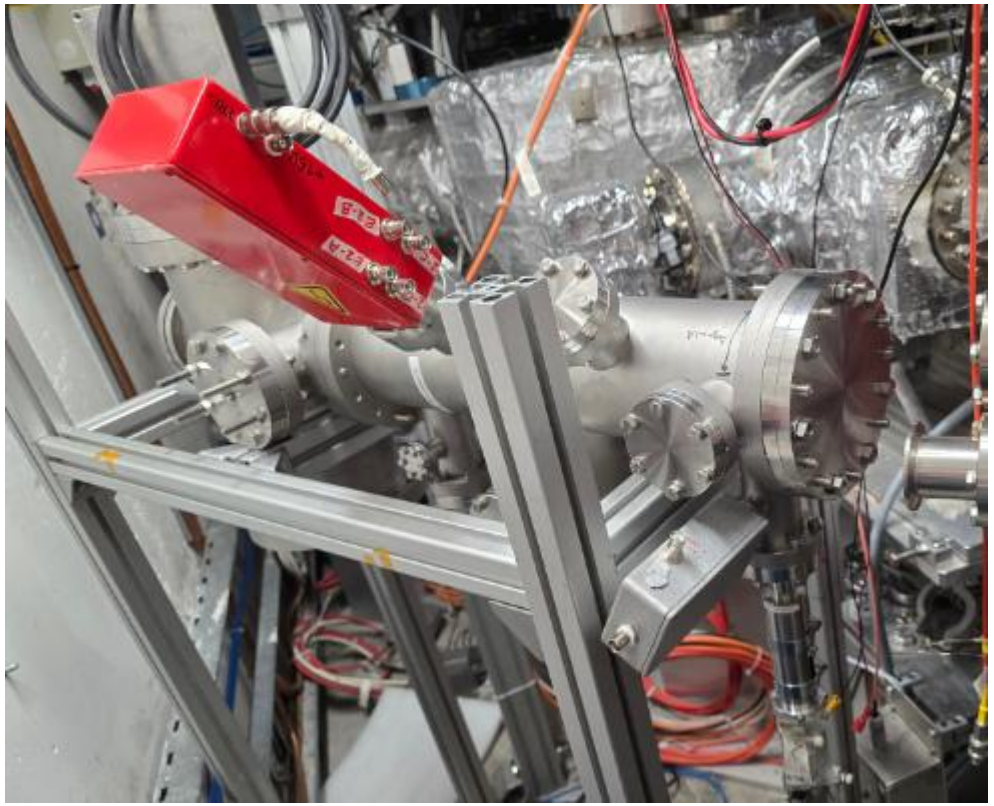
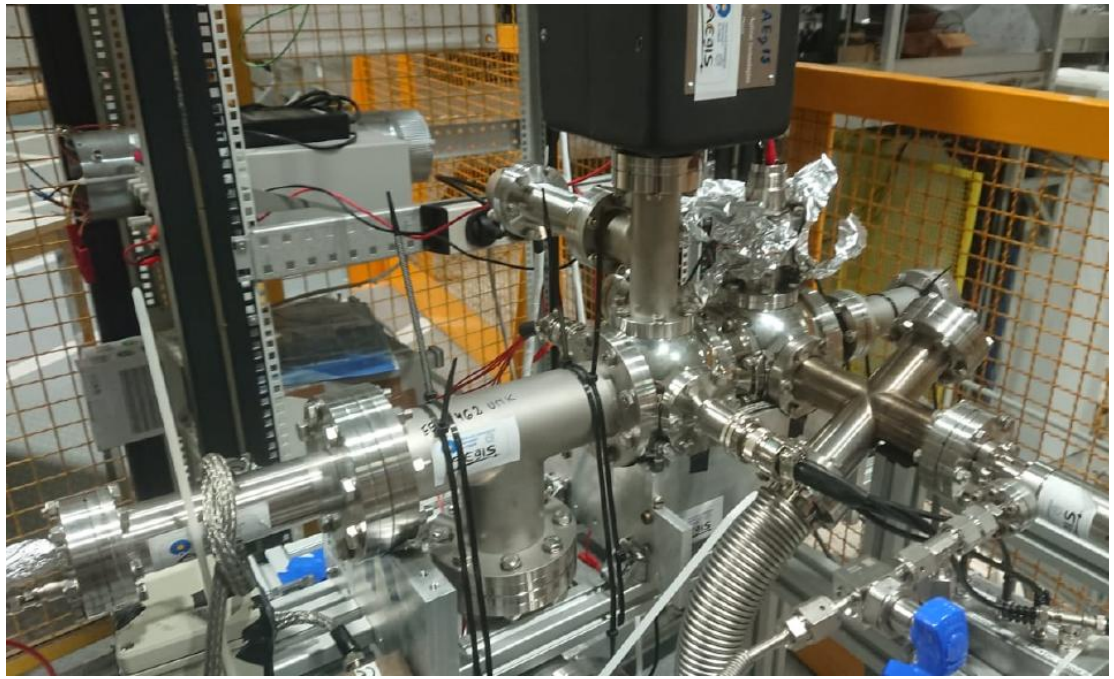
Ion sources for exotic atoms



C_2^- source (Borealis)



I^- source (UMK Toruń)

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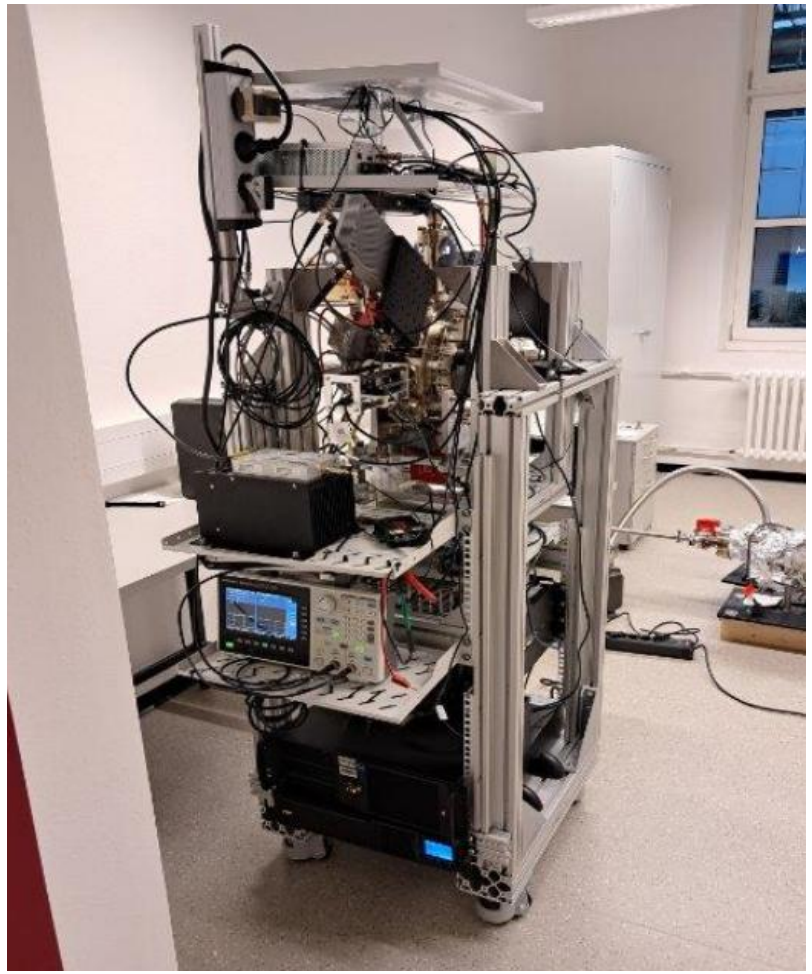
Portable trap

- Aimed for transporting antiprotons for quantum technologies and annihilation-based synthesis
- Linear Paul trap in room temperature ($\bar{p}$ energy >100 eV)



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Runs in 2024

1. Efficient antiproton accumulation and handling:
   - Steering rights for injection line from ELENA
   - Introduction of feedback loop with ALPACA → 10D optimisation of injection and trapping process

2. Positron source upgrade and efficient Ps formation

3. TOF spectrometry of highly charged ions in traps

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Thank you!

Questions?