PREVENTIVI 2026

LEA - ALPHA

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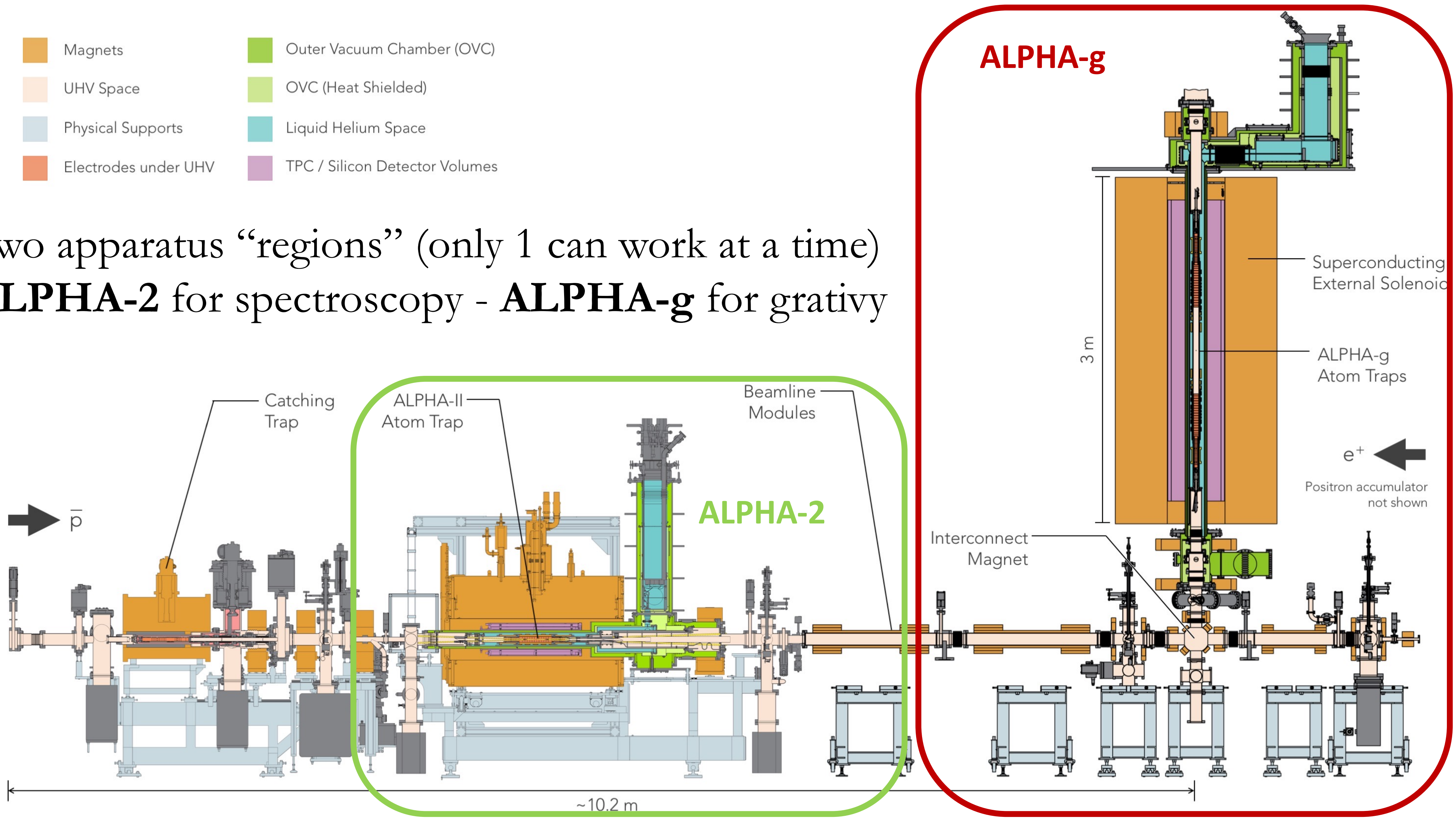
LEA_ALPHA / 2025 & 2026

In 2025 & 2026 the focus will be both on ALPHA-2 (for spectroscopy) and ALPHA-g (gravity)

Two apparatus “regions” (only 1 can work at a time)
ALPHA-2 for spectroscopy - **ALPHA-g** for grativy



LEA_ALPHA – 2025 data taking activities and objectives

Over the last century, the general theory of relativity has passed a number of stringent experimental tests [1]. Among its core tenets, still experimentally unchallenged, is the Einstein equivalence principle (EEP). The EEP, in its modern form [2], consists of three parts: the universality of free fall, also known as the weak equivalence principle (WEP), local Lorentz invariance (LLI) and local position invariance (LPI). The WEP implies that **all objects fall at the same rate**, regardless of their internal composition or structure

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Observation of the effect of gravity on the motion of antimatter

E. K. Anderson, C. J. Baker, W. Bertsche, N. M. Bhatt, G. Bonomi, A. Capra, I. Carli, C. L. Cesar, M. Charlton, A. Christensen, R. Collister, A. Cridland Mathad, D. Duque Quiceno, S. Eriksson, A. Evans, N. Evetts, S. Fabbri, J. Fajans, A. Ferwerda, T. Friesen, M. C. Fujiwara, D. R. Gill, L. M. Golino, M. B. Gomes Gonçalves, ... J. S. Wurtele + Show authors

Nature **621**, 716–722 (2023) | Cite this article

Abstract

Einstein's general theory of relativity from 1915[1] remains the most successful description of gravitation. From the 1919 solar eclipse[2] to the observation of gravitational waves[3], the theory has passed many crucial experimental tests. However, the evolving concepts of dark matter and dark energy illustrate that there is much to be learned about the gravitating content of the universe. Singularities in the general theory of relativity and the lack of a quantum theory of

[1] Will, C.M. The confrontation between general relativity and experiment. Living Rev. Relativ. 2014, 17, 1-117.

[2] Dicke, R.H. Experimental relativity. Relativ. Groups Topol. Relativ. Topol. 1964, 165-313

$$a_g = [0.75 \pm 0.13\ (\text{statistical} + \text{systematic}) \pm 0.16\ (\text{simulation})]\ g$$

LEA_ALPHA – 2025 data taking activities and objectives

2025/2026 activities

1) Antihydrogen spectroscopy

[now ~ 10000 trapped "cold (<0.5 K)" anti-hydrogen every night] + laser cooling ~ 15 mK

o) 1S-2S at the beginning and at the end of the data taking [under way]

o) Improve 2023/24 limits (1S-2S, 2S-2P, GSHFS)

o) excited state spectroscopy: other spectral lines (e.g. 2S-3S; 2S-4P) [lower priority]

2) Gravity with antihydrogen – better "precision" measurement

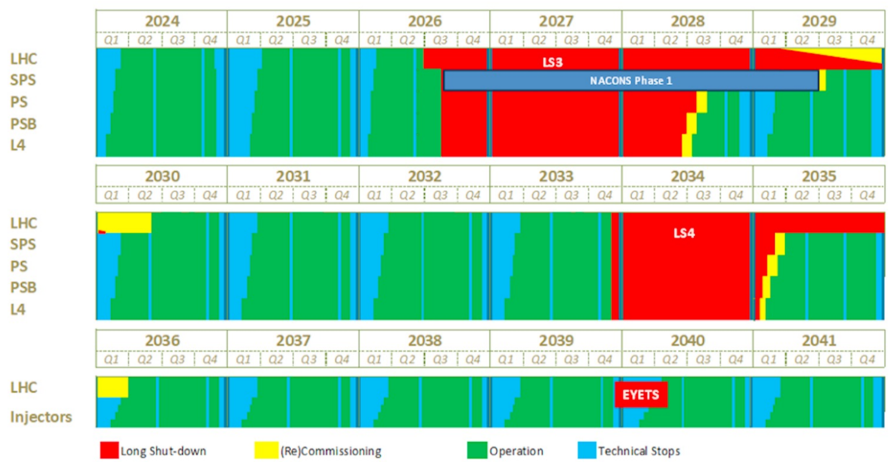
o) Laser cooling in ALPHA-g

o) Be+ system in ALPHA-g

o) Commissioning of the other ALPHA-g traps

o) Gravity measurement (few %)

Long Term Schedule for CERN Accelerator complex



LEA_ALPHA – Attività 2025/2026 INFN

Le attività in cui **saremo** coinvolti sono le seguenti:

Software

- Simulazioni MC (per ALPHA-g e ALPHA-2)
- Analisi dei dati per la misura del Ground State Hyperfine Splitting
- Analisi dei dati della misura di accelerazione di gravità
- *Service work di mantenimento e sviluppo del software «online» e «offline» dell'esperimento*

Hardware

- Acquisto e installazione di «sonde di Hall» per ALPHA-g per ridurre l'incertezza sulla misura di g [S.J.]
- Contributo per la costruzione e l'installazione di una sorgente di protoni (per confronti diretti idrogeno-antidrogeno nella stessa «trappola» - diminuzione di sistematici) – Richiesta di finanziamento da spalmare su più anni (dovrebbe essere pronta per il Run4) [2027/2028]

Funzionamento generale dell'esperimento

- Partecipazione ai turni di presa dati (senior >*4 settimane*, junior *almeno 10 settimane*)

Percentuali e richieste finanziarie 2026

Partecipazione ad LEA_ALPHA con 3 (4) **persone**:
INFN PV [Germano Bonomi 30%, Adriano Del Vincio 100%]
INFN PI [Simone Stracka 50%]
INFN FI [Guglielmo Tino 20%]

Richieste finanziarie

Common Fund (2 x 8 kCHF)	= **17 k€**
Missioni (3.5 mesi uomo CERN (turni) + 0.5 mesi uomo + missioni Italia)	= **25 k€**
Consumo:	= **1 k€**
Servizi (affitto auto CERN, affitto moduli CERN pool)	= **2 k€**
Per il 2026 si prevedono richieste per l'hardware	
Acquisto «sonde di Hall» per diminuzione incertezza su B	= **~15 k€ (sub judice)**

Se ci fosse la possibilità, la collaborazione sarebbe disponibile a ricevere già nel 2025 il contributo del Common Fund 2026 (che quindi non verrebbe pagato l'anno prossimo).

Milestone: 2025
- Improved GS-HFS measurement [80 % => 100 %]
- Improved 1S-2S measurement [40 % => 100 %]

Milestone: 2026
- Estensione improvement produzione anti-idrogeno in ALPHA-g

GS-HFS

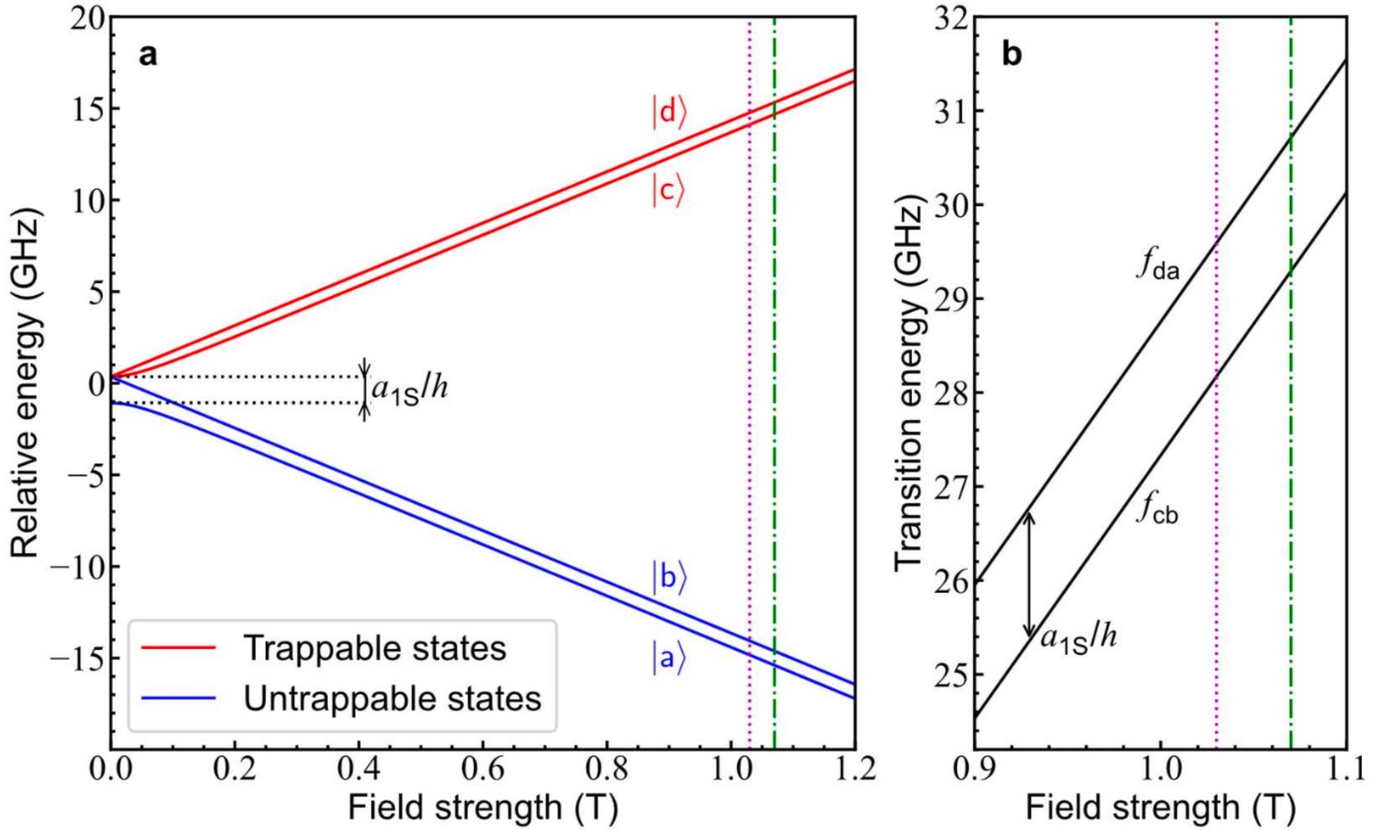
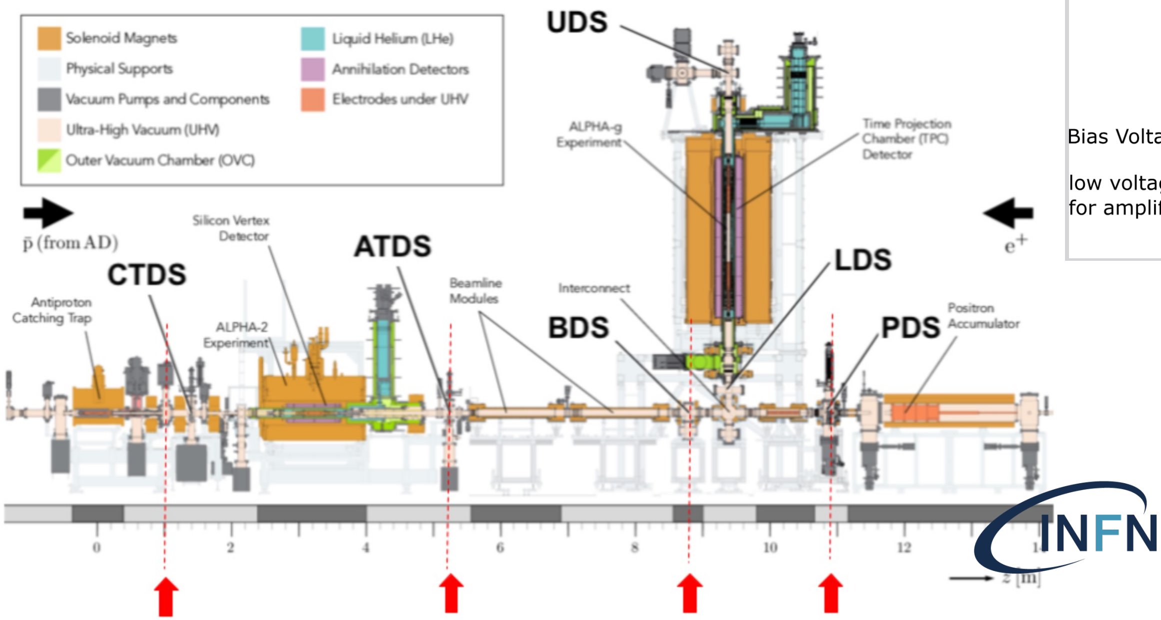


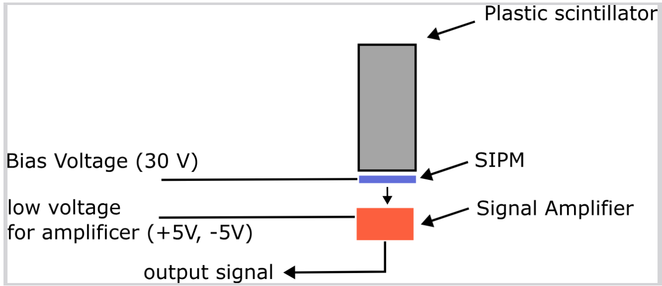
Figure 2: ***Ground state energy level diagram and transition frequencies a****. Relative energies of the four hyperfine sublevels of the ground state antihydrogen atoms as a function of magnetic field strength. The dotted purple line and dot-dashed green lines indicate the axial magnetic minimum fields where spectroscopy was performed.* ***b.*** *Frequencies of the two positron spin-flip transitions employed for spectroscopy* $|d\rangle \leftrightarrow |a\rangle$ *and* $|c\rangle \leftrightarrow |b\rangle$ *as a function of magnetic field strength. Frequencies are calculated assuming properties of antihydrogen mirror those of hydrogen.*

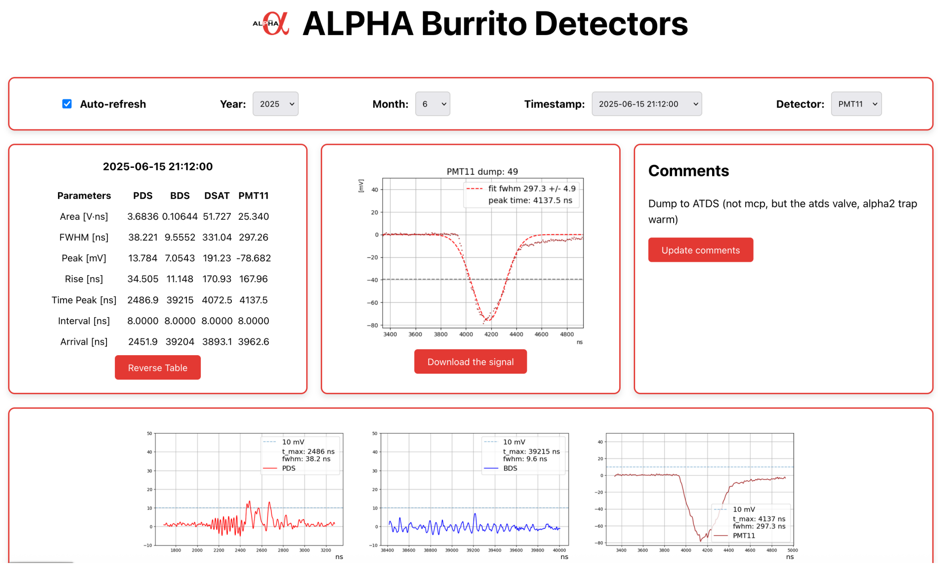
i “burritos”

LEA_ALPHA scintillator based positron and proton beam diagnostic system

This system was funded by INFN in 2023 and 2024. It evolved into an integrated system of fast scintillators (called Burritos) for measuring the e+ and pbar bunch length. Each detector is made by a plastic scintillator material that is coupled to SiPM, and read-out by red pitaya boards.







We are now responsible for the outer detectors diagnostic system (including previously installed scintillators with PMTs)

Proton source and beamline

PAPER • OPEN ACCESS

Development and commissioning of a hydrogen ion source for the CERN ALPHA experiment

To cite this article: M.A. Johnson *et al* 2024 *JINST* **19** C01021

Ion Source operation:

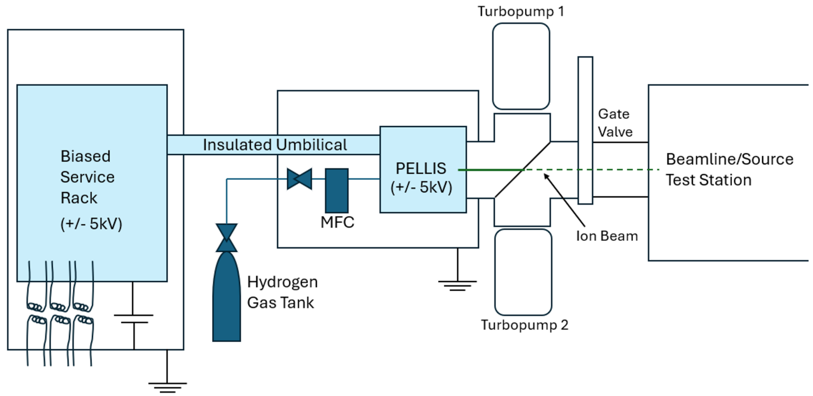


Figure 1. A simplified diagram of the proposed hydrogen ion source, including its attached electrical rack, gas feed, and differential pumping station.

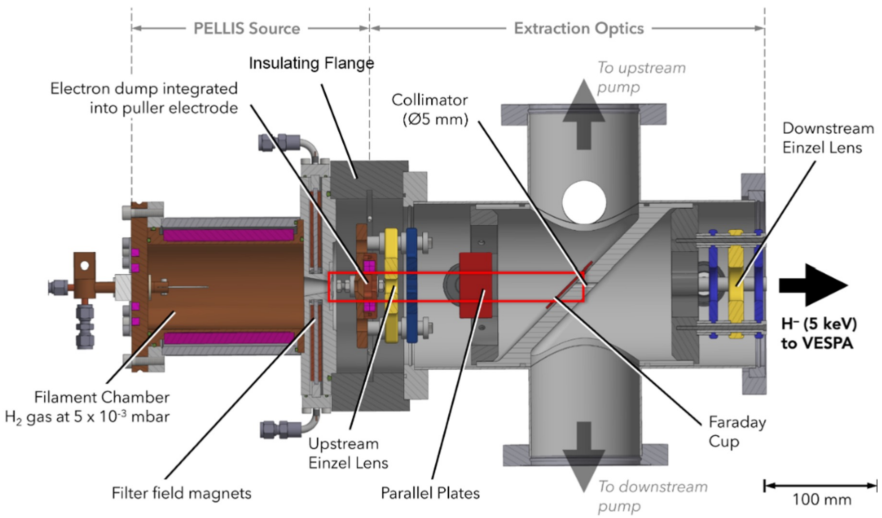


Figure 2. Schematic showing a cross section of the PELLIS source, including pumping chamber and extraction optics. Ref [3]

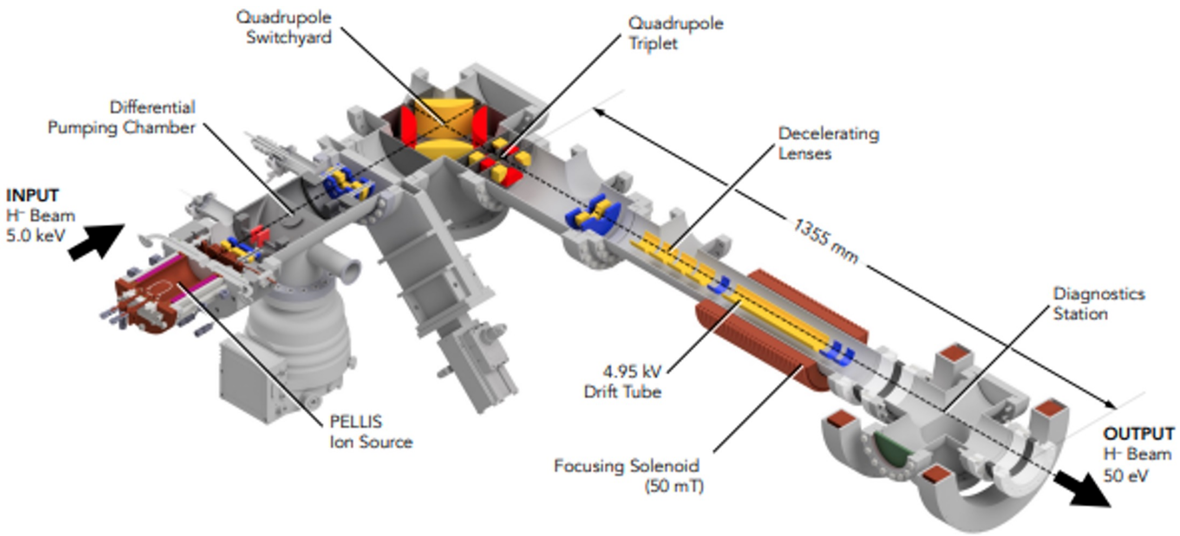


Figure 3. Diagram showing a cross-section of the proposed beamline design to transport H^- ions to the ALPHA experiment from a PELLIS-type ion source. Ref. [2]

Hall probes – Physics motivations

Antihydrogen has now been studied through both spectroscopic and gravitational measurements by the ALPHA collaboration. Antihydrogen confined in a magnetic trap has been an incredible tool in the first studies of this stable neutral antimatter system, but the presence of the magnetic fields required for trapping pose significant challenges. These challenges are most evident during the controlled magnetic release used for gravity experiments in ALPHA-g. A major systematic uncertainty in the groundbreaking 2023 measurement is the knowledge of the magnetic field inside the trapping region.

A technique electron magnetron phase imaging (EMPI) utilities small clouds of electrons to diagnose the magnetic field by probing the magnetron frequency of the cloud. The current limitation of this technique is the ratio of the magnetic field inside to trapping region to the magnetic field at the imaging position. The imaging position is inside the ultrahigh vacuum of ALPHA but at a significantly lower magnetic field than inside the trapping region, causing a radial expansion of the electron cloud as it is ejected. To improve the uncertainty on this ratio this proposal is to install Hall sensors at the point of imaging.

Having direct monitoring of the magnetic field at this location will help the ALPHA-g experiment on the route to a better than 1% determination of the gravitational acceleration of antihydrogen on Earth and have a longer-term impact on high precision atomic spectroscopy on antihydrogen.

Hall probes – Quotes

Quotation 2025-60170

Quotation No. : 2025-60170
Date : 5/13/2025

Item	Part number/description	Quantity/unit	Unit price/CHF	Total/CHF
1	**LS-F41** F41 single-axis teslameter with TruZero technology, touchscreen interface, and TiltView display	2 Stück	6,800.00	13,600.00
2	**LS-HGT-3010** Transverse Hall sensor	6 Stück	620.00	3,720.00
3	**CH-IMP** Standard import rate (including: cost for packing, shipment, free house delivery, customs, importation tax, administrative expenses)	1 Set(s)	200.00	200.00
			Net value CHF	17,520.00

plus local VAT

Tests are underway at CERN with a similar
Hall probe (vaccum, cryogenics, mechnanics).
If positive output (as expected) they should be bought in 2026 and installed in 2026/2027

Sub judice