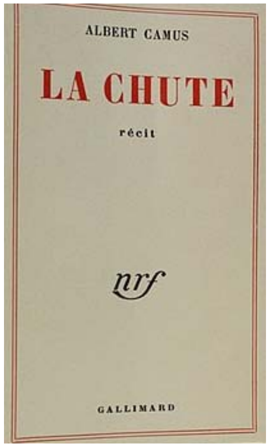
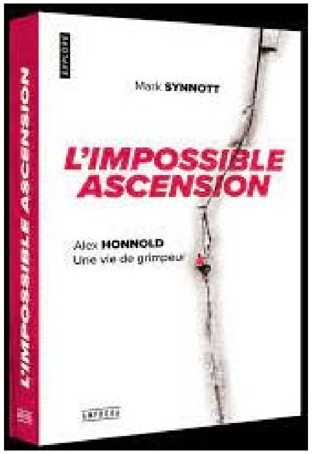
Gravitational Behavior of Antihydrogen at Rest:
The GBAR experiment at CERN

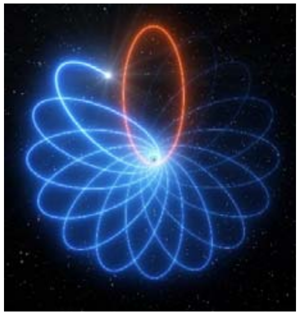
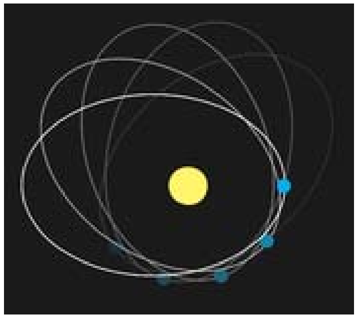
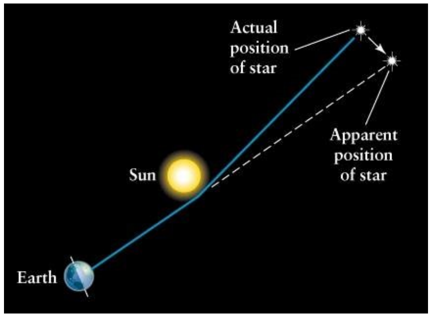
David Lunney, IN2P3/CNRS, Orsay
IJCLab, Université Paris-Saclay

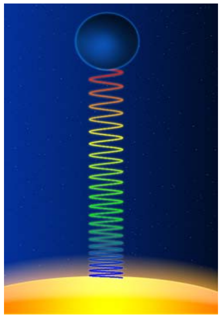
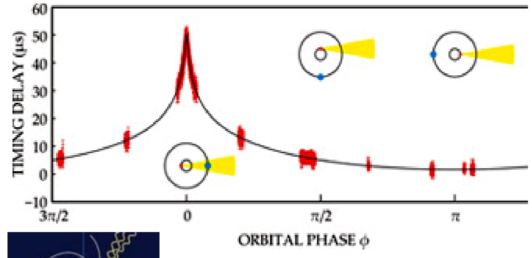


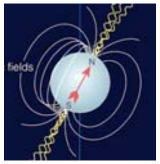
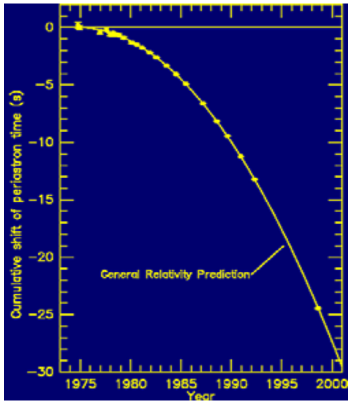


Goal: Test of General Relativity with Antimatter

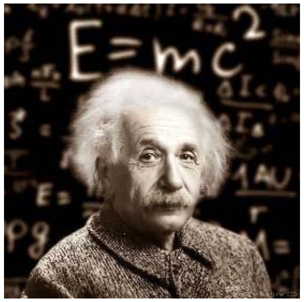
Einstein: General Relativity

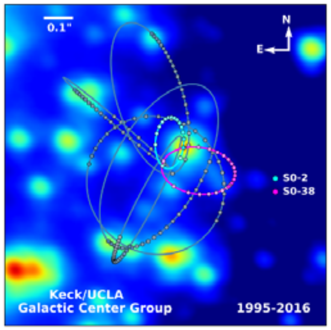



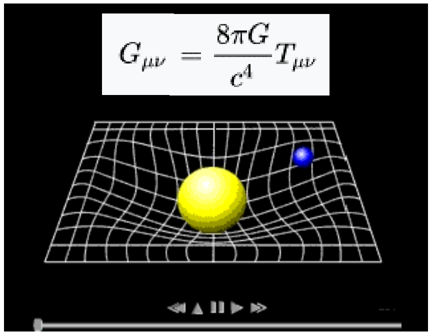



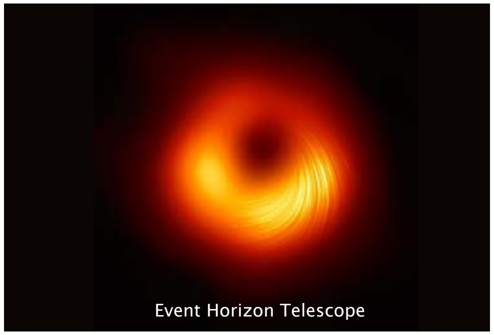
2020:
Nobel prize to
R. Penrose,
R. Genzer
and A. Ghez

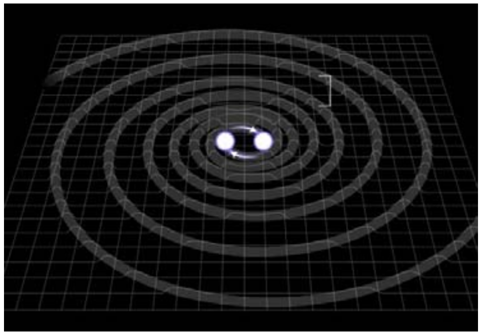



1905: Special Relativity (plus other papers!)
1907: equivalence principle of falling bodies
1915: theory of GR presented (Mercury's perihelion)
1919: Dyson, Eddington & Davidson (solar eclipse)
1959: Gravitational Redshift (Pound-Rebka experiment)
1964: Shapiro Delay (radio waves)
1974: Taylor-Hulse pulsar (Nobel prize in 1993)
2015: Gravitational waves (Nobel prize in 2017)
2019: First Black Hole image (Event Horizon Telescope)

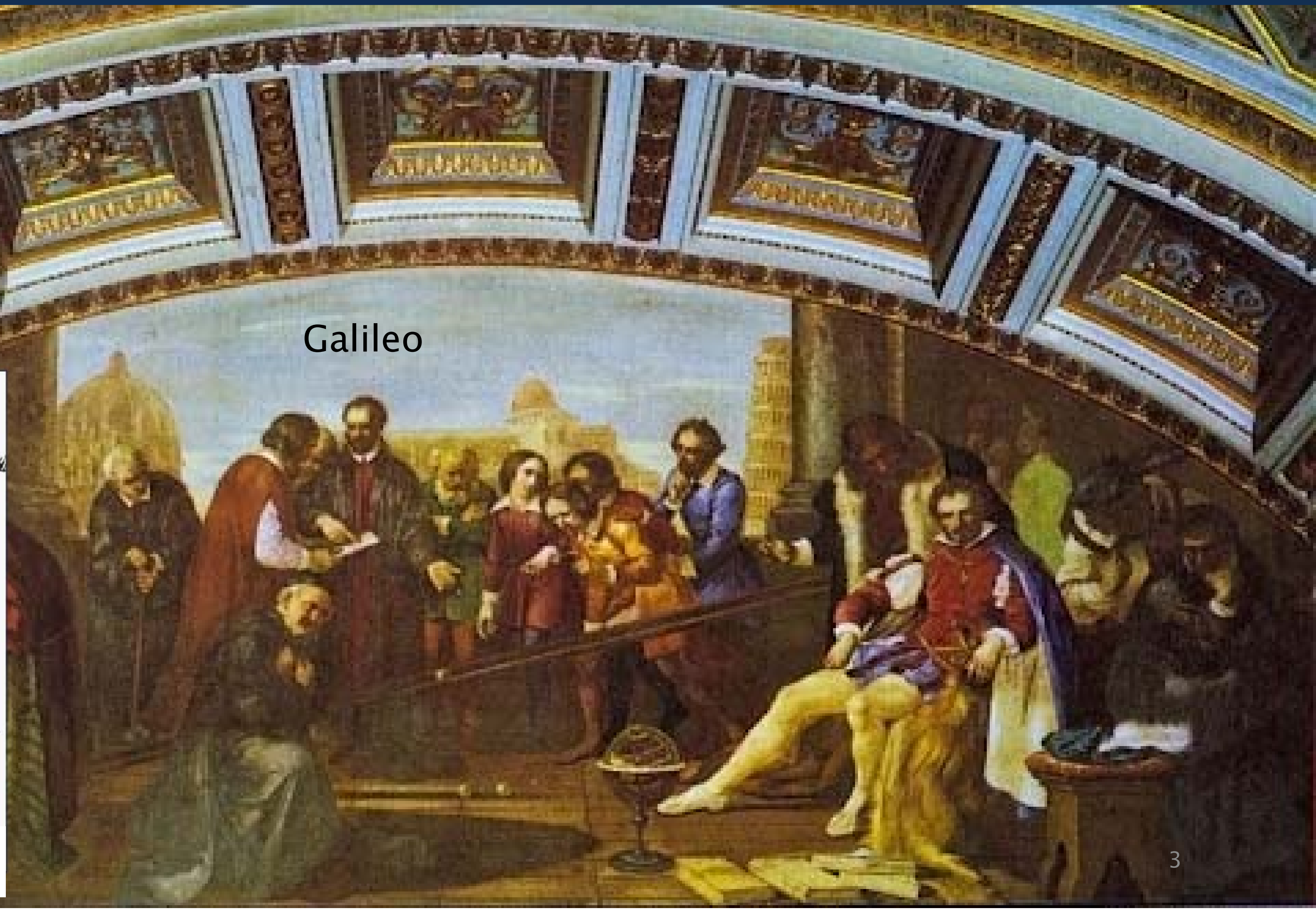


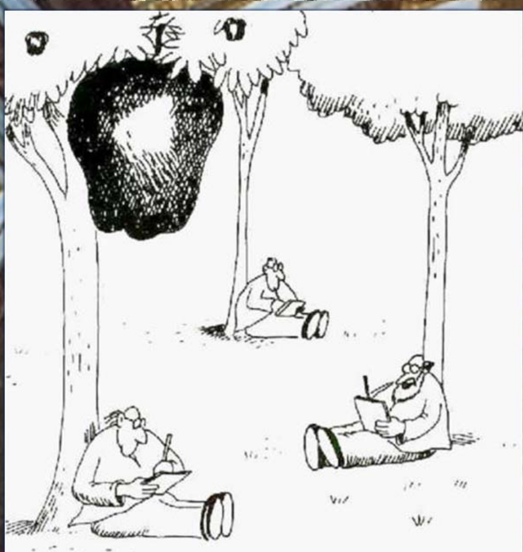






the equivalence principle: early experiments

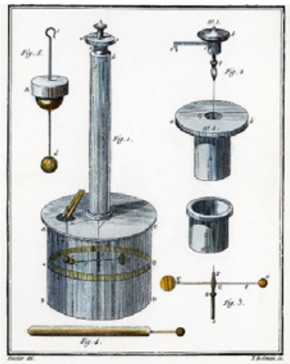




"Nothing yet – you, Newton?"
–Gary Larson, The Far Side

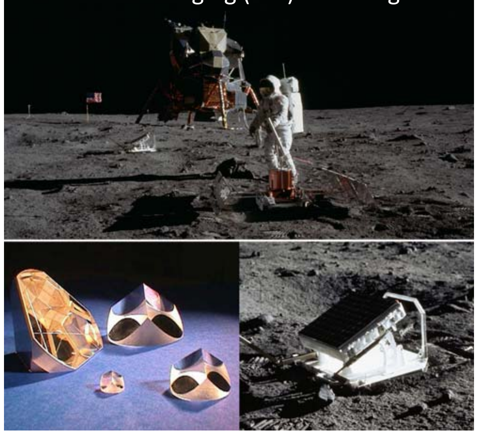
Testing the equivalence principle

The torsion balance

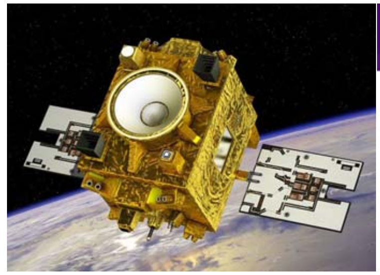


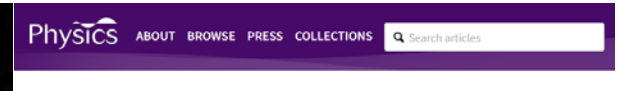
Coulomb → ***<u>Eötvös</u>*** → Eöt-Wash (Seattle)

Lunar Laser Ranging (LLR) → strong EP



J.G. Williams, S.G. Turyshev and D.H. Boggs,
Class. Quantum Grav. 29, 184004 (2012)





Physics ABOUT BROWSE PRESS COLLECTIONS

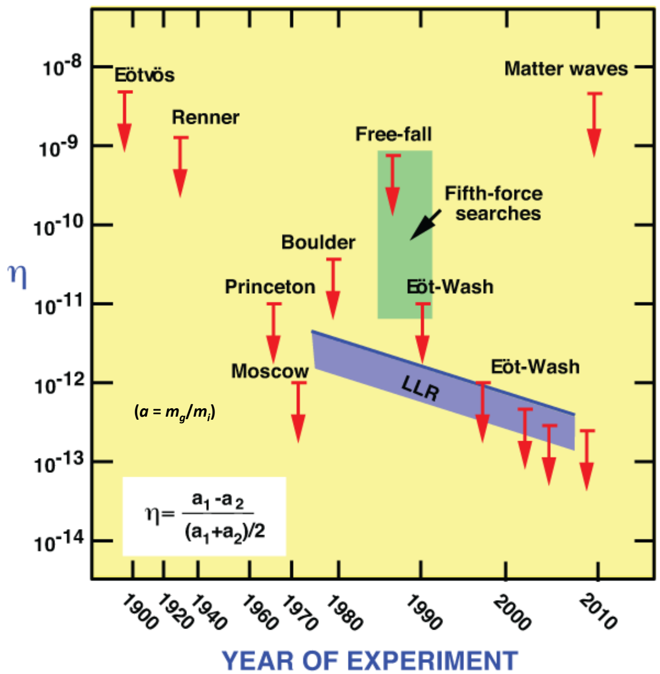
VIEWPOINT

Satellite Confirms the Principle of Falling

Philippe Brax
Institute of Theoretical Physics, University of Paris-Saclay, France

September 14, 2022 • *Physics* 15, 94

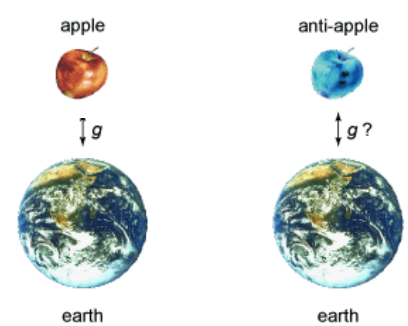
The *MICROSCOPE* satellite experiment has tested the equivalence principle with an unprecedented level of **10^{-15}**



C.M. Will, *Living Rev. Relativity* (2014)

EP holds!
at different locations and
for different masses…

…but never tested
with antimatter!



“anti” gravity?

$$G_{\mu\nu} + \Lambda g_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu}$$

GR: tensor interaction
spin–2 graviton
“charge” is mass

$$\frac{1}{c^2}\frac{\partial^2 \mathbf{E}}{\partial t^2} - \nabla^2 \mathbf{E} = 0$$

EM: vector interaction
spin–1 photon
charge: + or –

$a_t \downarrow \uparrow a_v$ $\quad \bar{a}_t \downarrow \downarrow \bar{a}_v$

tensor + vector gravity?
different acceleration
(antimatter faster)

Standard Model Extension (SME):
effective field theory adding General Relativity (GR) & CPT/Lorentz violation (LV)

$L_{SME} = L_{SM} + L_{LV} + L_{GR}$ A. Kostelecky and J.D. Tasson, Phys. Rev. D (2011)

$$L = \underbrace{\tfrac{1}{2}\left(m + \tfrac{5}{3}N^w m^w \bar{c}^w_{TT}\right)}_{m_{i,\mathrm{eff}}} v^2 - gz\underbrace{\left(m + N^w m^w \bar{c}^w_{TT} + 2\alpha N^w (\bar{a}_{\mathrm{eff}})^w_T\right)}_{m_{g,\mathrm{eff}}}$$

Isotropic ‘Parachute’ Model (IPM)

$$\tfrac{1}{3} m^w \bar{c}^w_{TT} = \alpha (\bar{a}_{\mathrm{eff}})^w_T$$

Matter

$$m_{i,\mathrm{eff}} = m_{g,\mathrm{eff}}$$
$$a = g$$

Antimatter

$$m_{i,\mathrm{eff}} \neq m_{g,\mathrm{eff}}$$
$$\bar{a} = g\left(1 - \frac{4m^w N^w}{3m}\bar{c}^w_{TT}\right)$$

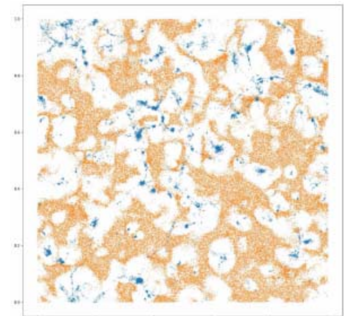
antimatter slower!
different acceleration
(not “antigravity”)

Negative mass – antigravity in GR (G. Chardin, 1997)
Dirac–Milne Universe (A. Benoit–Levy & G. Chardin, 2012)

Matter – antimatter repulsive

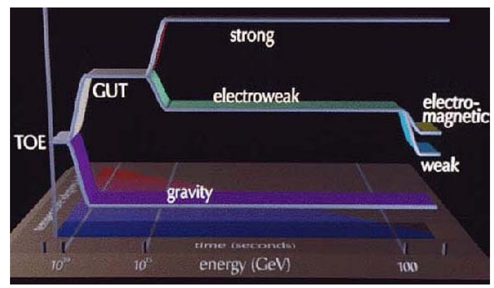
New simulations:
G. Manfredi et al., PRD, 2018
G. Manfredi et al., PRD, 2020

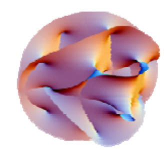
No dark matter!



Gravitational acceleration of Antimatter
(Nieto and Goldman, Phys. Rep., 1991)

Antigravity – a crazy idea?
(J. Scherk, Phys. Lett. B, 1979)





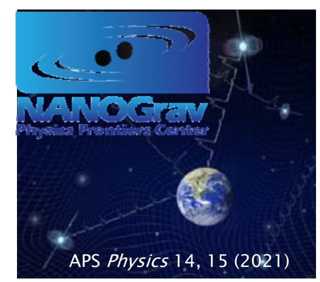
Quantum gravity

PHYSICAL REVIEW LETTERS

Hubble Tension as a Window on the Gravitation of the Dark Matter Sector

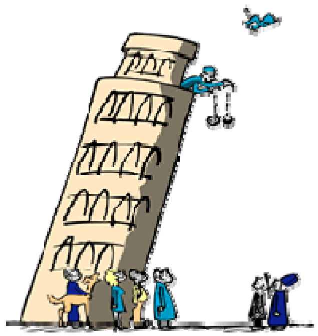
Cyril Pitrou and Jean-Philippe Uzan
Phys. Rev. Lett. **132**, 191001 – Published 6 May 2024

extension of GR with massless scalar field



APS *Physics* 14, 15 (2021)

The goal of GBAR: (firs er) test EP with antimatter



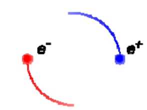
GBAR – CERN AD-7
Patrice Pérez (IRFU)
Spokesperson:

Free fall of
antihydrogen (at rest!)

use of anti-hydrogen ***ions***
(for sympathetic cooling)

J. Walz and T.W. Haensch, *Gen. Rel. Grav*. 36, 561 (2004)

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



P. Pérez & A. Rosowsky, *NIM* A 545, 20 (2005)

Witteborn & Fairbank, Nature (1968):
gravitational fall of the positron (E_g = 6E-11 V/m !)

M. Holtzscheiter et al. (CERN PS-200):
gravitational fall of the antiproton

Gabrielse et al. (CERN AD-2) Phys. Rev. Lett. (1999):
gravitational redshift trapped antiproton (indirect); BASE-2022

CPLEAR Collaboration, Phys. Lett. B (1999):
kaon-antikaon limits (indirect)

Supernova 1987A, e.g. Phys. Rev. D (1989):
(anti)neutrino time of flight (hypothesis)

past (indirect) attempts

Cassidy et al. Phys. Rev. Lett. (2015):
Rydberg Ps for free fall experiment

The LEMING Collaboration (Soter et al., PSI – proposal):
Free-fall of muonium atoms

The AEgIS Collaboration (CERN AD-6):
Interferometry of neutral antihydrogen beam

The ALPHA-g Collaboration (CERN AD-5):
Neutral antihydrogen

current (free-fall) attempts

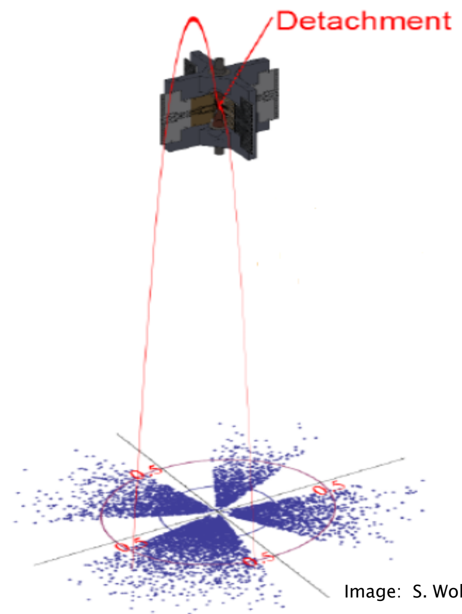


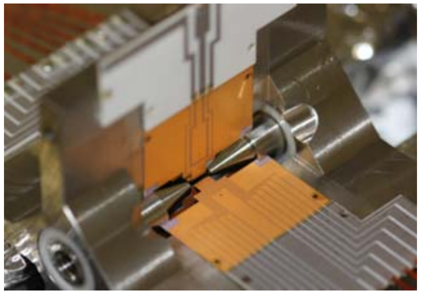
Image: S. Wolf (Mainz)

<u>Room temperature $\bar{H}$ ion:</u>

8000 km/h →	2200	m/s
4 K $\bar{H}$ ions:	500	m/s
100 uK:	1	m/s
1 uK:	0.1	m/s

Sympathetic cooling of trapped $\overline{\mathrm{H}}^+$ ions

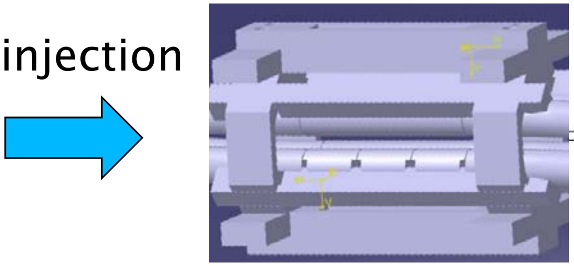
No transition to laser cool $\overline{\mathrm{H}}$
→ sympathetic cooling
with laser coolable ^{9}Be

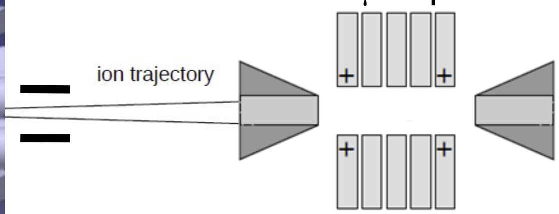


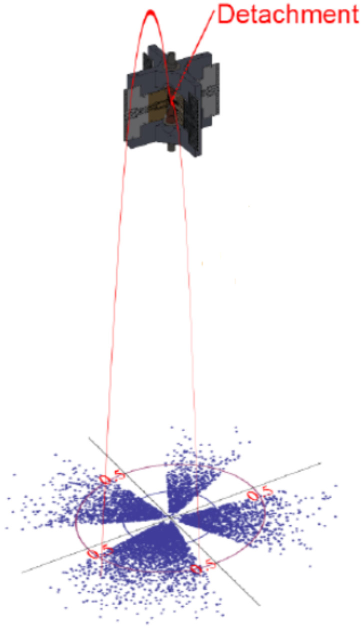
precision (56-MHz)
µtrap

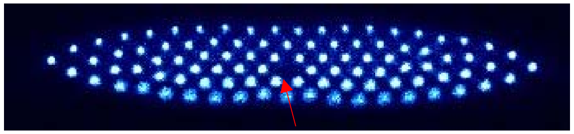
injection

Be-filled capture trap

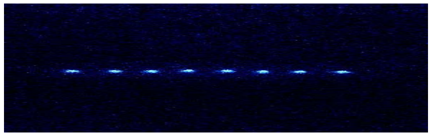








dark ion in capture trap (H_2^+ or H_3^+)
L. Hilico, J.-Ph. Karr et al. (LKB-Paris)



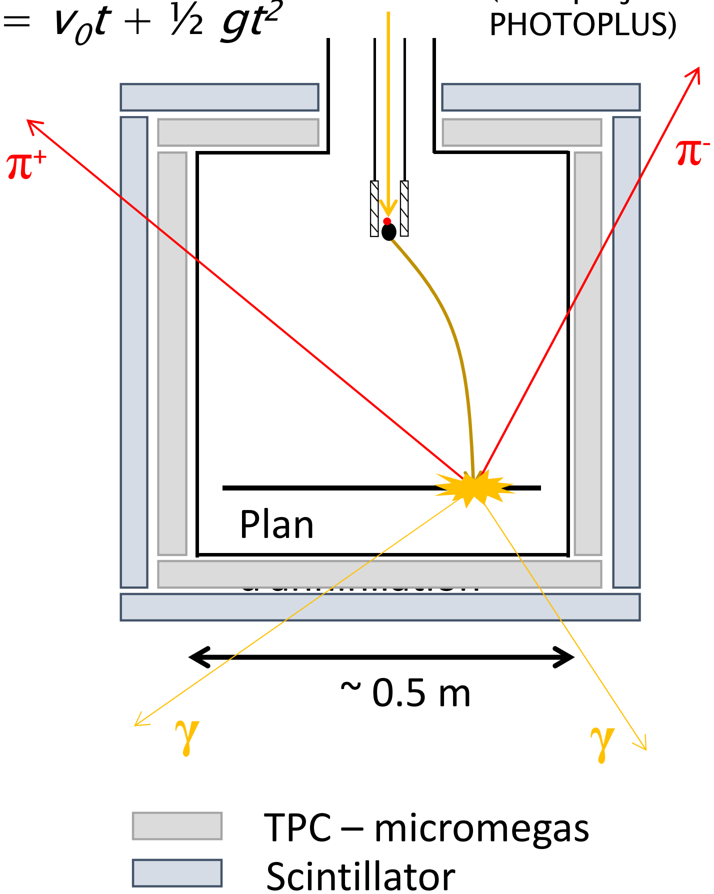
First results (using Ca ions)
S. Wolf, F. Schmidt-Kaler (Mainz)

$\overline{\mathrm{H}}^+$ cooled by Be "ice cubes" (ANR project ESPRIT)

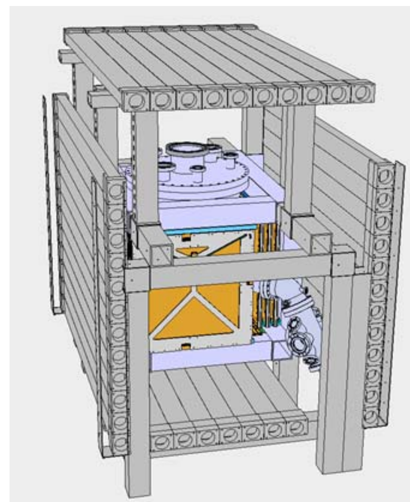
The ultimate (drop) step

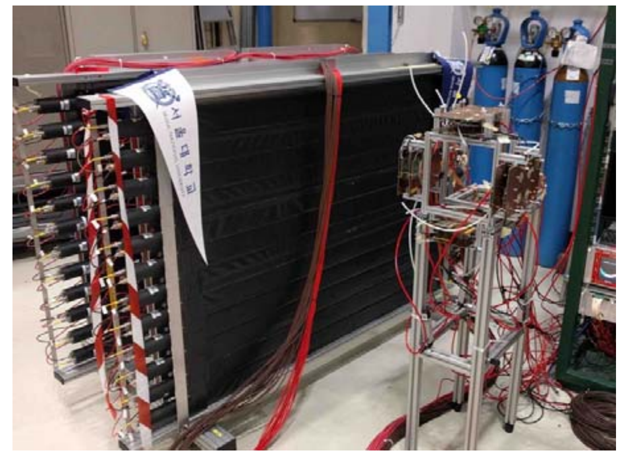
$y = v_0 t + \frac{1}{2} g t^2$

(ANR project PHOTOPLUS)



Free-fall chamber
IRFU/ETH and LKB





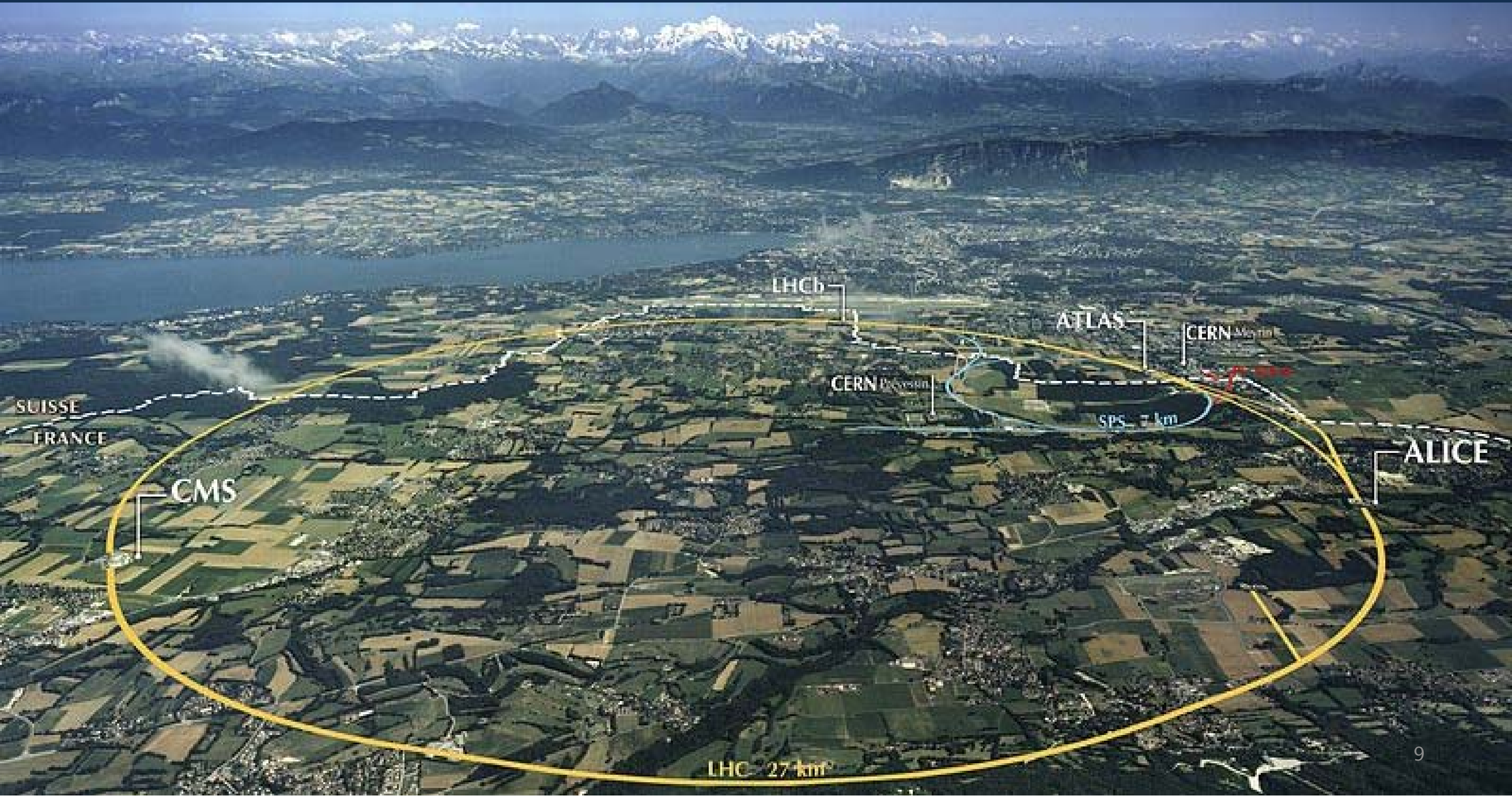
Micromegas: P. Crivelli and team (ETH)

TOF scintillater wall: Sun Kee Kim and team (SNU)

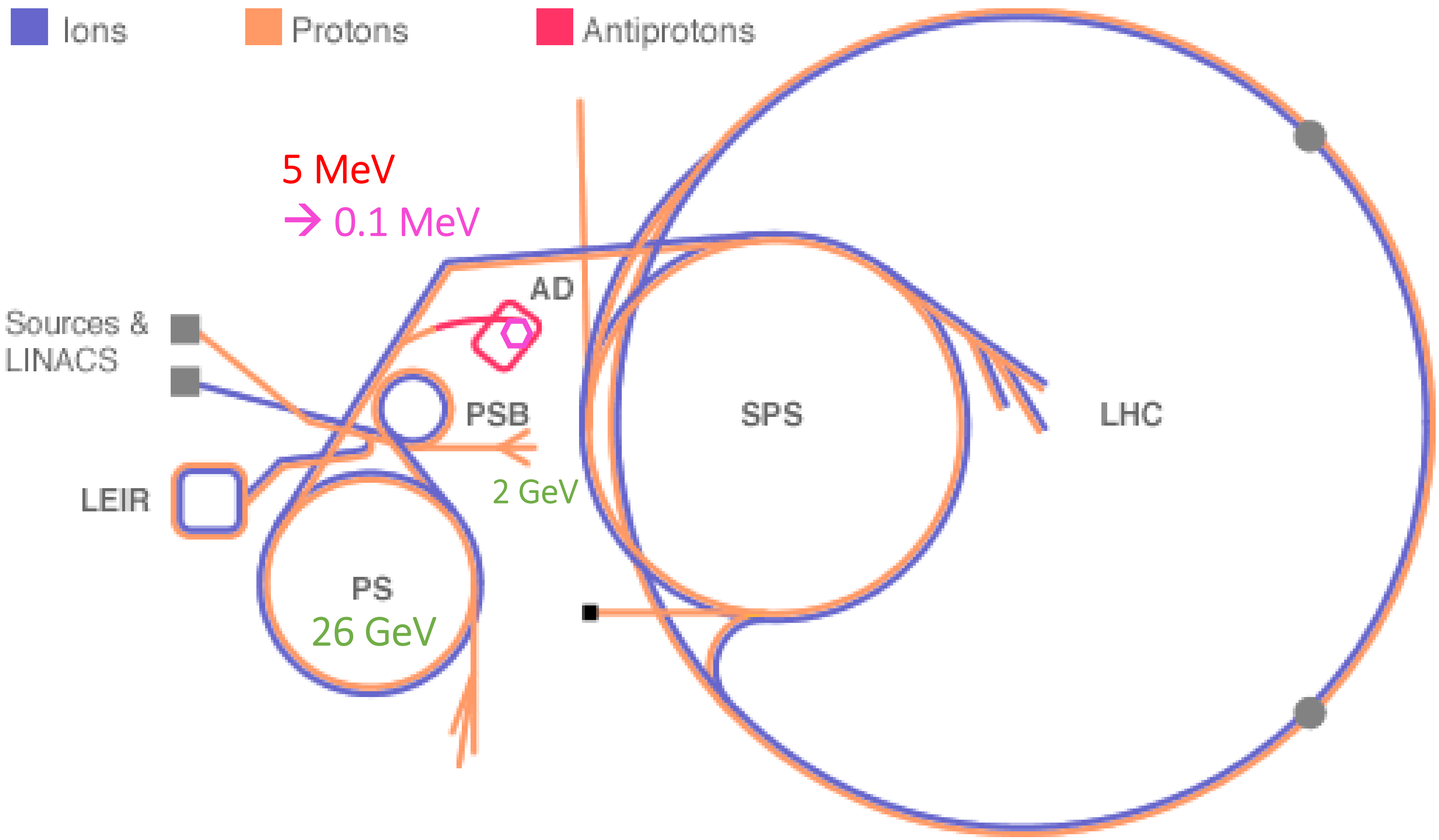
For 1 $\bar{H}^+$:
Need 10^7 $\bar{p}$
10^{12} Ps/cm²
(10^{10} e^+)
in 1 AD cycle
(115 s)

$\bar{H}$ ions (10 μK)	$\Delta g/g$
10^3	0.02
10^4	0.006
5×10^5	0.001

CERN – home of antimatter



The CERN accelerator chain

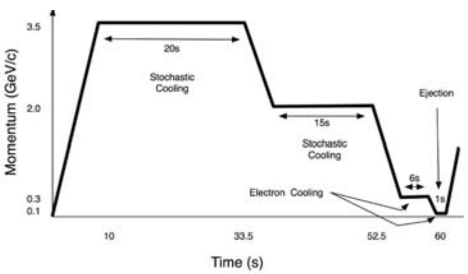


The AD/ELENA facility – CERN's "antimatter factory"

CERN-AD/ELENA (Extra-Low ENergy Antiproton) facility

AD:
3.5 GeV → 5 MeV

ELENA:
5 MeV → 100 keV

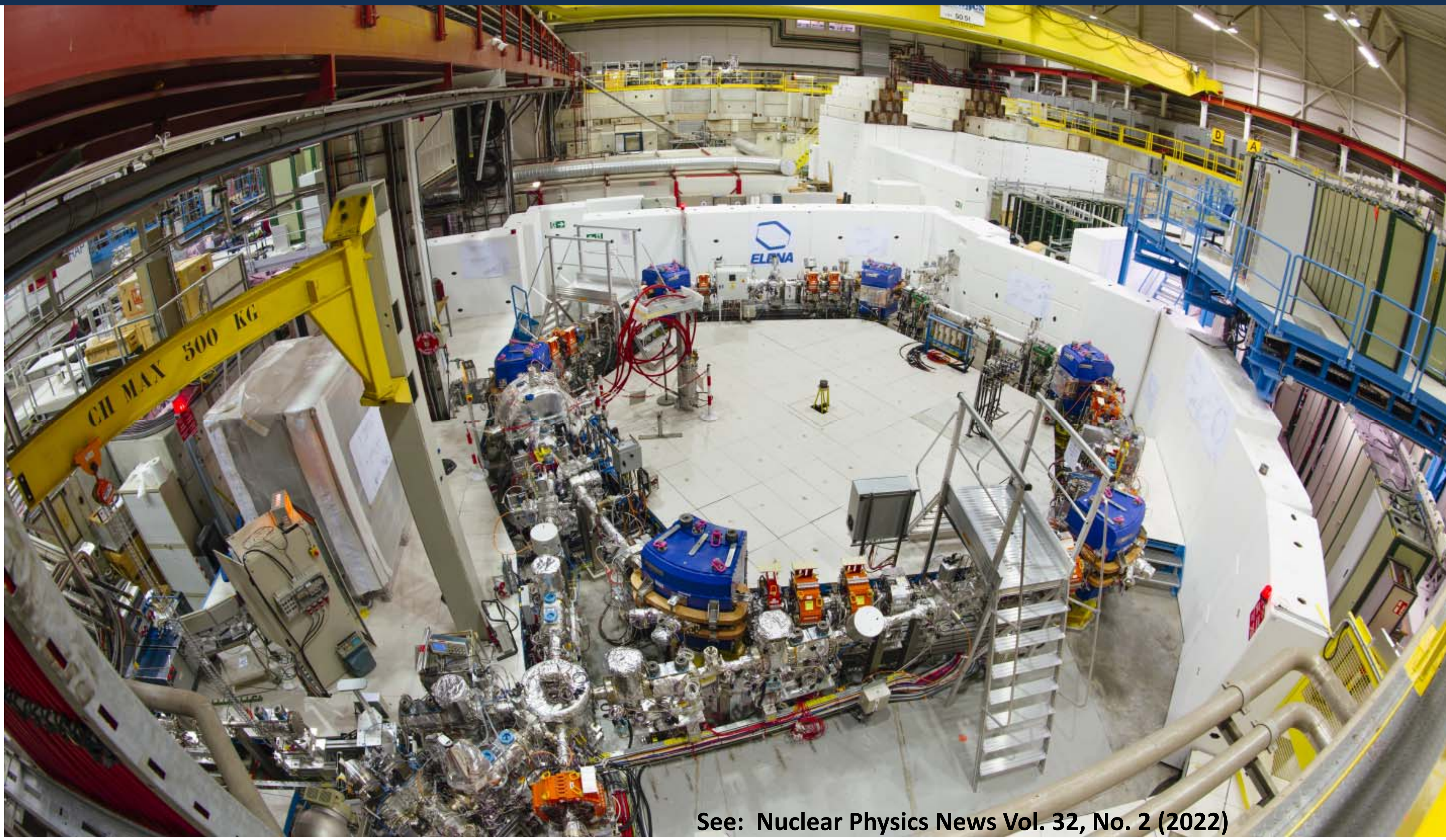


Antihydrogen:
ALPHA, AEgIS, ASACUSA
(ATRAP until recently)

Antigravity:
ALPHA, AEgIS, GBAR

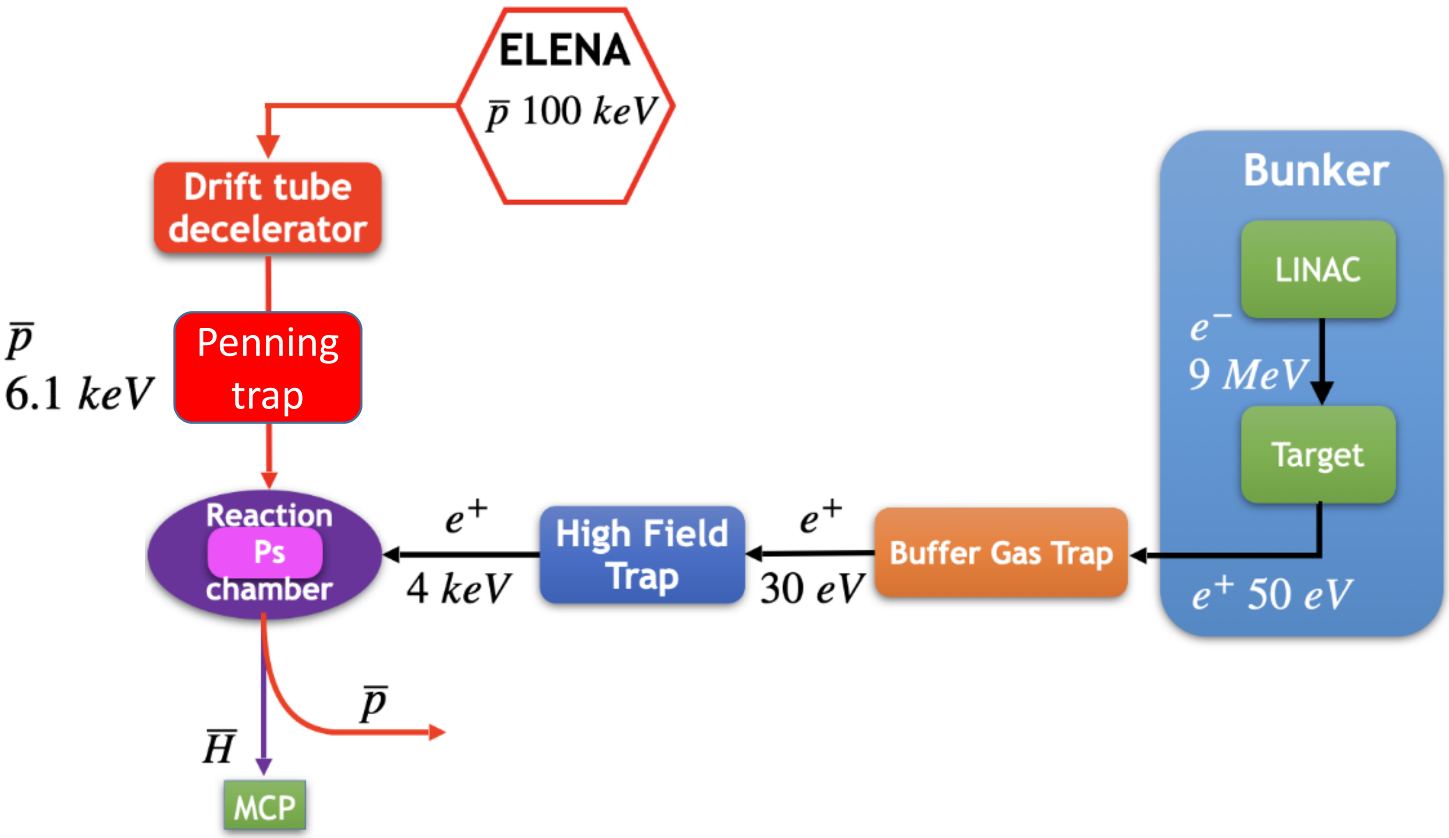
Unique facility worldwide

Extra Low ENergy Antiproton ring (ELENA)

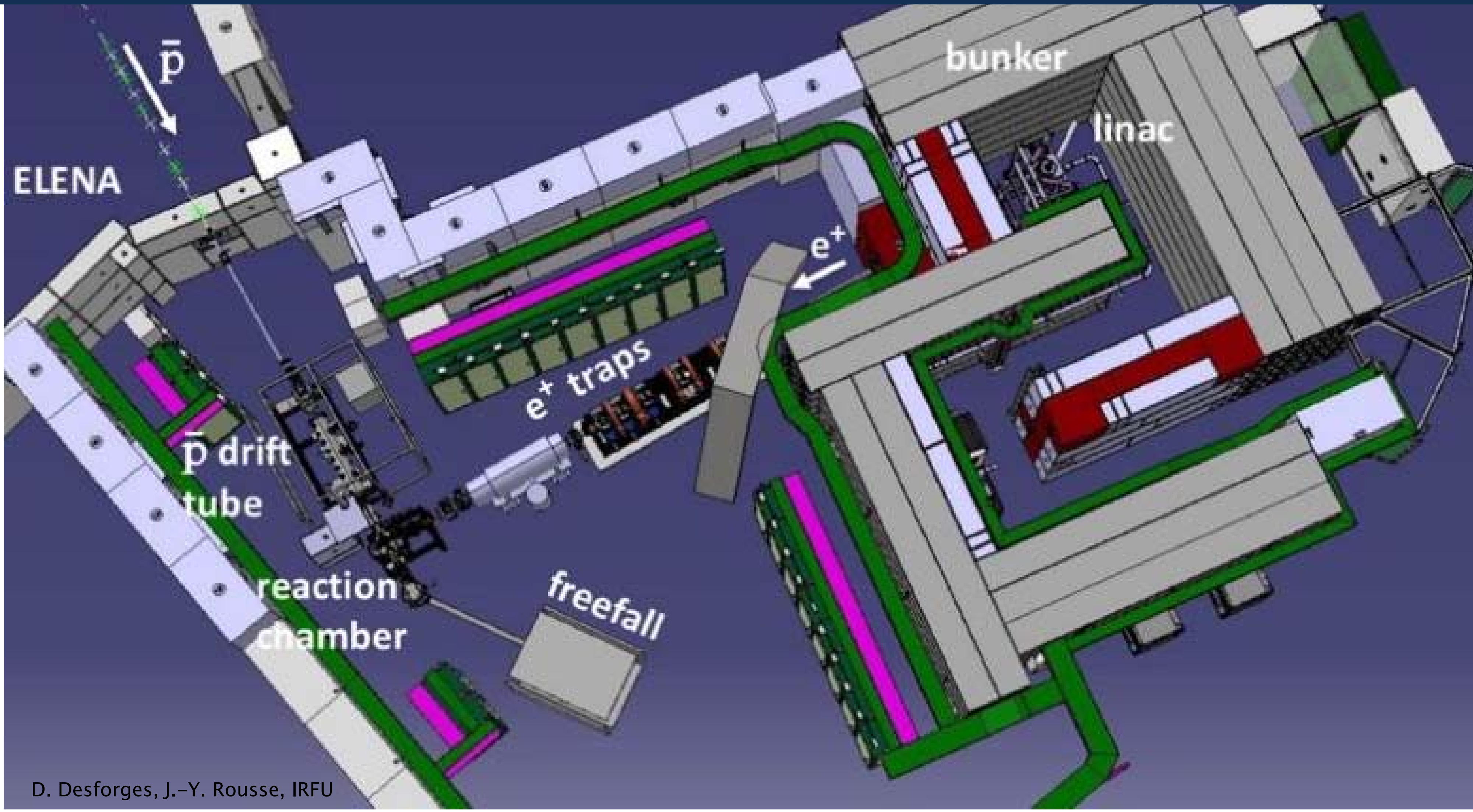


See: Nuclear Physics News Vol. 32, No. 2 (2022)

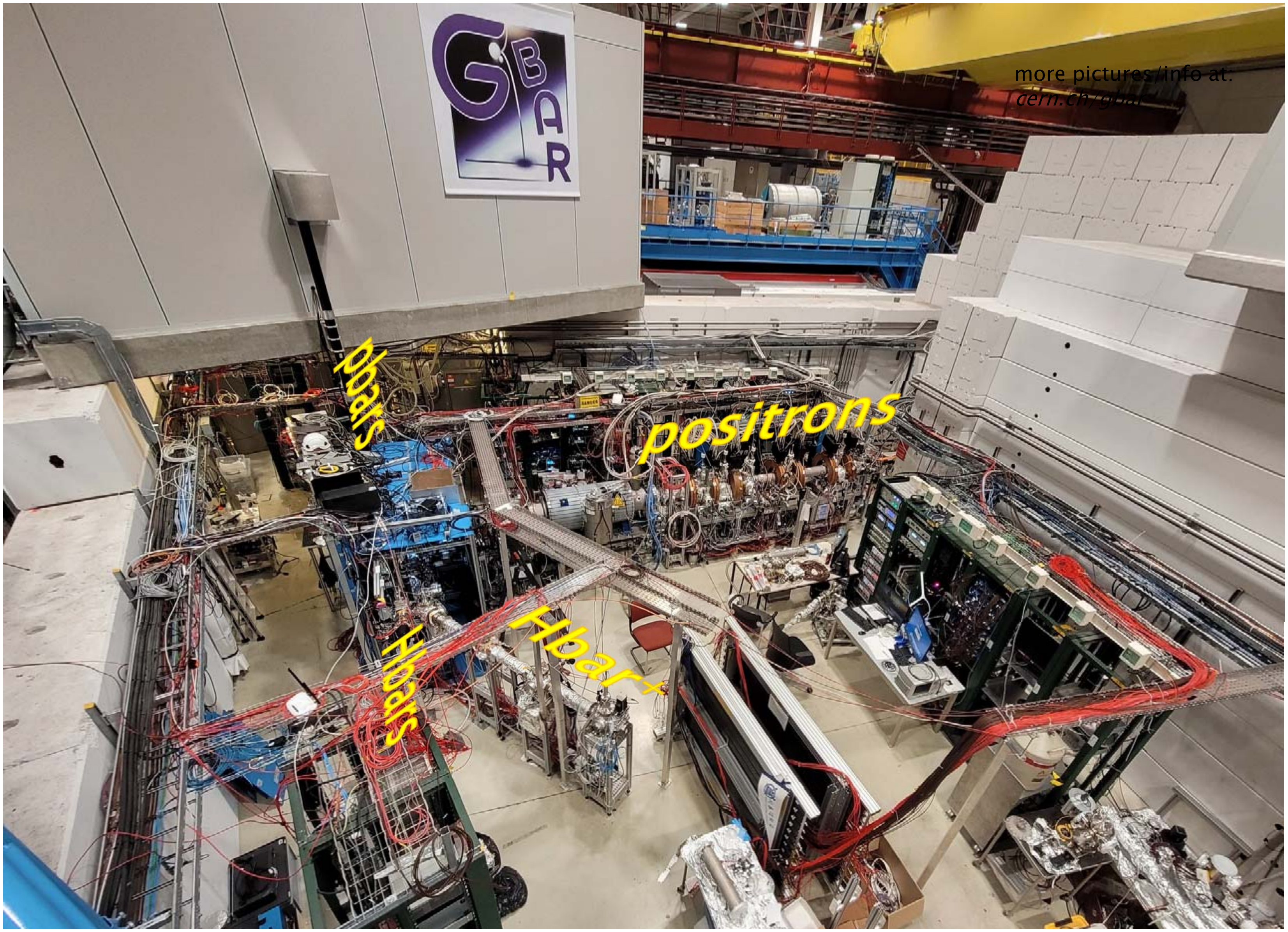
GBAR experiment schematic



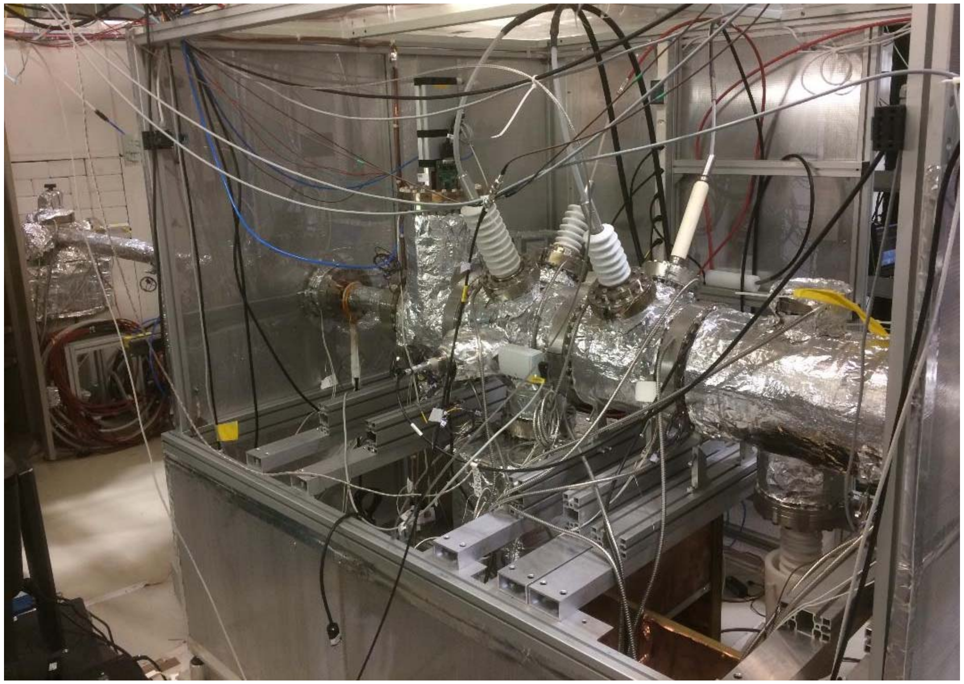
GBAR layout at CERN-AD

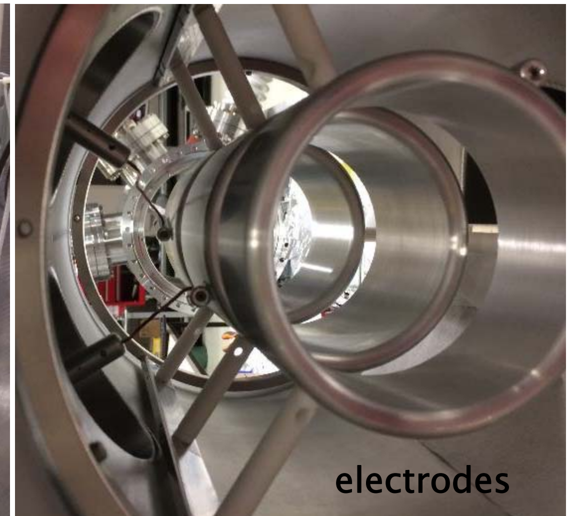


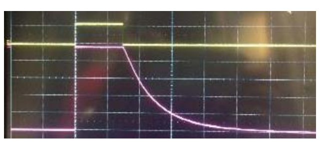
D. Desforges, J.-Y. Rousse, IRFU

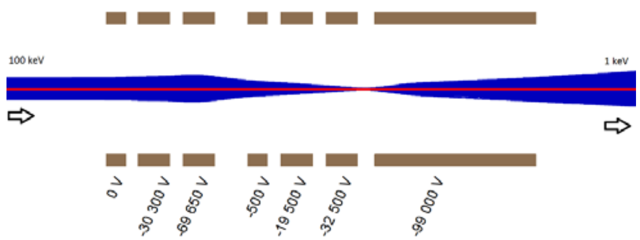

GBAR
pbars
positrons
Hbar+
Hbars
more pictures/info at:
cern.ch/gbar

GBAR antiproton decelerator setup (product of IN2P3)

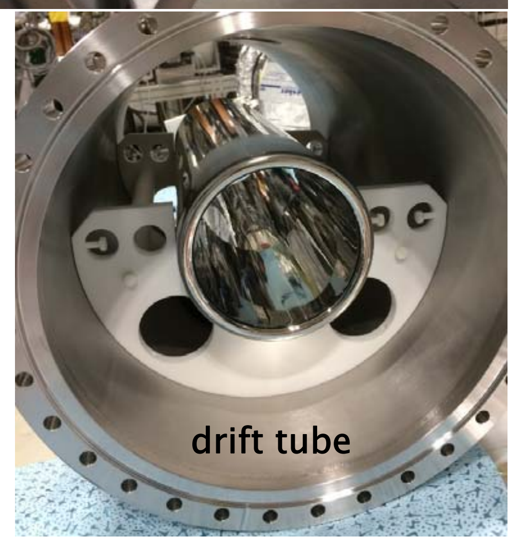








A. Husson (CSNSM/U.Paris-Saclay) PhD (2018)
A. Husson et al. NIM A (2021)
→ Copied by PUMA and ASACUSA



GBAR (IN2P3) Timeline

Letter of Intent SPSC-2007-038

Research Board AD-7

GBAR MoU w. CERN

2007 2011 2012 2014

Proposal SPSC-P-342

CERN FRC

GBAR off-line commissioning

GBAR installation

GBAR on-line commissioning

Protons, FFC, Pbar trap

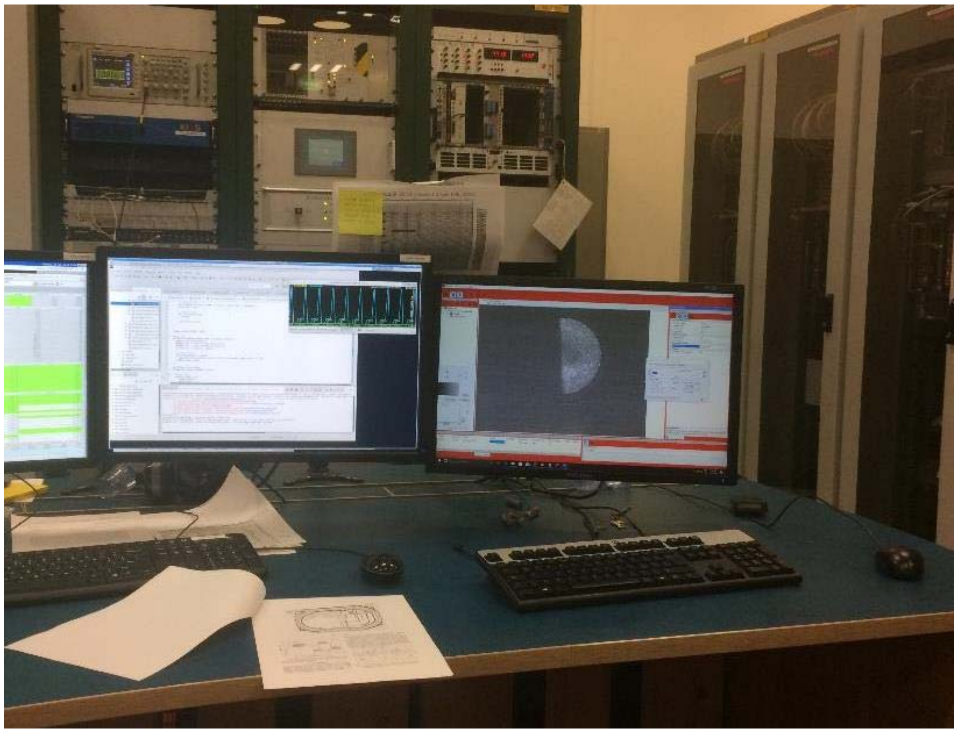
2016 2017 2018 LS2...

ELENA commissioning

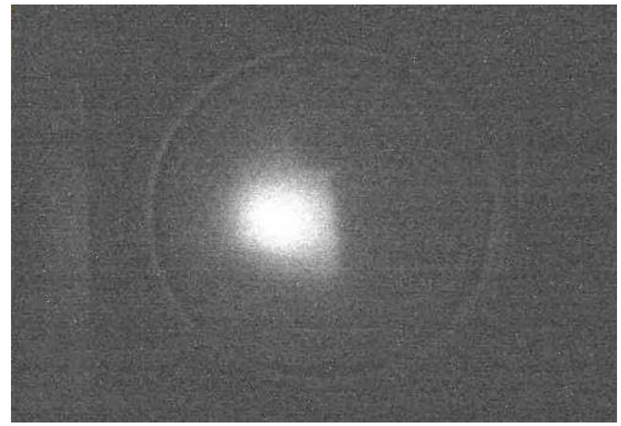
March 2017

First beams decelerated from ELENA (2018)

H⁻ : July 10, 2018



$\bar{p}$: July 20, 2018

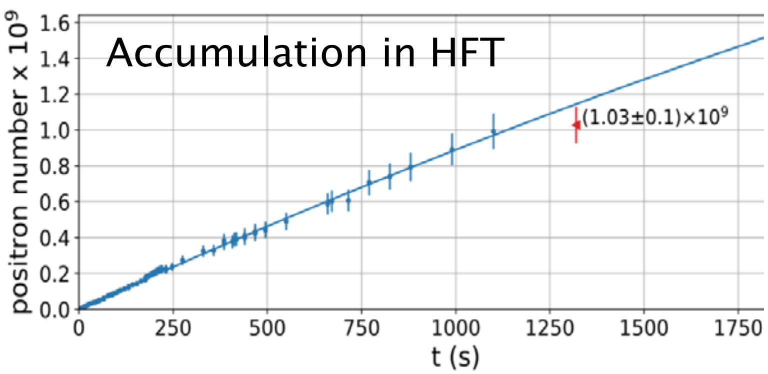


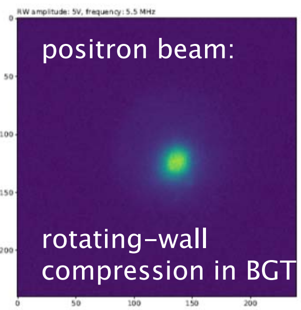
beams from ELENA:
$\bar{p}$ every 110 s
H^- 5 s

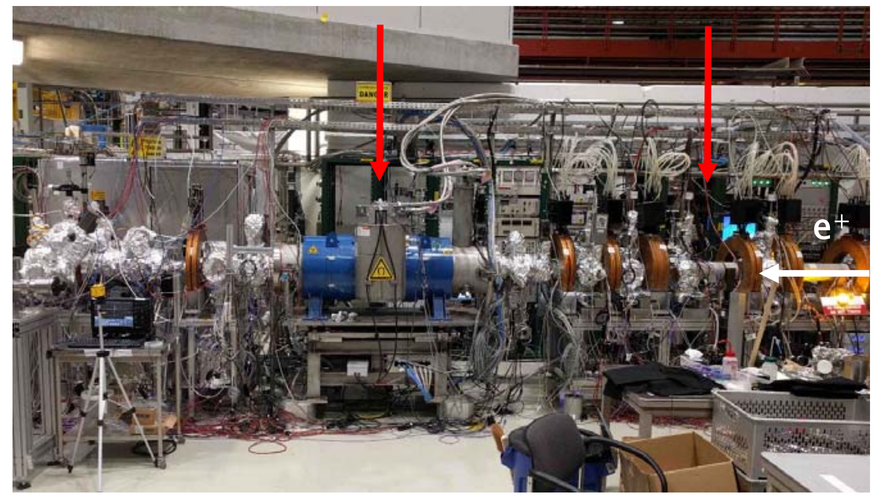
A. Husson (CSNSM/U.Paris-Saclay) PhD (2018)
A. Husson et al. NIM A (2021)

2022: positron accumulation record

Early work: P. Grandemange, CSNSM/U. Paris-Sud PhD (2013)







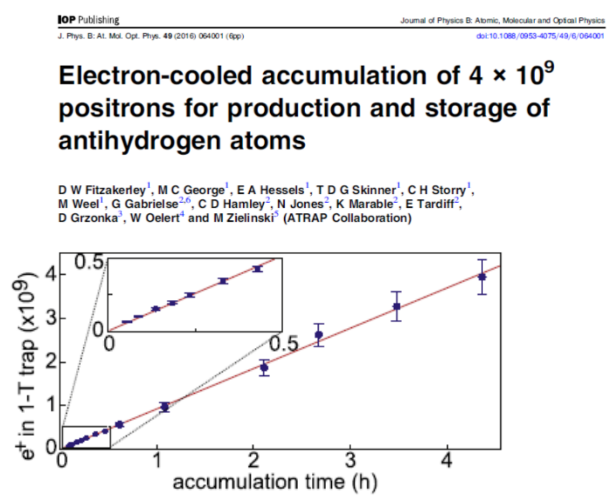
With linac at 200 Hz: 1 x 10^9 e^+ in 1100 s (< 20 min)
(S. Niang, IRFU/U. Paris-Saclay PhD, 2020 → IJCLab post-doc)

Publication: P. Blumer et al. NIMA (2022)

May 2024: 3 x 10^9 e^+
June 2024: 7 x 10^9 e^+

(P. Comini/L. Liszkay, IRFU)

Goal: at least 10^{10} e^+ in 115 s


IOP Publishing — Journal of Physics B: Atomic, Molecular and Optical Physics

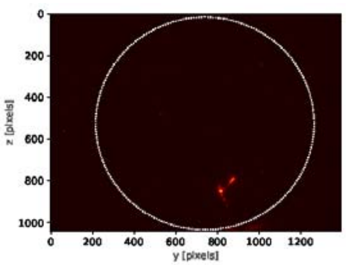
Electron-cooled accumulation of 4 × 10^9 positrons for production and storage of antihydrogen atoms

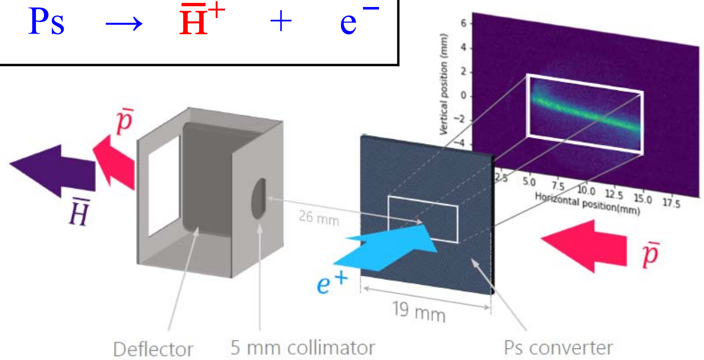
D W Fitzakerley[1], M C George[1], E A Hessels[1], T D G Skinner[1], C H Storry[1], M Weel[1], G Gabrielse[2,6], C D Hamley[2], N Jones[2], K Marable[2], E Tardiff[2], D Grzonka[3], W Oelert[4] and M Zielinski[5] (ATRAP Collaboration)

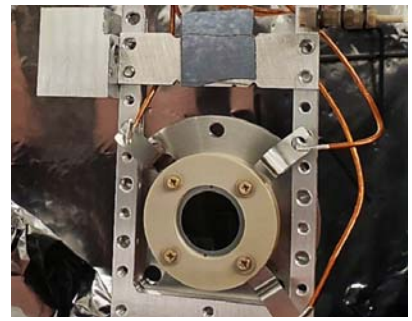
Antihydrogen production

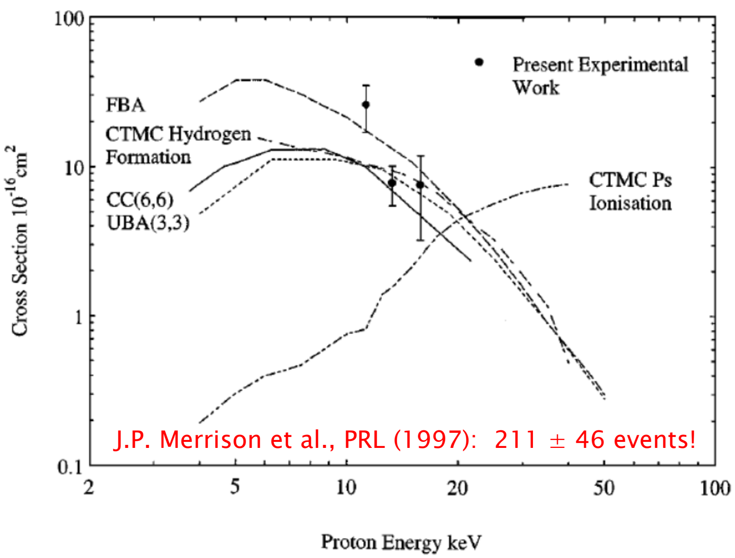
$$\bar{p} + Ps \rightarrow \bar{H} + e^-$$

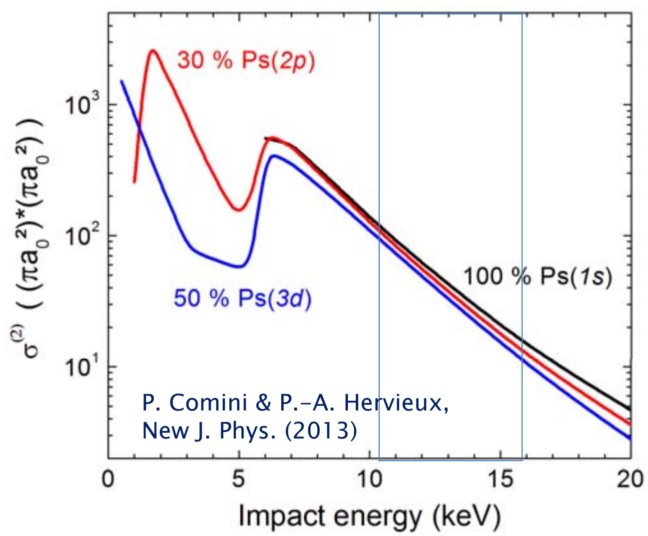
$$\bar{H} + Ps \rightarrow \bar{H}^+ + e^-$$





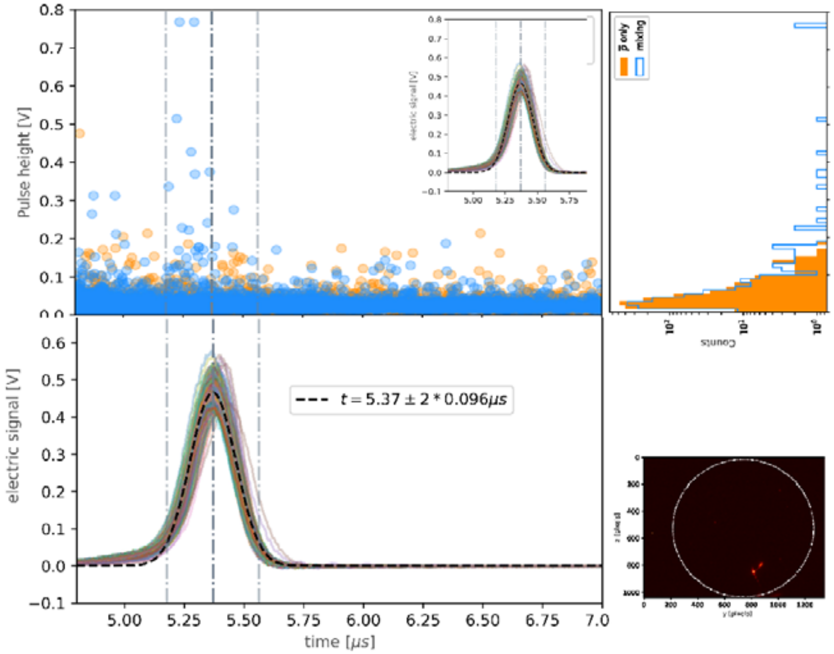


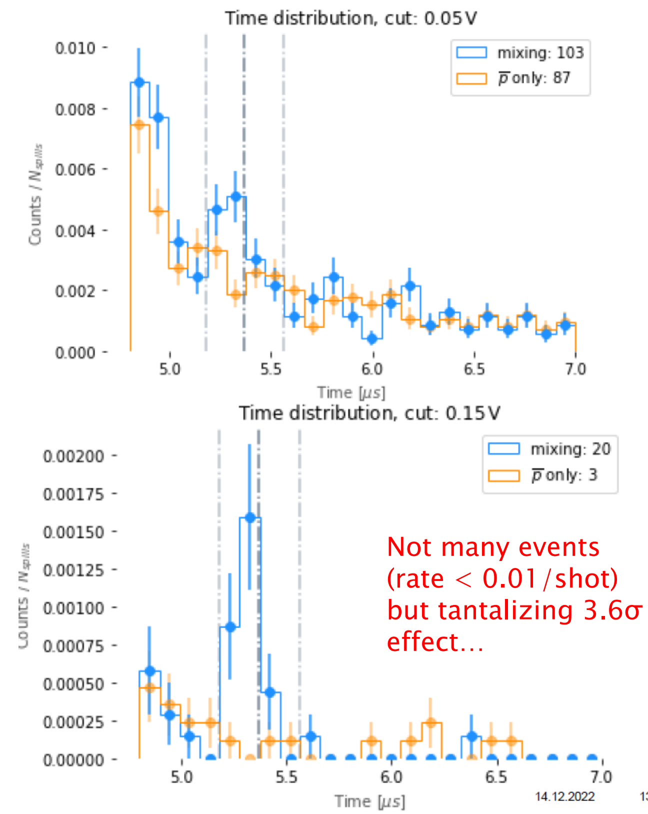




ANR JC –
SPHINX,
P. Comini
(2023–2026)

GBAR antihydrogen production





- **Pbar only**: 8468 events — 280 hours
- **Mixing**: 6897 events — 230 hours
- Measured expected time of flight:
  - $t_{TOF} = 5.37 \pm 2 \times 0.096$ μs

positron bkgd ~ 0

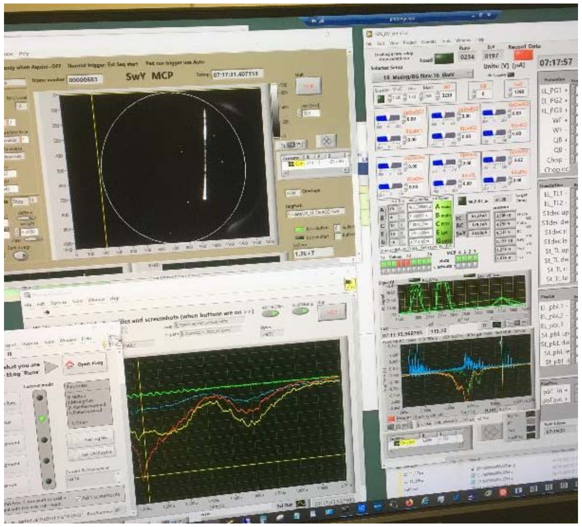
Not many events (rate < 0.01 / shot) but tantalizing 3.6σ effect…

Antihydrogen production rate: 0.01 / AD cycle (115 s)

Analysis by Ph. Blumer (ETH-Zurich) & T. Tanaka (U. Tokyo)

Making antihydrogen: GBAR joins an elite club!

1996–98:	CERN–LEAR (2 GeV) / FermiLab (6 GeV)
2002:	ATHENA / ATRAP (trapped p^-/e^+)
2008–10:	ATRAP / ALPHA (trapped Hbar)
2010–14:	ASACUSA (cusp trap/extraction)
2021:	AEgIS (trapped p^-/e^+)
2022:	GBAR (6 keV in flight)



Happy, relieved (and drunk) GBARistas at CERN (Dec. 2022)

2023 scientific highlights

Eur. Phys. J. C (2023) 83:1004
https://doi.org/10.1140/epjc/s10052-023-12137-y

THE EUROPEAN PHYSICAL JOURNAL C

Regular Article - Experimental Physics

Production of antihydrogen atoms by 6 keV antiprotons through a positronium cloud

P. Adrich[1,24], P. Blumer[2], G. Caratsch[2], M. Chung[3], P. Cladé[4], P. Comini[5], P. Crivelli[2], O. Dalkarov[6], P. Debu[5], A. Douillet[4,7], D. Drapier[4], P. Froelich[8,21], N. Garroum[4,22], S. Guellati-Khelifa[4,9], J. Guyomard[4], P.-A. Hervieux[10], L. Hilico[4,7], P. Indelicato[4], S. Jonsell[8], J.-P. Karr[4,7], B. Kim[11], S. Kim[12], E.-S. Kim[13], Y. J. Ko[11], T. Kosinski[1], N. Kuroda[14], B. M. Latacz[5,23], B. Lee[12], H. Lee[12], J. Lee[11], E. Lim[13], L. Liszkay[5], D. Lunney[15], G. Manfredi[10], B. Mansoulié[5], M. Matusiak[1], V. Nesvizhevsky[16], F. Nez[4], S. Niang[15,23], B. Ohayon[2], K. Park[11,12], N. Paul[4], P. Pérez[5,a], C. Regenfus[2], S. Reynaud[4], C. Roumegou[15], J.-Y. Roussé[5], Y. Sacquin[5], G. Sadowski[5], J. Sarkisyan[2], M. Sato[14], F. Schmidt-Kaler[17], M. Staszczak[1], K. Szymczyk[1], T. A. Tanaka[14], B. Tuchming[5], B. Vallage[5], A. Voronin[6], D. P. van der Werf[18], A. Welker[19,22], D. Won[12], S. Wronka[1], Y. Yamazaki[20], K.-H. Yoo[3], P. Yzombard[4]

Accès rapides | Actualités | Agenda | Espace institut | Grand public | Livres | Annuaire | cnrs.fr | FAIRE UN DON

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Expérience GBAR au CERN. ©CERN

Accueil > Actualités

Antimatière : l'expérience GBAR du CERN rejoint l'anticlub !

29 juin 2023

PHYSIQUE DES PARTICULES RÉSULTATS SCIENTIFIQUES

L'expérience GBAR, au CERN, vient de rejoindre le club très sélect des expériences qui ont réussi à synthétiser des atomes d'antihydrogène. Il s'agit d'une étape majeure pour la collaboration GBAR dont l'objectif est de mesurer si l'antimatière se comporte à l'identique de la matière dans le champ de gravité terrestre. Les équipes françaises du CNRS et du CEA sont fortement impliquées dans l'expérience.

Abstract We report on the first production of an antihydrogen beam by charge exchange of 6.1 keV antiprotons with a cloud of positronium in the GBAR experiment at CERN. The 100 keV antiproton beam delivered by the AD/ELENA facility was further decelerated with a pulsed drift tube. A 9 MeV electron beam from a linear accelerator produced a low energy positron beam. The positrons were accumulated in a set of two Penning–Malmberg traps. The positronium target cloud resulted from the conversion of the positrons extracted from the traps. The antiproton beam was steered onto this positronium cloud to produce the antiatoms. We observe an excess over background indicating antihydrogen production with a significance of 3–4 standard deviations.

[a] e-mail: patrice.perez@cern.ch (corresponding author)

1 Introduction

The GBAR experiment at CERN aims at a precise measurement of the free fall acceleration of neutral antihydrogen

Published online: 06 November 2023

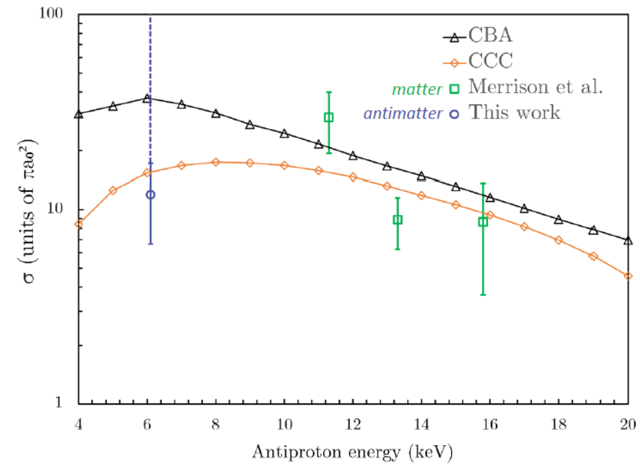
Springer

THESE DE DOCTORAT

NNT : 2023UPASP093

université PARIS-SACLAY

Synthesis of antihydrogen from in-flight charge exchange of decelerated antiprotons in



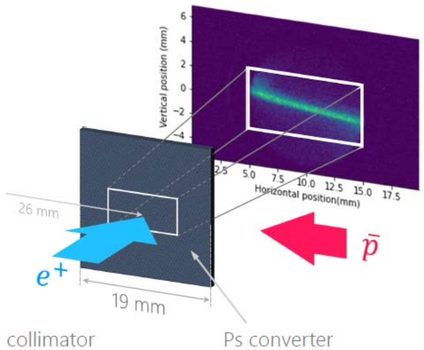
Corentin ROUMEGOU

Composition du jury

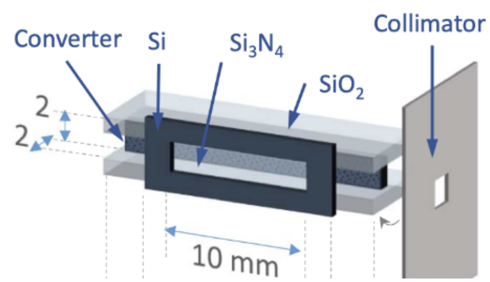
Membres du jury avec voix délibérative

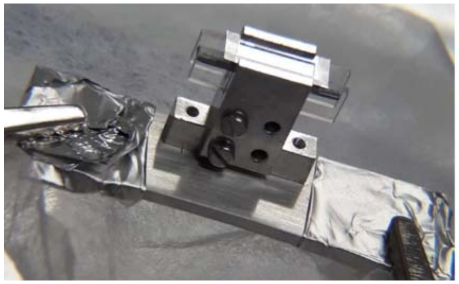
Laurette PONCE Ingénieure de recherche, CERN	Présidente
Michael DOSER Senior Research Physicist, CERN	Rapporteur & Examinateur
Anna SOTER Professeure, ETH Zürich	Rapporteuse & Examinatrice
Paul INDELICATO Directeur de recherche, LKB/Sorbonne Université	Examinateur

2024: improvements to produce antihydrogen → ions

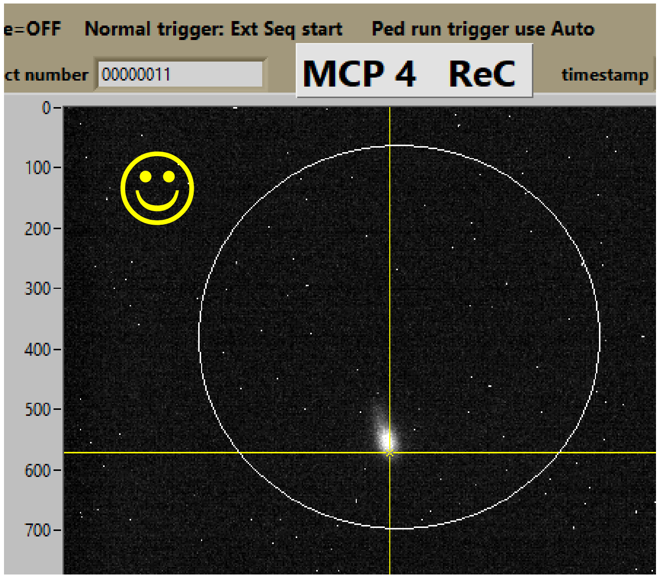


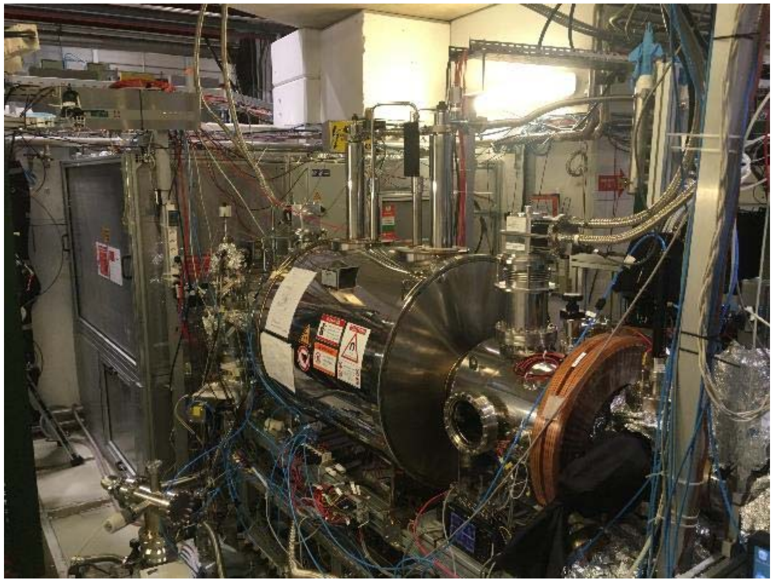
Higher Ps density

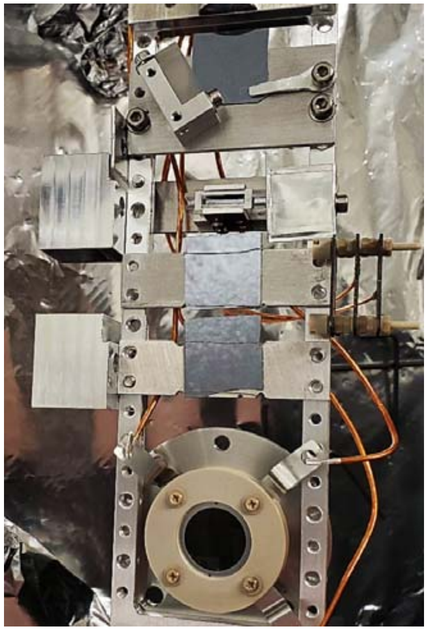




Higher pbar flux





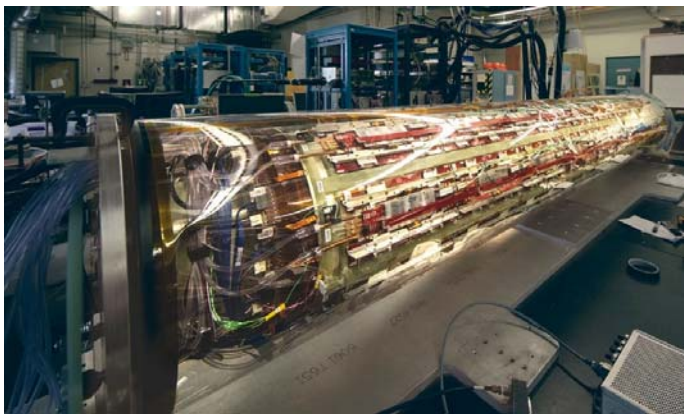


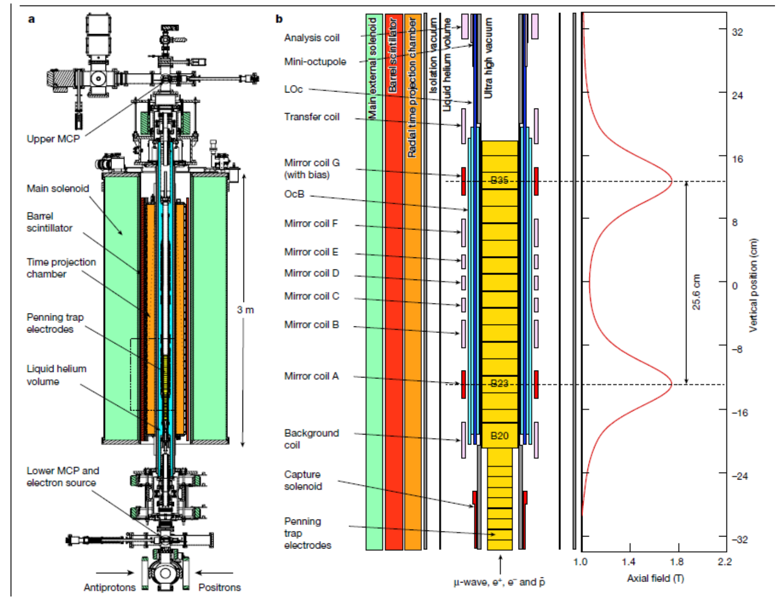
Article

Observation of the effect of gravity on the motion of antimatter

https://doi.org/10.1038/s41586-023-06527-1
Received: 6 May 2023
Accepted: 9 August 2023
Open access
Check for updates

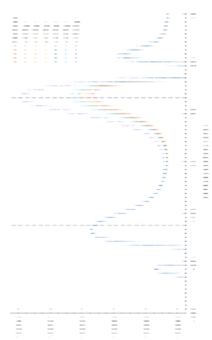
E. K. Anderson[1], C. J. Baker[2], W. Bertsche[3,4], N. M. Bhatt[2], G. Bonomi[5], A. Capra[6], I. Carli[6], C. L. Cesar[7], M. Charlton[2], A. Christensen[8], R. Collister[6,9], A. Cridland Mathad[2], D. Duque Quiceno[6,9], S. Eriksson[2], A. Evans[6,9], N. Evetts[9], S. Fabbri[3,10], J. Fajans[8], A. Ferwerda[11], T. Friesen[12], M. C. Fujiwara[6], D. R. Gill[6], L. M. Golino[7], M. B. Gomes Gonçalves[2], P. Grandemange[6], P. Granum[1], J. S. Hangst[1], M. E. Hayden[13], D. Hodgkinson[3,8], E. D. Hunter[8], C. A. Isaac[2], A. J. U. Jimenez[6], M. A. Johnson[3,4], J. M. Jones[2], S. A. Jones[14], S. Jonsell[15], A. Khramov[6,9,16], N. Madsen[2], L. Martin[6], N. Massacret[6], D. Maxwell[2], J. T. K. McKenna[1,3], S. Menary[11], T. Momose[6,9,17], M. Mostamand[6,17], P. S. Mullan[2,18], J. Nauta[2], K. Olchanski[6], A. N. Oliveira[1], J. Peszka[2,18], A. Powell[12], C. Ø. Rasmussen[19], F. Robicheaux[20], R. L. Sacramento[7], M. Sameed[3,21], E. Sarid[22,23], J. Schoonwater[2], D. M. Silveira[7], J. Singh[3], G. Smith[6,9], C. So[6], S. Stracka[24], G. Stutter[1,25], T. D. Tharp[26], K. A. Thompson[2], R. I. Thompson[6,12], E. Thorpe-Woods[2], C. Torkzaban[8], M. Urioni[5], P. Woosaree[12] & J. S. Wurtele[8]

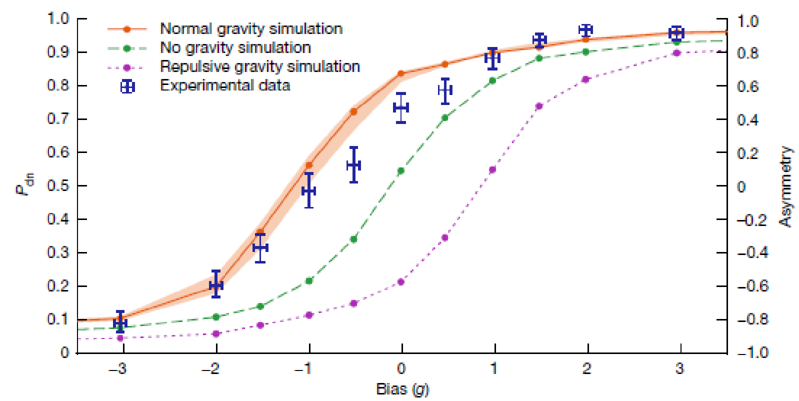


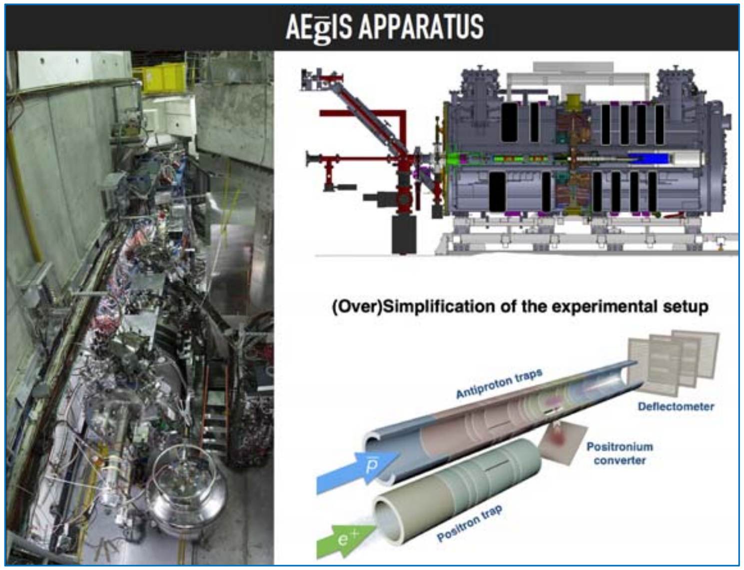


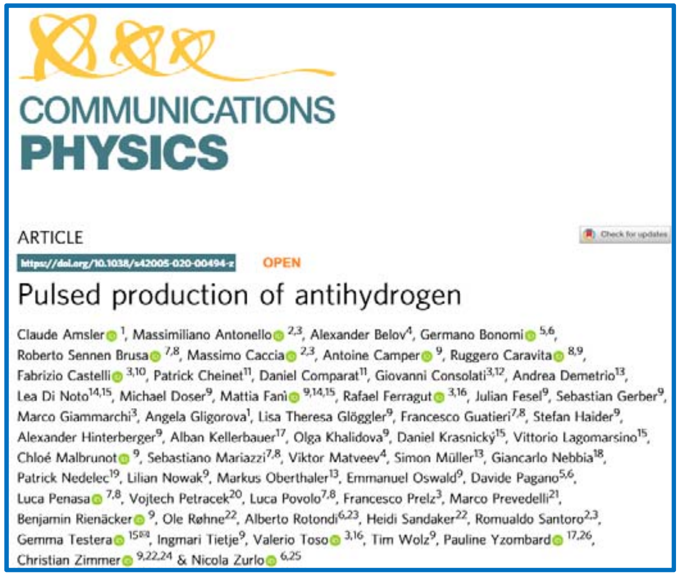
$a = 0.75(21)\,g$

Future: laser cooling of Hbar (15 mK)








COMMUNICATIONS PHYSICS

ARTICLE

https://doi.org/10.1038/s42005-020-00494-z OPEN

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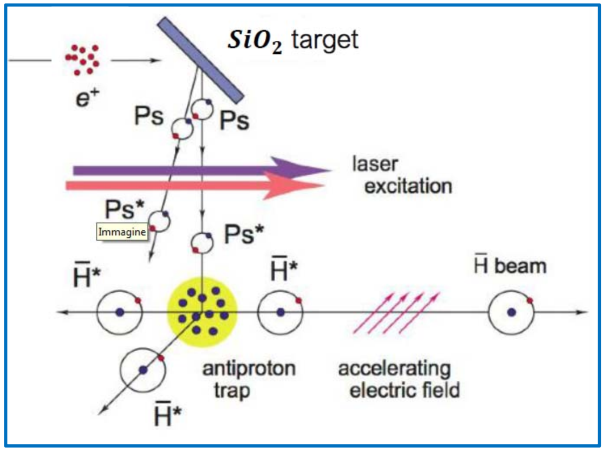
Pulsed production of antihydrogen

Claude Amsler[1], Massimiliano Antonello[2,3], Alexander Belov[4], Germano Bonomi[5,6], Roberto Sennen Brusa[7,8], Massimo Caccia[2,3], Antoine Camper[9], Ruggero Caravita[8,9], Fabrizio Castelli[3,10], Patrick Cheinet[11], Daniel Comparat[11], Giovanni Consolati[3,12], Andrea Demetrio[13], Lea Di Noto[14,15], Michael Doser[9], Mattia Fanì[9,14,15], Rafael Ferragut[3,16], Julian Fesel[9], Sebastian Gerber[9], Marco Giammarchi[3], Angela Gligorova[1], Lisa Theresa Glöggler[9], Francesco Guatieri[7,8], Stefan Haider[9], Alexander Hinterberger[9], Alban Kellerbauer[17], Olga Khalidova[9], Daniel Krasnický[15], Vittorio Lagomarsino[15], Chloé Malbrunot[9], Sebastiano Mariazzi[7,8], Viktor Matveev[4], Simon Müller[13], Giancarlo Nebbia[18], Patrick Nedelec[19], Lilian Nowak[9], Markus Oberthaler[13], Emmanuel Oswald[9], Davide Pagano[5,6], Luca Penasa[7,8], Vojtech Petracek[20], Luca Povolo[7,8], Francesco Prelz[3], Marco Prevedelli[21], Benjamin Rienäcker[9], Ole Røhne[22], Alberto Rotondi[6,23], Heidi Sandaker[22], Romualdo Santoro[2,3], Gemma Testera[15], Ingmari Tietje[9], Valerio Toso[3,16], Tim Wolz[9], Pauline Yzombard[17,26], Christian Zimmer[9,22,24] & Nicola Zurlo[6,25]

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Refroidissement laser réussi du positronium !

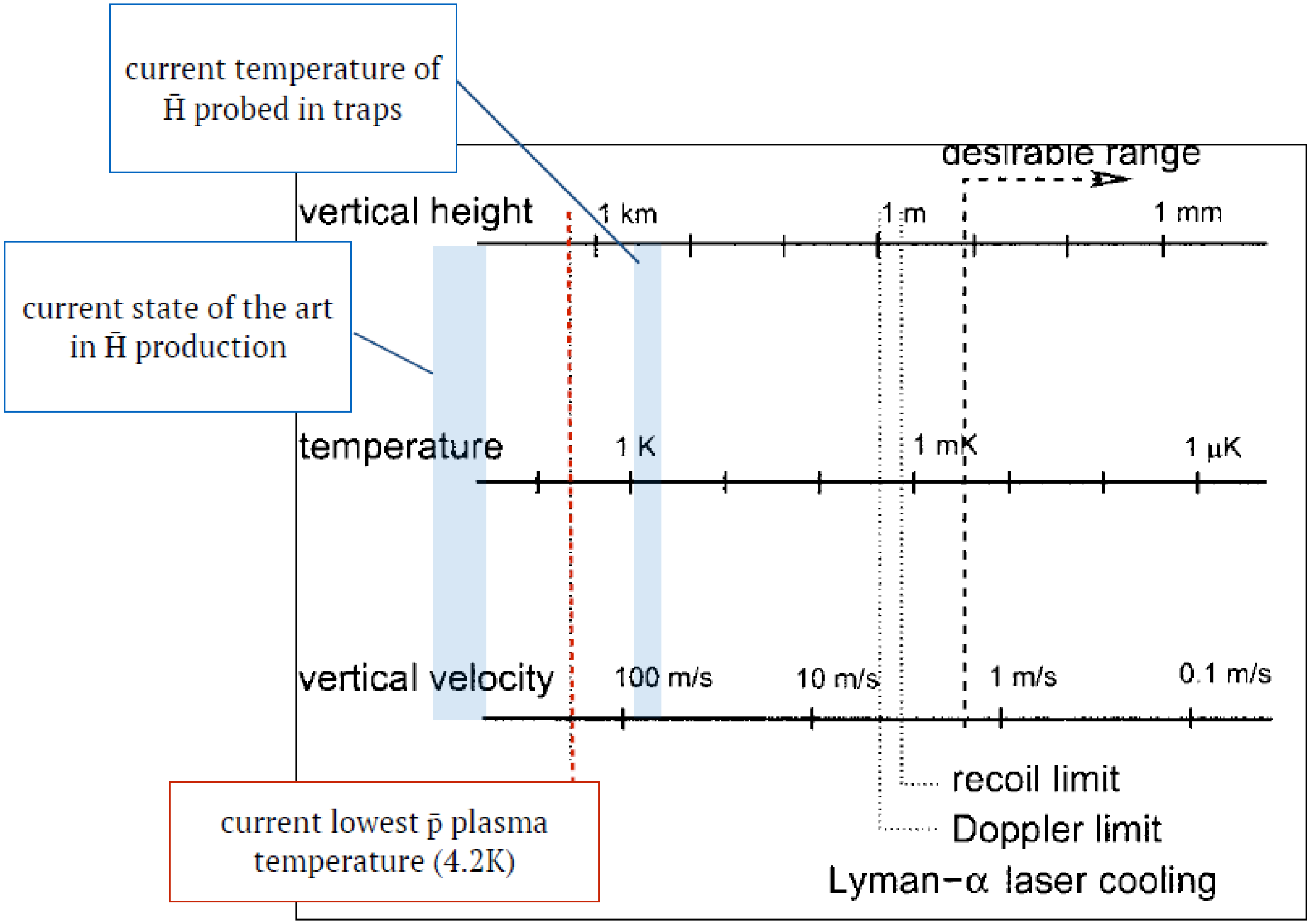
23 février 2024

RÉSULTAT SCIENTIFIQUE

L'impact d'un faisceau de positrons (e+) produit du positronium (e+ - e-) chaud qui est refroidi par laser à 243nm © AEgIS CERN

Le refroidissement laser du positronium a été pour la première fois observé au CERN, après des années d'efforts internationaux pour réaliser cette prouesse qui ouvre la voie à une nouvelle catégorie d'expériences pour entre autres sonder la matière au-delà du modèle standard.

Prospects for gravity test with $\bar{H}$: overview of the scales



Slide from C. Malbrunot

Investments, personnel and plans

International Research Networks (IRN)

GBAR IRN (2021-2025) 15 k€/an (soit 3 k€/equipe):
France, Corée du Sud, Allemagne, Russie, Suède, Pologne, Royaume-Uni, Japon, Suisse

Year	AP (k€)	other (k€)	ETP
2012	0	50	3.5
2013	0	50	3.5
2014	0	50	3.5
2015	0	24	2.5
2016	0	13	1.8
2017	3	13	2.0
2018	9.5	31	2.0
2019	21	4	0.9
2020	21	0	1.2
2021	19	2	2.8
2022	17	2	2.5
2023	13.6	1	1.75
2024	15.1	2	1.75

ETP pour 2024: 1.75

1.00 doctorant;
0.25 stagiaires M1/L3
0.50 Lunney

Bourse de these (2023-2026)
Sarah GEFFROY, ED PHENIICS

pbar transport simulations and optimization
production cross-section measurements
and data-analysis coordination

2022 — 2024 — 2025 — LS3…

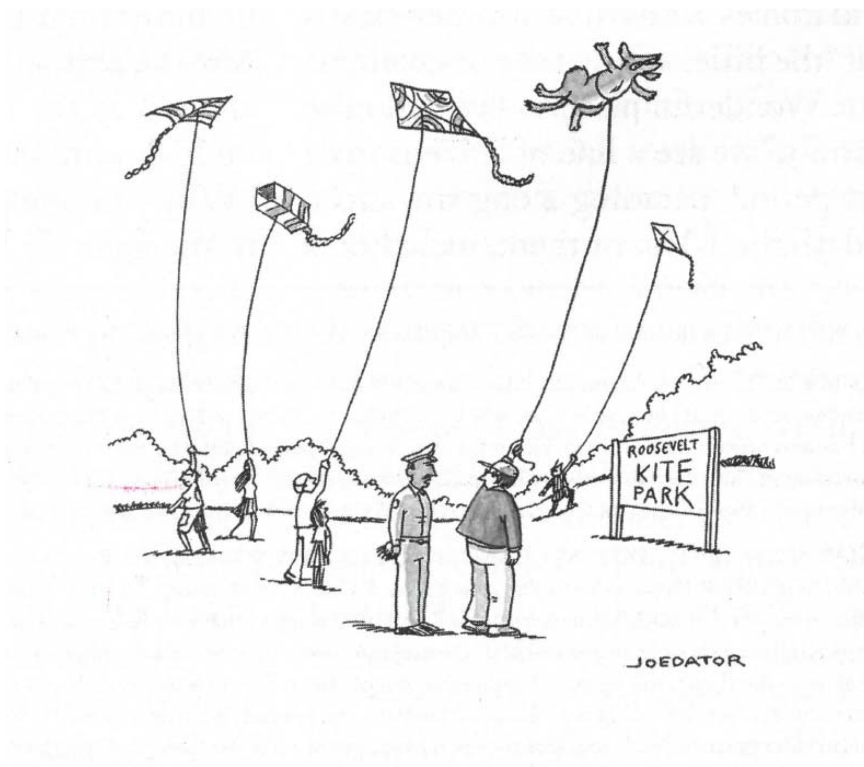
First free-fall experiment ?

- 2022: Antihydrogen!
- 2024: Lyman-α, pbar radius & cross-sections
- 2025: Synthesize Anti-H ion ?

Summary

- ❖ Fundamental physics goal
- ❖ Intersection of many disciplines
- ❖ GBAR has made antihydrogen ☺
- ❖ Performance steadily improving!
- ❖ Breakthrough technology
- ❖ Intense competition!
- ❖ GBAR potentially more accurate
- ❖ Still, a long road ahead…

- ❖ IN2P3 is a pillar of GBAR!
- ❖ Modest financial cost (AP)
- ❖ Success from ANR/Labex
- ❖ Good publicity
- ❖ But, needing FTE injection…



"Sir, I don't make the laws of gravity, I just enforce them."

GBAR Collaboration (65 authors; 19 institutes)

P. Adrich[1], P. Blumer[2], G. Caratsch[2], M. Chung[3], P. Cladé[4], P. Comini[5], P. Crivelli[2], O. Dalkarov[6], P. Debu[5], A. Douillet[4,7], D. Drapier[4], P. Froelich[8,20], N. Garroum[4,21], S. Guellati-Khelifa[4,9], J. Guyomard[4], P-A. Hervieux[10], L. Hilico[4,7], P. Indelicato[4], S. Jonsell[8], J-P. Karr[4,7], B. Kim[11], S. Kim[12], E-S. Kim[13], Y.J. Ko[11], T. Kosinski[1], N. Kuroda[14], B.M. Latacz[5,22], B. Lee[12], H. Lee[12], J. Lee[11], E. Lim[13], L. Liszkay[5], D. Lunney[15], G. Manfredi[10], B. Mansoulié[5],

M. Matusiak[1], V. Nesvizhevsky[16], F. Nez[4], S. Niang[15,22], B. Ohayon[2], K. Park[11,12], N. Paul[4], P. Pérez[5], C. Regenfus[2], S. Reynaud[4], C. Roumegou[15], J-Y. Roussé[5], Y. Sacquin[5], G. Sadowski[5], J. Sarkisyan[2], M. Sato[14], F. Schmidt-Kaler[17], M. Staszczak[1], K. Szymczyk[1], T.A. Tanaka[14], B. Tuchming[5], B. Vallage[5], A. Voronin[6], D.P. van der Werf[18], A. Welker[22], D. Won[12], S. Wronka[1], Y. Yamazaki[19], K-H. Yoo[3], P. Yzombard[4]

S. Geffroy, I. Belošević